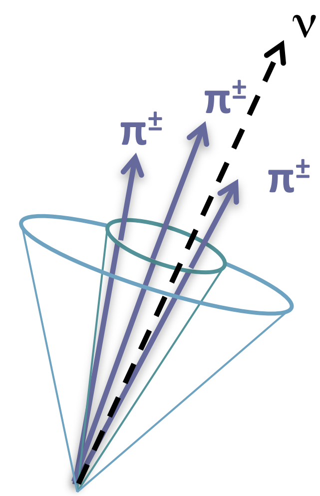
W-> $\tau\nu$ Observation at ATLAS

University of Pennsylvania HEP Seminar
Tuesday, April 5, 2011

Sarah Demers
Yale University

Outline

- ***SHORT*** **ATLAS Introduction**
- Why W-> $\tau\nu$?
  - Why taus?
- Event Selection
  - Trigger
  - Offline
- Observation
- Future Plans



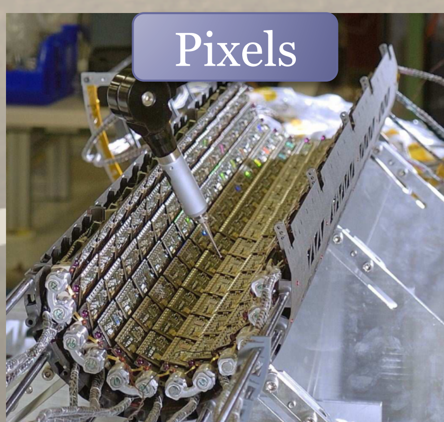
Special Mention of the analyzers
for the observation:

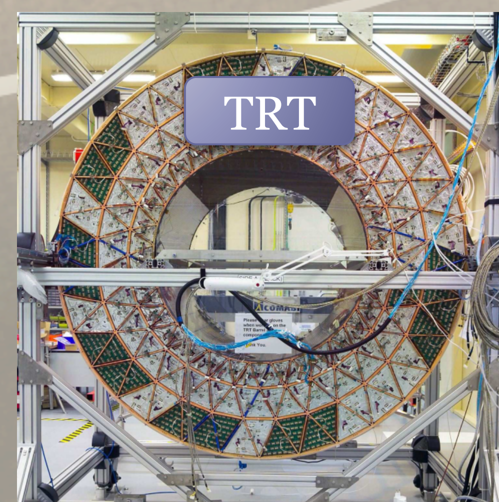
Guilherme Nunes Hanninger (*Bonn*)
Lidia Dell'Asta (*INFN, Milano*)
Zofia Czyczula (*Yale, now Oslo*)

Current analysis team includes many others!

The ATLAS Detector at CERN's LHC

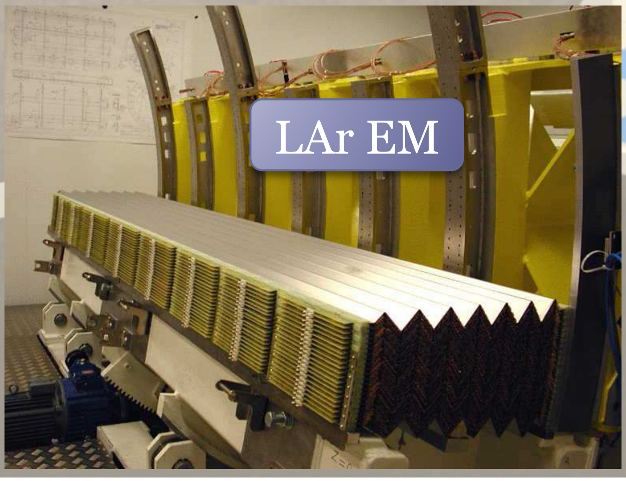
- **Tracking detectors** for momentum and charge (and in the case of the TRT) particle ID
- Sampling Calorimeters
- Trigger and Data Acquisition





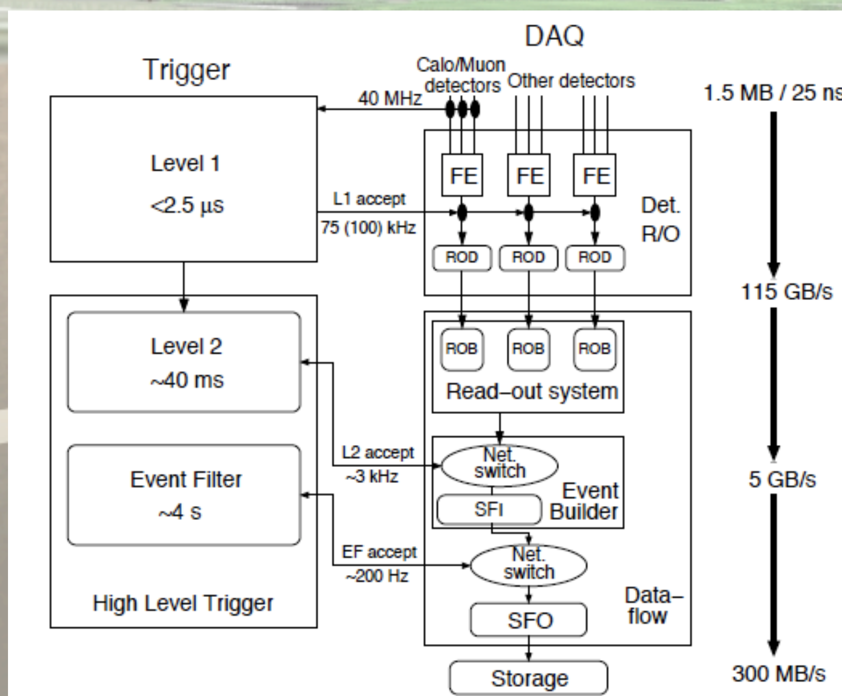
The ATLAS Detector at CERN’s LHC

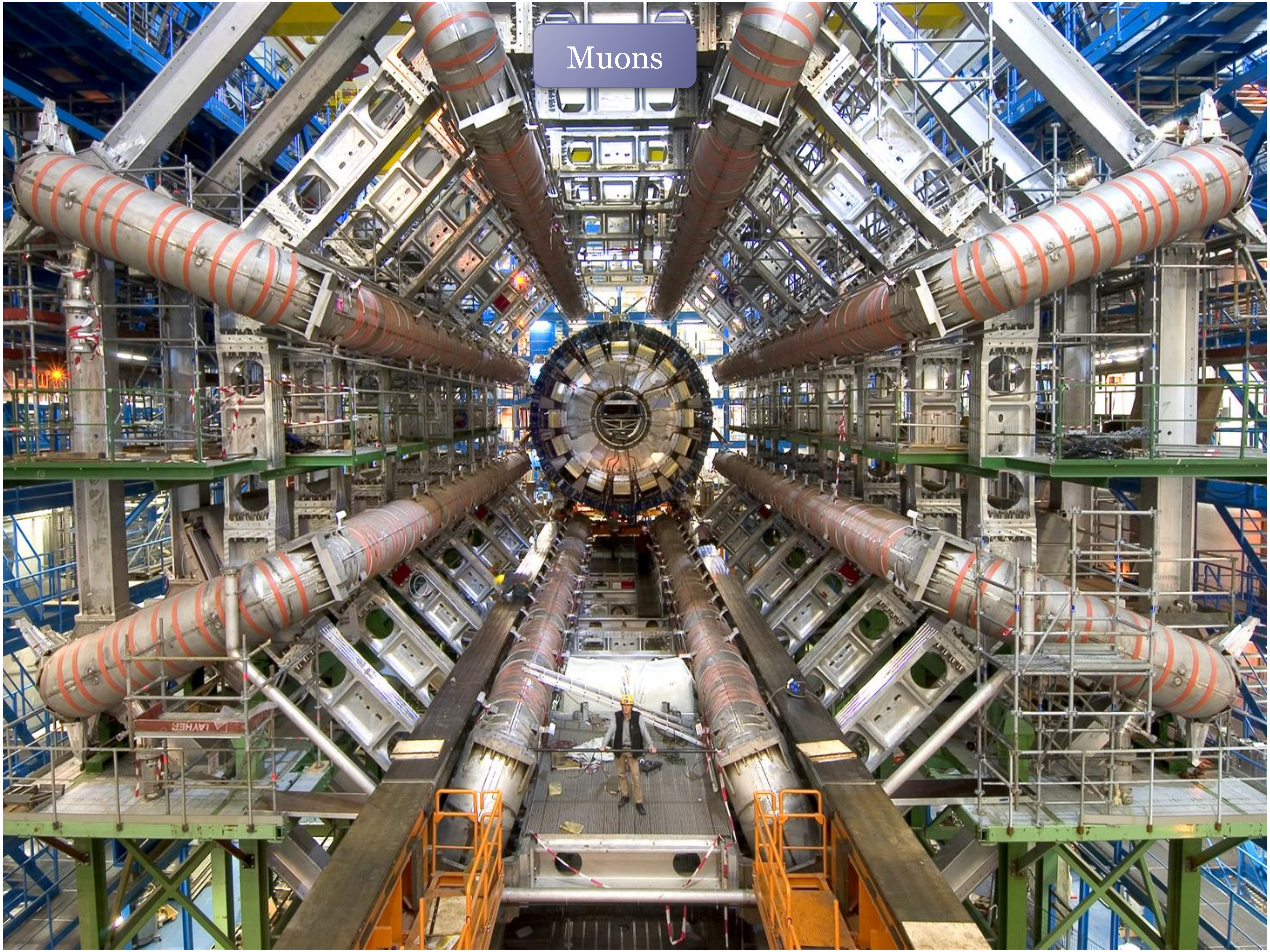
- Tracking detectors
- **Sampling Calorimeters** for energy deposits with fine granularity for shape discrimination
- Trigger and Data Acquisition



