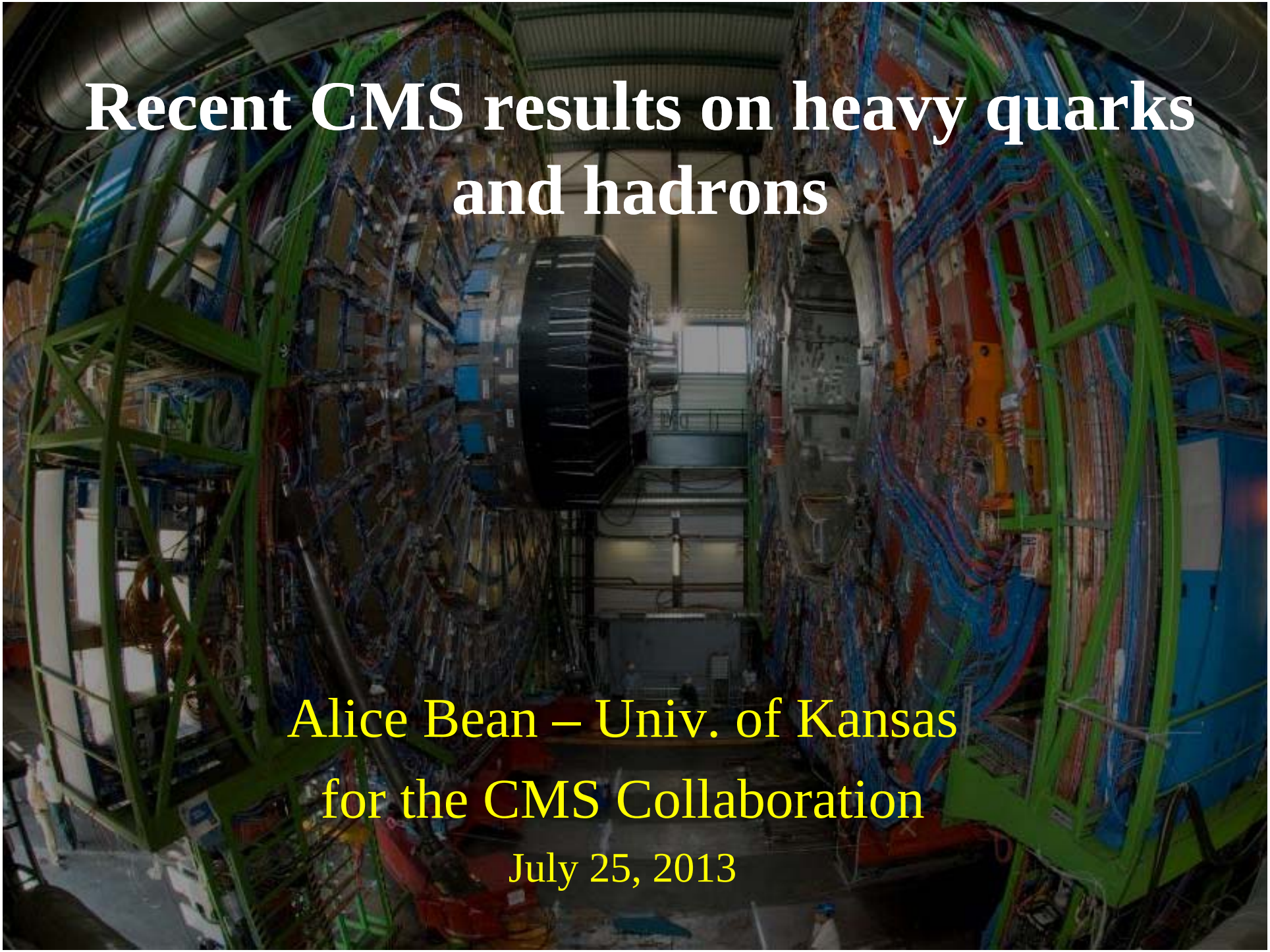


Recent CMS results on heavy quarks and hadrons

Alice Bean – Univ. of Kansas

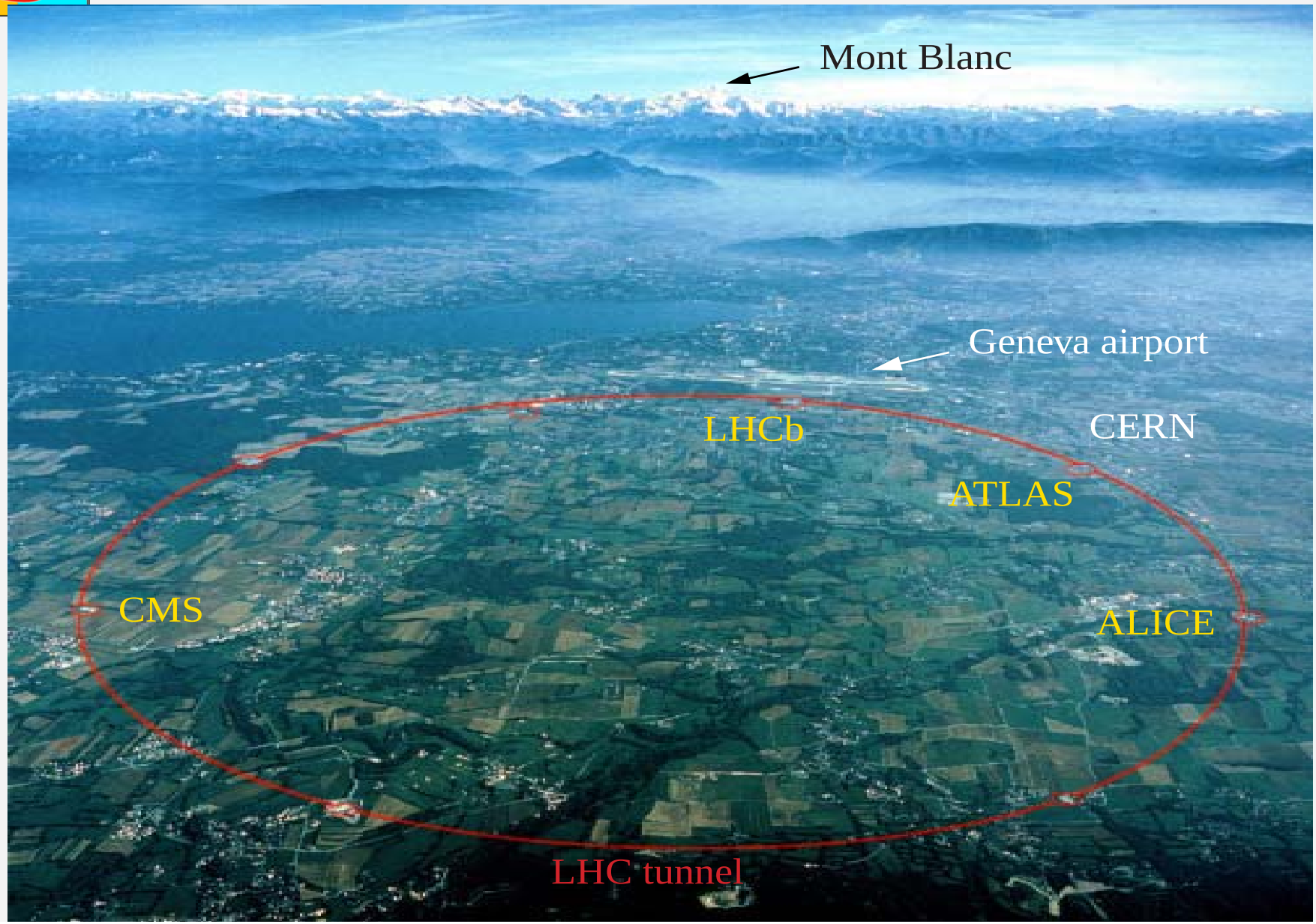
for the CMS Collaboration

July 25, 2013

Outline

- CMS at the Large Hadron Collider
- Cross section measurements
- Search for state decaying to $\Upsilon(1S)\pi^+\pi^-$
- $\Upsilon(nS)$, J/Ψ and $\Psi(2S)$ Polarization measurements
- A measurement of the Λ_b lifetime
- $B_S \rightarrow \mu^+\mu^-$, $B^0 \rightarrow \mu^+\mu^-$

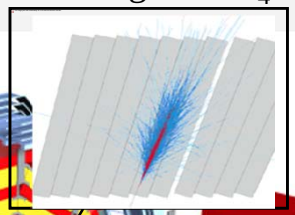
The Large Hadron Collider



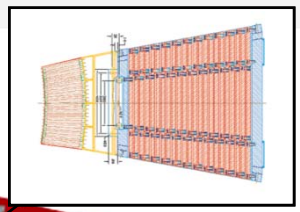
Compact Muon Solenoid

CALORIMETERS

ECAL Scintillating $PbWO_4$ Crystals



HCAL Plastic scintillator copper sandwich

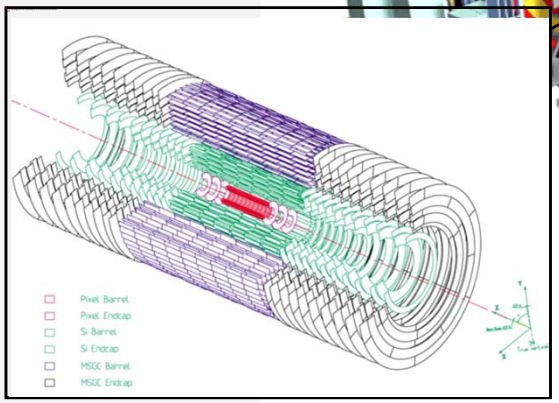


SUPERCONDUCTING COIL

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

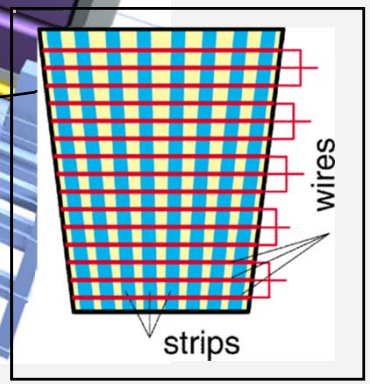
IRON YOKE

TRACKERs



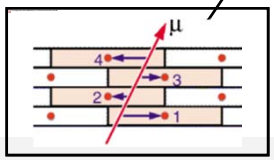
Silicon Microstrips
Pixels

MUON ENDCAPS

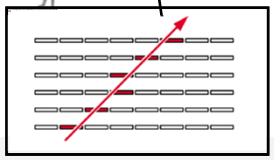


Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

MUON BARREL



Drift Tube Chambers (**DT**)



