MANCHESTER 1824

The University of Manchester

Top quarks at the LHC: the early days

Detector commissioning and first results

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Standard Model workshop
UCL, London, 31 March 09

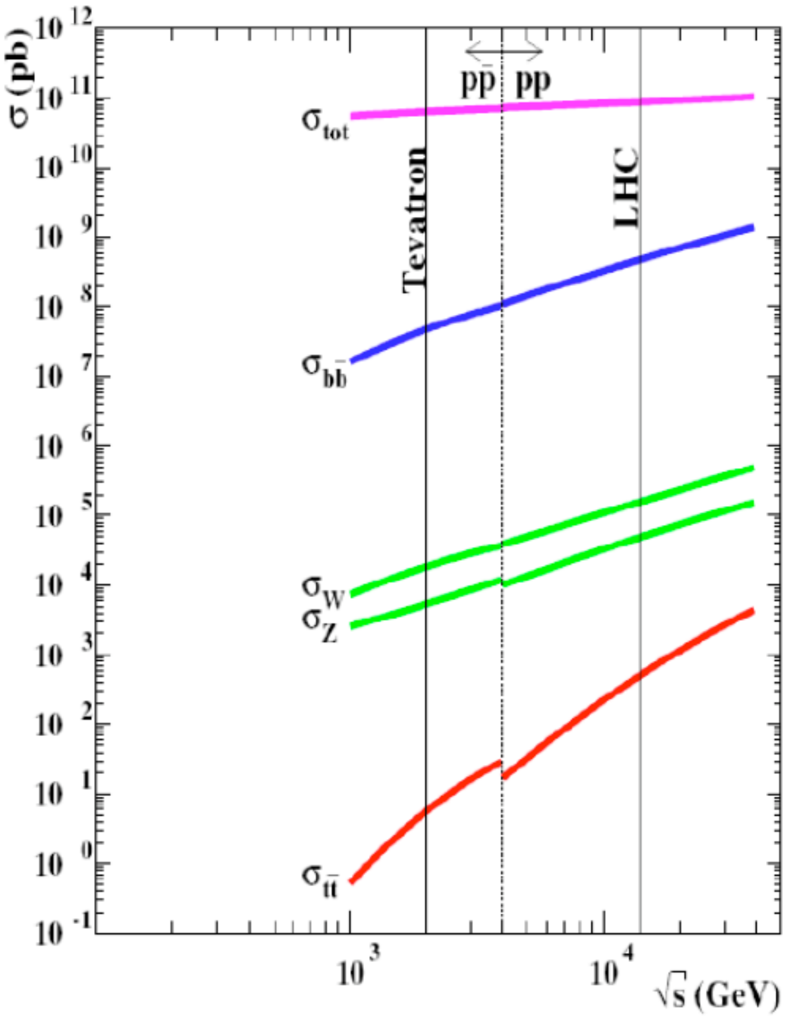
What (I hope) you will take away from this

- LHC running in 2009/10 and first results in top physics
  - LHC running scenario
  - Data samples expected from the first physics run
  - Expected precision on σ(tt) from this run

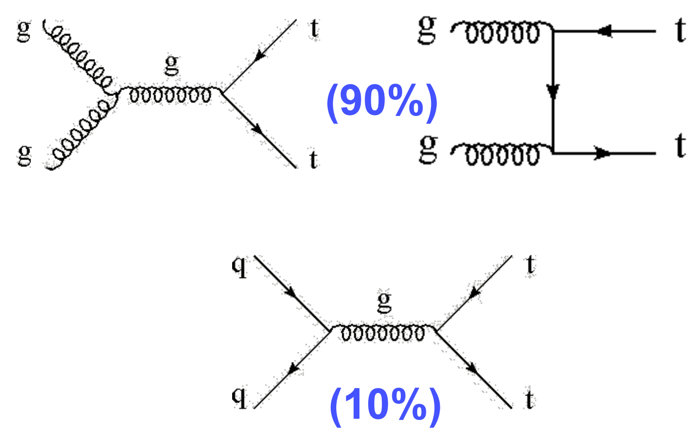
- Use cases of tt events for detector calibration
  - Calibration of the light jet energy scale
  - b-tagging performance

In this talk: tt ≡ $t\bar{t}$

LHC as a top factory



- LHC will produce top quarks in heaps



  - σ(tt) is about 850 pb (x100 Tevatron) @ 14 TeV
  - rate of tt events is ~ Hz
  - Expect millions per year

σ(tt) @ 10 TeV ~ ½ σ(tt) @ 14 TeV [all results shown for 14 TeV]

The 2009/10 LHC Run

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH

Typical Run/Shutdown setup

Would leave little time for running in 2009

Delay may mean no running before autumn 2010!

- Decisions taken
  - Physics run as soon as possible
  - Do not warm up all sectors
  - Top energy is 5 TeV (had been reached for all other sectors)
  - No winter shutdown 2009/10
- Consequences
  - 8 M Euro additional electricity cost
  - Gain 20 weeks of physics running
  - Further delays of a few weeks have small impact on physics 09/10
  - Enough data to compete with Tevatron in many areas by end of 2009/10 run

The 2009/10 data sample

- Beam energy
  - No intention of long running below 5 TeV/beam
  - Short collision run at injection energy 450 GeV/beam
  - Possibly stop along the way several times for machine commissioning
  - Reach 5 TeV/beam a.s.a.p.

- Data volume
  - Peak Luminosities from 5×10^{31} to 2×10^{32} $cm^{-2}s^{-1}$
  - First 100 days of operation ~ 100 pb^{-1}
  - Next 100 days of operation ~ 200 pb^{-1}

→ Large Uncertainties: somewhere between 100 – 500 pb^{-1} ?

