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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.

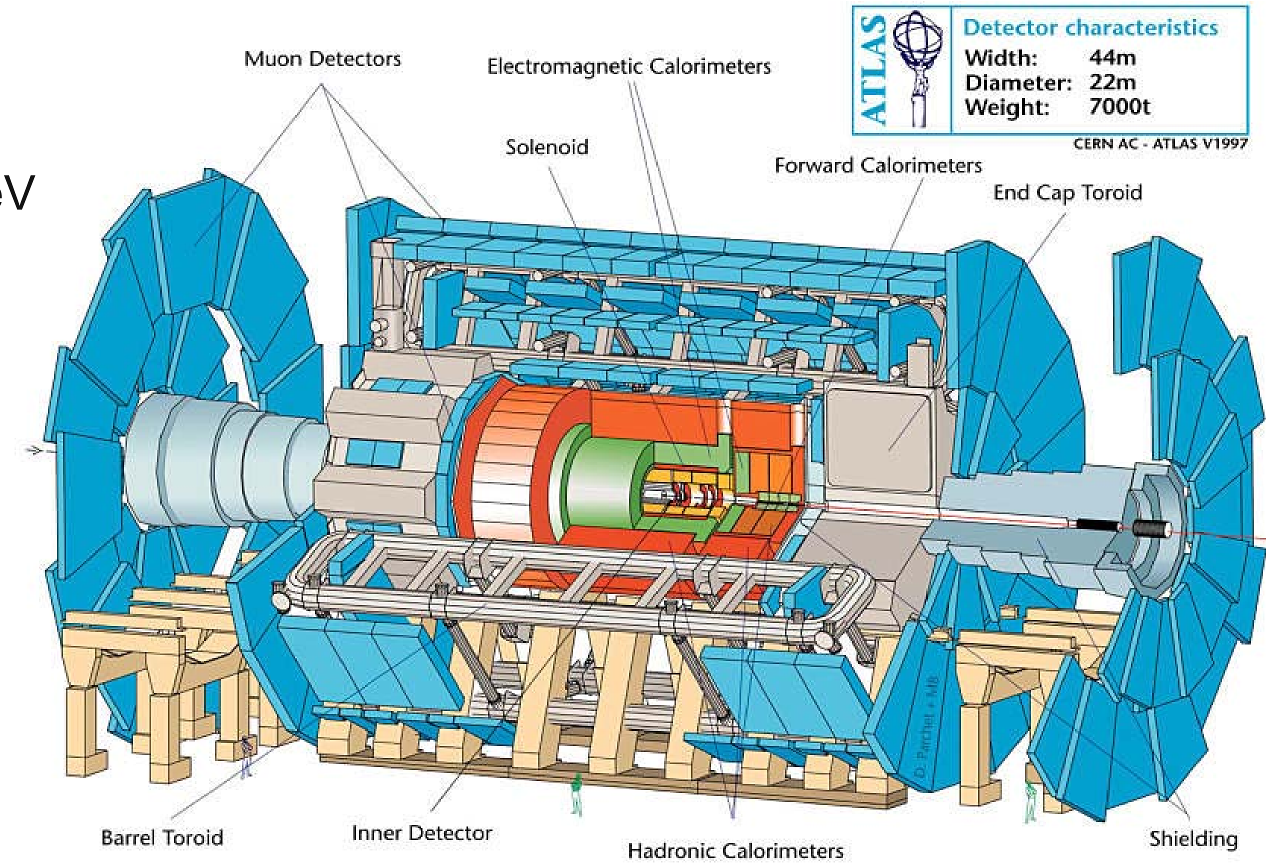
And now we'll discuss some **old physics**…

# *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

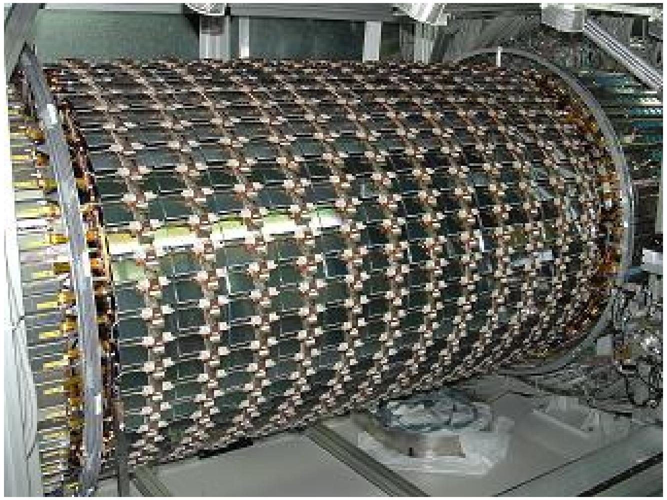



I'll describe the status of the detector over the next few slides…

# What happened in Sector 3-4?

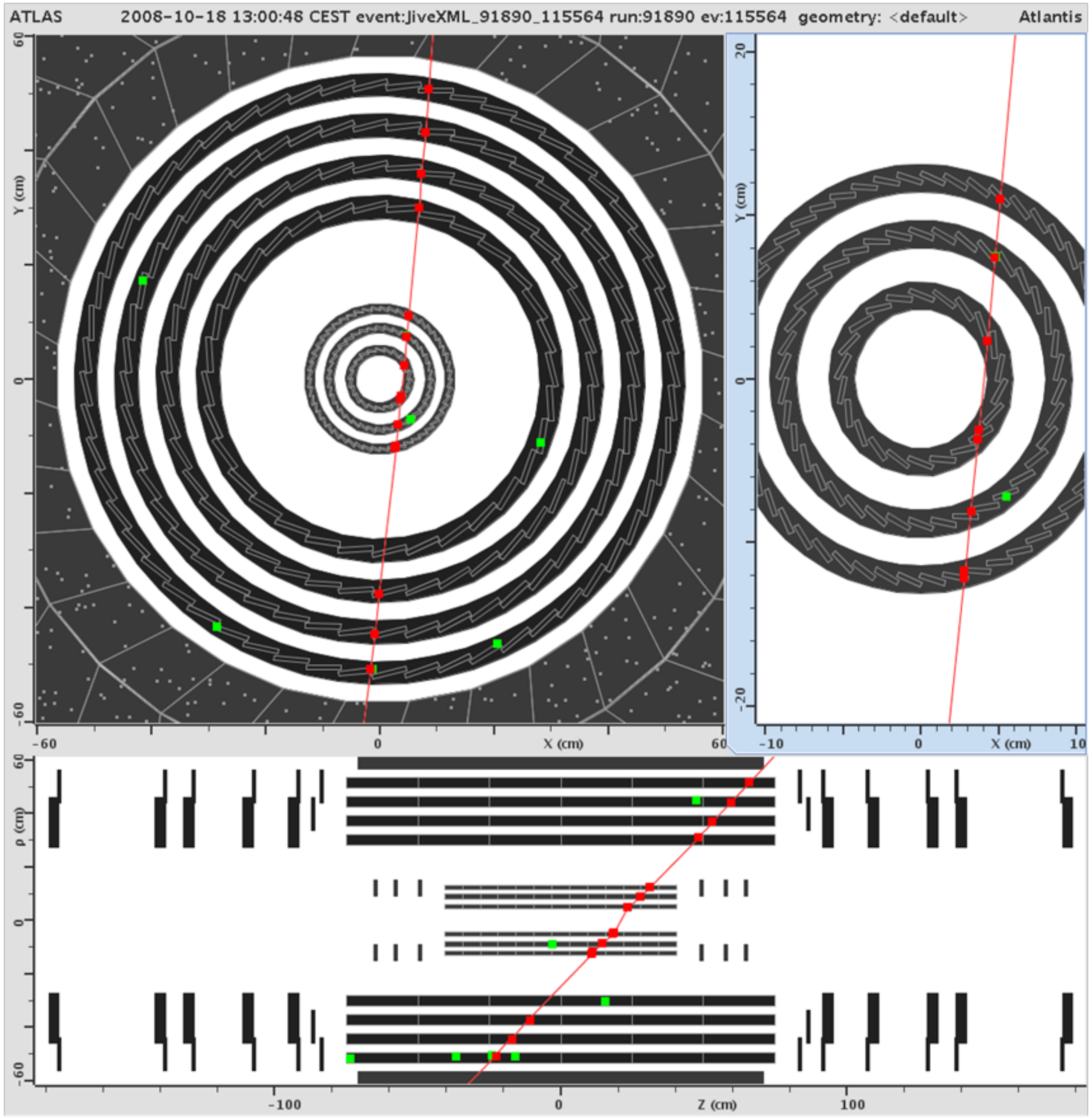
- The plan for collisions in 2008 did not survive the accident
- We have embarked on a long cosmic ray run
  - 260,000,000 events so far
  - Perhaps another ~300,000,000 or so to come
- Cosmic rays are not as good as collisions to commission the detector
  - But we have them, so we will use them

