Beyond the Standard Model Searches

- Introduction
- Model-independent Searches
- Supersymmetry Searches
- Beyond Supersymmetry
- Conclusions

Beate Heinemann

University of California, Berkeley and Lawrence Berkeley National Laboratory

EPS 2007, Manchester, July 2007

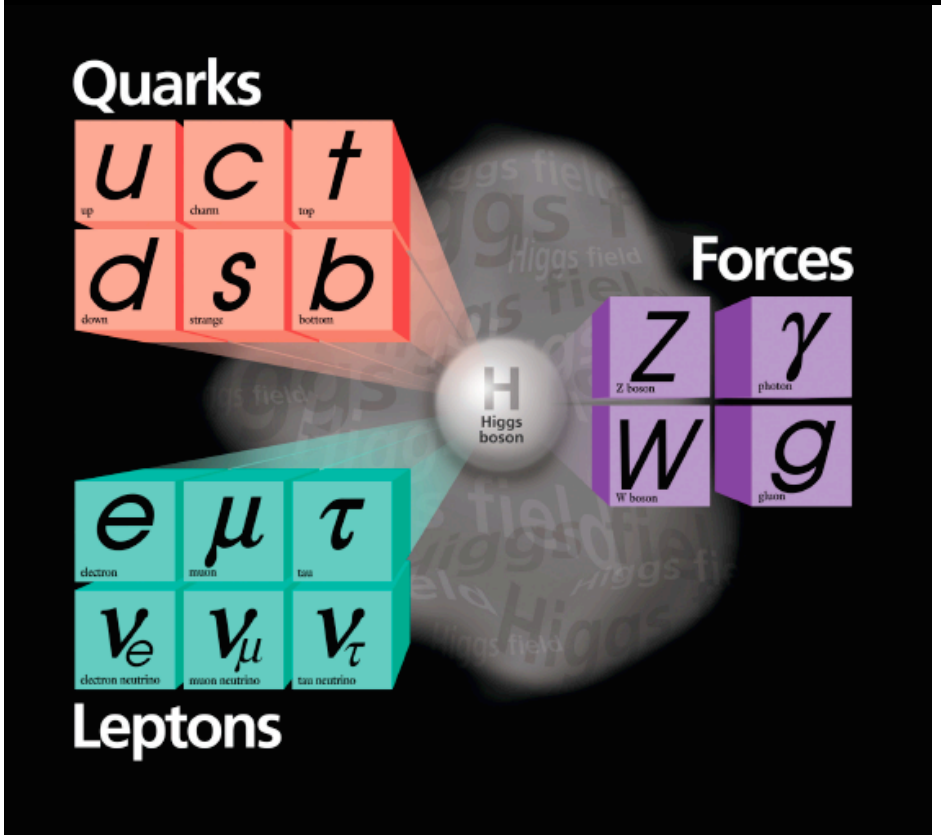
49 Parallel Session Talks

- Very busy session with large attendence:
  - 25 experimental talks
    - 5 HERA
    - 9 Tevatron
    - 7 LHC (see talk by O. Buchmüller)
    - 2 Belle/BaBar
    - 1 NA48

    } Lepton Flavor Violation
    Joint Session with B Physics
  - 24 theory talks (see talk by G. Giudice)
  - Conveners: Volker Büscher, Jose Espinosa, Emanuelle Perez
- Focus on results since ICHEP'06
  - Apologies for not being able to cover all the results!

Many thanks to: H. Abramowicz, C. Diaconu, Y. Gerstein, J.-F. Grivaz, C. Hays

The Standard Model and the Standard Questions We Have



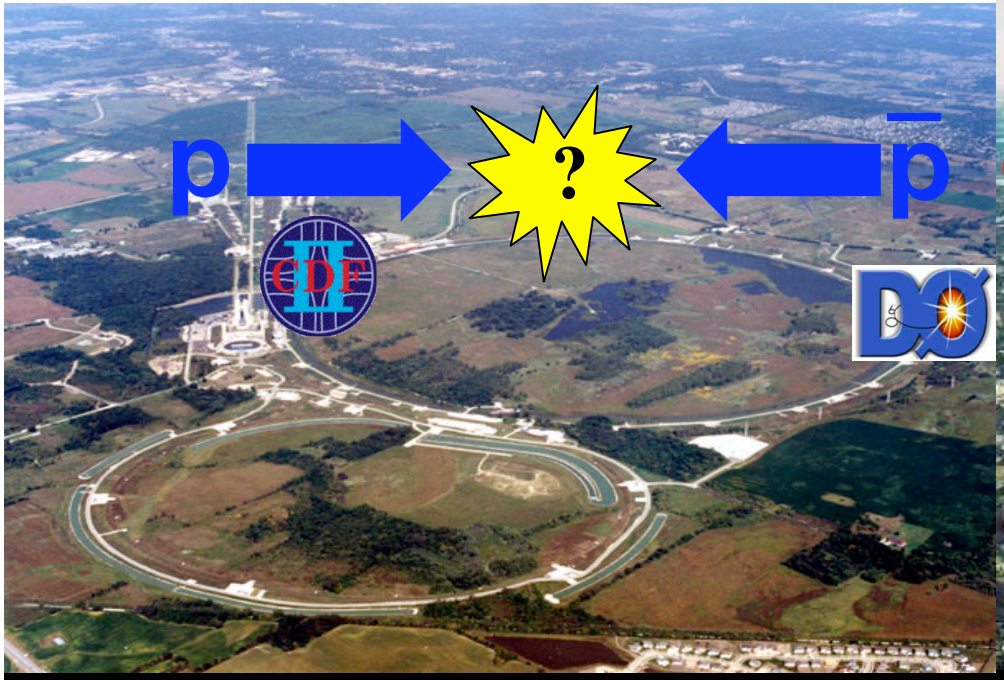
- What is the origin of electroweak symmetry breaking?
  - Is there a Higgs boson?
  - WHERE IS IT?
- What is the Dark Matter?
  - Is it produced at colliders?
- Is Nature supersymmetric?
- Are there new dimensions of space?
- Is there anything maybe that nobody has thought of and no one has looked for and we missed it?

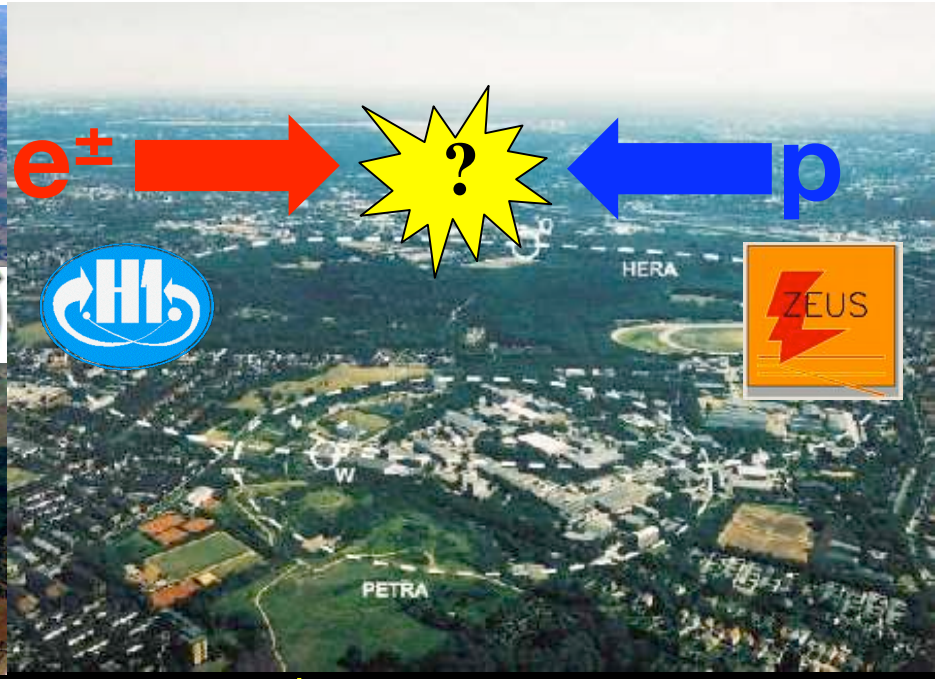
- Hierarchy problem:
  - New physics should be at the TeV scale!

High Energy Colliders: Tevatron and HERA

Tevatron Run II
$\int Ldt = 3\ fb^{-1}$ /exp

HERA Run I+II
$\int Ldt = 0.5\ fb^{-1}$ /exp





$\sqrt{s}$=1.96 TeV

$\sqrt{s}$=0.32 TeV

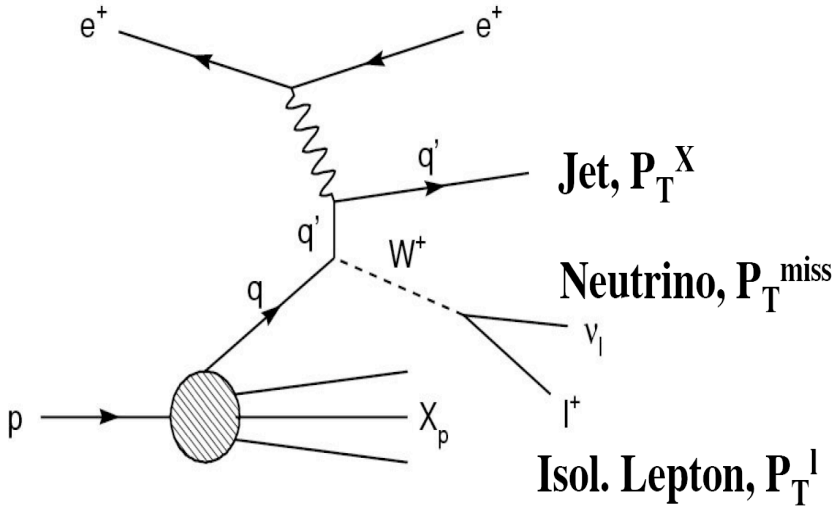
Model-independent Searches

HERA "Isolated Leptons"

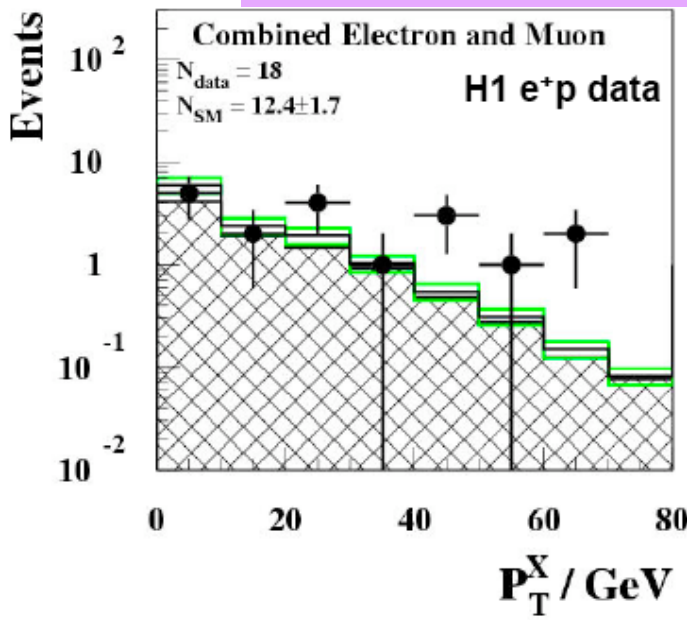
- Longstanding excess from HERA Run I e^+p data ($\int Ldt \sim 100\ pb^{-1}$):

e^+p data	H1	ZEUS
$P_T^X>0$	19/14.4	36/32.5
$P_T^X>25$ GeV	**11/3.4**	7/5.7

- Main SM contribution from W production
- Excess concentrated at high p_T^X and only present in H1
- ZEUS and H1 had quite different selection cuts



Phys. Lett. B 561 (2003) 241



[talk by D. South]

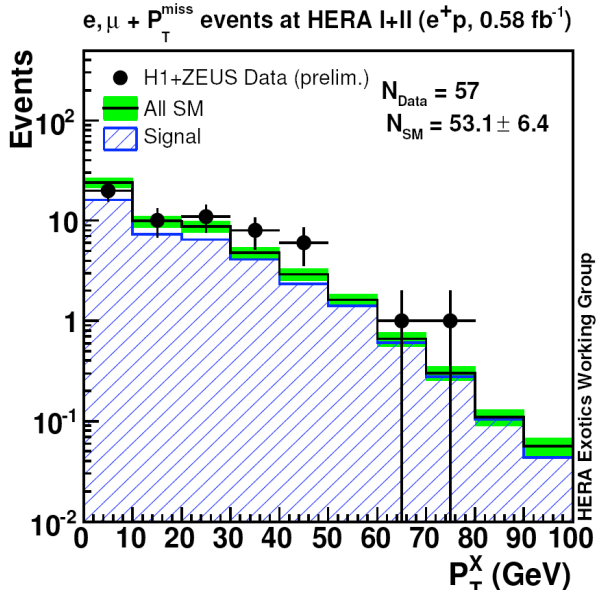
HERA 2 "Isolated Leptons"

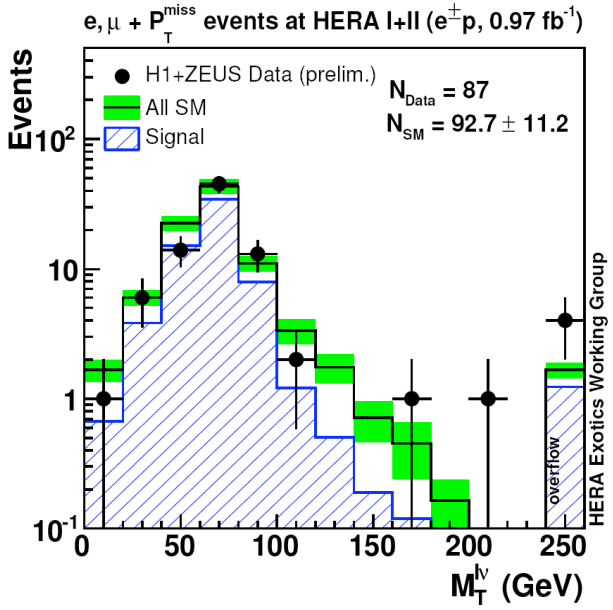
- Use full HERA 2 luminosity
  - Just 3 weeks after end of HERA!
- H1 and ZEUS settled on a common set of cuts

e^+p data	H1	ZEUS	H1+ZEUS
P_T^X>25 GeV	**17/7.1±0.9**	**6/7.5 ±1.1**	**23/14.6±1.9**

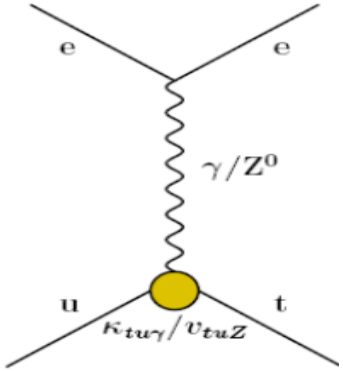
- H1 still sees excess (~3σ) and ZEUS does not
  - Consistency of experiments: 2σ
  - Combined significance of excess 1.8σ

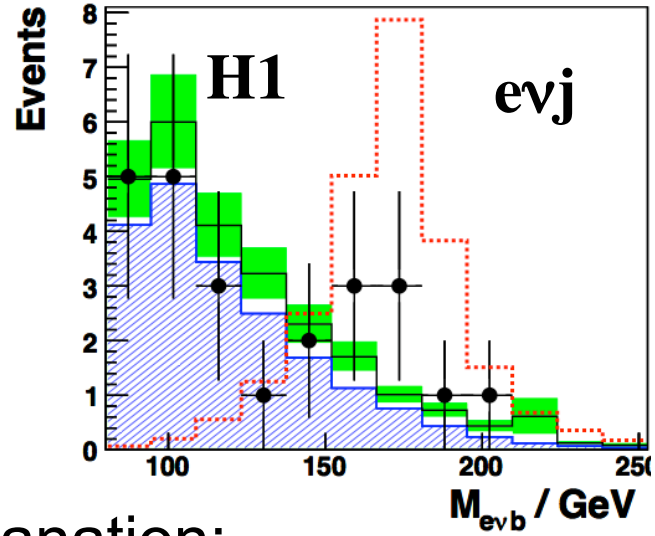
- **Excess will remain unresolved**
  - Unless other collider sees something…
- On the bright side there is now a nice sample of **87 W candidates in $e^{\pm}p$ data**

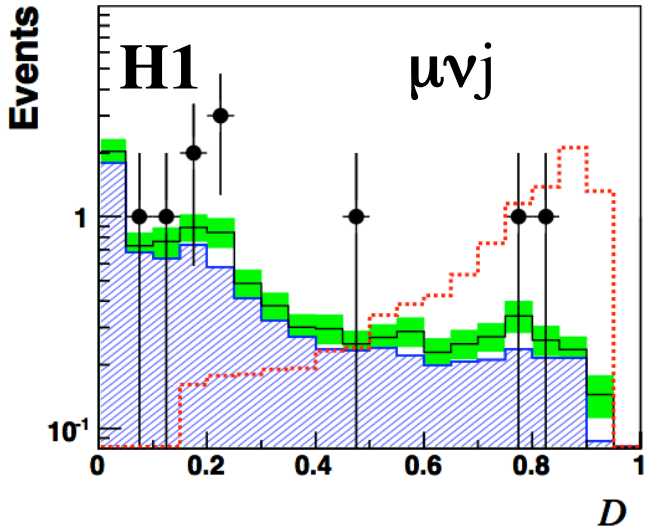




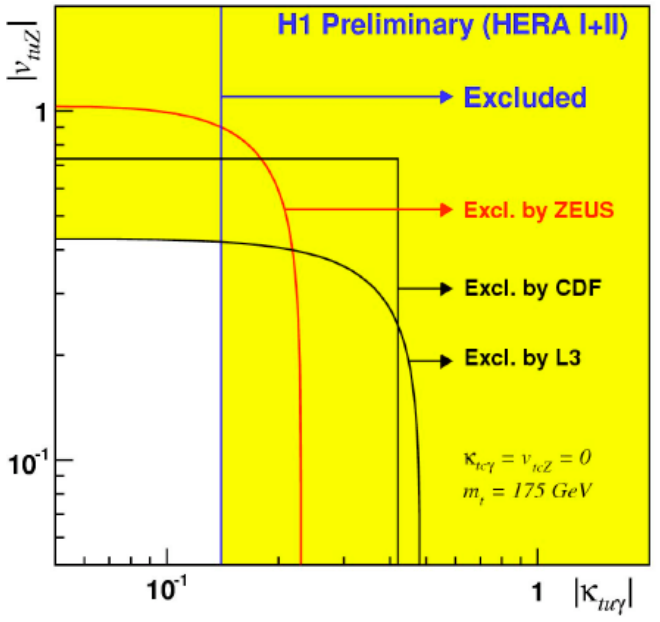
Flavor Changing Neutral Currents





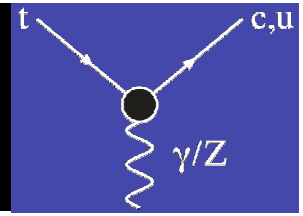


- Possible explanation:
  - ep →t+X → lνb+X
  - Requires flavor-changing neutral current
- Optimized selection using likelihood discriminant
  - Data seem not consistent with this hypothesis
- $|\kappa_{tu\gamma}|<0.14$ at 95% CL



