Searches for New Phenomena

Beate Heinemann, University of Liverpool

- Introduction
- Supersymmetry:
  - Squarks and Gluinos
  - Charginos and Neutralinos
  - Indirect search: $B_s \rightarrow \mu\mu$
- High-Mass Phenomena:
  - Z'
  - Large Extra Dimensions
- Summary and Outlook

Parallel Session Talks

- Many new results presented at ICHEP (session 12)
- Tevatron:
  - A. Lath: New Phenomena
  - E. Kajfasz: Large Extra Dimensions
  - A. Meyer: SUSY
- HERA:
  - A. Schoening: New Phenomena
  - C. Niebuhr: Lepton-Flavour Violation
  - C. Nguyen: SUSY
- LEP:
  - J. Devivie: SUSY
  - S. Ask: Large Extra Dimensions
  - G. Giacomelli: New Phenomena

Related plenaries:
Higgs: D. Denisov
Future: R. Barbieri

Focus on post-LEP results:
Mostly Tevatron Run II and the first HERA Run II

Beyond the Standard Model

- Why not the Standard Model?
  - Hierarchy problem: $m_h \ll m_{Pl} \Rightarrow$ new physics at TeV scale
  - Most Dark Matter in our universe unaccounted for
  - No unification of forces …+ many more
- What is beyond the Standard Model?
  - Supersymmetry (SUSY):
    - rather complex (>100 parameters)
  - Extra Dimensions
  - Techni- and Topcolor
  - Little Higgs
  - Extended Gauge groups or compositeness:
    - Z', excited fermions, leptoquarks, …

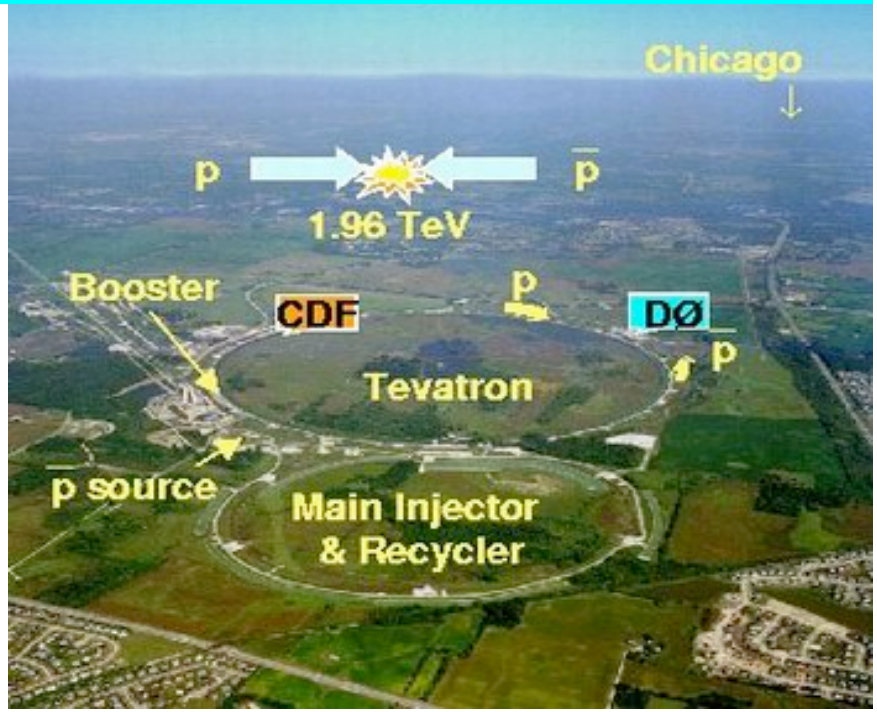
New particles heavy
⇒Direct production at
high energy colliders

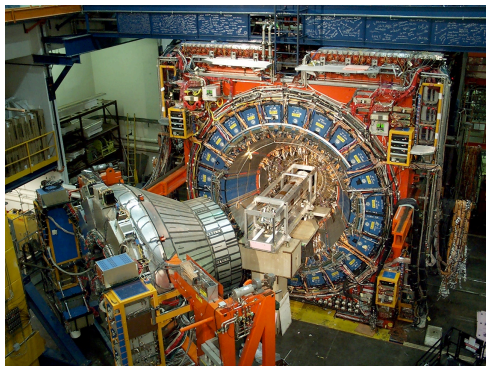
Tevatron Run II

- Upgrade completed in 2001
- Accelerator:

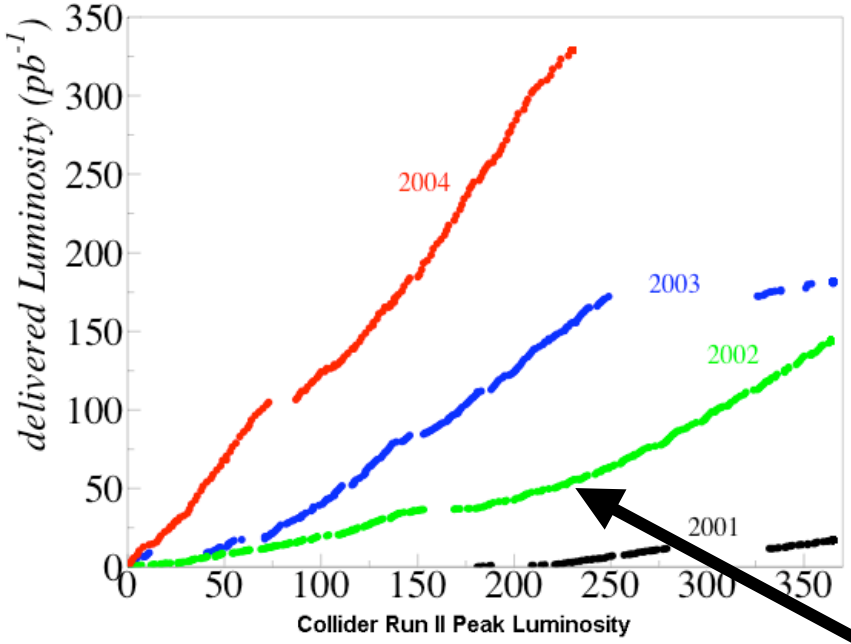
	$\sqrt{s}$(TeV)	Δt(ns)	L($cm^{-2}\ s^{-1}$)
Run I	1.8	3500	2.5×10^{31}
Run II	1.96	396	1.0×10^{32}

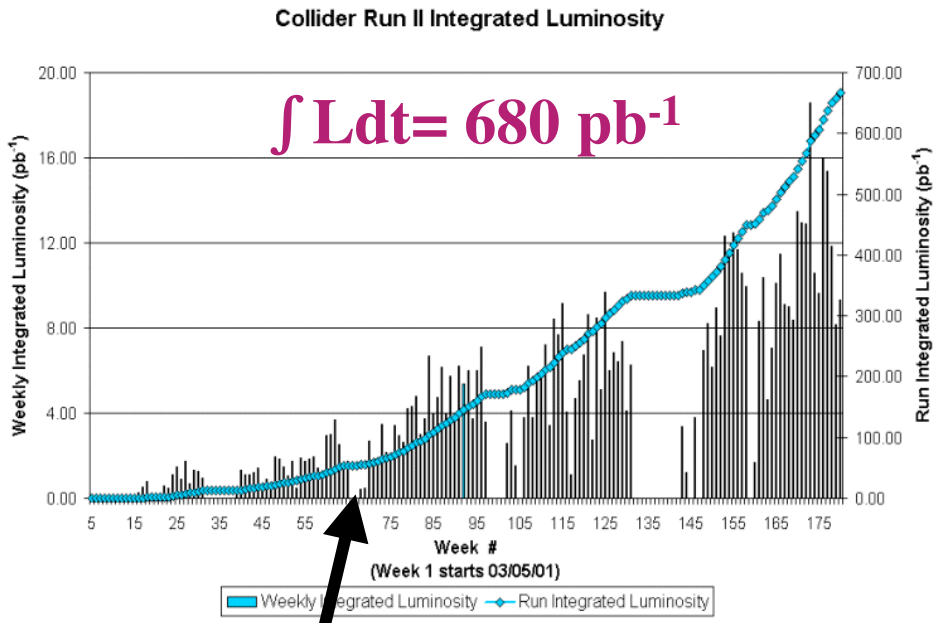
- Experiments CDF and D0:
  - New tracking systems
  - New RO electronics+trigger
  - Many other substantial new components and upgrades
  - Data taking efficiency>85%

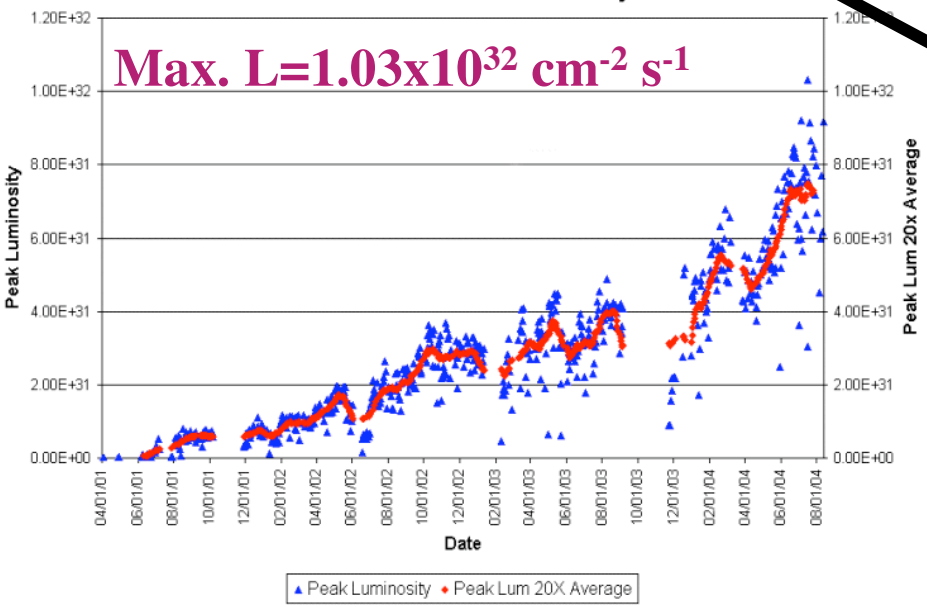




Tevatron Performance







ICHEP 2002

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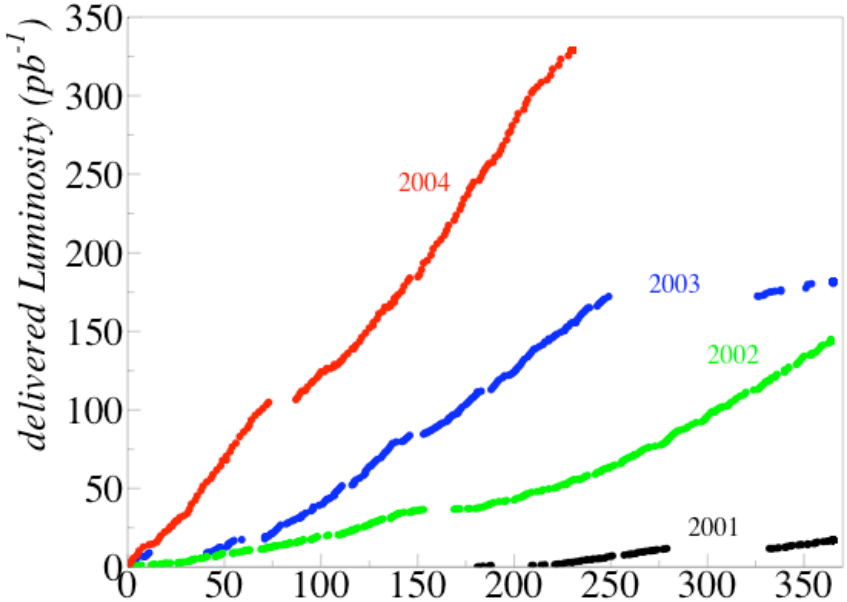

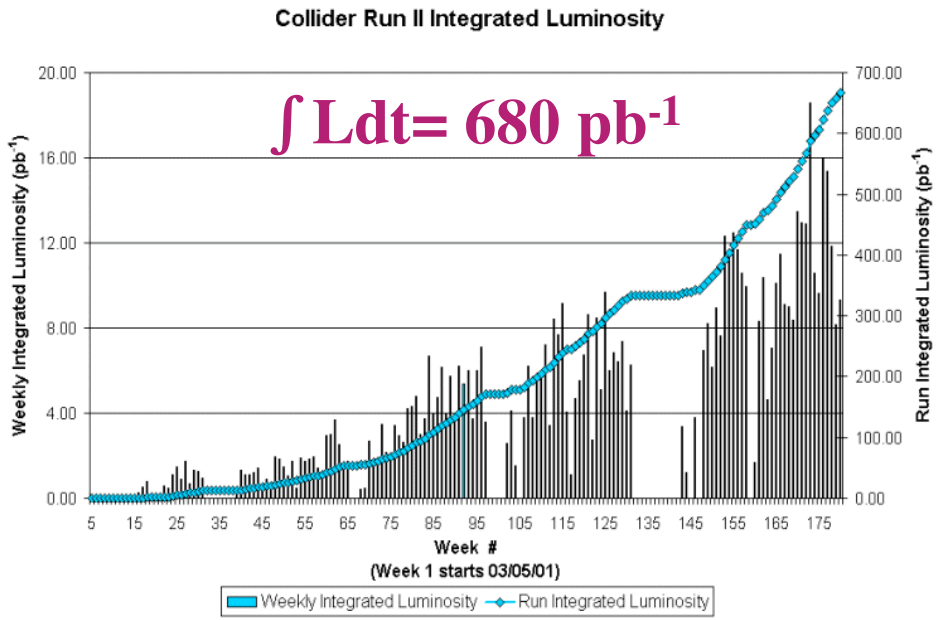

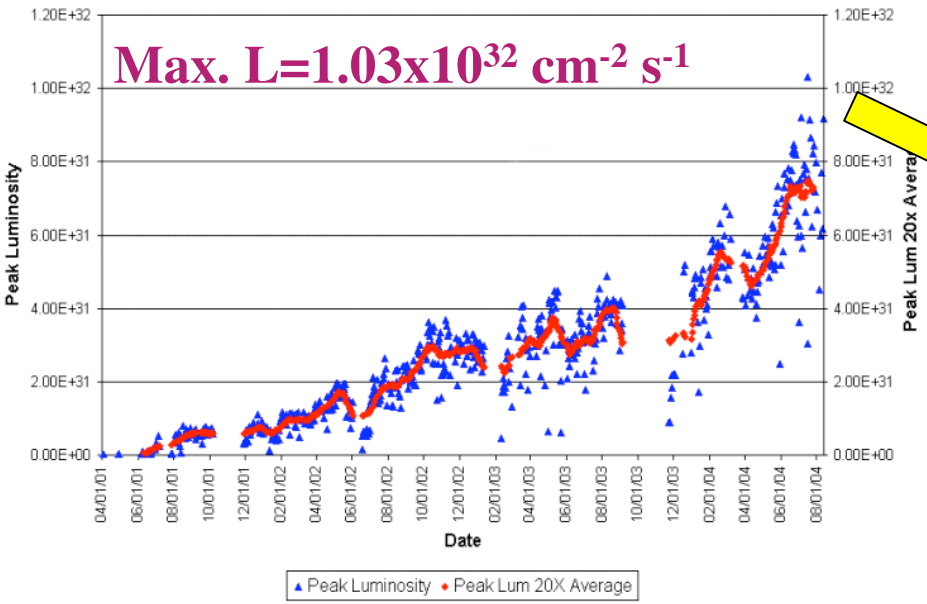

SUSY

SUSY Particles

Particles R=1 $R = (-1)^{3B+L+2S}$ **SParticles R=-1**

fermions S=1/2	e μ τ	leptons	sleptons	$\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$	bosons S=0		
	ν_e ν_μ ν_τ	neutrinos	sneutrinos	$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$			
	u c t	quarks	squarks	$\tilde{u}$ $\tilde{c}$ $\tilde{t}$			
	d s b			$\tilde{d}$ $\tilde{s}$ $\tilde{b}$			
bosons S=1	$W^\pm$ $H^\pm$		charginos	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$	fermions S=1/2		
	γ Z^0 h^0 H^0 A^0		neutralinos	$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$			
	g_i	gauge particles	gluinos	$\tilde{g}_i$			
	G		gravitino	$\tilde{G}$			