# ATLAS Silicon



ATLAS Silicon Tracker: pixels are obscured by the strips

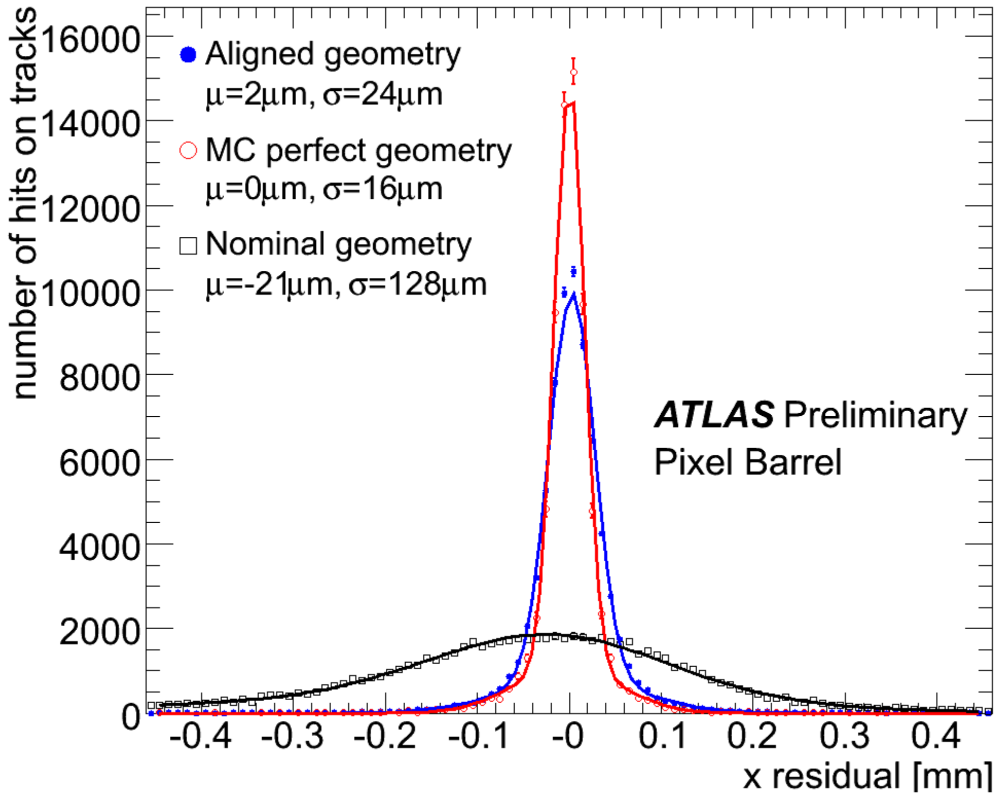
One Cosmic Ray traversing both pixels and strips

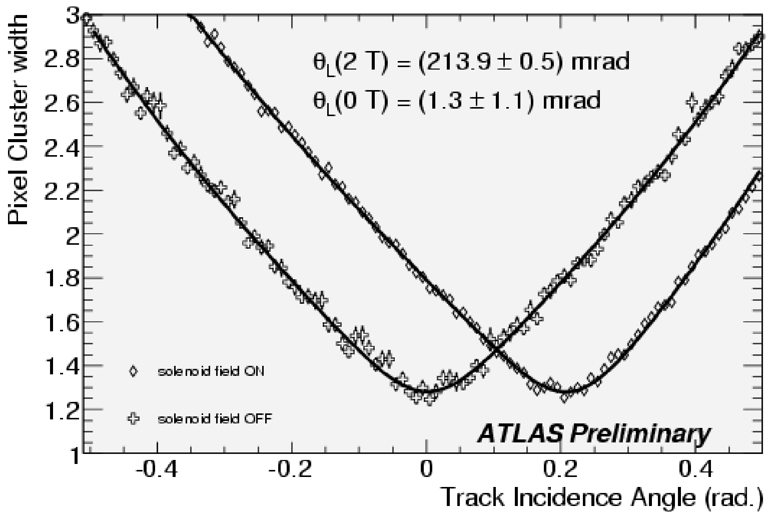


# Understanding the Silicon

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.

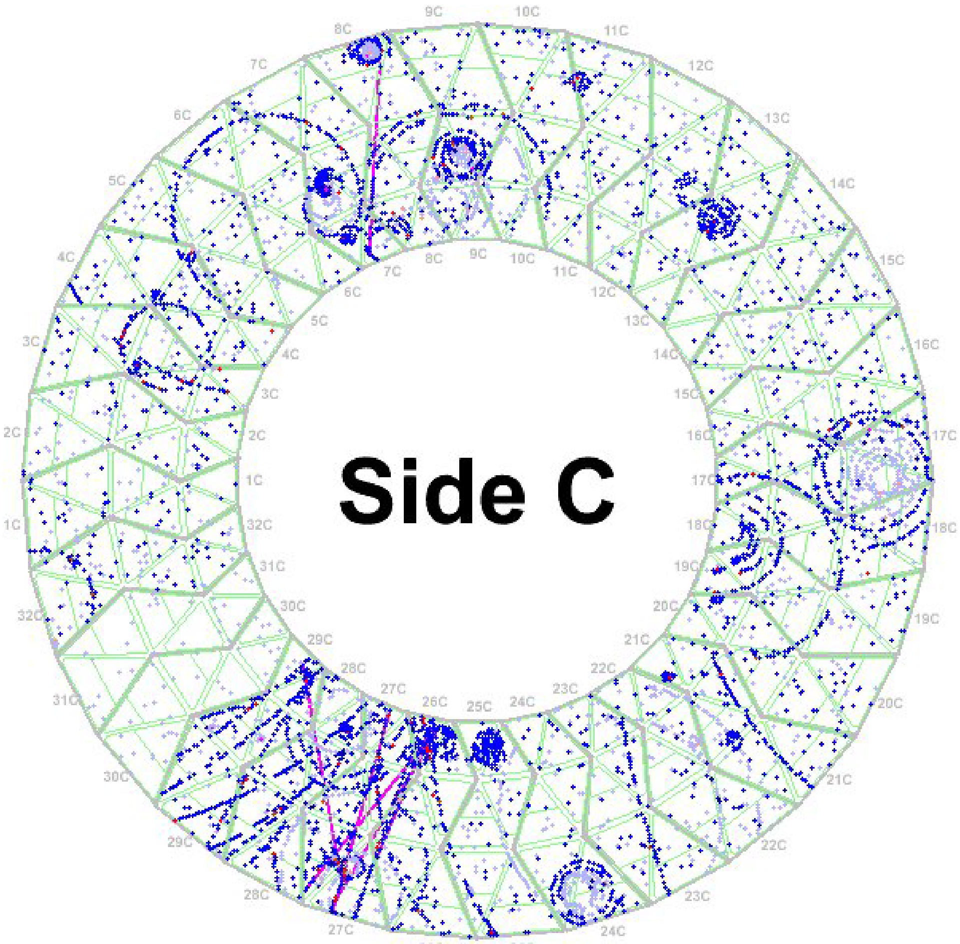


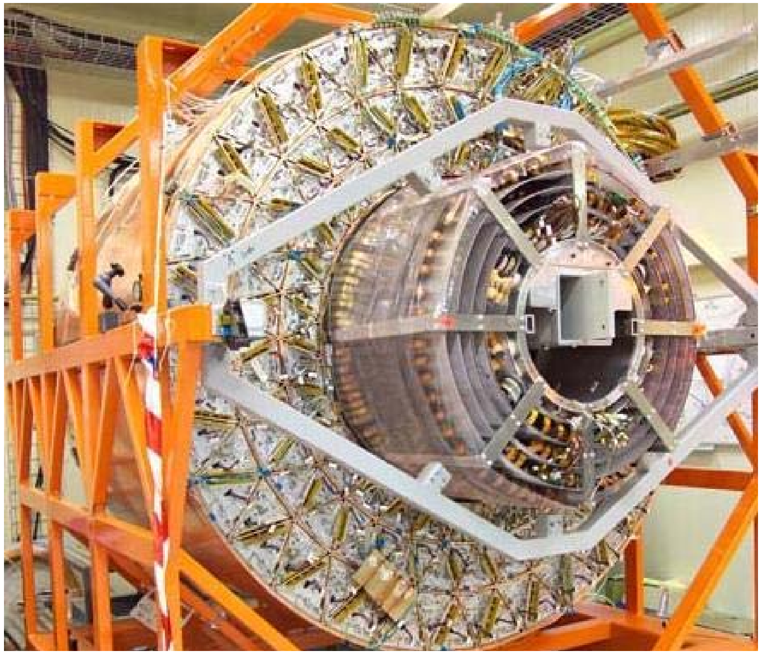




We may have some sort of early B-tagging available in 2009. (Ultimately, we will need to tune the algorithms on data).

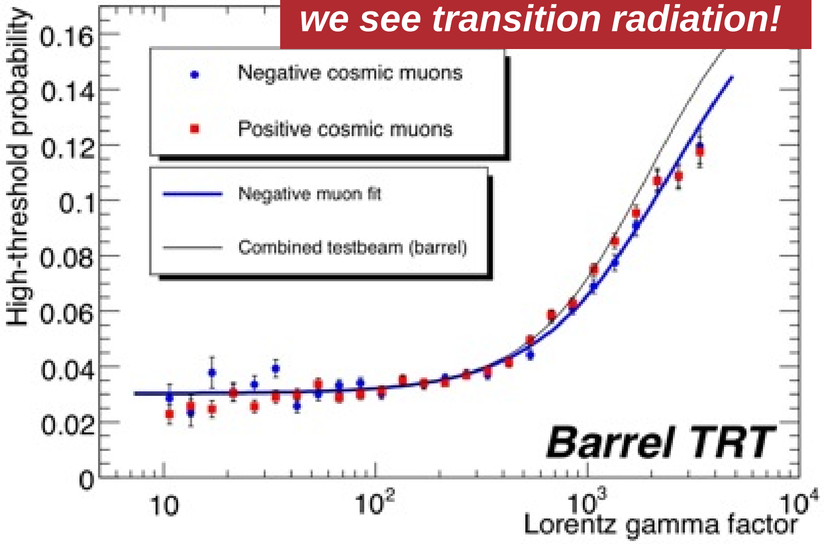
A cute thing: we can see the Lorentz angle of the electron drift in the silicon.