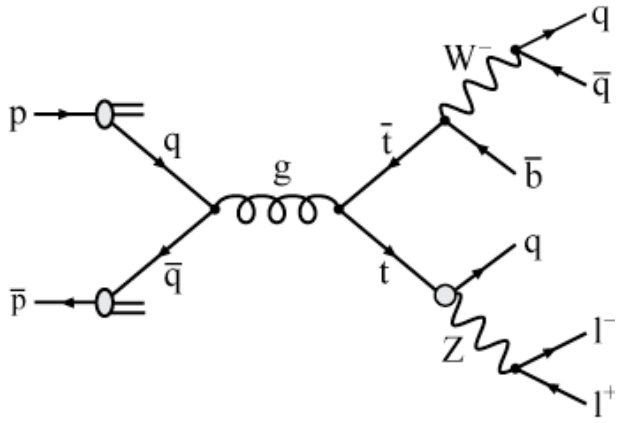
[talk by D. South]

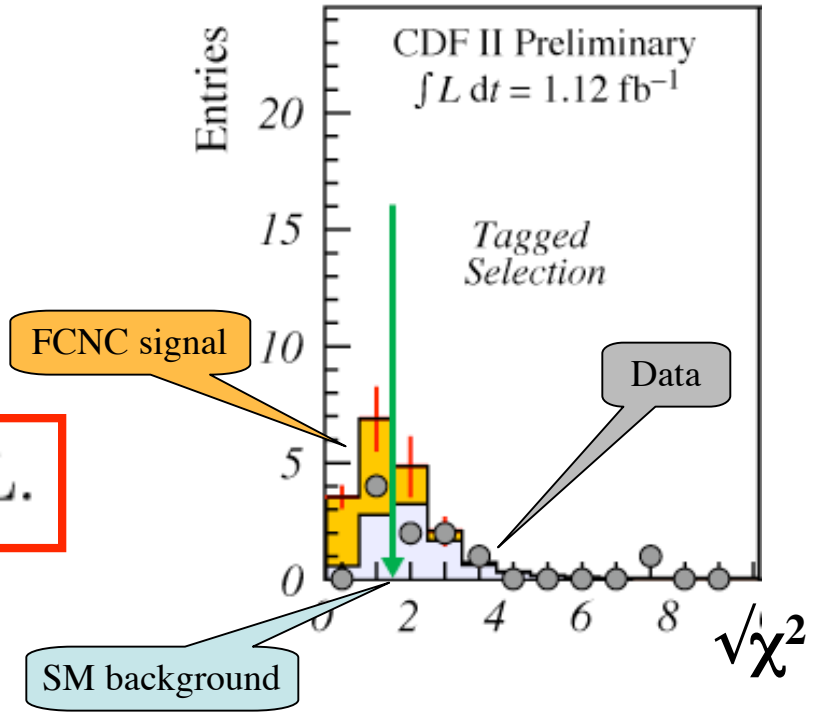
FCNC: t→Z+q



- Standard Model predicts:
  - BR(t→Wb) > 99%
  - BR(*t*→*qZ*) ≈ O(10^{-14})
- Select events with 2 leptons and 4 jets:
  - With or without b-tag
  - Use χ^2 estimator to assess kinematic consistency with top production
- Data consistent with background estimate
  - Main background: Z+jets production
- Result:

$$\mathcal{B}(t \to Zq) < 10.6\% \text{ @ } 95\% \text{ C.L.}$$

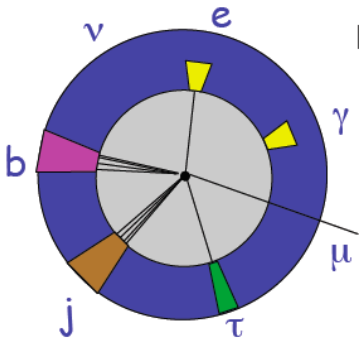


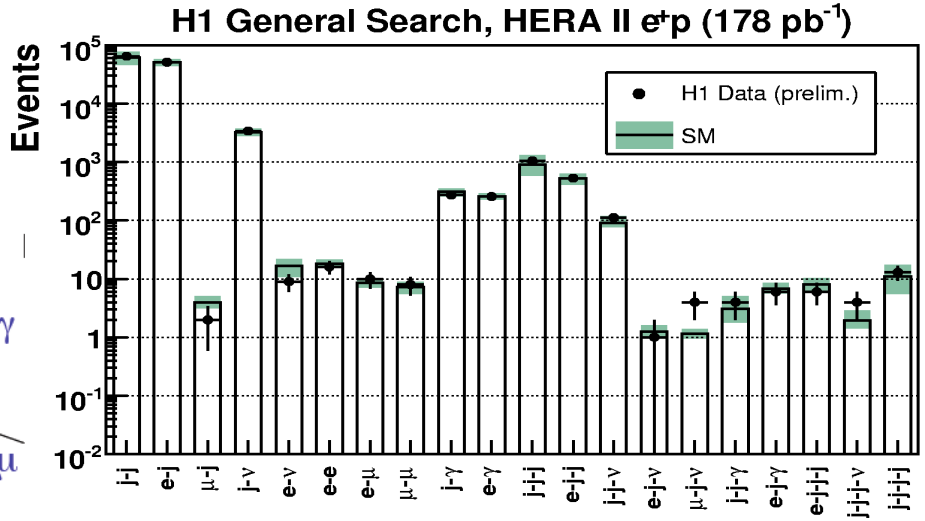


[talk by A. Harel]

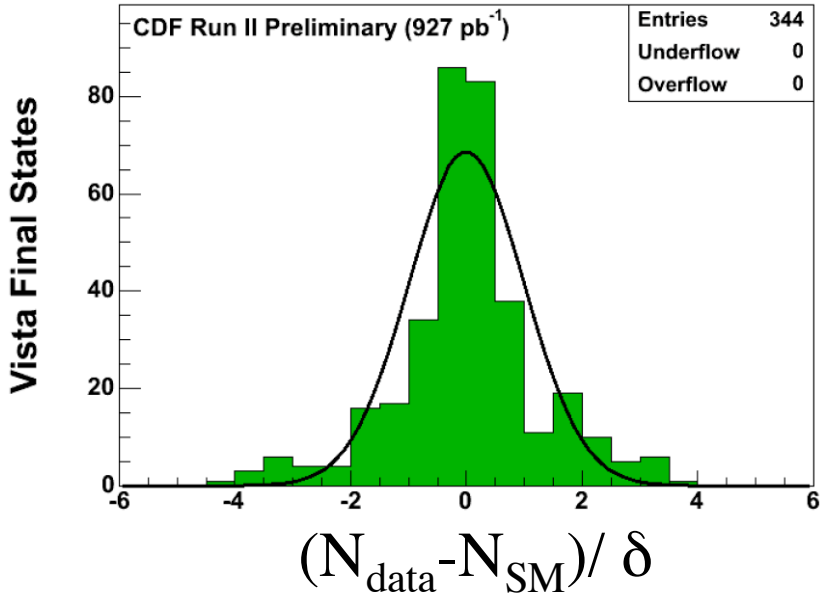
Generic Searches: H1 and CDF

- Compare data to SM in "all" event topologies, e.g.:
  - ee,eμ…eμτγb…



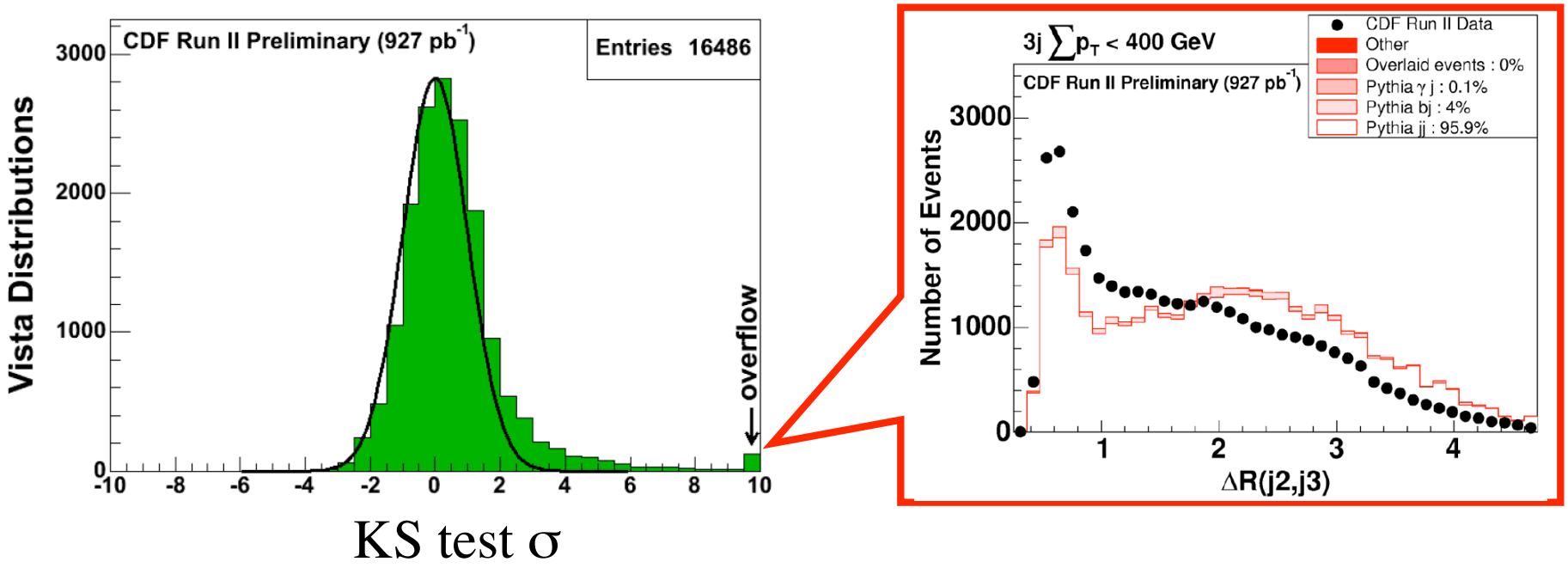


- Data in good agreement with Standard Model in overall event count
  - H1 looked in 99 final states
    - both e^+p and e^-p data
  - CDF looked in 344 final states



[talk by A. Schöning]

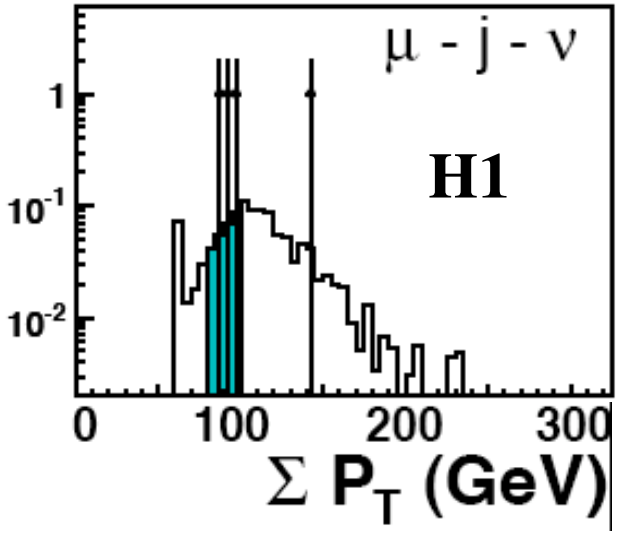
CDF: Test of distributions

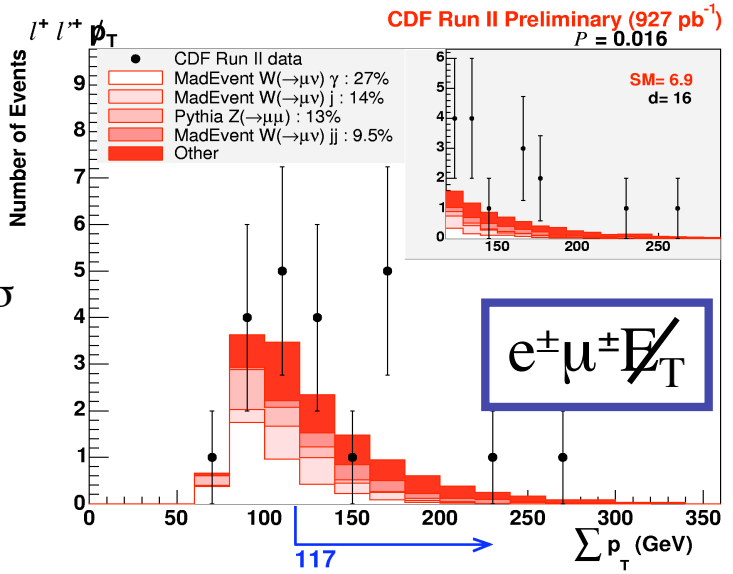


- Analyse ~16500 kinematic distributions using Kolmogorov-Smirnov test
- Some disagreements in kinematic distributions
  - but appears to be due to QCD mismodeling and not due to new physics

Global Search for Excess at high p_T

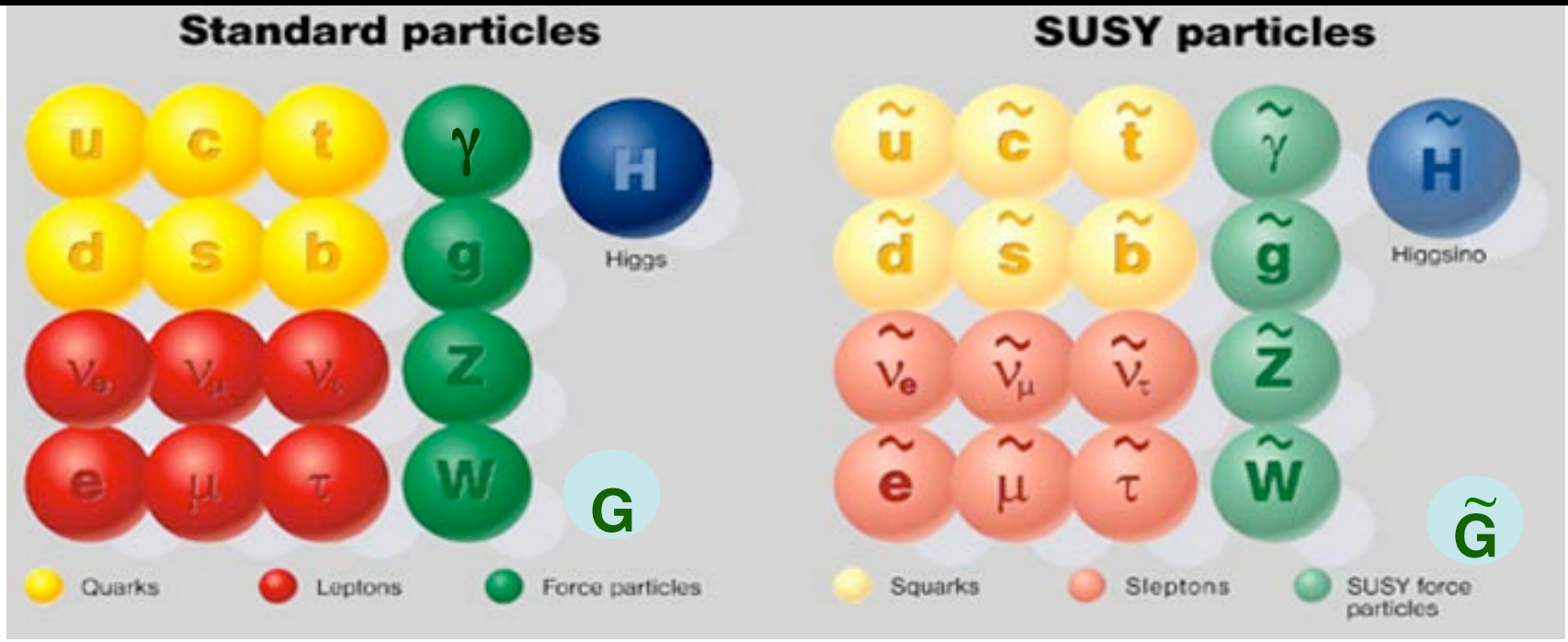
- **Evaluate most discrepant tail/region in $\sum p_T$ distribution**
  - H1 uses also inv. Mass of all objects
- **Found no significant discrepancy**
  - Excess in most discrepant distribution is not significant
- **Only sensitive if new physics is large and at high $\sum p_T$:**
  - Useful for looking for the unexpected
  - Typically less sensitive than dedicated analysis, e.g. at CDF
    - WZ production:
      - Would need O(10) times more data for 5σ discovery
    - Z´ production
      - Would need O(2) times more data for 5σ discovery at ~250 GeV



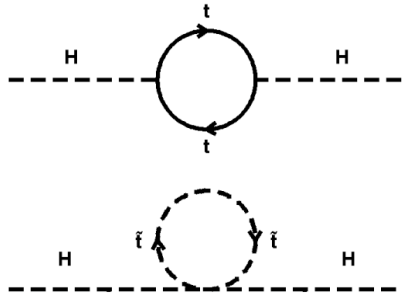


Supersymmetry

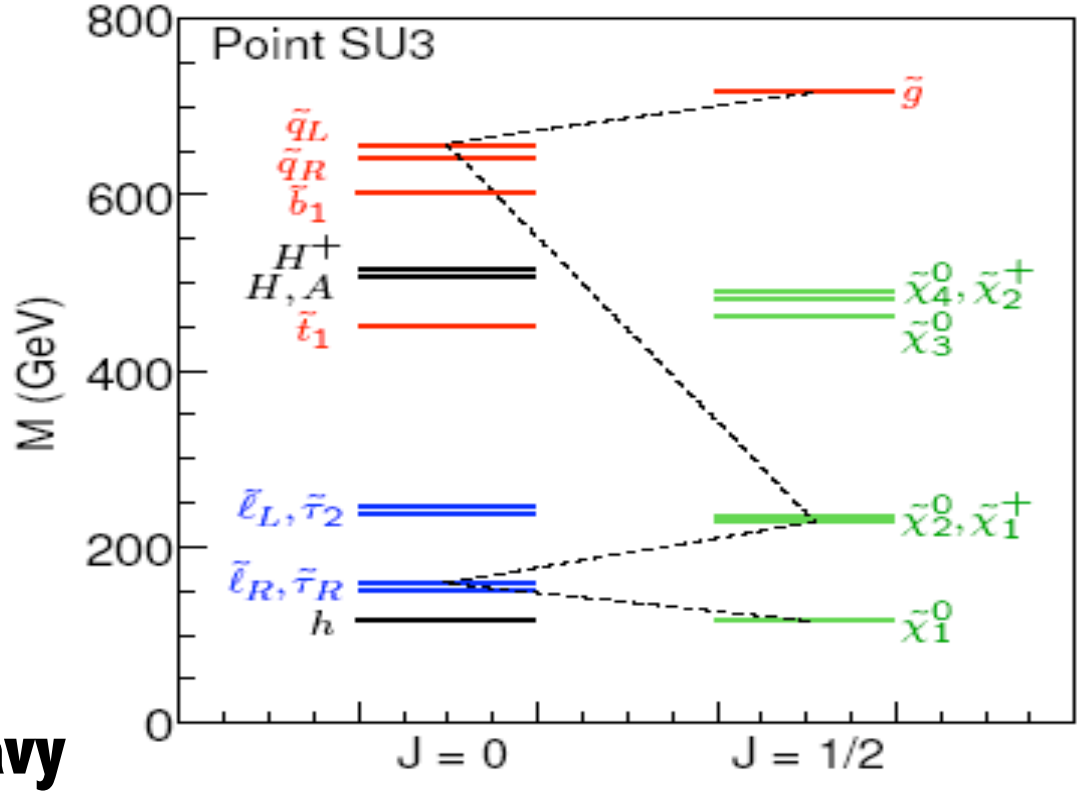
Supersymmetry (SUSY)



- 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
- SUSY can solve the fine-tuning problem



