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ATLAS Trigger Strategies and Early Physics Perspectives

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My Goals For This Talk

- I was thinking of subtitling the talk "Why we won't be writing a SUSY discovery paper ten minutes after first collisions".
- My target audience is the "interested phenomenologist"
- I hope to share some of what needs to happen in the first year to make ATLAS a long-term success
  - Sometimes this is not so sexy or exciting
  - But it is important

Year One (2009-2010) Running Conditions

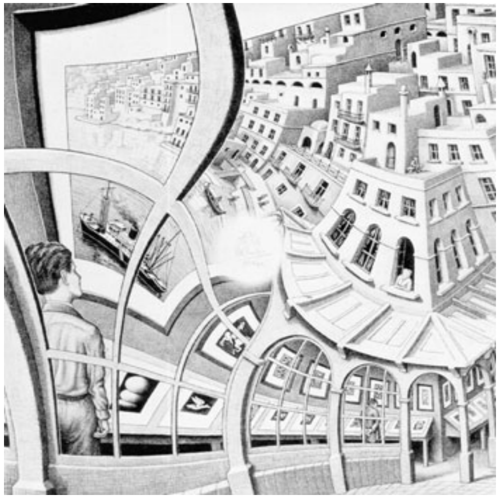
It is difficult to predict, especially the future. – N. Bohr

- 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
- 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.

See T. Wengler slides for more details

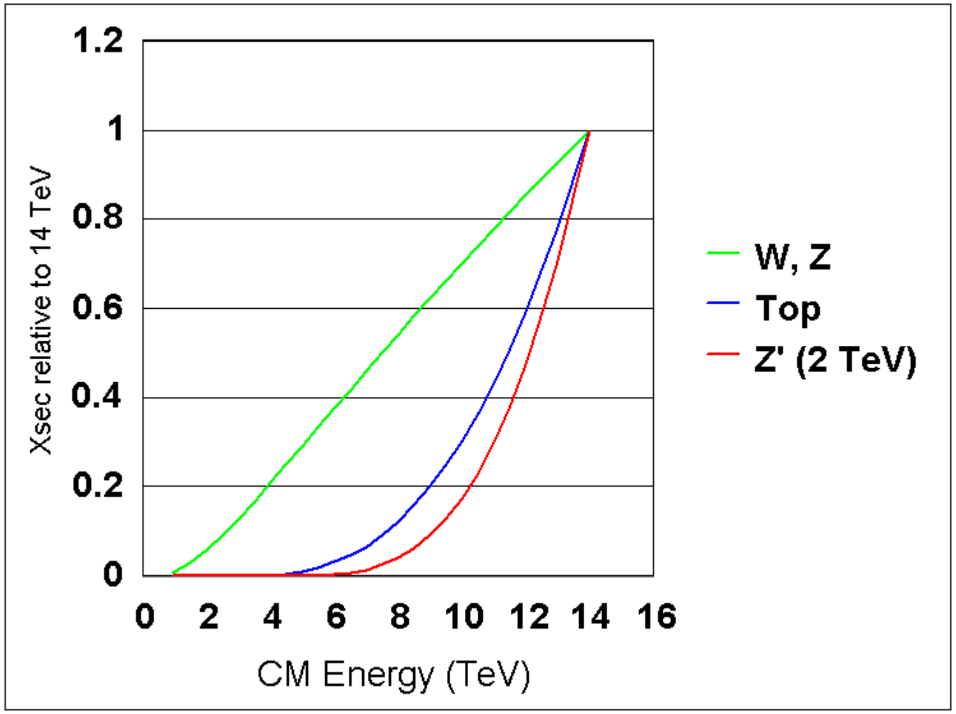
Some Perspective



- 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.



ATLAS' Key Tasks For 2009-2010

- Commission and Understand the Detector
  - See T. Wengler's talk
- 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.

ATLAS Trigger: the Problem

- 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

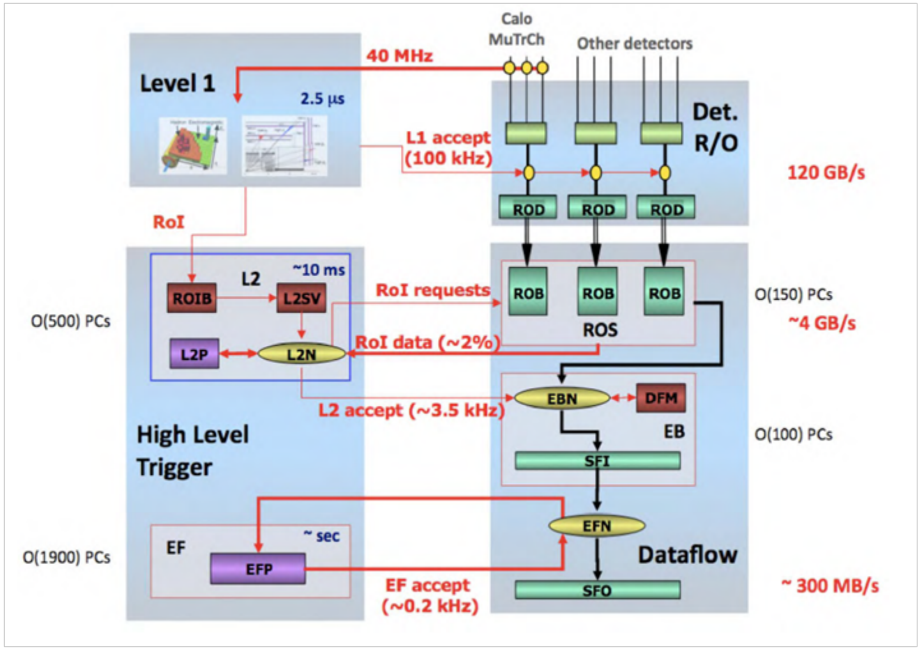
(output rate is 5×10^{-6} of the input rate)

The ATLAS Trigger

- Level One
  - Hardware Based
  - 75 kHz output (→ 100 KHz)
  - Factor of ~1000 rejection
- Level Two
  - Software Based
  - 10 ms per event
  - Factor of ~100 rejection
- Event Filter
  - Software Based
  - ~1 s per event
  - Factor of ~5 rejection

Collectively, the High Level Trigger

200 Hz to Tape



Combining this with the luminosity estimate, one concludes:

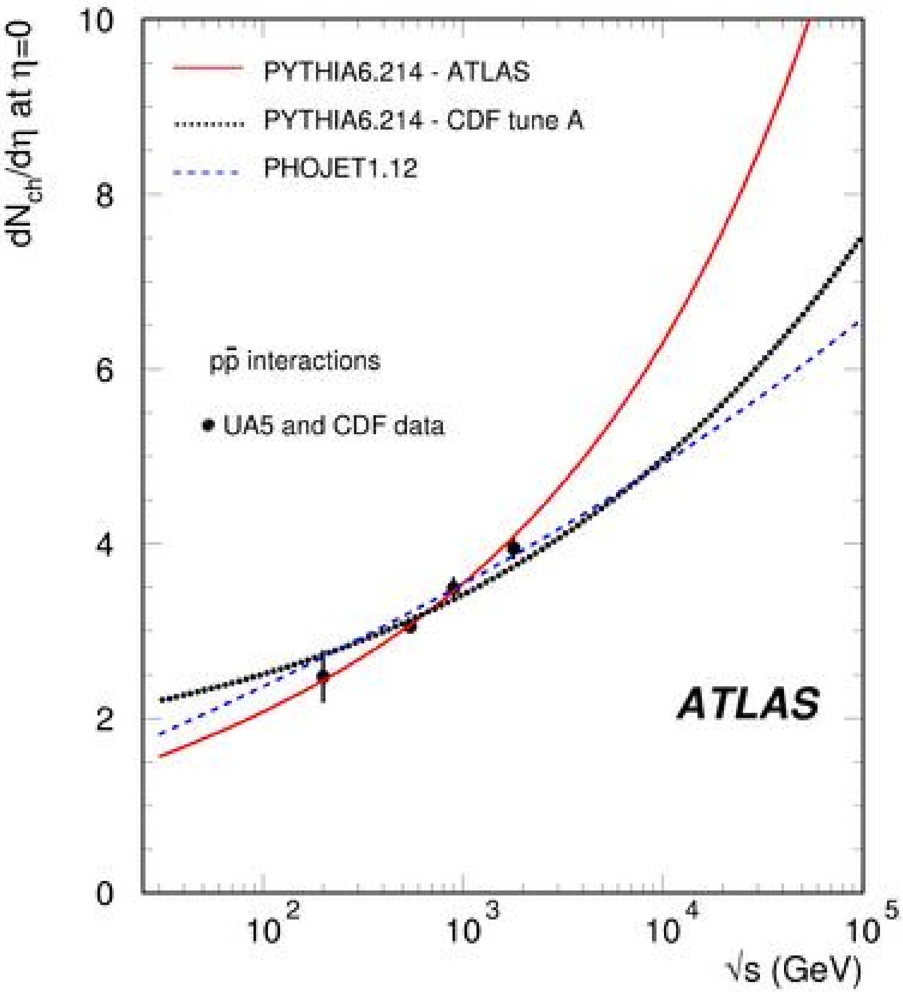
1. Level One *must* work (by 5 x 10^{29})
2. Either L2 or the EF *must* work.

It's highly desirable to have all three levels commissioned and working.

Minimum Bias

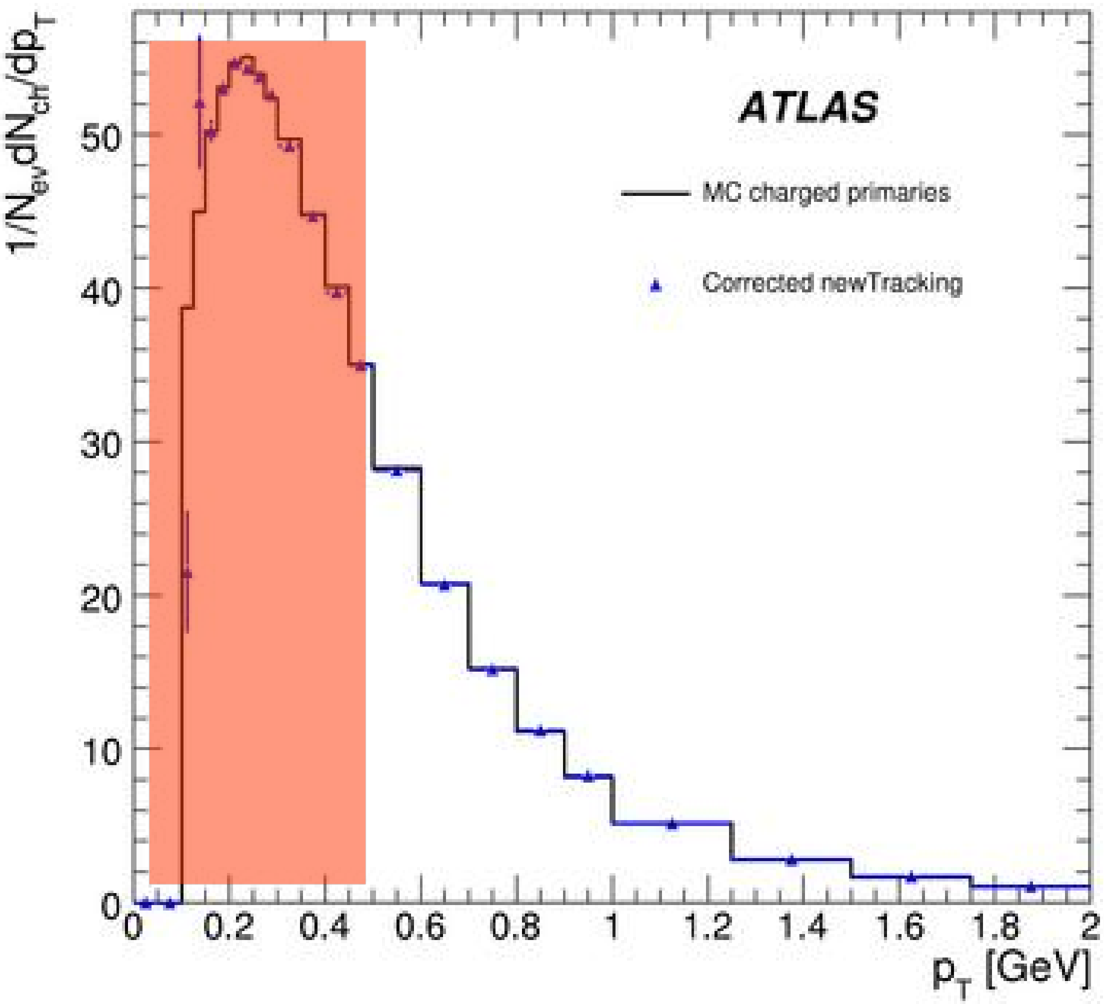
- These are the events that are part of the million, not (necessarily) the five.
- Even if you aren't a fan of soft QCD, these events are extremely important to ATLAS
  - We need to understand pileup
  - These are exactly the events that pile-up.
- The trickiest part of this measurement is the part that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

(See P. Behera's talk)



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.

