Prospects of high-energy nuclear physics

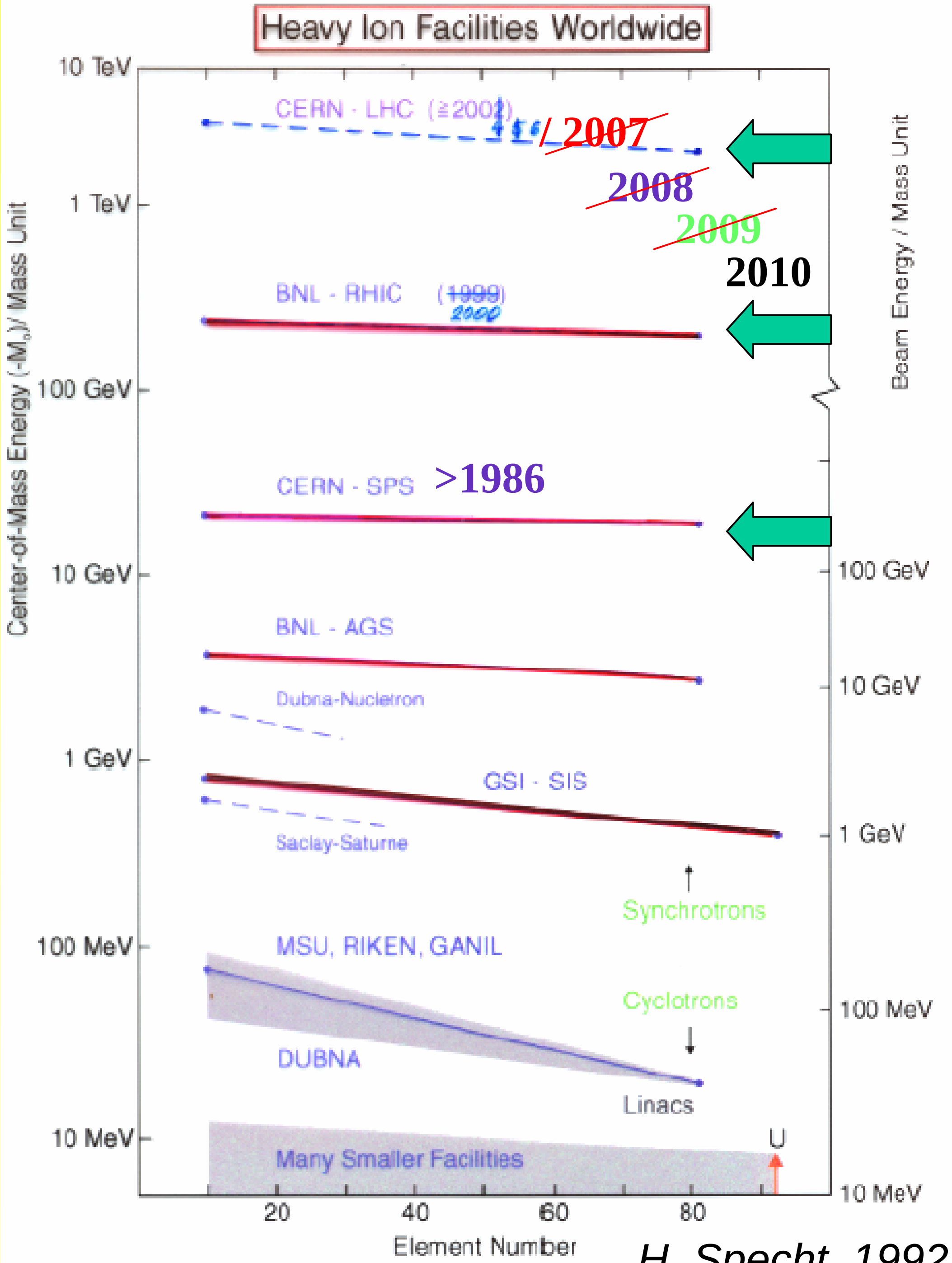
- Status and prospects
  - LHC, FAIR, NICA
- ALICE
  - **Great Russian & JINR Contribution**
  - **Great success!** Detectors work very well, results are coming
  - Look forward at first HI data, discovery machine from day one
- FUTURE
  - Fertile field for science and for Italian-Russian Collaboration
    - ALICE various detectors (direct collaboration in the muons arm, Particle ID (TOF and HMPID), ITS, and collaboration on Physics analysis
    - Important to complete the program and the detector (PHOS)
    - A relevant program of Upgrades already developing = > room for important collaboration
    - NICA is an opportunity to be explored

Paolo Giubellino
INFN Torino
ITALY-RUSSIA
Round Table
December 19 2009

A bit of history: Accelerators of Heavy Ions

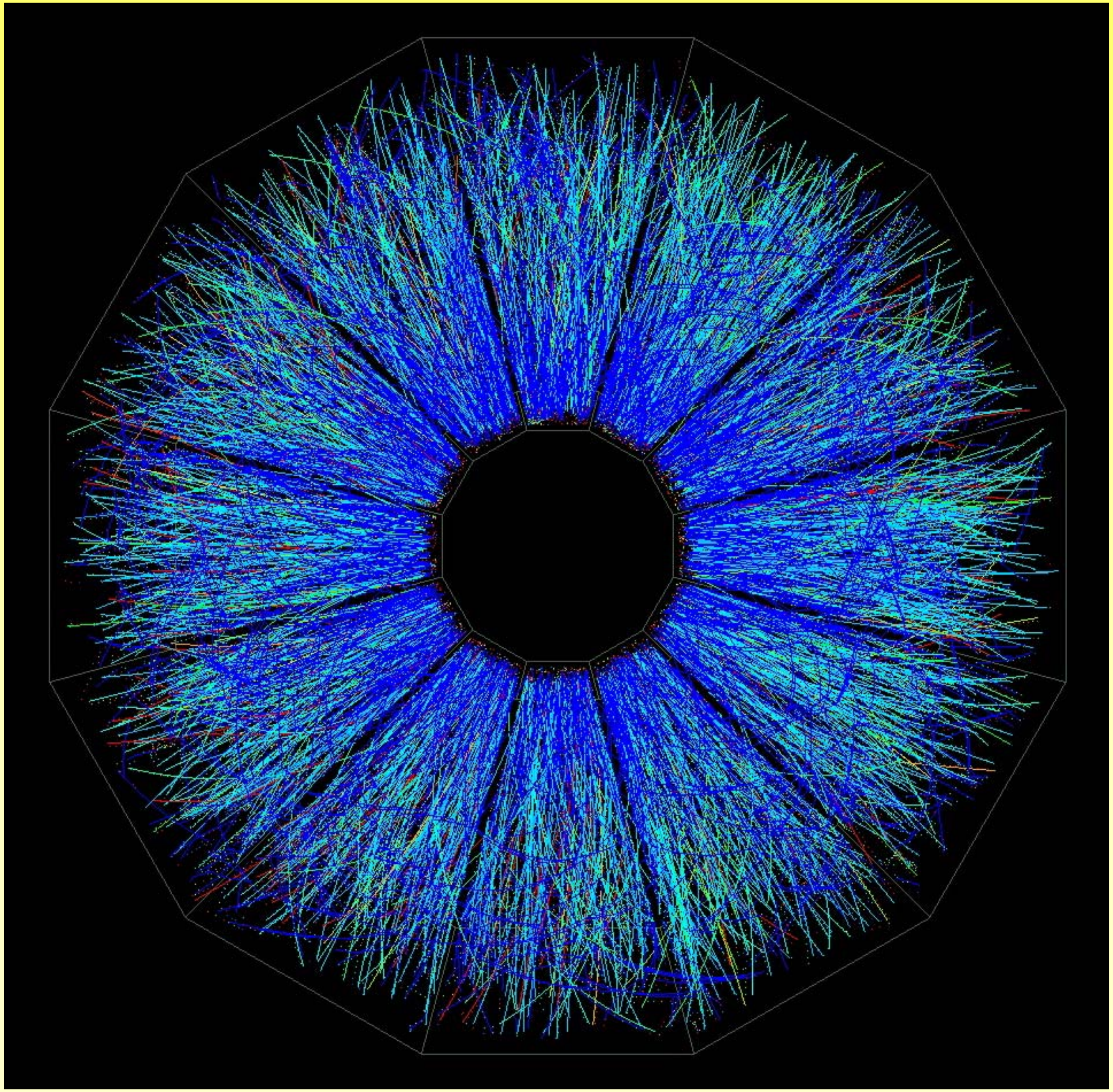
- Experimental programs with High Energy nuclear beams have been carried out for more than 20 years
- After the pioneering work at the Bevalac in the late seventies, 4 facilities at really high energy: AGS, SPS, RHIC and LHC
- Two communities joined:
  - particle physicists
  - nuclear physicists

•Latest news: Pb injection in the LHC performed succesfully!



H. Specht, 1992

Very difficult experiments...



central Au-Au event

@ ~130 GeV/nucleon

CM energy

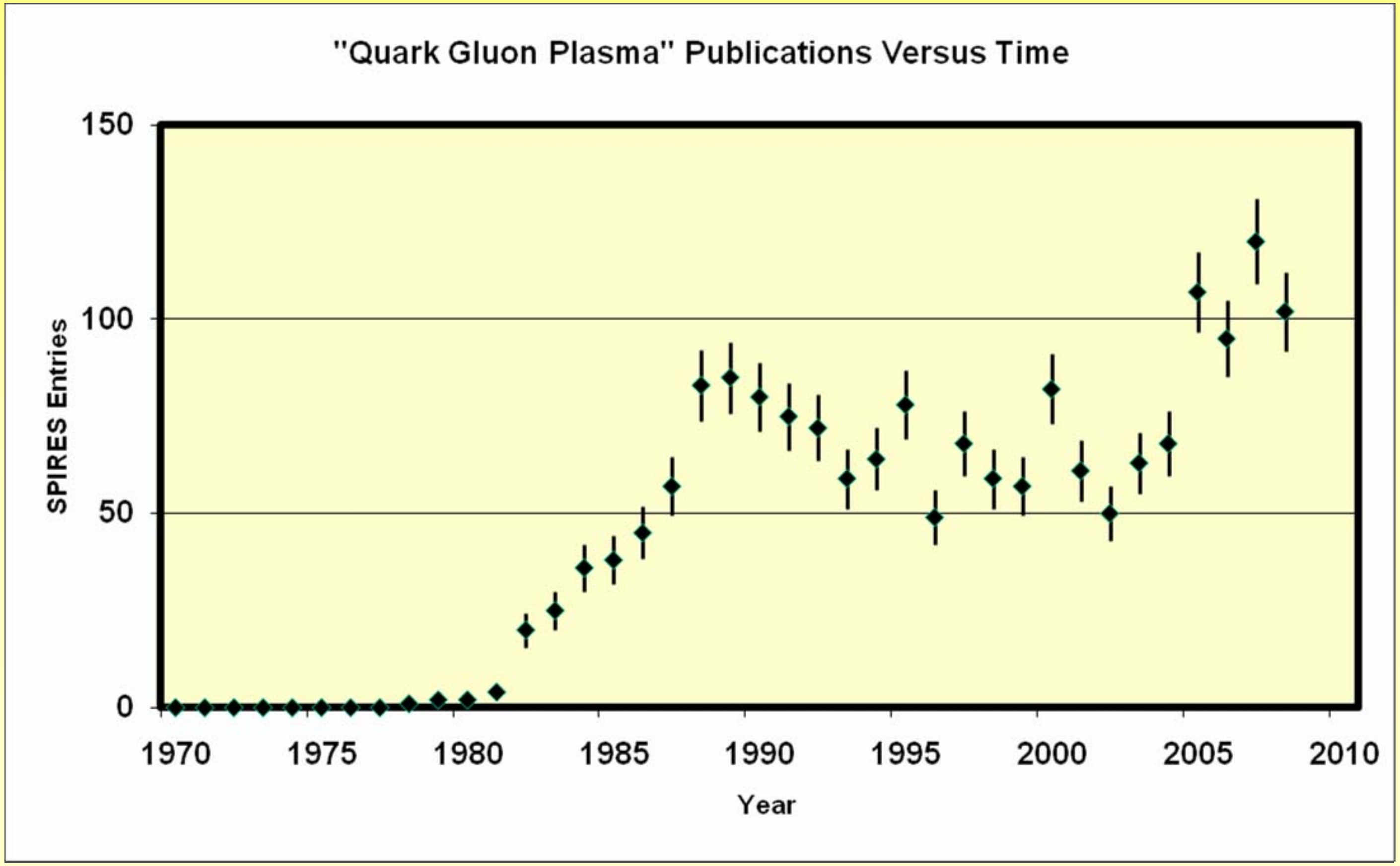
STAR

… a developing field!

- SPIRES query for all publications with

  QGP, SQGP, QUARK-GLUON PLASMA, QCD PLASMA, STRONGLY COUPLED PLASMA, STRONGLY-COUPLED PLASMA

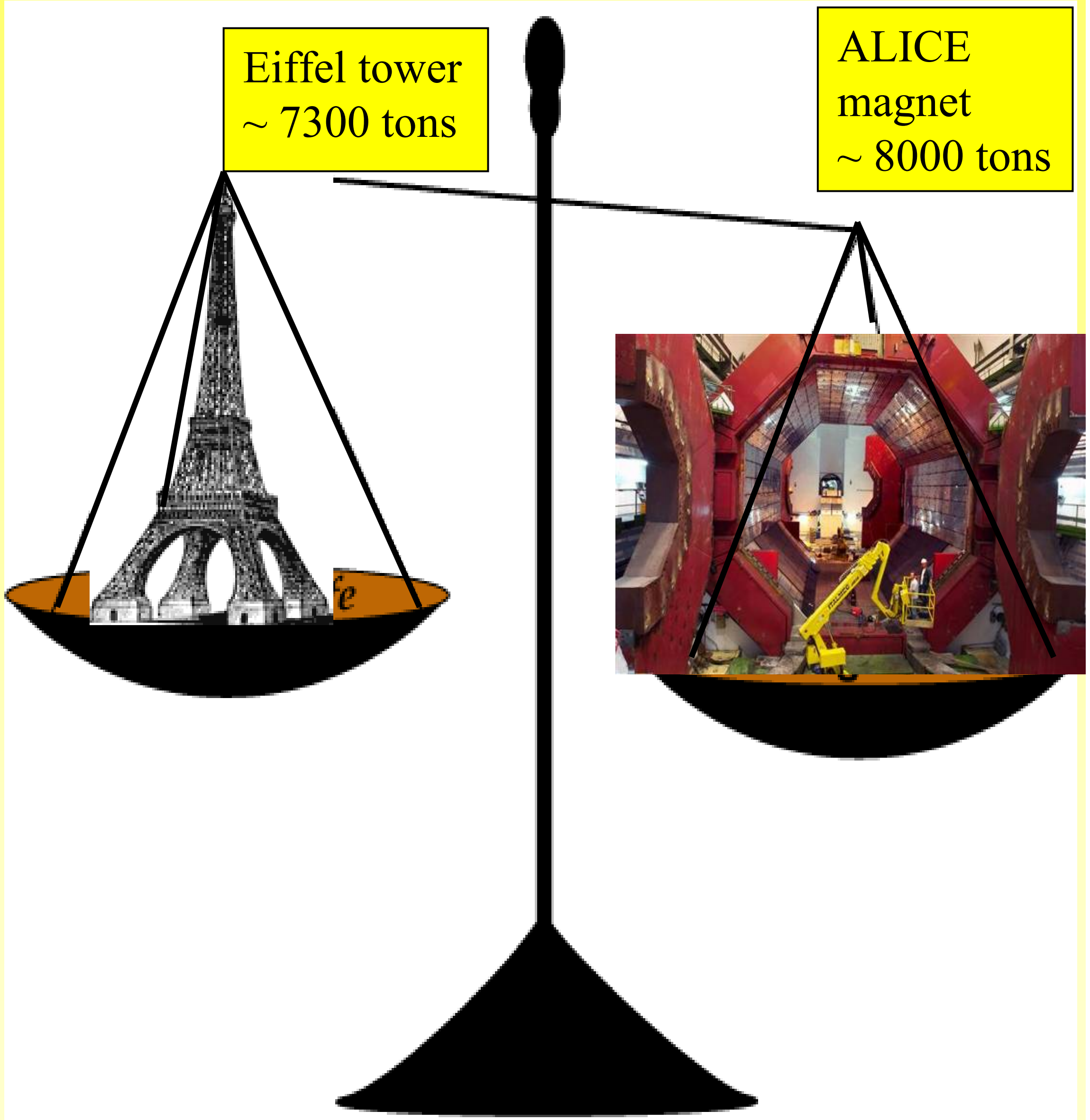
  in their title:



Field has gone from the periphery into a central activity of contemporary Nuclear Physics

Nuclear Physics has changed a lot…

- Size, complexity and time span of projects have grown enormously, and they develop over decades, carried by large international collaborations



Even the "simplest" element requ... ll o...

To do what?
… explained very well by Prof. Di Giacomo just now!

Early Ideas

- Hagedorn 1965: mass spectrum of hadronic states $\rho(m) \propto m^{\alpha} \exp(m/B)$
  => Critical temprature T_c=B
- QCD 1973: asymptotic freedom
  – D.J.Gross and F.Wilczek, H.D. Politzer

Quantum Chromo Dynamics (QCD) is the theory that describes the interactions between quarks and gluons [Nobel Prize 2004]

- 1975: asymptotic QCD and deconfined quarks and gluons
  – N. Cabibbo and G. Parisi, J. Collins and M. Perry

Interpretation of the Hagedorn temperature as a phase transition rather than a limitingT:
"We suggest … a different phase of the vacuum in which quarks are not confined"

Volume 59B, number 1 PHYSICS L

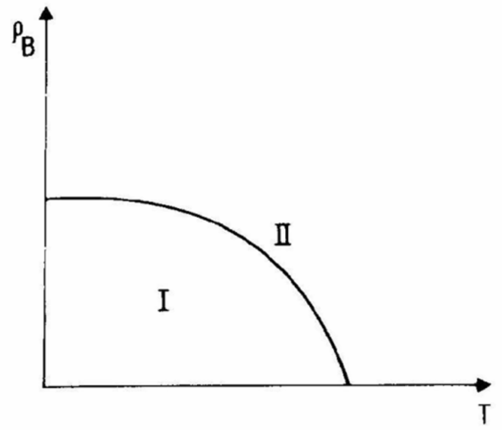


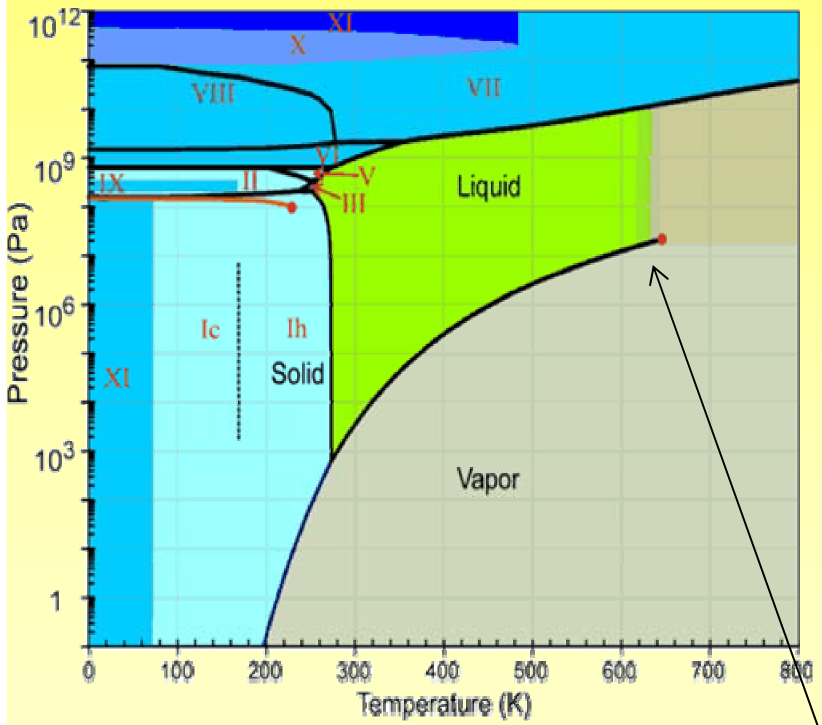
Fig. 1. Schematic phase diagram of hadronic matter. ρ_B is the density of baryonic number. Quarks are confined in phase I and unconfined in phase II.

First schematic phase diagram (Cabibbo and Parisi, 1975)

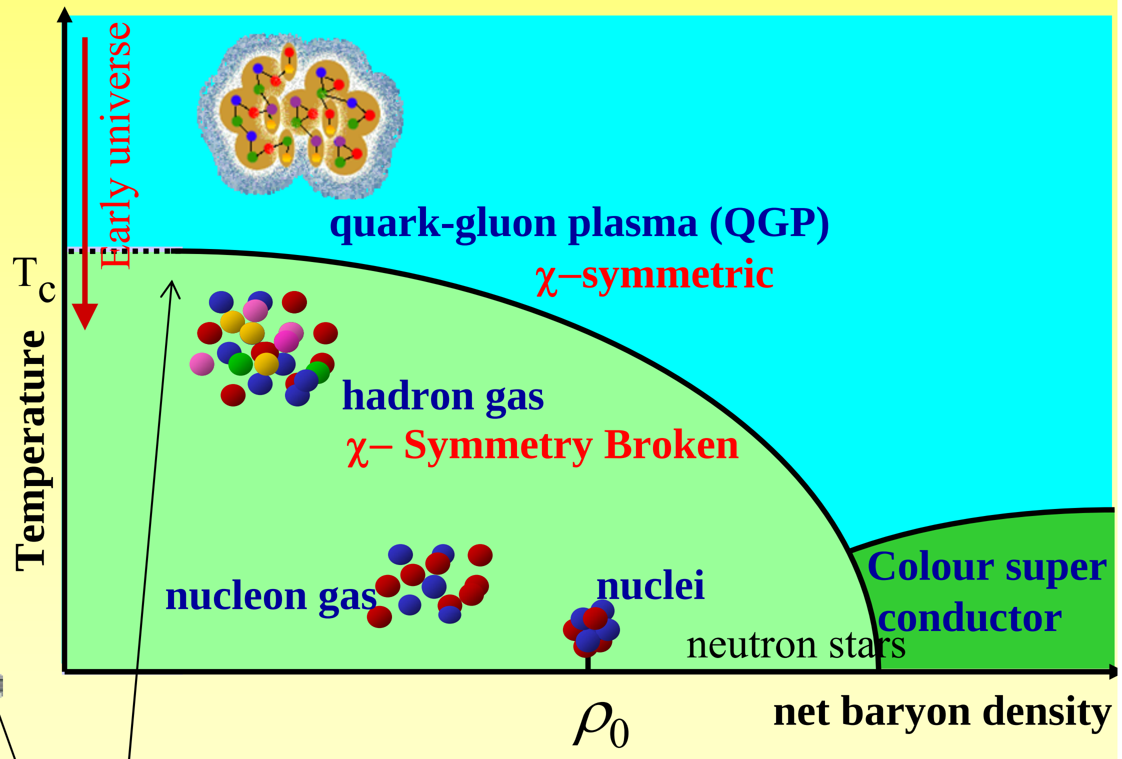
Exploring the QCD phase diagram

T.D. Lee (1975) "it would be interesting to explore new phenomena by distributing a high amount of energy or high nuclear density over a relatively large volume " **How?** ➡ Colliding nuclei at very high energy

Complex picture, with many features



Phase diagram for H_2O

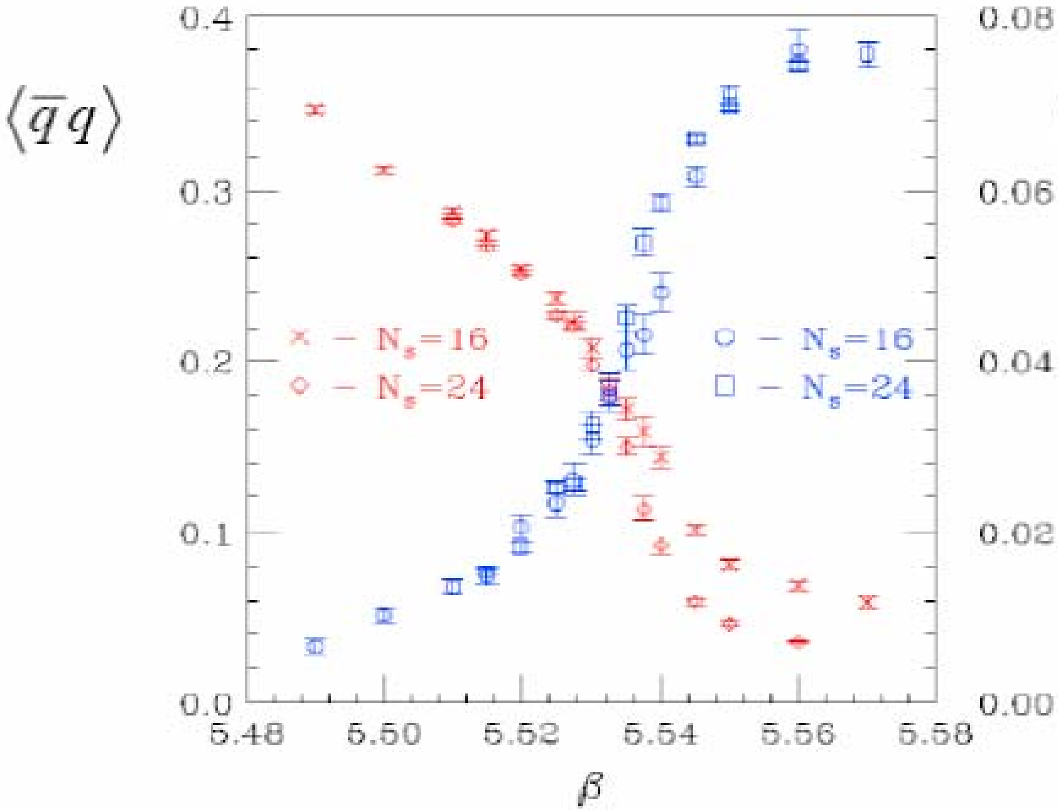


Critical endpoint

Study how collective phenomena and macroscopic properties of strongly interacting matter emerge from fundamental interactions

Lattice QCD

predicts a rapid transition, with correlated deconfinement and chiral restauration



$$\langle L \rangle = \left\langle \mathrm{tr}\, \exp(i \int_0^{1/T} A_4\, d\tau) \right\rangle$$

$$\sim \exp(-F_Q / T)$$

N_f=2, χQCD
Kogut and Sinclair, hep-lat/0408003

In a nutshell

- Study Matter under Extreme Conditions of temperature (100,000 times that of the center of the Sun) and density
- ‘state of matter’ at high temperature & energy density: **The QGP**
  - ground state of QCD & primordial matter of the Universe
    - partons are **deconfined** (not bound into composite particles)
    - **chiral symmetry** is restored (partons are ~ massless)
  - **‘the stuff at high T where ordinary hadrons are no longer the relevant d.o.f’**
- Mission of Ultrarelativistic Heavy Ions
  - **search** for the QGP phase
  - **measure** its properties
  - **discover** new aspects of QCD in the strongly coupled regime
- Answer some of the most fundamental questions about our Universe and its development
  - A small “big bang” in the laboratory….

