Physics at the Tevatron

Lecture IV

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Outline

- Lecture I
  - The Tevatron, CDF and DØ
  - Production Cross Section Measurements
    - Lepton identification
- Lecture II
  - The Top Quark and the Higgs Boson
    - jet energy scale and b-tagging
- Lecture III
  - B_s mixing and $B_s \rightarrow \mu\mu$ rare decay
    - Vertex resolution and particle identification
- Lecture IV
  - Supersymmetry and High Mass Dileptons
    - Missing E_T and tau-leptons

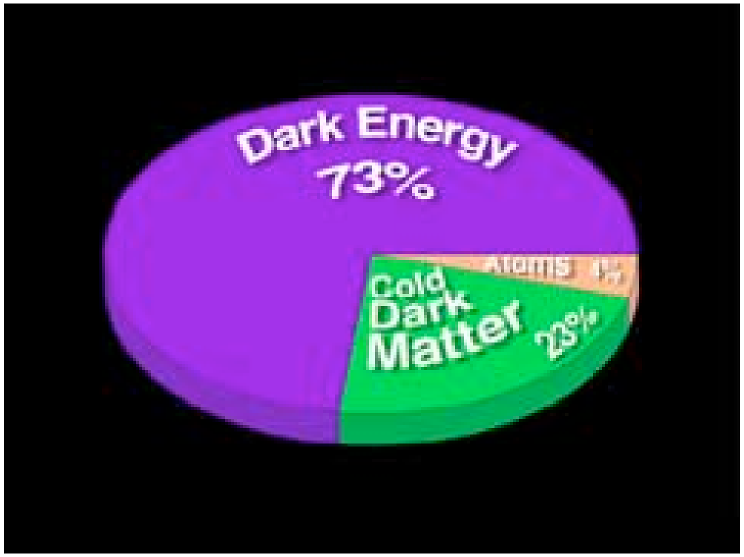
Does the Standard Model work?

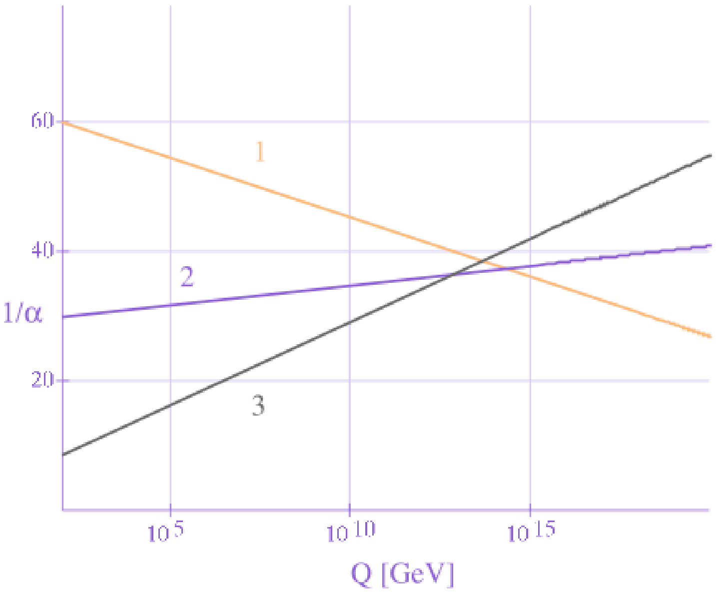
pro’s:

- Is consistent with electroweak precision data

con’s:

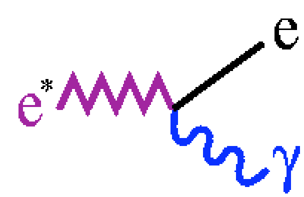
- Accounts for only 4% of energy in Universe
- Lacks explanation of mass hierarchy in fermion sector
- does not allow grand unification of forces
- Requires fine-tuning (large radiative corrections in Higgs sector)
- Where did all the antimatter go?
- Why do fermions make up matter and bosons carry forces?

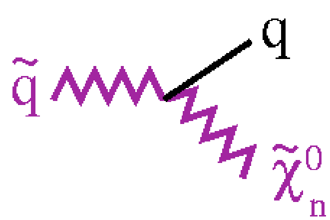


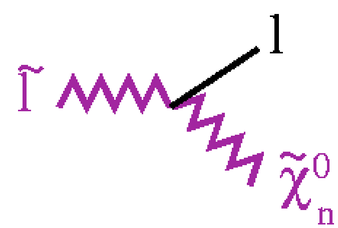


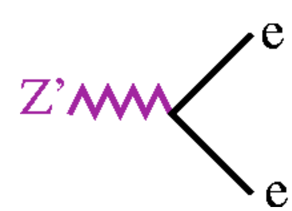
The Unknown beyond the Standard Model

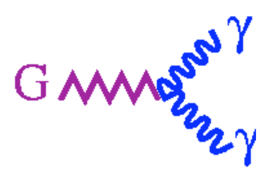
- Many good reasons to believe there is as yet unknown physics beyond the SM:
  - Dark matter + energy, matter/anti-matter asymmetry, neutrino masses/mixing +many more (see later)
- Many possible new particles/theories:
  - Supersymmetry:
    - Many flavours
  - Extra dimensions (G)
  - New gauge groups (Z’, W’,…)
  - New fermions (e*, t’, b’, …)
  - Leptoquarks
- Can show up!
  - As subtle deviations in precision measurements
  - In direct searches for new particles

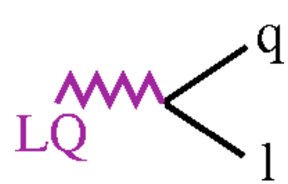


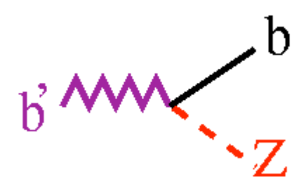




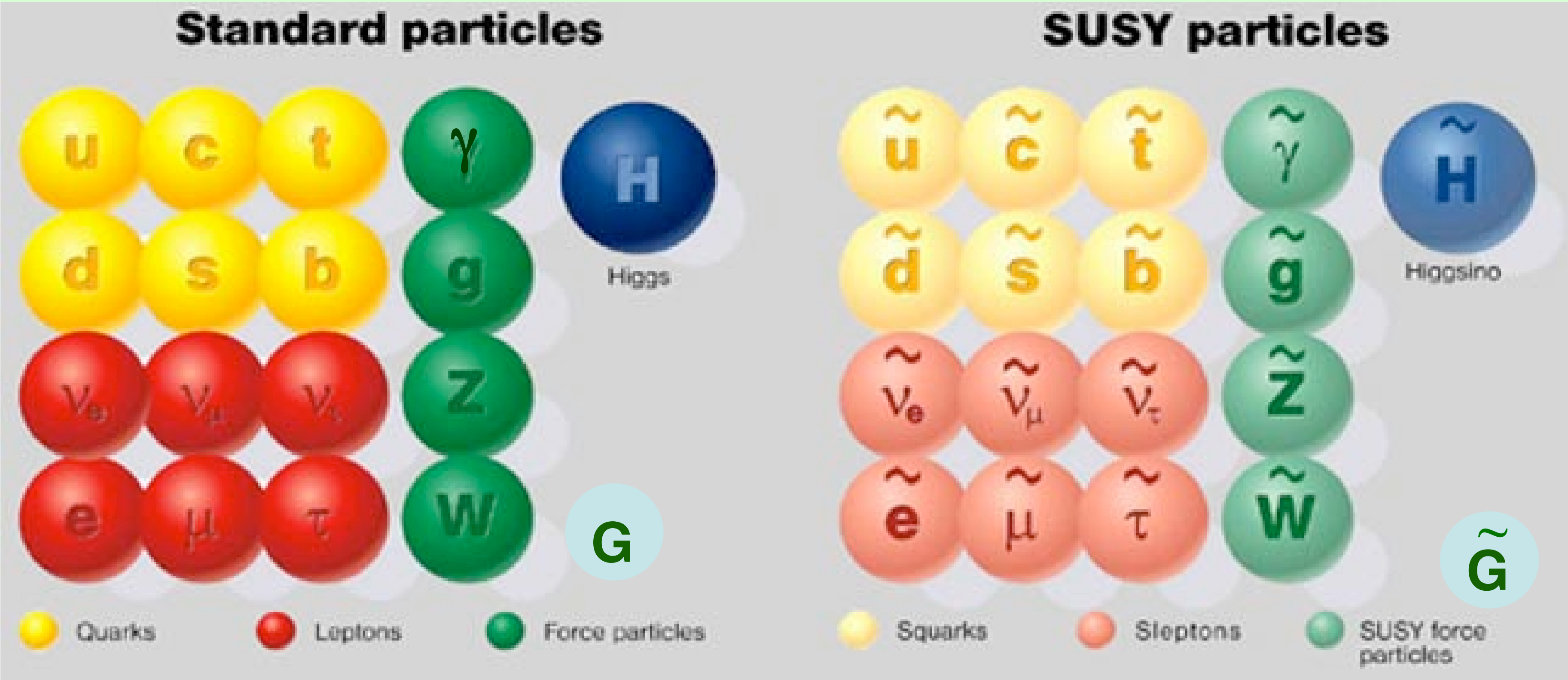








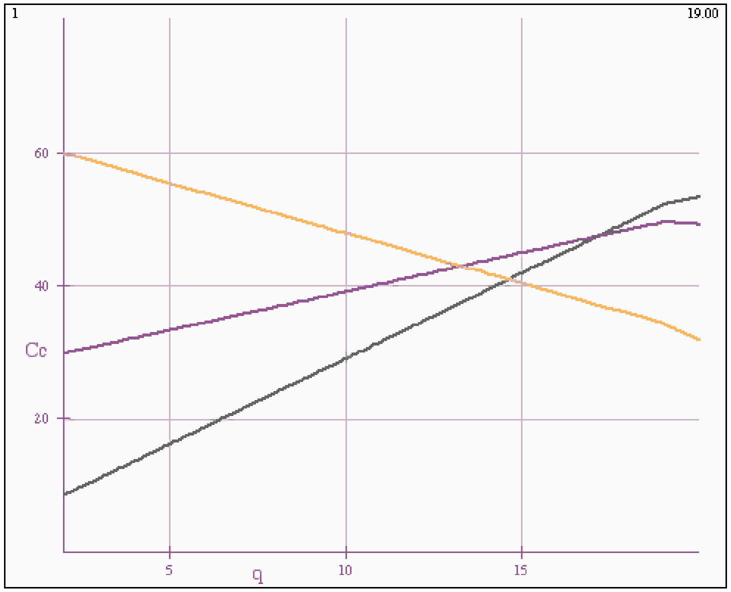
Supersymmetry (SUSY)



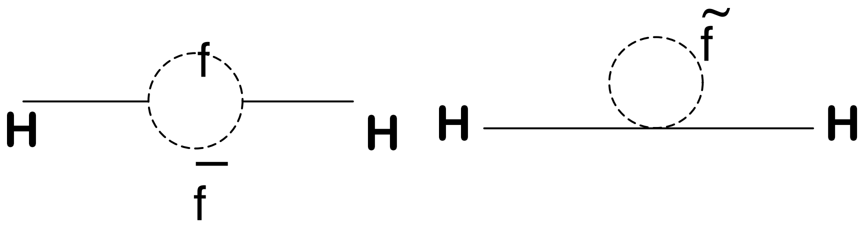
- SM particles have supersymmetric partners:
  - Differ by 1/2 unit in spin
    - **Sfermions** (squarks, selectron, smuon, ...): spin 0
    - **gauginos** (chargino, neutralino, gluino,…): spin 1/2
- No SUSY particles found as yet:
  - SUSY must be broken: breaking mechanism determines phenomenology
  - More than 100 parameters even in “minimal” models!

What's Nice about SUSY?

- Introduces symmetry between bosons and fermions
- Unifications of forces possible
  - SUSY changes runnning of couplings
- Dark matter candidate exists:
  - The lightest neutral gaugino
  - Consistent with cosmology data
- No fine-tuning required
  - Radiative corrections to Higgs acquire SUSY corrections
    - Cancellation of fermion and sfermion loops
- Also consistent with precision measurements of M_W and M_{top}
  - But may change relationship between M_W, M_{top} and M_H

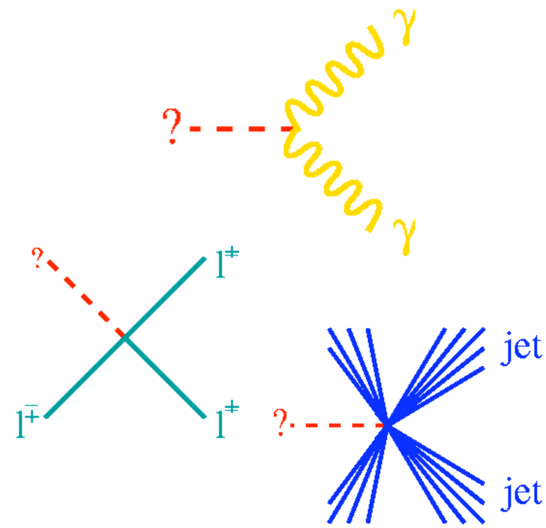


From C. Quigg



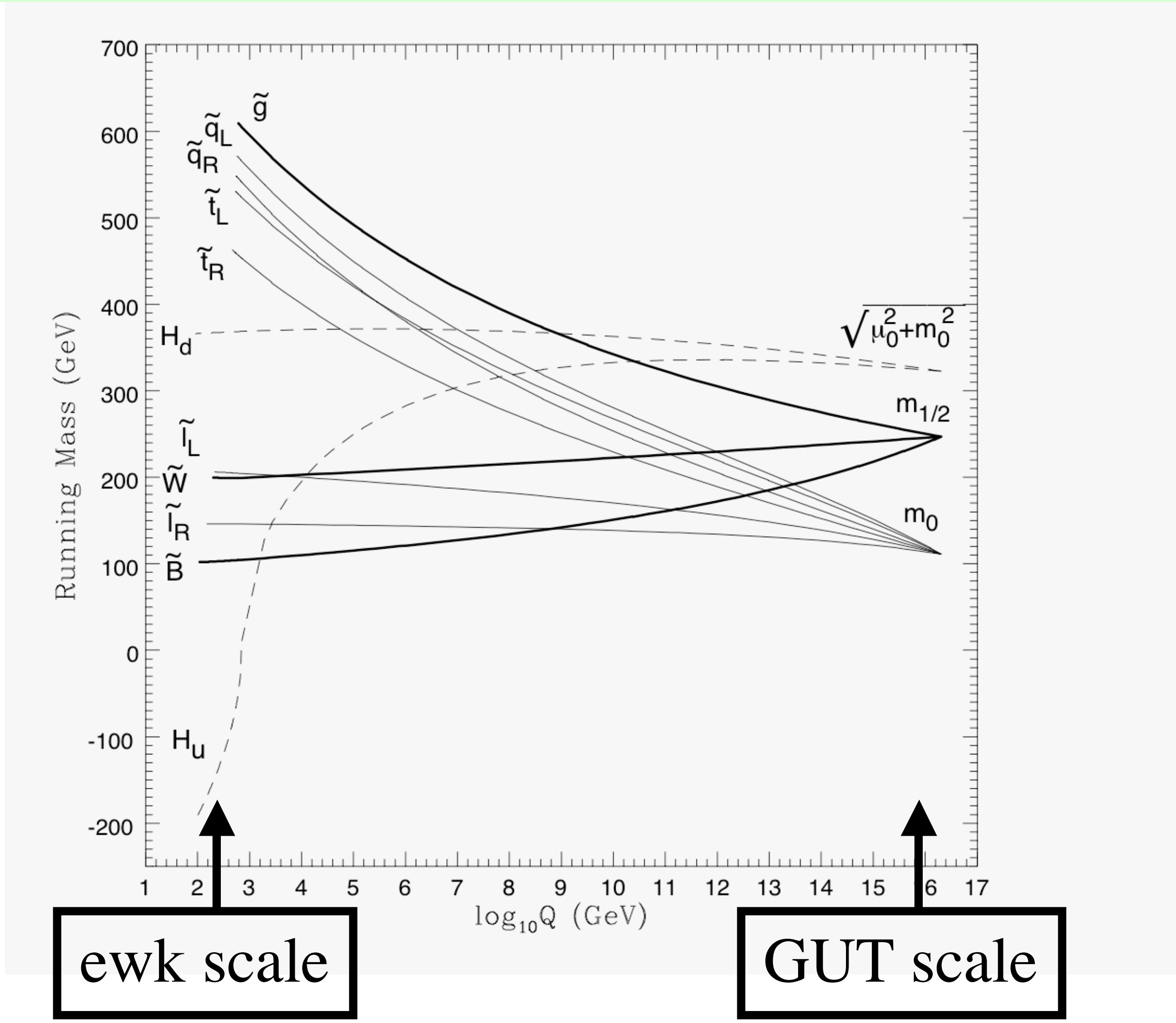
SUSY Comes in Many Flavors

- Breaking mechanism determines phenomenology and search strategy at colliders
  - GMSB:
    - Gravitino is the LSP
    - Photon final states likely
  - mSUGRA
    - Neutralino is the LSP
    - Many different final states
    - Common scalar and gaugino masses
  - AMSB
  - Split-SUSY: sfermions very heavy



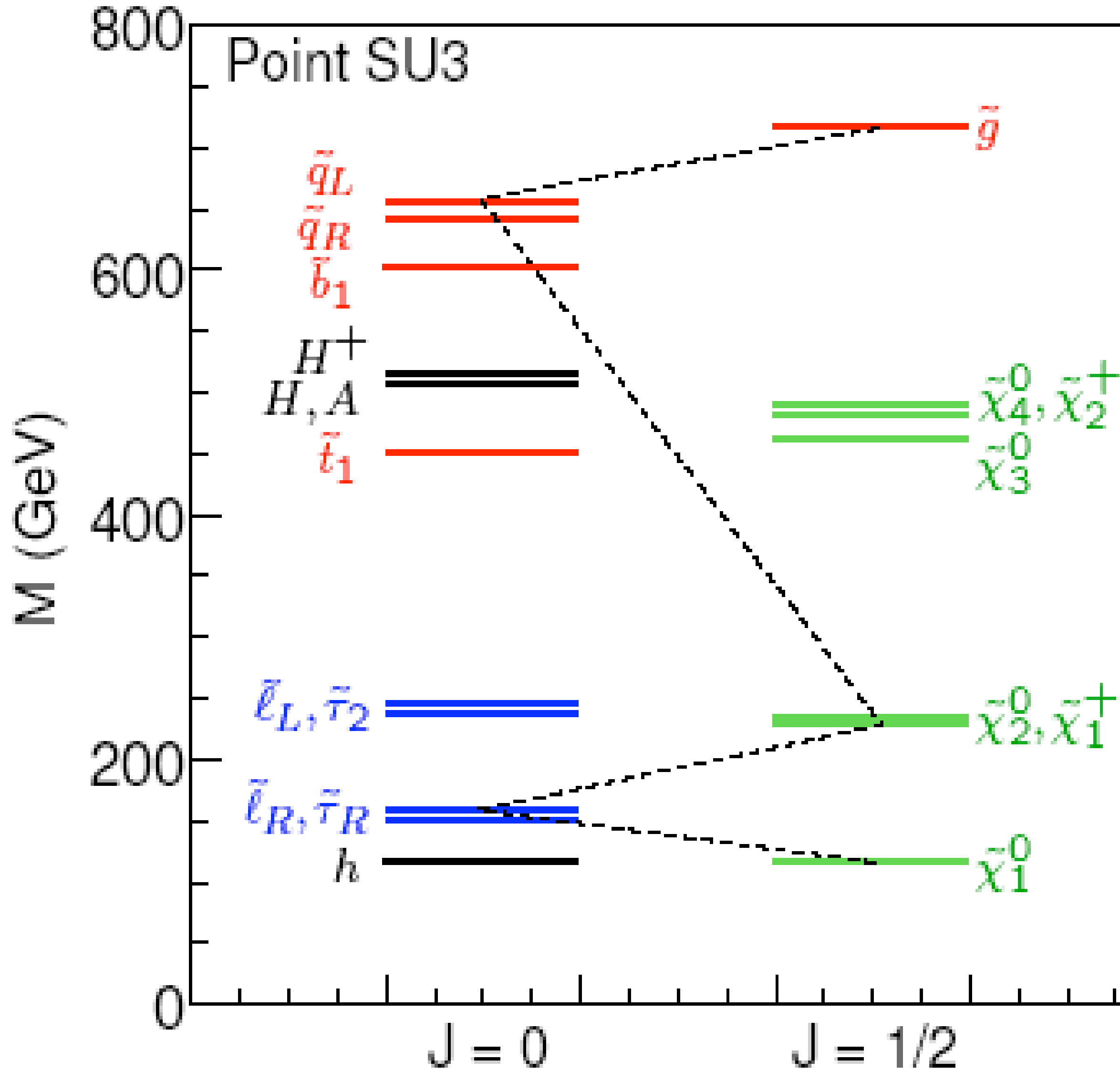
- R-parity
  - Conserved: Sparticles produced in pairs
    - natural dark matter candidate
  - Not conserved: Sparticles can be produced singly
    - constrained by proton decay if violation in quark sector
    - Could explain neutrino oscillations if violation in lepton sector

Mass Unification in mSUGRA

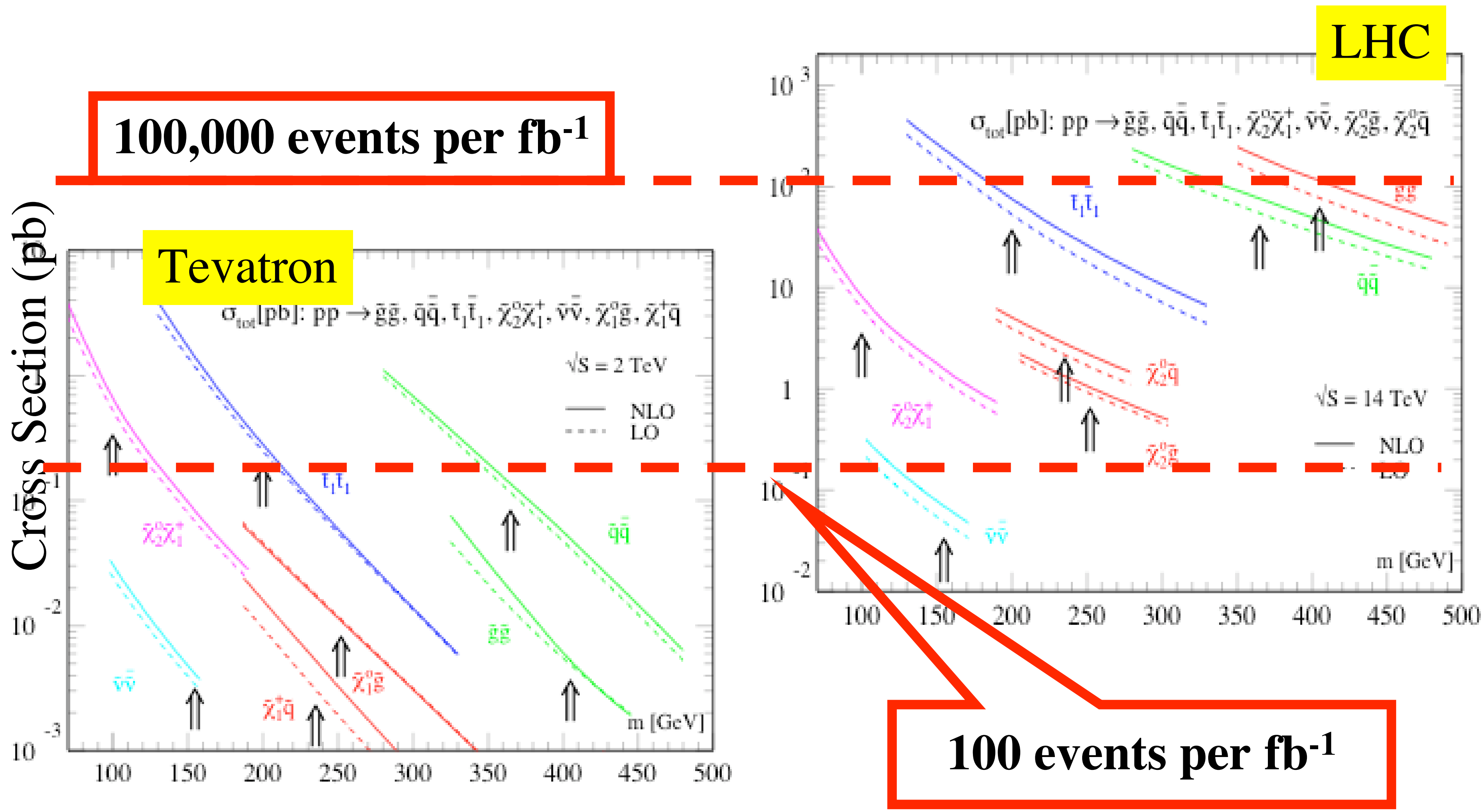


- Common masses at GUT scale: m_0 and $m_{1/2}$
  - Evolved via renormalization group equations to lower scales
  - Weakly coupling particles (sleptons, charginos, neutralions) are lightest

A Typical Sparticle Mass Spectrum

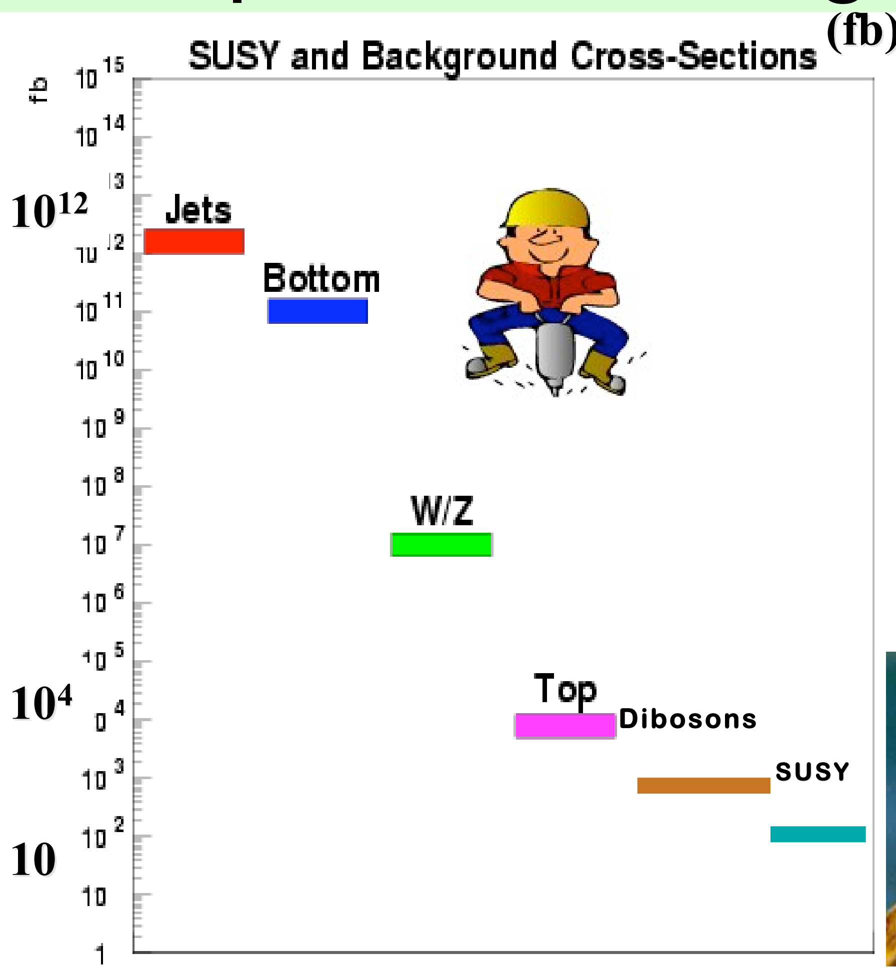


Sparticle Cross Sections



T. Plehn, PROSPINO

SUSY compared to Background



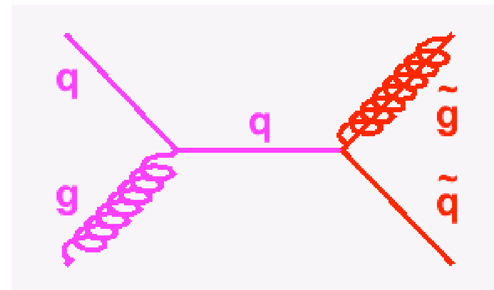
- Cross sections rather low
  - Else would have seen it already!
- Need to suppress background efficiently