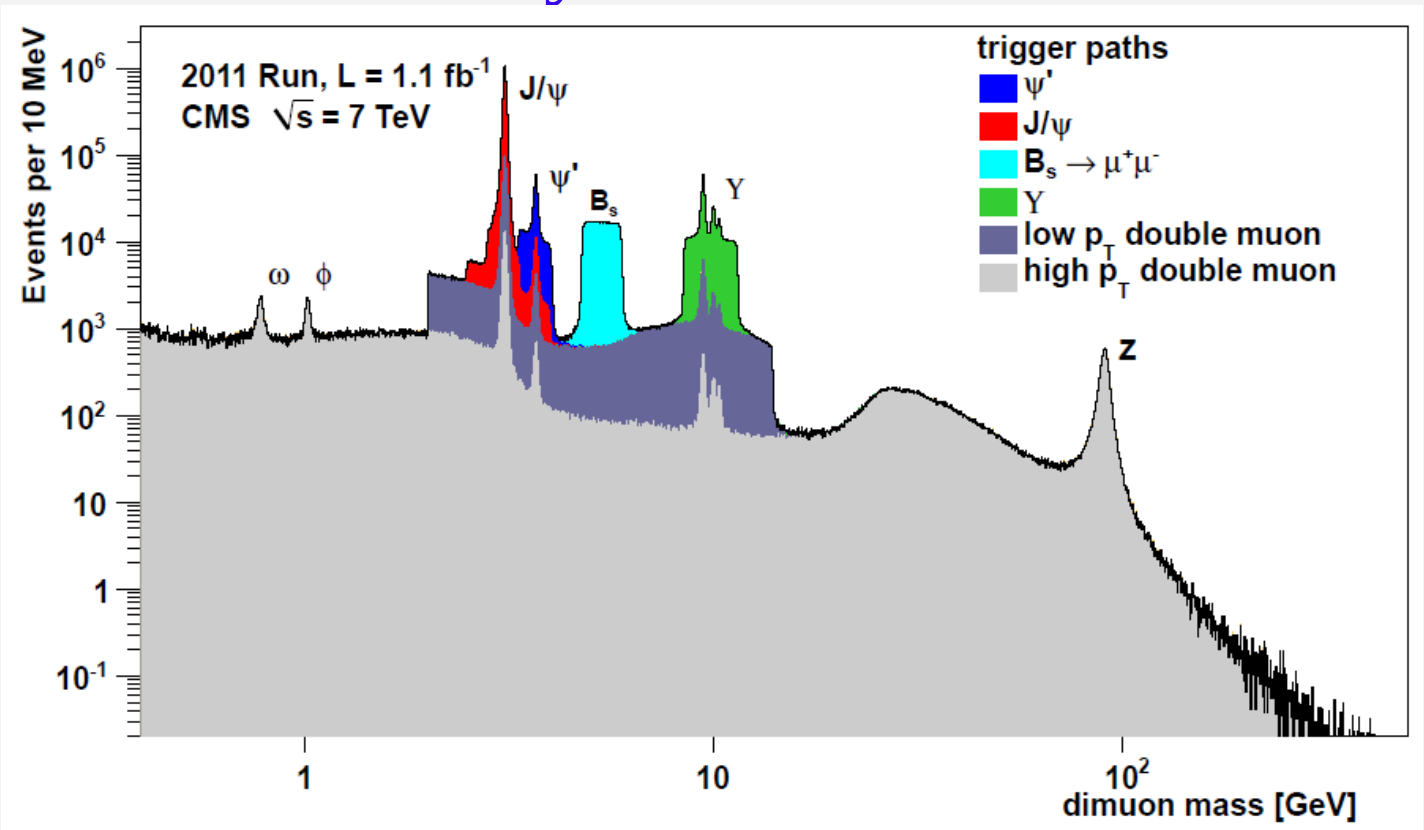
Resistive Plate Chambers (**RPC**)

Muons are important

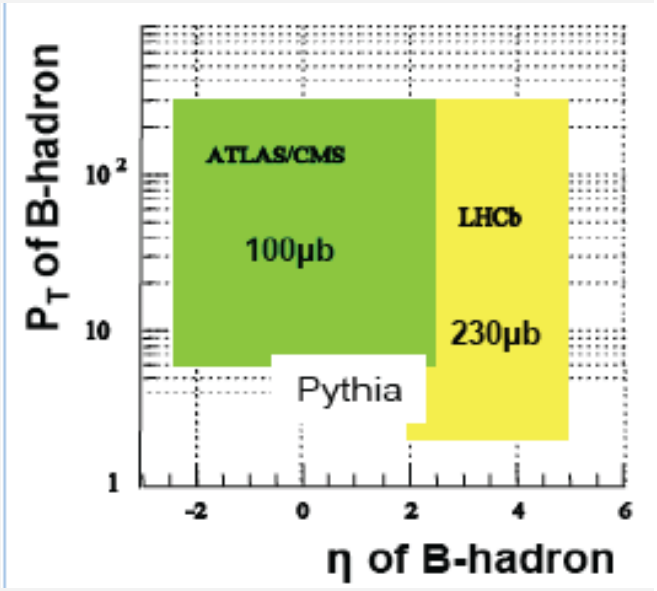
To study channels with b-quarks in them, CMS

* triggers on muons

* measures decay channels with muons well



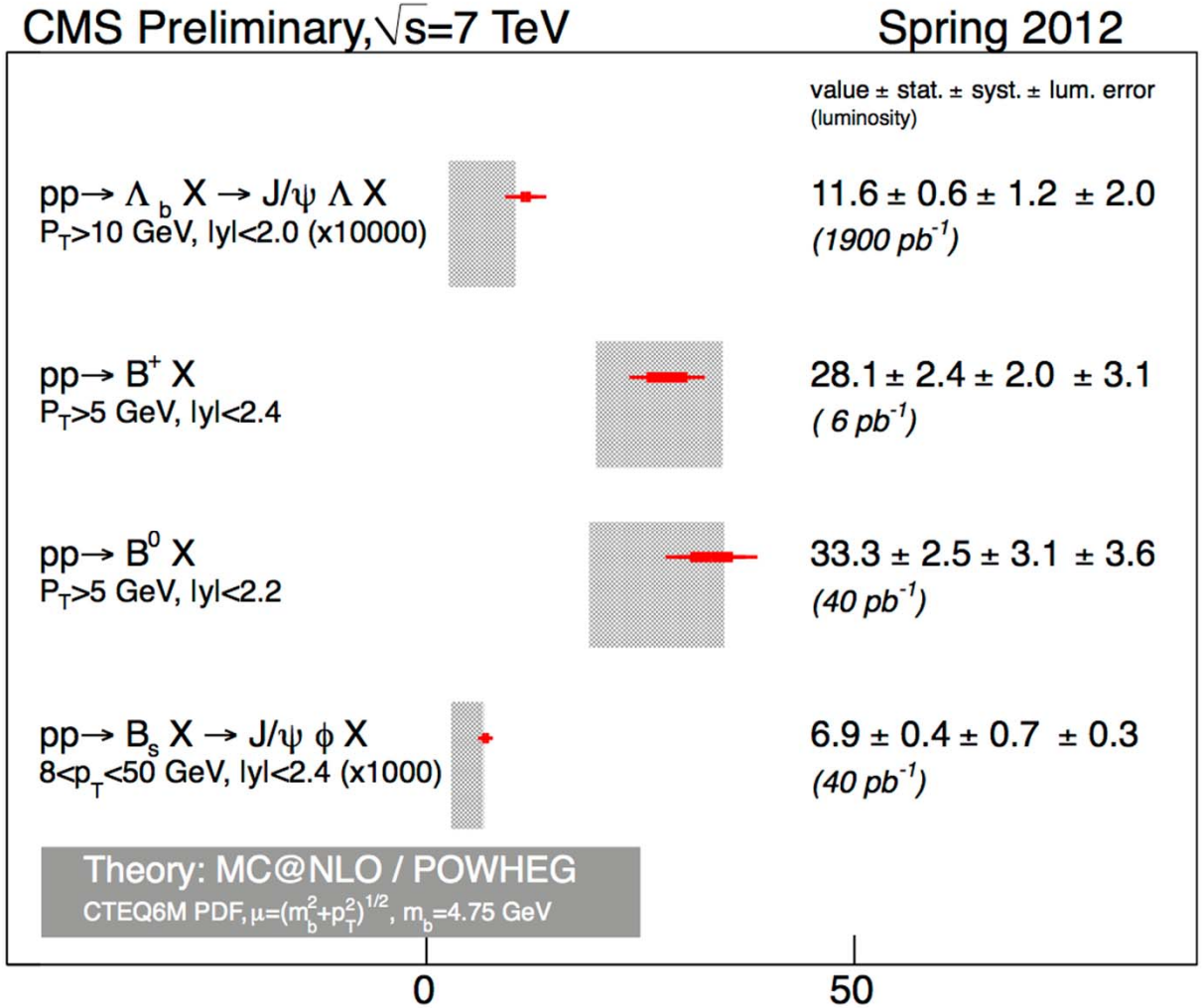
CMS proton-proton Data



- Good tracking implies $|\eta|<2.4$
- 2010, collisions at 7 TeV
  - Single muon triggers $p_T>5$ GeV/c
  - Lots of b-physics available
- 2011, collisions at 7 TeV ~ $5fb^{-1}$
  - Use dimuon triggers with raised p_T thresholds
- 2012, collisions at 8 TeV ~$20fb^{-1}$
  - B-physics trigger bandwidth lowered (p_T threshold raised)