What do we measure? Language

- We all have in common basic nuclear properties
  - *A*, *Z* …
- But some are specific to heavy ion physics
  - v_2 Fourier coefficient of azimuthal anisotropies “flow”
  - R_{AA} 1 if yield = perturbative value from initial parton-parton flux
  - T Temperature (MeV)
  - μ_B Baryon chemical potential (MeV) ~ *net* baryon density
  - η Viscosity (MeV ^{3}) *indirectly inferred from R_{AA} and v_2*
  - s Entropy density ~ “particle” density
  - ε Energy density (Bjorken 1983): $\varepsilon = \frac{dE_T}{A_T dz} = \frac{1}{\pi R^2 \tau} \frac{dE_T}{dy}$

Collision Geometry

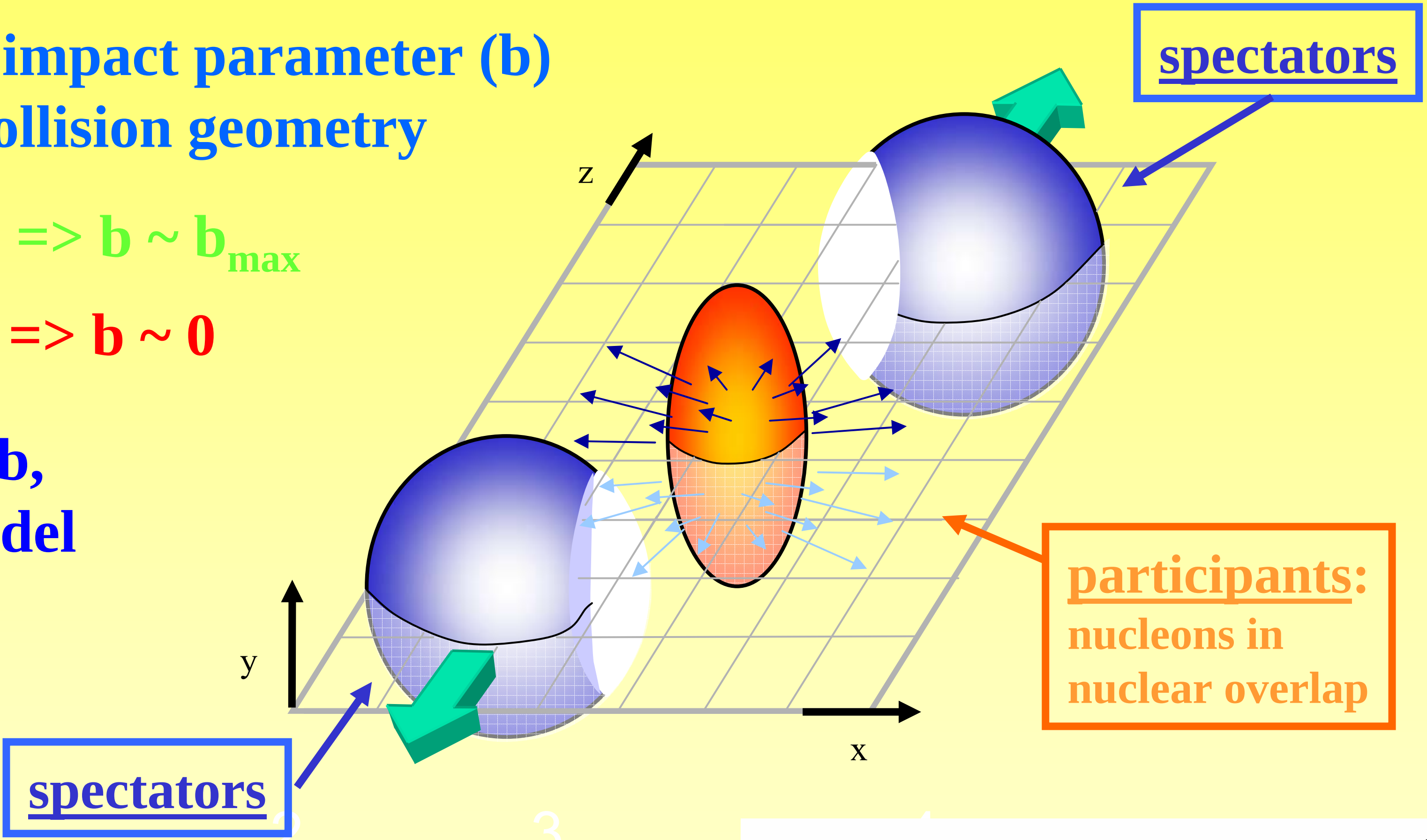
In these complicated events, we have (*a posteriori*) control over the event geometry:

Centrality → impact parameter (b) selection on collision geometry

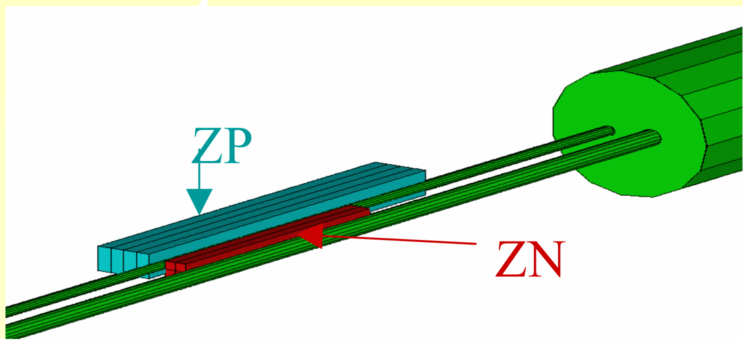
"peripheral" => b ~ b_{max}

"central" => b ~ 0

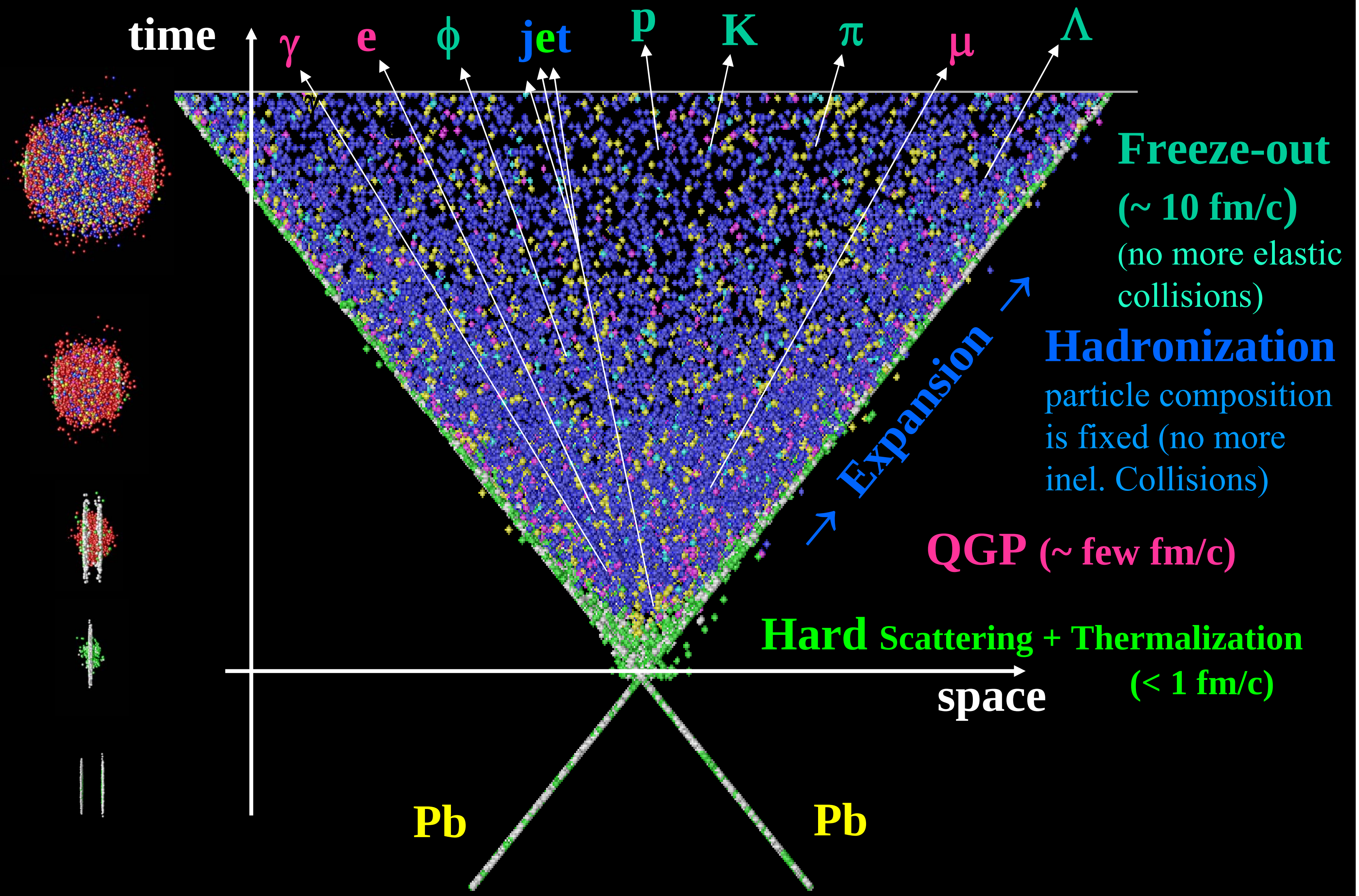
For a given b, Glauber model gives N_{part} and $N_{bin\ coll}$



Measured with Zero Degree Calorimeters
Detecting the spectator nucleons
~ 100m away from theinteraction point
Or via transverse energy / part. multiplicity

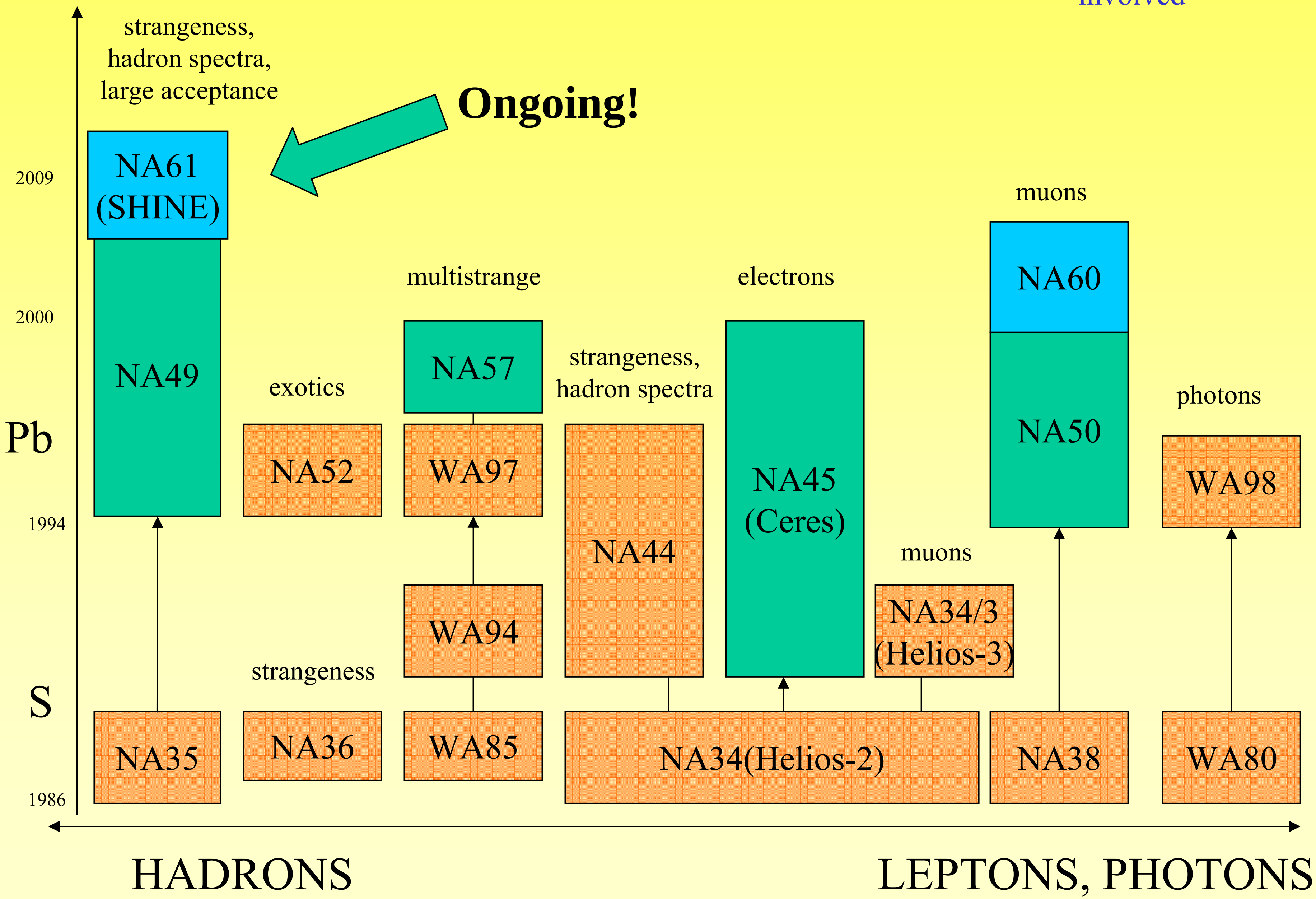


Space-time Evolution of the Collisions



HI experiments at the SPS

@2000: 25 countries, about 500 physicists involved



Experiments at RHIC

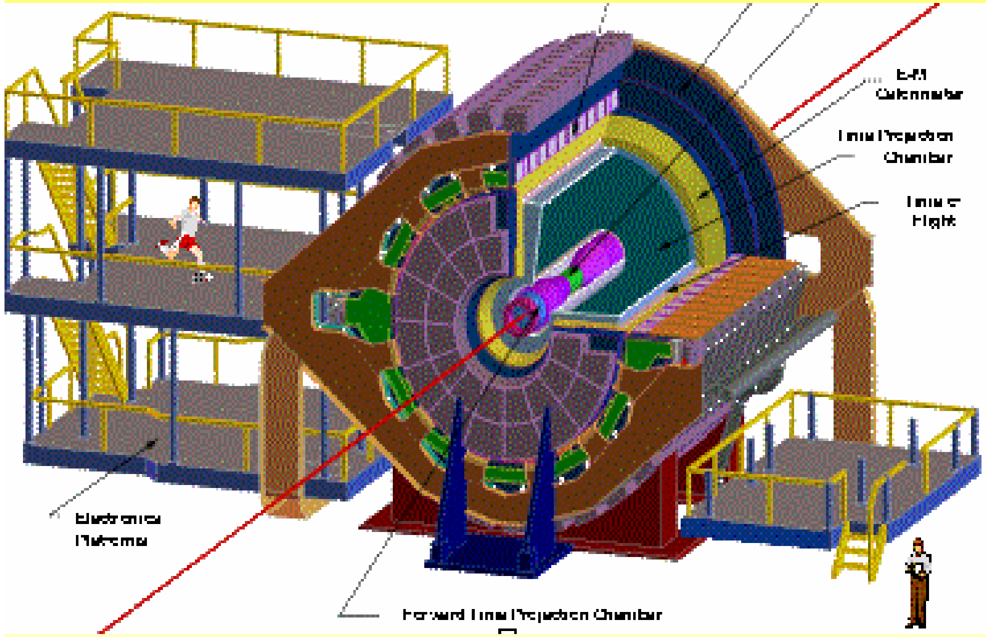
STAR

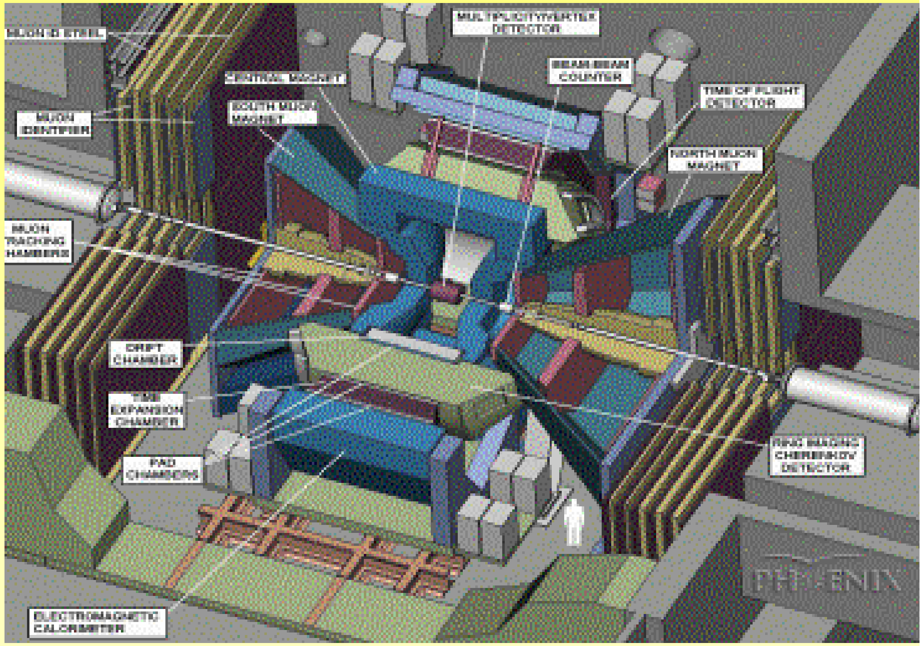
- **Hadronic Observables**
- **Large Acceptance**

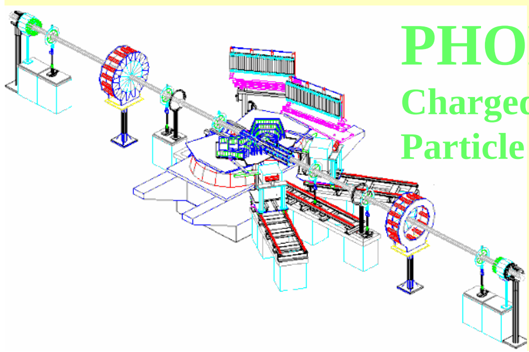
Both running (energy scan) and being upgraded (TOF, HBD, Vertex dets)

PHENIX

- **Leptons, Photons, & Hadrons**





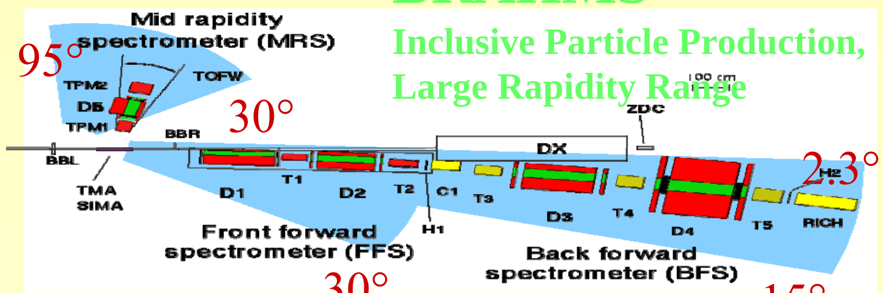


PHOBOS

Charged Hadrons,
Particle Correlations

BRAHMS

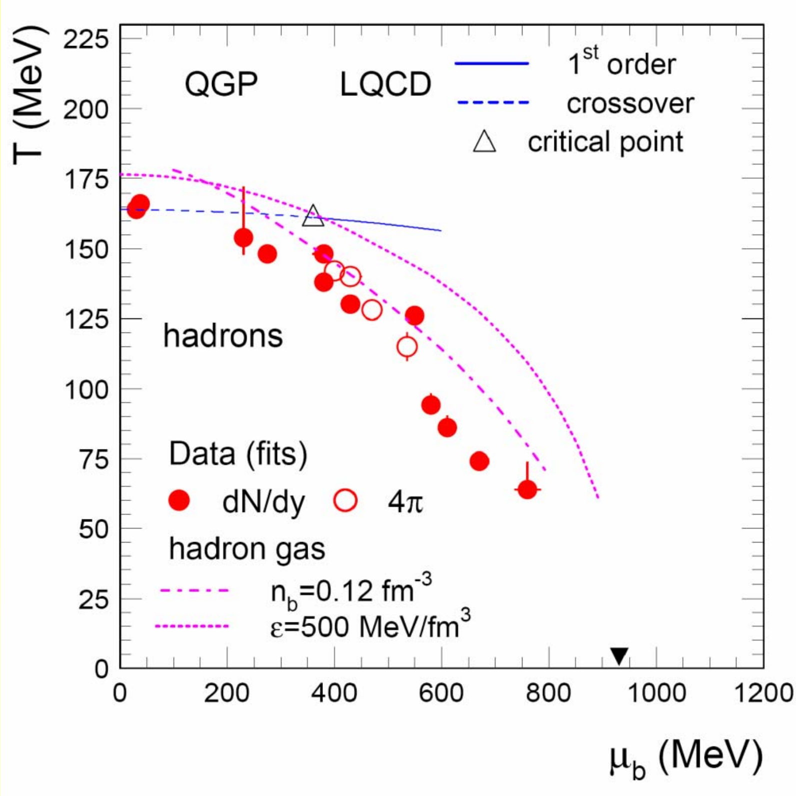
Inclusive Particle Production,
Large Rapidity Range

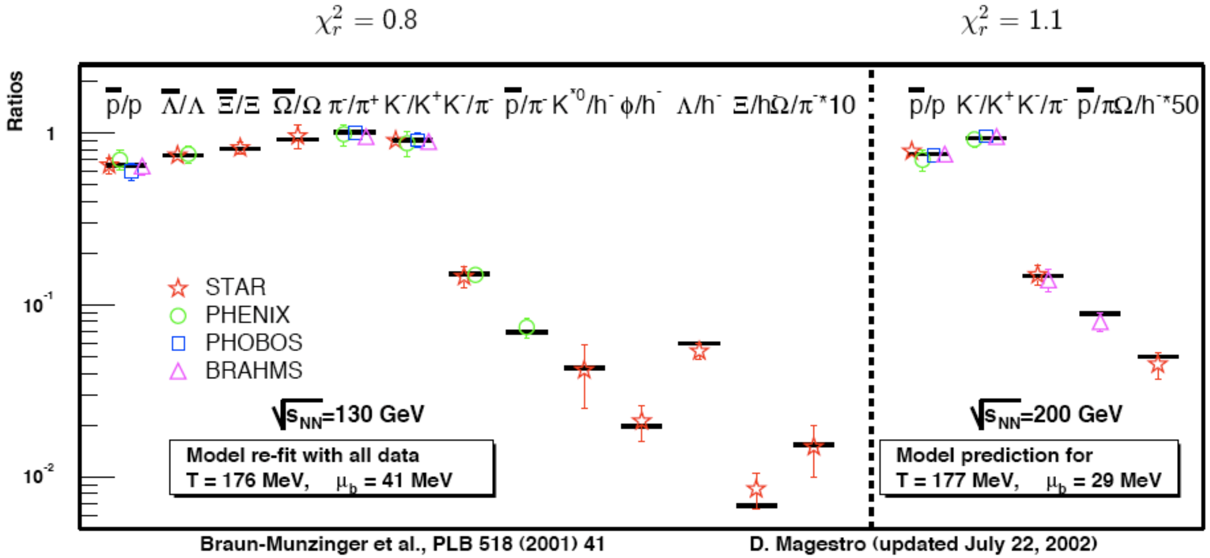


Both completed

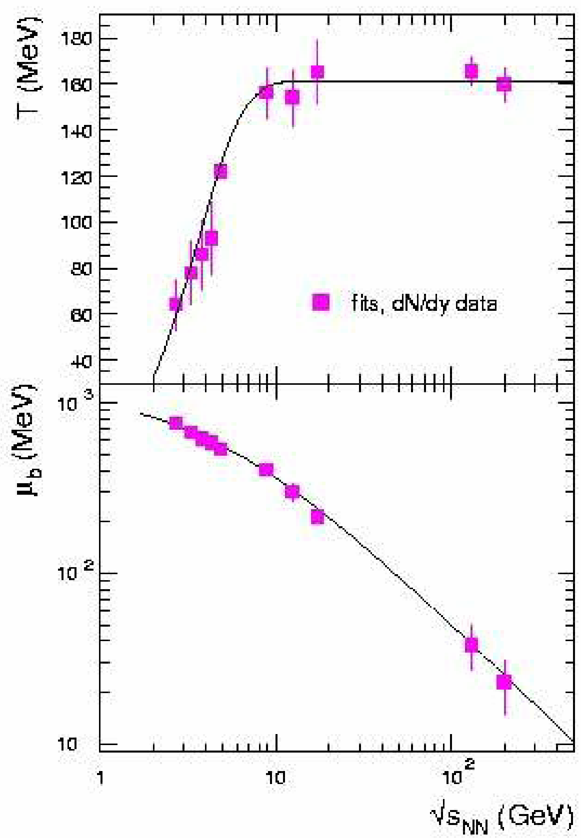
A few fundamental results

- Experimental results have been populating the phase diagram
- The fireball emits hadrons fron an equilibrium state
  - All data at the different energies are in agreement with a thermal model with 3 parameters: T, μ_B , V
  - A limiting temperature emerges as a function of c.m. energy , matching predictions from Lattice QCD for a phase limit
- The fireball expands collectively like an almost ideal fluid
  - hydrodynamic flow characterized by azimuthal anisotropy coeffient v2
  - The system has very low viscosity (close to the AdS/CFT limit)
  - Flow builds up at the partonic level
- At high T (RHIC energies) the matter produced is opaque to hard probes (high-pT particles suppressed, opposite-side jet absorbed)
- At RHIC multiplicities consistent with gluon saturation effects

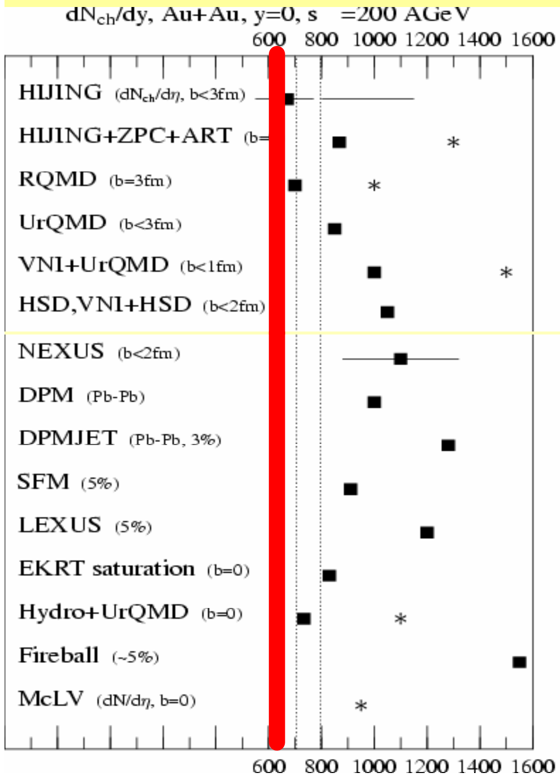




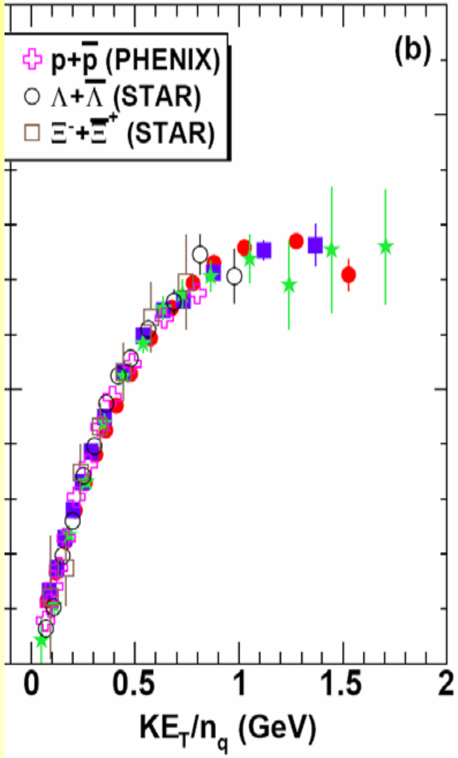
$\chi_r^2 = 0.8$
$\chi_r^2 = 1.1$
Ratios
p̄/p Λ̄/Λ Ξ̄/Ξ Ω̄/Ω π⁻/π⁺ K⁻/K⁺ K⁻/π⁻ p̄/π⁻ K*0/h⁻ φ/h⁻ Λ/h⁻ Ξ/h⁻ Ω/π⁻*10
p̄/p K⁻/K⁺ K⁻/π⁻ p̄/π Ω/h⁻*50
STAR
PHENIX
PHOBOS
BRAHMS
√sNN=130 GeV
Model re-fit with all data
T = 176 MeV, μb = 41 MeV
√sNN=200 GeV
Model prediction for
T = 177 MeV, μb = 29 MeV
Braun-Munzinger et al., PLB 518 (2001) 41
D. Magestro (updated July 22, 2002)



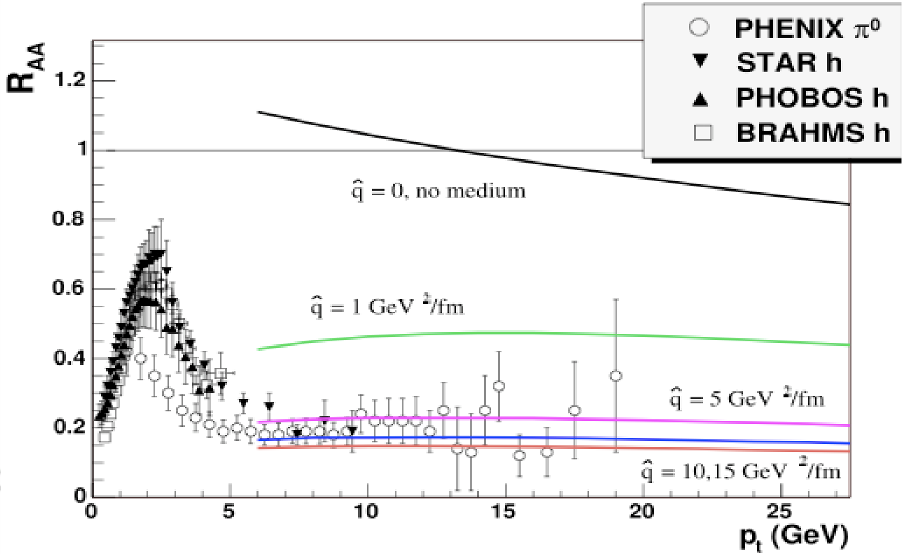
T (MeV)
fits, dN/dy data
μb (MeV)
√sNN (GeV)



dNch/dy, Au+Au, y=0, s =200 AGeV
600 800 1000 1200 1400 1600
HIJING (dNch/dη, b<3fm)
HIJING+ZPC+ART
RQMD (b=3fm)
UrQMD (b<3fm)
VNI+UrQMD (b<1fm)
HSD,VNI+HSD (b<2fm)
NEXUS (b<2fm)
DPM (Pb-Pb)
DPMJET (Pb-Pb, 3%)
SFM (5%)
LEXUS (5%)
EKRT saturation (b=0)
Hydro+UrQMD (b=0)
Fireball (~5%)
McLV (dN/dη, b=0)



p+p̄ (PHENIX)
Λ+Λ̄ (STAR)
Ξ⁻+Ξ̄⁺ (STAR)
(b)
KET/nq (GeV)



RAA
PHENIX π⁰
STAR h
PHOBOS h
BRAHMS h
q̂ = 0, no medium
q̂ = 1 GeV ²/fm
q̂ = 5 GeV ²/fm
q̂ = 10,15 GeV ²/fm
pt (GeV)

What is going on?

