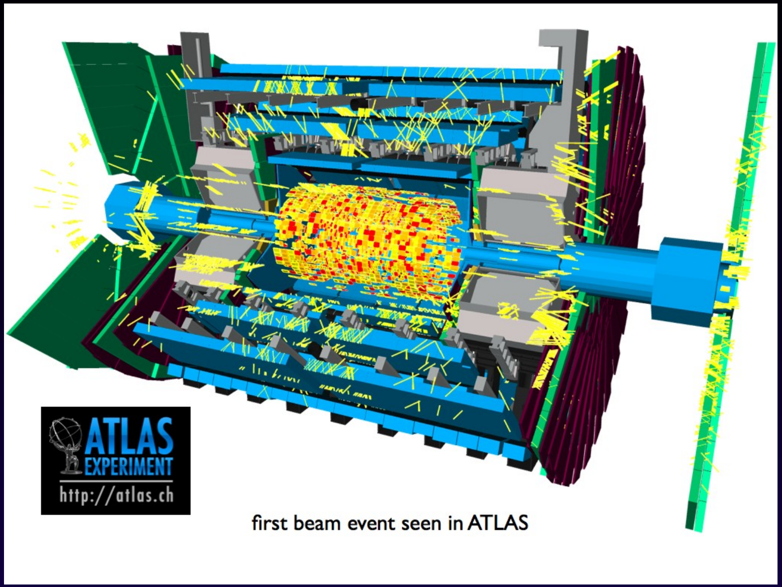
Rediscovering standard model physics with the ATLAS detector



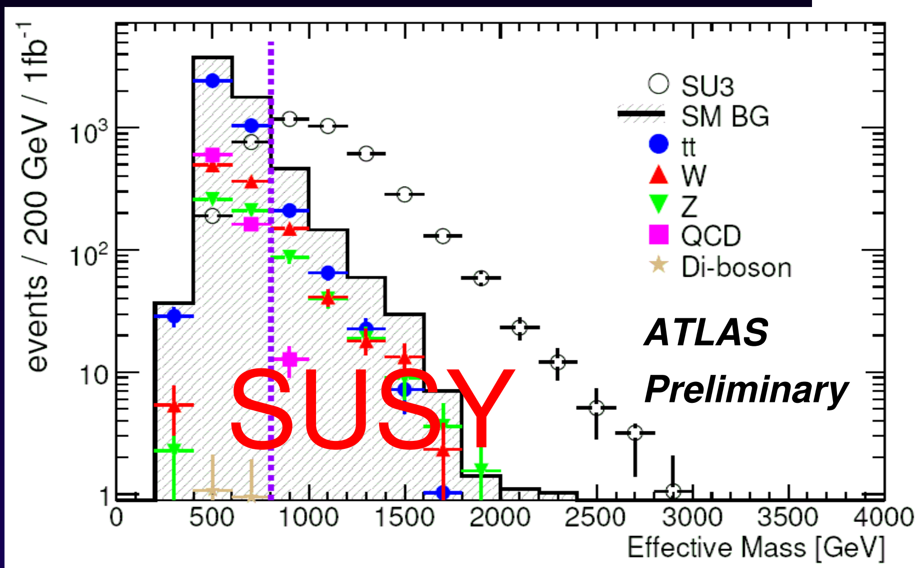
International Conference on Particle Physics
In Memoriam of Engin Arik and her Colleagues
29/10/08

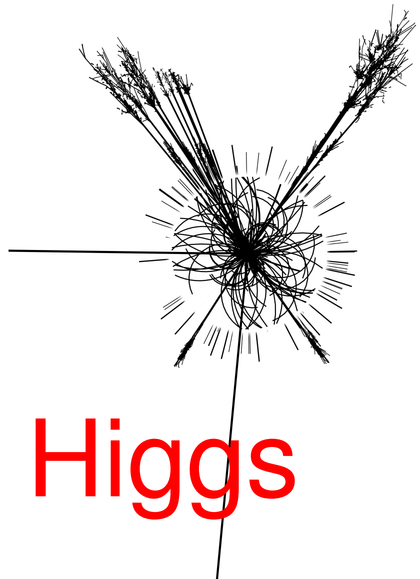
M. Flowerdew, University of Liverpool
on behalf of the ATLAS collaboration

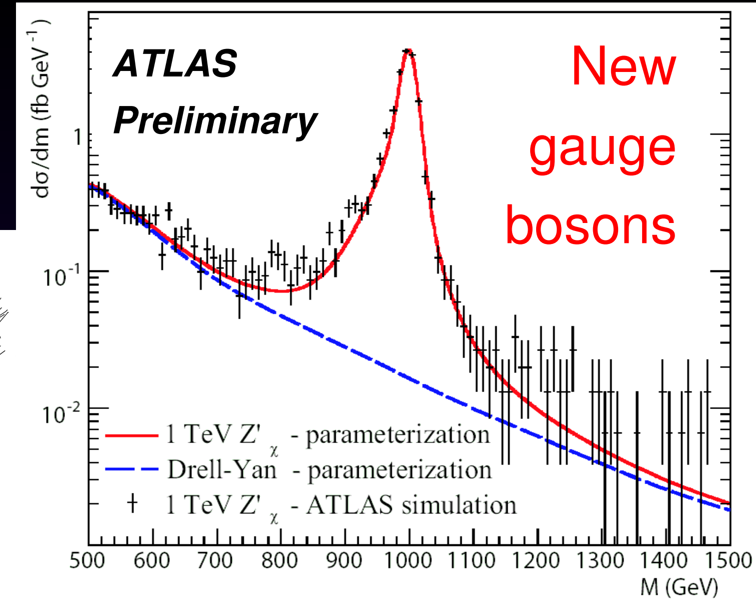
UNIVERSITY OF LIVERPOOL

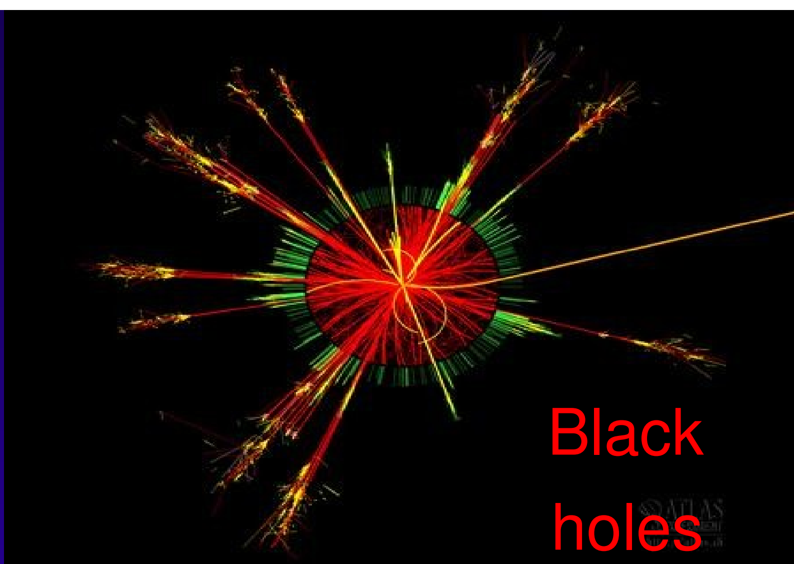
ATLAS EXPERIMENT http://atlas.ch

ATLAS physics day X?









