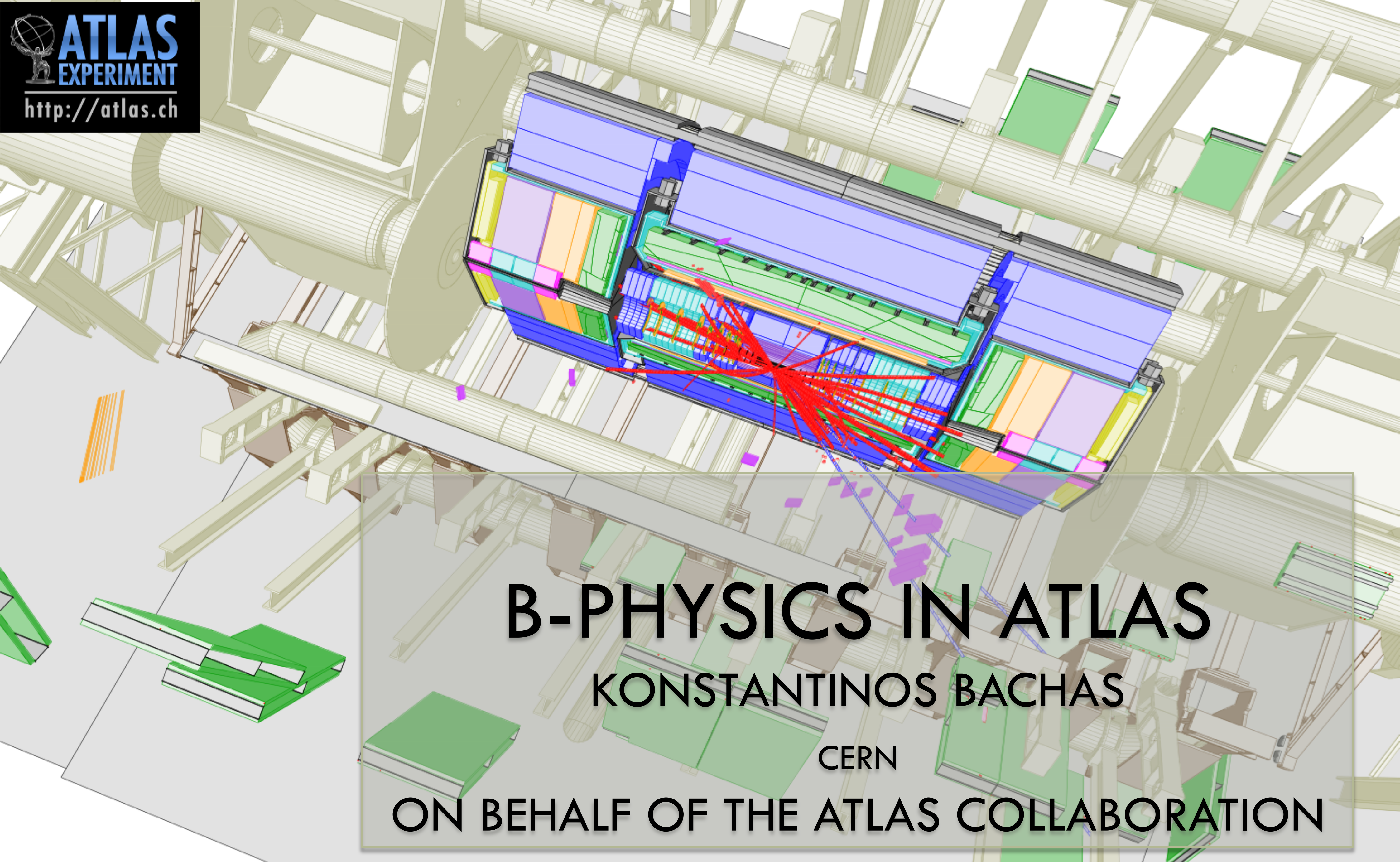


B-PHYSICS IN ATLAS

KONSTANTINOS BACHAS

CERN

ON BEHALF OF THE ATLAS COLLABORATION

The ATLAS B-physics time line

- Performance for trigger/tracking/ alignment with J/ψ, Υ and D meson
- Early measurements of pp→J/ψ, bb→J/ψ, B$^{\pm}$→ J/ψ K^{+}
- bb/cc separation

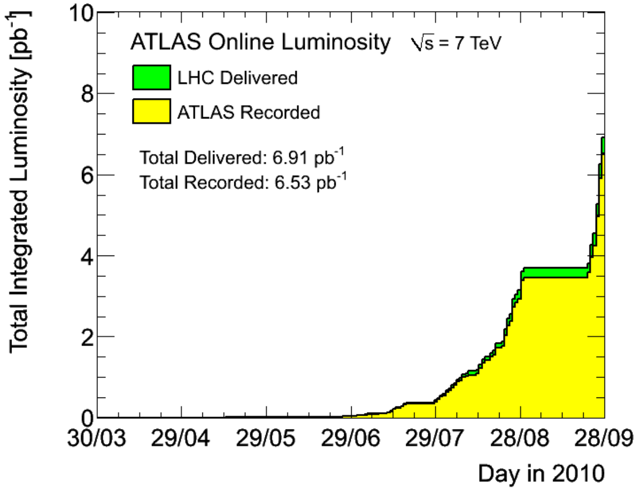
- Explore B-hadron properties
- Start setting new decay limits
- Understand backgrounds for rare decays

- Searches for CP-violation in weak decays of B-mesons
- Start rare decay searches, Λb polarization

- Rare decays
- CP-Violation

$\int Ldt$ Startup — 10pb^{-1} — 100pb^{-1} — 1fb^{-1} — 10fb^{-1} — 100fb^{-1}

We are here!
This talk covers topics from this period with first few nb^{-1}



~94% of the delivered luminosity recorded by ATLAS

Topics and motivation

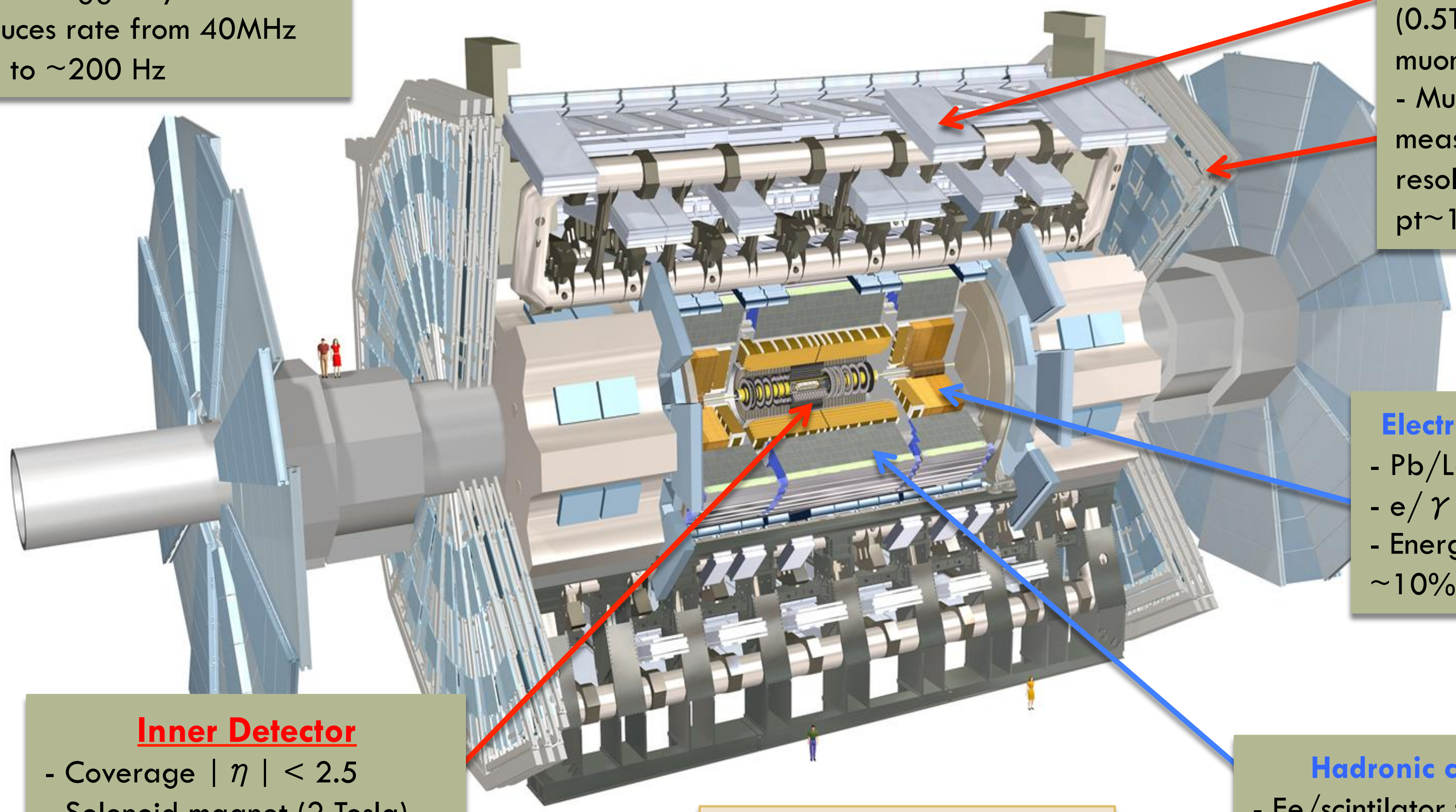
- Understand quarkonium production mechanism
  - Upgraded energy regime compared to Tevatron
  - Use quarkonium to determine low-x gluon PDFs
- Excellent tool for detector performance measurements and tuning
  - Momentum scale, resolution
  - Alignment
  - Tracking
- Quarkonia are important background for several B-physics processes at LHC
- Spin alignment of quarkonia states not yet understood

