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Testing Our Expectations with The First ATLAS Data

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Duck Soup (1933)

Rufus T. Firefly: And now, members of the cabinet we'll take up old business.

Cabinet Member: I wish to discuss the tariff.

Rufus T. Firefly: Sit down, that's new business. No old business? Very well we'll take up new business.

Cabinet Member: Now, about that tariff...

Rufus T. Firefly: Too late, that's old business already. Sit down.

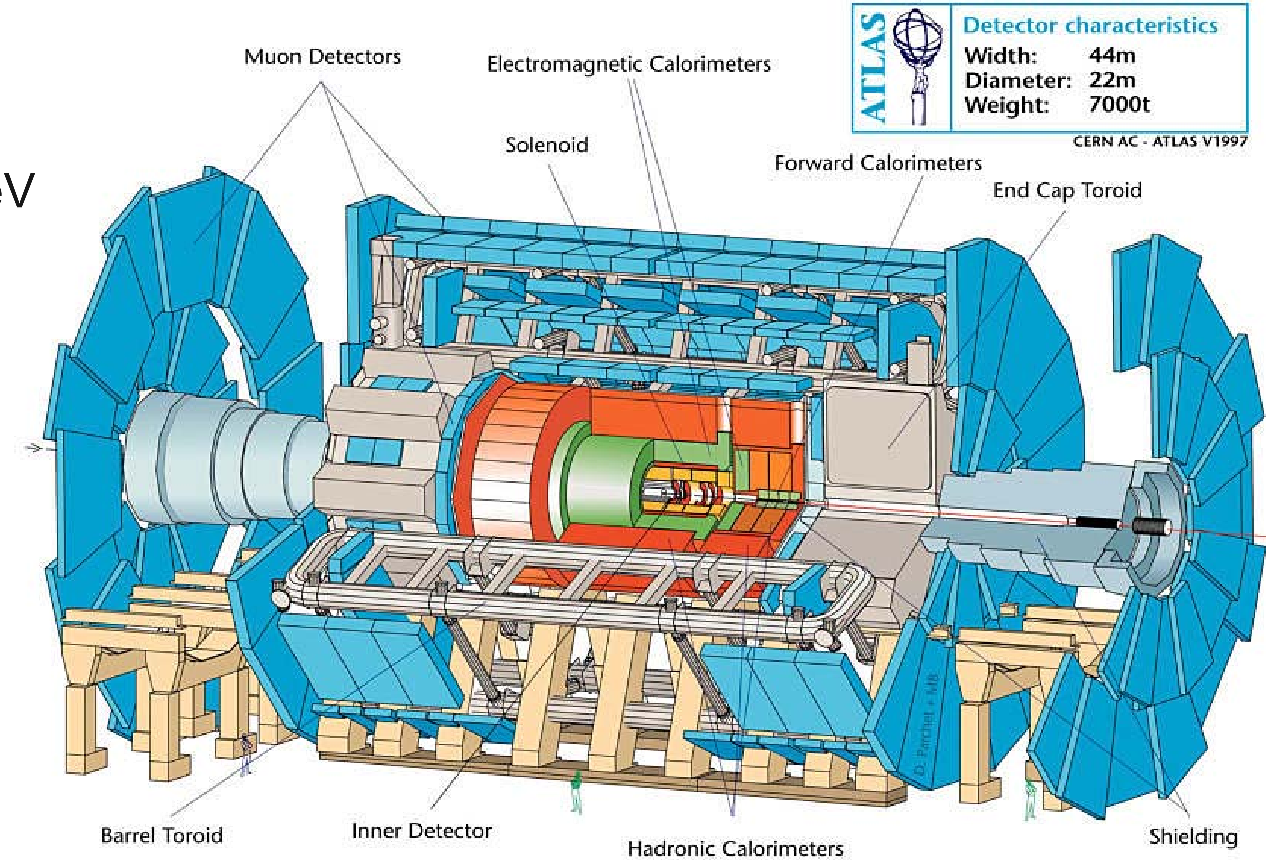
And now we'll discuss some **old physics**…

Outline

- Description of ATLAS
  - A tour through the detector describing not just what's there, but how well we think it's working based on cosmic rays
  - Cosmic rays are ATLAS first data
- Goals and Opportunities for Early Running
- A Few Selected Plans for Measurements

ATLAS (Who Hasn't Seen This Before?)

- Large air-core toroids
  - Permits 10% measurement of TeV muons
- Liquid Argon + Iron/Scintillator Calorimeters
- Transition Radiation Tracker
  - ionization in Xe
- Silicon strips and pixels

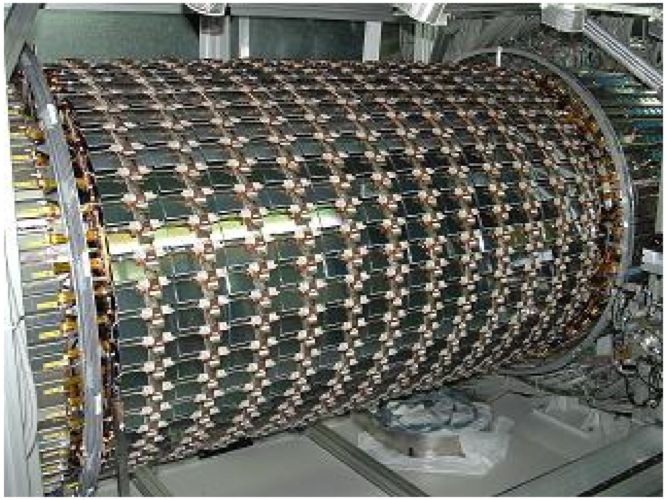


I'll describe the status of the detector over the next few slides…

What happened in Sector 3-4?

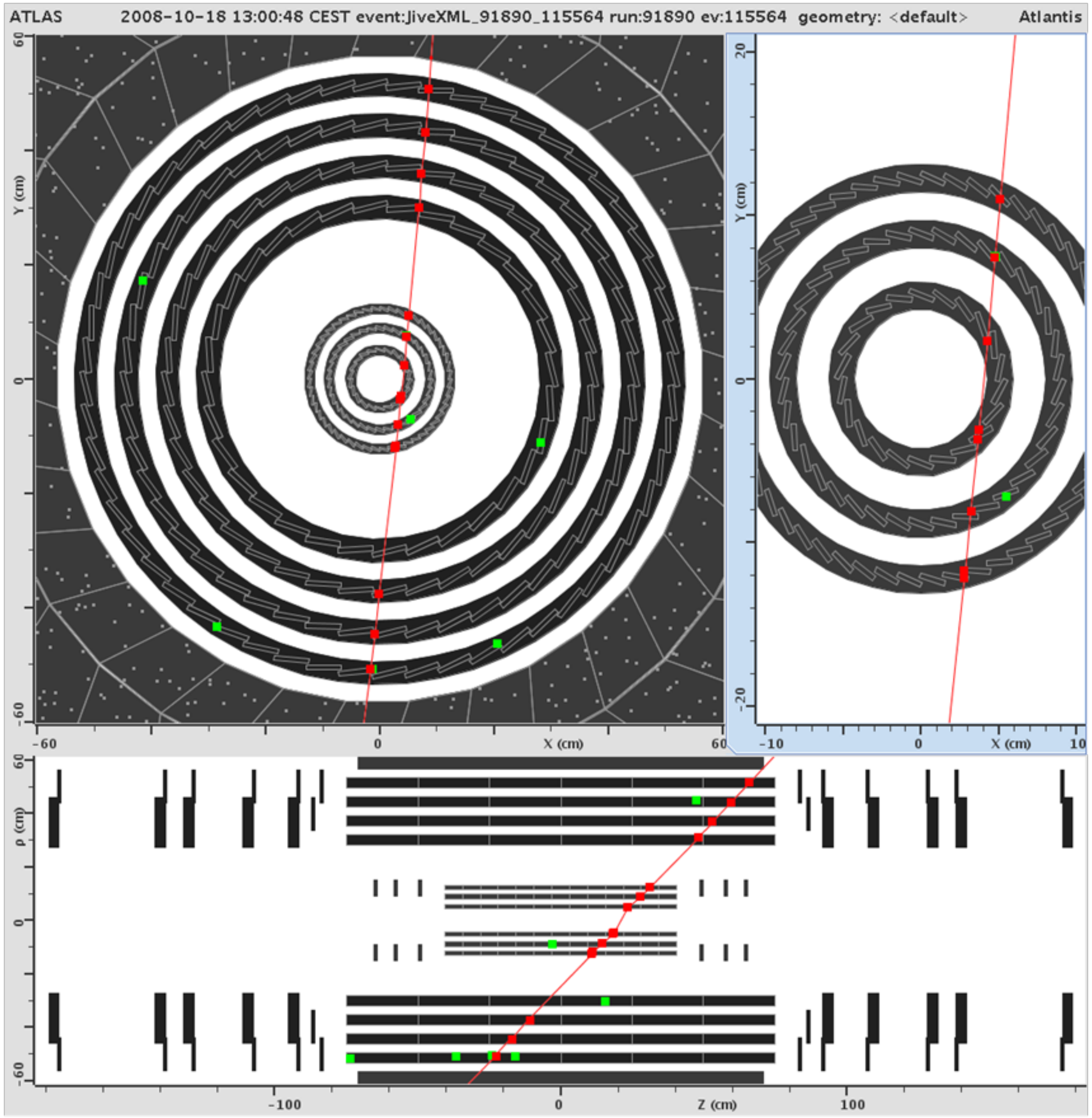
- The plan for collisions in 2008 did not survive the accident
- We have embarked on a long cosmic ray run
  - 260,000,000 events so far
  - Perhaps another ~300,000,000 or so to come
- Cosmic rays are not as good as collisions to commission the detector
  - But we have them, so we will use them

ATLAS Silicon



ATLAS Silicon Tracker: pixels are obscured by the strips

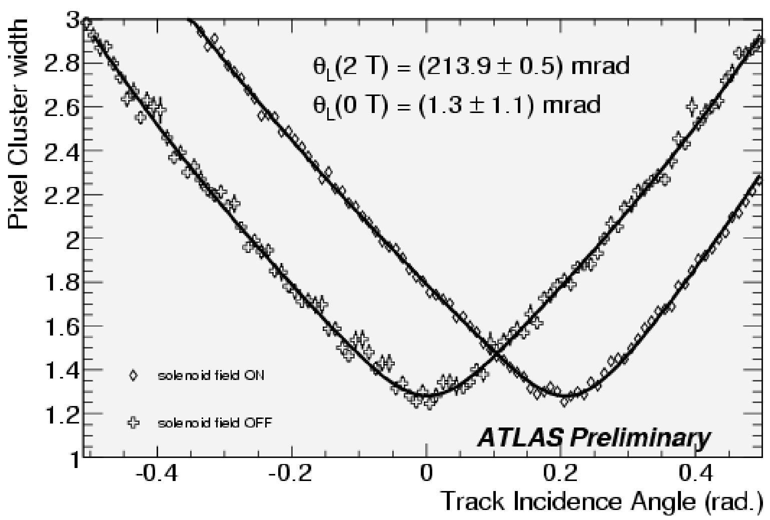
One Cosmic Ray traversing both pixels and strips