ATLAS was built as a discovery machine

- Target: to find Higgs and new physics requiring extensions to the standard model (SM)
- Sensitive to many different event signatures

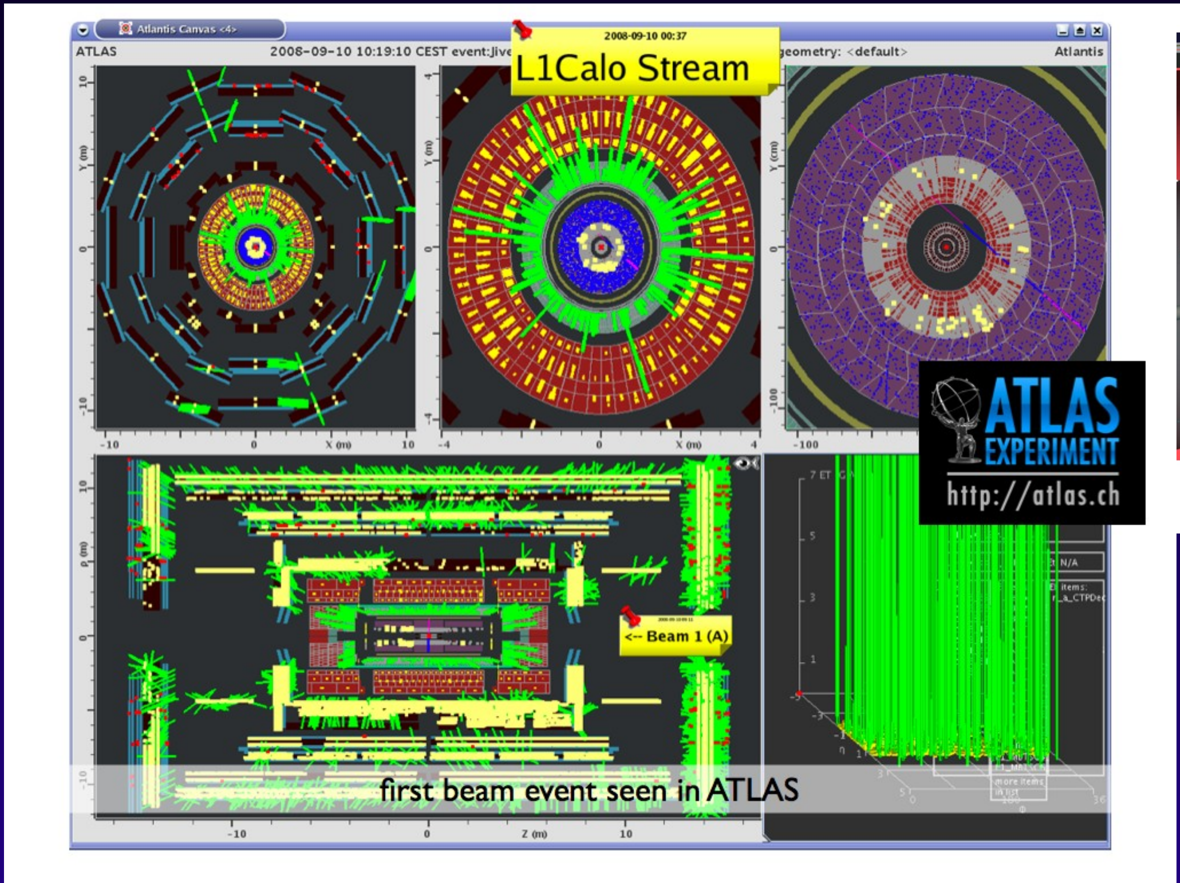
Key issues which need to be addressed, before any discoveries are announced:

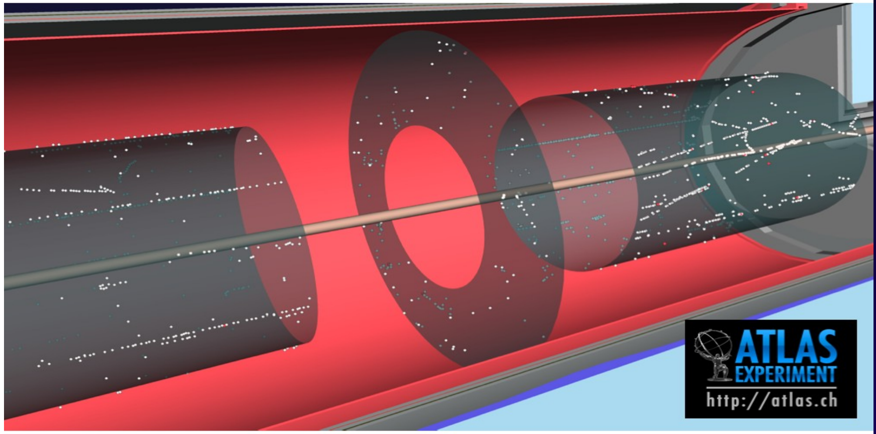
- Understanding of ATLAS
- SM background processes

First beam events, 2008

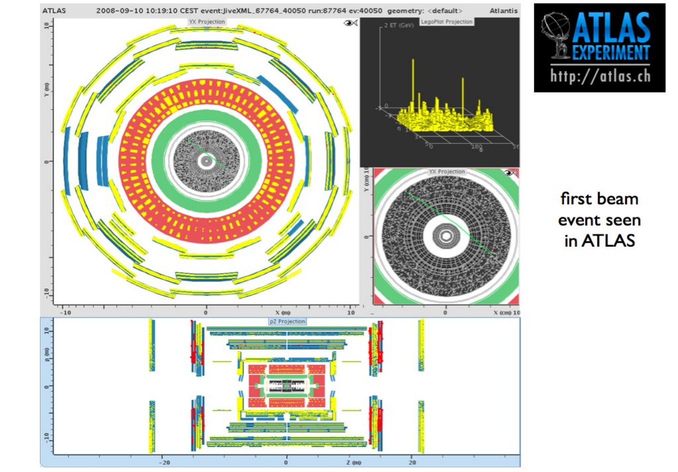
No collisions in 2008, but ATLAS makes the best use of time:

- Extensive commissioning performed with single beam and cosmic data





beam halo event seen in ATLAS



first beam event seen in ATLAS

ATLAS is ready for 2009 and the first few fb^{-1} of data

All cross sections/results shown for 14 TeV c.m. energy

Outline

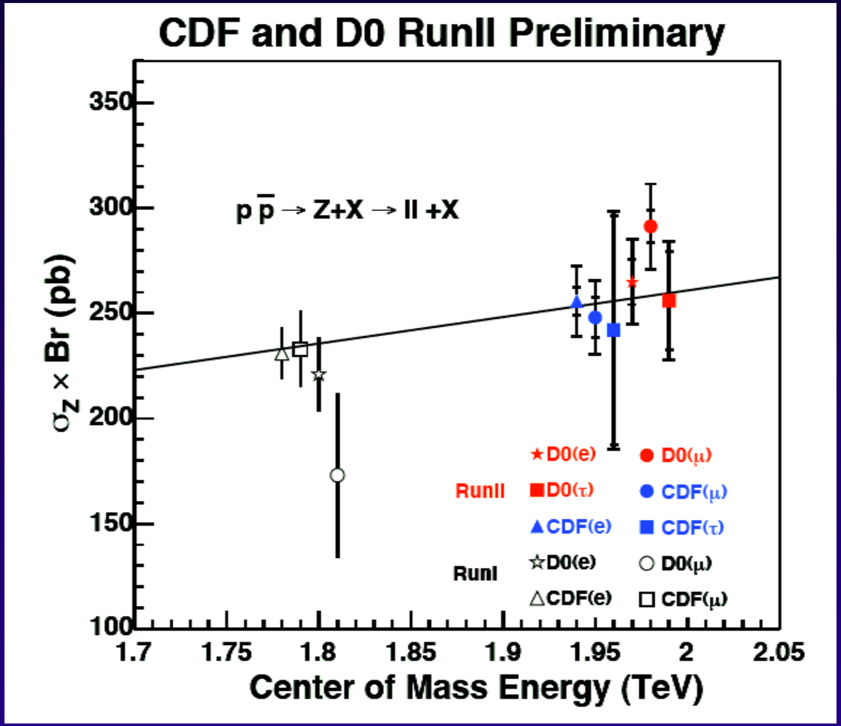
This talk focuses on standard model measurements with early data:

- W, Z boson and top quark production
- Physics targets with W,Z,t
- Physics and performance with W,Z:
  - pdf sensitivity
  - Inclusive cross section measurement
  - Lepton trigger and identification efficiencies
  - Missing E_T performance
  - Associated production with jets
- Measurements using top:
  - Light jet energy scale
  - High p_T top quarks

W,Z and t production at the LHC

Large, well-predicted cross sections at LHC:

- $\sigma_W \times BR(W \rightarrow l\nu)$ = 20.5 nb per flavour
- $\sigma_Z \times BR(Z \rightarrow ll)$ = 2.02 nb per flavour
- σ_{tt} ~ 833 pb (100x more than Tevatron)



SM performance topics:

- Lepton identification/triggering efficiencies
- Electron/Muon energy scales and resolutions
- Missing E_T (MET) scale and resolution
- Jet energy scale
- b-tagging quality

