New Physics Searches

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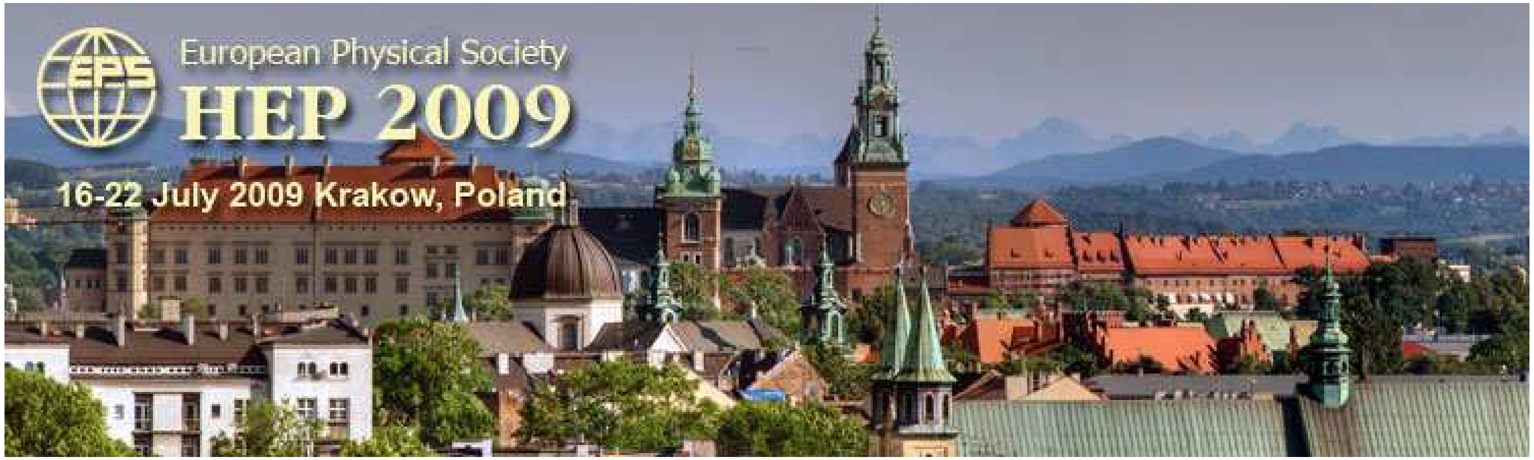
Selection of results from the ATLAS, CDF, CMS and DØ Collaborations

EPS 2009, July 20, 2009



- Supersymmetry
- New high-mass states
- Exotic Signals

Tevatron: 2 TeV

Proton-Antiproton

In operation since 2001

7 fb^{-1} delivered, expect 12 fb^{-1} by 2011

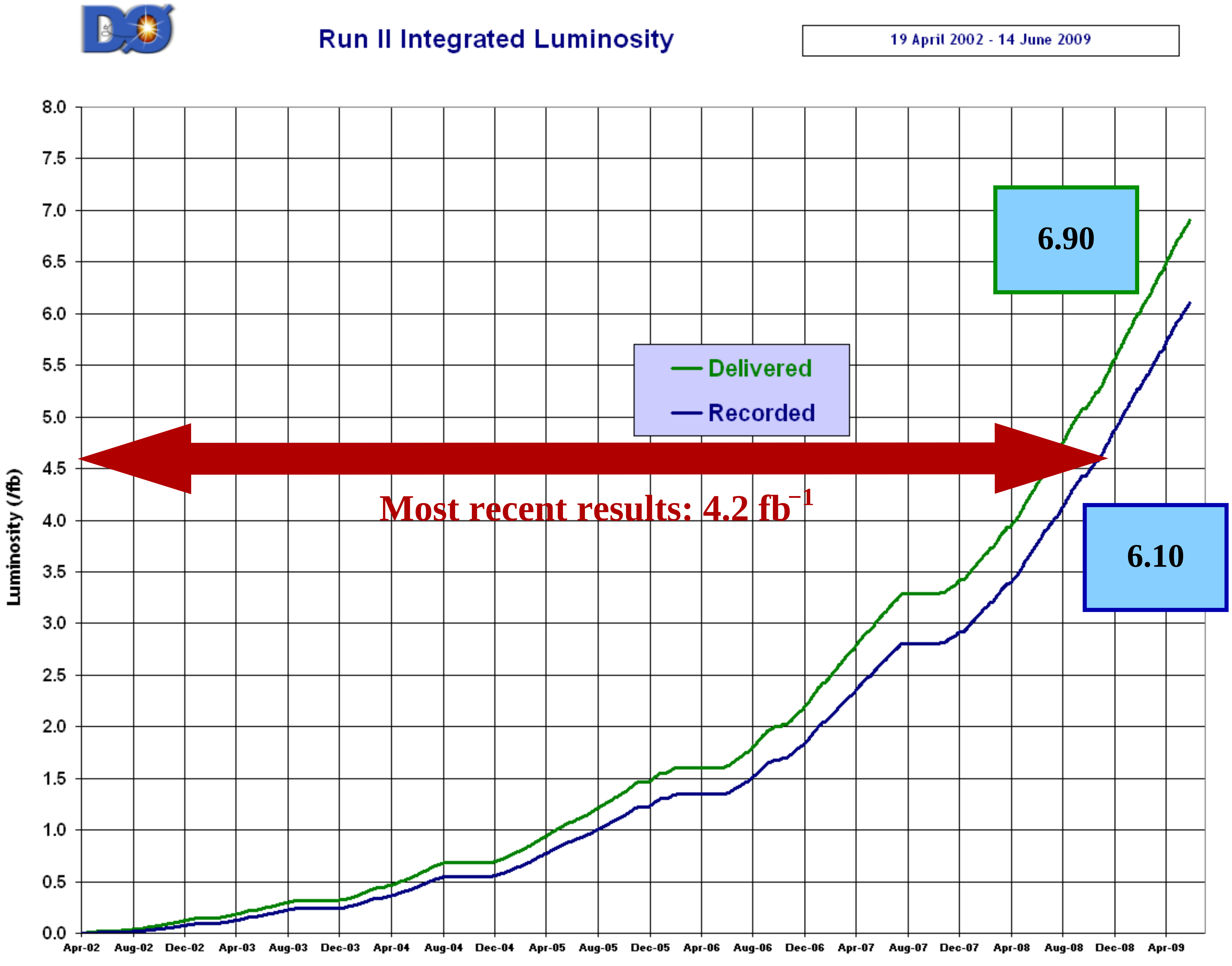
LHC: 14 TeV

Proton-Proton

Scheduled to restart in Fall 2009

expect 200 pb^{-1} at $\sqrt{s}=10$ TeV in 2010

The Tevatron Experiments – Dataset



Supersymmetry

The idea: particle physics is symmetric under transformation of Fermion $\leftrightarrow$ Boson

$\longrightarrow$ one supersymmetric partner for each SM particle

$\longrightarrow$ stabilizes Higgs mass, unification of coupling constants, dark matter candidate

Superpartners are heavy $\longrightarrow$ SUSY is broken $\longrightarrow$ masses unknown

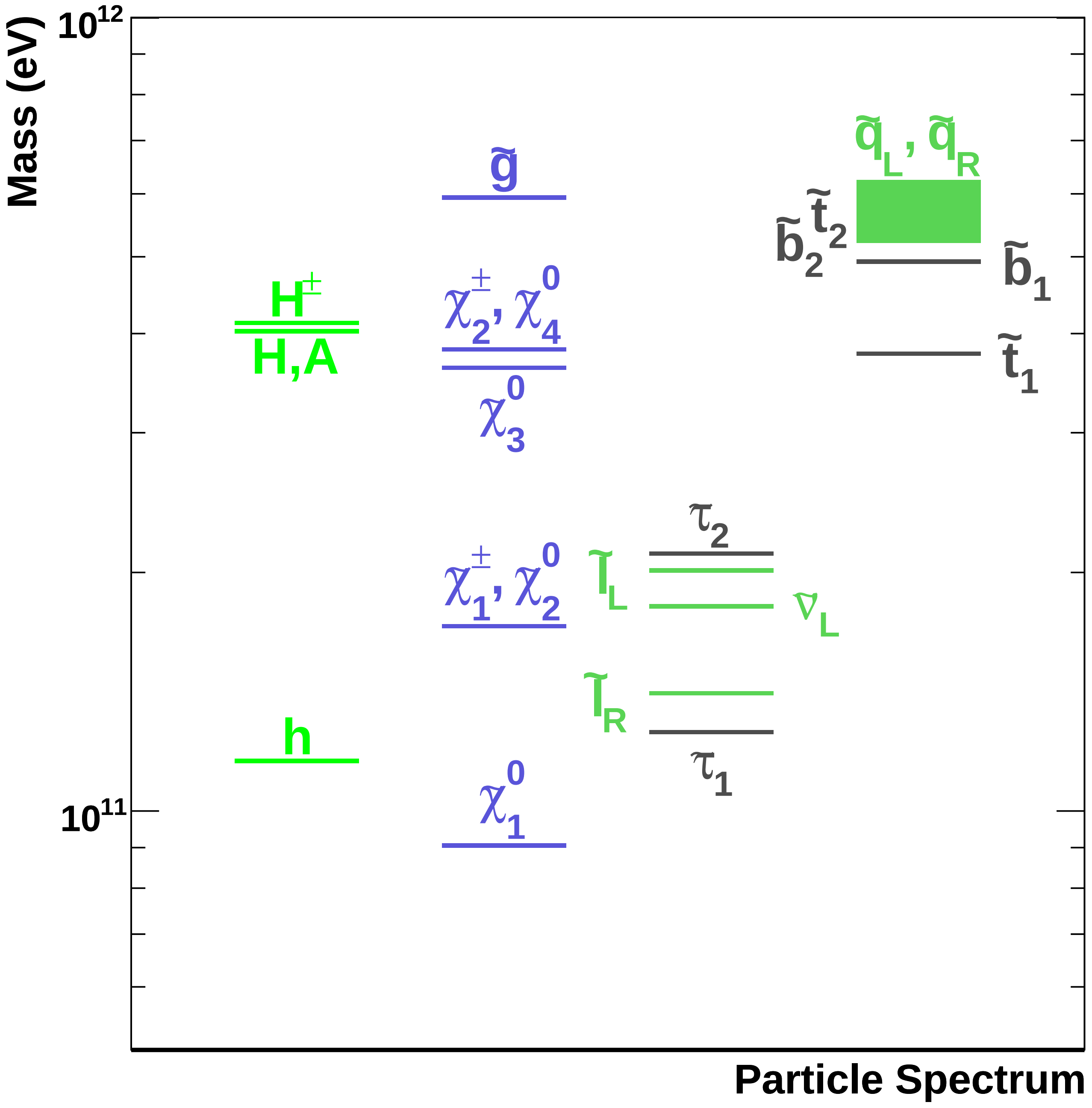
Prediction:

- Extended Higgs sector: 5 Higgs bosons h,H,A,H$^{\pm}$
- Many new particles: Charginos/Neutralinos/Gluinos, Squarks, Sleptons

Names		spin 0	spin 1/2
squarks, quarks	Q	$(\widetilde{u}_L \quad \widetilde{d}_L)$	$(u_L \quad d_L)$
($\times$3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$
sleptons, leptons	L	$(\widetilde{\nu} \quad \widetilde{e}_L)$	$(\nu \quad e_L)$
($\times$3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$
Higgs, higgsinos	H_u	$(H_u^+ \quad H_u^0)$	$(\widetilde{H}_u^+ \quad \widetilde{H}_u^0)$
	H_d	$(H_d^0 \quad H_d^-)$	$(\widetilde{H}_d^0 \quad \widetilde{H}_d^-)$

Names	spin 1/2	spin 1
gluino, gluon	$\widetilde{g}$	g
winos, W bosons	$\widetilde{W}^\pm \quad \widetilde{W}^0$	$W^\pm \quad W^0$
bino, B boson	$\widetilde{B}^0$	B^0

A typical Mass Spectrum



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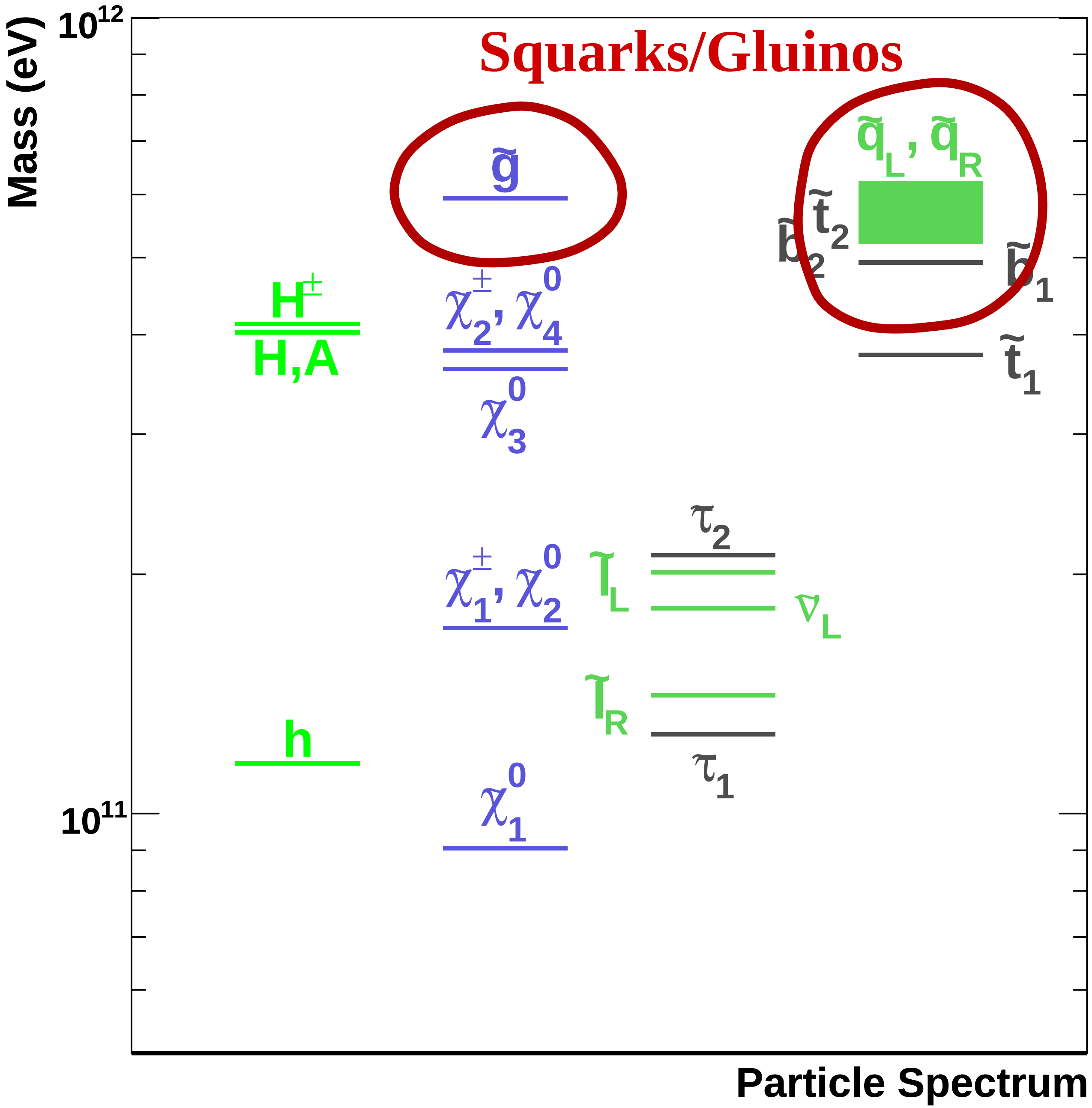


Inclusive Search for generic Squarks/Gluinos

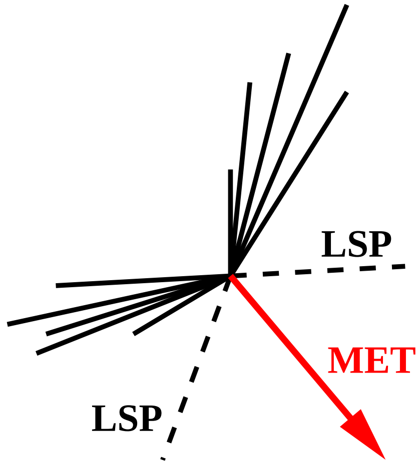
Squarks/Gluinos produced via strong interaction

