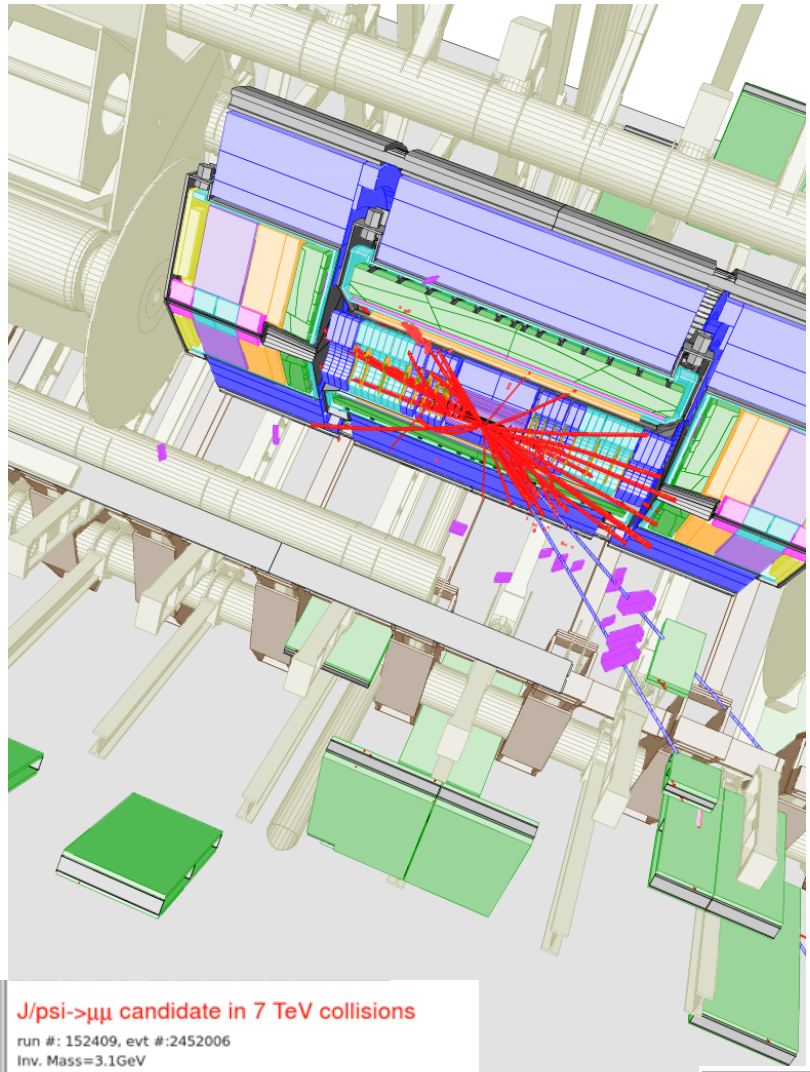


IFAE 2011
Incontro di Fisica delle Alte Energie
Perugia
27-29 April 2011

# Heavy flavour in ATLAS

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Università degli Studi di Napoli Federico II

On behalf of ATLAS Collaboration

# Outline

- Heavy Flavour Physics Programm
- The ATLAS Detector

- J/ψ observation
- Measurements of J/ψ inclusive production and non-prompt to prompt cross-section

  **Submitted Nuc. Phys. B**

- Observation of Y system

- Exclusive B-meson decays

  **ATLAS-CONF-2010-098**

- D mesons decays

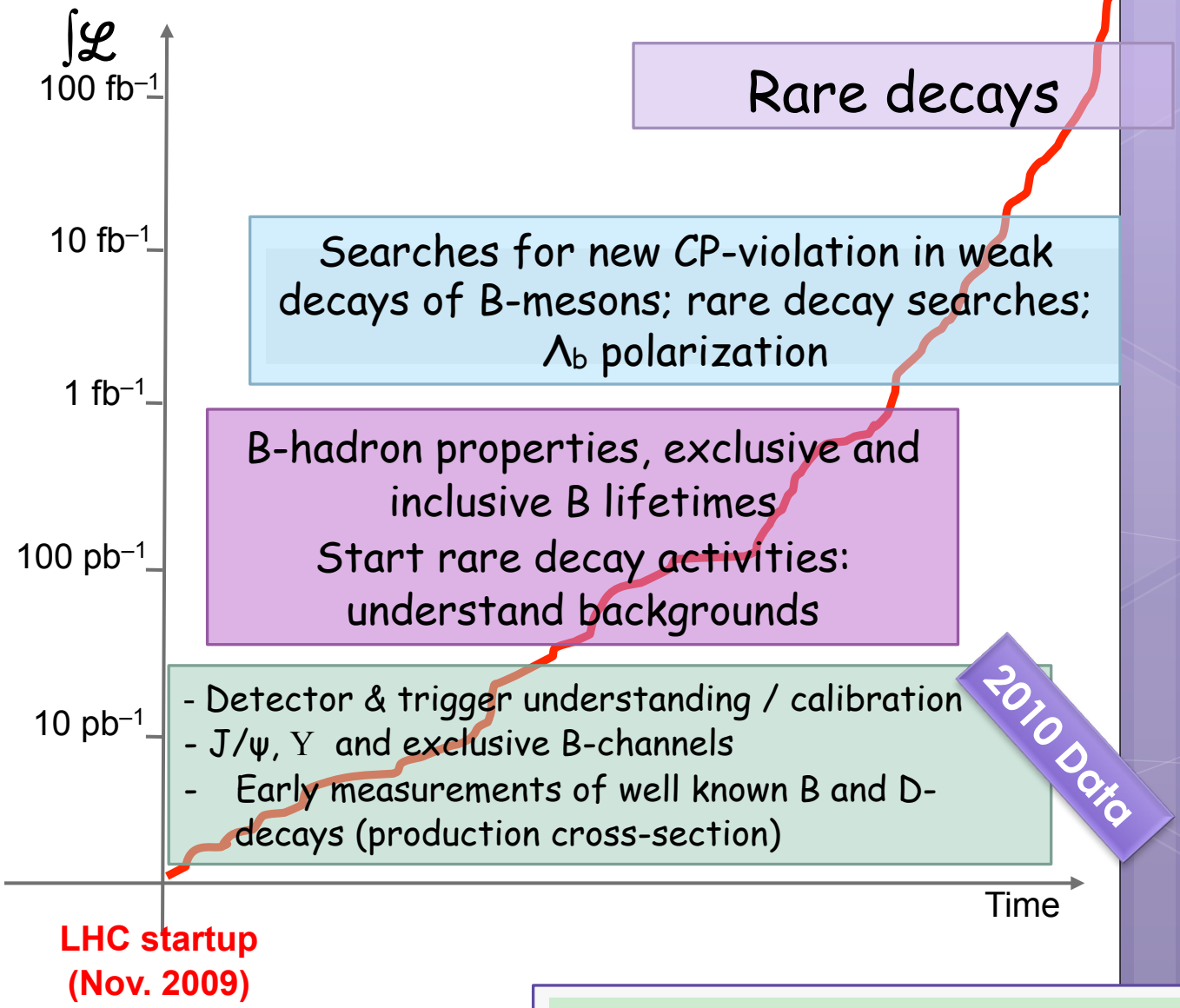
  **ATL-COM-PHY- 2010-034, ATLAS-CONF-2011-017**

