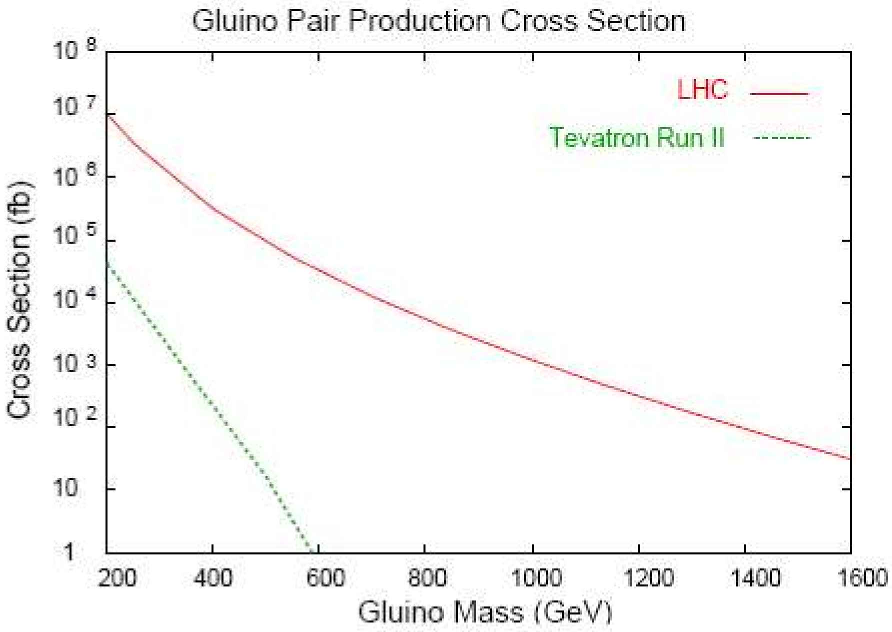
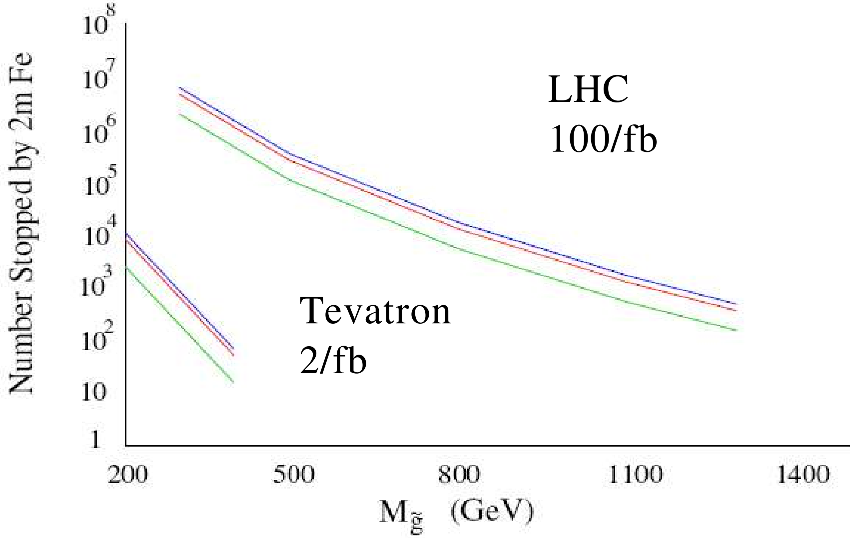
# Search for Stopped Gluinos

