DØ New Phenomena Searches*

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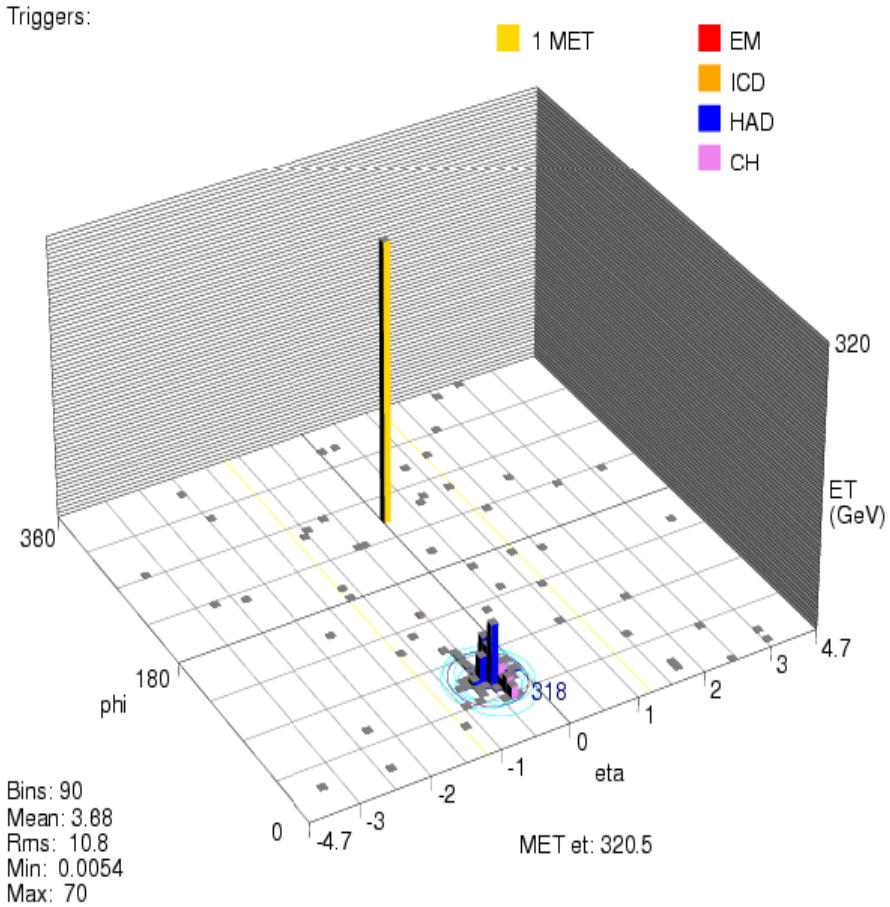
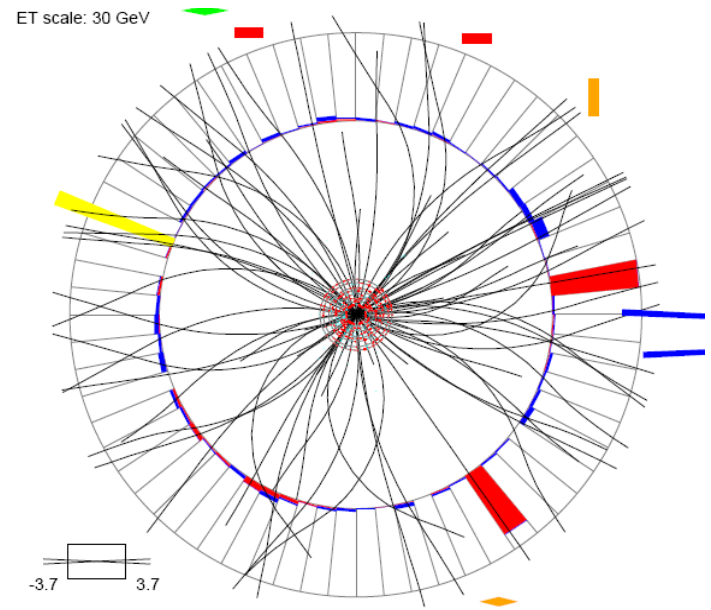
CDF/DØ/Theory
New Phenomena Workshop
Oct. 16, 2006

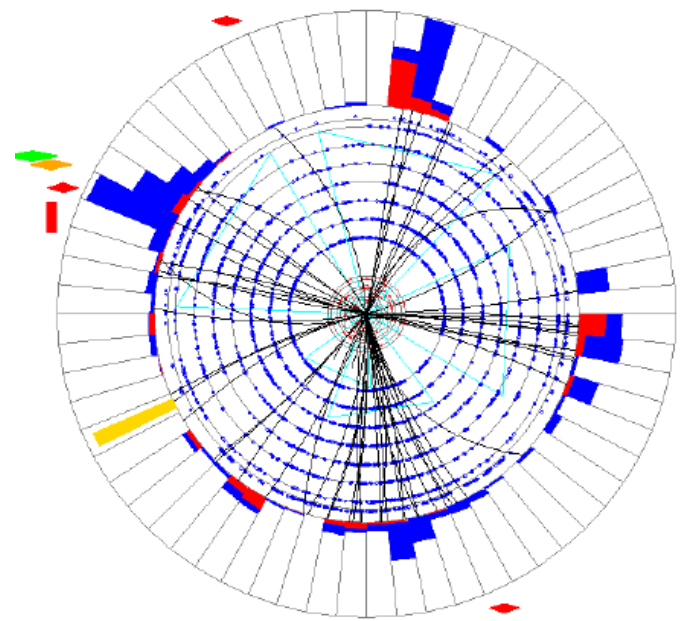


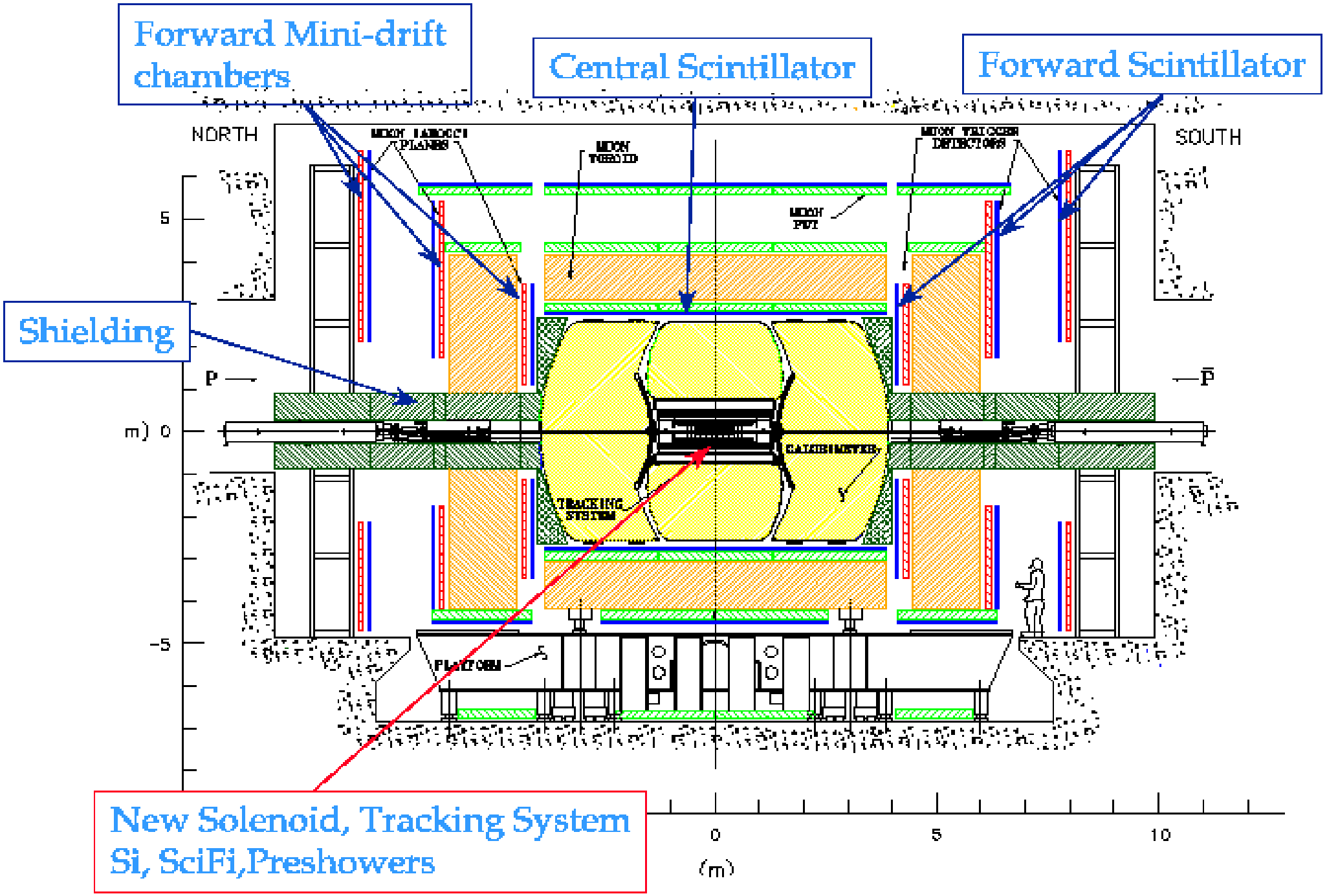
*Other NP topics are being covered in the CDF talk...

Outline

- The D0 detector, and improvements for Run IIb
- MET+leptons
  - Chargino/neutralino ("tri-leptons")
  - RPV SUSY
- Jets+leptons
  - Scalar top (cc+MET, t->b l nu)
  - RPV SUSY resonant sleptons
  - Resonant Z+jets
  - Technicolor
- Other searches
  - Stopping Particles -> Late Jet +mET (Split-SUSY inspired)
  - Charged Massive "Stable" Particles (Anomaly-mediated SUSY-breaking inspired)
  - Neutral Long-Lived Particles (->mumu) (RPV SUSY / NuTeV, inspired)
- New searches on the horizon...






Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
Shielding
New Solenoid, Tracking System
Si, SciFi,Preshowers
NORTH
SOUTH
MUON TOROID
MUON PIT
TRACKING SYSTEM
CALORIMETER
PLATFORM
P
P̄
5
0
-5
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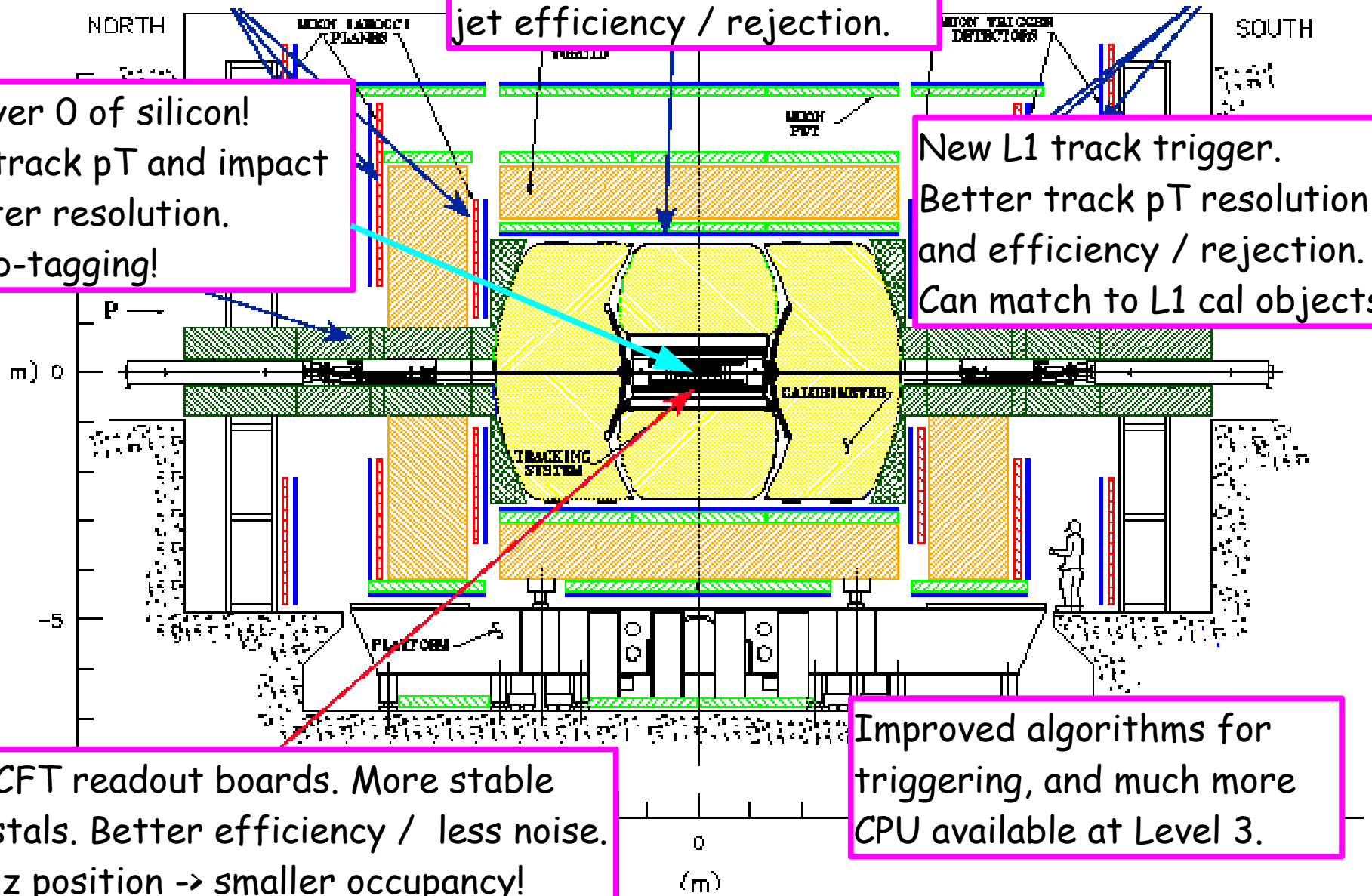
10
(m)

New L1 calorimeter trigger. Much better electron and jet efficiency / rejection.

New Layer 0 of silicon! Better track pT and impact parameter resolution. Better b-tagging!

New L1 track trigger. Better track pT resolution and efficiency / rejection. Can match to L1 cal objects!

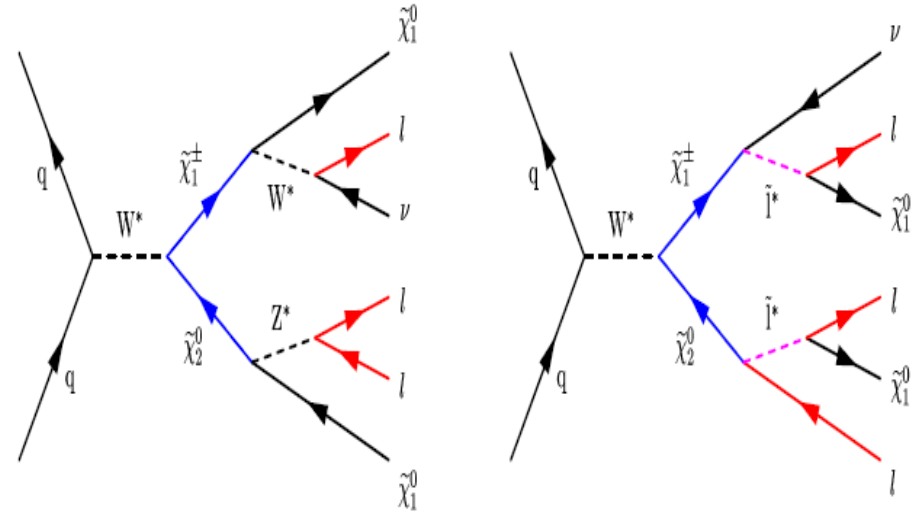


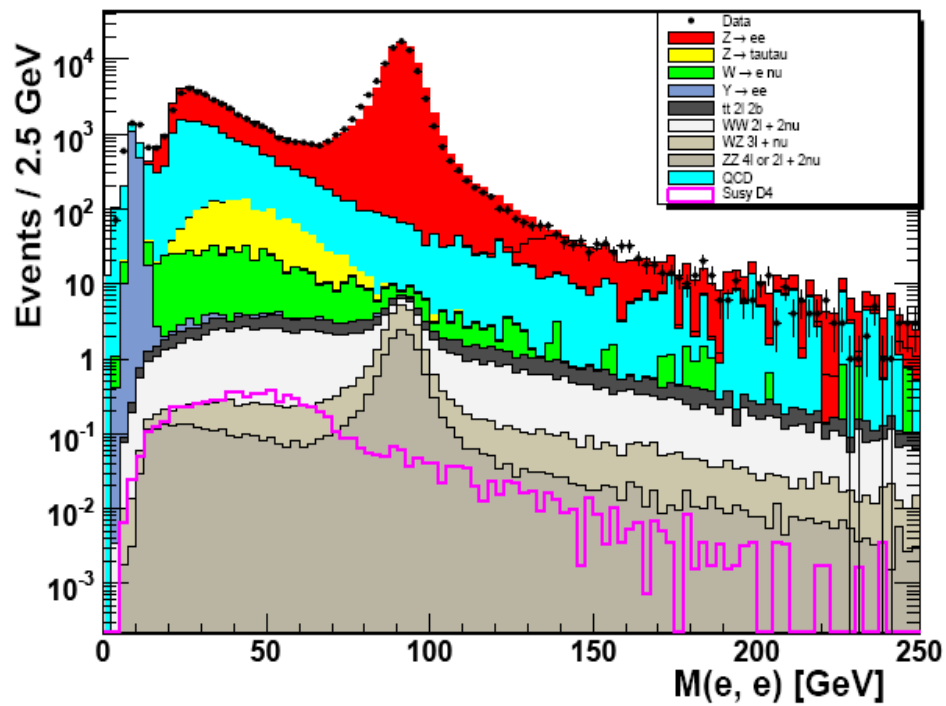
New CFT readout boards. More stable pedestals. Better efficiency / less noise. Read z position -> smaller occupancy!

Improved algorithms for triggering, and much more CPU available at Level 3.

Chargino/Neutralino: “tri-leptons”

- Combine analyses for
  - 2 e,mu,or tau + lepton (6 combinations!), and like-sign mumu+lepton
  - “lepton” can be either an isolated e,mu,tau or track
- Typical cuts:
  - pT leading leptons > 12, 8 GeV
  - 18<M<60 GeV, dphi<2.9 (anti-Z/Y)
  - Ht<80 GeV (anti-tt)
  - Isolated* track pt3 > 4 GeV
  - mET > 22 GeV, Sig(mET)> 8
  - mET x pt3 > 220 GeV
- *Isolated means:
  - Sum track pT < 1 GeV in hollow cone of 0.1<dR<0.4
  - Cal pT < 3 GeV and < 0.6*sqrt(track pT) in hollow cone of 0.2<dR<0.4
  - Designed so as not to cut taus, which can also be signal



