Searches for New Phenomena at CDF

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

Seminar at LBNL, January 9th 2006

New Phenomena: Why and What?

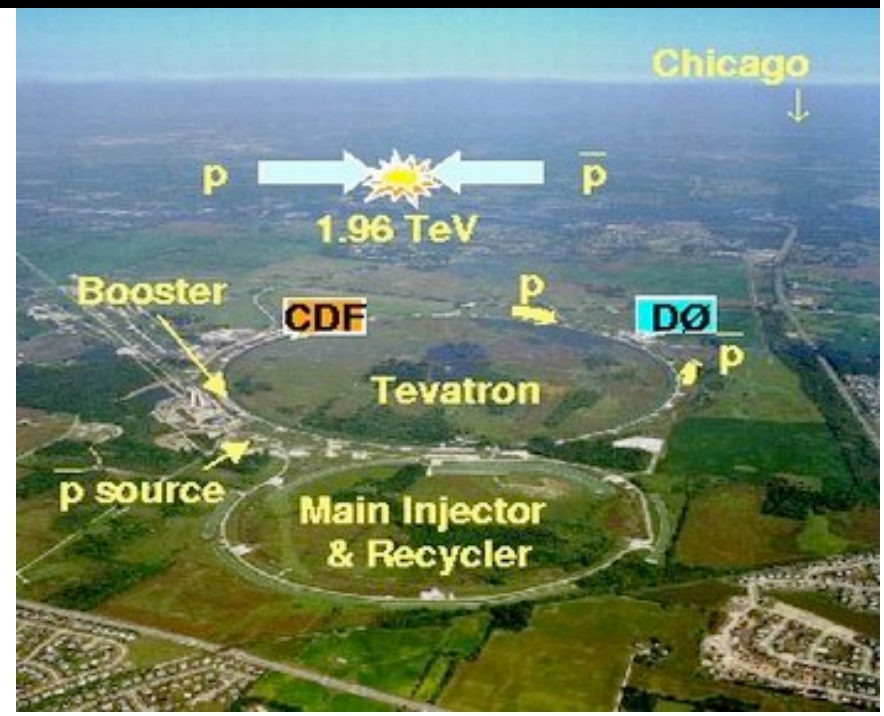
- Why not the Standard Model?
  - Hierarchy problem: $m_h \ll m_{Pl} \Rightarrow$ new physics at TeV scale
  - Most Dark Matter in our universe unaccounted for
  - No unification of forces …
  - + many more
- What New Phenomena could there be?
  - Supersymmetry (SUSY):
    - rather complex (>100 parameters)
  - 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

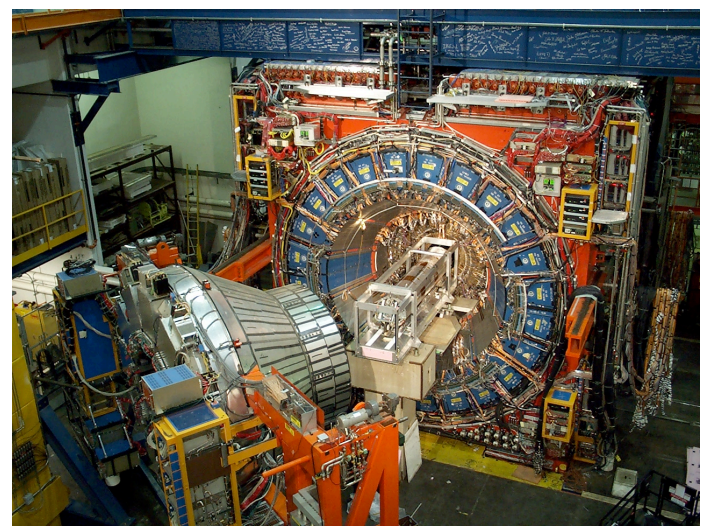
Tevatron Run II

- 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}



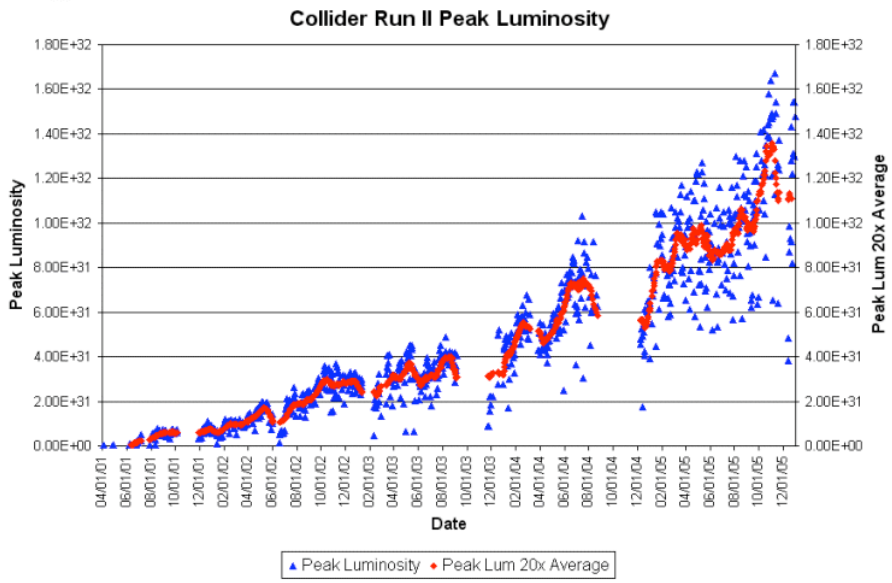
- Experiment CDF:
  - New tracking systems:
    - Silicon and drift chamber
  - New readout electronics+trigger
  - New forward calorimeters
  - Many other substantial upgrades



Tevatron Luminosity

Congratulations Fermilab!

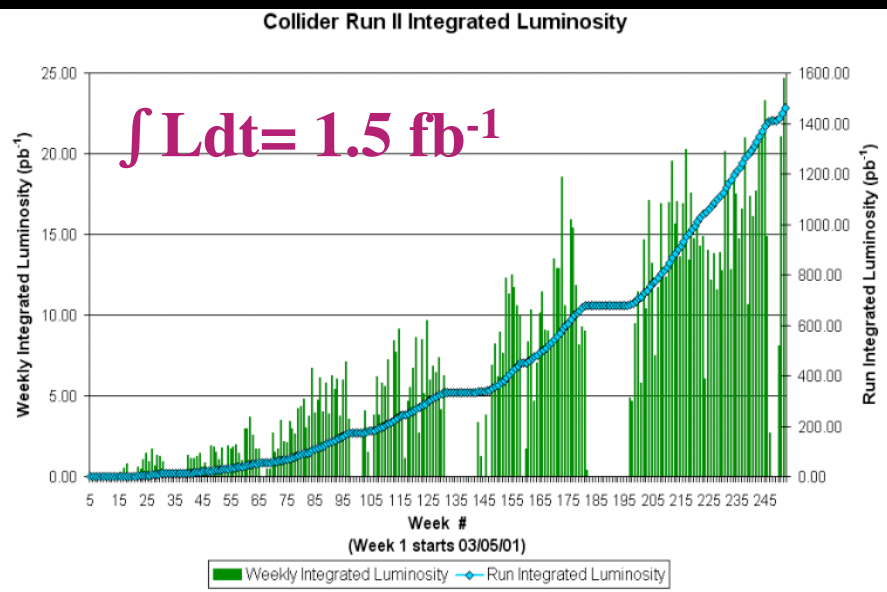
Fermilab has set a world record for peak luminosity of a hadron collider! Operations established store 4431 at 9:11 a.m. yesterday, October 4, with an initial luminosity, or brightness, of 141E30 $cm^{-2}sec^{-1}$. This record exceeds the previous Tevatron record by almost 8 percent, and it exceeds the world record for peak luminosity of a hadron collider achieved 23 years ago by the ISR proton-proton collider at CERN. The ISR achieved a peak luminosity of 140E30 $cm^{-2}sec^{-1}$ at a collision energy of 62 GeV. The Tevatron produces collisions between protons and antiprotons at a collision energy of 1960 GeV. The peak luminosity of the Tevatron has greatly increased since Fermilab began Run II in March 2001, and Fermilab expects to improve the Tevatron peak luminosity even further.

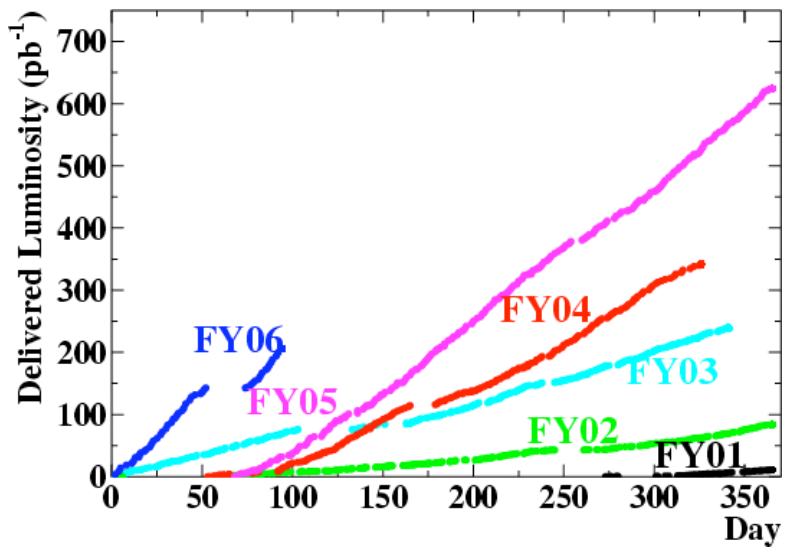


Tevatron Has Another Peak Luminosity Record in 2006

The Tevatron collider set a new peak luminosity record at 3:28 this morning, January 6. Store 4581 reached 171E30 cm^{-2} sec^{-1}. Congratulations.

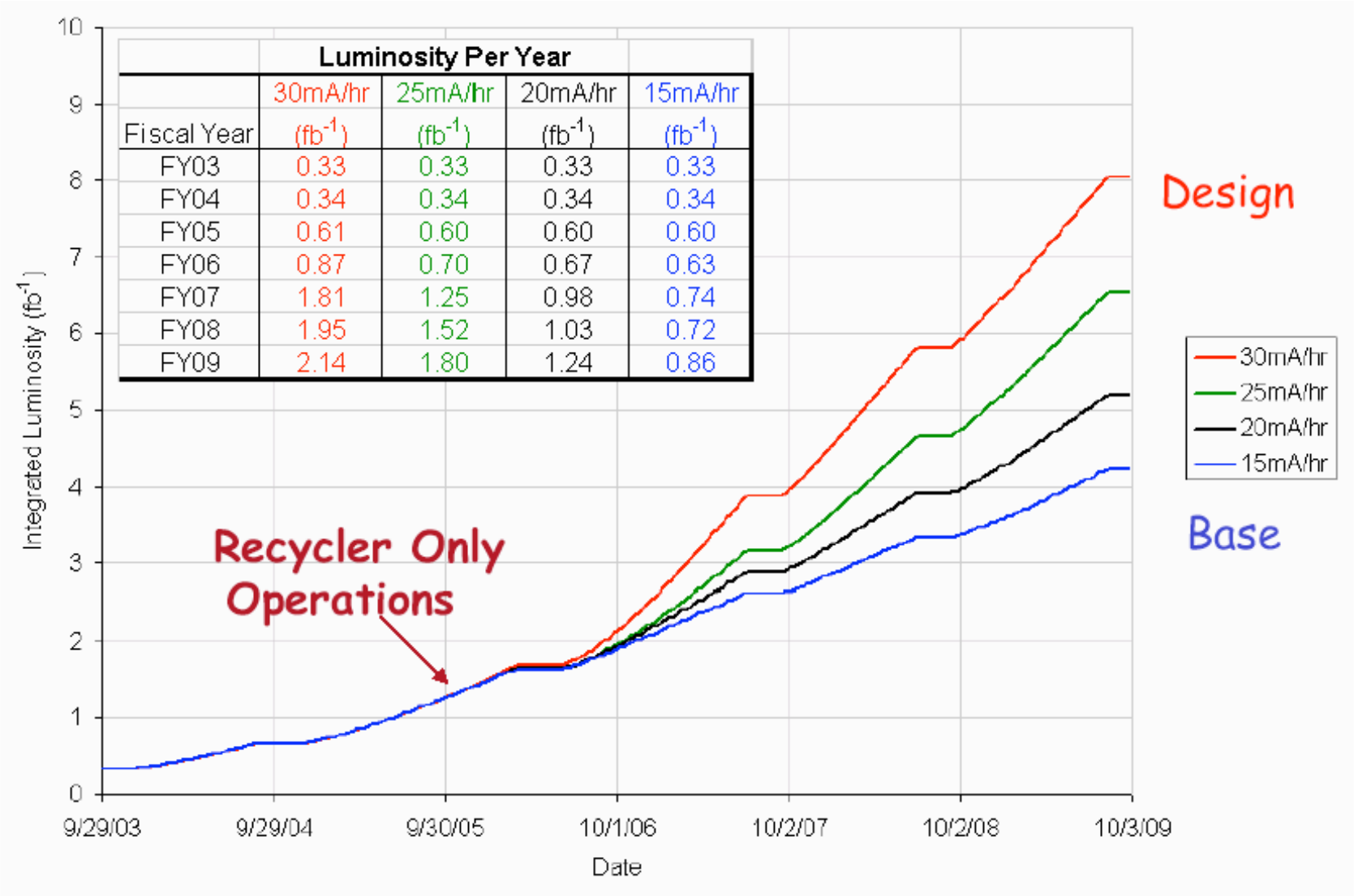
Tevatron Performance





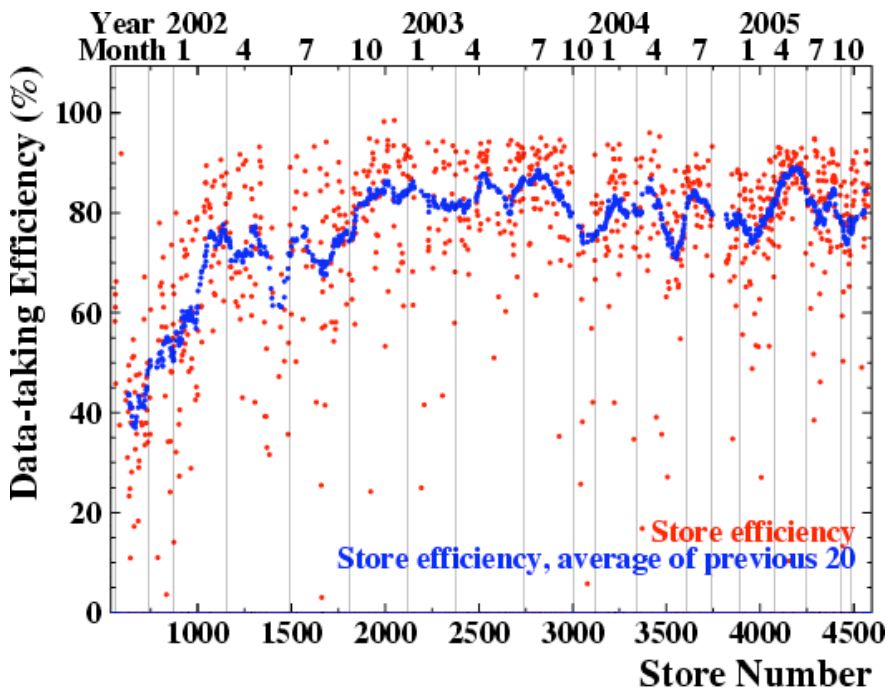
- Integrated luminosity more than 1 fb^{-1} by now
- Plan to shutdown for four months on March 1st
- Improvements:
  - Electron cooling of anti-protons working
  - Anti-proton production rate and transfer efficiency still uncertain

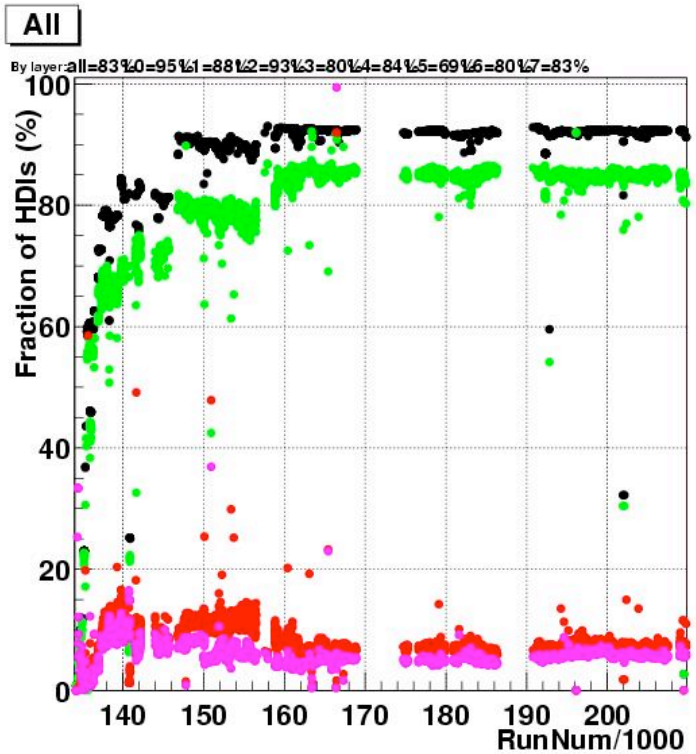
Tevatron: Future



Luminosity Per Year				
	30mA/hr	25mA/hr	20mA/hr	15mA/hr
Fiscal Year	(fb^{-1})	(fb^{-1})	(fb^{-1})	(fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

CDF Performance





- Data taking efficiency about 83%
- All components working very well:
  - 93% of Silicon detector operates, 84% working well
  - Expected to last up to 8 fb^{-1}

Supersymmetry

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	$W^\pm$ $H^\pm$	gauge particles	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		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**

SUSY Particles

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						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	$\tilde{\chi}^\pm_1$	$\tilde{\chi}^\pm_2$		fermions S=1/2
	γ	Z^0	h^0	H^0 A^0	neutralinos	$\tilde{\chi}^0_1$	$\tilde{\chi}^0_2$	$\tilde{\chi}^0_3$	$\tilde{\chi}^0_4$
	g_i			gauge particles	gluinos	$\tilde{g}_i$			
	G				gravitino	$\tilde{G}$			

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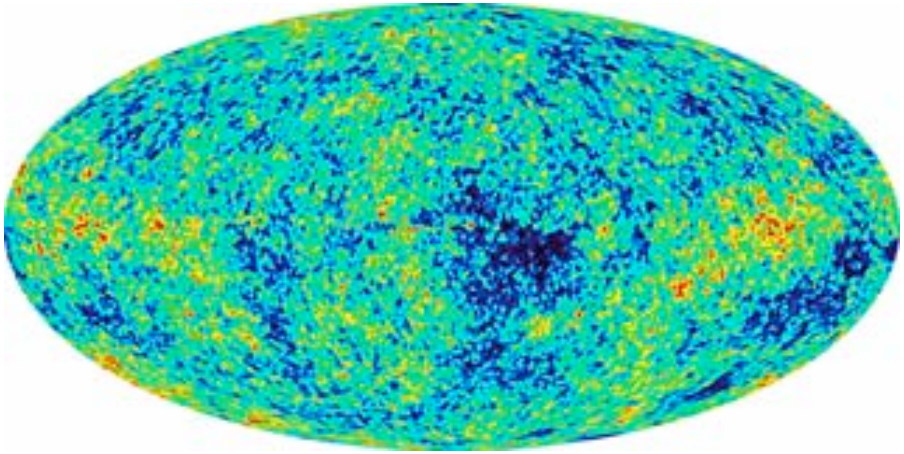
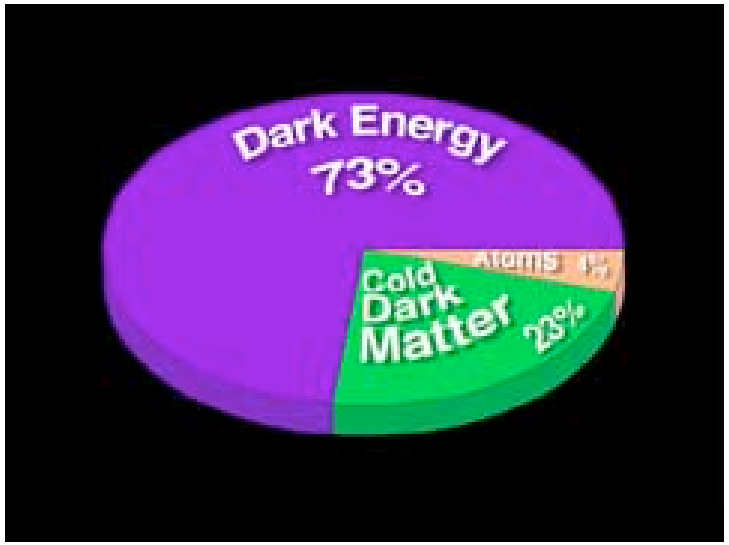
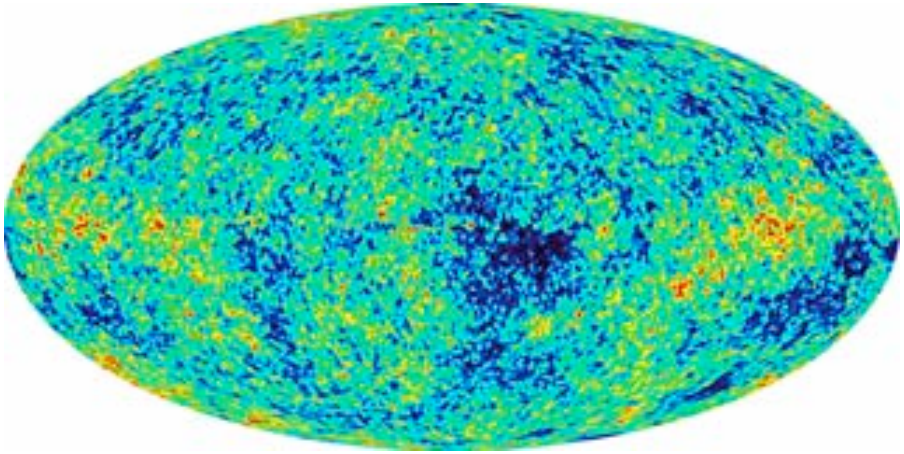
- **SUSY is a broken symmetry**

