Flavour Physics at ATLAS: Status and Perspectives

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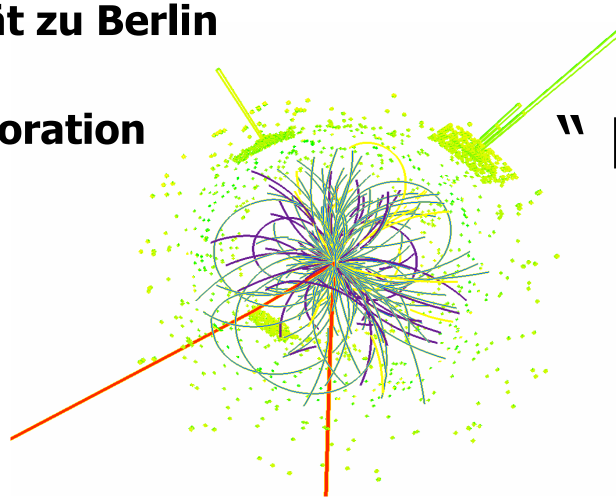


Workshop on
" Heavy Flavour Physics"
July 5th – 8th 2010
Capri/Italy

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

ATLAS Flavour Physics Program

understanding detector performance: **alignment, tracking, trigger** using c- and b-quark SM processes

$10\ nb^{-1}$

validation of ID/trigger performance and alignment, data quality monitoring with J/Ψ and Υ

now !

measurement of cross sections for B-hadrons, and J/Ψ and Υ mesons to **test QCD predictions** at LHC energies

$100\ pb^{-1}$

continuing performance studies, measurements of cross section ratios: $bb \rightarrow J/\Psi$, $pp \rightarrow J/\Psi$, $B^+ \rightarrow J/\Psi K^+$

2010: ~ 200 pb^{-1}

studies of properties of complete B-meson family: $\mathbf{B^+, B_s, B_c, \Lambda_b}$ **+ CC**

$1\ fb^{-1}$

collect larger samples of main B-decays, contribute to B-hadron properties, set limits on rare decay branching ratios

2011: ~ 1 fb^{-1}

search for rare B-decays: $\mathbf{B_s \rightarrow \mu^+\mu^-}$

$10 - 100\ fb^{-1}$

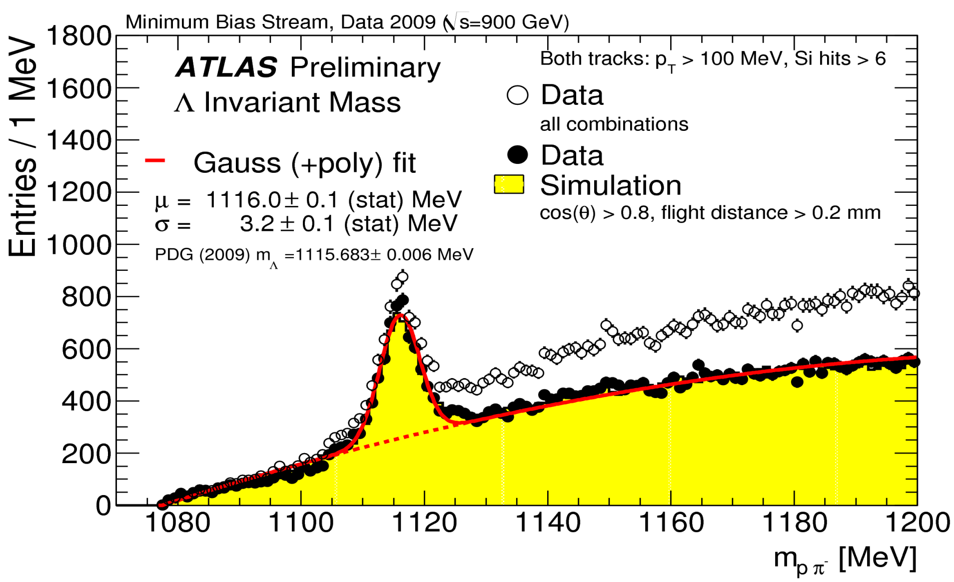
Contents

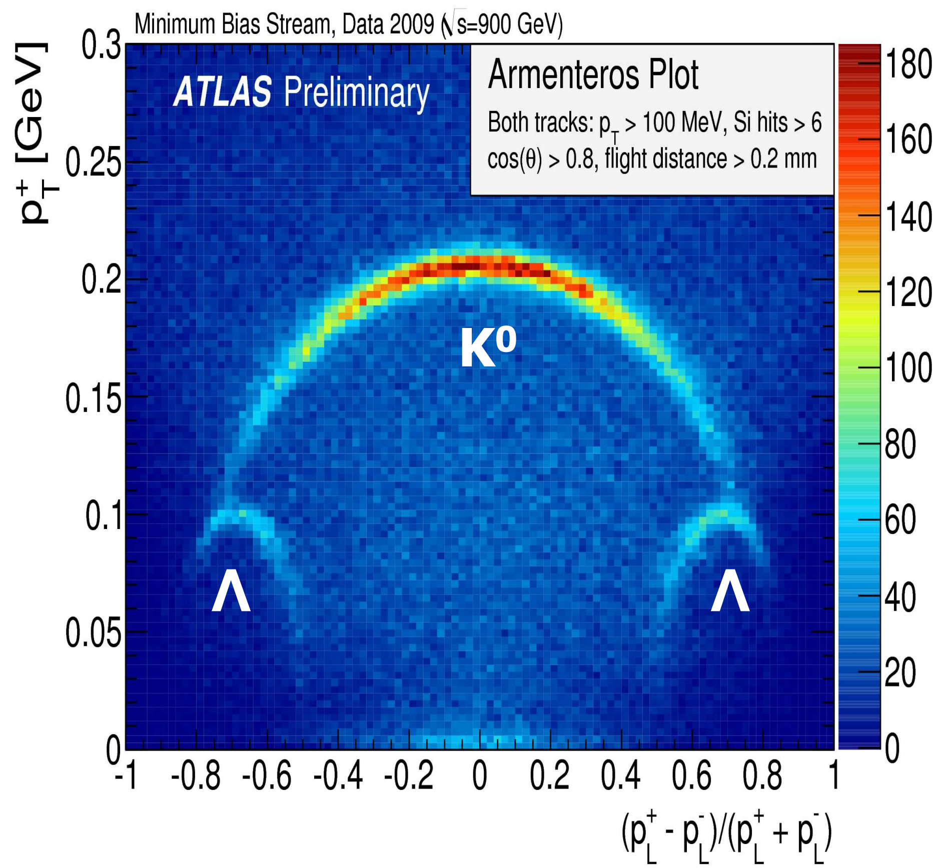
- **First measurements at 7 TeV**
  - **K^0_s and Λ decays**
  - **hidden charm: J/Ψ measurements**
  - **open charm: D-mesons**
  - **b-quark jets**
- **Perspectives**
  - **studies for 14 TeV**
  - **quarkonia production**
  - **B-meson family**
  - **rare B-decays**

Mass Peaks in Minimum Bias Events

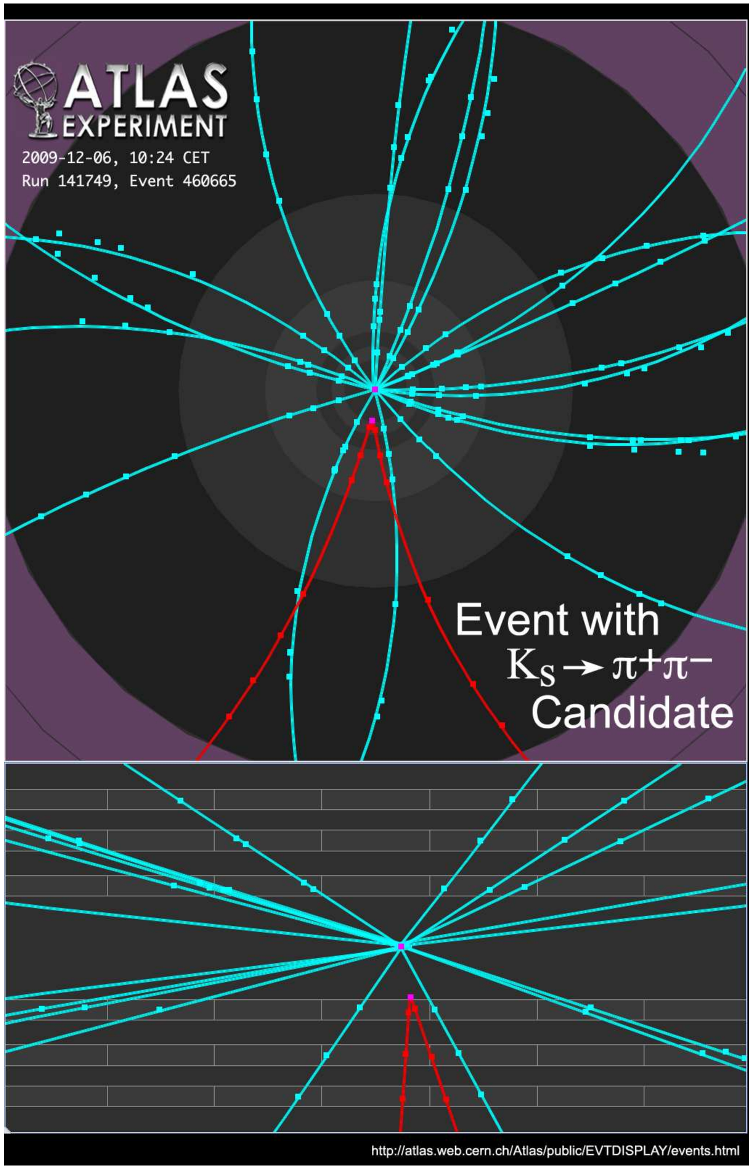
weak decay (V_0) reconstruction provides a stringent test of tracking performance:

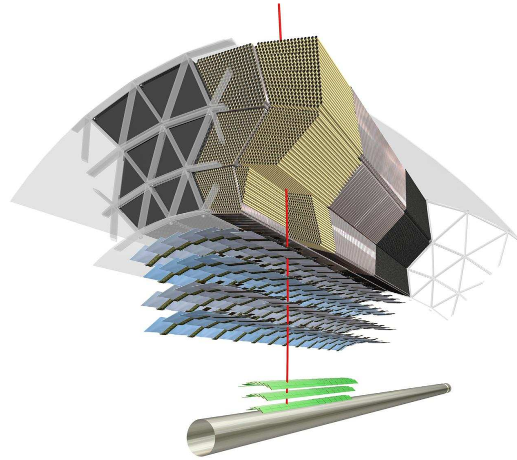
- reconstructed K_s and Λ masses **close to PDG value**
- width of the invariant mass peaks well reproduced by Monte Carlo
- more sensitive test with higher momentum tracks (i.e. alignment)