# Transition Radiation Tracker



**_we see transition radiation!_**

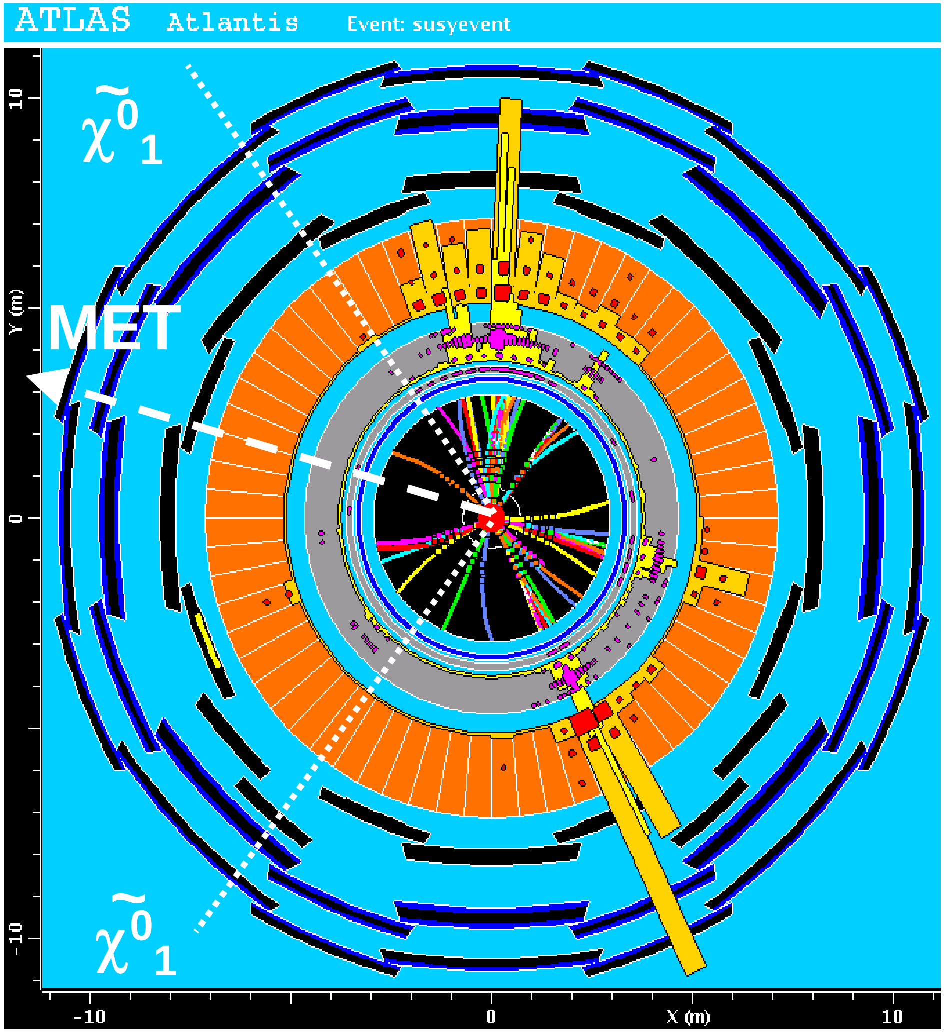



**_We see tracks, and…_**

# 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*

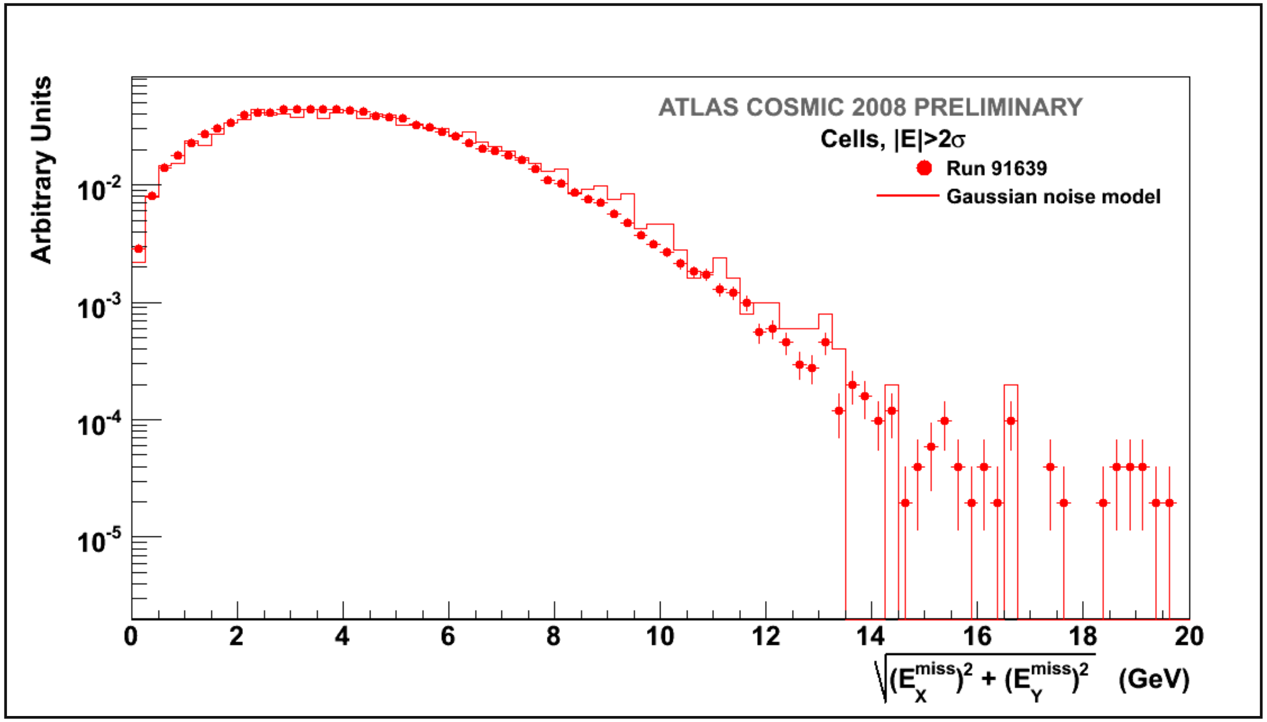
- Many free parameters:
  - A very common feature is the presence of events with large missing energy
  - Neutralinos look just like neutrinos to ATLAS




A simulated SUSY event

See Bruce Mellado's talk

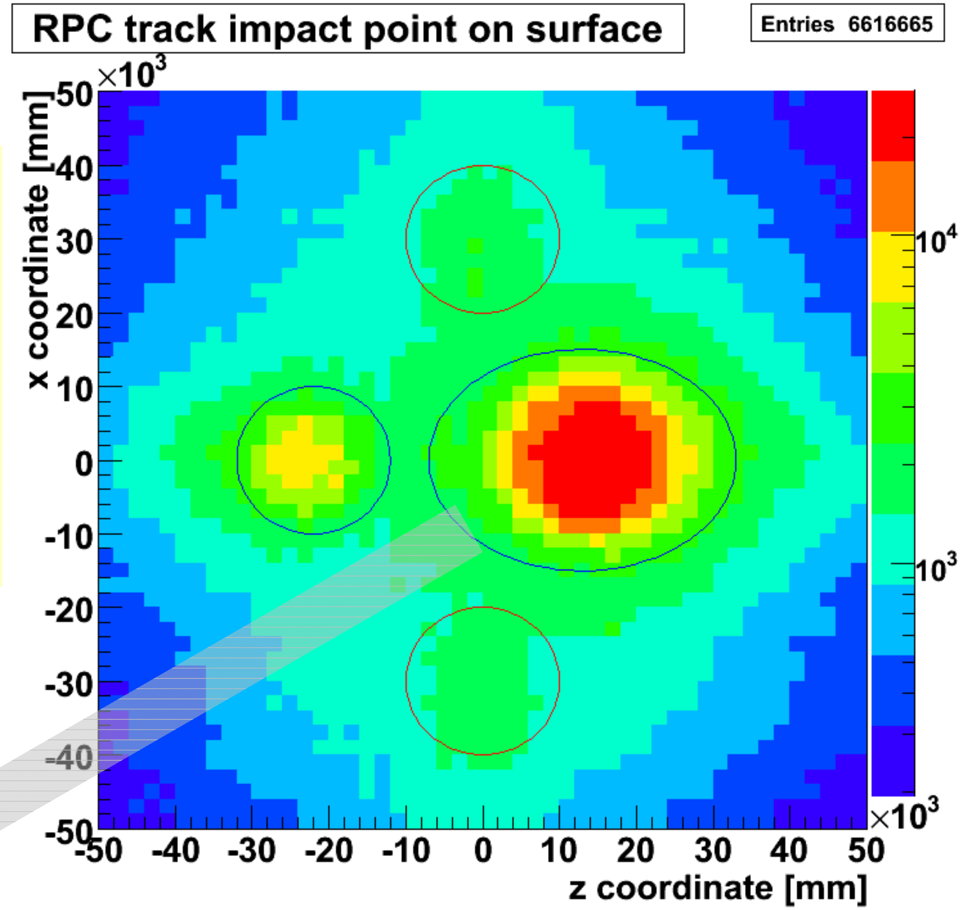
# *Fake Missing Energy in the Calorimeter*




