Beyond the Standard Model - experimental

$$\delta(M_H^2) = -(\frac{\Lambda}{0.7TeV}200GeV)^2$$

New physics around ~ TeV?

Here searches for BSM in:

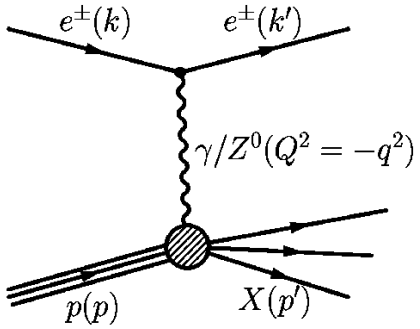
- Supersymmetry
- Compositeness models
- Extra dimensions, Z',W'

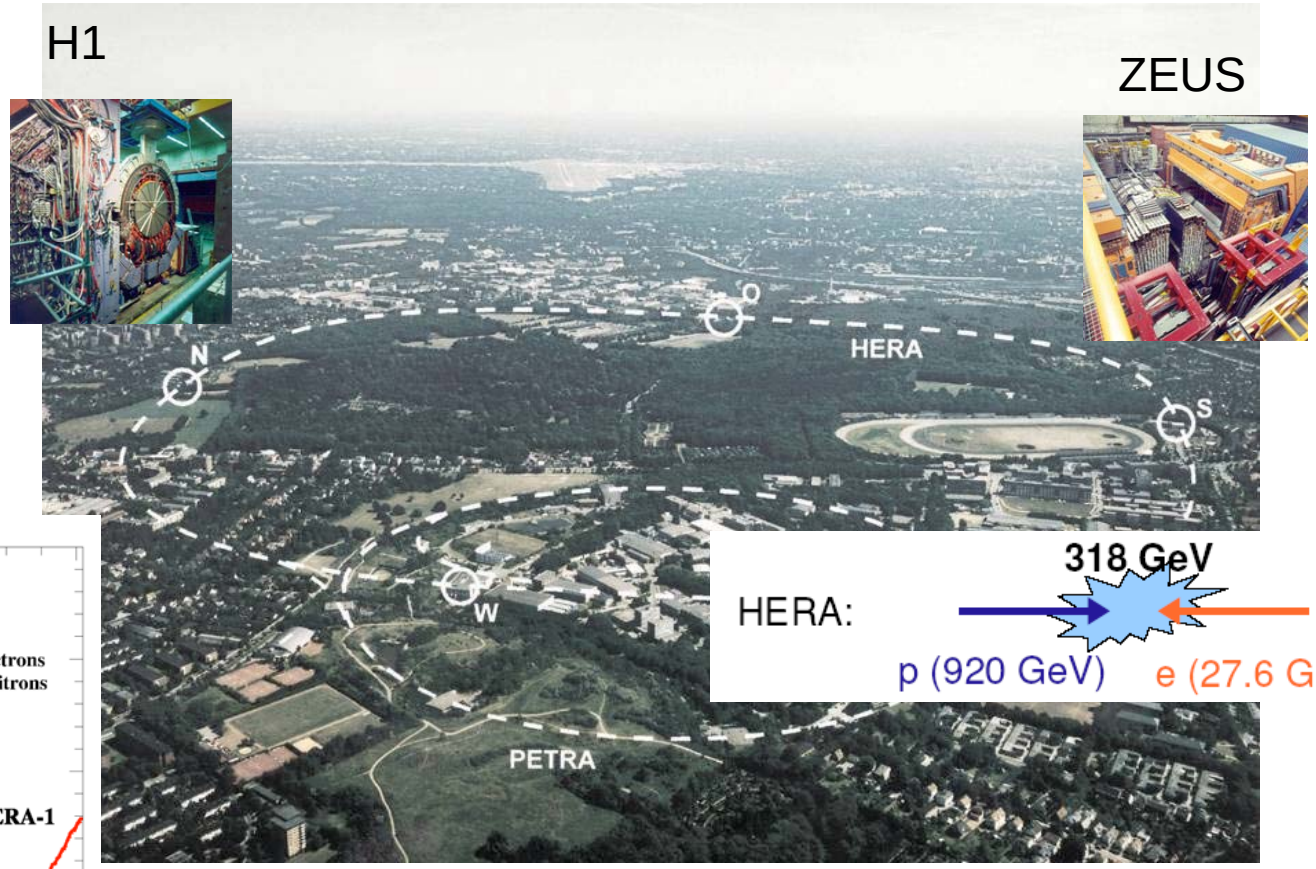
and some special signatures:

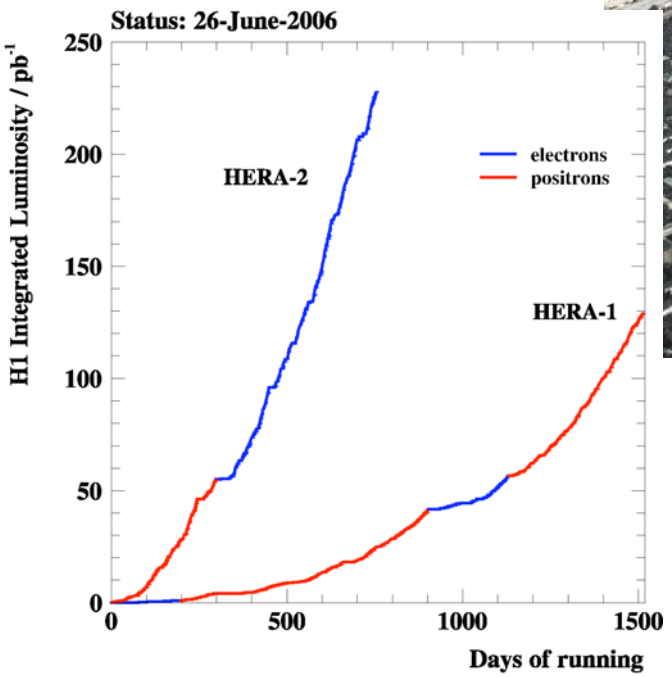
- isolated leptons at HERA

Searches at Tevatron, HERA and some prospects at LHC (no SM Higgs, no MSSM Higgs, See Tevatron and LHC talks)

The experiments: at HERA







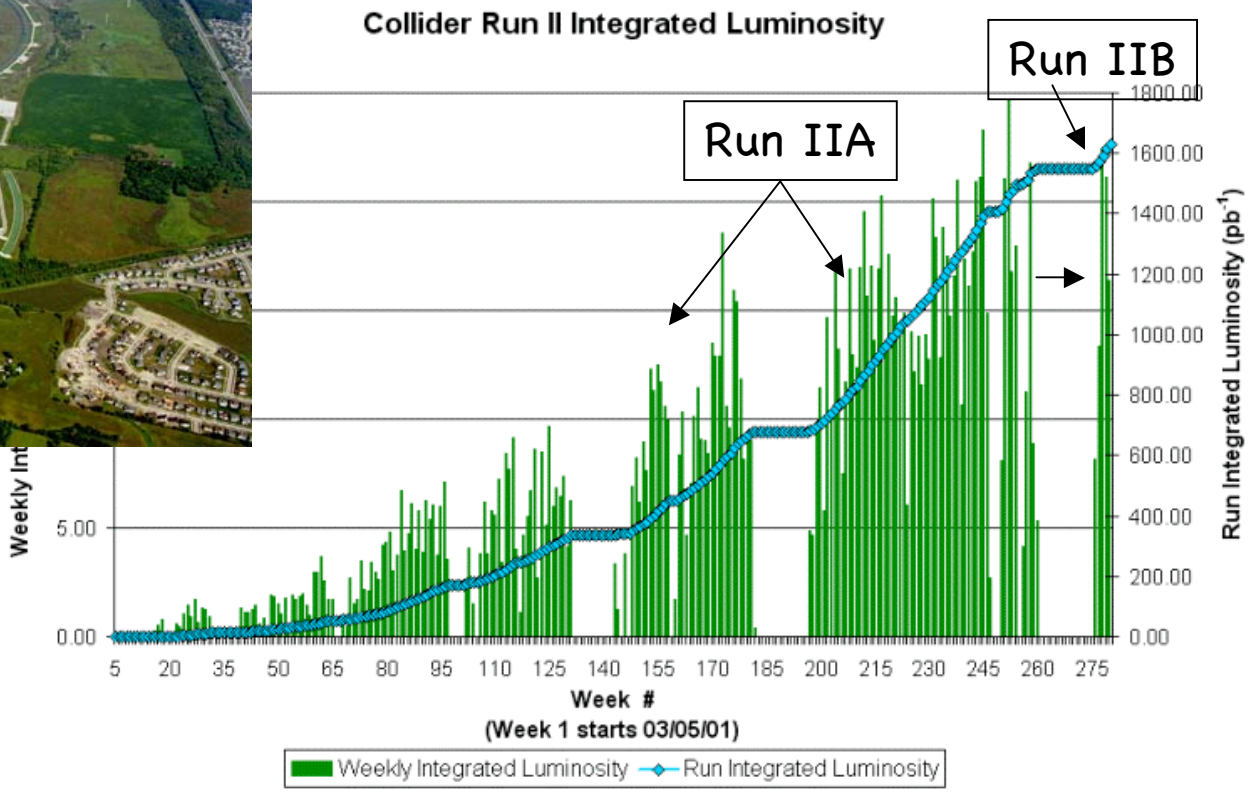
HERA II results covered here, or
HERA I+II up to ~350 pb^{-1}

The experiments: at Tevatron

Tevatron II results covered here up to

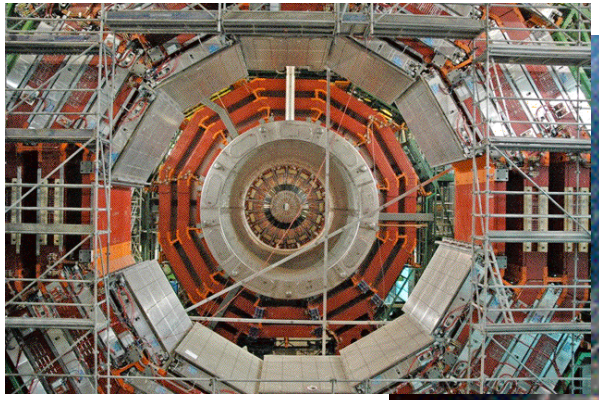
~1.2 fb^{-1}

$\sqrt{s}$ = 1.96 TeV

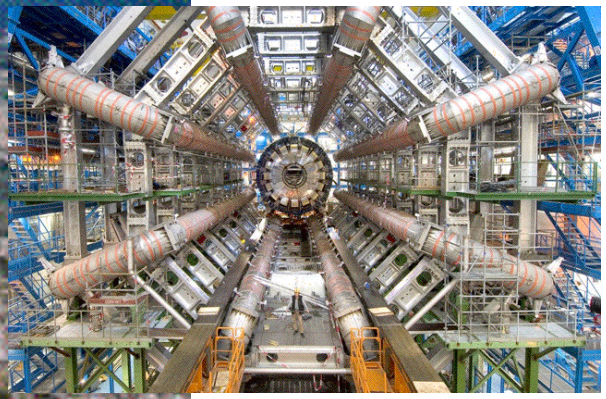


The experiments: at LHC, prospects

CMS



ATLAS



Proton-proton collider, $\sqrt{s}$ = 14 TeV

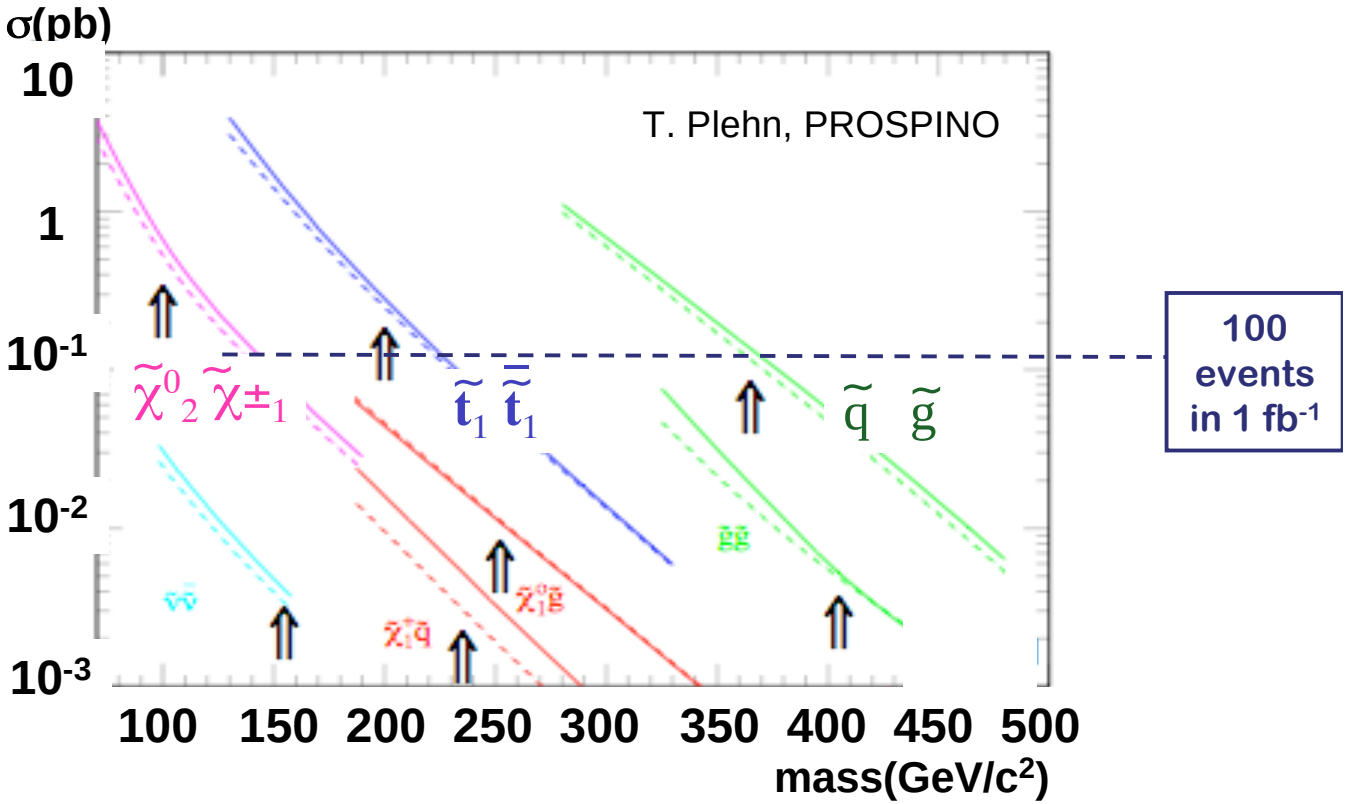
Low luminosity phase: L = $2X10^{33}$ cm^{-2} sec^{-1}

High luminosity phase: L = 10^{34} cm^{-2} sec^{-1} (100 fb^{-1} /yr)

Why SUperSYmmetry

- It solves the hierarchy problem
- provides unification at the GUT scale
- may provide a Dark Matter candidate (the LSP)

- Cross sections are small, but not impossible, i.e. at TeVatron ⟶
- Need to model and understand very well SM background, challenging analyses



SM and SUSY particles

e μ τ ν_e ν_μ ν_τ u c t d s b	$R_p=+1$	$\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$ $\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$ $\tilde{u}$ $\tilde{c}$ $\tilde{t}$ $\tilde{d}$ $\tilde{s}$ $\tilde{b}$	$R_p=-1$ sleptons squarks
$W^\pm$ $H^\pm$ γ h^0 H^0 A^0 Z g, G		$\tilde{\chi}^\pm_{1,2}$ $\tilde{\chi}^0_{1,2,3,4}$ $\tilde{g}$ $\tilde{G}$	charginos neutralinos gluino, gravitino

MSSM: $R_p=(-1)^{(3B+L+2S)}$ conserved, LSP is usually the lightest neutralino; 2 Higgs doublets, 5 Higgs, described by m_A and tanβ at tree level; > 100 parameters; M(electron)≠M(selectron), SUSY is a broken symmetry

SUSY models

R-parity is conserved:

- sparticles are produced in pairs
- LSP is stable (lightest neutralino)
- sparticles at the end decay in LSP

Missing E_T (MET) topology

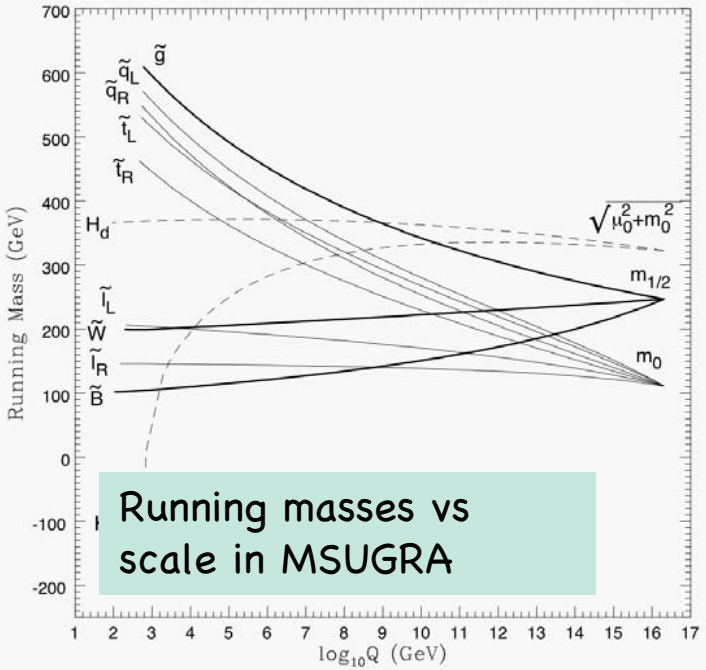
Searches at Tevatron

Some Susy Breaking mechanisms models:

- mSUGRA: m_0 , $m_{1/2}$, A_0 tanβ, sign(μ)
- GMSB
- split SUSY

EW scale

GUT scale



Running masses vs scale in MSUGRA

R-parity is not conserved:

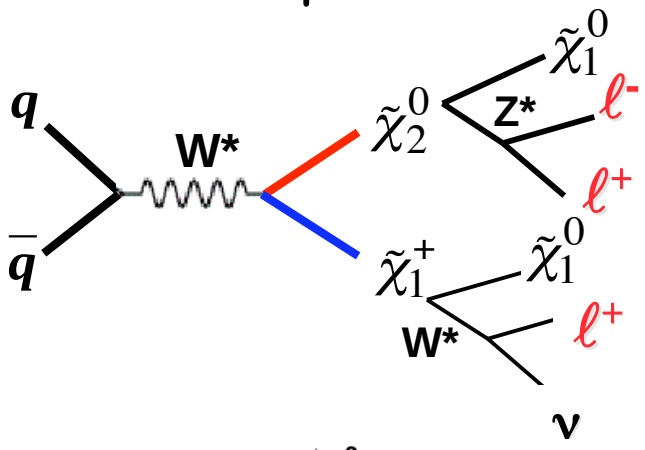
- sparticle can be produced singly

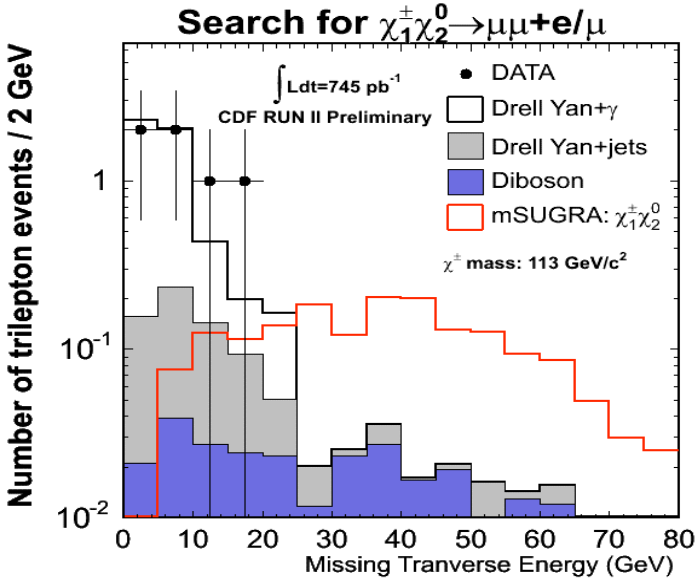
Also possible at HERA

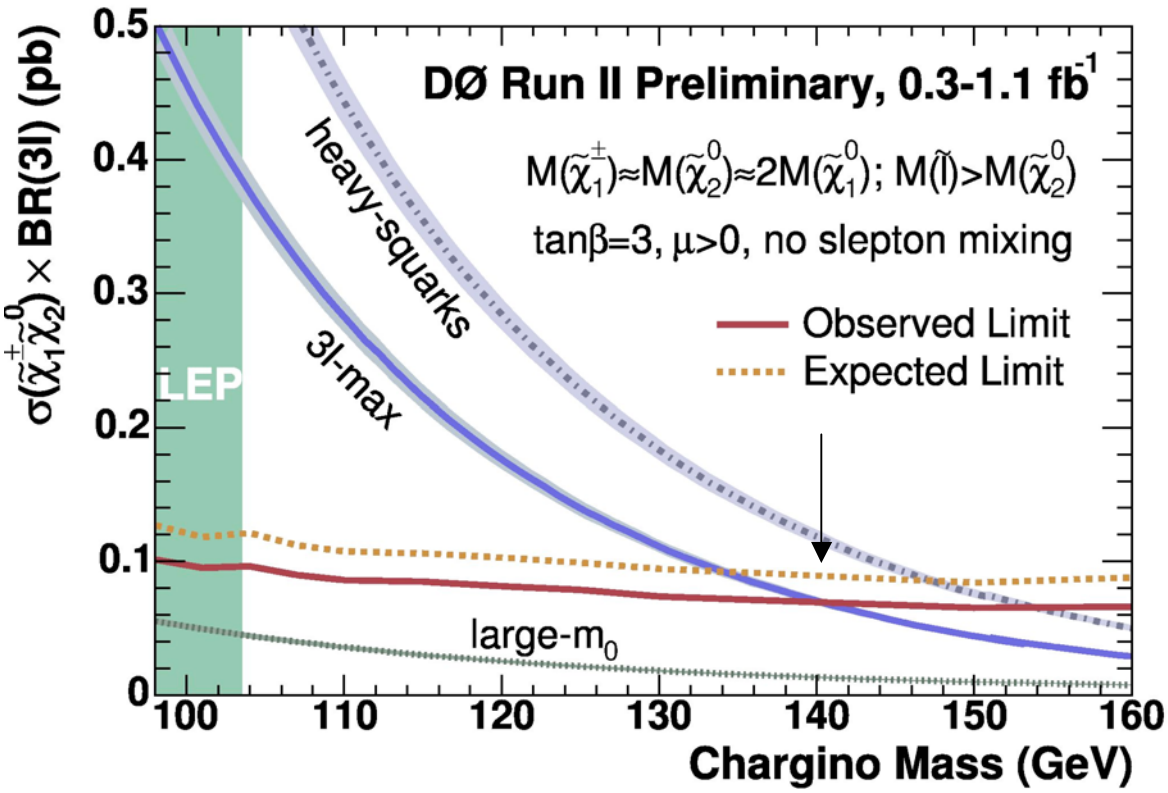
Search for charginos/neutralinos at Tevatron

Golden signature at Tevatron
Low background, but low rate
Require 2-3 leptons

$$M(\tilde{\chi}^{\pm}) > 127(CDF) - 140(D0)\,GeV$$

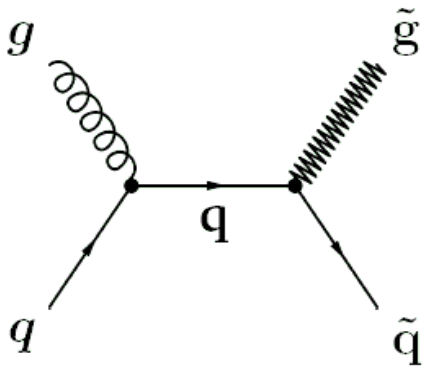






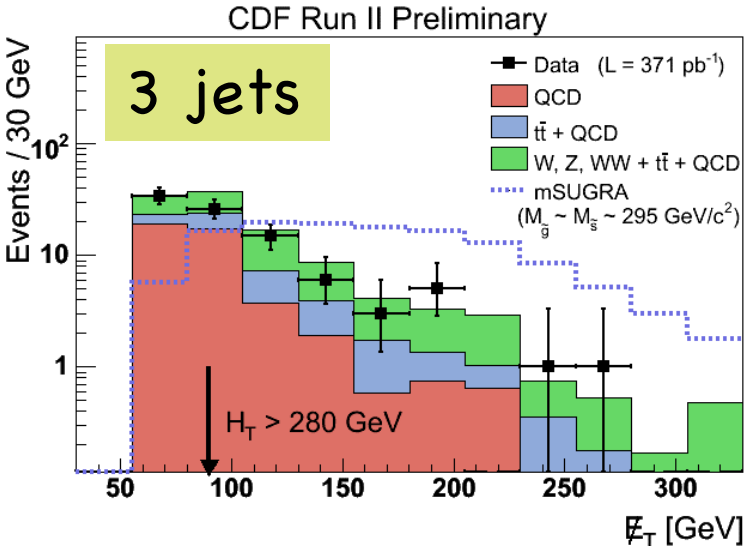
Search for squarks/gluinos at Tevatron

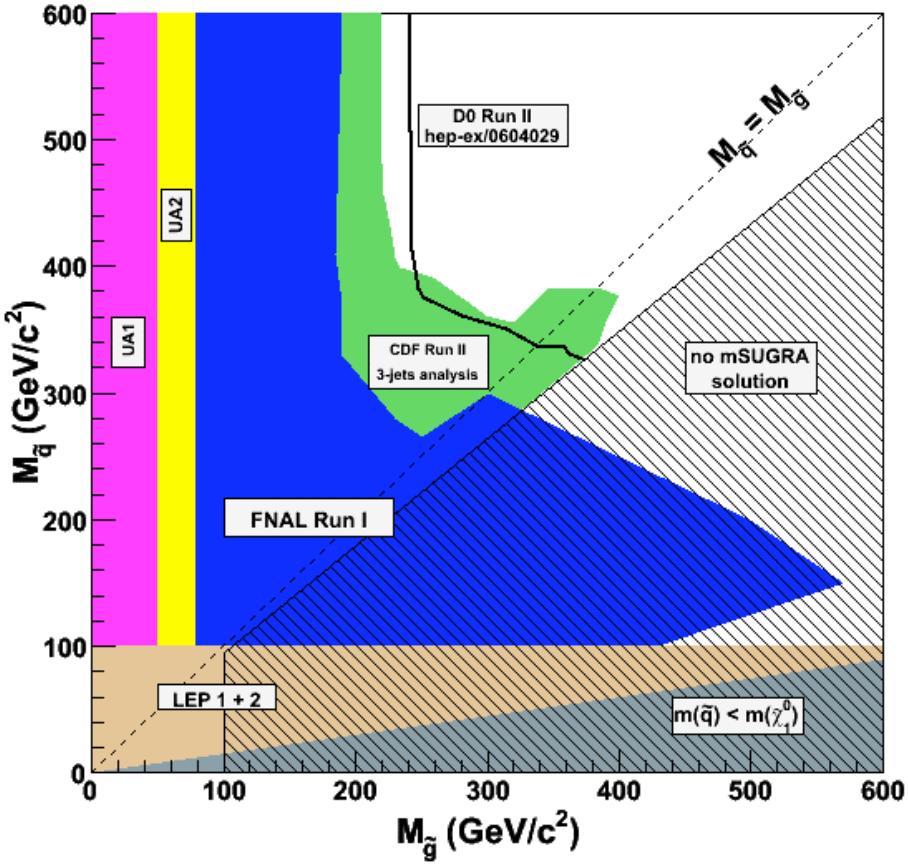
- large cross-section, but large background, example→ of production for m(squark)~m(gluino)



$$\tilde{q} \rightarrow q\tilde{\chi}_1^0$$

$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$$





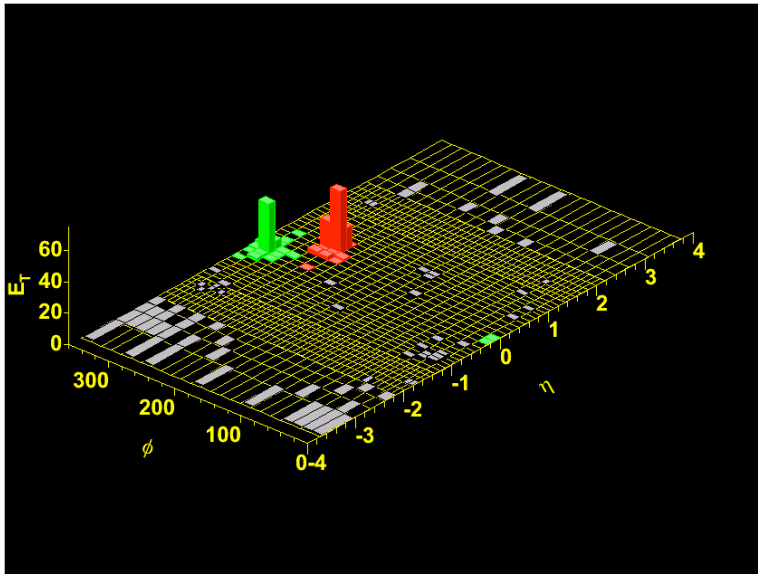
M(squark)> 325 GeV

M(gluino)> 241 GEV @95% CL

>387 GeV for equal masses

Search for RPC stop/sbottom at Tevatron

- For 3rd gen squarks, large mixing in the L- and R-handed weak eigenstates could lead to light stop or sbottom quark.

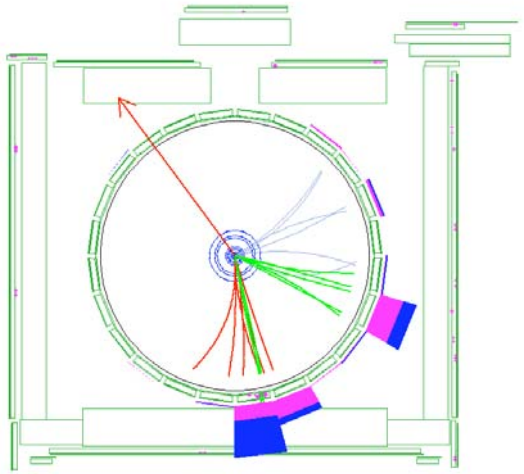


- Produced in pairs at Tevatron for Rp conserving (RPC), cross section could be high.

- Assume they decay in q+LSP

$$p\bar{p} \rightarrow \tilde{t}_1\bar{\tilde{t}}_1 \rightarrow c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$$

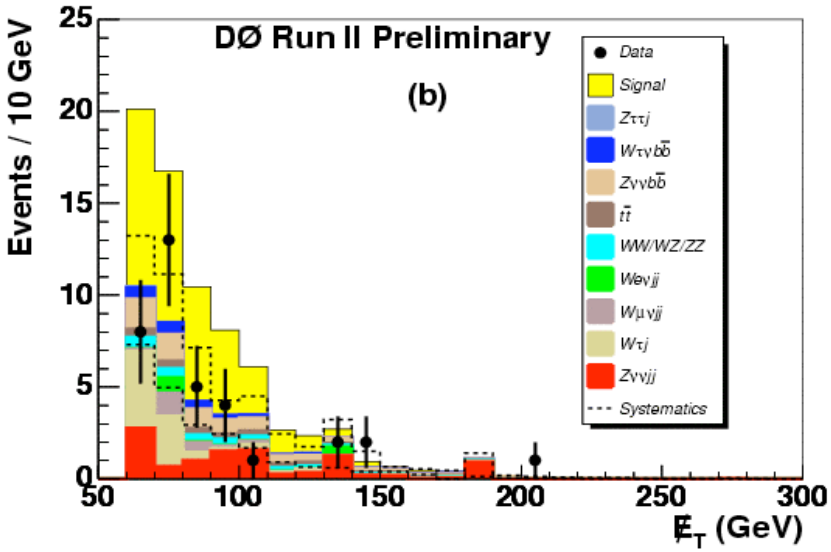
$$p\bar{p} \rightarrow \tilde{b}_1\bar{\tilde{b}}_1 \rightarrow b\tilde{\chi}_1^0\bar{b}\tilde{\chi}_1^0$$



i.e. two acoplanar b-jets and MET

Search for RPC sbottom at Tevatron

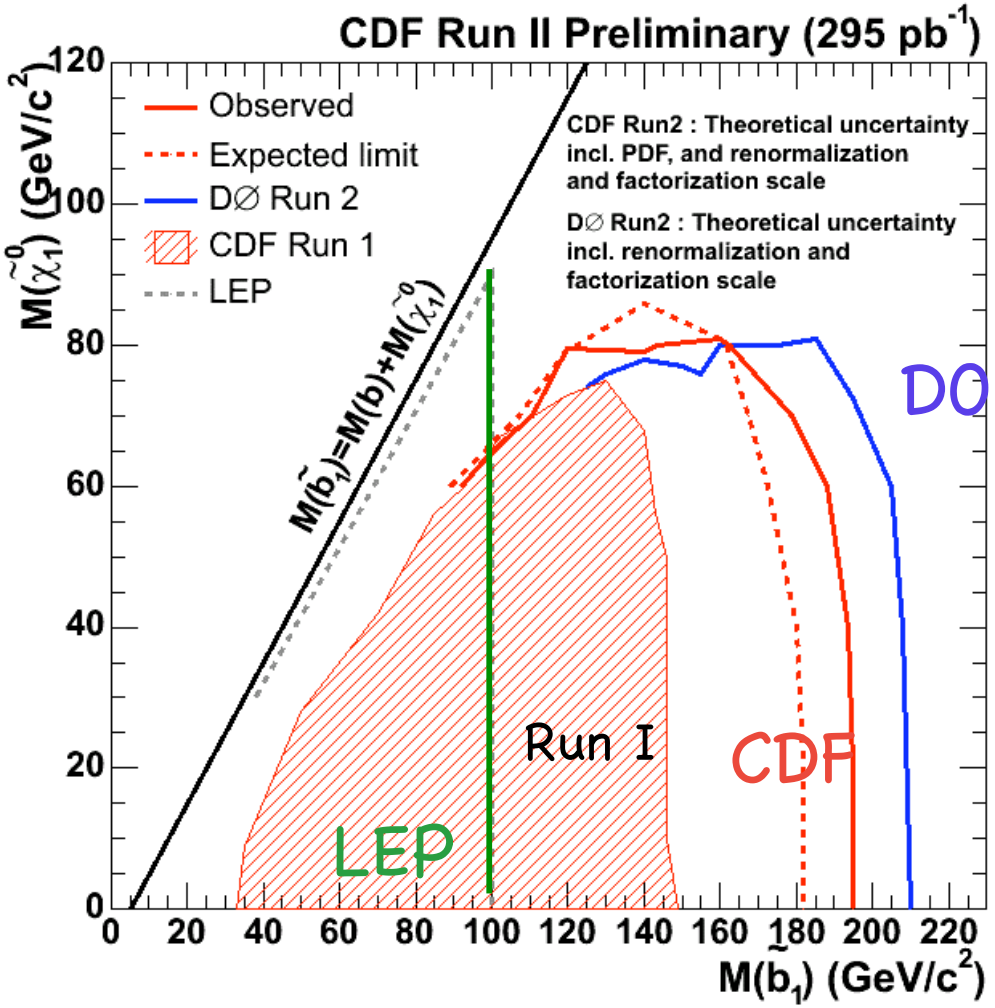
$$p\bar{p} \rightarrow \tilde{b}_1\bar{\tilde{b}}_1 \rightarrow b\tilde{\chi}_1^0\bar{b}\tilde{\chi}_1^0$$