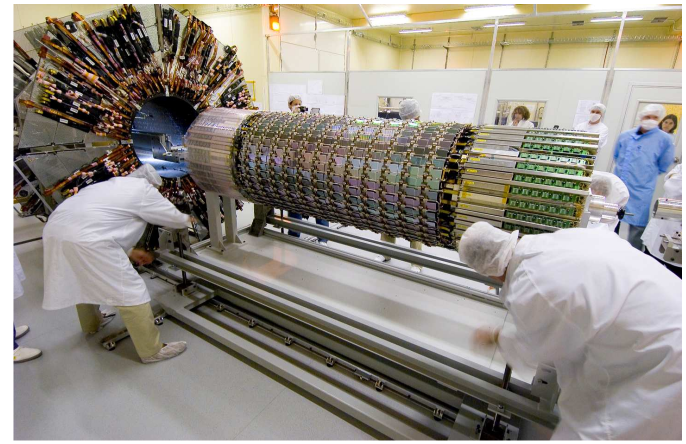


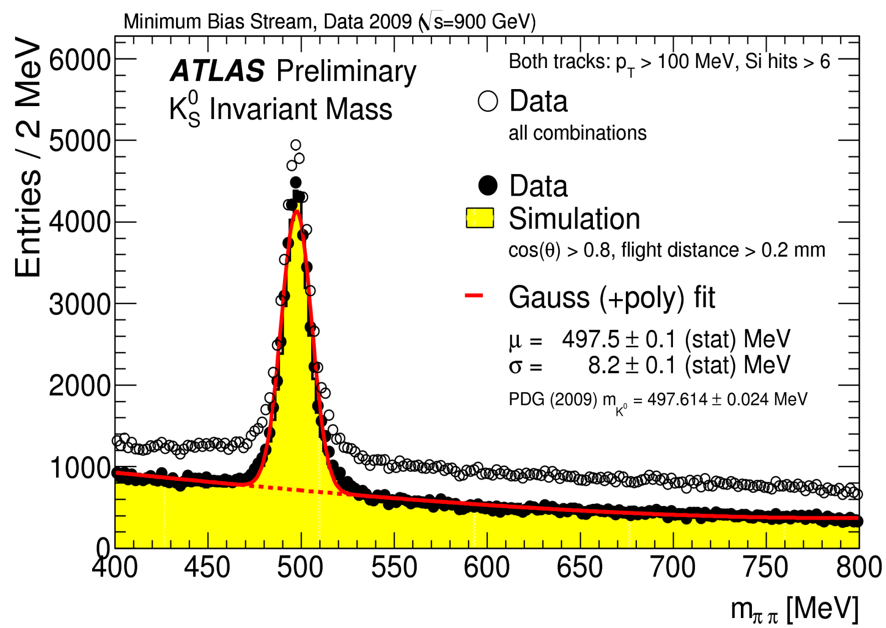


Reconstruction of Secondary Vertices

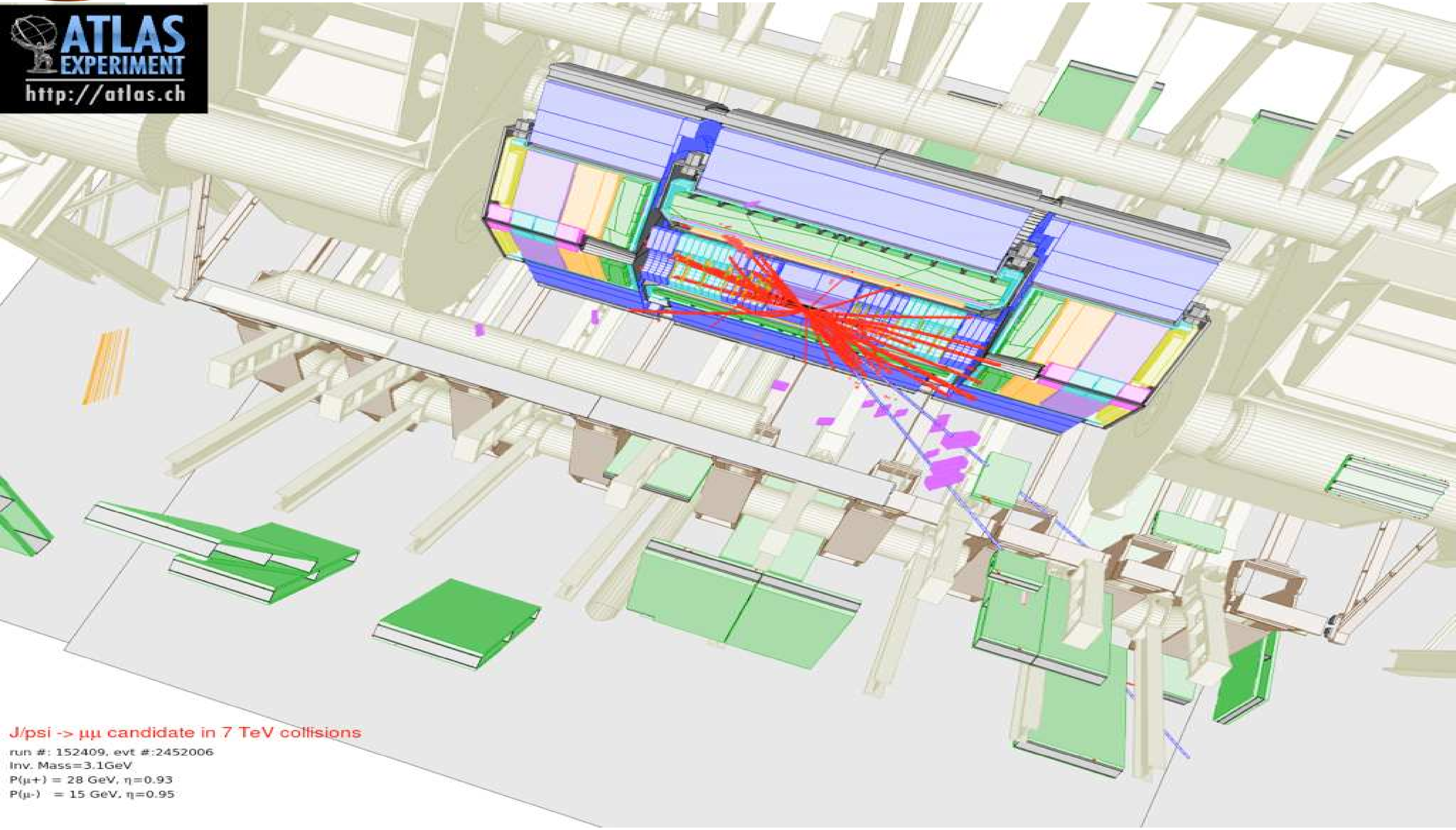








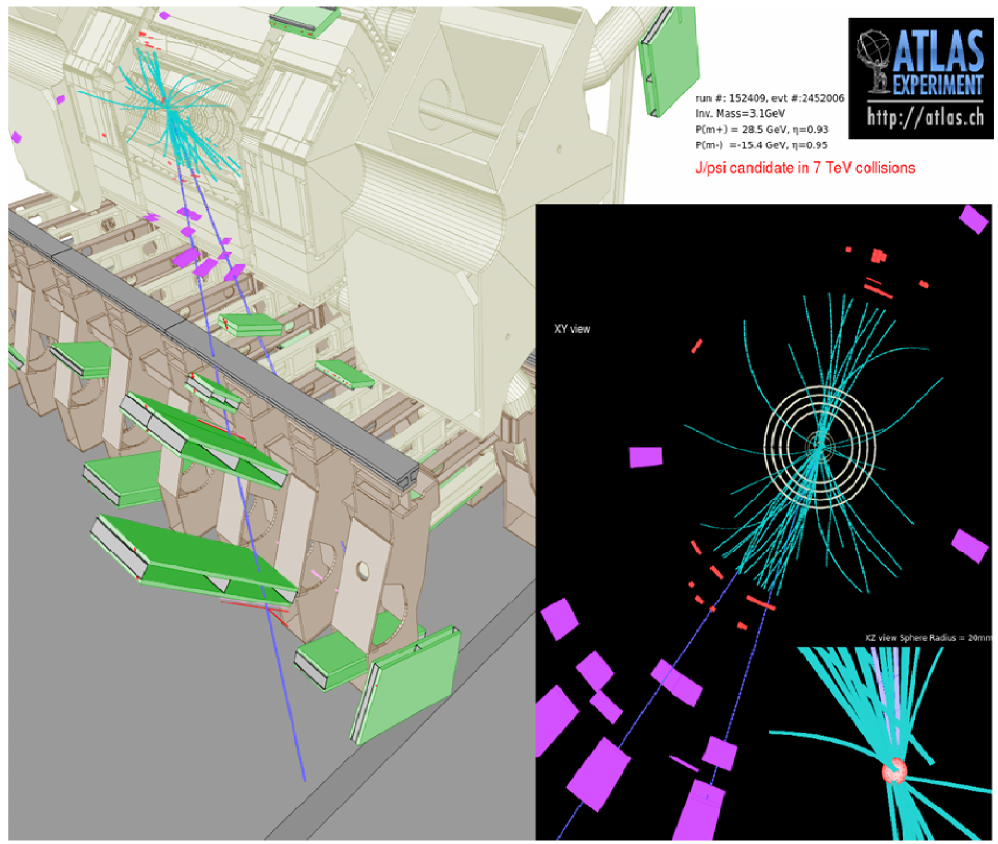
$J/\psi \rightarrow \mu^+\mu^-$ Event at ALTAS



$J/\psi \rightarrow \mu^+\mu^-$ Selections

loose selections applied to understand shape of background:

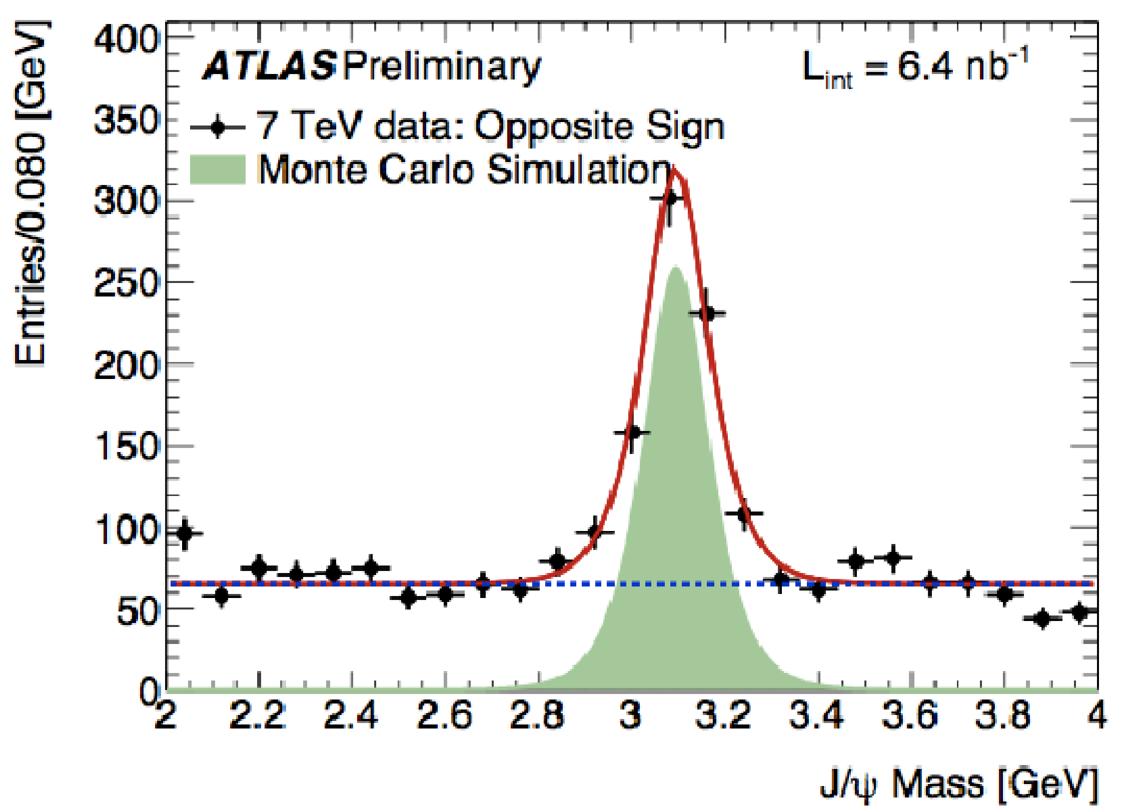
- **Trigger: Level 1 (L1) and Higher Level Event Filter (EF)**
  - **Minimum Bias Trigger Scintilators** MBTS $2.09 < |\eta| < 3.84$: 2 coincidence hits on either side of detector (**L1**)
  - **muon activity in MS** found by the muon trigger
  - muon triggers combined with MBTS (**EF**)
- **collision events**
  - at least 3 tracks associated with same primary vertex
  - **track quality:** at least 1 hit in the pixel detector; at least 6 hits in semiconductor tracker
  - track reconstruction applies **p_T>0.5 GeV** cut to all ID tracks
- **muons**
  - each muon has ID track with the before mentioned track quality cuts
  - combination of muon tracks with tracking system



- **common vertex fit + opposite sign**
- **mass region 2-4 GeV**

$J/\psi \rightarrow \mu^+\mu^-$ Signal

- **data:** 7 TeV runs, L = 6.4 ± 1.3 nb^{-1}
- **basic selection**



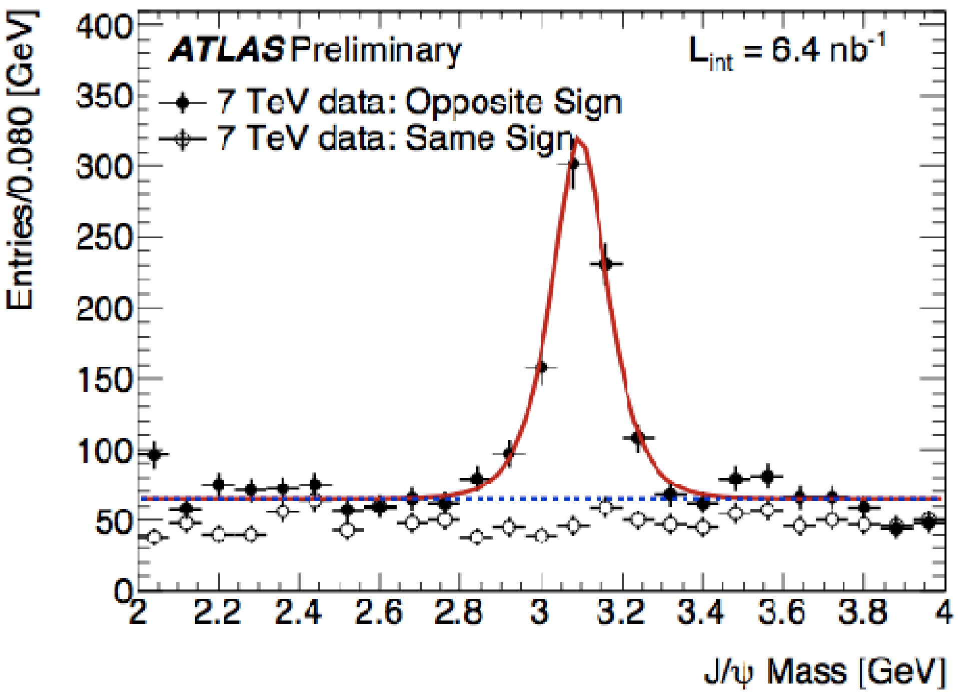
- unbinned event-by-event maximum likelihood fit, applied to data and MC
- N_{sig} and N_{bg} defined in 3 σ region around J/Ψ
- MC: signal only

N_{sig}	612±34
N_{bg}	332±9
Mass [GeV]	3.095±0.004
σ_M [MeV]	82±7
σ_M(MC)[MeV]	74.0±0.4

$J/\psi \rightarrow \mu^+\mu^-$ same Sign/opposite Sign

invariant mass distribution of same sign and opposite sign muon pairs after vertexing

- same sign is (as expected) flat
- smaller contribution from same sign than from opposite sign:
  - both have contributions from combinatorial BG and π/K decays in flight
  - opposite side bands: additional contributions from heavy flavour decays



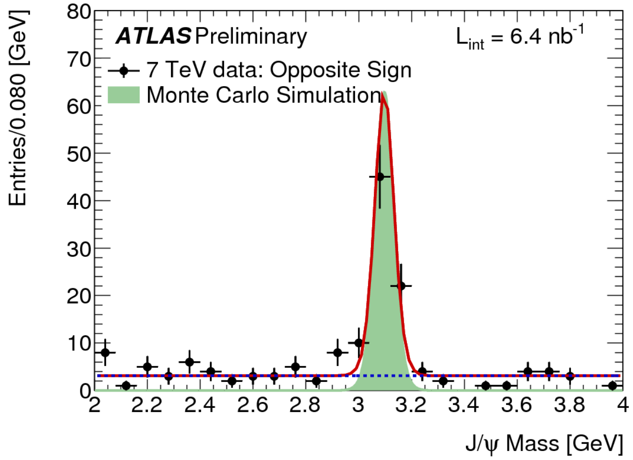
N_{sig}	612±34
N_{bg}	**351±10 / 332±9**

before Vertexing / after Vertexing:

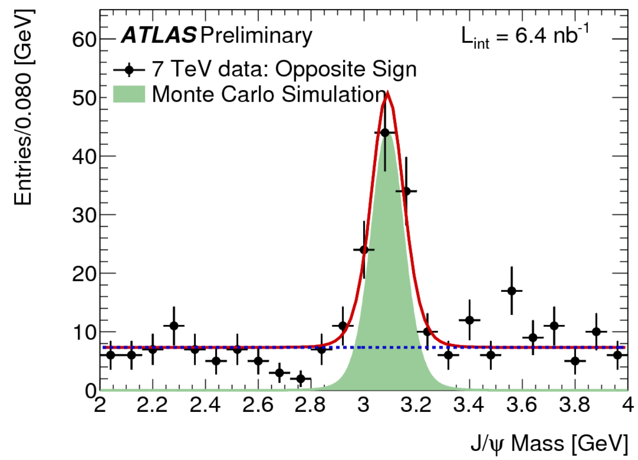
- improvements not expected at this stage, most data from primary vertex
- background reduction only by ~6%

J/Ψ Mass Resolution

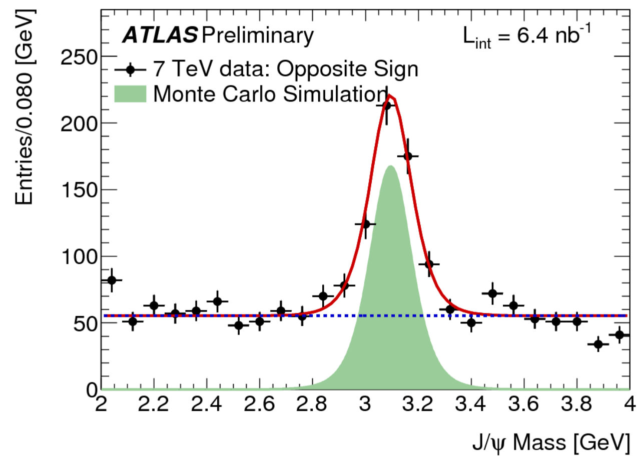
BB: both μ in barrel



EB: 1 μ in barrel / 1 μ in endcap



EE: both μ in endcap

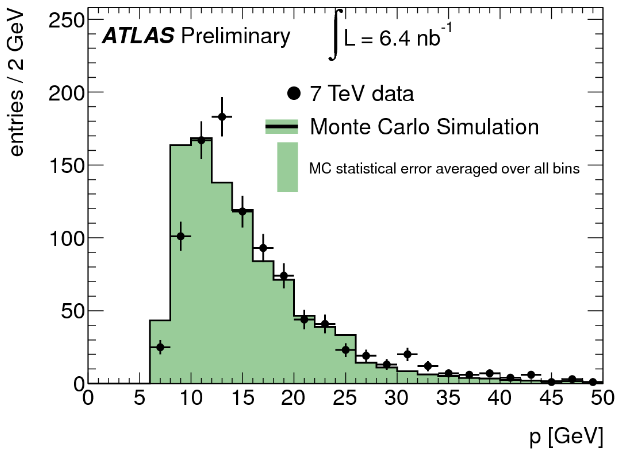


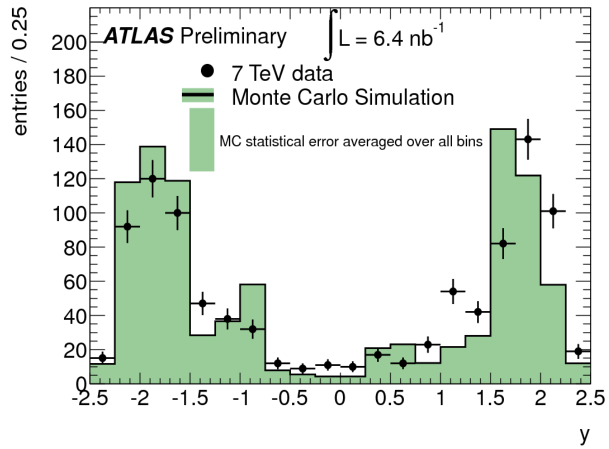
	BB (|η|< 1.05)	EB	EE (1.05<|η|<2.5)
N_{sig}	69±9	88±11	437±31
N_{bg}	8±1	34±3	324±10
Mass [GeV]	3.097±0.005	3.089±0.008	3.095±0.006
σ_M [MeV]	**36±6**	**66±12**	**88±9**
σ_M(MC)[MeV]	**37.0±0.7**	**53.0±0.8**	**82.0±0.5**

