Beauty 2001
Amsterdam, April 6 2011

Dimuon Reconstruction for B Physics in ATLAS

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on behalf of the ATLAS collaboration

Outline

- The Atlas detector
- Muon reconstruction and performances
- Muon triggers for B physics
- Dimuon spectra
- Dimuon composition
- Conclusions

B-physics at Atlas with dimuons

B-cross section at LHC is large: $\sigma(b\bar{b})=O(0.3\text{ mb})$
but backgrounds are large too: $\sigma(tot)=O(50\text{ mb})$
-> need to trigger/select clean signatures: <u>dimuons</u>

Goals, roughly in order of increasing luminosity:

- Detector performance studies exploiting J/ψ signals
  -> resolution, energy scale, efficiency, characterisation of backgrounds

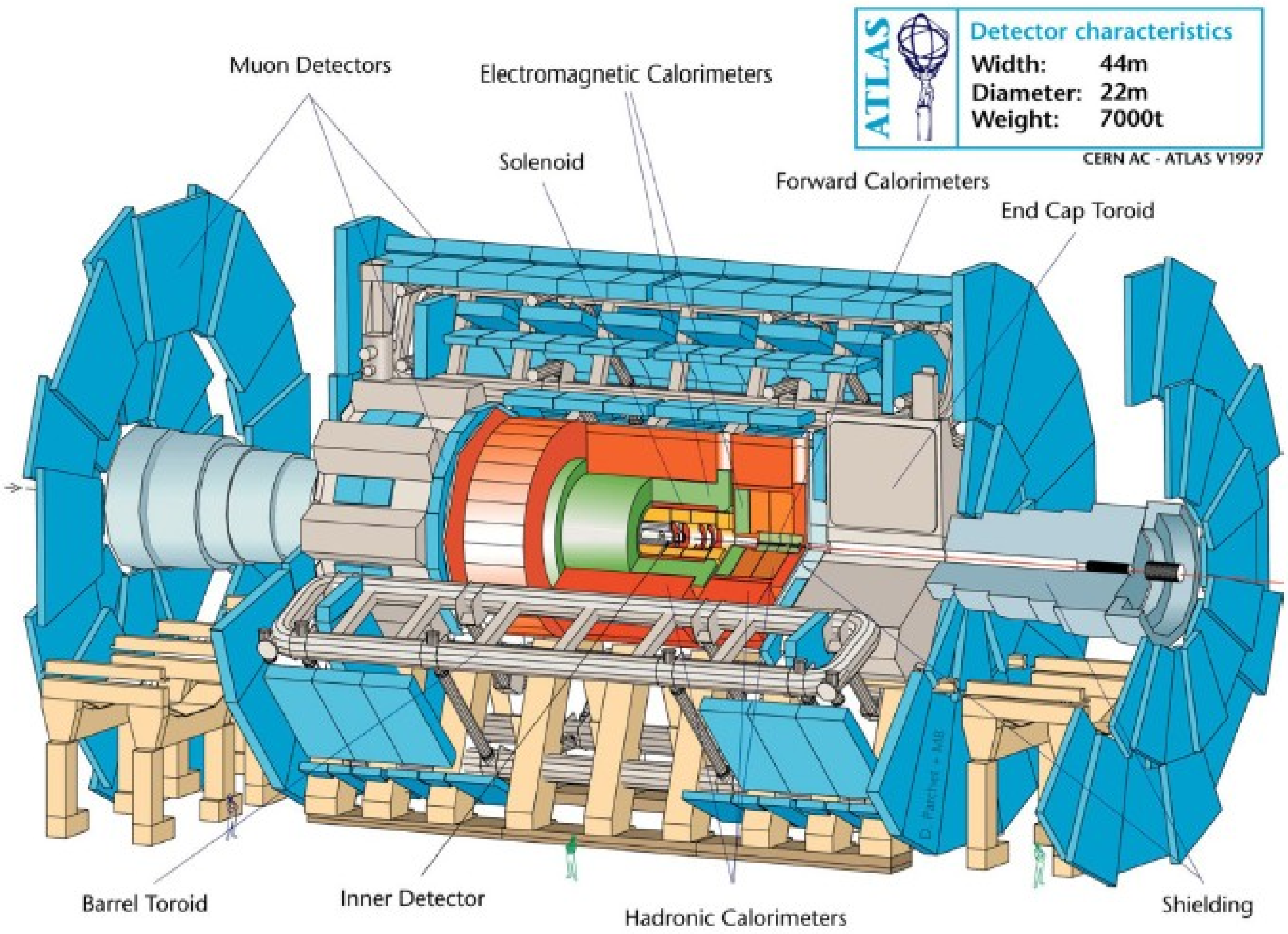
- Production cross sections:

You are here → prompt J/ψ, open B from B->J/ψ X
  exclusive B-hadrons, ψ', Y

- B hadron properties: lifetimes, BR, fragmentation, masses, polarisation

- CP violation, rare decays

The ATLAS detector



- ID: inner detector
  Silicon pixels+strips
  + transition radiation tracker
  $|\eta|<2.5$ Solenoid B~2 T
  $\sigma(d0)\sim 10\mu m$ (high p_T)
  $\sigma(q/p)\sim 1.5\%$ (low p_T)

- EM calorimeters
  Pb-Liquid Argon $|\eta|<3.2$
  $\sigma(E)/E\sim 10\%/\sqrt{E}$

-Hadronic calorimeters
  Fe+Scintillator $|\eta|<1.5$
  Pb+LAr $1.5<|eta|<3.2$
  $\sigma(E)/E\sim 50\%/\sqrt{E}$
  W/Cu-LAr $3.2<|eta|<4.9$

- MS: Muon System
  $|\eta|<2.7$ Toroids B*L=4-5 Tm
  $\sigma(p)/p\sim 4\%$ (high p_T)

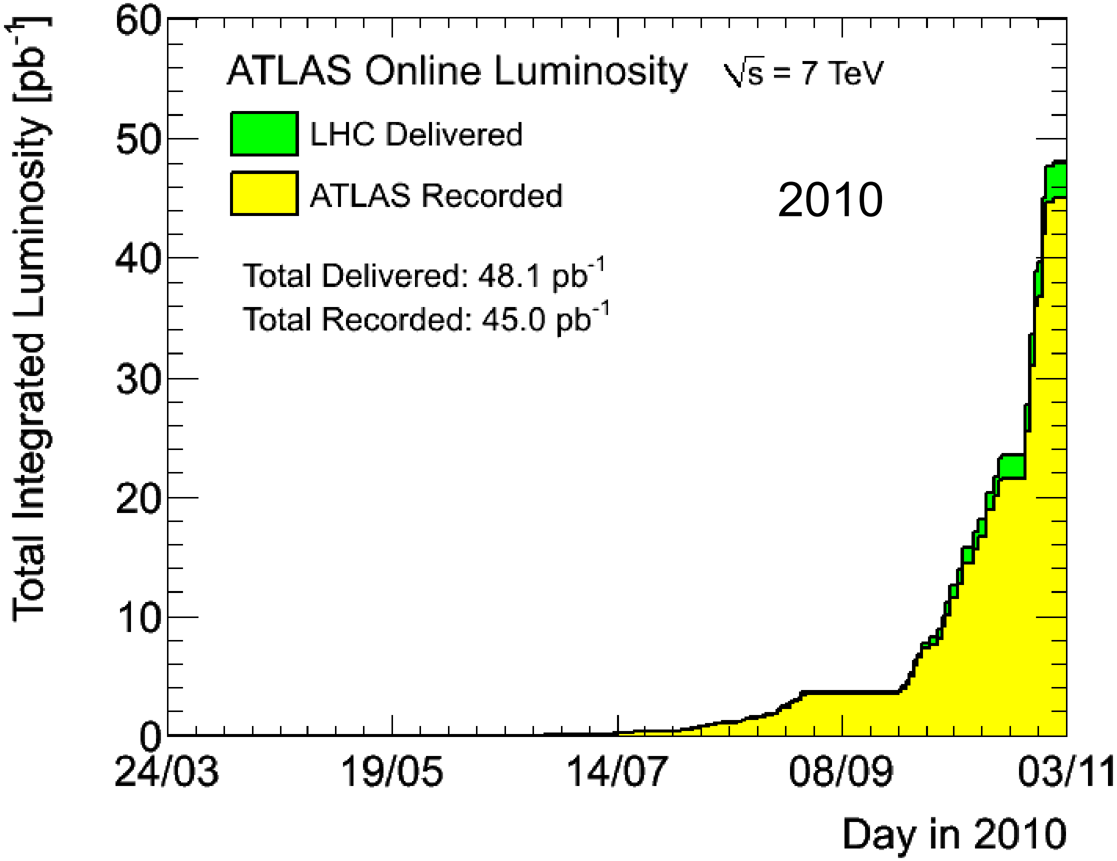
Data taking in 2010

pp collision at E_{cms}=7 TeV

Integrated luminosity:
- LHC delivered 48 pb^{-1}
- Atlas recorded 45 pb^{-1}
- Used for physics ~40 pb^{-1}

Peak luminosity: 2.1×10^{32} $cm^{-2}s^{-1}$

(plus 9.2 μb^{-1} of Pb-Pb collisions)



Luminosity measured with 3.4% uncertainty

- relative run-by-run measurement from dedicated monitor (LUCID) cross-checked with other detectors (MB scintillators, LAr)

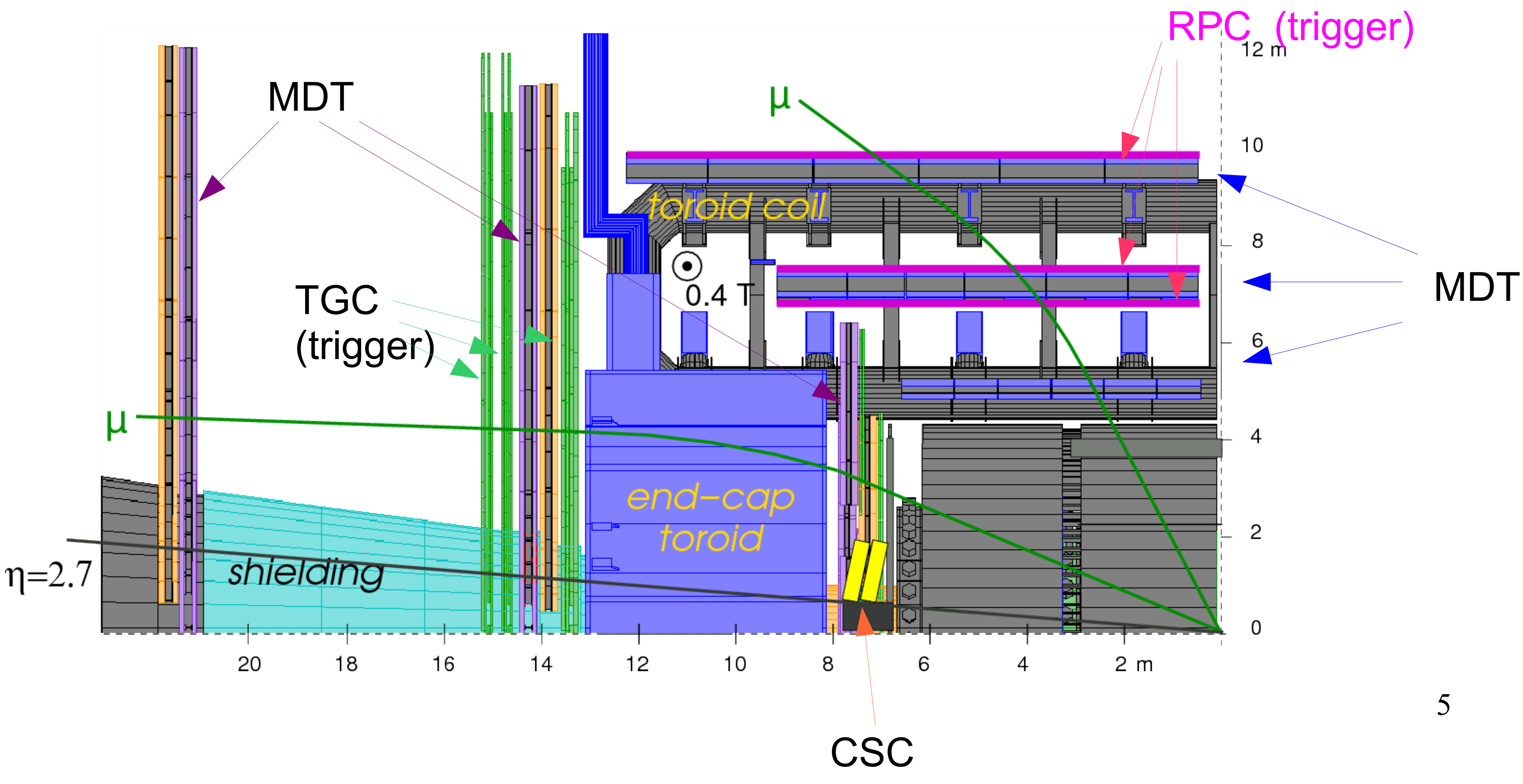
- Absolute calibration from beam current and interaction-region size measured with “Van der Meer” scans

The ATLAS muon system

- Air-coil toroidal field B=0.4 T

- >= 3 stations of precision chambers measure η (bending plane):
  - MDT (drif tubes) (6-8 tubes/station, hit resol. 80 μm)
  - CSC (cathode strip) inner station for 2<|η|<2.7

- Trigger + φ coordinate:
  - RPC in barrel / TGC in Endcaps



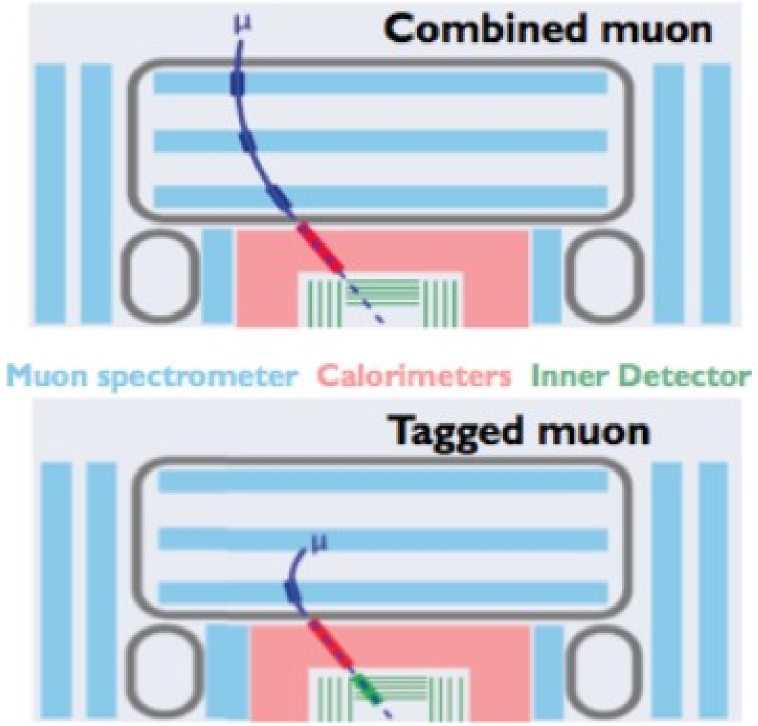
Muon reconstruction

Two types of reconstructed muon considered here:

- Combined (CB) muons
  ID track combined to a full muon track in MS
  Main muon class, highest quality

