Title: Preparations for ATLAS Searches

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Abstract: TBA

BSM Physics at the LHC in 2010

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Perimeter Institute
October 2009

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Introduction

- I will focus on searches for new physics that can be done in the first year of running
  - With 7-10 TeV centre-of-mass energies
  - With 100-200 pb^{-1} of int. luminosity
- For early searches we will not yet have a "mature" understanding of the detector and backgrounds
  - Focus on analyses with simple topologies and/or analyses with low backgrounds and/or spectacular final states
  - We have developed data-driven techniques to understand and estimate backgrounds (rely less on MC -> MC will require time to tune)

Some General Comments

- LHC allows us to explore energy regime beyond that of the Tevatron at low integrated luminosities
  - Start of LHC run is different than start of Run II: in Run II there was nothing new to find or exclude with first 100 pb^{-1}
  - Low integrated luminosity at LHC opens up exploration of new high mass regime
- Most exotics results (hopefully not all!) will be limits on physics beyond the SM
  - Although less exciting than a discovery, first limits from ATLAS/CMS can (will!) be the best in the world
  - First limits will make the important statement that LHC has explored new territory beyond the previous energy frontier
  - We will start to reduce the existing new physics phenomenological phase space

Early LHC Exotic Analyses

Earliest Analyses

- W' resonance (assuming large missing Et tails under control)
- lljj resonance (Left-Right Symmetric models, leptoquarks)
- Black Holes and String Balls
- Dijet resonances
- Quark compositeness (possibly based on angular variables to reduce dependence on absolute jet energy scale)
- ee/μμ/eμ resonances (Z', Gravitons, technicolour) or contact interactions- may need a bit more luminosity
- Diphoton resonances

Early Analyses

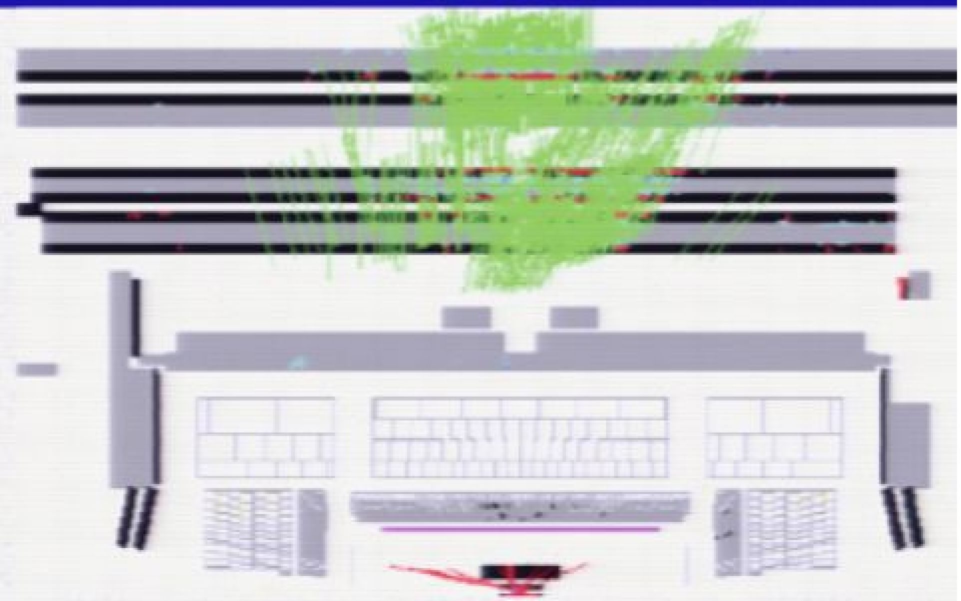
- Monojets (data driven background requires Z+jet and W+jet samples with high pt jet)
- Dijet+Etmiss (leptoquarks)
- ttbar resonances
- UED (diphoton+ Etmiss)
- Excited electron
- Heavy quarks
- Heavy neutrinos
- Some Hidden Valley scenarios and some long-lived particles (R-Hadrons, monopoles etc.)

Why Look at Signatures?

- We need to compare SM predictions to data in various final states whether or not there is a popular new physics model that predicts an excess in that final state
  - You never know what could turn up: new physics, badly understood backgrounds or detector effects, etc.
  - If there isn't a popular model now, there could be one next year. Also we generally focus on "minimal" versions of these models
  - Simple final states at hadron colliders like 1 jet + missing E_T, two-jets + missing Et must be examined
- LHC Inverse Problem: if we find something, how will we know what it is?
  - We will need to look at all channels to start to pin down what new physics we are dealing with

First Things First: Triggers

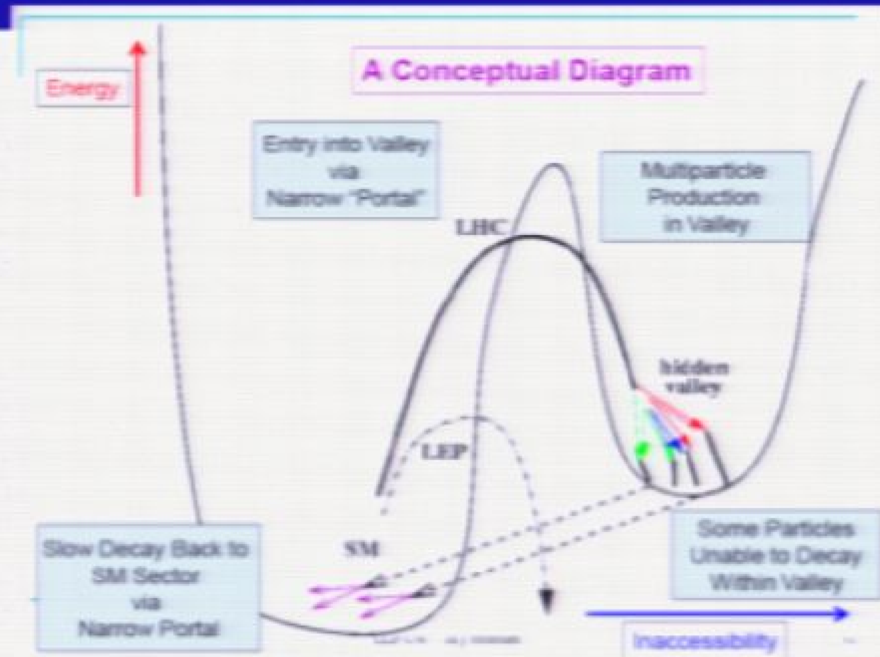
- Collision rate up to 40 MHz.
- Need to reduce this rate by more than 10^5
- Events with very high pt (isolated) leptons, jets get written to tape
- What about events with:
  - Slow moving particles
  - Late-decaying particles
  - Particles that decay to "lepton jets"
  - Magnetic charges
  - Very busy events
  - Quirks and other exotica



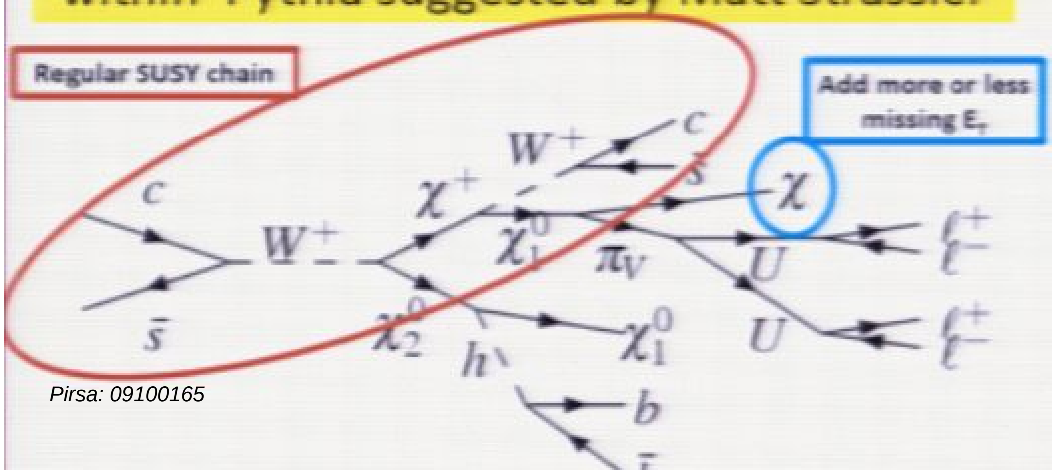
- If you have an idea and you don't know if we can trigger on it, let us know!
- If we don't trigger on it, these events are forever lost…
- There are no triggers for "unknown unknowns"

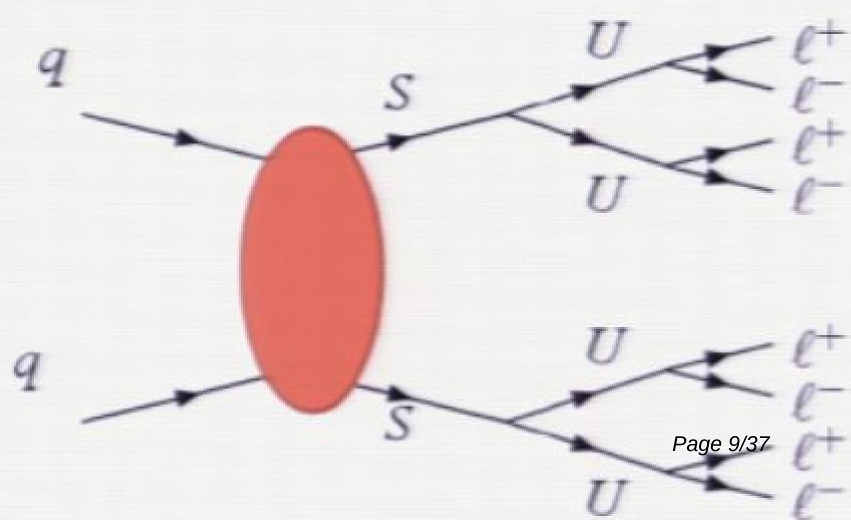
Exotic Triggers (example)

- Much work in ATLAS to make sure we can trigger efficiently on Hidden Valley Models
- Trigger efficiency studied in a generic way:



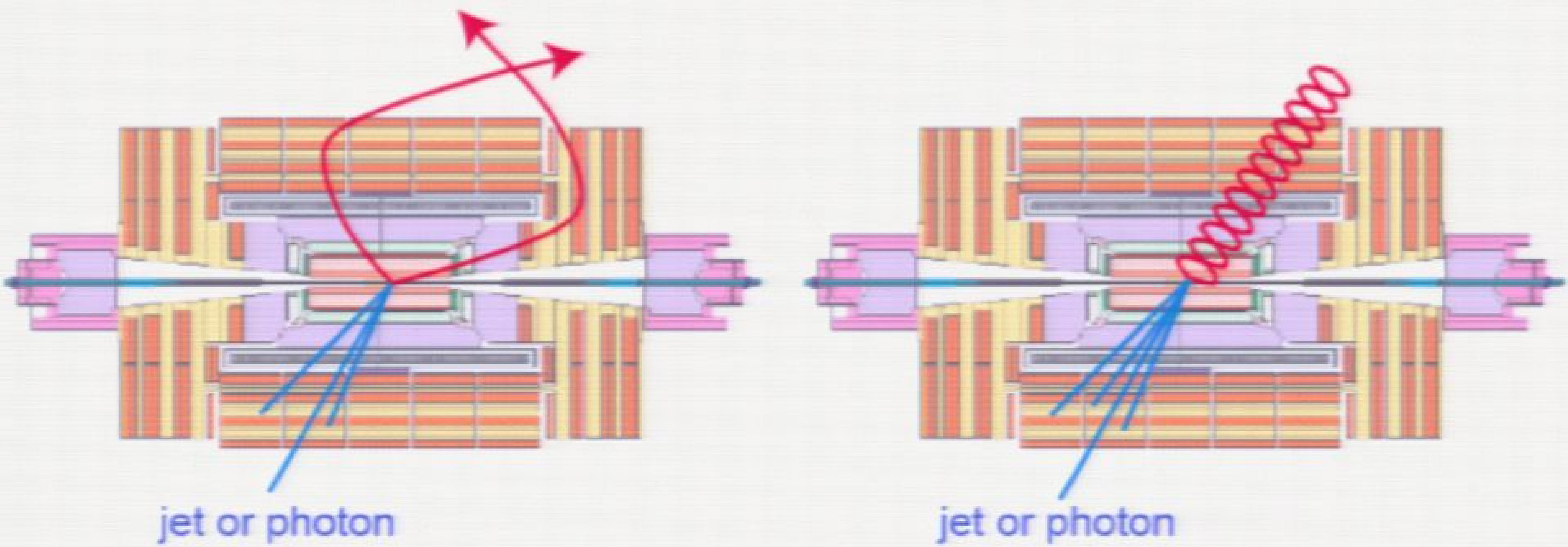
Generic MC generator imbedded in SUSY within Pythia suggested by Matt Strassler





Exotic Exotic Triggers?

