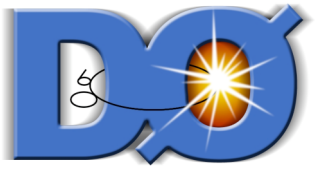
New Searches Results from 

Yuri Gershtein

There Must Be New Physics!

- Explain low mass of Higgs (hierarchy problem)
- Explain Dark Matter
  - why shouldn't it be produced at colliders?
- Explain matter-antimatter imbalance in the Universe
- Explain why Yukawa couplings range more than 11 orders of magnitude from electron neutrino to top quark
- Would be nice to unify gauge forces and incorporate gravity

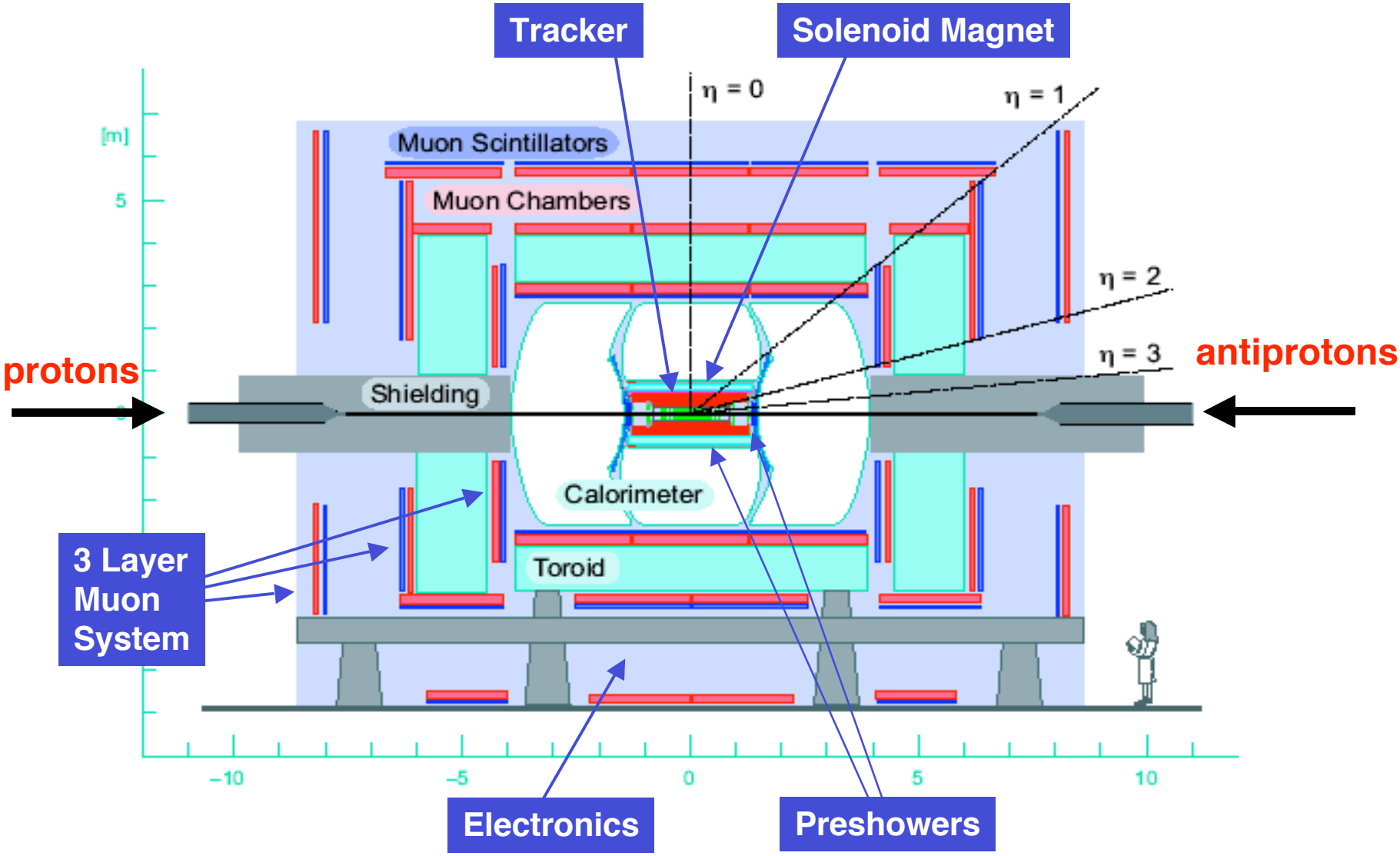
We also have ideas what this new physics could be - which lead us to believe that there is something new at energies ~ electroweak scale

- so where is it?

Outline

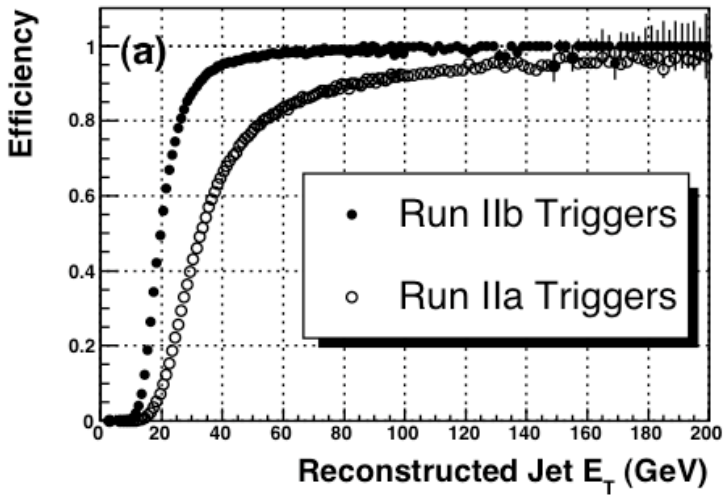
- DØ detector
- Searches for things we looked for for the last N years: supersymmetry, new strong dynamics, extra dimensions - the way we looked for the last N years with more $\int L dt$
  - In this talk:
    - SUSY in Jets + MET and trileptons
    - GMSB SUSY in di-photons
- New physics can hide from us if decays are through hard to observe cascades - improvements in object ID
  - In this talk:
    - SUSY in Jets + MET + τ
    - Leptoquarks decaying into bτ
- New physics can hide from us if the final states are altogether unusual - long lifetimes, non-isolated leptons, R-hadrons, etc…
  - In this talk:
    - Long-lived particles decaying into Z bosons

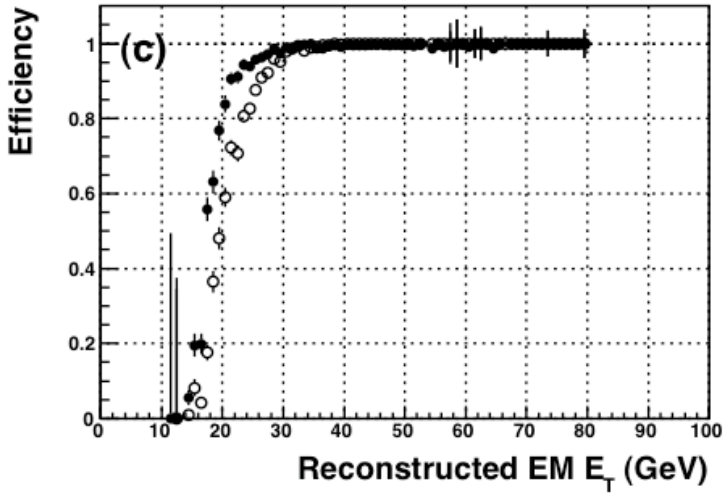
DØ Detector


Tracker
Solenoid Magnet
η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
protons
antiprotons
Calorimeter
Toroid
3 Layer Muon System
Electronics
Preshowers
[m]
5
−10
−5
0
5
10

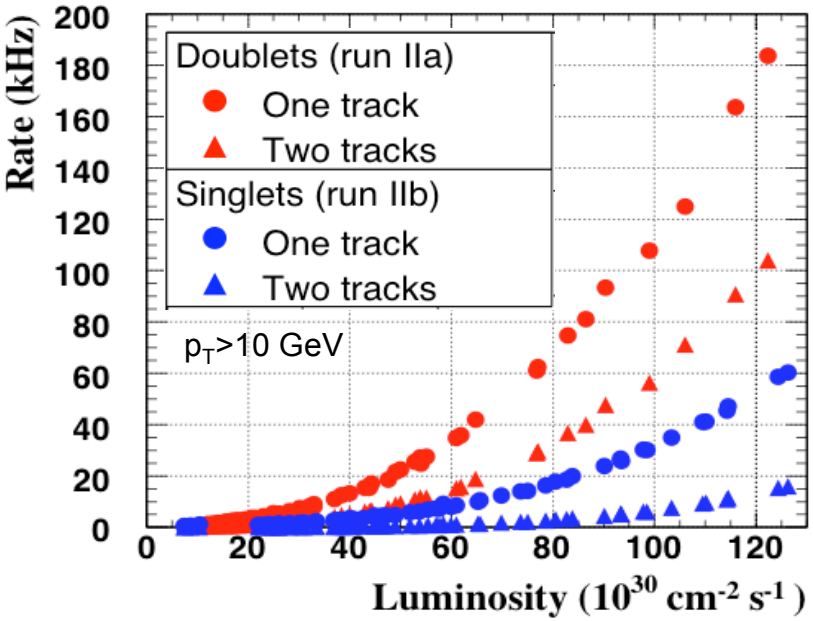
Run IIb Upgrades

- new calorimeter trigger
  - replaced the last major piece of electronics from the 80's





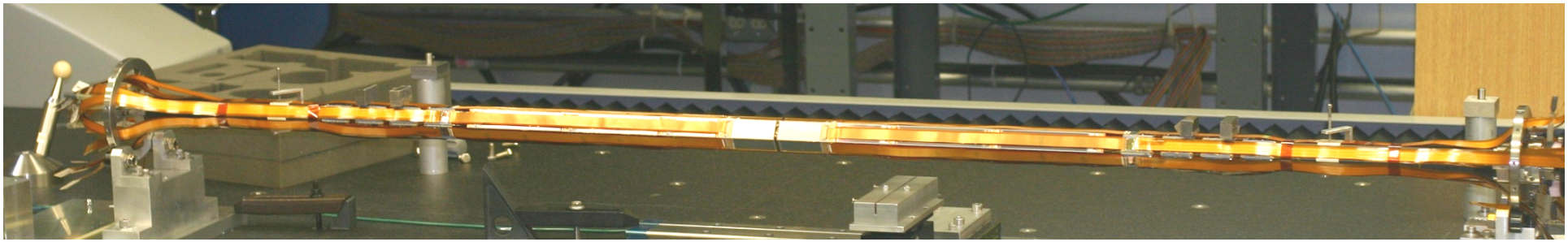
- new tracker electronics & trigger
  - less noise and better trigger granularity

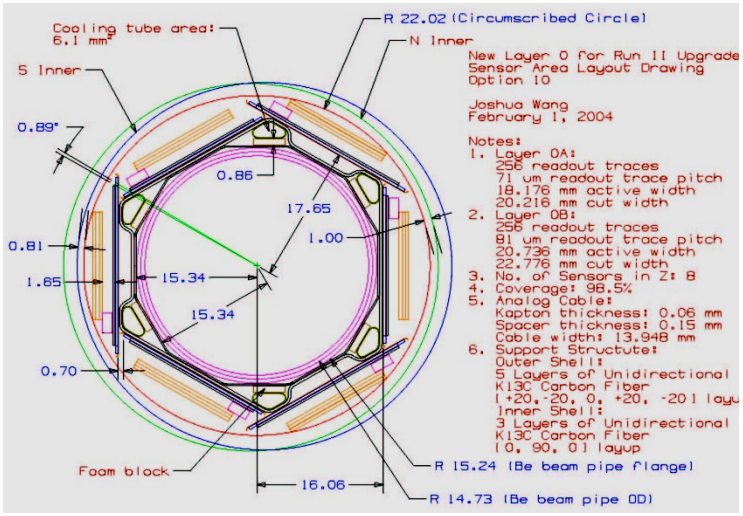


Now can match calorimeter and tracker at Level 1

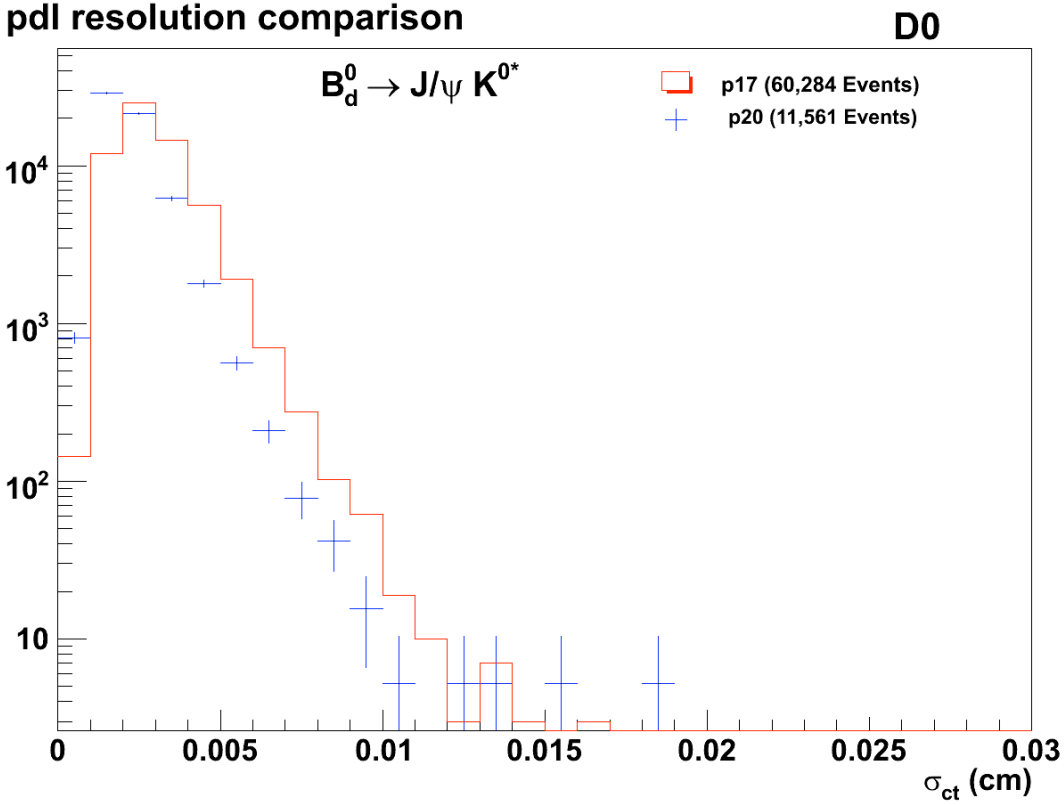
Silicon Layer 0

- Better tracks with better IP resolution





19 bad channels out of total of 12,288 channels



Supersymmetry

- SUSY is one of more popular extensions of the SM
- Fundamental symmetry bosons ↔ fermions

SUSY particles:

lepton l (J=½)	→ slepton $\tilde{l}$ (J=0)	
quark q	→ squark $\tilde{q}$	
gluon g (J=1)	→ gluino $\tilde{g}$ (J=½)	
photon γ (J=1)	→ photino $\tilde{\gamma}$ (J=½)	mix to give physical neutralions χ^0_i (i=1,4)
Z	→ zino $\tilde{Z}$	
Higgs ϕ_1	→ Higgsino $\tilde{\phi}_1$	
Higgs ϕ_2	→ Higgsino $\tilde{\phi}_2$	
$W^\pm$	→ wino $\tilde{W}$	mix to give physical charginos $\chi^\pm_i$ (i=1,2)
Higgs $H^\pm$	→ Higgsino $\tilde{H}^\pm$	

