Standard Model physics with taus in ATLAS

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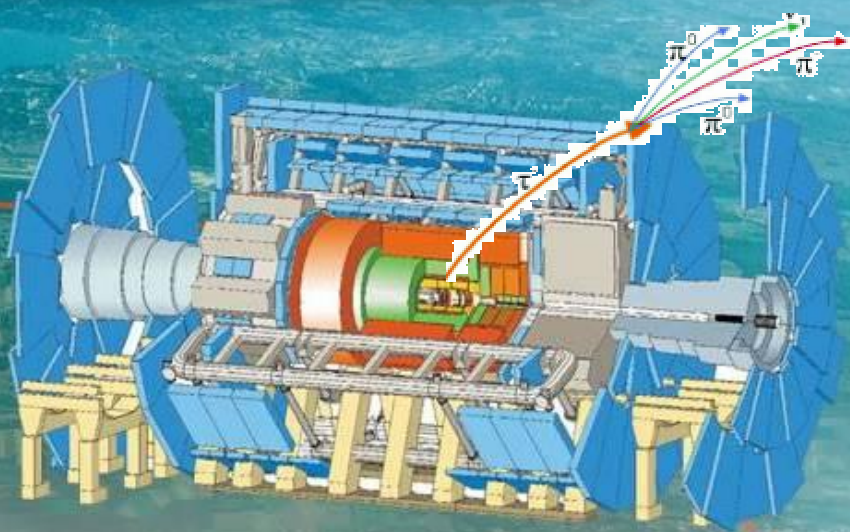


Why we are interested in taus?

Tau leptons play an important role in the physics program of the ATLAS experiment as they are „tools" in many areas

- Tau leptons provide useful signatures in searches for new phenomena like
  - Higgs bosons
  - Supersymmetry
  - Exotics scenarios
- Standard Model processes with taus in final states will be also the key
  - to understand the detector (for example $Z \to \tau\tau$ as golden channel)
  - measurement of Z/W production with taus in final states
    - interesting itself as first time at so high energy
    - background to New Physics searches

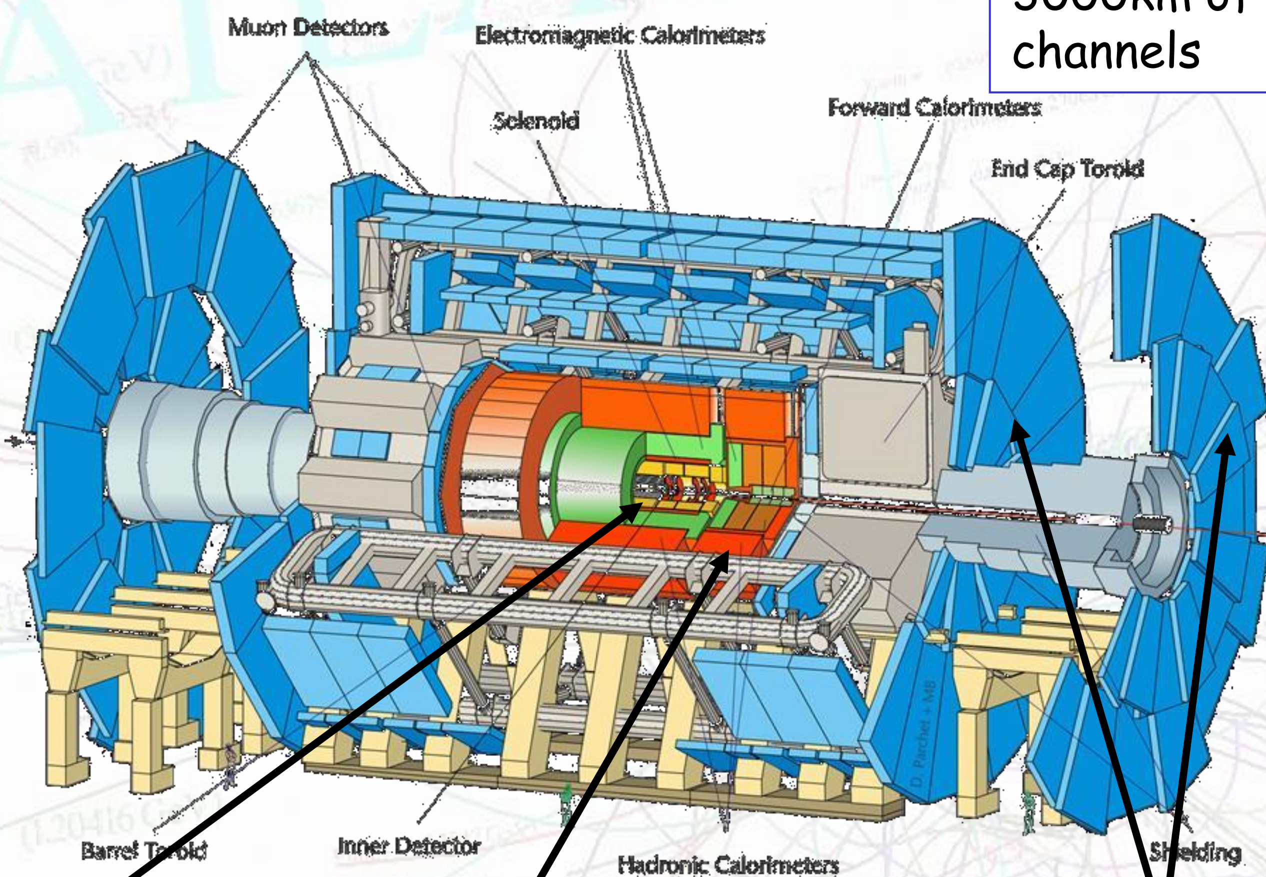
Today

- Few words about hadronic tau reconstruction and identification in ATLAS
- First observation of Z->tautau events (approval of cross-section paper tomorrow)
- First observation W->tau nu (cross-section analysis under approval)
- Some ideas for taus in top – anti top events

ATLAS – A Toroidal LHC ApparatuS

25m diameter, 46m long, weighing 7000T, with 3000km of cables and 10^8 channels

p 3.5TeV



p 3.5TeV

Tracking ($|\eta|<2.5$, B=2T):
- Silicon pixels and strips
- Transition Radiation Tracker

σ/PT=0.05% PT + 1%
(2%@20GeV)
σ(d0)=15 um@20 GeV

Calorimetry ($|\eta|<5$)
EM : Pb-LAr
HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

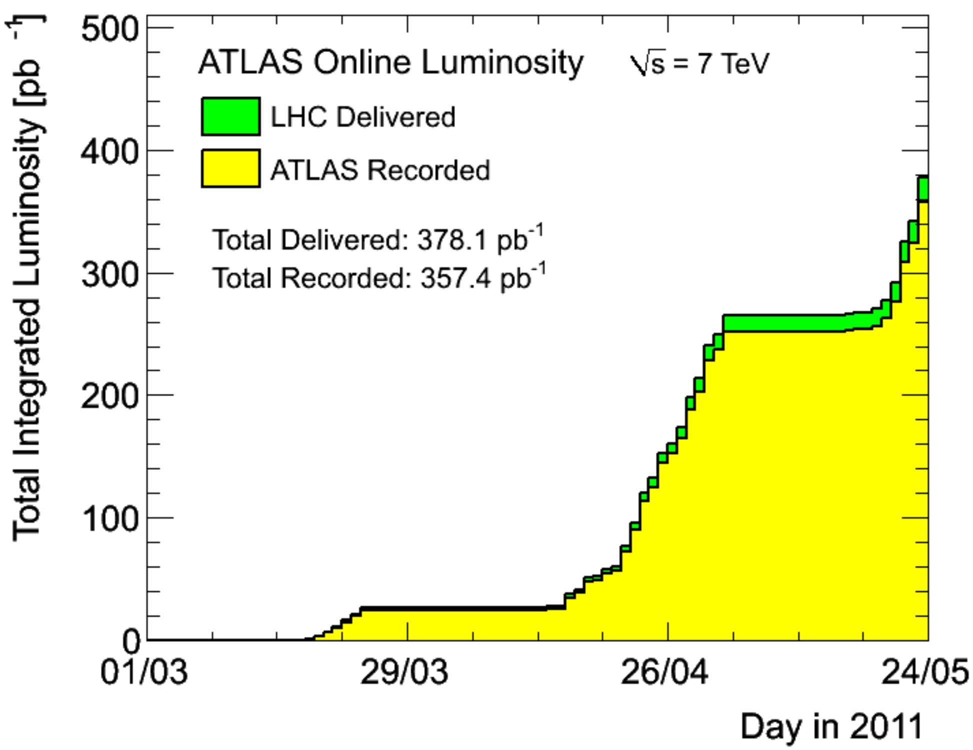
EM :	$\sigma(E)/E = 10\%/\sqrt{E} + 0.7\%$
Hadron :	$\sigma(E)/E = 50\%/\sqrt{E} + 3\%\ (\eta < 3)$
	$\sigma(E)/E = 100\%/\sqrt{E} + 10\%\ (\eta > 3)$

Muon spectrometer ($|\eta|<2.7$, B=4T max)
Toroid magnet system with precision and trigger chambers

σ/PT=2-7%

Current status of detector operation

- LHC and ATLAS are back in business after the technical stop
  - since last Thursday we collect again physics data
- New record!
  - peak luminosity: **1.1 x 10^{33}** achieved at ~2AM on Monday 23 May
- Total integrated luminosity in 2011: ~ **387 pb^{-1}**
- 15-30 pb^{-1} per day over the last few days
- In the next weeks/months can reach 5 x 10^{33}
  - average ~20 events pile-up !?



- The LHC has performed over 2010 in a superb way at 7 TeV collision energy, and delivered a good sample of data in stable pp beam operation (~ 48 pb^{-1} integrated luminosity)
- Unfortunately all results I can show you today are based on 2010 data and some on small fraction of 2010 luminosity
  - a lot of interesting results under approval just now!

Reconstruction of hadronic tau decays

$\tau^- \to$	$e^- \bar{\nu}_e \nu_\tau$	17.8%	leptonic 35.2%
	$\mu^- \bar{\nu}_\mu \nu_\tau$	17.4%	
	$\pi^- \pi^0 \nu_\tau$	25.5%	1 prong 49.5%
	$\pi^- \nu_\tau$	10.9%	
	$\pi^- 2\pi^0 \nu_\tau$	9.3%	
	$K^- (N\pi^0)(NK^0) \nu_\tau$	1.5%	
	$\pi^- 3\pi^0 \nu_\tau$	1.0%	
	$\pi^- \pi^- \pi^+ \nu_\tau$	9.0%	3 prong 15.2%
	$\pi^- \pi^- \pi^+ \pi^0 \nu_\tau$	4.6%	

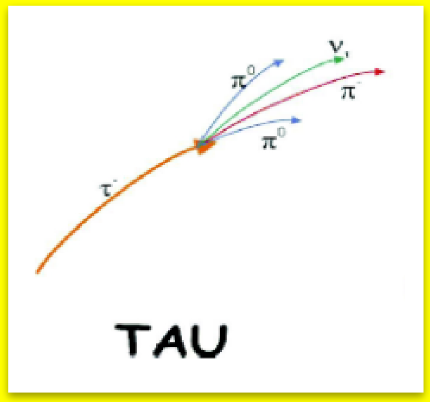
mass = 1.78 GeV
cτ = 87 μm

- Because of short lifetime, it is difficult to separate tau ->e/μ from prompt e/μ
  - we focus on reconstruction of hadronic decays of tau leptons

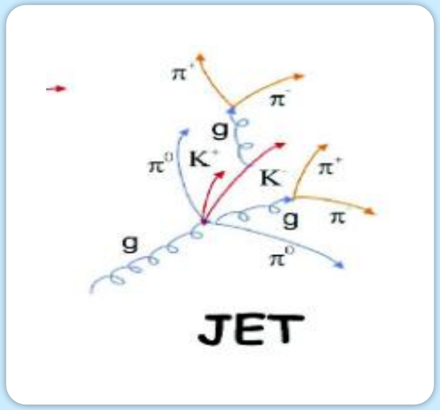
Main sources of fake taus

- QCD jets
- Electrons
- Muons

Main challenge: separate out a clean sample of taus from the overwhelming QCD jet rate!



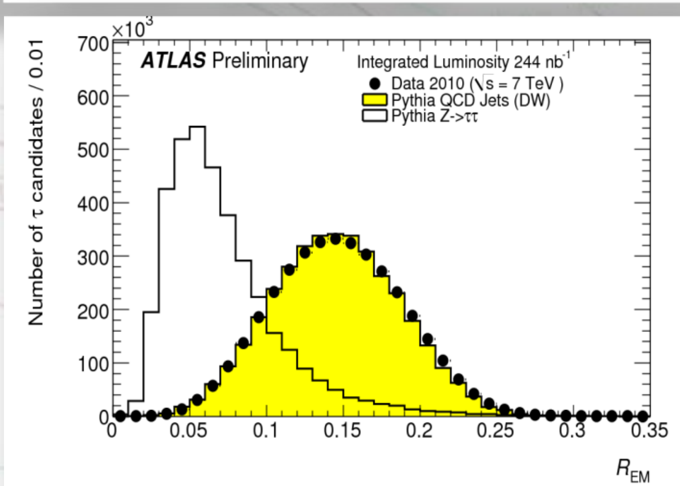
- narrow, collimated
- 1 or 3 tracks
- leading track carries much of tau momentum



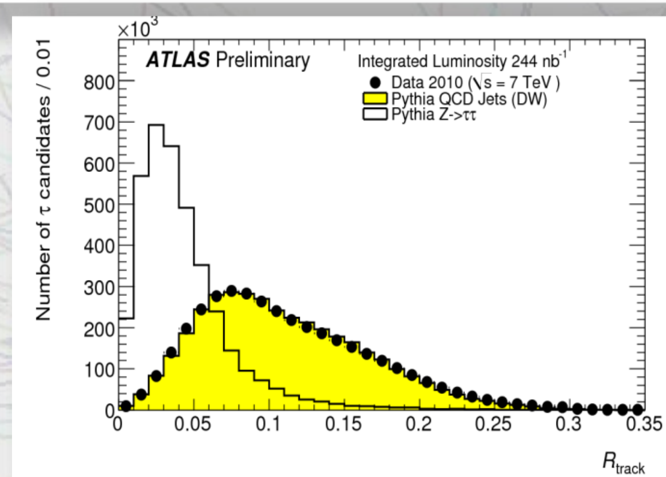
- wide
- can have many tracks
- jet momenta spread over tracks

Tau Identification Method

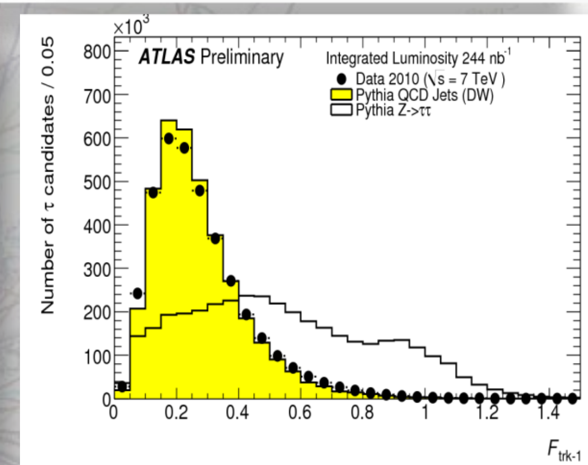
- Identification method for tau candidates used in presented studies is based on simple cuts
- The cut-based ID uses 3 variables: electromagnetic and track radius and leading track momentum fraction



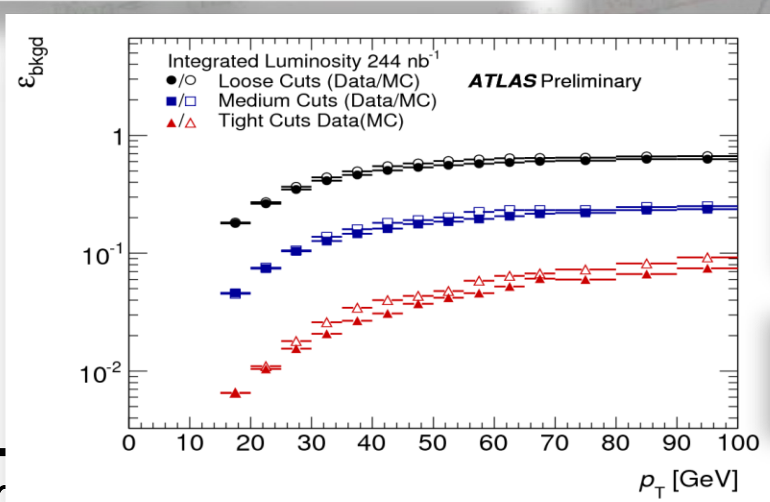
Electromagnetic radius: E_T weighted shower width in EM Calo