- Segment-tagged muons (ST)
  ID tracks matched to segments
  Add extra efficiency at low p_T and in some region

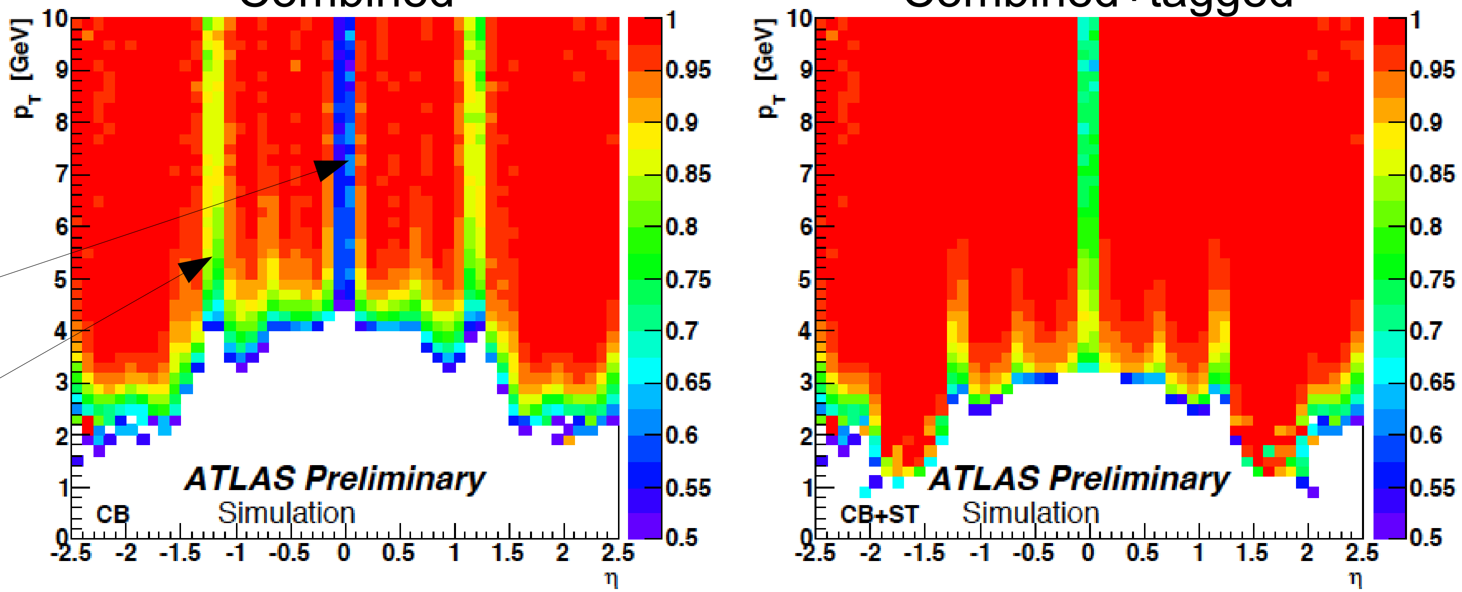
- Two independent reco. chains used for cross-check,
  similar performances



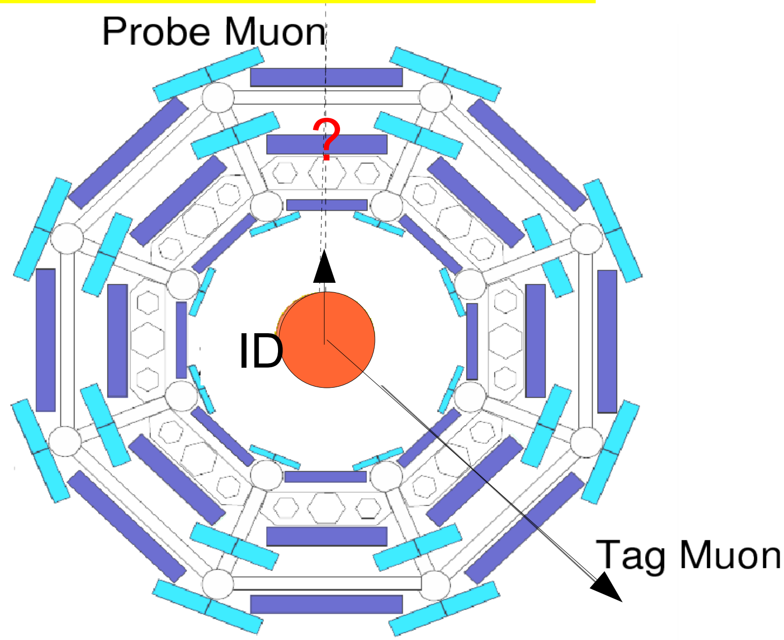
MC efficiency in η-p_T

η=0 crack

Barrel/EC transition



Muon reconstruction efficiency measurement



- Reconstruction efficiencies measured with "tag and probe" method

- Basic idea: use an unbiased sample of ID tracks (probes) identified as μ independently from MS to test efficiency

- J/Ψ-based analysis:
  - Tag: CB muon p_T>4 GeV associated to event trigger
  - Probe: any ID track passing quality cuts

Signal extracted for:
N(match)=J/Ψ signal for probes found by MS
N(unmatch)=J/Ψ signal for probes not found by MS

efficiency= N(match) / [N(match)+N(unmatch)]

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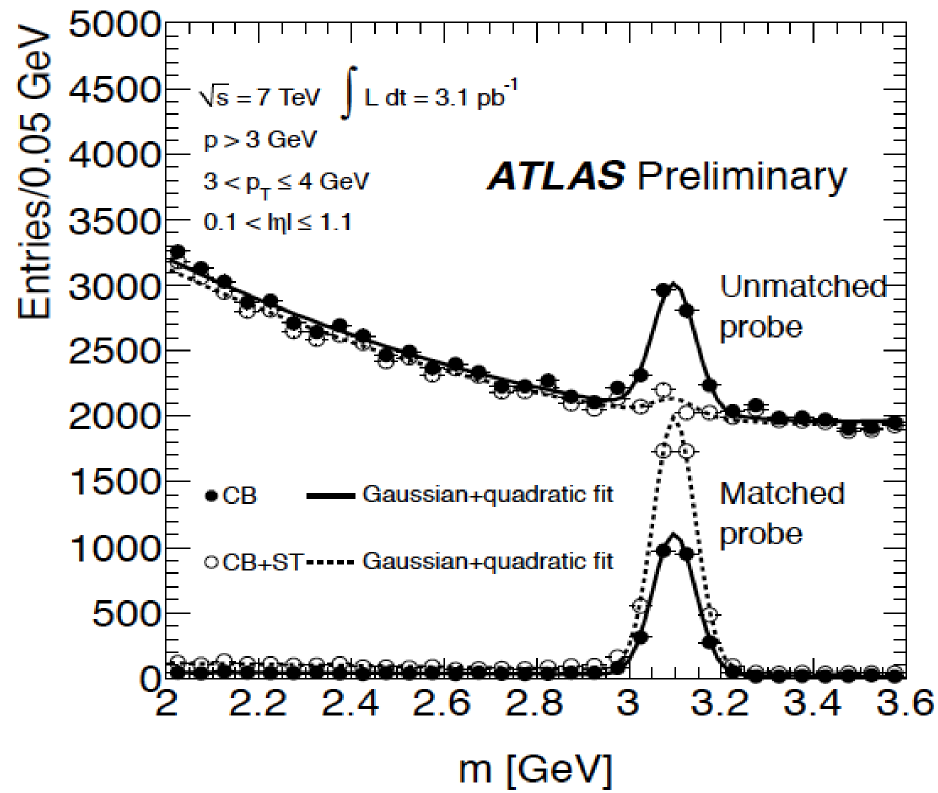


Reconstruction efficiency with “tag & probe”

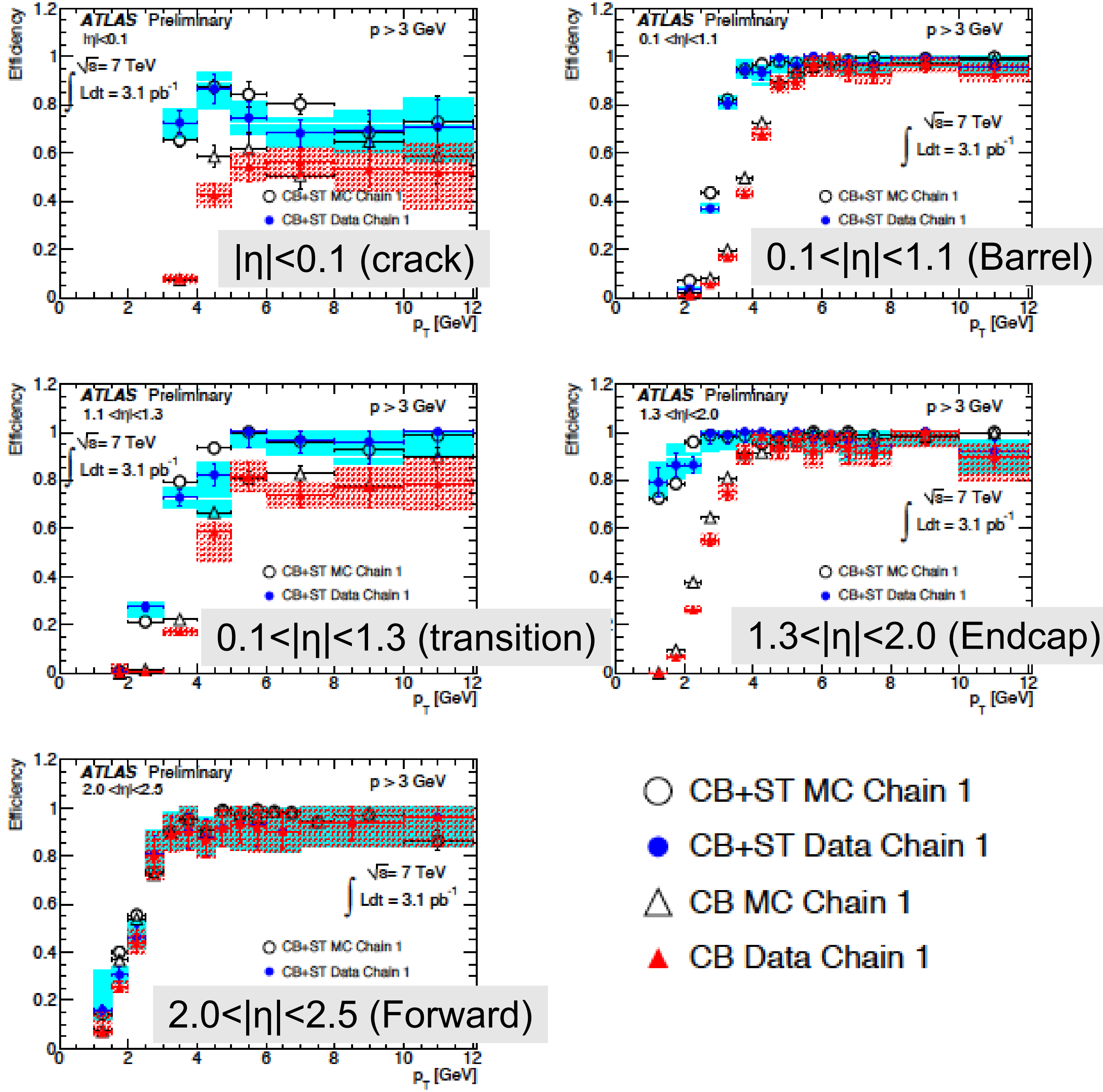
- Results based on 3.1 pb^{-1}
  Single μ triggers,
  ~ 50k J/ψ in the mass peak
  (sample of σ(J/ψ) analysis)

- Turn-on curves in eta bins

- Well reproduced by MC

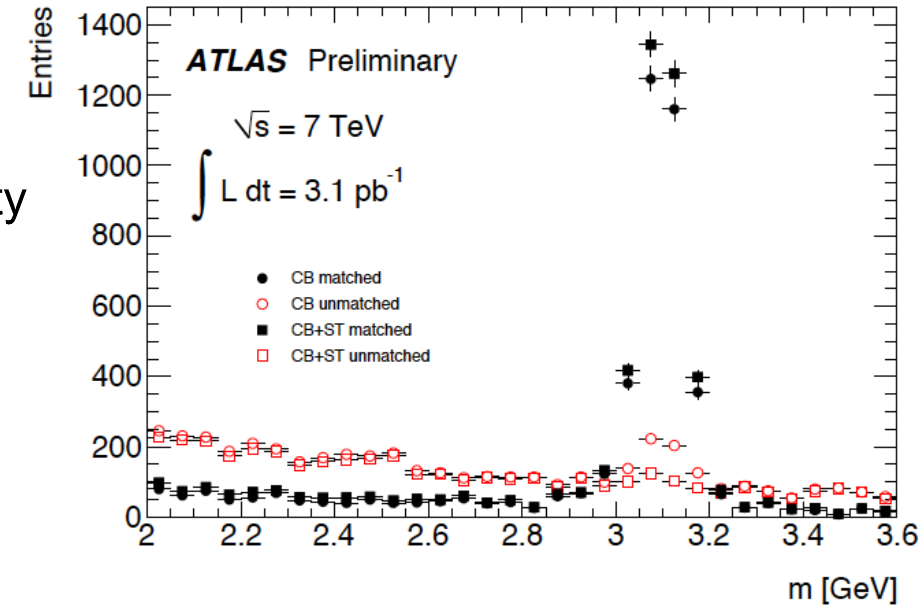
- Plateau for CB+ST muons starts at p_T>3-2 GeV

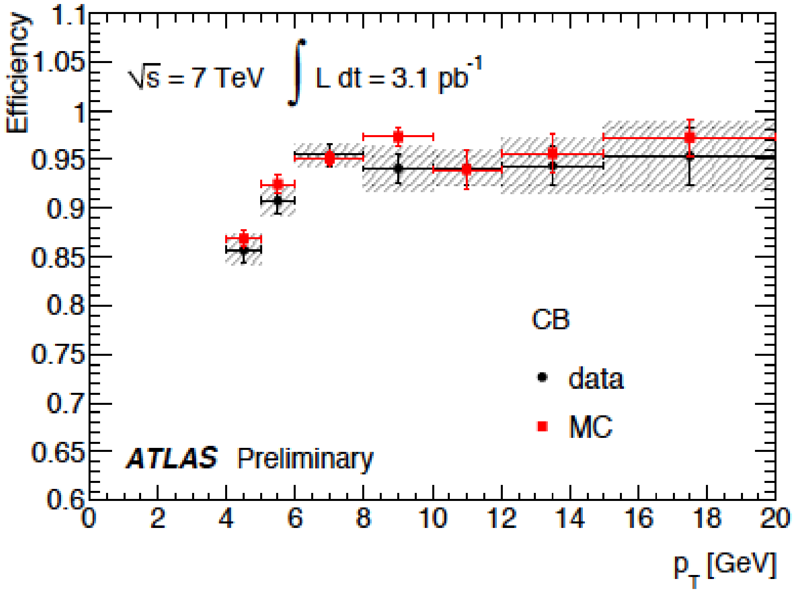
- Typical uncertainty ~3-10%,
  main systematic:
  background subtraction