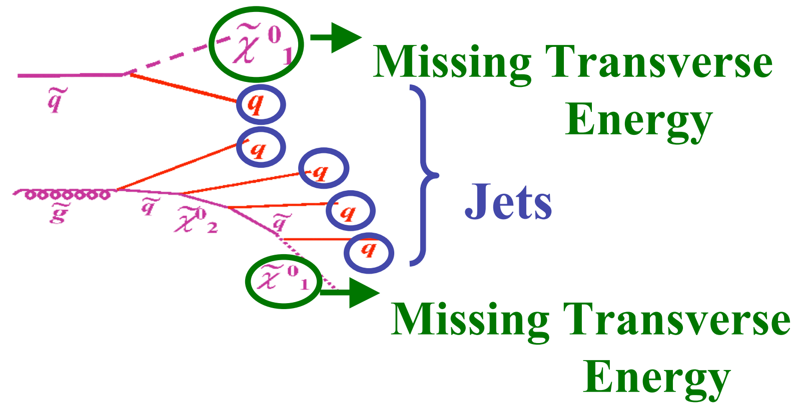
Strategy for SUSY Searches

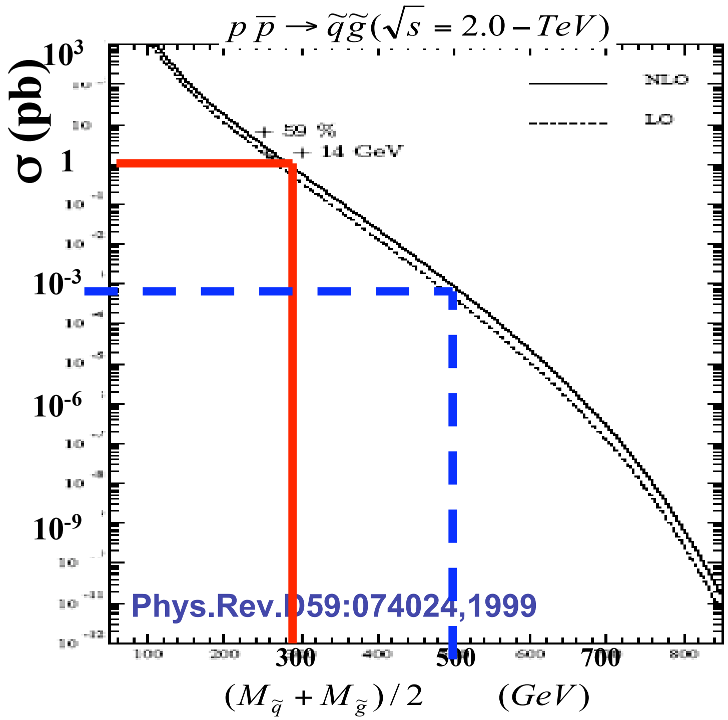
- MSSM has more than 100 parameters
  - Impossible to scan full parameter space
  - Many constraints already from
    - Precision electroweak data
    - Lepton flavour violation
    - Baryon number violation
    - …
- Makes no sense to choose random set
  - Use simplified well motivated “benchmark” models
    - Ease comparison between experiments
- Try to make interpretation model independent
  - E.g. not as function of GUT scale SUSY particle masses but versus EWK SUSY particle masses
  - Limits can be useful for other models
  - Working model is mSUGRA

Generic Squarks and Gluinos

- Squark and Gluino production:
  - Signature: jets and $\not{E}_T$



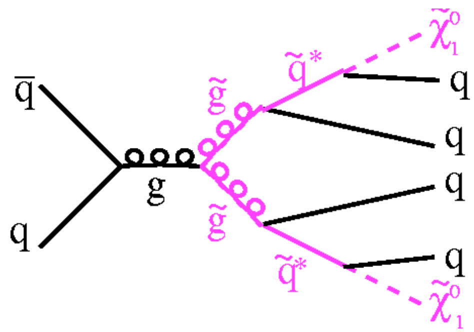


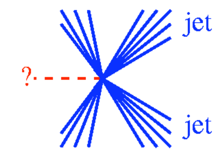


- Strong interaction => large production cross section
  - for $M(\tilde{g}) \approx 300$ GeV/c^2:
    - 1000 event produced
  - for $M(\tilde{g}) \approx 500$ GeV/c^2:
    - 1 event produced

Signature depends on $\tilde{q}$ and $\tilde{g}$ Masses

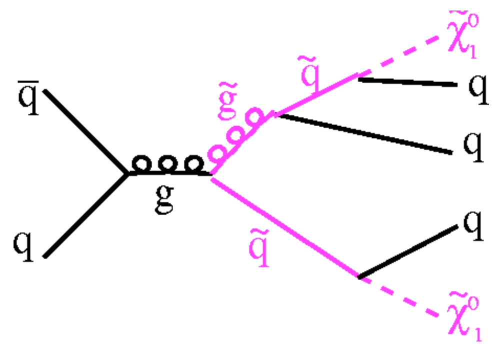
- Consider 3 cases:
  1. $m(\tilde{g}) < m(\tilde{q})$

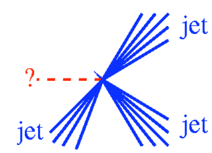




4 jets + E_T^{miss}

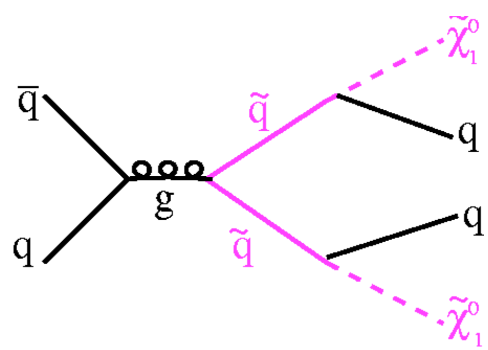
  2. $m(\tilde{g}) \approx m(\tilde{q})$

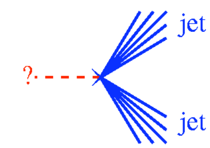




3 jets + E_T^{miss}

  3. $m(\tilde{g}) > m(\tilde{q})$





2 jets + E_T^{miss}

Optimize for different signatures in different scenarios

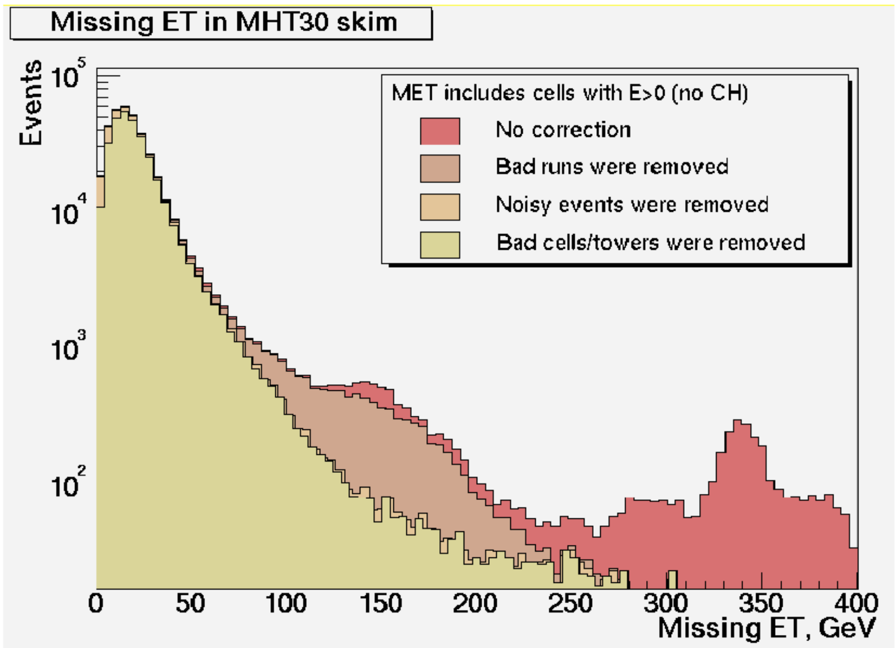
Selection and Procedure

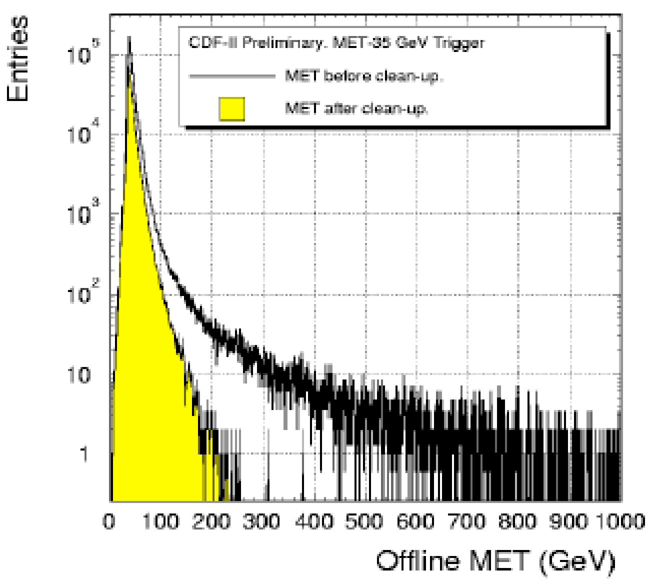
- Selection:
  - Large missing E_T
    - Due to neutralinos
  - Large H_T
    - $H_T = \sum E_T^{jet}$
  - Large $\Delta\phi$
    - Between missing E_T and jets and between jets
    - Suppress QCD dijet background due to jet mismeasurements
  - Veto leptons:
    - Reject W/Z+jets, top

- Procedure:
  1. Define signal cuts based on background and signal MC studies
  2. Select control regions that are sensitive to individual backgrounds
  3. Keep data "blind" in signal region until data in control regions are understood
  4. Open the blind box!

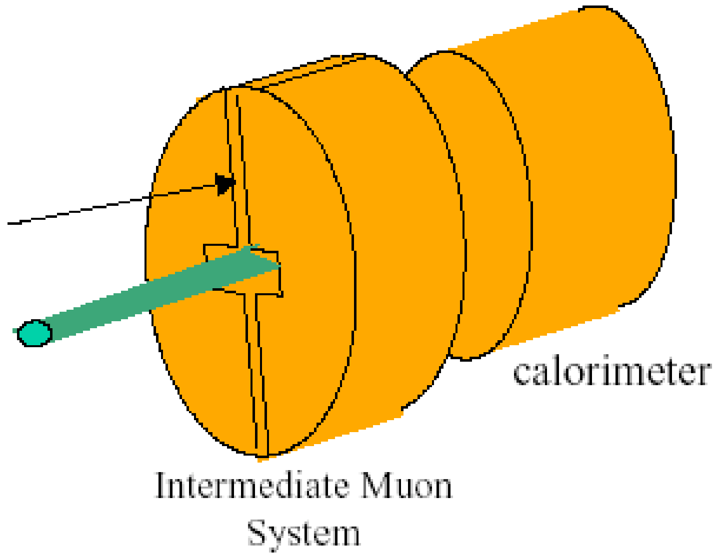
Missing Energy

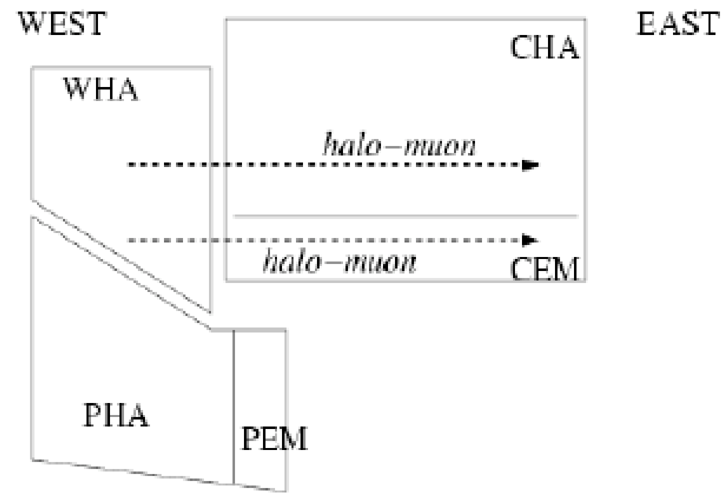
- Data spectrum contaminated by
  - Noise
  - Cosmic muons showering
  - Beam halo muons showering
- Needs cleaning up!
  - track matched to jet
  - electromagnetic energy fraction
  - Removal of hot cells
  - Topological cuts against beam-halo



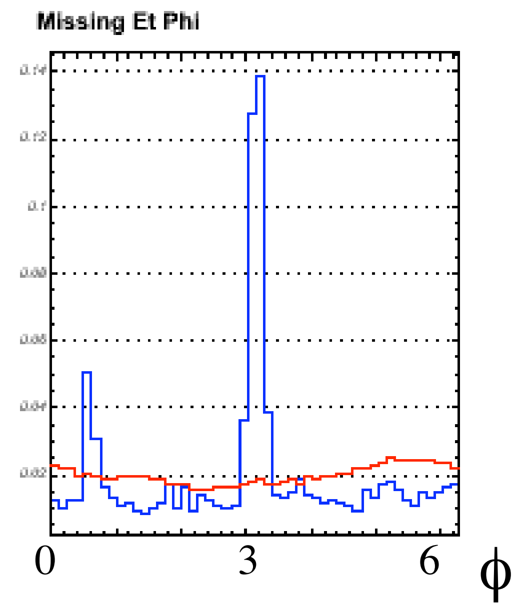


Beam-Halo Muon Background

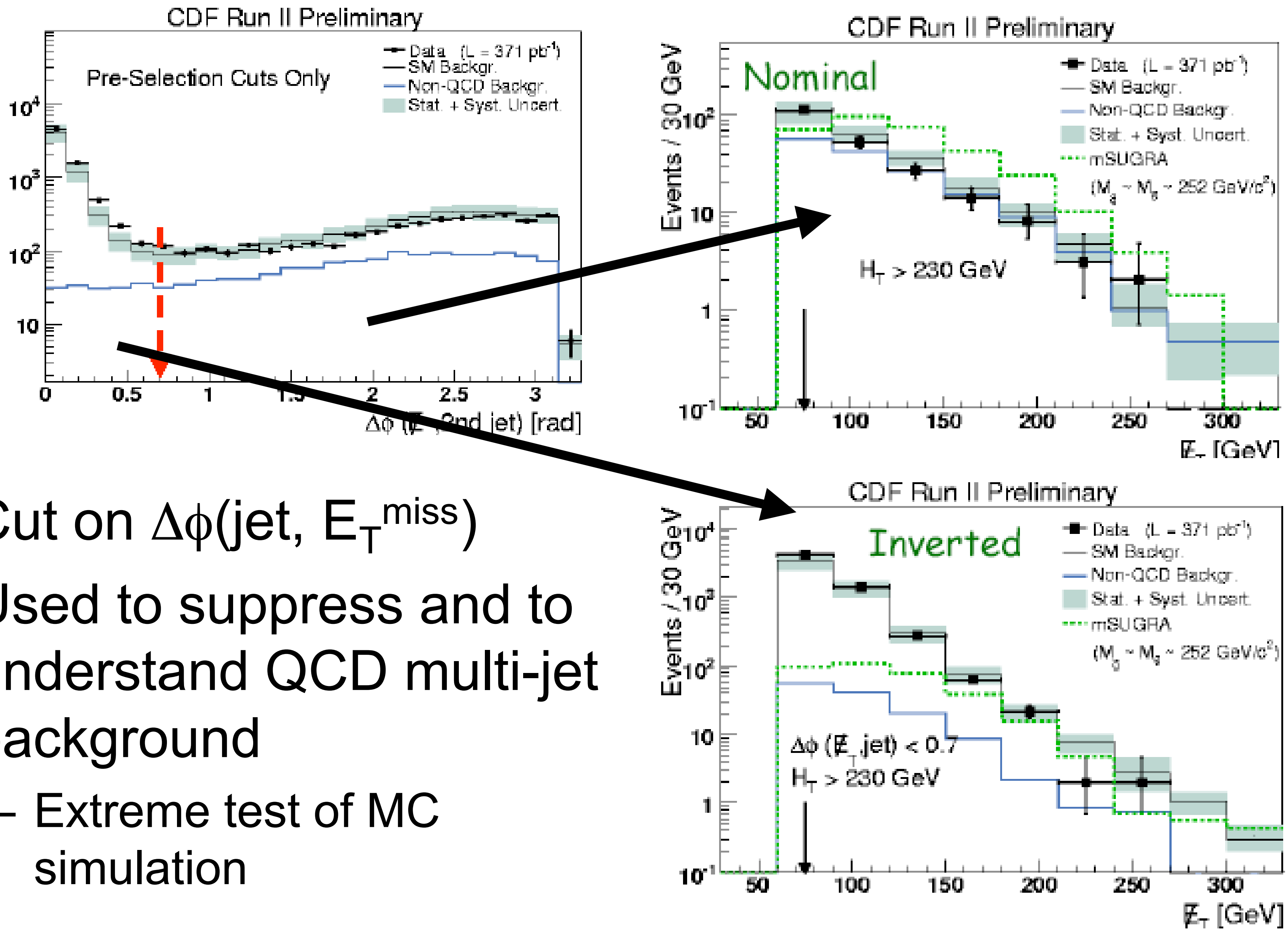




- Muon that comes from beam and goes through shielding
- Can cause showers in calorimeters
  - Shower usually looks not very much like physics jet
    - Often spike at certain azimuthal angles: π
  - But there is lots of those muons!
  - Can cause problem for trigger rate



QCD Dijet Rejection Cut



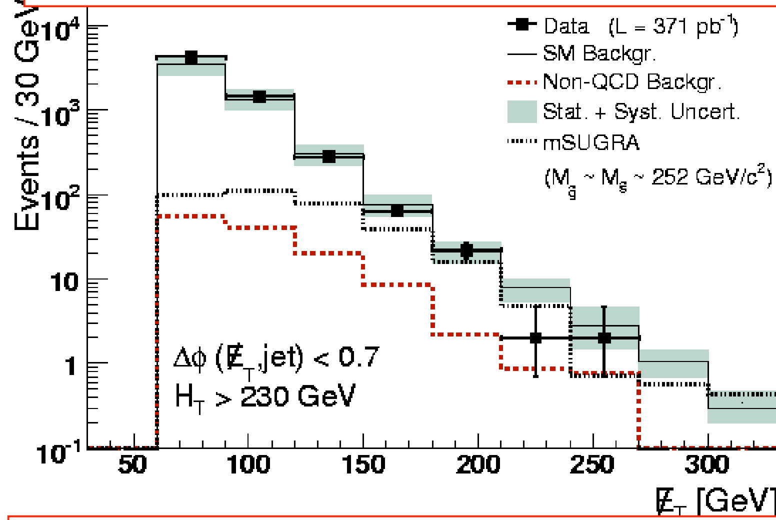
- Cut on $\Delta\phi$(jet, E_T^{miss})
- Used to suppress and to understand QCD multi-jet background
  - Extreme test of MC simulation

Backgrounds and Control Regions

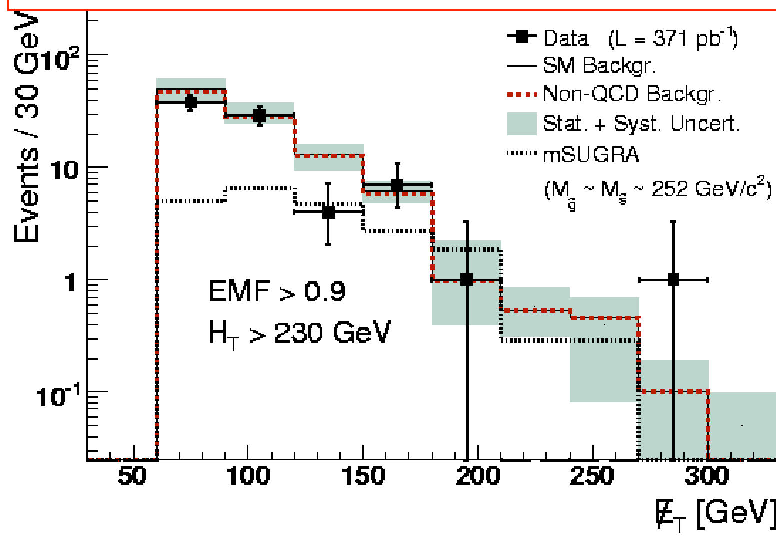
- Background sources:
  - W/Z+jets, top
  - QCD multijet

- Control regions:
  - QCD multijet:
    - Make all selection cuts but invert deltaphi cut
    - CDF simulates jet background
    - DØ determines it from data
  - W/Z+jets, top
    - Make all selection cuts but invert lepton veto

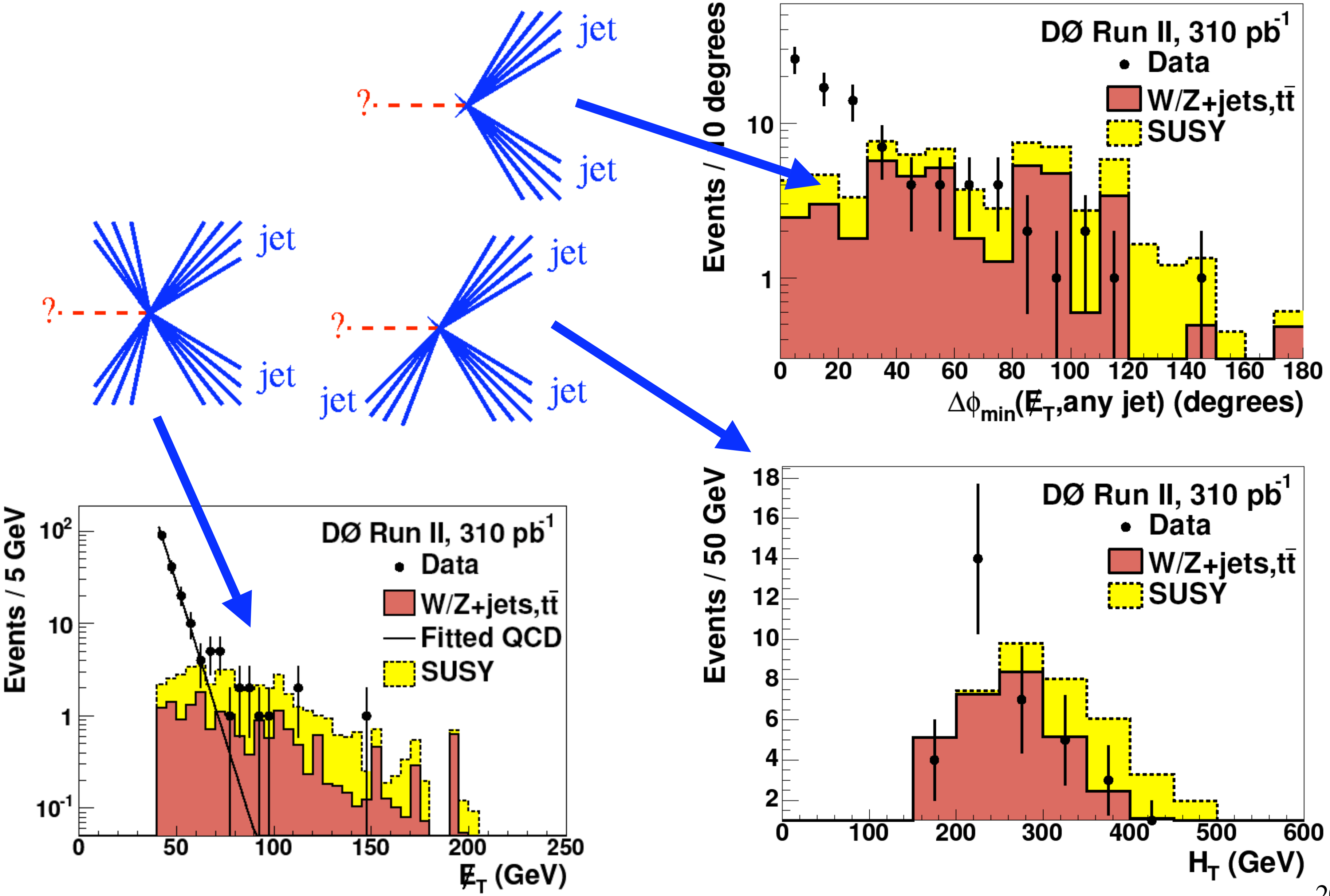
QCD Multijet Control Region



W/Z+jets, top Control Region

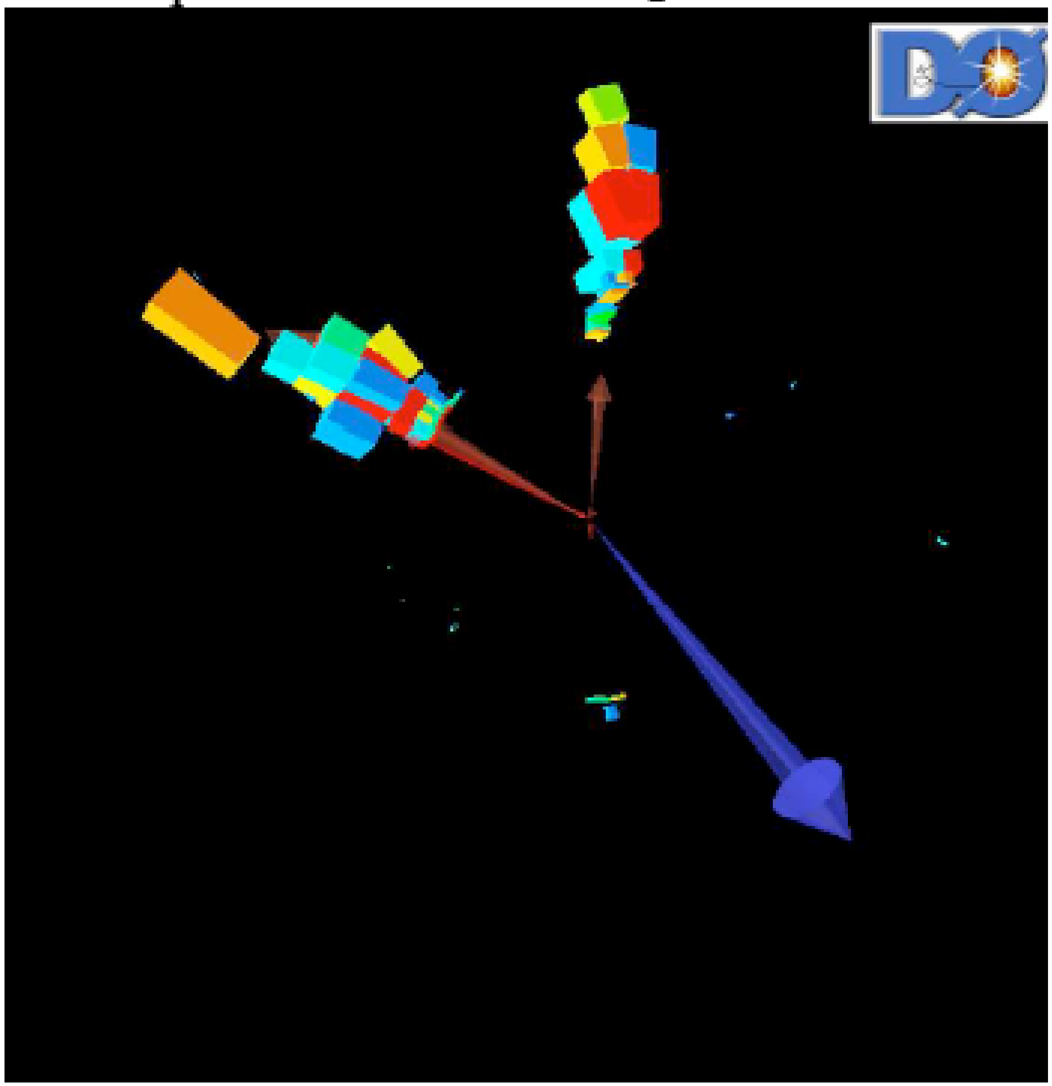


The Data in Different Topologies

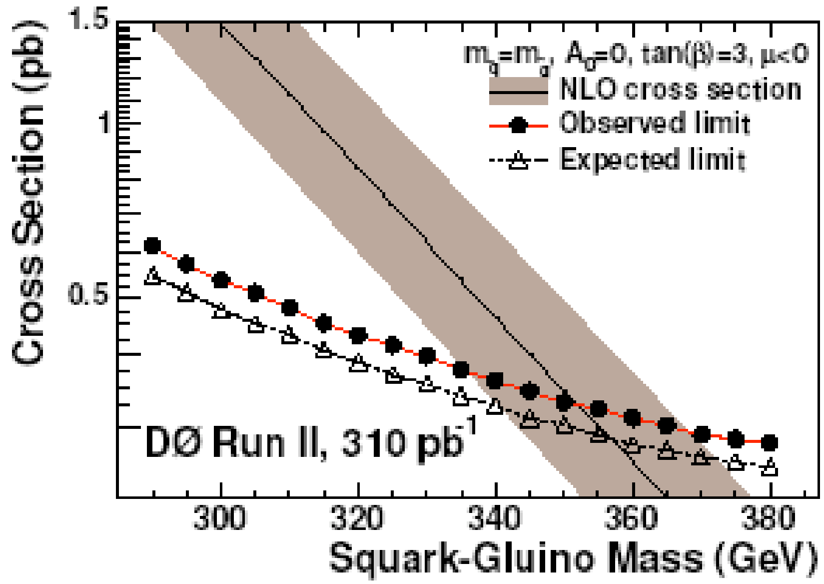


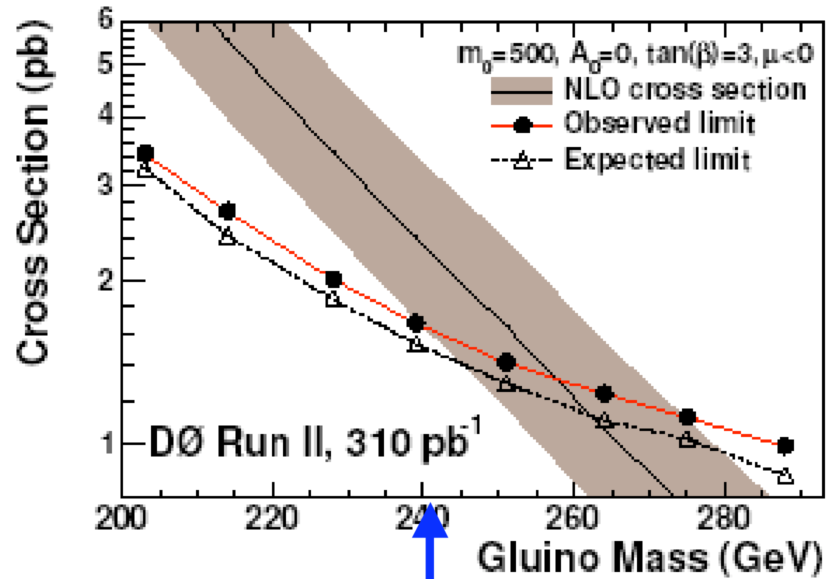
A Nice Candidate Event!

