



# Performance of muon and tau identification at ATLAS

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On behalf of ATLAS collaboration

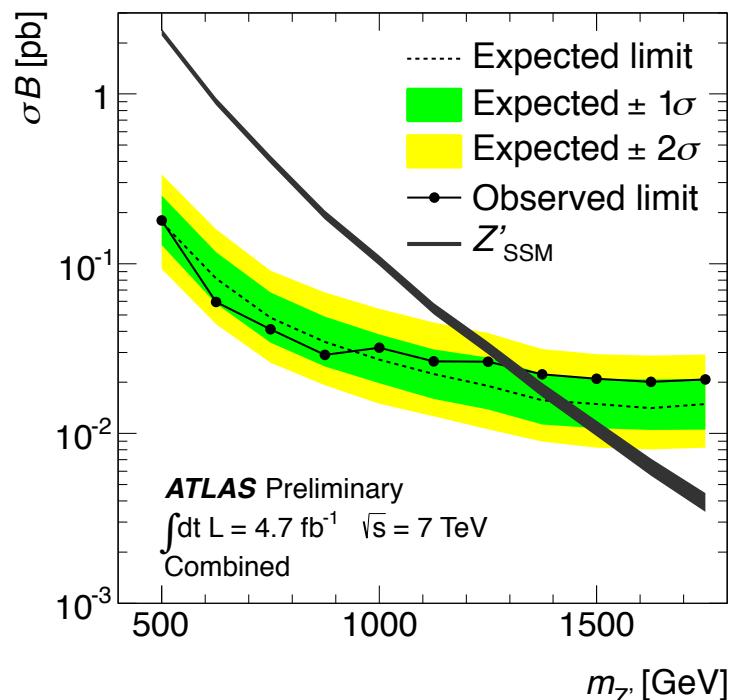
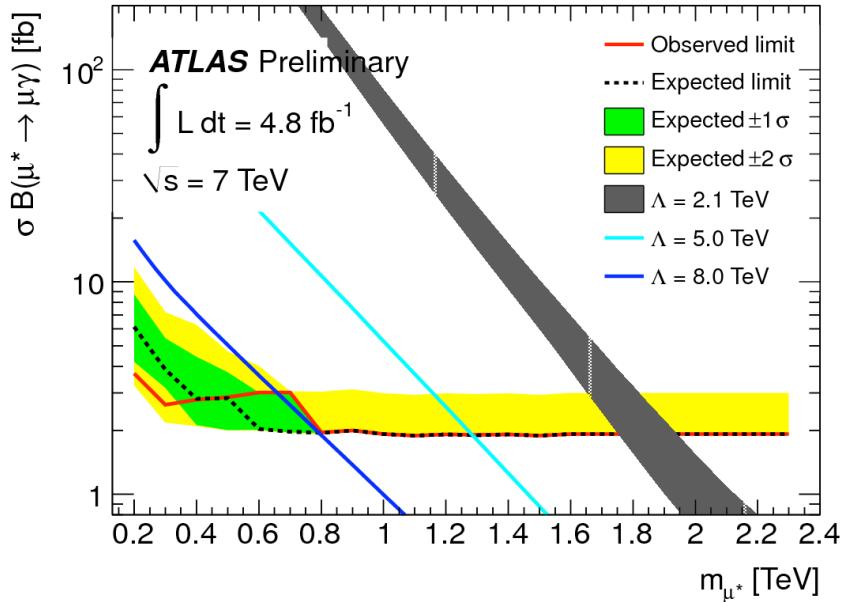
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Melbourne

# Outline

- ATLAS detector
- Muon
  - Various types
  - Reconstruction and isolation efficiencies
  - Momentum resolution
- Hadronic tau
  - Decays
  - Reconstruction and identification efficiencies
  - Energy scale and uncertainty

# Physics with muons and taus

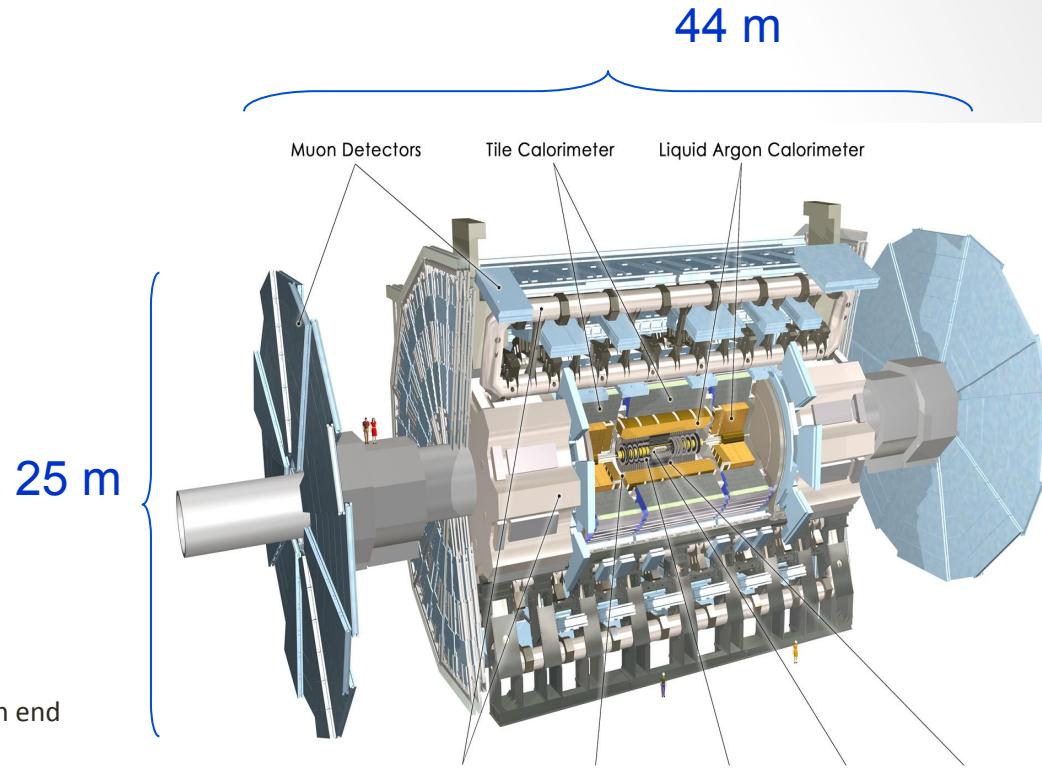
- Intense physics program in ATLAS
  - Standard Model
    - Electroweak: W, Z and top quark decays
    - Tau polarization
    - Higgs boson searches



