

The charmonium and beauty physics programme in ATLAS

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Layout of the talk

- ATLAS J/ψ selection strategy for early beam conditions
- Mass determination, method, results
- Kinematic properties of J/ψ with early selections
- First performance results with J/ψ
- B-physics program
 - two examples of early measurements under preparation
 - two examples future high sensitivity B-measurements

Early J/ψ : event selections

- p-p collision data at 7 TeV, taken between March 30th and May 17th 2010
- Integrated luminosity of data used for this study: $6.4 \pm 1.3 \text{nb}^{-1}$
- **Strategy:**
collect largest possible statistics; determine mass, resolution and J/ψ properties, understand backgrounds
- **Trigger requirements:**
 - Minimum Bias Trigger Scintillators (MBTS) mounted at each end of the detector in front of the Liquid Argon Endcap-Calorimeter cryostats at $z = \pm 3.56 \text{m}$. The MBTS trigger - requires at least two hits from either sides of the detector.
 - L1 minimum bias trigger was not prescaled for runs with luminosity $< 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$.
 - A dedicated muon software trigger commissioning chain at the Event Filter level initiated by the MBTS L1 trigger searches for muon track in the entire Muon Spectrometer
 - Analysing data in MBTS stream we requested at least one muon must pass the EF muon-commissioning chain with a muon of any p_T reconstructed in the Muon System
- To ensure collision events are selected, at least 3 tracks form a primary vertex.

$\mu\mu$ and J/ψ selections

Types of muons used:

- Combined muon:
 - statistical combination of track parameters and the covariance matrices of Muon System (MS) track and Inner detector (ID) track;
 - the tracks with tight matching criteria selected to create a combined muon track traversing the ID and MS
- Tagged muon:
 - muon segments matched to ID tracks extrapolated to MS. Reconstructed muon adopts parameters of ID track.
- Pairs of muons with at least one Combined muon were retained

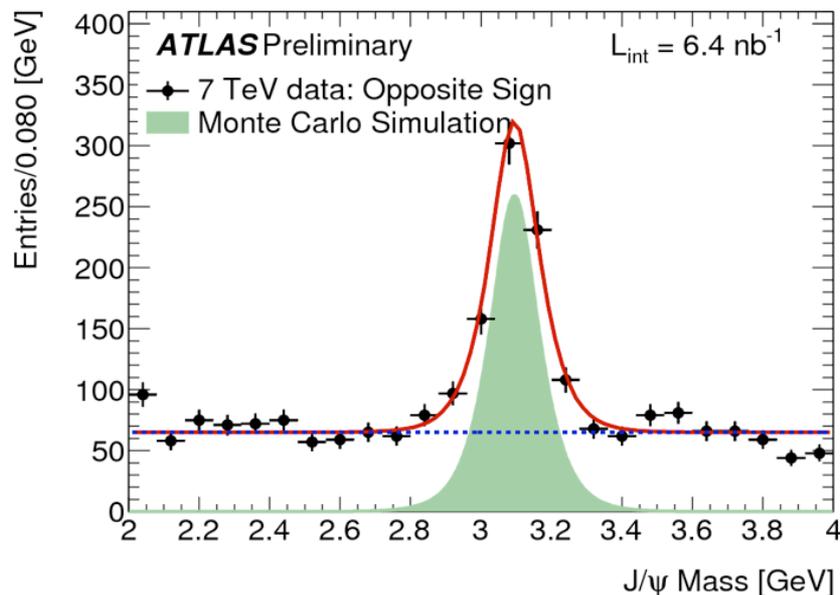
Cosmic ray background:

- may come from a pair formed by a cosmic muon and a muon from the collision. The probability is very small ($< 10^{-4}$) from the 900 GeV data analysis
- A cosmic muon mimicking a J/ψ decaying back-to-back is excluded - muons detected in the MS can only have momentum higher than 3 GeV.