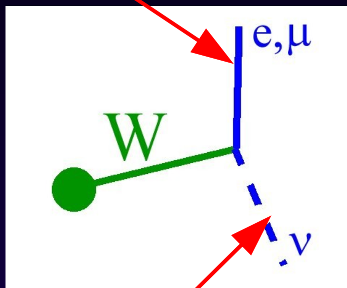
SM physics “exportables”

- Parton density functions (pdfs)
- Relative (then absolute) luminosity
- Backgrounds for BSM searches

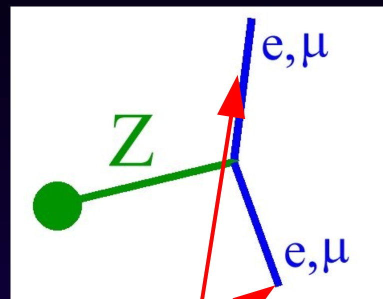
W/Z: Next-to-next-to leading order QCD using FEWZ by Melnikov, Kirill and Petriello
tt: NLO+next-to-leading-log (NLL) soft gluon resummation, by Bonciani et al

Physics with W,Z,t

High p_T lepton (electron or muon)



Missing E_T (MET)



Two high p_T leptons (electrons or muons)

W and Z physics:

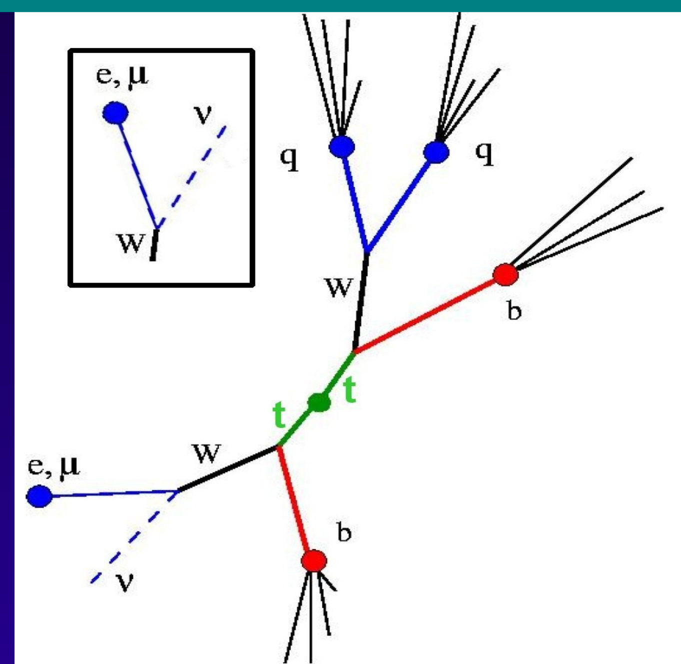
- Total/differential cross sections
- Production with jets
- W charge asymmetry
- W mass, $\sin^2\theta_W$
- Di-boson production (cf Dan Levin talk)
- High mass Drell-Yan cross section

Deviations in any/all may point to new physics

Top physics has possible direct access to new physics:

- tt cross section
- Single top cross section
  - Direct access to couplings
- m_t
- Top charge, spin and correlations
- Rare decays

See Jochen Schieck's talk for more details



High p_T lepton

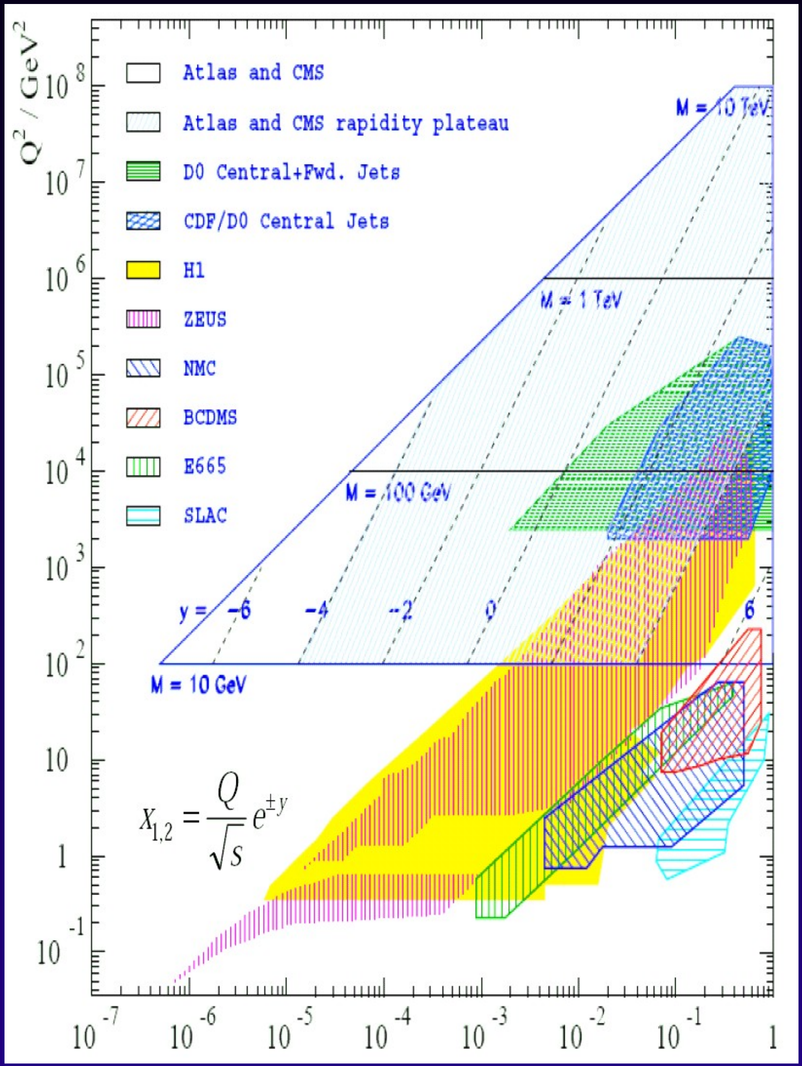
High MET

2 b-jets (b-tag optional)

4 jets total

OR Extra lepton

pdf sensitivity with ATLAS

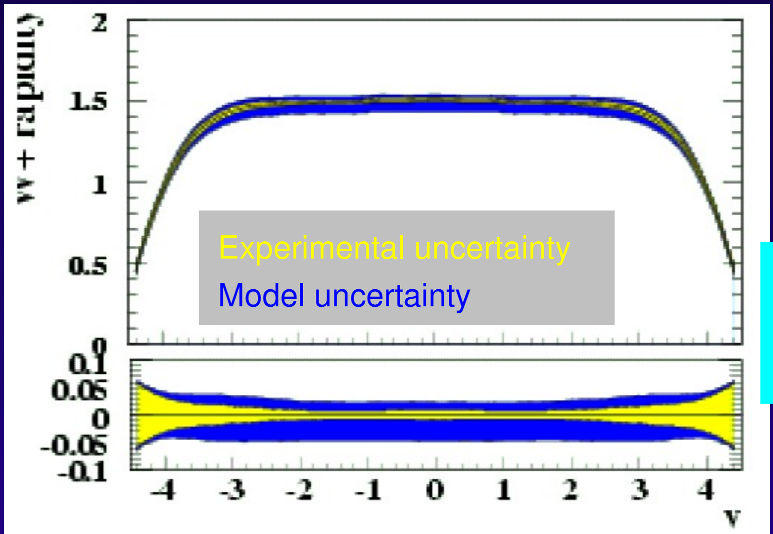


SM physics at the LHC probes low x regions

- Sensitive to gluon pdf

Current predictions set tough challenge for W/Z measurements

- pdf uncertainties ~1-2% at central rapidities
- Model uncertainties: ~3%
  - Low scale (Q_0) and parameterisation
- Total uncertainty probably larger than this