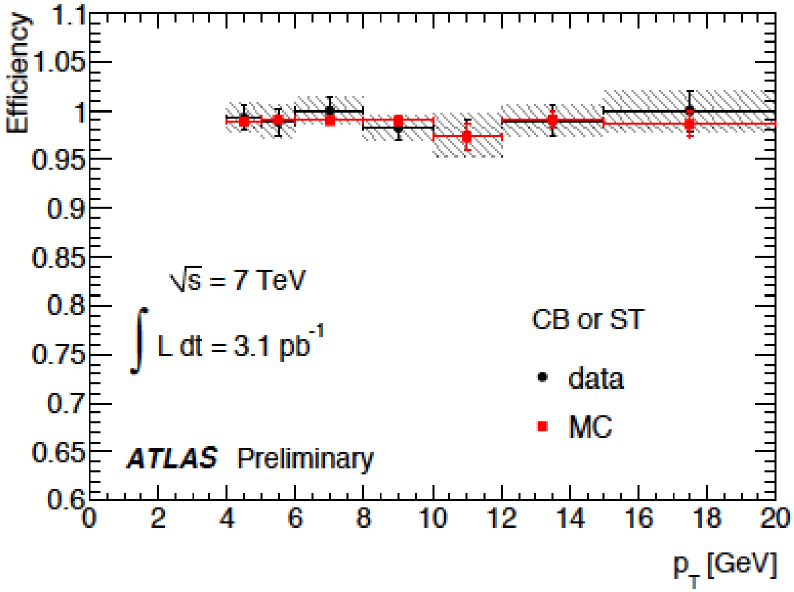


Using calorimeter-tagged muons as probes

- Same tag and probe but requiring the probe found in calorimeters as a mip
- Much reduced background, smaller uncertainty
- At the moment limited to p_T>4 GeV
- Uncertainty at plateau ~1%
- Data/MC agreement





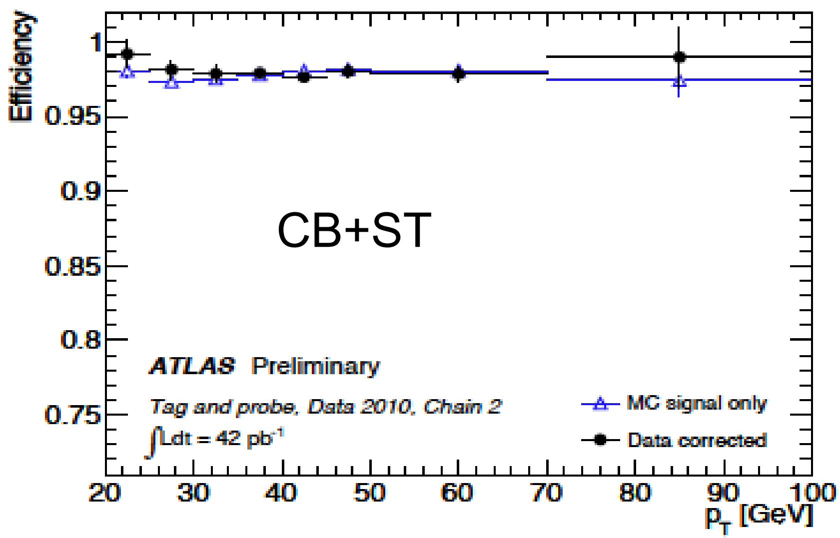


Muon efficiency with the Z

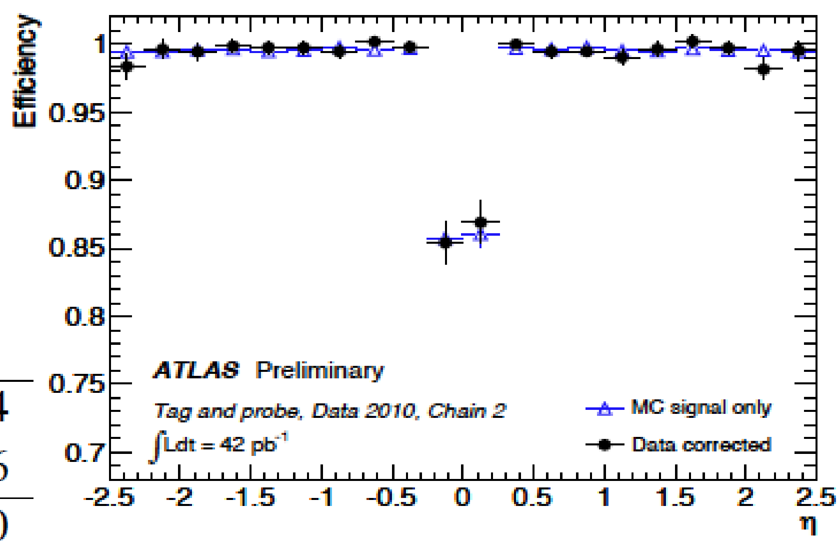
- Tag and probe with Z->μμ, 42 pb^{-1}
  p_T(probe)>20 GeV

- Efficiency ~98% for CB+ST

- Small backgrounds, large sample uncertainties within 1%



(d) Chain 2 efficiency as a function of muon p_T



(f) Chain 2 efficiency as a function of muon η

Data/MC efficiency scale factors: eff(data)/eff(MC)

Algorithm		j/ψ, p_T>6 GeV s.f.	± stat.	± syst.	Z, p_T>20 GeV s.f.@Z	± stat.
chain 1	CB	0.980	0.007	0.005	0.9806	0.0024
	CB+ST	1.009	0.004	0.003	0.9990	0.0016
chain 2	CB	0.993	0.007	0.007	0.9918	0.0020
	CB+ST	1.011	0.003	0.005	1.0006	0.0015

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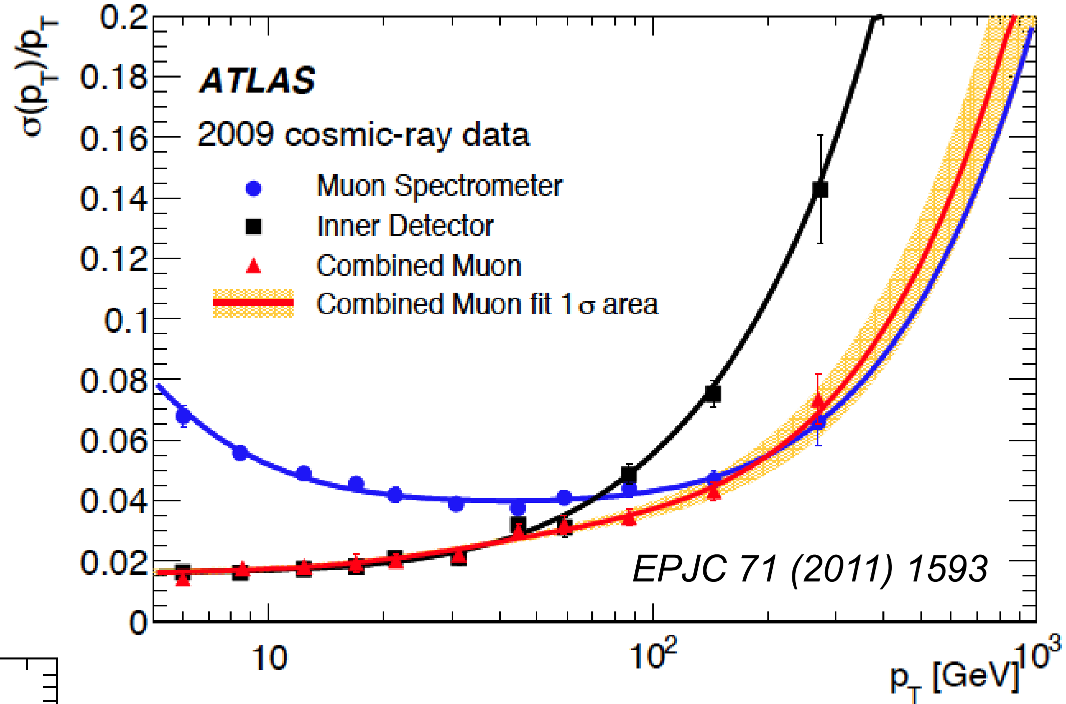
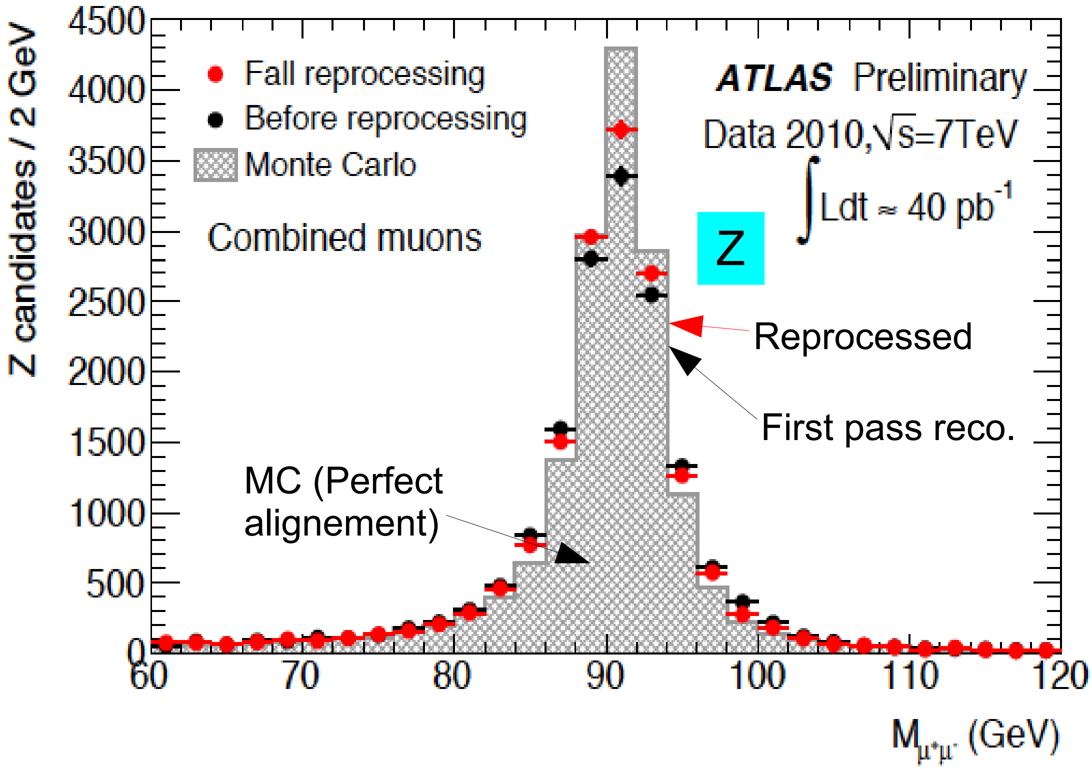
Muon momentum resolution

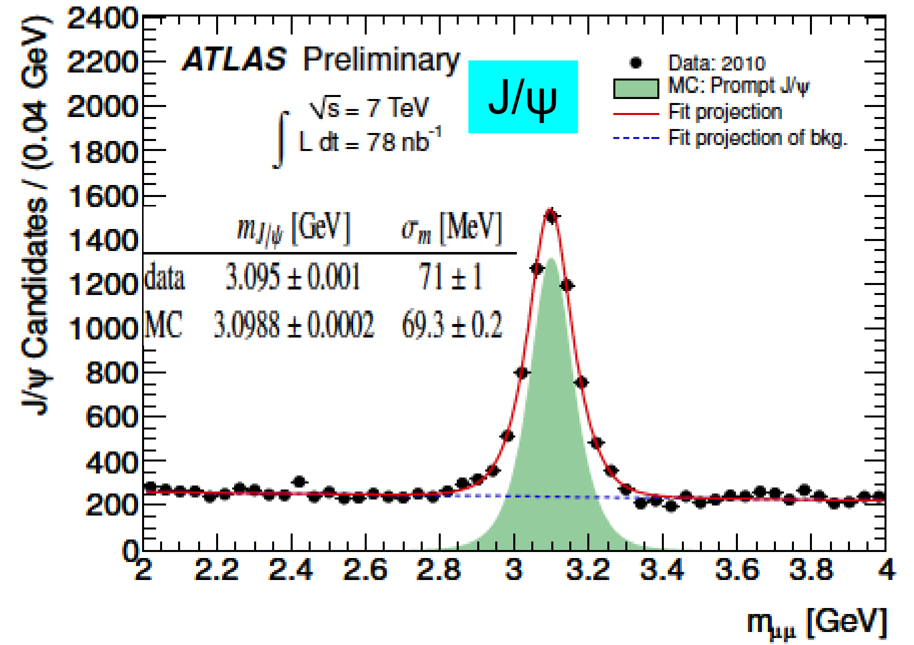
Resolution on μ momentum
CB muons: depends on MS and ID resolution

- Improved with time as alignment improved

- Still margin for improvement at large p_T

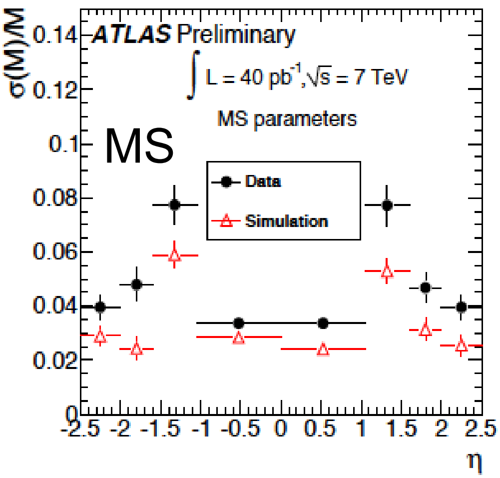


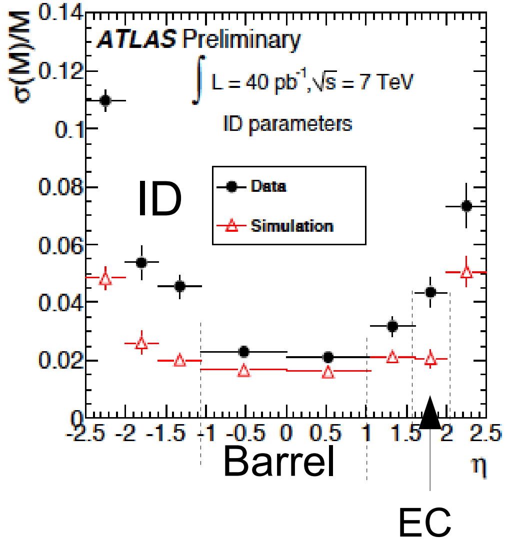




Momentum resolution measurement

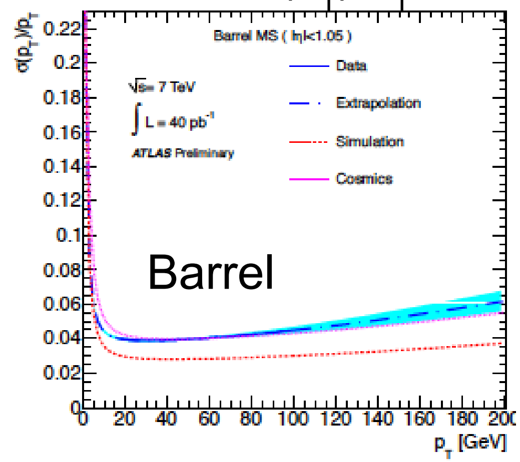
MS and ID contribution to Z resolution



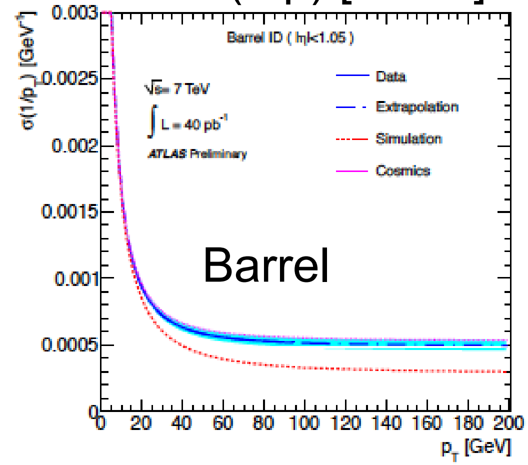


MS $\sigma(p_T)/p_T$

ID: $\sigma(1/p)$ [GeV^{-1}]