No SUSY particles observed so far – SUSY is a broken symmetry

SUSY models make assumptions about the nature of the breaking

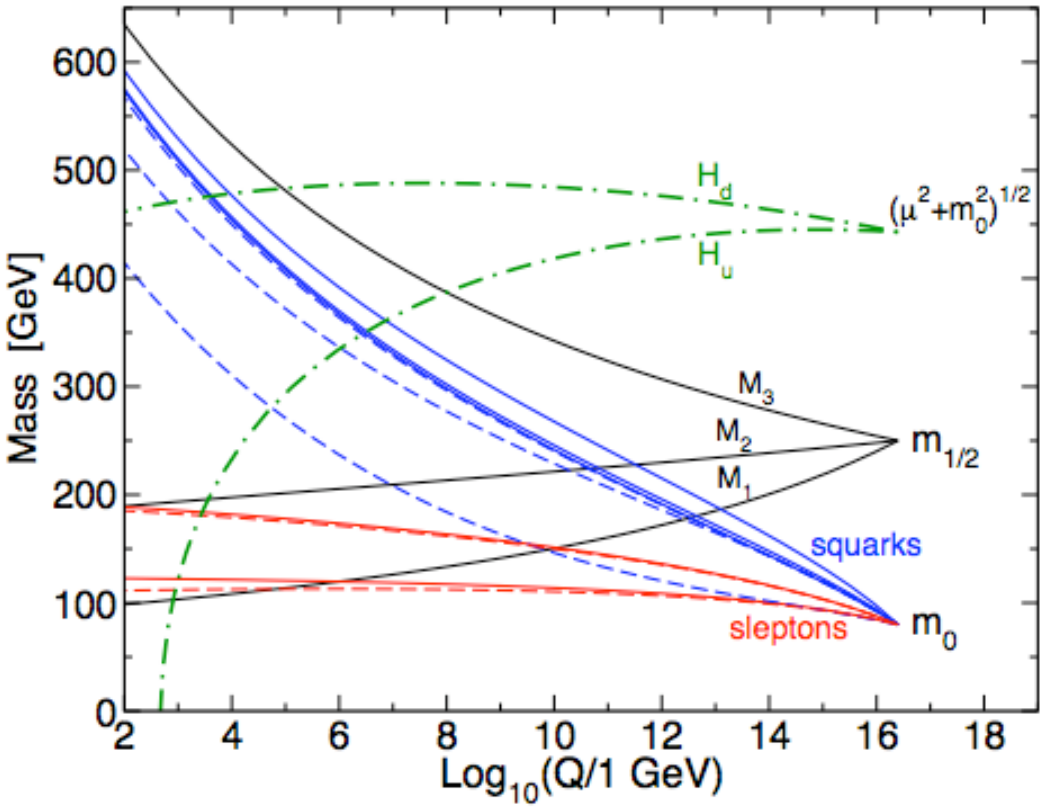
Collider phenomenology strongly depends on model – very broad search program…

- Despite large number of free parameters – many attractive features: stable Higgs mass, connection to super-strings, …

mSUGRA

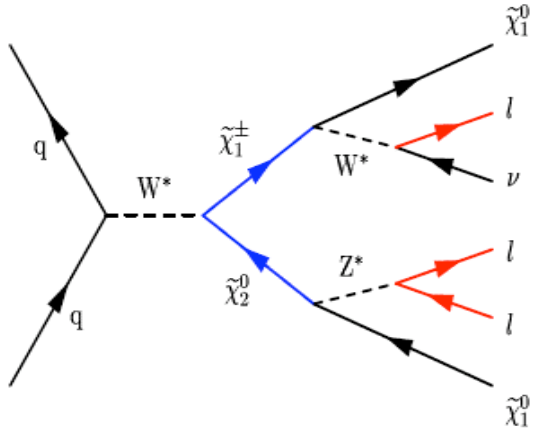
- Supersymmetry breaking is mediated by gravity at ~GUT scale

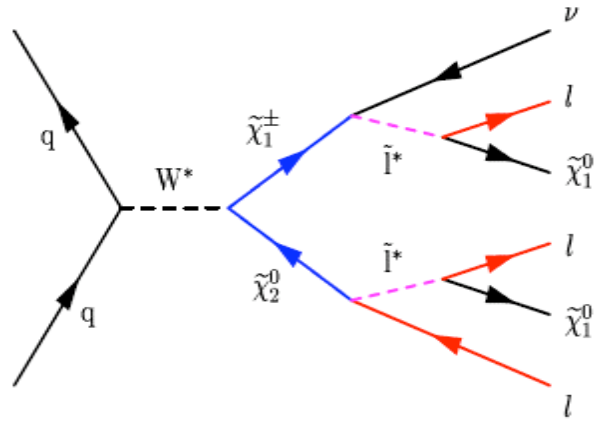
- Reduced number of parameters
  - Universal scalar mass m_0
  - Universal fermion mass $m_{1/2}$
  - Ratio of the two Higgs doublet's vev tanβ
  - Trilinear interaction coefficient A_0
  - sign of higgsino mass parameter sign(μ)

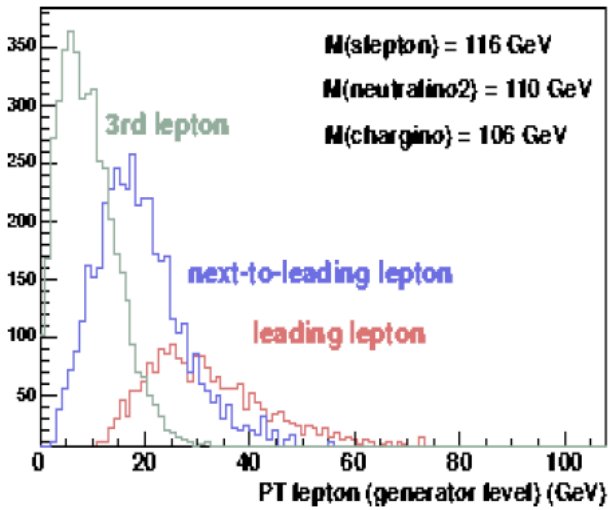


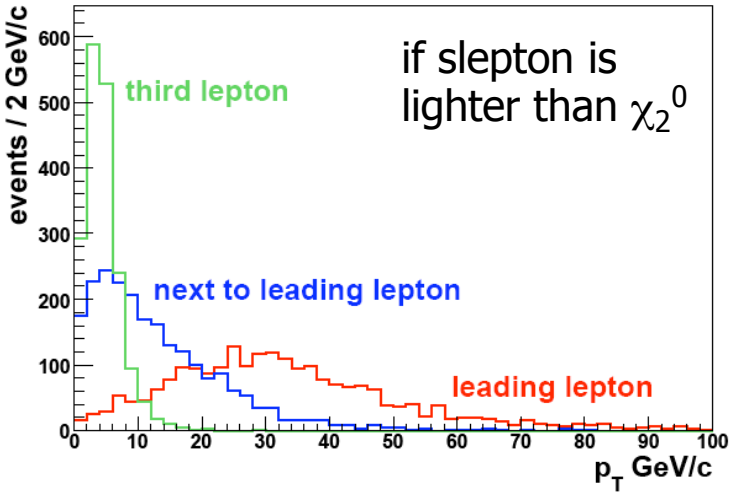
Trileptons

- Gauginos are pair-produced and decay either through sleptons or gauge bosons (branchings depend on mass differences)



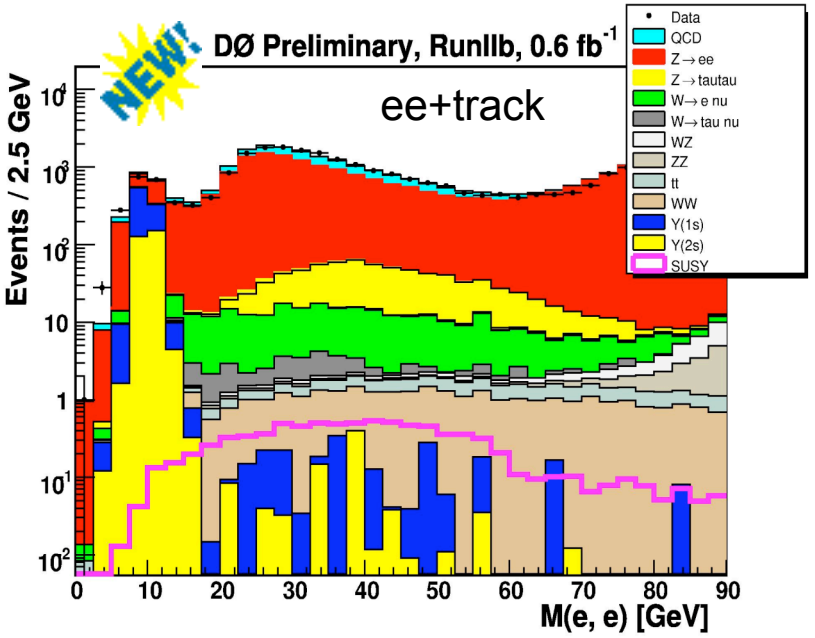


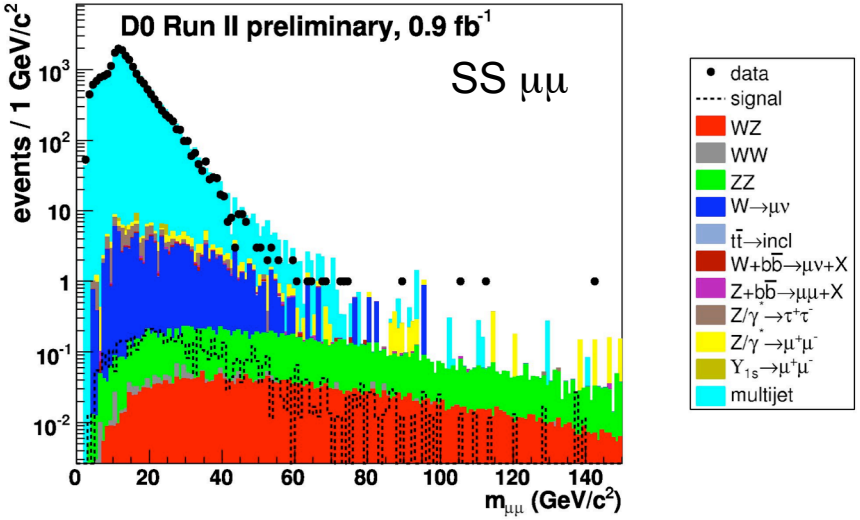




Trileptons

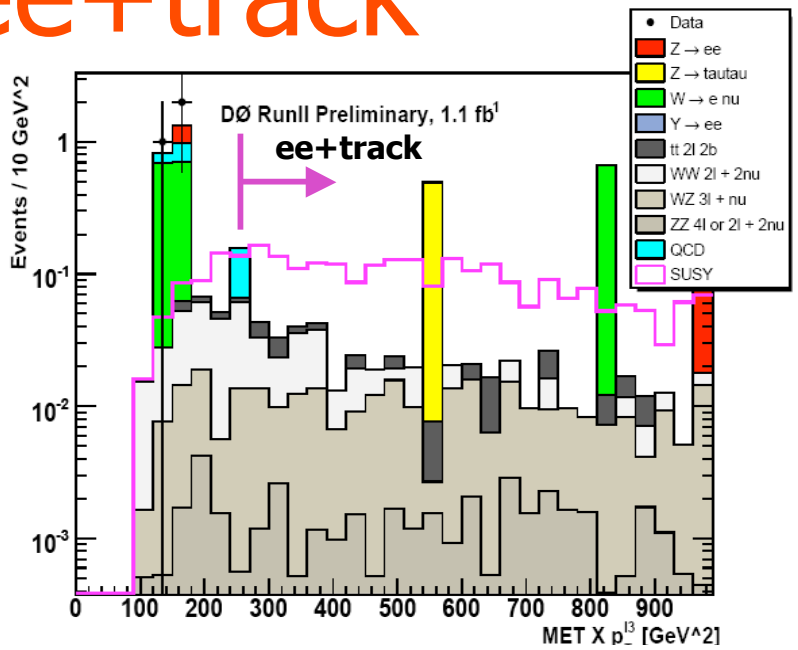
- Require two leptons (e or μ) plus an isolated track
  - isolation in a hollow cone to include τ
  - anti-Z/DY/diboson and anti-top cuts
  - significant missing E_T
- Require two leptons of same sign
  - now dimuons only (clean)
  - anti-Z/DY/diboson and anti-top
  - significant missing E_T
- At preselection stage the signal to background is miniscule, and the number of backgrounds is large

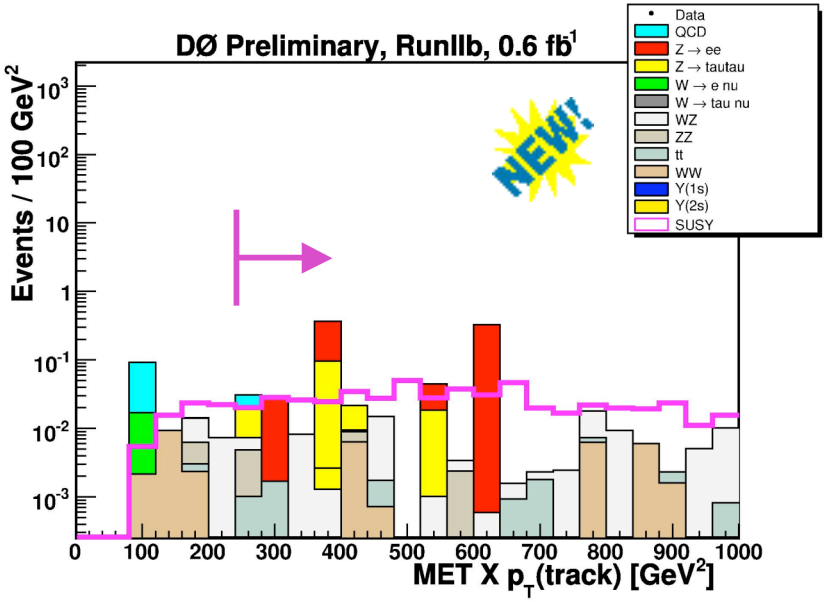




Trileptons: ee+track

- New challenge for Run IIb: instantaneous luminosity
- L = $3 \cdot 10^{32} \Rightarrow \sim 10$ int/crossing!
  - trigger
  - track reconstruction
  - lepton identification (isolation)
- Seem to be under control
  - Layer 0 helps
  - optimize track quality cuts
  - Have preliminary ee+l result
  - expect 2 fb^{-1} results for all channels soon!

