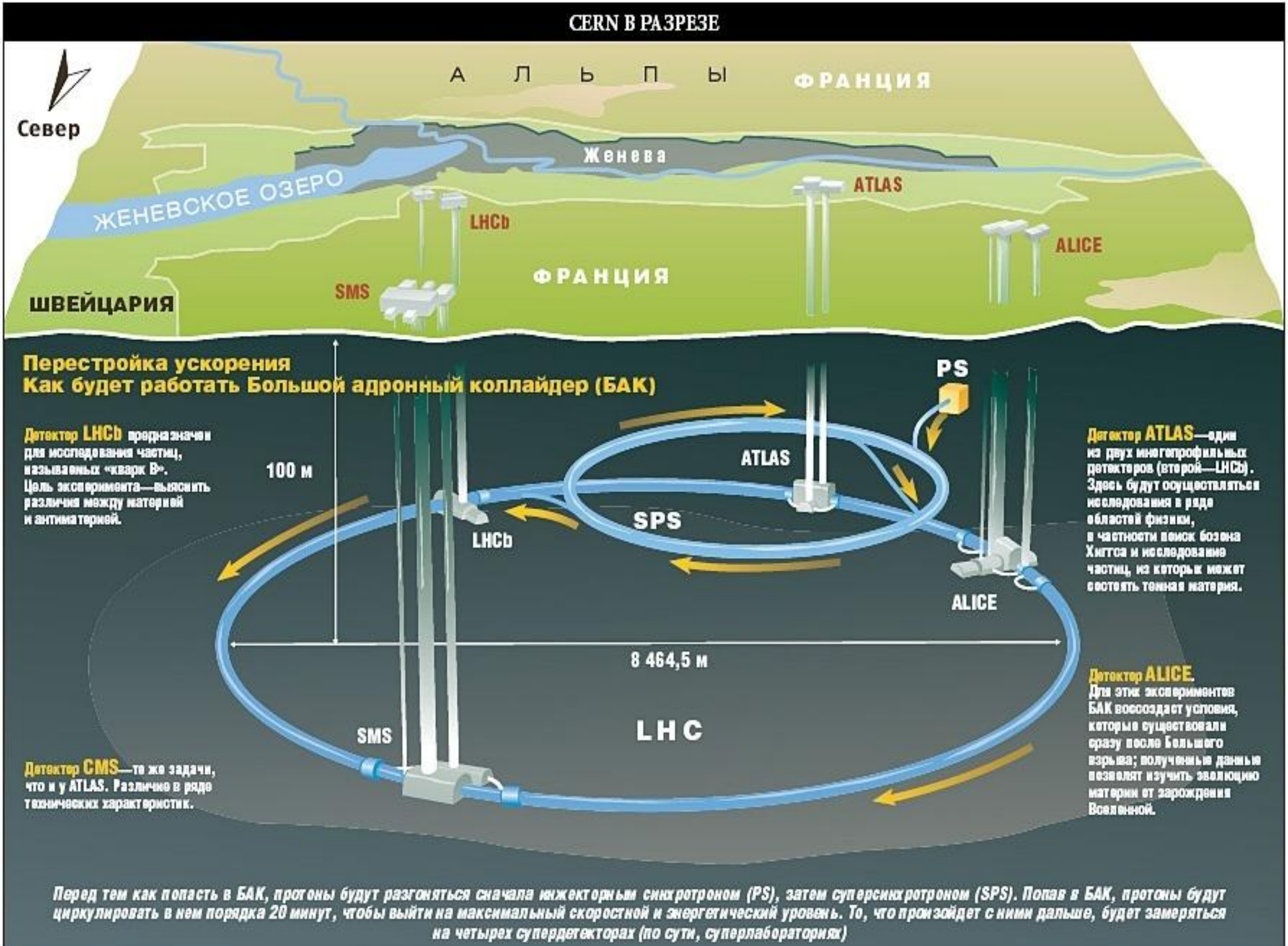
Эксперимент АТЛАС

В.А.Бедняков
ЛЯП ОИЯИ

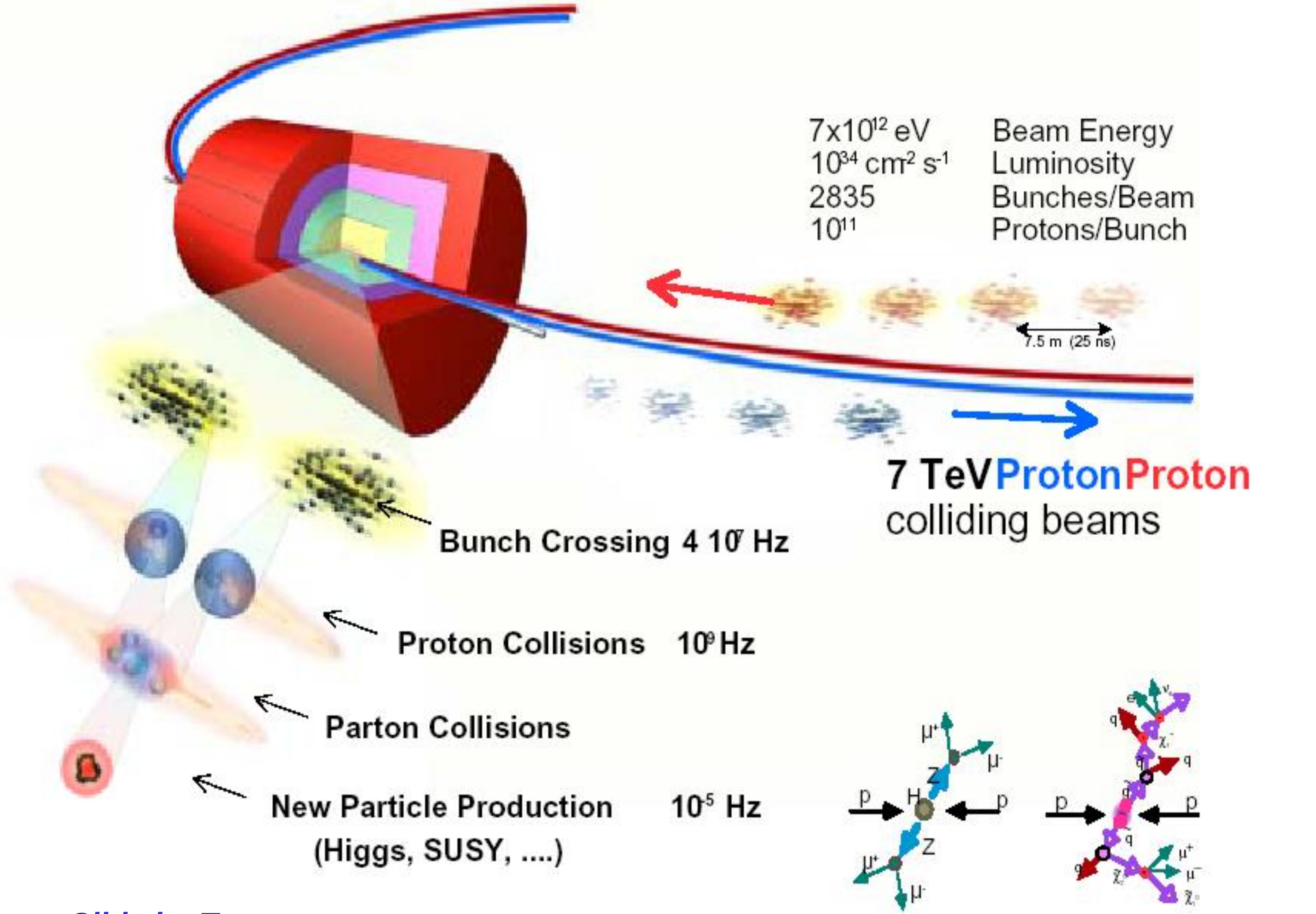
О чем?

- Что такое LHC?
- Зачем нам (да и Вам, тоже) LHC?
- Детектор АТЛАС
- Некоторые результаты АТЛАС 2011 года
- --
- Вклад ОИЯИ в эксперимент АТЛАС
- Что дальше?
- О фундаментальной науке, ОИЯИ и т.п.

LHC – Large Hadron Collider (БАК – Большой Адронный Коллайдер)


CERN В РАЗРЕЗЕ
Север
А Л Ь П Ы
ФРАНЦИЯ
Женева
ЖЕНЕВСКОЕ ОЗЕРО
ATLAS
LHCb
ALICE
ФРАНЦИЯ
SMS
ШВЕЙЦАРИЯ
Перестройка ускорения
Как будет работать Большой адронный коллайдер (БАК)
PS
Детектор LHCb предназначен для исследования частиц, называемых «кварк B». Цель эксперимента—выяснить различия между материей и антиматерией.
100 м
ATLAS
SPS
LHCb
Детектор ATLAS—один из двух многопрофильных детекторов (второй—LHCb). Здесь будут осуществляться исследования в ряде областей физики, в частности поиск бозона Хиггса и исследование частиц, из которых может состоять темная материя.
ALICE
8 464,5 м
Детектор ALICE. Для этих экспериментов БАК воссоздаст условия, которые существовали сразу после Большого взрыва; полученные данные позволят изучить эволюцию материи от зарождения Вселенной.
LHC
SMS
Детектор CMS—те же задачи, что и у ATLAS. Различие в ряде технических характеристик.
Перед тем как попасть в БАК, протоны будут разгоняться сначала инжекторным синхротроном (PS), затем суперсинхротроном (SPS). Попав в БАК, протоны будут циркулировать в нем порядка 20 минут, чтобы выйти на максимальный скоростной и энергетический уровень. То, что произойдет с ними дальше, будет замеряться на четырех супердетекторах (по сути, суперлабораториях)

Столкновения протонов (ионов свинца) на LHC

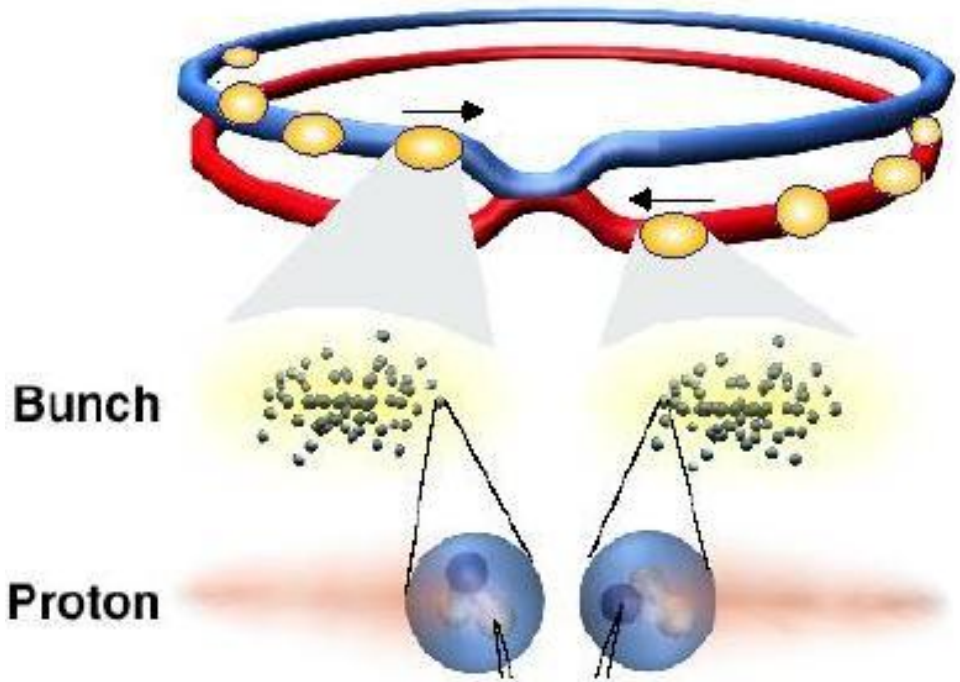


Slide by T. Virdee

Selection of 1 event in 10,000,000,000,000

Collisions at the LHC: counter-rotating, high-intensity bunches of protons or heavy ions.

The rate of **new particle's production** is proportional to the **luminosity**:



$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

Key parameters:

- N_i = bunch intensity
- n_b = number of bunches
- σ = colliding beam size

Nominal LHC parameters (7 TeV): ***2808*** *bunches of* ***1.1x10^{11}*** *protons,* ***0.000016*** *m size.*

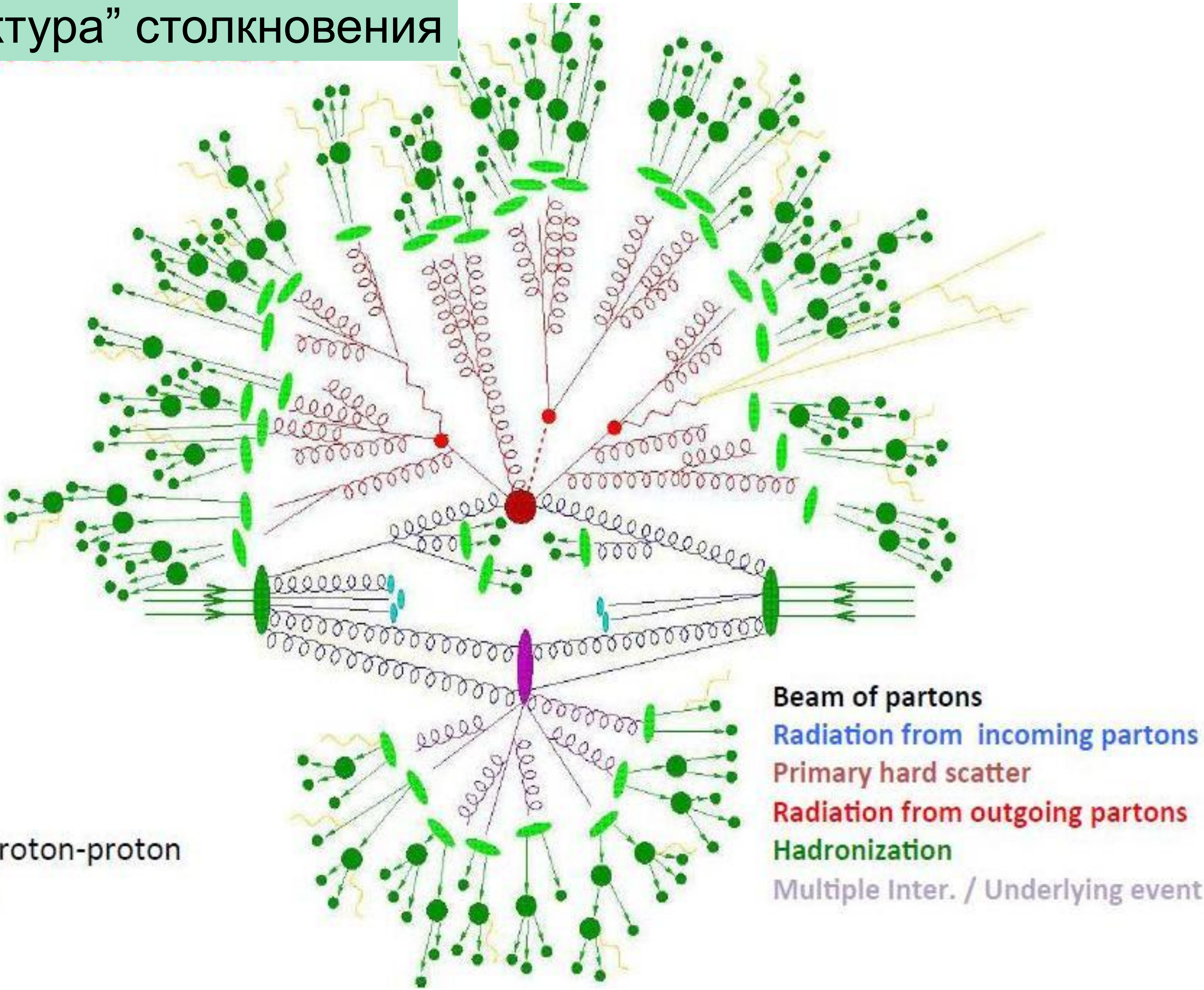
Units for the luminosity:

Peak luminosity given in event rate per unit of area *$cm^{-2}s^{-1}$*: ***2010 goal = $10^{32}cm^{-2}s^{-1}$***

Integral luminosity (prop. to number of collisions) *fb^{-1}* : ***2011 goal = 1 fb^{-1}***

Достигнуто 5 fb^{-1} !!!

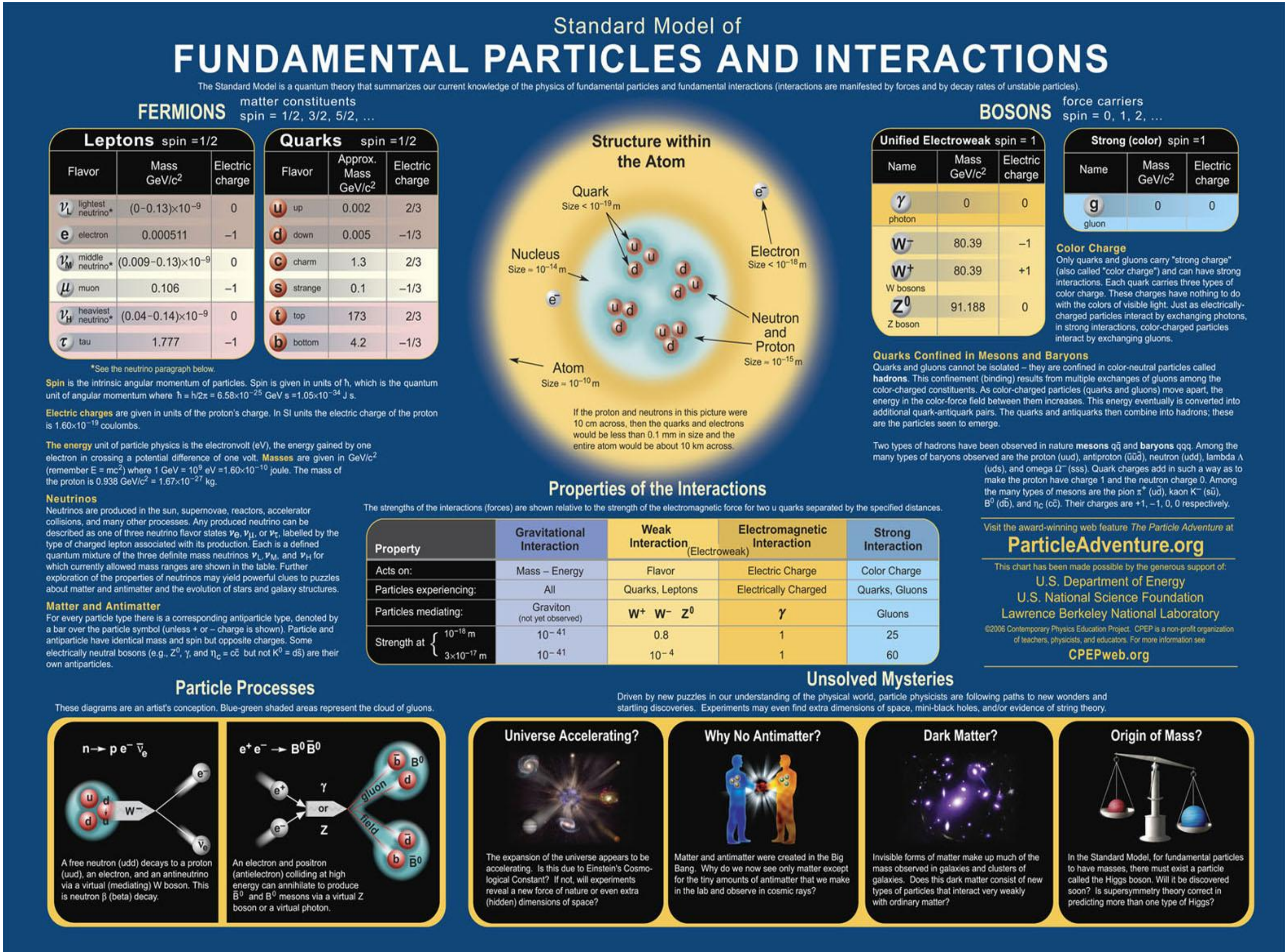
“Структура” столкновения



Typical proton-proton collision

И зачем все это надо?

Картина Мира = Стандартная Модель



Стандартная Модель

Описывает (объединяет) взаимодействия частиц:

- сильное
- слабое (распады)
- электромагнитное

Были предсказаны теоретически!

Симметрия и состав полей = СМ

$$\mathcal{L} = -\frac{1}{4g'^4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4g^2}W^a_{\mu\nu}W^{\mu\nu a} - \frac{1}{4g_s^2}G^a_{\mu\nu}G^{\mu\nu a}$$
$$+\bar{Q}_i i\not{D}Q_i + \bar{u}_i i\not{D}u_i + \bar{d}_i i\not{D}d_i + \bar{L}_i i\not{D}L_i + \bar{e}_i i\not{D}e_i$$
$$+(Y_u^{ij}\bar{Q}_i u_j\tilde{H} + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + c.c.)$$
$$-\lambda(H^\dagger H)^2 + \lambda v^2 H^\dagger H$$

Частицы материи

Переносчики взаимодействия

Прекрасно подтверждается многими экспериментами!

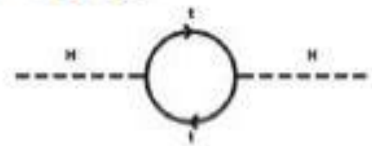
Стандартная Модель – ОДНАКО!?

- Каковы границы применимости СМ?
- Каково происхождение свободных параметров СМ, почему их так много?
- Как фундаментальные частицы приобретают массы и почему они так различны (топ-кварк и нейтрино)?
- Почему масса бозона Хиггса "не убегает" на массу Планка?
- Куда подевалось анти-вещество из Ранней Вселенной?
- Что делать с Гравитацией в СМ или какова Геометрия Вселенной, существуют ли дополнительные измерения?
- Нет объединения констант взаимодействия – существуют ли новые частицы и взаимодействия?
- Что происходит с адронами (КХД-материей) при больших плотностях энергии, существует ли кварк-глюонная плазма?
- **Астрофизика** – Какова природа темной материи и энергии?

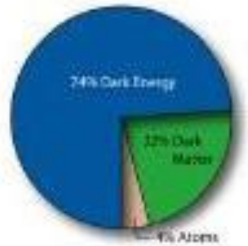
То же, но по-английски …

Problems with the SM:

- hierarchy problem

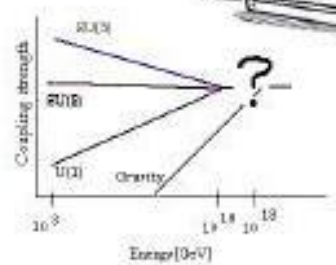


- dark matter

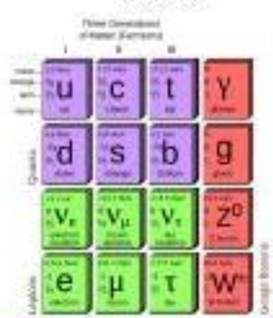


- matter-antimatter asymmetry

- gauge unification



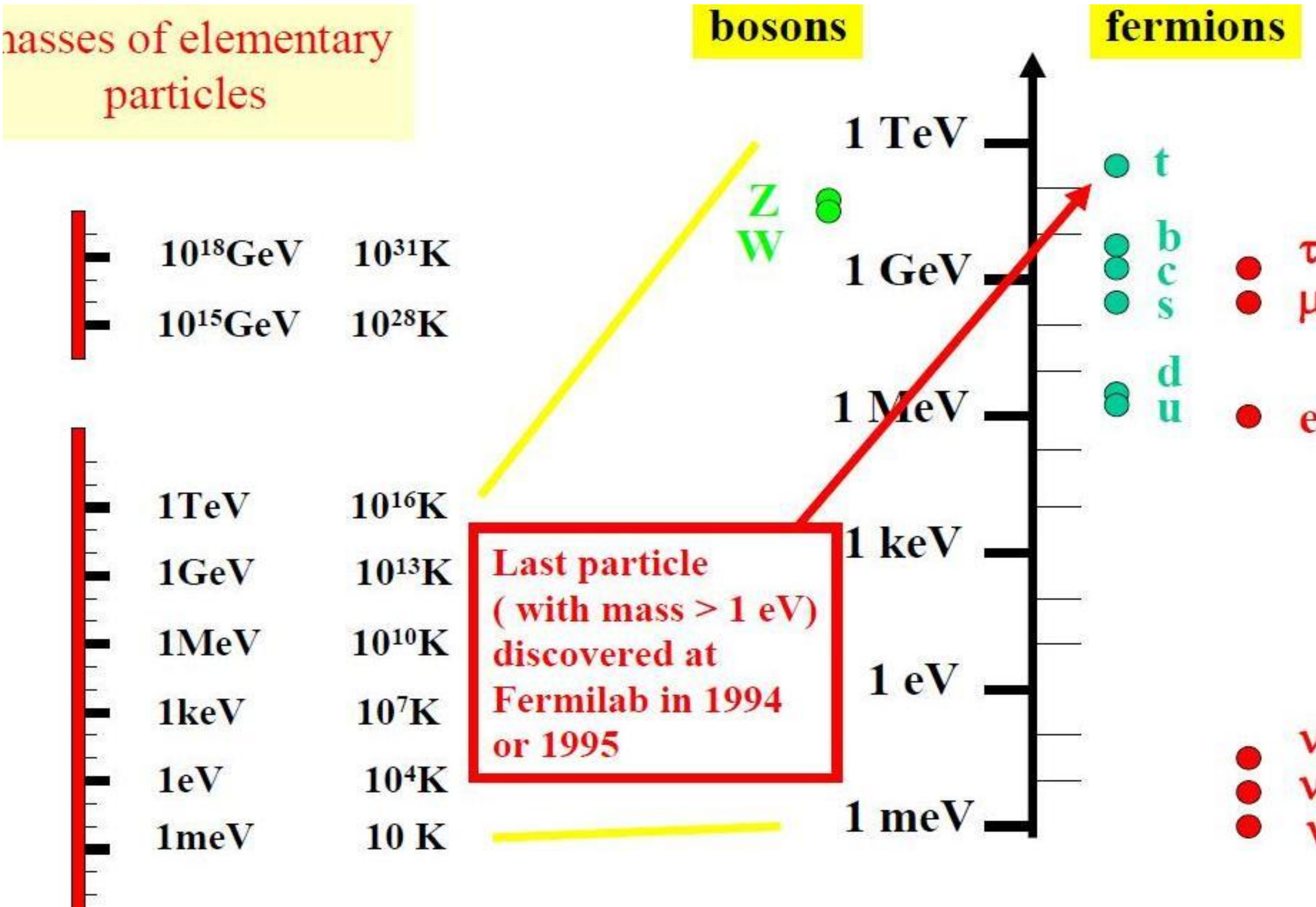
- SM structure, free parameters



→ SUSY

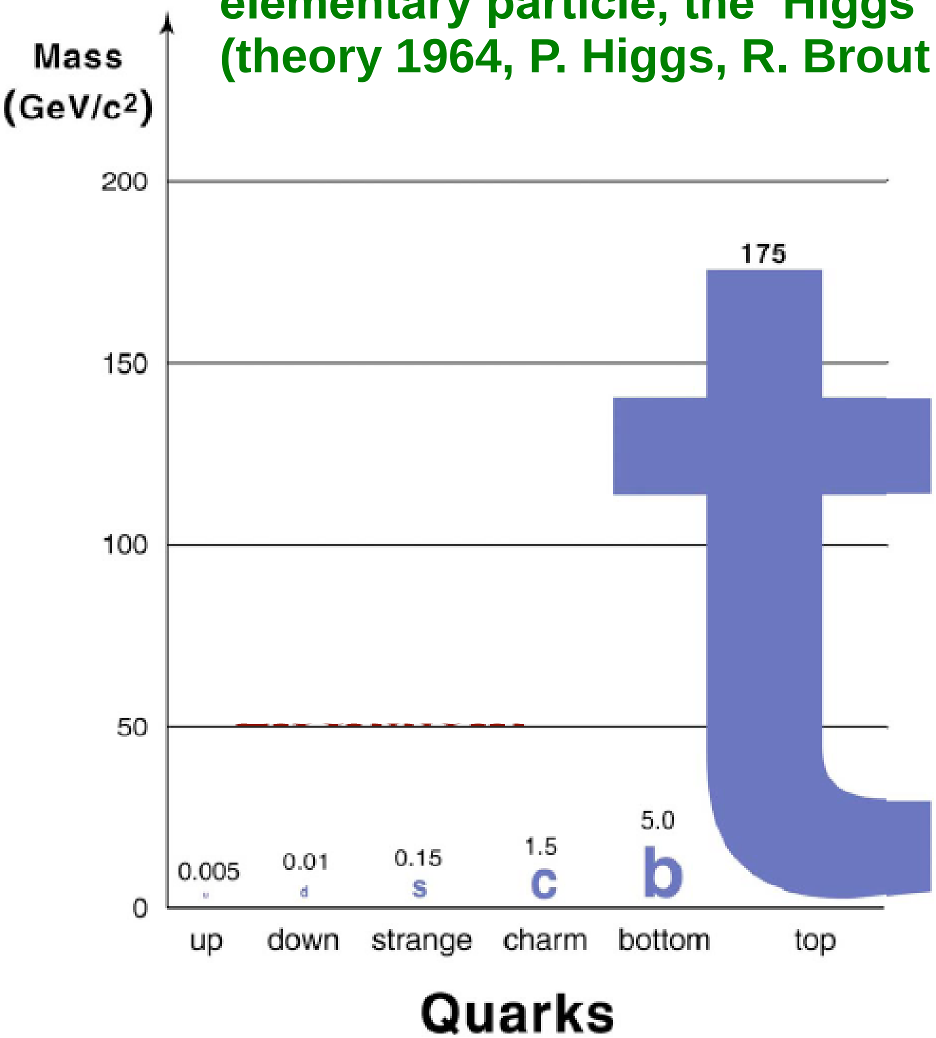
→ Exotics

Массы и Масштабы



Why particles have (so different) masses ?

The mass mystery could be solved with the ‘Higgs mechanism’ which predicts the existence of a new elementary particle, the ‘Higgs’ particle.
(theory 1964, P. Higgs, R. Brout and F. Englert)



The Higgs (H) particle has been searched for decades at accelerators, but not yet found…

The LHC will have sufficient energy to produce it for sure if it does exist …

Why do we need the Higgs?

Fermions

families,
with leptons

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \nu_R, e_R$$

and quarks

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R$$

Gauge Symmetries ⇒ **Bosons, Interactions**

$U(1)_Y$: $\psi(x) \rightarrow \exp\left[i\frac{g'}{2} Y_\psi \omega(x)\right]\psi(x)$

$SU(2)_L$: $\psi_L(x) \rightarrow \exp\left[i\frac{g}{2}\vec{\sigma}.\vec{\theta}(x)\right]\psi_L(x)$

→ γ : QED

→ Z, $W^\pm$: Weak

$$\tan\vartheta_W = \frac{g'}{g}$$

$SU(3)_c$: $\psi_q(x) \rightarrow \exp\left[i\frac{g_s}{2}\lambda_a\theta^a(x)\right]\psi_q(x)$ → gluons : QCD

A mass term couples L & R and would violate $SU(2)_L$

Solution: The Higgs mechanism

Thanks: P. Janot

Действующая (на пляже) модель механизма Хиггса – иллюстрирует возникновение сил инерции

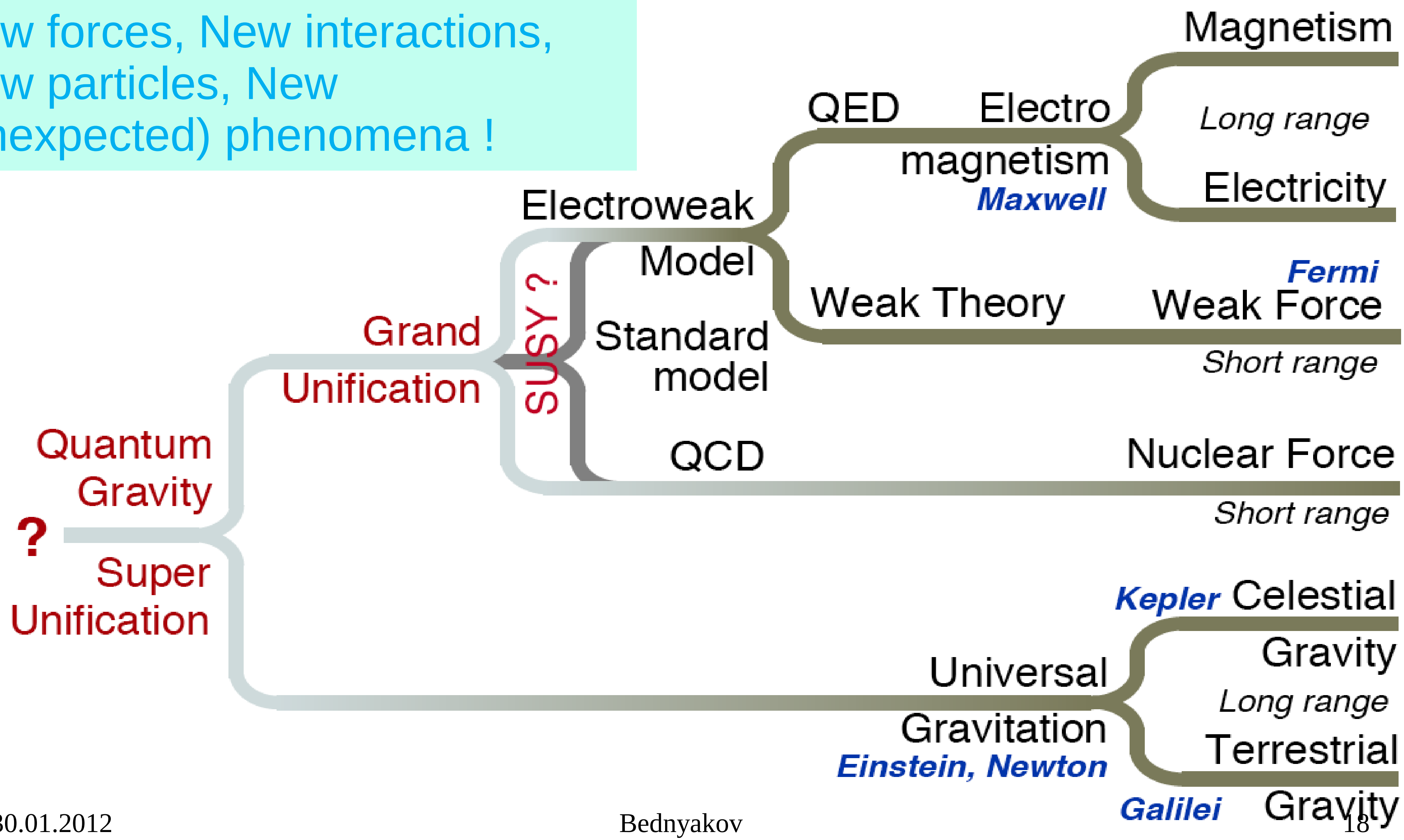
Поле Хиггса, пока невзаимодействущее

Элементарная частица попала в зону действия поля Хиггса

Взаимодействие!
Теперь ей трудно двигаться (ускоряться) – она стала массивной!

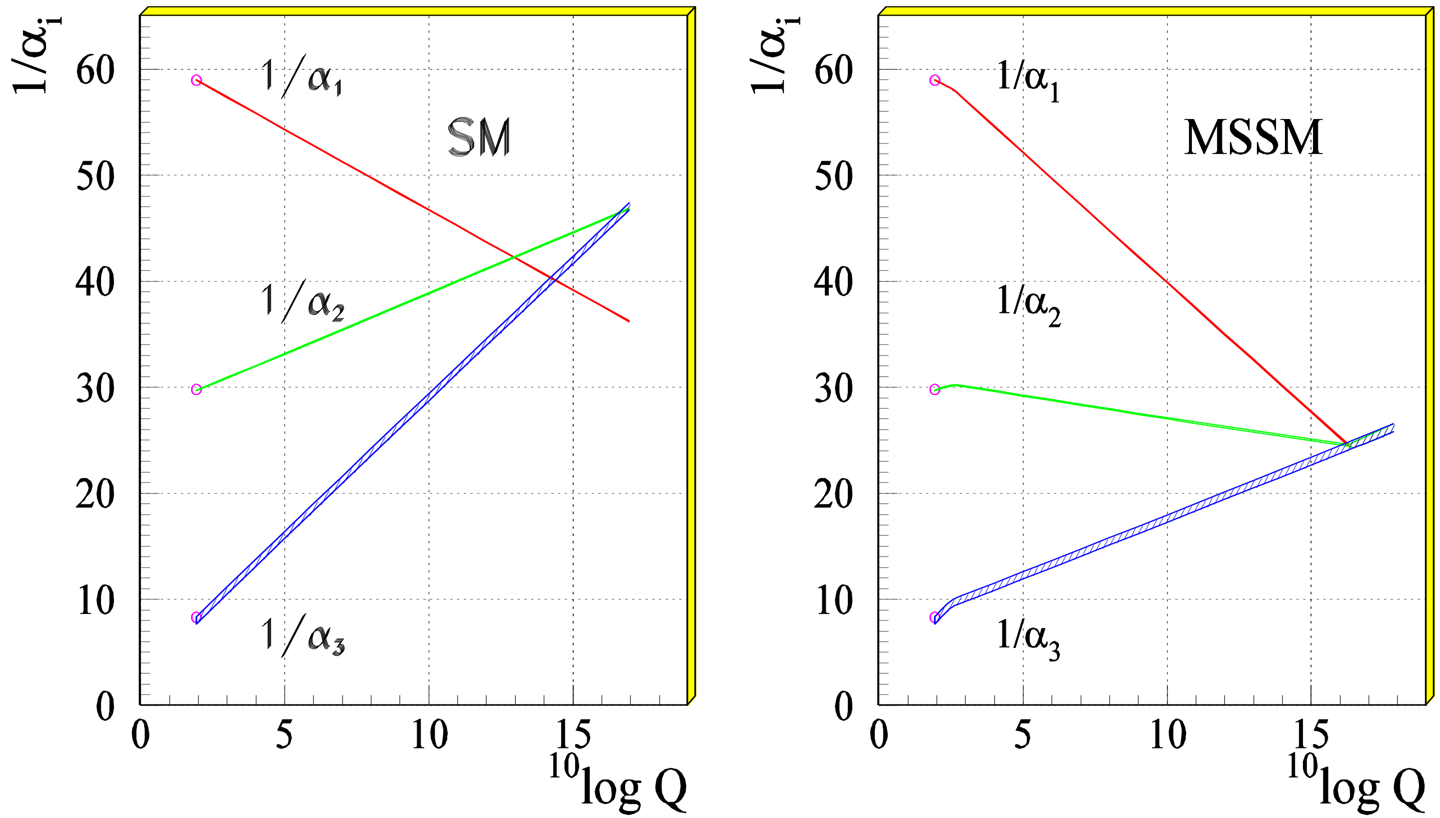
Объединение сил Природы – древняя мечта человечества

New forces, New interactions, New particles, New (unexpected) phenomena !



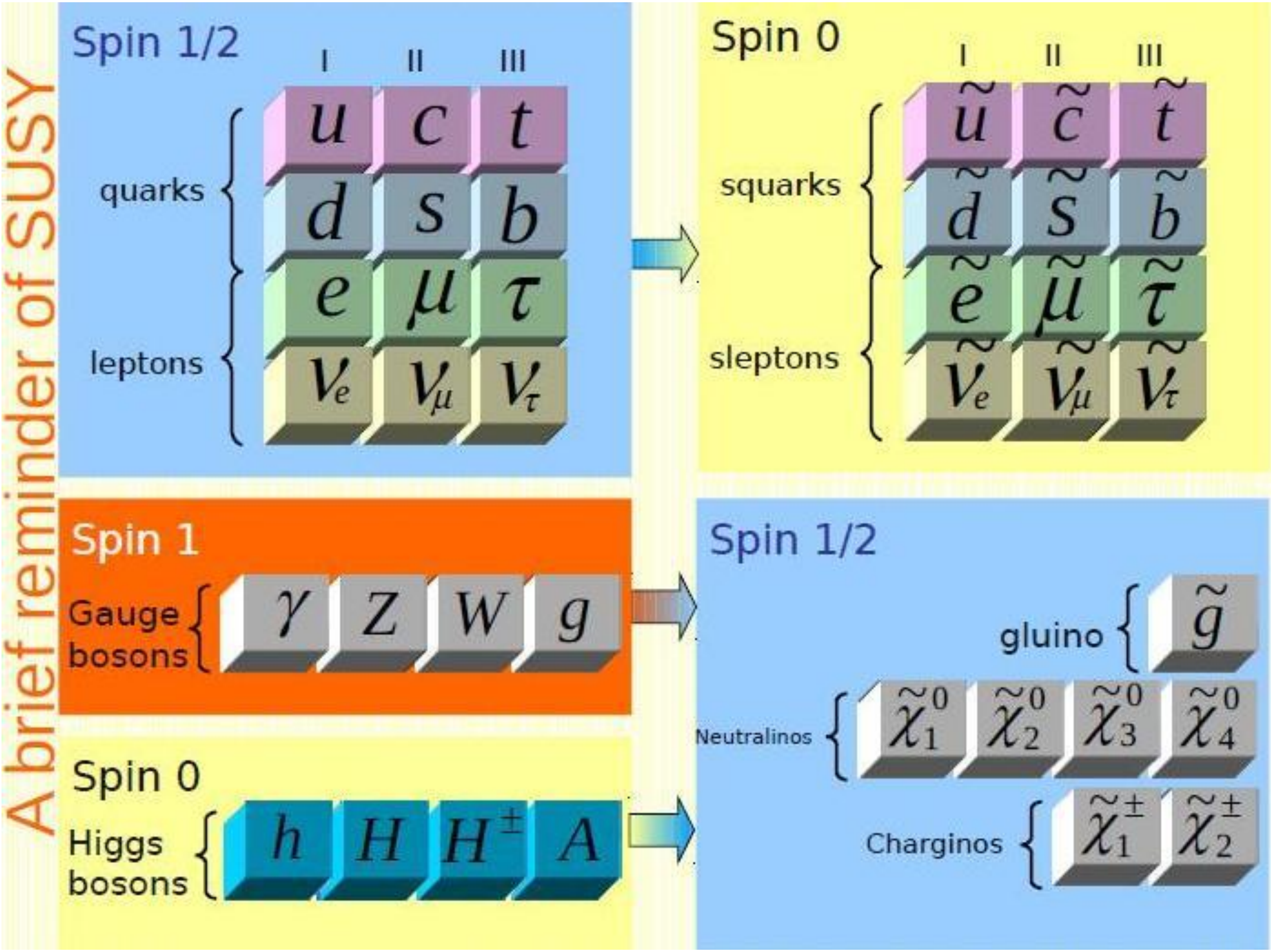
Но, увы, не в Стандартной модели …

Эволюция “бегущих” констант взаимодействий в СМ и минимальной суперсимметричной моделях (MSSM)



Дополнительный петлевой вклад суперпартнеров изменяет характер эволюции “бегущих” констант и их объединение уже происходит (при этом M_{SUSY} ~ 1 ТэВ) !

SUSY – хорошее решение всех проблем СМ!



SUSY – хорошее решение всех(?) проблем СМ!

(+) Каковы границы применимости СМ?

(+) Каково происхождение свободных параметров СМ, почему их так много?

(+) Как фундаментальные частицы приобретают массы и почему они так различны (топ-кварк и нейтрино)?

(+) Почему масса бозона Хиггса “не убегает” на массу Планка?

(±) Куда подевалось анти-вещество из Ранней Вселенной?

- Что делать с Гравитацией в СМ или какова Геометрия Вселенной, существуют ли дополнительные измерения?

(+) Нет объединения констант взаимодействия – существуют ли новые частицы и взаимодействия?

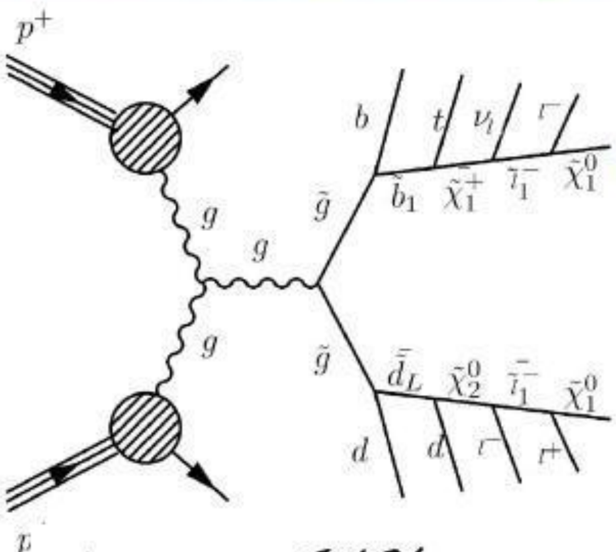
- Что происходит с адронами (КХД-материей) при больших плотностях энергии, существует ли кварк-глюонная плазма?

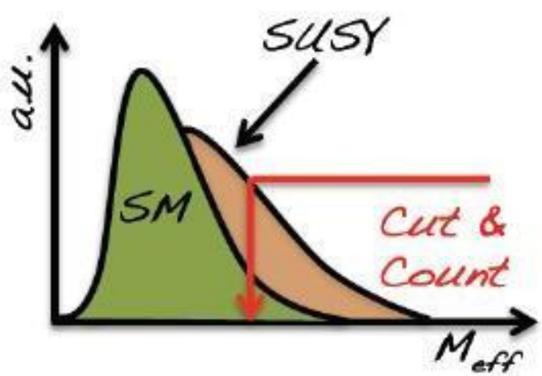
(±) Астрофизика – Какова природа темной материи и энергии?

Но не все так уж просто с SUSY!