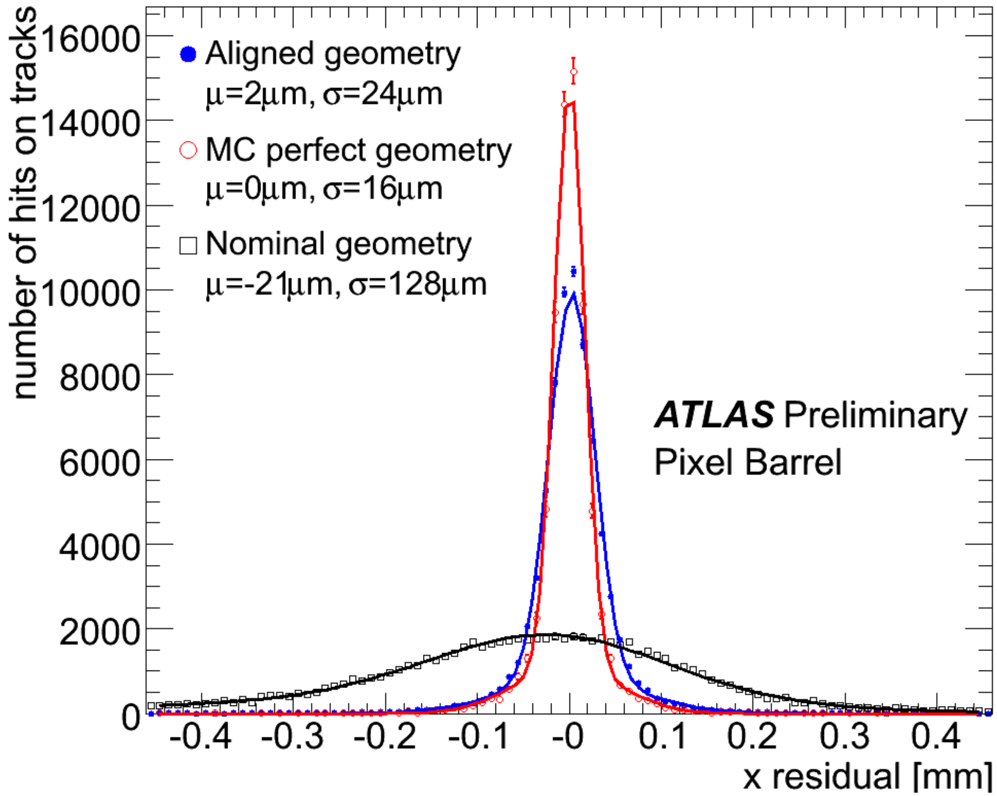
Understanding the Silicon

Silicon alignment is 5x better than it was without using cosmic rays.

We're within a factor of ~1.5 of what we would expect with perfect alignment.

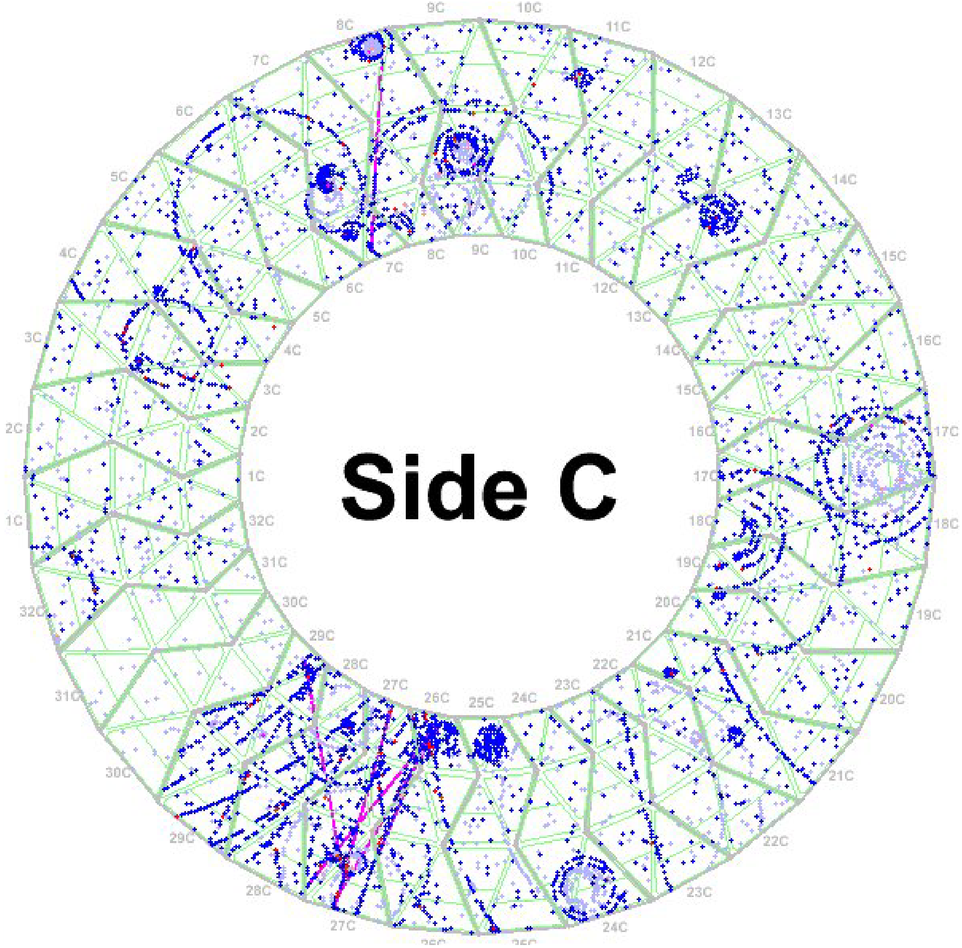


A cute thing: we can see the Lorentz angle of the electron drift in the silicon.

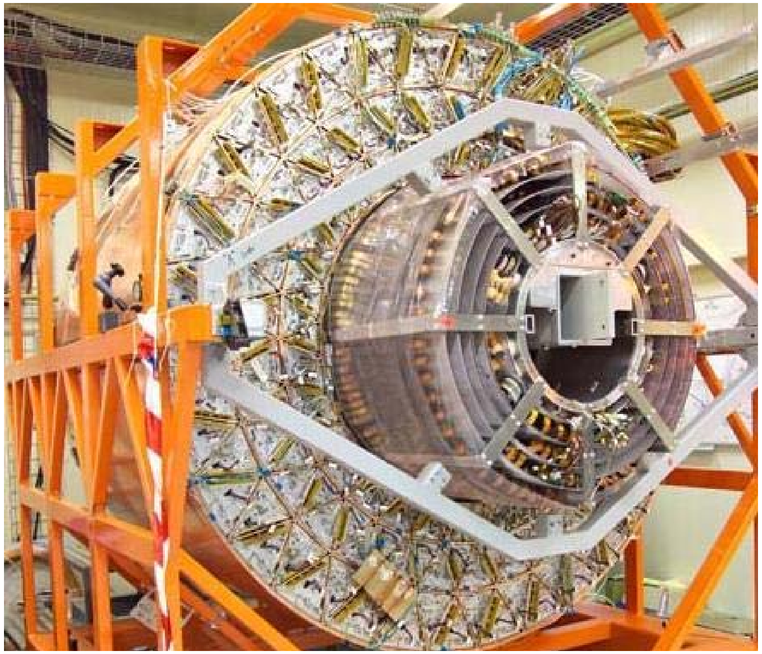


We may have some sort of early B-tagging available in 2009. (Ultimately, we will need to tune the algorithms on data).

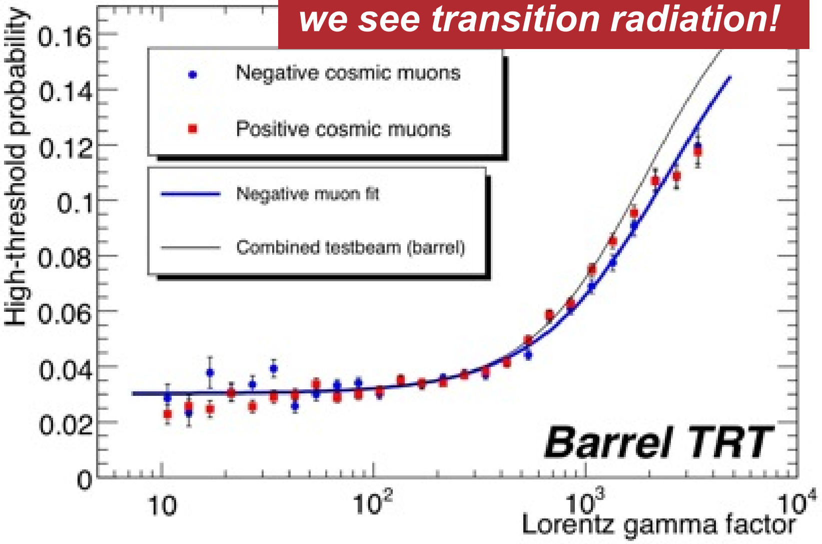
Transition Radiation Tracker



We see tracks, and…



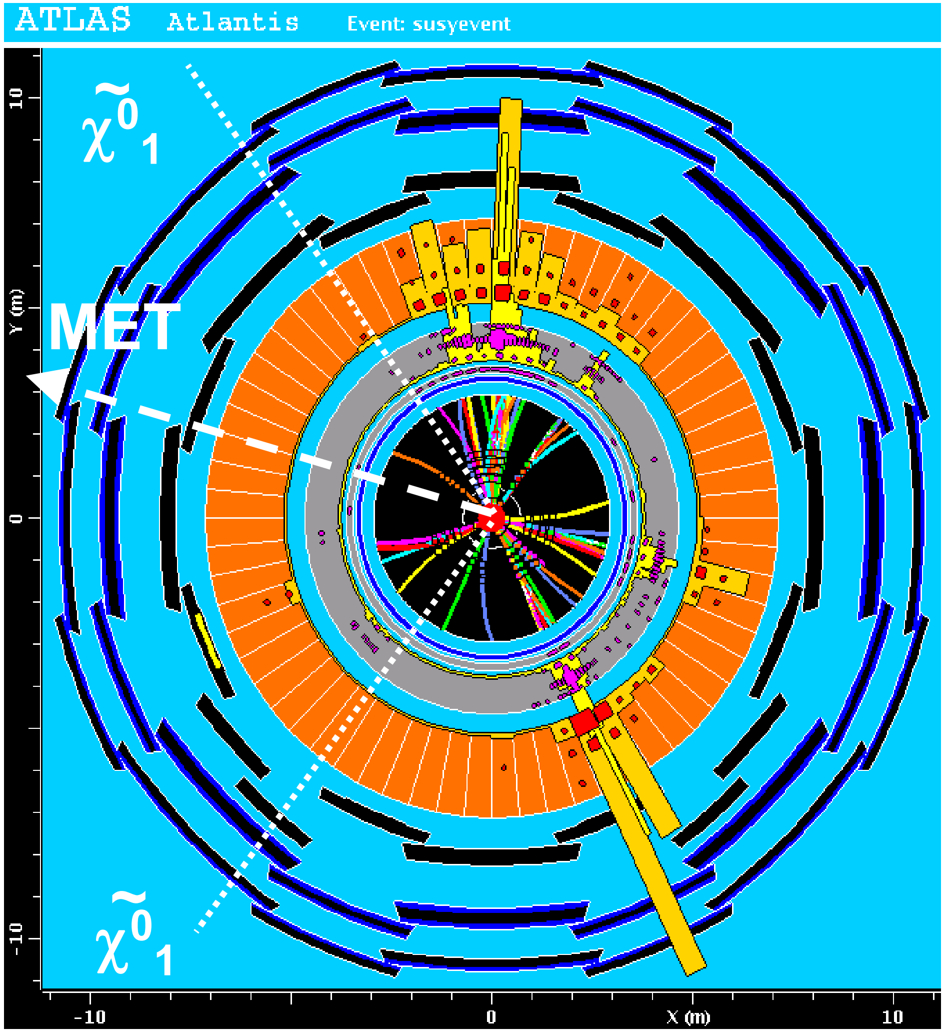
we see transition radiation!