W^+ rapidity using new HERAPDF0.1 predictions

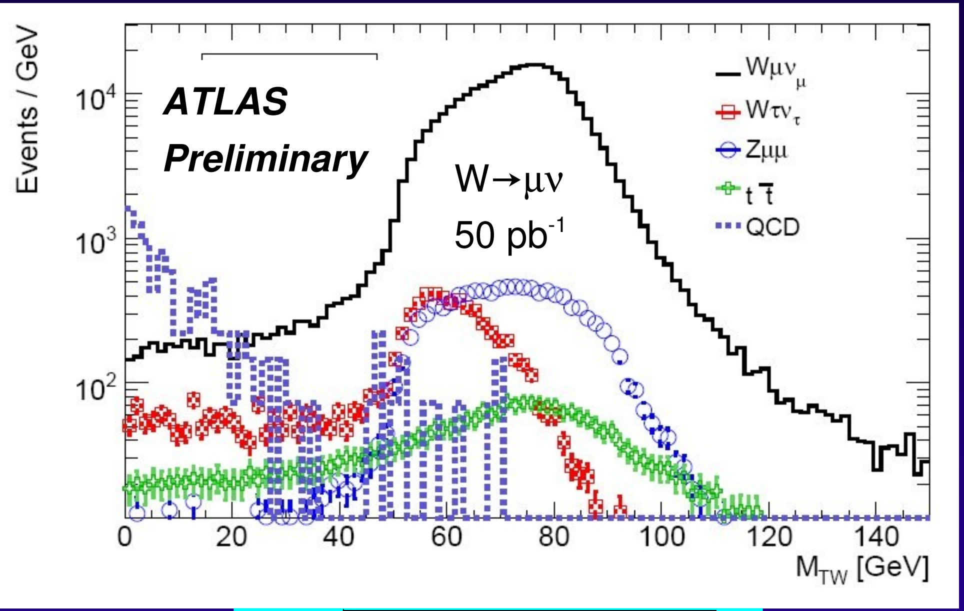
A. Cooper-Sarkar, HERA and the LHC workshop, May 2008

W,Z boson inclusive cross section measurements

Electron and muon channels analysed independently

Begin with simple cuts for benchmark measurement

- Electron shower shape
- Muon isolation
- Mass/Transverse mass cut

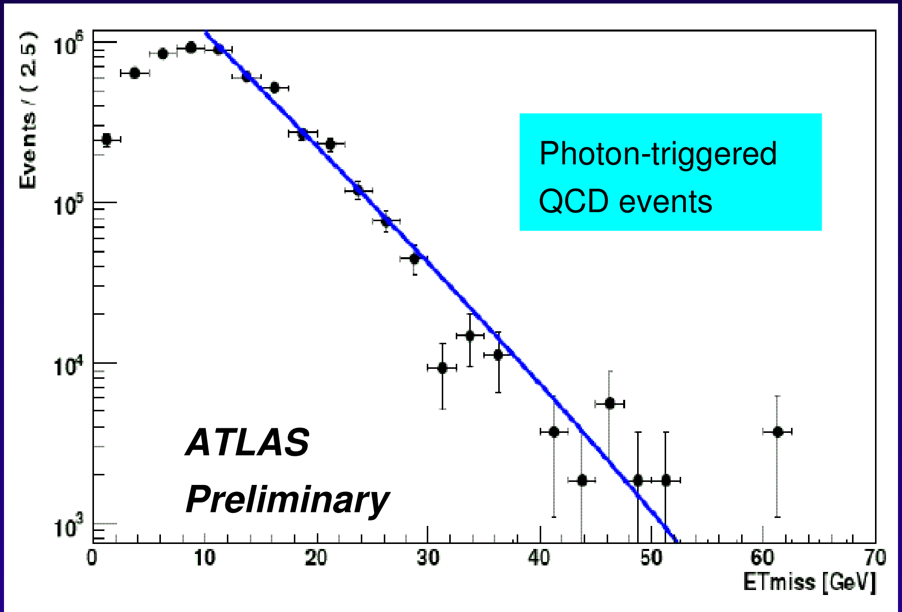


$$m_T^W = \sqrt{2\, p_T^l\, p_T^\nu (1 - \cos(\phi^l - \phi^\nu))}$$

Where possible, backgrounds estimated from data (esp. QCD)

Example: W→eν:

- Fit MET shape in QCD events passing photon trigger
  - W & Z removal cuts
  - Normalise using signal MET sideband



Michael Flowerdew

ICPP, Istanbul, 29/10/08

W,Z cross section: expected performance

$$\sigma = \frac{N - B}{\mathscr{L} A \varepsilon}$$

Projected yield (after selection) and cross section uncertainties for 50 pb^{-1}

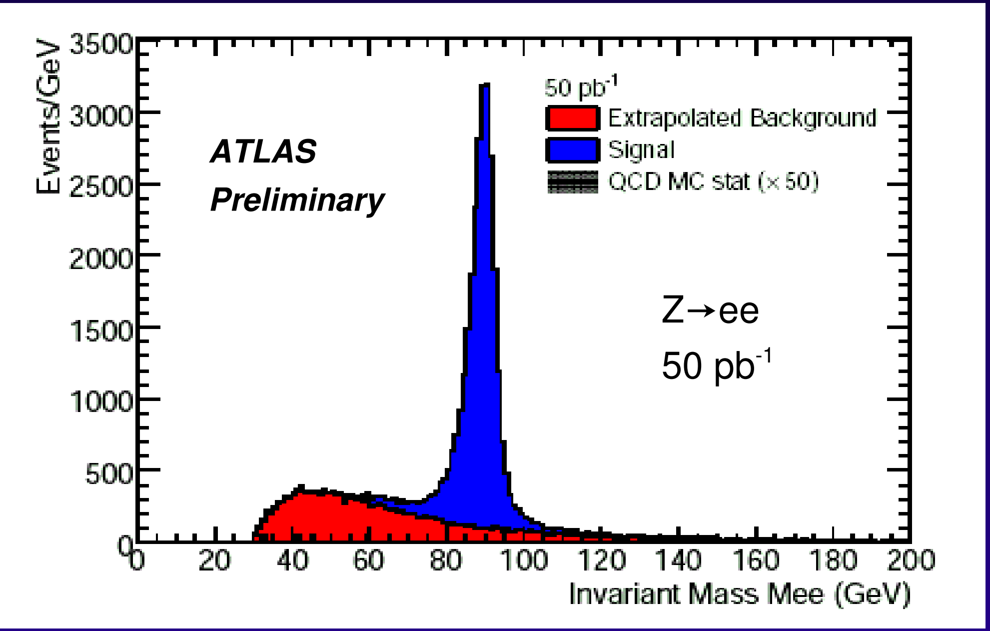
	N events (×10^4)	Δσ/σ stat	Δσ/σ syst	Δσ/σ lumi
$W \to e\nu$	23	0.2%	5.2%	10.0%
$W \to \mu\nu$	30	0.2%	3.1%	10.0%
$Z \to ee$	2.7	0.8%	4.1%	10.0%
$Z \to \mu\mu$	2.6	0.8%	3.8%	10.0%

Projection for 1fb^{-1}:

- Statistical uncertainties negligible
  - Efficiency uncertainty down to <1% using data-driven methods (next slide)
- Backgrounds reduced through selection
- Theoretical uncertainty dominates other systematics
- ALFA will reduce luminosity uncertainty

Principal systematic uncertainties with 50pb^{-1}:

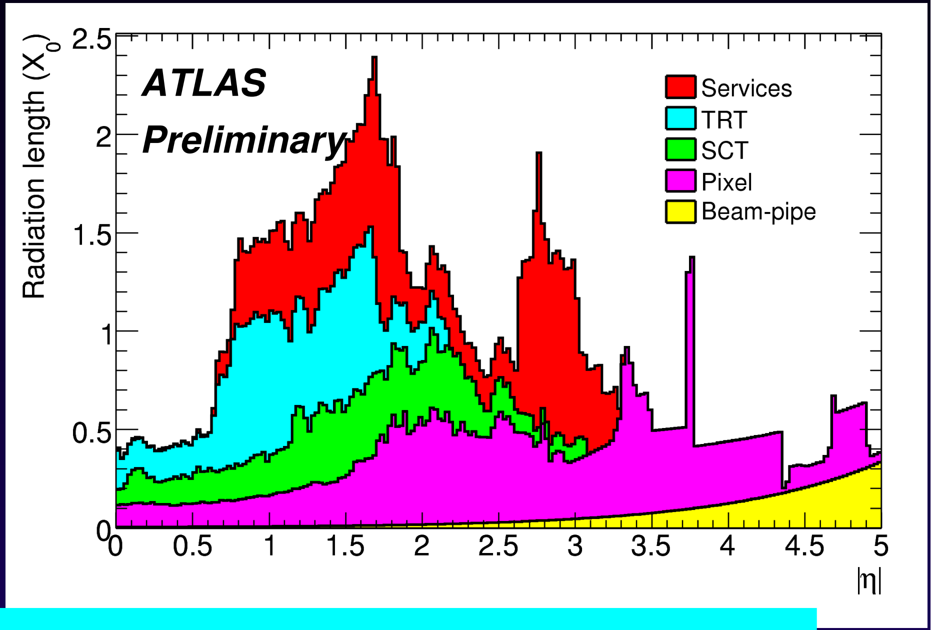
- Identification efficiencies 2-3%
- Backgrounds ~1-4% (electrons)
  - <1% (muons)
- Theory (incl. Acceptance) ~2%:
  - pdfs
  - Renormalisation/Factorisation scales
  - ISR, FSR