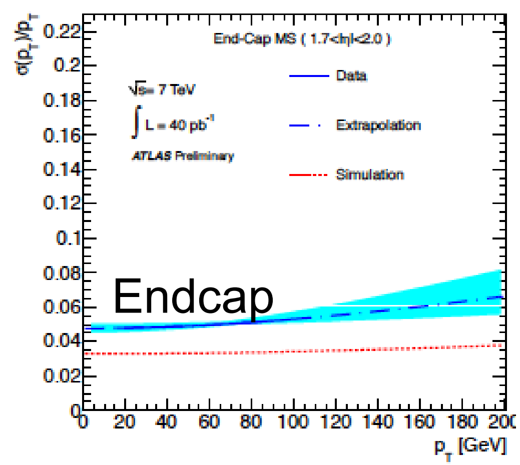
(a) MS resolution p_T curve for $0 < |\eta| < 1.05$



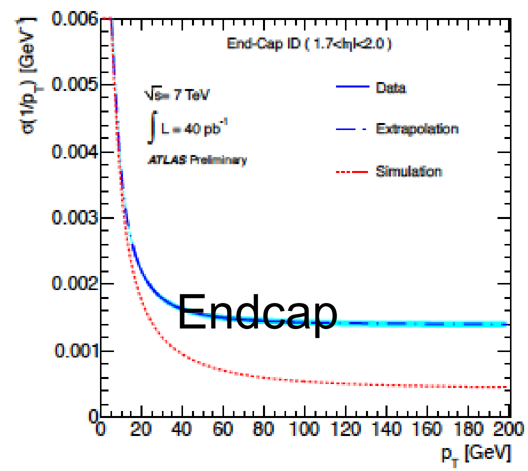
(a) ID resolution p_T curve for $0 < |\eta| < 1.05$

- MS and ID resolution measured from Z width and ID/MS comparison in Z and W events (first pass reconstruction)

- Somewhat worse than MC at high p_T, largest deviation fwd ID,



(c) MS resolution p_T curve for $1.7 < |\eta| < 2.0$



(c) ID resolution p_T curve for $1.7 < |\eta| < 2.0$

Parametrisation of ID resolution:

Barrel: $\sigma(p)/p = 0.016 + 0.49 \cdot (p_T/\mathrm{TeV})$

Endcaps: $\sigma(p)/p = 0.034 + 1.39 \cdot (p_T/\mathrm{TeV})$

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Fake probability

- “Fake probability”:
  Fraction of π/K reconstructed as μ

- Studied using π from K^0s

- Initial studies show that
  fake probability is $<3 \times 10^{-3}$ for
  CB muons, higher for ST muons

- MC describes fakes well

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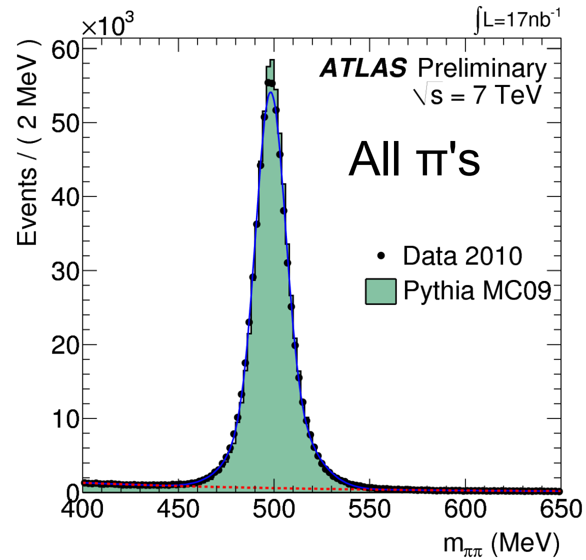
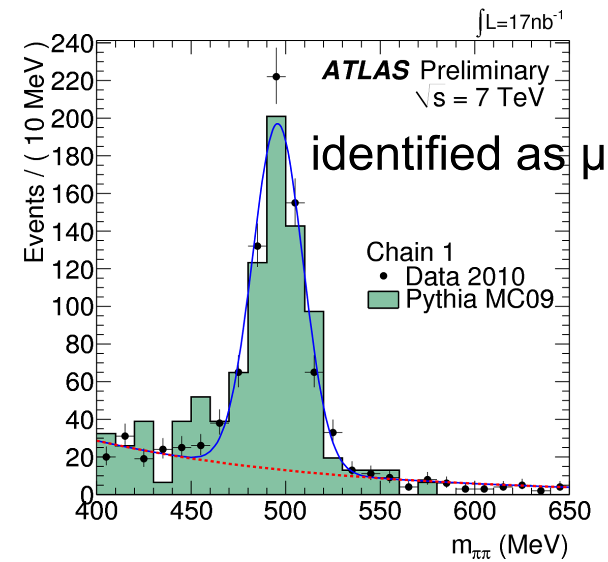
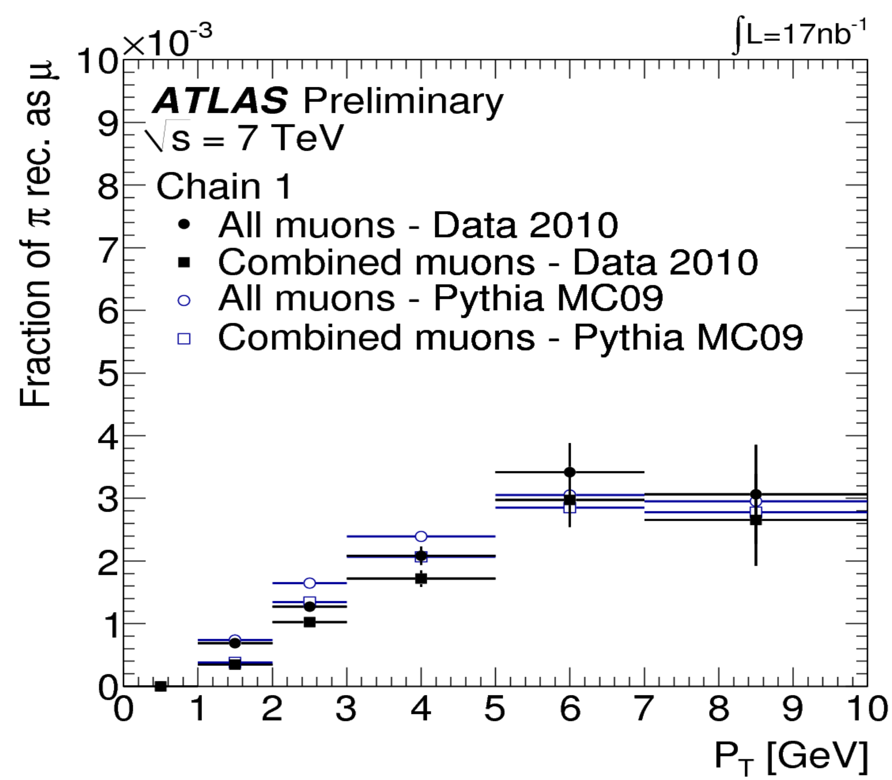




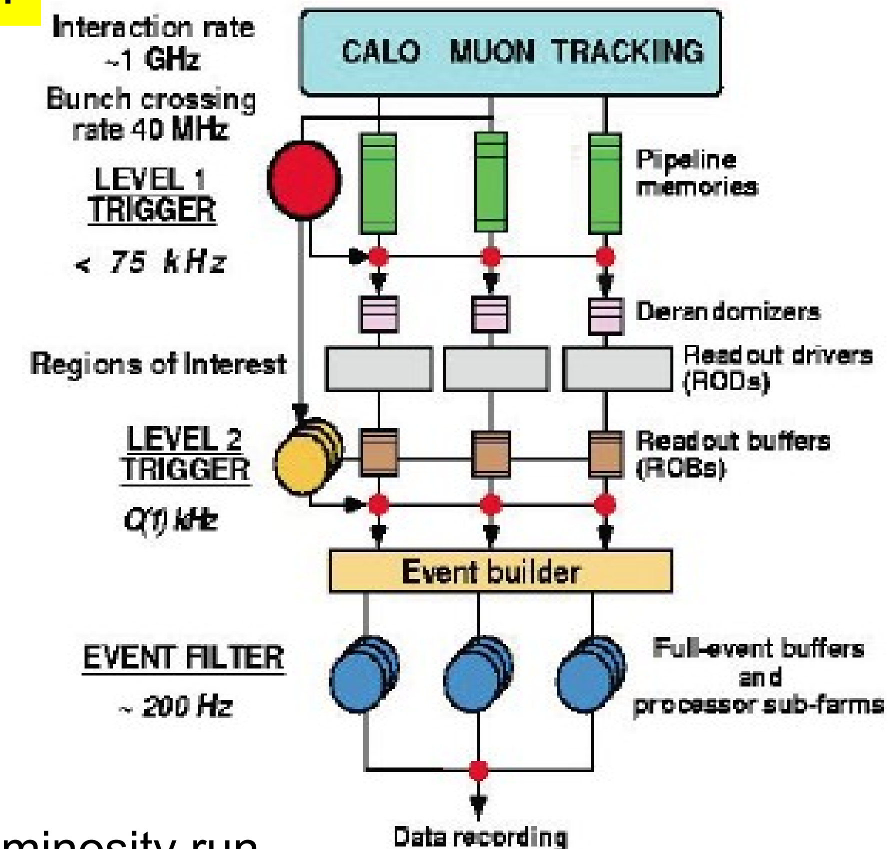


The ATLAS trigger

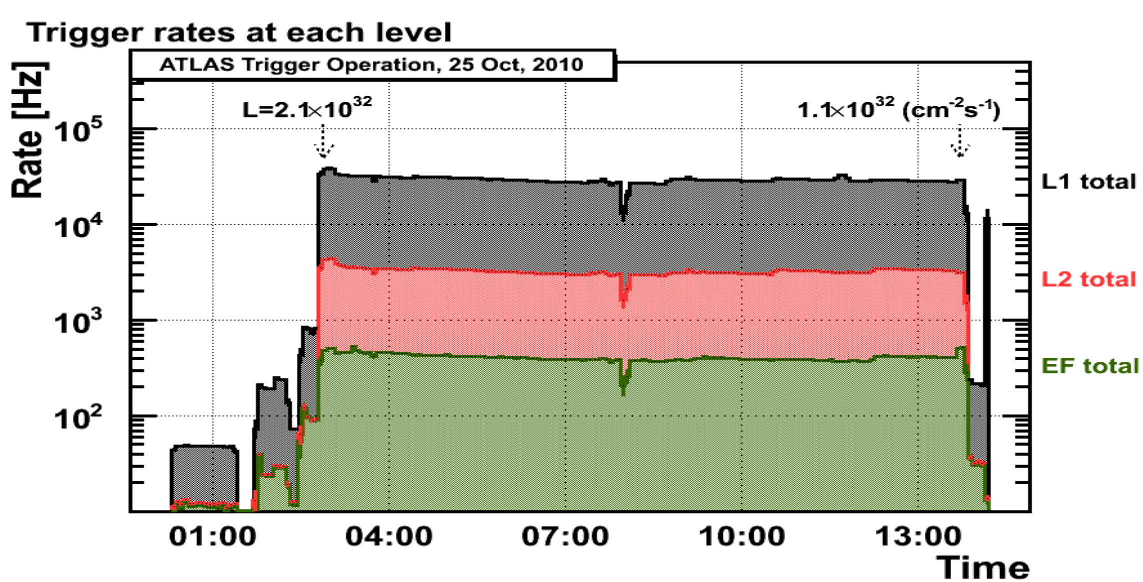
- Level 1 (L1), O(50 kHz)
  Hardware trigger from muon/calo

- Level 2 (L2), O(1 kHz)
  Fast SW algorithms,
  RoI concept: only data from the region
  around L1 trigger is analysed