- mass resolution affected by ID: (different in barrel and endcap)
- J/Ψ reconstruction in different regions
  - BB: both μ in barrel
  - EB: 1 μ in barrel / 1 μ in endcap
  - EE: both μ in endcap

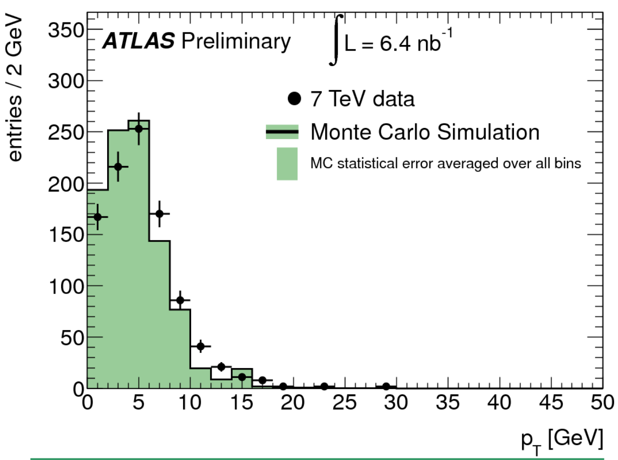
- in good agreement with MC simulation: much work done with **cosmics data**, **Geant4** and **early data** to describe / understand the ATLAS detector so well
- most candidates in **EE**

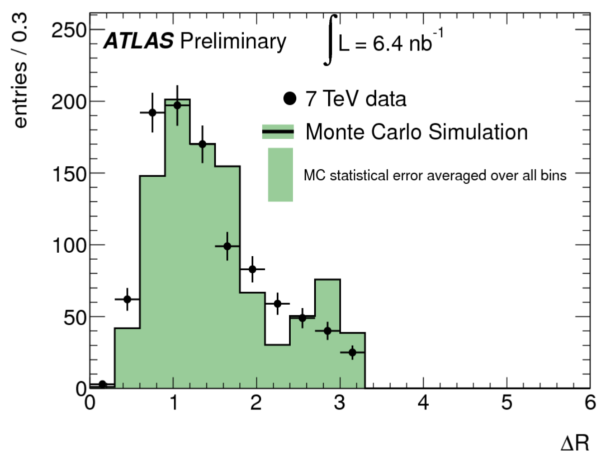
J/Ψ Kinematics

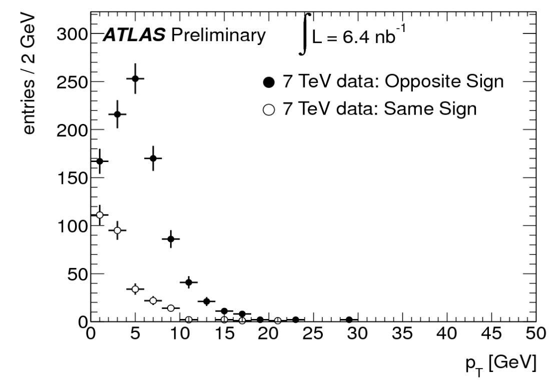


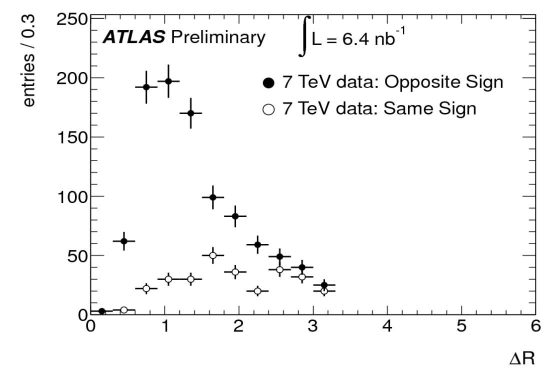


- mainly low p_T J/Ψ accessed
- sample dominated by high rapidity J/Ψ ($p >> p_T$)
- candidates in mass region $M_{J/\Psi} \pm 3\sigma = [2.86, 3.34]$GeV







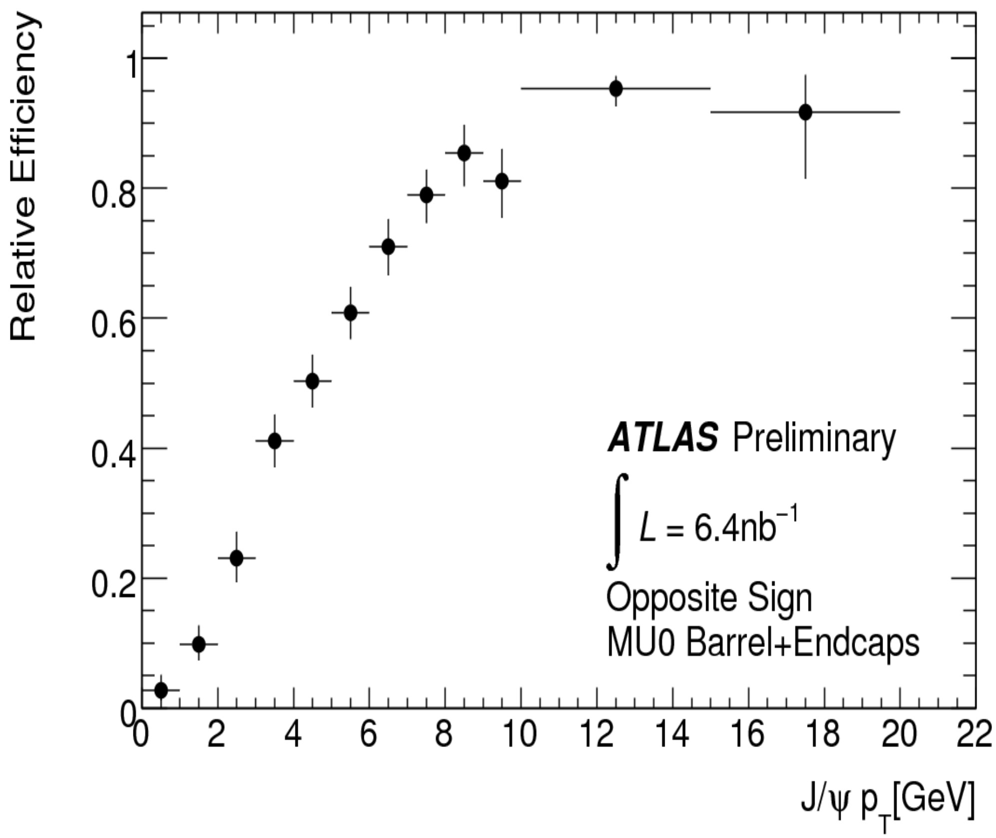


MC:
J/Ψ signal and Minimum Bias background

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

kinematics different for same and opposite sign μ pairs

L1-muon Trigger



data collected with **LVL1 Minimum Bias trigger**

good opportunity to study **L1 muon trigger efficiency**

MU0: loose muon trigger, no p_T threshold applied

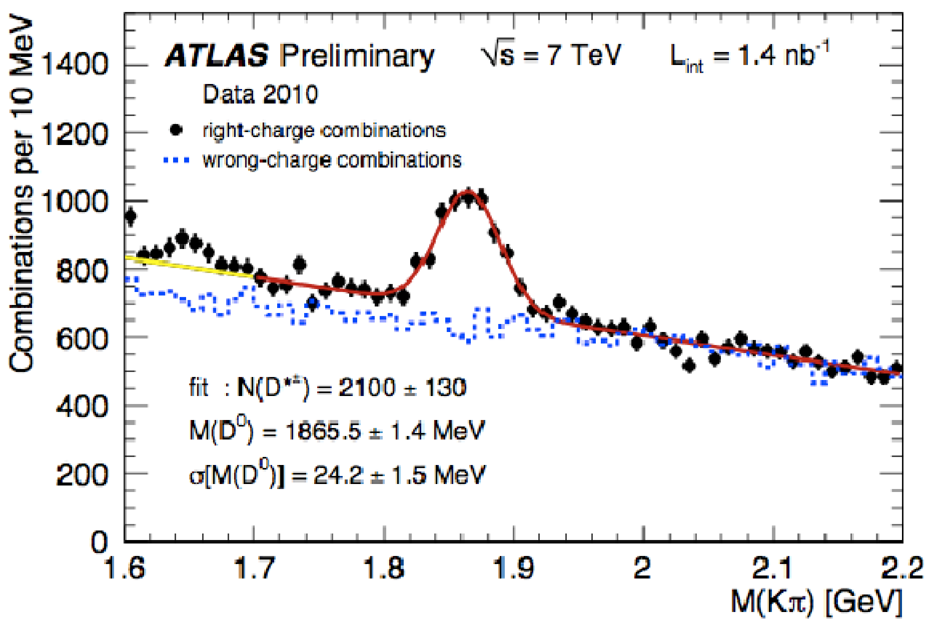
efficiency measurement for all J/Ψ candidates: require at least one reconstructed muon to match to L1 MU0 trigger object within $\Delta R < 0.5$

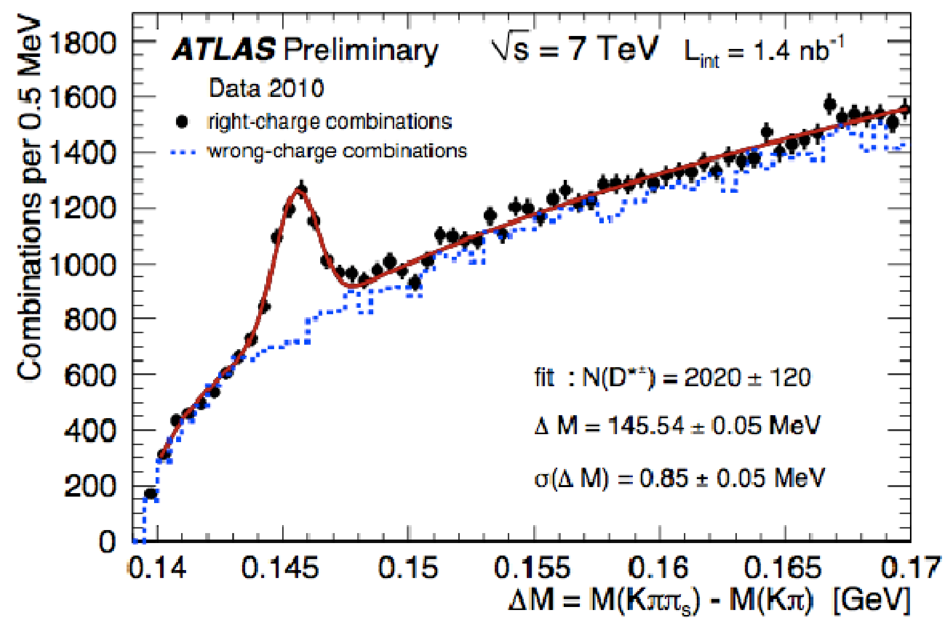
low J/Ψ p_T important for polarization studies