The ATLAS Detector at CERN's LHC

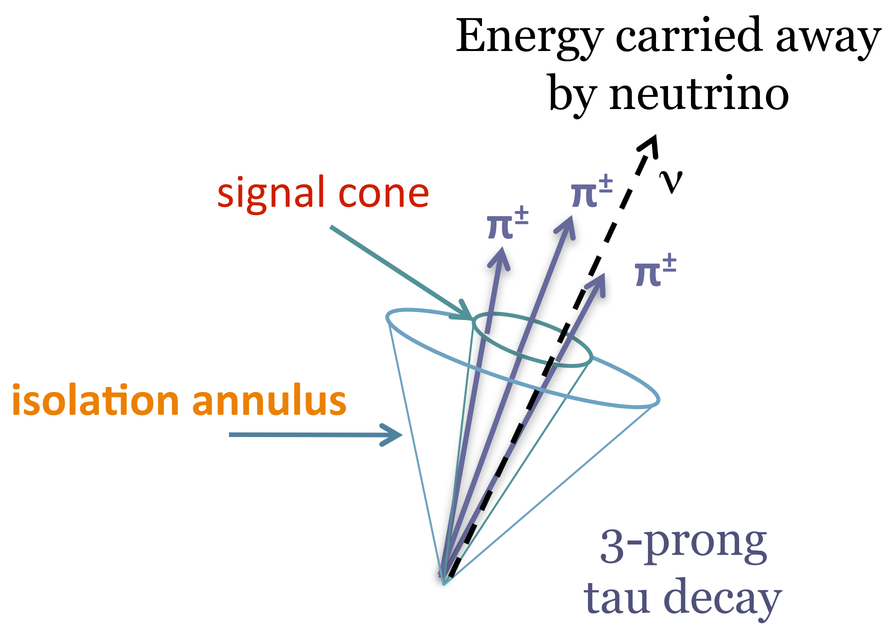
Trigger and Data Acquisition capable of handling 40 MHz interaction rate and writing out events at a rate of O(100 Hz)



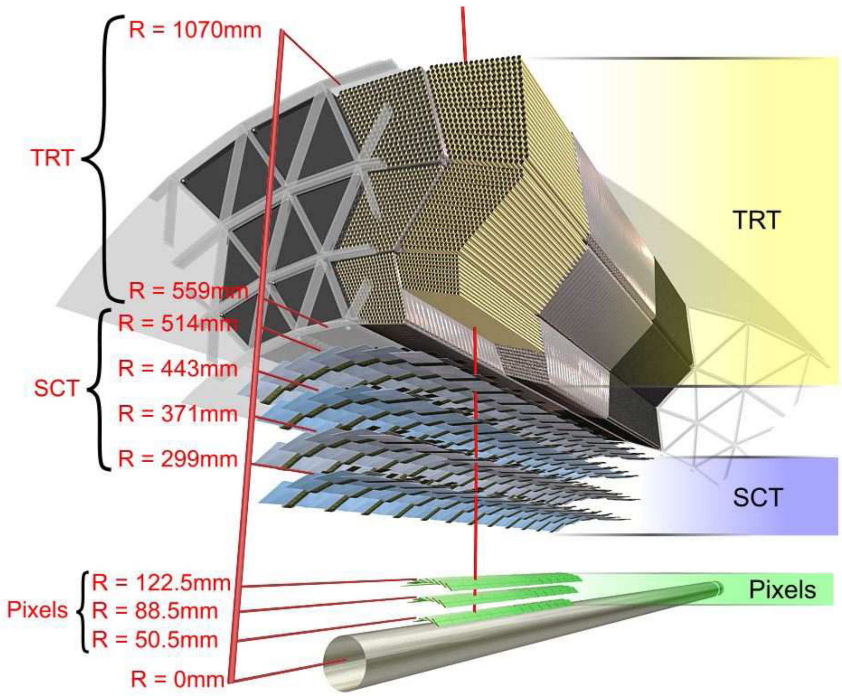

Muons

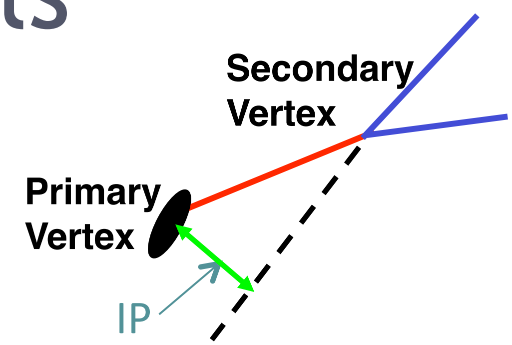
Visible energy and momentum

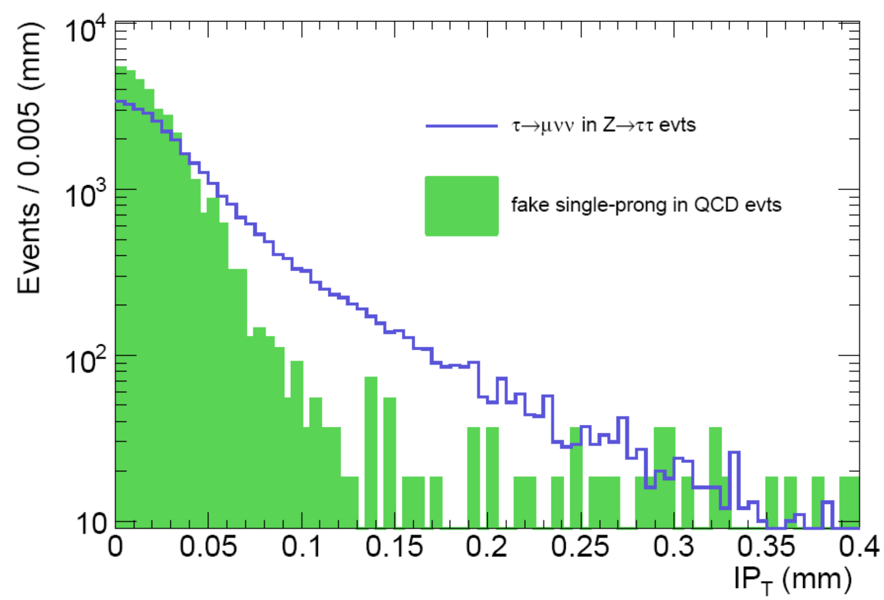
Decay modes	TAUOLA-CLEO
$\tau \to e\nu_e\ \nu_\tau,$	17.8 %
$\tau \to \mu\nu_\mu\ \nu_\tau$	17.4 %
$\tau \to h^\pm neutr.\nu_\tau$	49.5 %
$\tau \to \pi^\pm\nu_\tau$	11.1 %
$\tau \to \pi^0\pi^\pm\nu_\tau$	25.4 %
$\tau \to \pi^0\pi^0\pi^\pm\nu_\tau$	9.19 %
$\tau \to \pi^0\pi^0\pi^0\pi^\pm\nu_\tau$	1.08 %
$\tau \to K^\pm neutr.\nu_\tau$	1.56 %
$\tau \to h^\pm h^\pm h^\pm neutr.\nu_\tau$	14.57 %
$\tau \to \pi^\pm\pi^\pm\pi^\pm\nu_\tau$	8.98 %
$\tau \to \pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	4.30 %
$\tau \to \pi^0\pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	0.50 %
$\tau \to \pi^0\pi^0\pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	0.11 %
$\tau \to K^0_S X^\pm\nu_\tau$	0.90 %
$\tau \to (\pi^0)\pi^\pm\pi^\pm\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	0.10 %
other modes with K	1.30 %
others	0.03 %



Some tau-specific details







The "taus" we identify are actually hadronic decay products.

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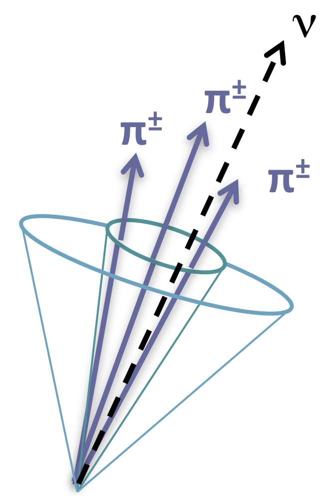
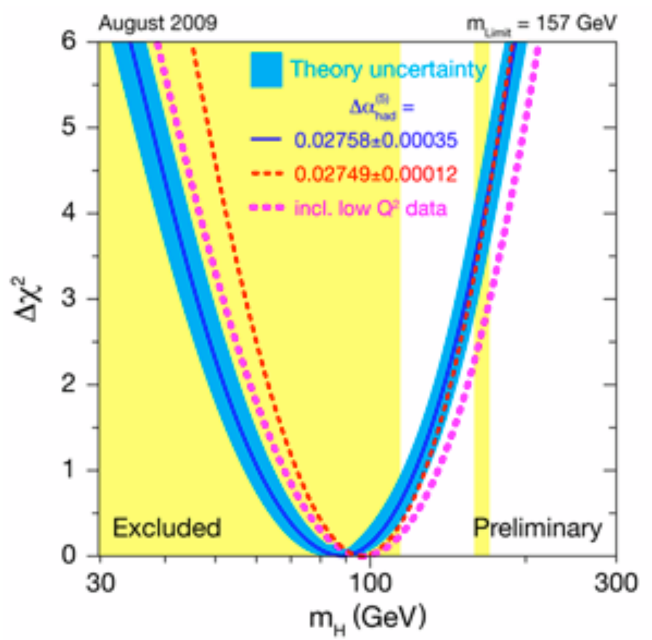
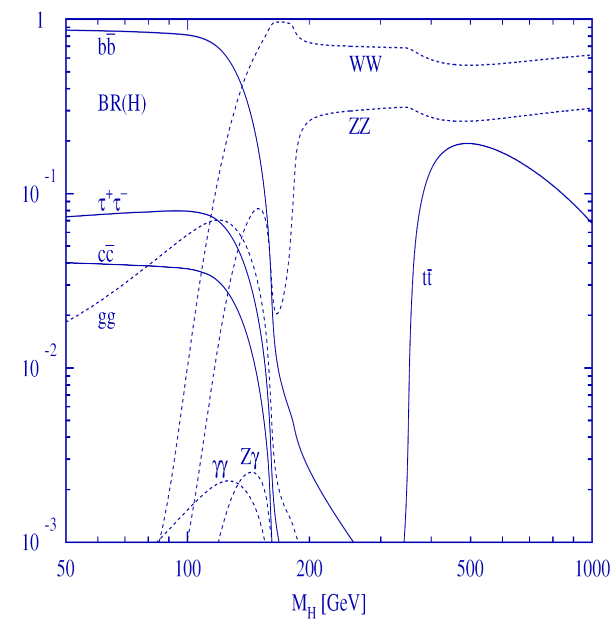


