B Physics at ATLAS and CMS

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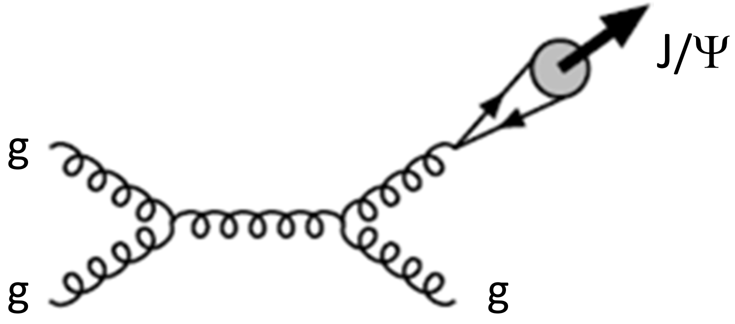
Outline

- Upsilon production [ATLAS, CMS]
- Observation of $\chi_b(3P)$ [ATLAS], Ξ_b^{*0} [CMS]
- Mass, lifetime measurements: Λ_b [ATLAS], B_c [CMS]
- B_s^0 Lifetime Studies [ATLAS, CMS]
- Search for Rare Decays: $B_s^0 \rightarrow \mu^+\mu^-$ [ATLAS, CMS]
- Summary

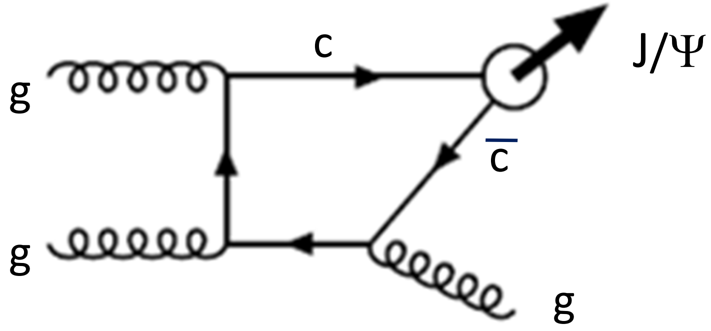
UPSILON PRODUCTION: [ATLAS, CMS]

Quarkonium Production

- Production of heavy quarkonium at LHC offers possibility to test QCD: are color octet contributions significant?
- Non-Relativistic QCD (NRQCD), color-singlet (CSM) models



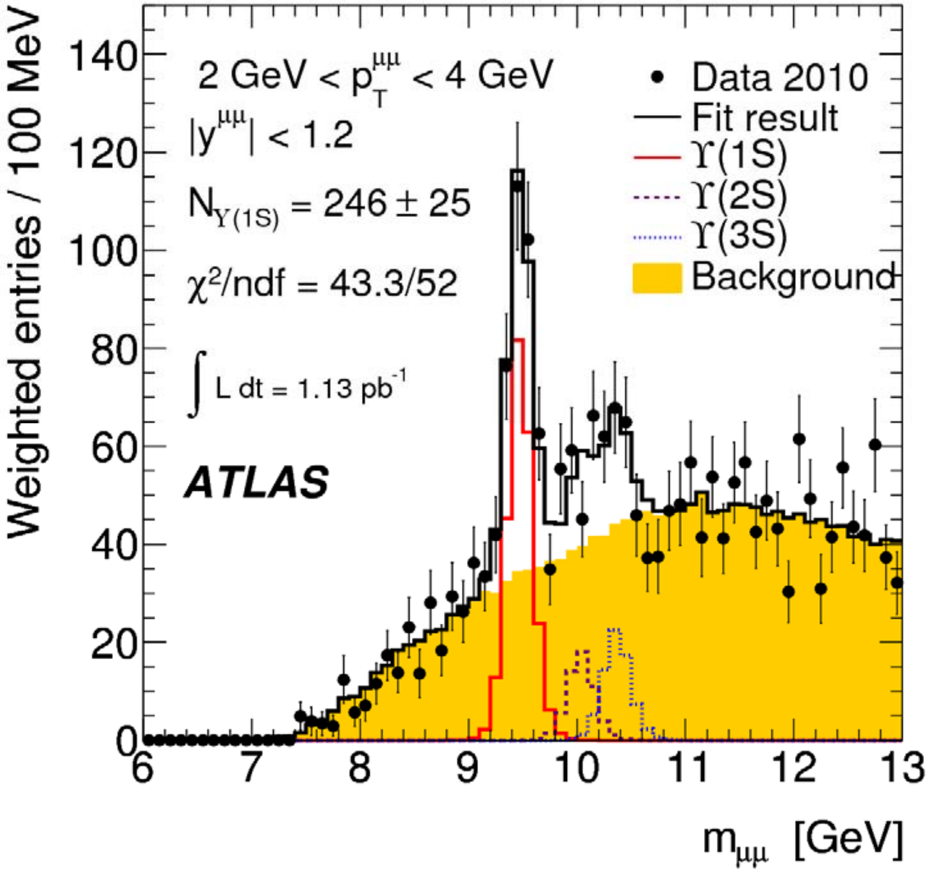
Example of color-octet fragmentation



Leading order color singlet

Υ(1S) Production: ATLAS

PLB 705 (2011) 9



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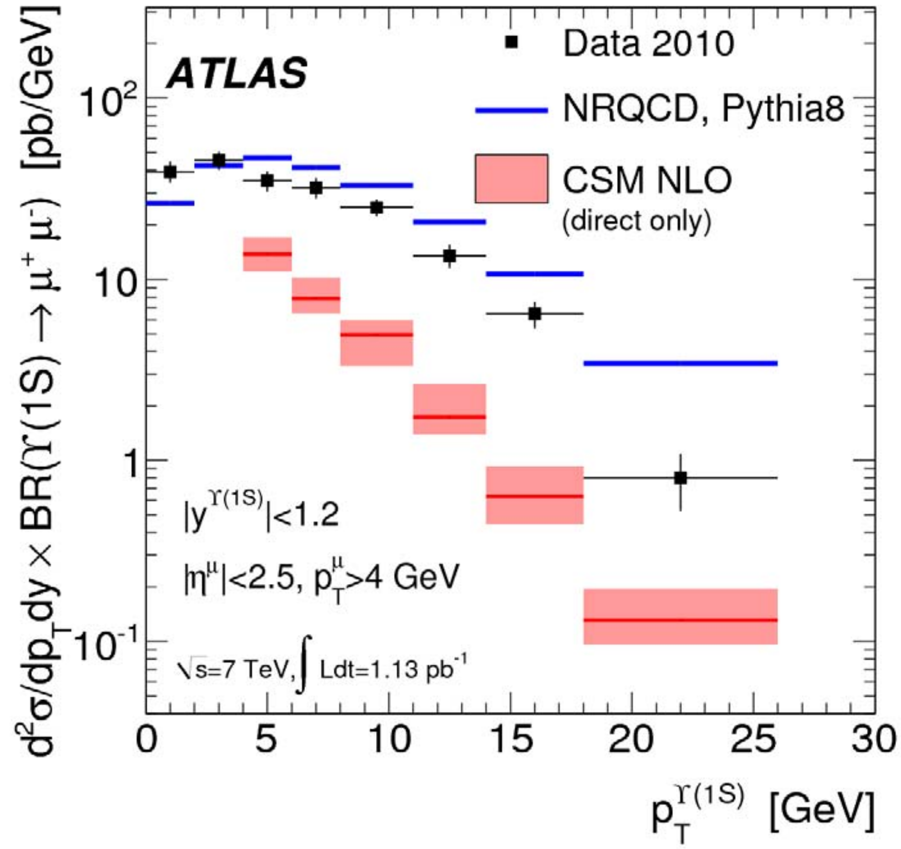
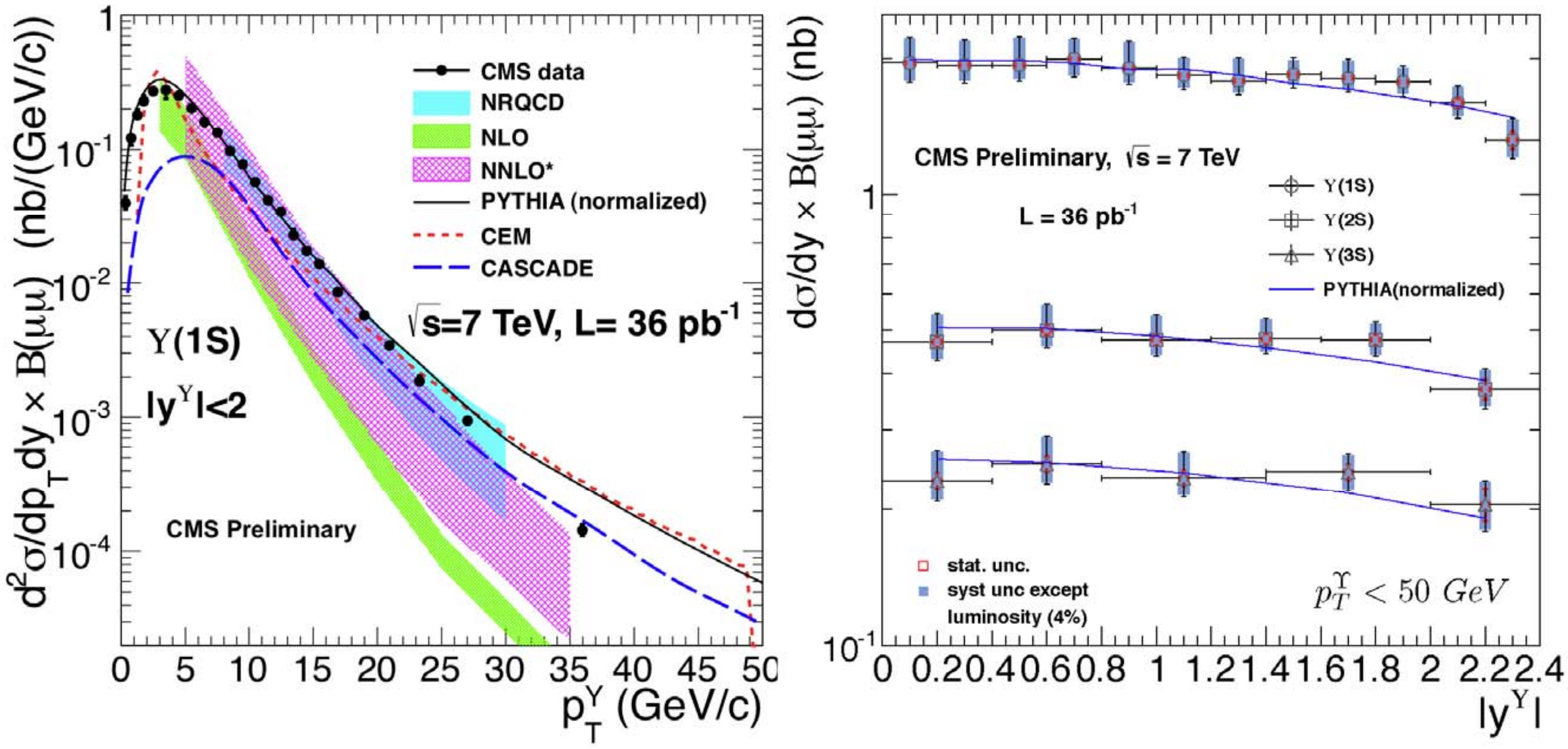


- Only prompt contribution for Υ(1S) production
- Overall scale not well predicted by theory
- Note: ATLAS has also published b-hadron production cross-section from D*μX final states

Upsilon Production: CMS

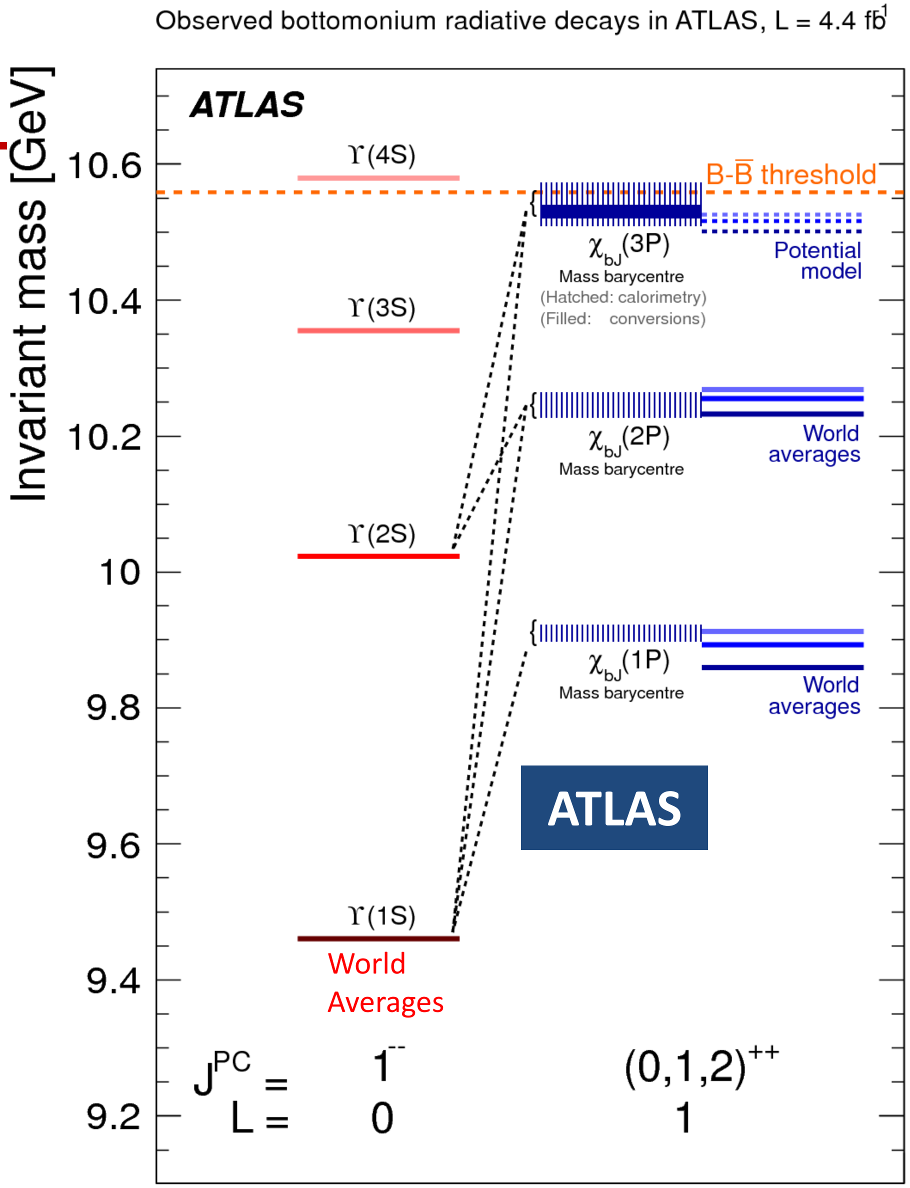


From "**New CMS Results on Flavor Physics" by Ernest Aguiló (HEPHY, Vienna) on behalf of the CMS collaboration, CERN-PH LHC Seminar, 26 Jun 2012**

OBSERVATION OF χ_b STATE [ATLAS]

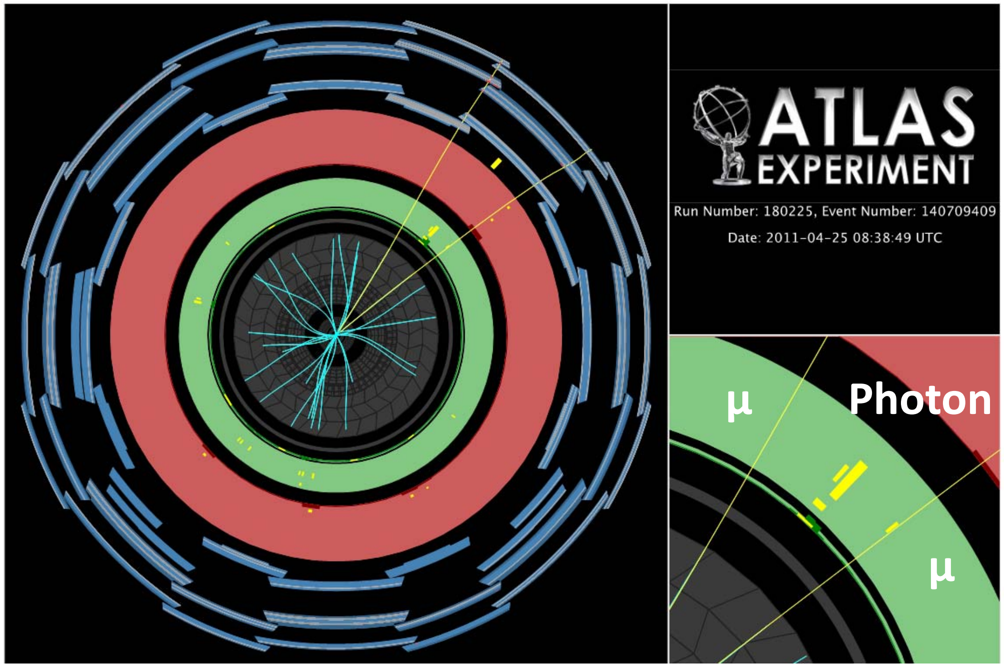
Observation of a new χ_b state: The Spectrum

