Long-lived Particles Decaying in the Calorimeter: From D0 to ATLAS

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First, me in a nutshell...

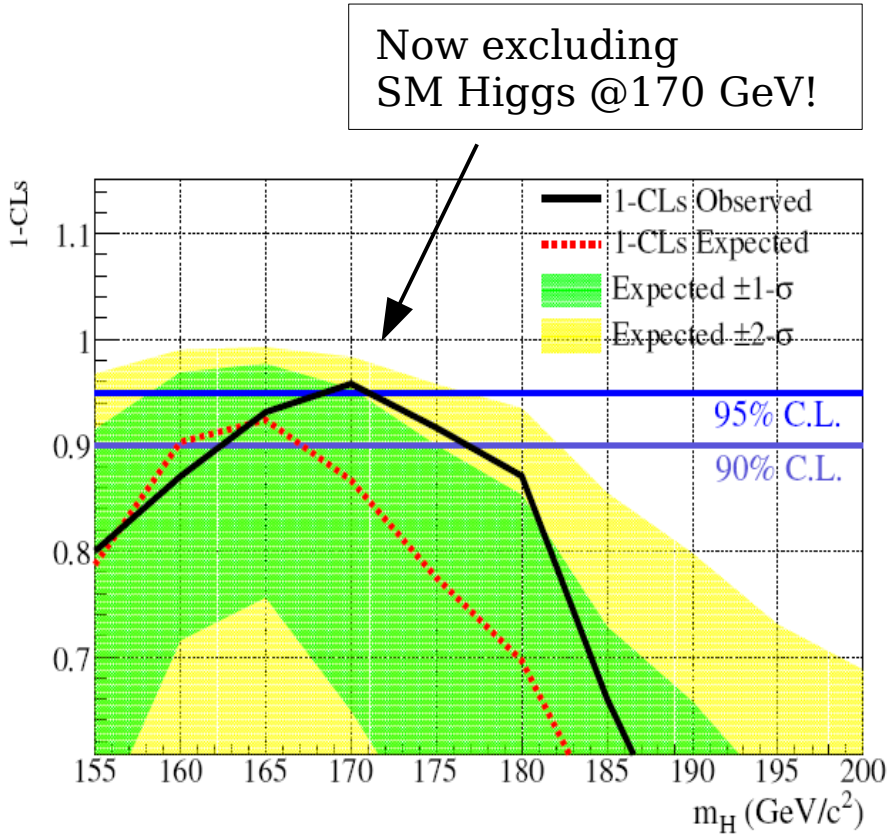
Brown U. -> U. of Washington -> Columbia U. ->
Likely joining the SLAC ATLAS group soon!

On D0 at the Fermilab Tevatron since 1997

- Ethernet DAQ / Level 3 trigger system
- In situ hadronic calorimeter calibration (di-jet balancing)
- Track reconstruction / event display
- Bottom-quark ID (b-ID co-convener, 2005-7)
- Higgs group co-convener since 2007

MSSM Higgs bosons in the bbb(b) final state
Stopped Gluinos decaying the D0 calorimeter
SM Higgs boson in ZH->ll+bb
SM Higgs boson in H->WW->ll+MET
Also working on:

- h->aa->4mu, 2mu+X
- Hidden Valley (long-lived -> bb)



First, me in a nutshell...

Also worked ~2 years on ATLAS (2004-6)

LAr Calorimeter Frond-end Readout Boards (FEBs)

- Life-time testing
- Installation and commissioning at CERN
- Online data quality monitoring