Searches for SUSY at the LHC

Characteristic SUSY production and decay

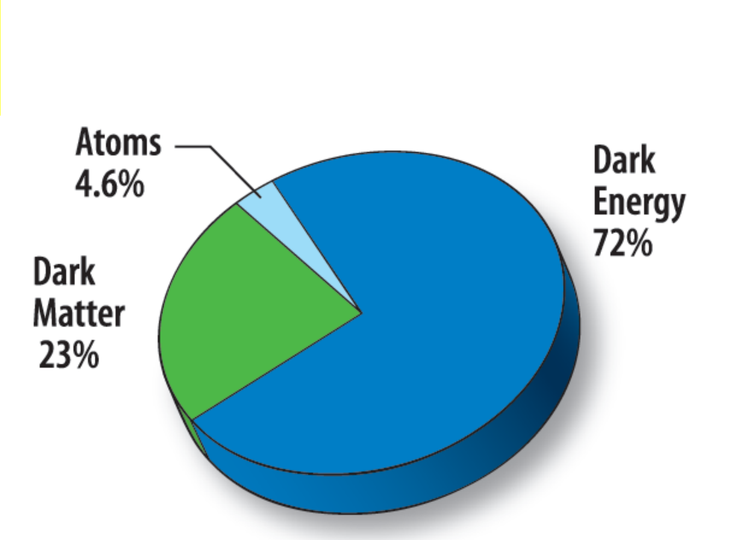


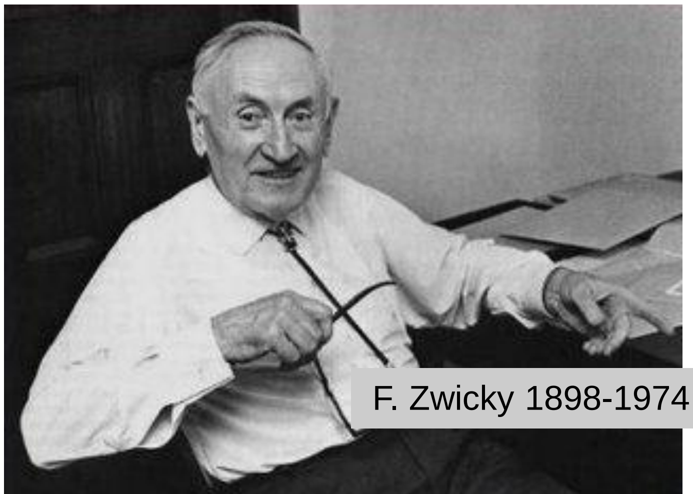


- In R-parity is conserved, SUSY particles are produced in pairs and the lightest SUSY particle (LSP) becomes stable
    - $R=(-1)^{3(B-L)+2s}$
- No direct observation of SUSY particles, but only SM particles are reconstructed directly
    - No mass peaks
- LSP escapes the detector undetected producing a missing transverse energy (E_T^{miss})
- Evidence of SUSY is done by establishing an excess of events in some region of phase space
    - Crucial to understand the contribution from SM processes

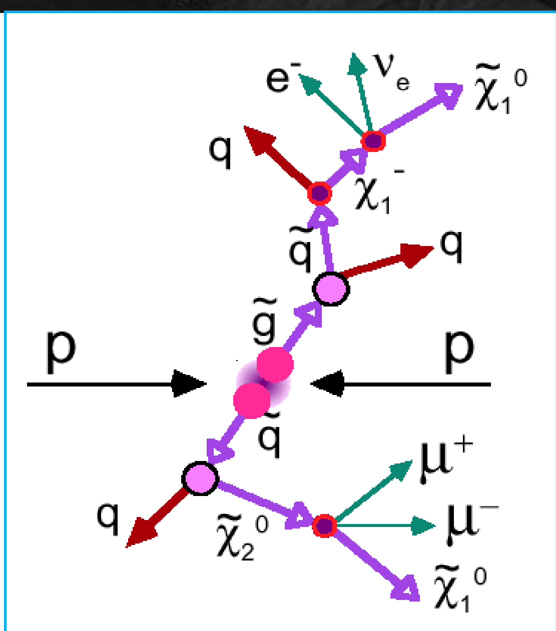
Dark Matter in the Universe

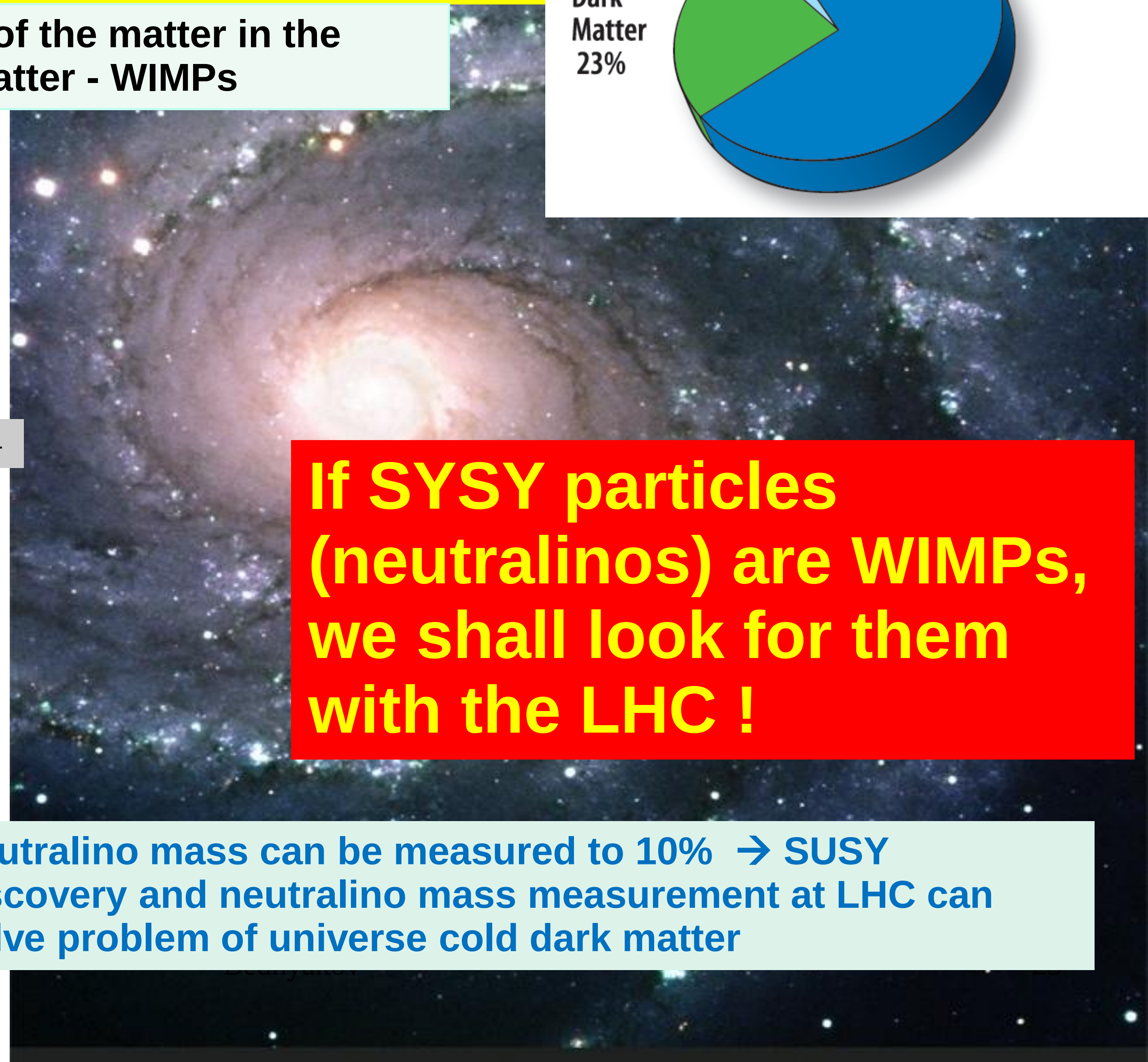
Astronomers say that most of the matter in the Universe is Invisible Dark Matter - WIMPs





F. Zwicky 1898-1974



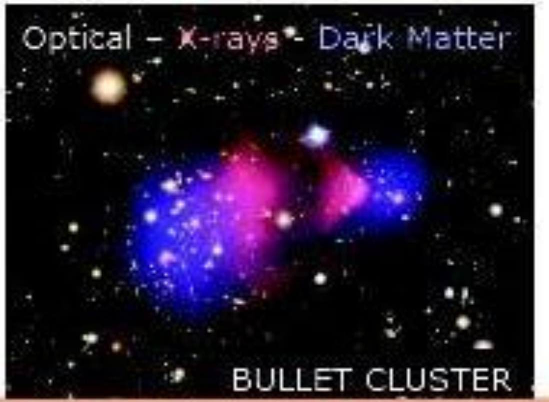


If SYSY particles (neutralinos) are WIMPs, we shall look for them with the LHC !

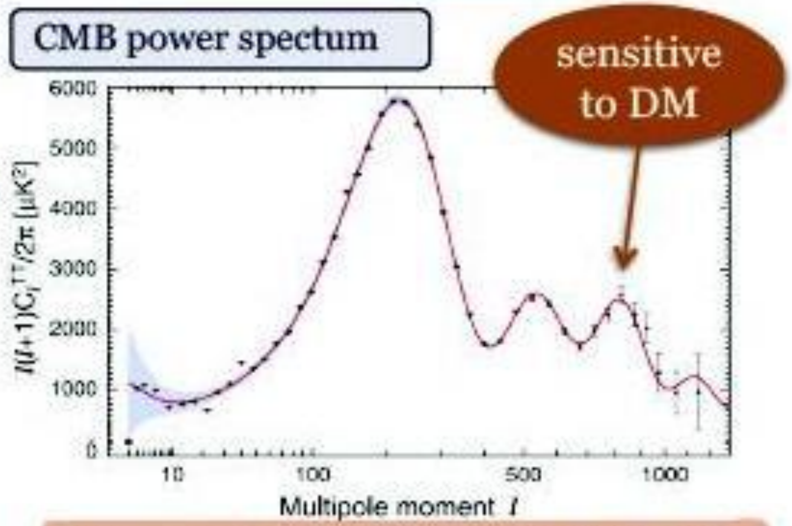
Neutralino mass can be measured to 10% → SUSY discovery and neutralino mass measurement at LHC can solve problem of universe cold dark matter

Dark matter cosmological evidence

- Astrophysical (gravitational) observations
  - galactic rotation curves
  - velocity dispersions of galaxies
  - gravitational lensing
  - structure formation
- The case for *Cold DM*
  - large structure formation disfavour:
    - ulta-relativistic (*hot DM*): neutrinos ...
    - relativistic (*warm DM*): sterile neutrinos
  - ➔ CDM: non-relativistic matter
- Precise DM measurements
  - Cosmic Microwave Background (CMB)
  - WMAP



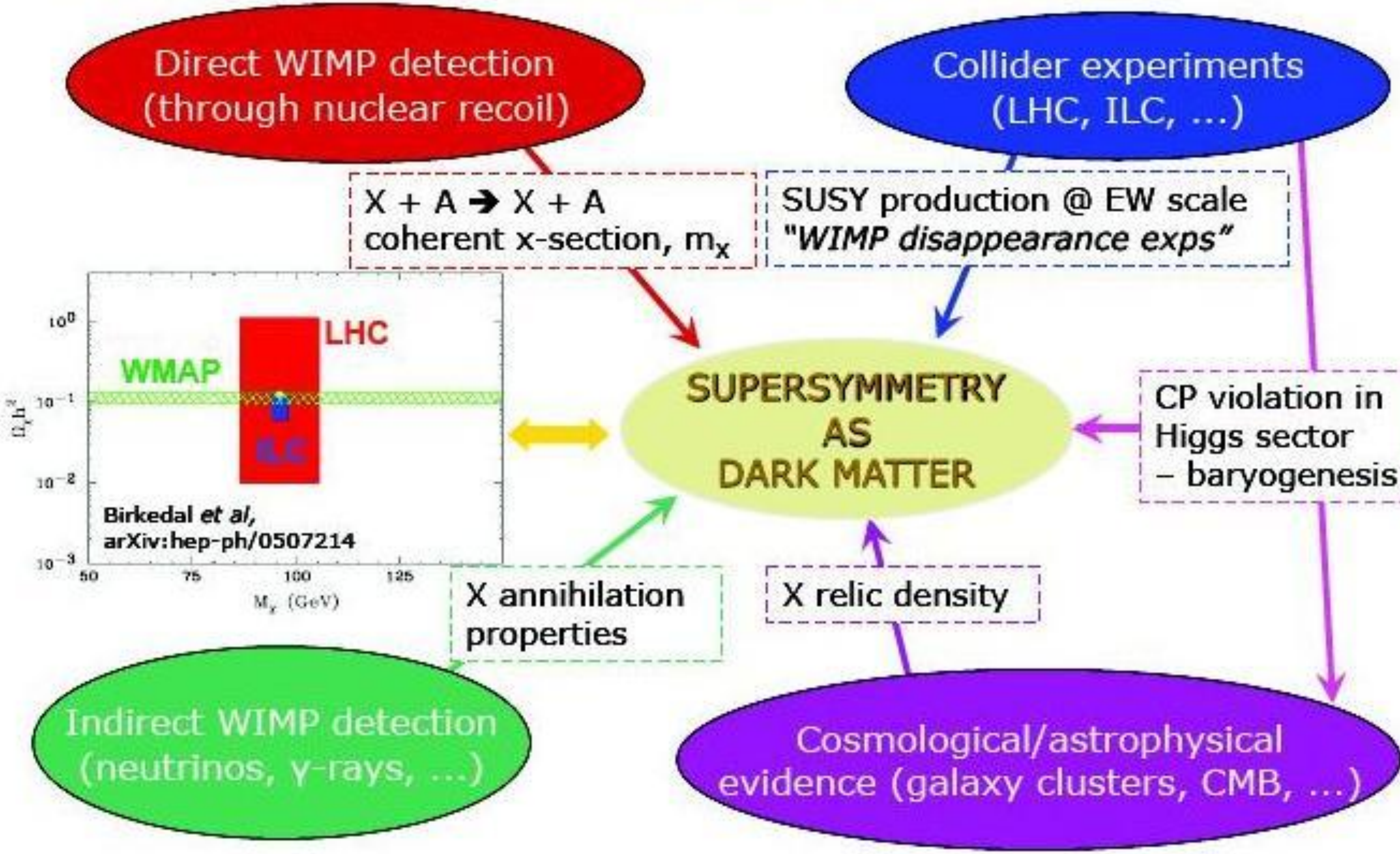
Bradac et al, ApJ 652 (2006) 937



D Larson et al [WMAP], arXiv:1001.4635

Можно ли “увидеть” темную материю НЕ-гравитационно?

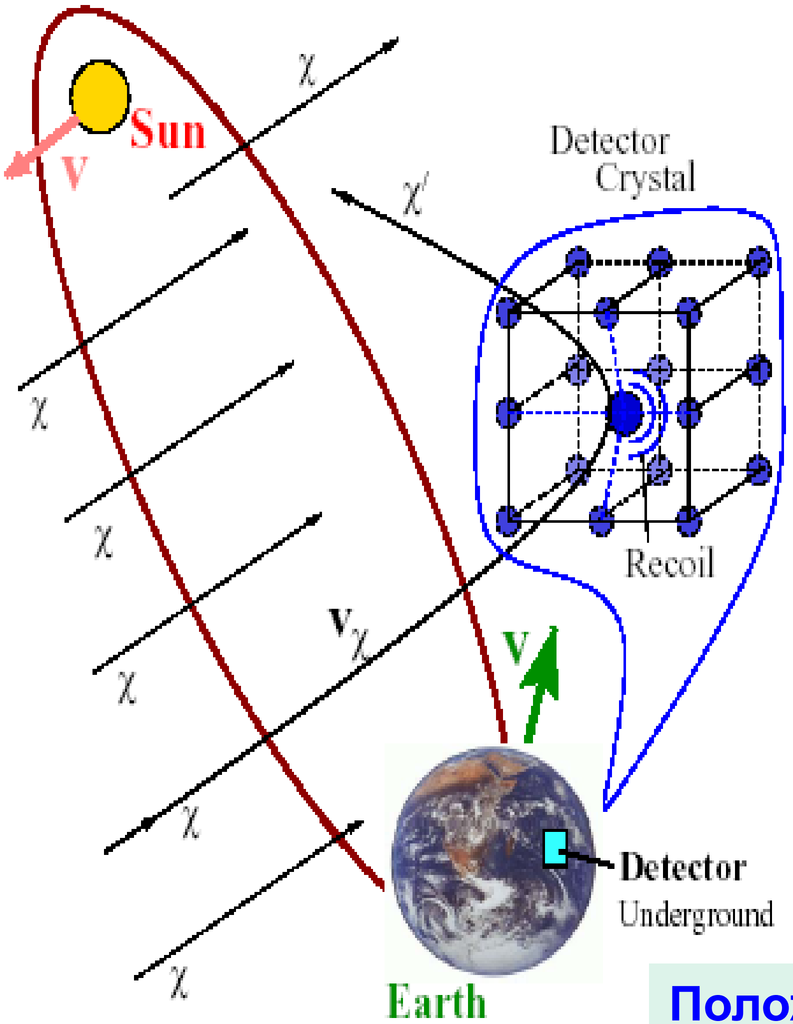
WIMP/SUSY dark matter overview



Прямое детектирование темной материи

The lightest SUSY particle (LSP) neutralino-χ is stable (R-parity!)

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

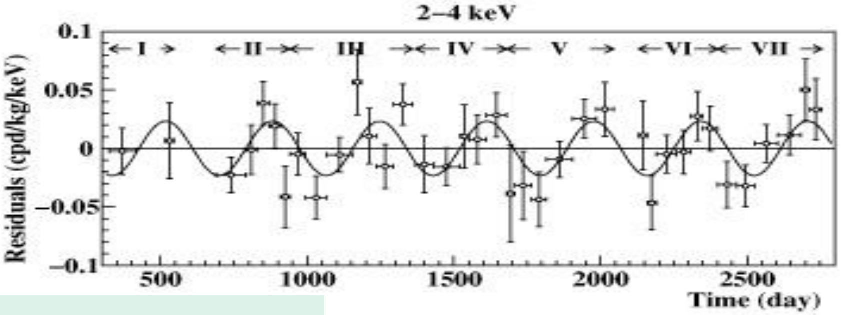


The LSP can be detected in the dark matter detector by elastic scattering.

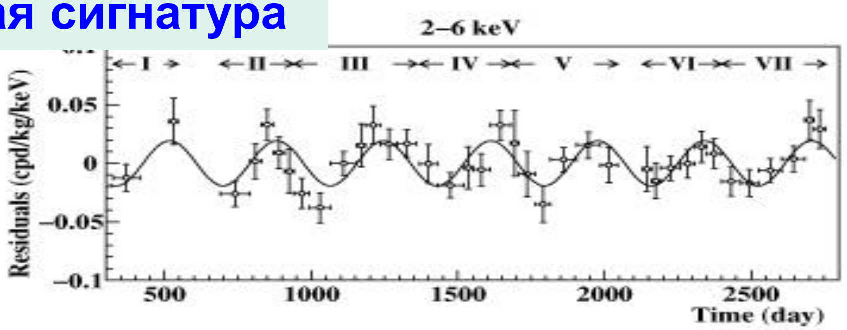
The recoil can be detected by ionization or scintillation, etc.

The evidence for existence of SUSY can be proved in these experiments.

The DAMA/LIBRA claims observation of DM due to ANNUAL MODULATION.

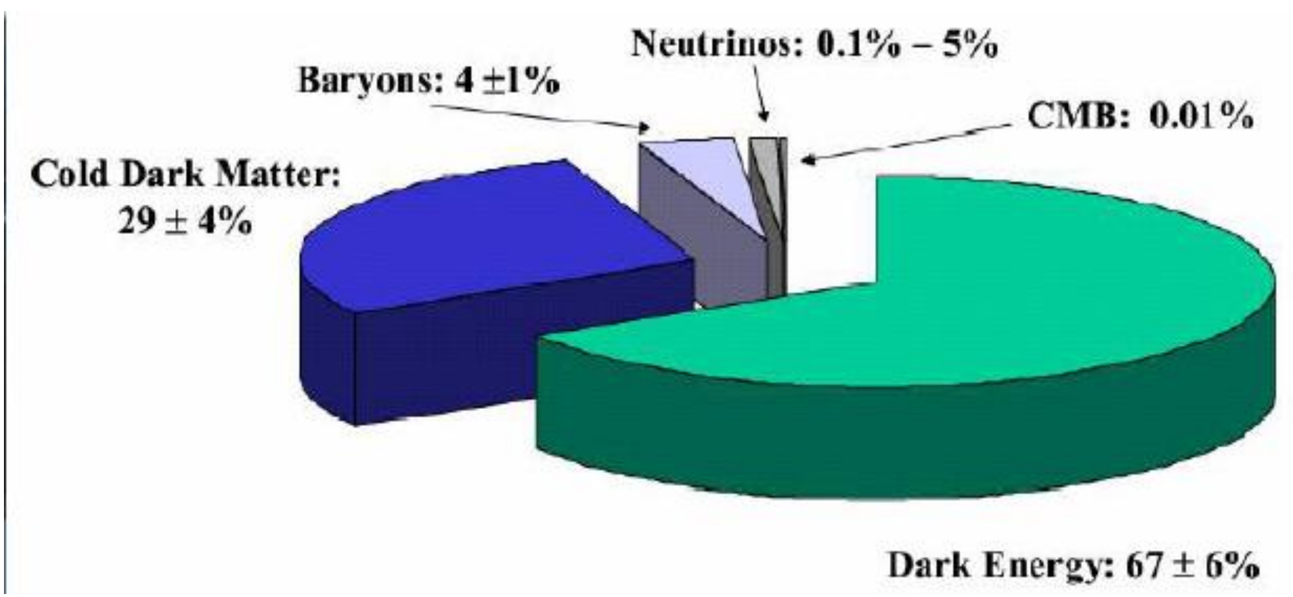


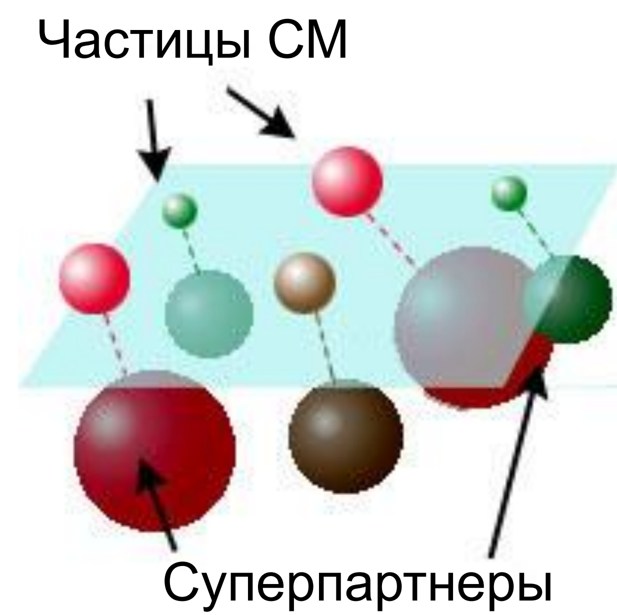
Положительная сигнатура



“Установка” для детектирования темной материи на Земле путем регистрации годовой вариации сигала (annual modulation)

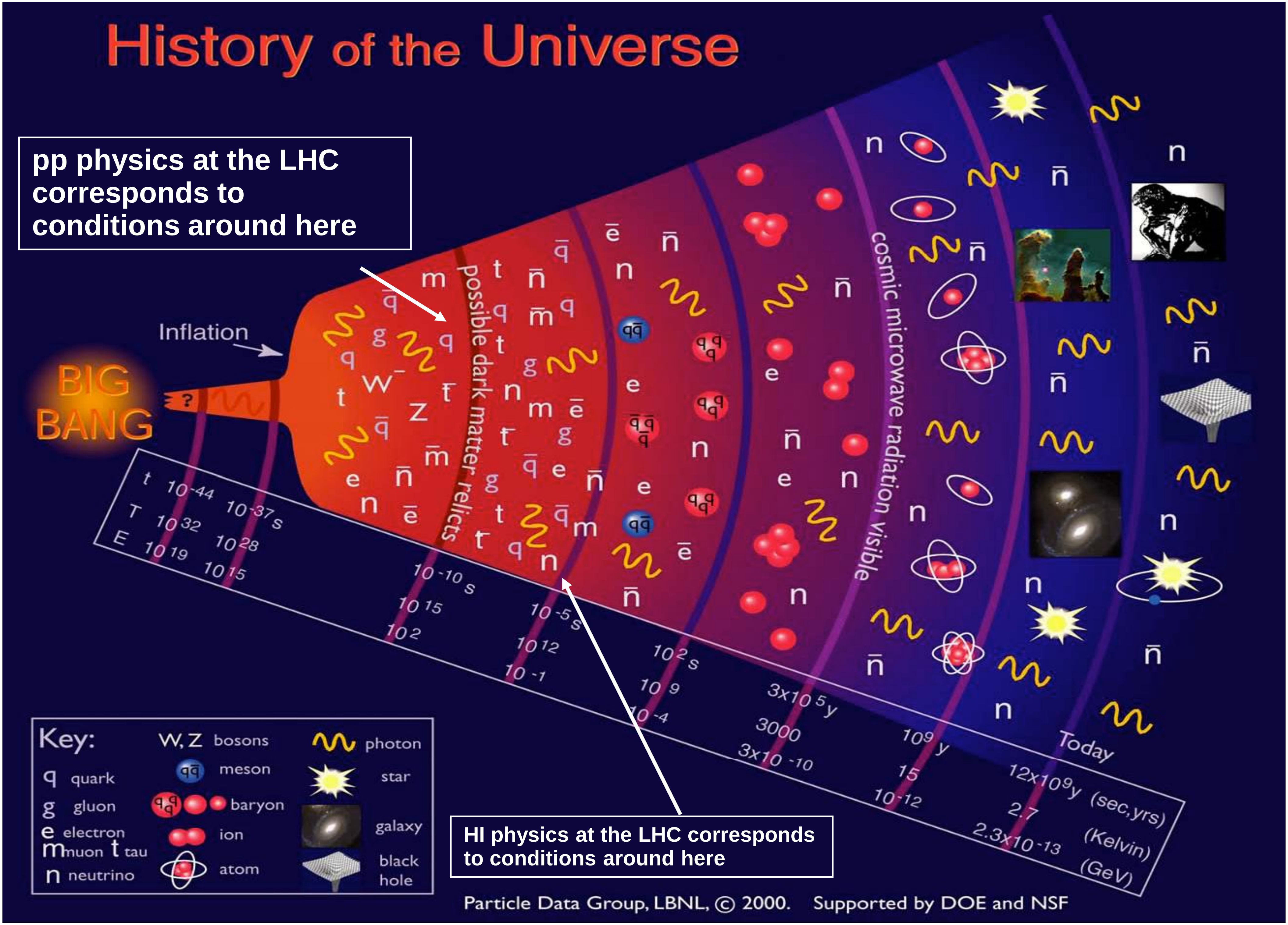
Суперсимметрия (SUSY) – отличное решение проблемы темной материи!





Решение проблемы нехватки массы во Вселенной (холодной темной материи) — легчайший суперпартнер!

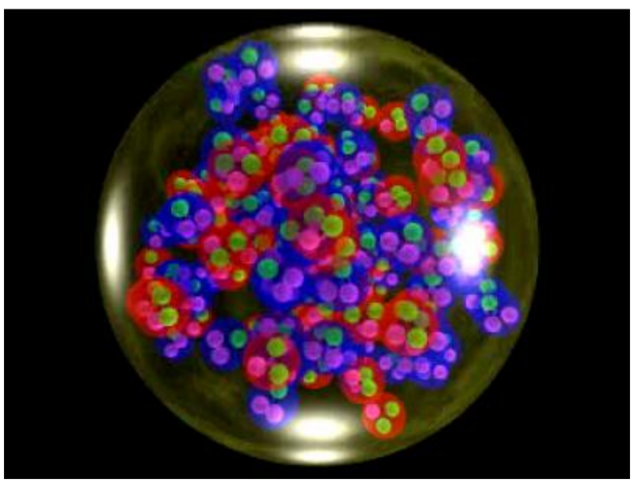
pp physics at the LHC corresponds to conditions around here



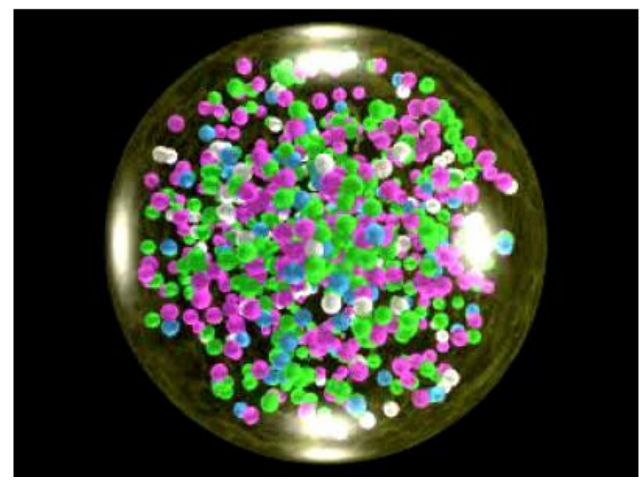
HI physics at the LHC corresponds to conditions around here

Что еще нового хотим найти?

- Исследовать новое состояние вещества — кварк-глюонную плазму, возникающую при столкновении сильно разогнанных ядер свинца.
- Согласно модели Большого Взрыва в таком состоянии было вещество через 10^{-25} секунды после Большого Взрыва.



Газ адронов



Газ кварков

Однако не надо упускать из вида (почти) бесконечную разницу в гравитационном заряде ранней Вселенной и двух протонов БАК!

Детектор АТЛАС

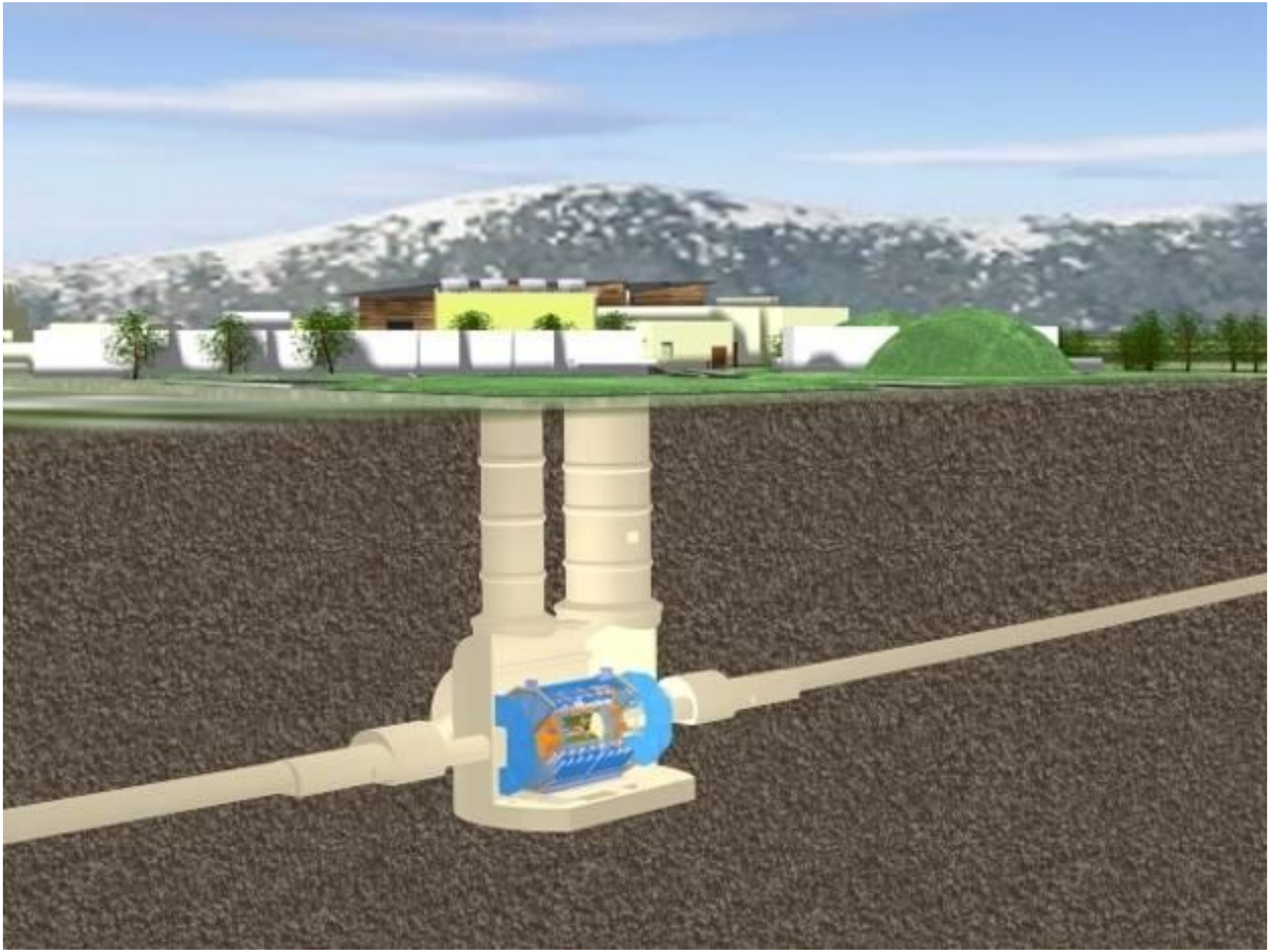
Размер установки АТЛАС не уступает по высоте 6-и этажному дому в ЦЕРН

ATLAS и CMS – многоцелевые экспериментальные установки, нацеленные на решение всего спектра физических задач LHC

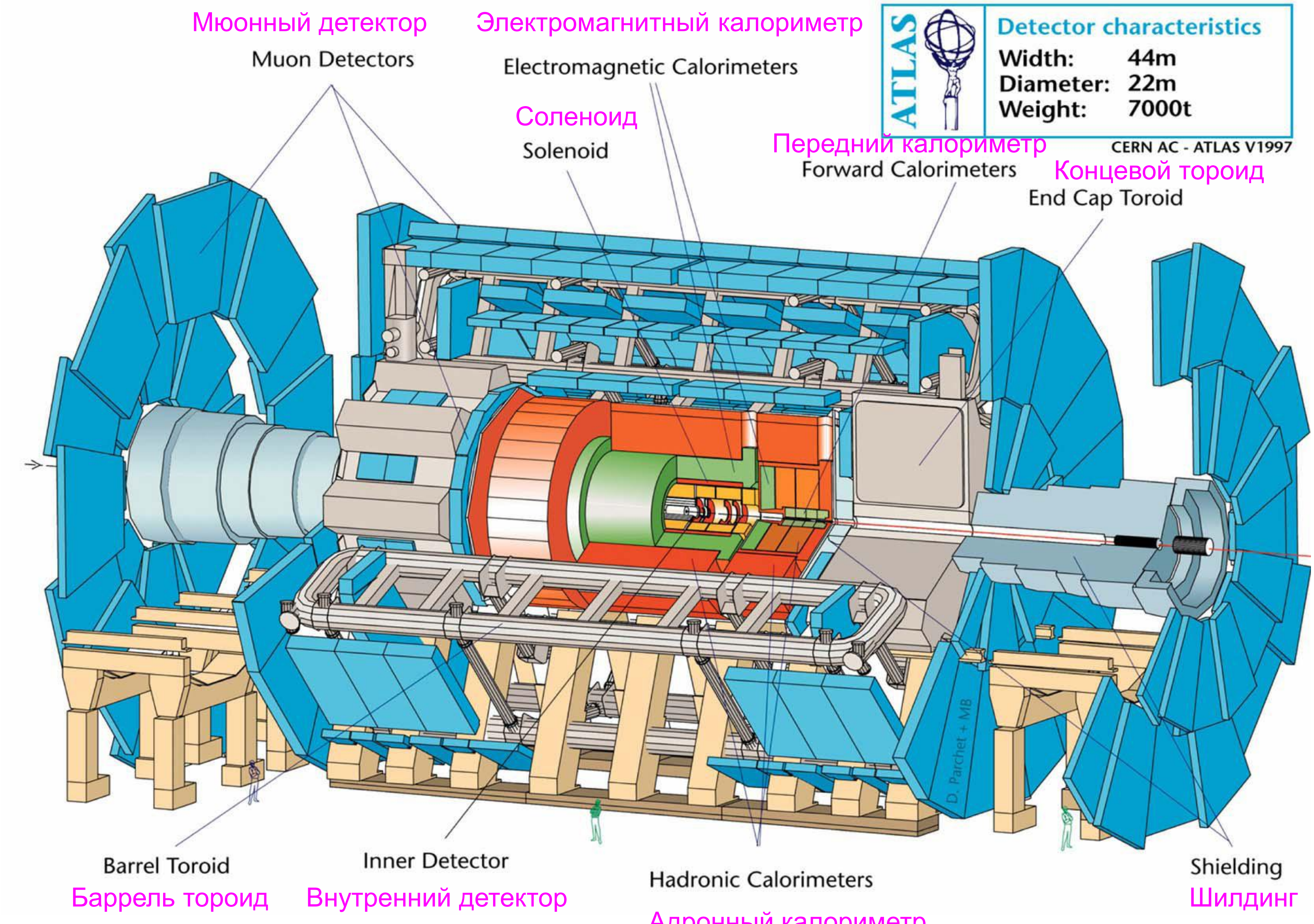
Вид сверху на место расположения АТЛАС

(Across the street from the CERN main entrance)

The Underground Cavern at Pit-1 for the ATLAS Detector



Структура Установки АТЛАС



The ATLAS detector

Для измерение импульсов мюонов

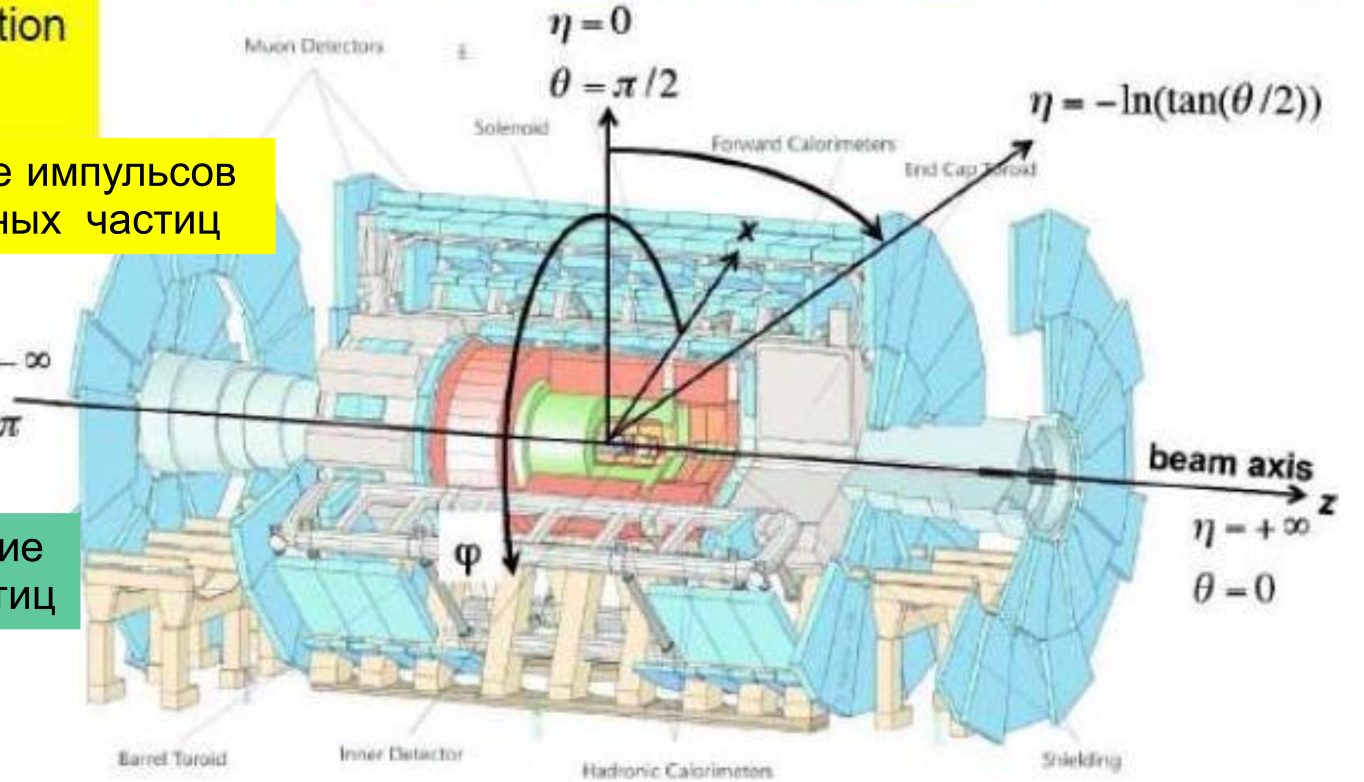
Muon spectrometer (|η|<2.7) : air-cores toroids with gas-based chambers. Trigger and measurement. Momentum resolution <10% up to $E\mu \sim 1$ TeV

Inner Detector (|η|<2.5) :
Si pixel, SCT, TRT
Tracking and vertexing. e/π separation
$\sigma/p_T \sim 0.038\%\ p_T\ (\mathrm{GeV}) \oplus 1.5\%$

Для измерение импульсов всех заряженных частиц

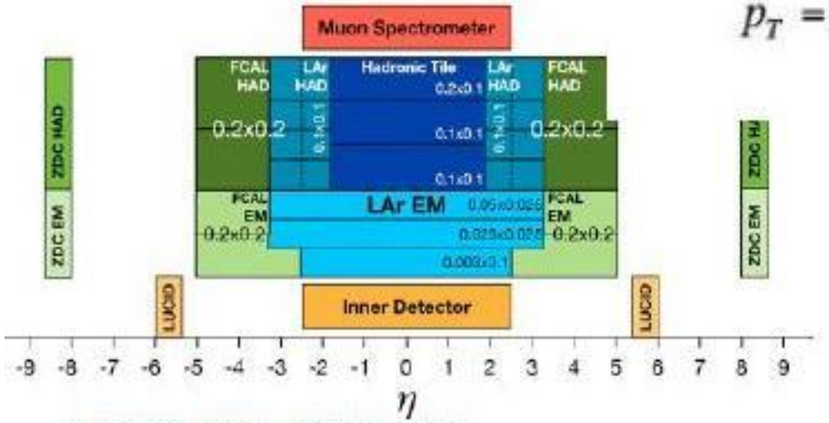
EM calorimeter (|η|<3.2) :
Pb/LAr accordion
Trigger and e/γ reco and id
$\sigma/E \sim 10\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 0.7\%$

Для измерение энергий частиц



$$\vec{p}_T = (p_x, p_y) \qquad p_T = p\sin\theta, \quad E_T = E\sin\theta \qquad \vec{E}_T^{miss} = -\sum_{clusters\, i} E_i \hat{n}_i$$

ZDC (|η|>8.3) :
Zero Degree Calorimeter
for Heavy Ions studies

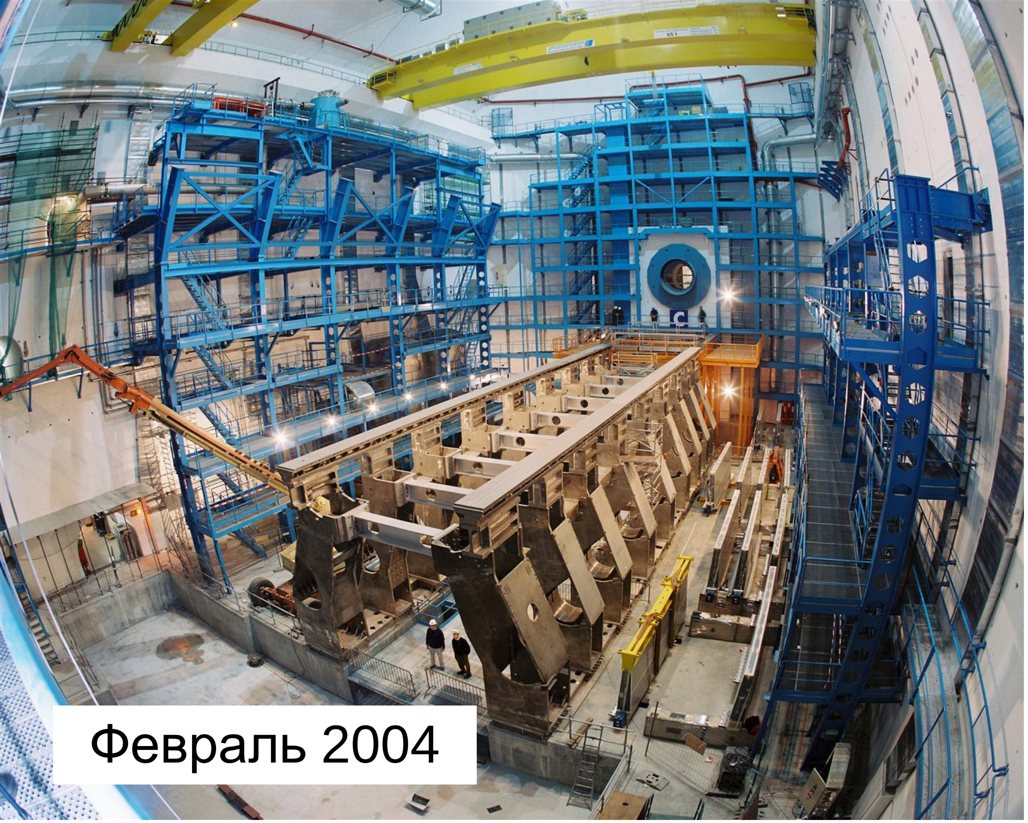


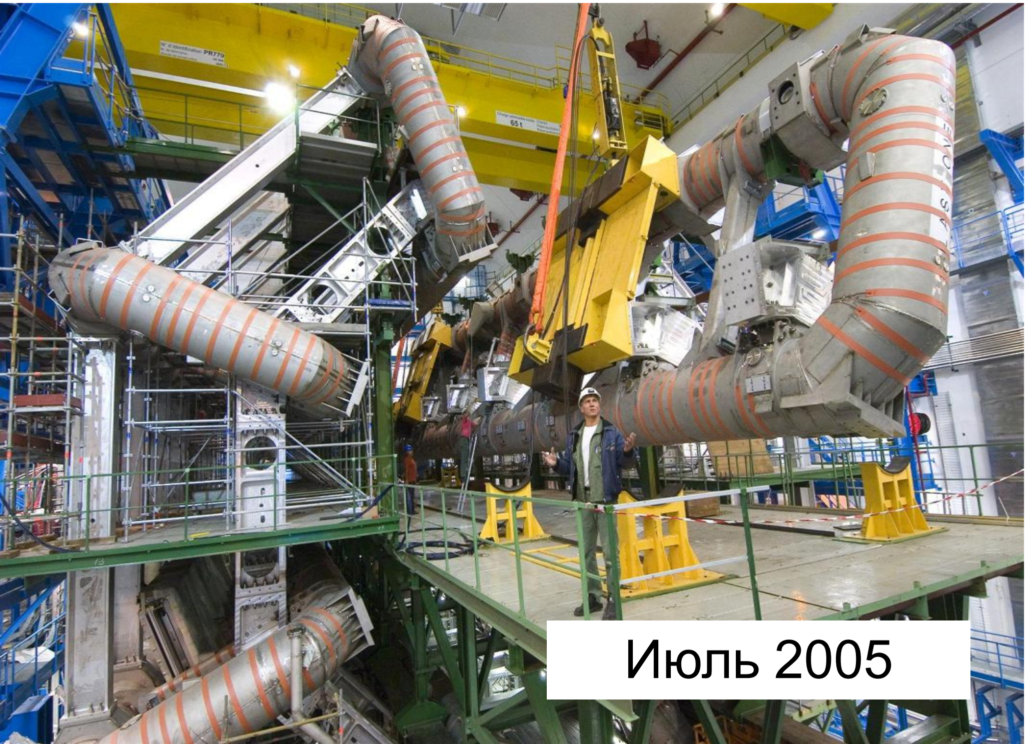
HAD calorimeter (|η|<5) :
Fe/scintillator tiles (central),
Cu/W Lar (fwd),
Trigger, jets and Etmiss.
$\sigma/E \sim 50\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 3\%$