$\longrightarrow$ large cross sections at hadron colliders

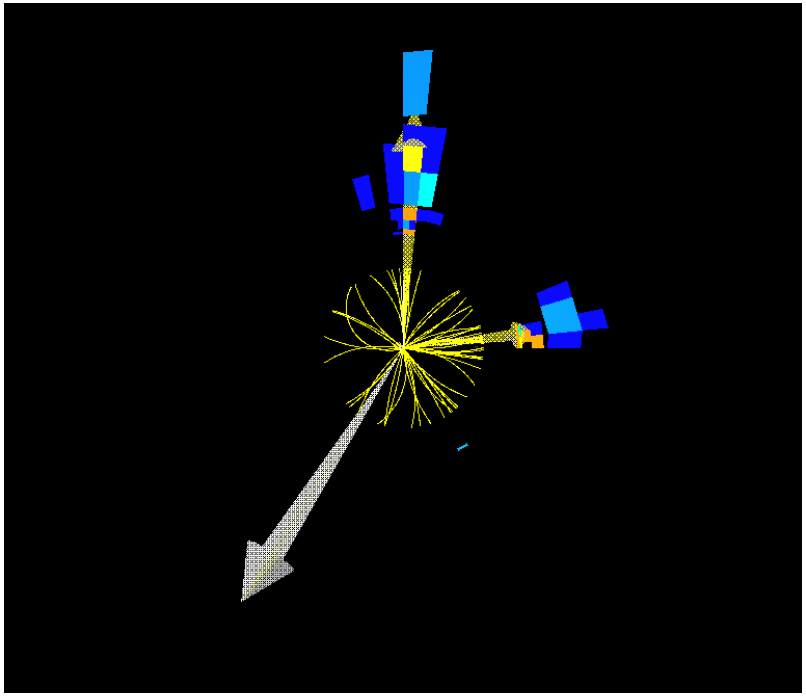
Decays: jets + LSP

– LSP assumed to be stable ($\not R_p$ conserved)

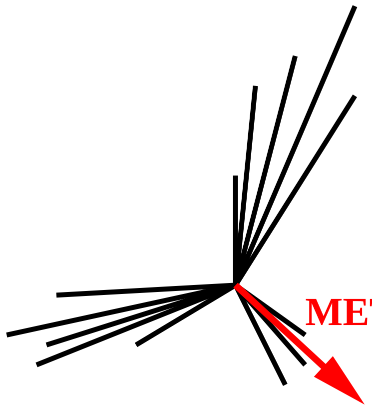
$\longrightarrow$ Signature: jets + $\not E_T$



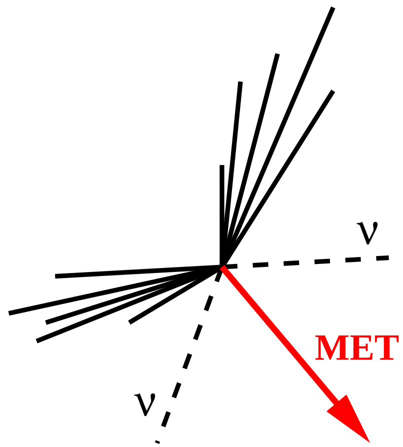
$\tilde{q}\tilde{q} \longrightarrow qq + \not E_T$



$\tilde{q}\tilde{q}$ candidate event in DØ



Multijet Background

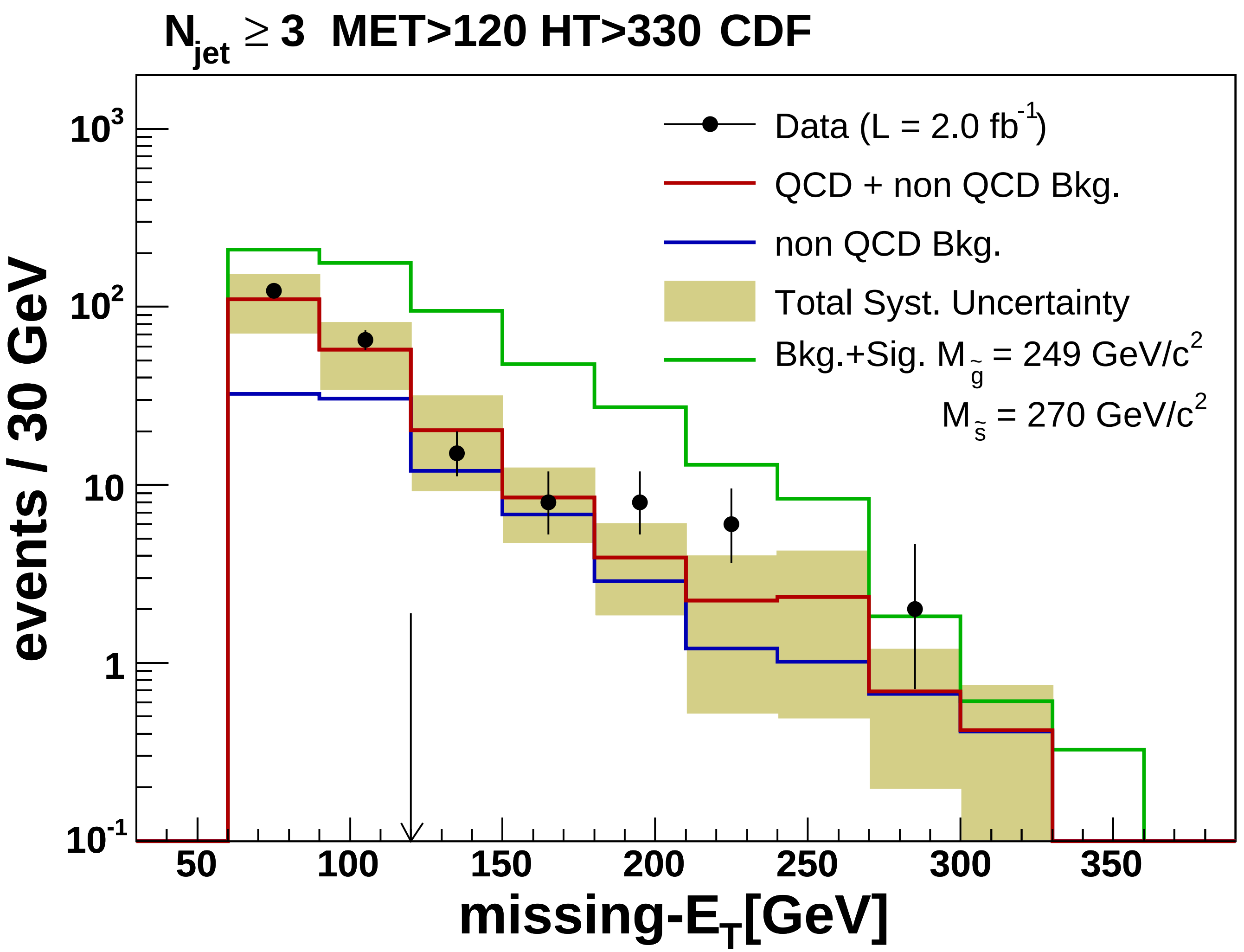


Background:

Z$\longrightarrow \nu\nu$+jets

Inclusive Search for generic Squarks/Gluinos

PLB 660, 449 (2008)
PRL 102, 121801 (2009)



- No evidence for squark/gluino production at the Tevatron
- Limits in squark/gluino mass plane, probing squark/gluino masses up to 400/320 GeV
- starting to be limited by parton luminosities

Inclusive Search for generic Squarks/Gluinos

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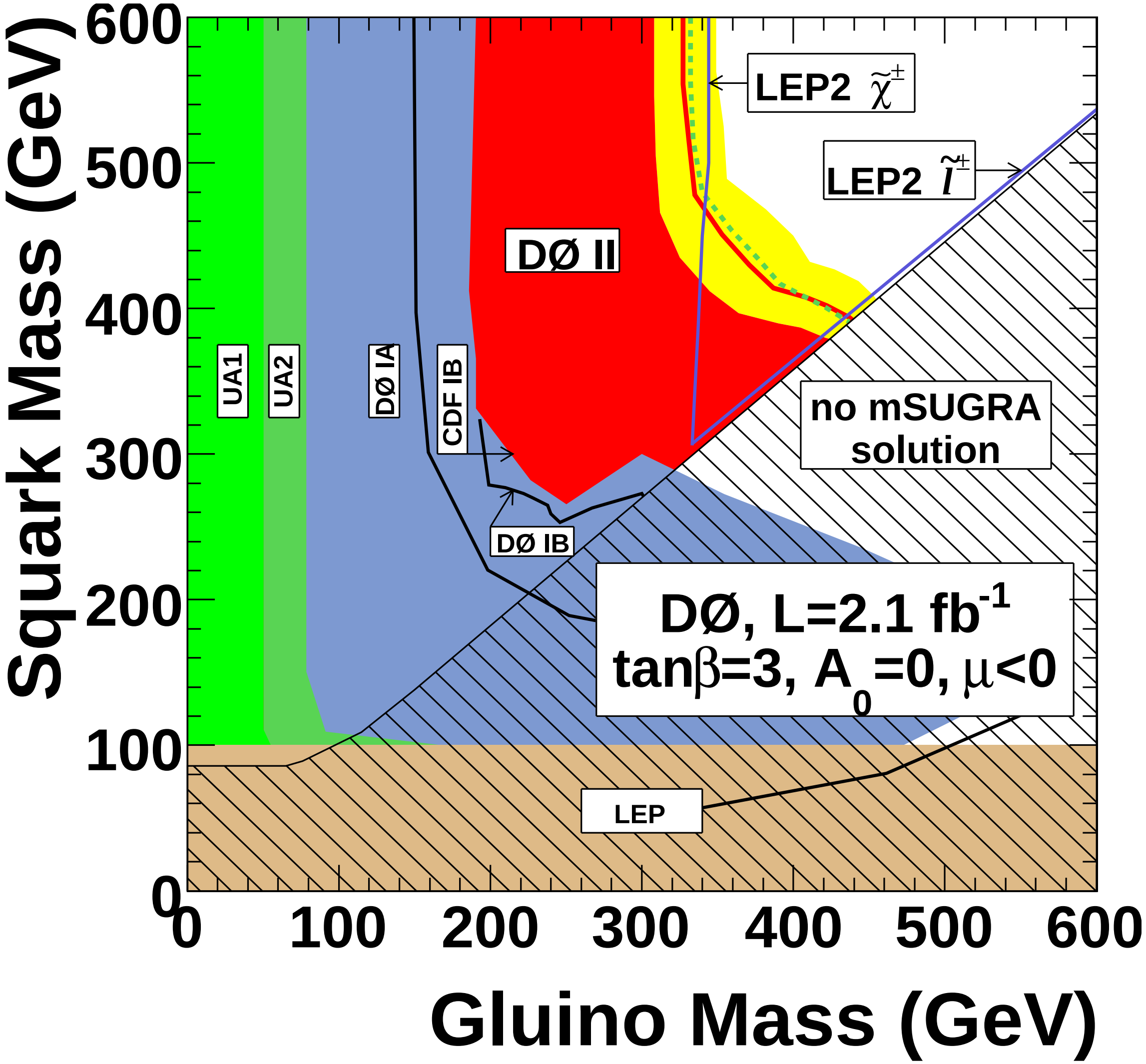

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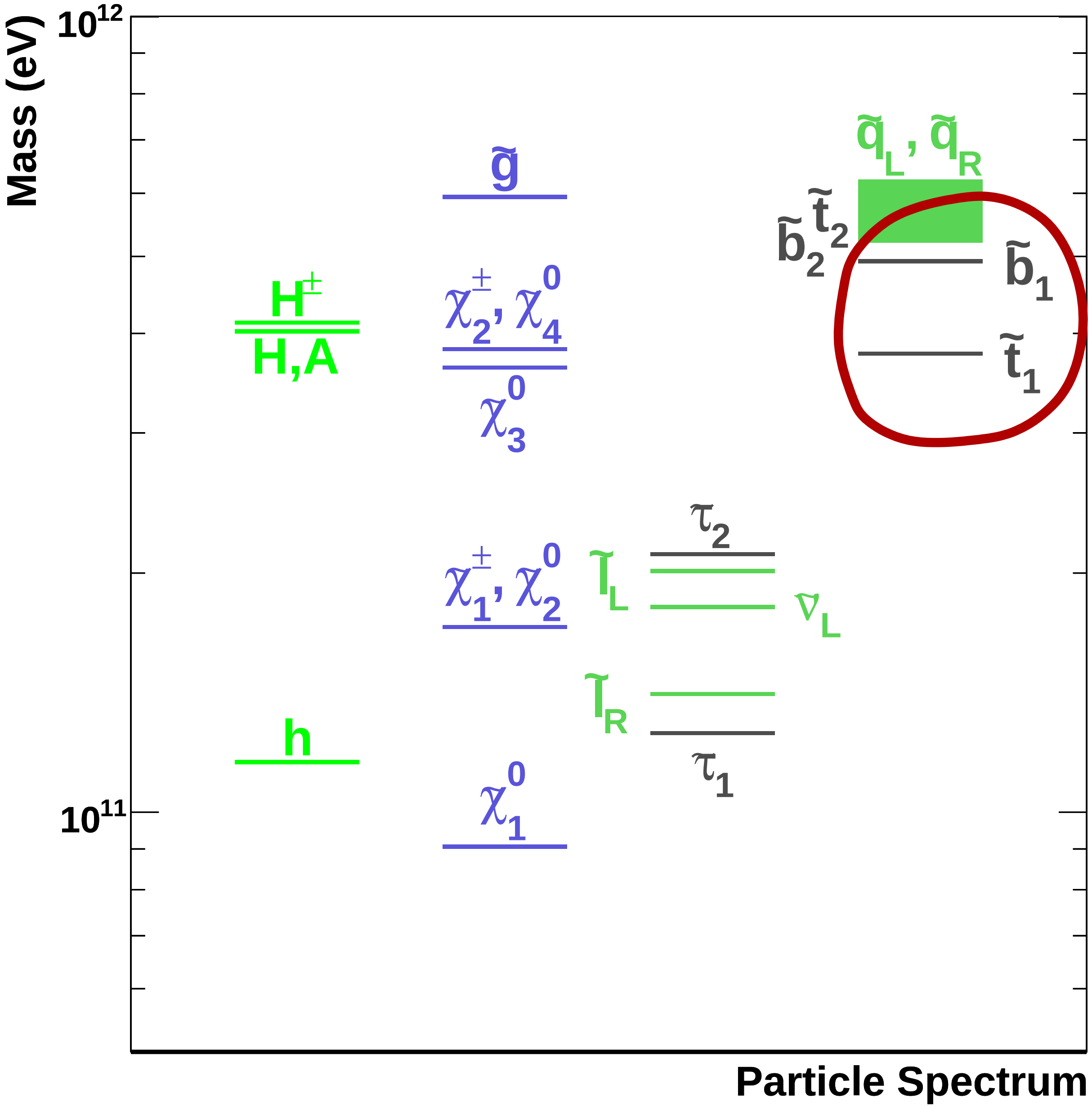
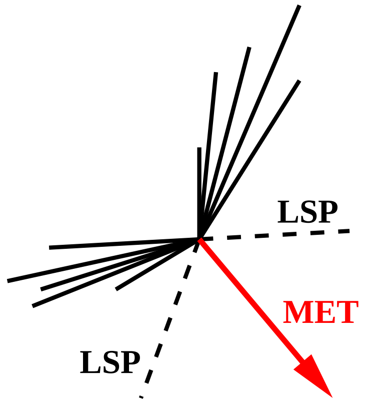
What SUSY particles to look for?