- Event Filter (EF), O(200 Hz)
  Full event reconstruction on computer farm



Typical high-luminosity run



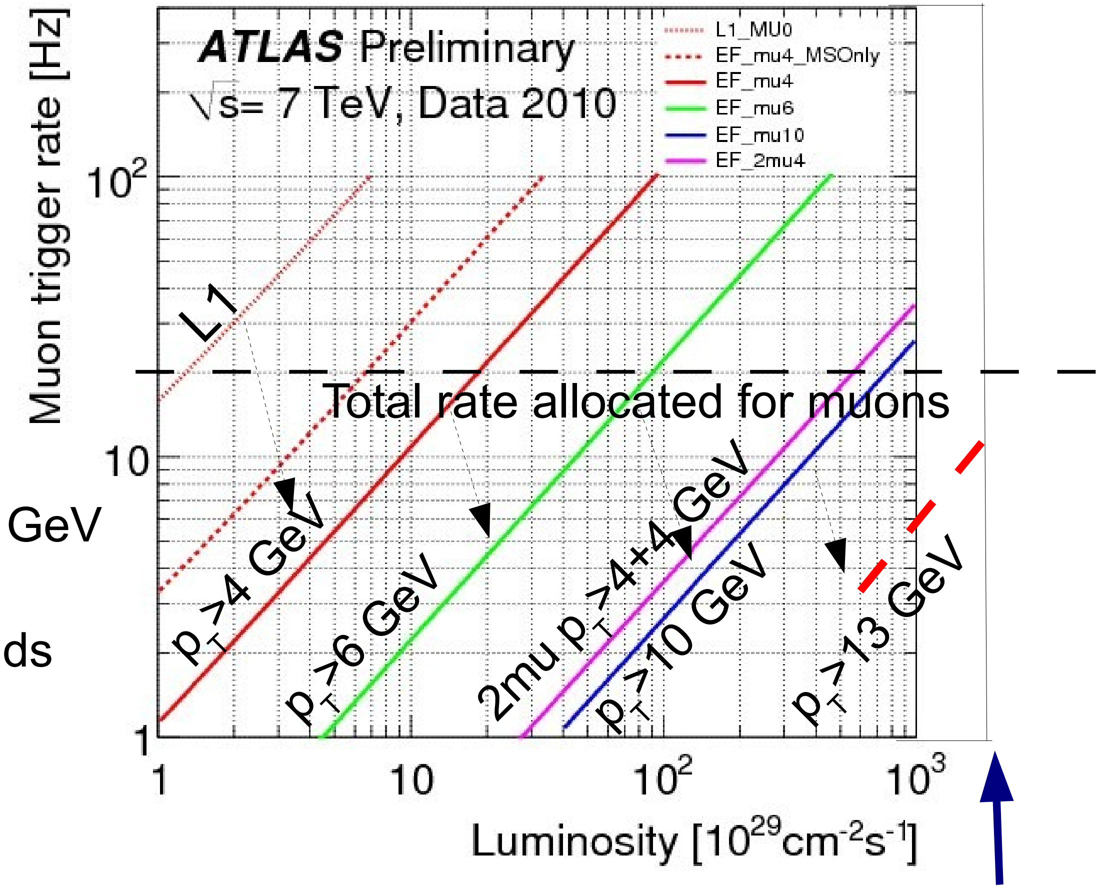
Muon trigger rates

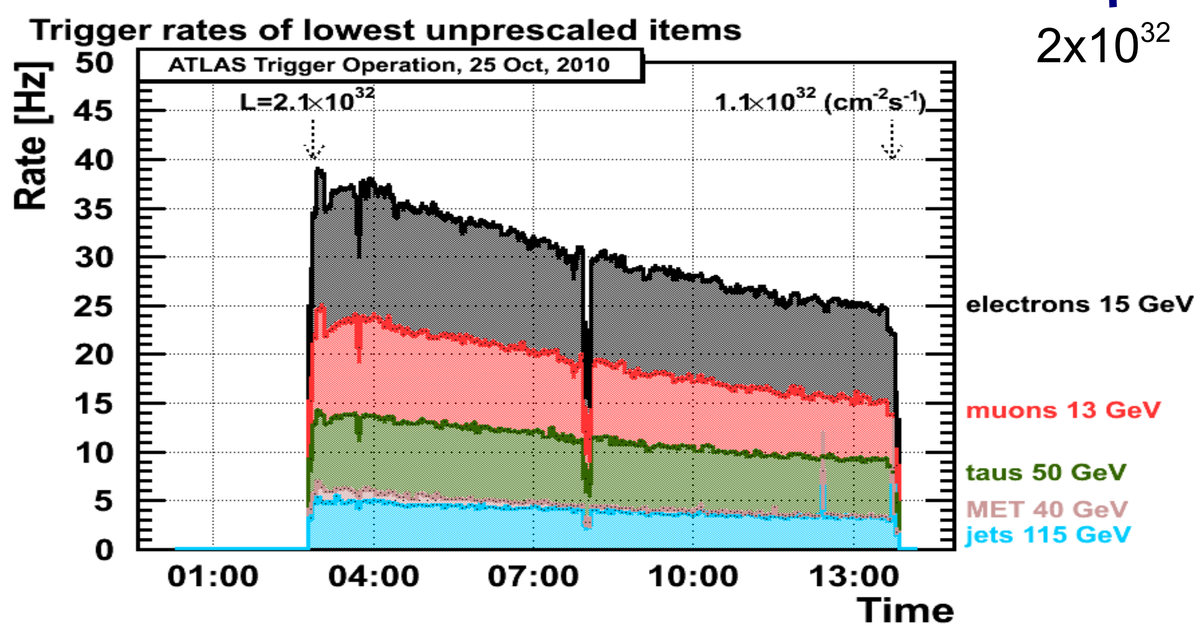
ATLAS average output rate ~200 Hz
 - allocated to muons+B-physics 10-20%

Single-μ triggers with low thresholds turned off (prescaled) as luminosity increase

Lowest (unprescaled) single-μ trigger: p_T>13 GeV

Initial sample of ~3 pb^{-1} with single-μ thresholds of p_T>4 and later p_T>6 GeV was used for J/ψ cross section measurement





Dimuon triggers

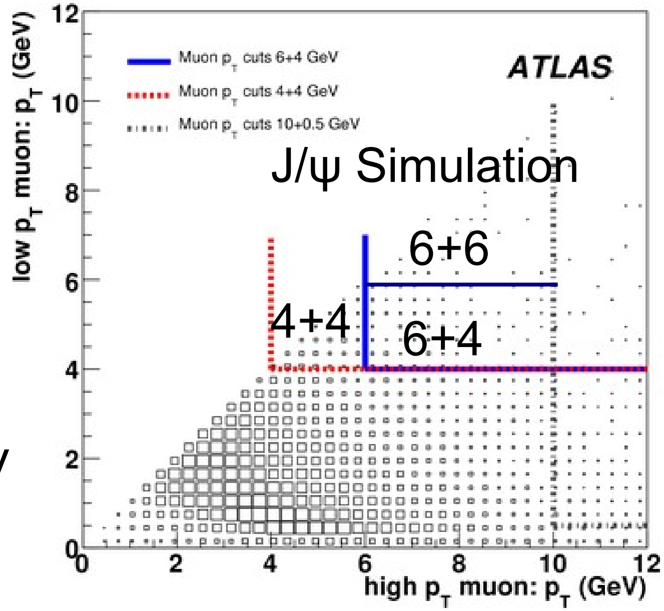
Single muon trigger thresholds too high for b-phyiscs

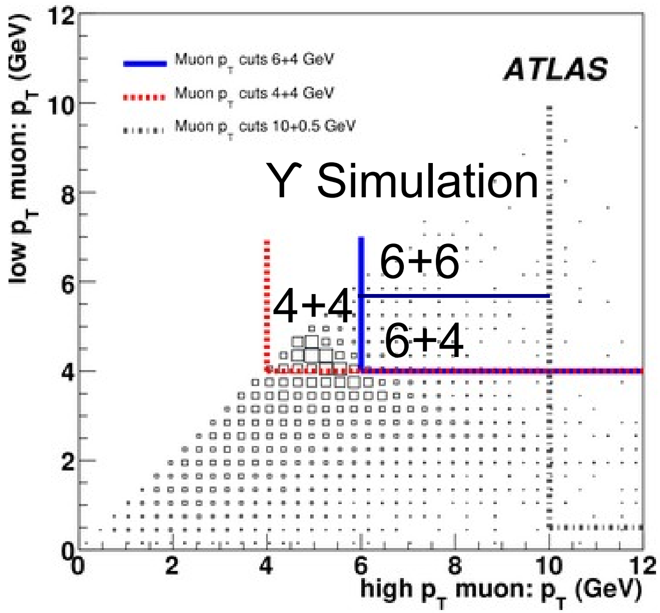
Two types of Dimuon triggers in 2010:

- Triggers requiring two L1 muons
  - plain dimuon triggers (p_T>6+6 GeV)
  - with additional charge, mass, and vertex cuts, p_T>4+4 GeV

- Triggers requiring one L1 muon p_T>4, confirmed by L2,EF
  + 1 "tagged" muon found at L2
  Additional requirements on invariant mass,
  opposite charge, vertex matching

- Only high-p_T tail of J/ψ's taken by dimuon triggers
- Most Υ taken, down to p_T(Υ)=0

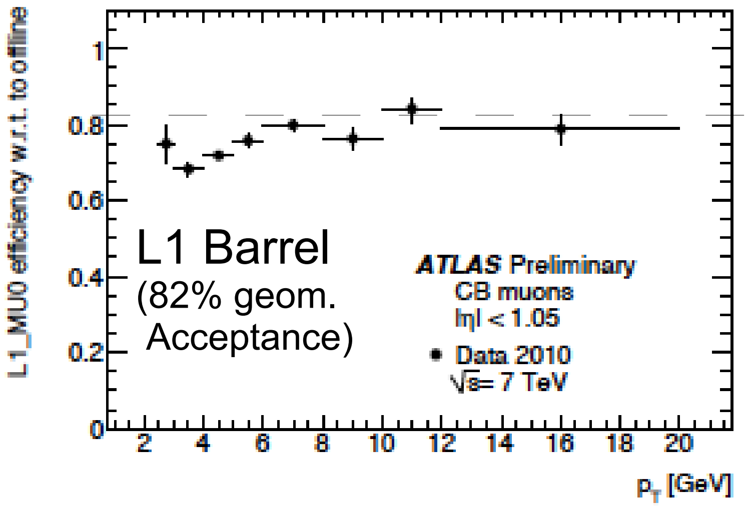


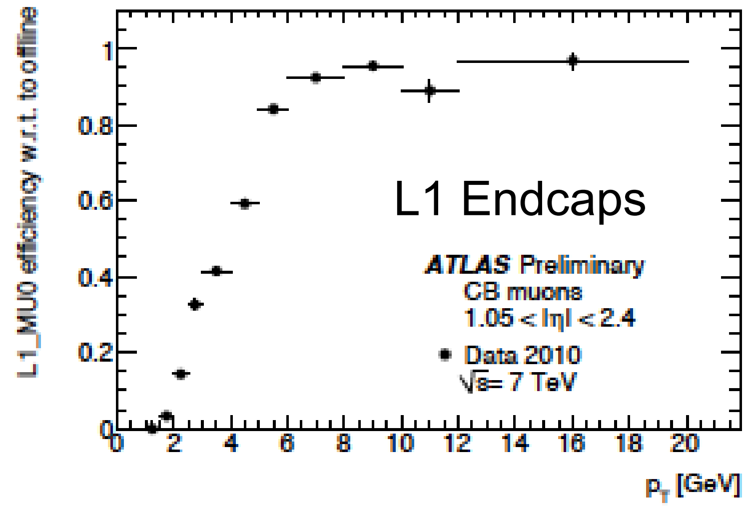


Trigger efficiency from J/psi tag and probe

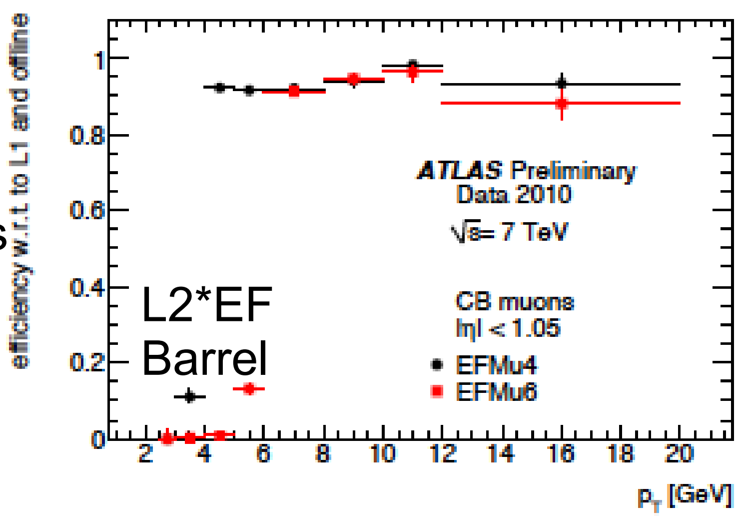
- Trigger efficiencies measured with “tag and probe” method for p_T>4, 6 GeV thresholds
- same sample as for J/ψ cross section analysis
- high-p_T (not shown) measured with Z events

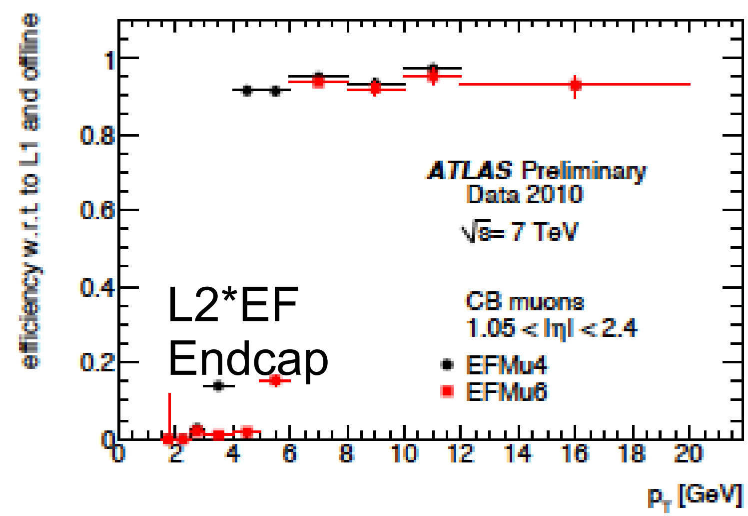
L1 efficiency wrt reco. CB muons





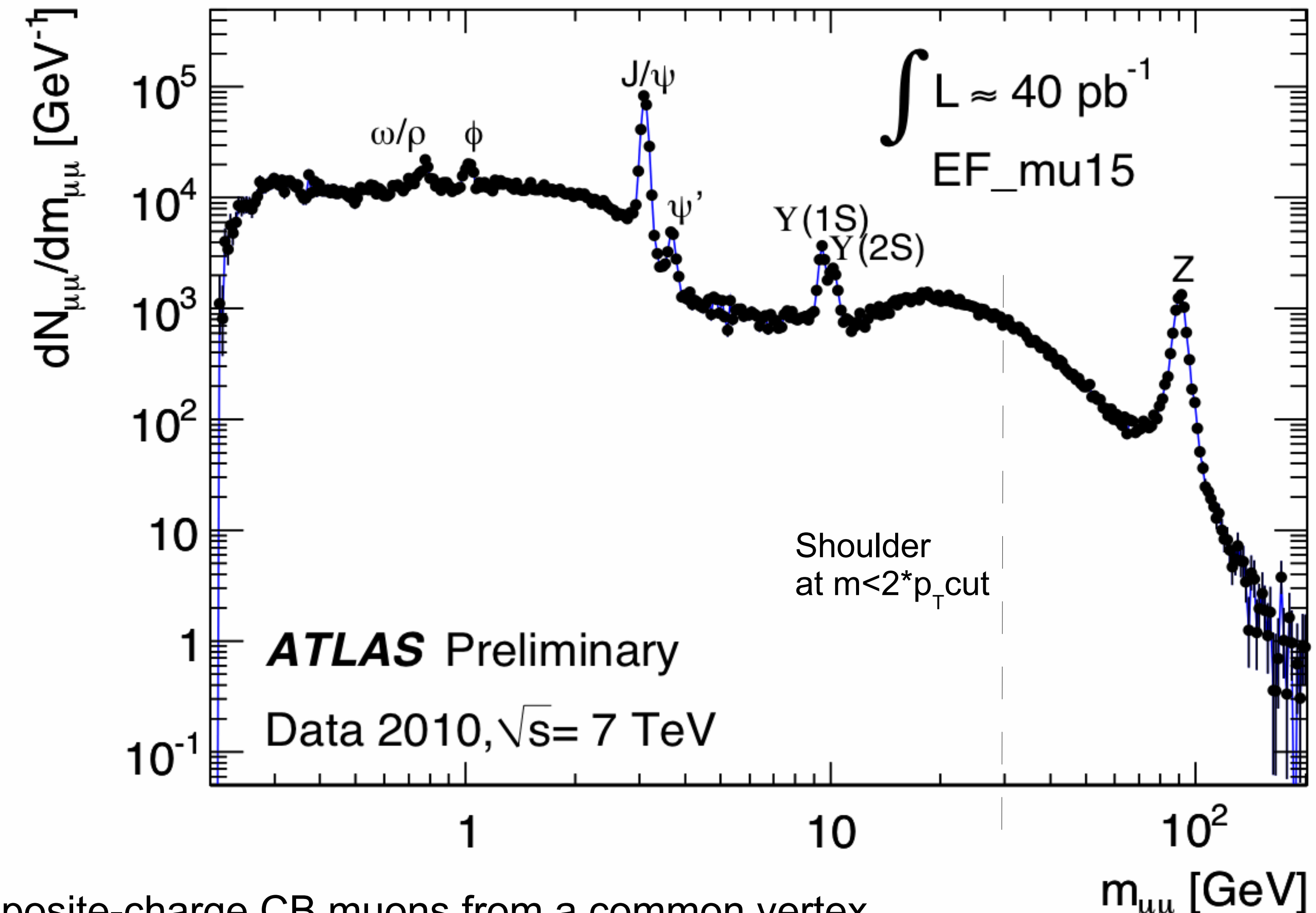
L2&EF efficiency wrt L1 & reco. CB muons