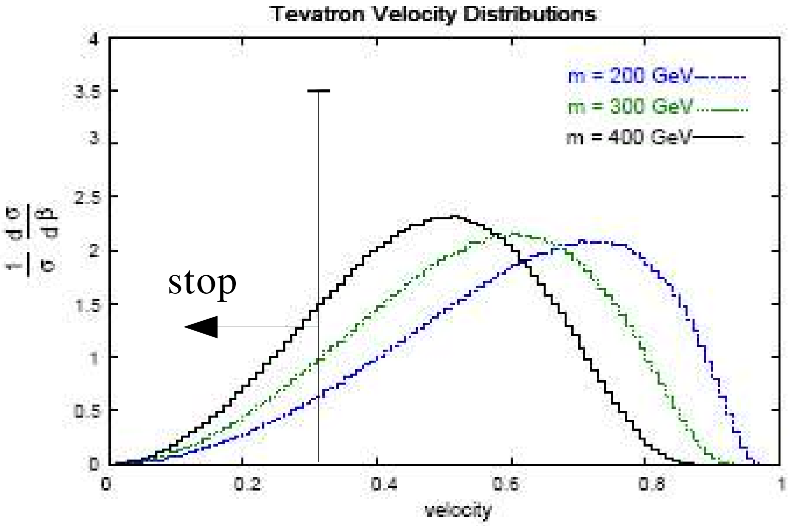
- Split SUSY -> heavy scalars -> long-lived gluino
    - Lifetime <100s due to nucleosynthesis constraints, but >10ns if $M_{SUSY}$~$10^6$ GeV
- Gluinos hadronize into "R-hadrons"
    - Most are neutral, lose a small fraction of their momentum, and escape undetected
    - Not many reconstructed tracks -> bad for classic charged massive stable particle search
- Gluinos can radiate gluons
    - This would create a monojet signature, but it would be hard to resolve the nature of the monojet signal from the monojets alone
- R-hadrons can become charged when undergoing nuclear interactions, and then some may lose enough momentum to stop (most likely in the calorimeter), see hep-ph/0506242
    - These "stopped gluinos" would later decay to jets+MET, giving a very unique, one-sided, jet signal, uncorrelated with beam-interactions
    - If both gluinos eventually stop (~30% of the time) and are detected, the time-coincidence would be a way (the only way!) to measure the gluino lifetime, and thus $M_{SUSY}$
- Other new particles could also give rise to a stopped-gluino-like signal, like the stau NLSP, see hep-ph/0409278
- Another simple motivation: this is an interesting "final-state" which has never been explored before (to my knowledge)

# Production

- Gluinos are “copiously” produced
- Some ~10-20% or so would stop
  - 30% of that time, both would stop
- About 300 stopped gluinos in 2/fb for $m_g$=300 GeV
- The stopped gluinos are mostly central (|eta|<1)







# Signal / Data

- Large “jet” (E>100 GeV)
- No tracks pointing to the jet
- All energy on one side of the detector (even if the other gluino stops and decays, it's unlikely it would be during the same bunch-crossing!)
- Unrelated to a p-pbar interaction
  - Require no min-bias interaction or underlying event to eliminate the beam-related background
- Use the DIFF skim, selecting only triggers:
  GapSN+CJT(2,3)+L3JET(15) – about 1Hz
  GapSN+CJT(2,5)+L3JET(45) – about 0.1Hz
- I've processed about 100/pb of PASS2 data: 3.6M events
  - Require MET>100 GeV
- Most of the events are not gluinos. Backgrounds include:
  - Cosmic muons (about half of all events)
  - Beam muons (the other half of the events)
  - Detector effects (50% of events that have no muon segs)
  - Other?
    - Cosmic neutrons?
    - Beam and cosmic neutrinos (yes, I'm serious!)?
    - Double-diffractive interactions?