Track radius: p_T weighted track width

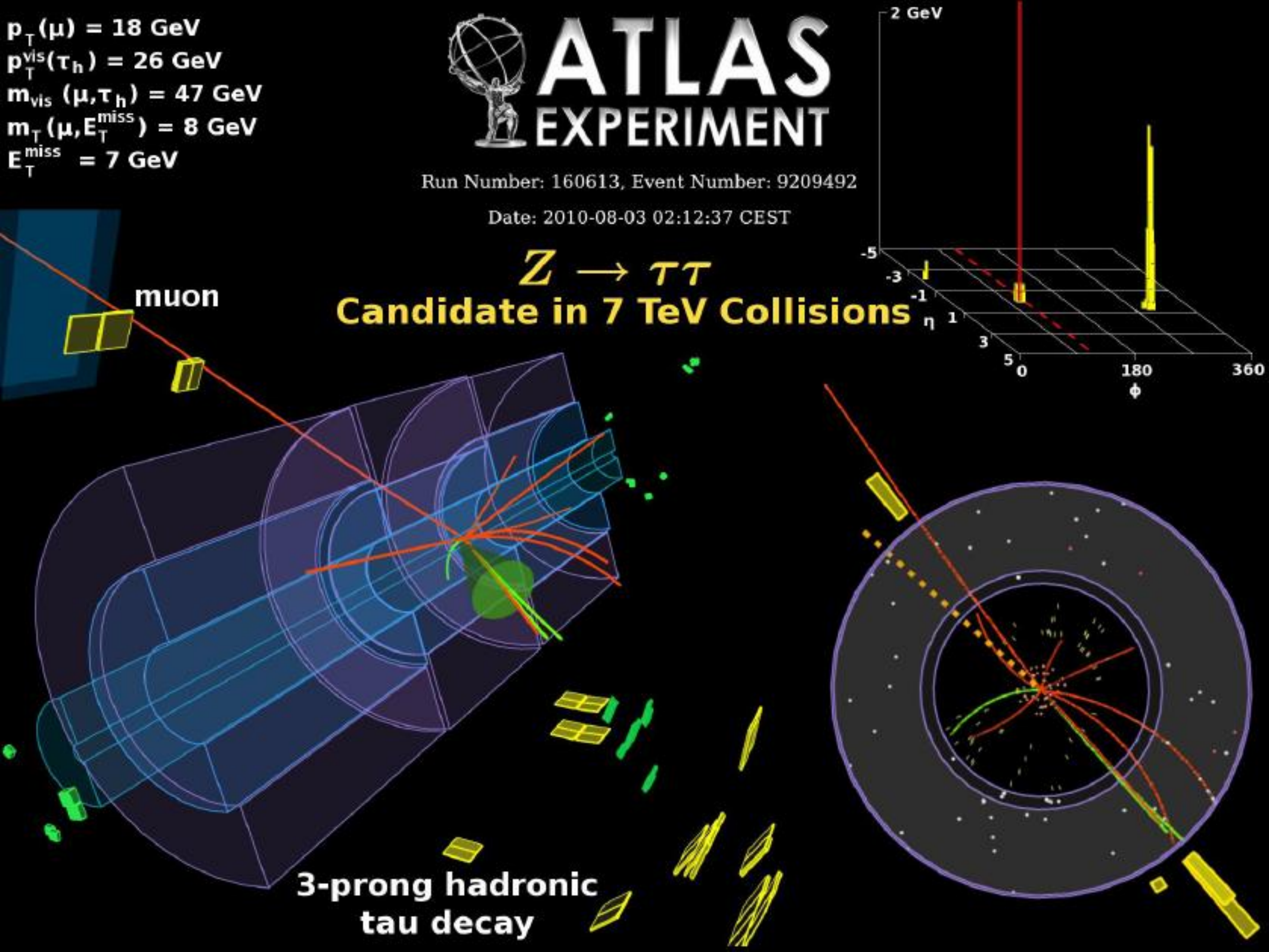


Leading track momentum fraction



Background efficiencies for data and MC samples as a function of reconstructed $p_T(\tau)$

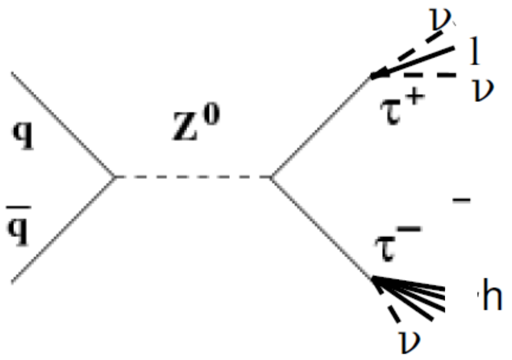
Three selections signal efficiencies 30% (tight), 50% (medium) and 60% (loose) are optimized.

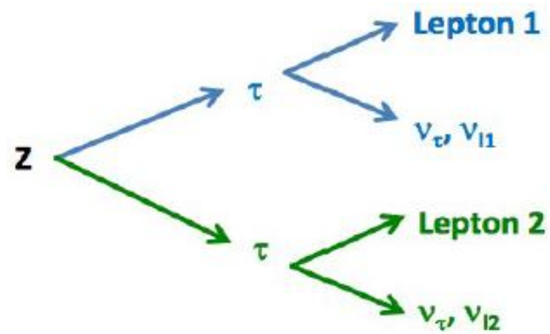

$p_T(\mu)$ = 18 GeV
$p_T^{vis}(\tau_h)$ = 26 GeV
$m_{vis}(\mu,\tau_h)$ = 47 GeV
$m_T(\mu,E_T^{miss})$ = 8 GeV
E_T^{miss} = 7 GeV
ATLAS EXPERIMENT
Run Number: 160613, Event Number: 9209492
Date: 2010-08-03 02:12:37 CEST
$Z \rightarrow \tau\tau$
Candidate in 7 TeV Collisions
muon
3-prong hadronic tau decay
2 GeV
-5
-3
-1
1
3
5
η
0
180
360
ϕ

Z->ττ final states

$Z \to \tau_{lep}\tau_{had}$

• Two decay modes considered for Z->ττ decays: „semileptonic" and fully leptonic
• In „semileptonic" mode we are selecting events with one τ decaying leptonically and other hadronically (σ × BR ~ 0.45 nb),
  • such mode is an important source of hadronically decaying τ leptons
  • one can trigger on the lepton (e/μ) providing an unbiased sample of hadronic τ decays
  • to get a control sample of tau and to measure the tau identification, tau trigger efficiency and tau energy scale
  • invariant mass sensitive to the scale of the missing transverse energy
  • both tau(muon)tau(had) and tau(ele)tau(had) are considered
• In fully leptonic channel lower signal yield, but two clean leptons in final state (σ × BR ~ 0.062 nb)
  • for the observation studies only tau(ele)tau(mu) channel considered
  • for cross-section measurement also tau(mu)tau(mu) -> real challenge because of Drell-Yan background!





• First step towards new measurements was to confidently observe Z→ττ events in data

$Z \to \tau_{lep}\tau_{had}$ process and background sources

$Z \to \tau_{lep}\tau_{had}$

- **Signal:** one of τ's decays hadronically and other to electron or muon.
  - In final state: lepton and τ candidate of opposite charge and missing energy

- **Backgrounds:** ID of hadronic τ decays difficult and suffers from higher fake rates, than from ID of electrons or muons -> most of backgrounds: true lepton with jet misidentified as a hadronically decaying τ
  - **QCD multijets** dominant background due to their very large cross-section
    - lepton may be real (heavy-flavour decays) or fake, while τ is typically a misidentified QCD jet
  - **W+jets** has cross section about an order of magnitude higher than signal
    - lepton and the jet in this process are biased towards having an opposite sign, similarly to the signal.
  - **Z->ee, μμ**
    - one of the leptons fakes a τ candidate, or Z produced with a jet misidentified as a τ candidate and at the same time one of the leptons not reconstructed.
  - **Top anti-top** production, in the semi-leptonic and di-leptonic decay modes
    - may contain a true τ lepton, or else jets or leptons that can fake a τ, as well as at least one real electron or muon. However cross section is small.
  - Contributions from **single-top, diboson production and low-mass $\gamma^*/Z \to \ell\ell$** processes negligible.

Event & Object Selection

$Z \rightarrow \tau_{lep}\tau_{had}$

- Analysis based on collision data at $\sqrt{s}$=7 TeV from March to September 2010 (full 2010 data ~35 pb^{-1})
  - Muon channel: 8.5 pb^{-1}, Electron channel: 8.3 pb^{-1}
- Events required to pass basic beam and data quality requirements
- Events selected using single-lepton triggers, with threshold on the trigger object of p_T(muon) = 10 GeV in the muon channel and E_T(ele) = 15 GeV in the electron channel.
- At least one primary vertex with at least 4 reconstructed tracks
- Tau-jet & MET cleaning cuts to reject candidates caused by out-of-time cosmic events or known noise effects in the calorimeters
- Object Selection -> four distinct steps
  - Object pre-selection
  - Overlap Removal
    - Remove pre-selected tau candidates within $\Delta R<0.4$ of e or μ
    - Remove pre-selected e within $\Delta R<0.2$ of μ
  - Full object selection
  - Lepton isolation cuts

Object Preselection and Selection

$Z \rightarrow \tau_{lep}\tau_{had}$

Electrons:

- Preselection:
  - ET>10 GeV, |eta|<2.47 (excluding 1.37< |eta| < 1.52), not in bad region of EM calorimeter, medium ID
- Selection:
  - ET>15 GeV, tight ID

Muons:

- Preselection:
  - pT>10 GeV, |eta|<2.4, CombinedMuon, |z0|< 10 mm
- Selection:
  - pT> 15 GeV, additional quality cuts on ID track, and difference between pT of track from muon system and tracker

Taus:

- Preselection:
  - pT>15GeV, |eta|<2.5, loose ID
- Selection:
  - tight ID, vetos against candidates reconstructed from electrons and muons

Missing transverse energy:

- No cut on it in this analysis, but enters calculation of other quantities used for the suppression of W+jets backgrounds.

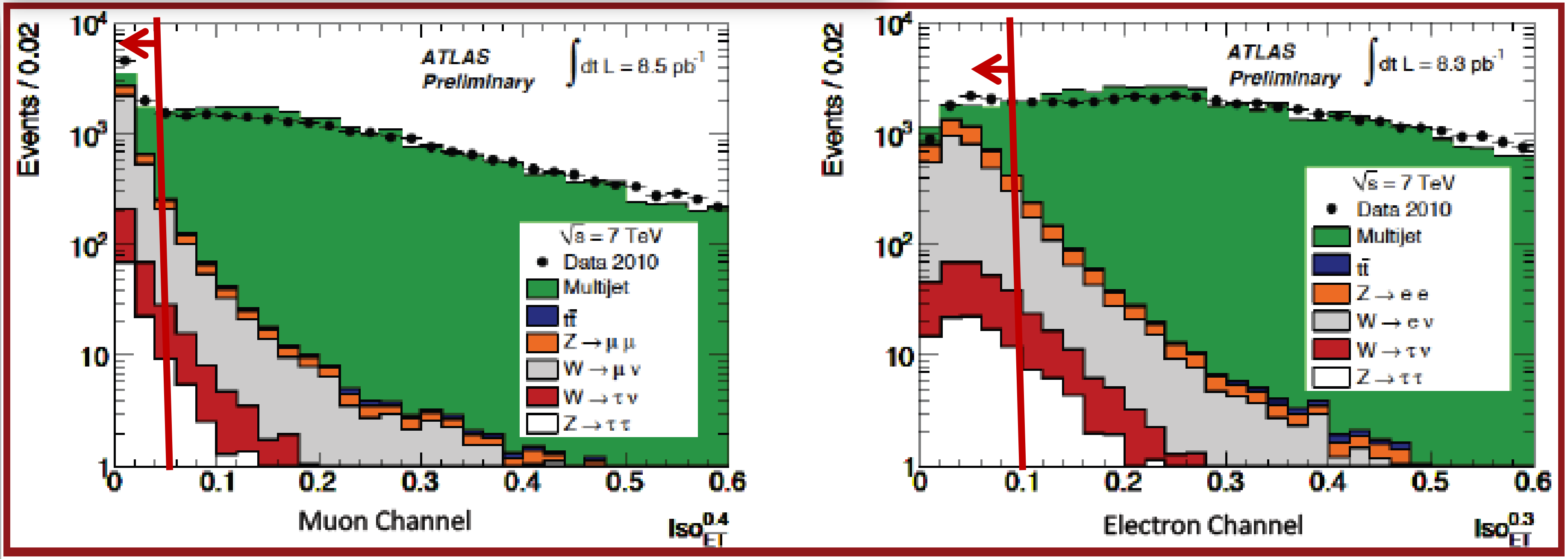
Lepton Isolation

$Z \to \tau_{lep}\tau_{had}$

- Important tool for rejecting QCD background
- Isolation cuts optimized using Monte Carlo

$Iso_{PT}^{0.4}$	Sum of transverse momentum of associated tracks to charged particles in a cone of ΔR = 0.4
$Iso_{ET}^{\Delta R}$	Sum of transverse energy of particles in calorimeter in a cone of ΔR = 0.4 around muon or ΔR = 0.3 around electron

Isolation variable
muon p_TCone40$/p_T < 0.06$
muon E_TCone40$/p_T < 0.06$
electron p_TCone40$/p_T < 0.06$
electron E_TCone30$/p_T < 0.1$



Event Selection

$Z \to \tau_{lep}\tau_{had}$

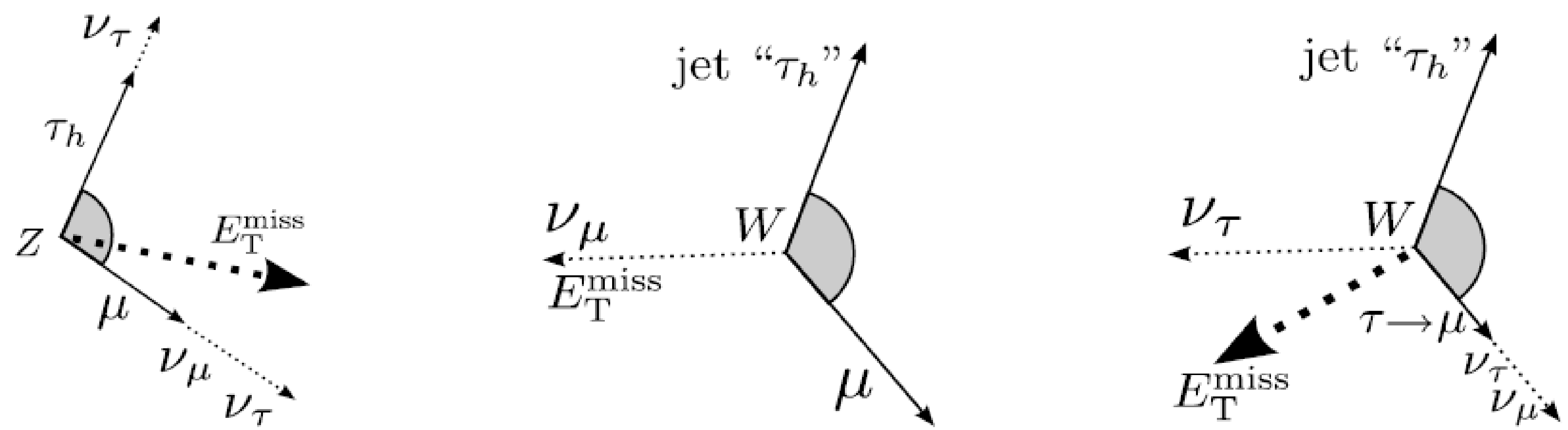
- Once the multijet background has been suppressed by τ-ID and lepton isolation cuts, events having W->lν, W->τν ->lννν, and Z->ll decays become the dominant background.