$\mu\mu$ and J/ψ selections, cont

- **ID selections, Vertexing:**
 - ≥ 1 hit in the pixels and 6 hits in silicon strip layers
 - $p_T > 0.5$ GeV on each track
 - Tracks fitted to a common vertex using vertexing tools based on Kalman filter.
 - No constraints on mass or pointing to the primary vertex, and a very high vertex fit χ^2 upper limit is applied ($\chi^2 < 200$).
- Only ID track parameters of muons used for this J/psi study
- **Same sign pairs retained for cross-checking.**
- **Cuts not optimized to reject backgrounds, since the aim of this study is to understand the shape of the low p_T combinatorial background**

Early J/ψ signal in ATLAS



$$L = \prod_{i=1}^N \left[f_{signal}(m_{\mu\mu}^i) + f_{bkg}(m_{\mu\mu}^i) \right]$$

$$f_{signal}(m_{\mu\mu}, \delta m_{\mu\mu}) \equiv a_0 \frac{1}{\sqrt{2\pi} S \delta m_{\mu\mu}} e^{-\frac{(m_{\mu\mu} - m_{J/\psi})^2}{2(S\delta m_{\mu\mu})^2}}$$

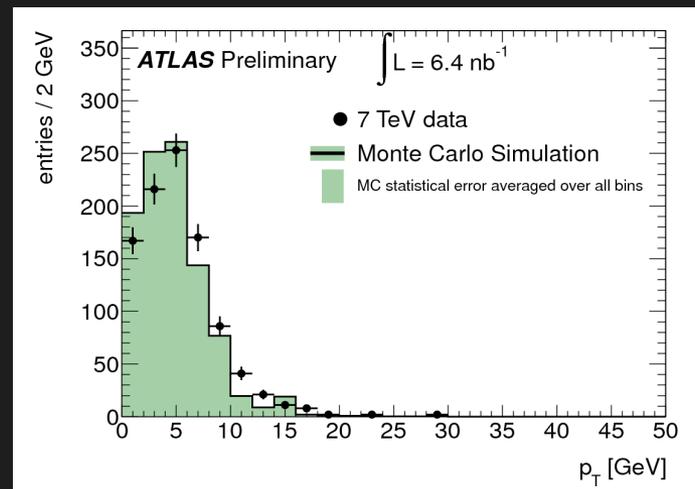
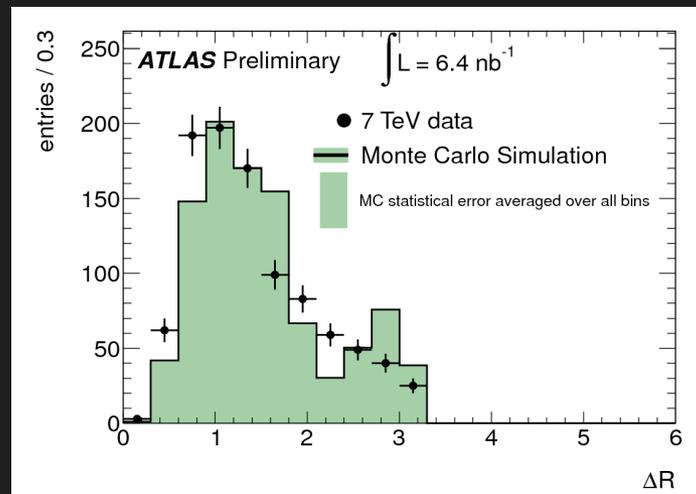
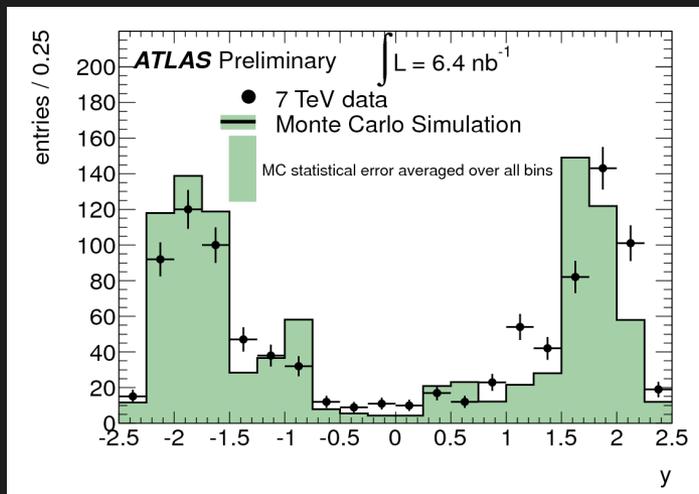
$$f_{bkg}(m_{\mu\mu}) \equiv (1 - a_0)$$

- $\delta m_{\mu\mu}$ - measured mass uncertainty of each pair of muon tracks
- S - scale factor to cover for unaccounted uncertainties on track parameters (e.g. non-gaussian tails)

| | | $m_{J/\psi}$, GeV | σ_m , MeV | N_{sig} | N_{bck} |
|-----|------|--------------------|------------------|--------------|-------------|
| all | data | 3.095 ± 0.004 | 82 ± 7 | 612 ± 34 | 332 ± 9 |
| | MC | 3.098 ± 0.001 | 74 ± 0.4 | | |