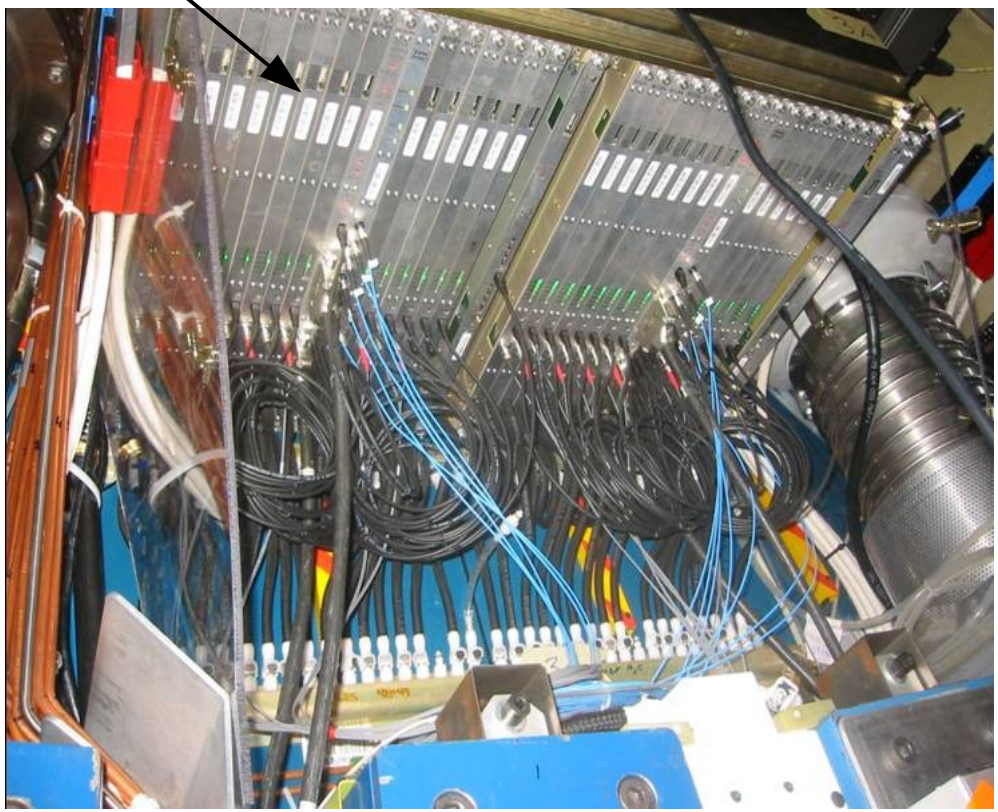
ATHENA analysis

- MC search for h->bb in SUSY events

Atlantis Event Display

- Added “lego” plot
- Calorimeter data display

First EM barrel readout crate



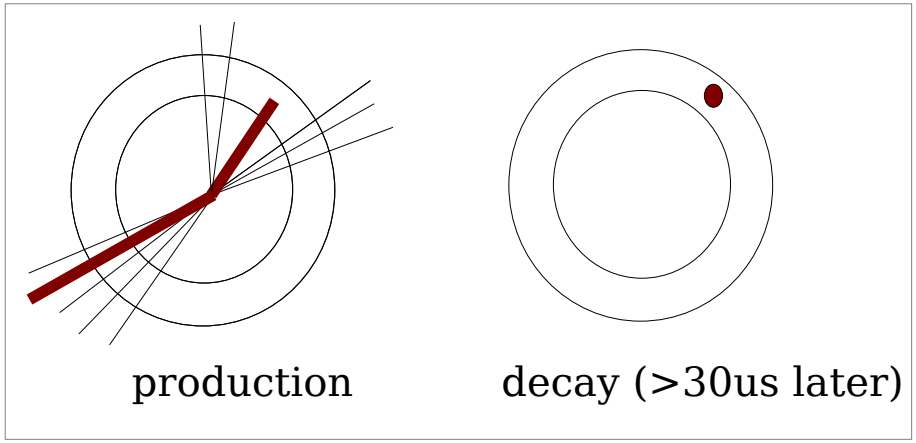
Stopped Gluinos

Split SUSY -> gluino is long-lived

- *hadronizes* into “R-hadrons”

Some lose enough momentum through ionization to *stop in the calorimeters*

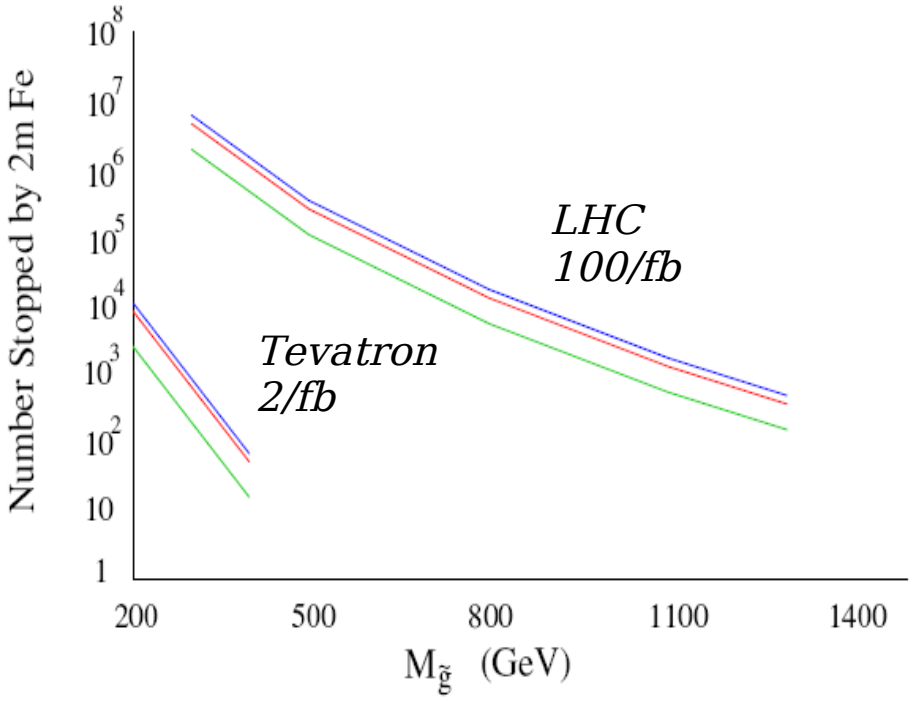
- Decay *later* into gluon+LSP
- Lifetime depends on M_{SUSY}
- See hep-ph/0506242, J. Wacker et al.



Signature:

- Large, isolated energy deposit in the calorimeter
- Rest of the “event” very empty

Some production at Tevatron, more at LHC !



D0 Search for Stopped Gluinos

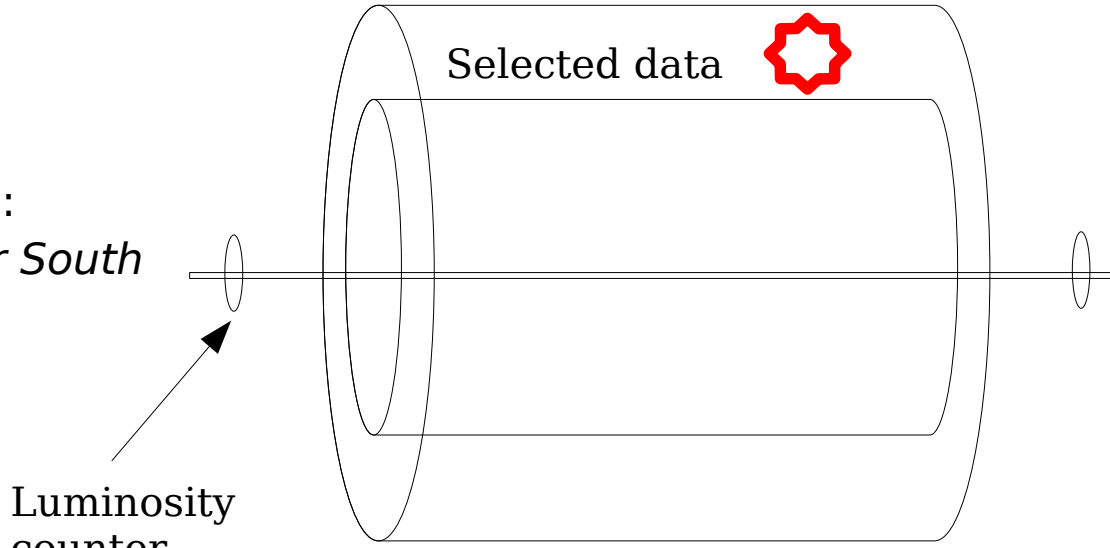
Want to trigger on “empty crossing”
(no inelastic p-pbar scattering)
with a large calorimeter shower