- Supersymmetry
  - Neutral Higgs: A/H/h-
  - Charged Higgs
  - Models with stau being the lightest lepton
- Exotics
  - $Z'$ ,  $W'$
  - Leptoquarks

# ATLAS Detector

- A general purpose detector
- Inner detector (ID)
  - Pixel
  - Silicon microstrip tracker (SCT)
  - Transition radiation tracker (TRT)
- Solenoid
  - 2T magnetic field
- Calorimeter
  - Electromagnetic (EM)-Liquid Argon (LAr)
  - Hadronic (HAD)
    - scintillating tiles in the central barrel, LAr in end caps (EC)
- Muon Spectrometer (MS)
  - Monitored drift tubes (MDT) and cathode strip chambers (CSC) used for position measurement in bending plane
  - Resistive plate chambers (RPC) and thin gap chambers (TGC) used for triggering and position measurement in non-bending plane
- Three large superconducting toroids
  - One barrel and two EC
  - Eight-fold azimuthal symmetry around calorimeter
  - 0.5T magnetic field



$\eta \equiv -\ln \tan(\theta/2)$ ; polar angle  $\theta$  is the angle from the beam axis

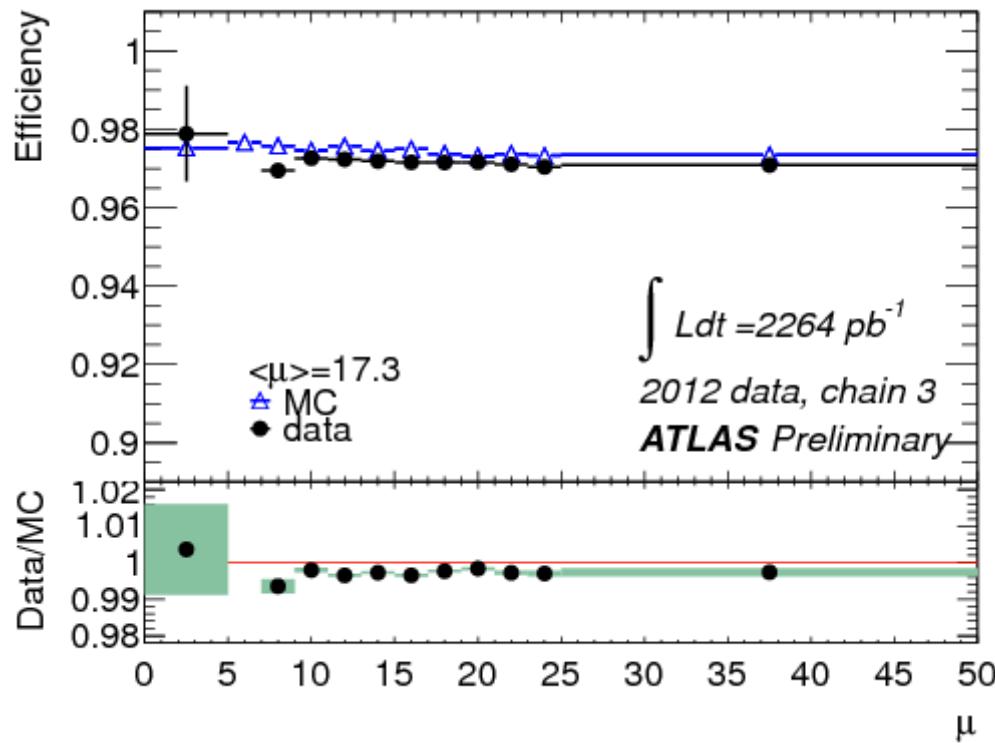
Detector component	$\eta$ coverage	
	Measurement	Trigger
Tracking	$\pm 2.5$	
EM calorimetry	$\pm 3.2$	$\pm 2.5$
Hadronic calorimetry (jets) barrel and end-cap forward	$\pm 3.2$	$\pm 3.2$
	$3.1 <  \eta  < 4.9$	$3.1 <  \eta  < 4.9$
Muon spectrometer	$\pm 2.7$	$\pm 2.4$