What can we do with a few 100 pb^{-1}

Lets state the obvious:

Data volume is only one ingredient

How fast and well we can understand our brand new detectors is at least as important

Timing, tracking/calorimeter uniformity, alignment, detector resolutions, particle ID, energy scales, b-tagging performance, missing E_T signature, …

This has to be kept in mind for what follows

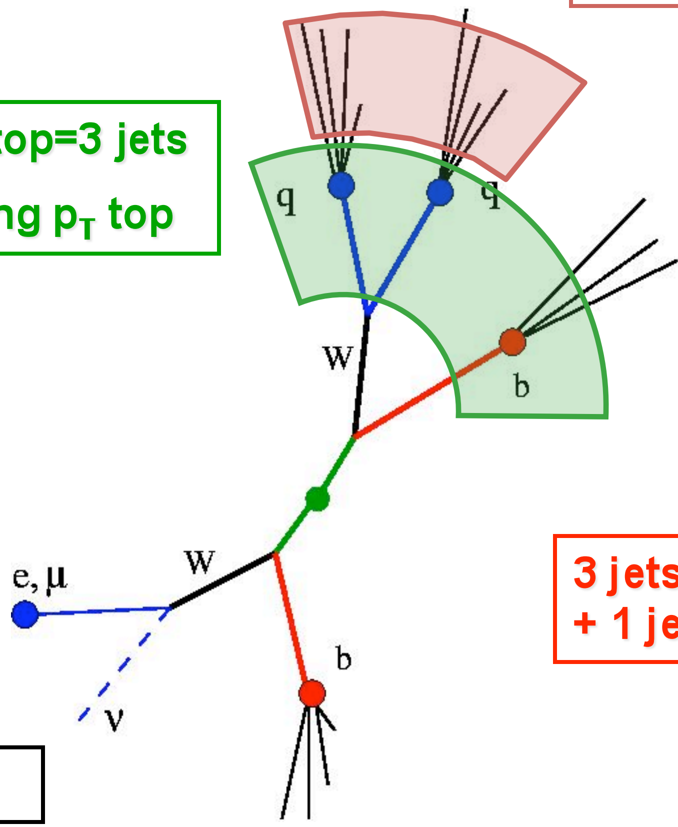
How to see top events on “day 1”

Keep it as simple as possible:

W =2 jets maximising p_T W in jjj rest frame

$|m_{jj}-m_W| < 20$ GeV

Hadronic top=3 jets maximising p_T top



Isolated lepton $p_T > 20$ GeV

3 jets $p_T > 40$ GeV + 1 jet $p_T > 20$ GeV

$E_{T,miss} > 20$ GeV

tt is fairly easy to trigger on

Sample of tt semileptonic with W→eν

Relative to offline analysis selection

ATLAS

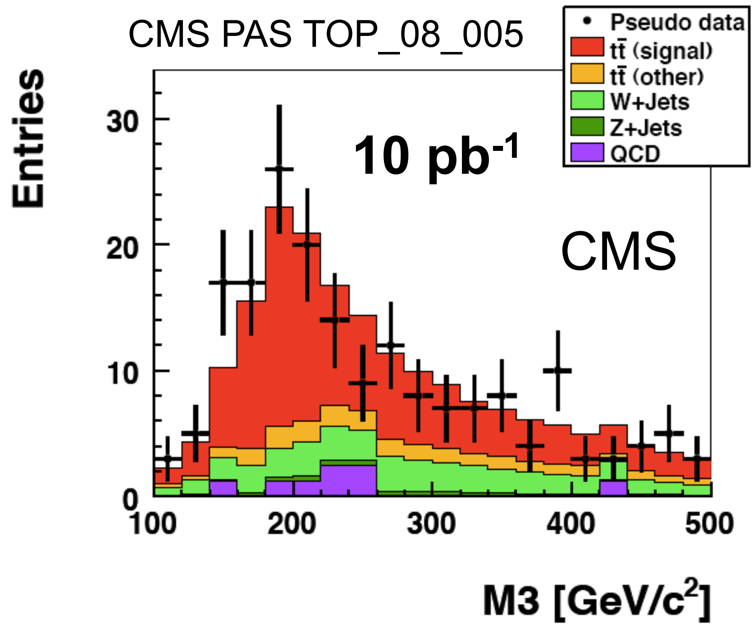
Trigger	Compared to Monte Carlo Eff. [%]	Compared to offline selection Eff. [%]
e22i:		
L1 EM18I	74.7 ± 0.5	96.0 ± 0.6
L2 e22i	59.6 ± 0.6	92.7 ± 0.9
EF e22i	52.9 ± 0.6	89.8 ± 1.0
e12i:		
L1 EM7I	83.6 ± 0.4	98.6 ± 0.3
L2 e12i	66.7 ± 0.5	92.6 ± 0.8
EF e12i	63.5 ± 0.5	91.8 ± 0.8

Selection cuts:

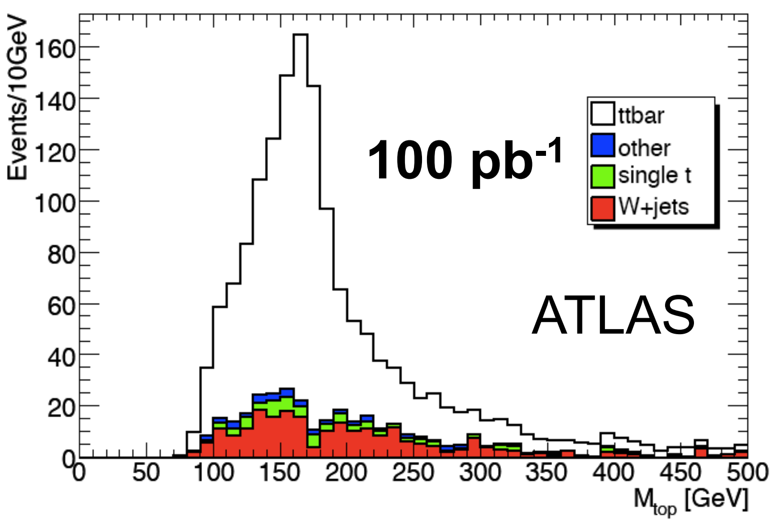
- > 1 electron, p_T> 20 GeV
- $E_{T,miss}$ > 20 GeV
- > 3 Jets w/ p_T>40 GeV
  > 4 Jets w/ p_T>20 GeV