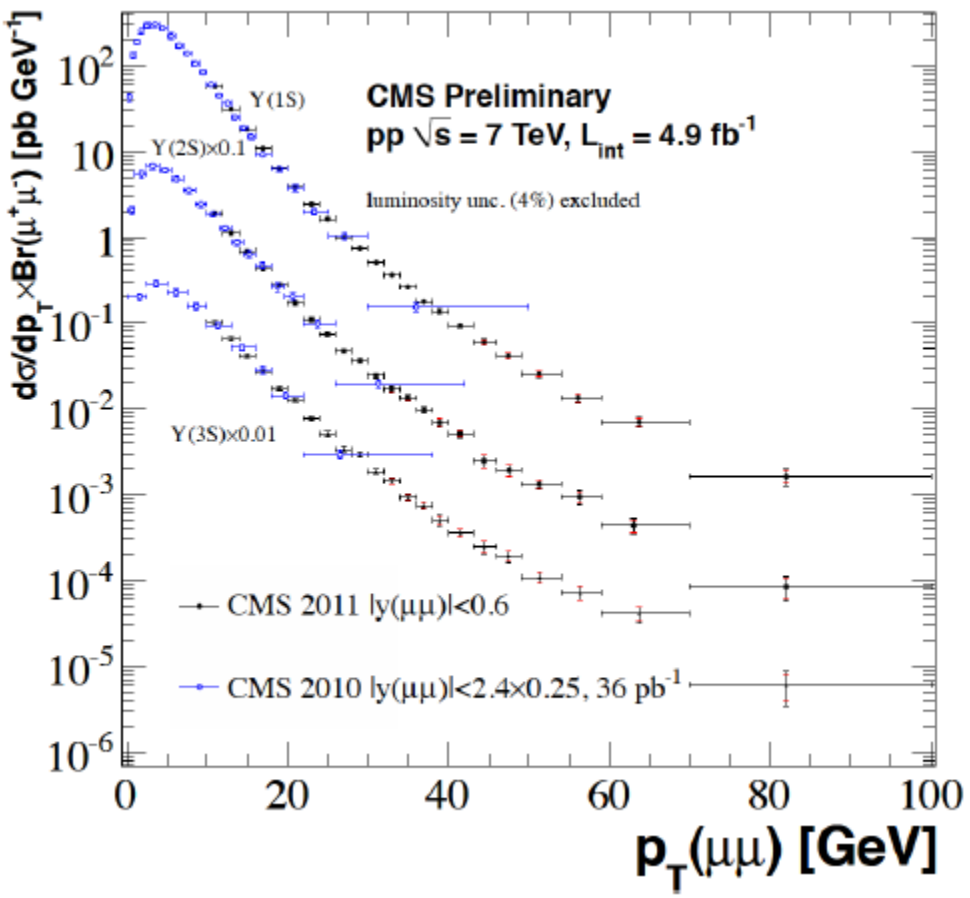
Cross Section Measurements

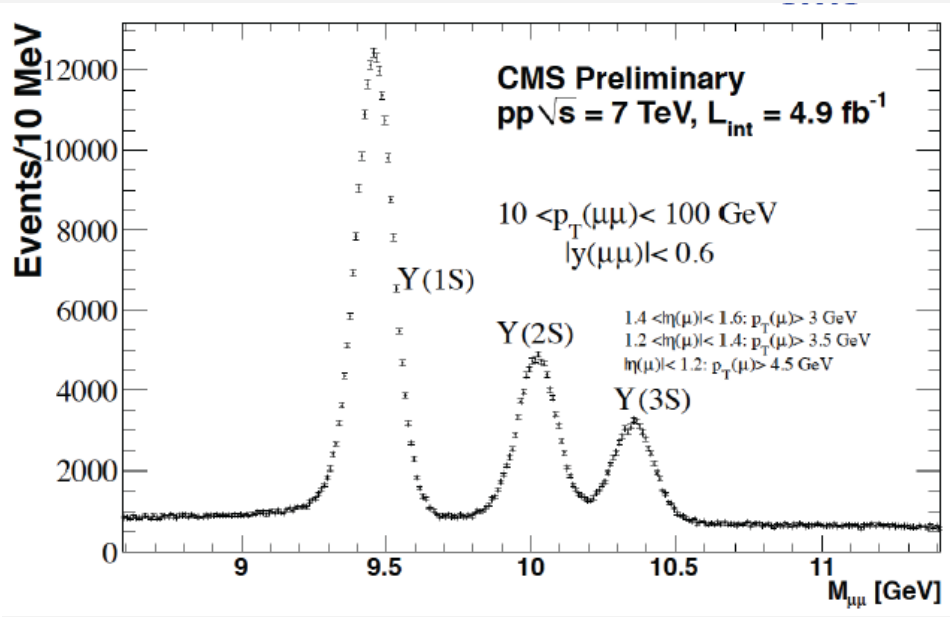
Early CMS measurements



Upsilon Cross Section

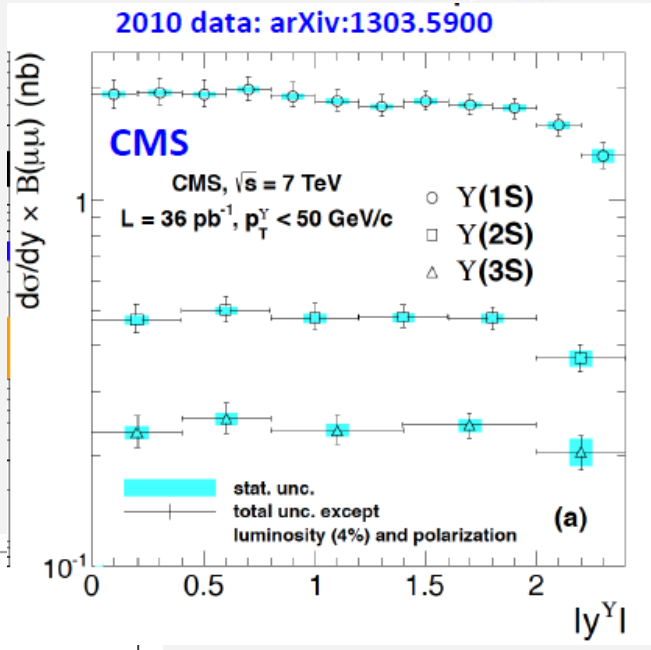
- Clean signals, lots of events
- Paper accepted by Phys. Lett. B

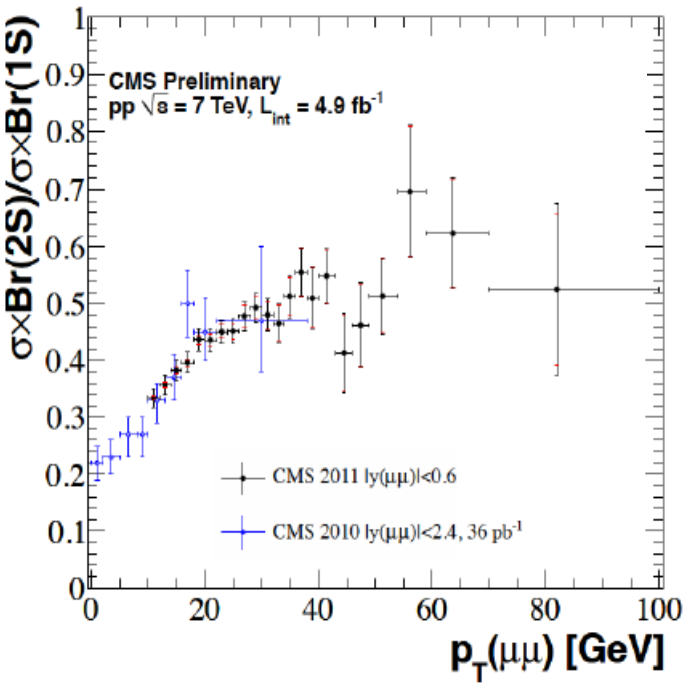


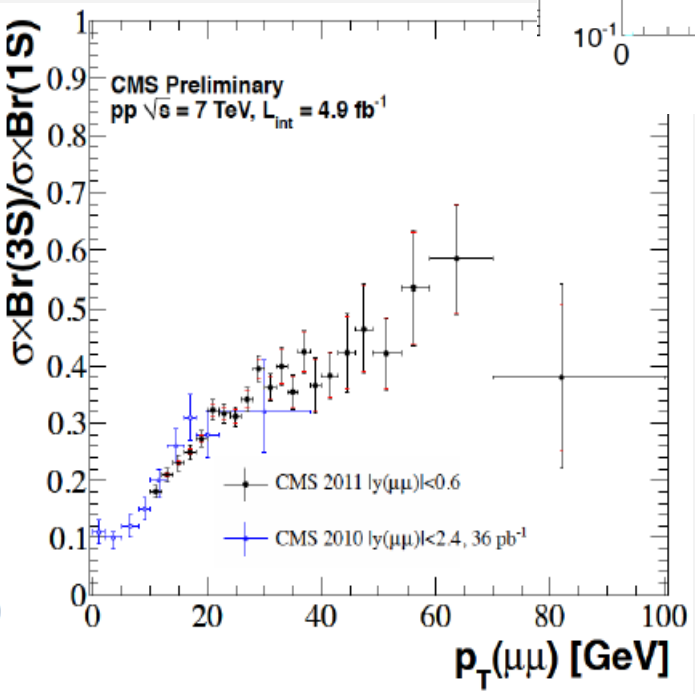


Ratios of Υ cross sections

- Υ(nS)/Υ(1S) ratios are flat in rapidity (out to 2)
- They increase with p_T and then flatten out

