b and c physics with early ATLAS data

PLHC 2010, DESY, June 11th 2010

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on behalf of the ATLAS Collaboration

ATLAS b and c physics program

- Understanding the detector performance (alignment/tracking/ B-trigger) using well understood b and c processes
- Measurement of production cross sections for B-hadrons and J/ψ,ϒ to test QCD predictions for pp collisions at the LHC
- Studies of the properties of the complete B-meson family (B^+, B_s, B_c, Λ_b + h.c.)
- Precise measurements of weak B-hadron decays to search for BSM CP-violating effects
- Searches for rare B-decays (such as $B_s \rightarrow \mu\mu$)

$\int \mathcal{L}$

10 nb^{-1} — **Validation of ID/trigger performance and alignment, data quality monitoring with J/ψ and ϒ**

10 pb^{-1} — **Continuing performance studies: measurements of bb→J/ψ, pp→J/ψ, and B+→J/ψK+ cross section ratios**

Collect larger numbers of the main B decays; start to contribute to world averages on B-hadron properties; start to set limits on rare decay branching ratios

1 fb^{-1}

Searches for new CP-violation in weak decays of B-mesons; rare decay searches; onia and Λ_b polarization studies

10 fb^{-1}

"High" LHC luminosity - main period for rare dimuon decay searches

100 fb^{-1}

ATLAS b and c physics program

- Understanding the detector performance, B-trigger, b and c processes

We are here!

Focus mainly on recent $J/\psi \to \mu^+\mu^-$ and $D^{(*)}$ observations

- Measurements of cross sections for B-hadrons and J/ψ,ϒ to test QCD predictions for pp collisions at the LHC

- Studies of the properties of the complete B-meson family (B^+, B_s, B_c, Λ_b + h.c.)

- Precise measurements of weak B-hadron decays to search for BSM CP-violating effects

- Searches for rare B-decays (such as $B_s \to \mu\mu$)

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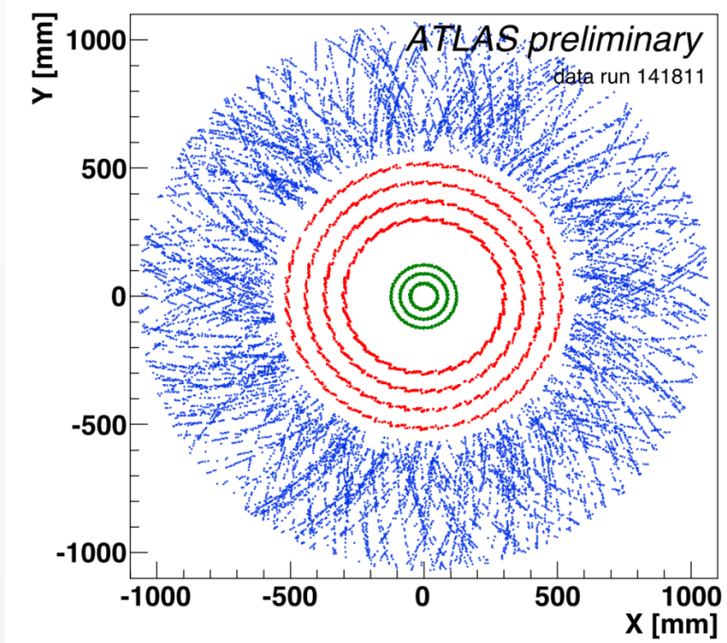
100 fb^{-1} — **"High" LHC luminosity - main period for rare dimuon decay searches**

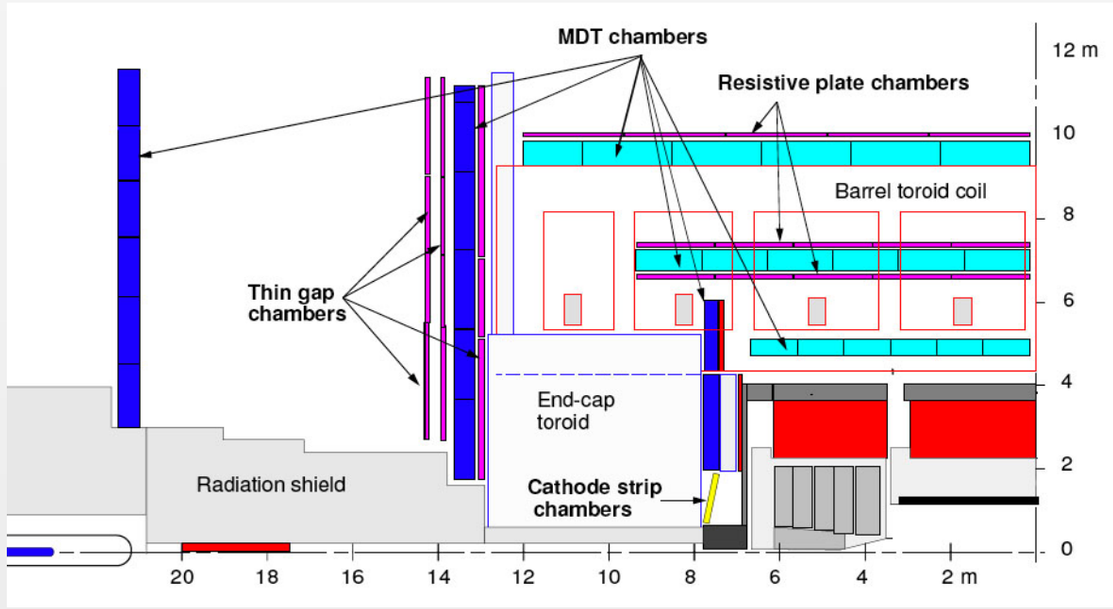
Ingredients of the analysis

- **Trigger**
  - Minimum Bias Trigger Scintilators (MBTS): $2.09 < |\eta| < 3.84$
  - Muon trigger
  - See Monday, Tuesday talks: I. Grabowska, R. Mackeprang



- **Inner Detector (ID)**
  - Solenoid magnet B: 2 Tesla
  - Pixel Detector ($|\eta|<2.5$)
    - $\sigma_{r\varphi} \sim 10$ μm, $\sigma_z \sim 115$ μm
  - Semiconductor Tracker (SCT) ($|\eta|<2.5$)
    - $\sigma_{r\varphi} \sim 17$ μm, $\sigma_z \sim 580$ μm
  - Transition Radiation Tracker (TRT) ($|\eta|< 2$)
    - $\sigma_{r\varphi} \sim 130$ μm per tube
  - See Monday talk: I. Potrap

- **Muon Spectrometer (MS)**
  - Magnet toroid B_{avg}: 0.5 Tesla
  - Tracking chambers:
    - Monitored Drift Tubes (MDTs): $0<|\eta|<2.7$
    - Cathode Strip Chambers (CSCs): $2.0<|\eta|<2.7$
  - Trigger chambers:
    - Resistive Plate Chambers (RPCs): barrel, $|\eta|<1.05$
    - Thin Gap Chambers: (TGCs): endcap, $1.05<|\eta|<2.4$
  - See Monday talk: T. Cornelissen



- **J/ψ studies combined 2 detector systems: ID for tracking, MS for muon identification**

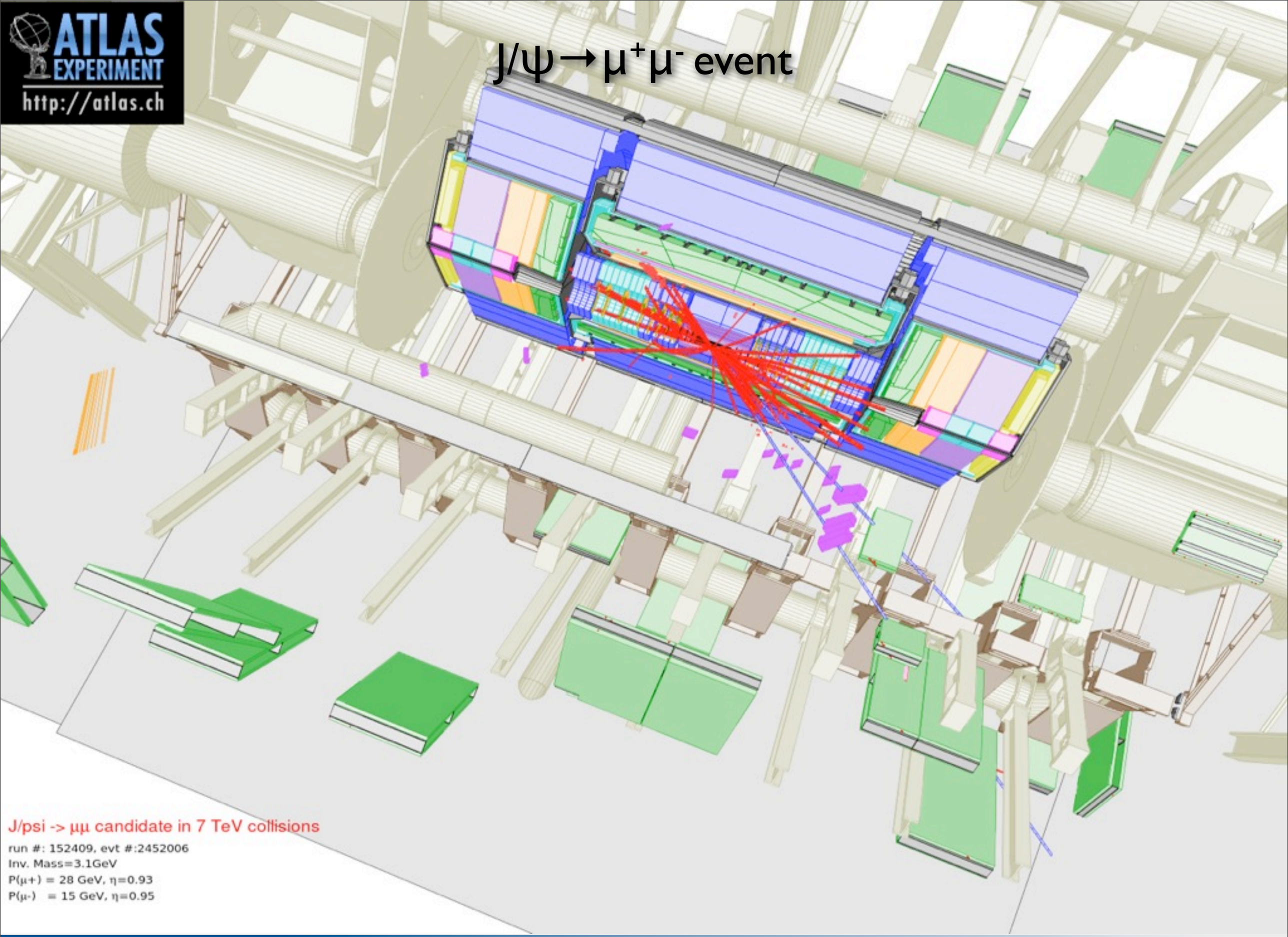
$J/\psi \rightarrow \mu^+\mu^-$ Selections