Для измерение энергий частиц

Строительство АТЛАС

Cavern preparation 2000

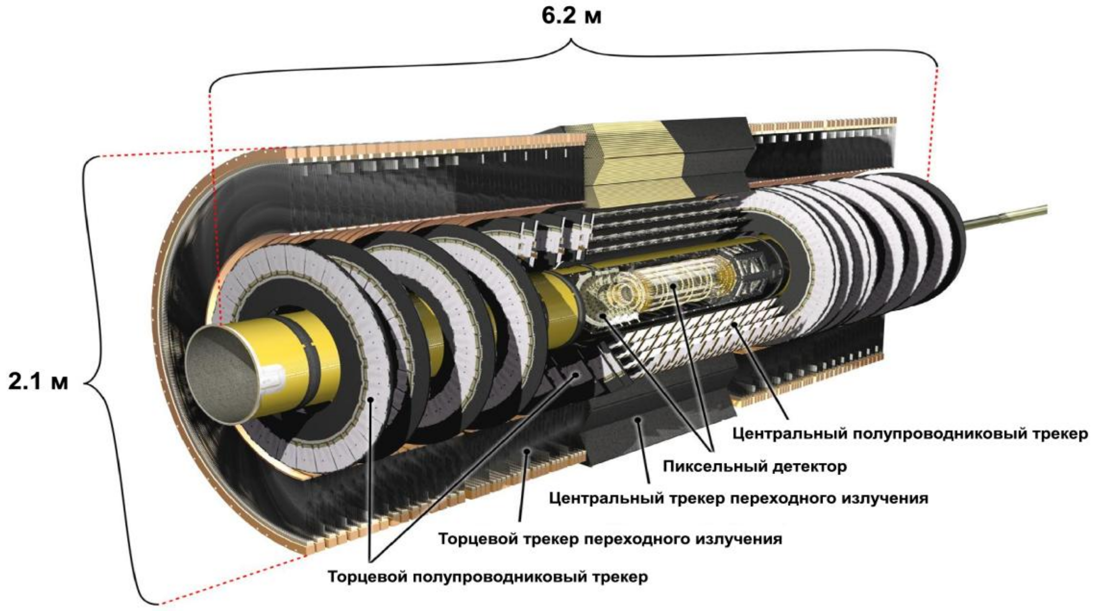


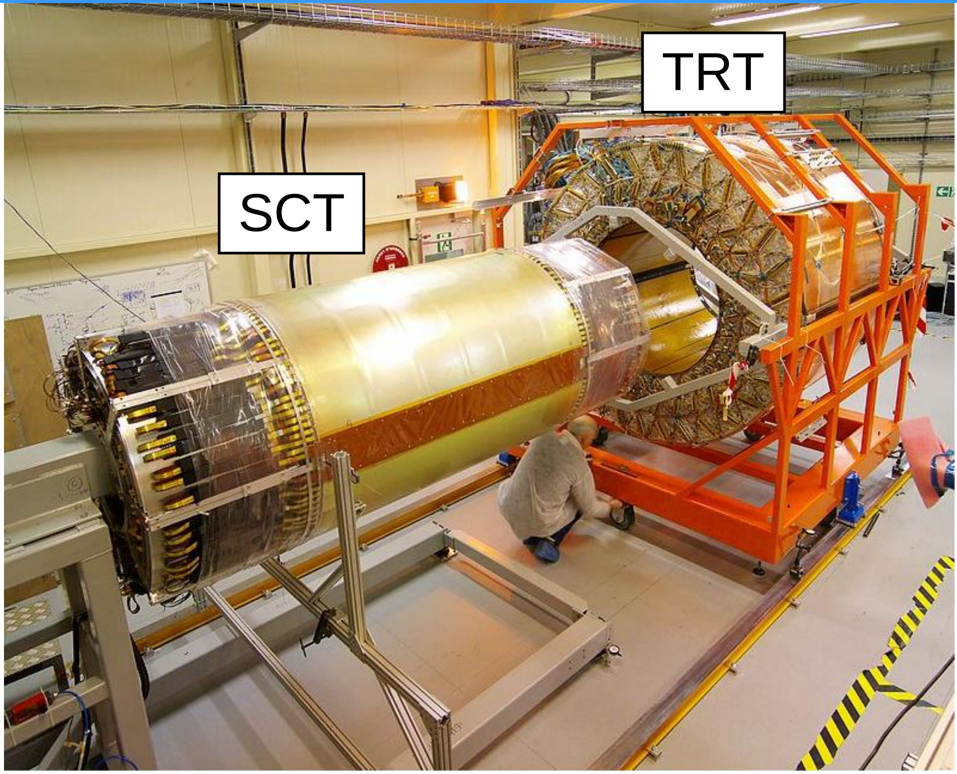


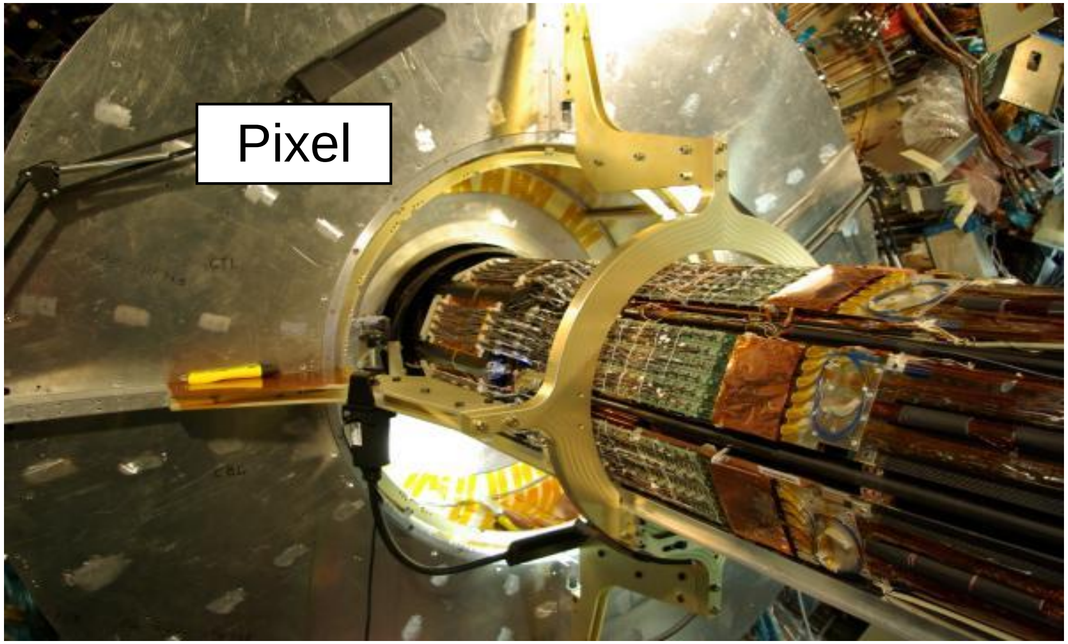
Длина 25.3 м
Внешний диаметр 20.1 м
Всего 8 катушек
Общий вес ~830 тонн
B=4 T
I=20.5 kA
T=4.7 K

Внутренний детектор

B=2T, 100 млн каналов





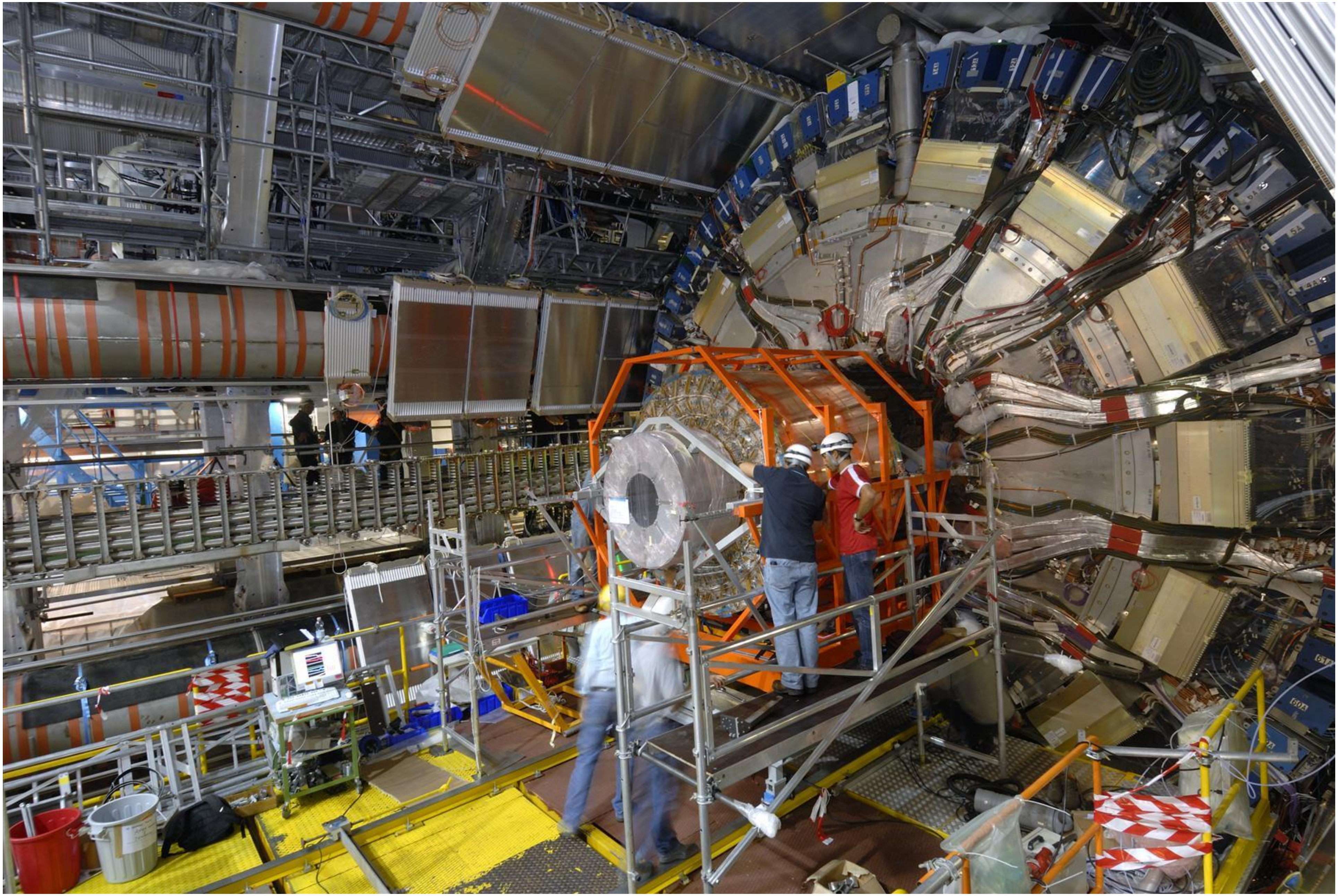


Pixel: 1744 «модуля»; акт. вещество - Si 250 мкм толщиной4; ~47 000 пикселей на модуль и 50x400 мкм каждый. При R=4см -- "B-слой" (B-физика)

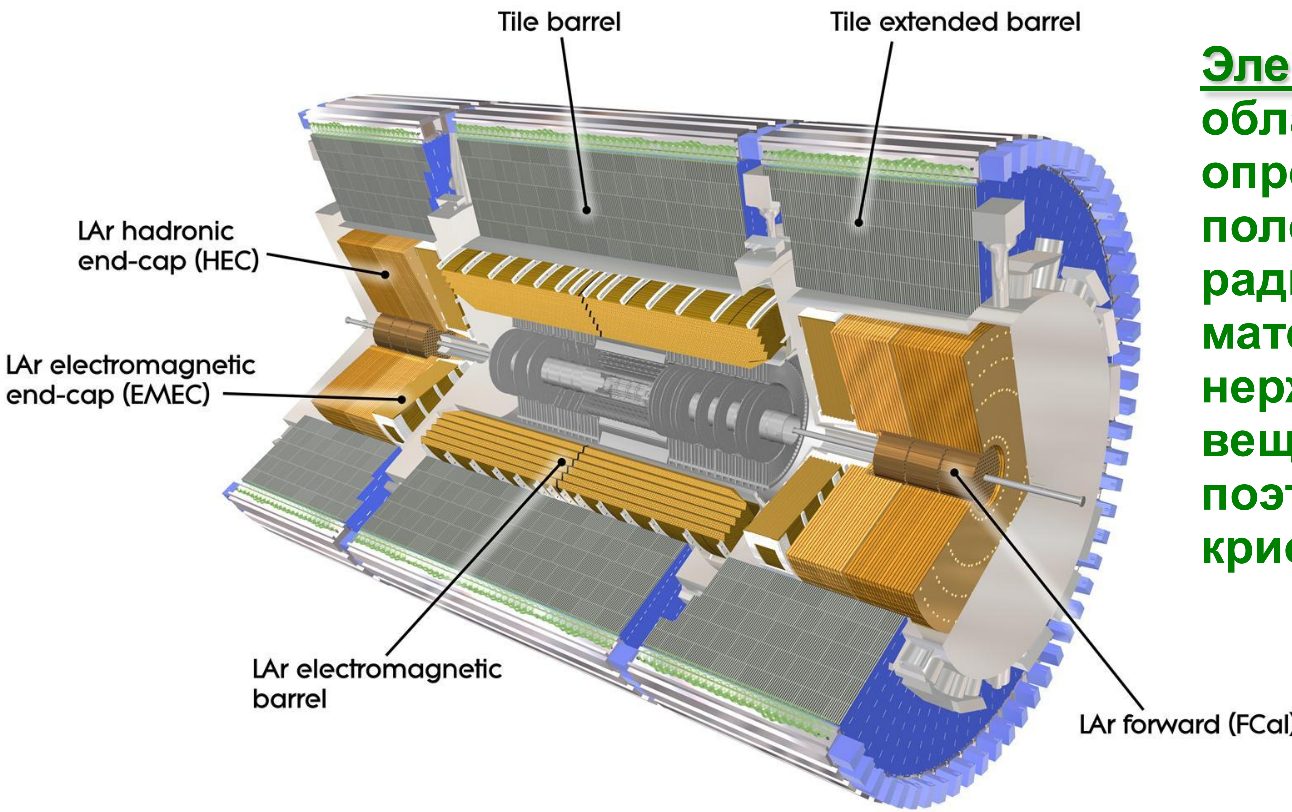
SCT: 4 двойных слоя кремниевых "полосок", расположенных вдоль плоскости, перпенд-й оси пучка. В двойном слое 2-й слой повернут на 40 мрад по отношению к 1-му. Каждая "полоска" имеет ширину 80 мкм и длину 12 см.

TRT: состоит из ~36 слоев трубок диаметром 4 мм и длиной 144 см, расположенных вдоль оси пучка

Внутренний детектор



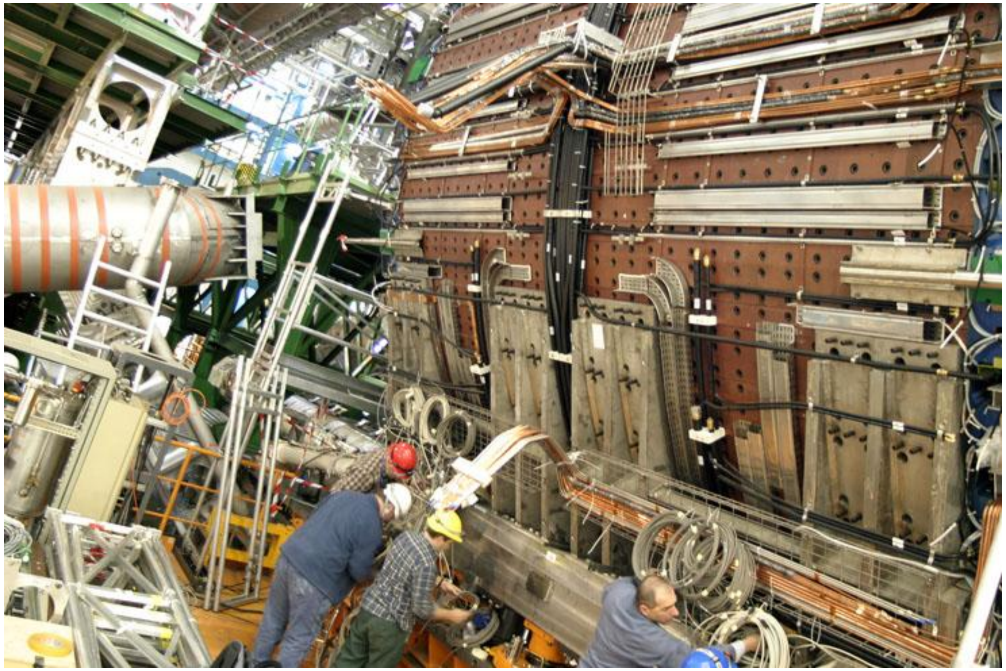
Система калориметров



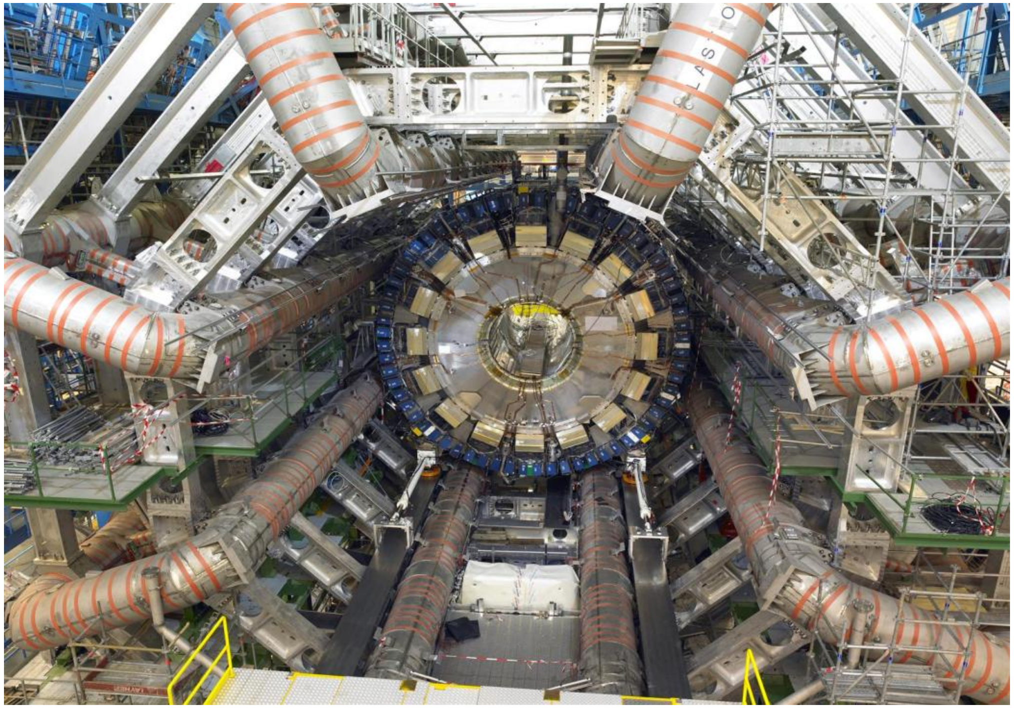
Электромагнитный калориметр обладает высокой точностью определения энергии и положения этой энергии (0,025 радиан). Поглощающие энергию материалы — свинец и нержавеющая сталь, а активное вещество — жидкий аргон, поэтому он находится в криостате.

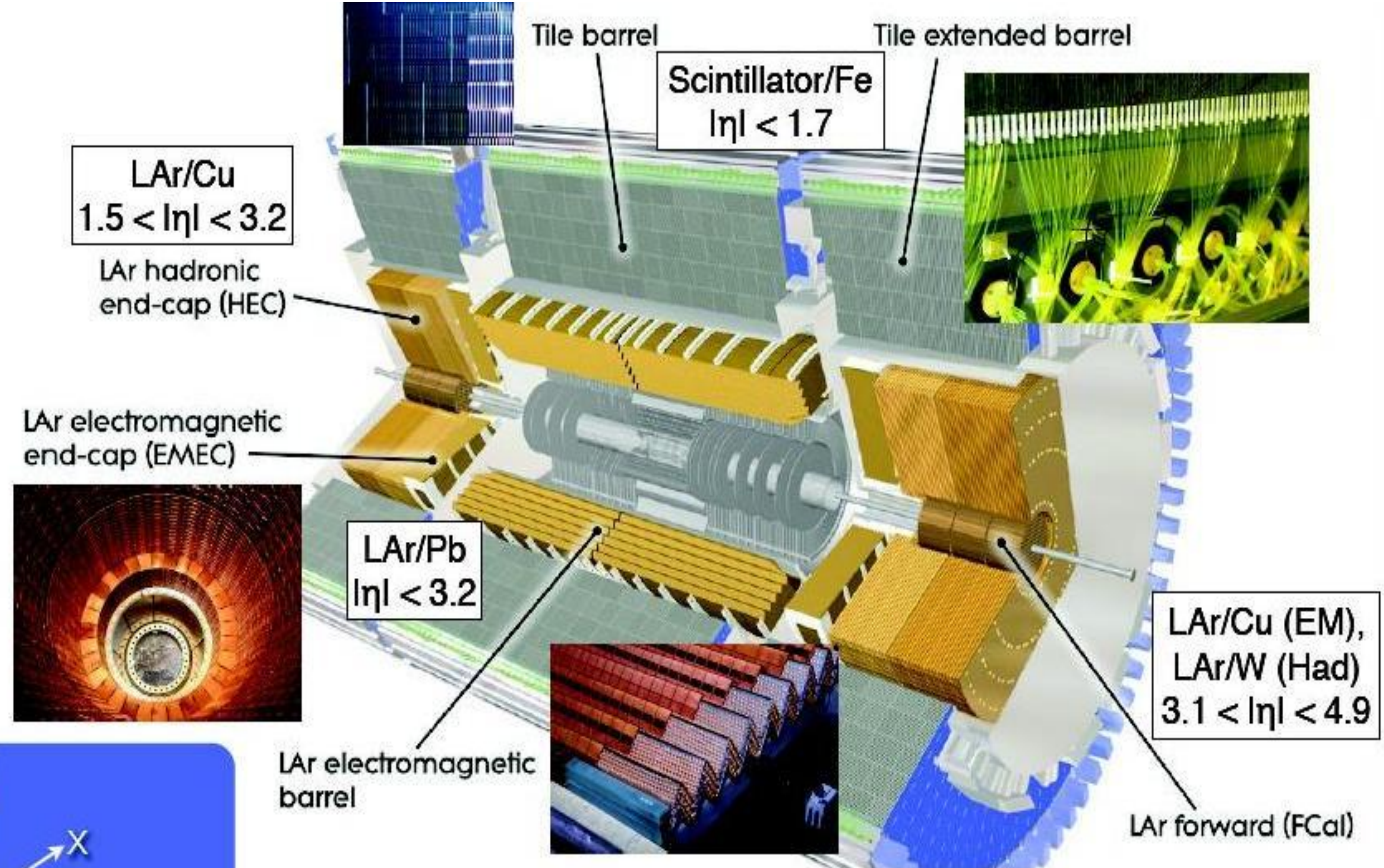
Адронный калориметр обладает меньшей точностью в определении энергии и положения этой энергии (0,1 радиан). Поглощающие энергию материалы — нержавеющая сталь, а активное вещество — сцинтилляционные пластинки.

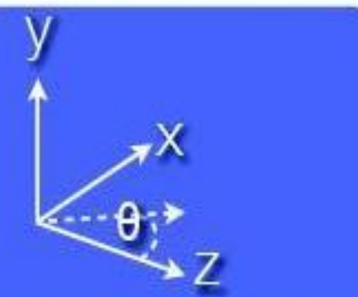
Октябрь 2004



Ноябрь 2005







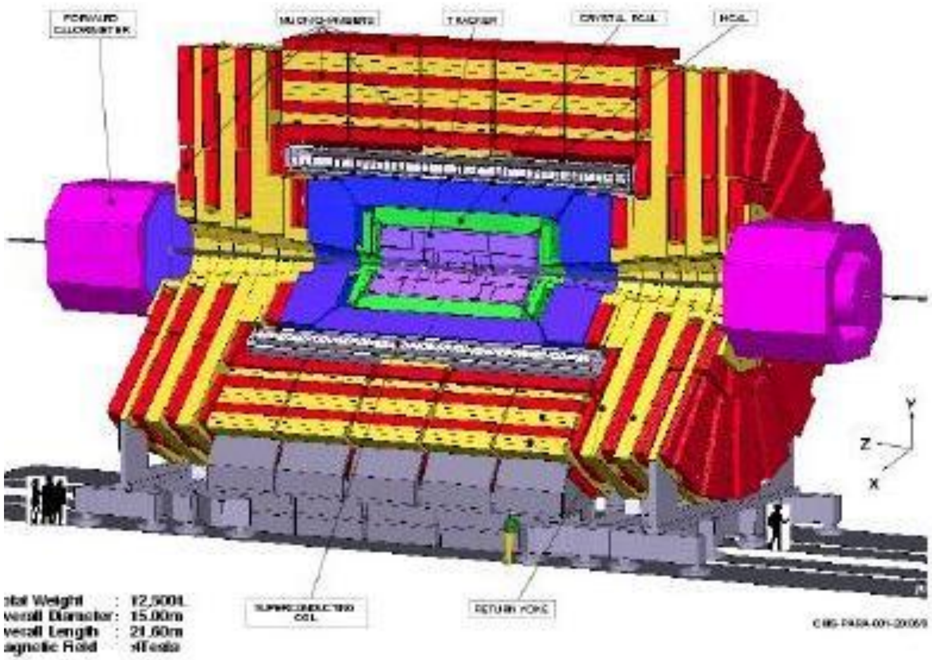
$$\eta = -\ln(\tan\theta/2)$$

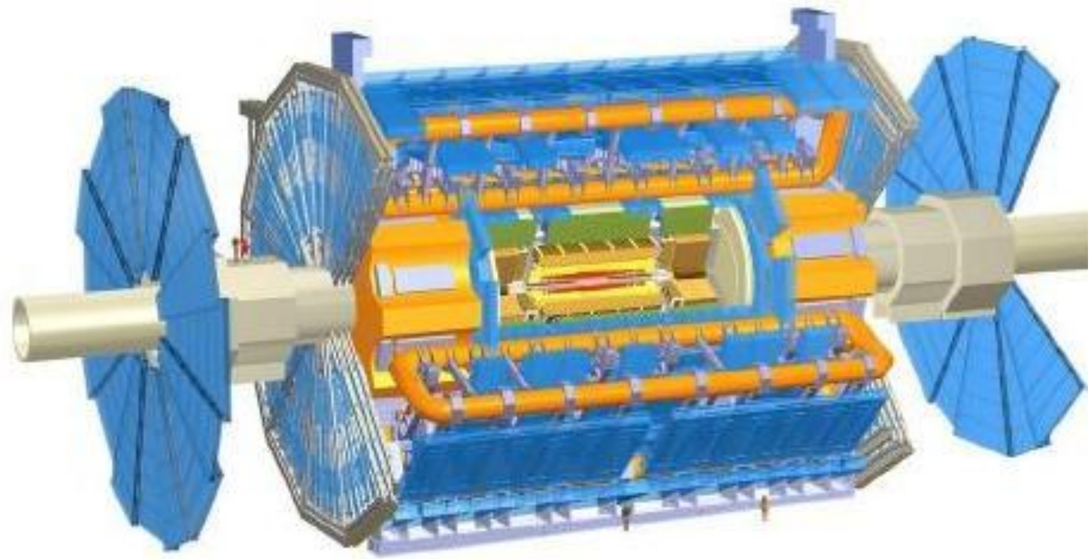
$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

ATLAS Calorimeters

Главное преимущество
Установки АТЛАС

CMS and ATLAS detectors





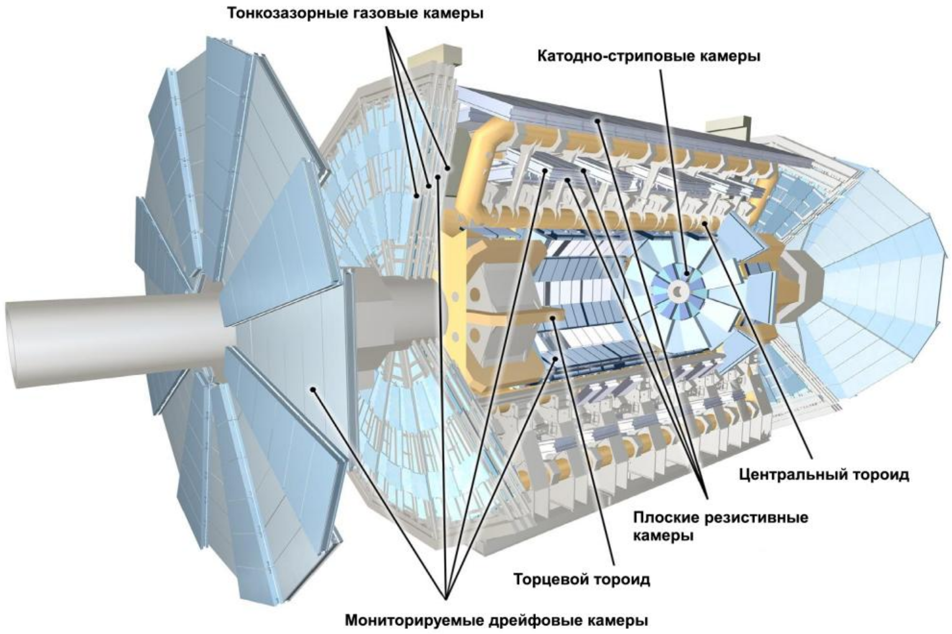
CMS:

- silicon det. (pixel, strips)
- 4T solenoid magnet
- crystal EM calorimeter $\sigma(E)/E \sim 3\%/\sqrt{E} + 0.003$, brass and scintillator had. calorimeter $\sigma(E)/E \sim 100\%/\sqrt{E} + 0.05$
- muon chambers $\sigma(p)/p < 10\%$ at 1TeV

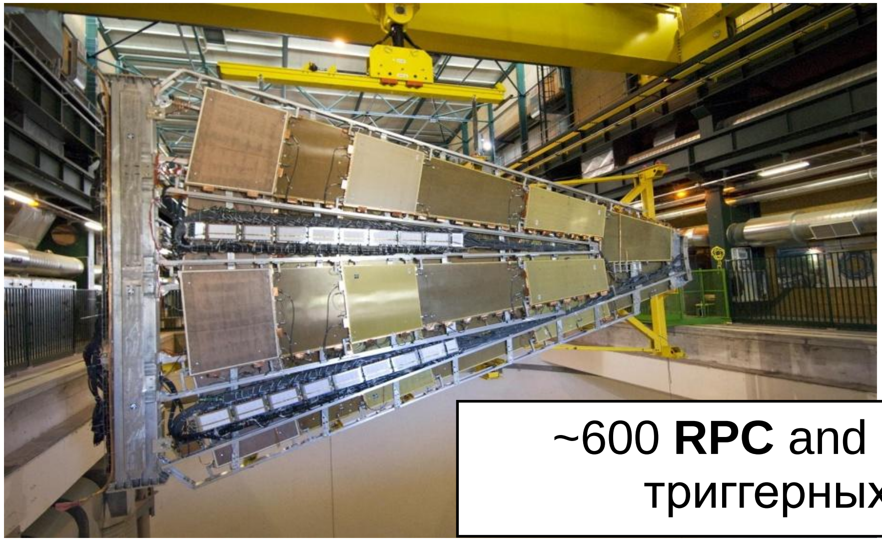
ATLAS:

- silicon det. (pixel, strips) +TRT
- 2T solenoid + toroid magnets
- LAr EM calorimeter $\sigma(E)/E \sim 10\%/\sqrt{E} + 0.007$, tile+ scintillator had. calorimeter $\sigma(E)/E \sim 50\%/\sqrt{E} + 0.03$
- muon chambers $\sigma(p)/p < 10\%$ at 1TeV

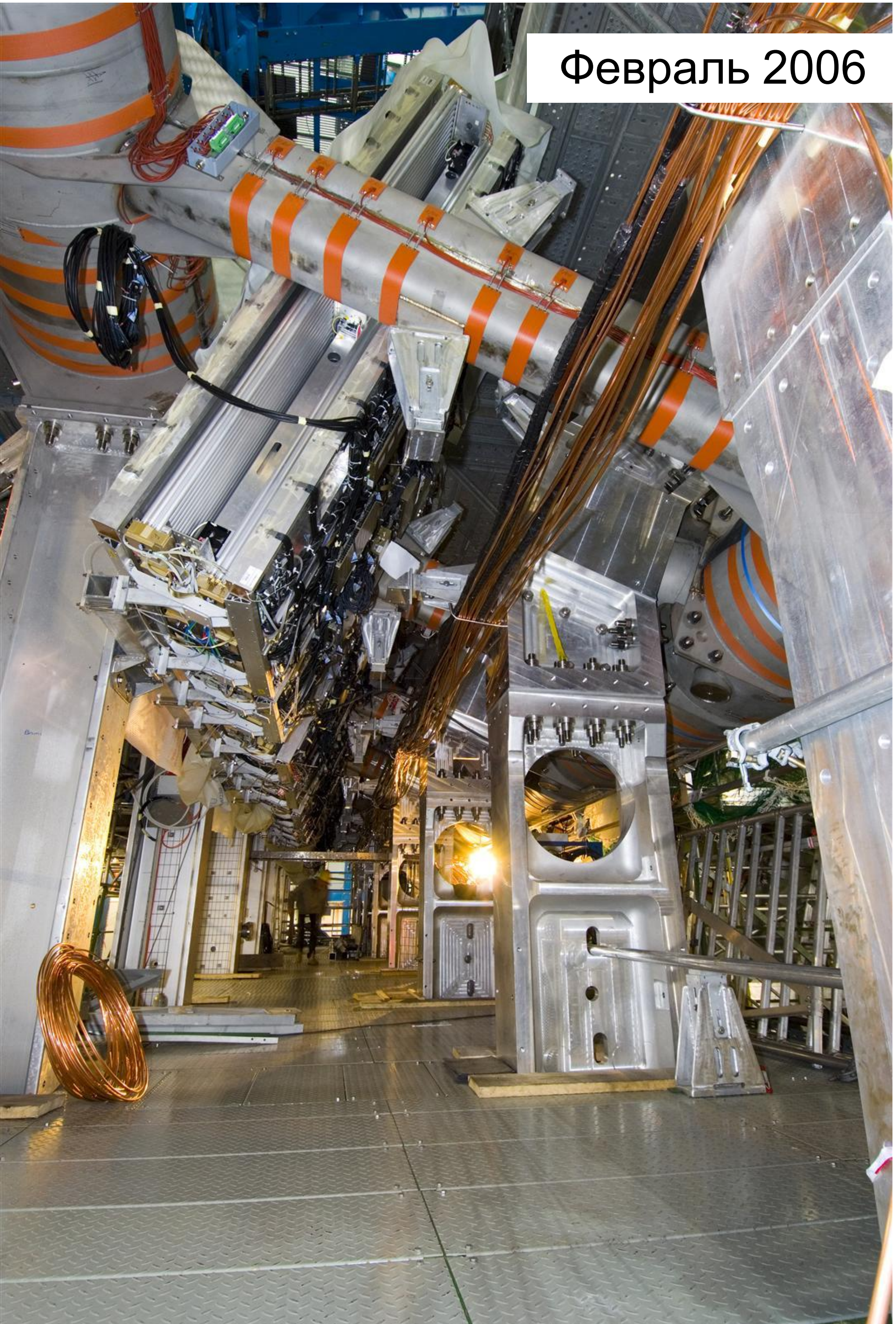
Мюонная система



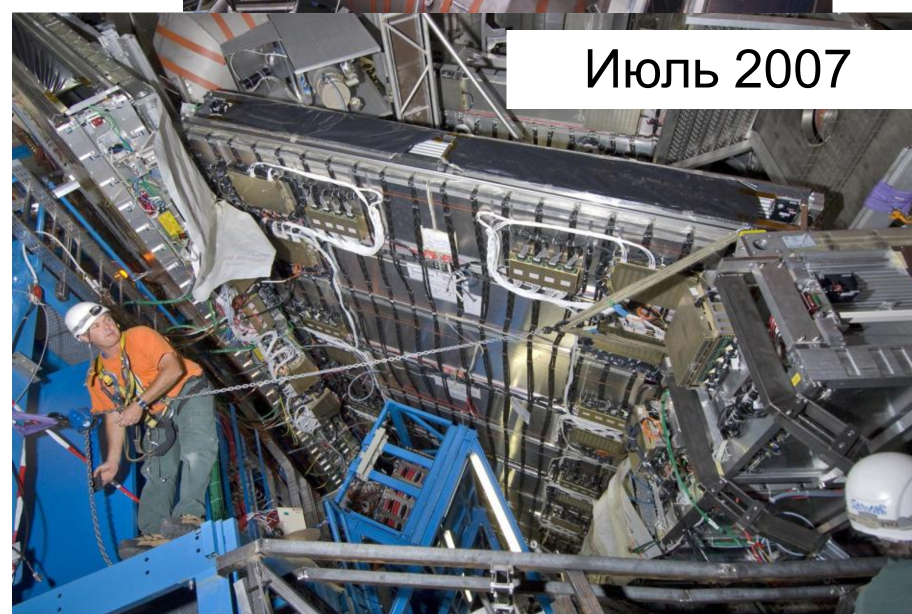
~1200 **MDT** прецизионных камер для восстановления треков частиц (**+ CSC)**

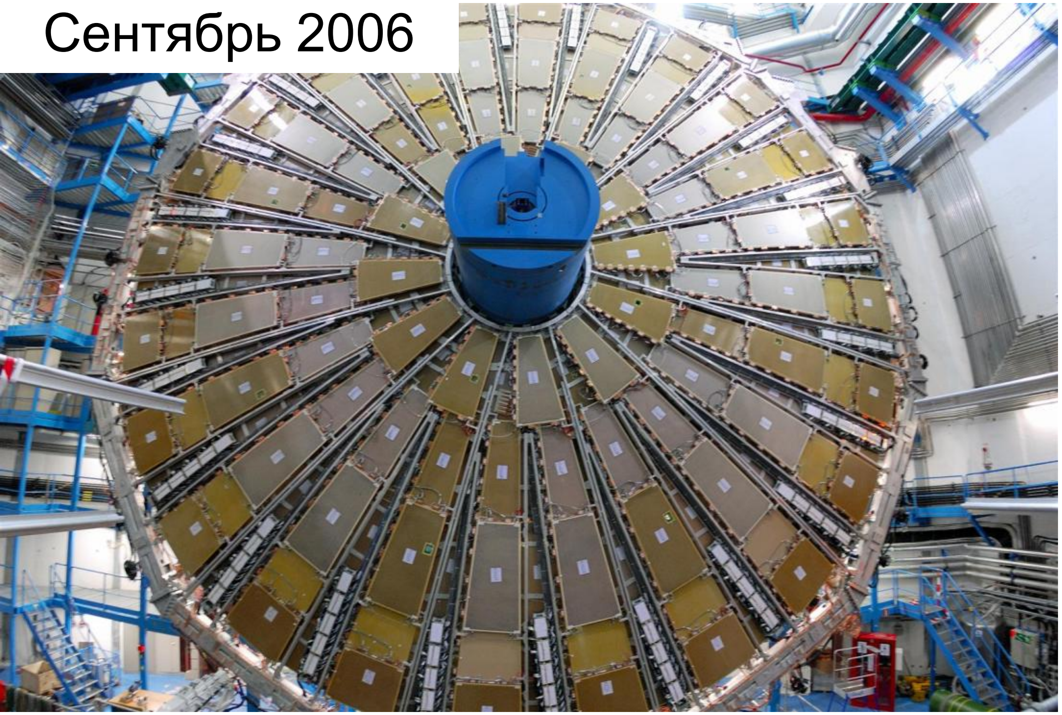


~600 **RPC** and ~3600 **TGC** триггерных камер


Февраль 2006


Октябрь 2006


Июль 2007

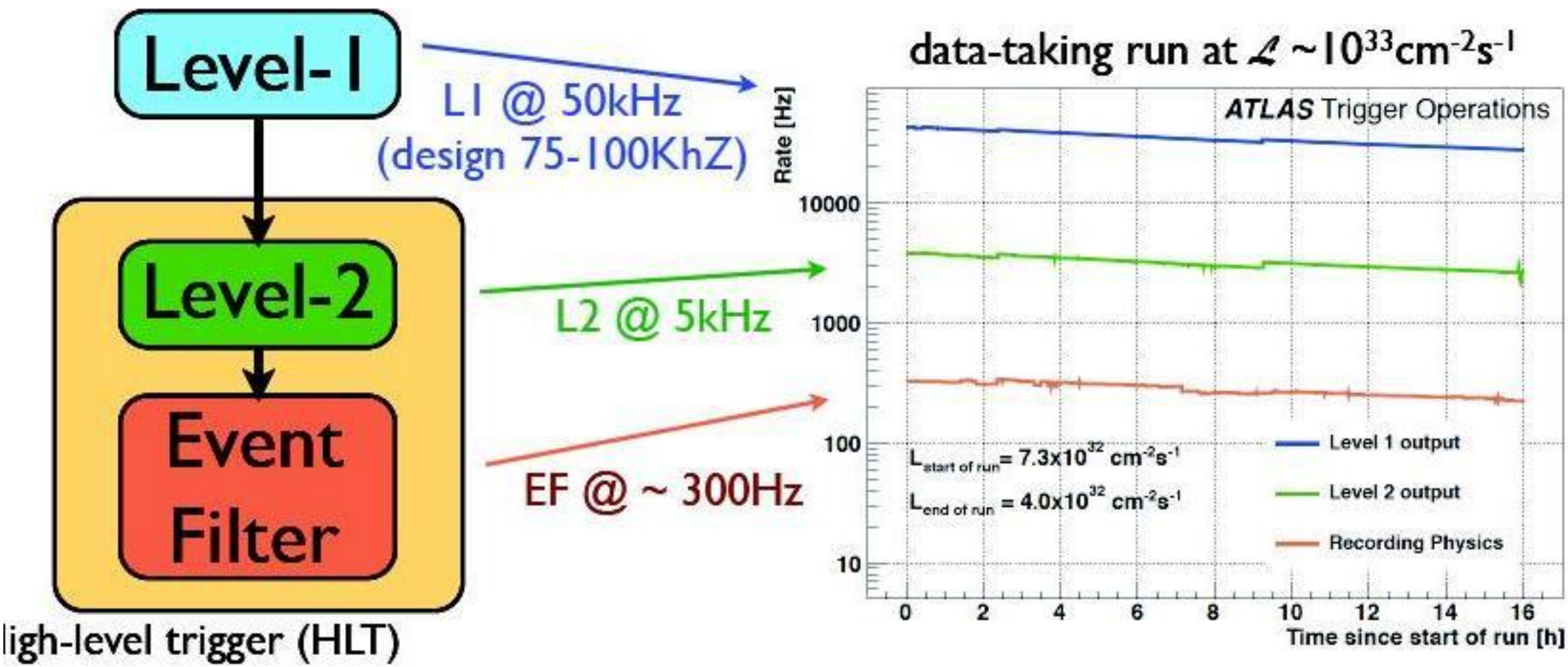


Сентябрь 2006

Сентябрь 2007

Февраль 2008

ATLAS trigger system

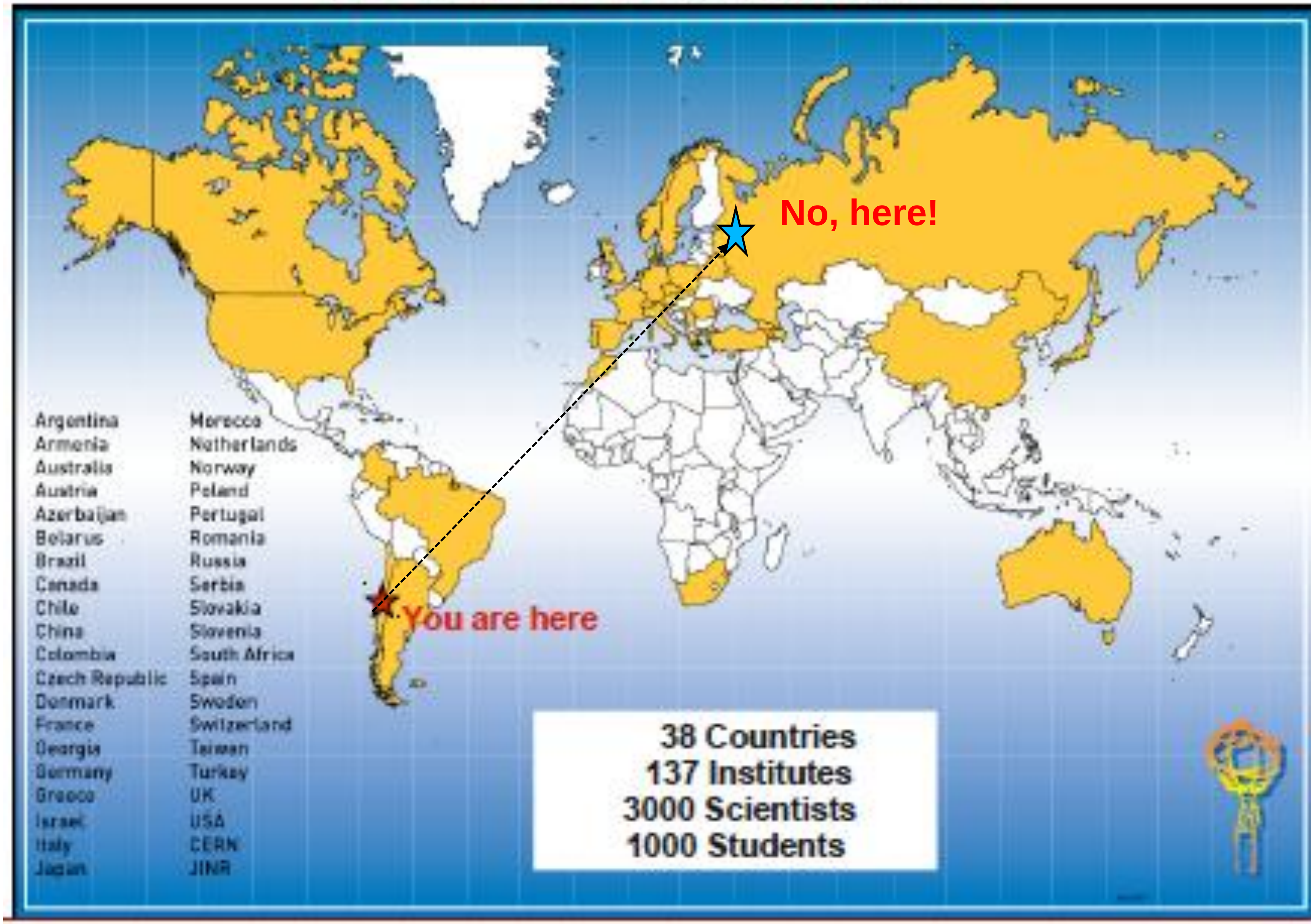


- Level-1 trigger: hardware based
- Level-2 trigger: Region of Interest based, offline-like reconstruction in the region defined by the L1 trigger
- Event Filter (EF): offline-like reconstruction of the full event

Main ATLAS triggers

Trigger objects	Offline Selection (p_T thresholds)	Trigger Selection L1	Trigger Selection EF	L1 Rate (kHz) at 3 10^{33}	EF Rate (Hz) at 3 10^{33}
Single leptons	Single muon > 20 GeV	11 GeV	18 GeV	8	100
	Single electron > 25 GeV	16 GeV	22 GeV	9	55
Two leptons	2 muons > 4 GeV	11 GeV	15,10 GeV	6	5
	2 electrons, > 15 GeV	2x10 GeV	2x12 GeV	2	1.3
	2 $\tau \rightarrow$ h > 45, 30 GeV	15,11 GeV	29,20 GeV	7.5	15
Two photons	2 photons, > 25 GeV	2x12 GeV	2x20 GeV	3.5	5
E_T^{miss}	E_T^{miss} > 170 GeV	50 GeV	70 GeV	0.6	5
Multi-jets	5 jets, > 55 GeV	5x10 GeV	5x30 GeV	0.2	9
Single jet plus E_T^{miss}	Jet p_T > 130 GeV & E_T^{miss} > 140 GeV	50 GeV & 35 GeV	75 GeV & 55 GeV	0.8	18
Total rate (peak)				55 kHz	550 Hz

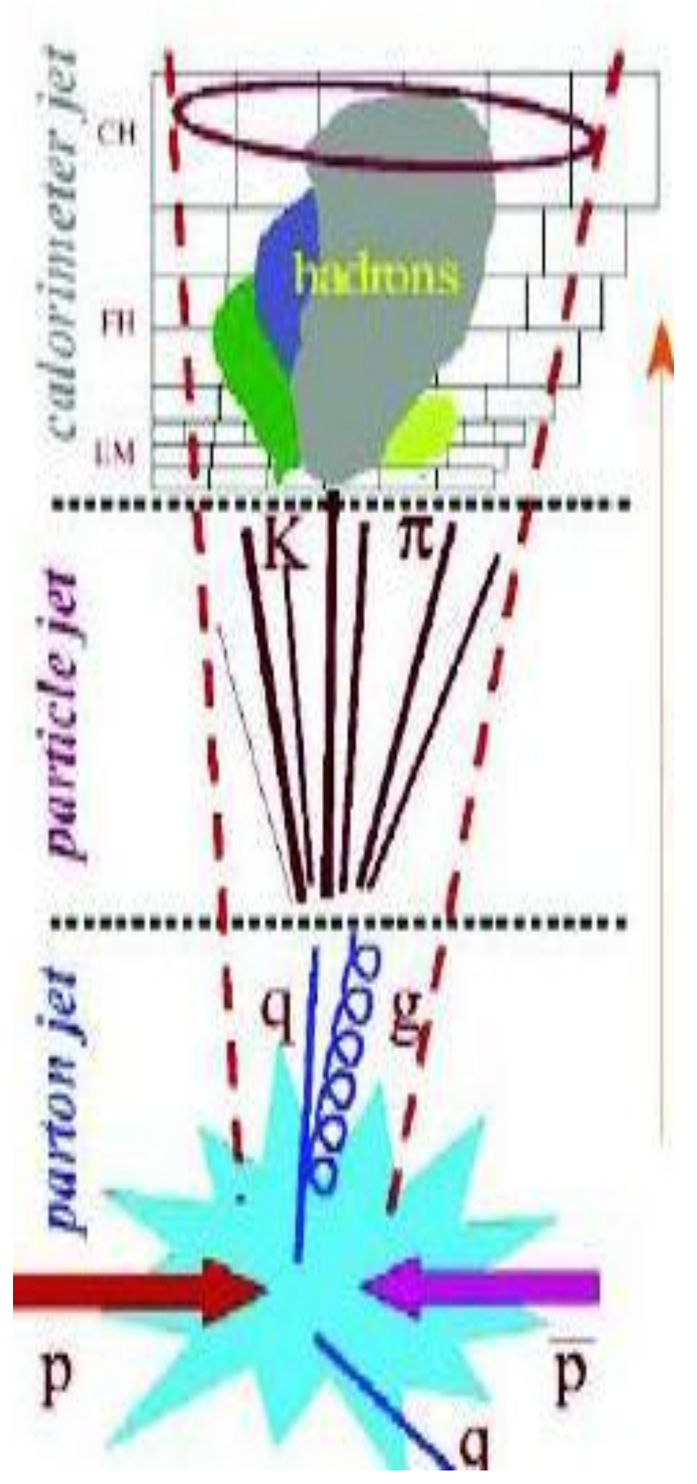
ATLAS Collaboration



Что измеряется?