Squark Candidate: $\not{E}_T$=381 GeV



Cross Section Limits



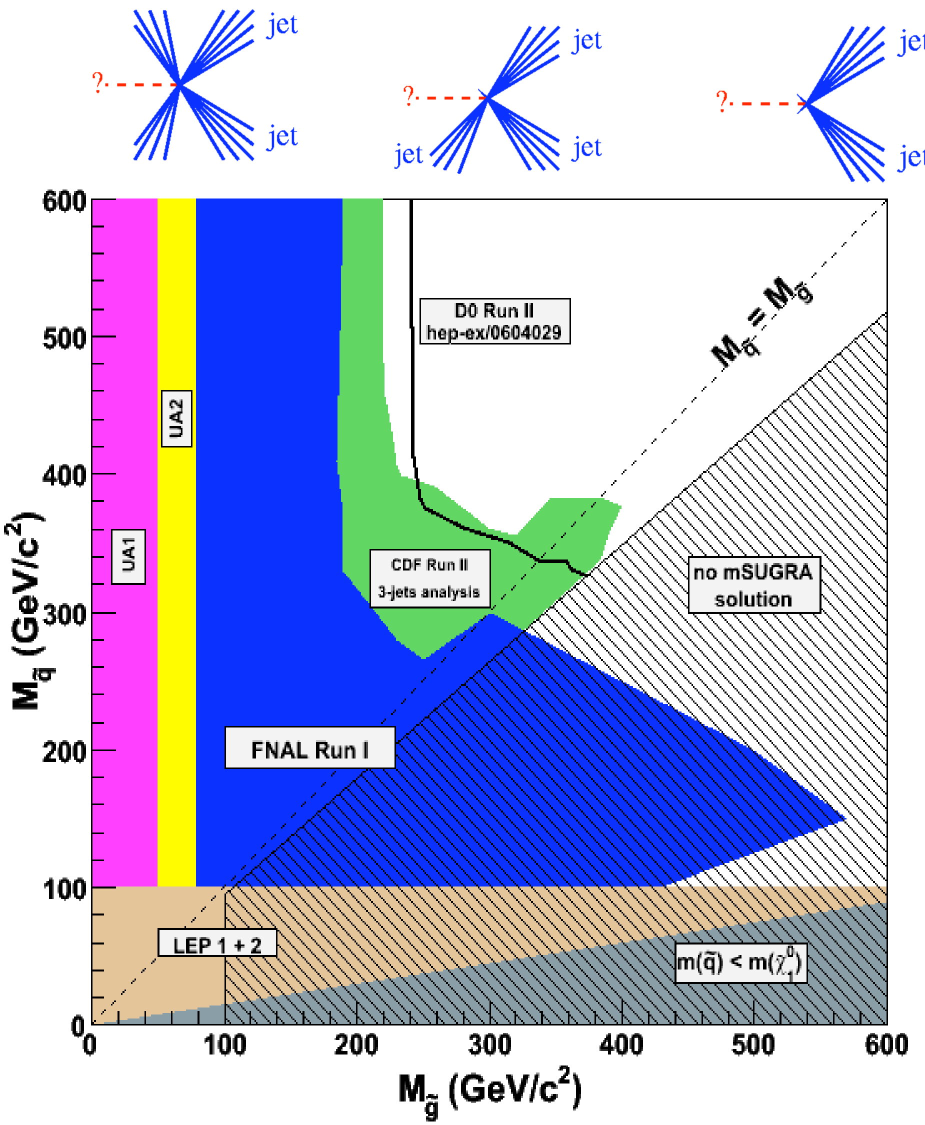


$m(\tilde{g}) > 241$ GeV

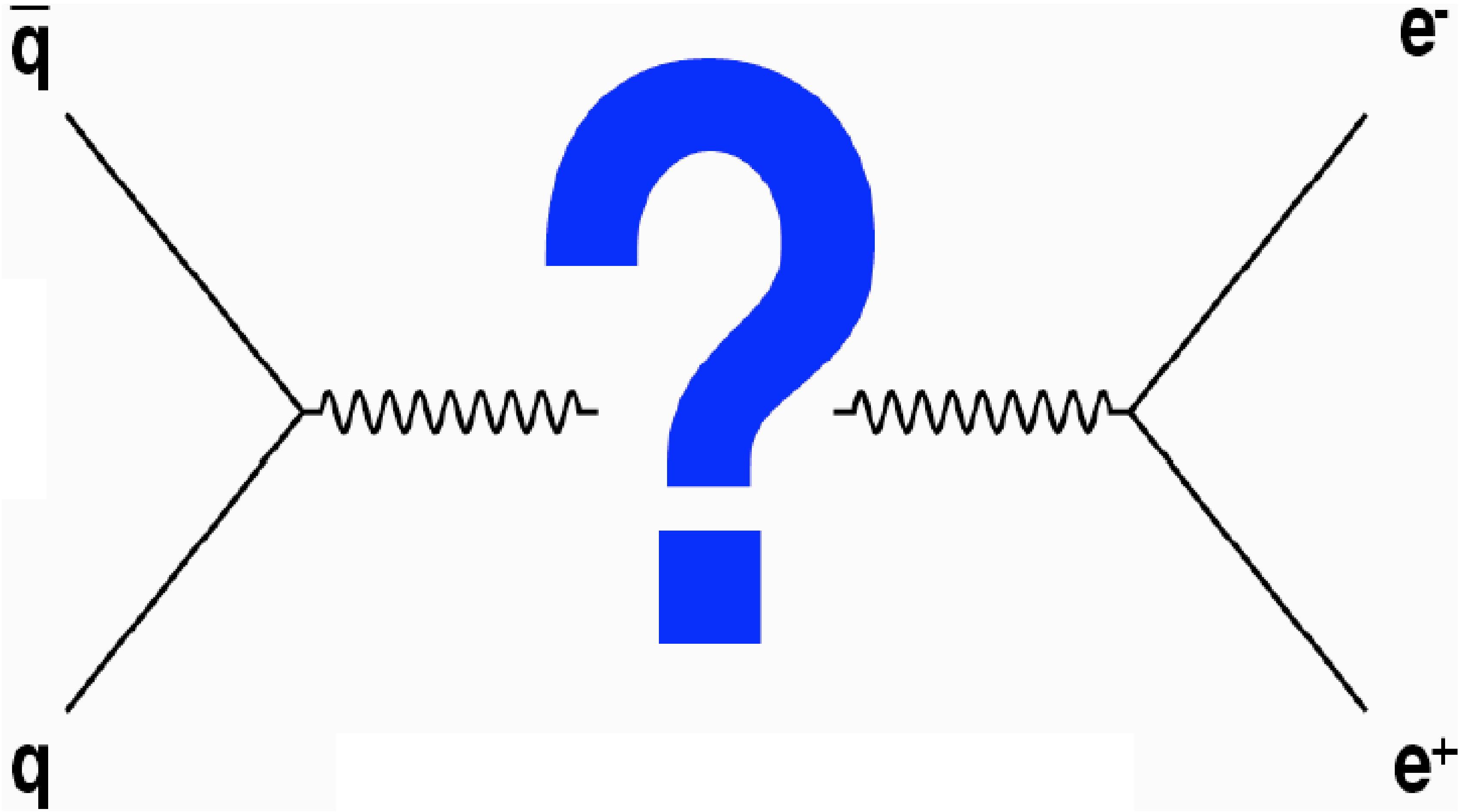
- No excess in data
  - Evaluate upper limit on cross section
  - Find out where it crosses with theory
- Theory has large uncertainty: ~30%
  - Crossing point with theory lower bound represents limit on squark/gluino mass

Squark and Gluino Mass Limits

- No evidence for excess of events:
  - DØ excluded gluinos up to 241 GeV independent of squark mass:
    - Mostly due to 4-jet analysis
  - CDF reaches 400 GeV exclusion for $m(\tilde{q}) \approx m(\tilde{g})$
    - Statistical downward fluctuation
    - Optimised for this region
- Stop and sbottom quarks are excluded/negligible in analyses:
  - They introduce model dependence and are better looked for differently

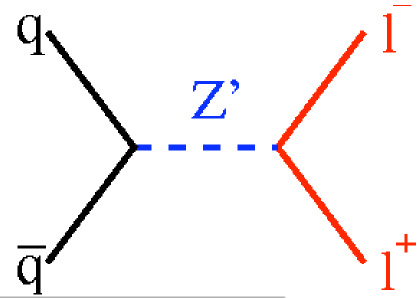


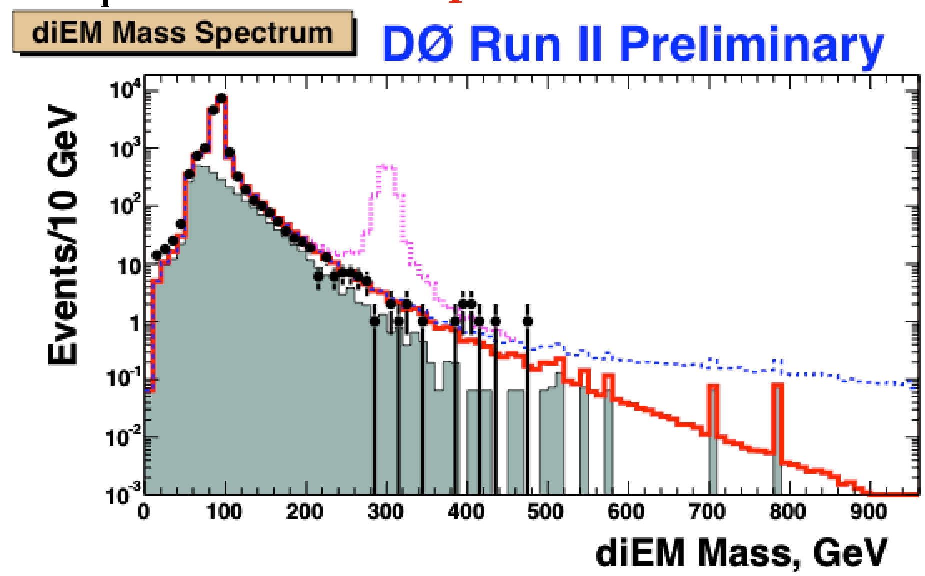
High Mass Resonances

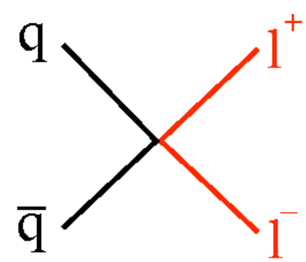


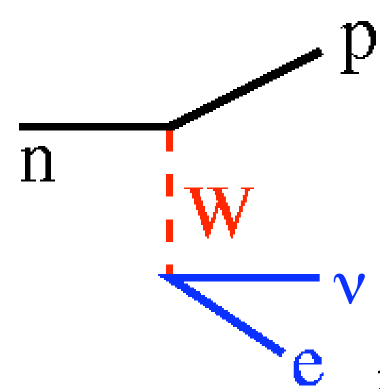
Resonances or Tails

- New resonant structure:
  - New gauge boson:
    - Z' $\rightarrow$ ee, $\mu\mu$, $\tau\tau$, tt
    - W' $\rightarrow$ eν, $\mu\nu$, $\tau\nu$, tb
  - Randall-Sundrum Graviton:
    - G $\rightarrow$ ee, $\mu\mu$, $\tau\tau$, $\gamma\gamma$, WW, ZZ,…
- Tail:
  - Large extra dimensions (ADD model)
    - Many many many resonances close to each other:
    - "Kaluza-Klein-Tower": ee, $\mu\mu$, $\tau\tau$, $\gamma\gamma$, WW, ZZ,…
  - Contact interaction
    - Effective 4-point vertex
      - E.g. via t-channel exchange of very heavy particle
    - Like Fermi's β-decay



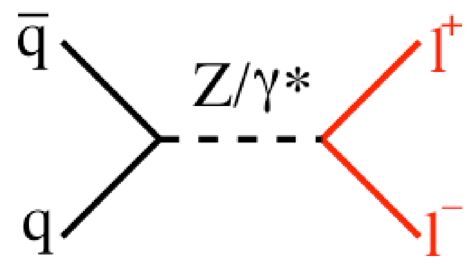


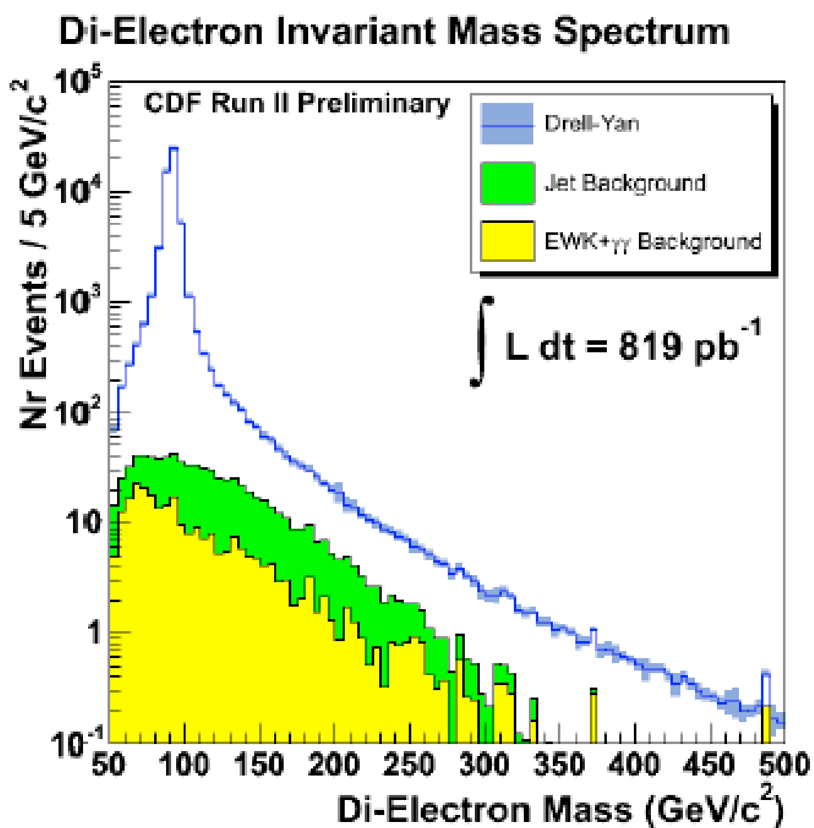




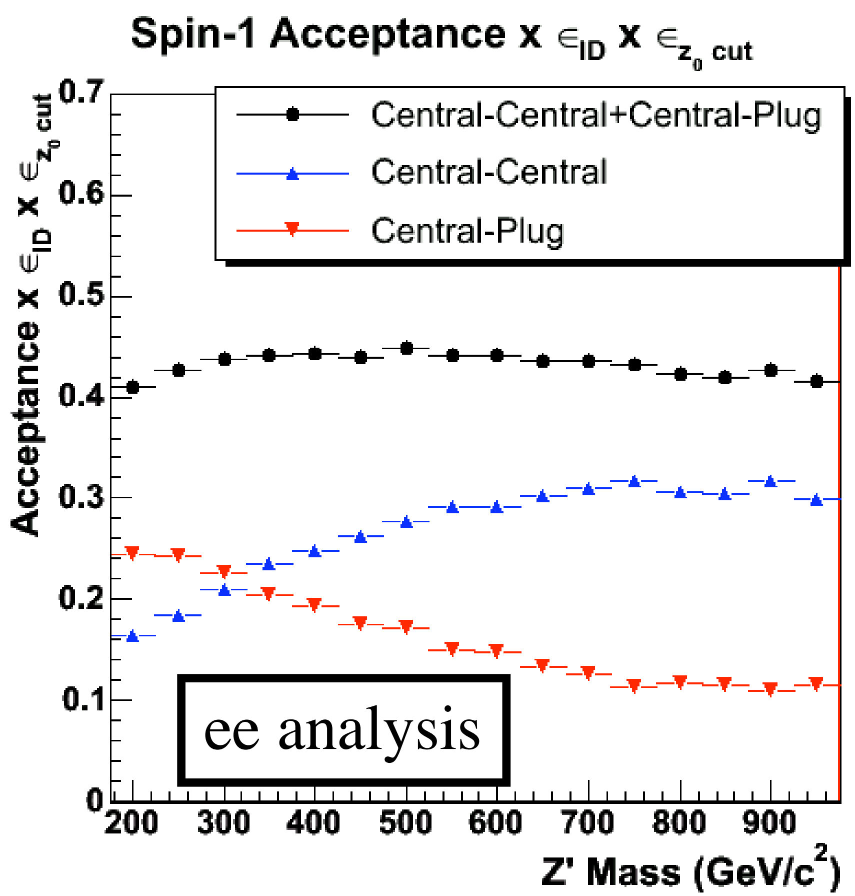
Dilepton Selection

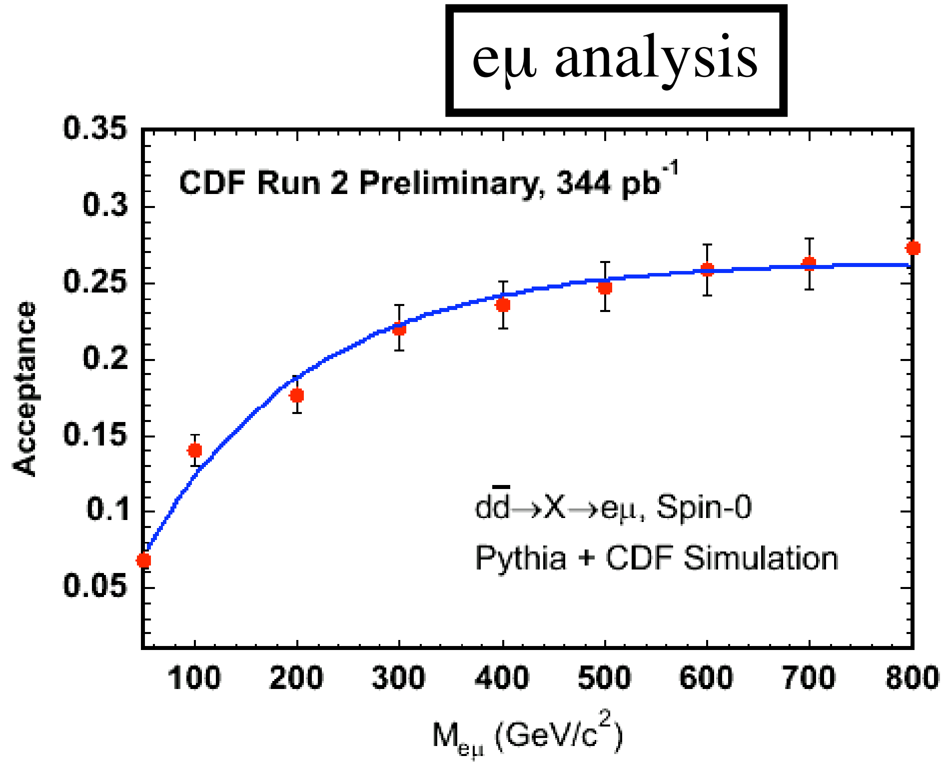
- Two high momentum leptons
  - irreducible background is Drell-Yan production
  - Other backgrounds:
    - Jets faking leptons: reject by making optimal lepton ID cuts
    - WW, diphoton, etc. very small
- Have searches for
  - Dielectrons
  - Dimuons
  - Ditaus
  - Electron+muon
    - flavor changing





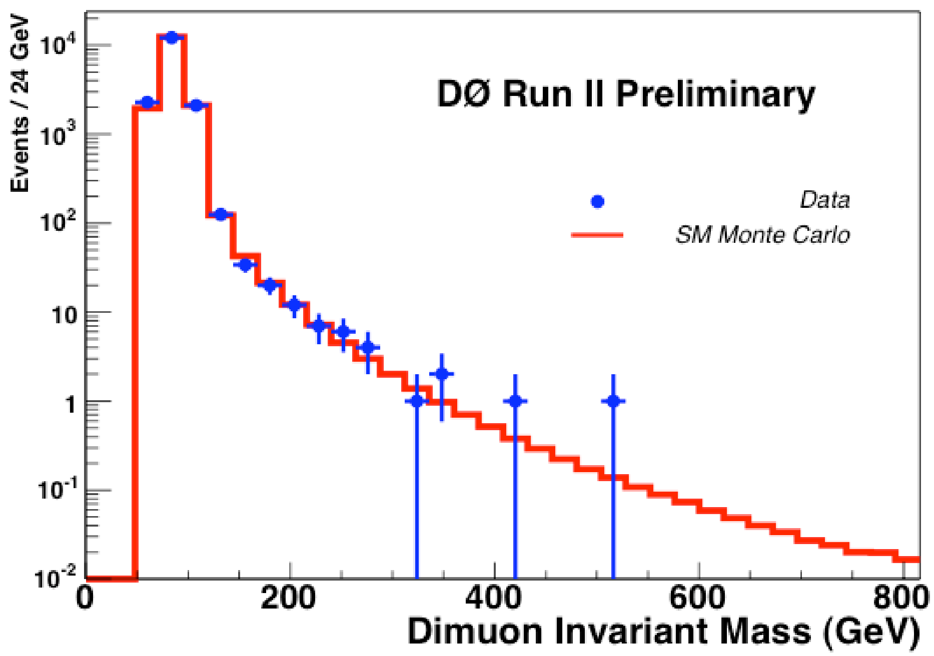
Dilepton Acceptance x Efficiency

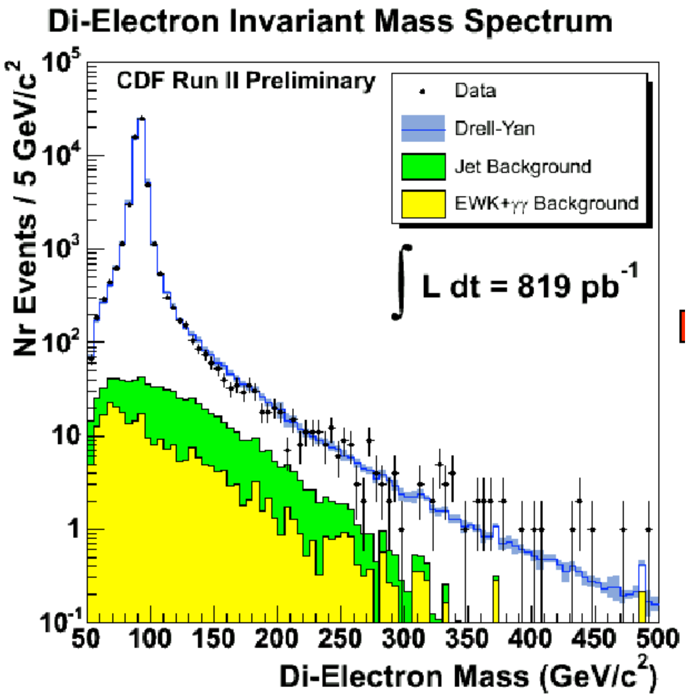




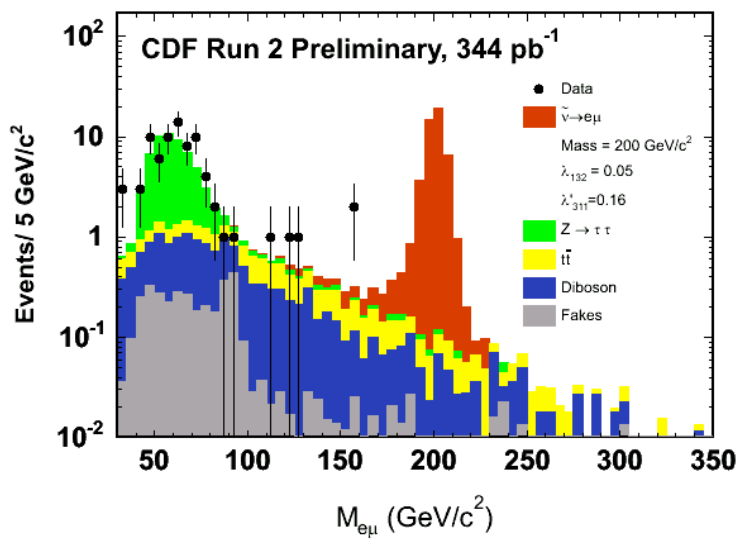
- Acceptance typically 20-40% for ee, μμ and eμ analyses

Neutral Spin-1 Bosons: Z'

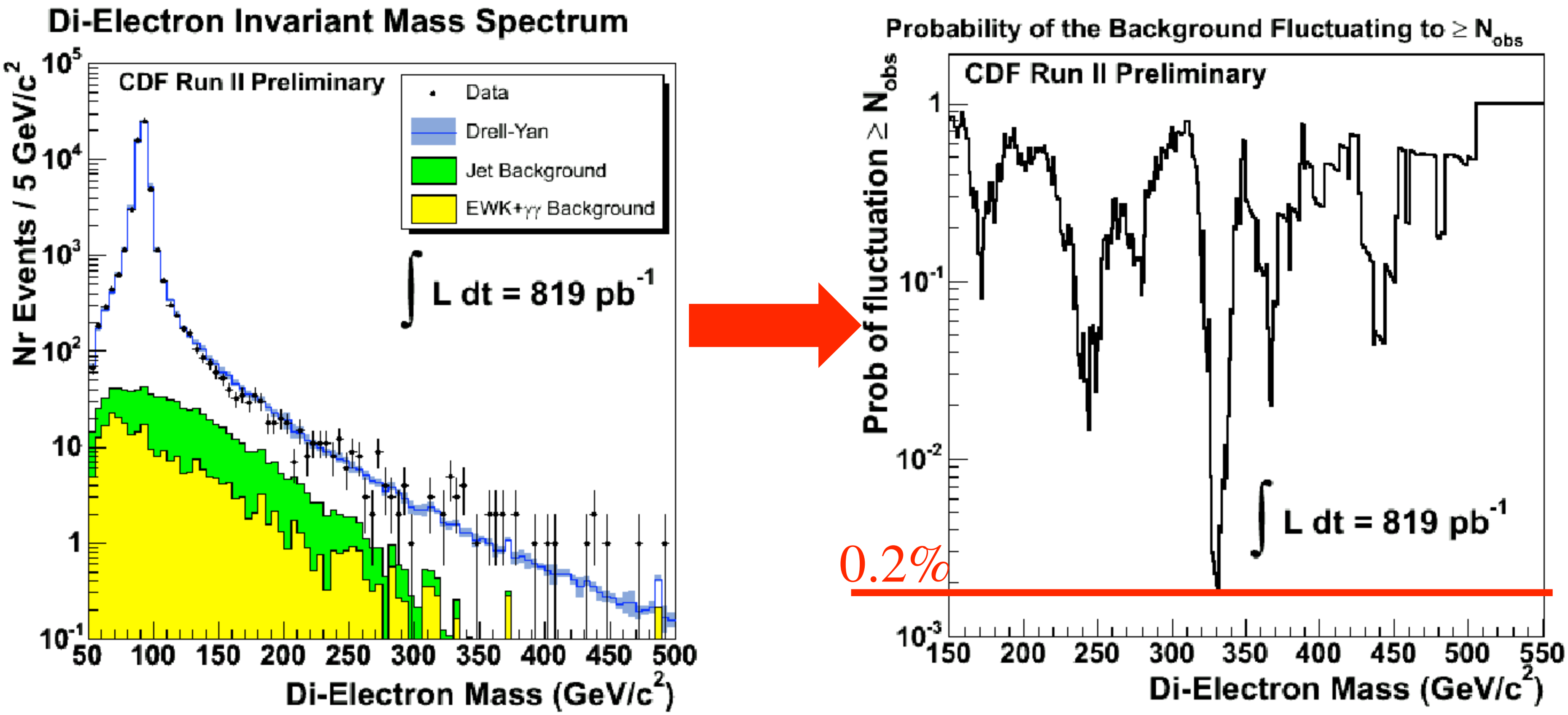




- 2 high P_T leptons: ee, μμ or eμ
- Data look like they agree well with background
  - Let's evaluate this more closely!