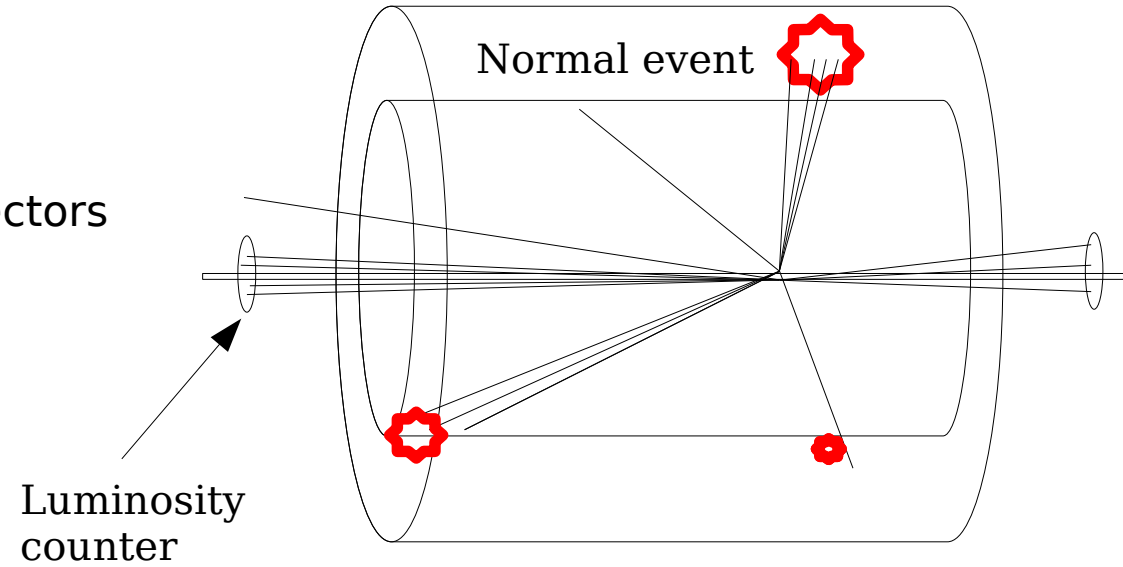
Use triggers designed for diffractive physics:

- Require *no hits in either the North or South luminosity counters (scintillators)*
- 3 cal towers > 5 GeV L1/L2
- E_T > 45 GeV “jet” at L3

Offline pre-selection cuts:

- Require one jet with E>90 GeV
- Veto on any other jets (above E_T of 8 GeV)
- No vertex found using tracking detectors





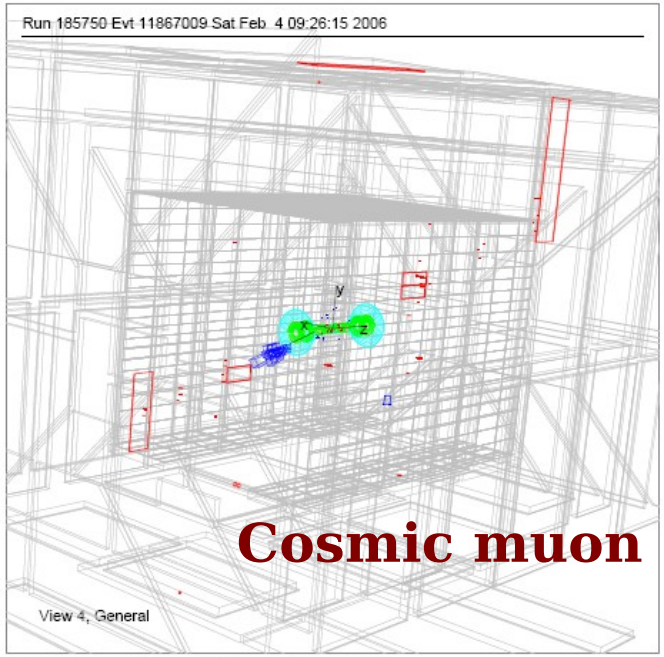
Backgrounds – Cosmics

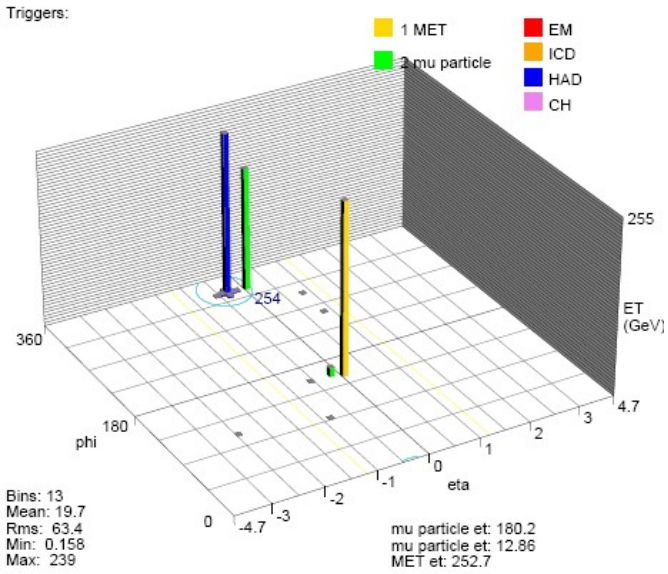
A major background, due to high rate

Usually at least one reconstructed muon segment

Hard Bremsstrahlung photon is dominant
- Narrower showers than “jets”