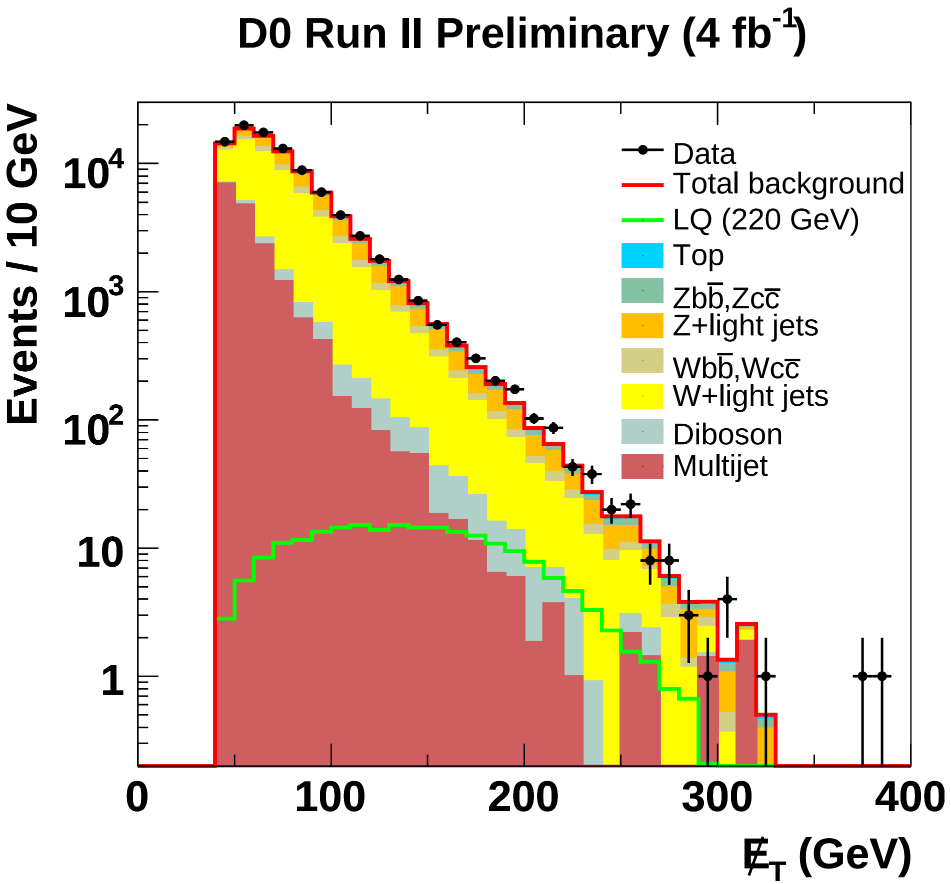
stop/sbottom
expected to be light

Search for Supersymmetry – Sbottom Quarks

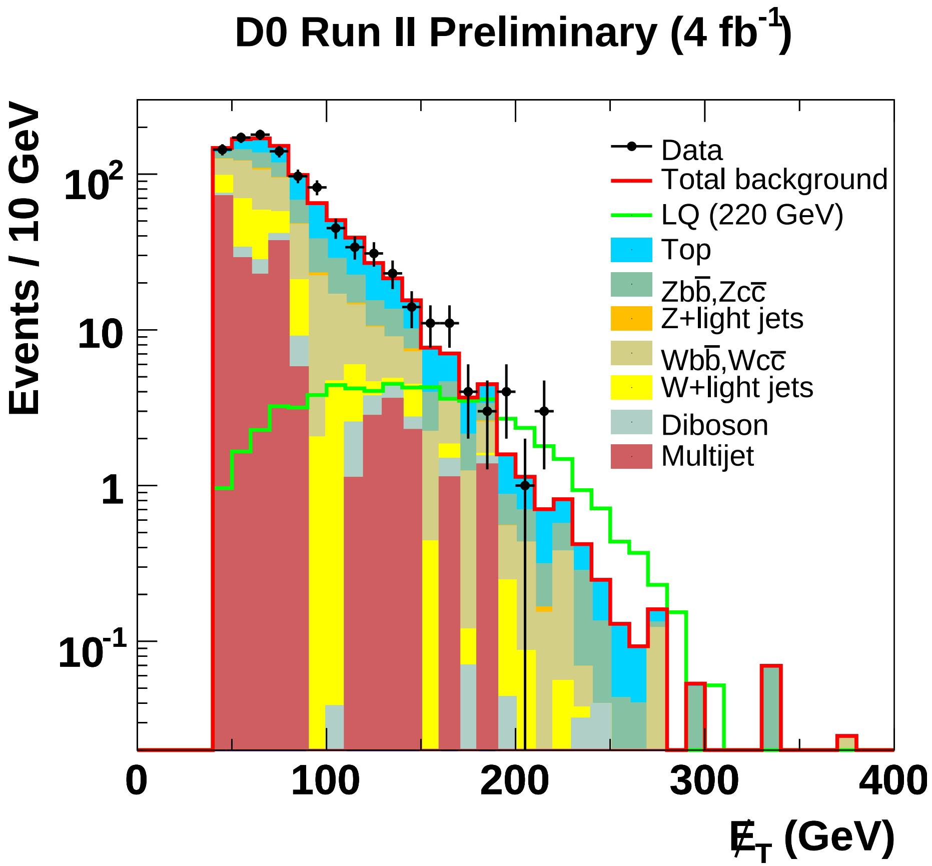


Decay: $\tilde{b} \rightarrow b + \tilde{\chi}_1^0$

$\rightarrow$ jets+$\not{E}_T$ analysis with b-tagging



before b-tagging



after b-tagging

Search for Supersymmetry – Sbottom Quarks

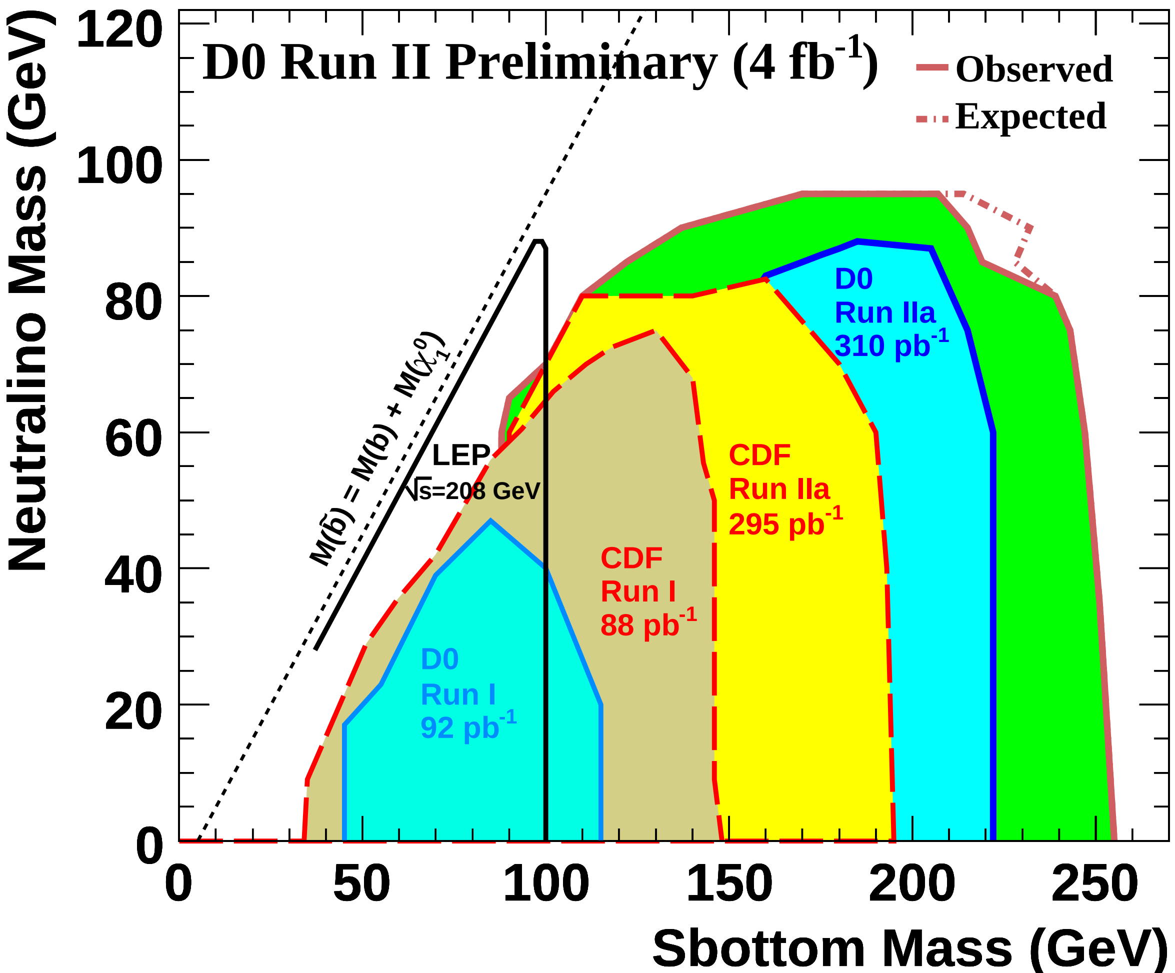
Visible energy in event depends on $\tilde{\mathrm{b}}$-$\tilde{\chi}_1^0$ mass difference Δm

Low Δm analysis: 483 events observed, 493$\pm$12 events expected

– No reach for $\tilde{\mathrm{b}}$-$\tilde{\chi}_1^0$ mass differences below 30 GeV (trigger)

High Δm analysis: 7 events observed, 7.1$\pm$0.4 events expected

– Probing sbottom masses up to 250 GeV



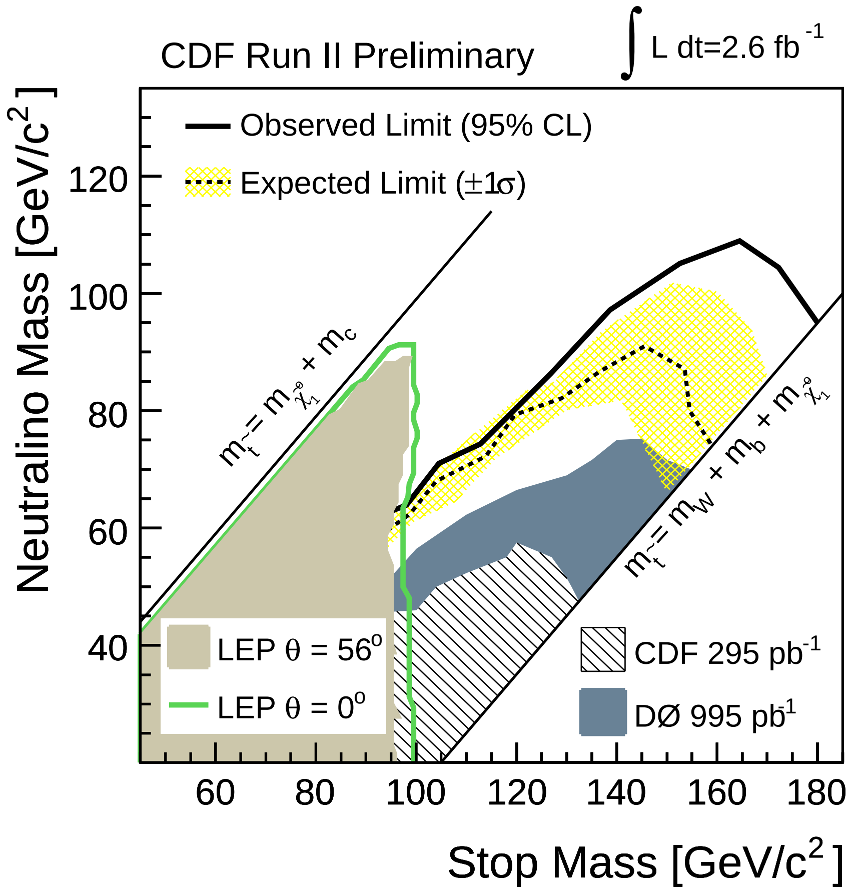
Search for Supersymmetry – Stop Quarks

For light stop, $\tilde{t} \to t + \tilde{\chi}_1^0$ not allowed

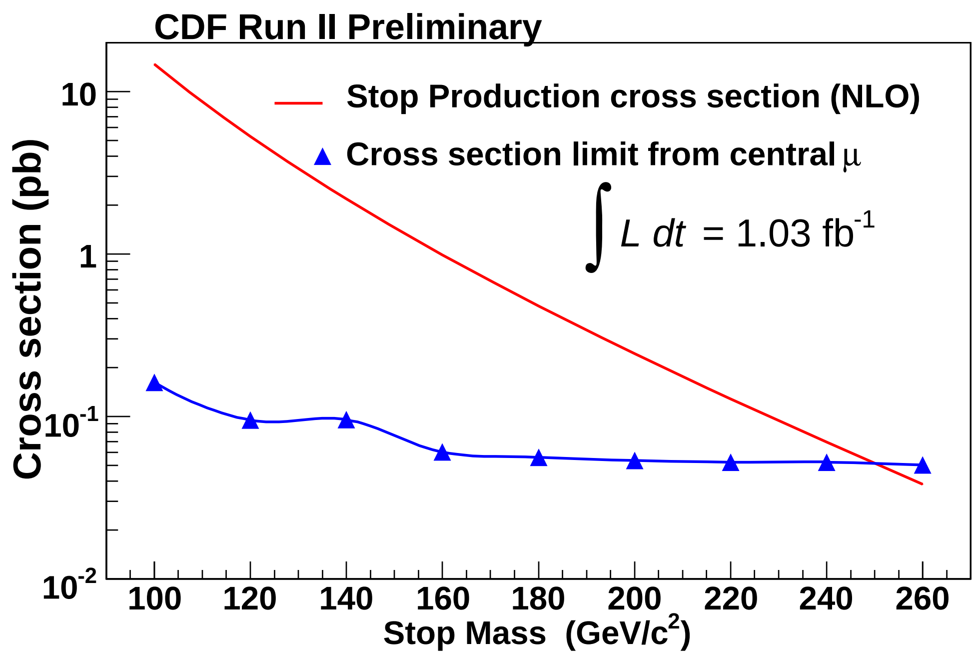
Dominant decay mode depends on other SUSY masses:

- **If stop is next-to-lightest SUSY particle: loop-induced decay $\tilde{t} \to c + \tilde{\chi}_1^0$**

Prompt decays: 2 c-jets + $\not{E}_T$



Long-lived Stop Quark



Search for Stop Quarks: $\tilde{t} \rightarrow b + \tilde{\chi}_1^{\pm}$

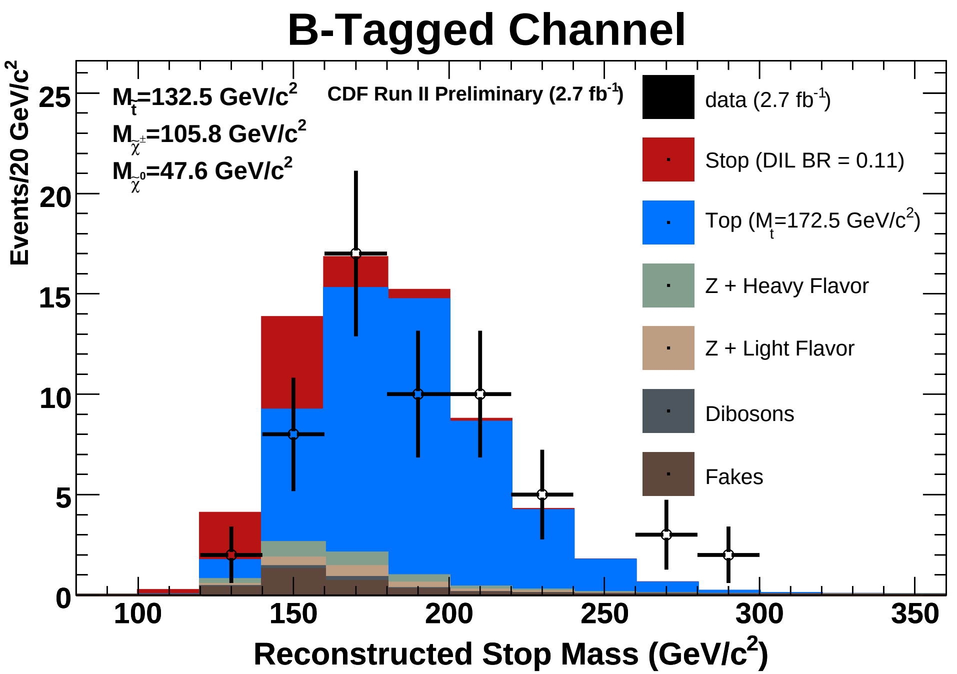
If Chargino light enough: $\tilde{t} \rightarrow b + \tilde{\chi}_1^{\pm}$

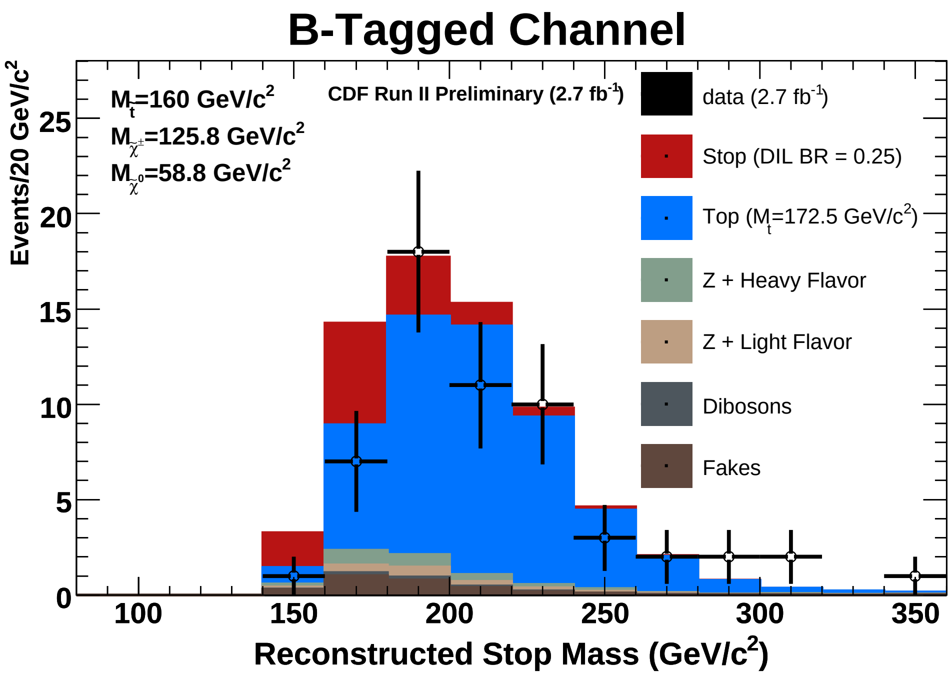
With $\tilde{\chi}_1^{\pm} \rightarrow \ell\nu\tilde{\chi}_1^0$, final state very similar to dileptonic top decays