- 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

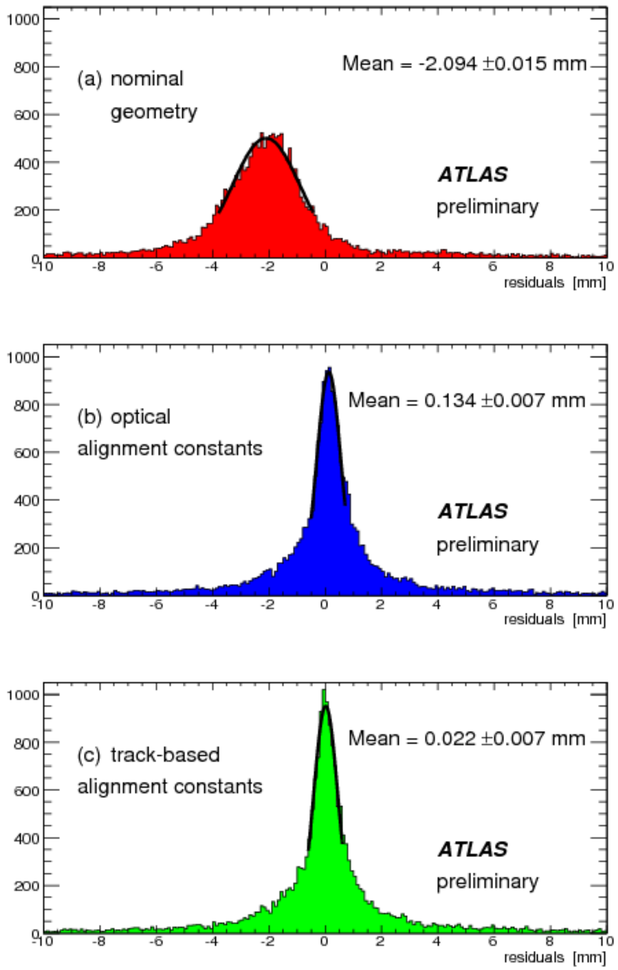
# Muon Spectrometer

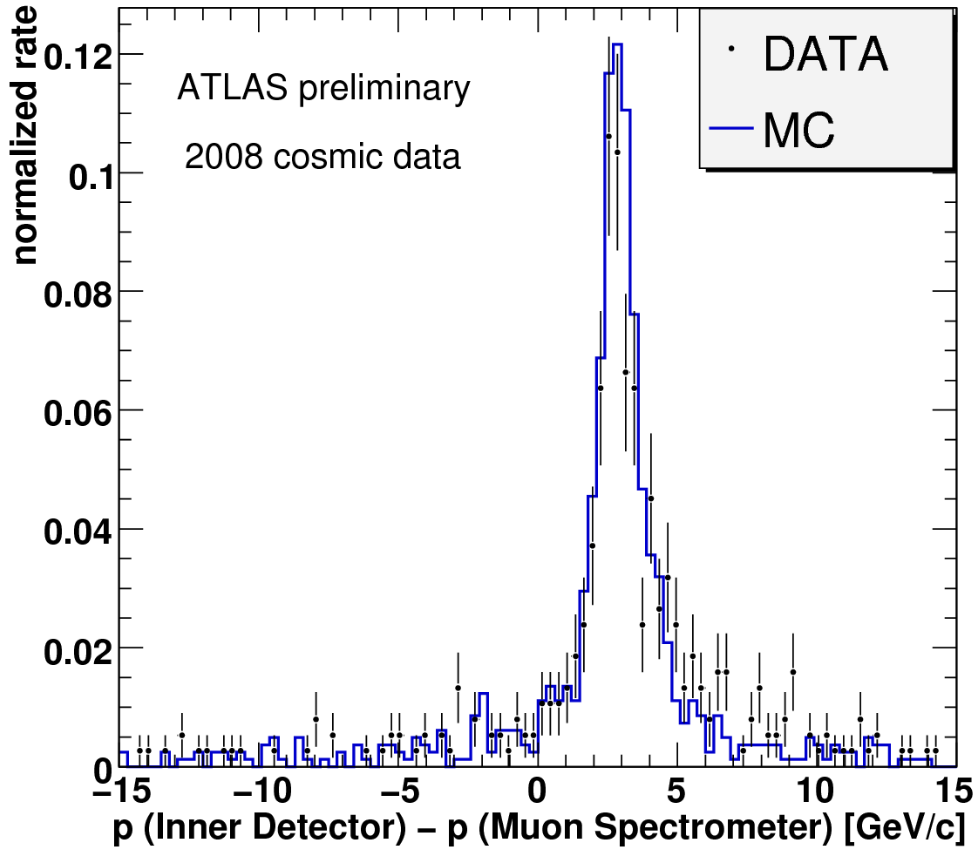
- Since cosmic rays are (mostly) muons, this is a terrific opportunity to shake down the muon spectrometer.
- The fact that ATLAS is large compared to the 25ns bunch crossing time has made cosmic ray studies a little less simple than we would have liked.




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

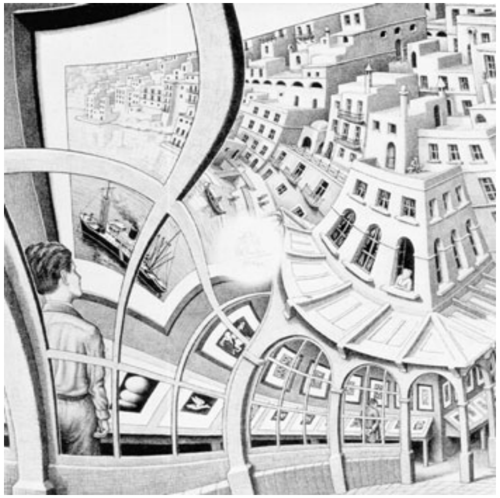
It is difficult to predict, especially the future. – N. Bohr

- 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.

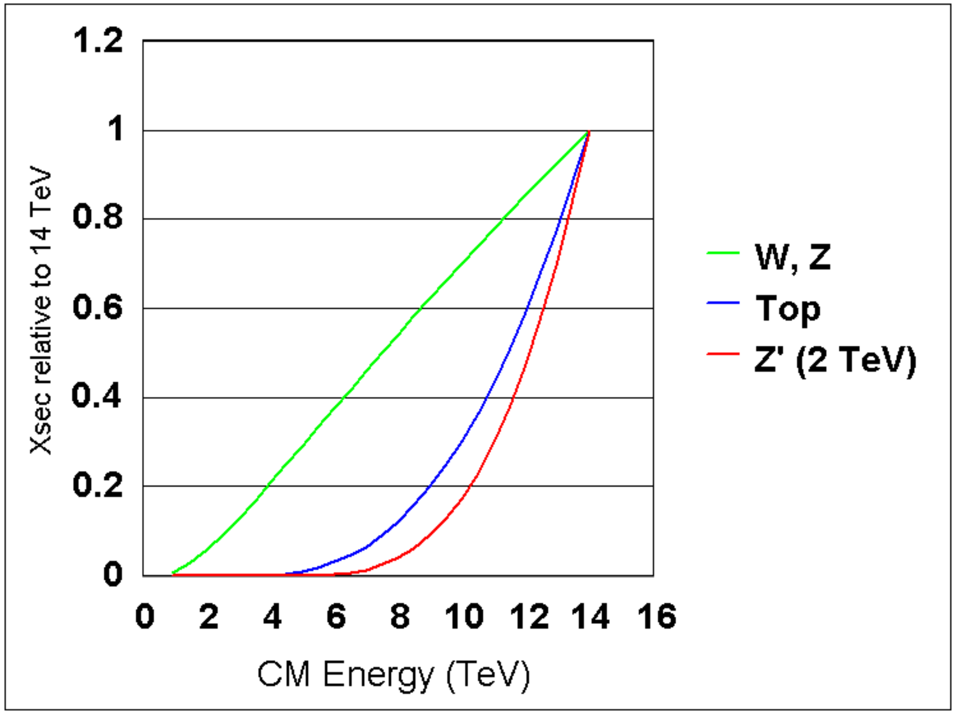
# Some Perspective

- 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

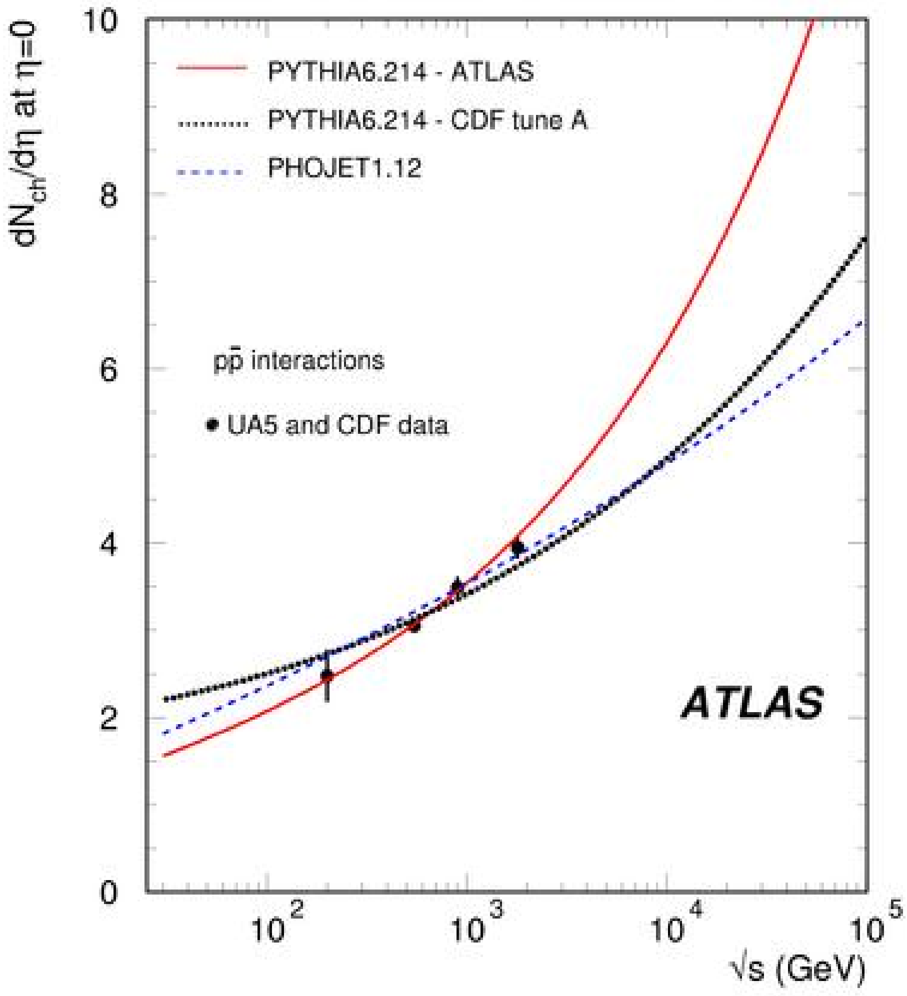
(output rate is $5 \times 10^{-6}$ of the input rate)