But *hadronic* showers are also possible
- Inelastic nuclear scattering





Estimate rate of cosmic hadronic showers without muons
by looking at rate of cosmic *narrow* showers without muons

Probability to not reconstruct muon is 11+-1%
- Coverage only up to eta of 2.0

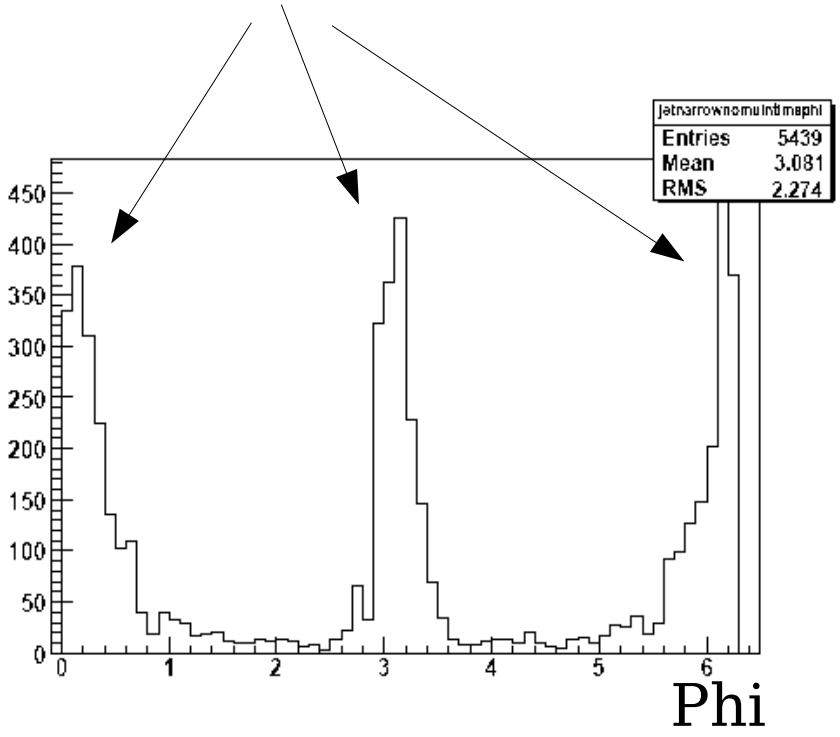
Backgrounds – Beam Muons

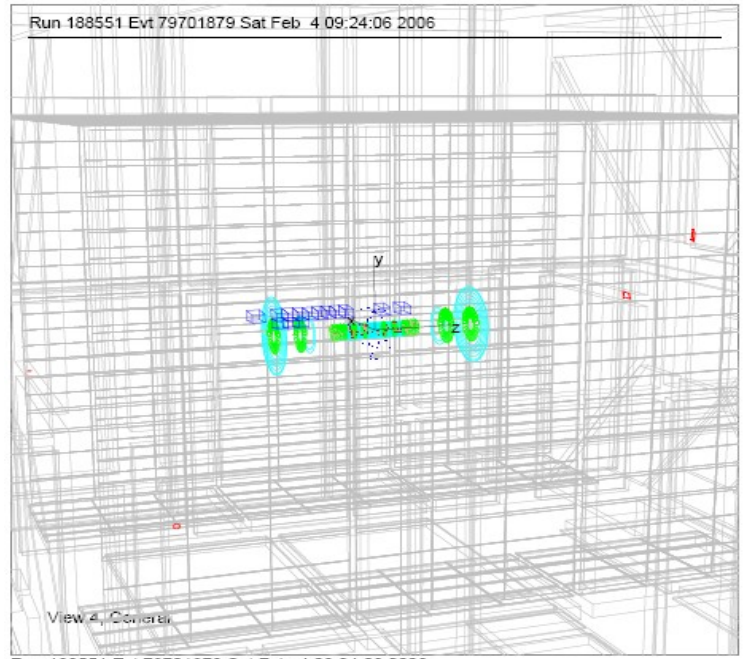
Protons (or anti-protons) hit gas or the beampipe and create pions, which decay to muons

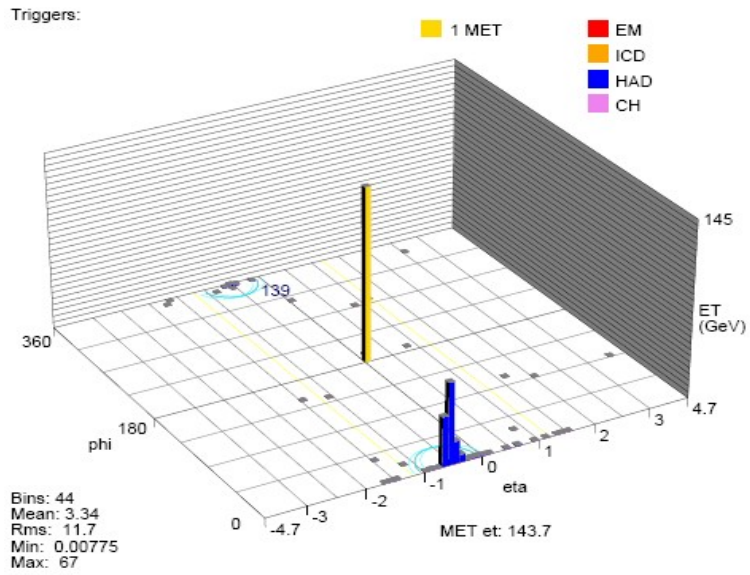
Shower is very narrow in phi but wide in eta

Often a forward muon segment, or scintillator hits... “in time” with bunch crossing

In the plane of the beam!