- Quarkonium $b\bar{b}$-state with with parallel spins
  - $b\bar{b}$ S-wave state: Υ
  - $b\bar{b}$ P-wave state: χ_b with J=0,1,2 triplet spin state
  - χ_b(1P) and χ_b(2P) experimentally studied



Observation of a new χ_b state: Technique for unconverted photons

- Reconstruction of χ_b through radiative decays
  - $\chi_b(nP) \rightarrow \Upsilon(1S)\,\gamma$ and $\chi_b(nP) \rightarrow \Upsilon(2S)\,\gamma$
  - γ well reconstructed with calorimeter measurement (or via conversion to e^+e^- pairs)

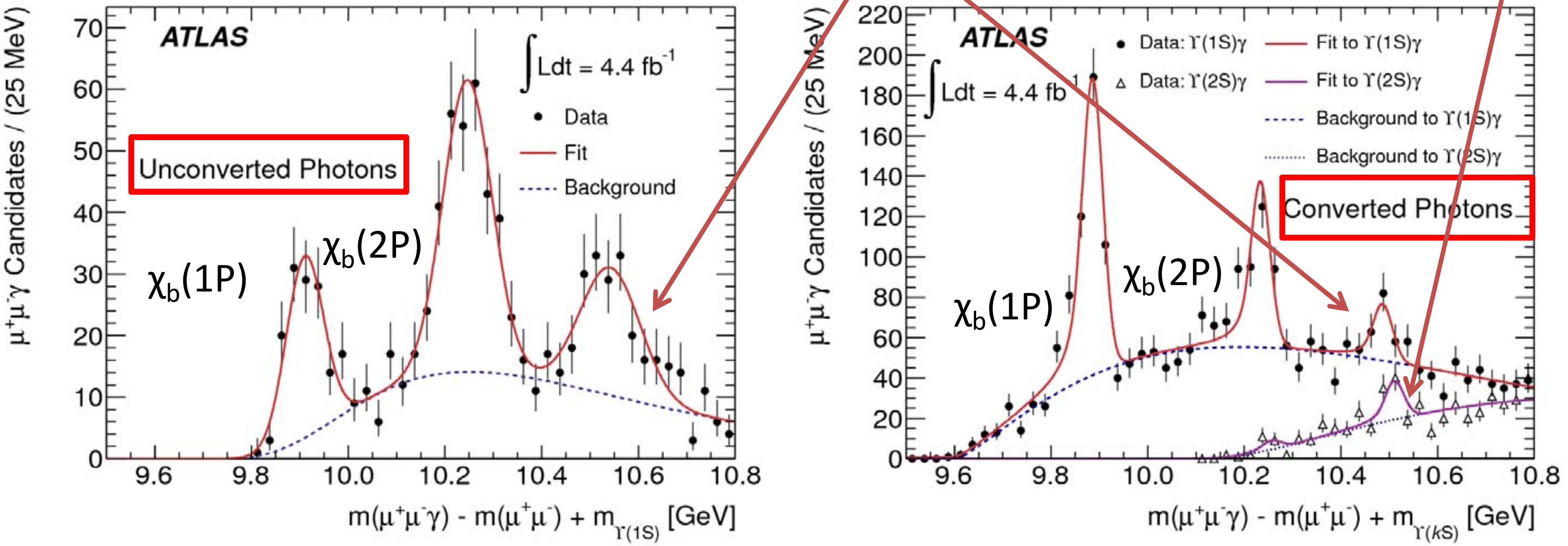


Observation of a new χ_b state: Result

$\chi_b(3P) \rightarrow \Upsilon(1S)\gamma$

$\chi_b(3P) \rightarrow \Upsilon(2S)\gamma$

Phys. Rev. Lett.
108, 152001 (2012)



Unconverted photons m_3 =

10.541 ± 0.011 (stat.) ± 0.030 (syst.) GeV/c^2.

Theory (spin averaged): 10.525 GeV

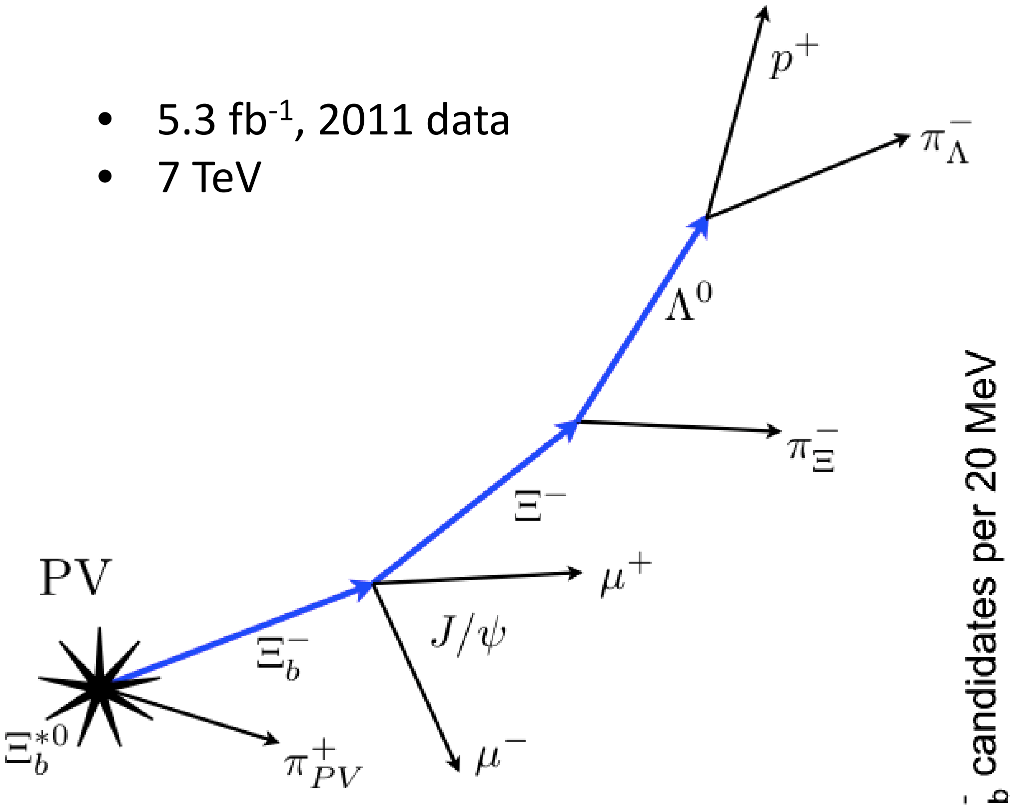
Converted photons m_3 = 10.530 ± 0.005 (stat.) ± 0.009 (syst.) GeV/c^2.

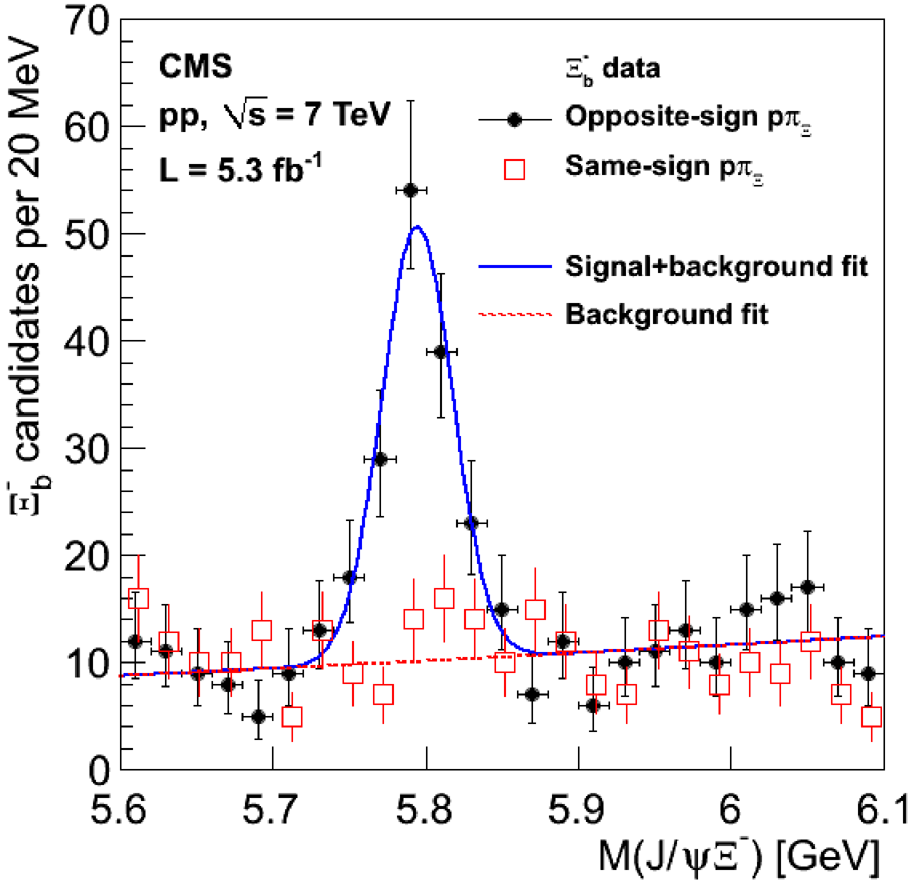
This value is used instead of the unconverted case for the final result due to the smaller systematic. The systematic error is due to a variety of sources: relative normalizations of the 3 peaks, background modeling variations, constraints on the masses of the n = 1, 2 peaks, etc.

OBSERVATION OF Ξ_b^{*0}: CMS

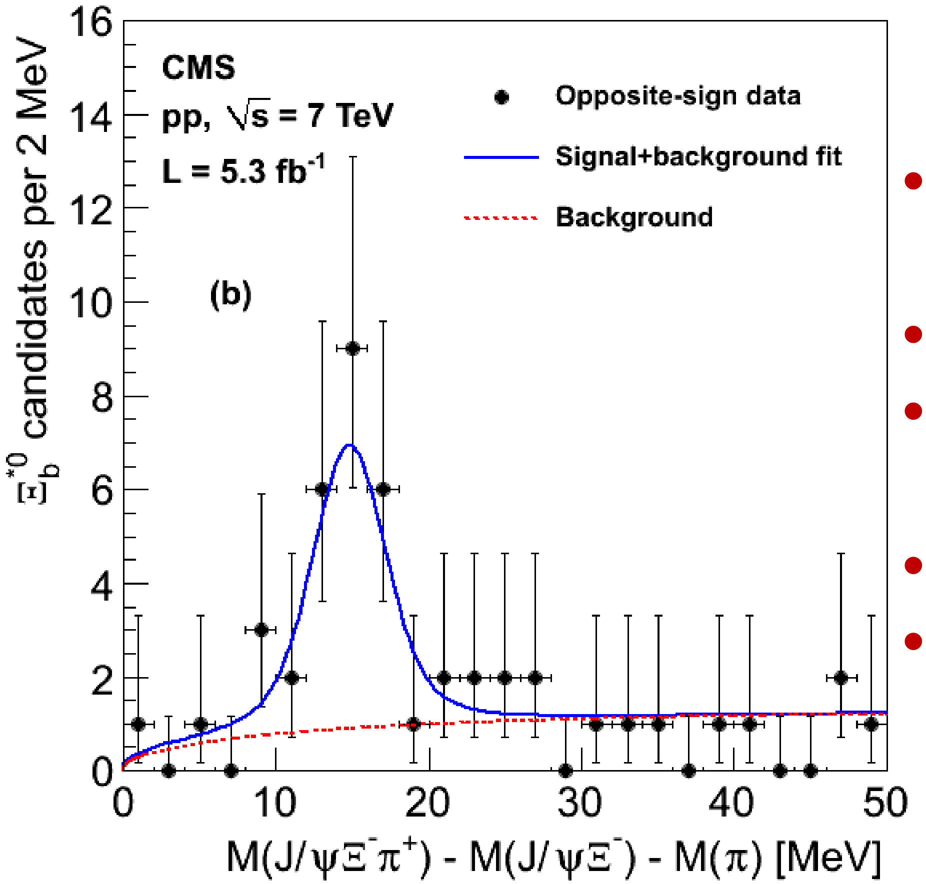
Ξ_b^{*0} Observation: CMS

- 5.3 fb^{-1}, 2011 data
- 7 TeV





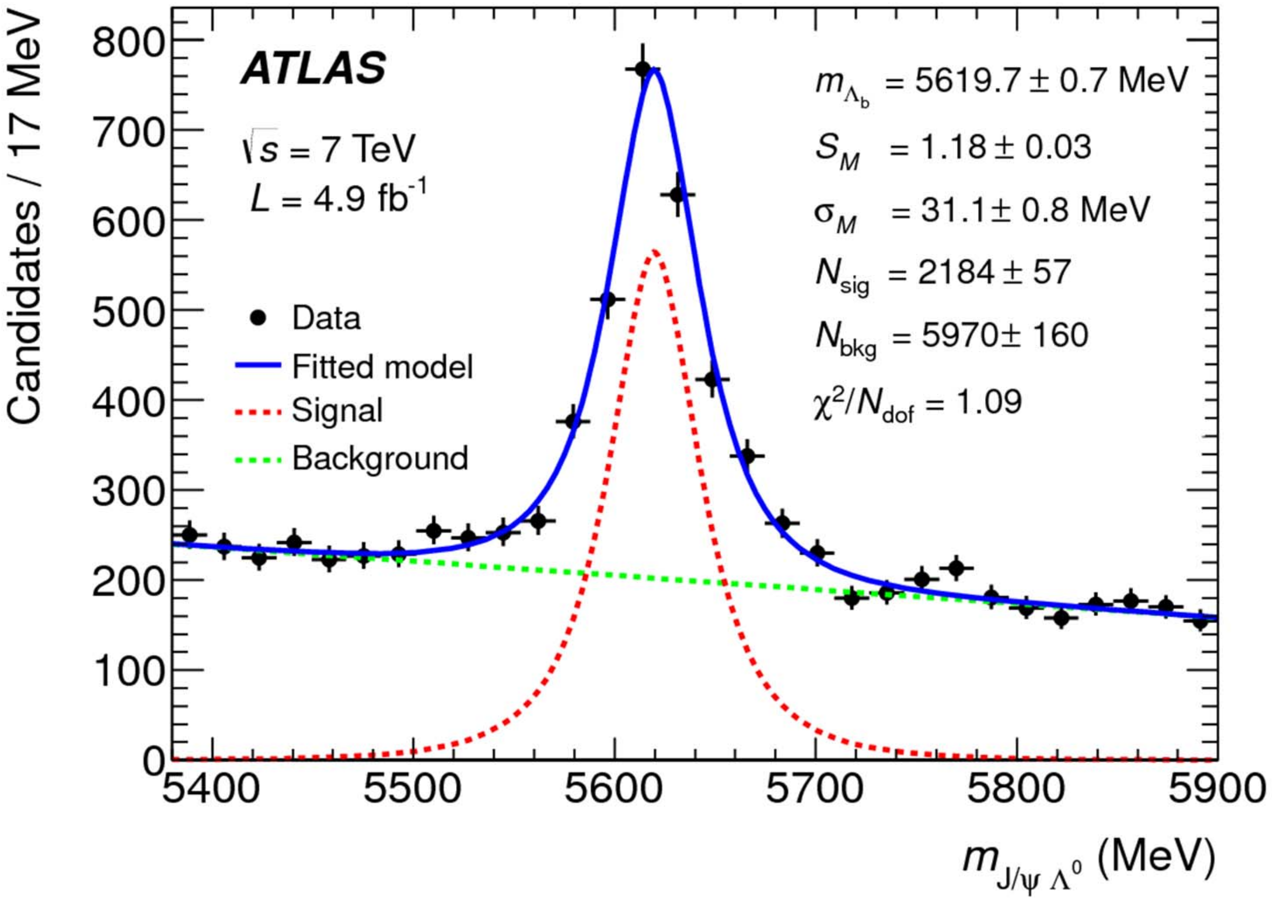
Ξ_b^{*0} Observation: CMS



- Expected bkgd 3.0 ± 1.4 events
- 21 events in 12-18 MeV of Q
- Q peak at 14.84 ± 0.74 ± 0.26 MeV
- 5 σ significance
- First new baryon at LHC