1. D meson observation
2. J/ψ, Υ observation
3. $pp \to J/\psi \to \mu\mu$ differential production cross-section
4. $\sigma(pp \to bb \to J/\psi)/\sigma(pp \to J/\psi)$ production cross-sections ratio

The ATLAS detector

Trigger System
- 3 level trigger system
- Reduces rate from 40MHz down to ~200 Hz

Muon Spectrometer
- Coverage $|\eta| < 2.7$
- Air-core toroids magnets (0.5Tesla) with gas based muon chambers
- Muon trigger and measurement with momentum resolution < 10% up to pt~1TeV



Electromagnetic calorimeter
- Pb/Lar accordion shape
- e/γ trigger
- Energy resolution σ/E ~10% $/\sqrt{E} \pm 0.2\%$

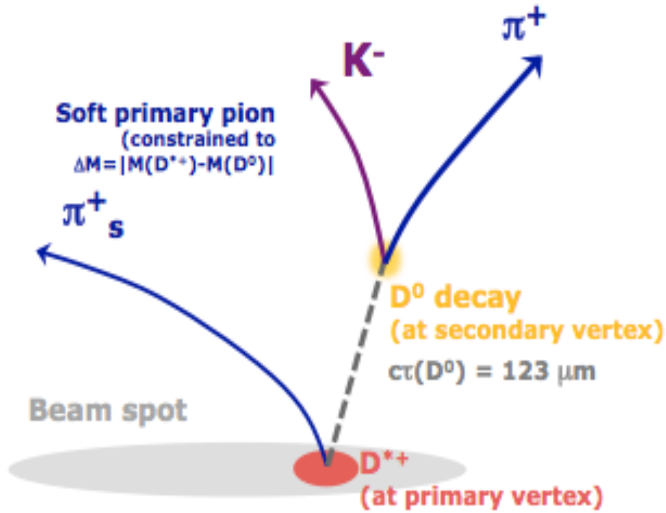
Inner Detector
- Coverage $|\eta| < 2.5$
- Solenoid magnet (2 Tesla)
- 3 subsystems 2 silicon, 1transition radiation detector
- Momentum resolution σ/pt ~ 3.4×10^{-4} pt + 0.015

General purpose detector
Length :~46m Radius :~12m
Weight : ~ 7000 tons
~10^8 electronic channels

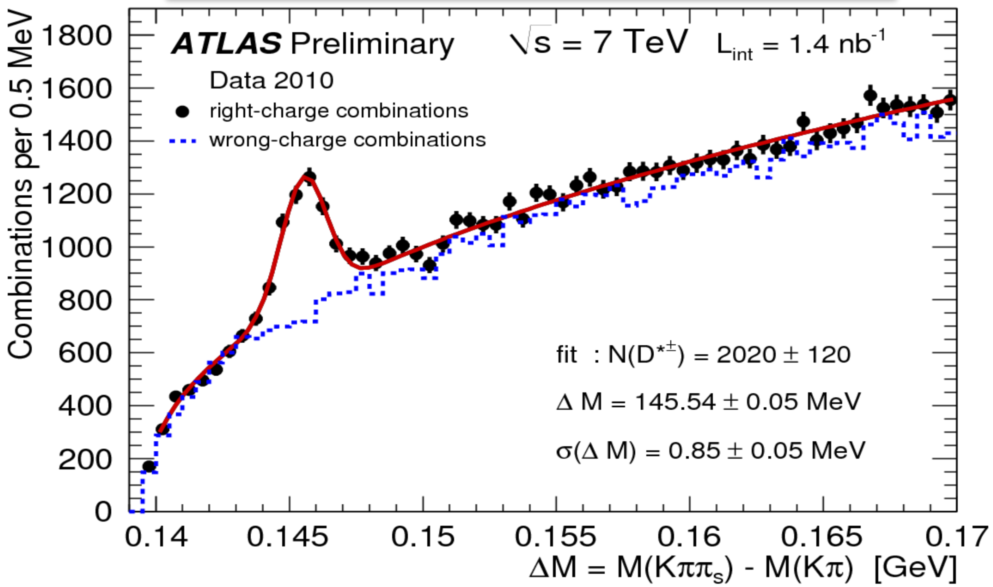
Hadronic calorimeter
- Fe/scintilator tiles
- Jet and EtMiss measurements
- Energy resolution: σ/E ~50% $/\sqrt{E} \pm 3\%$

Observation of $D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\,\pi_s^+$

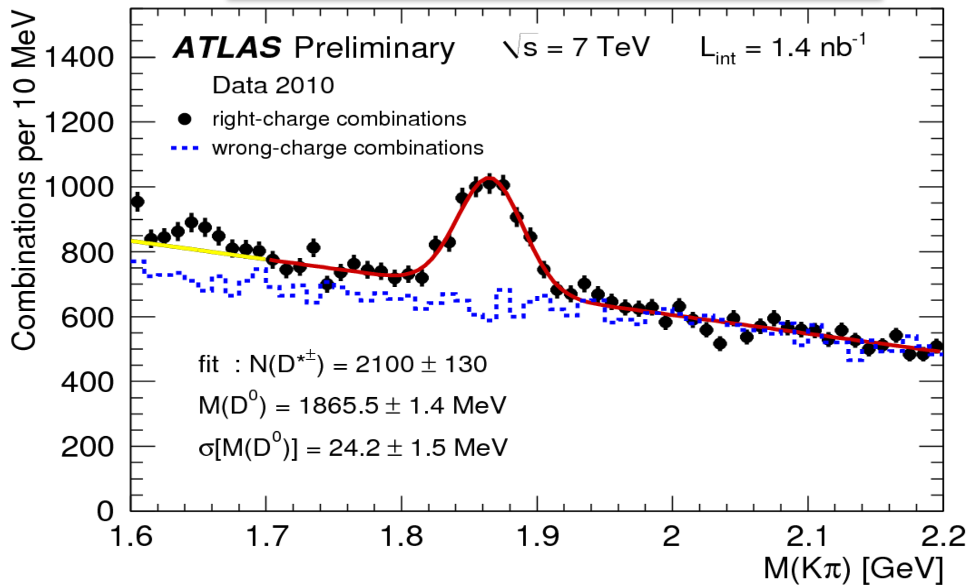
- Key elements for $D^{*\pm}$ observation are ID track reconstruction and vertexing of the D^0
- Combine two oppositely-charged tracks
  - assign K/π mass hypothesis to each
  - pt(K,π)>1.0 GeV
  - D^0 candidate Lxy > 0
- Add a third (soft) track, assign pion mass, and pt>0.25 GeV
- ΔM = M(Kππ) – M(Kπ) provides powerful discrimination