$\rightarrow$ search top dilepton sample for hints of stop quarks

Reconstruct stop quark mass to distinguish from top:

- build a "heavy neutrino" from LSP+neutrino, then use neutrino weighting technique
- extract limits in 3d space of $m_{\tilde{t}}$, $m_{\tilde{\chi}_1^{\pm}}$, $m_{\tilde{\chi}_1^0}$





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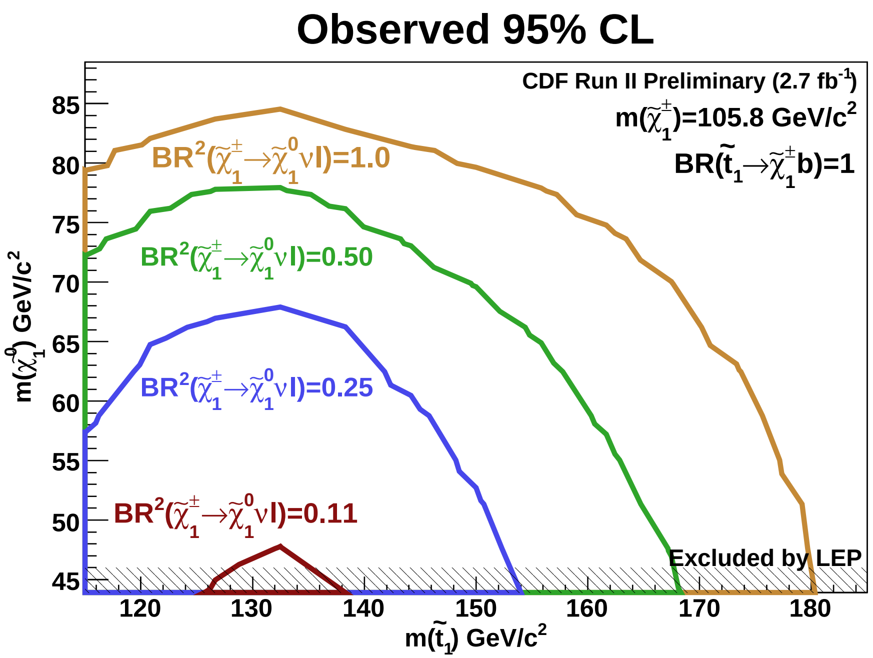
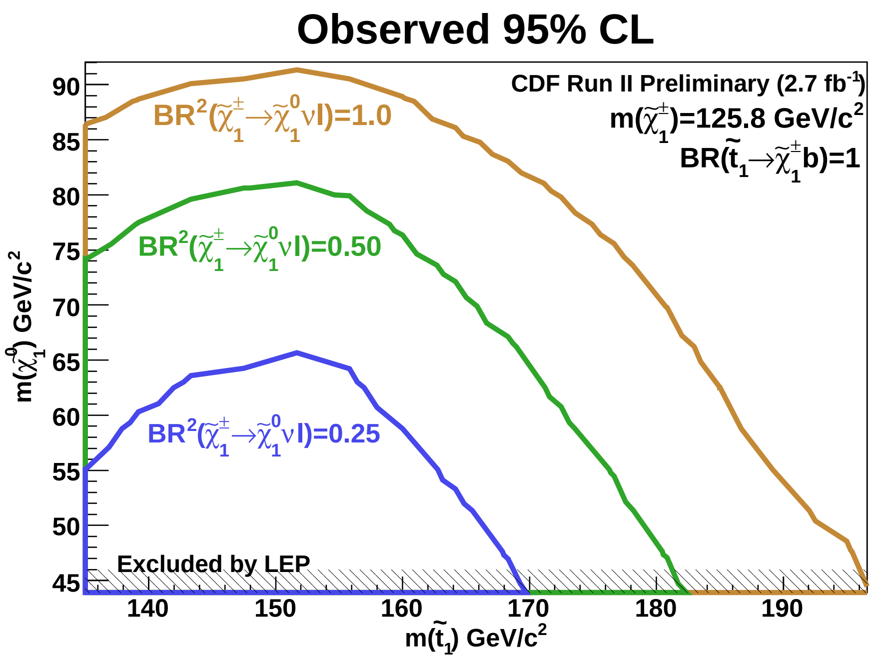




Search for Stop Quarks: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$

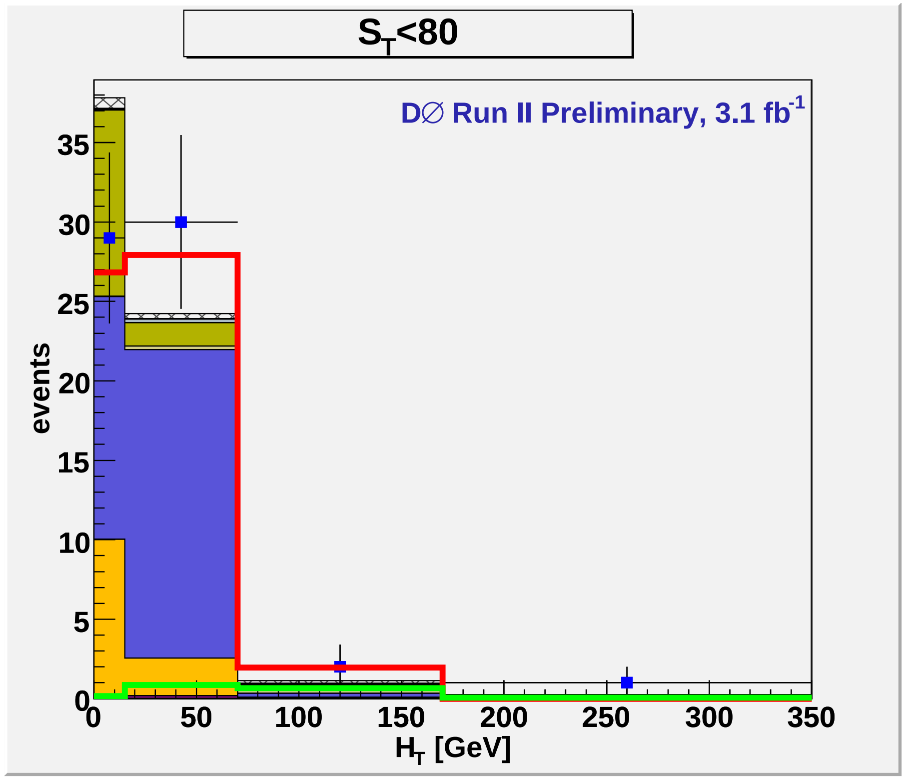
If Sneutrino light enough: $\tilde{t} \rightarrow b + \ell + \tilde{\nu}$ with $\tilde{\nu} \rightarrow \nu + \tilde{\chi}_1^0$

Most sensitive channel: 2b+e+μ+$\not{E}_T$

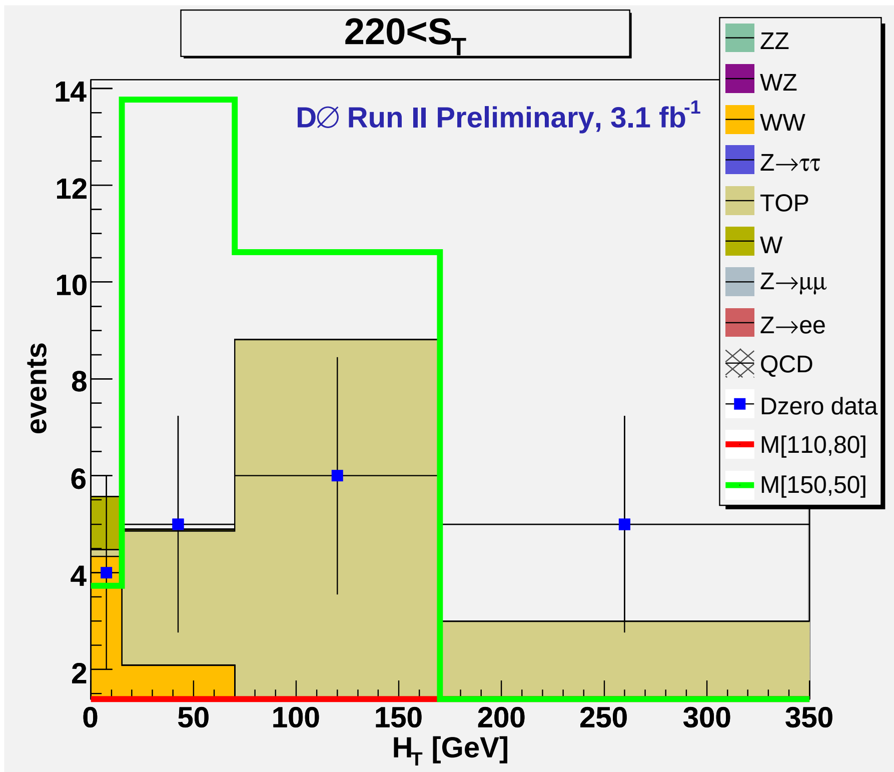
Mass difference between stop and sneutrino determines transverse energy in event

$\rightarrow$ **analysis split into several transverse energy bins**

Low energy
Background: Z$\rightarrow$ $\tau\tau$ $\rightarrow$eμ+$\not{E}_T$



High energy
Background: $t\bar{t}$ $\rightarrow$2b+eμ+$\not{E}_T$



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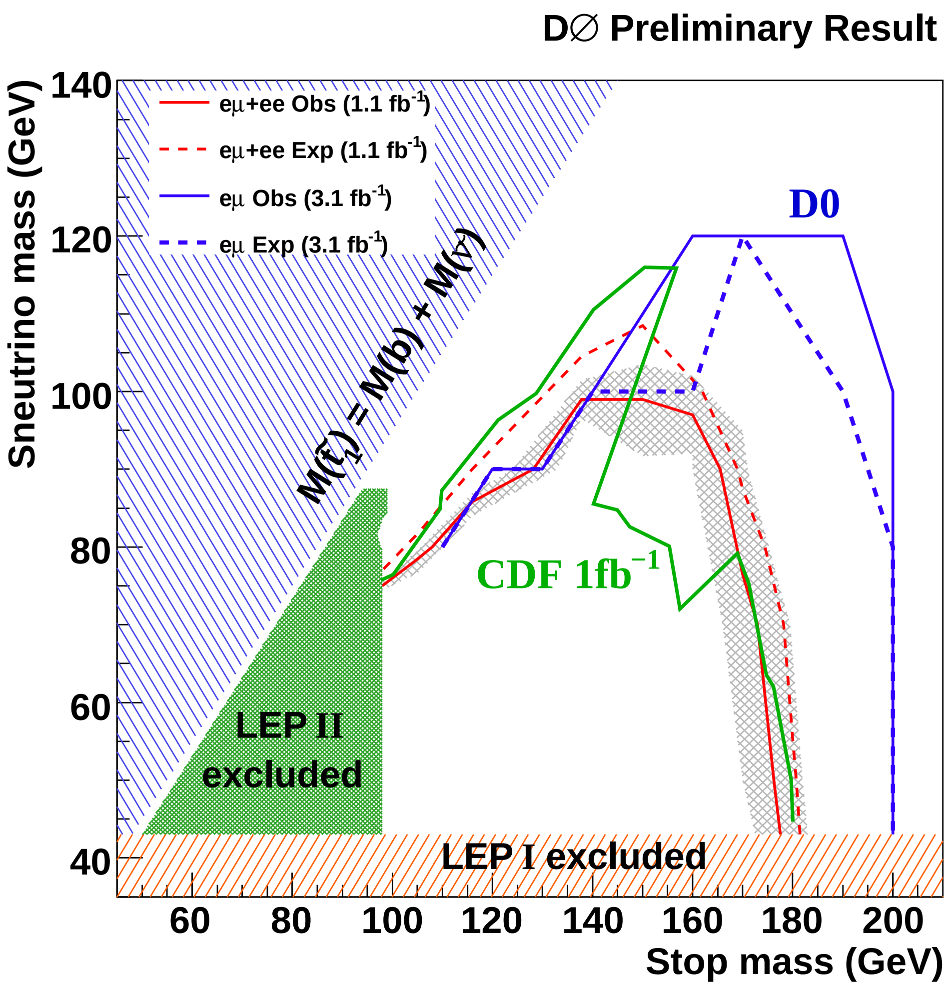
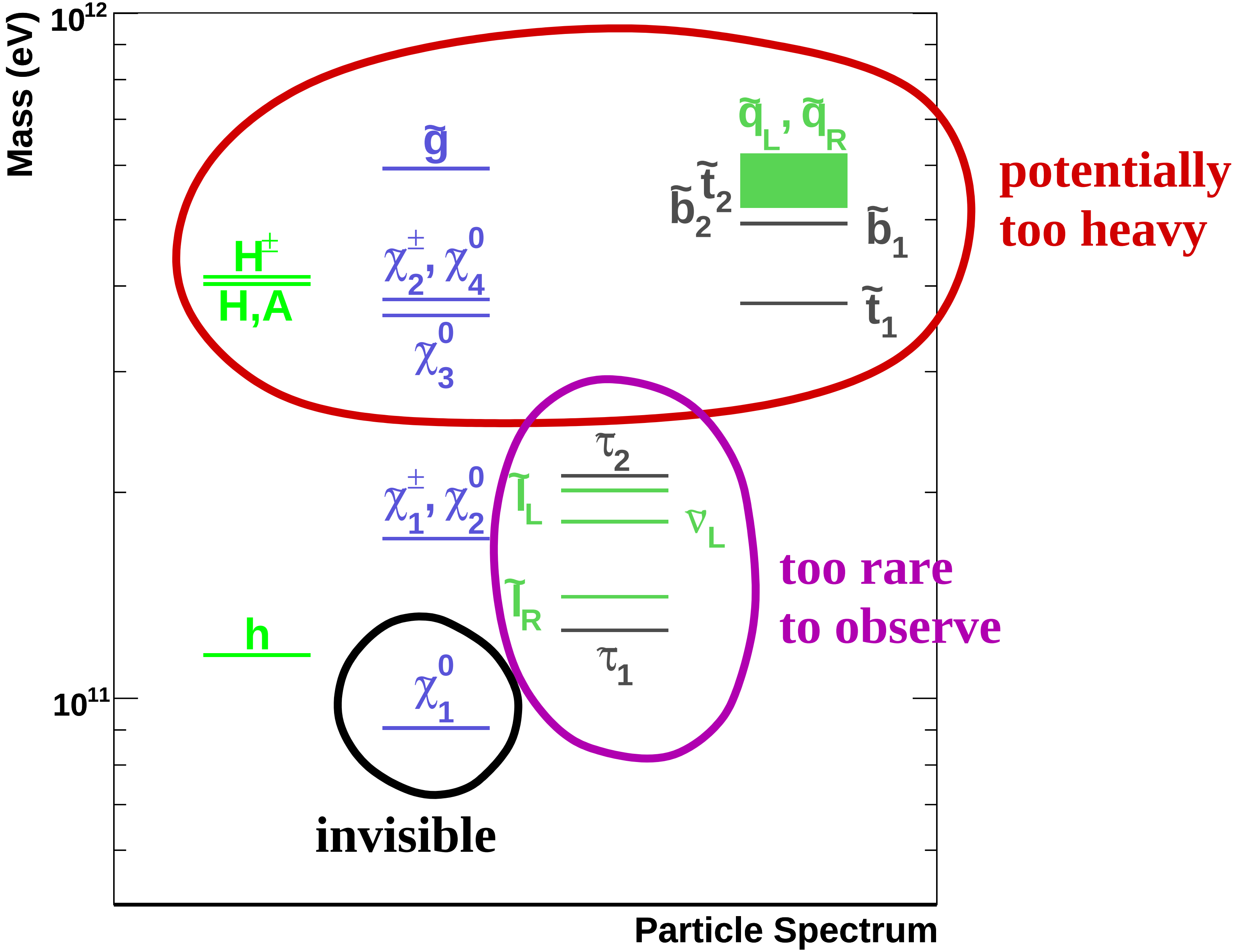


What other SUSY particles to look for?