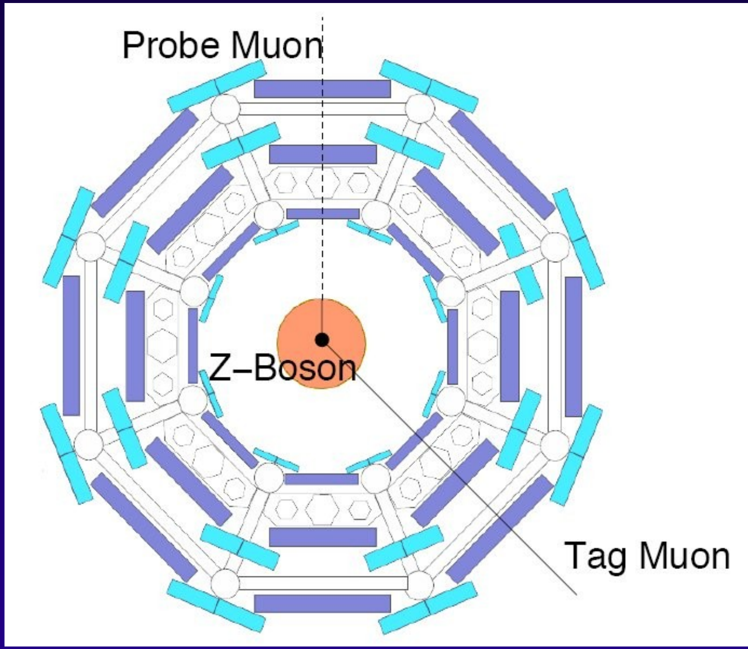
Measuring efficiencies with the Z

Need a **data-driven** efficiency measurement for identification and triggering

- Use $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$
- Needed because ATLAS is complex
  - Efficiencies will not be flat in η, p_T, even ϕ!
  - Need differential measurements to reduce bias



Material distribution (X_0) at exit of inner detector envelope



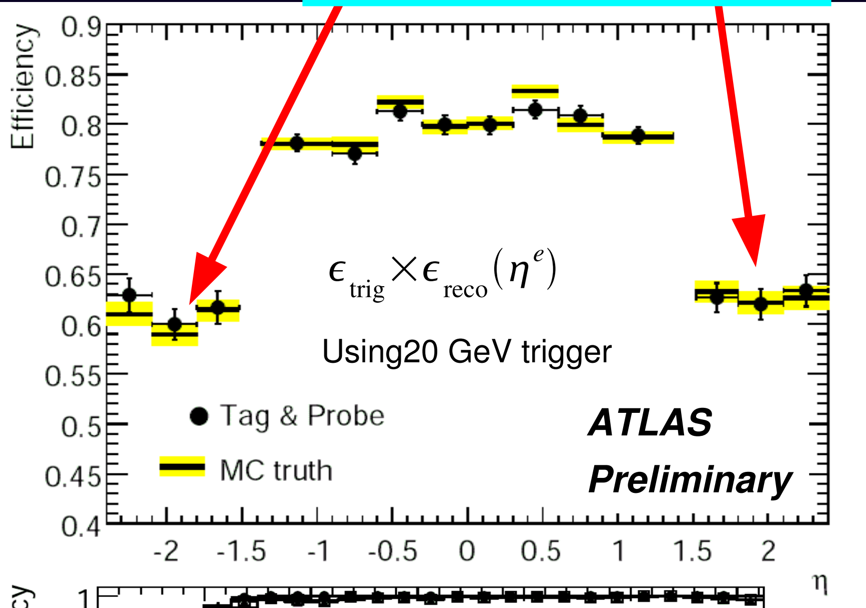
Method:

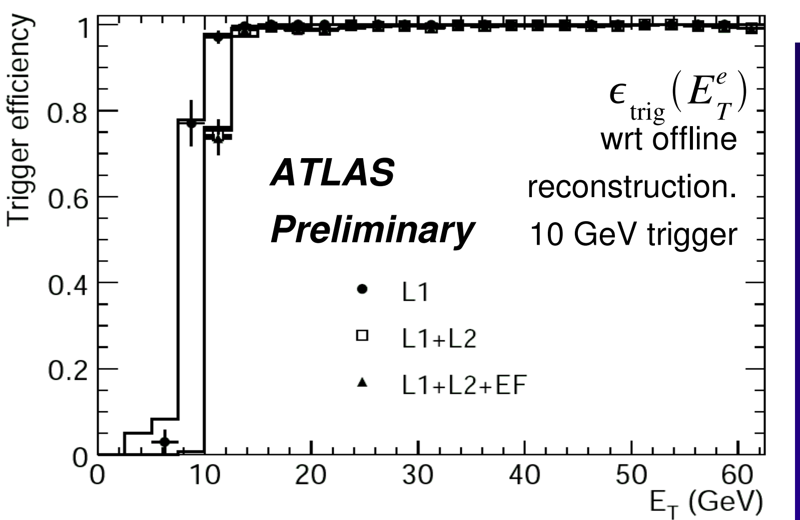
- **Tag** passes full selection (incl. Trigger)
- **Probe** passes looser preselection
  - With Z mass constraint
- Count number of probes passing full selection
  - Can factorise the different cuts

Tag and probe results with 50 pb^{-1}

Electrons

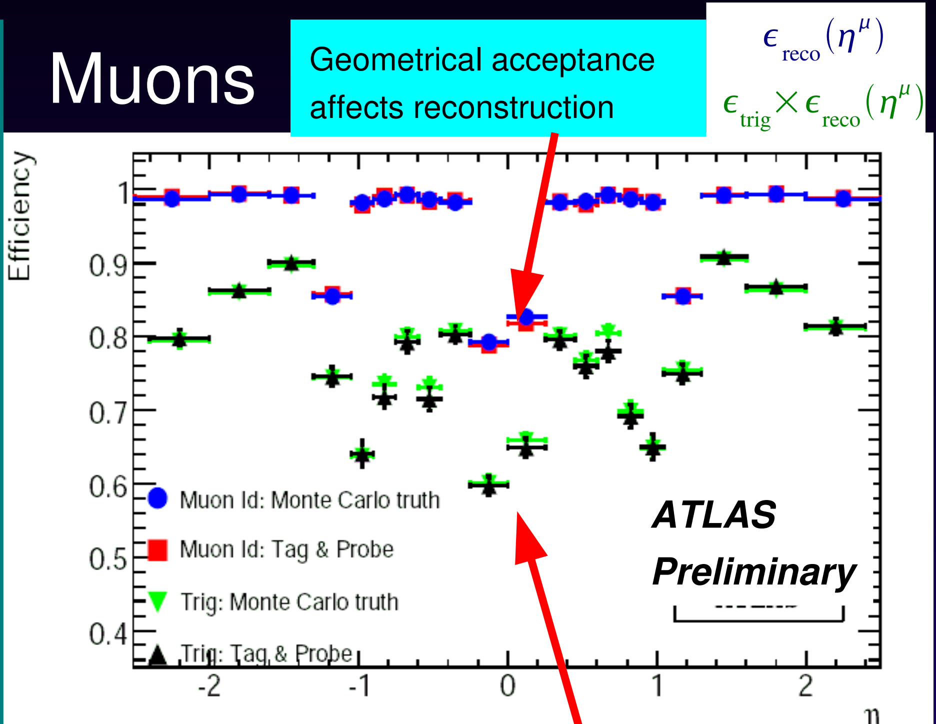
Inner detector material reduces reconstruction efficiency at high η