Sparticle Spectrum



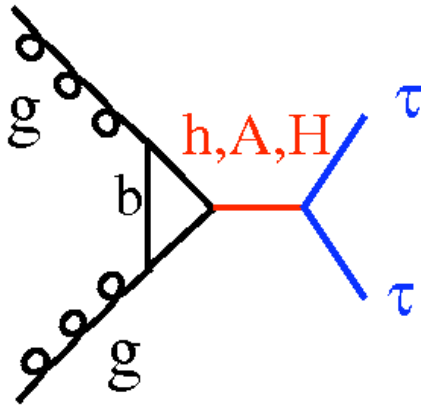
Typical features:

- **Squarks and gluinos heavy**
- **Sleptons light**
- **5 Higgs bosons (in MSSM)**
- **Charginos and neutralinos light**
- **Third generation partners lightest (τ, t, b,..)**

MSSM Higgs Boson Search

[talk by P. Jonsson]

- 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

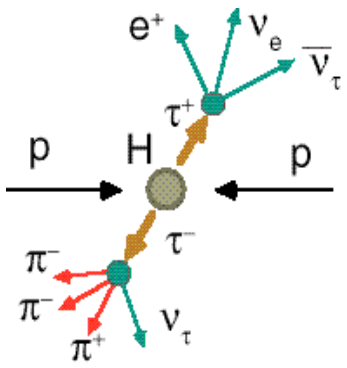


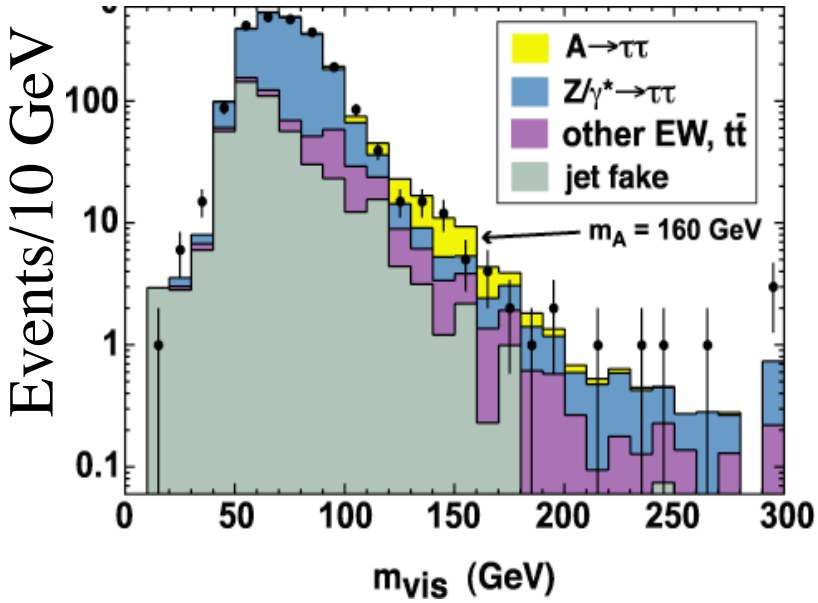
$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan\beta^2}{(1+\Delta_b)^2} \times \frac{9}{[9+(1+\Delta_b)^2]}$$

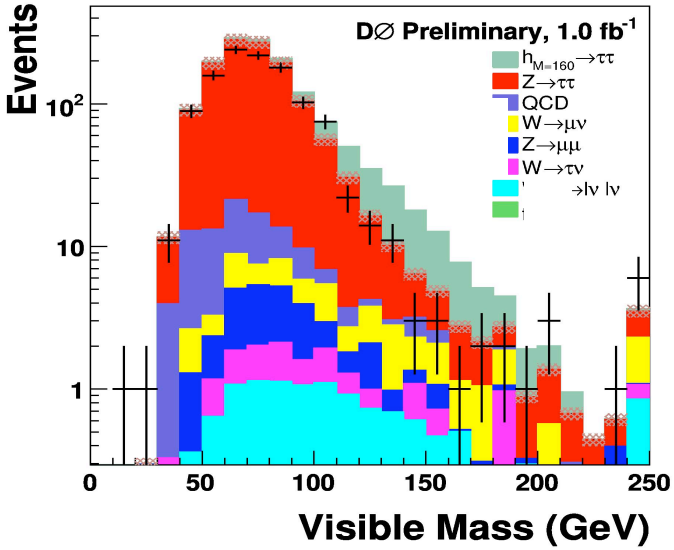
- At high tanß:
  - A is degenerate in mass with either h or H
    - Decay into either ττ or bb for m_A<300 GeV:
    - BR(A →ττ) ≈ 10%, BR(A→ bb) ≈ 90%
  - Cross section enhanced with $\tan^2\beta$

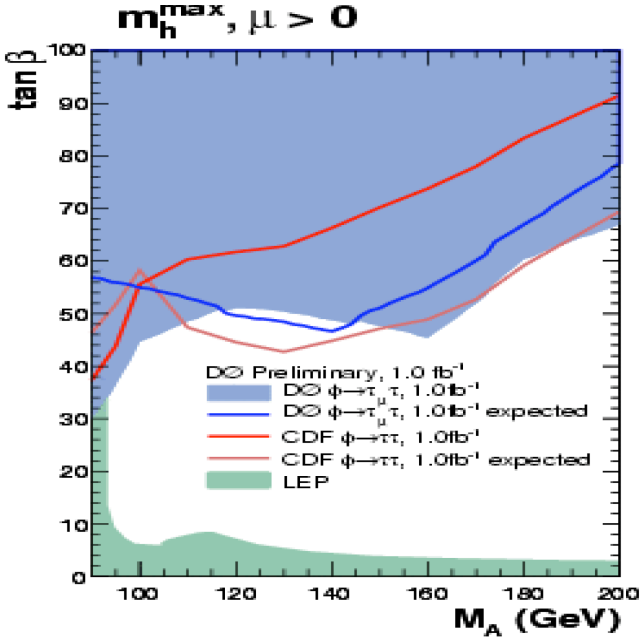
•C. Balazs, J.L.Diaz-Cruz, H.J.He, T.Tait and C.P. Yuan, PRD 59, 055016 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 60, 075010 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 62, 055008 (2000)

MSSM Higgs Boson Search





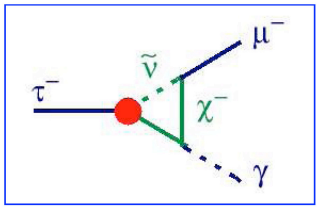


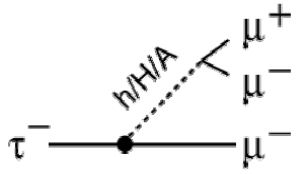


- Data mass distribution agrees with SM expectation mostly:
  - CDF: Slight excess (~2σ)
  - DØ: slight deficit in that region
- Sensitive to tanβ≈50

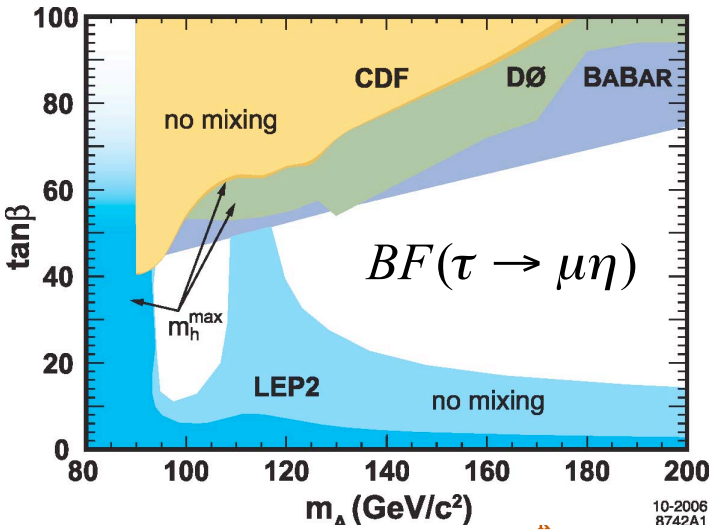
[talk by P. Jonsson]

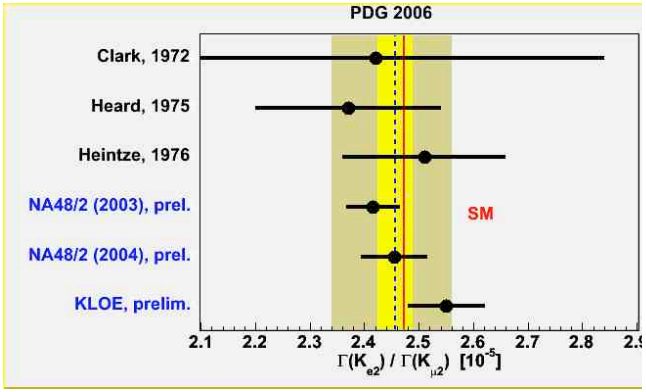
Lepton Flavor Violation

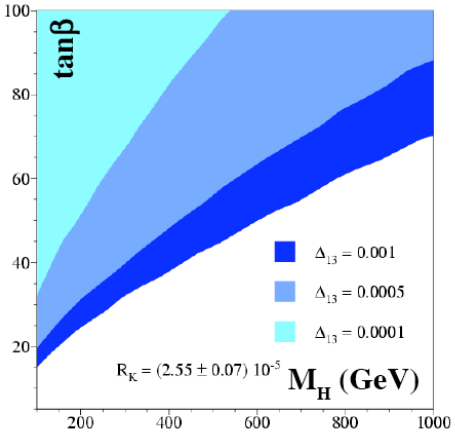




- Lepton flavor violation is clear signal of new physics
  - e.g. sensitive to SUSY at high tanβ
- Belle/Babar:
  - BR(τ→μγ,μη,…)
  - BR(τ→μγ)<10^{-54} in SM, up to 10^{-7} in BSM
  - **Experiments are now probing BR~10^{-8}**
- NA48/KLOE:
  - R_K=Γ(K→μν)/ Γ(K→eν)
  - Enhanced by $\tan^6\beta/m_{H\pm}^4$
  - **Current precision ~2-3%**
    - Goal 0.3%
    - Also Γ(K→μν)/ Γ(π→μν)







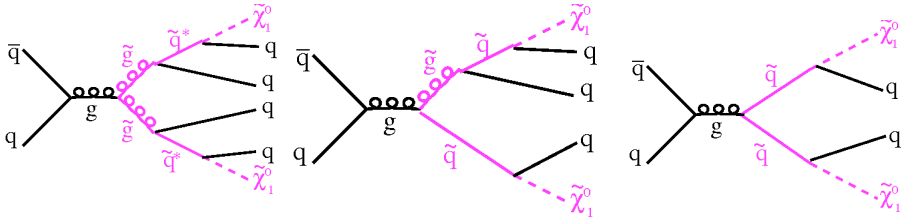
Strong constraints on new physics and nicely complementary with direct searches

[talks by T. Spadaro, R. Fantechi, Y. Miyazaki, F. Wilson]

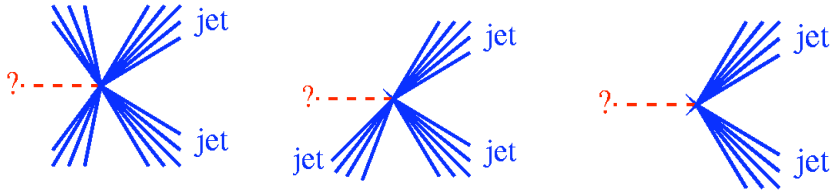
$B_s \to \mu\mu$, $B \to \tau\nu$: A.Savoy-Navarro, J.Haba

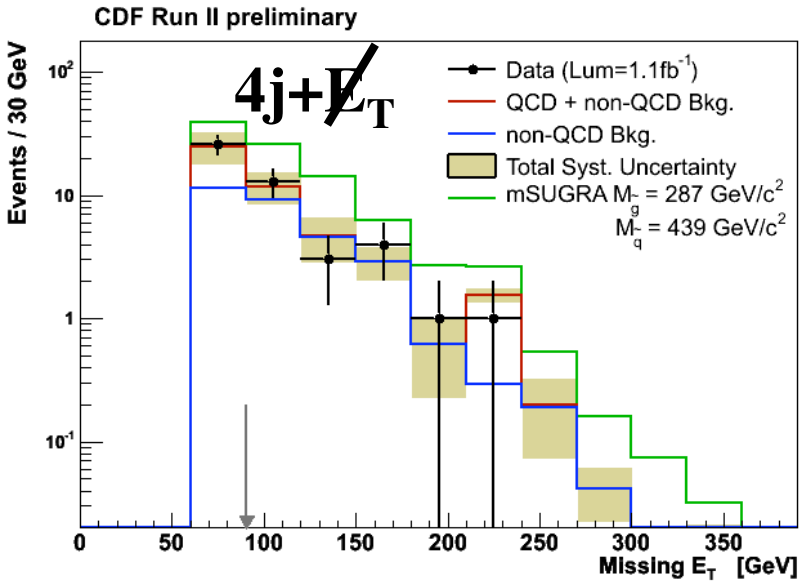
Squarks and Gluinos

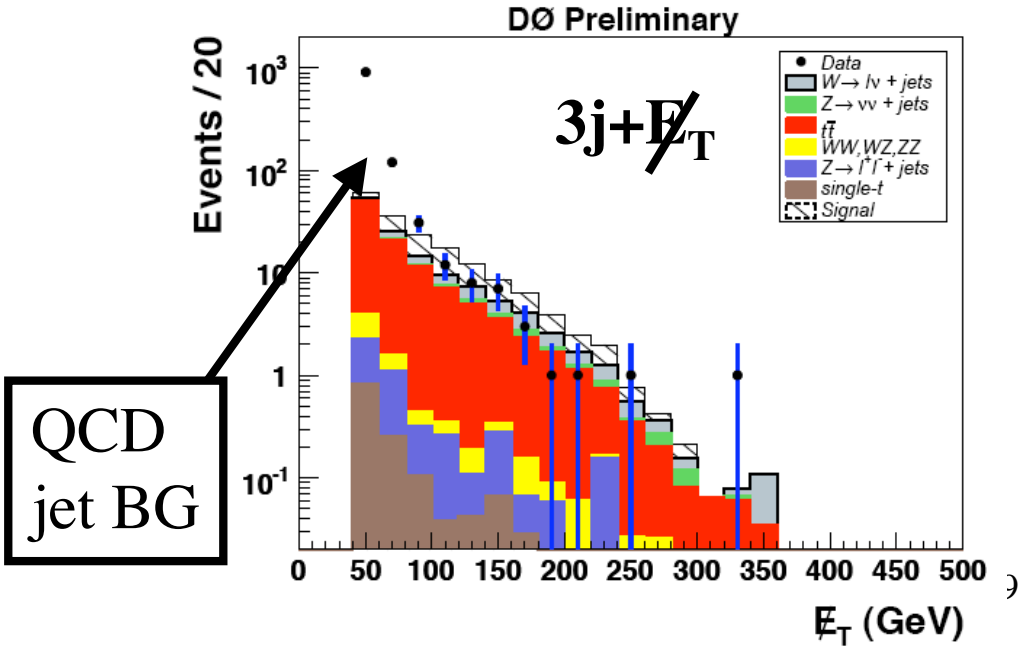
- Squark and Gluino production:
  - Signature: jets and $\not\!\!E_T$
  - At Tevatron no long cascades to leptons expected:
    - Lepton veto applied
- Analysis optimized depending on mass hierarchy



$m(\tilde{q}) >> m(\tilde{g})$ $m(\tilde{q}) \approx m(\tilde{g})$ $m(\tilde{q}) << m(\tilde{g})$

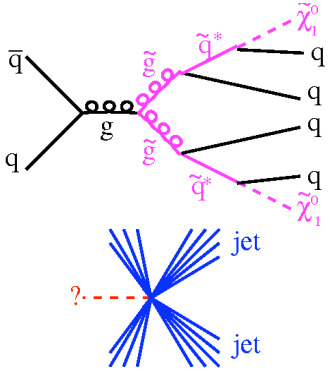


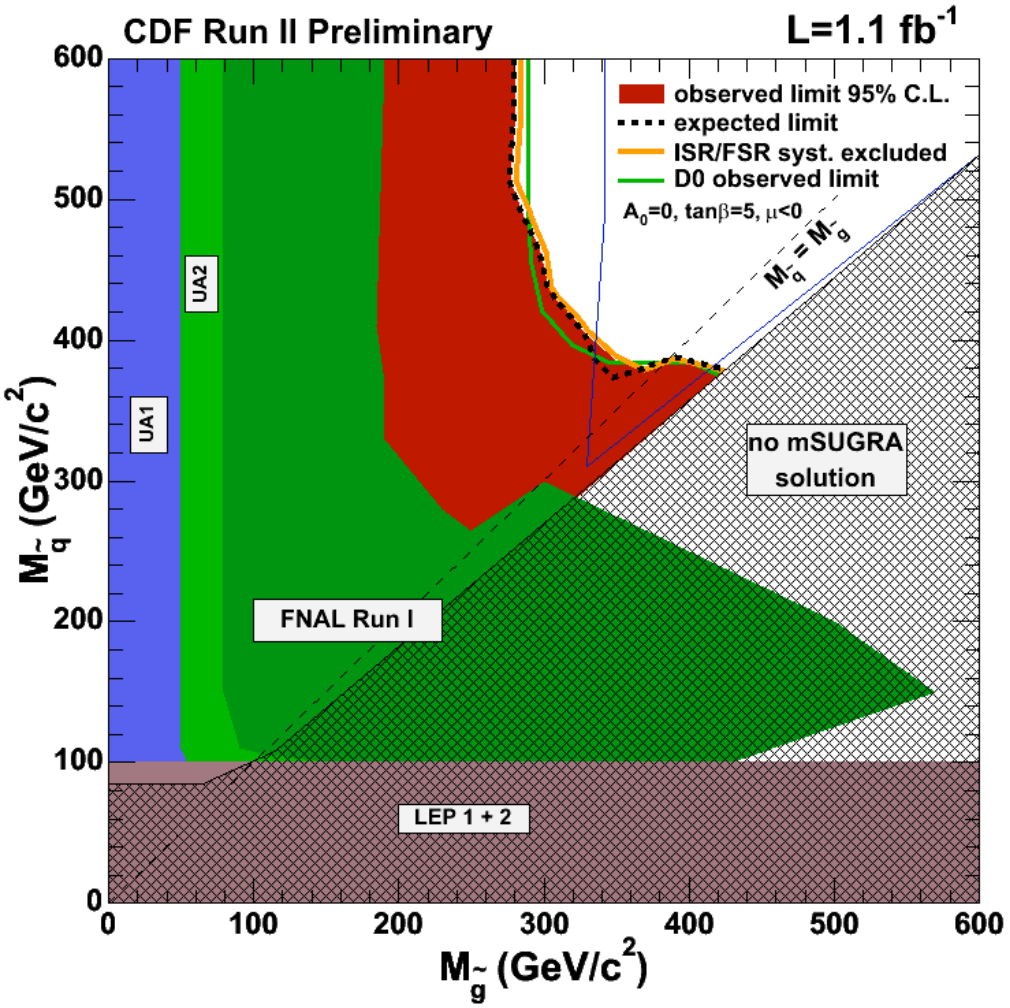


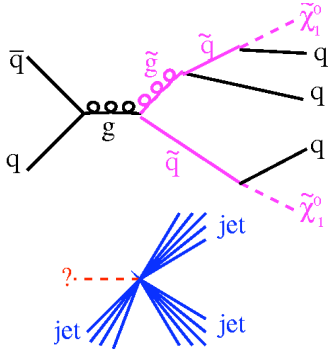


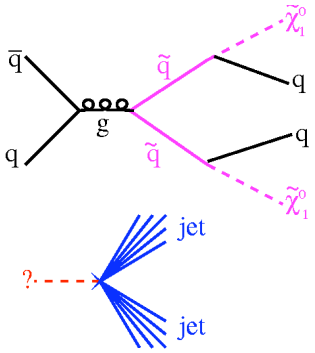
[talk by X. Portell]

