b hadron properties and decays (ATLAS)

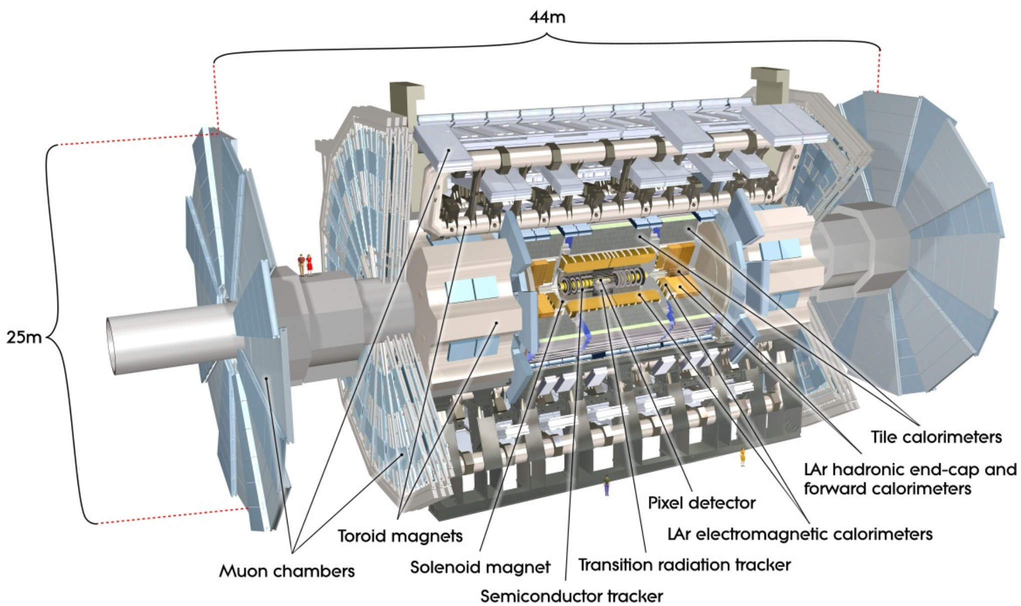
Milind V. Purohit
Univ. of South Carolina, USA
for the ATLAS collaboration

Outline

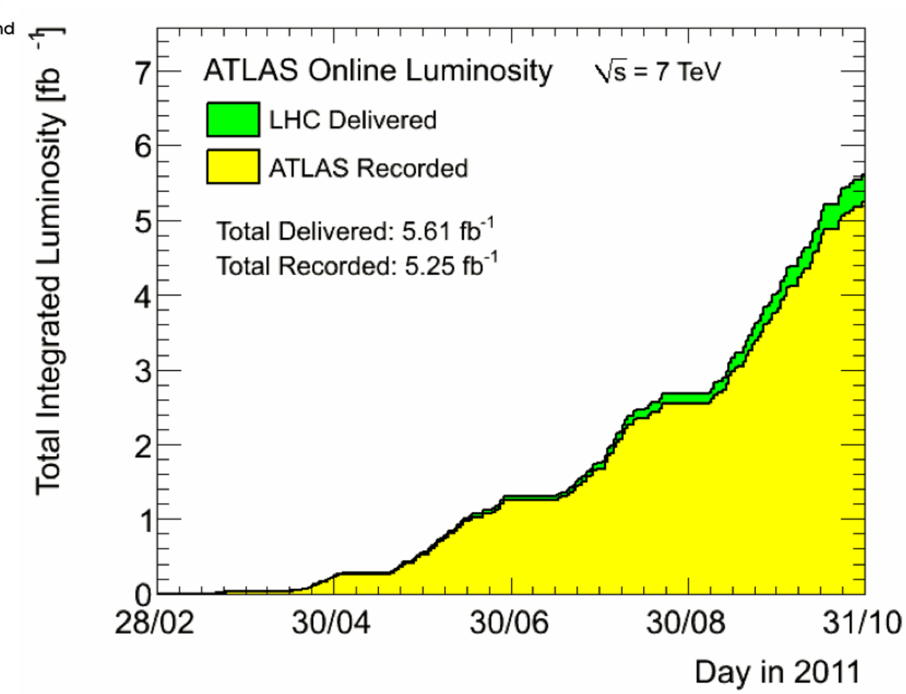
- Detector, Di-muon trigger,
  Performance: Mass, vertex resolutions
- Quarkonium, Upsilon (1S) production
- Observation of a new $\chi_b(3P)$ state
- B lifetime measurements
- Search for Rare Decays
- Conclusion

Detector and Data

ATLAS

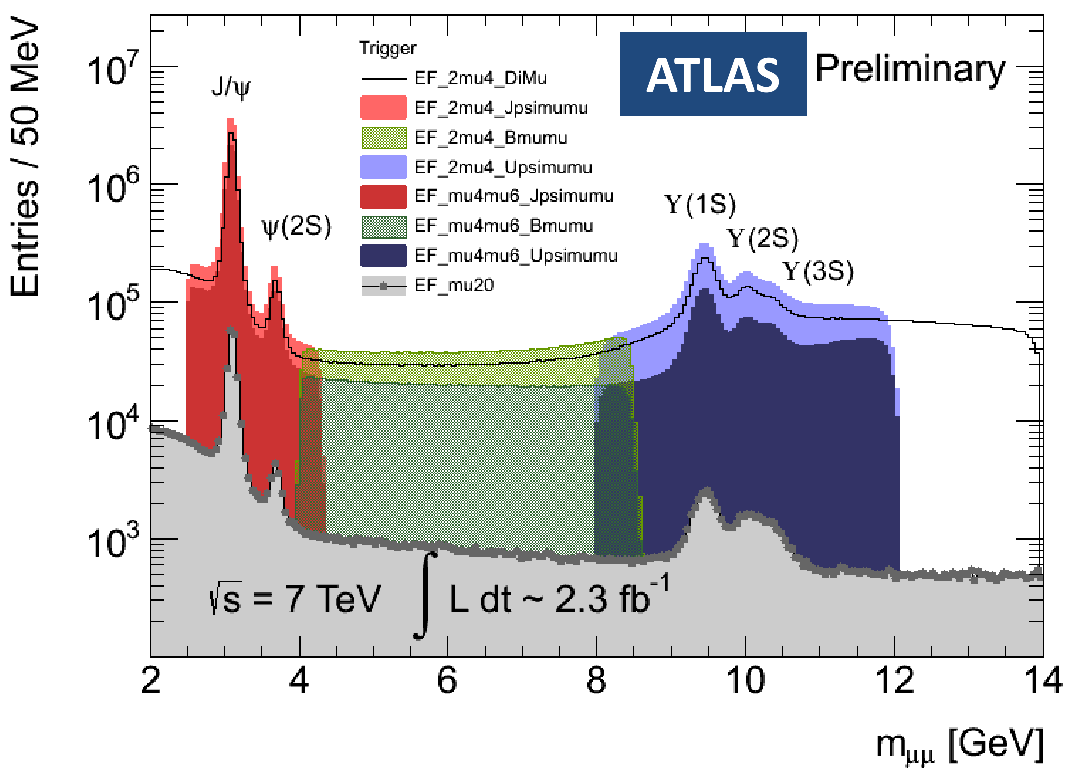


- 2T solenoid field, 0.5-2T toroid field
- 10 μm impact parameter for tracks
- $\sigma(p_T)/p_T \sim 0.05\%\ p_T \oplus 1.5\%$
- σ(m) (J/ψ-ϒ) ~ 45-120 MeV (ID dominated)