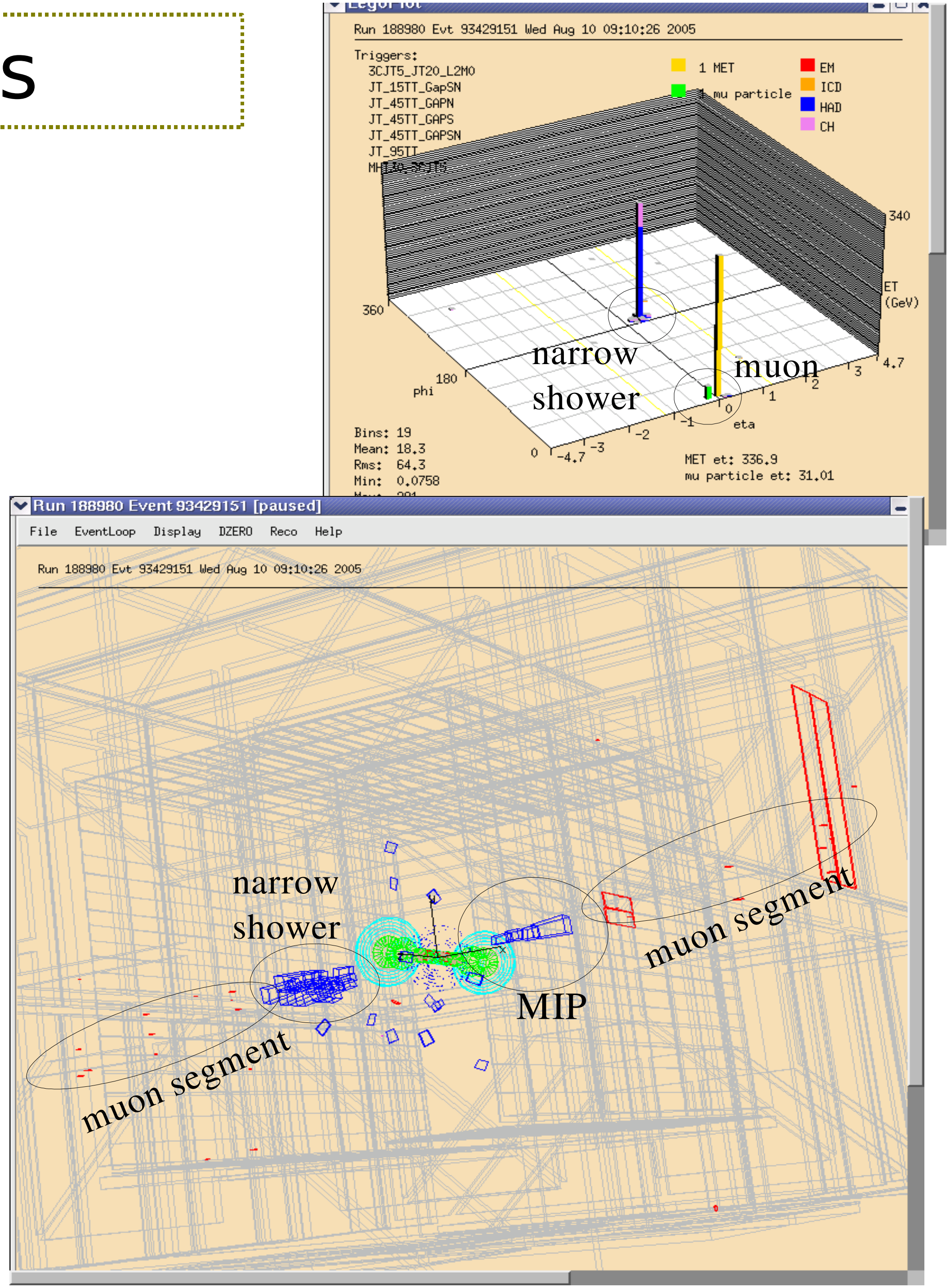
# Cosmic Muons

- Most of these are pretty clear…
- Usually at least one muon segment (nseg=-3,-2,-1)

  There are two chances to see the muon (on the way in, and going out)
- Showers in the calorimeter can be quite large (>1 TeV !)

  Hard Bremstralung photon

  Narrower than “jets”:
  - More energy in single cells / towers
  - Smaller phi-width and eta-width
- Usually an observable MIP trail



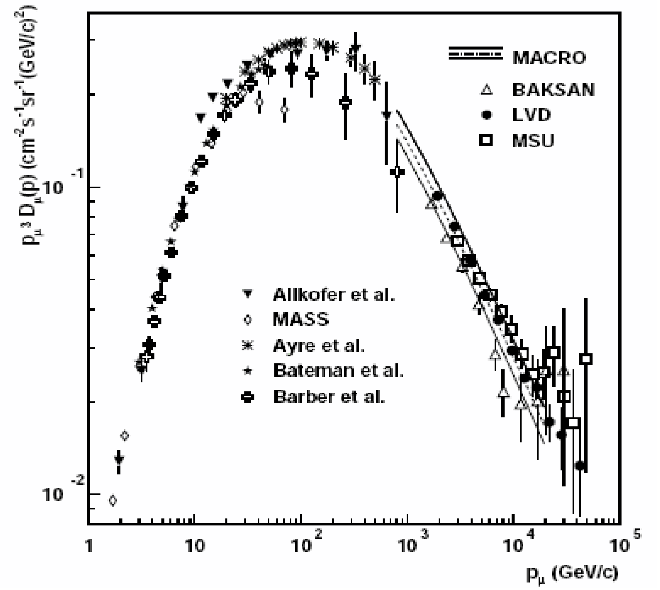
```
Run 188980 Evt 93429151 Wed Aug 10 09:10:26 2005

Triggers:
  3CJT5_JT20_L2M0
  JT_15TT_GapSN
  JT_45TT_GAPN
  JT_45TT_GAPS
  JT_45TT_GAPSN
  JT_95TT
  MHT30_3CJT5

Bins: 19
Mean: 18.3
Rms:  64.3
Min:  0.0758

MET et: 336.9
mu particle et: 31.01
```