- Loose selections applied so to understand shape of background

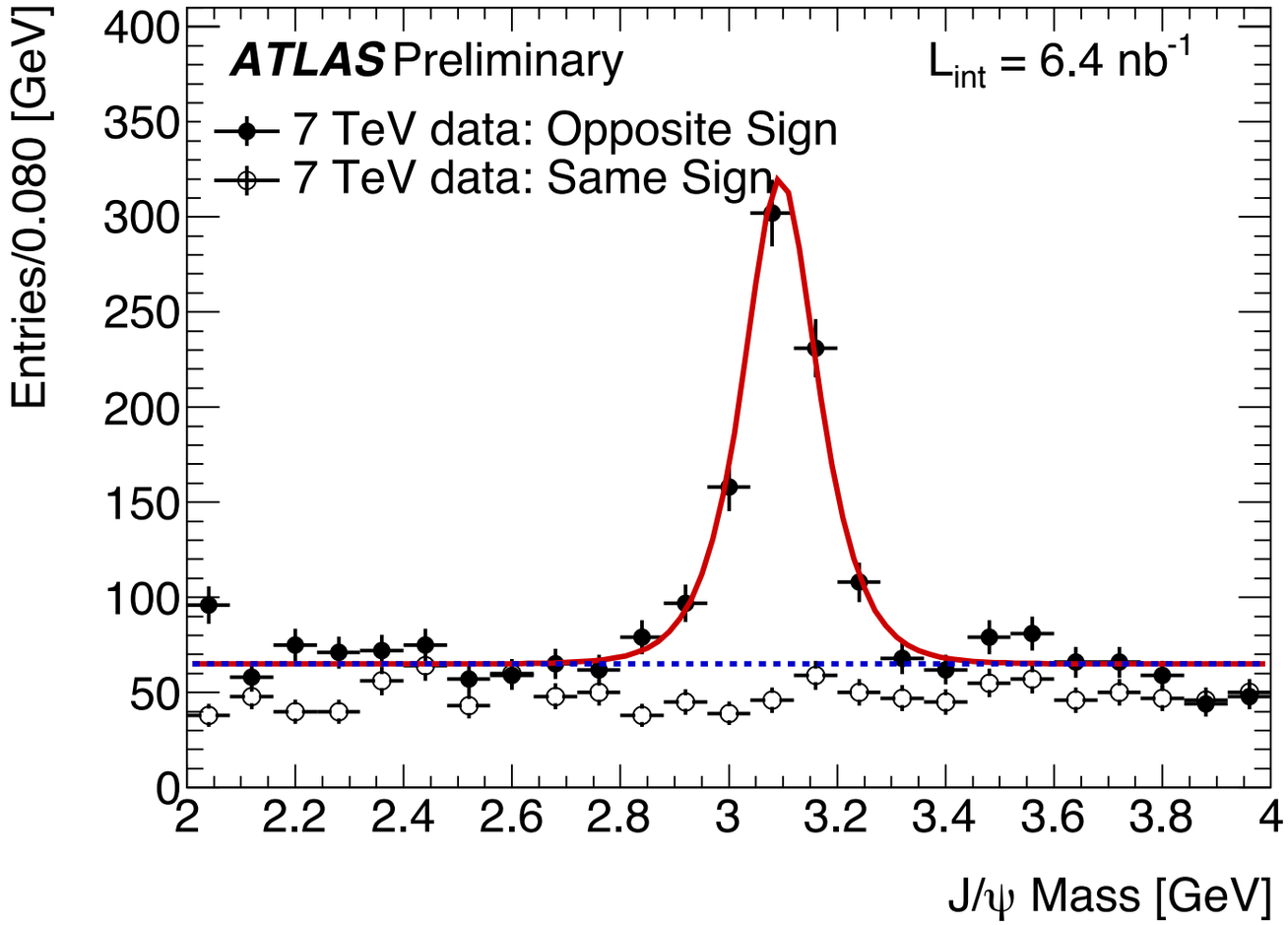
- **Trigger**
  - MBTS: 2 coincidence hits on either side of detector
  - Muon activity in MS found by the muon trigger
- **Collision events**
  - At least 3 tracks associated with same primary vertex
  - Track quality: At least 1 hit in the pixel detector; At least 6 hits in semiconductor tracker (SCT)
  - ID track reconstruction applies p_T>0.5 GeV cut to all ID tracks
- **Muons**
  - Each muon has ID track with the aforementioned track quality cuts
  - At least one "tight" muon
- **Common vertex fit + opposite sign**
- **Mass region 2-4 GeV**

- $J/\psi \rightarrow e^+e^-$: See Thursday talk, N. Kreschen

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



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



Data
7 TeV runs March 30th - May 17th 2010 $\int \mathcal{L}$ = **6.4±1.3 nb^{-1}** after data quality selections

	Before vertexing	After vertexing
N_{sig}	612±34	612±34
N_{bck}	351±10	332±9
mass [GeV]	3.095±0.004	3.096±0.004
σ_m [MeV]	82±7	82±7

- Improvements from vertexing not expected at this stage. Most data coming from primary vertex
  - Background reduced by ~6%

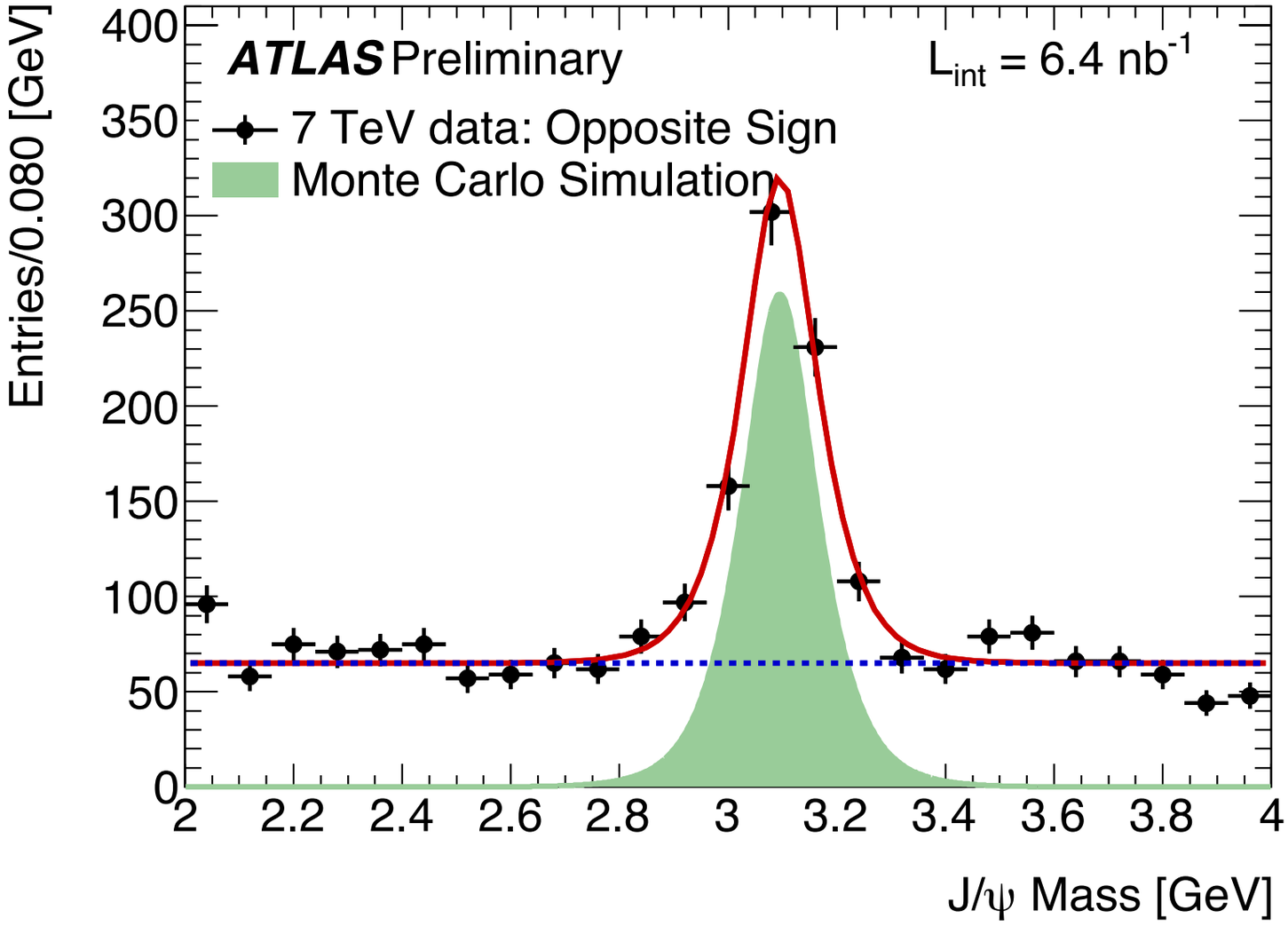
- Invariant-mass distribution of same-sign and opposite-sign muons pairs after vertexing
- Smaller same-sign than opposite-sign
  - Same/opposite-sign: expected contributions from combinatorial b/g, π/K decays in flight
  - Opposite-sign side-bands: expected additional contributions from heavy flavor decays

$J/\psi \rightarrow \mu^+\mu^-$ data/MC

- **J/ψ signal** compared to **J/ψ MC**
  - J/ψ MC normalized to J/ψ signal
- Unbinned event-by-event maximum-likelihood fit applied to both **data** and **J/ψ MC** sample
- Mass width in agreement with MC

- N_{sig}, N_{bck} defined in 3σ region around J/ψ mass

N_{sig}	612±34
N_{bck}	332±9
mass [GeV]	3.095±0.004
σ_m [MeV]	82±7
MC σ_m [MeV]	74±0.4