MSSM

MSSM has 124 parameters:
M_1, M_2, M_3, Gaugino masses, Sfermion masses
$\tan\beta$, μ, m_A Higgs(ino) mass/mixing
A_τ, A_b, A_t (+45 RPV)

- **SUSY is a broken symmetry**

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Particles R=1 $\quad R = (-1)^{3B+L+2S} \quad$ **SParticles R=-1**

R conserved, mSUGRA: $\tilde{\chi}^0_1$ LSP and stable

fermions S=1/2	e	μ	τ	leptons	sleptons	$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	bosons S=0	
	ν_e	ν_μ	ν_τ	neutrinos	sneutrinos	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$		
	u	c	t	quarks	squarks	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$		
	d	s	b			$\tilde{d}$	$\tilde{s}$	$\tilde{b}$		
bosons S=1	$W^\pm$	$H^\pm$			charginos	$\tilde{\chi}^\pm_1$	$\tilde{\chi}^\pm_2$			MSSM
	γ	Z^0	h^0	H^0 A^0	neutralinos	$\tilde{\chi}^0_1$	$\tilde{\chi}^0_2$	$\tilde{\chi}^0_3$	$\tilde{\chi}^0_4$	fermions S=1/2
	g_i			gauge particles	gluinos	$\tilde{g}_i$				
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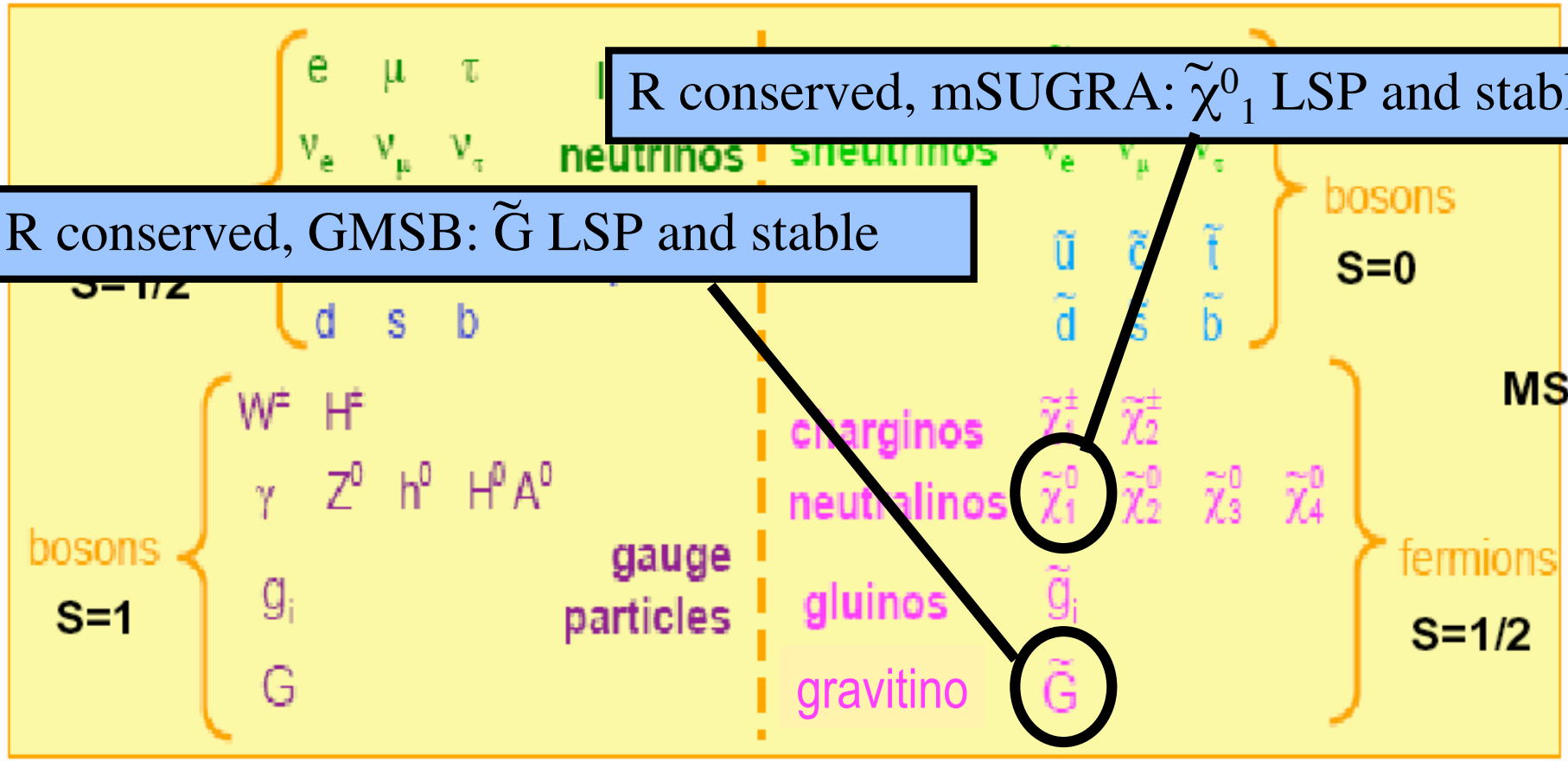
R conserved, GMSB: $\tilde{G}$ LSP and stable



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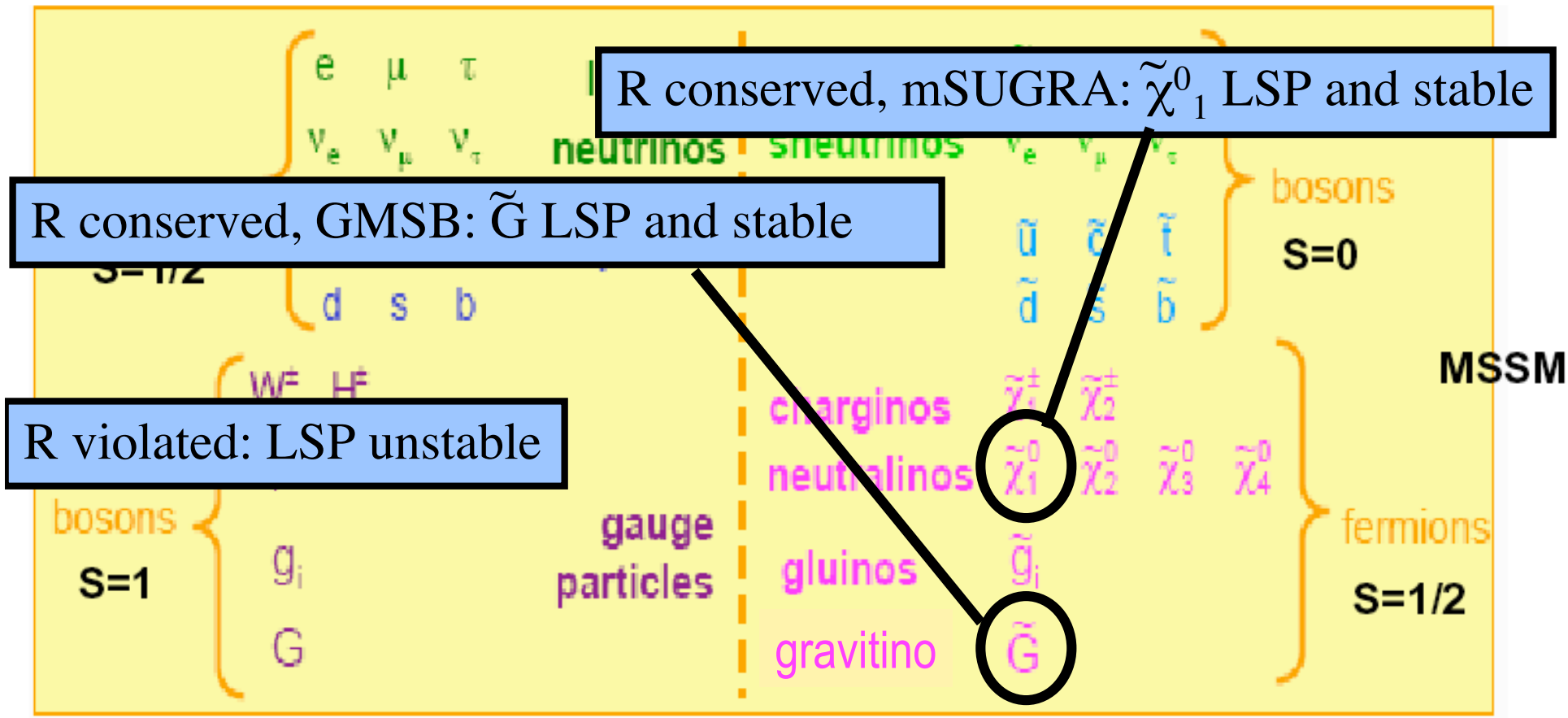
Particles R=1 $R = (-1)^{3B+L+2S}$ **SParticles R=-1**



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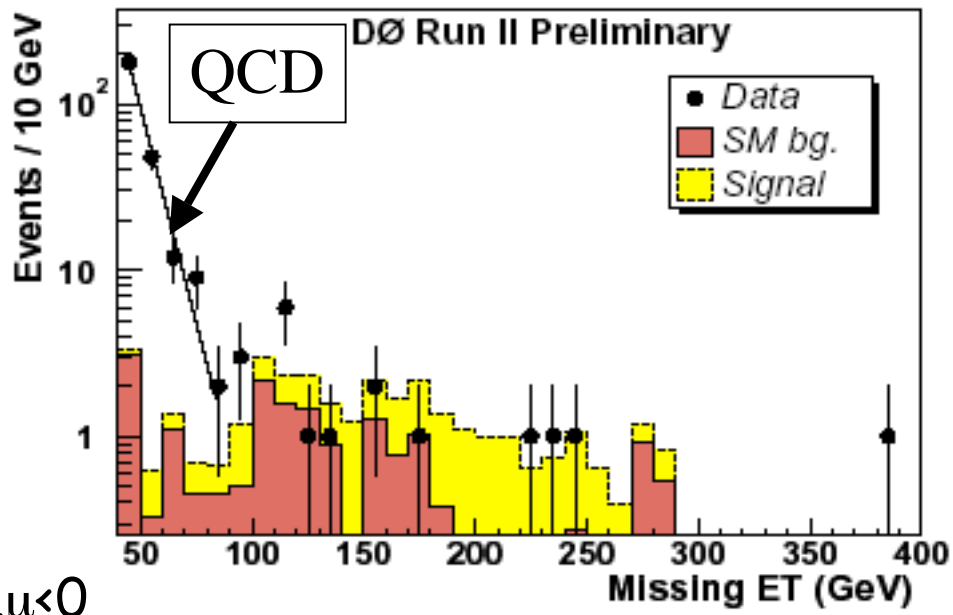
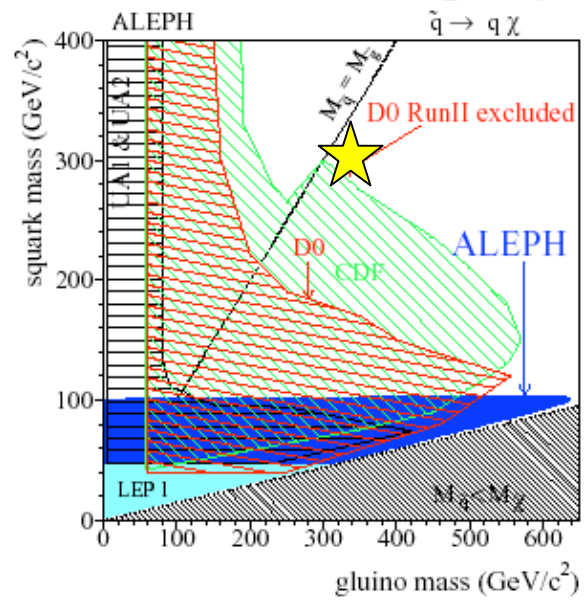
- **SUSY is a broken symmetry**

Generic Squarks and Gluinos

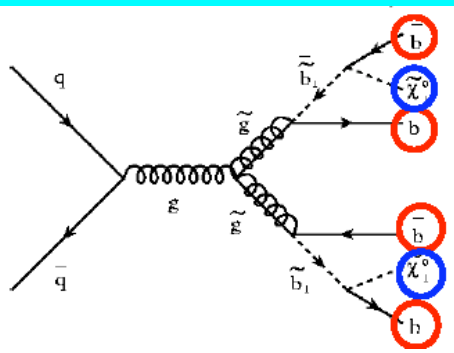
- Signature: $\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0 q\tilde{\chi}_1^0$
  - 2 jets and $\not{E}_t$
  - $\sum P_t^{jet} > 275$ GeV
  - $\not{E}_t > 175$ GeV
- Observe: 4, Expect: 2.7±1.0
- mSugra
  - Fix: m_0=25 GeV, tanβ=3, A_0=0,μ<0
  - Exclude: m(q/g) < 292/333 GeV
- Improves Run I limits:
  - Include more data
  - Scan parameter space

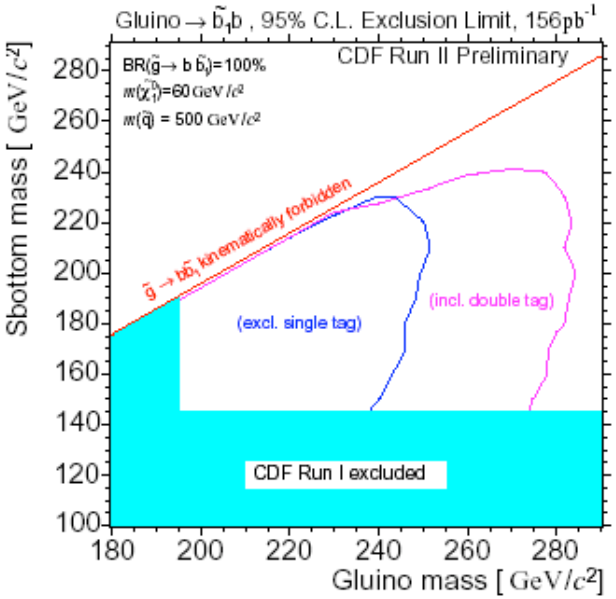




Bottom Squarks

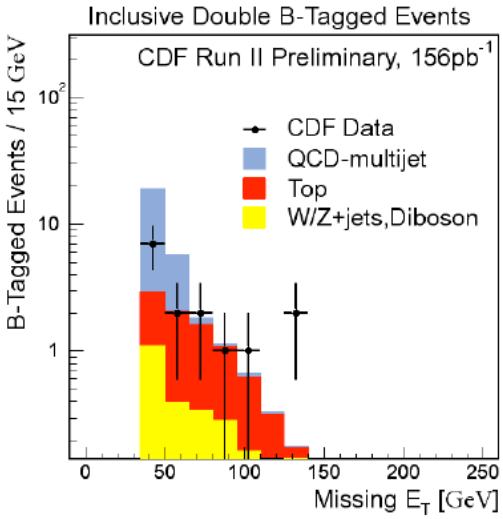
- High tanβ scenario:
  - Sbottom could be light
- This analysis:
  - Gluino rather light: 200-300 GeV
  - BR($\tilde{g}$->$\tilde{b}$b)~100% assumed
- Spectacular signature:
  - 4 b-quarks + $\not{E}_t$
- Require b-jets and $\not{E}_t$>80 GeV