- These backgrounds are suppressed with several event-level cuts
  - Dilepton veto
    - Any event with >1 preselected e/μ is rejected, suppressing $Z \to ll$
  - W+jets suppression cuts
    - These backgrounds are suppressed by cutting on two variables that exploit kinematic correlations between the lepton and transverse missing energy -> next slide
  - Visible mass cut: 35<mvis<75 GeV
    - mvis: invariant mass of l-τ_{had} system
  - Tau-jet cuts: number of tracks 1 or 3; |charge|=1
  - Opposite sign (lepton-τ_{had}) cut

W+jet suppression

$Z \to \tau_{lep}\tau_{had}$

- As mass of Z is much larger than mass of τ, the τ's in $Z \to \tau\tau$ will be boosted such that their decay products will be collimated along trajectory of the parent τ lepton
  - E_T^{miss} will be vector sum of p_T of neutrinos. The majority of Z will have low p_T, and τ's will be back-to-back, but in case Z has significant nonzero boost, the E_T^{miss} vector will fall in the angle between decay products of Z
- In contrast, in events from the $W \to l\nu$+jets the neutrino, jet, and lepton should all point in different directions, balancing p_T in the transverse plane.
  - E_T^{miss} vector should point along the neutrino which is not in the angle between the fake τ candidate and the lepton.
- In $W \to \tau\nu \to l\nu\nu\nu$ events, there are two additional neutrinos, but the E_T^{miss} will still tend to point outside of the angle between fake τ candidate and the lepton.

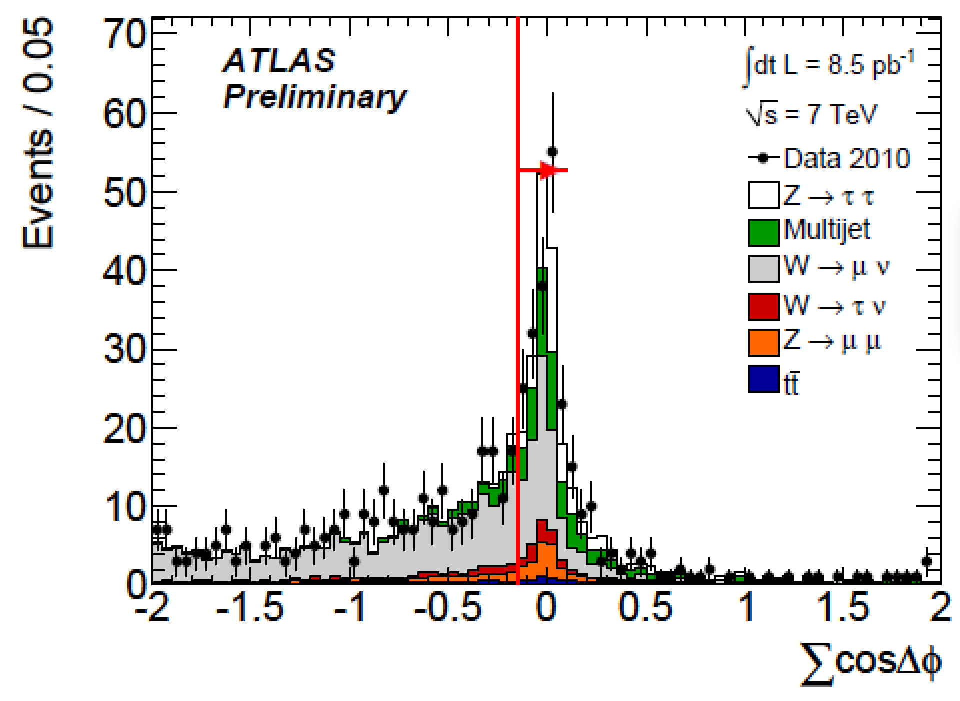


(a) $Z \to \tau\tau \to \mu\tau_h$ (b) $W \to \mu\nu$ (c) $W \to \tau\nu \to \mu\nu\nu\nu$

W+jet suppression

$Z \to \tau_{lep}\tau_{had}$

- $\sum \cos\Delta\phi = \cos(\phi(\ell) - \phi(E_T^{miss})) + \cos(\phi(\tau_h) - \phi(E_T^{miss}))$



Muon channel
After full selection and dilepton veto

$\Sigma \cos(\Delta\varphi) > -0.15$

- Cut on transverse mass of lepton-missing transverse energy system

$$m_T(\ell, E_T^{miss}) = \sqrt{2\, p_T(\ell) \cdot E_T^{miss} \cdot (1 - \cos\Delta\phi(\ell, E_T^{miss}))}$$

- $m_T < 50$ GeV

Background Estimation

$Z \to \tau_{lep}\tau_{had}$

In order to estimate the final purity and significance of the selected Z->ττ events, the number of background events passing the selection must be estimated.

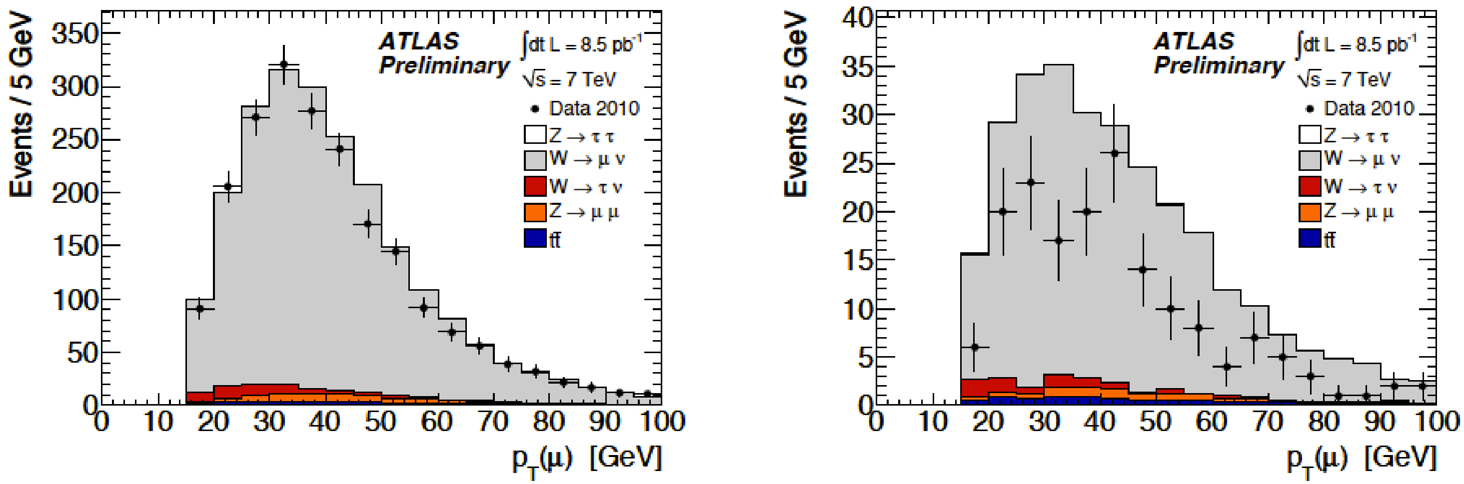
- The estimated number of background events from Z -> ll and ttbar is taken from the Monte Carlo expectations
- Monte Carlo simulation is used for W ->lν and W->τν but the samples were renormalized with a scale factor in order to agree with the data
  - Next slide
- The multijets background, was estimated using a data-driven method as rates of real and fake leptons in QCD dijets are not expected to be modeled well in Monte Carlo
  - Two data-driven estimates (one primary and one for cross-check)

W+jets Scale Factor

$Z \rightarrow \tau_{lep}\tau_{had}$

W+jet MC agrees well prior to requiring tau ID, but MC overestimates when requiring tau ID. Tau ID rejection known to be underestimated in MC (ATL-CONF-2010-086)

- Need to calculate a scale factor from data in W rich control region (WCR) defined by
  - Events passing dilepton veto
  - <u>Invert both W-suppression cuts</u>
  - Other cuts not applied



(a) loose but not tight τ candidate

(b) tight τ candidate

- Subtract (small) Z & tt contributions (from MC), QCD contamination negligible
- Calculate scale factor such that MC events equal observed events

$$k_W = \begin{cases} 0.94 \pm 0.02\ (\text{stat.}) & \text{muon channel, loose + not tight tau}, \\ 0.57 \pm 0.05\ (\text{stat.}) & \text{muon channel, tight tau}, \\ 0.96 \pm 0.03\ (\text{stat.}) & \text{electron channel, loose + not tight tau}, \\ 0.69 \pm 0.06\ (\text{stat.}) & \text{electron channel, tight tau}. \end{cases}$$

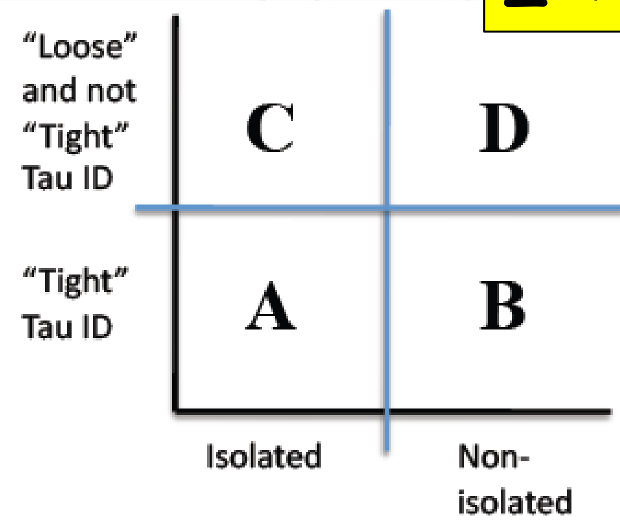
QCD estimation – main method

$Z\to\tau_{lep}\tau_{had}$

$$N^A = N^B\left(\frac{N^C}{N^D}\right) = N^B R_{\rm iso}$$

$$N^i = N^i_{Data} - N^i_{Z\to\ell\ell} - N^i_{t\bar{t}} - k_W(N^i_{W\to\ell\nu} + N^i_{W\to\tau\nu})$$

$$i = \mathrm{B, C, D} \;\; \text{and} \;\; \ell\ell = ee, \mu\mu, \tau\tau$$



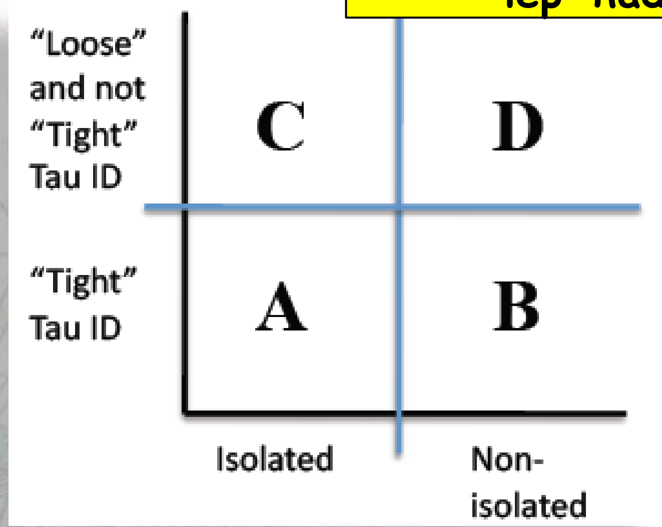
- Obtain QCD-rich control region (B) by inverting isolation
- Scale number of observed events in CR by isolation ratio to get estimate for signal region (A)
- Isolation ratio: calculated in an independent pair of QCD rich CRs (C, D), obtained by loosening tau selection ("loose" but not "tight")
- Subtract all non-QCD contributions

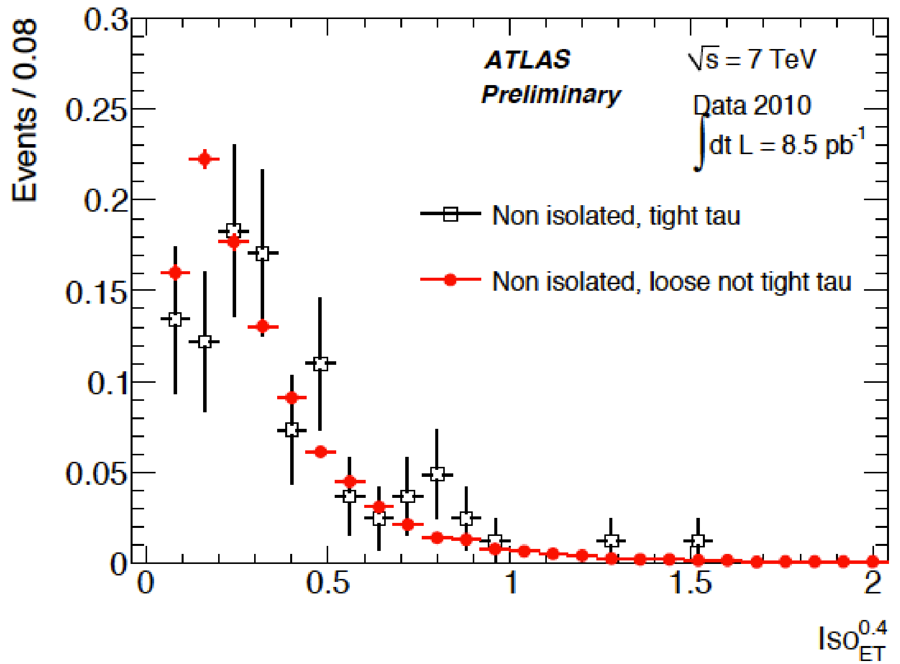
$$N^A_{\rm QCD} = \begin{cases} 5.2 \pm 0.7\,(\text{stat.}) \pm 0.7\,(\text{syst.}) & \text{muon channel} \\ 6.8 \pm 0.6\,(\text{stat.}) \pm 0.7\,(\text{syst.}) & \text{electron channel.} \end{cases}$$

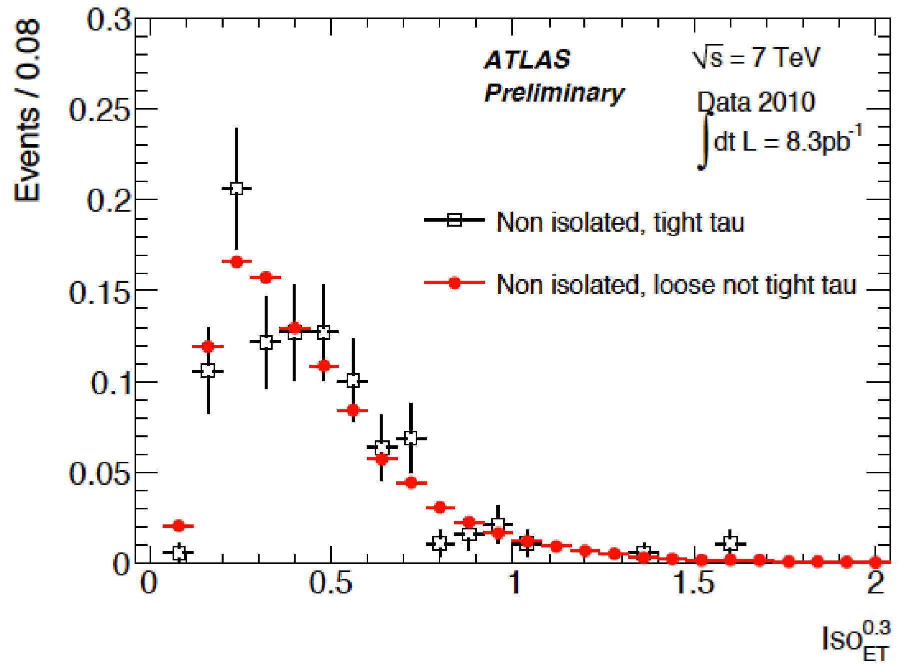
QCD Estimation – main method

$Z \to \tau_{lep} \tau_{had}$

- The key assumption of this method is that the isolation ratio in multijet events is independent of the τ identification requirement
- The validity of these assumptions and possibility of correlations between lepton isolation and τ-ID are checked and considered as systematics
- The shapes of the isolation in region B are similar to those in D