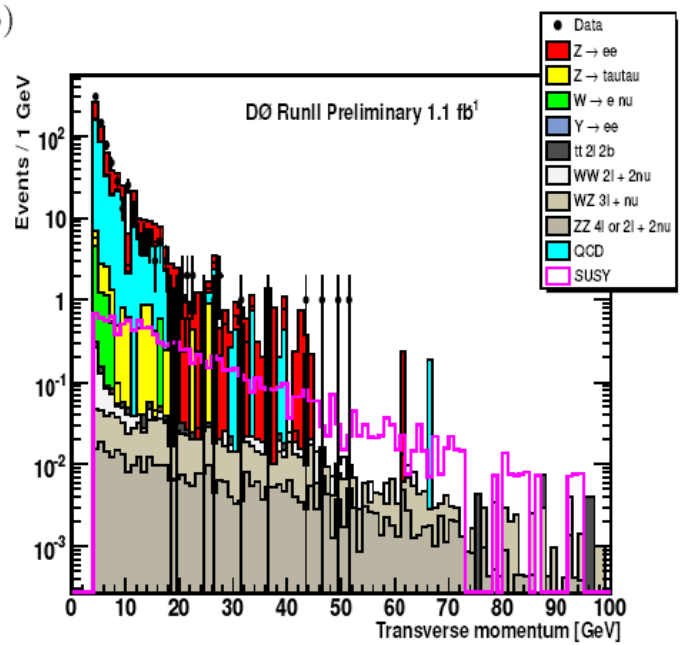


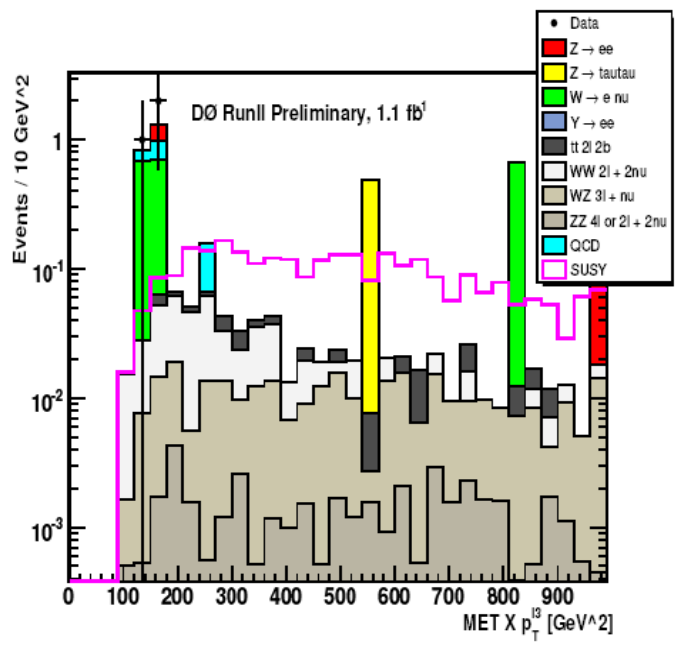
Chargino/Neutralino: “tri-leptons”

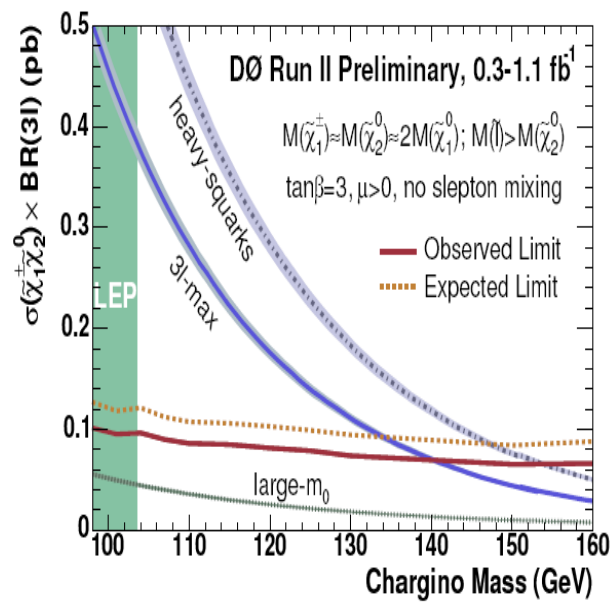
- Final background dominated by Z->tautau and di-boson. Reducible?
- Can other selections be relaxed? (anti-Z?, anti-top?, anti-QCD?)
- Also seems like a good candidate for a NN or other multivariate technique!

Cut	Data	Sum BG	$Z/\gamma^* \to ee$	$W \to e\nu$	$Z/\gamma^* \to \tau\tau$	WW/WZ	WZ	fakes
(1) Presel	118518	113592±175	95885±119	499±17	1029±18	83±0.43	18±0.4	16037±95
(2) Anti-Z	17459	18036±89	11053±51	297±12	287±11	26±0.33	2.01±0.04	6698 ±66
(3) Isolated Track	776	650±18	281±8	7.86±2.07	12±2	0.80±0.02	0.79±0.03	347±13
(4) $\not\!\!E_T$ related	2	1.97±0.73	0.16±0.16	1.77±0.73	0.32±0.32	0.43±0.02	0.46±0.02	0.48±0.28
(5) Tr×$\not\!\!E_T$	0	0.76±0.67	0.0±0.16	0.0 ±0.59	0.32±0.32	0.14±0.011	0.25±0.01	0.00±0.09

(b)

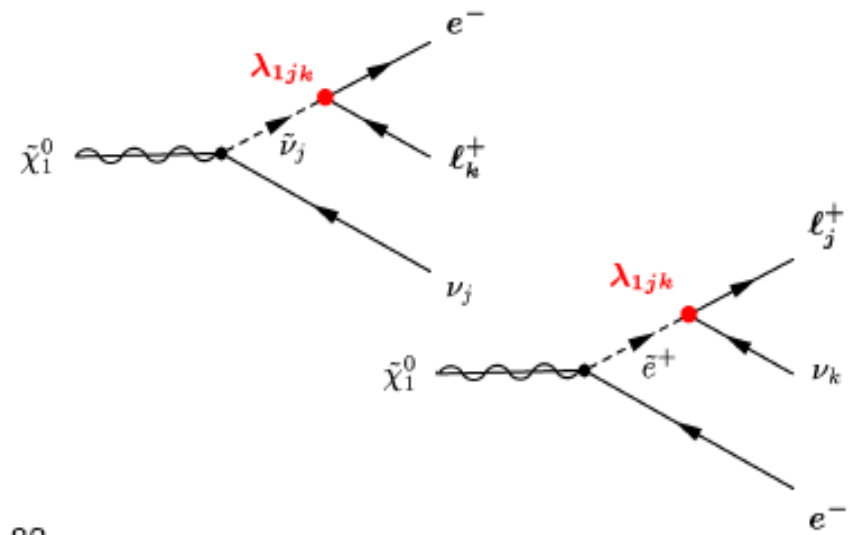




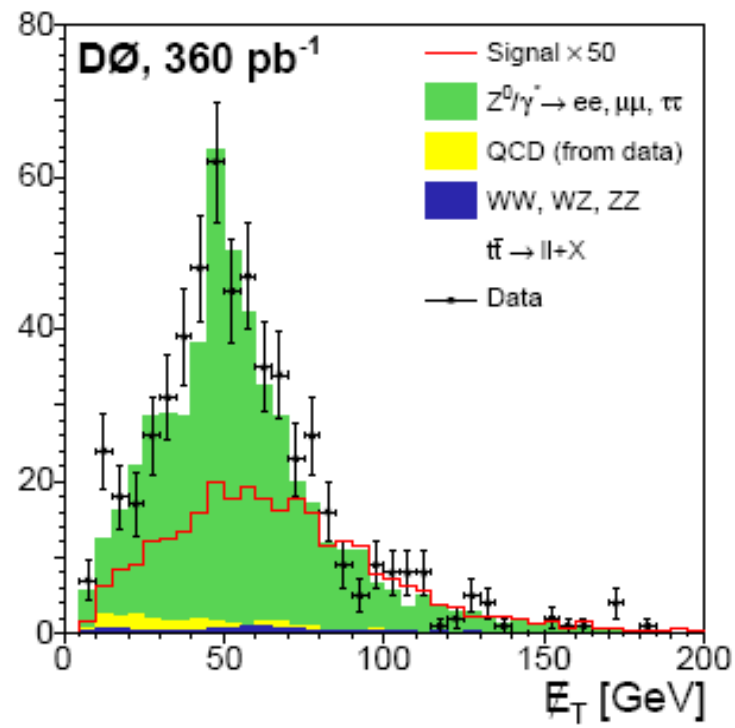


RPV SUSY: more leptons

- Consider the pair production of Chargino/Neutralino, followed by RPV decays
- More leptons in final state, but less mET
  - Require 3rd lepton, not just a track
- No candidate events

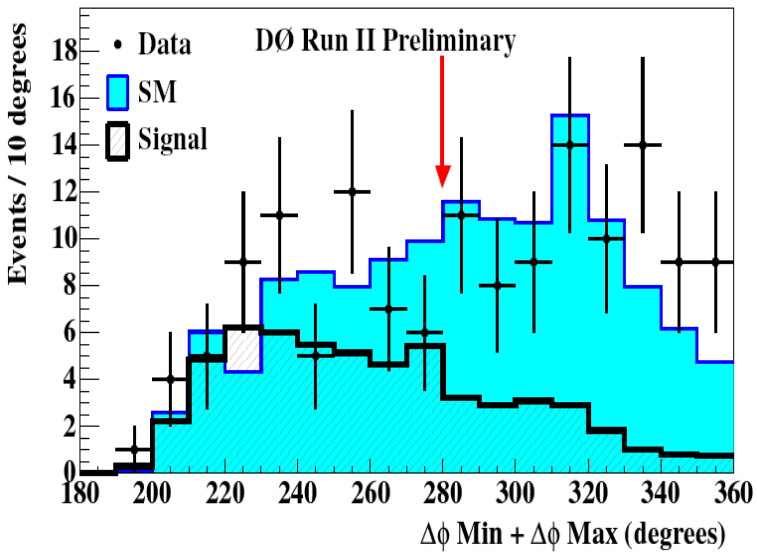


	Cut	Data	Background
I	$p_T^{\ell 1} > 12$ GeV, $p_T^{\ell 2} > 8$ GeV	19283	$19588 \pm 81 \pm 3332$
II	$\Delta\varphi(\mu_i, \not{E}_T) > 0.1$	14918	$15275 \pm 72 \pm 2598$
III	Υ and Z veto $(\not{E}_T, M_{\mu\mu})$ plane		
	$\Delta\varphi(\mu\mu) < 2.53$ for $\not{E}_T < 44$ GeV	564	$506 \pm 13 \pm 86$
IV	$p_T^{\mu 3} > 4$ GeV or $p_T^{e} > 5$ GeV		
	$\Delta\varphi(e, \not{E}_T) > 0.1$		
	$\sum p_T^{\ell i} > 50$ GeV	0	$0.4 \pm 0.1 \pm 0.1$