- The field, which is largely data-driven, has seen a major development in the last few years, both in theory and experiment, and has ambitious plans for the coming decade:
  - A vigorous exploration of the QCD phase diagram
    - In the high-μ_B direction
    - In the high-T direction
    - At the liquid-gas boundary
  - Different methods and approaches, with a common aim: a qualitative step towards a description of high-density and temperature nuclear matter calculable from first principles

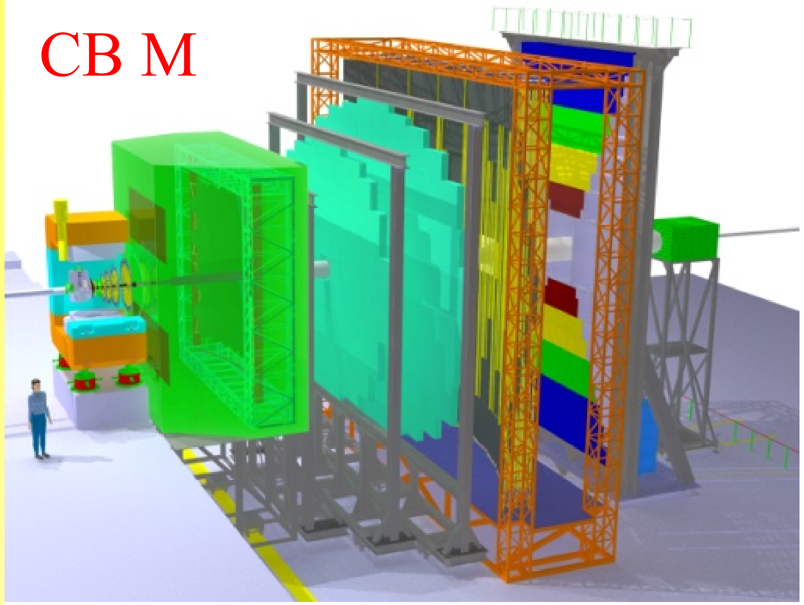
Exploring high baryon densities

A field of great interest! Search for the critical point, study phase transition, EOS

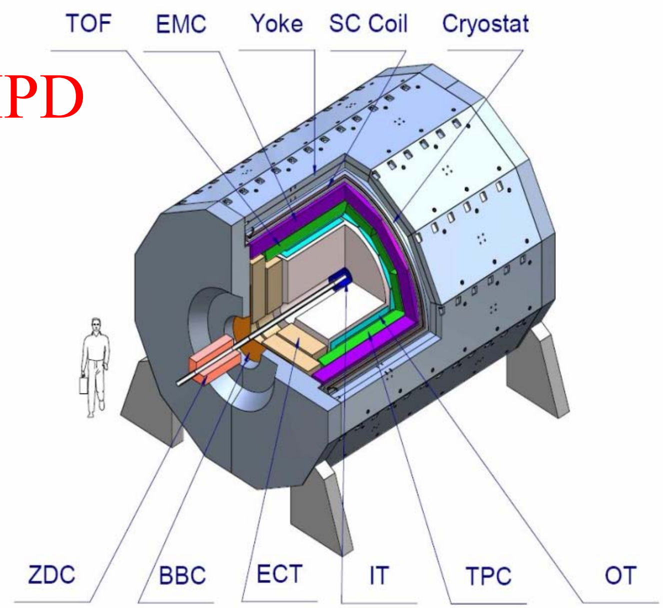
- **CERN:**
  - NA61 (SHINE) experiment
- **RHIC**
  - Energy scan
- **GSI:**
  - A very lively program ongoing at SIS (FOPI, KaoS, HADES)
  - A rich future: FAIR (CBM)
    - 100*SPS beam intensity
- **DUBNA**
  - NICA HI collider with MPD Detector:
    - Good systematics (like RHIC)
    - High rate (10* SPS)

→ Second Generation Experiments

CB M



MPD



Critical point, critical phenomena

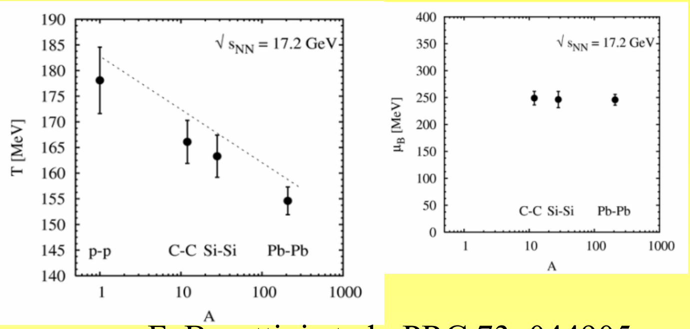
Critical Opalescence as observed in CO_2 liquid-gas transition

$T > T_C$ $T \sim T_C$ $T < T_C$

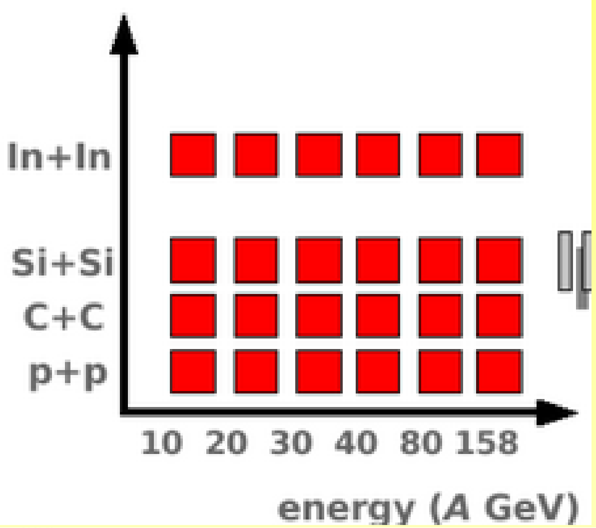
T. Andrews. Phil. Trans. Royal Soc., 159:575, **1869**

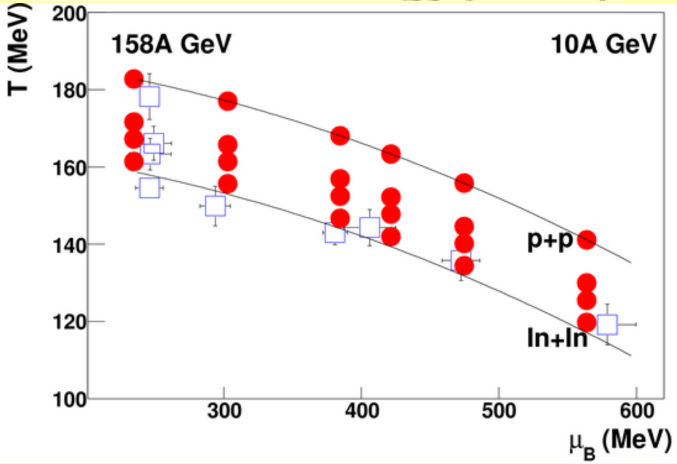
Current : SPS - SHINE

A significant difference between freeze-out and transition temperature can lead to dilution of the signatures of the QCD critical point. One way address this is to vary system size/colliding ion size.



F. Becattini et al., PRC 73, 044905





What is the difference vs. NA49 ?

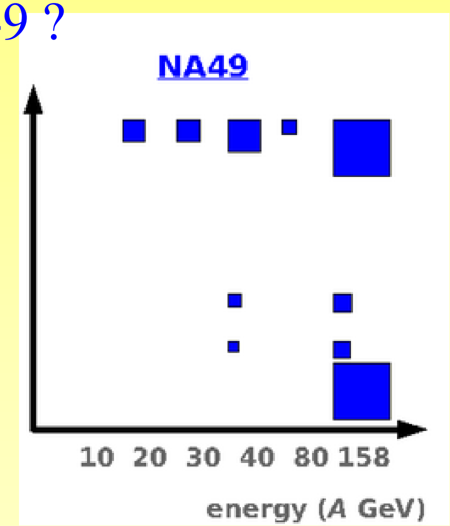
Experimental set up :

New spectator calorimeter for centrality selection

Forward Time-Of-Flight

Beam pipe

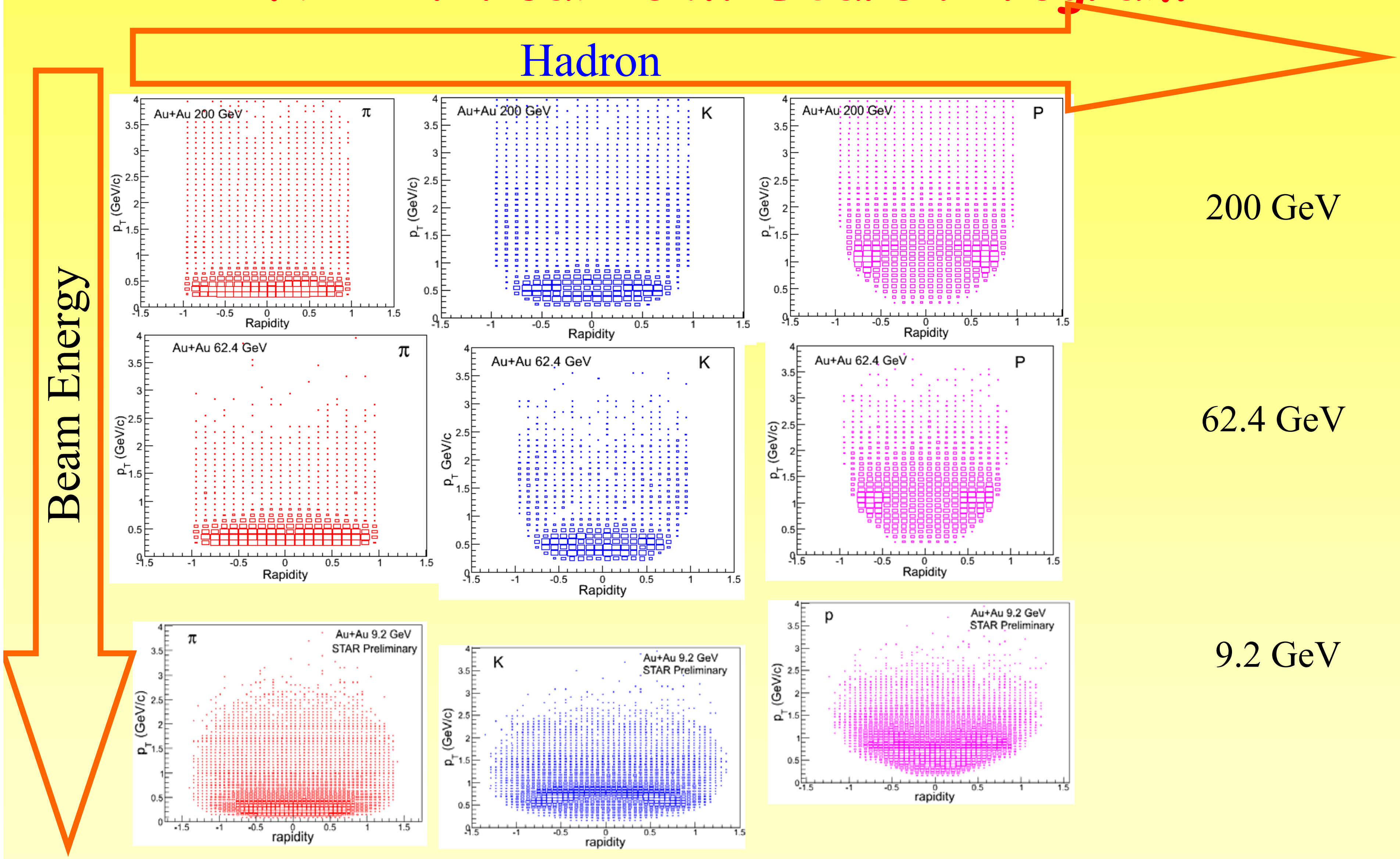
TPC readout speed



Physics Program :

Studying QCD Critical Point and Onset of various observations with varying colliding ion size, collision centrality and having a proper p+p baseline

RHIC Critical Point Search Program



Uniform acceptance for different particle species and for different beam energies in the same experimental setup (advantage over fixed traget expt.)

PROBLEM: low luminosity at low energy

Future: CBM @ FAIR

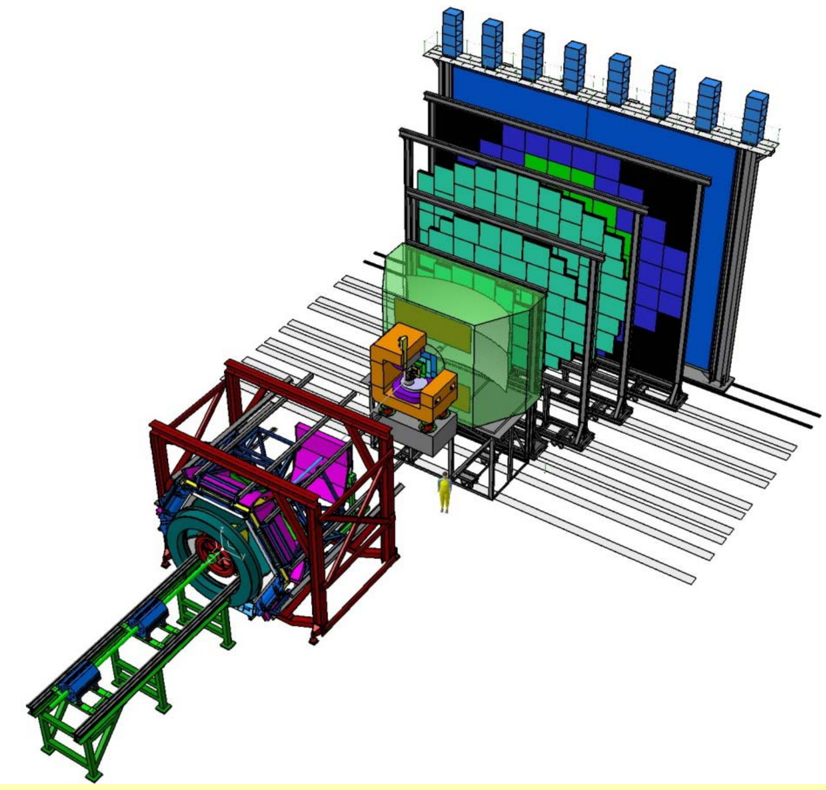
CBM at SIS 300 will start in > 2017

10-45A GeV beam energy, high availability of beam (order of 10 weeks per year), interaction rates up to 10 MHz

"CBM light" at SIS 100 in 2015 Au beam up to 11A GeV, p beam up to 30 GeV (multistrange hyperons, charm production in pA)

Assume 10 weeks beam time, 25A Gev Au+Au (minbias), no trigger, 25 kHz interaction (and storage) rate:

- "unlimited statistics" of bulk observables, e.g. ~$10^{10\text{-}11}$ kaons, 10^{10} Λ
- low-mass di-electrons with high statistics, 10^6 ρ, ω, ϕ -mesons (each)
- multistrange hyperons with high statistics, 10^8 Ξ, 10^6 Ω

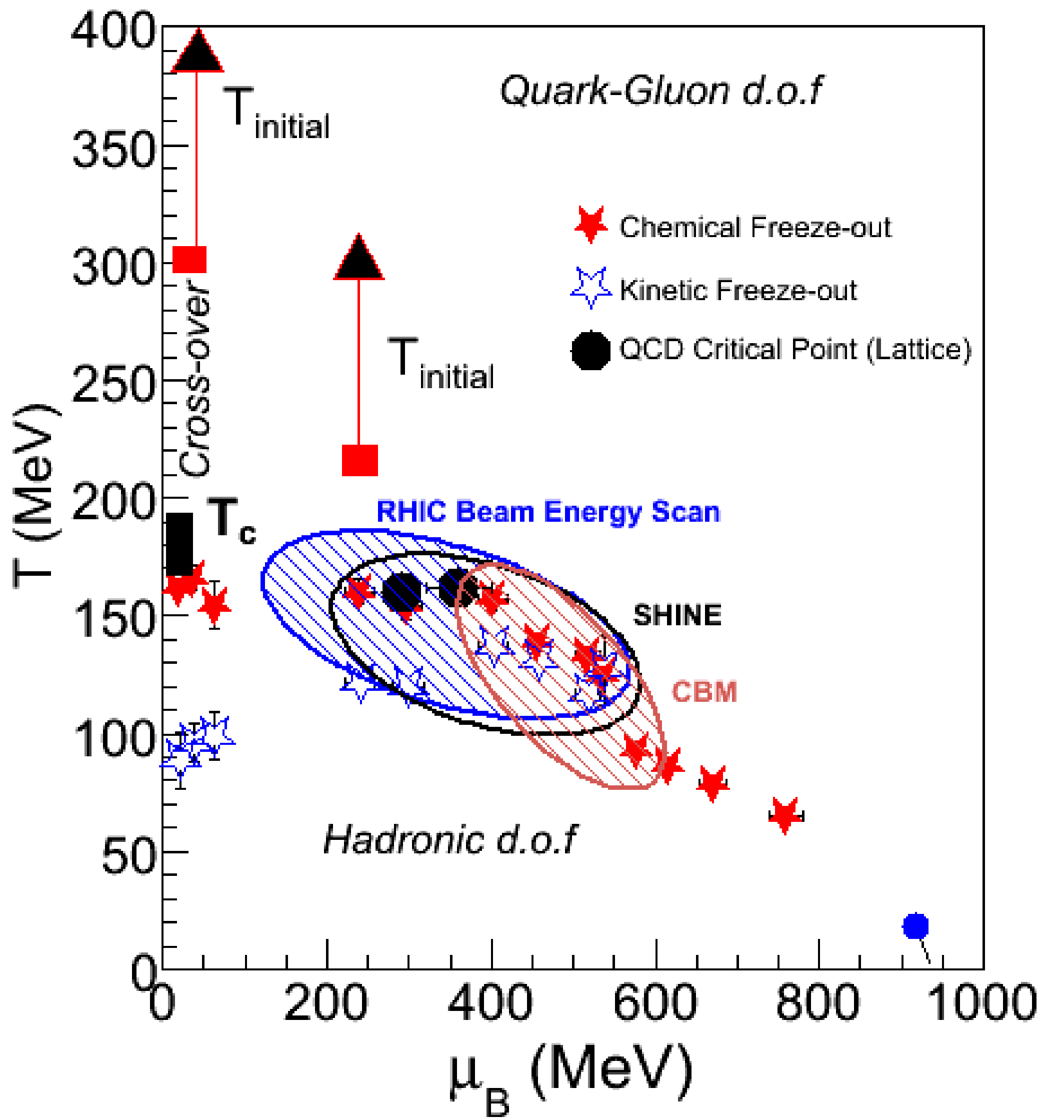


CBM physics program:

- Equation-of-state at high ρ_B (3-10 ρ_0)
- Deconfinement phase transition
- QCD critical endpoint
- Chiral symmetry restoration

High luminosity, rare probes, higher μ_B reach

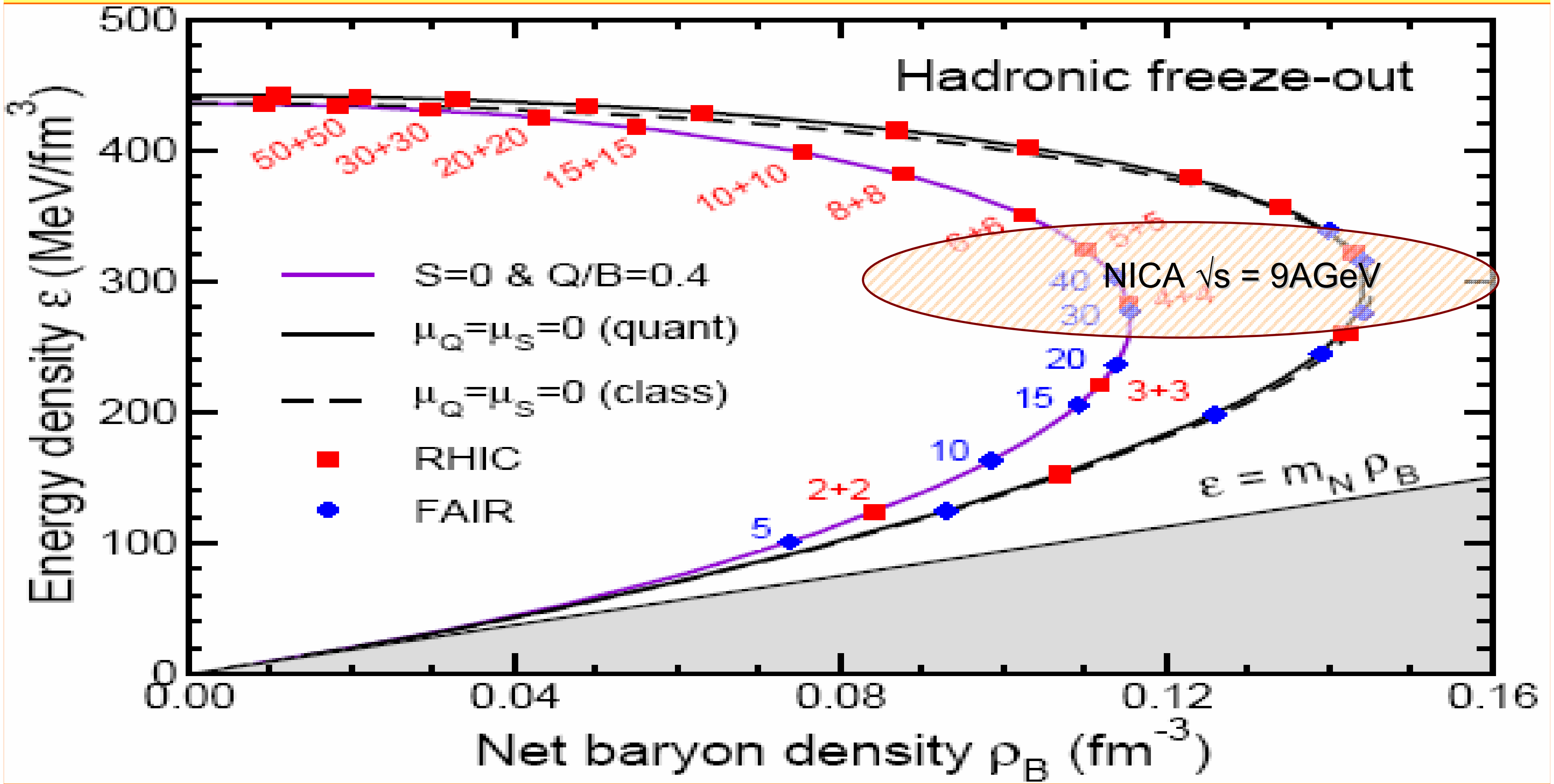
Phase diagram exploration



- Lattice and other QCD based models :
  - $\mu_B = 0$ - Cross-over
  - $T_C \sim 170\text{-}195$ MeV
  - $\mu_B > 160$ MeV - QCD critical point
- No signatures of QCD critical point established, possible hints at SPS

NICA strategy: Collider advantages with high rate => complementary program

NICA @ max baryonic densities



The High-Energy Frontier: LHC as an Ion Collider

- **Running conditions for 'typical' Ion year:**

Collision system	$\sqrt{s_{NN}}$ (TeV)	L_0 ($cm^{-2}s^{-1}$)	$\langle L \rangle / L_0$ (%)	Run time (s/year)	σ_{inel} (b)
PbPb	5.5	10^{27}	70-50	10^6 **	7.7

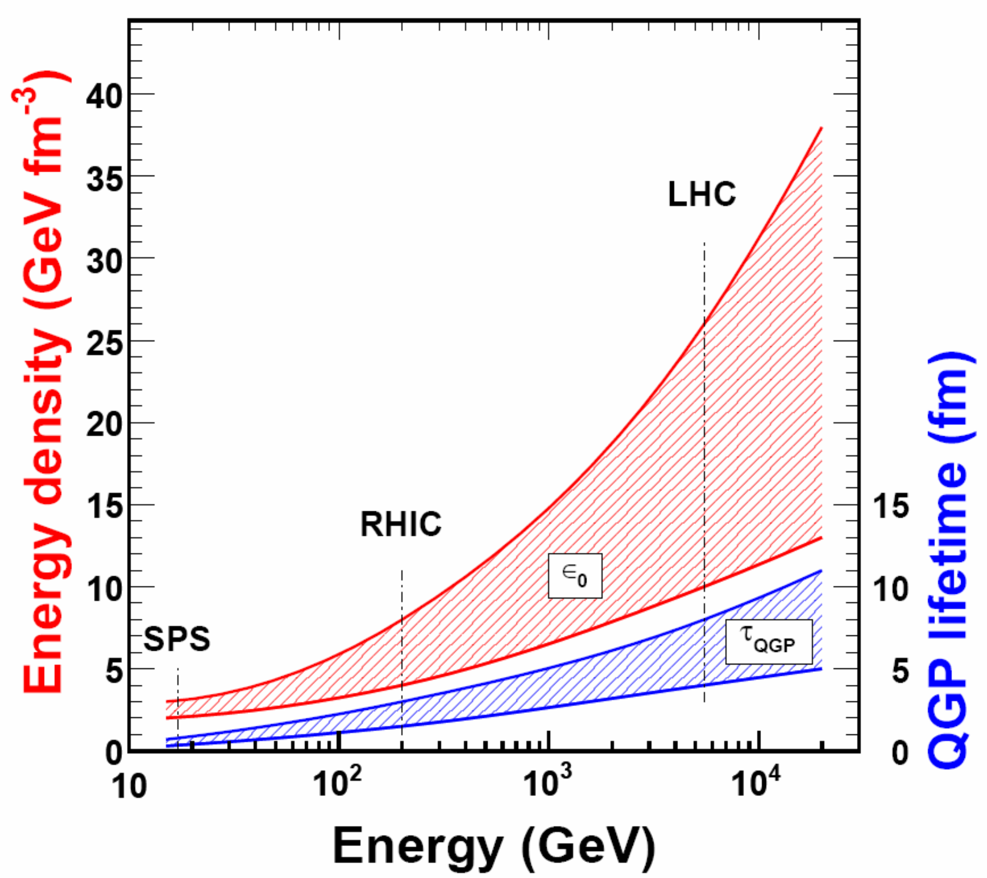
** $\int L\,dt \sim 0.5\ nb^{-1}$/year

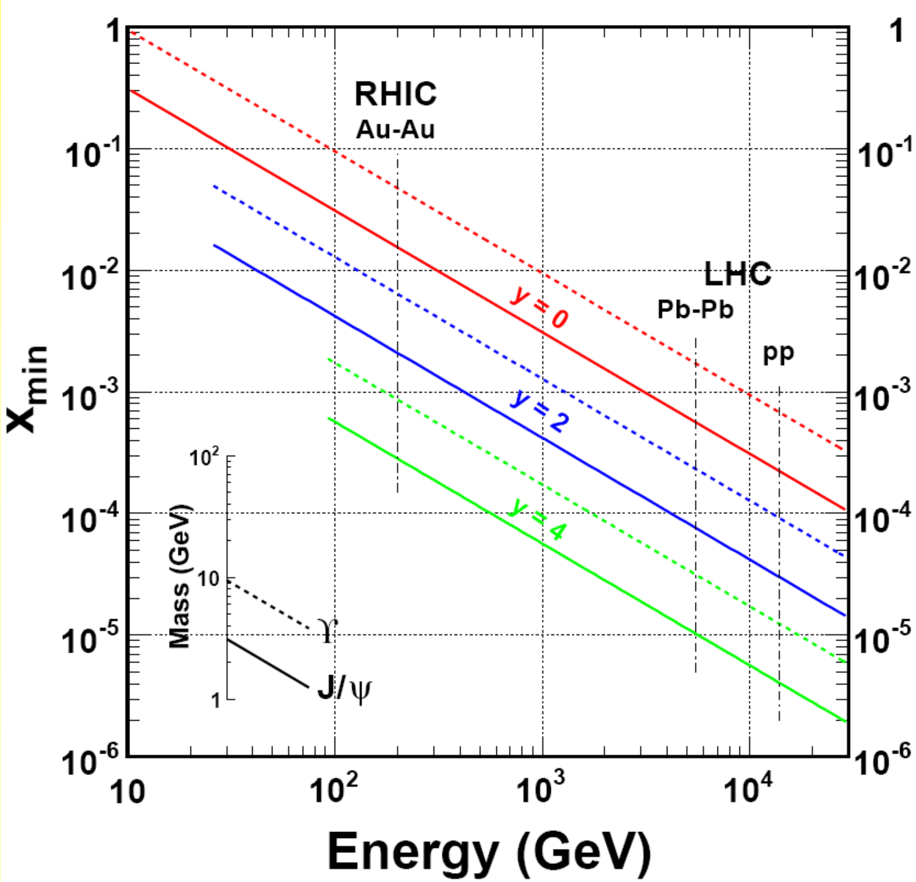
A x28 jump in energy as compared to RHIC

- Running plan:
  - First short low-luminosity run (~1/20th design, i.e. $\mathcal{L} \sim 5\text{x}10^{25}\ cm^{-2}s^{-1}$)
    - **late 2010 (confirmed)**
  - Following few years **(1HI 'year' = 10^6 effective s, ~like at SPS)**
    - **2 - 3 years Pb-Pb :** targeting integrated $\mathcal{L}$ ~1nb^{-1} — **$\mathcal{L} \sim 10^{27}\ cm^{-2}s^{-1}$**
    - **1 year p - Pb 'like'** (**p**, d or α) — **$\mathcal{L} \sim 10^{29}\ cm^{-2}s^{-1}$**
    - **1 year light ions** (eg Ar-Ar) — **$\mathcal{L} \sim$ few 10^{27} to $10^{29}\ cm^{-2}s^{-1}$**
  - Later: different options depending on Physics results