# Muon types in ATLAS

- Combined (CB)
  - coverage:  $|\eta| < 2.5$
  - inner detector (ID) and muon spectrometer (MS) contribute to momentum accuracy
  - best momentum resolution
- Stand-alone (SA)
  - coverage:  $|\eta| < 2.7$
  - high momentum resolution
  - momentum from MS
- Segment tagged (ST)
  - coverage:  $|\eta| < 2.5$
  - momentum from ID
  - needed for low pT to fill acceptance gap at  $\eta \approx -1.2$
- Calorimeter tagged (CT)
  - available for  $|\eta| < 2.5$
  - lowest purity
  - uniform efficiency near MS acceptance gap at  $\eta \approx 0$

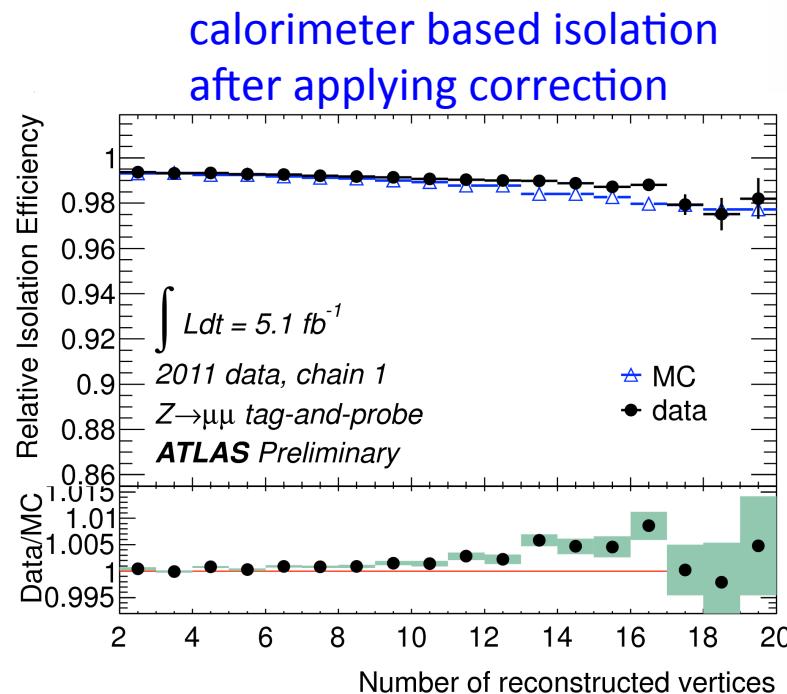
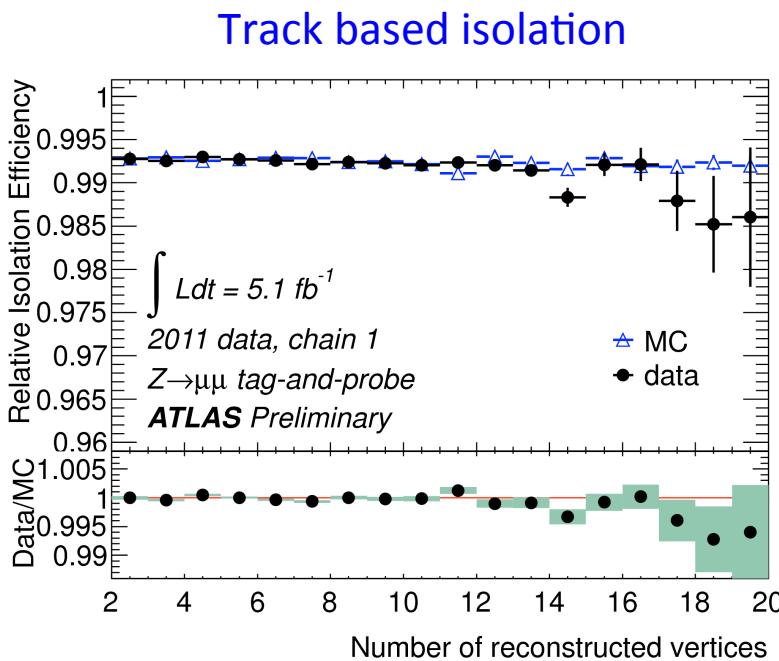
# Muon reconstruction efficiency

- Tag and probe selection
  - One good muon reconstructed in ID and MS selected as tag
  - Second object identified by one of the systems taken as probe muon if invariant mass of two muons is close to
    - $J/\psi$  mass for low  $p_T$  range
    - $Z$  boson mass for high  $p_T$  range
- Efficiency = fraction of probe objects identified as muons