- Some signatures are just too strange for us to be able to trigger on: we hope we will trigger on those if they are produced with associated high-pt SM objects
- Quirks in CMS (from talk by M. Luty)



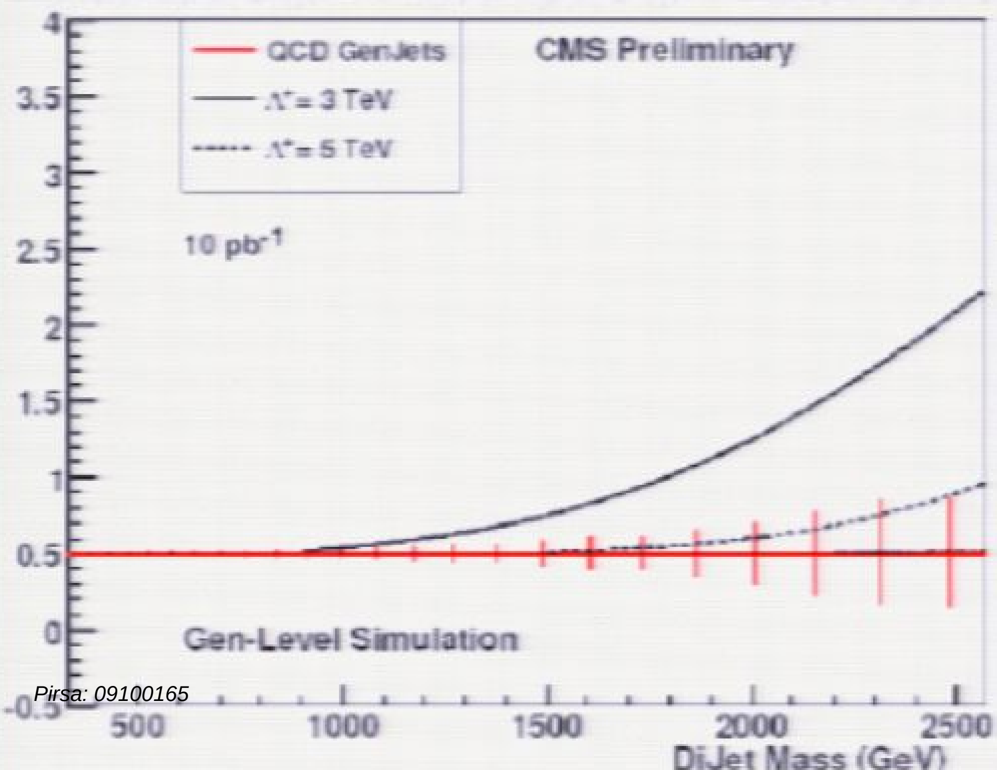
Dijet analyses

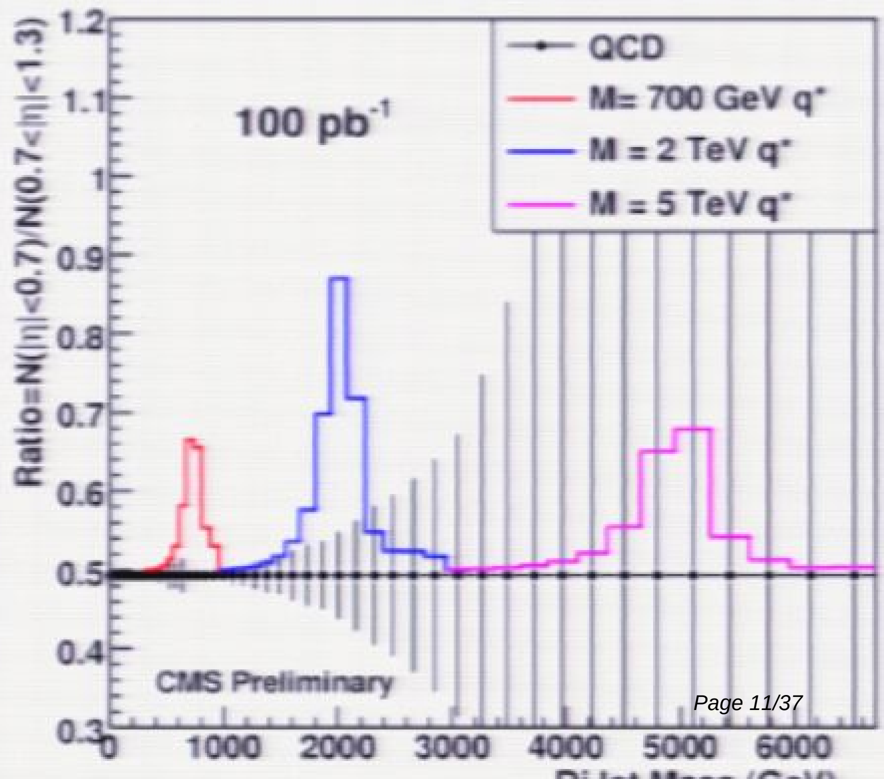
Contact interactions: quark compo., gravity, etc.

- Use kin. distributions less sensitive to systematics

Dijet resonances: q*, axigluons, colorons, etc.

- Resonances produced by the strong force can have very large cross sections

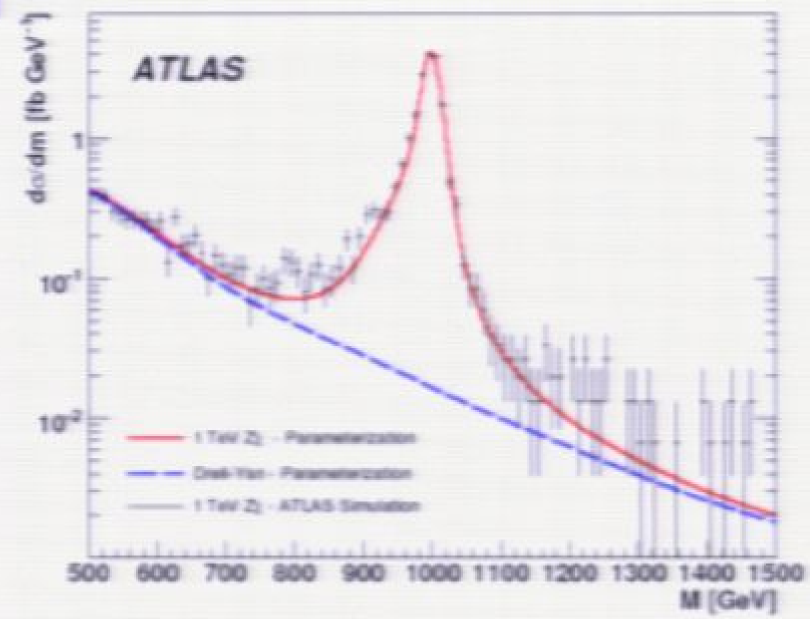


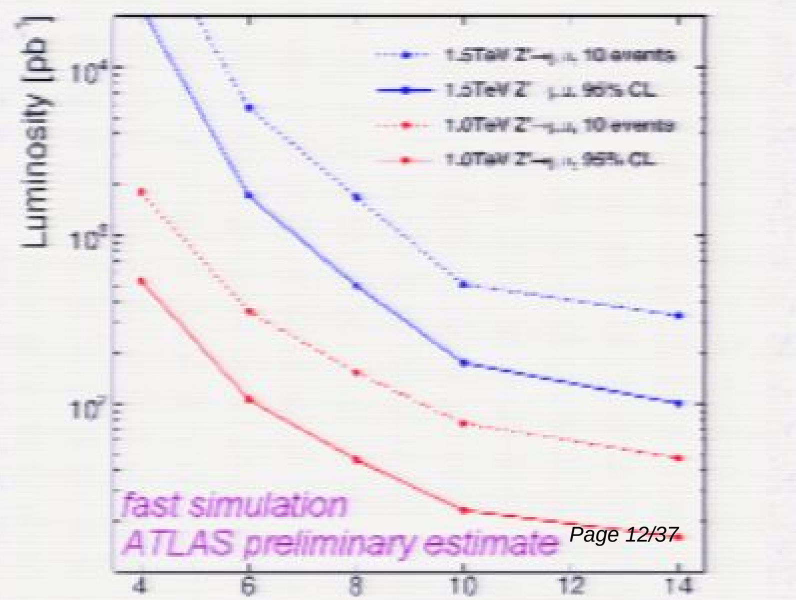


Dilepton/Diphoton Resonances

Dilepton, diphoton resonances

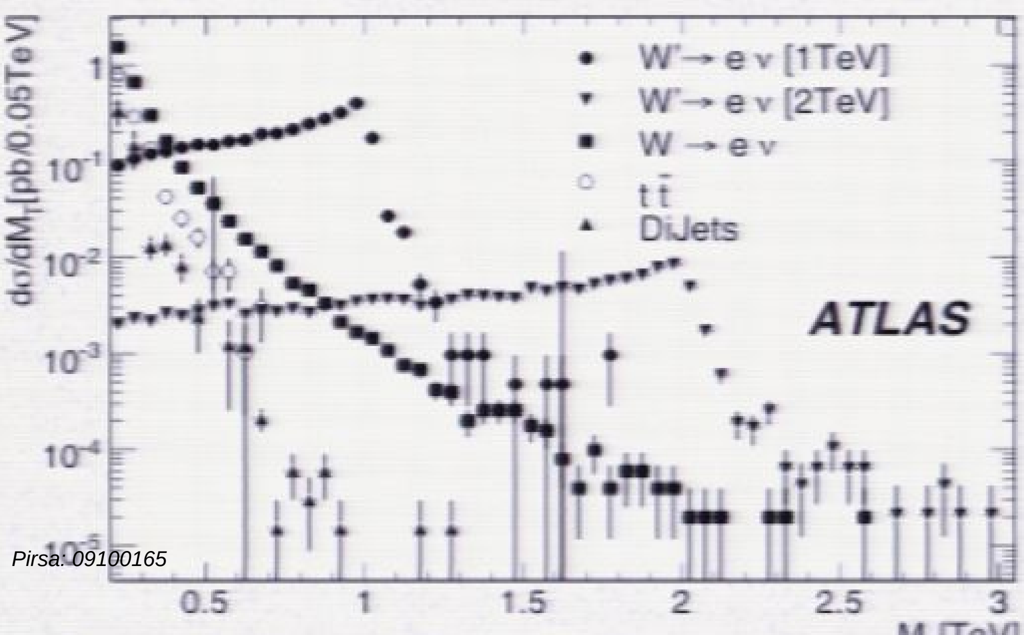
- Z', ZH, G(RS), G(KK), ρ_T, ω_T, etc.
- In general, large signal to background ratios
- Background obtained directly from data
- With "early data" systematics uncertainties, we can extend mass range explored by Tevatron with few tens of pb^{-1}