Reminder: SUSY

- Many people like this theory
  - It keeps the Higgs mass stable
  - It allows the running of the coupling constants to meet at a single point
    - *Well, sort of*
  - It explains dark matter
    - *Well, maybe*

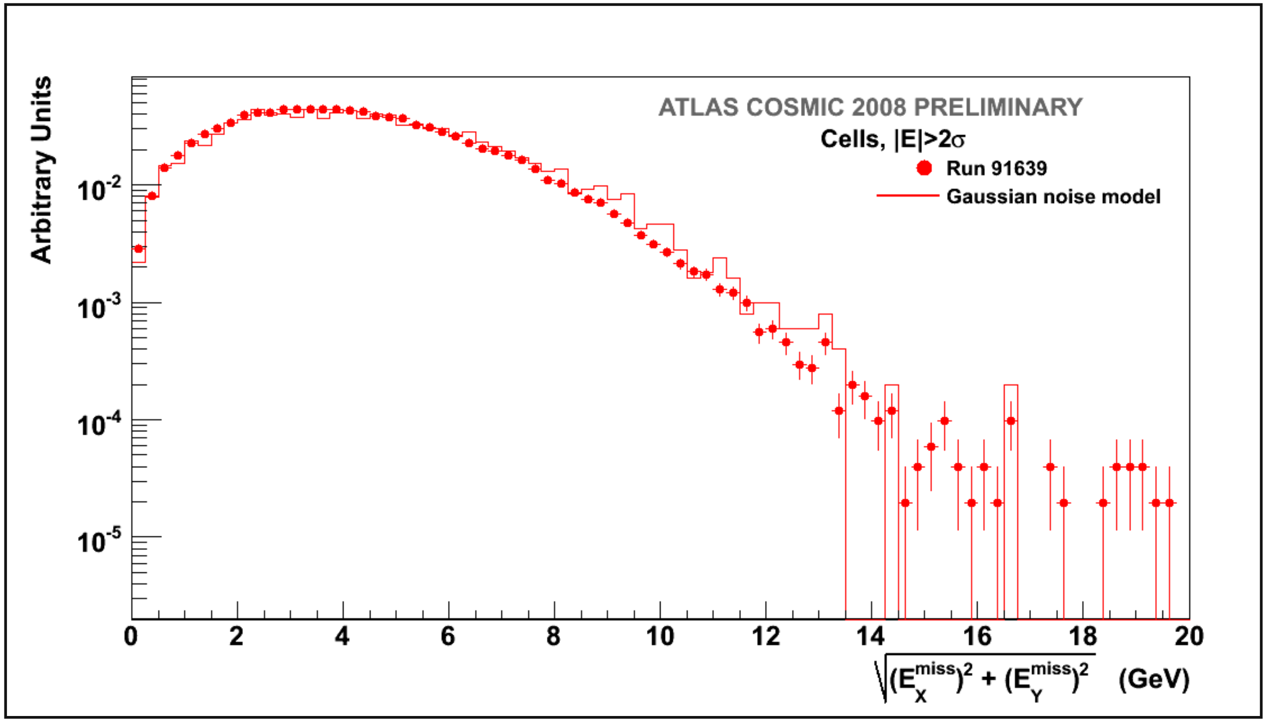
- Many free parameters:
  - A very common feature is the presence of events with large missing energy
  - Neutralinos look just like neutrinos to ATLAS



A simulated SUSY event

See Bruce Mellado’s talk

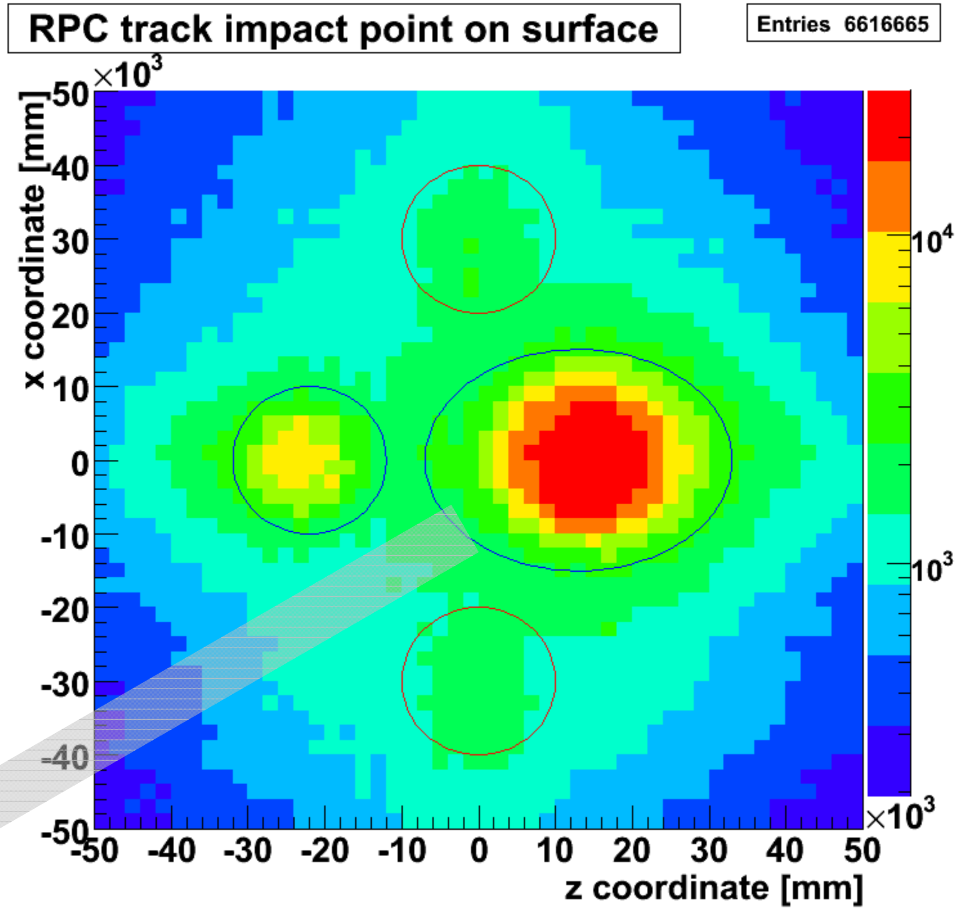
Fake Missing Energy in the Calorimeter



- One source of fake missing E_T is purely instrumental.
  - The above plot (from cosmic rays) shows that it is quite small
  - Perhaps more importantly, we're able to model the detector noise
  - Remember, though, this is not the biggest source

