B-physics in ATLAS

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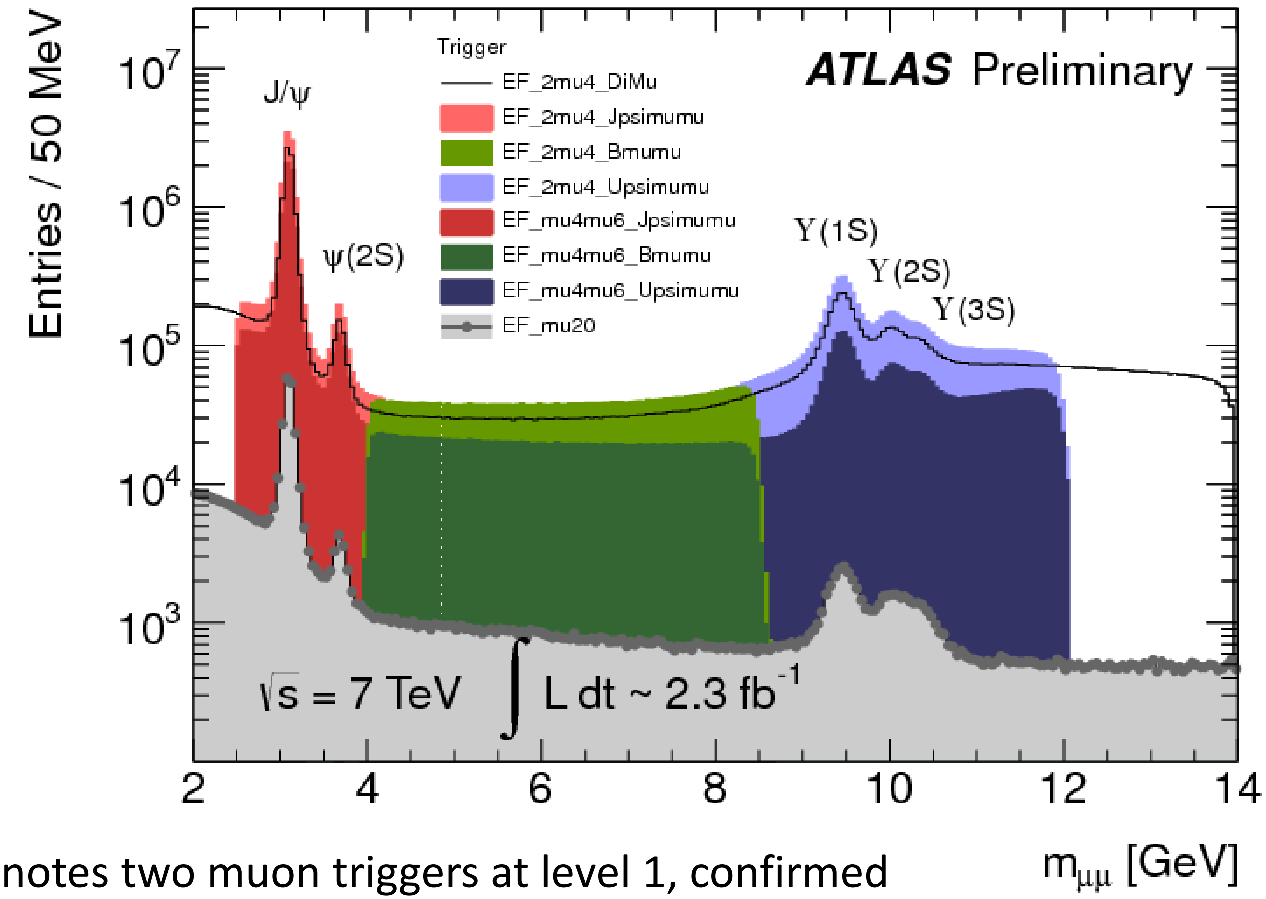
on behalf of ATLAS collaboration

Outline

- B-physics triggers
- Quarkonium production and spectroscopy
- Measurement of the b-hadron production cross section
- Measurement of Λ_b lifetime and mass
- Limit on BR($B_s \rightarrow \mu^+\mu^-$)
- CP-violating parameters in B_s decays

Invariant mass of oppositely charged muon candidate pairs for different triggers at the beginning of 2011 data



EF_2mu4_ denotes two muon triggers at level 1, confirmed at the high level trigger, with both objects passing a threshold of 4 GeV

EF_mu20 denotes a single muon trigger at level , passing a threshold of 20GeV

Jpsimumu, Bmumu, Upsimumu and DiMu denote coarse invariant mass windows, as calculated using the trigger objects

The EF_2mu4_DiMu trigger was prescaled for some of the later data taking periods

Trigger and selection requirements

- Dimuon triggers are the main working tool of the B-Physics group. Many processes of interest have di-lepton final state , or di-lepton plus additional soft object – photon or track(s). At relatively small transverse momenta, dimuons provide significantly better mass resolution and a clean trigger in comparison with electrons.

- CP-violation and rare decay studies are based on low-p_t dimuon triggers. Some studies are based on a single muon triggers.

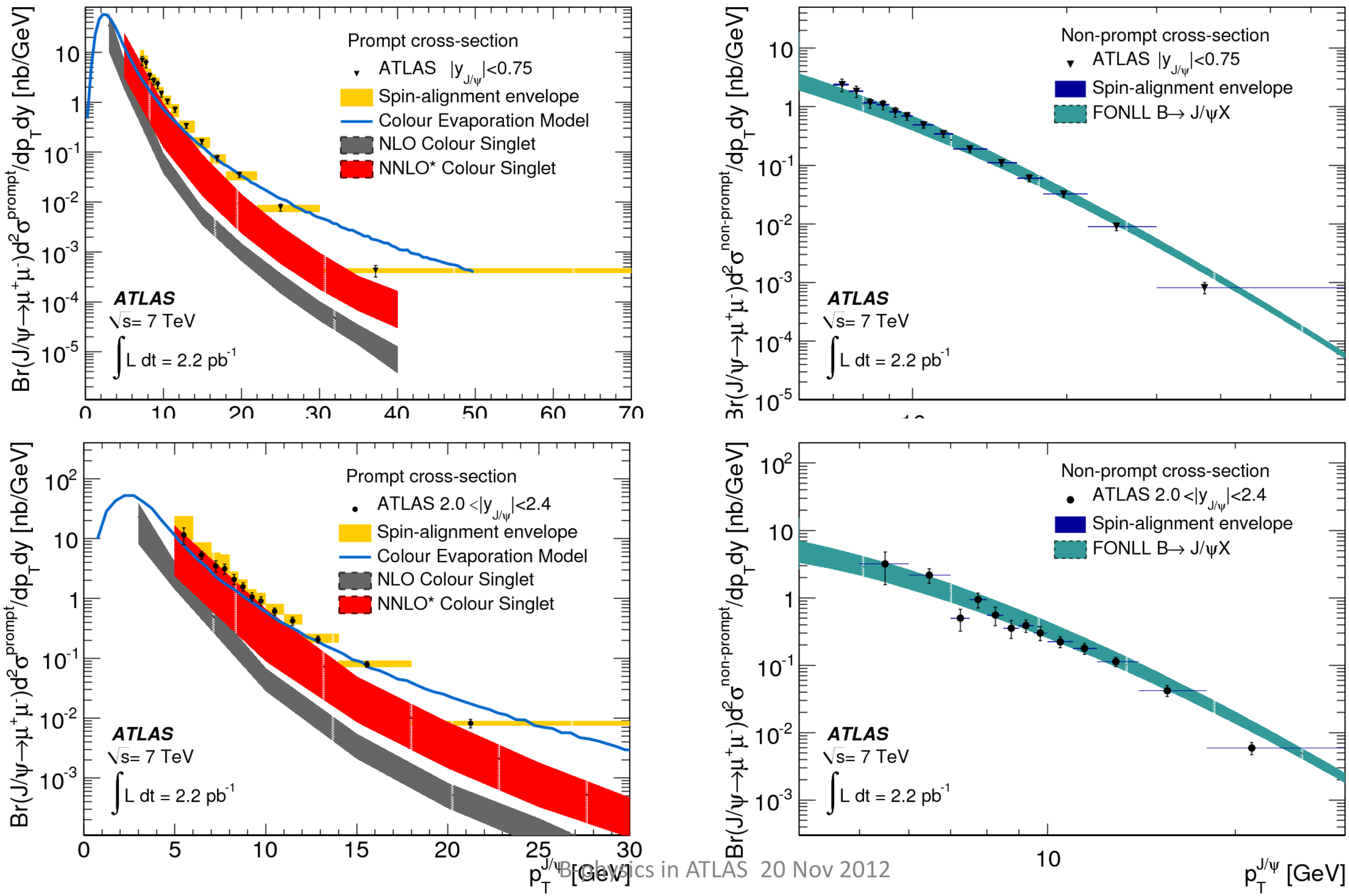
- In 2011 run the EF_2mu4 J/ψ and Upsilon triggers had no prescale.