Supersymmetry Parameter Space





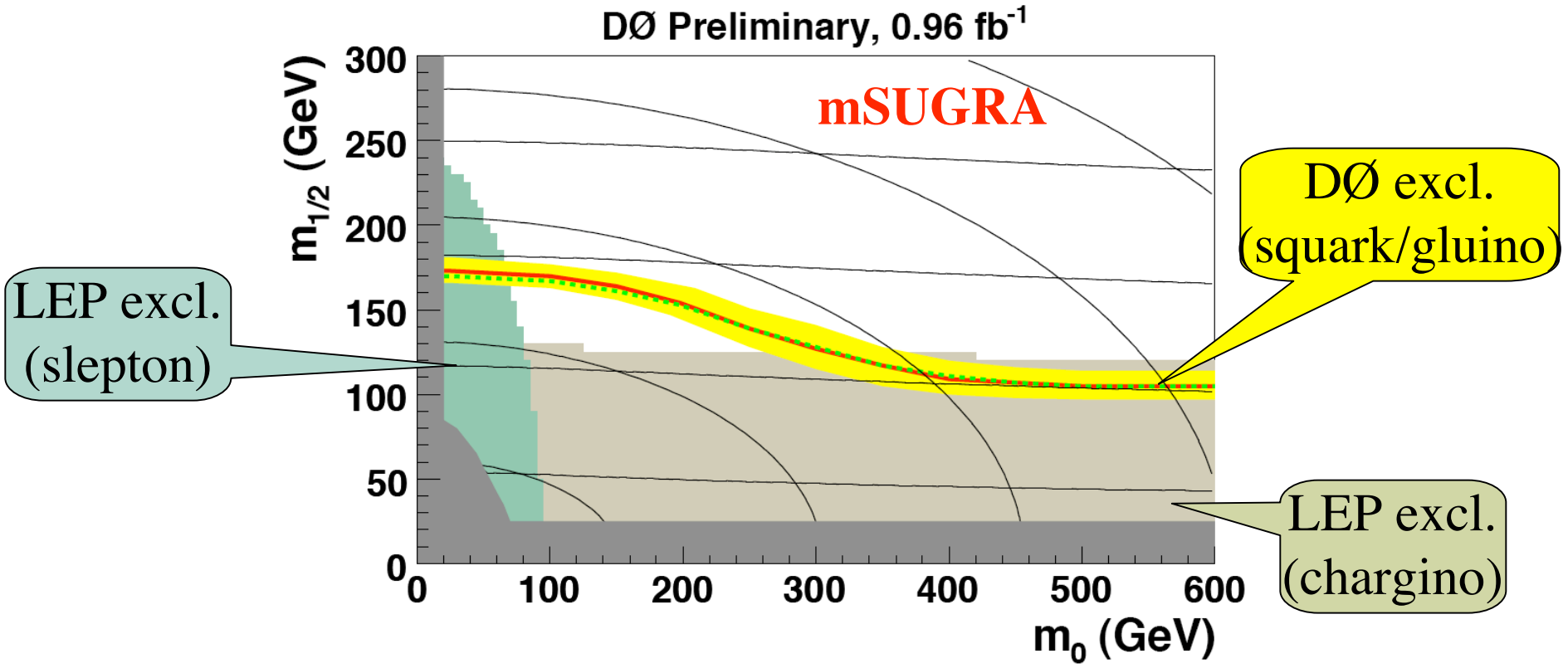




M(g̃)>290-410 GeV, M(q̃)>375 GeV

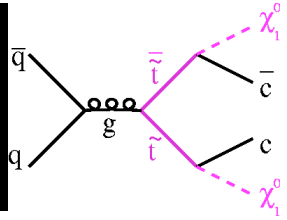
NB: up to 10 GeV differences depending on treatment of theoretical cross section uncertainties

Exclusion of GUT scale parameters



- Nice interplay of hadron colliders and e^+e^- colliders:
  - Similar sensitivity to same high level theory parameters via very different analyses
  - Tevatron is starting to probe beyond LEP in mSUGRA type models

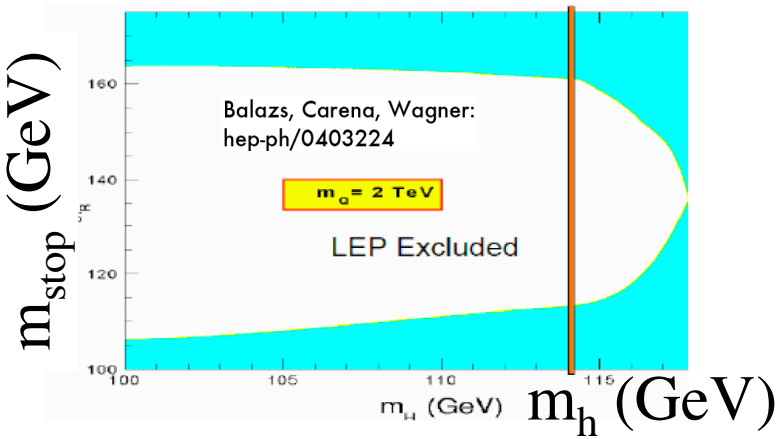
Third Generation Squarks



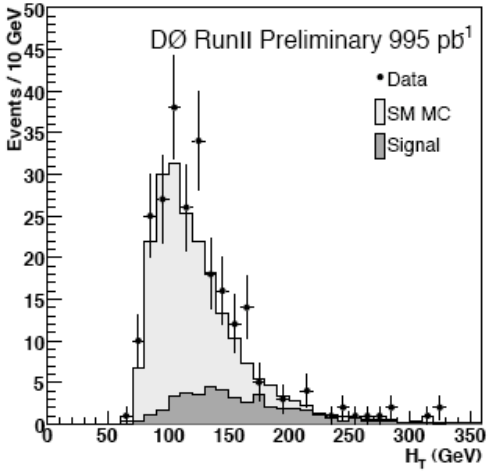
- The lightest $\tilde{q}$'s:

$$m^2_{\tilde{t}_{1,2}} = \frac{1}{2}(m^2_{\tilde{t}_L} + m^2_{\tilde{t}_R}) \mp \frac{1}{2}\sqrt{(m^2_{\tilde{t}_L} - m^2_{\tilde{t}_R})^2 + 4m_t^2(A_t - \mu \tan\beta)^2}$$

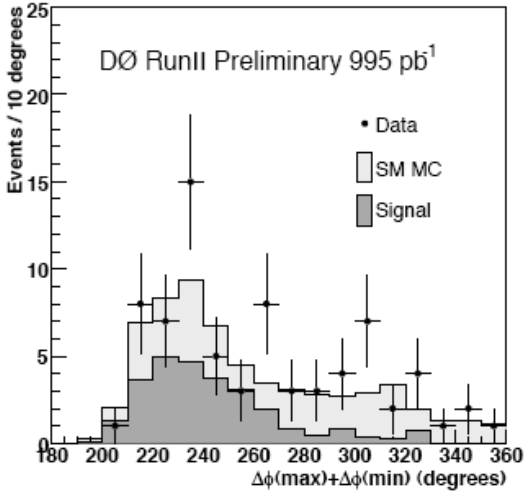
  - Due to large SM top mass
- Dedicated searches for stop and sbottom:
  - $\tilde{t} \rightarrow c\tilde{\chi}^0_1$ and $\tilde{b} \rightarrow b\tilde{\chi}^0_1$
- Signature:
  - Two heavy flavor jets + large missing E_T



H_T	P	# observed	#Expected
> 100	< 260	83	$81.9 \pm 4.0^{+13.9}_{-14.1}$
> 140	< 300	57	$57.1 \pm 3.1^{+8.6}_{-8.6}$
> 140	< 320	66	$64.2 \pm 3.2^{+9.0}_{-9.1}$



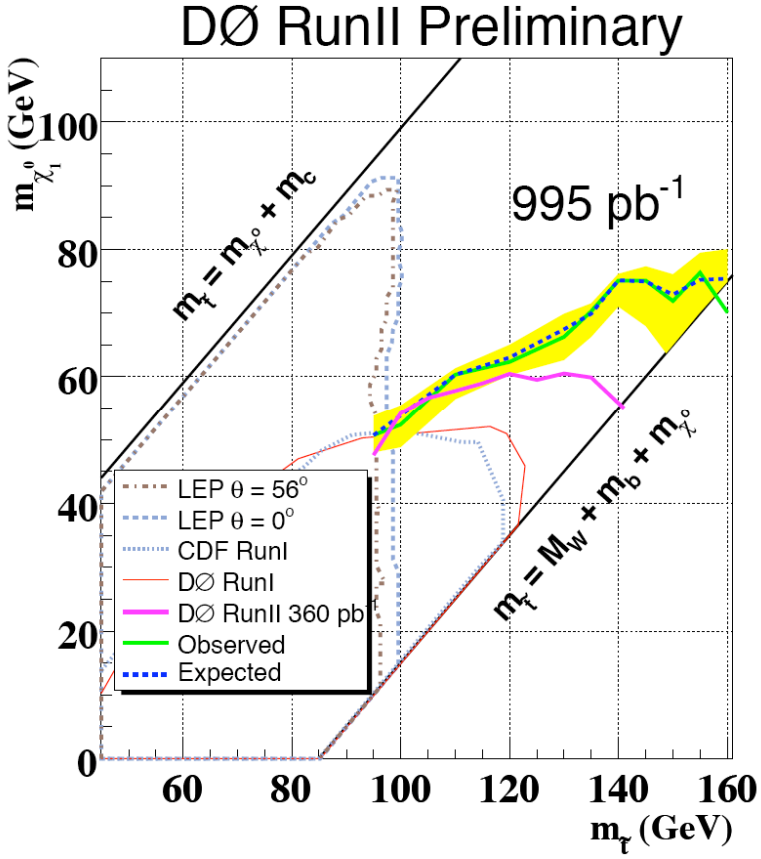
$H_T = \Sigma P_T^{jet}$

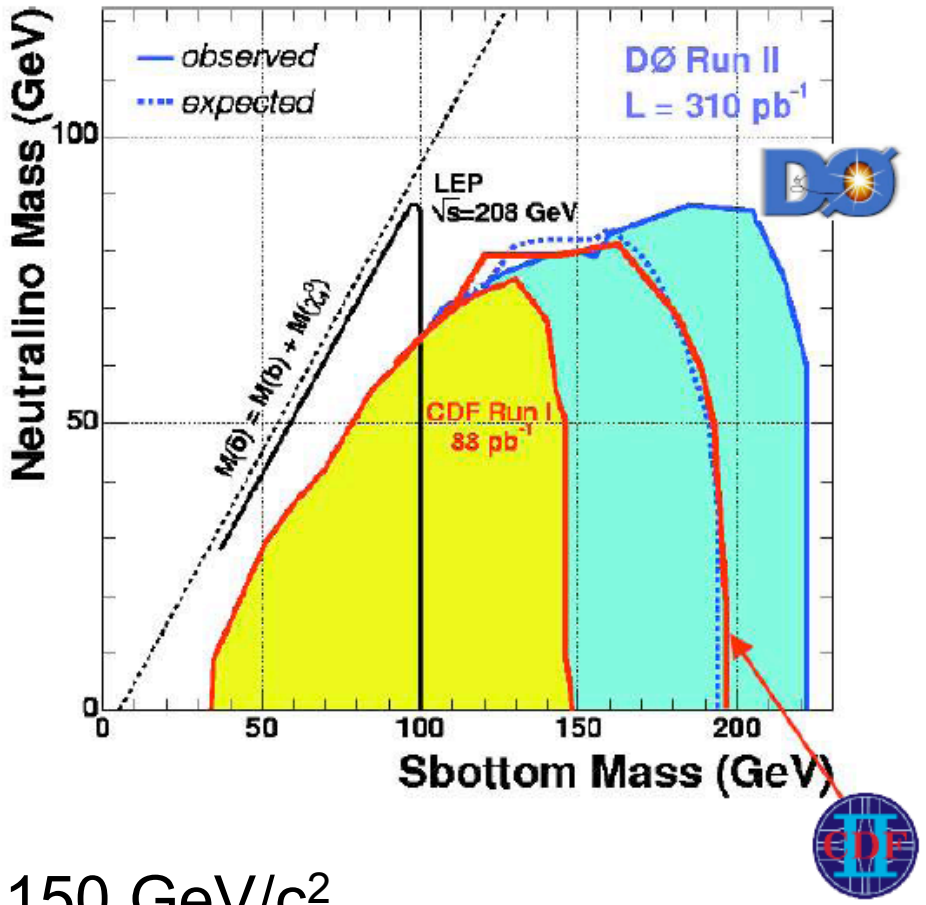


$\Delta\phi^{max} + \Delta\phi^{min}$

[talk by C. Biscarat]

Stop and Sbottom Mass Exclusion

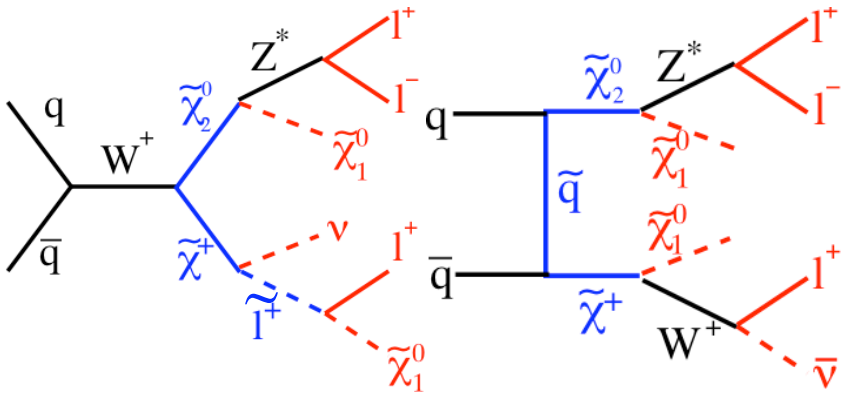


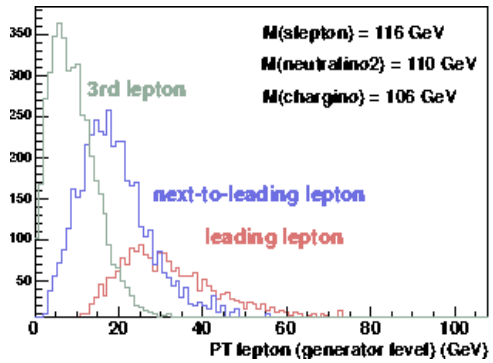


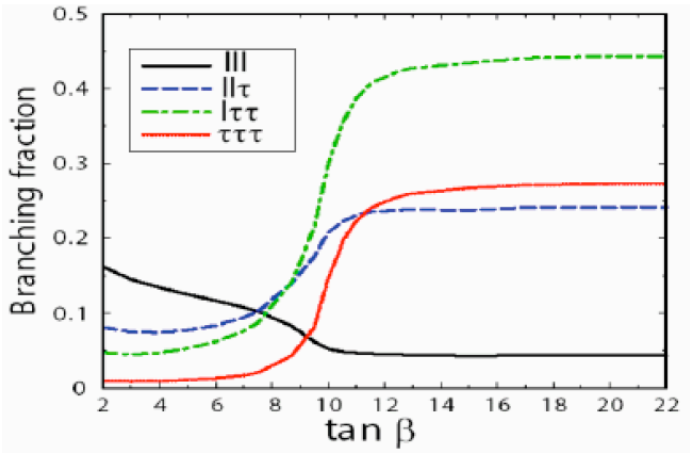
- Stop masses excluded up to 150 GeV/c^2
  - If $m(\tilde{t})$-$m(\tilde{\chi}^0_1)$>60 GeV/c^2
- Sbottom masses excluded up to 220 GeV/c^2
  - If $m(\tilde{\chi}^0_1)$<80 GeV/c^2

Charginos and Neutralinos

- Charginos and Neutralinos:
  - Mixed states of SUSY partners of
    - W, Z, γ , Higgs
  - Typically among the lightest SUSY particles
- Challenges:
  - Maximize lepton acceptance!
  - Large fraction of events contain τ's
- Selection:
  - Isolated leptons:
    - 3 leptons (e,μ or "track")
    - 2 leptons of same electric charge
  - Missing E_T







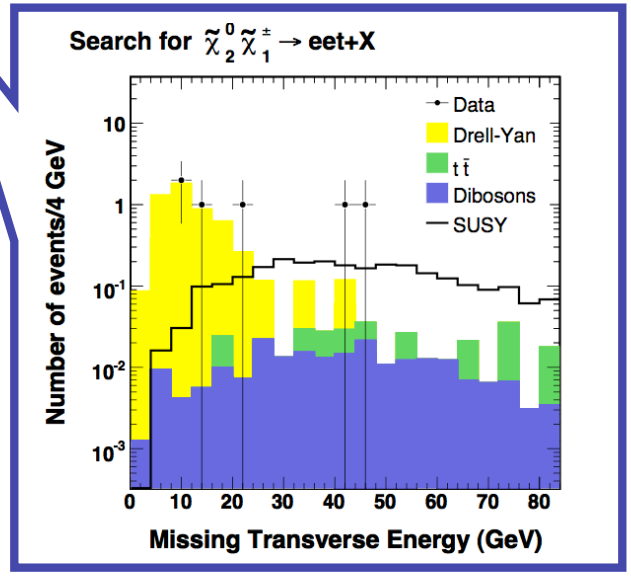
Trileptons: Result

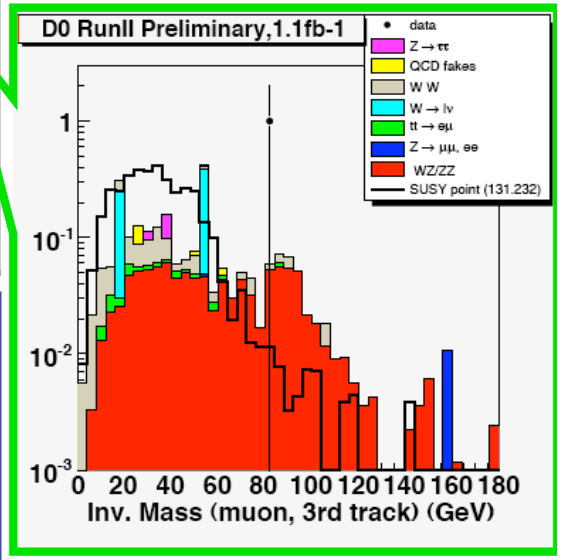
CDF

Analysis	Expected background	Data
μll	1.3±0.3	1
ell	0.8±0.4	0
ee + track	1.0±0.3	3
μμl	0.4±0.1	1
$e^{\pm}e^{\pm}$	3.0±0.5	4
$e^{\pm}\mu^{\pm}$	4.0±0.6	8
$\mu^{\pm}\mu^{\pm}$	0.9±0.1	1

DØ

eμ+track	$0.9^{+0.4}_{-0.1}$	0
ee+track	0.8 ± 0.7	0
μμ+track	$0.3^{+0.7}_{-0.1}$	2
$\mu^{\pm}\mu^{\pm}$	1.1 ± 0.4	1