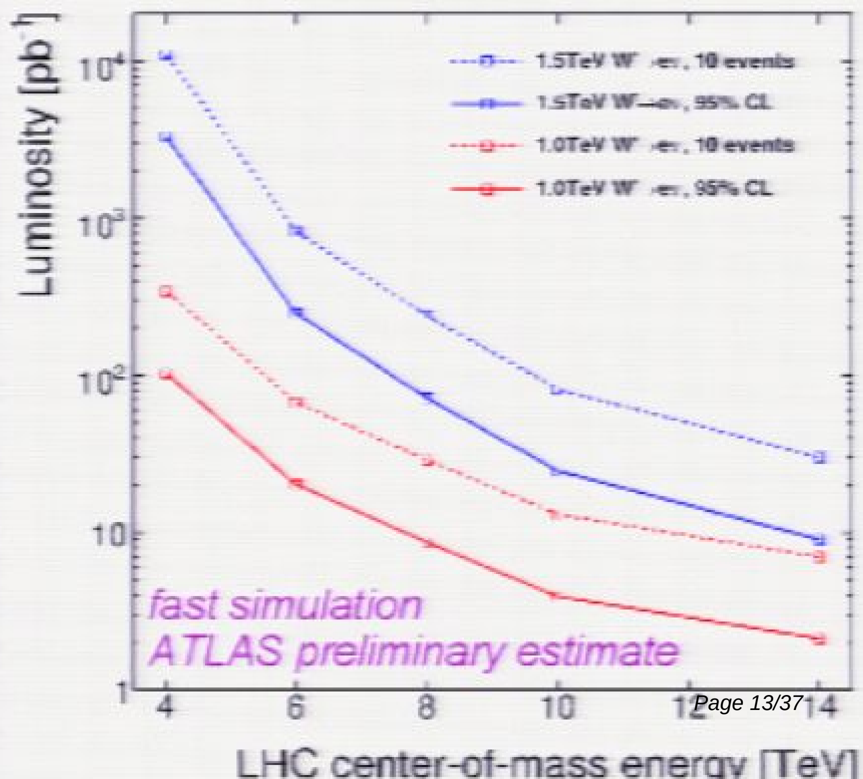




W' Boson Decay to lν

- Current limits from the Tevatron at around 1 TeV
- Cross section is higher than Z' but challenge is to understand/control Missing Et tail
- Main background from W tail below 1 event/bin at ~500 GeV
- Discovery reach for 1.5 TeV W' in eν with approx. 100 pb^{-1} (10 events)
- 95% CL limit for 1.5 TeV W' with 20-30 pb^{-1}

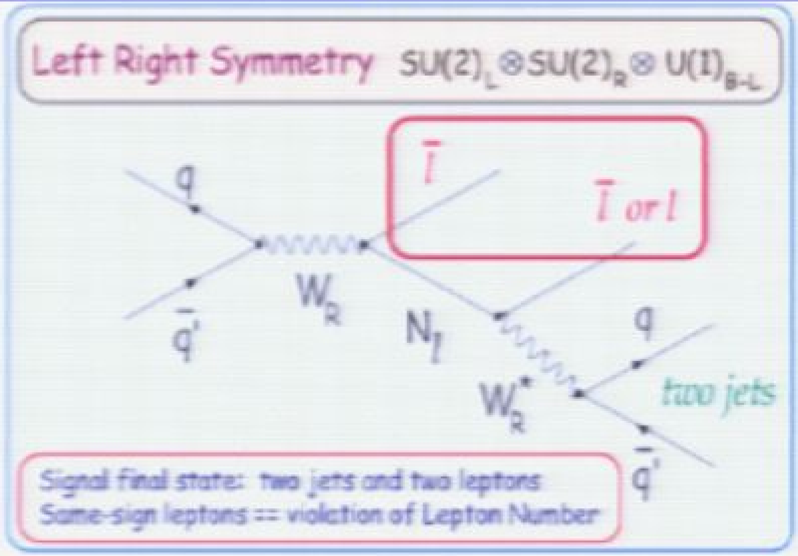


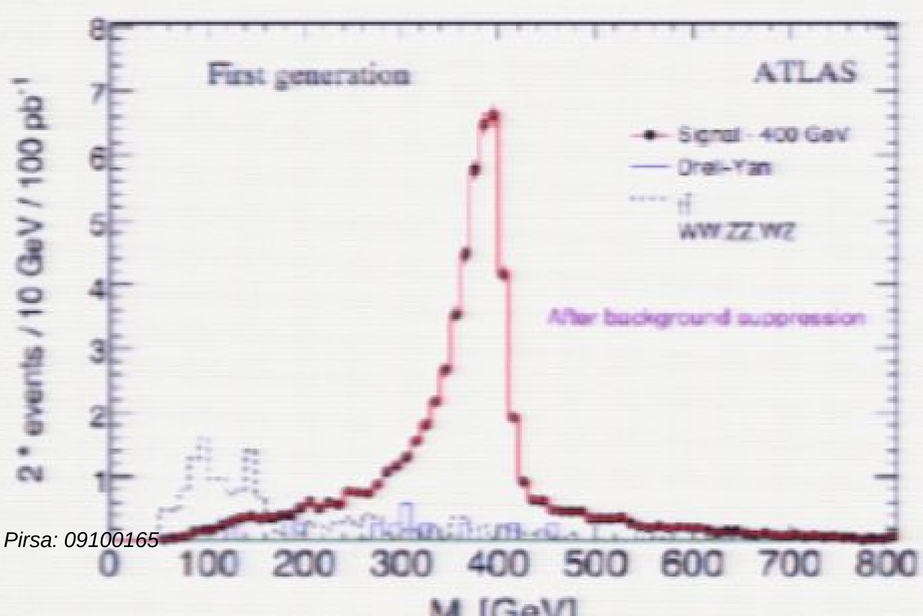


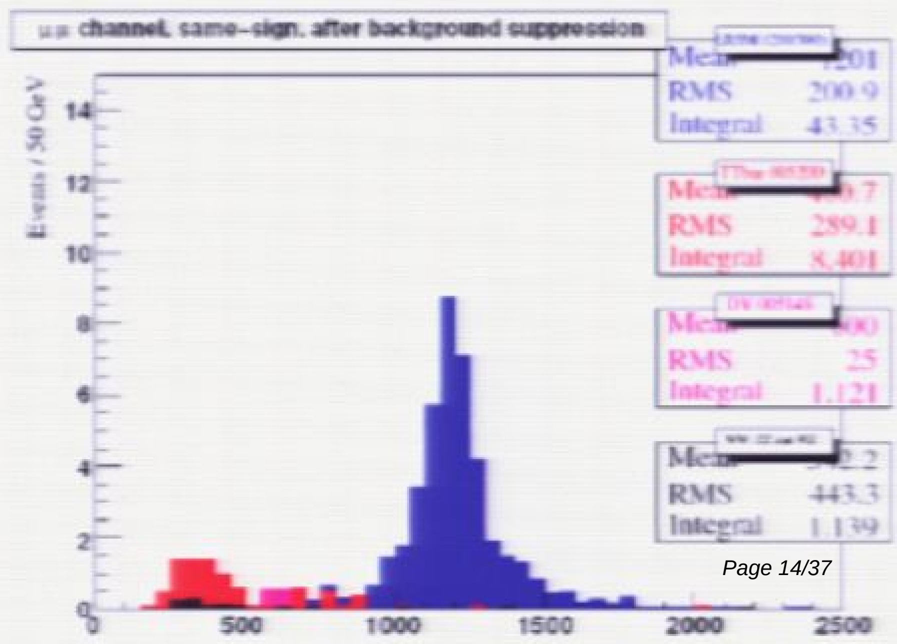
lljj Resonances
Benchmark: Leptoquarks and Heavy Neutrinos

Current LQ limits from the Tevatron ~ 300 GeV

Left-Right Symmetric Models with heavy neutrinos allow same-sign dilepton final state (left)

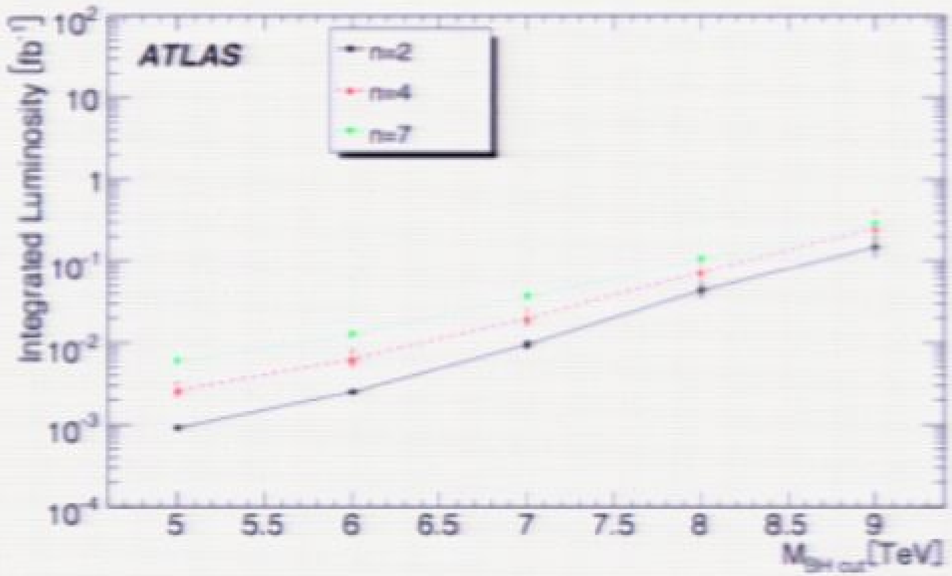


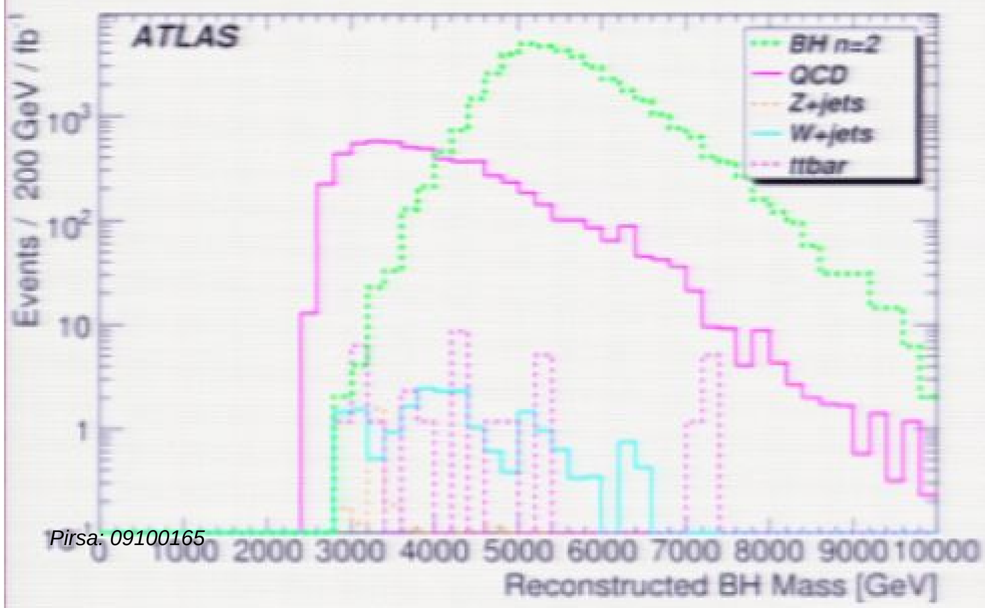


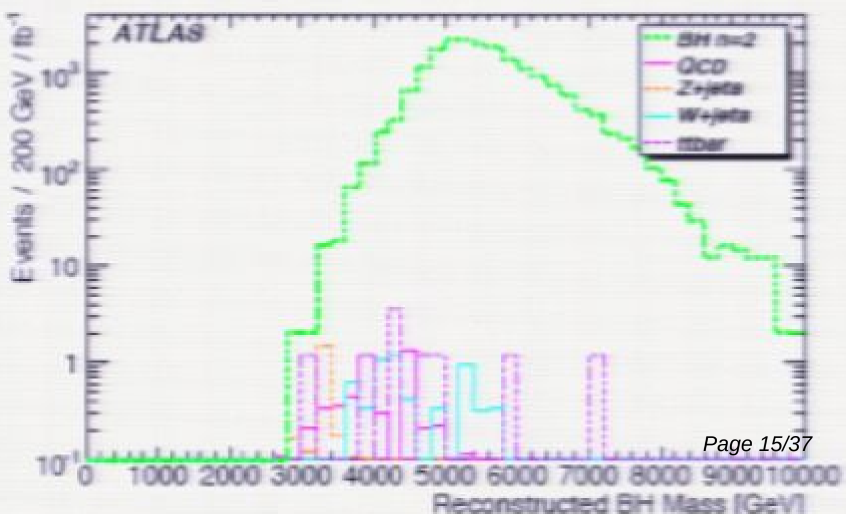


High-P_T, High Multiplicity Events
Benchmark: Classical Black Holes

- Spectacular final states that typically feature high-pt jets, leptons, Etmiss
- Very large cross sections: easy to observe or exclude