# Muon isolation efficiency

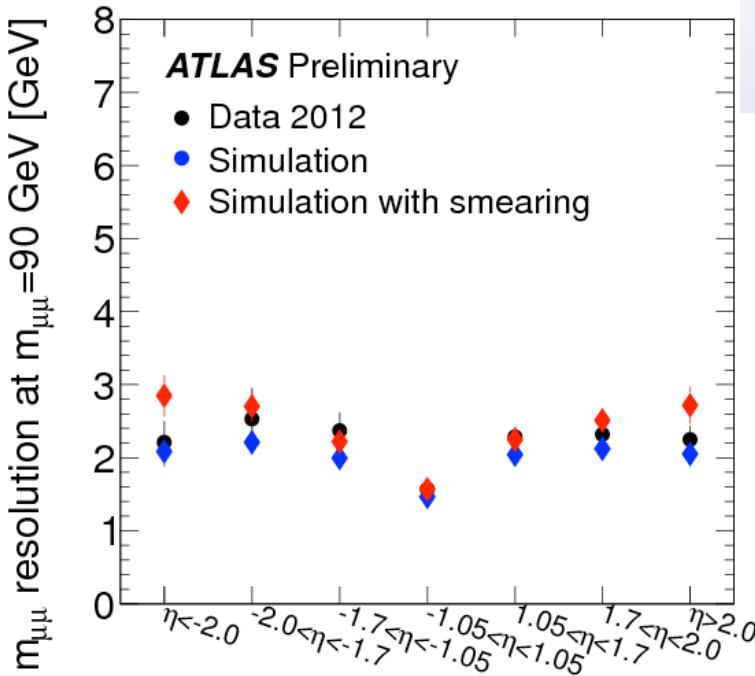
- Muons required to be isolated to suppress background in many analyses
  - Calorimeter based isolation  $\Sigma E_t(\Delta R < 0.3)/pt < X$ 
    - Corrections applied to remove pile-up dependence
  - Track based isolation  $\Sigma p_t(\Delta R < 0.3)/pt < Y$ 
    - Pile-up robust



# Muon momentum resolution

- Dimuon mass resolution
  - Combined muons from Z boson decays
  - Resolution: width of Gaussian convoluted with dimuon mass resolution at generator level
  - Fit range for  $m(\mu\mu)$ : [75 GeV, 105 GeV]

Mass resolution for combined muons



MS resolution:

$$\frac{\sigma(p)}{p} = \frac{p_0^{MS}}{p} \oplus p_1^{MS} \oplus p_2^{MS} p$$

ID resolution:

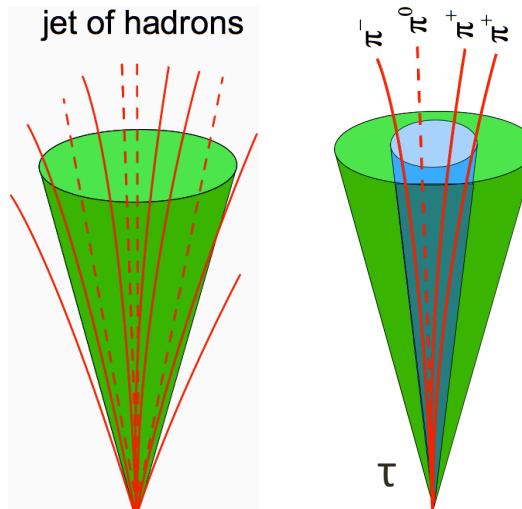
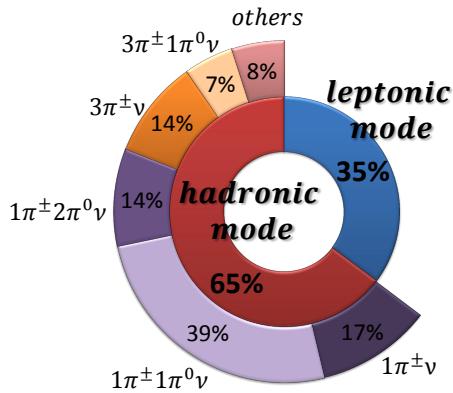
$$\frac{\sigma(p)}{p} = p_1^{ID} \oplus p_2^{ID} p_T$$

## Main contributions and results for barrel

	p <sub>0</sub> (TeV) Energy losses in calorimeters	p <sub>1</sub> (%) Multiple scattering	p <sub>2</sub> (TeV <sup>-1</sup> ) Intrinsic resolution
ID		1.60 ± 0.32	0.49 ± 0.04
MS	0.23 ± 0.01	3.75 ± 0.10	0.24 ± 0.04

# Decays and reconstruction of tau

- Hadronic decays of tau: 65%
- Reconstruction seeded by anti-kt jets( $R=0.4$ )
  - $p_T > 10 \text{ GeV}$ ,  $|\eta| < 2.5$
  - calibrated 3D topological clusters
  - good quality tracks with  $p_T > 1 \text{ GeV}$
  - discriminating variables
    - combined information from calorimeter and tracking
    - input to multi-variate algorithms



Topological clustering

0	0	0	0	0	0	0	0
0	0	0	2	2	0	0	0
0	0	2	2	2	2	0	0
0	0	2	2	2	2	0	0
0	2	2	4	2	0	0	0
0	0	2	2	2	0	0	0
0	0	0	2	0	0	0	0
0	0	0	0	0	0	0	0