Expect:2.6±0.7

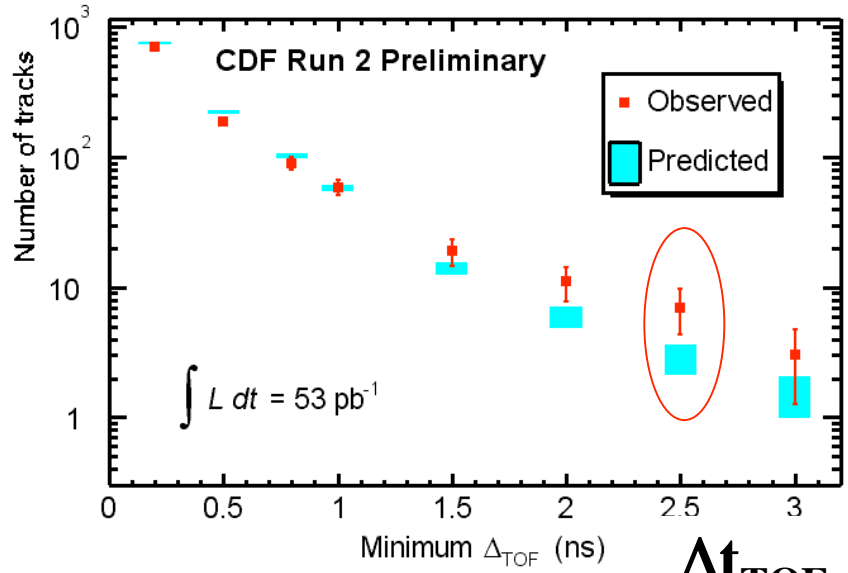
Observe: 4



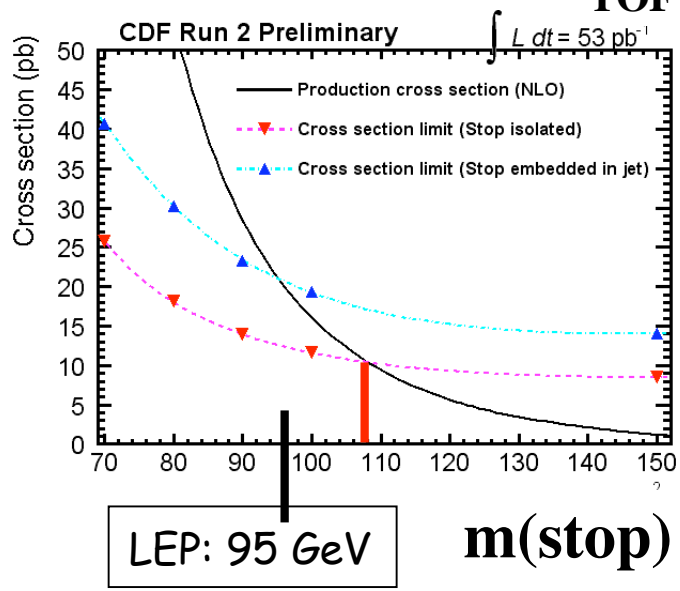
Exclude new parameter space in gluino vs. sbottom mass plane

Stop Quarks

- Model:
  - any charged massive particle (e.g. stop, stau) with long lifetime: "quasi-stable"
  - Assume: fragments like b-quark
- Signature
  - Use Time-Of-Flight Detector:
    - $R_{TOF} \approx 140$cm
    - Resolution: 100ps
  - Heavy particle=> v<<c
  - $\Delta t_{TOF} = t_{track} - t_{event}$ = 2-3 ns
- Result for Δt_{TOF} >2.5 ns:
  - expect 2.9±3.2, observe 7
- σ<10-20pb at m=100 GeV
- $M(\tilde{t})$>97-107 GeV @ 95%C.L.

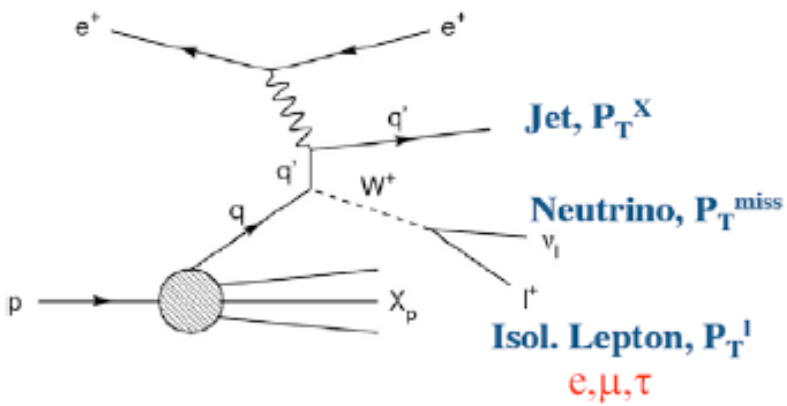


Δt_{TOF}



m(stop)

HERA I: "Isolated Leptons"



Observed/expected events

e+μ	H1:I	ZEUS:I
P_T^X>0	19/14.4	36/32.5
P_T^X>25 GeV	11/3.4	7/5.7

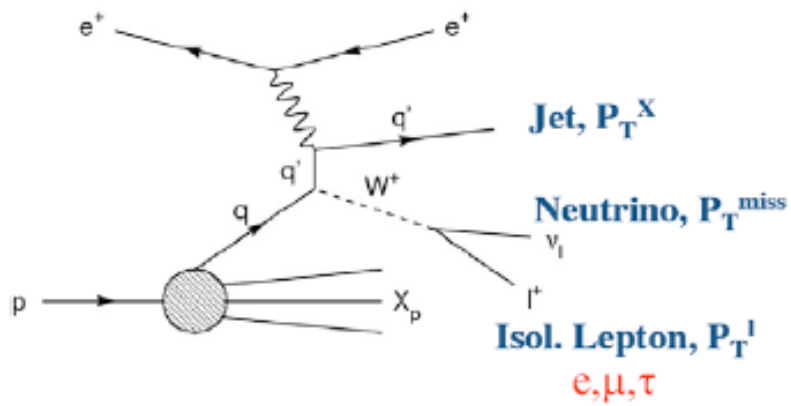
NB: τ channel also analysed but inconclusive

- HERA Run I (~120 pb^{-1}):
  - H1 saw excess at high P_T^X
  - ZEUS does not confirm

Check with independent sample: first 45 pb^{-1} of HERA Run II data!

See also talk by A. Schoening

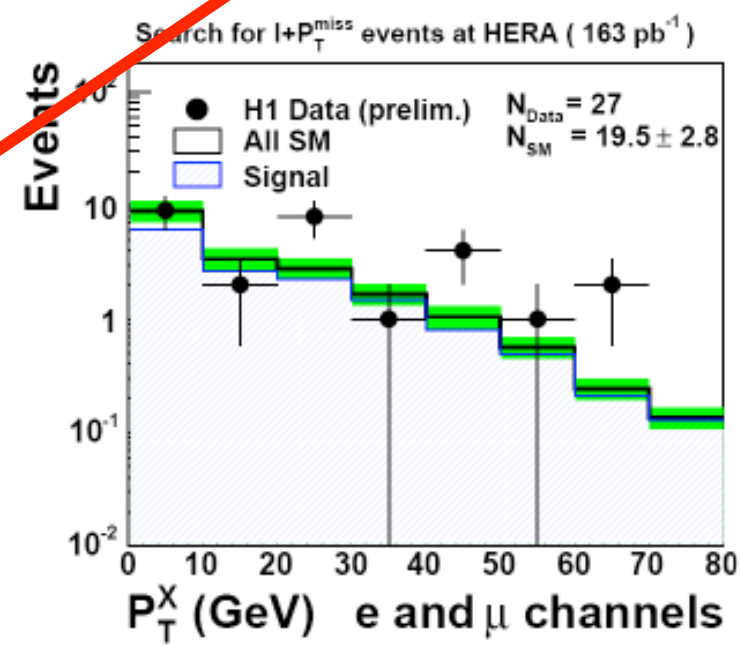
HERA II: "Isolated Leptons"



Observed/expected events

e+μ	H1:I	H1:II	ZEUS:I
P_T^X>0	19/14.4	8/5.1	36/32.5
P_T^X>25 GeV	11/3.4	3/1.6	7/5.7

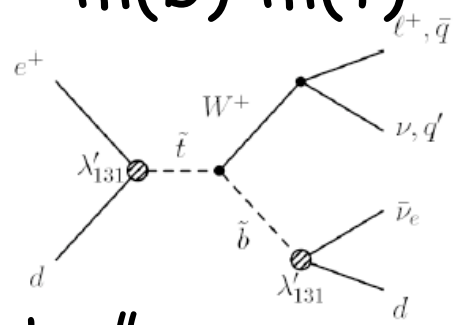
- HERA Run I (~120 pb^{-1}):
  - H1 saw excess at high P_T^X
  - ZEUS does not confirm
- New data (45 pb^{-1}):
  - Not conclusive: need more!

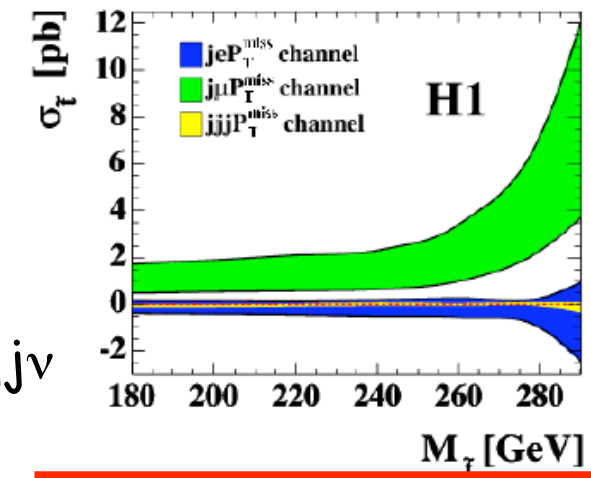


See M. Klein for HERA Run II

HERA: RPV stop

- RPV SUSY: $m(\tilde{b})<m(\tilde{t})$
  - production of single $\tilde{t}$
- HERA: need $\lambda'_{131}>0.01$
  - Could explain "isolated lepton" excess (see earlier)
- Analyses
  - H1: $m(\tilde{b})<m(\tilde{t})$
    - 3 modes: $j\mu\nu\nu$, $je\nu\nu$, $jjj\nu$





μ channel consistent with e and j channels at 1% level -> limit

HERA: RPV stop

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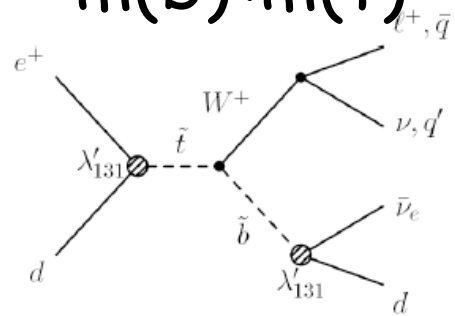
- Analyses
  - H1: $m(\tilde{b})<m(\tilde{t})$
    - 3 modes: jμνν, jeνν, jjjν
  - ZEUS: $m(\tilde{t})<m(\tilde{b})$
    - 2 modes: ejjj, νjjj

$m(\tilde{b})<m(\tilde{t})$



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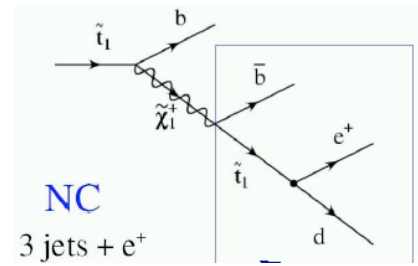
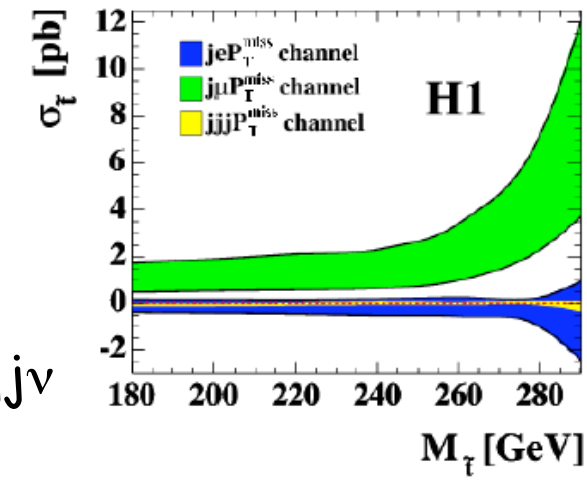
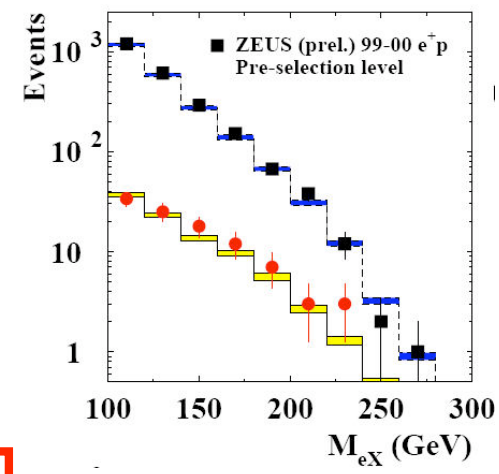