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

- **data:** 7 TeV runs, L = 1.4 nb^{-1}
- **basic selection:**
  - $p_T(D^*) > 3.5$ GeV
  - $|\eta(D^*)| < 2.1$
  - χ^2(vertex) < 5, Lxy>0
  - $p_T(D^*)/E_T > 0.02$

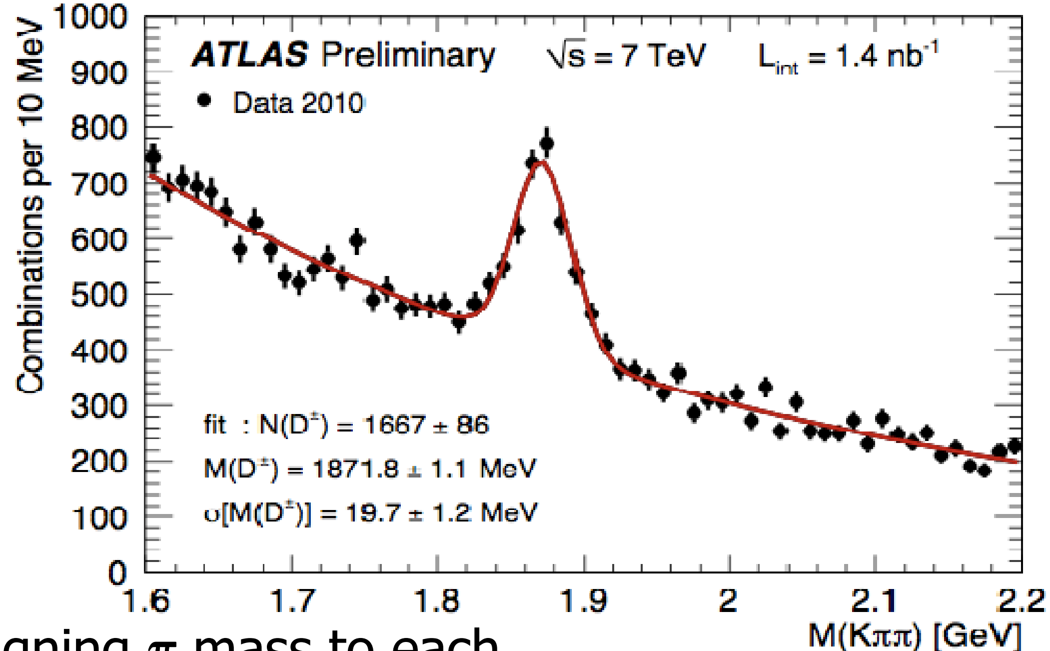
- **$M(K\pi)$:**
  - combining 2 opposite sign track (p_T>1.0GeV),
  - assigning K/π–masses to each track
  - 2098±128 D^{*+} candidates in $1.83 < M(K\pi) < 1.90$ GeV
- **$\Delta M = M(K\pi\pi_s) - M(K\pi)$:**
  - 2010±115 D* candidates in $114 < \Delta M < 147$ MeV





$D^+ \to K^- \pi^+ \pi^-$

- **data:** 7 TeV runs, L = 1.4 nb^{-1}
- **basic selection:**
  - $p_T(D^+) > 3.5$ GeV,
  - $|\eta(D^+)| < 2.1$
  - χ^2(vertex) < 6, L_{xy} > 1.3 mm
  - $p_T(D^+)/E_T > 0.02$
  - $\cos\theta^*(K) > -0.8$

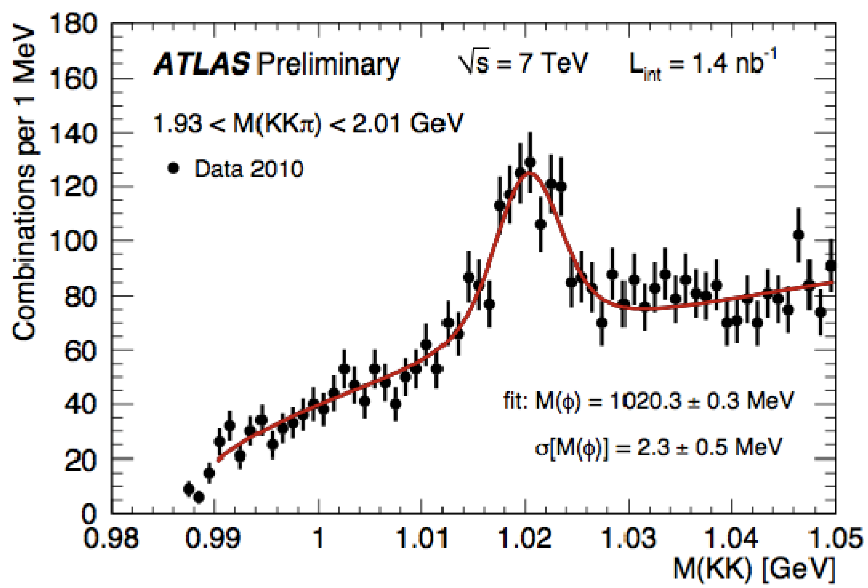


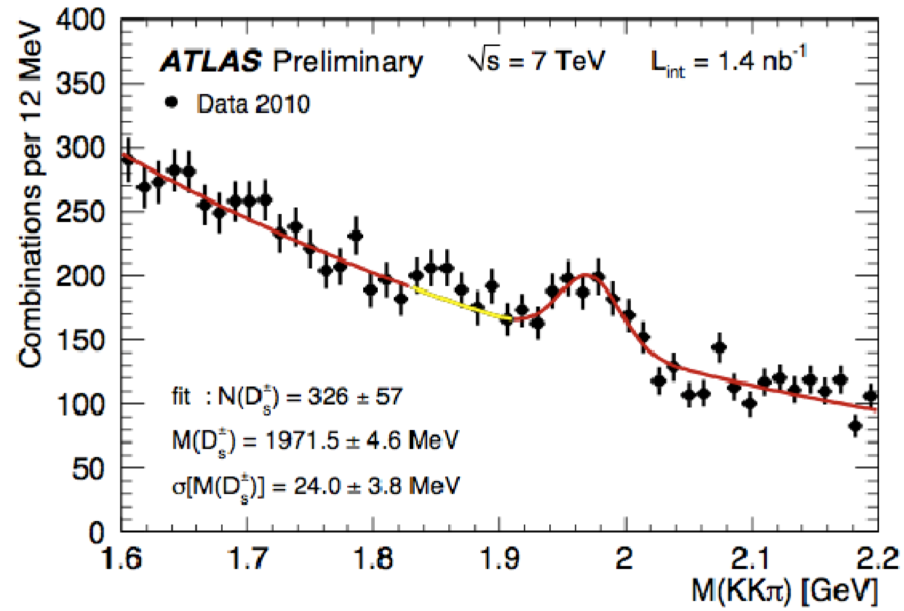
- combine 2 same-charge tracks assigning π mass to each
  - $p_T(\pi_1) > 0.8$ GeV, $p_T(\pi_2) > 1.0$ GeV
- combine with third track with assigned K mass
  - $p_T(K) > 1.0$ GeV
- suppression of $D^{*\pm}$ and $D_s^+ \to \varphi\pi^+ \to (K^-K^+)\,\pi^+$ reflections:
  - remove $\Delta M_{1,2} < 150$ MeV to suppress D^{*+} and $|M(K^+K^-) - M(\varphi)_{PDG}| < 8$ MeV to suppress D_s^+

$D_s^+ \rightarrow \varphi\, \pi^+ \rightarrow (K^- K^+)\pi^+$

- **data:** 7 TeV runs, L = 1.4 nb^{-1}
- **basic selection:**
  - $p_T(D_s^+) > 3.5$ GeV,
  - $|\eta(D_s^+)| < 2.1$
  - χ^2(vertex) < 6, L_{xy}> 0.4 mm
  - $p_T(D^+)/E_T > 0.04$
  - $\cos\theta^*(\pi) < 0.4$
  - $|\cos^3\theta'(K)| > 0.2$

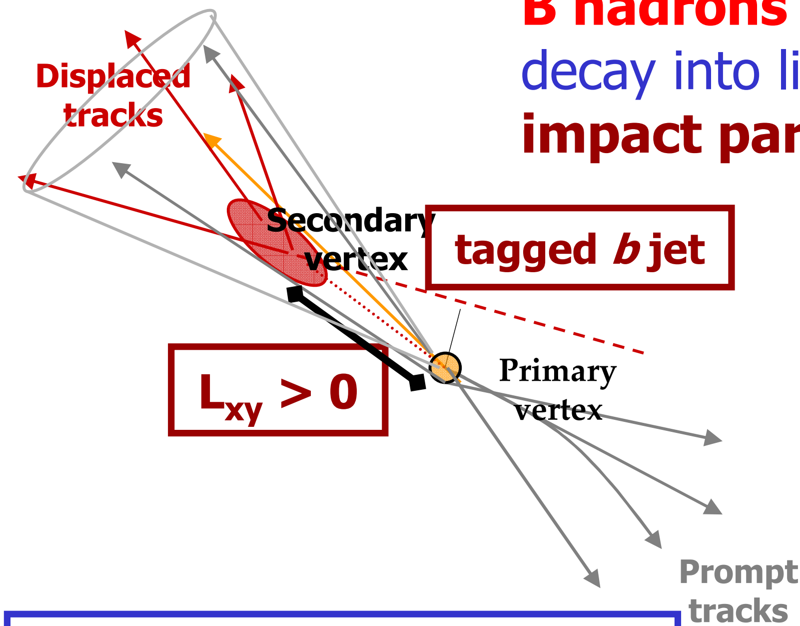
- combine 2 opposite-charge tracks assigning K mass to each
  - $p_T(K_1,K_2) > 0.7$ GeV
- $M(K^+K^-)$
  - select $|M(K^+K^-) - M(\varphi)_{PDG}| < 6$ MeV
- combine with third track with assigned π mass
  - $p_T(\pi) > 0.8$ GeV