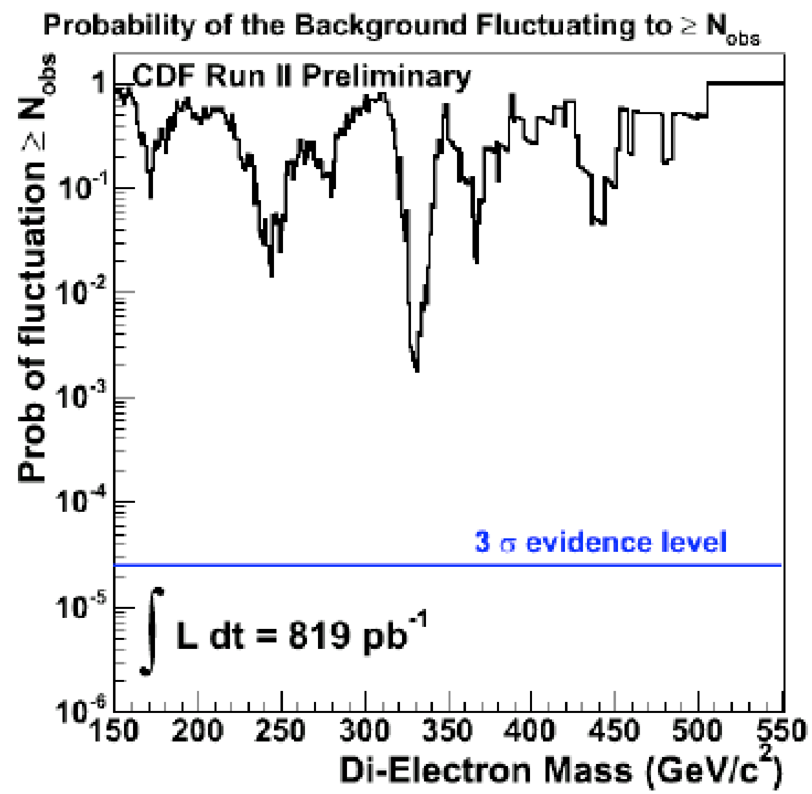
How consistent are the data with the SM?



- Calculate probability of data vs SM prediction at each mass:
  - Mass window size adapted to mass resolution (~3%)
- At 330 GeV the probability is only 0.2%!
  - Have we observed a Z'?

Have we observed a Z'?

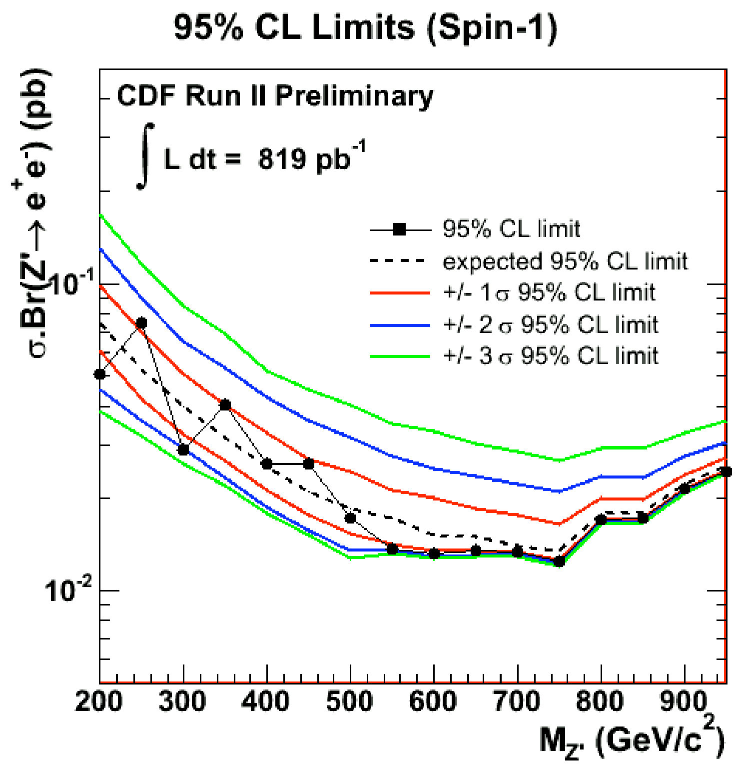
- Need to take into account the "trial factor"
  – We are looking in many mass bins
- Right question:
  – How often do we see a signal as large as 0.2% anywhere in the mass spectrum?
- Answer:
  – Often: 19% of all experiments
  – Evaluated using pseudo-experiments
- But, surely we should keep an open eye with more data!!



For 3σ evidence we would need 0.002% at one mass value!

Interpreting the Mass plots

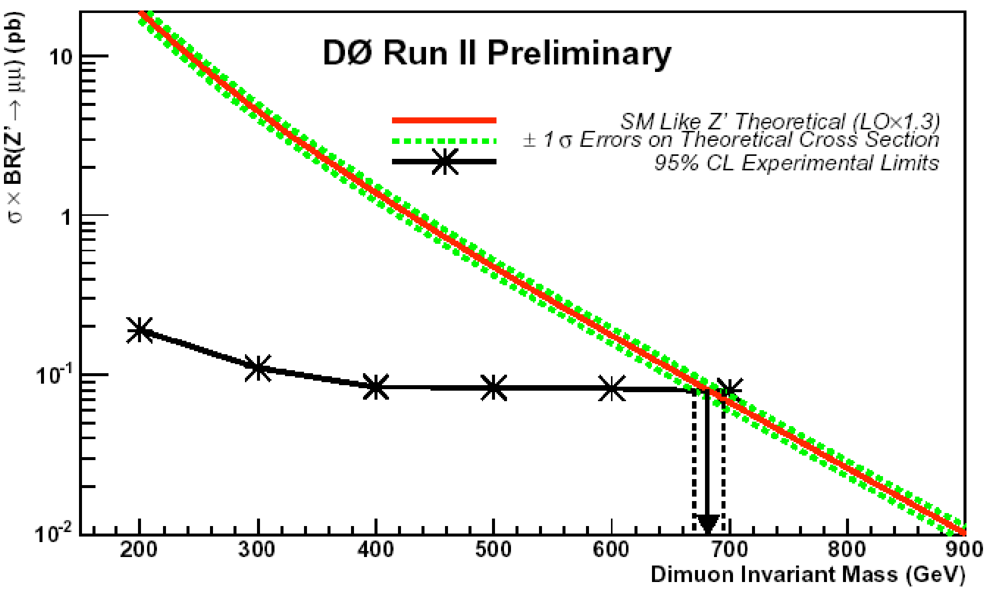
- No evidence for any deviation from Standard Model => Set limits on new physics
  - Set limits on cross section x branching ratio
    - This is model independent, i.e. really what we measure
    - Any theorist can overlay their favourite curve
    - It remains valid independent of changes in theory
    - Always publish this!
  - can also set limits on Z' mass within certain models
    - This is model dependent
    - Nice though for comparing experiments, e.g. LEP vs Tevatron

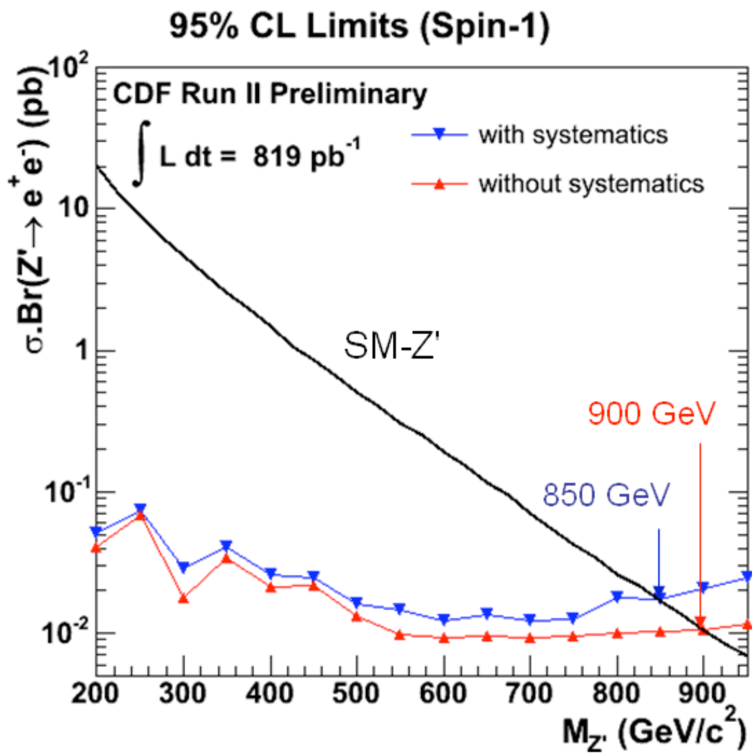


Observed limit is as expected within 1σ

Neutral Spin-1 Bosons: SM-like Z´

- 95% C.L. Limits for Z´ boson with SM couplings

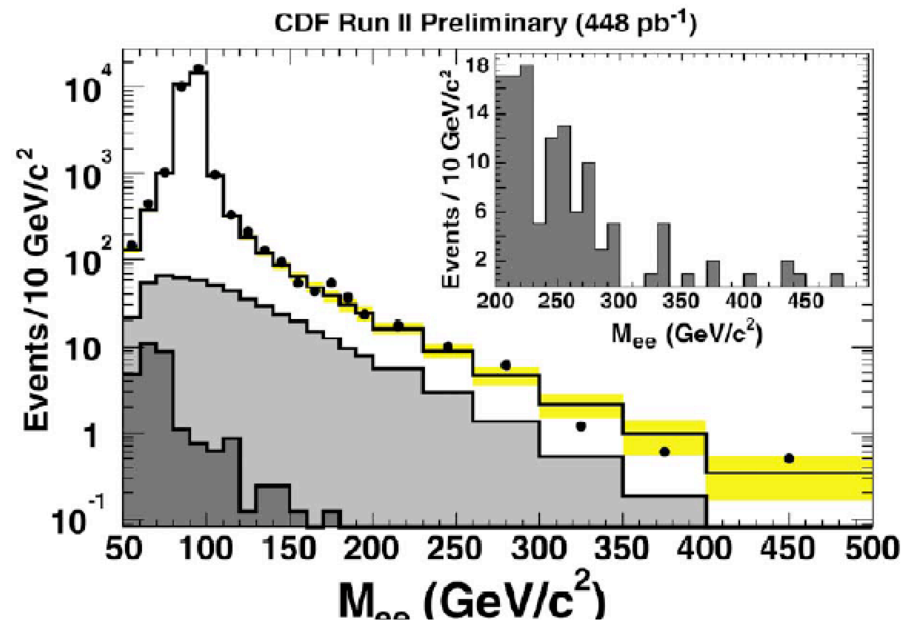


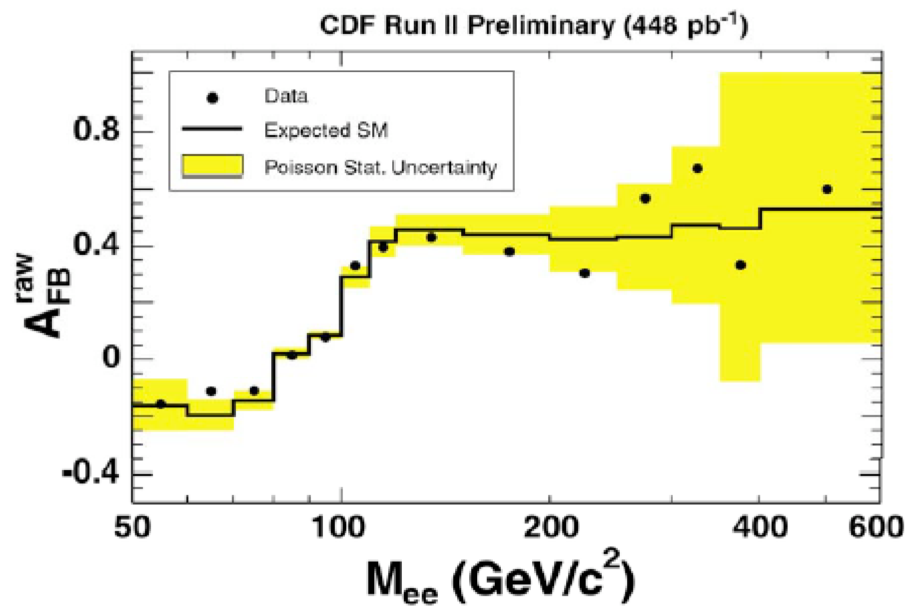


	ee	μμ
CDF	>850 GeV	>735 GeV
D0	>780 GeV	>680 GeV

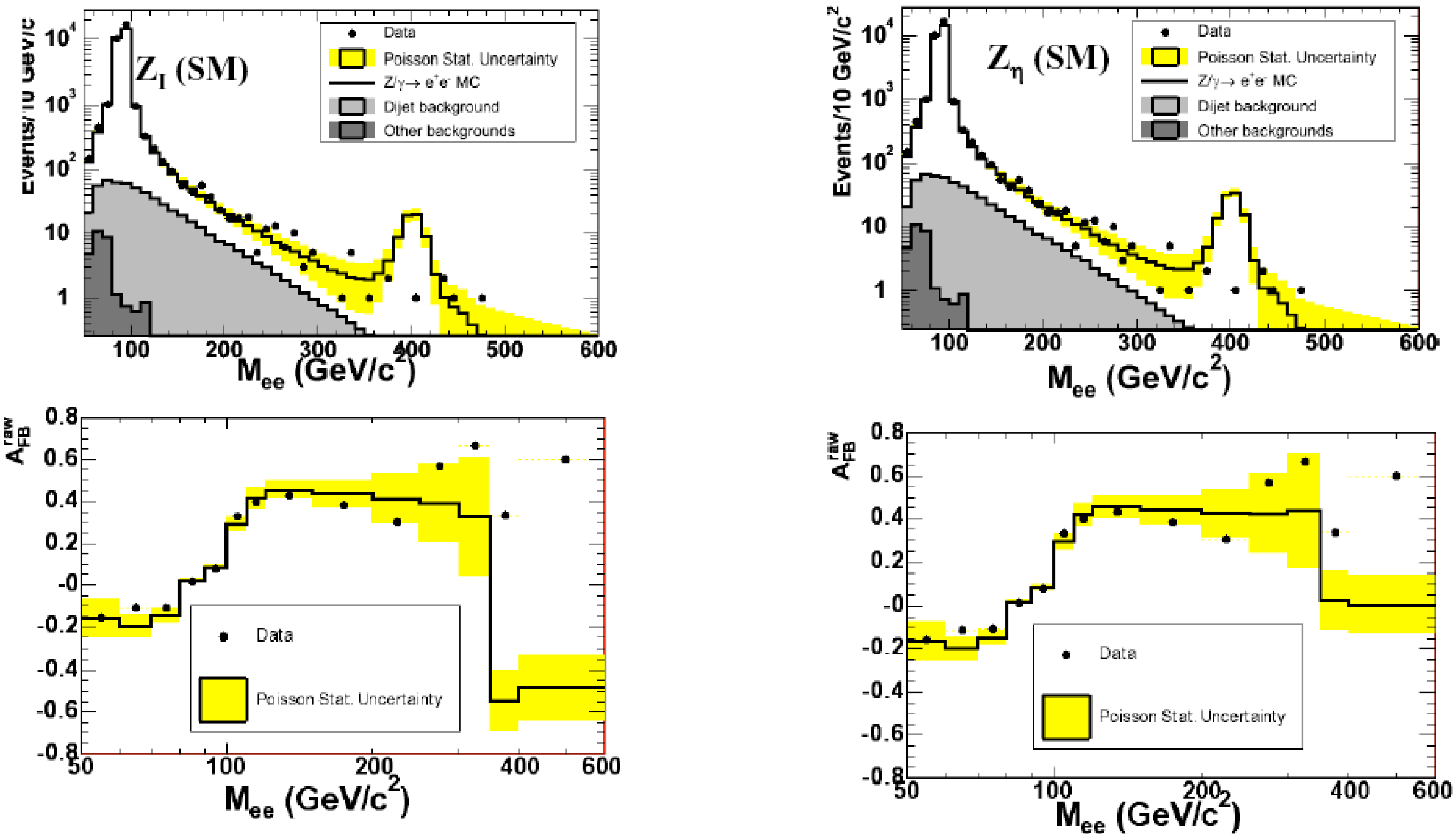
Z′→ee Search: 2-dimensional

- Use now dielectron mass spectrum and angular distribution:
  - 2D analysis improves sensitivity
- Data agree well with Standard Model spectrum
  - No evidence for mass peak or different angular spectrum





Z′→ee Signal Examples



Angular distribution has different sensitivity for different Z' models

Limits on New Physics

- Mass peak search:

Model	Z_{SM}	Z_χ	Z_ψ	Z_η	Z_I	Z_N	Z_{sec}
Mass limit (GeV/c^2)	860	735	725	745	650	710	675

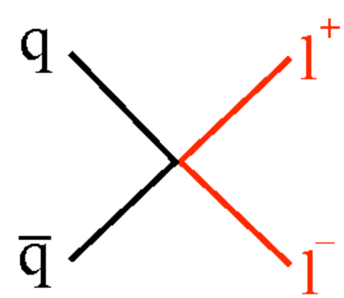
- Tail enhancement: contact interaction

Contact interactions *qqee* $\sum_q \sum_{i,j=L,R} \frac{4\pi\eta}{\Lambda_{ij}^2} \bar{e}_i \gamma^\mu e_i \bar{q}_j \gamma_\mu q_j$

CDF RunII Preliminary (448 pb^{-1})

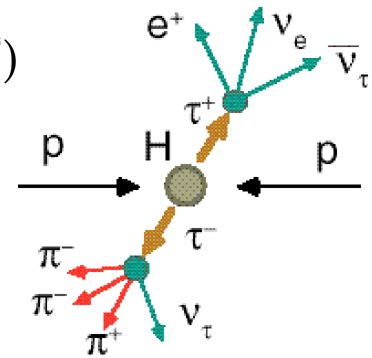
Interaction	LL	LR	RL	RR	VV	AA
Λ_{qe}^{+} limit (TeV/c^2)	3.7	4.7	4.5	3.9	5.6	7.8
Λ_{qe}^{-} limit (TeV/c^2)	5.9	5.5	5.8	5.6	8.7	7.8

VV=LL+LR+RL+RR; AA = LL+RR-RL-LR

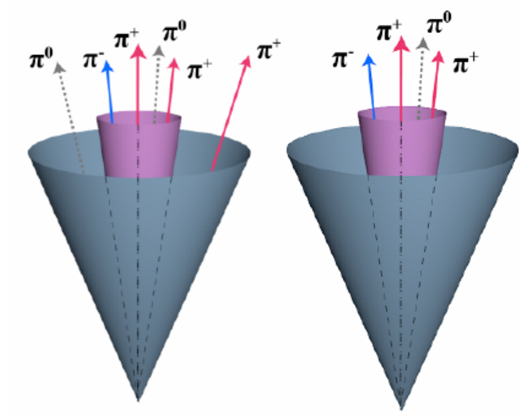


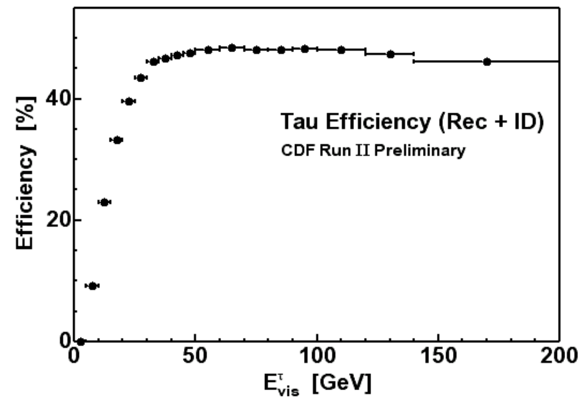
Heavy Object could couple mostly to τ's

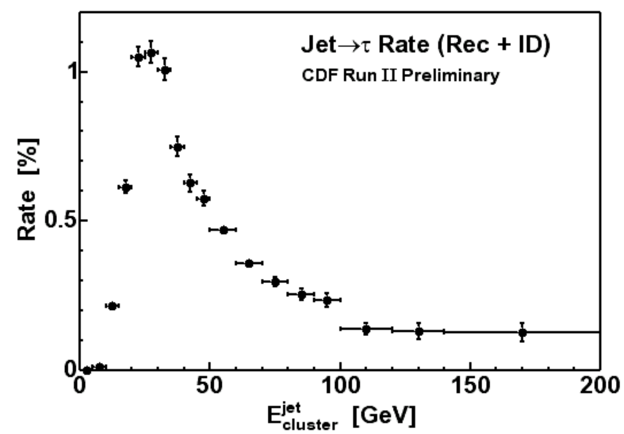
- Maybe the third generation is special?
  - E.g. Higgs bosons couple to mass!
  - Search for Z' or Higgs boson decaying to two τ's
- Selection:
  - one electron or muon ("τ_e ,τ_μ ")
    - From leptonic tau-decay
  - one hadronic tau ("τ_h ")
    - From hadronic tau-decay
  - Both should be isolated



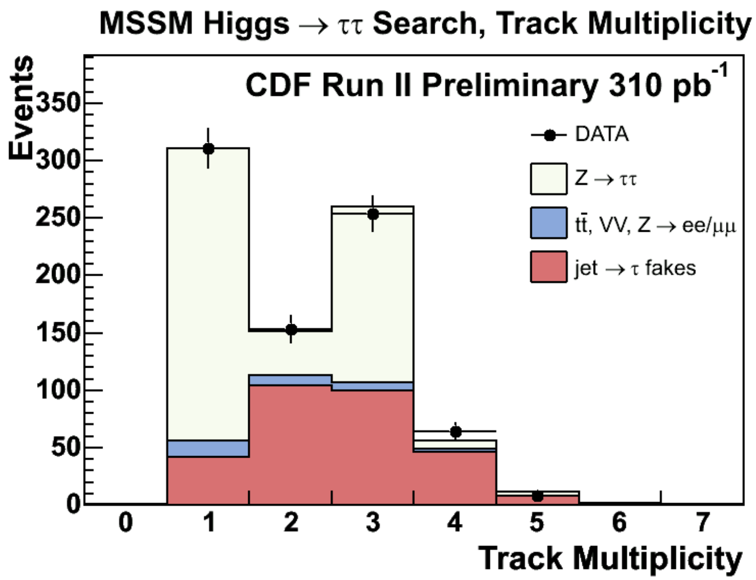
- Hadronic Tau ID:
  - Select 1- and 3-prong decays
  - Efficiency: ~20-50%
  - Jet fake rate: ~1-0.1%
    - 100-10 times higher than for electrons or muons!

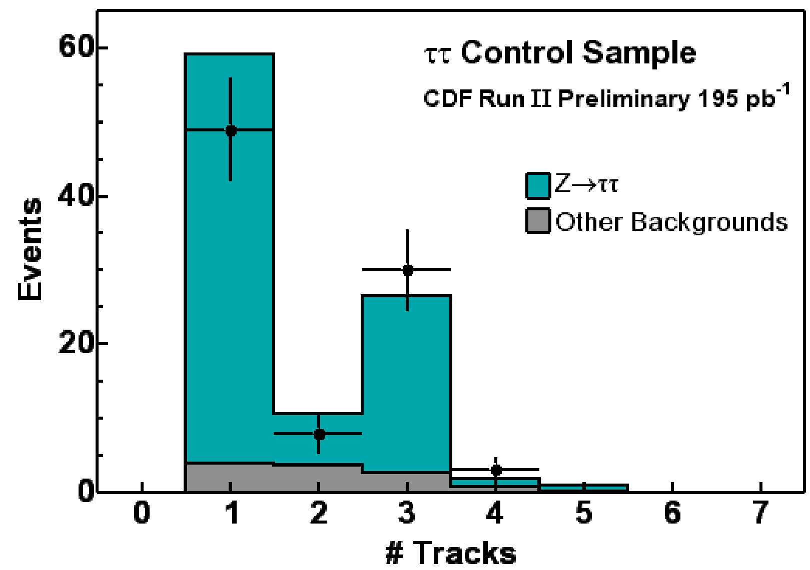




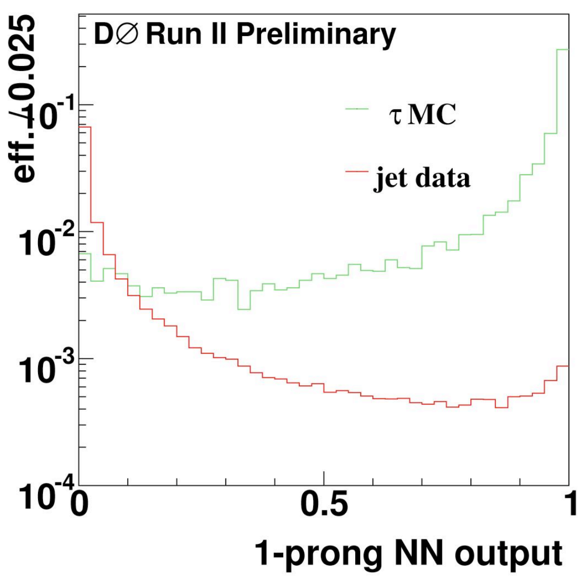


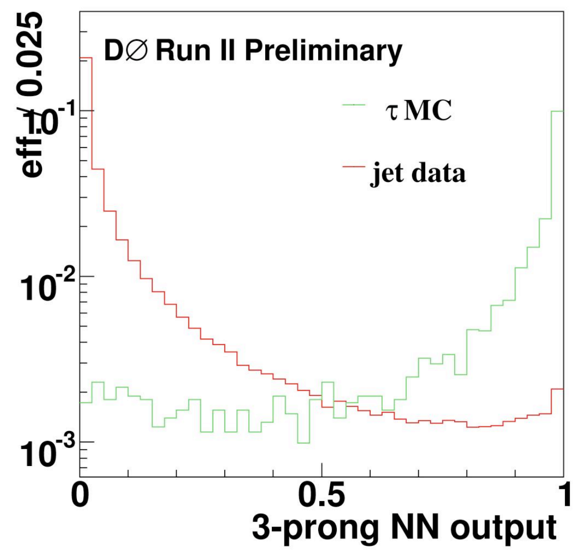
Tau Signals!