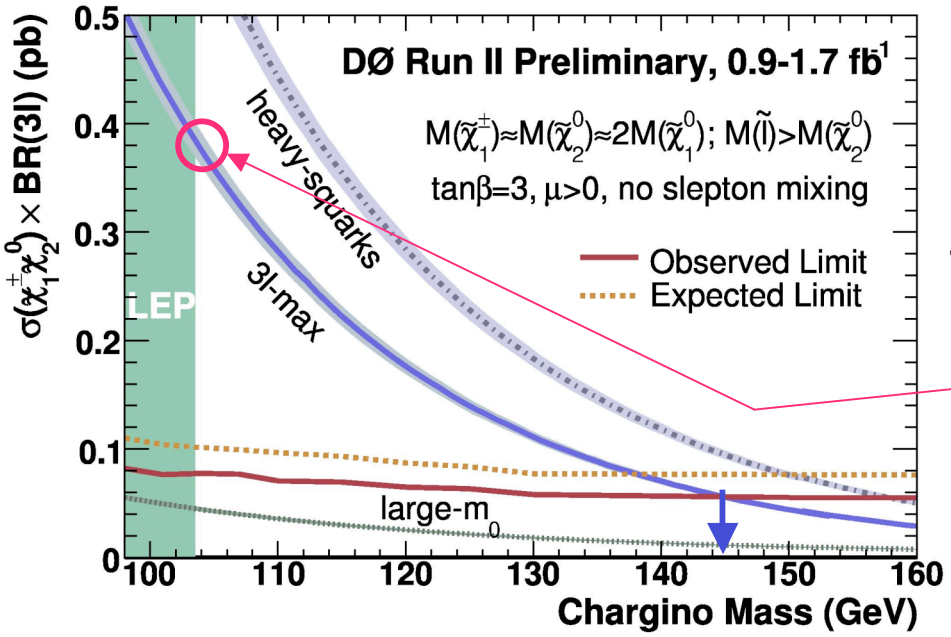


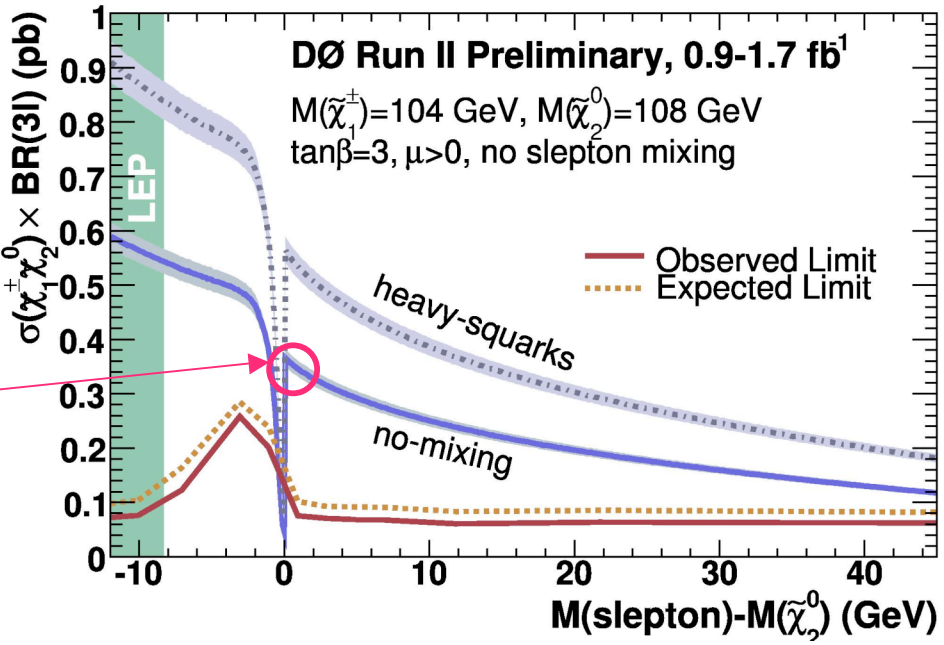


Trileptons

- Need model to set limits: "favorably tweaked" mSUGRA
  - slepton mass degenerate and no stau mixing ⇒ no tau enhancements
- Scenarios:
  - Heavy-squarks: largest possible $\chi_1^+\chi_2^0$ cross-section
  - Large m_0: heavy sleptons, χ decays mostly through W^*/Z^*, lower branchings
  - 3l-max: slepton mass is just above χ_2^0, χ decays mostly though sleptons

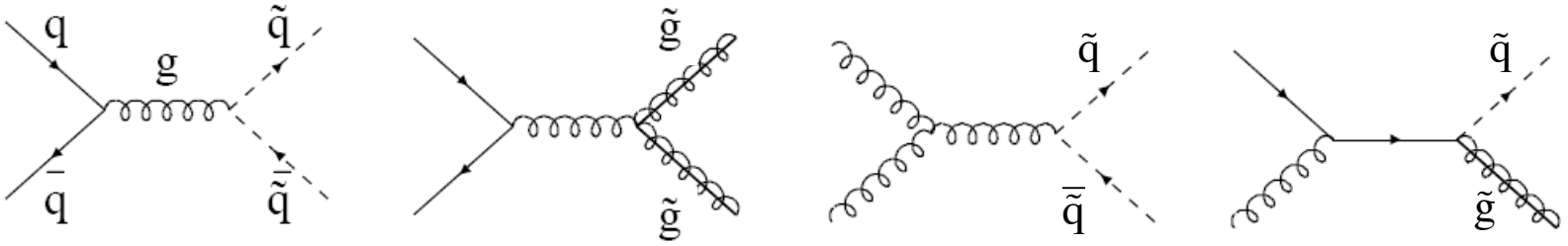
DØ Analysis	Lumi (fb^{-1})	Predicted Background	Observed data
ee+track	0.6	1.0±0.3	0
	1.1	0.8±0.7	0
μμ+track	1.1	$0.3^{+0.7}_{-0.3}$	2
eμ+track	1.1	$0.9^{+0.4}_{-0.1}$	0
SS μμ	0.9	1.1 ± 0.4	1
eτ+track	0.3	0.6±0.1	0
μτ+track	0.3	0.4±0.1	1





Squarks and Gluinos

- Produced by strong interaction – expect large cross-section at hadron colliders
- If R-parity is conserved
  - SUSY particles are produced in pairs



  - squarks and gluinos decay into regular quarks and gluons and lighter SUSY particles
  - lightest SUSY particle (LSP) is stable (dark matter candidate)
  - final state has (at minimum) jets and two LSP's which escape detection – missing transverse energy
- Unfortunately, squarks and gluinos are likely the heaviest SUSY particles - reduced cross-sections

Gluino / Squark Searches

jets+MET

- Generic squarks and gluinos
  - $m_{\tilde{q}} << m_{\tilde{g}}$ $\quad \tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_1^0$ - two jets + MET
  - $m_{\tilde{q}} \approx m_{\tilde{g}}$ $\quad \tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$ - three jets + MET
  - $m_{\tilde{q}} >> m_{\tilde{g}}$ $\quad \tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$ - four jets + MET

  1.1 fb^{-1} preliminary this winter
- High tanβ (cascades with τ-leptons)
  - $\tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_1^+ \rightarrow q\tilde{\chi}_1^0 \bar{q}\tau\nu_\tau\tilde{\chi}_1^0$
  - $\tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_2^0 \rightarrow q\tilde{\chi}_1^0 \bar{q}'\tau\tau\tilde{\chi}_1^0$

  NEW!
- Light sbottom
  - $\tilde{b}\bar{\tilde{b}} \rightarrow b\tilde{\chi}_1^0 \bar{b}\tilde{\chi}_1^0$ two b-jets + MET

  0.4 fb^{-1} PRL 97 171806 (2006)
- Light stop (if stop is lighter than top + neutralino)
  - for heavy sneutrino $\tilde{t} \rightarrow c\tilde{\chi}_1^0$ - two c-jets + MET
    $\tilde{t} \rightarrow bW^+\tilde{\chi}_1^0$ - top-like final state
  - for light sneutrino $\tilde{t} \rightarrow bl\tilde{\nu}$ 0.4 fb^{-1} Submitted to PLB FERMILAB-PUB-07/352-E

NEW! NEW!

New this summer

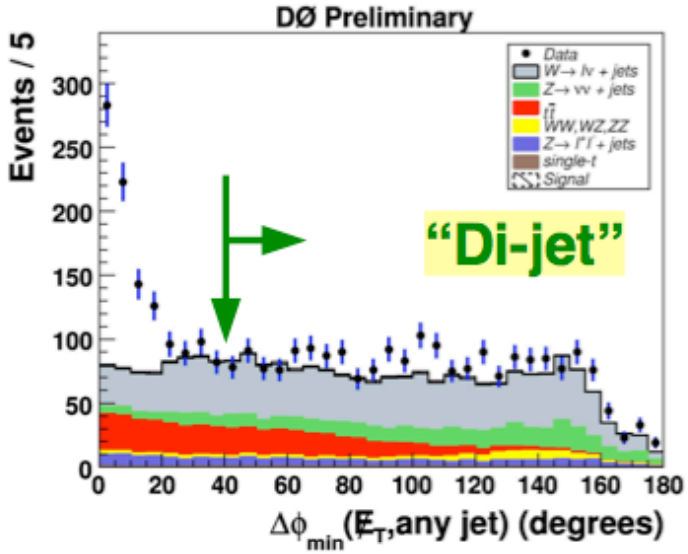
Lepton(s) + softer jets+MET

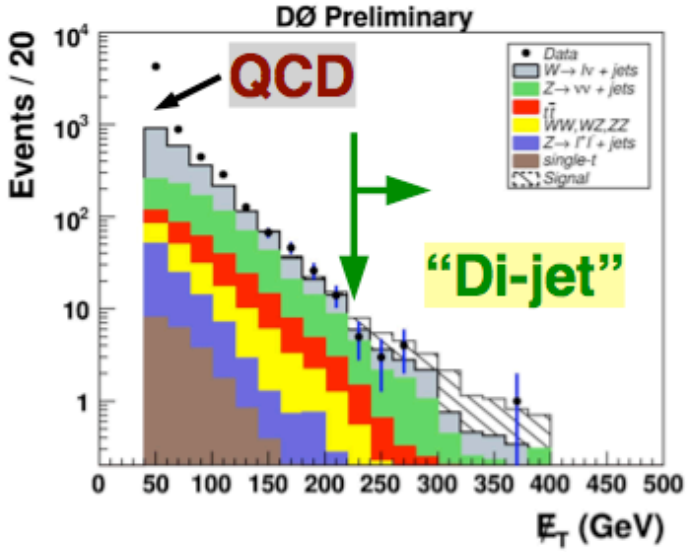
Squarks and Gluinos: Selection

A. Meyer W&C, March 16 2007

- Main backgrounds: $Z \rightarrow \nu\nu$ + jets, ttbar, W+jets (Alpgen)
- QCD negligible in the end
- Common preselection:
  - 2 acoplanar jets ($\Delta\varphi < 165°$) with E_T>35 GeV and $|\eta|$<0.8, confirmed by tracks
  - MET > 40 GeV
- Jet 3 / 4: $|\eta| < 2.5$, $E_T > 35 / 20$ GeV
- MET isolated from jets
- Veto isolated electrons and muons
- Optimize final cuts on MET and H_T for best expected limit:

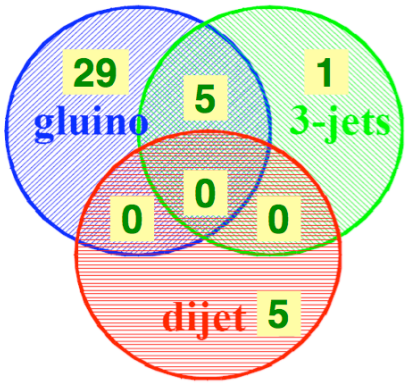
"Di-jet"	MET > 225 GeV	HT > 300 GeV
"3-jet"	MET > 150 GeV	HT > 400 GeV
"Gluino"	MET > 100 GeV	HT > 300 GeV

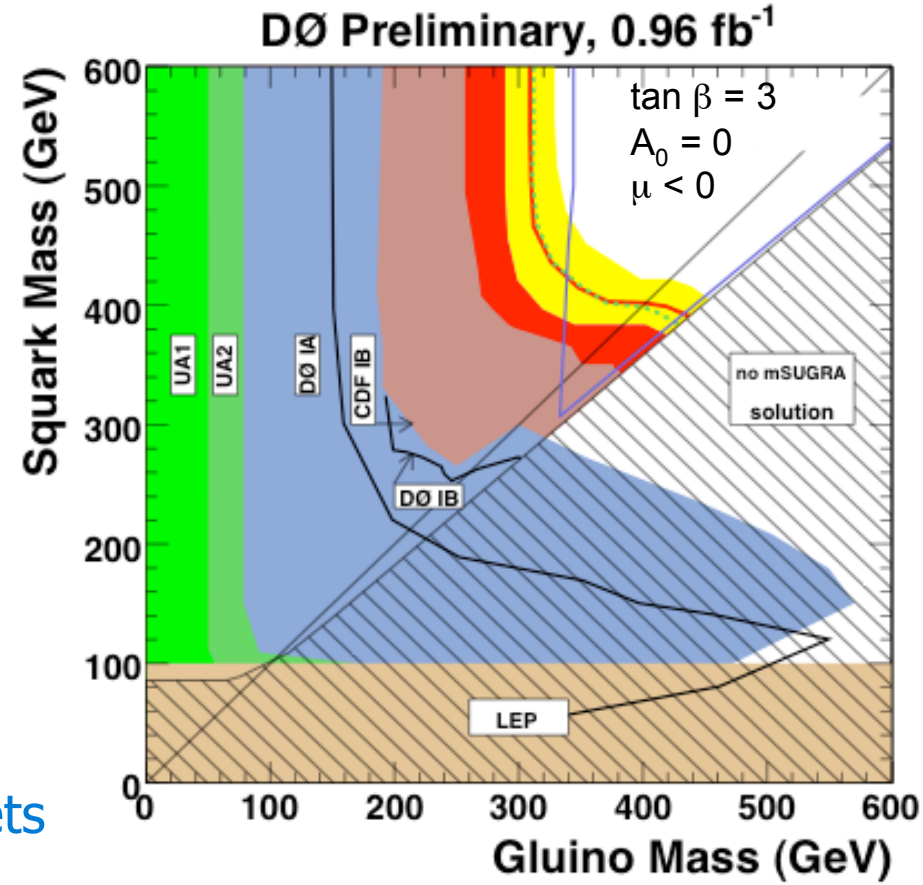




Squarks and Gluinos

	Data	SM Expectation
"Di-jet"	5	7.5 ± 1.1 + 1.3 - 1.0
"3-jet"	6	6.1 ± 0.4 + 1.3 - 1.2
"Gluino"	34	33.4 ± 0.8 + 5.6 - 4.9



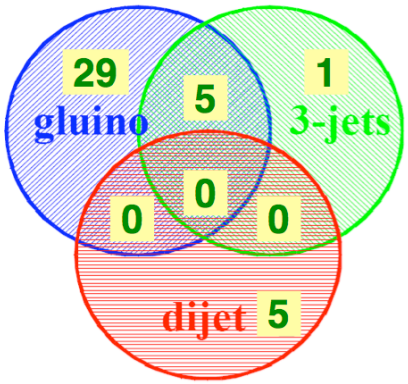


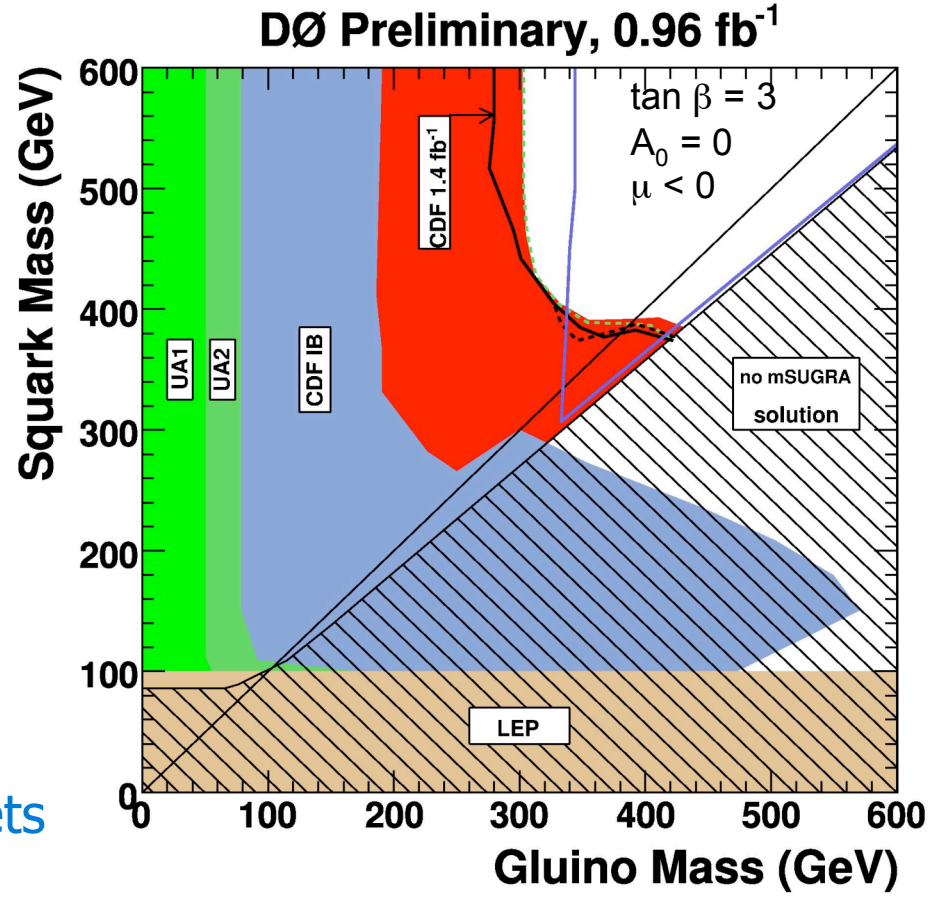
- Main physics background is W+jets
  - reason for lepton veto
  - acceptance for cascade decays is diminished
  - at high tanβ cascades go mainly through τ-leptons

    Require hadronic τ and relax other cuts

Squarks and Gluinos

	Data	SM Expectation
"Di-jet"	5	7.5 ± 1.1 + 1.3 - 1.0
"3-jet"	6	6.1 ± 0.4 + 1.3 - 1.2
"Gluino"	34	33.4 ± 0.8 + 5.6 - 4.9