Candidates with 1.83<M(Kπ) < 1.90 GeV

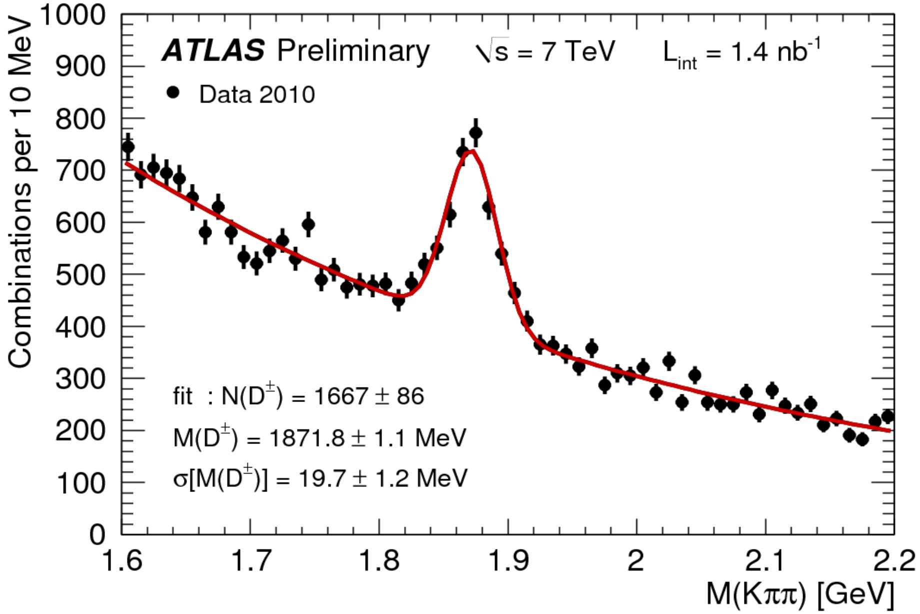


Candidates with 144<ΔM < 147 MeV



Observation of $D^+ \rightarrow K^- \pi^+ \pi^+$

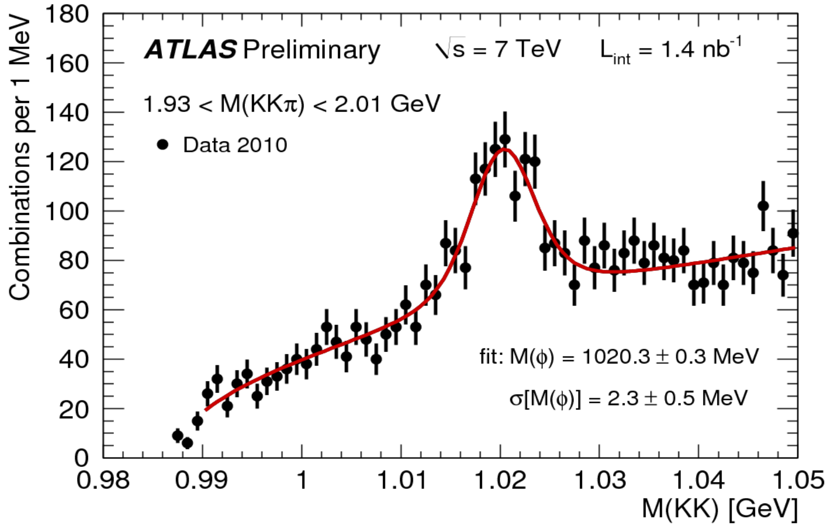
- Assign pion mass to 2 same charge tracks with pt>0.8GeV
- Combine the above with another opposite charge track of pt>1.0GeV to form a D^+ candidate
- Fit them all 3 tracks to a common vertex with $\chi^2 < 6$
- Suppression of D^{*+}
  - remove combinations with $M(K\pi\pi)-M(K\pi)<150$ MeV
- Suppression of $D^+_s \rightarrow \phi(K^+K^-)\pi^+$
  - require $|M(K^+K^-) - M(\phi)_{PDG}|>8$ MeV

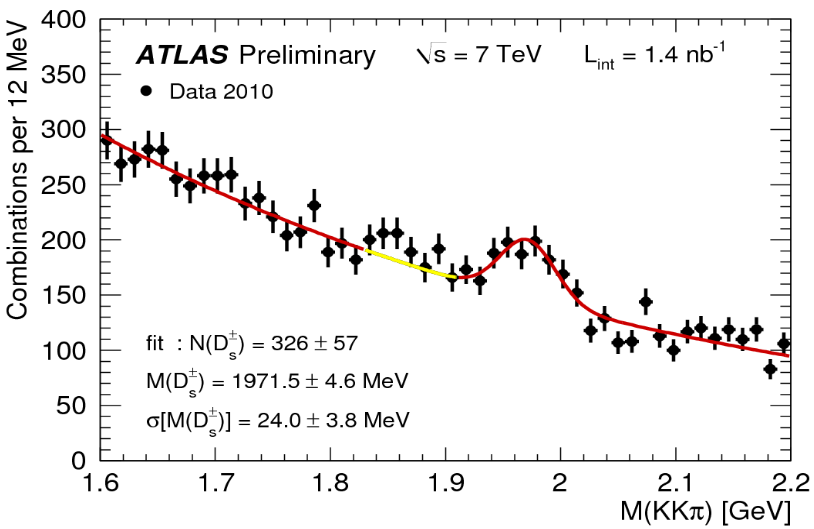


$M(D^+) = 1871.8 \pm 1.1$ MeV in agreement with expectation from PDG

Observation of $D_s^{\pm} \rightarrow \phi\pi^{\pm} \rightarrow (K^+K^-)\pi^{\pm}$

- Search for 2 opposite charge tracks with pt(K)>0.7 GeV to assign Kaon mass
- A ϕ candidate mass should fulfill $|M(KK)|$ <6 MeV of PDG value
- A third track of pt(π)>0.8 GeV, is assigned the mass of the pion of the decay



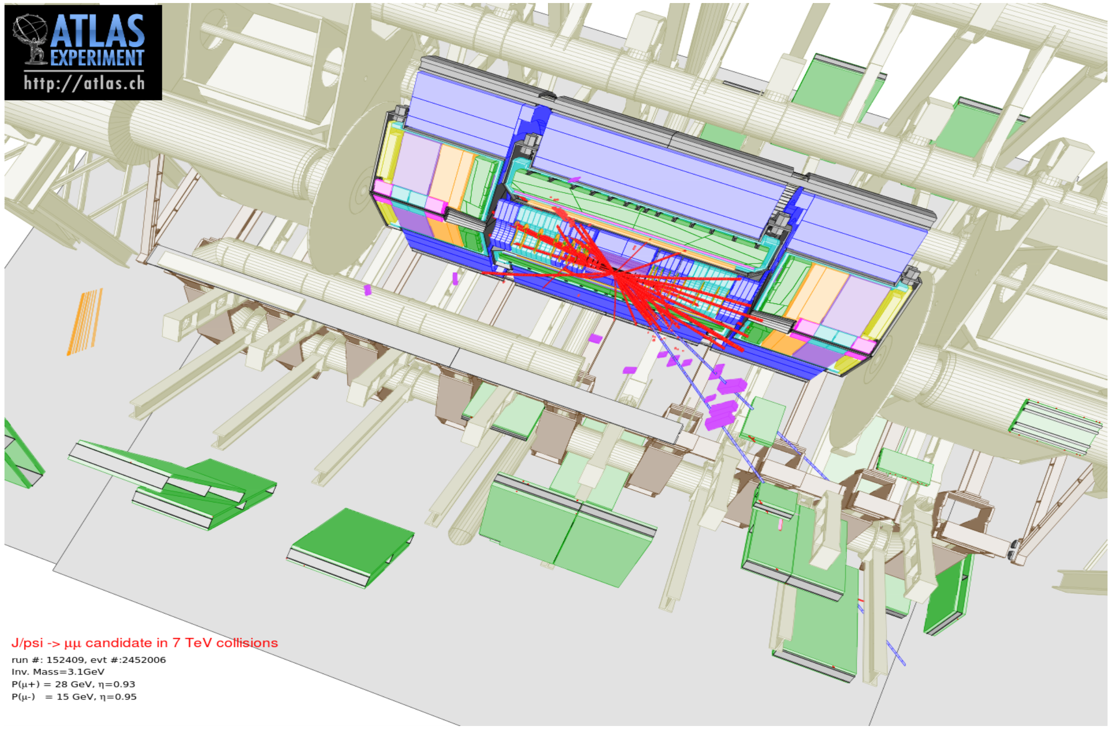


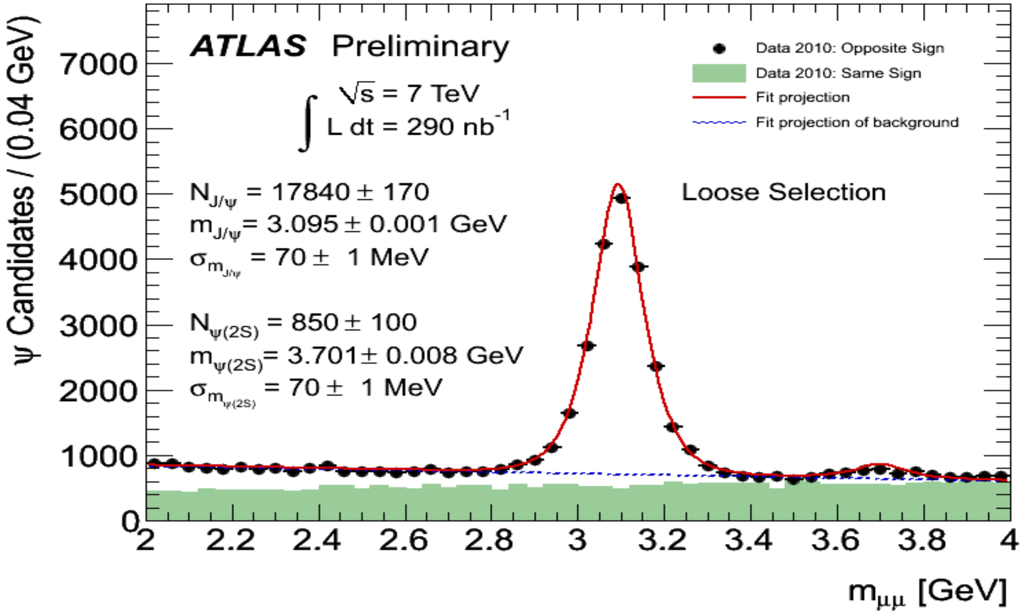
- M(KKπ) fitted with Gaussian for the signal and an exponential for the background
- Range 1.83 – 1.91 GeV excluded from the fit to avoid including signal from the D^+ decays