# 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.

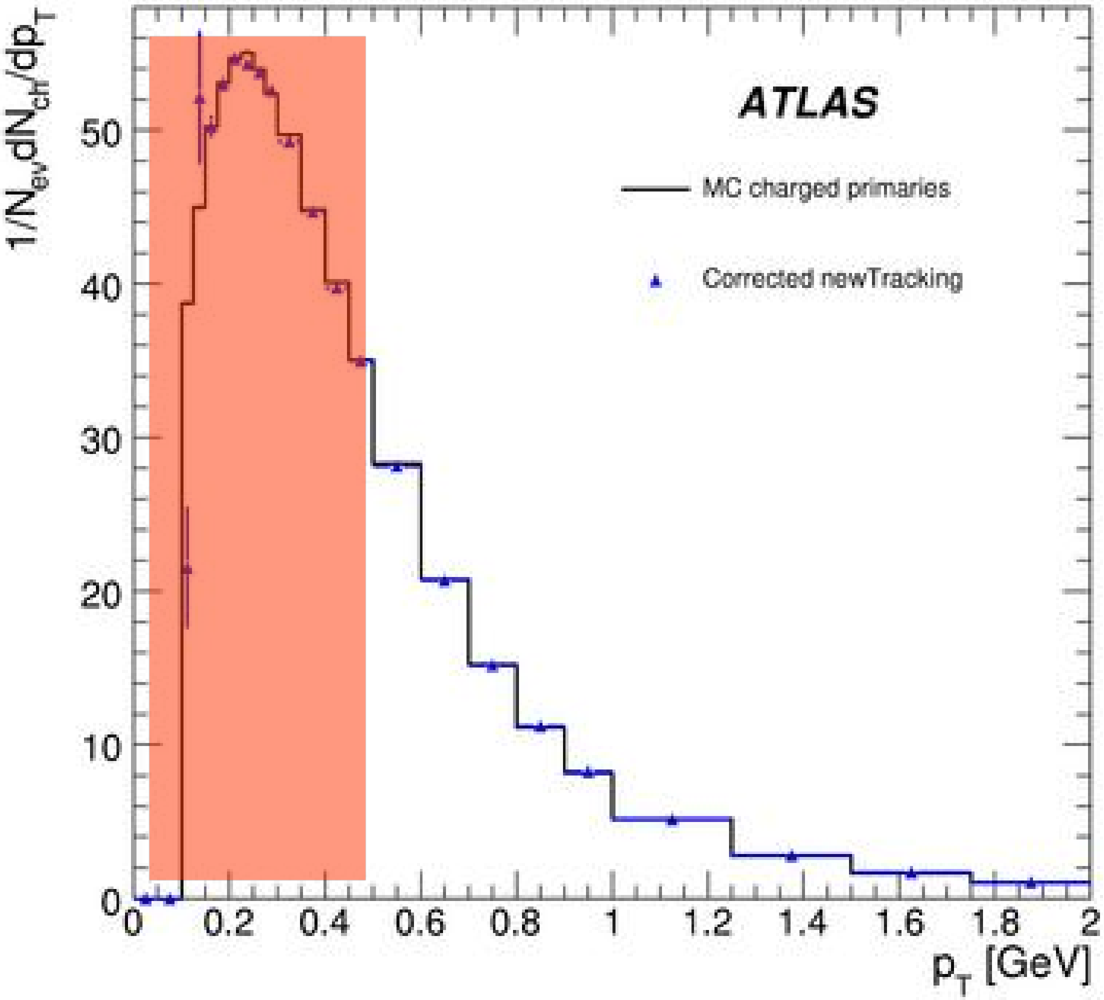
# *Minimum Bias*

- 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%

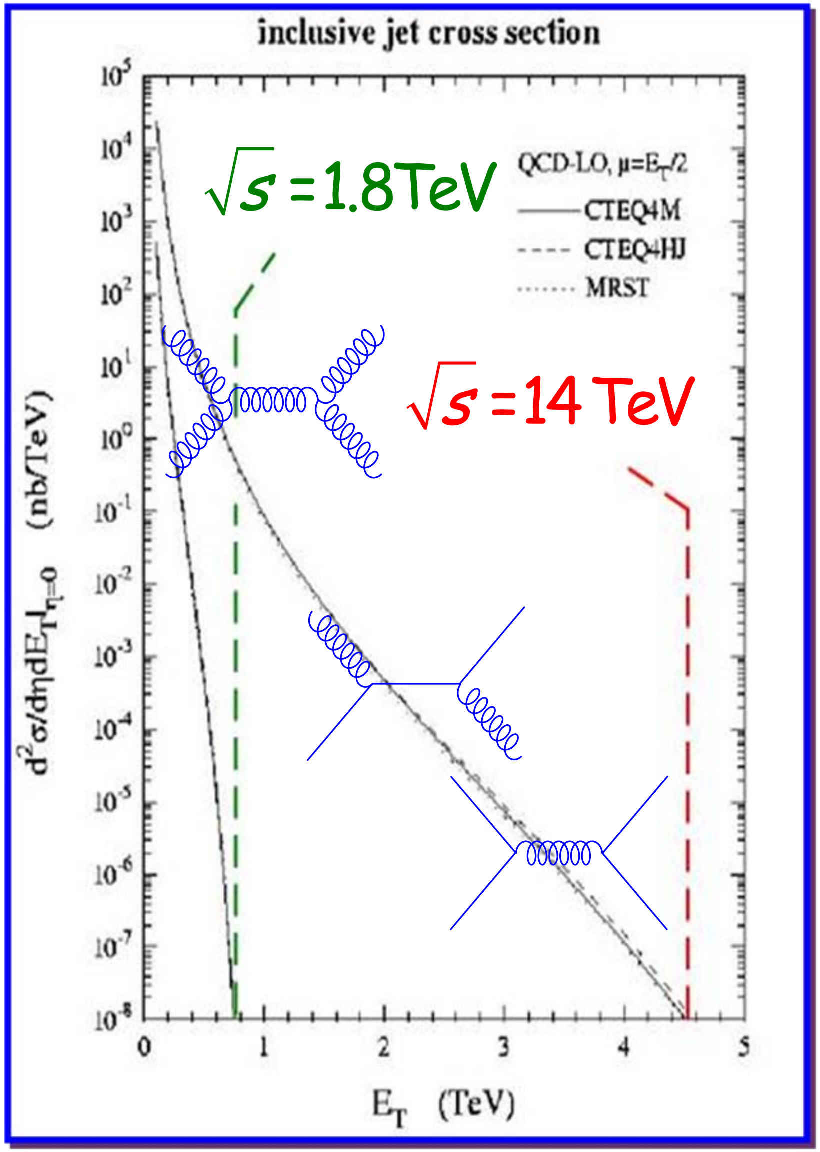
# Reconstructing Low $p_T$ Tracks




- 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?



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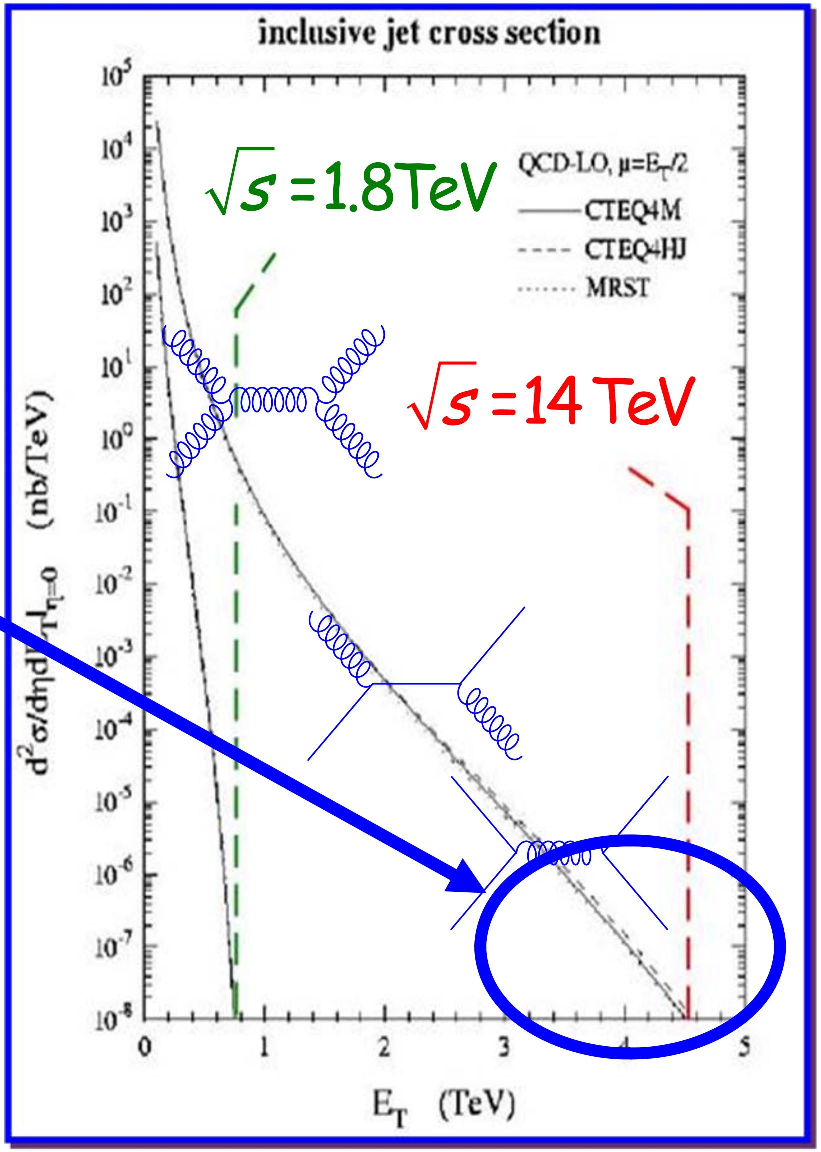
- An excess of events at large $E_T$ is a signal for new physics
  - Last time this happened, the new physics was an increase in the gluon distribution