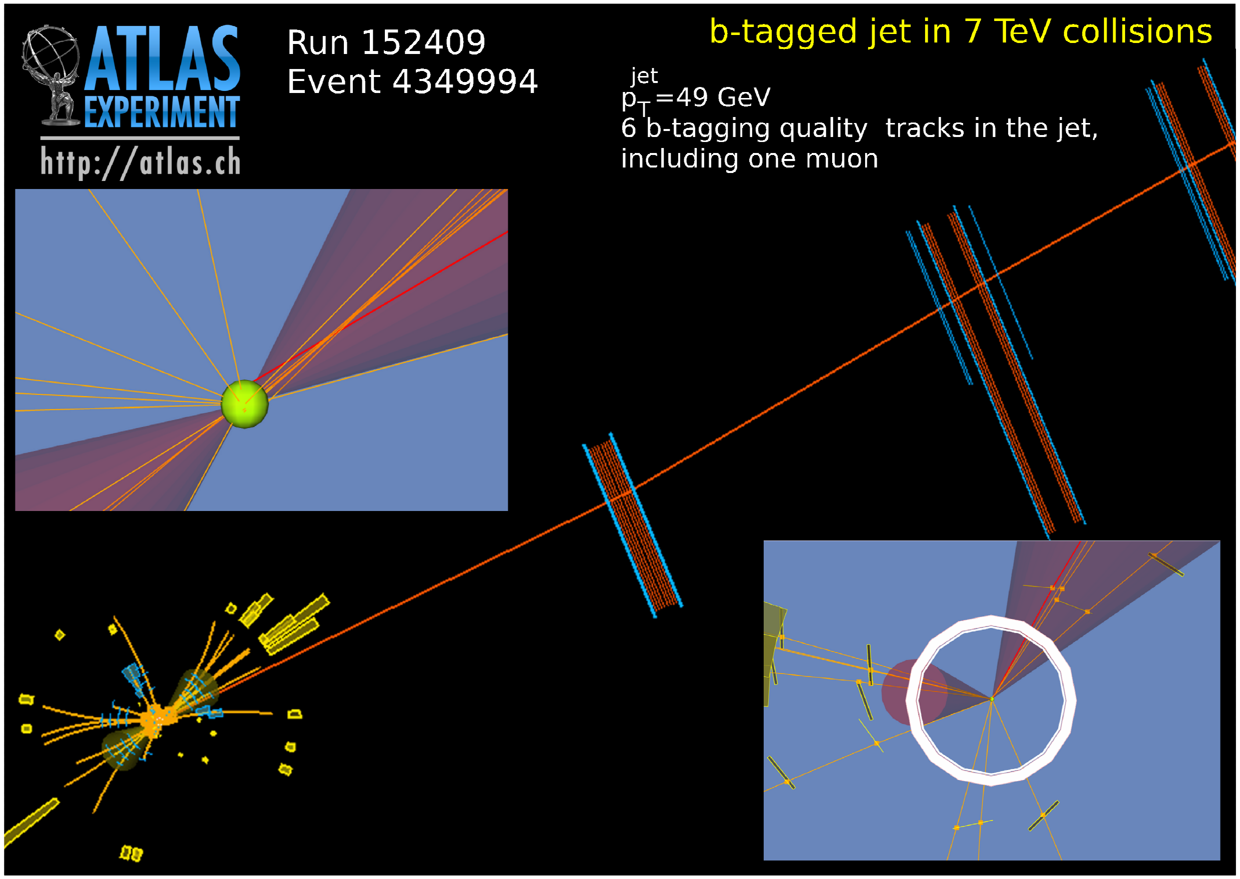




B-jet tagging with early data

B hadrons are massive and long-living ($c\tau \sim 460\ \mu m$): decay into lighter flavors with **secondary vertices and impact parameters** on same hemisphere as b-jet



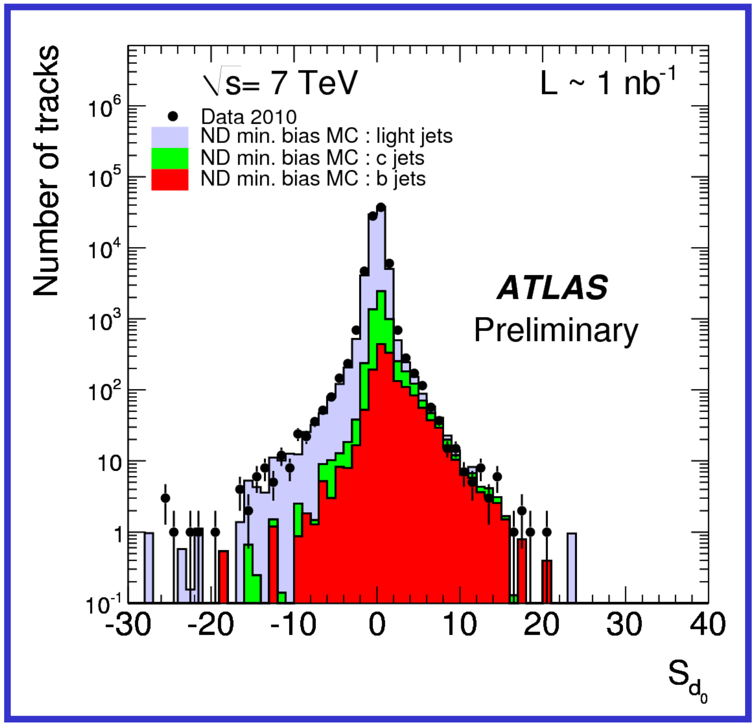


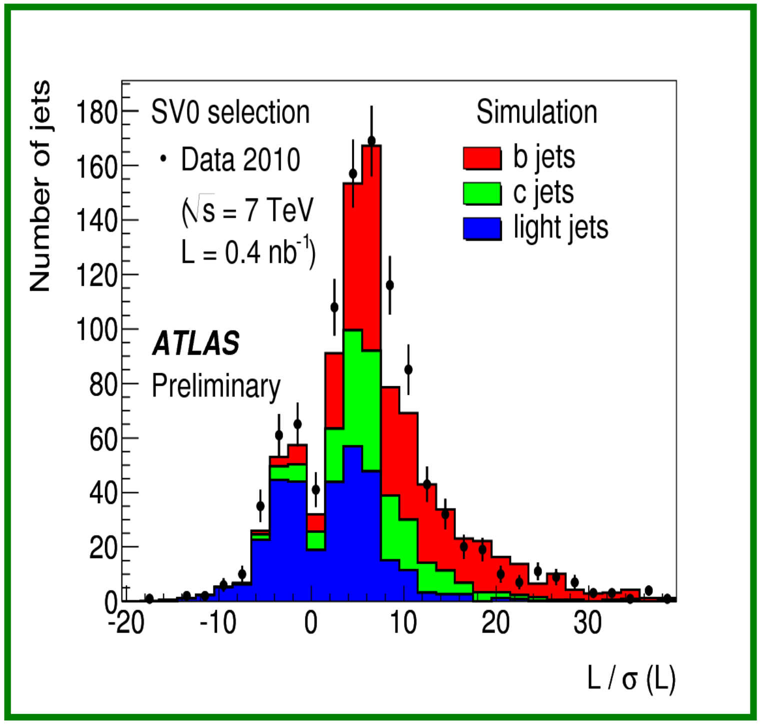
impact parameters and **secondary vertices** used to define various different **Tag Weights** based on
- **significances**
- **resolution functions**
- **probability ratios**

Heavy Flavour Selection Variables

tagging b-jets is elementary for many analyses at LHC

- all top-related Standard Model analyses
- many searches for new physics (MSSM)
- good knowledge of **impact parameter** and **secondary vertices** also crucial for B-Physics





impact parameter significance (second highest, **tag weight**), **comparison of real Data and Monte Carlo**

decay length significance, signed with respect to the calorimeter jet axis (**tag weight**), **comparison of real Data and Monte Carlo**

Contents

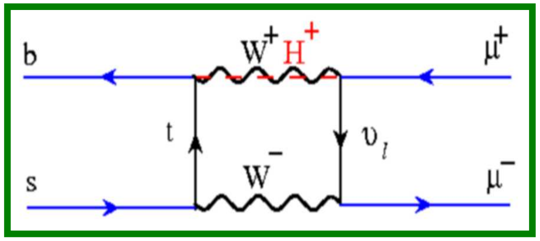
- **First measurements at 7 TeV**
  - K^0_s and Λ decays
  - hidden charm: J/Ψ measurements
  - open charm: D-mesons
  - b-quark jets
- **Perspectives**
  - studies for 14 TeV
  - quarkonia production
  - B-meson family
  - rare B-decays

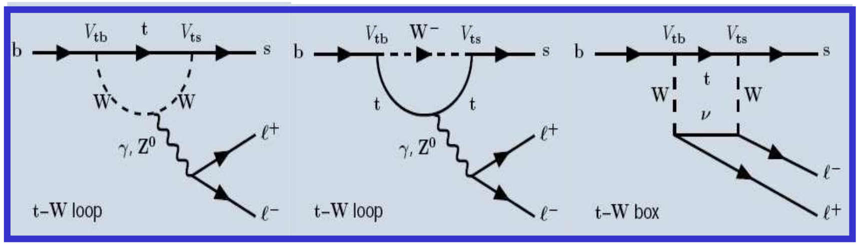
Perspectives for more Luminosity

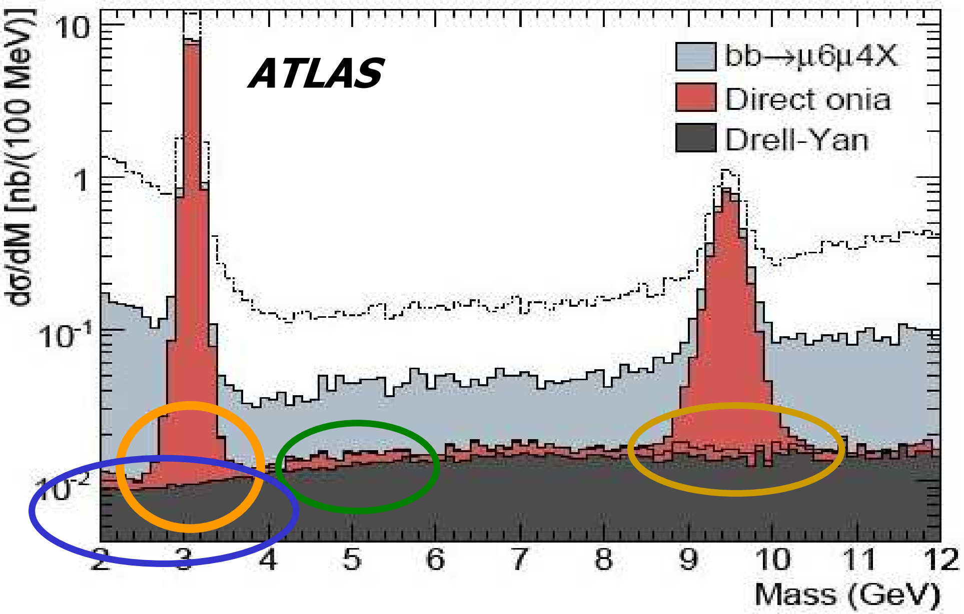
- based on 14 TeV simulations
- some selected highlights shown:
  - B-Trigger Strategy
  - quarkonia production
  - $B^+ \rightarrow J/\Psi\ K^+$
  - $B_s \rightarrow J/\Psi\ \varphi$ and $B_d \rightarrow J/\Psi\ K^{0*}$
  - $B_s \rightarrow \mu^+\mu^-$
- longer term goals for more luminosity