After b-tagging

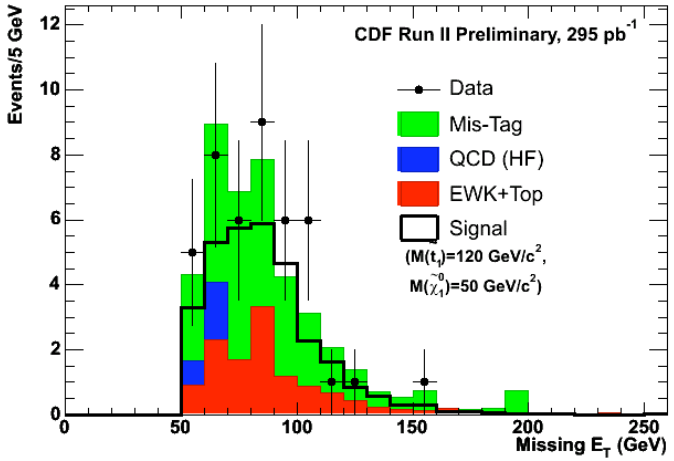
Dominant backg is W/Z+jets

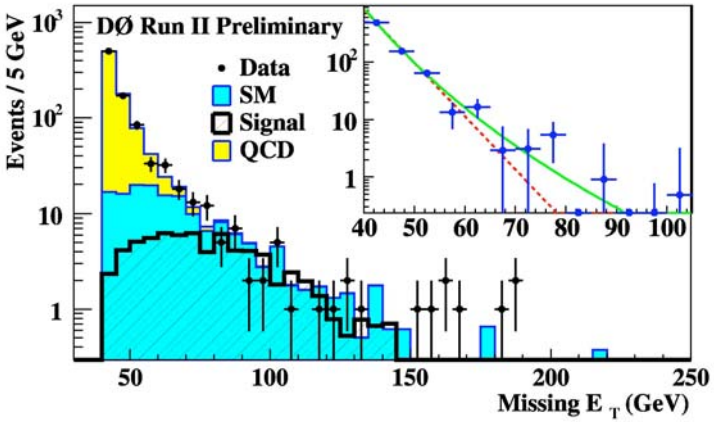
No excess observed, previous limits are improved

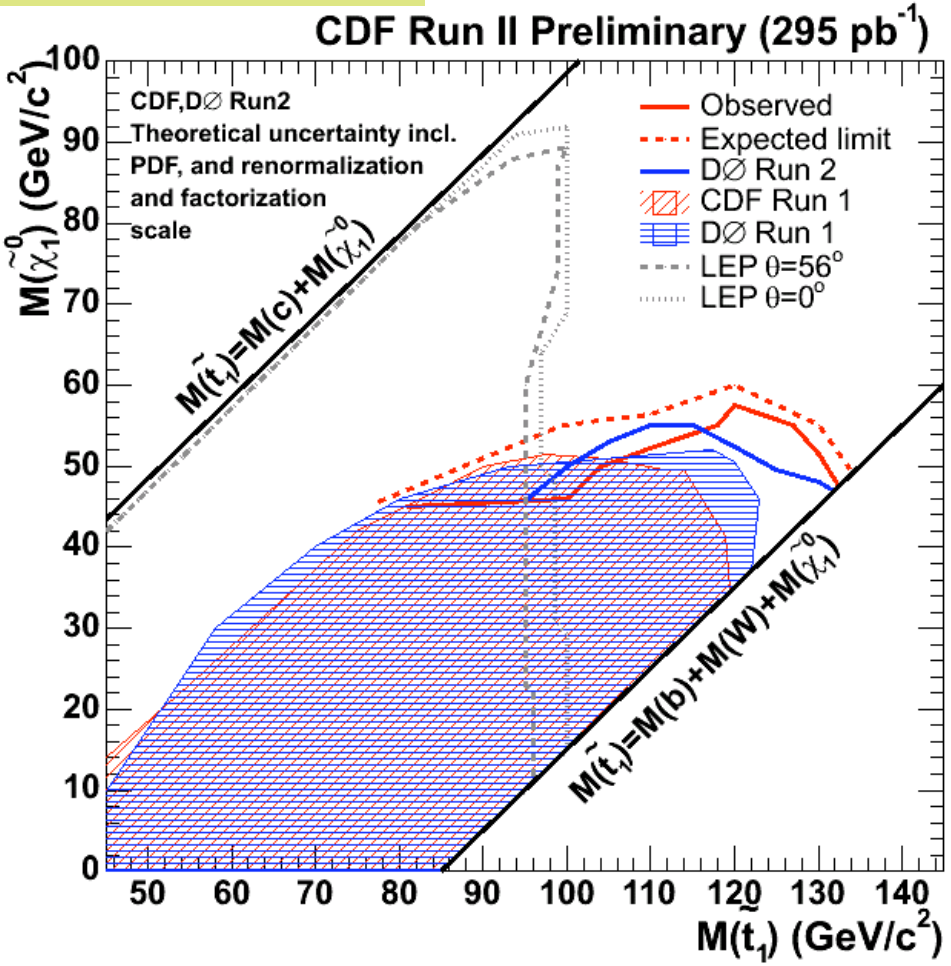


Search for RPC stop at Tevatron

$$p\bar{p} \rightarrow \tilde{t}_1\bar{\tilde{t}}_1 \rightarrow c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$$







Main SM backg is W/Z+jets

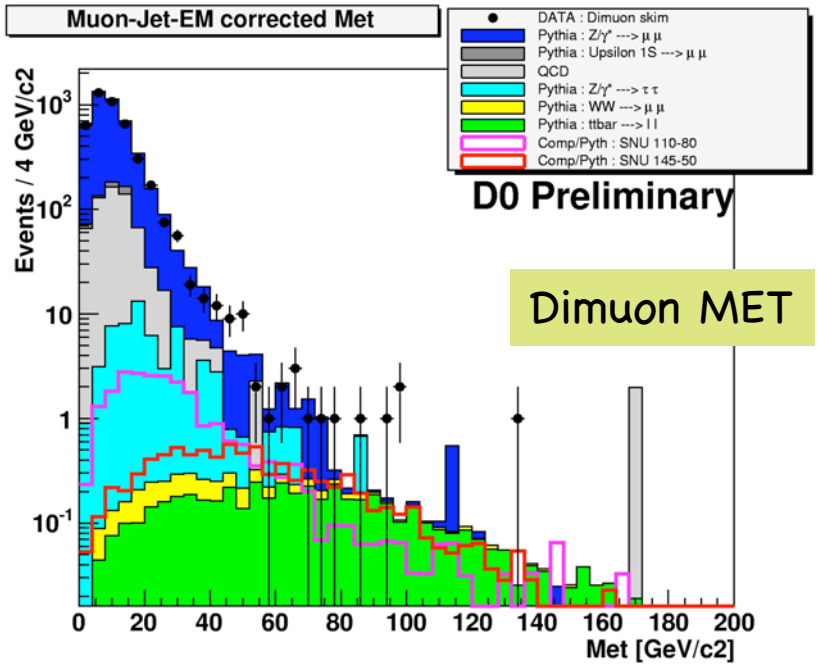
D0: 8 obs./3 exp. At MET>150 GeV

But not in the stop signal region

Largest stop mass excluded is

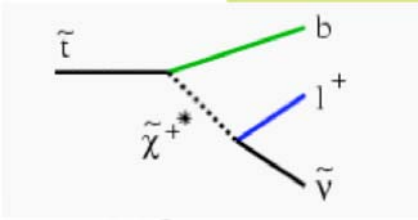
>131 GeV for M(neutralino)=46 GeV

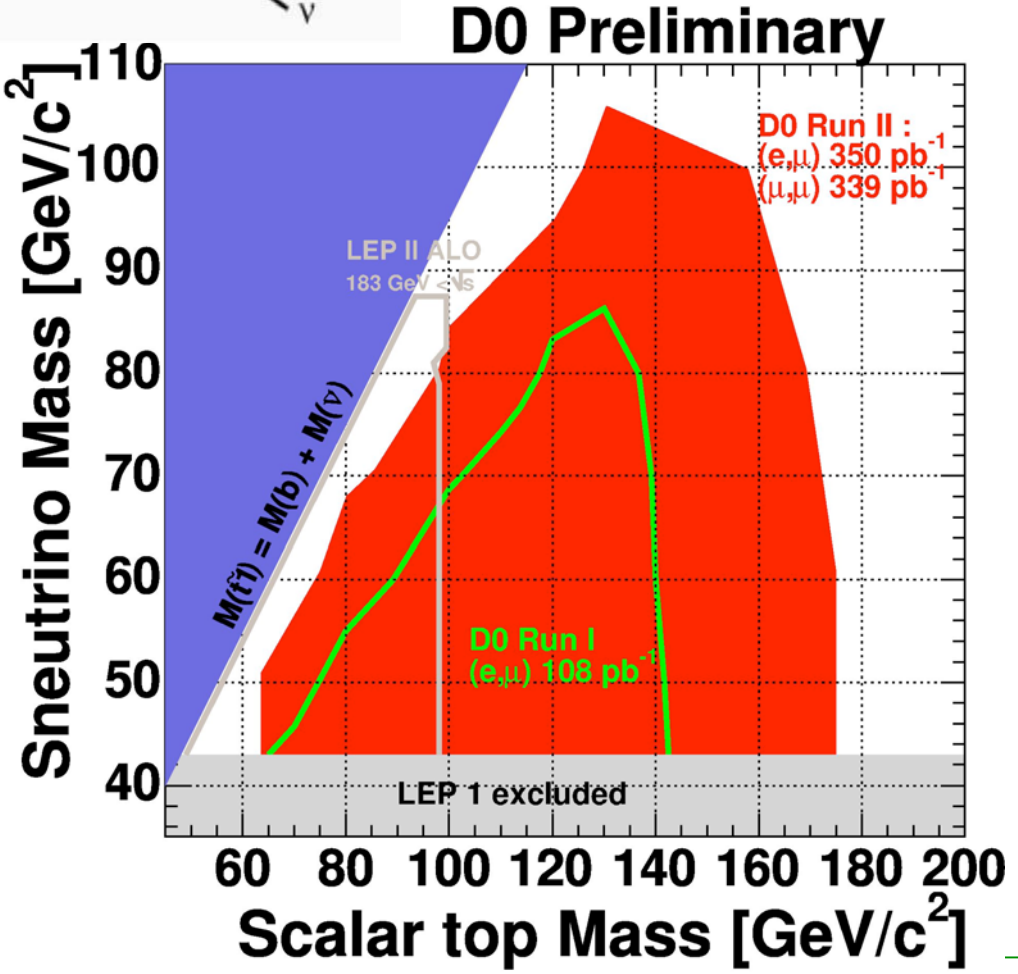
Search for stop in b-l-sneutrino



Dimuon MET

$$p\bar{p} \rightarrow \tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\tilde{\chi}^+\,\bar{b}\,\tilde{\chi}^+, \chi^+ \rightarrow \tilde{\nu}\,l$$





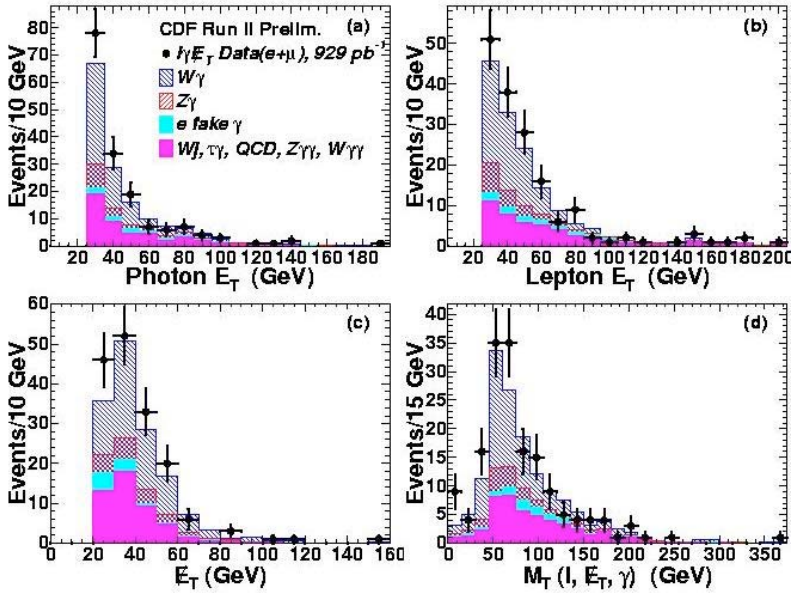
- Two channels considered: dimuon, e-muon
- Require also loose b-tagged jet, MET, acoplanarity
- Stringent limits on M(stop), 175 GeV for a sneutrino mass of 60 GeV

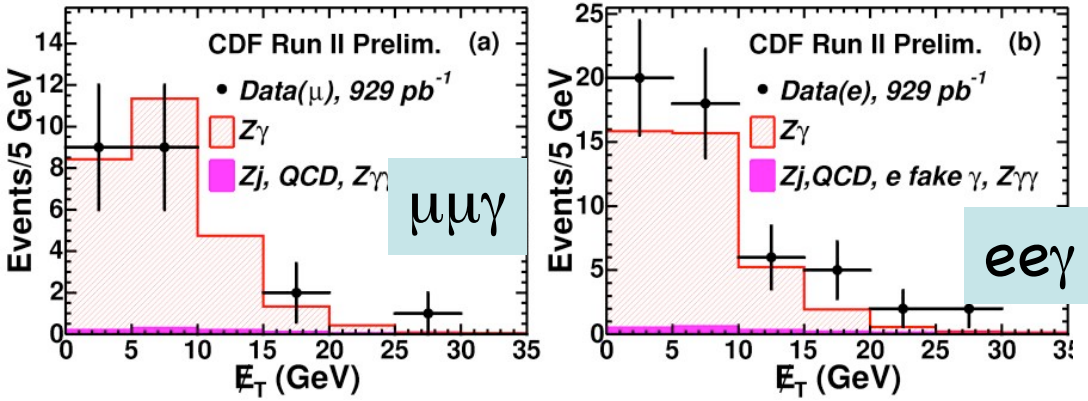
Lepton(s)+photon(s)+MET events at TeVatron

- 1 spectacular event eeγγ+MET observed in CDF I (55 GeV MET, expected in SM from WWγγ was 10^{-6} events).
- CDF in Run I observed 16 events lepton+γ+MET, 7.6±0.7, 2.7 sigma effect
- Possible explanation for the 1 event was GMSB:

$$p\bar{p} \to \tilde{e}\tilde{e} \to ee\tilde{\chi}_2^0\tilde{\chi}_2^0 \to ee\gamma\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$$

lγMET



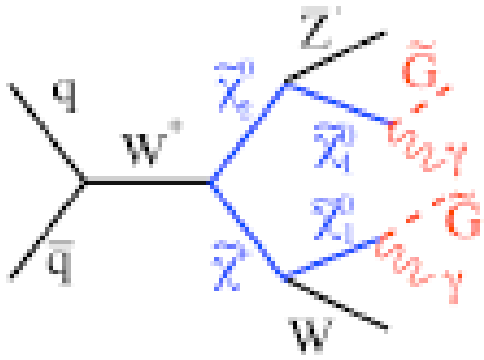


Multilept.+photon: 74 obs/64.9±7.7 exp - highest MET observed is <30 GeV, no event like eeγγMET

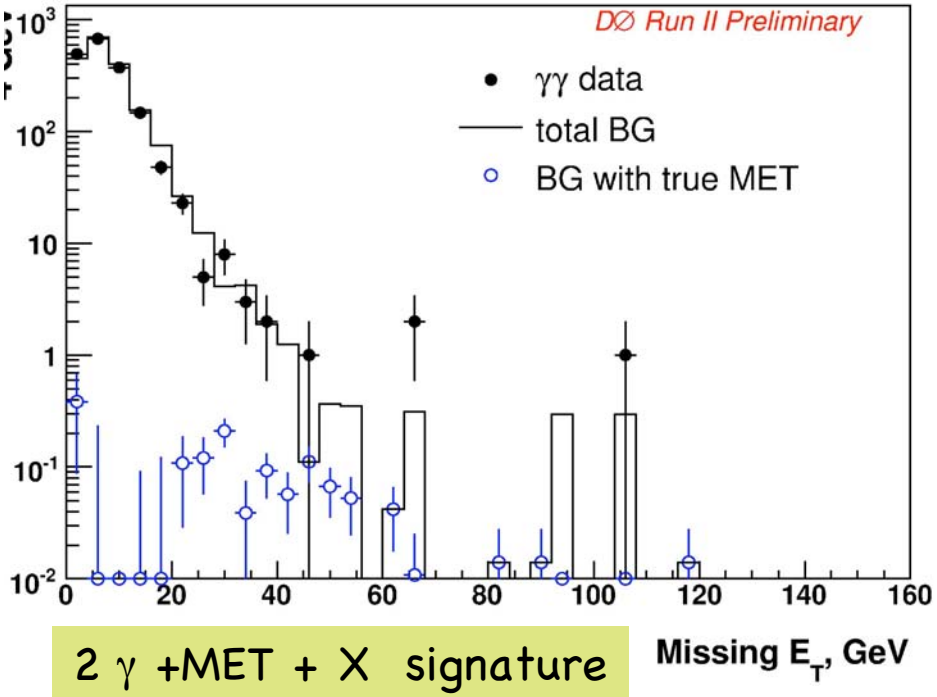
163 obs/148.1 ±13.0 exp

GMSB searches at Tevatron

- search in the $\gamma\gamma$+MET topology
- Rp is conserved, NLSP is lightest neutralino, gravitino is the LSP, NLSP decays in LSP+γ