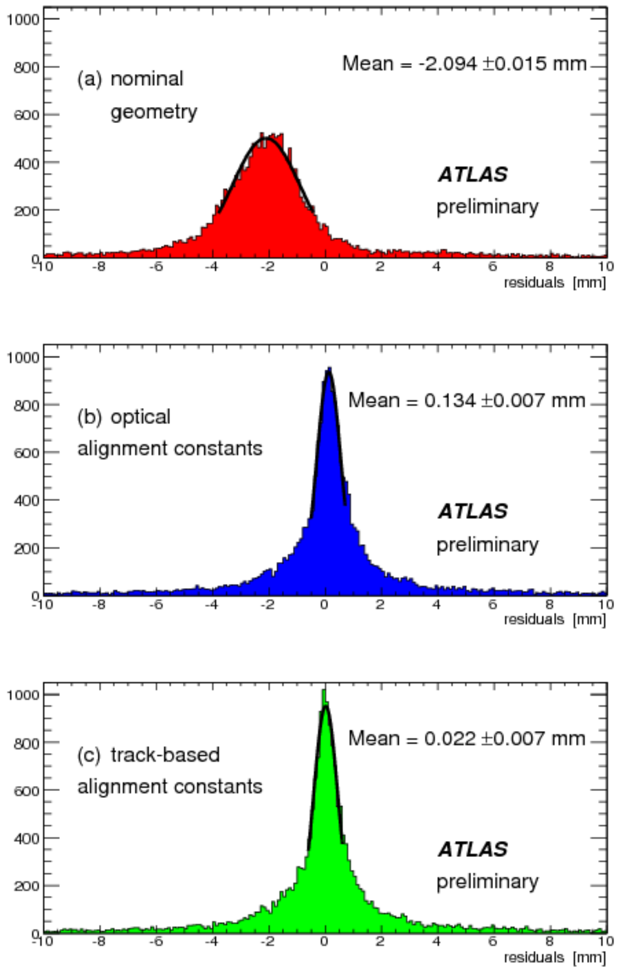
Muon Spectrometer

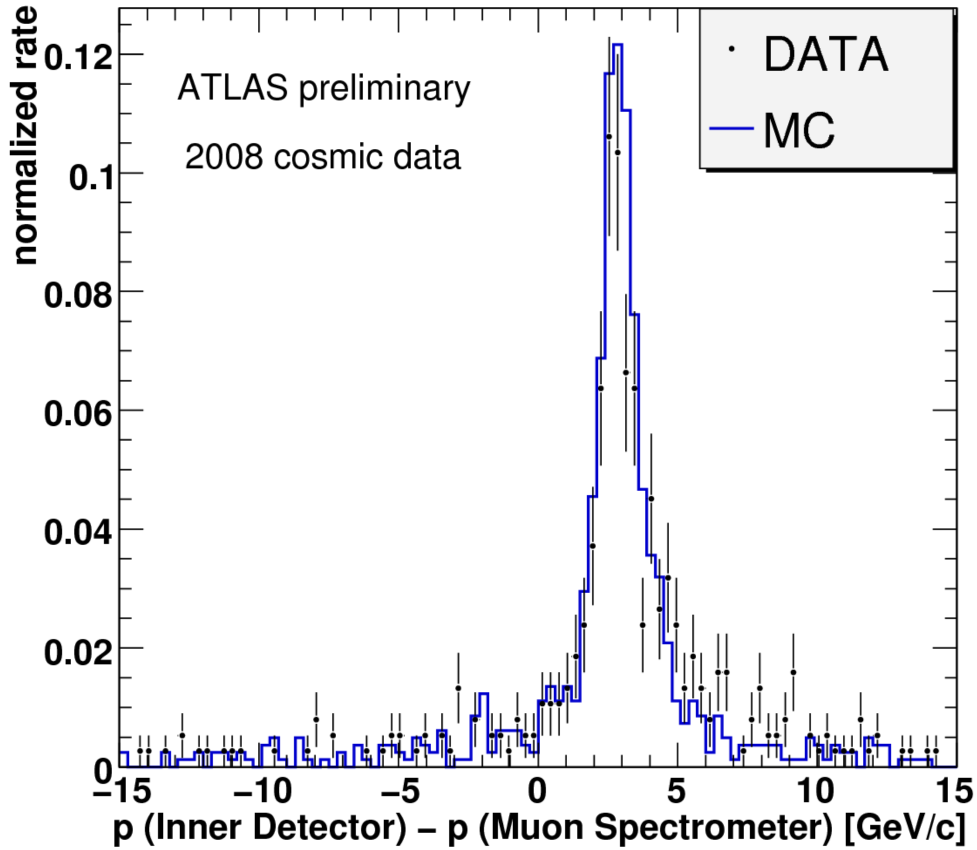
- Since cosmic rays are (mostly) muons, this is a terrific opportunity to shake down the muon spectrometer.
- The fact that ATLAS is large compared to the 25ns bunch crossing time has made cosmic ray studies a little less simple than we would have liked.



Position of the intersection of tracks projected back from ATLAS with a fictitious plane at the surface.

Muon Progress





Shows that on average, a muon loses ~3 GeV traversing the calorimeter – about what we expect.

The Shape of Things To Come

- Correlation between energy loss of the muon as it traverses the calorimeter and energy as measured in the calorimeter:
  - Uses all of ATLAS in a *single analysis*
  - Can someone make me this plot? *

- In the late stages of approval are a series of plots investigating high energy (> several GeV) delta-rays produced by muons
  - These would allow tests of reconstruction of real electrons in ATLAS
  - These would also allow tests of the triggering
  - Bonus: a check that the sign of the magnetic field is right!

Now, onto our plans for collision data…

* Hopefully the results will be more positive than “can someone rid me of this meddlesome priest?”

Year One (2009-2010) Running Conditions

- We're planning for an 11 month run, with a total delivered luminosity of ~few 100's of pb^{-1}.
  - This implies an average luminosity of ~3 x 10^{31} cm^{-2}/s
  - Peak luminosity could be an order of magnitude larger

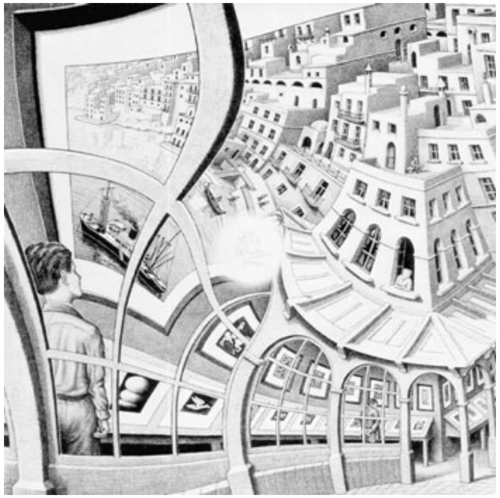
- The number of bunches per ring will vary dramatically over the course of the year:
  - 2 → 43 → 156 → 1404 → 2808 (25 ns)
  - Luminosity plus bunch structure implies that there will be pile-up during the 2009-2010 run

It is difficult to predict, especially the future. – N. Bohr

- We are planning for a run of 10 TeV center-of-mass energy
  - Perhaps stopping for a few fills at lower energy on the way to 10 TeV
    - *900 GeV (injection) is almost certainly one of those energies.*

Of course, this is subject to change as we gain operational experience.

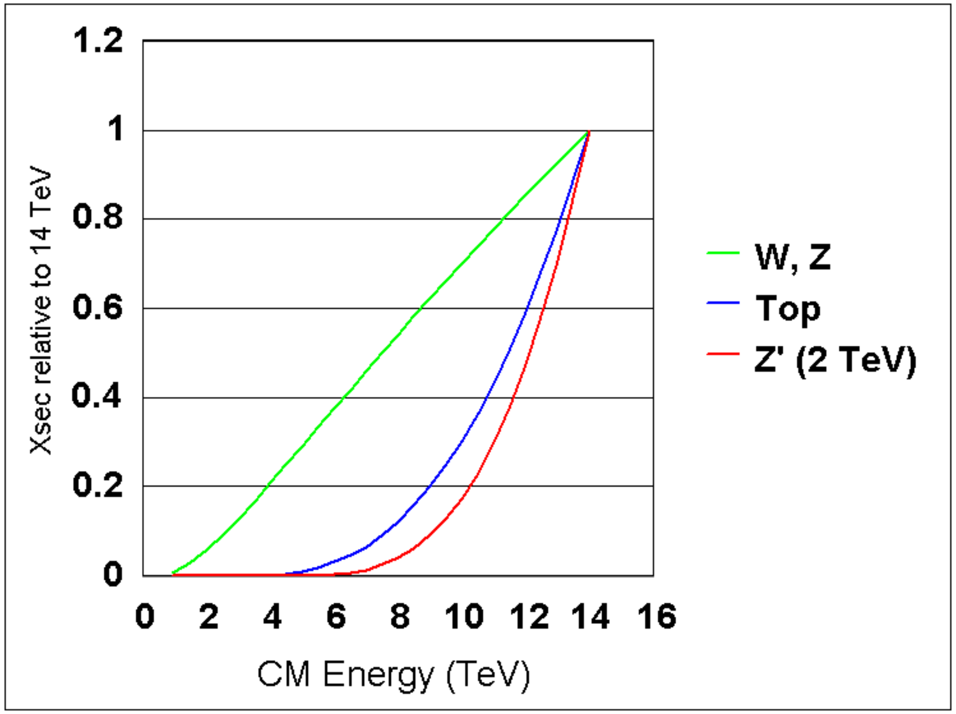
Some Perspective



- One can get a very good idea of production rates just by looking at relative partonic luminosities
  - Plot uses CTEQ6M
- Hardly a precision estimate, but good for “rules of thumb”

RULES OF THUMB

- Running at 10 TeV takes ~twice as much data as 14 TeV for equivalent sensitivity
- Running at 8 TeV takes ~twice as much data as 10 TeV for equivalent sensitivity
- Below 8 TeV things go “pear shaped” quickly.



So, What Can We Expect?

- The size of the 2009-2010 dataset gives us “sensitivity” (i.e. partonic luminosities) comparable to the Tevatron
  - Details are process dependent
    - *In general, the LHC does better for high mass objects (Bruce’s talk)*
    - *The Tevatron does better for mine.*
- I think it’s fair to say the LHC has better detectors
- I also think it’s fair to say that the Tevatron has better understood detectors
  - This comes from ~~years~~ decades of experience
  - We need to develop our own experience as quickly as possible.

The 2009-2010 run is the beginning of the story…not the end.

One Slide on Triggering

- At design luminosity of 10^{34}, we have 25 events per 25ns
  - I write it that way because a trigger selects *crossings* – not events
- ATLAS can afford to write ~200 Hz to tape

We need to be able to select this…

From this

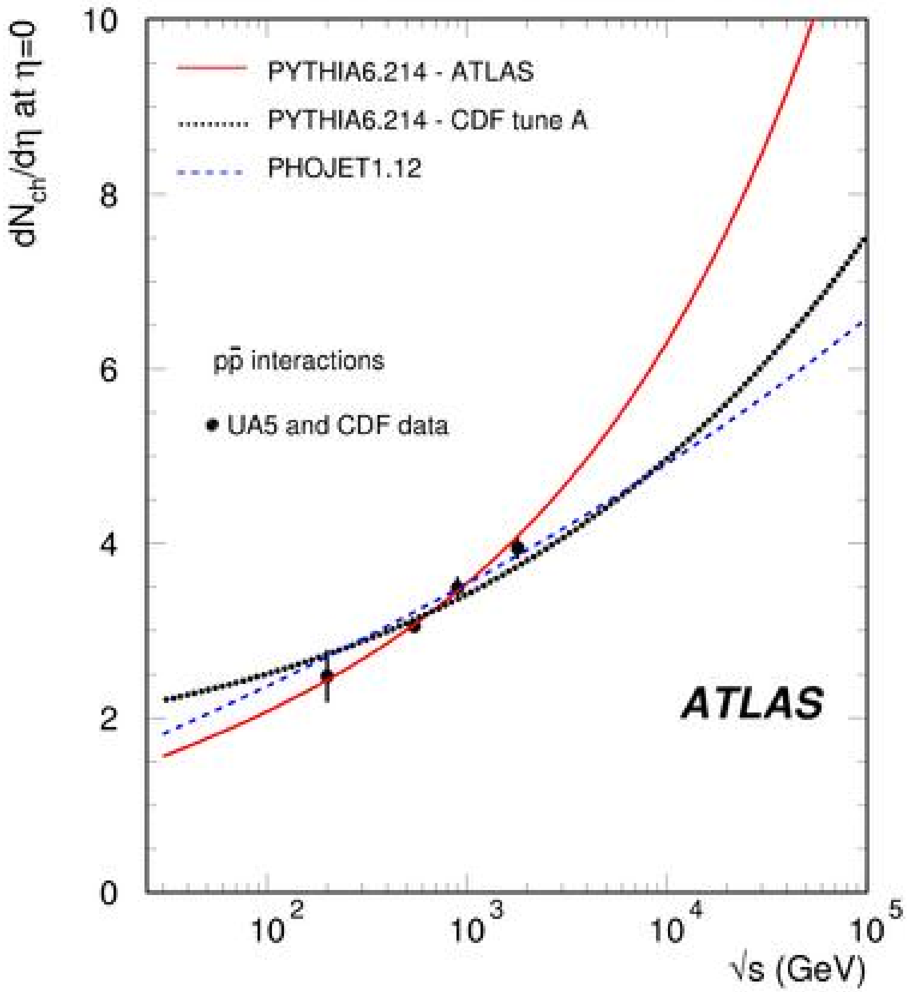
(output rate is 5 x 10^{-6} of the input rate)

ATLAS' Key Tasks For 2009-2010

- Commission and Understand the Detector
- Commission and Understand the Trigger
  - You can't analyze an event you didn't trigger on
- Do some physics!
  - As important as this is, it can't get in the way of #1 and #2
  - By the end of 2010 we need #1 and #2 working well enough to do physics in 2011.