Dimuons with single muon trigger

Dimuon spectrum from single muon trigger p_T>15 GeV



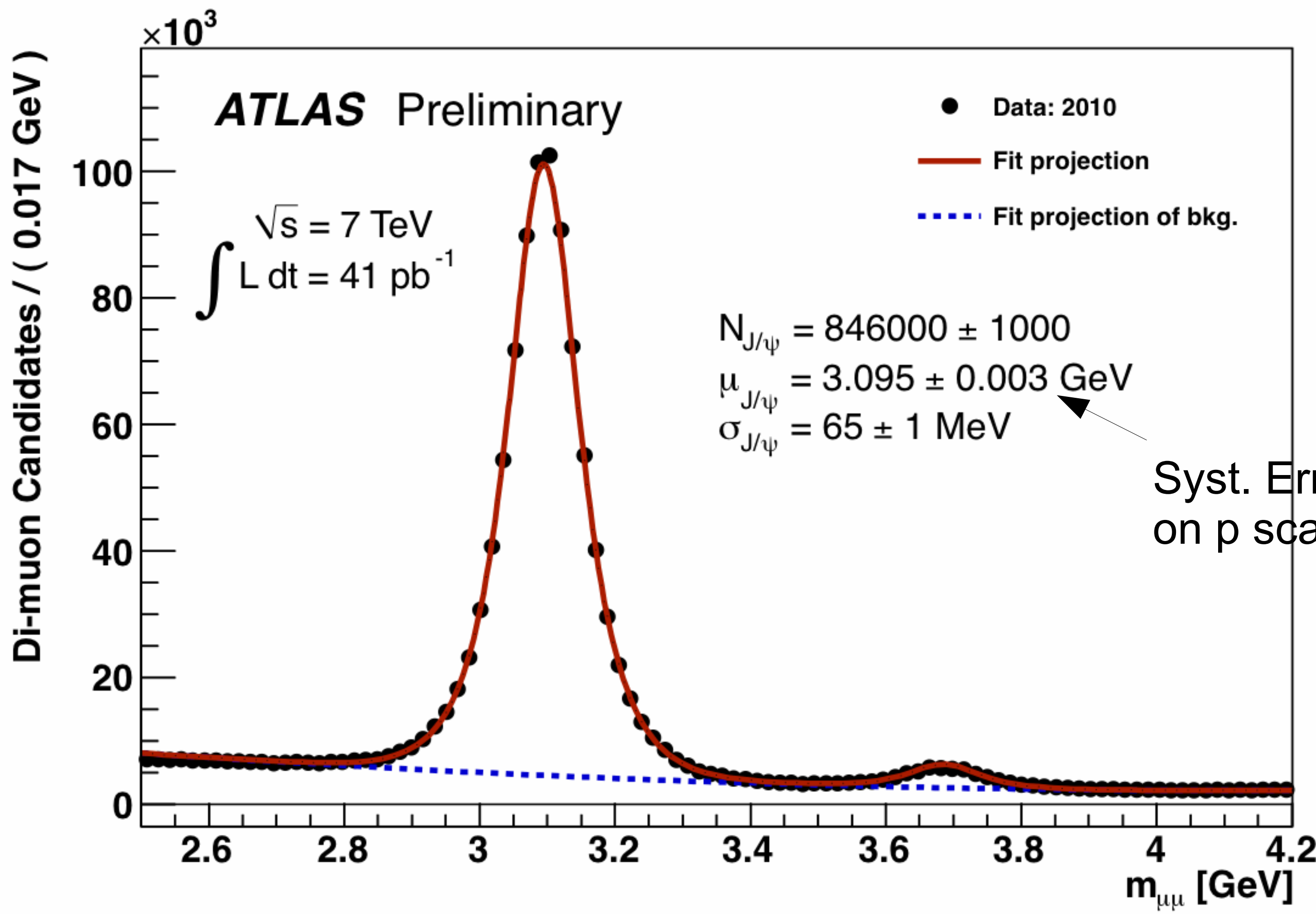
Two opposite-charge CB muons from a common vertex

Full J/ψ sample including dimuon triggers

- Selection:
  Single- or di-muon triggers
  2 opposite sign muons fitted to the same vertex:
    1 combined p_T>4 GeV
    1 segment-tagged p_T>2.5 GeV

- 846k J/ψ

- nice ψ' peak



Syst. Error on p scale

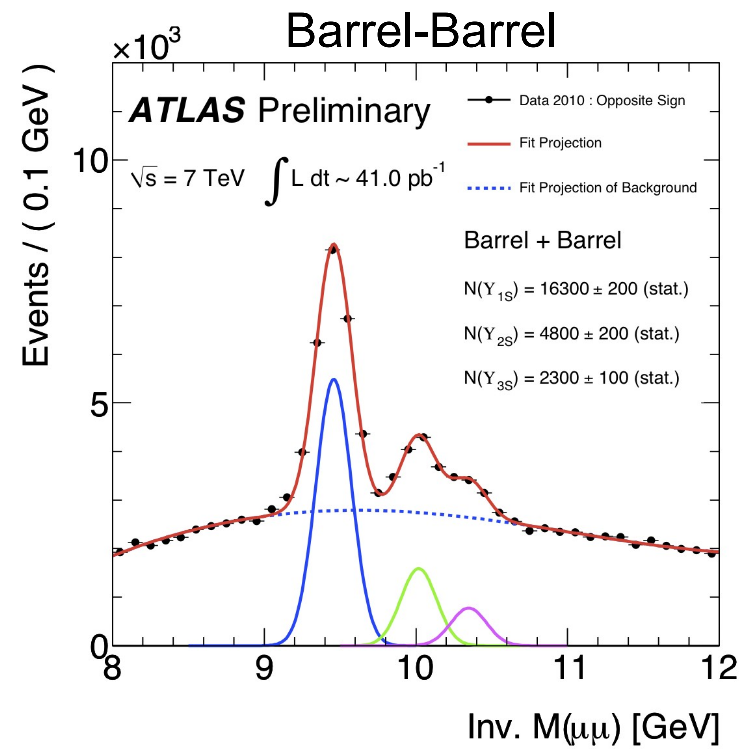
Collected Υ sample

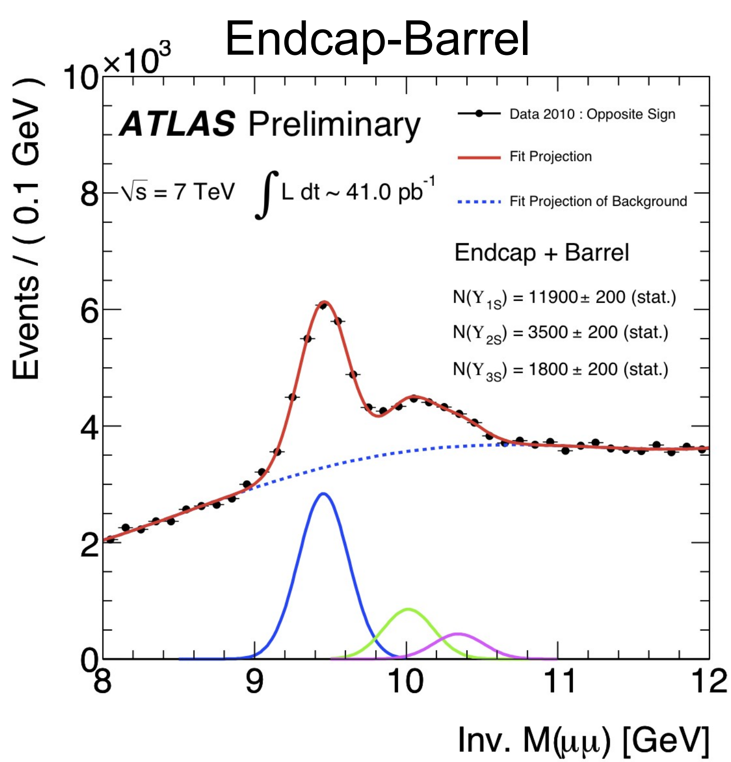
- Same selection as before

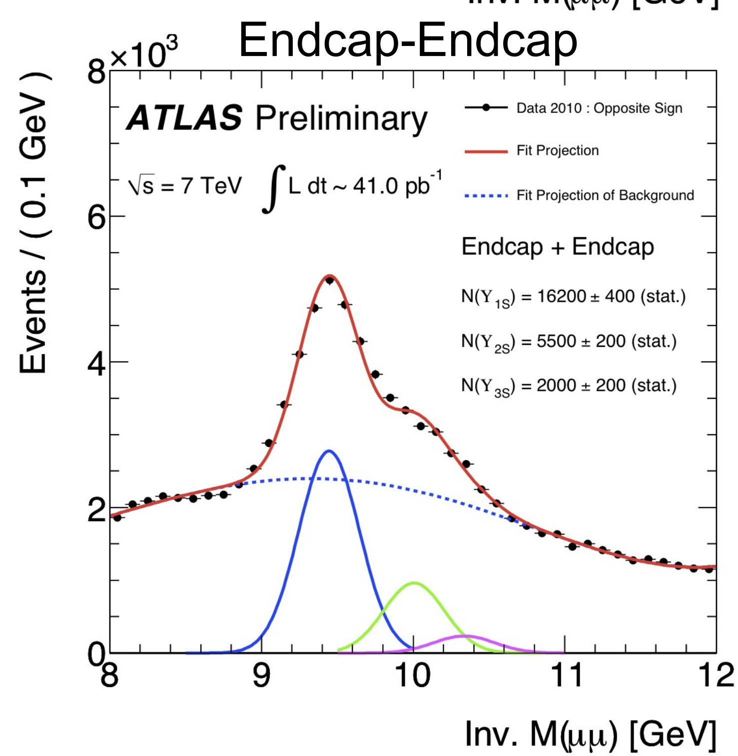
- Different mass resolution depending on η regions

-fit: 3 Gaussians with fixed mass difference + polynomial background

- 44k Y(1S)





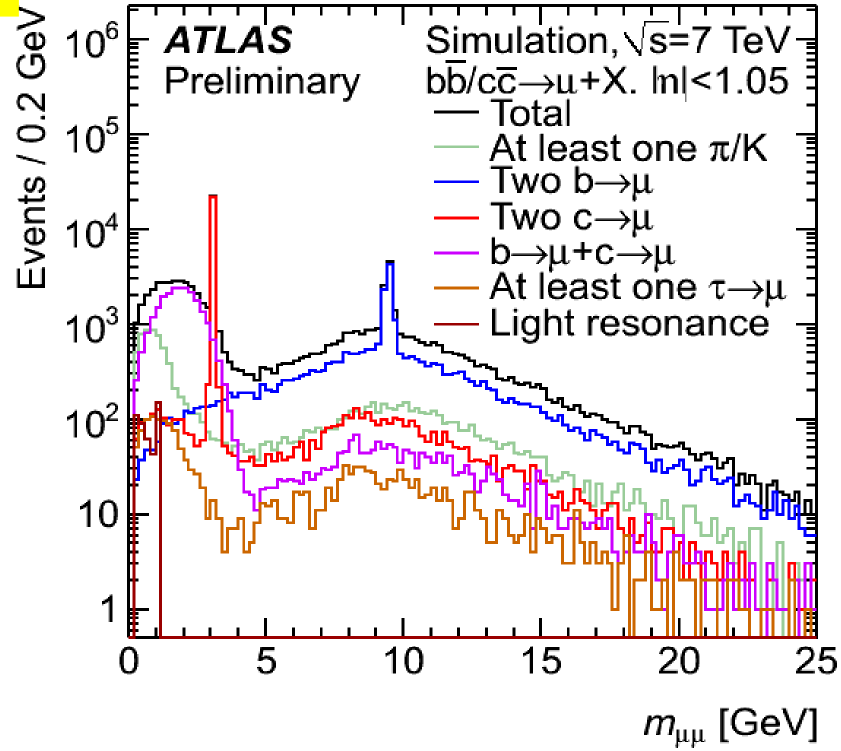


Dimuon composition

- Dimuon samples consist of
  - Quarkonia, Drell-Yan dimuons
  - $b+\bar{b}$, $c+\bar{c}$ decays
  - B->μ (c->μ) cascade decays
  - “fake” pairs including >=1 muon from π/K decays or punch-through

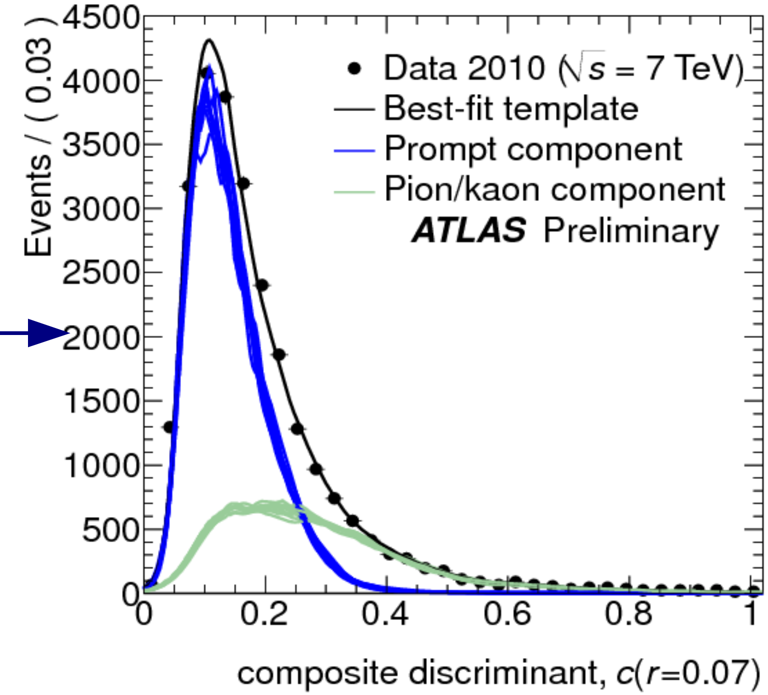
- “Fake” muon content studied with discriminant based on
  1) momentum balance between MS and ID
  2) scatter angle significance in the ID (sensitive to kink from π/K decays in flight Inside ID)

- Study based on 1.5 pb^{-1},
  Selection: 2 CB muons with p_T>3,4 GeV from common vertex