$M(D_s^{\pm})$ = 1971.5±4.6 MeV in agreement with expectation from PDG

J/ψ → μμ selection

- Most of J/ψ's populate the forward region and have very low pt
  - Measured by Inner Detector and identified by MS
- Fully unbiased trigger based on Minimum Bias Trigger Scintillators
- Tracks from the same vertex
- Tracks must pass hit quality cuts: ≥1 pixel hit, and ≥6 SCT hits

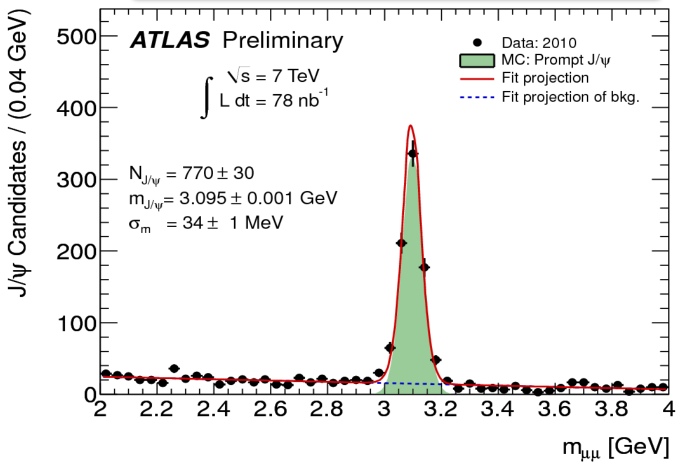




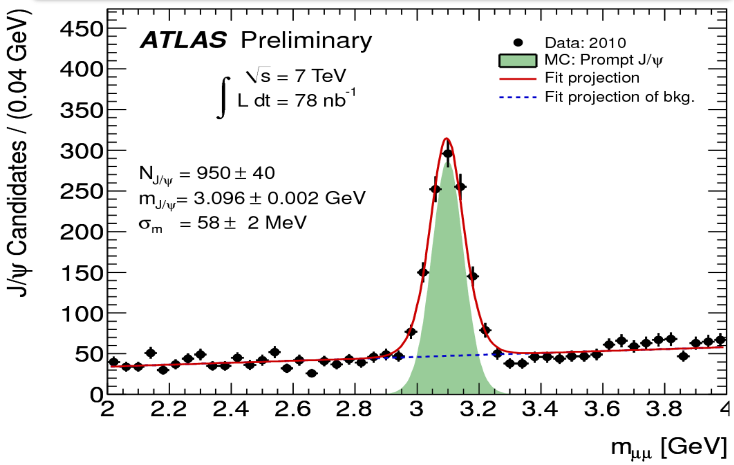
- Mass position compatible with PDG
- Resolution compatible with MC expectation
- About 65 J/ψ→μμ reconstructed per 1 nb^{-1}

Tracking performance of Inner detector with J/ψ→μμ

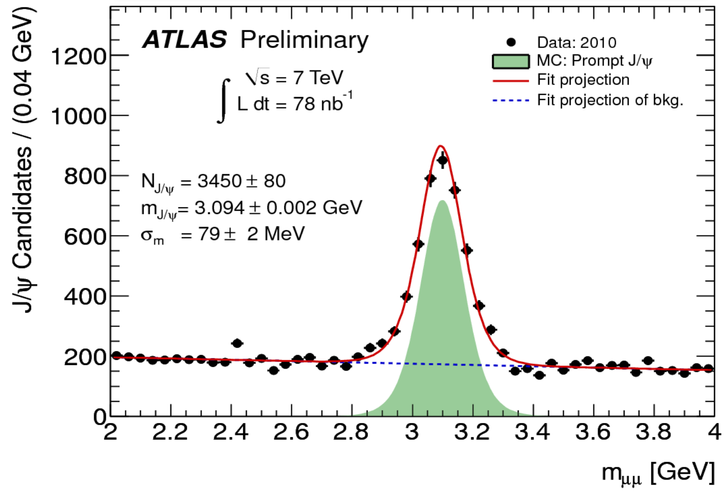
Barrel-Barrel |η|<1.05



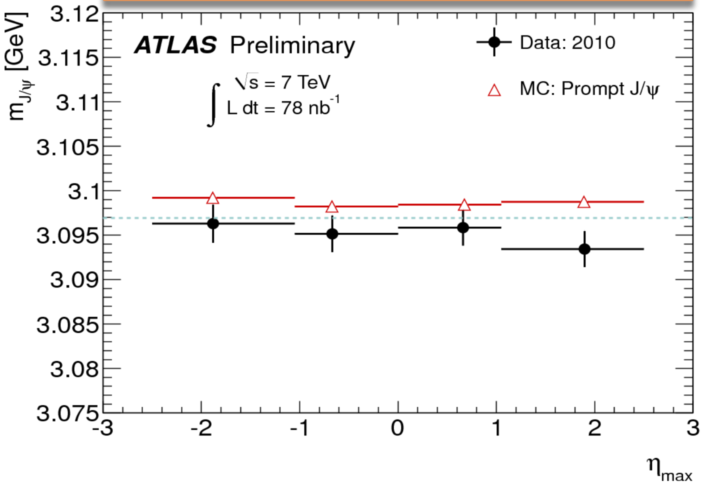
Barrel-EndCap |η|<1.05, |η|>1.05



Endcap-Endcap |η|>1.05

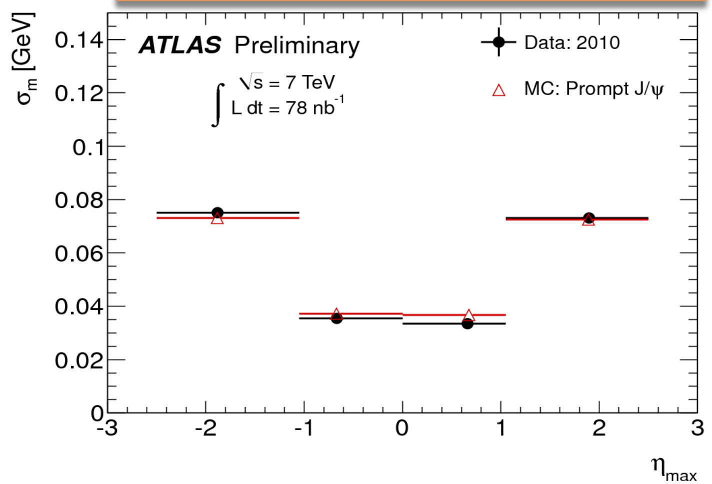


J/ψ mass peak vs muon η



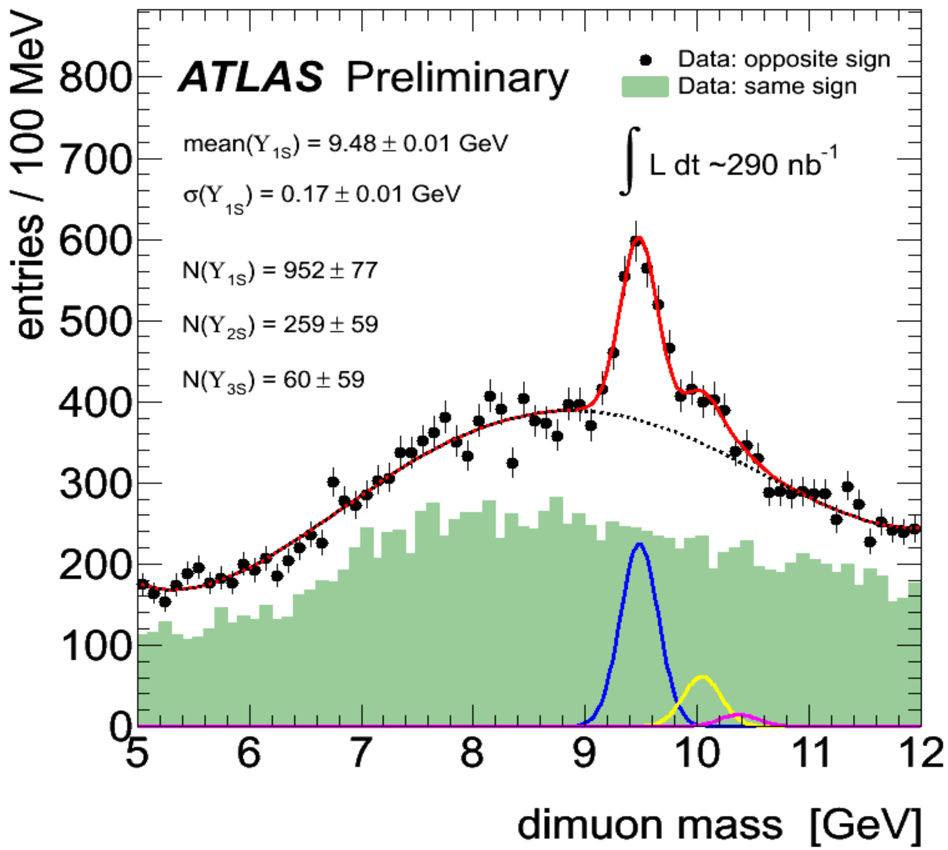
- Mass resolution known to ~2%. Well described by MC
- Mass peak close to PDG value