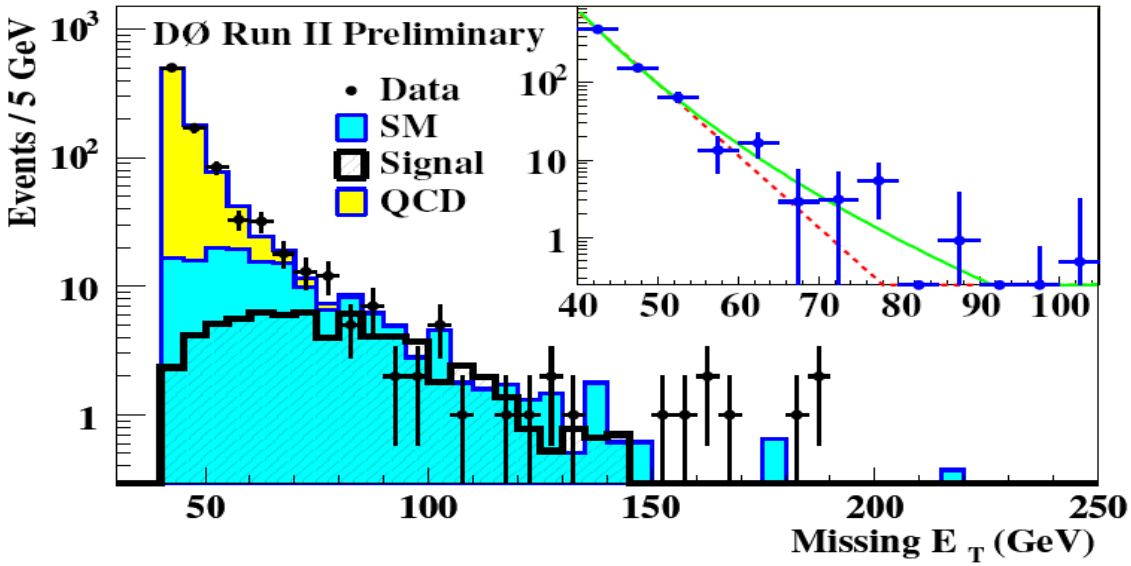


Scalar Top, t->c+MET

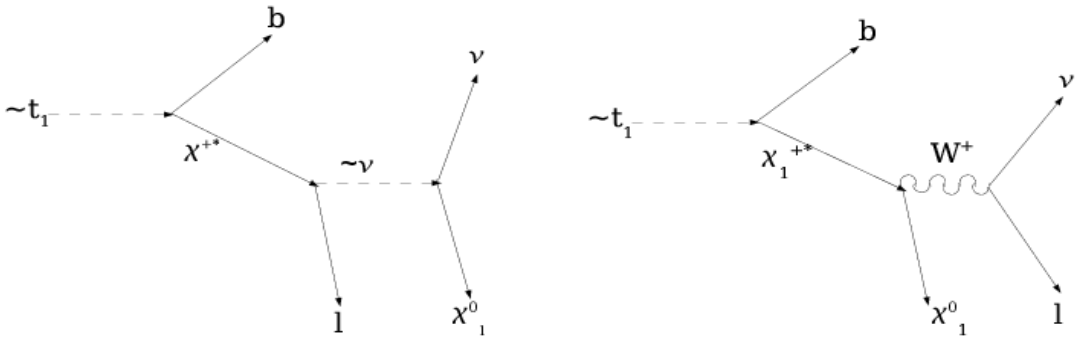
- Signature is two acoplanar c-jets
- Cuts:
  - Exactly two jets, pT > 40, 20 GeV, dphi<165
  - Quality cuts on mET vs. jet directions
  - At least one jet lifetime tag (c-tag)
  - mET>70 GeV (optimized for each stop mass)
- Slight excess in data at high mET



$Z \to \nu\nu$+2-jets	15.7 ± 2.8
$Z \to \nu\nu + b\bar{b}$	3.8 ± 0.2
$Z \to \nu\nu + c\bar{c}$	1.8 ± 0.3
$W \to \ell\nu$+jets	24.6 ± 7.8
$W \to \ell\nu + b\bar{b}$	1.9 ± 0.2
$W \to \ell\nu + (c\bar{c}$ or c+jet)	1.6 ± 0.4
$t\bar{t}$ and single top	4.1 ± 0.3
WW, WZ, ZZ	2.5 ± 0.3
Total SM background	$56.1 \pm 8.3 \pm 9.7$
Instrumental background	3.3 ± 1.6
Total background	$59.4 \pm 8.3 \pm 9.8$
Data events selected	60
Reference signal	$39.5 \pm 2.0 \pm 4.8$

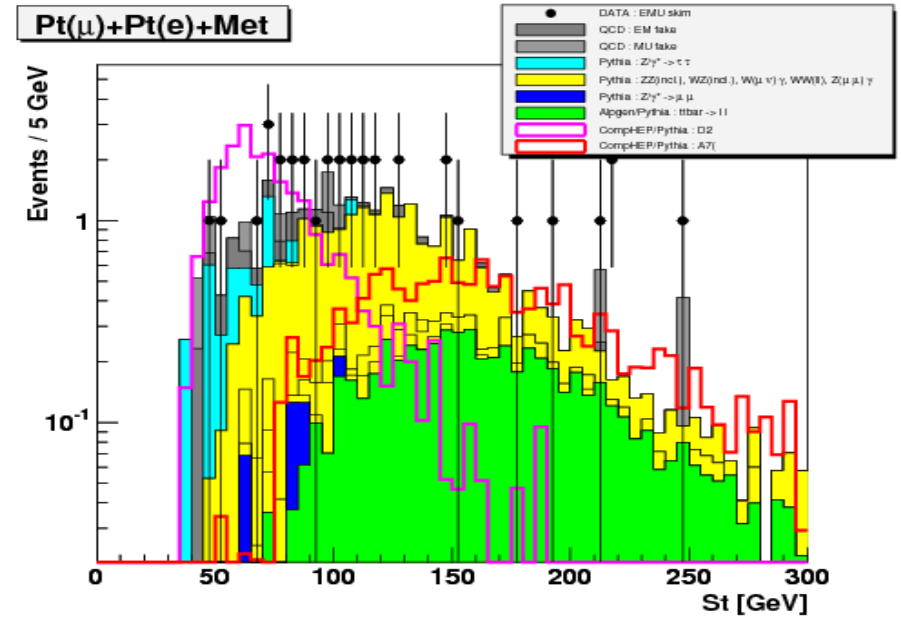


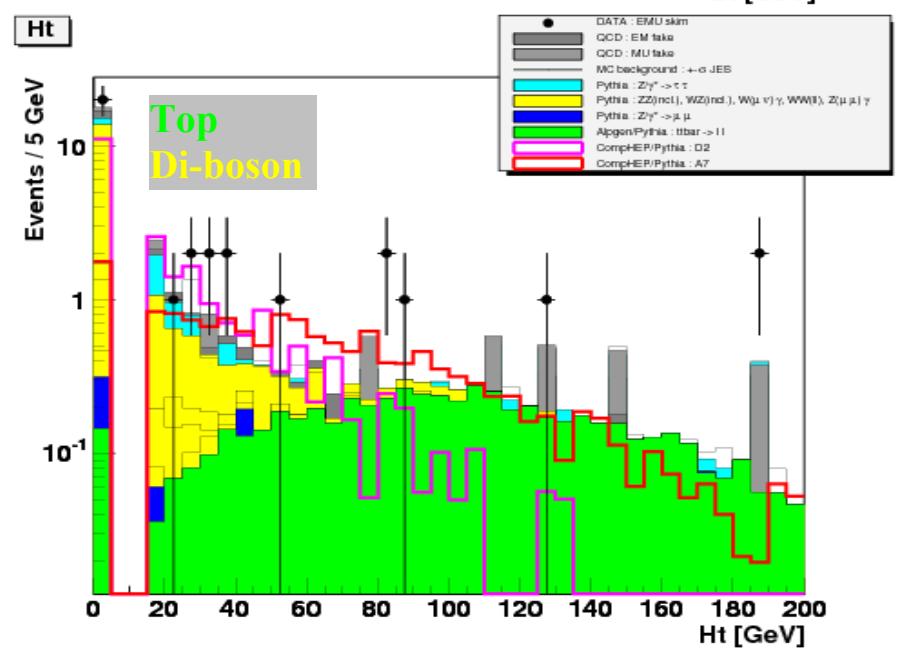
Scalar Top -> b+l+mET



- If the sneutrino is relatively light, these decays dominate over c+X decays
- Use kinematic variables of leptons and mET to separate signals (for different candidate stop, snu masses) from the tt and di-boson backgrounds
- No evidence seen of either a light stop or snu

Point	stop mass	snu mass
D2 (magenta)	110.4	80.5
A7 (red)	145.6	50.9





RPV SUSY: Resonant Sleptons

- Look at events with 2 muons and 2 jets
  - look for resonances in muon+dijet and dimuon+dijet invariant masses
- Cuts:
  - Isolated muons, pT> 15, 8 GeV
  - Jet pt> 15, 15 GeV
- Additional signal-tuned selections:
  - dimuon mass
  - dijet mass
  - sums of muon and jet momenta
- Data agrees with background:

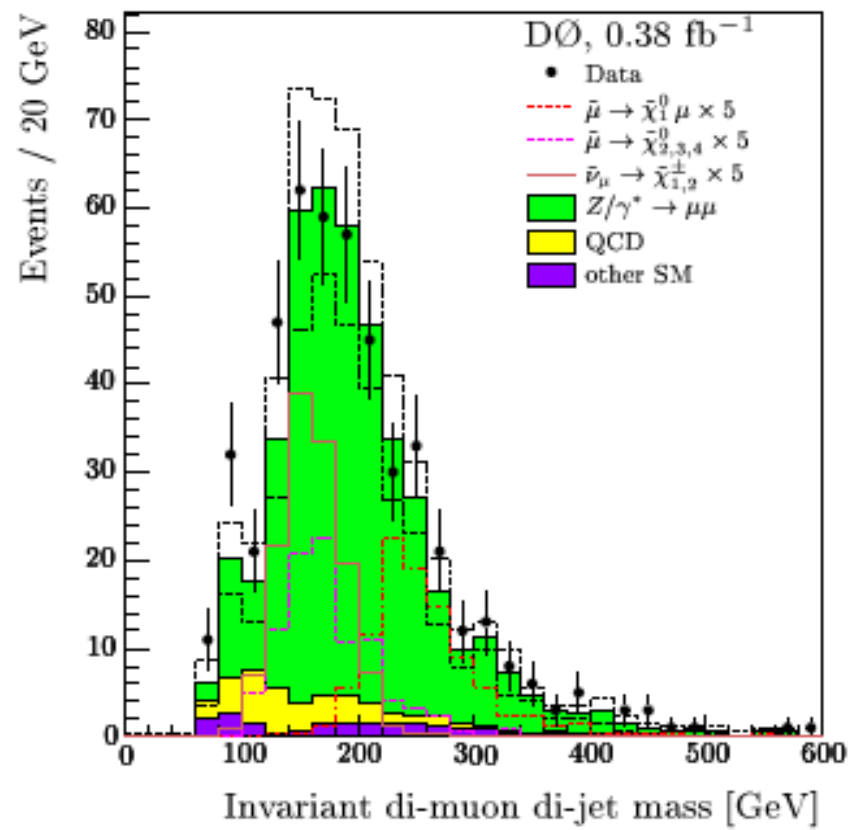
  14, 28, and 8 observed,
  for production scenarios i,ii, and iii vs.
  11.9, 25.4, and 6.5 expected

production scenarios:

$$\text{(i) } \tilde{\mu} \to \tilde{\chi}_1^0 \mu, \text{ (ii) } \tilde{\mu} \to \tilde{\chi}_{2,3,4}^0 \mu, \text{ and (iii) } \tilde{\nu}_\mu \to \tilde{\chi}_{1,2}^{\pm} \mu$$