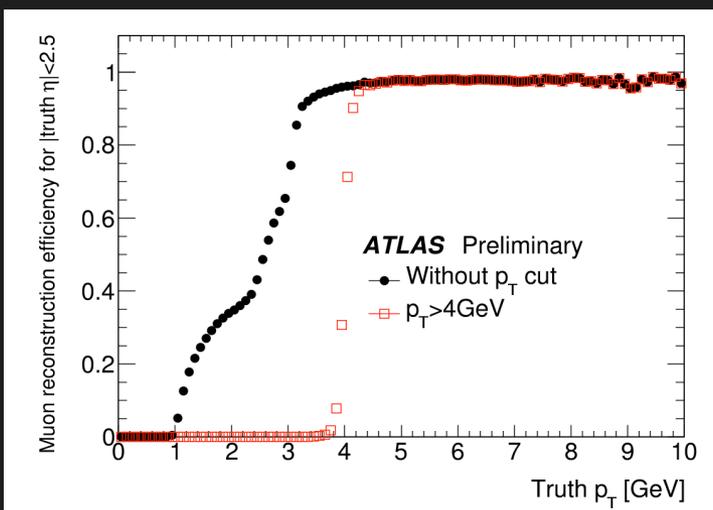
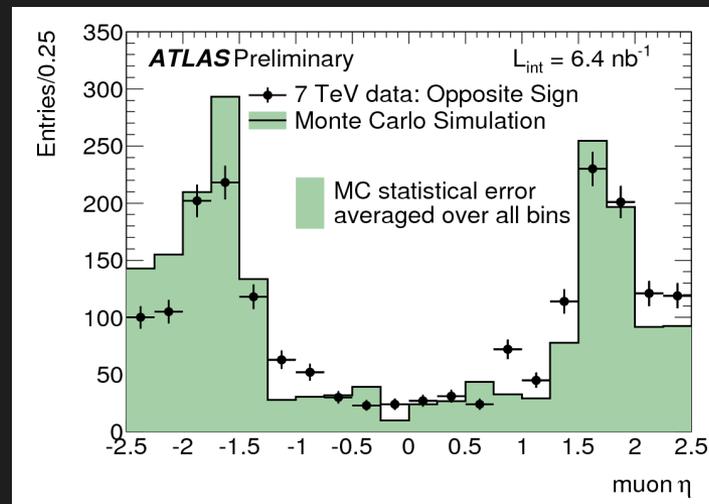
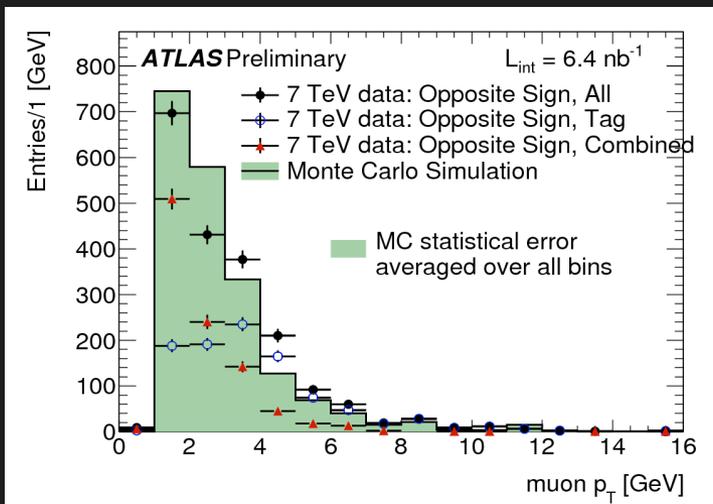
- The measured mass agrees with PDG within statistical precision of first data
- mass resolution agrees with that expected from MC