Mass resolution vs muon η



Υ states observation

- Cuts on muon pt of 2.5 GeV and 4 GeV
- The three signal fits are Gaussian with a fourth-order Chebyshev polynomial for the background
- The differences between the three peaks are fixed using the PDG masses
- Position on the invariant mass scale is allowed to float in the fit



$J/\psi \rightarrow \mu^+\mu^-$ differential x-section measurement: approach

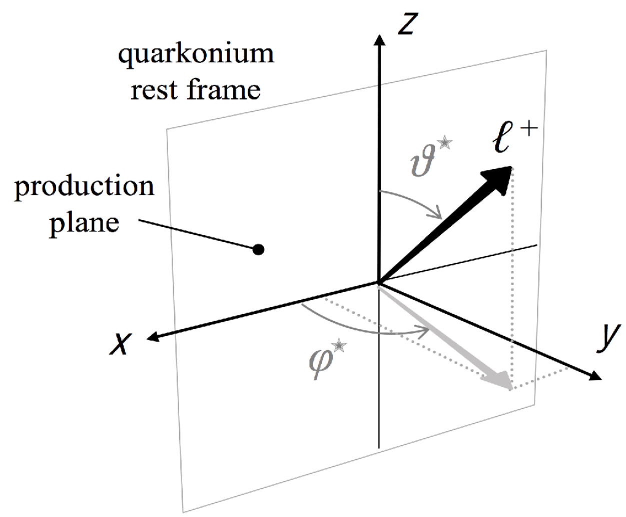
- Assign a weight event by event to correct for acceptance and reconstruction/ trigger efficiencies

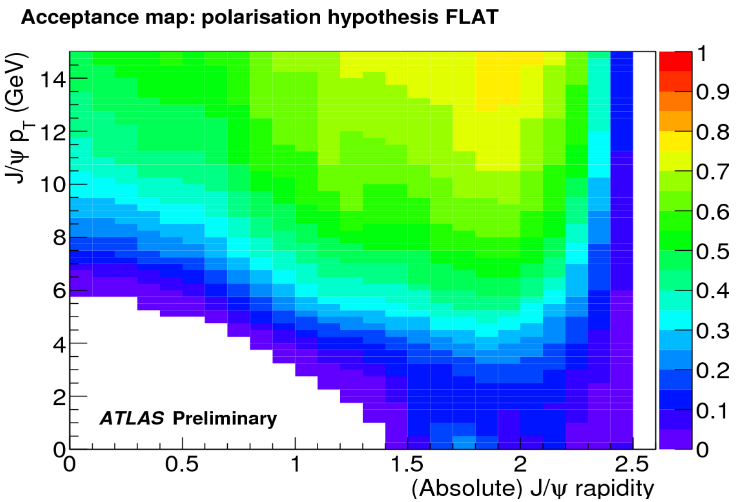
$$w^{-1} = A(p_T, y, \lambda_i) \times \varepsilon_{rec}(p_1) \times \varepsilon_{rec}(p_2) \times \varepsilon_{trig}(p_1, p_2)$$

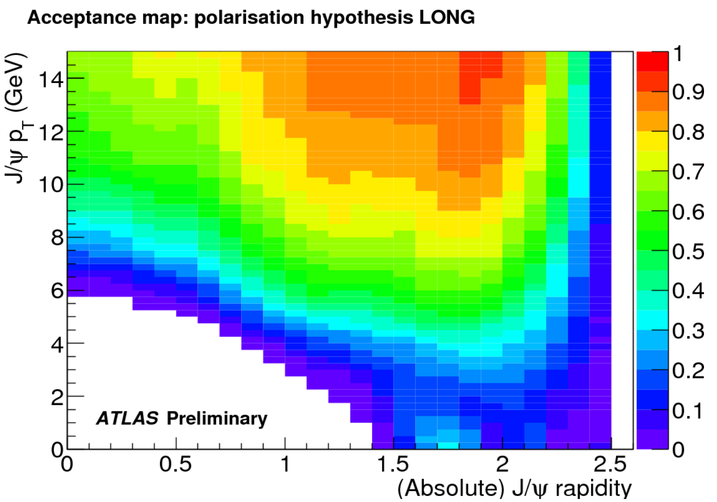
  - $A(p_T, y, \lambda_i)$ = Kinematic Acceptance
    - Probability that decay happens within the fiducial volume of ATLAS with specific polarization scenario λ_i , transverse momentum p_T and rapidity y
  - $\varepsilon_{rec}(p_i)$ = Reconstruction efficiency
    - Obtained from Monte Carlo Simulation and confirmed by preliminary data driven calculation using tag and probe
  - $\varepsilon_{trig}(p_1, p_2)$ = Trigger efficiency
    - Muon trigger efficiency relative to offline reconstruction calculated from Minimum Bias data
- Bin J/ψ candidates in 2-dimentional bins (pt,y)
  - Likelihood fit to dimuon invariant mass in each bin to obtain signal yield

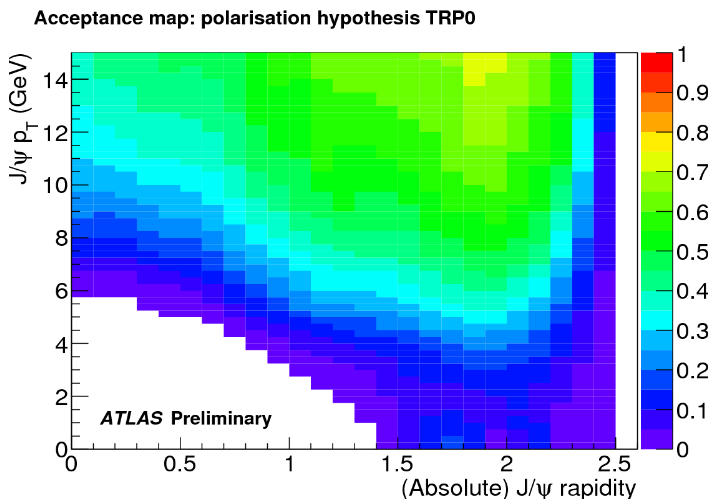
$J/\psi \rightarrow \mu^+\mu^-$ differential x-section measurement: Acceptance

- Acceptance depends on 5 variables
  - 3 variables of the J/ψ itself → pt, y and azimuthal angle ϕ
  - 2 variables depending on the polarization hypothesis
    - θ*: angle between direction of μ+ in J/ψ decay frame and the momentum of J/ψ in laboratory frame
    - ϕ*: angle between J/ψ production and decay frames in the laboratory frame
- Five different polarization scenarios
  - Together these map out an envelope in pt and y of possible spin alignment configurations
  - J/ψ polarization has not been measured yet at the LHC → theoretical uncertainty on the final result