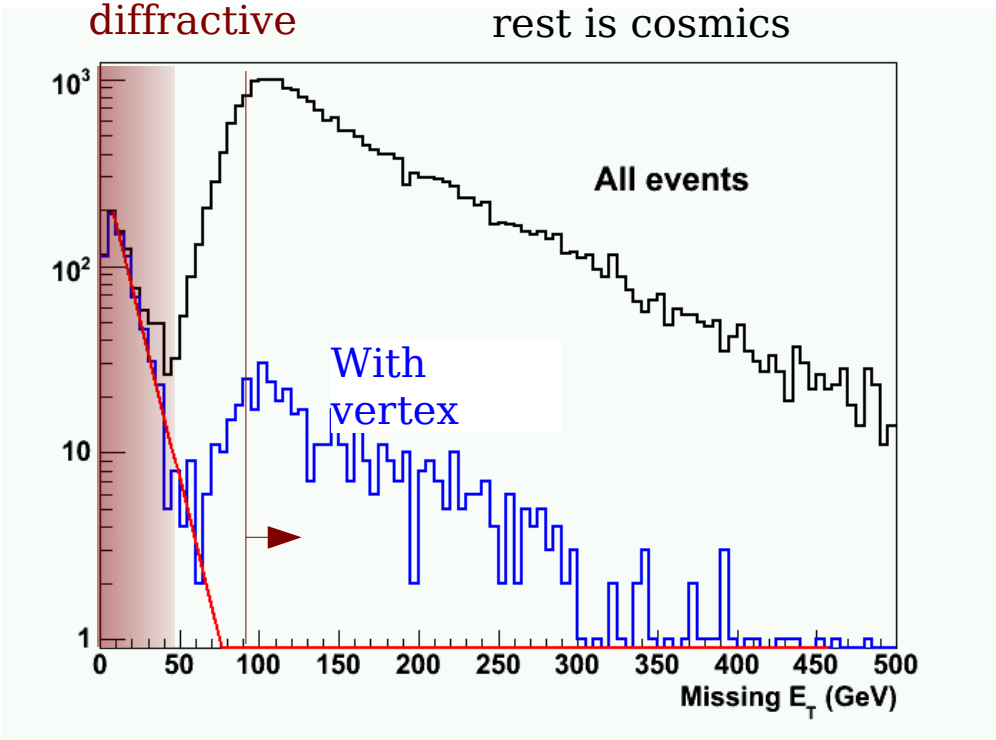
Other Backgrounds

Diffractive events
- Negligible at high MET

Detector / readout / noise problems
- Localized areas of the calorimeter
- Localized run periods
- Different jet “shape”

Cosmic neutrons
- 1/1000th the muon rate
- Would shower preferentially on outer calorimeter

Cosmic neutrinos
- Assuming same rate / spectrum as cosmic muons, expect rate of 10^-8 Hz
- 0.1 event / year!