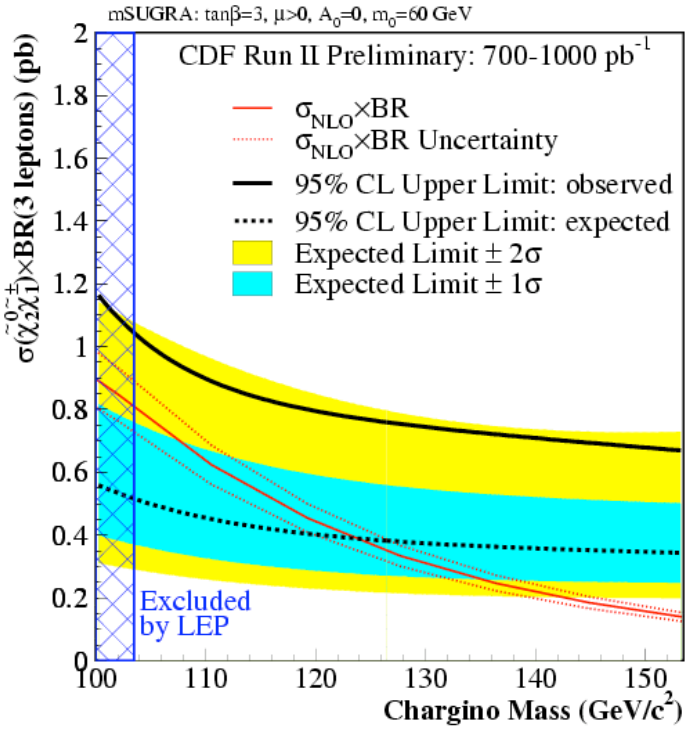


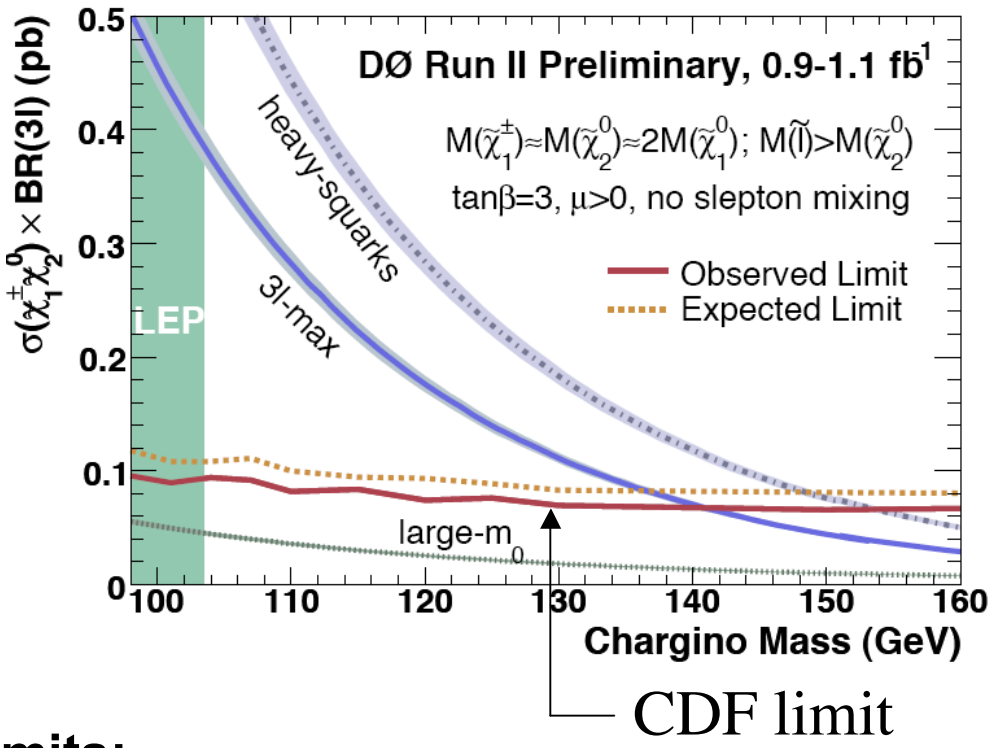


- Main backgrounds:
  - –Instrumental: Z+γ, Z+jet
  - –Genuine: WZ/γ*

[talk by H. Fox]

Constraints on SUSY

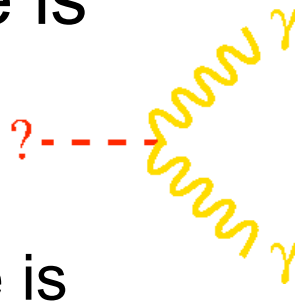




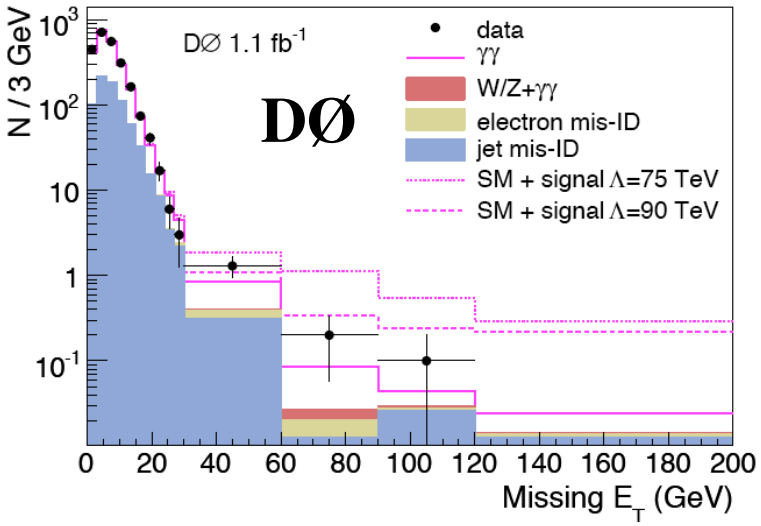
- **Strongly model-dependent limits:**
  - No-mix scenario:
    - **CDF $m(\tilde{\chi}^{\pm}_1)$>129 GeV/c², DØ: $m(\tilde{\chi}^{\pm}_1)$>140 GeV/c²**
  - Starting to probe mSUGRA
  - No sensitivity at large m_0 yet (i.e. if sleptons heavy)
- **Sensitive up to $m(\tilde{\chi}^{\pm}_1)$~200 GeV with full Run 2 luminosity**

Gauge Mediated SUSY Breaking

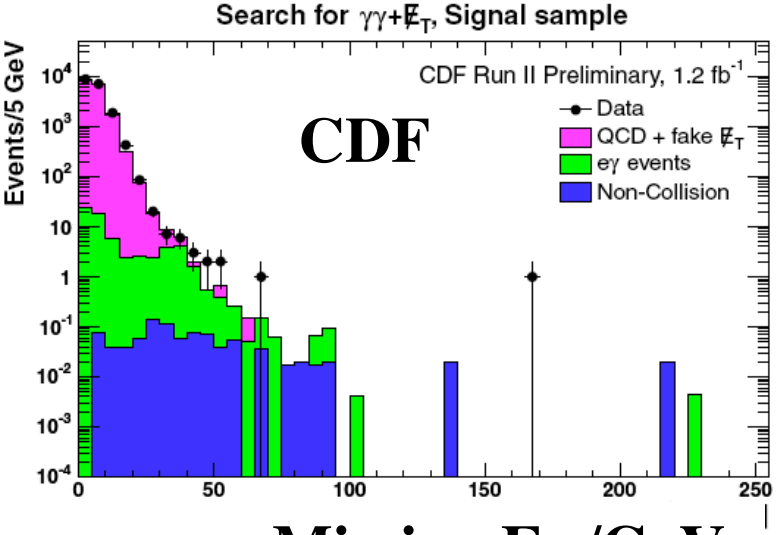
- Lightest SUSY particle is gravitino:
  - Mass ~ 1 keV
  - Next-to-lightest particle is
    - neutralino→ γG
    - Reaction: $p\bar{p} \rightarrow \tilde{X}\tilde{X} \rightarrow \gamma\gamma GG$
- Cleanest signature:
  - 2 photons+missing E_T



[talk by S.-S. Yu]



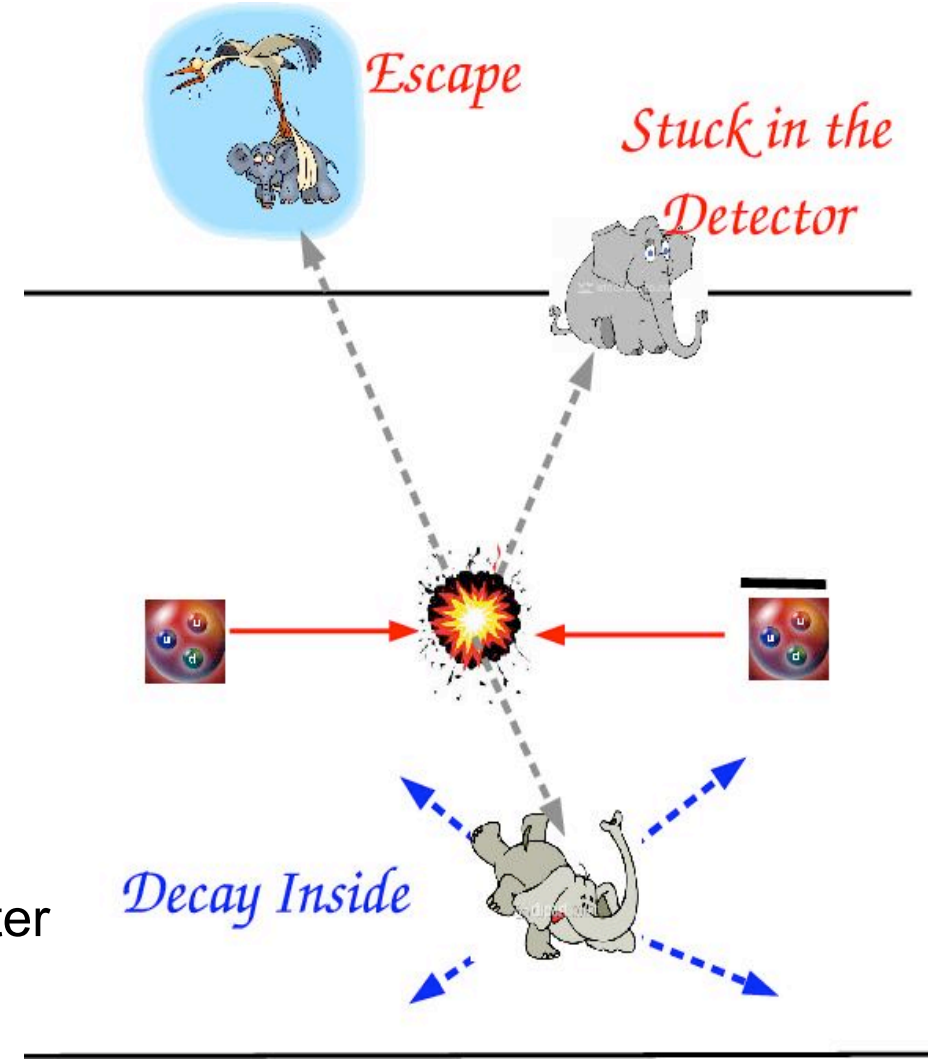
	DØ		CDF	
	E_T>30	E_T>60	E_T>30	E_T>50
BG	9.8 ± 1.1	1.5±0.4	19.5 ±2.5	1.6 ± 0.3
Data	**16**	**4**	**22**	**4**



- **Slight excess in both experiments**
- **DØ Data exclude chargino masses below 231 GeV**

Long-lived particles

- Particles can be stable or long-lived if decay forbidden due to
  - Conservation law
  - Kinematically disfavored
- Example Models:
  - Split-SUSY:
    - gluino
  - GMSB, AMSB:
    - stau, stop, chargino
- In the detector
  - Decay after some lifetime
  - Get stuck in detector and decay later
  - Escape detector completely



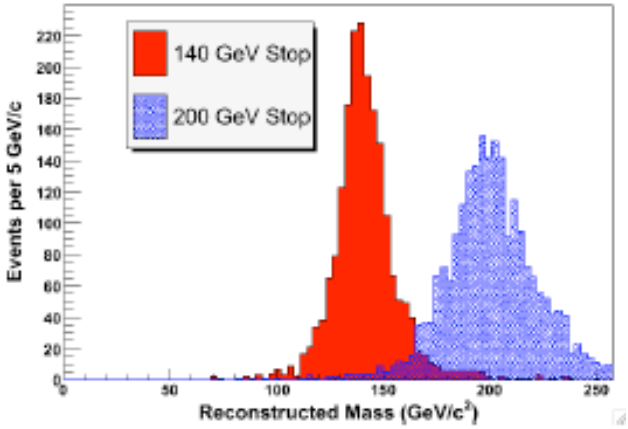
[talk by M. Goncharov]

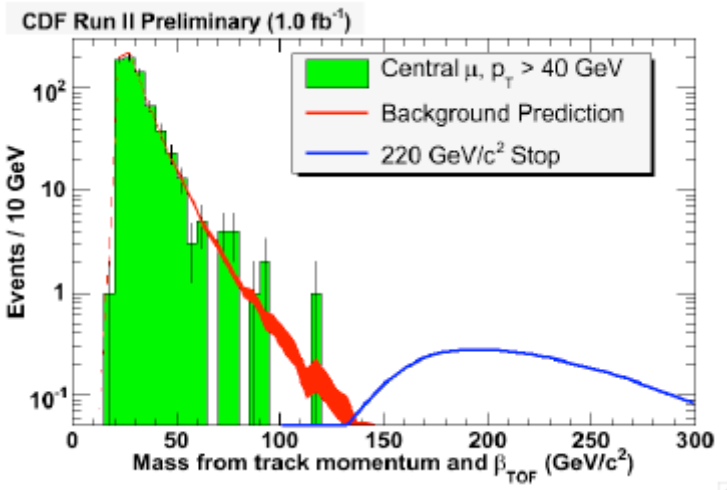
CHAMPS: Charged Massive Stable Particles

- Scenario:
  - Escape detector completely
- Experimentally:
  - Search for "muons" that travel at $\beta<<1$
    - CDF: Time-Of-Flight detector and drift chamber
    - D0: muon system
  - Reconstruct mass from p and β
- Cross Section Limits

  (for $p_T>40$ GeV and $|\eta|<1$, $0.4<\beta<0.9$)
  - Weakly interacting ($\tilde{\tau}$, $\tilde{\chi}_1^{\pm}$):
    - $\sigma<10$ fb at 95% CL
  - Strongly interacting (stop):
    - σ <48 fb at 95% CL
    - Assumes stop stays charged up to muon system with P=43±7%

$$m = p\sqrt{1/\beta^2 - 1}$$

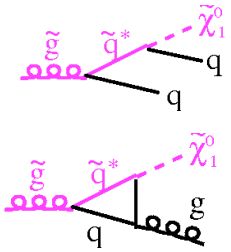




CDF: m($\tilde{t}$)>250 GeV
DØ: m($\tilde{\chi}_1^{\pm}$)>140-170 GeV

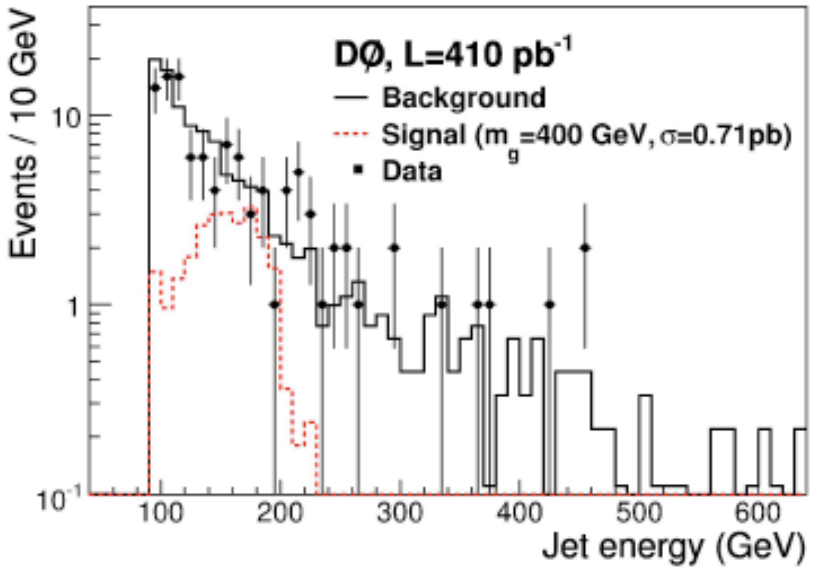
Stable particles: “stopped Gluinos”

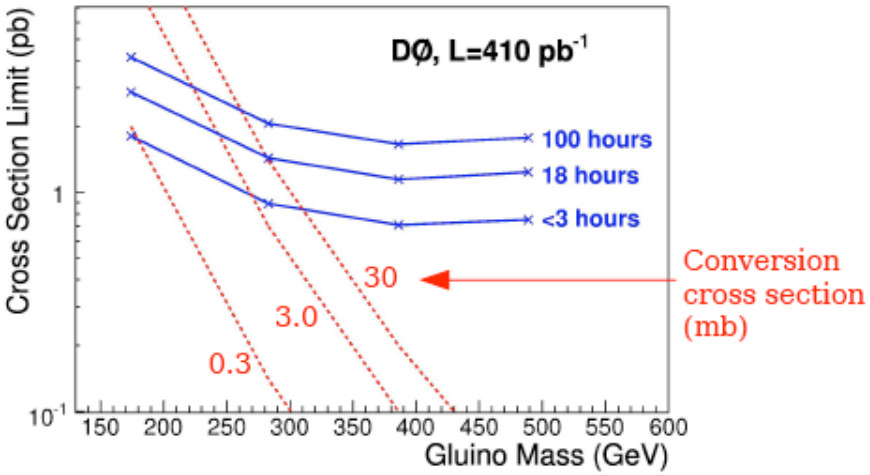
- Particles can be rather stable:
  - Lifetime ~hours
    - Interact in calorimeter and decay at some later time
  - Split-SUSY:
    - $m(\tilde{q})>10^2$ TeV, $m(\tilde{g})$~TeV
    - Gluino long-lived



- Trigger on events with
  - “no interaction” but jet activity
- Main background:
  - Cosmic ray and beam-halo muons
- Result: **$m(\tilde{g})>270$ GeV** @95%CL

for $\tau(\tilde{g})<3h$, $\sigma(R_m \rightarrow R_b)=3mb$,
$BR(\tilde{g} \rightarrow g\tilde{\chi}_1^0)=100\%$, $m(\tilde{\chi}_1^0)=50$ GeV





[A. Arvanitaki et al.: hep-ph/0506242]

Beyond SUSY

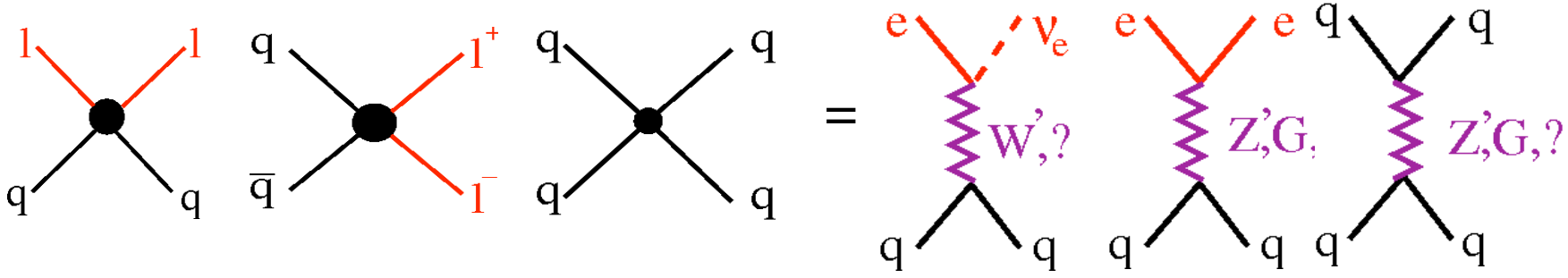
What else could be there?