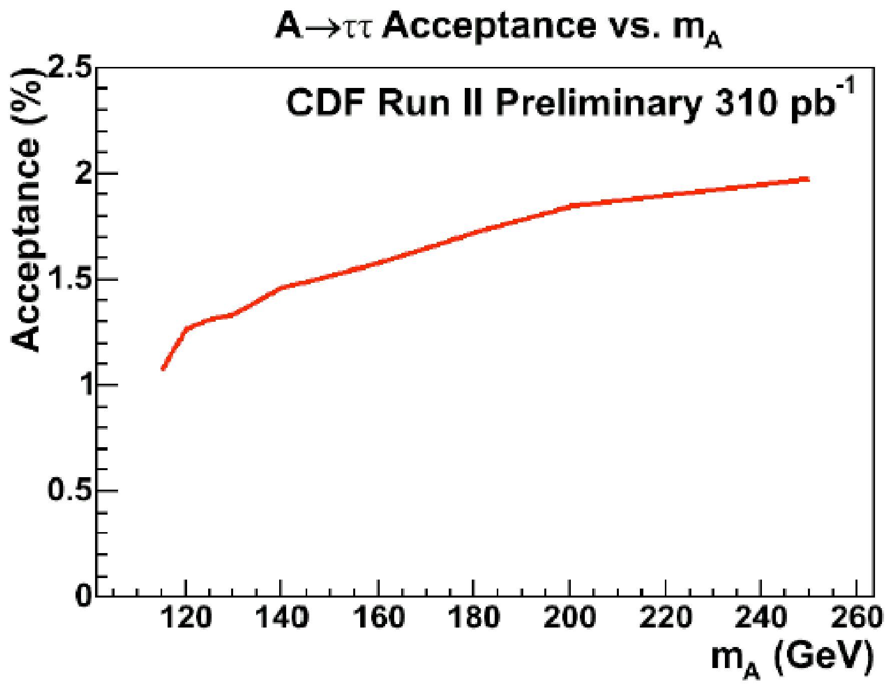


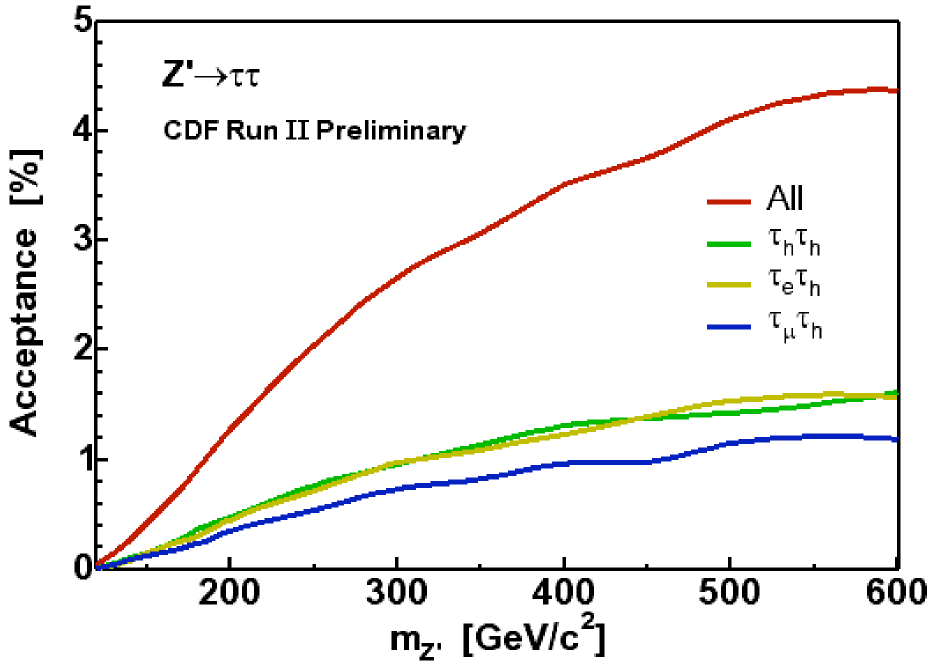
- Clear peaks at 1 and 3 tracks:
  - Typical tau signature
- DØ use separate Neural Nets for the two cases:
  - Very good separation of signal and background





Acceptance for di-tau events

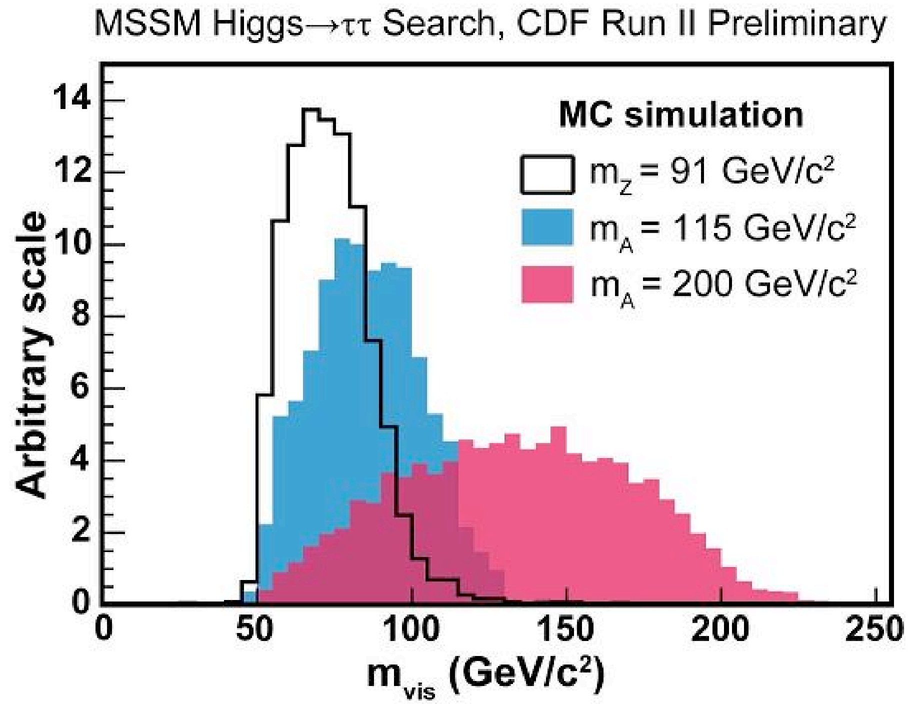




- Typical acceptance 1-4%
  - Factor 10 lower than for electrons and muons

Di-tau Mass reconstruction

- Neutrinos from tau-decay escape:
  - No full mass reconstruction possible
- Use "visible mass":
  - Form mass like quantity: $m_{vis}=m(\tau,e/\mu,\not{E}_T)$
  - Good separation between signal and background
- Full mass reconstruction possible in boosted system, i.e. if $p_T(\tau, \tau)$>20 GeV:
  - Loose 90% of data statistics though!
  - Best is to use both methods in the future



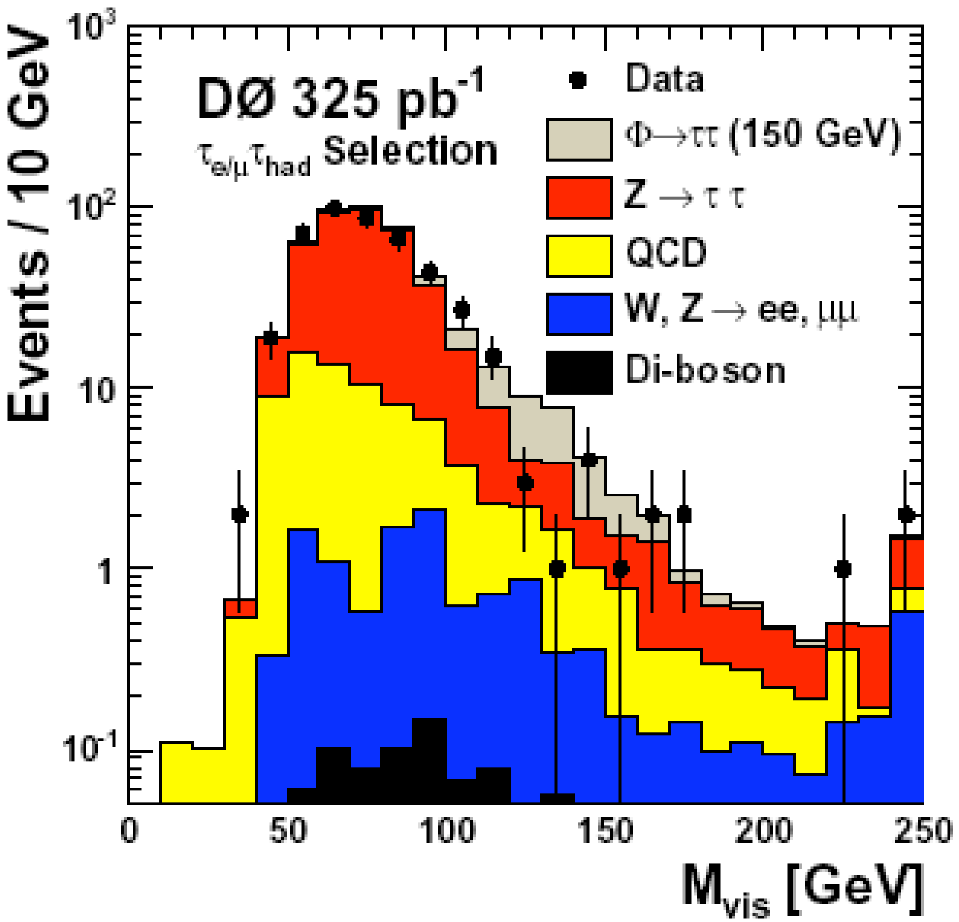
Neutral Spin-1 Bosons: Z'

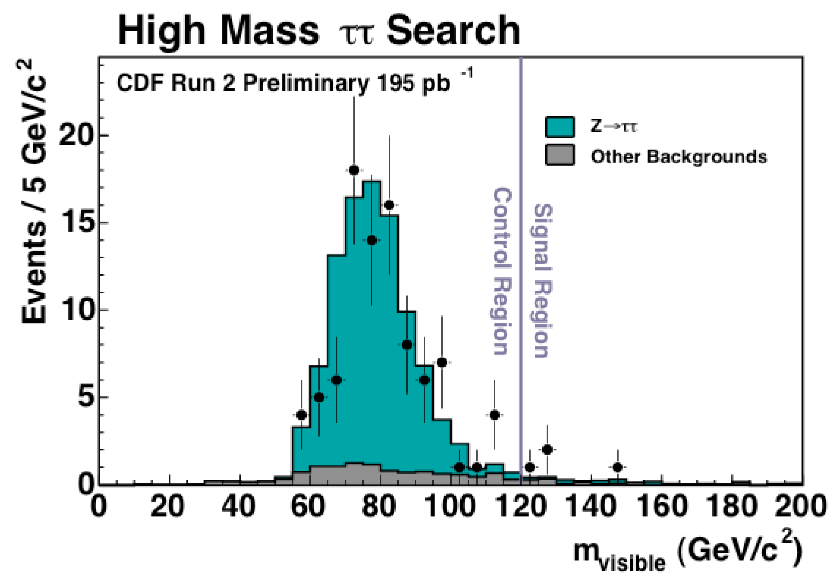
- Excitement with "blind" data analysis:
  - Count events with m_{vis}>120 GeV

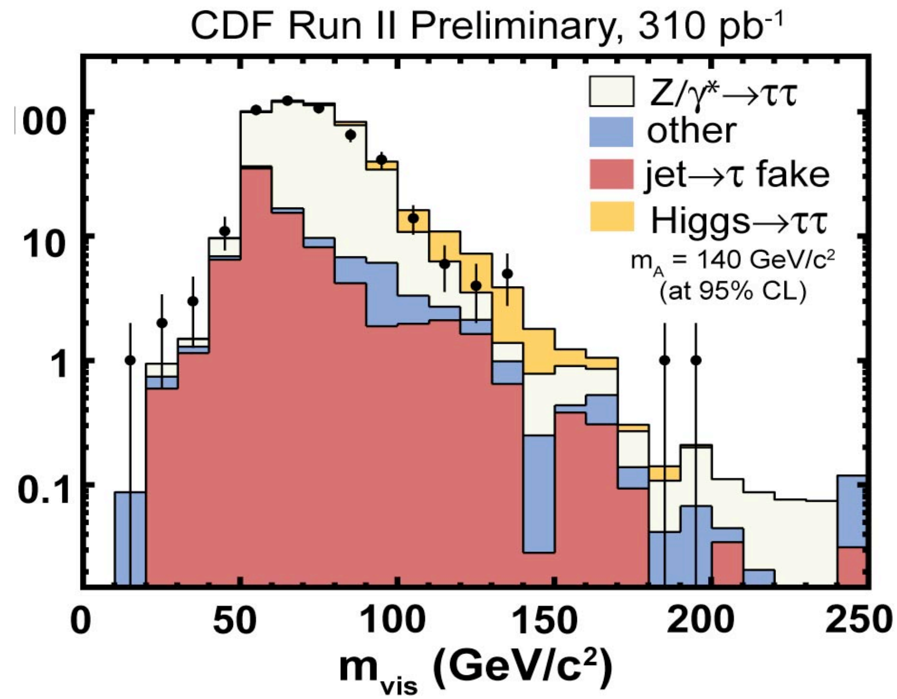
	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$	total
expected	1.01	1.18	0.64	2.93
observed	[redacted]			

Final Mass Spectra

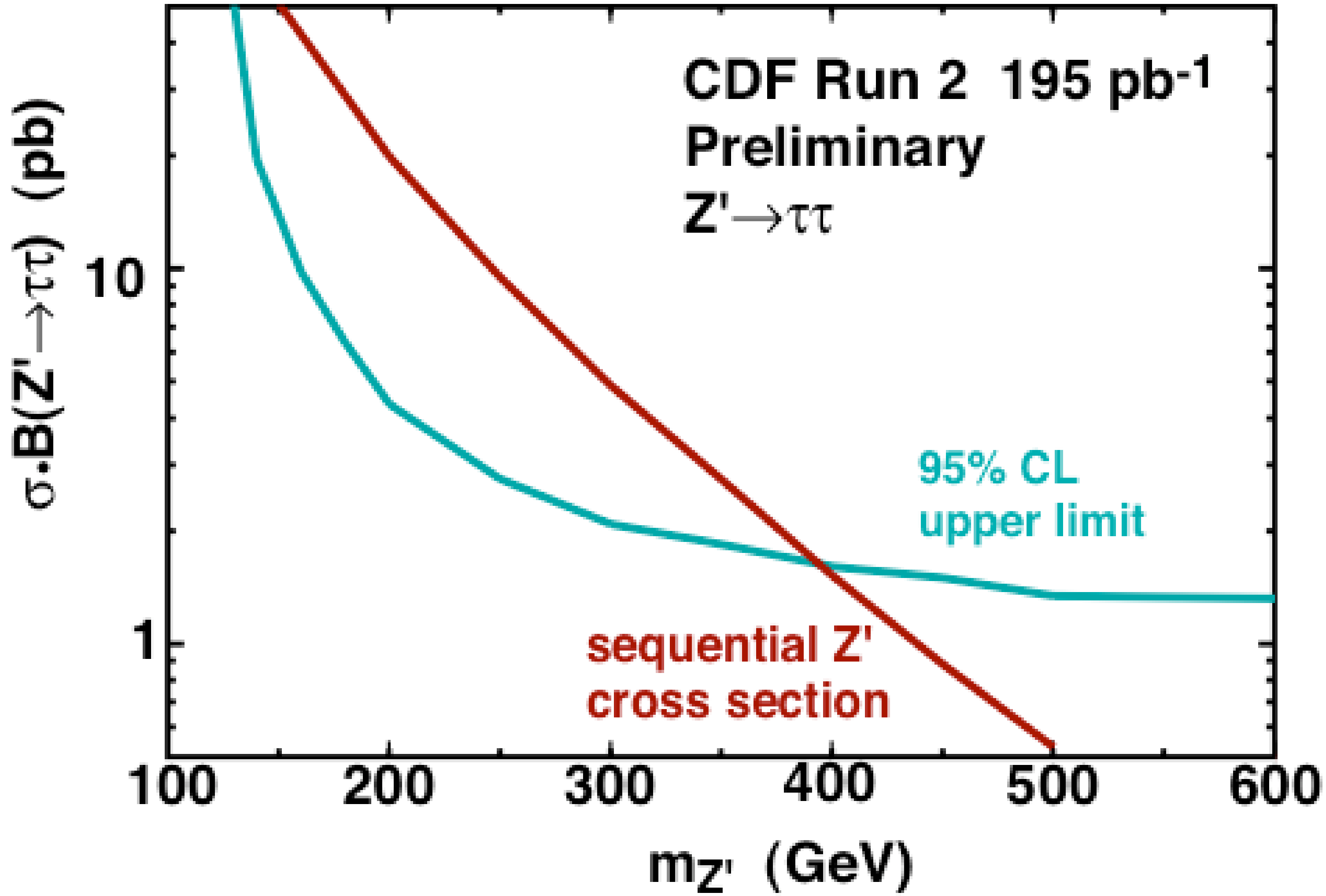
- Mass spectra show no abnormal signals
  - Set limits on models







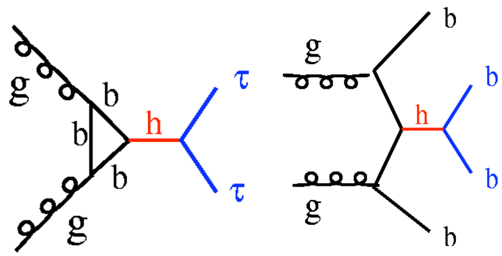
Limit on Z' →ττ



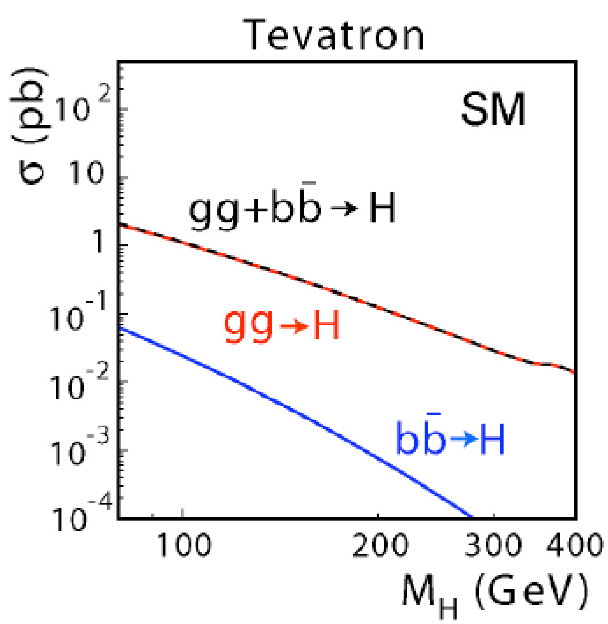
Result: $m_{Z'} > 395$ **GeV**

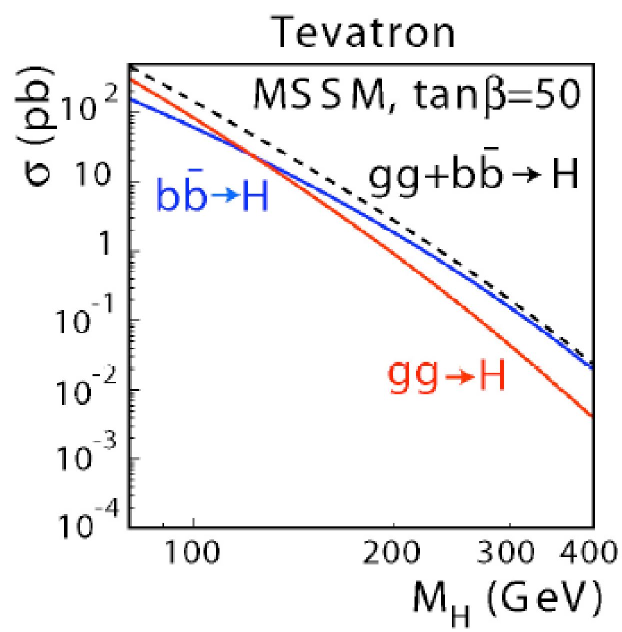
Higgs in the MSSM

- Minimal Supersymmetric Standard Model:
  - 2 Higgs-Fields: Parameter $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs bosons: h, H, A, $H^{\pm}$
- Neutral Higgs Boson:
  - Pseudoscalar A
  - Scalar H, h
    - Lightest Higgs (h) very similar to SM



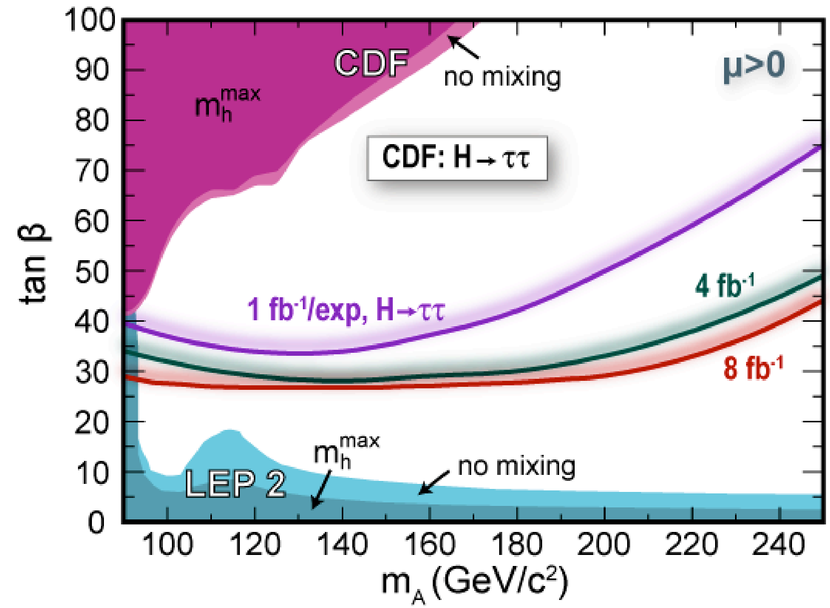
$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan\beta^2}{(1+\Delta_b)^2} \times \frac{9}{[9+(1+\Delta_b)^2]}$$



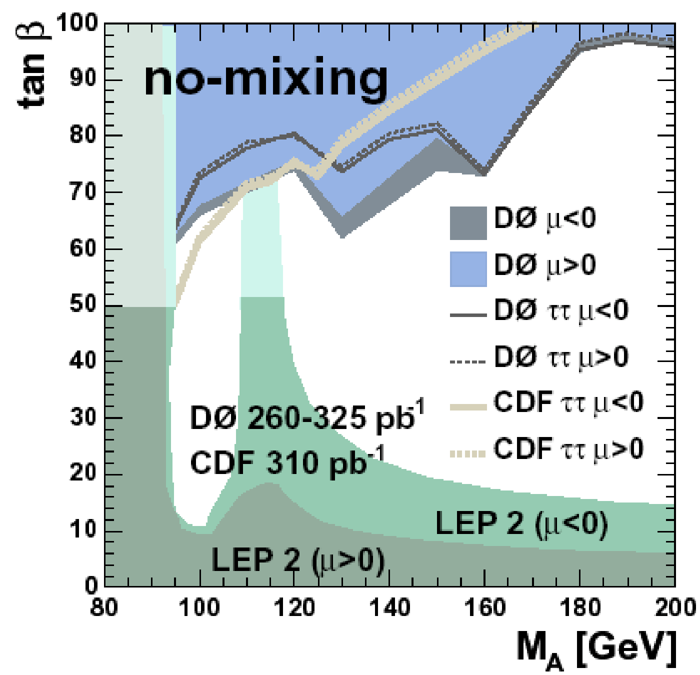


MSSM Higgs: Results

- $p\bar{p} \rightarrow A+X \rightarrow \tau\tau+X$
  - Sensitivity at high tanβ
  - Exploiting regime beyond LEP
- Future (L=8 fb^{-1}):
  - Probe values down to 25-30!



- Complementary search for Higgs bosons decaying to b-quarks ongoing
  - Combined with $\tau\tau$ search in DØ analysis



Conclusions: Lecture IV

- Searches for Physics Beyond the Standard Model are extremely important
  - This can revolutionize our subject and solve many (or at least a few) questions
- I showed you:
  - Squarks and Gluinos:
    - Best to optimize for physical mass regions at electroweak scale
  - High mass resonances: Z' and MSSM Higgs
- Most analyses done blindly
  - Avoid experimental bias
  - You get to have an exciting day!
  - Blind analysis does not mean "not looking at the data"
    - Look at data in background dominated regions
- Not found any new physics (yet)

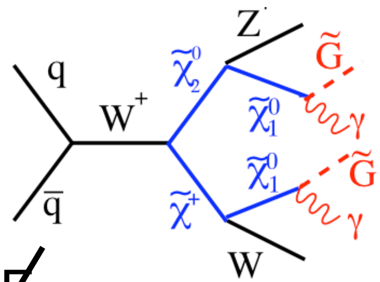
Overall Conclusions

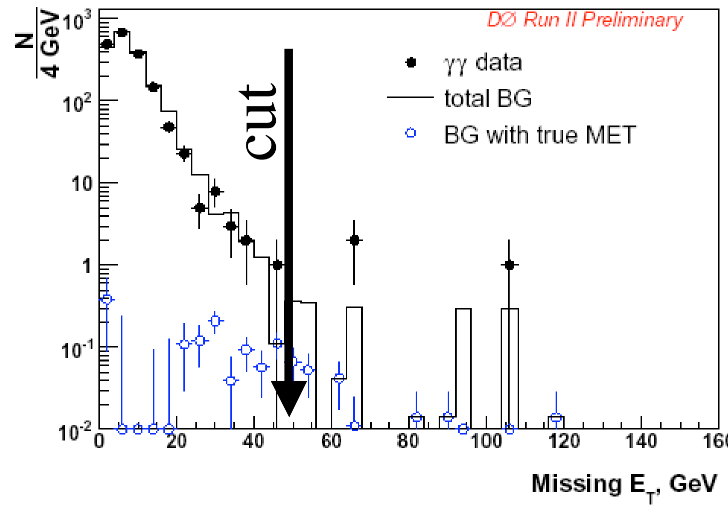
- The Tevatron physics programme is very rich:
  - Probing the electroweak, the strong, the flavour sector of the Standard Model and looking for the unknown
  - Possible due to excellent detector and trigger capabilities
- The Tevatron is operating at the highest energies
  - And it is operating very well now: 1.5 fb^{-1} delivered
  - A hadron collider environment is challenging but doable!
- There is a lot I could not show you, see also
  - http://www.cdf-fnal.gov/physics/physics.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results.html

I hope you enjoyed the lecture,
and we'll see New Physics soon!