Properties of early J/ψ in ATLAS



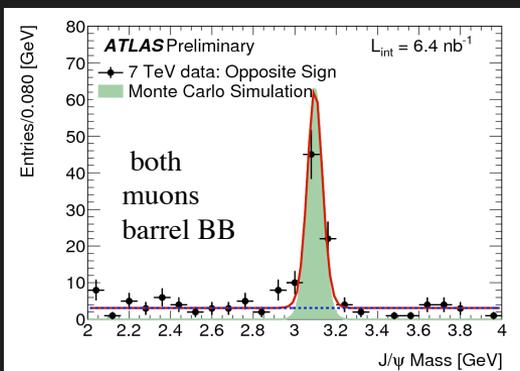
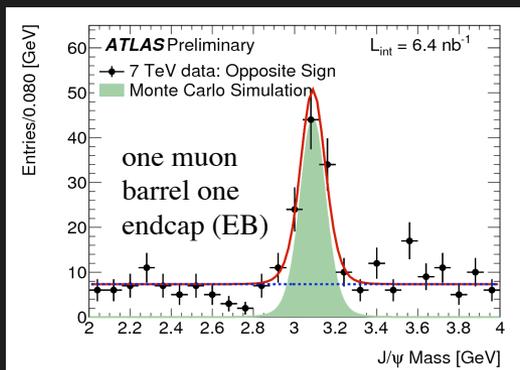
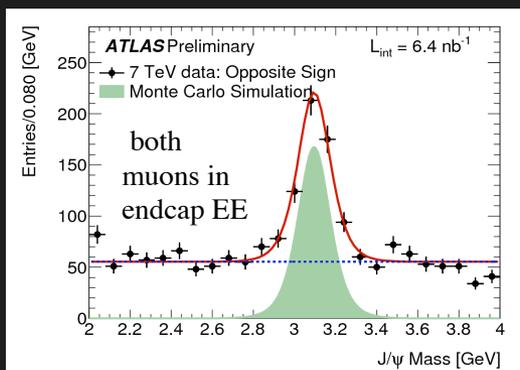
- Data agree with MC predictions of resolution and PDG mass
- Also good agreement between data and MC on kinematic properties of J/ψ
 - Essential conclusions derived from these first J/ψ signal studies.

Properties of muons from early J/ψ



- Our early analysis can access very low p_T J/ψ producing soft p_T muons, see left top
- Muons with enough energy to cross the calorimeters reach the MS mainly in the forward region
- This is a consequence of the muon acceptance of the ATLAS detector without any threshold requirement on the muon trigger, see the muon efficiency (left bottom, black) determined from MC

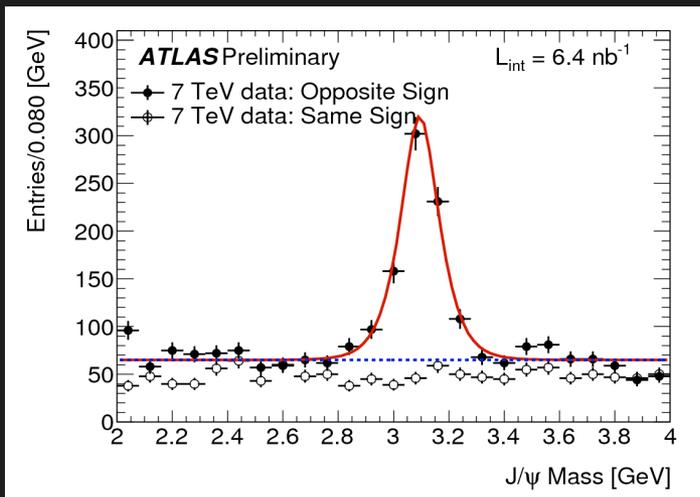
Performance of early J/ψ in ATLAS



- J/ψ mass resolution varies with the pseudorapidity of muons accordingly to MC expectations
 - endcap $2.5 > |\eta| > 1.05$, barrel $|\eta| < 1.05$
- no statistically significant mass shifts from the PDG value observed in any of the pseudorapidity regions

| | | $m_{J/\psi}, \text{ GeV}$ | $\sigma_m, \text{ MeV}$ | N_{sig} | N_{bck} |
|-----|----------|---------------------------|-------------------------|--------------|--------------|
| all | data | 3.095 ± 0.004 | 82 ± 7 | 612 ± 34 | 332 ± 9 |
| | MC | 3.098 ± 0.001 | 74 ± 0.4 | | |
| | data n/v | 3.096 ± 0.004 | 82 ± 7 | 612 ± 34 | 351 ± 10 |
| BB | data | 3.097 ± 0.005 | 36 ± 6 | 69 ± 9 | 8 ± 1 |
| | MC | 3.098 ± 0.001 | 37 ± 0.7 | | |
| | data n/v | 3.099 ± 0.005 | 38 ± 7 | 69 ± 9 | 8 ± 1 |
| EB | data | 3.089 ± 0.008 | 66 ± 12 | 88 ± 11 | 34 ± 3 |
| | MC | 3.097 ± 0.001 | 53 ± 0.8 | | |
| | data n/v | 3.089 ± 0.009 | 66 ± 12 | 87 ± 11 | 36 ± 3 |
| EE | data | 3.095 ± 0.006 | 88 ± 9 | 437 ± 31 | 324 ± 10 |
| | MC | 3.098 ± 0.001 | 82 ± 0.5 | | |
| | data n/v | 3.096 ± 0.006 | 88 ± 9 | 437 ± 31 | 344 ± 10 |