Muons

Geometrical acceptance affects reconstruction



20 GeV trigger used

Limited coverage of first level trigger chambers observed

Good agreement with simulated truth throughout

- Successfully follows non-trivial variations

For more on electron & muon reconstruction, see talks by Victor Maleev and Edward Moyse

Missing E_T reconstruction

Missing E_T (MET) understanding is vital for ATLAS physics:

- SM measurements (eg of W boson, m_t)
- Discoveries (SUSY, extra dimensions, $H \rightarrow \tau\tau$)

Cell-based and object-based measurements

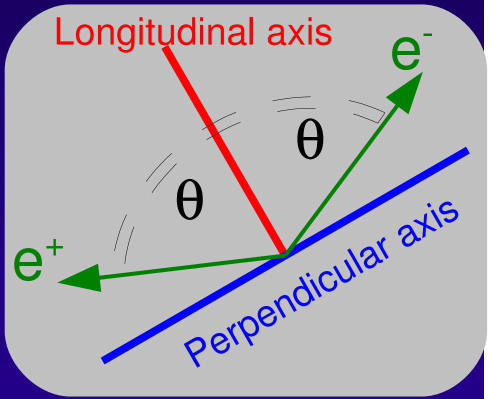
- Include muons, out-of-cluster corrections and noise suppression
- Dead/noisy channels masked in real data

Scale and resolution from $Z \rightarrow ll$:

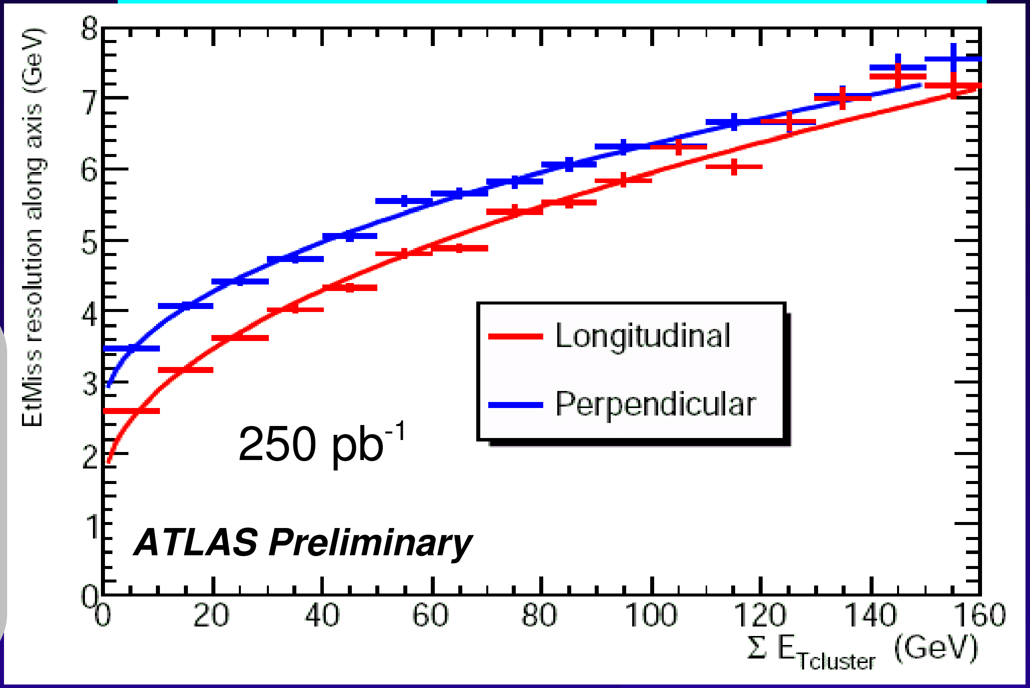
- No real MET – only mismeasurement
- Measure bias and spread of MET from 0 along optimised axes
  - Best use of angular resolution

Other SM handles on MET:

- Drell Yan $W \rightarrow l\nu$
- $Z \rightarrow \tau\tau$
- Semi-leptonic tt



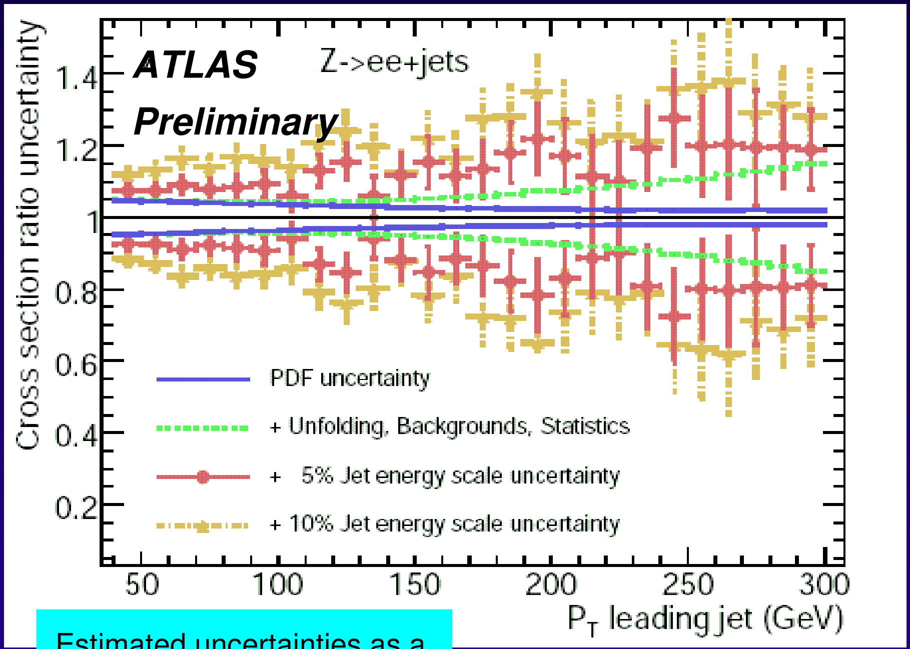
Reconstructed MET resolution as a function of total hadronic energy in simulated $Z \rightarrow ee$ events



W/Z+jets

W/Z+jets are a major challenge for ATLAS

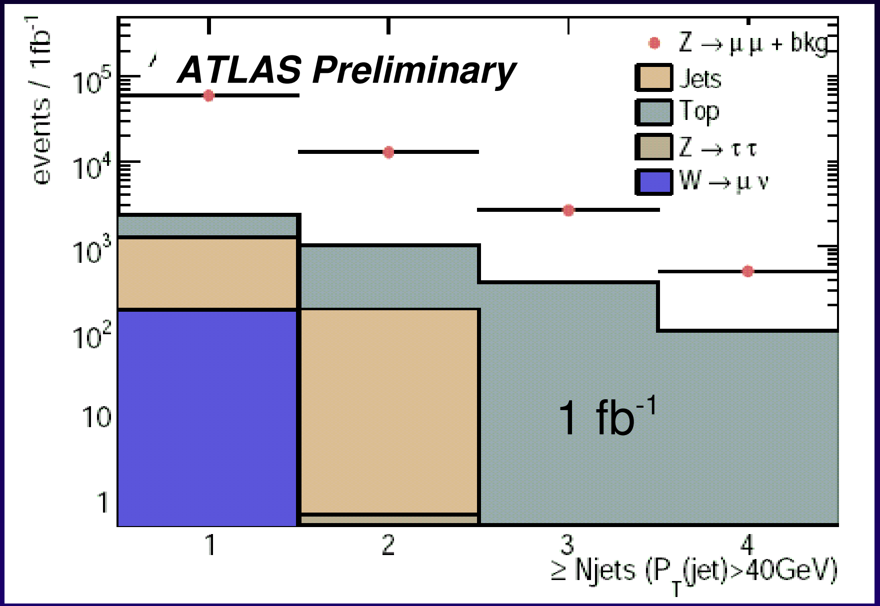
- Large **cross section**
- Test of **pQCD**
  - NLO corrections ~20-30% (1-2 jets)
  - Generator differences ~10-60%
- **Background** for SM and searches
  - High multiplicity events



Estimated uncertainties as a function of the leading jet p_T

Event selection

- Leptons similar to inclusive case
  - Efficiencies evaluated accounting for hadronic environment
- Cone jets, calibrated at hadron level
  - Corrections for fragmentation and underlying event
- QCD and tt backgrounds dominate
  - 10-15% (depending on multiplicity)
  - Estimate QCD background from data