Не так уж и много:

Мюоны, электроны (фотоны) и струи (треки)



Object reconstruction with ATLAS

- Design requirements
  - High granularity
  - $\sim 4\pi$ coverage in solid angle
  - Fast response and readout
  - Radiation hardness
- Performance specifications
  - Large acceptance
  - Very good particle ID
  - Precise vertex reconstruction
  - Excellent Jet & Etmiss resolution

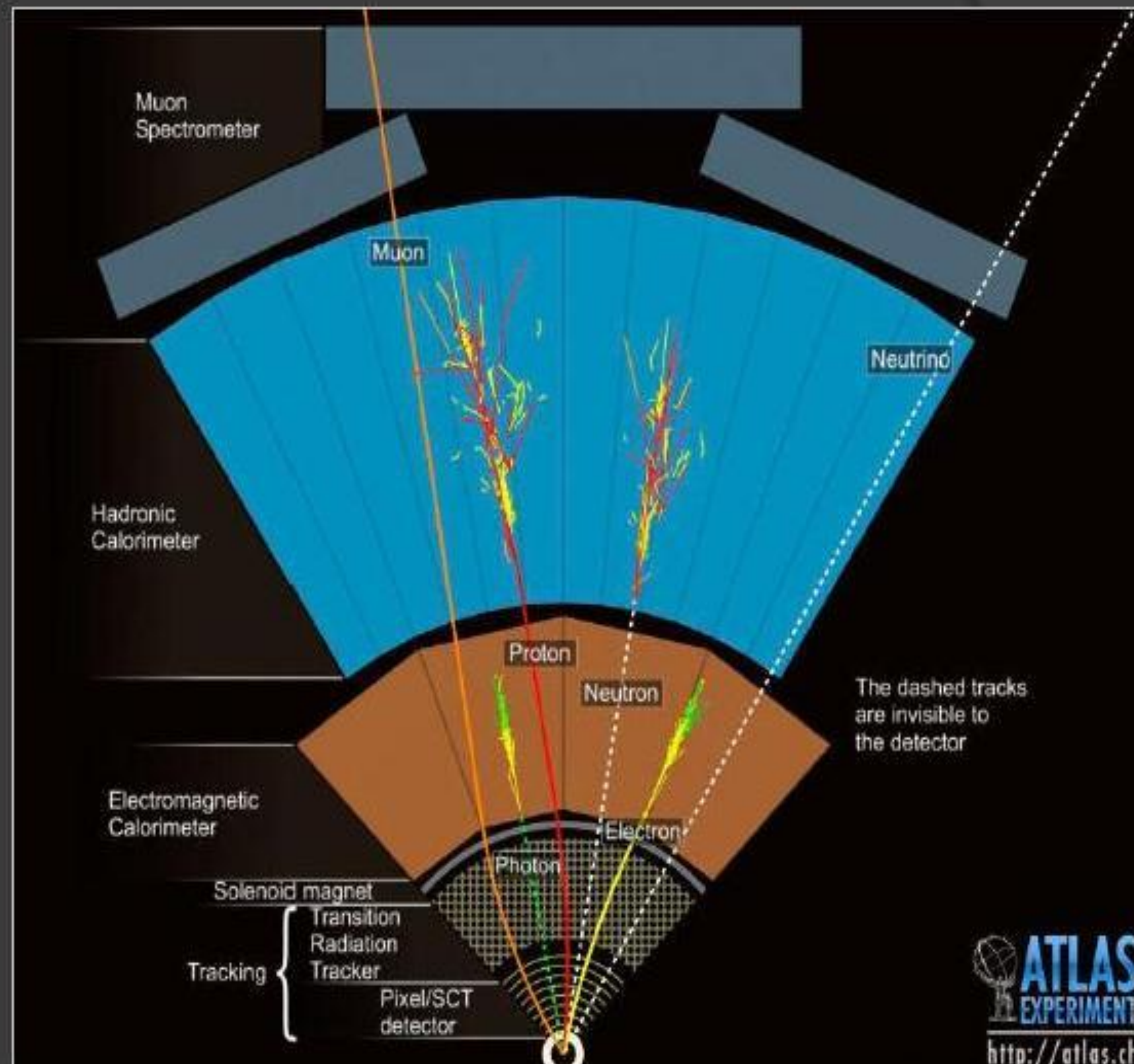
- **Inner tracker**

  $\sigma/p_T \approx 0.038\% p_T \oplus 1.5\%$
- **EM calorimeter**

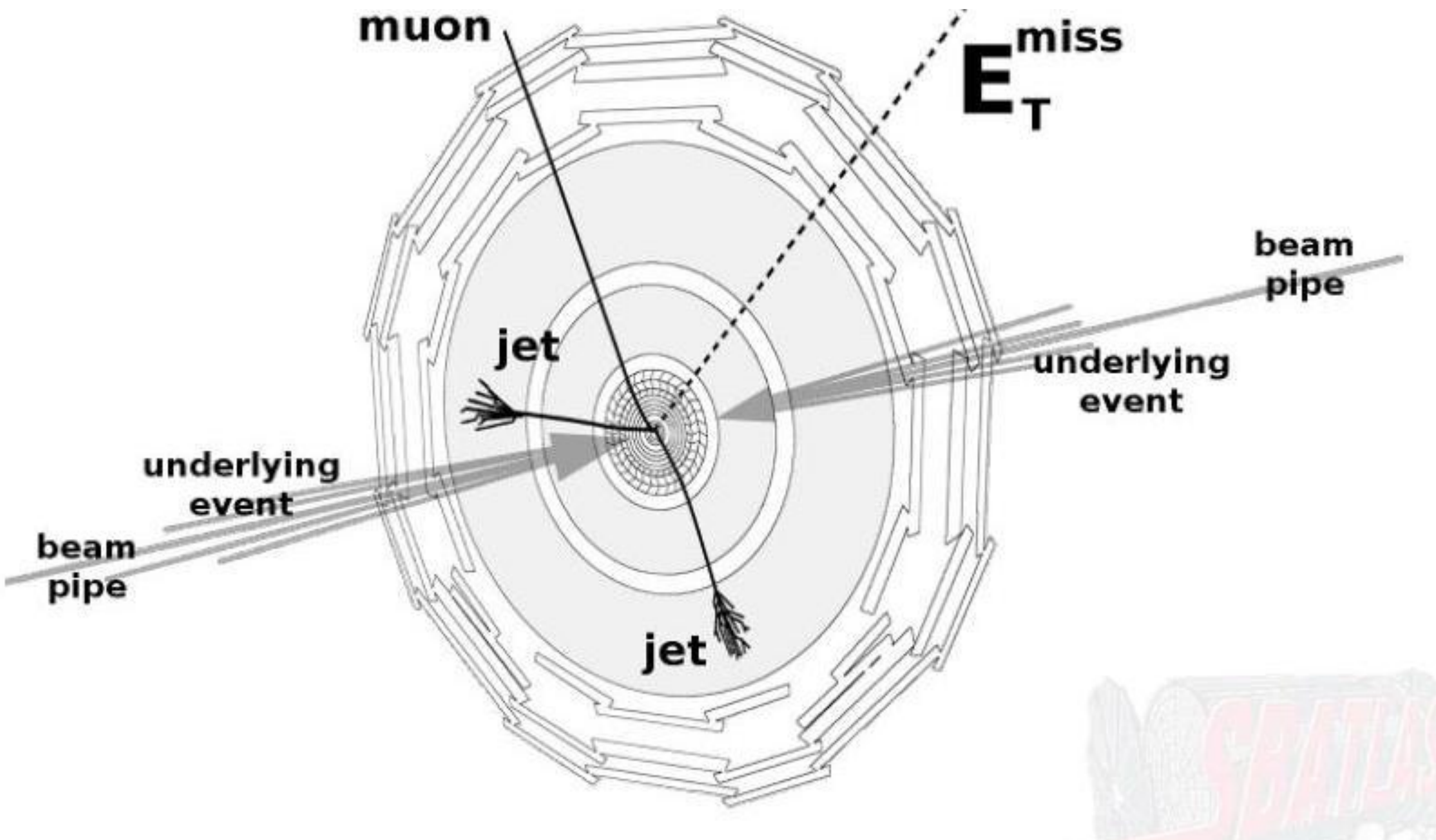
  $\sigma/E \approx 10\%/\sqrt{E} \oplus 0.7\%$
- **Hadronic calorimeter**

  $\sigma/E \approx 50\%/\sqrt{E} \oplus 3\%$
- **Muon spectrometer**

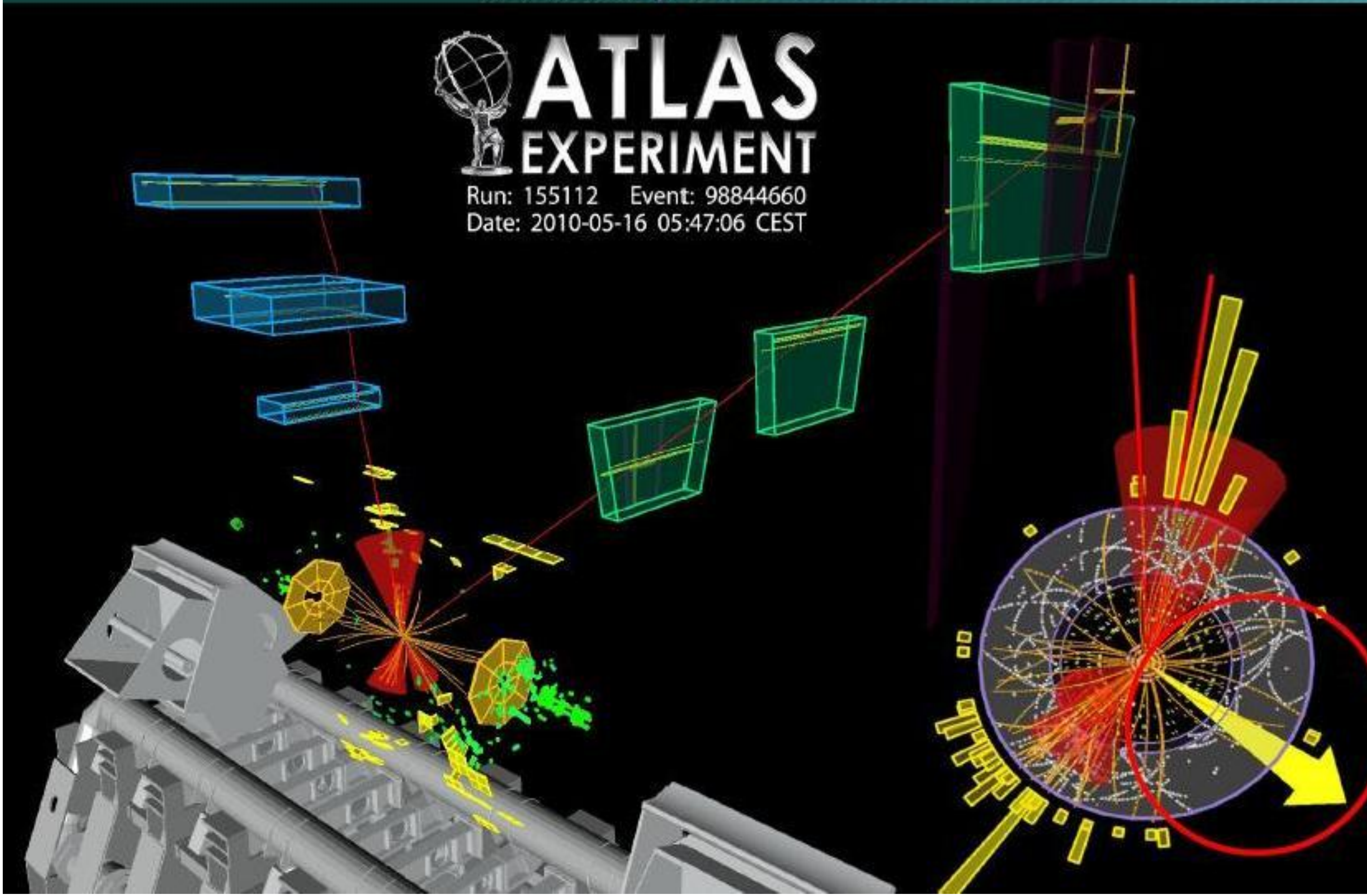
  $\Delta p_T/p_T < 10\%$ up to 1 TeV



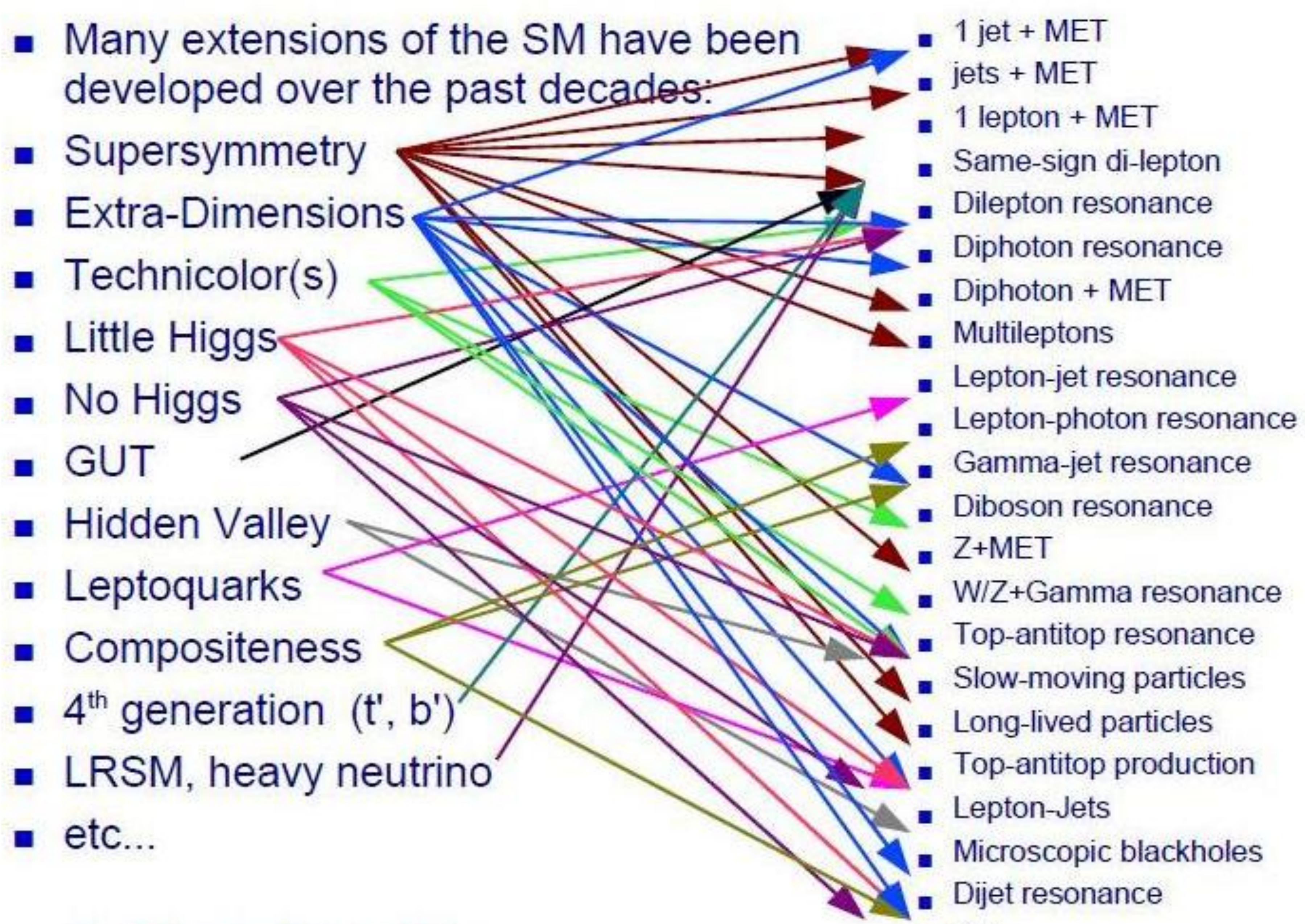
Мюон, струя, струя …
+ недостаток энергии



E_T^{Miss}


ATLAS EXPERIMENT
Run: 155112 Event: 98844660
Date: 2010-05-16 05:47:06 CEST

Наблюдаемые

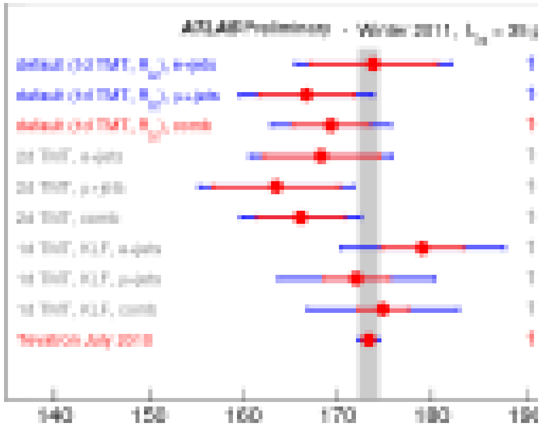


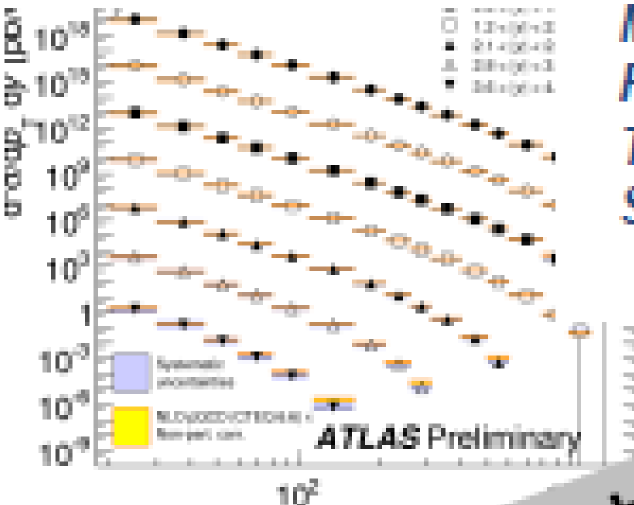
Некоторые результаты эксперимента АТЛАС

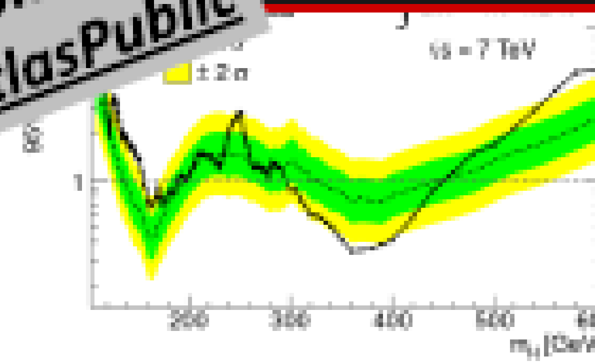
ATLAS publications

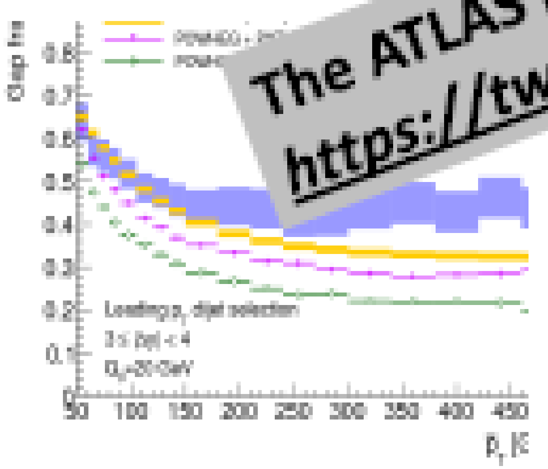
over 100 journal papers
about 300 conference notes
several EPJ highlights

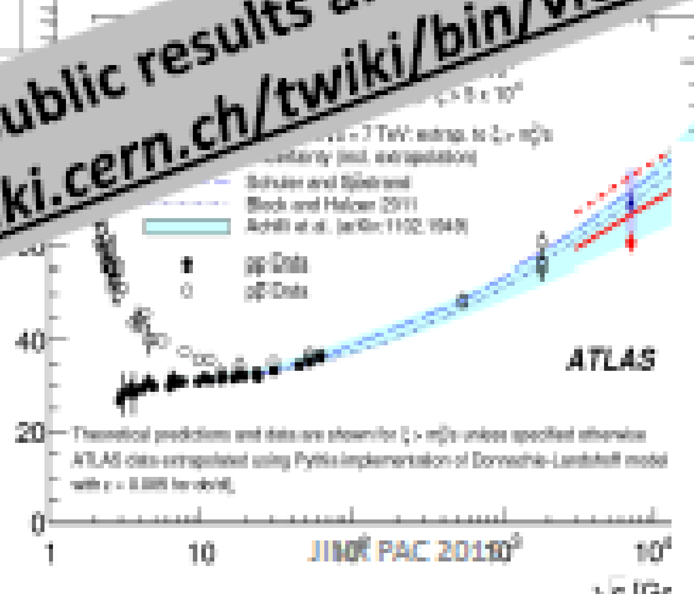
Minimum bias, Jets, W, Z, Prompt photons, Di-bosons, Top quark, B physics, Higgs, Super-symmetry, Exotics, Heavy Ions

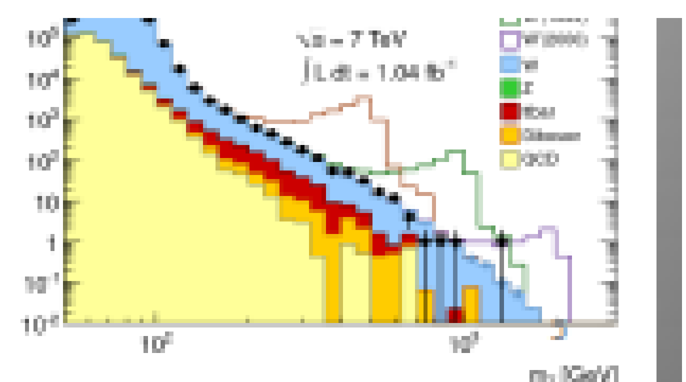












The ATLAS public results are available from https://twiki.cern.ch/twiki/bin/view/AtlasPublic

По следам 3-х докладов …

50th International Winter Meeting on Nuclear Physics
Bormio, Italy
January 23 – 27, 2012

Recent ATLAS Results

Martin Wessels
on behalf of the ATLAS Collaboration

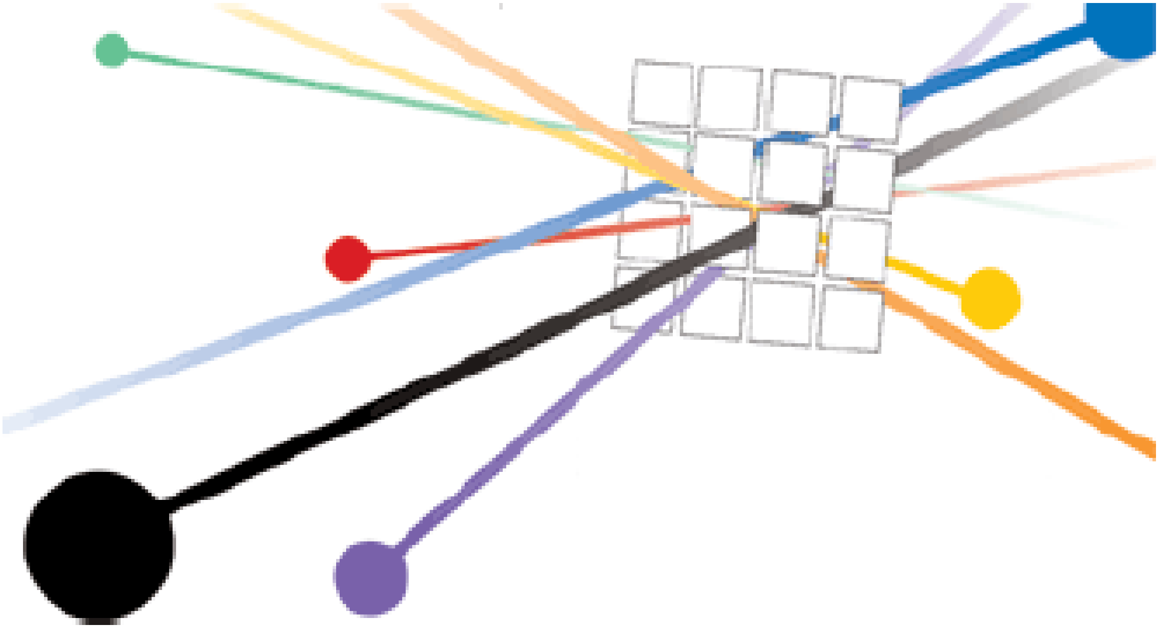
Kirchhoff Institute for Physics
University of Heidelberg, Germany

SUSY Searches at ATLAS

Khramov Evgeny

Поиски Хиггс-бозона:
обзор состояния дел
И.Р.Бойко

Standard Model Measurements



Jet Physics

W and Z Production

W/Z with heavy flavour

Di-Bosons

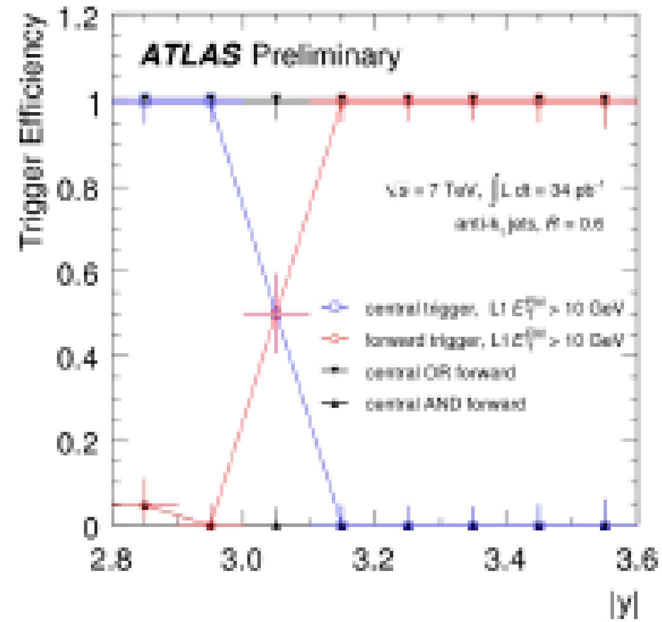
Top Physics

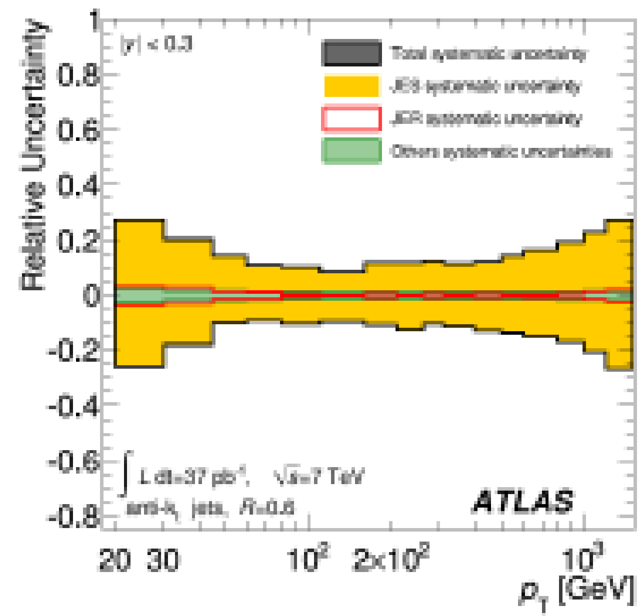
B Physics

Inclusive Jets

arXiv:1112.6297
$\mathcal{L} = 37pb^{-1}$

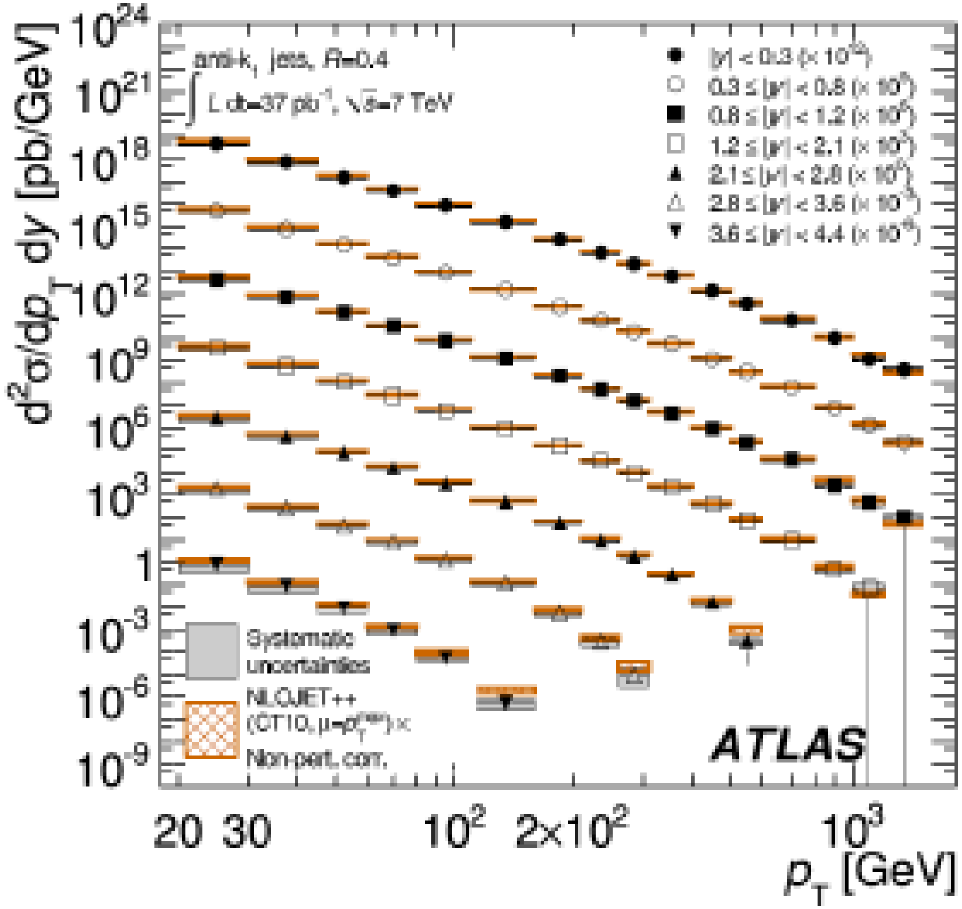
- Inclusive and di-jet measurement which covers never before explored phase space regions:
  - Jet p_T up to 1.5 TeV
  - Di-jet mass up to 5 TeV
- Dominant LHC process at high p_T, probes pQCD at highest energies, also sensitive to new physics creating di-jet resonance
- Uses both anti-k_T R=0.4 and R=0.6 jets with p_T>20 GeV and |y|<4.4
- Exploits combination of central and forward jet triggers such that the efficiency is >99% for all rapidities
- Largest systematic uncertainty arises from jet energy scale, relative error on cross section is ~10-30% for central jets
- Data compared to NLO QCD calculations corrected for non-perturbative effects



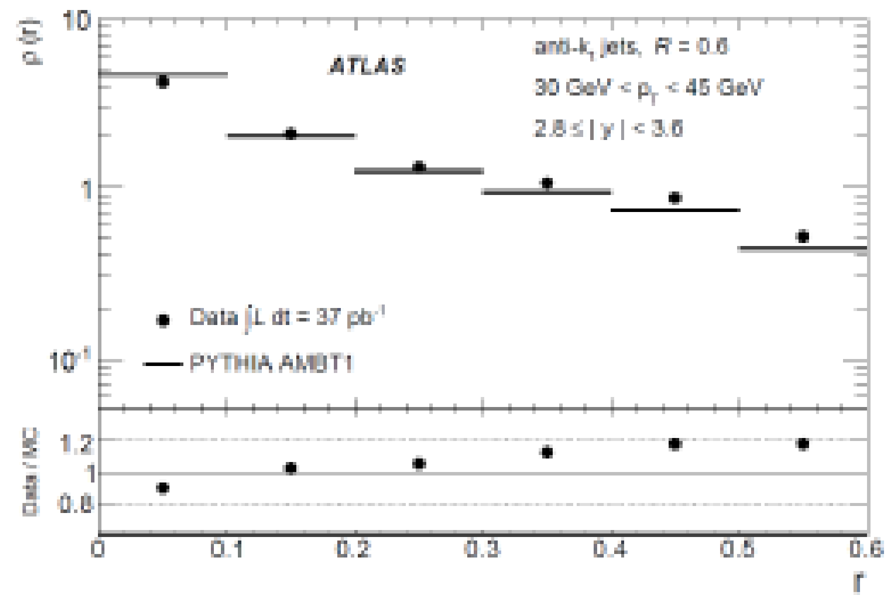


Inclusive Jets

arXiv:1112.6297
$\mathcal{L} = 37pb^{-1}$



- Good agreement between data and NLO predictions (using CTEQ 10)
- Additional results: comparison of data to POWHEG and different PDF sets

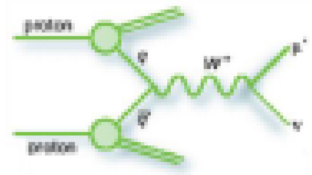


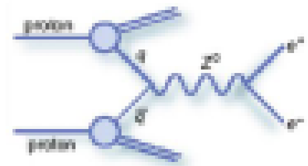
- Study of energy flow around the jet core provides information on parton-to-jet fragmentation
- ρ(r) = ratio of energy in a ring of thickness Δr=0.1 and jet energy, as a function of distance r from jet centre
- The maximum disagreement between data and MC is less than 20%
- Also see: arXiv:1101.0070

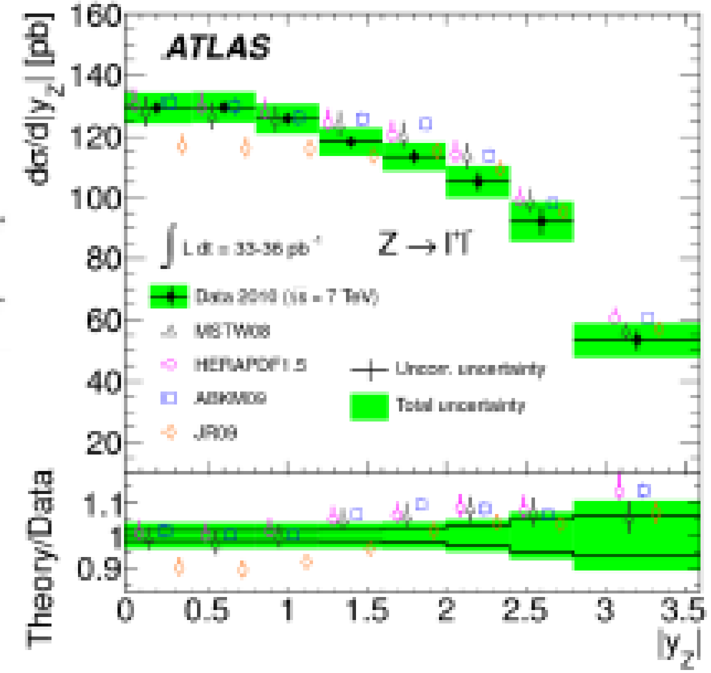
W and Z Production

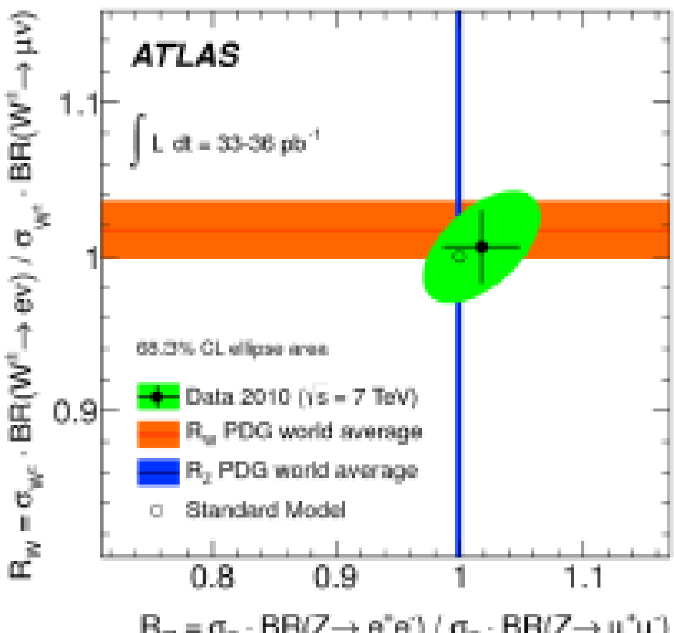
arXiv:1109.5141
$\mathcal{L} = 33 - 36\, pb^{-1}$

- Precision measurement of Drell-Yan W/Z production cross sections important test for QCD
- Measured in leptonic decay channels: W→lν, Z-> ll (l=e, μ)
- Basic selection includes: leptons with p_T>20 GeV, for W neutrinos with p_T>25 GeV and transverse mass M_T>40 GeV, for Z: 66 < M_{ll} < 116 GeV





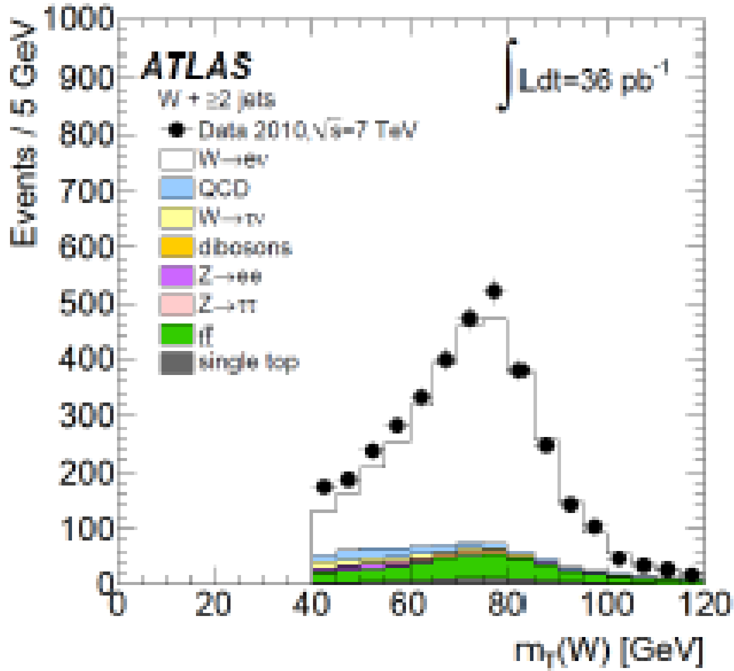


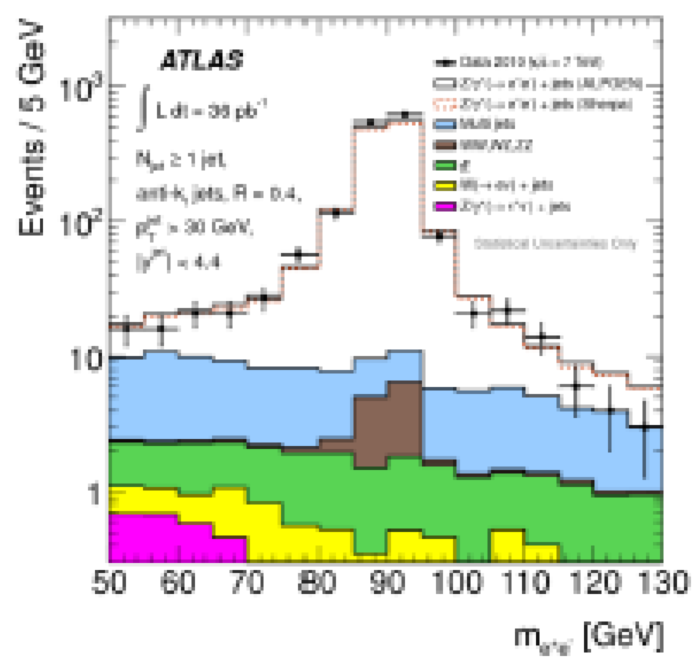


- Measure integrated fiducial and total as well as differential cross sections (rapidity of Z boson and W charged lepton).
- Comparison of W vs. Z cross section shows reasonable agreement with NNLO predictions
- Universality of PDFs and pQCD work up to kinematic range of W and Z at LHC

W/Z + Jets

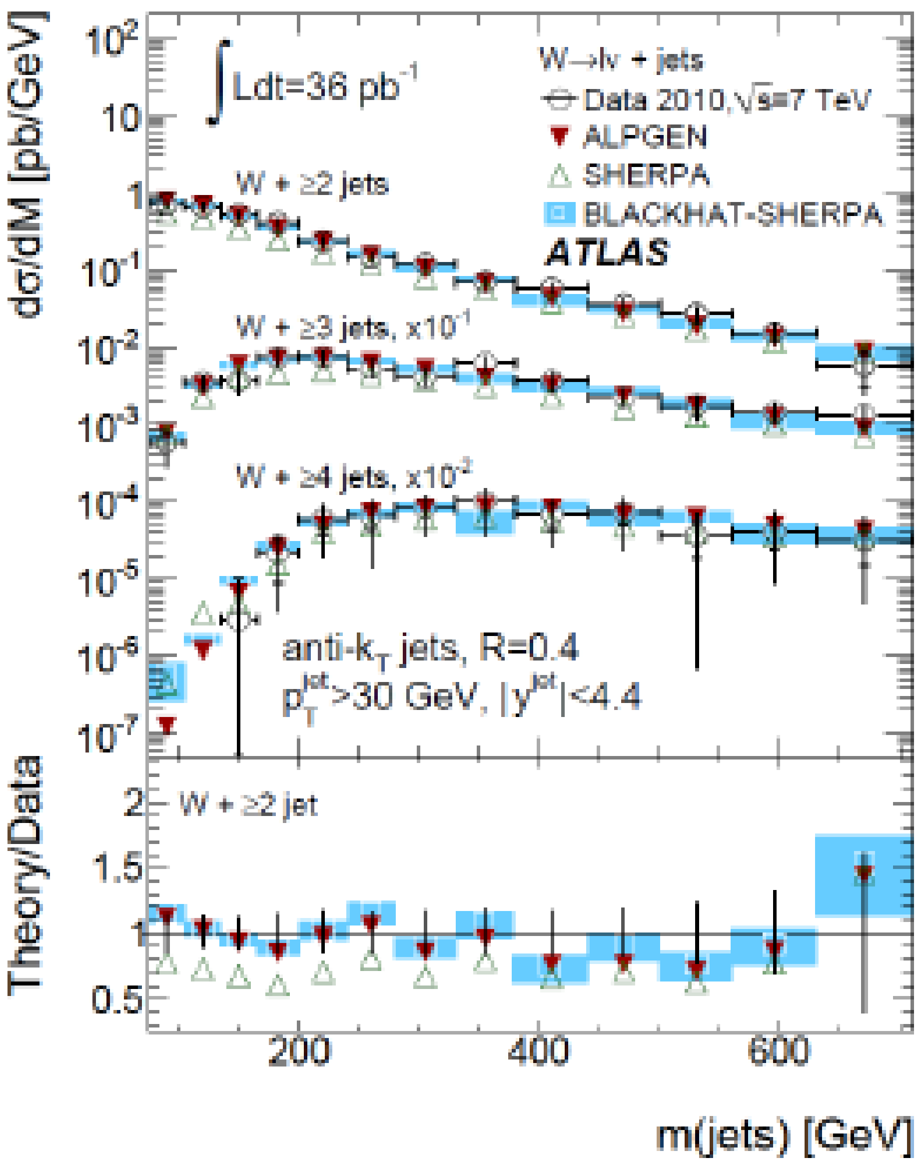
- Recent years have been a "NLO revolution": theoretical predictions have gone from 2 to 4 (5) processes
- W/Z selection similar to previous slide, additional jet selection: anti-k_T jets with R=0.4, p_T>30 GeV and $|y|$<4.4
- Very extensive measurement including differential cross sections as a function of jet p_T, H_T, di-jet mass, rapidities and angular separations
- QCD backgrounds determined fully data driven while background including leptons is derived from MC