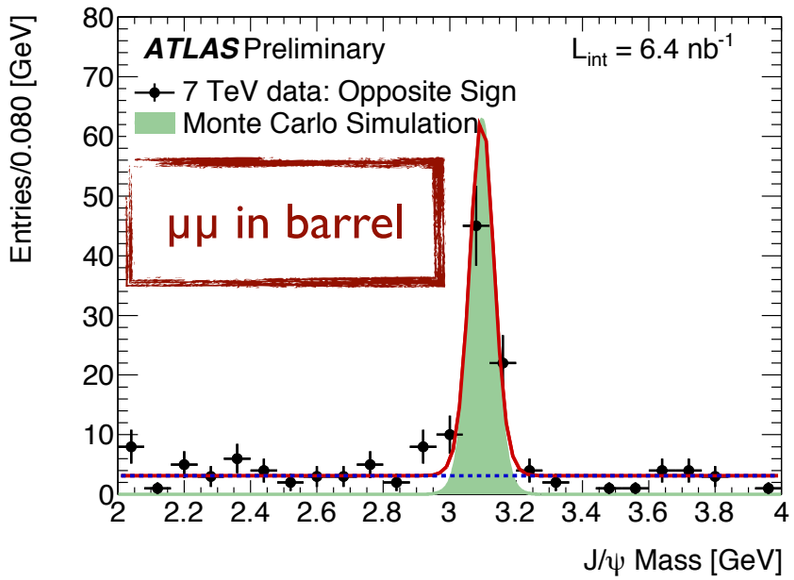


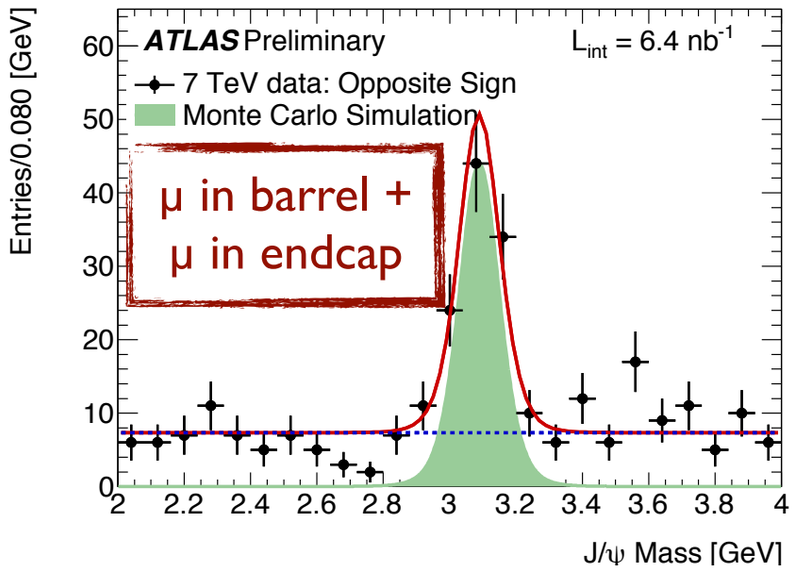
J/ψ mass resolution

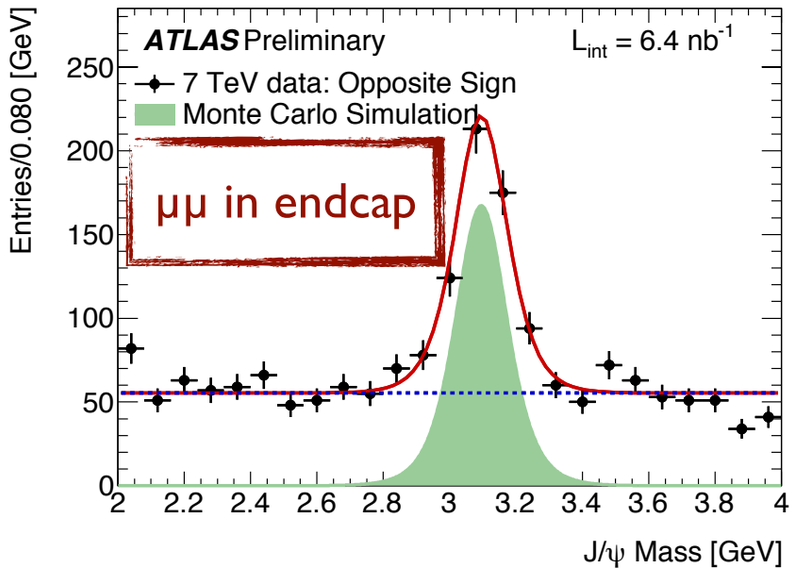
- Mass resolution affected by ID resolution which is different in barrel and endcap
- Illustrated by dividing J/ψ candidates to regions
  - 2 muons in barrel (|η|<1.05) (BB)
  - 1 muon in barrel, 1 muon in endcap (EB)
  - 2 muons in endcap (1.05<|η|<2.5) (EE)

	BB	EB	EE
N_{sig}	69±9	88±11	437±31
N_{bck}	8±1	34±3	324±10
mass [GeV]	3.097±0.005	3.089±0.008	3095±0.006
σ_m [MeV]	36±6	66±12	88±9
MC σ_m [MeV]	37±0.7	53±0.8	82±0.5

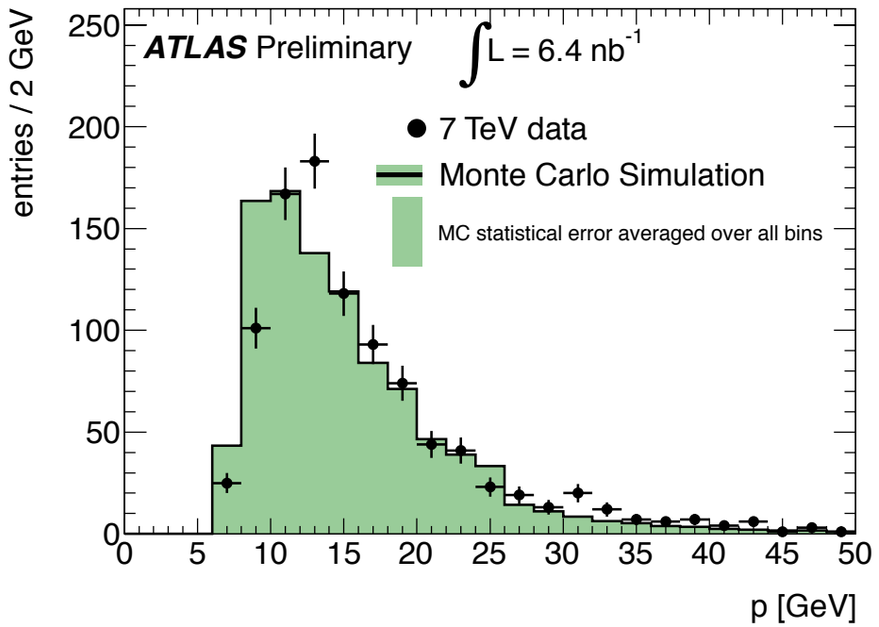
- Most candidates in EE
- Results are in good agreement with MC simulation
  - Consequence of the work done with cosmic events and earlier collisions to attain good understanding of detector

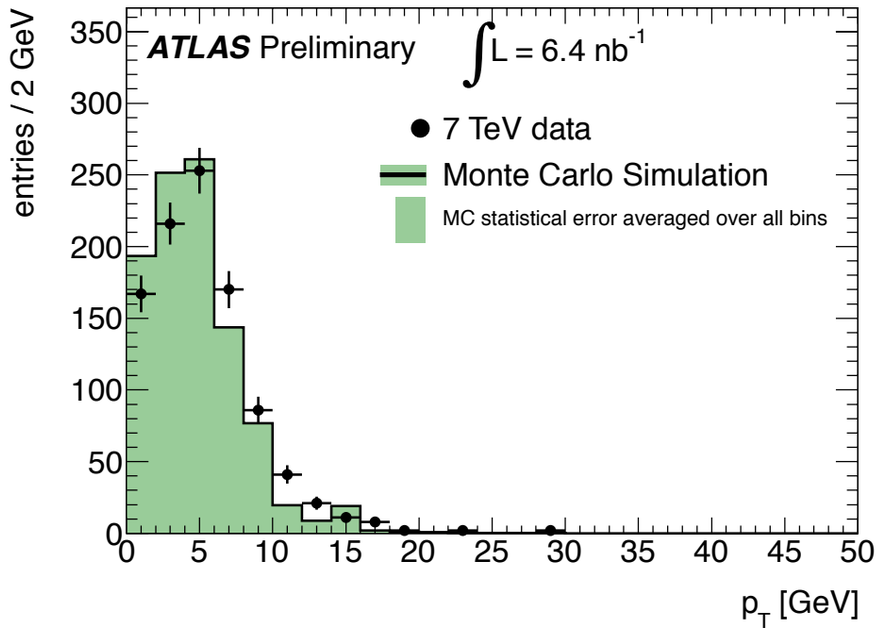


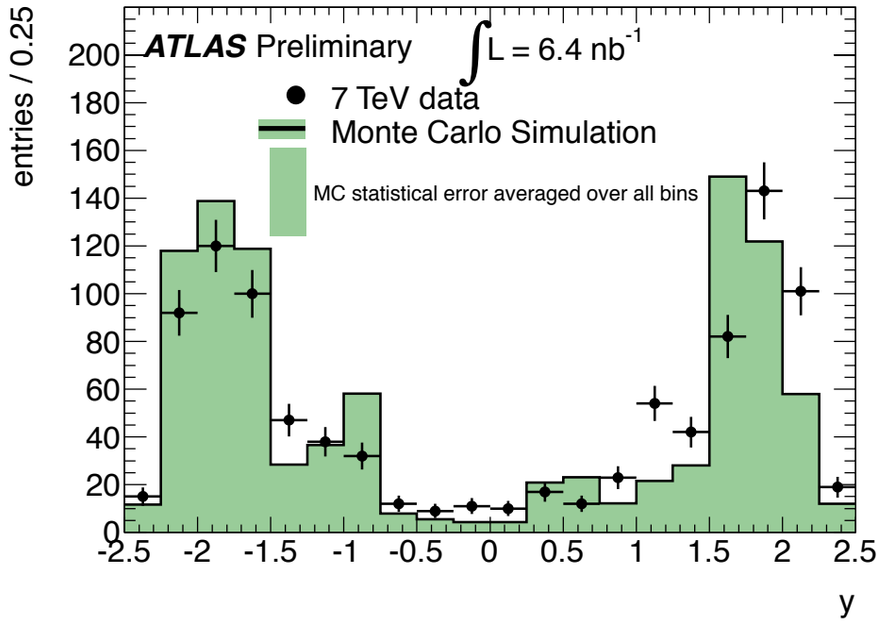


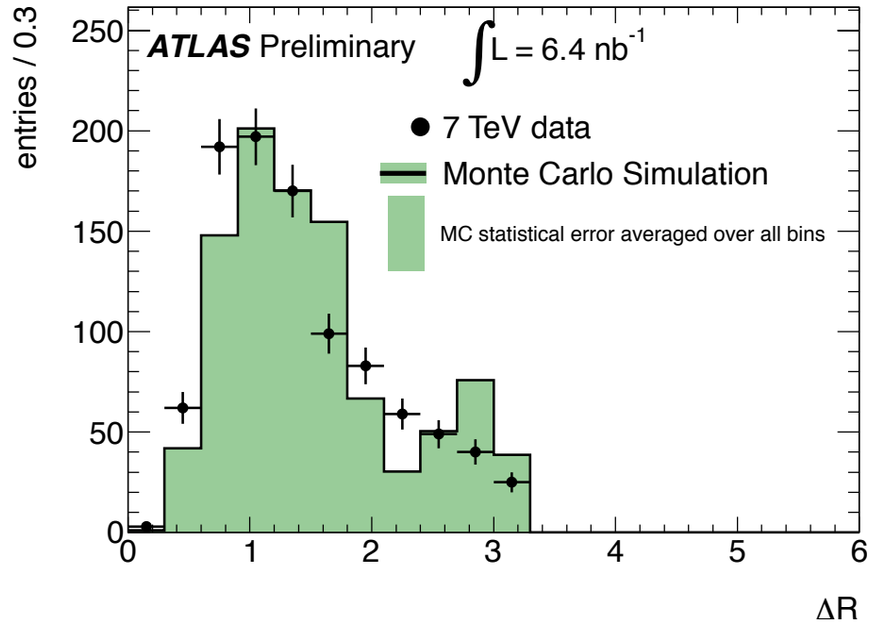


J/ψ kinematics









Candidates in mass region 2.86 – 3.34 GeV (±3σ)