- 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

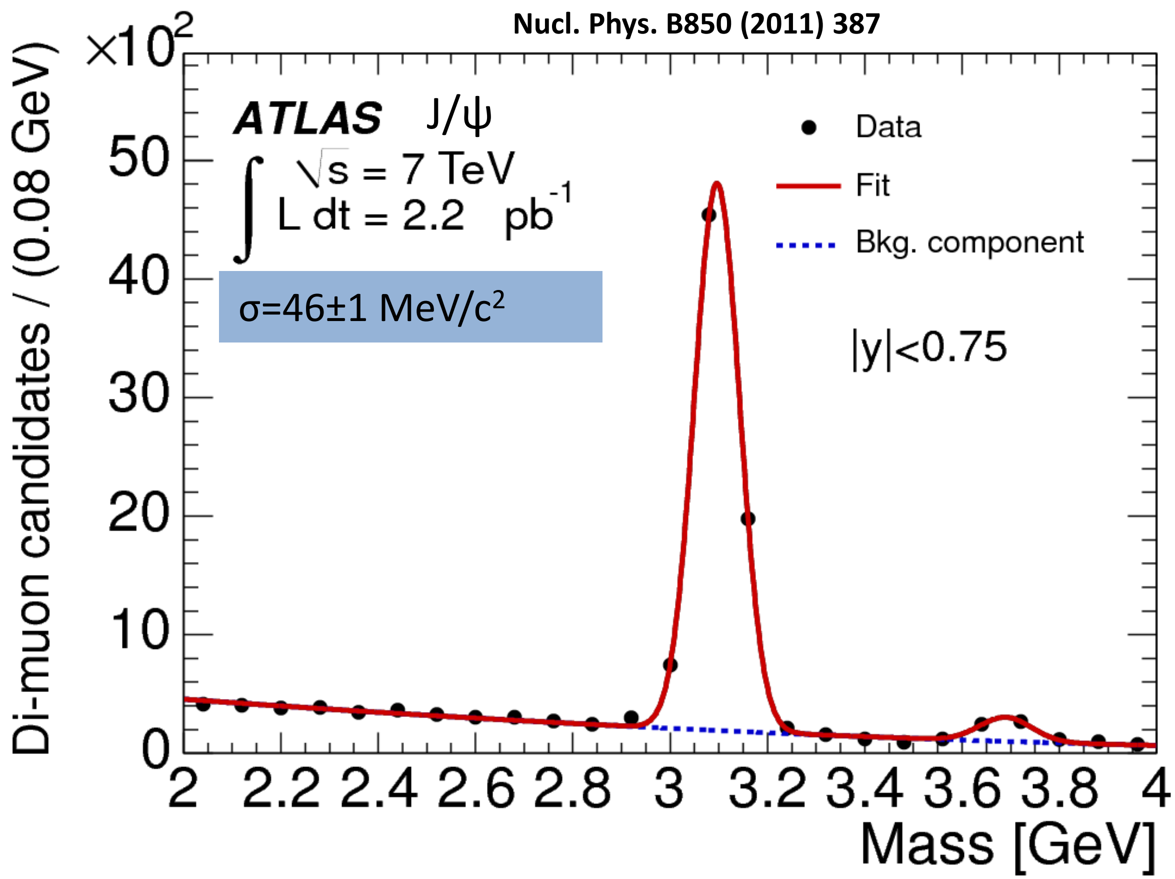


Trigger name example: EF_mu4mu6_ denotes dimuon triggers at level 1, confirmed at the high level trigger, with one object passing a threshold of 4 GeV and the other 6 GeV. Jpsimumu, Bmumu, Upsimumu and DiMu denote coarse invariant mass windows in the regions of the J/ψ (2.5-4.3 GeV), Bs (4-8.5 GeV) and 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