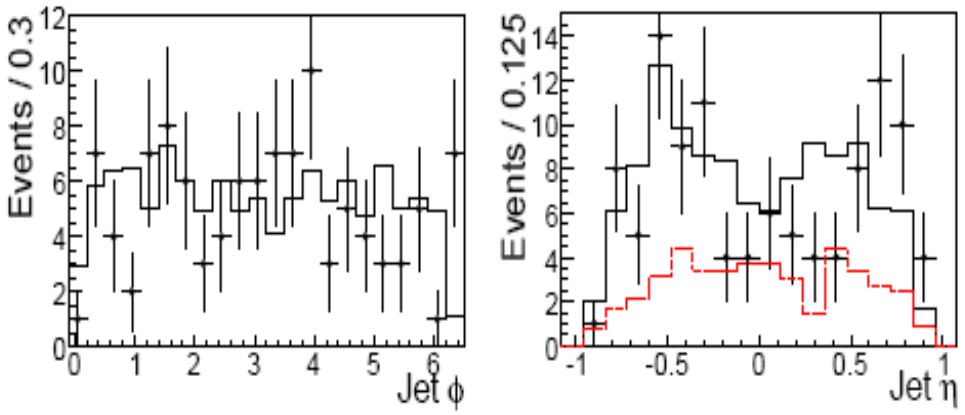


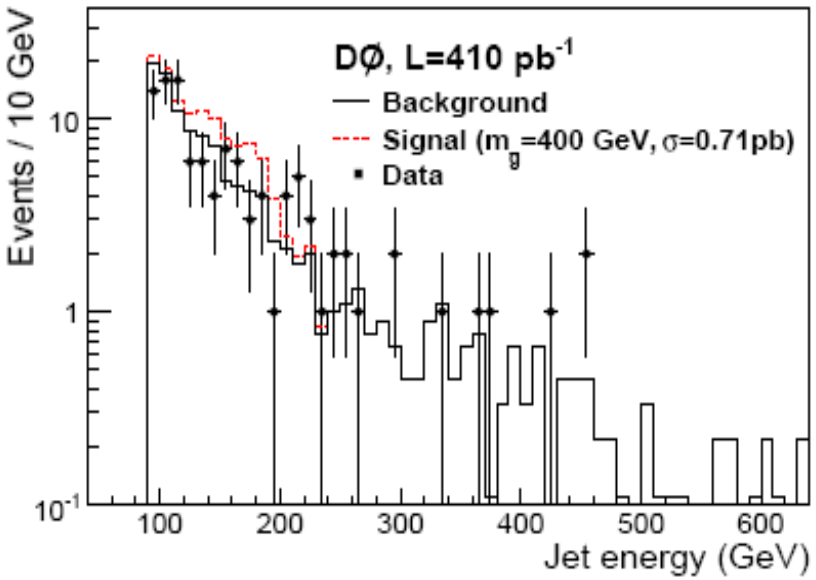
Data / Background Comparison

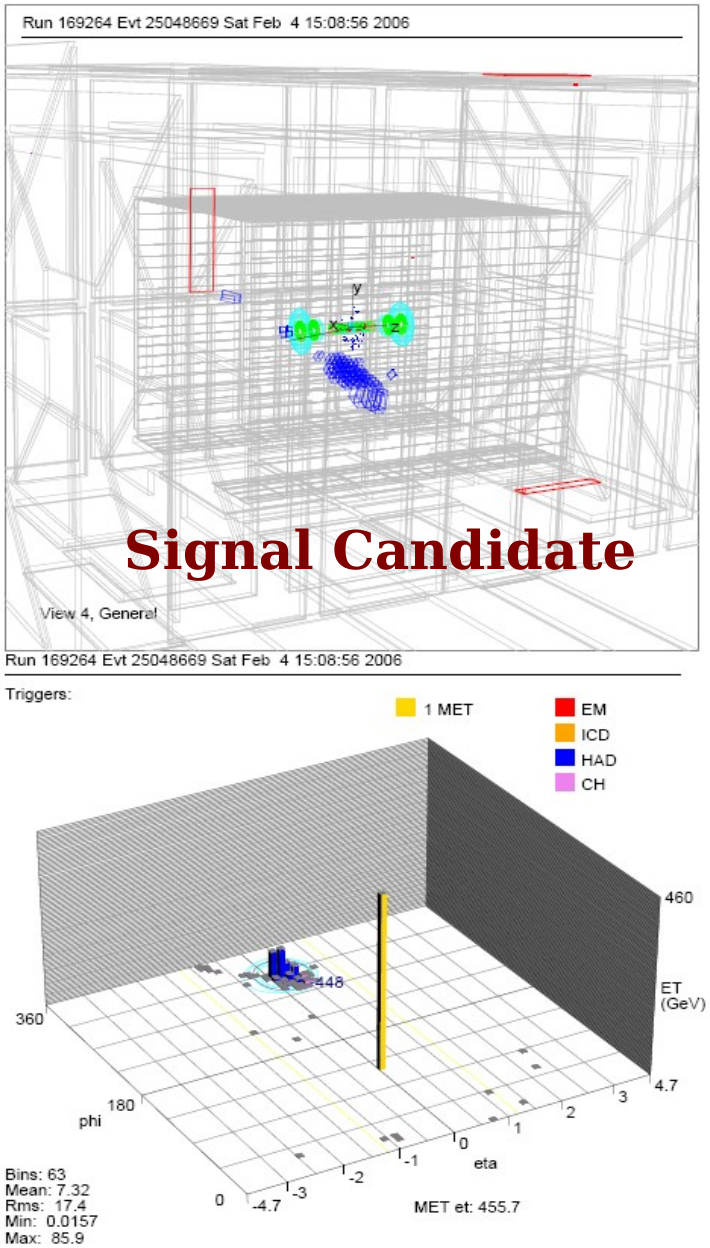
Data looks like background

Exclude signals...

- but need to know signal efficiency!





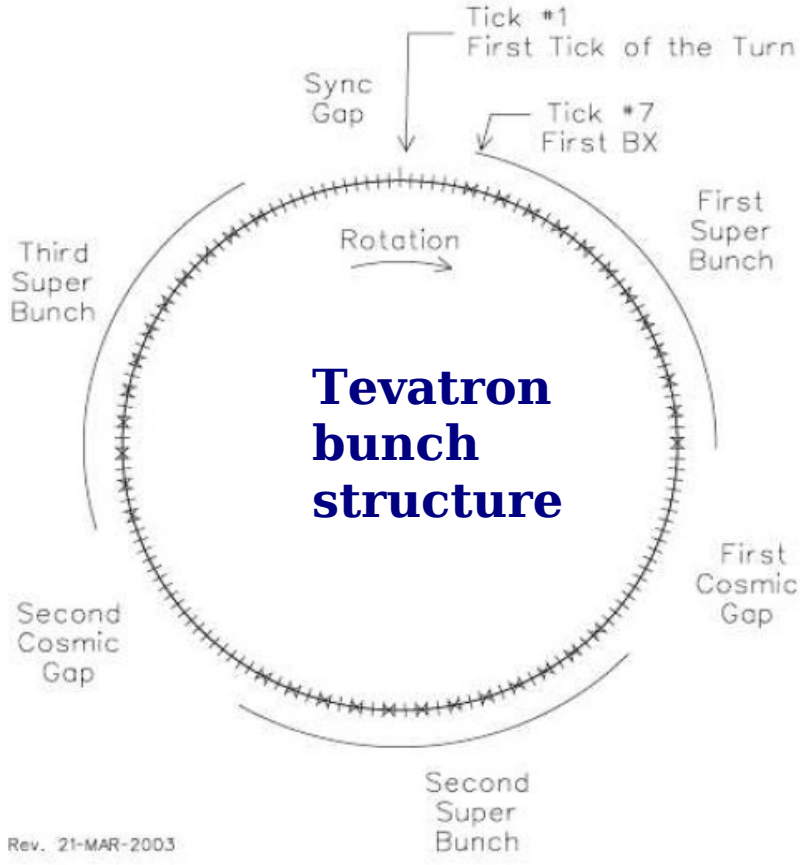


Trigger Efficiency

Dead during “accelerator gaps”
(66% efficient)

- D0 can't easily trigger there, otherwise a great place to look!