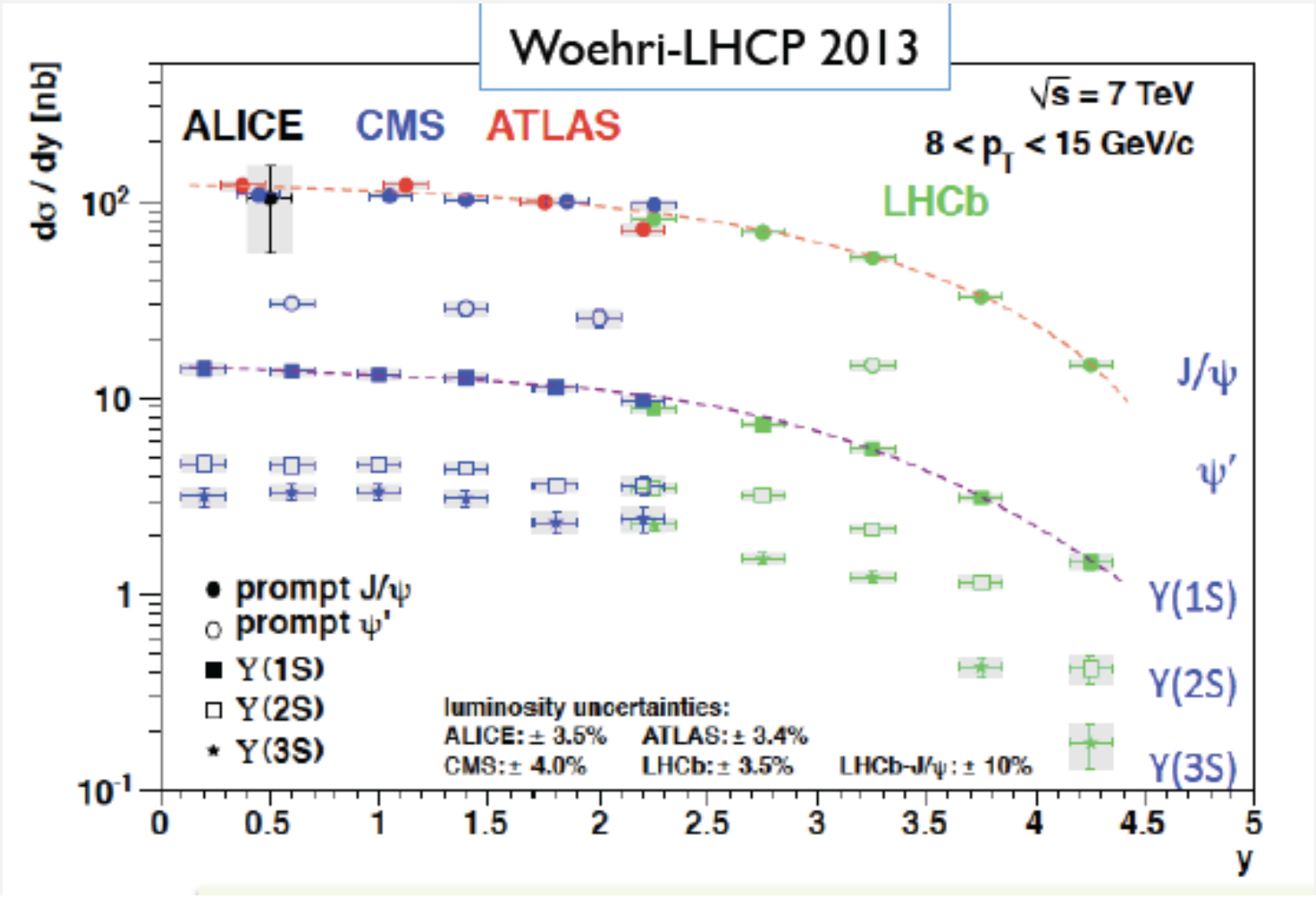






Cross section summary

- Consistent picture between experiments



X(3872) $\rightarrow J/\Psi\pi^+\pi^-$

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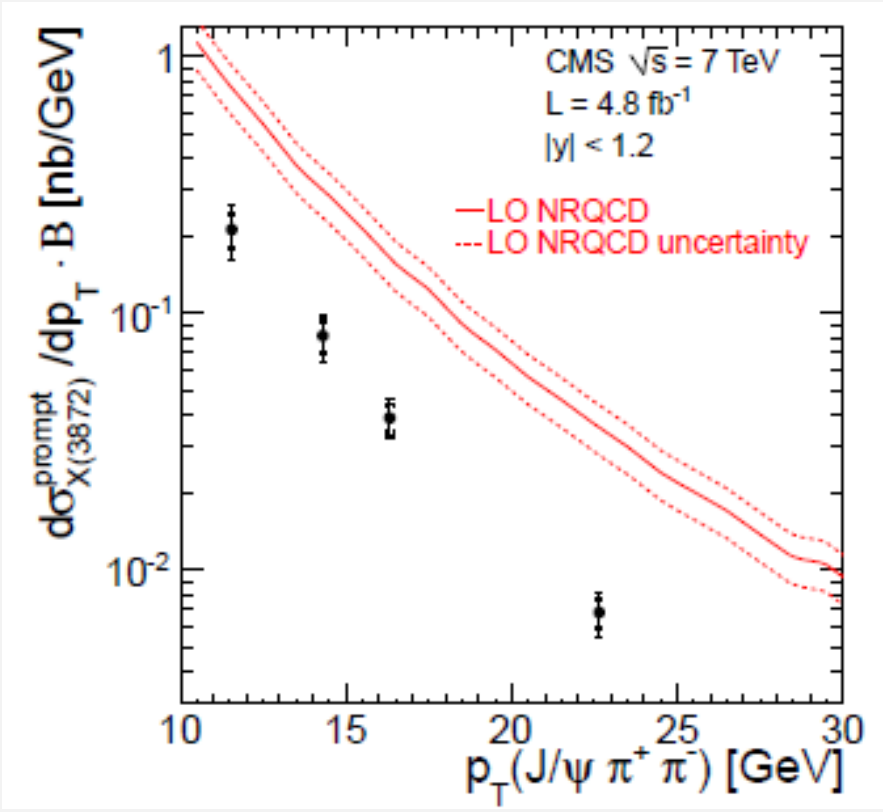
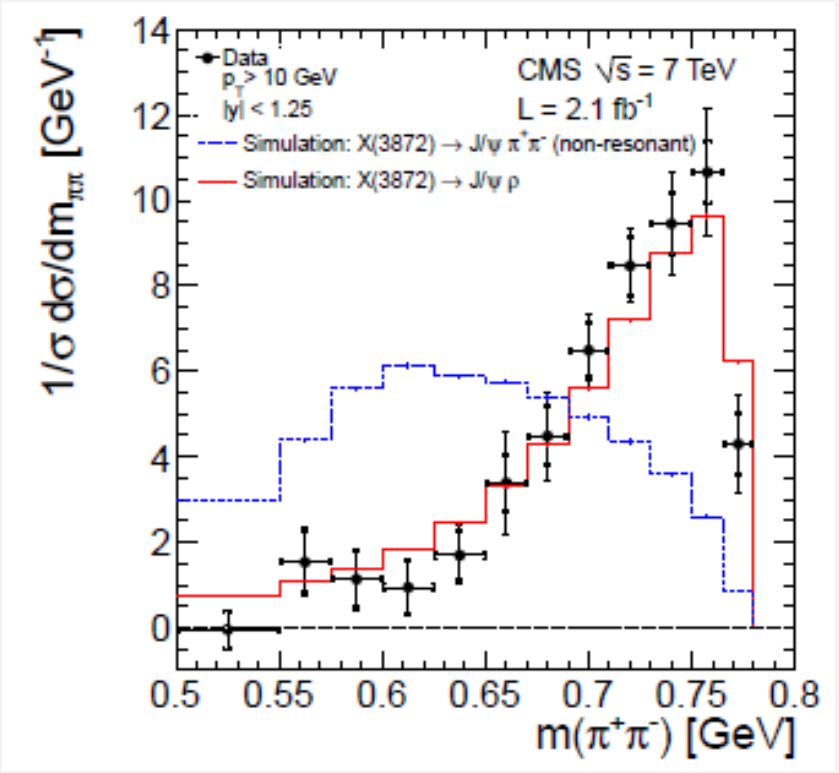
~12,000 candidates

Fraction of X(3872) from B-hadron decays 0.263±0.023±0.016

Cross sections assume no polarization, data are consistent with $\rho\rightarrow\pi\pi$



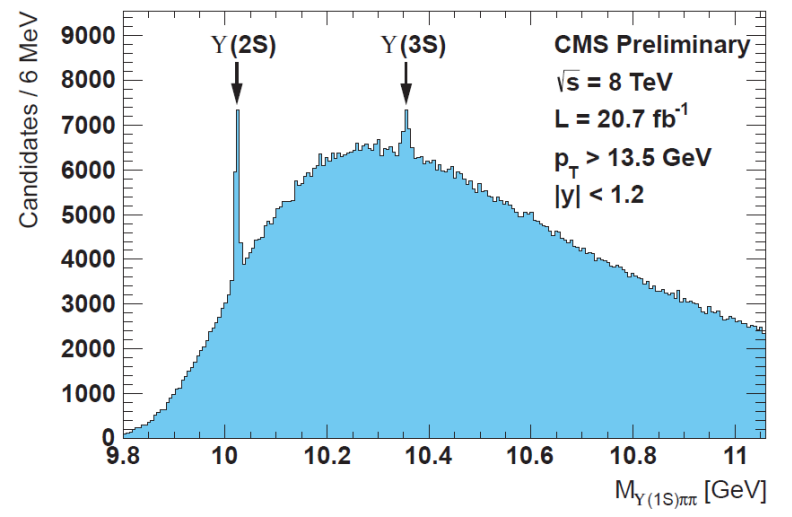


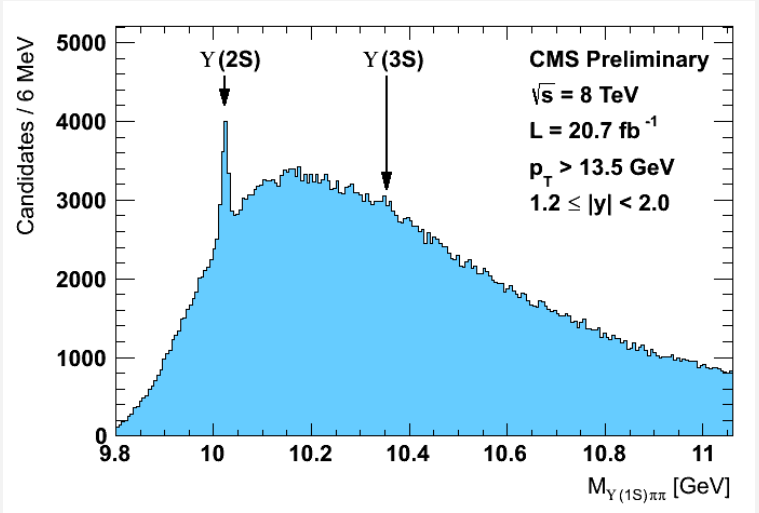
Search for decay to $\Upsilon(1S)\pi^+\pi^-$

$X_b \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \rightarrow \mu^+\mu^-$

- Similar to X(3872), but for bottomonium

Look for peaks in mass spectrum





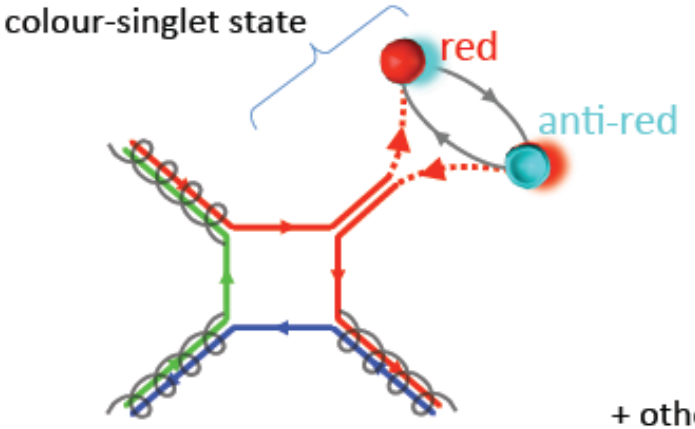
95% C.L. Upper limits set on the ratio

$\sigma(pp \rightarrow X_b \rightarrow \Upsilon(1S)\pi^+\pi^-)/\sigma(pp \times \Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-)$ from 0.008-0.046

Ψ and ϒ Polarization

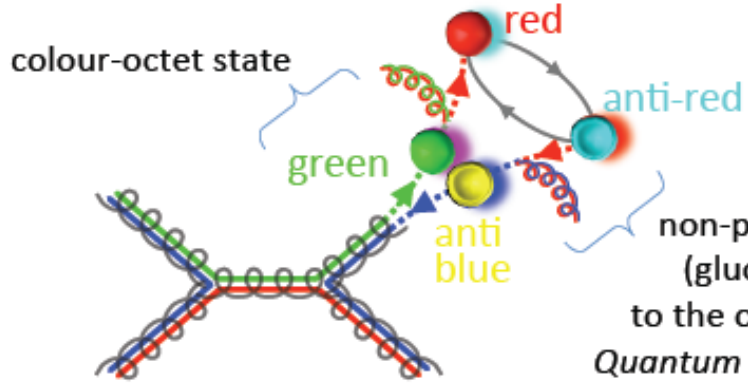
- NRQCD should describe. It is dominated by "color octet" production which predicts strong transverse polarizations

- **Colour Singlet Model**: quarkonia always produced directly as observable ***colour-neutral*** *Q-Q*bar pairs



+ other colour combinations

- **NRQCD factorization**: quarkonia also produced as ***coloured*** *Q-Q*bar pairs *of any possible quantum numbers*



non-pert. transition (gluon emission) to the observable state

Quantum numbers change !

Figures by Pietro Faccioli

- Two options leading to strong polarizations (longitudinal and transverse, resp.) for the directly-produced S-states → polarization measurements are fundamental