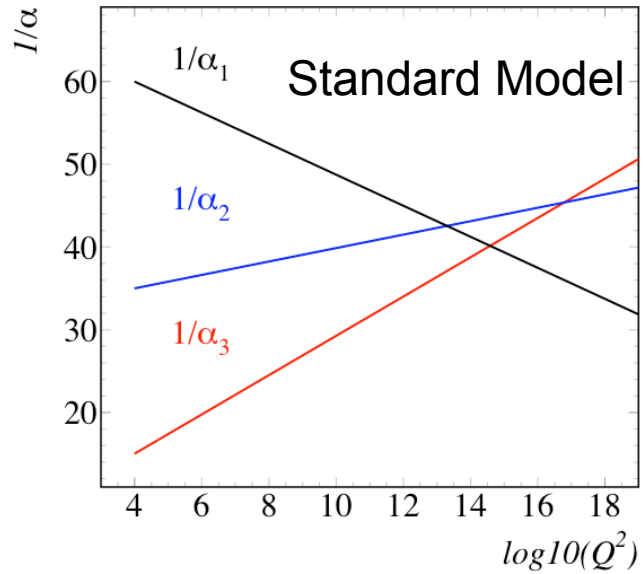
SUSY solves some problems

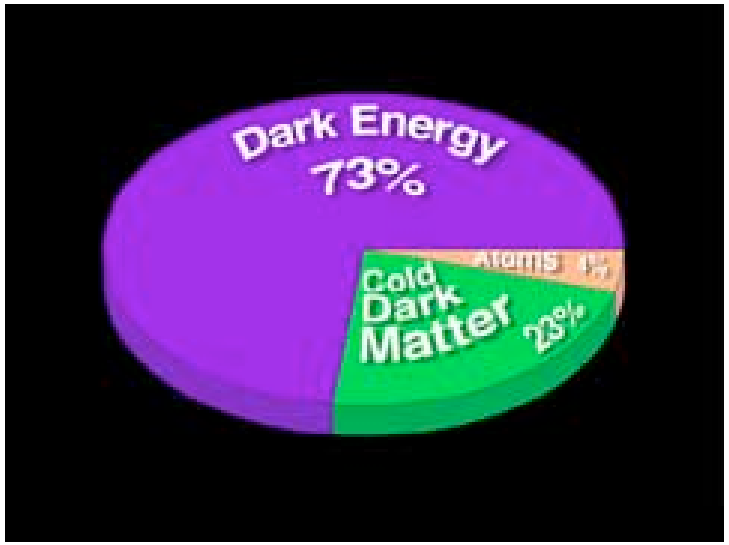


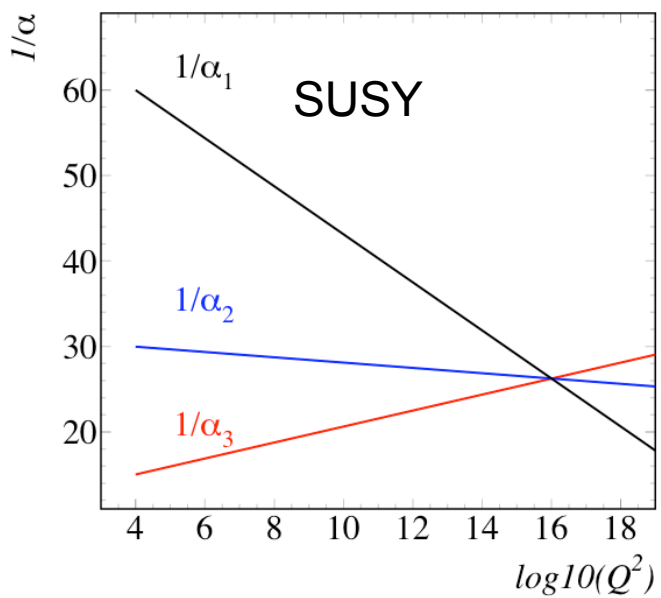


SUSY solves some problems

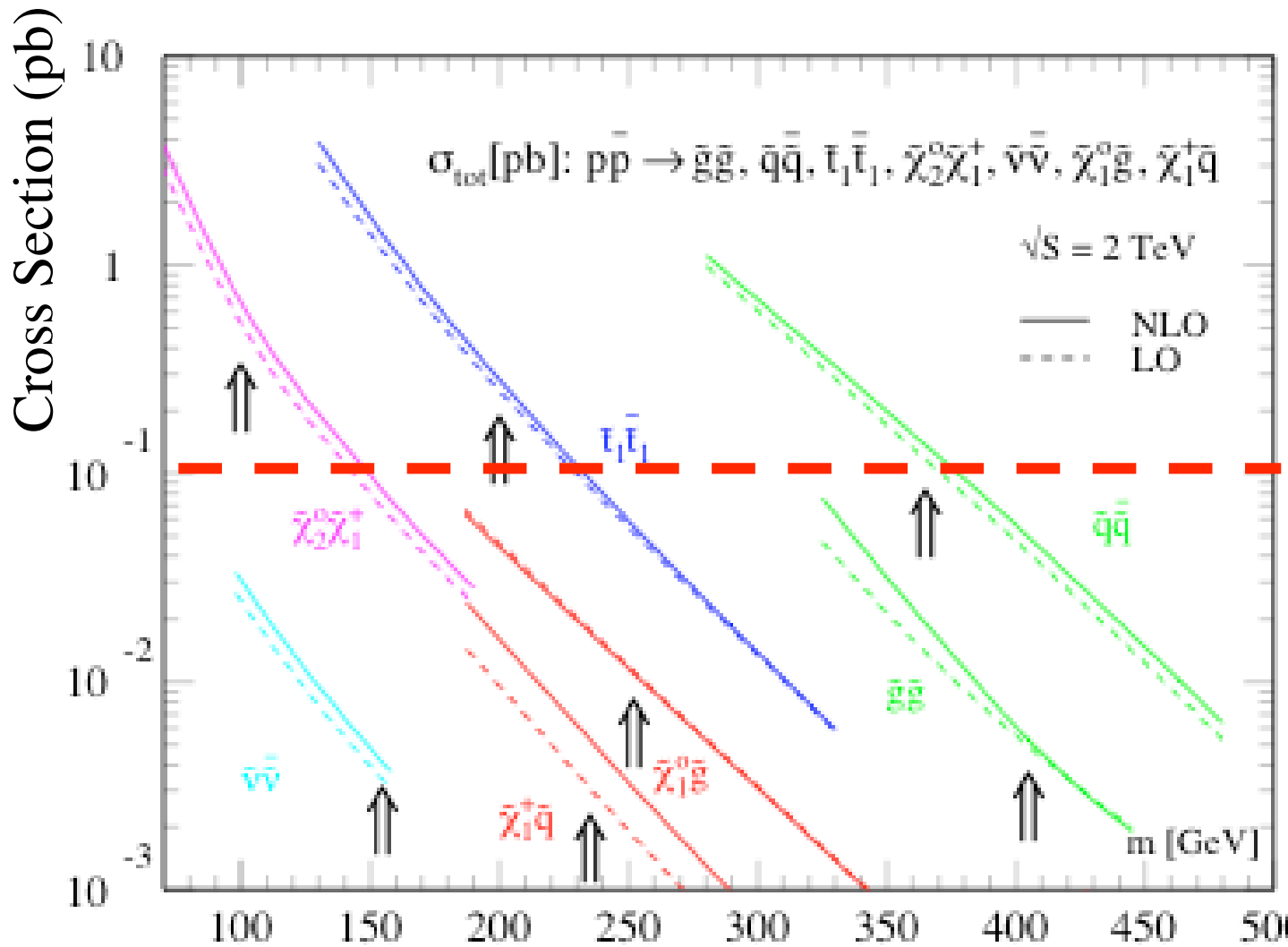








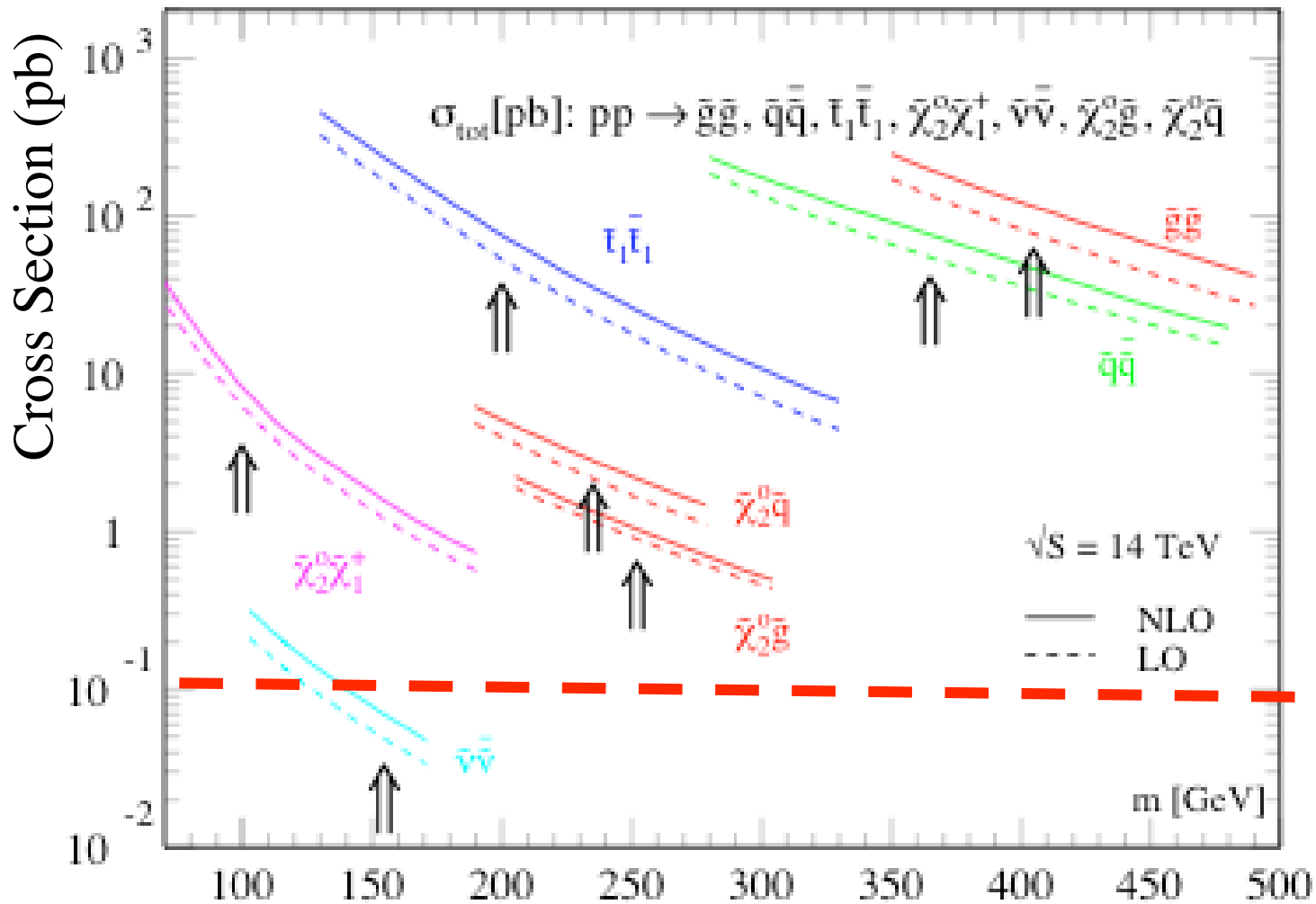
Sparticle Cross Sections: Tevatron



150 events produced so far (1.5 fb^{-1})

T. Plehn, PROSPINO

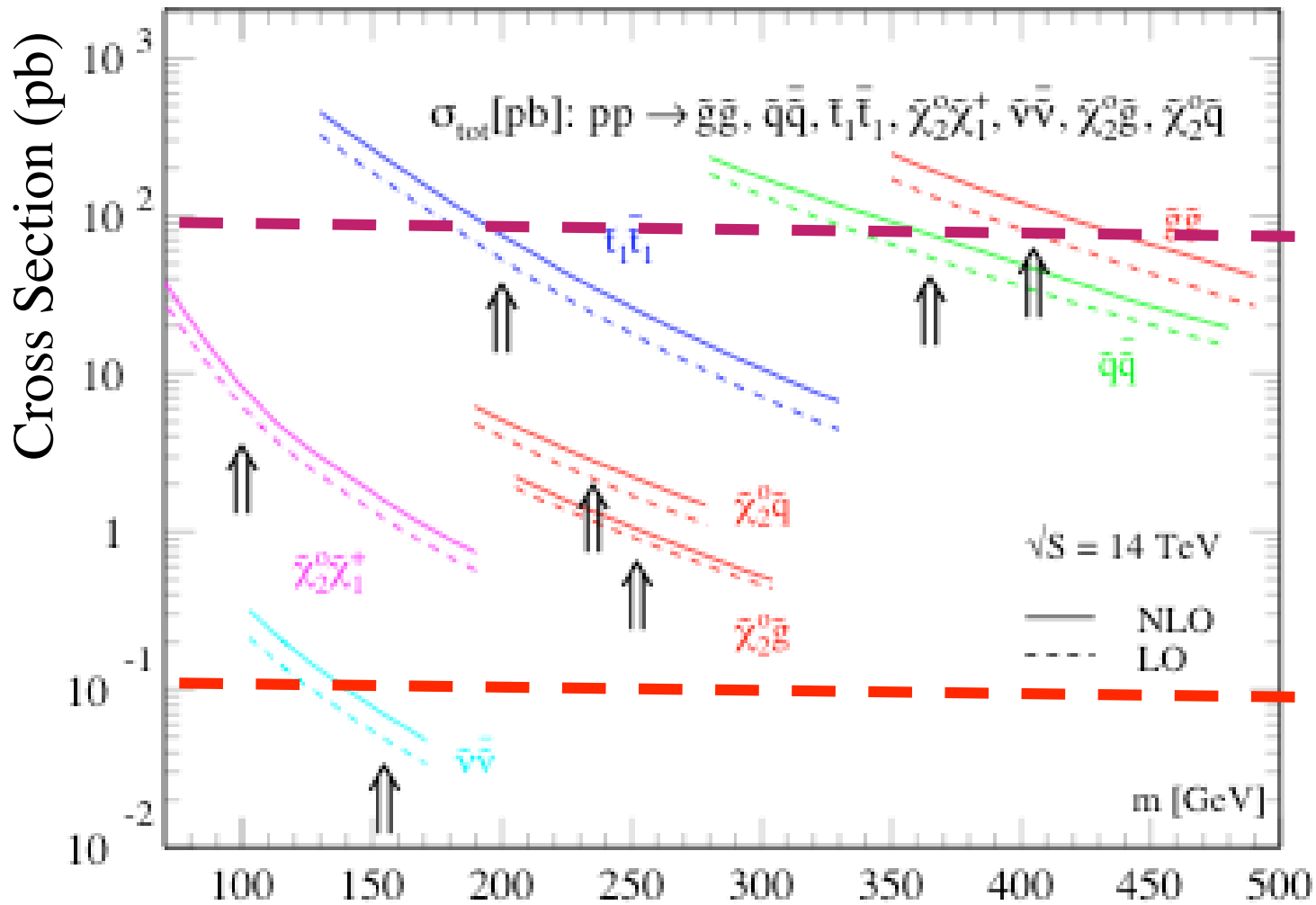
Sparticle Cross Sections: LHC



100 events with 1 fb^{-1}

T. Plehn, PROSPINO

Sparticle Cross Sections: LHC



100 events with 1 pb^{-1}

100 events with 1 fb^{-1}

T. Plehn, PROSPINO

Higgs in the MSSM

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

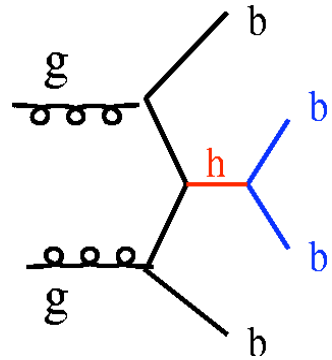
$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan\beta^2}{(1+\Delta_b)^2} \times \frac{9}{[9+(1+\Delta_b)^2]}$$

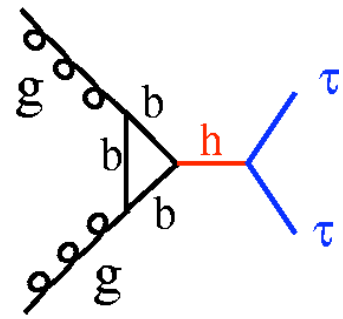
- At high tanß:
  - A is degenerate in mass with either h or H
    - Decay into either $\tau\tau$ or bb for m_A<300 GeV:
    - BR($A \rightarrow \tau\tau$) ≈ 10%, BR($A \rightarrow$ bb) ≈ 90%
  - Cross section enhanced with $\tan^2\beta$

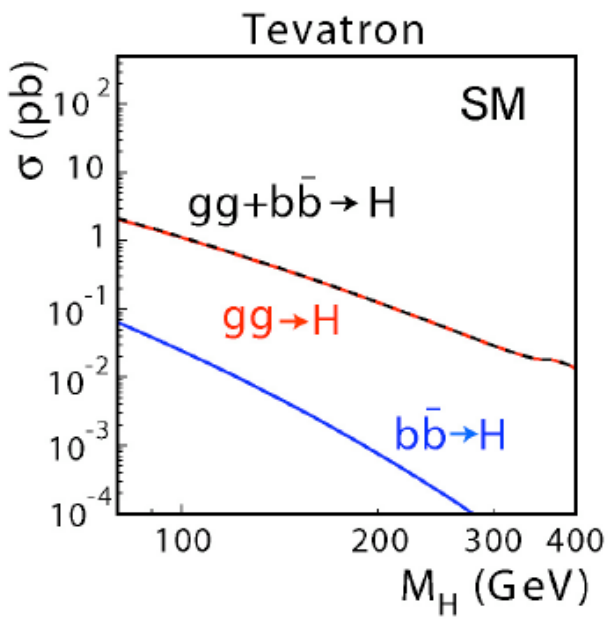
•C. Balazs, J.L.Diaz-Cruz, H.J.He, T.Tait and C.P. Yuan, PRD 59, 055016 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 60, 075010 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 62, 055008 (2000)

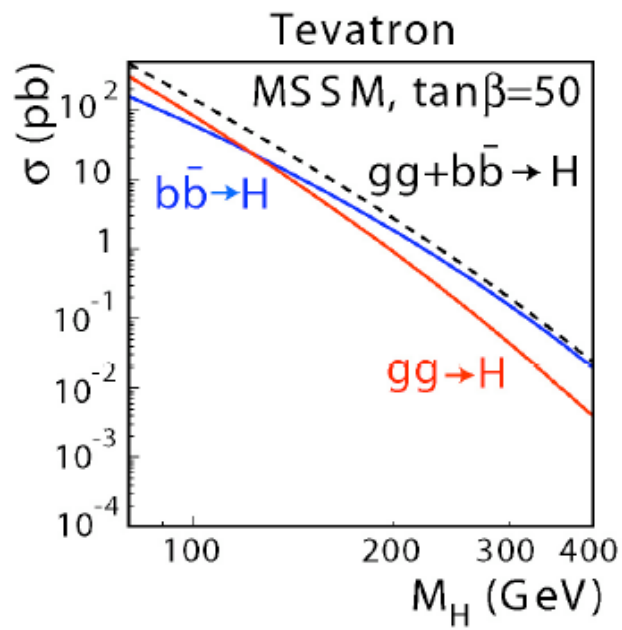
Neutral MSSM Higgs

- Production mechanisms:
  - $b\bar{b} \rightarrow A/h/H$
  - $gg \rightarrow A/h/H$
- Experimentally:
  - $p\bar{p} \rightarrow \Phi b+X \rightarrow b\bar{b}b+X$
  - $p\bar{p} \rightarrow \Phi+X \rightarrow \tau\tau+X$