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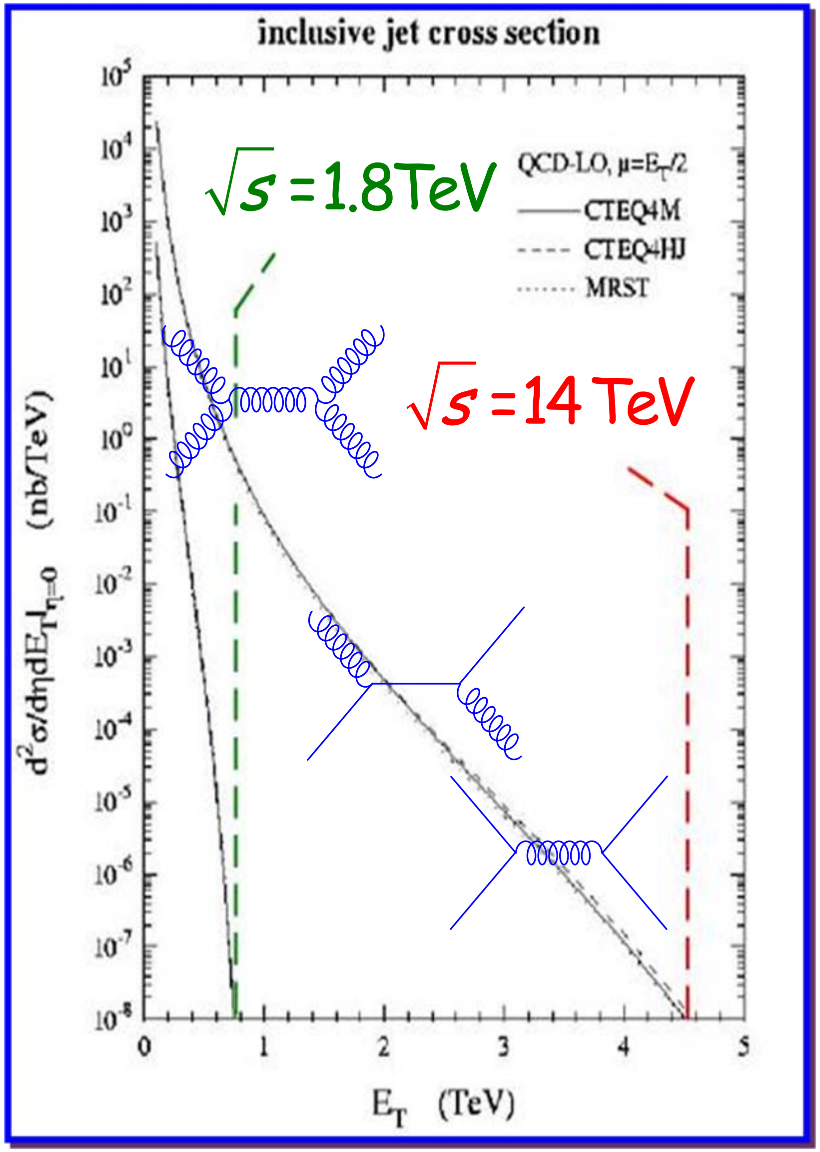
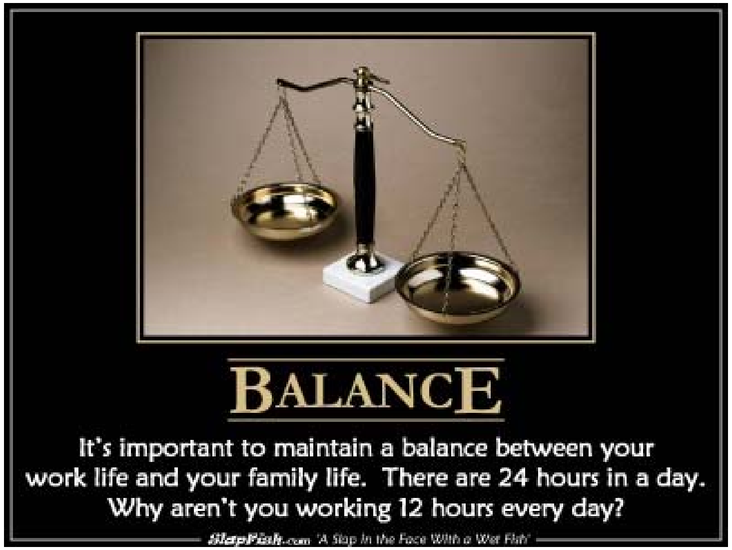
  - Last time this happened, the new physics was an increase in the gluon distribution
- Understanding the jet energy scale is a critical piece to this.



# Jet Energy Scale



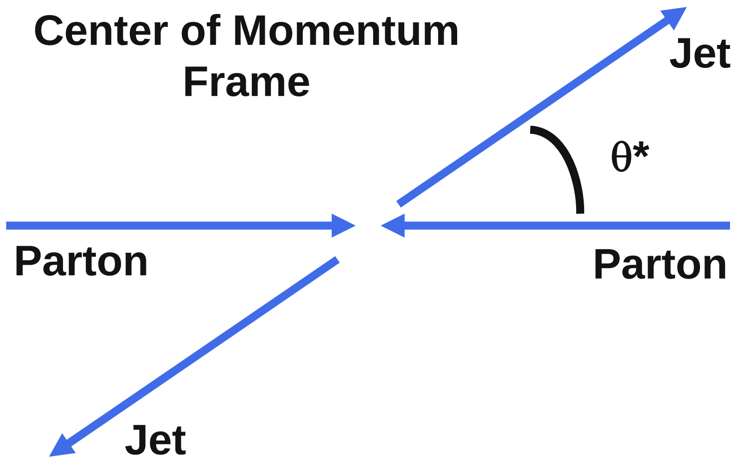

- Jet-jet balancing
  - Sets the relative scale, but not the absolute scale
  - Even without radiation, dijets shouldn't necessarily balance
    - *Because the spectrum falls steeply with $E_T$, there is a resolution/scale bias*
    - *Jets with a worse resolution are biased high*
- Photon-jet balancing
  - 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

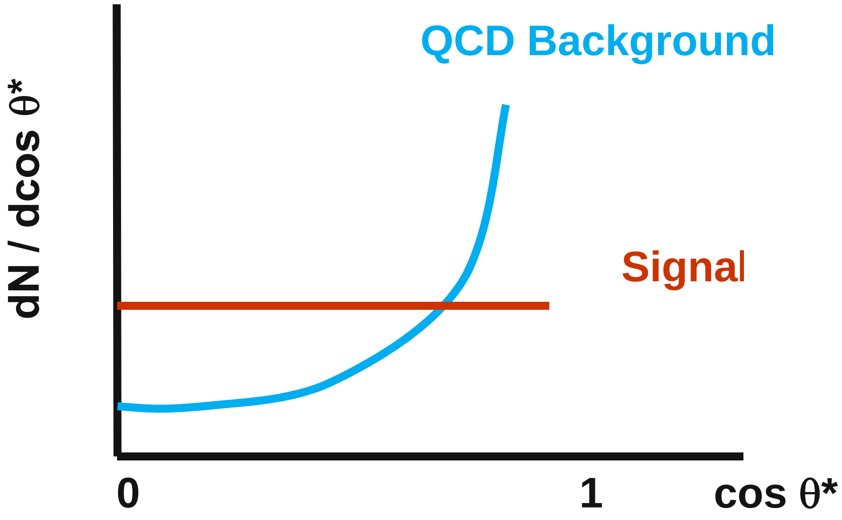
This is not insolvable. Neither is it trivial.