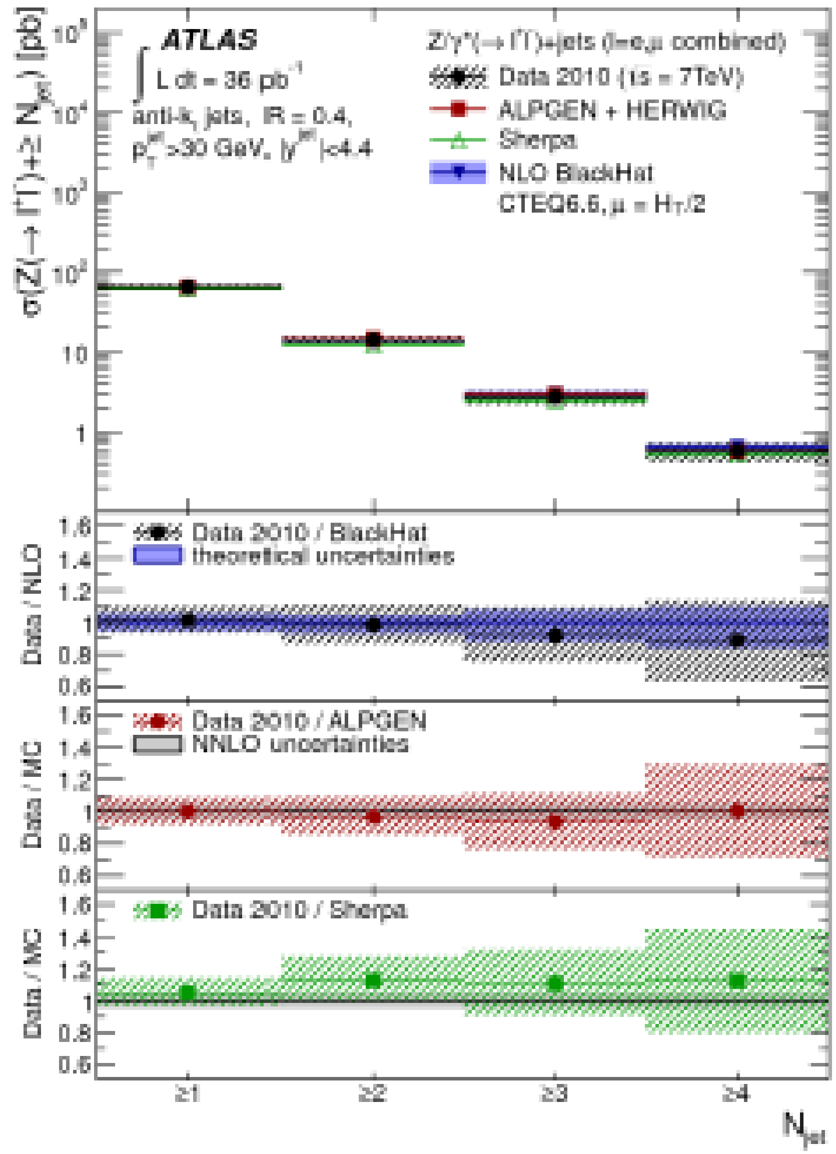




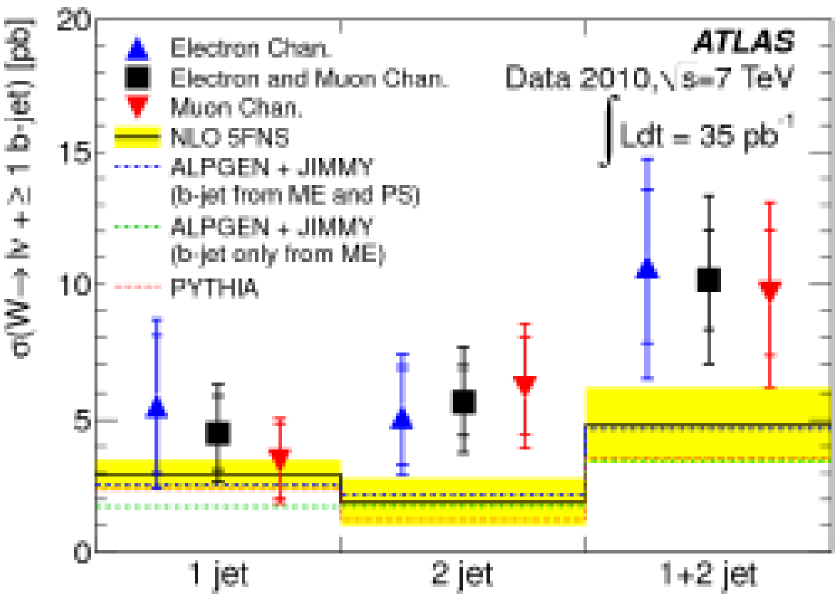
W/Z + Jets

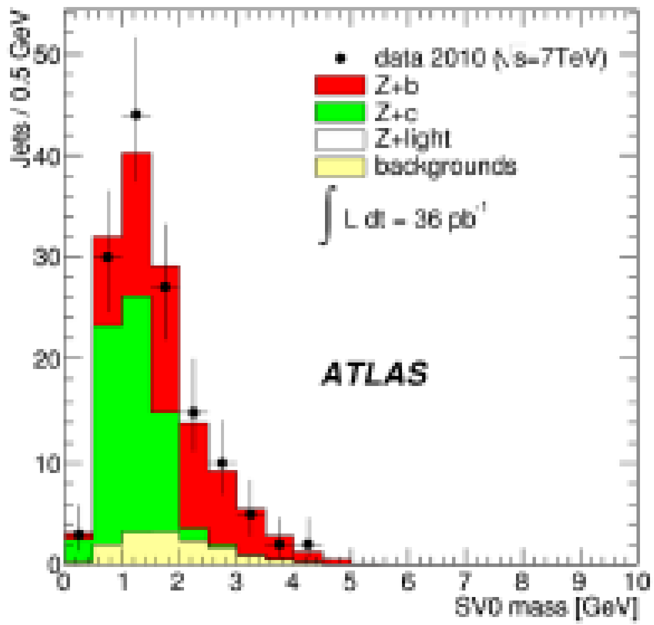
→ Good agreement between data and NLO calculations





W/Z with Heavy Flavour



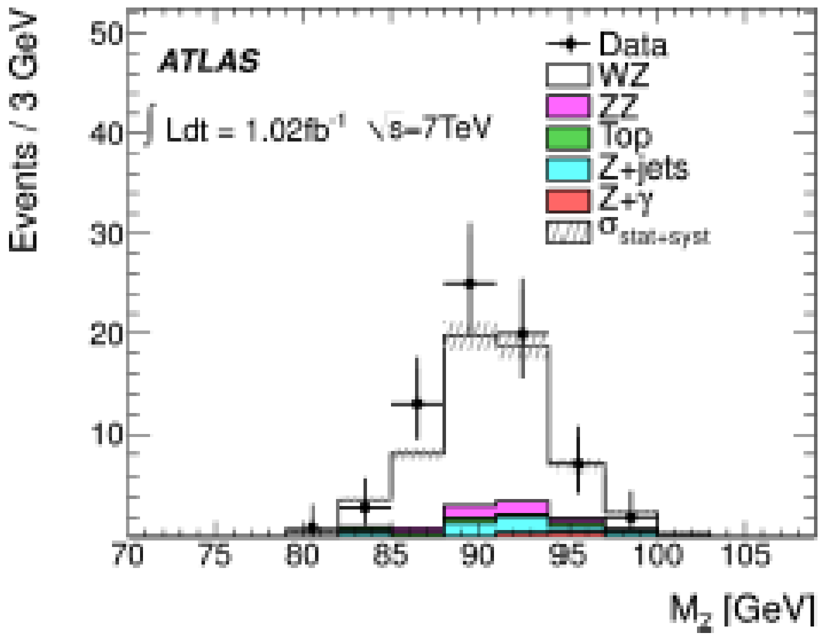


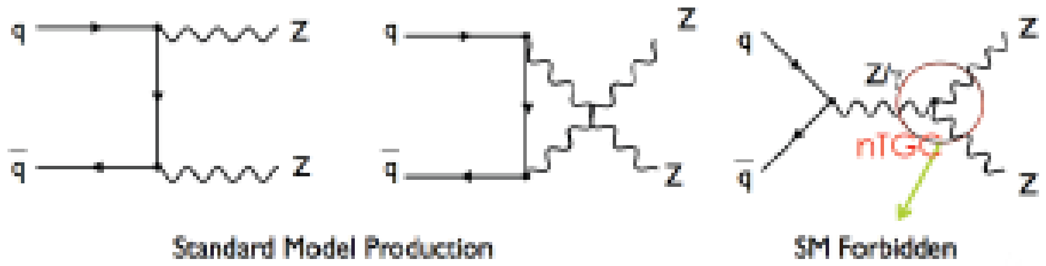
- Cross section measurement of W production with one or two jets of which at least one jet is a b-jet
- Measurement sensitive to HV quarks in the initial state as well as a background to Higgs and BSM searches
- NLO predicts a smaller cross section, though consistent with the measured value (within 1.5σ)

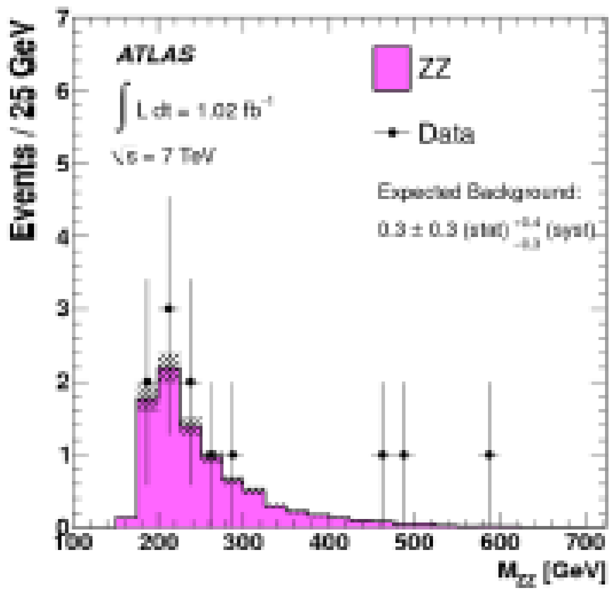
- Cross section measurement of Z production with at least one b-jet
- Uses invariant mass of the charged particle tracks from secondary vertex (SV0 mass) in order to extract the b-jet fraction on statistical bases
- pQCD NLO calculation agrees well, LO generators reproduce the average number of b-jets per event

Di-Bosons

- Measure Wγ, Zγ, WW, WZ and ZZ final states
- WW→lνlν, WZ→lllν, ZZ→llll all observed
- Check for anomalous triple gauge couplings (TGC):
  - Charged TGCs: WWγ, WWZ non-zero in the Standard Model
  - Neutral TGCs: ZZγ, Zγγ are zero





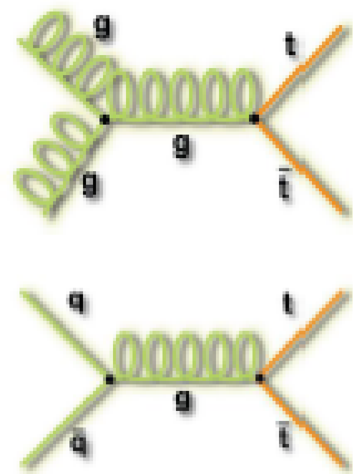


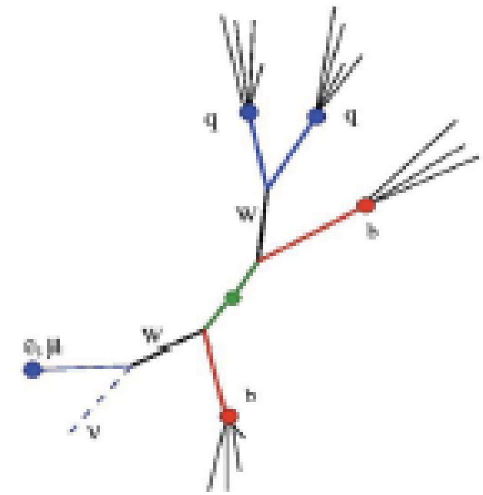
→ Data in agreement with SM prediction, limits on neutral TGCs derived

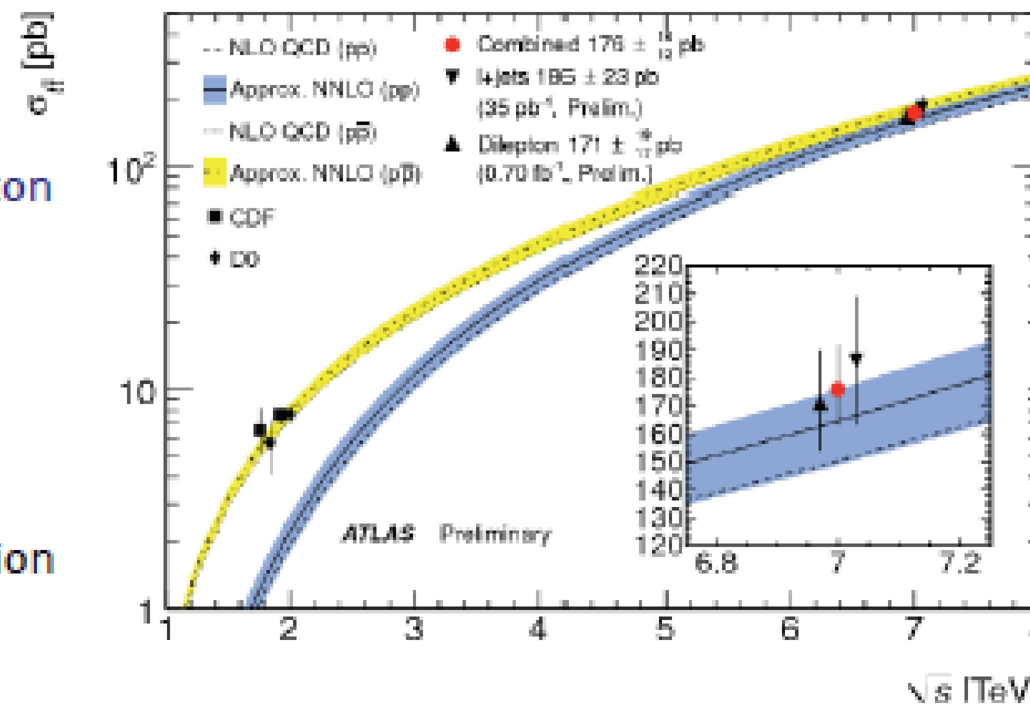
Top Production

- Measurement of top quark production cross-section allows a precision test of pQCD
- LHC is "top factory", important background in many BSM searches, may also be sensitive to new physics
- Dominantly produced in pairs via the strong interaction (87% gluon fusion)
- Decay via EW interaction before hadronisation, BR(t→Wb)~1, two (taggable) b-jets in final states

→ Reconstruct top in lepton+jets, di-lepton and all-jet events, with and w/o b-tag







Latest l+jets result: $\sigma_{t\bar{t}} = 187^{+22}{}_{-21}\,pb$

→ Agrees well with SM prediction

→ Most precise published top cross section measurement at the LHC

Рождение пары топ-кварков. Процесс КХД:

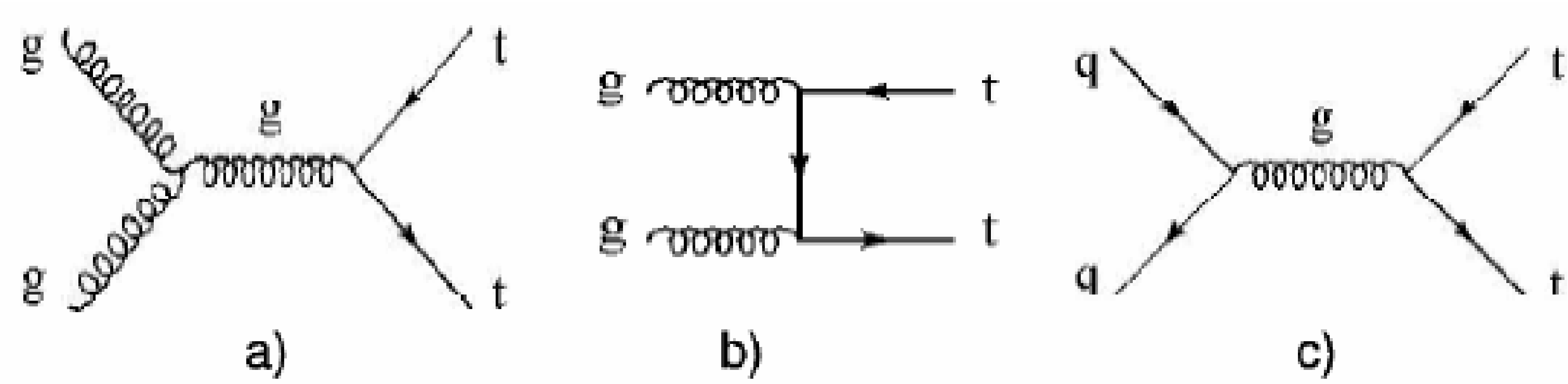


Figure 1: Lowest level diagrams of the $t\bar{t}$ production. Gluon scattering processes, a) and b), are the dominant processes at LHC energies, while quark scattering, process c), is the dominant one at TeVatron energies.

Одиночное образование топ-кварка. Слабый процесс:

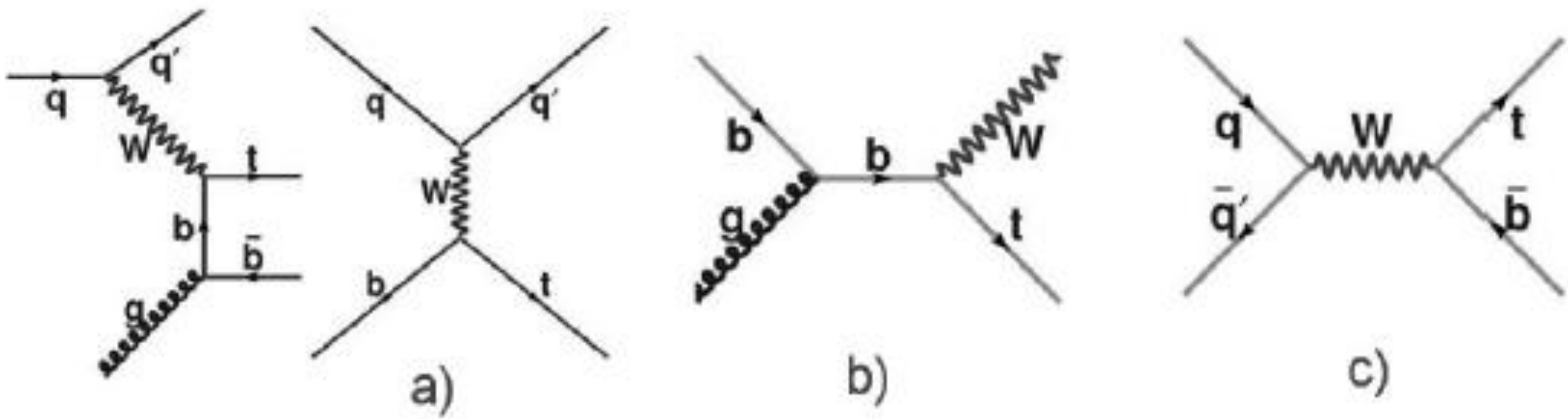
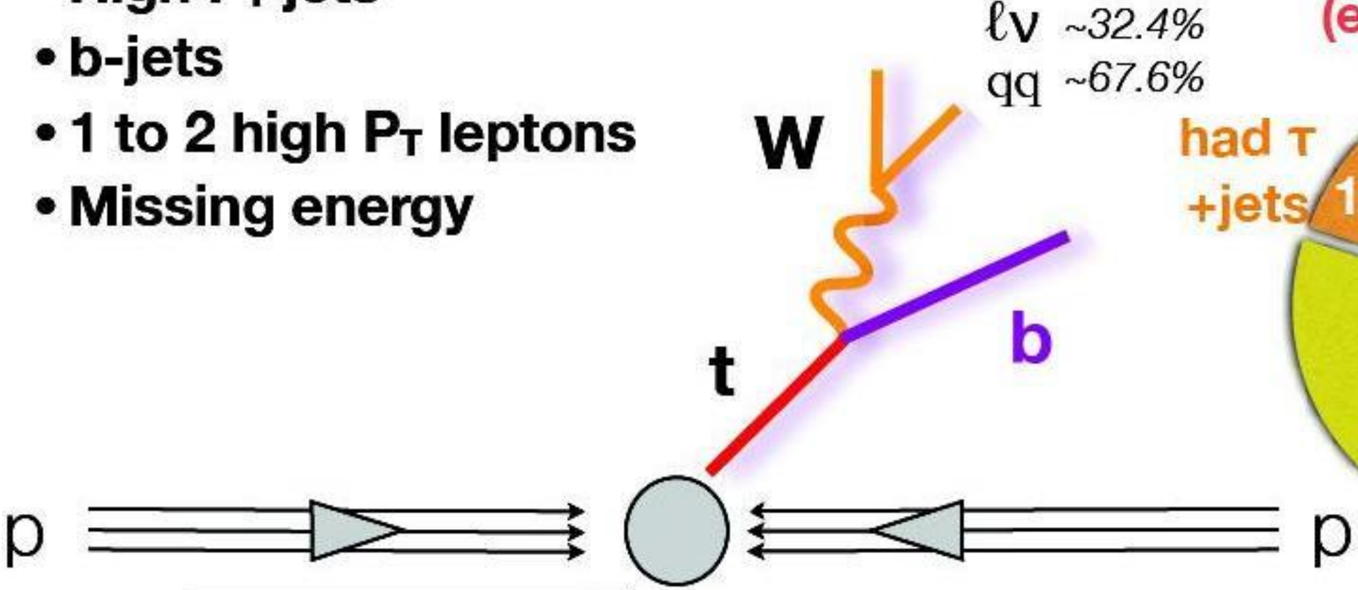
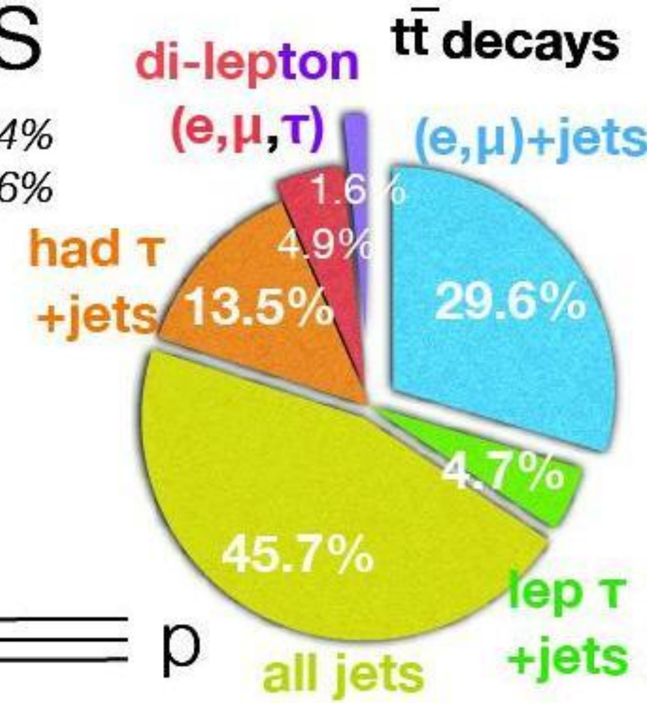


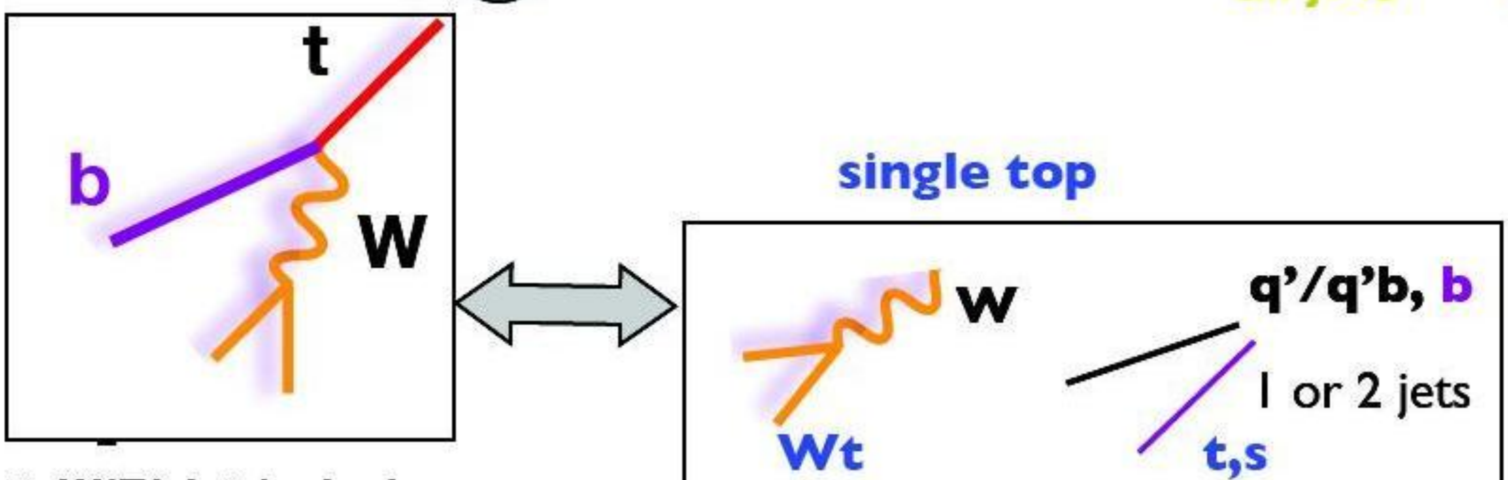
Figure 2: Diagrams of single top production at the lowest level: a) t-channel, b) Wt associated production, c) s-channel.

Top signatures

- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**







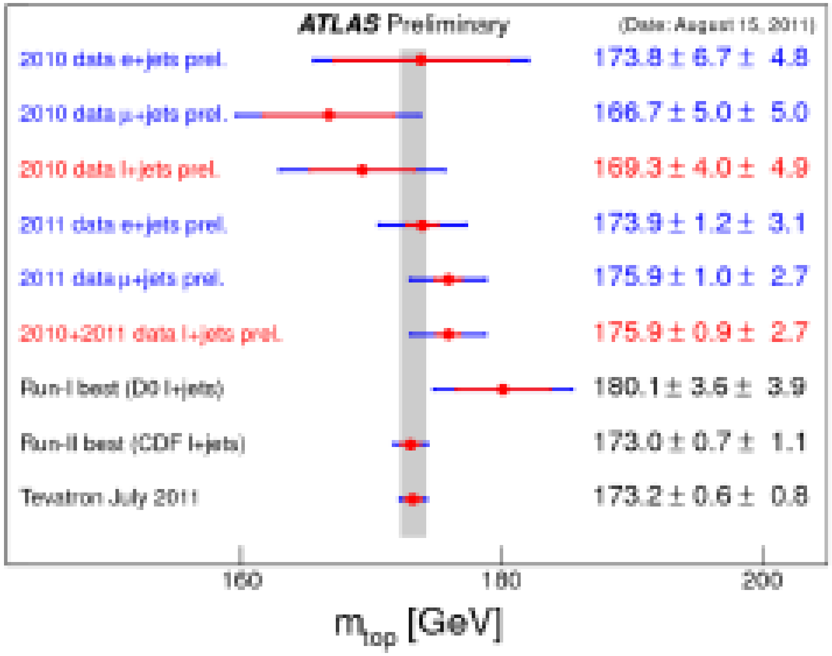
bkgs_tt: W/Z(+jets), single top, QCD, Di-bosons

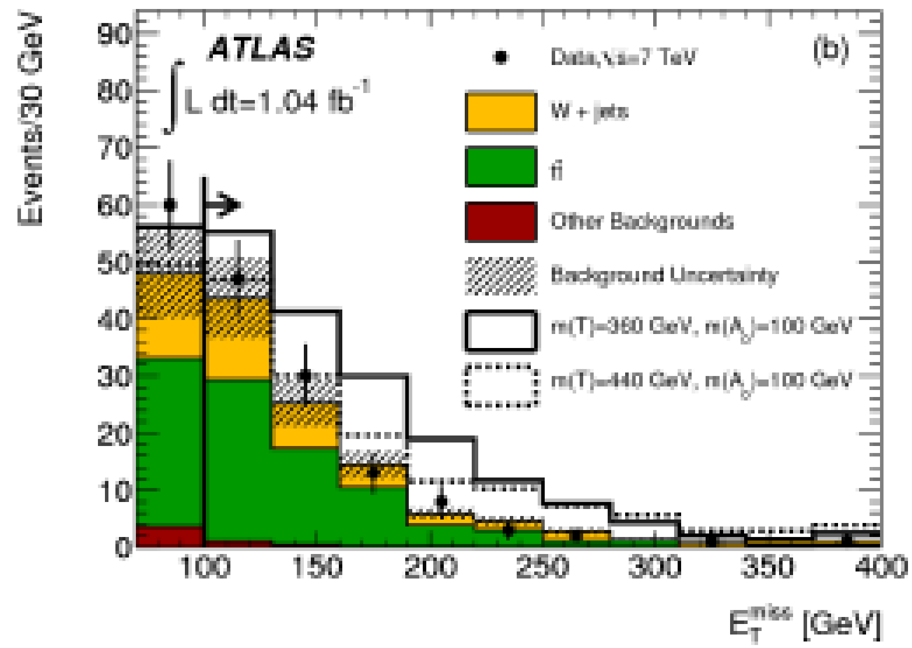
bkgs_single_t: tt +some bkgs_tt

ATLAS-CONF-2011-120
$\mathcal{L} = 35\,pb^{-1} - 0.70\,fb^{-1}$

More Top Results

arXiv:1109.4725
$\mathcal{L} = 1.04\,fb^{-1}$

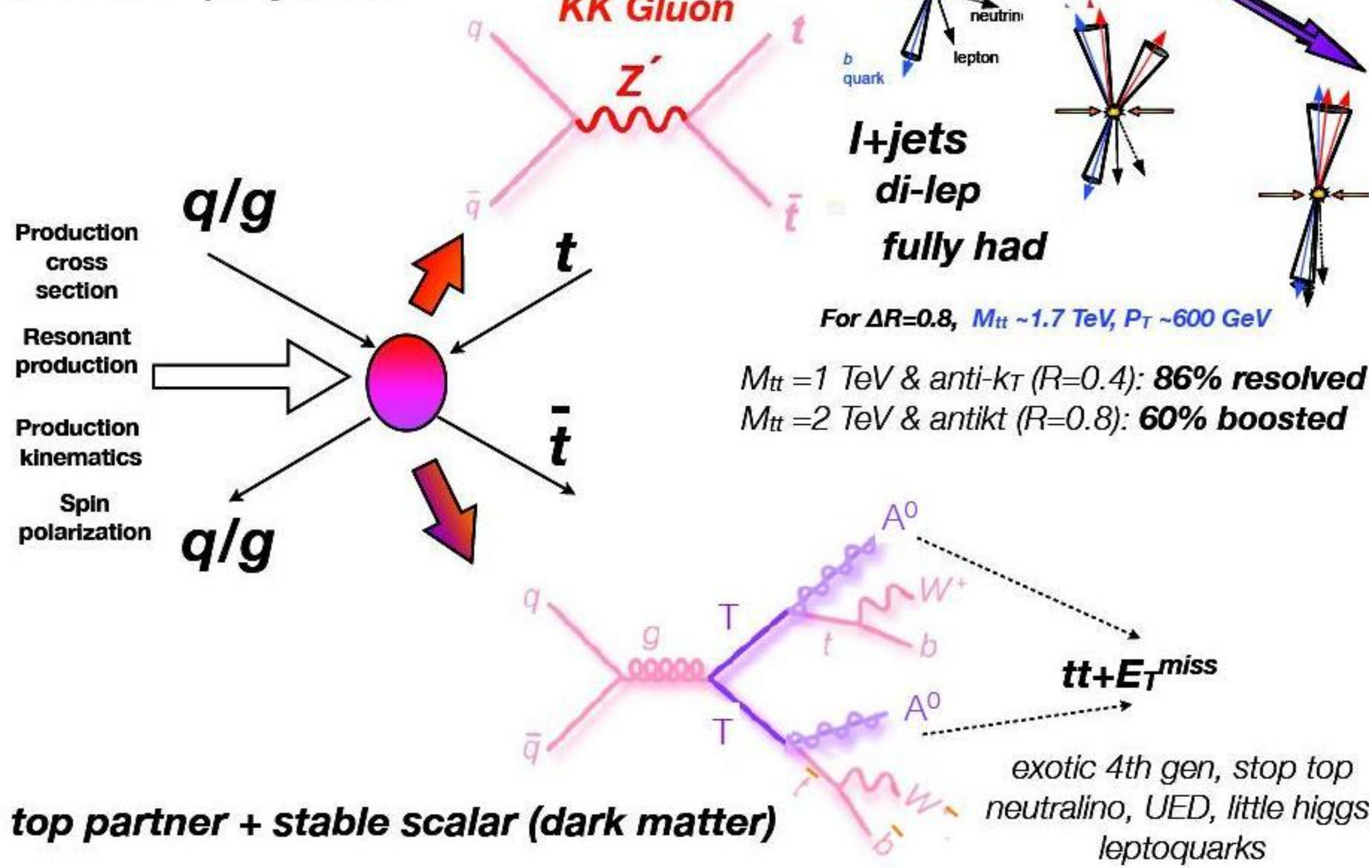




- Top mass measurement using l+jets channel in agreement with SM prediction
- Measurement dominated by systematic uncertainty
- Main sources are relative jet energy scale uncertainty between light jets ad b-jets, ISR and FSR modelling and choice of MC generator

- Search for new phenomena in ttbar events with leptons, jets and large E_T^{miss}
- Signal region defined as m_T>150GeV and E_T^{miss}>100GeV
- No evidence of an excess of events found, establish limits on new pair-produced quark like objects

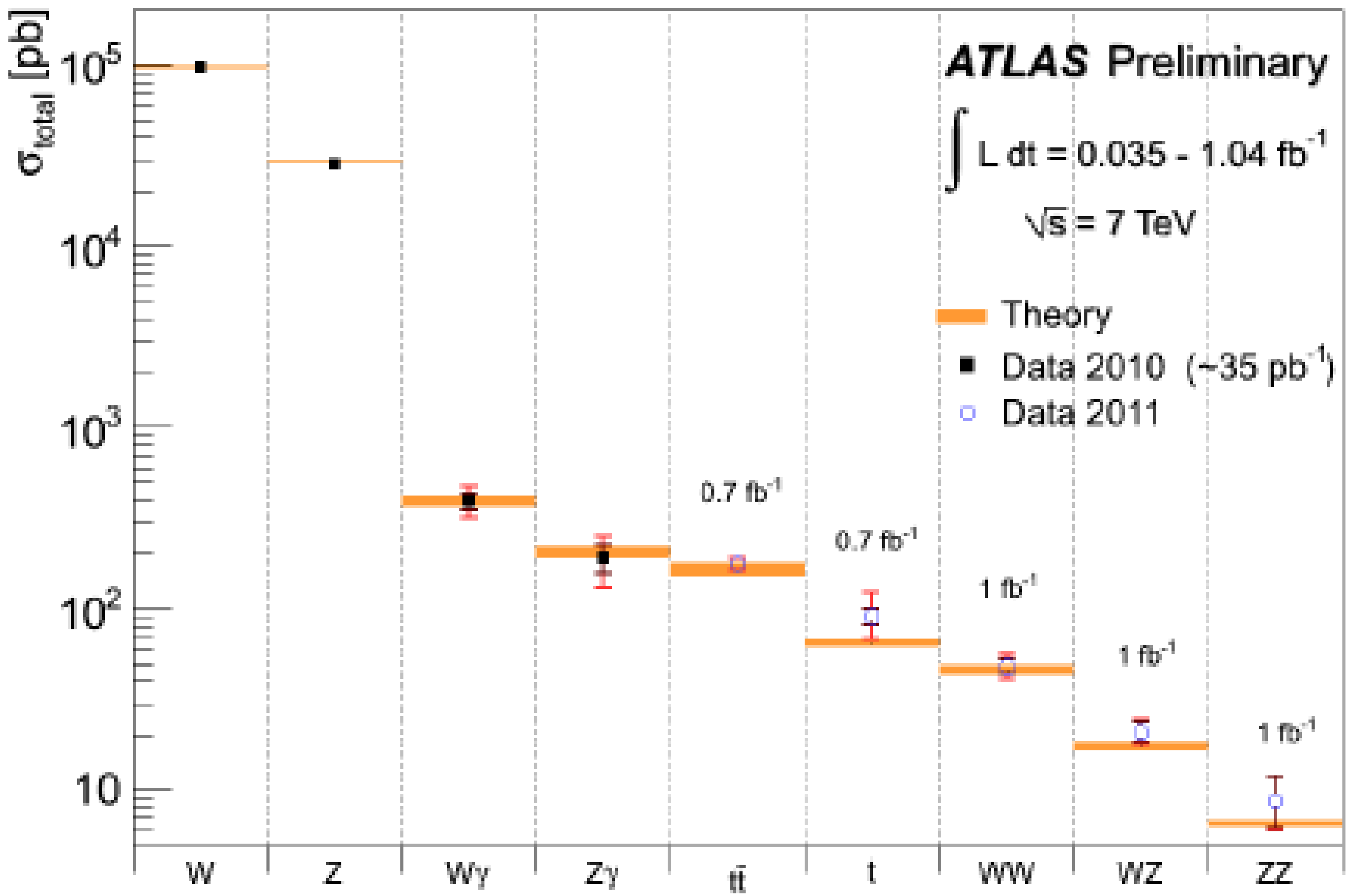
Top production as a window on new physics



Физика топ-кварка на LHC. 2011:

- Сечение образования пары топ-анти-топ кварков измерено во всех возможных каналах СМ (180 pb), с точностью на уровне NNLO СМ расчетов.
- Одиночное рождение топ-кварка в t-канале точно установлено (90 pb), необходимы дополнительные данные для наблюдения Wt-канала и s-канала (слабого) образования топ-кварка.
- Измерены характеристики топ-кварков: масса, разница масс топ и анти-топ кварков, спиральность W-бозона в распаде топ-кварков, топ-анти-топ кварковая асимметрия, заряд (знак) топ кварка, корреляции спинов в паре топ-анти-топ кварков и тп.
- Новая область энергии LHC и все возрастающая интенсивность пучков позволили заметно улучшить пределы на проявление новой физики (FCNC, Z’,…) в процесса с участием топ-кварков.

SM Cross Section Summary



inner error: statistical, outer error: total

→ Good agreement between data and Standard Model expectation

→ Experimental precision starts to challenge theory calculation

Observation of a New χ_b State

arXiv:1112.5154
$\mathcal{L} = 4.4\ fb^{-1}$

- The χ_b(nP) quarkonium is a $b\bar{b}$ system bound in a *P*-orbital of energy level *n*
- Measurements of its properties provide a unique insight into QCD close to the $b\bar{b}$ threshold
- Reconstruction via radiative decays

  $$\chi_b(nP) \to \Upsilon(1S)\,\gamma \quad \text{and} \quad \chi_b(nP) \to \Upsilon(2S)\,\gamma$$

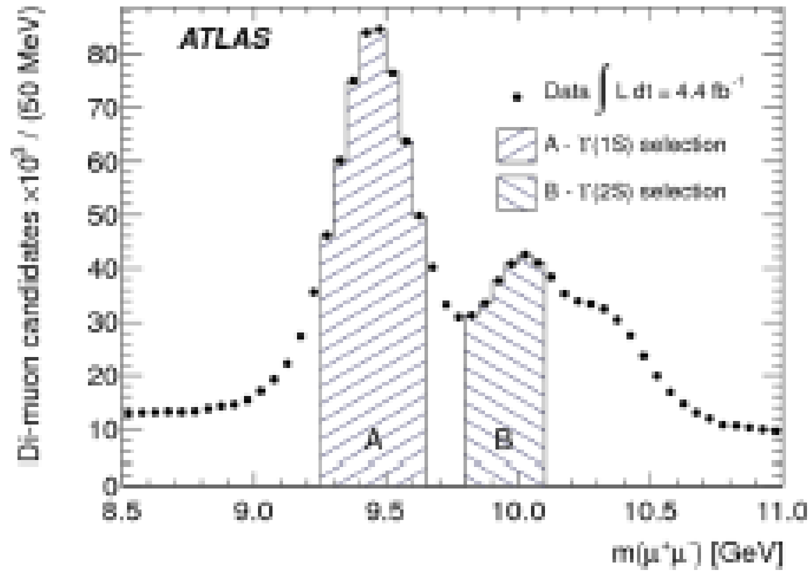
  $$\text{in which} \quad \Upsilon(1S, 2S) \to \mu^+\mu^-$$

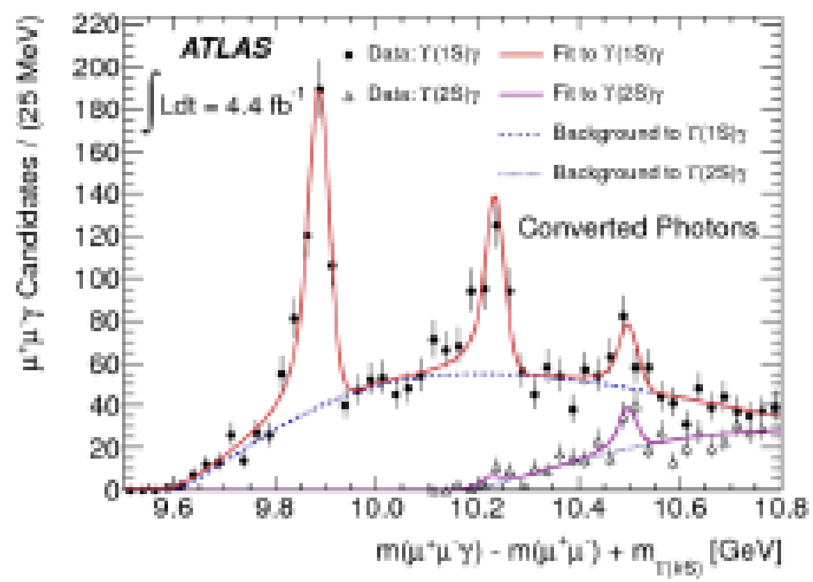
- Select events with oppositely charged muons with inv. masses near $\Upsilon(1S)$ and $\Upsilon(2S)$, avoiding $\Upsilon(3S)$
- χ_b candidates are formed by associating a $\Upsilon \to \mu^+\mu^-$ candidate with a reconstr. photon (conv. or unconv.)
- Calculate $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-)$ to minimise mass resolution effects, plot summed with mass of Υ(kS)

→ χ(3P) with M=10.539±0.004(stat.)±0.008(syst.) GeV

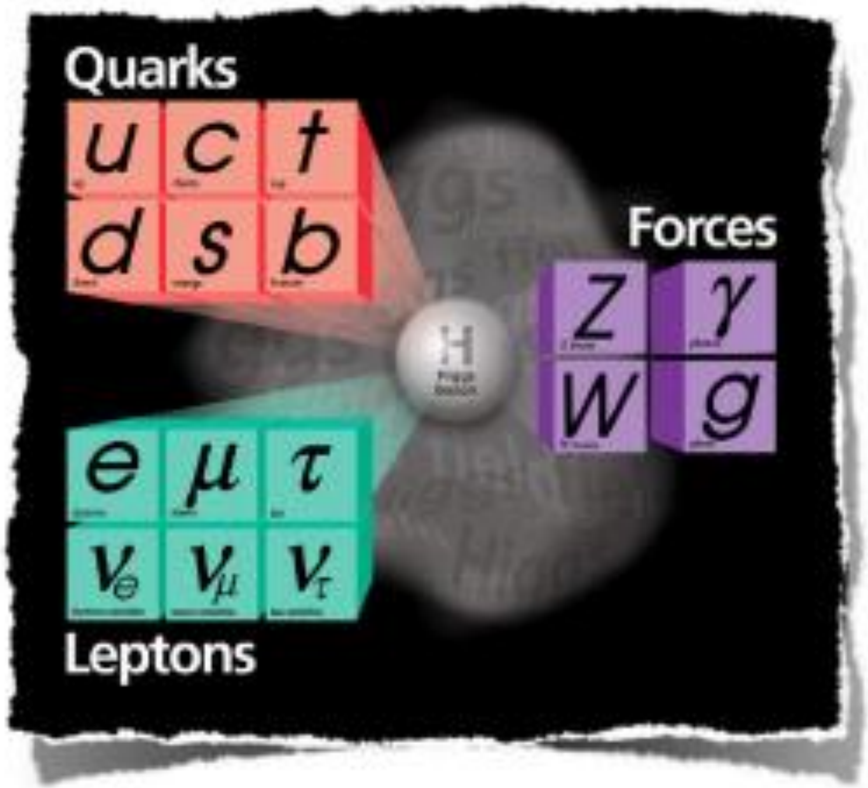
→ First observation, predicted with M~10.52GeV

- Hyperfine splitting between triplet states J=0,1,2 of similar size as mass resolution