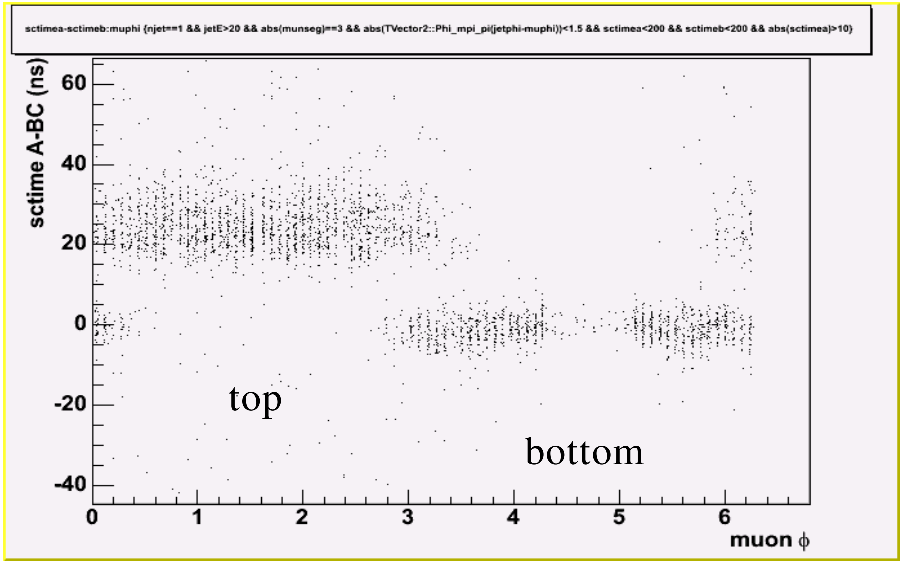
```
Run 188980 Event 93429151 [paused]
Run 188980 Evt 93429151 Wed Aug 10 09:10:26 2005
```

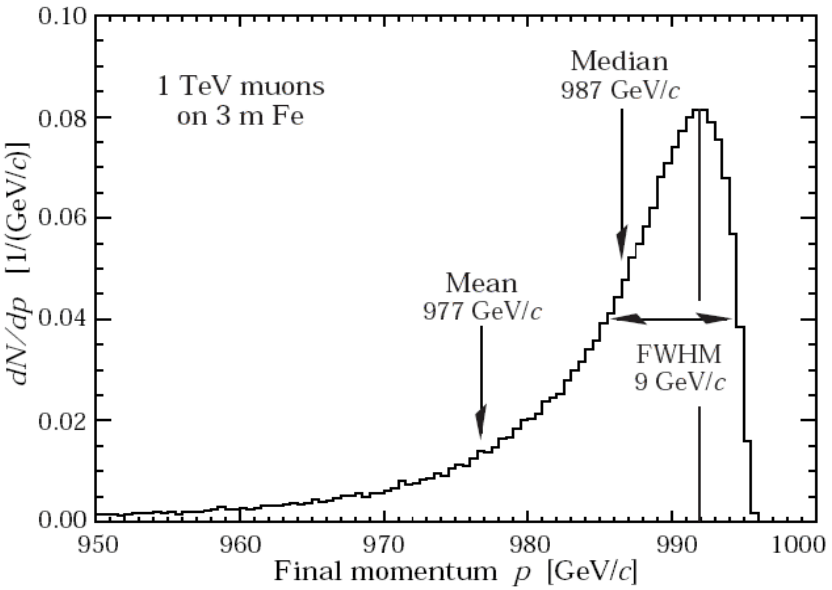
# Cosmic Muons

- The observed rate is consistent with expectations
  - Spectrum at sea-level is known: About $10^{-3}/\mathrm{cm}^2/\mathrm{s}$ above 100 GeV
  - Rate of hard Bremstralung is known: About 0.1% will lose >10% of their energy
  - $10\mathrm{m}^2 \times 10^{-3}/\mathrm{cm}^2/\mathrm{s} \times 0.1\% = 0.1\mathrm{Hz}$
- The muon and shower distributions are reasonable
  - Phi, Eta, and timing of muon scintillators

    Muons are coming from the sky, and are being blocked by the earth!