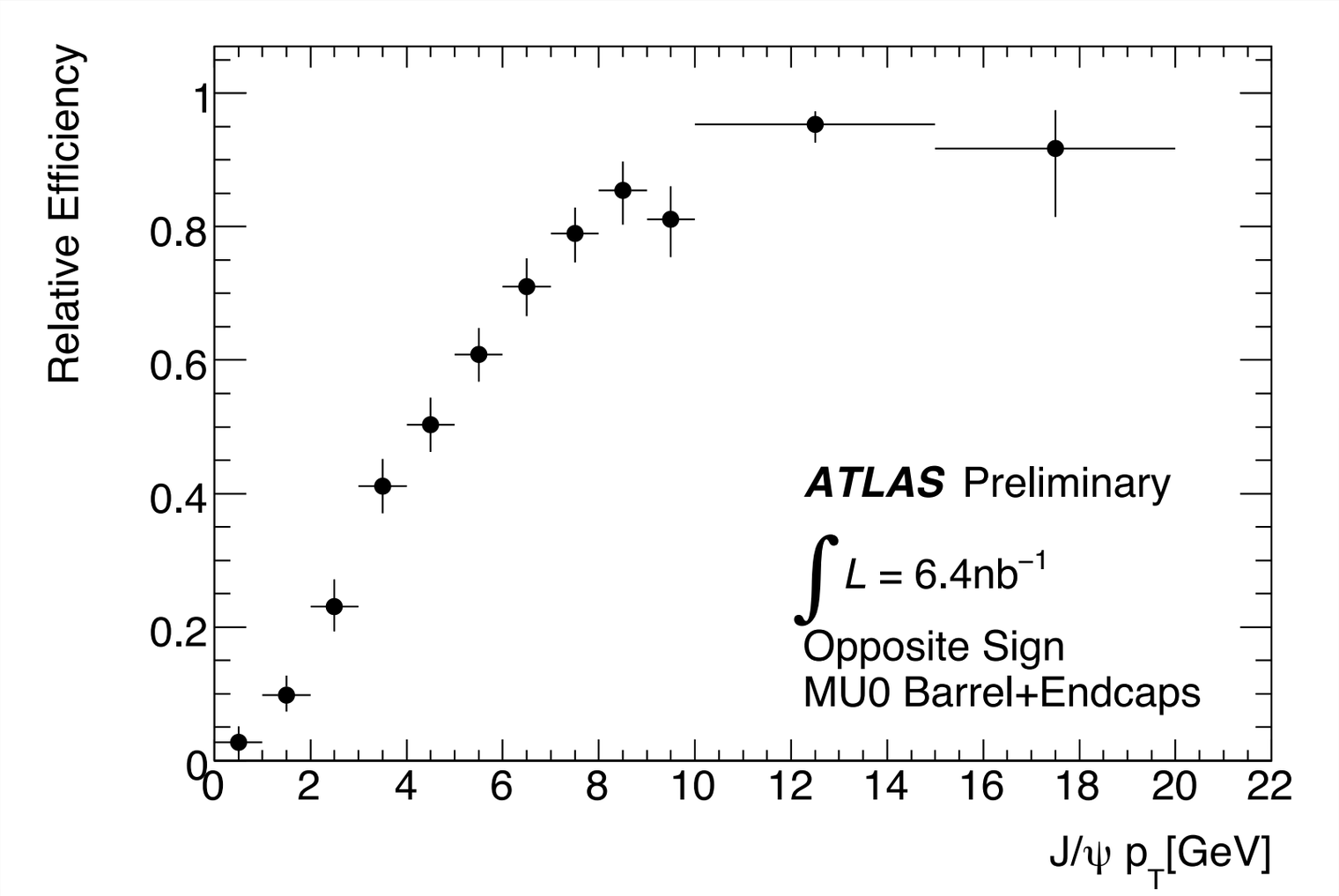
- Analysis mainly accesses very low pT J/ψs
- Sample is dominated by high rapidity J/ψs (p >> p_T)
- Low Statistics for Minbias MC - large fluctuations

MC

Composed of J/ψ signal and minimum bias b/g
Flat spin-alignment distribution assumed
MinBias: $\int \mathcal{L}$ = 0.4 nb^{-1}

Level-1 muon trigger

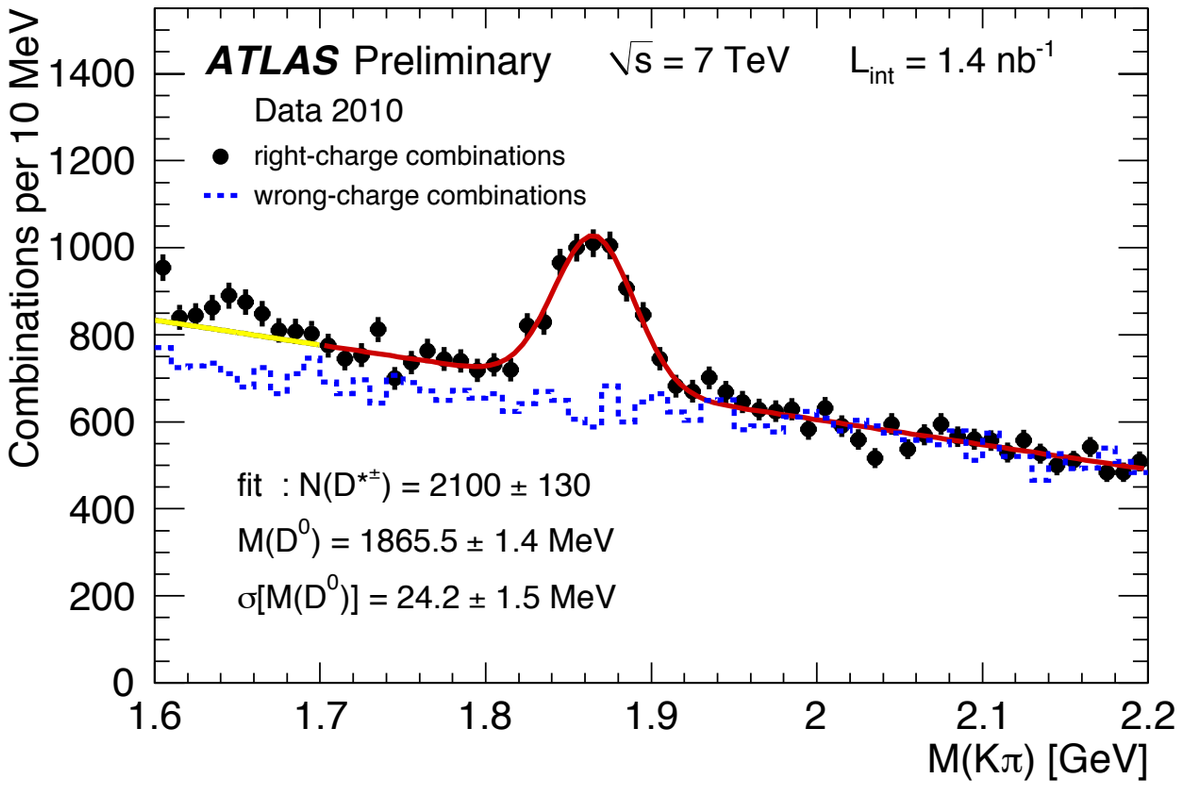
- Data collected using the Level-1 minimum bias trigger
  - Good for studying Level-1 muon trigger efficiency which will be used to select muons at higher luminosities
- Level-1 muon trigger: loose muon trigger - no p_T selection applied ("MU0")
- Efficiency of Level-1 muon trigger to select muons from J/ψ candidate
  - At least one muon matches the trigger within $\Delta R < 0.5$
- Possible to trigger on very low J/ψ p_Ts - important for polarization studies

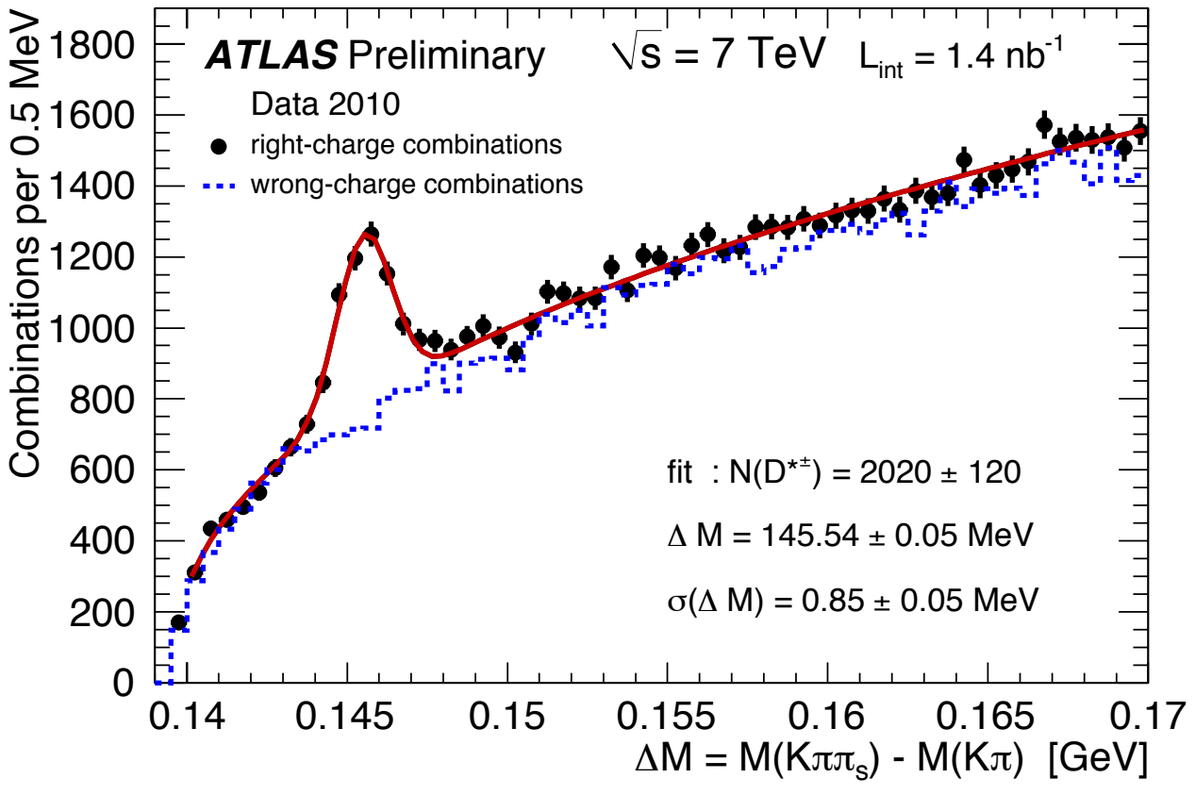


$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+)\ \pi_s^+$

- $D^{(*)}$ analysis using slightly smaller dataset than J/ψ
- Combine 2 opposite-sign tracks, assigning K/π masses for each tracking term
  - $p_T(K,\pi) > 1.0$ GeV
- Combine with a third track with assigned π mass
  - $p_T(\pi_s) > 0.25$ GeV
- M(Kπ)
  - D^{*+} candidates satisfying $144 < \Delta M < 147$ MeV: 2100 ± 130
- $\Delta M = M(K\pi\pi_s) - M(K\pi)$
  - D^{*+} candidates satisfying $1.83 < M(K\pi) < 1.90$ GeV: 2020 ± 120