Jet(s) + ETMiss: Monojets

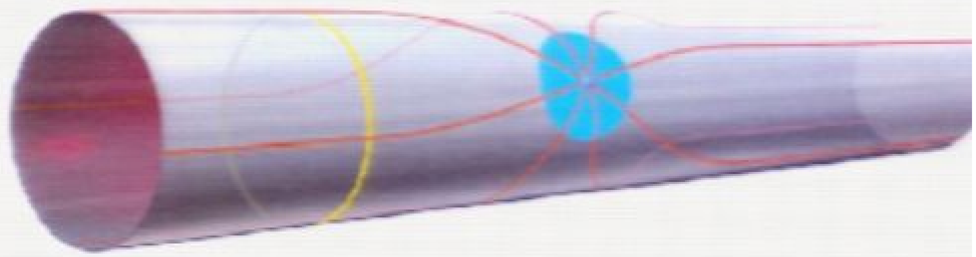
- Excess of monojets seen by UA1 in the 80s. Excess not observed by UA2. Excess probably due to underestimated W and b background
- Monojet searches became popular again when ADD Large Extra Dimensions scenario was published
- Run I search performed by D0 and CDF
- There was no early Run II search

Monojet Benchmark: Large Extra Dimensions

(Arkani-Hamed, Dimopoulos, Dval

- **Gravitational potential in 3 dimensions (Newton):**

$$V(r) = G_N \frac{m_1 m_2}{r} = \frac{1}{(M_{Pl})^2} \frac{m_1 m_2}{r}$$



- **n extra dimensions compactified at radius R:**

r<<R $$V(r) \sim \frac{1}{(M_D)^{n+2}} \frac{m_1 m_2}{r^{n+1}}$$

r>R $$V(r) \sim \frac{1}{(M_D)^{n+2}} \frac{m_1 m_2}{R^n} \frac{1}{r}$$

$$(M_{PL})^2 \sim R^n (M_D)^{2+n}$$

Gravitons escape in bulk of extra dimensions
Parton level processes:
$qq \rightarrow gG$, $qg \rightarrow qG$ and $gg \rightarrow gG$
$\Rightarrow$ Jet + EtMiss

Jets +$E_T$miss Analyses

- Early analysis strategies
  - Rely on data-driven estimates of backgrounds as much as possible
  - Design the analysis such that background calculation does not require precise knowledge or a good model of:
    - Jet Energy Scale and resolution
    - Pile up and underlying event
    - PDF and ISR/FSR effects
    - Luminosity
    - Note that interpretations won't be immune...

Overview of Monojet Event Selections

- Selections for reducible backgrounds:

⇒ **Reject cosmic, detector, and beam background**

-Event and jet cleanup cuts (more later)

⇒ **Reject QCD dijet events (crucial !)**

- $\not{E}_T$ not in the same azimuthal direction (ϕ) as any jet.

⇒ **Reject events with charged leptons**

- no isolated track with $P_T > 10$ GeV/c
- no calorimeter cluster with > 90% of E_T in the EM

Jet + Missing E_T Selections: example from CDF

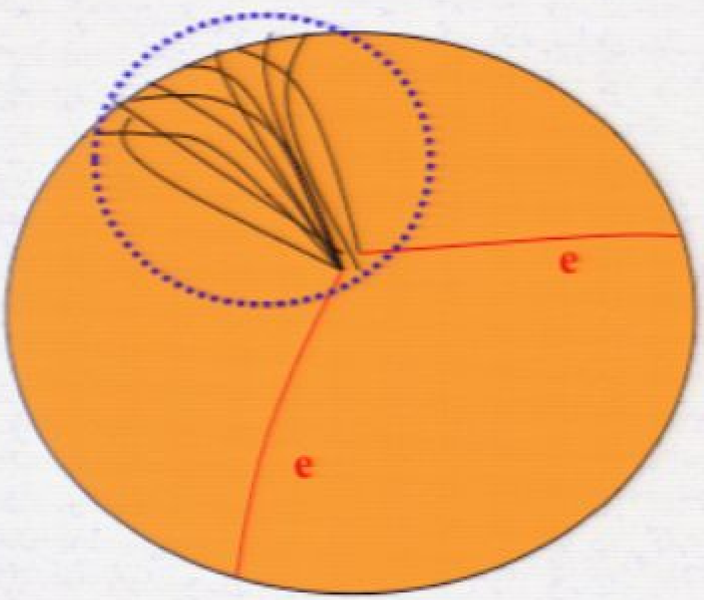
- Event Cleanup
  - Vertex reconstructed from 6+ tracks with $|Z_{vtx}| < 60$cm
    - Make sure a hard scattering occurred (reduce cosmic contribution)
  - Event jet EM fraction > 0.1
    - Reduce cosmic ray contribution in hadronic calorimeter
- Lepton removal
  - No jet with EM fraction > 0.9
    - Remove badly reconstructed electrons and reduce cosmics
  - No isolated track with $p_T > 10$ GeV in the event
    - Remove badly reconstructed muons (and electrons)

Jet + Missing E_T Selections: example from CDF

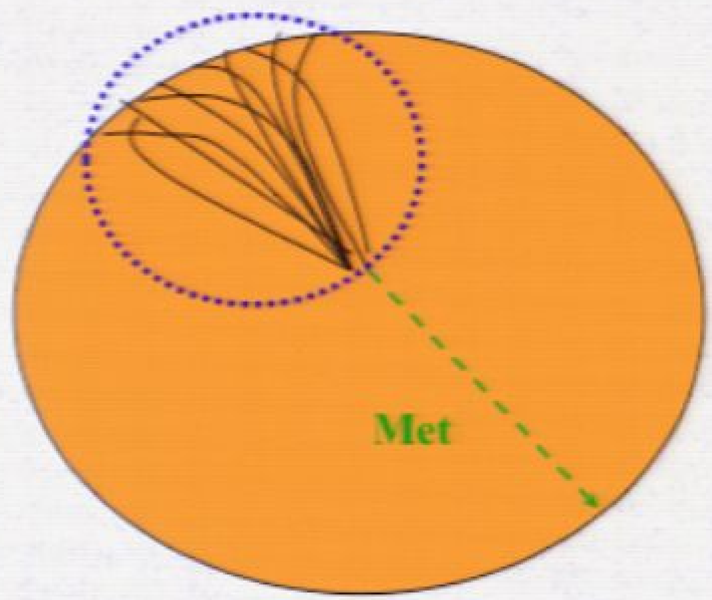
- Loose Jet Clean-up cuts (for all jets in event)
  - If $|\eta_{det}| < 1.0$, jet charge fraction > 0.1
  - The jet must be fully contained in the calorimeter volume
    - Not located in chimney or central crack ($|\eta_{det}| > 0.05$)
    - Not too forward ($|\eta_{det}| < 2.4$)
  - $\Delta\phi$ between missing E_T and jet > 0.5 radians

Data-driven backgrounds

- After previous cuts in Jets + Missing E_T analyses, the most important backgrounds are:
  - Electroweak (1-jet + $Z \to \nu\nu$ and 1-jet + $W \to \ell\nu$: ℓ is lost)
    - We can use Z/W + jet events in the data with reconstructed leptons to estimate this background



$Z \to ee$ + 1-jet



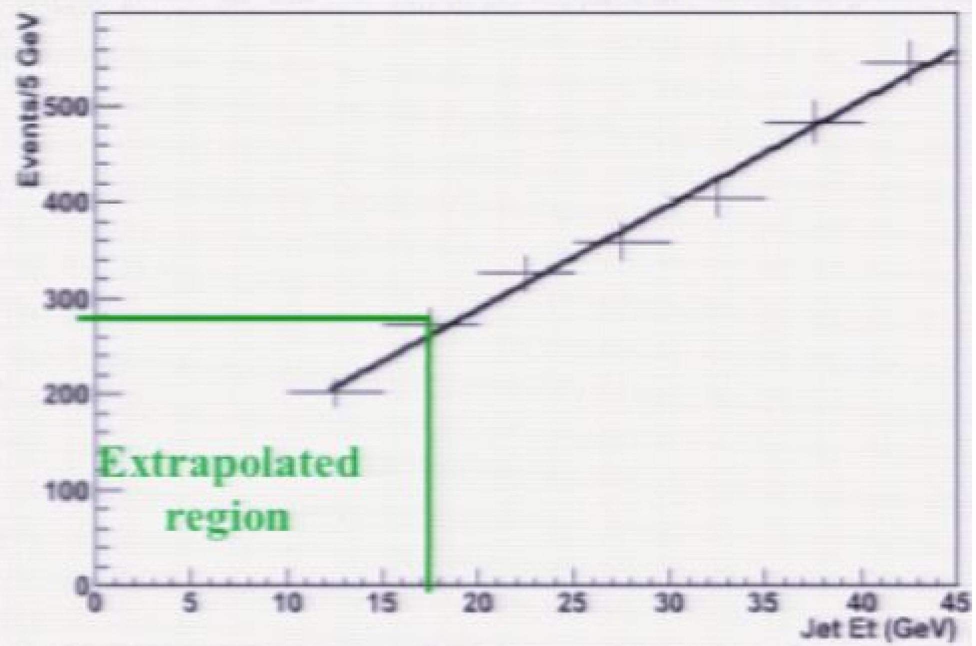
$Z \to \nu\nu$ + 1-jet

Data-driven background estimate: QCD background

- Two main sources for QCD contribution:
  - Dijet events for which one of the jets is lost (~85%)
  - 3-jets events in which two jets are mismeasured and at least one of which is lost (~15%)

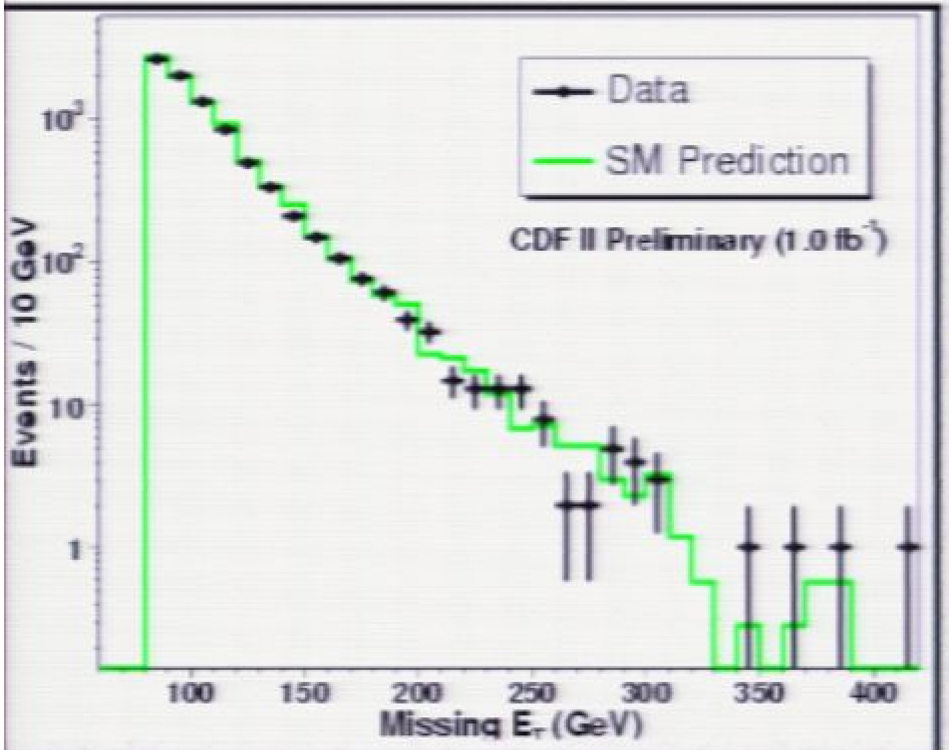
  From MC

- To estimate the first contribution:
  - Select dijet events where the MET points towards a jet
  - Extrapolate second jet E_T below 20 GeV