LHC vs RHIC

- Unexplored low x regime.
- Energy density and QGP lifetime increase by a factor 2 ÷3

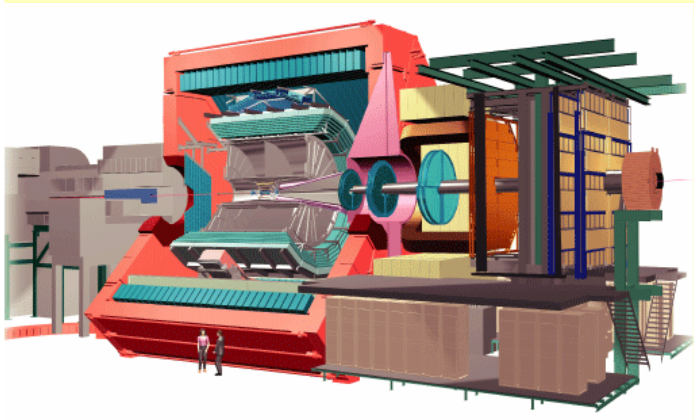


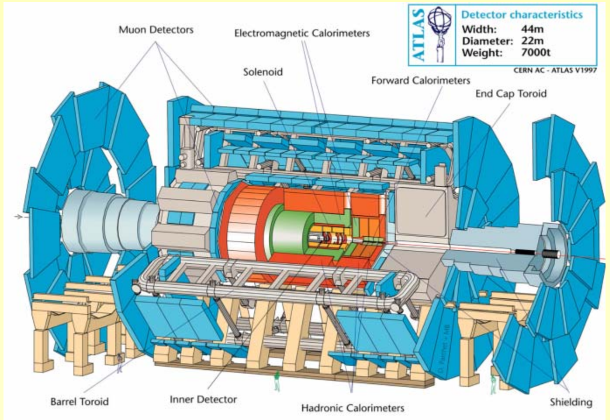


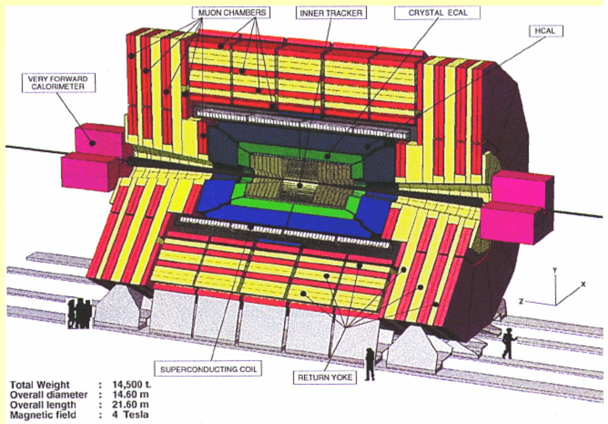
- But also new probes: Jets, Heavy Quarks

HI Experiments at the LHC

- One dedicated Heavy-Ion experiment: ALICE
  - Needs to cover essentially all relevant observables
  - Designed to be able to cope with the highest multiplicities
  - The design evolved with time (latest addition: EMCAL)
  - Now over 1000 Physicists from 100 Institutions in 30 Countries
- CMS and, to a lesser extent, ATLAS progressively expanded their interest in the Heavy-Ion runs
  - Very healthy competition!
  - Now about 150 Physicists involved
  - Major role or Russia (especially in CMS, O. Kodolova leads the HI Physics Group)







ALICE is different…

- What makes ALICE different from ATLAS, CMS and LHCb ?
  - Experiment designed for Heavy Ion collision
    - only dedicated experiment at LHC, must be comprehensive and be able to cover all relevant observables
    - VERY robust tracking
      - high-granularity detectors with many space points per track, very low material budget and moderate magnetic field
    - PID over a very large p_T range
    - Hadrons, leptons and photons
    - Very low p_T cutoff
    - Excellent vertexing
- Complementary to the other experiments

Experimental Constraints from the Heavy Ion running

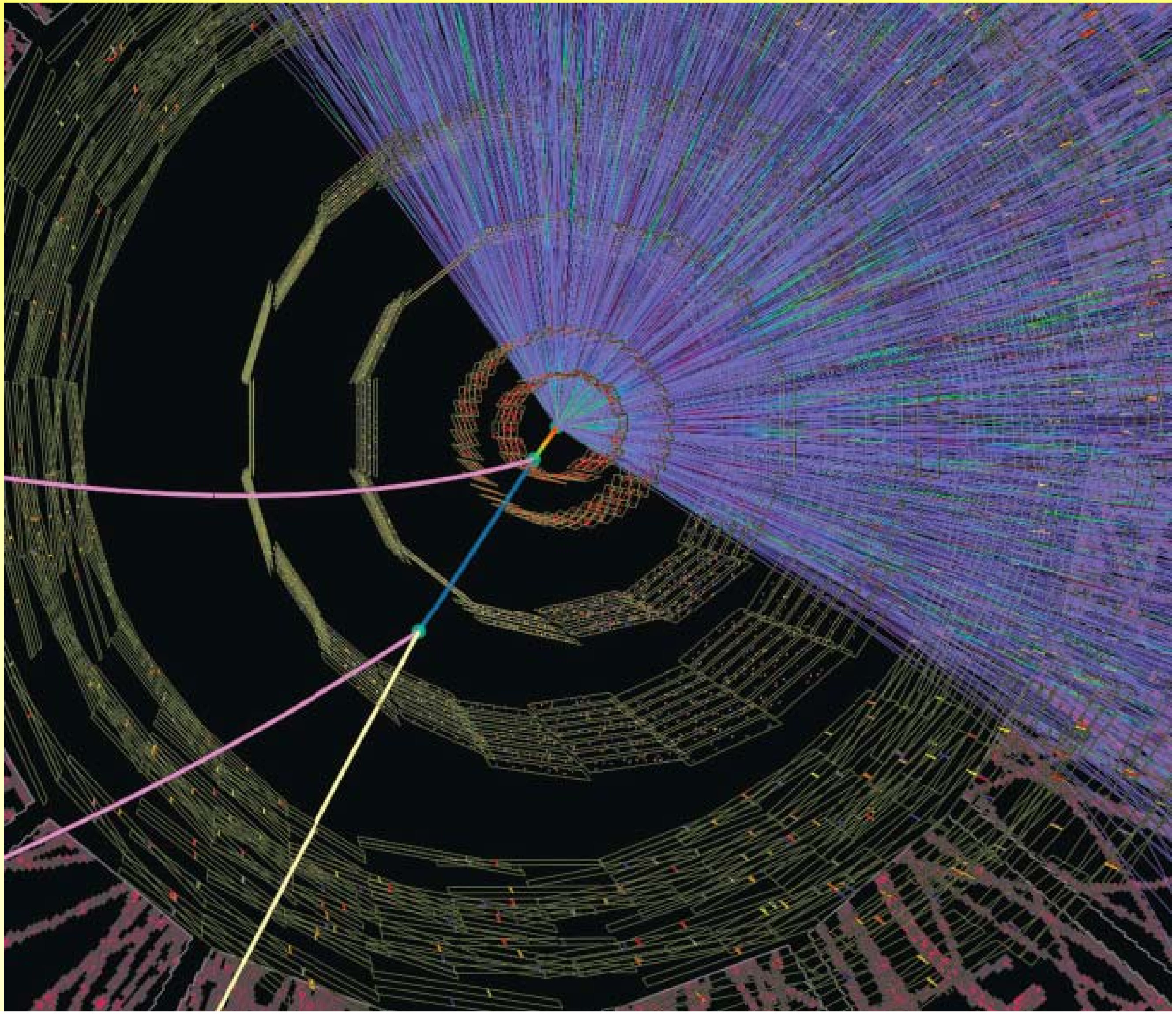
- extreme particle density ($dN_{ch}/d\eta \sim 2000 - 8000$)
  - **x 500** compared to pp @ LHC
- large dynamic range in p_T:
  - from very soft (**0.1 GeV/*c***) to fairly hard (**100 GeV/*c***)
- lepton ID, hadron ID, photon detection
- secondary vertices
- modest Luminosity and interaction rates
  - **10 kHZ** (Pb-Pb) to **300 kHZ** (pp) (< 1/1000 of pp@10^{34})

Tracking challenge

Excellent tracking + vertexing + PID capabilities are the key factors

With part of the event removed, displaced vertices can be seen

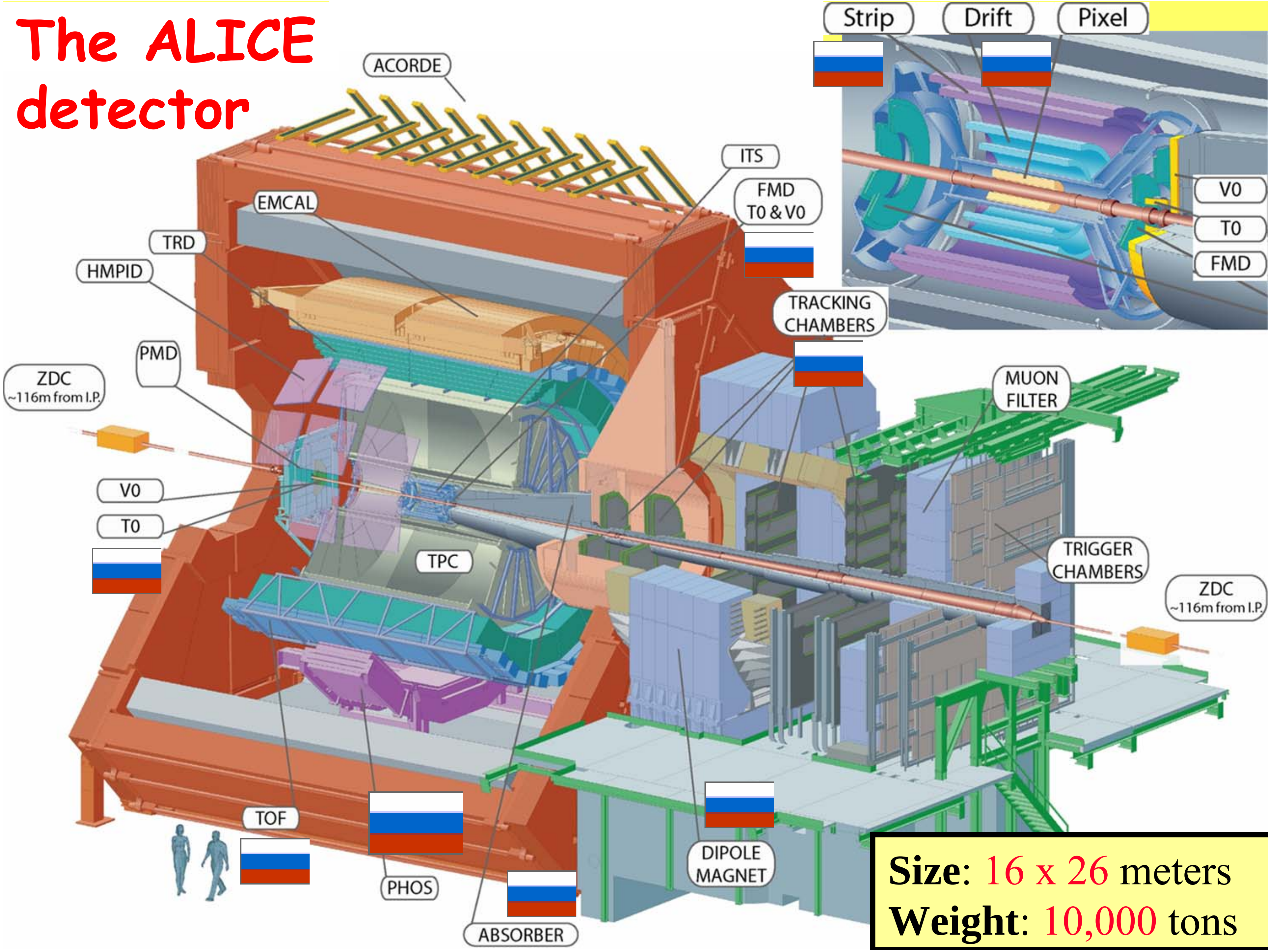
$$\Xi^- \rightarrow \Lambda\pi^-$$



ALICE Experimental Solutions

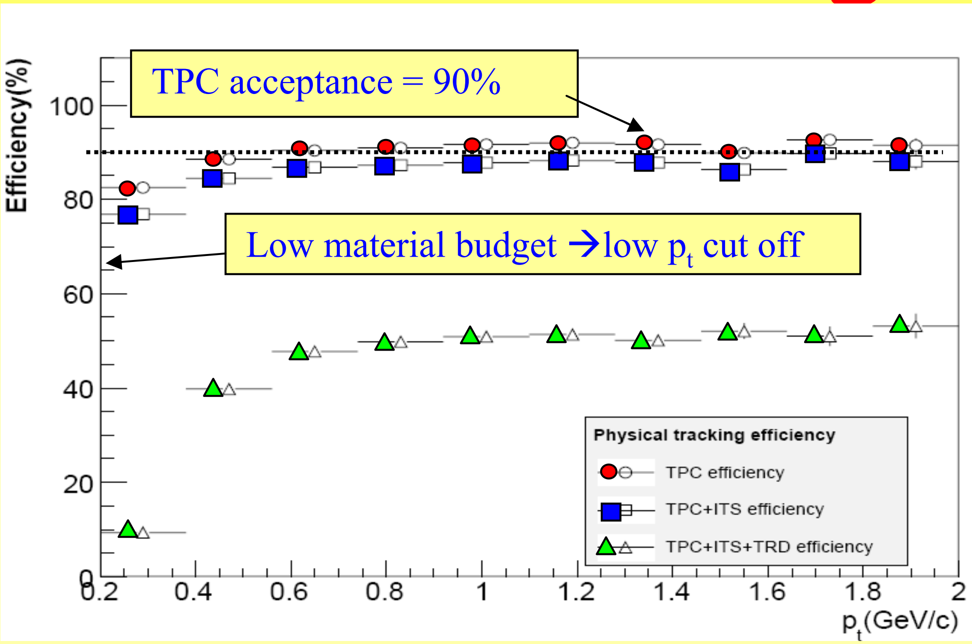
- **$dN_{ch}/d\eta$:** high **granularity**, **3D** detectors (**560 million** pixels in the TPC alone, giving 180 space points/track, largest ever: $88m^3$), large **distance** to vertex (use a VERY large magnet)
  - emcal: high-density crystals of $PbWO_4$ at **4.6 m** (typical is 1-2 m !)
- **p_t coverage**: **thin** det, moderate field (low p_t), large lever arm + resolution (large p_t)
  - ALICE: **$< 10\%X_0$** in r < 2.5 m (typical is 50-100%X_0), B= **0.5T**, **BL^2** ~ like CMS !
- **PID**: use of essentially all known technologies
  - dE/dx, Cherenkov & transition rad., TOF, calorimeters, muon filter, topological
- **rate:** allows slow detectors (TPC, SDD), moderate radiation hardness

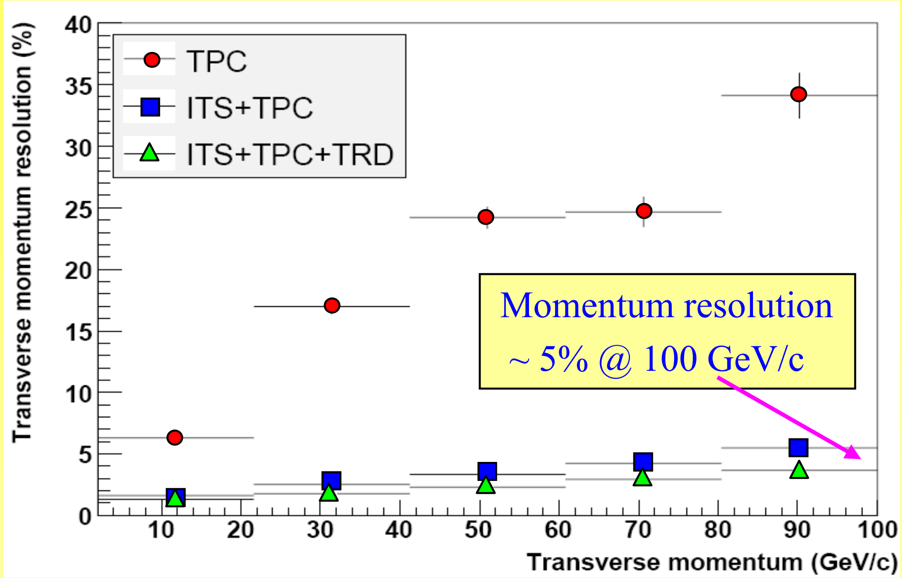
The ALICE detector

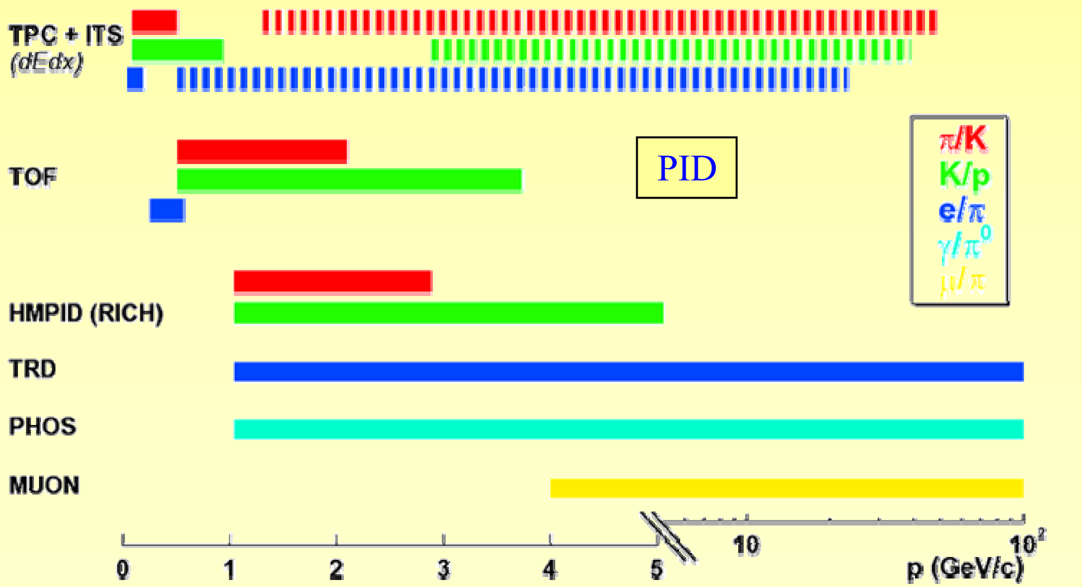


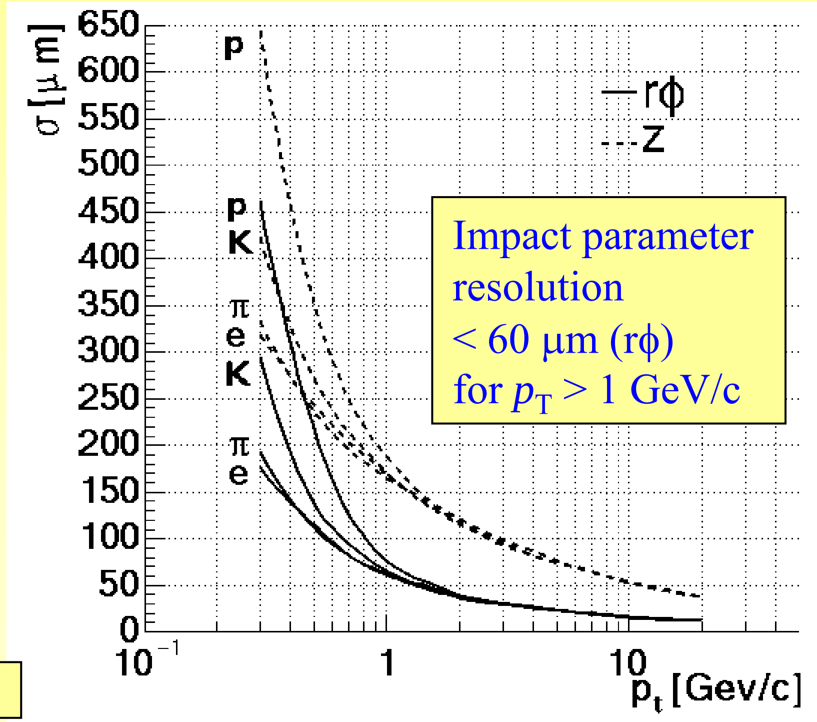
Size: 16 x 26 meters
Weight: 10,000 tons

ALICE Design Performance





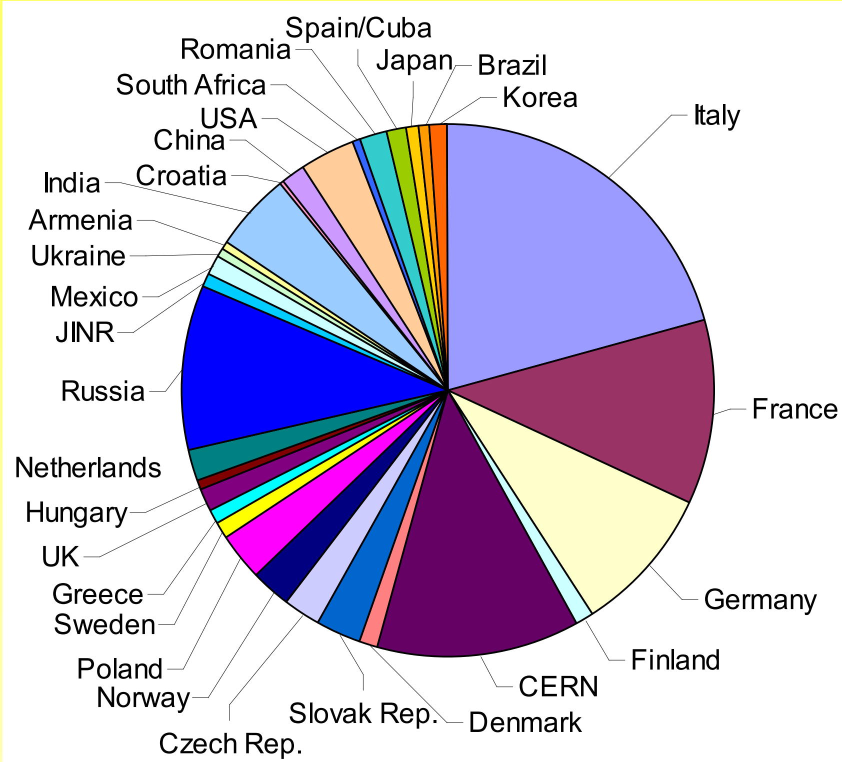




+ decay topologies ((K^0, K^+, K^-, Λ, ϕ, D) K and Λ beyond 10 GeV/c

Who is ALICE

~ 1000 **Members**
from both NP and HEP communities
~30 **Countries**
~100 **Institutes**
~ 150 **MCHF capital cost**
(+ 'free' magnet)



History

1989-1996: Design
1992-2002: R&D
2000-2010: Construction
2002-2007: Installation
2008 -> : Commissioning
3 TP addenda along the way: 1996 : muon spectrometer 1999 : TRD 2006 : EMCAL

Russia and Italy are the largest national groups

A decade of R&D…

In detector Hardware and VLSI Electronics

=> successfully **completed**

across the decade of the 1990's:

- Inner Tracking System (ITS)
  - Silicon Pixels (RD19)
  - Silicon Drift (INFN/SDI)
  - Silicon Strips (double sided)
  - low mass, high density interconnects
  - low mass support/cooling
- TRD
  - bi-dimensional (time-space) read-out, on-chip
  - trigger (TRAP chip)
- TPC
  - gas mixtures (RD32)
  - advanced digital electronics
  - low mass field cage
- EM calorimeter
  - new scint. crystals (RD18)
- PID
  - Multigap RPC's (LAA)
  - solid photocathode RICH (RD26)

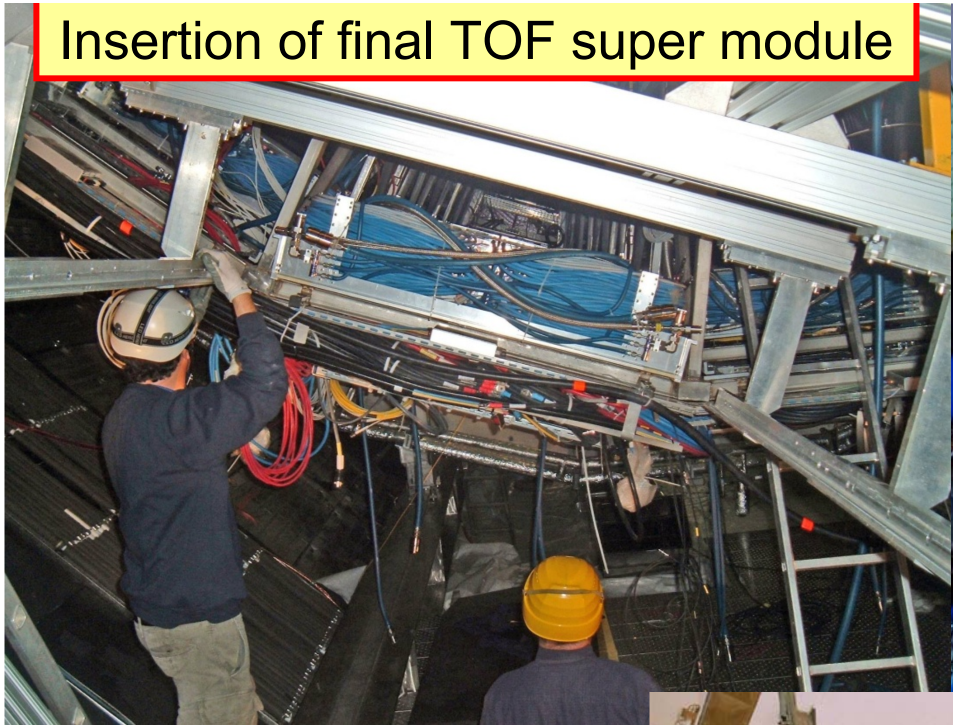
In DAQ & Computing

=> in progress **now**

- scalable architectures with consumer electornics commercial components (COTS)
- high perf. storage media
- GRID computing