- Strong theoretical desire for SUSY to be true
  - particularly due to the **lack of SUSY observation…**
- There could be many other theories/particles, e.g.:
  - Extra gauge groups: **Z', W'**
    - Occur naturally in GUT scale theories
  - **Extra spatial dimensions:**
    - "Solve" hierarchy problem by making gravity strong at TeV scale
  - **Compositeness:**
    - excited leptons, leptoquarks
  - **Preons:**
    - We have always found smaller things before
      - atom->proton->quarks->preons ?
  - **…**

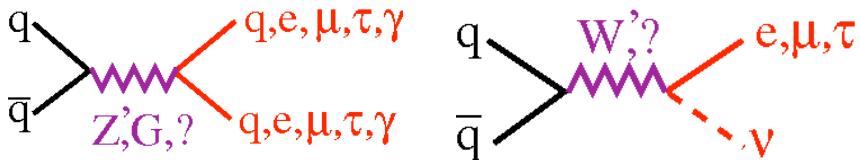
High Mass Production

- Probes contact interactions:

$$\mathcal{L}_{CI} = \pm\frac{4\pi}{\Lambda^2}(f\gamma^\mu f)(f'\gamma^\mu f')$$



- Probes new resonances: Z', W', Extra Dimensions

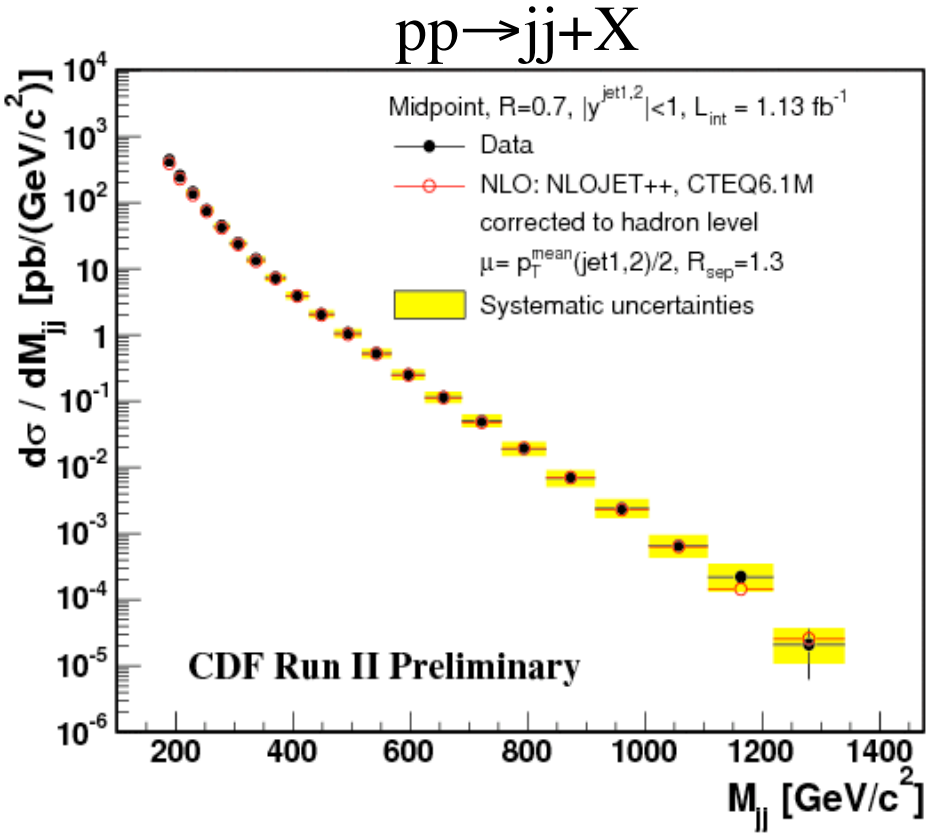


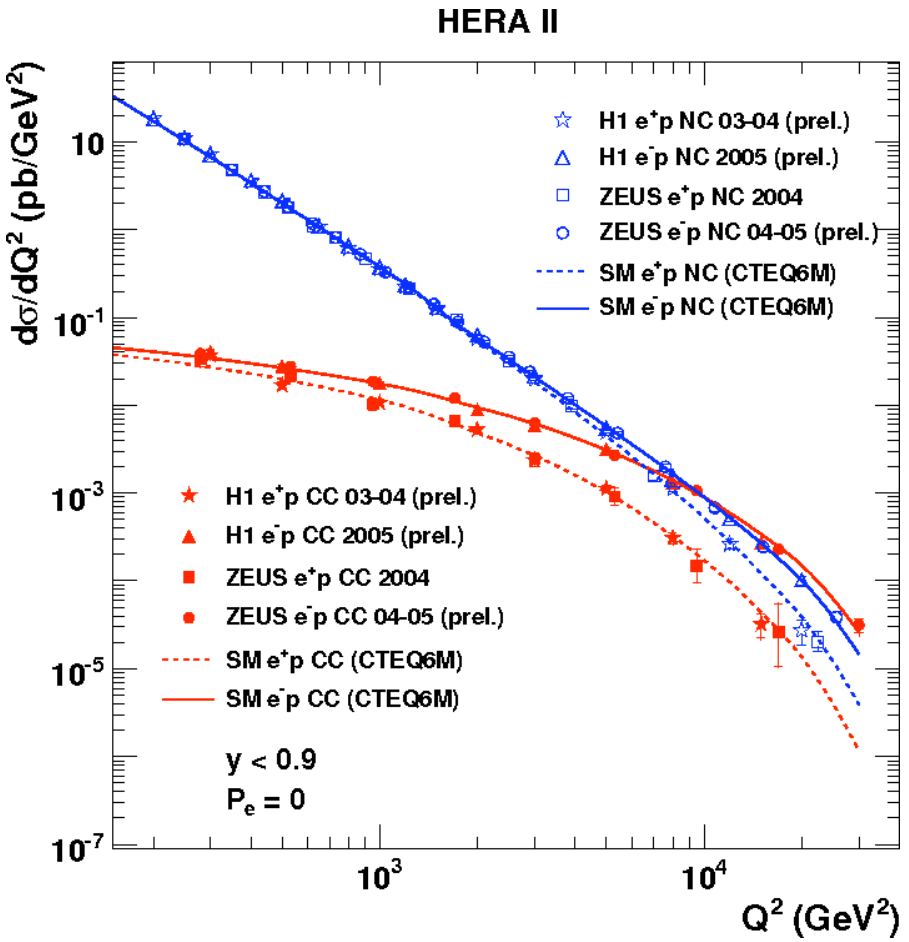
- Probes fermion substructure

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2)$$

where $f(Q^2) = 1 - \frac{\langle r^2\rangle}{6} Q^2$

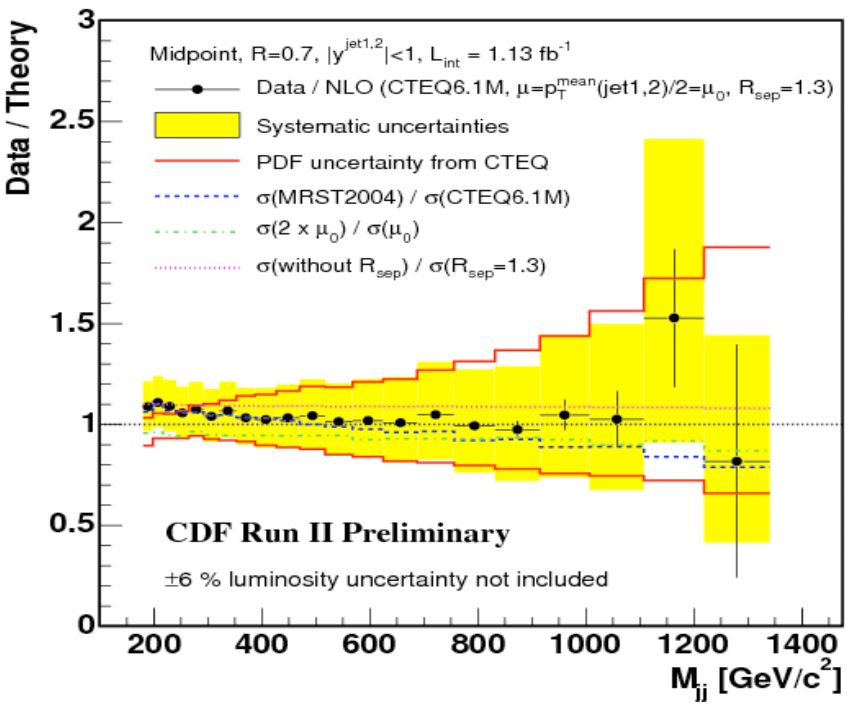
High Mass Production

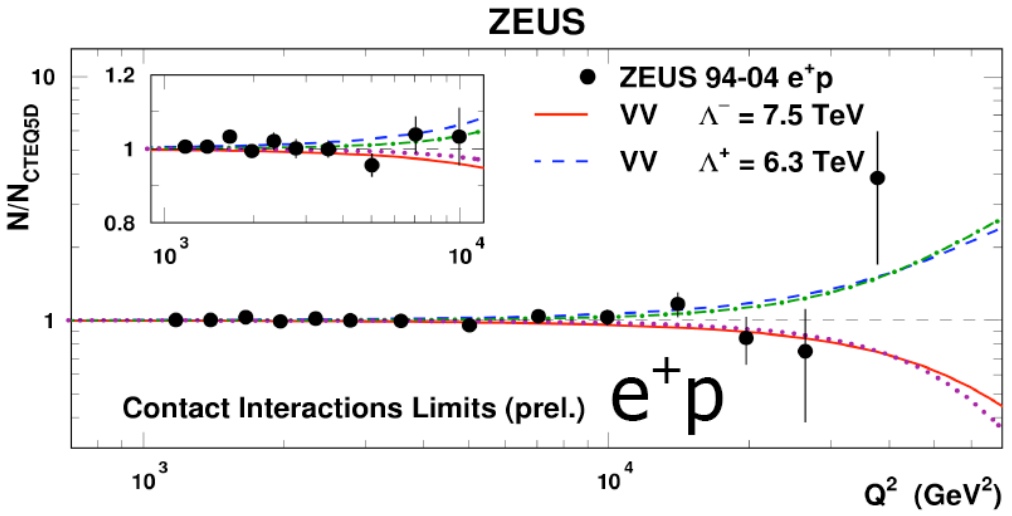




- Inclusive cross sections:
  - HERA: $d\sigma/dQ^2$ (CC and NC)
  - Tevatron: $d\sigma/dM(l^+l^-,jj,\gamma\gamma)$
- Excellent agreement with prediction over many orders of magnitude

Contact Interactions + Quark Substructure





Quark Radius (ZEUS)

$R_q < 0.67\ 10^{-18}$ m

No indication of substructure or contact interactions

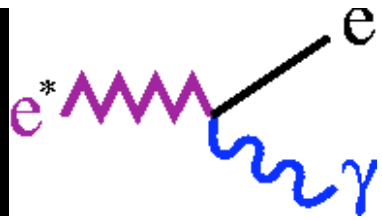
Contact Interaction: eeqq

Λ Constraints in TeV

	constructive		destructive	
	ZEUS	DØ	ZEUS	DØ
LL	4.2	3.6	4.2	6.2
RL	3.6	4.3	2.3	5.0
VV	6.3	4.9	7.5	9.1

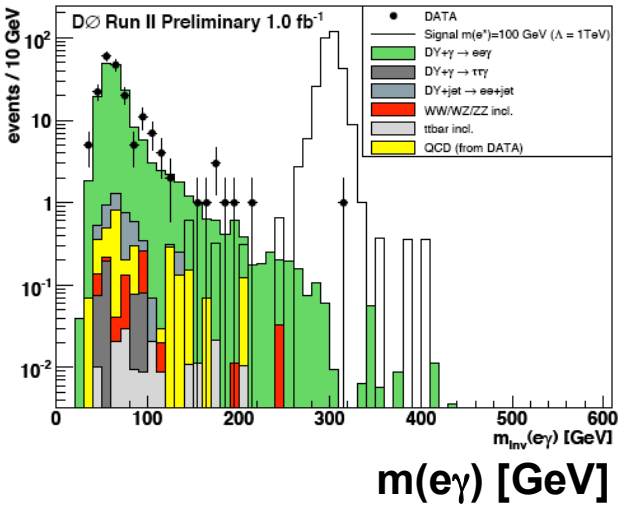
[talk by R. Placakyte]

Excited Leptons

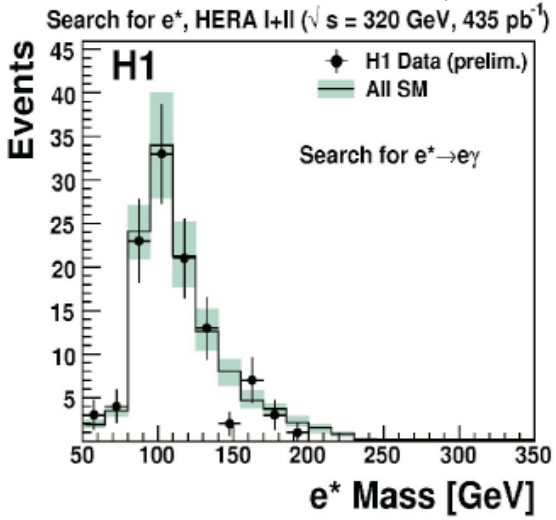


- Excited leptons appear in compositeness models
- Decay modes:
  - f*→f'γ, f*→f'W, f*→f'Z
- Search for peak in invariant mass spectra:
  - E.g. e* → eγ, e*→eZ, ν*→eW etc.

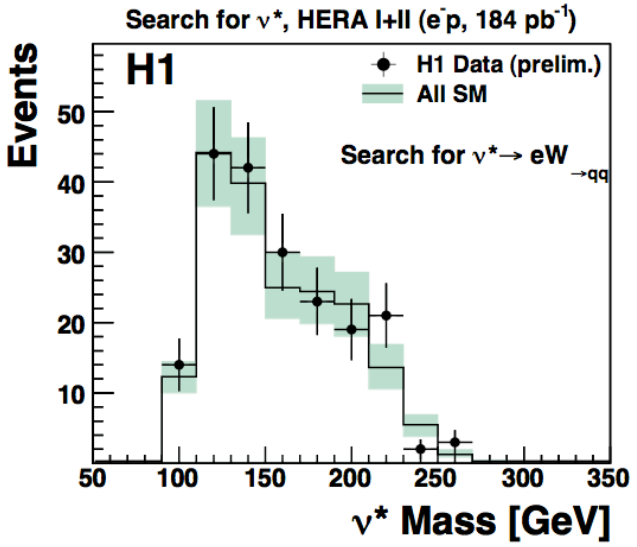
DØ: e* → eγ



H1: e* → eγ

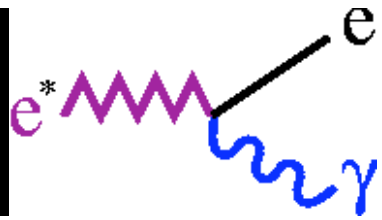


H1: ν*→eW

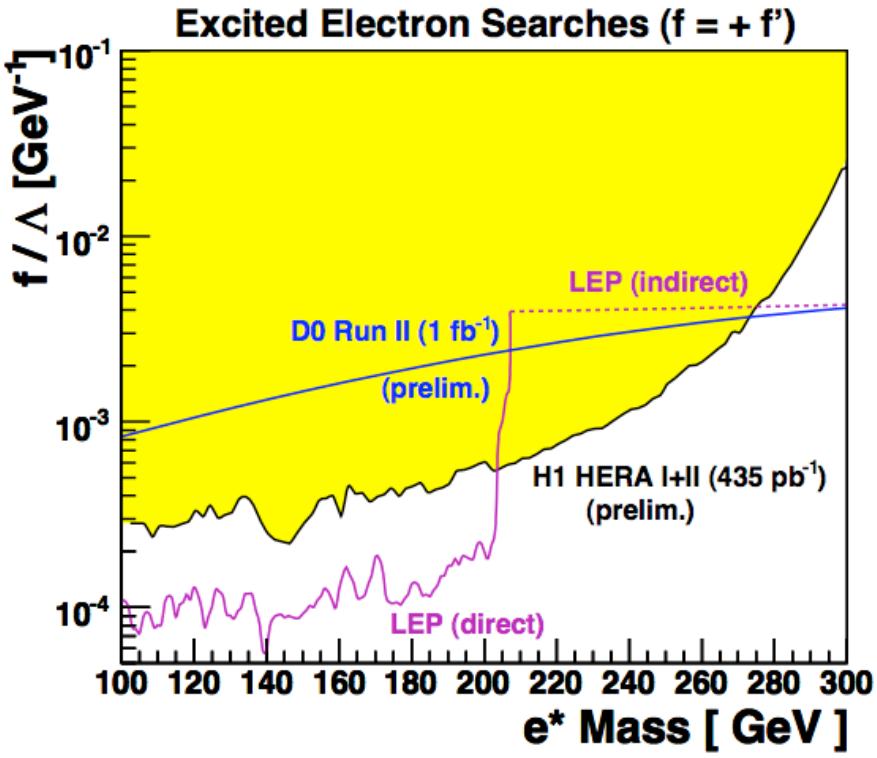


[talk by E. Sauvan]

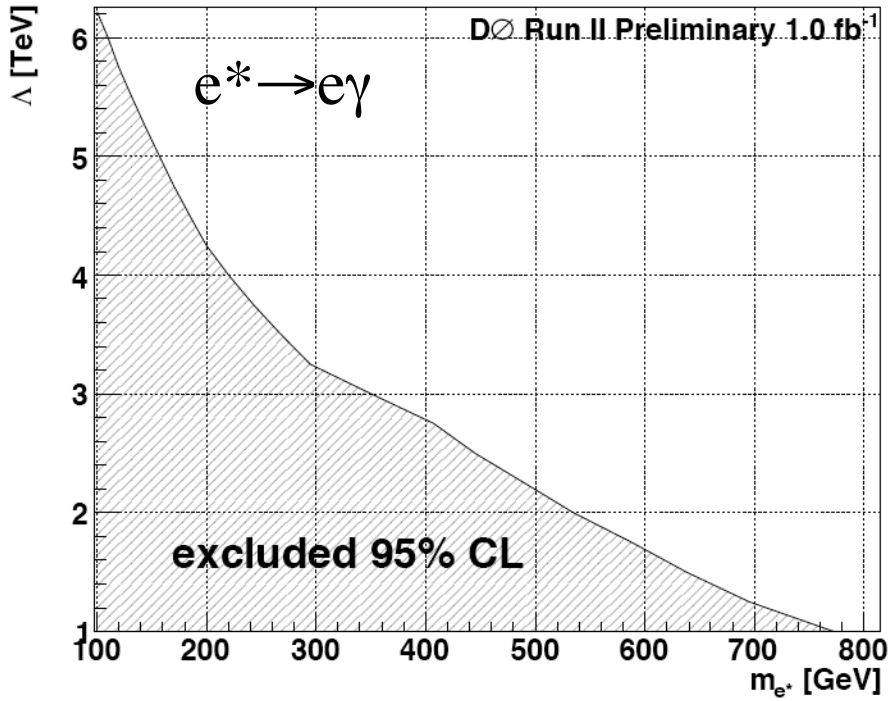
Excited Leptons



Gauge Model:



Contact Interaction Model:



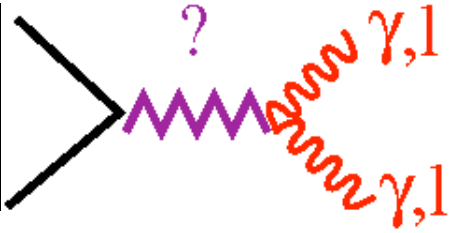
$$\mathcal{L}_{GM} = \frac{1}{2\Lambda}\bar{F}_R^*\sigma^{\mu\nu}\left[gf\frac{\tau^a}{2}W^a_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu} + g_s f_s\frac{\lambda^a}{2}G^a_{\mu\nu}\right]F_L$$

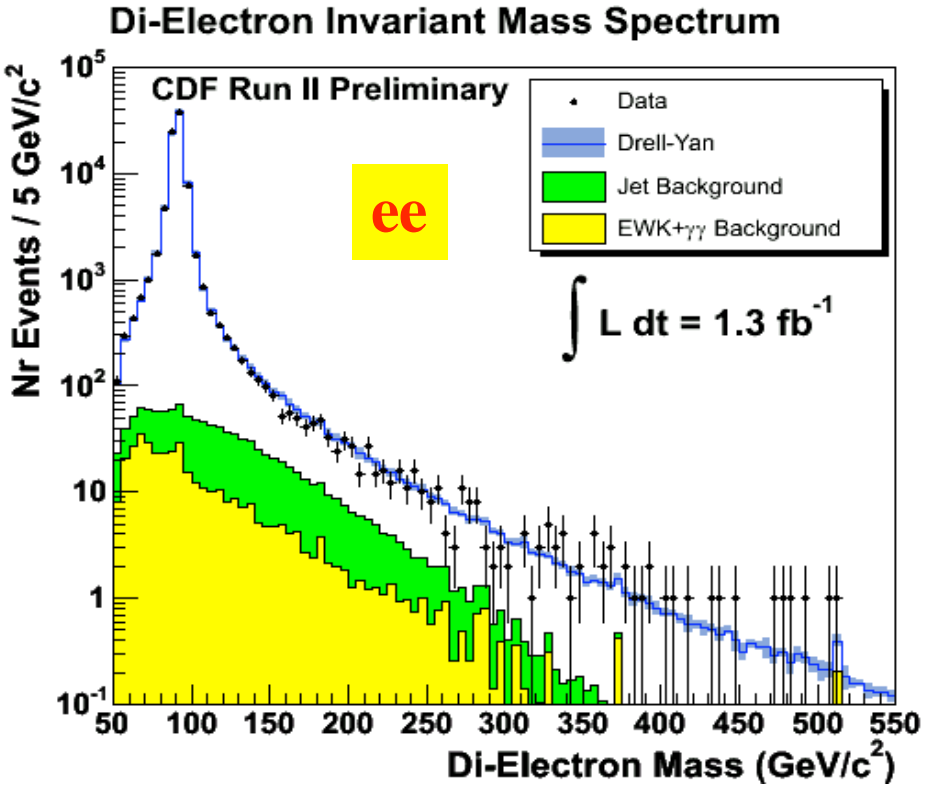
SU(2) U(1) SU(3)

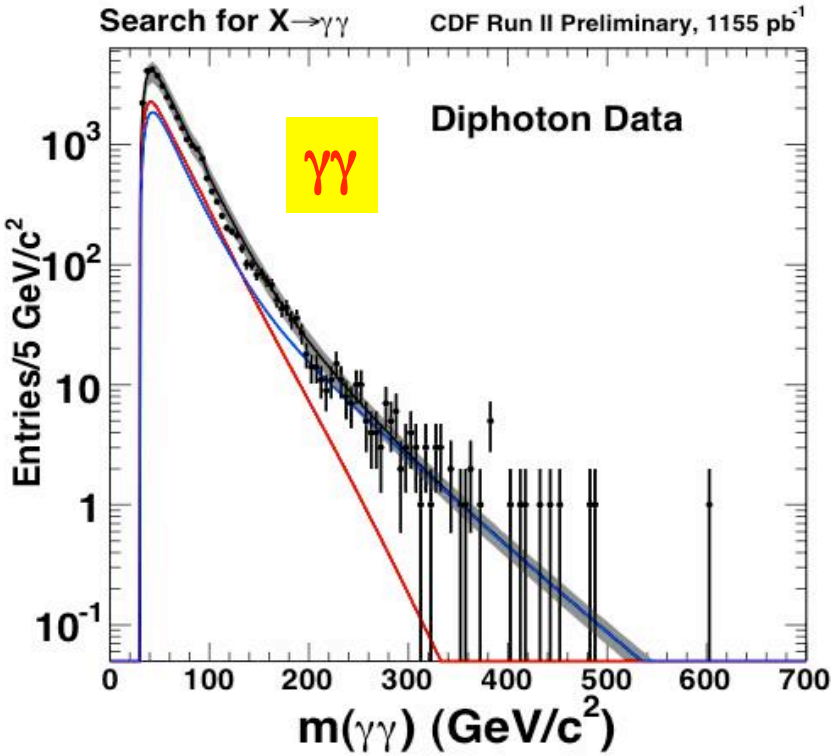
$$\mathcal{L}_{CI} = \frac{g^2}{2\Lambda^2}j^\mu j_\mu$$

- Compositness scale Λ, relative strengh to γ,Z,g: f, f', fs

ee and γγ Mass Spectra



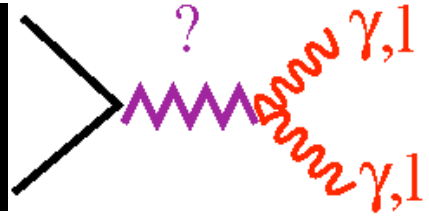




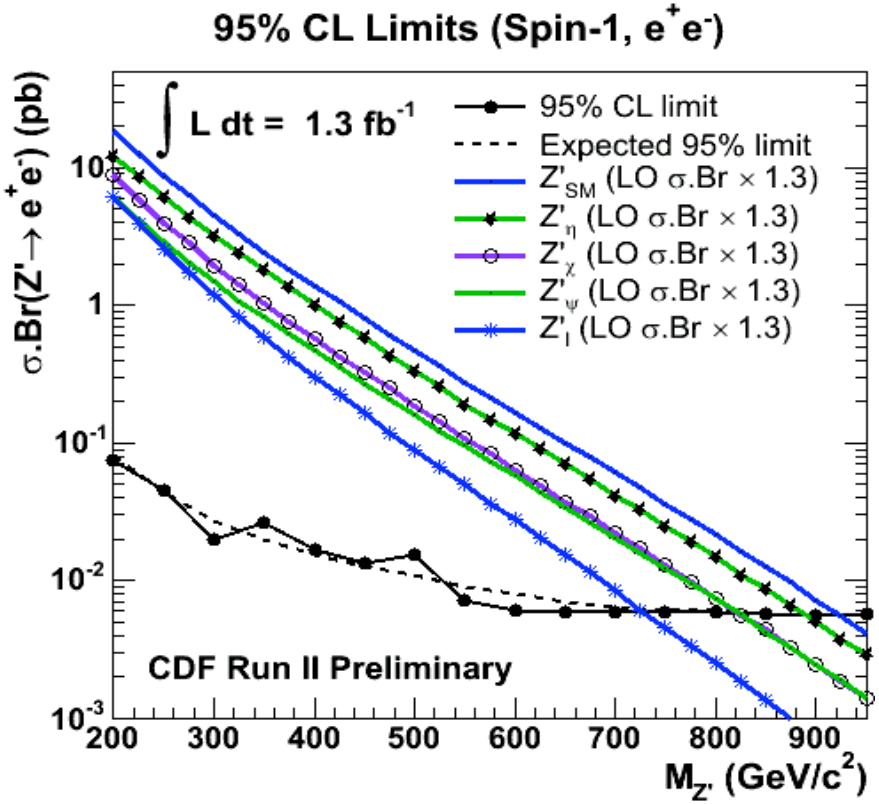
- Dielectron mass spectrum and diphoton mass distributions
  - Data agree well with Standard Model spectrum
  - No evidence for mass peak or deviation in tail

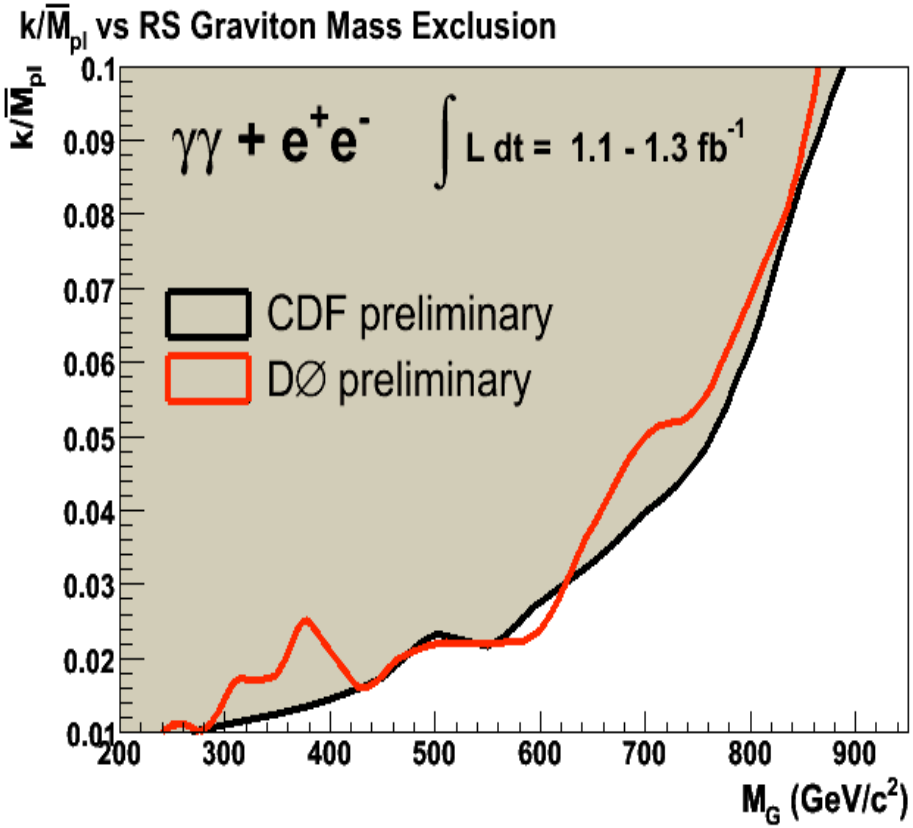
[talk by S. Kermiche]

High Mass e^+e^- and $\gamma\gamma$



- Resonance in diphoton or dielectron mass spectrum predicted in
  - Z' models (ee only): Spin 1
  - Randall-Sundrum graviton (ee and $\gamma\gamma$): Spin 2





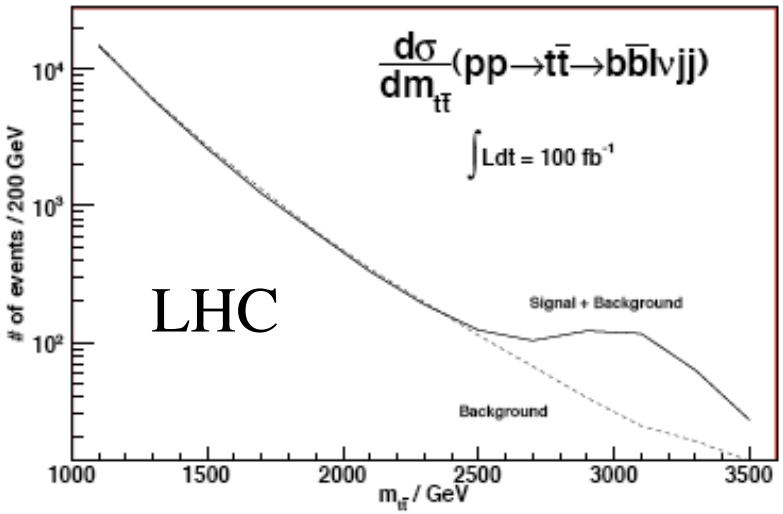
$M_{Z'} \gtrsim 925$ GeV for SM-like Z'

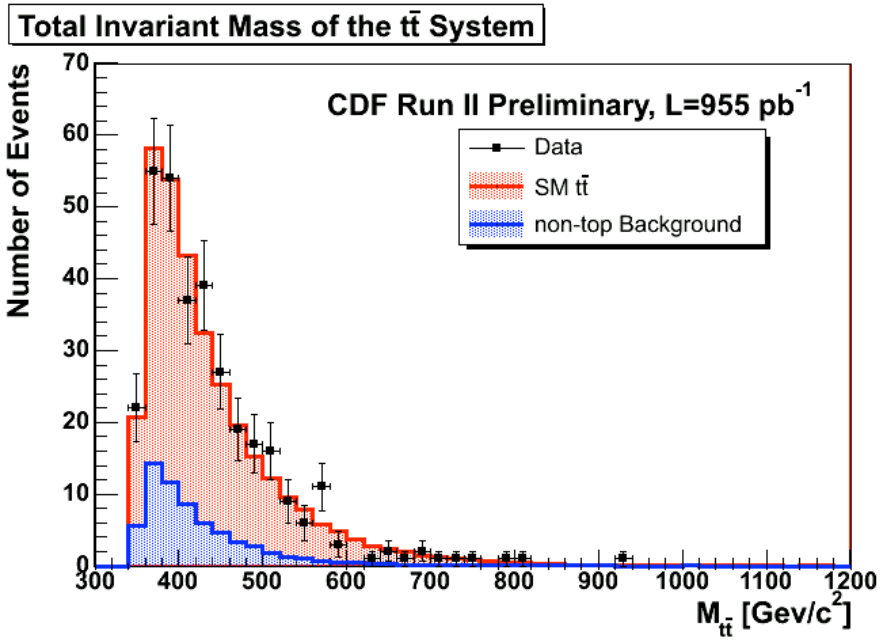
$M_G > 890$ GeV for $k/M_{Pl}=0.1$

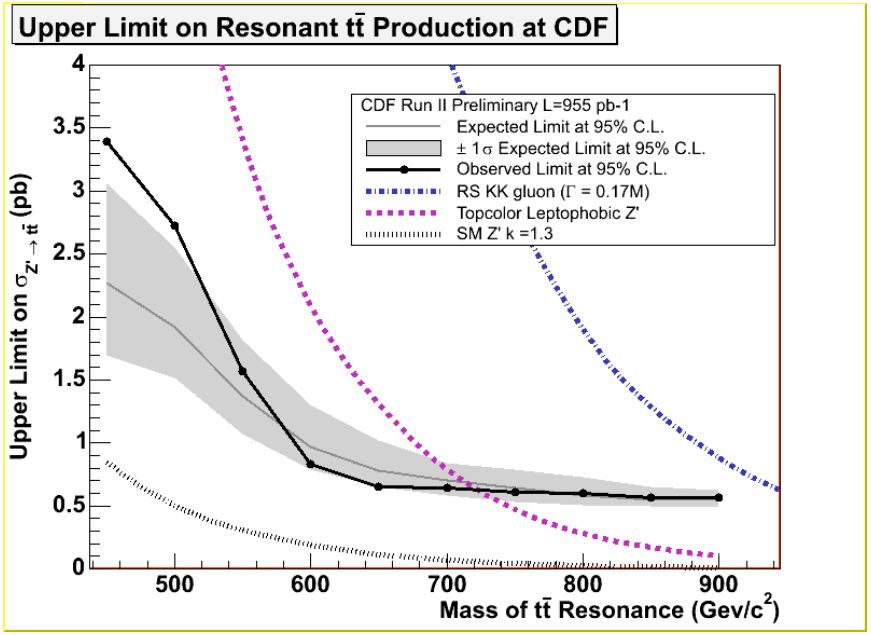
High Mass $t\bar{t}$ Production

- **Recent interest in KKG → $t\bar{t}$**
  - Good discovery potential at LHC
    - Agashe et al.: hep-ph/061215
    - Lillie, Randall, Wang: hep-ph/0701166
- CDF analysis
  - **Excludes M<720 GeV in topcolor models**
  - Reinterpretation in KKG models ongoing