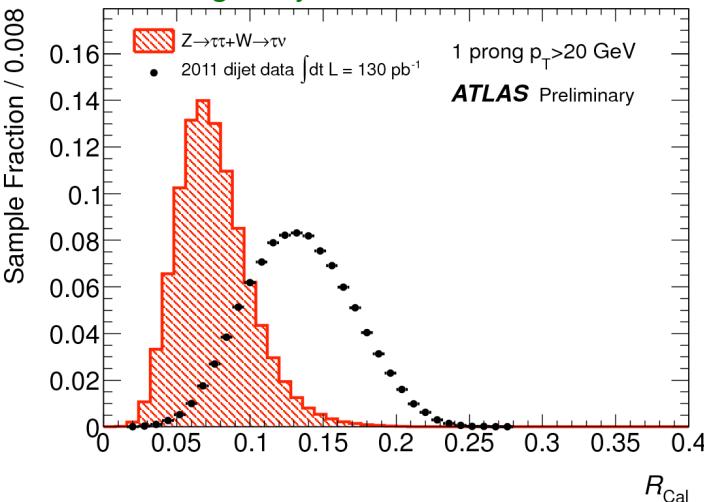
phi

eta

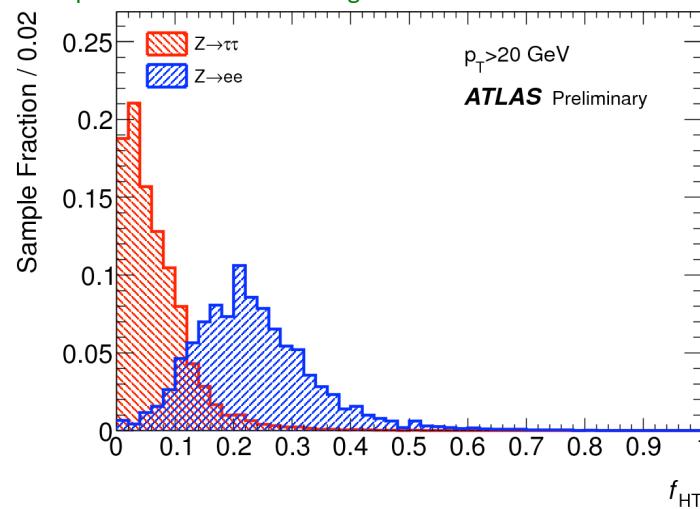
# Tau identification

Decay properties of tau	Detector information used
Collimated decay products	Jet width in tracker and calorimeter
Leading charged hadron	Leading track
No gluon radiation	Isolation
Low invariant mass	Invariant mass of tracks and clusters
Lifetime	Impact parameter, secondary vertex
EM energy fraction different from electrons	Longitudinal position of energy deposits
EM component from $\pi^0$	LAr strip
Less transition radiation than electrons	TRT

Energy weighted calorimeter radius provides discrimination against jets

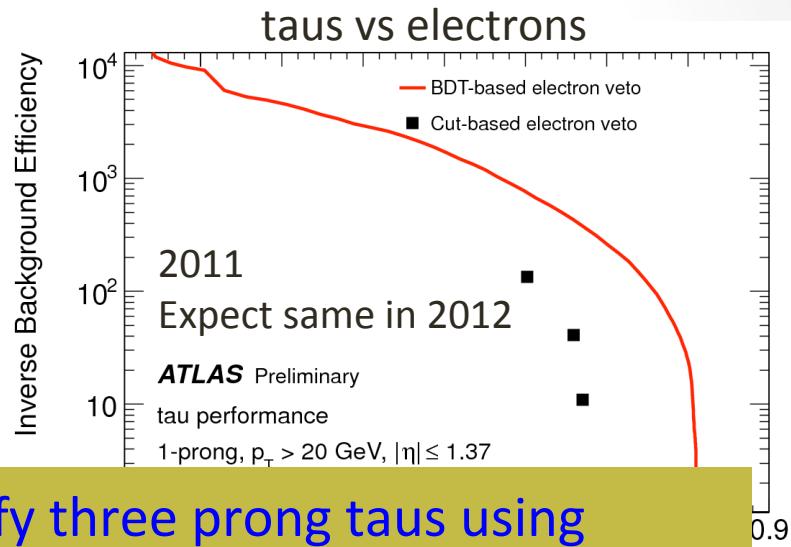
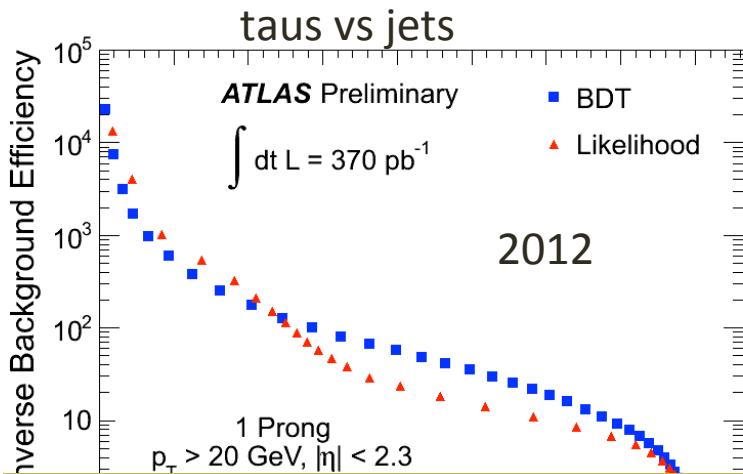


Ratio of high threshold to low threshold hits in TRT for leading track provides discrimination against electrons