B-Trigger Strategy

- **low p_T single- and di-muon**
  - control samples, for very low luminosities, first beams
- **di-muon (common vertex) in final state**
  - different mass ranges: **J/Ψ** or **Y** decaying to **$\mu^+\mu^-$**
  - **very rare $B \rightarrow \mu^+\mu^-$ (box diagrams)**
  - **semi-leptonic rare $B \rightarrow X_s\mu^+\mu^-$ (penguin diagrams)**
- **sidebands around the signal peak needs to be covered (bb and cc contributions)**
- **control measurements di-muon low mass: $M(\mu^+\mu^-) < 13$ GeV**



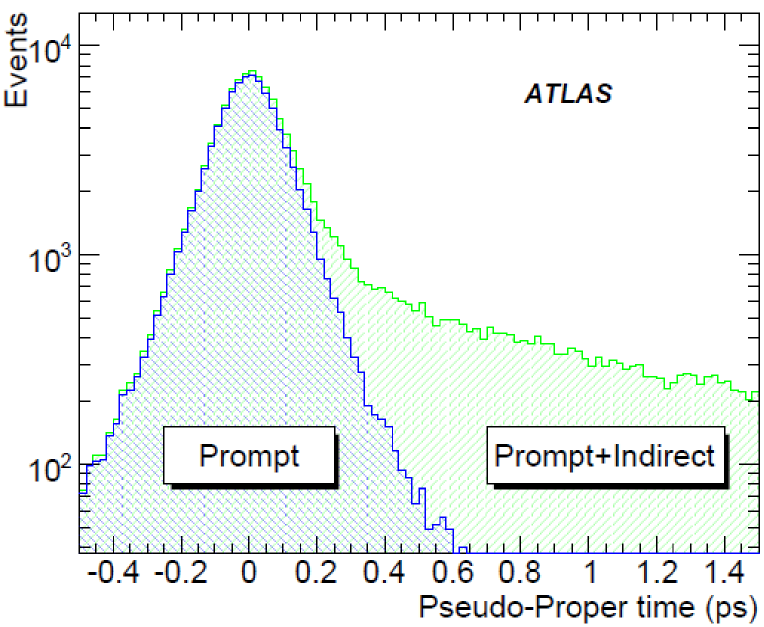




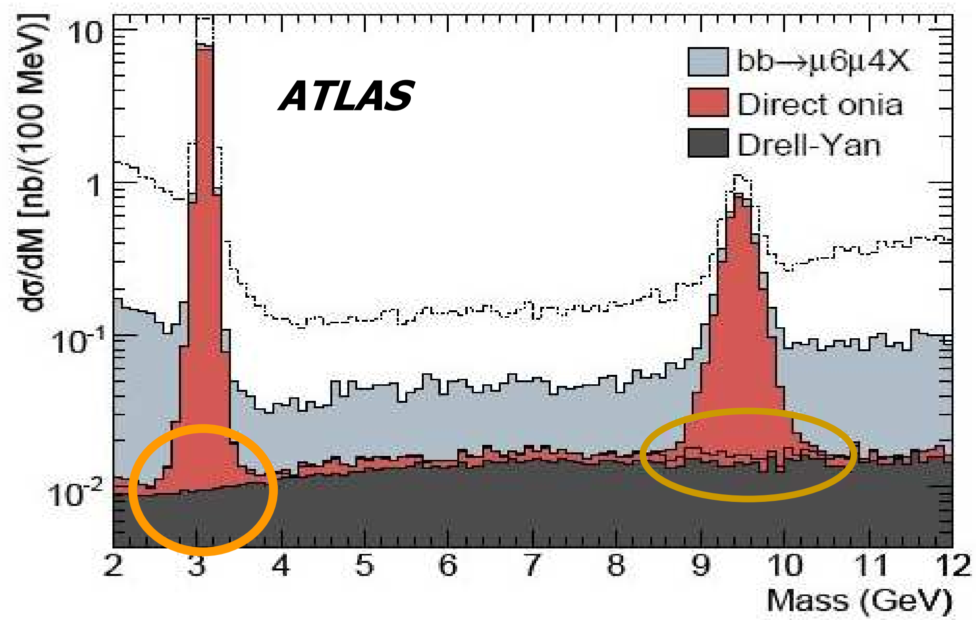
Quarkonia Production

- seeded by **L1 di-muon trigger**, tracks fitted to common vertex
  - background suppression for J/Ψ: pseudo proper time < 0.2 ps
- R_{pi} measurement relies on separation of those processes
- with **1 pb^{-1}**, R_{pi} can be measured as a function of $\mathbf{p_T}$ and **η** at **~ 10% precision**

$$R_{pi} = \frac{\sigma(b\bar{b} \to J/\Psi)}{\sigma(pp \to J/\Psi)}$$



$$= \frac{L_{xy} \cdot M_{J/\Psi}}{p_T(J/\Psi) \cdot c}$$

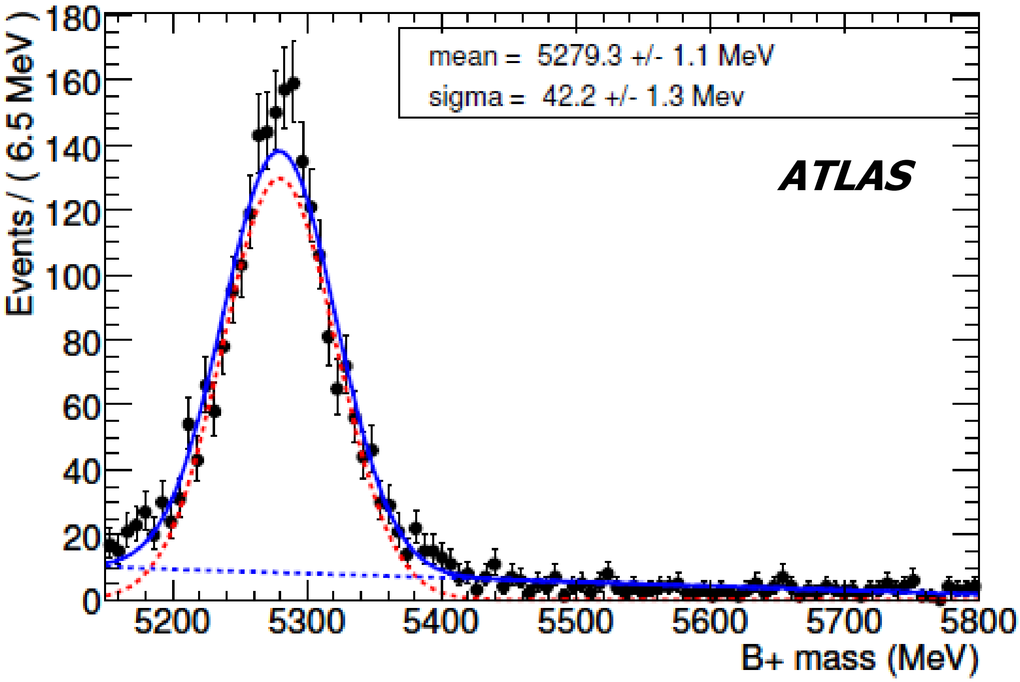


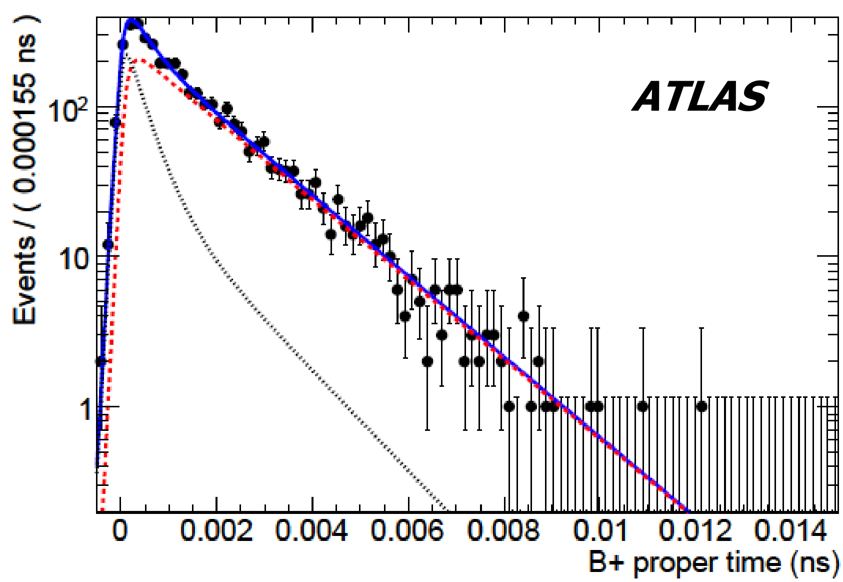
$B^+ \rightarrow J/\Psi(\mu^+\mu^-)\, K^+$

- important reference channel for searches for rare B-decays
- using di-muon trigger (p_T > 4/6 GeV),

experimental precision for 10 pb^{-1}:

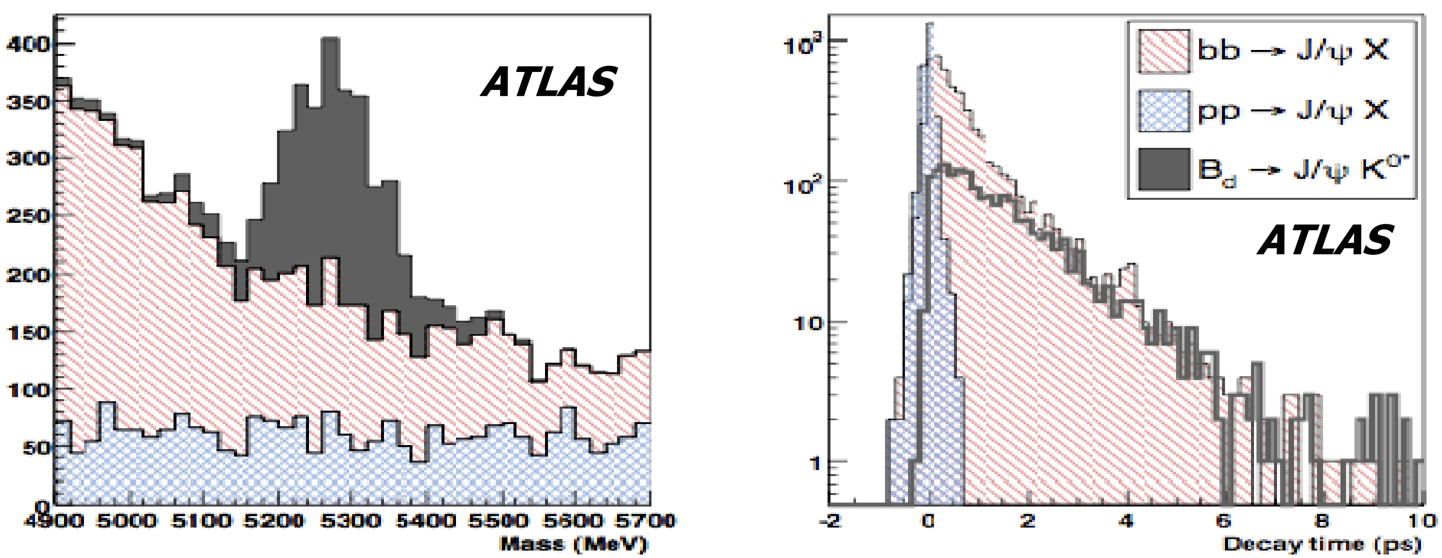
cross section	statistical	total
total	~3%	~15%
dσ/dpT	~10%	~16-20%
signal lifetime	~2.5%	