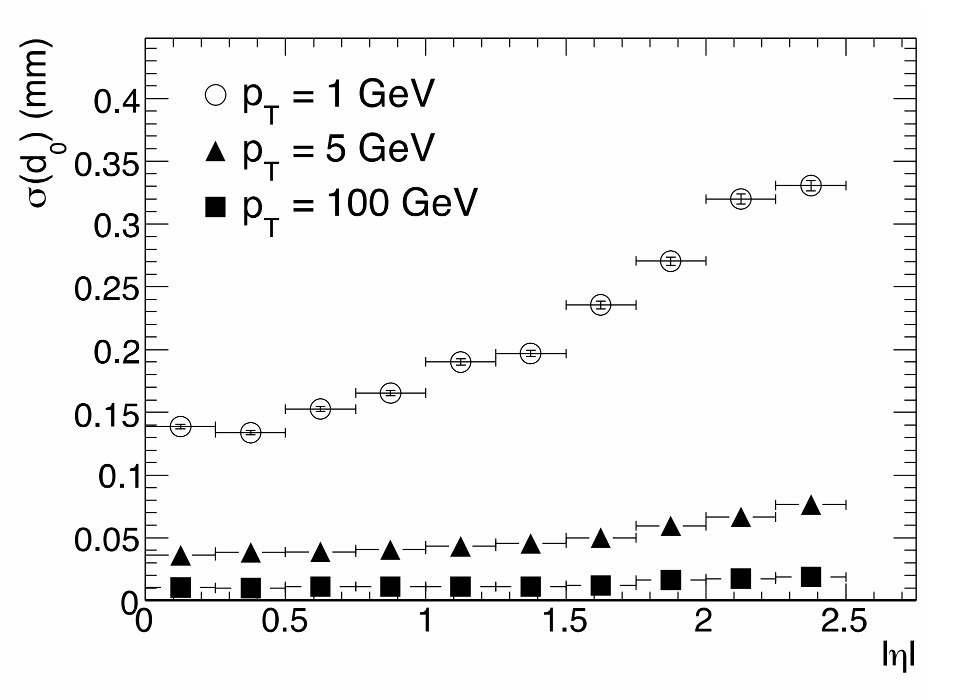
Nucl. Phys. B850 (2011) 387



- 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

2008 JINST 3 S08003



- Good impact parameter resolution required for lifetime based measurement

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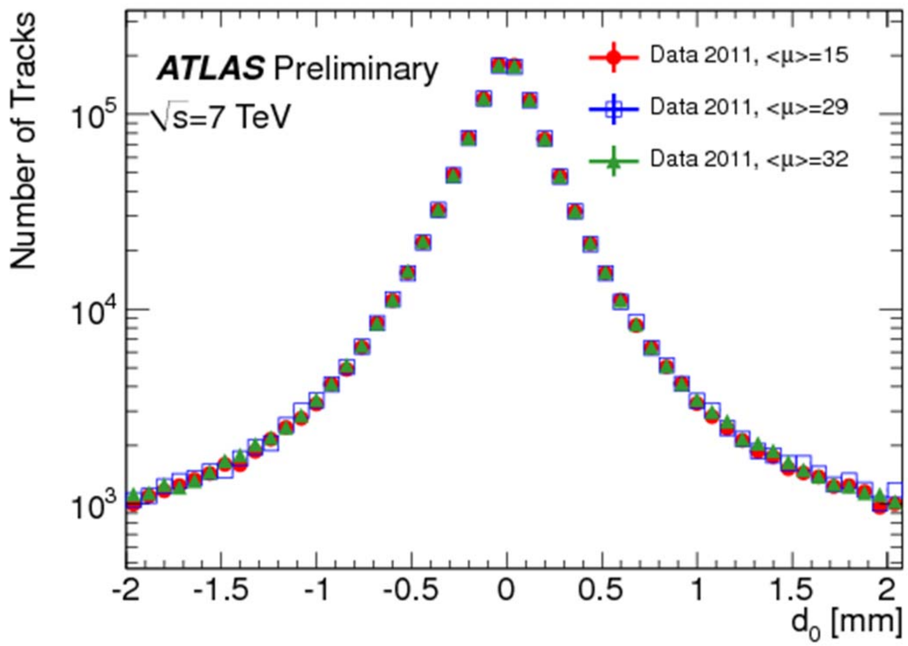
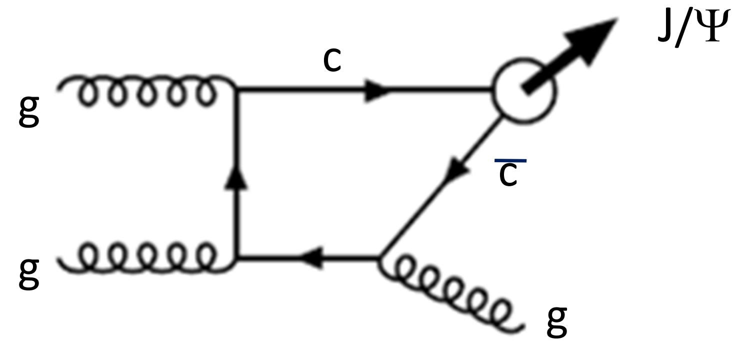