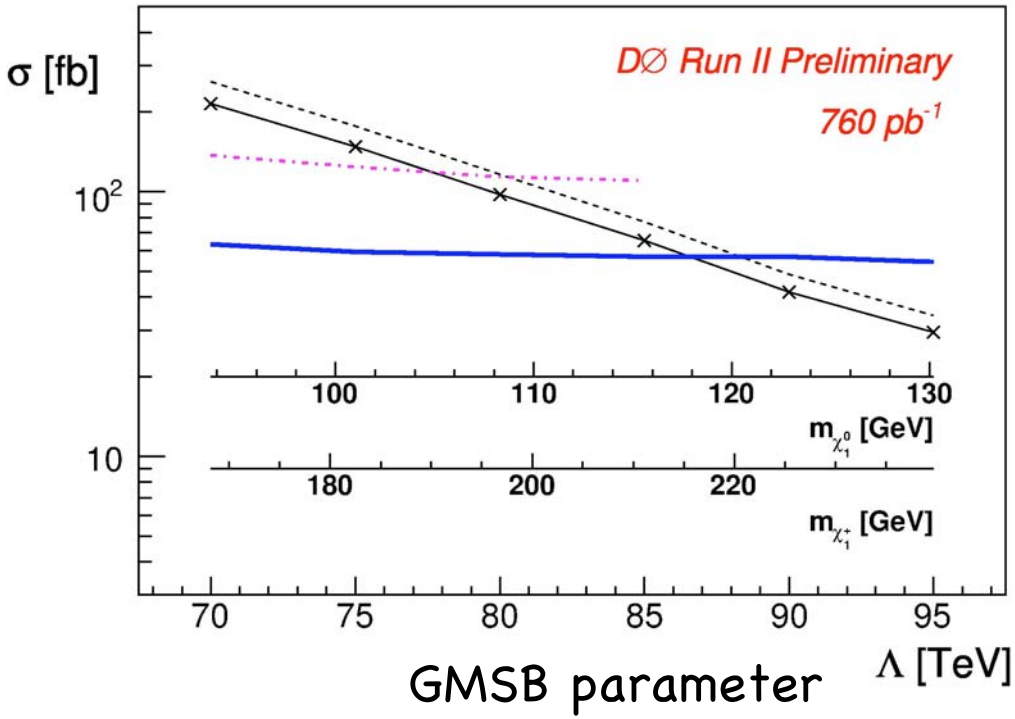


$m(\chi_1^{\pm})>220$ GeV/c^2, $m(\chi_1^0)>120$ GeV/c^2



2 γ +MET + X signature

4 obs./2.1±0.7 exp

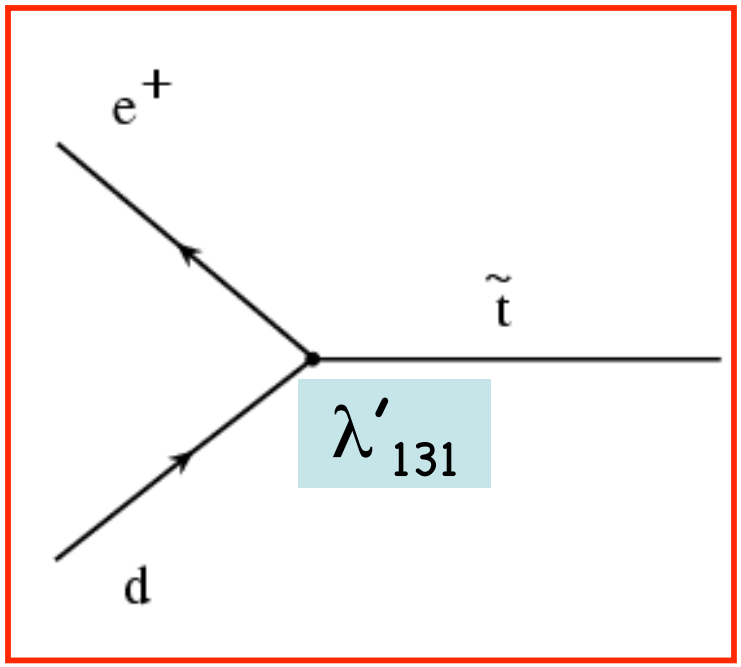


Search for R-parity violation SUSY

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

- 45 more parameters, assume one dominates
- LSP is not stable, more complicated topologies (no missing E_T)
- sparticle can be produced singly
- RPV is also possible at HERA

  i.e. λ'_{131}

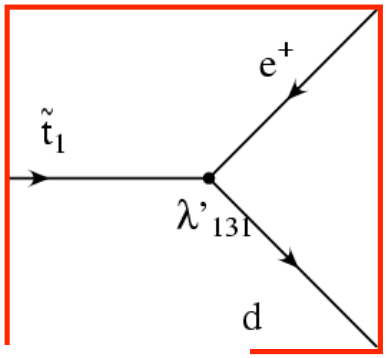


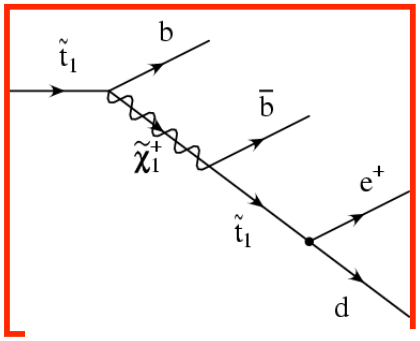
Search for RPV stop at HERA

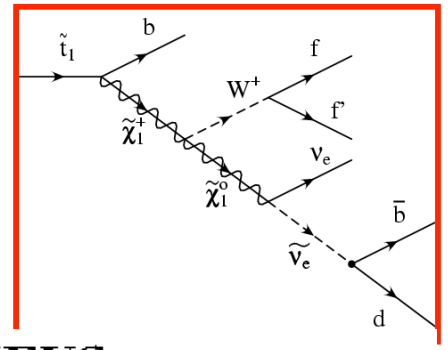
Σ decays~ 70%

search in eJ, eMJ,

νMJ final states



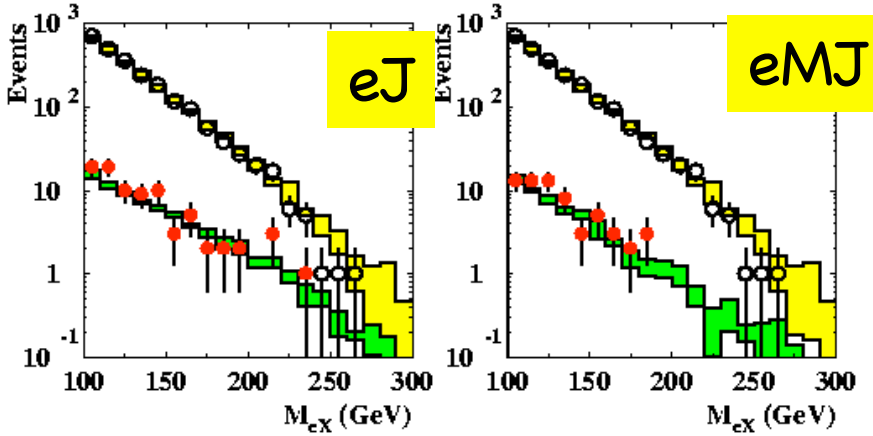




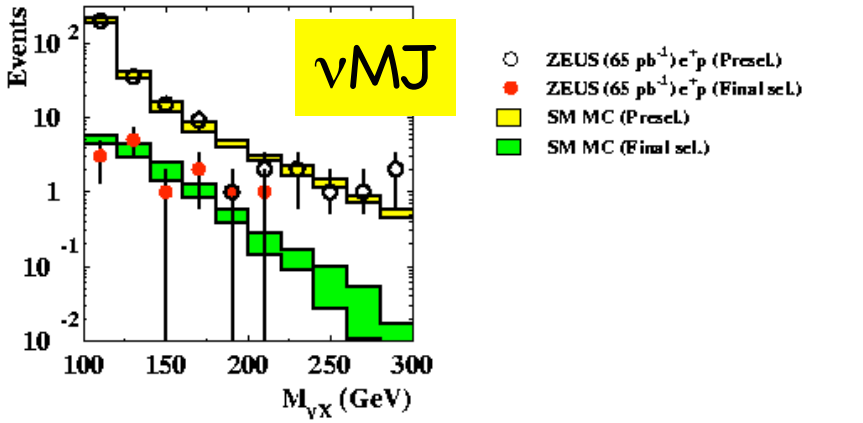
ZEUS

eJ

eMJ

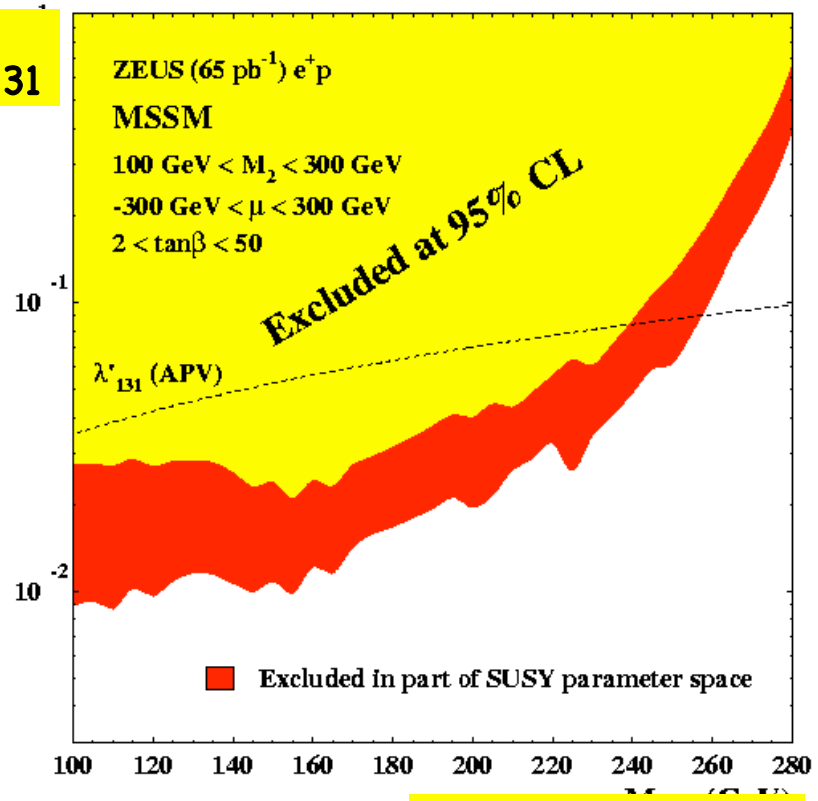


νMJ



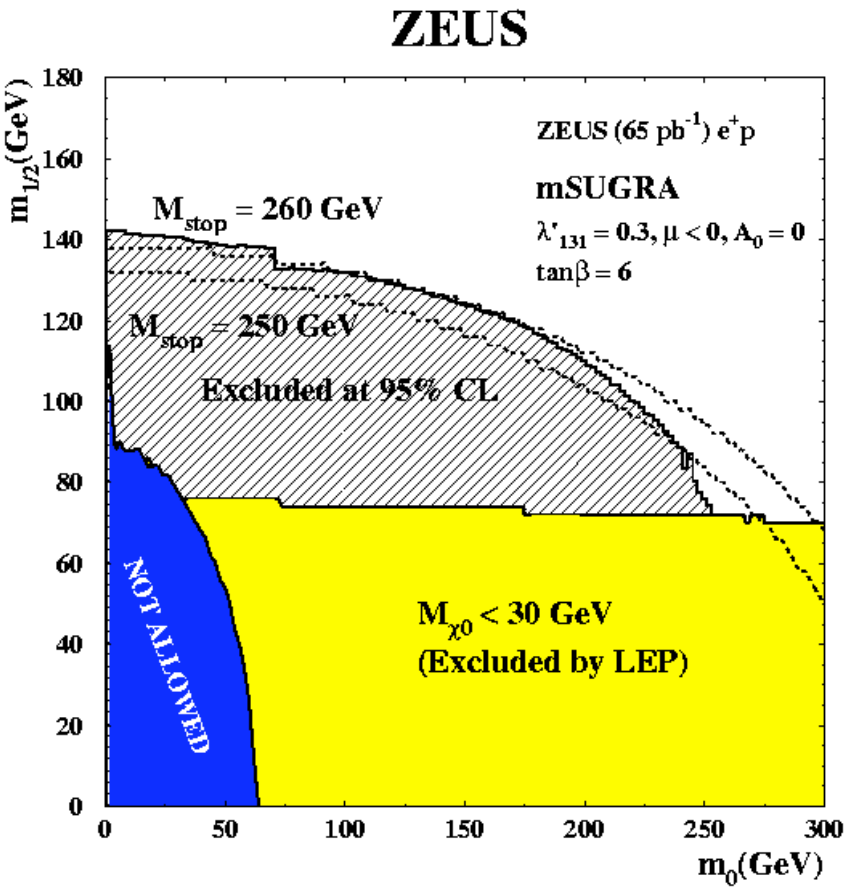
ZEUS

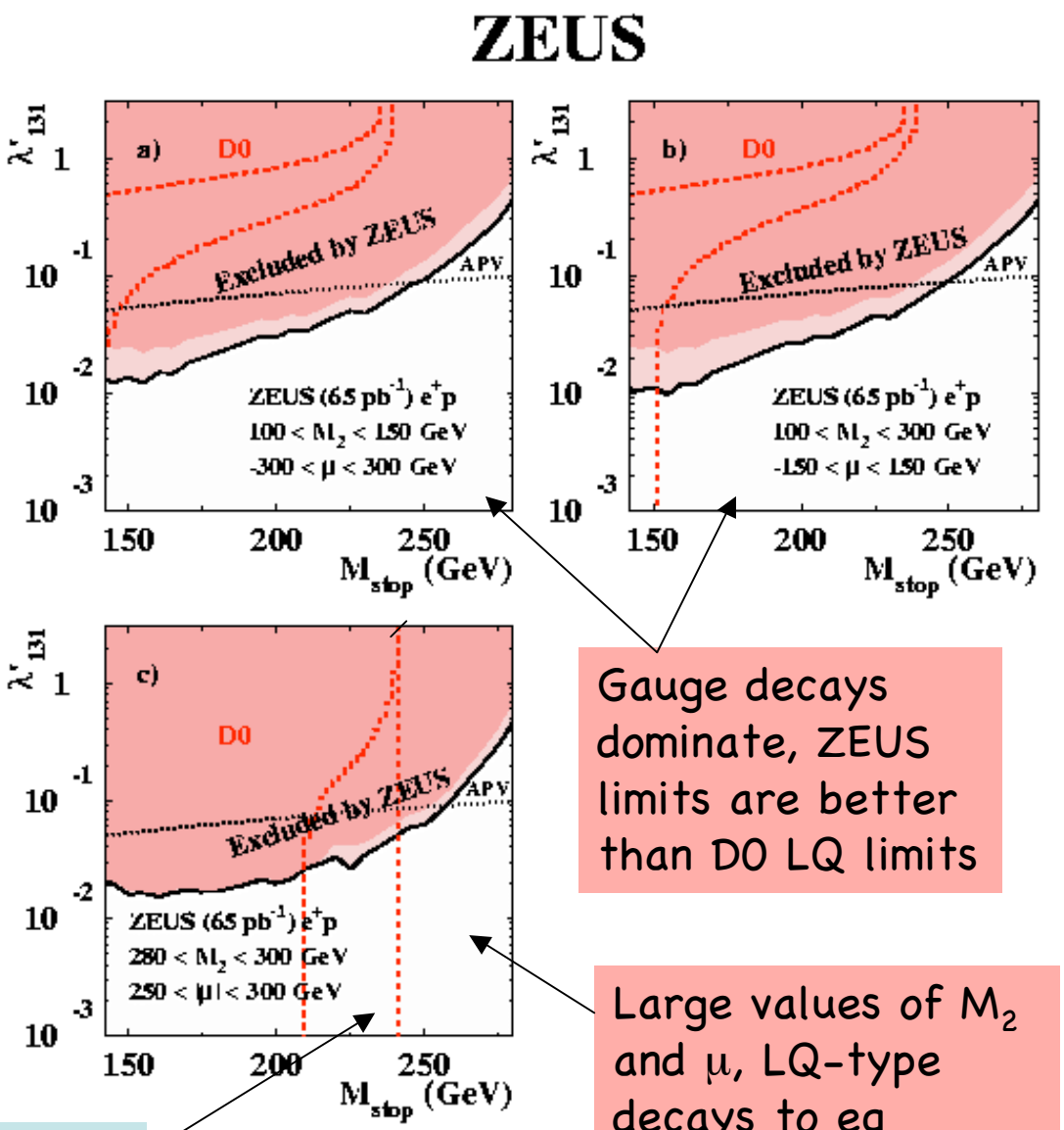
λ'_{131}



M(stop) GeV

Search for RPV stop at HERA/Tevatron





For λ'_{131}=0.3, M(stop) excluded up to ~260 GeV in large mSUGRA parameter space

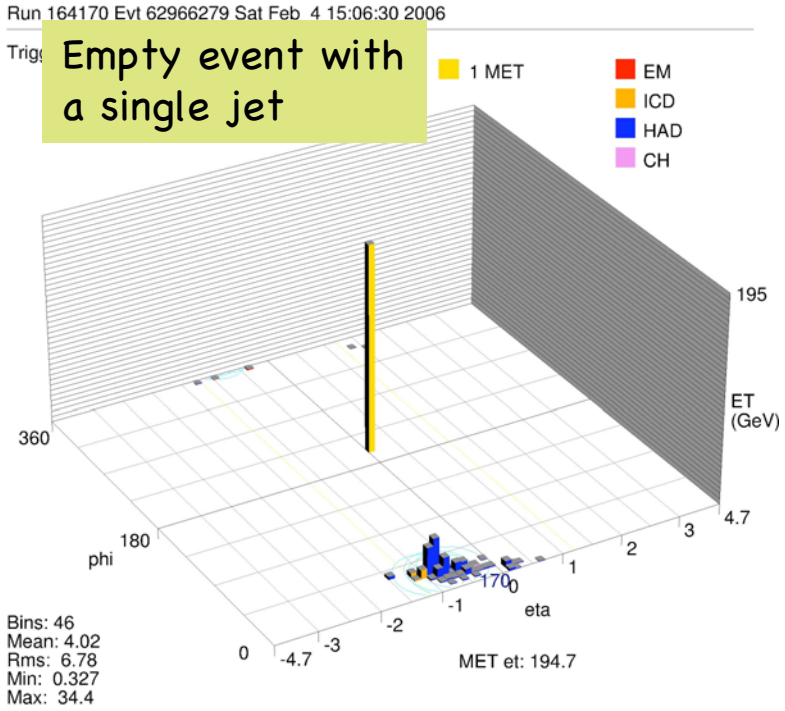
Gauge decays dominate, ZEUS limits are better than D0 LQ limits