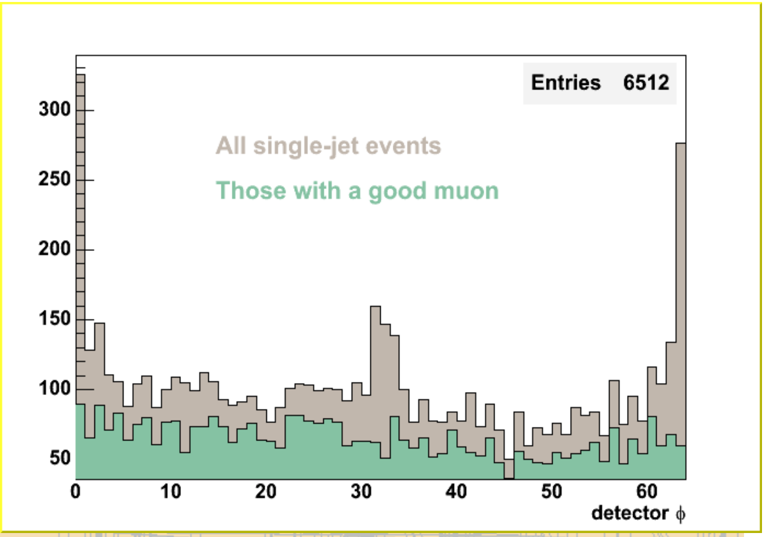


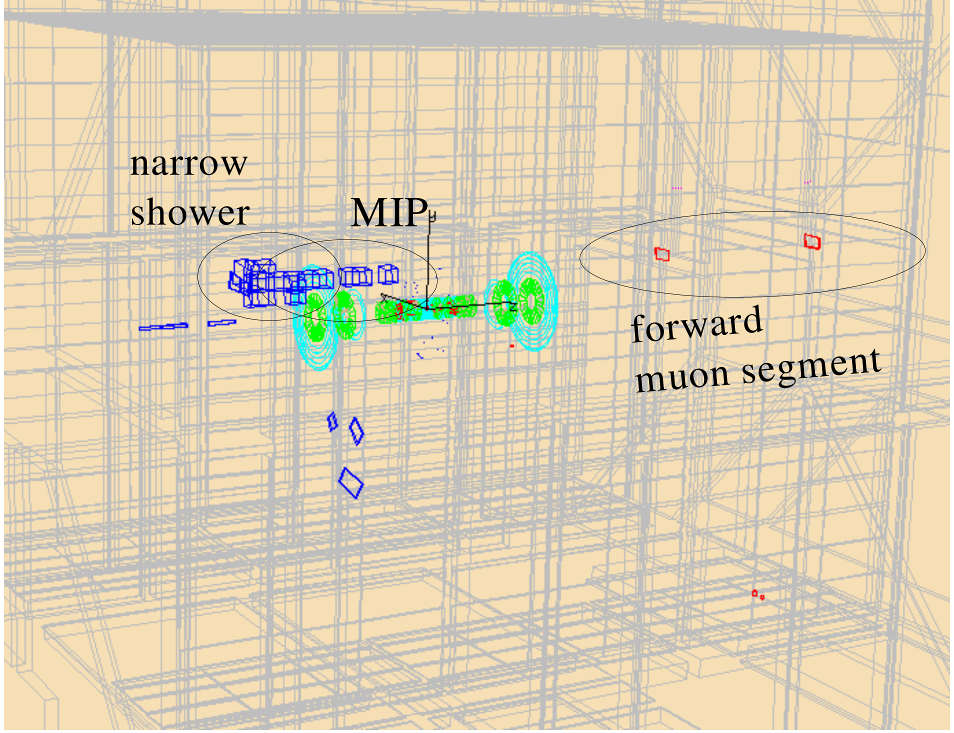
# Beam Muons

- There are a large number of events (about as many as cosmic muons) which I believe are “beam muons”
- Often a forward muon segment, or scintillator hits, or MDT hits
  - Scintillators are “in time” (|t|<10ns)
- Protons (or anti-protons) hit gas in the beampipe or the beampipe itself to create pions, which decay to muons
- Muons get bent by the dipoles, but have less momentum than the protons, so get bent to the “inside” of the ring -> phi=0

  Another class of beam muons can escape the beampipe earlier on the beam curve and end up at the “outside” ->phi=pi

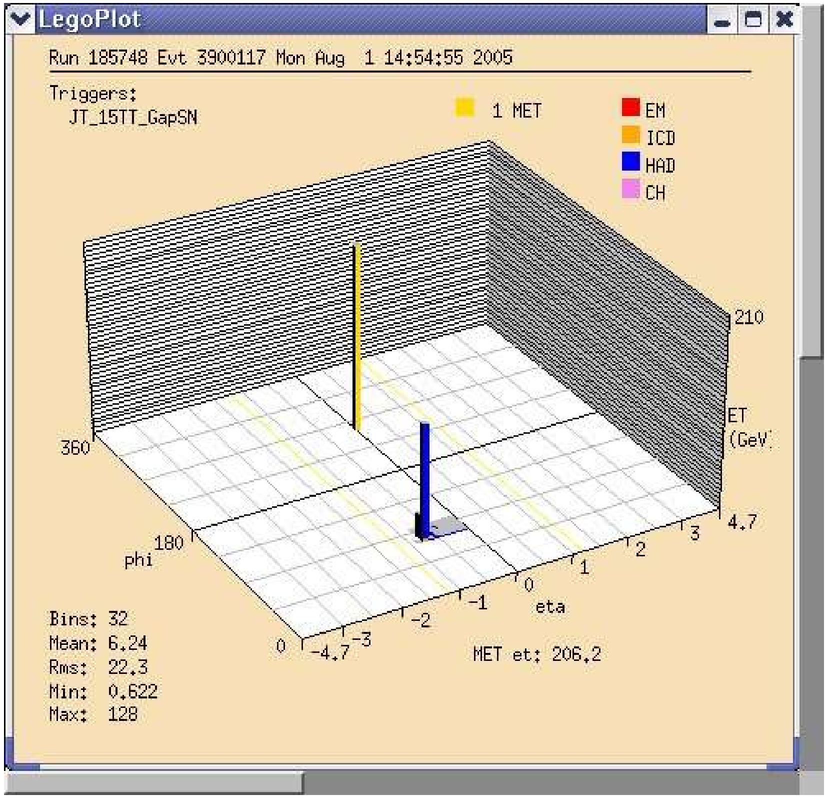
  Some beam muons are at the other phi locations, rather evenly, but 99% are within dphi=.2 of phi=0 or pi
- The MIP trail of the muon is usually visible
- The shower is very narrow in phi (phiwidth<0.05)
  - A typical jet has phiwidth>0.1