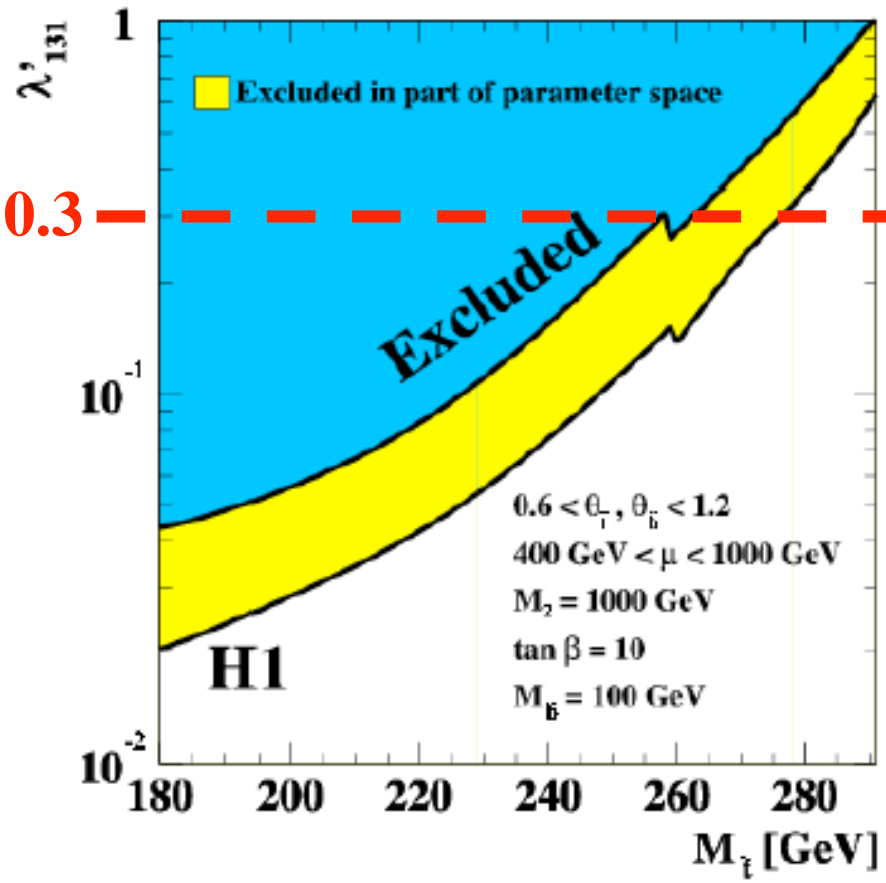


μ channel consistent with e and j channel at 1% level -> limit

Scan mass of ejjj system

HERA: RPV stop

$m(\tilde{b})<m(\tilde{t})$



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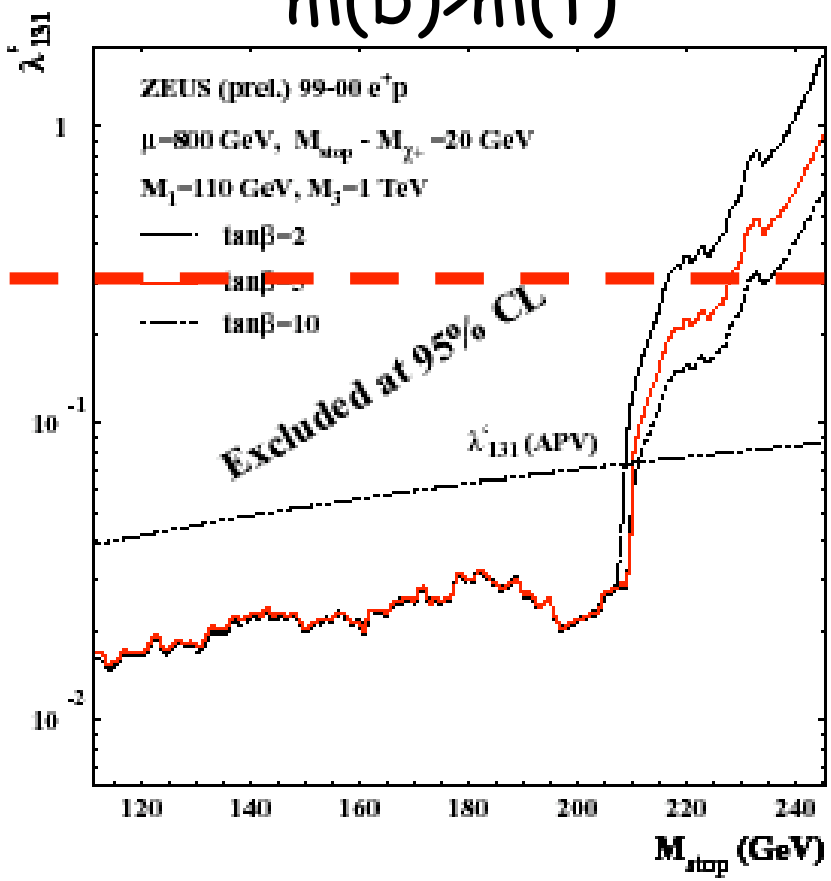


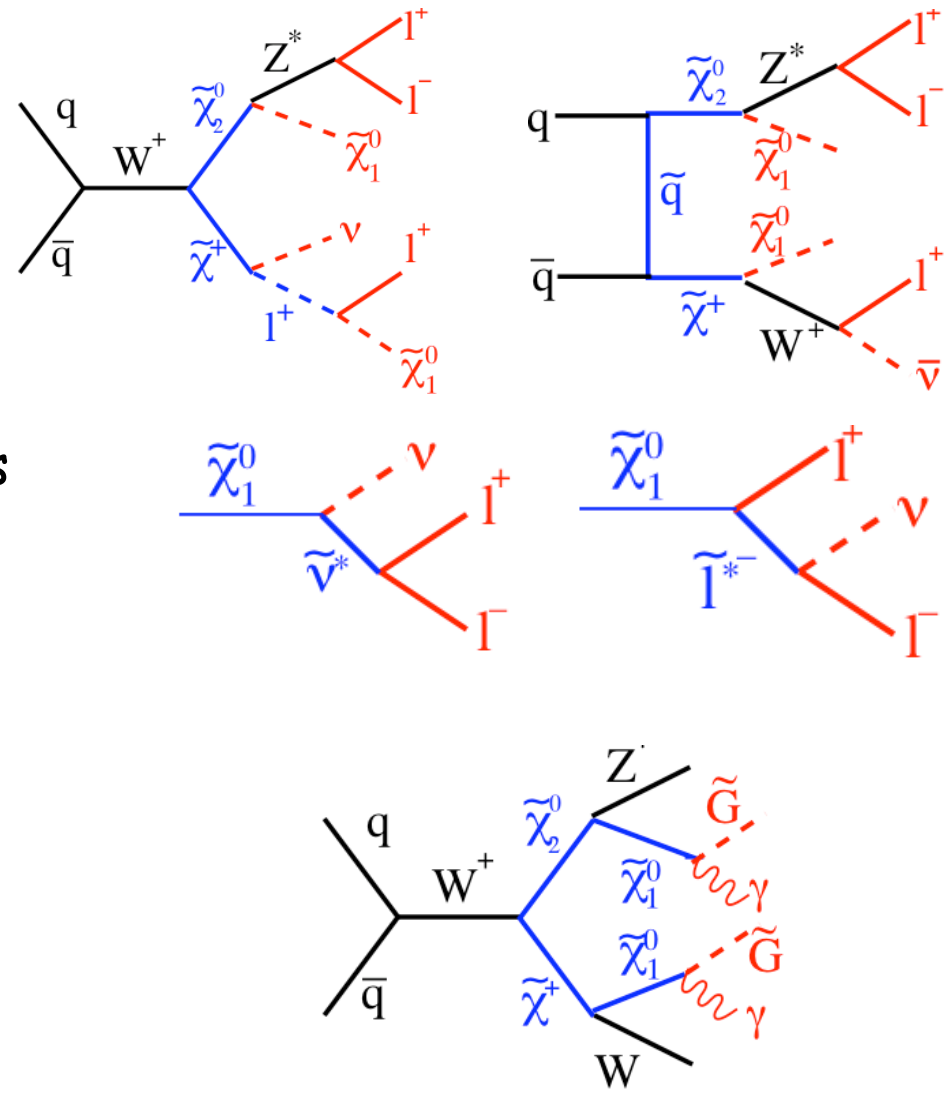
λ'_{131}=0.3: $m(\tilde{t})$>260-280 GeV

–λ'_{131}=0.3: $m(\tilde{t})$>210-230 GeV

-$m(\tilde{t})$<200 GeV: $\lambda'_{131}<10^{-2}$

Charginos and Neutralinos

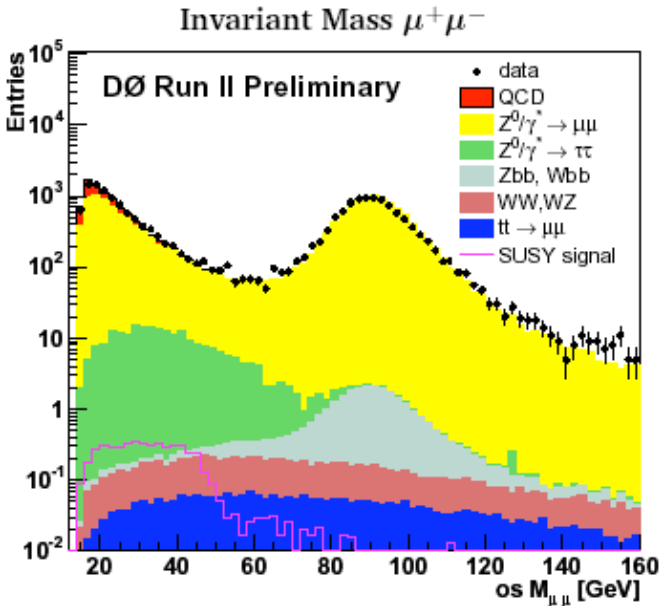
- mSUGRA inspired
  - Neutralino LSP
  - 3 leptons + $\not{E}_t$
- R-parity violation: $\lambda_{ijk}>0$
  - Neutralino decay into leptons
  - 4 leptons + $\not{E}_t$
- GMSB inspired:
  - Gravitino LSP
  - Here: Neutralino (NLSP)->$\tilde{G}\gamma$
  - 2 photons + $\not{E}_t$ + X

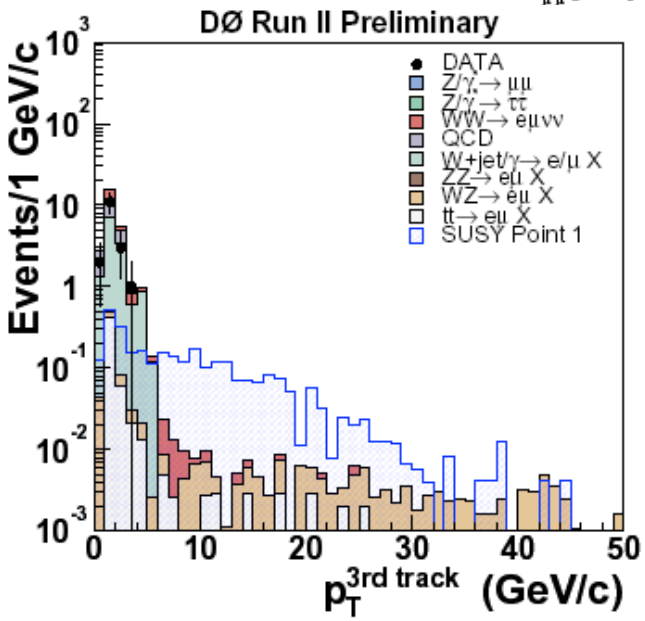


3 leptons + $\not{E}_T$

- Challenge:
  - σxBR low (<0.5 pb)
  - Backgrounds large
- Selection
  - 2 l (l=e,μ) + isolated track or $\mu^\pm\mu^\pm$
  - Significant $\not{E}_T$
  - Topological cuts

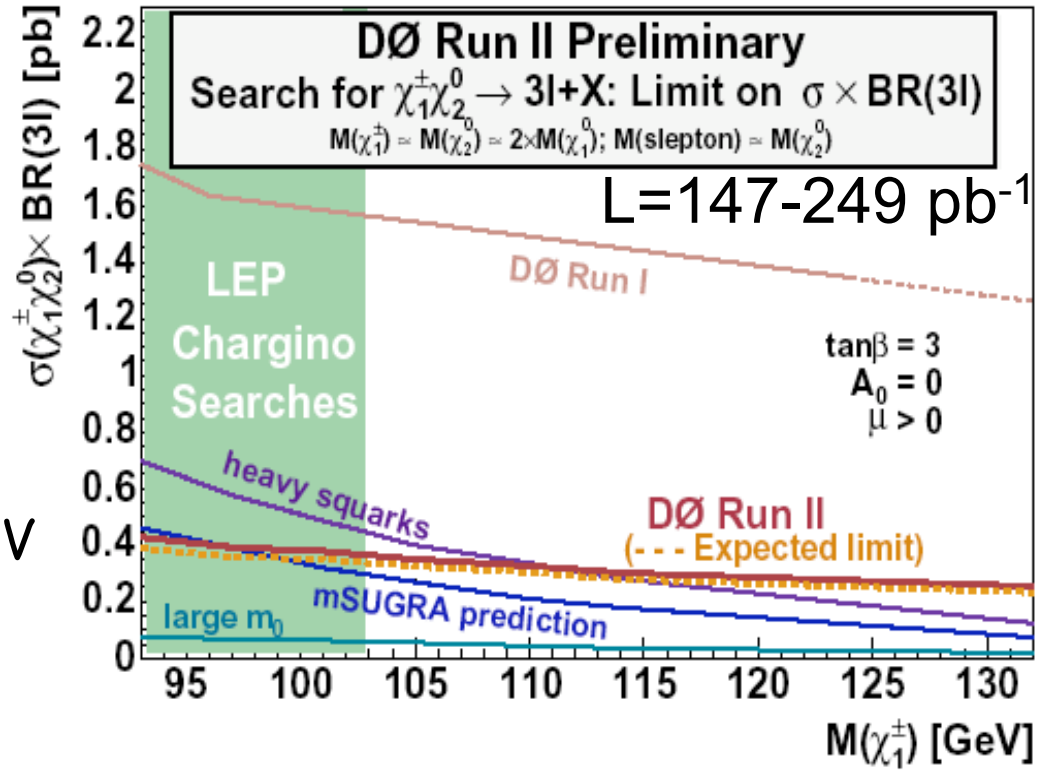
selection	background	observed
eel	0.7±0.5	1
eμl	0.3±0.3	0
$\mu\mu$l	1.8±0.4	1
$\mu^\pm\mu^\pm$	0.1±0.06	1





mSUGRA: 3-lepton result

- Combined result:
  - σxBR<0.3-0.4 pb
- Theory comparison
  - mSugra: $m(\chi^{\pm})$>97 GeV
    - $\tan\beta$=3, A_0=0, μ>0
    - $M(\chi^{\pm})\approx M(\chi^0_2)\approx 2M(\chi^0_1)$
  - Heavy squarks: $m(\chi^{\pm})$>111 GeV
    - Reduce destructive interference
  - Large m_0:
    - Sleptons heavy
    - Very difficult



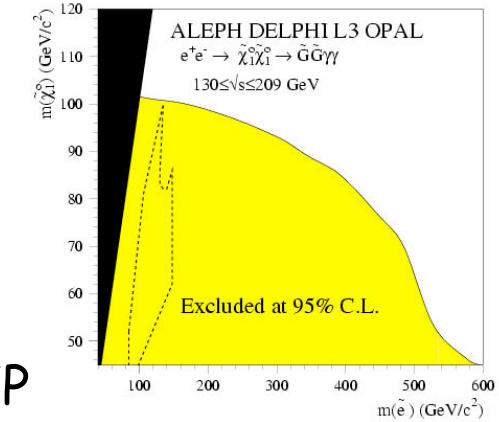
Also, new limits for RPV decay of χ^0_1 :

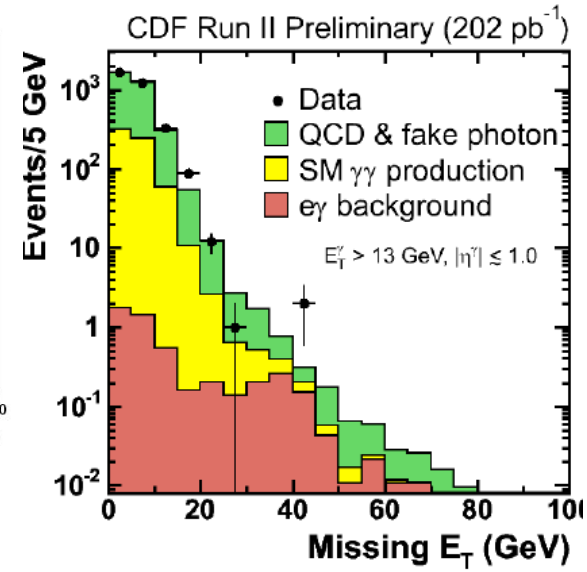
$m(\chi^+_1)$>183 (160) GeV for λ_{121} (λ_{122}) for μ<0

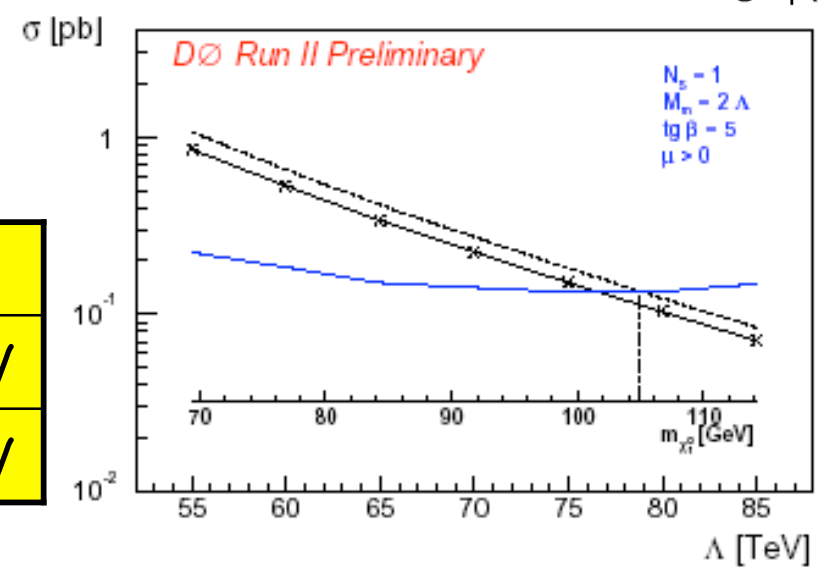
Will extend sensitivity to mSUGRA beyond LEP with just 25% more data: 75% more already on tape!