Fake discriminant in inclusive μ sample

Fit using templates from MC, checked with μ and π data samples



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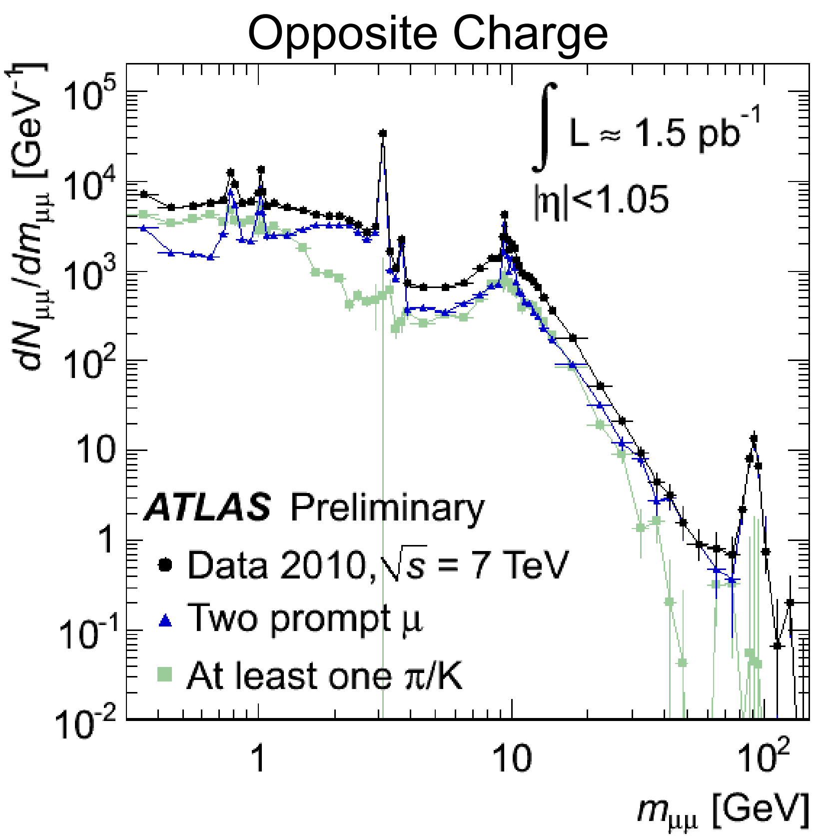
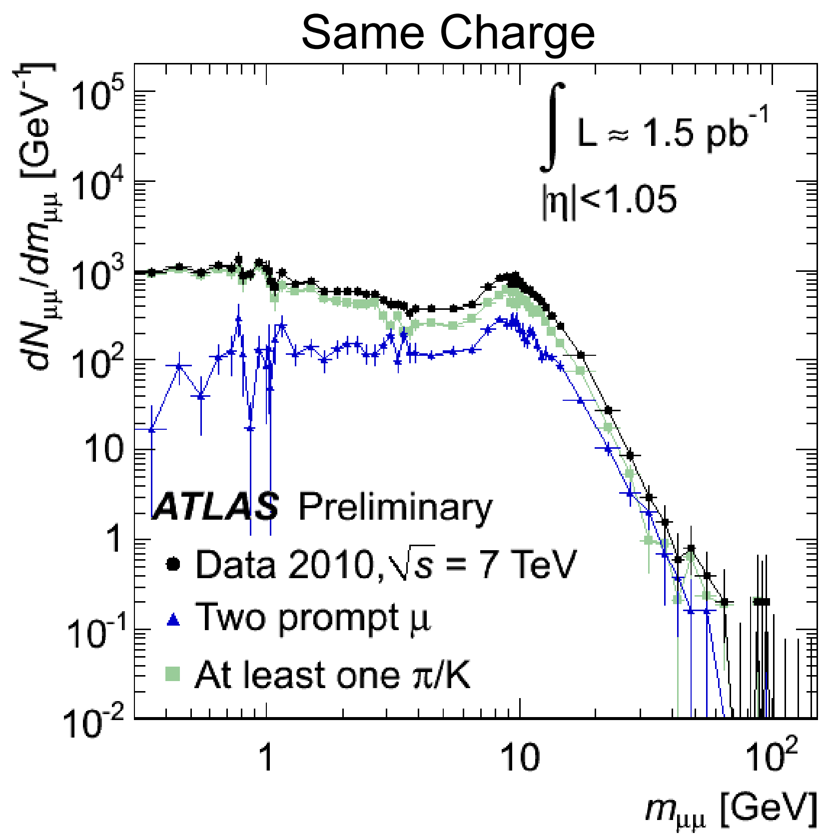
Dimuon composition: results





- Discriminant fitted in bins of mass
- OC: overall 31% of dimuons with >=1 fake
  mostly at $m_{\mu\mu}$<1 GeV, negligible in J/ψ region, ~50% for 5<$m_{\mu\mu}$<20 GeV
- SC: 68% of dimuons with >=1 fake

Plain dimuon selection without “quality” cuts:
Fake dimuons can be further reduced by cutting on π/K discriminant variables

Dimuon spectrum at large mass

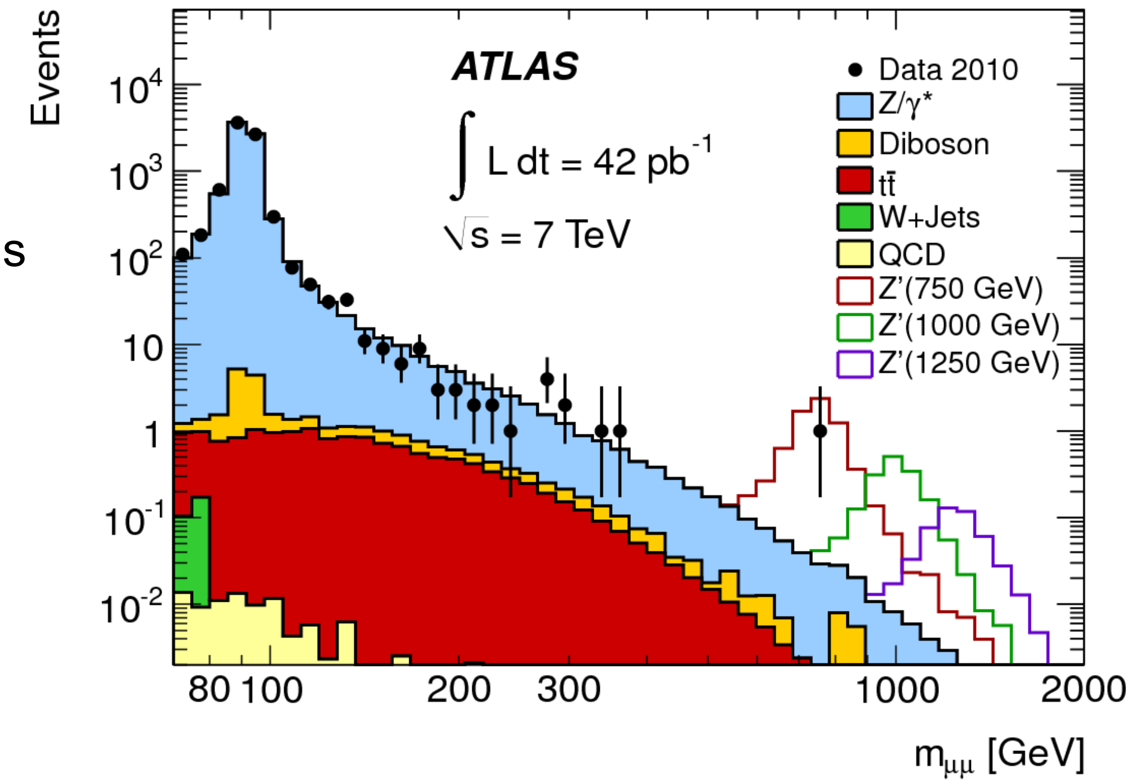
- Search for Z' resonances

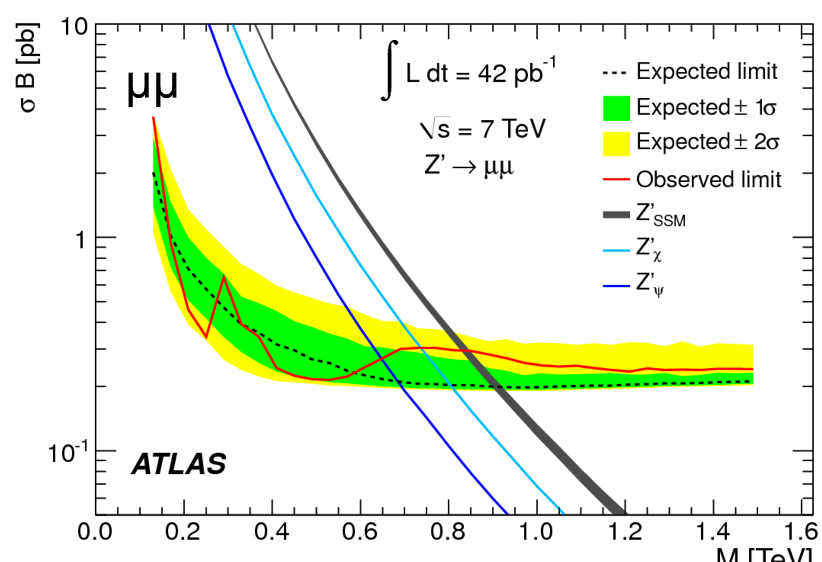
- Nice agreement with SM expectations

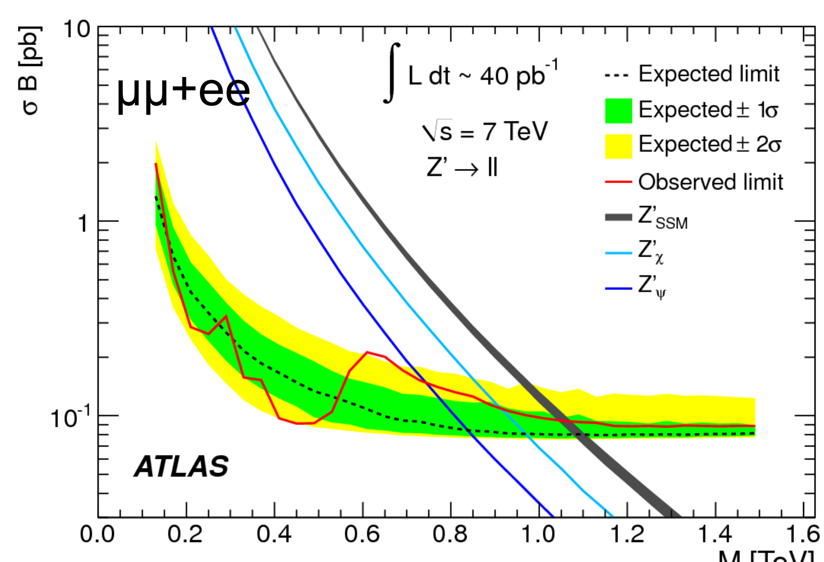
Limit combining
dimuons and dielectrons:

Z'(SSM)>1.048 GeV

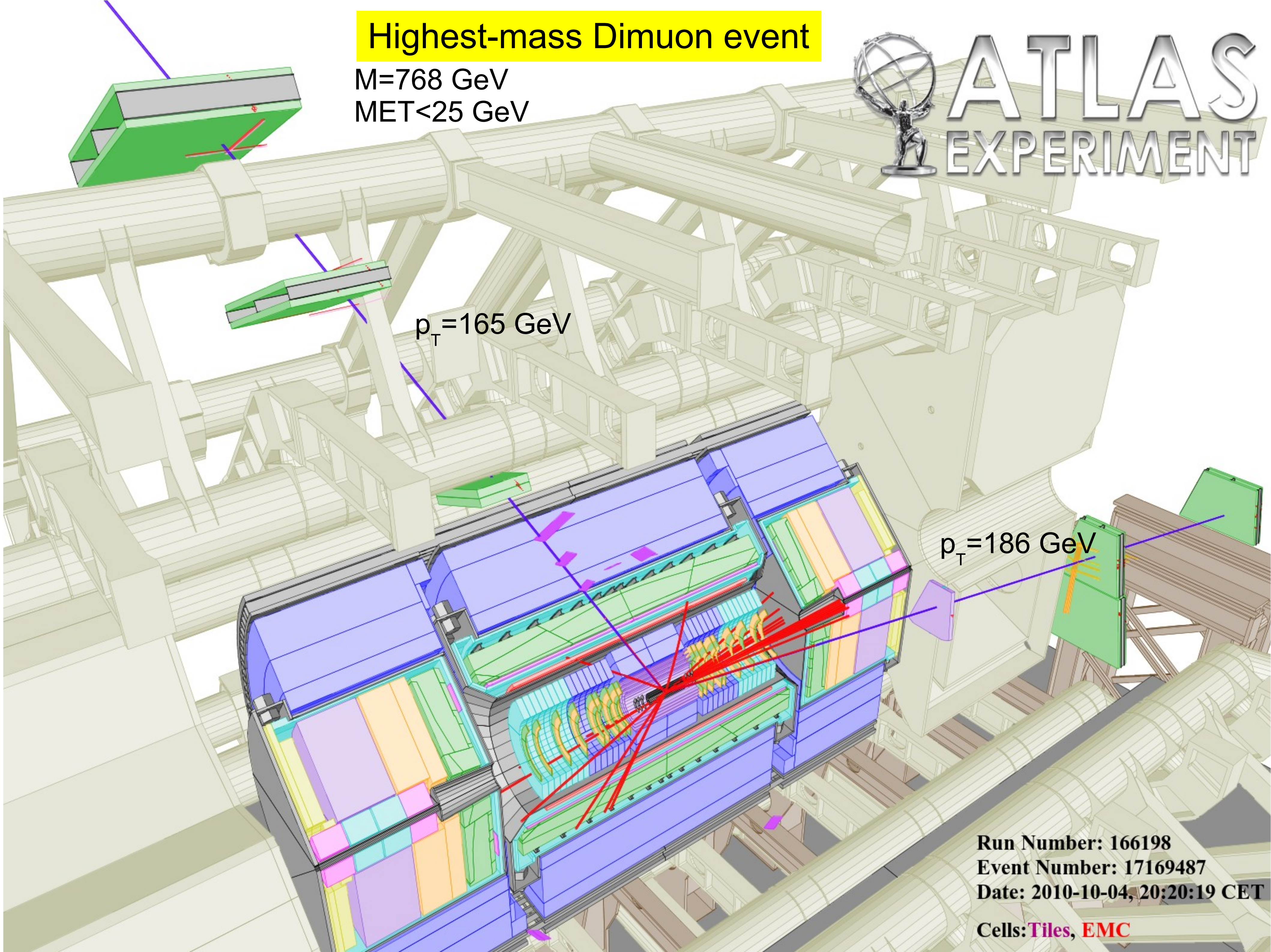
arXiv:1103.6218







Highest-mass Dimuon event



Conclusions

- Atlas took 41 pb^{-1} good for b-physics analysis in 2010

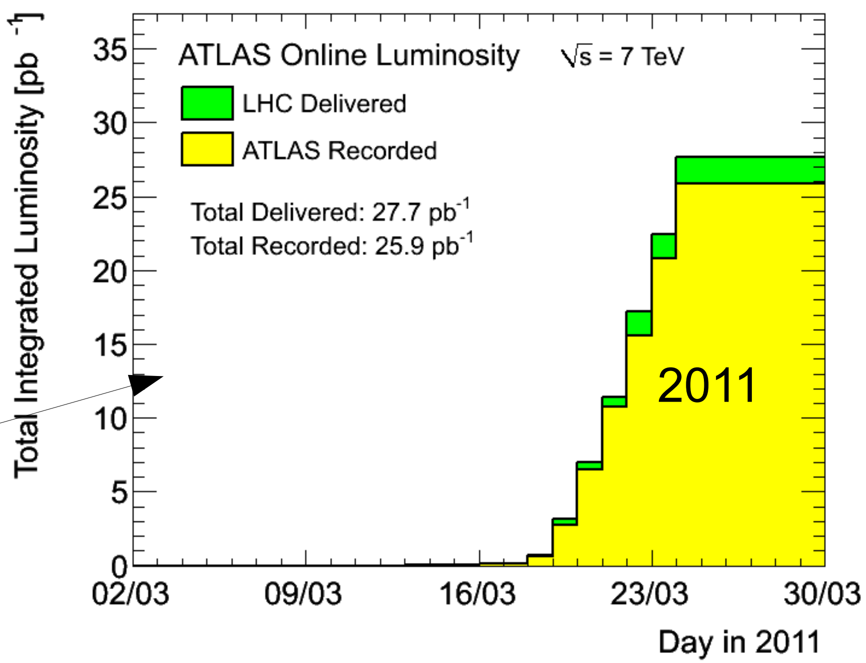
- Muon reconstruction in good shape and well understood:
  - efficiency at plateau 98-99% in agreement with MC
  - pion fake probability <0.3%
  - close to final resolution at high mass