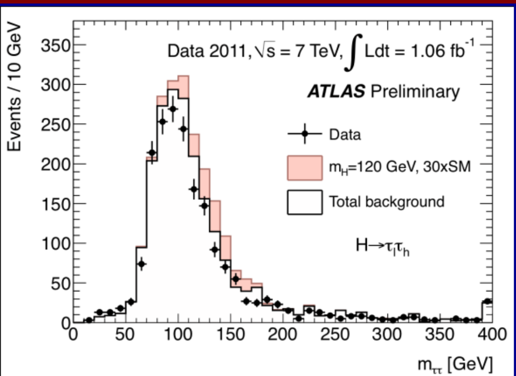
Standard Model Higgs Searches

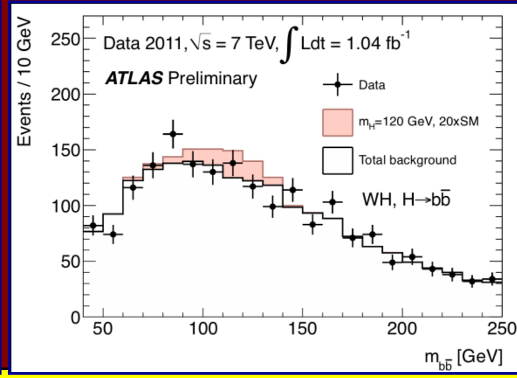


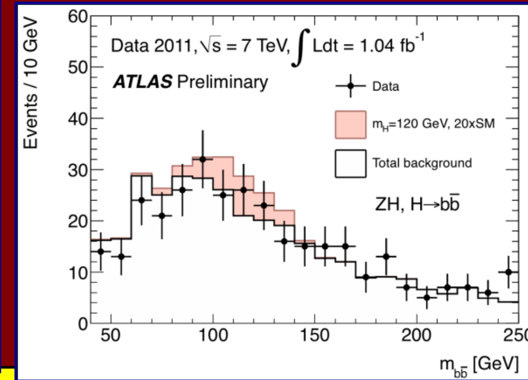
$H \rightarrow ZZ$

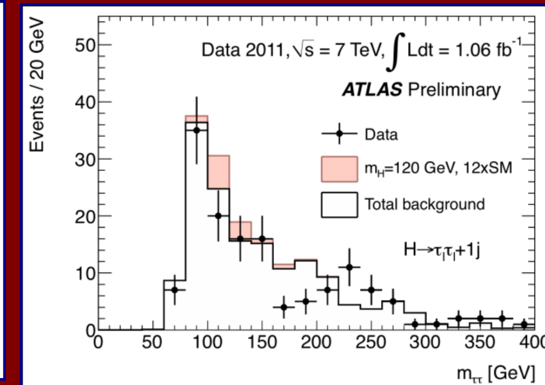
$H \rightarrow \gamma\gamma$

Combinations



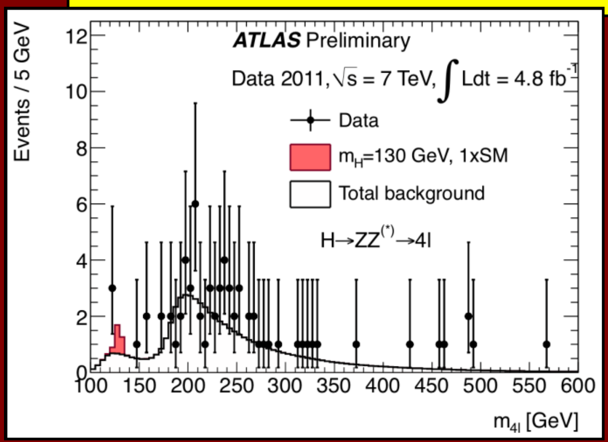


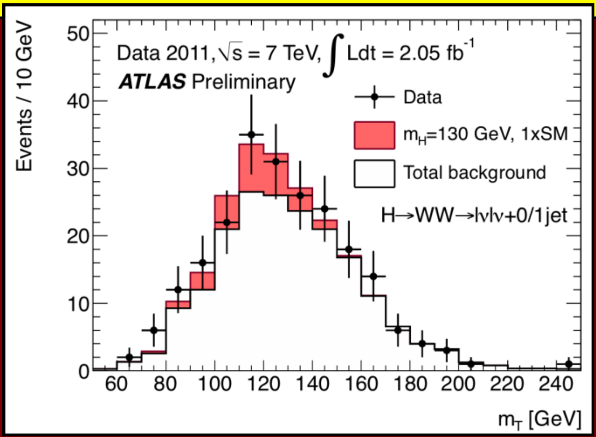


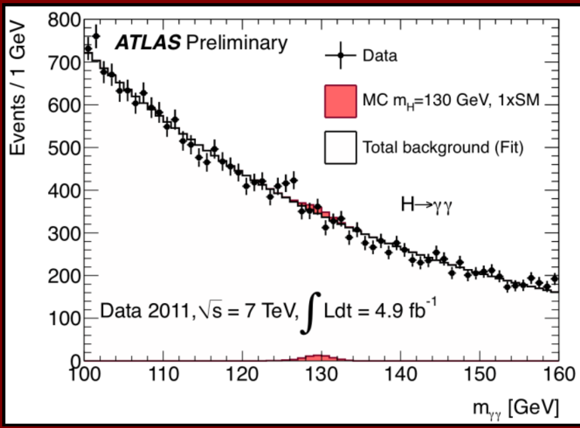


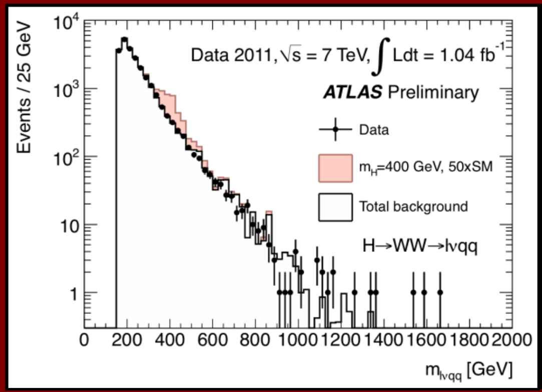
Update of Standard Model Higgs searches in ATLAS

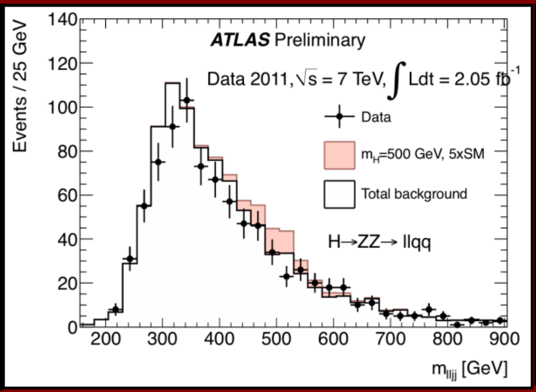
Fabiola Gianotti,
representing the
ATLAS Collaboration

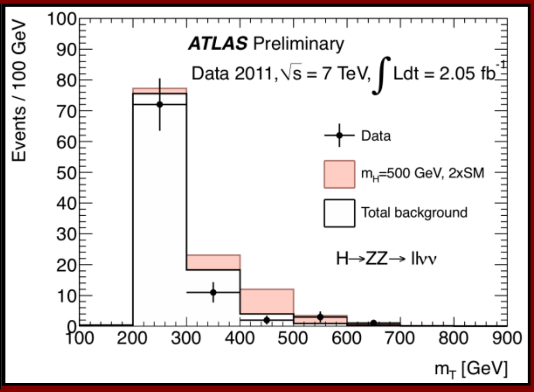


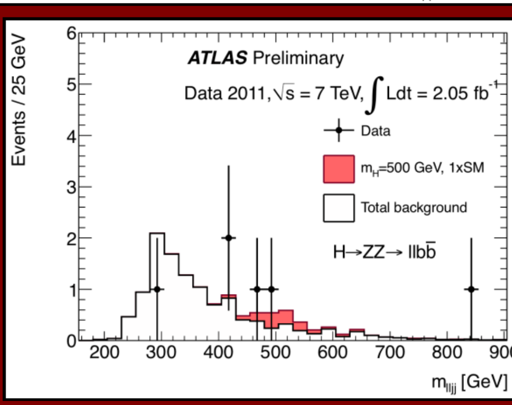






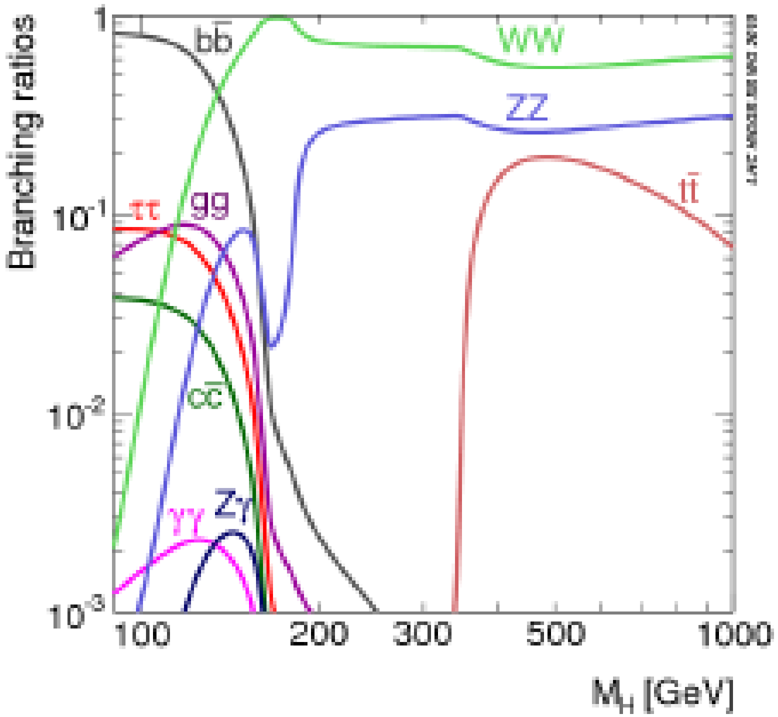


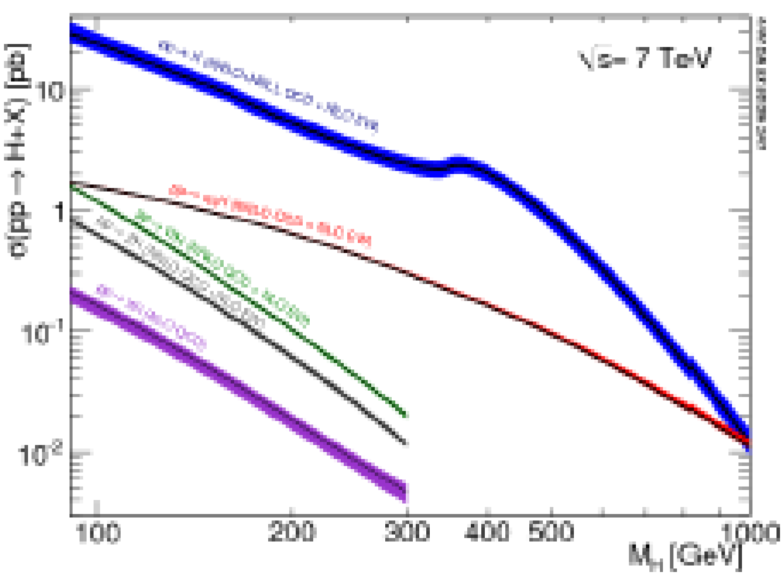




SM Higgs Production and Decay

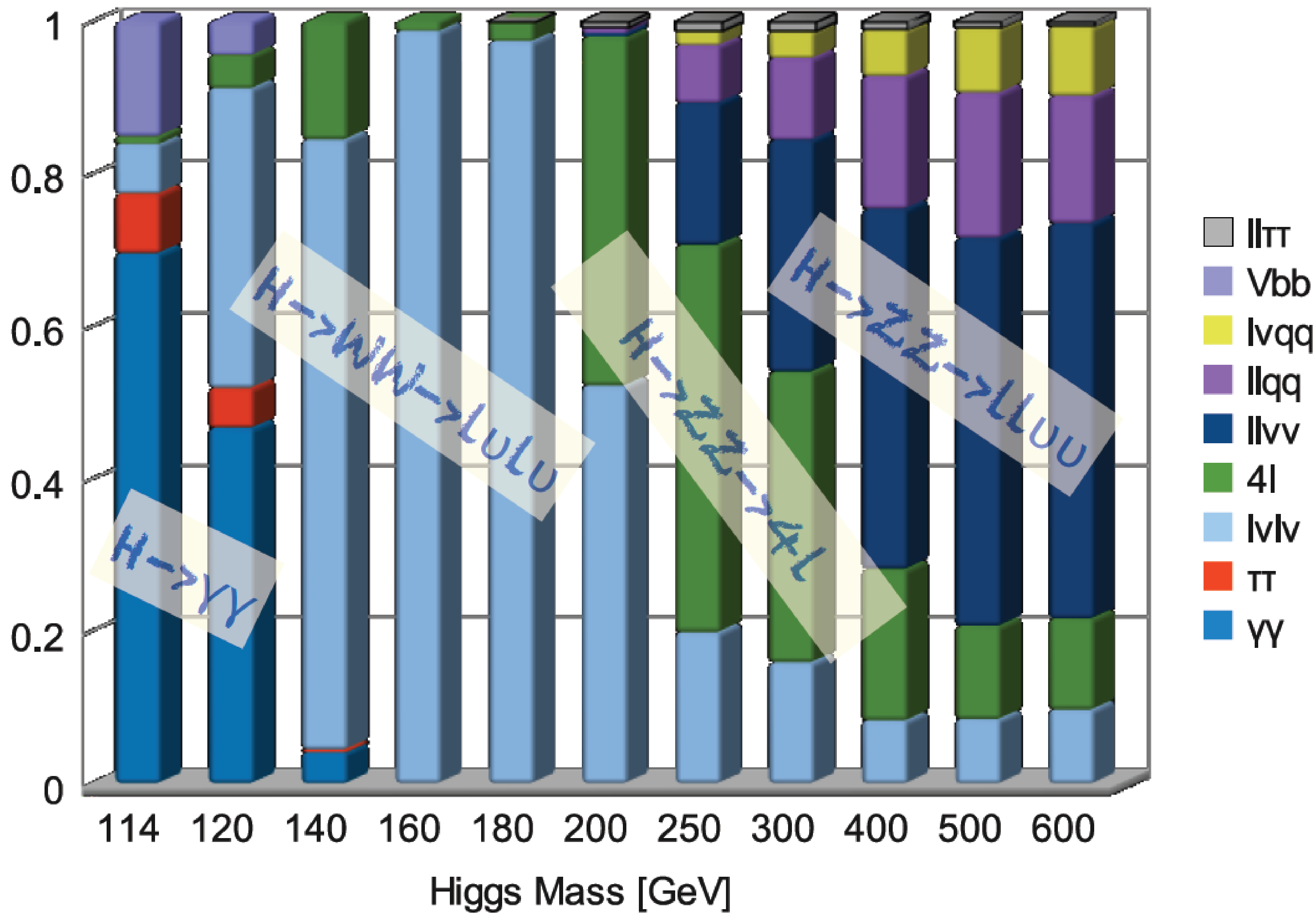
- Dominant production $gg \to H$, subdominant VBF $q\bar{q} \to q\bar{q}H$ and W/Z bremsstrahlung $q\bar{q} \to VH$, small $gg \to ttH$ associated production
- Total cross section ~20 times higher than at Tevatron for M_H=120 GeV





- Higgs decay depends on its mass, searches performed in M_H range of 110 - 600 GeV
- M_H<135 GeV: $b\bar{b}$ dominant, WW^* and $\tau\tau$ subdominant, $\gamma\gamma$ best despite low BR
- M_H>135 GeV: WW^* dominant, ZZ^* cleanest ($4l$ decay golden channel), rates must be scaled by leptonic BR

«Вес» разных мод распада



Моды распада хиггс-бозона

$$\Gamma(H \to f f) \sim M_H M_f^2$$

$$\Gamma(H \to WW) \sim M_H^3/2$$

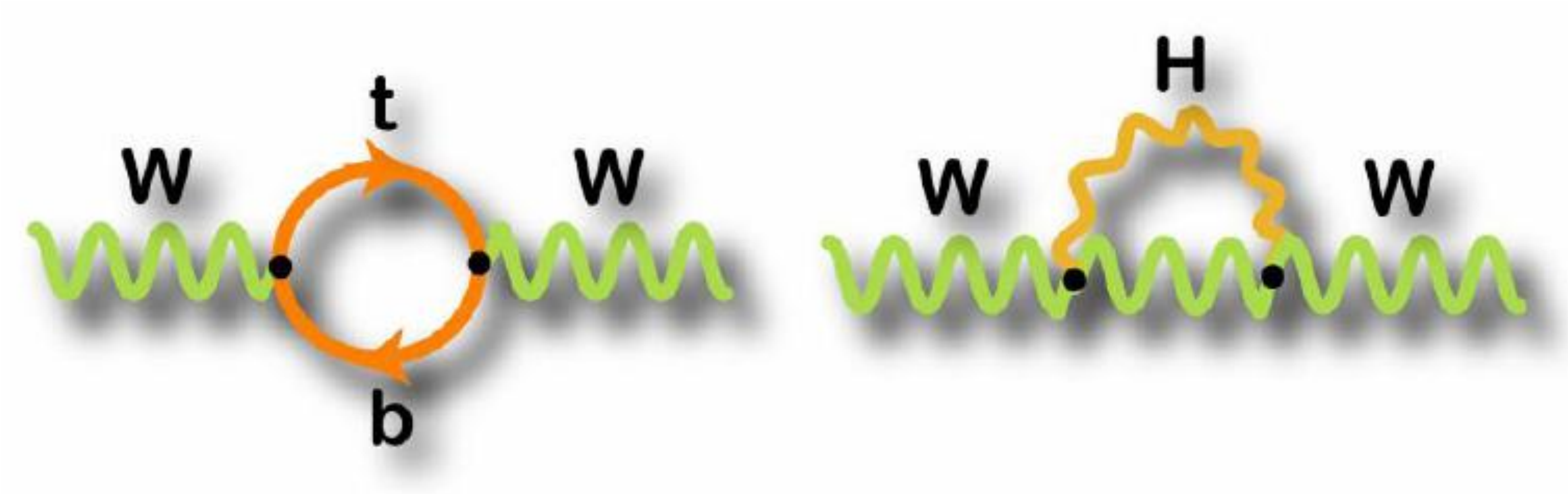
$$\Gamma(H \to ZZ) \sim M_H^3/4$$

$$\Gamma(H \to gg) \sim M_H^3 \frac{\alpha_S^2}{9\pi}$$

$$\Gamma(H \to \gamma\gamma) \sim M_H^3 \frac{49\alpha_{EM}^2}{32\pi}$$

- Ширины фермионных распадов пропор-циональны квадрату массы фермиона
- Хиггс-бозон распадается на пару самых тяжёлых фермионов (b-кварки)
- Распады на бозоны WW и ZZ становятся доминирующими, как только $M_H > 2M_{W(Z)}$

Радиационные поправки



$$\rho = \frac{M_W^2/M_Z^2}{1-\sin^2\Theta_W} =$$

$$= 1 + \frac{3G_F}{8\pi^2\sqrt{2}} m_t^2 + \frac{\sqrt{2}G_F}{16\pi^2} m_t^2 \left[\frac{11}{3} \ln\left(\frac{M_H^2}{M_W^2}\right) + \ ... \right] + ...$$

Overview on ATLAS analyses

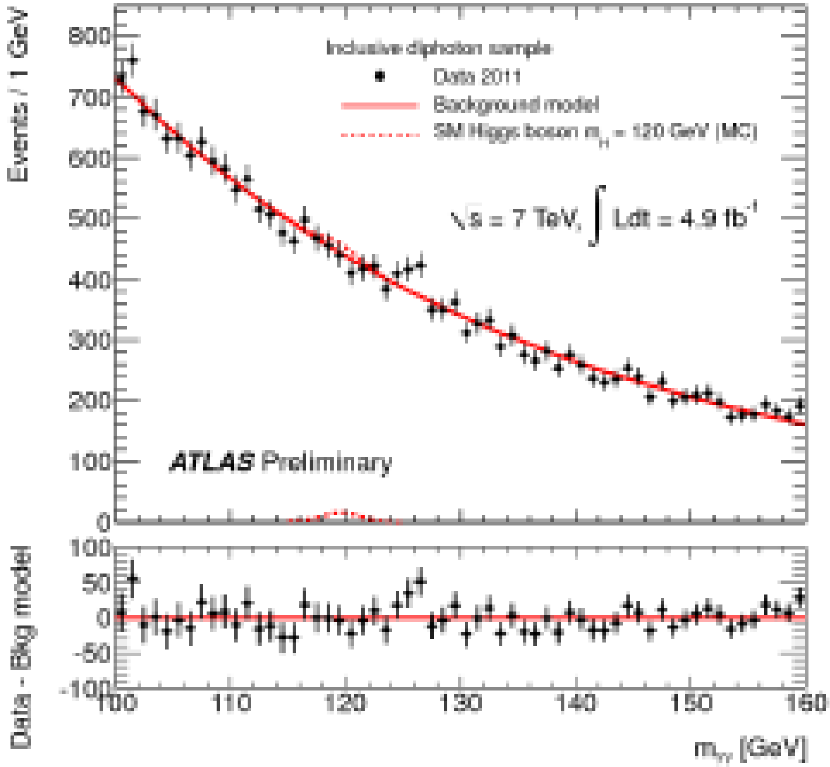
Channel	Mass range (GeV)	L_{int} (fb^{-1})	Main backgrounds
Low mass:			
$H \rightarrow \gamma\gamma$	110 – 150	4.9	$\gamma\gamma$, γj, jj
$H \rightarrow ZZ^* \rightarrow 4l$	110 - 180	4.8	ZZ^*, tt, Zbb
$H \rightarrow WW^{(*)} \rightarrow l\nu\, l\nu$	110 – 180	2.1	WW, tt, Z+jets
$H \rightarrow \tau\tau \rightarrow ll + \ldots$ $\rightarrow \tau\tau \rightarrow l\, \tau_{had} + ..$	110 – 140 100 - 150	1.1 1.1	$Z \rightarrow \tau\tau$, tt $Z \rightarrow \tau\tau$, tt
$W(Z)\, H \rightarrow ll(l\nu)\, bb$	110 – 130	1.1	W(Z) + jets, tt ,..
High mass:			
$H \rightarrow WW \rightarrow l\nu\, l\nu$ $\rightarrow l\nu\, qq$	180 – 300 240 - 600	2.1 1.1	WW, tt, Z+jets W+jet, tt, jets (QCD)
$H \rightarrow ZZ \rightarrow 4l$ $\rightarrow ll\, \nu\nu$ $\rightarrow ll\, qq$	180 – 600 200 – 600 200 – 600	4.8 2.1 2.1	ZZ ZZ, tt, Z+jets Z+jets, tt

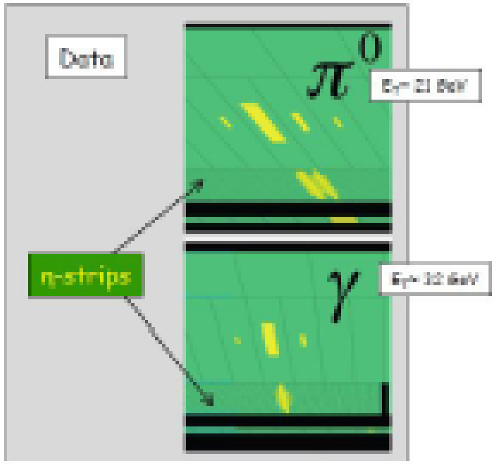
- Searches in $\gamma\gamma$ and 4l final states are based on the full data set
- Updates of the other channels expected by end of January / Moriond 2012 (requires a solid understanding of more complex signatures at high luminosity, e.g E_T^{miss})

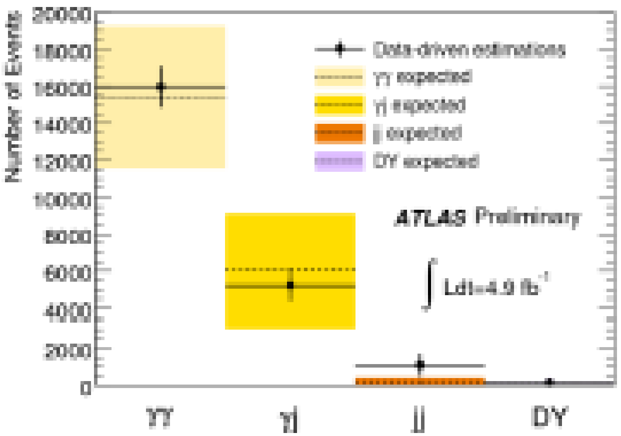
$H \to \gamma\gamma$

ATLAS-CONF-2011-161
$\mathcal{L} = 4.9\ fb^{-1}$

- Small rate but simplest and clean final state: two high-p_T isolated photons
- Main background: γγ continuum, irreducible or fake
- 'Benchmark channel' which drove the design of the experiments: mass resolution and fake rejection
- π^0 fake reduction from jets of γj and jj events utilising the fine lateral segmentation of first layer of EM calorimeter



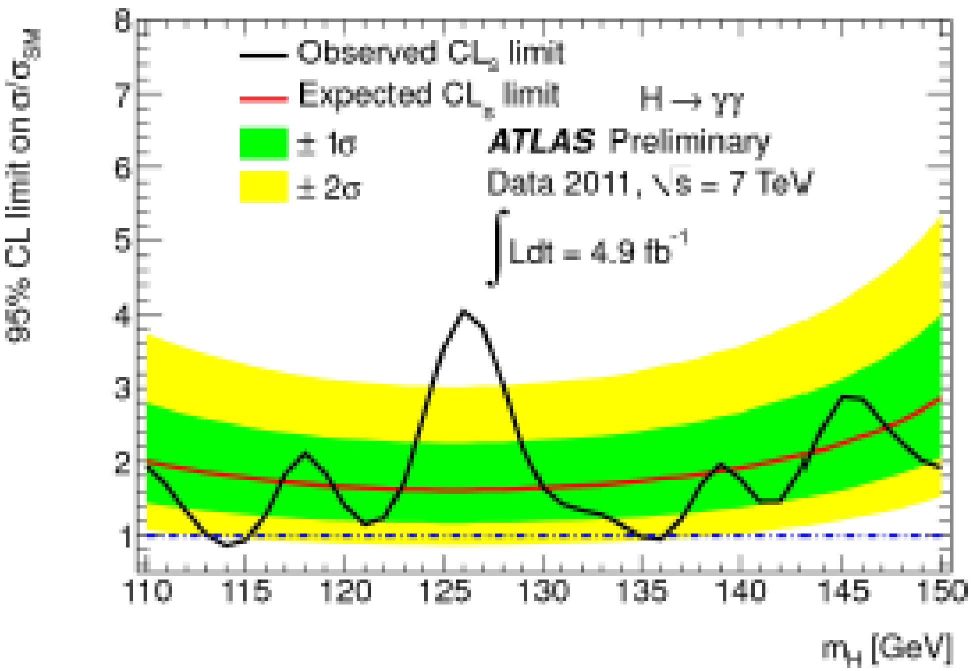


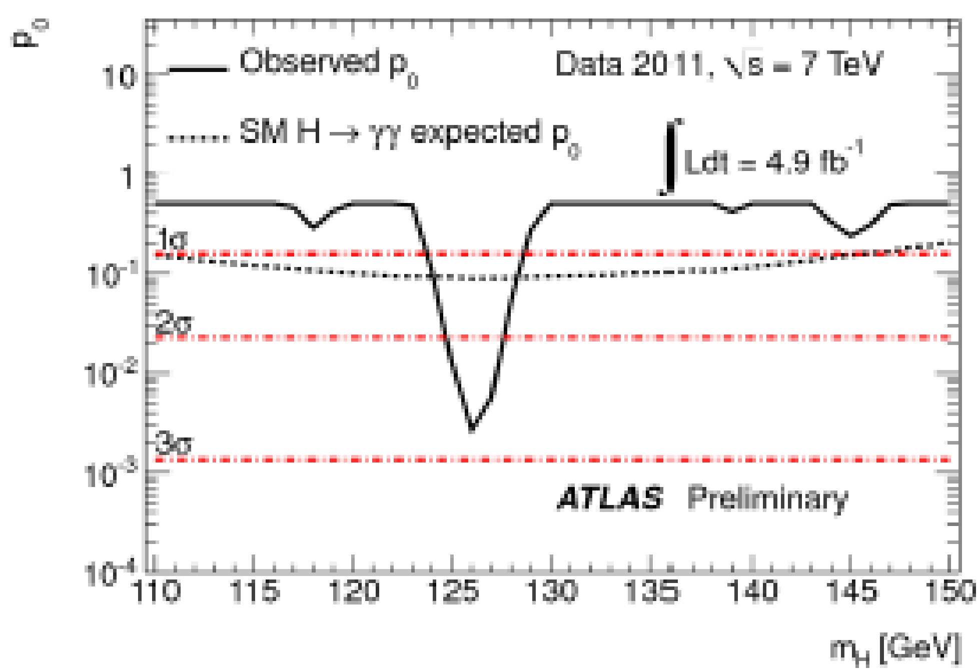


- After all cuts 22489 data events with $100 < M_{\gamma\gamma} < 160$ GeV
- Sample dominated by genuine γγ events

$H \to \gamma\gamma$

ATLAS-CONF-2011-161
$\mathcal{L} = 4.9\ fb^{-1}$





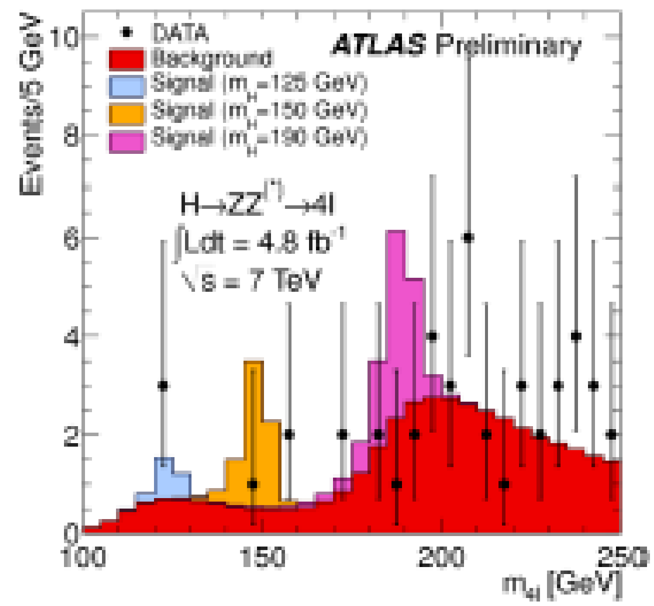
- Excluded at 95% CL: 114 < M_H < 115 GeV and 135 < M_H < 136 GeV

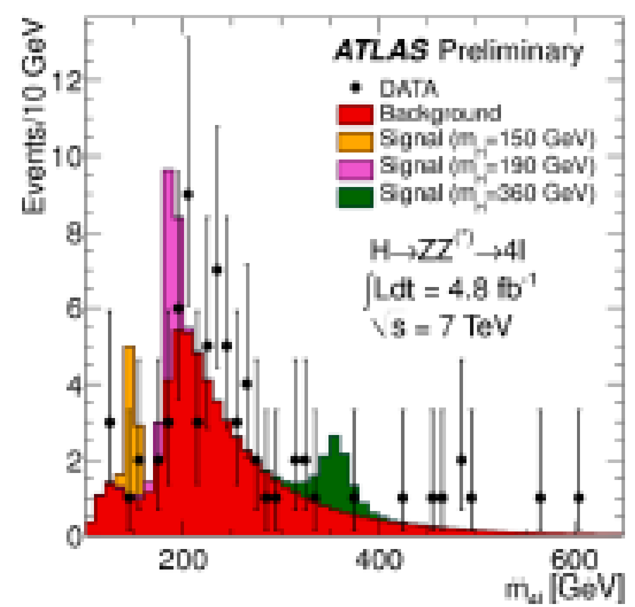
- Maximum deviation from background-only expectation at M_H ~ 126 GeV
  - Local p_0 value: 0.27% or 2.8σ, expected from SM Higgs: ~1.4 σ
  - Global p_0 value: ~7% or 1.5σ (includes „look-elsewhere-effect")

$H \to ZZ^{(*)} \to 4l$

ATLAS-CONF-2011-162
$\mathcal{L} = 4.8\ fb^{-1}$

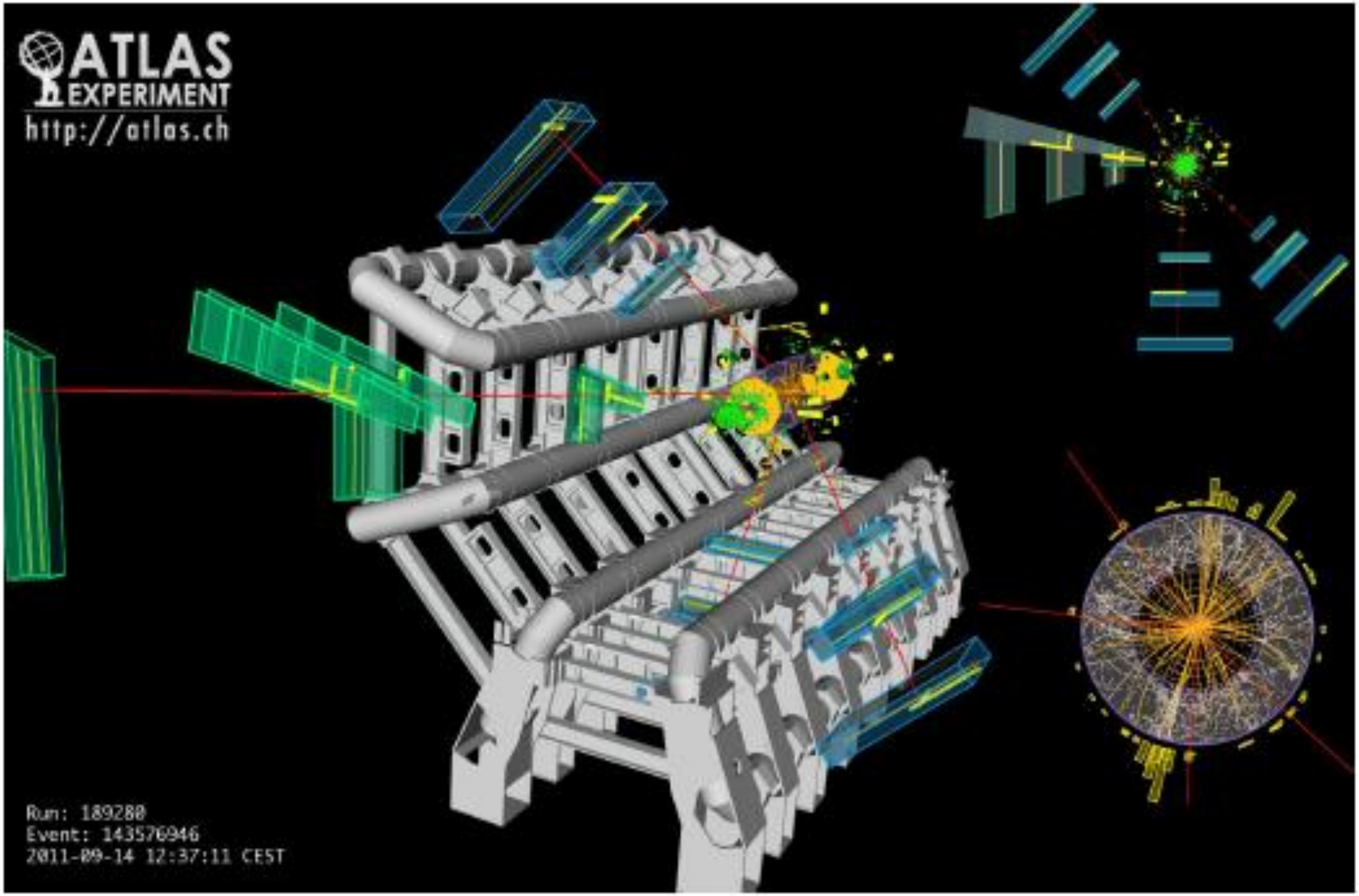
- The 'golden channel': low rate but clean final state, low background, narrow mass peak
- Two isolated same-flavour lepton pairs (e or μ) with opposite charge, one pair close to Z mass
- Backgrounds: irreducible $ZZ^{(*)}$ and reducible Z+jets, Zbbar, ttbar
- Full mass range:
  - Observed in data: 71 (24 4μ + 30 2e2μ + 17 4e)
  - Expected background: 62 ± 9
- For M_{4l} < 180 GeV:
  - Observed in data: 8 (3 4μ + 3 2e2μ + 2 4e)
  - Expected background: 9.3 ± 1.5
- For M_{4l} < 141 GeV (not yet excluded):
  - Observed in data: 3 = 2e2μ (123.6 GeV) + 2e2μ (124.3 GeV) + 4μ (124.6 GeV)





$H \rightarrow ZZ^{(*)} \rightarrow 4l$

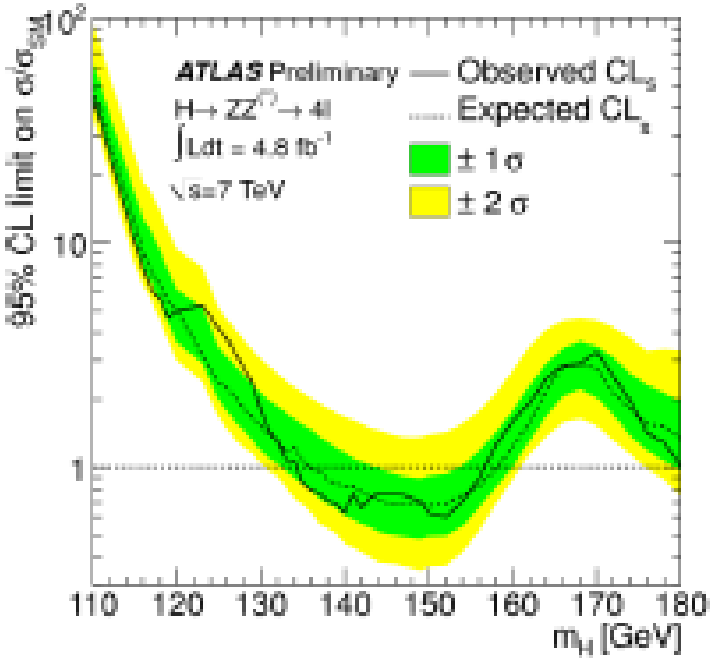
ATLAS-CONF-2011-162
$\mathcal{L} = 4.8\ fb^{-1}$

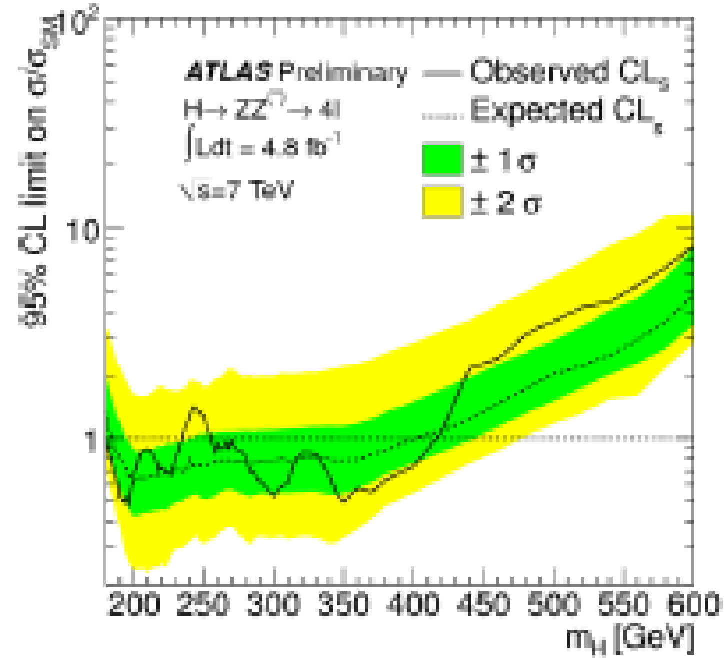


4μ candidate with $M_{4\mu}$= 124.6 GeV

$H \rightarrow ZZ^{(*)} \rightarrow 4l$

ATLAS-CONF-2011-162
$\mathcal{L} = 4.8\ fb^{-1}$



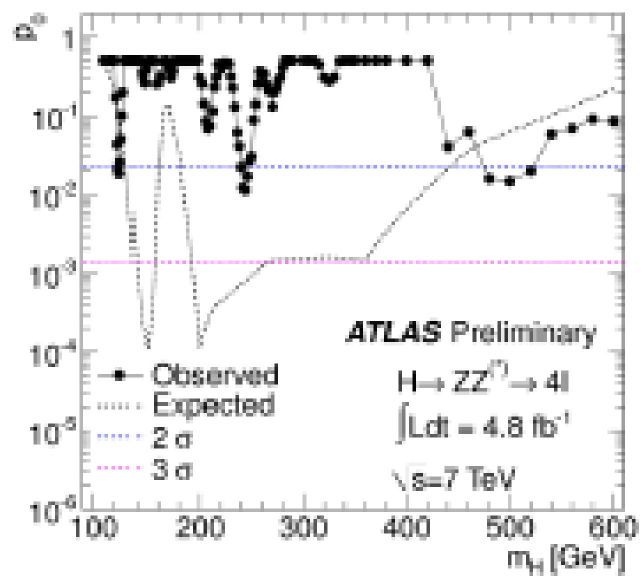


Excluded at 95% CL

- Observed: $135 < M_H < 156$ GeV, $181 < M_H < 415$ GeV (except 234 - 255 GeV)
- Expected: $137 < M_H < 158$ GeV, $185 < M_H < 400$ GeV

Largest deviations

M_H = 125 GeV: p_0=1.8%, M_H = 244 GeV: p_0=1.1%,
M_H = 500 GeV: p_0=1.4%



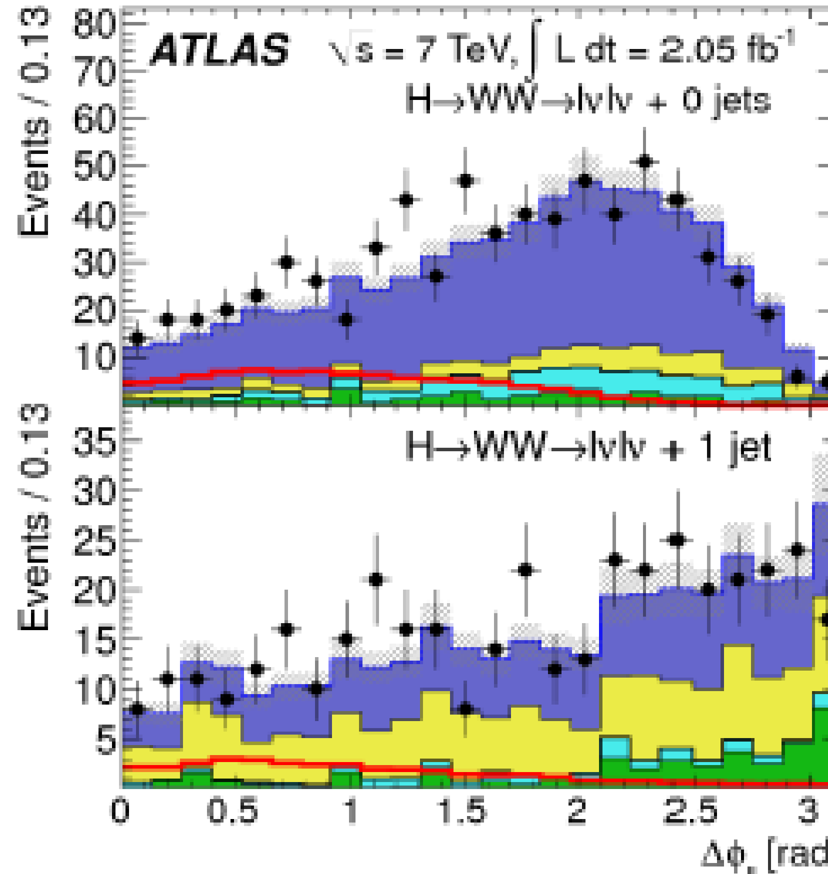
Once the "look-elsewhere-effect" is considered, none of these excesses is significant by itself

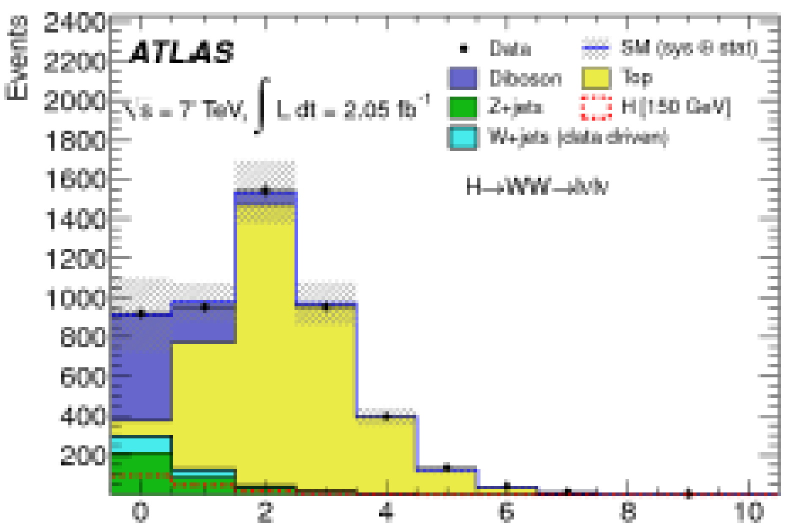
$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

arXiv:1112.2577

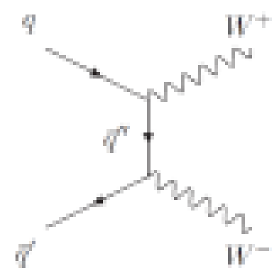
$\mathcal{L} = 2.05\ fb^{-1}$

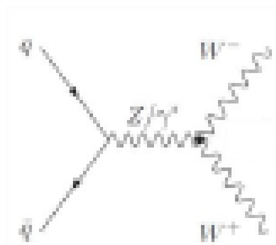
- Most sensitive channel in intermediate mass range ~ 125-180 GeV
- Higgs mass reconstruction impossible due to two neutrinos in final state
- Select events with two high p_T opposite sign leptons (e or μ)
- Largest background is irreducible WW SM production, W/Z+jets and top when looking at events with jets (N_{jets}= 0 or 1)