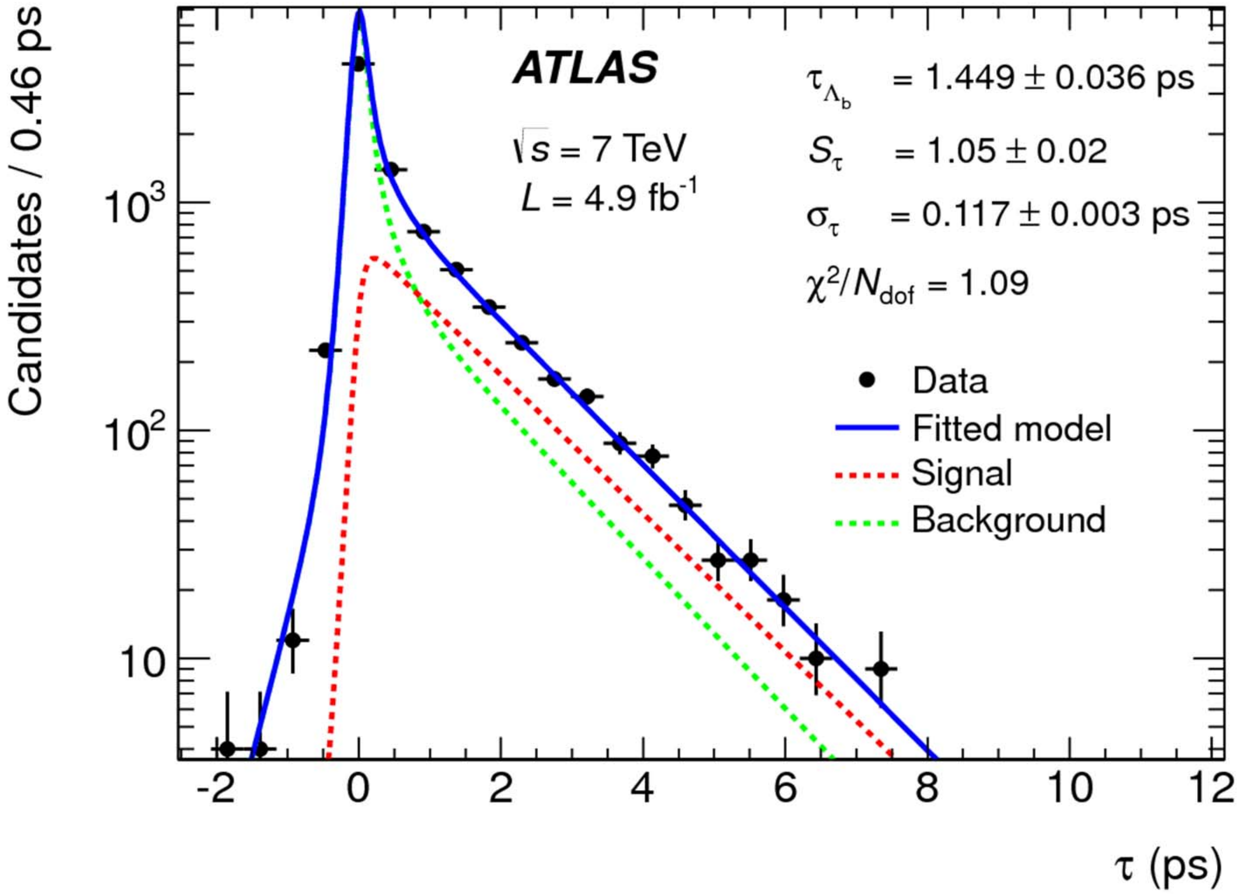
MASS, LIFETIME: Λ_B [ATLAS], B_C [CMS]

ATLAS: $\Lambda_b \rightarrow J/\Psi\Lambda$



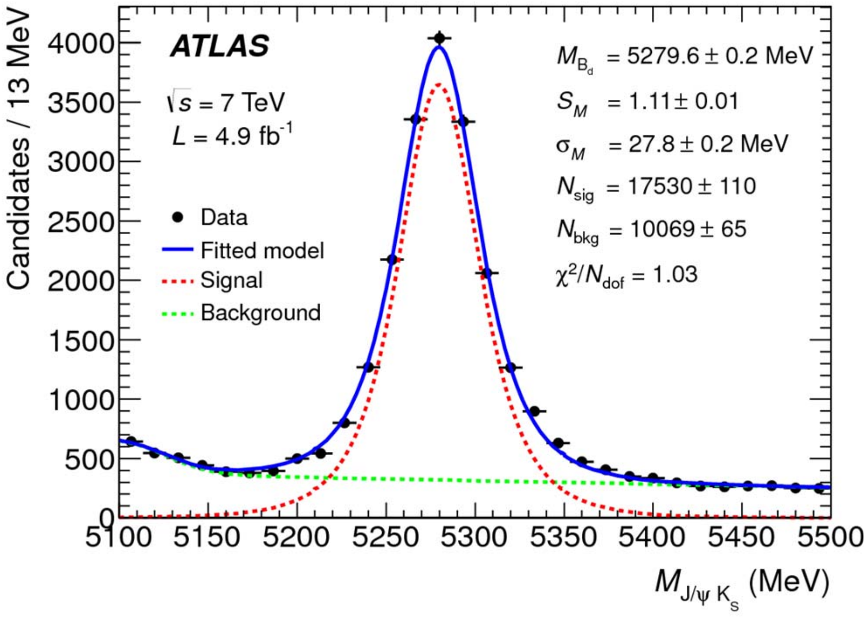
- 4.9 fb^{-1}, 2011 data
- 7 TeV
- Yield: 2184 ± 57

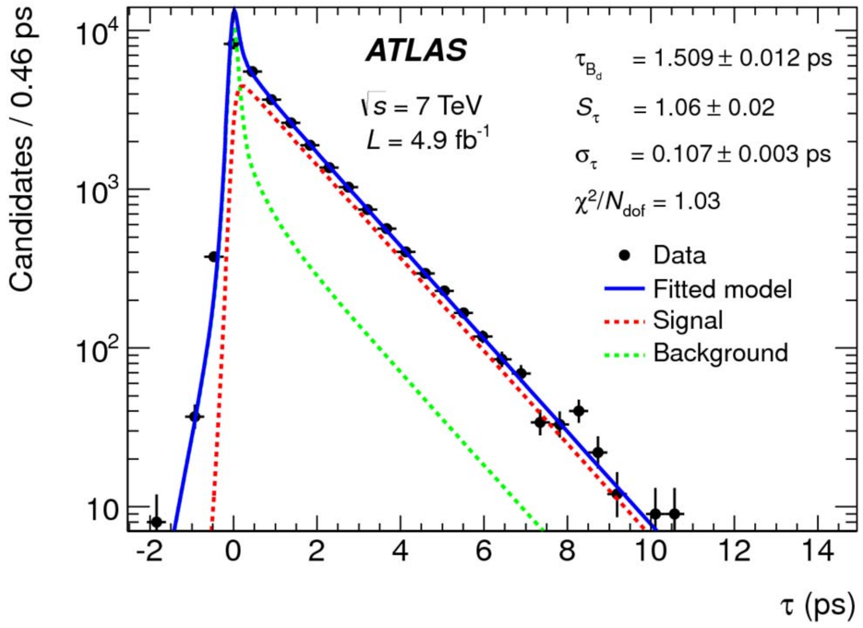
ATLAS: Λ_b, Lifetime measurement



- 4.9 fb^{-1}, 2011 data
- 7 TeV
- Yield: 2184 ± 57

ATLAS Λ_b: m, τ reference, results
[$B_d \to J/\Psi\,(\mu^+\mu^-)\,K_s\,(\pi^+\pi^-)$]





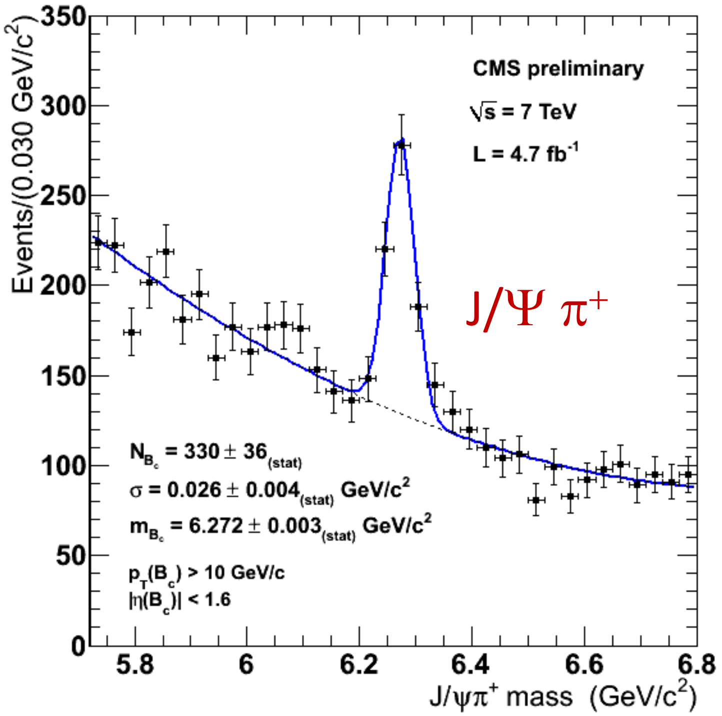
- Trigger efficiency is modeled using MC and fit with a simple exponential
- Systematics studied include event selection bias, background model, B_d contamination,   residual ID misalignment, …
- Results in agreement with world average, recent LHCb result

$$\tau_{\Lambda_b} = 1.449 \pm 0.036(\mathrm{stat}) \pm 0.017(\mathrm{syst})\ \mathrm{ps},$$

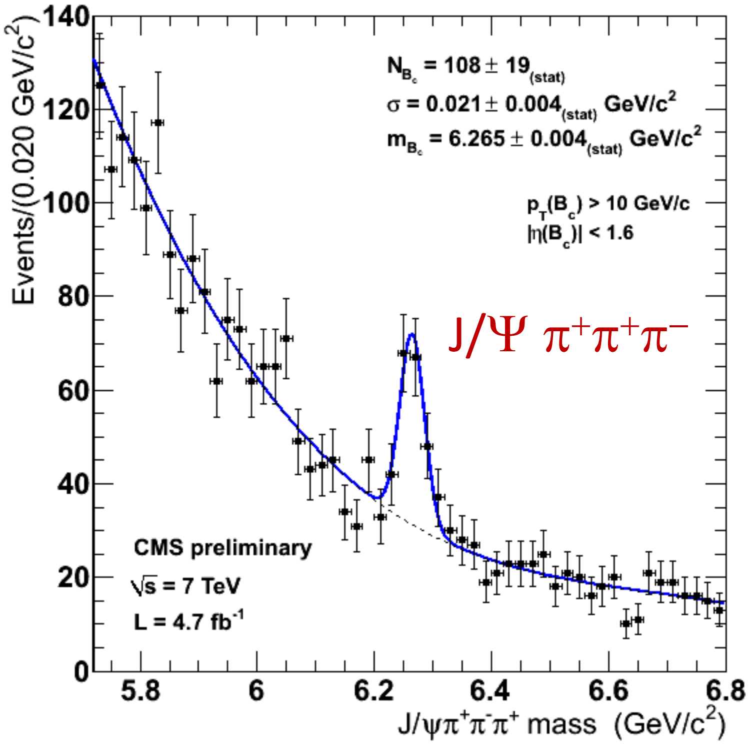
$$m_{\Lambda_b} = 5619.7 \pm 0.7(\mathrm{stat}) \pm 1.1(\mathrm{syst})\ \mathrm{MeV}.$$

$$R = \tau_{\Lambda_b}/\tau_{B_d} = 0.960 \pm 0.025(\mathrm{stat}) \pm 0.016(\mathrm{syst}).$$

CMS: B_c



$J/\Psi\ \pi^+$



$J/\Psi\ \pi^+\pi^+\pi^-$

- 4.7 fb^{-1} of 7 TeV 2011 data
- Yields are 330 ± 36 ± 23 for the $J/\Psi\ \pi^+\pi^+\pi^-$ mode and 108 ± 19 ± 14 for the $J/\Psi\ \pi^+\pi^+\pi^-$
- S/sqrt(S+B) varies between 5.4 and 6.7 for the $J/\Psi\ \pi^+\pi^+\pi^-$ data
- Confirmation of $J/\Psi\ \pi^+\pi^+\pi^-$ (new decay channel seen by LHCb)

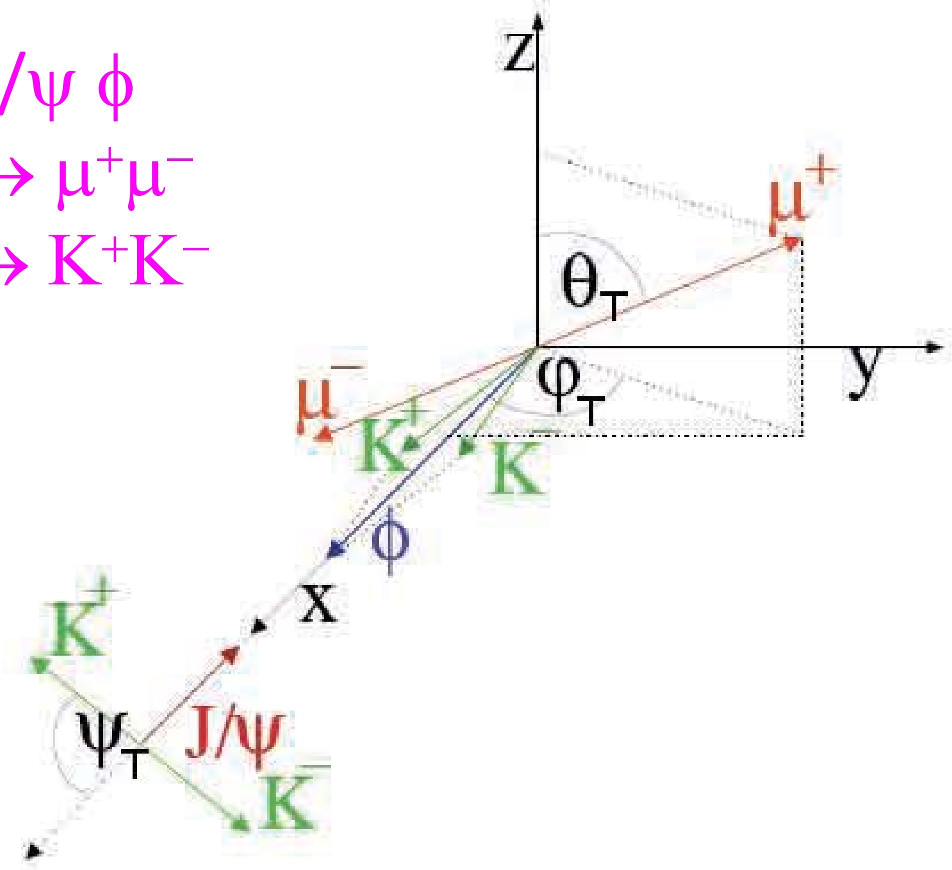
$B_S{}^0$ LIFETIME STUDIES [ATLAS, CMS]

B_s Lifetime Kinematics

$B_s \to J/\psi\ \phi$

$J/\psi \to \mu^+\mu^-$

$\phi \to K^+K^-$



Kinematic Variables

- Proper decay time t
- 3 angles in the Transversity basis: θ_T, ϕ_T, ψ_T

B_s Lifetime Decay Distribution - I

$B_s \rightarrow J/\psi\ \phi$

$J/\psi \rightarrow \mu^+\mu^-$

$\phi \rightarrow K^+K^-$

The decay of vector mesons is further described by the time evolution of three different amplitudes with different angular dependencies. The amplitudes at time $t = 0$ are defined using the longitudinal component $A_0(0)$ for $L = 0$, which is CP-even, and the transverse components $A_\perp(0)$ for $L = 1$ and $A_{||}(0)$ for $L = 2$ which are CP-odd and CP-even, respectively. In addition, the two strong phases are denoted by $\delta_{||}$ and $\delta_\perp$. The differential decay rate as a function of the proper decay time t and angular variables Θ can be represented [4] as

$$\frac{d^4\Gamma(B_s(t))}{d\Theta\, dt} = f(\Theta, t; \alpha) = \sum_{i=1}^{6} O_i(\alpha, t).g_i(\Theta) \ , \qquad (1)$$

where O_i are kinematics-independent observables, g_i are the angular distributions, and α denotes a set of physics parameters of interest (Γ_s, $\Delta\Gamma_s$, $|A_0|^2$, $|A_\perp|^2$, $\delta_{||}$). The kinematic observables are described using the following equations:

$$\begin{aligned}
O_1 &= |A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_2 &= |A_{||}(t)|^2 = |A_{||}(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_3 &= |A_\perp(t)|^2 = |A_\perp(0)|^2 e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) + \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \qquad (2) \\
O_4 &= Im(A_{||}^*(t) A_\perp(t)) = |A_{||}(0)||A_\perp(0)| e^{-\Gamma_s t}[-\cos(\delta_\perp - \delta_{||}) \sin\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_5 &= Re(A_0^*(t) A_{||}(t)) = |A_0(0)||A_{||}(0)| \cos\delta_{||} e^{-\Gamma_s t}[\cosh(\Delta\Gamma_s t/2) - \cos\phi_s \sinh(\Delta\Gamma_s t/2)] \\
O_6 &= Im(A_0^*(t) A_\perp(t)) = |A_0(0)||A_\perp(0)| e^{-\Gamma_s t}[-\cos\delta_\perp \sin\phi_s \sinh(\Delta\Gamma_s t/2)] \ ,
\end{aligned}$$

where ϕ_s is the mixing phase. Constraining ϕ_s to zero allows the terms containing $O_4(\alpha, t) \cdot g_4(\Theta)$ and $O_6(\alpha, t) \cdot g_6(\Theta)$ to be omitted. The individual angular distributions are given by the following equations:

B_s Lifetime Decay Distribution - II

where ϕ_s is the mixing phase. Constraining ϕ_s to zero allows the terms containing $O_4(\alpha,t)\cdot g_4(\Theta)$ and $O_6(\alpha,t)\cdot g_6(\Theta)$ to be omitted. The individual angular distributions are given by the following equations:

$B_s \to J/\psi\ \phi$

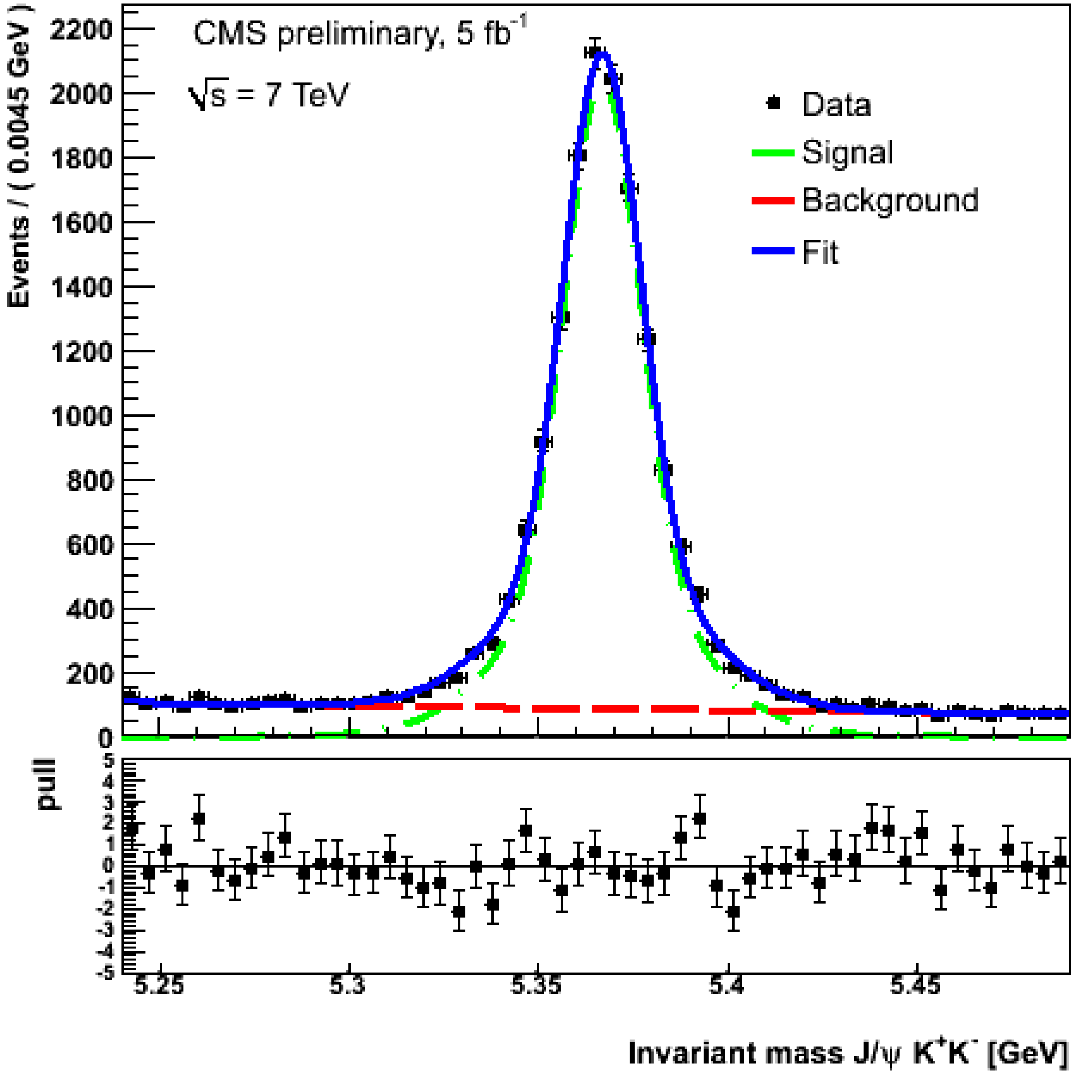
$J/\psi \to \mu^+\mu^-$

$\phi \to K^+K^-$

$$\begin{aligned} g_1 &= 2\cos^2(\psi_T)(1-\sin^2(\theta_T)\cos^2(\varphi_T)), \\ g_2 &= \sin^2(\psi_T)(1-\sin^2(\theta_T)\sin^2(\varphi_T)), \\ g_3 &= \sin^2(\psi_T)\sin^2(\theta_T), \\ g_4 &= -\sin^2(\psi_T)\sin^2(2\theta_T)\sin(\varphi_T), \\ g_5 &= \frac{1}{\sqrt{2}}\sin(2\psi_T)\sin^2(\theta_T)\sin(2\varphi_T), \\ g_6 &= \frac{1}{\sqrt{2}}\sin(2\psi_T)\sin(2\theta_T)\sin(\varphi_T)\ . \end{aligned} \tag{3}$$

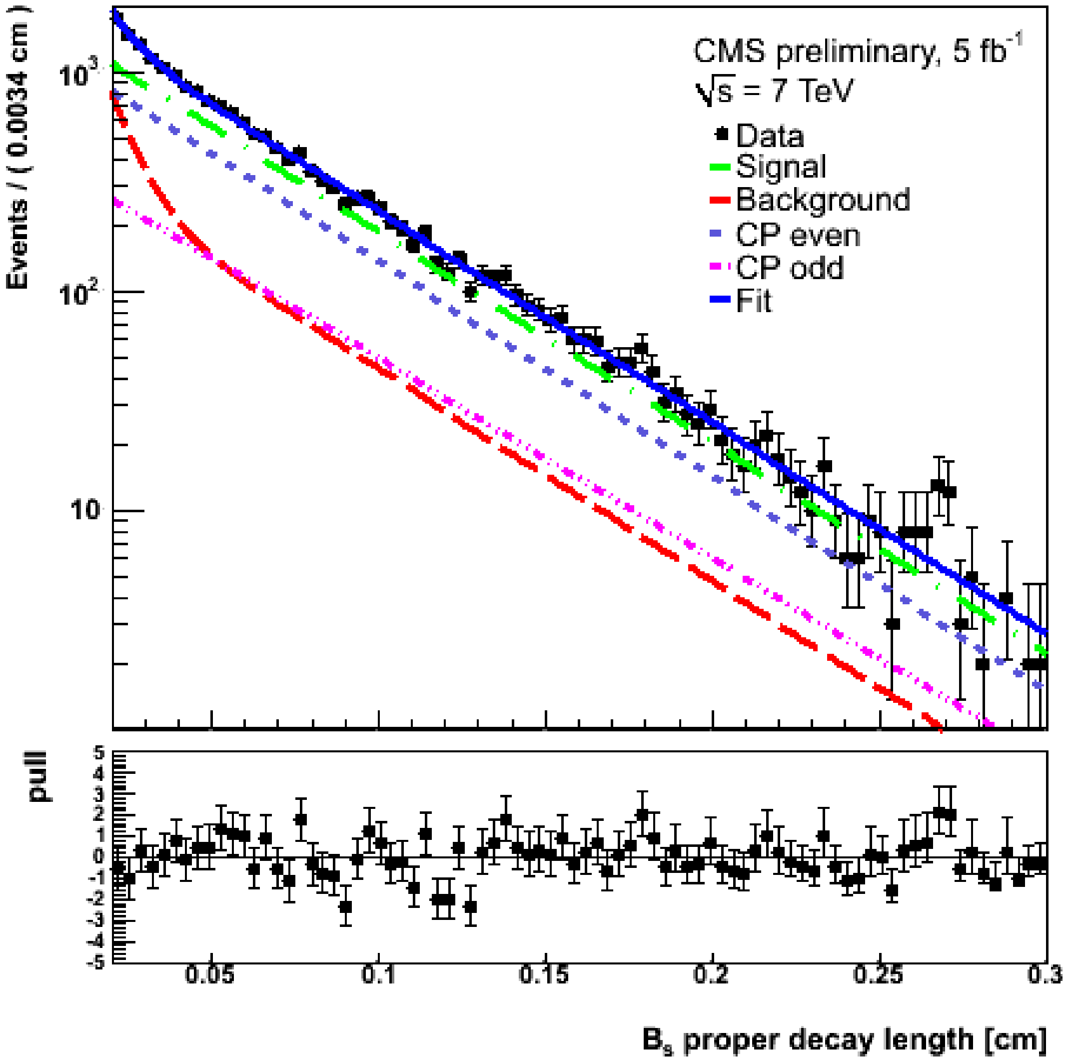
The theoretical expectation for the ratio $\Delta\Gamma_s/\Gamma_s$ is 0.12 ± 0.06 [1]. The S-wave component is assumed to be negligible in the signal model. The analysis uses a data sample corresponding to an integrated luminosity of $5.0 \pm 0.1\ \mathrm{fb}^{-1}$ in pp collisions at $\sqrt{s} = 7$ TeV collected with the CMS detector in the year of 2011.

CMS: B_s Lifetime

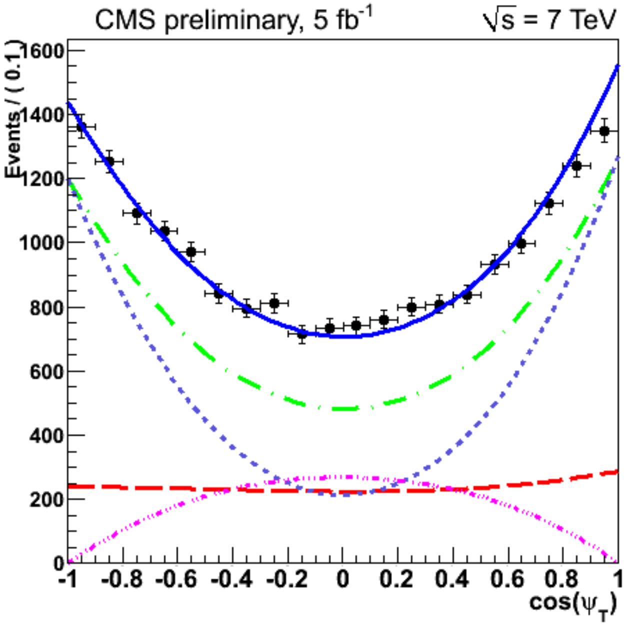


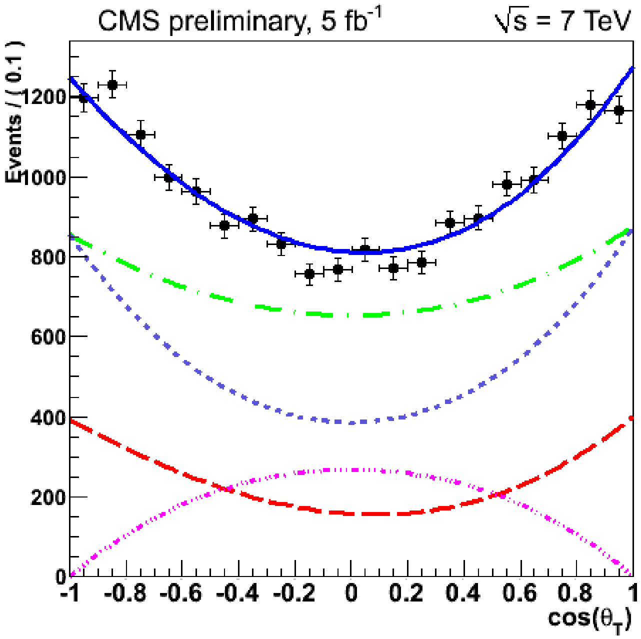
- 5 fb^{-1}, 2011 data
- 7 TeV
- J/ψ K* used for t reference
- Yield: 14456 ± 140
- Mass: 5366.8 ± 0.1 MeV.