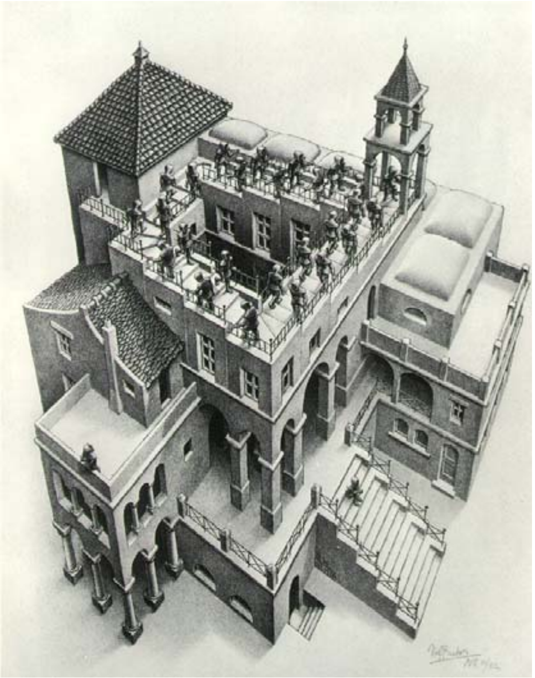
Commissioning Level One

- "If Level One buys a factor ~1000 reduction, and is good to 10^{34}, can't we live without it up to 10^{31}?"
  - No. At 10^{34}, there are 25 interactions per crossing.
  - We need Level One in cutting mode above ~5 x 10^{29} or so
    - *Assumes we use the HLT*
    - *If we don't, this number is more like 10^{27}*

- If we run Level One in "tagging" mode, we get very few events
  - 200 Hz means one event that should have passed the trigger every 5 seconds
  - Having ~50 Level One menu items means one event that should have passed *per trigger* every 5 *minutes*.
  - A 1% efficiency measurement takes 50,000 minutes: half the run

- We need to commission Level One in stages:
  - Instead of a factor of 1000, do this as 30 x 30
  - One stage takes you from minimum bias to (e.g.) low p_T leptons
  - The second stage takes you from low p_T leptons to high p_T leptons

Commissioning Steps



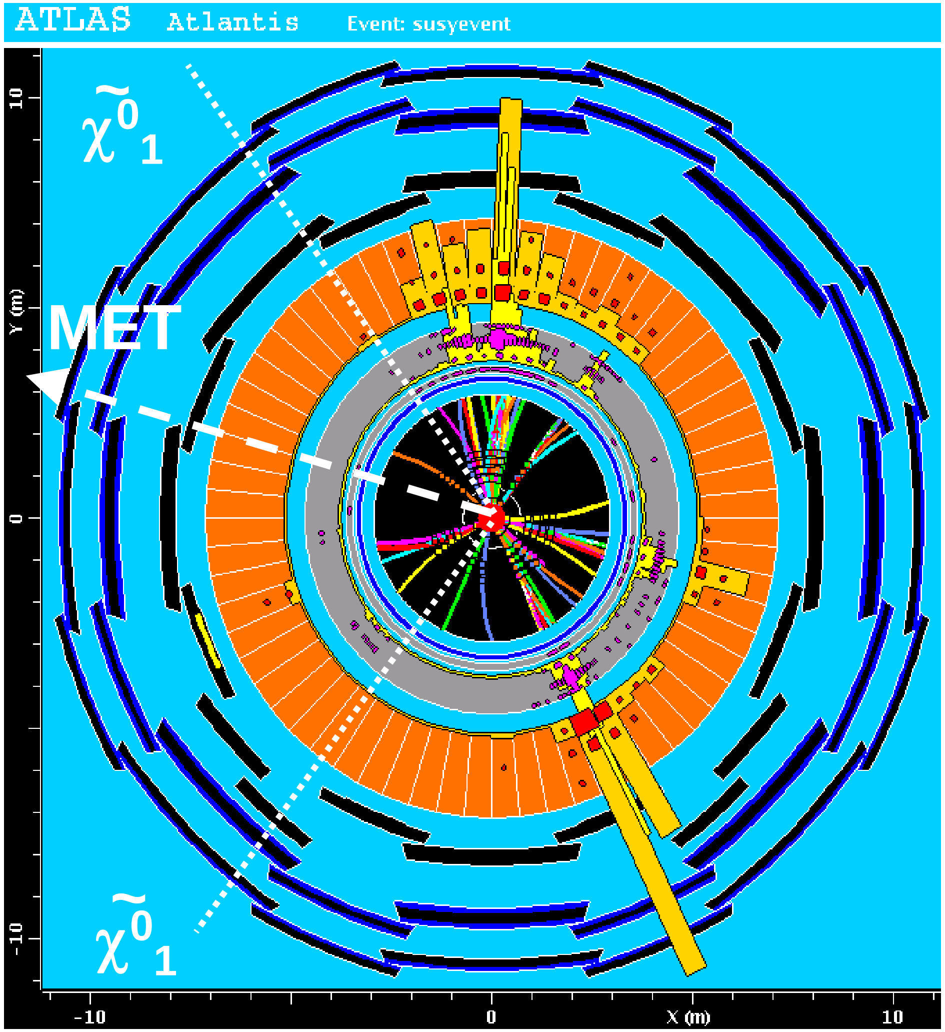
- Start with a beam pickup trigger
  - Trigger on the right crossing
- Use that to get the minimum bias trigger scintillators understood and in the trigger
- Then use the minimum bias events to commission a low-threshold Level One
  - Select the ~1% of events with a hard scatter
- Use those events to commission the standard Level One menu
- Bring in the HLT (Level Two and Event Filter) in tagging mode
- Finally, cut events based on the HLT.

Repeat as necessary.