- Impact parameter distributions not seriously impacted by pileup

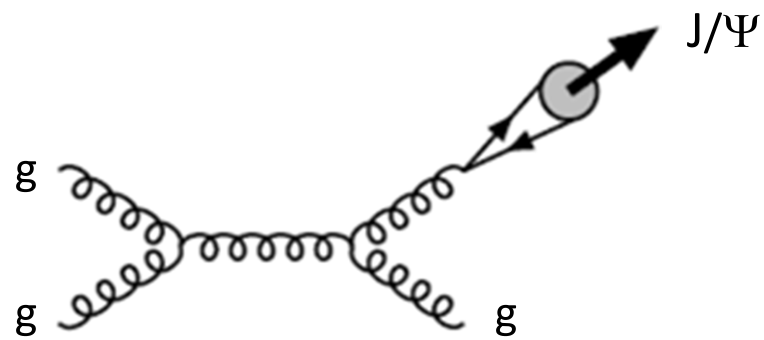
B-HADRON PRODUCTION

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



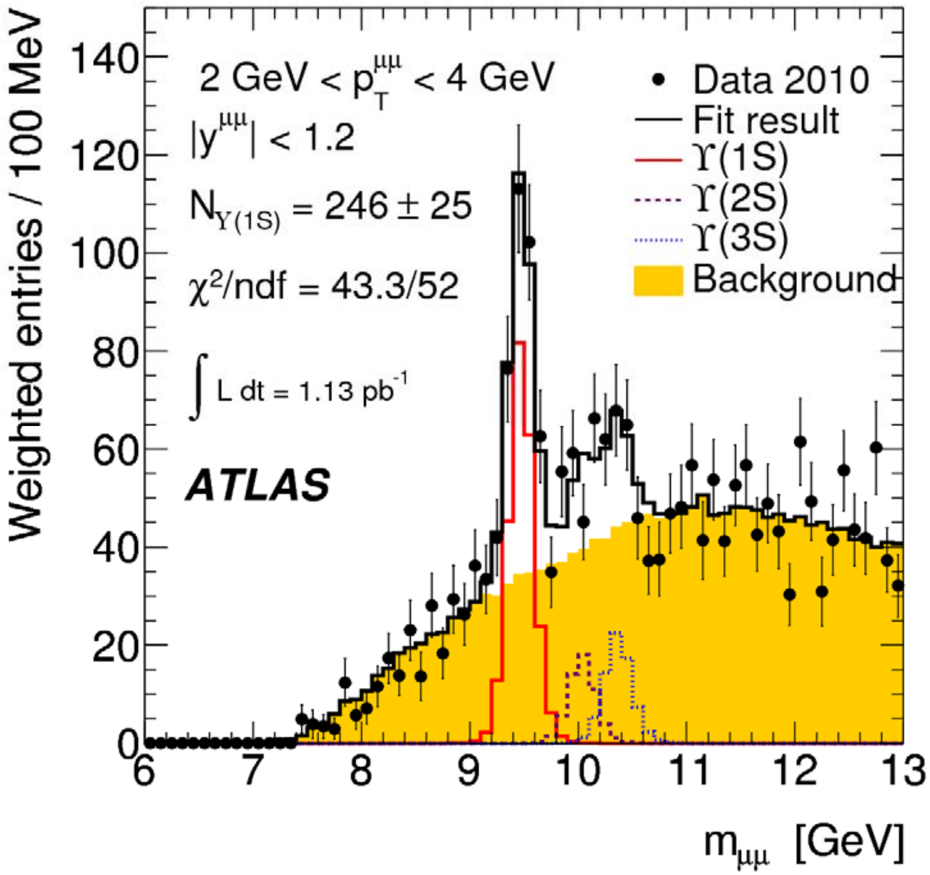
Leading order color singlet



Example of color-octet fragmentation

Υ(1S) Production

PLB 705 (2011) 9



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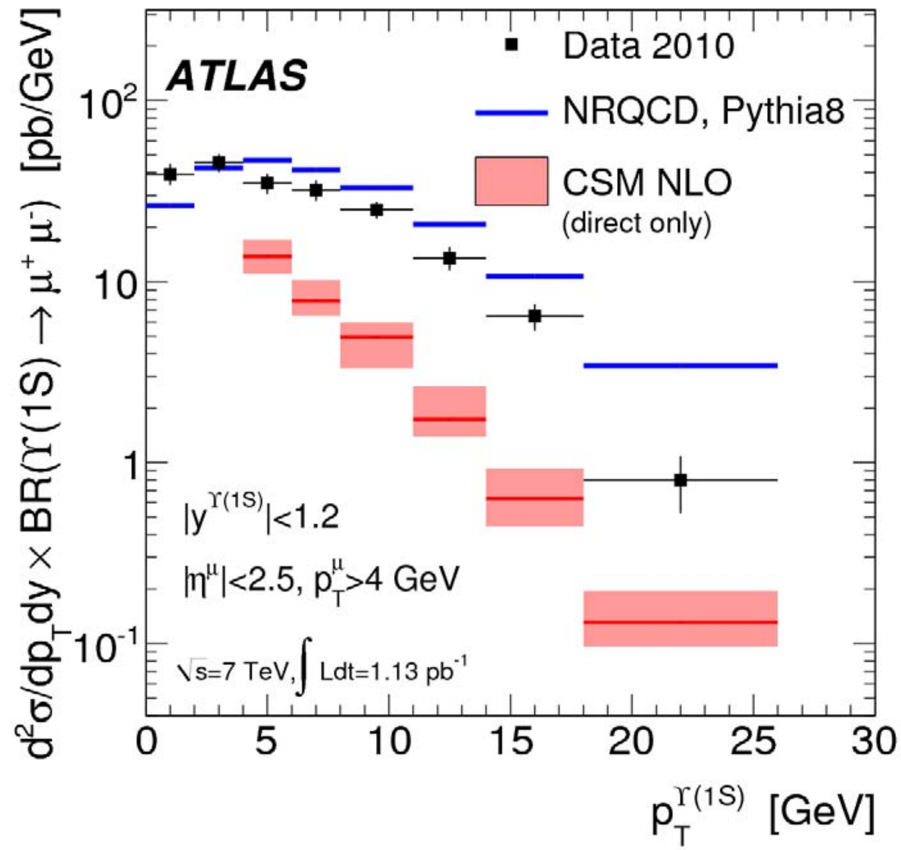
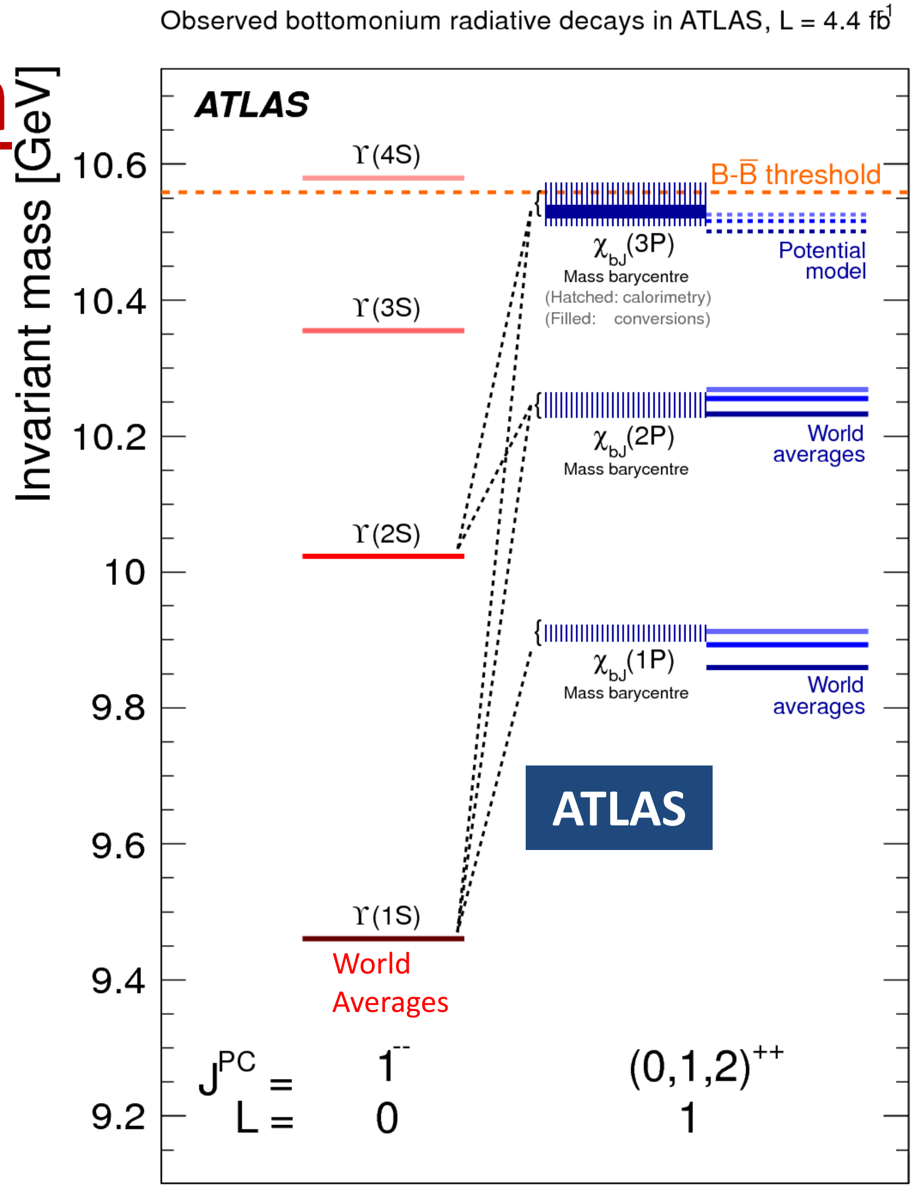


- Only prompt contribution for Υ(1S) production
- Overall scale not well predicted by theory