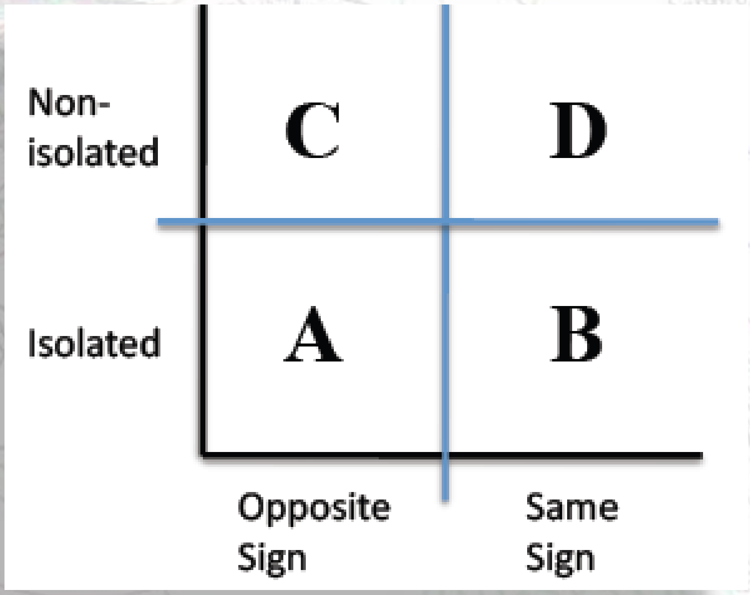
QCD Estimation – second method

$Z \to \tau_{lep}\tau_{had}$

- Use same-sign (SS) region to obtain number of events in OS (signal) region
- Ratio OS/SS theoretically expected to be 1
  - measured in separate control regions of inverted isolation
- Non-QCD contributions subtracted in control regions
- Method limited by very poor statistics in SS region
- Result in statistical agreement with main method

$$R_{OSSS} = \begin{cases} 1.10 \pm 0.22\,(\text{stat.}) \pm 0.07\,(\text{syst.}) & \text{muon channel} \\ 1.15 \pm 0.16\,(\text{stat.}) \pm 0.17\,(\text{syst.}) & \text{electron channel} \end{cases}$$

$$N^{A}_{QCD} = \begin{cases} 2.14 \pm 2.35(\text{stat.}) \pm 0.42(\text{syst.}) & \text{Muon Channel} \\ 2.73 \pm 2.36(\text{stat.}) \pm 0.71(\text{syst.}) & \text{Electron Channel} \end{cases}$$



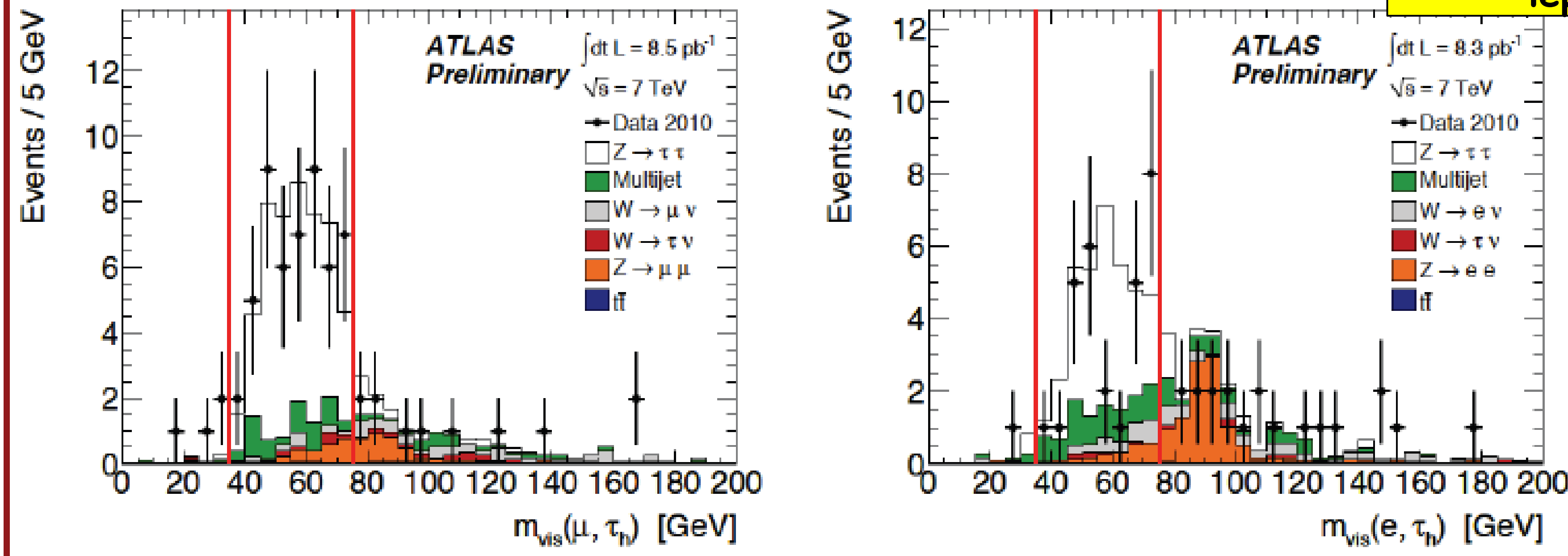
Systematic Uncertainties

$Z \rightarrow \tau_{lep}\tau_{had}$

- MC-based Z, tt background estimates: systematics on MC/data agreement
  - lepton trigger efficiency, lepton ID efficiency, lepton isolation, lepton fake rates of taus, jet fake rates of taus
  - Energy scale (6-20%), pile-up, MC UE tune and calo shower modeling (9%), xsection and lumi
  - Dominant: jet fake rates of taus (50%)
- W background estimate: uncertainty on kW scale factor and energy scale
- QCD estimate (14-19%):
  - Effect of MC/data disagreement due to MC-subtraction in CRs
  - Uncertainty of method itself (assumptions, stability of ratios)
  - Note: Statistical uncertainty from CRs comparable to systematic uncertainties

Observation of $Z \rightarrow \tau_{lep}\tau_{had}$

$Z \rightarrow \tau_{lep}\tau_{had}$



(a) muon channel (b) electron channel

	Muon Channel (8.5 pb^{-1})	Electron Channel (8.3 pb^{-1})
Data (after all selections)	51	29
Total Estimated Background	9.9 ± 2.1	11.8 ± 1.7
Estimated Multijet Background	*5.2 ± 0.7(stat.) $\pm$ 0.7 (syst.)*	*6.8 ± 0.6(stat.) $\pm$ 0.7 (syst.)*
Estimated W, Z, $t\bar{t}$ Background	*4.7 ± 0.5(stat.) $\pm$ 1.5(syst.)*	*5.0 ± 0.6 (stat.) $\pm$ 1.4(syst.)*
Data (after background subtraction)	41.1 ± 7.1(stat.) $\pm$ 2.1(bkg. est.)	17.2 ± 5.4(stat.) $\pm$ 1.7(bkg. est.)
SM Signal Expectation	39.9 ± 1.8(stat.) $\pm$ 6.7(syst.)	24.5 ± 1.4(stat.) $\pm$ 7.9(syst.)

Observed signal consistent with SM expectation

$Z \to \tau(electron)\ \tau(muon)$

$Z \to \tau_e \tau_{mu}$

Muon Preselection:
$p_T > 10$ GeV, $|\eta| < 2.4$
STACO isCombined
$|d0| < 10$ mm
Charge =+/- 1
Muon Cleaning cuts
(MCPAnalysisGuidelinesRel15)

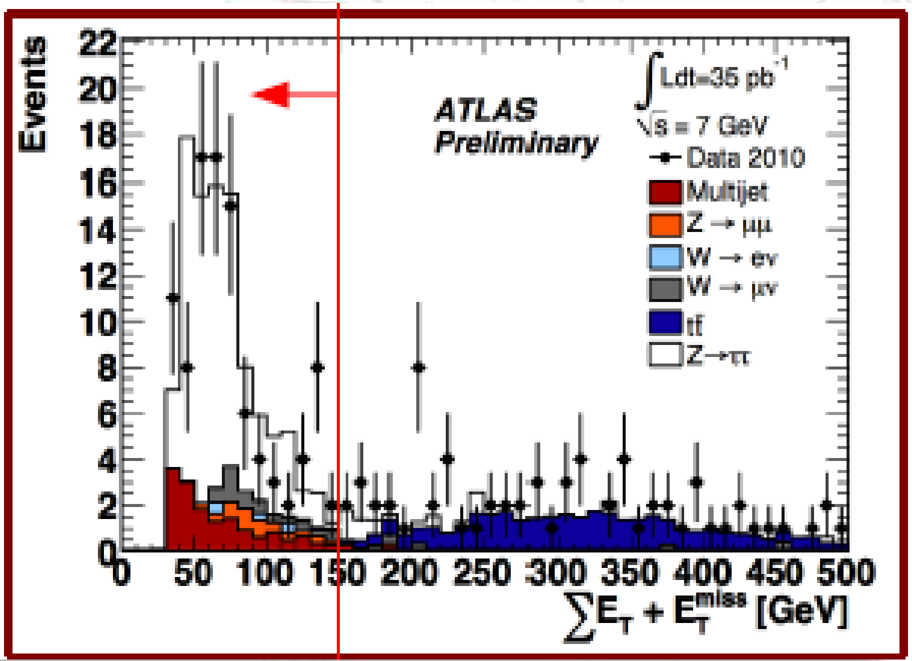
Electon Preselection:
$p_T > 15$ GeV
$|\eta| < 2.47$, $!(1.35 < |\eta| < 1.52)$,
IsEM Robust Medium,
Author == 1 OR 3
OTX Map (from run 167521 in MC)
Charge = +/- 1

Full available integrated luminosity from year 2010 used: 35 pb^{-1}

Jet Preselection:
AntiKt4 Jets
TopoEM + JES
$p_T > 20$ GeV,
$|\eta| < 4.5$

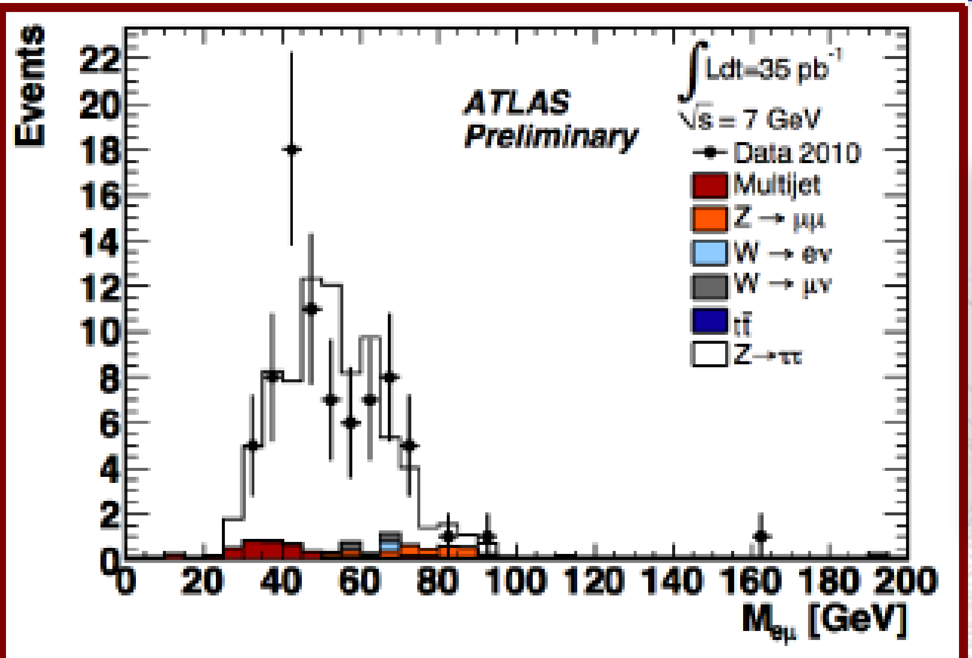
MET:
LocHadTopo + MuonBoy
– RefMuon Track

- Cuts to remove QCD multijet background:
  - Electrons: PtCone40/p_T < 0.06, EtCone30/p_T < 0.1
  - Muons: PtCone40/p_T < 0.06, EtCone40/p_T < 0.06
- $\Sigma\cos\Delta\Phi = \cos(\Phi_{lep1} - \Phi_{MET}) + \cos(\Phi_{lep2} - \Phi_{MET}) > -0.15$
- Σ[Et(leptons) + Et(Jets)] + MET < 150 GeV
- 25 < m(Lep Lep) < 80 GeV



Observation: Z->τ(electron) τ(muon)

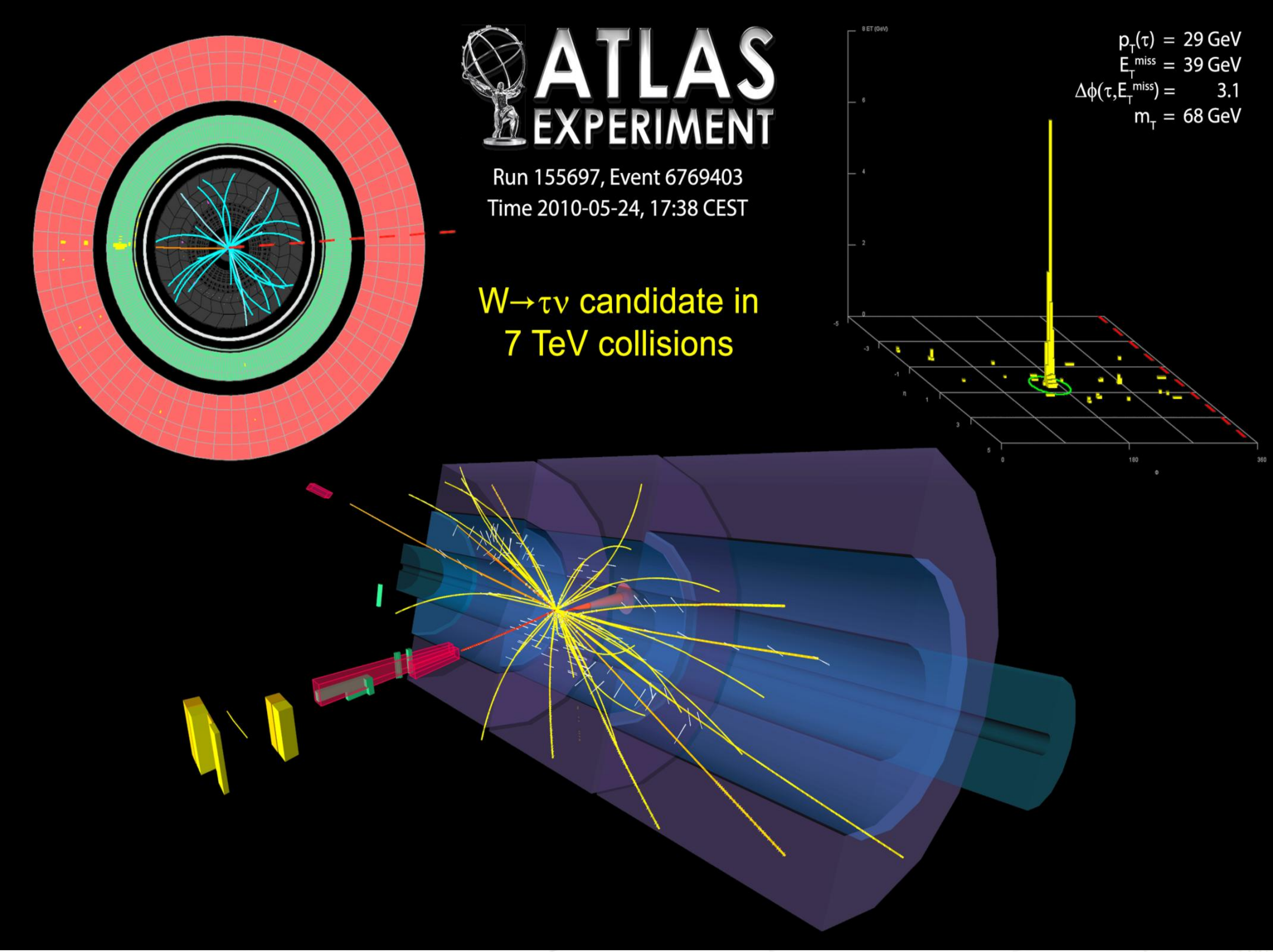
$Z \to \tau_e \tau_{mu}$



- Electron-Muon invariant mass after all cuts apart from M_{emu}
- QCD background from data
- Clear $Z \to \tau\tau \to e\mu + 4\nu$ signal above background

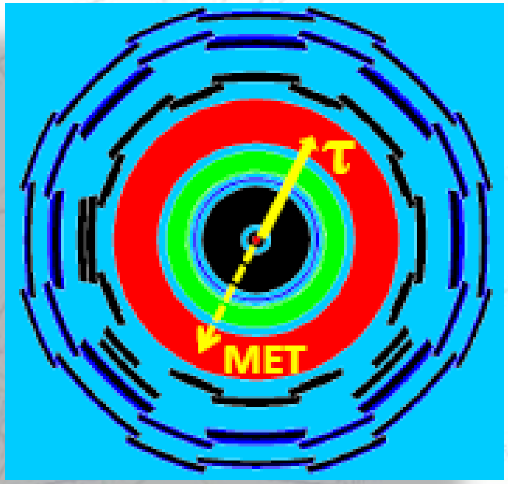
Samples	Number of candidates
Data	75
$Z \to \tau\tau$	69 ± 5 (stat.) ± 15 (sys.)
$Z \to \ell\ell$, W, $t\bar{t}$ background	3.0 ± 0.7 (stat.) ± 0.7 (sys.)
QCD Multijet background (data)	3.4 ± 3.7 (stat.) ± 0.6 (sys.)
Total background	6.4 ± 3.9
Data (after background subtraction)	68.6 ± 8.7 (stat.) ± 3.9 (bkg. est.)