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 Florian Ahles' talk

Early Thoughts on SUSY

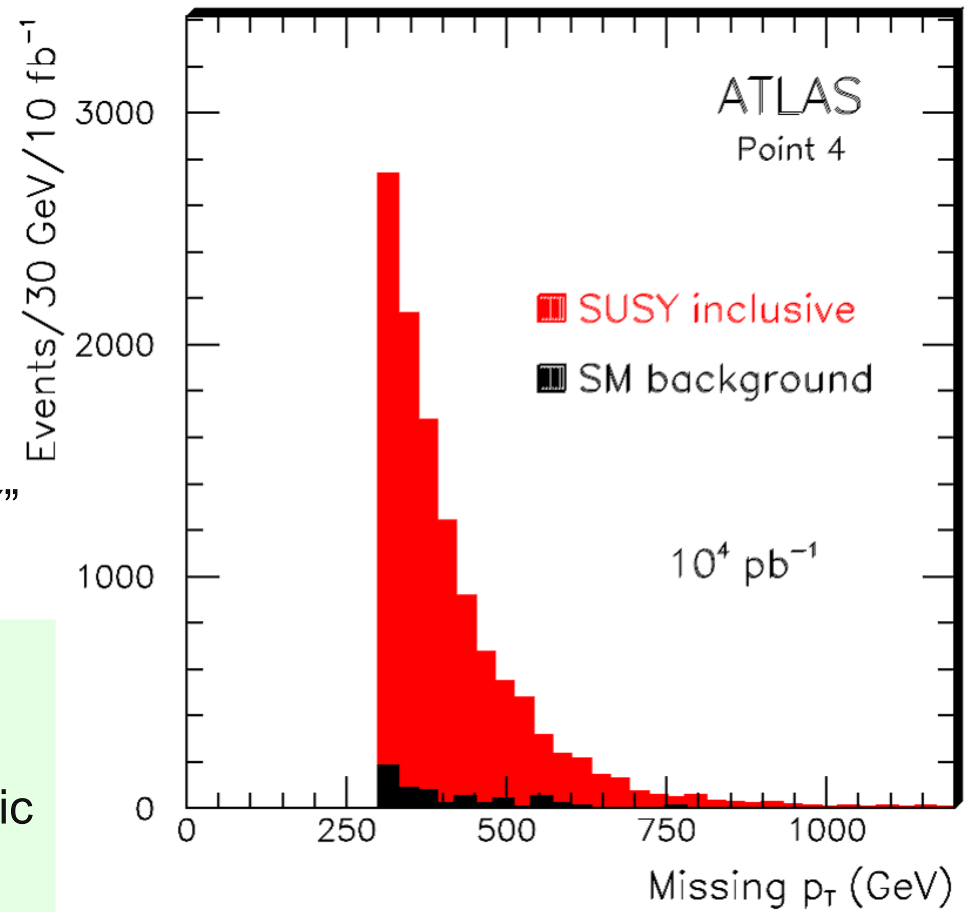
- There was a time when a SUSY discovery would be "easy"
  - Just plot Missing E_T and you have it!

- "The background to SUSY is SUSY"

We now know things are not that simple:

A low luminosity run has less kinematic reach in missing E_T. So does a low energy run. (These are both simply statements about partonic luminosities):

Irrespective of model, this means things are harder in 2009 than we thought 13 years ago.

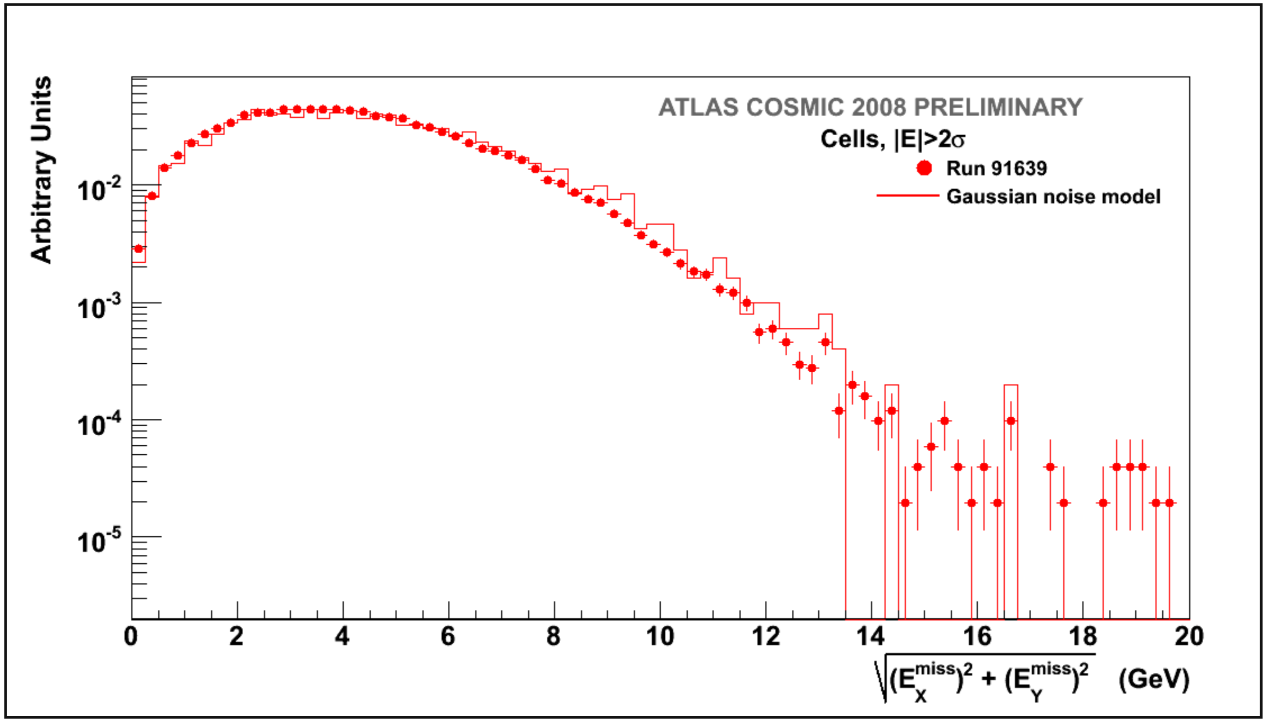


A 1996 plot on ATLAS' sensitivity to one point of SUSY parameter space.

Note the large S/B.

Fake Missing Energy

See Dimitris Varouchas' talk



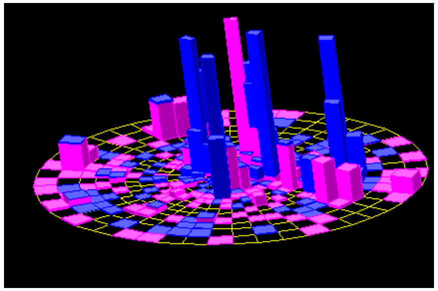
- One source of fake missing E_T is purely instrumental.
  - The above plot (from cosmic rays) shows that it is quite small
  - Perhaps more importantly, we're able to model the detector noise

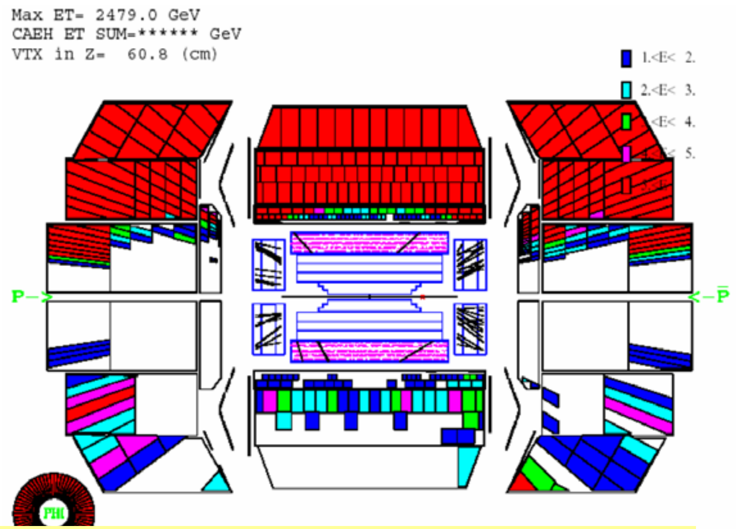
Our biggest issue will not be instrumental – it will be from real energy in ATLAS

Missing E_T In Data

- History tells us…
  - Find and remove the largest source of missing E_T and then…
  - …you are able to see the second largest source.