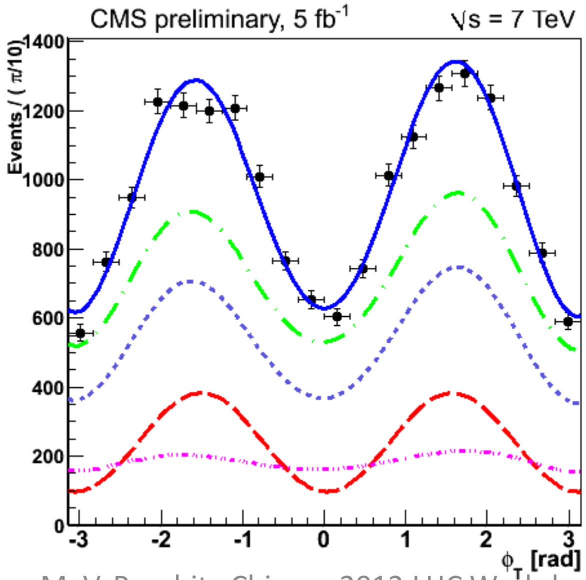
CMS: B_s Lifetime, t dependence



CMS: B_s Lifetime, Angular dependence



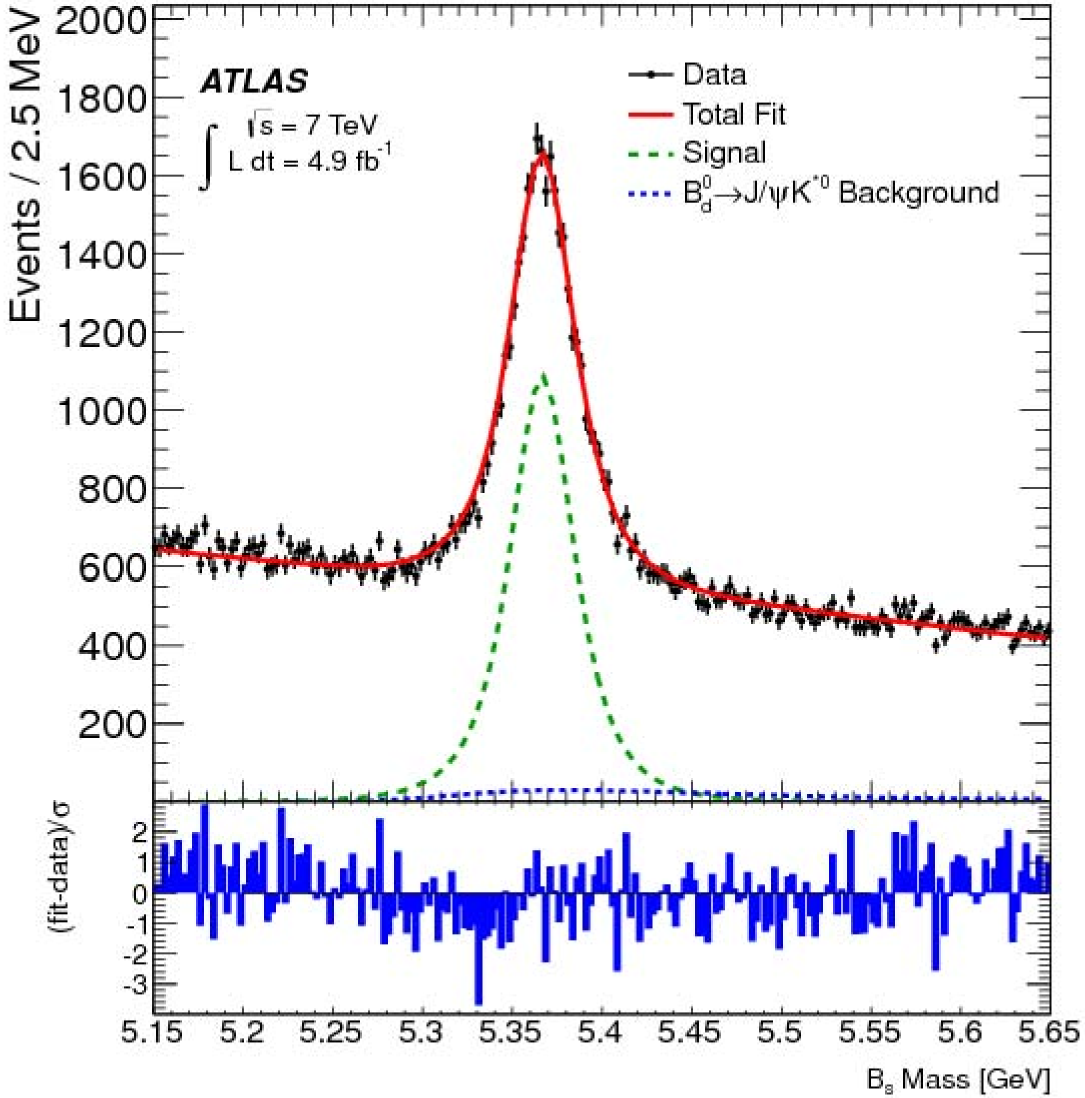




CMS: B_s Lifetime, results

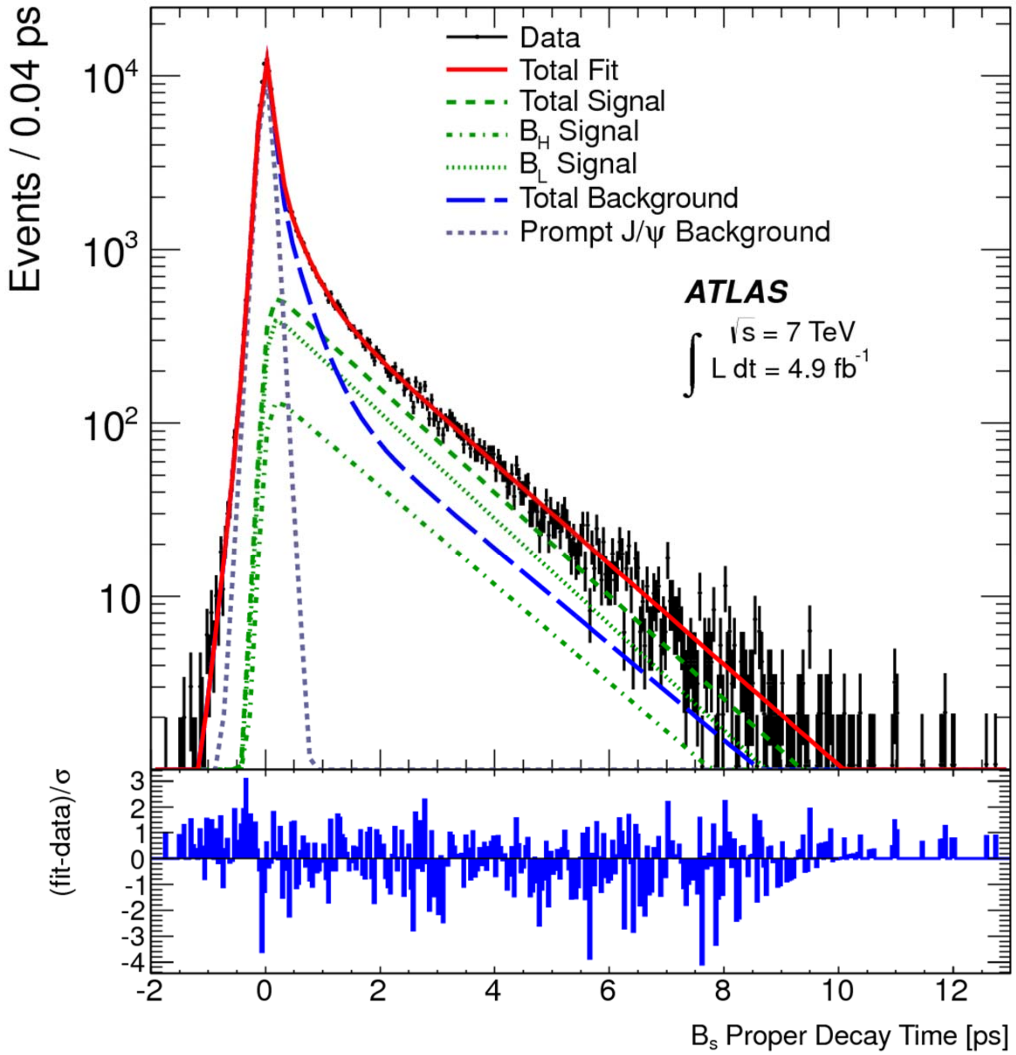
$$\begin{aligned}
\Delta\Gamma_s &= 0.048 \pm 0.024\,(\mathrm{stat.}) \pm 0.003\,(\mathrm{syst.})\,\mathrm{ps}^{-1}\,,\\
\tau_{B_s} &= 0.04580 \pm 0.00059\,(\mathrm{stat.}) \pm 0.00022\,(\mathrm{syst.})\,\mathrm{cm}\,,\\
|A_0|^2 &= 0.528 \pm 0.010\,(\mathrm{stat.}) \pm 0.015\,(\mathrm{syst.})\,,\\
|A_\perp|^2 &= 0.251 \pm 0.013\,(\mathrm{stat.}) \pm 0.014\,(\mathrm{syst.})\,,\\
\delta_{||} &= 2.79 \pm 0.14\,(\mathrm{stat.}) \pm 0.19\,(\mathrm{syst.})\,\mathrm{rad}\,.
\end{aligned}$$

ATLAS: B_s Lifetime

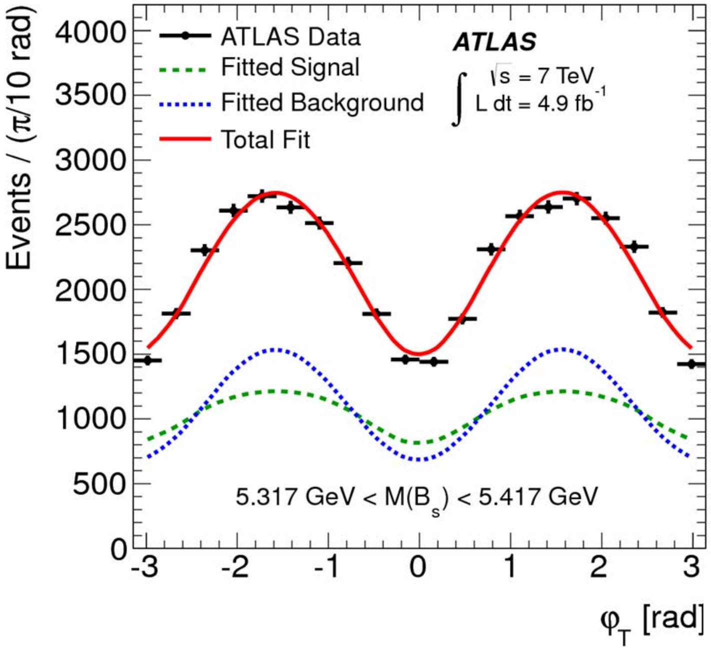


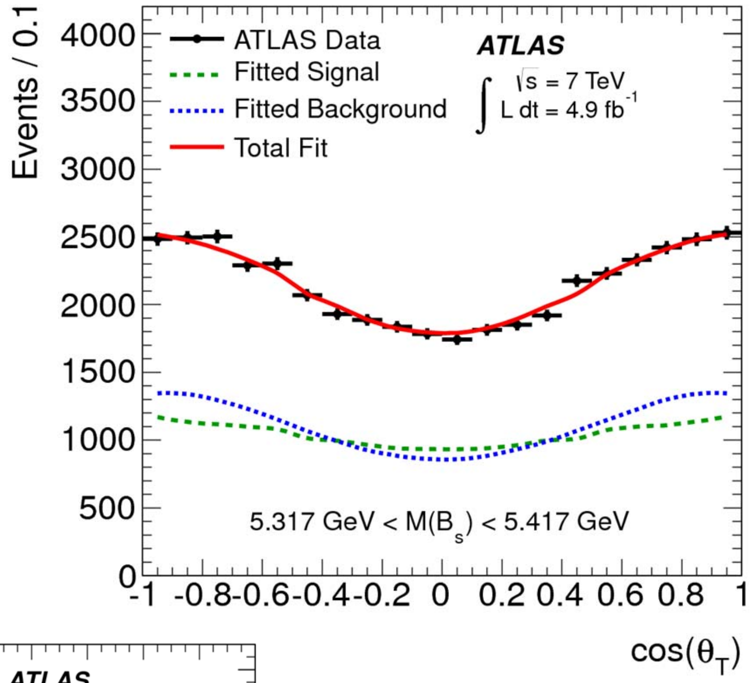
- 4.9 fb^{-1}, 2011 data
- 7 TeV
- Yield: 22690 ± 160

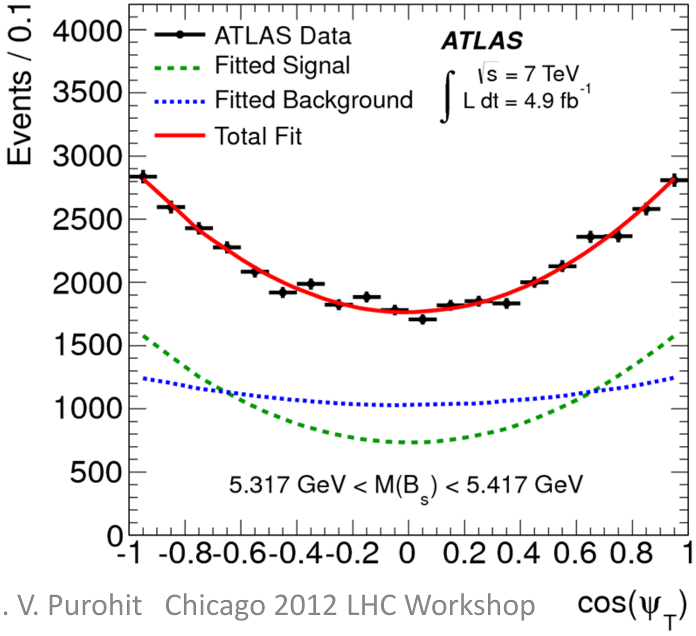
ATLAS: B_s Lifetime, t dependence



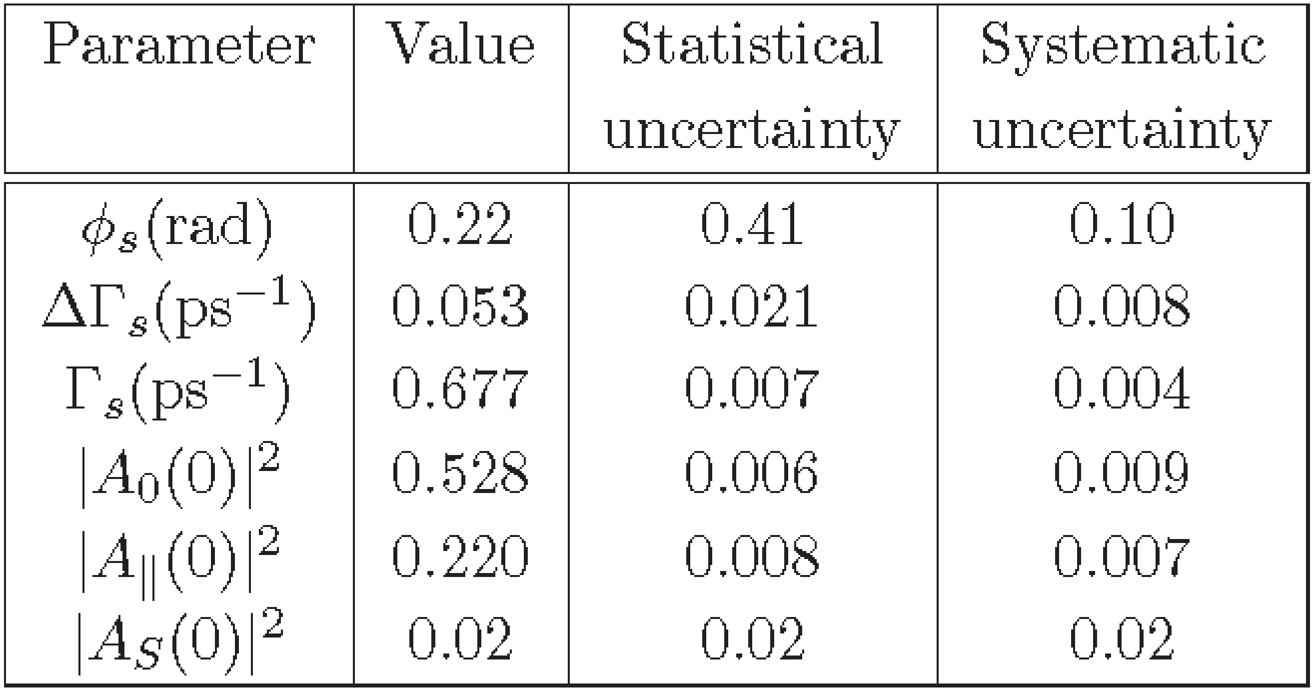
ATLAS: B_s Lifetime, angular dependence





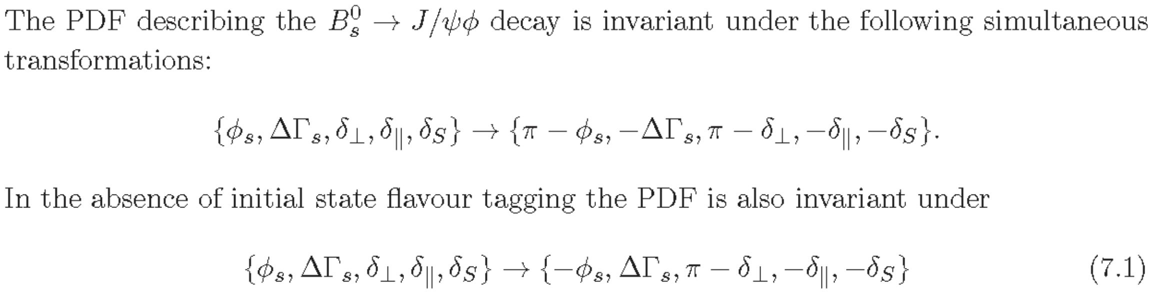


ATLAS: B_s Lifetime, results



Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s(rad)	0.22	0.41	0.10
$\Delta\Gamma_s$(ps^{-1})	0.053	0.021	0.008
Γ_s(ps^{-1})	0.677	0.007	0.004
$\|A_0(0)\|^2$	0.528	0.006	0.009
$\|A_{\|\|}(0)\|^2$	0.220	0.008	0.007
$\|A_S(0)\|^2$	0.02	0.02	0.02

The strong phase $\delta_\perp$ is taken from the LHCb measurement, as are the choices of ambiguities:



The PDF describing the $B_s^0 \to J/\psi\phi$ decay is invariant under the following simultaneous transformations:

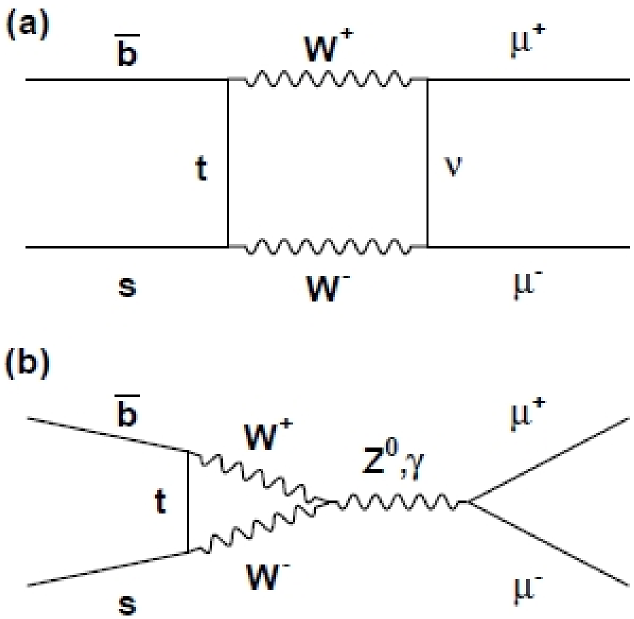
$$\{\phi_s, \Delta\Gamma_s, \delta_\perp, \delta_\|, \delta_S\} \to \{\pi - \phi_s, -\Delta\Gamma_s, \pi - \delta_\perp, -\delta_\|, -\delta_S\}.$$

In the absence of initial state flavour tagging the PDF is also invariant under

$$\{\phi_s, \Delta\Gamma_s, \delta_\perp, \delta_\|, \delta_S\} \to \{-\phi_s, \Delta\Gamma_s, \pi - \delta_\perp, -\delta_\|, -\delta_S\} \qquad (7.1)$$

$B_s^0 \rightarrow \mu^+\mu^-$ [ATLAS, CMS]

Why Search for Rare $B_s^0 \to \mu^+\mu^-$ Decays?