- Summary

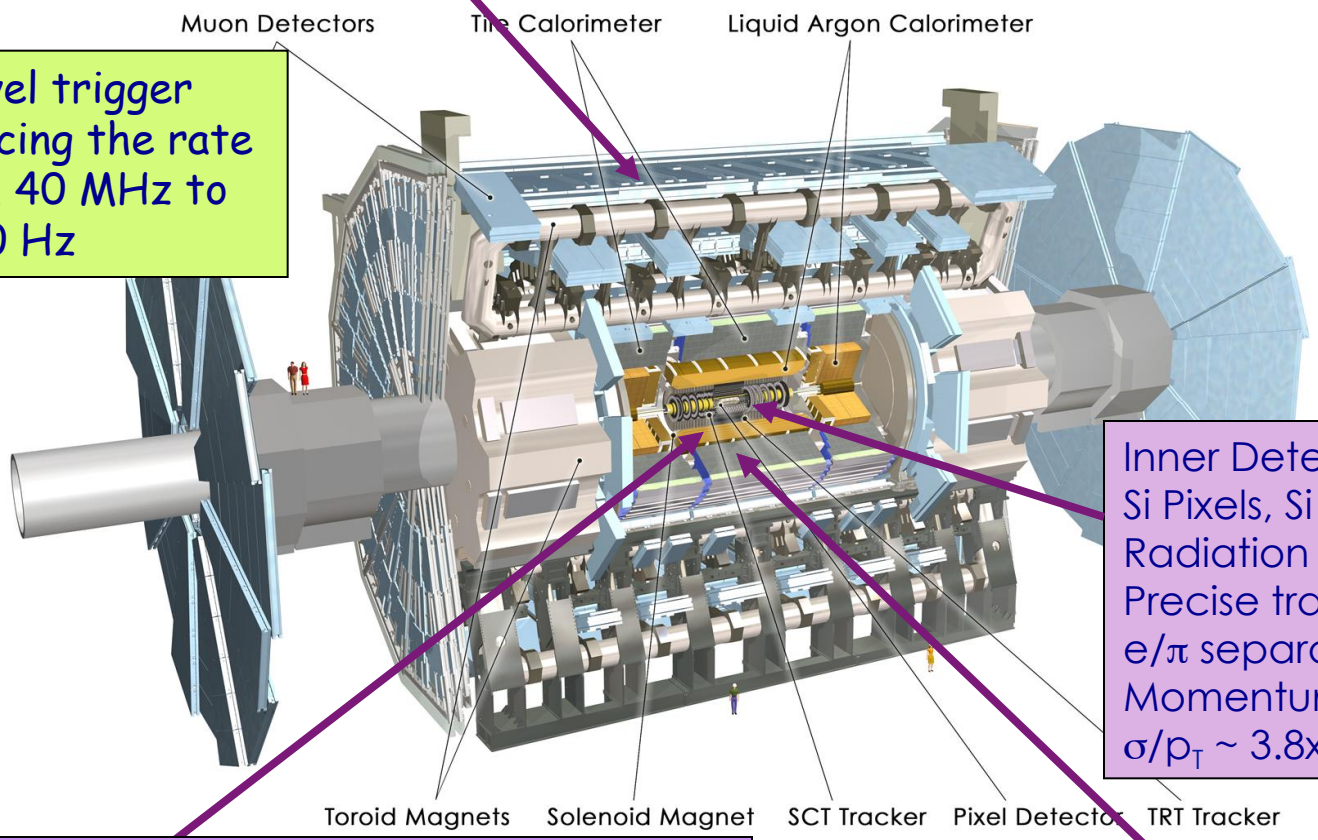
# Heavy Flavour Program at ATLAS

**Key elements for B-Physics searches:**

- ✧ Efficient low pt muon trigger
- ✧ Very good:
  - Muon coverage
  - Track momentum resolution
  - Mass resolution
  - Vertex resolution
  - Well understood MC



**Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers**
**Muon trigger and measurement with momentum resolution < 10% up to $E_\mu$ ~ 1 TeV**



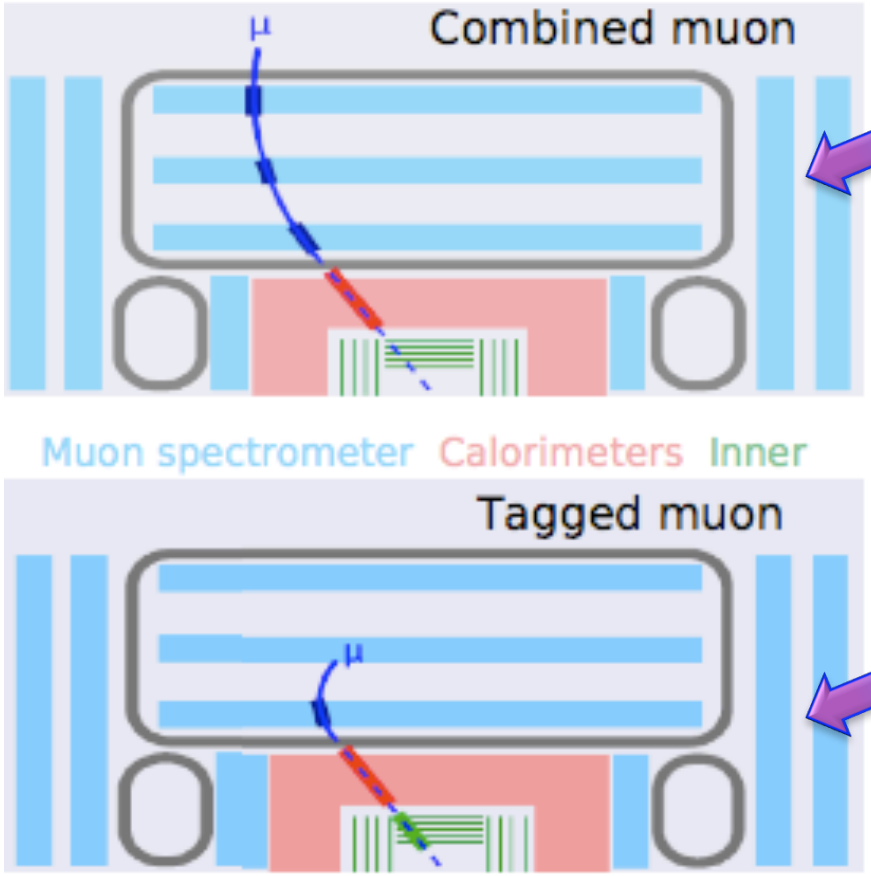

3-level trigger reducing the rate from 40 MHz to ~200 Hz

Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, $e/\pi$ separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\ p_T\ (\text{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
$e/\gamma$ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing $E_T$
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

# Muon reconstruction in ATLAS




**Combined Muons:** Muons with an ID track matched to a MS track and refitted through the detector to give the best measurement.

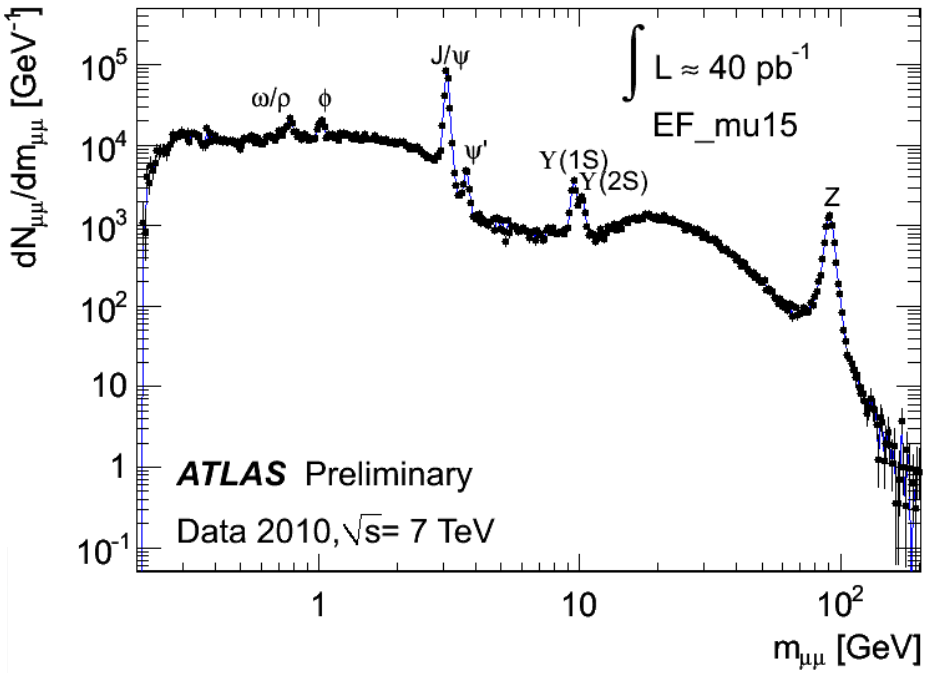
**Tagged Muons:** Muons with an ID track matched to a segment when extrapolated to the MS. Such muons generally have low momentum.