- Some things that have affected Tevatron experiments
  - Main ring splash
  - Flying wires
  - “The Ring of Fire”
  - Crack seeking leptons & jets
  - Cosmic rays
  - Texas towers





ATLAS will surely have it’s own list, and we will, like all experiments, have to work down it, checking off items one by one.

Triggering on Missing E_T

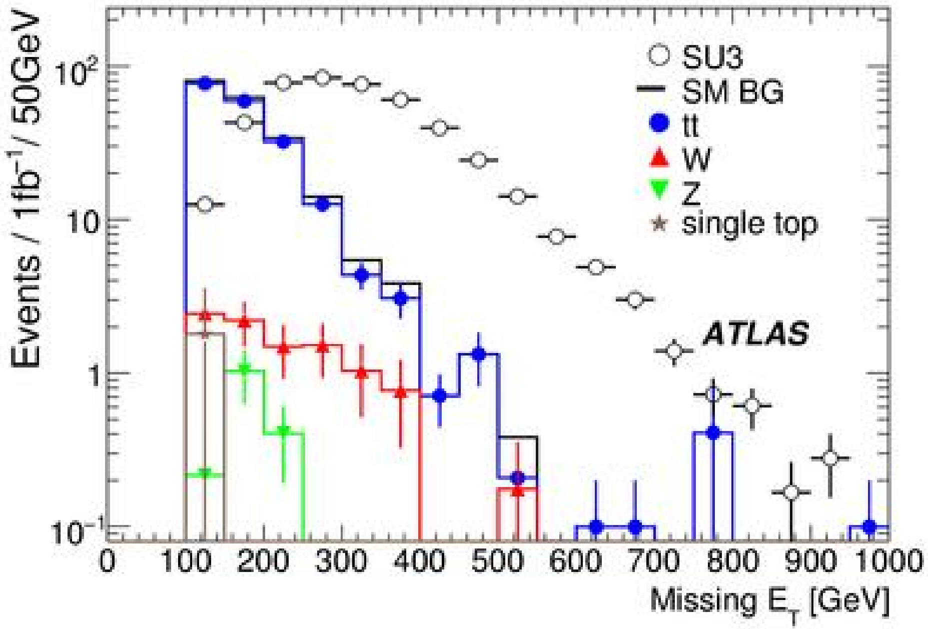
- Of course ATLAS has an inclusive Missing E_T trigger.
  - We want the threshold as low as possible
  - Perhaps 40 GeV, perhaps higher

- All we can do now is worry about resolution and muon corrections.
  - The trigger works based on calorimetry
  - Muons don't deposit (much) energy in the calorimeter
    - *Note: not so simple to add it back in at L2, as we have only the trigger level information. Things are better at the Event Filter.*

- Once we get data, the game changes
  - We need to find the characteristics of fake missing E_T events and cut against them.
  - The job of the trigger becomes to ***reject background***.

So What Is An Experimenter To Do?

- What do we always do?
  - Fall back on leptons
  - A ~20 GeV threshold seems achievable
- If we *restrict ourselves to models with leptonic signatures*…
  - The triggering issue goes away
  - We now have a check on the
  - Offline MET
    - *Is there a correlation between MET and leptons?*
- Sensitivity is comparable to the Tevatron
  - But not much more - in early data



Expect (in general) searches with leptons to be further along than searches without.

See Gemma Woden’s talk on electron id

Another Rule of Thumb

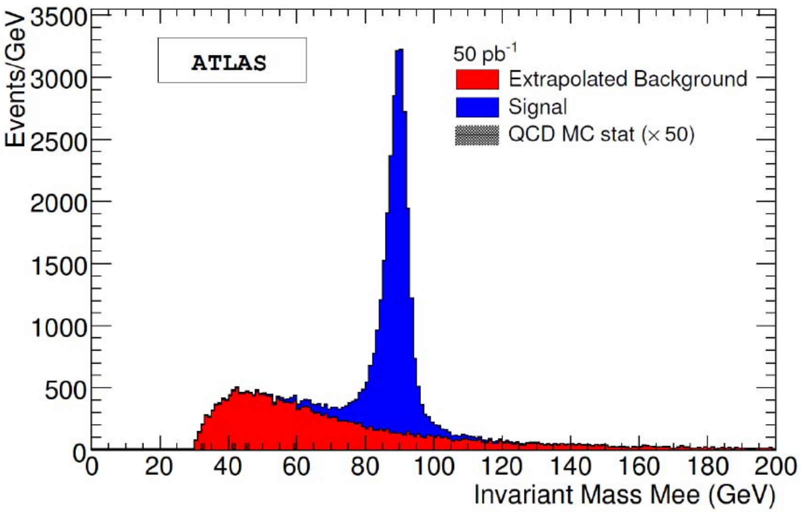
ATLAS sensitivity with a few 100 pb^{-1} of data corresponds to Tevatron sensitivity with a few fb^{-1} of data.

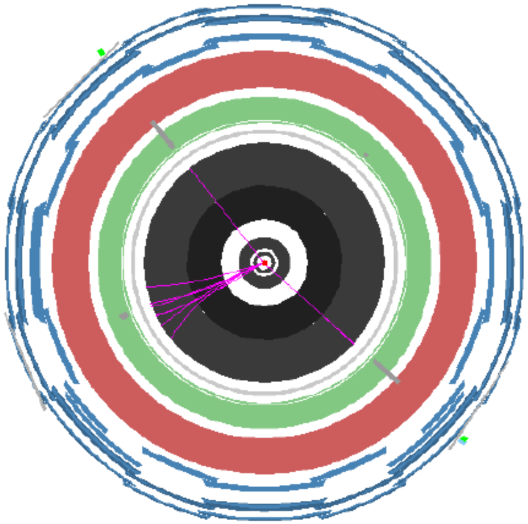
This is not very profound – it's another statement on parton densities and partonic luminosity

Of course this varies from analysis to analysis. The higher the mass of the object you are producing, the more center of mass helps you. The lower, the more luminosity helps you.