Main ref. here and below:
ATLAS: CERN-OPEN-2008-20
CMS: CERN-LHCC-2006-001

The first top signals



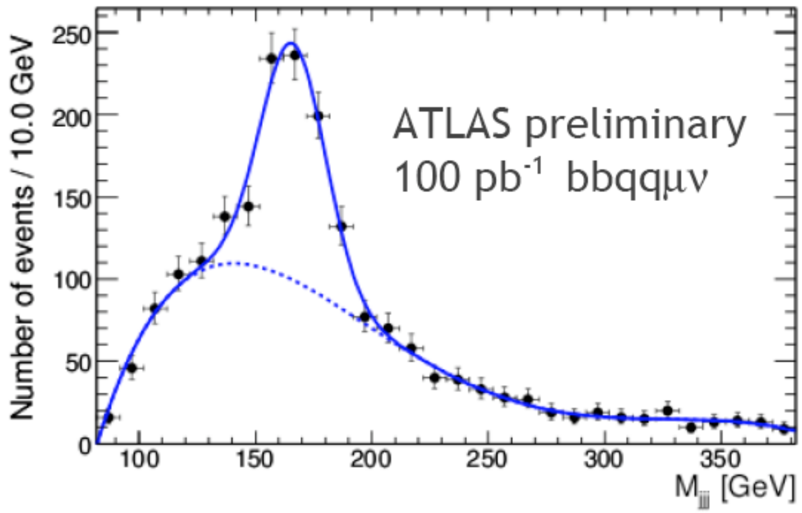
- tt → semileptonic (μ)
- 1 isolated muon, p_T > 30 GeV
- 1 jet w/ p_T > 65 GeV + 3 more w/ p_T > 40 GeV
- No b-tagging
- S/B ~ 1.5
- Selection Efficiency ~ 10%



- tt → semileptonic (e)
- 1 isolated electron, p_T > 20 GeV
- 3 jets w/ p_T > 40 GeV + 1 more w/ p_T > 20 GeV
- No b-tagging
- Loose m_W constraint
- S/B ~ 3.5
- Selection Efficiency ~ 10%

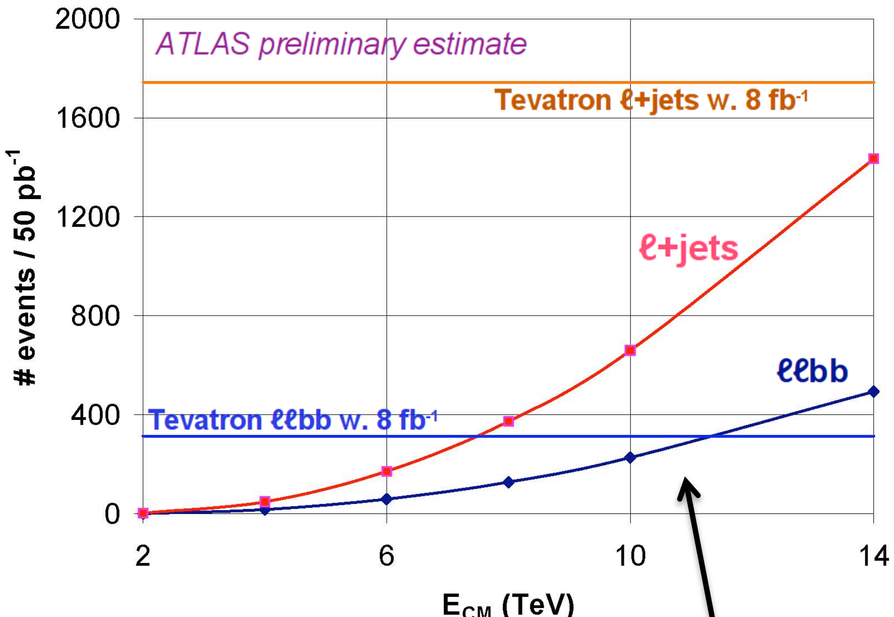
First σ(tt) measurements

Expect $\Delta\sigma/\sigma$ ~ 17% for σ(tt) from 100 pb^{-1}



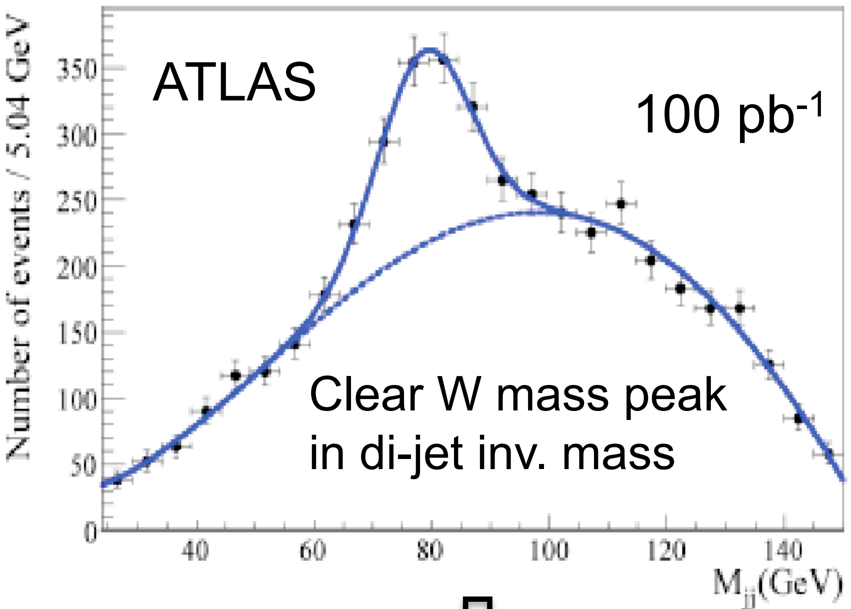
- Invaluable for detector studies
  - fires many triggers
  - mass peak tells you if you got it
  - calibration of light jet scale from W→ jet jet, study b-tagging

At ~200 pb^{-1} more top-quarks than the Tevatron!