- Correct for the EWK contributions to the Jet 2 E_T distribution
- Need to account for the 3-jets contribution

Does it work? (example 1)



Background	80/80	150/120	180/150
$Z \to \nu\nu$ + jet	3203 ± 137	390 ± 30	141 ± 17
$W \to \tau\nu$ + jet	2010 ± 69	187 ± 14	58 ± 5
$W \to \mu\nu$ + jet	1570 ± 54	117 ± 9	35 ± 3
$W \to e\nu$ + jet	824 ± 28	58 ± 4	18 ± 2
$Z \to ll$ + jet	87 ± 3	6 ± 1	2 ± 0
QCD	708 ± 146	23 ± 20	12 ± 12
γ + jet	209 ± 41	17 ± 5	8 ± 3
Non-collision	52 ± 52	10 ± 10	3 ± 3
Predicted	8663 ± 332	808 ± 62	277 ± 30
Observed	8449	809	319

Results from CDF Jet+Etmiss analysis

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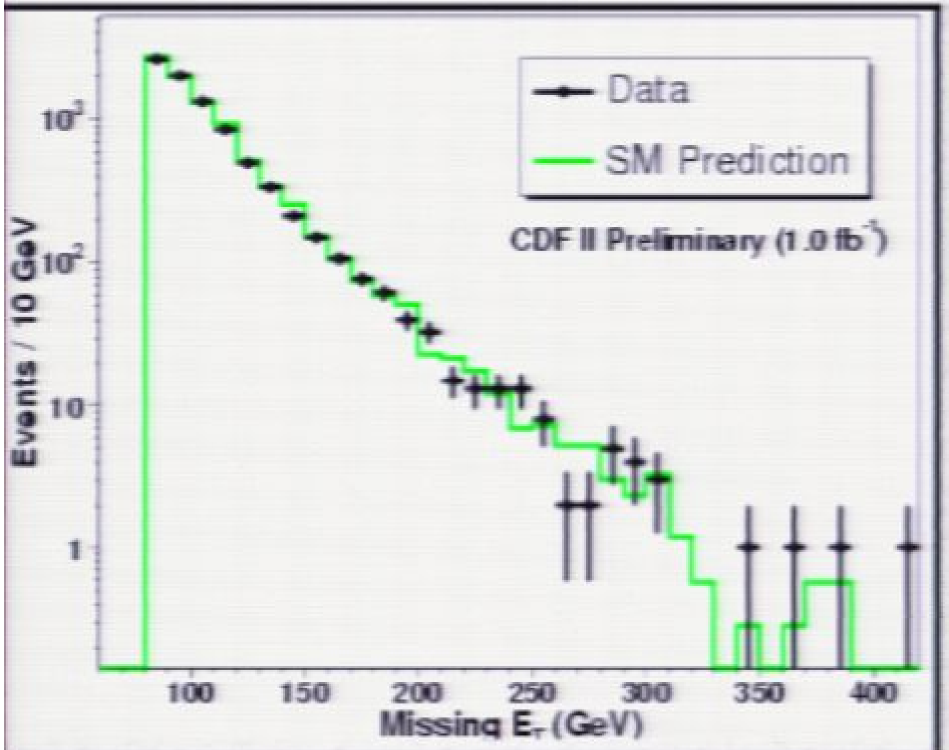

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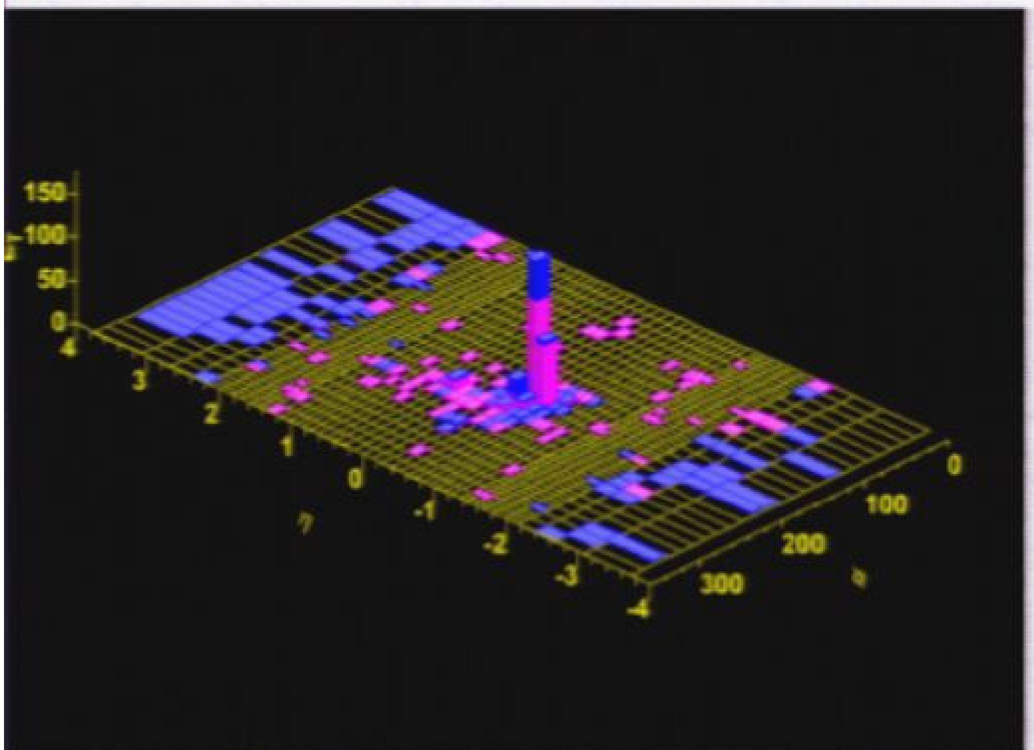
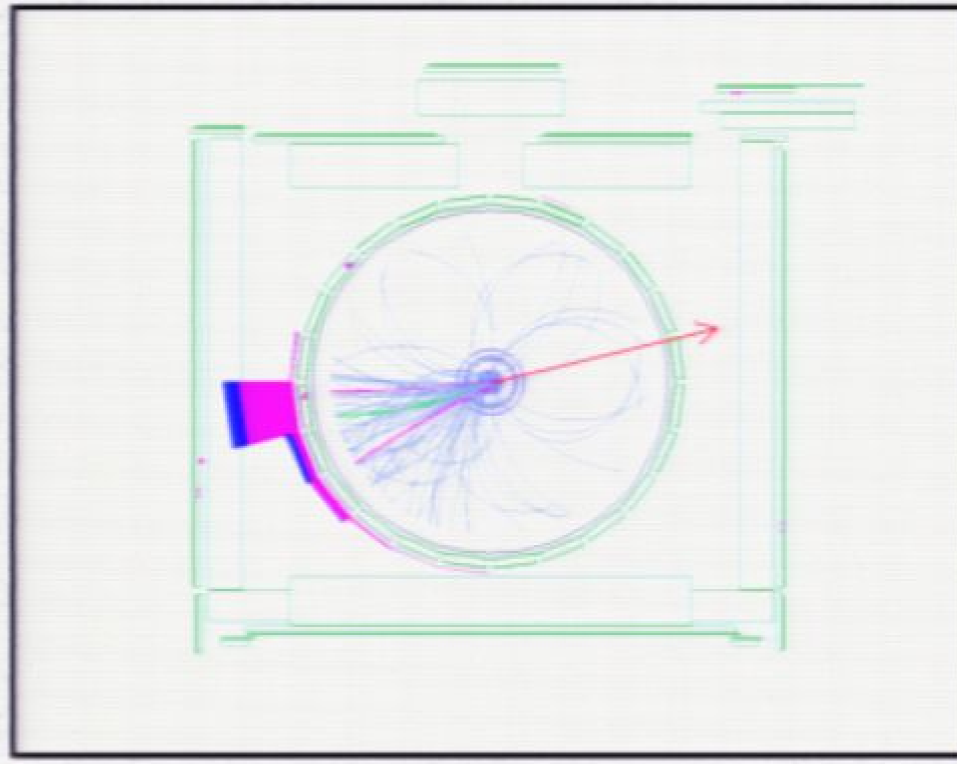
Results from CDF Jet+Etmiss analysis