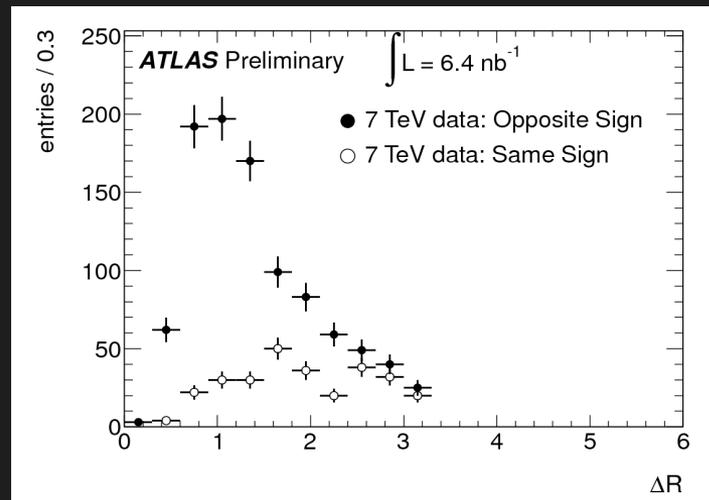
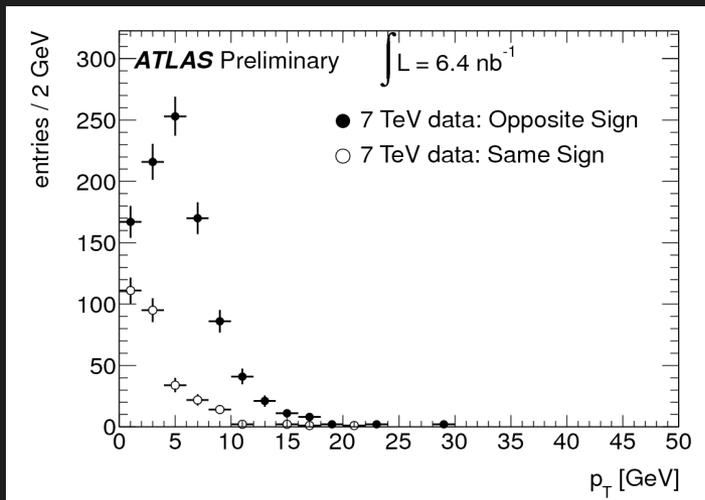
Comparison with like sign pairs



Early di-muon pairs selected at lowest p_T have specific features visible when comparing like sign pairs with J/ψ candidates

- like sign pairs almost match the level of the J/ψ background (unlike pairs) in the side bands
 - source of both dominated by muons from K/π decays
 - very little b/c content in tails

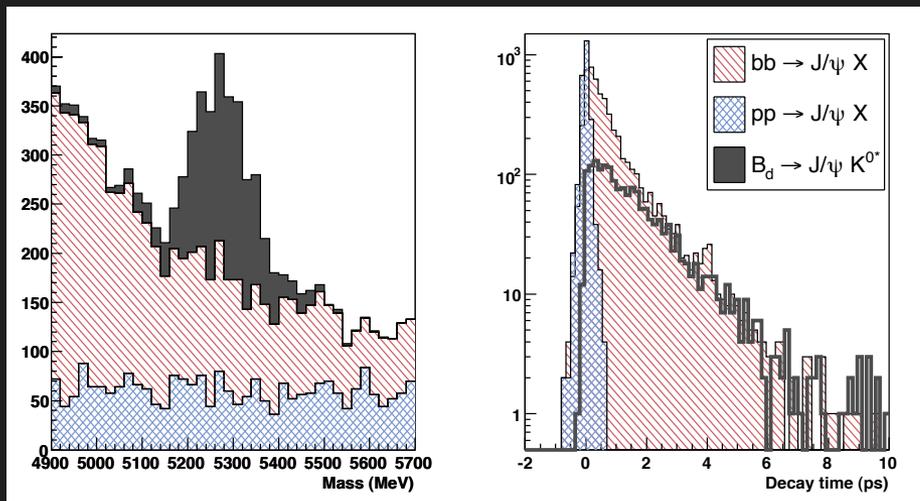
Di-muon pairs of opposite sign in the J/ψ region have evidently different kinematic properties from the like sign pairs