Dead during inelastic collisions
(60% efficient)

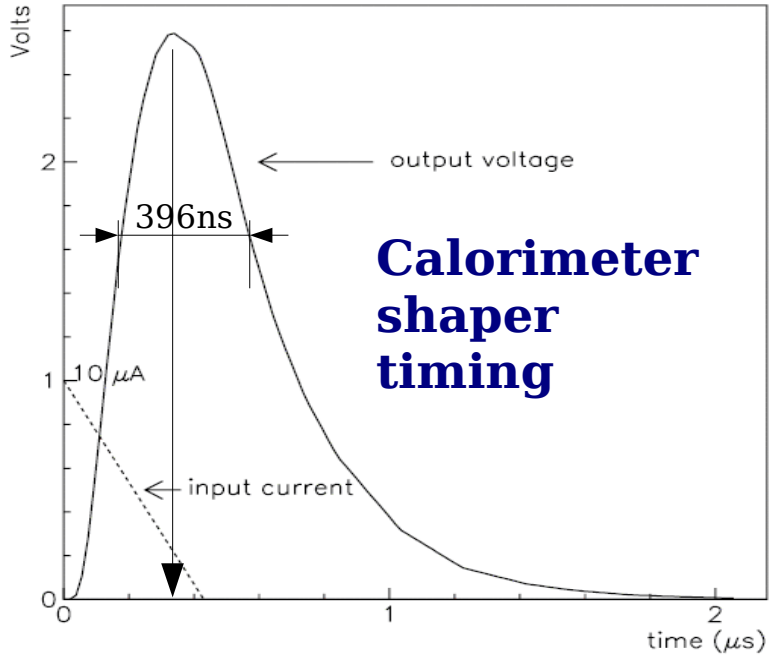


Signal Energy

Calorimeter electronics sample the shaped pulse in each cell only *once per 396ns*
– at the assumed signal peak

Out of time energy under-estimated!