- With the rise of instantaneous luminosity in 2012, the trigger requirements become significantly tighter. The L1_2mu4 trigger has been prescaled by a factor >10 at L=5.0 x 10^{33} and the muon stream data were collected with L1_mu4mu6 or L1_2mu6 triggers.

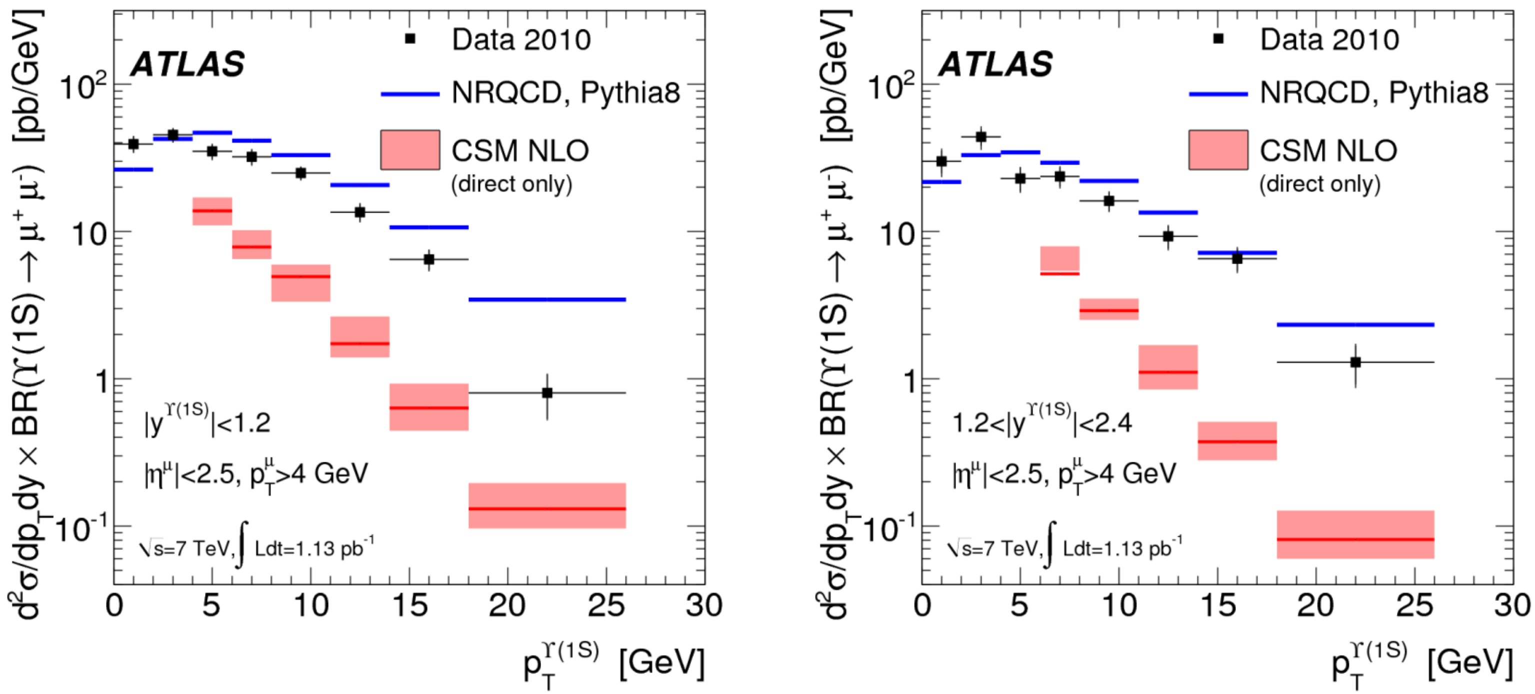
- B-physics analyses based mainly on combined muons (reconstructed in Inner detector plus muon spectrometer), with muon transverse momentum greater than 4 GeV and with small impact parameters with respect to the primary vertex. Some analyses use specific triggers with one or two muons in the Barrel, there is a better reconstruction precision and less BG in comparison with Endcaps. Some analyses accept also muons tagged in calorimeters with tracks reconstructed in Inner detector only.

- The photon in χ_b study is reconstructed either through conversion to $e^+ e^-$ or by direct calorimetric measurement, with the ‘‘loose’’ photon selection and a minimum photon transverse energy of 2.5 GeV. Data sample used for this study has been acquired at √s=7 TeV and corresponding to an integrated luminosity of 4.4 fb^{-1} . Final result is obtained with converted photons, with requirements on p_t >0.5 GeV for both tracks, a small angle between track, a confirmation of e-hypothesis in TRT and a distance between reconstructed vertex and the beam > 4 cm.

Differential cross-sections of inclusive, prompt and non-prompt J/ψ at √s=7 TeV using L=2.3 pb^{-1}



Υ(1s) production cross section



Results are based on an integrated luminosity of 1.13 pb^{-1}

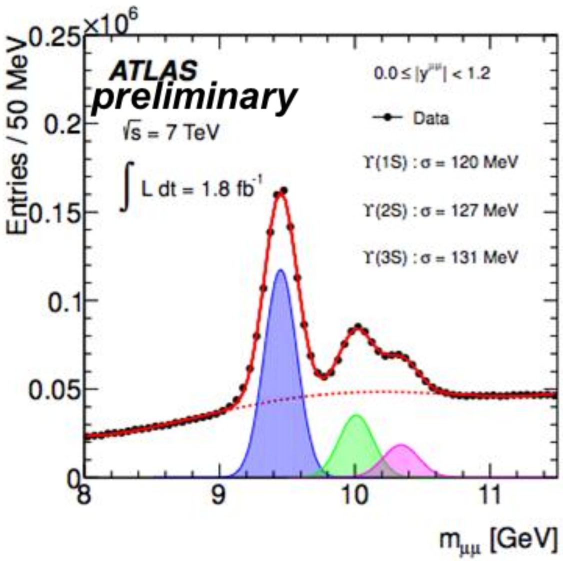
Both muons have p_t^{μ} > 4 GeV and absolute pseudorapidity $|\eta_{\mu}| < 2.5$

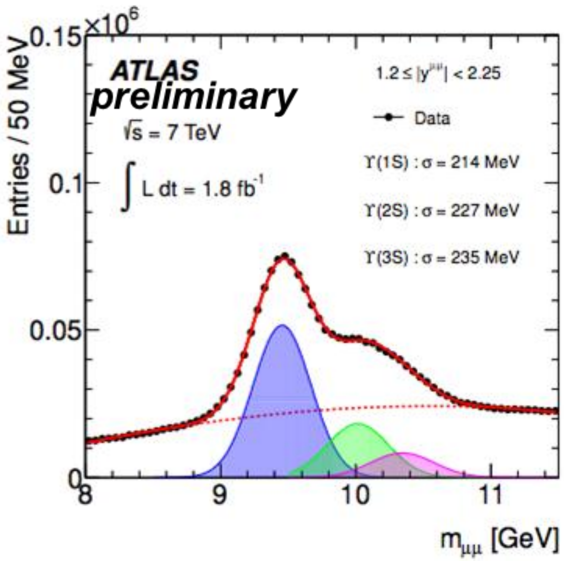
Upsilon production

ATLAS preliminary

Measurements of ϒ(1,2,3S) a test of production mechanisms and complementary to J/ψ measurements:

- No contributions from B-decays
- Heavier quark mass provides better perturbative convergence
- More excited states Y(1,2,3S) and χ_b(nP) add complication
- Larger background contributions, Upsilon states merge together





Current analysis uses 1.8 fb^{-1} of 2011 data

~10^7 ϒ(nS) candidates (background subtracted)

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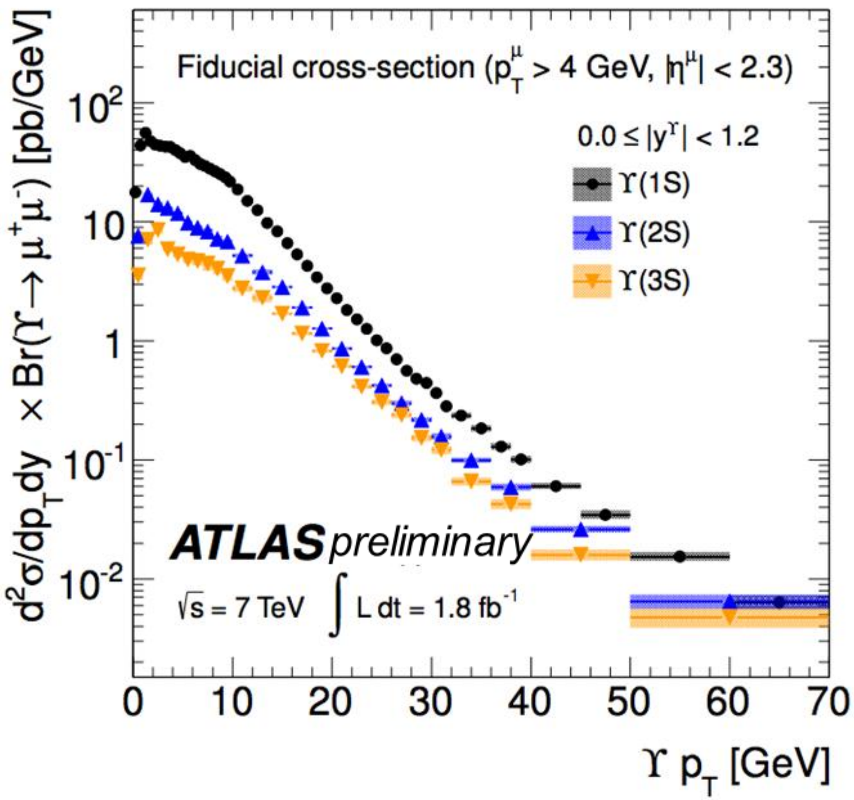
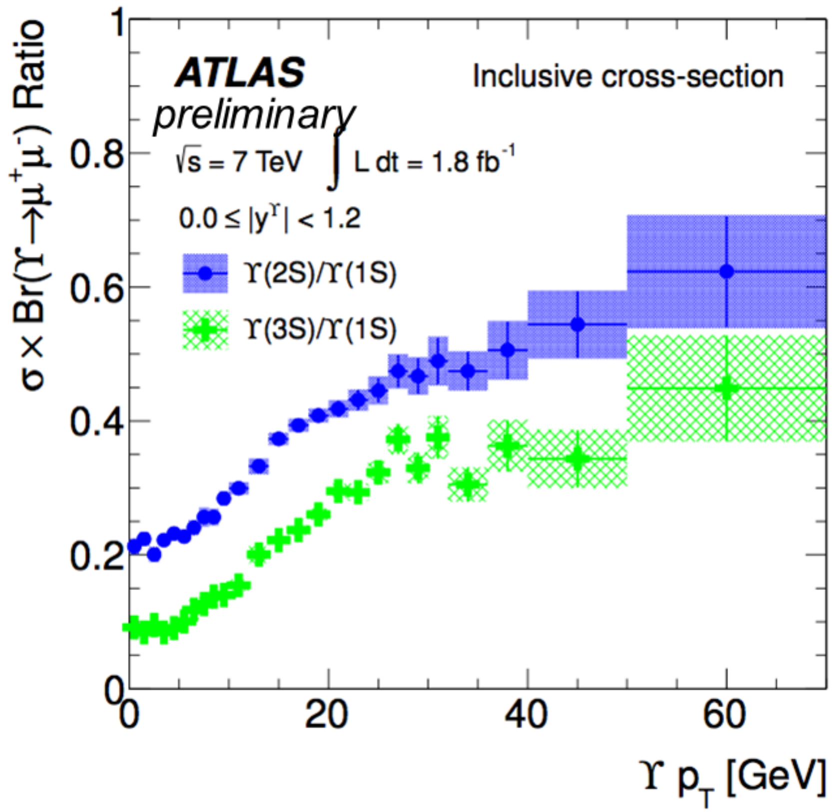
Measure inclusive/fiducial production cross-sections as function of ϒ p_T in central and forward rapidities, and as p_T-integrated rapidity spectra for each of the Upsilon states

Also measure production ratios between states vs p_T and rapidity

Upsilon cross-section measurements

ATLAS preliminary





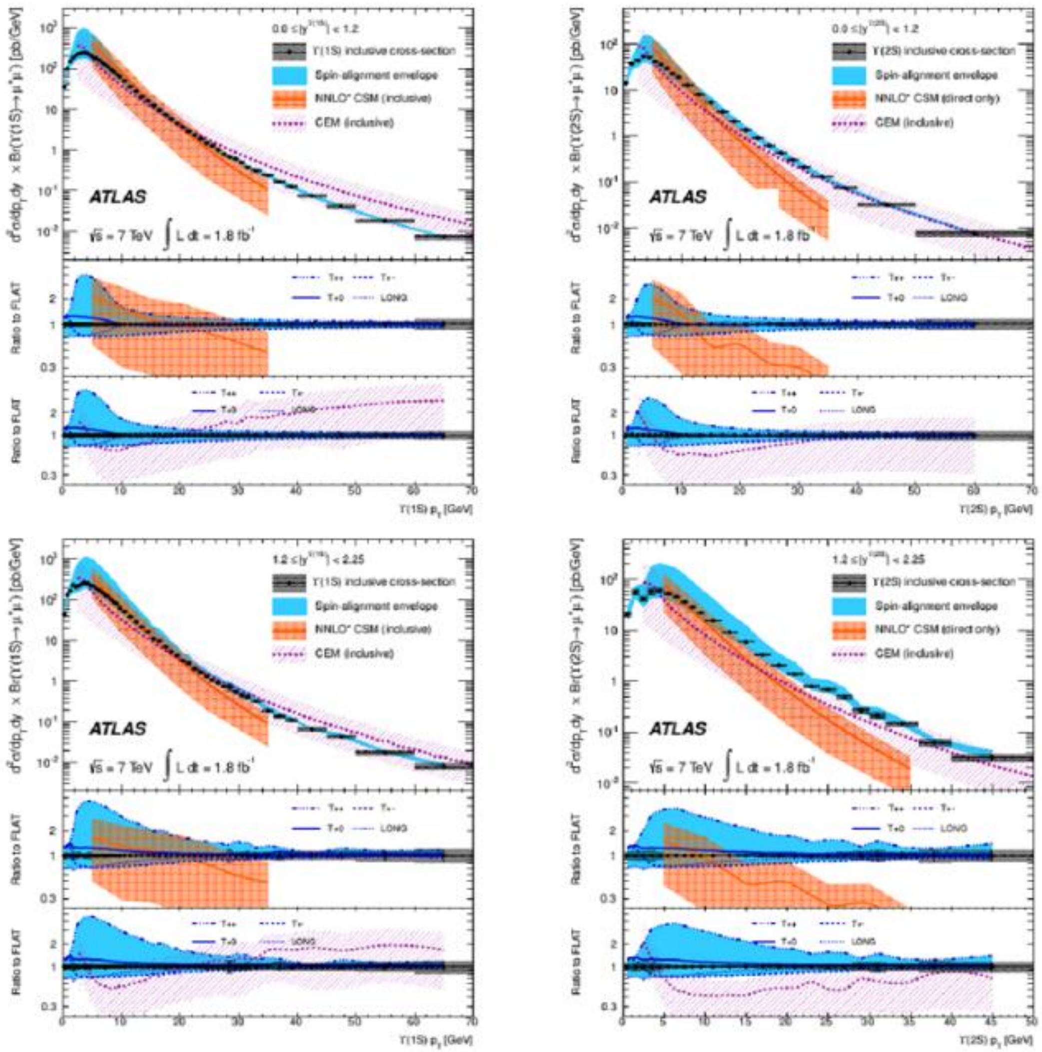
Fiducial cross-section measurements in $p_T(\mu)$>4 GeV, $|\eta(\mu)|$<2.3
Most precise, most differential, widest p_T range measurement (uncertainties ~6% on average)