↑ ↑ Two analysis categories

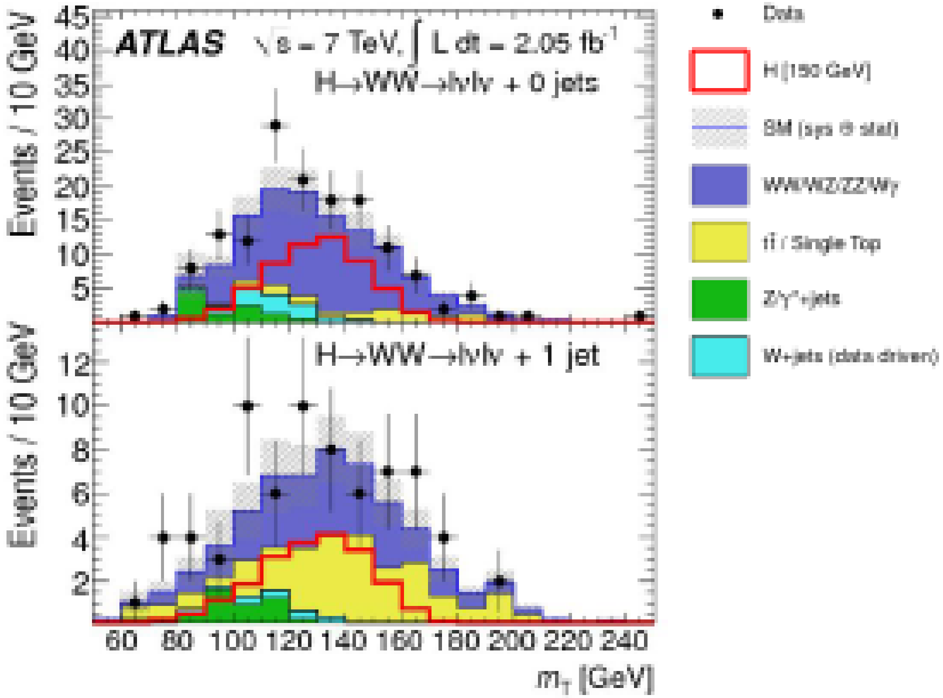


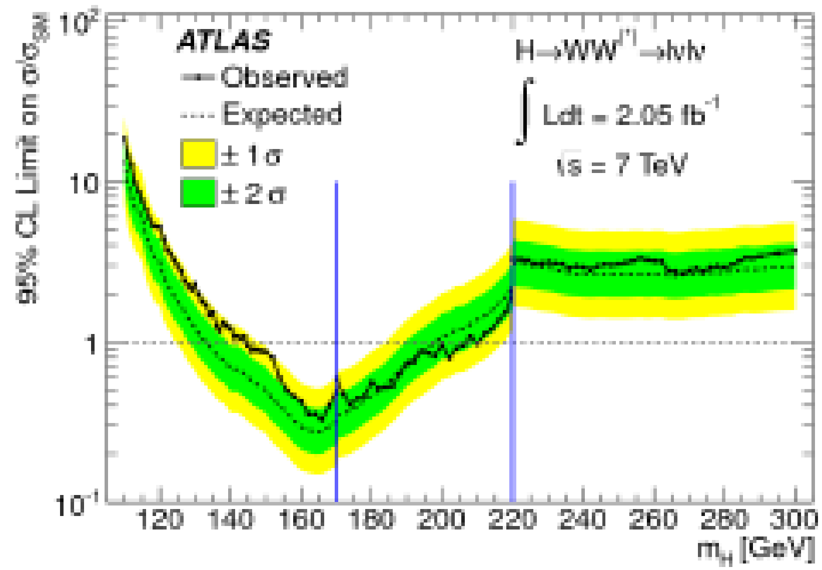


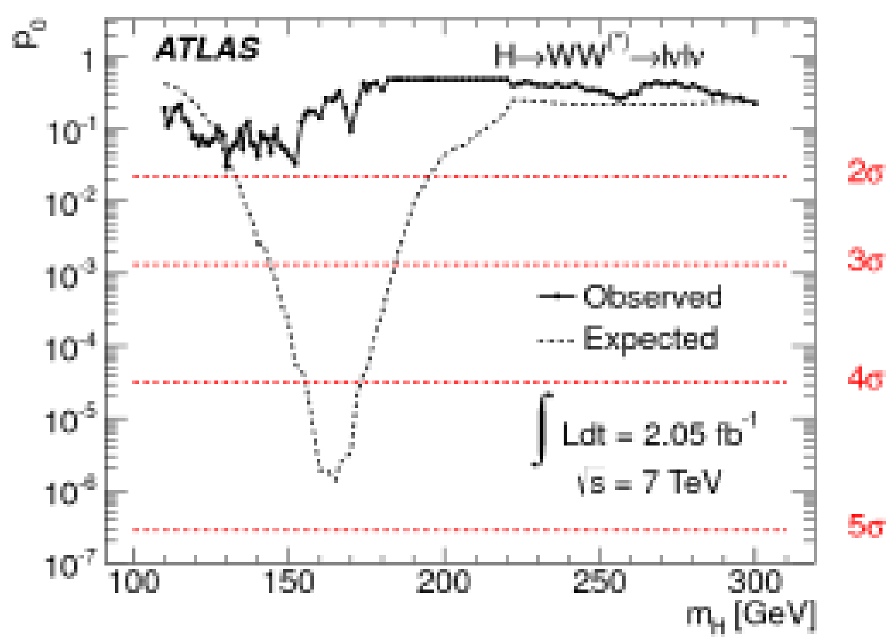
- Make use of spin correlation to supress WW background: leptons from Higgs (spin 0) are collinear

$H \to WW^{(*)} \to l\nu l\nu$

arXiv:1112.2577
$\mathcal{L} = 2.05\ fb^{-1}$







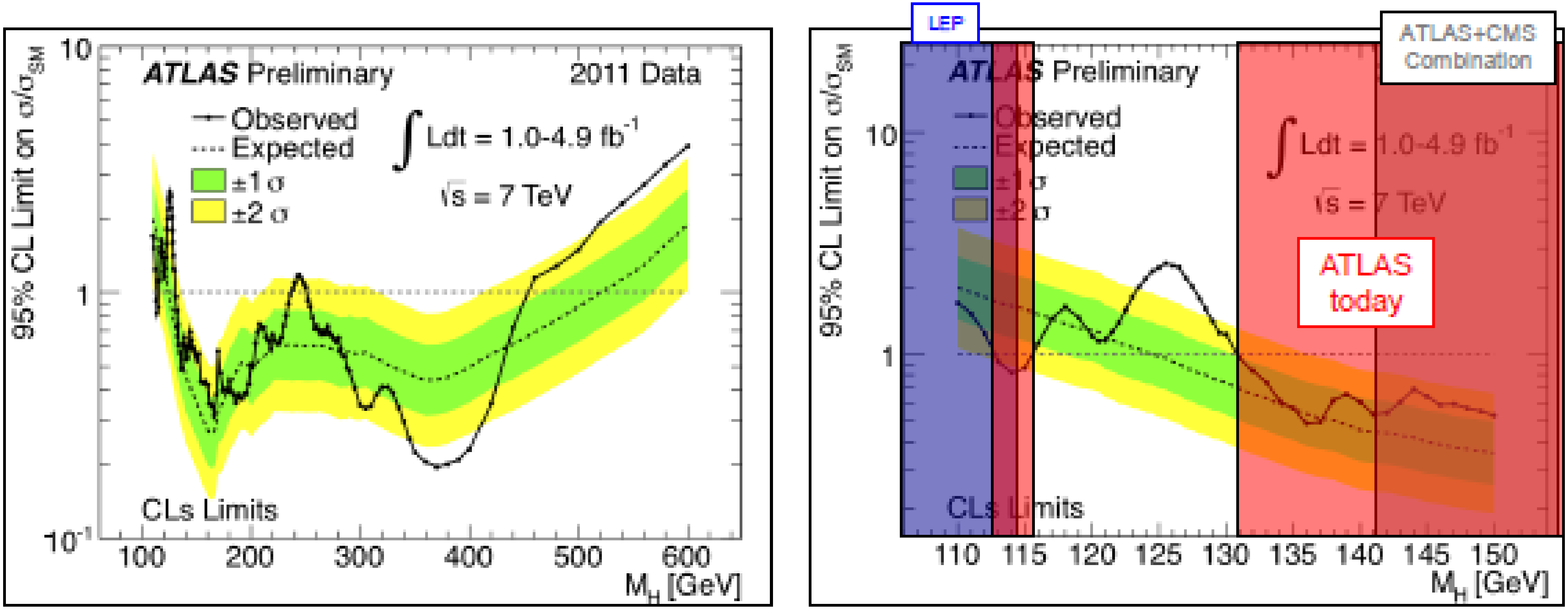
After all cuts, e.g. H+0-jets (signal M_H=150 GeV)

- Observed in data: 81 events
- Expected background: 63±9 events
- Expected signal: 40±9 events

→ Excluded (95% CL): 145<M_H<206 GeV

→ Max observed deviation from background-only expectation is 1.9σ for M_H ~130GeV

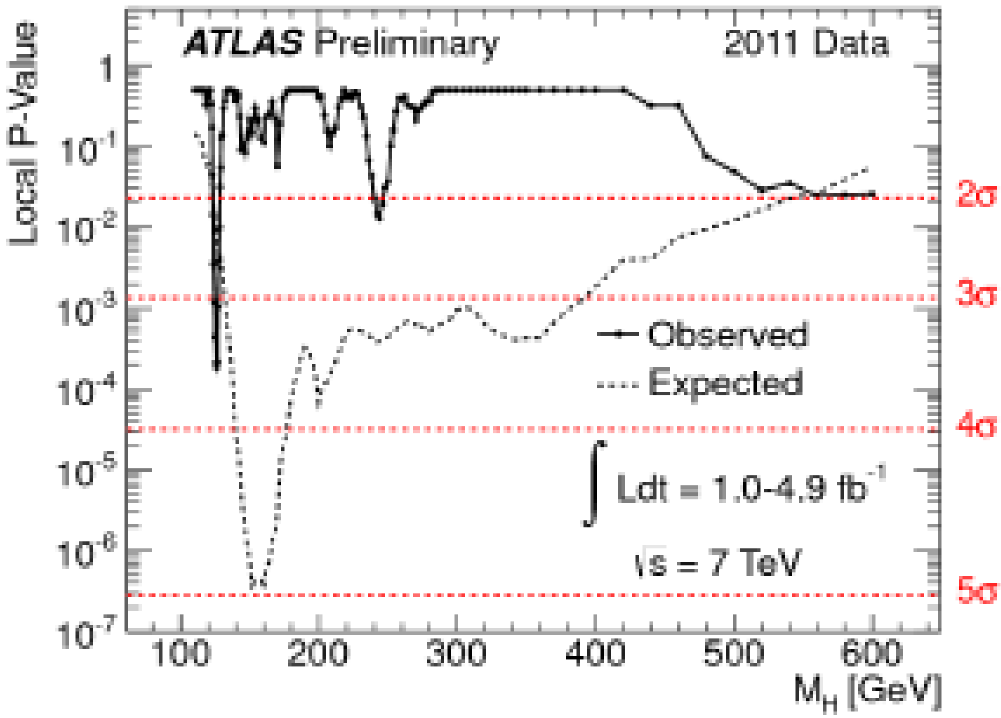
Higgs Combination

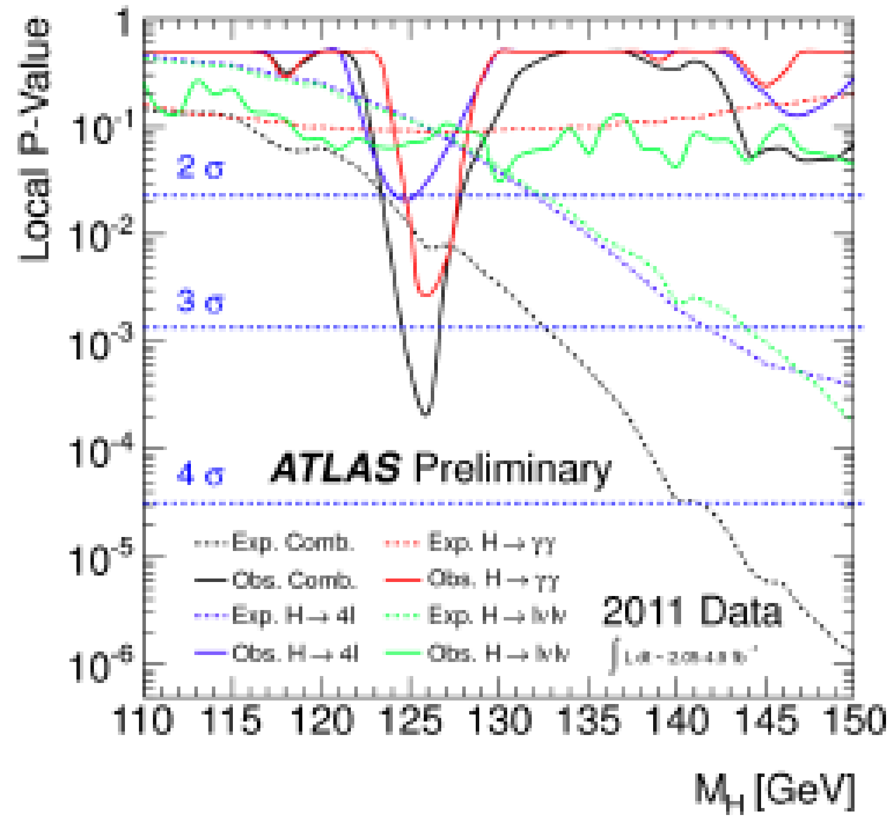


- Experimental and theoretical systematic uncertainties taken into account with proper correlation
- Expected exclusion at 95% CL if no signal: $124.6 < M_H < 520$ GeV
- M_H ranges excluded at 95% CL: 112.7 – 115.5 GeV, 131 – 453 GeV except 237-251 GeV
- M_H ranges excluded at 99% CL: 133 – 230 GeV, 260 – 437 GeV

Higgs Combination

ATLAS-CONF-2011-163
$\mathcal{L} = 1.0 - 4.9\ fb^{-1}$





Consistency of the data with background-only expectation

- Maximum deviation observed for M_H~126 GeV with local p_0 value $1.9\cdot10^{-4}$
- Local significance of excess: 3.6σ ~ 2.8σ H→γγ, 2.1σ H→4l, 1.4σ H→lνlν
- Global p_0 value: 2.2σ including "look-elsewhere-effect" over 110-600 GeV

Бозон Хиггса 2011 (4.9 fb^{-1}):

95% CL исключены массы:

С 112.7 по 115.5 ГэВ/c^2

С 131 по 237 ГэВ/c^2

С 251 по 468 ГэВ/c^2

Наблюдается (когерентное) превышение событий над фоном при массе 126 ГэВ/c^2

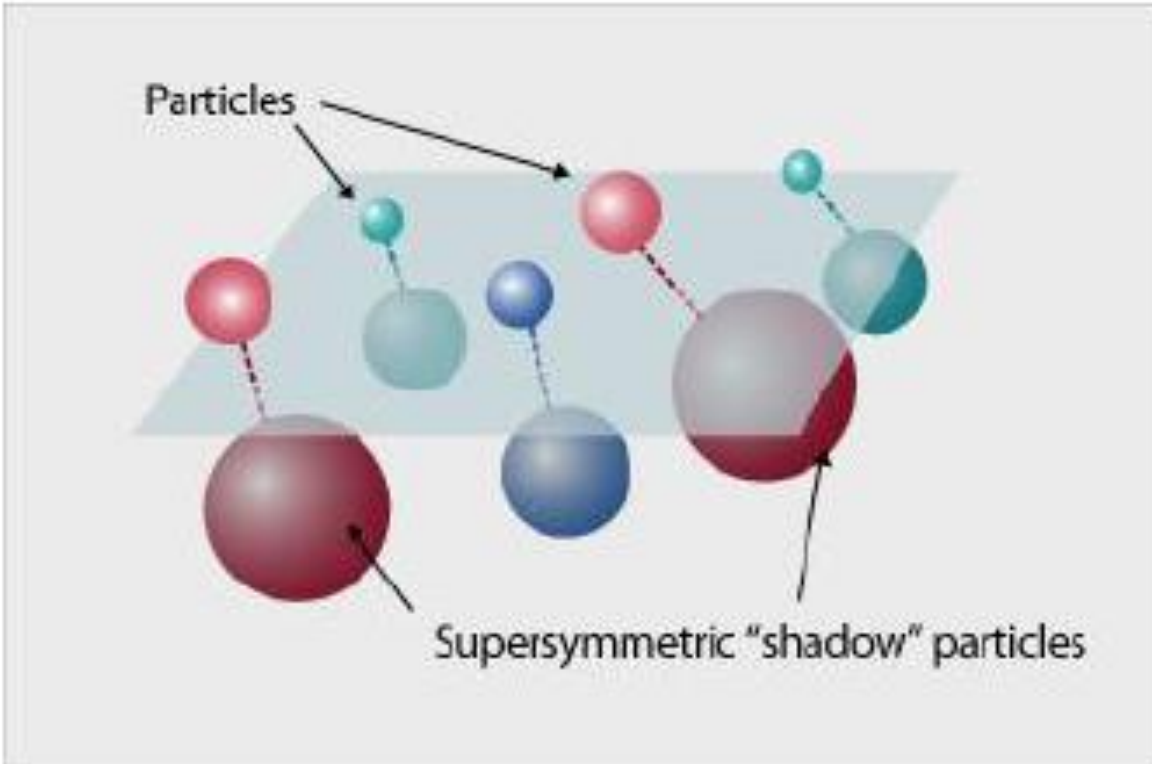
В 2.8 σ для распада $H \to \gamma\gamma$

В 2.1 σ для распада $H \to Z Z^* \to l^+l^-l^+l^-$

В 1.4 σ для распада $H \to WW^* \to l^+l^-\nu\nu$

Совместно три канала дают превышение в 3.6 σ (пока?)

Beyond the Standard Model

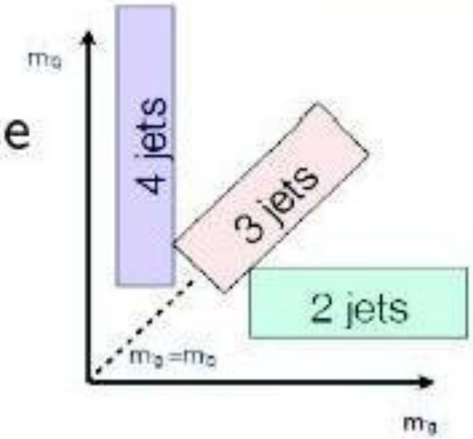


Super Symmetry

Beyond SUSY

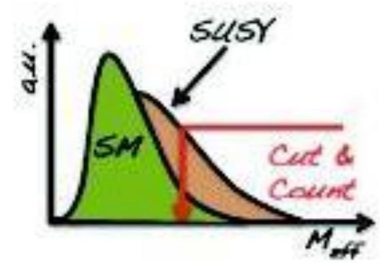
General Search Strategy

- Definition of **Signal Regions** (SRs) that maximise sensitivity to different models
  - → based on **discriminating variables**



- Identification and estimation of **SM backgrounds**
  - → different techniques (preferably data-driven)

- Search for **non-SM excess**
  - → cut & count
  - → resonances

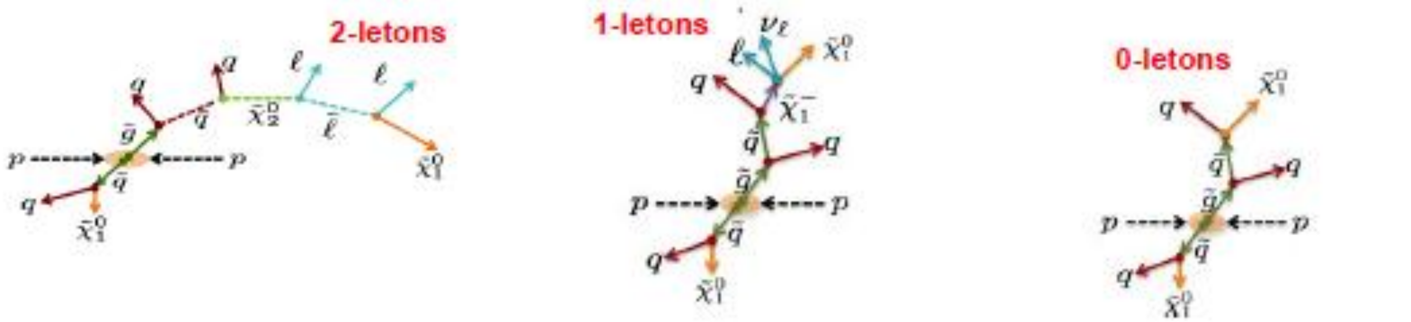


- If no excess, **model independent limits** set
  - → different stat. methods
  - → different interpretations

$$\sigma_{\text{BSM}} \times \varepsilon \times A$$

Поиск SUSY

SUSY search strategies



R-Parity violating searches (RPV)	R-Parity conserving searches (RPC)

- LSP: no need to be neutral nor stable.
- LSP decay: possibility to explore new signals, exploit LSP invariant mass and decay properties
- Single Sparticles production is possible
- Not so large E_T^{miss}

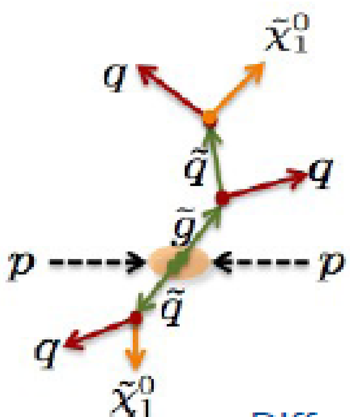
✓ 0-lepton
✓ 1-lepton
✓ 2-leptons
✓ b-jet searches
✓ Photon searches

- Neutral Stable LSP
- Sparticles produced in pairs
- Large E_T^{miss}

Сохранение R-четности

0-lepton searches

0-letons



✔ Strong production of massive particles:

jet+E_T^{miss} signature (taus treated as jets)

✔ Leptons are vetoed

Different techniques/strategies developed:

m_{eff} search
Excess at large E_T^{miss} and/or large H_T

Long cascades
Excess at large jet multiplicities

b-jets
jets + missing E_T plus 1 or 2 b-tags

$$m_{\rm T} = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\rm T}^{\rm miss} \cdot (1 - cos(\Delta\phi(\ell, E_{\rm T}^{\rm miss}))},$$

$$H_T = p_T^{\ell} + \sum_{i=1}^{3(4)} p_T^{jet_i},$$

$$m_{\rm eff} = H_T + E_{\rm T}^{\rm miss} = p_T^{\ell} + \sum_{i=1}^{3(4)} p_T^{jet_i} + E_{\rm T}^{\rm miss}$$

Сохранение R-четности

m_{eff} search 1.04 fb^{-1}

Backgrounds:

- Multijets
- $Z(\rightarrow \nu\nu)$ + jets
- W+jets
- ttbar+single top

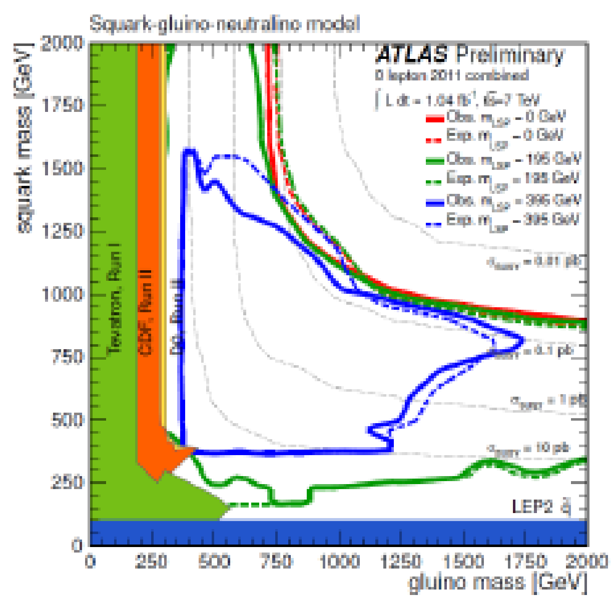
✔ Transfer Function (MC): move from CR to SR

✔ Likelihood fit: combine all the information and correlation among uncertainties

✔ Jet energy scale (~15%) and theoretical Uncertainties (~25%) dominate

Signal Region	≥ 2-jet 'A'	≥ 3-jet 'B'	≥ 4-jet 'C' / 'D'	High mass 'E'
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff} (leading 2, 3, 4 jets)	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} (leading 2, 3, 4 jets)	> 1000	> 1000	> 500/1000	–
m_{eff} (jets with $p_T > 40$ GeV)	–	–	–	> 1100
Background events	62.4 ± 10	54.9 ± 8.1	1015 ± 150/33.9 ± 6.8	13.1 ± 3.1
Observed events	58	59	1118/40	18
Limit on $(\sigma \times A \times \epsilon)$ / fb	22	25	429/27	17

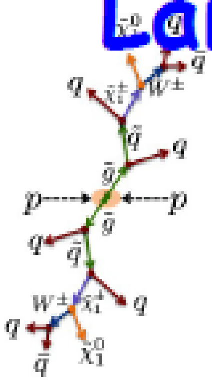
Table 1: Top rows: criteria for admission to each of the five overlapping signal regions (m_{eff}, E_T^{miss} and p_T in GeV). Bottom rows: expected background and observed event count, and extracted cross section upper limit for new physics at 95% C.L. (A = acceptance, ϵ = efficiency).



Data are in agreement with SM expectations in all regions

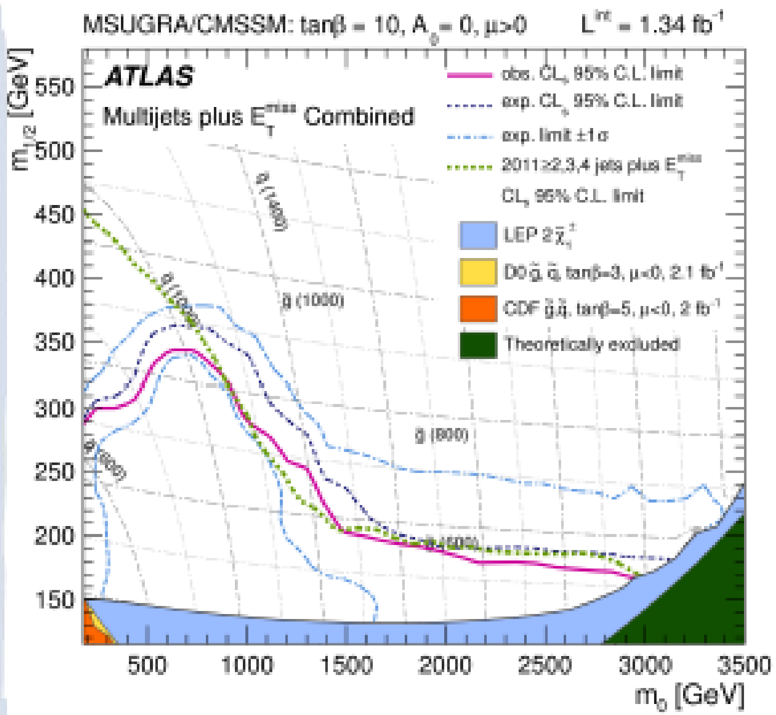
Сохранение R-четности

Large multiplicities 1.34 fb^{-1}



Key observation:
$E_T^{miss}/\mathrm{sqrt}(H_T)$

Signal region	7j55	8j55	6j80	7j80
Jet p_T	> 55 GeV		> 80 GeV	
Jet $\|\eta\|$	< 2.8			
ΔR_{jj}	> 0.6 for any pair of jets			
Number of jets	≥ 7	≥ 8	≥ 6	≥ 7
$E_T^{\mathrm{miss}}/\sqrt{H_T}$	> 3.5 GeV$^{1/2}$			



Main background is multijet production

Signal region	7j55	8j55	6j80	7j80
Multi-jets	26 ± 5.2	2.3 ± 0.7	19 ± 4	1.3 ± 0.4
$t\bar{t} \to q\ell, \ell\ell$	10.8 ± 6.7	$0^{+4.3}$	6.0 ± 4.6	$0^{+0.13}$
W + jets	0.95 ± 0.45	$0^{+0.13}$	0.34 ± 0.24	$0^{+0.13}$
Z + jets	$1.5^{+1.8}_{-1.5}$	$0^{+0.75}$	$0^{+0.75}$	$0^{+0.75}$
Total Standard Model	39 ± 9	$2.3^{+4.4}_{-0.7}$	26 ± 6	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3

Data are in agreement with SM expectations in all regions

Сохранение R-четности

b-jets 0.83 fb^{-1}

Gluino decays to sbottom in 2 or 3-bodies:

$$\tilde{g} \rightarrow \tilde{b}_1 b$$
$$\tilde{b}_1 \rightarrow b\chi_1^0$$
$$\tilde{g} \rightarrow b\bar{b}\chi_1^0$$

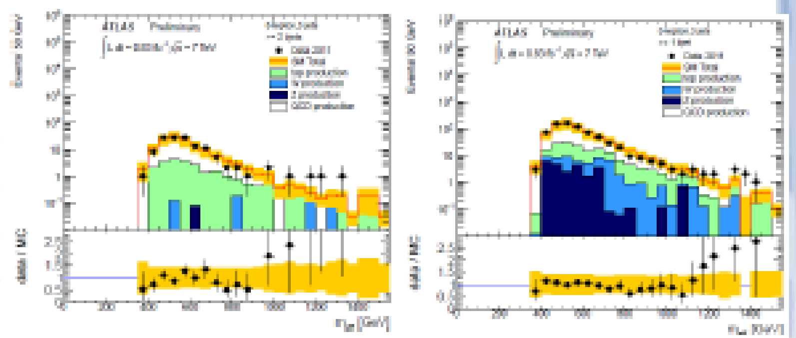
4 Signal regions

3JA: ≥1 b-jet, m_{eff}>500 GeV

3JB: ≥1 b-jet, m_{eff}>700 GeV

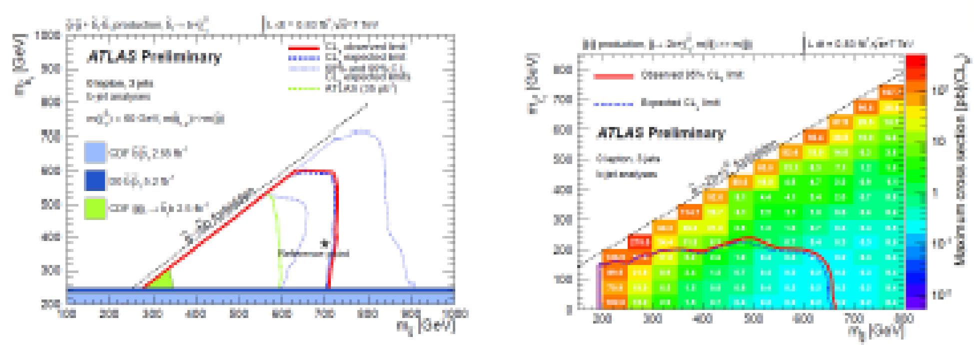
3JC: ≥2 b-jet, m_{eff}>500 GeV

3JD: ≥2 b-jet, m_{eff}>700 GeV



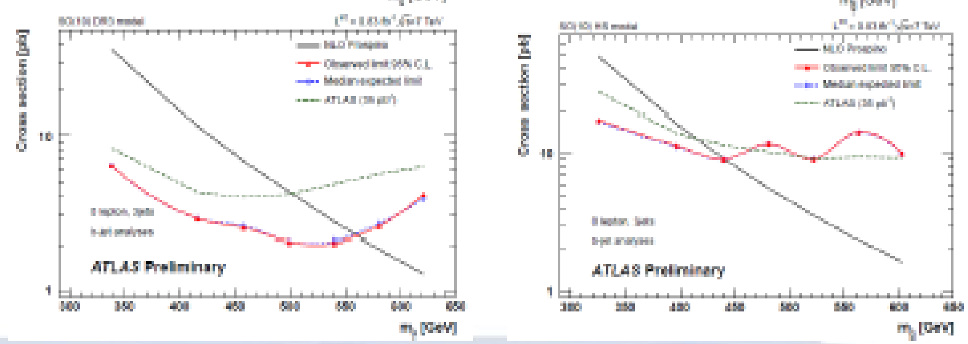
Event selection:

- Lepton veto
- ≥3 jets with p_T(130,50,50) GeV
- E_T^{miss}>130 GeV



Background:

- ttbar production
- W/Z+jets production
- QCD

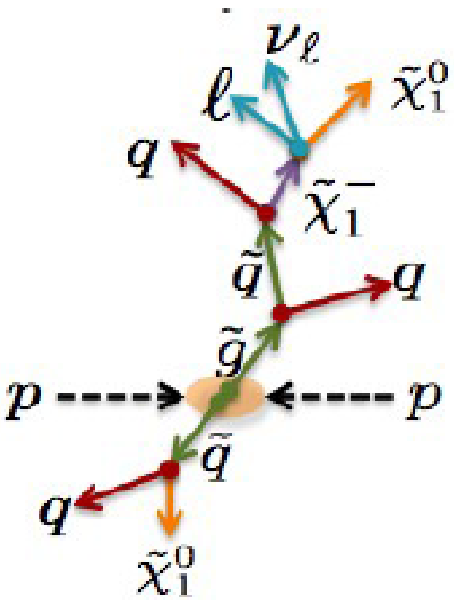


Data are in agreement with SM expectations in all regions

Сохранение R-четности

1-lepton searches (1.04 fb^{-1})

- cascades including charginos or neutralinos can lead to final states with one, two, three or more isolated leptons
- advantage: suppress QCD background, help in trigger
- analysis requires exactly 1 lepton (e: p_T > 25 GeV or muon: p_T > 20 GeV) and ≥ 3/4 jets → four signal regions



Background:

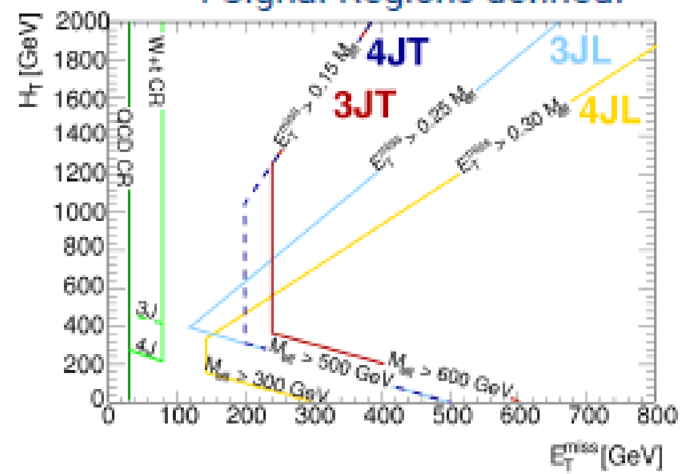
- *ttbar pair production*
- *WlvNp*
- *ZllNp*
- *WW, WZ, ZZ*
- *Wt*
- *QCD*

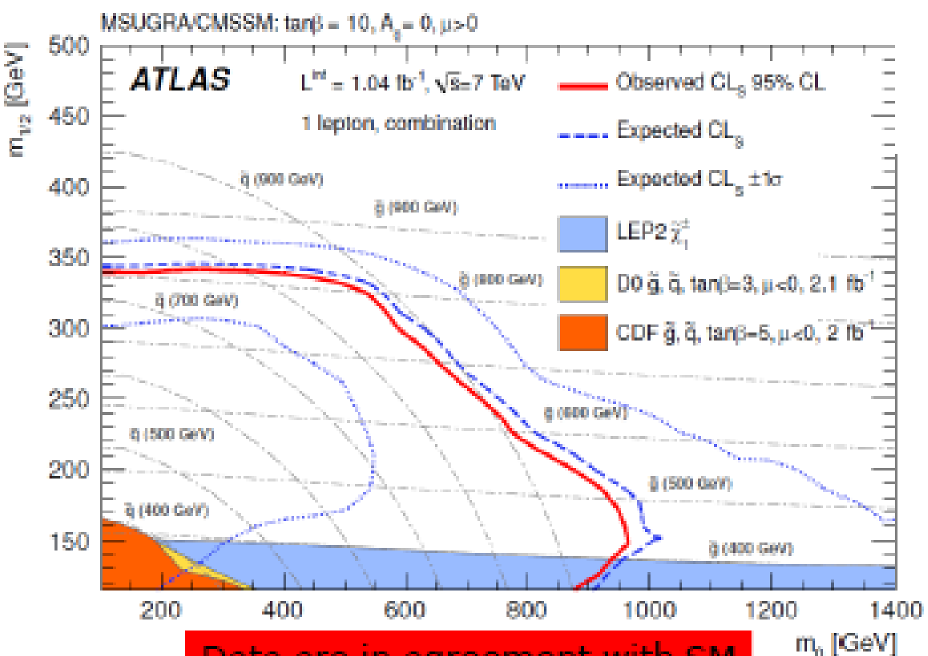
Сохранение R-четности

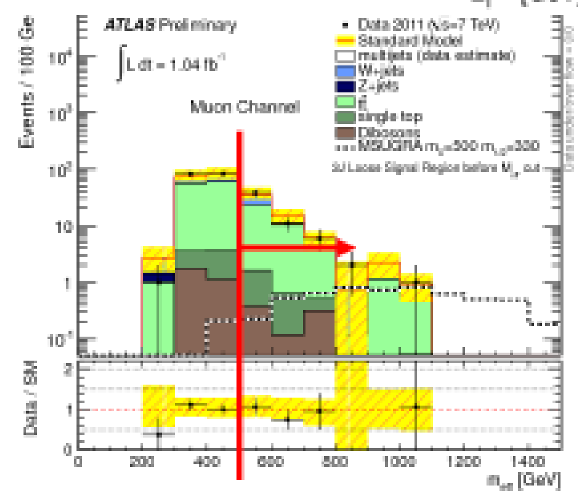
1-lepton searches ($1.04\ fb^{-1}$)

- observed number of events in data consistent with SM
- uncertainties dominated by jet energy scale and resolution, theory and MC modeling and statistics

4 Signal Regions defined:







Data are in agreement with SM expectations in all regions

Сохранение R-четности

b-jets 1.03 fb^{-1}

Searching for:

1) $\tilde{g} \to t\tilde{t}$ with:
   a) $\tilde{t} \to b\tilde{\chi}_1^{\pm}$
   b) $\tilde{t} \to t\tilde{\chi}_1^{0}$
2) $\tilde{g} \to t\bar{t}\tilde{\chi}_1^{0}$

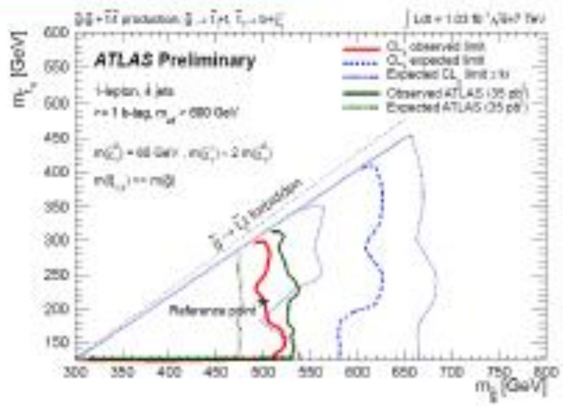
Signal region

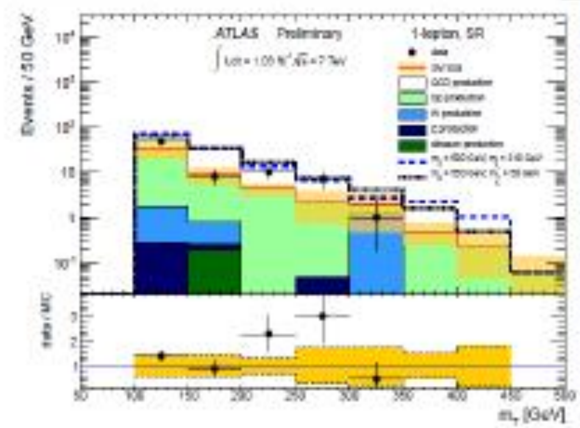
m_T > 100 GeV
m_{eff} > 600 GeV

Cuts	≥ 4 jets	≥ 1 b jet	$E_T^{miss} > 80$ GeV	$m_T > 100$ GeV	$m_{eff} > 600$ GeV
			Total		
top	3360 ± 1250	2590 ± 970	810 ± 337	103 ± 53	48 ± 27
W+jets	1850 ± 750	210 ± 130	55 ± 36	3.7 ± 3.1	3.1 ± 2.9
Z+jets	410 ± 170	39 ± 24	2.4 ± 3.1	0.4 ± 0.4	0.4 ± 0.3
diboson	87 ± 36	10 ± 6	4.0 ± 2.5	0.4 ± 0.4	0.2 ± 0.2
QCD (d-d)	870 ± 270	247 ± 121	9.7 ± 16.8	1.1 ± 2.3	0.9 ± 1.2
SM (MC)	6574 ± 1870	3096 ± 1042	881 ± 356	109 ± 55	52 ± 28
SM (d-d)					54.9 ± 13.6
data	6659	3361	989	141	74

Event selection:

- e/μ p_T > 25/20 GeV
- ≥4 jets with p_T > 50 GeV
- E_T^{miss} > 80 GeV

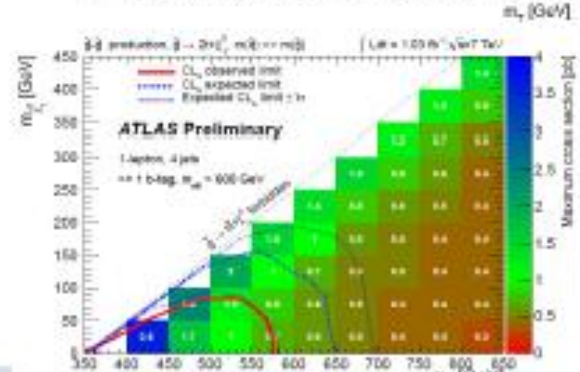




Background:

- ttbar production
- W/Z+jets production
- WW, ZZ, WZ

Physics process	σ· BR [nb]	
$W \to \ell\nu$ (+jets)	31.4±1.6	[20–22]
$Z/\gamma^* \to \ell\ell$ (+jets)	3.20±0.16	[20–22]
$Z \to \nu\nu$ (+jets)	5.82±0.29	[20–22]
$t\bar{t}$	$0.165^{+0.011}_{-0.016}$	[23–25]
Single top	0.085±0.003	[26, 27]

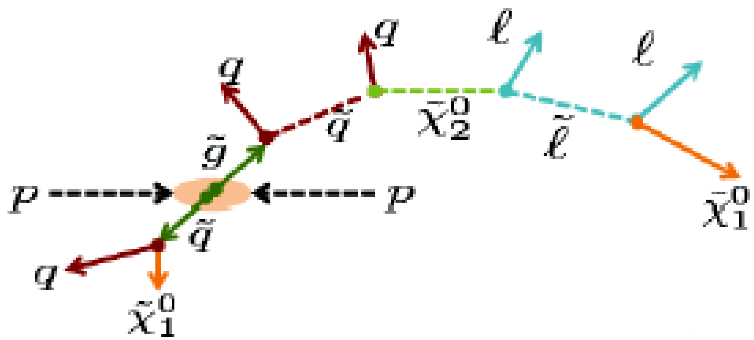


Data are in agreement with SM expectations in all regions

SM exp: 54.9±13.6
Data: 74

Сохранение R-четности

2-leptons searches (1.04 fb^{-1})



Opposite sign:
- three signal region → E_T^{miss} / jets
- main background → top pairs, Z+jets

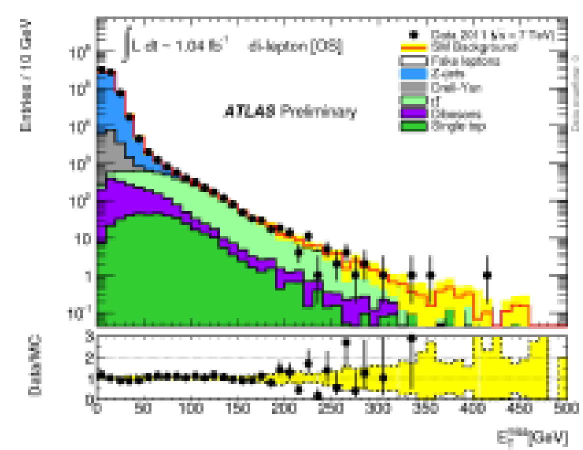
Same sign:
- two signal region → E_T^{miss} / jets
- main background → fake leptons from jets, opposite sign leptons with charge mismeasurement

- 2 leptons from chargino/neutralino decays
- 3 analyses, searching for dilepton events:

1) opposite sign (OS)
2) same sign (SS)
3) with flavour subtraction (FS)

(exploit the natural cancellation of flavour-symmetric background events)

ee: pT > 25/20 GeV
eμ: pT > 25/10 GeV
μe: pT > 20/20 GeV
μμ: pT > 20/10 GeV



- selection: exactly 2 isolated leptons

Сохранение R-четности

2-leptons searches (1.04 fb^{-1})

Signal Region	OS-SR1	OS-SR2	OS-SR3	SS-SR1	SS-SR2	FS-SR1	FS-SR2	FS-SR3
E_T^{miss} [GeV]	250	220	100	100	80	80	80	250
Leading jet p_T [GeV]	-	80	100	-	50	-	-	-
Second jet p_T [GeV]	-	40	70	-	50	-	-	-
Third jet p_T [GeV]	-	40	70	-	-	-	-	-
Fourth jet p_T [GeV]	-	-	70	-	-	-	-	-
Number of jets	-	≥ 3	≥ 4	-	≥ 2	-	≥ 2	-
m_{ll} veto [GeV]	-	-	-	-	-	80-100	-	-

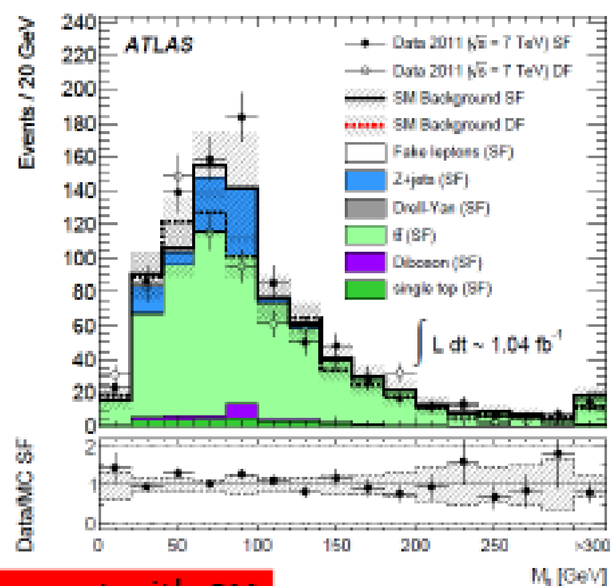
	Background	Obs.	95% CL
OS-SR1	15.5 ± 4.0	13	9.9 fb
OS-SR2	13.0 ± 4.0	17	14.4 fb
OS-SR3	5.7 ± 3.6	2	6.4 fb
SS-SR1	32.6 ± 7.9	25	14.8 fb
SS-SR2	24.9 ± 5.9	28	17.7 fb

S - excess of the same-flavour events over different-flavour events

	S_{obs}	$\bar{S}_b$	RMS
FS-SR1	131.6±2.5(sys)	118.7±27.0	48.6
FS-SR2	142.2±1.0(sys)	67.1±28.6	49.0
FS-SR3	-3.06±0.04(sys)	0.7±1.6	4.5

The agreement is better than 2 in all cases

FS-SR2

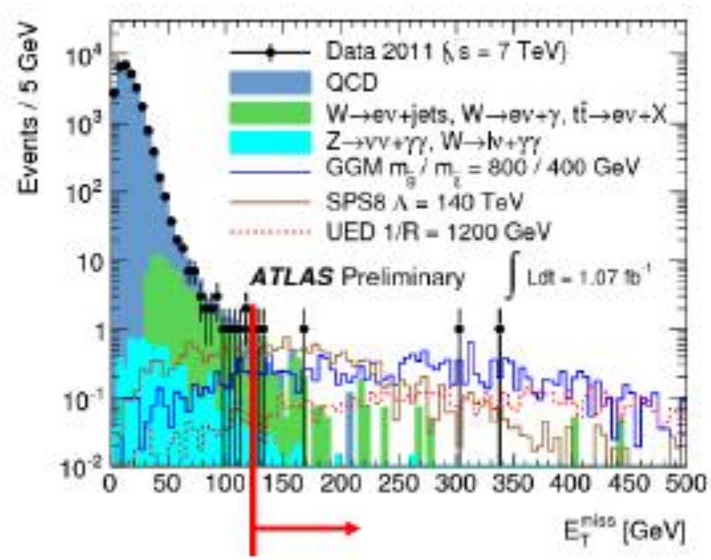


Data are in agreement with SM expectations in all regions

Сохранение R-четности

Photons (1.07 fb^{-1})

- Gauge Mediated SUSY Breaking (GMSB)
  - the very light gravitino is the LSP
  - event topology defined by next to lightest sparticle (NLSP)
  - large parameter space has neutralino NLSP: neutralino decays to photon and gravitino
- final state: diphoton (+ jets) + MET
  - 2 photons (E_T > 25 GeV)
  - missing E_T > 125 GeV
  - QCD and EW background estimated from control regions, irreducible background from MC
- result:
  - observed events: 5
  - expected events: 4.1 ± 0.6 ±1.6