- Triggers:
  - single muon triggers used for first analyses
  - dimuon trigger:
    sample of ~850k J/ψ and ~44k Υ(1S) available using dimuon triggers

- Dimuon composition:
  capability to measure/reduce "fake muon" contamination in data

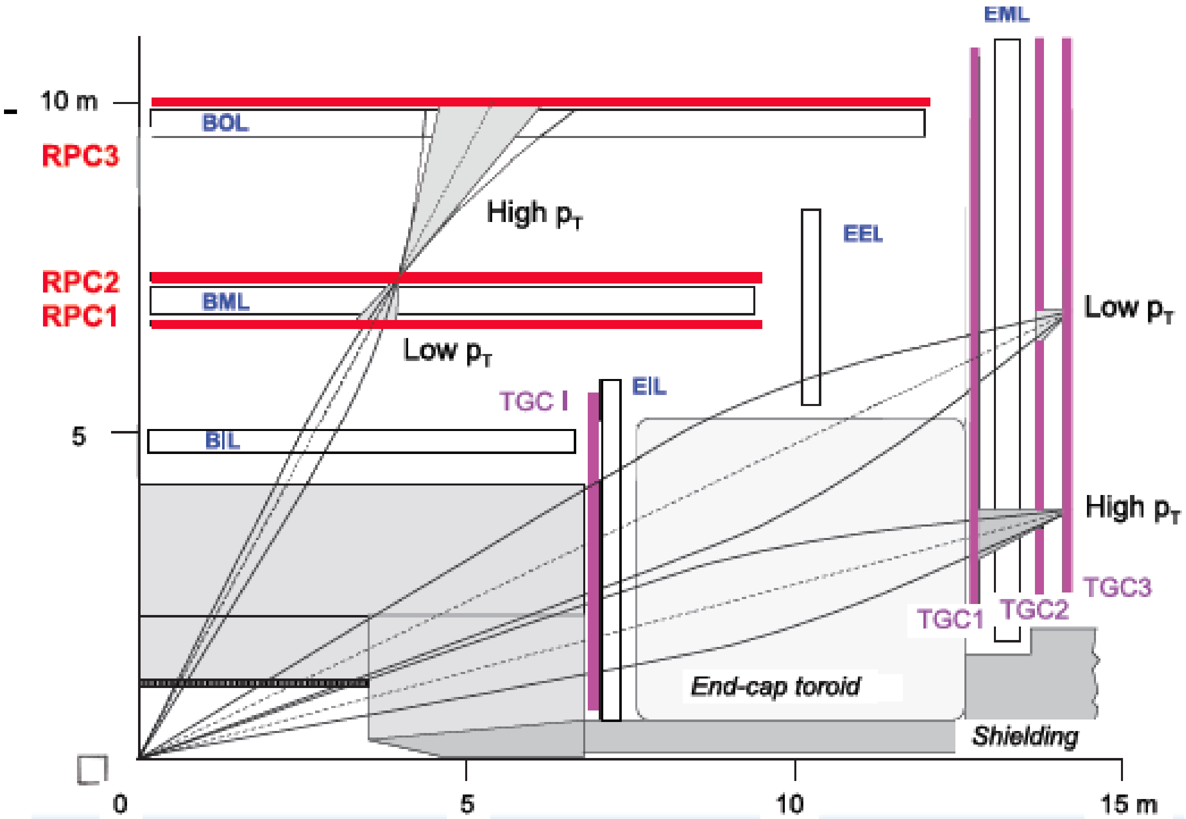
- Large mass: limits on Z'

2011 data arriving



EXTRAS

Muon L1 trigger



After Same-Charge subtraction

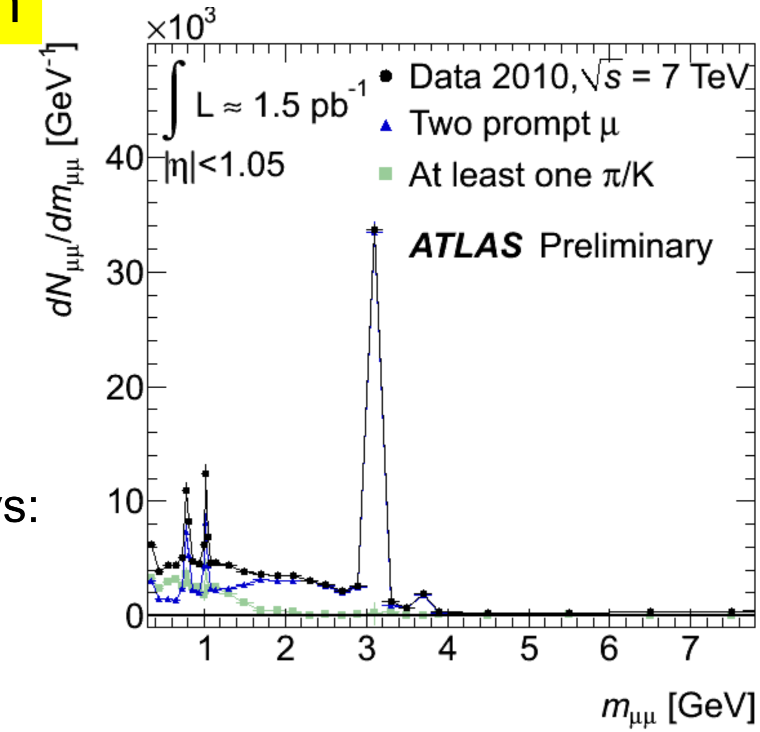
- Same results but subtracting SC from OC
  Fake contribution is expected to be charge-symmetric

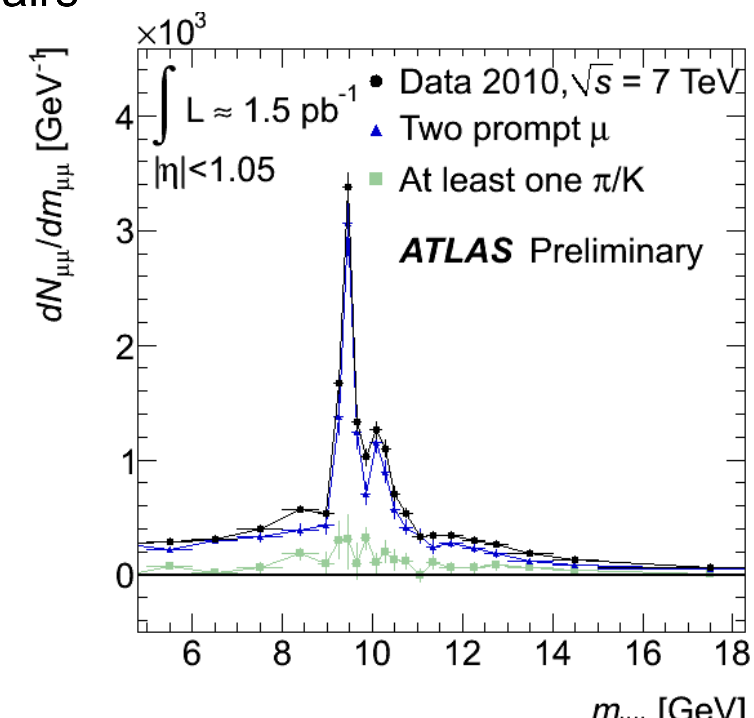
- Fake contribution after SC subtraction at m<1.5 GeV
  true and fake muon from same decay chain
  e.g. $D^0 \to \mu^+ \nu$ ($K^- \to \mu X$)

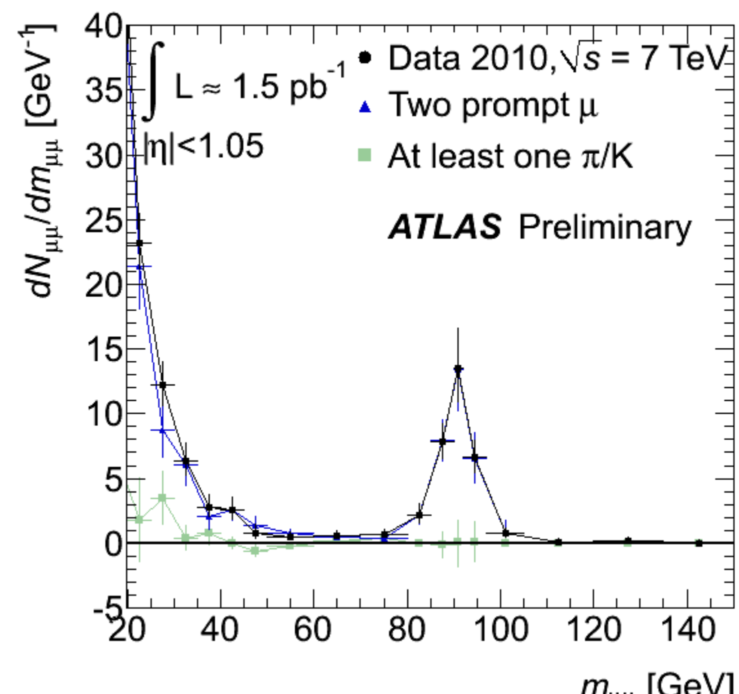
- Prompt contribution for m<3 GeV from B cascade decays:
  $B \to \mu \nu$ ($D \to \mu \nu X$)

- Continuum from ($c \to \mu^+ X$, $\bar{c} \to \mu^- X$) and ($b \to \mu^- X$, $\bar{b} \to \mu^+$)
  and from Drell-Yan pairs

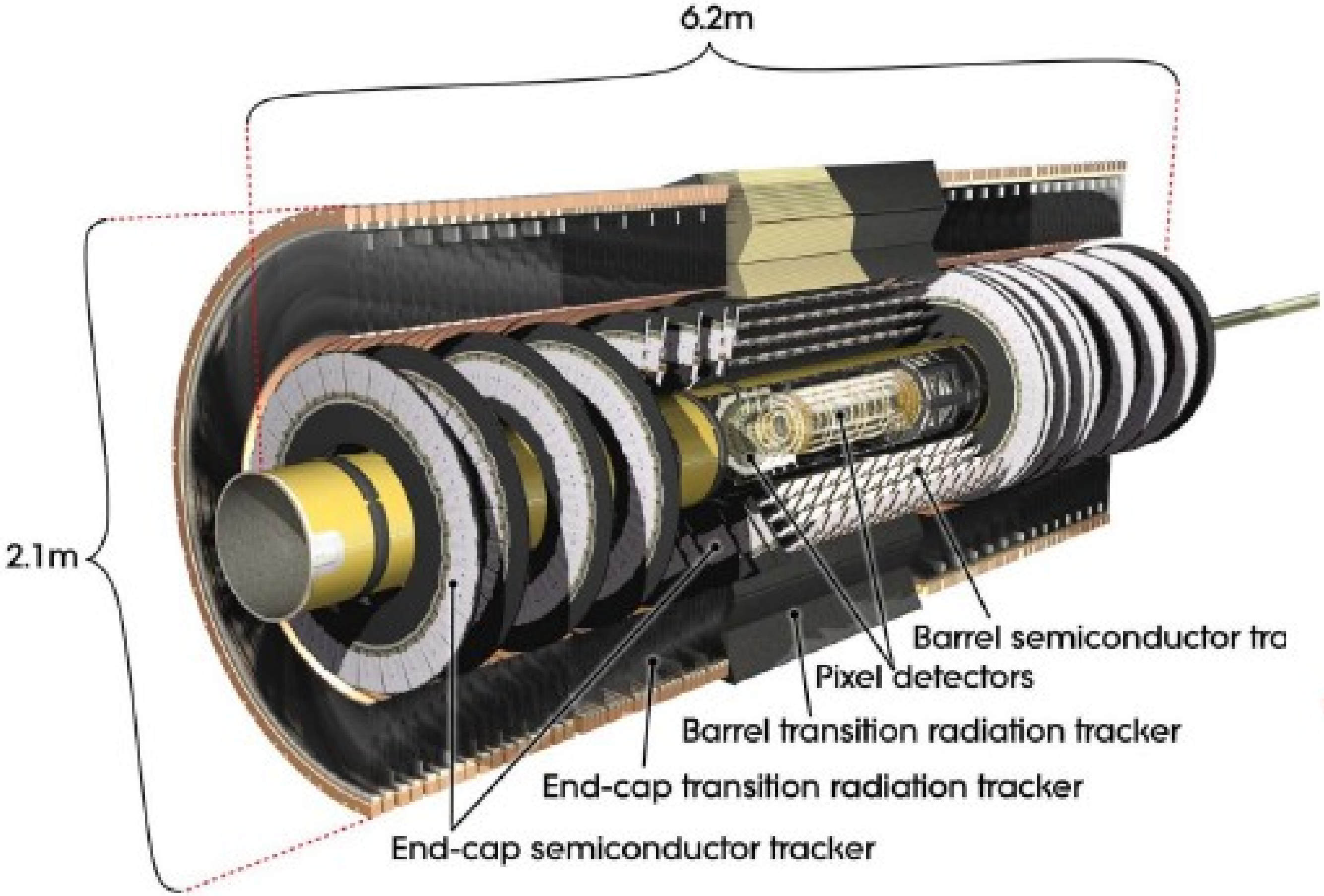
- Peaks from onia
  and Z







Inner Detector



Coverage: $|\eta_{Si}|<2.5$

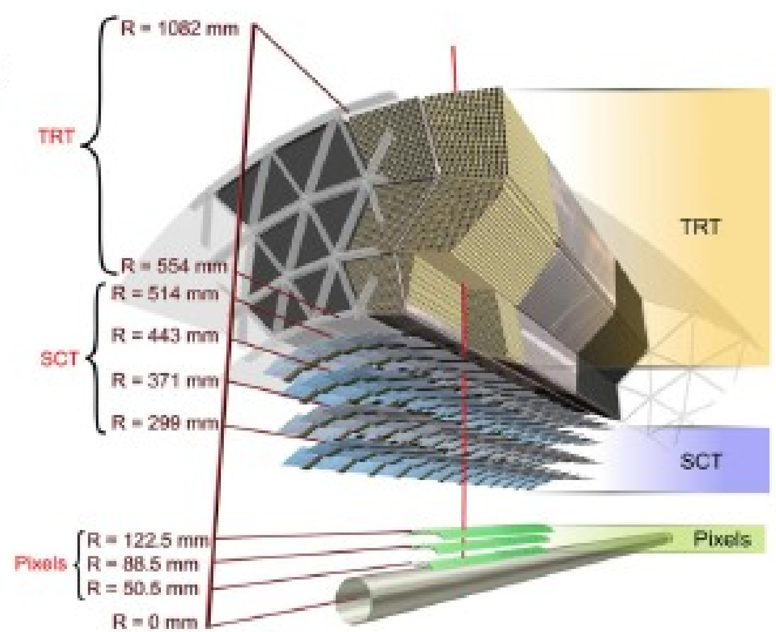
$|\eta_{TRT}|<2.0$

2 T Solenoid field

Pixel: 80M channels

SCT: 6M channels

TRT: 350k Xe-filled straws



Precise Tracking and Vertexing

e/π separation

Momentum Resolution: $\sigma/p_T \sim 3.8\text{x}10^{-4}\, p_T\,(\text{GeV}) \oplus 0.015$