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 efficiency
- This is not the only way to measure the trigger 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

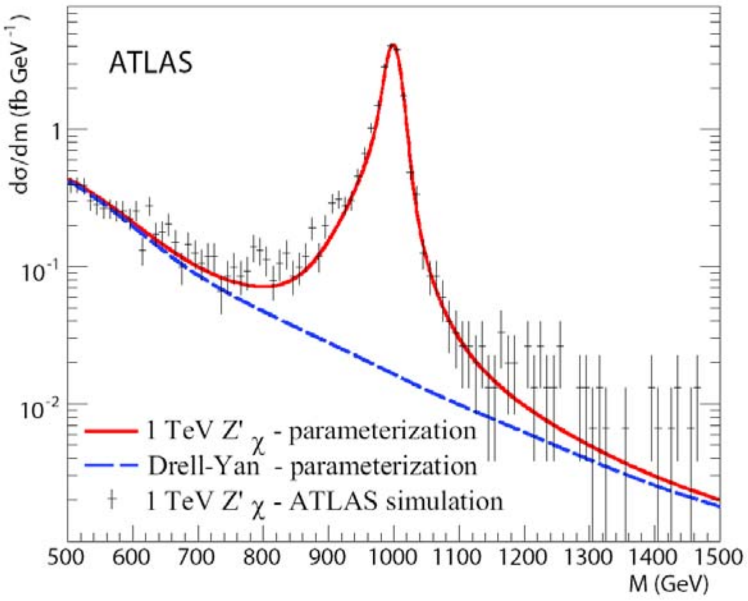




See Markus Bendel's talk for more details

Other Things One Can Do With Leptons

- Obviously one can search for new particles
  - W' and Z' are obvious examples

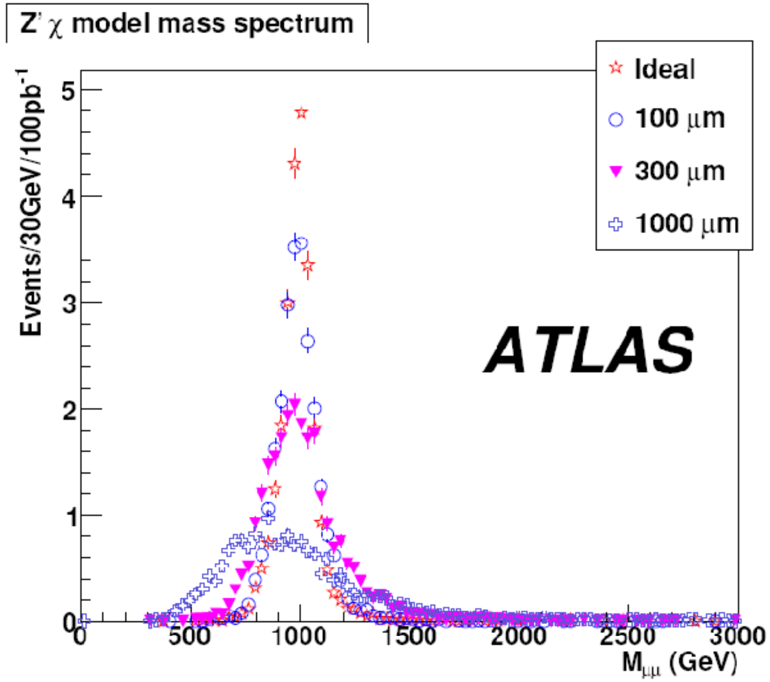


- We expect limits in the neighborhood of
  - 1.0-1.5 TeV for a Z'
  - A few 100 GeV higher for a W'
  - These assume sequential gauge bosons, not anything more exotic

- One can make all sorts of searches based on these combinations
  - Photon + muon = excited lepton
  - Jet + electron = leptoquark
  - And so on and so on…

See S. Ferrag's talk

Two Complications



- Sensitivity in the real world is a strong function of detector understanding
  - The plot shows the effect of alignment on the resolution of the Z'
  - Reaching our Year One sensitivity will take some time
- Suppose you expect a background of 0.2 events and see 0. Or 1.
  - You know how to calculate a limit.
  - Instead, suppose you see 10.
  - You've discovered something – but did you discover new physics?
    - *Or is there a problem with backgrounds?*

Rightly or wrongly, it's easier to set a limit than to make a discovery.

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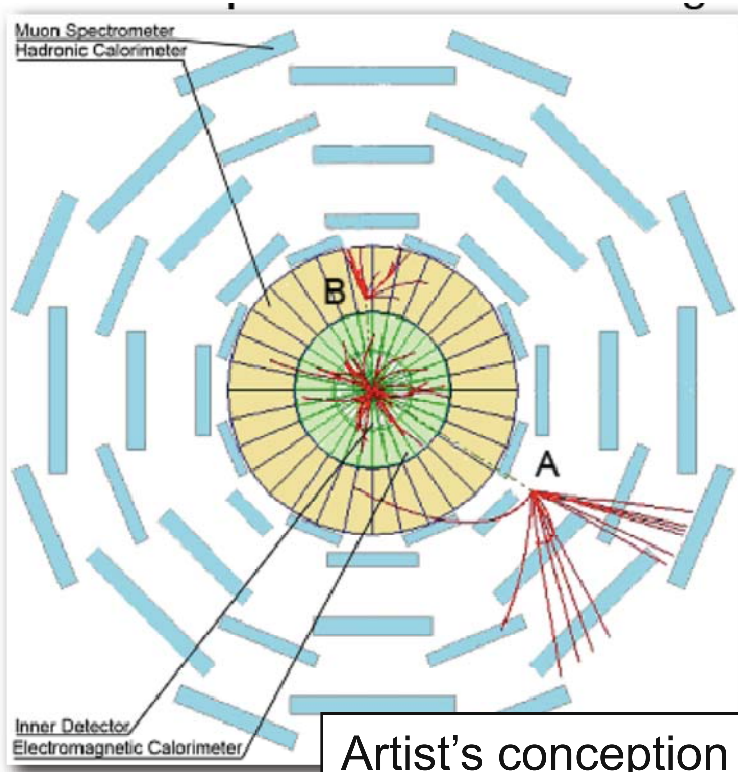
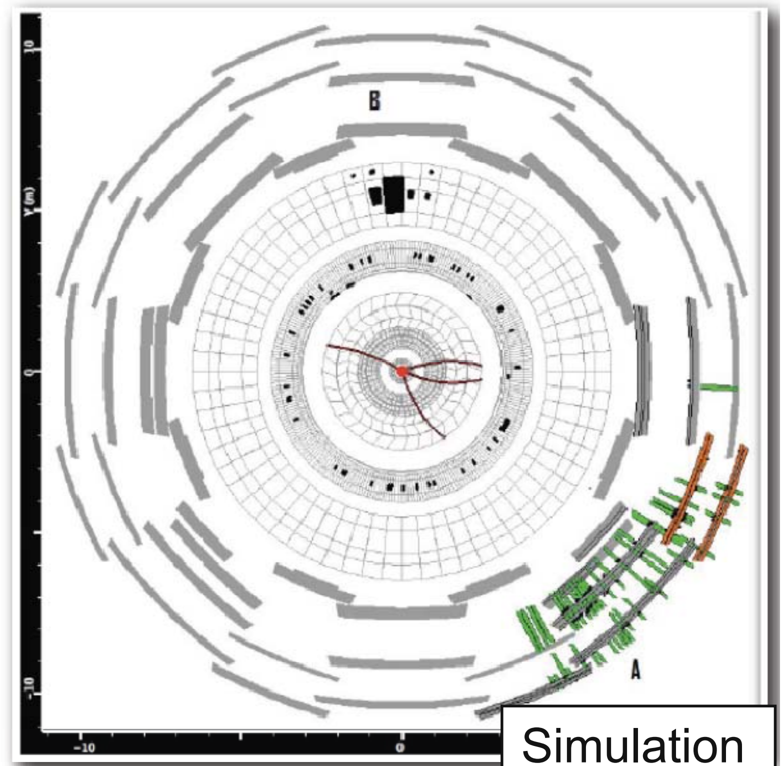
What About Surprises?