- Flavor changing neutral currents (FCNC) are highly suppressed in the Standard Model

$$\mathrm{BF}(\mathrm{B_s} \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

$$\mathrm{BF}(\mathrm{B_d} \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

- BF might be greatly enhanced in BSM models by $\tan^4\beta$ (2HDM) or $\tan^6\beta$ (MSSM)
- Considered golden channels for BSM physics due to very small theoretical uncertainties and high sensitivity to new physics (comparable to $\mu \to e\gamma$)

The ATLAS Search for $B_s^0 \to \mu^+\mu^-$ Decays

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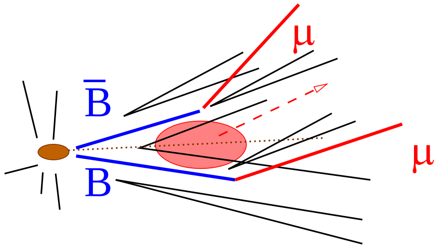
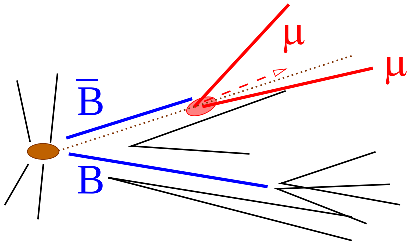
- ATLAS search features
  - – Integrated luminosity of 2.4 fb^{-1} from 7 TeV, 2011.
  - – Mass resolution:
    - ATLAS: $\sigma_{B \to \mu\mu} \sim 60$ (barrel) – 110 (forward) MeV
- Main background sources:
  - continuum with smooth di-muon invariant mass
    - – estimated from sidebands
    - – dominant background contribution
  - contribution from hadrons misidentified as muons
    - – irreducible background, estimated using MC





ATLAS Search for $B_s^0 \to \mu^+\mu^-$: Selection and Technique

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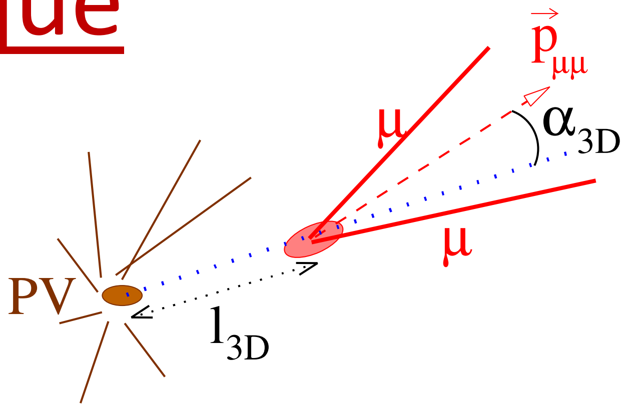
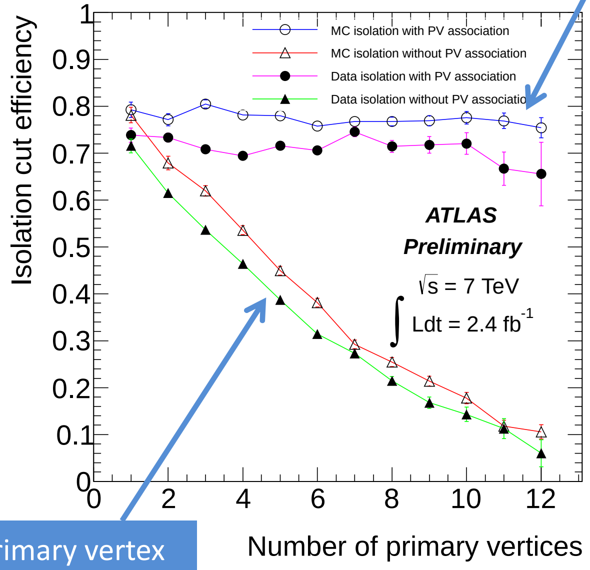
- Event selection based on decay topology
  - use boosted decision tree (BDT) classifier calculated with 14 input variables: α_{2D}, ΔR, L_{xy}, ct significance, χ^2_{xy}, χ^2_z, isolation, …
  - selection independent of number of primary vertices
- Calculate branching ratio with respect to the high statistics decay mode $B^\pm \to J/\psi\, K^\pm$



with primary vertex association

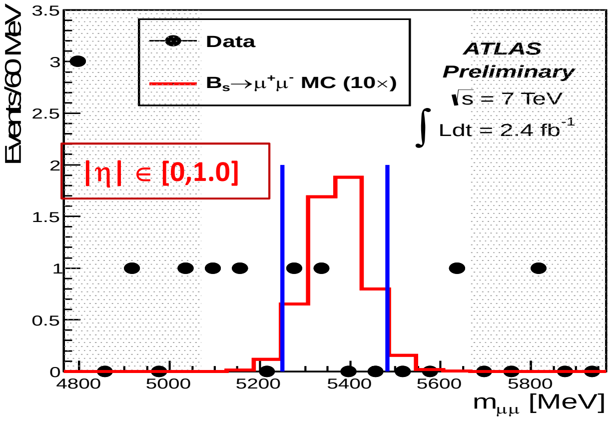


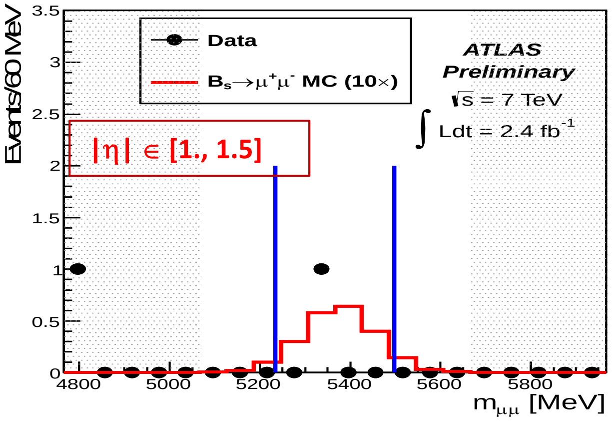
without primary vertex association

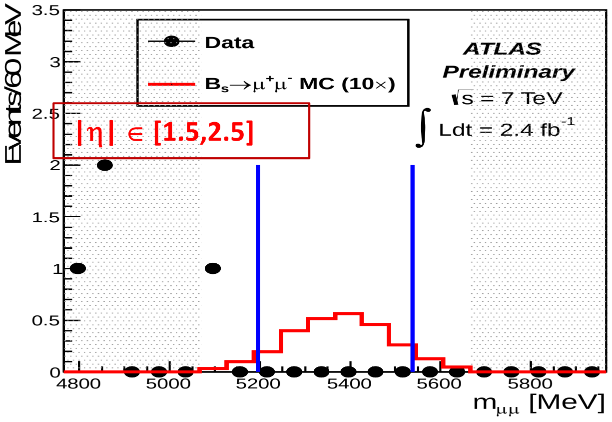
ATLAS Search for $B_s^0 \to \mu^+\mu^-$ Decays: Backgrounds

- Optimization and estimation of background events performed on different sideband event samples using $\varepsilon_{sig} / (1 + \sqrt{B})$
  - avoid bias on expected limit
- Use different categories in mass resolution (in η)
- MC shown (red) assumes BF = 3.5×10^{-8}

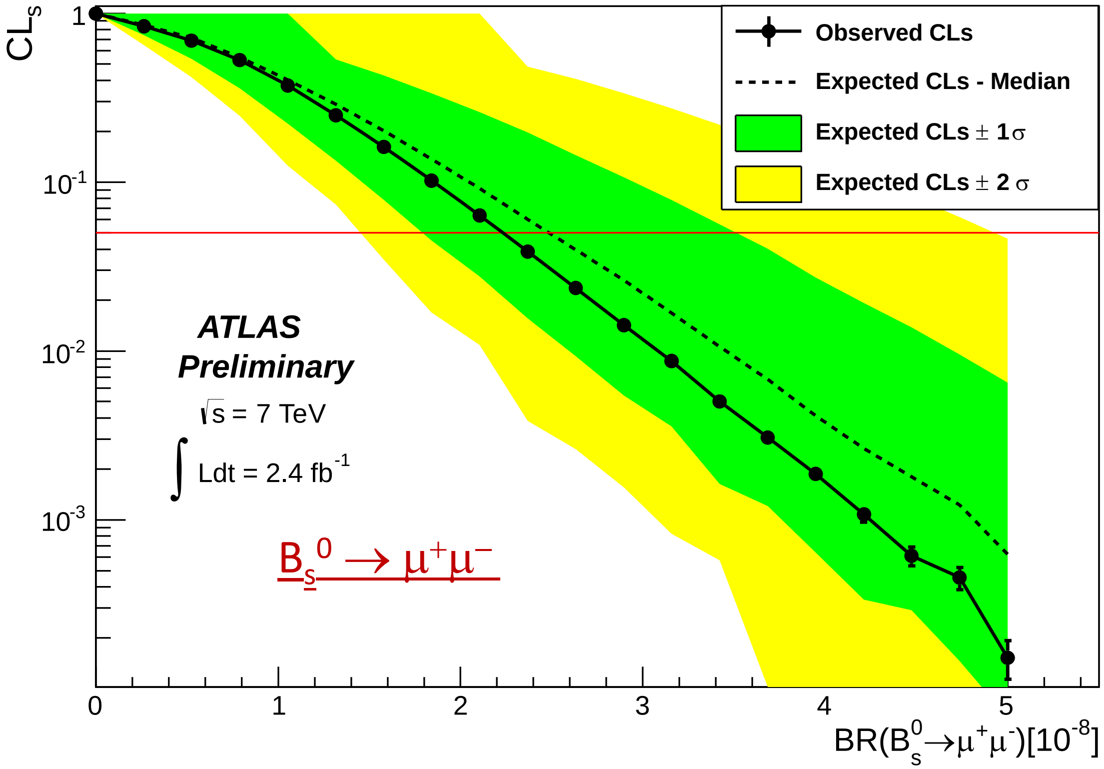
|η| Range	0-1.0	1.0-1.5	1.5-2.5
Sideband count N_{bg} (even numbered events)	5	0	2
bkg. scaling factor	1.29	1.14	0.88
expected resonant bg	0.1	0.06	0.08
search region count N_{sig}	2	1	0







ATLAS Search for Rare Decays: Results



ATLAS: $BF(B_s \to \mu^+\mu^-) < 2.2 \times 10^{-8}$ (2.4 fb^{-1})

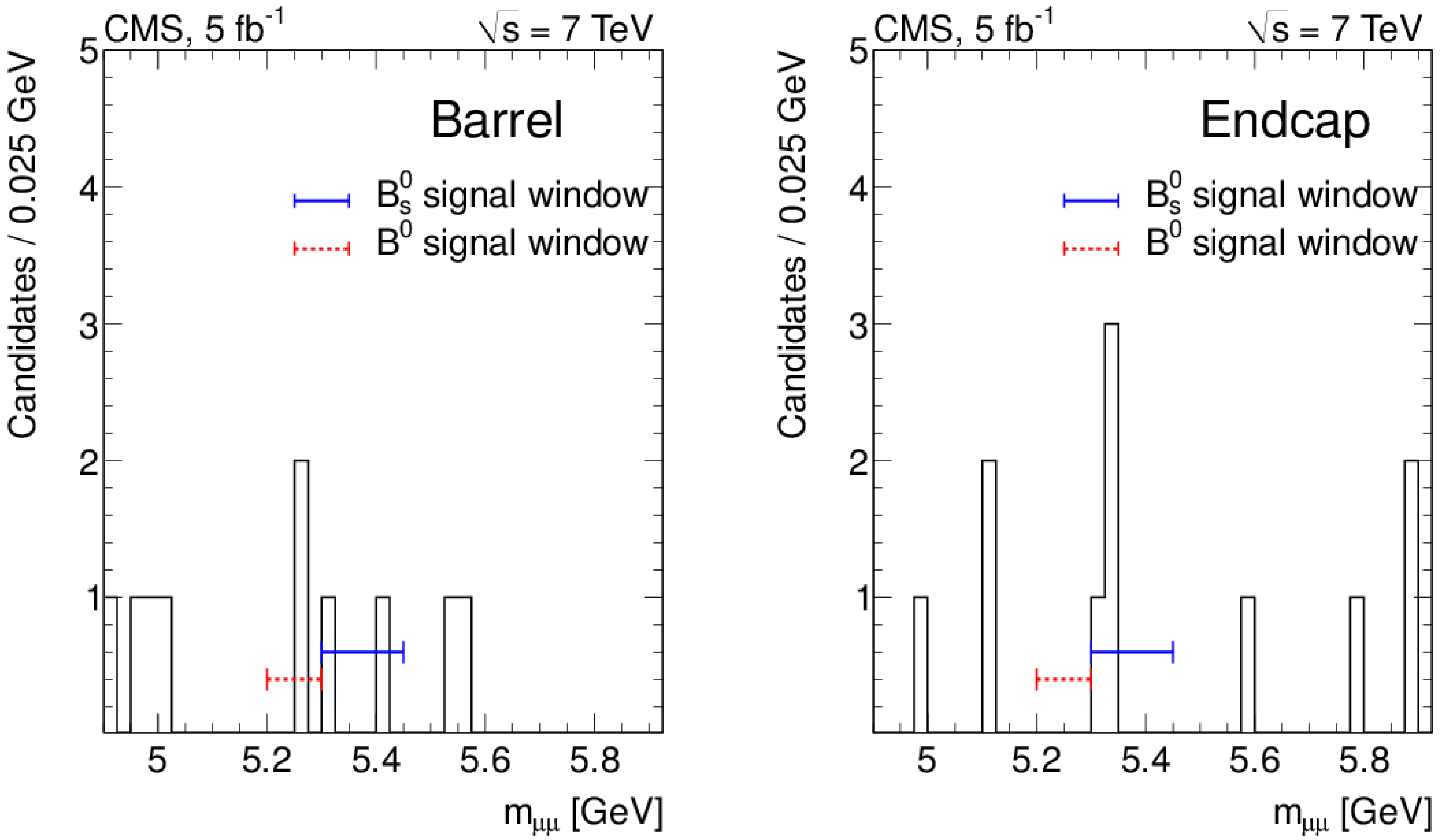
CMS: $BF(B_s \to \mu^+\mu^-) < 7.7 \times 10^{-9}$ (4.9 fb^{-1})

LHCb: $BF(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9}$ (1 fb^{-1})

(all at 95% CL)

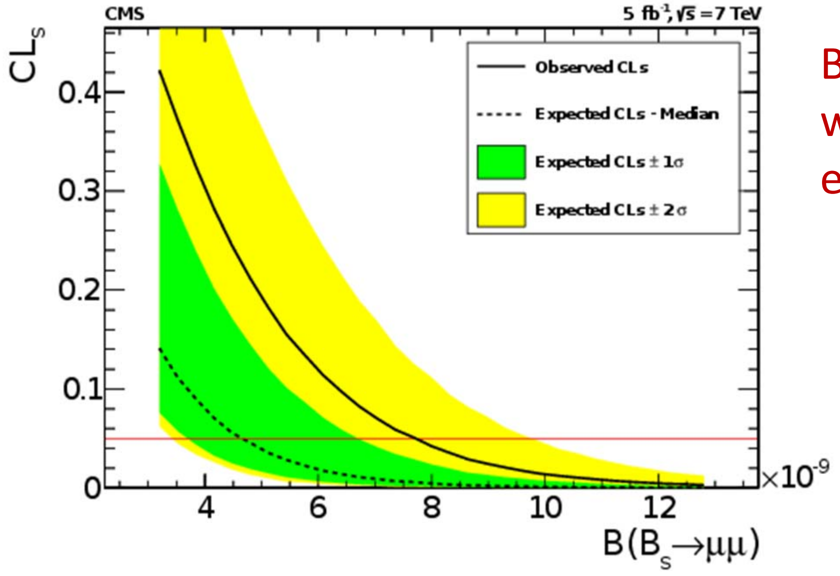
- No excess of signal events over expected background observed
  - limit on branching ratio
  - Median expected limit that contains 68% of background-only pseudo-experiments: BF_{exp}: $(2.3^{+1.0}_{-0.5}) \times 10^{-8}$
- Measurement consistent with expectation from SM (BF_{SM}: $(3.5 \pm 0.3) \times 10^{-9}$)

CMS Search for Rare Decays: Mass



(all at 95% CL)

CMS Search for Rare Decays: Results



$B_s^0 \to \mu^+\mu^-$ with bkg only expectation

- No excess of signal events over expected background observed
- Measurement consistent with $B_s^0 \to \mu^+\mu^-$ expectation from SM (BF$_{SM}$: $(3.5 \pm 0.3) \times 10^{-9}$)
- Results have been combined with ATLAS and LHCb data to yield best limits