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

- Assume χ^0_1 is NLSP:
  - Decay to $\tilde{G}+\gamma$
  - $\tilde{G}$ light M~O(1 keV)
  - Inspired by CDF $ee\gamma\gamma+\not{E}_t$ event: now ruled out by LEP
- D0 (CDF) Inclusive search:
  - 2 photons: E_t > 20 (13) GeV
  - $\not{E}_t$ > 40 (45) GeV



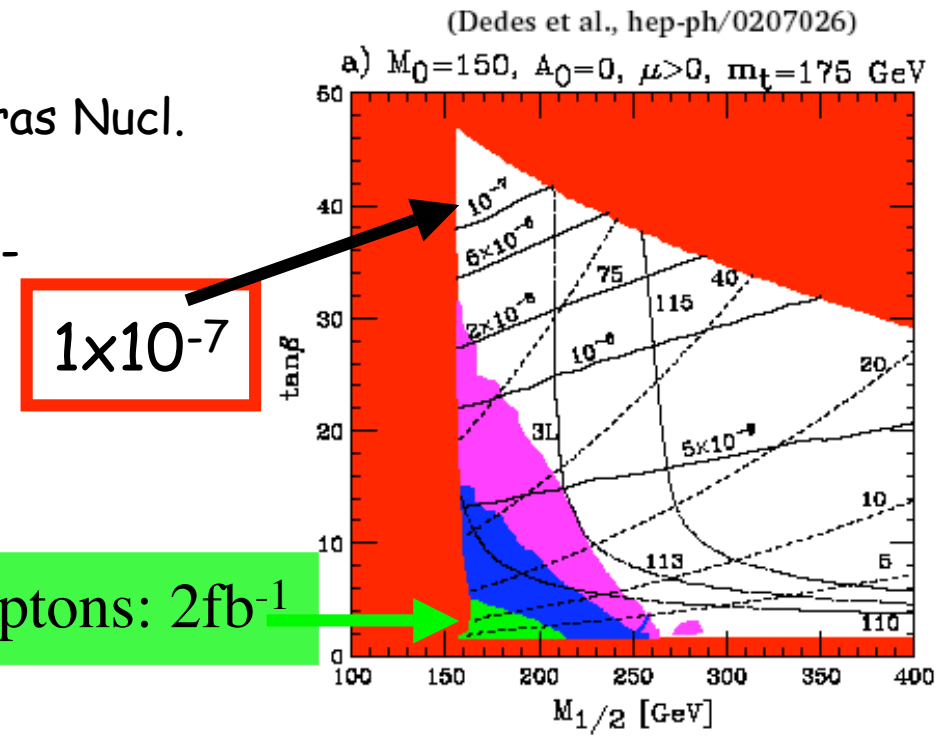




	Exp.	Obs.	$M(\chi^+_1)$
D0	2.5±0.5	1	>192 GeV
CDF	0.3±0.1	0	>168 GeV

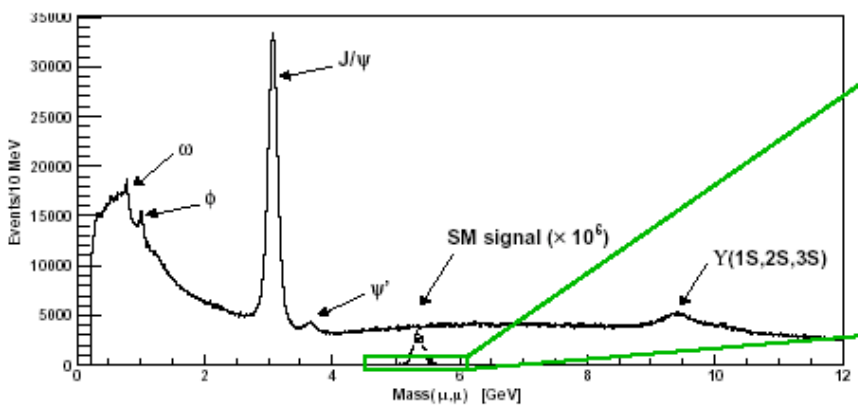
Indirect Search: $B_s \to \mu\mu$

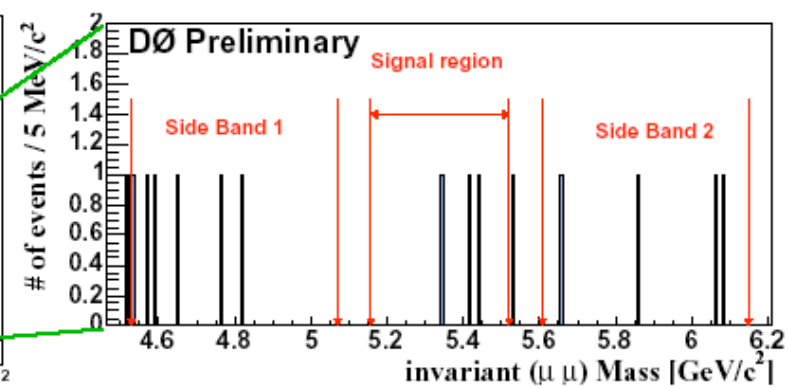
- BR($B_s \to \mu\mu$):
  - SM: 3.5×10^{-9} (G. Buchalla, A. Buras Nucl. Phys. B398, 285)
  - SUSY: $\propto \tan^6\beta$ (G. Kane et al., hep-ph/0310042)
- Selection:
  - 2 muons, displaced vertex
  - Topological cuts



1×10^{-7}

Trileptons: $2fb^{-1}$





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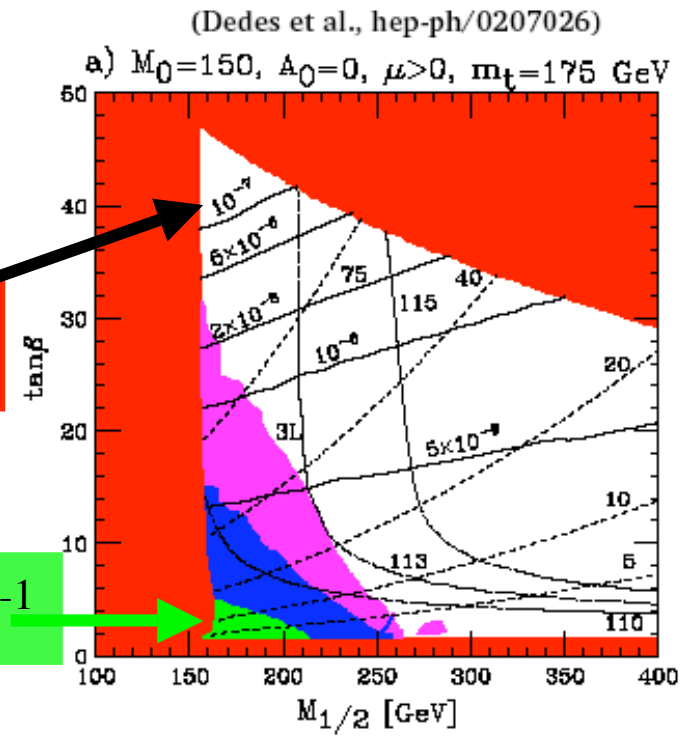


1×10^{-7}

Trileptons: $2fb^{-1}$

World's best limit!

	D0 (prel.)	CDF
expected	3.7±1.1	1.1±0.3
observed	4	1
BR@90% C.L.	$<3.8\times10^{-7}$	$<5.8\times10^{-7}$

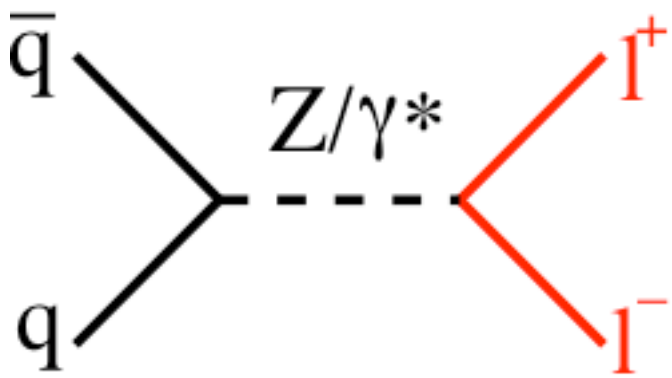
- CDF&D0 (M. Herndon):
  - $BR(B_s \to \mu\mu) < 2.7\times10^{-7}$
- More b-physics results tomorrow:

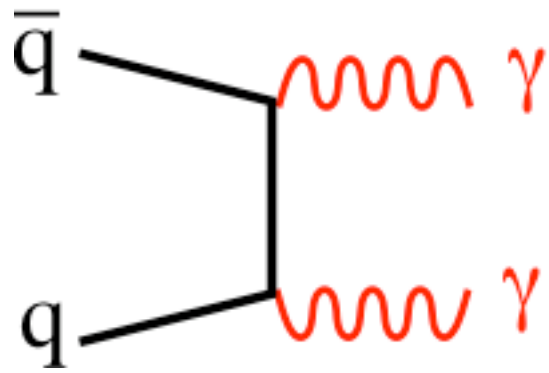
D. Lucchesi

High Mass Searches

High Mass Dileptons and Diphotons

Standard Model high mass production:



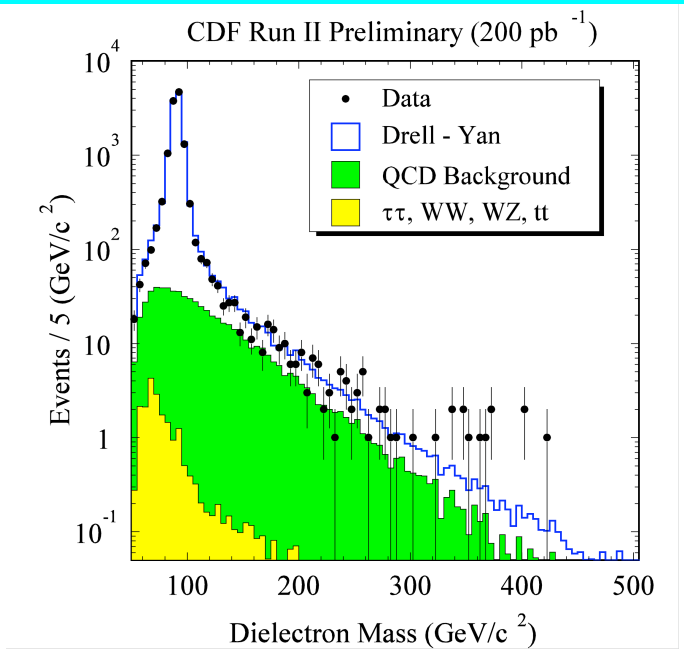


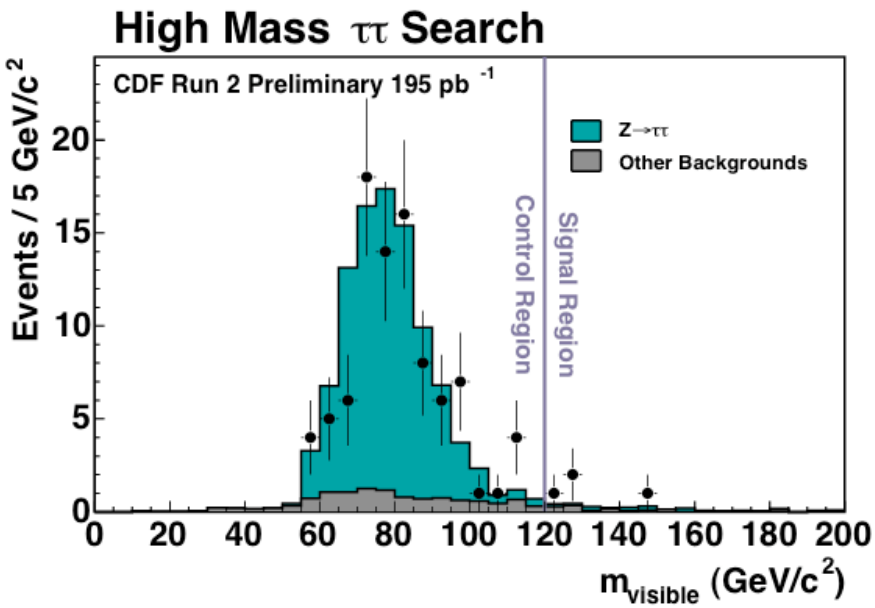
New physics at high mass:

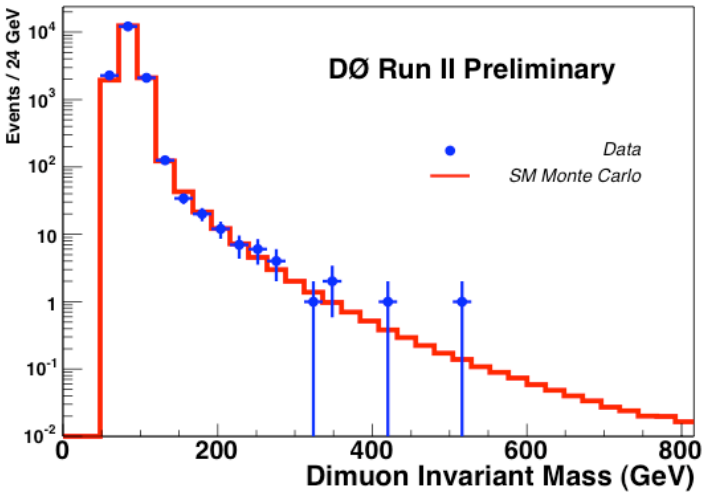
- Resonance signature:
  - Spin-1: Z'
  - Spin-2: Randall-Sundrum (RS) Graviton
  - Spin-0: Higgs
- Tail enhancement:
  - Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)
  - Contact interaction

Neutral Spin-1 Bosons: Z'

- 2 high-Pt electrons, muons, taus
- Data agree with BG (Drell-Yan)
- Interpret in Z' models:
  - E6-models: ψ, η, χ, I
  - SM-like couplings (toy model)