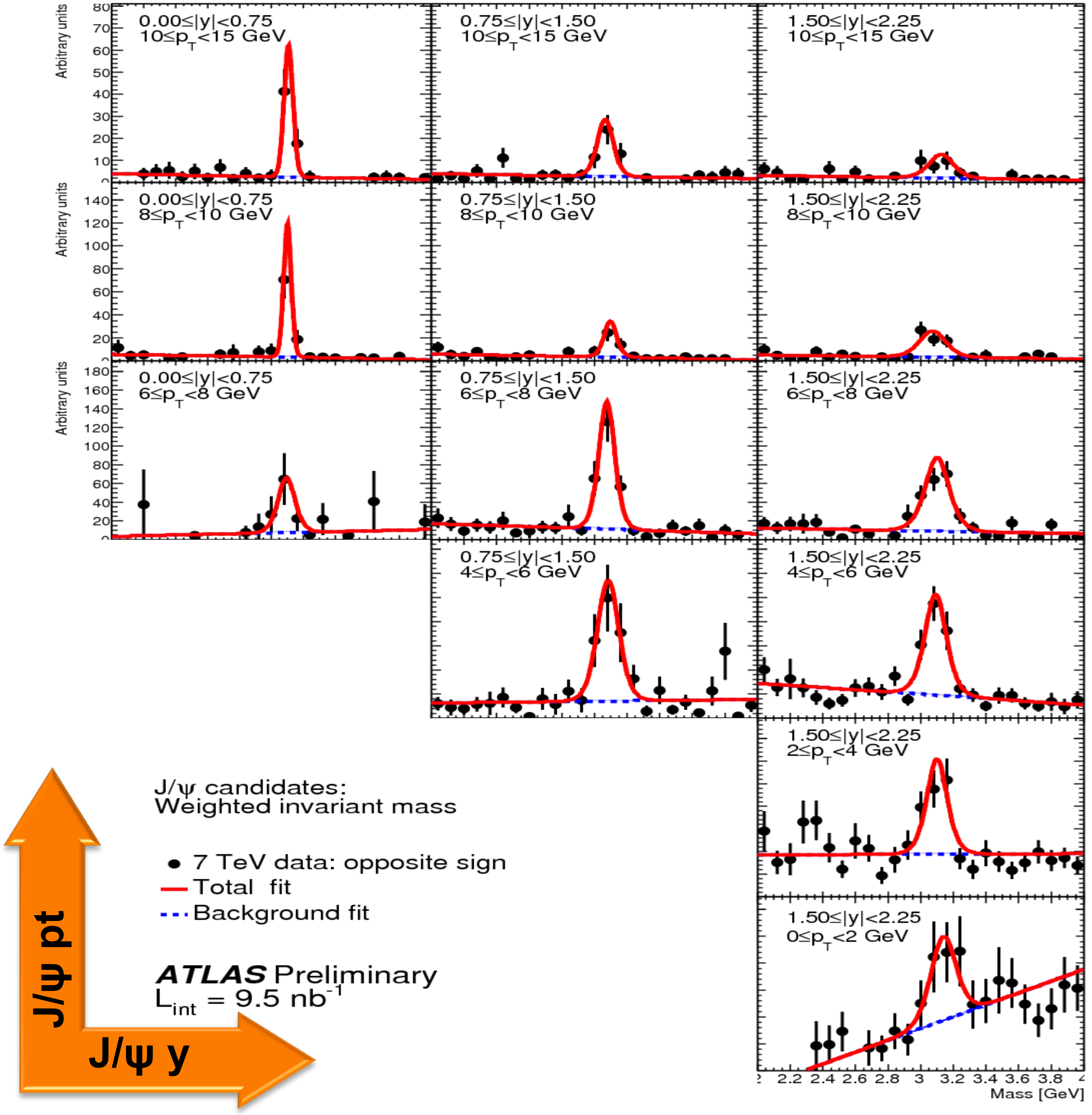






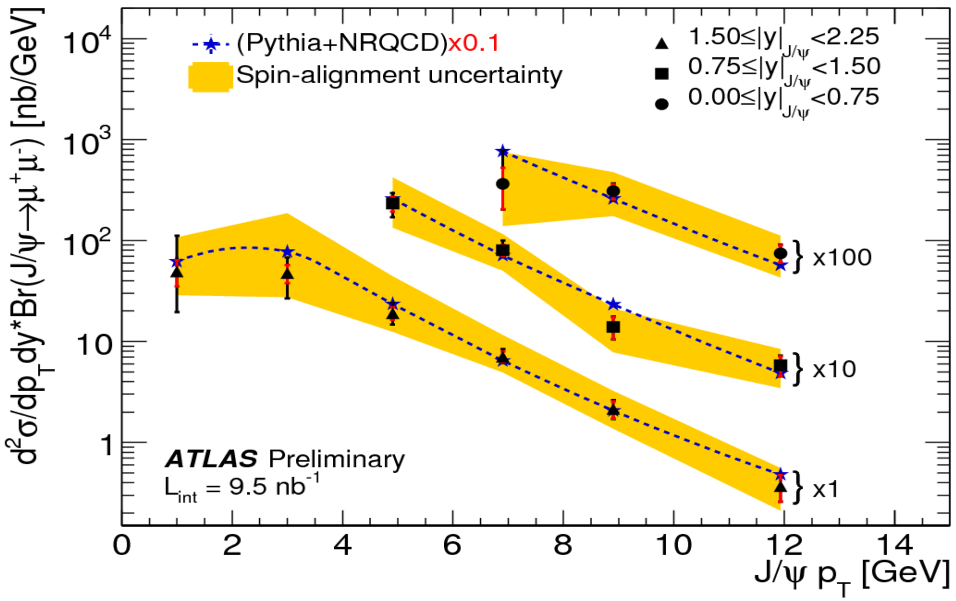
Di-Muon Mass in pt and y Bins, after Weighting

- 6 bins in pt
  - 0-2, 2-4, 4-6, 6-8,8-10, 10-15
- 3 bins in y:
  - 0.0-0.75, 0.75-1.5, 1.5-2.25
- Unbinned maximum likelihood fit
  - Gaussian for signal and linear for background



Differential x-section measurement

- First result from ATLAS on differential x-section vs pt in 3 y bins
- Shapes between data/Pythia are in good agreement
- Yellow bands represent the span of the extreme polarization hypotheses
- Results are in good agreement with LHCb and CMS results
- The factor of 10 in absolute normalization with Pythia is traced to tuning by ATLAS/the structure functions used



- Most significant systematics:
  - Fit model used
  - Spin alignment configuration
  - Binning for acceptance and efficiency

$\sigma(pp \to bb \to J/\psi)/\sigma(pp \to J/\psi)$ production x-section ratio

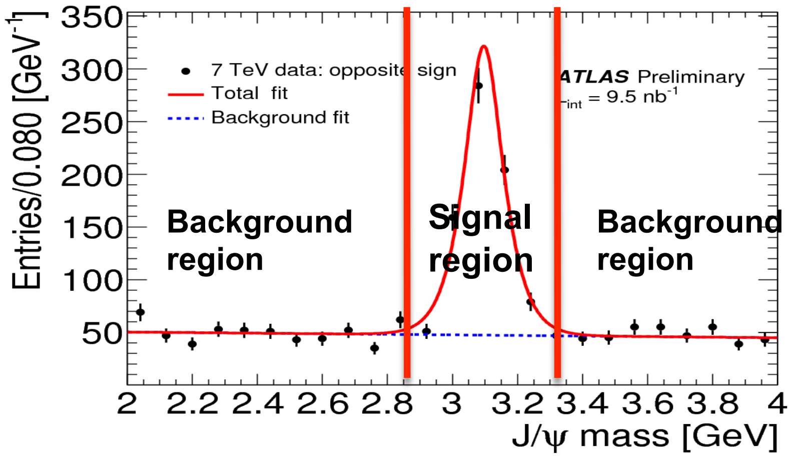
- Measure the prompt production of J/ψs and the production from B-hadron decays
  - Exploit the difference that prompt J/ψs decay at the production point (primary vertex) while non-prompt decay point is displaced
- Define displacement of J/ψ from primary vertex, projected on pt(J/ψ)

$$L_{xy} = \vec{L} \cdot \vec{p}_T(J/\psi)/p_T(J/\psi)$$

- Define pseudo-proper time to be used as discriminating variable

$$\tau = L_{xy} m(J/\psi)/p_T(J/\psi)$$

- Fit the mass distribution to define signal region ($m_{J/\psi} \pm 3\sigma_m$) and background regions in the sidebands
  - Sidebands used to check the compatibility of the background component in the signal region

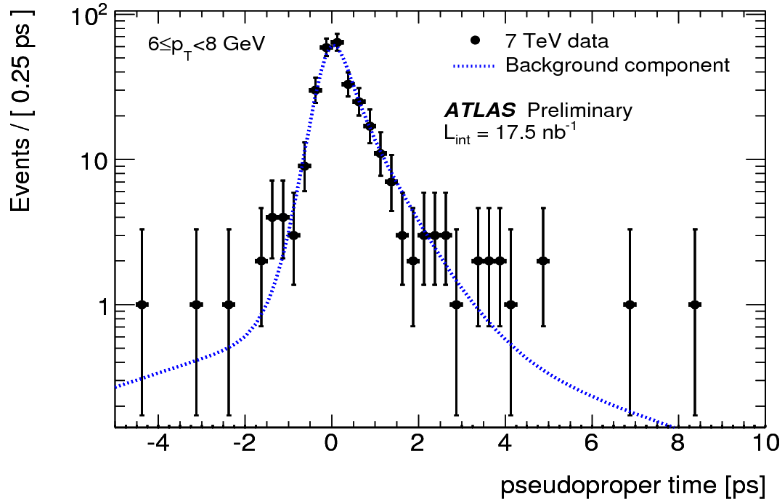


Pseudo-proper time fits example

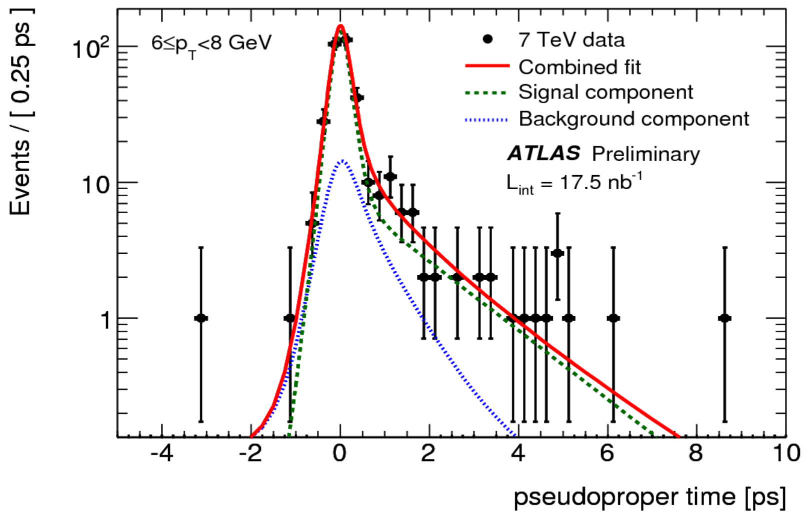
- Fit the mass and pseudo-proper time simultaneously, in whole mass region (2-4 GeV) in pt bins (1-4, 4-6, 6-8, 8-10, 10-15 GeV) with an unbinned maximum likelihood fit

$$\ln L = \sum_{i=1}^{N} \ln F(\tau, \delta_\tau, m_{\mu\mu}, \delta_m)$$

- Signal : δ function (prompt) plus exponential on positive side (non-prompt) convoluted with Gaussian (resolution function)
- Background : δ function plus two exponentials on both positive and negative sides convoluted with Gaussian