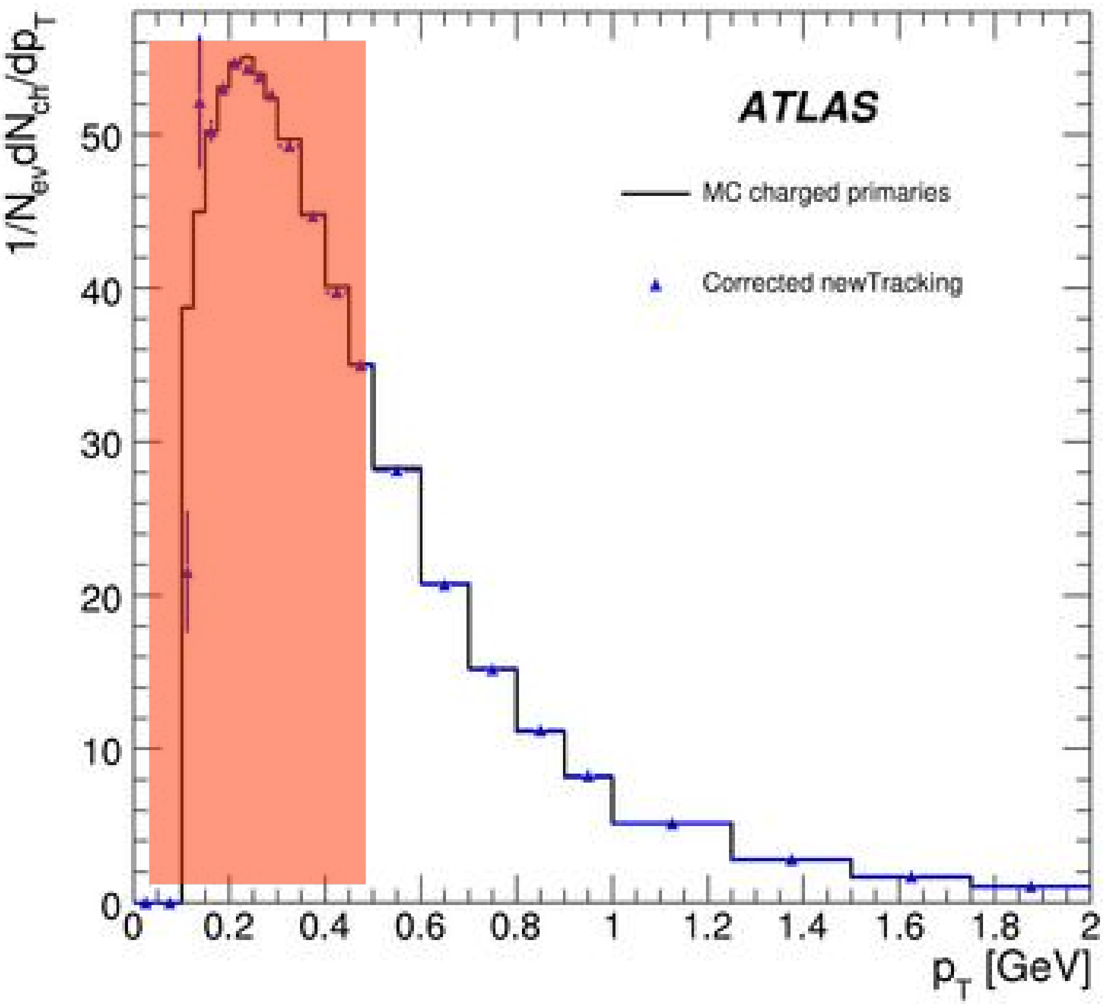
Minimum Bias

- These are the events that are part of the million, not (necessarily) the five.
- Even if you aren't a fan of soft QCD, these events are extremely important to ATLAS
  - We need to understand pileup
  - These are exactly the events that pile-up.
- The trickiest part of this measurement is the part that looks simplest: "N".



Predictions vary by ~50%

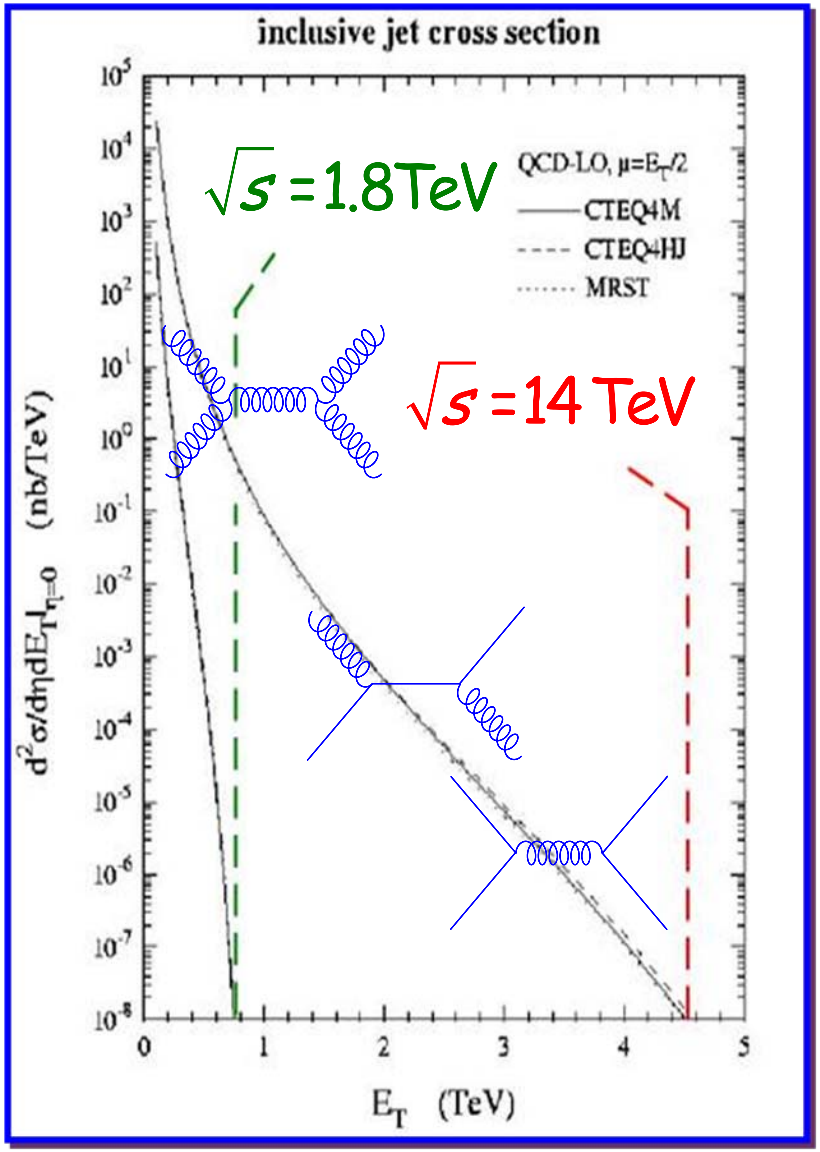
Reconstructing Low p_T Tracks



- The red zone is where the standard tracking becomes inefficient
- Most of the cross-section is below that point – we need a special version of tracking
- We may be in a position to say something about the high p_T side before we are confident of the full spectrum.

Jets

- Jets are our among highest cross-section processes
  - What else did you expect with a gluon-gluon collider?