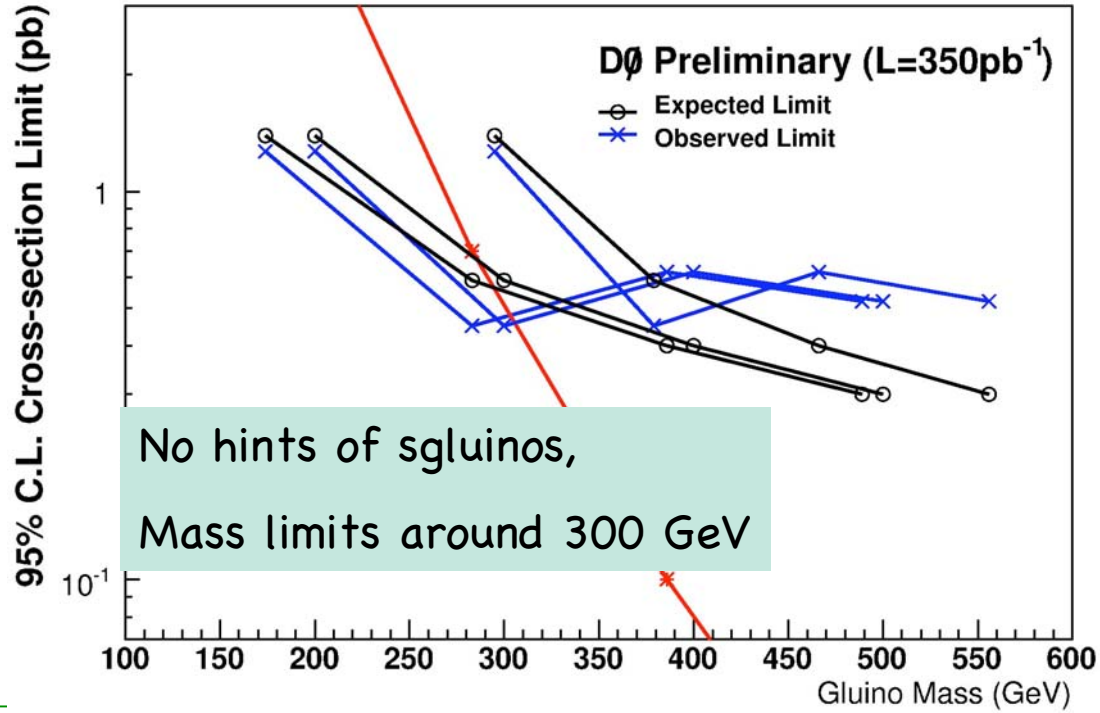
Large values of M_2 and μ, LQ-type decays to eq dominates, D0 limits are better

D0 II limit on M(LQ→eq)

Search for stopped gluino in split-SUSY

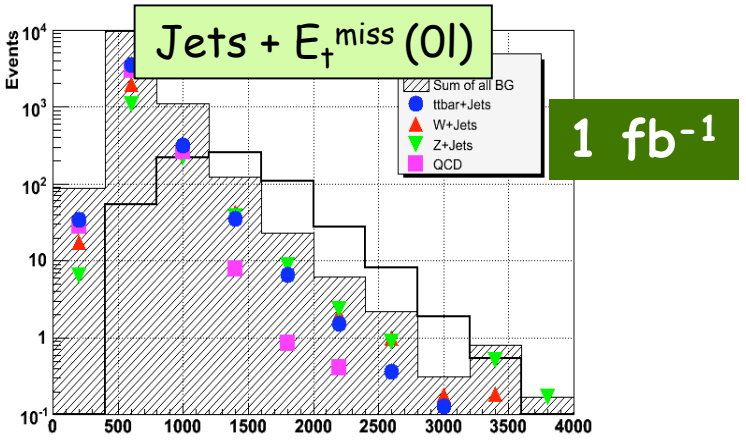
- split SUSY: scalars are heavy, fermions are light
- Gluino cannot decay in squarks and is long-lived. It hadronizes is R-hadrons. These R-hadrons come at rest in the calorimeter (stopped gluino) and decay later in gluon-neutralino, out of sync with the beam crossing.

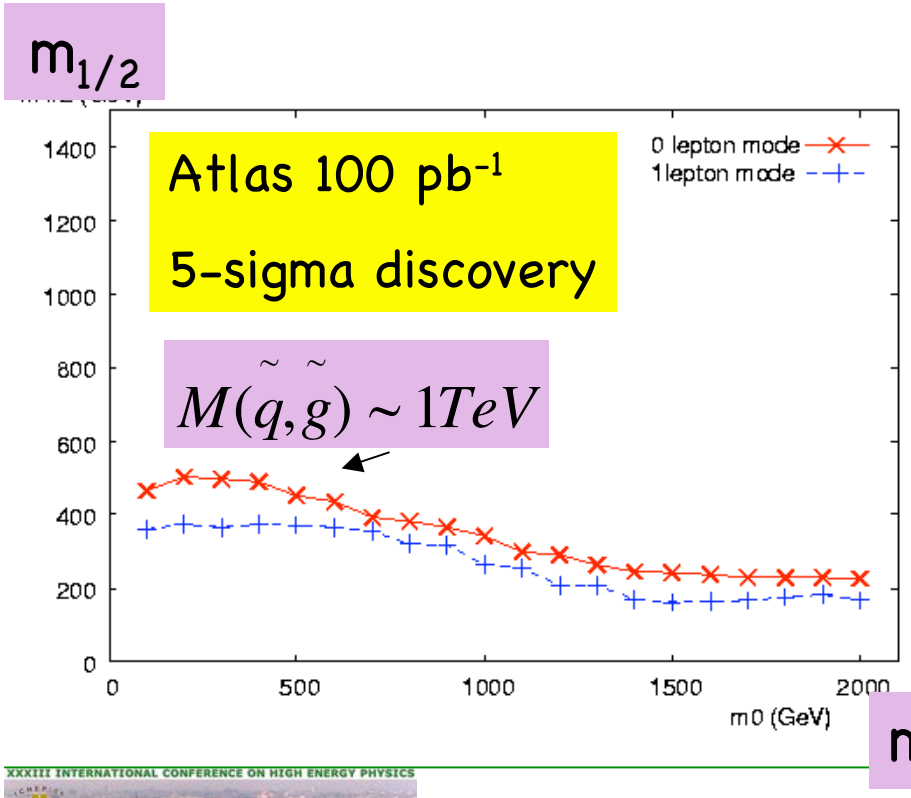


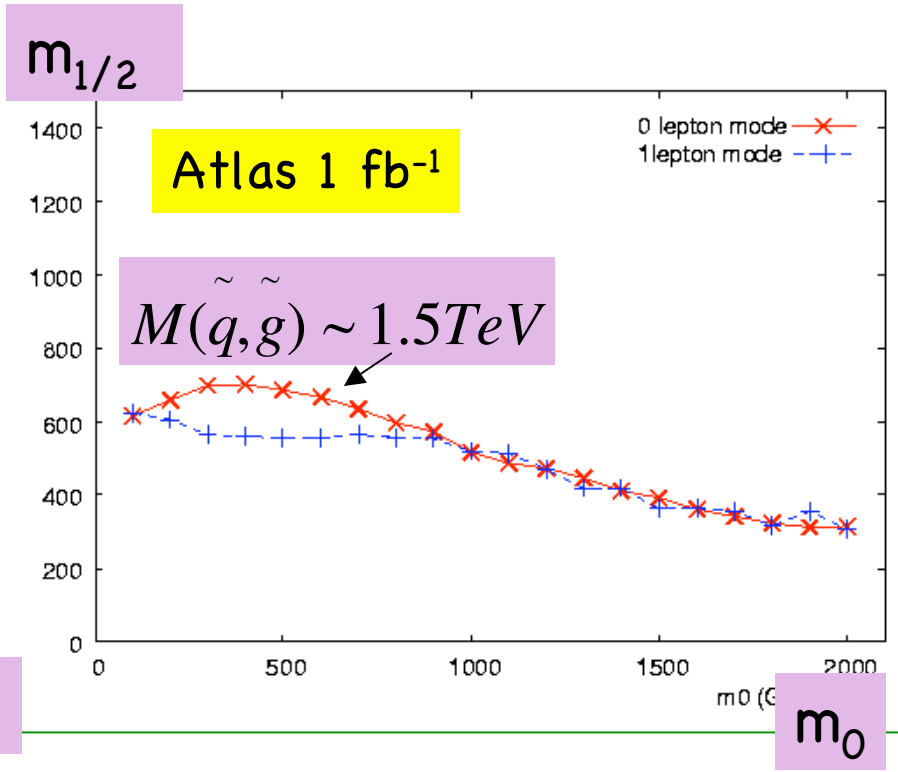


SUSY prospects at LHC

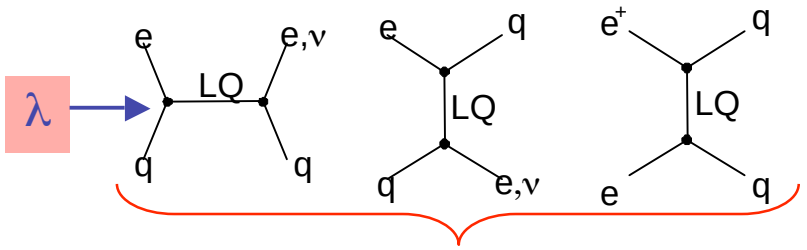
LEP SUSY limits improved by Tevatron
LHC: with 1 fb^{-1} of data possible discovery of squark and gluino below 1.5 TeV. Missing Et fundamental variable, importance of understanding SM processes ($M_{eff}=\Sigma p_T+MET$) ⟶



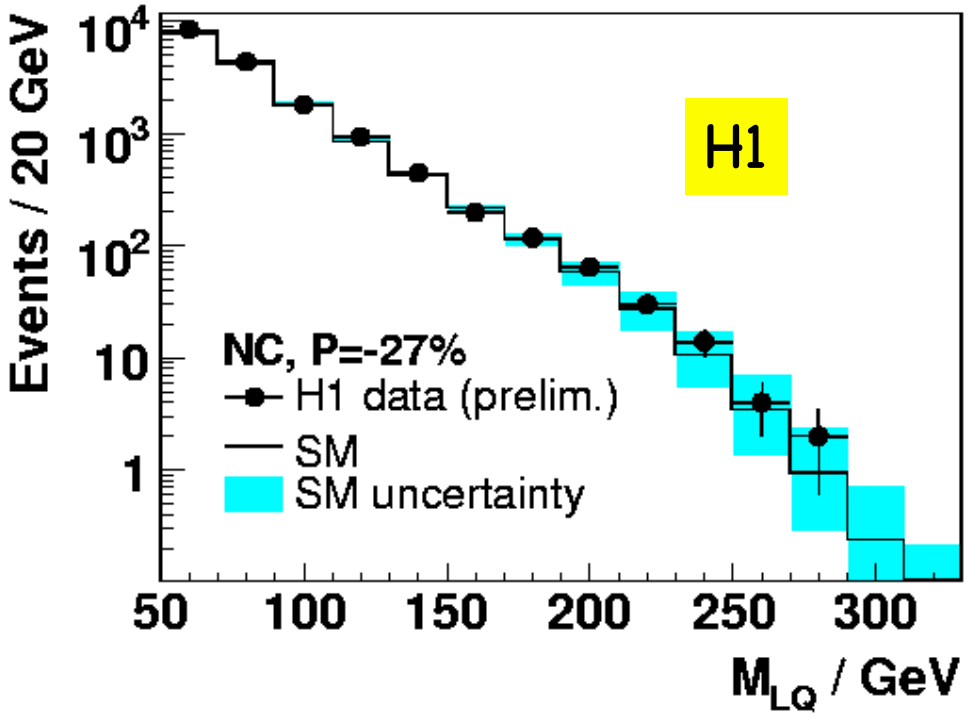


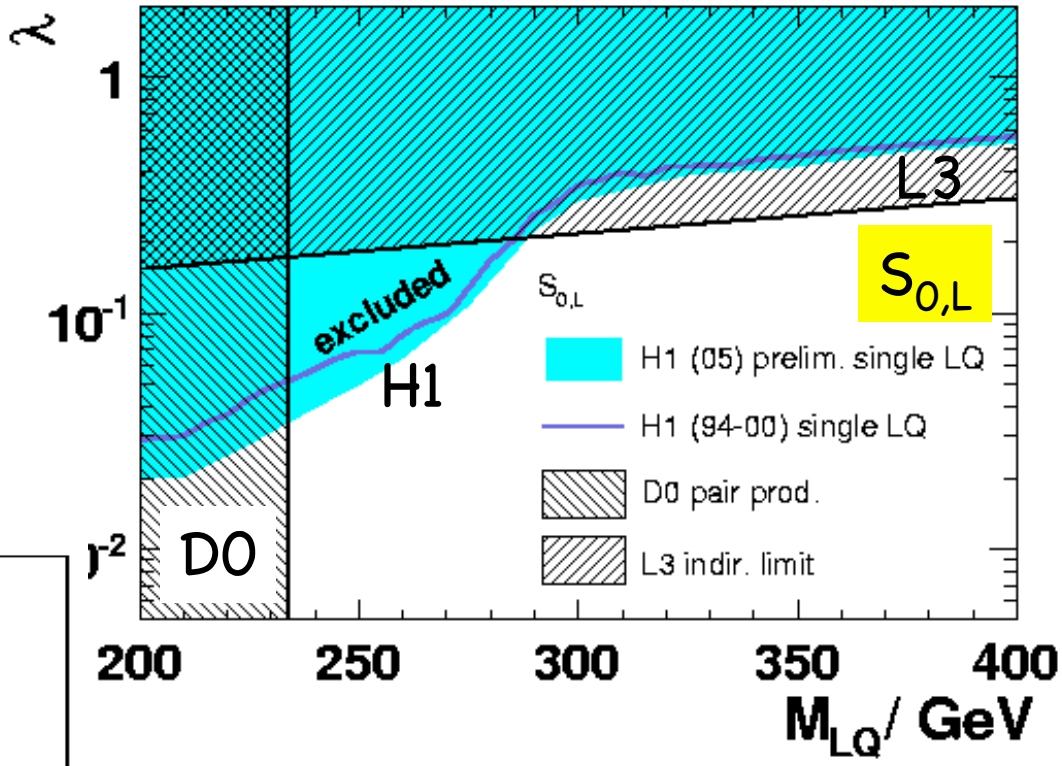


Search for leptoquarks at HERA



• New results at HERA II on searches for BRW leptoquarks with F=2 (e^-q)



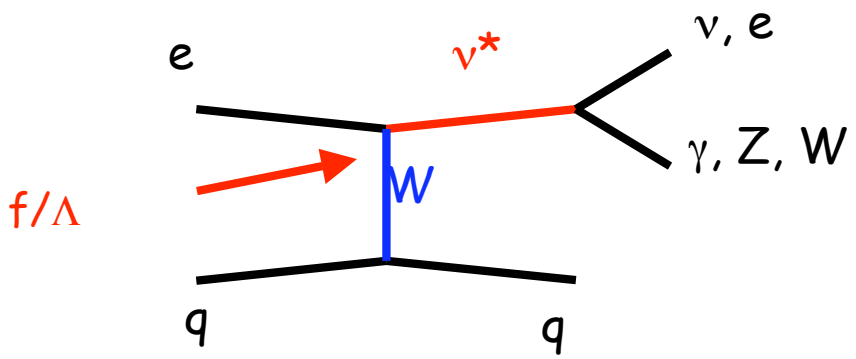


LEP indirect limit from ee →qq

At Tevatron and LHC pair production: D0 Run I+RunII M(LQ)>234 GeV for BR(LQ→eq)=1/2

LHC discovery reach of 1.3 TeV with 30 fb^{-1}

Excited neutrinos at HERA

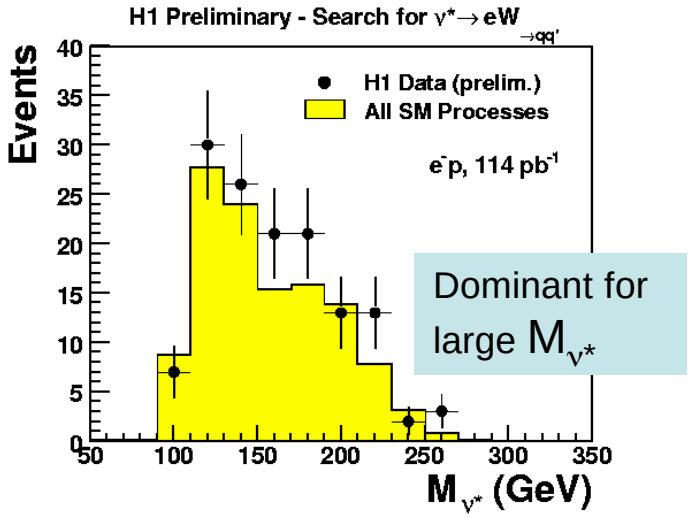


$\sigma(e^-p) \sim 100 \times (e^+p)$

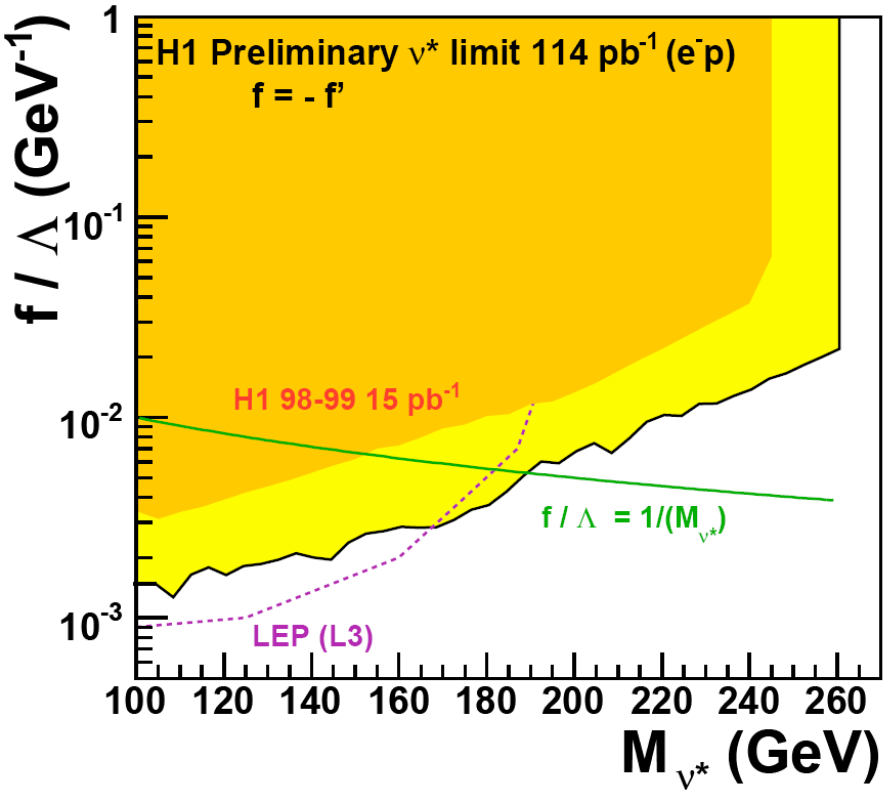
New results from H1 with 10x int. luminosity in HERA II 04-05 compared to HERA I 98-99