Projection of fit in the sidebands

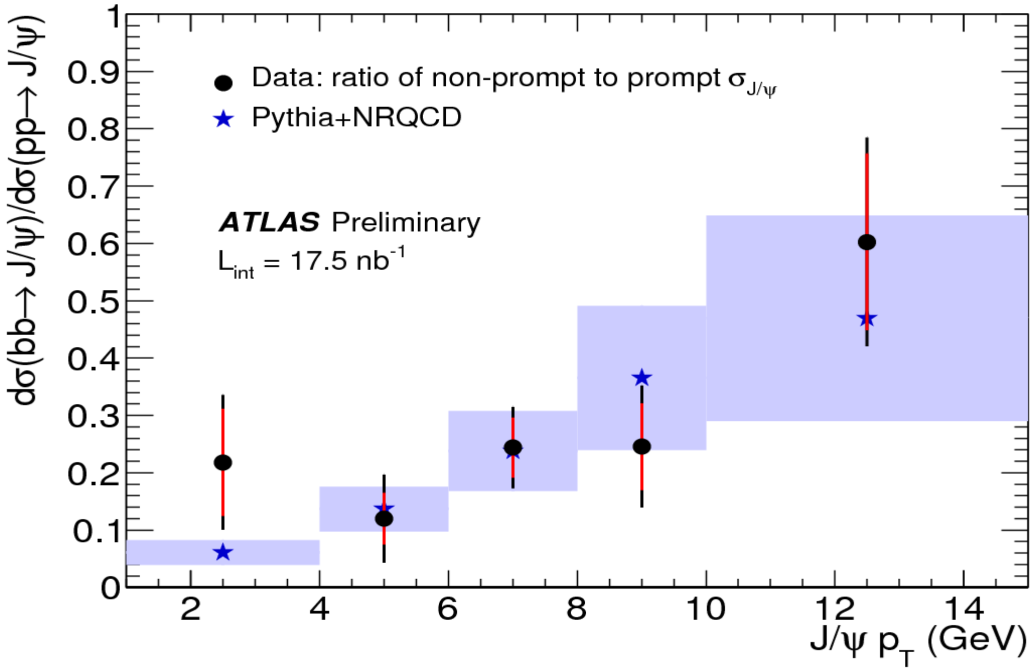


Projection of fit in signal region

σ (pp→bb→J/ψ)/σ (pp→J/ψ) production

x-section ratio results

- Good agreement between data and MC within errors is obtained
- Systematics studies
  - PDF description of the background in the mass distribution
  - Using a double Gaussian for a resolution function
  - Using higher order polynomials during the mass spectrum fit



Band = Pythia prediction
Red bar = statistical error
Black bar = statistical + systematic error

Summary

- ATLAS performs well and delivers results of high quality
  - Excellent performance results already with first data and few nb^{-1}
- Clean $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ signals have been reconstructed with first data
  - Mass position and resolutions compatible with expectations
- Observation of Upsilon family
- pp→J/ψ→μμ differential production cross-section has been measured
  - Shapes agree well with MC
  - Overall normalization discrepancy with MC
- Non-prompt to prompt J/ψ production x-sections has been measured
  - Good agreement with expectations within errors
- A very exciting B-physics program is yet to come!

BACKUP slides

The ATLAS Trigger system

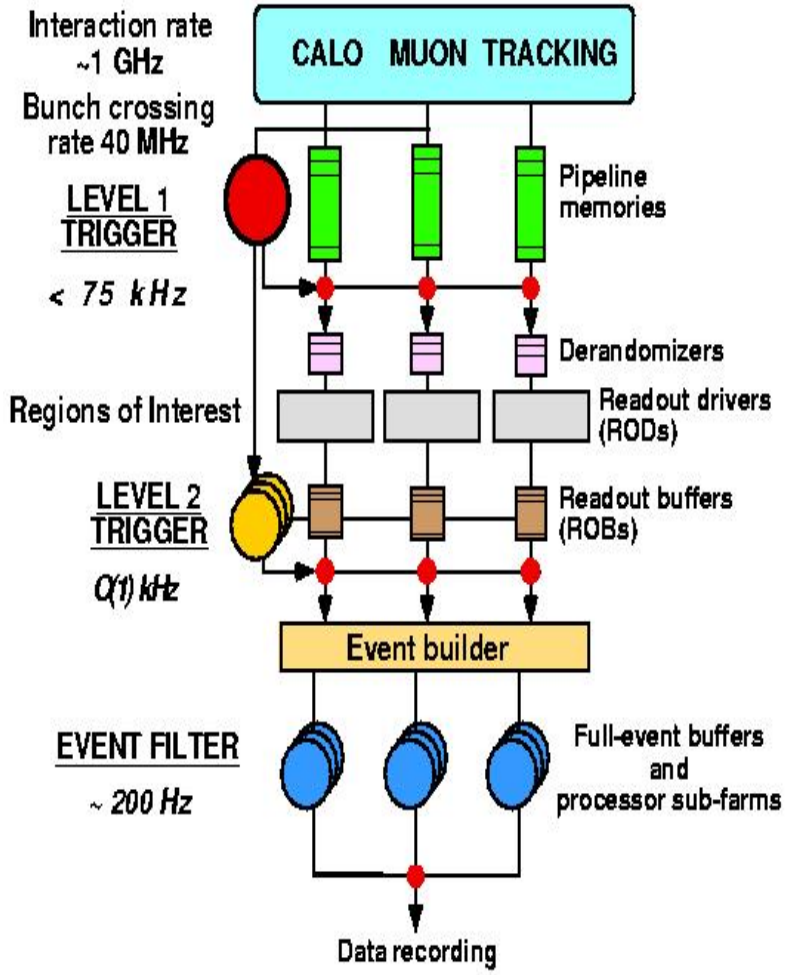
40 MHz

~200 Hz

- 3 level trigger system in ATLAS
- Level 1: input from muon, calorimeter systems and minimum bias trigger scintilators (MBTS)
  - Searches for hit coincidences of trigger chambers within predefined geometrical windows
- Level 2: software based, refinement of L1 decision, tracking in Region of Interest (RoI)
- Event Filter: event selection using more complex algorithms

HLT

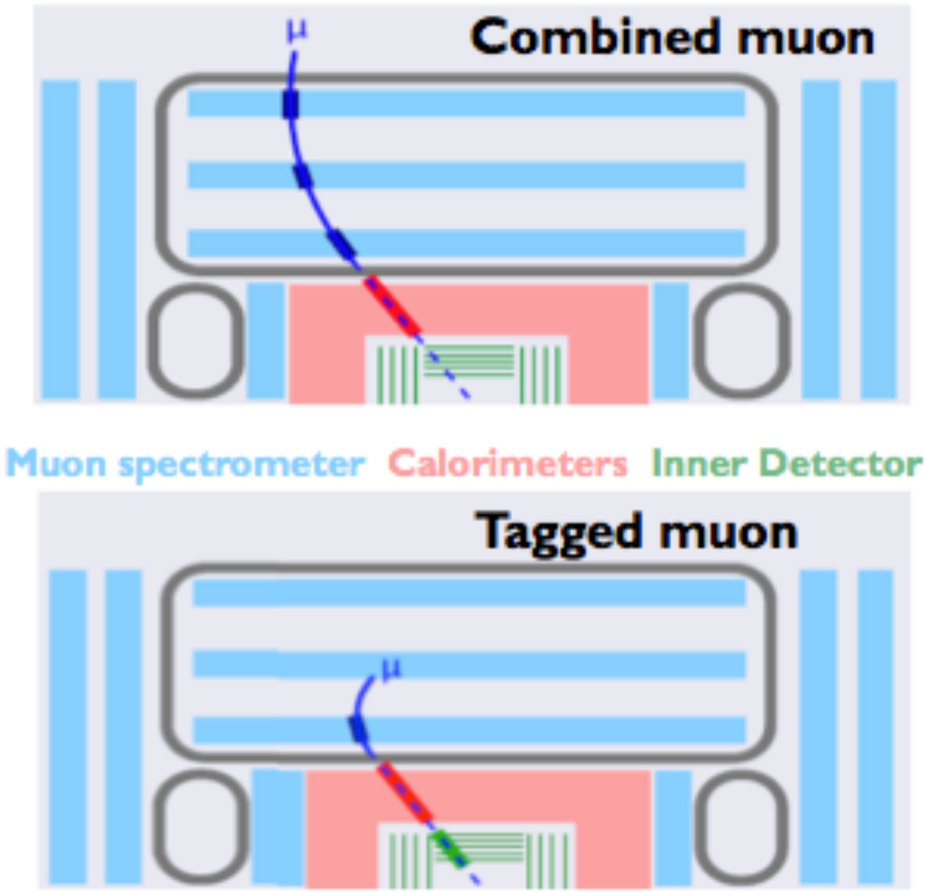
- Prescales adjusted to maintain output rate to ~200Hz
- J/ψ differential cross-section measurement
  - MBTS+full scan EF muon confirmation
- Ratio measurement
  - Single L1 muon trigger or (MBTS+EF confirm)