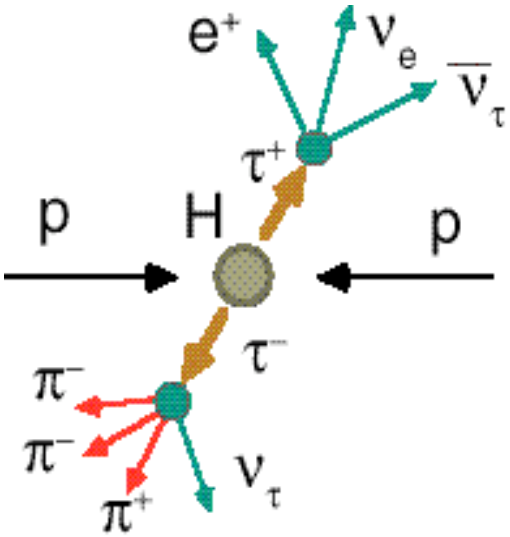


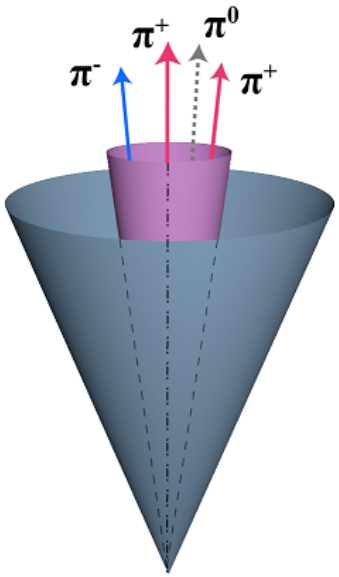




MSSM Higgs: Tau-Selection

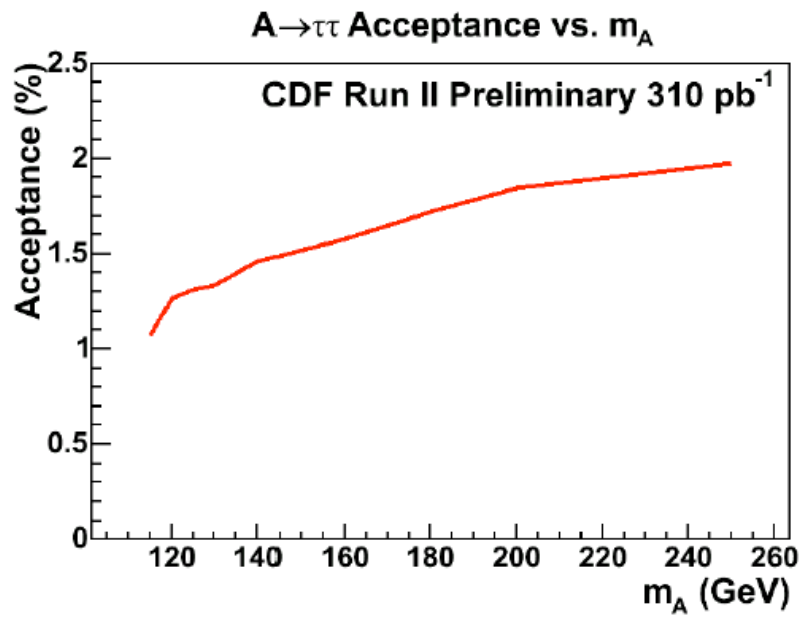
- Select $\tau\,\tau$ Events:
  - One τ decays to e or μ
  - One τ decays to hadrons
- Require:
  - e or μ with p_T>10 GeV
  - Hadronic τ:
    - Narrow Jet with low multiplicity
    - 1 or 3 tracks in 10° cone
    - No tracks between 10° and 30°:
      - Cone size descreasing with increasing energy
    - Low π^0 multiplicity
    - Mass<1.8 GeV
- Kinematic cuts against background:
  - W+jets
  - Photon+jets
  - Dijets

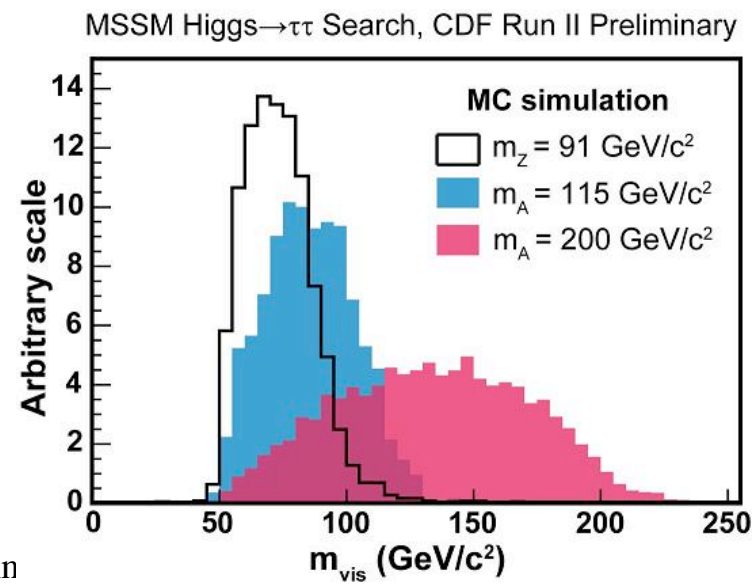




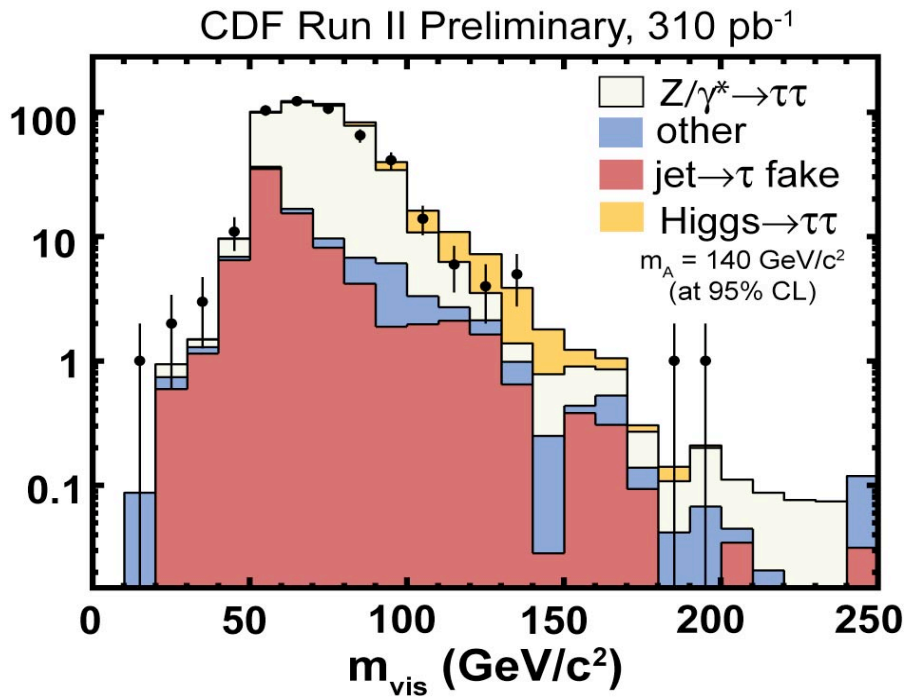
Acceptance and Background

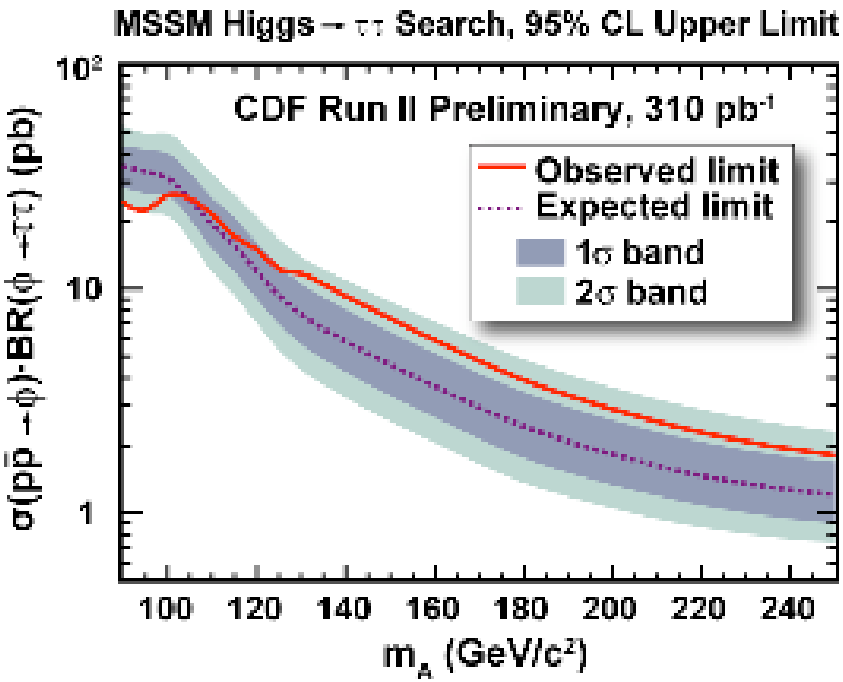
- Acceptance for Higgs about 1-2%
- Main background:
  - Drell-Yan $\tau\tau$
  - Indistinguishable signature => Separate kinematically
- No full mass reconstruction possible for low Higgs p_T:
  - Form mass like quantity: $m_{vis}=m(\tau,e/\mu,\not{E}_T)$
  - Good separation between signal and background





MSSM Higgs: Mass Distribution

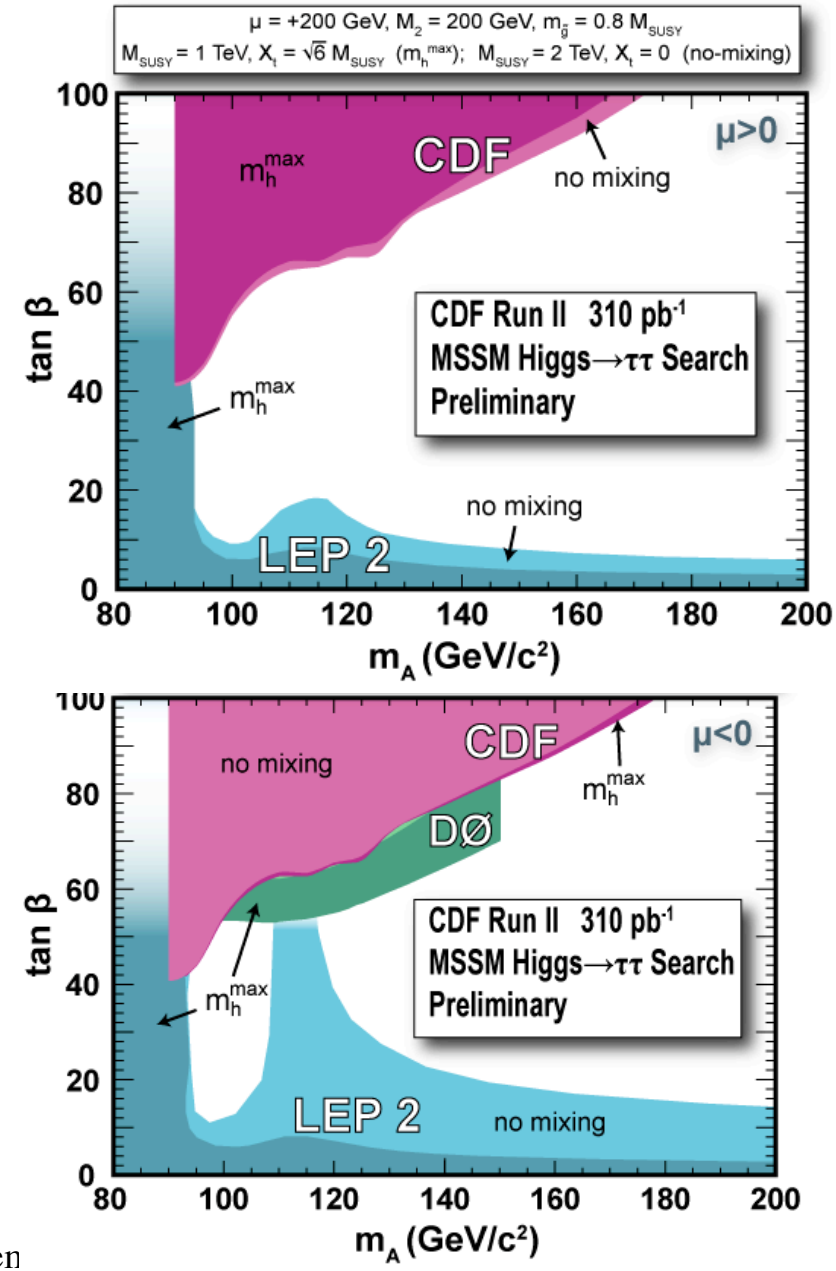




- Data mass distribution agrees with SM expectation:
  - M>120 GeV: 8.4±0.9 expected, 11 observed
- Fit mass distribution for Higgs Signal
  - Exclude signals at 95% C.L.
  - Upper limit on cross section times branching ratio
  - We interpret in MSSM benchmark scenarios

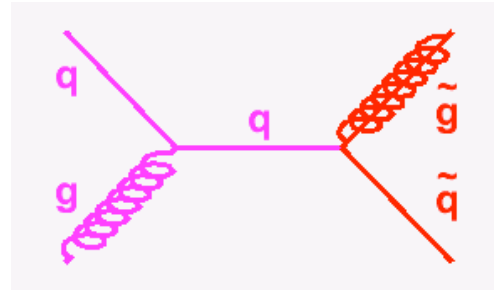
MSSM Higgs: Results

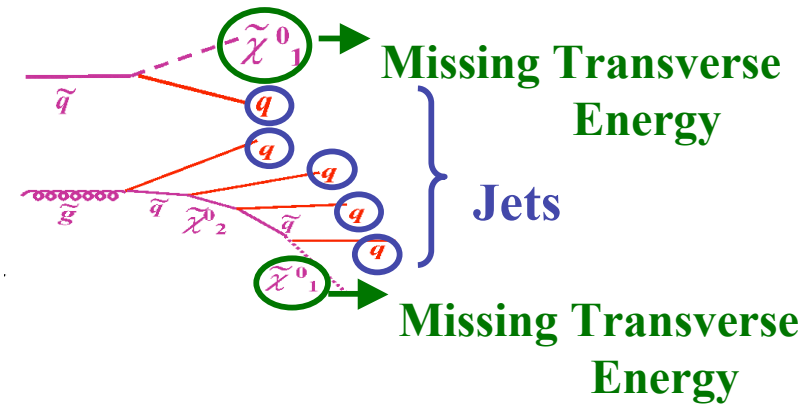
- $p\bar{p} \rightarrow A+X \rightarrow \tau\tau+X$ (CDF)
  - Sensitivity similar for
    - Min. and max. mixing
    - $\mu>0$ and $\mu<0$
- $p\bar{p} \rightarrow bA+X \rightarrow bbb+X$ (DØ)
  - Best sensitivity for $\mu<0$
  - Lower sensitivity for $\mu>0$
- Nice complementarity of both modes
  - Particularly important if we see any deviation in either mode

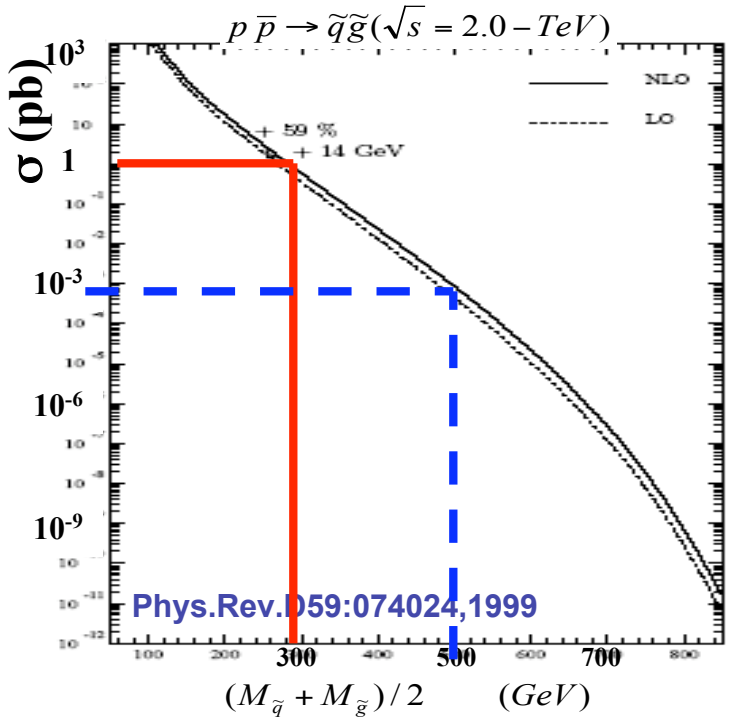


Generic Squarks and Gluinos

- Squark and Gluino production:
  - jets and $\not{E}_t$
  - Golden signature at LHC



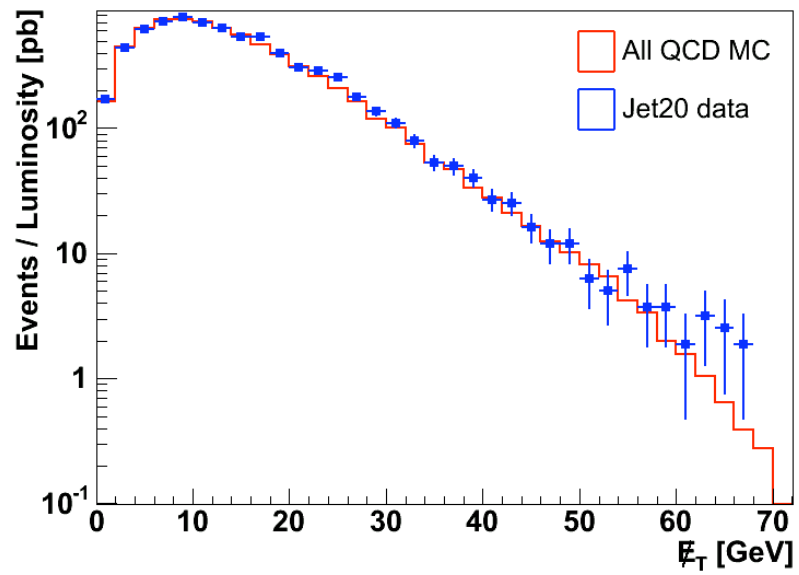


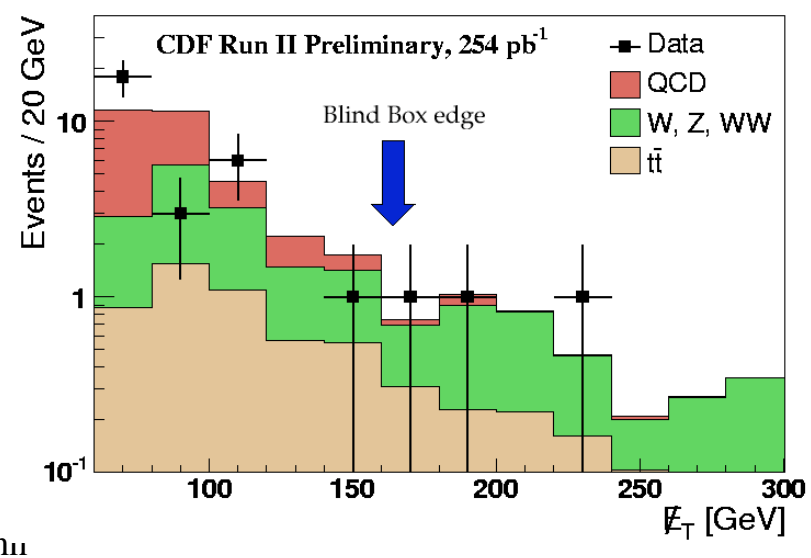


- Strong interaction => large production cross section
  - for $M(\tilde{g}) \approx 300\ GeV/c^2$:
    - 1000 event produced
  - for $M(\tilde{g}) \approx 500\ GeV/c^2$:
    - 1 event produced