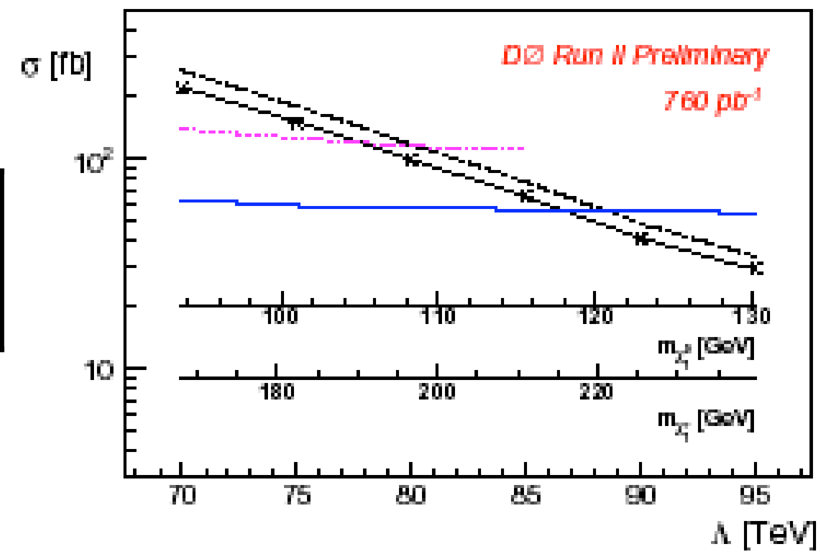
GMSB: $\gamma\gamma+\not{E}_t$

- Assume $\tilde{\chi}^0_1$ is NLSP:
  - Decay to $\tilde{G}+\gamma$
  - $\tilde{G}$ light: m ≈ 1 keV
  - Inspired by CDF $ee\gamma\gamma+\not{E}_t$ event in Run I
    - SM exp.: 10^{-6}
- D0 inclusive search with $\int Ldt=780\ pb^{-1}$:
  - 2 photons: $E_t > 25$ GeV
  - $\not{E}_t > 45$ GeV





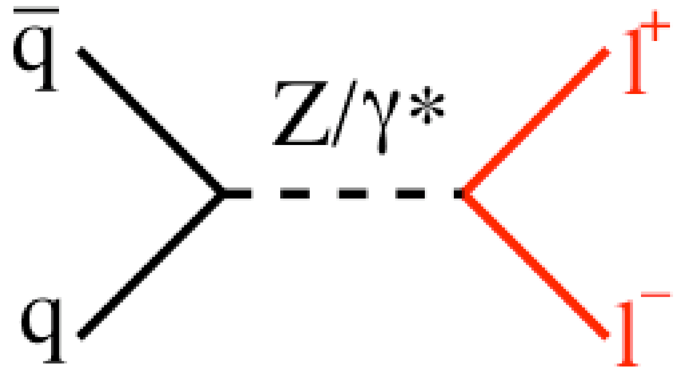
	Exp.	Obs.	$m(\tilde{\chi}^+_1)$
DØ	2.1±0.7	4	>220 GeV

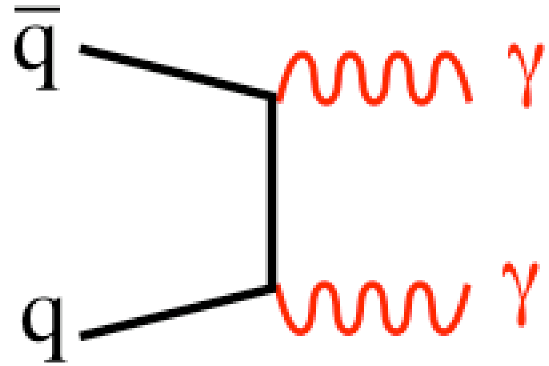


CDF result: $m(\chi^+_1)>168$ GeV with 200 pb^{-1}

High Mass Dileptons and Diphotons

Standard Model high mass production:



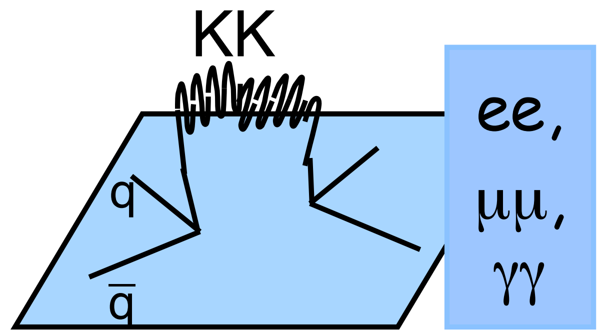


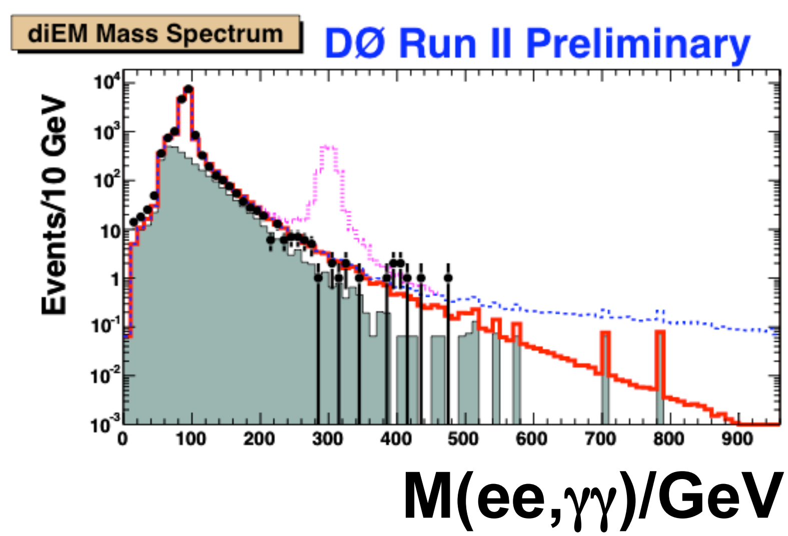
New physics at high mass:

- Resonance signature:
  - Spin-1: Z'
  - Spin-2: Randall-Sundrum (RS) Graviton
  - Spin-0: Higgs
- Tail enhancement:
  - Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)
  - Contact interaction

Extra Dimensions

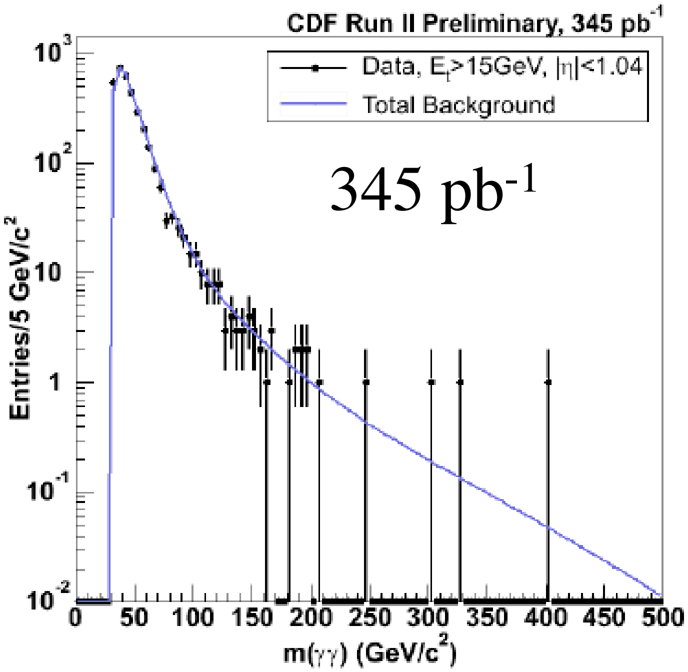
- Attempt to solve hierarchy problem by introducing extra dimensions at TeV scale
- ADD-model:
  - n ED's large: 100μm-1fm
  - $M^2_{PL} \sim R^n M_S^{n+2}$ (n=2-7)
  - Kaluza-Klein-tower of Gravitons ⇒continuum
  - Interfere with SM diagrams: λ=±1 (Hewett)
- Randall Sundrum:
  - Gravity propagates in single curved ED
  - ED small $1/M_{Pl}=10^{-35}$ m
  - Large spacing between KK-excitations
    ⇒ resolve resonances
- Signatures at Tevatron:
  - Virtual exchange:
    - 2 leptons, photons, W's, Z's, etc.
    - BR(G->γγ)=2xBR(G->ll)

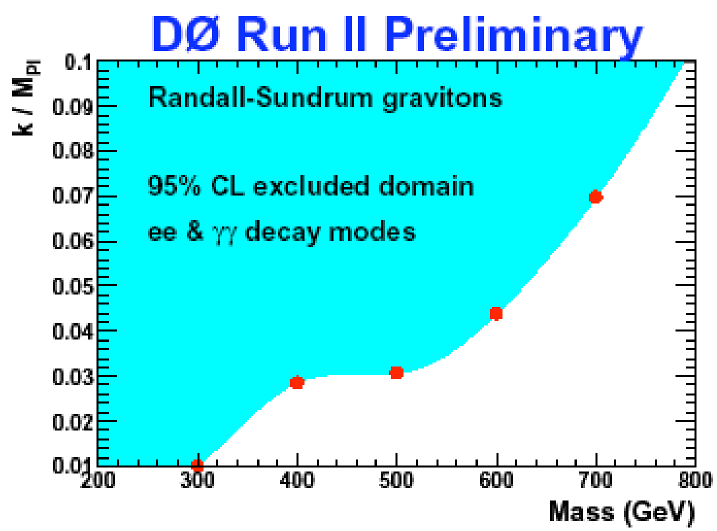




Randall-Sundrum Graviton

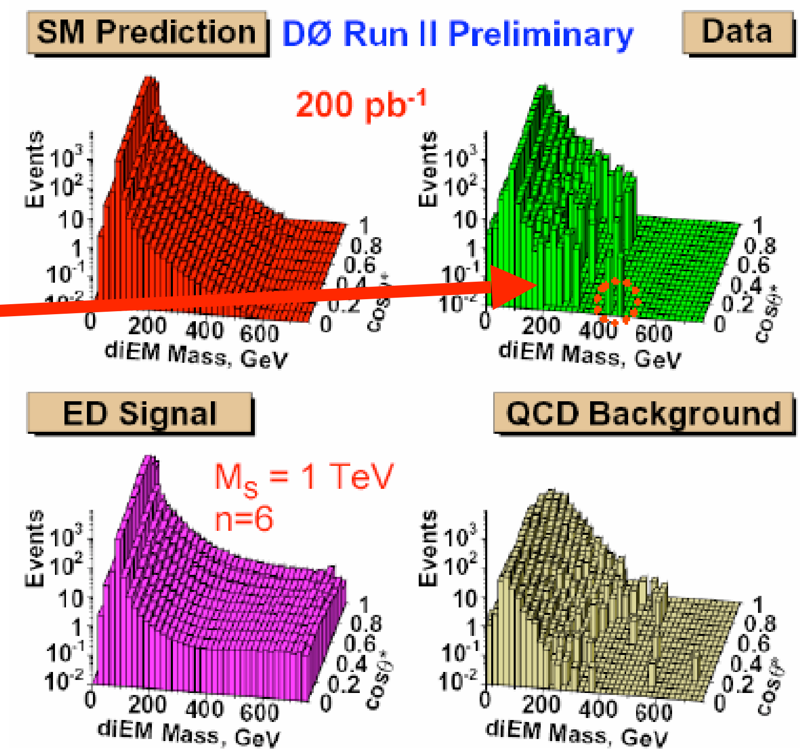
- Analysis:
  - D0: combined ee and $\gamma\gamma$
  - CDF: separate ee, $\mu\mu$ and $\gamma\gamma$
- Data consistent with background
- Relevant parameters:
  - Coupling: k/M_{Pl}
  - Mass of 1^{st} KK-mode
- World's best limit:
  - M>785 GeV for k/M_{Pl}=0.1





Large Extra Dimensions: ADD

- D0:
  - 2D analysis: Mass vs cos(θ*)
  - spin-2 particle expected at high mass and low cos(θ*)
- Nice competition between Tevatron, LEP and HERA!
- Lower limit on M_S (Hewett):

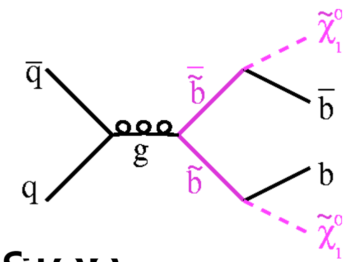


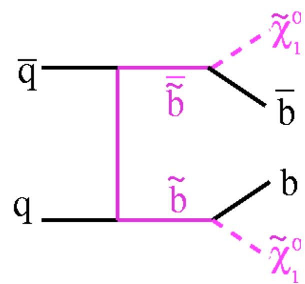
	D0		CDF	LEP	H1	ZEUS
	ee+γγ	μμ	ee	ee	eq	eq
λ=+1	1.28	0.97	0.96	1.20	0.82	0.78
λ=-1	1.16	0.95	0.99	1.09	0.78	0.79

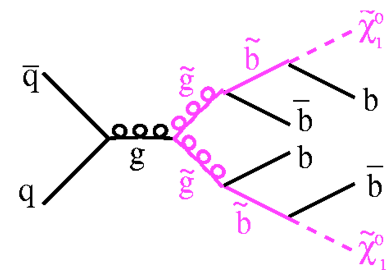
D0: most stringent direct lower limit on M_S>1.28 TeV

3rd generation Squarks

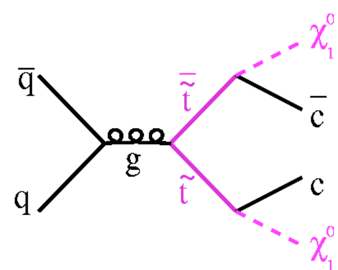
- 3rd generation is special: mass could be much lower
- Direct production or from gluino decays:
  - $pp \to \tilde{b}\tilde{b}$ or $\tilde{t}\tilde{t}$
  - $pp \to \tilde{g}\tilde{g} \to bbbb$ or $tttt$

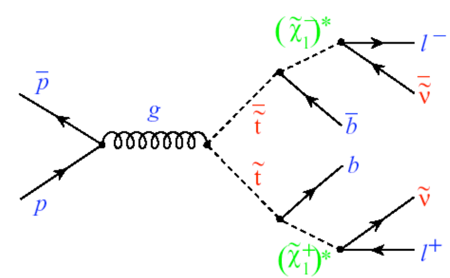




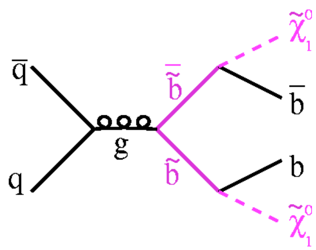


- Decay of sbottom and stop:
  - $\tilde{b} \to b\tilde{\chi}^0$
  - Stop depends on mass:
    - Heavy: $\tilde{t} \to t\tilde{\chi}^0$
    - Medium: $\tilde{t} \to b\tilde{\chi}^{\pm} \to bW\tilde{\chi}^0$
    - Light: $\tilde{t} \to c\tilde{\chi}^0$

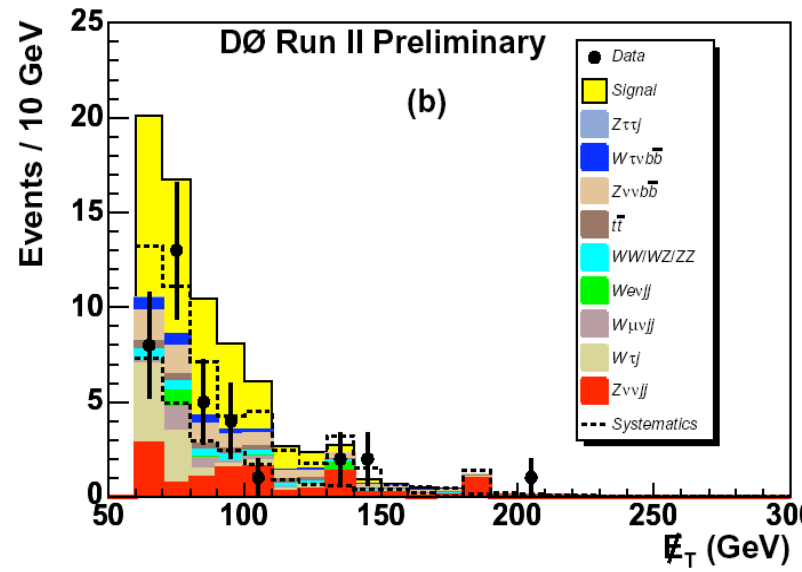


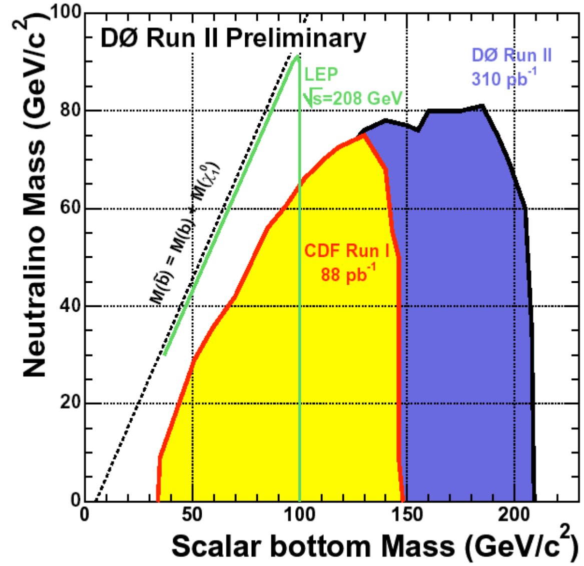


Sbottom Quarks



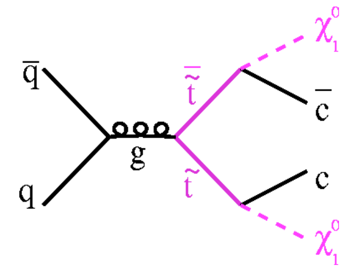
- Selection:
  - Two jets, one b-tagged:
    - E_{T1}>40-70 GeV
    - E_{T2}>15-40 GeV
  - Missing E_T>60-100 GeV
  - Optimisation of cuts for different mass regions
- Result:
  - Data agree well with background
  - Exclude sbottom masses up to 200 GeV
    - Depending on neutralino mass

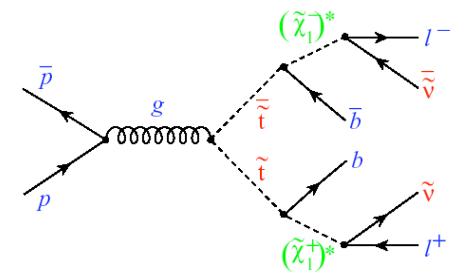


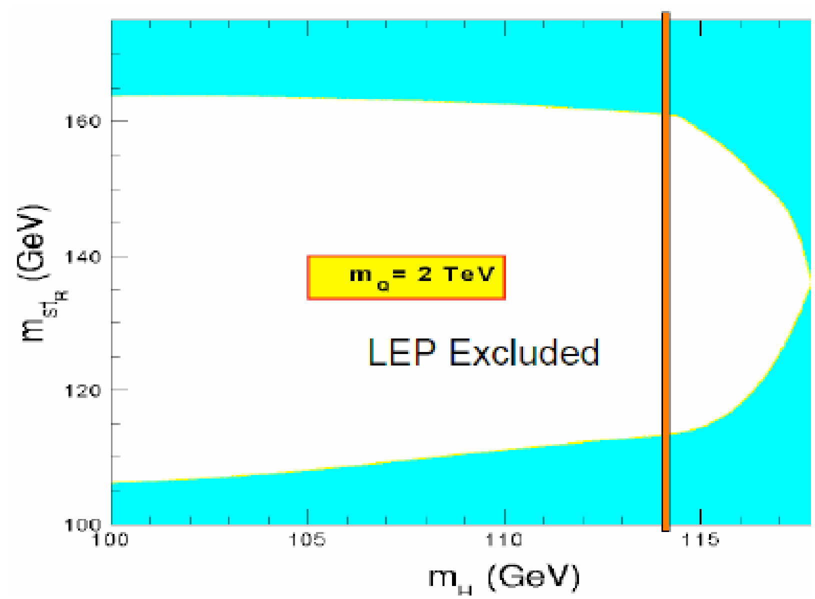


Light Stop-Quark: Motivation

- If stop quark is light:
  - decay via $\tilde{t}\to bl\tilde{\nu}$ or $\tilde{t}\to c\tilde{\chi}_1^0$
- E.g. consistent with baryogenesis:
  - Balazs, Carena, Wagner: hep-ph/0403224
  - $m(\tilde{t})-m(\tilde{\chi}_1^0)\approx 15\text{-}30$ GeV/c^2
  - $m(\tilde{t})<165$ GeV/c^2

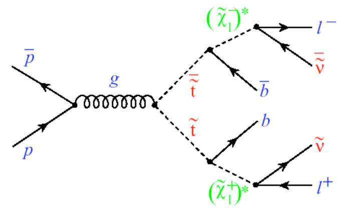


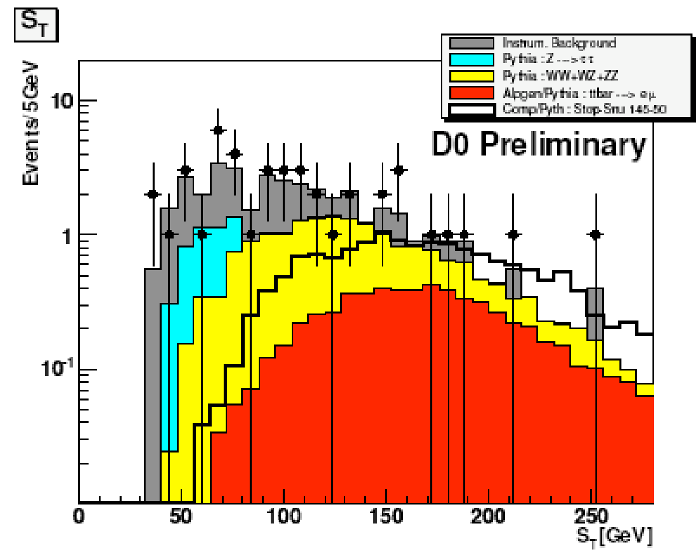




Stop

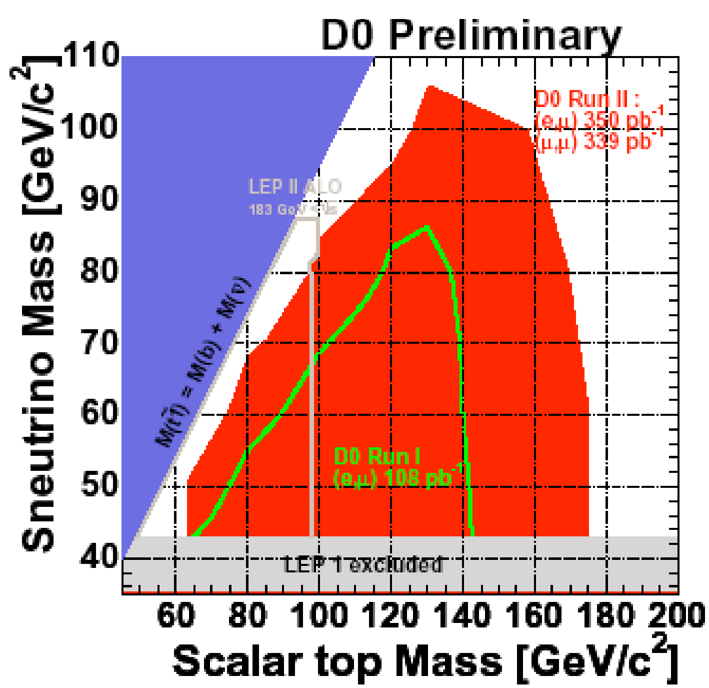
- Selection by DØ
  - 2 leptons: eμ, μμ
  - Missing E_T>15 GeV
  - Topological cuts to suppress background
    - Optimized depending on mass difference of stop and sneutrino





- Results

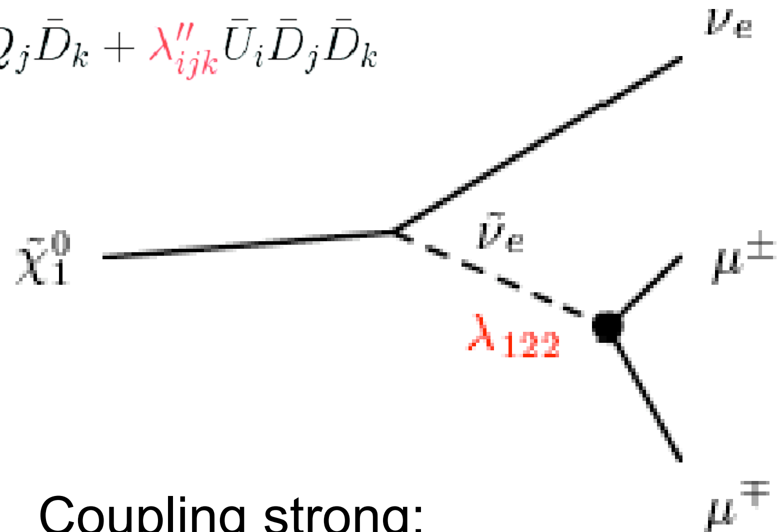
Cut	SM Bg.	Obs.
A	23.0+-3.1	21
B	34.6+-4.0	34
C	40.7+-4.4	42



Exclude stop masses up to m_{top}

R-parity violation

$$W_{\not R_p} = \boxed{\lambda_{ijk} L_i L_j \bar{E}_k} + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

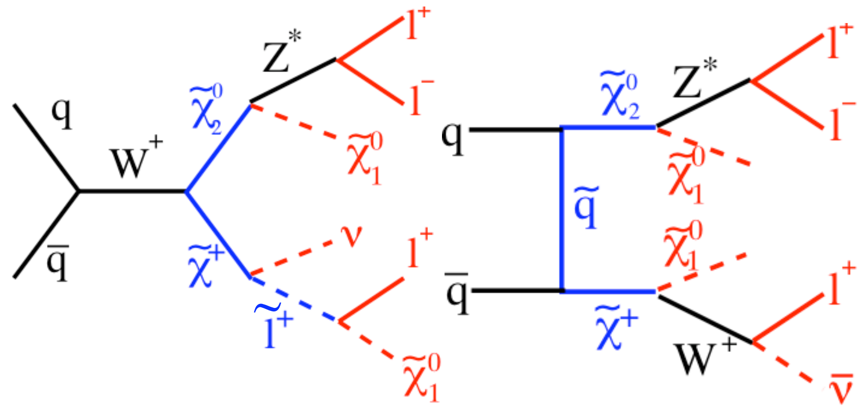


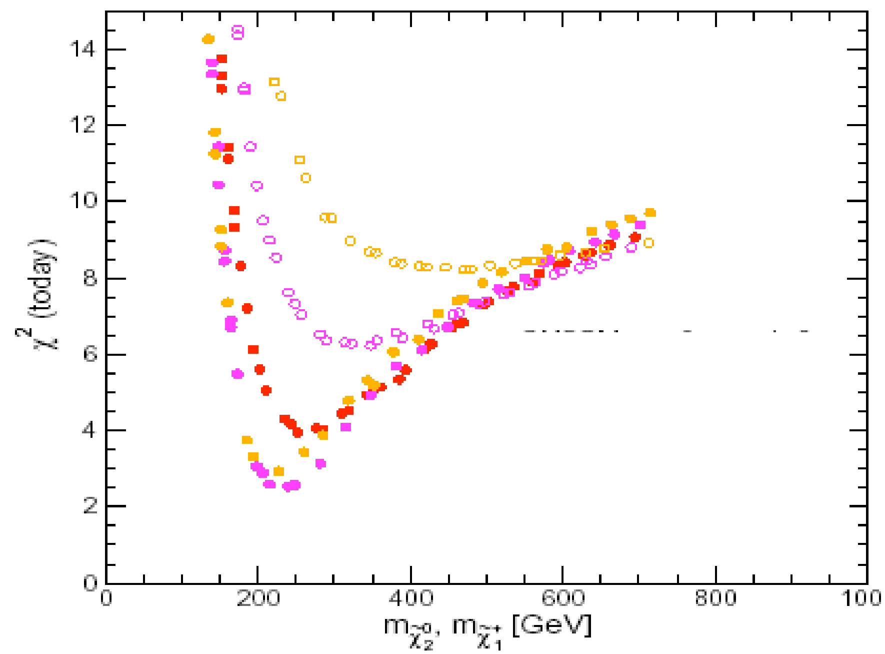
- Search for R-parity violating decay of LSP to leptons:
  - λ_{121}, λ_{122}
  - No bounds from proton decay
  - Enables neutrino oscillations
- Specifically:
  - Decay of lightest neutralino into leptons
  - Can happen in any SUSY process

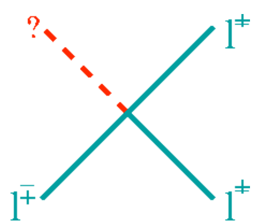
- Coupling strong:
  - Prompt decay: $\tau \approx 0$
- Coupling weak:
  - Lifetime large: $\tau > 0$
- Coupling very weak:
  - Lifetime large: $\tau \gg 0$ => decay products not observed in detectors

Charginos and Neutralinos

- Charginos and Neutralinos:
  - SUSY partners of W, Z, photon, Higgs
  - Mixed states of those
- Signature:
  - 3 leptons + $\not{E}_T$
  - “Golden” signature at Tevatron
- Recent analyses of EWK precision data:
  - J. Ellis, S. Heinemeyer, K. Olive, G. Weiglein:
    - hep-ph/0411216
  - Light SUSY preferred