Why W-> τν ?
Taus as Probes for "New" Physics

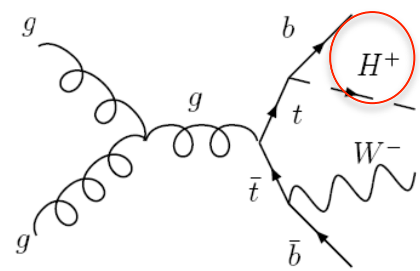


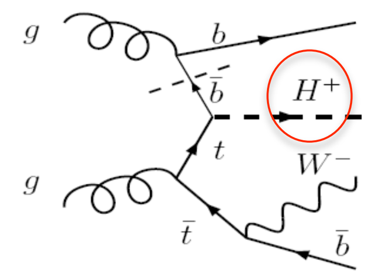


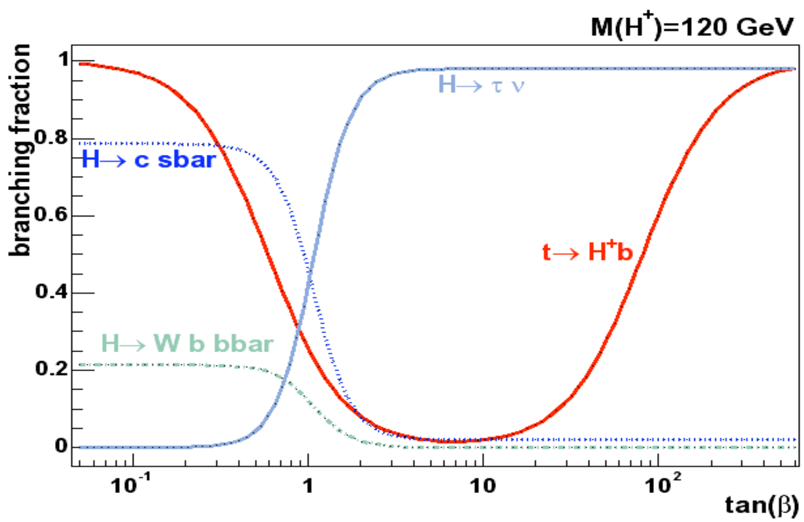
The tau, the heaviest lepton, couples strongly to the Higgs, and is key to a 5σ discovery in the important, but challenging, range of 115 – 125 GeV.

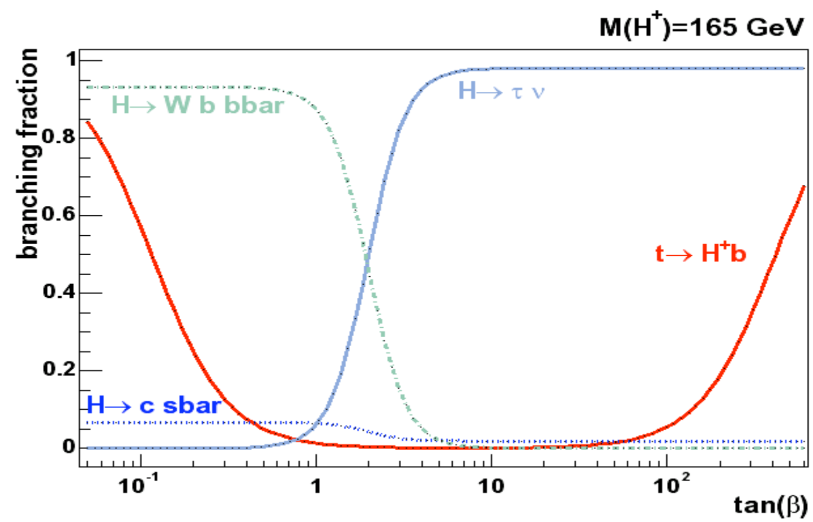
This analysis will rely (at least partially) on tau triggers!

Charged Higgs (SUSY)

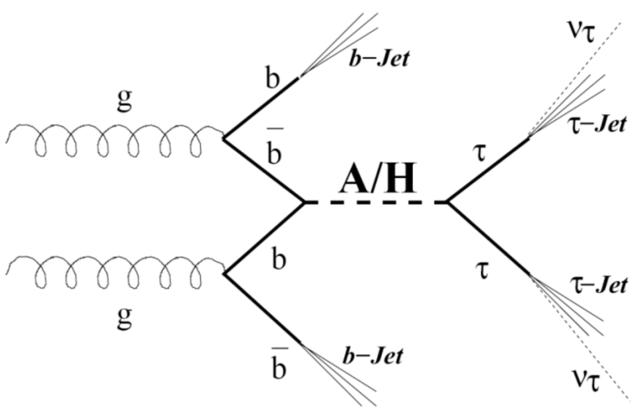


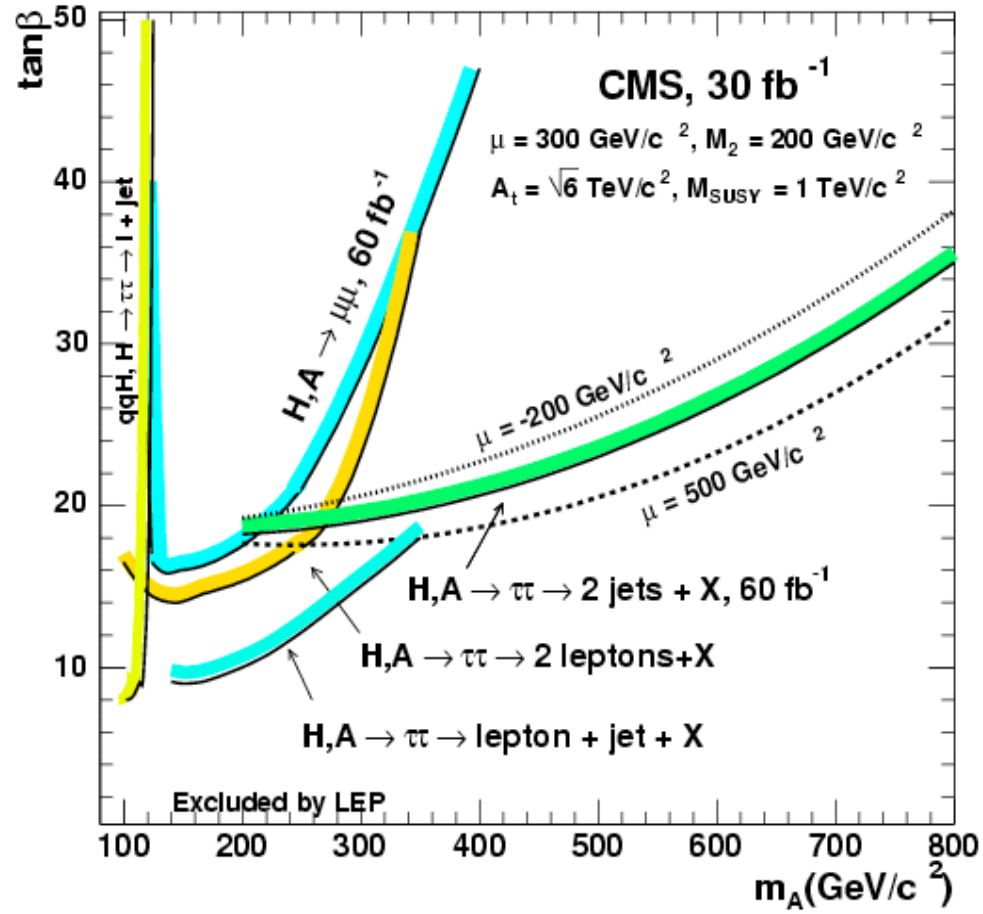






Neutral Higgs (SUSY)