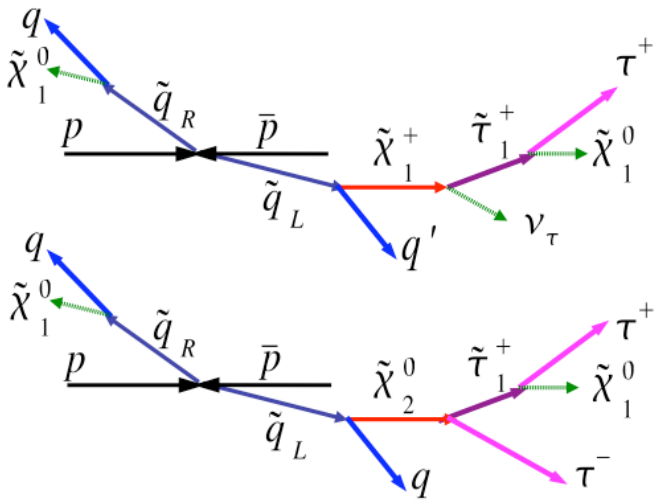


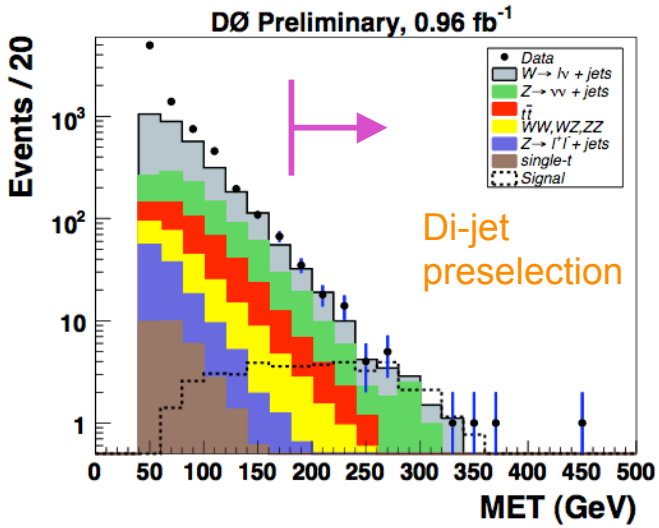


- Main physics background is W+jets
  - reason for lepton veto
  - acceptance for cascade decays is diminished
  - at high tanβ cascades go mainly through τ-leptons

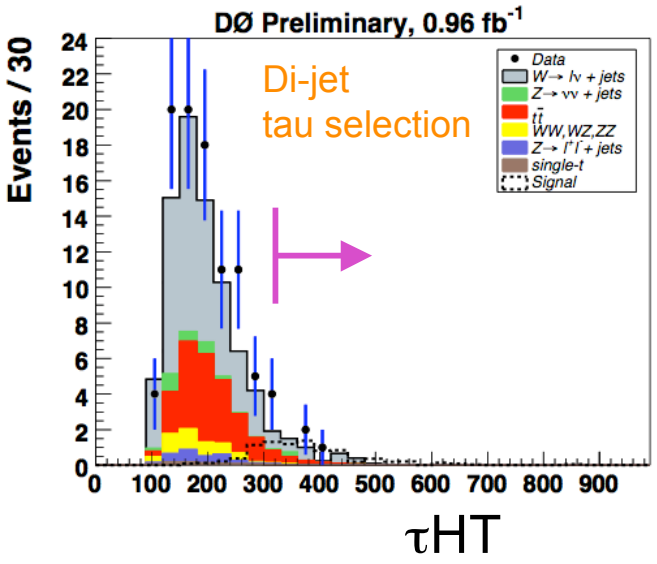
    Require hadronic τ and relax other cuts

Squarks and Gluinos: jet+MET+tau





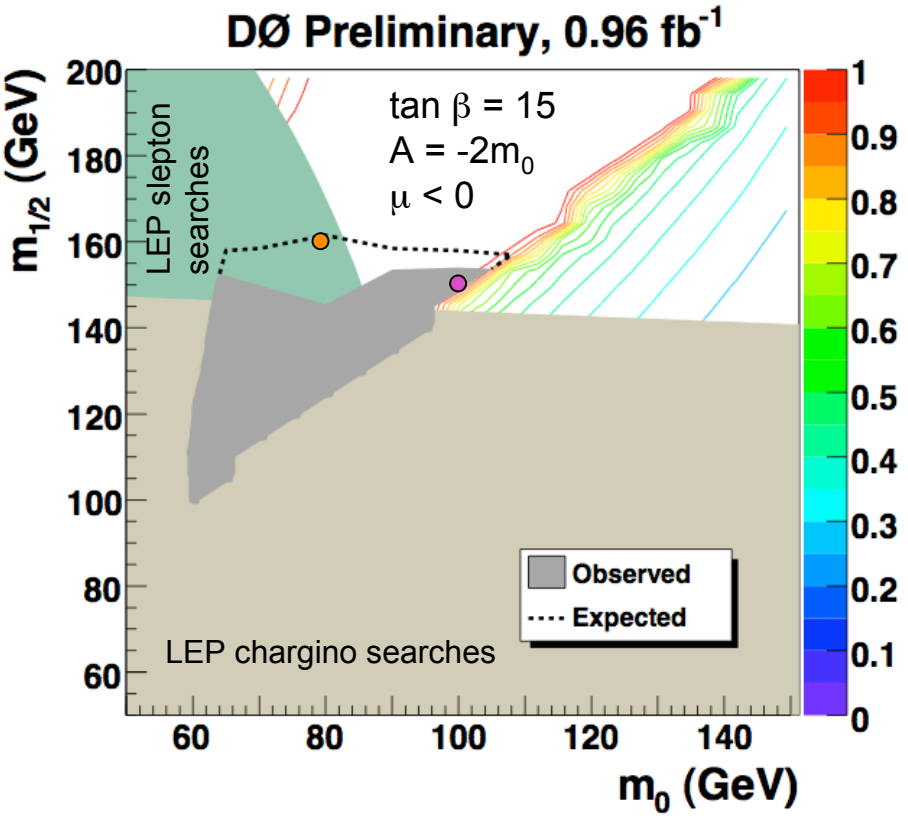
- Same selection as generic jets+MET analysis up to final cuts on MET and H_T
- Two analyses streams: di-jet and multijet
- At least one τ candidate $\Delta R(\tau, j_{1,2})>0.5$
- $\tau HT = E_T^{j1}+E_T^{j2}+E_T^{\tau} > 325$ GeV
- MET > 175 GeV
- H_T > 200 GeV (multijet stream only)

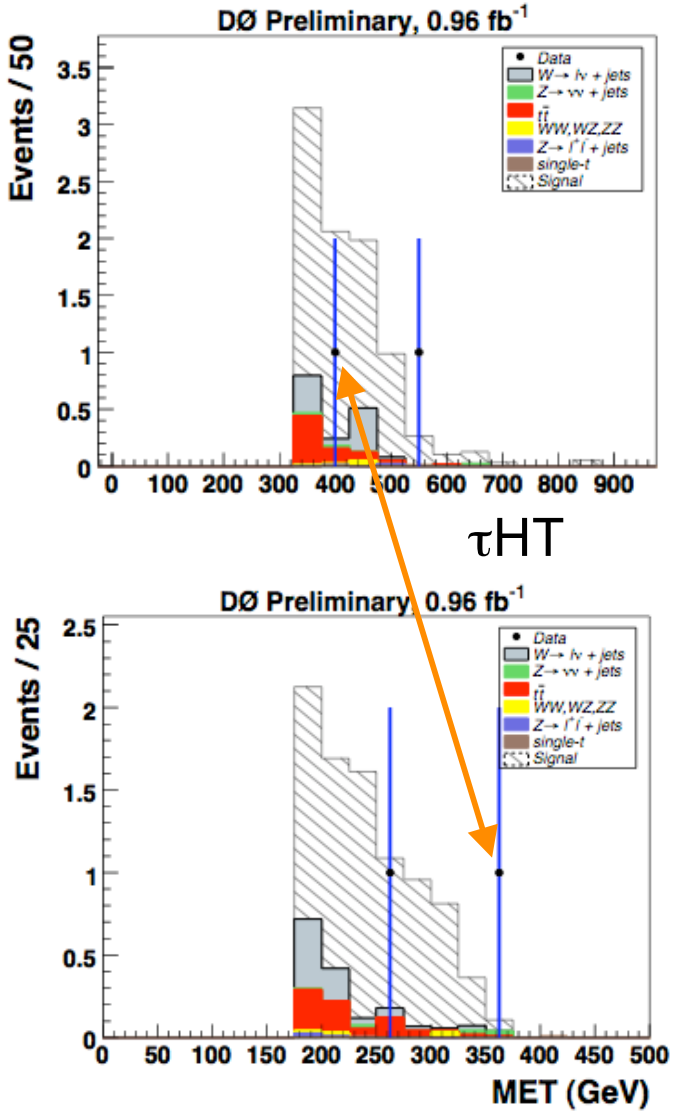


Squarks and Gluinos: jet+MET+tau

m_0, $m_{1/2}$

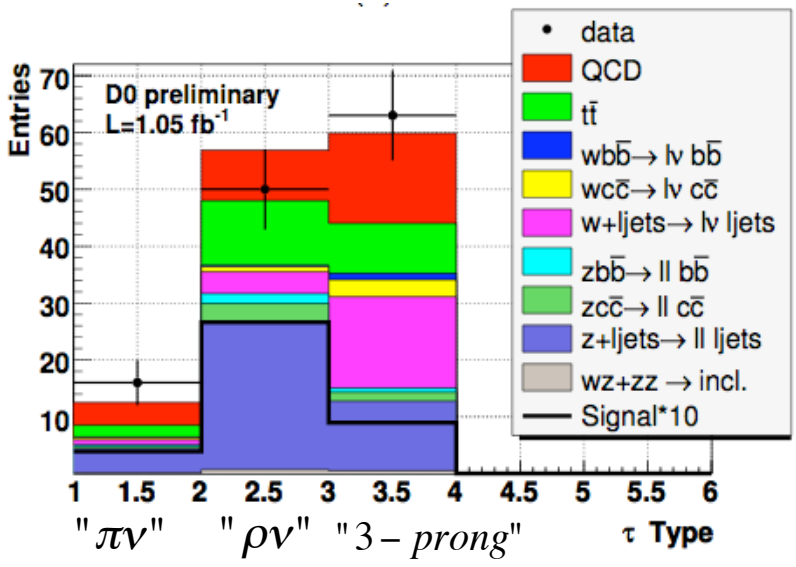
observed	SM expected	(80,160)	(100,150)
2	$1.7^{+0.7}_{-0.4}$	4.7±0.4	7.1±0.6

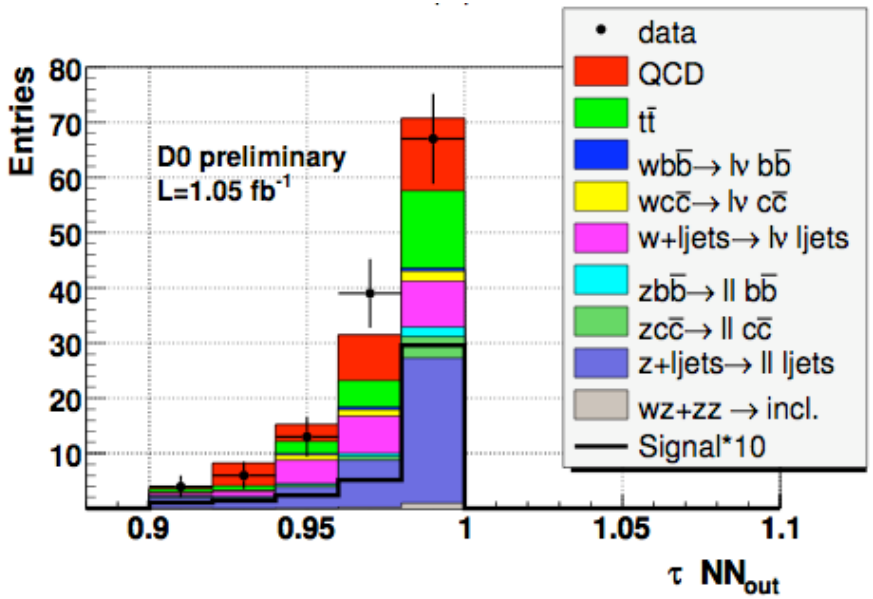




Third generation leptoquarks in bbττ

- Charge -4/3 decays 100% into $LQ_3 \to \tau b$
- Charge -2/3 decays into $LQ_3 \to \tau \bar{b}$ (and $\to \nu_\tau \bar{t}$ if kinematically allowed)
- One tau decays leptonically, one hadronically:
  - require one isolated muon p_T > 8 GeV
  - opposite charge hadronic tau candidate E_T>15 GeV (20 for 3-prong decays)
  - two jets, E_T>25, 20 GeV
- Two analysis streams: exactly one or two NN b-tags



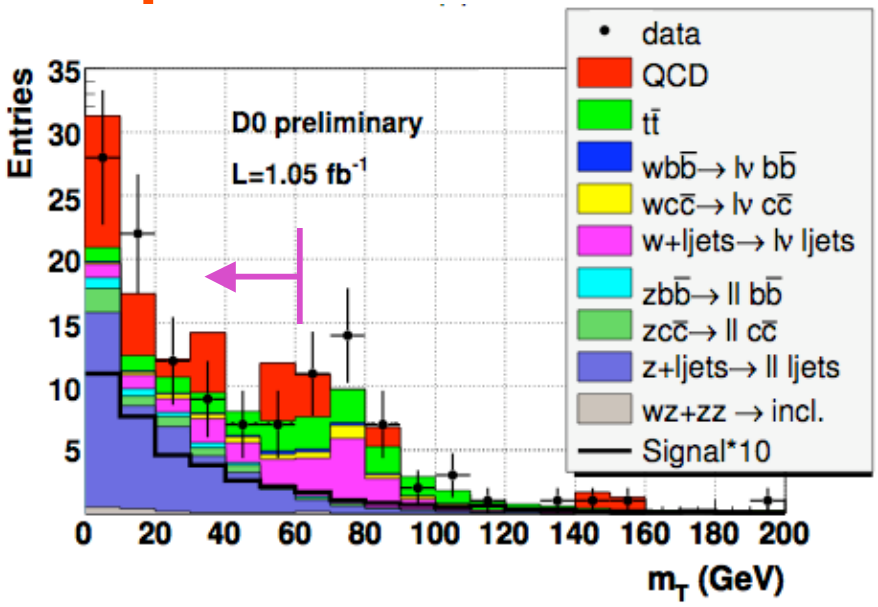


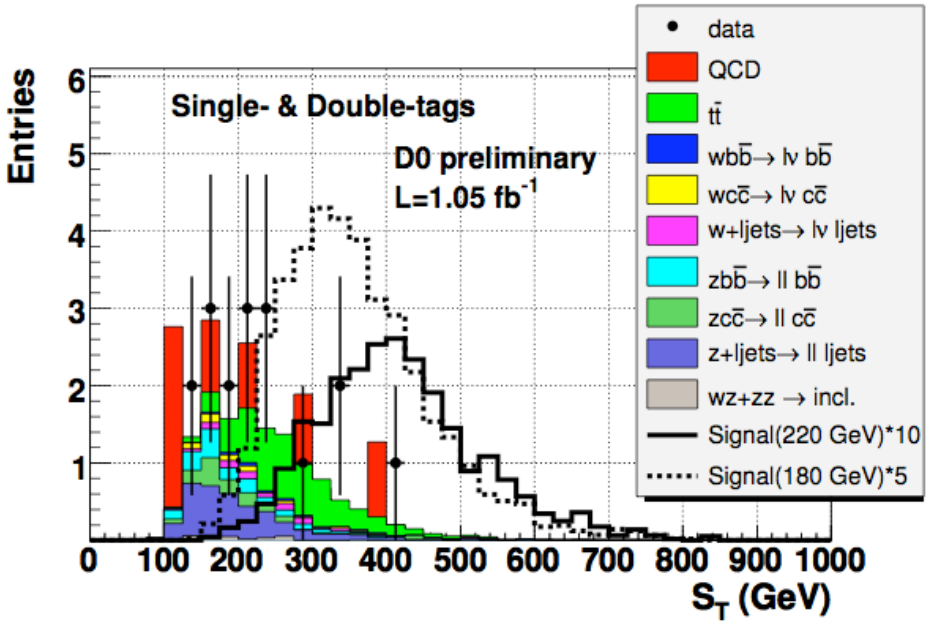
Third generation leptoquarks in bbττ

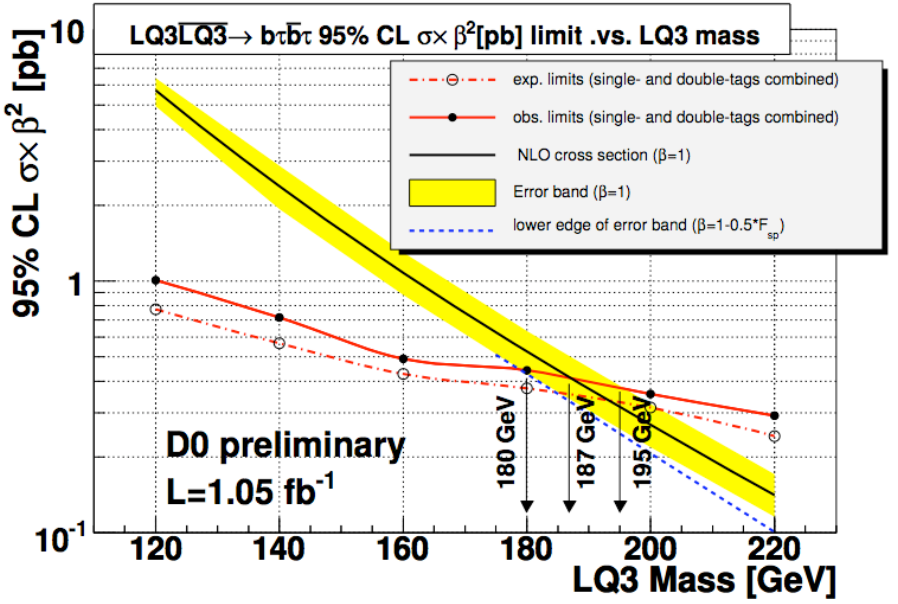
- Two more handles
  - $m_T(\mu,MET)$ - suppress W+jets & top
  - $S_T=p_T(\mu)+p_T(\tau)+E_T(j_1)+E_T(j_2)+MET$