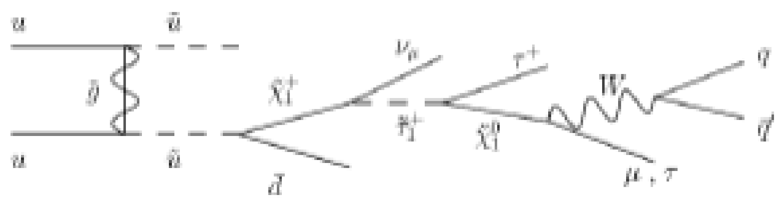


Нарушение R-четности

Bilinear RPV (1.04 fb^{-1})

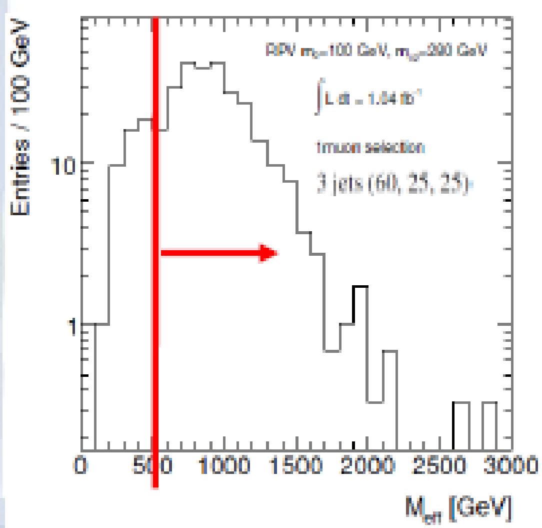
4 Signal regions

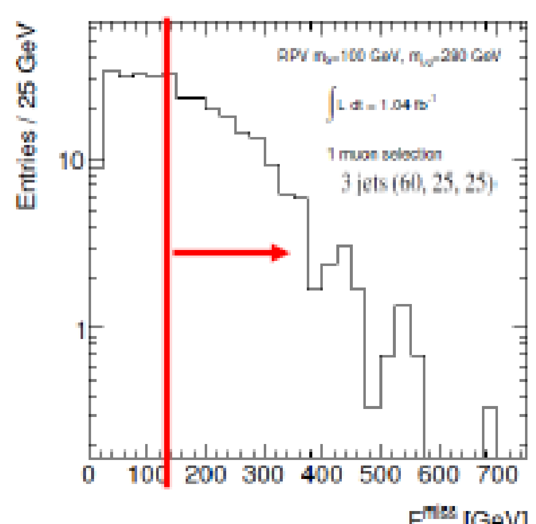
Selection	3JL	3JT	4JL	4JT'
Number of jets	≥ 3		≥ 4	
Leading jet p_T (GeV)	60	80	60	60
Subsequent jet p_T (GeV)	25	25	25	40
$\Delta\Phi$(jet, E^{miss}_T)	[>0.2(mod. π)]for all 3 (4) jets			
m_T (GeV)	> 100			
E^{miss}_T (GeV)	> 125	> 240	> 140	> 200
E^{miss}_T / M_{eff}	> 0.25	> 0.15	> 0.30	> 0.15
M_{eff} (GeV)	> 500	> 600	> 300	> 500

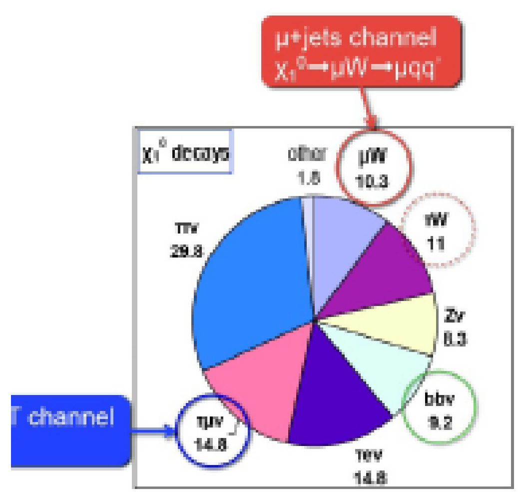


More than 30% of the decays produce a muon

Only 1-muon channel is considered

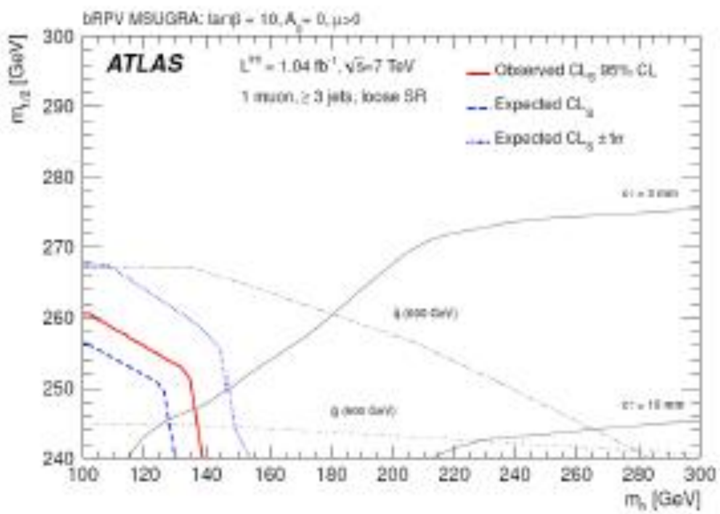


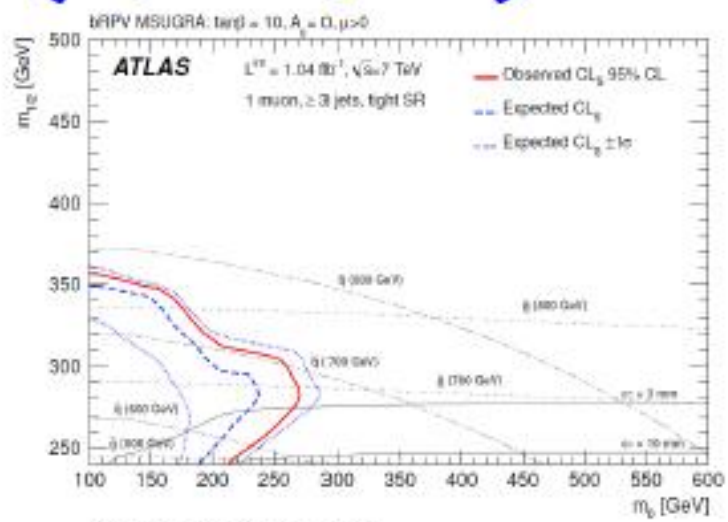


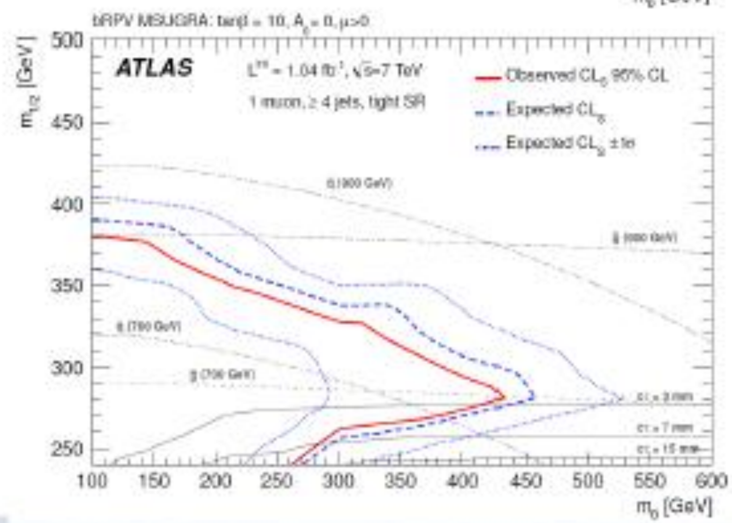


Нарушение R-четности

Bilinear RPV (1.04 fb^{-1})







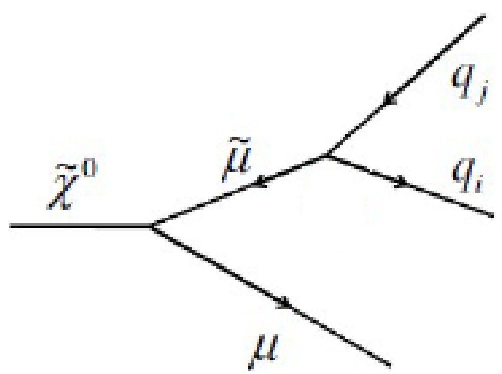
	Muon channel	
	Observed Events	Fitted sum of background Events
3JL SR	58	63 ± 19
3JT SR	11	13.9 ± 4.3
4JL SR	50	53 ± 16
4JT SR	7	6.9 ± 2.7

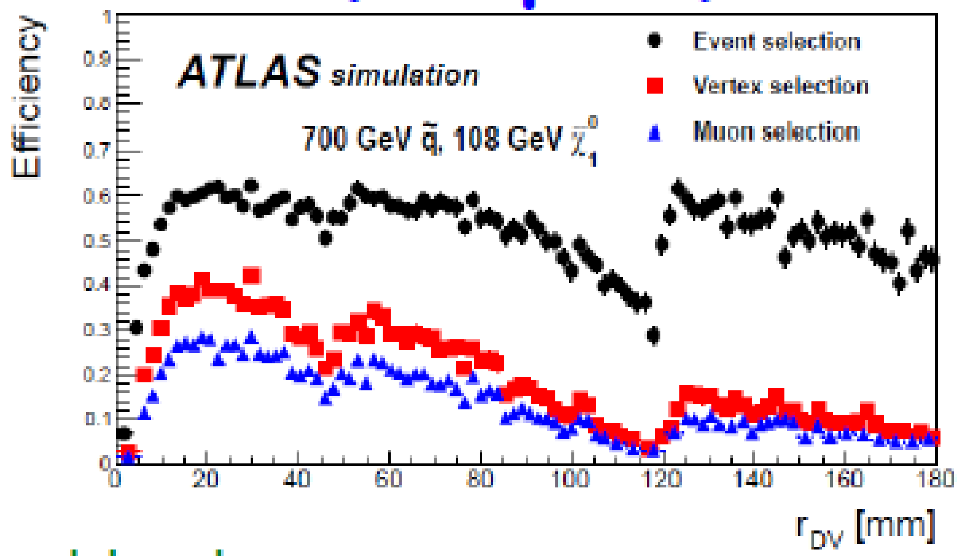
For the 4JL selection no exclusion was obtained for the considered region.

Data are in agreement with SM expectations in all regions

Нарушение R-четности

Displaced RPV (33 pb^{-1})





A heavy particle decaying into several charged particles at a distance of order millimeters to tens of centimeters from the pp interaction point, in events containing a muon with high transverse momentum (p_T >45 GeV).

It may also be the result of other models with heavy, longlived particles that decay into or are produced in association with a high-p_T muon.

Reconstruction of the displaced vertex (DV):

- ✓ Take every pair of tracks (p_T > 1 GeV; impact parameter > 2mm; Vertex fit χ^2<5) with no hit between the PV and the DV;
- ✓ Combine vertices which share tracks and are close to each other (D<3σ), otherwise the smallest χ^2 vertex is chosen;
- ✓ DV within $|z_{DV}|$ < 300 mm and $|r_{DV}|$ < 180 mm (barrel pixel region);
- ✓ Extra requirements to remove tracks from the PV.
- ✓ At least 4 tracks in every DV.

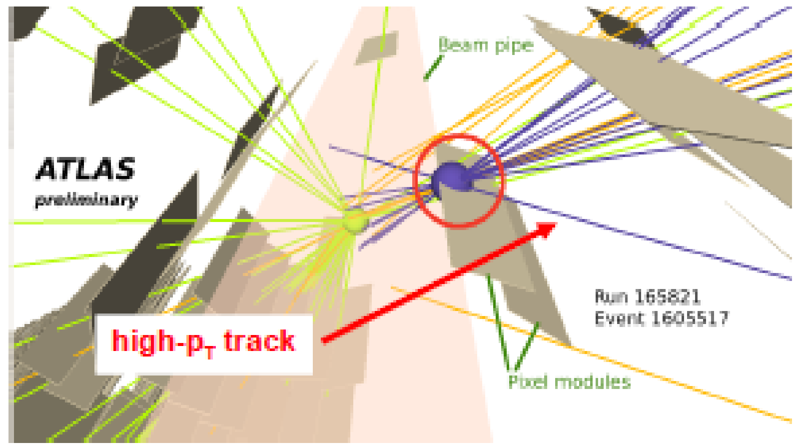
Нарушение R-четности

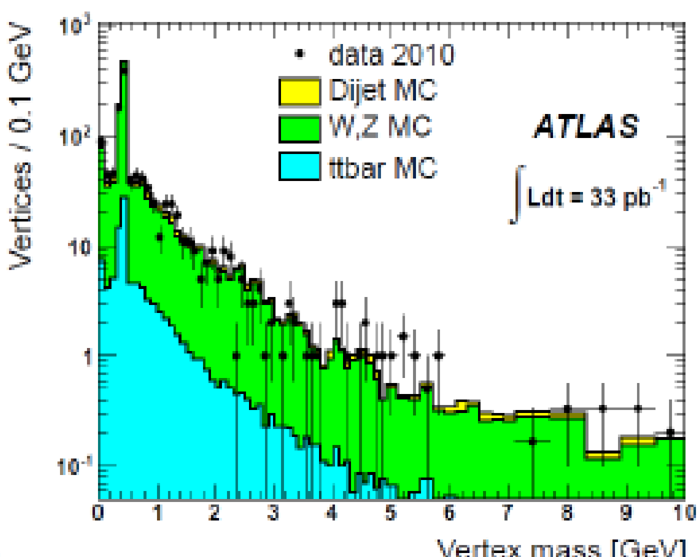
Displaced RPV (33 pb^{-1})

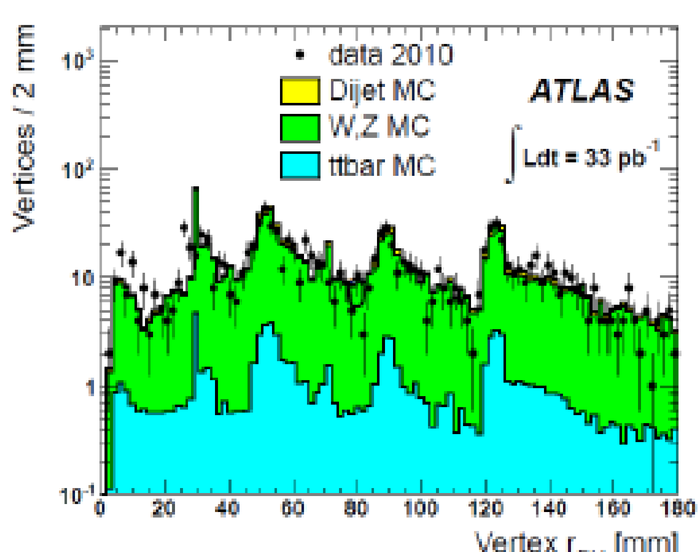
Background:

Background due to particle interactions with material is further suppressed by requiring m_{DV} > 10 GeV;

High-m_{DV} background may arise from random spatial coincidence of such a vertex with a high-p_T track; High-m_{DV} vertices reconstructed within $|z_{DV}|$ < 300 mm, 40 < r_{DV} < 180 mm bins are rejected.



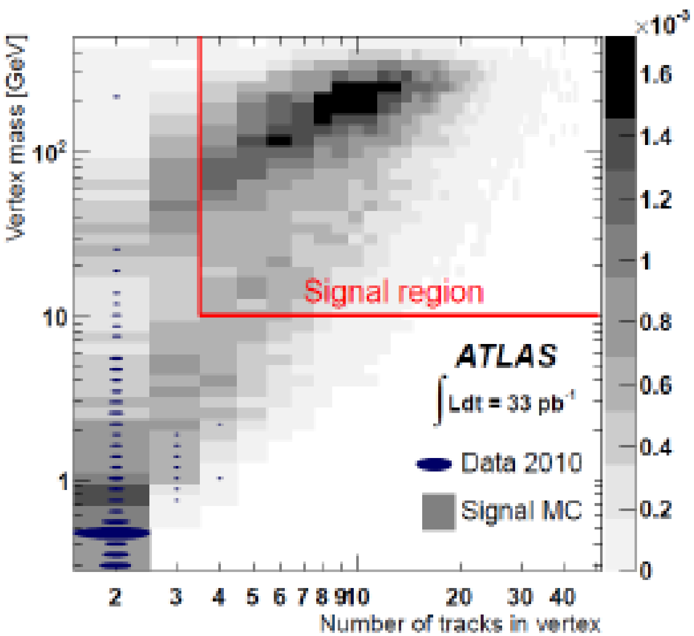




Нарушение R-четности

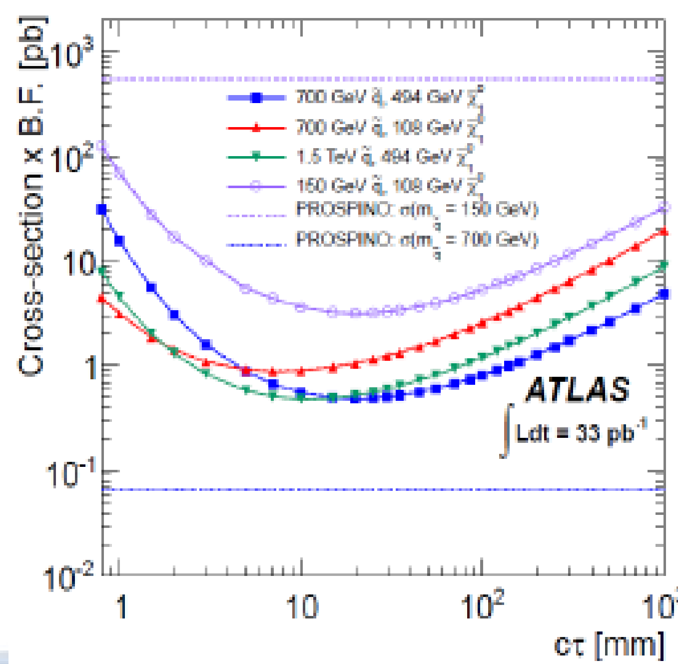
Displaced RPV (33 pb^{-1})

Number of events passing the selected requirements except for the m_{DV} and $N_{DVtracks}$. No data events observed in the SR.



Data are in agreement with SM expectations in all regions

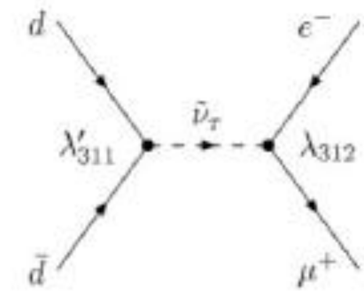
Upper limits at 95% CL on the production cross-section times branching fraction vs. the neutralino lifetime times the speed of light for di
erent combinations of squark and neutralino masses.



Нарушение R-четности

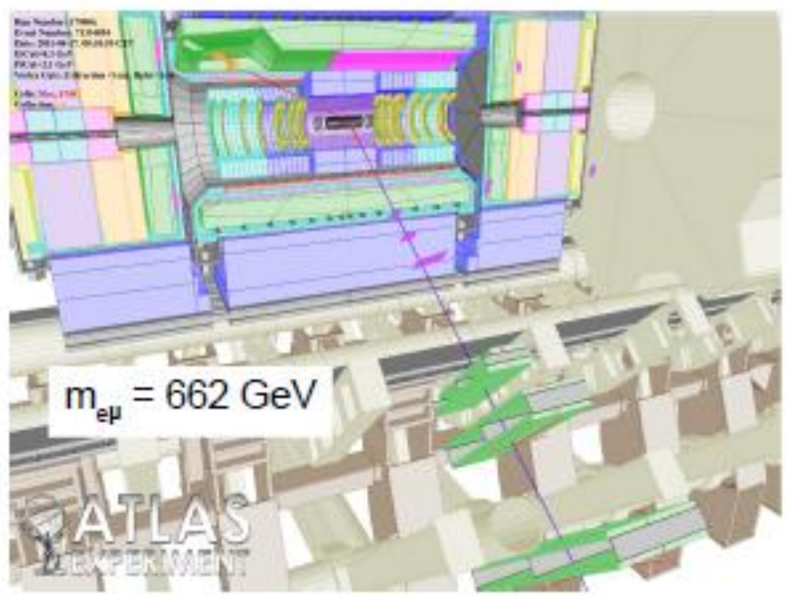
eμ resonance RPV (1.07 pb^{-1})

Search for short-lived particles that decay into two oppositely signed leptons of different flavors, $e^{\pm}\mu^{\mp}$.



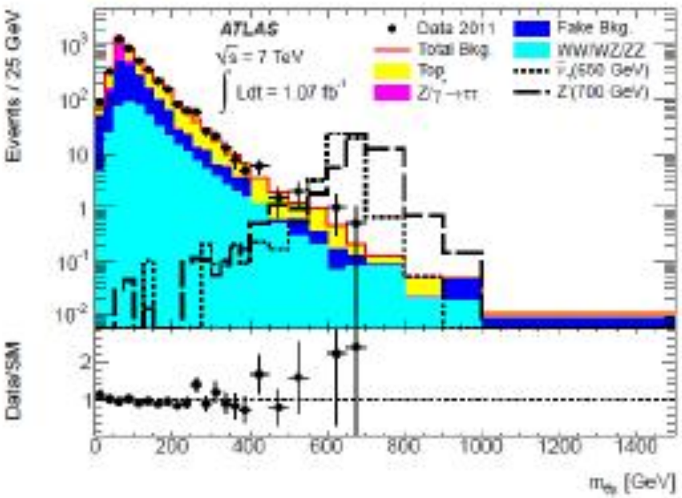
The eμ candidate events are required to have exactly one electron and one muon with opposite charge and p_T>25 GeV.

Process	Number of events
$t\bar{t}$	1580 ± 170
Jet fake	1180 ± 120
$Z/\gamma^* \to \tau\tau$	750 ± 60
WW	380 ± 31
Single top	154 ± 16
$W/Z + \gamma$	82 ± 13
WZ	22.4 ± 2.3
ZZ	2.48 ± 0.26
Total background	4150 ± 250
Data	4053

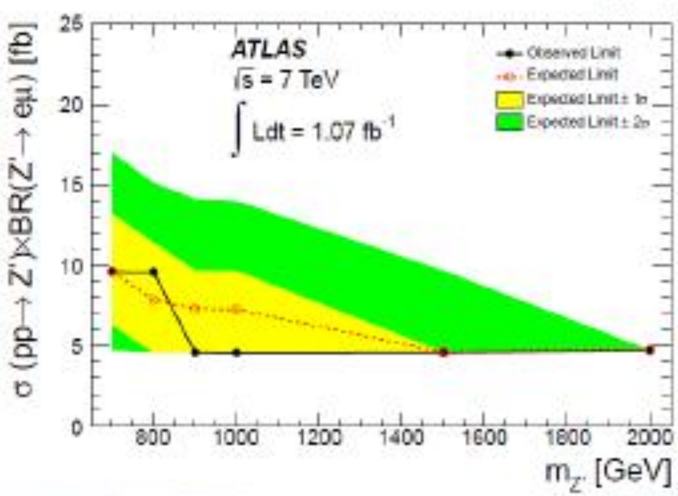


Нарушение R-четности

eμ resonance RPV (1.07 pb^{-1})



$m_{e\mu}$	Data	SM prediction
> 200 GeV	286	288 ± 22
> 250 GeV	152	136 ± 11
> 300 GeV	70	67 ± 6
> 350 GeV	35	34.0 ± 3.0
> 400 GeV	22	17.7 ± 1.7
> 450 GeV	10	10.5 ± 1.2
> 500 GeV	7	6.8 ± 0.9
> 550 GeV	3	4.3 ± 0.6
> 600 GeV	3	2.4 ± 0.4
> 650 GeV	1	1.49 ± 0.31
> 700 GeV	0	1.07 ± 0.25

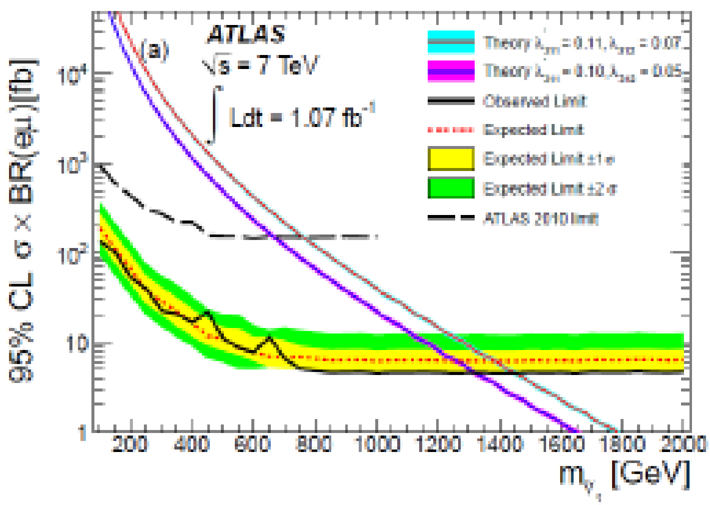


The observed 95% C.L. upper limits on (pp → Z') × BR(Z' → eμ)

Data are in agreement with SM expectations in all regions

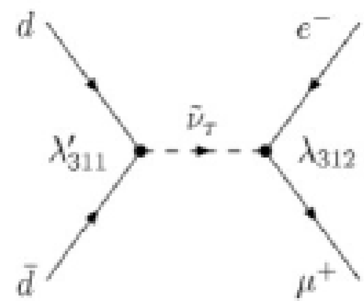
Нарушение R-четности

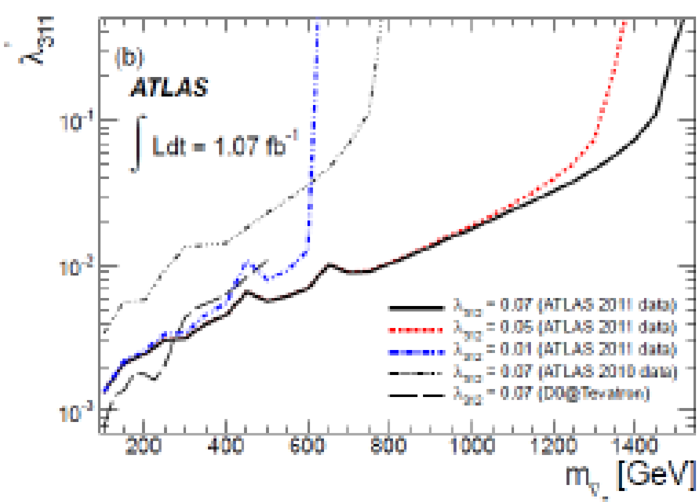
eμ resonance RPV (1.07 pb^{-1})



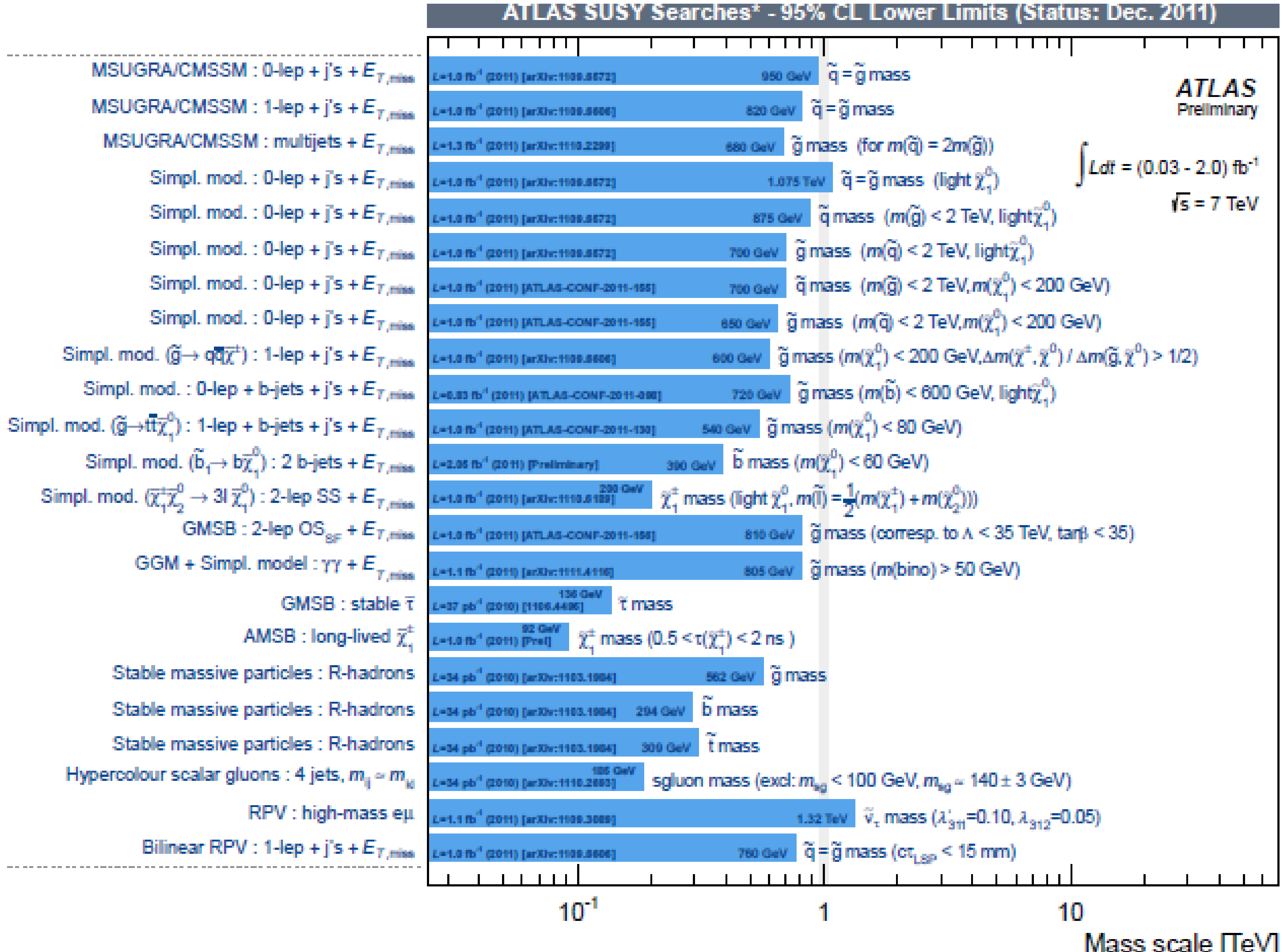
The observed 95% C.L. upper limits on (pp → sneutrino) × BR(sneutrino → eμ) as a function of sneutrino mass.

$$\Gamma_{\tilde{\nu}_\tau} = (3\lambda'^2_{311} + 2\lambda^2_{312}) m_{\tilde{\nu}_\tau}/16\pi$$





The 95% C.L. upper limits on the λ_{311} coupling as a function of sneutrino mass for three values of λ_{312}. The regions above the three curves represent ranges of λ_{311} values that are excluded.



*Only a selection of the available results leading to mass limits shown

ATLAS Exotics Searches

Beyond SUSY

Additional heavy gauge bosons

Extra-dimensions

Leptoquarks

Excited quarks and leptons

4th generation particles

Black holes

Contact interactions

Majorana neutrinos

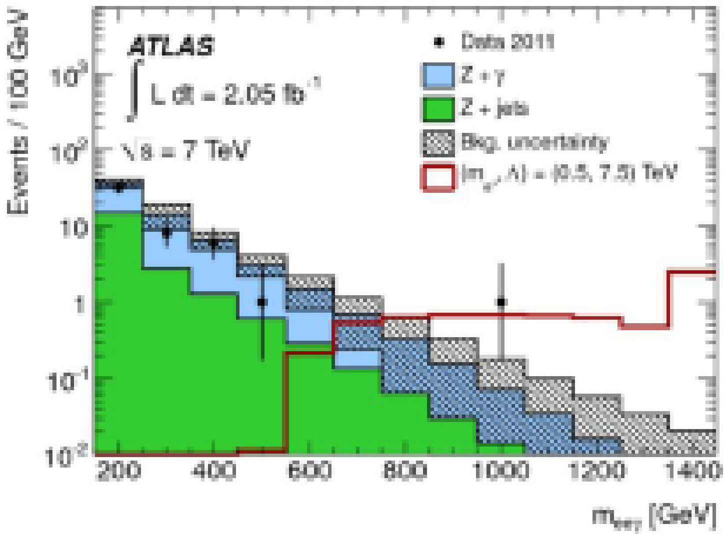
Technicolour particles

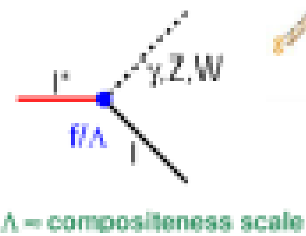
...

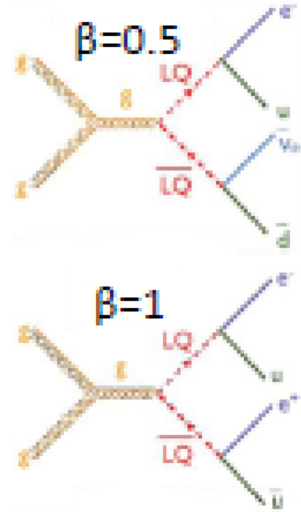
→ Large spectrum of Exotics searches at ATLAS arXiv:1201.3293 $\mathcal{L} = 2.05\ fb^{-1}$

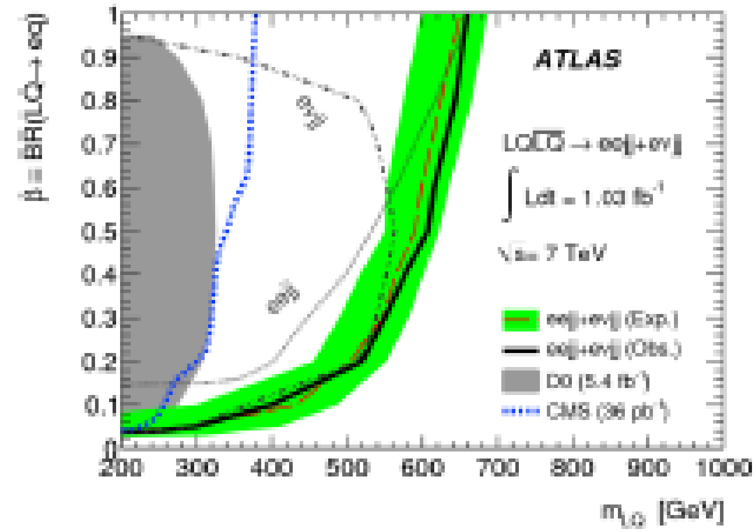
Excited Leptons and Leptoquarks

arXiv:1112.4828 $\mathcal{L} = 1.03\ fb^{-1}$









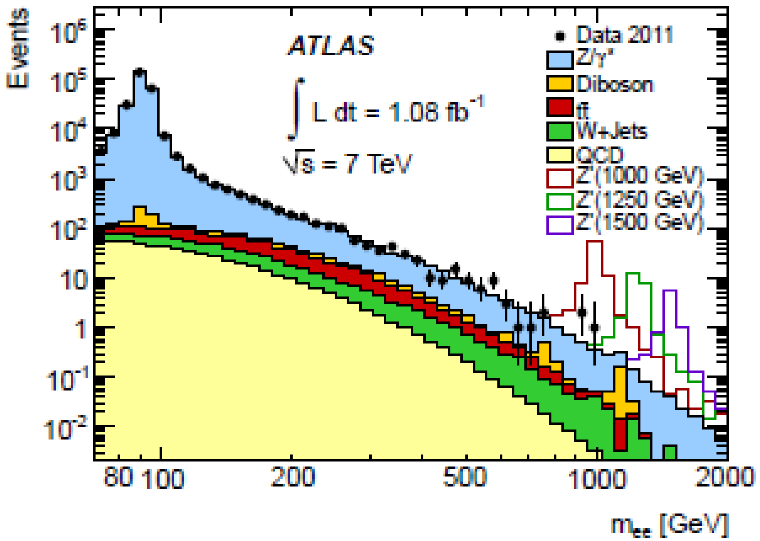
- Unambiguous signature for new matter substructure: → observation of exited states
- Predicted by compositeness models, dominantly singly produced $q\bar{q} \rightarrow l^*\bar{l}$
- Search performed in clean elm. radiative decay channel: $l^* \rightarrow l\gamma$ with $l = e, \mu$

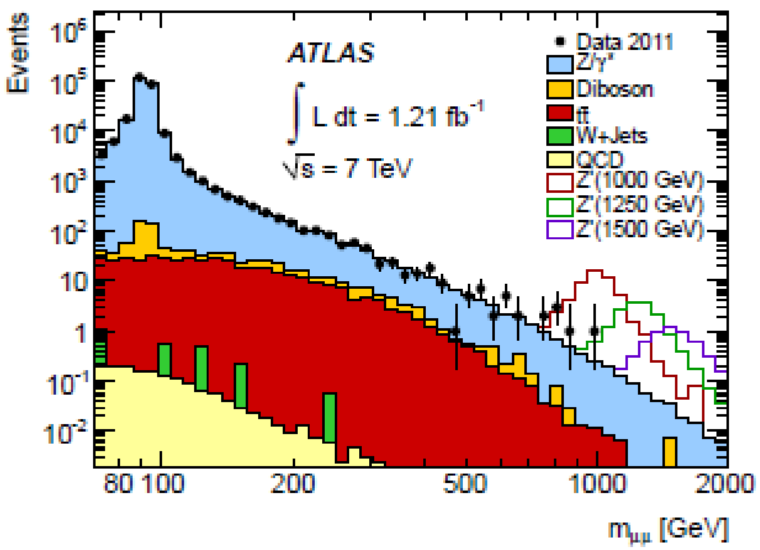
→ No evidence for excited leptons found, limits set on Λ as function of m_{l*}

→ For $\Lambda = m_{l*}$ masses below 1.87 (1.75) TeV excluded for excited electrons (muons)

- Symmetry of quark and lepton generations rises question of direct interactions → Leptoquarks LQ
- Look for 1st generation scalar LQ pair production in $LQ\overline{LQ} \rightarrow eejj$ and $e\nu jj$
- Results from the two finals states are combined and limits derived in the m_{LQ} vs. β frame with β=BR(LQ→eq)
- Observed (expected) limits:
  - β=1: $M_{LQ} > 660\ (650)$ GeV
  - β=0.5: $M_{LQ} > 607\ (587)$ GeV

Двух-лептонные распады тяжелых резонансов





$pp \rightarrow Z'/Z^{*}X \rightarrow \ell^{+}\ell^{-}X$

	E_6 Z' Models			
Model	Z'_ψ	Z'_N	Z'_η	Z'_I
Mass limit [TeV]	1.49	1.52	1.54	1.56

	E_6 Z' Models		
Model	Z'_S	Z'_χ	Z'_{SSM}
Mass limit [TeV]	1.60	1.64	1.83

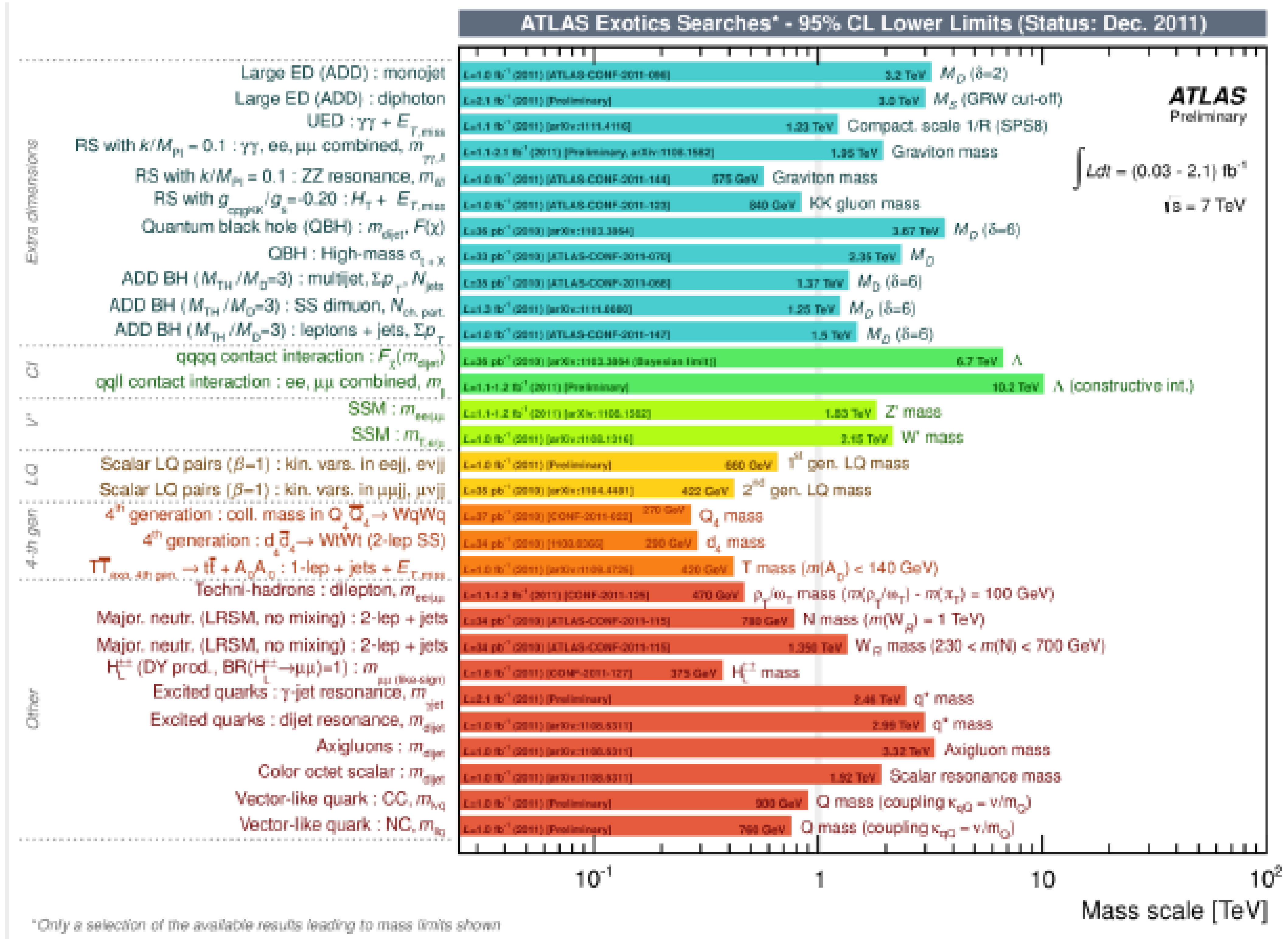
G^* Coupling k/M_{Pl}	0.01	0.03	0.05	0.10
Mass limit [TeV]	0.71	1.03	1.33	1.63

Table 1: 95% confidence level lower mass exclusion limits for various Z' models and RS graviton k/M_{Pl} couplings, decaying to two leptons (dielectron or dimuon).

Fig. 1: Invariant mass spectrum for the electron (top) and muon (bottom) channel dilepton resonance search. Various possible Z'_{SSM} signals are overlayed to show how an expected signal would manifest itself.

Другие резонансы

- Распадающиеся на лептон и нейтрино
  - например, заряженные W'- и W^*-бозоны
- Распадающиеся на мюоны одного знака
  - например, $H^{++} \to \mu^+\mu^+$
- Распадающиеся на две адронные струи
  - например, $W' \to q + q' \to jet + jet'$
- Распадающиеся на фотон и струю
- Распадающиеся на два фотона (± MET)
  - например, $G \to \gamma\gamma$ …



ATLAS Exotics Searches* - 95% CL Lower Limits (Status: Dec. 2011)
ATLAS
Preliminary
∫Ldt = (0.03 - 2.1) fb⁻¹
√s = 7 TeV
Extra dimensions
Large ED (ADD) : monojet
Large ED (ADD) : diphoton
UED : γγ + E_T,miss
RS with k/M_Pl = 0.1 : γγ, ee, μμ combined, m_γγ,ll
RS with k/M_Pl = 0.1 : ZZ resonance, m_lljj
RS with g_qqκκ/g_s=-0.20 : H_T + E_T,miss
Quantum black hole (QBH) : m_dijet, F(χ)
QBH : High-mass σ_t+X
ADD BH (M_TH/M_D=3) : multijet, Σp_T, N_jets
ADD BH (M_TH/M_D=3) : SS dimuon, N_ch. part.
ADD BH (M_TH/M_D=3) : leptons + jets, Σp_T
CI
qqqq contact interaction : F_χ(m_dijet)
qqll contact interaction : ee, μμ combined, m_ll
V'
SSM : m_ee/μμ
SSM : m_T,e/μ
LQ
Scalar LQ pairs (β=1) : kin. vars. in eejj, evjj
Scalar LQ pairs (β=1) : kin. vars. in μμjj, μvjj
Other
Techni-hadrons : dilepton, m_ee/μμ
Major. neutr. (LRSM, no mixing) : 2-lep + jets
Major. neutr. (LRSM, no mixing) : 2-lep + jets
H_L^±± (DY prod., BR(H^±±→μμ)=1) : m_μμ (like-sign)
Excited quarks : γ-jet resonance, m_γjet
Excited quarks : dijet resonance, m_dijet
Axigluons : m_dijet
Color octet scalar : m_dijet
Vector-like quark : CC, m_lvq
Vector-like quark : NC, m_llq
3.2 TeV M_D (δ=2)
3.0 TeV M_S (GRW cut-off)
1.23 TeV Compact. scale 1/R (SPS8)
1.95 TeV Graviton mass
575 GeV Graviton mass
840 GeV KK gluon mass
3.67 TeV M_D (δ=6)
2.35 TeV M_D
1.37 TeV M_D (δ=6)
1.25 TeV M_D (δ=6)
1.5 TeV M_D (δ=6)
6.7 TeV Λ
10.2 TeV Λ (constructive int.)
1.83 TeV Z' mass
2.15 TeV W' mass
660 GeV 1st gen. LQ mass
422 GeV 2nd gen. LQ mass
270 GeV Q_4 mass
290 GeV d_4 mass
420 GeV T mass (m(A_0) < 140 GeV)
470 GeV ρ_T/ω_T mass (m(ρ_T/ω_T) - m(π_T) = 100 GeV)
780 GeV N mass (m(W_R) = 1 TeV)
1.350 TeV W_R mass (230 < m(N) < 700 GeV)
375 GeV H_L^±± mass
2.46 TeV q* mass
2.99 TeV q* mass
3.32 TeV Axigluon mass
1.92 TeV Scalar resonance mass
900 GeV Q mass (coupling κ_qQ = v/m_Q)
760 GeV Q mass (coupling κ_qQ = v/m_Q)
10⁻¹
1
10
10²
Mass scale [TeV]
*Only a selection of the available results leading to mass limits shown

Краткие итоги:

- Стандартная Модель – ОК (пока?)
- Найдено новое связанное состояние b-кварков
- Масса СМ бозона Хиггса (похоже?) = 126 ГэВ
- Нет признаков “Новой Физики” (пока?)
- Получено много новых, более жестких, ограничений на “Новую Физику”
- 2012 полон огромных ожиданий (увеличение светимости и энергии)
- Еще физика – во второй части

Конец первой части ….