ATLAS B-physics program

- ATLAS B-physics program is realised in following sub-projects
 - HF quarkonia measurements
 - $B \rightarrow J/\psi$ (inclusive, exclusive) channels
 - Rare B-decays $B_{sd} \rightarrow \mu\mu$, $b \rightarrow s \mu\mu$, $b \rightarrow d \mu\mu$
 - Production properties of B and D-mesons decaying into hadrons
- Each sub-project has tasks/measurements for early, medium and advanced periods
 - First measurements, in addition to physics results, serve to improve understanding of detector performance to allow later high precision measurements
- Selected examples of MC based studies are given further for the early and for advanced periods
 - Complete B-physics program [arXiv:0901.0512](https://arxiv.org/abs/0901.0512) ; CERN-OPEN-2008-020, Chapter 11.

Early measurements with exclusive $B \rightarrow J/\psi$



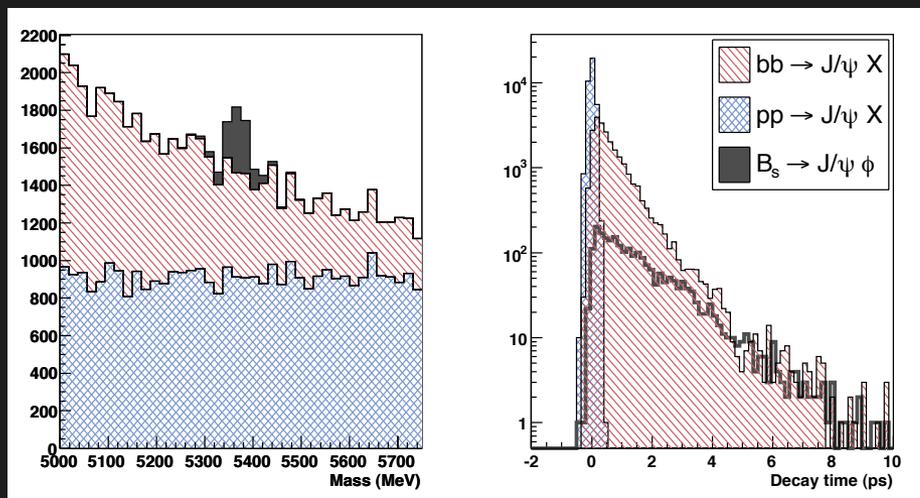
| Parameter | Simulated value | Fit result with statistical error |
|-----------------------------|-----------------|-----------------------------------|
| Γ , ps^{-1} | 0.651 | 0.73 ± 0.07 |
| $m(B)$, GeV | 5.279 | 5.284 ± 0.006 |

| | | |
|-------------------------------|-------|-------------------|
| Γ_s , ps^{-1} | 0.683 | 0.743 ± 0.051 |
| $m(B)$, GeV | 5.343 | 5.359 ± 0.006 |

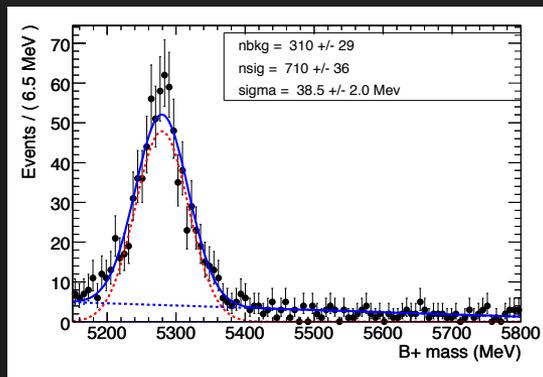
Applying simultaneous mass - lifetime likelihood fit to events

- $B \rightarrow J/\psi K^{0*}$ (10 pb^{-1})
- $B_s \rightarrow J/\psi \phi$ (150 pb^{-1})

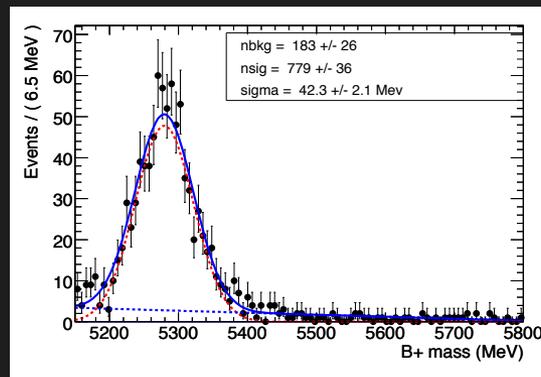
Lifetimes measured with sensitivity better than 10%. Early lifetime measurements test the calibrations and alignments necessary for precise CPV studies