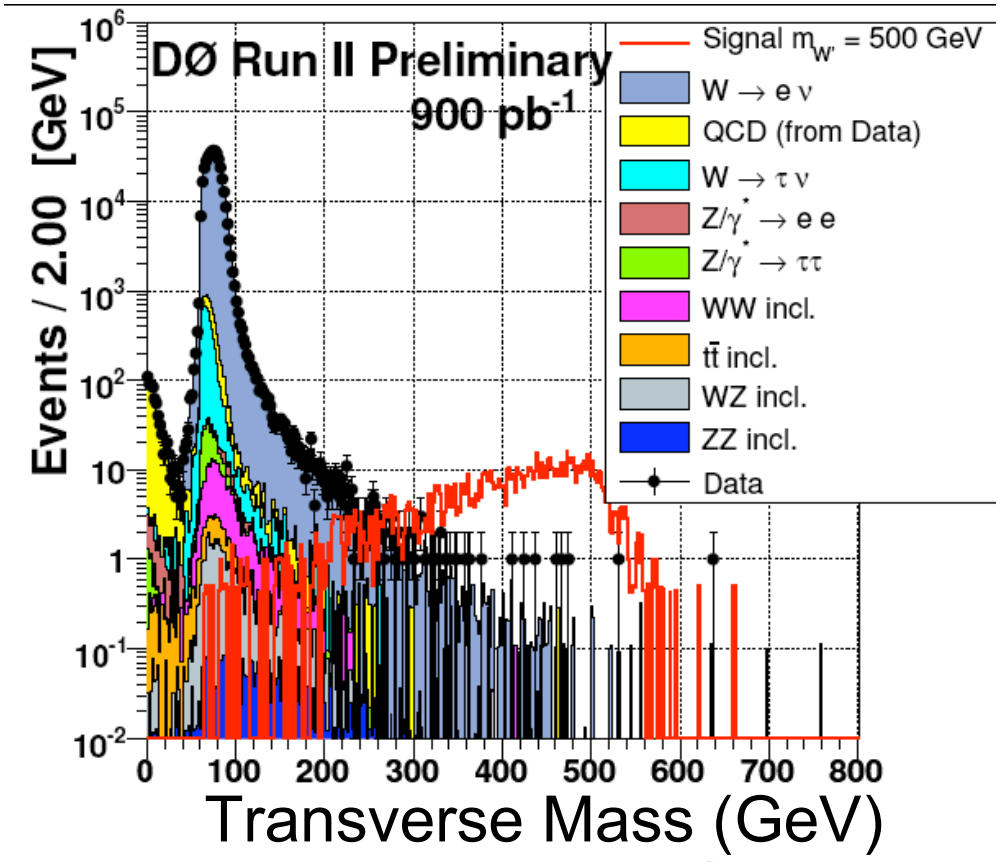
hep-ph/061215

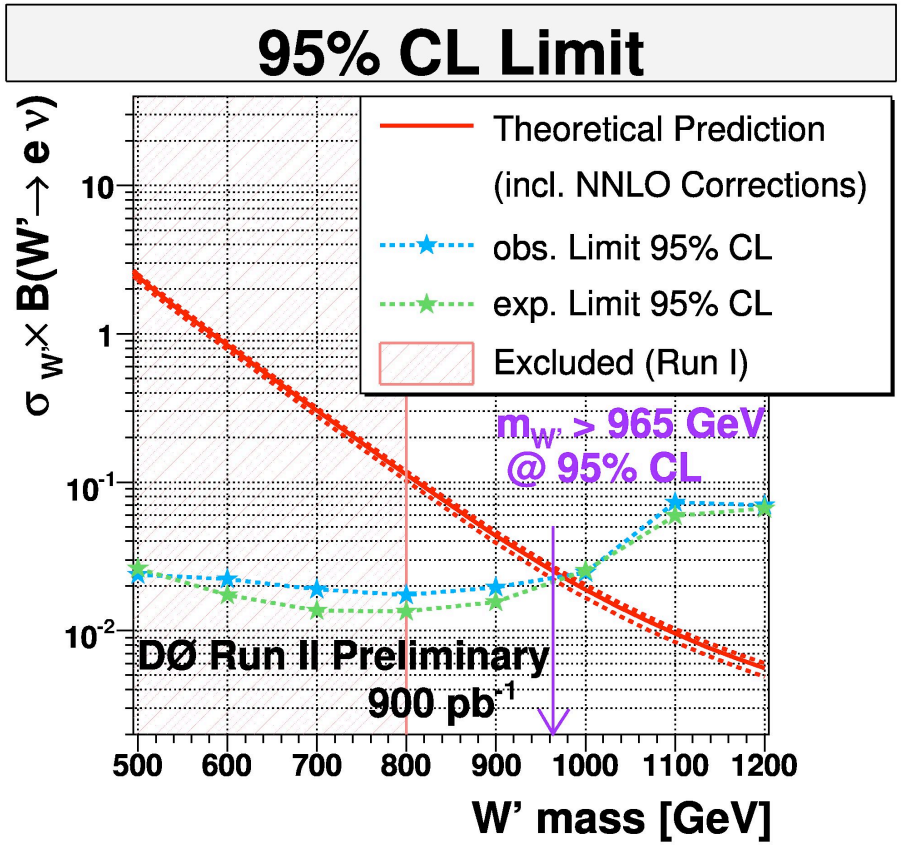






W´ →e ν_e

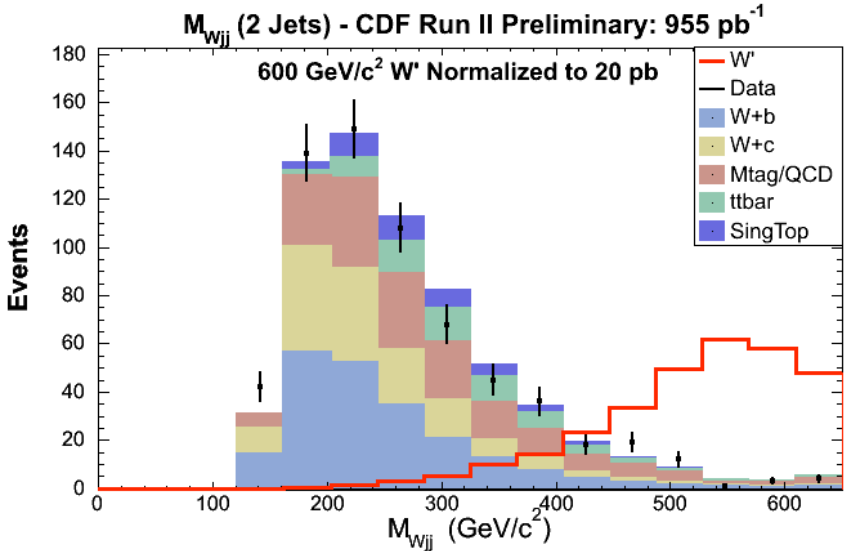


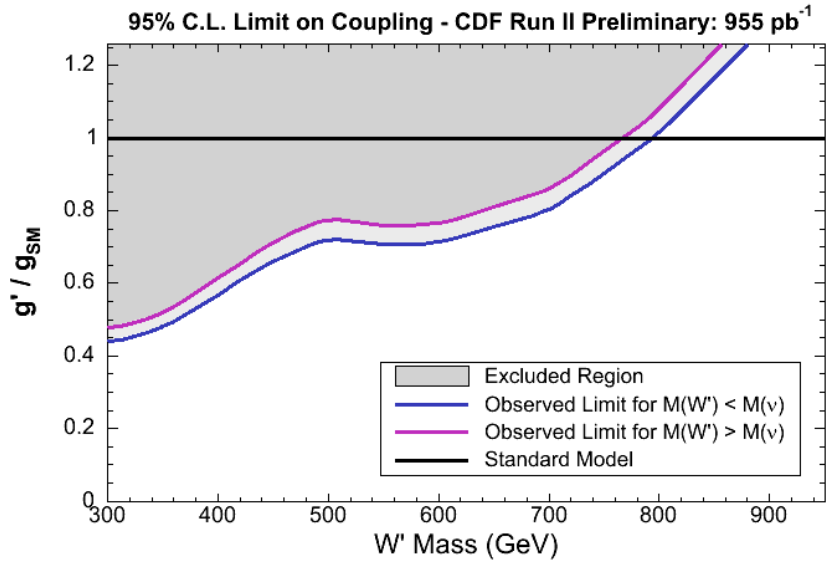


- W´ boson searched for in tail of transverse mass distribution
- New DØ limit: **m(W´) > 965 GeV at 95% CL**

W´→tb

- Complementary:
  - W´→eν probes lefthanded current
  - W´→tb probes left- and righthanded current
- Use Invariant mass of
  - W(→lν)+2 jets (≥1 b-tag)
  - Selection as in CDF single top analysis (see T. Wyatt's talk)
- Mass limit
  - **M(W´)>760 GeV for g´=g_{SM}**





Conclusions

- **Huge efforts for finding physics beyond the Standard Model continue**
  - Tevatron presented many analyses with 1 fb^{-1}
    - Another 2 fb^{-1} are on tape and a total of 8 fb^{-1} is expected by 2009
  - HERA presented first results using their full luminosity
  - Interesting interplay with low-energy experiments
    - BaBar, Belle, KLOE, NA48..
- **No signs of new physics found**
  - Stronger and stronger constraints on new physics
  - No excesses larger than 2σ

Current experiments continue to improve sensitivity and LHC is starting next year…

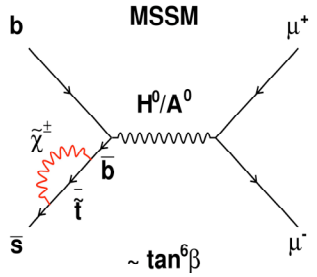
It has been a rainy decade for searches

Let's hope the next decade is sunnier…
starting with EPS 2009

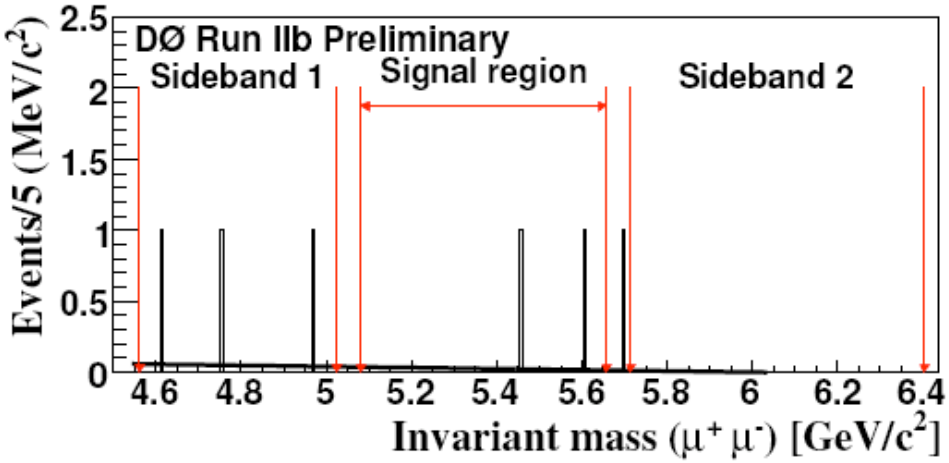

Backup Slides

$B_s \rightarrow \mu^+\mu^-$ Branching Ratio

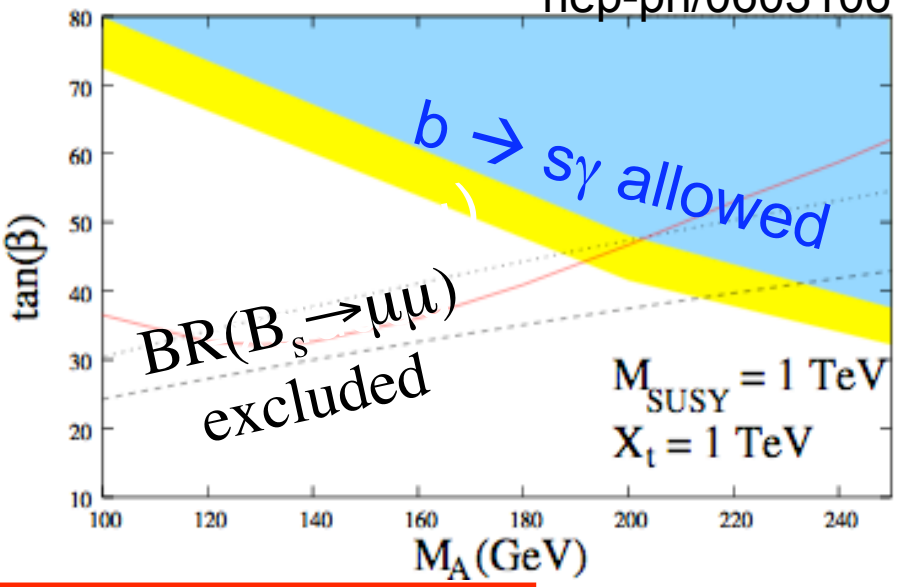
- Standard Model prediction:
  BR=(3.42±0.54) x 10^{-9}
  A.J. Buras Phys.Lett.B 566, 115 (2003)
- Large enhancements e.g. in Supersymmetry possible



$\sim \tan^6\beta/m_A^4$



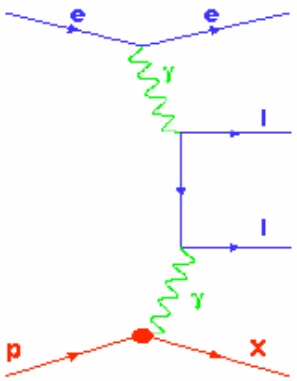
hep-ph/0603106

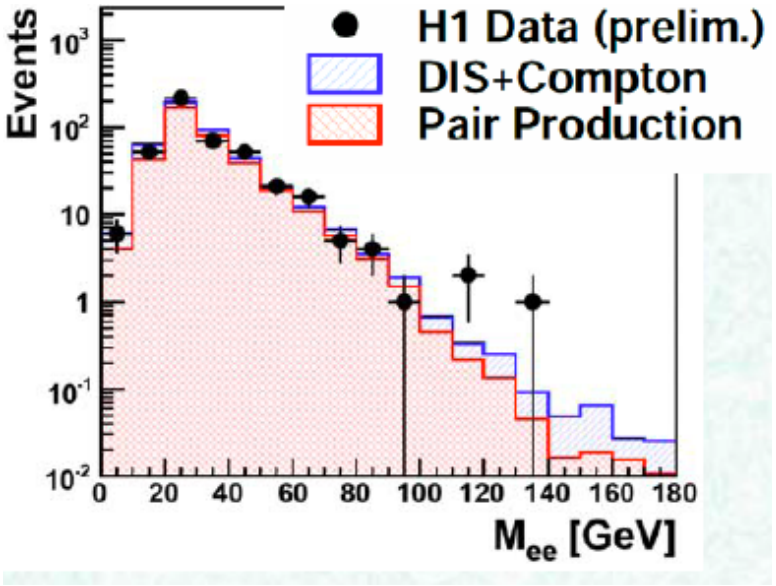


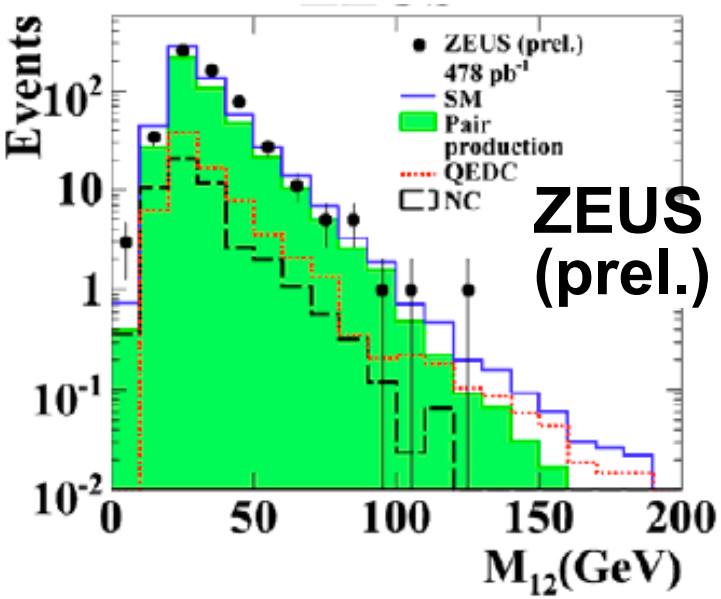
	CDF L=0.8 fb^{-1}	DØ L=2.0 fb^{-1}
N_{exp}	**1.47**	**2.3**
N_{obs}	**0**	**3**
Limit at 95%CL	**<10 x 10^{-8}**	**<9.3 x 10^{-8}**

Severe constraints on SUSY parameter space

Multi-Leptons at HERA







- Inclusive searches for
  - 2 or 3 leptons
  - Sensitive to $H^{\pm\pm}$ production
- Good agreement with SM
  - Also in eμ,μμ, eμμ
  - Limits derived on $H^{\pm\pm}$ production

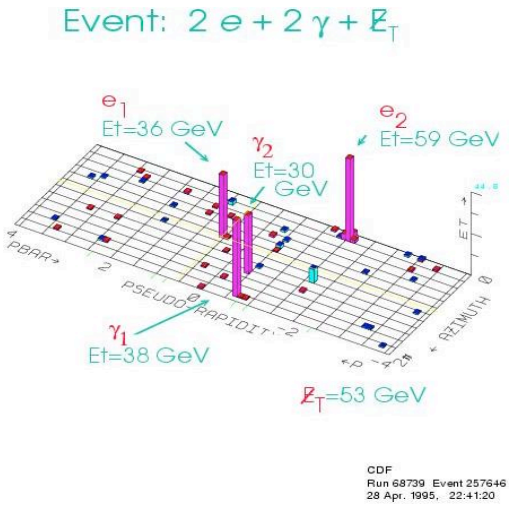
M_{ee}>100 GeV

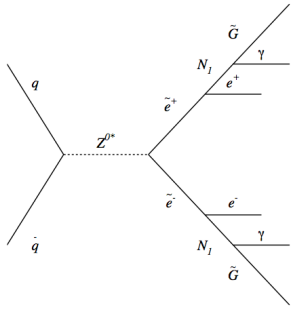
	H1 : $e^{\pm}p$ 459 pb-1	ZEUS: $e^{\pm}p$ 432 pb^{-1}
ee	3 1.5±0.3	5 4.3±1.1
eee	3 0.9±0.2	1 $1.1^{+0.5}_{-0.1}$

CDF Photon Events

- CDF Run 1: L~100 pb^{-1}
- One spectacular event:
  - ee$\gamma\gamma\not{E}_T$
  - SM expectation 10^{-6}
  - Inspired GMSB SUSY models:
    - Selectron pair production?

      [S. Ambriosano et al.]

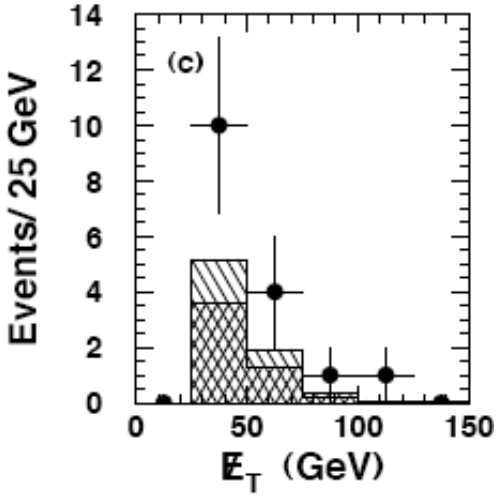


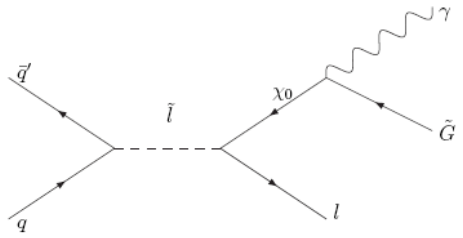


- Excess in $\mu\gamma\not{E}_T$ events
  - N_{Data}=16
  - N_{SM}= 7.6+-0.7
  - Could also be explained in GMSB with R-parity violation
    - Resonant smuon production?

      [B. Allanach et al.]

CDF Run 1: $\mu\gamma E_T$



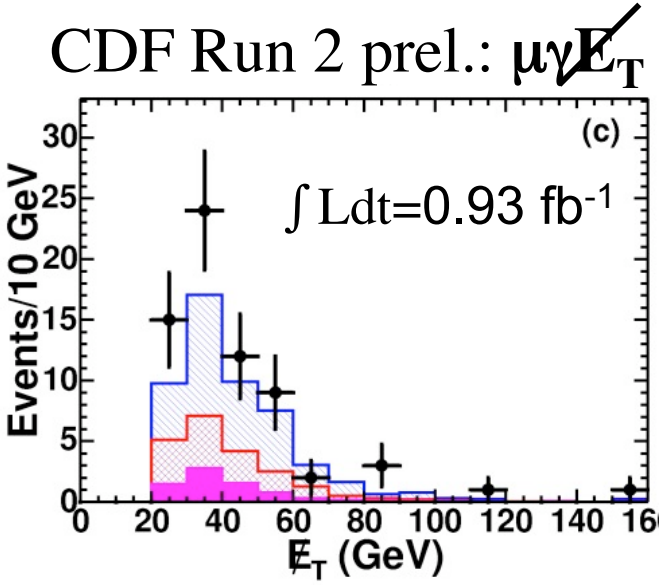


- Now follow up with 10 times more data

Follow up on Run1 CDF events

- Lepton+photon+$\not\!\!E_T$ analysis
  - Designed to use same cuts as Run 1
  - N_{Data}=67
  - N_{SM} =55.7±7.1
- ee$\gamma\gamma\not\!\!E_T$:
  - No event observed

[talk by S.-S. Yu.]



Multi-Photon + Lepton Events, $\mathcal{L} = 929$ pb^{-1}			
SM Source	$e\gamma\gamma$	$\mu\gamma\gamma$	$(e+\mu)\gamma\gamma$
$W^{\pm}\gamma\gamma$	0.021 ± 0.004	0.015 ± 0.003	0.036 ± 0.006
$Z\gamma\gamma$	0.045 ± 0.005	0.038 ± 0.005	0.083 ± 0.007
ℓee, $\ell\gamma e$, $e \to \gamma$	0.41 ± 0.12	$0^{+0.03}_{-0.0}$	0.41 ± 0.12
ℓjj, $\ell\gamma j$, $j \to \gamma$	0.05 ± 0.05	0.05 ± 0.05	0.10 ± 0.09
Total SM Prediction	$\mathbf{0.53 \pm 0.13}$	$\mathbf{0.10 \pm 0.06}$	$\mathbf{0.62 \pm 0.15}$
Observed in Data	**0**	**0**	**0**

Run 1 excesses not confirmed by Run 2 data

Search in γγ+MET Channel

- Highest MET event:
  - MET=165.1 GeV
  - Pho1 E_T=304.6 GeV (largest pho E_T)
  - Pho2 E_T=20.3 GeV
  - Jet E_T=143.6 GeV
  - H_T=633.6 GeV (2nd largest H_T)
  - N_{vx}=1, z_{vx}=-25.6 cm