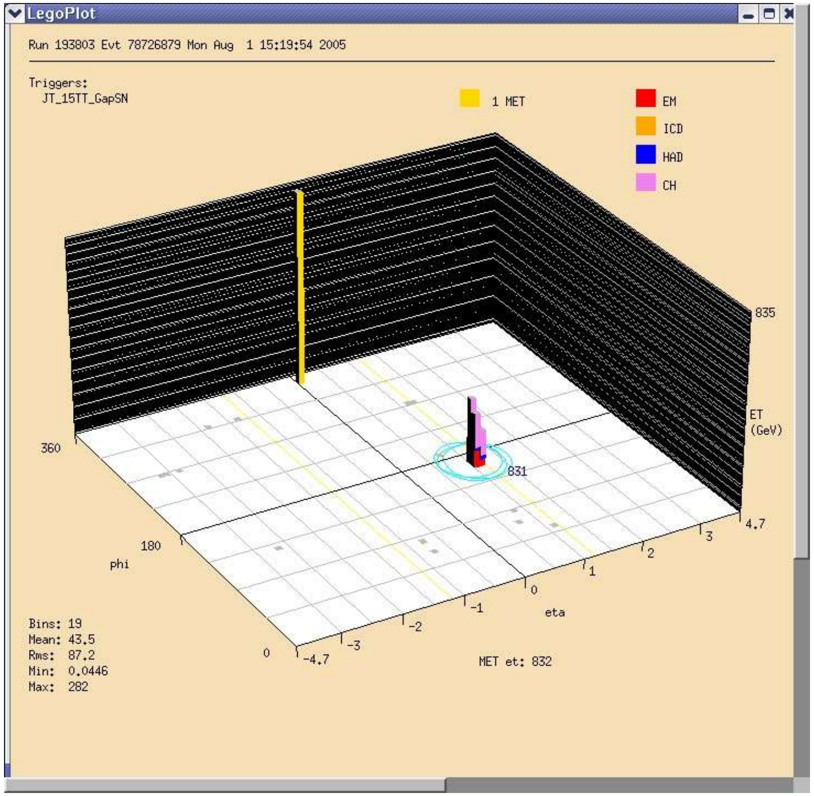
# “Detector Effects”

- Detector problems tend to be in isolated runs, and manifest themselves in isolated regions of the detector
  - These are easily cleaned… even if it is “by eye”



```
Run 185748 Evt 3900117 Mon Aug  1 14:54:55 2005
Triggers:
  JT_15TT_GapSN
MET et: 206.2
Bins: 32
Mean: 6.24
Rms:  22.3
Min:  0.622
Max:  128
```

There are ~100 of these events with a “jet” at eta=~.7 and phi=~1.35
Not in any isolated set of runs…



```
Run 193803 Evt 78726879 Mon Aug  1 15:19:54 2005
Triggers:
  JT_15TT_GapSN
MET et: 832
Bins: 19
Mean: 43.5
Rms:  87.2
Min:  0.0446
Max:  282
```

Run 193803 has lots of events like this…

# Background Estimation

- Understanding the number of expected background events which would pass the muon, MIP, and jet shape cuts is crucial
- We can make progress by assuming that the probability of passing each of these cuts is uncorrelated
  - This assumption can be tested, since we have 3 variables… signal free. For jets failing shape cuts, is there a correlation between losing the muon segments and losing the MIP trail?
- Look at muon events (with a reconstructed muon) and look at how often we miss the MIP trail and how often we fail the jet shower width cut
- Look at very narrow jet showers with a MIP trail, and measure how often we miss the muon
- The final probability to fail all 3 cuts is then just:

  $P_{back}$ = P(no muon) x P(no MIP) x P(good jet)

- The final number of expected background events is then simply:

  $N_{back} = N_{muon}/(1-P_{back}) \times P_{back}$

# Other Backgrounds

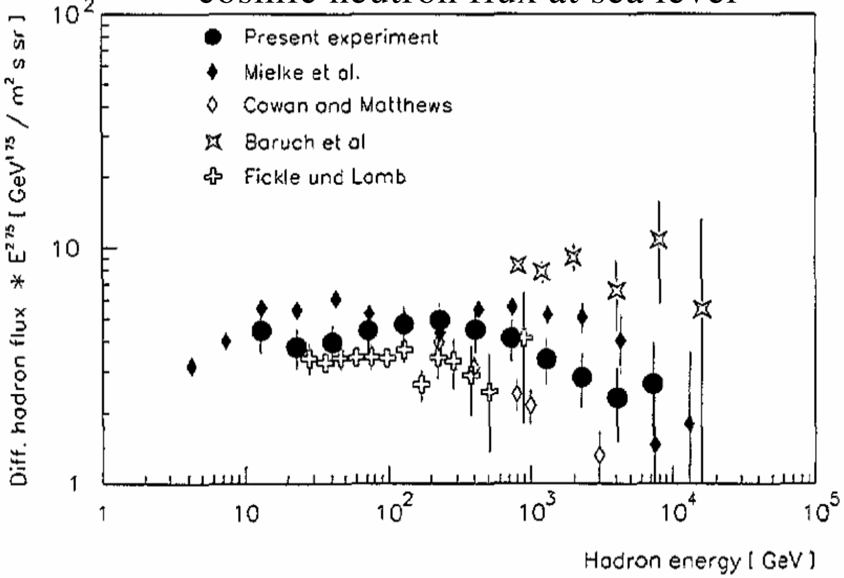
- Cosmic neutrons reach sea-level.
  No muon segment, no MIP trail, wide shower!
- The rate is 1/1000th of cosmic muons at the same energy… i.e. ~1/hour on detector
- They would have to get through the iron toroids this seems difficult
- Neutrons that did get through would deposit most of their energy in the Coarse Hadronic calorimeter (on the outside), and at the top of the calorimeter
  - This would be a good discriminant
- Neutrinos (!) would be a small background:

  Assuming a 1/1 ratio of muons/neutrinos from cosmic and beam sources

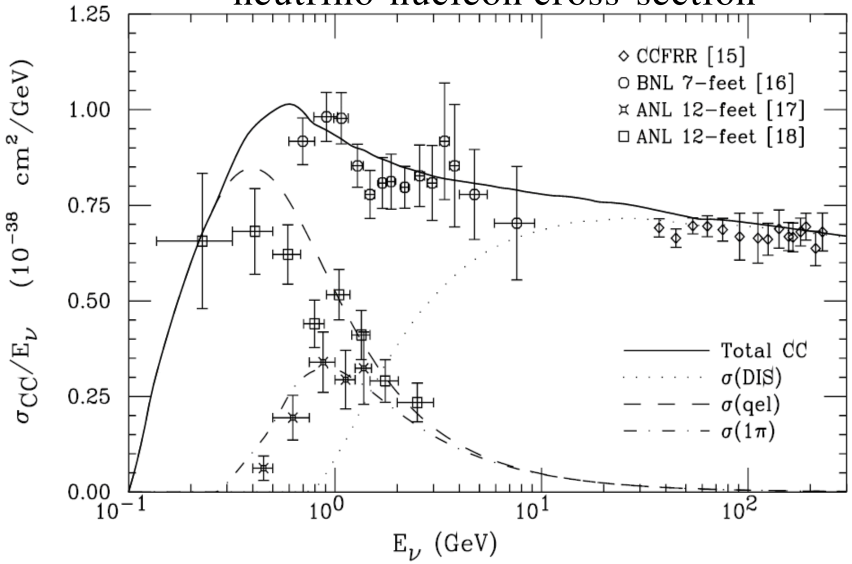
  0.1 Hz / 0.1% Brem * 6e23 * 17g/cm$^3$ / 238 g/mole * 400cm * 10e-38cm$^2$/GeV * 500 GeV =

  10e-8Hz = 0.1/year
- Could double-diffractive events slip through, giving jets with no tracks? How would you get large MET? No sign of these leaking through, so far.