# Di-muon invariant mass spectrum

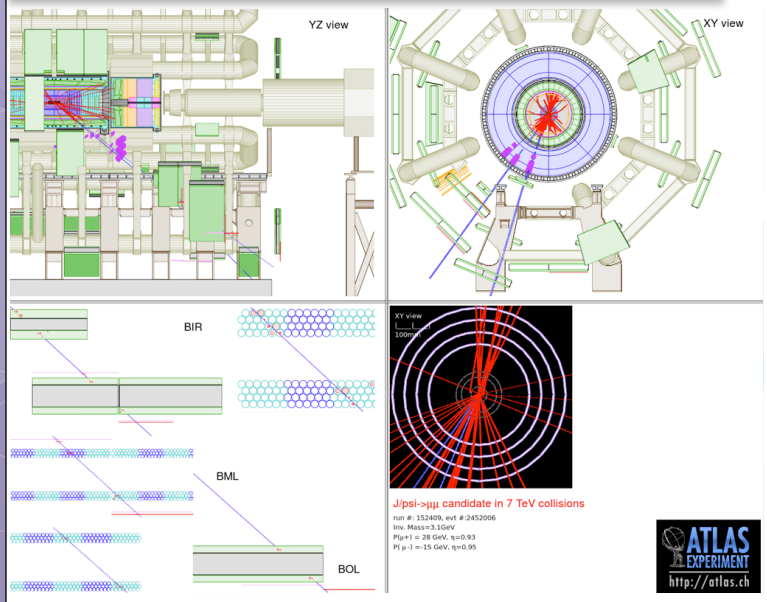
Combined (Inner detector + Muon Spectrometer) opposite sign muons with:

$p_T(\mu_1) > 15$ GeV/c

$p_T(\mu_2) > 2.5$ GeV/c




**Display of a candidate $J/\psi \rightarrow \mu\mu$ event**



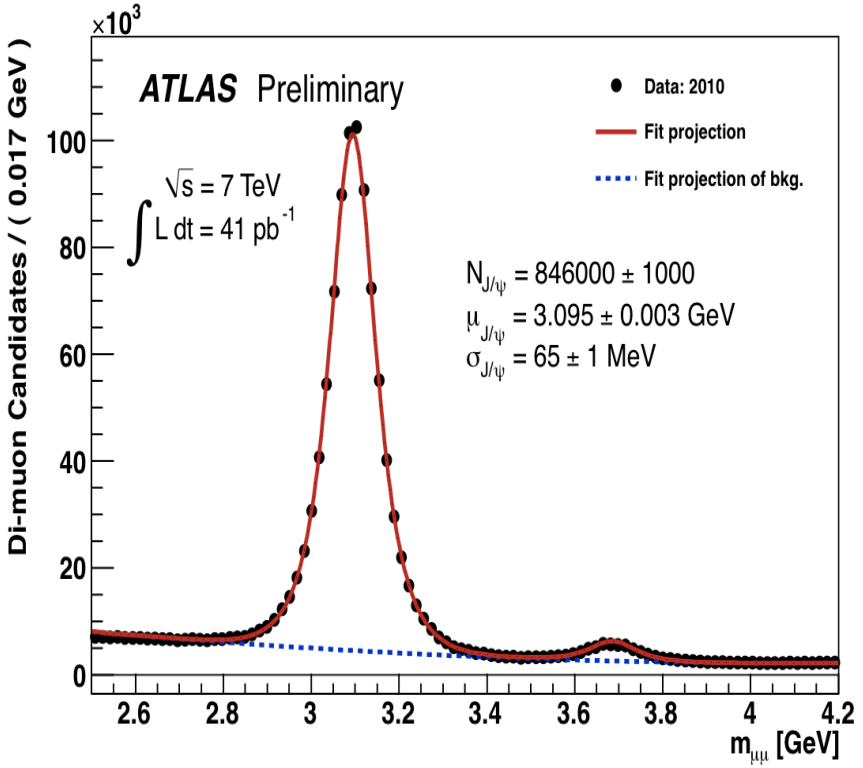

*High Level Trigger (EF) with $p_T$ threshold of 15 GeV/c has been required*

# J/ψ observation

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

## J/ψ events selection:

- At least 1 primary vertex with 3 tracks associated
- Quality cuts on the Inner Detector tracks to remove the badly measured muons
- Opposite charge muon pairs with successful vertex fit.
- One of the muon candidates needs to be combined
- Momentum Cut:
  $p_T(\mu_1) > 4$ GeV
  $p_T(\mu_2) > 2.5$ GeV
- $|\eta(\mu)| < 2.5$




J/ψ observation with L= 41pb $^{-1}$ measured mass and width in agreement with PDG

$M_{J/\psi}$ = **3.095 ± 0.003 GeV**

$\sigma(m_{J/\psi})$ = **65 ± 1 MeV**

# J/ψ Differential Cross-Section Measurement

**Uses data collected between April and August 2010**

- Maximum Likelihood fit of the J/ψ invariant mass in $p_T$ and y bins
- Each candidate is multiplied by $\omega$ in order to recover the true number of $J/\psi \rightarrow \mu^+\mu^-$ events:

$$w^{-1} = \mathcal{A}(p_T, y, \lambda_i) \times \epsilon_\mu(\vec{p}_1) \times \epsilon_\mu(\vec{p}_2) \times \epsilon_{trig}(\vec{p}_1, \vec{p}_2)$$

$\mathcal{A}$: detector acceptance; $\lambda_i$: spin-alignment scenario; $\epsilon_\mu$: reconstruction efficiency; $\epsilon_{trig}$: trigger efficiency

- Trigger efficiency extracted from data uses a data 'tag & probe' method combined with MC for finer binning.
- Efficiency to reconstruct muon in the detector determined from data using a 'tag and probe' method.