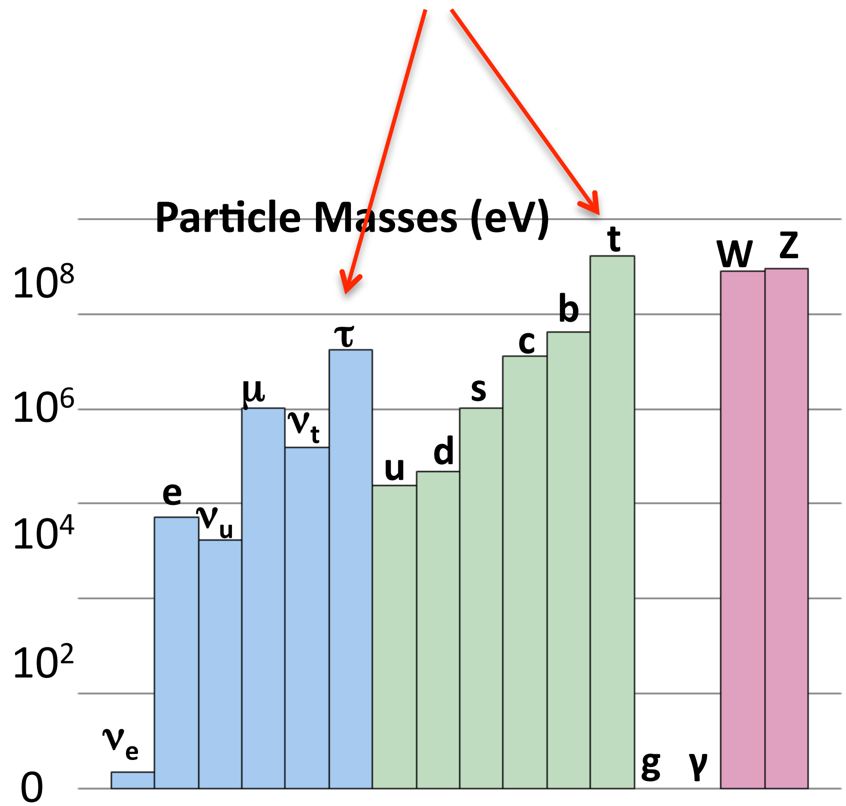




Sarah Demers, Yale University

Life without the Higgs?

Many Higgless theories include new particles with preferential couplings to the third generation, often motivated by trying to explain the very heavy top quark



Understanding New Physics

- All decay modes should be explored to understand the new physics
  - Not just electrons and muons!
- Tau decays can carry information about the polarization of the object that decays into them
  - Left-handed tau -> neutrino prefers to go in direction of tau

Why W-> $\tau\nu$?
My Version of the ATLAS Tau program

- Commission tau reco/ID and tau trigger
  - comparisons between data and monte carlo
- Measure efficiencies from the data with SM standard candles
  - Z->$\tau\tau$
  - eventually ttbar?
- Probe for New Physics signatures with taus

Why NOT W->$\tau\nu$?
Trigger and QCD background challenges
Is the physics interesting?

In Fall, 2009: What if the luminosity profile increases slowly?
Ws could provide the first evidence of taus!
Can we make an observation (cross section measurement?) with a "simplified" trigger?

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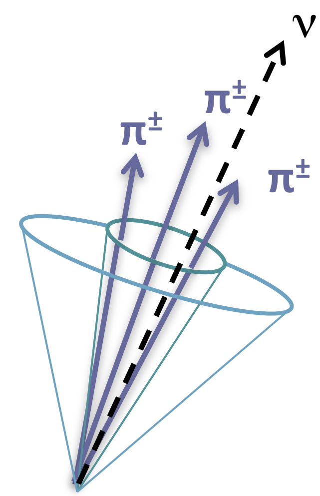
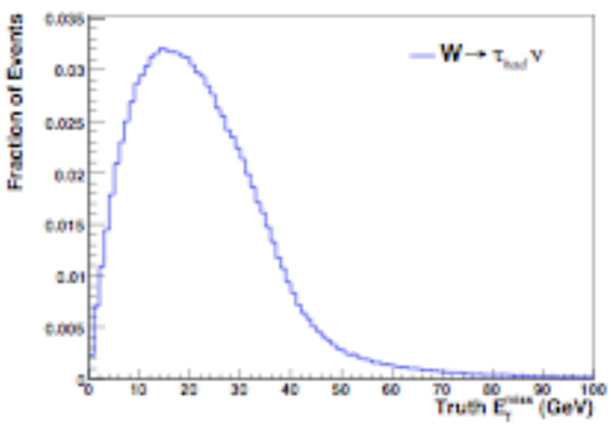
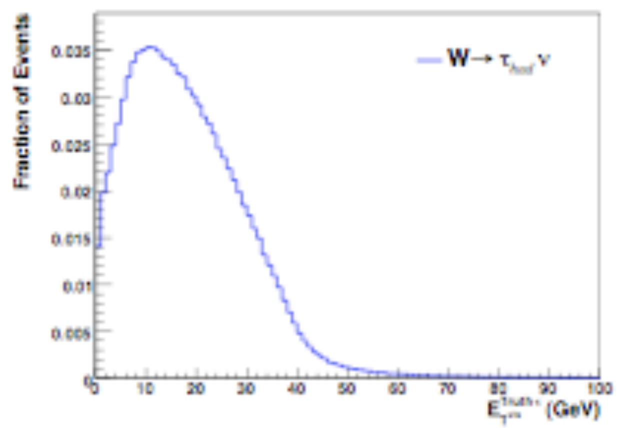


Selecting the W-> $\tau\nu$ events

- Trigger
- Separate the events from background offline
- W->$\tau\nu$ production cross section at 7 TeV at NNLO is 10.46 nb
  - About ten times higher than the Z->$\tau\tau$ production
  - Orders of magnitude lower than QCD di-jet production



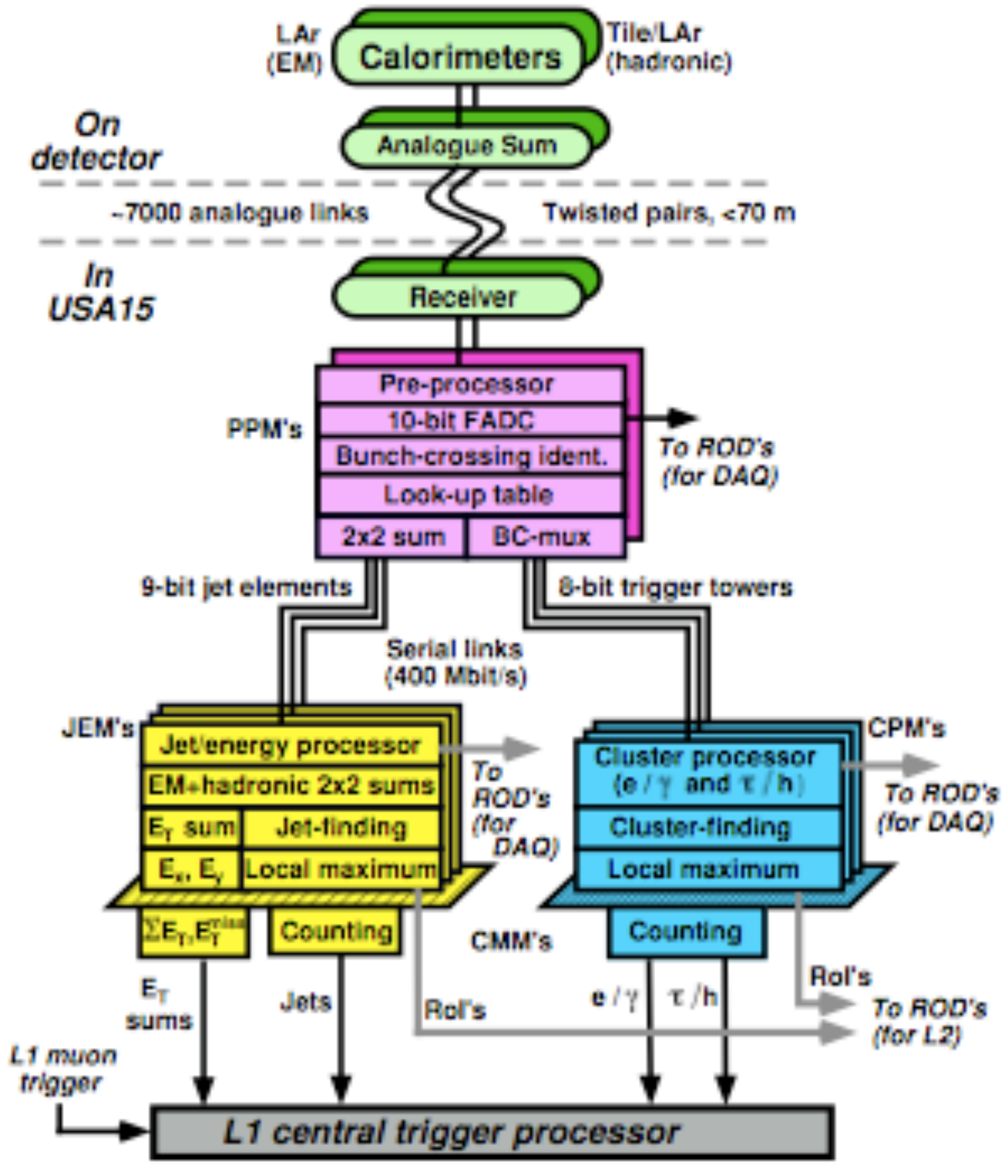


Relevant Analysis Cuts: Missing E_T > 30 GeV
tau p_T between 20 and 60 GeV

The trigger

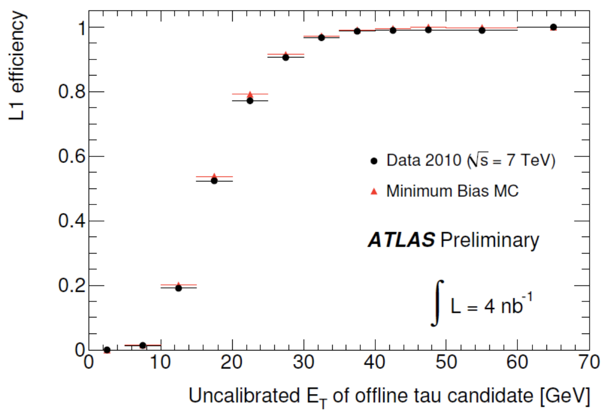
- There are only two objects in these events that we can use to control the trigger rate:
  - Missing transverse energy
  - Tau transverse energy
- Neither provide dramatic enough rate reduction, so the two need to be used in combination
- Keeping the rate low and measuring the trigger efficiency at the end of the day is challenging!
  - Particularly tricky: correlations between objects