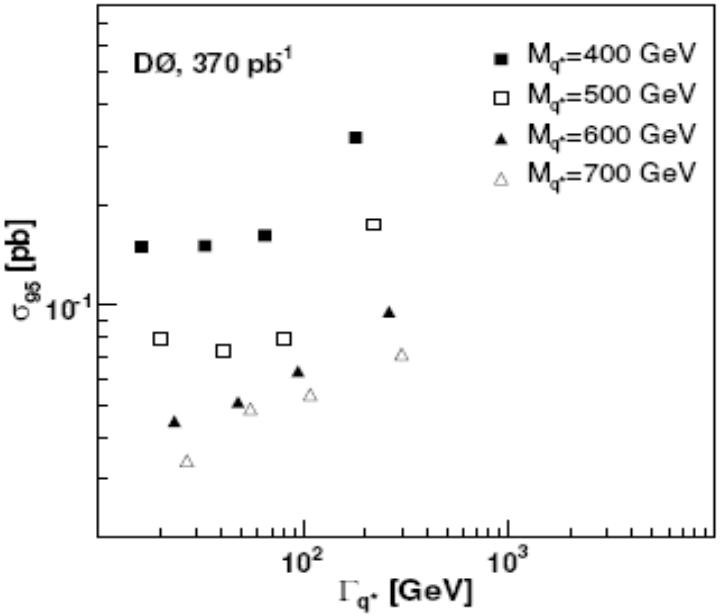
decay scenarios:

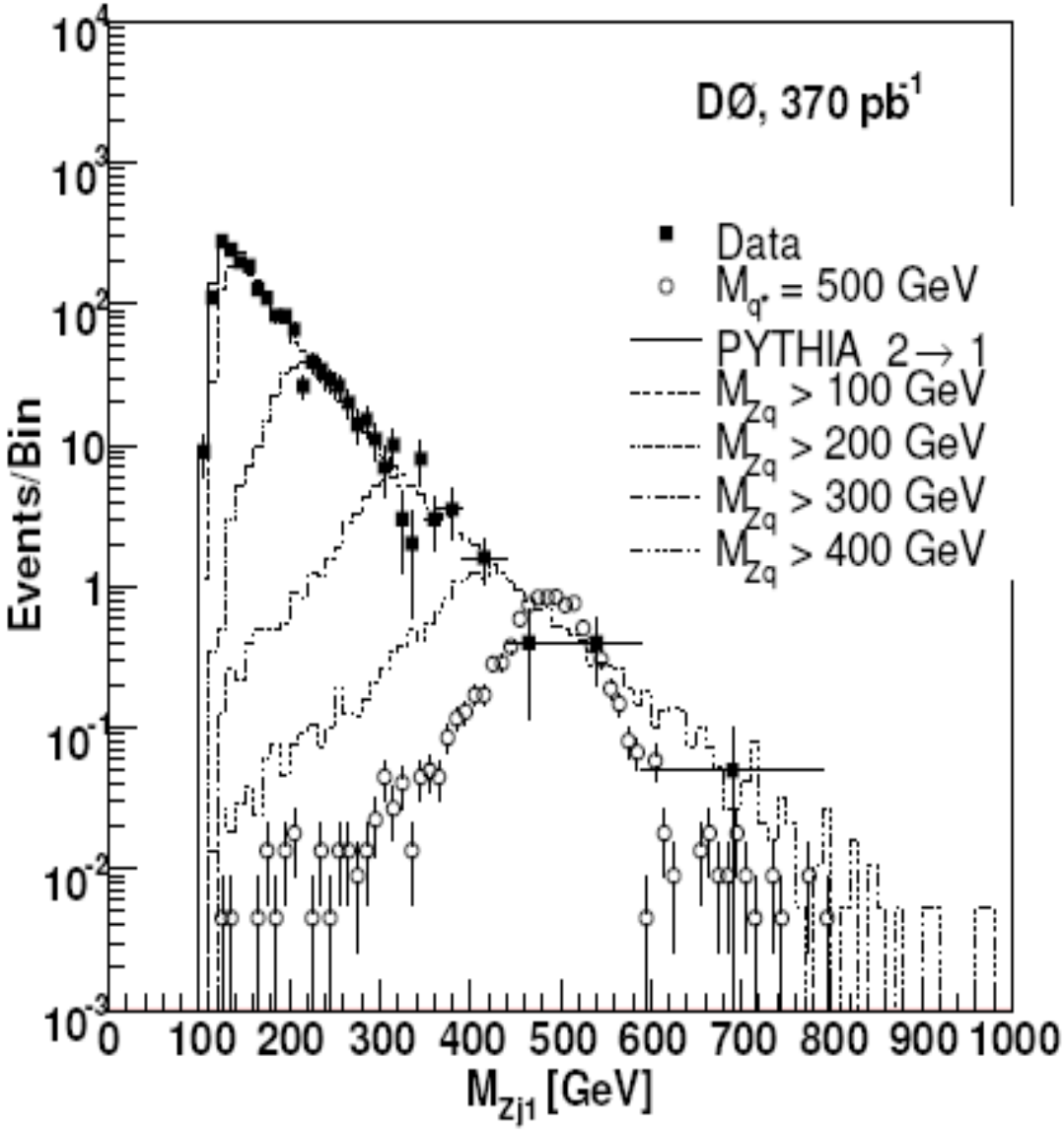
$$\tilde{\chi}_1^0 \to \mu q_1 \bar{q}_1' \text{ and } \tilde{\chi}_1^{\pm} \to q q' \tilde{\chi}_1^0$$



Resonant Z+jets

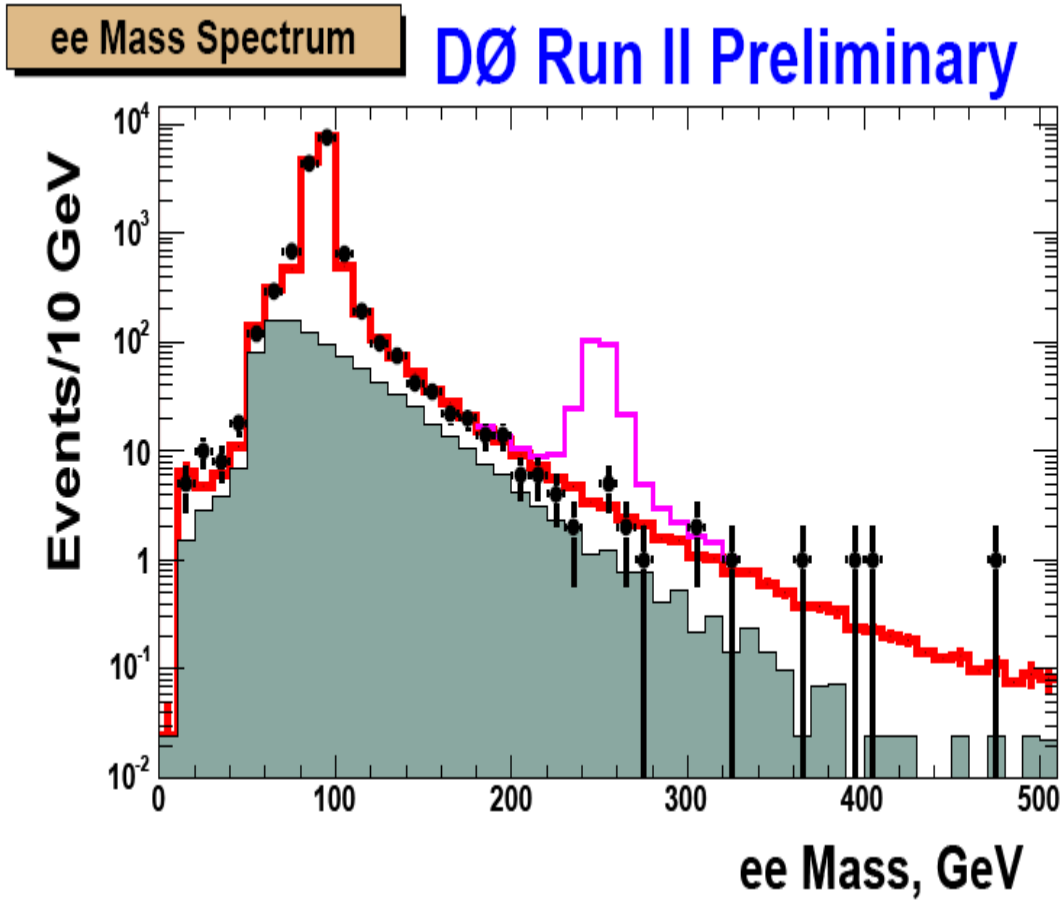
- Z candidate from leptons
- Jet pT > 20 GeV
- Look for resonance in the Z+jet invariant mass spectrum
- Set limits as a function of resonance mass and width
- Have also searched for resonances in dijet, W+jet (CDF), Z+photon, photon+jet, and ttbar channels in other analyses