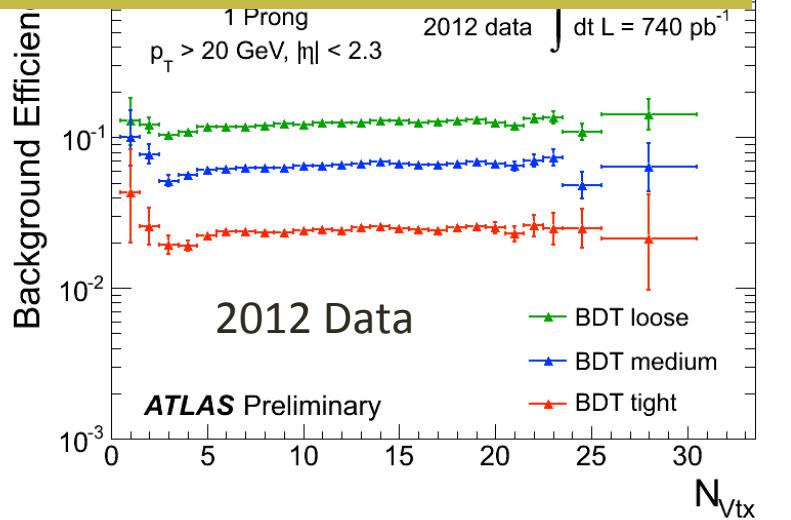
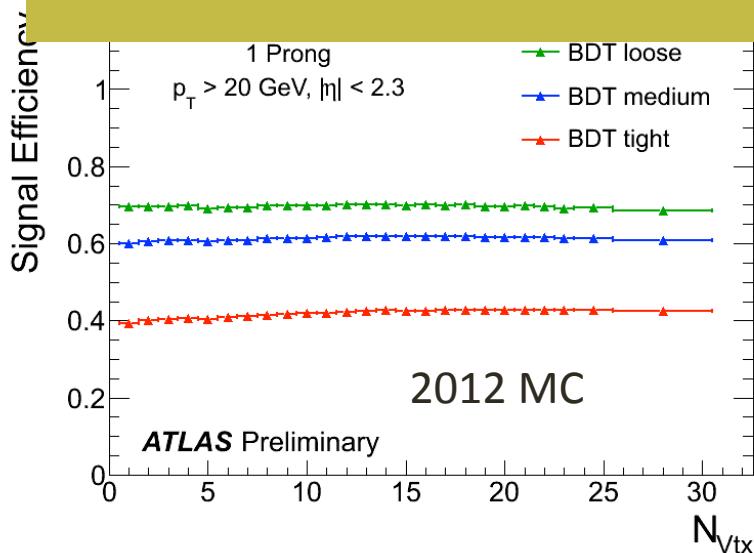


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# Performance of (1P) tau identification

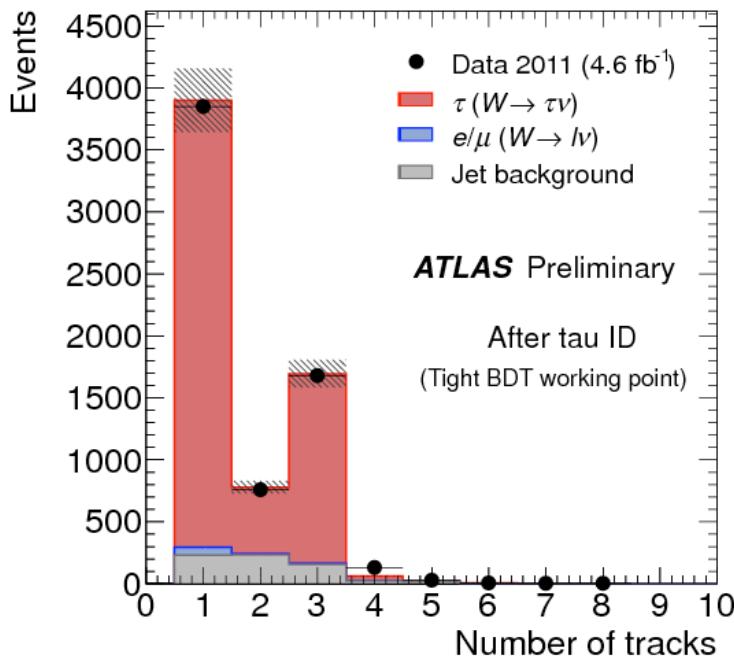


Same procedure applied to identify three prong taus using additional information on lifetime