cosmic neutron flux at sea level



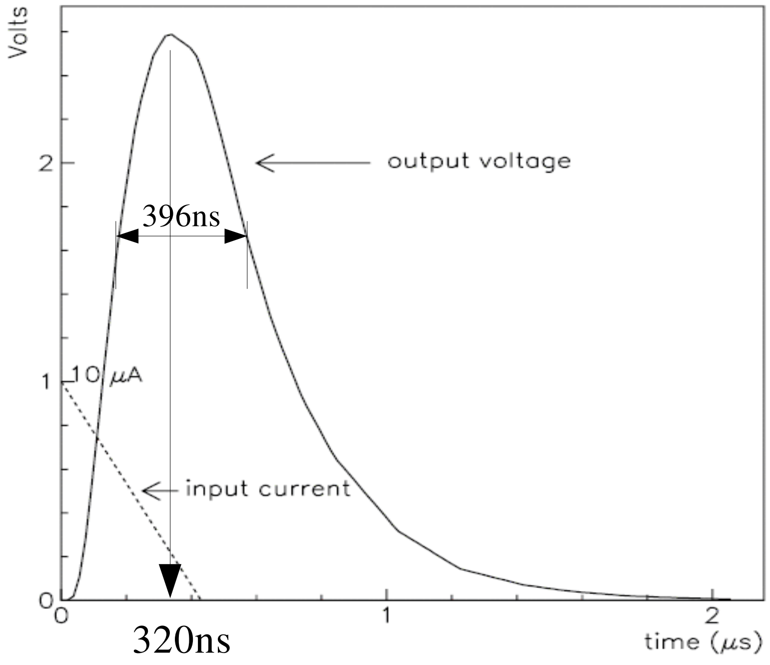
neutrino-nucleon cross-section

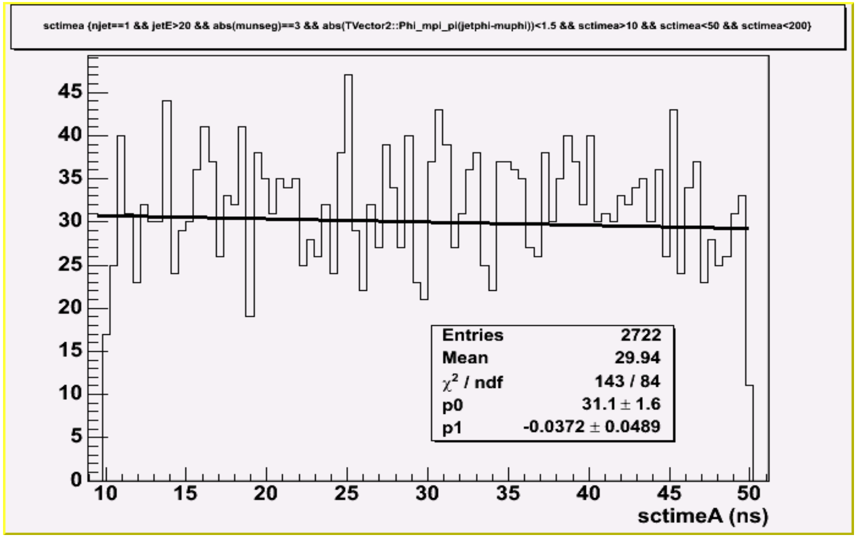


# Signal Efficiency

- The events have high energy deposits, trigger ~100%
- Offline, conservatively:
  - 90% have no MIP trail, 90% pass jet shower shape cuts, 90% have no muon segments.
    Overall efficiency: ~70 +- 20 %.
    More careful studies could be done...
- However, the energy deposits are “out of time” !
  - We only sample the energy ONCE, when the shaped signal is expected to be at its maximum
  - If the energy is “early” then we have to worry about BLS removing part of the signal energy
  - What happens at L1??? I've got rough answers from Dean, but need to talk to Dan Edmunds.
    The shaping time is much shorter (~120ns?).
    But there's no BLS...
    An estimate could be made using unbiased muon-triggered cosmic events.
- No falloff observed in the number of muon-induced calorimeter showers, vs. muon time
  - But muon window only goes out to ~60ns, and I would expect the calorimeter response to start to fall off after ~140ns...
  - The number within the muon scintillator time window (10-50ns) in a run is 2983 and outside there are 17254. Assuming the full event time is 396ns gives an estimate of the falloff:
    [(17254-2983)/2983] / [(396ns-40ns)/40ns] =~ 50%

    Comparable to a 50% decrease in measured energy.





# Current Results / Future Studies

- I am left with ~5 events in the 100/pb with:
  - E>200GeV
  - No muon segments or muon hits which line up with the calorimeter cluster
  - Jet phi width >0.05
  - No observable MIP trail
  - Does not fall into a “detector effect” pattern
- Assuming that each cut is 2% inefficient, the number of observed events is roughly explained by the number of background events we would expect to pass all the cuts
- Future plans / work:
  - Optimized and automated muon-segment, jet-shower, and MIP-trail cuts
  - A more precise estimate of the “muon backgrounds”
  - An estimate of the contributions from “other backgrounds”
  - A more precise estimate of the L1 trigger and offline inefficiency due to out-of-time energy
  - Look for time-coincidences in candidates (since 30% of the time, both gluinos stop, if one does)
  - Search for “di-jet” signature, since G->q+q+MET ~50% of the time
  - Claim discovery or set limits!