Level 1 Calo Trigger

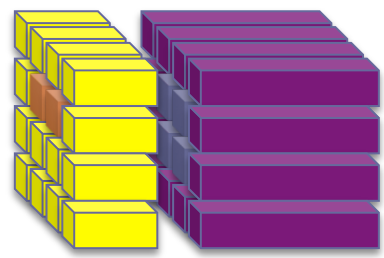


Level 1 Hardware Trigger: **5 GeV Tau** + 5 GeV Missing E_T

5 GeV L1 Tau Trigger

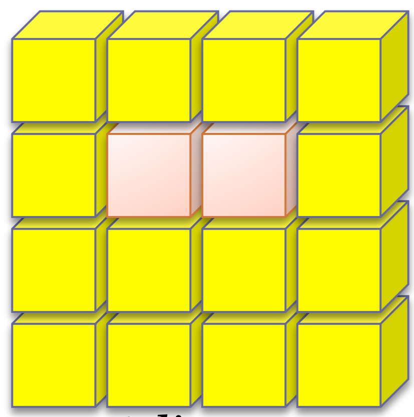


EM
Trigger Towers



HAD
Trigger Towers

Threshold Calculation =



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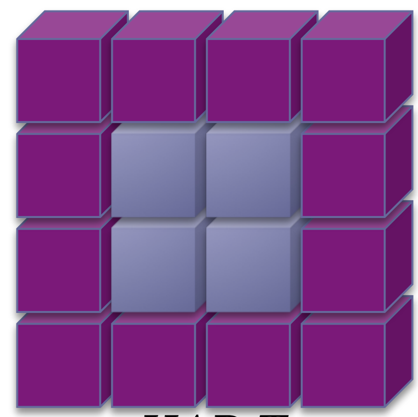
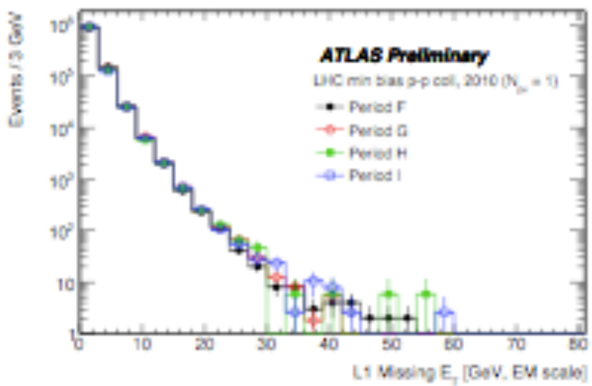
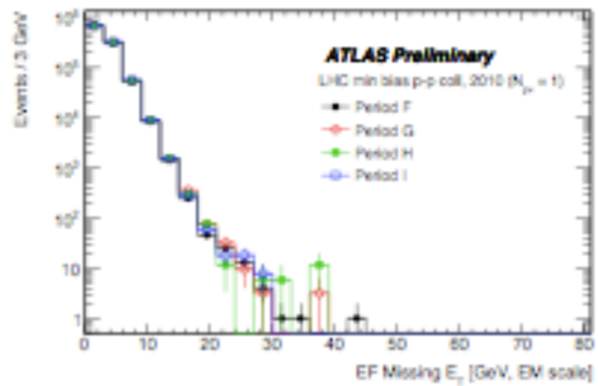


2 Adjacent EM Trigger Towers

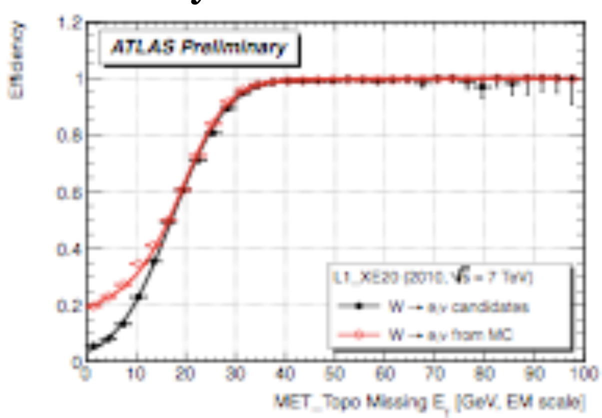
2x2 HAD Towers behind them

Level 1 Hardware Trigger: 5 GeV Tau + **5 GeV Missing E_T**

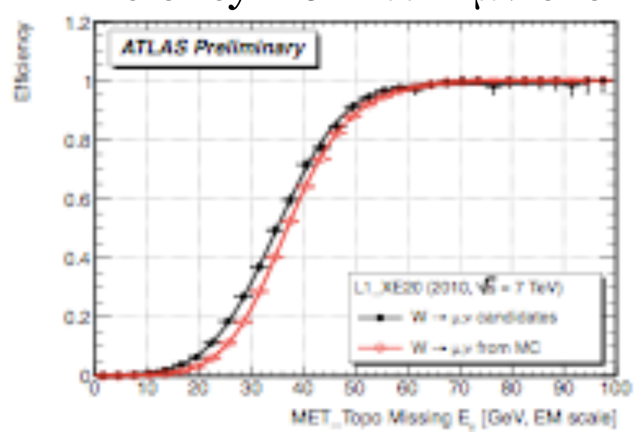




20 GeV Threshold
Efficiency from W->eν events

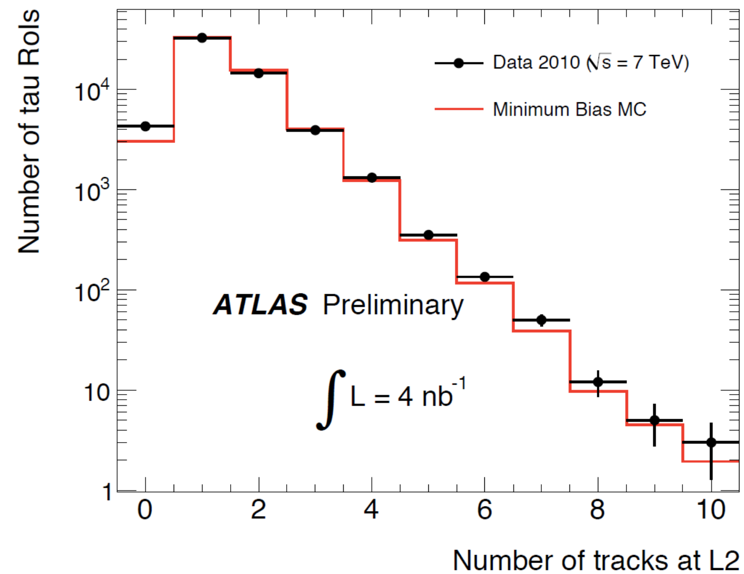


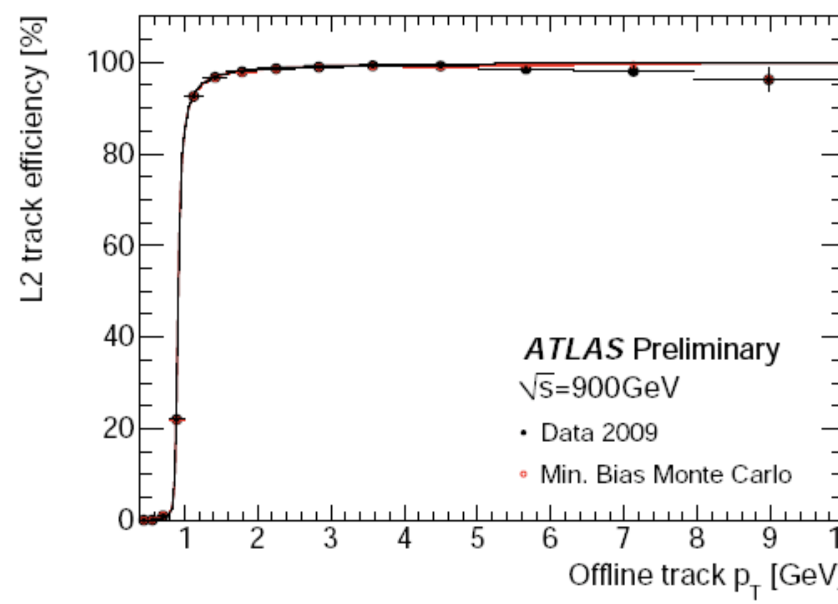
20 GeV Threshold
Efficiency from W->μν events



Level2 Trigger

- Only access to small fraction of data is available (a few percent) via L1 tau region of interest
- Refined Missing ET
  - Missing ET > 5 GeV
- On the tau side, require only a track
  - Track in tau RoI > 6 GeV