ATLAS input to LHC Chamonix 2009 meeting (2-6 February 2009)

Light jet energy scale



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Motivation

- tt → lepton + jets can be used to select an unbiased sample of W→ jet jet
- m_W constraint → light jet energy scale

Tight selection

- Exactly one isol. lepton, p_T > 20 GeV
- $E_{T,miss}$ > 20 GeV
- Exactly 4 jets, p_T > 40 GeV
- Exactly 2 jets tagged as b-jets

→ W purity ~ 80%

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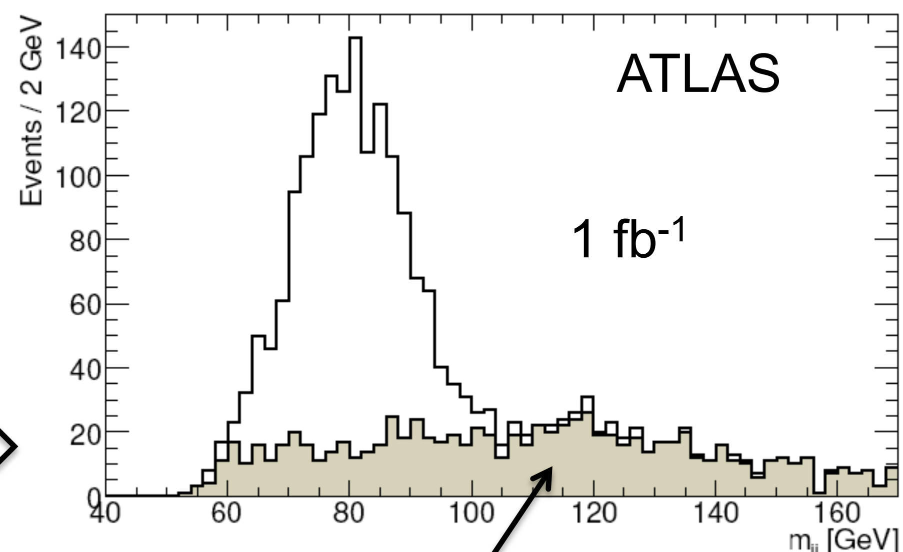
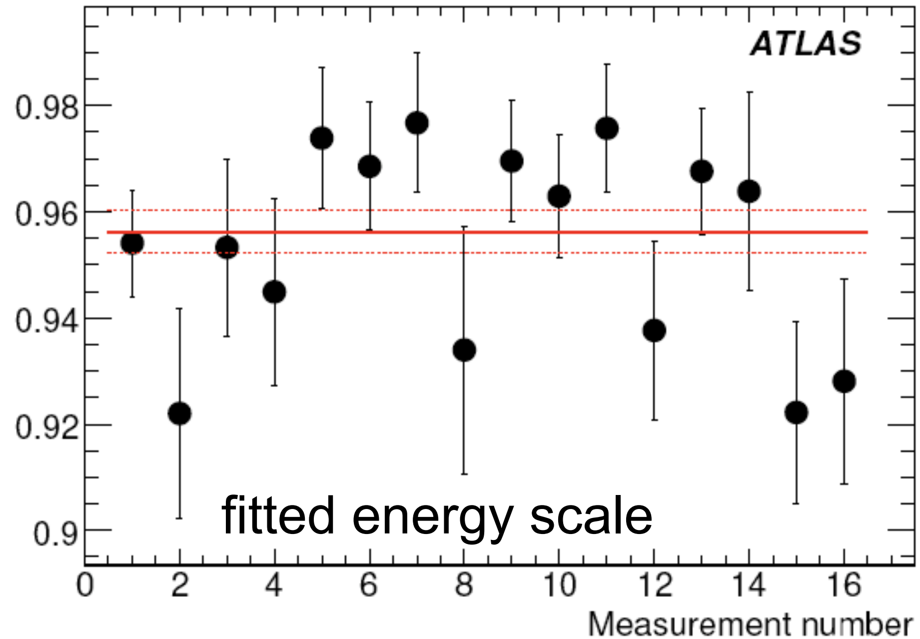


~ only combinatorial BKGS left

Light jet energy scale cont.

- Iterative re-scaling of E_{jet} in bins of E_{jet} and η to get $M_{W,PDG}$
  - Precision of ~ 2% for 1 fb^{-1}
- Fit template distributions with energy scale α / resolution β
  - Precision of ~ 1% for 1 fb^{-1} for overall scale
- How about in the beginning?
  - Split up into samples of about 50 pb^{-1} each
  - Average, scatter and RMS behave as expected
  - Within 3-4% of the fitted best value at 1 fb^{-1}

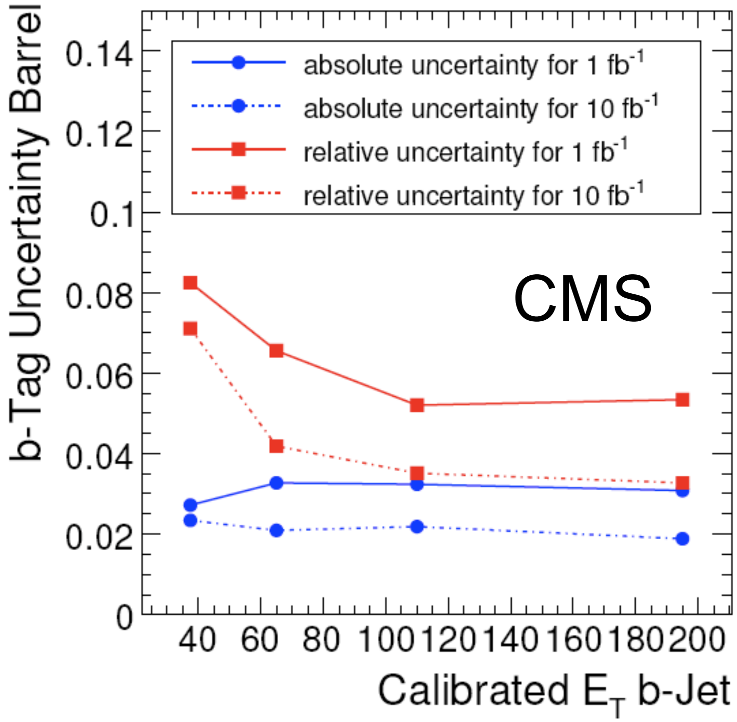


b-tag efficiency

Select b-enriched samples using tt sample

- t → W b ~ 100% → tagging top = tagging b
- Select pure b sample by using tt event topologies
  - 1(2) high p_T leptons, $E_{T,miss}$, m_W & m_t constraints
  - 70-80% b-purity after selection