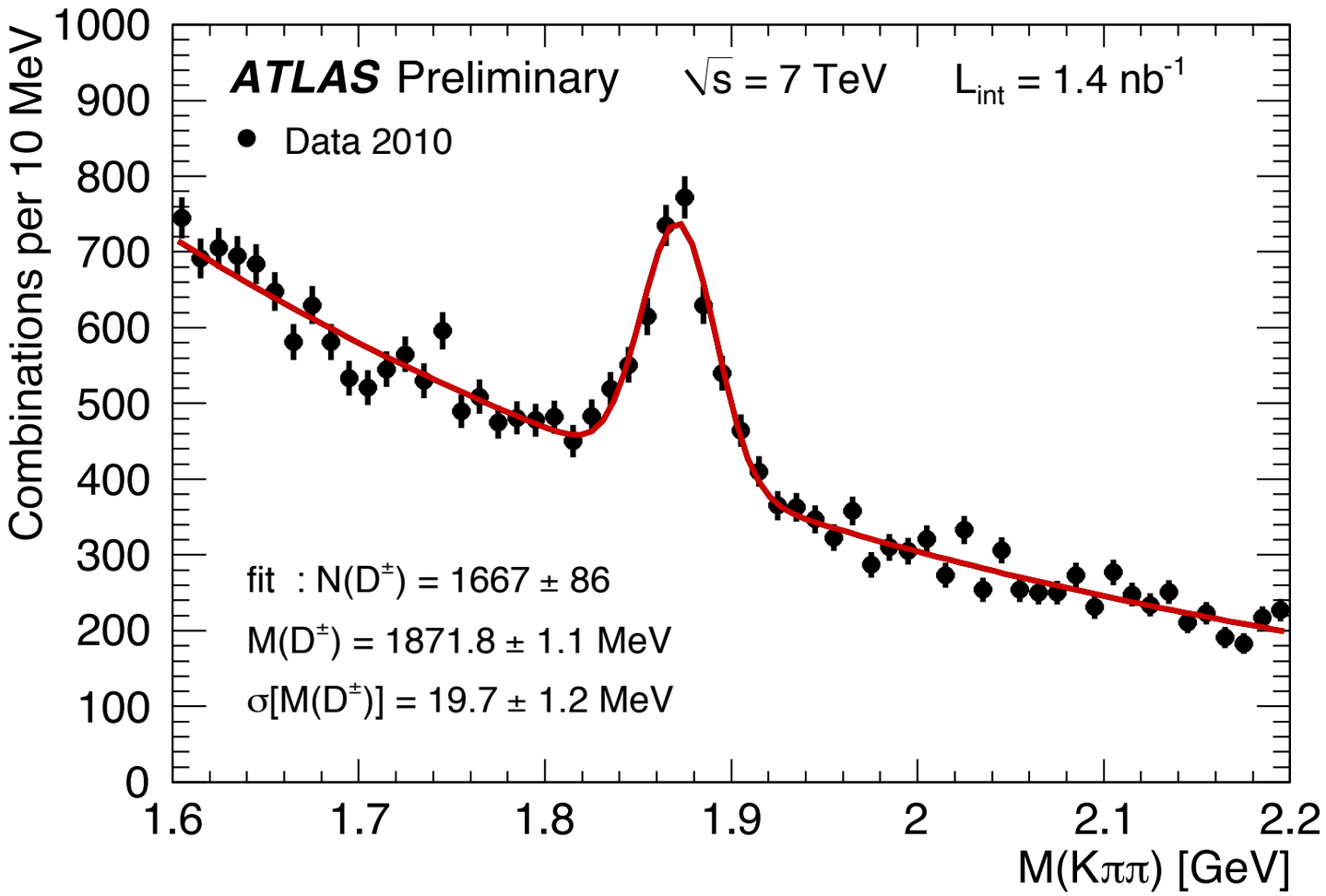
Data
7 TeV runs March 30th - May 2010 $\int \mathcal{L}$ = **1.4 nb^{-1}**
Primary Selections
$p_T(D^*) > 3.5$GeV $\lvert\eta(D^*)\rvert < 2.1$ Vertex $\chi^2 < 5$, $L_{xy}>0$ $p_T(D^*)/E_T > 0.02$





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

- 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 $D_s^+ \to \phi\pi+ \to (K^-K^+)\pi^+$ reflections:
  - remove $\Delta M_{1,2} < 150$ MeV to suppress D^{*+} and $|M(K^+K^-) - M(\phi)_{PDG}| < 8$ MeV to suppress D_s^+



Data

7 TeV runs
March 30th - May 2010
$\int \mathcal{L}$ = **1.4 nb^{-1}**

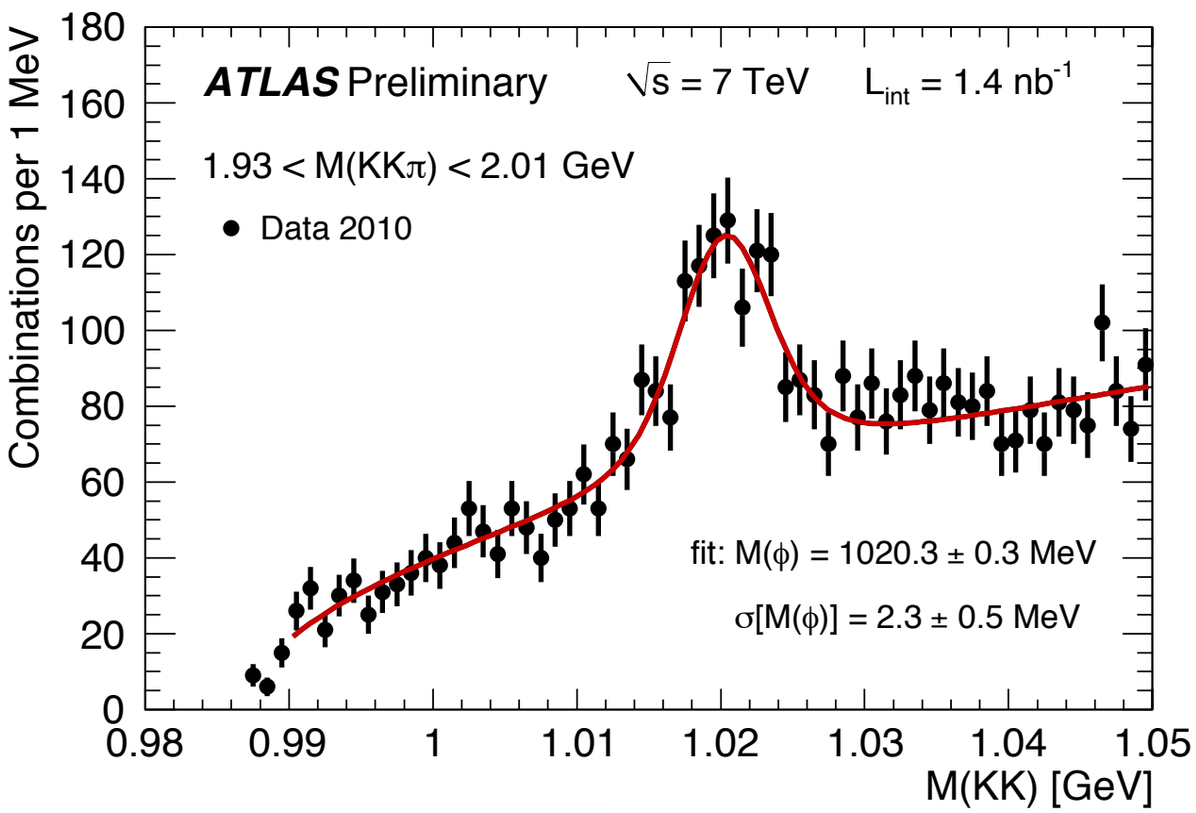
Primary Selections

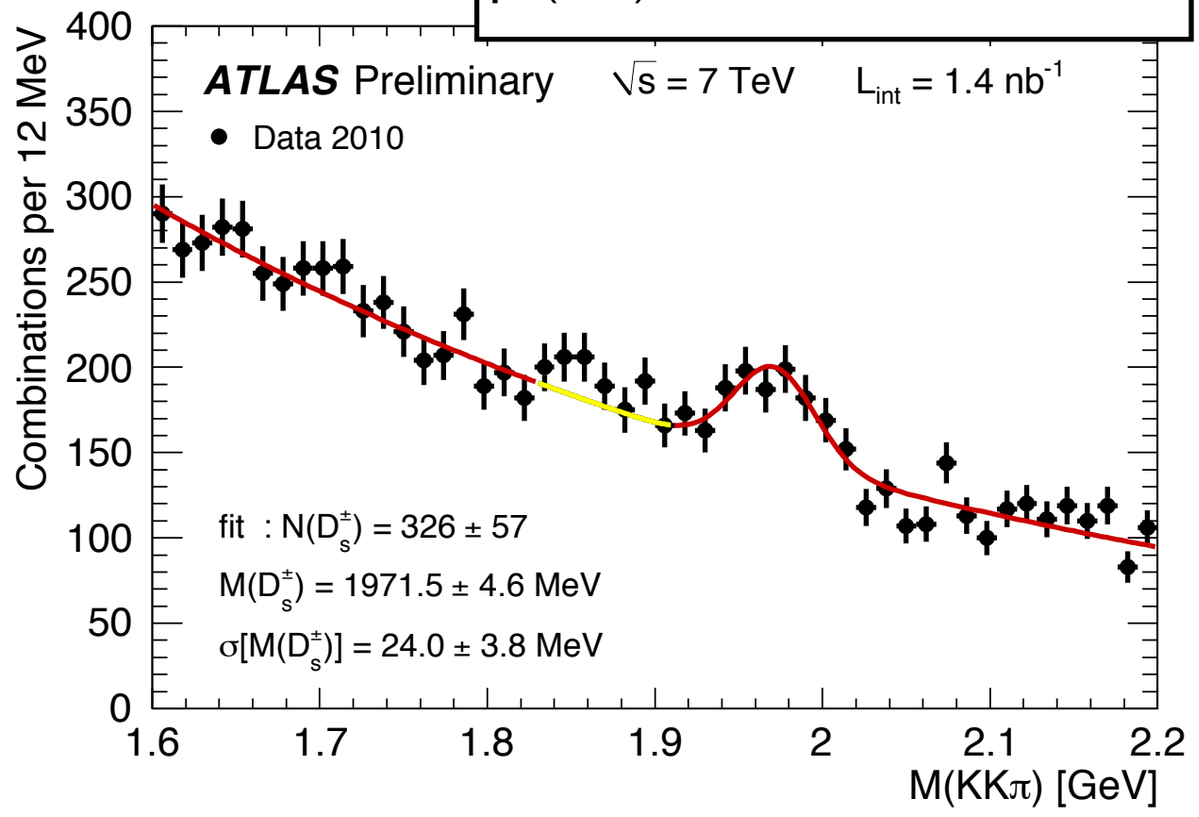
$p_T(D^+) > 3.5$GeV
$|\eta(D^+)| < 2.1$
$\cos\theta^*(K) > -0.8$
Vertex $\chi^2 < 6$, $L_{xy} > 1.3$mm
$p_T(D^+)/E_T > 0.02$