- CMS: BF($B_s \to \mu^+\mu^-$) < 7.7 x 10^{-9} (4.9 fb^{-1})
- CMS: BF($B_d \to \mu^+\mu^-$) < 1.8 x 10^{-9} (4.9 fb^{-1})
- Combined: BF($B_s \to \mu^+\mu^-$) < 4.2 x 10^{-9}
- Combined: BF($B_d \to \mu^+\mu^-$) < 8.1 x 10^{-9}

(all at 95% CL)

SUMMARY: [ATLAS, CMS]

Summary

- Measurements of heavy quark production cross sections allow precise studies of QCD: differential p_T distribution measured, excess observed at high p_T
- Observation of $\chi_b(3P)$ by ATLAS:

  m = 10.530 ± 0.005 (stat.) ± 0.009 (syst.) GeV/c^2.
- Observation of Ξ_b^{*0} by CMS:

  Q peak at 14.84 ± 0.74 ± 0.26 MeV.
- Λ_b mass and lifetime measured by ATLAS, consistent with world averages
- CMS observes $J/\Psi\ \pi^+$ and $J/\Psi\ \pi^+\pi^+\pi^-$ modes of B_c decay
- ATLAS and CMS have measured parameters $\Delta\Gamma_s$, amplitudes in B_s decays
- No sign yet of the rare decays $B_s \rightarrow \mu^+\mu^-$:

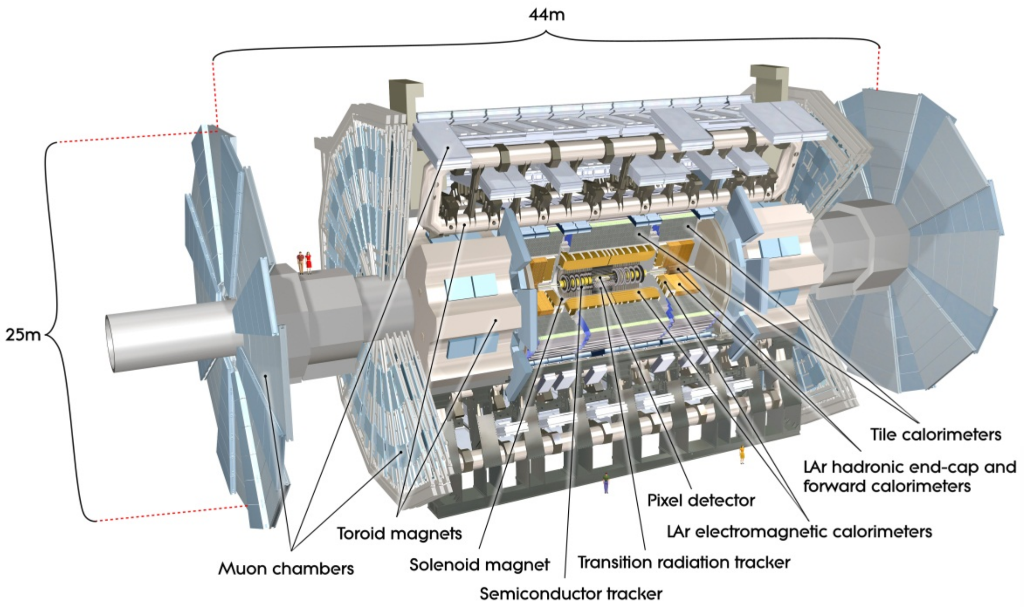
  $BF(B_s \rightarrow \mu^+\mu^-) < 2.2 \times 10^{-8}$ ($2.4\ fb^{-1}$), 95% CL: ATLAS

  $BF(B_s \rightarrow \mu^+\mu^-) < 7.7 \times 10^{-9}$ ($4.9\ fb^{-1}$), 95% CL: CMS

ADDITIONAL SLIDES

Detector and Data

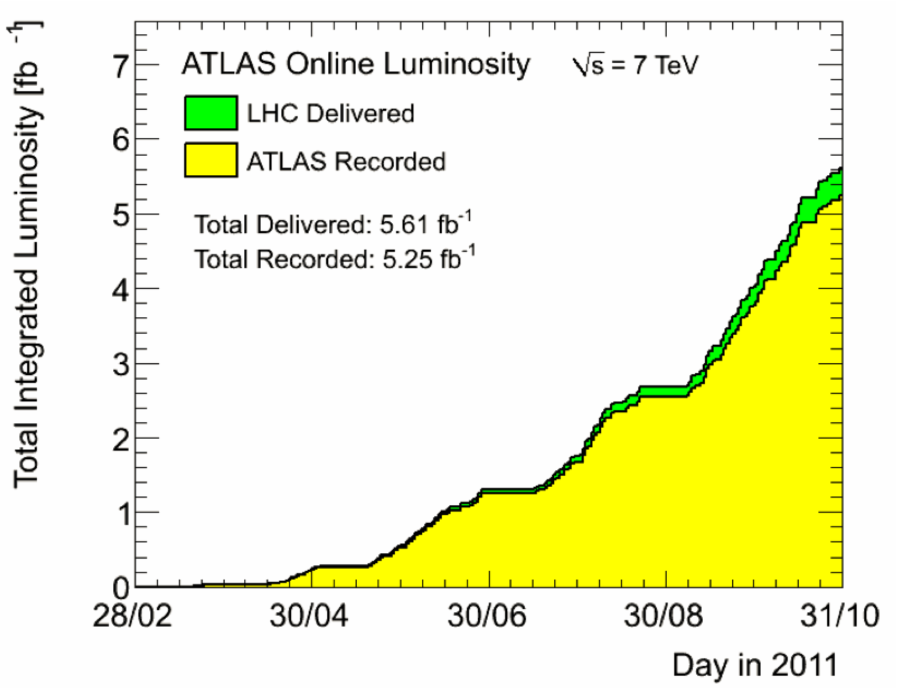
ATLAS



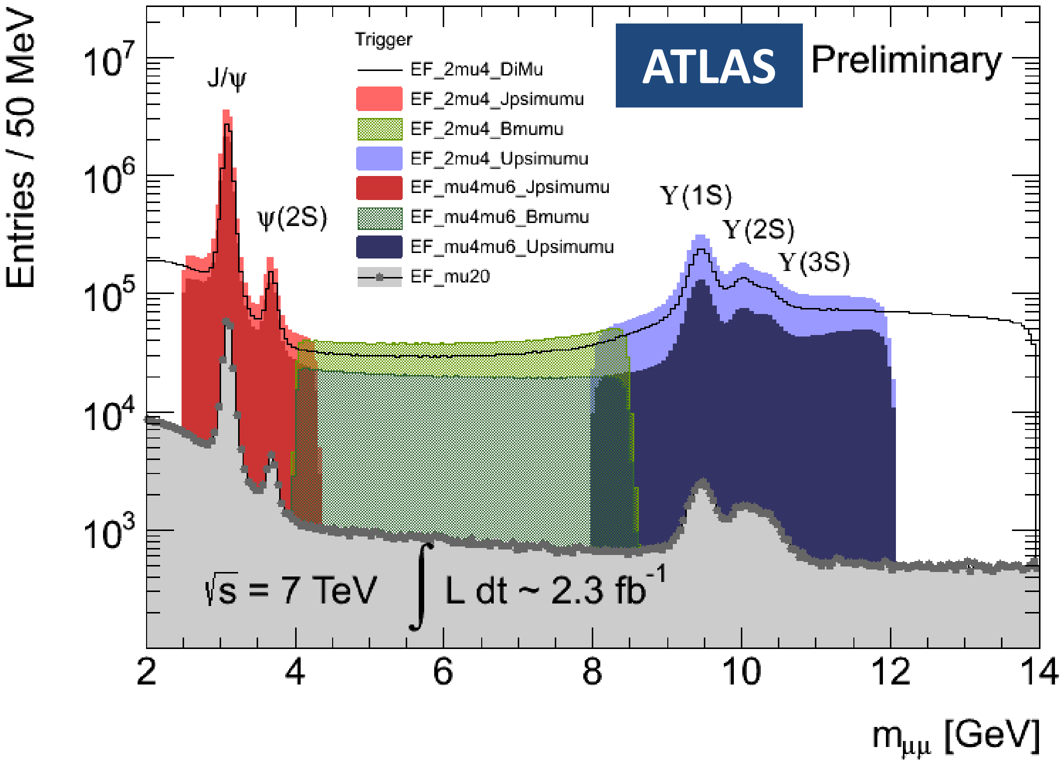
- 2T solenoid field, 0.5-2T toroid field
- 10 μm impact parameter for tracks
- $\sigma(p_T)/p_T$ ~ 0.05% $p_T \oplus$ 1.5%
- $\sigma(m)$ (J/ψ-ϒ) ~ 45-120 MeV (ID dominated)

- Max inst. luminosity is ≈ 3.5 x 10^{33} cm^{-2} s^{-1}

  (up to 12 collisions / event on average)
- Integrated luminosity about 5.2 fb^{-1} per experiment in 2011
- Instantaneous luminosity and pile-up steadily increasing



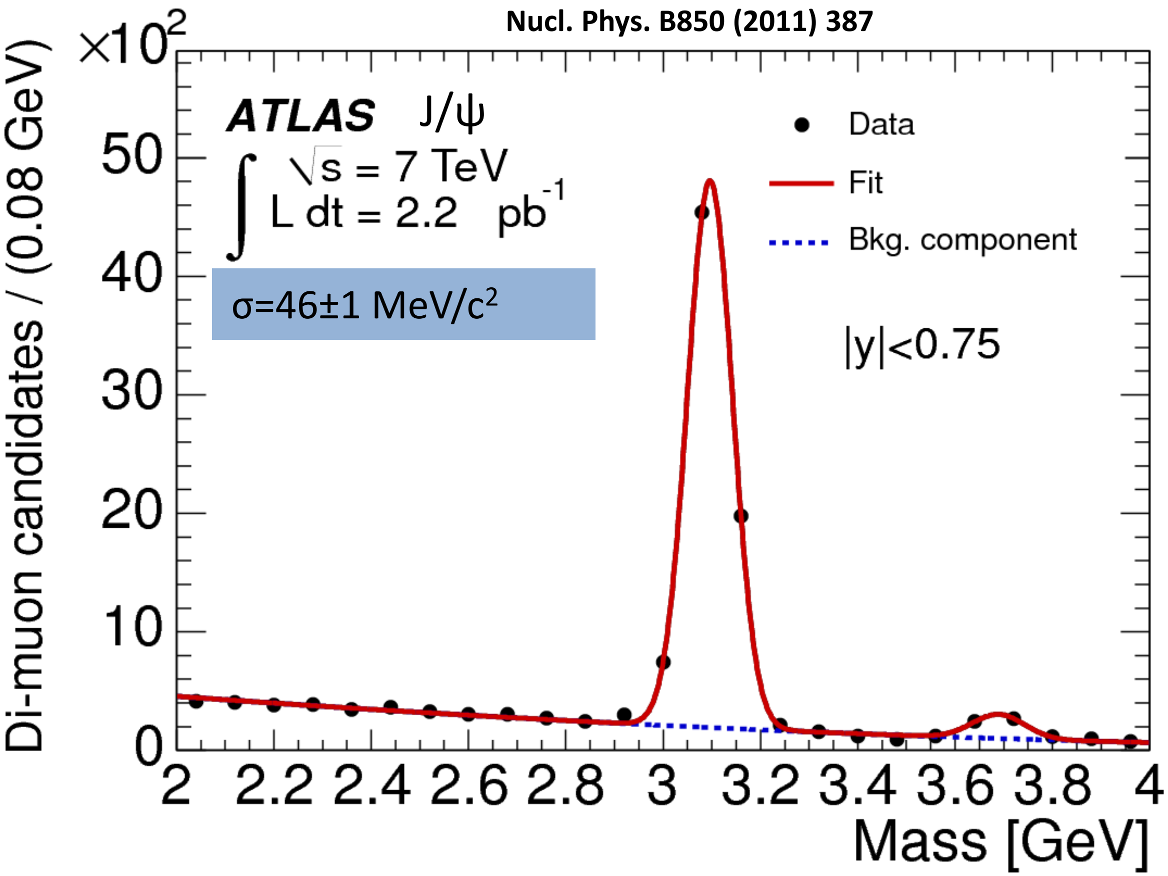
Di-μ Trigger for low p_T b hadron Events



Trigger name example: EF_mu4mu6_ denotes dimuon triggers at level 1, confirmed at the high level trigger, with one object passing a threshold of 4 GeV and the other 6 GeV. Jpsimumu, Bmumu, Upsimumu and DiMu denote coarse invariant mass windows in the regions of the J/ψ (2.5-4.3 GeV), Bs (4-8.5 GeV) and Upsilon (8-12 GeV) and the combined range of all three (1.5-14GeV) respectively, as calculated using the trigger objects.

- Higher luminosity required a dimuon trigger
- Constant trigger thresholds for B physics all across 2011
- Trigger efficiency: As an example, for the Υ(1S) production measurement the average trigger efficiency for the selected dimuon events lies between 80% and 95%.

Mass Resolution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- Excellent mass resolution required for good S/B performance
- Limited particle ID for hadrons (K/π separation for $p_T < 1$ GeV/c)

Impact Parameter Resolution

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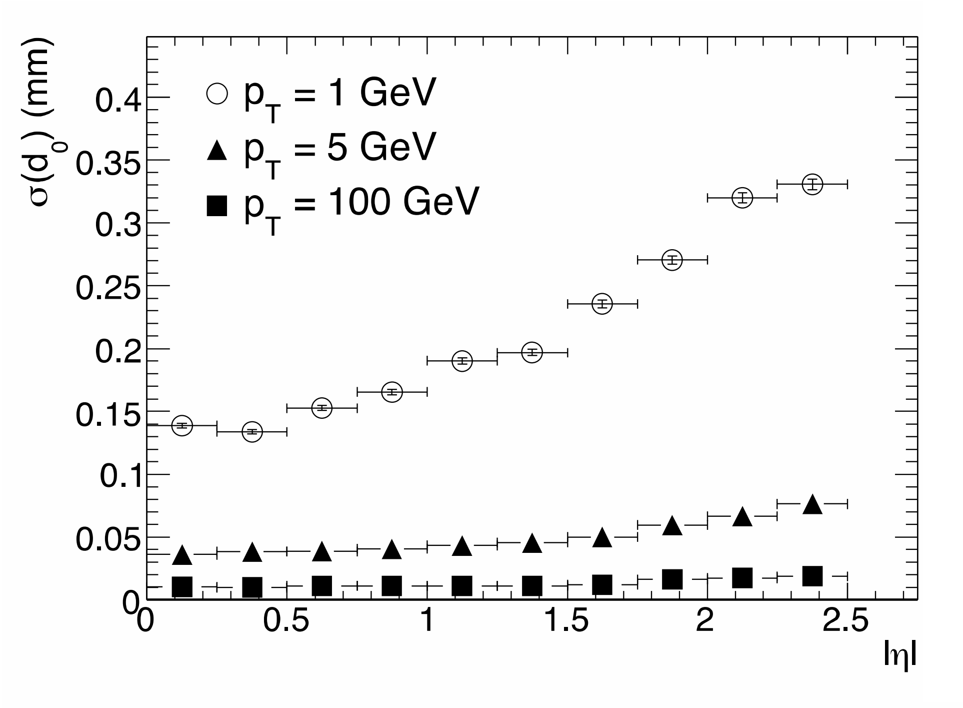
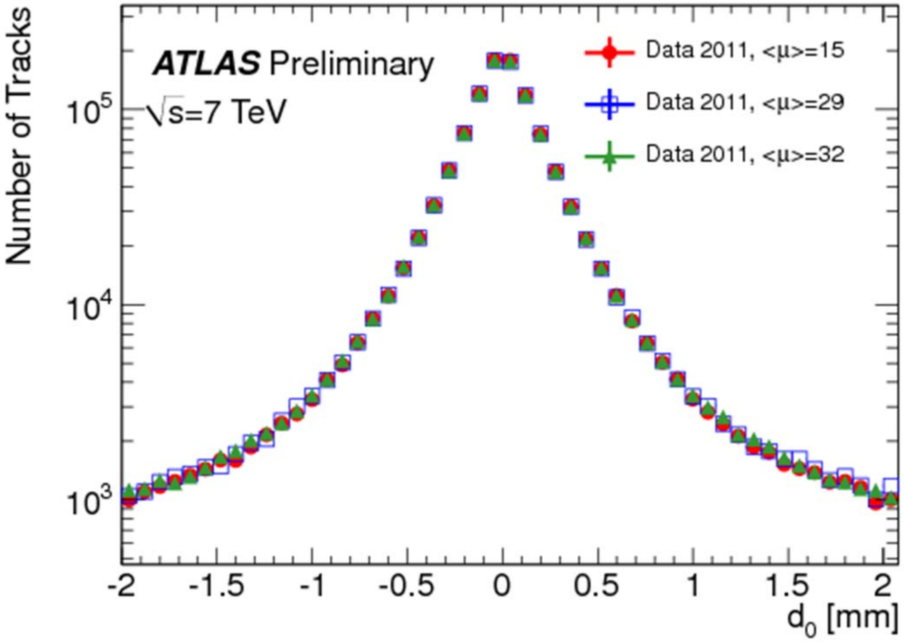
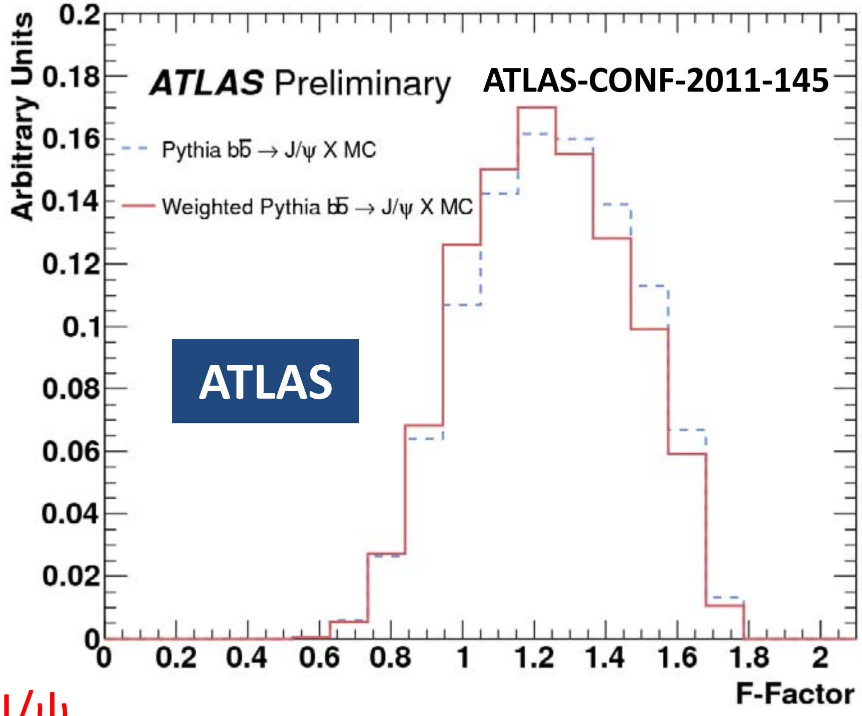