Simulate using info from *calibration pulses* →

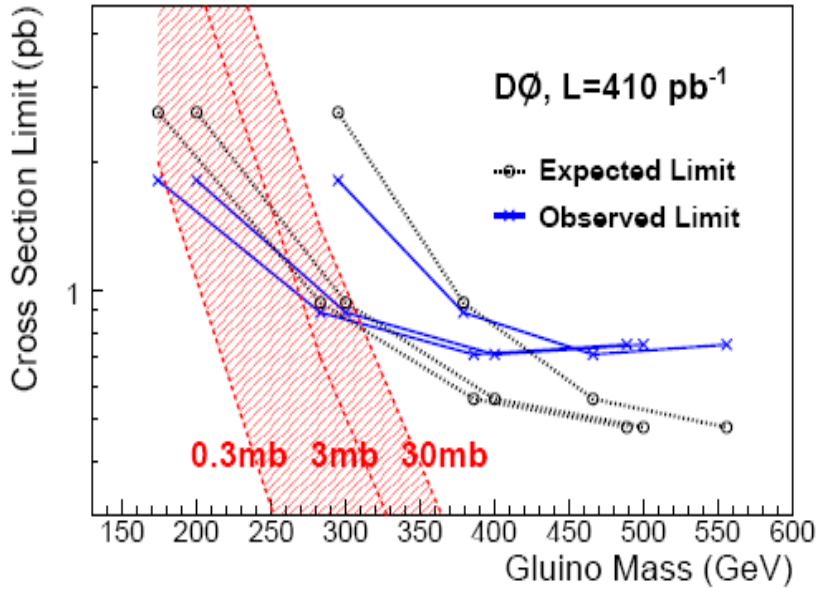


Complicates estimate of trigger efficiency too

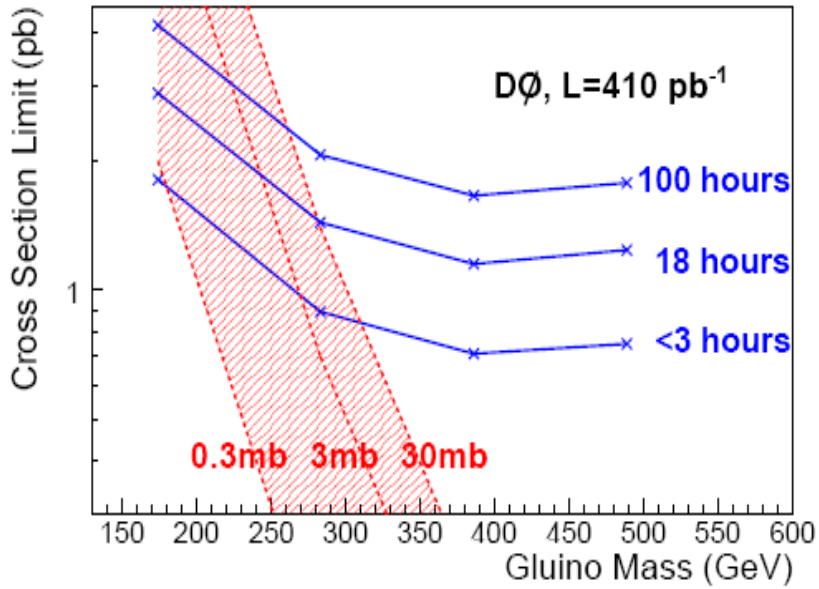
Results

Consider various gluino / neutralino masses

Consider various gluino lifetimes



Exclude gluino masses < ~250 GeV



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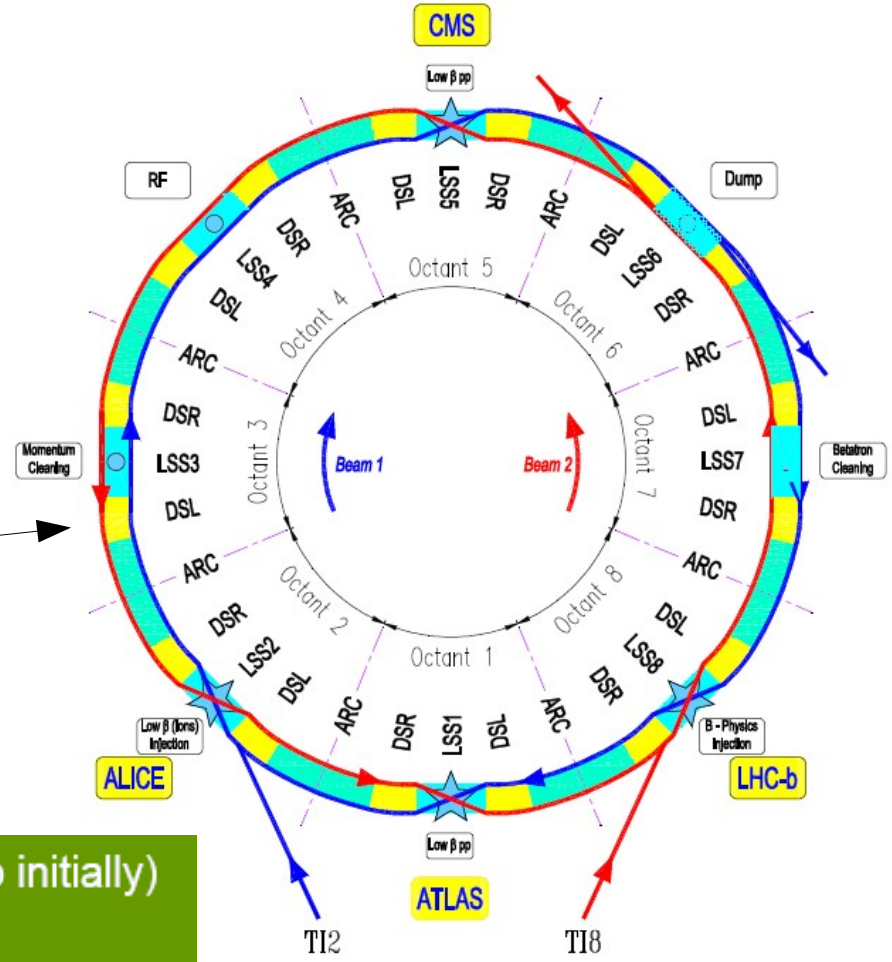
ATLAS Search for Stopped Gluinos

Problem: many inelastic interactions / crossing!



Trigger during “gaps”

- No bunches colliding
- Various “bunch groups”:

Bunch groups (would be good to keep 1 item per bunch group initially)

- BG0: BCR Veto during long gap
- BG1: filled paired bunches for physics triggers
- BG2: empty bunches during long gap for calibrations requests
- BG3: empty bunches for cosmics, random noise and pedestal triggers
- BG4: unpaired bunches for beam background studies clockwise
- BG5: unpaired bunches for beam background studies anti-clockwise
- BG6: empty bunches just after a filled bunch

Possible ATLAS Trigger

Require BG3,4,5,or 6

L1: “L1_J5”
- Cal tower above ~5 GeV
- Can be very loose, rate should be low!

L2: nothing?

L3: Jet E>20 GeV (pre-scaled),
50 GeV (not pre-scaled)

Aim for total rate of ~0.2 Hz

Muon cosmic terms already exist!

Can be used to measure efficiency / study out-of-time dependence of calorimeter triggers.

Bunch groups (would be good to keep 1 item per bunch group initially)
- BG0: BCR Veto during long gap
- BG1: filled paired bunches for physics triggers
- BG2: empty bunches during long gap for calibrations requests
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Out-of-time Energy

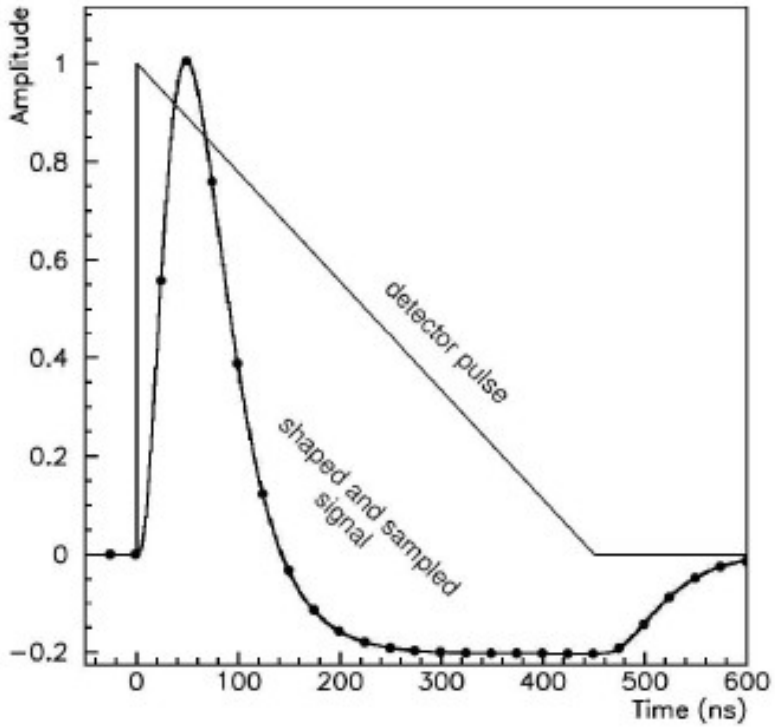
L1 LAr calorimeter can trigger every 25ns

- Some modification to measured energy when signal is out-of-time

Offline / L3 gets *5 samples*

- **measured time (+- few ns)**
- correct energy

TileCal out-of-time response???



Known Unknowns

What is the high-energy cosmic background rate?

Can be studied now using ATLAS cosmic data!

- Yes, we're 100m underground
- But there's no 1m-thick Iron-toroid magnet!
- How good is the muon system coverage and efficiency to reject cosmic muons? (especially when they're “out-of-time”?)

How empty will the accelerator gaps be?
(pileup? beam-gas?)

Beam-muon background?

Tile-cal out-of-time response???

Summary

D0 search for Stopped Gluinos (>~250 GeV)

- Based on empty bunch crossings

ATLAS search

- Base on accelerator gaps
- Several unknowns

Should be very sensitive

Will collect first data soon

Surpass Tevatron limits with first year's physics data (~1/fb)

Interesting and fun analysis

Ideal topic for a student and/or postdoc