Measurement of ϒ(nS) to ϒ(1S) production ratios vs. p_T and rapidity
NLO pQCD simply predicts these ratios to be 35% and 29% for the ϒ(2S) and ϒ(3S)

preliminary

Y(1,2S) differential cross sections

ATLAS preliminary



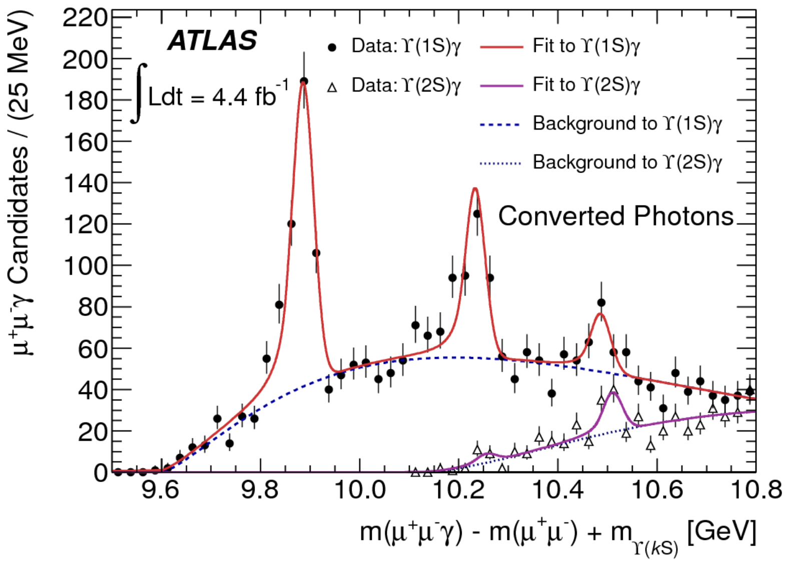
$d^2\sigma/dp_t\,dy$ x BR(Yn→μμ)for Y(1S) left, Y(2s) right;
at 0<|y|<1.2 (top) and 1.2<|y|<2.4 (bottom)

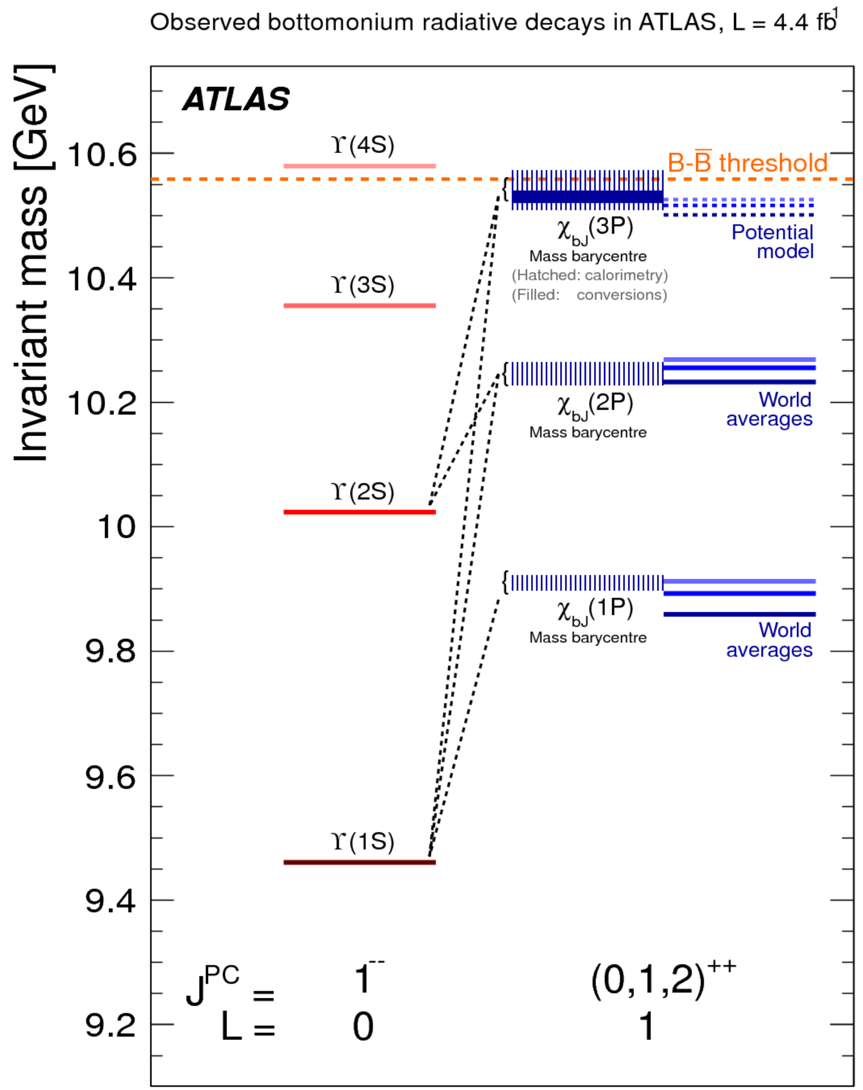
p_t range up to 70 GeV

Alignment variations in blue;
NNLO Color Singlet inclusive in red;
Color Evaporation Model in lilac lines

This result is much more complete than Tevatron or current CMS results.

$\chi_b \rightarrow$ (Upsilon(nS)+γ and χ_b(3P) discovery





End of last year ATLAS discovered new quark-antiquark bound state, the χ_{bJ}(3P).

Now has a new entry in the PDG 2012…

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$\chi_{bJ}(3P)$	10530 ± 10	?	?	$pp \rightarrow (\gamma\mu^+\mu^-)$...	ATLAS [35] (>6)	2011	NC!

Discovery now confirmed by LHCb and DØ:

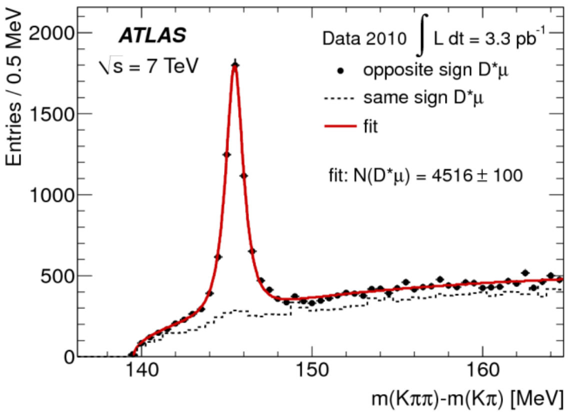
ATLAS mass: $10.530 \pm 0.005_{stat} \pm 0.008_{syst}$ GeV

LHCb mass: $10.535 \pm 0.010_{stat} \pm 0.???_{syst}$ GeV

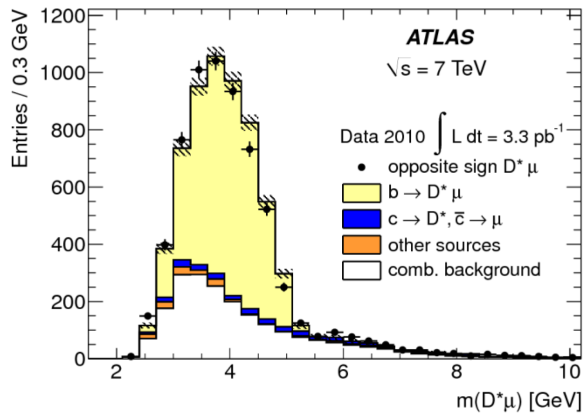
DØ mass: $10.551 \pm 0.014_{stat} \pm 0.017_{syst}$ GeV

ATLAS result remains most precise! Production x-sec and properties measurements ongoing!