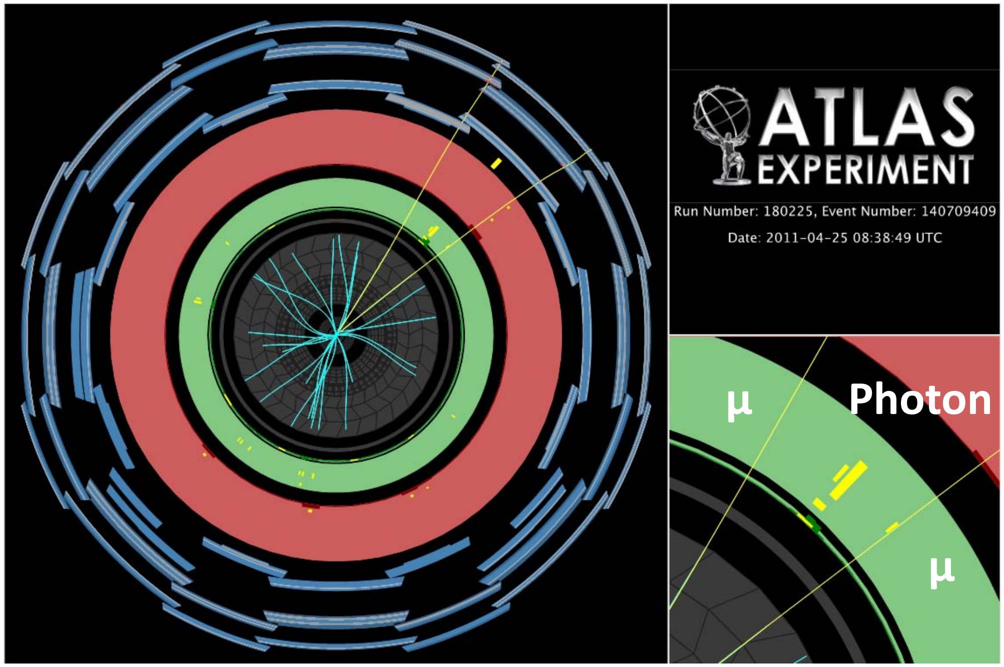
Observation of a new χ_b state: The Spectrum

- 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
  - $\chi_b(1P)$ and $\chi_b(2P)$ experimentally studied



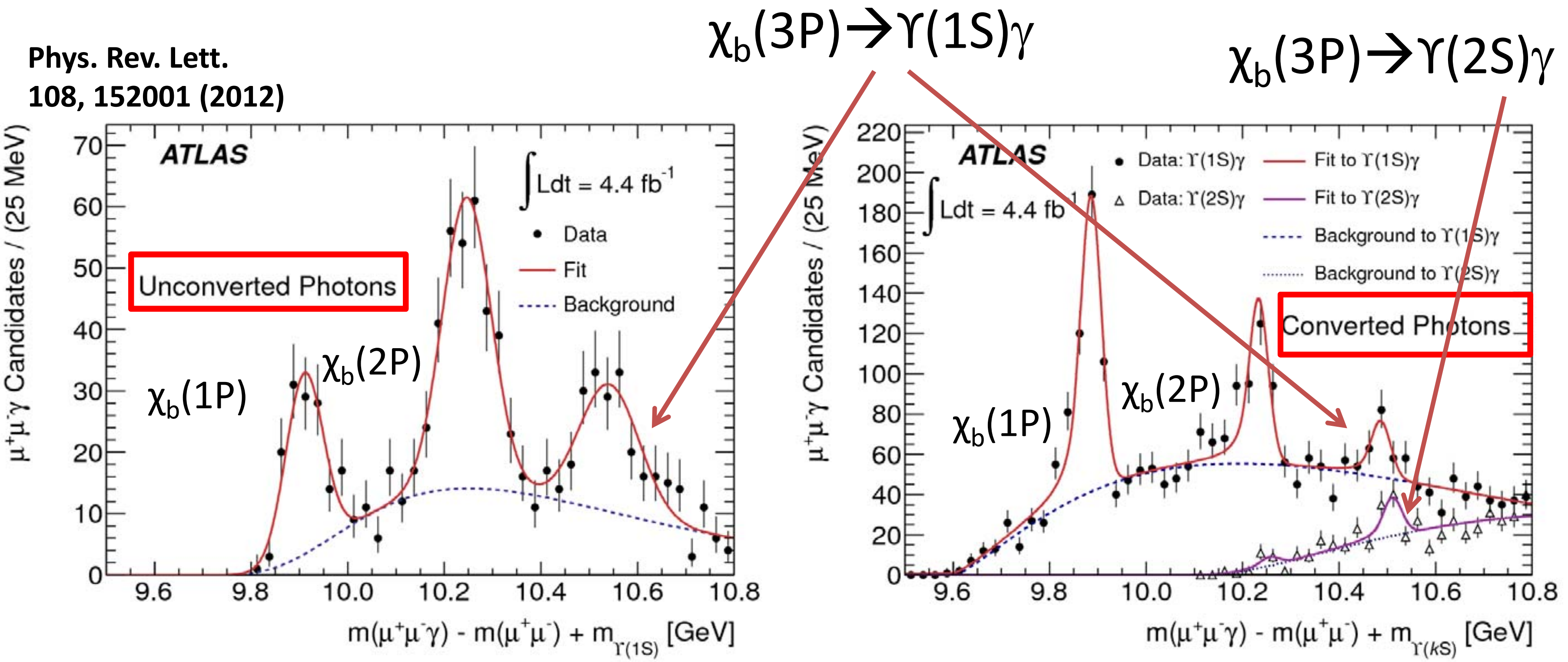
Observation of a new χ_b state: Technique for unconverted photons

- Reconstruction of χ_b through radiative decays
  - $\chi_b(nP) \rightarrow \Psi(1S)\,\gamma$ 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

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.