Monojet: Most Energetic Event

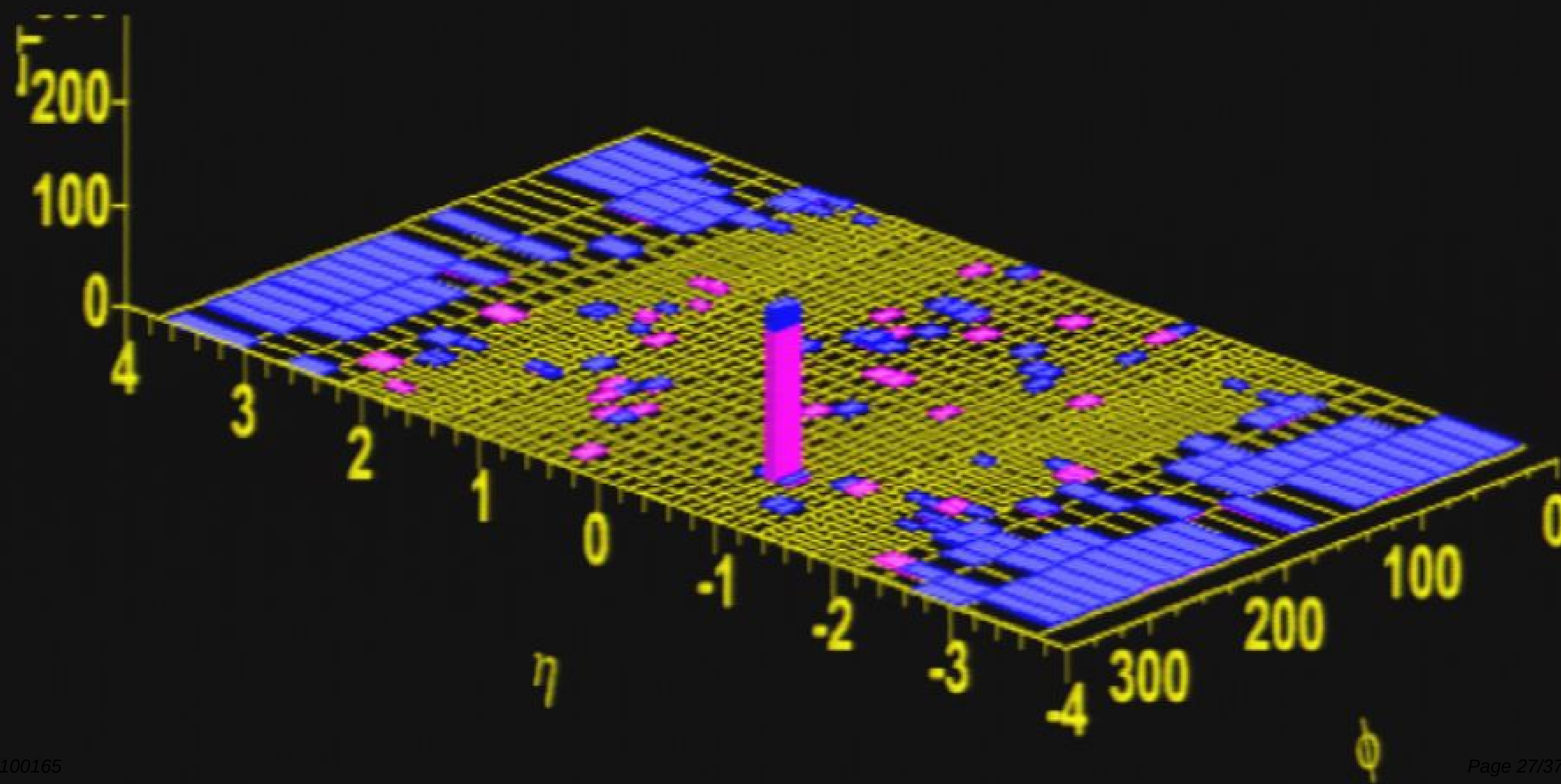




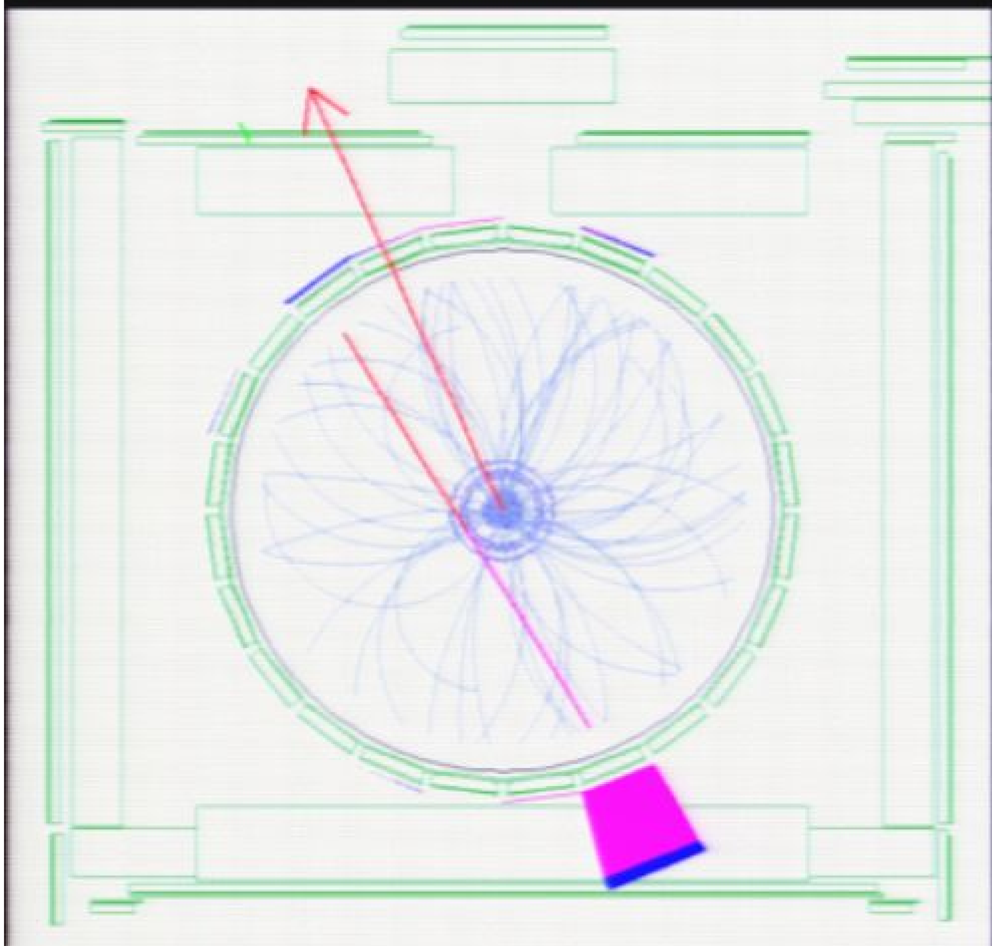
Jet ET = 419 GeV, Missing ET = 417 GeV

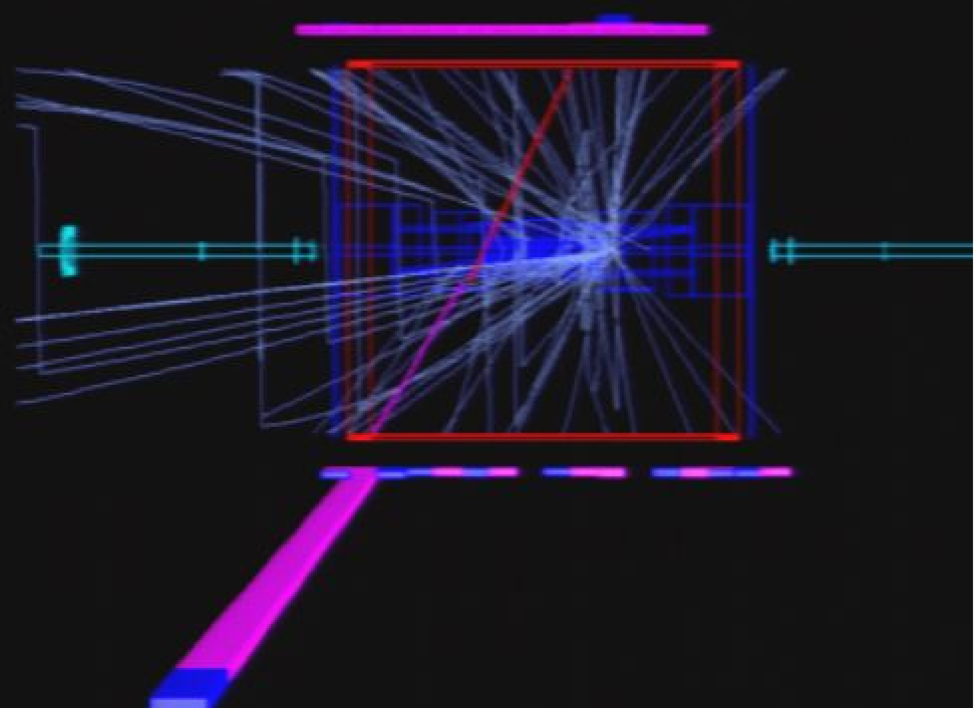
Non-Collision Backgrounds

High E_T Jet and Missing E_T triggered events need to be checked carefully

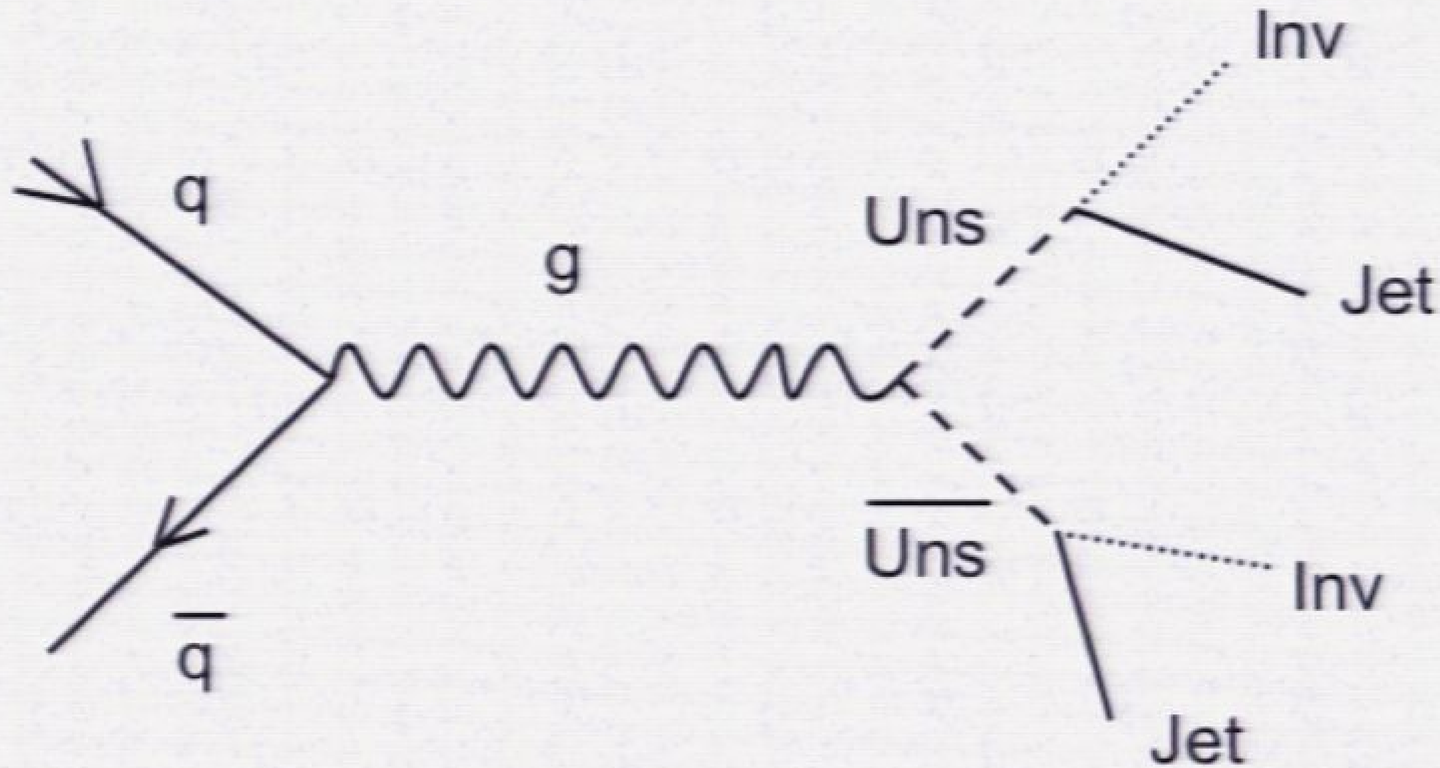


Our candidate LED event turns out to be a cosmic ray...