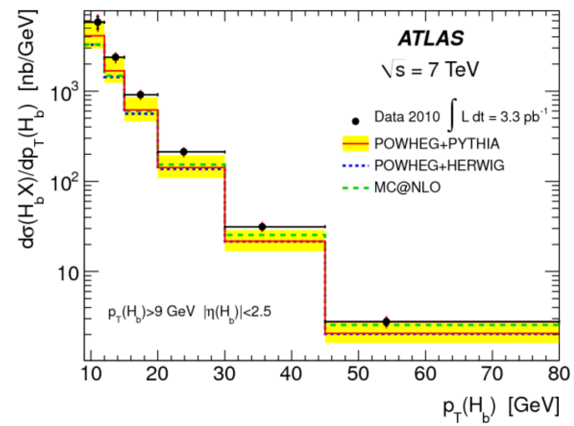
b-hadron production cross section using decays to $D^{*+}\mu^{-} X$ in *pp* collisions at $\sqrt{s}$=7 TeV



Δm for $D^{*+}\mu$ combinations of opposite sign and same sign (dashed)



m($D^{*+}\mu$) *for* combinations of opposite sign and within $\pm 3\sigma$ of the Δm peak



Differential cross section for H_b production as a function of p_t in the fiducial kinematical region $p_t(H_b) > 9$ Gev; $|\eta(H_b)|<2.5$

Used dataset corresponding to integrated luminosity L=3.3 pb^{-1}, collected during the 2010 LHC run

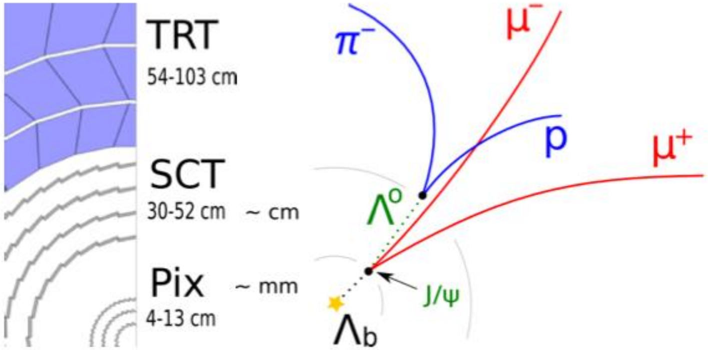
Measurement of Λ_b lifetime and mass

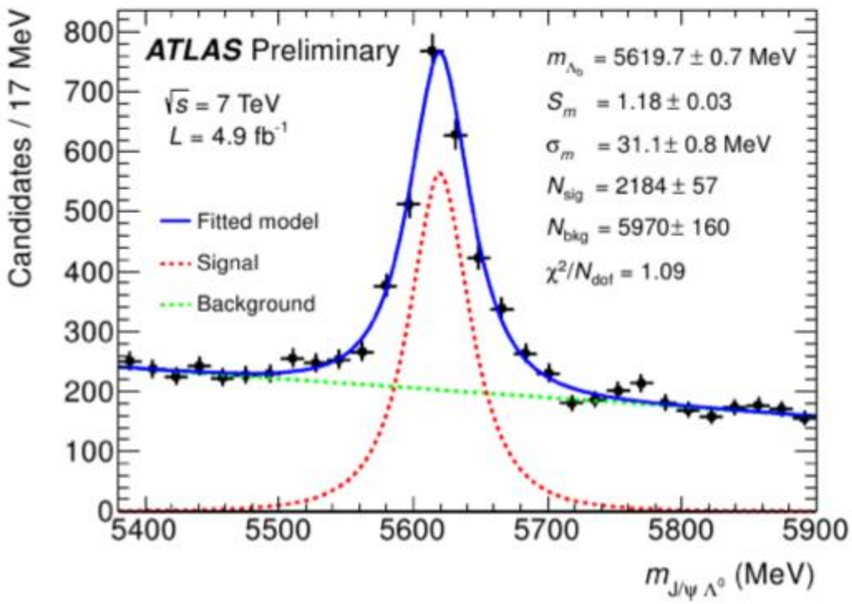
Λ_b lifetime and mass measured in $\Lambda_b \to J/\psi\Lambda(p\pi)$ channel:

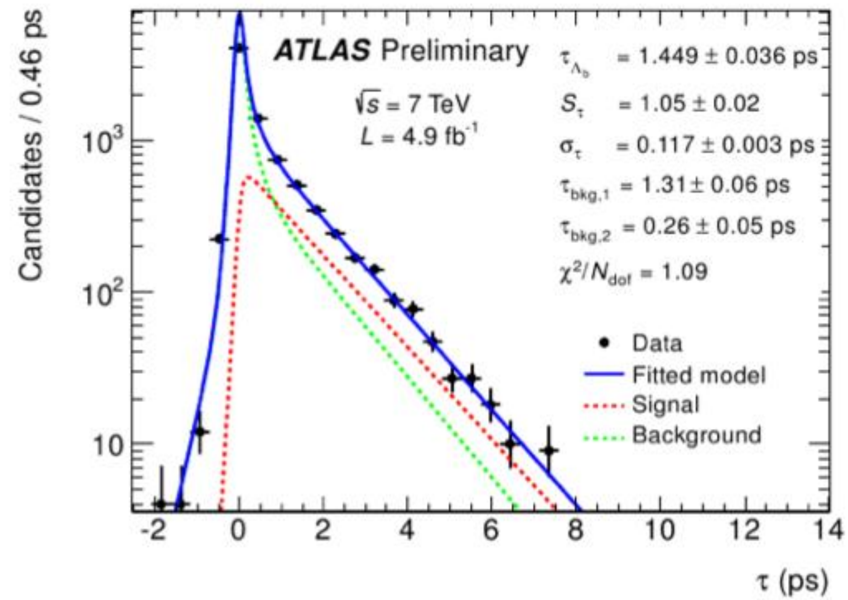
Discrepancies observed between CDF and DØ results (1.8σ difference) in Λ_b lifetime

Λ_0 vertex efficiency decreases with distance from center of detector – careful study needed to avoid selection biases;

Trigger inefficiency depending on the impact parameter of a single muon was studied in details and included in syst. error







Measurement of Λ_b lifetime and mass

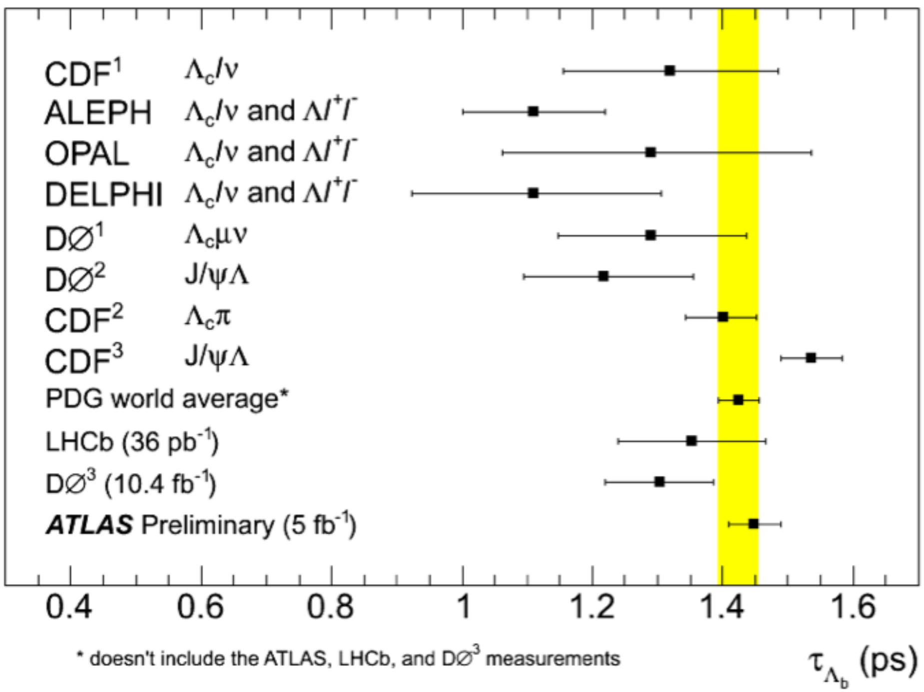
Λ_b lifetime measurement:

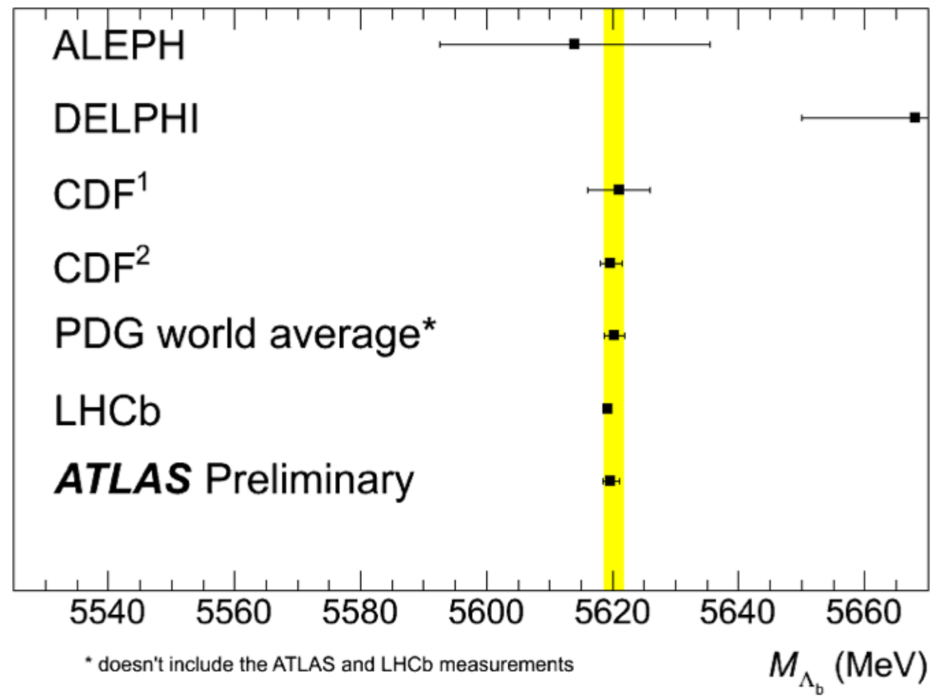
ATLAS measures **1.499±0.036±0.017 ps (=±0.040 ps)**, better than the existing best measurements

Λ_b mass measurement:

ATLAS measures **5619.7±0.7±1.1** compares well with recent LHCb 5919.19±0.7±0.3

it is the second best measurement and reduces the PDG error in the average from 0.7 to 0.6 MeV.

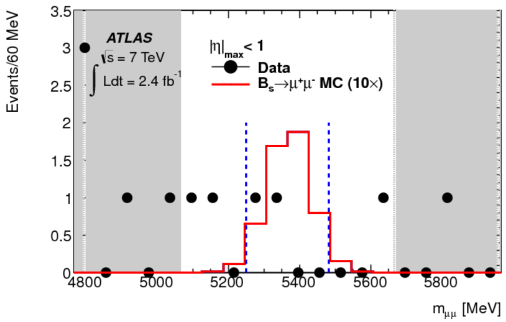


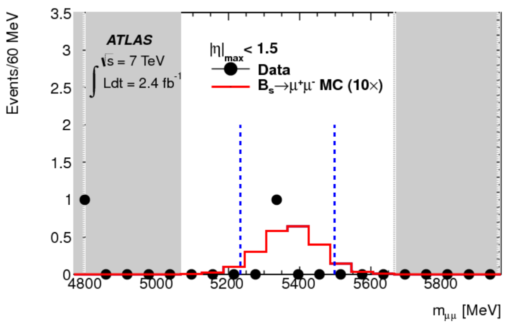


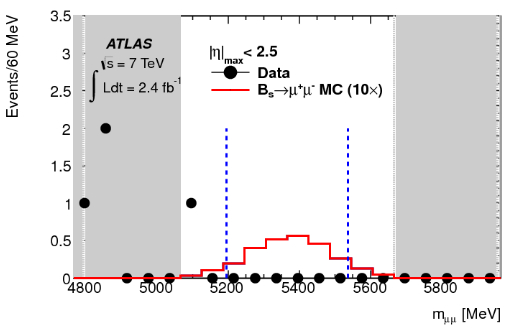
Limit on BR($B_s \rightarrow \mu^+ \mu^-$)

- A limit on the branching fraction BR($B_s \rightarrow \mu^+ \mu^-$) is set using 2.4 fb^{-1} of integrated luminosity collected in 2011. The process $B^{+-} \rightarrow J/\psi K^{+-}$, with $J/\psi \rightarrow \mu^+ \mu^-$, is used as a reference channel for the normalization of integrated luminosity, acceptance and efficiency. The final selection is based on a multivariate analysis performed on three categories of events determined according to their mass resolution (the largest pseudorapidity value of two muons $|\eta_{max}|<1.0$, $1.0<|\eta_{max}|<1.5$, $1.5<|\eta_{max}\}<2.5$), yielding a limit of BR($B_s \rightarrow \mu^+\mu^-$) < 2.2(1.9) x 10^{-8} at 95% (90%) Conf. Level.
- Next step is to double statistics with full 2011 data, but hope to gain more than a ~sqrt(2) improvement on sensitivity due to improvements in the analysis.
- Comment: in the 2012 data number of events per inverse femtobarn dropping due to trigger conditions, therefore the expected improvement is less than sqrt(lumi).

Limit on BR($B_s \to \mu^+\mu^-$)