- Good impact parameter resolution required for lifetime based measurement

- Impact parameter distributions not seriously impacted by pileup

B Lifetime Measurements: Inclusive Technique



- Average B Lifetime using

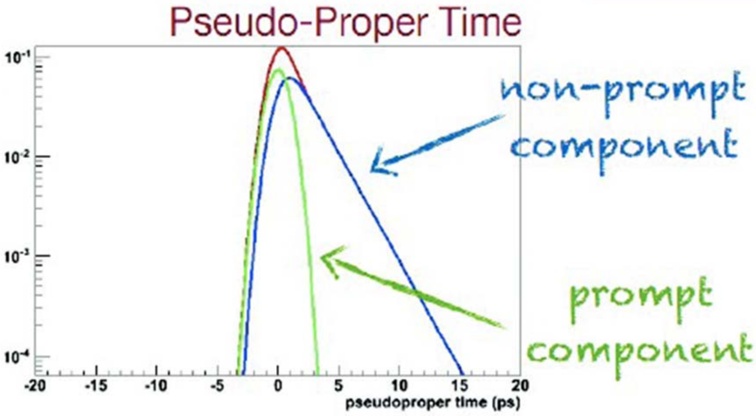
$$B_x \rightarrow J/\psi X \rightarrow \mu^+\mu^- X$$

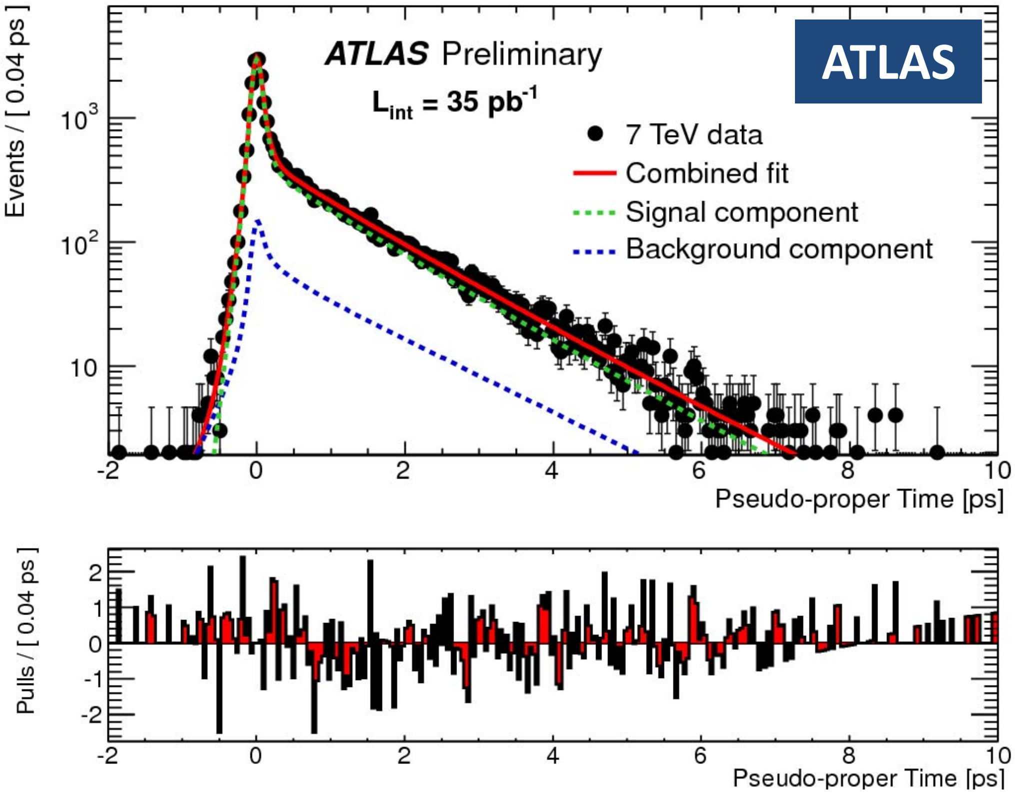
- Use pseudo proper time:

$$\tau_B = \frac{L_{XY}\cdot m_B^{PDG}}{p_T(B)} = \frac{L_{XY}\cdot m_{J/\psi}^{PDG}}{p_T(J/\psi)}\cdot\boxed{F}$$

- J/ψ carries only part of the initial p_T of the B-Meson
  - correction factor F to take into account momentum difference between B and J/ψ determined from MC weighted according to BaBar
  - When this is done, the difference in the mean p* distribution of J/ψ mesons in B decays from Pythia and BaBar data drops from 0.076 GeV to 0.003 GeV.

B Lifetime Measurement: Inclusive Result





- Main systematic uncertainty for preliminary measurement:
  - time background model
  - residual misalignment
- Ongoing study with 2011 data will reduce very significantly the systematic uncertainties on the lifetime
- no lifetime bias in trigger selection

$\langle\tau_B\rangle$ = 1.489 ± 0.016 (stat.) ± 0.043 (syst.) ps

[PDG: 1.568 ± 0.009 ps, dominated by LEP.
CDF B^+: 1.639 ± 0.009 (stat) ± 0.009 (syst) ps,
CDF B^0: 1.507 ± 0.010 (stat) ± 0.008 (syst) ps.]

B Lifetime Measurement: Exclusive Result

- Measure lifetime of exclusive reconstructed events:

$B_d \rightarrow J/\psi K^{*0}$ and $B_S \rightarrow J/\psi\phi$

- Detector performance well understood
- Important milestone for measurement of CPV parameter β_s

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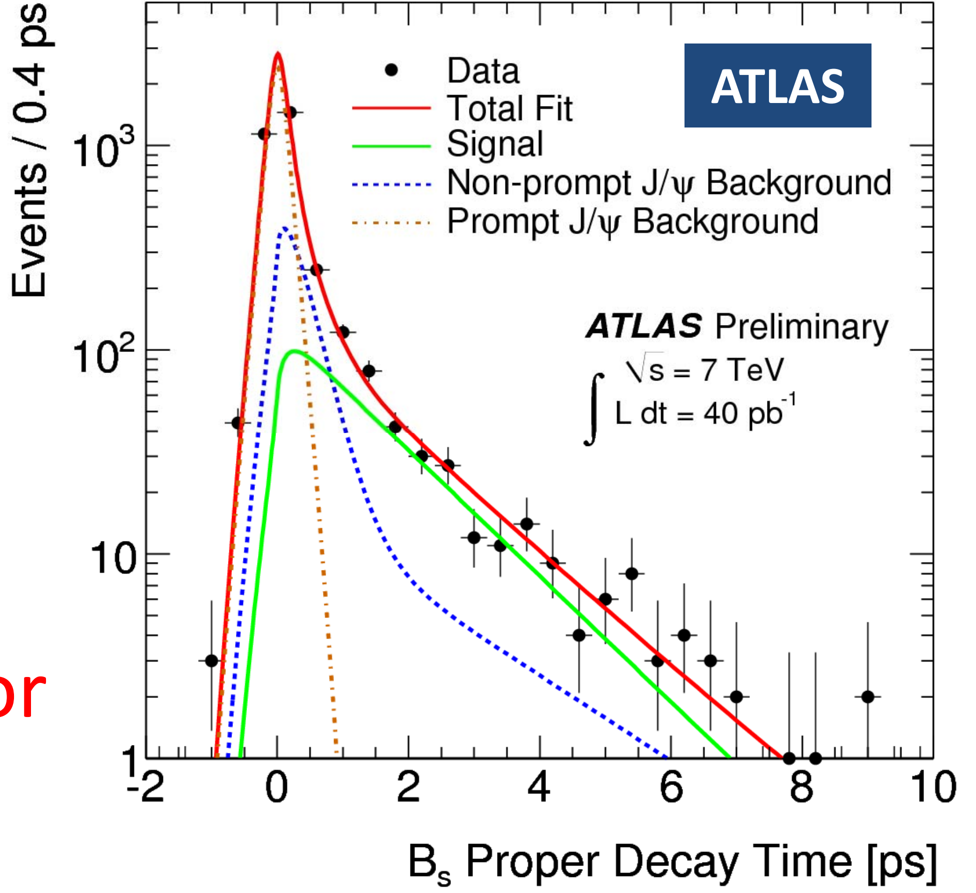
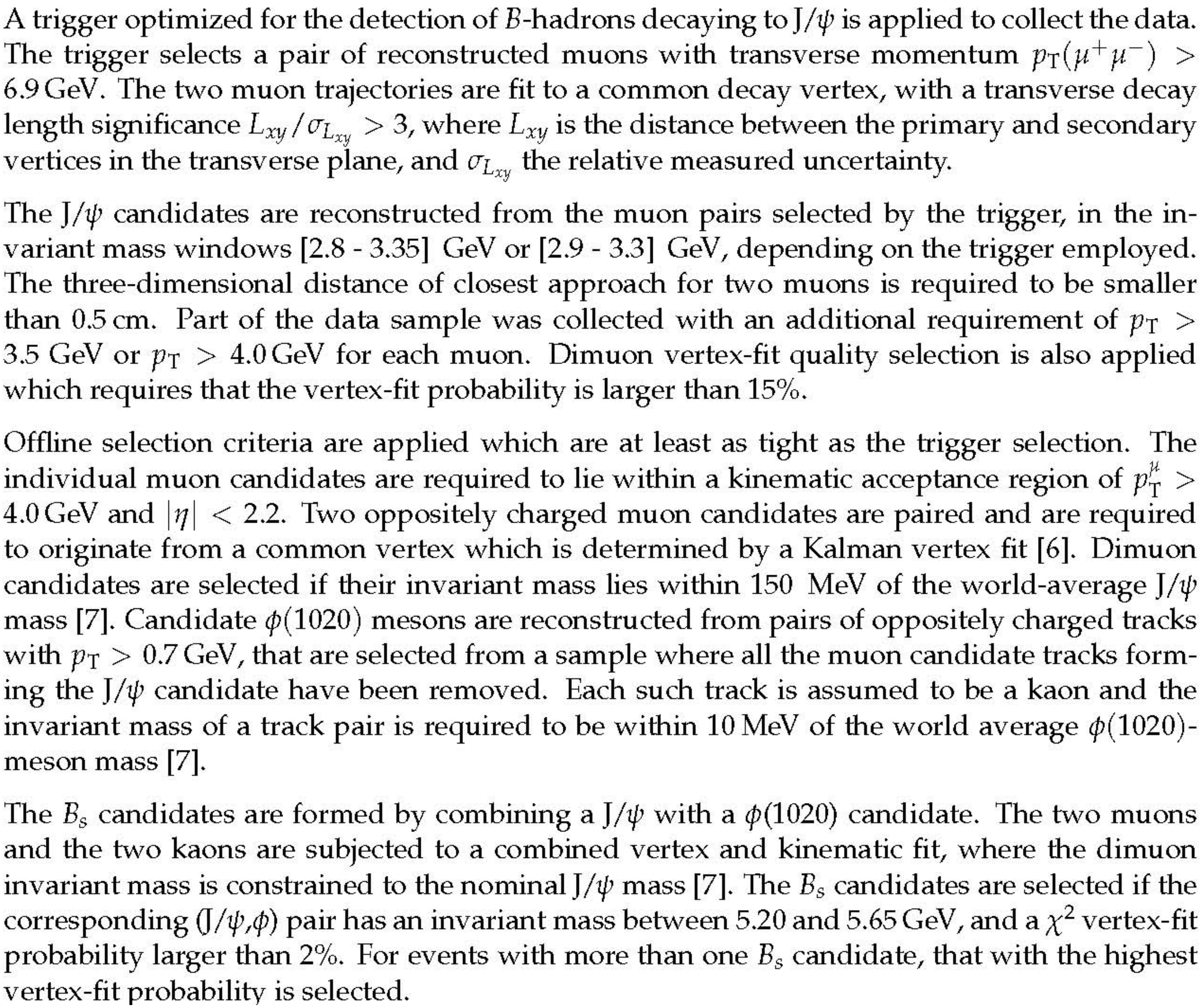


τ_{Bs} = 1.41 ± 0.08 (stat.) ± 0.05 (syst.) ps

PDG: $1.472^{+0.024}_{-0.026}$ ps

CMS: B_s Lifetime, Event Selection



A trigger optimized for the detection of B-hadrons decaying to J/ψ is applied to collect the data. The trigger selects a pair of reconstructed muons with transverse momentum $p_T(\mu^+\mu^-) > 6.9\,\text{GeV}$. The two muon trajectories are fit to a common decay vertex, with a transverse decay length significance $L_{xy}/\sigma_{L_{xy}} > 3$, where L_{xy} is the distance between the primary and secondary vertices in the transverse plane, and $\sigma_{L_{xy}}$ the relative measured uncertainty.

The J/ψ candidates are reconstructed from the muon pairs selected by the trigger, in the invariant mass windows [2.8 - 3.35] GeV or [2.9 - 3.3] GeV, depending on the trigger employed. The three-dimensional distance of closest approach for two muons is required to be smaller than 0.5 cm. Part of the data sample was collected with an additional requirement of $p_T > 3.5$ GeV or $p_T > 4.0\,\text{GeV}$ for each muon. Dimuon vertex-fit quality selection is also applied which requires that the vertex-fit probability is larger than 15%.

Offline selection criteria are applied which are at least as tight as the trigger selection. The individual muon candidates are required to lie within a kinematic acceptance region of $p_T^{\mu} > 4.0\,\text{GeV}$ and $|\eta| < 2.2$. Two oppositely charged muon candidates are paired and are required to originate from a common vertex which is determined by a Kalman vertex fit [6]. Dimuon candidates are selected if their invariant mass lies within 150 MeV of the world-average J/ψ mass [7]. Candidate $\phi(1020)$ mesons are reconstructed from pairs of oppositely charged tracks with $p_T > 0.7\,\text{GeV}$, that are selected from a sample where all the muon candidate tracks forming the J/ψ candidate have been removed. Each such track is assumed to be a kaon and the invariant mass of a track pair is required to be within 10 MeV of the world average $\phi(1020)$-meson mass [7].

The B_s candidates are formed by combining a J/ψ with a $\phi(1020)$ candidate. The two muons and the two kaons are subjected to a combined vertex and kinematic fit, where the dimuon invariant mass is constrained to the nominal J/ψ mass [7]. The B_s candidates are selected if the corresponding $(J/\psi,\phi)$ pair has an invariant mass between 5.20 and 5.65 GeV, and a χ^2 vertex-fit probability larger than 2%. For events with more than one B_s candidate, that with the highest vertex-fit probability is selected.