Angular distribution

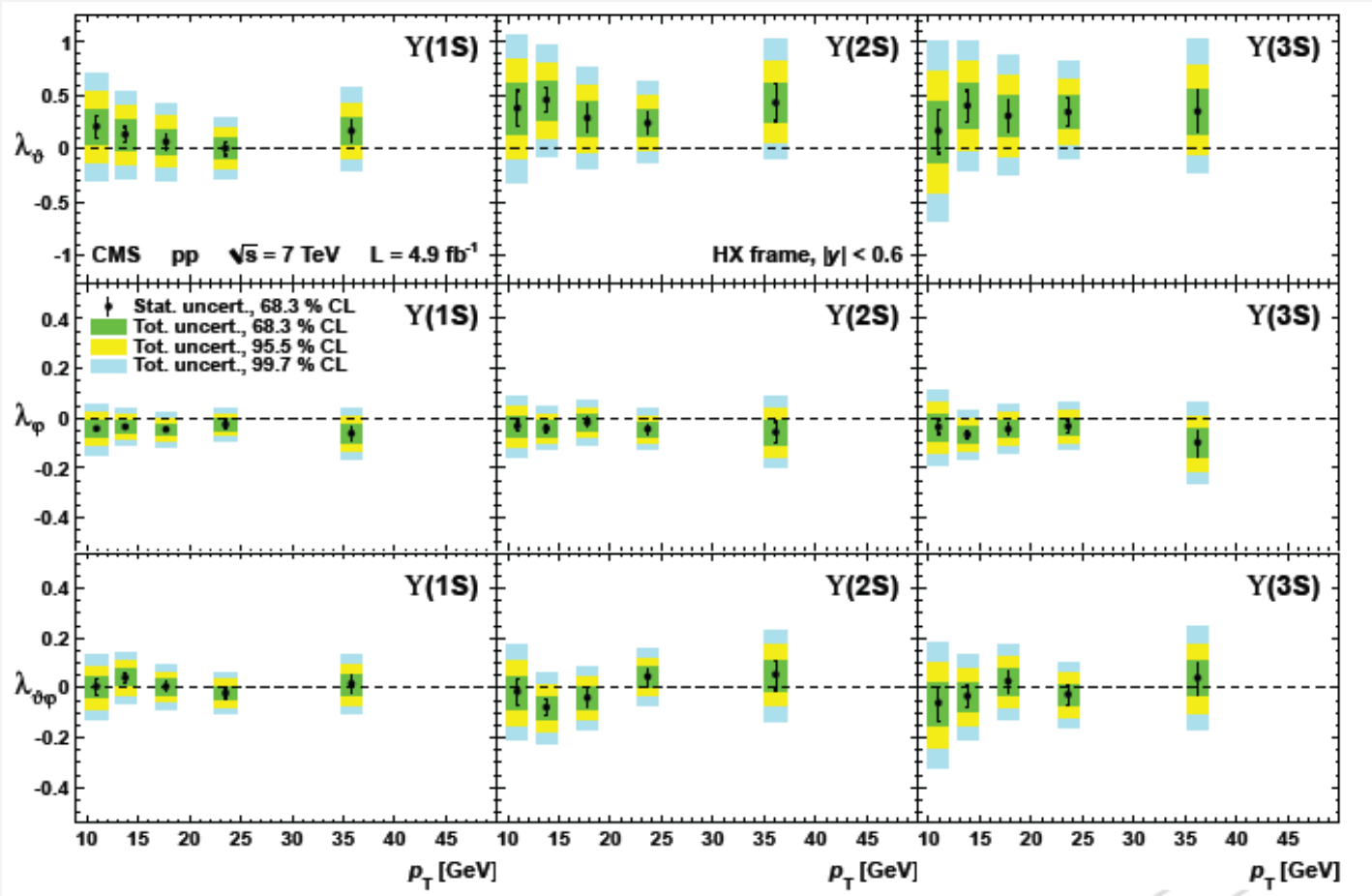
- Look at μ^+ direction with respect to z-axis from either Ψ or $\Upsilon \rightarrow \mu^+\mu^-$

$$W(\cos\vartheta, \varphi|\vec{\lambda}) \propto \frac{1}{(3+\lambda_\vartheta)}(1+\lambda_\vartheta\cos^2\vartheta + \lambda_\varphi\sin^2\vartheta\cos 2\varphi + \lambda_{\vartheta\varphi}\sin 2\vartheta\cos\varphi)$$

- 3 parameters measured in different polarization frames. Present results for center-of-mass of helicity frame (HX)
  - Z axis coincides with direction of Ψ(nS) or Υ(nS) momentum in the laboratory
- Polarization measured for prompt decays using proper time distribution

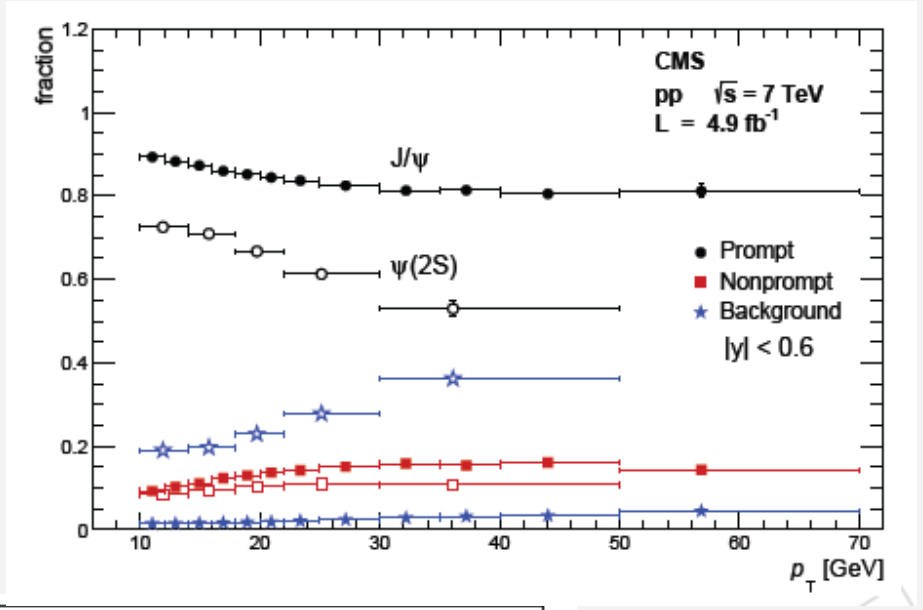
ϒ(nS) Polarizations

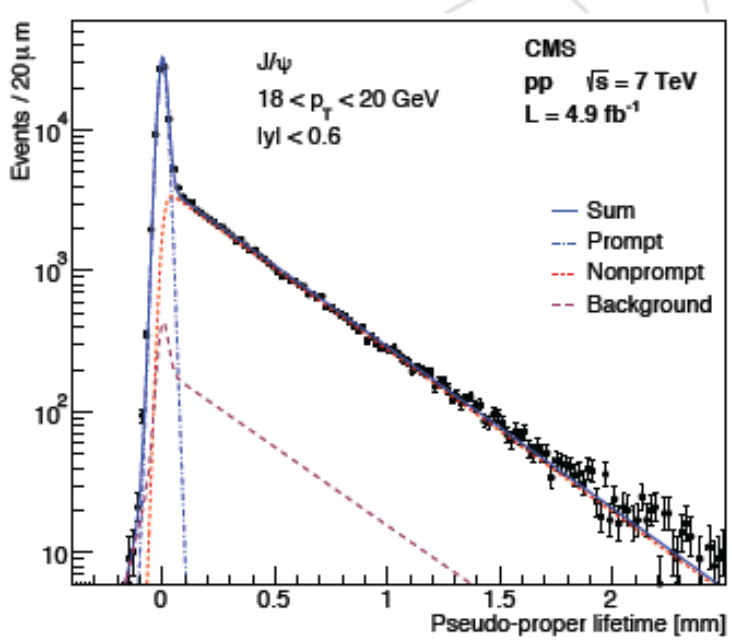
- Previously measured ϒ(1S), ϒ(2S),ϒ(3S) polarizations
  - PRL 110,0818022
- No significant polarization!