Search for Charginos and Neutralinos

arXiv.org:0901.0646

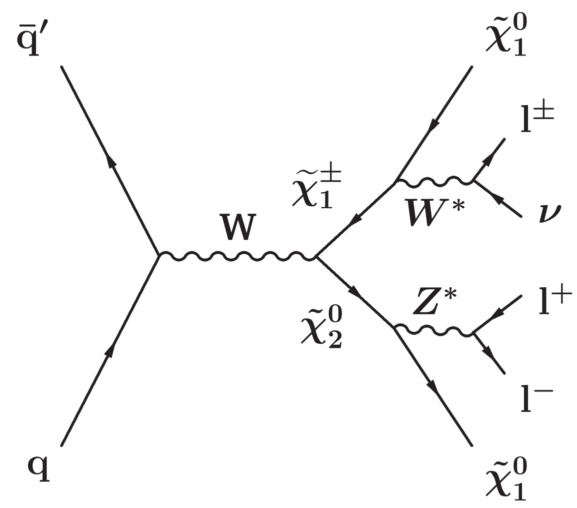
Golden channel: $\tilde{\chi}^{\pm}\tilde{\chi}_2^0 \rightarrow 3\ell + \not{E}_T$

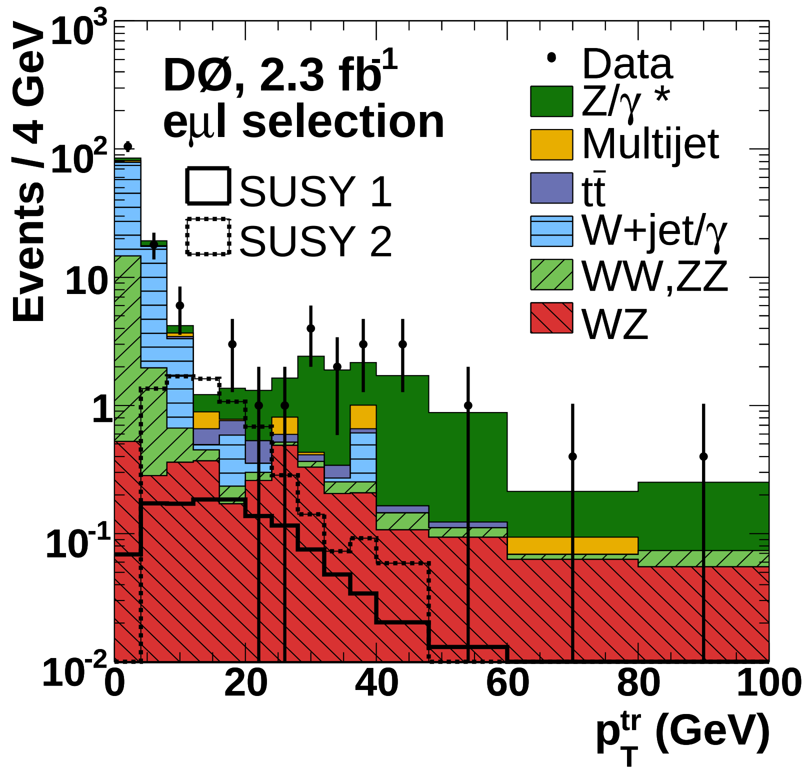
Challenges:

- production cross section (electroweak) relatively small
- low-p_T leptons

Large number of trilepton and dilepton plus track analyses from CDF and DØ

- pt cuts as low as 3 GeV



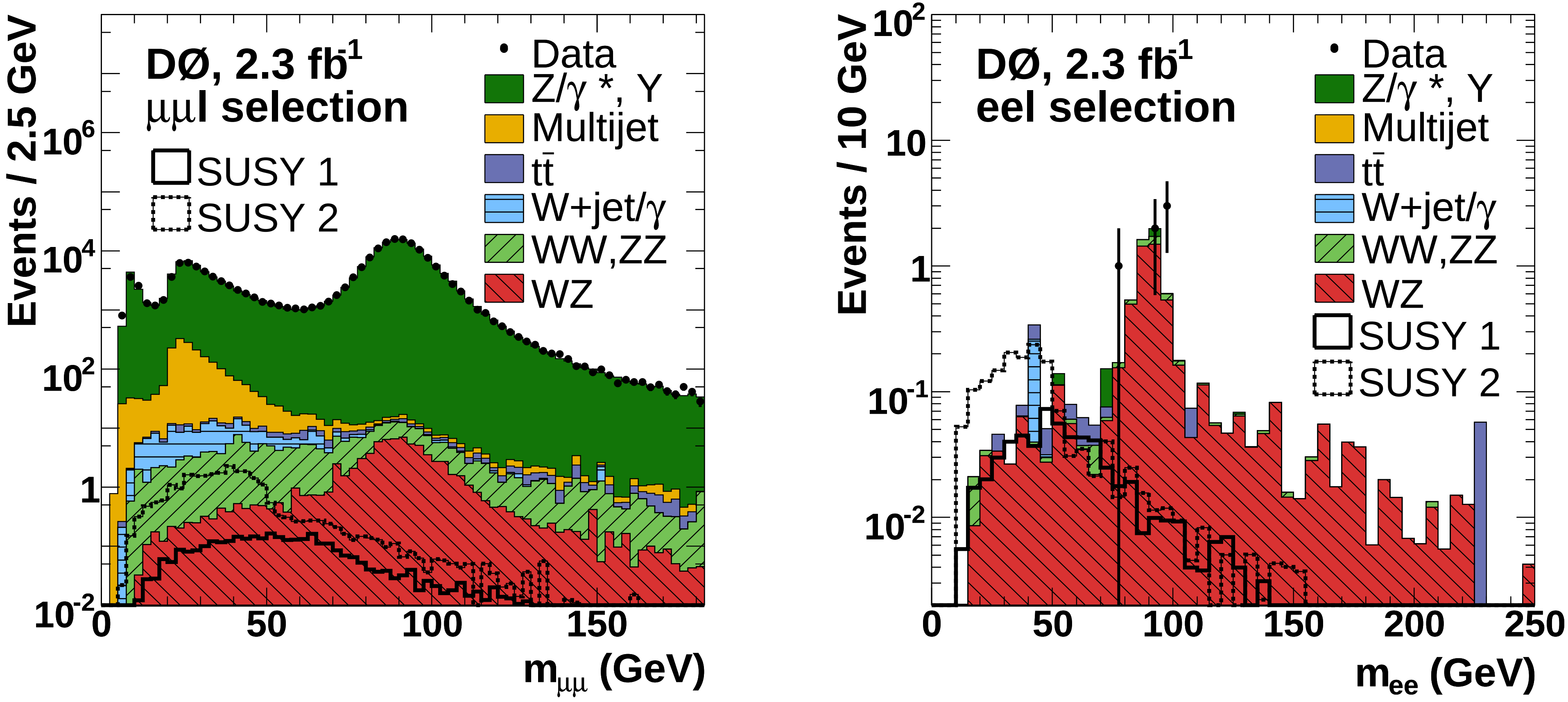


Search for Charginos and Neutralinos

arXiv.org:0901.0646

requiring 2 leptons

requiring 3 leptons

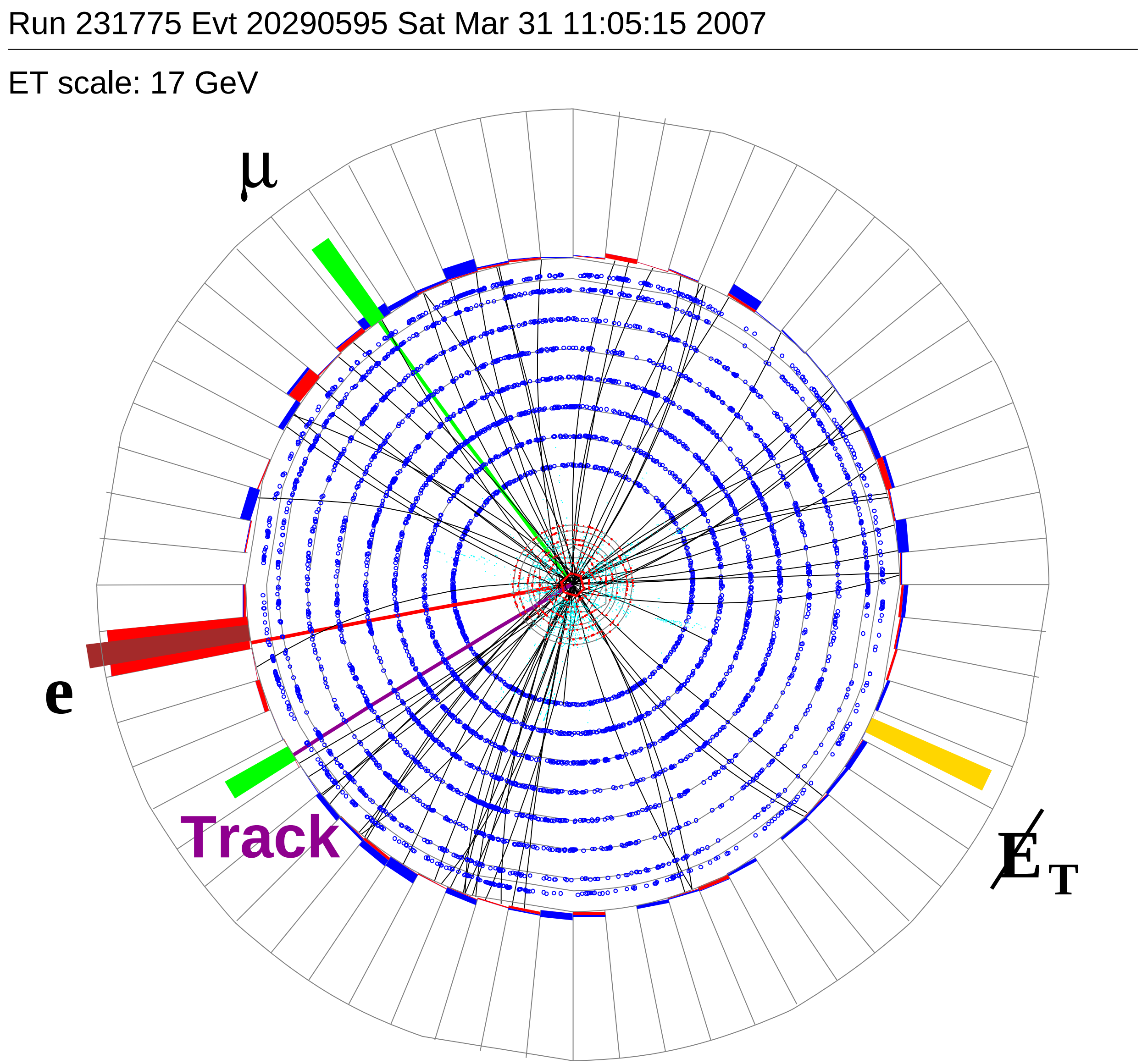


Observed number of events is consistent with expected background

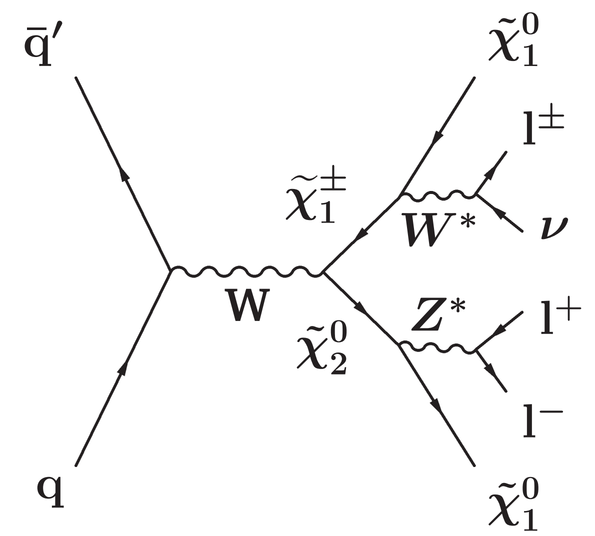
→ No evidence for chargino/neutralino production