$D_s^+ \to \phi\pi^+ \to (K^-K^+)\pi^+$

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

Data
7 TeV runs March 30th - May 2010 $\int \mathcal{L}$ = **1.4 nb^{-1}**
Primary Selections
$p_T(D_s^+) > 3.5$GeV $\|\eta(D_s^+)\| < 2.1$ $\cos\theta^*(\pi) < 0.4$, $\|\cos^3\theta'(K)\| > 0.2$ Vertex $\chi^2 < 6$, L_{xy}>0.4mm $p_T(D_s^+)/E_T > 0.04$





Conclusions

- $J/\psi \rightarrow \mu^+\mu^-$ resonane observed in ATLAS data with $\int \mathscr{L}$ of 6.4±1.3 nb^{-1}
  - Mean in good agreement with the PDG table mass within statistical uncertainties
  - Mass resolution is consistent with MC expectations in all parts of the detector
  - Signal events: 612±34 over a background of 332±9

- Clear $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ signals reconstructed with the ATLAS detector with $\int \mathscr{L}$ of 1.4 nb^{-1}
  - $D^{*\pm}$: 2020±120
  - $D^{\pm}$: 1667±86
  - $D_s^{\pm}$: 326±57
  - Position in agreement with PDG value

- Confirm high performance of ATLAS detector for precision measurement

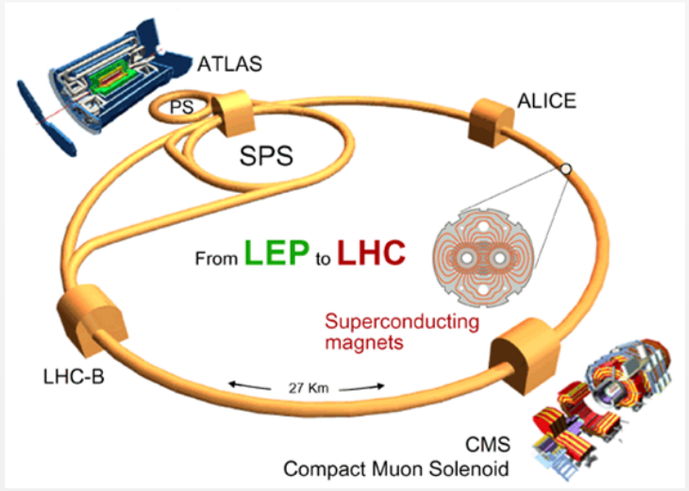
- In short term future
  - Ratio measurement: prompt J/ψ to non-prompt J/ψ
  - J/ψ cross section measurement
  - J/ψ polarization measurement
  - Exclusive b decays
  - D measurement
  - b**b** and c**c** separation

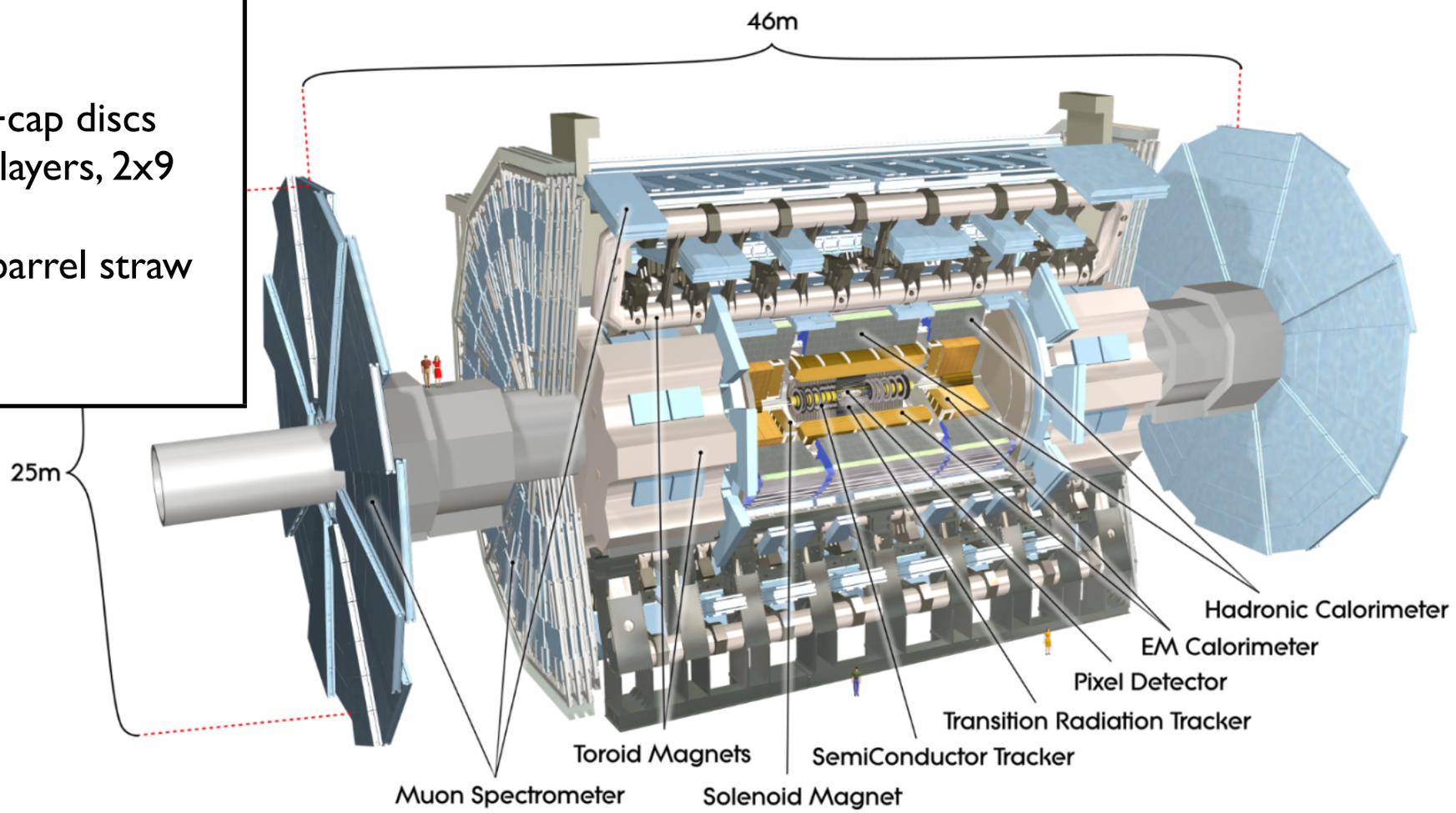
Backup slides

ATLAS

Inner Detector

$|\eta|<2.5$
$50.5mm < R < 1066mm$
2 Tesla
Pixel Detector: 3 barrel layers, 2x3 end-cap discs
Semiconductor Tracker (SCT): 4 barrel layers, 2x9 end-cap discs
Transition Radiation Tracker (TRT): 73 barrel straw layers and 2x160 end-cap radial layers





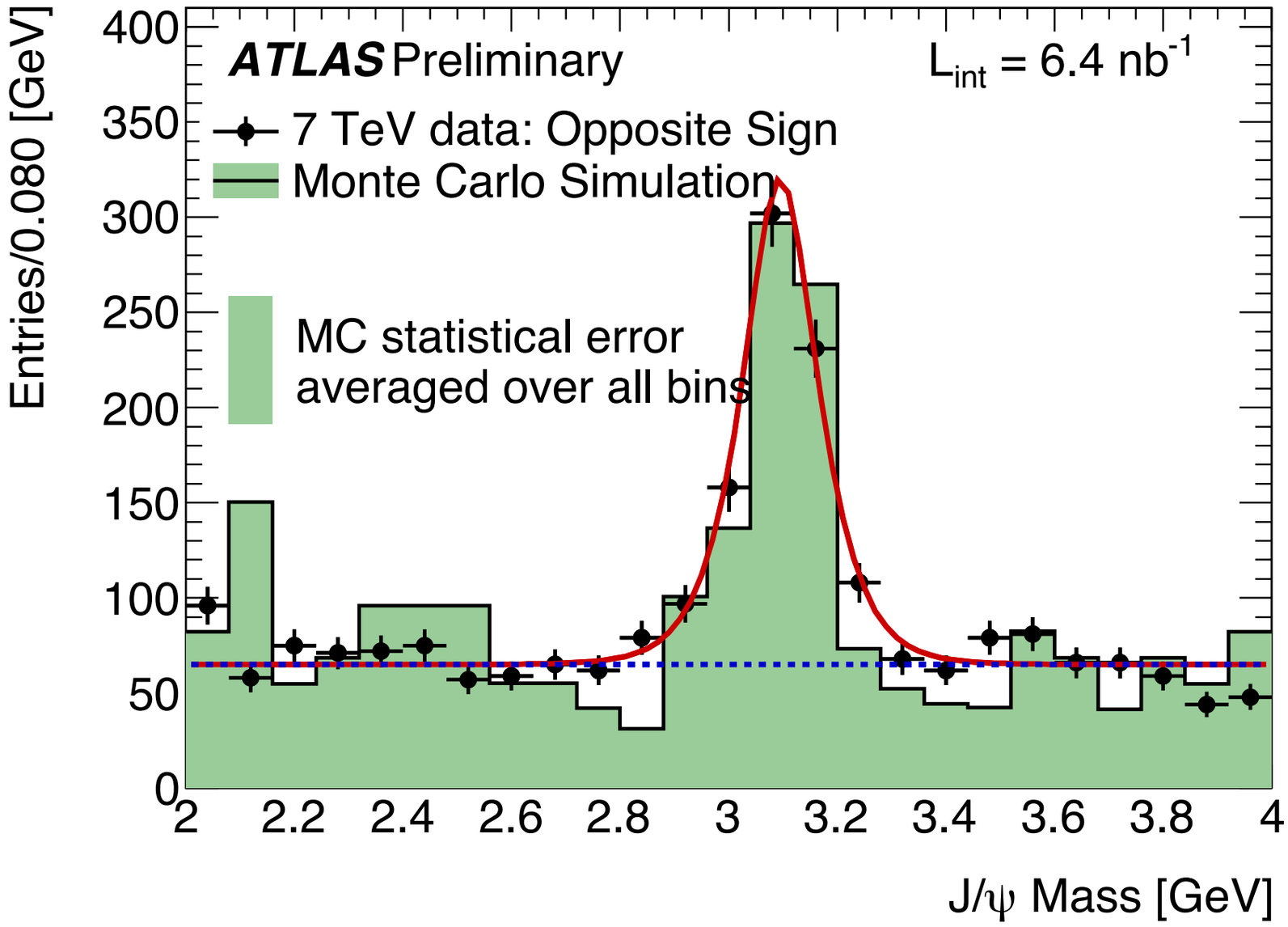
Muon Spectrometer

$|\eta|<2.7$
0.5 Tesla average
Barrel: MDTs, RPCs
Endcap: MDTs, CSCs, TGCs

Tracking

- See Monday talk: Peformance of muon identification and reconstruction in ATLAS
- Muon reconstruction software uses ID and MS tracks
  - Standalone Muons: MS-only reconstructed track extrapolated to IP
  - Combined Muons: Statistical combination of the ID and MS tracks
  - Tagged Muons: ID track with a track segment in MS

$J/\psi \rightarrow \mu^+\mu^-$ signal (MC: Minbias + J/ψ)