Generic Squarks and Gluinos

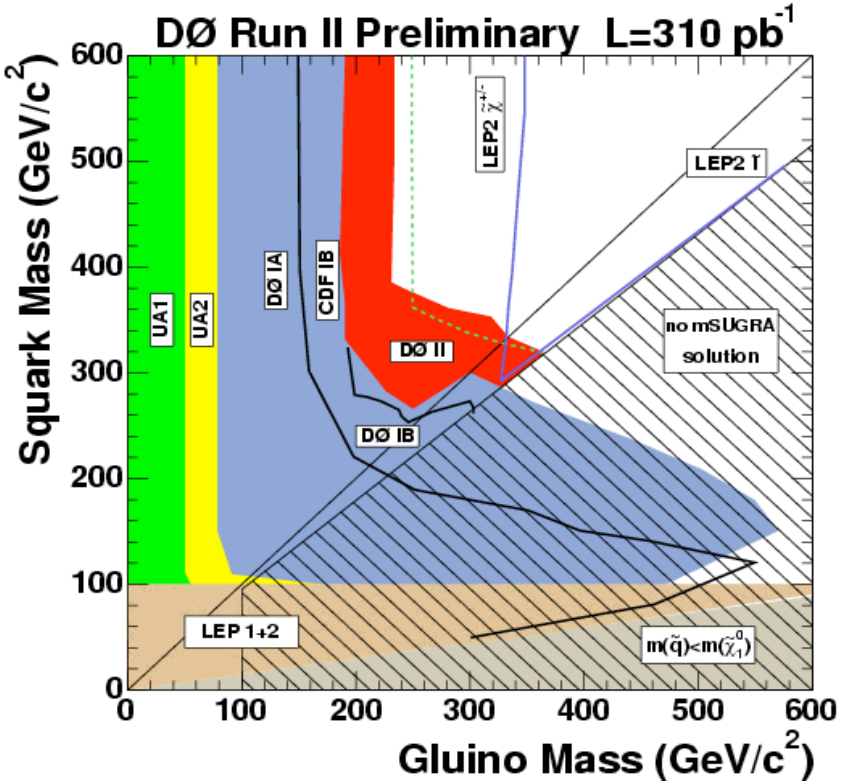
- Selection:
  - 3 jets with E_T>125 GeV, 75 GeV and 25 GeV
  - Missing E_T>165 GeV
  - $H_T=\sum$ jet E_T > 350 GeV
  - Missing E_T not along a jet direction:
    - Avoid jet mismeasurements
- Background:
  - W/Z+jets with $W\rightarrow l\nu$ or $Z\rightarrow\nu\nu$
  - Top
  - QCD multijets
    - Mismeasured jet energies lead to missing E_T
- Observe: 3, Expect: 4.1±1.5





Impact on SUSY

- No evidence for excess of events:
  - Exclude squarks and gluinos for certain mass values
  - D0 excluded gluinos up to 230 GeV
  - CDF:
    - Interpretration still ongoing
    - Likely similar to D0
- Stop and sbottom quarks are excluded from CDF analysis
  - 3rd generation is special…

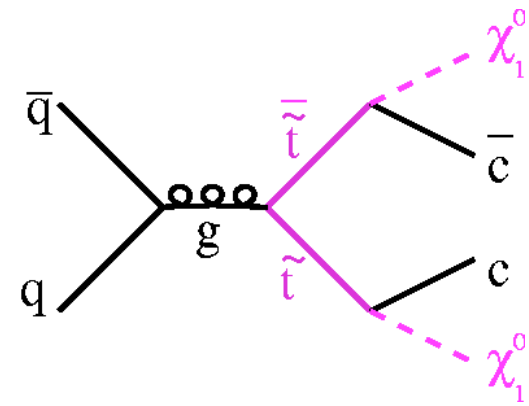


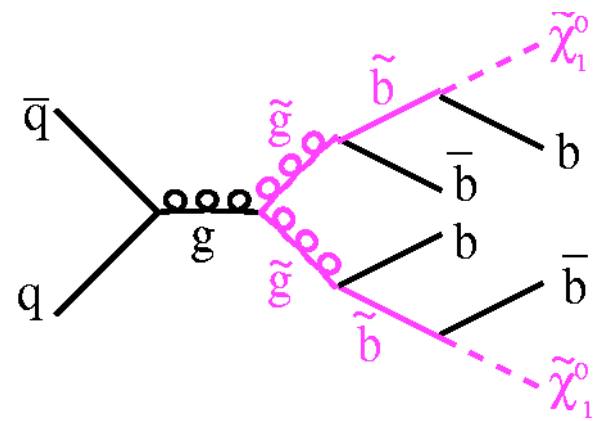
3rd generation Squarks

- 3rd generation is special:
  - Masses of one can be very low due to large SM mass
  - Particularly at high tanβ

$$m^2_{\tilde{b}_{1,2}} = \frac{1}{2}\left(m^2_{\tilde{b}_L} + m^2_{\tilde{b}_R}\right) \mp \frac{1}{2}\sqrt{\left(m^2_{\tilde{b}_L} - m^2_{\tilde{b}_R}\right)^2 + 4m_b^2(A_b - \mu\tan\beta)^2}$$

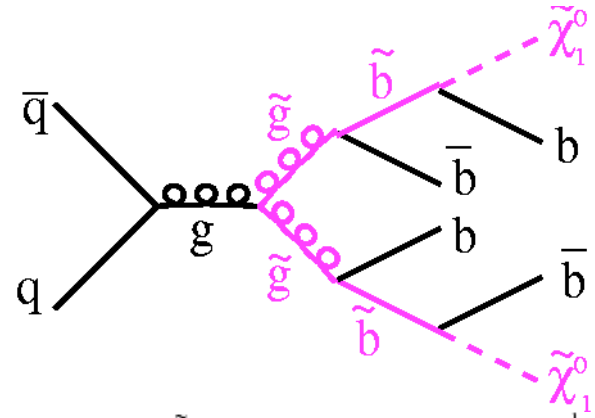
- Direct production or from gluino decays:
  - $pp \to \tilde{b}\tilde{b}$ or $\tilde{t}\tilde{t}$
  - $pp \to \tilde{g}\tilde{g} \to \tilde{b}\tilde{b}\tilde{b}\tilde{b}$ or $\tilde{t}\tilde{t}\tilde{t}\tilde{t}$
- Decay of sbottom and stop:
  - $\tilde{b} \to b\tilde{\chi}^0$
  - Stop depends on mass:
    - Heavy: $\tilde{t} \to t\tilde{\chi}^0$
    - Medium: $\tilde{t} \to \tilde{b}\chi^\pm \to bW\tilde{\chi}^0$
    - Light: $\tilde{t} \to c\tilde{\chi}^0$

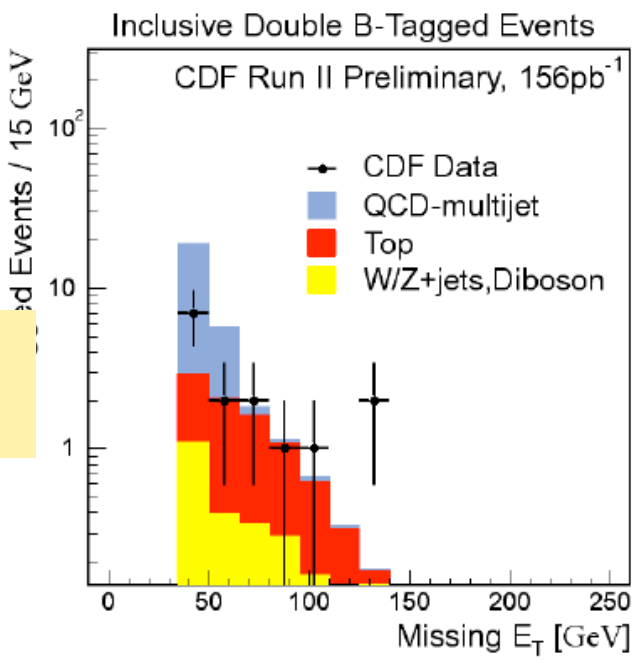




Bottom Squarks

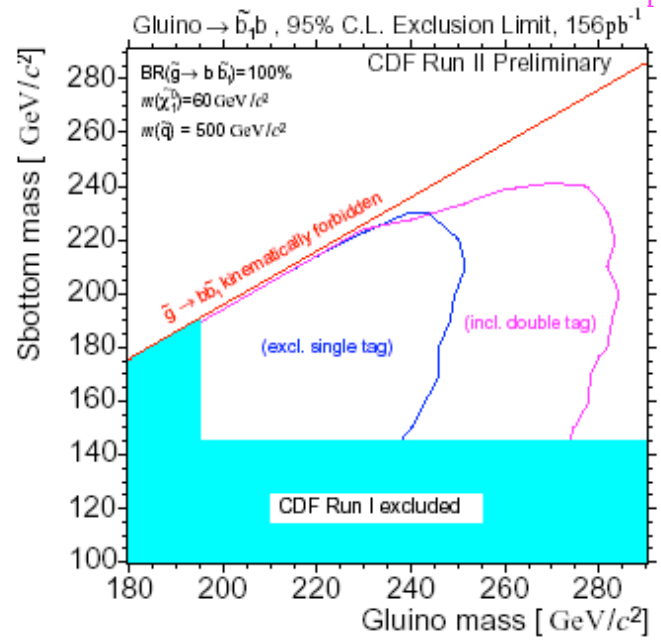
- This analysis:
  - Gluino rather light: 200-300 GeV
  - BR($\tilde{g}$->b$\tilde{b}$)=100% assumed
- Spectacular signature:
  - 4 b-quarks + $\not{E}_T$
- Require b-jets and $\not{E}_T$>80 GeV





Expect:2.6±0.7

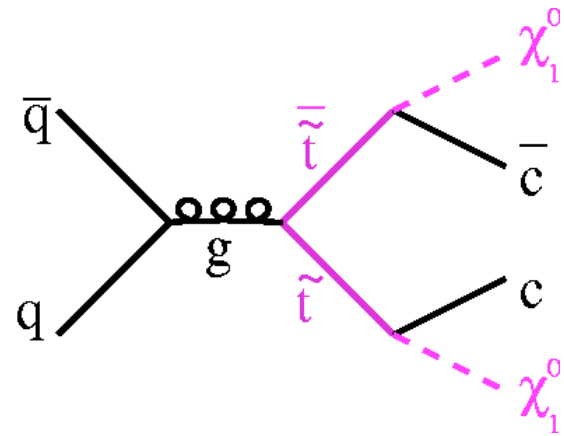
Observe: 4

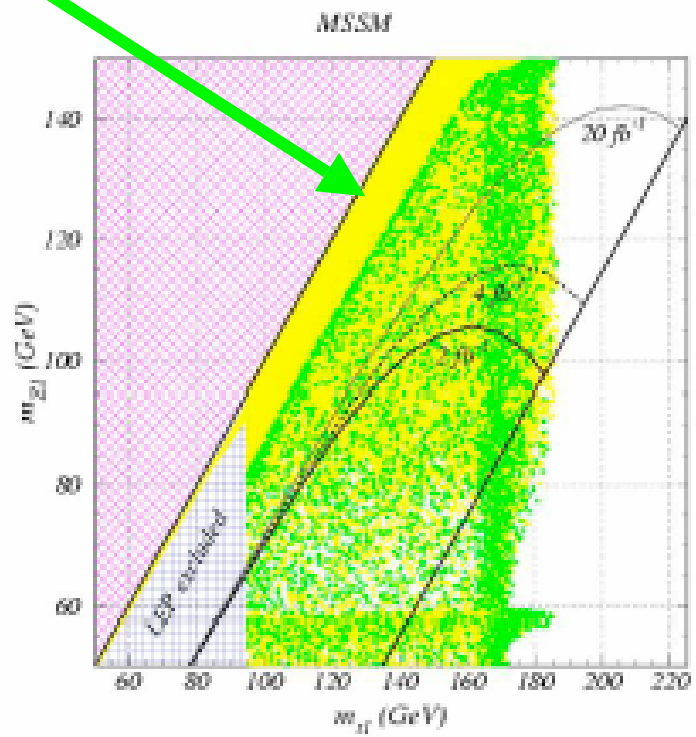


Exclude new parameter space in gluino vs. sbottom mass plane

Light Stop–Quark: Motivation

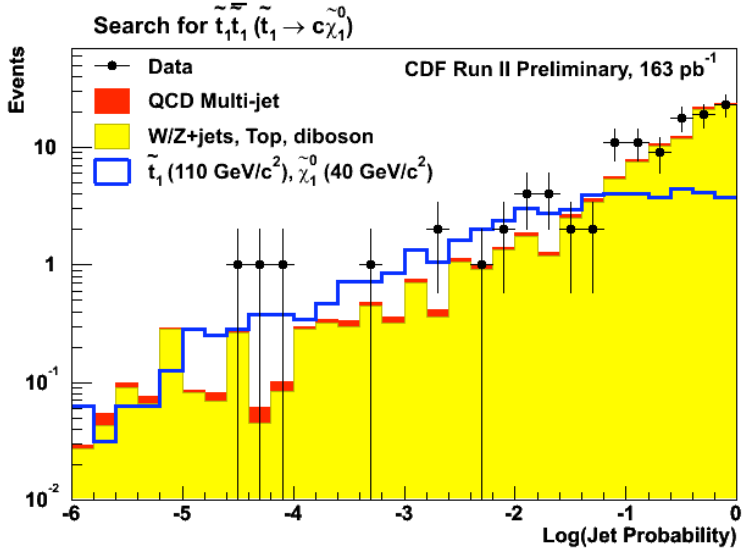
- If stop quark is light:
  - decay only via $\tilde{t} \to c\tilde{\chi}_1^0$
- E.g. consistent with relic density from WMAP data
  - Balazs, Carena, Wagner: hep-ph/0403224
  - $\Omega_{CDM}=0.11+-0.02$
  - $m(\tilde{t})-m(\tilde{\chi}_1^0)\approx 15\text{-}30$ GeV/c^2
  - $m(\tilde{t})<165$ GeV/c^2
- Search for 2 charm-jets and large $\not{E}_t$:
  - E_T(jet)>35, 25 GeV
  - $\not{E}_T$>55 GeV

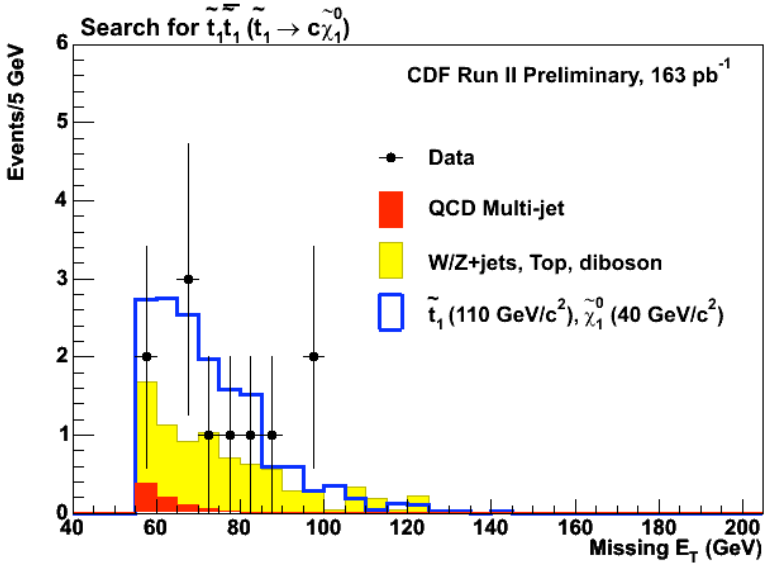




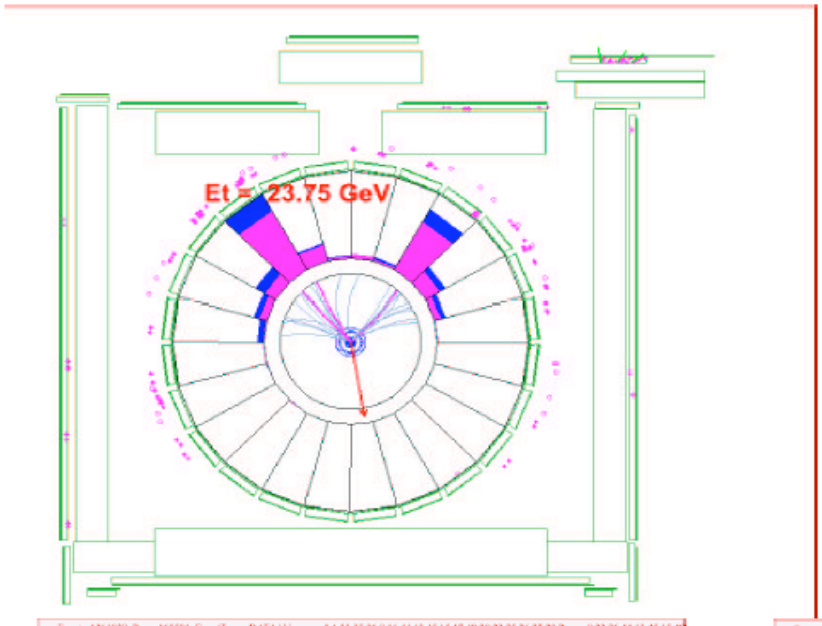
Light Stop–Quark: Result

- Charm jets:
  - Use "jet probability" to tag charm:
    - Probability of tracks originating from primary vertex
  - Require:
    - First jet: <5%
    - 2nd jet: <45%
  - Improves signal to background ratio:
    - Signal Efficiency: 30%
    - Background rejection: 92%
- Data consistent with background estimate
  - Observed: 11
  - Expected: $8.3^{+2.3}_{-1.7}$
- Main background:
  - Z+ jj -> ννjj
  - W+jj -> τνjj





Stop Candidate event



Event Display

Run: 160591 Evt: 1361839

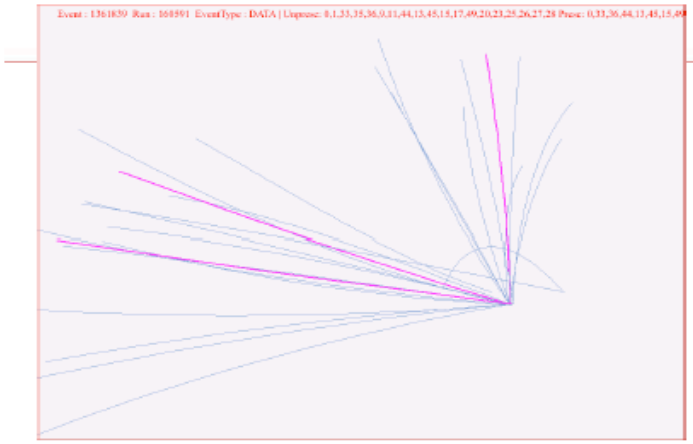
MET=59.3 GeV

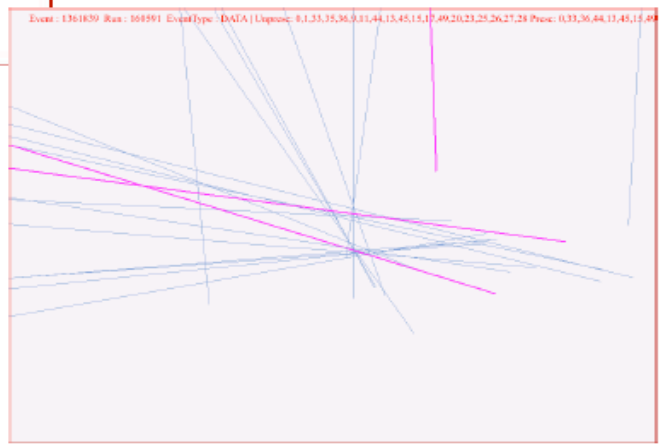
Et1=41.8 GeV

Et2=31.4 GeV

JP(1)=5.2e-5

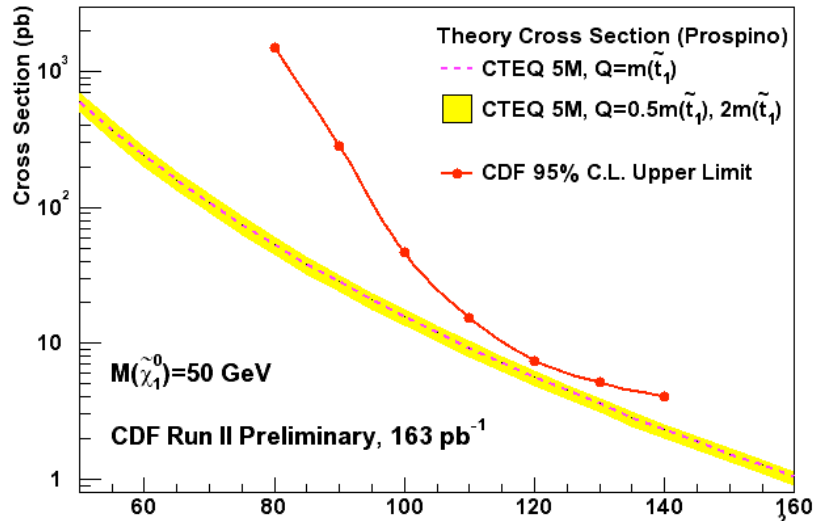
JP(2)=1.5e-4

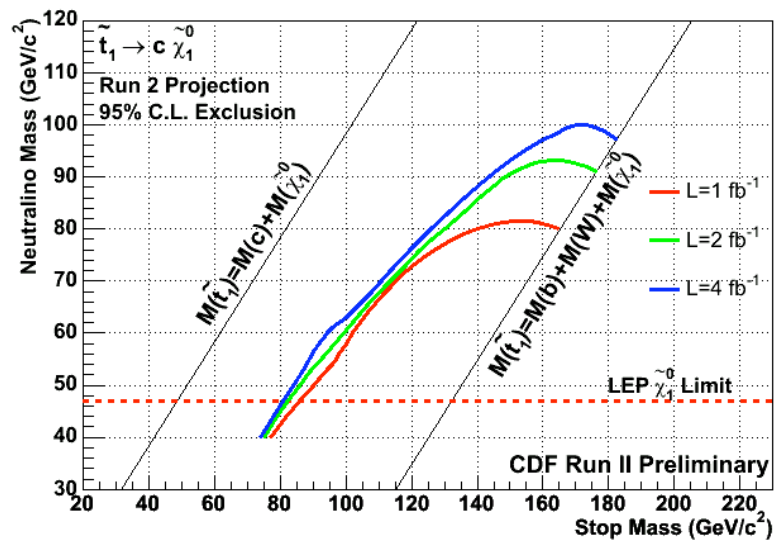


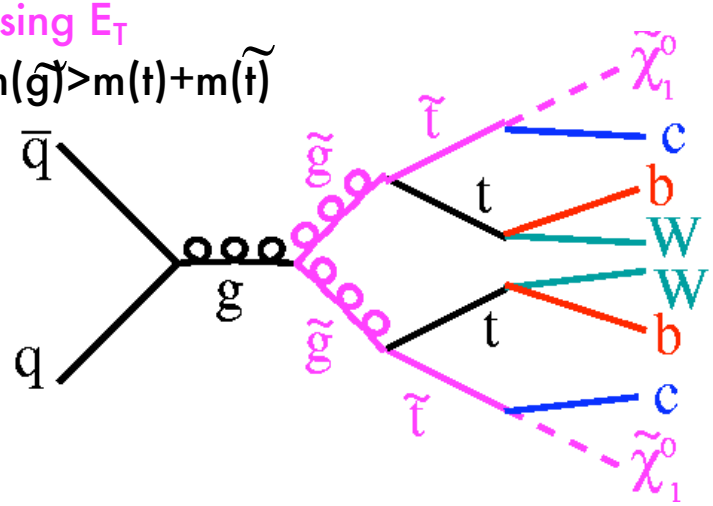


Stop Quark: Result and Future

- Due to slight excess in data:
  - No limit set on stop quark mass yet
- Future light stop reach :
  - L=1 fb^{-1}: $m(\tilde{t})<160$ GeV/c^2
  - L=4 fb^{-1}: $m(\tilde{t})<180$ GeV/c^2
- LHC:
  - Direct production will be tough to trigger
  - But gluino decay to stop and top yields striking signature!
    - Two W's, two b-quarks, two c-quarks and missing E_T
    - If $m(\tilde{g})>m(t)+m(\tilde{t})$