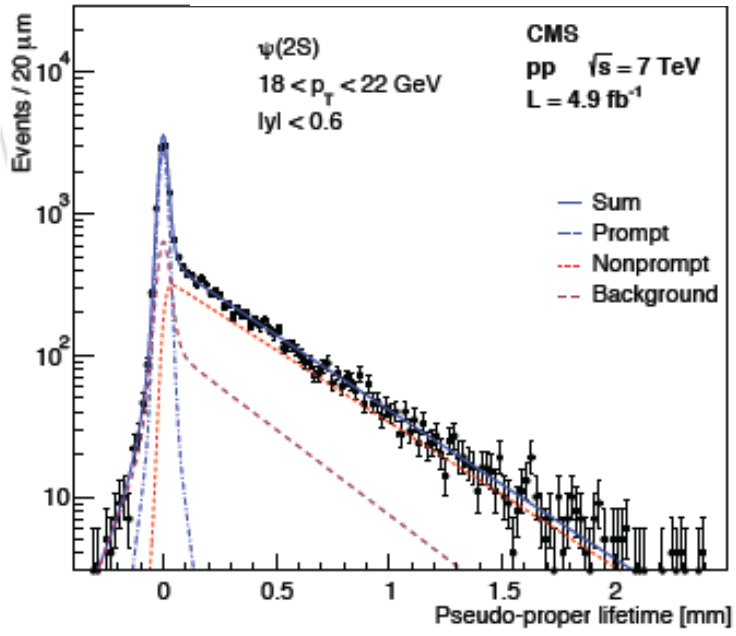


J/Ψ and Ψ(2S) polarization

- Polarization measured for prompt decays
  - Use proper lifetime distributions

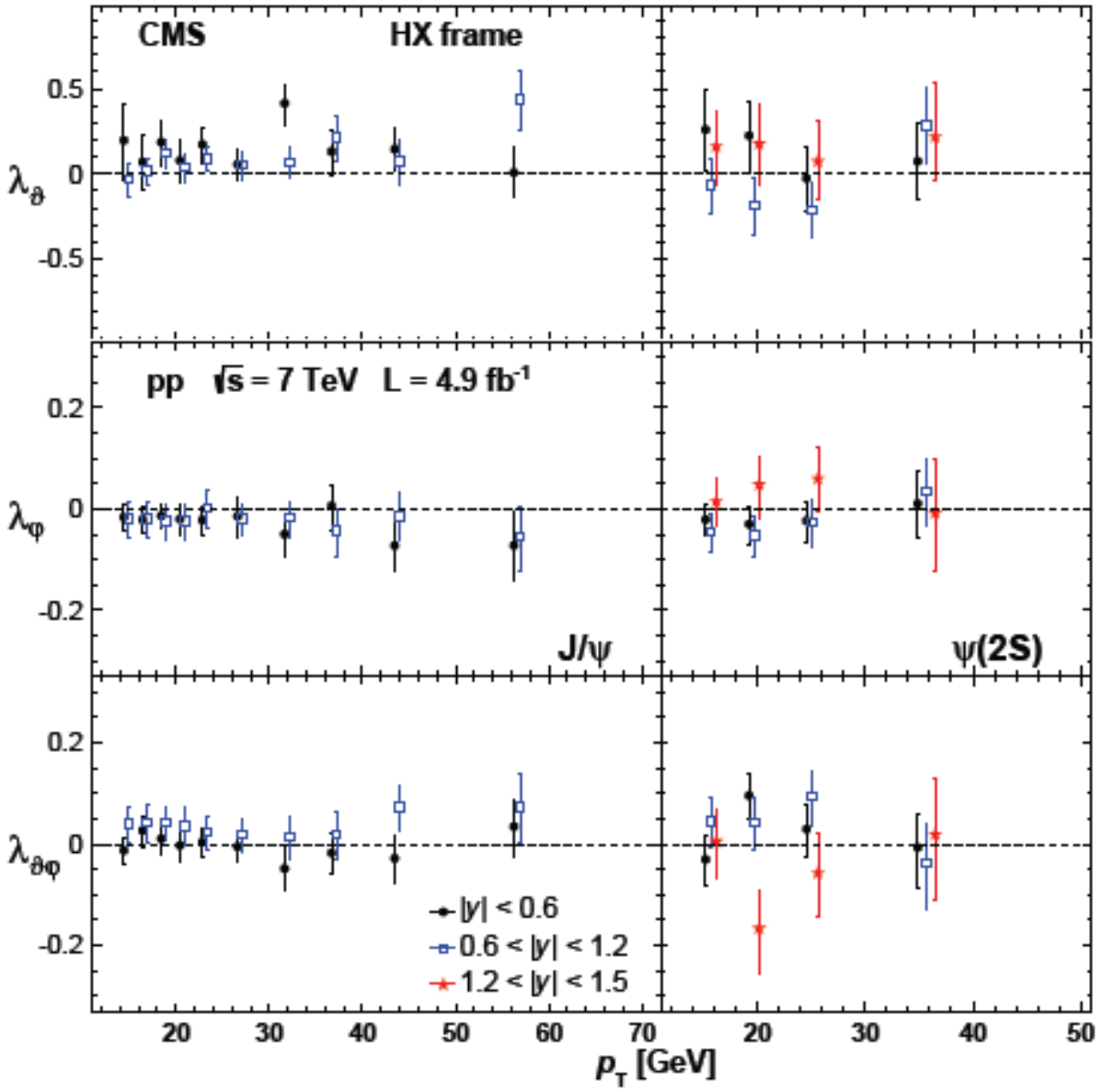






J/Ψ and Ψ(2S) polarization

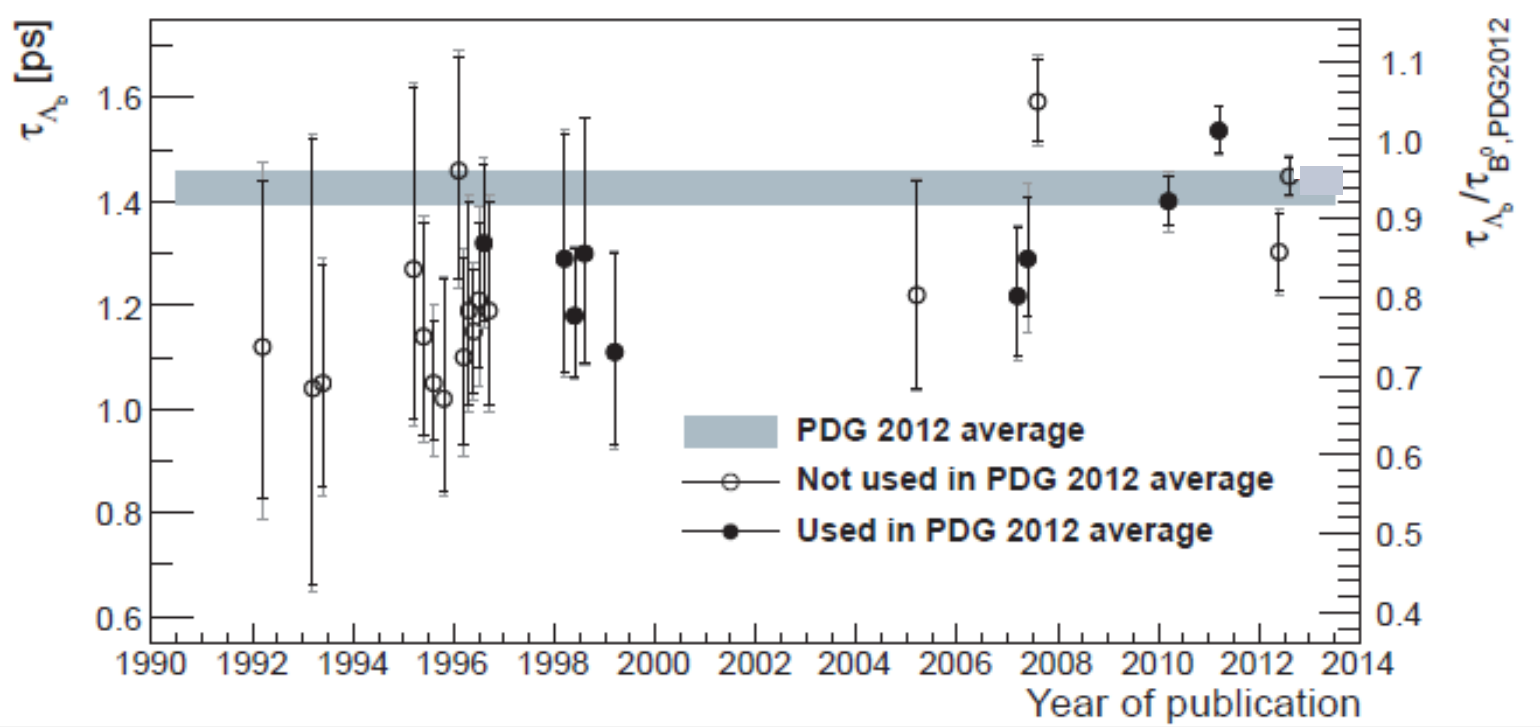
- No evidence for large transverse polarizations!
- Just submitted paper and arXiv



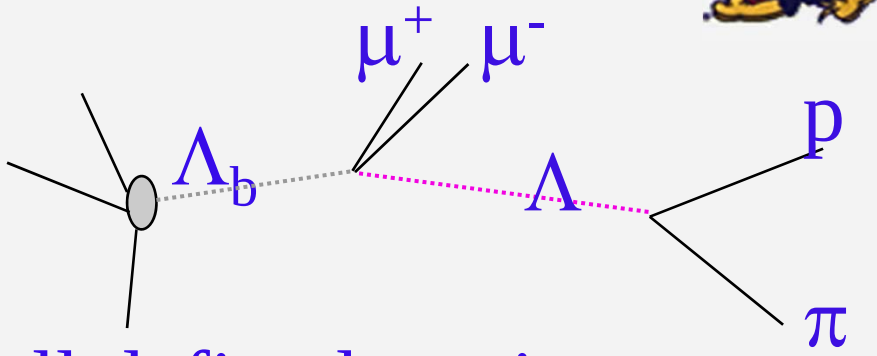
Λ_b lifetime

- Heavy quark expansion model of perturbative QCD predicts
  $\tau_{\Lambda_b^0} / \tau_{B^0}$ >0.90

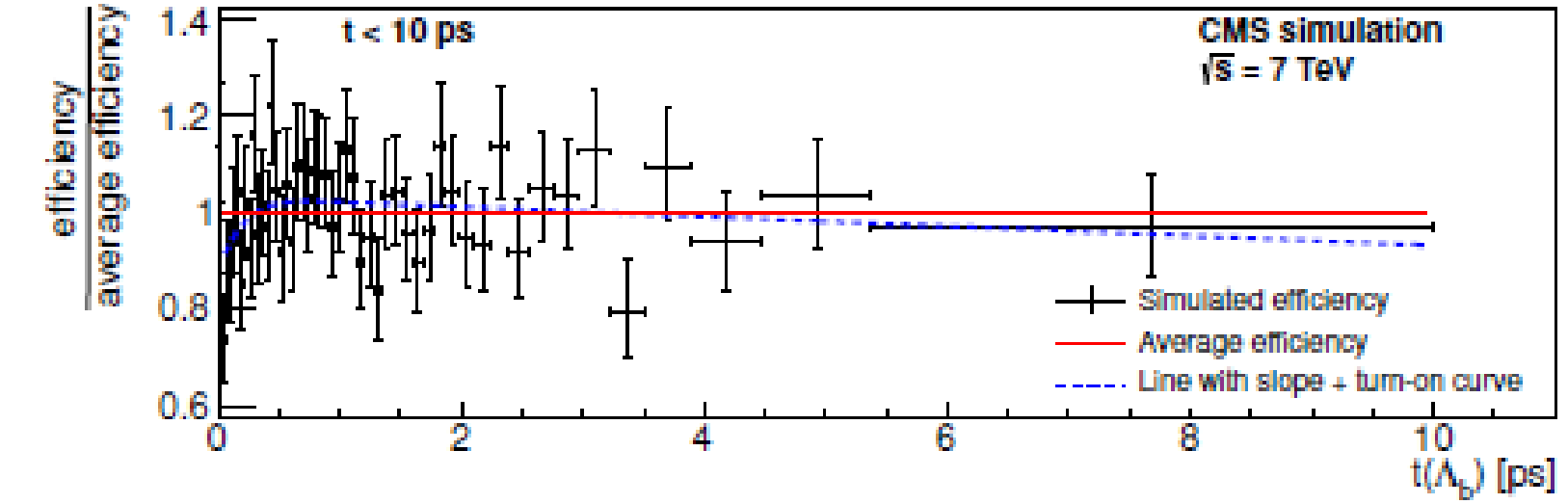
- Widespread values in previous measurements