LIFETIME MEASUREMENTS

B Lifetime Measurements: Inclusive Technique

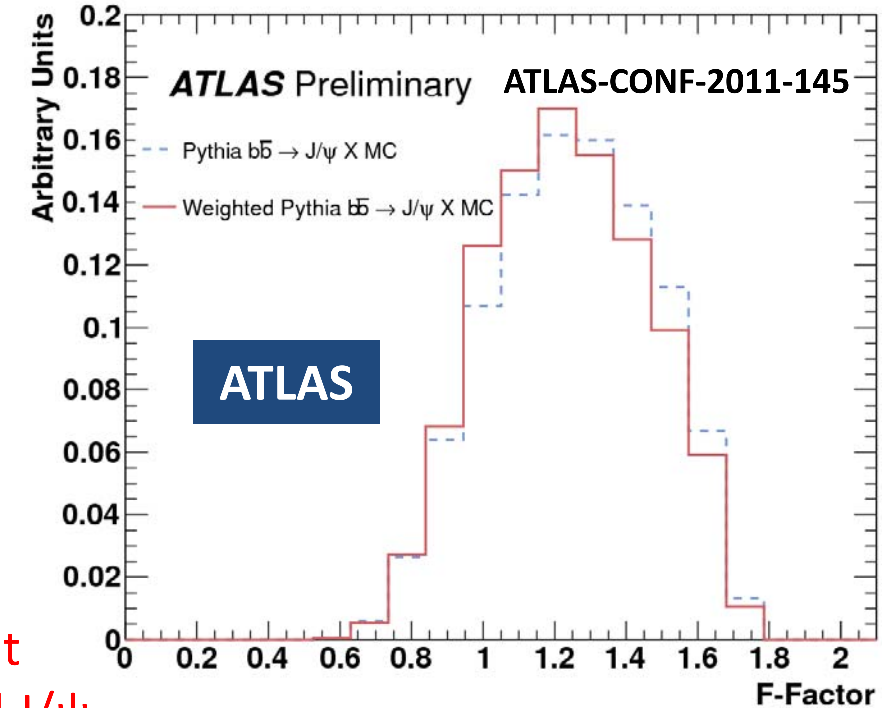
- Average B Lifetime using

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

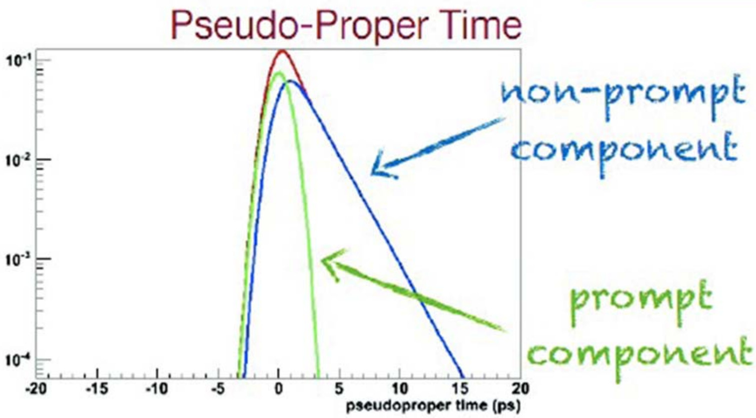
- Use pseudo proper time:

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

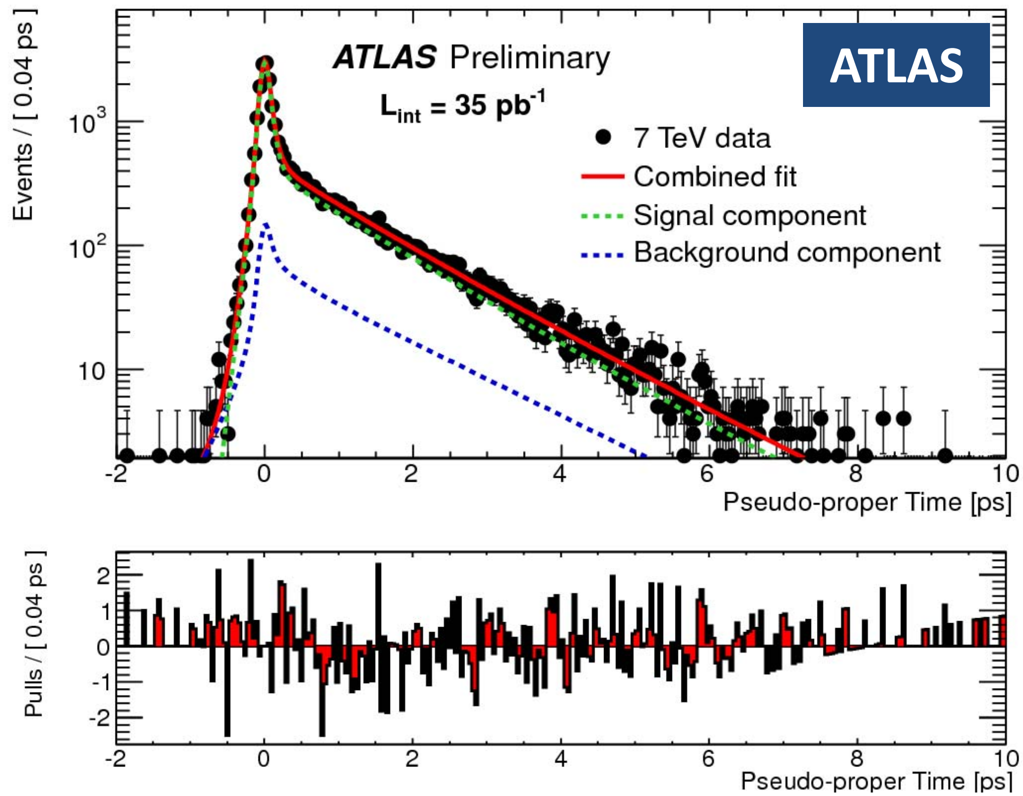
- J/ψ carries only part of the initial p_T of the B-Meson
  - correction factor F to take into account momentum difference between B and J/ψ determined from MC weighted according to BaBar
  - When this is done, the difference in the mean p* distribution of J/ψ mesons in B decays from Pythia and BaBar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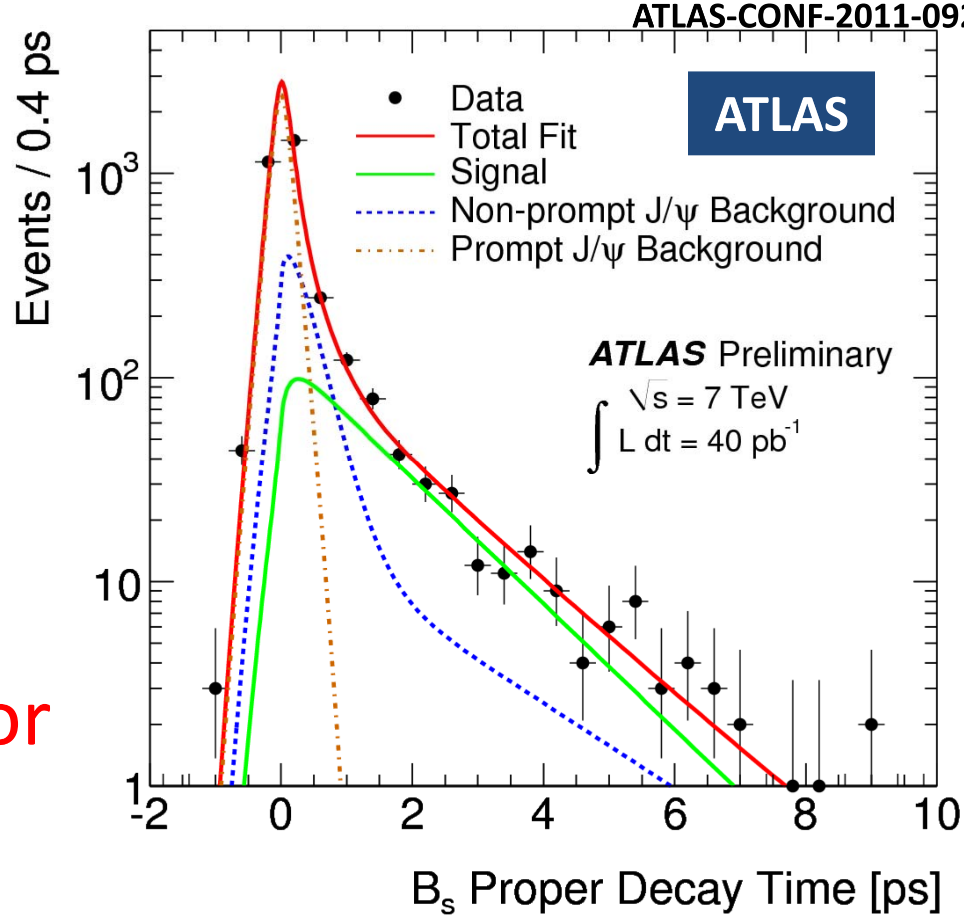
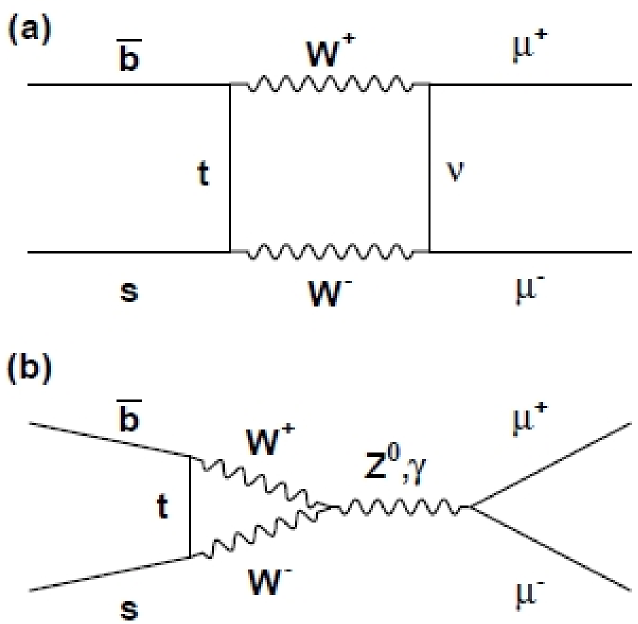