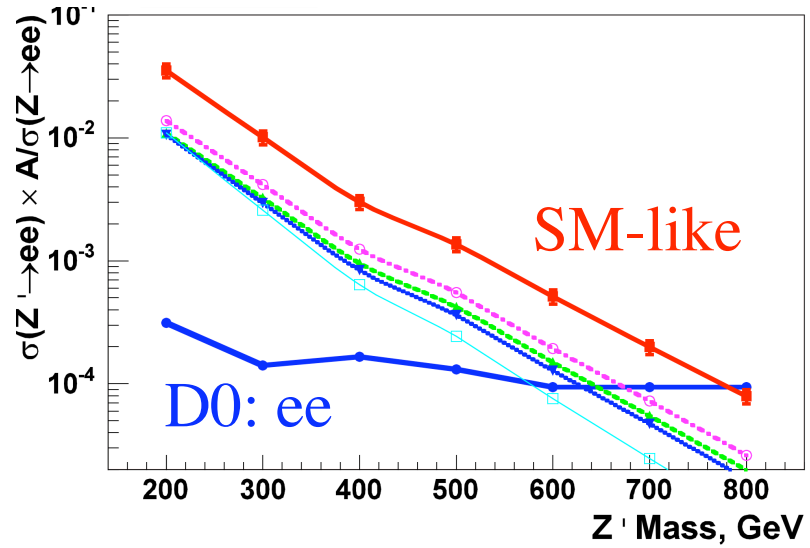


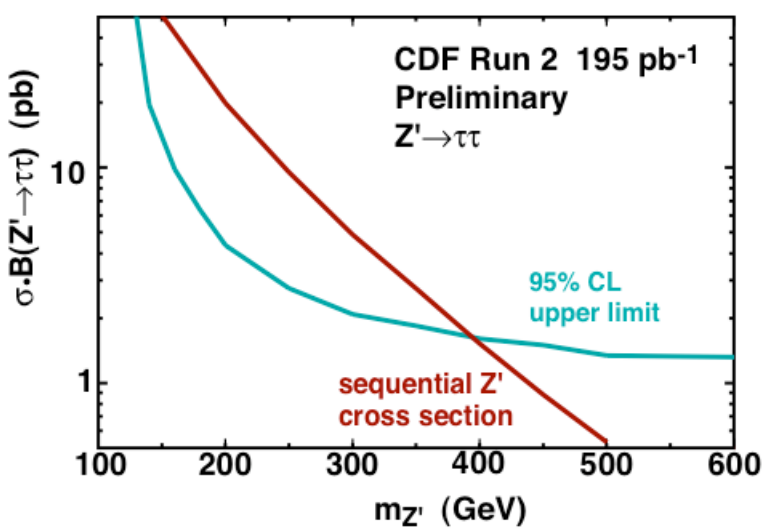
Neutral Spin-1 Bosons: Z′

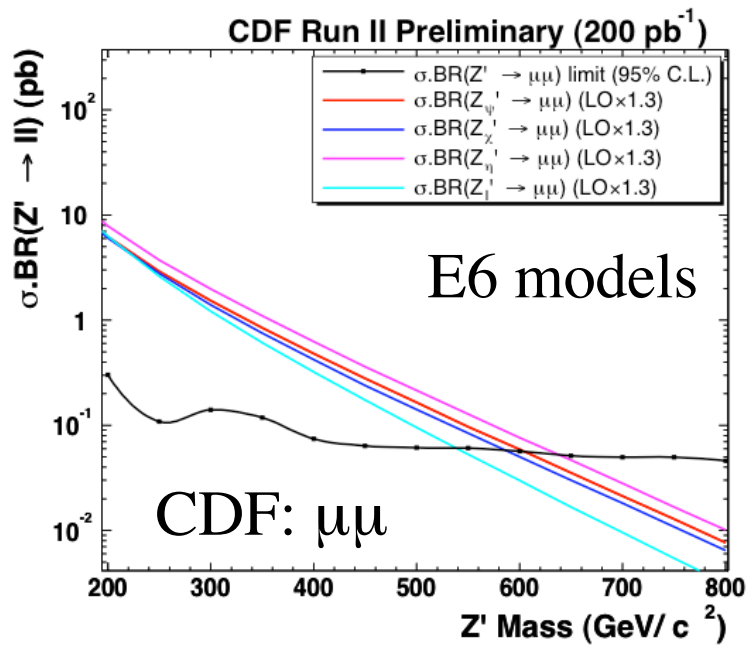
- 95% C.L. Limits for SM-like Z′ (in GeV):

	ee	μμ	ττ
CDF	>750	>735	>395
D0	>780	>680	-

Best limits to date!

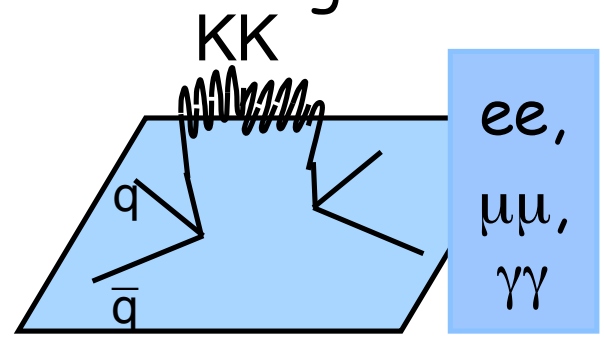




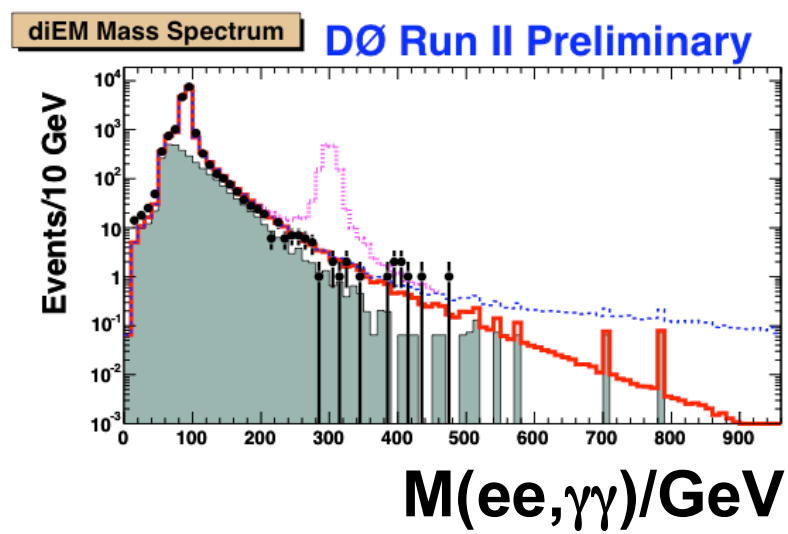


Extra Dimensions

- 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: $\lambda=\pm1$ (Hewett)

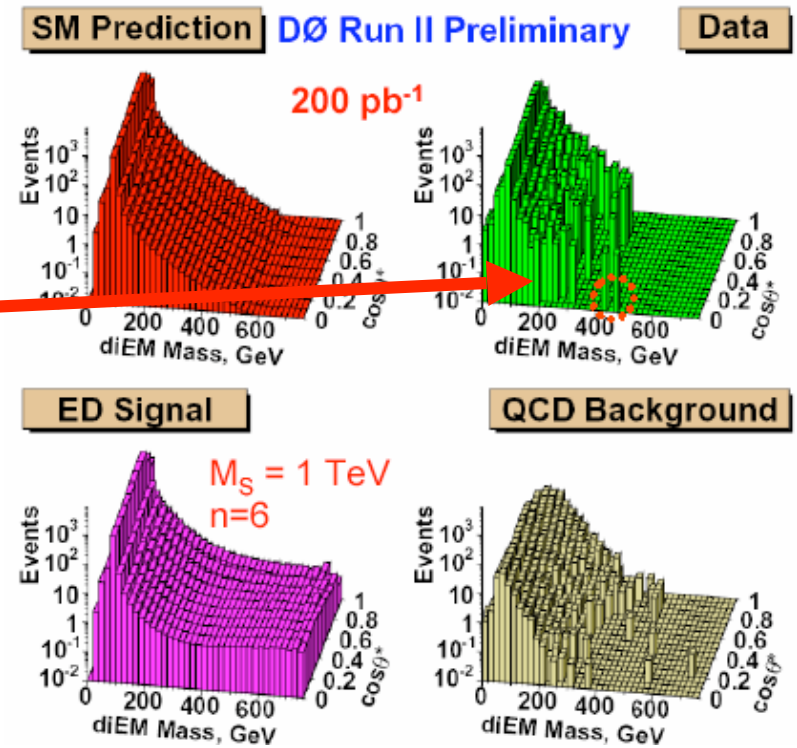


- Randall Sundrum:
  - Gravity propagates in single curved ED
  - ED small $1/M_{Pl}=10^{-35}$ m
  - Large spacing between KK-excitations
    ⇒ resolve resonances
- Signatures at Tevatron:
  - Virtual exchange:
    - 2 leptons, photons, W's, Z's, etc.
    - BR(G->γγ)=2xBR(G->ll)



Large Extra Dimensions: ADD

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

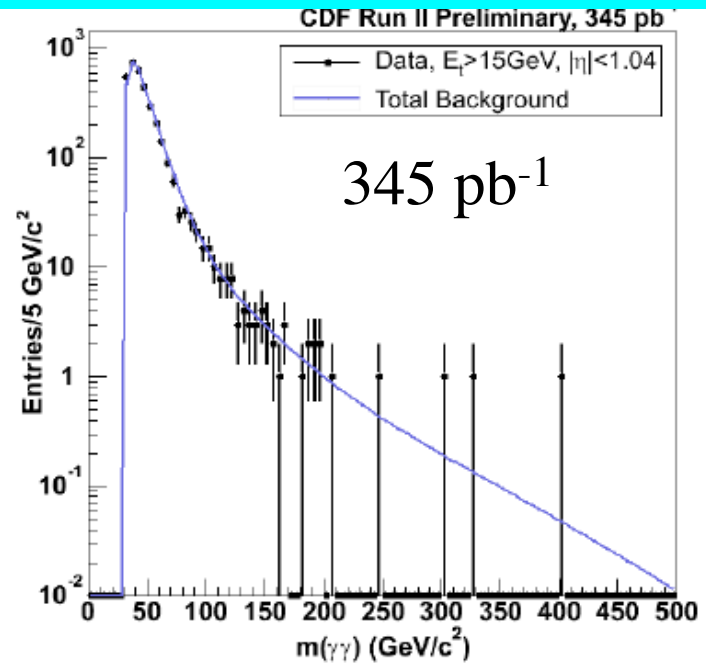


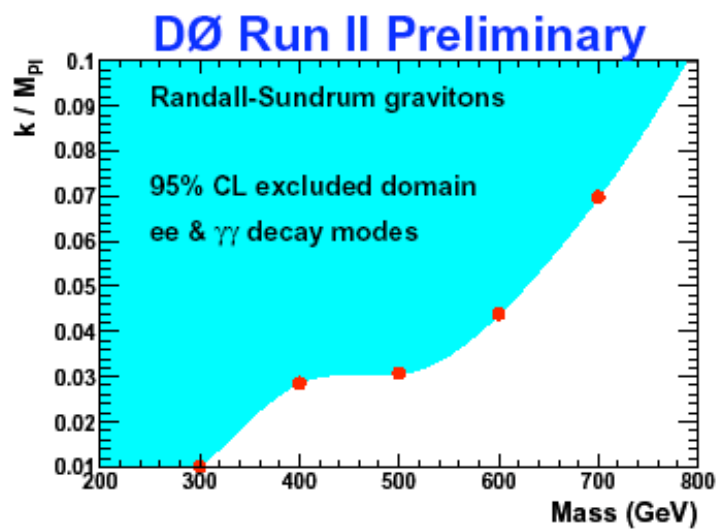
	D0		CDF	LEP	H1	ZEUS
	ee+γγ	μμ	ee	ee	eq	eq
λ=+1	1.28	0.97	0.96	1.20	0.82	0.78
λ=-1	1.16	0.95	0.99	1.09	0.78	0.79

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

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 1st KK-mode
- World's best limit:
  - $M>785$ GeV for $k/M_{Pl}=0.1$

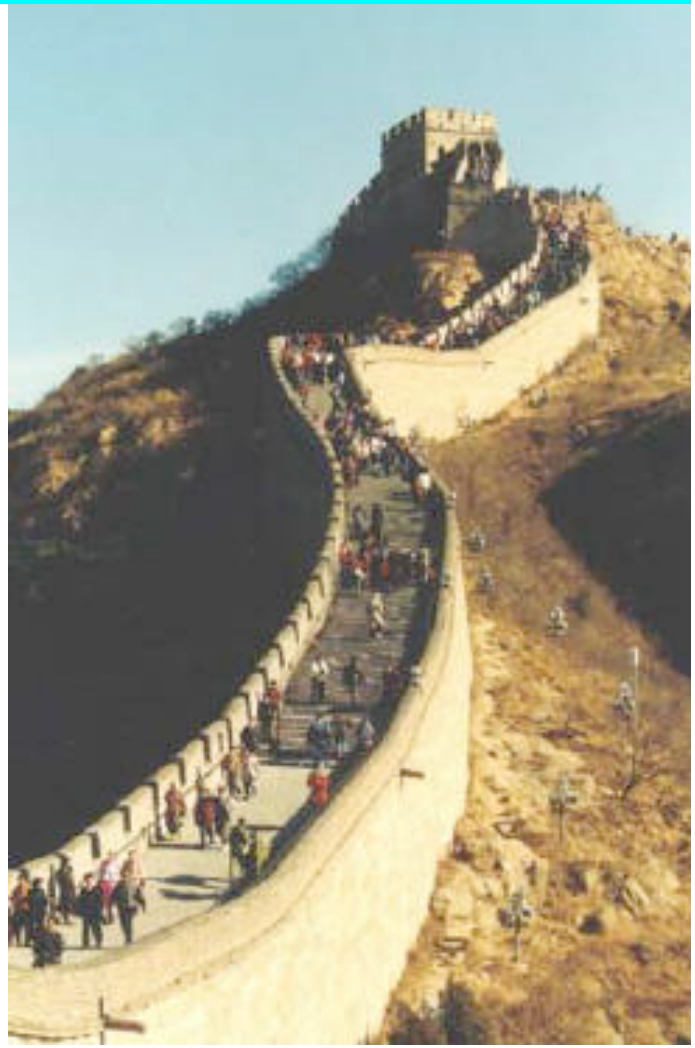




Summary and Outlook

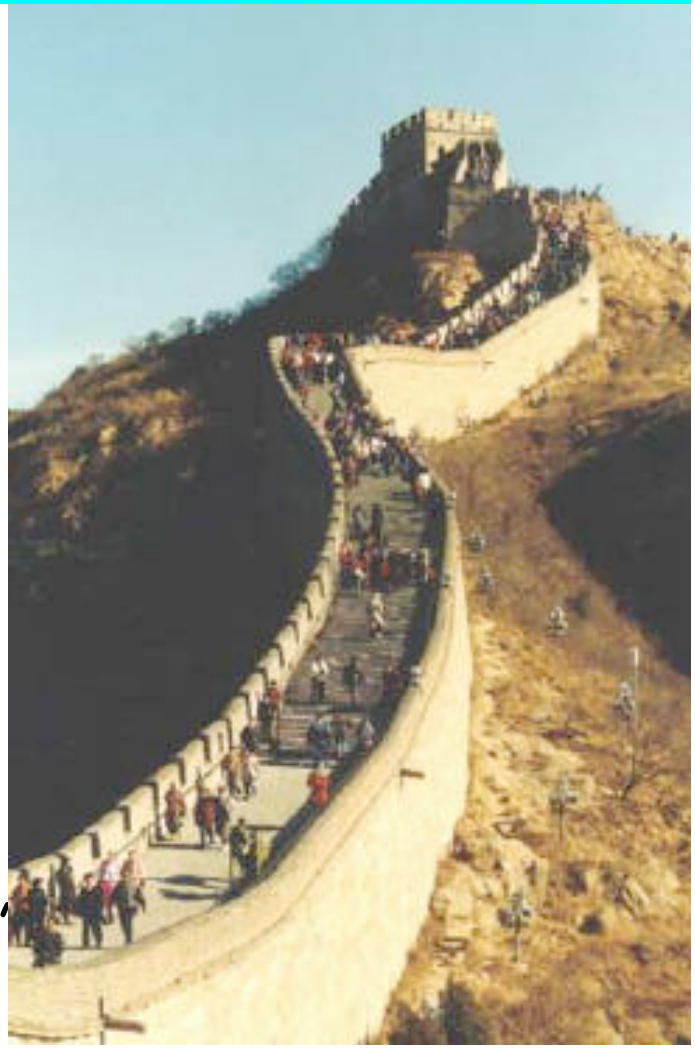
- Tevatron Run II has many new results
  - Machine and experiments running great!
  - Often already world's best constraints
  - Have got 2x more data on tape!
  - Anticipate 1.5-2 fb^{-1} by 2007 and

    4.4-8.6 fb^{-1} by 2009
- HERA has 1st Run II results
- Unfortunately not found anything yet
- We are well on our way to finding new physics if mother nature gives it to us!