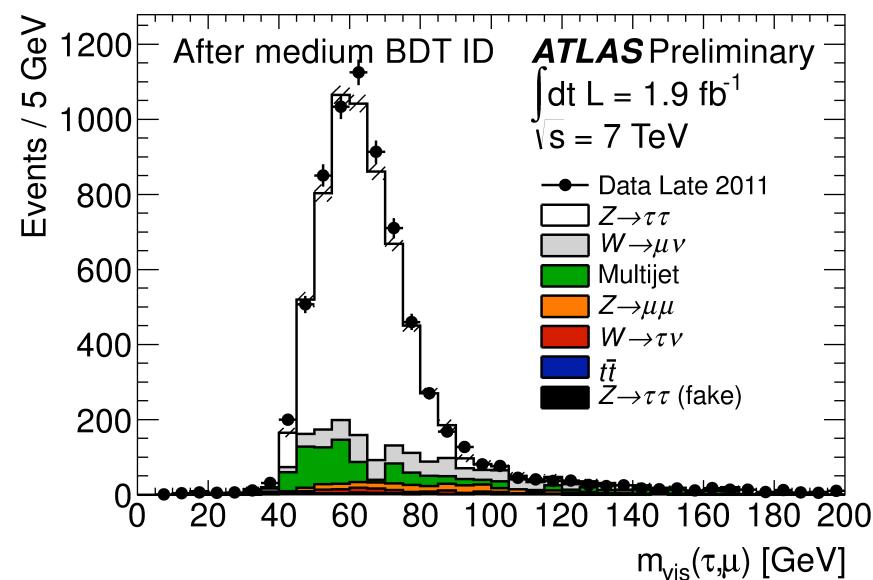
# Tau ID efficiency measurement

- Efficiency measured in data using
  - $Z \rightarrow \tau_\mu \tau_h$  and  $W \rightarrow \tau \nu$  events with tag and probe selection
    - require events to pass muon/MET trigger to tag a tau
    - probe hadronically decaying tau
  - Data/MC scale factors (SF) consistent with 1



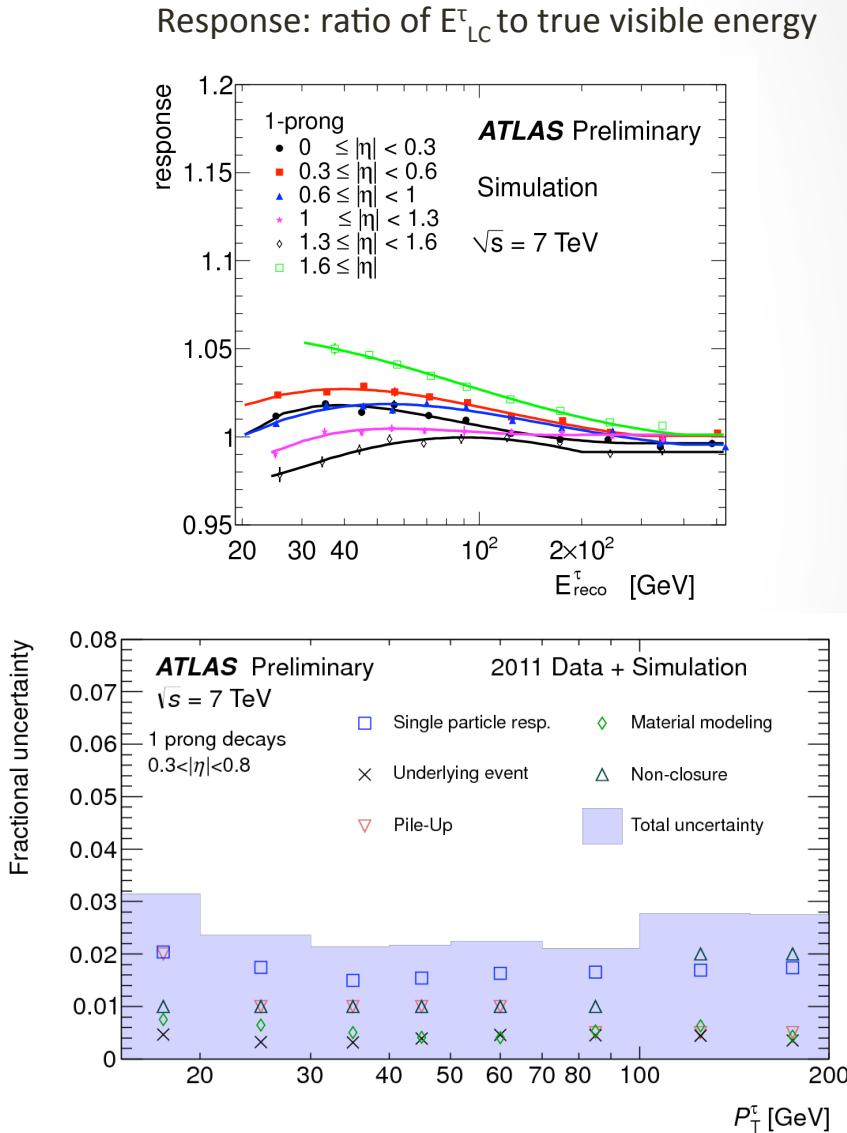
% uncertainty on data/MC SF

Tau ID	$p_T > 22$ GeV		
	Inclusive	1-prong	3-prong
LLH Loose	5	4	10
LLH Medium	4	5	10
LLH Tight	5	5	11
BDT Loose	4	4	8
BDT Medium	4	5	8
BDT Tight	4	4	7



# Tau energy scale and uncertainty

- Topological clusters calibrated using local hadron calibration (LC)
- LC accounts for
  - Non-compensation of calorimeters
  - Energy deposited outside the reconstructed cluster
  - Dead material
- LC weights derived from MC
- Additional corrections applied to restore true energy value (TES)
- Uncertainty on TES
  - 3-5% depending on eta and prong of tau
- Reduced uncertainty due to inclusion of
  - particle responses from isolated single hadrons and combined test beam data instead of MC samples