Observed signal consistent with SM expectation


ATLAS EXPERIMENT
Run 155697, Event 6769403
Time 2010-05-24, 17:38 CEST
W→τν candidate in 7 TeV collisions
$p_T(\tau)$ = 29 GeV
E_T^{miss} = 39 GeV
$\Delta\phi(\tau, E_T^{miss})$ = 3.1
m_T = 68 GeV

$W \to \tau_{had} \nu$ final state

- $W \to \tau\nu$ is predicted to be produced with $\sigma \times BR$ = 10.46 nb which is about 10x higher than for $Z \to \tau\tau$ events.
- Since purely leptonic τ decays cannot be easily distinguished from electrons and muons from $W \to e\nu$ or $W \to \mu\nu$ decays, the analysis presented uses only hadronically decaying τ
- This channel allowed first observation of hadronic decays of tau leptons
- important background in new physics searches
- also important for τ_{had} performance studies



- **Signal:** dominated by low-p_T W's producing τ's with visible p_T 10-40 GeV. $E_T$miss, associated with the neutrinos from W and τ_{had} decays, has a maximum around 20 GeV and a significant tail up to about 80 GeV.
- **Backgrounds:**
- **QCD multijets** dominant background due to their very large cross-section
- **$W \to e/\mu(\tau_{e/\mu})\nu$** contributes if lepton from the W-boson decay is identified as a 1-prong hadronically decaying τ lepton or if a fake τ_h candidate from initial-state QCD radiation.
- **$Z \to ee/\mu\mu$** contributes if one of leptons makes fake τ_h and the other one is lost.
- **$Z \to \tau^+\tau^-$** contributes to the background if one of the τ leptons is identified as a hadronically decaying τ lepton while the second one is lost
- **Top anti-top** much smaller cross section. It contributes if one of W's produces a τ lepton in its decay and the other one decays into a pair of quarks, electron or muon which are no reconstructed. Fully hadronic decays can contribute to the fake τh identification.

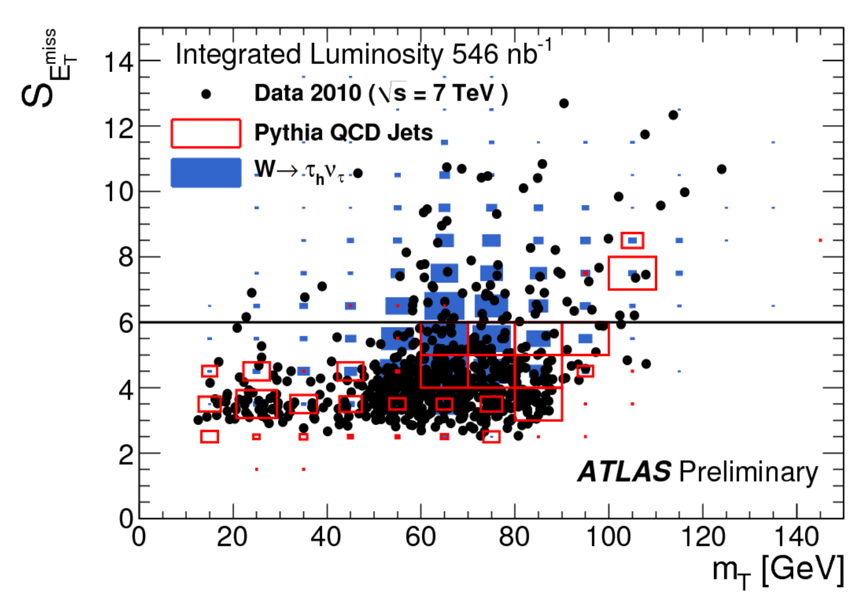
Event & Object Selection

$W \to \tau_{had} \nu$

- Analysis based on **546 nb^{-1}**
- Events required to pass basic beam and data quality requirements
- At least one primary vertex with at least 3 reconstructed tracks
- Tau-jet & MET cleaning cuts to reject candidates caused by out-of-time cosmic events or known noise effects in the calorimeters

Selection for analysis with 546 nb^{-1}:

- $\tau_h + E_T^{miss}$ trigger: $p_{T,\tau} > 6$(track)/12 GeV , $E_T^{miss} > 12/15$ GeV
- Tight τ_h with 20 GeV < p_T < 60 GeV
- Veto on leptons with $p_T > 5$ GeV
- $\Delta\phi$(jet, E_T^{miss}) > 0.5
- $E_T^{miss} > 30$ GeV
- $S_{E_T^{miss}} > 6$ with $S_{E_T^{miss}} = \dfrac{E_T^{miss}}{0.5 \cdot \sqrt{\sum E_T}}$



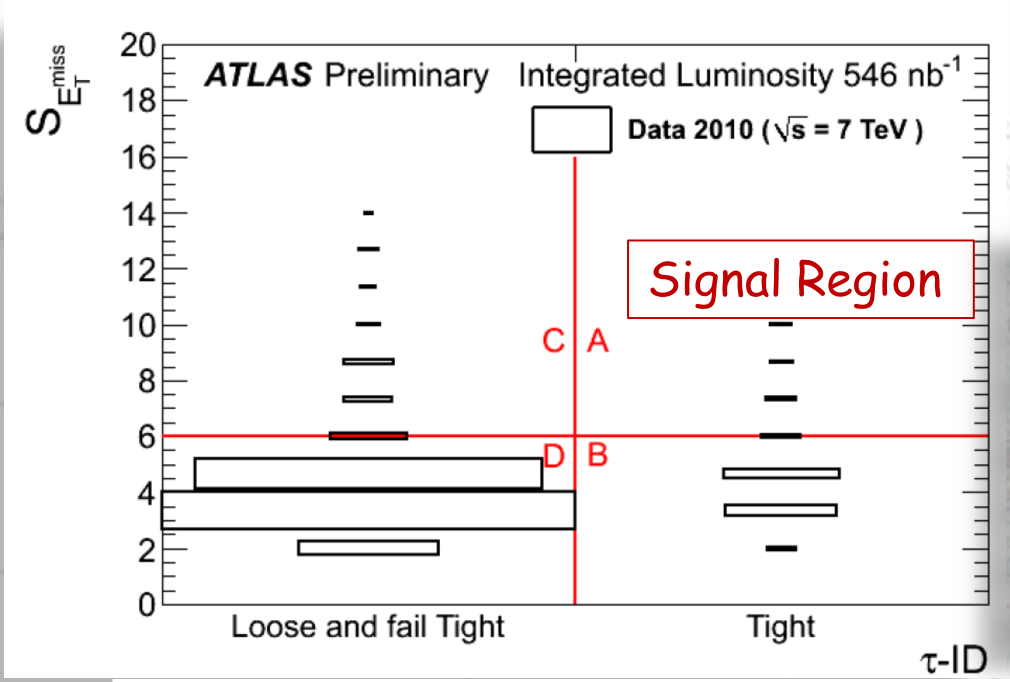
$$m_T = \sqrt{2 \cdot E_T^{\tau_h} \cdot E_T^{miss} \cdot \left(1 - \cos\Delta\phi\left(\tau_h, E_T^{miss}\right)\right)}$$

- The selection results in **78 events in data**
- From Monte Carlo, the expected number of signal that pass the selection is **55.3±1.4**
- The background from other W and Z decays is **11.8±0.4** events

Background estimation

$W \rightarrow \tau_{had}\nu$

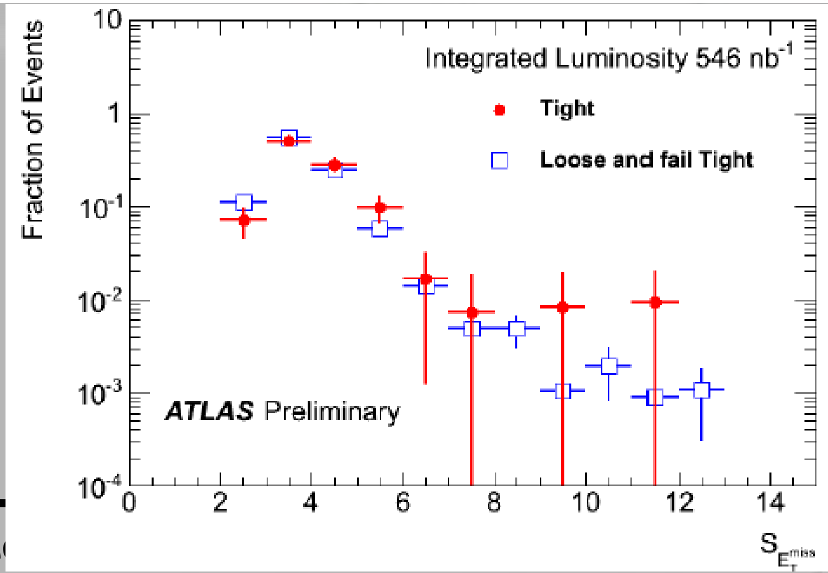
QCD Background: not enough statistics and large cross section uncertainties → data-driven method

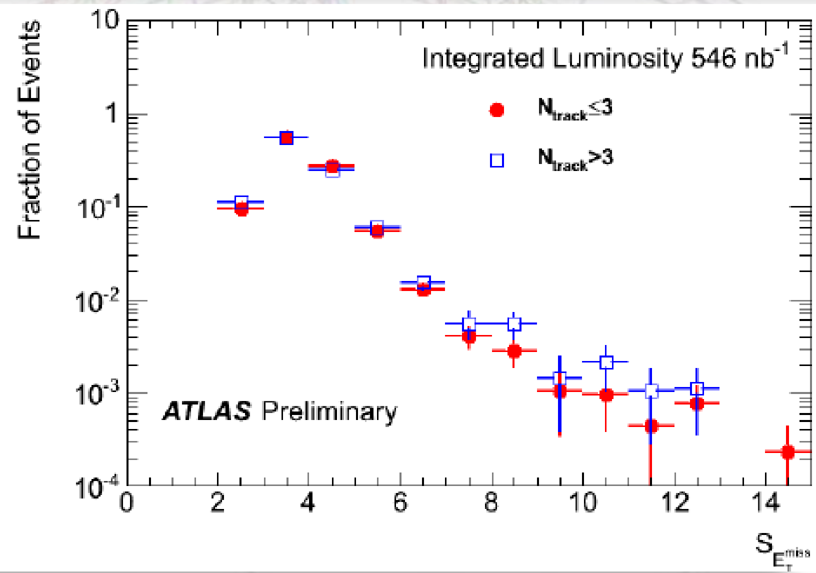


$$N^{A}_{QCD} = N^{B} N^{C} / N^{D}$$

Two assumptions:

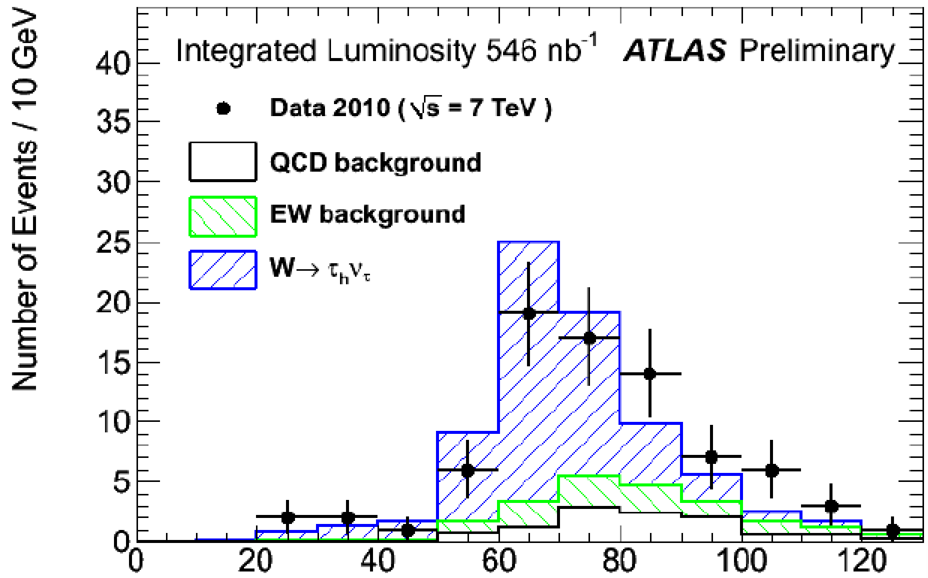
- that the shape of the SE_Tmiss distribution for QCD background is the same in the combined regions AB and CD
- that the signal and EW background contribution in the three control regions is negligible (-> correction applied)



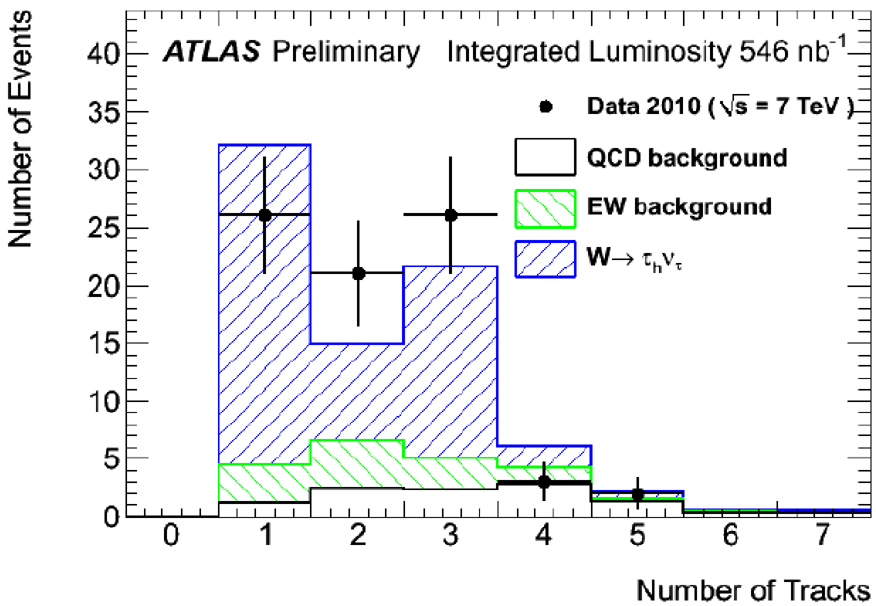


Observation: W->τ(had) nu

$W \to \tau_{had} \nu$



$$m_T = \sqrt{2 \cdot E_T^{\tau_h} \cdot E_T^{miss} \cdot \left(1 - \cos\Delta\phi\left(\tau_h, E_T^{miss}\right)\right)}$$