- CMS study 1(10) fb^{-1}
  - Efficiencies 40% to 60% (at $E_{T,b\text{-}Jet}$ > 100) GeV
  - Uncertainty 4-6% for large data samples



- ATLAS study 100 pb^{-1}
  - Similar efficiencies, purities
  - Estimated uncertainty ~10%

Conclusions

tt events: the LHC collision equivalent of a Swiss army knife

100-200 pb^{-1} @ 10 TeV would be enough to

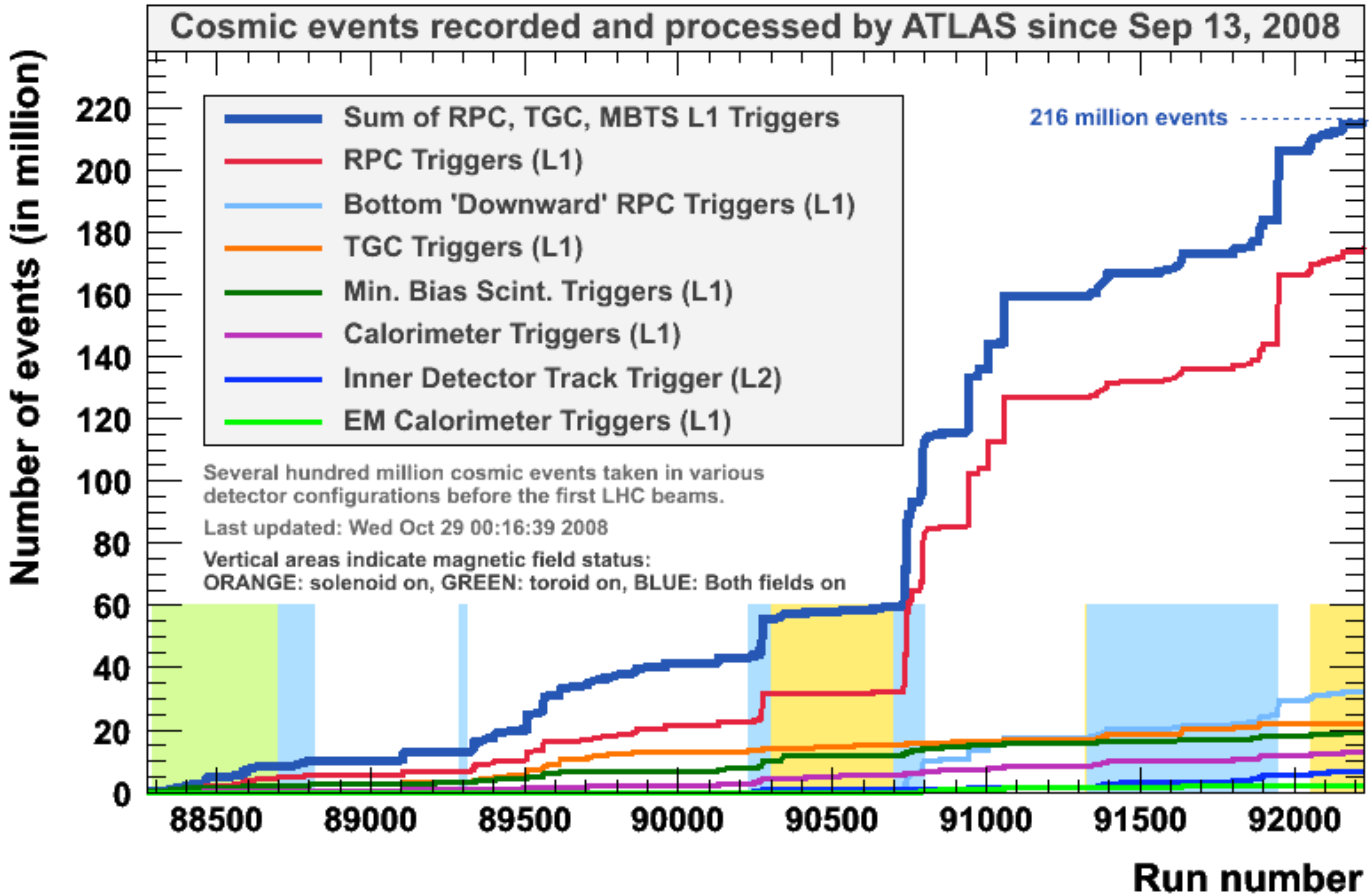
- Measure $\sigma(tt)|_{10TeV}$ to better than 20% (worlds best measurement!)
- Get clean samples for b-jet and W→jj
- Determine the light jet energy scale to ~ 5%
- Determine the b-tagging efficiency to ~ 10% (down to ~5% [top-event specific] with b-jet tag counting
- … and much more, in top physics and elsewhere …

The 2009/10 running period will not just be
a technical trial run –
It has the potential for some real physics
and even some surprises!