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

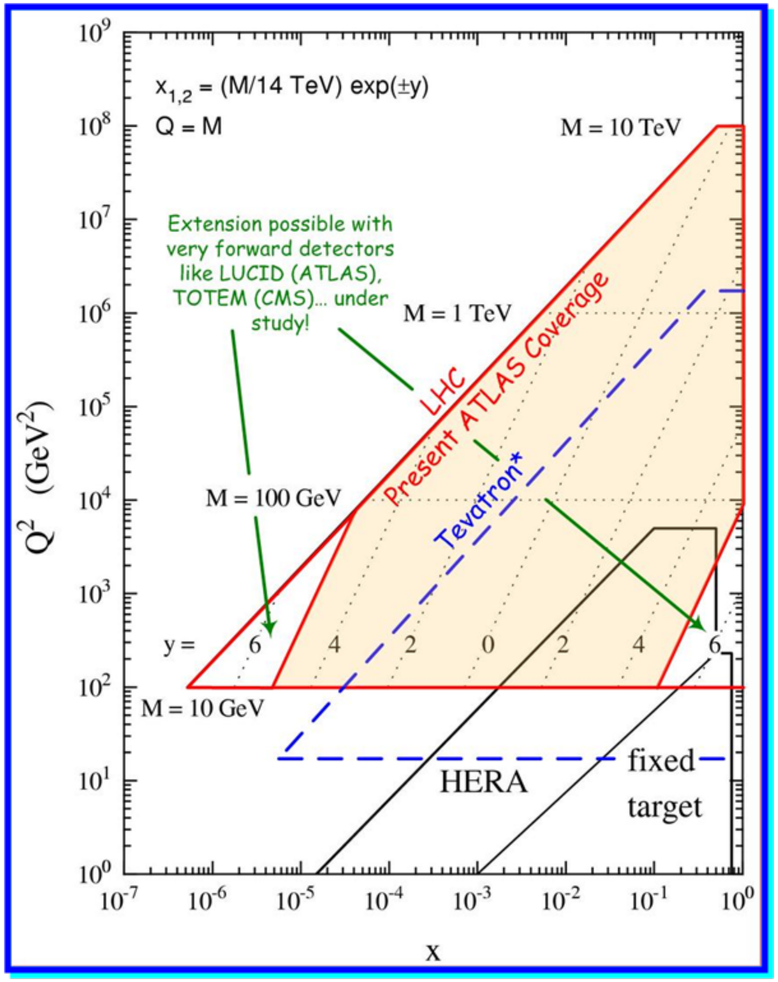



Diagrams: R. Harris, CMS

# 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

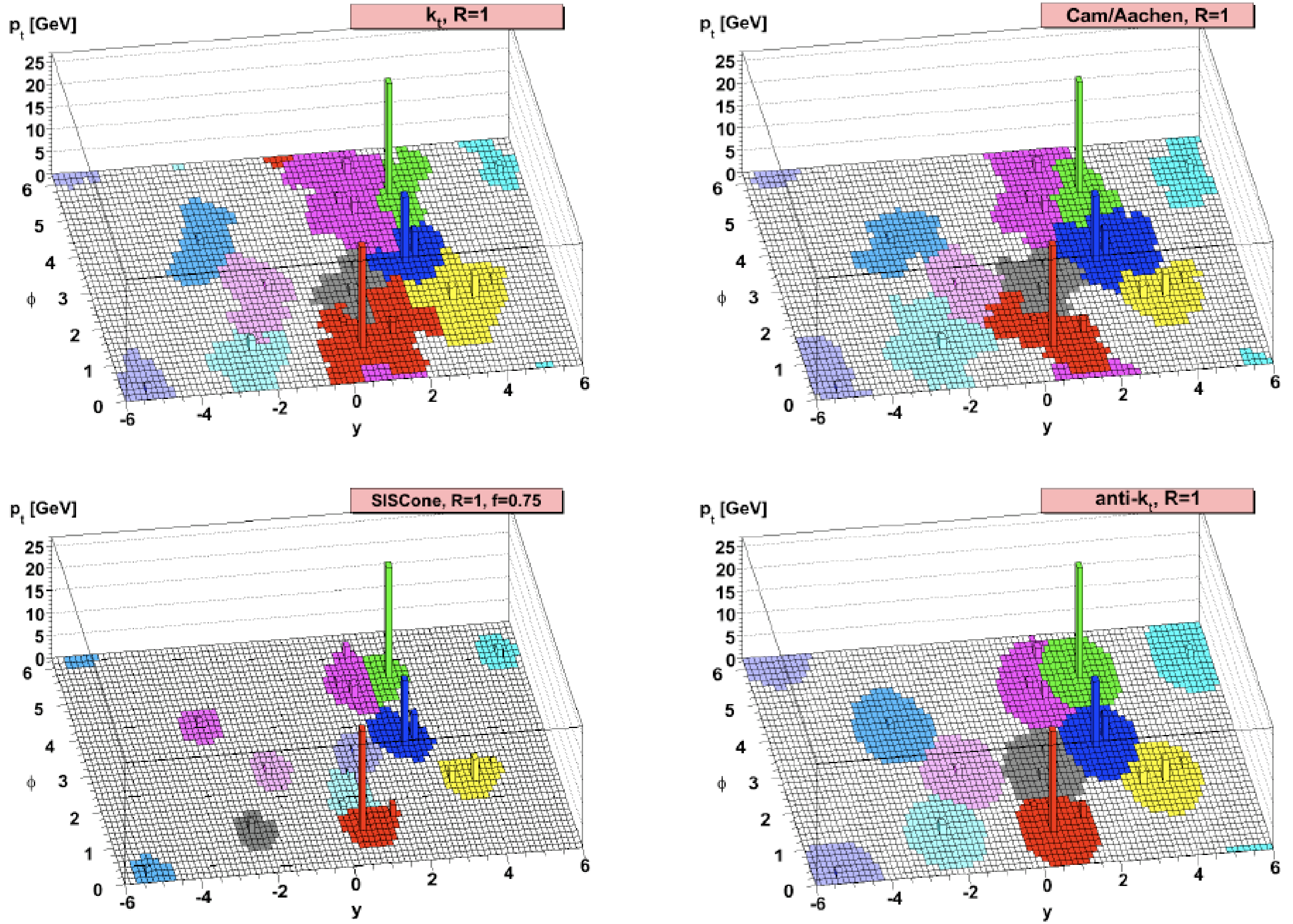
- "A jet is what a jet algorithm finds"

- 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.

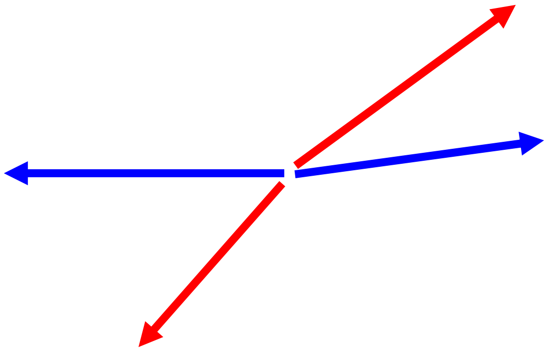
# *An Orphan Topic: Double Parton Scattering*

- Two independent partons in the proton scatter:

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

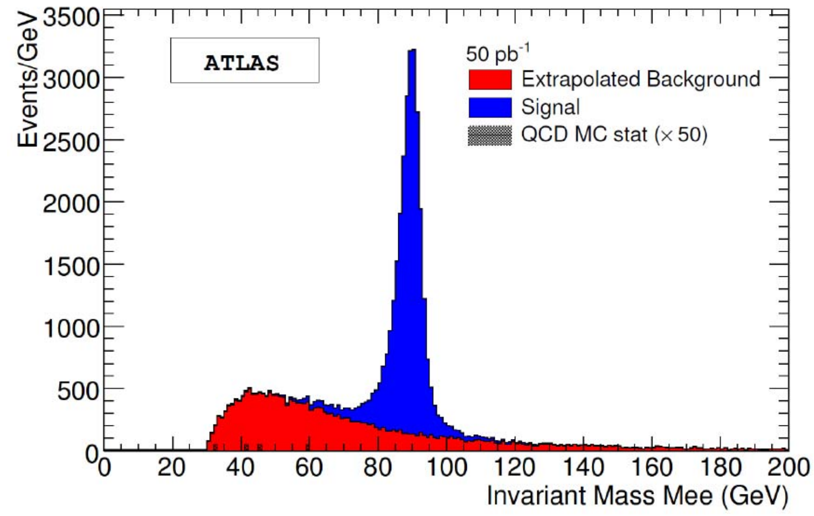
- Searches for complex signatures in the presence of QCD background often rely on the fact that decays of heavy particles are “spherical”, but QCD background is “correlated”
  – This breaks down in the case where part of the signature comes from a second scattering.
  – Probability is low, but needed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

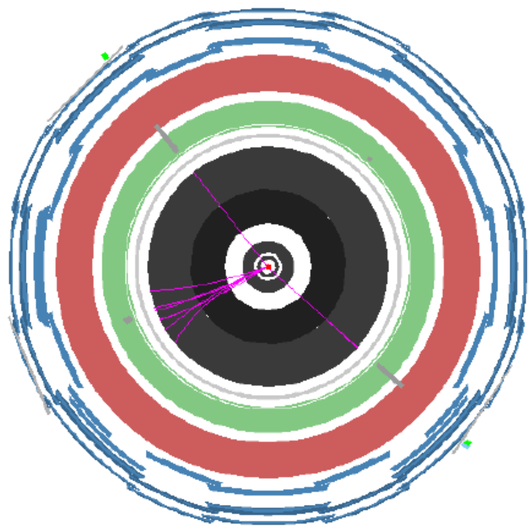
- We’re thinking about bbjj as a good signature
  – Large rate/large kinematic range
  – Relatively unambiguous which jets go with which other jets.