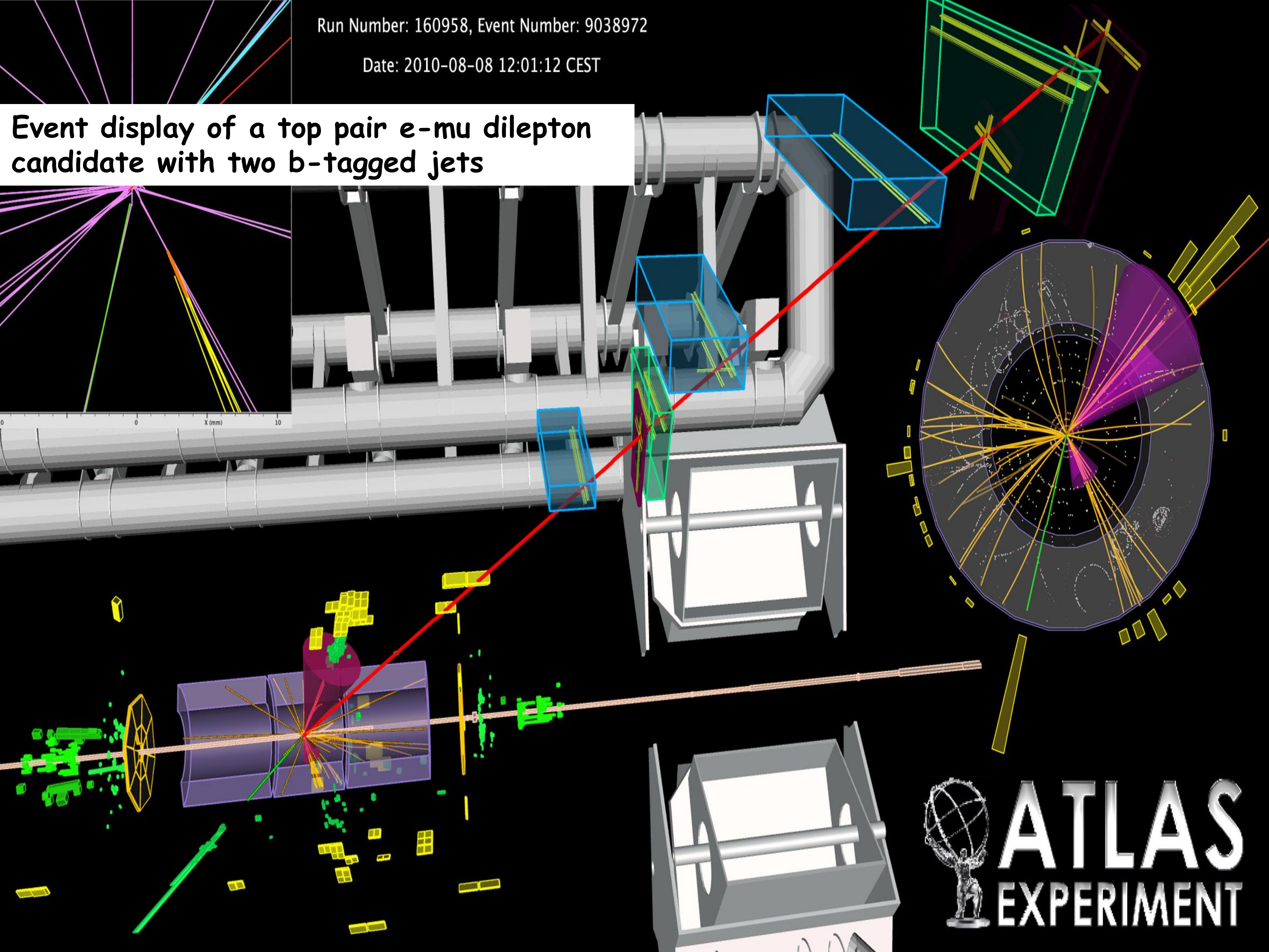


- 78 events have been selected in 546nb^{-1}
  - QCD Background = 11.1 ± 2.3$_{(stat.)}$ ± 3.2$_{(syst.)}$ (Data-driven)
  - EW Backgrouds = 11.8 ± 0.4$_{(stat.)}$ ± 3.7$_{(syst.)}$ (Monte Carlo)
  - Excess = 55.1 ± 10.5$_{(stat.)}$ ± 5.2$_{(syst.)}$
  - Signal = 55.3 ± 1.4$_{(stat.)}$ ± 16.1$_{(syst.)}$

Observed signal consistent with SM expectation

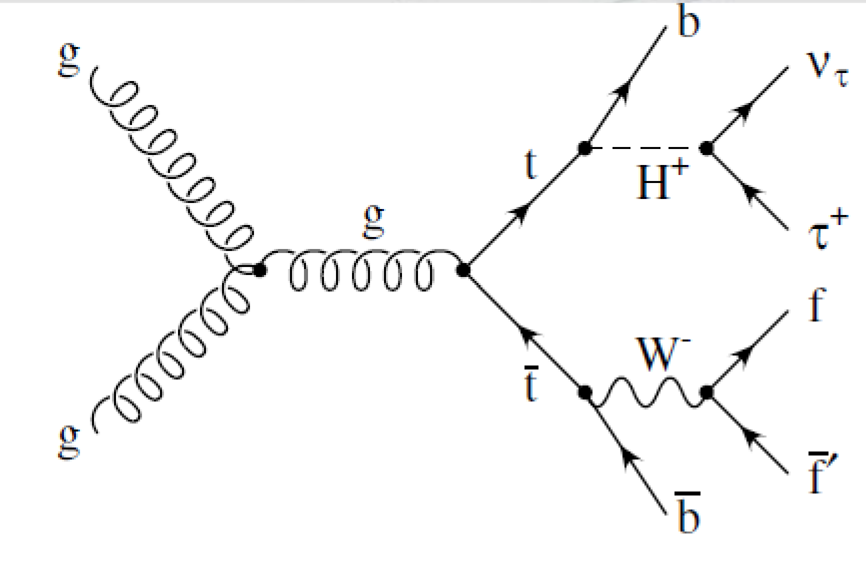
Main systematic uncertainties: energy scale (21-14%), MC model (16-17%)

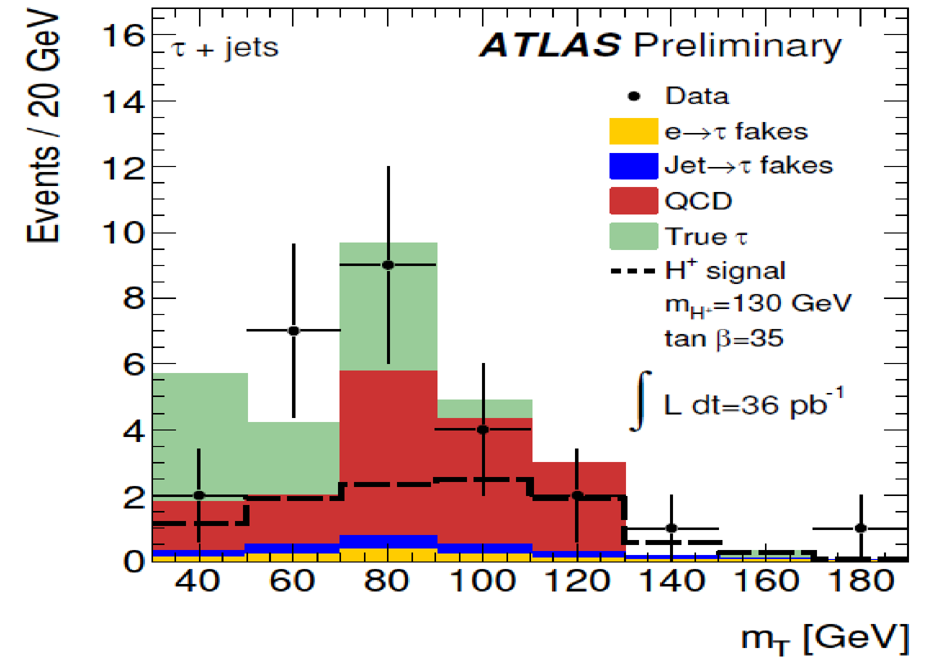
Event display of a top pair e-mu dilepton candidate with two b-tagged jets



Top-anti top final states with taus

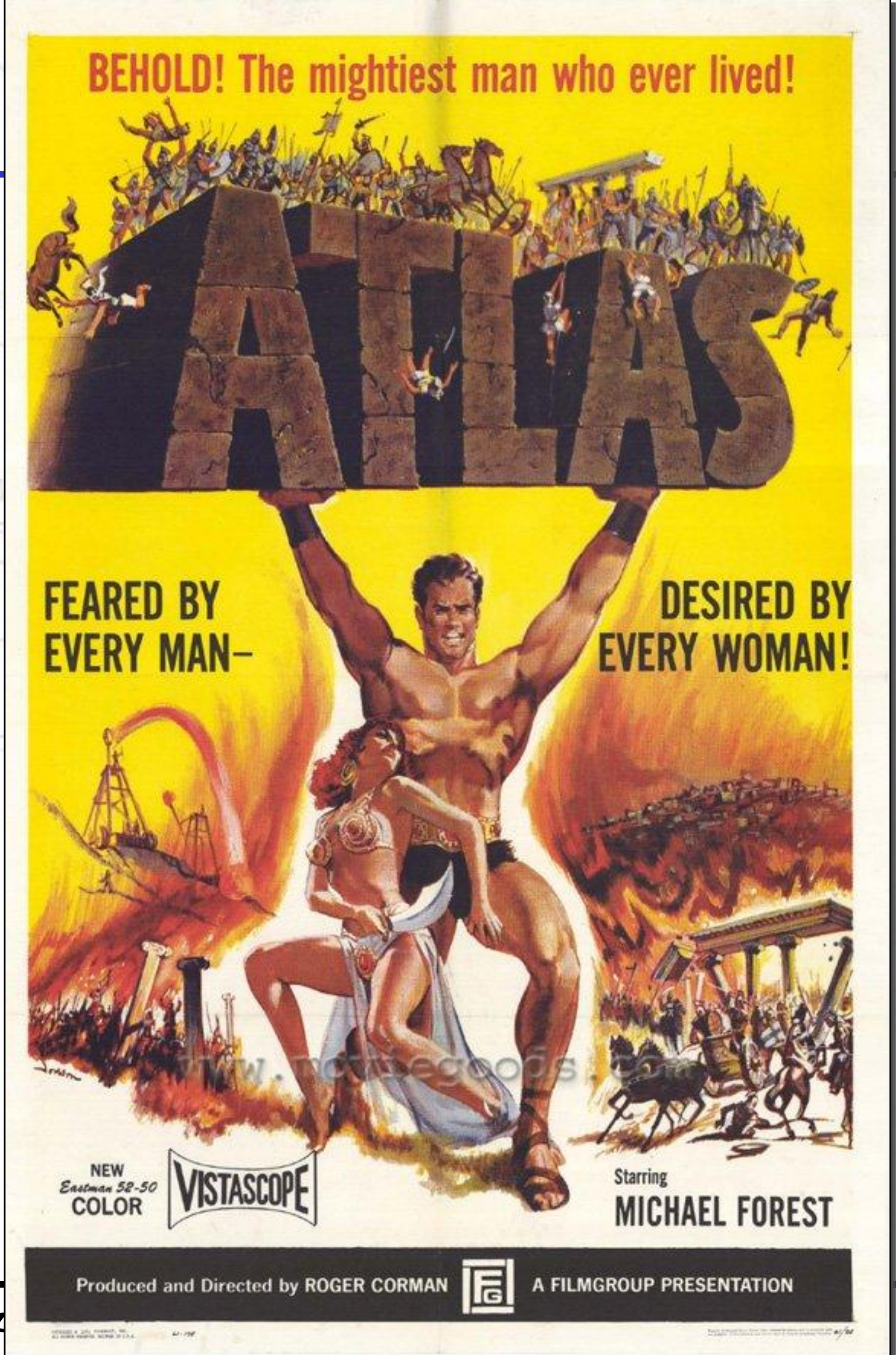
- Interesting as it can open a window to physics beyond the Standard Model
- In the SM, the top quark decays ~100% of the time into a W boson and a b-quark
- The W->tau nu BR has been measured with a high precision, and it is in a very good agreement with the SM expectations. The best measurement at the Tevatron of $\sigma(t\bar{t}) \times \mathrm{BR}(t \to \tau\nu + b)$ has an uncertainty of 25%.
- If a charged Higgs exists, as required by the MSSM, and its mass is lower than the top quark mass minus the b quark mass, the top quark can have a substantial BR to H^+ b
- For large values of tanβ charged Higgs decays mainly to tau and can increase the top quark branching ratio signicantly.
- The much larger cross section for tt production at the LHC provides us with an opportunity to measure that BR with a higher precision, and thus increase the sensitivity to H^+ or other processes that enhance this branching ratio.





Summary

- Observation of hadronically and leptonically decaying tau leptons in ATLAS established
- Clear signal of $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ observed
  - In good agreement with Standard Model expectation
  - Cross section measurements under approval
- Interesting studies for taus in top – anti top events with 2011 data ongoing
- Looking forward to results with more data in tau decay channels
  - they should come soon - Stay Tuned!

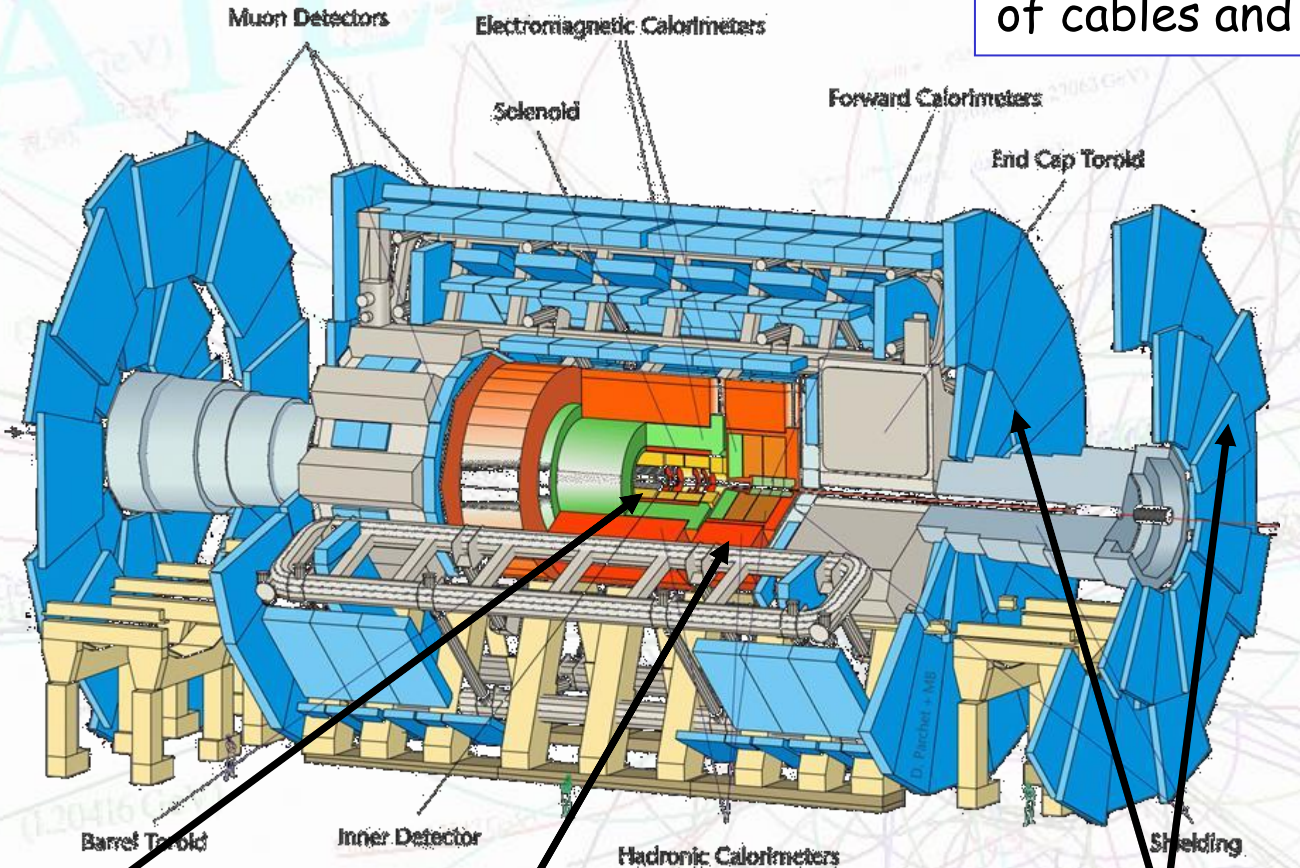


thank you for your attention!