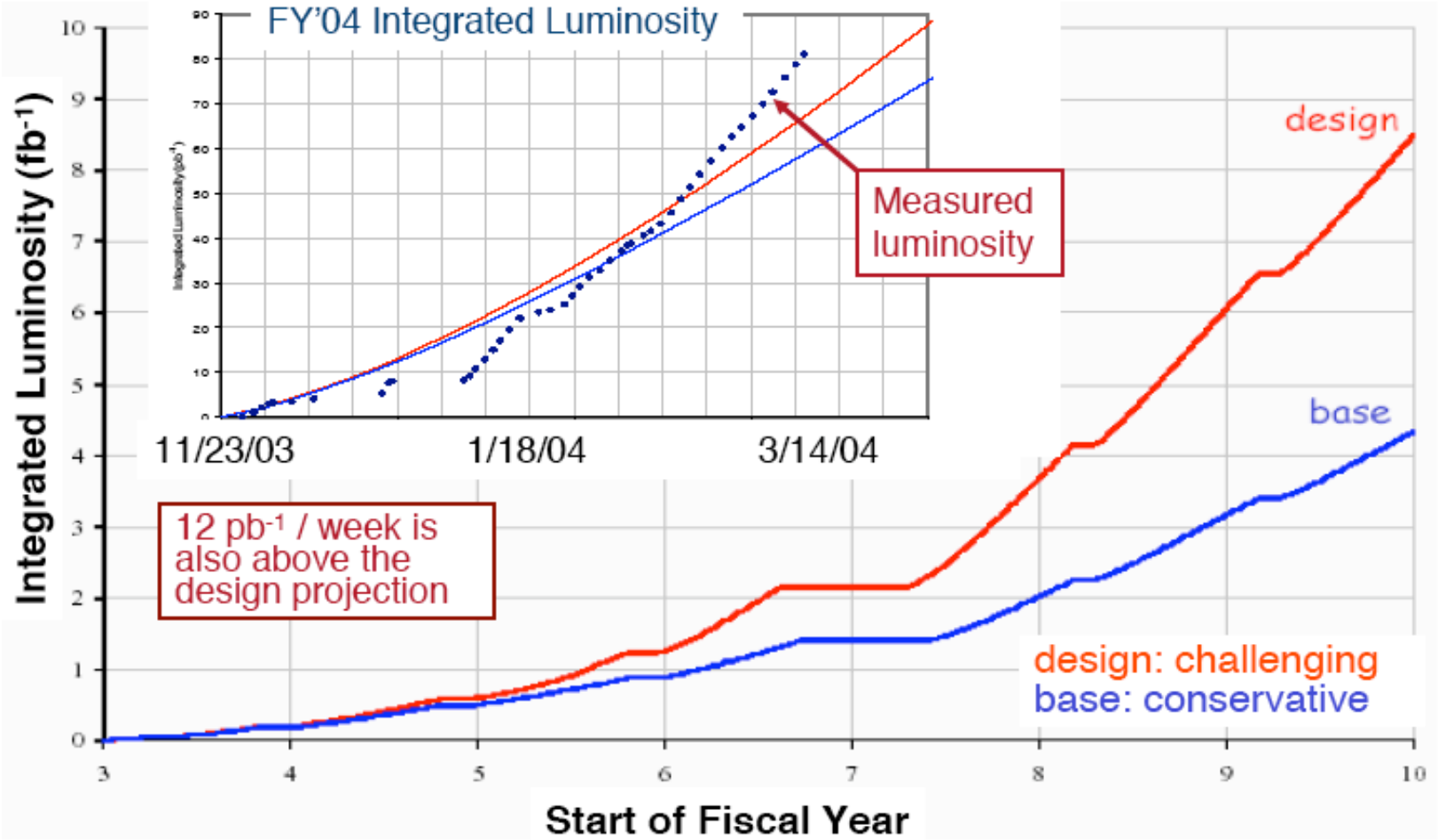
Thanks!!!

- ICHEP organisers
- P. Allport, R. Barbieri, P. Booth, F. Bedeschi, G. Belletini, V. Buescher, J. Devevie, R. Erbacher, J.-F. Grivaz, T. Kamon, Y.-K. Kim, M. Klein, E. Kajfasz, G. Landsberg, A. Lath, T. Liss, G. Manca, A. Meyer, H. Montgomery, J. Qian, T. Pratt, A. Schoening, R. Wallny, M. Witherell, R. Yoshida, FNAL and DESY Beams Divisions, CDF, D0, H1 and ZEUS



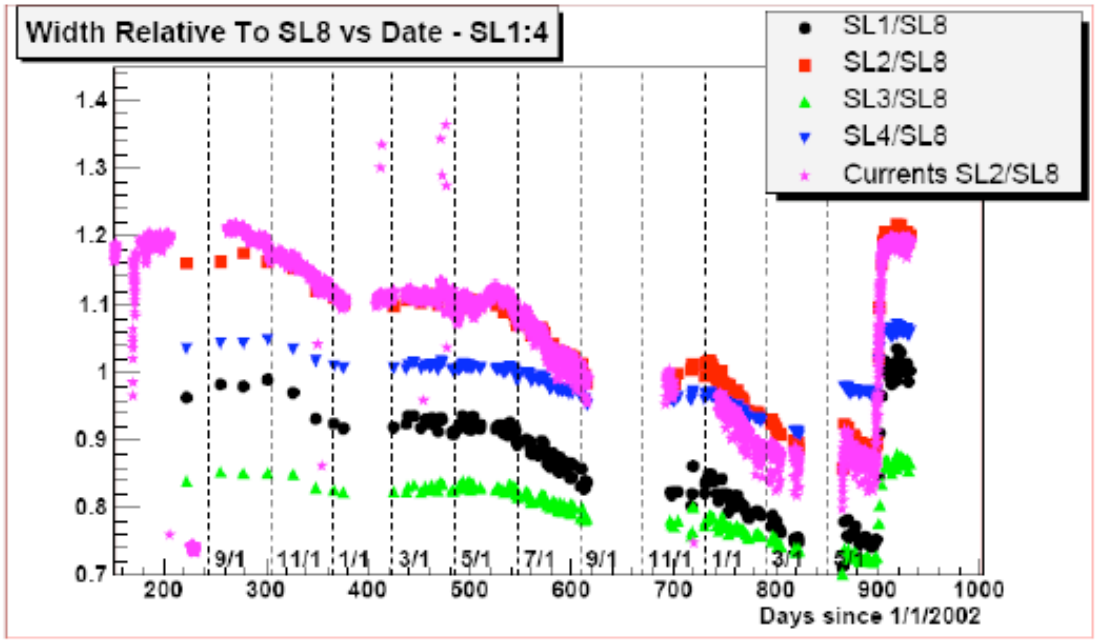
Backup Slides

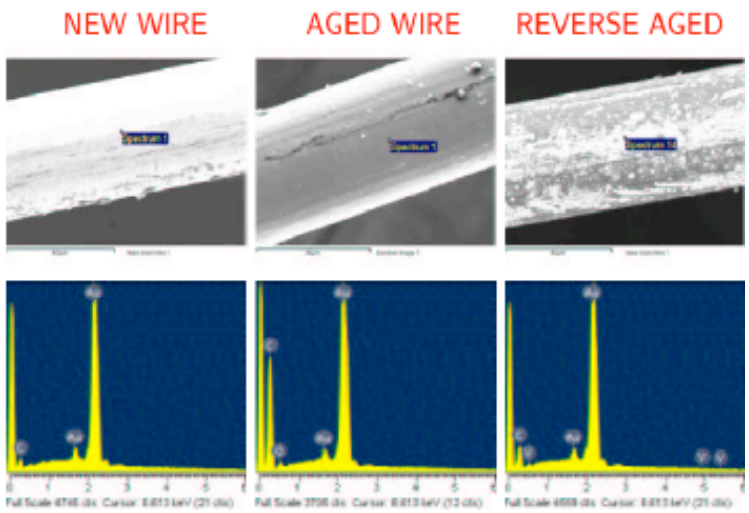
Luminosity Perspectives



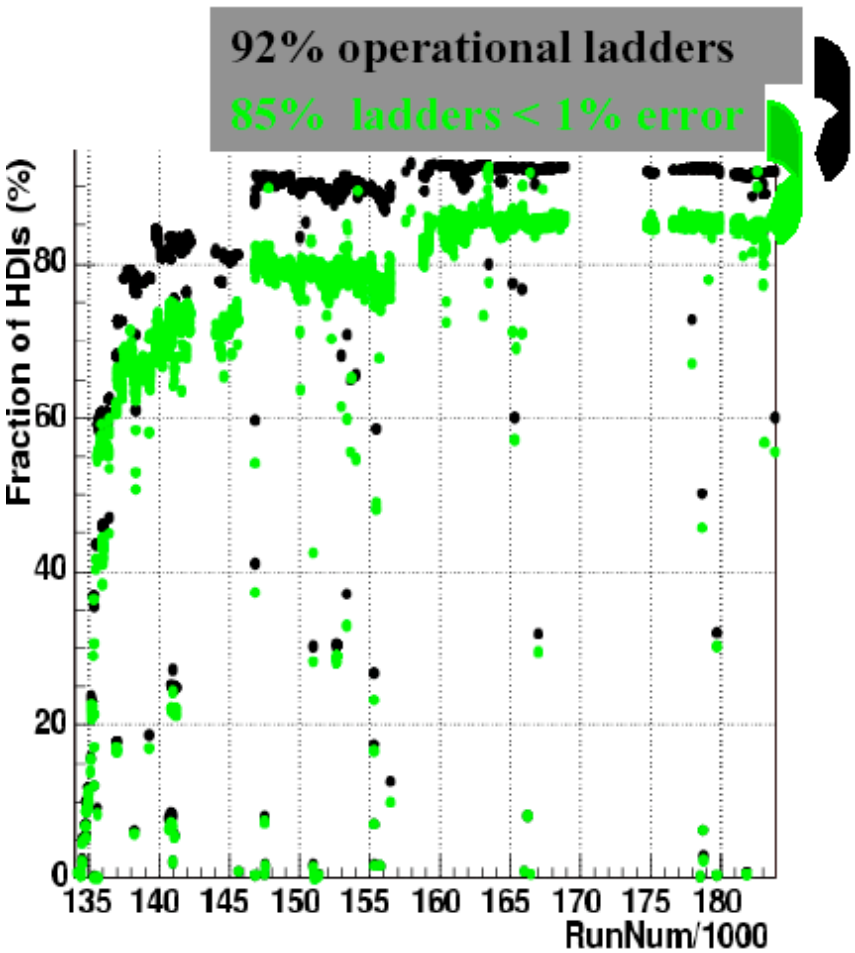
CDF: COT Aging Problem Solved!

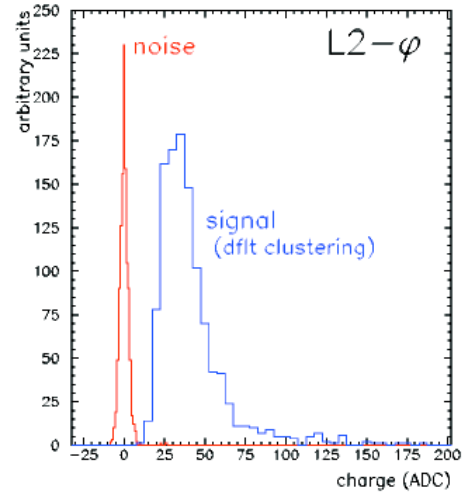
- Gaseous tracking chamber COT: wire aging problem seen in 2003-2004
- hydrocarbon residue detected on sense wires where gain had been falling
- addition of air (probably the oxygen) reverses the aging
- Chamber gains back go pre-aged status
- Voltages reduced on inner superlayers from February to May 2004