$\tau_{Bs} = 1.41 \pm 0.08$ (stat.) ± 0.05 (syst.) ps

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

RARE DECAYS

Why Search for Rare B-Decays?



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

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

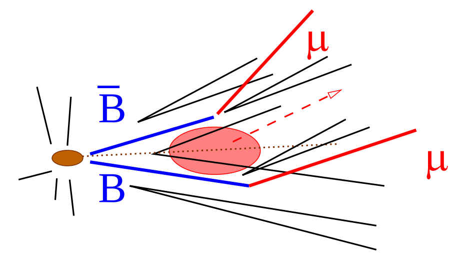
$$\mathrm{BF}(\mathrm{B_d} \rightarrow \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

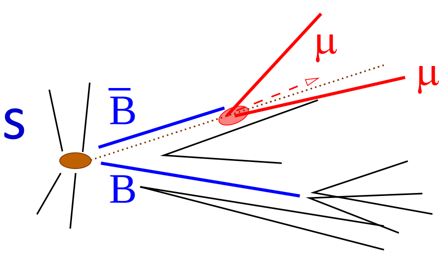
- Branching fractions might be substantially enhanced by coupling to non-SM particles
- Orthogonal search for physics beyond the standard model

The ATLAS Search for Rare Decays

arXiv:1204.0735

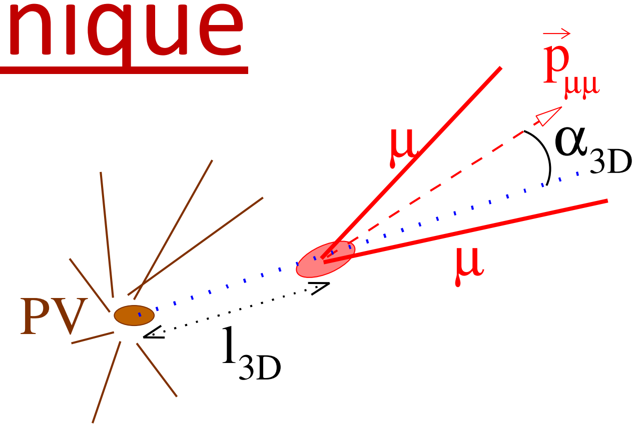
- ATLAS search features
  - Integrated luminosity of 2.4 fb^{-1}
  - Mass resolution:
    - ATLAS: $\sigma_{B\rightarrow\mu\mu}$ ~ 60 (barrel) – 110 (forward) MeV
- Main background sources:
  - continuum with smooth di-muon invariant mass
    - estimated from sidebands
    - dominant background contribution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



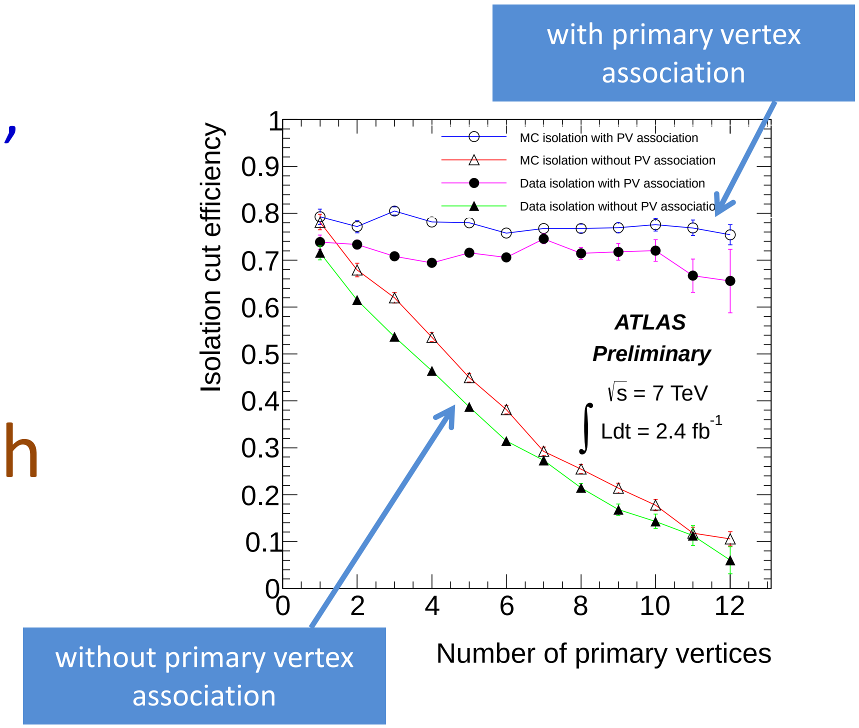


Search for Rare Decays: Selection and Technique

arXiv:1204.0735



- 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 $B^{\pm} \rightarrow J/\psi\ K^{\pm}$