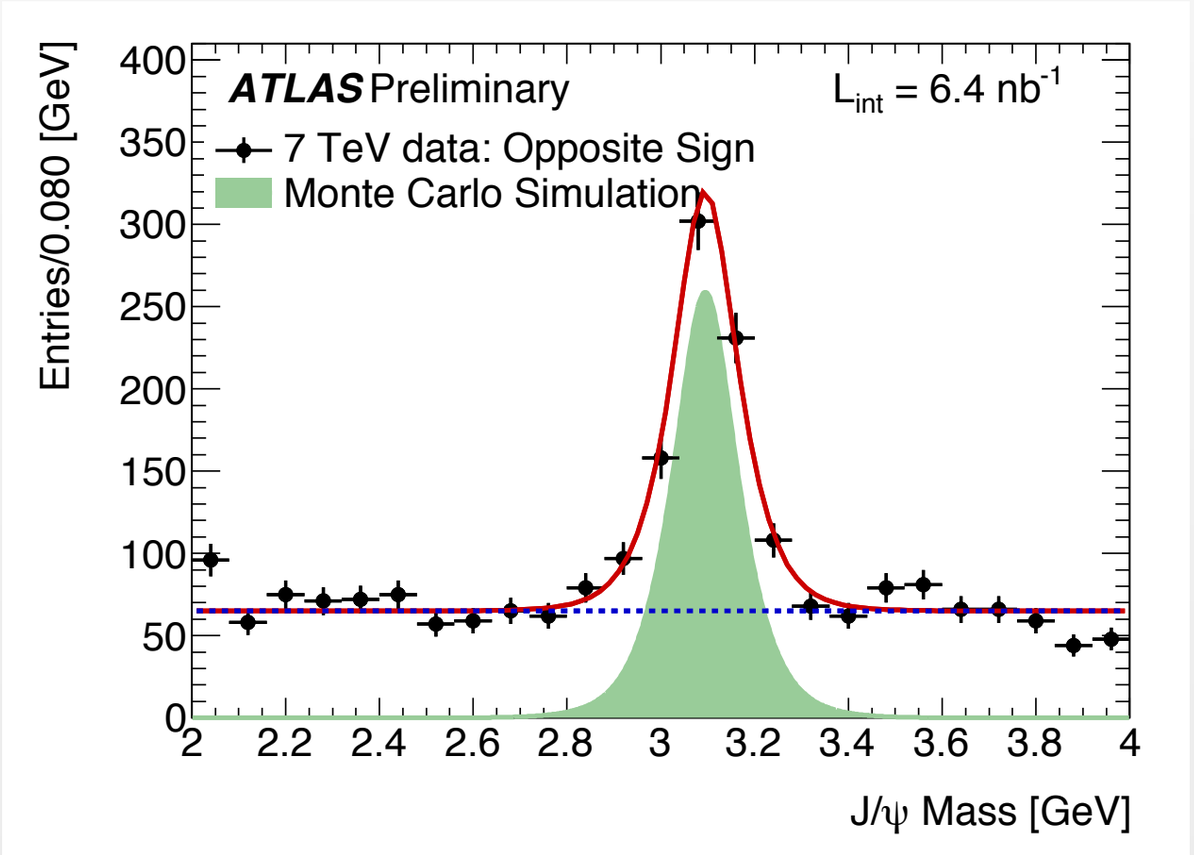


MC

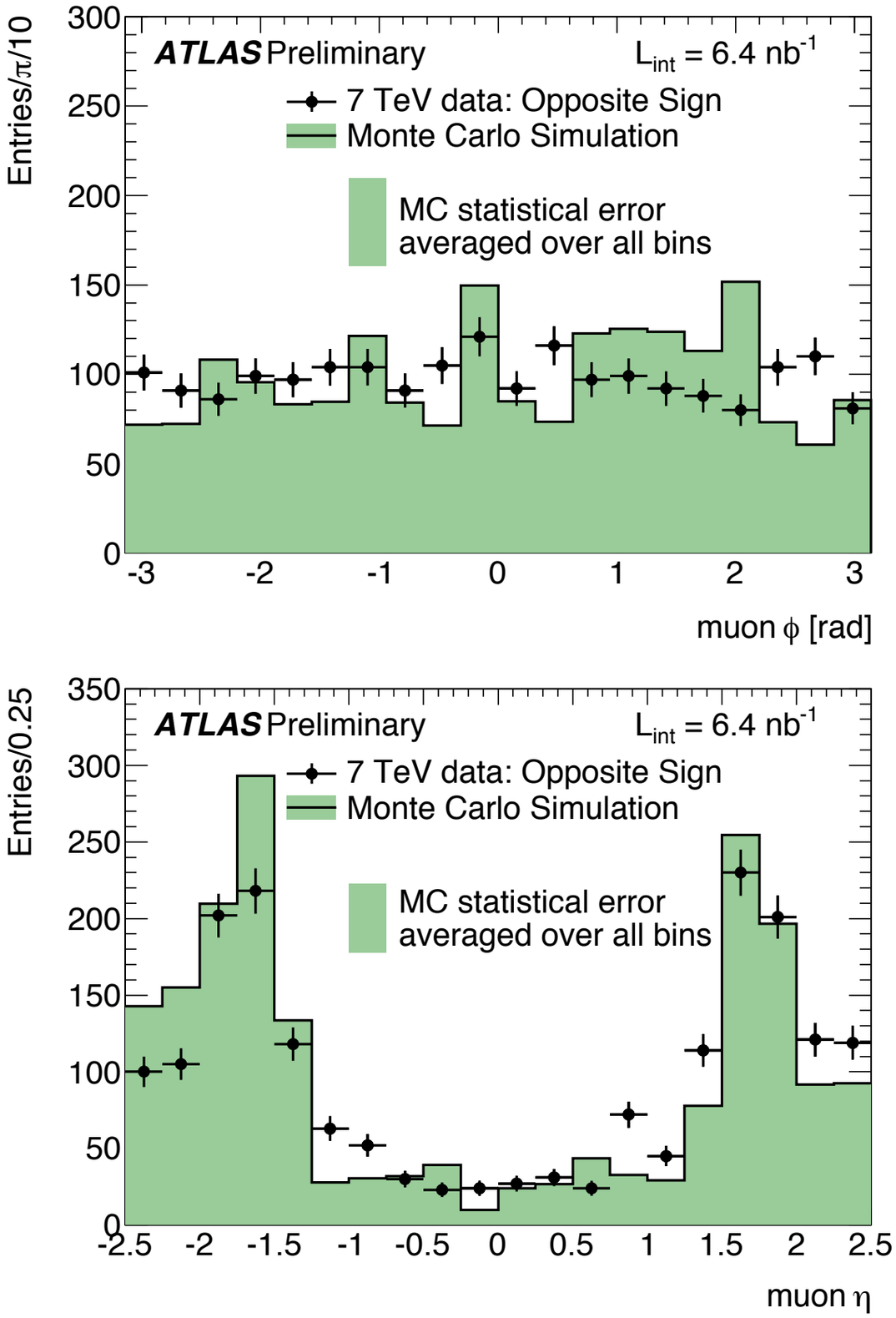
Composed of J/ψ signal and a minimum bias b/g
Flat spin-alignment distribution assumed
MinBias: $\int \mathcal{L}$ = 0.4 nb^{-1}

Event-by-event Maximum Likelihood

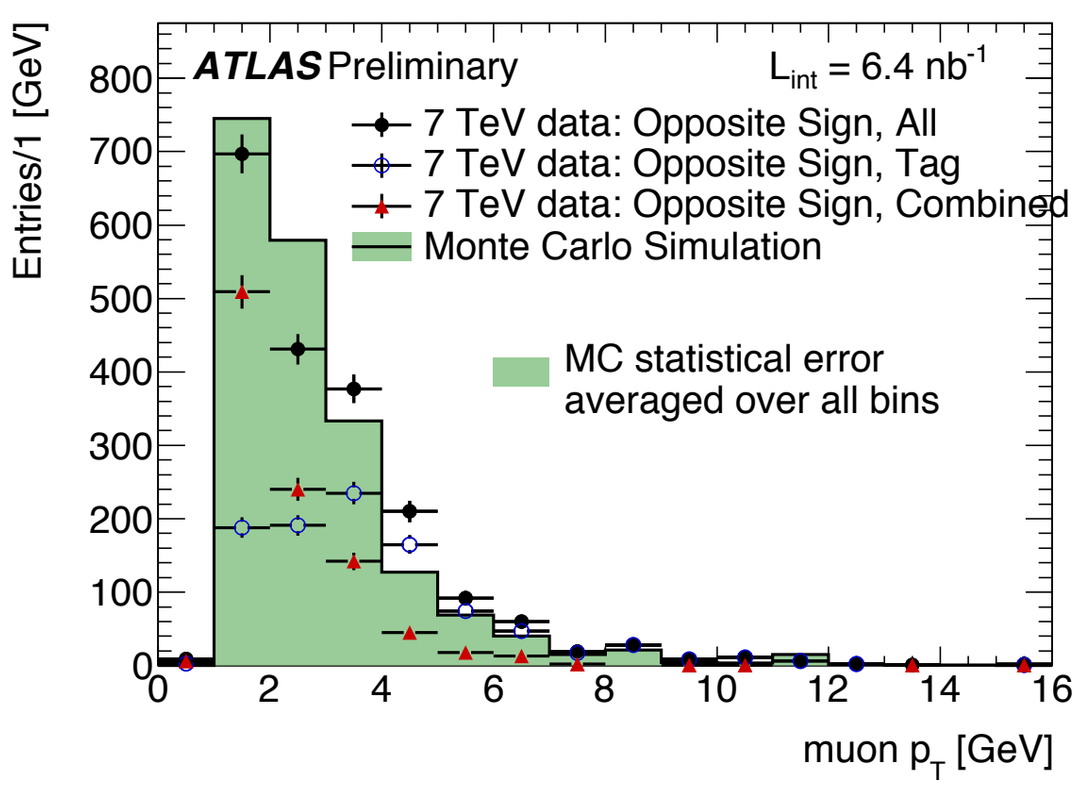
- Likelihood function: $L = \prod_{i=1}^{N} f_{signal}(m^i_{\mu\mu}) + f_{bkg}(m^i_{\mu\mu})$
- Signal function: $f_{signal}(m_{\mu\mu}) \equiv a_0 \frac{1}{\sqrt{2\pi}\, S\, \delta m_{\mu\mu}} e^{\frac{-(m_{\mu\mu}-m_{J/\psi})^2}{2(S\delta m_{\mu\mu})^2}}$
- Background function: $f_{bkg}(m_{\mu\mu}) \equiv (1 - a_0)$
- S, a_0, $m_{J/\psi}$ free fit parameters
- σ_m calculated by interval for which integral f_{signal} retains 68.27% of N_{sig}