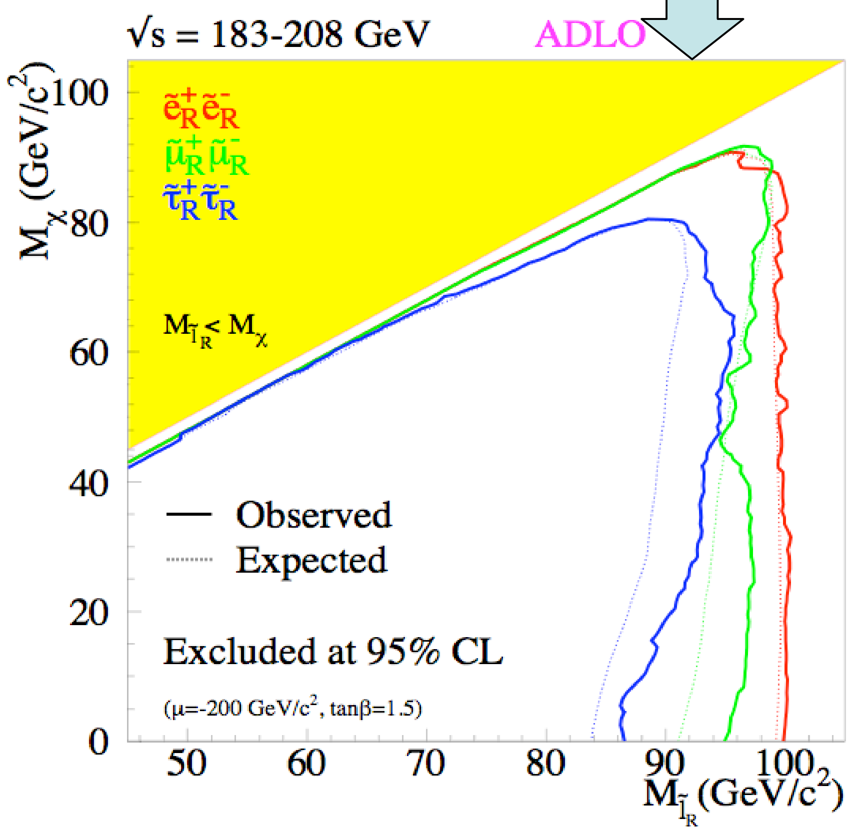


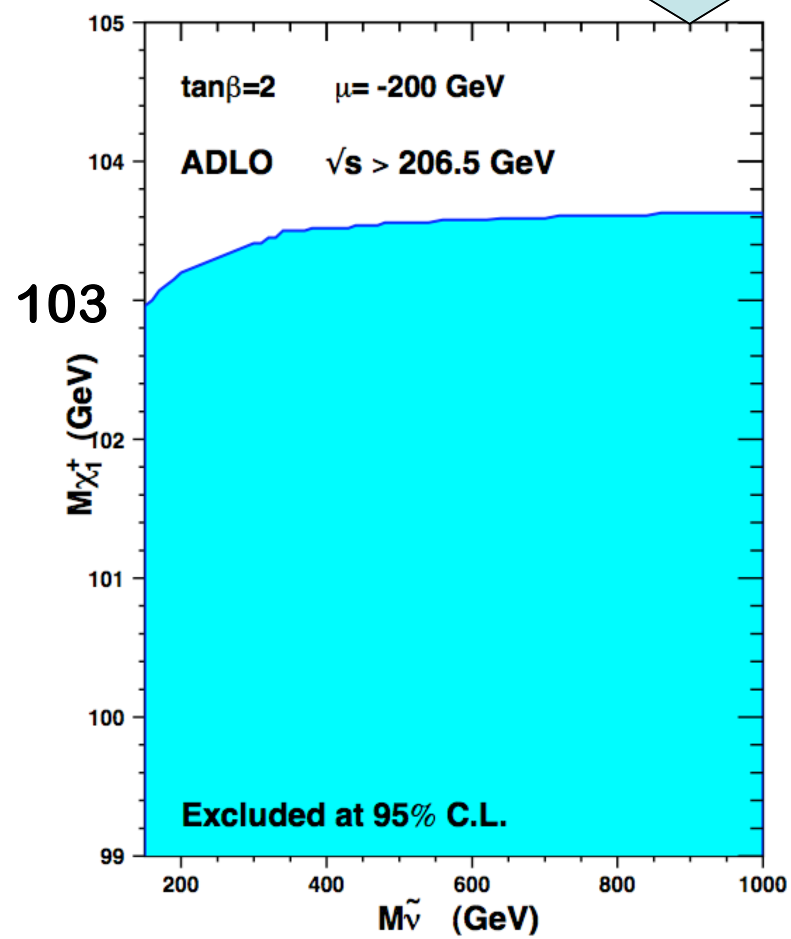




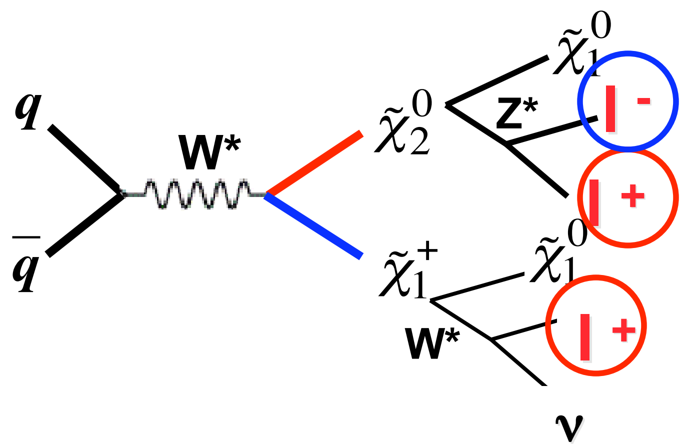
mSugra Existing Limits : LEP

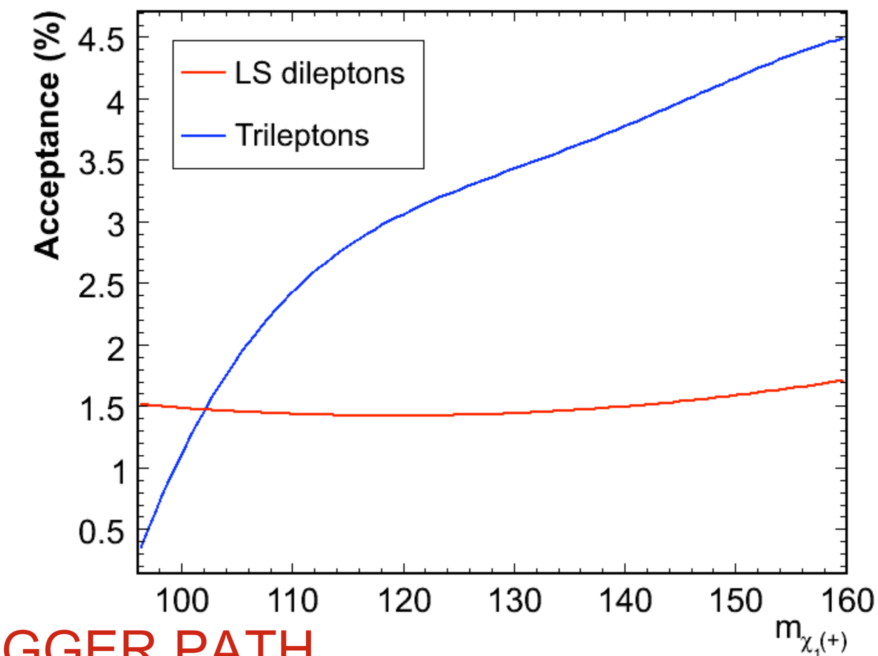
- LSP > $M_Z/2$
- Chargino > 103 GeV/c² (heavy sneutrinos);
- Sleptons > 90-100 GeV/c² for $M(\chi_0^1)<M(l_R)$





Analyses Overview





CHANNEL	LUM	TRIGGER PATH
$e^\pm e^\pm, e^\pm\mu^\pm, \mu^\pm\mu^\pm$	710	High p_T Single Lepton
μ**l** + e/μ	750	High p_T Single Lepton
ee + e/μ	350	High p_T Single Lepton
$\mu\mu$ + e/μ	310	Low p_T Dilepton
ee + track	610	Low p_T Dilepton

No third lepton requirement
=> Higher acceptance

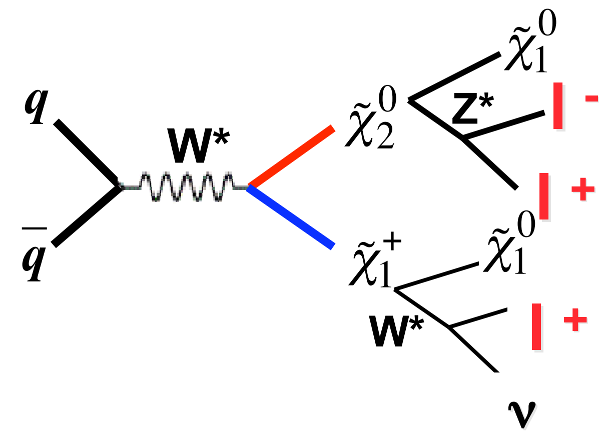
Use e/mu only
=>Very small backgrounds

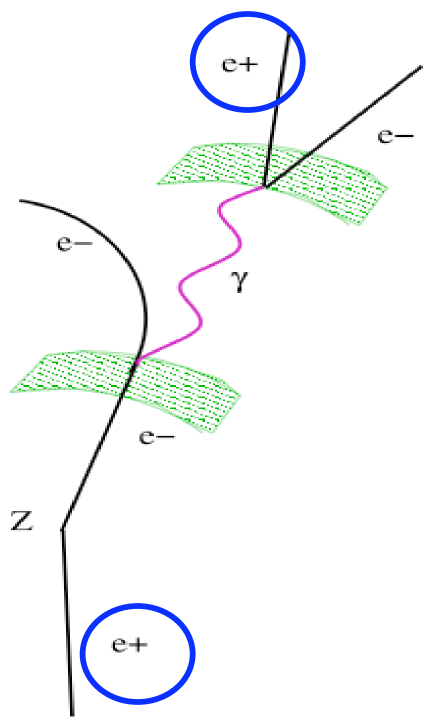
Sensitive to taus as 3rd lepton
=> Keeps acceptance at high tanβ

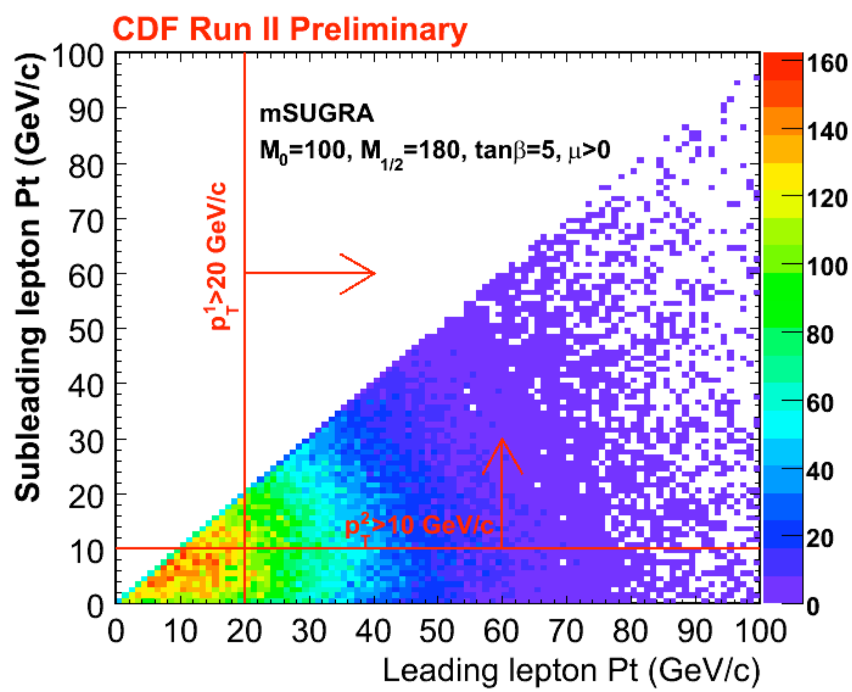
Like-Sign Dileptons

- Sensitive to both chargino-neutralino and squark-gluino production
- Ask for 2 high-pt (20,10) isolated leptons of the same charge
- Main background :

  conversions!

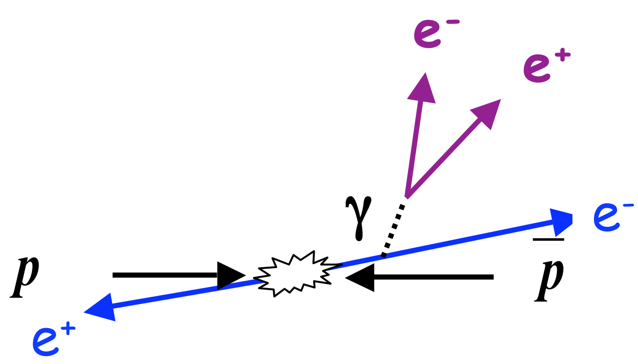




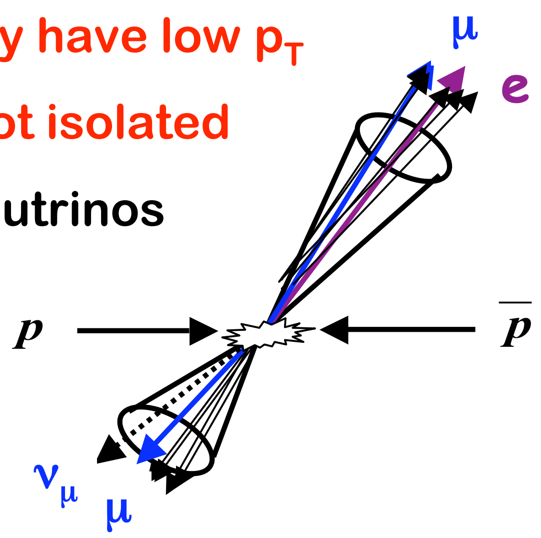


how to reduce them

- **DRELL YAN PRODUCTION + additional lepton**
  - Leptons have mainly high p_T
  - Small MET
  - Low jet activity



- **HEAVY FLAVOUR PRODUCTION**
  - Leptons mainly have low p_T
  - Leptons are not isolated
  - MET due to neutrinos

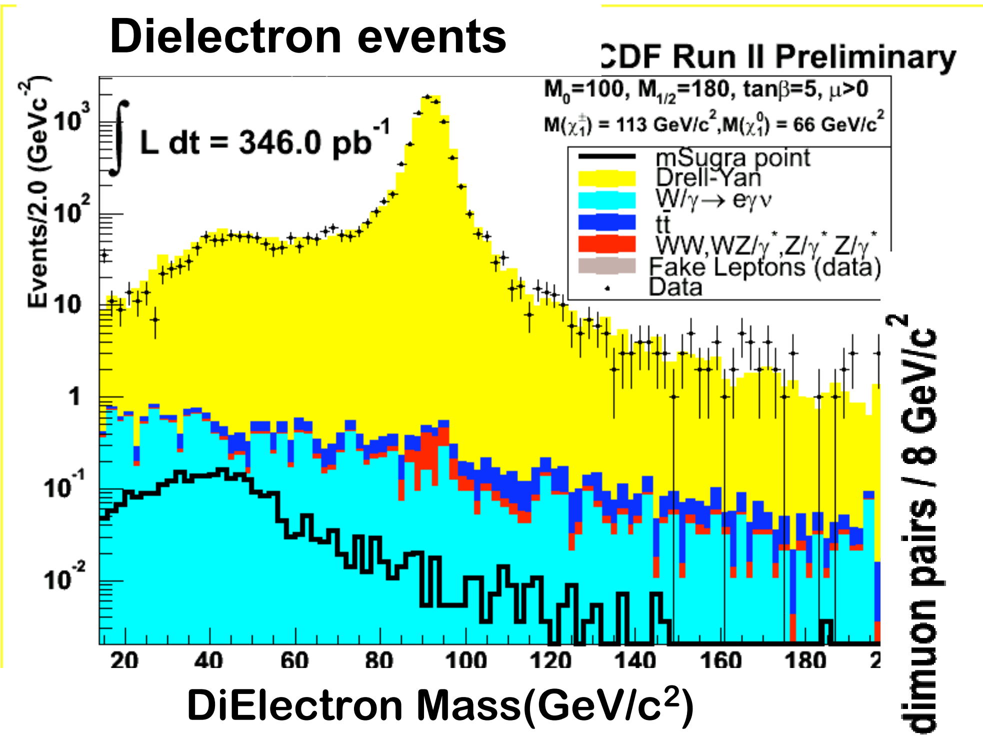


- **DIBOSON (WZ,ZZ) PRODUCTION**
  - Leptons have high p_T.
  - Leptons are isolated and separated
  - MET due to neutrinos

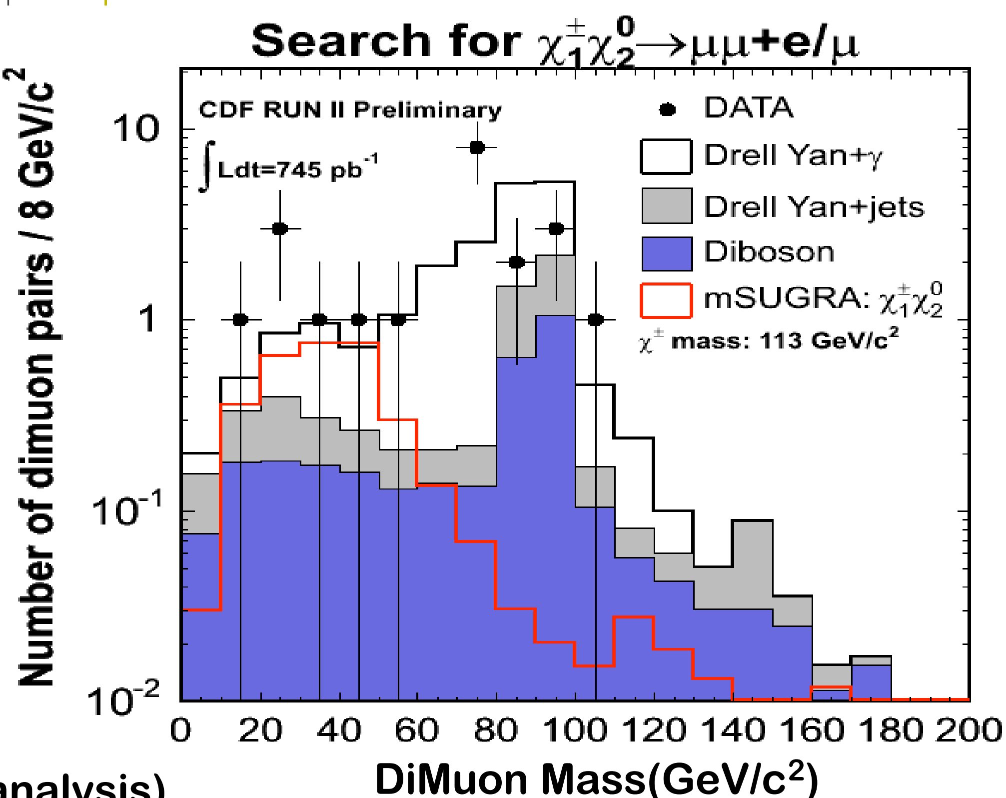
irreducible background

Selection criteria: (I) Mass

Rejection of J/Ψ, Υ and Z



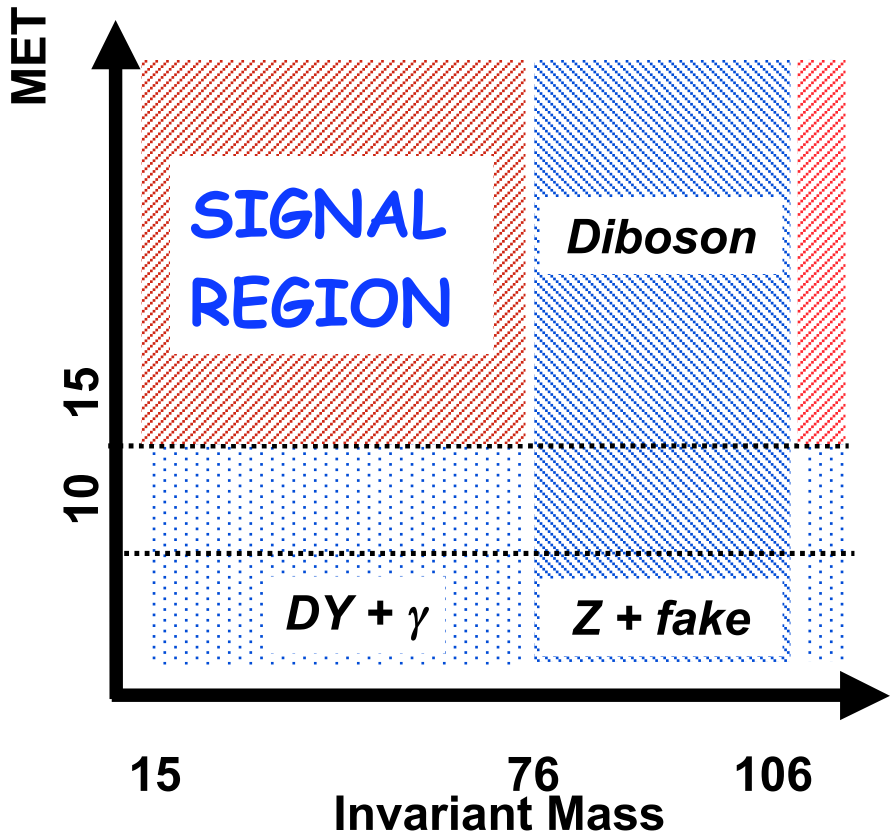
Asking for the third lepton…



- M_{ll}<76 GeV & M_{ll} >106 GeV
- M_{ll}> 15 (20,25) GeV
- min M_{ll} < 60 GeV (dielectron+track analysis)

Understanding of the Data: The Control Regions

Control regions defined as a function of M(l l) and MET:

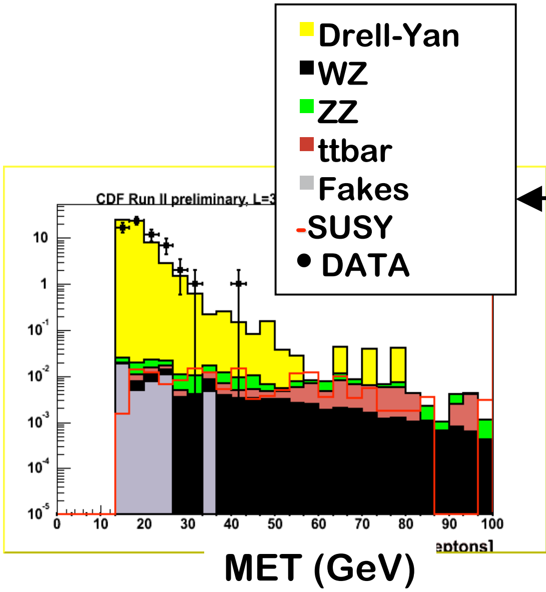


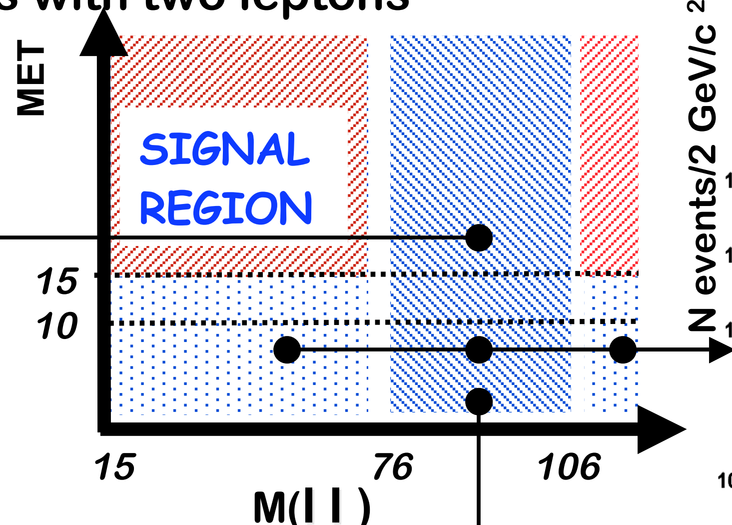
Each CONTROL REGION is investigated:

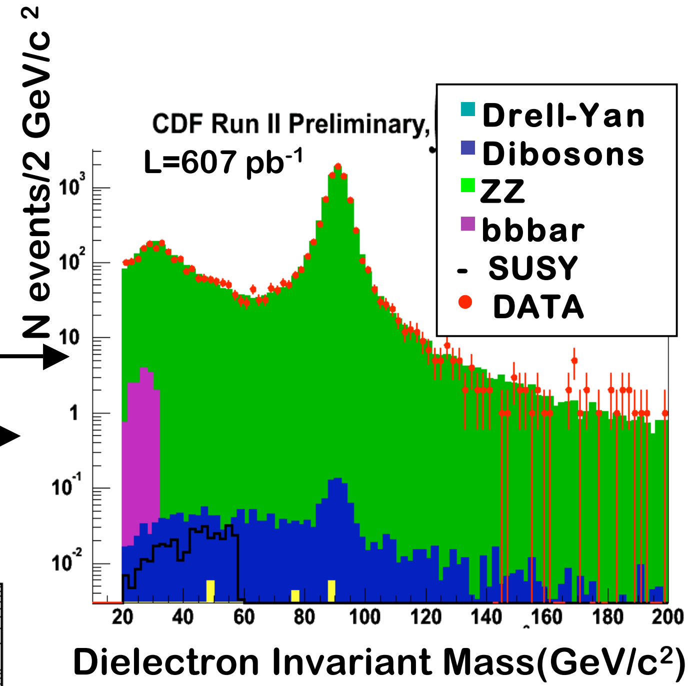
- ✓ **with different jet multiplicity**
  check NLO processes
- ✓ **with 2 leptons requirement**
  gain in statistics
- ✓ **with 3 leptons requirement**
  signal like topology

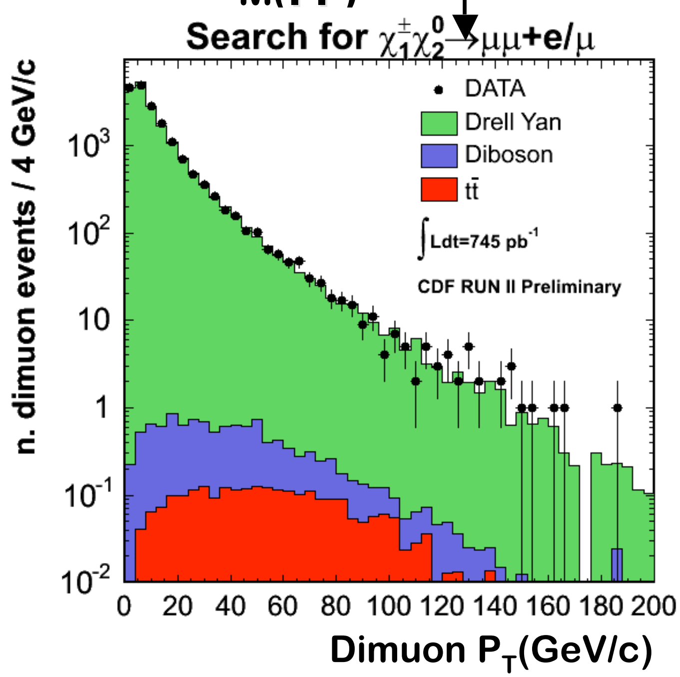
Control Regions for Trilepton Analyses

Testing Control Regions with two leptons





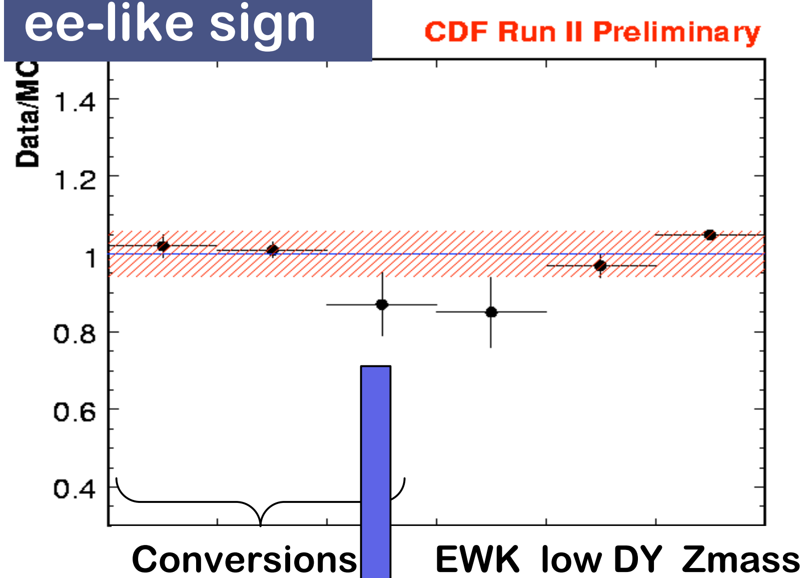




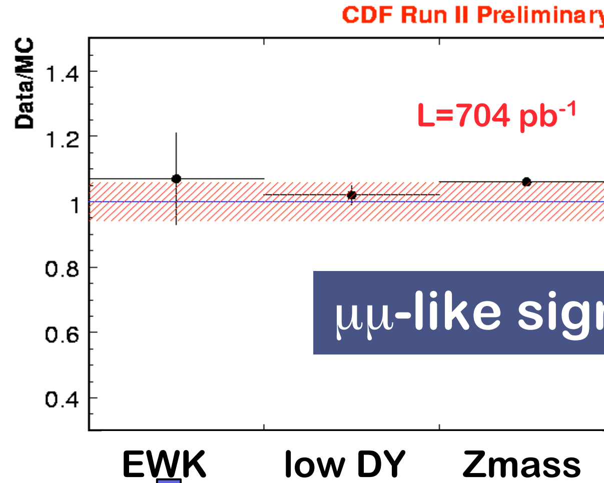
LS-dilepton analysis has additional Control Regions to test conversion removal