ALICE in 2001

Insertion of final TOF super module

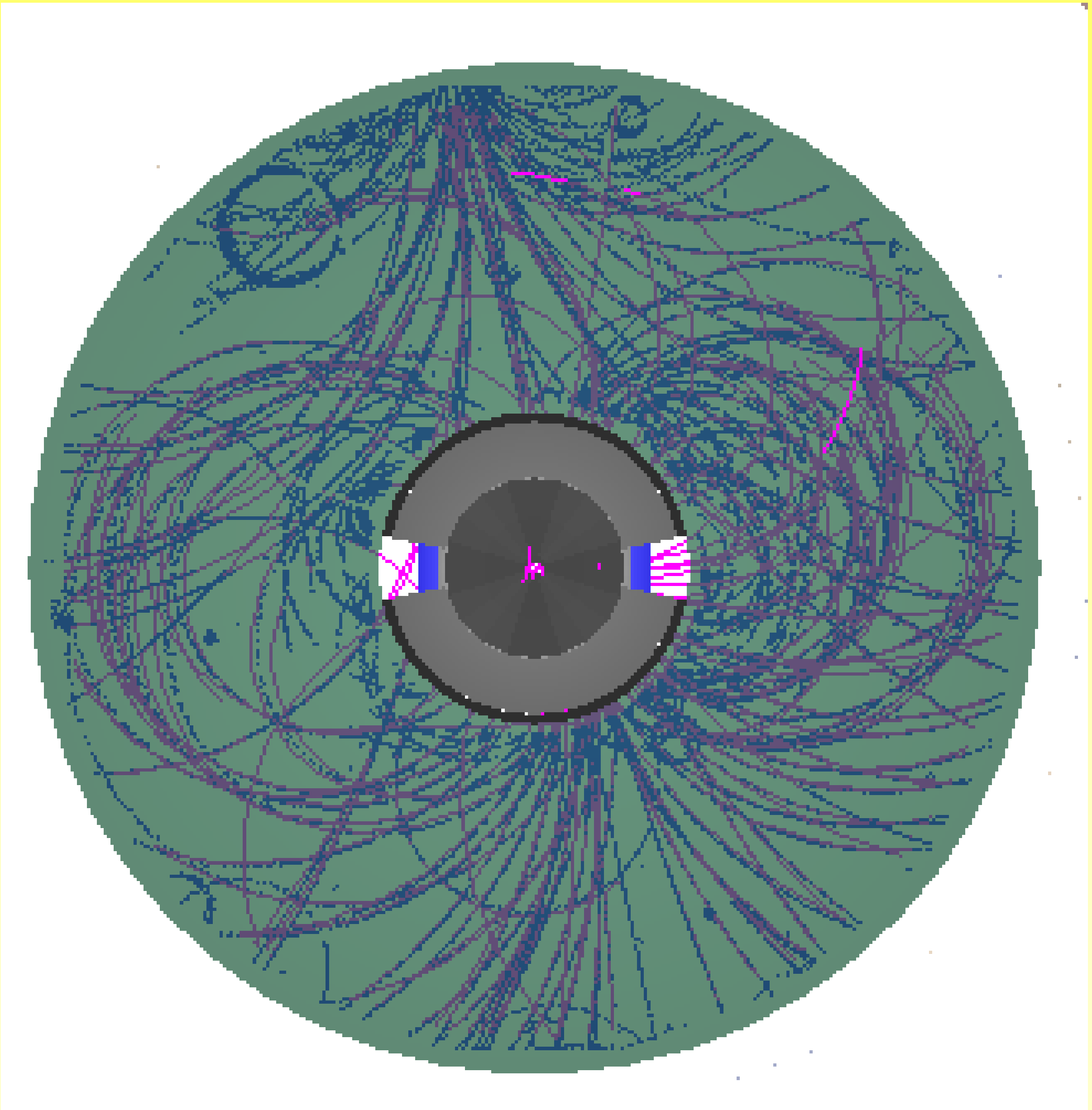


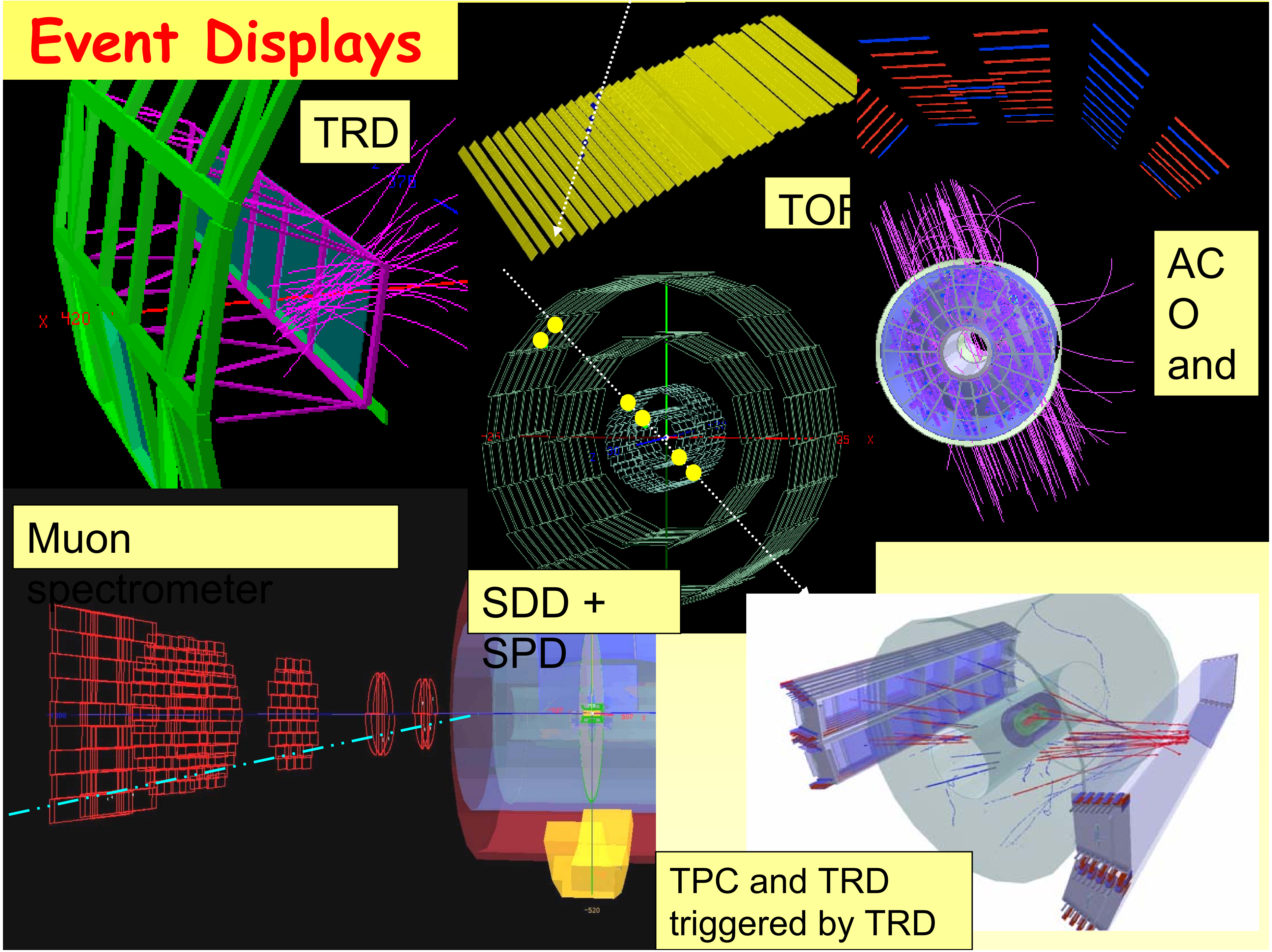
Installation of final muon chamber

ALICE in 2008

Formal end of ALICE installation July 2008

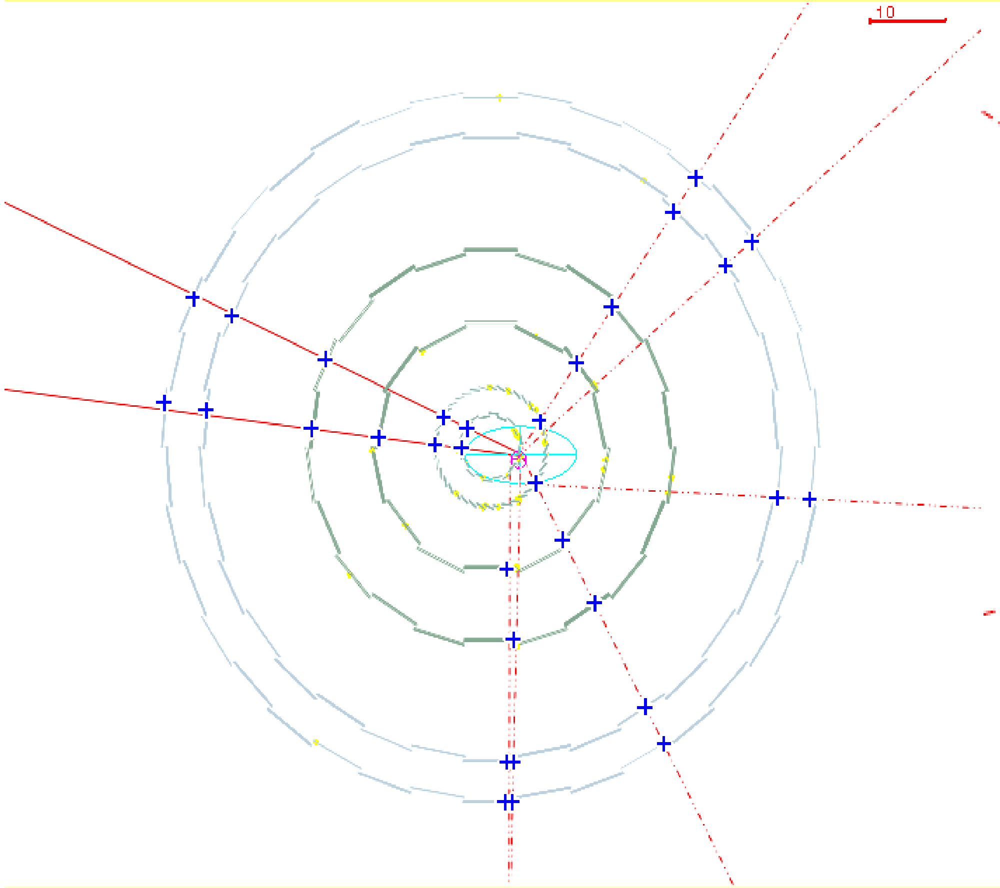
2008: cosmics!

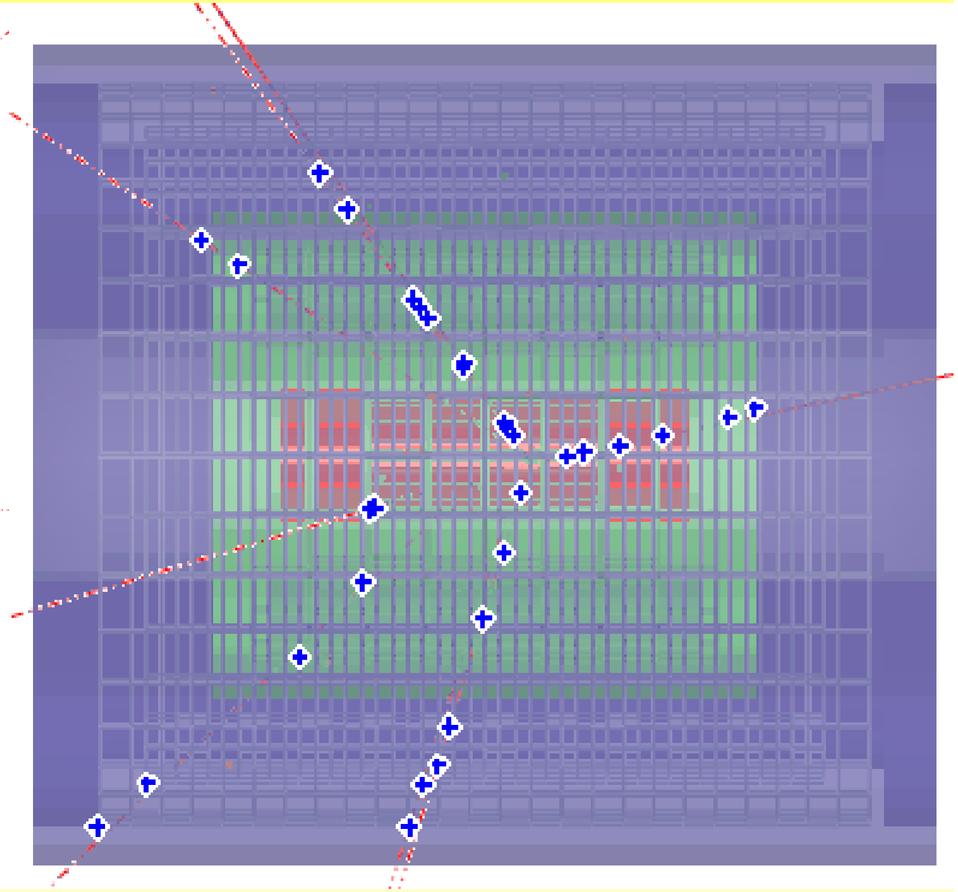



Event Displays
TRD
TOF
AC
O
and
Muon
spectrometer
SDD +
SPD
TPC and TRD
triggered by TRD

2008: First Interaction in ALICE

- LHC beam circulation tests on 11.09.2008.
- Collision of beam-halo particle with SPD: 7 reconstructed tracks from common vertex.

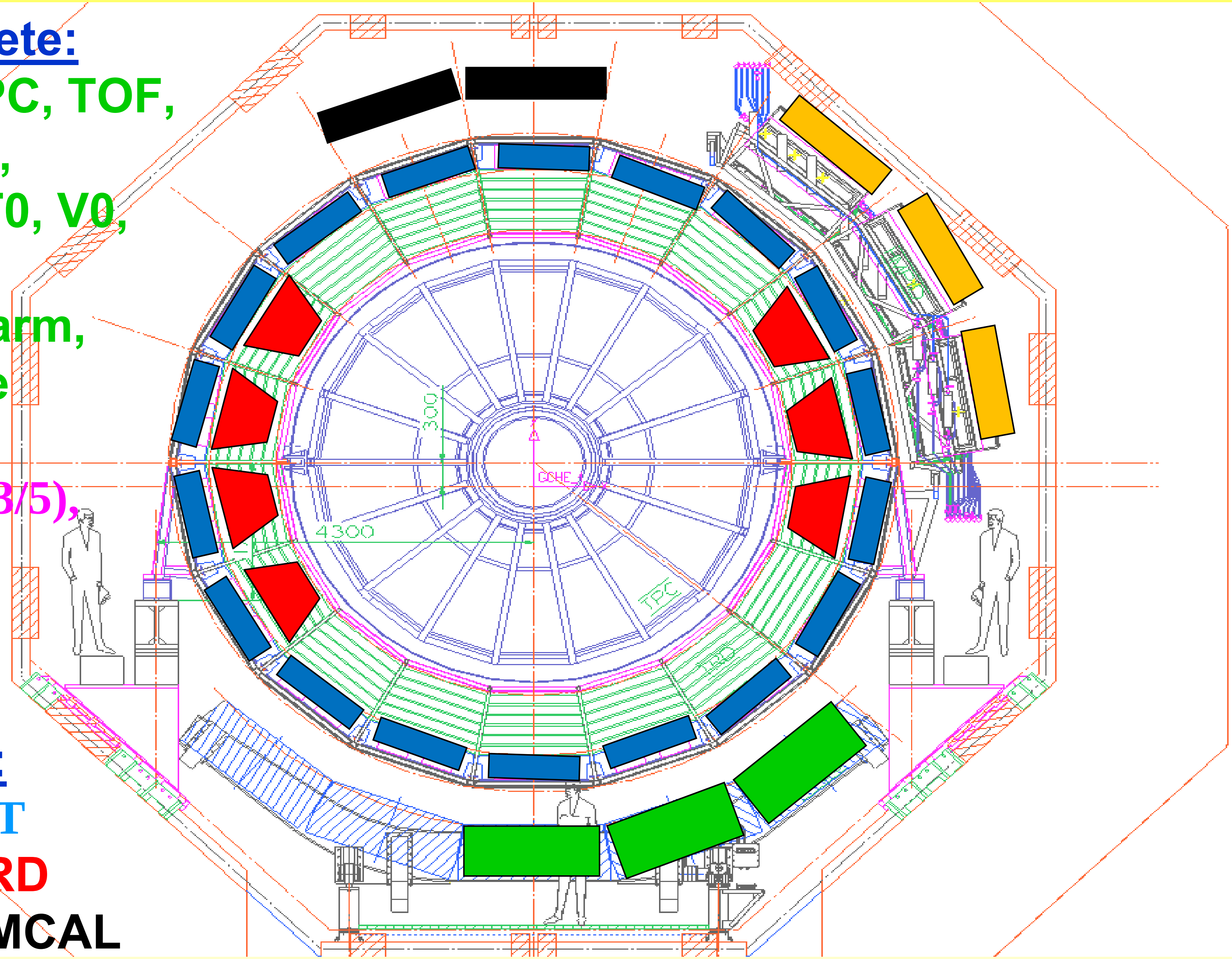




ALICE 2009: largely complete

Complete:

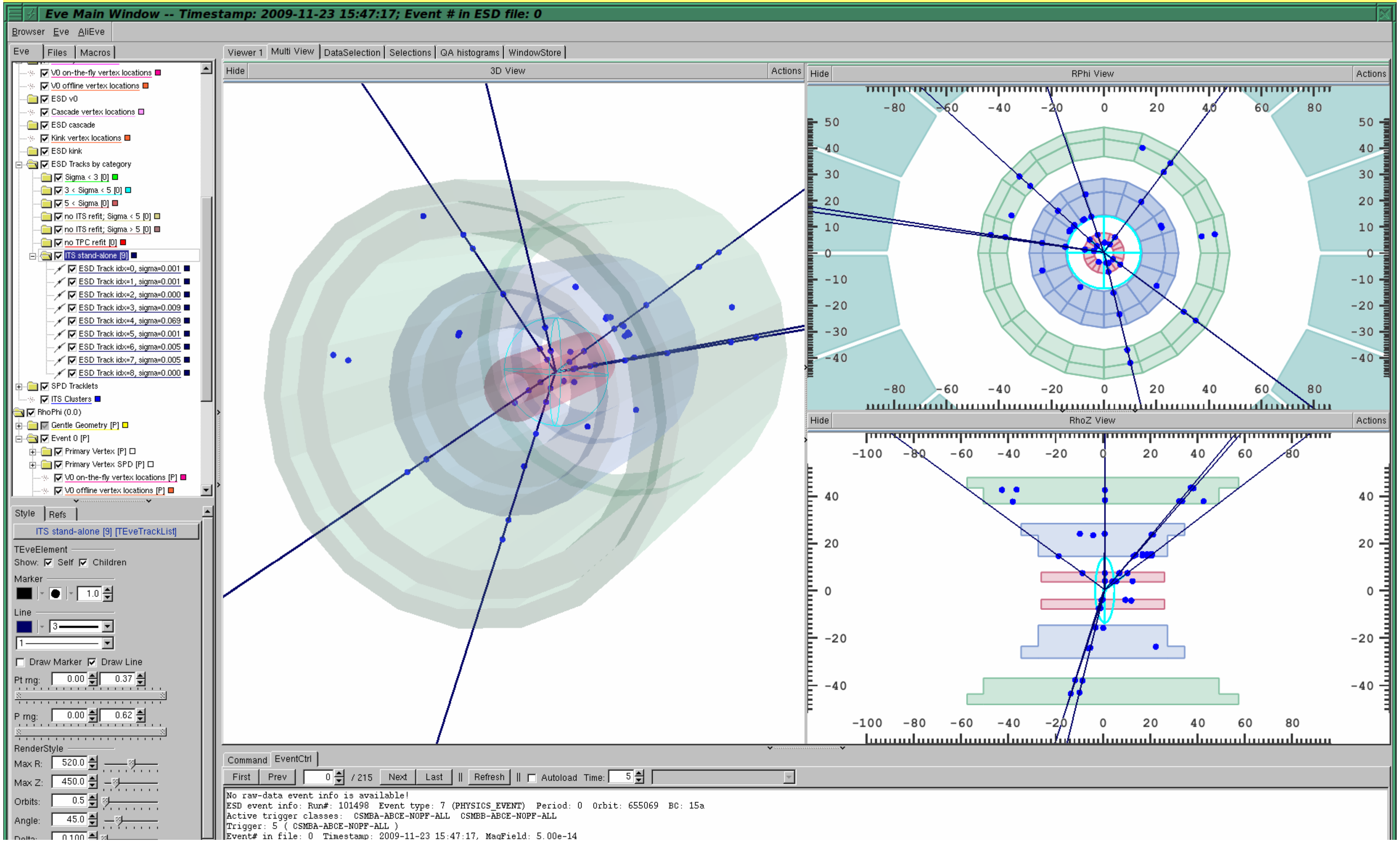
ITS, TPC, TOF,
HMPID,
FMD, T0, V0,
ZDC,
Muon arm,
Acorde
PMD ,
PHOS(3/5),
DAQ



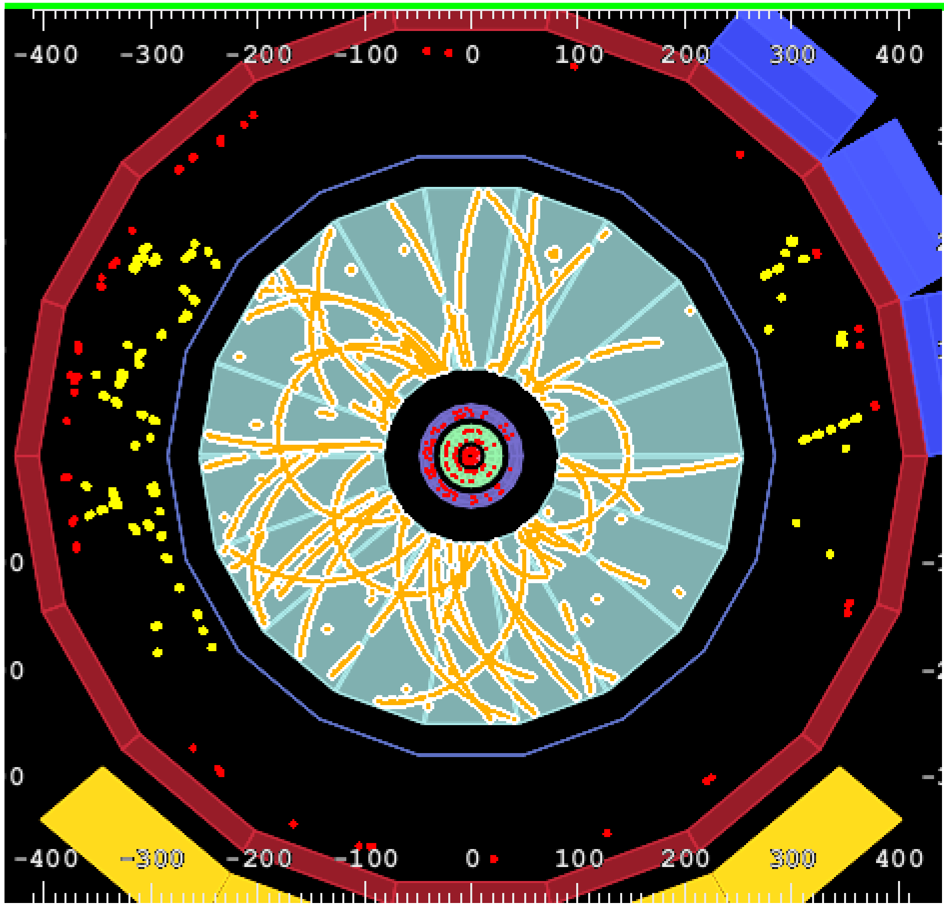
Partial:

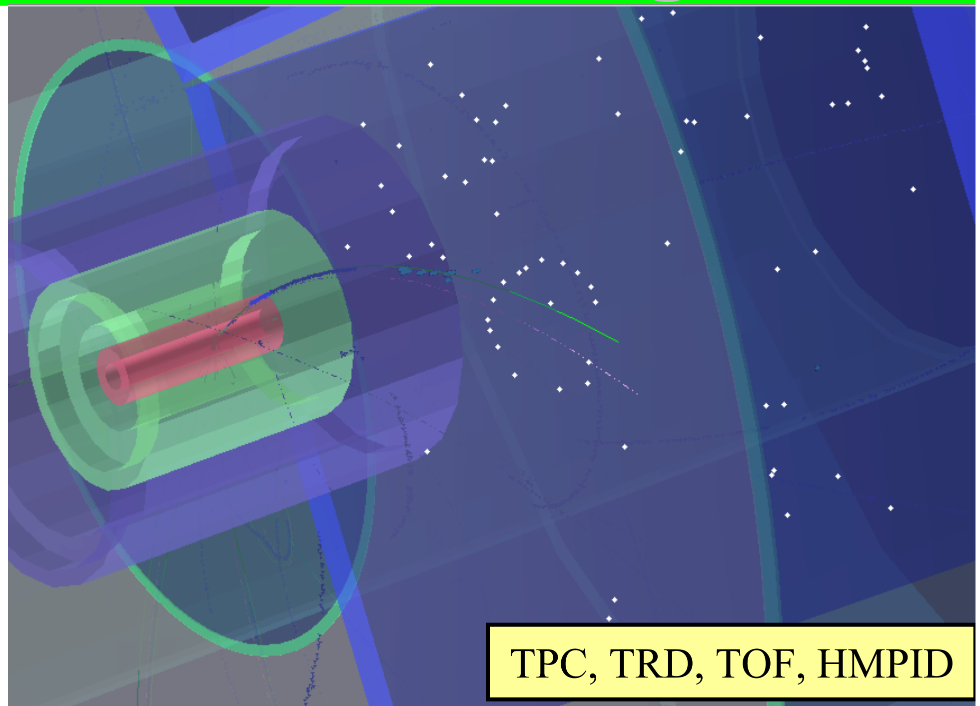
2/3 HLT
7/18 TRD
4/12 EMCAL

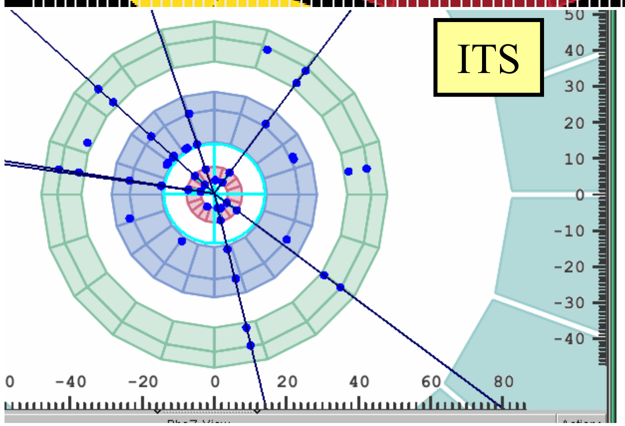
The First event!



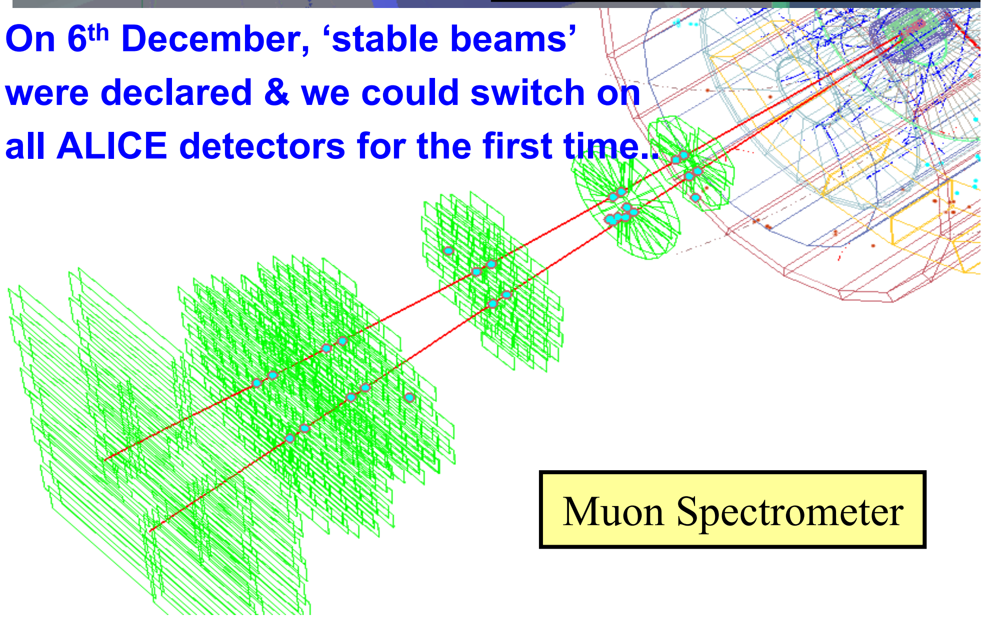
How well is the detector doing?







On 6th December, 'stable beams' were declared & we could switch on all ALICE detectors for the first time..

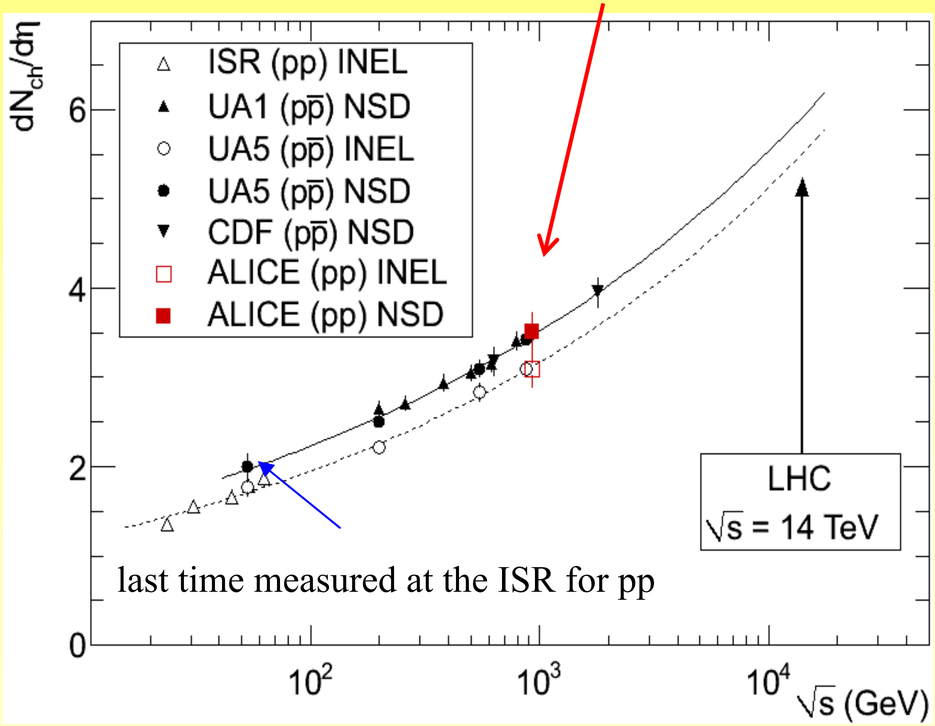


The first LHC Physics Paper!