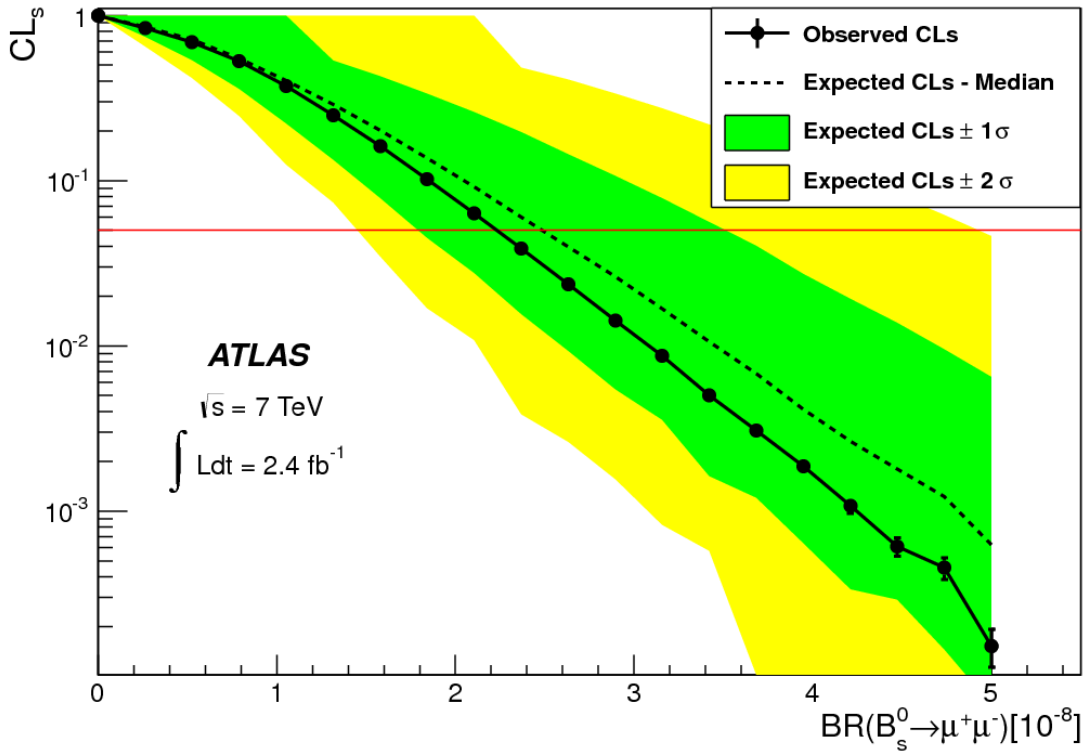






Invariant mass distribution of candidates in data.
For each mass-resolution category (top to bottom)
each plot shows the invariant mass distribution for the
selected candidates in data (dots),
the signal (continuous line) as predicted by MC assuming
BR($B_s^0 \to \mu^+ \mu^-$) = 3.5 x 10−8,
and two dashed vertical lines corresponding to the
optimized Delta_m cut.
The grey areas correspond to the sidebands used
in the analysis

Limit on BR($B_s \rightarrow \mu^+ \mu^-$)

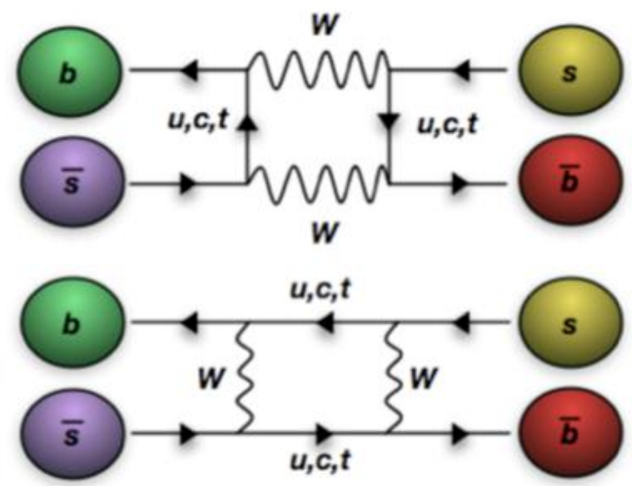


- Observed CLs (circles) as a function of BR($B_s \to \mu^+\mu^-$). The 95% CL limit is indicated by the horizontal (red) line. The dark (green) and light (yellow) bands correspond to ±1sigma and ±2sigma fluctuations on the expectation (dashed line), based on the number of observed events in the signal and sideband regions
- Note: LHCb just has submitted a paper based on 2011 + a half of 2012 statistics and got a BR value well consistent with SM prediction and with precision close to 3σ.

Physics of J/ψφ decay

- **There is "LHC Gold" B-cannel, new physics can increase SM predicted CP-violation**
- **This decay proceeds in S, P and D-waves, leading to CP-even final state in S and D-waves and to CP-odd state in P-wave decay.**
- **CP violation arises from interference of $B_s \rightarrow J/\psi\phi$ decay and B_s –antiB_s mixing (see next slide) and is proportional to a phase difference, ϕ_s, of the two complex weak amplitudes**
- **SM predicted value is small $\phi_s = 0.0363 \pm 0.0017$ rad, currently not accessible by any experiment, however it is within LHC potential**
- **Many New physics models predict extra contributions to ϕ_s. Searches started at Tevatron, continue at LHC.**
- **ϕ_s is extracted from $B_s \rightarrow J/\psi\phi$ data by time-dependent angular analysis with 7 unknown parameters**

B_s mixing



- Bs mixing is described at the lowest order by box diagrams involving 2 Ws and 2 up-type quarks.
- This leads to two mass eigenstates (Light and Heavy) which have different lifetimes.
- In the neutral Bs system, the two mass eigenstates have similar lifetimes and must be studied together.
- This is different from the neutral Kaon system, where the two mass eigenstates have very different lifetimes (~ factor 600). The eigenstates are thus refered to by their lifetime and can be effectively studied independently.

Method of CP-measurement in $B_s \rightarrow J/\psi\varphi$

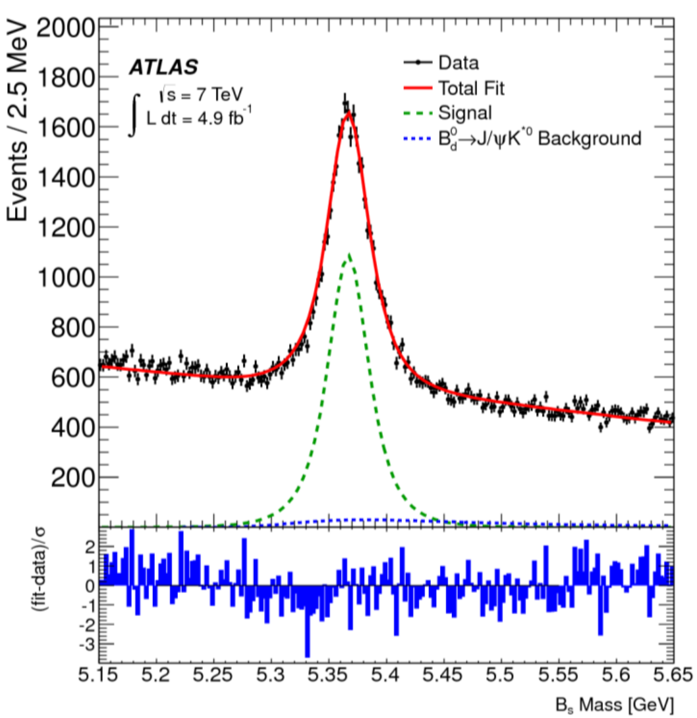
- Final state $J/\psi\phi$ is a mixture of CP-even (~75%) and CP-odd (~25%) states
- Three angular momentum states of $J/\psi\phi$
- L=0 S-wave CP-even
- L=1 P-wave CP-odd
- L=2 D-wave CP-even
- ϕ_s can only be measured if CP-states separated using angular distributions of final state particles (used two polar decay angles in J/ψ and ϕ rest frames and an azimuth angle between two decay planes)
- 4 additional parameters (strong helicity amplitudes) should be determined simultaneously with the weak parameters
- 7 parameters in total:
- Weak: ϕ_s, $\Delta\Gamma=(\Gamma_H - \Gamma_L)$, $\Gamma=(\Gamma_H + \Gamma_L)/2$;
- Strong: two phases and two absolute values (4 independent parameters of three helicity amplitudes). Without tagging and for small ϕ_s, one of the strong phase (ϕ_{perp} in the transversity notation) cannot be well measured, so the value measured by LHCb used for this quantity. The other phases are measured by ATLAS.

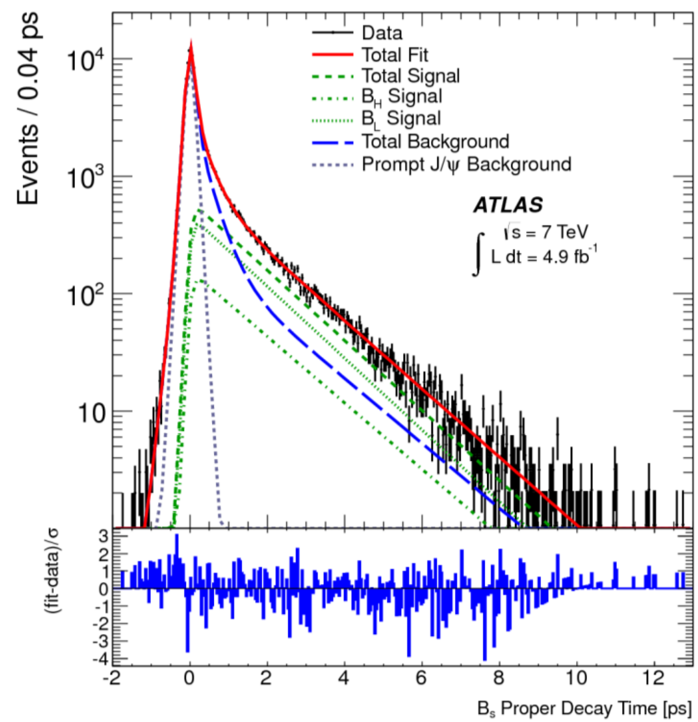
CP violation in $B_s \rightarrow J/\psi\phi(1020)$ decays