# Conclusions

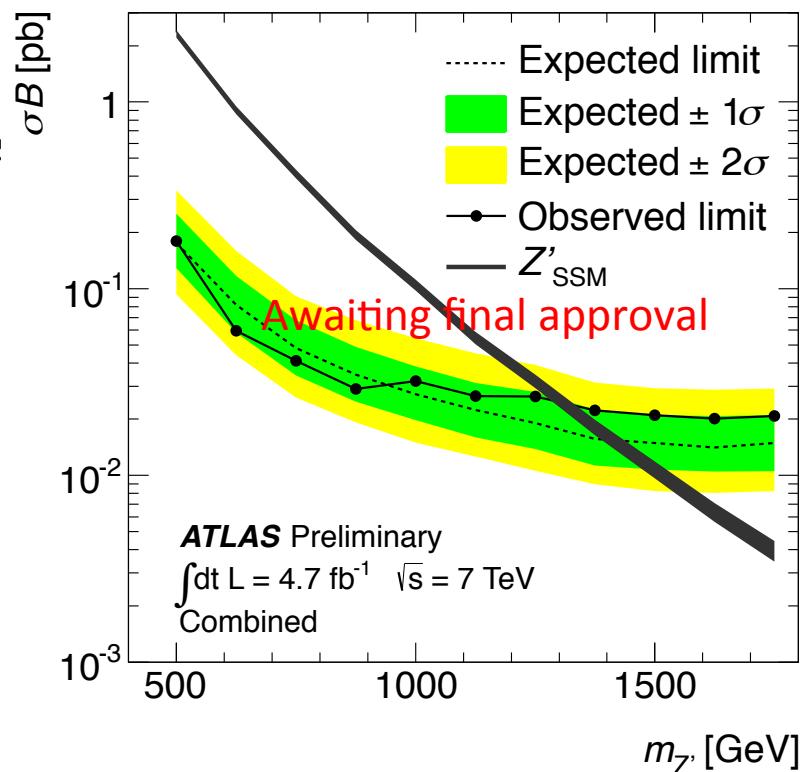
- ATLAS has extensive physics program with muons and taus
- Muon and tau reconstruction are well understood
- Performance of algorithms robust against pile-up
- Efficiencies measured separately for low and high  $p_T$  objects
- Continuous monitoring of performance and addition of improvements

# Tau CP CONF Notes

- <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-054/>
- <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-152/>

# Physics with muons and taus

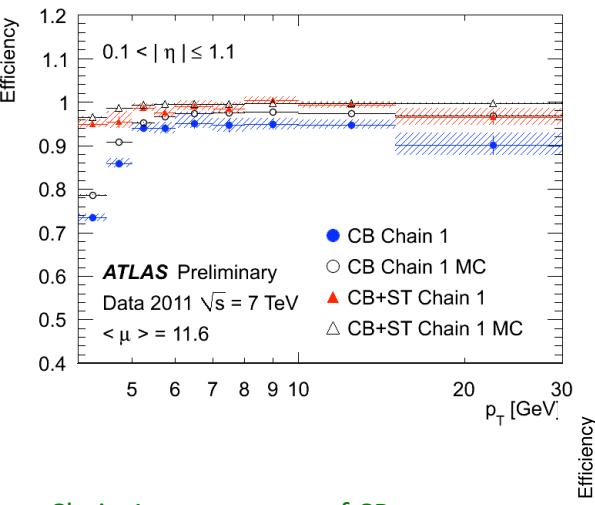
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  - Standard Model
    - Electroweak: W, Z and top quark decay:
      - Phys.Rev.D 84 (2011) 112006
      - Phys.Lett.B 706 (2012) 276-294
      - [arXiv:1205.2067v1](#)
      - [arXiv:1205.2531v1](#)
      - [arXiv:1204.1648v1](#)
    - Tau polarization
      - [arXiv:1204.6720v1](#)
    - Higgs boson searches
      - [arXiv:1206.5971v1](#)
  - Supersymmetry
    - Neutral Higgs: A/H/h-
      - Phys.Lett.B 705 (2011) 174-192
    - Charged Higgs
      - [arXiv:1204.2760v1](#),
      - ATLAS-CONF-2012-011
    - Models with stau being the lightest lepton
      - [arXiv:1203.6580v1](#)
      - [arXiv:1204.3852v2](#)
      - ATLAS-CONF-2012-035



- Exotics
  - $Z'$ ,  $W'$
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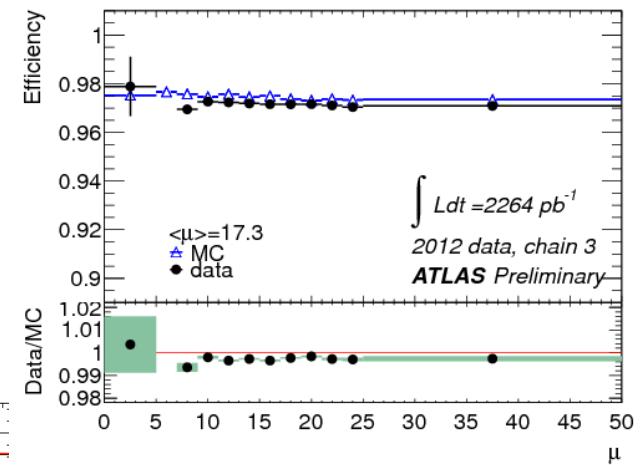
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Chain 1: momentum of CB muon is statistical combination of measurements in ID and MS

Chain 2: a combined track fit to all muon hits in ID and MS is performed



Chain 3: unified chains 1 and 2