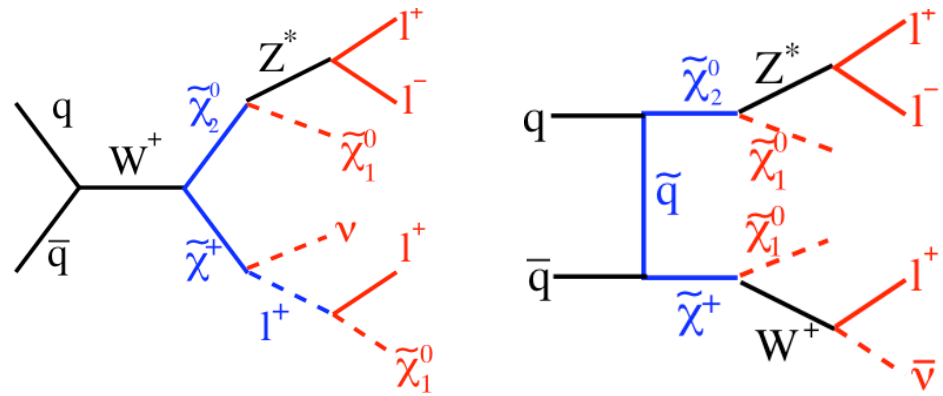


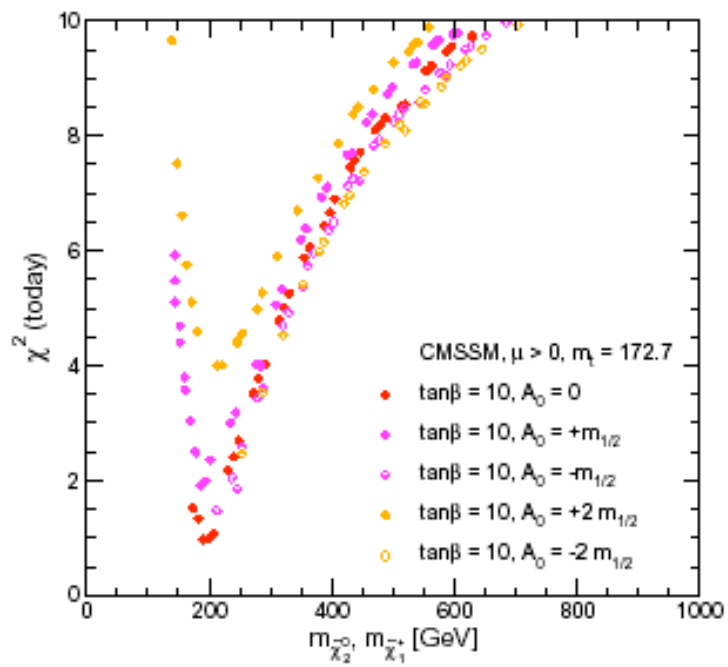




Charginos and Neutralinos

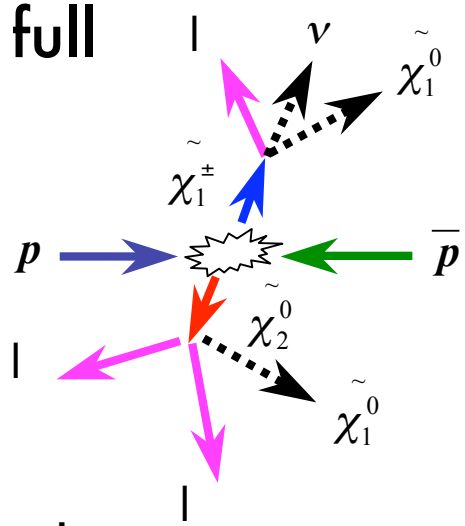
- Charginos and Neutralionos:
  - SUSY partners of W, Z, photon, Higgs
  - Mixed states of those
- Scenario here:
  - Neutralino LSP
  - 3 leptons + $\not{E}_t$
- Recent analyses of EWK precision data:
  - J. Ellis, S. Heinemeyer, K. Olive, G. Weiglein:
    - hep-ph/0411216
  - Light SUSY preferred

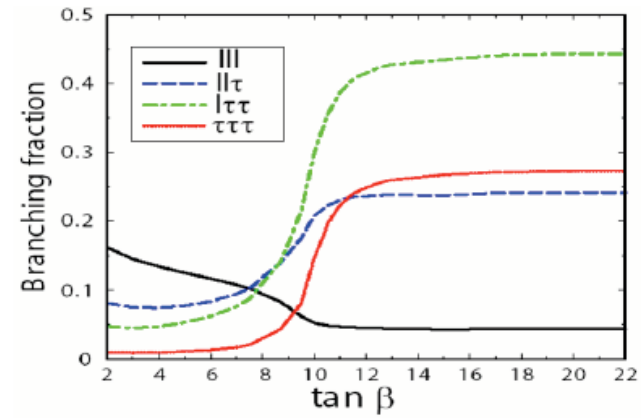




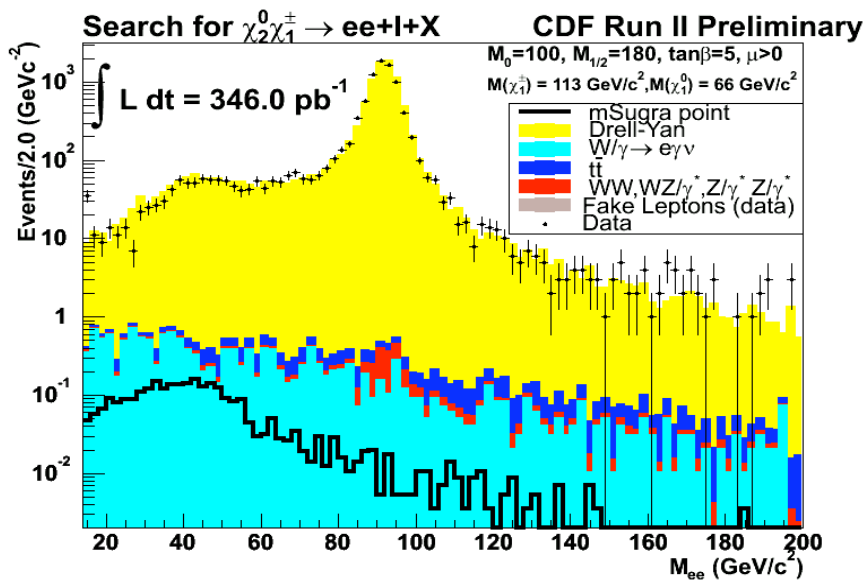
3 leptons + $\not{E}_t$

- Many analyses to cover full phase space:
  - Low tanβ:
    - 2e+e/μ
    - 2μ+e/μ
  - High tanβ:
    - 2e+isolated track
    - Sensitive to one-prong tau-decay



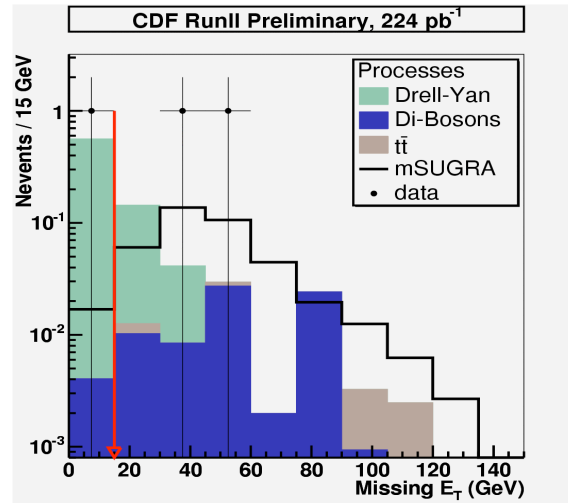


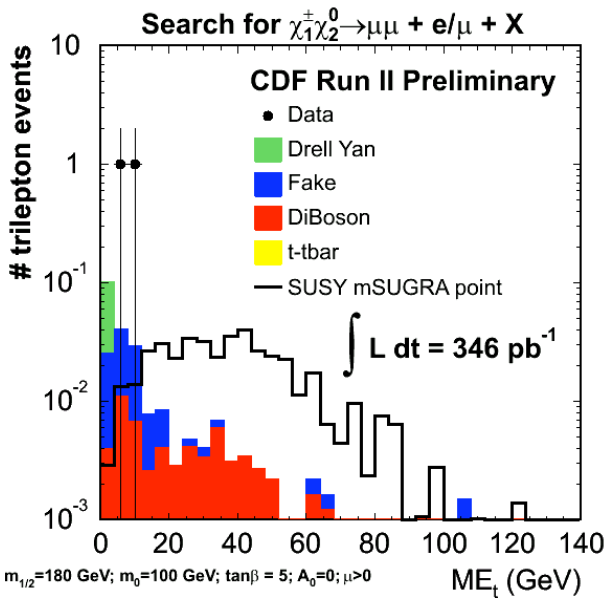
- Other requirements:
  - Significant $\not{E}_t$
  - Dilepton mass >15 GeV and not within Z mass range
  - Less than 2 jets

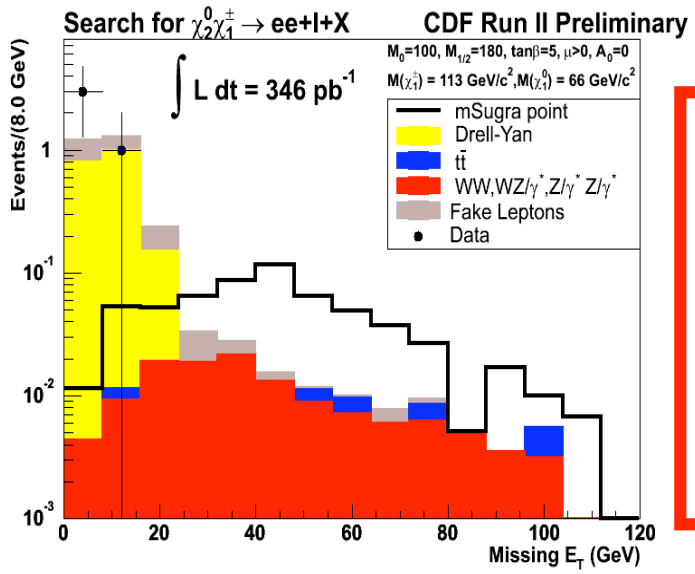


Trileptons: Result

Analysis	Total predicted background	Example SUSY Signal	Observed data
Trilepton ($\mu\mu$+l)	0.09±0.03	0.37±0.05	0
Trilepton (ee+l)	0.17±0.05	0.49±0.06	0
Dielectron +track	0.48±0.07	0.36±0.27	2







No hint of SUSY

- Interpretation in progress
- More data and more analyses soon

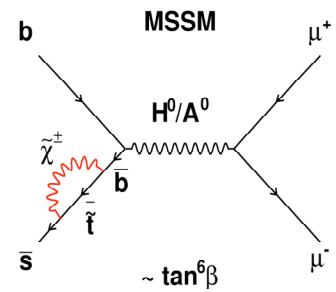
Rare Decay: $B_s \to \mu^+\mu^-$

- SM rate heavily suppressed:
  $$BR(B_s \to \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$$
  (Buchalla & Buras, Misiak & Urban)

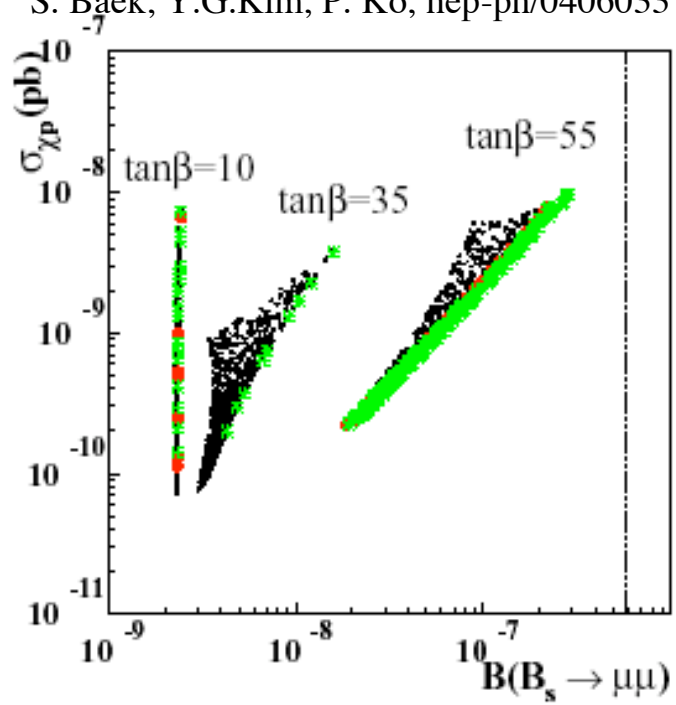
- SUSY rate may be enhanced:
  $$B(B_s \to \mu^+\mu^-) \propto \tan^6\beta / m_A^4$$
  (Babu, Kolda: hep-ph/9909476+ many more)

- Related to Dark Matter cross section (in one of 3 cosmologically interesting regions)
  $$\sigma_{\chi p} \propto \tan^2\beta / m_A^4$$

- Recently gained a lot of attention in WMAP data SUSY analyses, see e.g.
  - B. Allanach, C. Lester: hep/ph-0507383
  - J. Ellis et al., hep-ph/0504196
  - S. Baek, Y.G.Kim, P. Ko, hep-ph/0406033
  - R. Dermisek et al., hep-ph/0507233

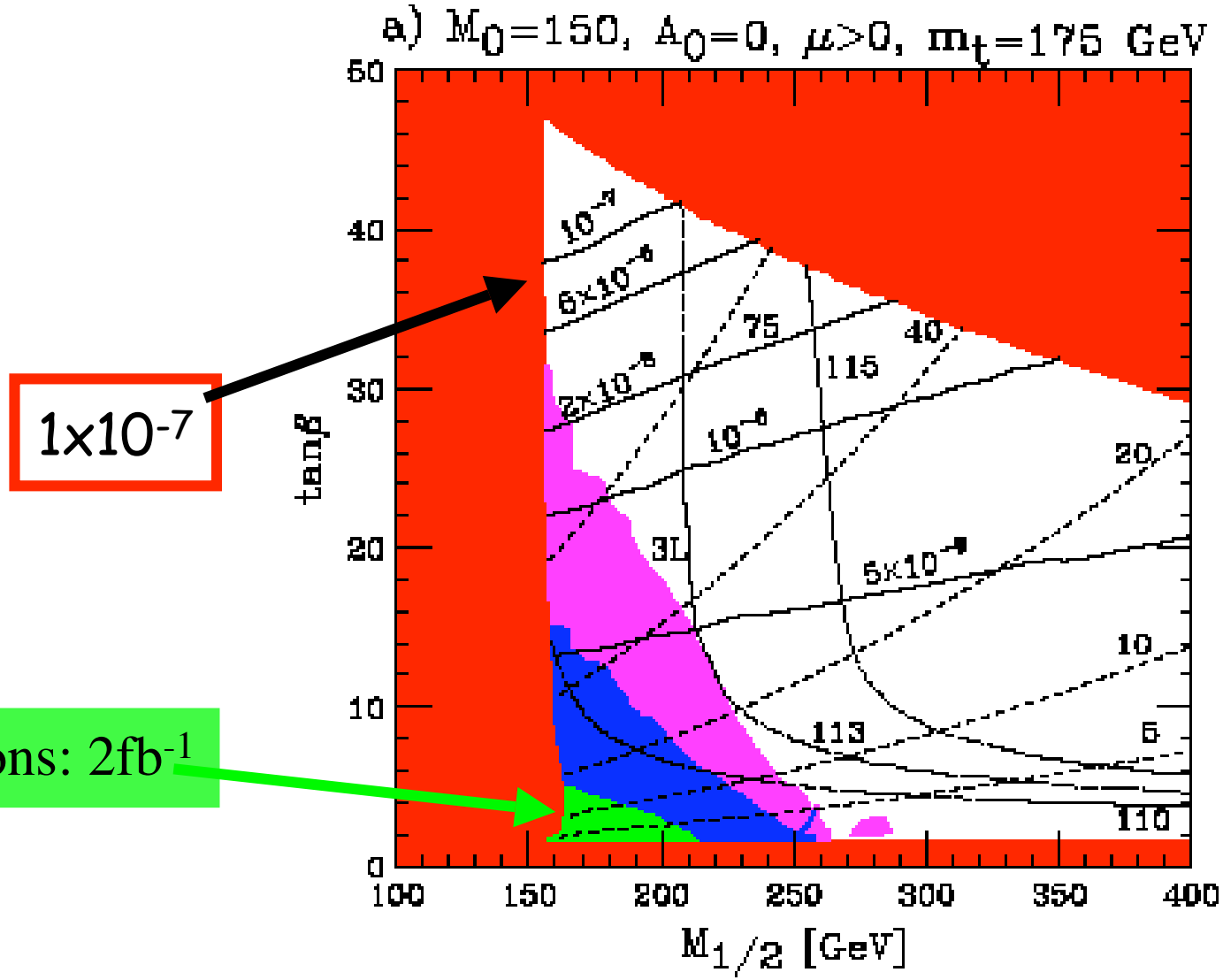


S. Baek, Y.G.Kim, P. Ko, hep-ph/0406033



$B_s \to \mu^+\mu^-$ vs. Trileptons

A.Dedes, S. Mrenna, U. Nierste, P. Richardson hep-ph/0507233

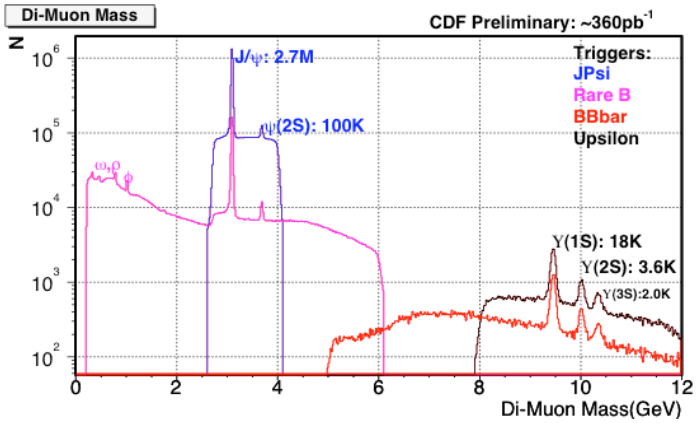


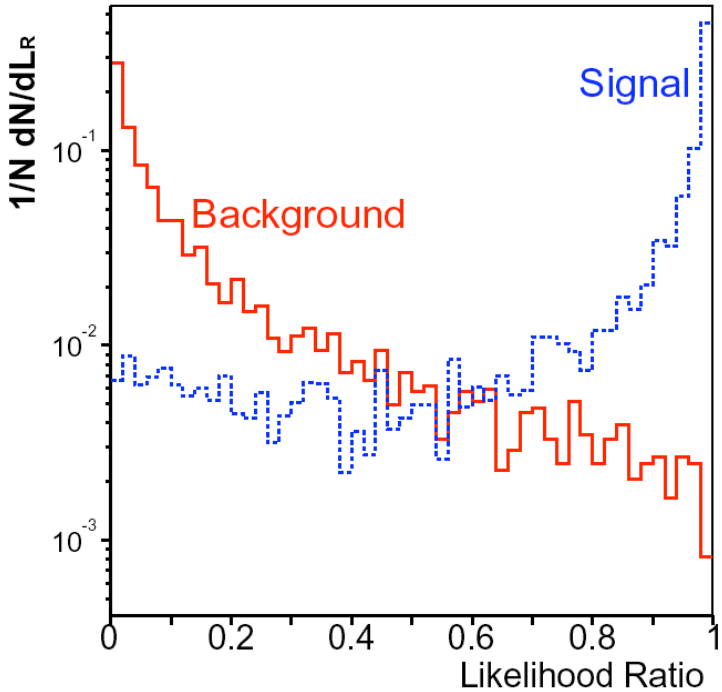
1×10^{-7}

Trileptons: $2fb^{-1}$

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

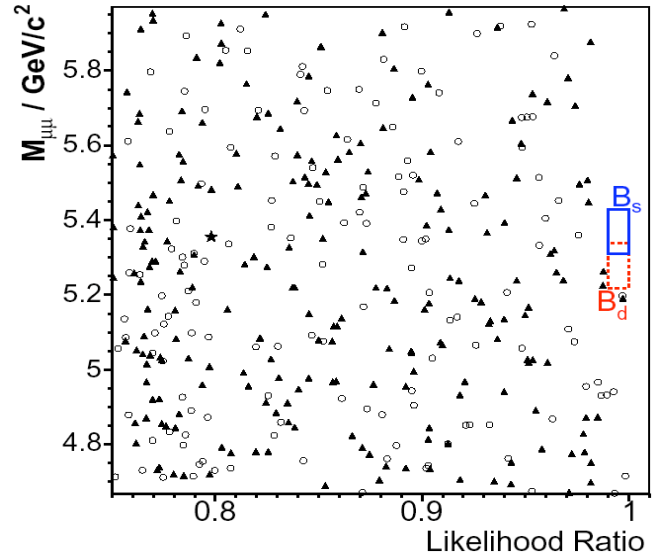
- Preselection:
  - Two muons with p_T>1.5 GeV/c
  - CMU-CMU and CMU-CMX
    - Two different muon detectors covering different angular regions
  - Dimuon vertex displaced from primary
- Identify variables that separate signal from background:
  - Dimuon mass
  - Decay length: λ
  - Points towards primary vertex
  - Isolated from other tracks
- Construct likelihood of last three variables:
  - Excellent separation
  - Cut at likelihood ratio >0.99