Performed a measurement of CP violation in $B_s \rightarrow J/\psi\varphi$ using *untagged* time-angular analysis of 4.9 fb^{-1} data collected in 2011

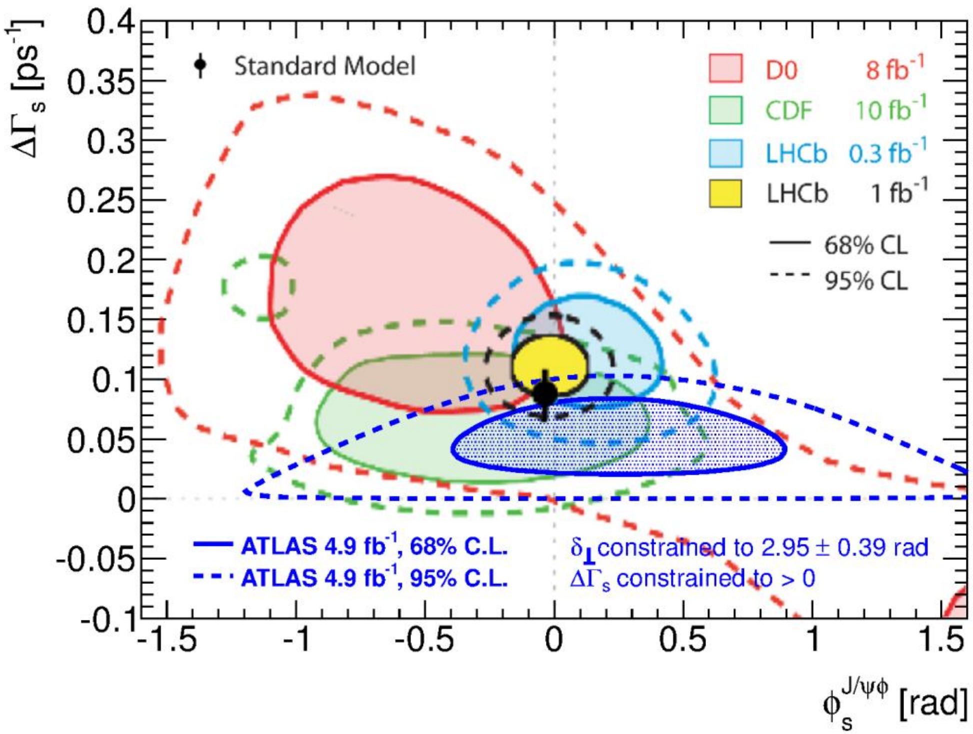
Untagged analysis: decay time distribution and angular correlation between muons and kaons in final state provide information on CP=±1 amplitudes and their interference.

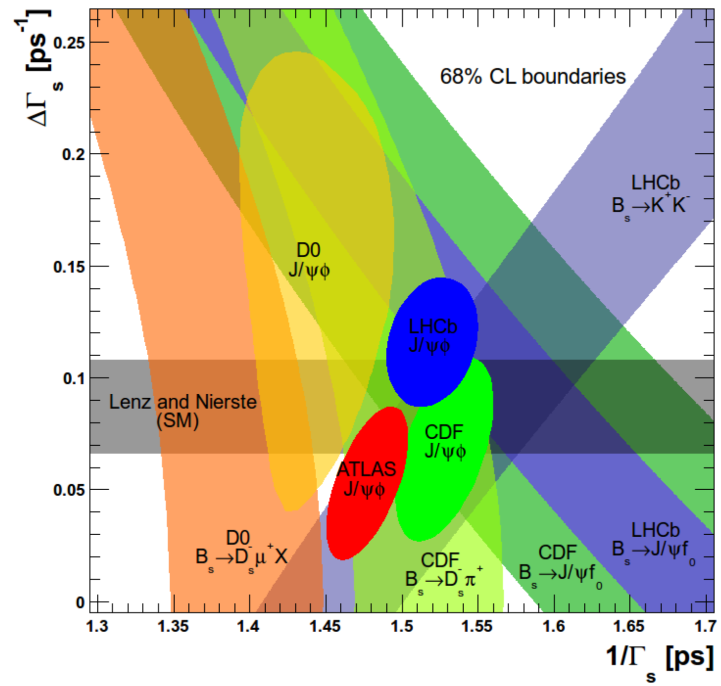
Large sample of events: 23 k reconstructed B_s from 2011 data sample.





Parameters of CP violation in $B_s \to J/\psi\phi$ decay





Several parameters describing the B_s system are measured: the mean B_s lifetime ($1/\Gamma_s$), decay width difference $\Delta\Gamma_s$, transversity amplitudes $|A_0(0)|$, $|A_{||}(0)|$ and weak phase φ_s.

The results are consistent with the world average values and with theoretical expectations, in particular $\boldsymbol{\varphi_s = 0.22 \pm 0.41 \pm 0.10}$ **rad** is within 1σ of the expected value in SM.

$\boldsymbol{\Delta\Gamma_s = 0.053 \pm 0.021_{stat} \pm 0.010_{syst}}$ **ps^{-1}** Precision of $\Delta\Gamma_s$ and Γ_s are competitive with LHCb.

$\boldsymbol{\Gamma_s = 0.677 \pm 0.007_{stat} \pm 0.004_{syst}}$ **ps^{-1}** Next steps: tagged analysis; add 2012 data

Conclusions

- B-physics at LHC is rich, and ATLAS experiment has produced competitive results in several fields, including spectroscopy, lifetime measurements and untagged analysis of CP-violation in B_s decays. Work on the B-tagging methods in ATLAS is ongoing.
- Many other analyses which were not mentioned in this talk are in progress, for example the ψ(2s) production, associated production of W-boson plus J/ψ, X(3772) study, B^{+-} cross section measurement, B_c study.

References

- **Measurement of the differential cross-sections of inclusive, prompt and non-prompt J/ψ production in pp collisions at √s = 7 TeV, NP B850 (2011) 387;**
- **Υ(1S) Fiducial Production Cross-Section in pp collisions at √s = 7 TeV in ATLAS, PL B705 (2011) 9;**
- **Observation of a new χ_b state in radiative transitions to *Υ(1S)* and *Υ(2S)* at ATLAS, G.Aad et al., Phys.Rev.Lett. 108 (2012) 152001;**
- **Search for the decay $B^0_s \rightarrow \mu^+\mu^-$ with the ATLAS detector , G.Aad et al., PL B713, (2012) 387;**
- **Measurement of the *b*-hadron production cross section using decays to $D^{*+}\mu^- X$ final states in *pp*-collisions at √s = 7 TeV with the ATLAS detector, G.Aad et al., Nucl. Phys. B 864 (2012) 341;**
- **Measurement of the Λ_b lifetime and mass in the ATLAS experiment, G.Aad et al., arXiv:1207.2284 [hep-ex], submitted to Phys. Rev. D;**
- **ϕ_s and $\Delta\Gamma_s$ from time dependent angular analysis of the decay $Bs_s \rightarrow J/\psi\phi$ by ATLAS, G.Aad et al., arXiv:1208.0572 [hep-ex], submitted to J.High Energy Phys.;**
- **Search for the rare decays B->μμ at the LHC with the ATLAS, CMS and LHCb experiments, ATLAS-CONF-2012-061;**
- **Measurement of Upsilon production in 7 TeV pp collisions at ATLAS, CERN-PH-EP-2012-295 ;**
- **Combined LHC limit to the decay $B_s^0 \rightarrow \mu\mu$ (ATLAS-CMS-LHCb note) ATLAS-CONF-2012-061**

$\chi_b \rightarrow$