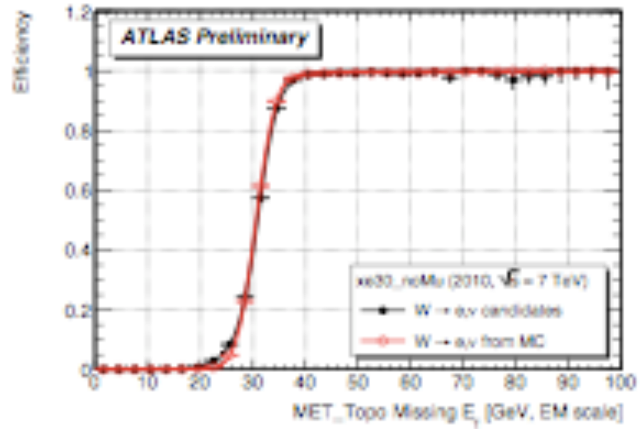


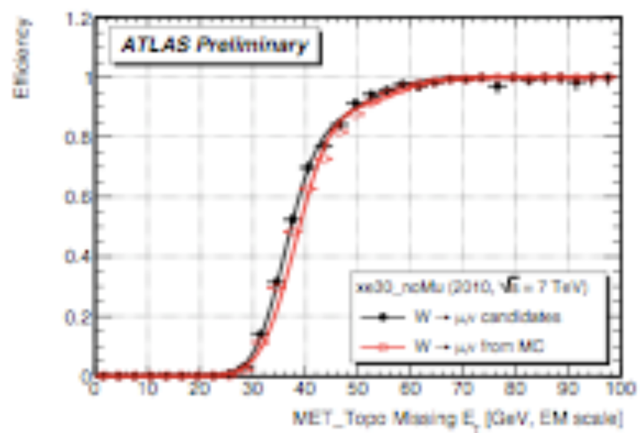
Trigger Summary

Object	Cut
L1 Missing ET	5 GeV
L1 Tau	5 GeV
L2 Missing ET	5 GeV
L2 Tau (track)	6 GeV
EF Missing ET	15 GeV
EF Tau	-

Trigger is >99% efficient with respect to offline cuts, as measured in MC

Event Filter Missing ET turn-on curves – very sharp!



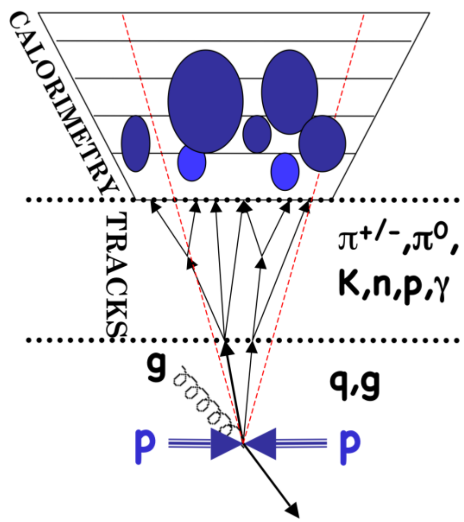


Offline Selection

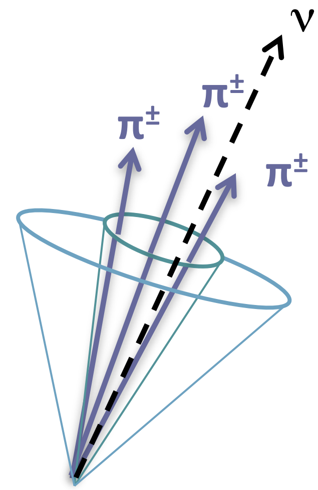
- Good data quality and cleaning cuts including
  - Primary vertex w/ 4 tracks p_T > 100 MeV
  - Jets cannot point toward Missing E_T
  - Objects cannot point toward overlap calo region (crack)
- Missing E_T > 30 GeV
- 20 GeV > tau candidate > 60 GeV
- Electron veto (loose electrons)
- Muon veto (combined muons)
- Missing ET significance > 6

Tau Identification

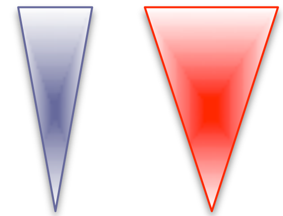
Jets



Taus



Sample	cross section X branching ratio	#events/8 hours (10^{31})
dijets (p_T 8 – 17 GeV)	1.7 X 10^{10} pb	5 X 10^9
dijets (p_T 17 – 35 GeV)	1.4 X 10^9 pb	4 X 10^8
dijets (p_T 35 – 70 GeV)	9.3 X 10^7 pb	3 X 10^7
W $\rightarrow \tau\upsilon$, $\tau \rightarrow$ *had*	1.1 X 10^4 pb	3200
Z $\rightarrow \tau\tau$, 1$\tau \rightarrow$ *had*	1.55 X 10^3 pb	450