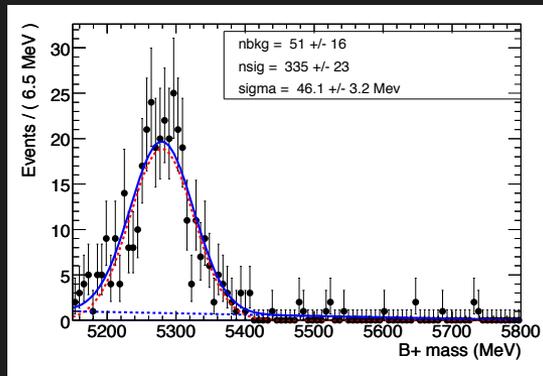
Differential cross section $B^+ \rightarrow J/\psi K^+$



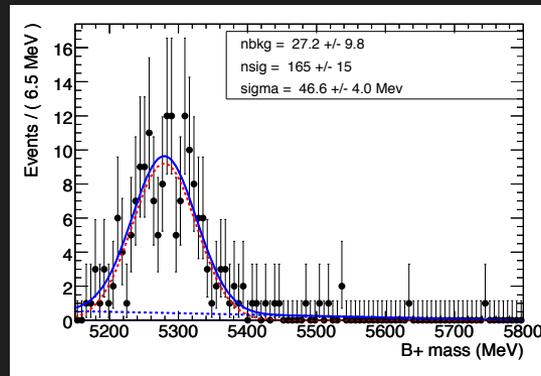
(a) $10 \leq p_T < 18$ GeV



(b) $18 \leq p_T < 26$ GeV



(c) $26 \leq p_T < 34$ GeV



(d) $34 \leq p_T < 42$ GeV

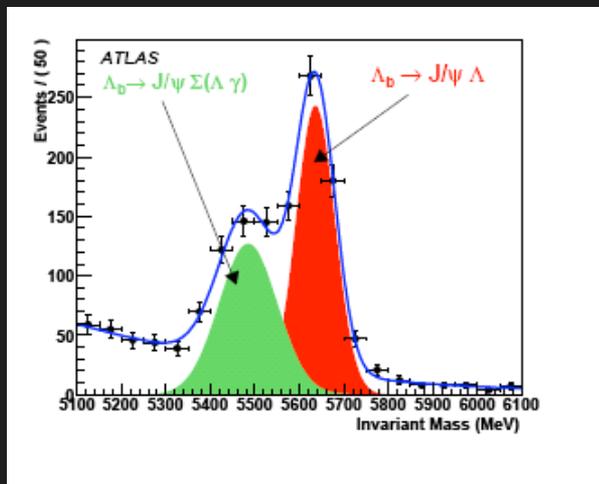
Fit of the B^+ mass in four p_T ranges

| p_T range [GeV] | $p_T \in [10, 18]$ | $p_T \in [18, 26]$ | $p_T \in [26, 34]$ | $p_T \in [34, 42]$ | $p_T \in [10, \text{inf})$ |
|---------------------------|--------------------|--------------------|--------------------|--------------------|----------------------------|
| stat. + \mathcal{A} [%] | 7.7 | 6.9 | 10.5 | 13.9 | 4.3 |
| total [%] | 16.1 | 15.8 | 17.6 | 19.8 | 14.8 |

The $B^+ \rightarrow J/\psi K^+$ total and differential production cross-sections

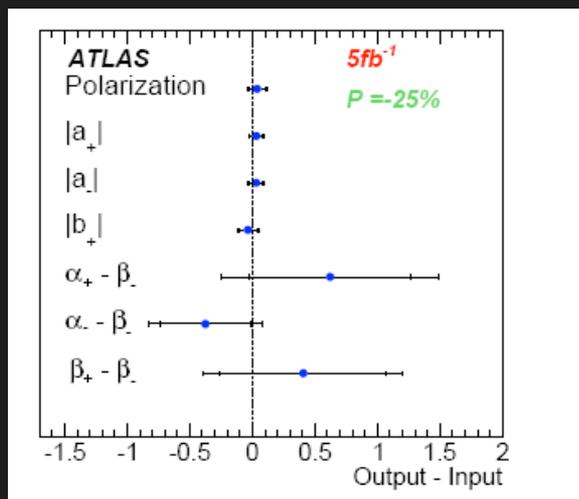
- With 10 pb^{-1} the total cross-section can be measured with a statistical precision better than 5%
- The differential cross-section with precision of the order of 10%.