Dedicated B trigger will be used with higher luminosity

Muon Reconstruction

- Muon reconstruction relies on
  - Inner detector for momentum measurement and tracking
  - Muon Spectrometer for triggering and identification
- 2 muon "flavours" ; combined and tagged
- One leg of J/ψ decay is requested to be combined muon



- Combined muons
  - an MS track is successfully combined with an ID track
  - Coverage $|\eta|<2.5$
- Tagged muons
  - low pt muons do not always leave a full track in the MS but only a track segment
  - An ID track is extrapolated and matched to the MS segment
  - Coverage $|\eta|<2.0$

Spin alignment scenarios

- The distributions of θ^* and ϕ^* are different for various possible spin alignment scenarios of the J/ψ
- The coefficients λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ in

$$\frac{d^2N}{d\cos\theta^* d\phi^*} \propto 1 + \lambda_\theta \cos^2\theta^* + \lambda_\phi \sin^2\theta^* \cos 2\phi^* + \lambda_{\theta\phi} \sin 2\theta^* \cos\phi^*$$

are related to the spin density matrix elements of the J/ψ spin wave function

$$|J/\psi\rangle = A_-|-1\rangle + A_0|0\rangle + A_+|+1\rangle$$

- 5 configurations:
  - Flat distribution: $\lambda_\theta = \lambda_\phi = \lambda_{\theta\phi} = 0$
  - Longitudinal: $\lambda_\theta = -1$, $\lambda_\phi = \lambda_{\theta\phi} = 0$ ($A_0=1$, $A_+=A_-=0$)
  - Transverse:
    - $\lambda_\theta = +1$, $\lambda_\phi = \lambda_{\theta\phi} = 0$ ($A_\pm=1$, $A_0=A_\mp=0$)
    - $\lambda_\theta = +1$, $\lambda_\phi = +1$, $\lambda_{\theta\phi} = 0$ ($A_+=A_-$, $A_0=0$)
    - $\lambda_\theta = +1$, $\lambda_\phi = -1$, $\lambda_{\theta\phi} = 0$ ($A_+=-A_-$, $A_0=0$)

Probability density functions for non-prompt to prompt J/ψ production ratio measurement

- Signal : δ function (prompt) plus exponential on positive side (non-prompt) convoluted with Gaussian (resolution function)
- Background : δ function plus two exponentials on both positive and negative sides convoluted with Gaussian
- Overall PDF is

$$F(\tau,\delta_\tau,m_{\mu\mu},\delta_m) = F_{sig}(\tau,\delta_\tau) f_{signal}(m_{\mu\mu},\delta_m) + F_{bkg}(\tau,\delta_\tau) f_{bkg}(m_{\mu\mu})$$

Pseudo-proper time PDF for signal

$$f_B \mathcal{F}_B(\tau,\delta_\tau) + (1 - f_B)\mathcal{F}_P(\tau,\delta_\tau)$$

$$R(\tau' - \tau, \delta_\tau) \otimes E(\tau') \qquad R(\tau' - \tau, \delta_\tau) \otimes \delta(\tau')$$

R denotes the signal resolution function

Pseudo-proper time PDF for background

$$R_{\text{bkg}}(\tau,\delta_\tau) + \exp\left(\frac{-\tau'}{\tau_{\text{eff1}}}\right) \otimes R_{\text{bkg}}(\tau' - \tau, \delta_\tau) + \exp\left(\frac{-|\tau'|}{\tau_{\text{eff2}}}\right) \otimes R_{\text{bkg}}(\tau' - \tau, \delta_\tau)$$

$$R_{\text{bkg}}(\tau' - \tau, \delta_\tau) \otimes \delta(\tau')$$

R_{bkg} denotes the background resolution function

Differential x-section for inclusive J/ψ production as a function of pt and y

$p_T(J/\psi)$ GeV	Mean p_T GeV	$\frac{d\sigma}{dp_T dy} \cdot \mathrm{Br}[J/\psi \to \mu^+\mu^-]$ (nb/GeV)	
		$0.0 \leq \|y\| < 0.75$	
		Data	PYTHIA
$6-8$	6.9	3.6 ± 1.6 (stat) $^{+3.9}_{-0.3}$ (syst) $^{+3.9}_{-2.3}$ (theory)	76.5 ± 1.5
$8-10$	8.9	3.08 ± 0.66 (stat) $^{+0.40}_{-0.22}$ (syst) $^{+1.7}_{-1.4}$ (theory)	26 ± 1
$10-15$	11.9	0.75 ± 0.18 (stat) $^{+0.11}_{-0.05}$ (syst) $^{+0.37}_{-0.32}$ (theory)	5.7 ± 0.3
		$0.75 \leq \|y\| < 1.50$	
		Data	PYTHIA
$4-6$	4.9	23.2 ± 4.0 (stat) $^{+5.2}_{-4.9}$ (syst) $^{+18.9}_{-9.9}$ (theory)	260 ± 3
$6-8$	6.9	8.0 ± 1.0 (stat) $^{+1.9}_{-0.6}$ (syst) $^{+3.6}_{-3.0}$ (theory)	72 ± 2
$8-10$	8.9	1.40 ± 0.34 (stat) $^{+0.18}_{-0.09}$ (syst) $^{+0.73}_{-0.62}$ (theory)	23.3 ± 0.9
$10-15$	11.9	0.58 ± 0.13 (stat) $^{+0.06}_{-0.04}$ (syst) $^{+0.26}_{-0.24}$ (theory)	4.9 ± 0.3
		$1.50 \leq \|y\| < 2.25$	
		Data	PYTHIA
$0-2$	1.0	49 ± 20 (stat) $^{+61}_{-26}$ (syst) $^{+58}_{-21}$ (theory)	621 ± 3
$2-4$	3.0	48 ± 10 (stat) $^{+18}_{-18}$ (syst) $^{+139}_{-20}$ (theory)	773 ± 3
$4-6$	4.9	19.1 ± 2.7 (stat) $^{+5.1}_{-3.5}$ (syst) $^{+25.1}_{-6.6}$ (theory)	235 ± 2
$6-8$	6.9	7.10 ± 0.88 (stat) $^{+1.32}_{-0.57}$ (syst) $^{+4.5}_{-2.2}$ (theory)	64 ± 1
$8-10$	8.9	2.14 ± 0.43 (stat) $^{+0.33}_{-0.10}$ (syst) $^{+1.1}_{-0.8}$ (theory)	20.7 ± 0.9
$10-15$	11.9	0.37 ± 0.11 (stat) $^{+0.06}_{-0.03}$ (syst) $^{+0.19}_{-0.16}$ (theory)	4.8 ± 0.3

Ratio σ(pp→bb→J/ψ)/σ(pp→J/ψ) production x-section results

$p_T(J/\psi)$ GeV	$\mathcal{R} \equiv \sigma(pp \to b\bar{b}X \to J/\psi X')/\sigma(pp \to J/\psi X'')_{\text{prompt}}$		χ^2/DoF	p-value
	Data	MC		
1 – 4	$0.22 \pm 0.09(stat) \pm 0.07(syst)$	0.061 ± 0.022	33.5/34	0.49
4 – 6	$0.12 \pm 0.05(stat) \pm 0.06(syst)$	0.137 ± 0.039	23.2/25	0.57
6 – 8	$0.24 \pm 0.05(stat) \pm 0.05(syst)$	0.238 ± 0.070	22.0/20	0.34
8 – 10	$0.25 \pm 0.08(stat) \pm 0.07(syst)$	0.365 ± 0.126	10.1/15	0.81
10 – 15	$0.60 \pm 0.15(stat) \pm 0.10(syst)$	0.469 ± 0.180	6.9/16	0.97