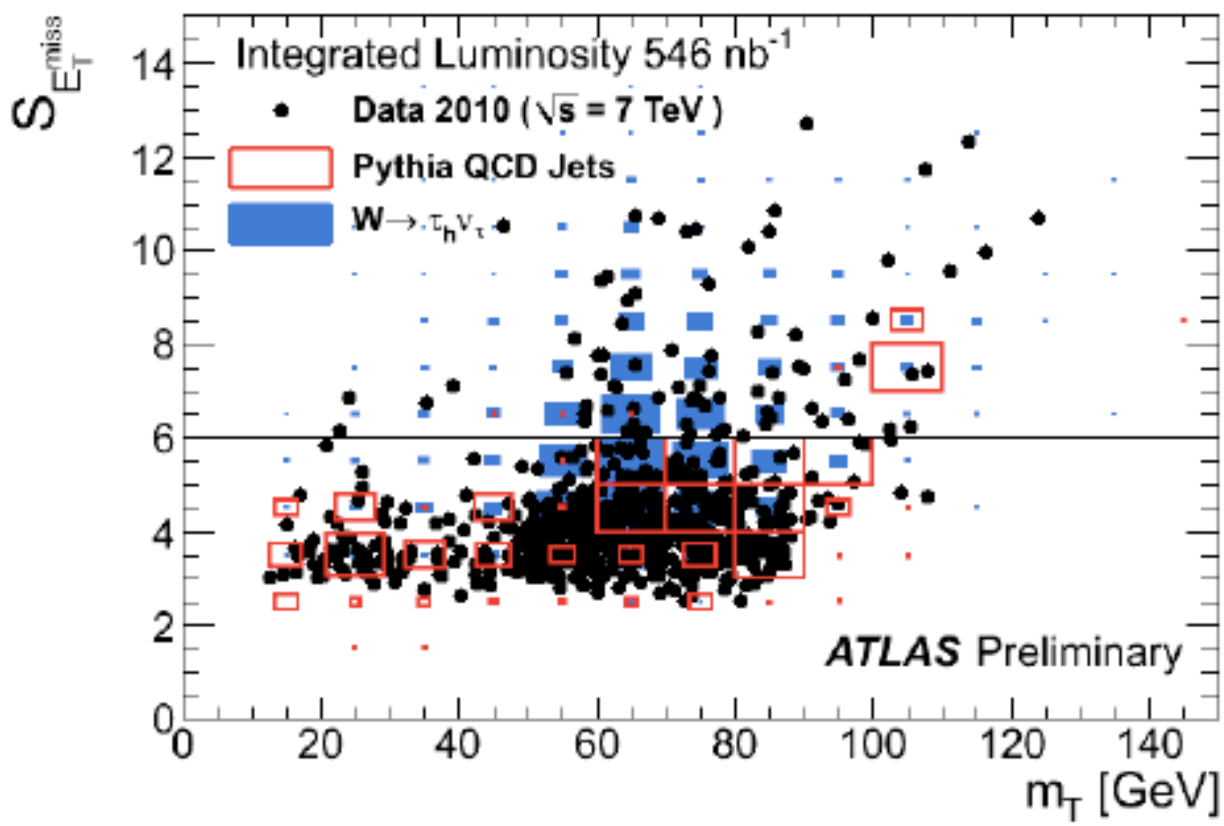
X GeV Tau X GeV Jet

Tau ID: Early Days

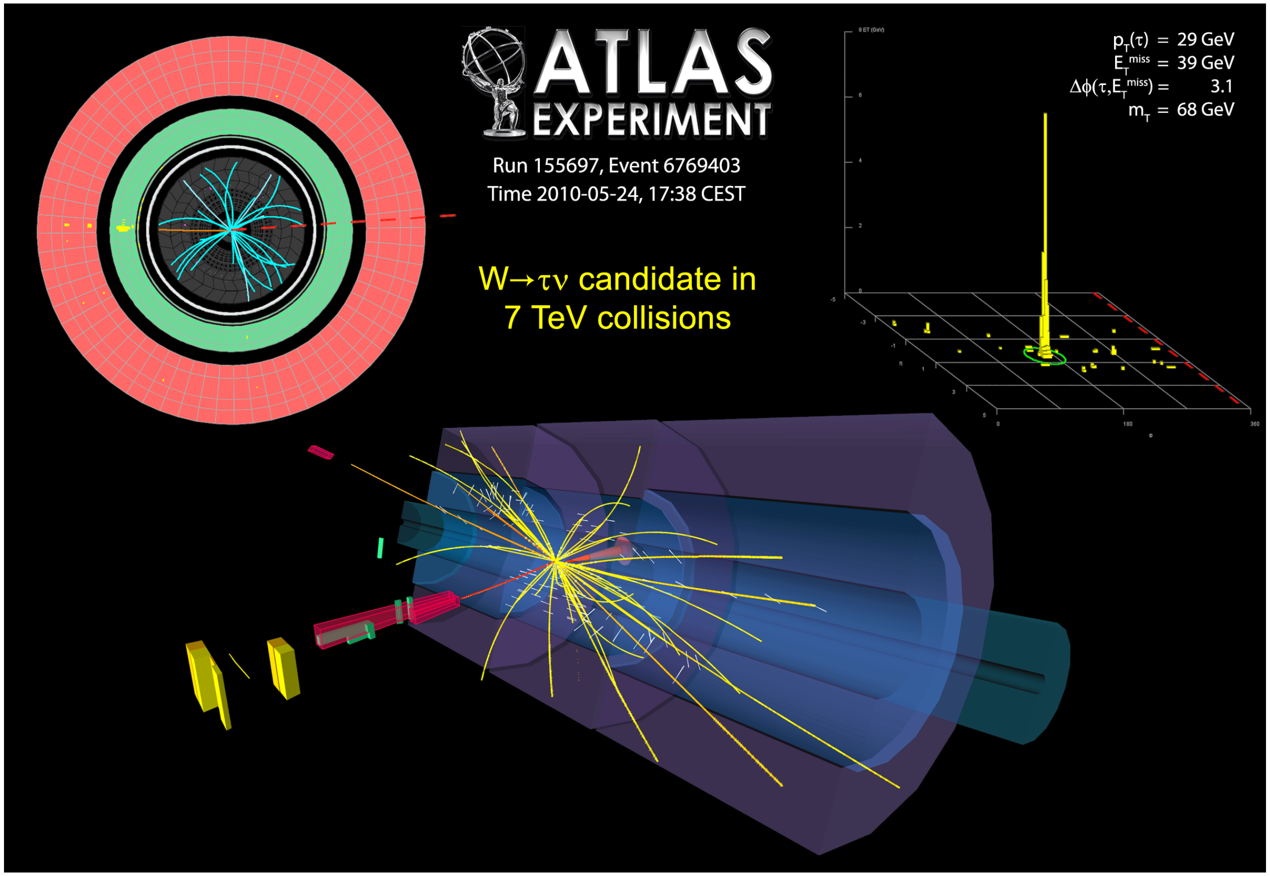
- "Double Seeded": 10 GeV energy deposit in the calorimeter matching 6 GeV track
- "Tight" Cuts tuned for 30% efficiency for selecting taus and 2% efficiency for selecting jets using:
  - **Track Radius**: p_T weighted ΔR of tracks associated with tau candidate
  - **Electromagnetic Radius**: E_T weighted ΔR of all cells in EM calorimeter associated with tau candidate
  - **Leading track momentum fraction**: ratio between p_T of lead track and total tau transverse momentum

Missing E_T Significance

$$S_{E_T^{miss}} = \frac{E_T^{miss}}{0.5 \cdot \sqrt{\sum E_T}}$$



First W-> $\tau\nu$ candidate at ATLAS May 24, 2010



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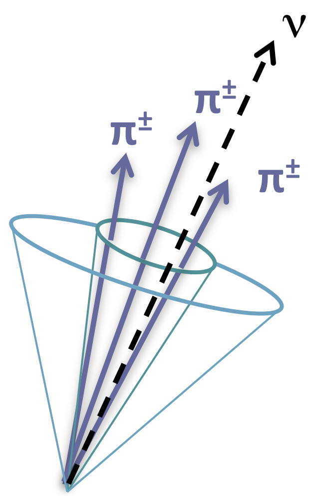
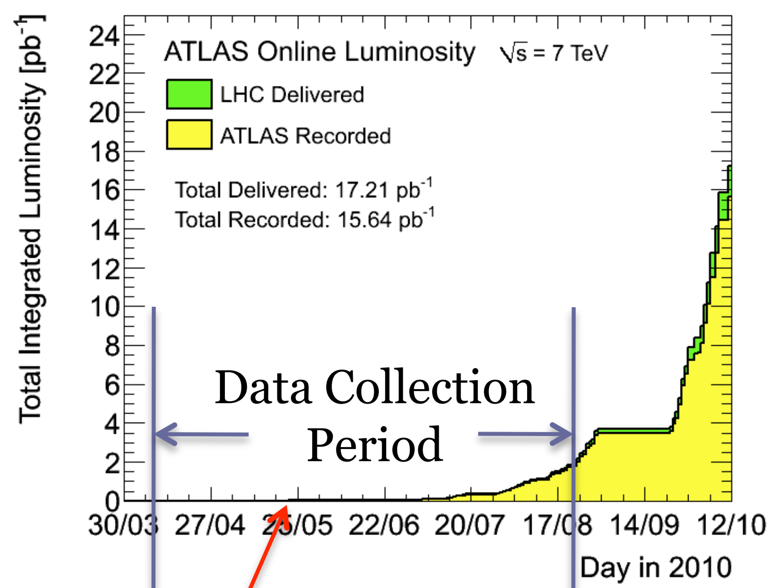


Timeline

- W-τν Observation approved by ATLAS Collaboration: Nov 2010
- 546 nb-1
- 78 events with excellent signal/background ratio



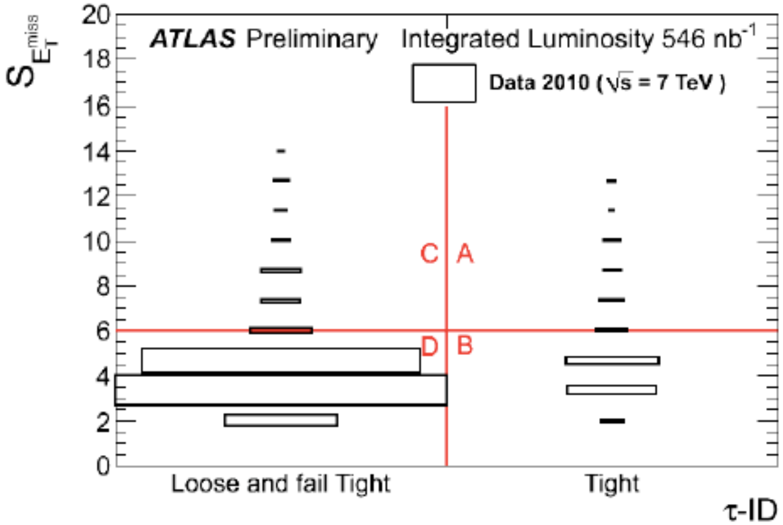
First W->τν candidate event
May 24, 2010

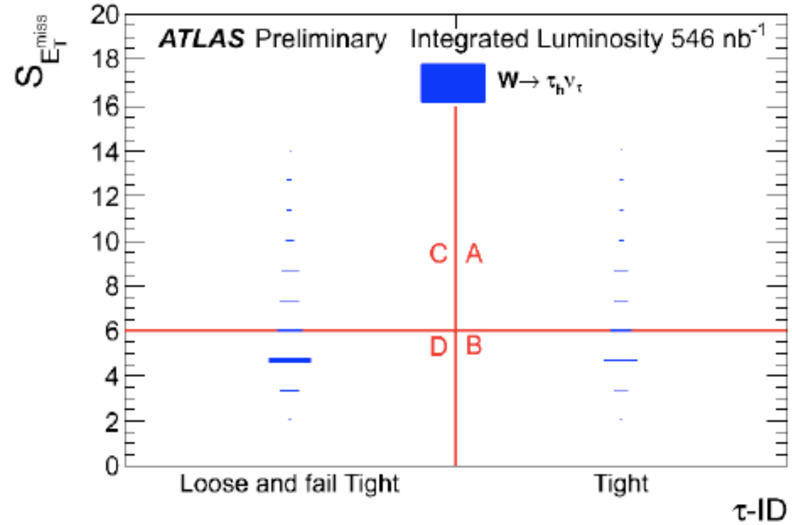
Summary

	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

Estimating QCD Background from Data

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





$$c_i = \frac{N^{i}_{sig} + N^{i}_{EW}}{N^{A}_{sig} + N^{A}_{EW}}, \qquad i = B, C, D$$

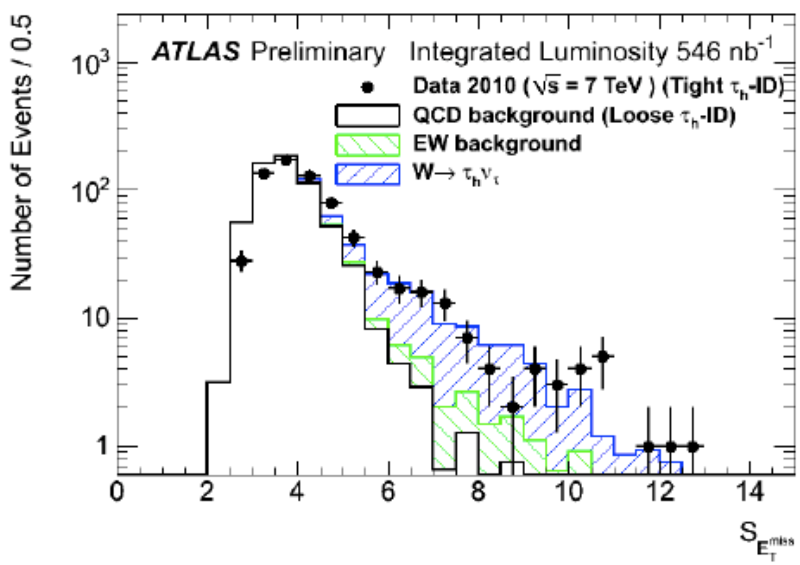
Region	A	B	C	D
Data	78	607	254	7107
$W \to \tau_h \nu_\tau$	55.3±1.4	39.5±1.2	71.0±1.6	54.2±1.4
EW	11.8±0.4	6.5±0.2	44.5±0.7	22.1±0.5
c_i		0.69±0.02	1.72±0.05	1.14±0.03