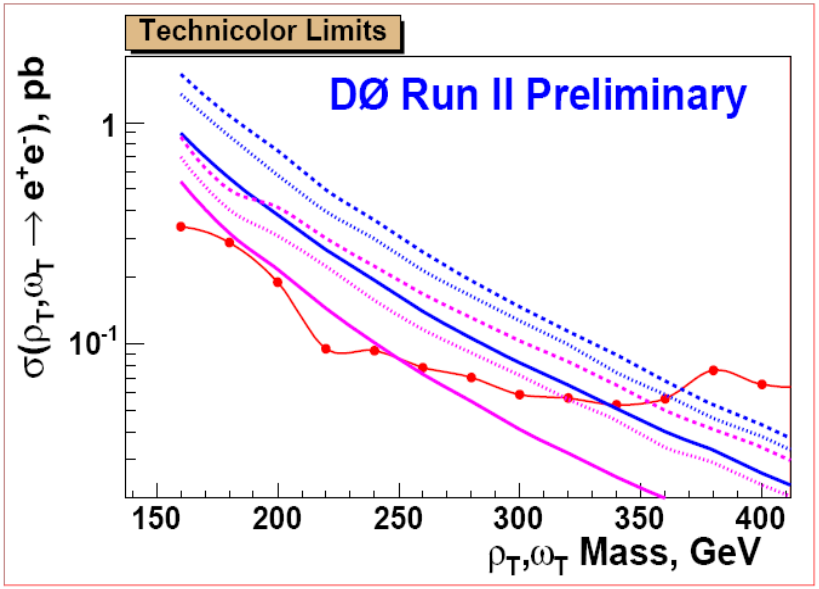




Technicolor

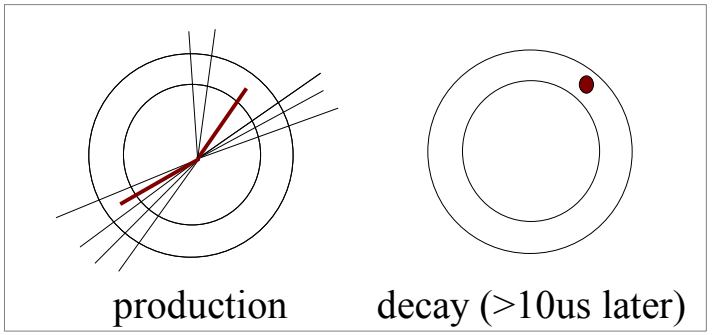
- Technihadrons -> ee
- 2 electrons, pT > 25 GeV
  - Look for bump in invariant mass spectrum
- Lots of things could show up here!
  - So far, all we see is Z

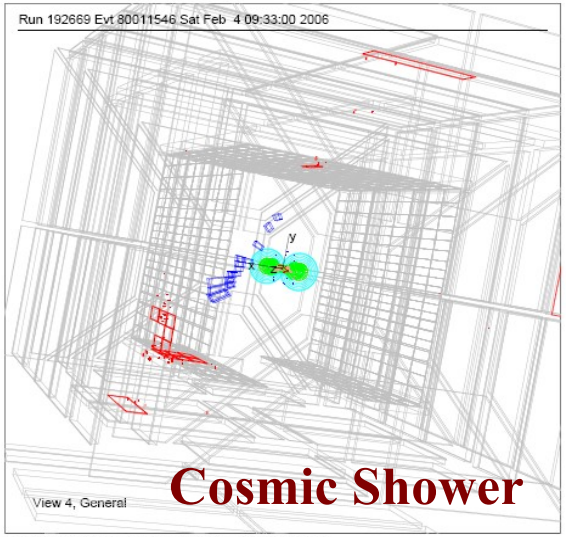


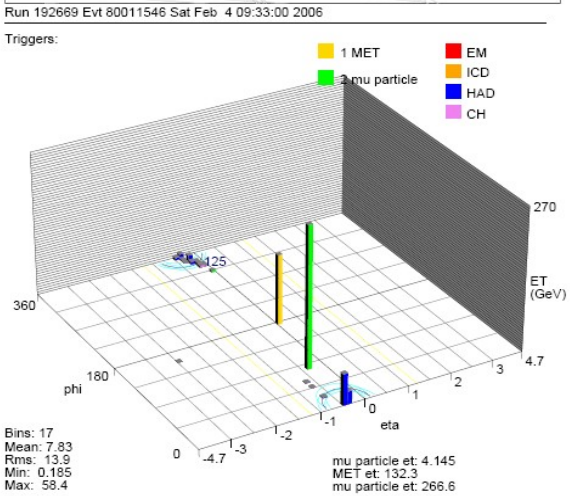


Stopped Gluinos -> Late Jet+mET

- Split SUSY -> heavy scalars -> long-lived gluino
- Some lose enough momentum through ionization to stop in the calorimeters, then decay later...
  - BR to gluon+LSP assumed to be 100%
  - Lifetime assumed to be >10us and <100 hours
- Signature:
  - isolated energy deposit in the calorimeter
  - otherwise empty event: no tracks or primary vertex
- Use "GAPSN" triggers
  - > 45 GeV jet, but no inelastic collision
  - Removes most background from beam
- Pre-selection cuts
  - Require a central jet with energy > 90 GeV
  - Require no other jets above 8 GeV
- Backgrounds remaining:
  - Cosmic muons
  - Beam muons (halo)
  - Diffractive ppbar events from beam
  - Detector problems, fake energy
  - Other : cosmic neutrons / neutrinos?



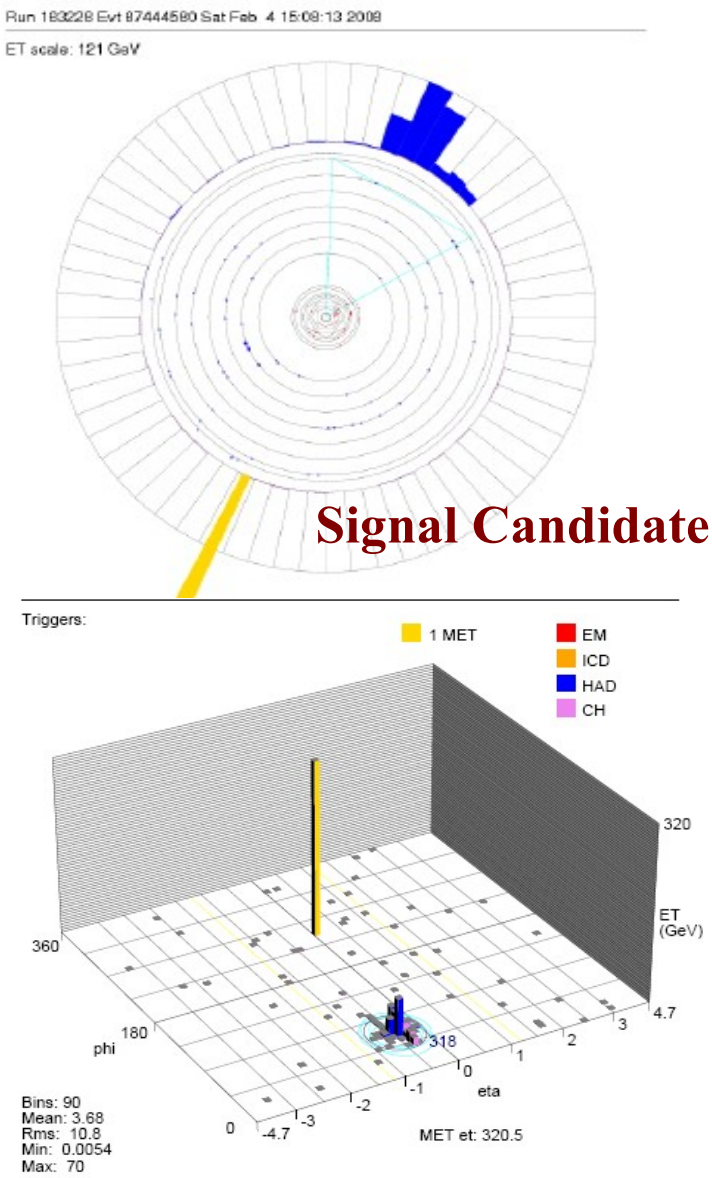


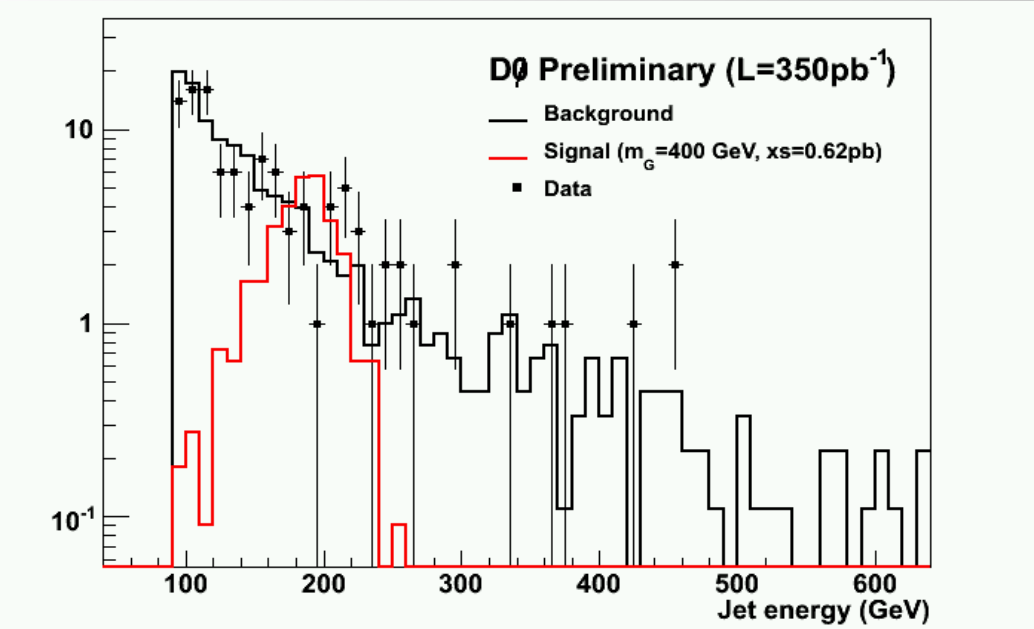


Stopped Gluinos -> Late Jet+mET

- Background estimated from data using muon shower events
  - Narrower showers (from EM photoproduction)
  - Tracks in the muon system
- Data is consistent with background
  - No bumps in the "jet" energy spectrum
- 4x more integrated luminosity on tape, but a new trigger is needed at high luminosity
  - min-bias overlap introduces significant inefficiency
- Since ~30% of gluinos have a pair-produced partner which also stopped, the *time-coincidence* of candidates should be studied