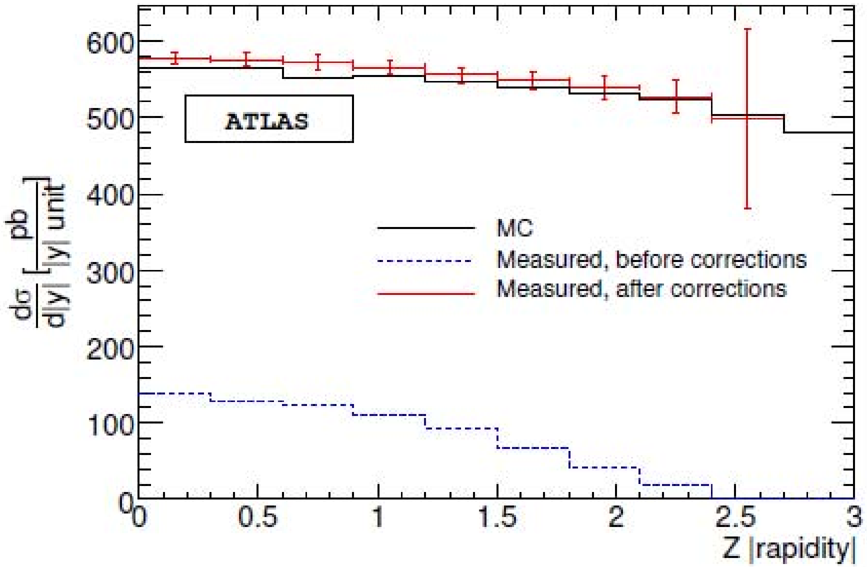
# *Turning to Leptons*

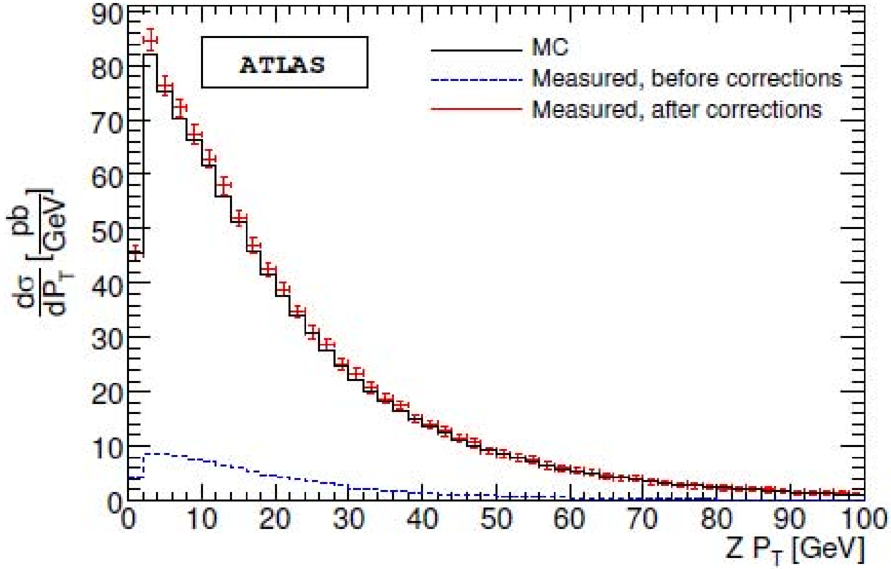
- Leptons have one huge advantage: Z → ll
- There are two leptons in the final state, but you only need one to trigger on.
  - You get two bites at the apple
  - One of the leptons is unbiased and can be used to measure the trigger & reconstruction efficiency
- This is not the only way to measure the 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*

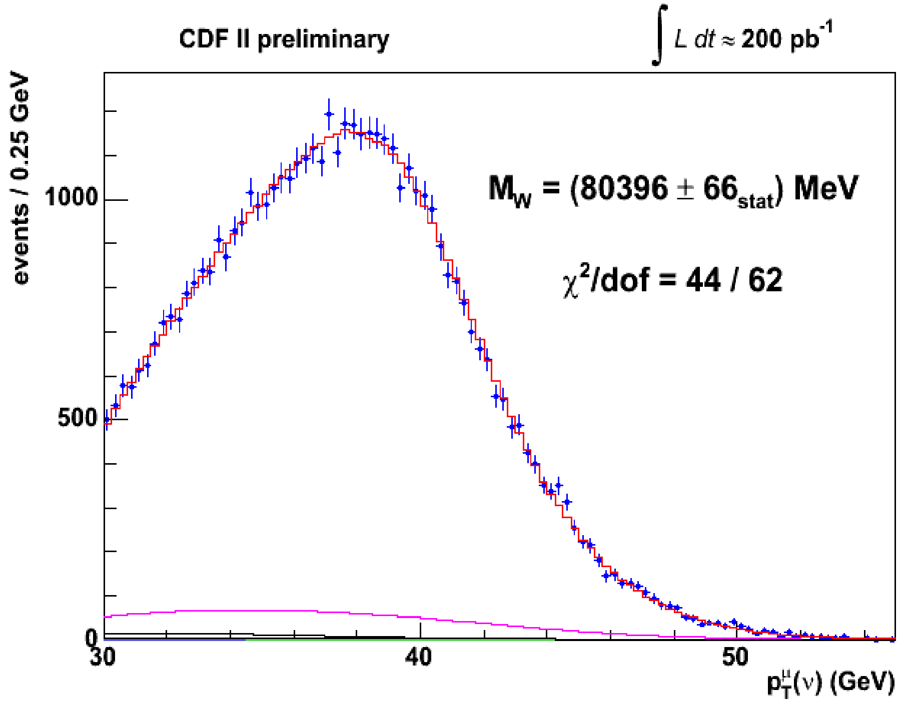



- Differential distributions can constrain PDF's
  - Roughly as much information in the shape as the magnitude
  - Early on, shape measurements will be much more reliable, as they do not rely on the absolute luminosity
- Note the fall off of the Z $p_T$ distribution
  - Has implications for Z-jet balancing

# *Something that Doesn't Fit Anywhere Else*

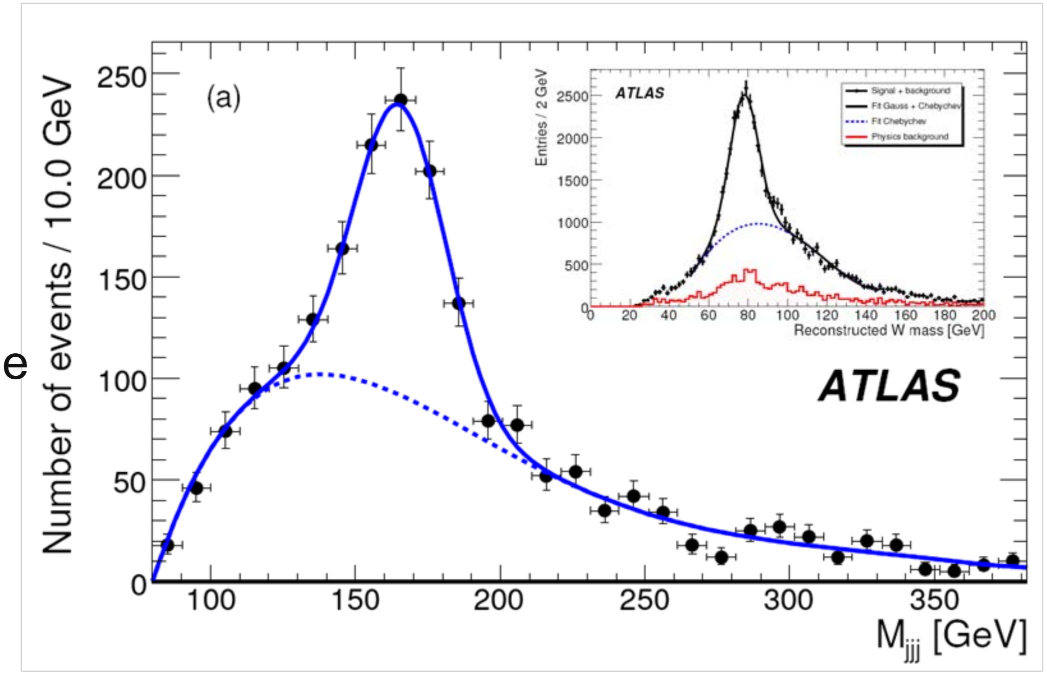
- It's possible to measure the W mass using Missing ET
- This isn't the best method
  - Typically, resolutions are ~20% worse than transverse mass




- 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



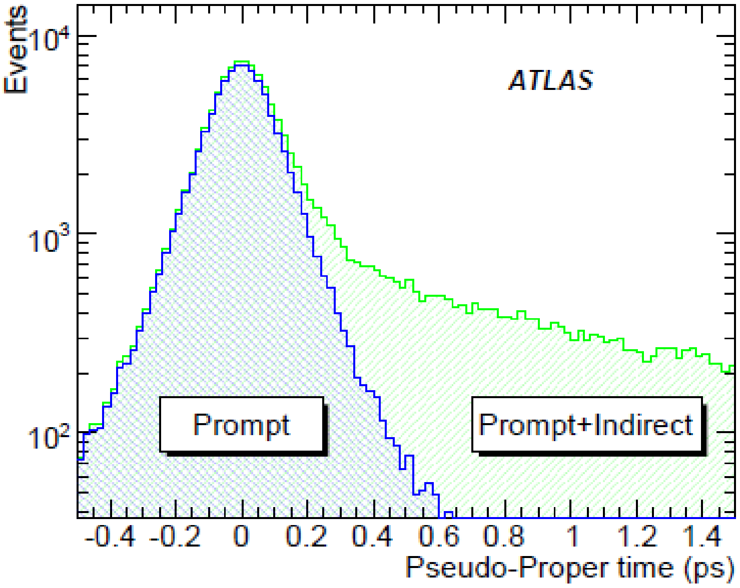

~100 $pb^{-1}$ at 14 TeV

- 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?<br>Maybe a few $pb^{-1}$ |
| Summer Conferences 2010 | Data up to March?<br>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