Jets

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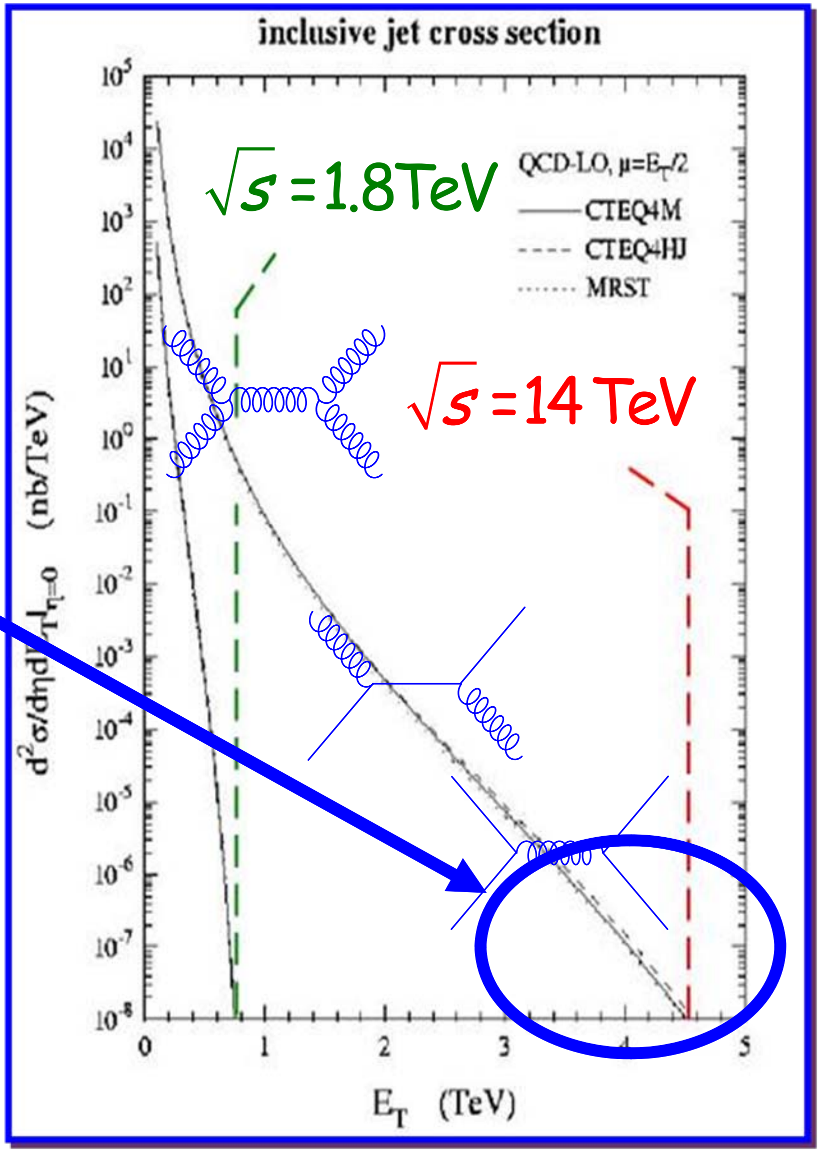
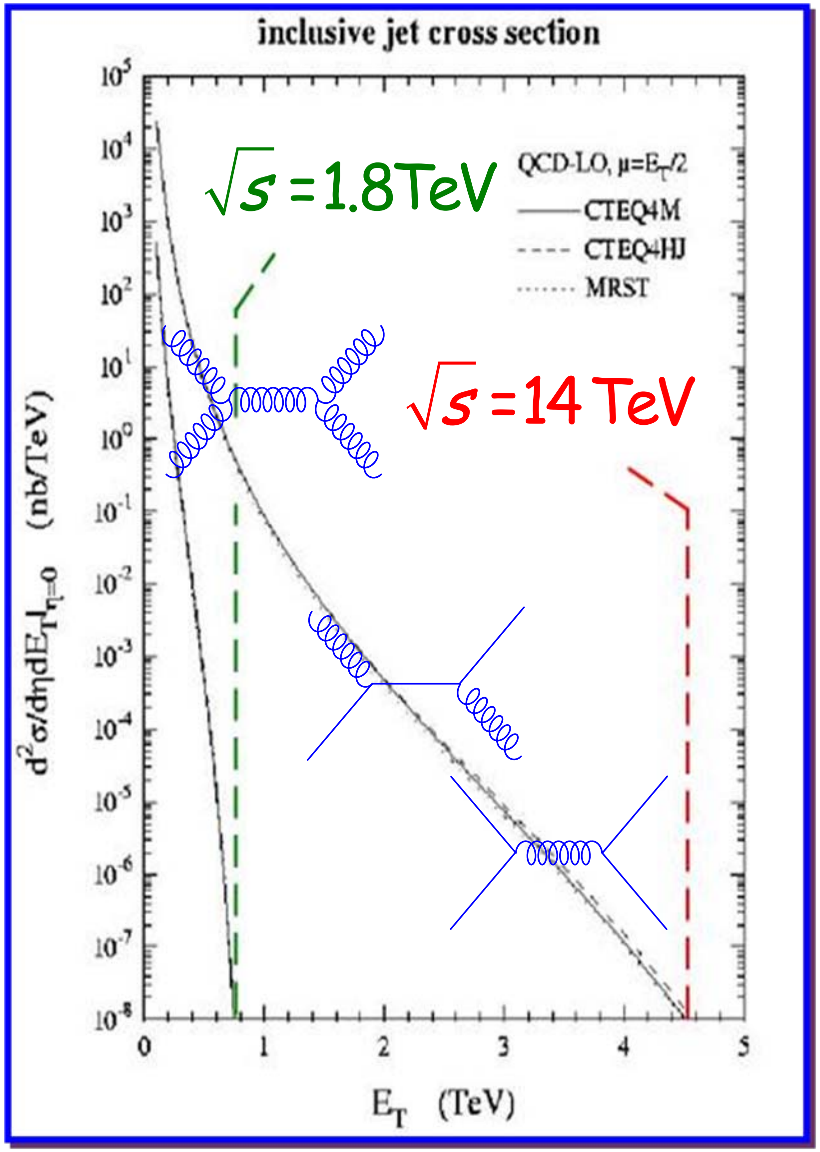
  - What else did you expect with a gluon-gluon collider?
- An excess of events at large E_T is a signal for new physics
  - Last time this happened, the new physics was an increase in the gluon distribution

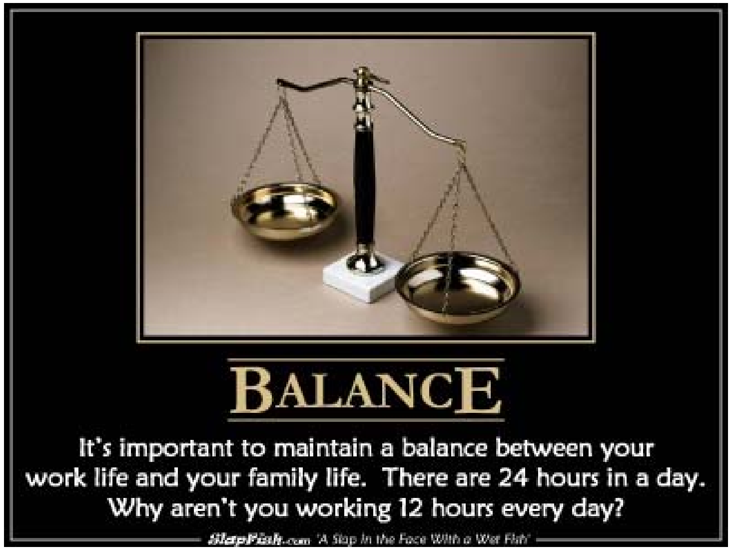


Jets

- Jets are our among highest cross-section processes
  - What else did you expect with a gluon-gluon collider?
- An excess of events at large E_T is a signal for new physics
  - Last time this happened, the new physics was an increase in the gluon distribution
- Understanding the jet energy scale is a critical piece to this.



Jet Energy Scale



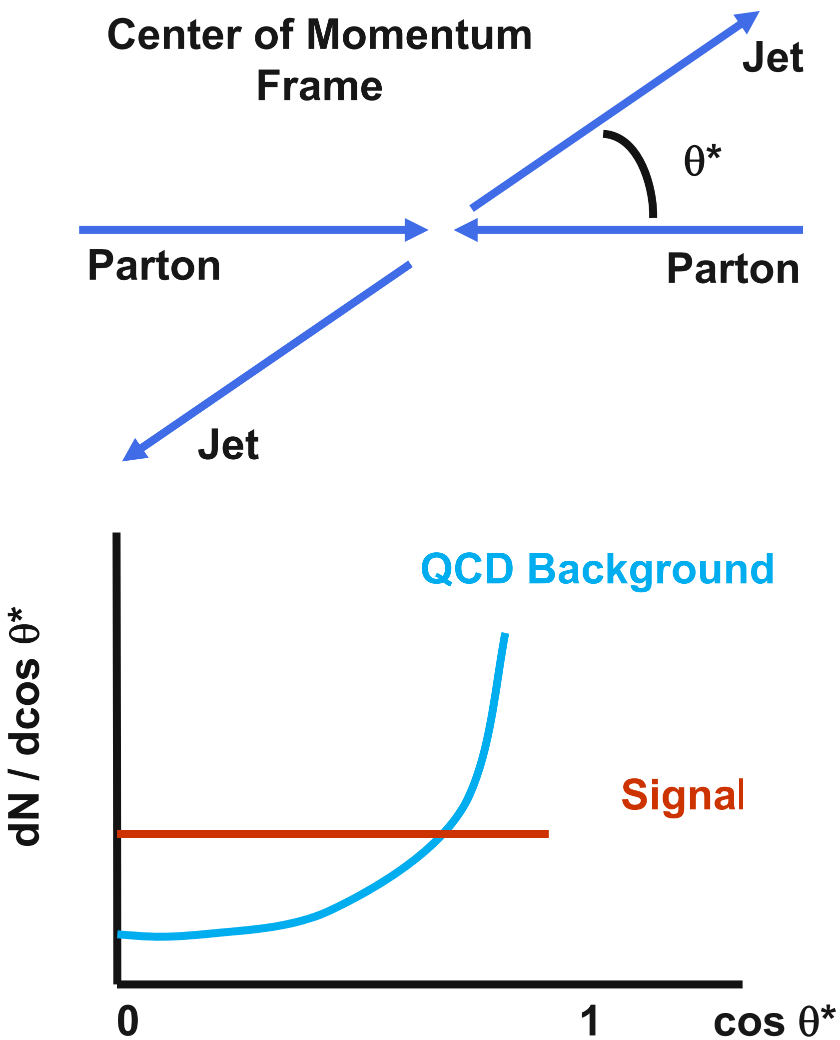
- Jet-jet balancing
  - Sets the relative scale, but not the absolute scale
  - Even without radiation, dijets shouldn't necessarily balance
    - *Because the spectrum falls steeply with E_T, there is a resolution/scale bias*
    - *Jets with a worse resolution are biased high*
- Photon-jet balancing
  - Radiation is an issue here too
  - How do you set the photon energy scale?
    - *The Tevatron operates at a convenient spot*
- Z-jet balancing
  - Statistics are an issue

This is not insolvable. Neither is it trivial.

It will take some time before we reach our ultimate JES understanding.

Angular Distribution of a Contact Interaction

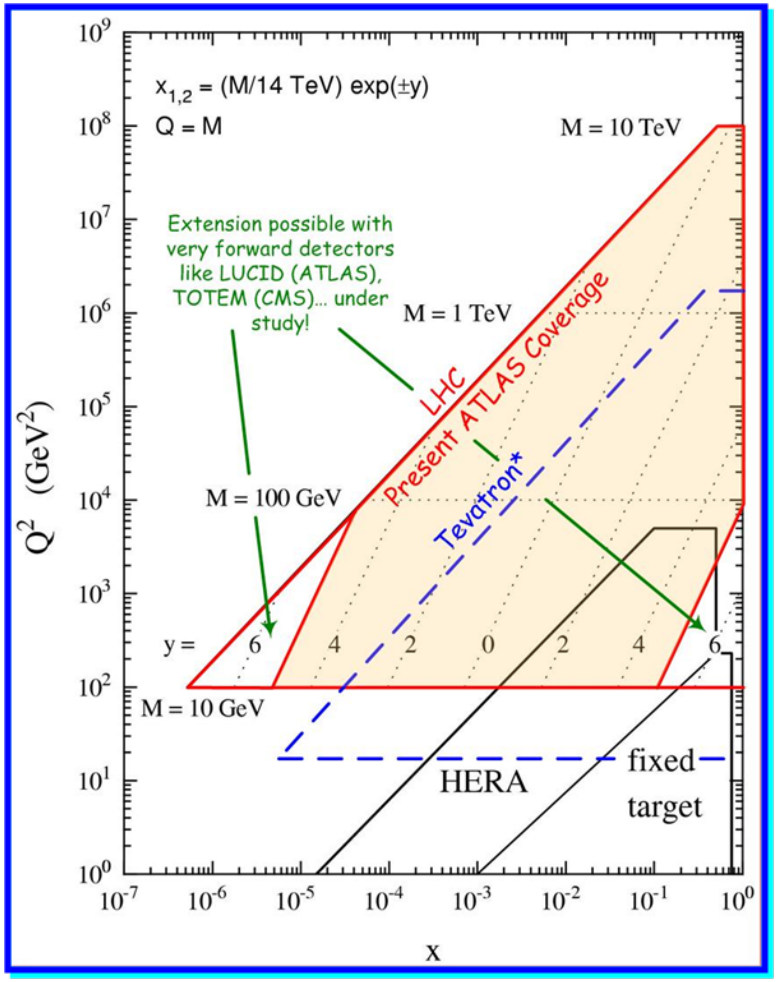
- It's harder to grossly mismeasure a jet's position than its energy.
- Contact interaction is often more isotropic than QCD
  - QCD is dominated by t-channel gluon exchange.
  - c.f. Eichten, Lane and Peskin (Phys. Rev. Lett. 50, 811-814 (1983)) for distributions from a contact interaction
- CMS (and D0) compress this distribution into a single ratio of central-to-forward jets