Dijet + Missing E_T: Generic Feynman Diagram

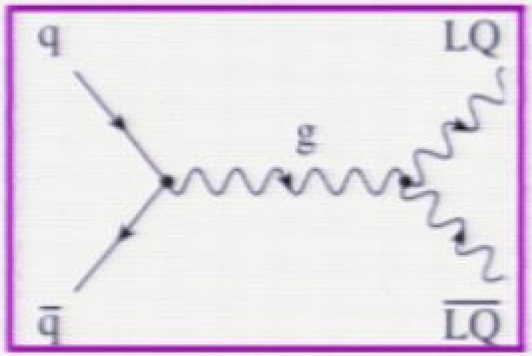


Uns = new unstable particle: squark, KK-quark, leptoquark

Inv = new invisible particle: neutralino, graviton, neutrino, etc

Dijets + Missing Et: Leptoquarks

- LHC/Tevatron searches focus on leptoquark pair production:
  - Pairs are produced via strong interaction only ($qq \rightarrow LQ\overline{LQ}$, $gg \rightarrow LQ\overline{LQ}$)
  - Production essentially depends on strong coupling and M_{LQ}
  - Decay more complicated

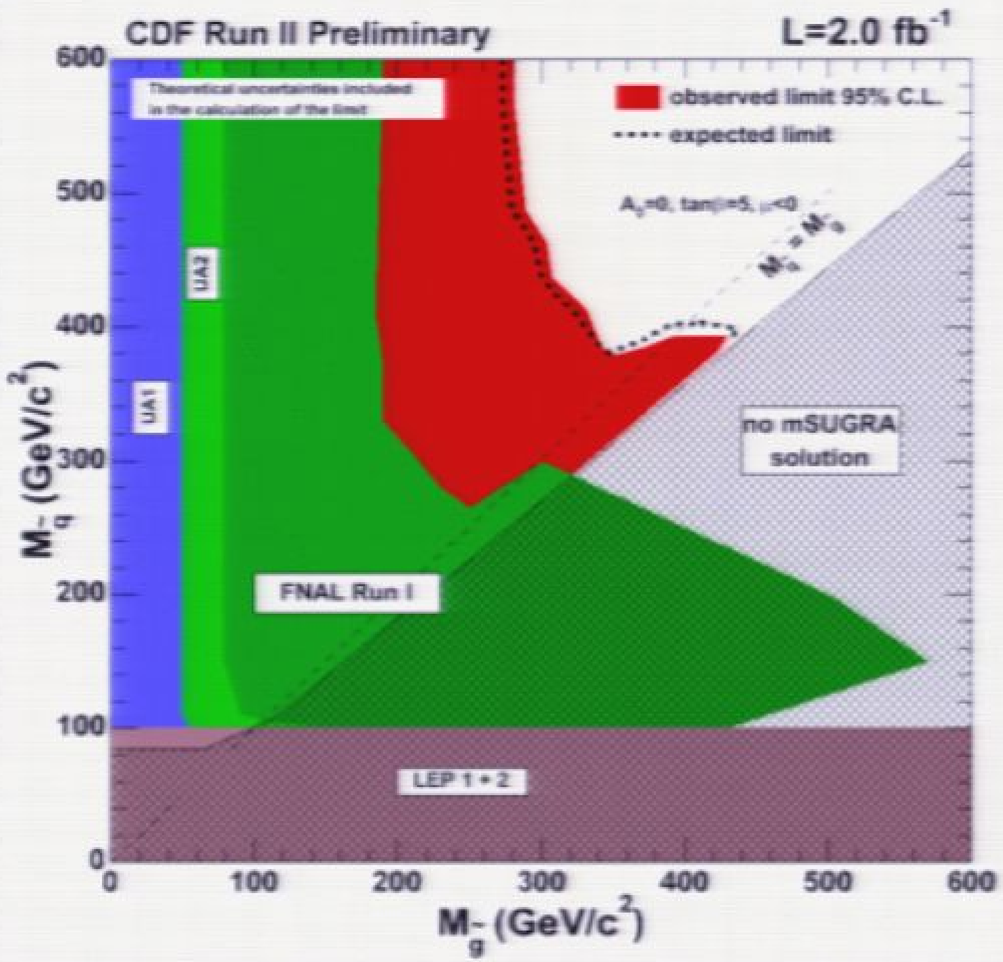


Dominant

- Can study 2^{nd} and 3^{rd} generation leptoquarks without having to assume Lepton Flavor Violation
- Can study leptoquarks that couple only to quarks and neutrinos (all three generations)

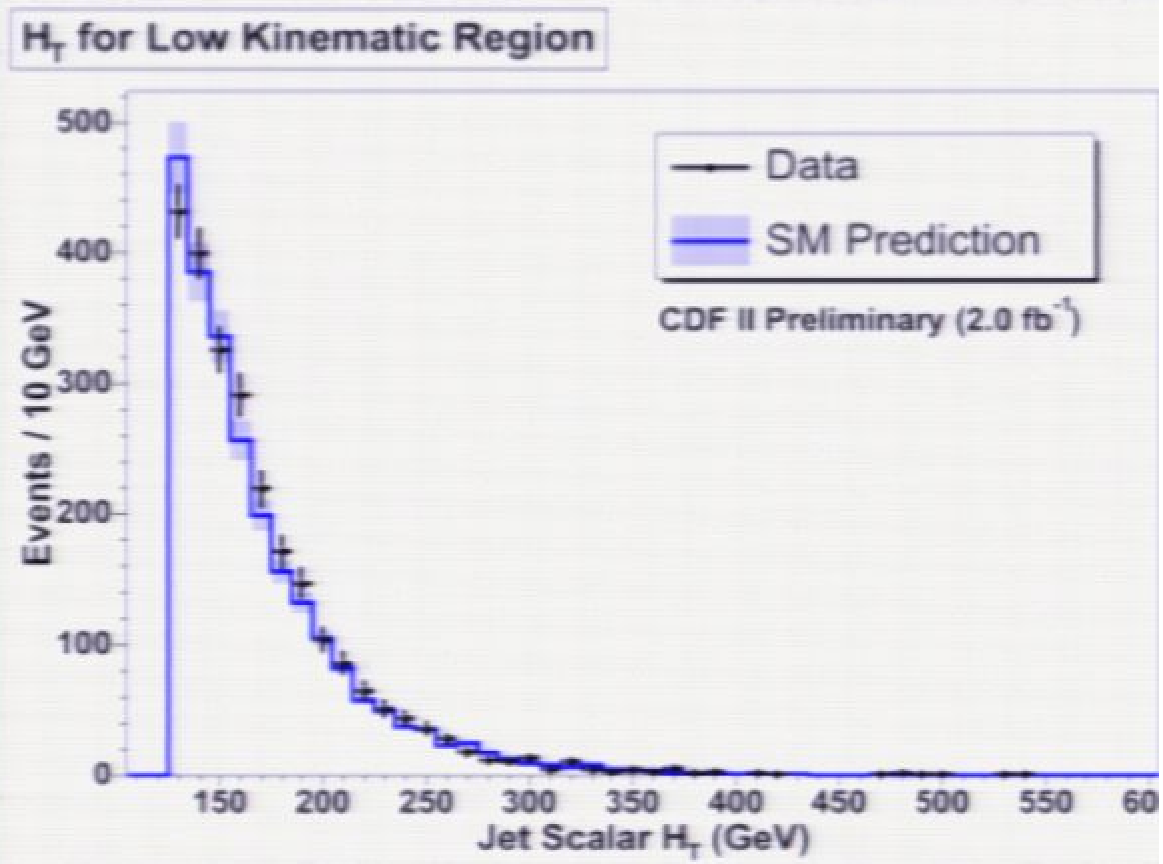
Dijets + Missing E_T (SUSY)

- Focus in Run II (and LHC) has been mostly on mSUGRA
  - No solutions for squark masses lighter than gluino masses
  - Final state with gluinos has more jets
  - mSUGRA analyses look for multi-jets + missing E_T
- Run I exclusion performed by Maria Spiropulu of CDF in MSSM, mSUGRA contexts



Does it work (example 2)

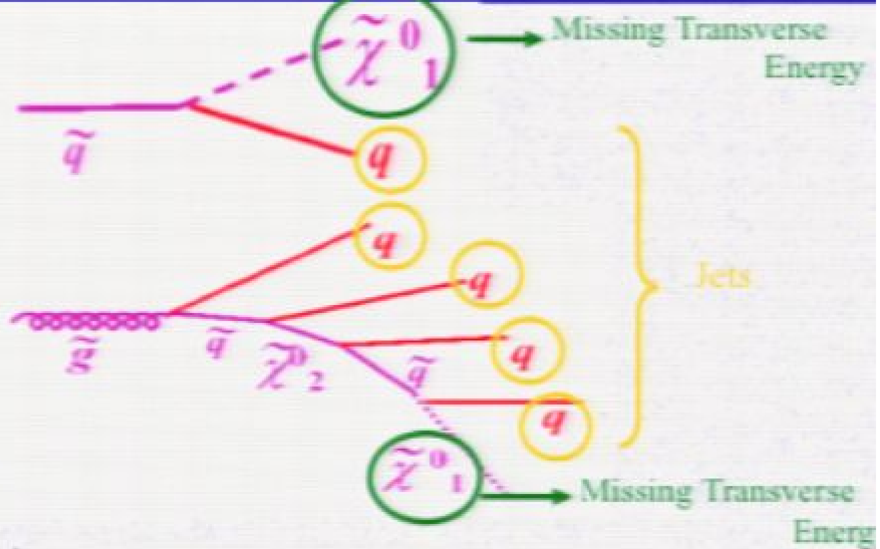
Background	Expected Events
$Z \to \nu\nu$	777 ± 49
$W \to \tau\nu$	669 ± 42
$W \to \mu\nu$	399 ± 25
$W \to e\nu$	256 ± 16
$Z \to ll$	29 ± 4
QCD	49 ± 30
γ + jets	55 ± 13
top	74 ± 9
non-collision	4 ± 4
Total	**2443 ± 145**
Observed	**2506**



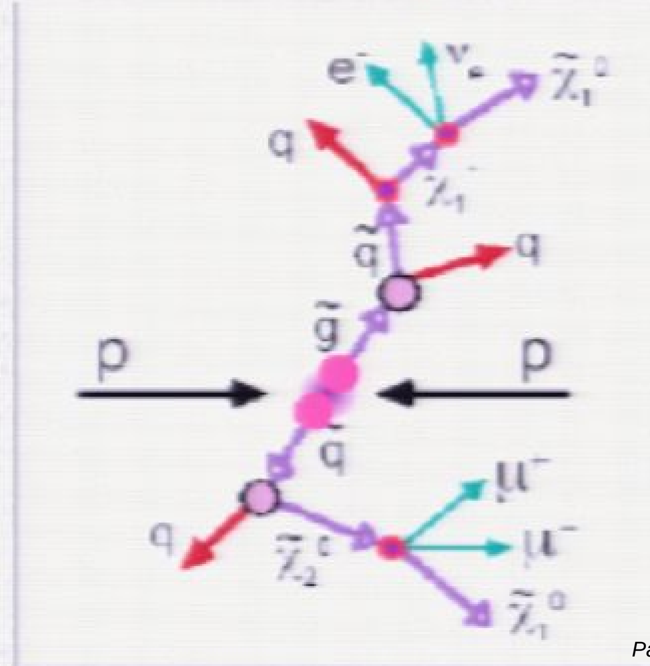
Results from CDF Dijet+Etmiss analysis

Jets+Etmiss (3 or more jets)

3 (or more) jets + $E_T$miss signature has additional (large)top background



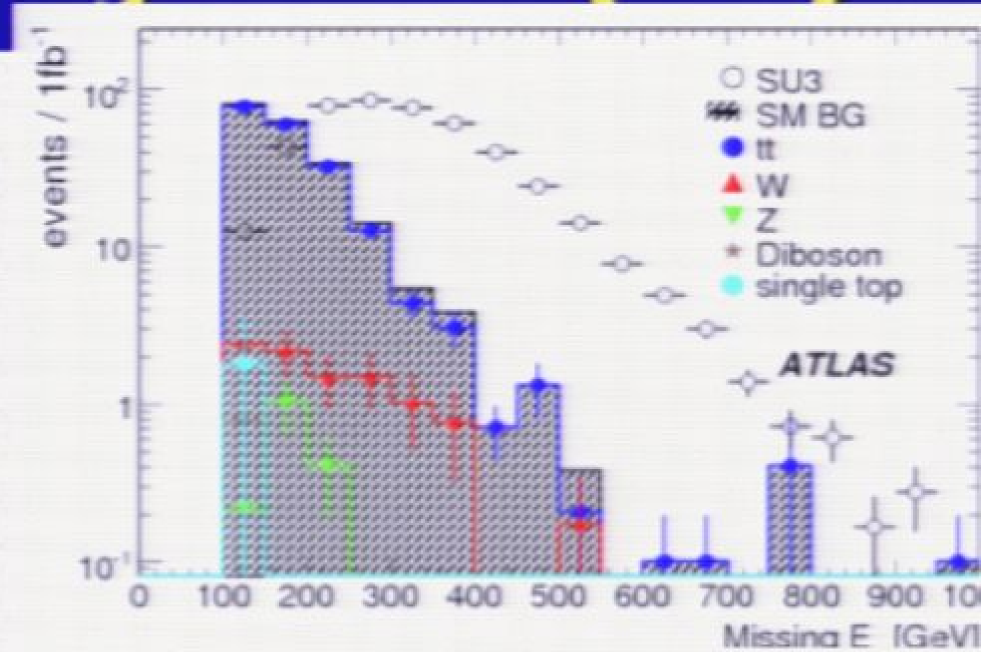
- Adding a high p_T lepton removes QCD background
- Understanding LHC top production is paramount
- Using transverse mass of lepton and $E_T$miss provides control sample