Candidate Event

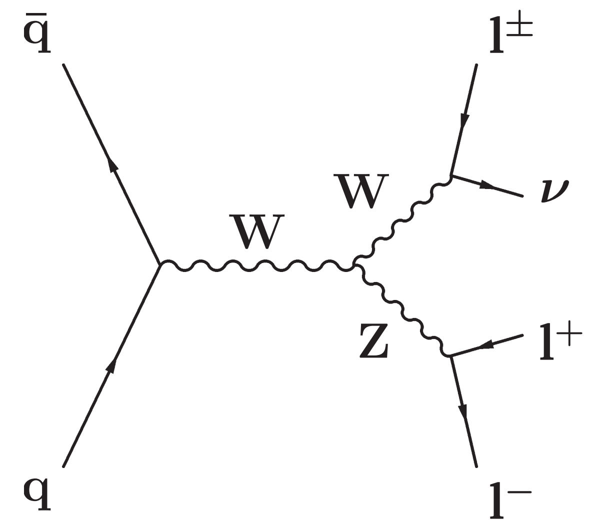
arXiv.org:0901.0646



SUSY: WZ + 2 LSP

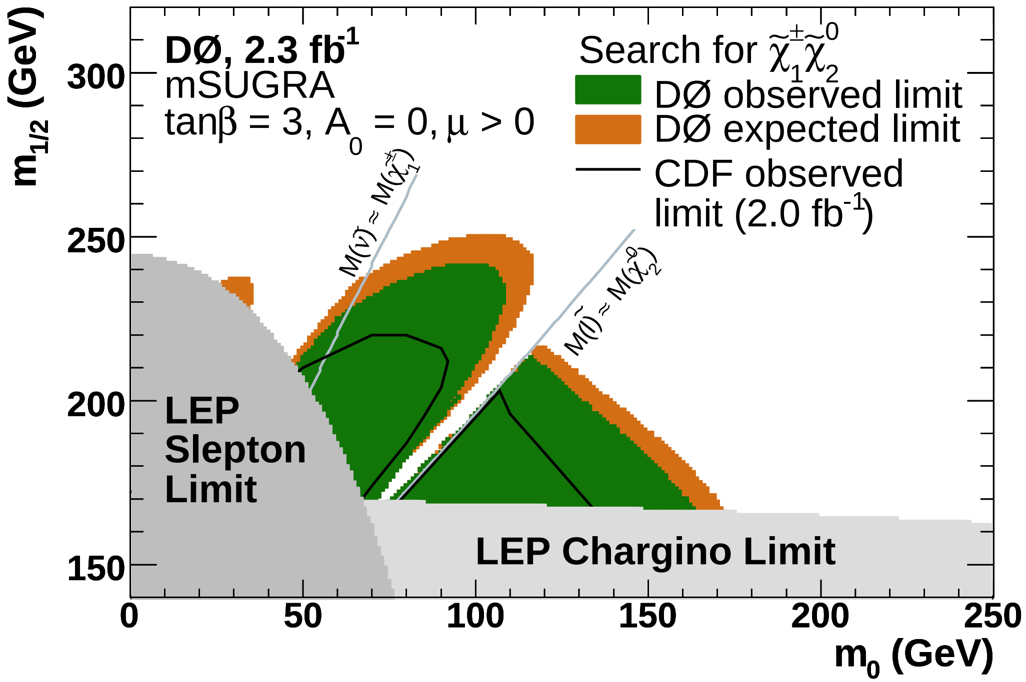


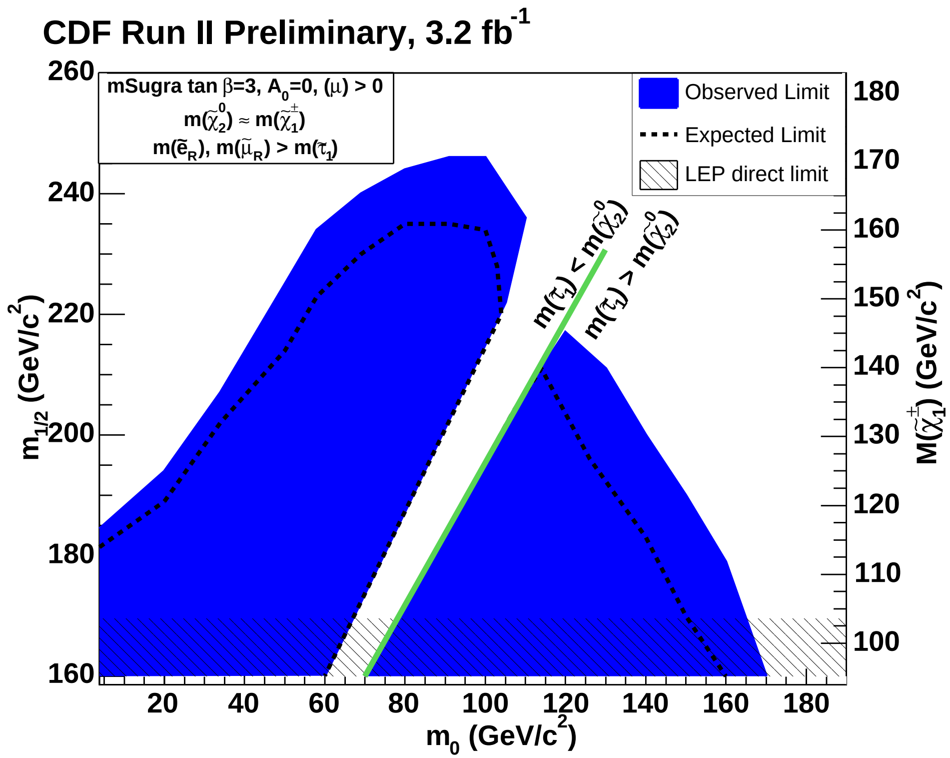
Standard Model: WZ



Search for Charginos and Neutralinos: Results

arXiv.org:0901.0646

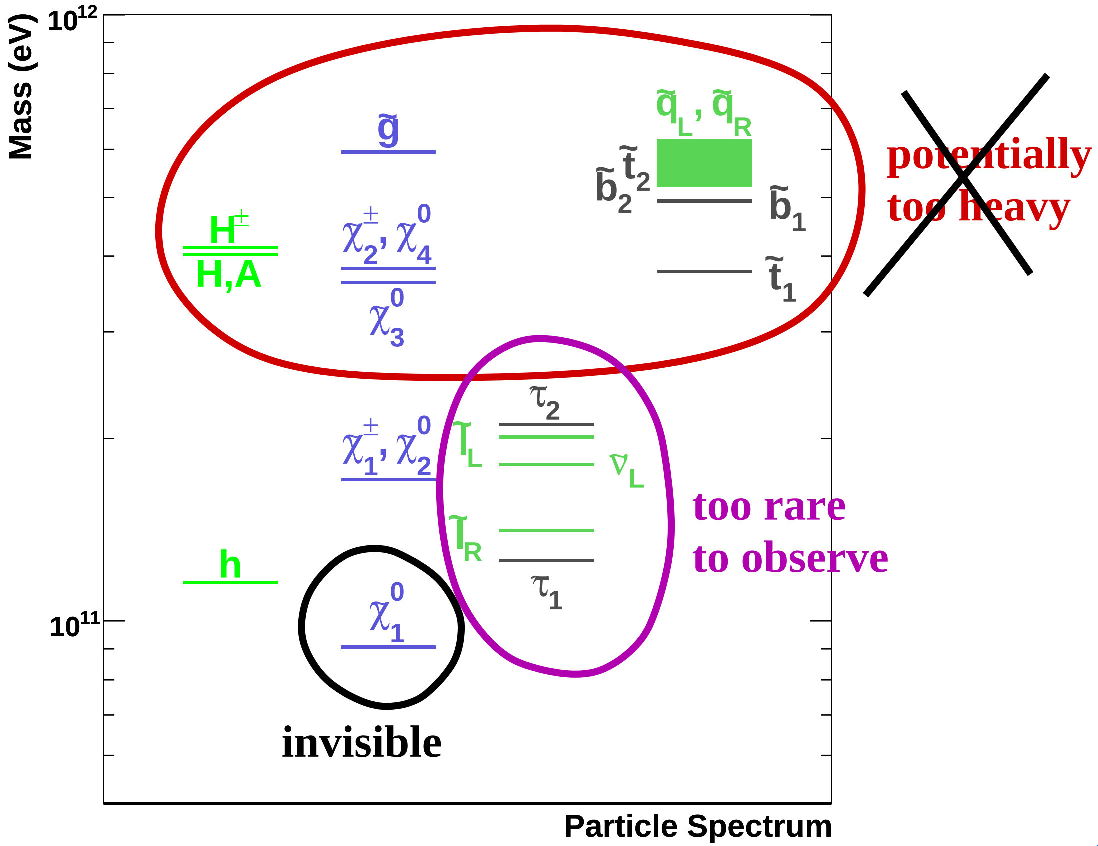




– **Analyses probing chargino masses up to 176 GeV**

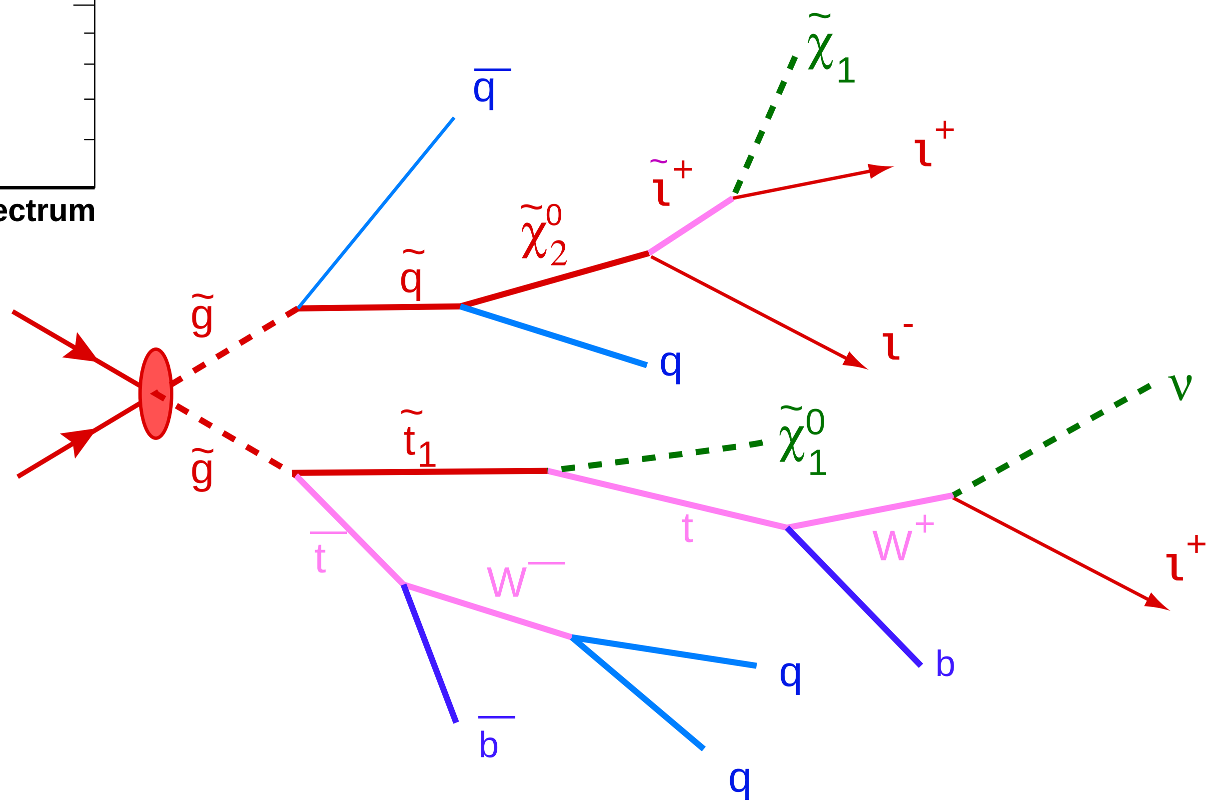
– **Reach degrades with increasing tanβ**

Search for Supersymmetry at the LHC



All particles accessible

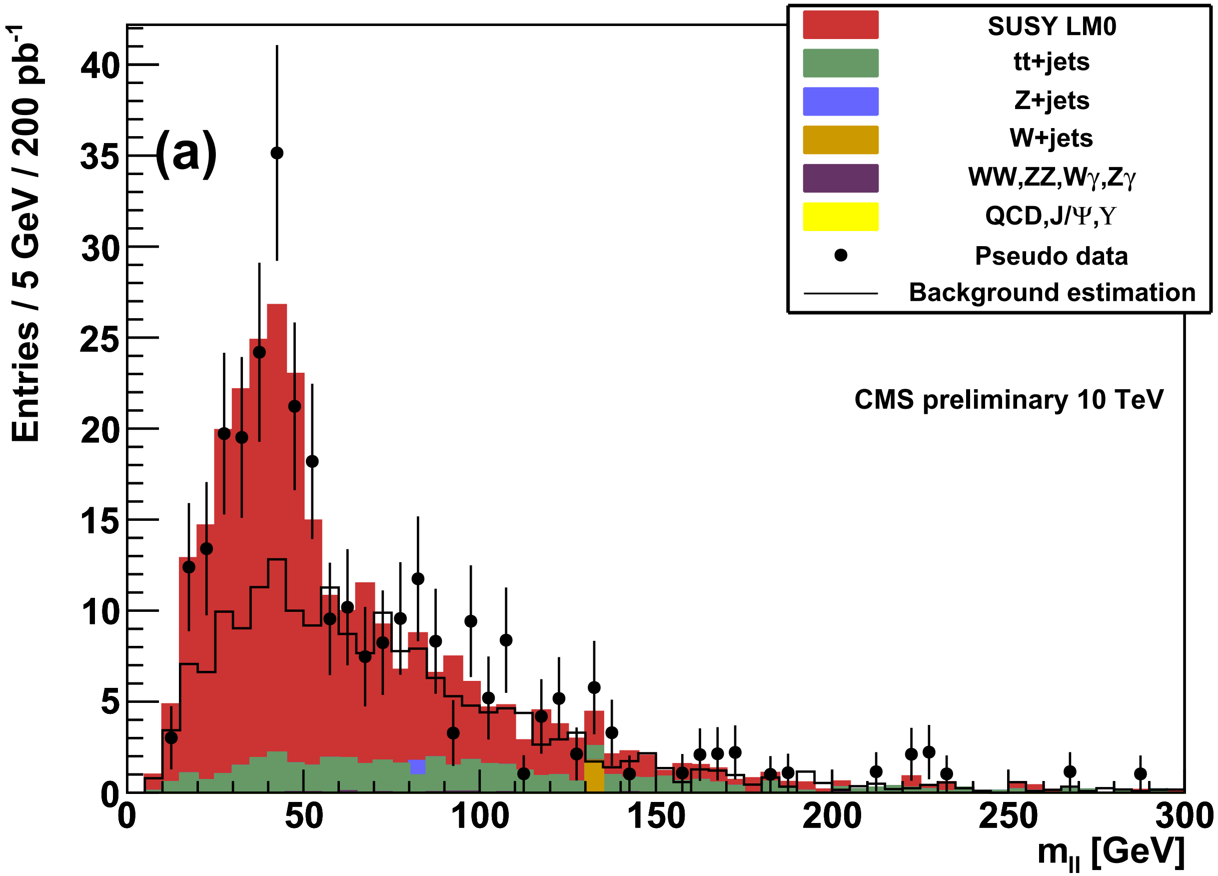
- strong production will dominate
- potentially long decay cascades



Search for Supersymmetry at the LHC

CMS: updated study of jets+2l+$\not{E}_T$ analysis ($\sqrt{s}$=10 TeV, $\int Ldt$=200 pb^{-1})

- excellent discovery potential for "light" SUSY
- for $\tilde{\chi}_2^0 \rightarrow \ell\ell\tilde{\chi}_1^0$ in cascade decays: $m_{\ell\ell} \leq m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$
- observation of signal would allow fit of dilepton endpoint with 4% accuracy



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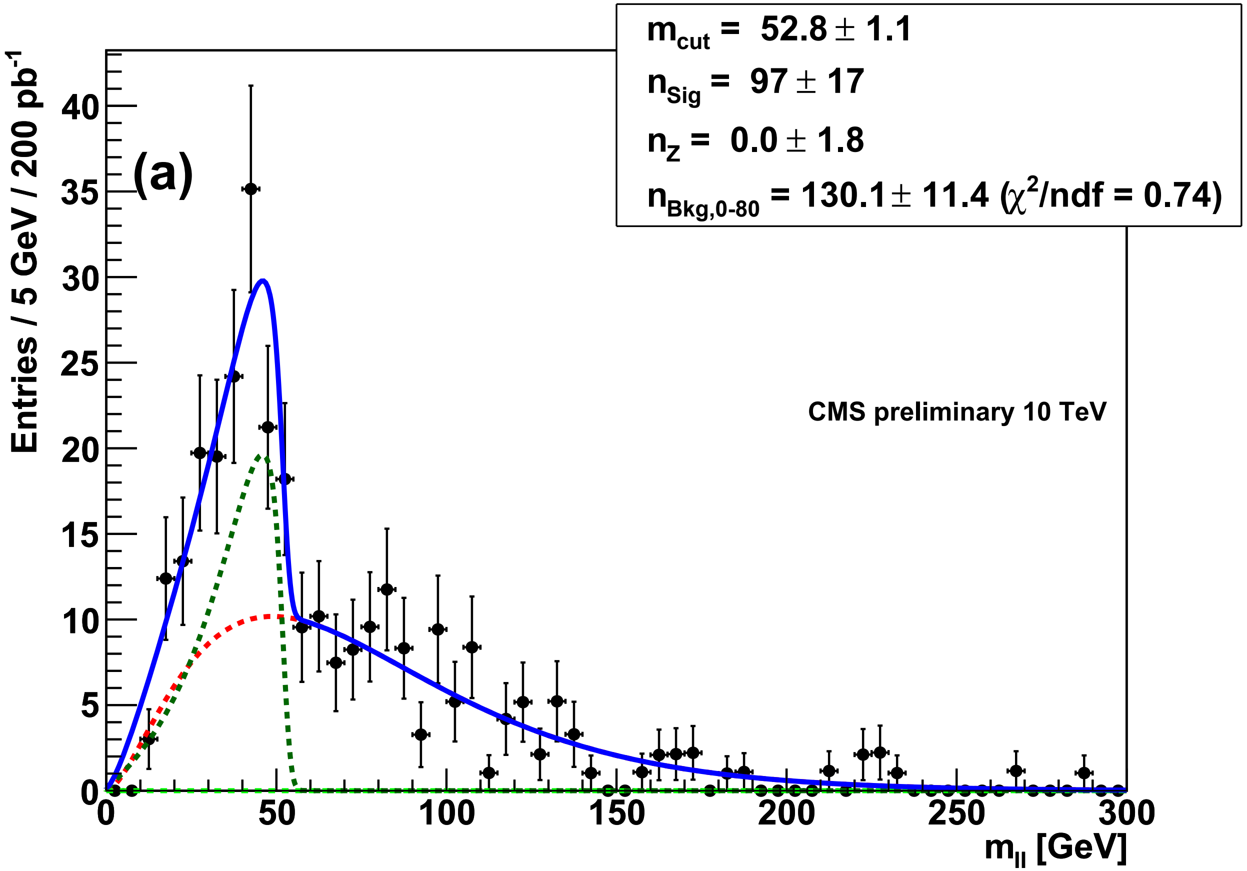
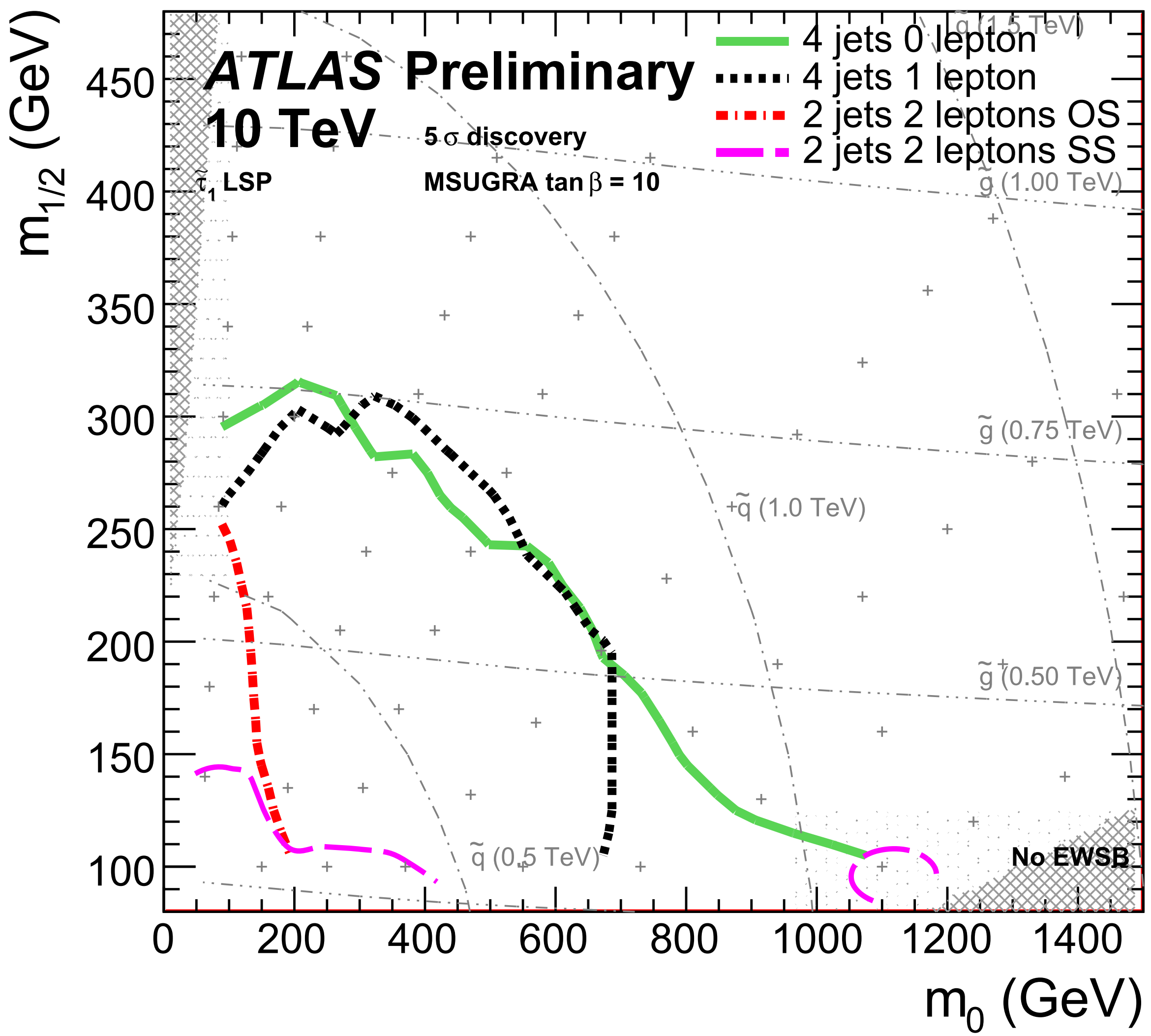


Search for Supersymmetry at the LHC

ATLAS: updated study of all inclusive search channels ($\sqrt{s}$=10 TeV, $\int Ldt$=200 pb^{-1})

– **excellent discovery potential for "light" SUSY**



New High-Mass States

Most models predict high-mass states X that fit 2 generic classes:

- resonant production of X$\rightarrow f\bar{f}, \gamma\gamma, VV$ (e.g. W',Z',RS-Gravitons etc.)
- X pair production (e.g. Leptoquarks, b', t' etc.)