Additional slides for curious kids

ATLAS – A Toroidal LHC ApparatuS

25m diameter, 46m long, weighing 7000T, with 3000km of cables and 10^8 channels



Tracking ($|\eta|<2.5$, B=2T):
- Silicon pixels and strips
- Transition Radiation Tracker

$\sigma/P_T=0.05\%\ P_T + 1\%$
(2%@20GeV)
$\sigma(d_0)$=15 um@20 GeV

Calorimetry ($|\eta|<5$)
EM : Pb-LAr
HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

EM : $\sigma(E)/E = 10\%/\sqrt{E} + 0.7\%$

Hadron : $\sigma(E)/E = 50\%/\sqrt{E} + 3\%\ (\eta < 3)$

$\sigma(E)/E = 100\%/\sqrt{E} + 10\%\ (\eta > 3)$

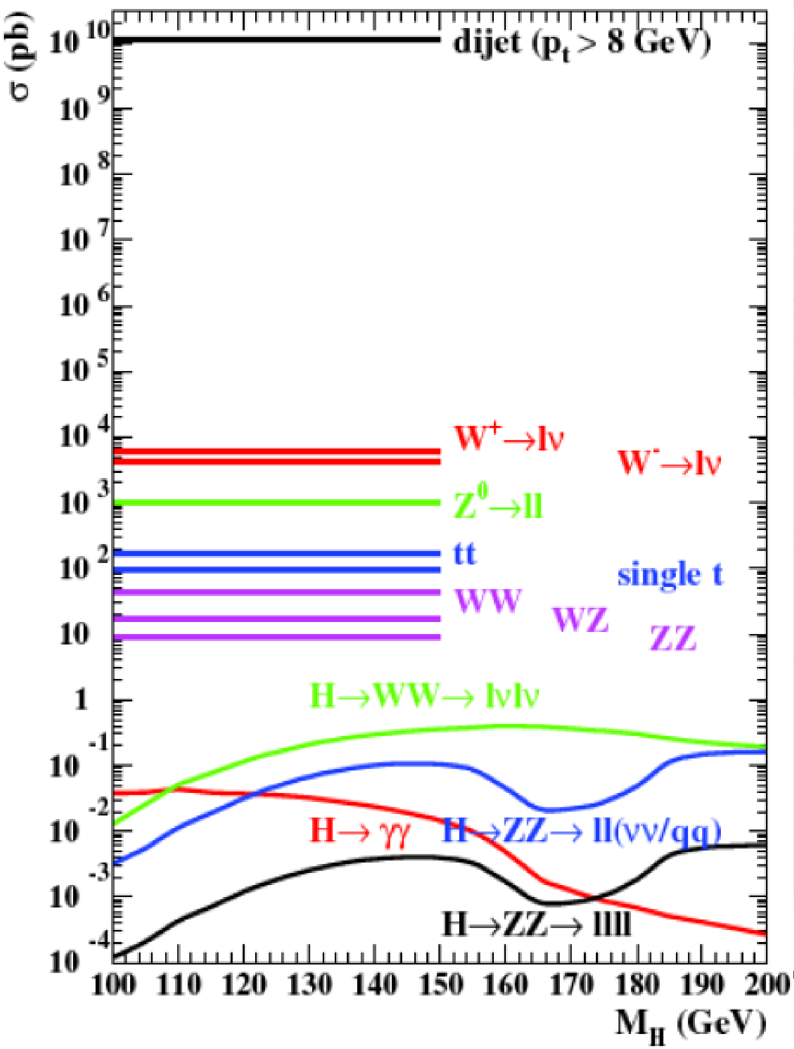
Muon spectrometer ($|\eta|<2.7$, B=4T max)
Toroid magnet system with precision and trigger chambers

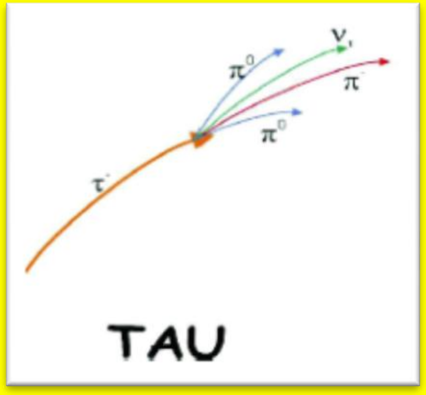
σ/P_T=2-7%

Main sources of fake taus

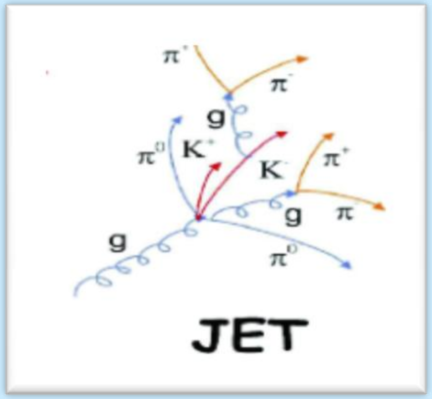
- QCD jets
- Electrons
- Muons

Main challenge: separate out a clean sample of taus from the overwhelming QCD jet rate!





- narrow, collimated
- 1 or 3 tracks
- can define isolation regions with low activity
- leading track carries much of tau momentum



- wide
- can have many tracks
- isolation regions busy
- jet momenta spread over tracks

Object Preselection and Selection

$Z \rightarrow \tau_{lep}\tau_{had}$

Electron preselection used for overlap removal and dilepton veto
$p_T > 10$ GeV
$\|\eta\| < 2.47$, but excluding $1.37 < \|\eta\| < 1.52$
not in bad OQmaps region
electron author 1 or 3
"robust medium" electron

Electron selection
$p_T > 15\ GeV$
"robuster tight" electron

τ Candidate Preselection
$p_T > 15$ GeV
$\|\eta\| < 2.5$
"loose" simple cuts τ-ID

τ Candidate Selection
author 1 or 3
passes e and μ vetos
"tight" simple cuts τ-ID

More information on particle identification:
Electron: arXiv:1010.2130
Muon: ATLAS-CONF-2010-036
Tau: ATLAS-CONF-2010-086

Object Preselection and Selection

$Z \rightarrow \tau_{lep}\tau_{had}$

Muon preselection used for overlap removal and dilepton veto
$p_T > 10$ GeV
$\lvert\eta\rvert < 2.4$
"isCombinedMuon"
$\lvert z_0\rvert < 10$ mm

Muon selection
$p_T > 15$ GeV
$p_T(mu^{MS}_{Track}) < 50$ GeV : $(p_T(mu^{MS}_{Track}) - p_T(mu^{ID}_{Track}))/p_T(mu^{ID}_{Track}) > -0.4$
nPixHits> 0
nSCTHits> 5
$\lvert\eta\rvert < 1.9$: nTRT Outliers / (nTRT Hits + nTRT Outliers) < 0.9
$\lvert\eta\rvert >= 1.9$ & nTRT Hits > 5: nTRT Outliers / (nTRT Hits + nTRT Outliers) < 0.9
"match" $\chi^2 < 150$

Missing transverse energy: No cut on it in this analysis, but enters calculation of other quantities used for the suppression of W+jets backgrounds.

Cut flow tables

$Z \to \tau_{lep}\tau_{had}$

Muon Channel

	data	$Z \to \tau\tau$	Multijets	$W \to \mu\nu$	$W \to \tau\nu$	$Z \to \mu\mu$	$t\bar{t}$
object selection	574	59(2)	78(3)	268(4)	25(1)	83.8(9)	25.9(3)
dilepton veto	522	58(2)	78(3)	267(4)	25(1)	33.7(6)	20.7(3)
W suppression cuts	173	52(2)	58(2)	33(1)	11.2(8)	12.7(3)	5.2(1)
$m_{vis} = 35 - 75$ GeV	91	46(2)	32(2)	6.3(6)	3.1(4)	4.2(2)	0.89(6)
$N_{trk}(\tau_h) = 1$ or 3, $\lvert Q(\tau_h) \rvert = 1$	55	40(2)	10(1)	2.1(4)	0.9(2)	2.7(2)	0.37(4)
opposite sign	51	40(2)	5.2(7)	1.2(3)	0.8(2)	2.4(2)	0.28(3)

Electron Channel

	data	$Z \to \tau\tau$	Multijet	$W \to e\nu$	$W \to \tau\nu$	$Z \to ee$	$t\bar{t}$
object selection	524	38(2)	109(3)	243(4)	18(1)	82.9(9)	21.6(3)
dilepton veto	485	37(2)	108(3)	243(4)	18(1)	48.9(7)	17.4(3)
W suppression cuts	163	33(2)	77(2)	34(2)	7.9(7)	26.5(5)	4.2(1)
$m_{vis} = 35 - 75$ GeV	76	28(2)	40(2)	7.3(7)	1.7(3)	5.4(2)	0.72(5)
$N_{trk}(\tau_h) = 1$ or 3, $\lvert Q(\tau_h) \rvert = 1$	33	25(2)	12.8(9)	2.9(5)	0.5(2)	2.6(2)	0.25(3)
opposite sign	29	25(2)	6.8(6)	2.3(4)	0.5(2)	1.9(1)	0.20(3)

Systematic Uncertainties - muon channel

$Z \to \tau_{lep}\tau_{had}$

Systematic	Uncertainty	Multijets	W+jets	Z & $t\bar{t}$	$Z \to \tau\tau$
μ efficiency	2.7%	±0.03*	-	±0.07	±1.1
μ trigger efficiency	2.0%	±0.01*	-	±0.05	±0.8
μ isolation	1.6%	±0.01*	-	±0.04	±0.7
Jet τ fake rate	50%	±0.17*	-	±1.34	-
Energy scale	13% ($W \to \mu\nu$) / 16% ($W \to \tau\nu$)	±0.26*	±0.28	±0.40	±2.4
	6% (signal) / 13% (Z) / 21% ($t\bar{t}$)				
Pile-up re-weighting	0.5% (signal) / 0.58% ($t\bar{t}$)	±0.01*	-	±0.10	±0.2
	3.9% (Z)				
MC underlying event model	7%	±0.04*	-	-	±2.8
MC showering model	6%	±0.04*	-	-	±2.4
Luminosity	11%	±0.07*	-	±0.30	±4.4
Theoretical cross-section	5% (Z)	±0.03*	-	±0.12	±2.0
	6% ($t\bar{t}$)	±0.01*	-	±0.02	-
W rescaling factor	8.8% in A, B	±0.04*	±0.17	-	-
	2.1% in C, D	-	-	-	-
Multijet est. (bkg subtraction)	-	±0.34	-	-	-
Multijet est. (method systematics)	-	±0.56	-	-	-
Total systematics	-	±0.66	±0.33	±1.44	±6.7

*: Taken into account for MC background subtraction in CRs

Systematic Uncertainties - electron channel

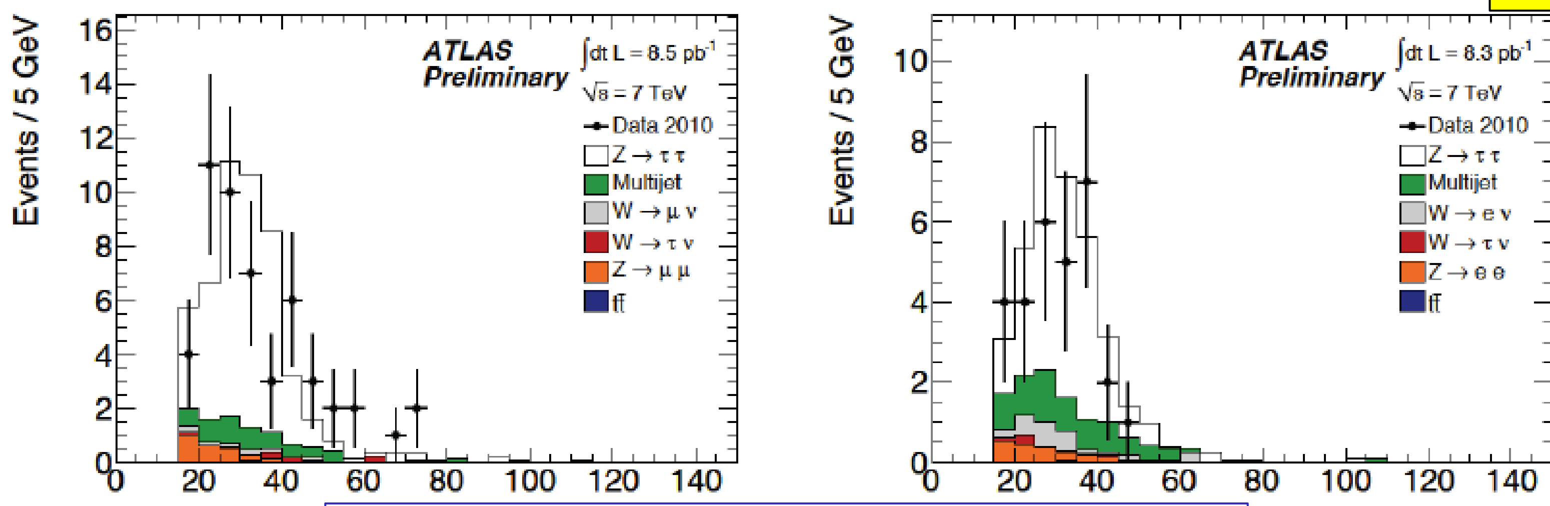
$Z \to \tau_{lep}\tau_{had}$

Systematic	Uncertainty	Multijets	W+jets	Z & $t\bar{t}$	$Z \to \tau\tau$
e efficiency	η, p_T dependent	±0.1*	-	±0.25	±4.7
e trigger efficiency	1%	±0.01*	-	±0.02	±0.2
e isolation	p_T dependent	±0.15*	-	±0.17	±3.7
e τ fake rate	33.5%	±0.19*	-	±0.65	-
Jet τ fake rate	50%	±0.29*	-	±1.07	-
Energy scale	13% ($W \to e\nu$) / 12% ($W \to \tau\nu$)	±0.28*	±0.36	±0.28	±1.7
	7% (signal) / 13% (Z) /15% (tt)				
Pile-up re-weighting	0.5% (signal) / 0.58% (tt)	±0.01*	-	±0.03	±0.1
	1.3% (Z)	-	-	-	-
MC underlying event model	8%	±0.03*	-	-	±2.0
MC showering model	13%	±0.05*	-	-	±3.2
Luminosity	11%	±0.07*	-	±0.24	±2.7
Theoretical cross-section	5% (Z)	±0.03*	-	±0.10	±1.2
	6% ($t\bar{t}$)	±0.01*	-	±0.01	-
W rescaling factor	8.7% in A, B	±0.04*	±0.24	-	-
	3.1% in C, D	-	-	-	-
Multijet est. (bkg subtraction)	-	±0.47	-	-	-
Multijet est. (method systematics)	-	±0.44	-	-	-
Total systematics	-	±0.65	±0.43	±1.35	±7.9