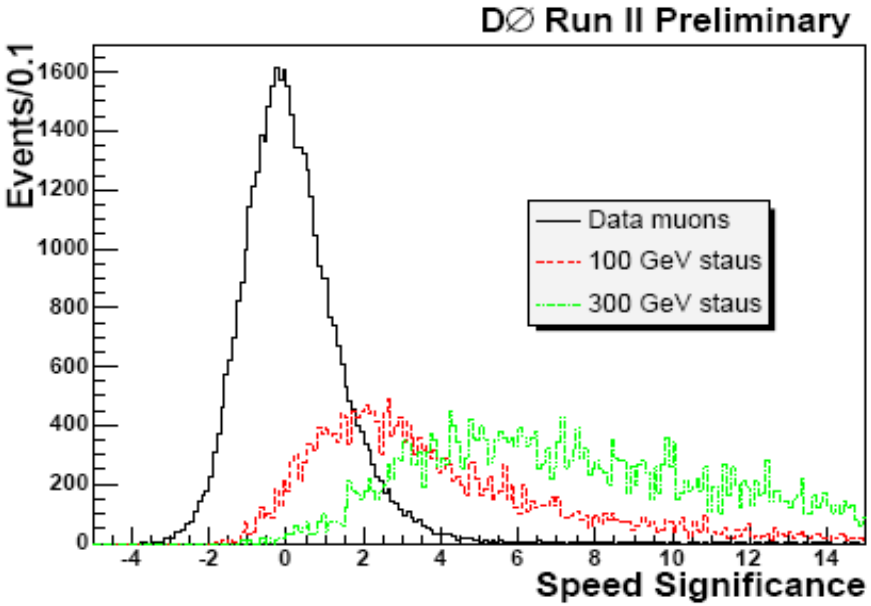
Notice: no tracks for jet...

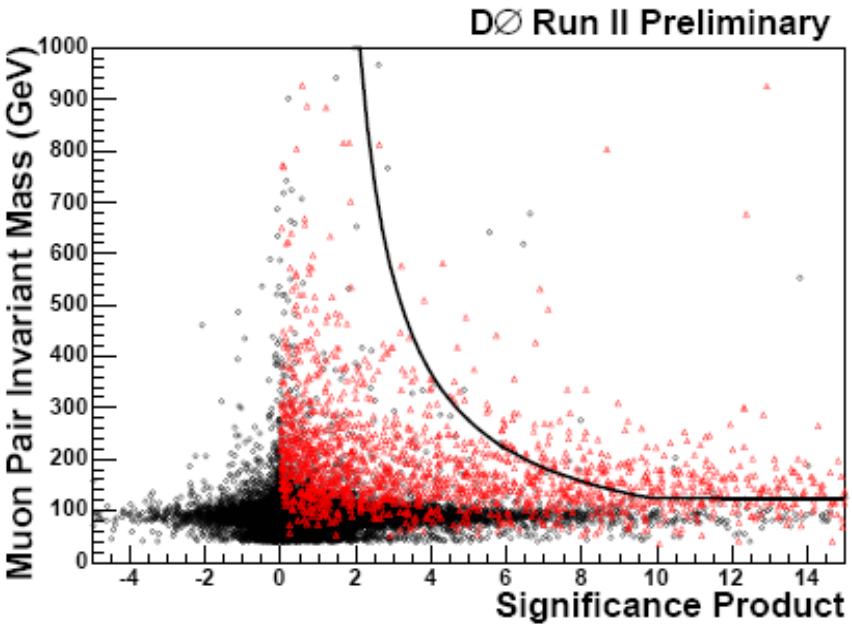


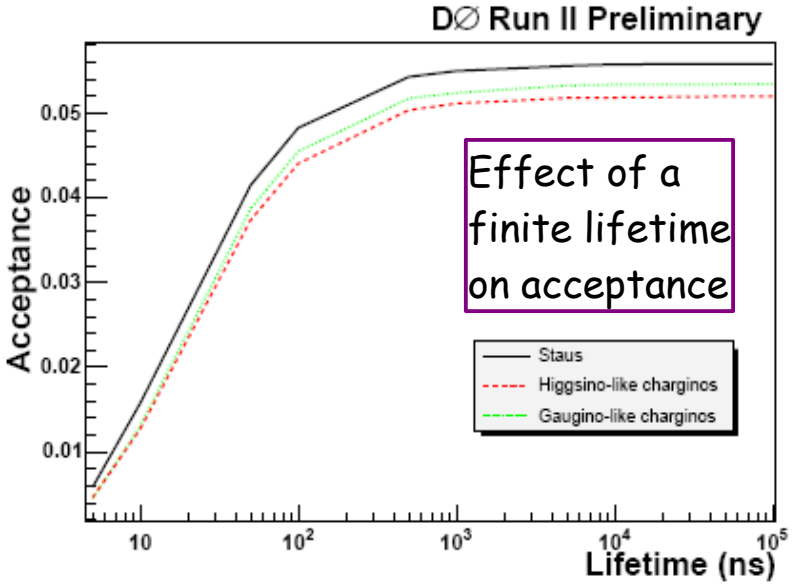


Charged Massive "Stable" Particles

- Look for *pairs* of "slow" muons
  - could be stau's, chargino's, or whatever
- Require dimuon trigger
  - Finite trigger window limits search to particles with speed > ½ c
- 2 muons, pT>15 GeV
  - matched to a central track
  - hits in at least 2 out of 3 scintillators
  - *at least one muon must be isolated*
  - dphi > 1 (anti-cosmic)
- Selection is made in the invariant mass vs. speed significance product plane
  - 0 events observed, 0.66+-0.08 expected

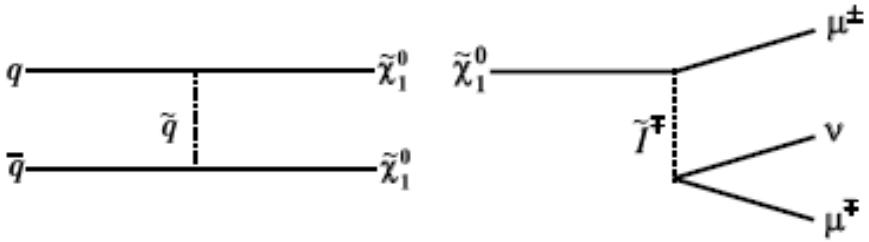


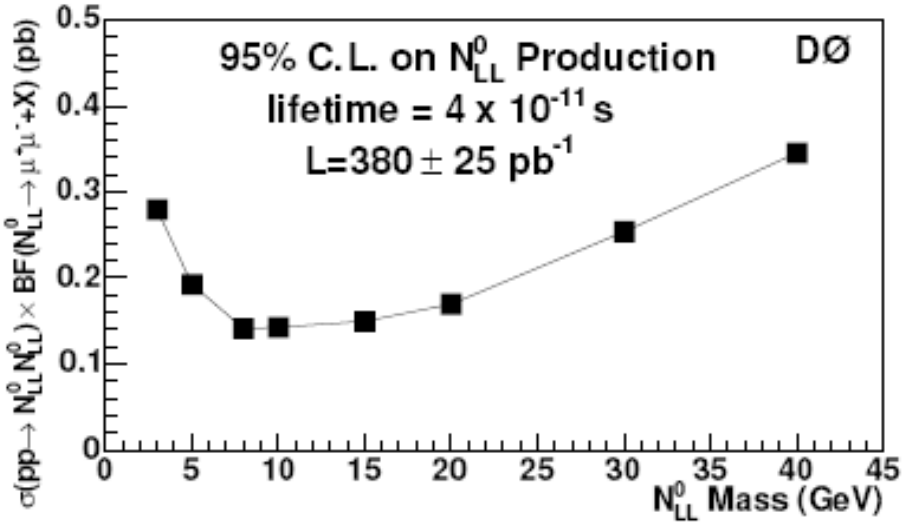




Neutral Long-Lived Particle -> muons

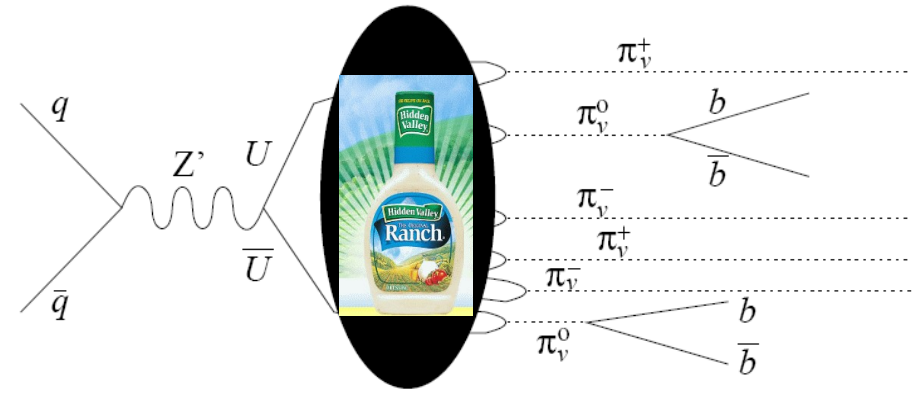
- Look for a di-muon vertex with:
  - radius > 5cm (long-lived) but also radius <20cm (inside fiber tracker)
  - study NuTeV anomaly (3 events observed, almost none expected)
  - could happen in some RPV model
- 2 muons, *pT>10 GeV*, matched to tracks
- Muon isolation required:
  - sum of track pT (other than muons) in dR<0.5 must be < 2.5 GeV
  - sum of calorimeter pT in 0.1<dR<0.4 must be < 2.5 GeV
- Muons are subject to cosmic veto (+-10 ns of expected scintillator time (beam +dist*c))
- Opening angle < 0.5 radians, opposite charge
- Backgrounds and efficiencies studied using Ks data and MC
- 0 events observed, 0.75+-1.1(stat)+-1.1(sys) expected