LS-Dileptons Control Regions

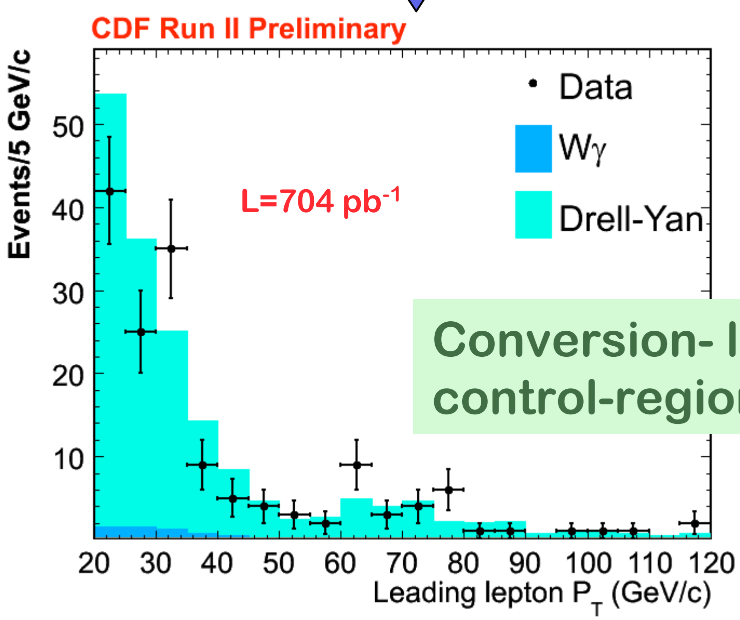
ee-like sign



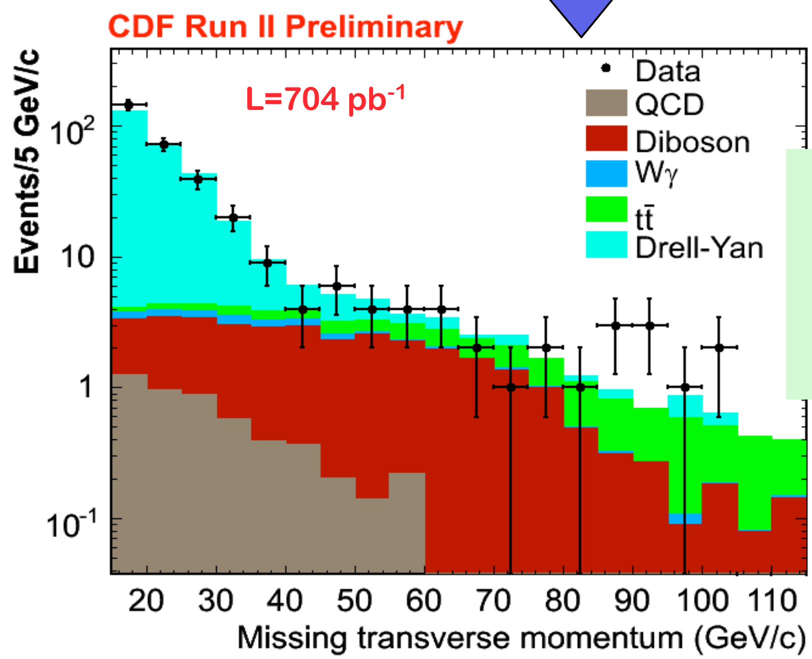
Very good agreement between SM prediction and observed data



μμ-like sign



Conversion- like control-region

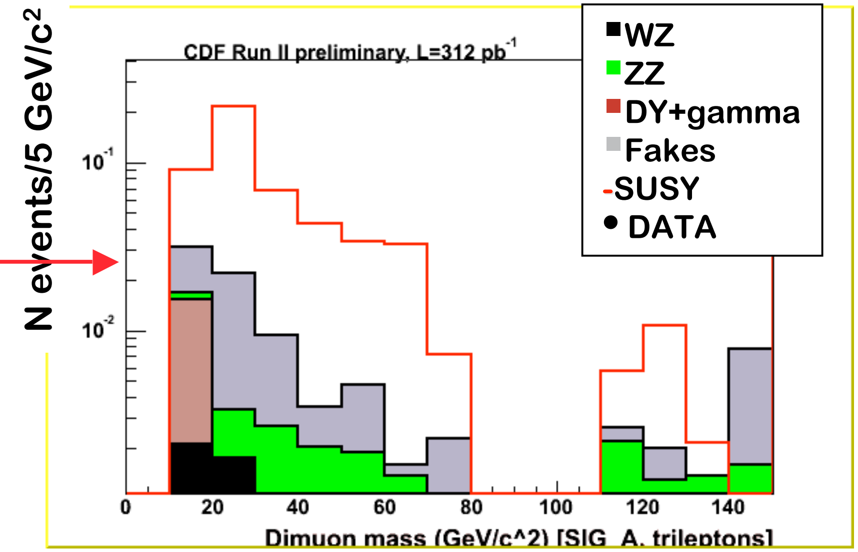


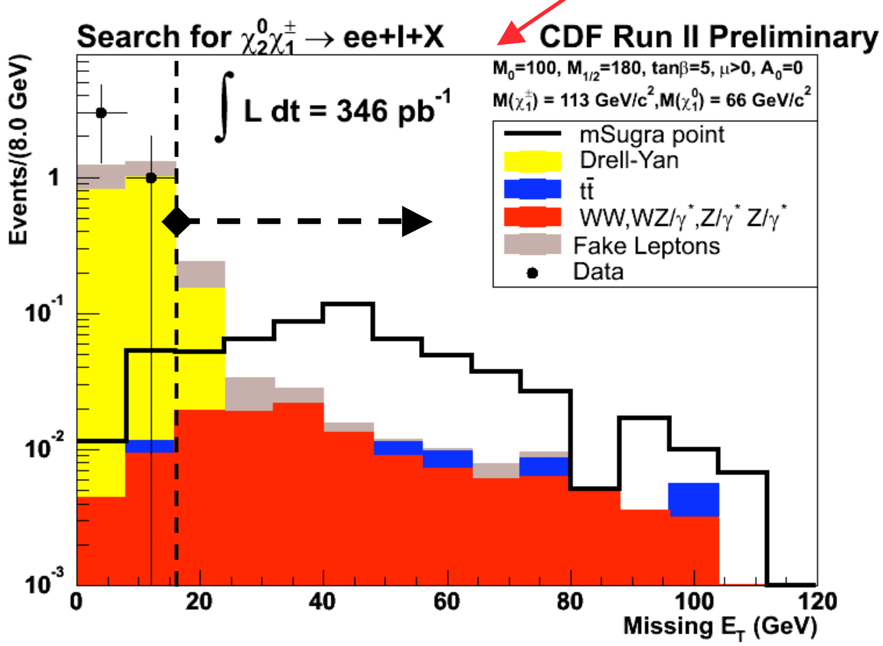
Signal-like but opposite sign

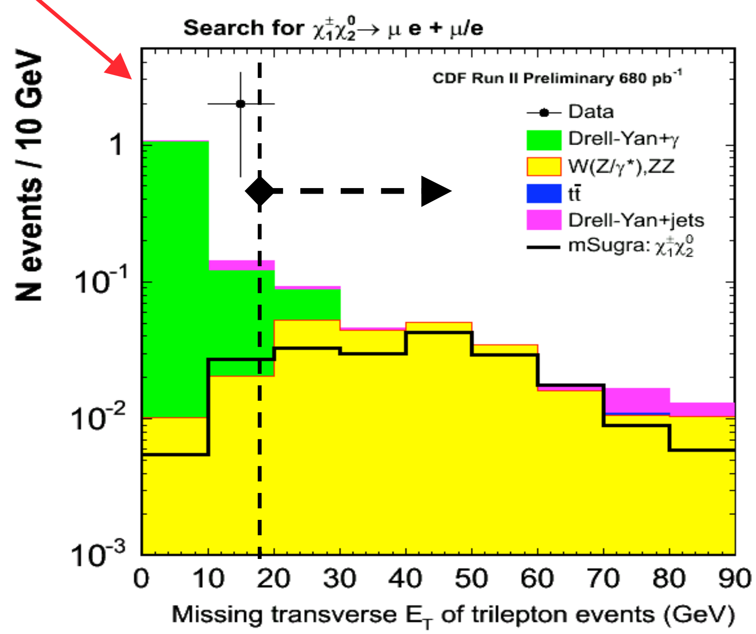
Results !

Look at the "SIGNAL" region

Analysis	Luminosity (pb^{-1})	Total predicted background	Example SUSY Signal	Observed data
$e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}, \mu^{\pm}\mu^{\pm}$	710	6.80±1.00	3.18±0.33	9
$\mu\mu$ +e/μ **(low-p_T)**	310	0.13±0.03	0.17±0.04	0
ee+track	610	0.48±0.07	0.90±0.09	1
ee + e/μ	350	0.17±0.05	0.49±0.06	0
$\mu\mu$ +e/μ	750	0.64±0.18	1.61±0.22	1
μe +e/μ	750	0.78±0.15	1.01±0.07	0







Results !

Look at the "SIGNAL" region

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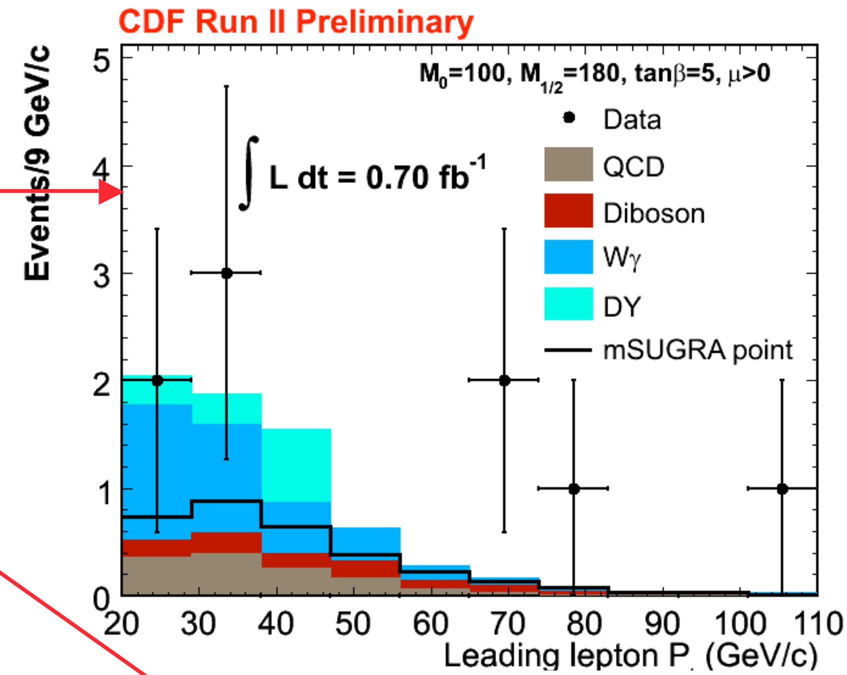
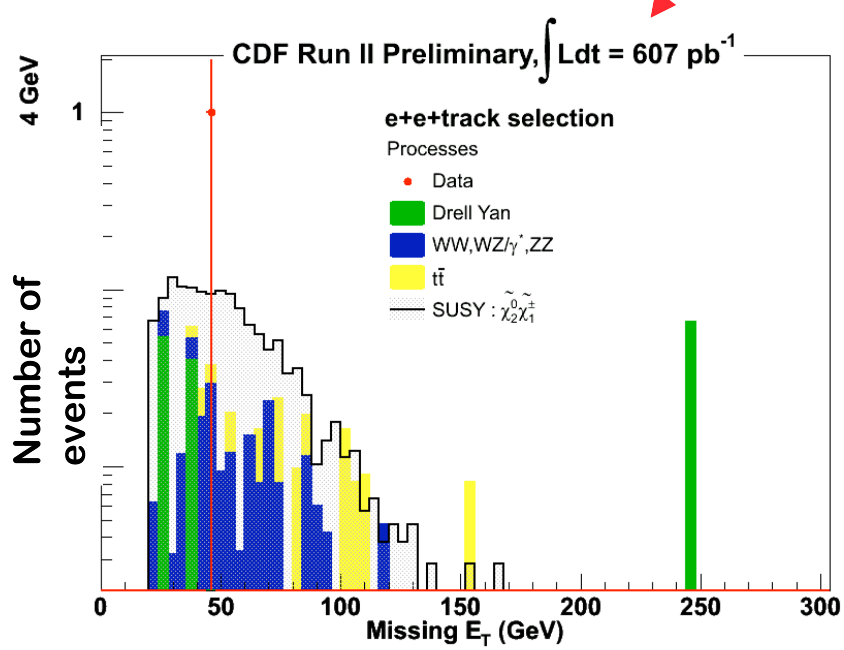
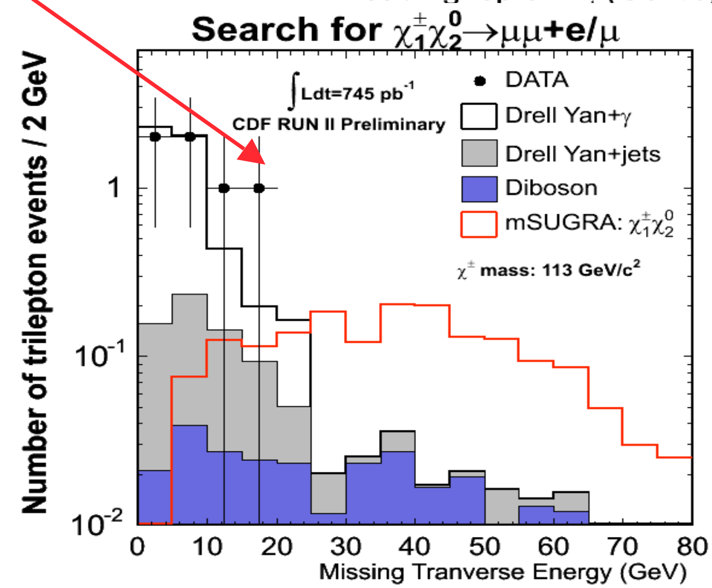
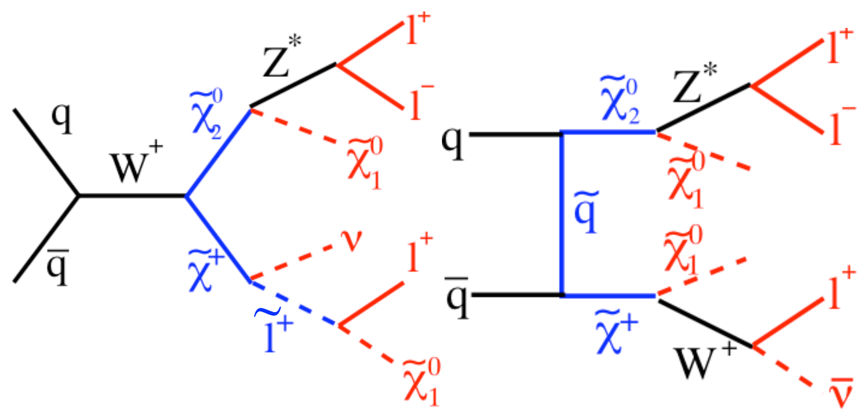


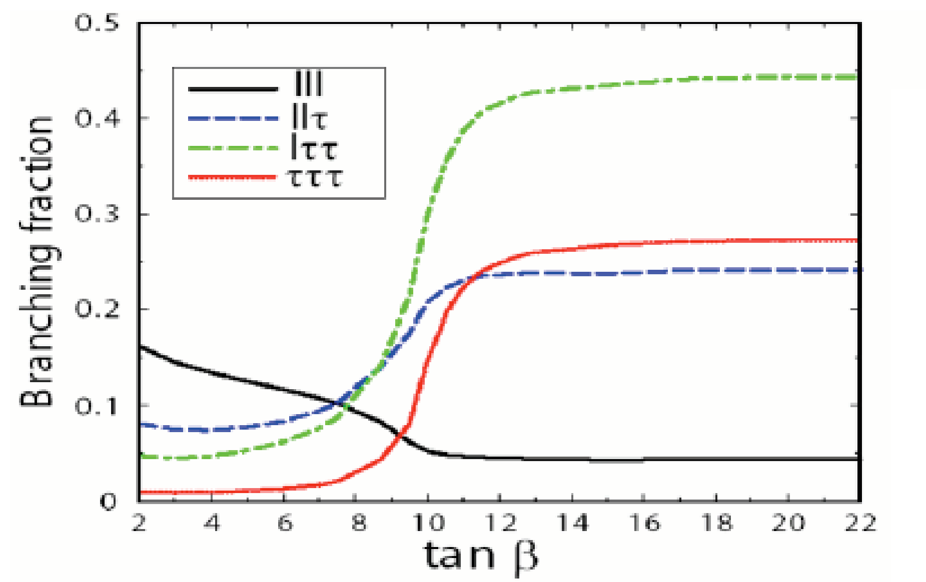




Charginos and Neutralinos

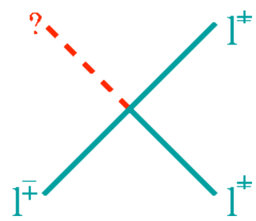
- Charginos and Neutralionos:
  - SUSY partners of W, Z, photon, Higgs
  - Mixed states of those
- Production diagrams interfere destructively
- Decays to leptons
  - depend on masses of sleptons
  - lepton flavor depends on tanβ
- "Golden" signature:
  - **3 leptons +$\not{E}_t$**
  - Low backgrounds

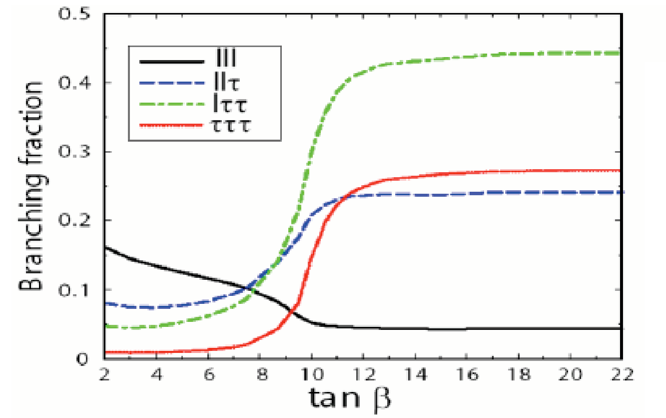


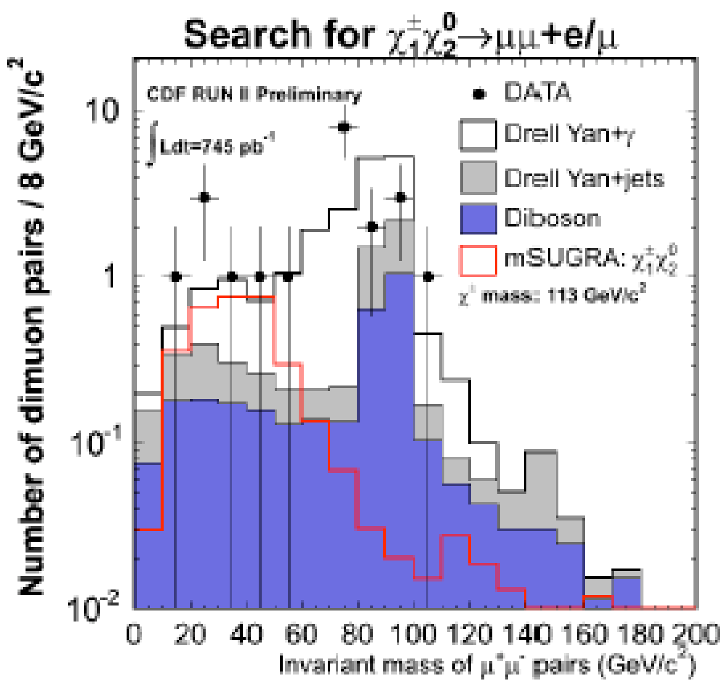


New analyses: 3 leptons + $\not{E}_T$

- Many analyses to maximise acceptance:
  - 3 leptons
  - 2 leptons+track
  - 2 leptons with same charge
- Other requirements:
  - Dilepton mass >15 GeV and not within Z mass range
    - For same flavor opposite charge leptons
  - Less than 2 jets
  - Significant $\not{E}_T$

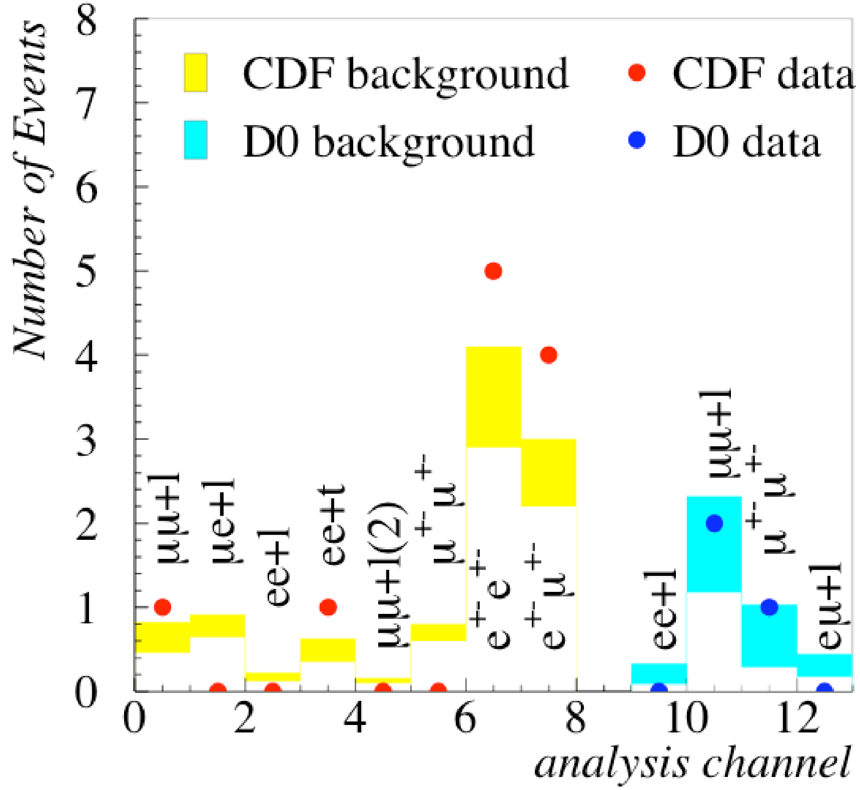


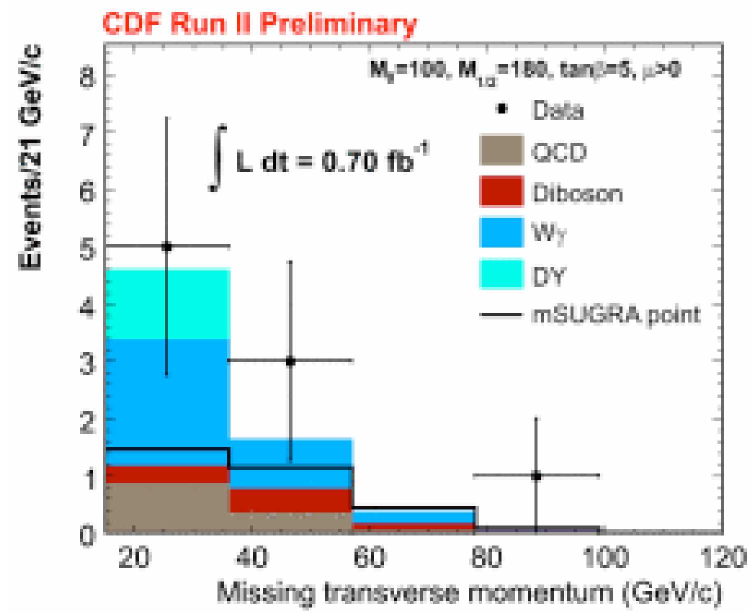


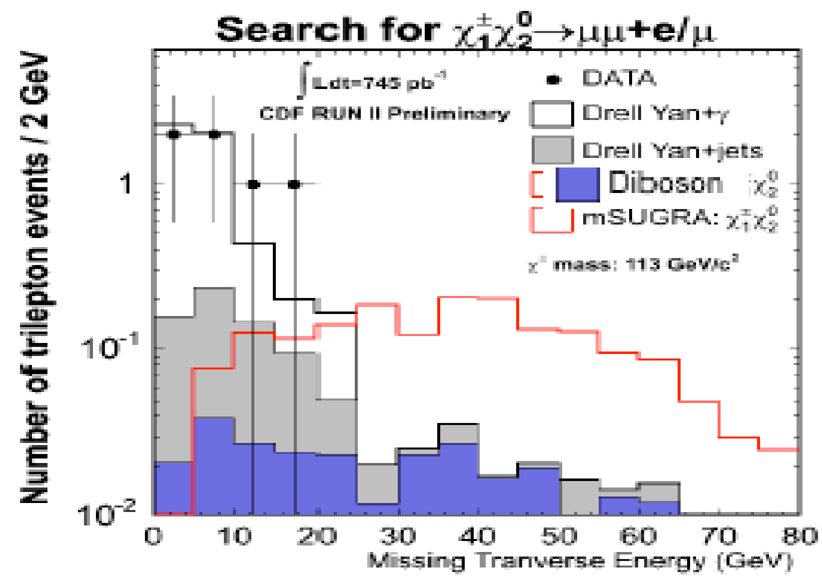


Trileptons: Result

Number of Events

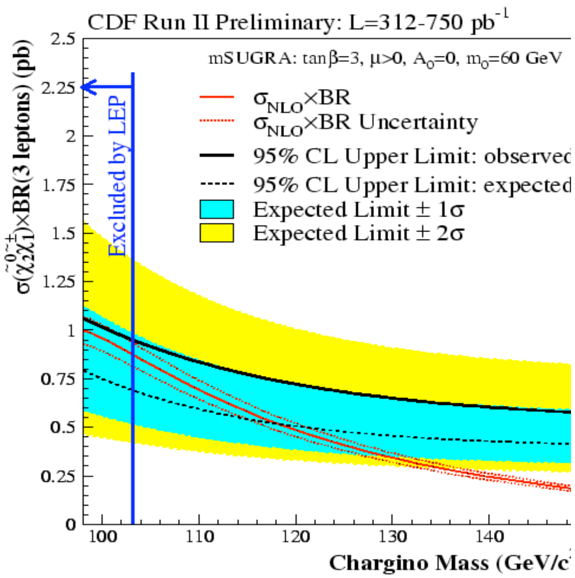


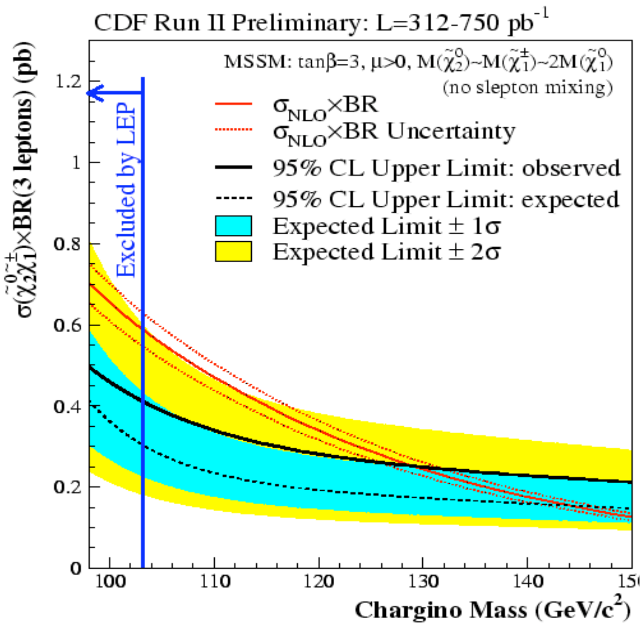




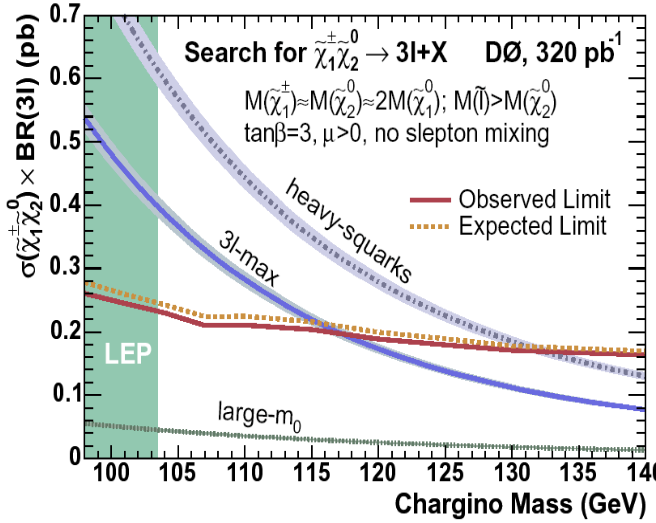
Limits on the Chargino Mass

- Scenario: slepton masses 100-120 GeV => BR to leptons high
- Slepton masses high => No sensitivity yet





PRL 95 151805 (2005)



- Slepton mixing (stau dominates):
  - Acceptance worse, no constraint yet
- No slepton mixing:
  - M()>127 GeV (CDF)
  - M()>117 GeV (DØ)

Probe values beyond LEP but very model dependent