	preselection	1 tag	2 tags
total BKGD	131.25 ± 2.11	14.79 ± 0.51	3.56 ± 0.11
Data	129	16	1
Sig.(220 GeV)	3.80 ± 0.09	1.37 ± 0.04	1.08 ± 0.04

- Use entire S_T distribution to set CL_S limits







stop in cc+MET

- Stop quarks are pair-produced
  - final state is two c-jets and MET
- Main backgrounds
  - W+jets (W→lν, lepton lost)
  - Z+jets (Z→νν)

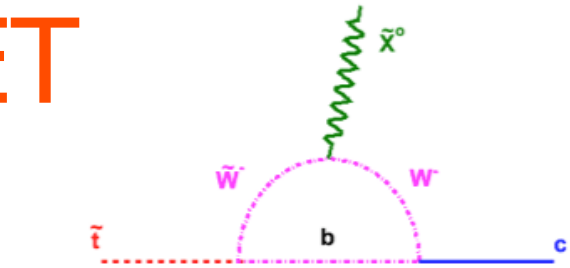
  } crosscheck / normalize to data
- Require exactly two acoplanar jets
  - $|\eta_j|<1.5$; $E_t^j > 40, 20$ GeV; track conf.
  - $\Delta\varphi(j_1,j_2) < 165^0$
  - $|\vec{E}_{T_1} + \vec{E}_{T_2}|$ = MHT > 40 GeV
- MET > 60 GeV, isolated from jets
  - $\Delta\varphi(j, \text{MET}) > 50^0$
- Veto leptons / isolated tracks
- Asymmetry and jet-MET separation

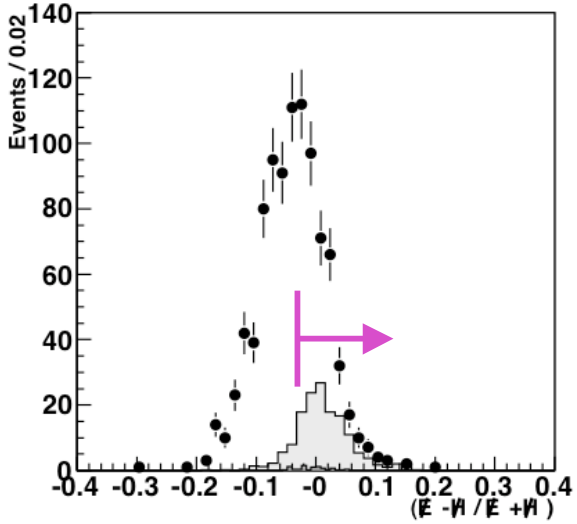
$$\Delta\varphi_{\max,\min} : \min,\max \; jet - MET separation$$

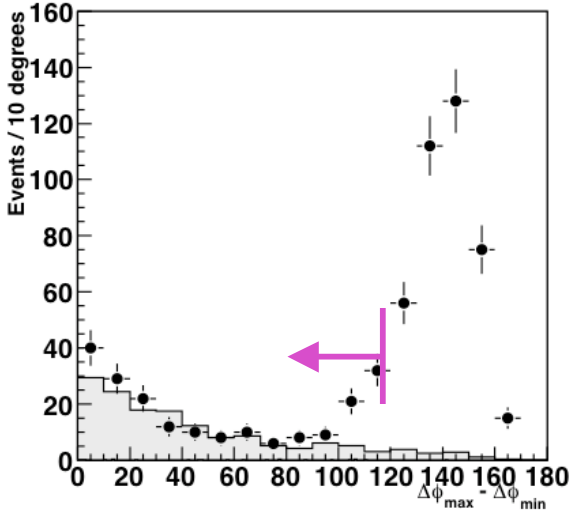
$$\Delta\varphi_{\max} - \Delta\varphi_{\min} < 120^0$$

$$A = \frac{\text{MET} - \text{MHT}}{\text{MET} + \text{MHT}} > -0.05$$

} Jets are softer than in generic squark/gluino search - need extra handles for QCD

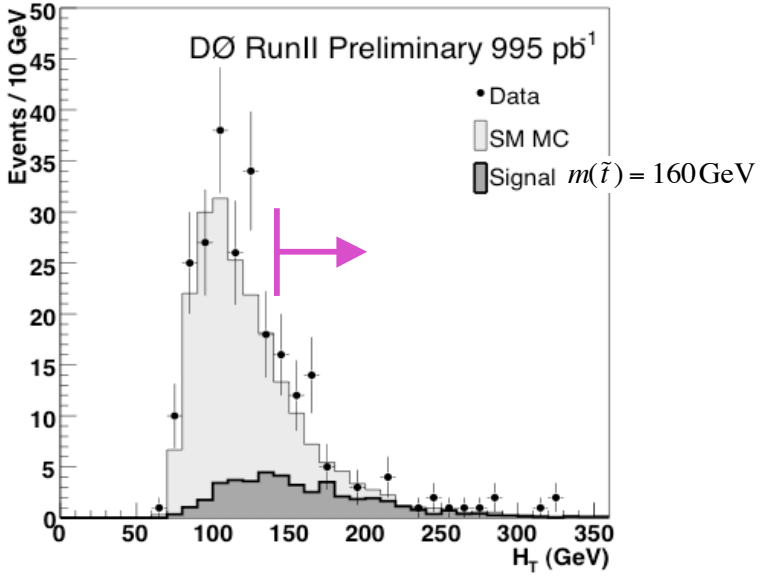






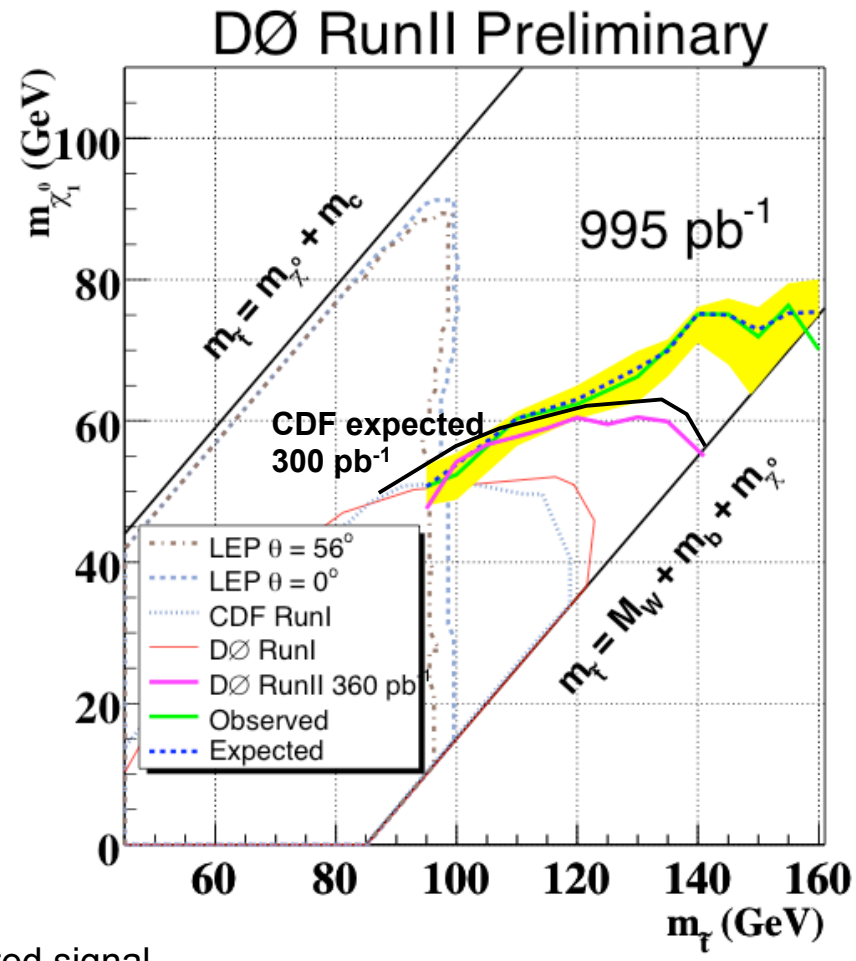
stop in cc+MET

- NN flavor tag at least one jet
- Optimize MET, MHT and $\Delta\varphi_{max}+\Delta\varphi_{min}$ for each stop/neutralino mass



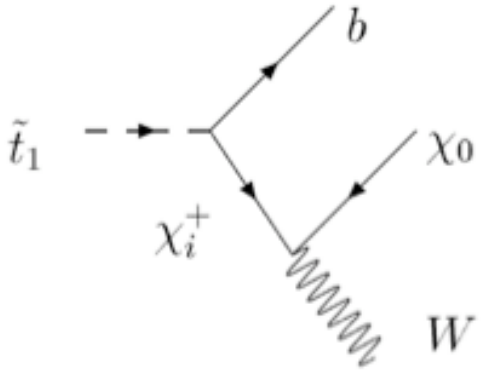
$W \to l\nu$+jets	20.6 ± 2.3
$Z \to \nu\nu$ +jets	13.2 ± 1.8
$W \to l\nu$ +HF $(b\bar{b}, c\bar{c})$	11.9 ± 1.1
$Z \to \nu\nu$+HF $(b\bar{b}, c\bar{c})$	11.6 ± 0.8
WW, WZ, ZZ	2.7 ± 0.3
$t\bar{t}$	2.3 ± 0.1
Single top	1.8 ± 0.1
$Z \to ll(e, \mu, \tau)$+jets	0.1 ± 0.1
$Z \to ll(e, \mu, \tau)$+HF $(b\bar{b}, c\bar{c})$	0.1 ± 0.1

Total BKG	64.3±3.2
Data	66

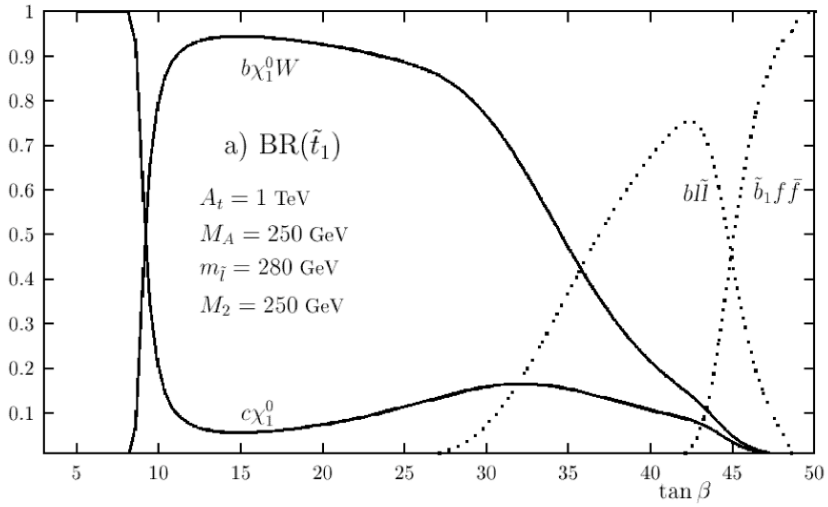


Expected signal
27± 2 events

stop in $bW\chi_1^0$



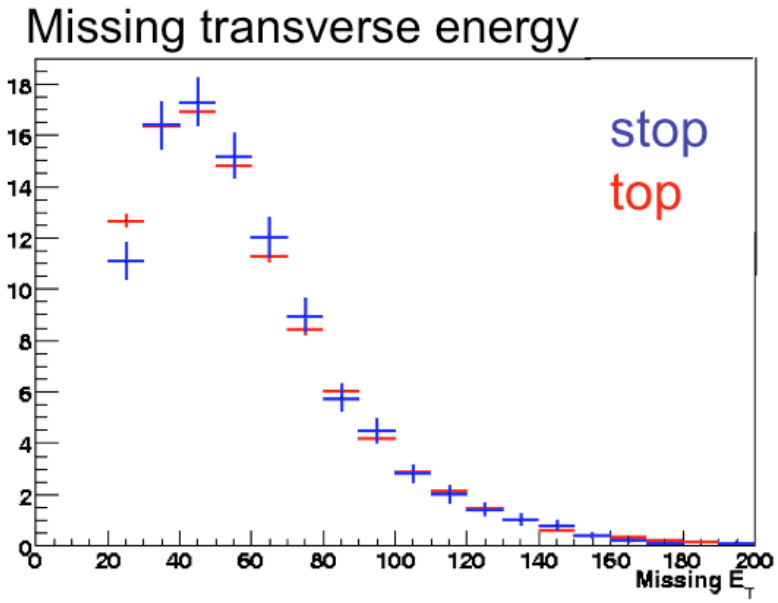
Djouadi, Mambrini, PRD 63 (2001) 115005



- The decay chain is

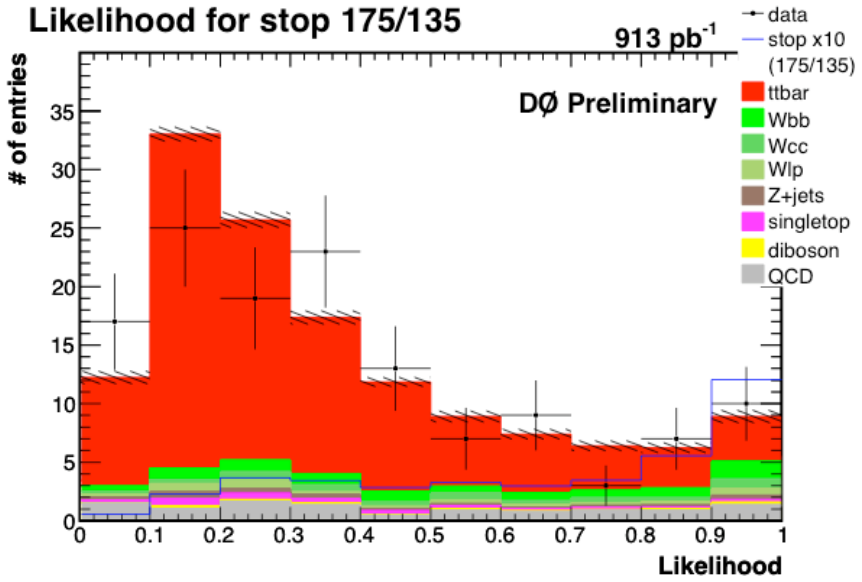
$$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\bar{b}W^+W^- + \tilde{\chi}_1^0\tilde{\chi}_1^0$$