Additional Slides

Data overview

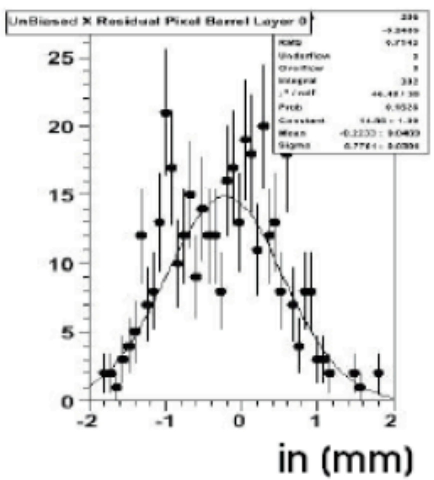
ATLAS then went into a sustained cosmic-ray data taking campaign



Pixel alignment

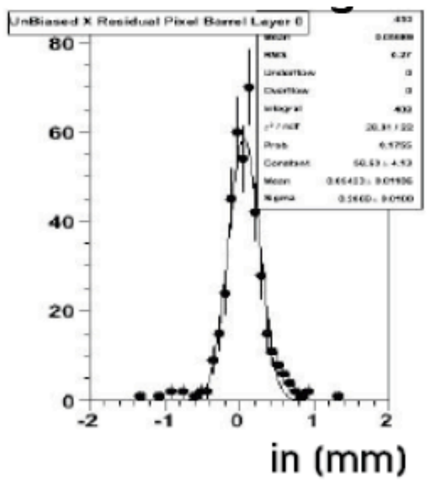
An example of using cosmic-ray data for detector alignment