Mass reach ultimately limited by parton luminosities: $\lesssim$ 1 TeV for X, $\lesssim$ 500 GeV for XX

	Sequential V'								RS-G. k/M_{Pl}=0.1		
X$\rightarrow$	eν	ee	$\mu\mu$	eμ	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

	Leptoquarks β=1					Sequential f'		Excited f*	
X$\rightarrow$	eq	μq	bτ	qν	bν	b'$\rightarrow$tW	t'$\rightarrow$qW	eγ	$\mu\gamma$
Limit (GeV)	256	316	210	205	252	325	311	796	853

* reviewers extrapolation

New High-Mass States: b'b'→2b+4W

X→	Sequential V'								RS-G. $k/M_{Pl}=0.1$		
	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

X→	Leptoquarks $\beta=1$					Sequential f'		Excited f*	
	eq	μq	bτ	qν	bν	b'→tW	t'→qW	eγ	$\mu\gamma$
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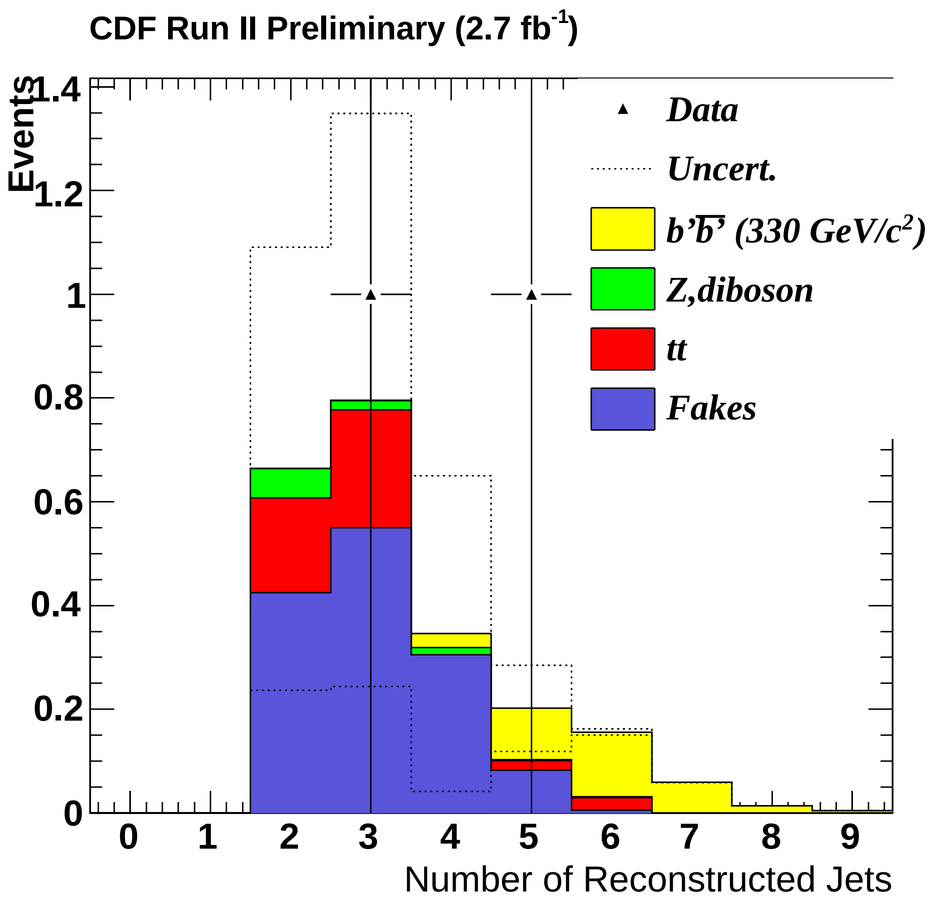

New High-Mass States: $X \to WV \to e\nu + 2j$

$X \to$	Sequential V'								RS-G. $k/M_{Pl}=0.1$		
	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

$X \to$	Leptoquarks $\beta=1$					Sequential f'		Excited f*	
	eq	μq	bτ	qν	bν	$b' \to tW$	$t' \to qW$	$e\gamma$	$\mu\gamma$
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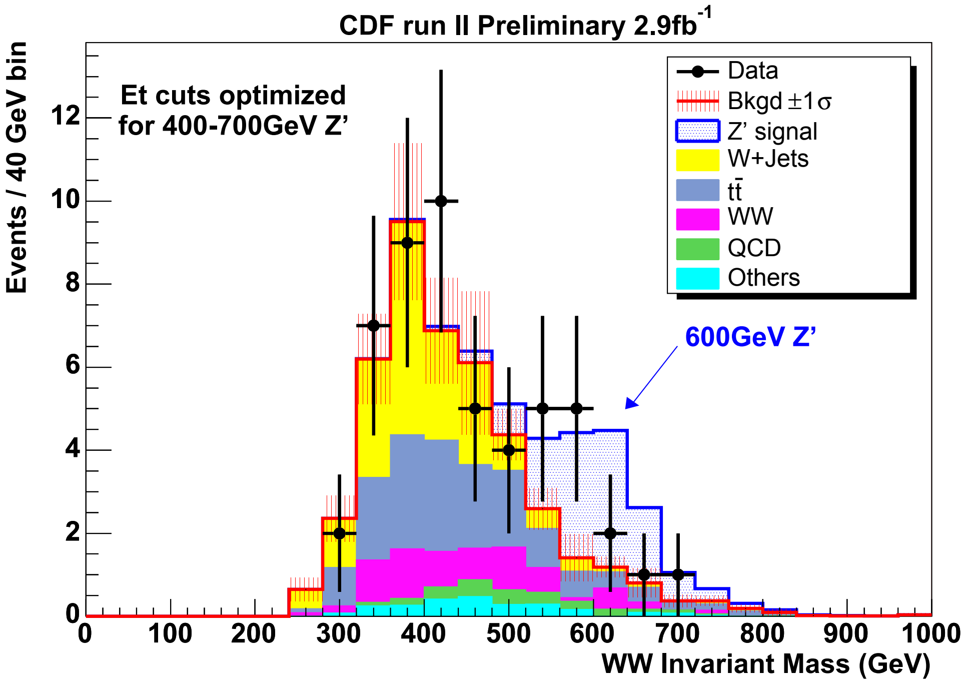

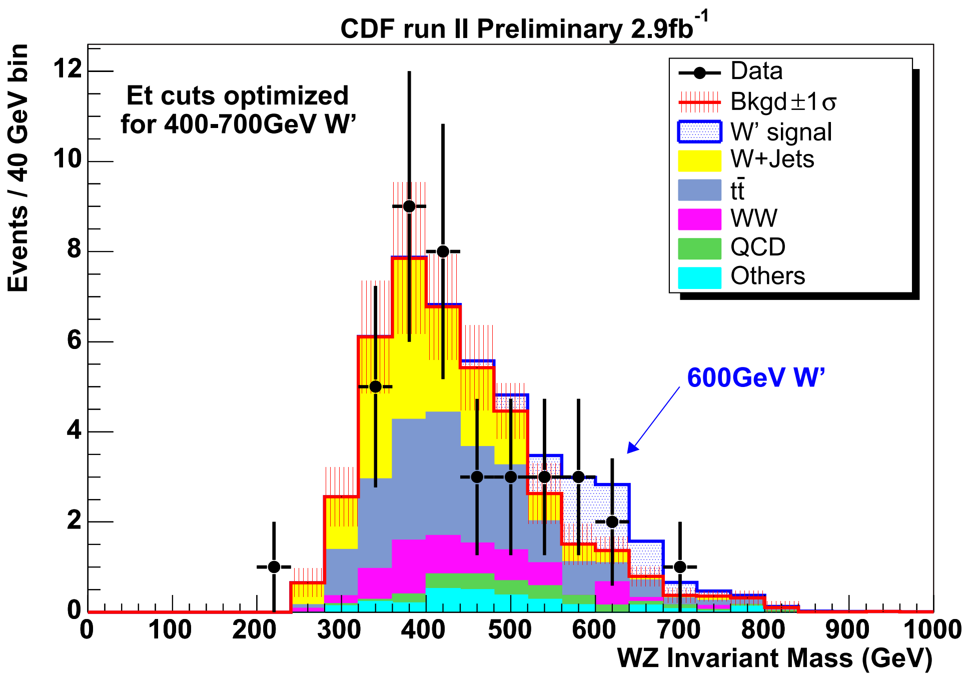

New High-Mass States: $X \to ZZ \to 4\ell$ or $2\ell + 2j$

	Sequential V'								RS-G. $k/M_{Pl}=0.1$		
$X\to$	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

	Leptoquarks $\beta=1$					Sequential f'		Excited f*	
$X\to$	eq	μq	bτ	qν	bν	$b'\to tW$	$t'\to qW$	eγ	$\mu\gamma$
Limit (GeV)	256	316	210	205	252	325	311	796	853

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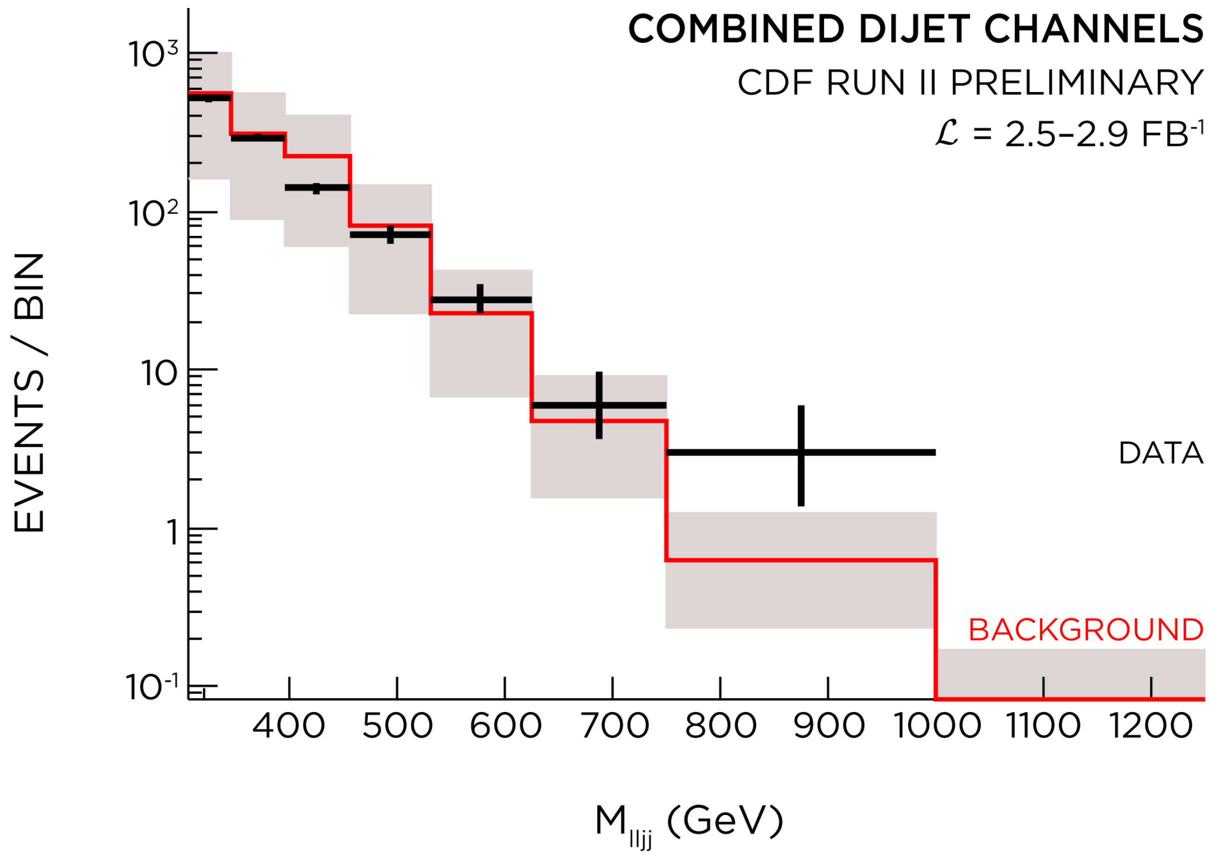

New High-Mass States: X⟶ee

	Sequential V’								RS-G. $k/M_{Pl}=0.1$		
X⟶	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

	Leptoquarks $\beta=1$					Sequential f’		Excited f*	
X⟶	eq	μq	bτ	qν	bν	b’⟶tW	t’⟶qW	eγ	$\mu\gamma$
Limit (GeV)	256	316	210	205	252	325	311	796	853

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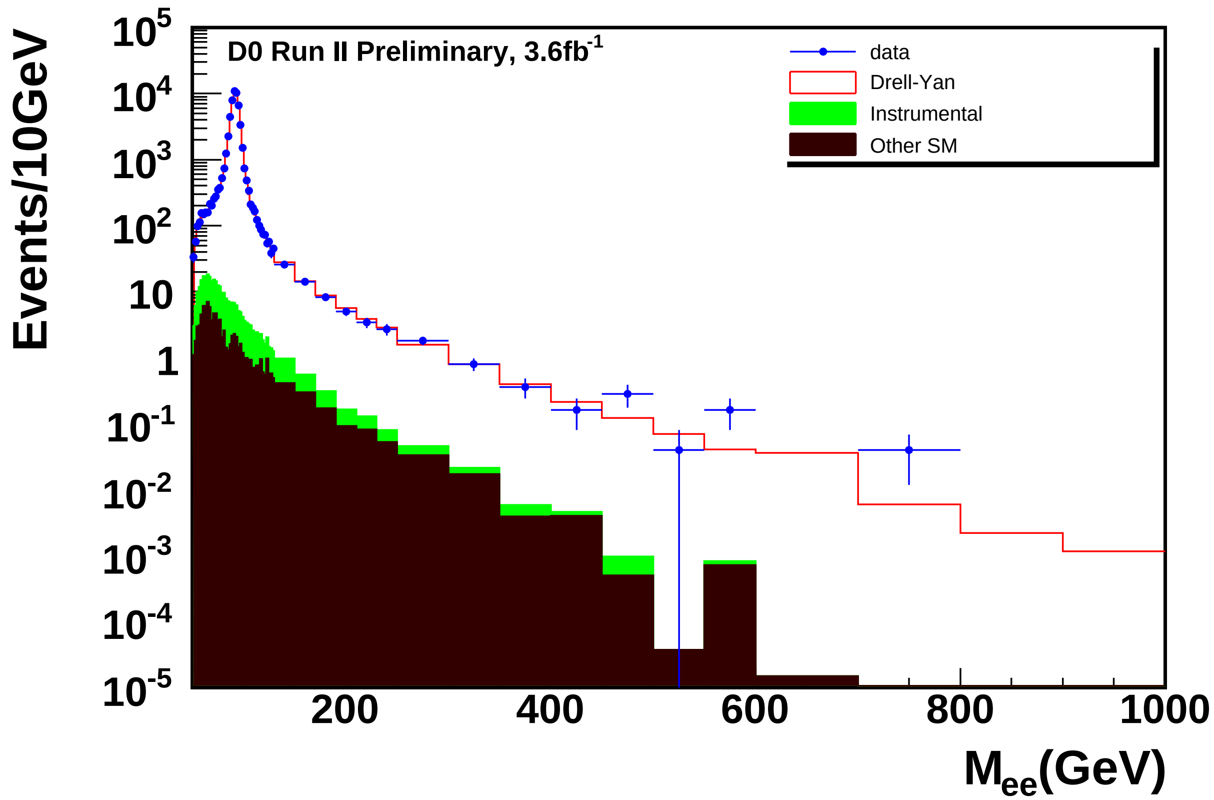