Diagrams: R. Harris, CMS

But Wait…That Was New Physics

- The increased center of mass energy relative to the Tevatron opens up a huge range of x and Q^2.
- We will be seeing parts of the proton that we have never seen before.
- Historically, a history of surprises:
  - Low x gluon from HERA
  - High x gluon from the Tevatron



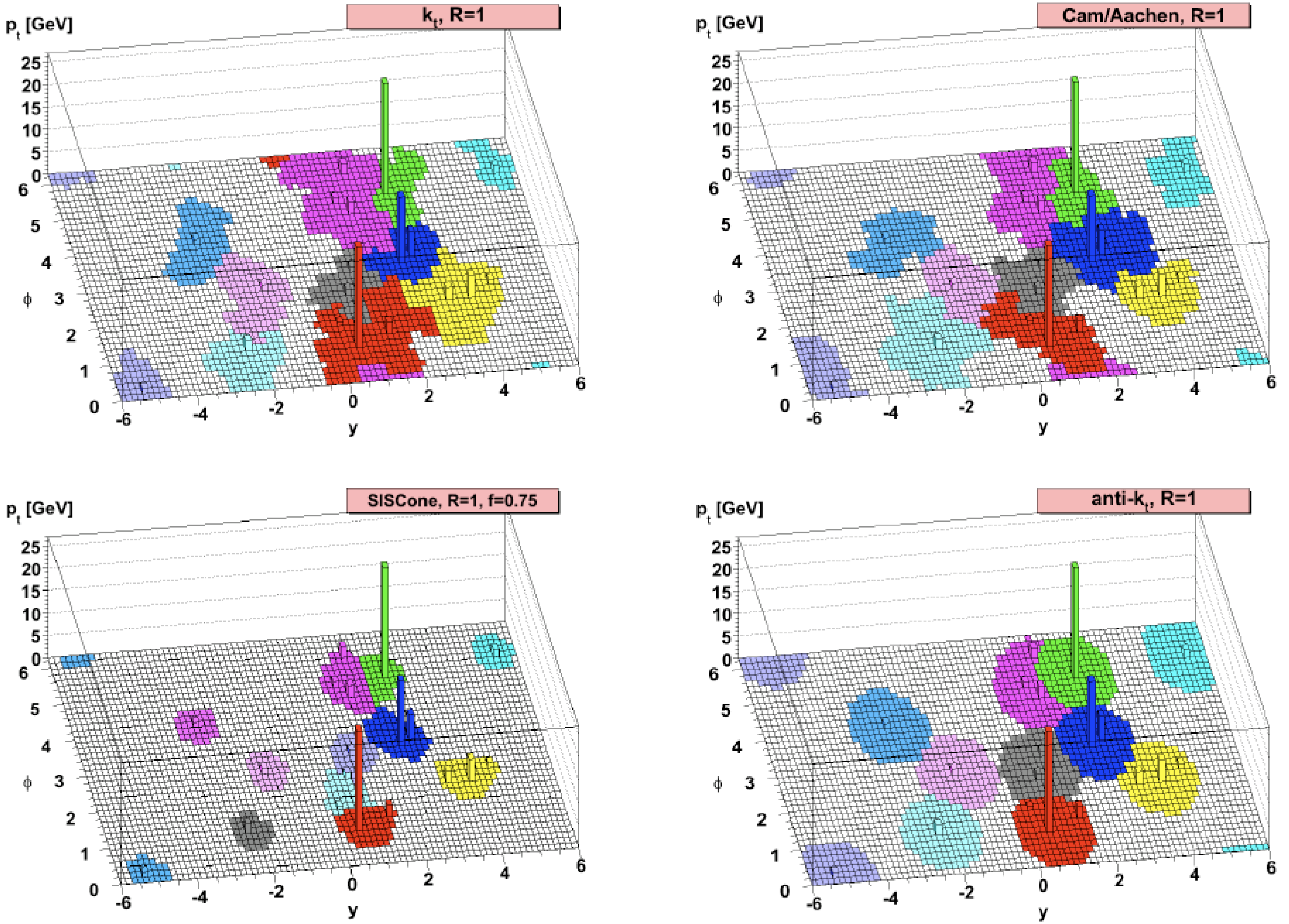
W. Stirling, LHCC Workshop "Theory of LHC Processes" (1998)
*annotation from J. Huston, Talk @ ATLAS Standard Model WG Meeting (Feb. 2004)

Zen and the Art of Jet Algorithms

- "A jet is what a jet algorithm finds"
- We want our algorithm to be infrared and collinear safe
  - Why, as an experimenter, do I care?
  - Because we need to compare with theory, and unlike at the Tevatron, often the process we want doesn't even *exist* until NLO.
  - ATLAS Cone is not it
- There are a bewildering array of algorithms on the market
  - People can use whatever they want
    - *Let a thousand flowers bloom*
  - One of them has to be calibrated first
    - *This will be anti-*k_T

Output of Some Jet Algorithms

Another plot everyone has seen, from Cacciari, Salam and Soyez



Why Anti-k_T

- It's IR and collinear safe

- It makes cone-shaped jets
  - Ironically, it makes more cone-shaped jets than the cone algorithms!
    - *What's in a name? That which we call a rose by any other name would smell as sweet .*
    - *Oversimplification of ten years of thought: "split-merge makes a mess"*

- In Monte Carlo, it performs well
  - In several tests, it's never the worst (and often the best).

- The fact that it's so geometric means the trigger – which knows nothing about IR safety – has the least bias

Could it fail in data because of something unexpected?
Sure…but so could any other algorithm.

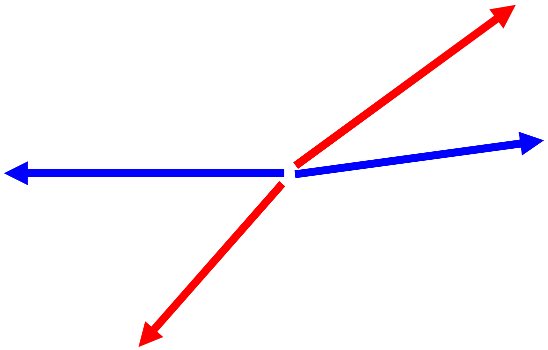
An Orphan Topic: Double Parton Scattering

- Two independent partons in the proton scatter:

$$\sigma_{AB} = \frac{\sigma_A \sigma_B}{\sigma_{Effective}}$$ might be better characterized by $$\sigma_{AB} = A(\hat{s}) \frac{\sigma_A \sigma_B}{\sigma_{Inelastic}}$$

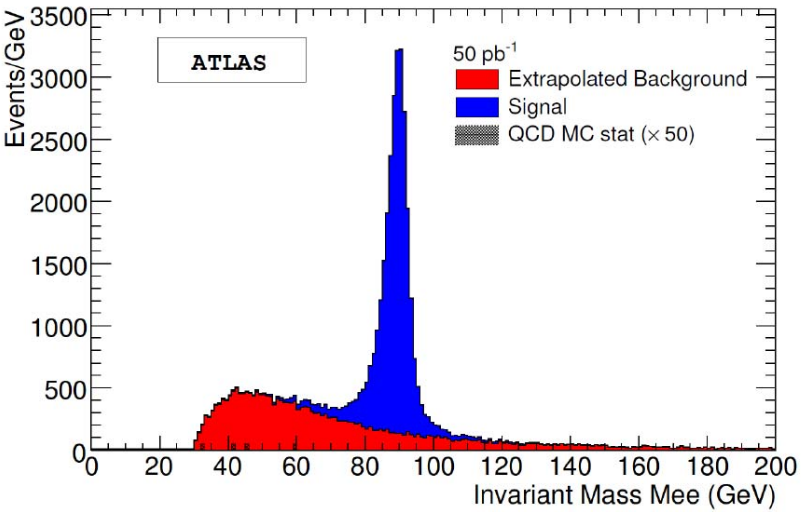
- Searches for complex signatures in the presence of QCD background often rely on the fact that decays of heavy particles are “spherical”, but QCD background is “correlated”
  - This breaks down in the case where part of the signature comes from a second scattering.
  - Probability is low, but needed background reduction can be high

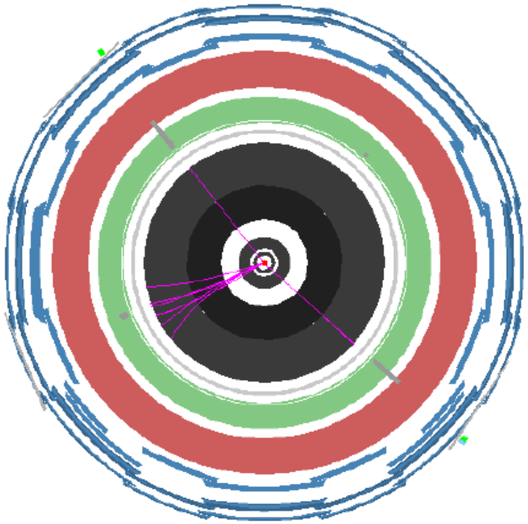
- We’re thinking about bbjj as a good signature
  - Large rate/large kinematic range
  - Relatively unambiguous which jets go with which other jets.