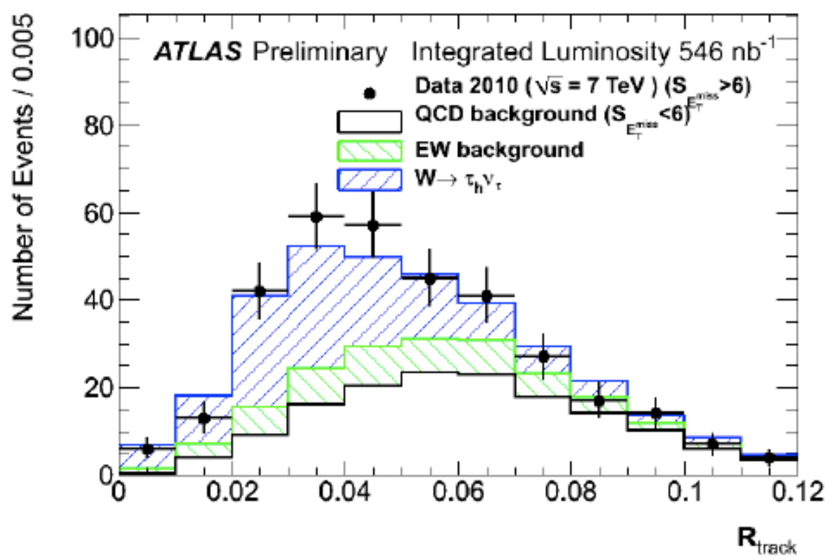
(Correct for Non-QCD in Control Regions)

$$N^{A}_{QCD} = (N^{B} - c_{B}(N^{A} - N^{A}_{QCD}))\frac{N^{C} - c_{C}(N^{A} - N^{A}_{QCD})}{N^{D} - c_{D}(N^{A} - N^{A}_{QCD})}$$

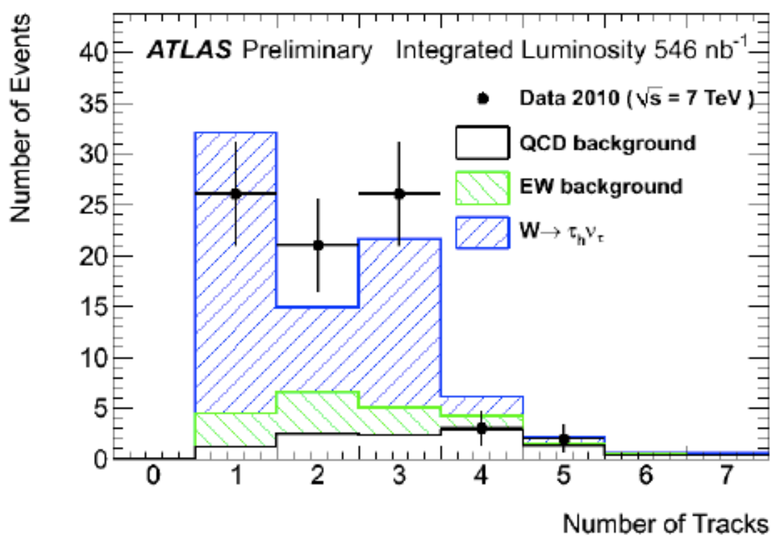
Estimated 11 QCD events in signal region (A)

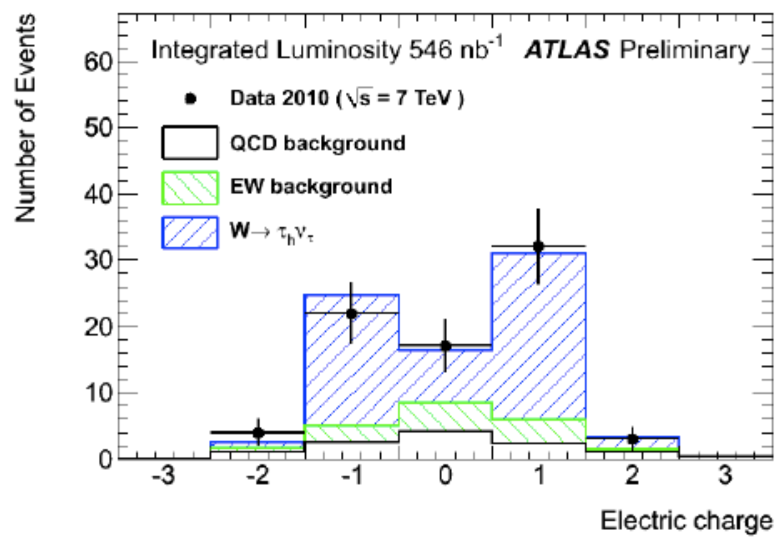
Sanity Checks



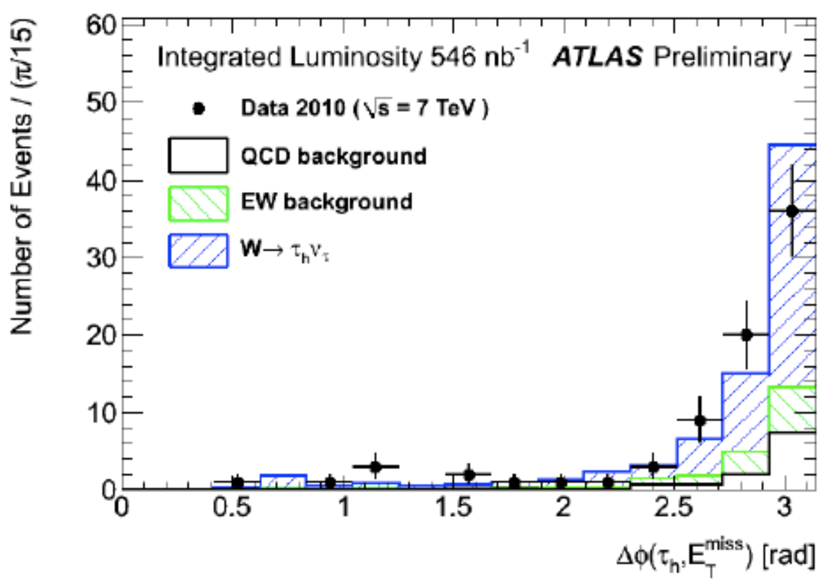


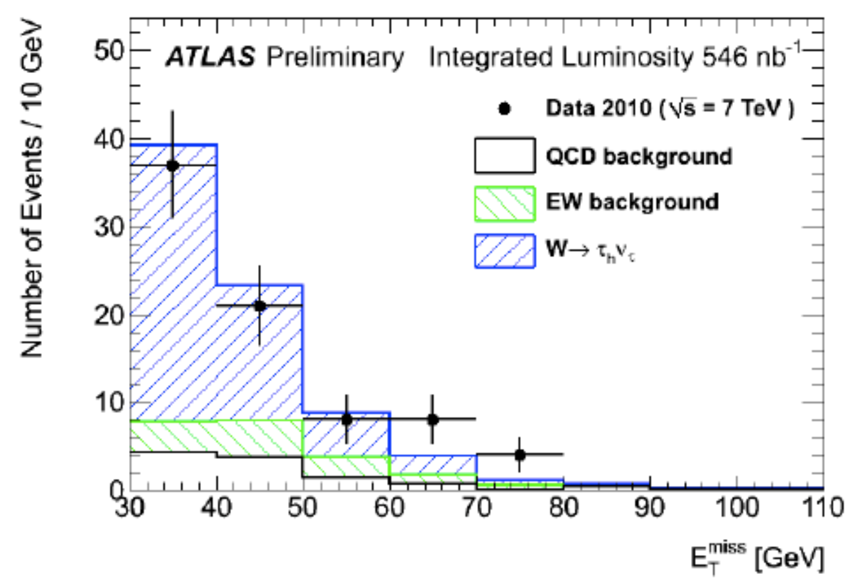
Track Multiplicity and Tau Charge





Tau-Missing E_T angle and Missing E_T

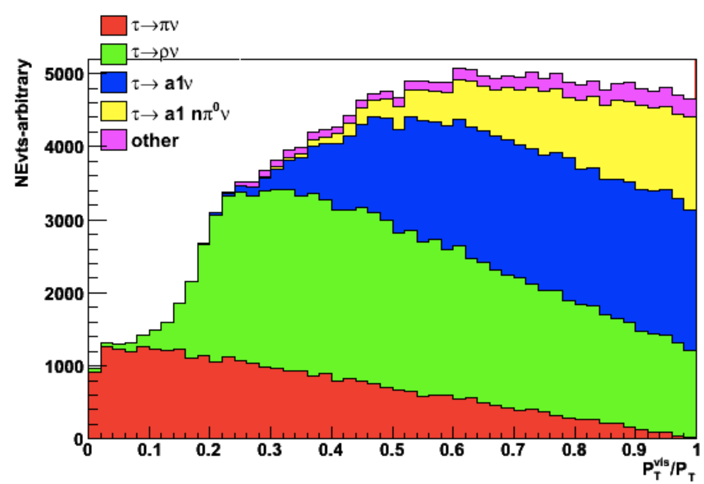




Future Plans

- W->τν Cross Section Measurement
  - Yale Group Postdoc (Cristobal Cuenca Almenar) supporting trigger efficiency measurement
- Exploit excellent signal to background in order to understand our ability to use tau decays to access polarization information

Toy Monte Carlo Study by Zofia



Conclusions

- The W->$\tau\nu$ analysis provides a fantastic benchmark channel for the trigger and a good test-bed for challenging physics studies
- The success in this channel bodes well for the future tau physics program at the LHC!
- Thanks very much to HEP at Penn for the invitation and to Jean O'Boyle for putting up with making my arrangements!