*: Taken into account for MC background subtraction in CRs

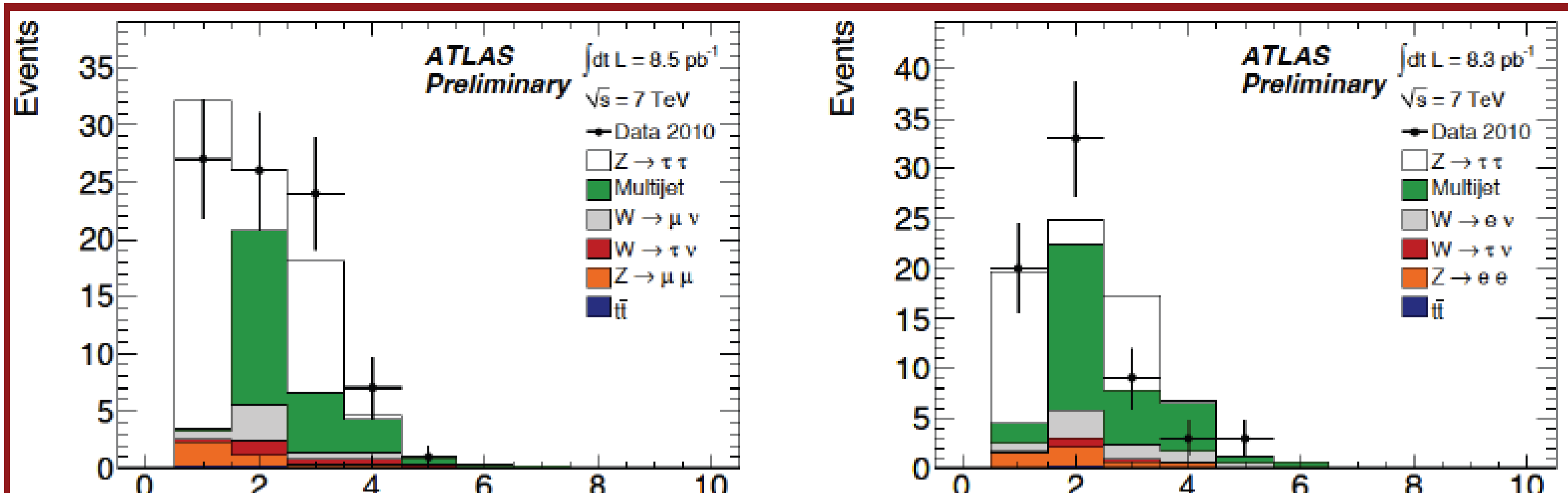
Observation – more plots

Z→$\tau_{lep}\tau_{had}$



Tau-jet transverse momentum after all cuts

(a) muon channel (b) electron channel

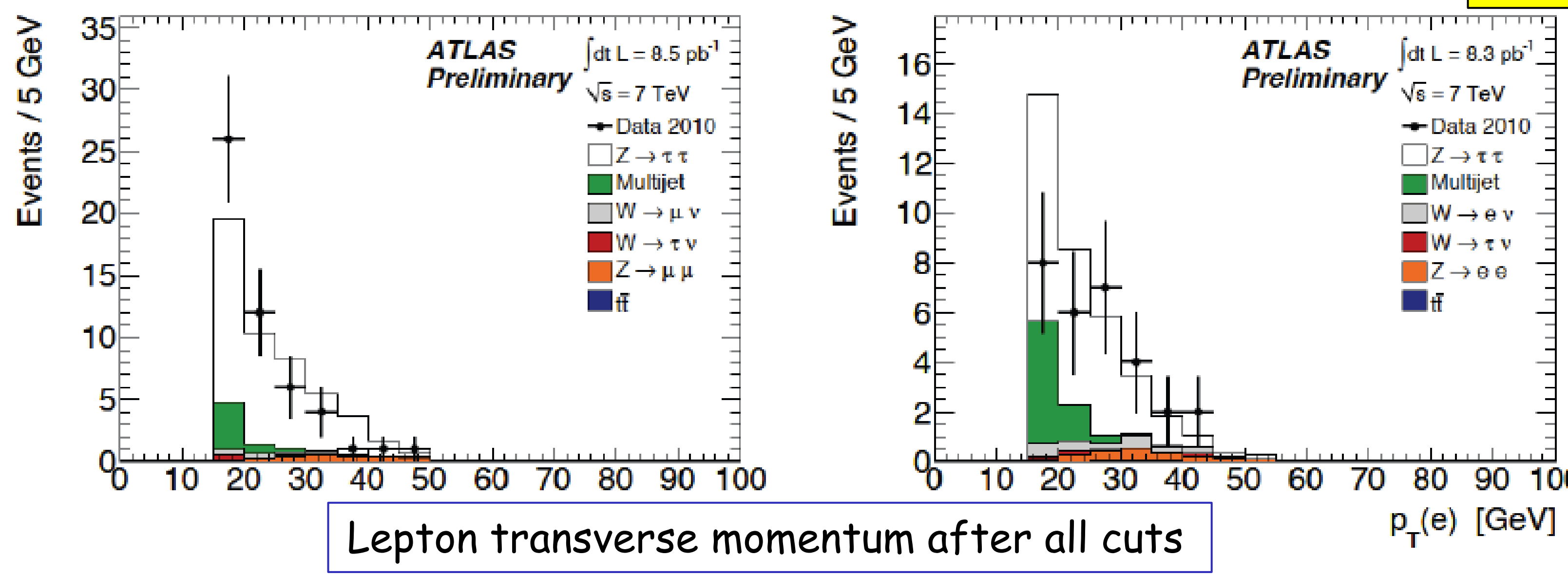


Tau-jet number of tracks (cuts on Ntrks and |Qτ| not applied)

(a) muon channel (b) electron channel

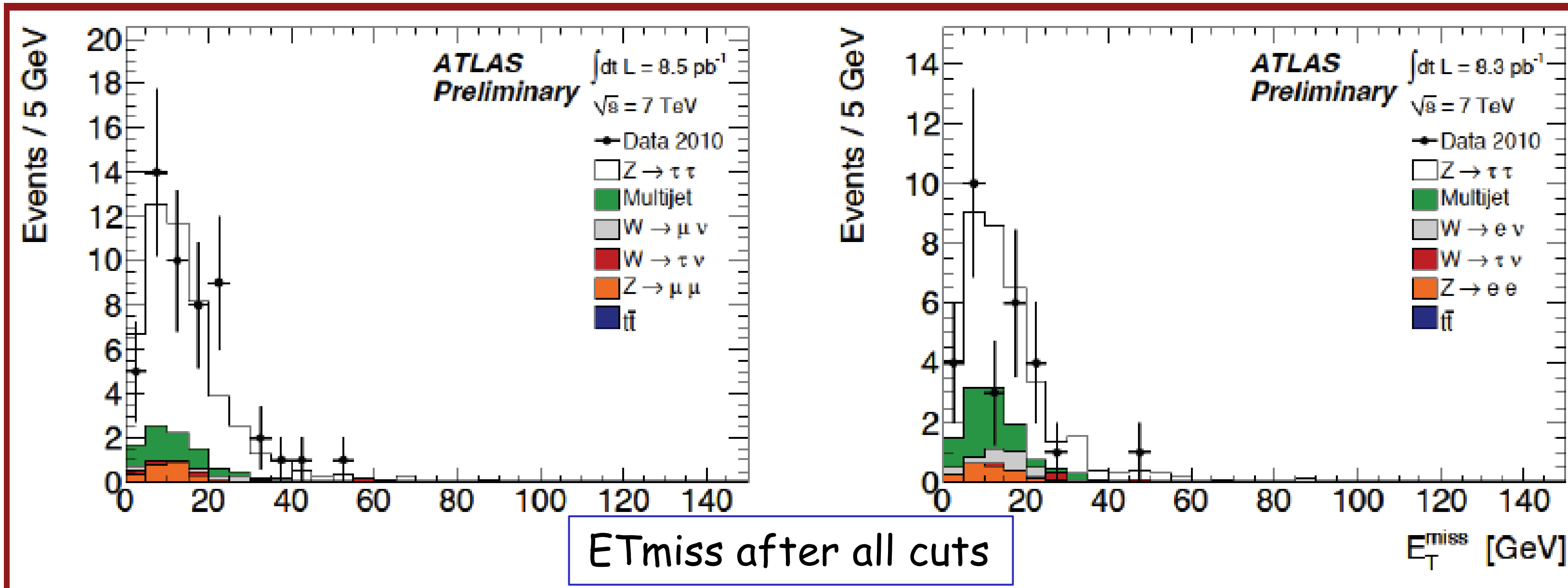
Observation – more plots

$Z \to \tau_{lep}\tau_{had}$



Lepton transverse momentum after all cuts

(a) muon channel (b) electron channel



ETmiss after all cuts

(a) muon channel (b) electron channel

QCD Bkg Estimation - Systematic Uncertainties

$Z \to \tau_{lep}\tau_{had}$

- The systematic uncertainty due to the stability of the isolation ratio with respect to relaxed cuts in region C and D
  - as a check, the multijet background was also estimated with all cuts applied for region C and D, at which point the statistical error on the estimate is quite large and the result is consistent with the default estimation.
- Assumption that isolation and τ identification are uncorrelated was tested by varying the non isolated region as well as the τ identification inversion. Both variations give a similar background estimate for region A.
- Several additional checks of the method were performed by comparing the shapes of various distributions between the regions and by checking the stability of the result while changing a number of conditions (such as the τ candidate pT or the number of associated tracks). In all cases the method was found to be robust, within statistical errors.
- The shapes of the isolation distributions in region B (tight τ candidate, inverted isolation) are similar to those in D (loose not tight τ candidate, inverted isolation)
- For the alternative multijet background estimation method the assumption that ROS/S S is independent of the isolation variables has been tested

Systematics

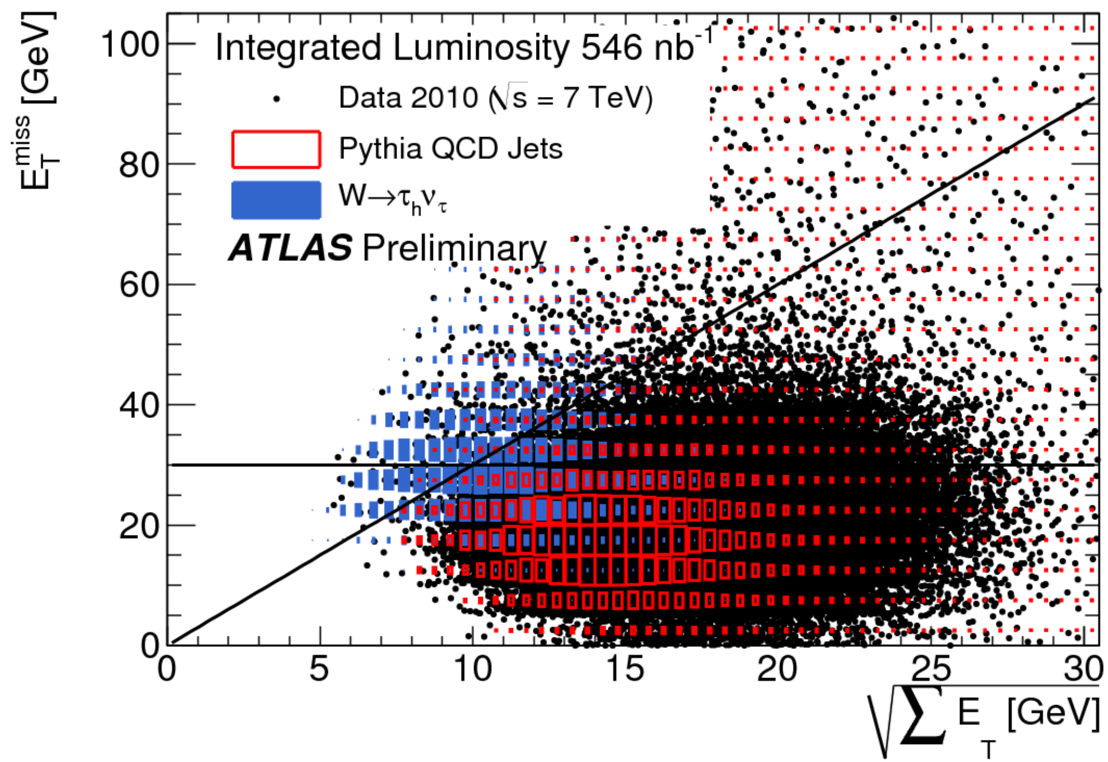
$Z \rightarrow \tau_e \tau_{mu}$

Systematic	Uncertainty	$Z \rightarrow \tau\tau$	$Z \rightarrow \ell\ell$	W	$t\bar{t}$	Multijet
e energy scale	3%	±2.2	±0.05	±0.18	±0.01	±0.11
e energy resolution	η dependent	±0.69	±0.06	±0.00	±0.02	±0.01
e reconstruction efficiency	E_T, η dependent	±4.0	±0.11	±0.10	±0.00	±0.12
e isolation efficiency	E_T dependent	±11	±0.26	±0.17	±0.01	±0.41
μ p_T scale	η dependent	±0.0	±0.00	±0.00	±0.00	±0.01
μ p_T resolution	η dependent	±0.7	±0.06	±0.00	±0.00	±0.00
μ reconstruction efficiency	η dependent	±0.7	±0.00	±0.00	±0.00	±0.04
μ isolation efficiency	p_T dependent	±2.0	±0.05	±0.03	±0.00	±0.08
trigger efficiency	1.6%	±1.1	±0.03	±0.02	±0.00	±0.04
pile-up reweight	Toy Monte Carlo	±3.0	±0.08	±0.05	±0.00	±0.13
underlying event	3.1%	±2.1	±0.06	±0.03	±0.00	±0.08
theoretical cross section	5%(Z,W), 6%($t\bar{t}$)	±3.5	±0.08	±0.04	±0.00	±0.08
luminosity	11%	±7.6	±0.20	±0.13	±0.01	±0.30
Total Systematic		±15.1	± 0.39	±0.31	±0.02	±0.57

- Systematics estimated using MC
- Feed through systematic uncertainties into multijet BG estimate
- Systematics due to QCD estimation method and fake rate small

$W \to \tau_{had}\nu$ process

	Data	$W \to \tau_h \nu_\tau$	$W \to e\nu_e$	$W \to \mu\nu_\mu$	$W \to \tau_\ell \nu_\tau$	$Z \to ee$	$Z \to \mu\mu$	$Z \to \tau\tau$
Trigger	986439	954.5±5.2	3560.7±3.4	521.4±1.6	296.5±2.8	75.3±0.2	59.7±0.2	115.1±0.7
QCD jets rejection	415951	728.3±4.7	2735.3±3.5	400.7±1.5	229.4±2.6	24.5±0.1	45.1±0.1	71.4±0.6
$E_T^{miss} > 30$ GeV	29686	411.5±3.8	1828.3±3.3	317.1±1.3	121.9±1.9	1.13±0.03	34.4±0.1	35.4±0.4
τ selection	2408	118.0±2.1	1482.0±3.1	26.6±0.4	34.4±1.0	0.59±0.02	3.24±0.04	11.9±0.3
Lepton rejection	685	94.8±1.9	6.7±0.2	4.9±0.2	2.3±0.3	<0.005	0.11±0.01	4.2±0.2
$S_{E_T^{miss}} > 6$	78	55.3±1.4	4.2±0.2	3.7±0.1	1.8±0.2		0.08±0.01	2.0±0.1



Sources of Systematic Uncertainties

$W \rightarrow \tau_{had} \nu$

- QCD background estimation with ABCD method
  - Dominated by correlations between MET significance and tau-ID (28%) (from variation od SETmiss cut)
  - Correction for the signal and EW background contaminations in the control regions (6%)
- EW and Signal:
  - **Monte Carlo Modeling**
    - Comparison between mc09 and DW tuning
  - **Lepton vetoes**
    - Tag-and-probe methods for electrons and muons ($Z \rightarrow e\,e$ / $Z \rightarrow \mu\,\mu$)
  - **Pileup**
    - Due to event weight to match observed vertex multiplicity distribution in data (<1%)
  - **Trigger**
    - Found to be negligible (offline selection cut within the trigger efficiency plateau)
  - **Energy Scale**
    - Adopted procedure from W → e υ CONF results
    - http://indico.cern.ch/getFile.py/access?contribId=24&sessionId=10&resId=0&materialId=slides&confId=91219
    - ATL-PHYS-COM-PHYS-2010-703 http://cdsweb.cern.ch/record/1288274

Systematic Uncertainties

	Signal	EW background	QCD background
Central values [events]	55.3	11.8	11.1
Statistical uncertainty [events]	±1.4	±0.4	±2.3
Systematic uncertainties			
Theoretical cross section	± 5%	±5%	–
Luminosity	± 11%	±11%	–
Energy scale	±21%	±14%	–
Lepton veto	–	±19%	–
Pile-up	±1%	±0.2%	–
Monte Carlo model	±16%	±17%	–
QCD background estimation	–	–	±29%
Total systematic uncertainty [events]	±16.1	±3.7	±3.2