nominal



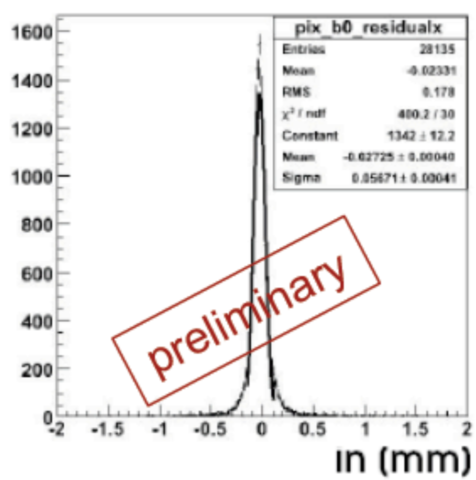
~1mm

~October 2008



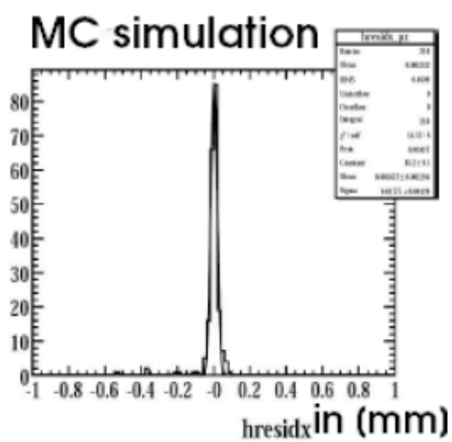
~250μm

now



~50μm

future



~15μm

Calibration and alignment

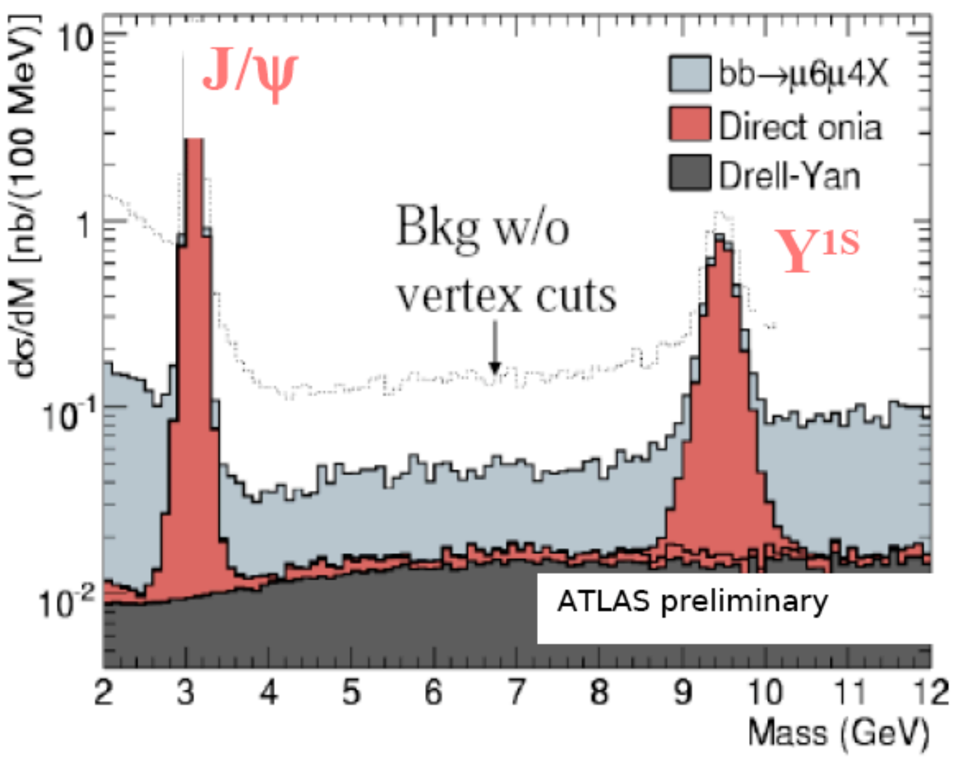
Initial values from

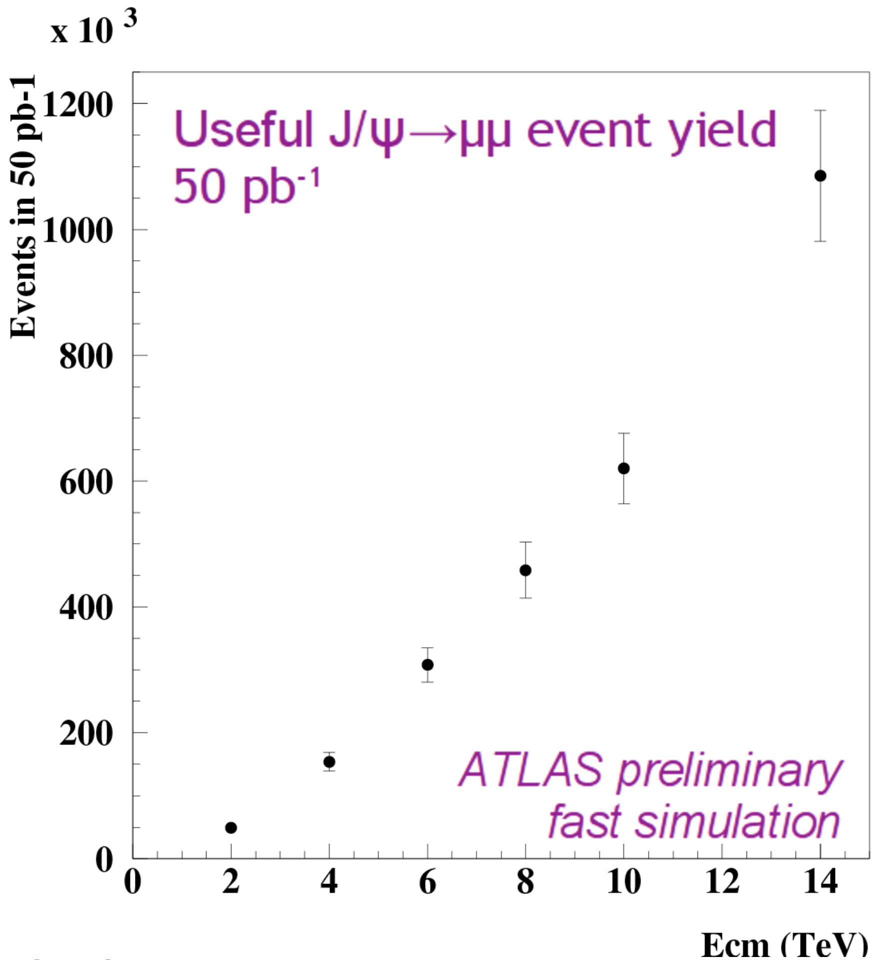
- test beam data
- calibration and alignment systems
- analysis of cosmic ray data

	Initial	Ultimate	Samples
e/γ E scale	~2%	0.1%	$Z \rightarrow ee$, J/ψ, π^0
e/γ uniformity	1-4%	0.5%	$Z \rightarrow ee$
jet E scale	5-10%	~1-2%	$W \rightarrow jj$ in tt, γ/Z+jets
tracking alignment	10-100μm	<10 μm	tracks, $Z \rightarrow \mu\mu$
muon alignment	?	30 μm	inclusive μ, $Z \rightarrow \mu\mu$

From the first collision data will be used to improve the detector performance with standard samples [iterative].

Example: J/ψ

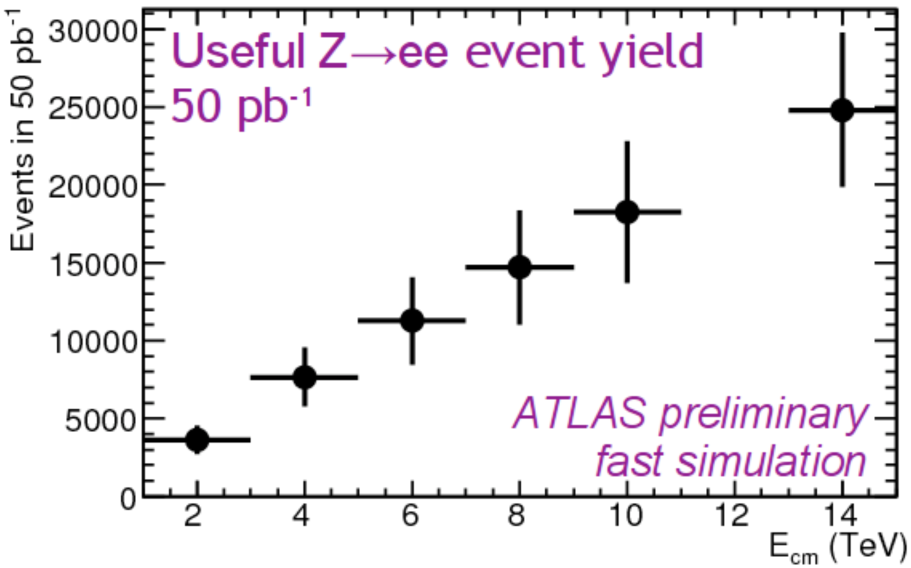




- Important standard candle for commissioning
- Huge statistics fast, especially in μμ channel
  - Easy to select, muon chamber, inner detector tracking alignment