Production polarization of Λ_b with 5 fb^{-1}



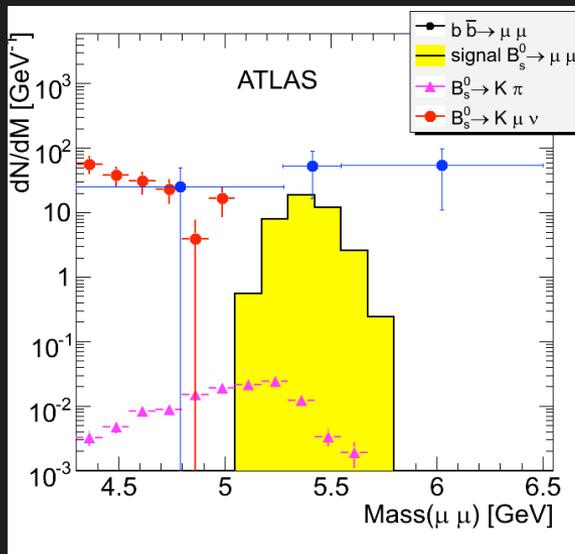
Polarization varies with pseudorapidity thus ATLAS/CMS and LHCb can perform complementary measurements to map full range.

With 5 fb^{-1} the Λ_b polarization in ATLAS can be measured with precision of 0.07



| Parameter | Value \pm Uncertainty (Polarization = -25%) |
|----------------------|--|
| Polarization | -0.213 ± 0.069 |
| $ a_+ $ | 0.461 ± 0.051 |
| $ a_- $ | 0.289 ± 0.058 |
| $ b_+ $ | 0.259 ± 0.071 |
| $\alpha_+ - \beta_-$ | -0.991 ± 0.640 |
| $\alpha_- - \beta_-$ | 0.856 ± 0.364 |
| $\beta_+ - \beta_-$ | -1.442 ± 0.666 |

ATLAS potential for $B \rightarrow \mu\mu$



$B_s \rightarrow \mu\mu$ signal and backgrounds after applying all selection cuts - relevant at $> 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

| Selection cut | $B_s^0 \rightarrow \mu^+\mu^-$ efficiency | $b\bar{b} \rightarrow \mu^+\mu^-X$ efficiency | |
|------------------------------|---|---|-------------------------------|
| $I_{\mu\mu} > 0.9$ | 0.24 | $(2.6 \pm 0.3) \cdot 10^{-2}$ | |
| $L_{xy} > 0.5\text{mm}$ | 0.26 | $(1.4 \pm 0.1) \cdot 10^{-2}$ | $(1.0 \pm 0.7) \cdot 10^{-3}$ |
| $\alpha < 0.017 \text{ rad}$ | 0.23 | $(8.5 \pm 0.2) \cdot 10^{-3}$ | |
| Mass in $[-\sigma, 2\sigma]$ | 0.76 | 0.079 | |
| TOTAL | 0.04 | $0.24 \cdot 10^{-6}$ | $(2.0 \pm 1.4) \cdot 10^{-6}$ |
| Events yield | 5.7 | | 14^{+13}_{-10} |

- The ATLAS performance was analysed for first $J/\psi \rightarrow \mu\mu$. Shown that di-muon performance with real data consistent with MC predictions
- The MC simulation of $B_s \rightarrow \mu\mu$ potential (left) to test potential with 10 fb^{-1} was done with trigger menus for $> 10^{33}$
 - both muons required $pT > 6 \text{ GeV}$.
- Low pT B-physics di-muon triggers will be applied at low instantaneous luminosities of early LHC period to maximize reach for first sensitivity
- At $\sim 10^{34}$ dedicated triggers prepared to use full ATLAS potential for $B_s \rightarrow \mu\mu$
- $B_s \rightarrow \mu\mu$ $B_d \rightarrow \mu\mu$ in physics program for ATLAS upgrade

Summary

- Early J/ψ data taken with minimum bias trigger show excellent agreement with expected performance
- Reproducing J/ψ PDG mass in all pseudorapidity regions – confirms that p_T scale understood at low p_T range
- J/ψ mass resolution over entire pseudorapidity regions of detector – consistent with MC.
- B-physics program prepared for both early and advanced periods.
- ATLAS will significantly contribute to $B \rightarrow \mu\mu$ potential as an instantaneous LHC luminosity will be increased to several times 10^{33} and to a nominal value 10^{34} Rare B decays for detector upgrade being prepared.