No signal seen from the invariant mass of the final reconstructed states in the 3 decays mode

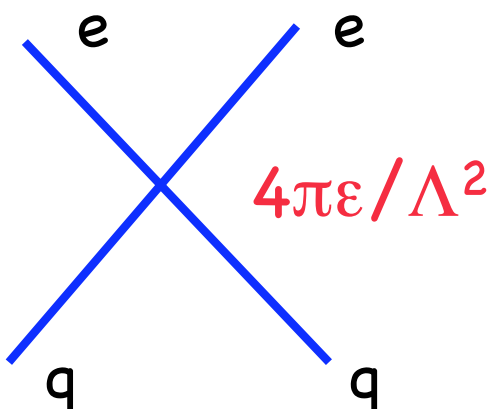
For $f/\Lambda = 1/M$
$M(\nu^*) > 188$ GeV



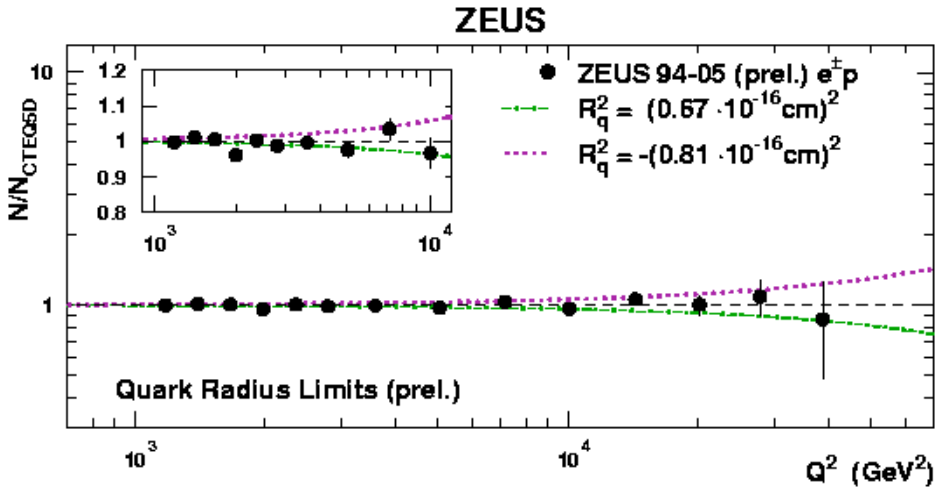
Dominant for large M_{ν^*}



Search for contact interactions at HERA



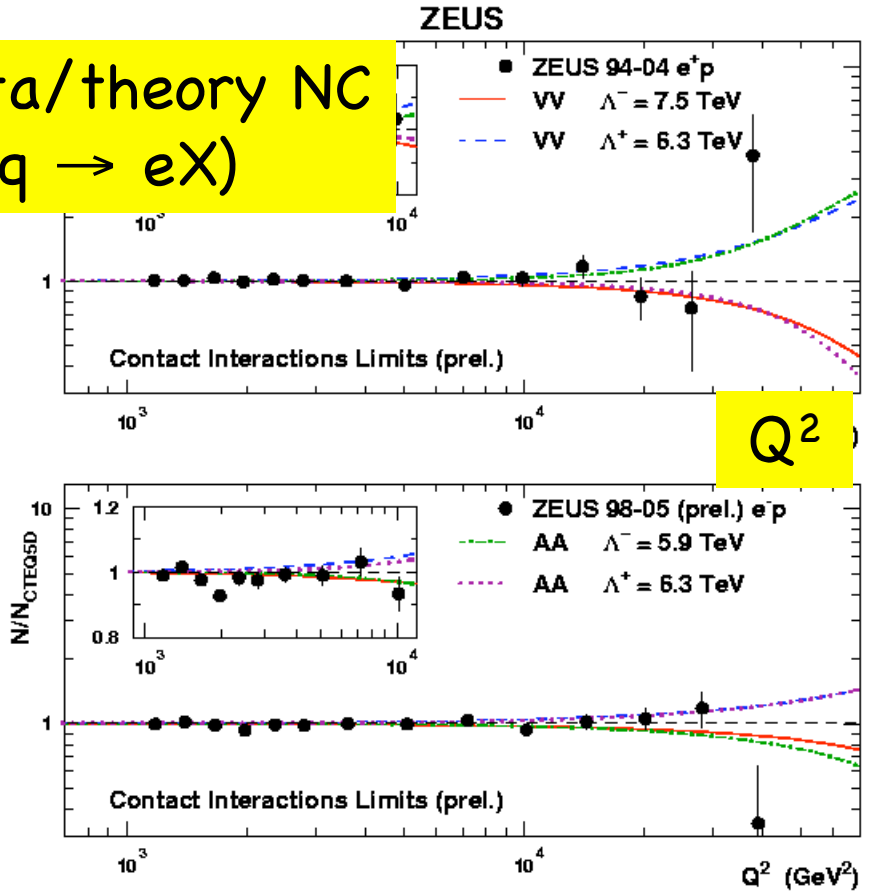
$$L_{CI} = \sum_{L,R}^{q} \varepsilon_{L,R}^{eq} \frac{4\pi}{\Lambda^2} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$



ZEUS I+II (274 pb^{-1}), quark radius limit of:

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

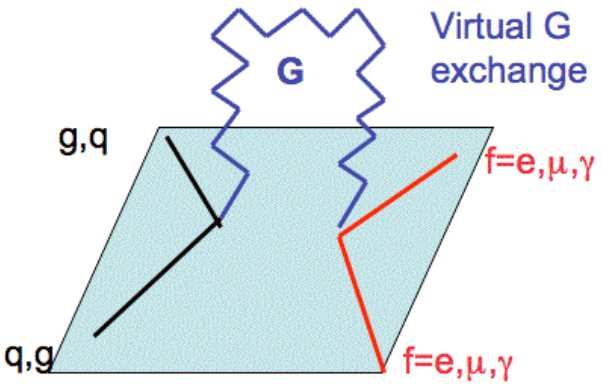
Data/theory NC $\sigma(eq \rightarrow eX)$



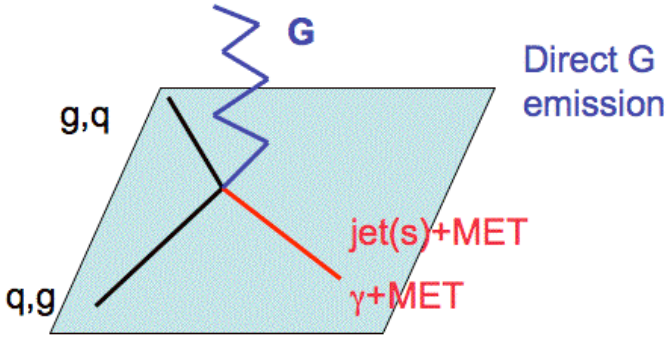
Tevatron best limits (CDF/D0):

VV 9.1/8.7; AA 7.8/7.8 TeV

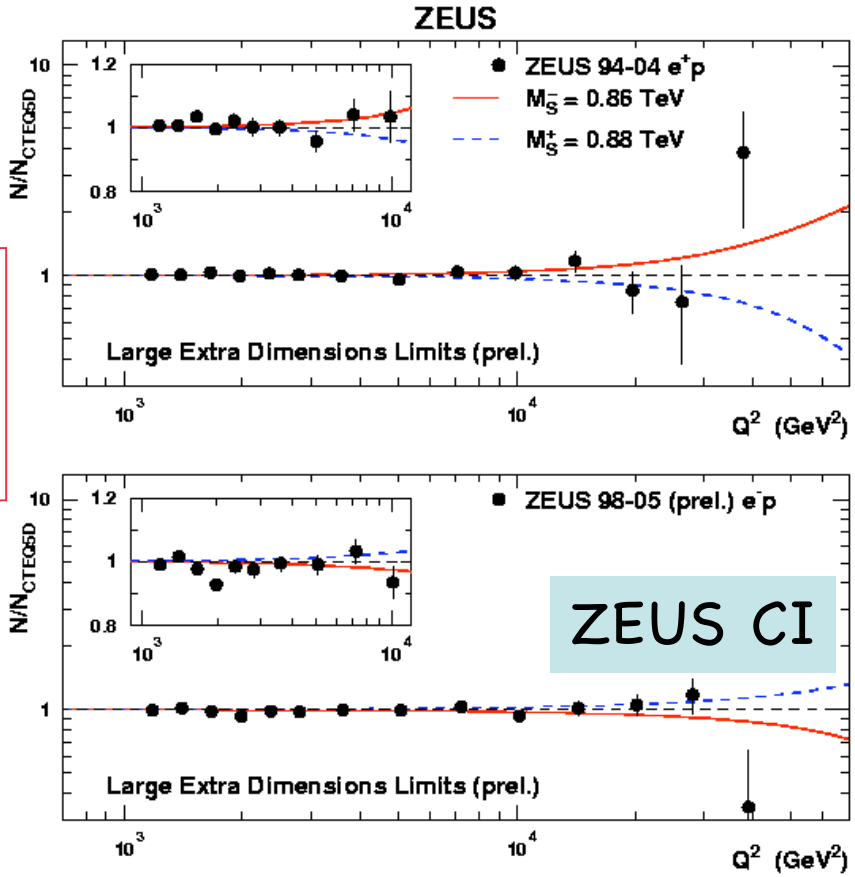
Search for Large Extra Dimensions



Indirect search of ADD gravitons, introduce effective coupling



Direct search at Tevatron, depends on number of dimensions n



ZEUS CI

$M^2_{Pl} \sim R^n M_S^{2+n}$

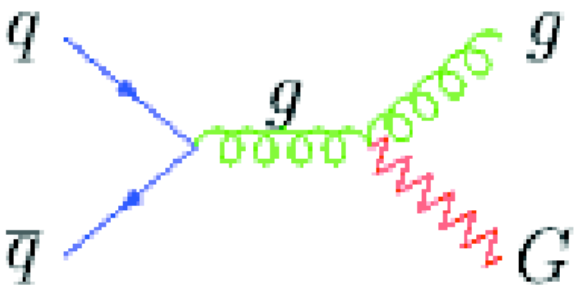
If $R = O(10\mu m) \rightarrow M_s \sim$ TeV

$M_S^- > 0.86$ TeV,

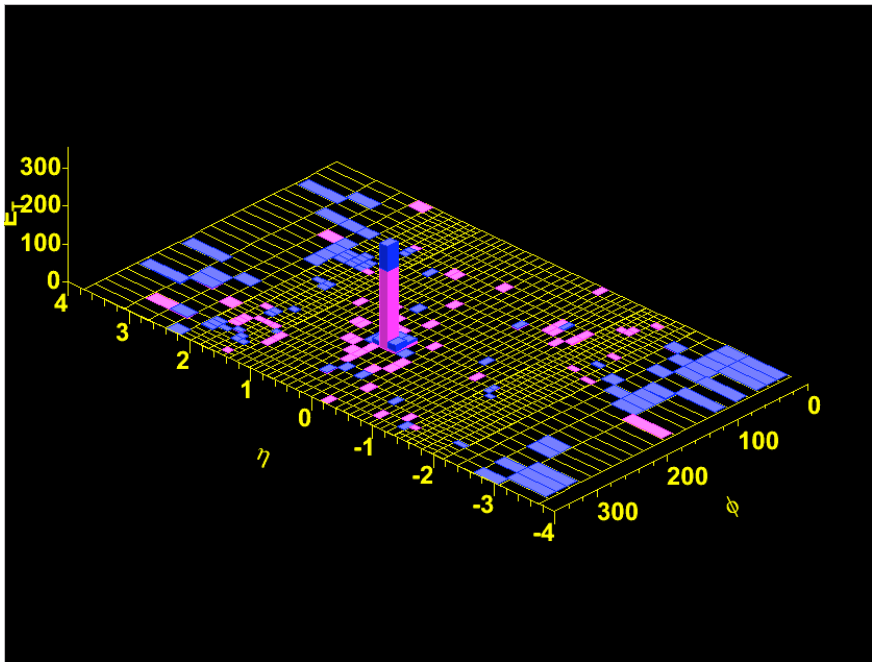
$M_S^+ > 0.88$ TeV

@ 95% CL

Search for LED at TeVatron/LEP

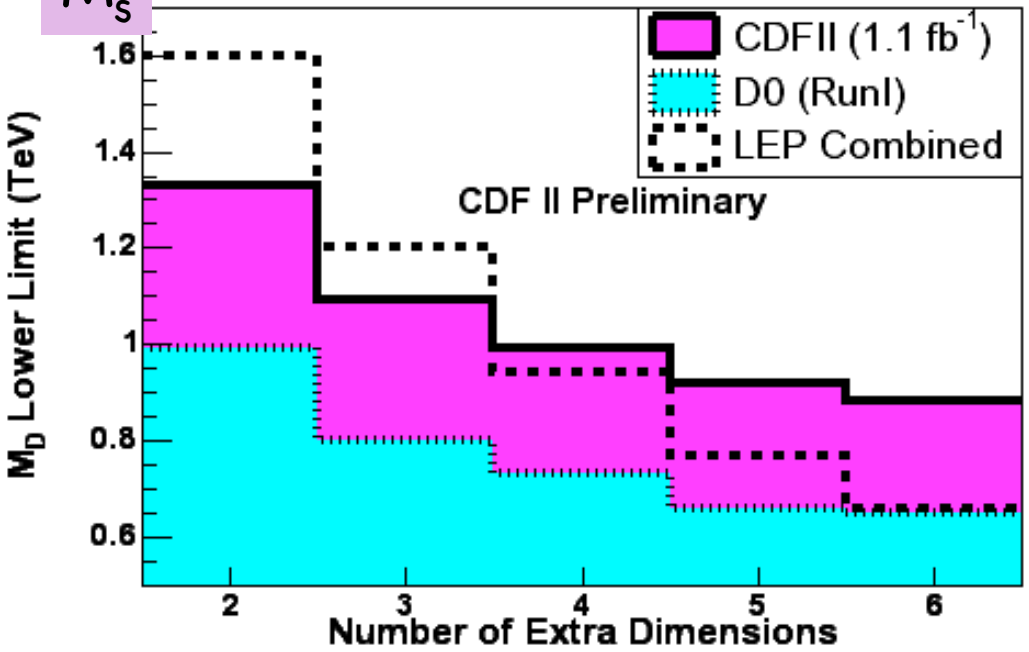


- Search for ADD gravitons produced directly: G escapes undetected in the bulk of extra-dimensions, the signature is jet+MET at Tevatron (single photon at LEP)



Monojet(Et=384 GeV)+MET(390GeV)

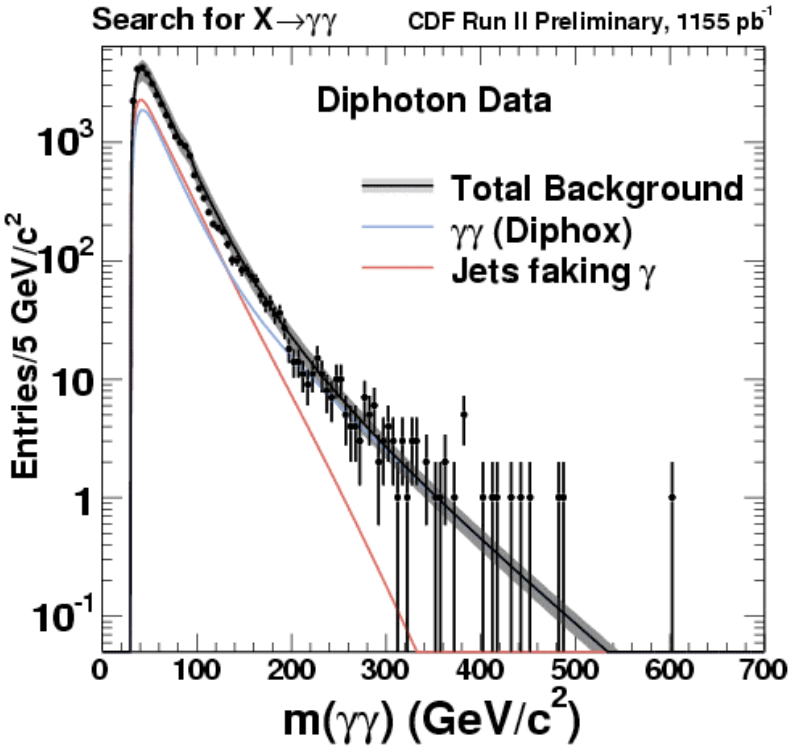
M_s

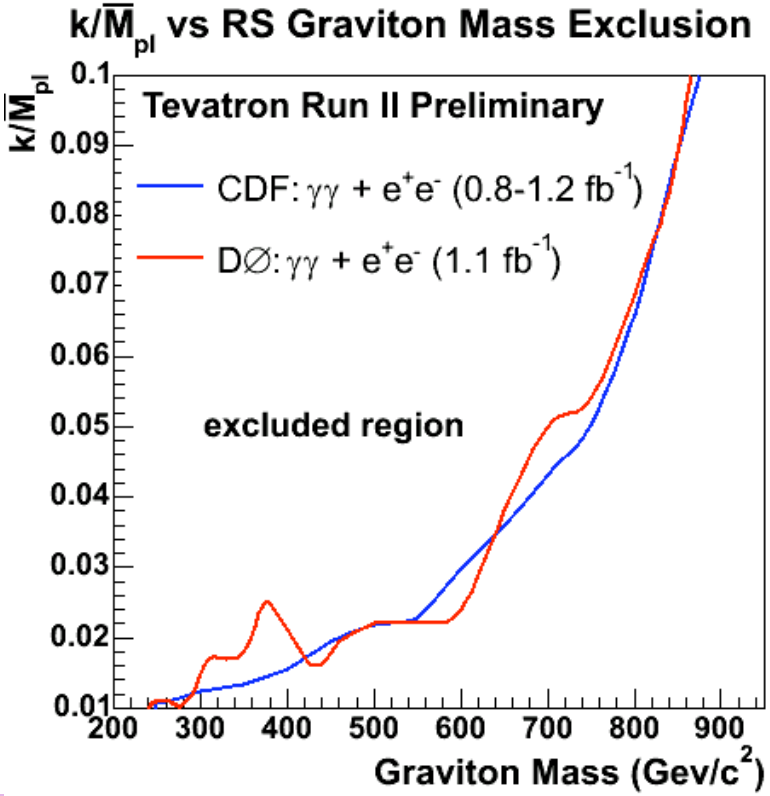


n(dimensions)