J/ψ muons kinematics



	Combined+ Combined	Combined+ Tagged
Data	27±2.7%	73±5.6%
MC	31±0.3%	69±0.5%

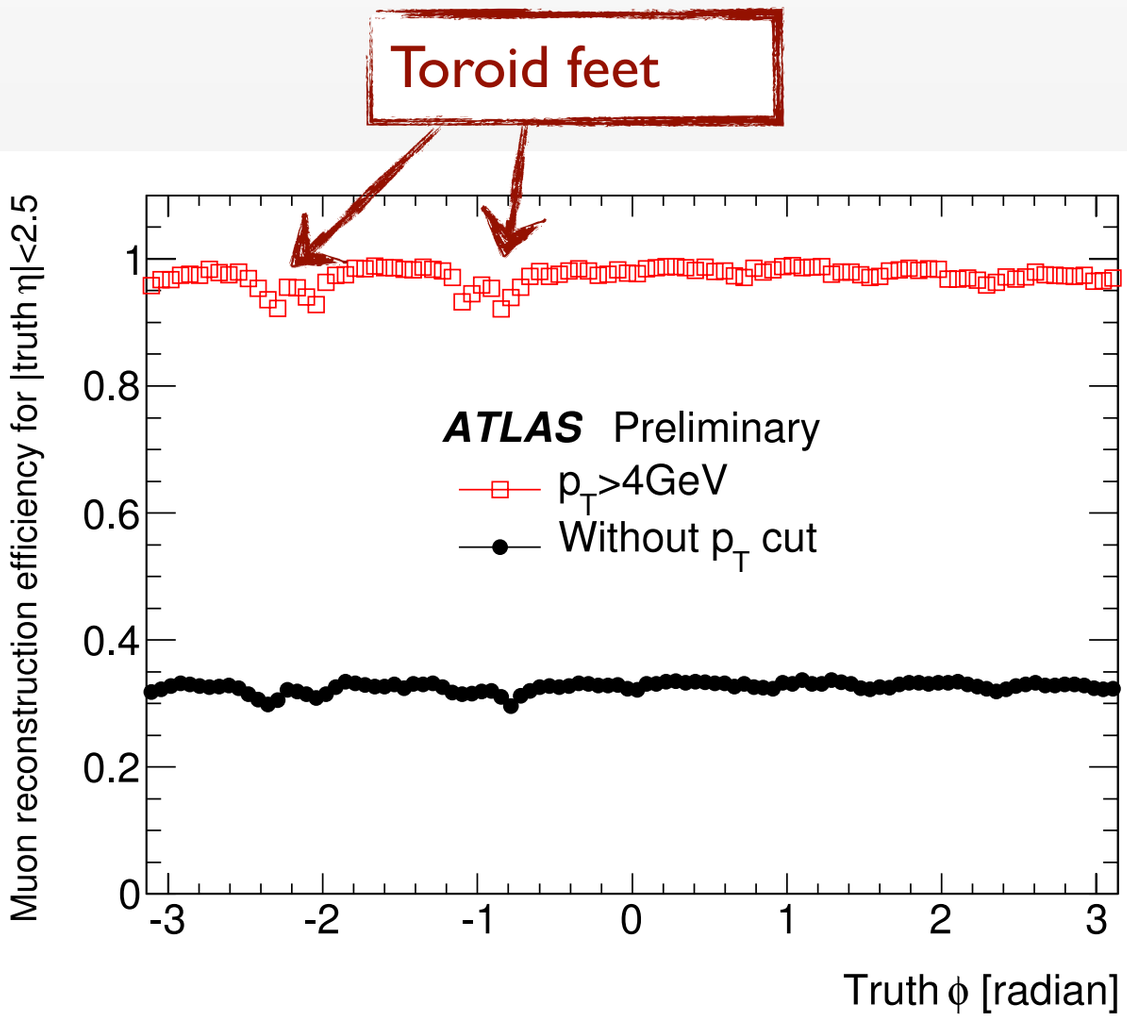


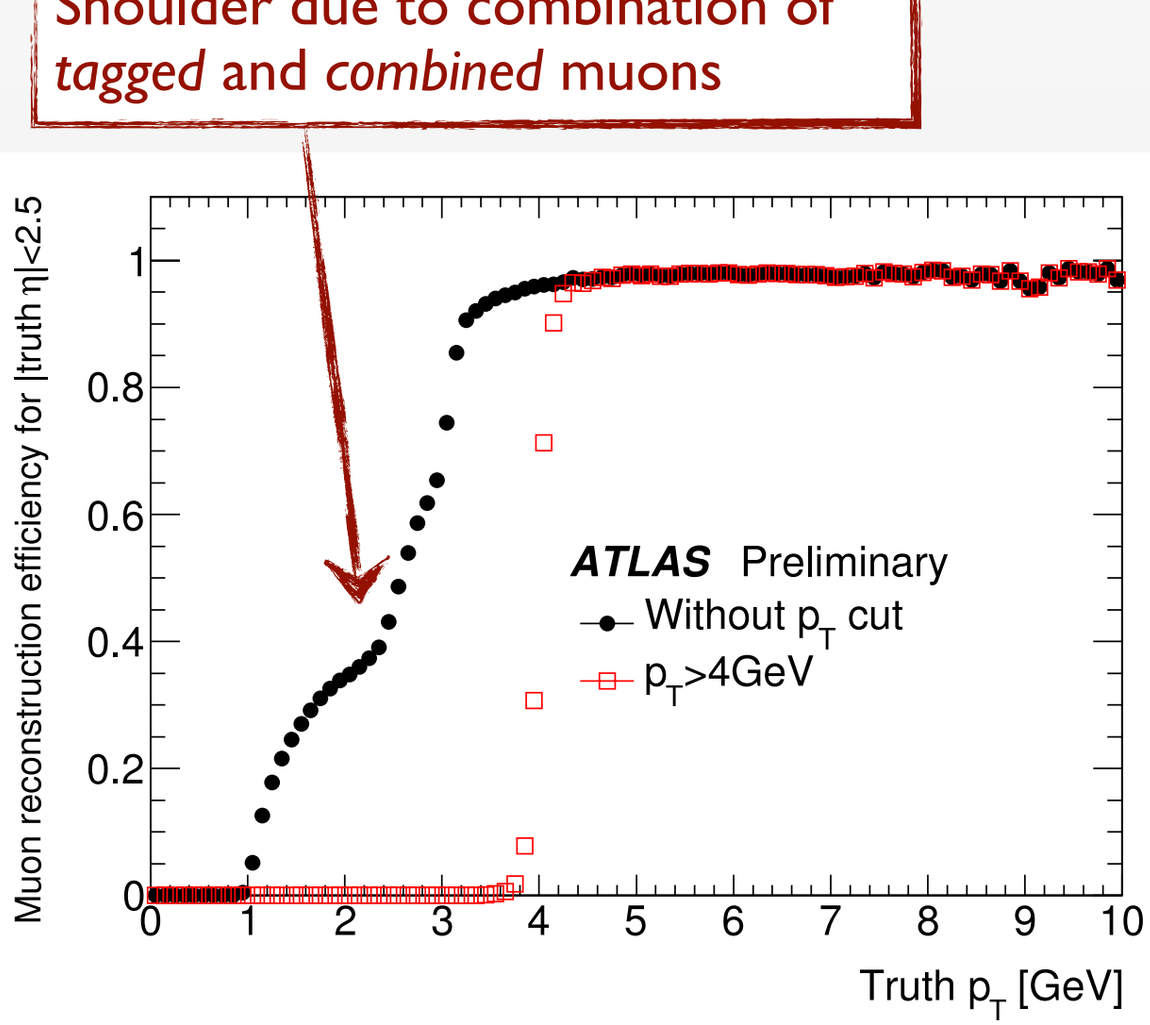
J/ψ muons reconstruction efficiency [MC]

- Reconstruction efficiency calculated in MC, compared to true muon
  - Both for no p_T cut and p_T > 4 GeV (lowest trigger)
- *Tagged* muons peak at 2 GeV, *combined* peak at ~3 GeV
  - See Monday talk: Peformance of muon identification and reconstruction in ATLAS

Toroid feet

Shoulder due to combination of *tagged* and *combined* muons

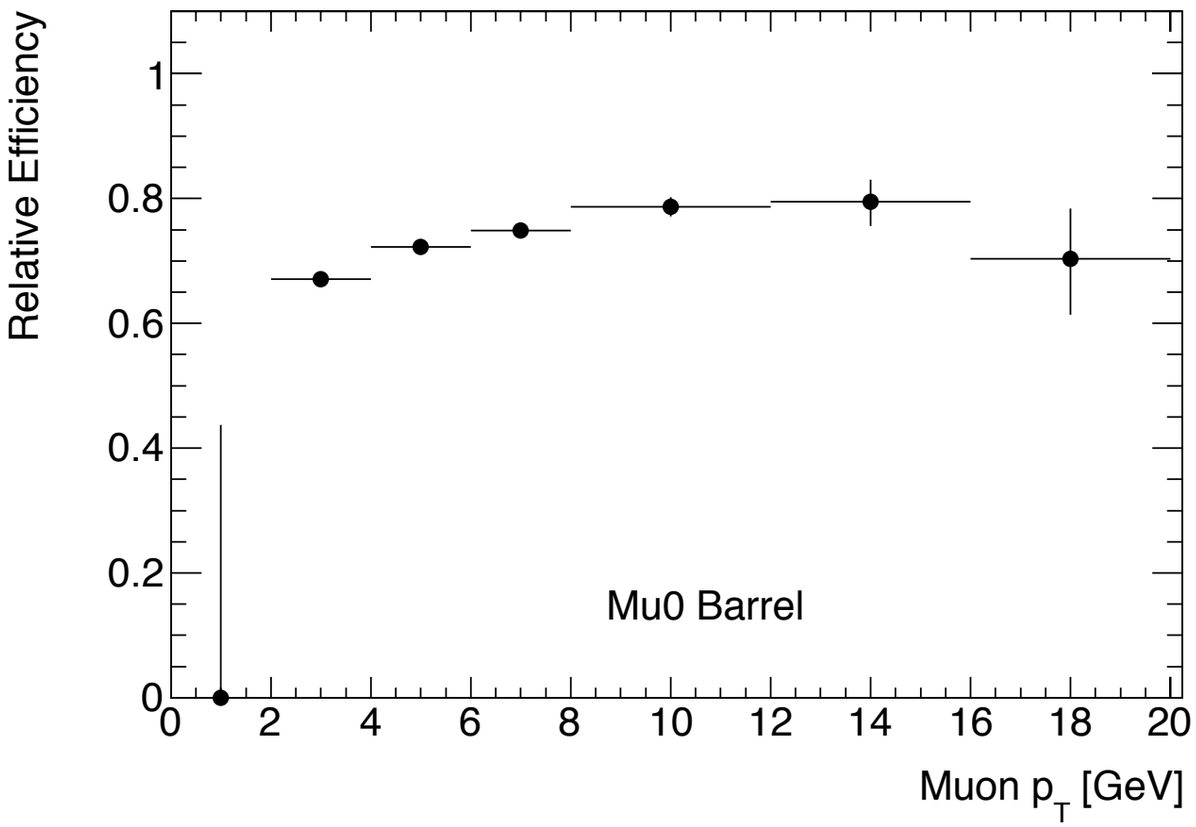




Level-1 muon trigger [RPC/TGC]

- Level-1 muon trigger efficiency (relative to offline reconstruction)
  - Using all prompt muons (in agreement with J/ψ muons)
  - *Combined* muons
  - Matching done with $\Delta R(\mu_{trigger}, \mu_{offline}) < 0.5$

RPC Level-1 efficiency



TGC Level-1 efficiency