# J/ψ Differential Cross-Section Measurement: Acceptance

**Detector Acceptance depends strongly on the spin alignment, or polarisation of the J/ψ**

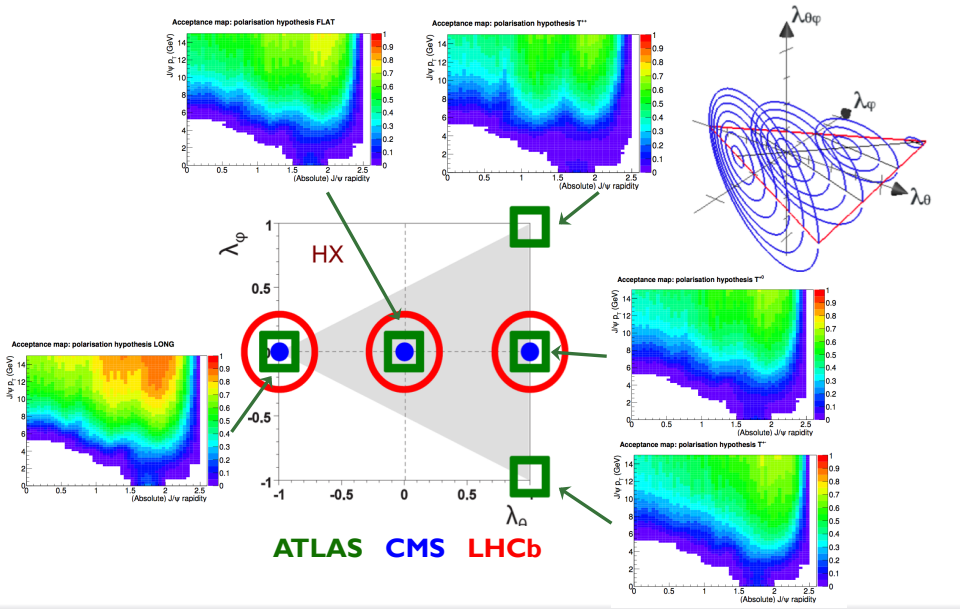
*not (yet) measured under LHC conditions and will be an important future measurement.*

$$\frac{dN}{d\Omega} = 1 + \lambda_{\theta^\star}\cos^2\theta^\star + \lambda_{\phi^\star}\sin^2\theta^\star\cos 2\phi^\star + \lambda_{\theta^\star\phi^\star}\sin 2\theta^\star\cos\phi^\star$$

$\frac{1-3|a_0|^2}{1+|a_0|^2}$ $\quad$ $\frac{2Re\,a^*_{+1}a_{-1}}{1+|a_0|^2}$ $\quad$ $\frac{\sqrt{2}Re\,[a^*_0(a_{+1}-a_{-1})]}{1+|a_0|^2}$

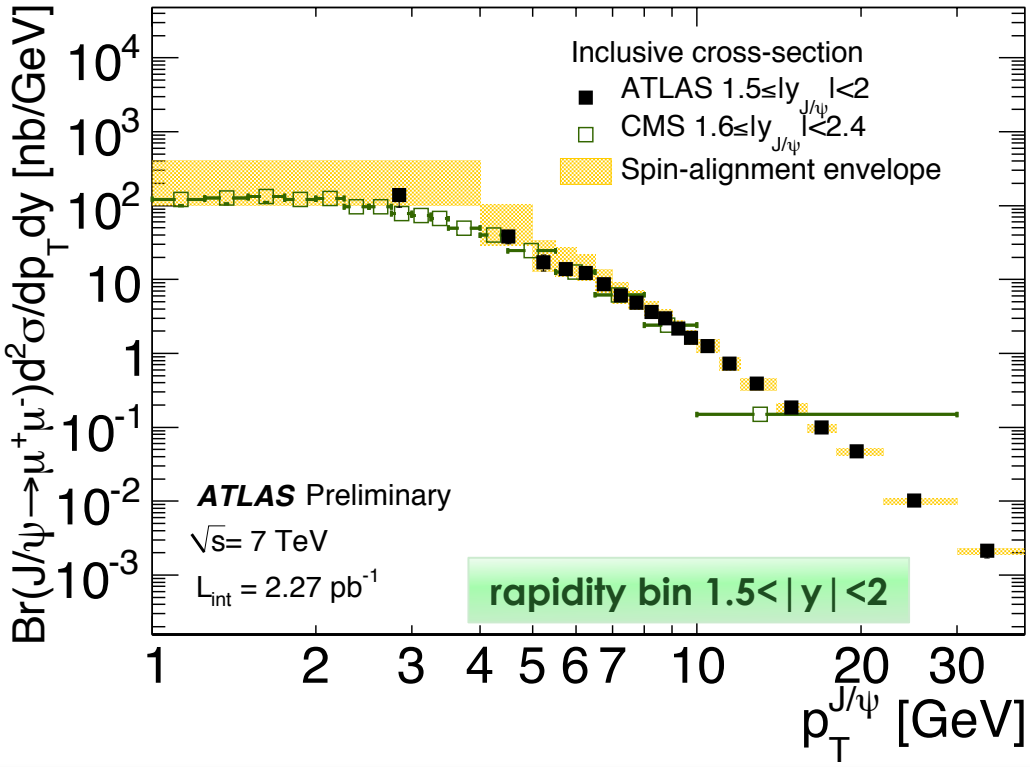
**Take 5 working points:**

*Covers maximum acceptance variations; applied as systematic uncertainty in final measurement.*



# Inclusive Differential CrossSection

**Inclusive J/ψ production cross-section as a function of J/ψ transverse momentum in the rapidity bin 1.5|y|<2.**




*Overlaid is a band representing the variation of the result under various spin-alignment scenarios representing a theoretical uncertainty.*

The green points are the equivalent results from CMS.

**The measurements made by ATLAS and CMS are in good agreement with each other in the overlapping range of moderate $p_T$ values and complement each other at high (ATLAS) and low (CMS) values of transverse momenta.**

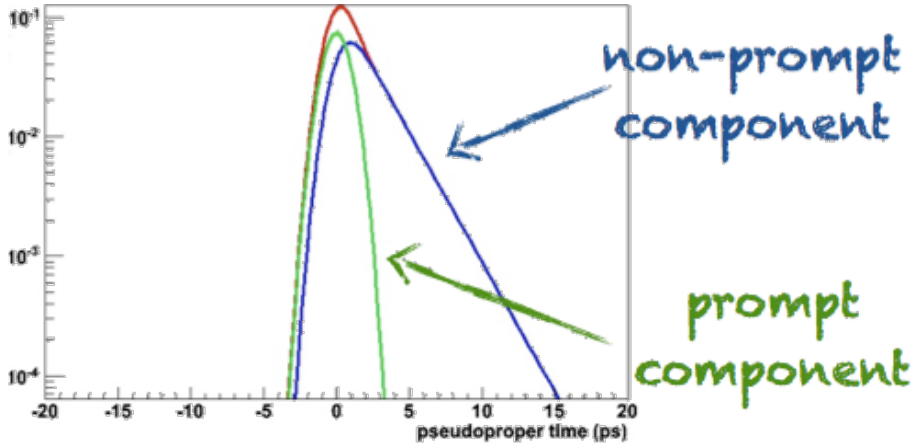
*For more details see the poster "J/ Ψ production cross section and non-prompt fraction measurement with the ATLAS detector " by Nicola Orlando*

# Non-Prompt to Prompt J/ψ Production Cross-Section Ratio

*Experimentally it is possible to distinguish between the J/ψs from decay of heavier charmonium state (prompt production) from the J/ψs produced via the decay of a B-hadron (non-prompt production).*
*We define the prompt to non-prompt ratio R as:*

$$R = \frac{\sigma(pp \to b\bar{b}X \to J/\Psi X')}{\sigma(pp \to J/\Psi X'')}$$

The pseudo-proper decay time separates prompt from non-prompt candidates:



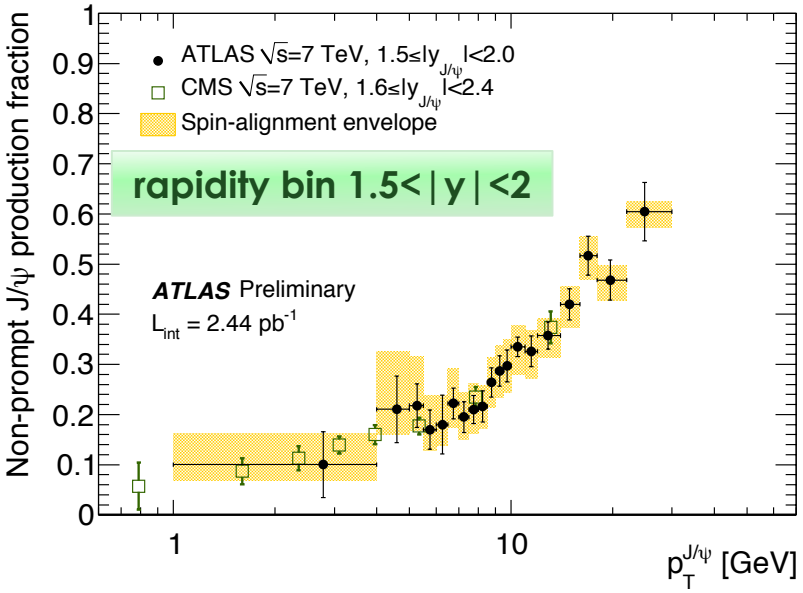

PseudoProperTime

$$\tau = \frac{L_{xy} m^{J/\Psi}}{p_T^{J/\Psi}}$$

Lxy → xy displacement of the candidate wrt the primary vertex and projected on its $p_T$

# Non-Prompt Fraction

**J/ψ non-prompt fractions as a function of J/ψ transverse momentum**

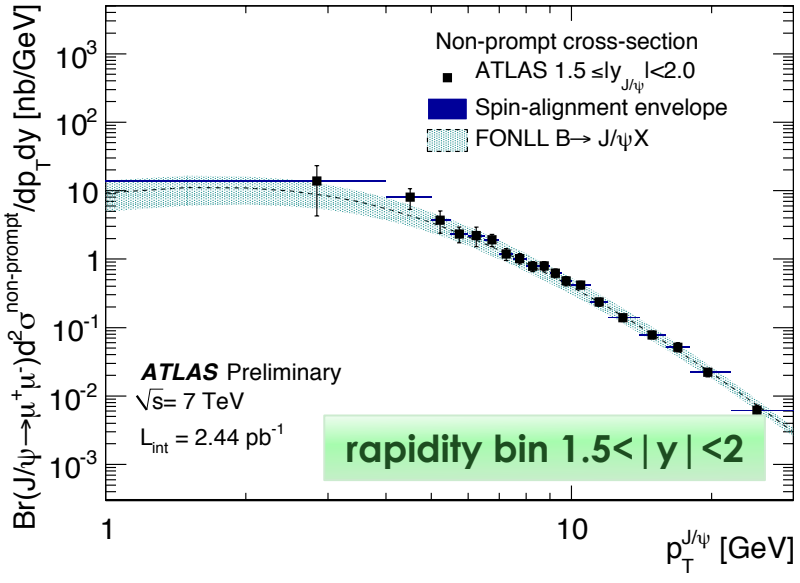



The yellow band represents the variation of the result under various spin-alignment scenarios representing a theoretical uncertainty.

**The green points are the equivalent results from CMS.**

**Good agreement with the CMS results**

**J/ψ non-prompt cross-section as a function of J/ψ transverse momentum**

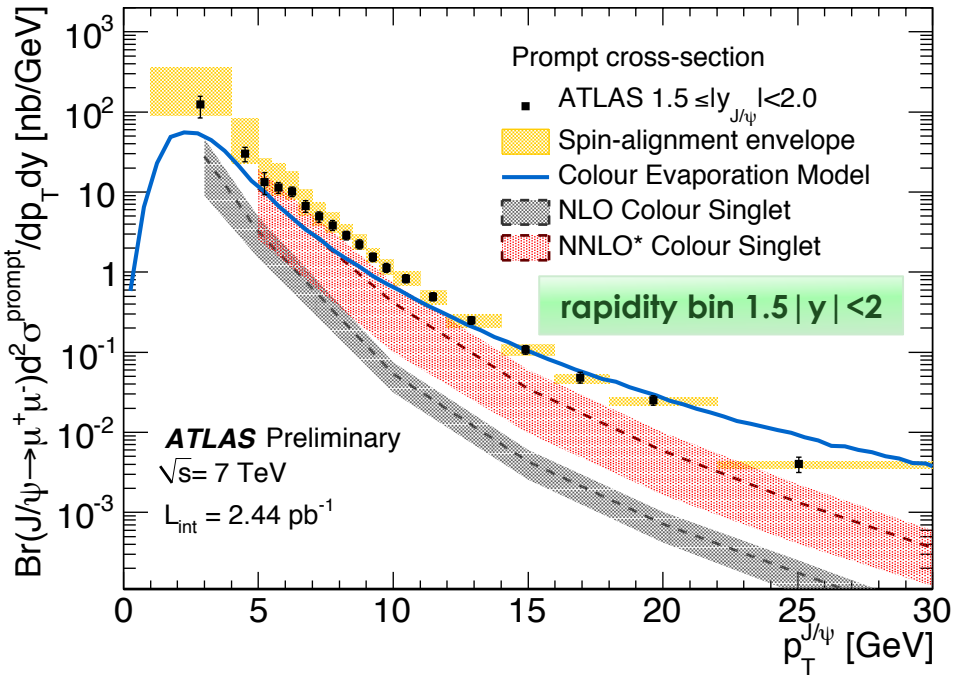



The error bars on the data points represent the combined statistical and systematic uncertainty. The luminosity uncertainty is not shown.

***Agreement is good with predictions***

# Prompt Cross-Section

Inclusive J/$\psi$ prompt cross-section as a function of J/$\psi$ transverse momentum in the rapidity bin 1.5 | y | <2.