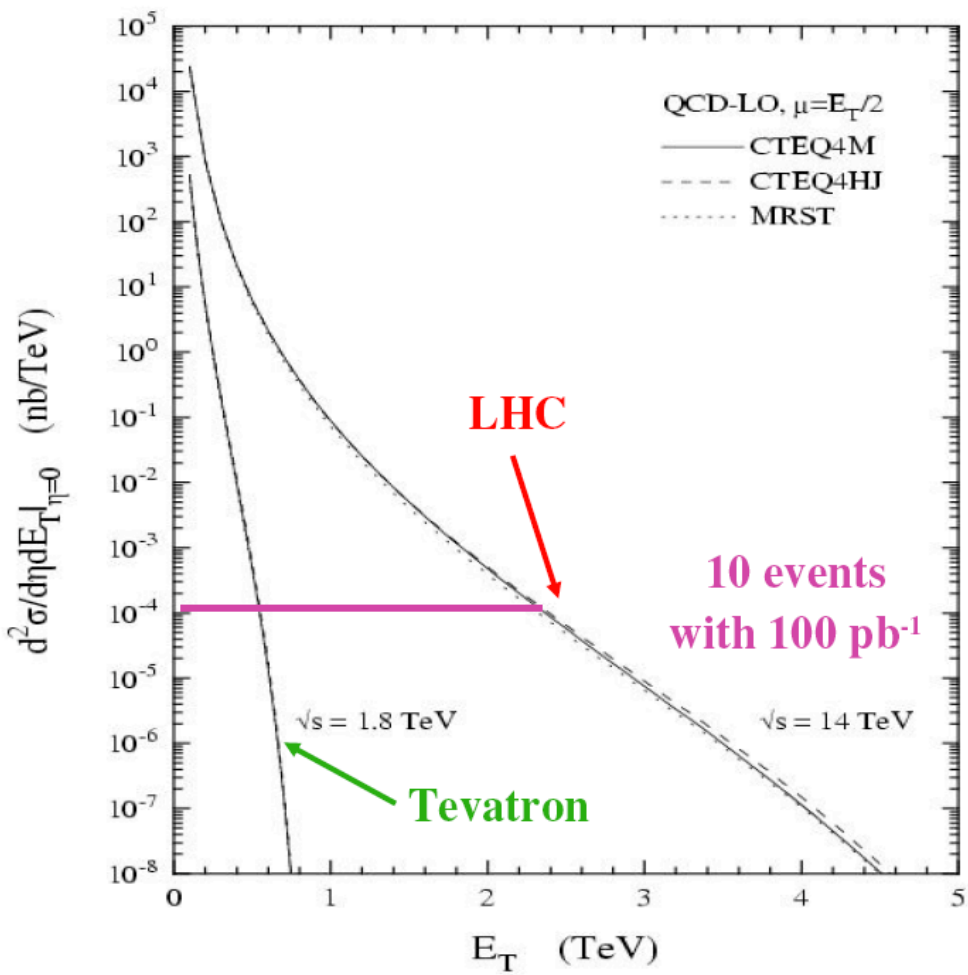
Example: Z→ ee

- Clean sample of di-electron events
  - e/γ uniformity
  - e/γ energy scale



After a short period of running large calibration samples will be available to start improving the detector performance

Jet spectra



- Very much driven by available centre-of-mass energy
- Will very soon surpass the Tevatron in sensitivity at high jet transverse momenta (10 or 14 TeV CME)

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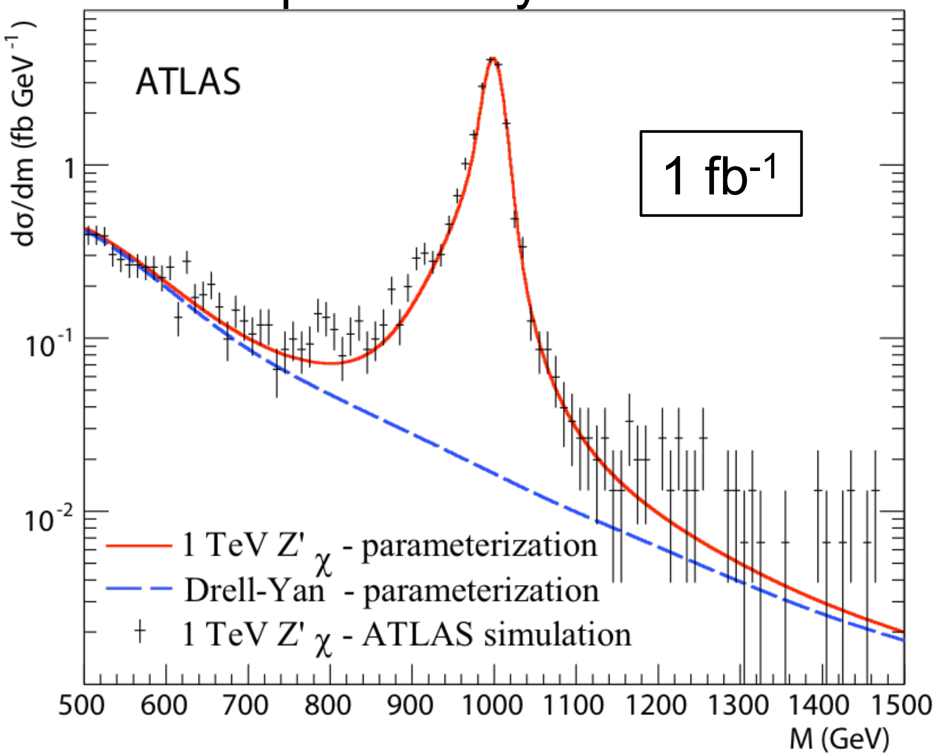
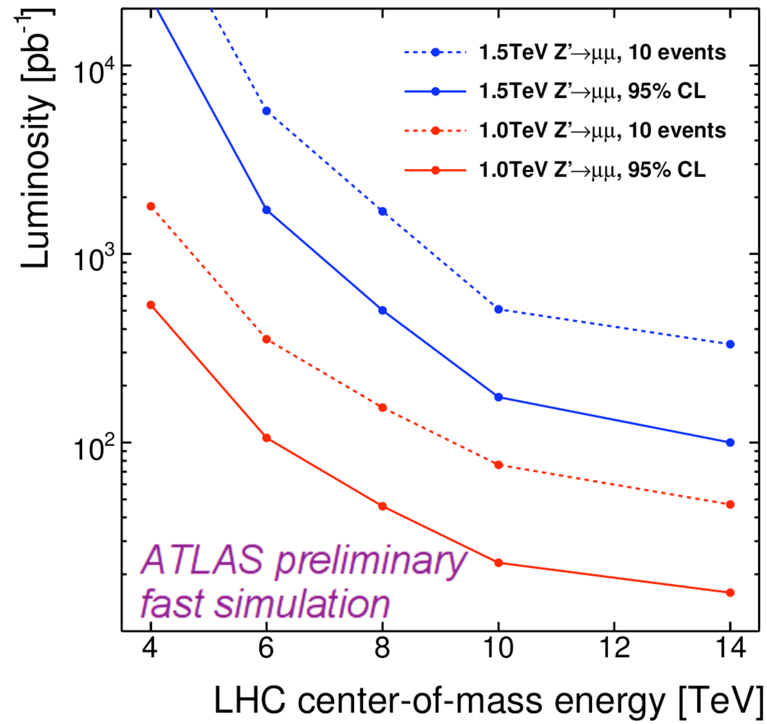
- Translates into sensitivity e.g. for contact interaction leading to modified high E_T spectrum
- Sensitivity beyond Tevatron reach from a few 10 pb^{-1}

New physics: Z’→ ll

ATLAS preliminary





- Z’ mass peak
  - small background, don’t need ultimate detector performance
  - can surpass current Tevatron limit (~1TeV) with ~ 100 pb^{-1}