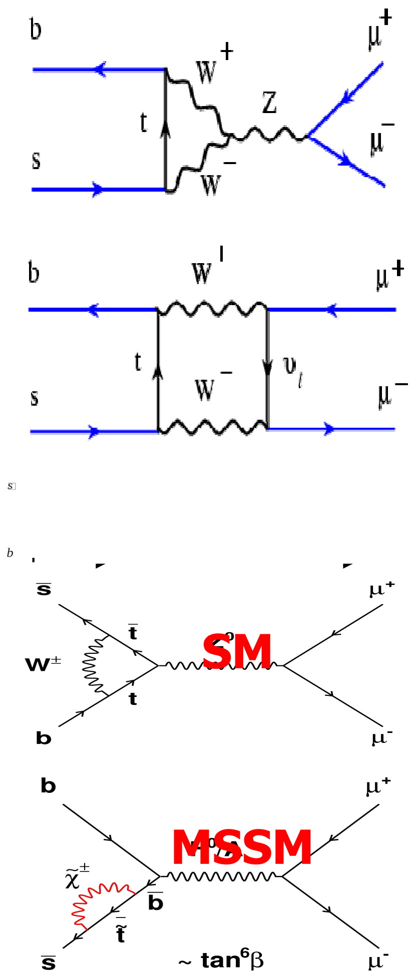


$B_s \to J/\Psi(\mu^+\mu^-)\varphi$ and $B_d \to J/\Psi(\mu^+\mu^-)K^{0*}$

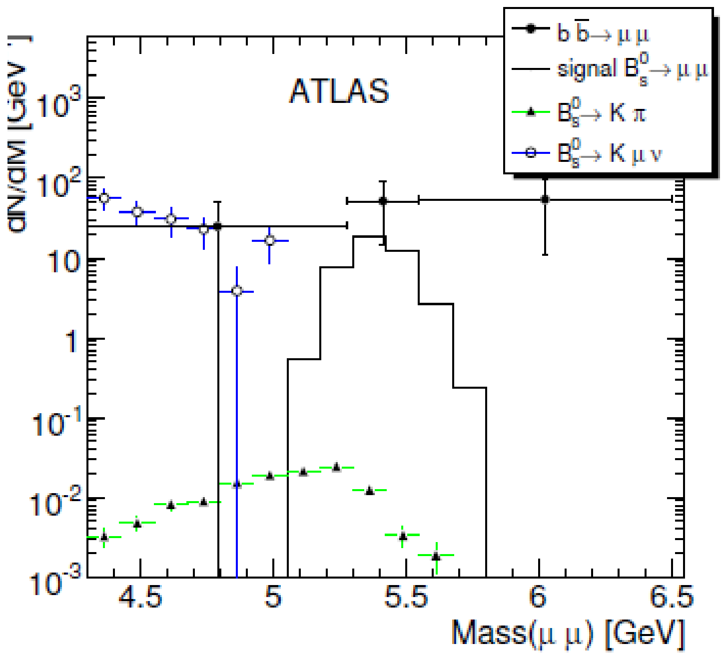
- **$B_s \to J/\Psi\varphi$ channel promising for indirect searches for New Physics**
  - "Weak mixing phase" ϕ_s **= (-0.0368±0.0018) very small in SM**
  - may be **enhanced by BSM processes**
- topologically identical **$B_d \to J/\Psi K^{0*}$ (15x greater statistics) primary background**; essential as a control channel (test of lifetime measurement and tagging calibration)
- simultaneous fit to mass and decay time can be used to extract signal mass and lifetime from data in the channel $B_d \to J/\Psi(\mu^+\mu^-)K^{0*}$ with $10 pb^{-1}$ (10 % precision expected)
- similar precision for $B_s \to J/\Psi(\mu^+\mu^-)\varphi$ mean lifetime achievable with 150 pb^{-1}



Expected Performance for $B_s \to \mu^+\mu^-$



- $B_s \to \mu^+\mu^-$ highly suppressed in **SM** (penguin and box diagrams)
  - **SM: BR($B_s \to \mu^+\mu^-$) = (3.42 ± 0.52) x 10^{-9}**
  - best limit: **CDF: BR($B_s \to \mu^+\mu^-$) < 5.8 x 10^{-8} (95% CL)**
- **sensitivity to new physics (MSSM): new particles in the loop**
- main challenge to control the background



- in **1 fb^{-1} O(10^6) di-muons** in the mass range [4,7]GeV expected
- allows tuning cuts and train multivariate analysis techniques
- use **$B^+ \to J/\Psi(\mu^+\mu^-)K^+$** as a reference channel
- BR estimated by normalization to **$B^+ \to J/\Psi(\mu^+\mu^-)K^+$** events
- **expectation with 10 fb^{-1} (one year at 10^{33})**

Conclusion for First Data

- **$J/\psi \to \mu^+\mu^-$ resonance observed in ATLAS data with $\int L$ of $6.4 \pm 1.3\ nb^{-1}$**
  - mass in good agreement with the PDG table mass within statistical uncertainties
  - mass resolution is consistent with MC expectations in all parts of the detector
- **clear $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ signals reconstructed with the ATLAS detector with $\int L$ of $1.4\ nb^{-1}$**
  - $D^{*\pm}$: 2020 ± 120, $D^{\pm}$: 1667 ± 86, $Ds^{\pm}$: 326 ± 57
  - positions in good agreement with PDG values
- **confirm high performance of ATLAS detector for precision measurement**
- **in short term future:**
  - ratio measurement: prompt J/ψ to non-prompt J/ψ
  - J/ψ and Y cross section and polarization measurement
  - exclusive B-meson decays
  - D-meson measurements
- **taggers for b-flavoured jets at ATLAS in good shape for data taking**
  - good agreement of impact parameter and secondary vertex significances with MC
  - essential basis for b-tagging weights based on them
  - vital for many top and BSM analyses

Conclusions for Expectations

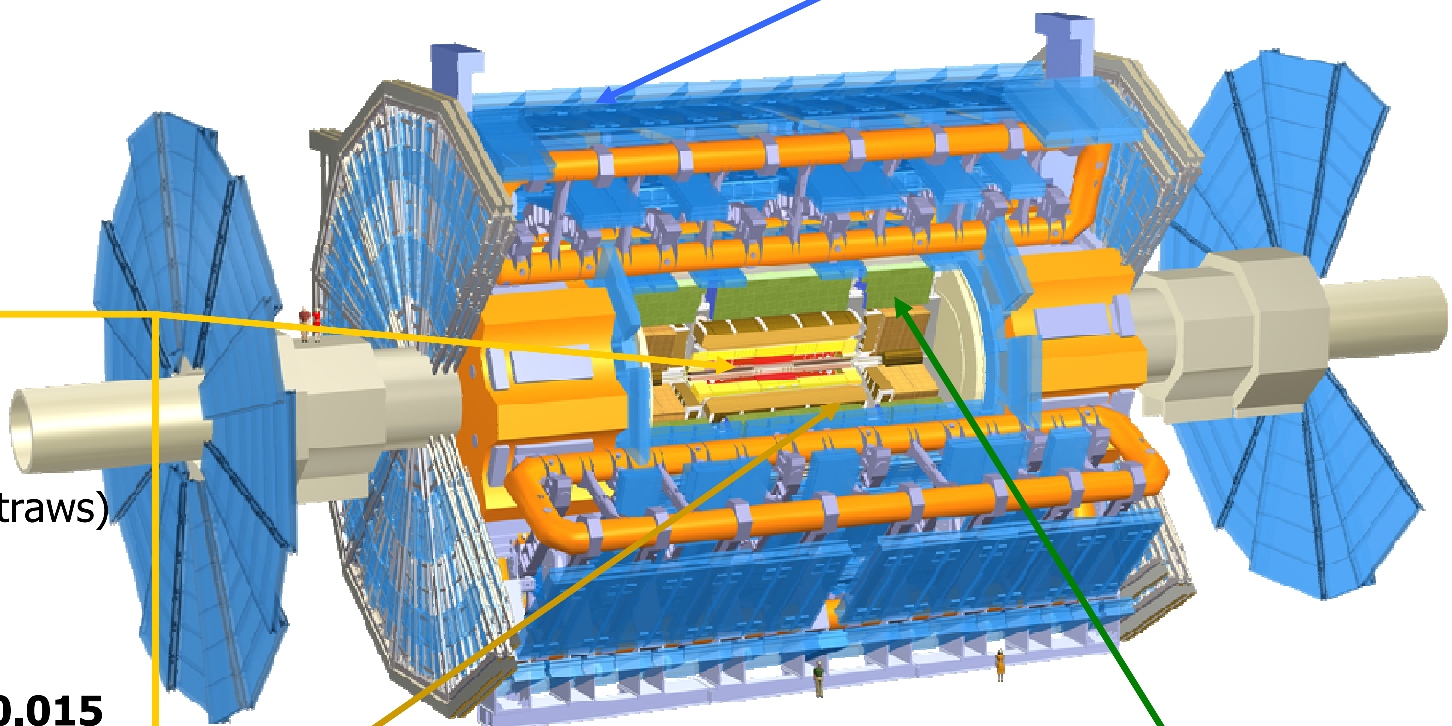
ATLAS ...

- **... has a long term flavour physics program.**
- **... allows important measurements for the search for new physics.**
- **... needs powerful and reliable di-muon trigger strategy for the Flavour-Physics program.**
- **... provides valuable information on the detector performance with early Flavour-Physics analyses.**
- **... supports searches for new physics with calibration studies with B-Physics.**

The ATLAS Detector

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

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



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

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

HAD calorimeter (|η|<5): segmentation, hermeticity Fe/scintilator Tiles (central), Cu/W-LAr (fwd) Trigger and measurement of jets and missing ET
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} + 0.03$