Jet multiplicity in $Z \rightarrow \mu\mu$ channel, with simulated backgrounds

Main uncertainties:

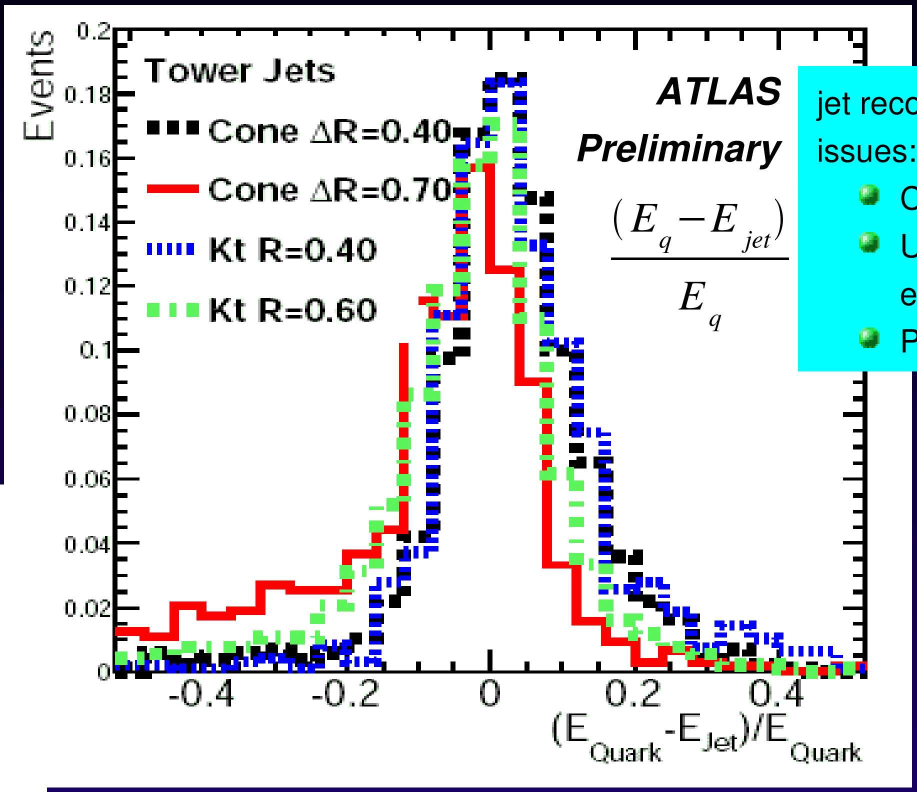
- Jet energy scale
  - Needs to be <5%
- pdf uncertainties
- Statistics (high jet p_T, N_{jets})

Light jet energy scale* from tt *(JES)

Top mass measurement needs small JES uncertainty (~1%) to reach 1 GeV precision

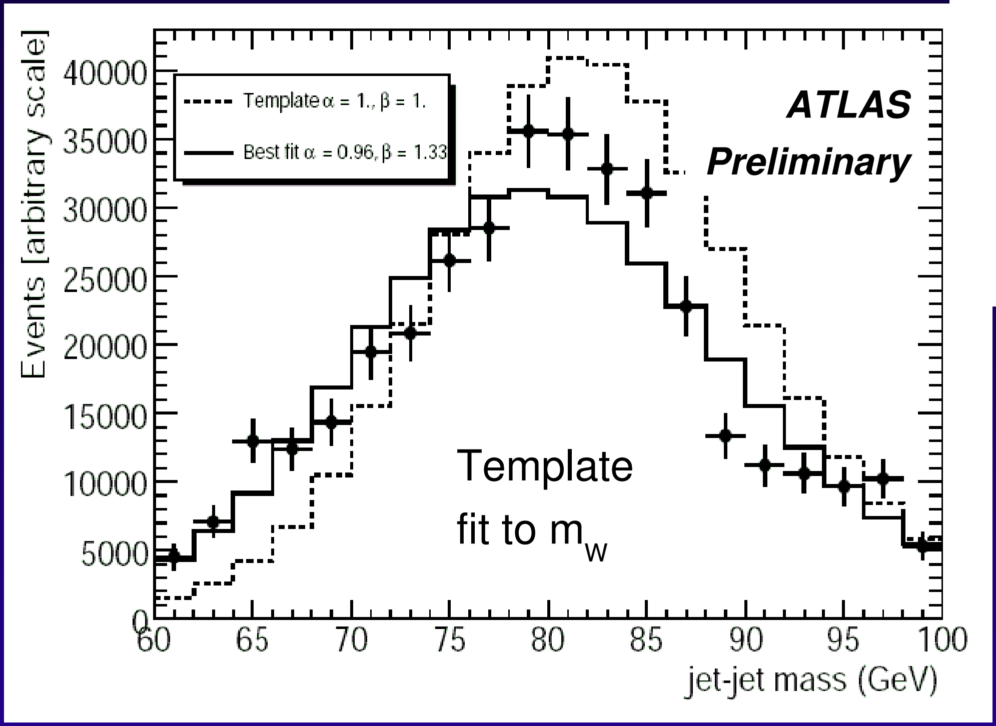
tt jets need their own in situ calibration

- No gluon jets – biases other estimates
- p_T cuts bias energy scale



jet reconstruction issues:

- Calibration
- Underlying event
- Pile up



Use m_W constraint to fix light jet scale

- Smear/scale template histograms
- χ^2 fit to find best values
- ~2% precision with 50pb^{-1}, <0.5% in time