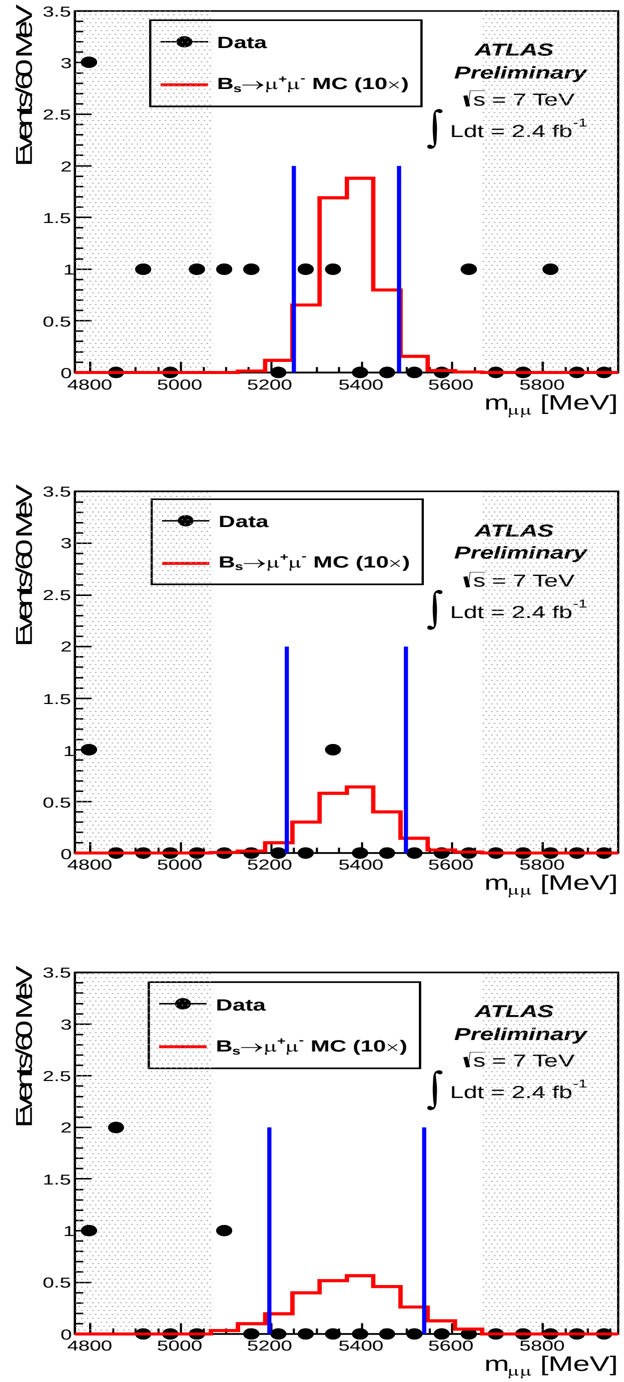


Search for Rare Decays: Backgrounds

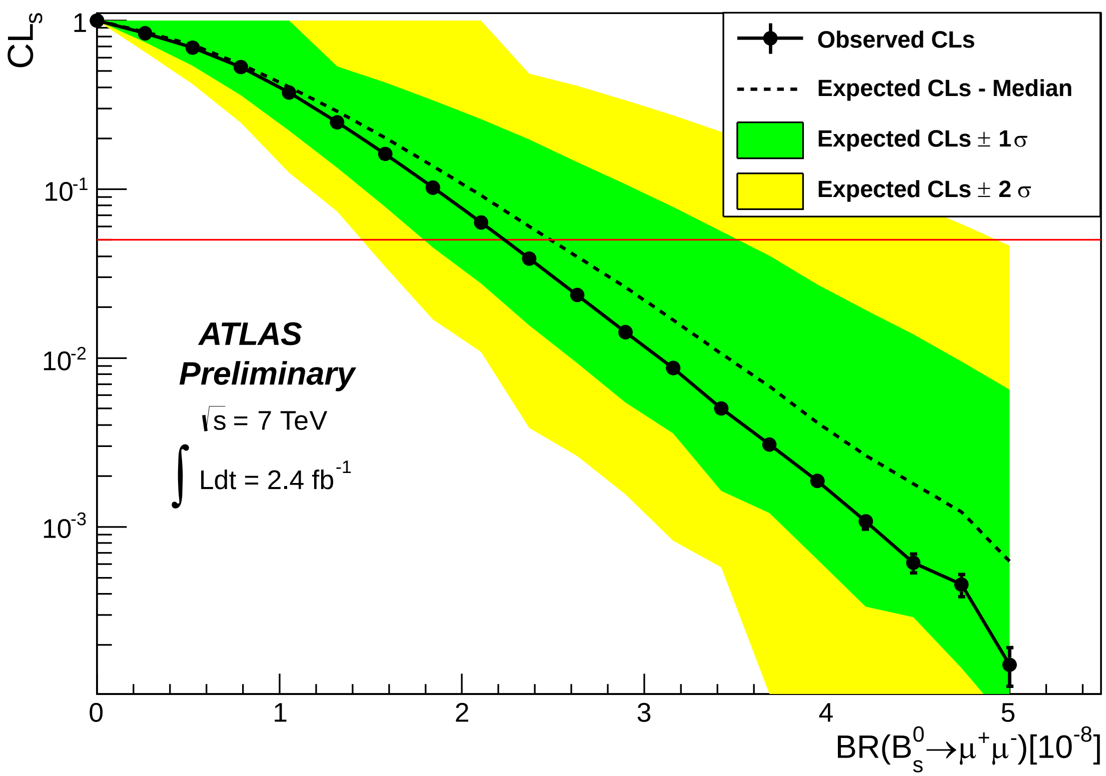
- Optimization and estimation of background events performed on different sideband event samples
  - avoid bias on expected limit
- Use different categories in mass resolution (in η)

$\lvert\eta_{max}\rvert$	0-1.0	1.0-1.5	1.5-2.5
side band 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

arXiv:1204.0735



Search for Rare Decays: Results



arXiv:1204.0735

- 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}:$(2.3^{+1.0}_{-0.5})$x10^{-8}
- Measurement consistent with expectation from SM (BF_{SM}: (3.5 ± 0.3)x10^{-9})

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

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

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

(all at 95% CL)

Conclusions

- Large available statistics and excellent detector performance have led to competitive heavy flavor measurements at ATLAS
- Measurements of heavy quark production cross sections allow precise studies of QCD: differential p_T distribution measured.
- Observation of new quarkonium state $\chi_b(3P)$:
  $m = 10.530 \pm 0.005$ (stat.) ± 0.009 (syst.) GeV/c^2.
- Lifetime measurements show excellent detector performance and open the possibility for time dependent CPV-measurements:
  $\tau_{Bs} = 1.41 \pm 0.08$ (stat.) ± 0.05 (syst.) ps.
- No sign yet of the rare decays $B_s \to \mu^+\mu^-$:
  $BF(B_s \to \mu^+\mu^-) < 2.2 \times 10^{-8}$ (2.4 fb^{-1}), 95% CL.