Phase 1: rediscovering the standard model (QCD in the case of ALICE)

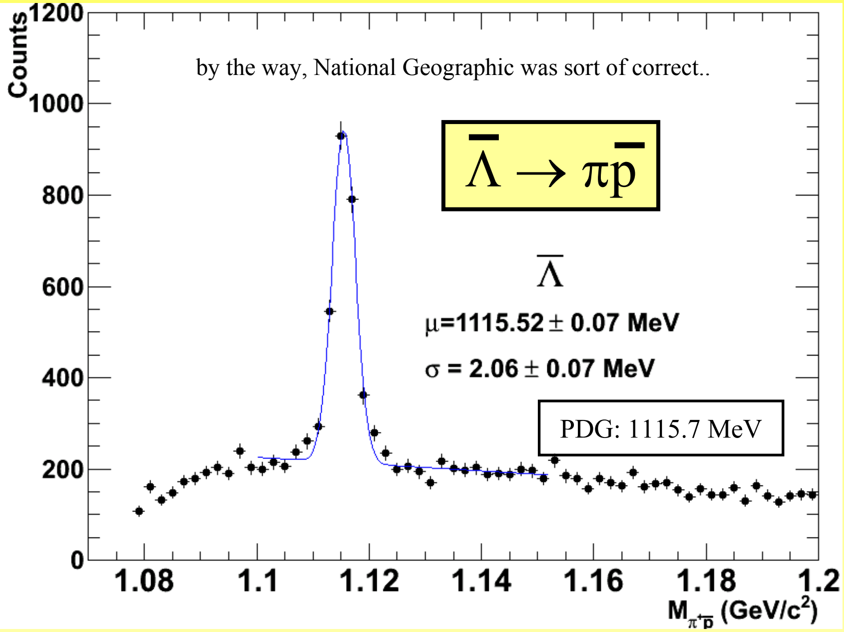
The average number of charged particles created perpendicular to the beam in pp collisions at 900 GeV is:

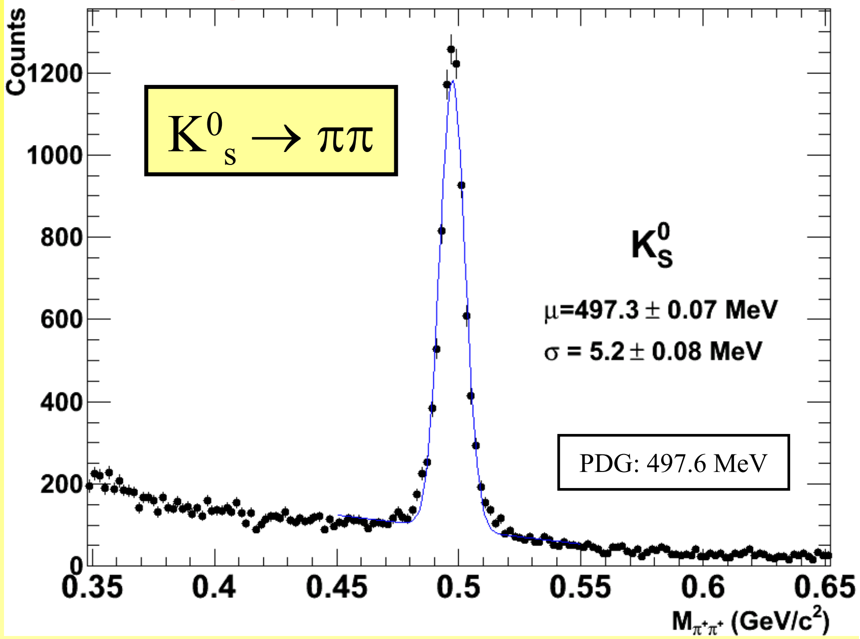
$dN/d\eta = 3.10 \pm 0.13\ (stat) \pm 0.22\ (syst)$



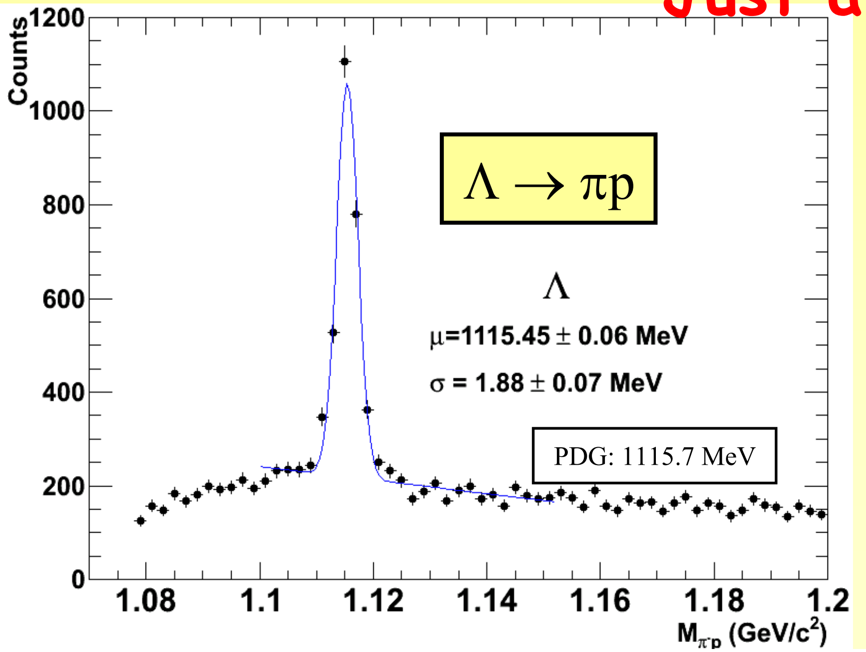
This is the first (and easiest) of many numbers we need to (re)measure to get confidence in our detectors, tune the simulations, study background, ... Discoveries are still a long way to go..

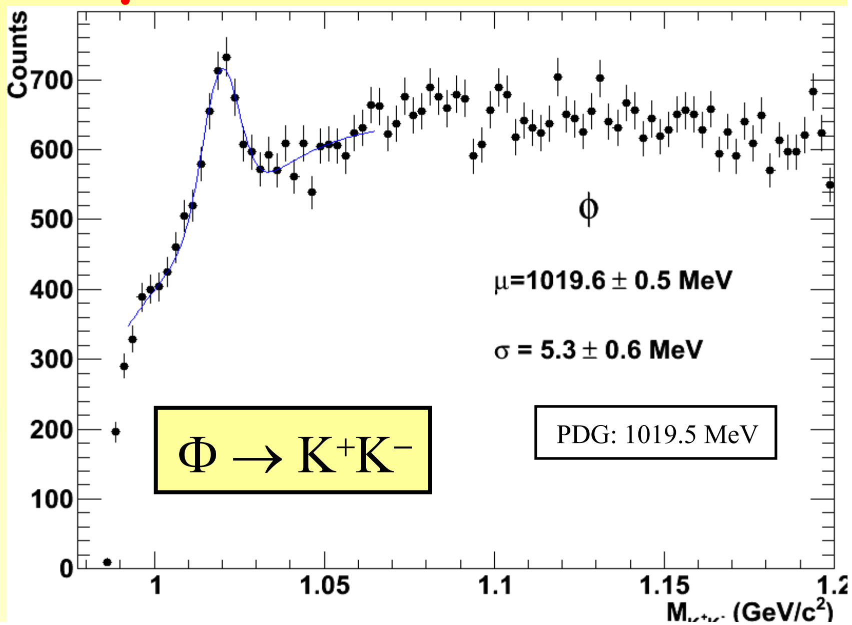
Results are flocking in:





Just a few examples…





Russian- JINR participation in ALICE

Russia: 9 Institutions

- **BINP (Novosibirsk)**
- **IHEP (Protvino)**
- **INR (Troitzk)**
- **ITEP (Moscow)**
- **MEPhI (Moscow)**
- **PNPI (Gatchina)**
- **RFNC "VNIIEF" (Sarov)**
- **RRC "Kurchatov Institute" (Moscow)**
- **St.PSU group (St. Petersburg)**

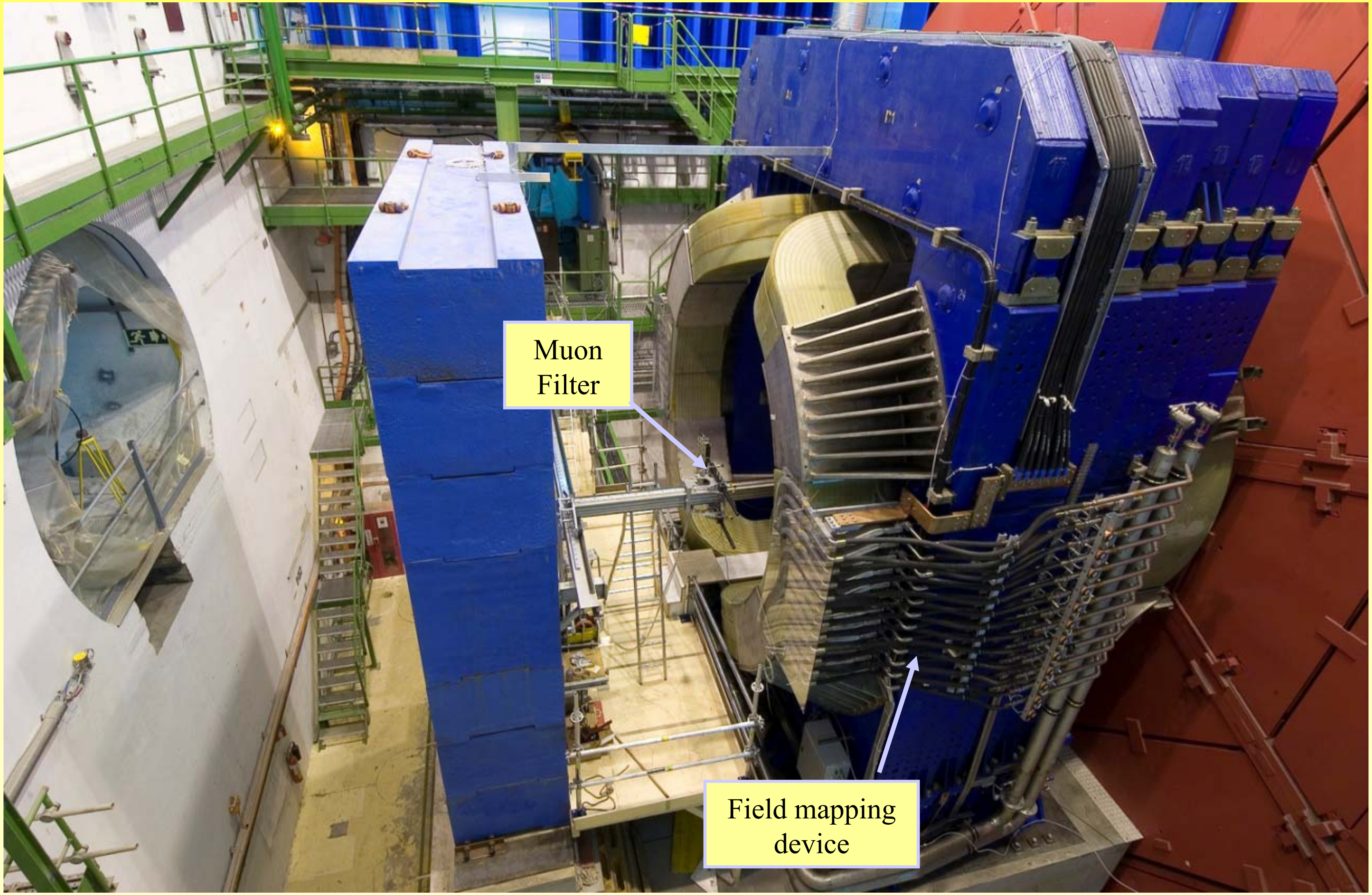
- **JINR (Dubna)**

Everywhere in the project

- **PHOS** ***(KI, Sarov, IHEP, JINR)***
- **DIMUON** ***(PNPI)*** ✓
- **T0** ***(MEPhI, INR, KI)***
- **TOF** ***(ITEP)*** ✓
- **ITS** ***(St.PSU)*** ✓
- **Common Projects ⇒ survey, infrastructure (A major one: the Muon Spectrometer Magnet Yoke at JINR)** ✓
- **Data analysis and physics (*RRC KI, JINR, ITEP, IHEP, INR, St.PSU, PNPI, MEPhI, Sarov)*** ✓
- **GRID computing infrastructure(*RRC KI, JINR, ITEP, IHEP, INR, St.PSU, PNPI)*** ✓

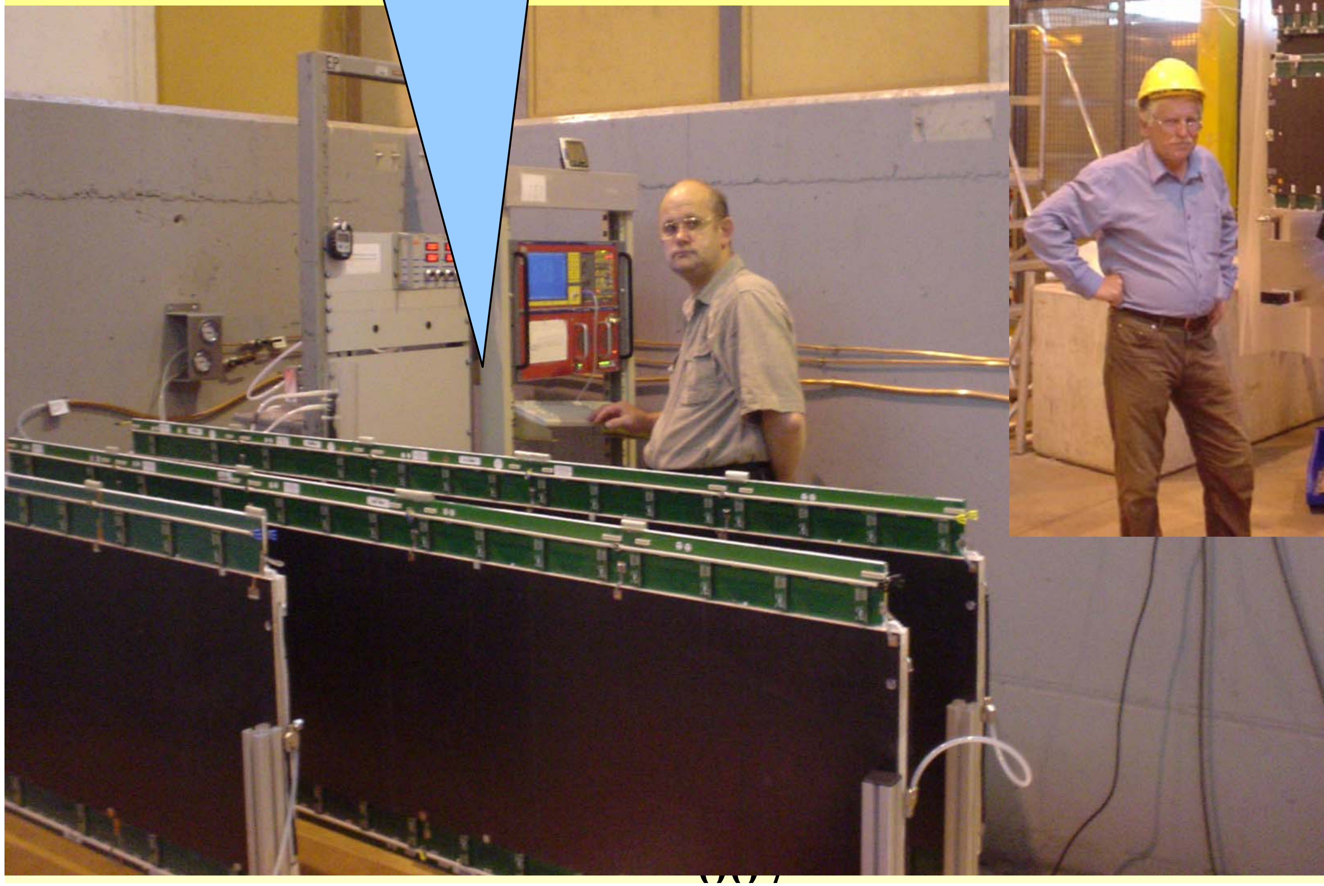
✓ ***: In direct collaboration with Italian groups***

The muon magnet

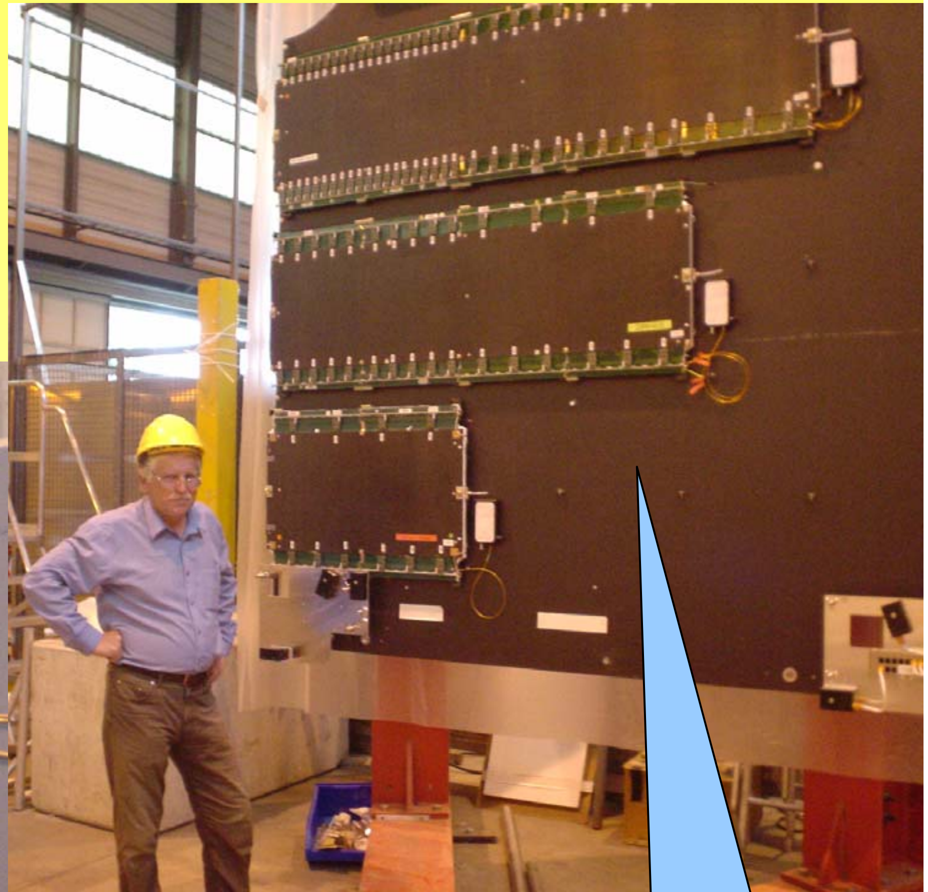


Muon Chambers: test and assembly at CERN

Muon arm tracking chambers fabricated at PNPI

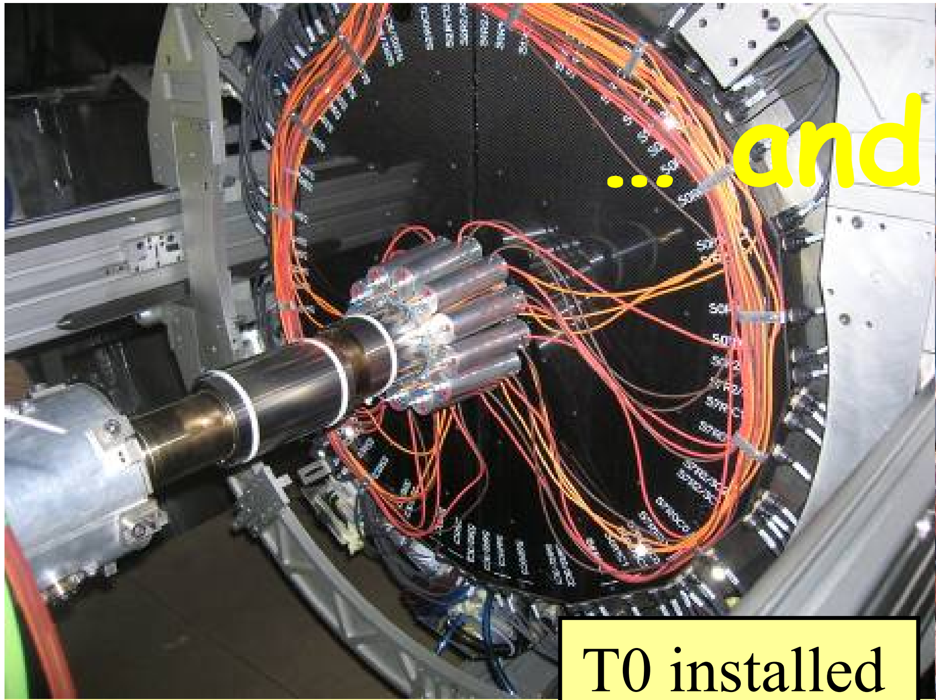


Slats during the pre-assembly tests



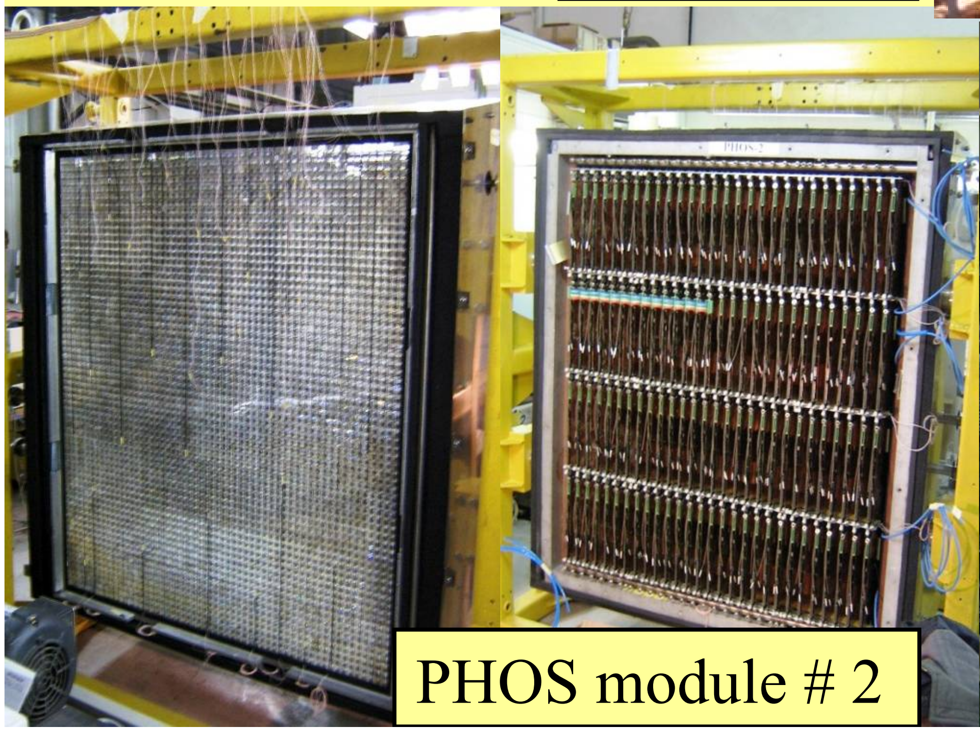
Slats fixed on the panel

… and more…



T0 installed

TOF CRTF

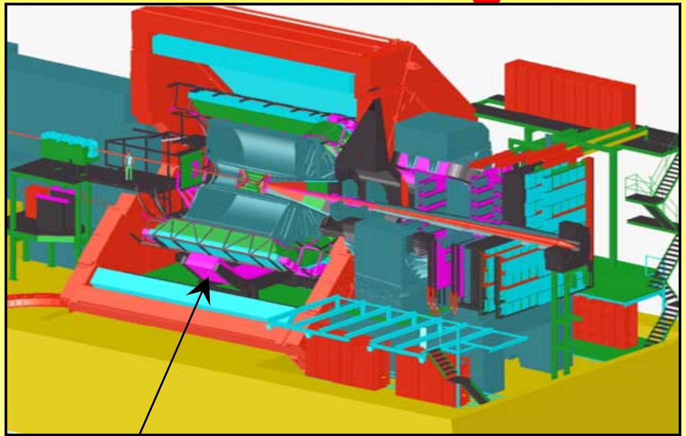


PHOS module # 2

ITS

Ladders

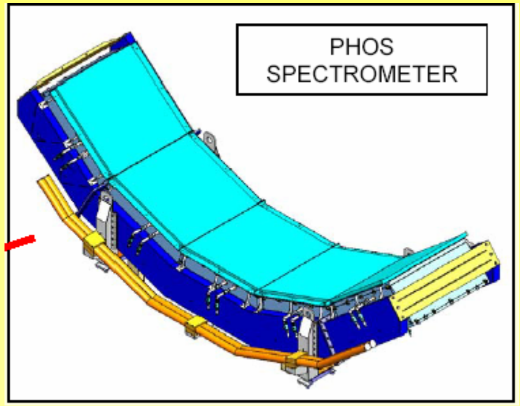
Photon spectrometer PHOS
Major Russian-led detector



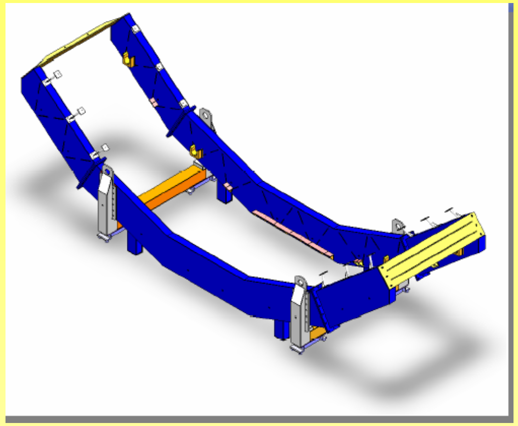
PHOS (PHOton Spectrometer) is a high resolution electromagnetic calorimeter consisting of 17920 detection channels based on lead-tungstate crystals(PWO).
=> Very far from Interaction Point to handle High Multiplicities

Kurchatov Institute, Sarov, IHEP(Protvino), JINR

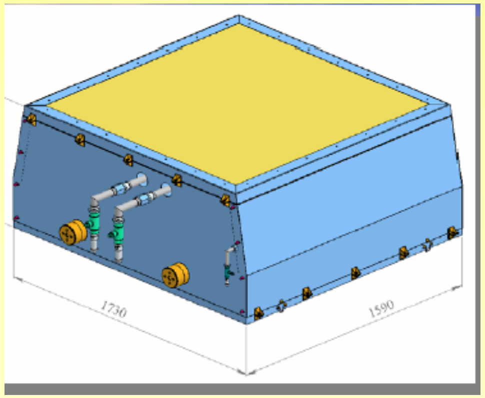
Oslo, Bergen, Prague, Warsaw, Nantes, Muenster, Beijing, Wuhan, Hiroshima, CERN



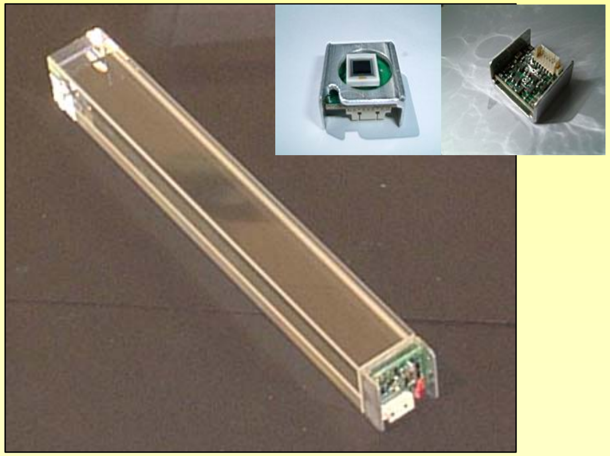
5 independent *modules* each of 3584 *crystal detector units*



PHOS cradle



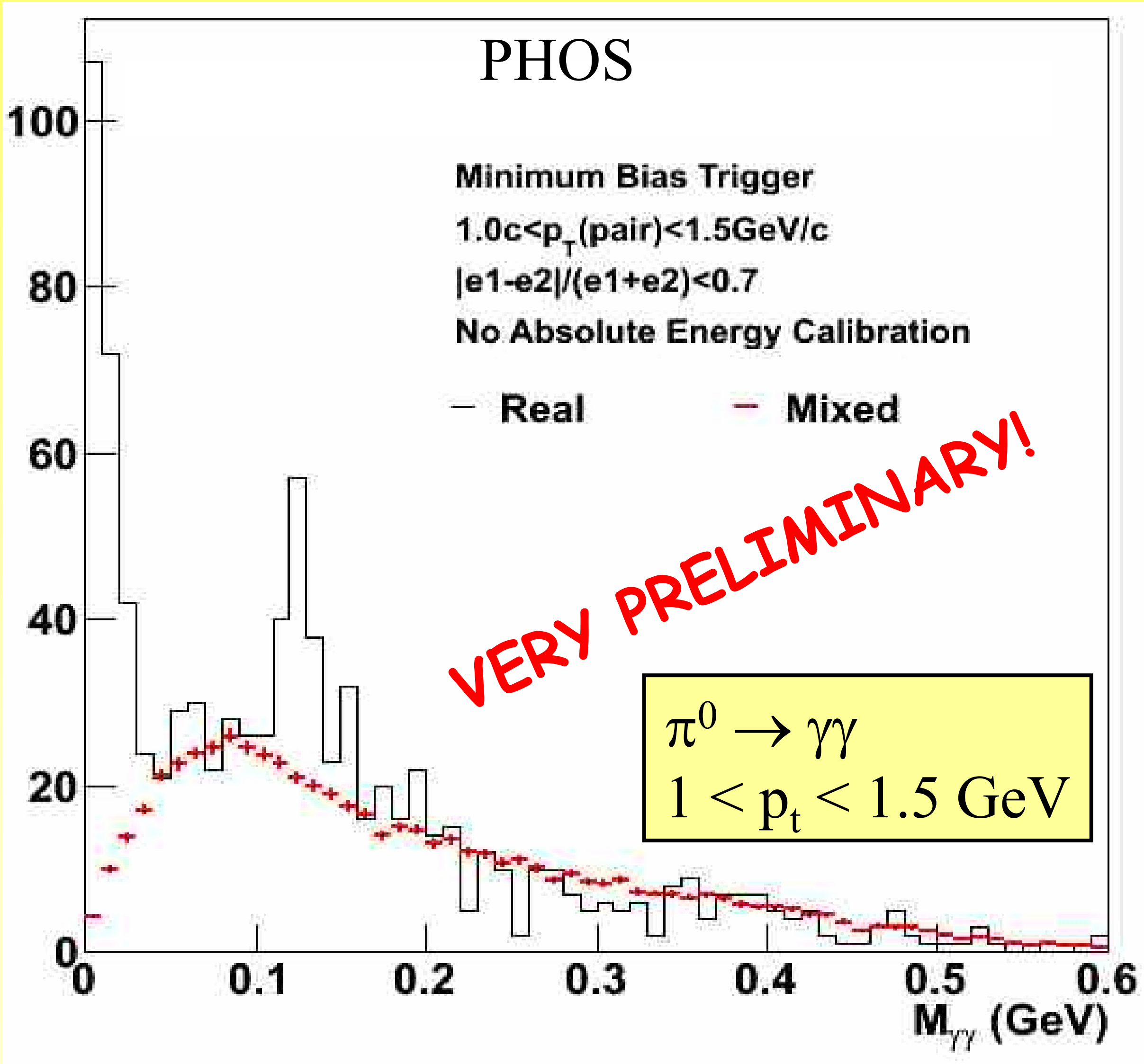
PHOS module
Working temperature: -25 ºC



crystal detector unit: PWO crystal+ APD+ preamp.