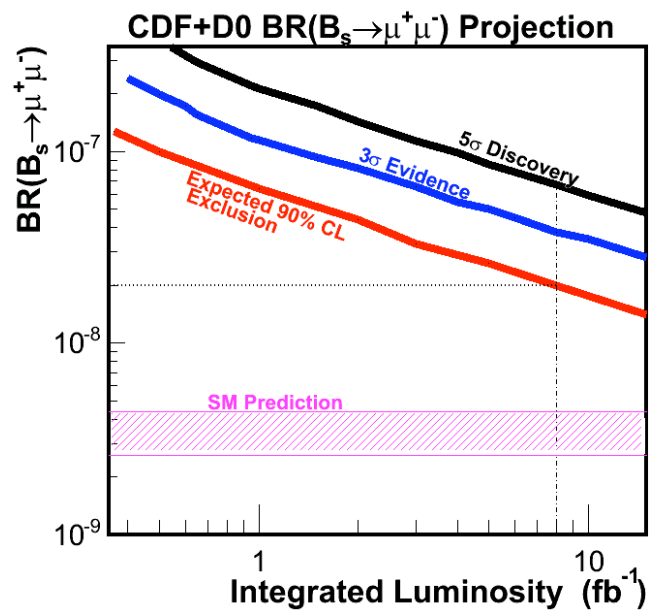




$B_s \to \mu\mu$:Result and Future

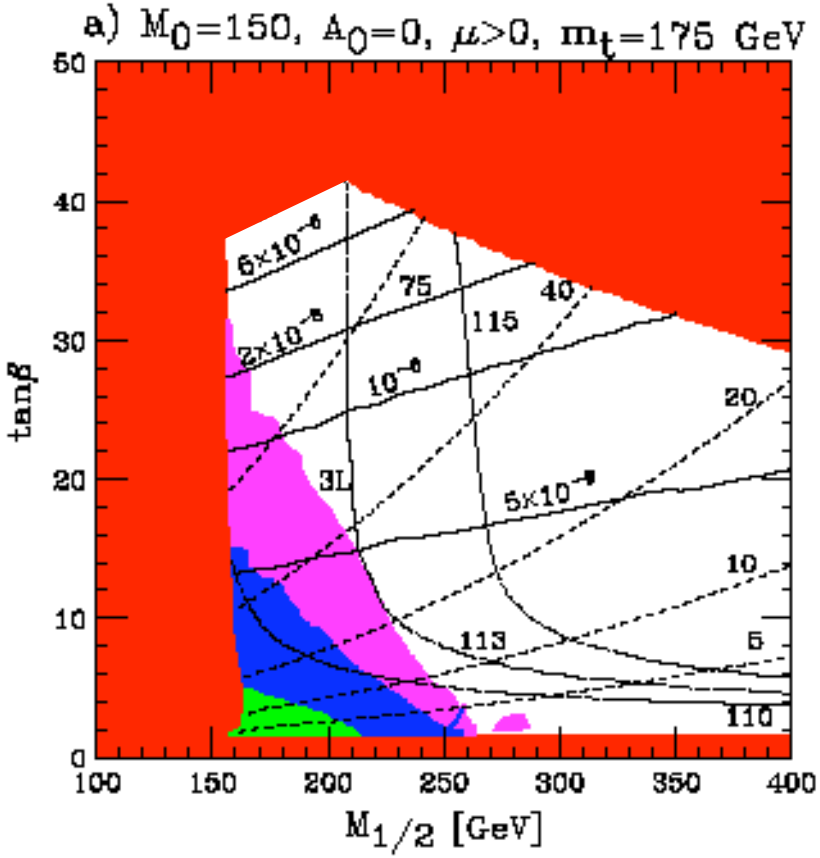
- Result:
  - 0 events observed
  - Backgrounds:
    - 0.81± 0.12 for (CMU-CMU)
    - 0.66 ± 0.13 for (CMU-CMX)
- Branching Ratio:
  - CDF:
    - $BR(B_s \to \mu\mu) < 1.5 \times 10^{-7}$ at 90%C.L.
  - Combined with D0:
    - $BR(B_s \to \mu\mu) < 1.2 \times 10^{-7}$ at 90%C.L.
- Future:
  - Probe values of 2×10^{-8}



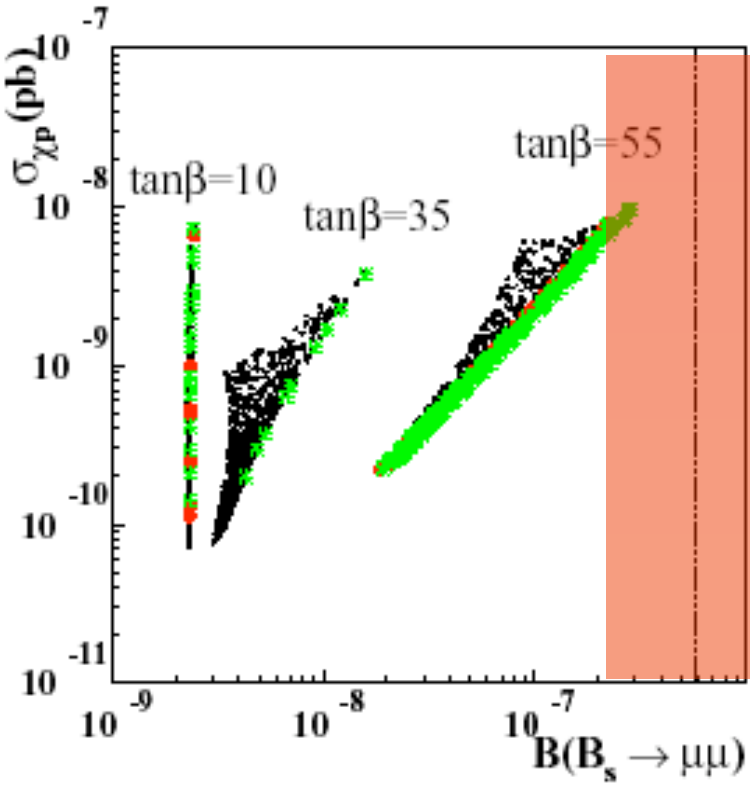


Impact of $B_s \to \mu^+\mu^-$ limits: Now

A.Dedes, S. Mrenna, U. Nierste, P. Richardson hep-ph/0507233



S. Baek, Y.G.Kim, P. Ko, hep-ph/0406033



- Starting to constrain MSSM parameter space

Impact of $B_s \to \mu^+\mu^-$ limits: L=8 fb^{-1}

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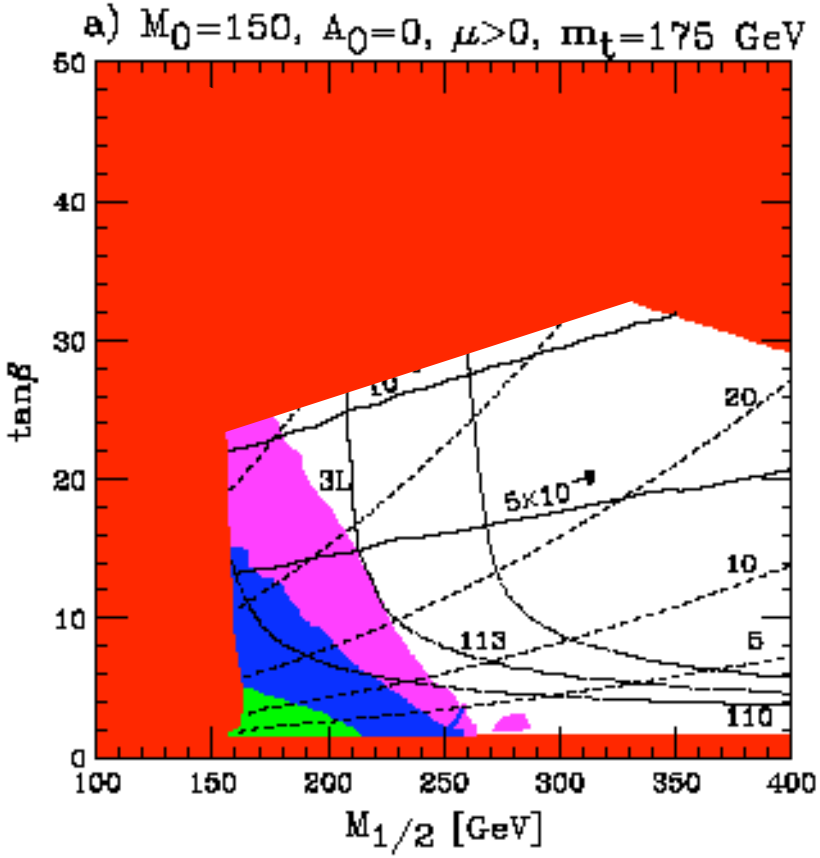
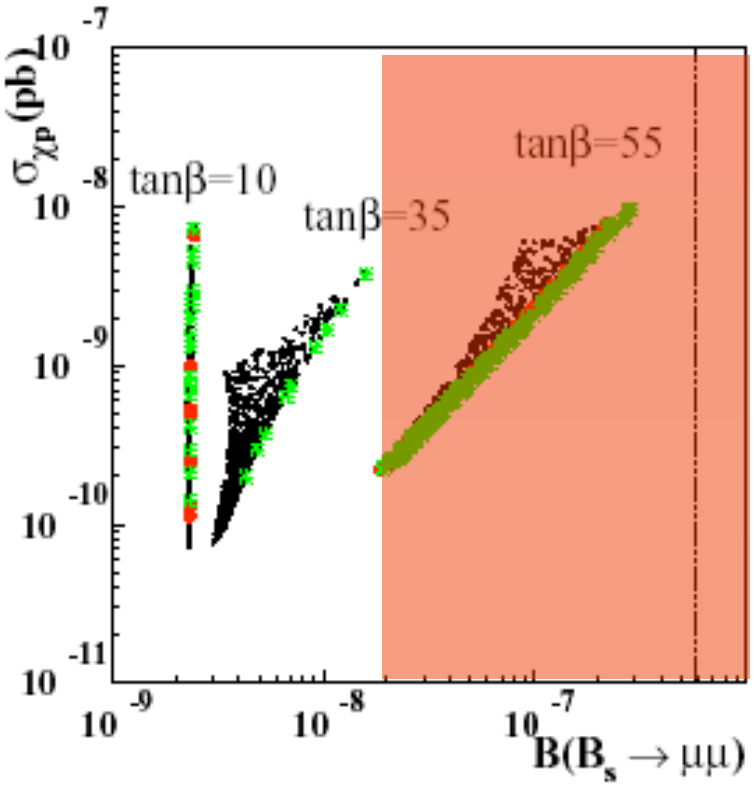


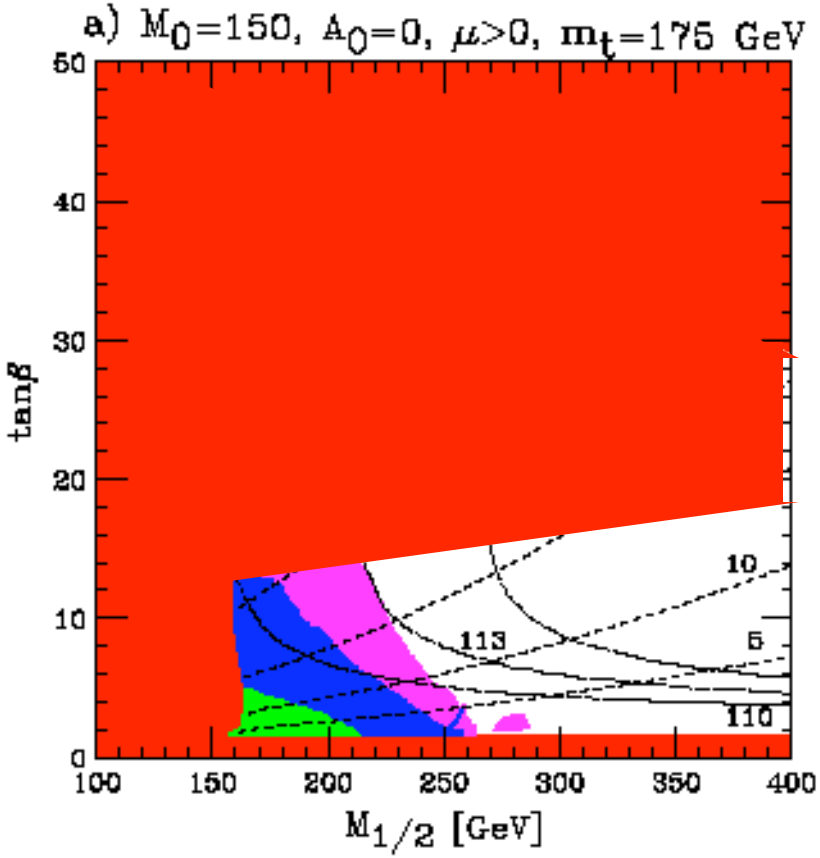
S. Baek, Y.G.Kim, P. Ko, hep-ph/0406033



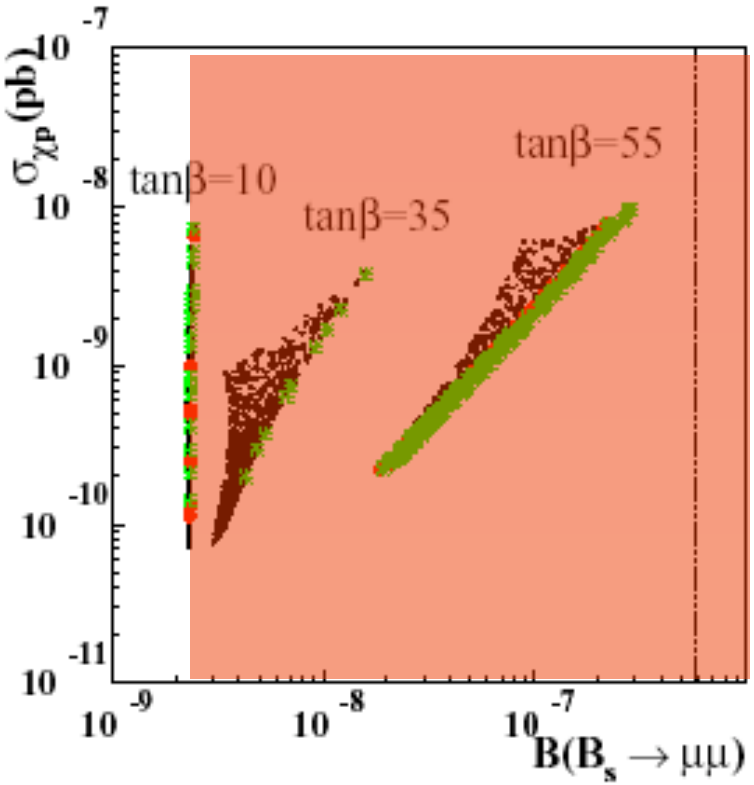
- Tevatron will severely constrain parameter space

Impact of $B_s \to \mu^+\mu^-$ limits: LHC

A.Dedes, S. Mrenna, U. Nierste, P. Richardson hep-ph/0507233



S. Baek, Y.G.Kim, P. Ko, hep-ph/0406033

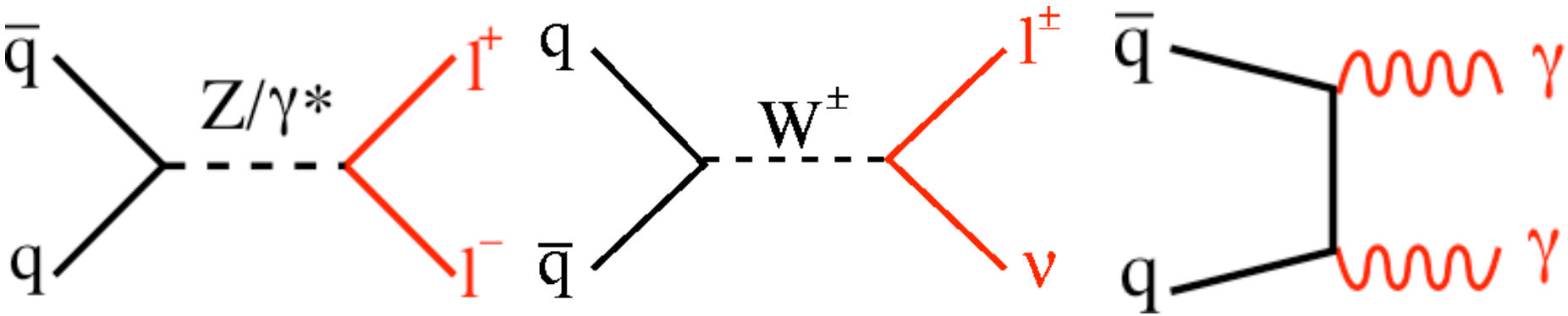


- LHC will probe SM value with about 100 pb^{-1}

High Mass Searches

High Mass Dileptons and Diphotons

Standard Model high mass production:

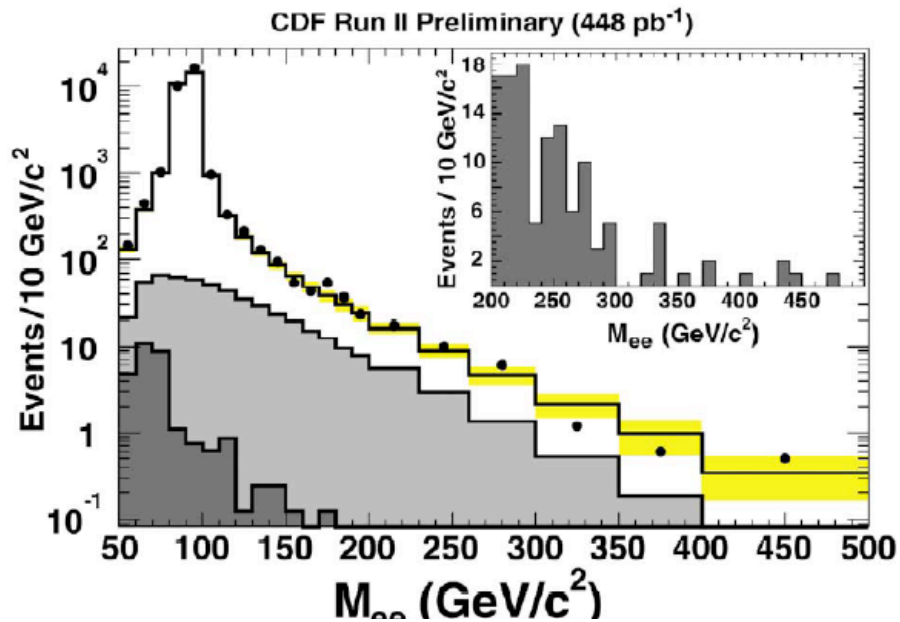


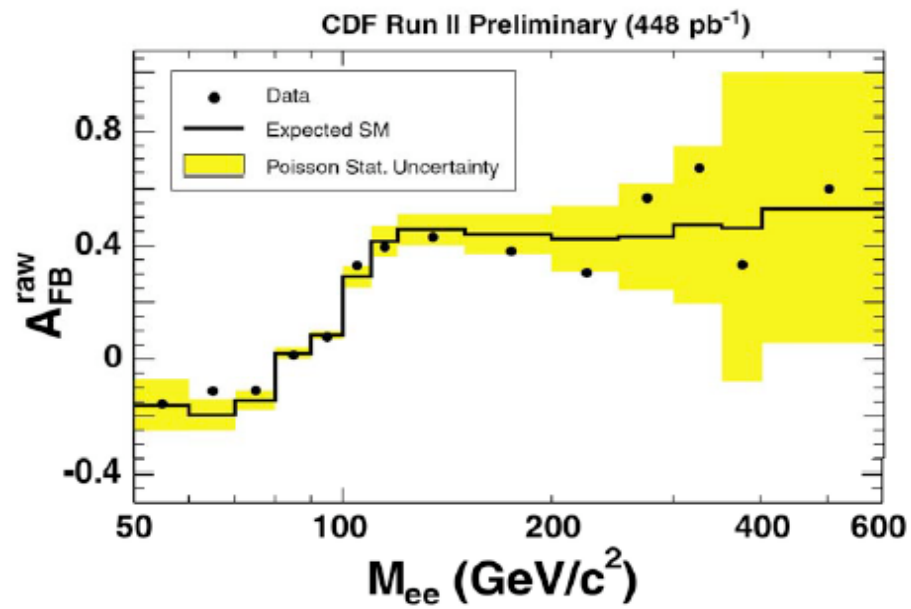
New physics at high mass:

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

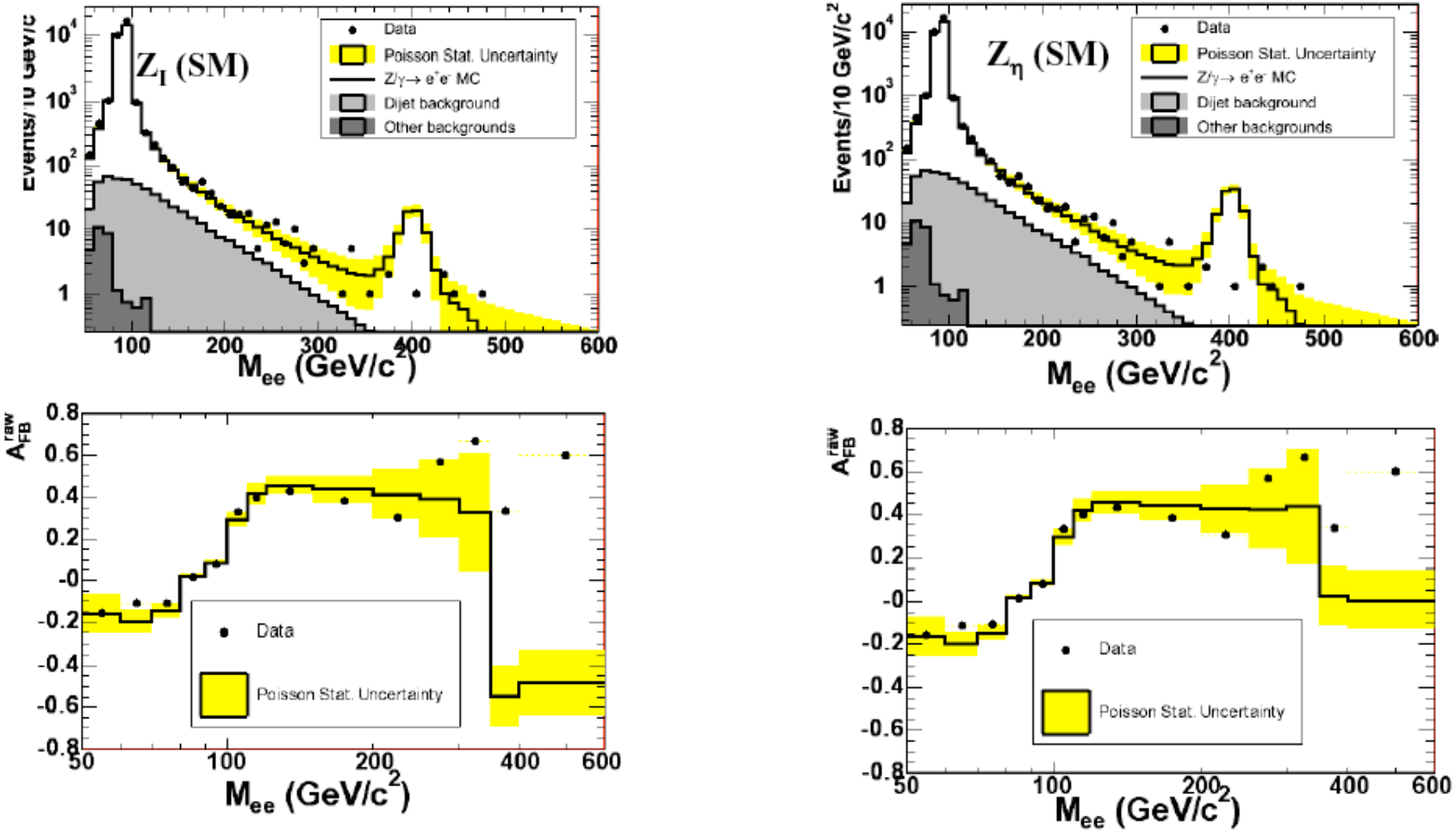
Z´→ee Search

- Dielectron mass spectrum and angular distribution:
  - 2D analysis improves sensitivity
- Data agree well with Standard Model spectrum
  - No evidence for mass peak





Z´→ee Signal Examples



- Angular distribution has different sensitivity for different Z′ models

Limits on New Physics

- Mass peak search:

Model	Z_{SM}	Z_{χ}	Z_{ψ}	Z_{η}	Z_{I}	Z_{N}	Z_{sec}
Mass limit (GeV/c^2)	860	735	725	745	650	710	675

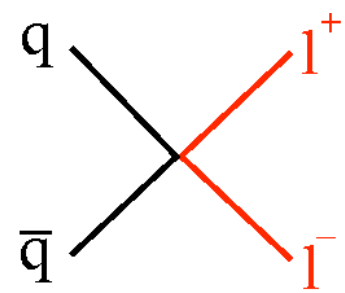
- Tail enhancement: contact interaction

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

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

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

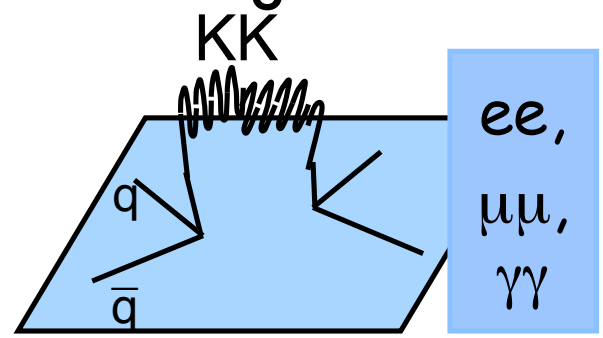
VV=LL+LR+RL+RR; AA = LL+RR-RL-LR



p

Extra Dimensions

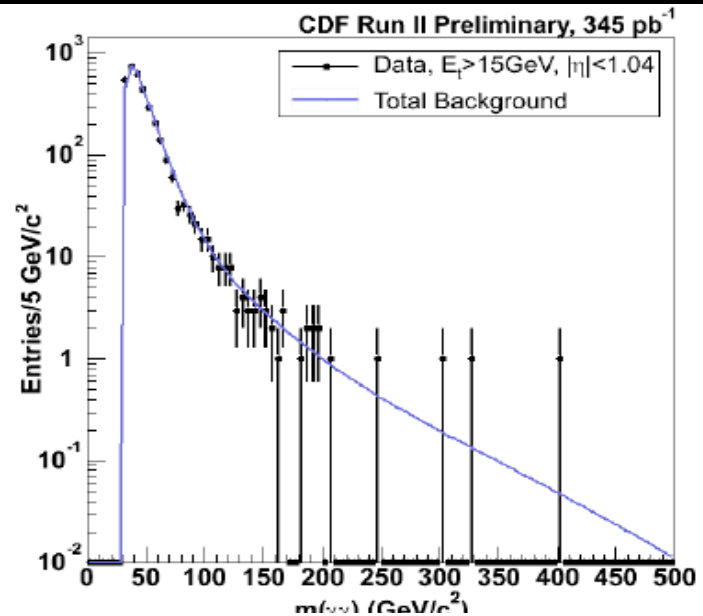
- Attempt to solve hierarchy problem by introducing extra dimensions at TeV scale
- ADD-model:
  - n ED's large: 100μm-1fm
  - $M^2_{PL} \sim R^n M_S^{n+2}$ (n=2-7)
  - Kaluza-Klein-tower of Gravitons $\Rightarrow$continuum
  - Interfere with SM diagrams: $\lambda=\pm1$ (Hewett)



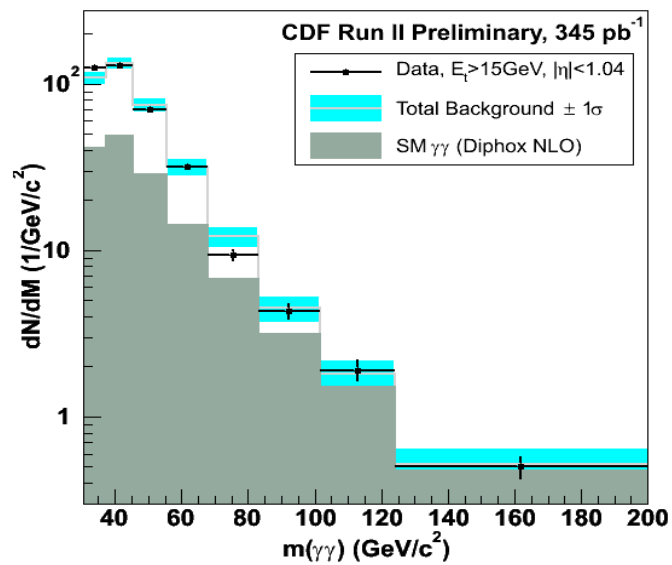
- Randall Sundrum:
  - Gravity propagates in single curved ED
  - ED small $1/M_{Pl}=10^{-35}$ m
  - Large spacing between KK-excitations
    $\Rightarrow$ resolve resonances
- Signatures at Tevatron:
  - Virtual exchange:
    - 2 leptons, photons, W's, Z's, etc.
    - BR(G->$\gamma\gamma$)=2xBR(G->ll)

Randall–Sundrum Graviton

- Analysis:
  - 2 photon mass spectrum
  - Backgrounds:
    - direct diphoton production
    - Jets: $\pi^0 \rightarrow \gamma\gamma$
- Data consistent with background

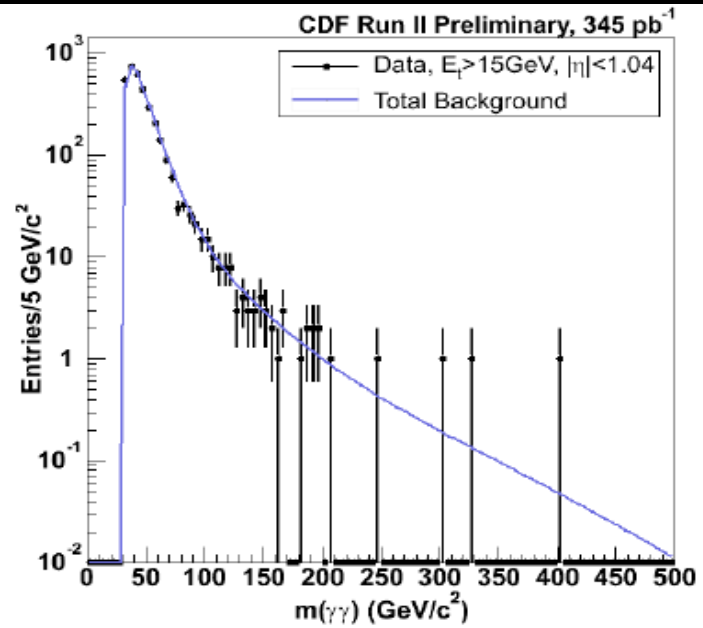


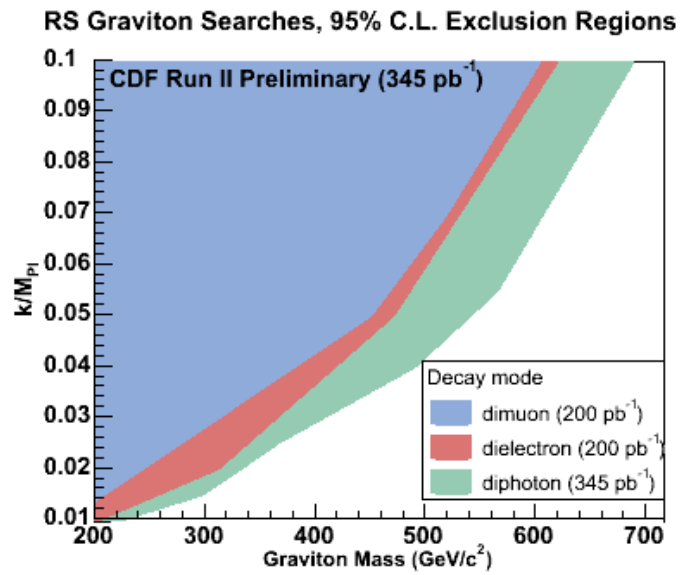
Diphoton RS Graviton Search



Randall–Sundrum Graviton

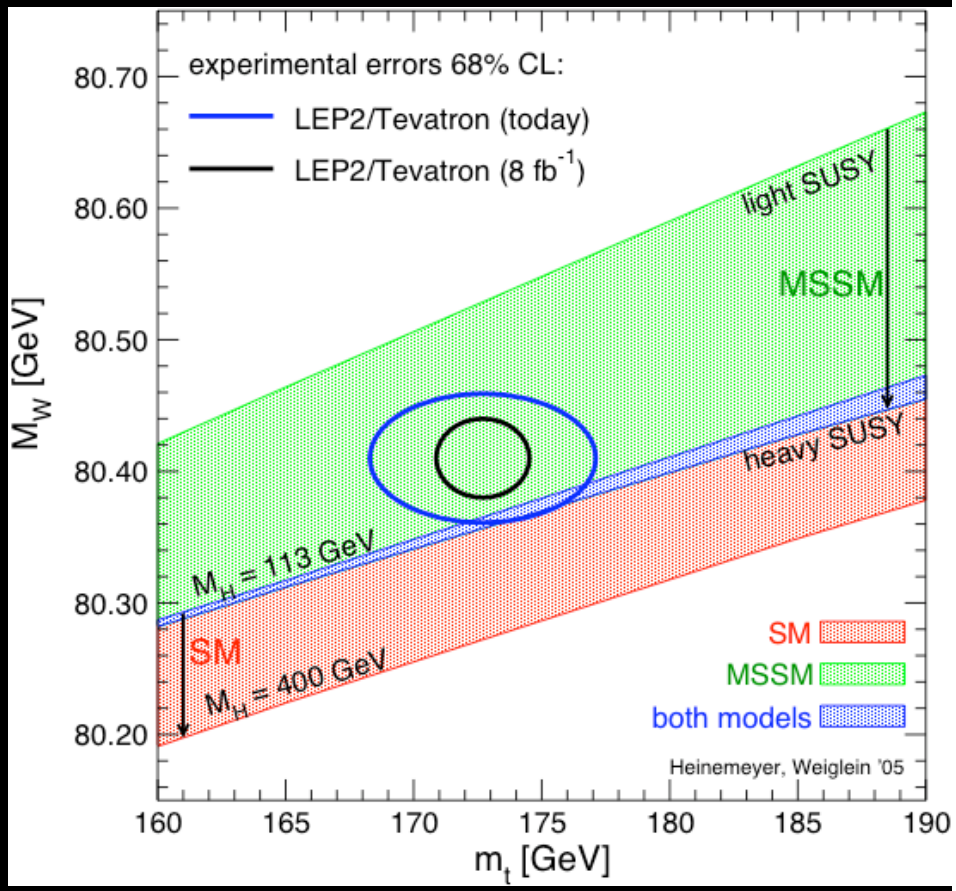
- Analysis:
  - 2 photon mass spectrum
  - Backgrounds:
    - direct diphoton production
    - Jets: $\pi^0 \rightarrow \gamma\gamma$
- Data consistent with background
- Relevant parameters:
  - Coupling: k/M_{Pl}
  - Mass of 1st KK-mode





Summary and Outlook

- CDF and Tevatron running great!
  - Often world's best constraints
  - Many searches on SUSY, Higgs and other new particles
- Most analyses based on up to 350 pb^{-1}
  - Will try to analyse 1 fb^{-1} by summer 2006
  - Anticipate 4.4-8.6 fb^{-1} by 2009
- If Tevatron finds no new physics it will provide further important constraints
  - And hopefully LHC will then do the job



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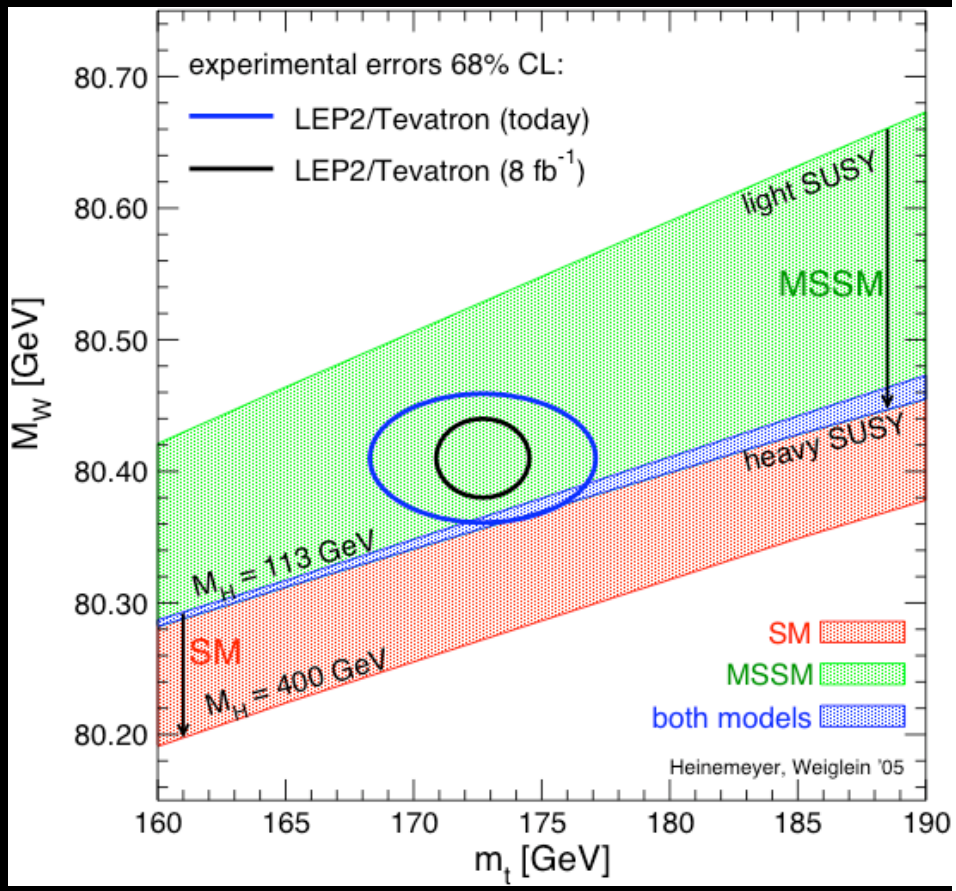
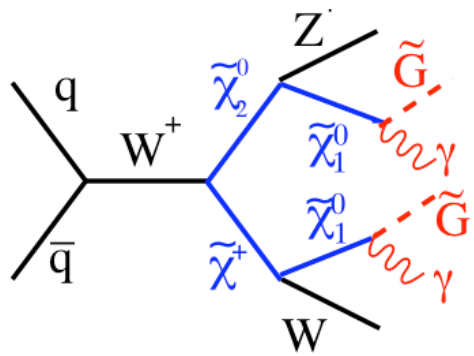


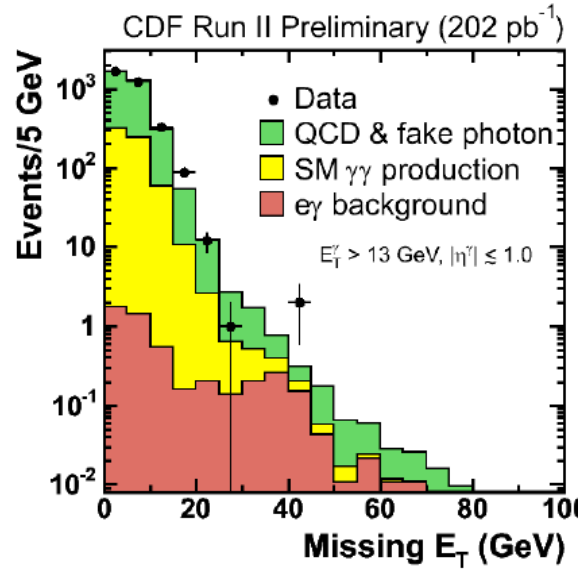
If we find something the real fun starts: What Is It?