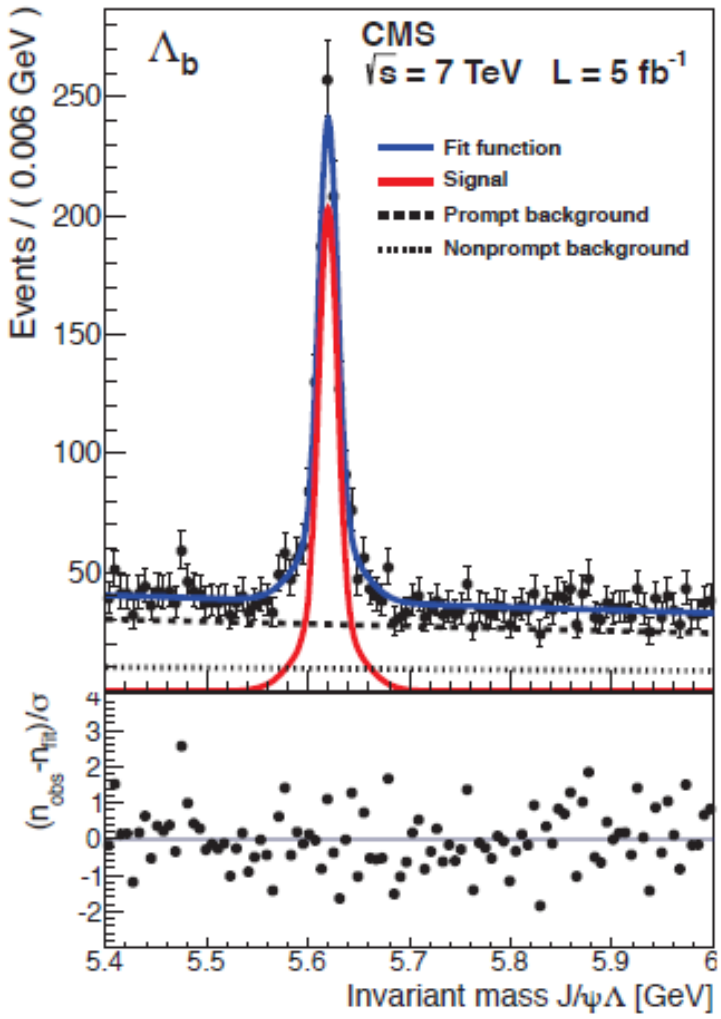
Λ_b lifetime

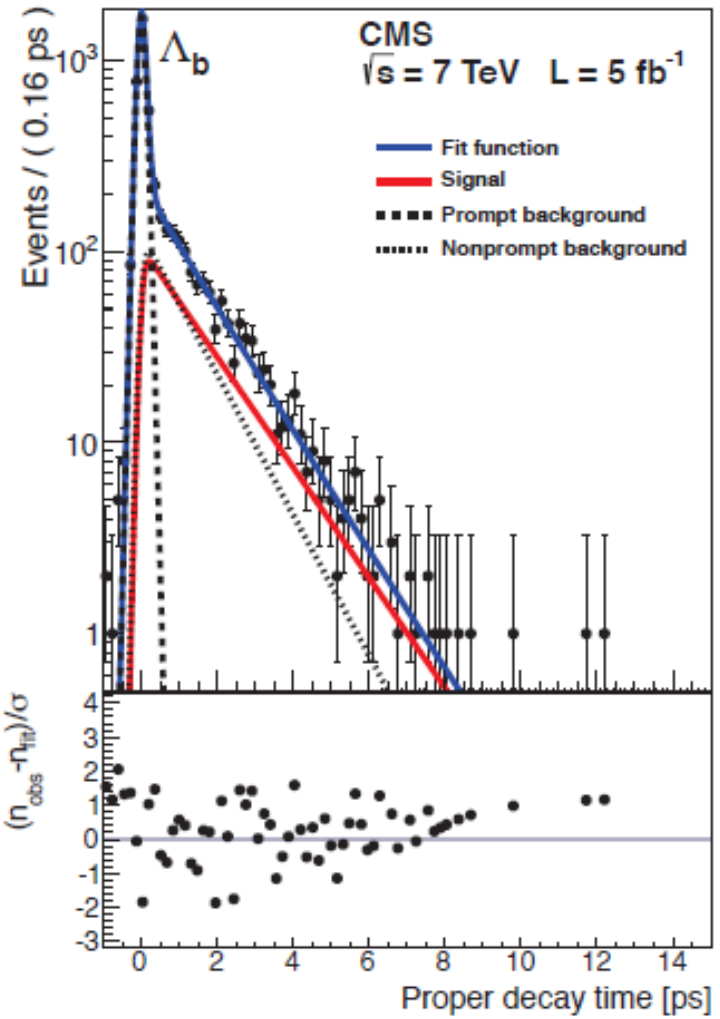


- $\Lambda_b \rightarrow J/\Psi \; \Lambda$
  - $J/\Psi \rightarrow \mu^+\mu^-$
  - $\Lambda \rightarrow p\pi$
- Kinematic fits for two well defined vertices and two body invariant mass consistency
- Efficiency as a function of lifetime is flat



$$\mathcal{L} = \prod_i \Big[N_{\rm sig} \cdot G2(m_i; m_{\rm sig}, \sigma_{m_1}, \sigma_{m_2}, f) \cdot \mathrm{e}^{-t/\tau_{\rm sig}} \otimes G(t_i; \mu, S \cdot \sigma_{t,i})$$
$$+ N_{\rm prompt} \cdot P(m_i; a) \cdot G(t_i; \mu, S \cdot \sigma_{t,i})$$
$$+ N_{\rm nonprompt} \cdot P(m_i; a) \cdot \mathrm{e}^{-t/\tau_{\rm nonprompt}} \otimes G(t_i; \mu, S \cdot \sigma_{t,i}) \Big],$$





Results

- Look at similar channel $B^0 \rightarrow J/\Psi K^0_S$ ($\mu^+\mu^-\pi^+\pi^-$)

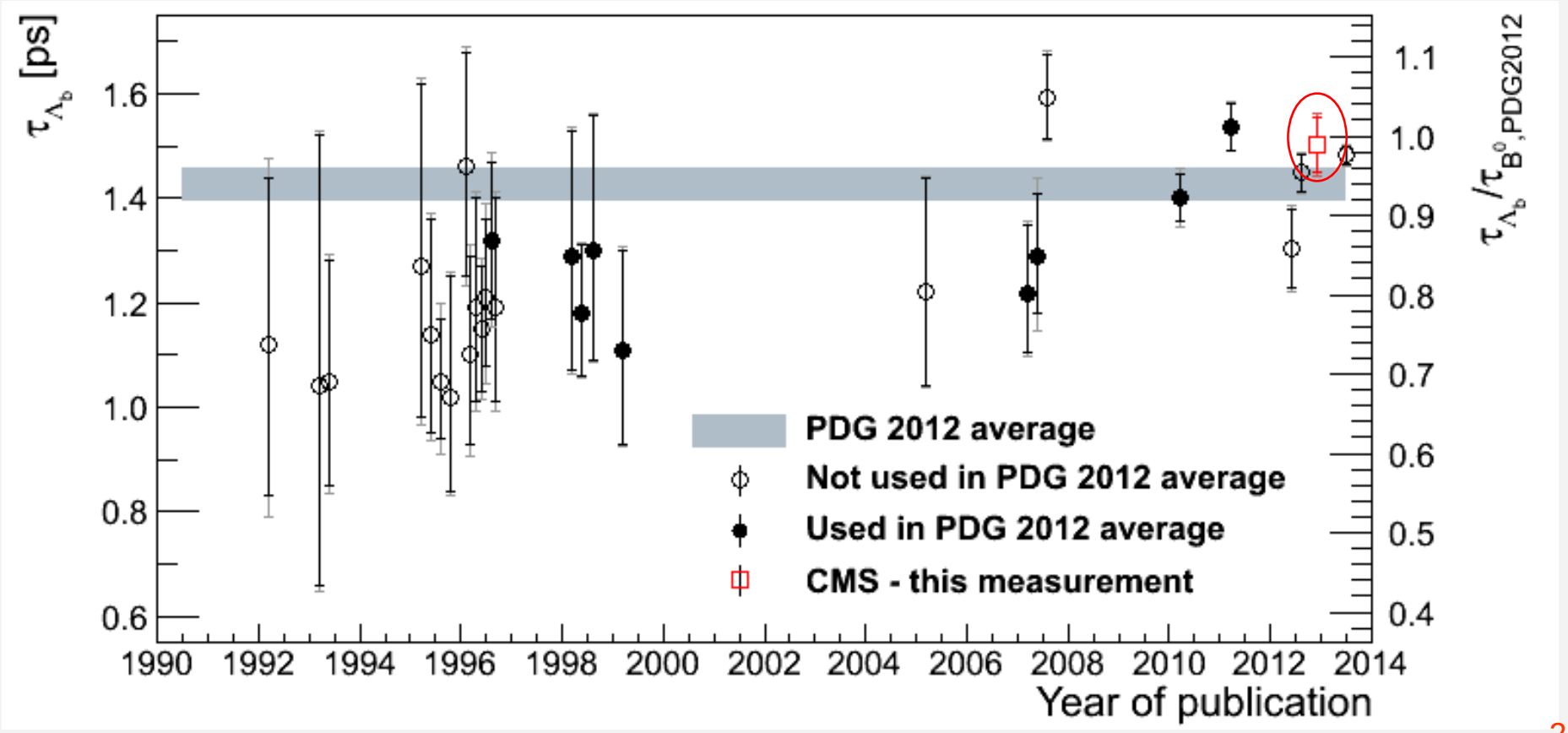
Hadron	N_{sig}	m (MeV)	τ (ps)
Λ_b^0	1013 ± 40	5619.7 ± 0.5	1.503 ± 0.052
B^0	6772 ± 87	5278.9 ± 0.2	1.526 ± 0.019

- Systematics

Source	Systematic uncertainty (ps)
Alignment	0.005
Efficiency	0.030
Event selection	0.005
Fit model	0.004
Total	0.031

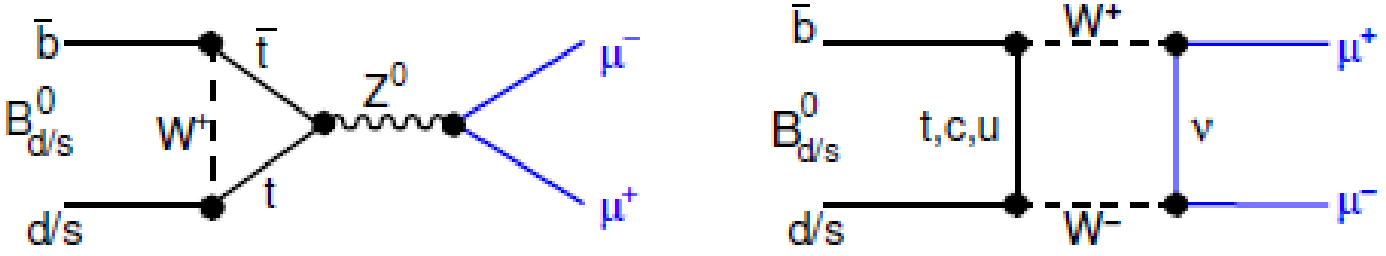
Λ_b lifetime

- CMS measurement $\tau_{\Lambda_b^0}$ = 1.503 ±0.052 (stat) ± 0.031 (syst)
- Consistent with World average 1.425±0.032 ps
  - New LHCb result $\tau_{\Lambda_b^0}$ = 1.482 ± 0.018 ± 0.012 ps (relative measurement)



$B_S \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$

Standard Model expectations



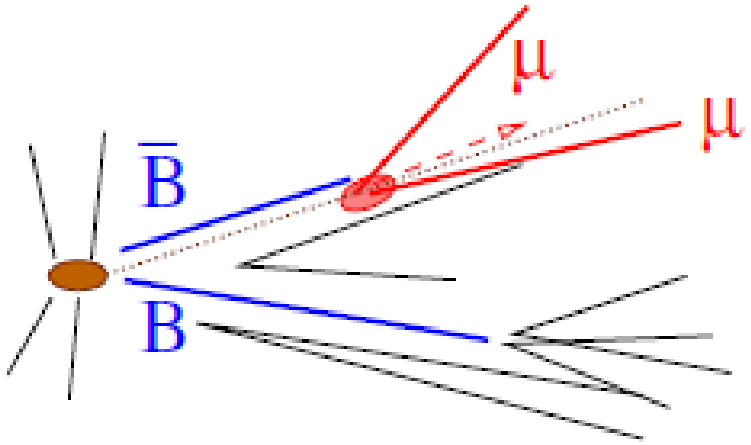
- box diagram is suppressed by $m_W^2/m_t^2 \approx 1/4$ with respect to Penguin

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.57 \pm 0.30) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \times 10^{-10}$$

(Buras 2012)

Analysis Overview

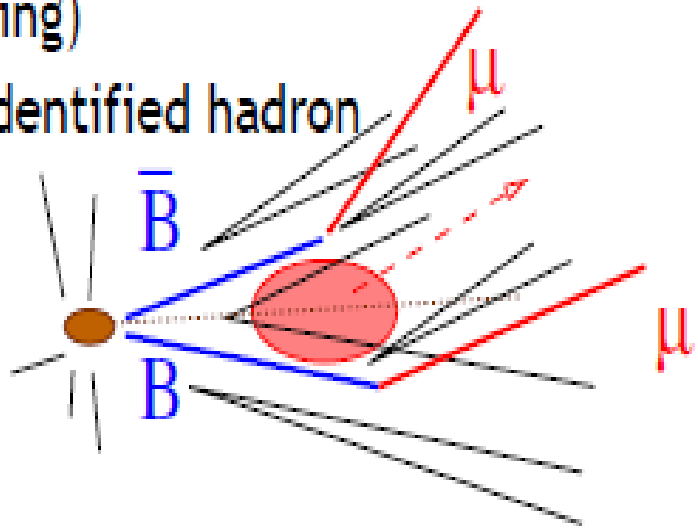
Signal: $\mu^+\mu^-$ from one decay vertex
- secondary vertex mom. aligned with flight direction
- isolated from jets



- Background
  - two semileptonic (B) decays (gluon splitting)
  - one semileptonic (B) decay and one misidentified hadron
  - rare single B decays

    non-peaking, e.g. $B_s^0 \to K^- \mu^+ \nu$

    peaking, e.g. $B_s^0 \to K^+ K^-$

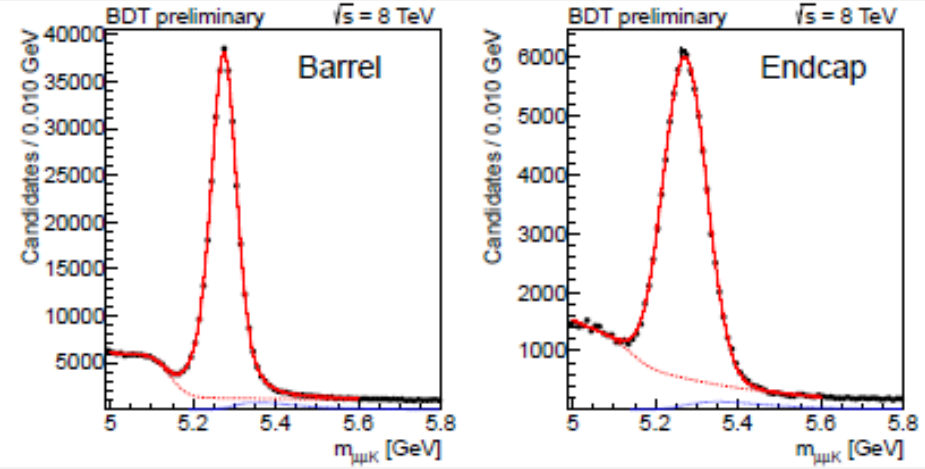


Latest Results – today!