Today:

- 3 modules installed and operational at nominal T of -20^o from day 1
- Even with the small statistics of the first 900 GeV pp run… first peak!



What Physics in the First year?

- Ions in LHC in November 2010
  - Tests with Pb all the way to LHC successful!
- From now on pp

pp Physics with ALICE

- ALICE detector performs very well in pp
  - very low-momentum cutoff (<100 MeV/c) x_T-regime down to 4×10^{-6}
  - p_t-reach up to 100 GeV/c
  - excellent particle identification
  - efficient minimum-bias trigger
  - Excellent vertexing capabilities

- first physics in ALICE will be pp
  - provides important reference data for heavy-ion programme
  - Minimum bias running
- unique pp physics in ALICE e.g.
  - Physics at high multiplicities, reachable thanks to the multiplicity trigger from the pixel detectors (7-10 times the mean muultiplicity of minimum bias collisions)
    - Same set of measurements and themes of Heavy-Ion collisions (strangeness production, jet-quenching, flow, …)
  - baryon transport
  - measurement of charm and beauty cross sections down to very low transverse momentum (major input to pp QCD physics) both open charm mesons and quarkonia
    - Essential the acceptance in the low-transverse momentum region

- **start-up**
  - some collisions at 900 GeV → connect to existing systematics
- **pp first high energy run**
  - **Ideal beam conditions for ALICE at low luminosity (50 ns scheme allows decoupling the luminosity in ALICE from the ones in ATLAS and CMS)**
  - first year will typically give in ALICE Luminosity around $2\cdot10^{29}$ cm^{-2} s^{-1} giving of the order of 10^9 events depending on run duration and efficiency

Ongoing!!

HI Physics with ALICE, summary

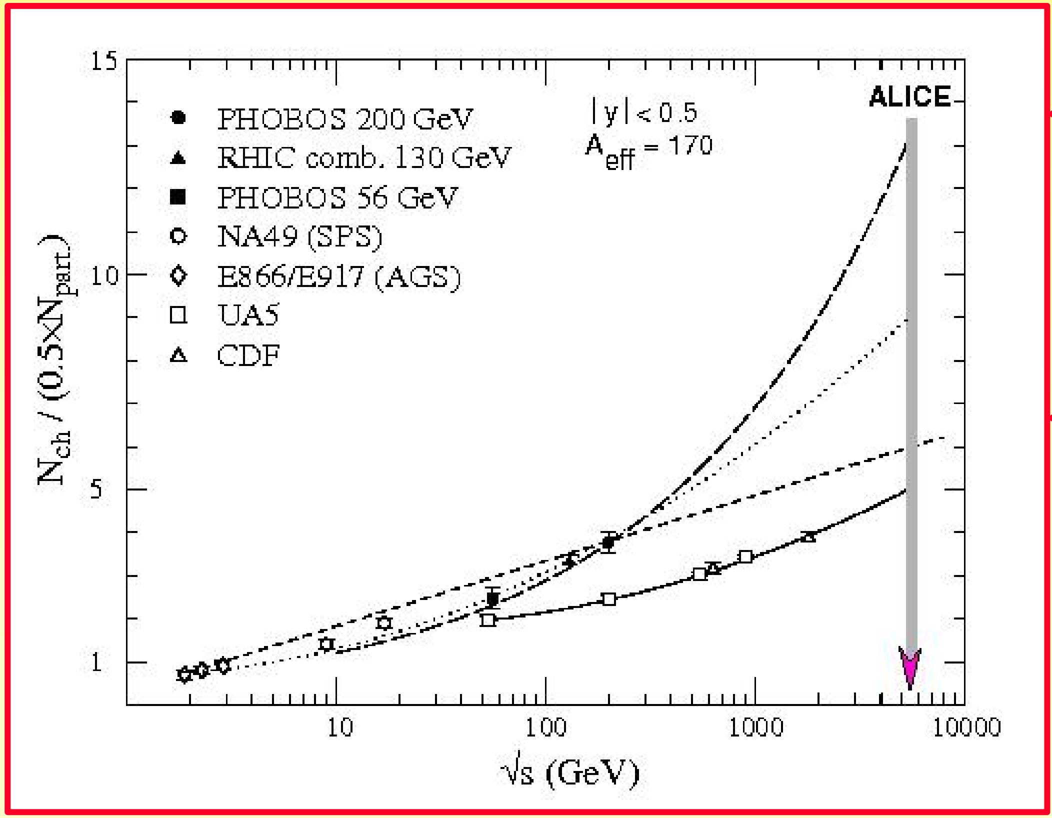
- **fully commissioned detector & trigger**
  - alignment, calibration available from pp
- **first 10^5 events:** global event properties
  - multiplicity, rapidity density
  - elliptic flow
- **first 10^6 events:** source characteristics
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- **first 10^7 events:** high-p_t, heavy flavours
  - jet quenching, heavy-flavour energy loss
  - charmonium production
- yield bulk properties of created medium
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition

- **early ion scheme**
  - 1/20 of nominal luminosity
  - $\int L dt = 5 \cdot 10^{25}\ cm^{-2}\ s^{-1} \times 10^6\ s$
    0.05 nb^{-1} for PbPb at 5.5 TeV
    $N_{PbPb\ collisions} = 4 \cdot 10^8$ collisions
    400 Hz minimum-bias rate
    20 Hz central (5%)
  - muon triggers:
    ~ 100% efficiency, < 1kHz
  - centrality triggers:
    bandwidth limited
    $N_{PbPbminb} = 10^7$ events (10Hz)
    $N_{PbPbcentral} = 10^7$ events (10Hz)

LHC, Physics of 'The First 3 Minutes': Multiplicity

→ **First estimate of energy density**
Saturation, CGC ?

integrated multiplicity distributions from Au-Au/Pb-Pb collisions and scaled pp collisions



$dN_{ch}/dy = 2600$

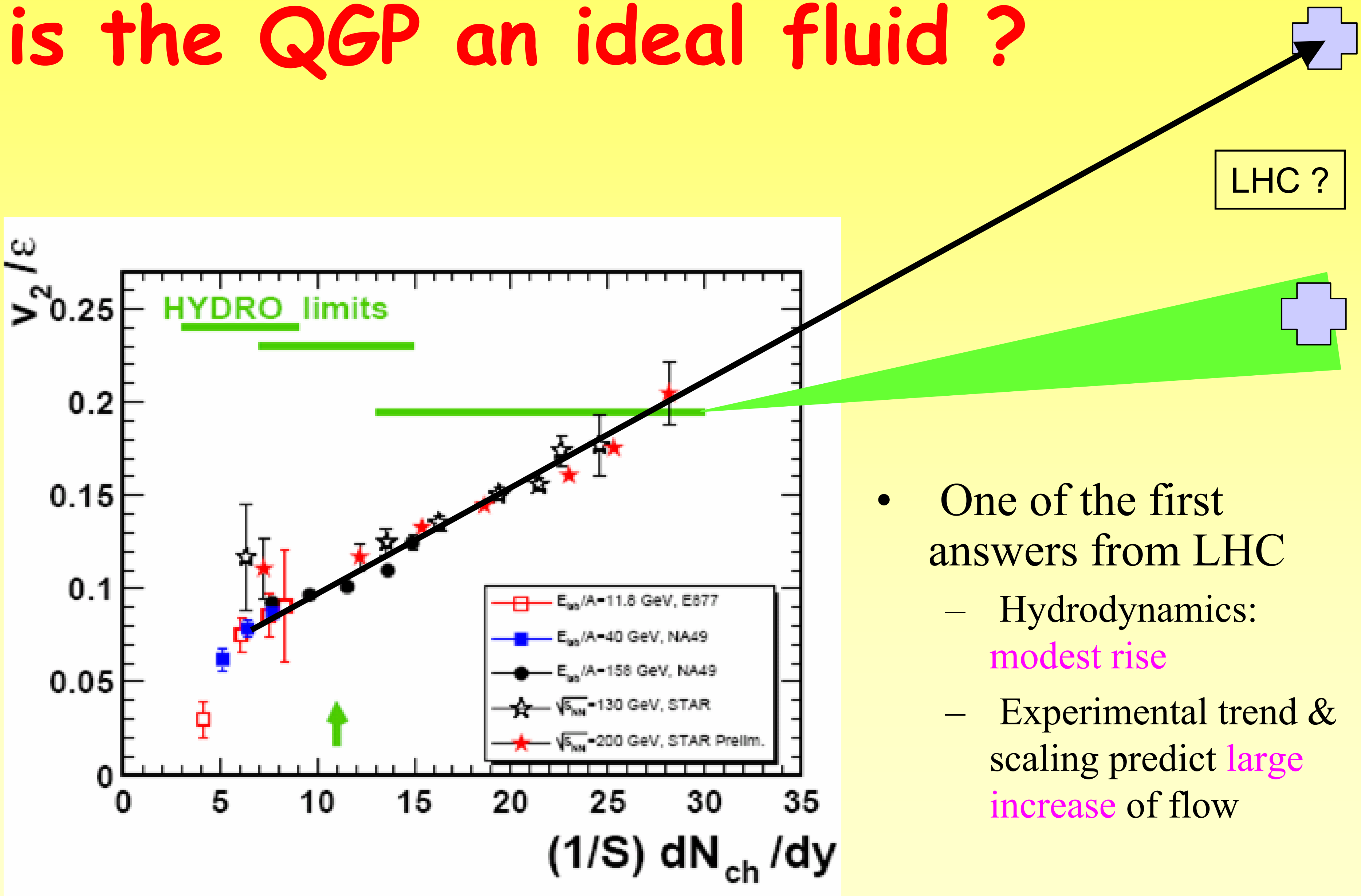
saturation model
Eskola hep-ph/050649

$dN_{ch}/dy = 1200$

ln(√s) extrapolation

Before RHIC, predictions for the LHC were considerably higher, ranging up to dN_{ch}/dy=8000

LHC, day 1 (10^5 events) : is the QGP an ideal fluid ?



- One of the first answers from LHC
  - Hydrodynamics: modest rise
  - Experimental trend & scaling predict large increase of flow

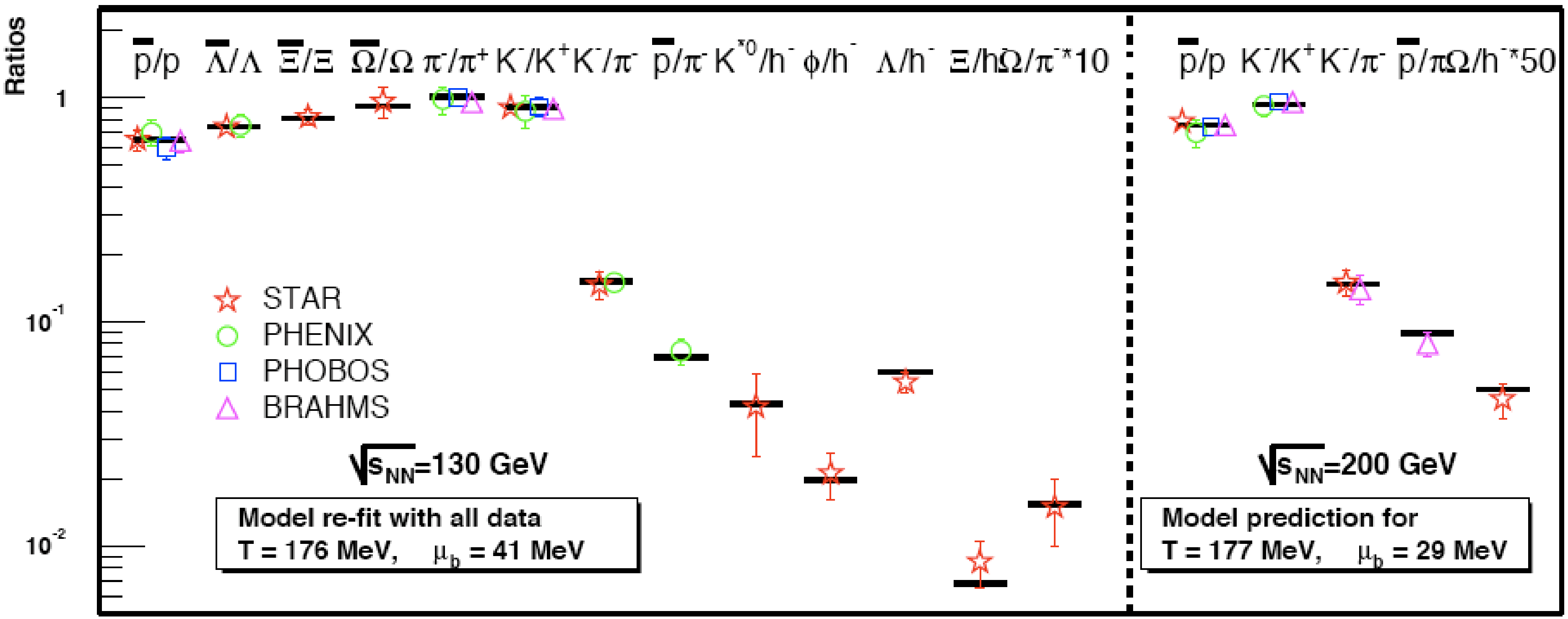
Chemical composition

Particle composition can be described in terms of a statistical model (grand canonical ensemble) with 2 free parameters (thermalization temperature and bariochemical potential). Consistent with a thermalization of the system with **T ~ 170 MeV , μ_B ~ 30 MeV**

Limiting temperature reached for large sqrt(s).

First data at LHC will check if the hypothesis survives at *20 the RHIC cm energy

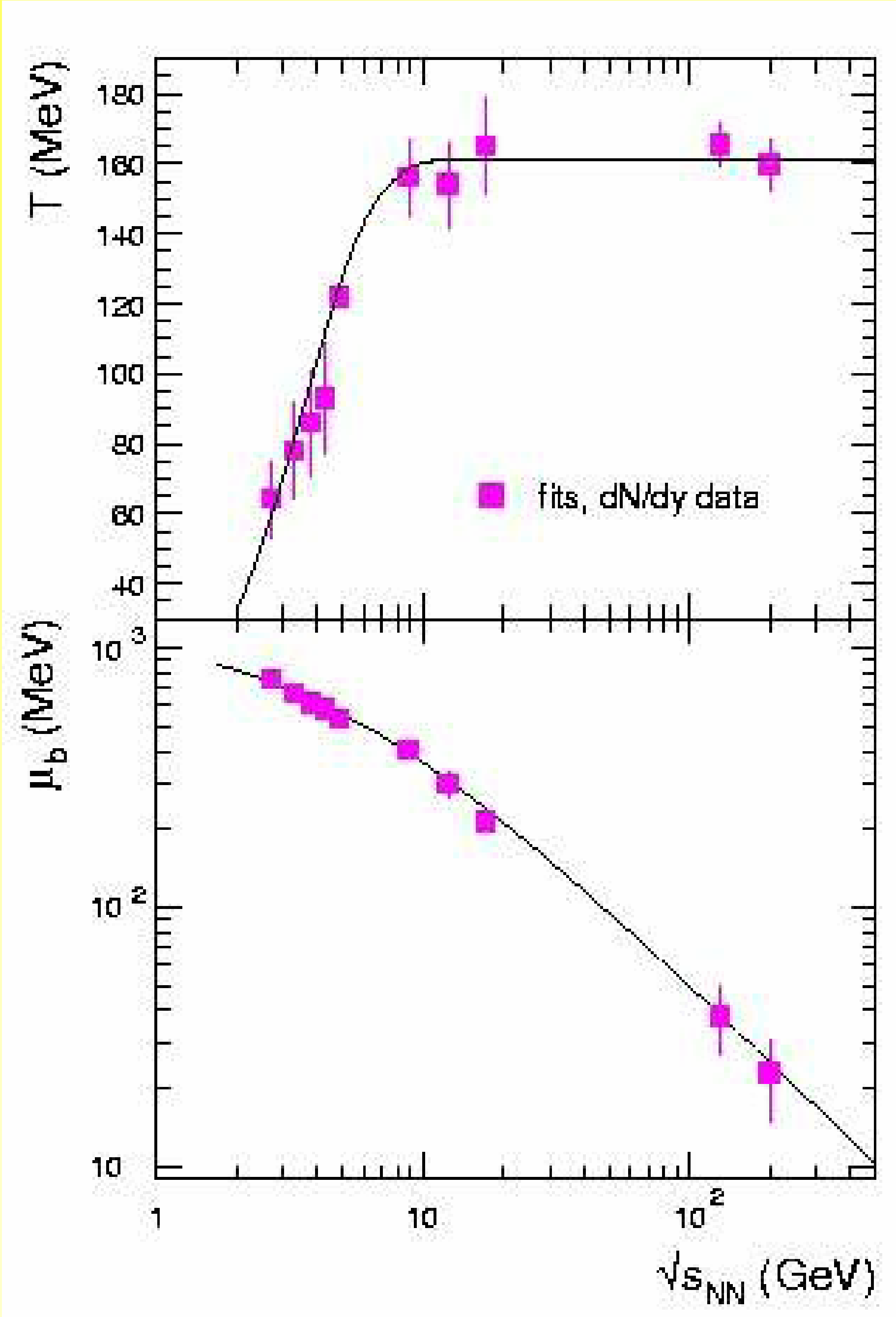
$\chi_r^2 = 0.8$ $\chi_r^2 = 1.1$



Braun-Munzinger et al., PLB 518 (2001) 41 D. Magestro (updated July 22, 2002)

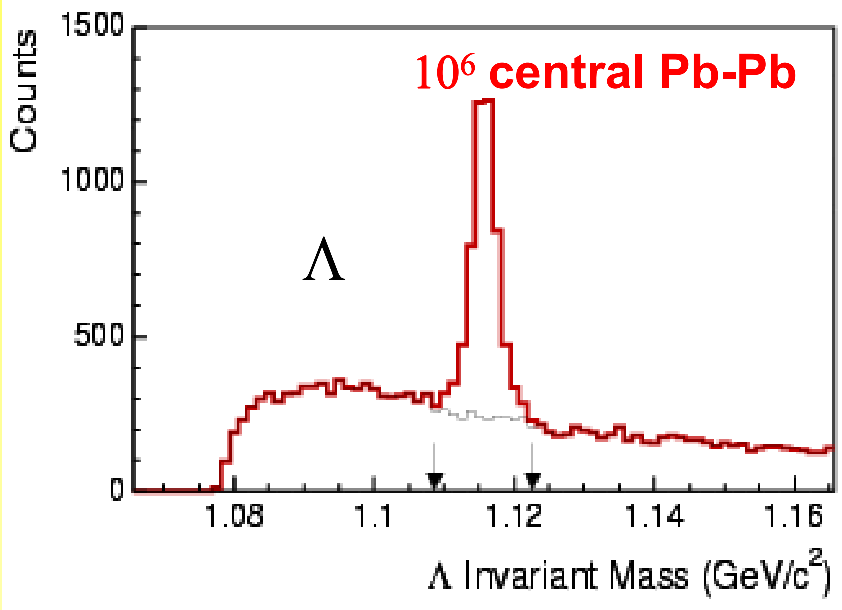
Parametrization of all freeze-out points

- If the fit parameters are plotted vs. Sqrt(s), a limiting T emerges at about 160 MeV
- **First data at LHC** will check if the hypothesis survives at *20 cm energy => **"DAY 1 PHYSICS"**



ALICE Pilot run Physics: ρ, φ, K* , K^0_s, Λ, Ξ, Ω...

Measure:
- strangeness production
- medium modification of mass and widths



10^7 events:

p_t reach φ,K,Λ

~ 13-15 GeV

p_t reach Ξ,Ω

~ 9-12 GeV

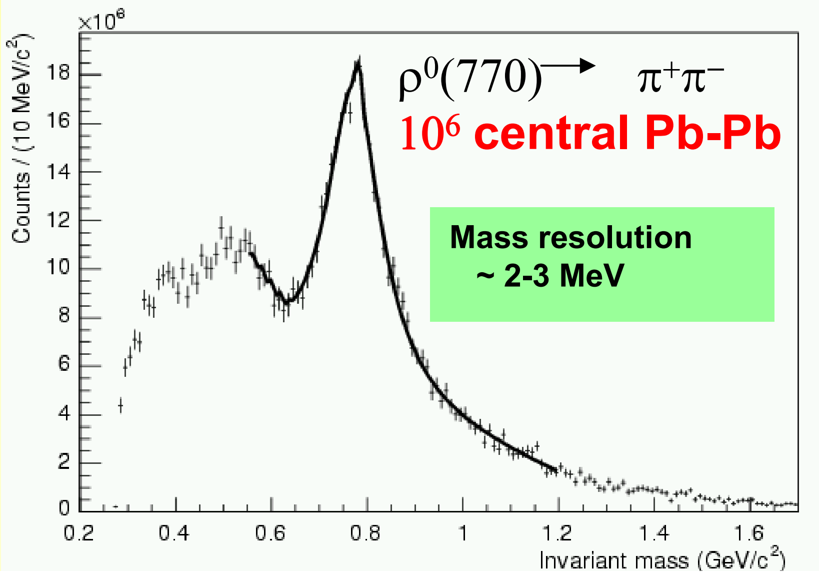
Reconstruction rates:

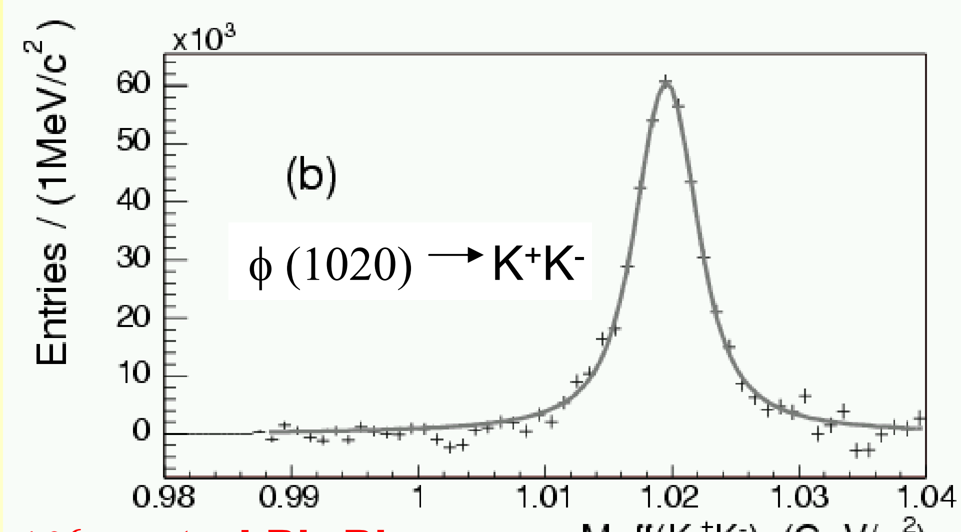
Λ: 13/event

Ξ: 0.1/event

Ω: 0.01/event

p_T: 1 to 3-6 GeV





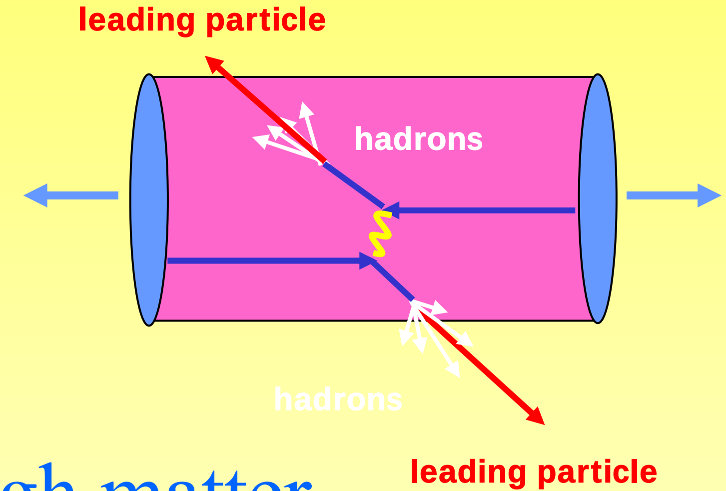
10^6 central Pb-Pb

Hard Scattering as a Probe

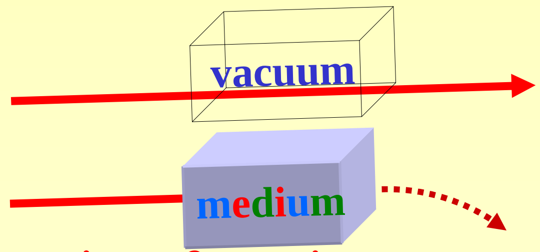
New for heavy ion physics → ***Hard Parton Scattering***

~ impossible at SpS, interesting at RHIC, perfect at LHC

- Jets
  - → high p_t leading particles
  - → azimuthal correlations
  - → jets in calorimeters



- Scattered partons propagate through matter radiate energy (~ few GeV/fm) in colored medium
  - suppression of high p_t particles called "parton energy loss" or "jet quenching"
  - alter di-jets, azimuthal correlations, jet fragmentation function



LHC vs RHIC hard probes

From RHIC to LHC

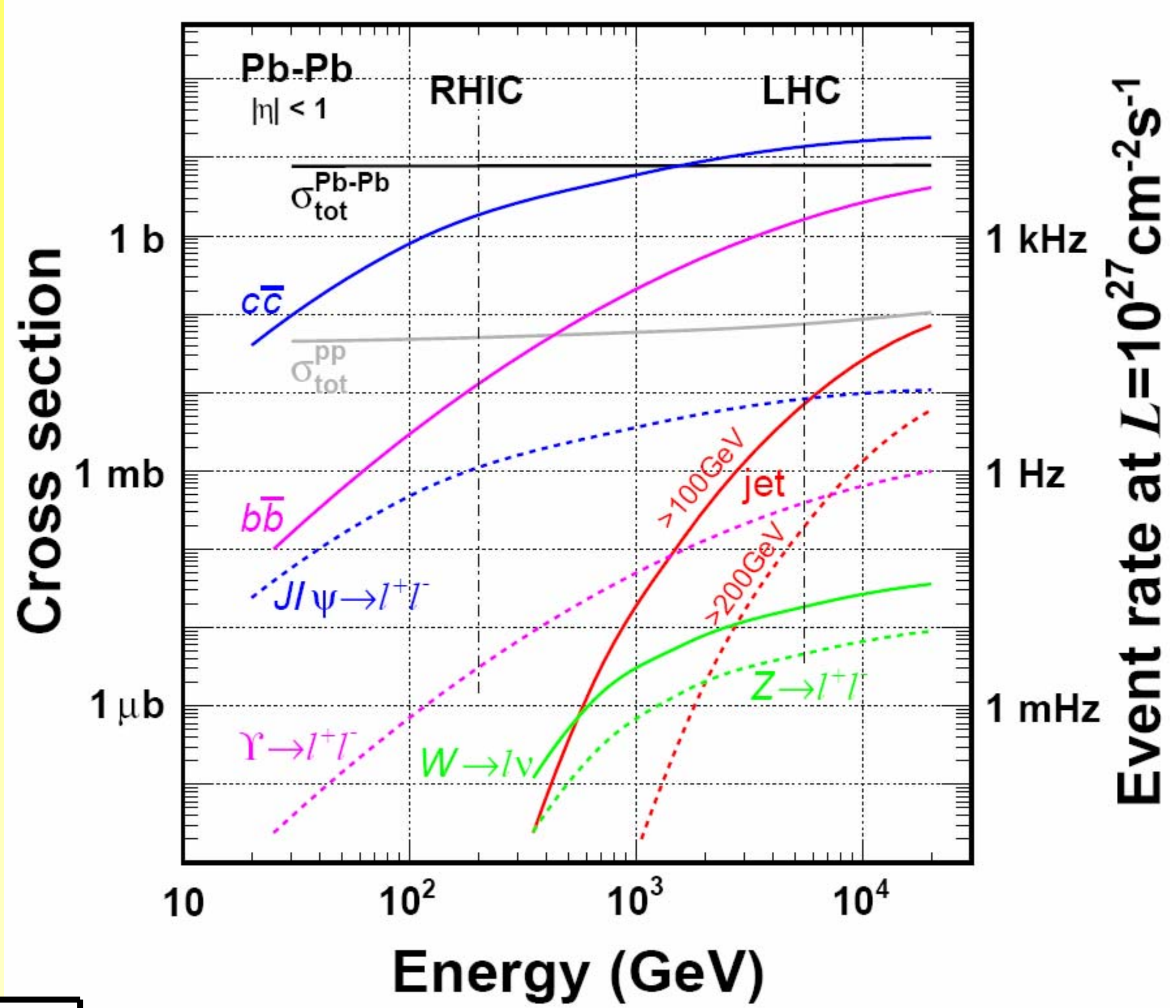
- Cross section for heavy flavours and jets grows by:

$\sigma_{c\bar{c}} \rightarrow \sim 10$

$\sigma_{b\bar{b}} \rightarrow \sim 100$

$\sigma_{jet>100GeV} \rightarrow \sim \infty$

$\sigma_{RHIC}(\Upsilon \rightarrow \ell\ell) \sim \sigma_{LHC}\,(Z \rightarrow \ell\ell)$



N($q\bar{q}$) per central PbPb collision

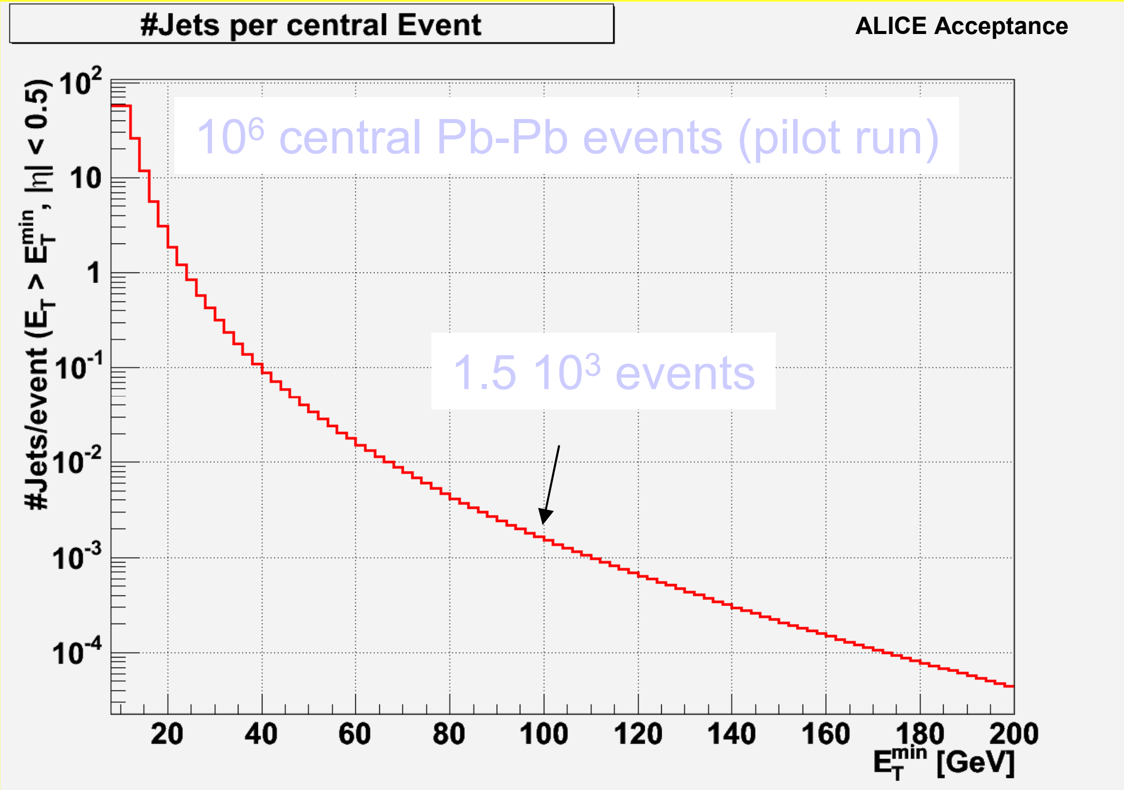
	SPS	RHIC	LHC
charm	0.2	10	200
bottom	-	0.05	6

LHC is a Hard Probes Machine!