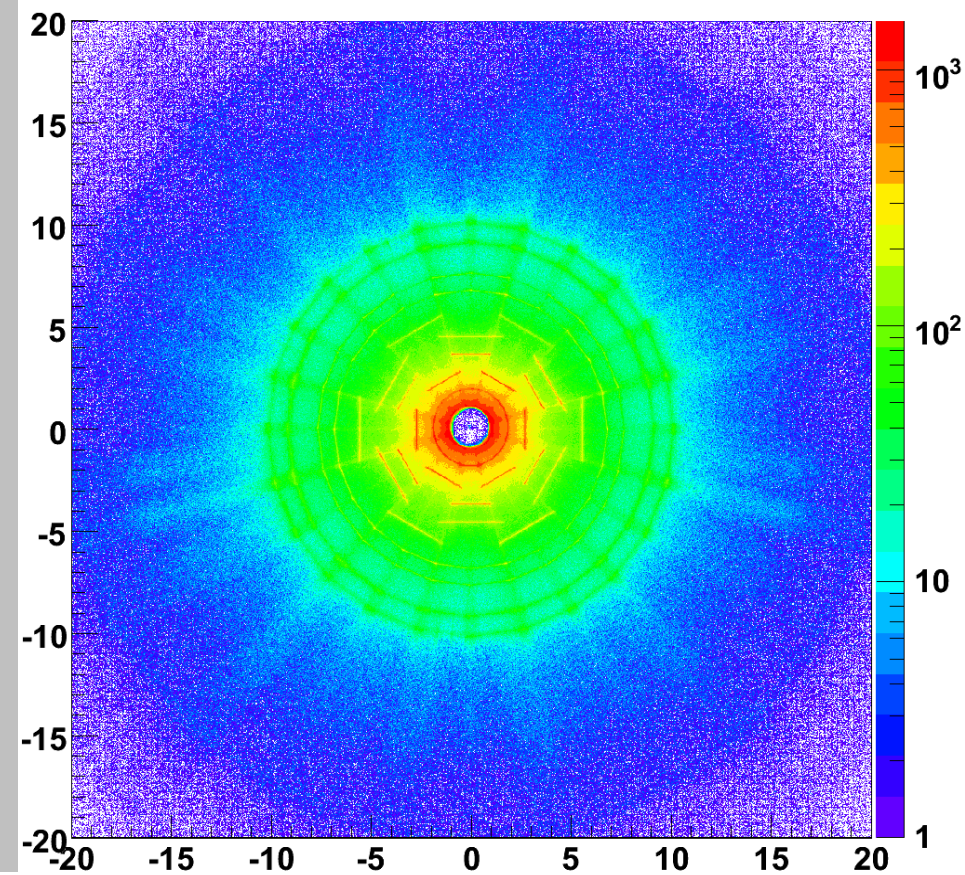




Neutral Long-Lived Particles -> bb (+mET)

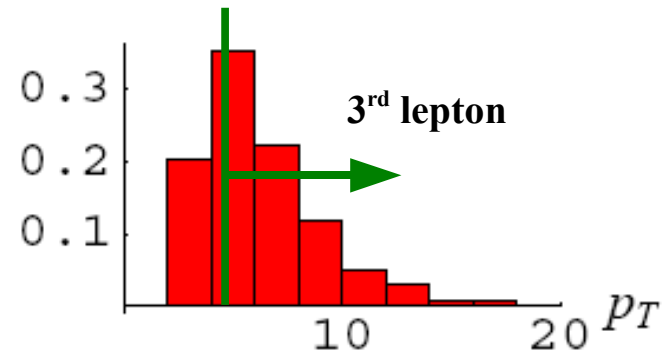
- Another search for long-lived neutral particles, but this is for decays to bb pairs
  - Many candidates could couple preferentially to massive particles, i.e. b's
  - "Hidden Valley", a new strongly-coupled gauge group, weakly-coupled to the SM: hep-ph/0604261 (M. Strassler)
- Signature:
  - A pair of nearby secondary vertices (from the bb pair), far from the primary vertex
  - Possibly another distant vertex pair on the other side, or large mET
- An interesting "final-state" which has not been carefully explored before experimentally!
- Trigger on muons (from the b's) and the jets (similar to the Z->bb analysis)
- Background due to outgoing particles interacting inelastically with detector material
- Careful work will be needed to separate signal from background
  - Try to distinguish the pairs of nearby b-vertices from single vertices
  - Take advantage of correlations with the other side of the event, either another vertex-pair, or large mET



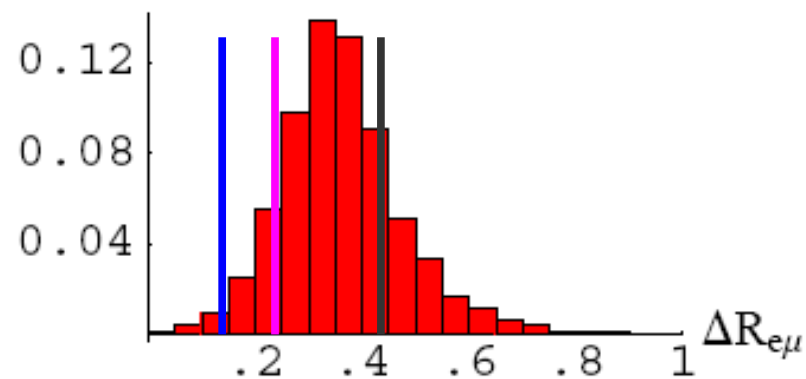


Overlapping Particles: h->aa->4tau

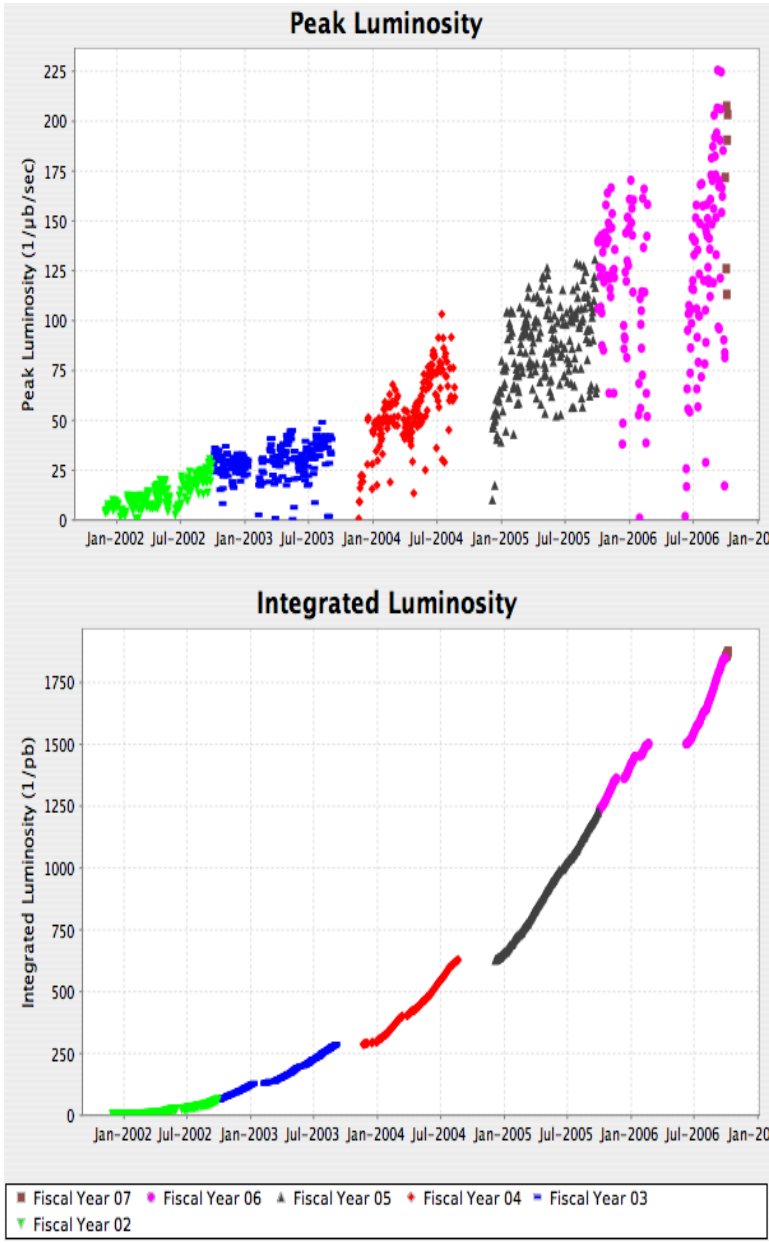
- What if the Higgs decays mostly to a new light pseudo-scalar, with 2tau<m<2b?
  - A loophole in LEP exclusions (mh>86 GeV)
  - Pretty natural in the NMSSM
  - Studied recently by Wacker et al. hep-ph/0605162
- Look for tri-leptons?
  - Even softer spectrum than SUSY...
  - Maybe require associated production, WH?
- Look for nearby e-mu pairs?
  - Looks promising, but overlapping leptons will require customized isolation criteria
  - Can also require a loose tau, or a jet-veto, on the opposite side
  - Backgrounds:
    - Di-boson?
    - jet + Upsilon->tautau?
    - bb ... how often does a b-jet fake an isolated e-mu pair???
- First step is to study b-jet di-lepton fake rates
  - A useful, general measurement!



The pT of the 3rd lepton needs to be above ~5 GeV in a tri-lepton analysis.



The tau's overlap...
The two lepton tracks will kill each others' track isolations!
The electron in the calorimeter will kill the muon's cal. isolation!

Conclusions and Comments

- Have we searched for everything? No!
  - That's why we're here. :)
- But, we have tried to...
  - be as model-independent as possible
  - cover as many final states as we can think of
  - optimize our sensitivity in the "standard" channels with *prompt*, *isolated* leptons, photons, mET, heavy-flavor, and/or taus in the final state
  - interact with theorists / other experiments and work hard to verify new signatures
    - NLLP->mu (excess from NuTeV)
    - Stopped Gluinos (new signature of SUSY)
    - and others are on the way...
- The future is bright!
  - Many analyses shown were done with ~0.3-0.9/fb
    - What will they look like with 8/fb ???
  - The D0 detector has been successfully upgraded to trigger at high luminosity and continue to extract physics efficiently
  - For better or for worse, it will still be many years before LHC analyses deliver useful results on many of these new-phenomena searches