- BPH-13-004 Submitted to PLB
- Full dataset taken with di-muon trigger
  - 2011 7 TeV 4.9 fb^{-1}
  - 2012 8 TeV 20.4 fb^{-1}

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+)$$

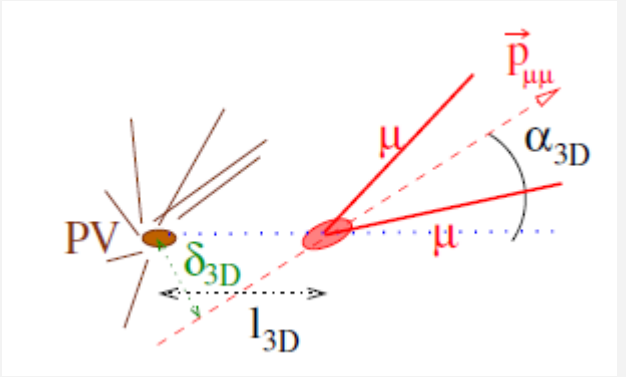
- Data in signal region kept "blind" until all analysis is defined.
- Normalization channel $B^+ \to J/\Psi K^+$, $J/\Psi \to \mu^+\mu^-$

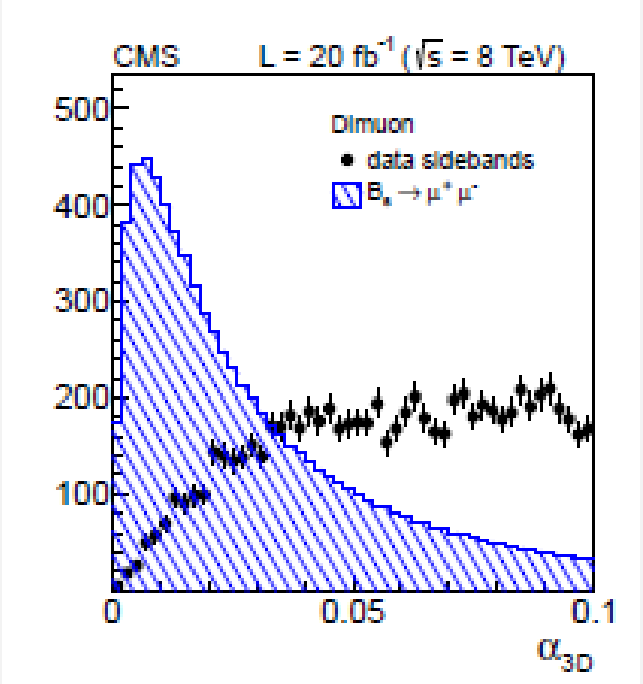


- Control channel $B^0_S \to J/\Psi\phi \to \mu^+\mu^- K^+ K^-$

$B_S \rightarrow \mu^+\mu^-$ Analysis

- Muons identified with Multi Variant Technique
  - Tight criteria limit K and π fakes
  - 10 variables including tracking and muon detector
- Use boosted decision tree with variables including those that isolate Primary vertex, B-vertex, and muons
  - Make cut with best $S/\sqrt{S+B}$

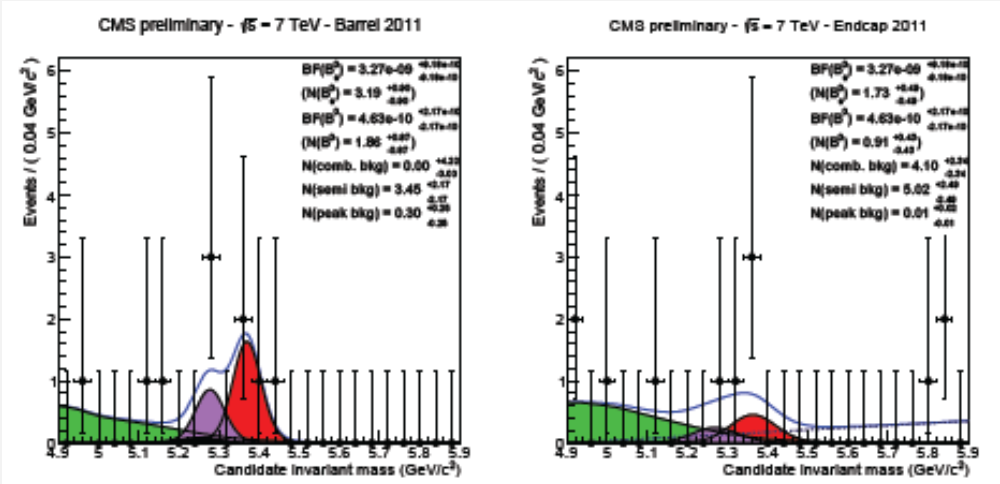




Likelihood fit $B_S \rightarrow \mu^+\mu^-$

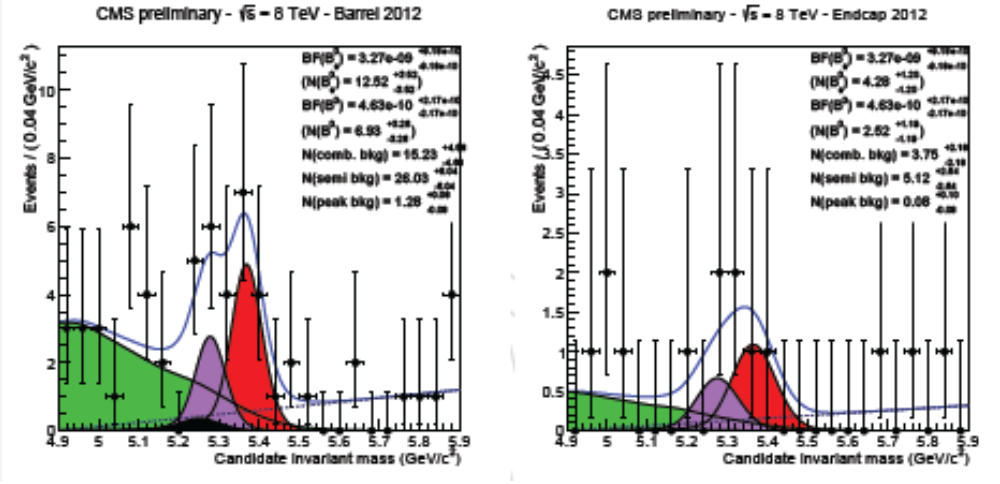
- Backgrounds divided into peaking and non-peaking
- Likelihood fit to obtain numbers of events

2011 barrel
4 B_S events observed



2011 endcap
4 B_S events observed

2012 barrel
16 B_S events observed



2012 endcap
4 B_S events observed

Observation of $B_S \to \mu^+\mu^-$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$$

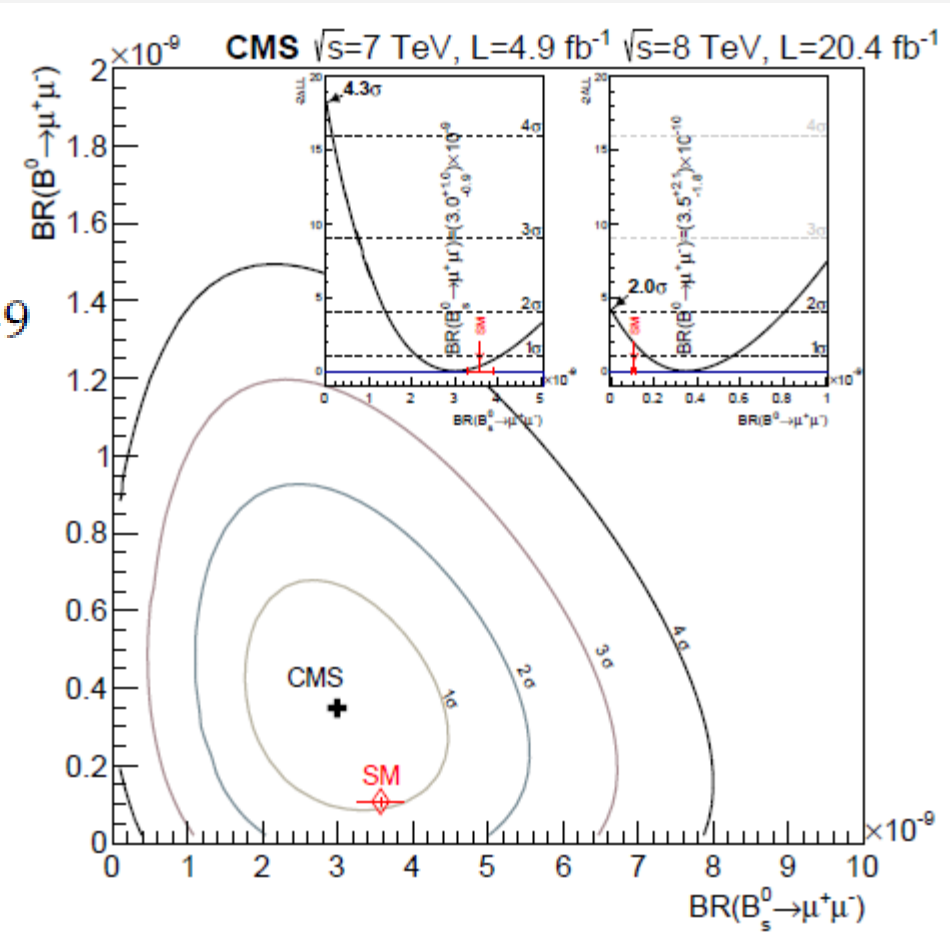
4.3 Standard deviations significance

arXiv:1307.5025

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$$

at 95% Confidence Level

Consistent with Standard Model



Summary

- CMS has results where decays include muons
  - New observation of $B_S \rightarrow \mu^+\mu^-$
  - Measurement of Λ_b lifetime
  - Search for $X_b \rightarrow \Upsilon(1S)\pi^+\pi^-$
  - $\Psi(2S), \Upsilon(nS)$ polarizations
  - $\Upsilon(nS)$ and other cross sections