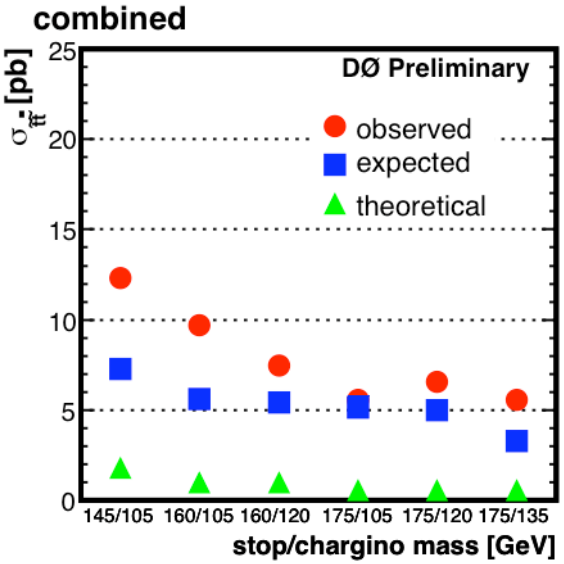
- Kinematically very close to standard model's ttbar
- Very tough to distinguish from top
  - need multivariate approach



stop in $bW\chi_1^0$

- Analysis is performed on the same sample as top cross-section measurement
  - good lepton and 4 jets
  - second lepton veto
  - at least one b-tagged jet
- Discriminating variables for m_{st}=175, $m_{\chi+}$ =135 GeV (list varies from mass point to mass point)
  - E_T of the leading b-tagged jet
  - ΔR(b, leading jet)
  - top mass from global fit
  - $\cos\theta^*$(b,b) from global fit
- Limits are ~factor of 10 above theoretical prediction
  - need more data…





SUSY
with gauge-mediated breaking

Gauge-Mediated SUSY Breaking

- Alternative to gravity mediated SUSY breaking
  - SUSY breaking occurs at scale Λ much lower than GUT (10 – 100 TeV)
  - Mediated by new gauge fields – "messengers"
  - Gravitino is very light (<keV) and is LSP
  - Dark Matter is a mix of the gravitino and the lightest "messenger"
- Lifetime of NLSP is a free parameter
  - All SUSY particles cascade to NLSP, so if R-parity is conserved all final states have two NLSPs
- NLSP can be neutralino or stau:

  $\chi_1^0 \rightarrow \gamma G$ or $\tau_1^+ \rightarrow \tau^+ G$
  - If neutralino is higgsino-like then it can also decay to hG and ZG
  - Gravitino is weakly interacting and is registered as missing transverse energy (MET)

Typical Final States

Same final states are predicted by other models (extra dimensions, 4th generation quarks, etc…)

	prompt decays	inside detector	outside detector
Stau	multiple τ + MET	tracks with kinks	muon-like highly ionising slow moving particles
Neutralino	$\gamma\gamma$ + MET	non-pointing photon(s)	mSUGRA-like
Higgsino	γ bb + MET, γ Z+MET	Non-pointing b-jets, detached Z	mSUGRA-like

- Snowmass slope E:
  - Λ - varies
  - $M_m = 2 \cdot \Lambda$
  - $N_5 = 1$
  - $\tan\beta = 15$
  - sign μ =+1

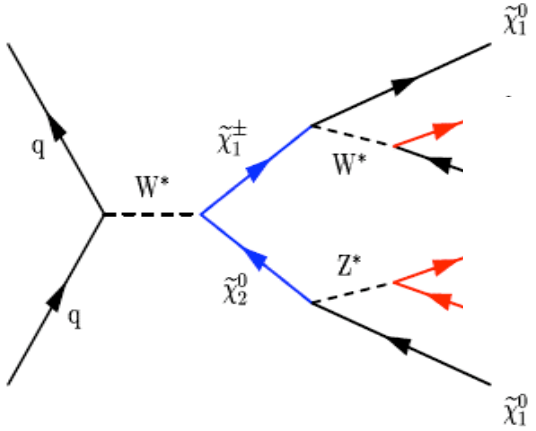
- Model Parameters:
  - Λ - mass parameter (effective scale of SUSY breaking)
  - M_m - messenger mass scale
  - N_5 - number of messenger fields
  - $\tan\beta = \langle\phi_1\rangle/\langle\phi_2\rangle$
  - sign μ =±1 - sign of higgsino mass term
  - C_{grav} - determines NLSP lifetime
- Gaugino masses proportional to N_5, scalar masses proportional to sqrt(N_5)

Di-photon Data Analysis

- If NLSP is neutralino:

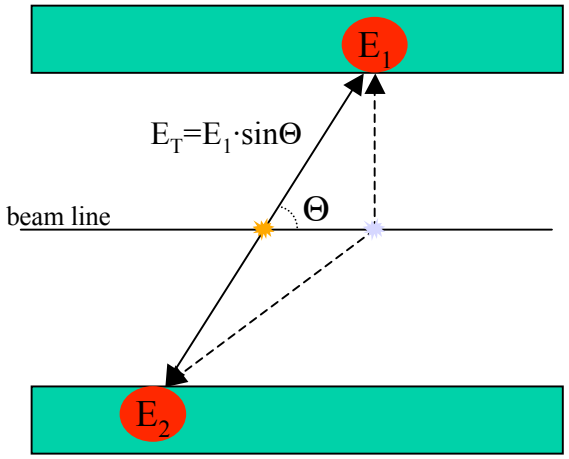
$$p\bar{p} \rightarrow gauginos \rightarrow \chi_1^0\chi_1^0 + X \rightarrow$$
$$\rightarrow \gamma\gamma + \tilde{G}\tilde{G} + X$$

Two photons and missing E_T



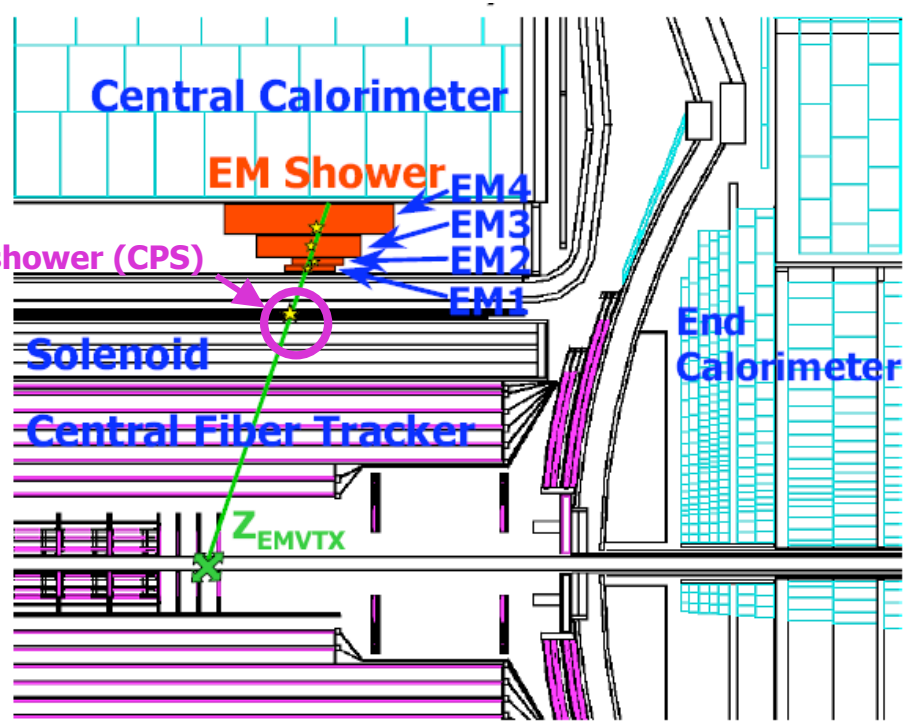
- Event selection
  - Two photons, E_T>25 GeV and $|\eta| < 1.1$
  - $\Delta\varphi$ (jet, MET) < 2.5 – for leading jet (if present) - to remove events with mismeasured missing E_T
  - use photon pointing to eliminate mis-vertexing

Photon Pointing & Vertex Selection

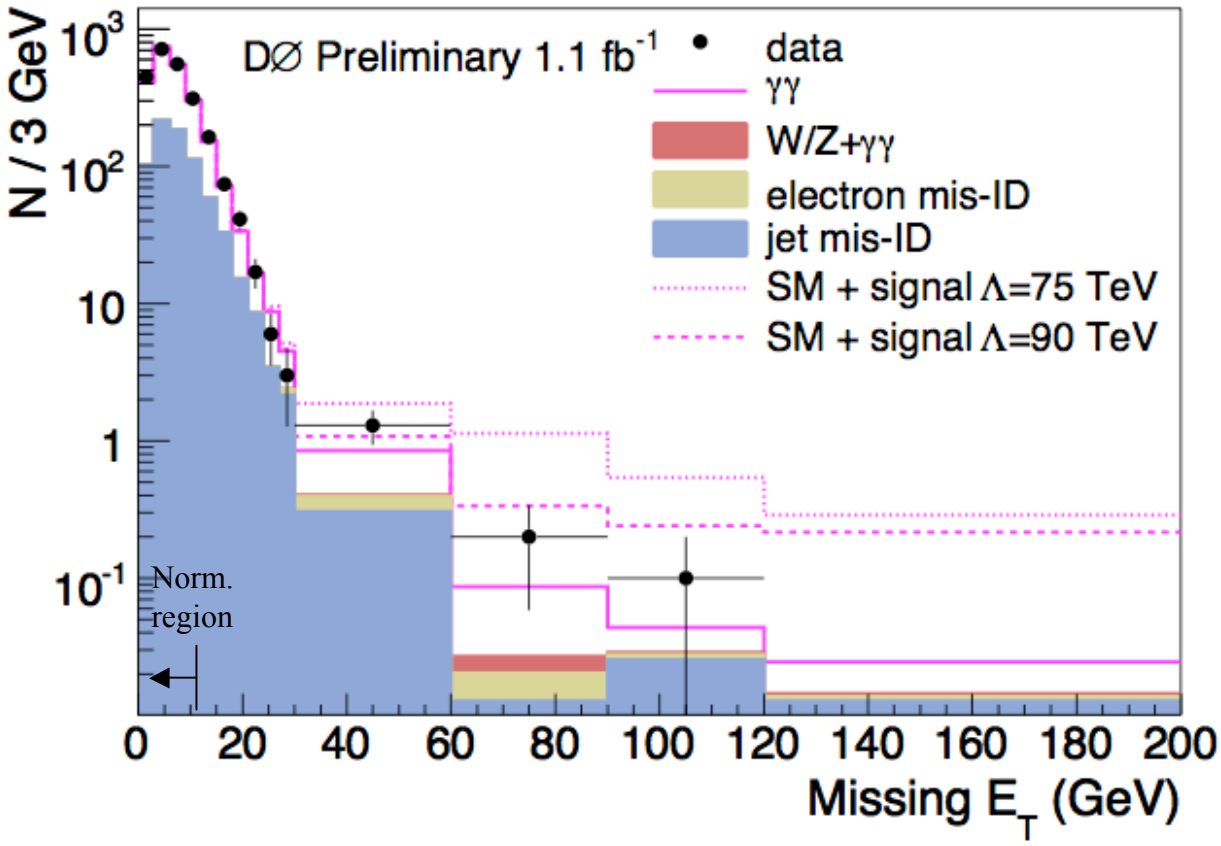


- There can be several interactions per event
- Vertex distribution RMS ~ 28 cm
- MET is significantly affected if the vertex is shifted by >10 cm
- Which vertex did the photons come from?

- DØ has four longitudinal EM layers and a preshower
- Fit a straight line through the five points (obtain resolution of each layer using Z→ee events)
- Z_{VTX} resolution ~ 2 cm (verified with Z→llγ events)
- In the analysis require at least one photon to have CPS cluster



MET in γγ Sample

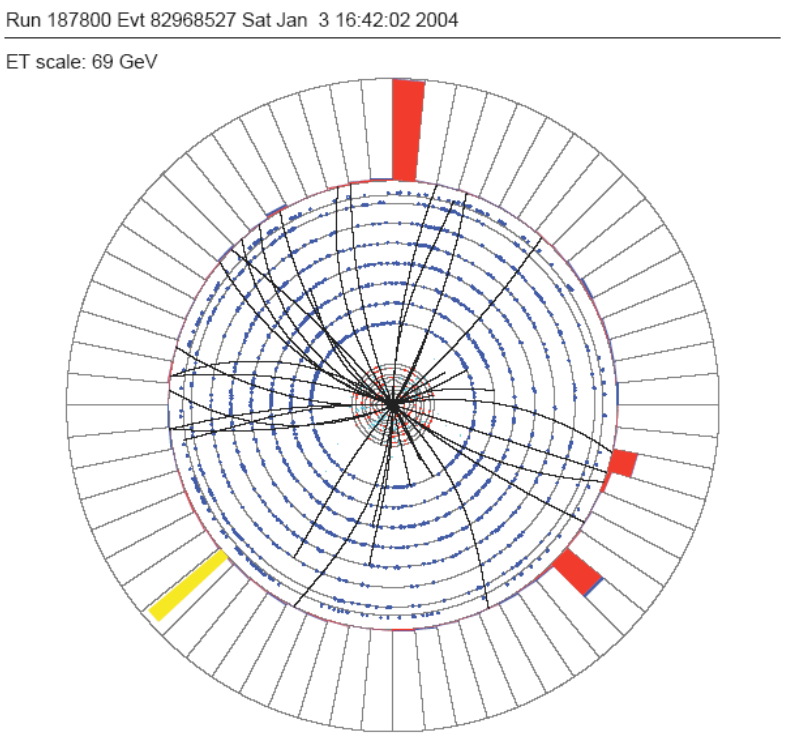


- Signal MC: ISAJET for masses and branchings, PYTHIA for event generation, full detector simulation plus real zero-bias events overlay to simulate multiple interactions per crossing