Diphoton/RS gravitons at TeVatron

Search for high mass diphoton resonances. i.e in Randall-Sundrum model, 1 dimension highly curved, k/M_{pl} is the curvature scale. Graviton decays in ee, $\gamma\gamma$ investigated

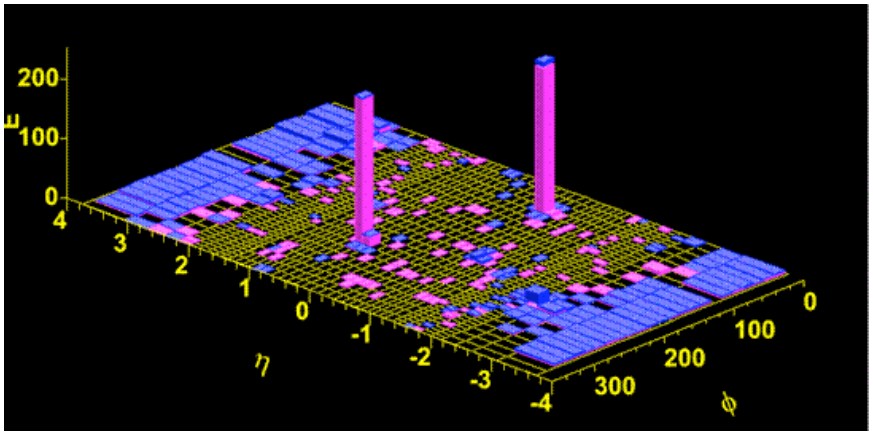




M(G)>875 GeV for k/M_{pl}=0.1 CDF

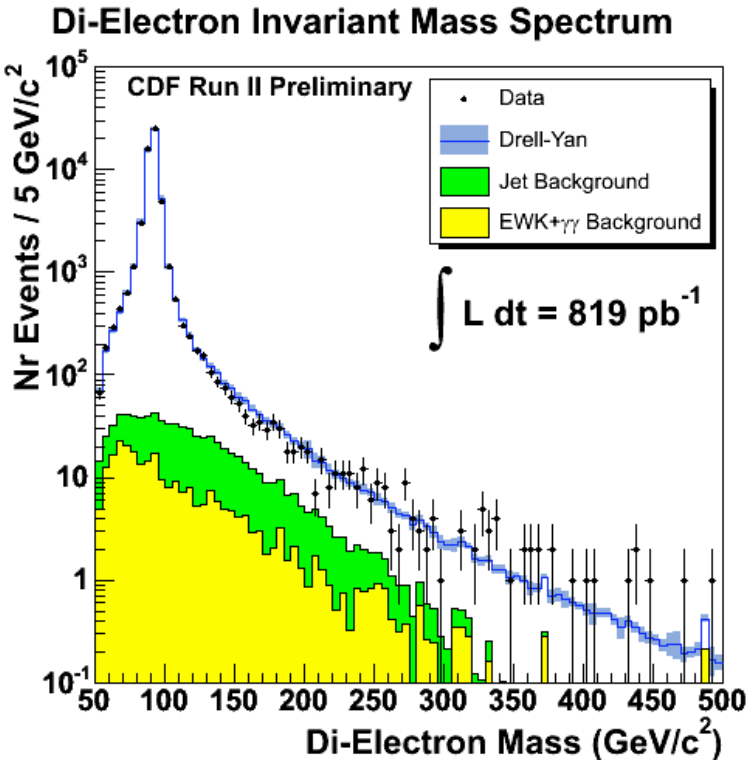
M(G)>865 GeV D0

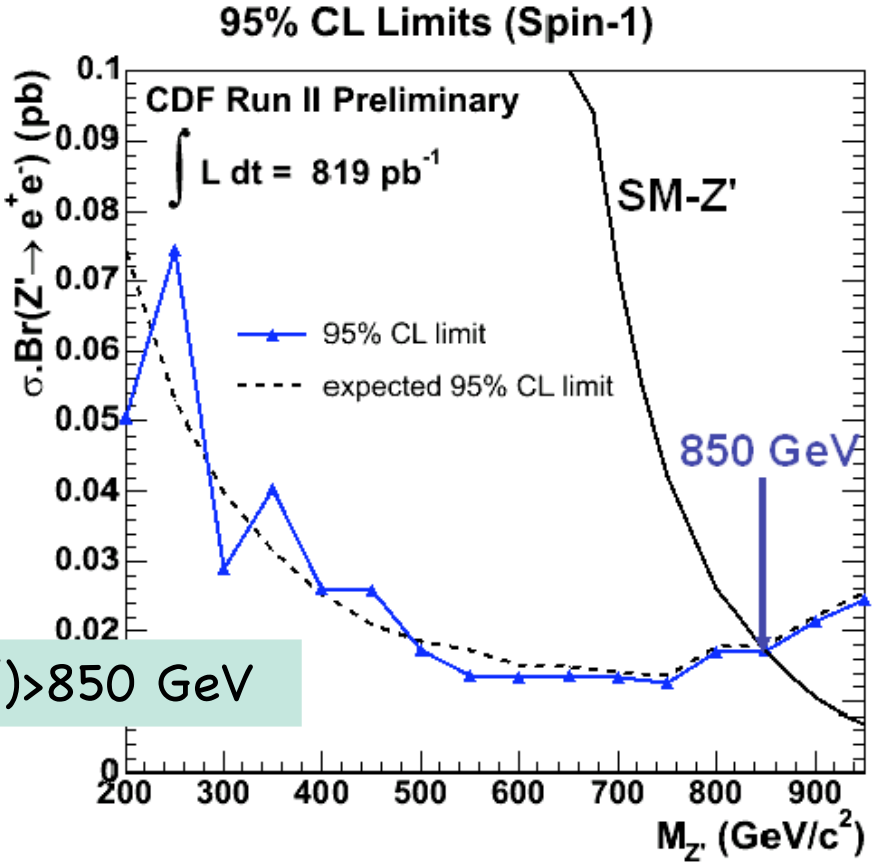
Search for Z' at TeVatron



Search for Z' -> ee

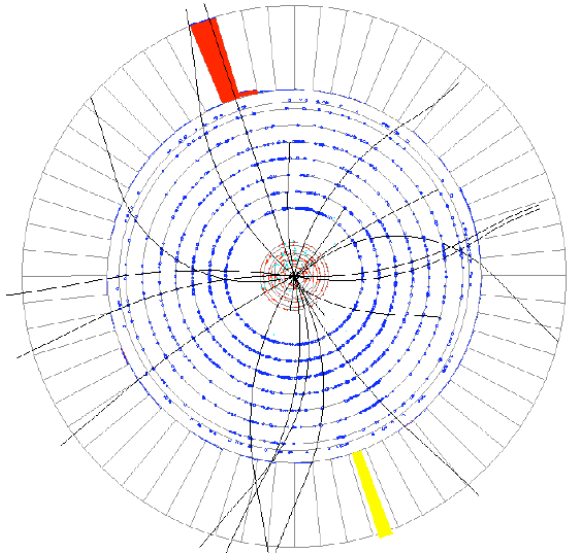
<- Highest mass event
M=491 GeV





M(Z')>850 GeV

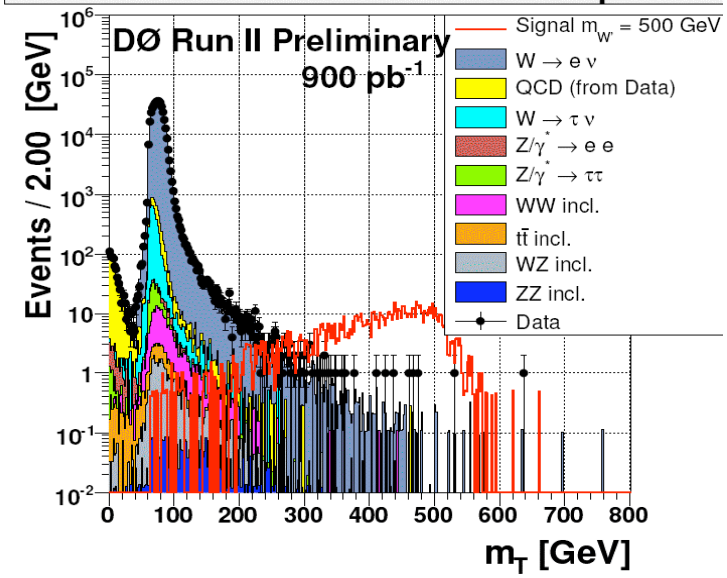
Search for W' at TeVatron



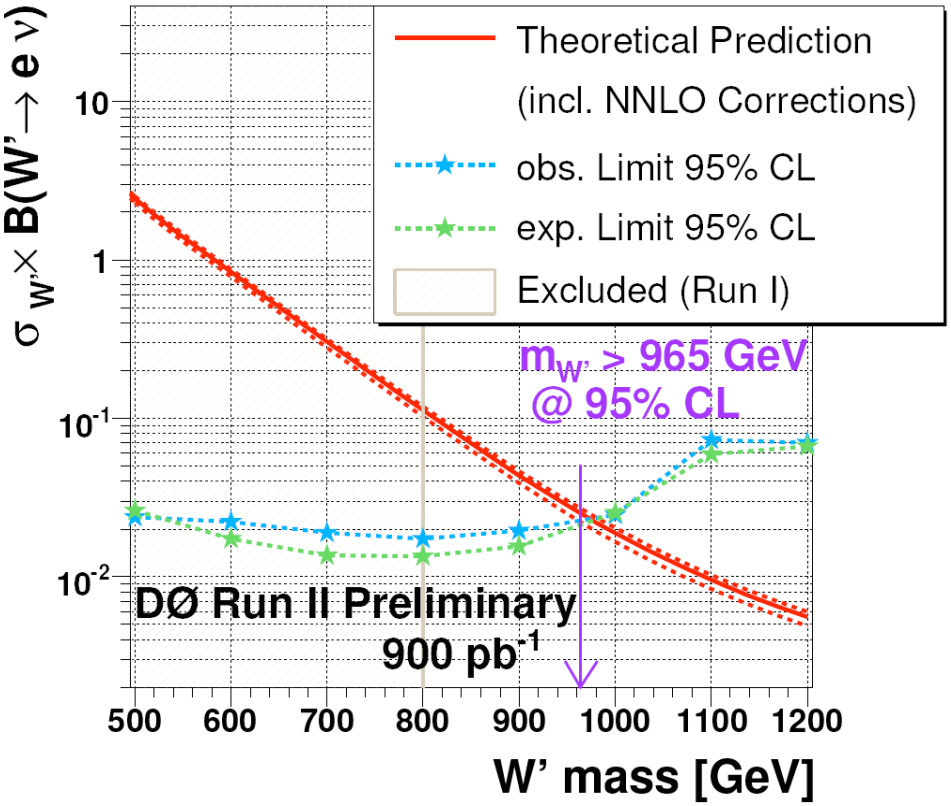
W'→eν cand.

E_t=265 GeV, MET 265 GeV

Transverse Mass m_T



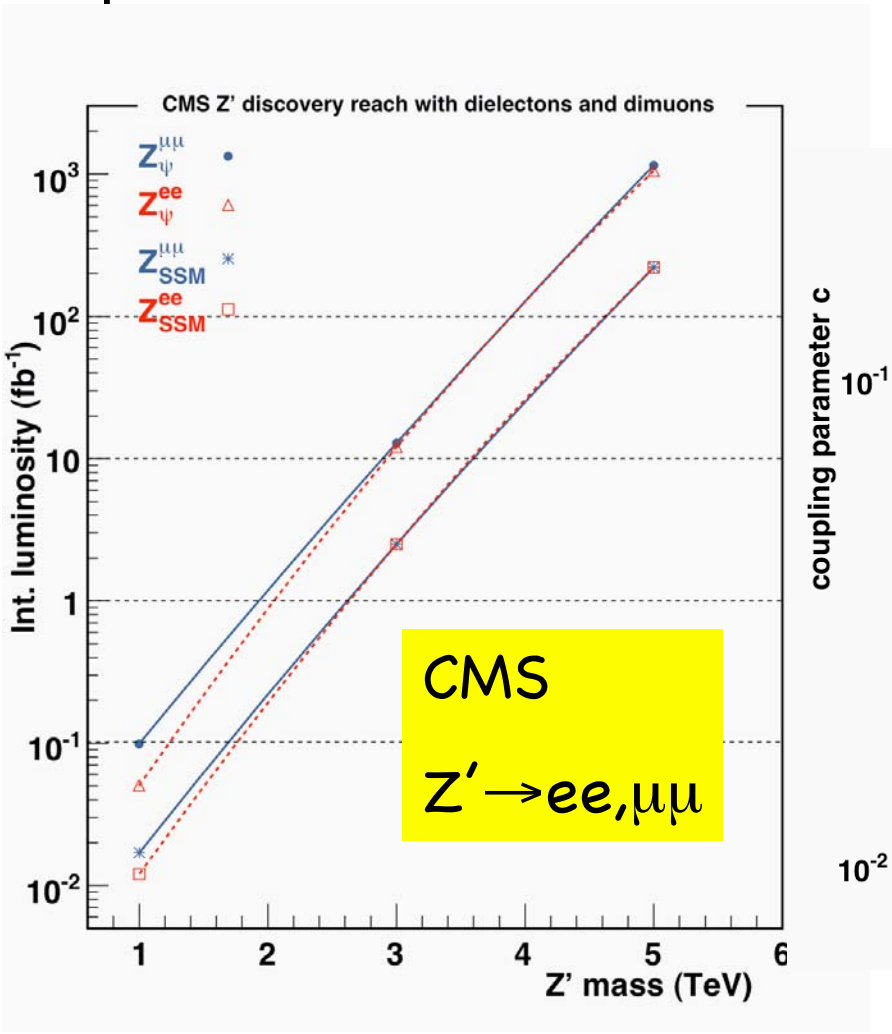
95% CL Limit



M(W')>965 GeV

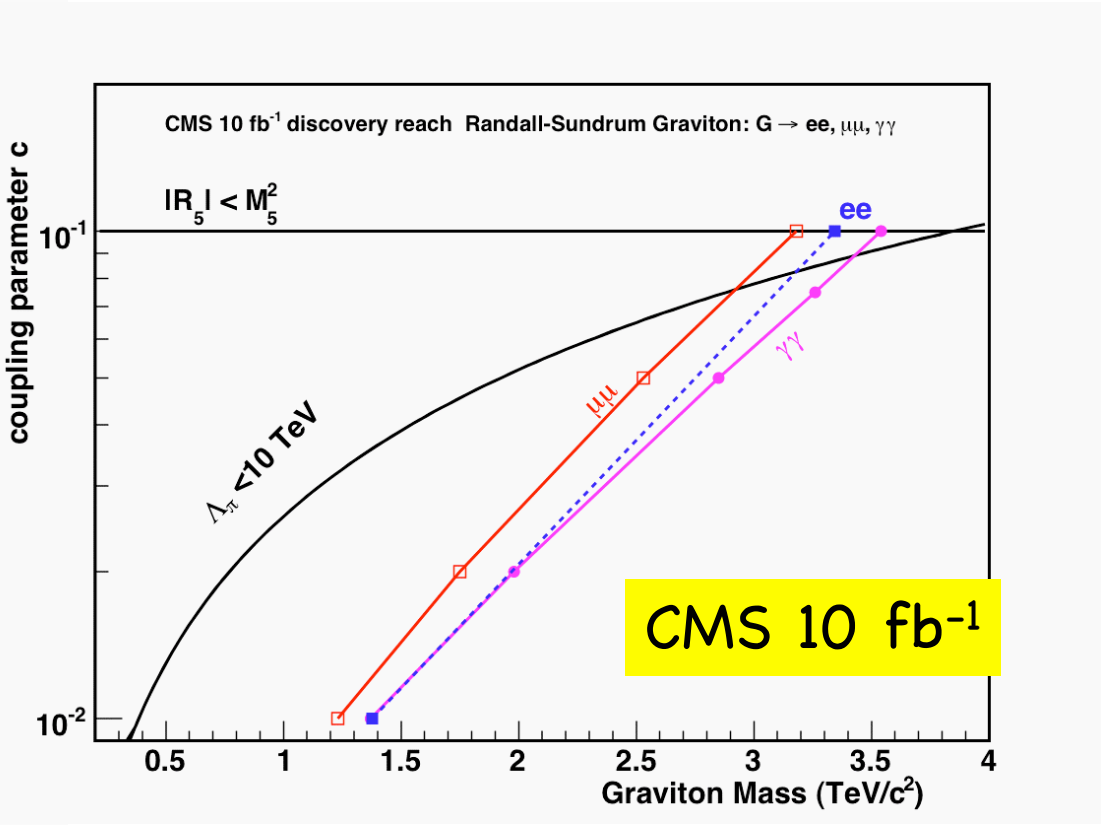
Prospects on LED/Z' at LHC

- Z' discovery at 1 TeV could be possible with 0.1 fb-1

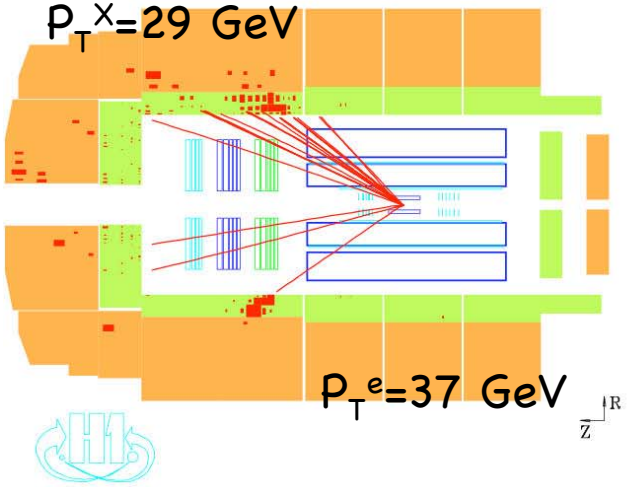


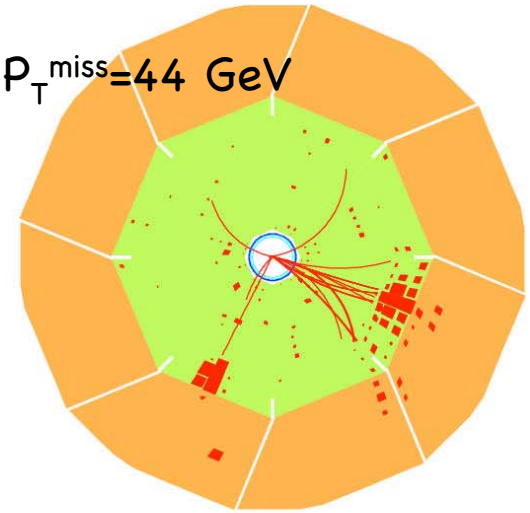
- in RS model:

pp -> G -> ee, μμ,γγ



Isolated leptons at HERA

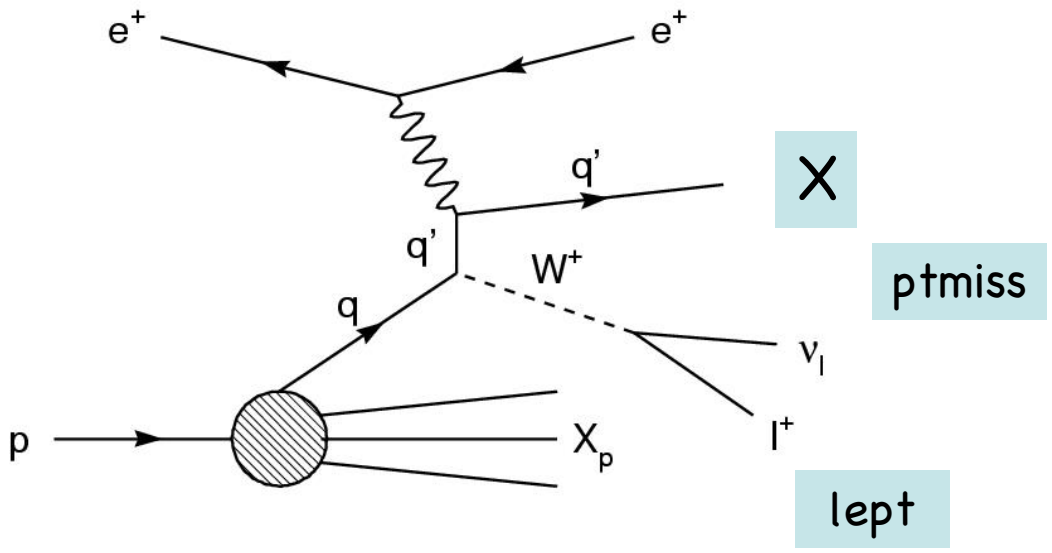


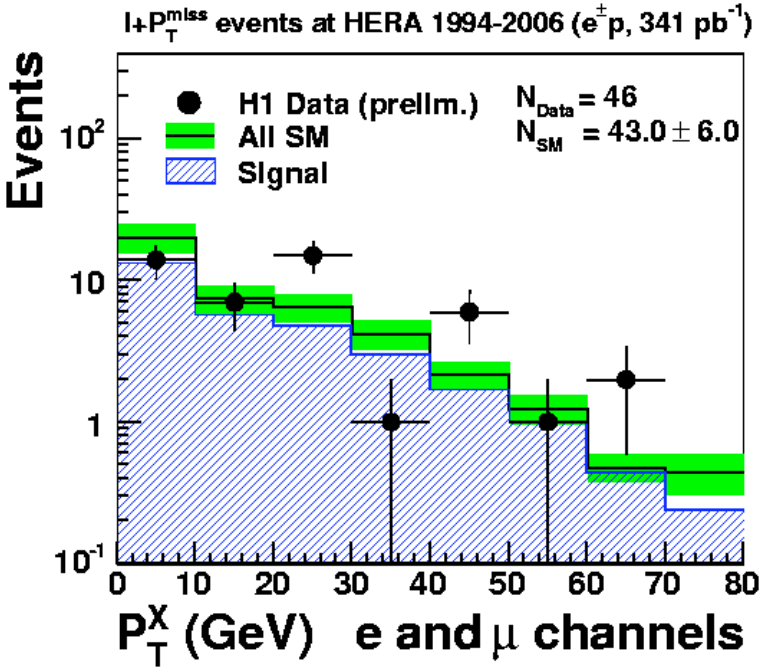


Analysis optimized for search for the SM process

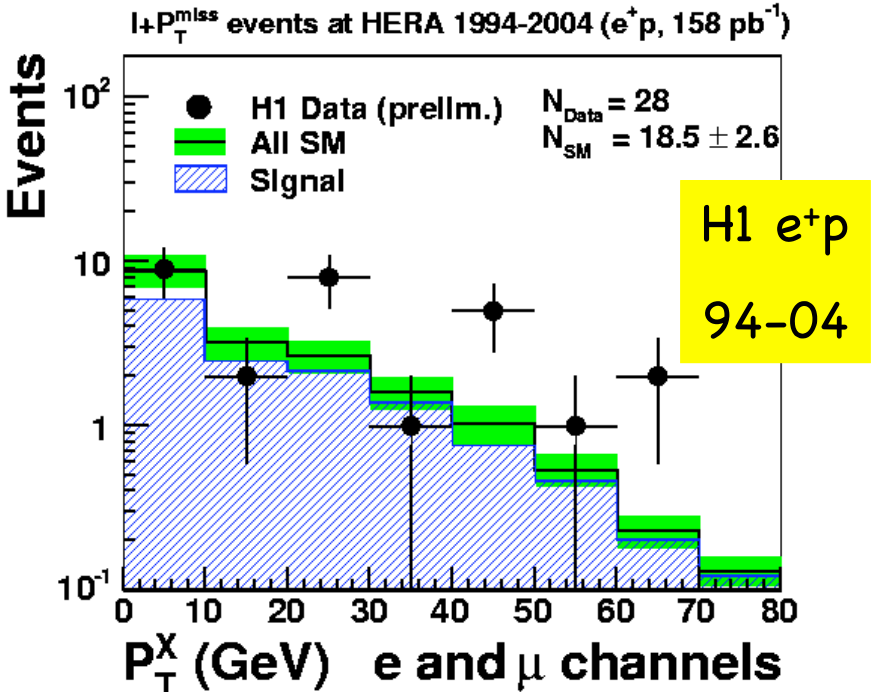
ep →(e)qW→ (e)lept+q+ptmiss

Excess at high P^X_T

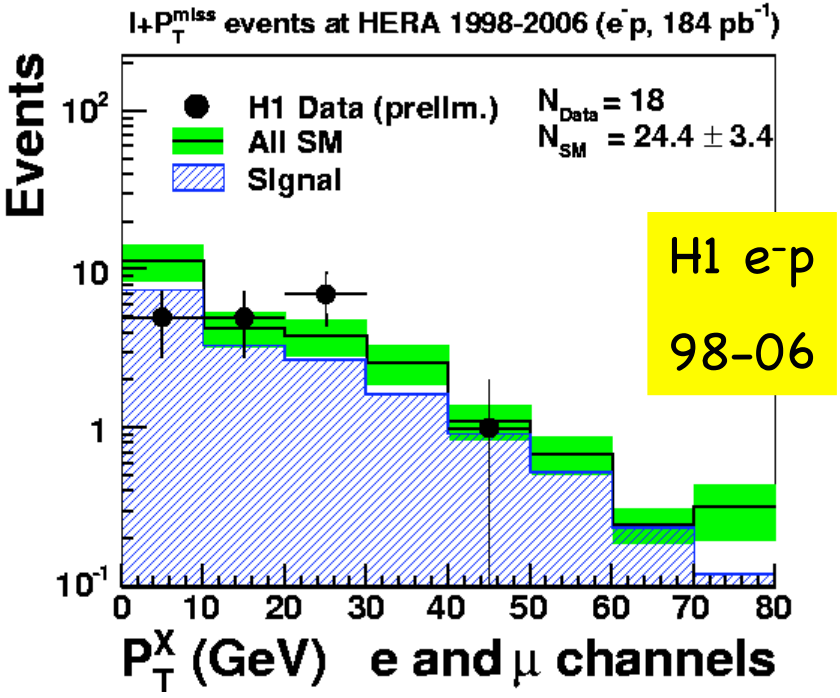




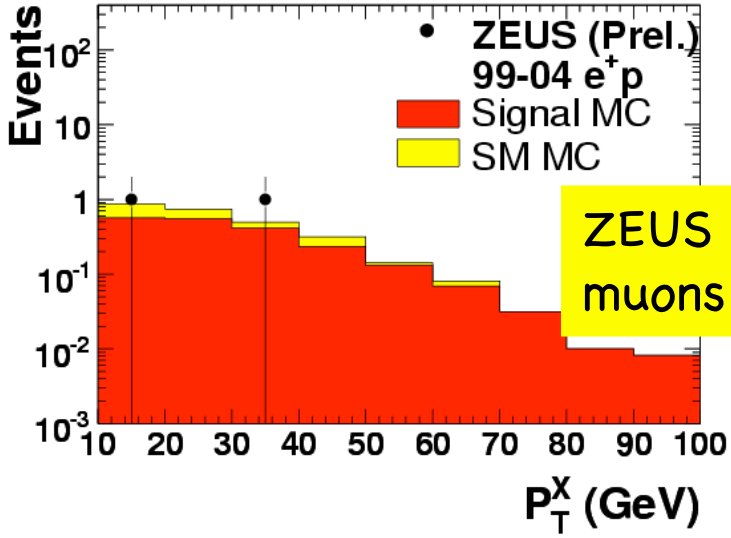
Isolated leptons at HERA



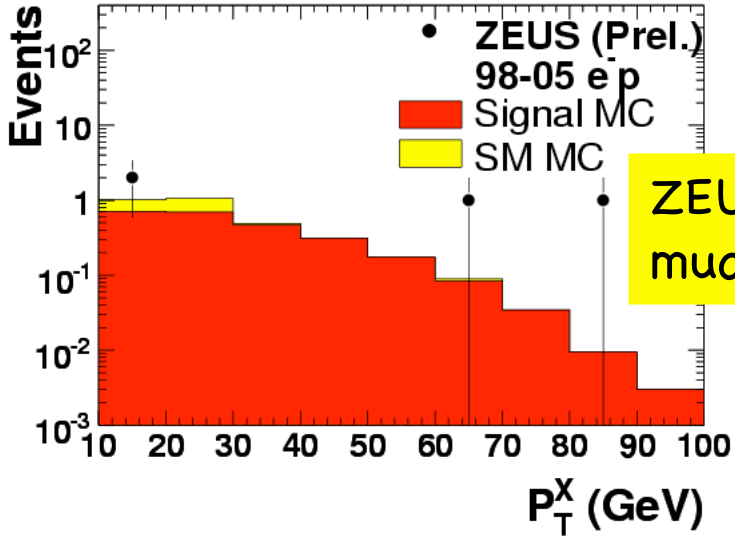
H1 e^+p 94-04



H1 e^-p 98-06



ZEUS e^+p muons



ZEUS e^-p muons

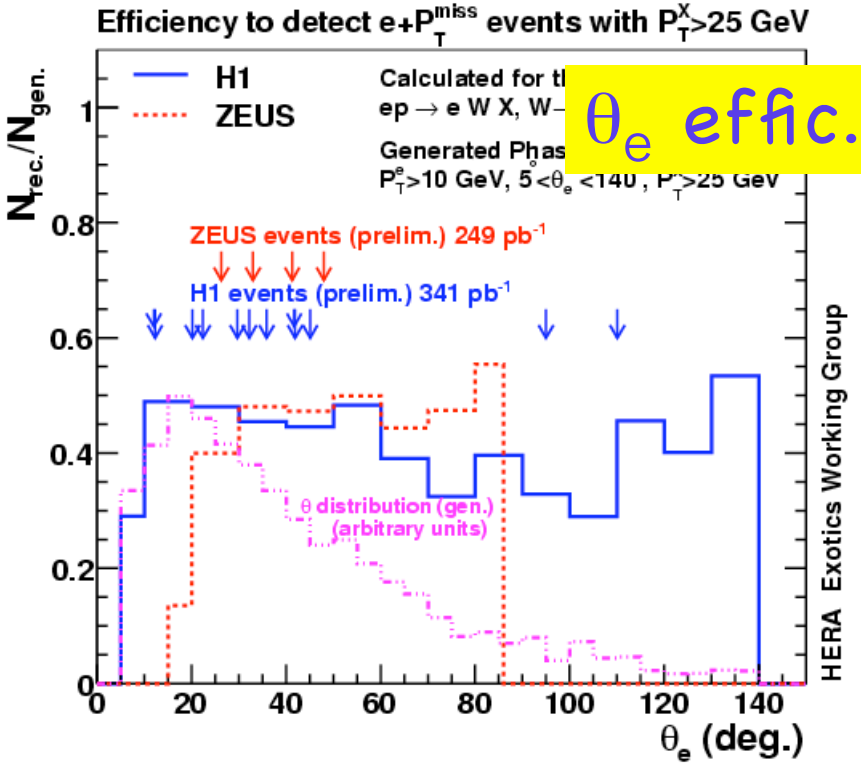
Excess seen by H1 in e^+p collisions

Isolated leptons at HERA

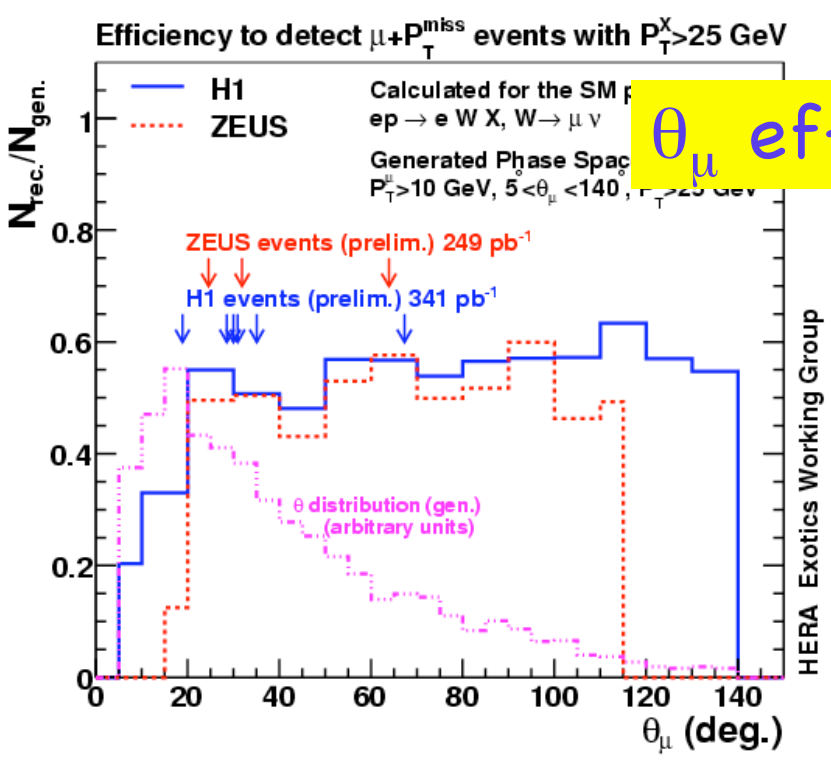
P_T^X > 25 GeV obs/exp. (SM)	e channel	μ channel	Combined e & μ	Tau channel
H1 Electrons, 98-06 ~184 pb^{-1}	3 /3.8	0 /3.1	3/6.9±1.0	3/0.4
H1 Positrons, 94-04 ~158 pb^{-1}	9 /2.3	6 /2.3	15 /4.6±0.8	0/0.4
ZEUS Electrons 98-05 ~143 pb^{-1}	3/2.9	2/1.6	ZEUS good agreement with SM	
ZEUS Positrons 99-04 ~106 pb^{-1}	1/1.5	1/1.5	ZEUS good agreement with SM	2/0.2 (120pb^{-1})

H1 excess is mainly in the e channel (in HERA II e^+ 5/0.8±0.2)

Isolated leptons at HERA



θ$_e$ effic.

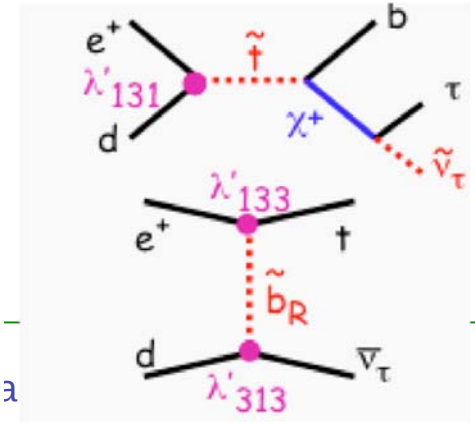


θ$_μ$ effic.

Are ZEUS and H1 compatible?

What could it be?

- same efficiency in overlapping acceptance region. H1 events are mostly in the common region
- ZEUS will try to increase the acceptance region
- 100 pb^{-1} of e$^+$p collisions needed to establish the effect in H1 from 3.4* → 4.5 sigma, will collect them until June 2007
*with ZEUS 2.6 sigma effect



Summary

- No convincing sign of new physics yet
- HERA II just started again to take data, expect >~100 pb^{-1} e+p, puzzle on isolated leptons to be solved, HERA II ends June 2007
- Tevatron just started Run IIB, expects 4-8 fb^{-1} by 2009, still many BSM results to come.
- We are all waiting eagerly for the start and first BSM results from LHC

Apologies for all the results I could not cover (more Tevatron and HERA searches, Atlas/CMS studies, LEP, but covered in the talks in the parallel sessions)

Thanks to D. Acosta, V.Buescher, M. Corradi, C. Diaconu, J. Ferrando, F. Gianotti, K. Korcsak-Gorzo, H. Greenlee, T. Hebbeker, B. Heinemann, D. Glenziski, J. F. Grivaz, A. Montanari, E. Perez, G. Polesello, S. Pronko, D. South, M. Spiropulu, Y. Yamazaki.