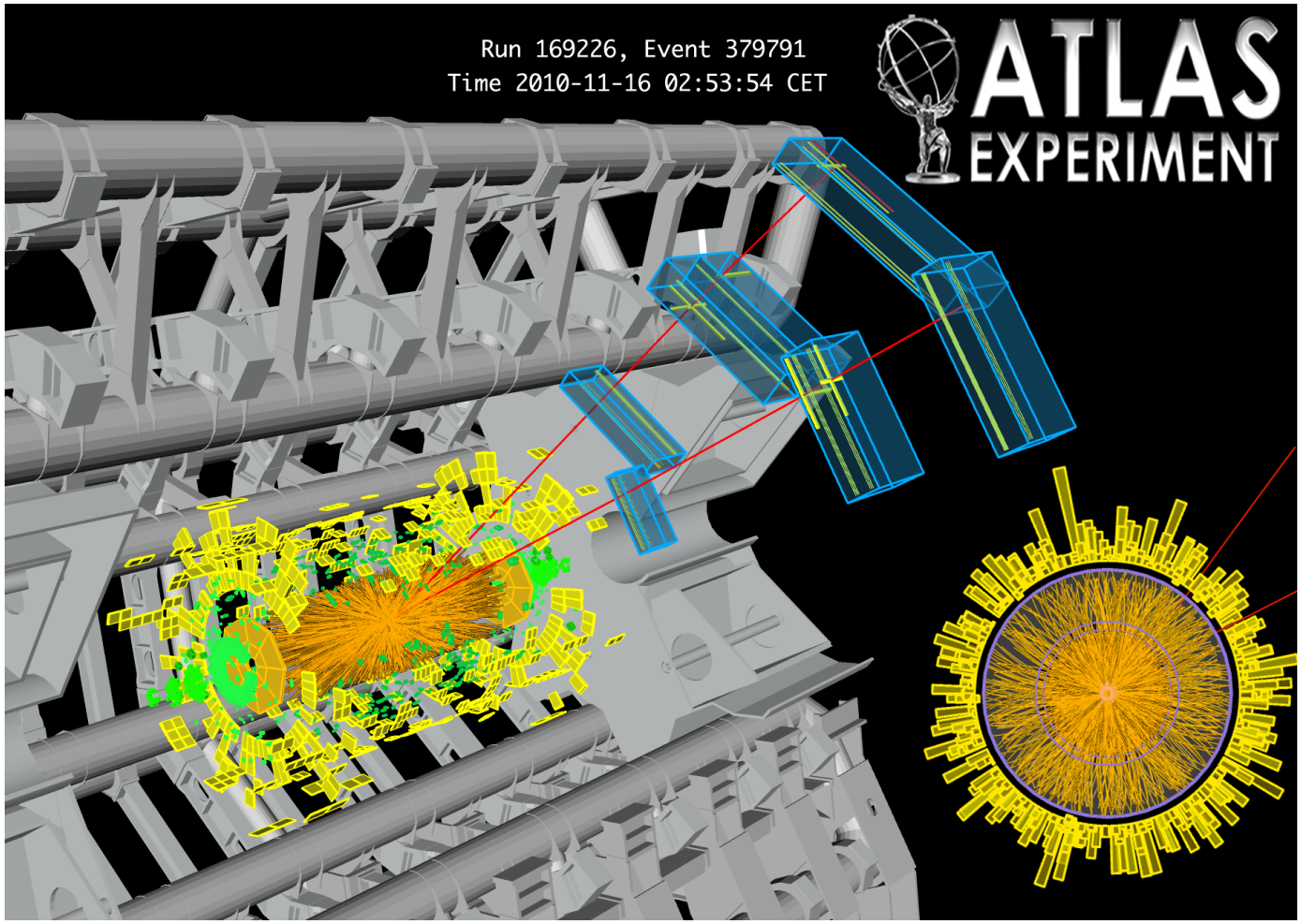



*Predictions from the three models are superimposed.*

Overlaid is a band representing the variation of the result under various spin-alignment scenarios representing a theoretical uncertainty.

The error bars on the data points represent the combined statistical and systematic uncertainty. The luminosity uncertainty is not shown.

# A heavy ion collision with a candidate $J/\psi \rightarrow \mu^+\mu^-$




See the talk **"Studio della produzione di J/psi e Z in collisioni piombo-piombo a LHC con l'esperimento ATLAS"** by Camilla MAIANI (ROMA1)

# Observation of the Upsilon System

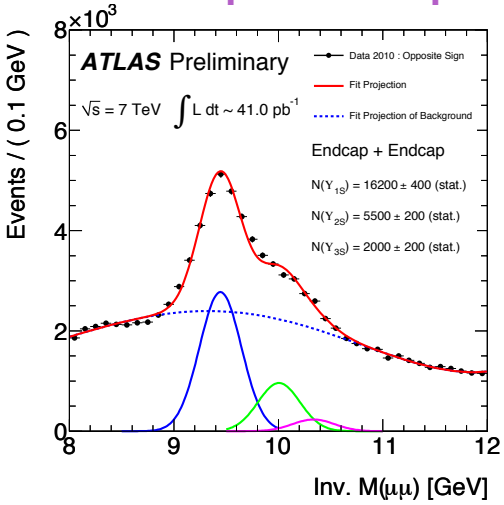
- Observation of the three Upsilon resonances separated into detector regions of muons in:
  - **Barrel – Barrel**
  - **Endcap – Barrel**
  - **Endcap – Endcap**
- Muons were required to have $p_T > (2.5, 4)$ GeV and to be reconstructed within a $|\eta| < 2.5$.

**Cross-section measurement in progress**

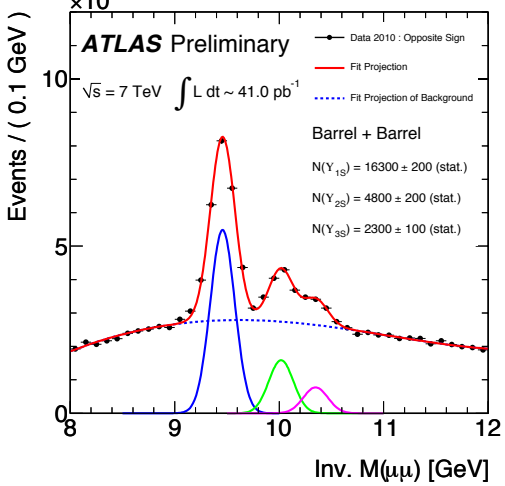
The signal lineshape fits are Gaussian with a fourth-order Chebyshev polynomial to model the background.

The separations of the three peaks are fixed using the PDG masses but the absolute position on the invariant mass scale is allowed to float in the fit.