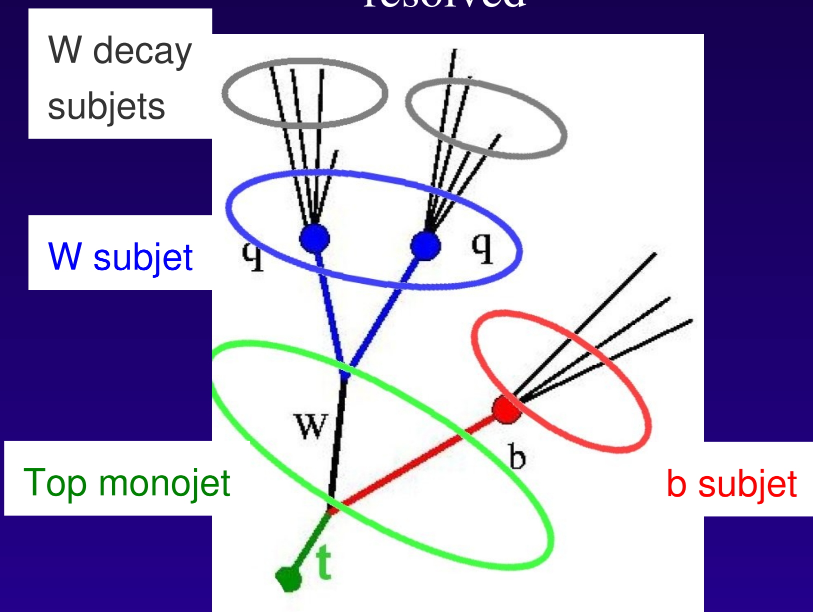
b-jet scale ~5% lower than light jets

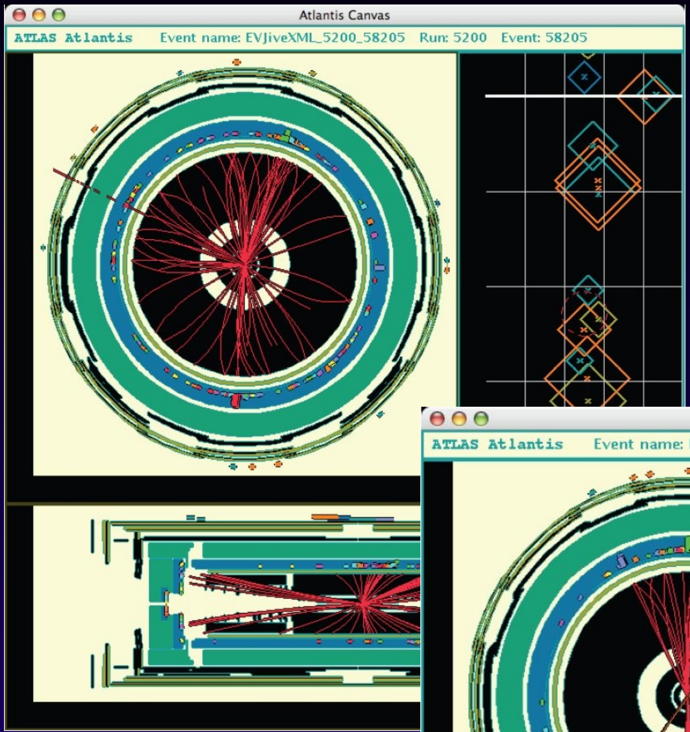
- Need to find this without fixing m_t

Into the realms of high p_T

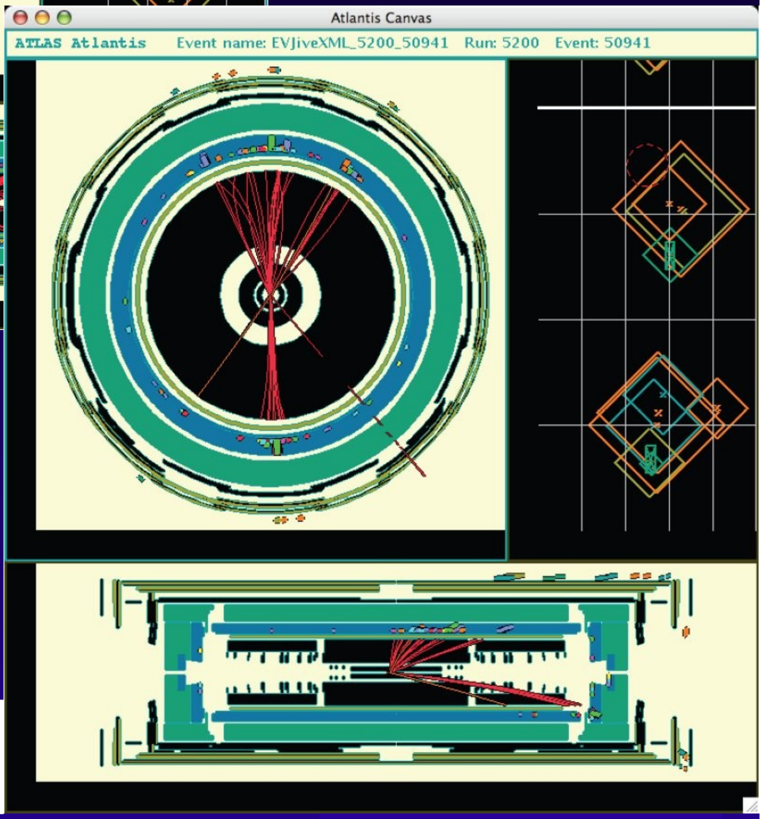
Vast LHC energies will produce very highly boosted top quarks

- Can reconstruct "monojets" for $p_T^t \gtrsim 300$ GeV
- Look at jet characteristics:
  - Jet mass
  - Mass scale where subjets are resolved





$p_T^t =$ 150 GeV



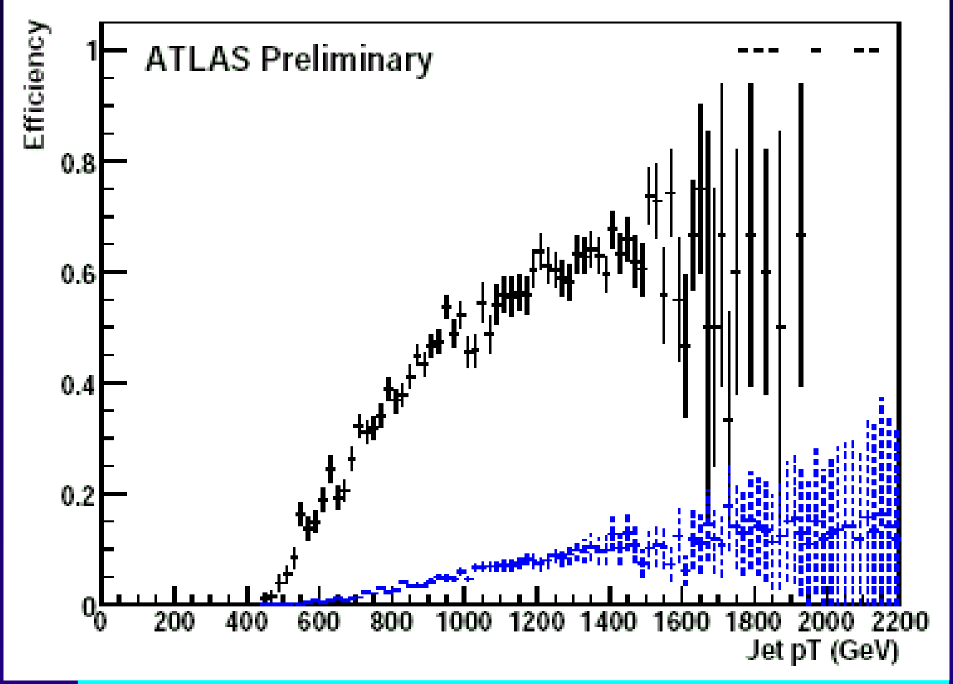
$p_T^t =$ 250 GeV

Event displays shown by A. Shibata, at HCP2008

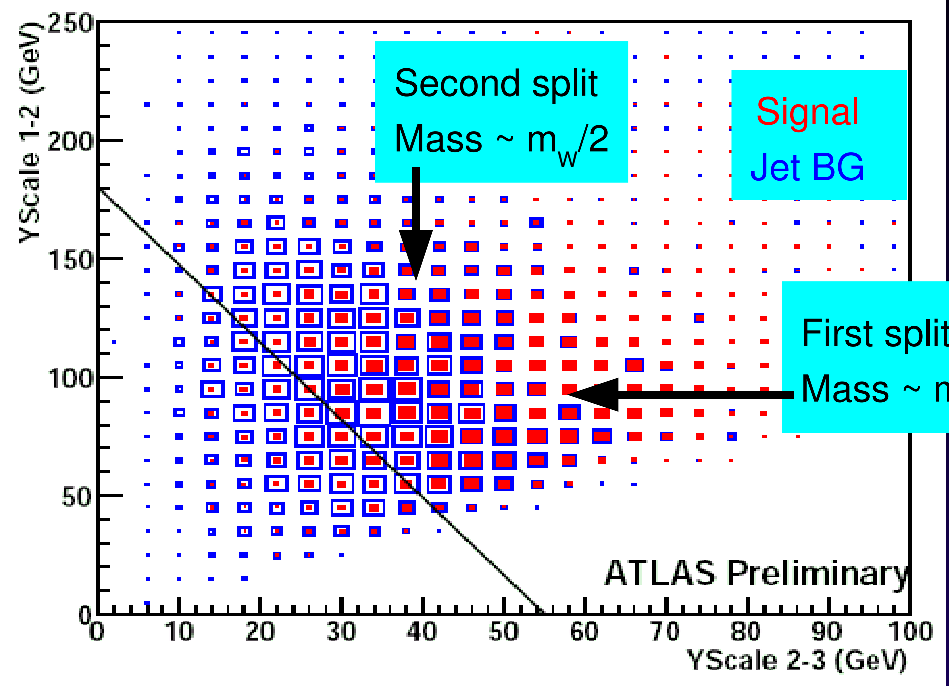
High p_T top – subjet structure

By comparing variables such as the subjet mass scales (eg right), good efficiency/rejection can be achieved

- Require lepton on “other side” of event
- Modified b-tagging could improve selection



Monojet reconstruction efficiency – cuts optimised “by eye”
Signal and Jet BG



Main uncertainties:

- Hadronisation effects
- Jet resolution, calorimeter noise

Similar methods under investigation for non-top events

- eg boosted H in ZH searches

Summary

ATLAS is ready for next year's data

- Commissioning using beam data + cosmics
- Early performance and physics goals defined
  - W,Z,t all crucial elements of this
  - Understand efficiencies/energy scales to few % with $50pb^{-1}$
  - Total cross sections first, then distributions
    - Not discussed: W/Z ratios
  - Top calibration for the first time
- Studies planned for $1fb^{-1}$ and beyond...