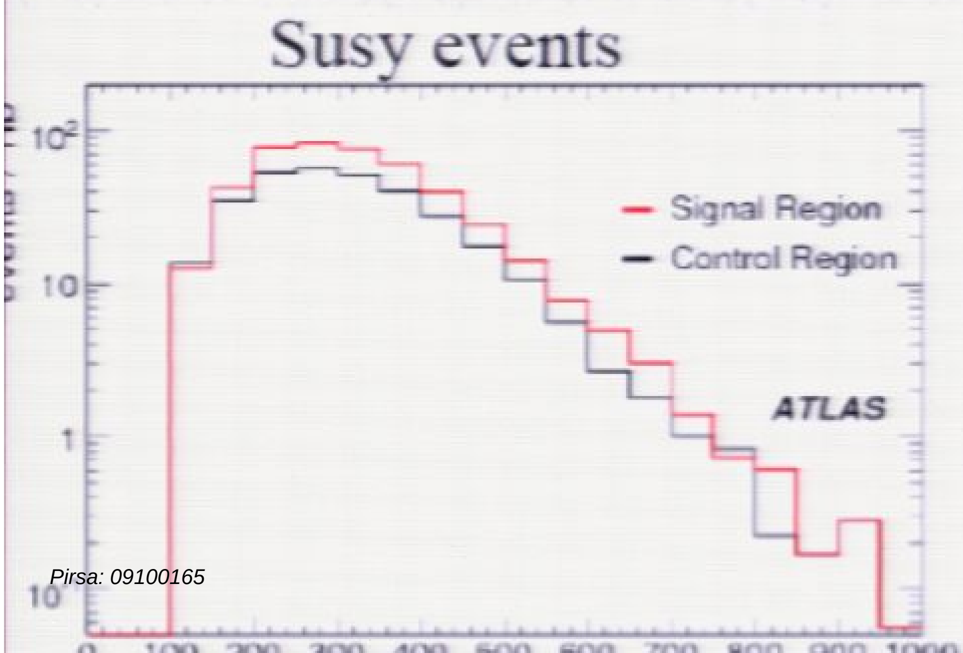


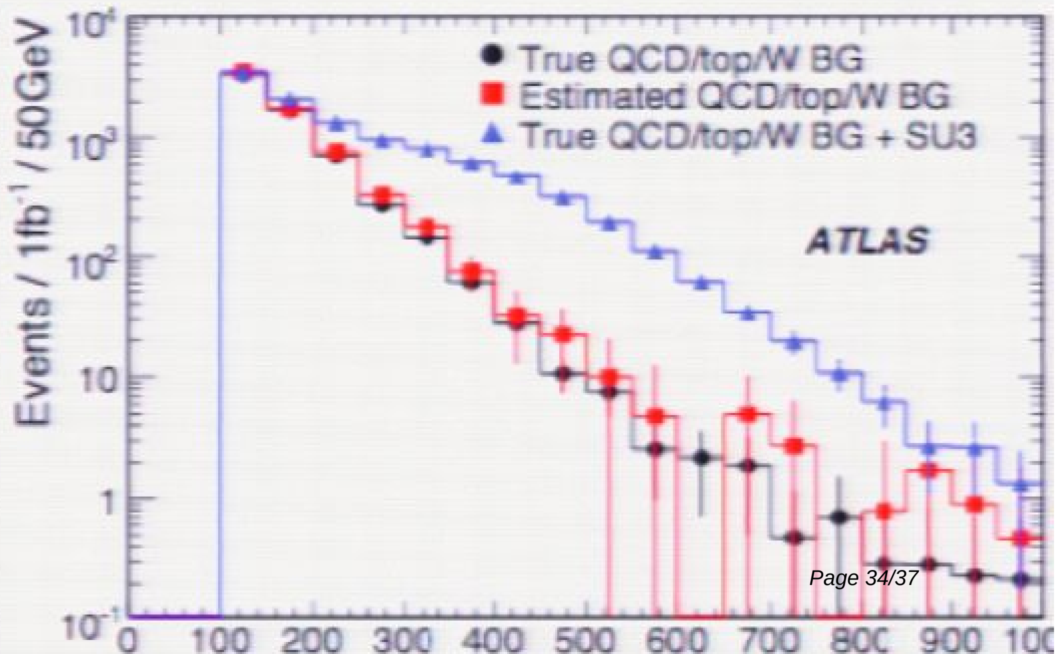
Data-Driven Backgrounds (III)

Top an W backgrounds have W bosons…

We can use transverse mass to define control sample:

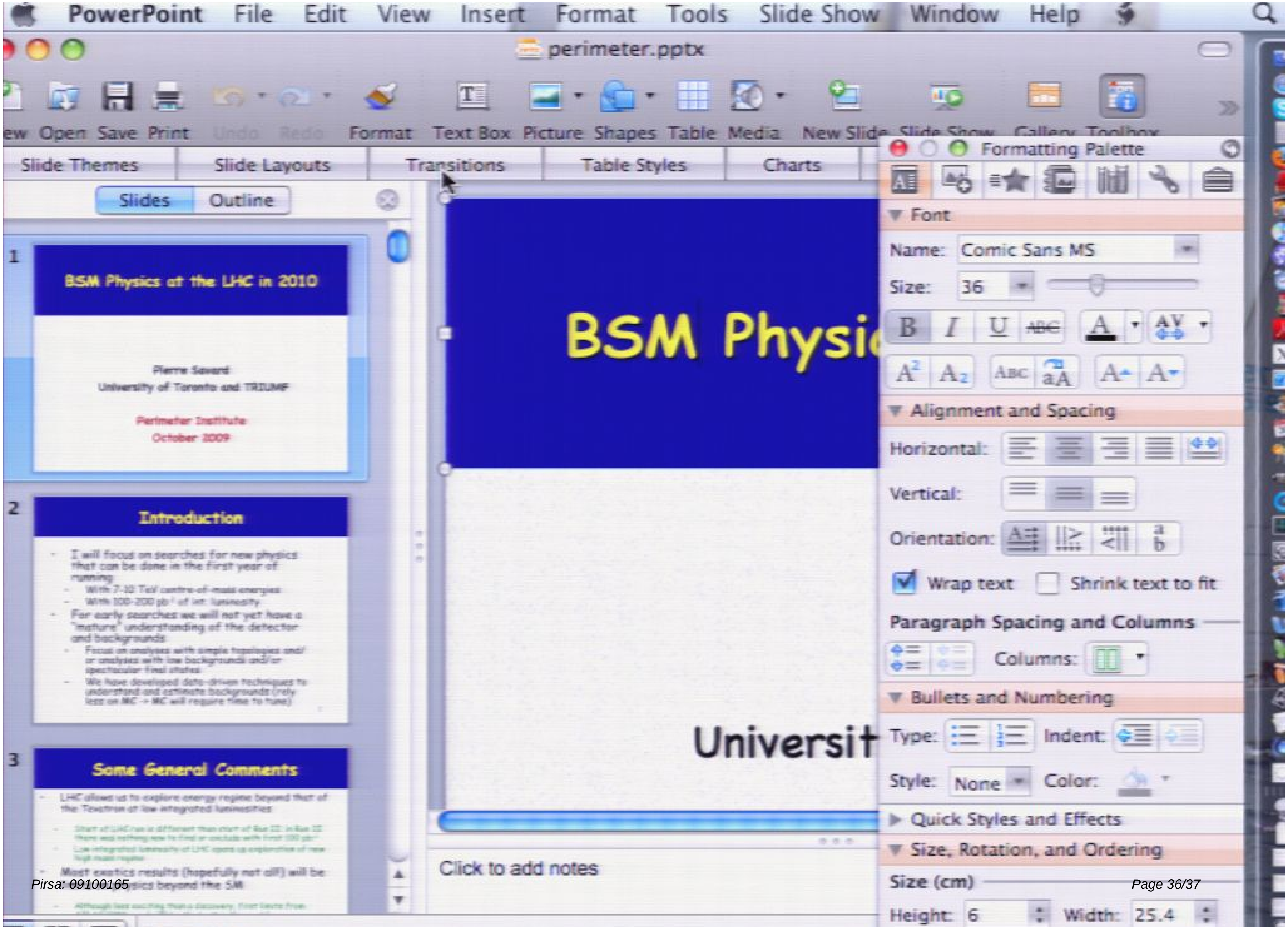






Conclusions

- Provided the LHC runs at high energy, we will be able to explore energy regime beyond that of the Tevatron with low integrated luminosities
  - We have many analyses that can set world's best limits with less than ~100-200 pb^{-1} at 7-10 TeV and we could find BSM physics
  - We need credible and defensible systematics for high-pt leptons and jets but they do not need to be small for us to produce world's best measurements
- Although the datasets we need are relatively small, we will of course need time to understand the data and tune the MC
  - Early analyses will use robust data-driven techniques to estimate the background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Pierre Savard
University of Toronto and TRIUMF
Perimeter Institute
October 2009
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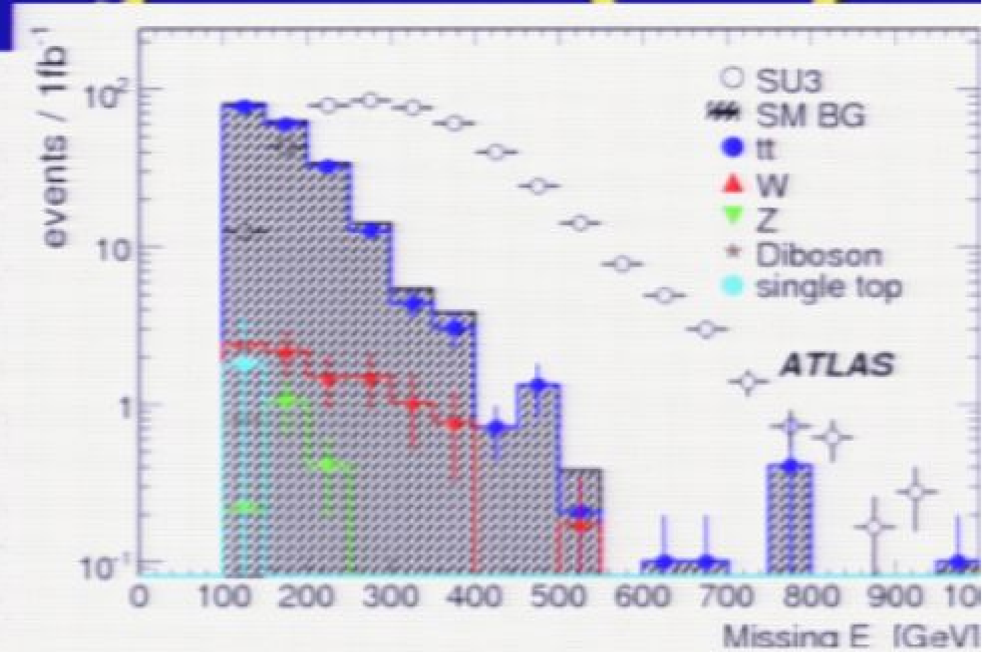
Alignment and Spacing
Horizontal:
Vertical:
Orientation:
Wrap text
Shrink text to fit
Paragraph Spacing and Columns
Columns:
Bullets and Numbering
Type:
Indent:
Style: None
Color:
Quick Styles and Effects
Size, Rotation, and Ordering
Size (cm)
Height: 6
Width: 25.4

Data-Driven Backgrounds (III)

Top an W backgrounds have W bosons...

We can use transverse mass to define control sample:



Susy events