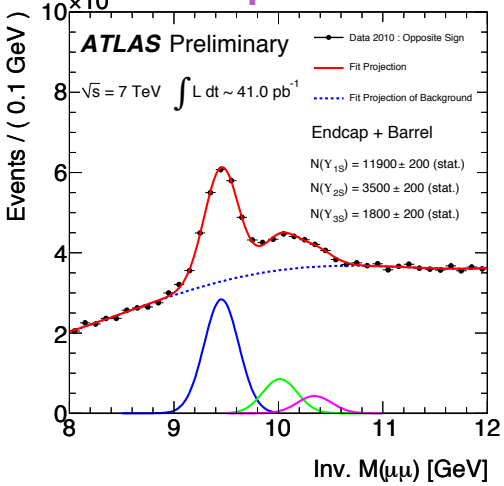
**Endcap – Endcap**




**Barrel – Barrel**

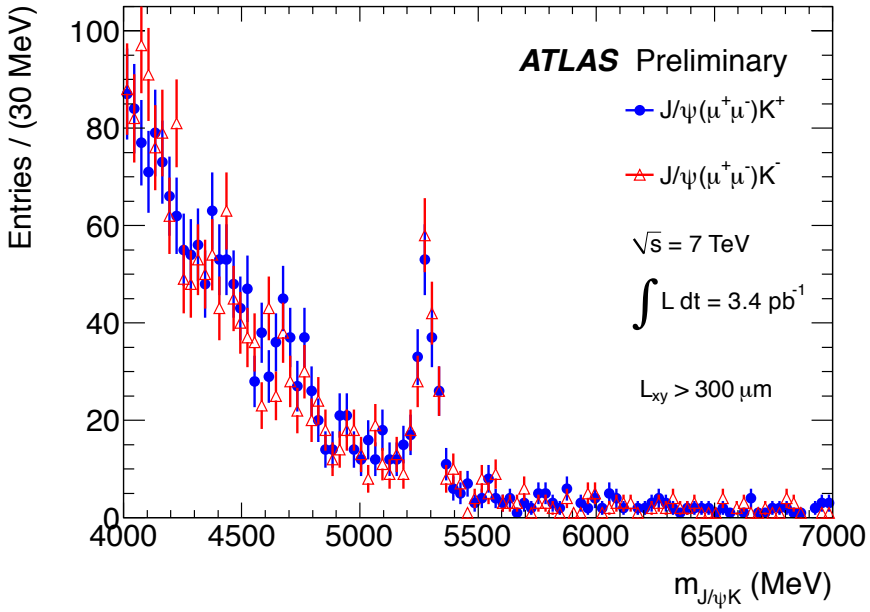


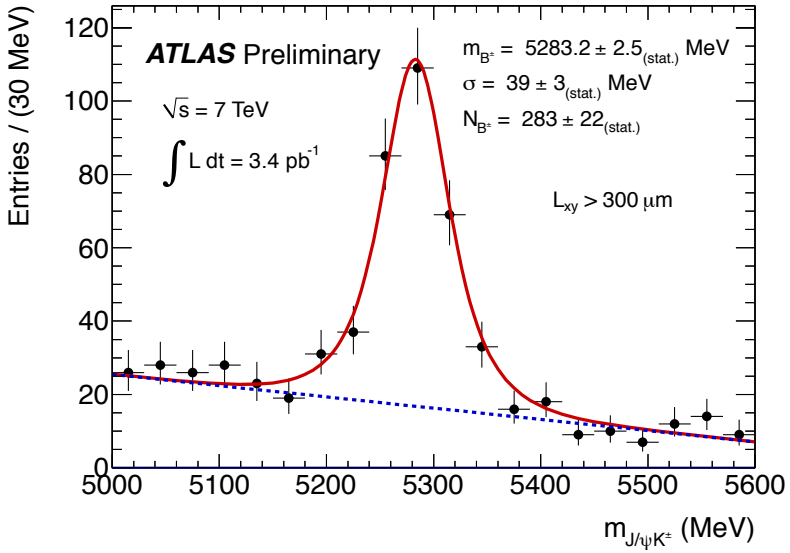

**Endcap – Barrel**



# Observation of $B^{\pm}$ mesons: $B^{\pm} \rightarrow J/\psi K$

- Dimuon in the $J/\psi$ mass range combined with a third track (kaon mass assigned).
- Fitted to a common vertex, with $J/\psi$ mass constraint on dimuon
- Background suppression by applying a cut on transverse decay length Lxy > 0.3 mm




**Mass compatible with PDG value:**

M(B) = 5283.2 ± 2.5 MeV

PDG: M(B) = 5279.17± 0.29MeV

$\sigma_B$ = 39 ± 3 MeV

$N_B$ = 283 ± 22

*ATLAS-CONF-2010-098*



See also "Charm and Beauty reconstruction in ATLAS" by A. Ferretto Parodi

# D-mesons production

- ✓ *D-mesons are produced in c and b fragmentation*
- ✓ *c and b quark production are hard processes ($m_Q >> \Lambda_{QCD}$)*
- ✓ *Theoretical calculations available up to NLO+NNLO level*
- ✓ *Still large theoretical uncertainties (scales, multiple interactions)*

**Reconstruction of *D-mesons already feasible with first ATLAS data*** *due to:*

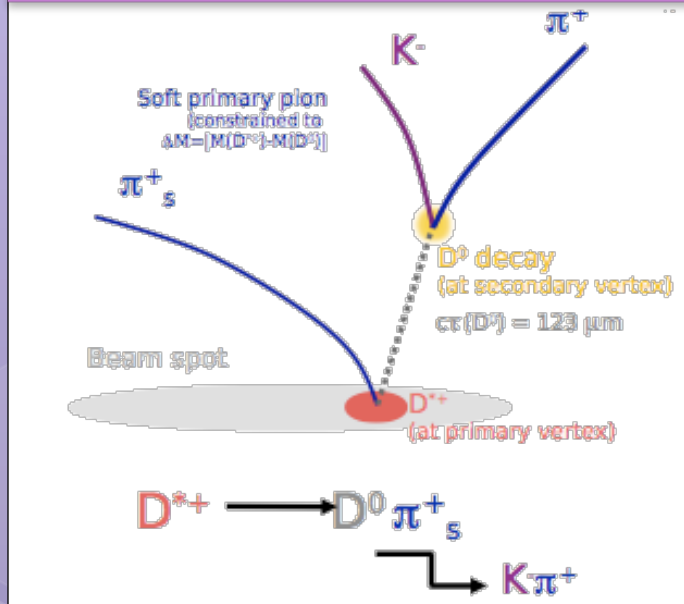
- ✧ *large cross-section values*
- ✧ *clean D-meson signatures*
- ✧ *precise ATLAS tracking and vertexing*

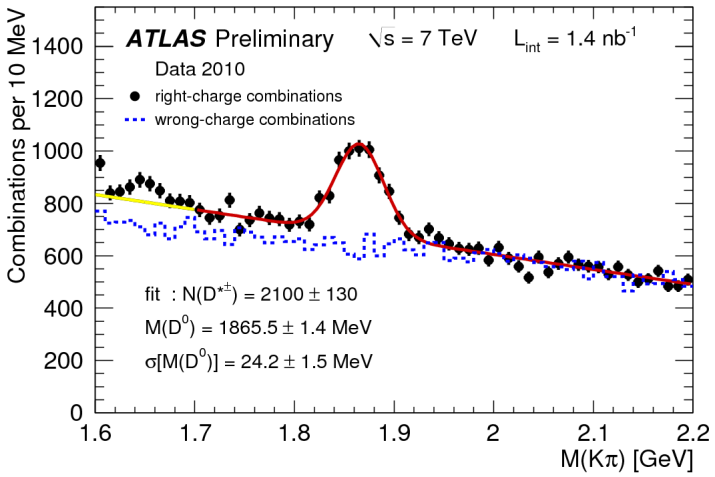
**expected cc and bb cross sections in p-p collisions at $\sqrt{s}$ = 7 TeV: $\sigma$ (cc ) ~ 4.4 mb $\sigma$ (bb) ~ 0.24 mb**
***first charm processes reconstructed in ATLAS:***

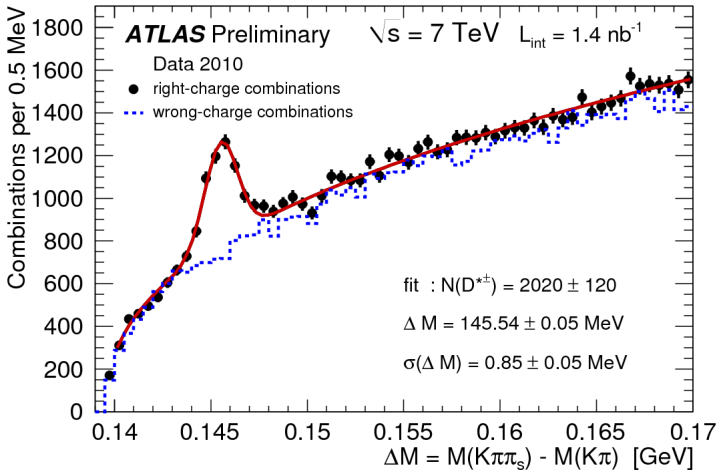
$D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$ (+c.c.)
$D^+ \rightarrow K^-\pi^+\pi^+$ (+c.c.)
$D_s^+ \rightarrow \Phi\,\pi^+ \rightarrow (K^-K^+)\pi^+$ (+c.c.)

# D-mesons production: D*

$D^{*+} \rightarrow D^0 \pi^+ \rightarrow (K^- \pi^+) \pi^+$ (+c.c.)




Build $D^0$ signal from M(Kπ) for $D^{*\pm}$ candidates
Additional discrimination from mass difference $\Delta M = M(K\pi\pi_s)-M(K\pi)$

Use presence of secondary vertex and properties of hard process to guide cut selection to enhance signal

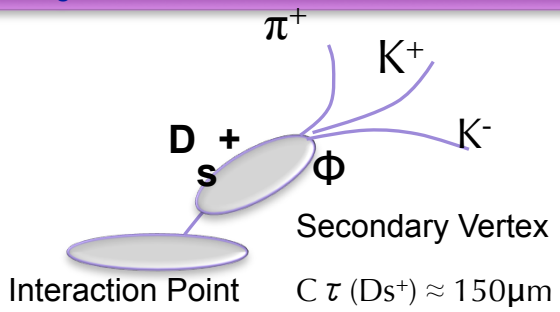
| Mesons | PDG Mass (MeV) | ATLAS Mass (MeV) |
|---|---|---|
| $D^* - D^0$ | 145.42 ± 0.01 | 145.54 ± 0.05 |
| $D^0$ | 1864.83 ±0.14 | 1865.5 ± 1.4 |