Two Highest MET Events

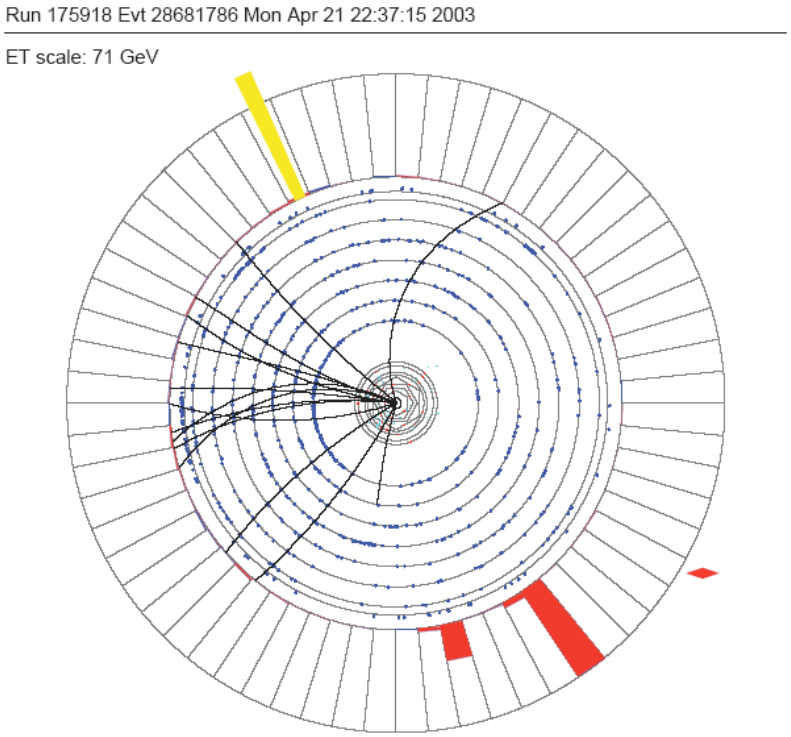
ME_T=63 GeV, $E_T(\gamma)$ = 69, 27 GeV

plus electron with E_T = 23 GeV



Expect ~0.15 events from $W\gamma\gamma$ with $E_T(\gamma)$>25 GeV

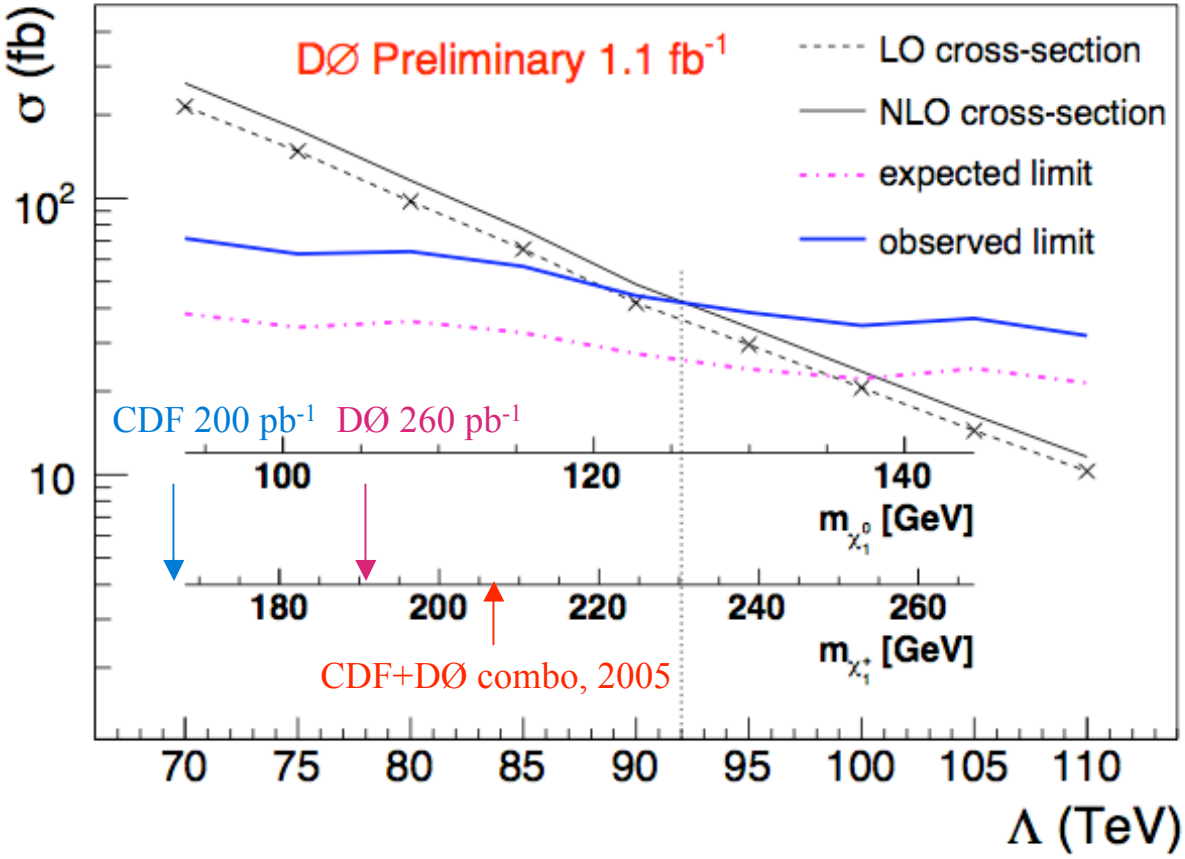
ME_T=105 GeV, $E_T(\gamma)$ = 82, 33 GeV



Expect ~0.1 event from $Z\gamma\gamma$ with $E_T(\gamma)$>25 GeV

Limit Setting

- Since data agrees with the MC proceed to limit-setting
- Use CL_S method - takes into account the shape of the distributions



@ 95% CL:

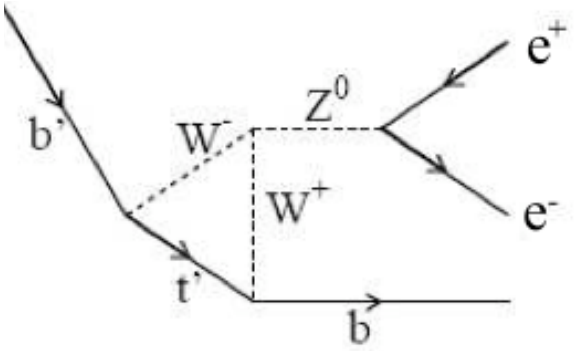
$\Lambda > 92$ TeV

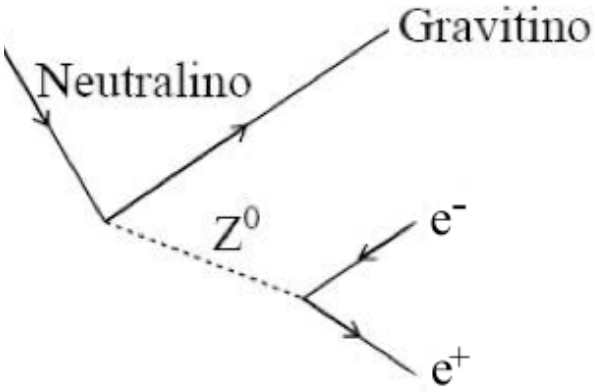
$m(\chi_1^0) > 126$ GeV

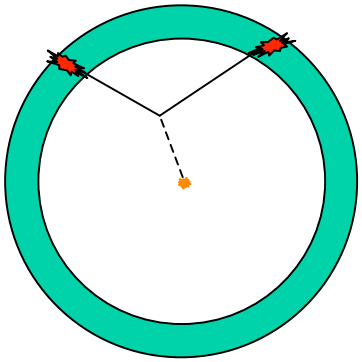
$m(\chi_1^+) > 230$ GeV

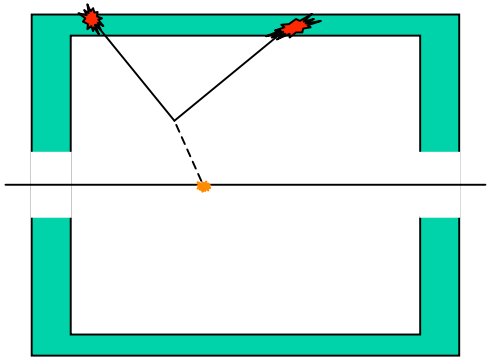
Long-Lived Particles decaying into Z

- Wide variety of possible scenarios leading to detached Zs
  - CDF has published limits on short decay lengths in muon channel, using tracking to reconstruct vertices (interpreting as b' limits)
  - Hidden Valley models also predict long-lived particles that can decay into a pair of electrons





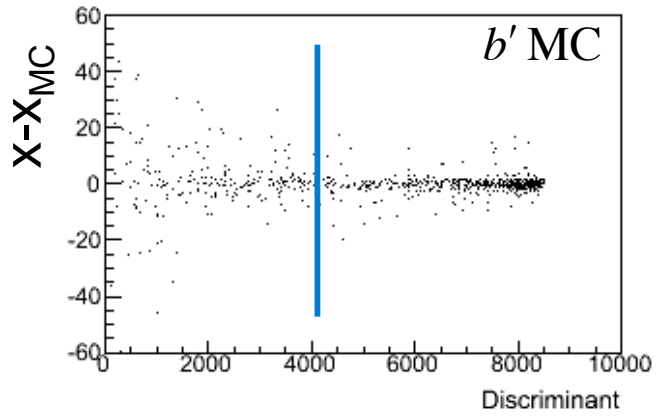


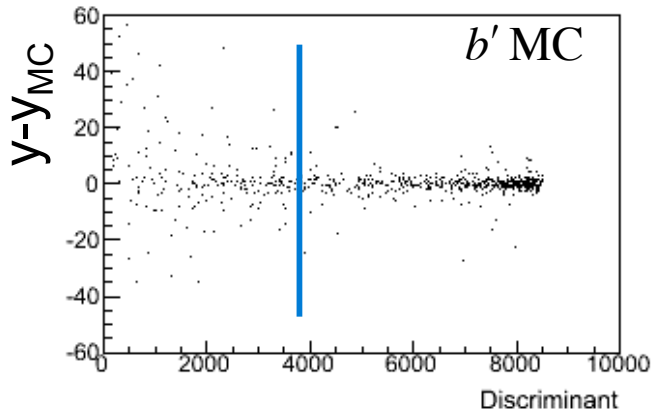


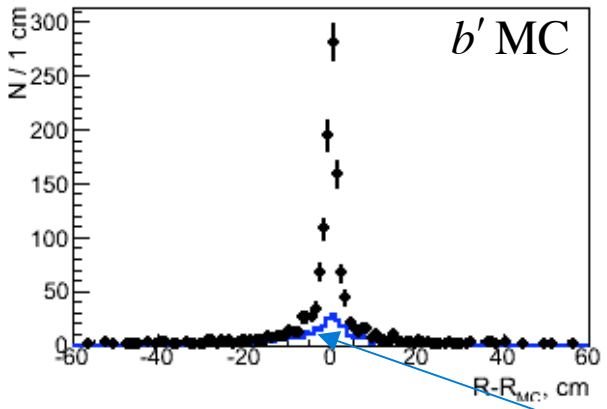
  - select events with two central EM objects
  - require no matched tracks to suppress Z→ee
  - apply standard photon ID (shower shape, isolation, track isolation)
  - use EM shower pointing to reconstruct vertices

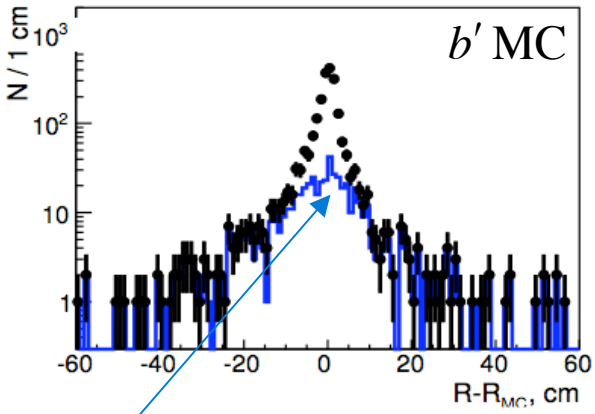
Vertexing with Calorimeter

- Use b′ as a benchmark signal (on this slide m(b′)=160, cτ=300 cm)
- Two straight lines intersecting – simple linear system to solve
  - Discriminant is proportional to sinθ (bad if lines are parallel)









D < 4000

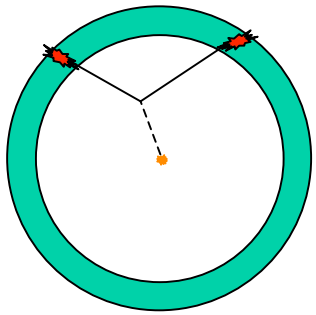
Vertex in azimuthal plane

Resolution ~2 cm

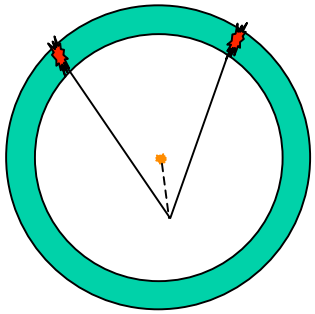
Vertexing with Calorimeter

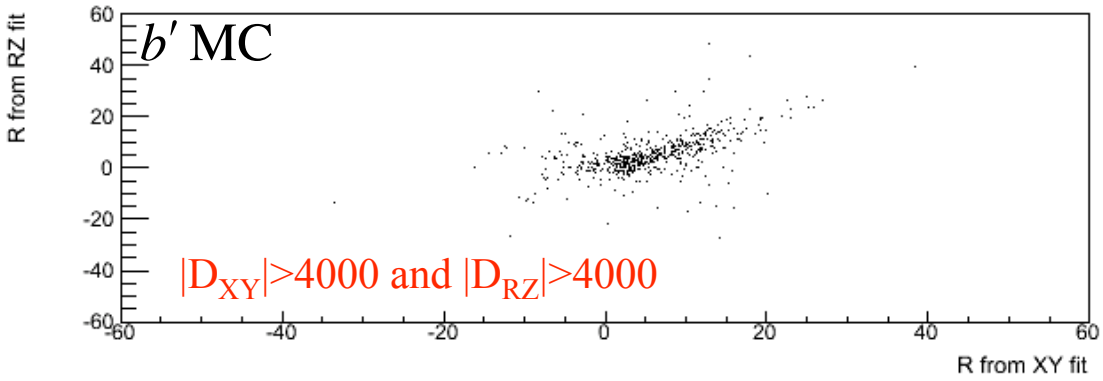
- RZ plane has poorer resolution, but XY and RZ fit agree