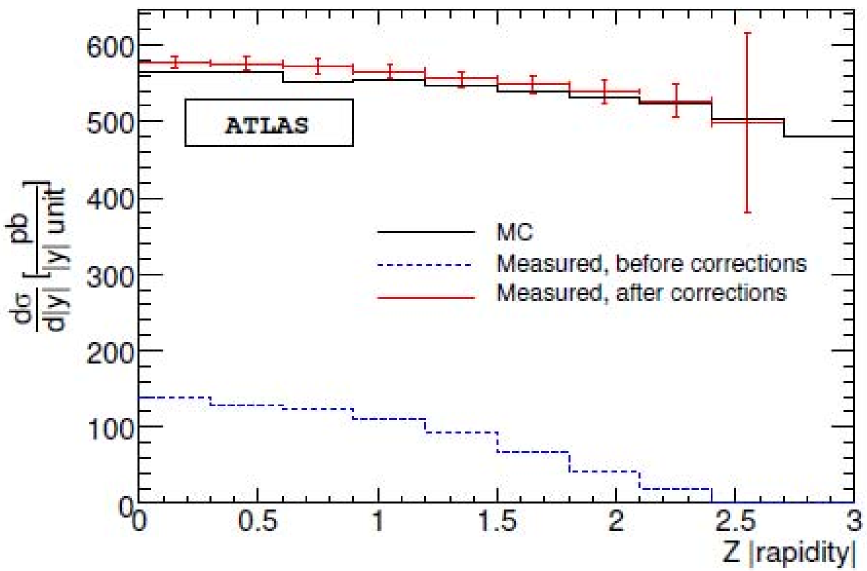
Turning to Leptons

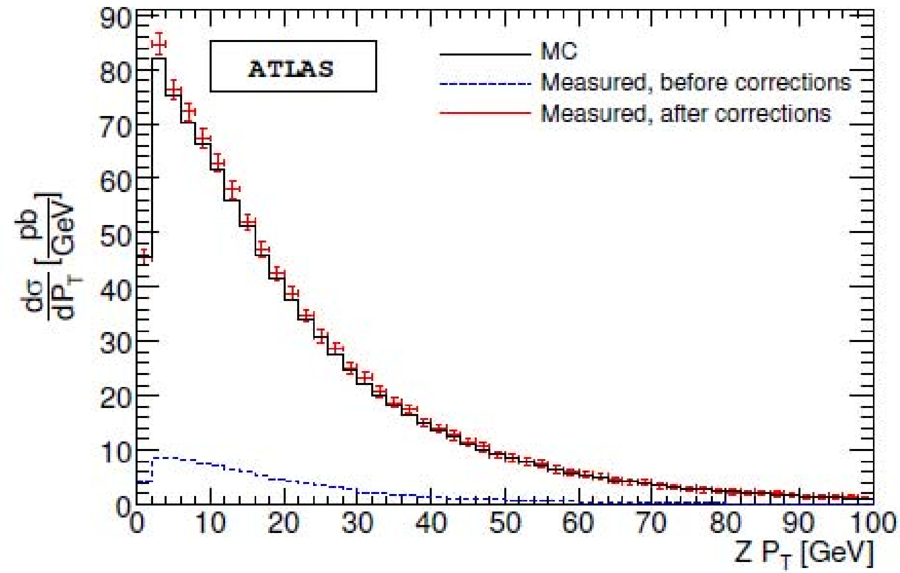
- Leptons have one huge advantage: $Z \rightarrow ll$
- There are two leptons in the final state, but you only need one to trigger on.
  - You get two bites at the apple
  - One of the leptons is unbiased and can be used to measure the trigger & reconstruction efficiency
- This is not the only way to measure the trigger & reconstruction efficiency
  - It may even not be the best way
  - It does, however pin any other measurement to the data – exactly where it's needed.
- Expectation is a few 10's of thousands of Z's





Differential Distributions



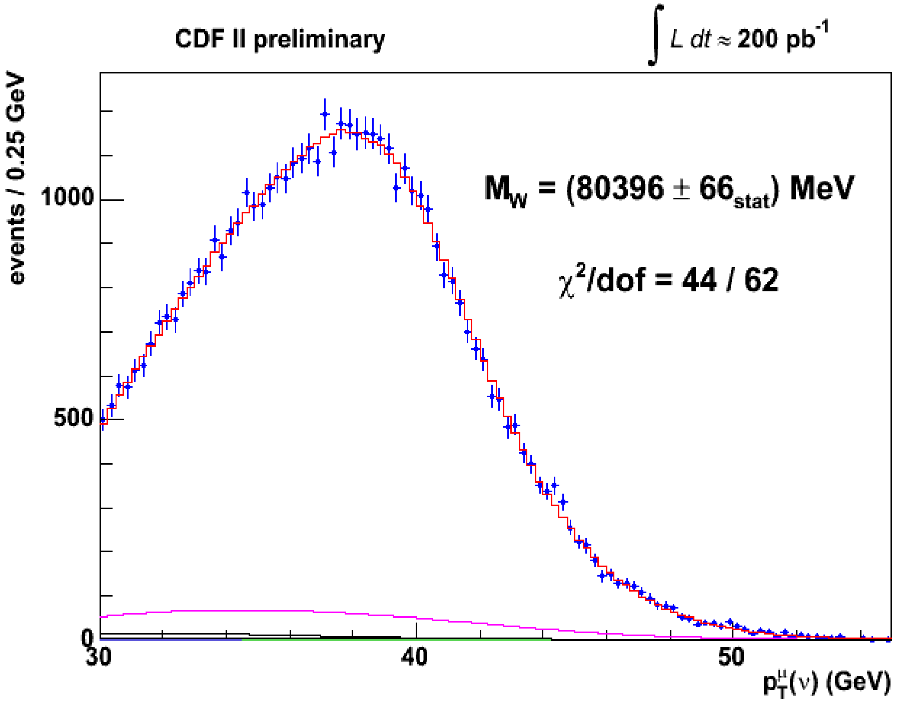


- Differential distributions can constrain PDF's
  - Roughly as much information in the shape as the magnitude
  - Early on, shape measurements will be much more reliable, as they do not rely on the absolute luminosity

- Note the fall off of the Z p_T distribution
  - Has implications for Z-jet balancing

Something that Doesn't Fit Anywhere Else

- It's possible to measure the W mass using Missing ET
- This isn't the best method
  – Typically, resolutions are ~20% worse than transverse mass



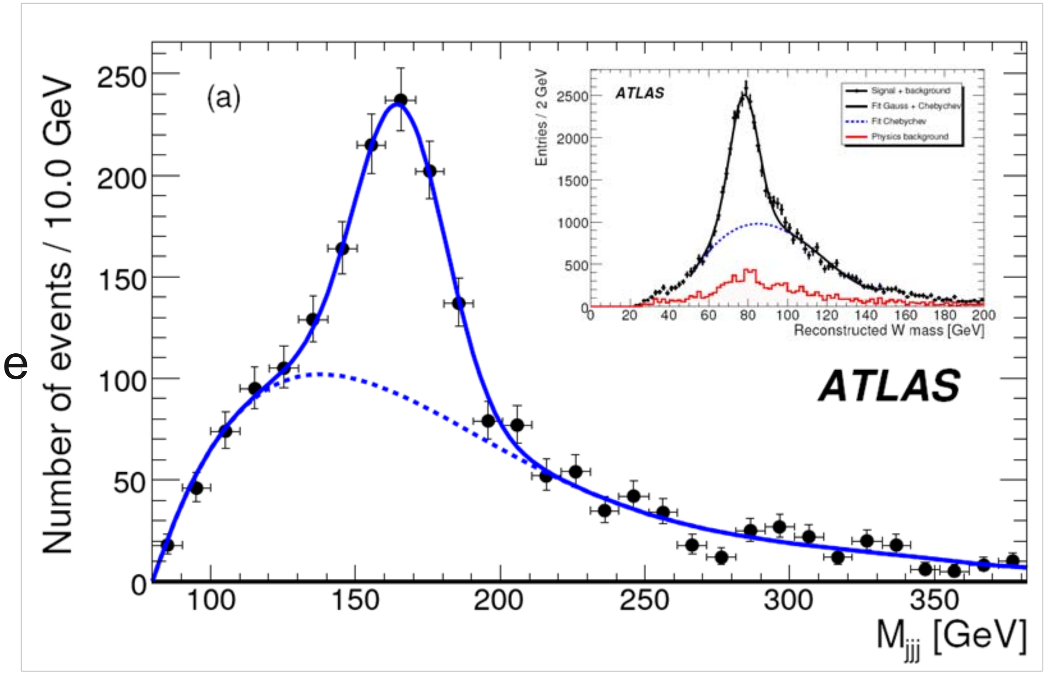
- Nevertheless, it would be extremely interesting to make this measurement and make sure that we get 80 GeV
  – In electron and muon channels
  – Irrespective of the number and energy of the jets in the event

A Word on Top

- At the Tevatron, top production is 90% q-qbar and 10% glue-glue

- At the LHC, this is reversed.

- So not only does the cross-section increase, but so does S/B



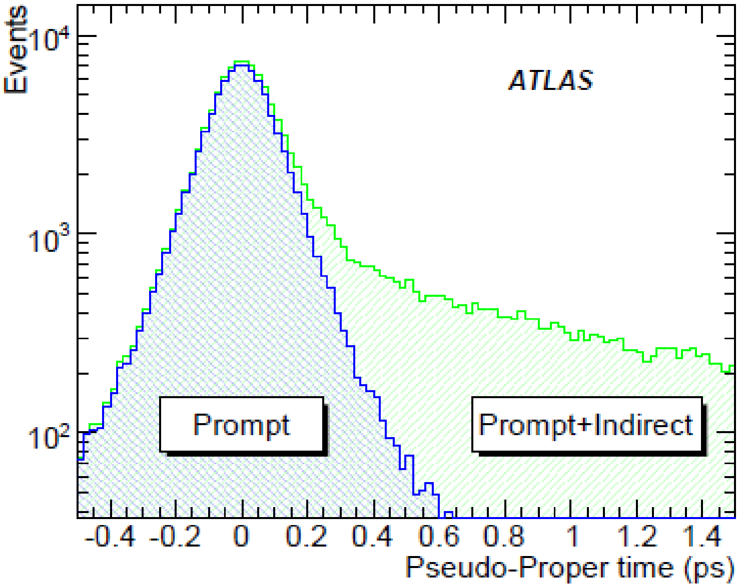
~100 pb^{-1} at 14 TeV

- This provides a large sample for studying top production, but also…
  - A sample of dijets where we know the invariant mass (80 GeV)
  - A sample of jets where we know the fraction that should be b-tagged

ATLAS will tell us about the top quark –

and the top quark will tell us about ATLAS

…and Bottom



- The silicon lets us separate J/ψ's that come from b decays from those produced promptly
  - The Tevatron has been doing this for years and years.
- An early ATLAS measurement will be the fraction of J/ψ's that come from b decays
  - One piece of the b cross-section measurement
  - At CDF, the best b cross-section measurement uses this method
- Side benefit – lets us test the silicon alignment
  - Is the b-fraction the same independent of silicon module?
  - What about the lifetime?
  - Probes a different – almost orthogonal – set of distortions than cosmic rays

One Possible (Incomplete) Roadmap

Spring Conferences 2010	Data up to December? Maybe a few pb^{-1}
Summer Conferences 2010	Data up to March? Maybe a few 10's pb^{-1}
Spring Conferences 2011	Full data set (100's of pb^{-1})

This is, of course, largely guesswork and subject to change – but nevertheless it's good to plan.

Summary

- The accident in Sector 3-4 was a disappointment
  - We've mostly recovered from it, and will be ready to try again in fall
  - We've put the intervening time to good use:
    - *It takes millions of cosmic rays to understand the detector as well as thousands of collisions – but we had one and not the other.*

- ATLAS is as well understood as its ever been

- We expect to have a rich program of Standard Model physics (including top and bottom) even with relatively little data
  - Some early preliminary results might be shown in the spring conferences
  - A few 100 pb^{-1} in the 2009-10 10 TeV run gives us sensitivity comparable to the Tevatron
    - *Better in some places, worse in others*

- Our physics goals revolve around preparing ATLAS for a multi-fb^{-1} run at 14 TeV in 2010-2011.
  - We'll see the first W's, Z's and tops this year – and an avalanche next year