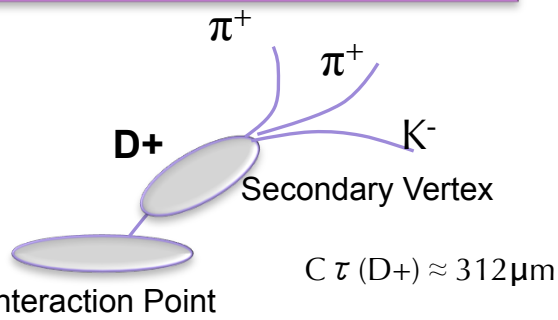
ATLAS-CONF-2010-034

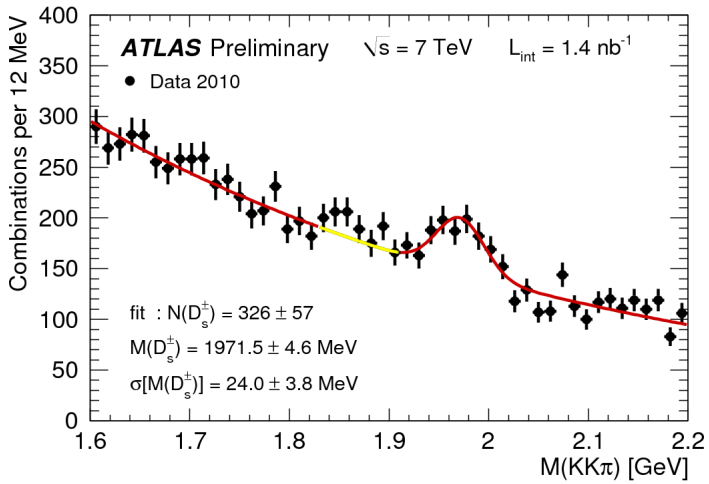
# D-mesons production: $D_s^+$ and $D^+$

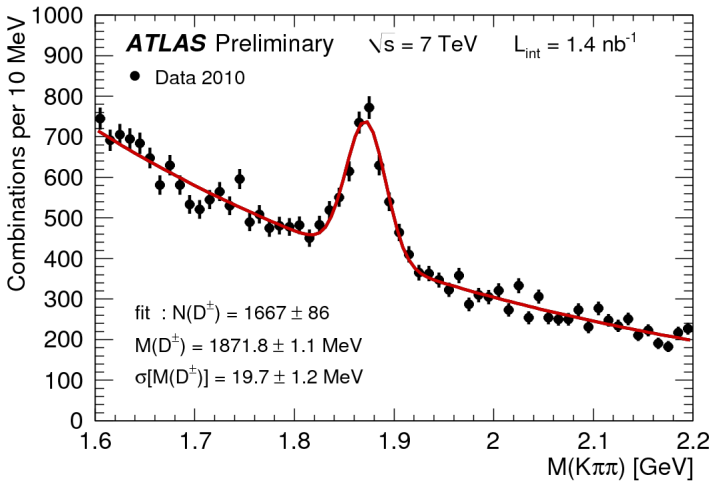
**$D_s^+ \rightarrow \Phi\,\pi^+ \rightarrow (K^-K^+)\pi^+(+c.c.)$**




**$D^+ \rightarrow K^-\pi^+\pi+ (+c.c.)$**



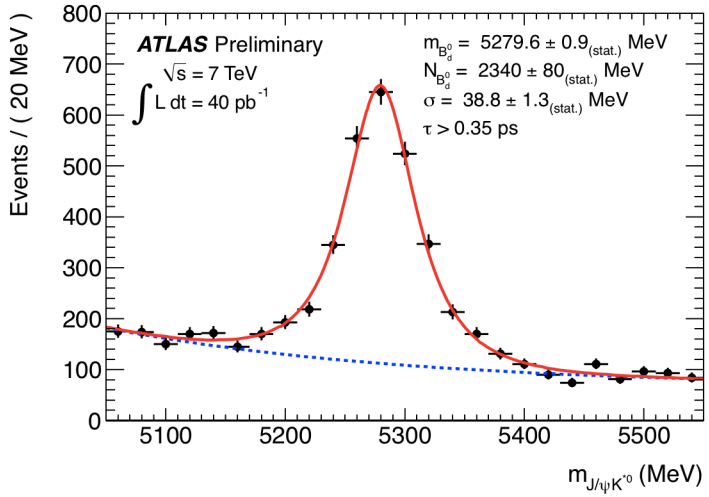




| Mesons | PDG Mass (MeV) | ATLAS Mass (MeV) |
|---|---|---|
| $D^\pm$ | 1869.60 ± 0.16 | 1871.8 ± 1.1 |
| $D_s^\pm$ | 1968.47 ±0.33 | 1971.5 ± 4.6 |

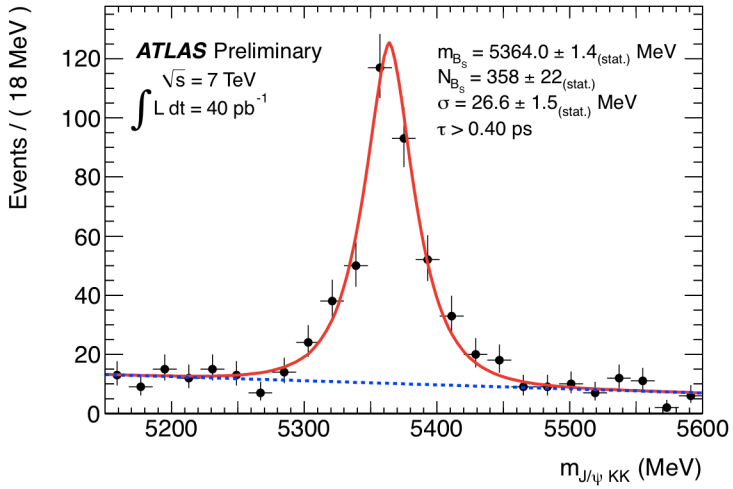
# $B^0_d \to J/\psi K^{0*}$ and $B^0_s \to J/\psi \phi$

Invariant mass distributions of reconstructed candidates of $B^0_d \to J/\psi K^{0*}$ and anti-$B^0_d \to J/\psi K^{0*}$




The solid line is the projection of the result of the unbinned maximum likelihood fit to all candidates in the mass range from 5050 MeV to 5550 MeV.

Invariant mass distributions of reconstructed $B^0_s \to J/\psi \phi$ candidates.




The solid line is the projection of the result of the unbinned maximum likelihood fit to all $J/\psi(\mu^+\mu^-)\phi$(KK) candidates in the mass range from 5150 MeV to 5600 MeV.

The points with error bars are data. The solid line is the projection of the result of The dashed line is the projection for the background component of the fit.

# Summary and Outlook

- First year of data-taking has been highly successful
  - Observation of $J/\psi$ and $\psi(2S)$.
  - Measurement performed of $J/\psi$ differential cross-section and fraction of non-prompt to inclusive decays, prompt and non-prompt differential cross-sections.
  - Observation of the three Upsilon states.
  - D meson states observed and cross section measued.
  - Observation of $B^{\pm} \rightarrow J/\psi(\mu\,\mu)K^{\pm}$, $B_d \rightarrow J/\psi(\mu\,\mu)K^{0*}$ and $B_s \rightarrow J/\psi(\mu\,\mu)\phi$

*Short and longer term plans include*

- Inclusive B lifetime
- Exclusive decays like $B^0_s \rightarrow J/\psi(\mu\,\mu)\phi$, $B^0_d \rightarrow J/\psi(\mu\,\mu)K^{0*}$
- Continue preparations for searches on rare decays such as $B_s \rightarrow \mu\,\mu$.

*2011 and beyond promises bring many more enthusiastic results*