Backup Slides

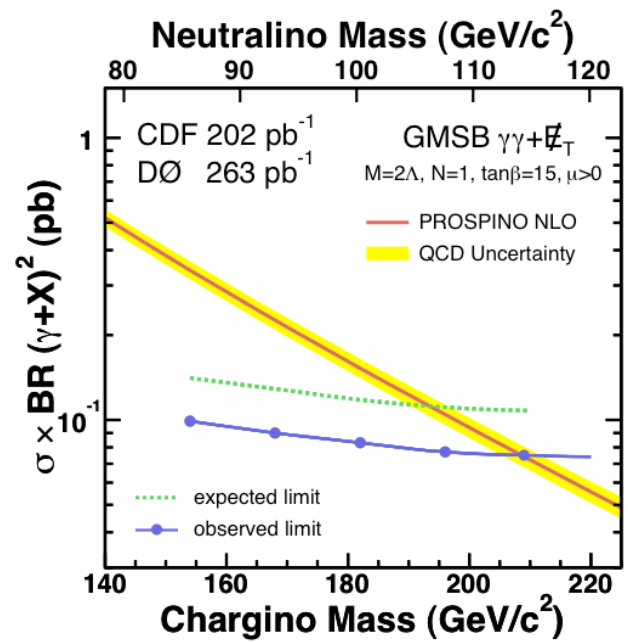
GMSB: $\gamma\gamma+\not{E}_t$

- Assume χ^0_1 is NLSP:
  - Decay to $\tilde{G}+\gamma$
  - $\tilde{G}$ light: m ≈ 1 keV
  - Inspired by CDF $ee\gamma\gamma+\not{E}_t$ event in Run I
    - NB: no such event in Run II yet
- D0 (CDF) Inclusive search:
  - 2 photons: E_t > 20 (13) GeV
  - E_t > 40 (45) GeV





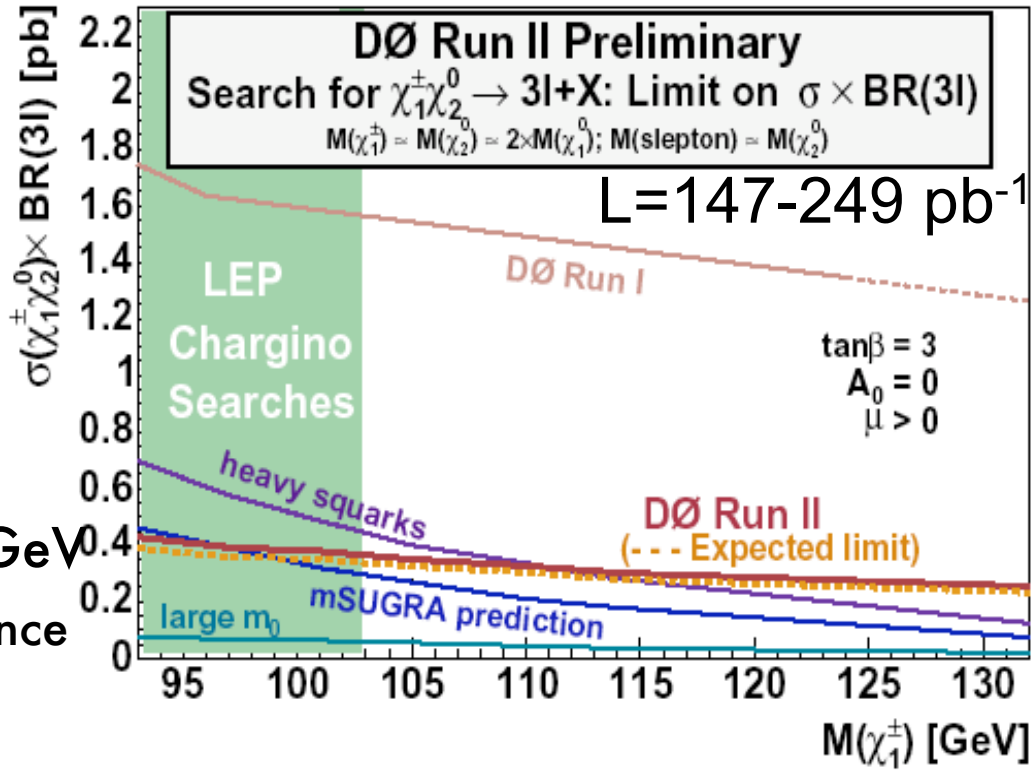
	Exp.	Obs.	$m(\chi^+_1)$
D0	2.5±0.5	1	>192 GeV
CDF	0.3±0.1	0	>168 GeV



D0+CDF: $m(\chi^+_1)$> 209 GeV/c^2

mSUGRA: 3–lepton result

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



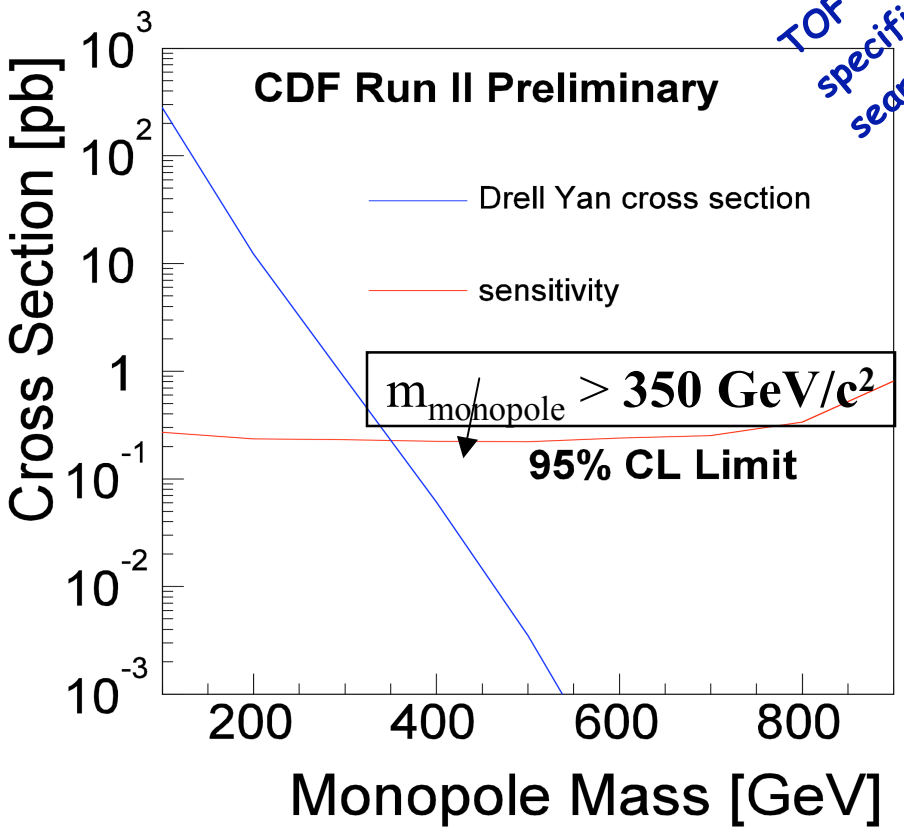
Will extend sensitivity to mSUGRA beyond LEP with just 25% more data: 75% more already on tape!

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

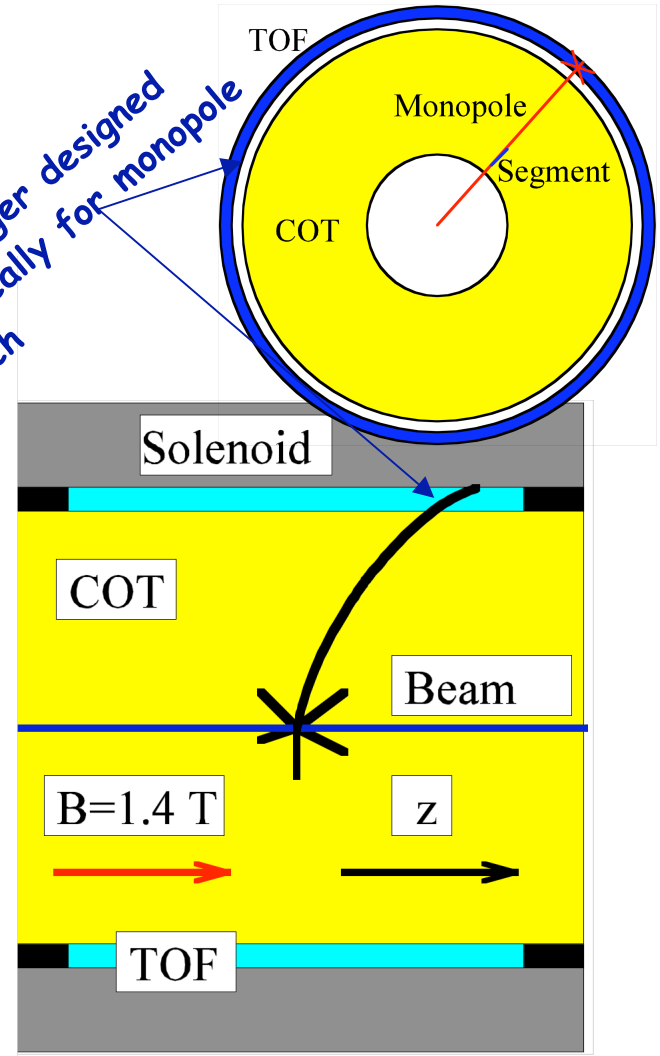
$m(\chi^+_1)>183$ (160) GeV for λ_{121} (λ_{122}) for $\mu<0$

Dirac Magnetic Monopole

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

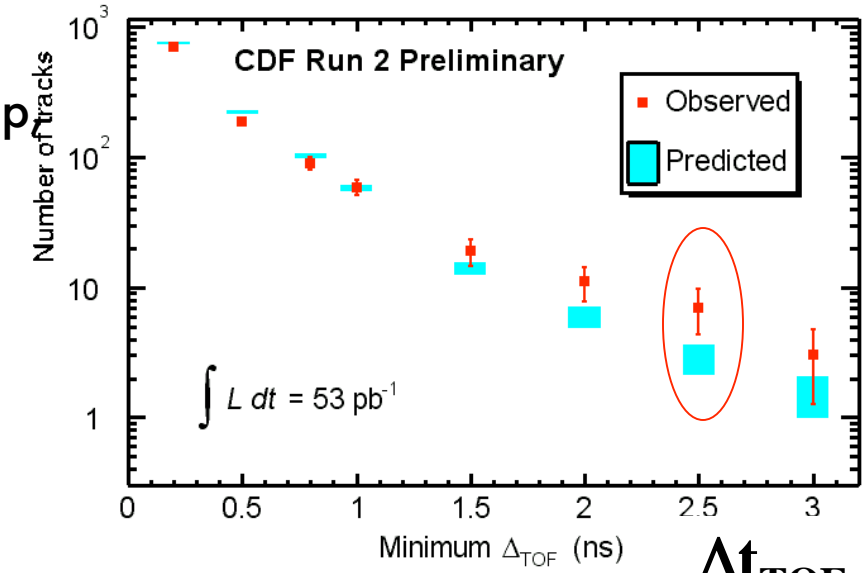


TOF trigger designed specifically for monopole search

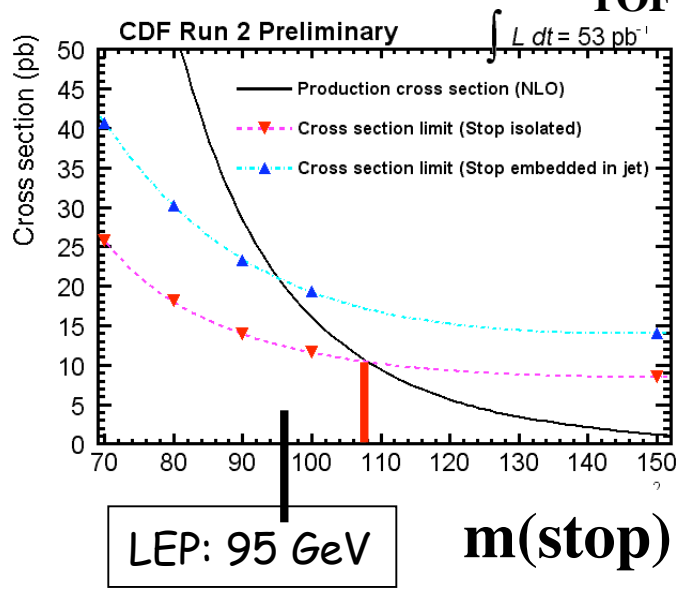


Long-lived particles

- 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(t)>97-107 GeV @ 95%C.L.



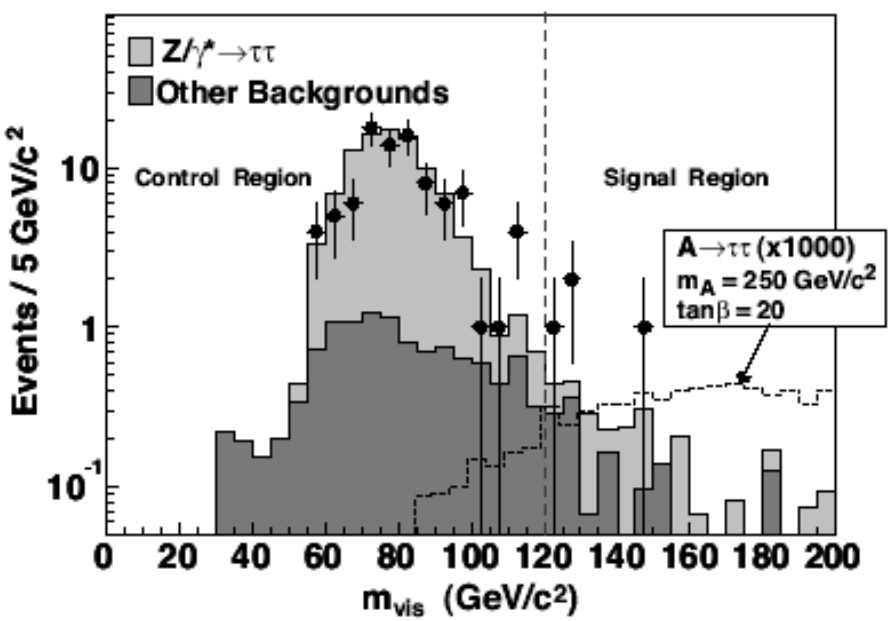
Δt_{TOF}

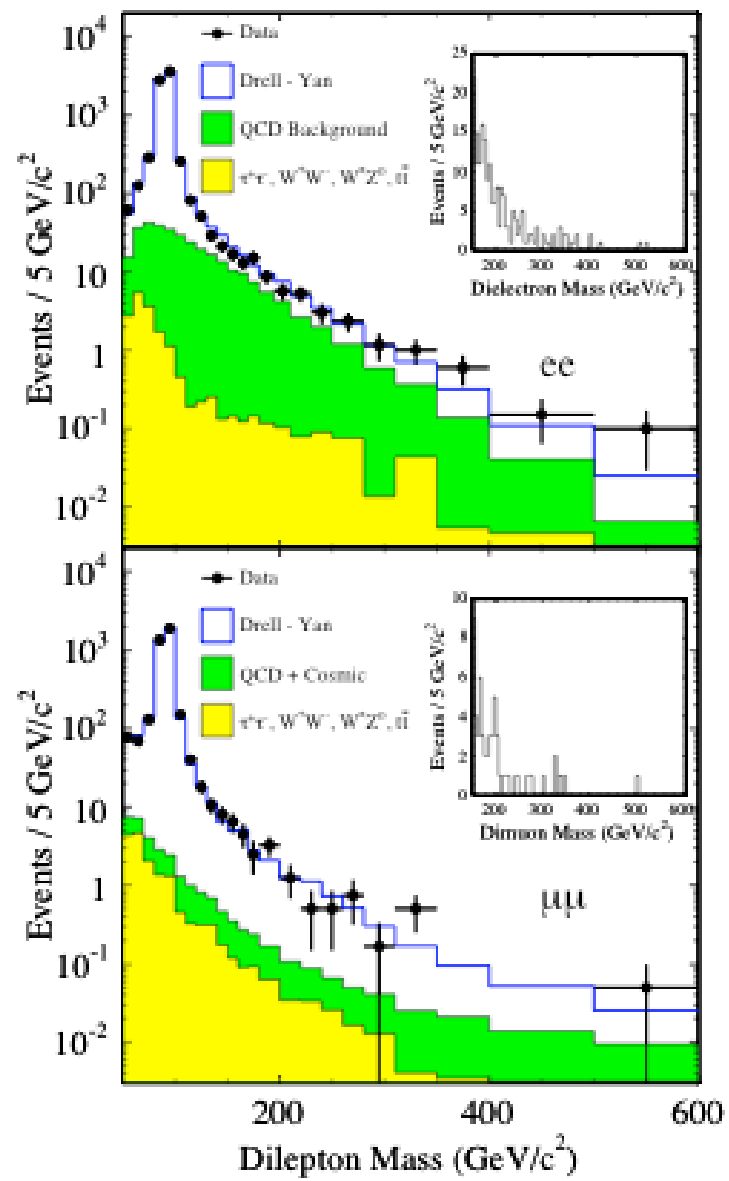


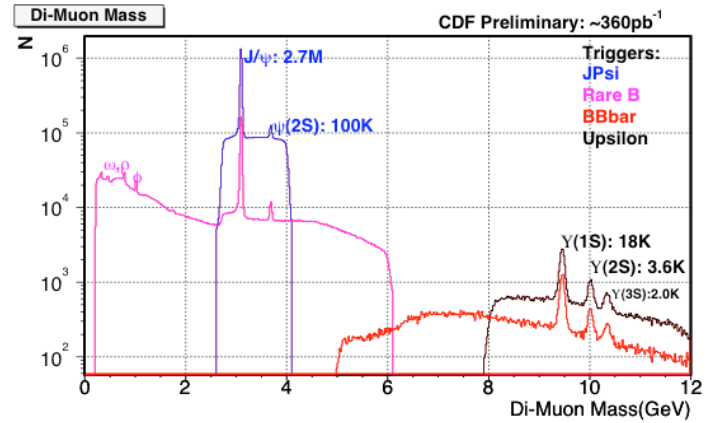
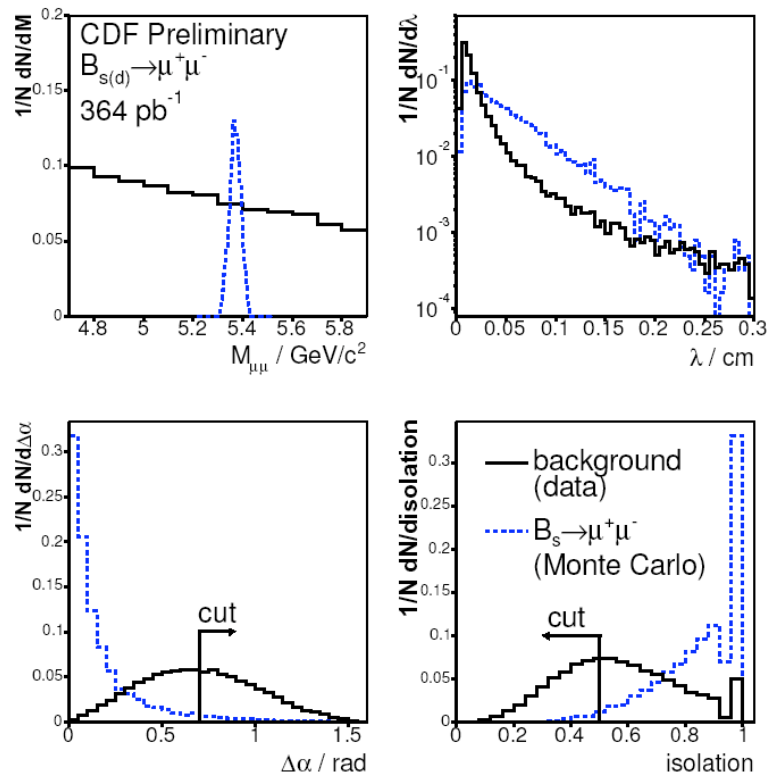
m(stop)

Neutral Spin–1 Bosons: Z'

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





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

- Preselection:
  - Two muons with p_T>1.5 GeV/c
  - Dimuon vertex displaced from primary
- Identify variables that separate signal from background:
  - Dimuon mass
  - Decay length: λ
  - Points towards primary vertex
  - Isolated from other tracks
- Construct likelihood of all these variables