LHC: the realm of Jets
Jet statistics in pilot Pb run

Jets are produced copiously…

2	20	100	200	p_t (GeV)
100/event	1/event	10^3 in first 10^6 Pb-Pb events		



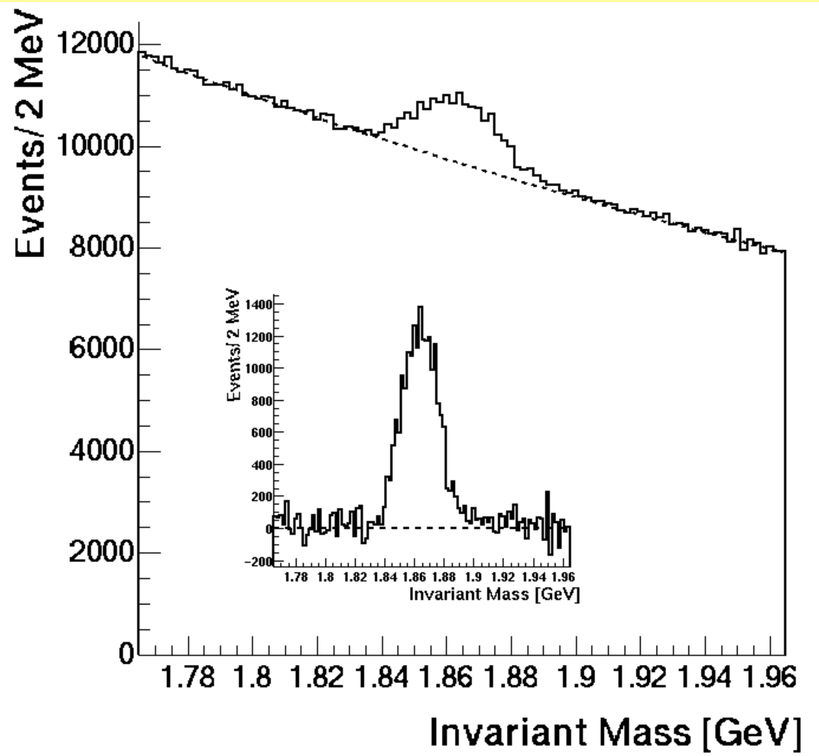
10^6 central PbPb collisions

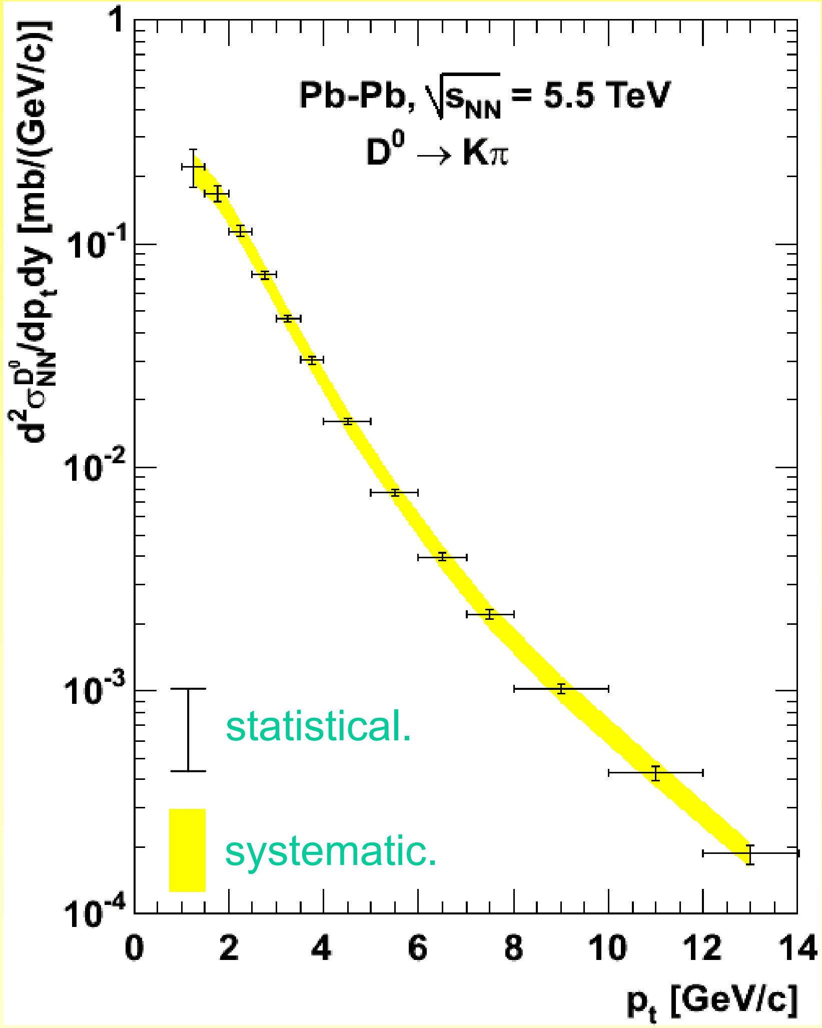
E_T threshold	N_{jets}
50 GeV	5×10^4
100 GeV	1.5×10^3
150 GeV	300
200 GeV	50

First full run Physics: $D^0 \to K^-\pi^+$

A major ALICE asset: measure Υ, B, J/ψ and D in the same experiment: natural normalization, Bkgd subtraction, in central region identify J/ψ from B decays

- Golden channel for open charm
- S/B ≈ 10%
- Significance for 1 month Pb-Pb run (10^7 events) : $S/\sqrt{(S+B)} \approx 40$

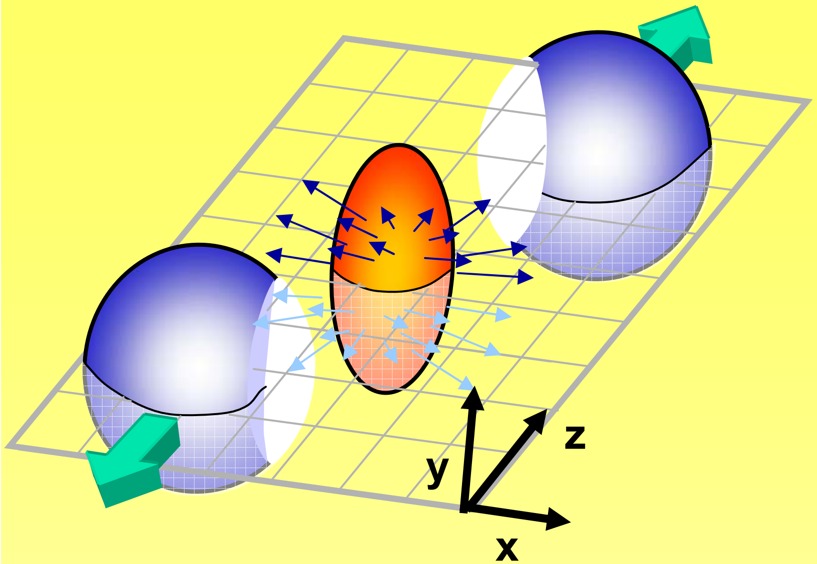




The Future

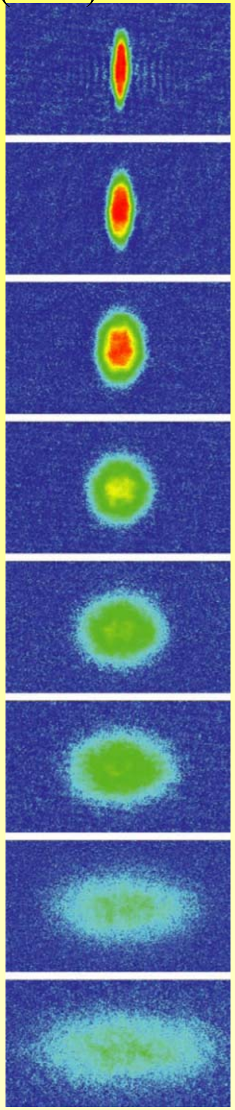
- After years of very successful collaboration between Italian and Russian & JINR Nuclear Physicists in ALICE, a very exciting future opens ahead of us:
  - ALICE Physics
    - ALICE will take data in its present form for **at least** 5-6 years (pp running + 1 year pilot PbPb, 2 years high Lum PbPb, 1 year pPb, 1-2 years of a lower-A nucleus). An extremely rich scientific program, which will see collaboration in analysis and computing. As early as possible PHOS should be completed.
  - ALICE upgrades
    - An extensive upgrade program is being studied, to extend the vertexing capabilities, Particle Identification at larger momenta, the overall rate capability and forward tracking and calorimetry (to access very low-x and therefore the physics of gluon saturation)
  - Experimentation at high baryon densities (MPD@NICA)
    - A new, challenging detector and a rich scientific program, opportunities of collaboration to be explored!

spares



Elliptic flow

SCIENCE Vol: 298 2179 (2002) ^{7}Li



Elliptic flow coefficient

$dn/d\phi \sim 1 + 2\, v_2(p_T) \cos(2\,\phi) + \ldots$

Where azimuth is measured w.r.t. the reaction plane

Flow: Correlation between coordinate and momentum space => azimuthal asymmetry of interaction region trasported to the final state

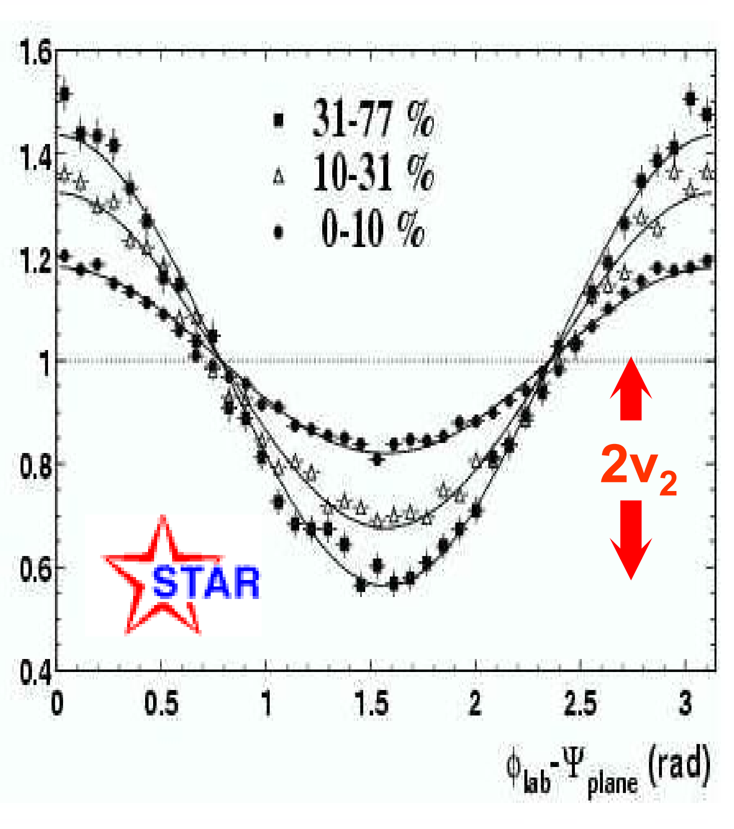
close particles move at similar velocity and direction

flow builds up in an interacting medium with pressure gradient

for given boundary conditions, flow profile depends on Equation of State EoS and viscosity η of 'fluid'

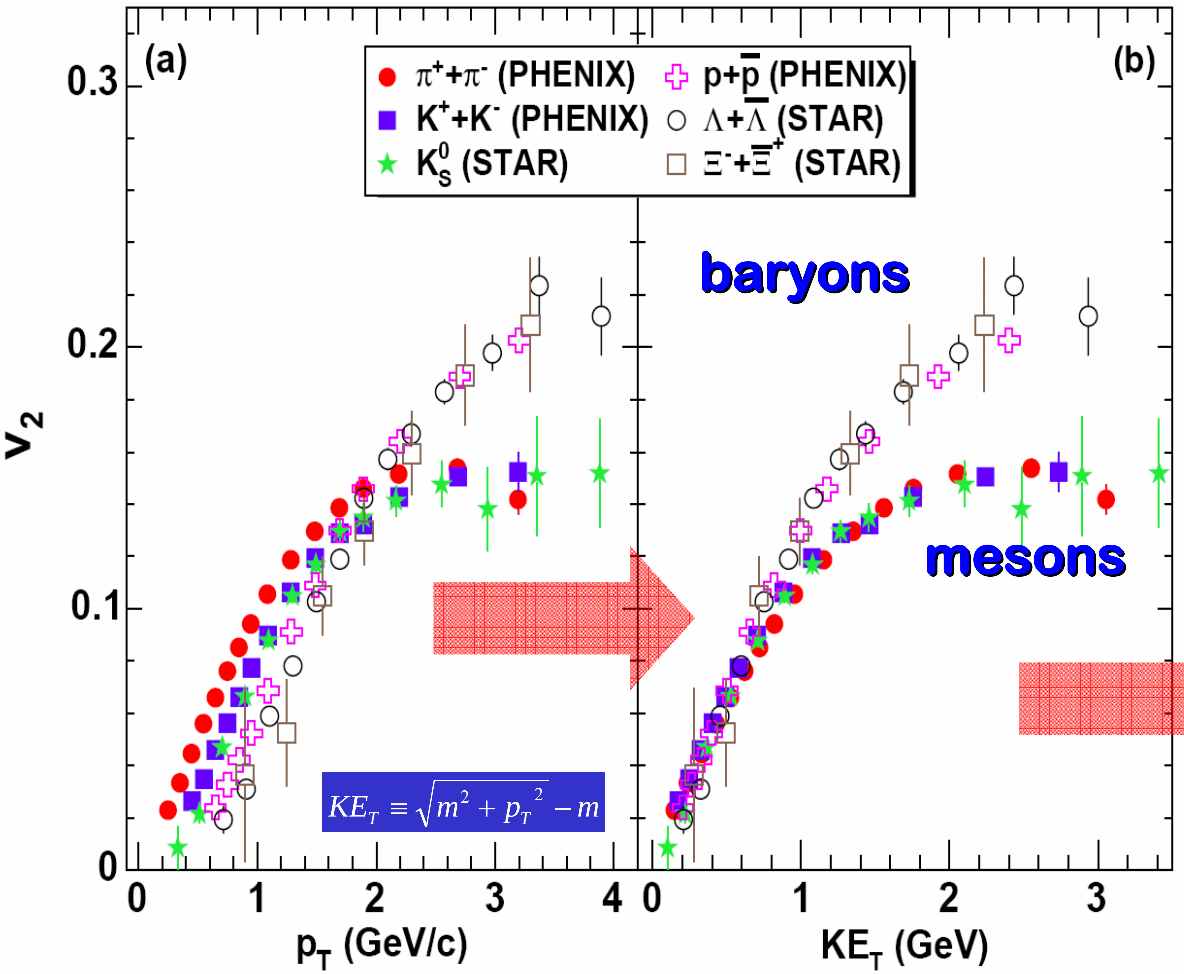
Hydrodynamics of perfect liquid: $\eta = 0, \lambda = 0$ ('strongly interacting')

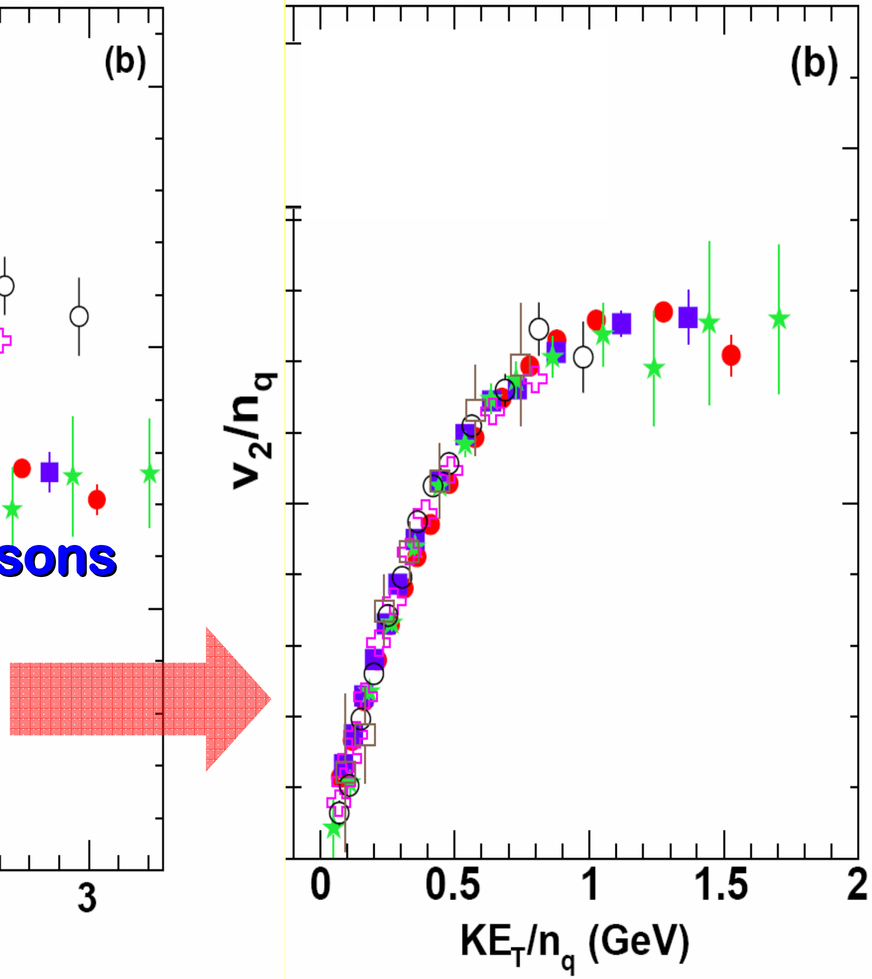
Flow acts at early times



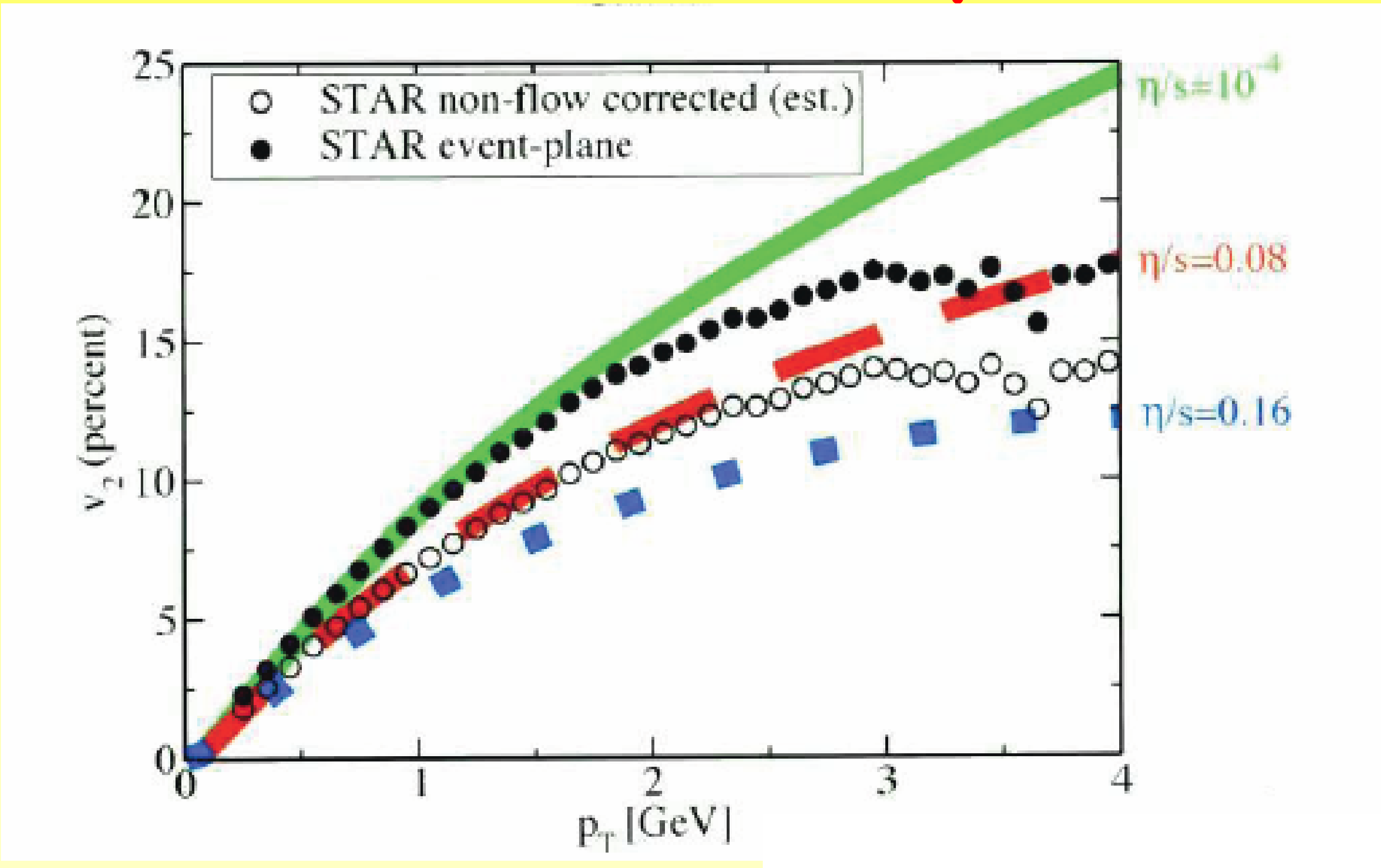
Ultra-cold ^{7}Li 10^{-12} eV , 2 ms of expansion

Flow "knows" quarks…



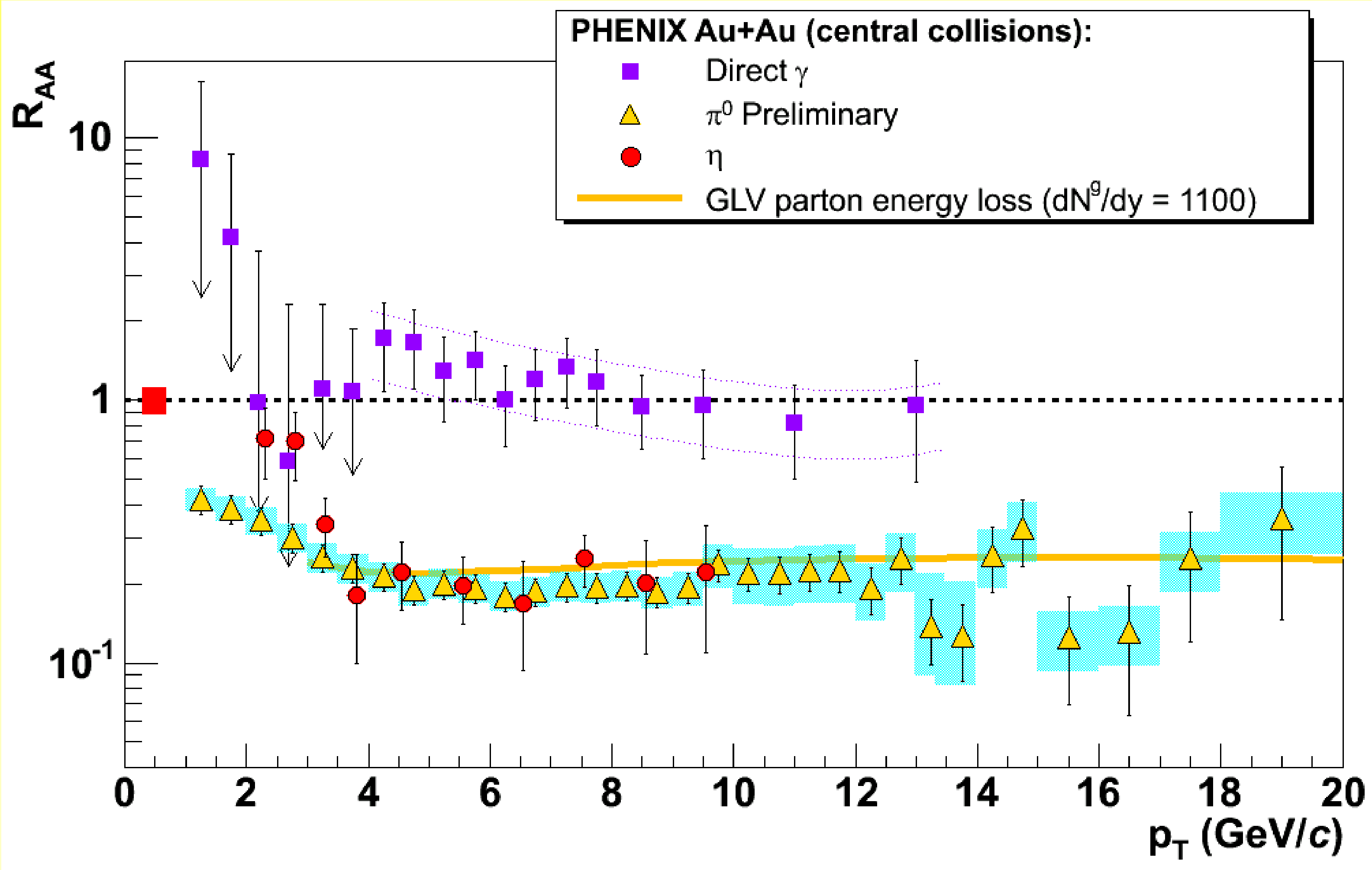


The fluid is strongly interacting => small viscosity



- Although the errors are large (especially from assumptions on initial spatial distribution: Glauber vs. CGC) the data rule out values of η/s much larger than 1/4π, the conjectured limit from AdS/CFT
- Also measured from fluctuations, heavy quark motion,...
- ***Most perfect liquid ever observed?***

One result among many: Photons shine, Pions (and η) don't



- Pions are strongly absorbed in the Hot/dense medium, while direct photons are *not*