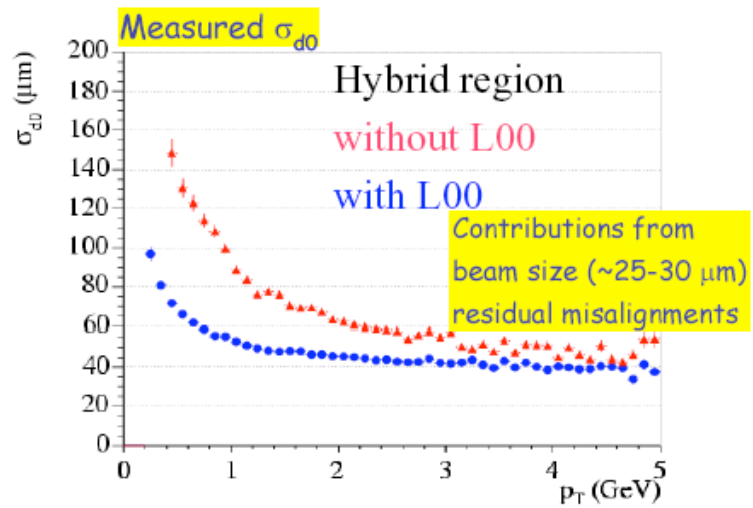




Silicon Performance



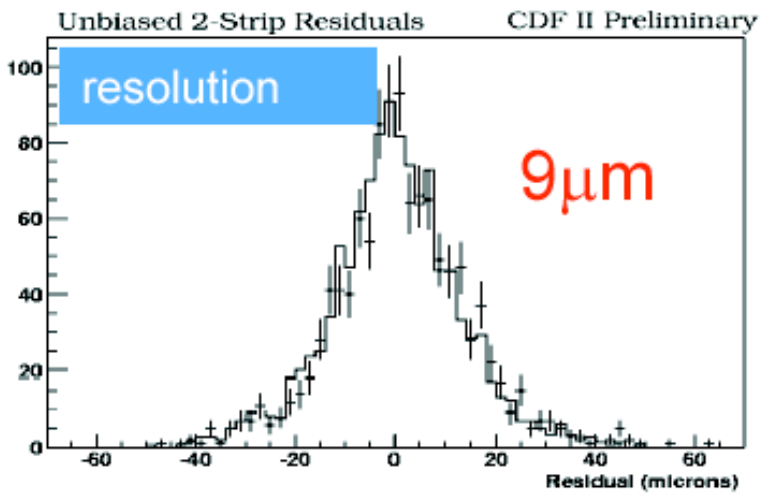


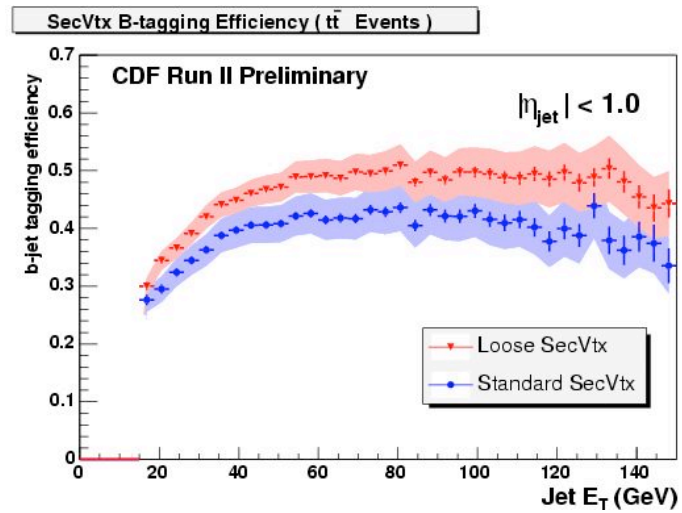


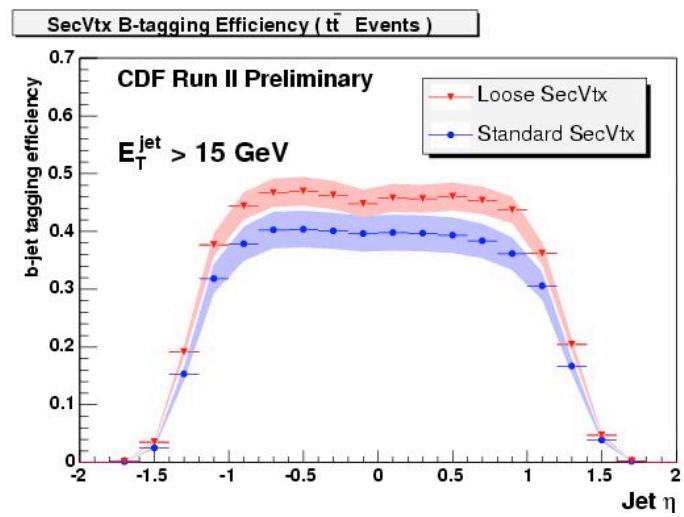
See talk by R. Wallny

CDF: B-tagging and tracking

Requirement	Efficiency	Requirement	Efficiency
$N_{r\phi} \geq 3$	94%	$N_z \geq 3$	80%
$N_{r\phi} \geq 4$	90%	$N_z \geq 4$	61%
$N_{r\phi} = 5$	46%	$N_z = 5$	26%



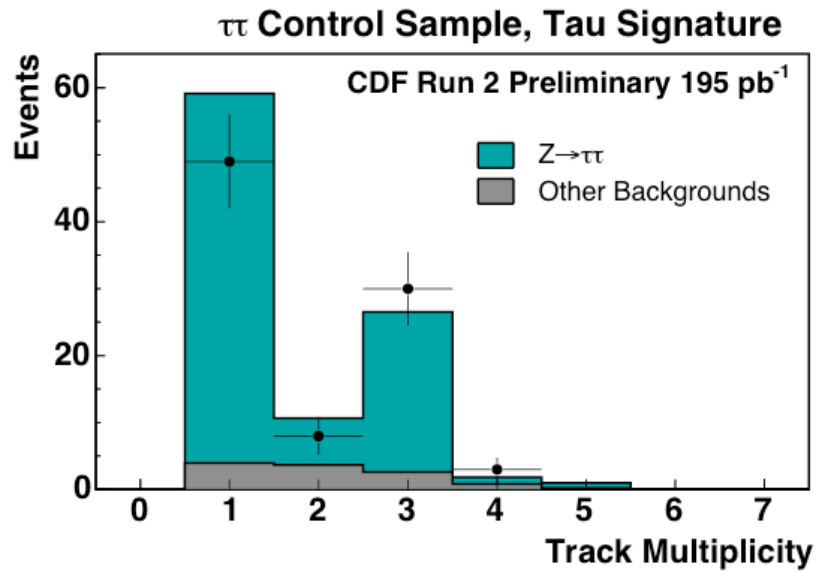


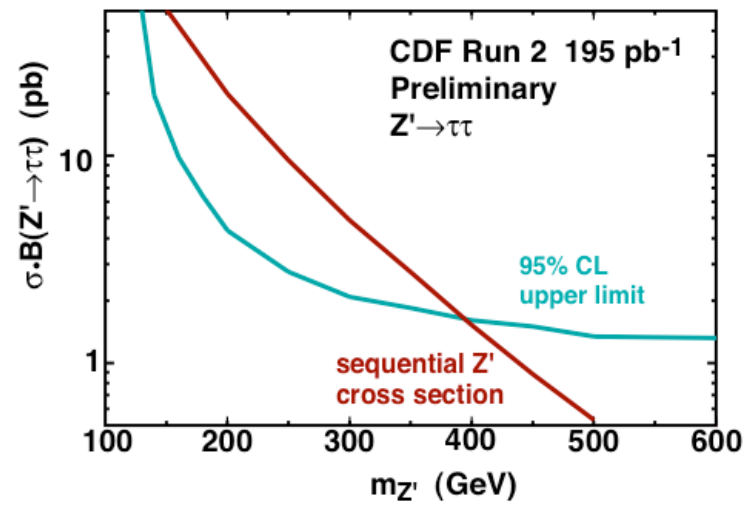


See talk by R. Wallny

Z' -> ττ

- τ's challenging at hadron colliders:
- τ signals established by CDF & D0: W->τν, Z->ττ
  - 1- and 3-prong seen
- Result for m_{vis}>120 GeV:
  - Observe: 4 events
  - Expect: 2.8±0.5
- M(Z')>395 GeV
- Ruled out by ee and μμ channel for SM Z' => explore other models with enhanced τ couplings





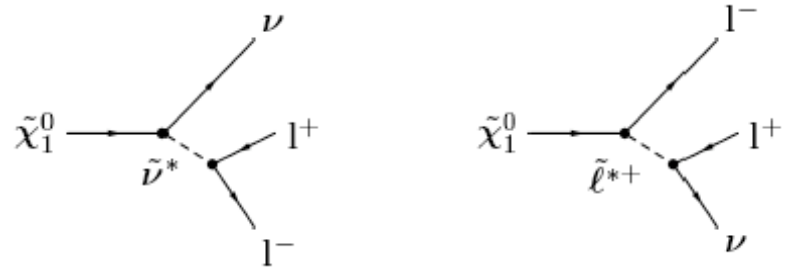
HERA I: Isolated Leptons

H1 1994-2000 $\mathcal{L}(e^{\pm}p) = 118$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau$^{\text{prel.}}$ obs./exp.	W contrib. $e\mu$ (τ)
Full sample	11 / 11.5 $\pm$1.5	8 / 2.94 $\pm$0.51	5 / 5.81 $\pm$1.36	$\approx$ 75(15)%
$P_T^X > 25$ GeV	5 / 1.76 $\pm$0.29	6 / 1.68 $\pm$0.30	0 / 0.53 $\pm$0.10	$\approx$ 85(50)%
$P_T^X > 40$ GeV	3 / 0.66 $\pm$0.13	3 / 0.64 $\pm$0.14	0 / 0.22 $\pm$0.05	$\approx$ 90(55)%

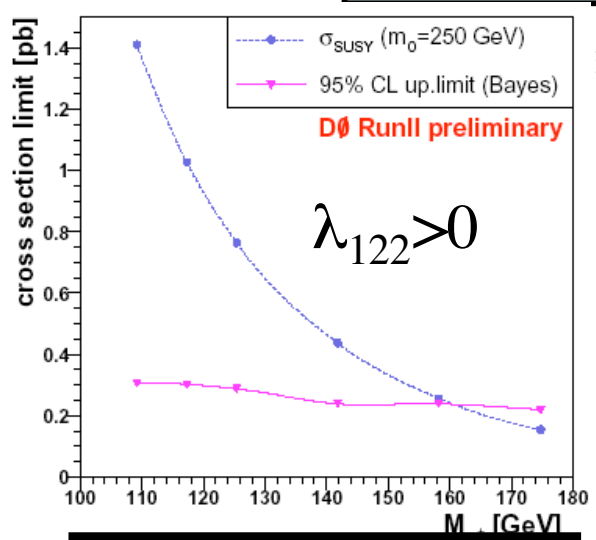
ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu$ (τ)
Full sample	24 / 20.6 $\pm$3.2	12 / 11.9 $\pm$0.6	3 / 0.4 $\pm$0.12	$\approx$ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 $\pm$0.46	5 / 2.75 $\pm$0.21	2 / 0.2 $\pm$0.05	$\approx$ 50(50)%
$P_T^X > 40$ GeV	0 / 0.94 $\pm$0.11	0 / 0.95 $\pm$0.12	1 / 0.07 $\pm$0.02	$\approx$ 60(70)%

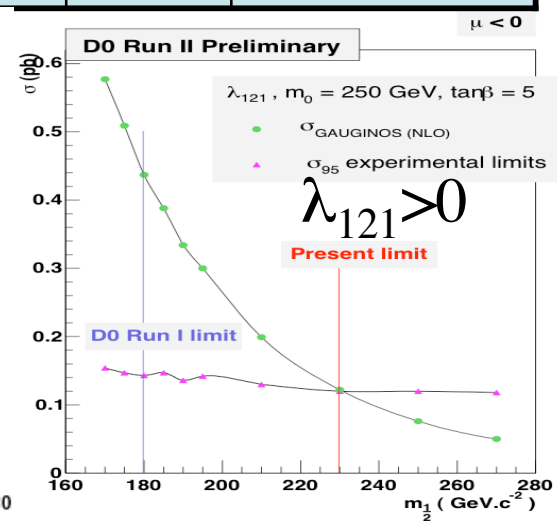
RPV Neutralino Decay

- Model:
  - R-parity conserving production => two neutralinos
  - R-parity violating decay into leptons
  - One RPV couplings non-0: λ_{122} , λ_{121}
- Final state: 4 leptons $+\not{E}_t$
  - eee, eeμ, μμe, μμμ
  - 3rd lepton P_t>3 GeV
  - Largest Background: $b\bar{b}$
- Interpret:
  - M_0=250 GeV, tanβ=5



	Obs.	Exp.
eel (l=e,μ)	0	0.5±0.4
μμl (l=e,μ)	2	0.6+1.9-0.6



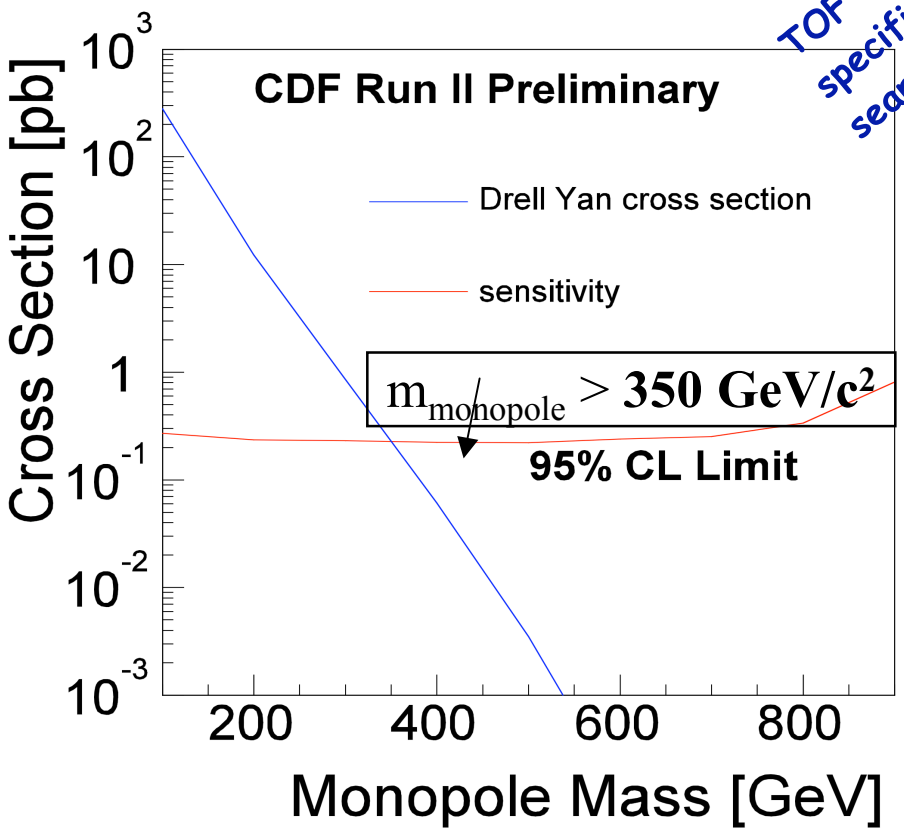
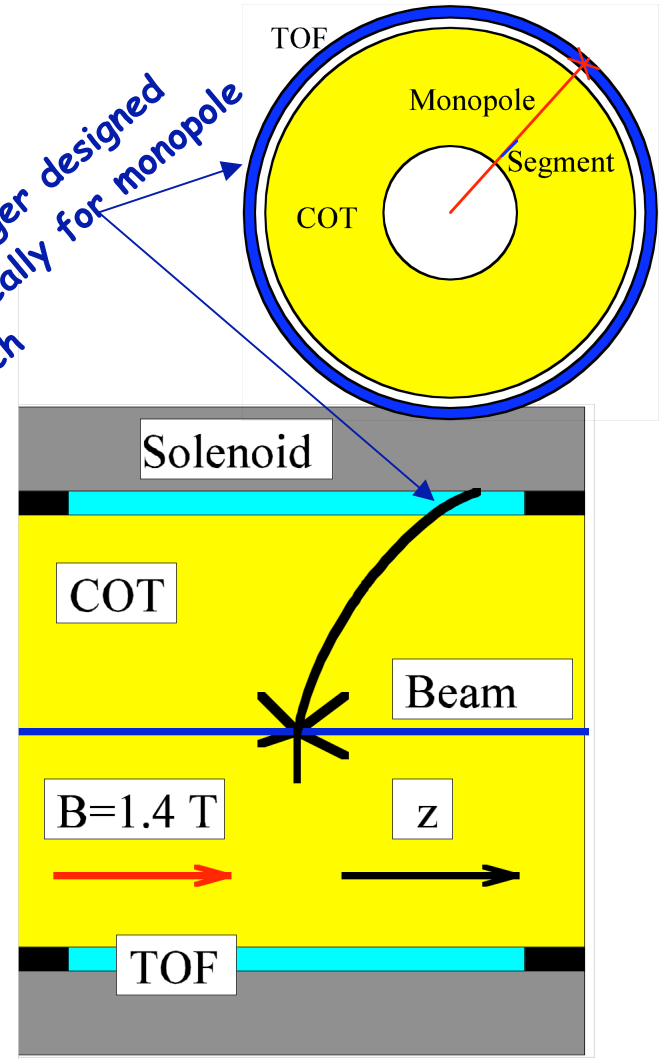


$m(\tilde{\chi}^+_1)$ >160 GeV

$m(\tilde{\chi}^+_1)$ >183 GeV

Dirac Magnetic Monopole

- Bends in the ***wrong*** plane (→ high pt)
- Large ionization in scint **(>500 Mips!)**
- Large dE/dx in drift chamber



TOF trigger designed specifically for monopole search