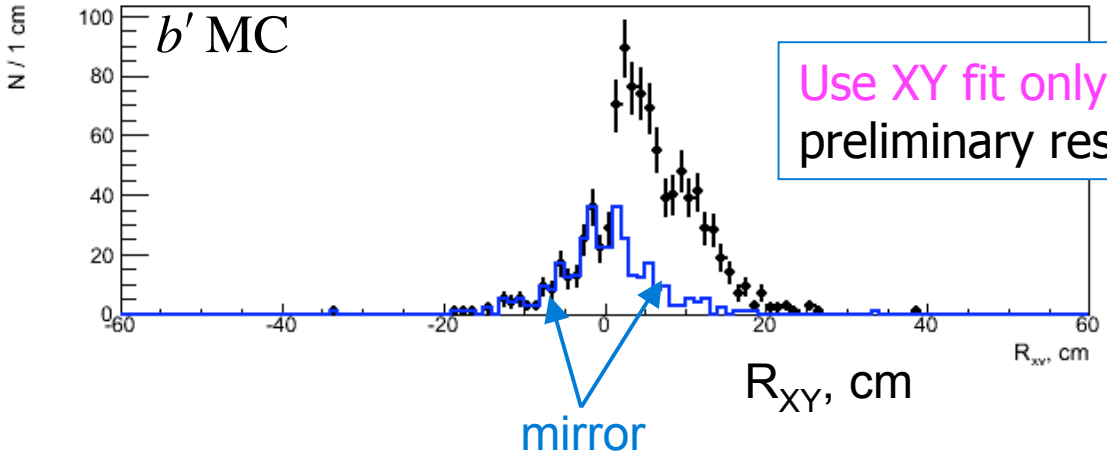
R>0



R<0



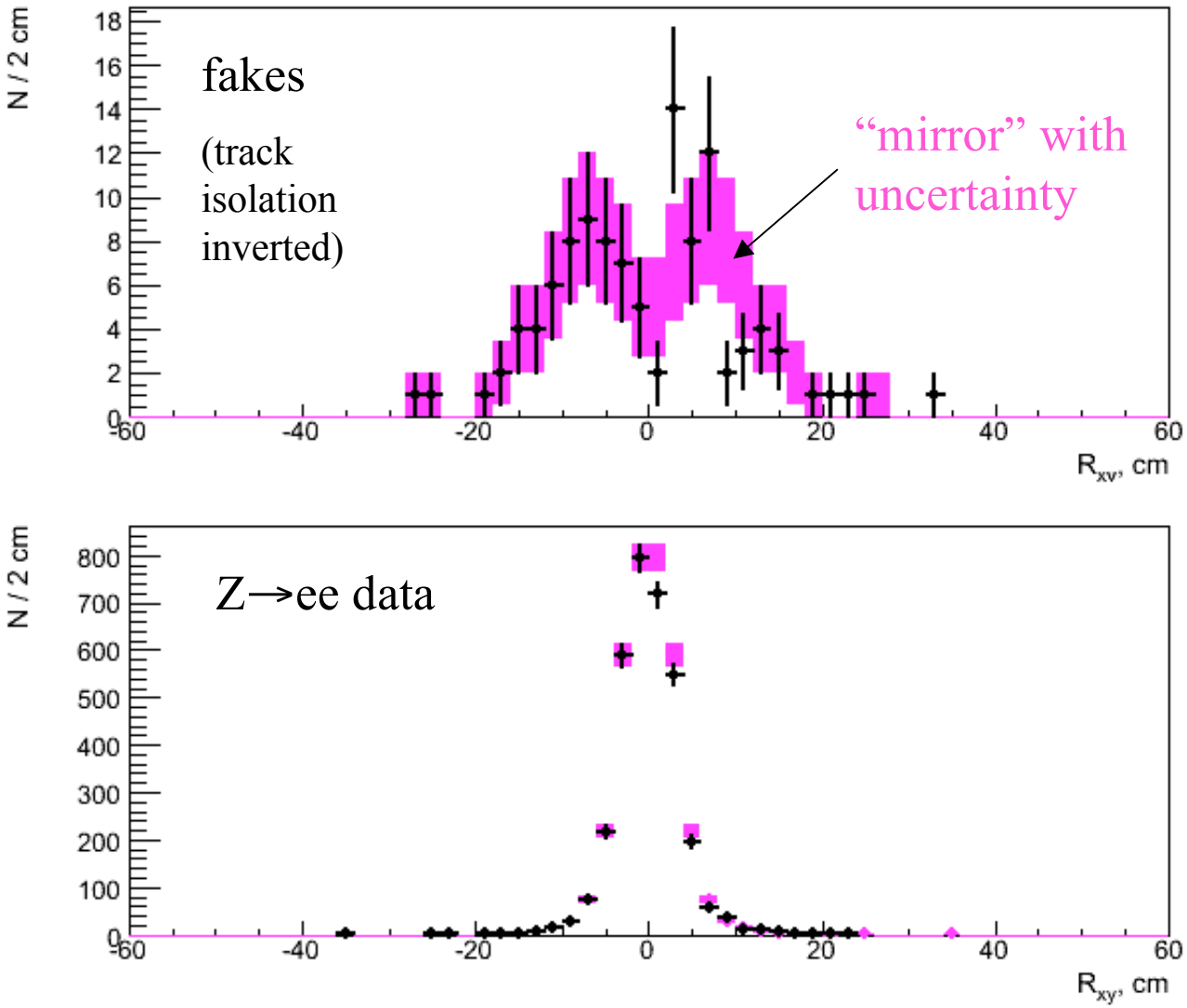




Use XY fit only - for the preliminary result

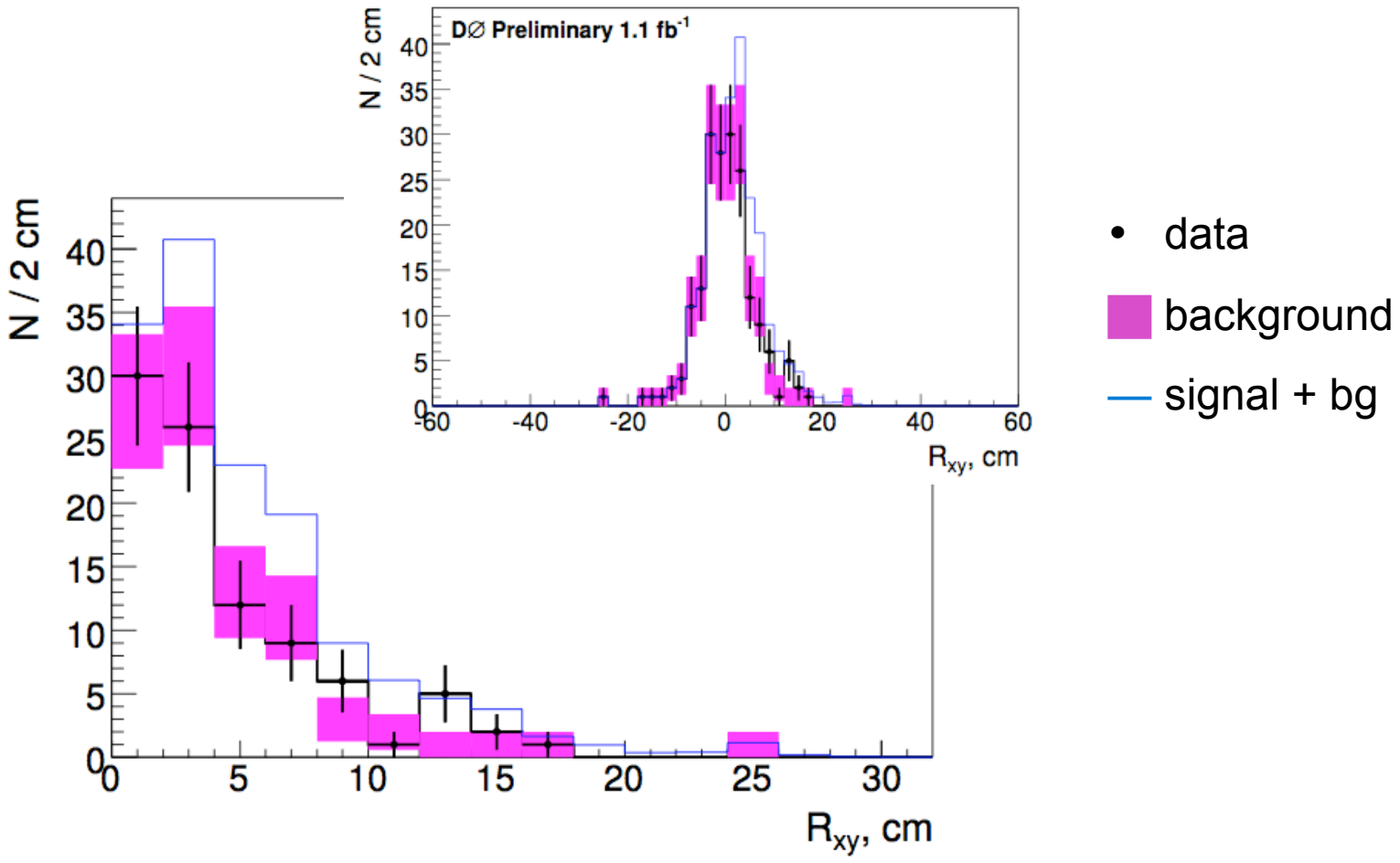
Use negative R distribution to predict background in positive R

Vertexing for Z→ee and fakes



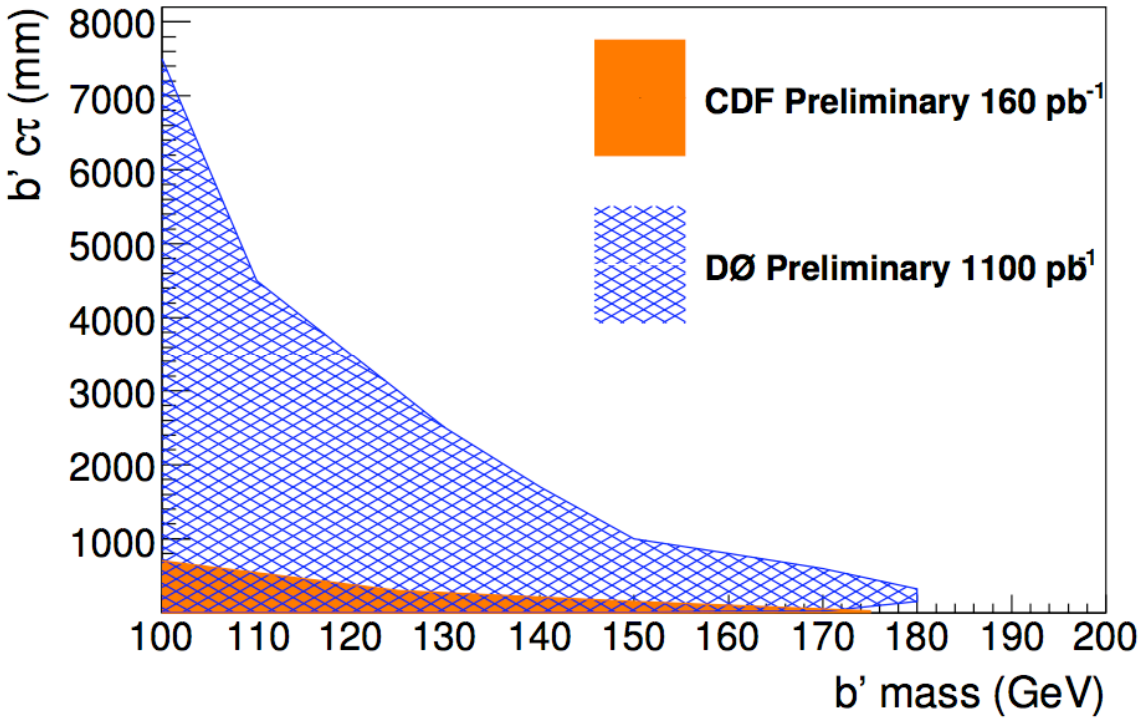
Long-Lived Parents of Z

- Determine diEM invariant mass and cut on it M > 75 GeV
  - keep sensitivity to high mass resonances



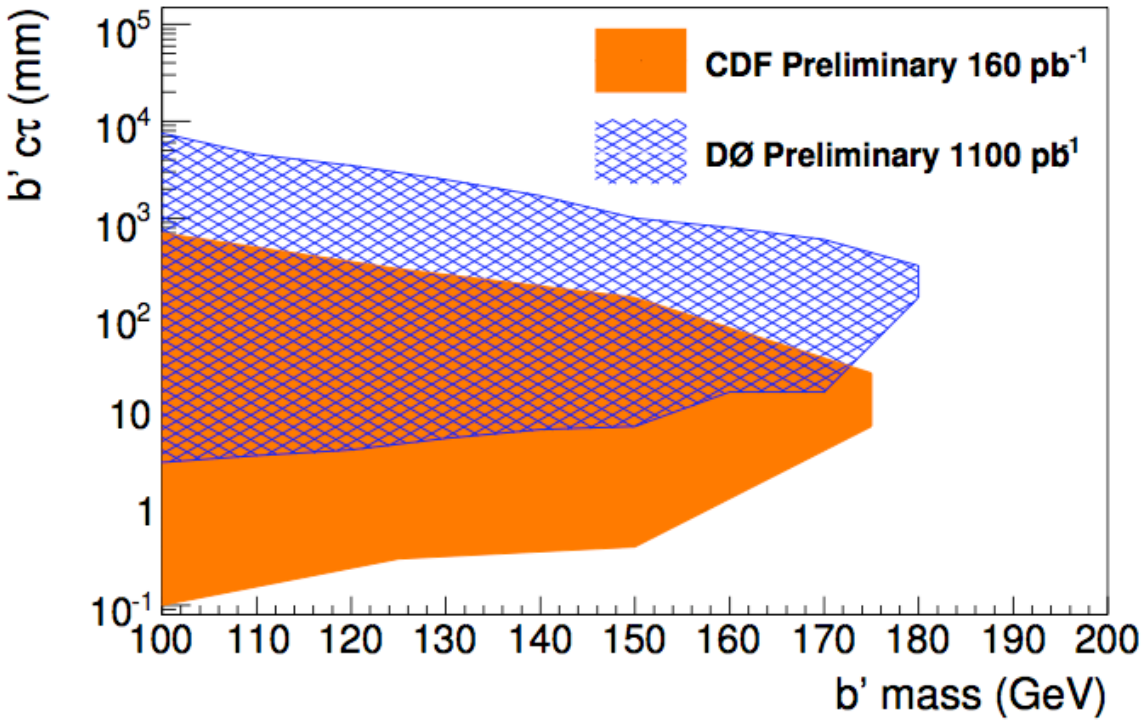
Long-Lived Parents of Z

- Upper limits in term of b' lifetime and mass



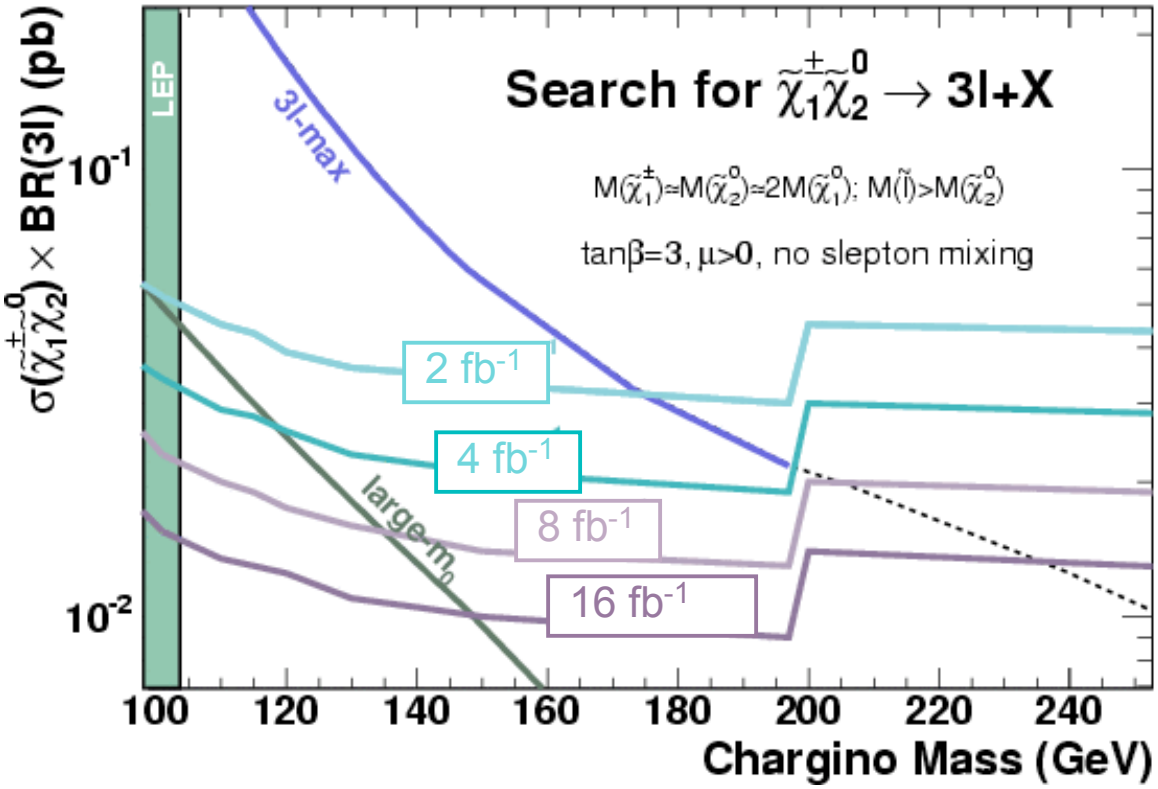
Long-Lived Parents of Z

- Upper limits in term of b' lifetime and mass



Summary & Outlook

- Wide search program, but no discoveries…
- Much more data yet to collect and analyze
  - keep an eye on specific final states (3-leptons, etc…)



Expected 95% CL exclusion limits

Summary & Outlook

- Move towards model-independent analysis (MIS) similar to DØ's Run I Sleuth and CDF's Vista
- pursue unusual signatures that MIS is unlikely to pick up
  - ~O(10 GeV) neutralino in RPV SUSY
  - stopped gluinos
  - charged massive stable particles
  - long-lived parents of Z
  - …
  - Will our theorists suggest a new place to look?

Extras

TABLE I: Selection criteria of both JT1 and JT2 analyses.

Preselection	All analyses	
$\not\!\!E_T$	$\geq$ 40 GeV	
number of reconstructed jets	≥ 2	
acoplanarity	$< 165^\circ$	
$\lvert \mathrm{PV}_z \rvert$	$<$ 60 cm	
1^{st} leading jet E_T, $\lvert\eta_{det}\rvert$, $CPF0$	$\geq$ 35 GeV , ≤ 0.8 , $\geq 85\%$	
2^{nd} leading jet E_T, $\lvert\eta_{det}\rvert$, $CPF0$	$\geq$ 35 GeV , ≤ 0.8 , $\geq 85\%$	
Jets and $\not\!\!E_T$ selection	JT1 analysis	JT2 analysis
trigger	acoplanar dijet	multijet
$\not\!\!E_T$	$\geq$ 75 GeV	$\geq$ 75 GeV
$\Delta\Phi(\not\!\!E_T, \mathrm{jet}_1)$	$\geq 90^\circ$	$\geq 90^\circ$
$\Delta\Phi(\not\!\!E_T, \mathrm{jet}_2)$	$\geq 50^\circ$	$\geq 50^\circ$
$\Delta\Phi_{min}(\not\!\!E_T, \text{any jet})$	$\geq 40^\circ$	-
number of reconstructed jets	-	≥ 3
3^{rd} leading jet E_T, $\lvert\eta_{det}\rvert$	-	$\geq$ 35 GeV , ≤ 2.5
H_T	-	$\geq$ 200 GeV
Tau candidate selection	All analyses	
number of tau candidate	≥ 1	
$\Delta R(\tau_{\mathrm{cand}}, \mathrm{jet}_1)$	≥ 0.5	
$\Delta R(\tau_{\mathrm{cand}}, \mathrm{jet}_2)$	≥ 0.5	