A. Policicchio, IFAE 2009



Artist's conception

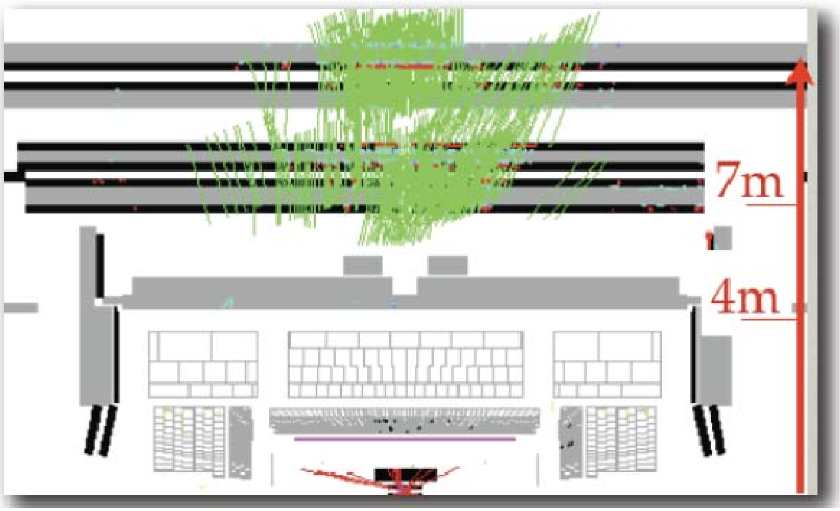


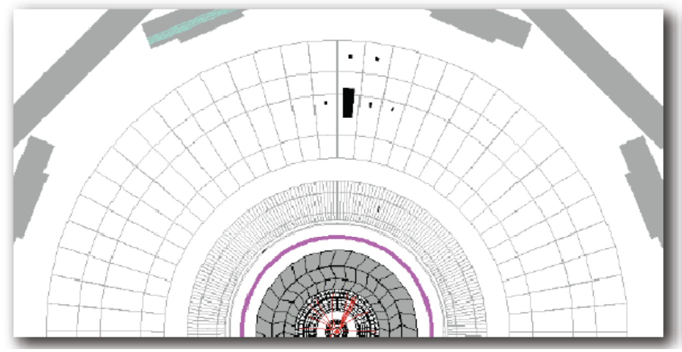
Simulation

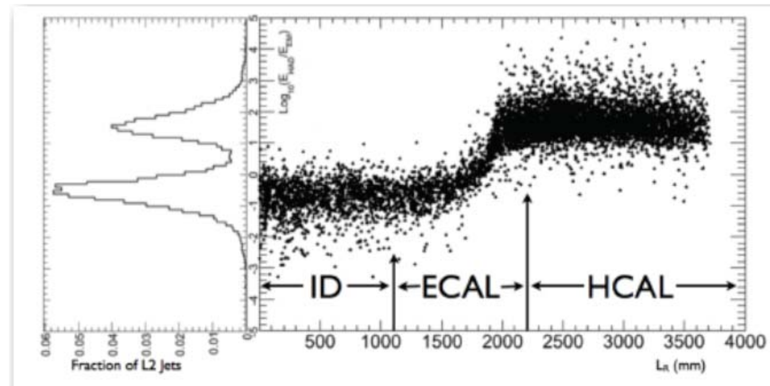
- Models predict particles with lifetimes of meters (RPV SUSY, Hidden Valley)
- ATLAS was designed long before these models were popular
  - If we can't trigger on them, we can't discover them!

There Is Hope…

These events look pretty spectacular.



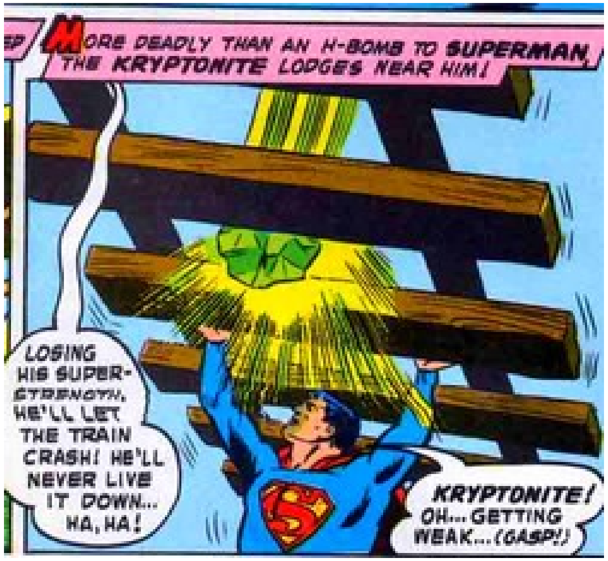




- Events with many, many “muons” are inherently interesting, and triggerable
  – Interesting no matter what the source (even background at first)

- Events with most of the energy in a single calorimeter are triggerable, at least at the HLT
  – Could be tricky – this is the same signature for noise.

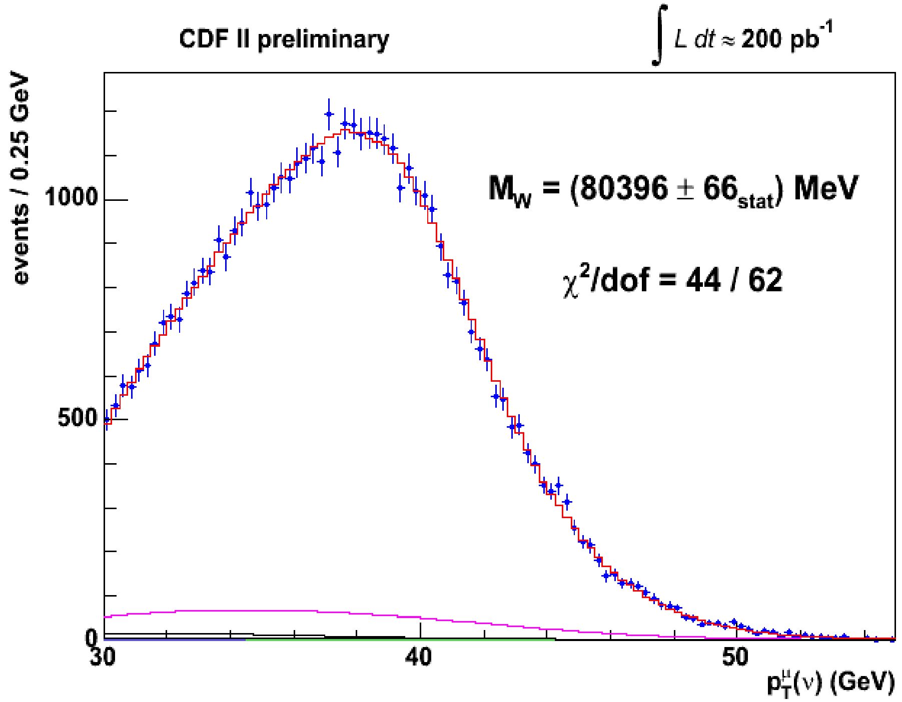
Why Am I Telling You This?



- Hidden Valley/RPV SUSY illustrates the strengths and the weaknesses of the trigger.
- We have the ability to trigger on event topologies unimagined when the trigger was designed
- However, we don’t have the sensitivity we would if we were a dedicated experiment.
  - Level One is the most troublesome.
  - It’s hardware, and relatively inflexible.
  - It helps to have event features similar to objects we expect to trigger on:
    - *Electrons, muons , photons and jets.*
- I could tell you a similar story for stopped R-hadrons, slow heavy particles, etc.

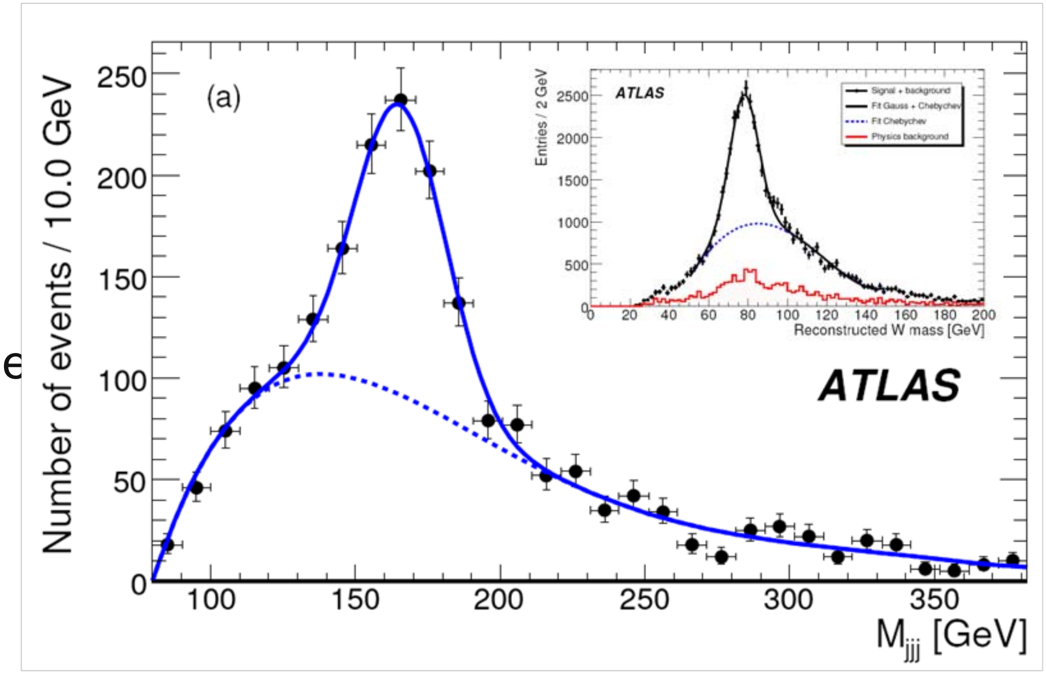
Something that Doesn't Fit Anywhere Else

- 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



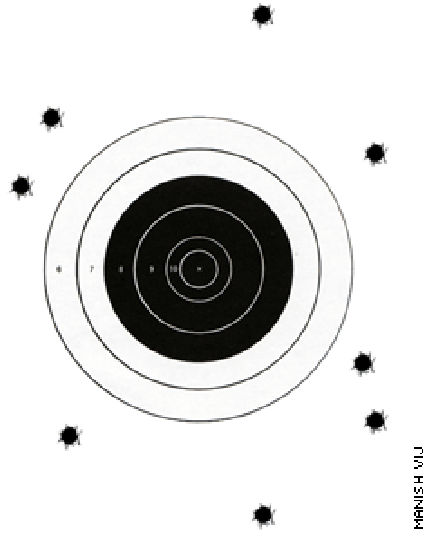
~100 pb^{-1} at 14 TeV

- 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
- 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

Two Things I Missed



See D. Price talk

- B-physics
  - Although the signatures are different, the fundamental issues parallel the high p_T program – getting the trigger working to the point where one can get a large sample of events to understand the detector.
  - Once that happens, one can think about making physics measurements
- Higgs
  - This analysis is complicated
  - Low luminosity and lowered energy doesn't help
  - I decided to focus on different examples
  - Again, the same themes hold for these searches
    - *Get the trigger working so you can…*
    - *Collect events to understand the detector, so you can then…*
    - *Do physics.*

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Summary

- ATLAS Tasks for this year are:
  - Commission and Understand the Detector
  - Commission and Understand the Trigger
  - Do some physics!

- We are well along the path to this – but there are many challenges.

- There is a complex interplay between the trigger and the physics
  - This is especially true during the commissioning period
  - What you can analyze depends on what you can trigger on.

- A 10 TeV run for a few 100 pb^{-1} is not a 14 TeV run for 100 fb^{-1}.
  - Nevertheless, this places ATLAS in a position to make competitive, world-class measurements.
    - *CMS could say the exact same thing.*

Thanks!

- Thanks to:
  - The organizers for inviting me
  - My ATLAS colleagues for their help in preparing this
  - D0 and CDF for pointing us in the right direction
  - CTEQ for making the PDF sets easily accessible