New High-Mass States: X$\longrightarrow \mu\mu$

	Sequential V'								RS-G. $k/M_{Pl}=0.1$		
X$\longrightarrow$	eν	ee	$\mu\mu$	eμ	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

	Leptoquarks $\beta=1$					Sequential f'		Excited f*	
X$\longrightarrow$	eq	μq	bτ	qν	bν	b'$\longrightarrow$tW	t'$\longrightarrow$qW	eγ	$\mu\gamma$
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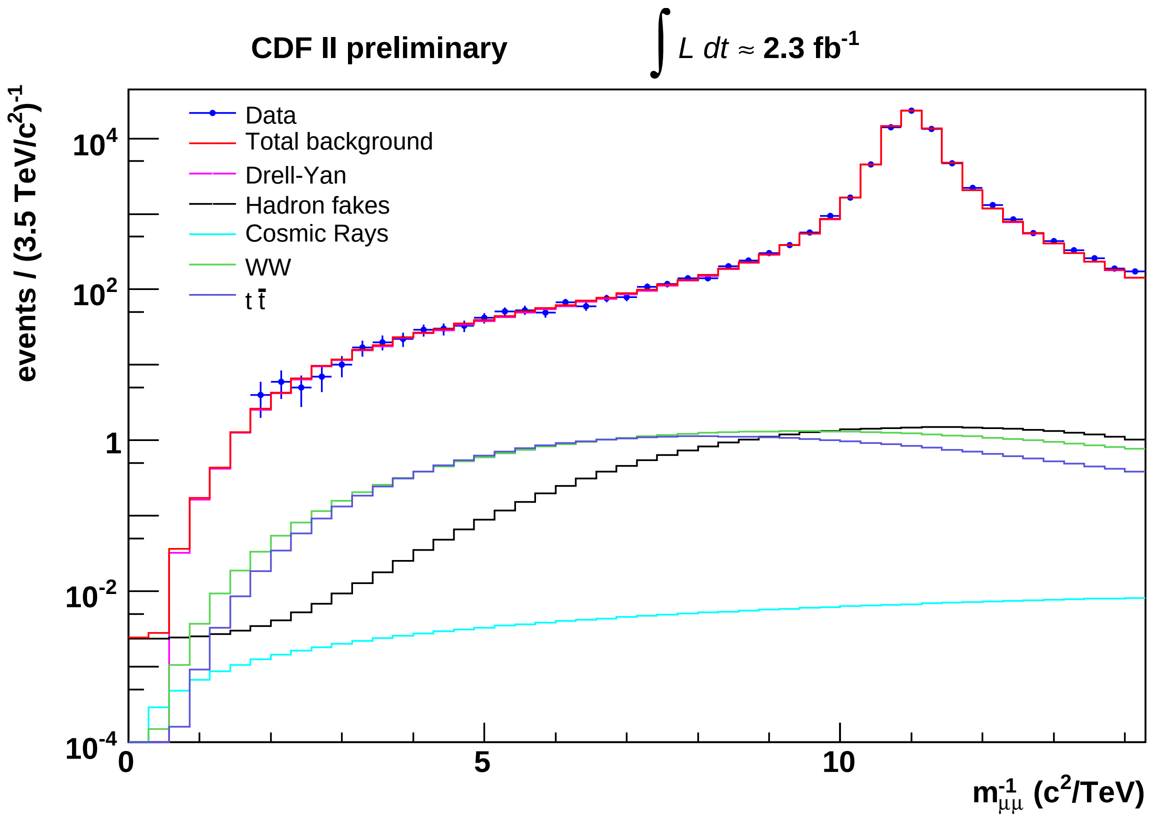

New High-Mass States: X→qq

PRD 79, 112002 (2009)

X→	Sequential V'								RS-G. $k/M_{Pl}=0.1$		
	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
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X→	Leptoquarks $\beta=1$					Sequential f'		Excited f*	
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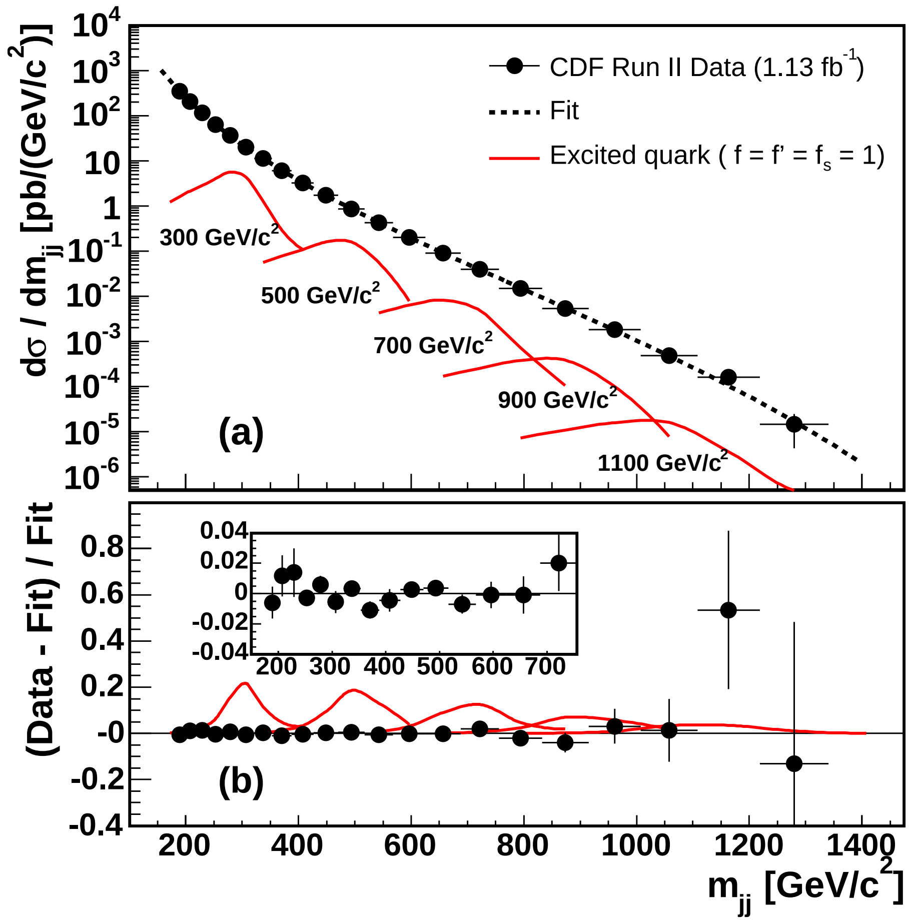

New High-Mass States: X$\to t\bar{t}$

	Sequential V'								RS-G. k/M_{Pl}=0.1		
X$\to$	$e\nu$	ee	$\mu\mu$	$e\mu$	$\tau\tau$	qq	$t\bar{t}$	tb	$\gamma\gamma$	WW/WZ	ZZ
Limit (GeV)	1000	966	1030	910*	399	840	820	800	900	606	490

	Leptoquarks β=1					Sequential f'		Excited f*	
X$\to$	eq	μq	bτ	qν	bν	b'$\to$tW	t'$\to$qW	eγ	$\mu\gamma$
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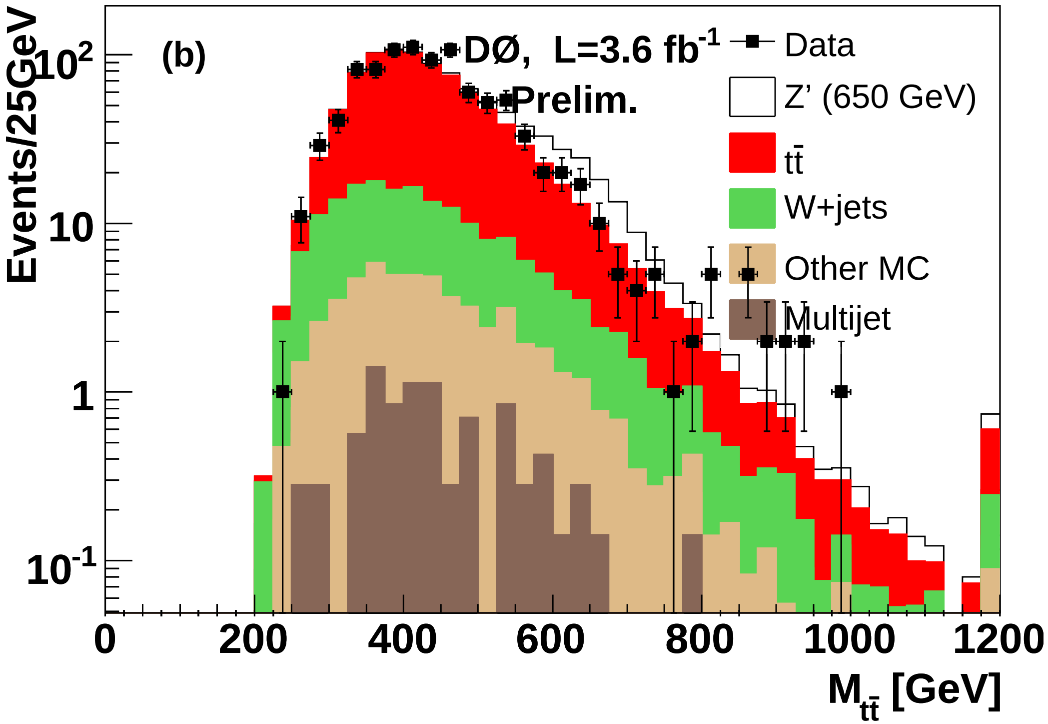
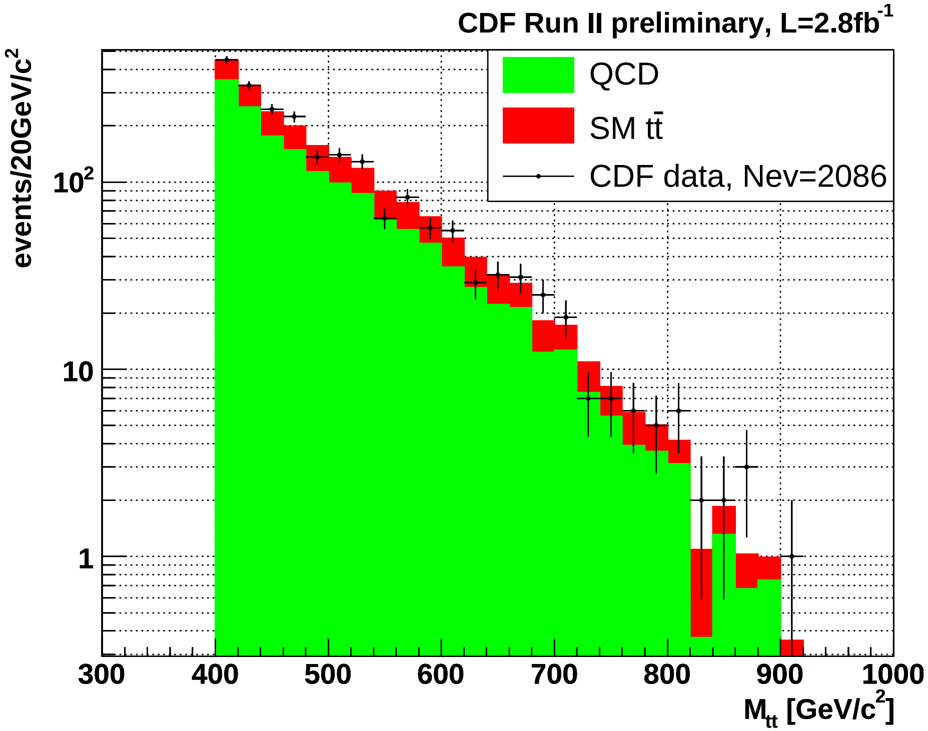


lepton+jets channel



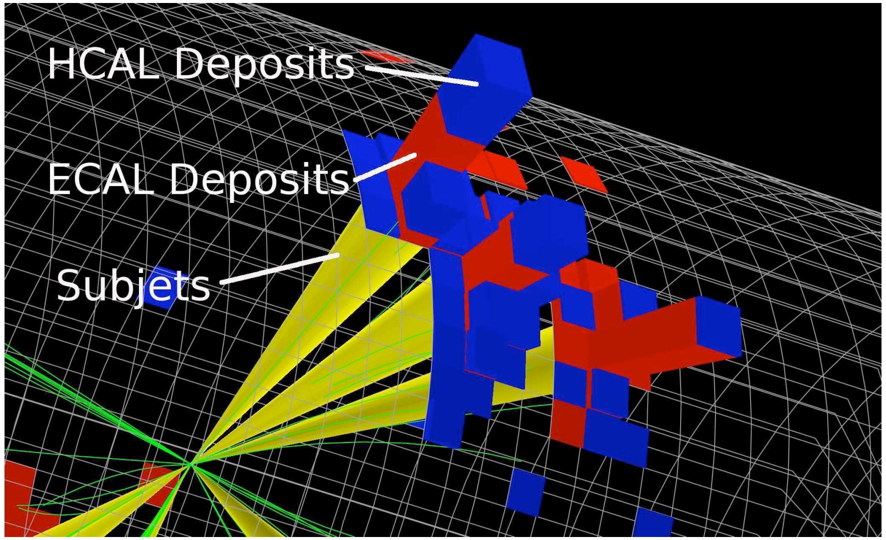
all-hadronic channel

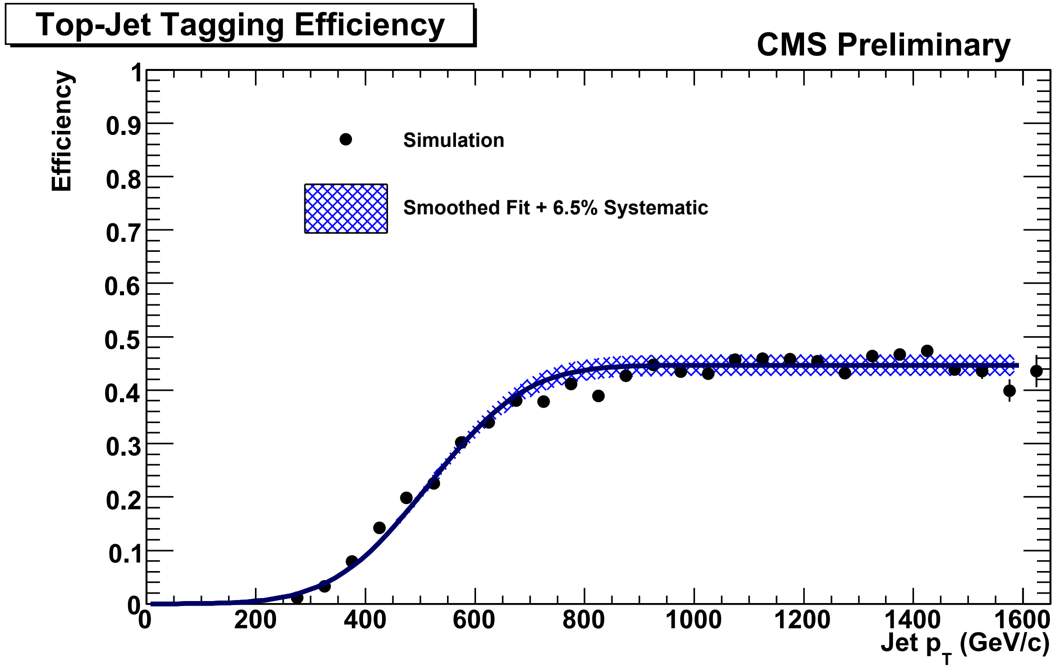
New High-Mass States at the LHC

Searches in all channels will be repeated at the LHC with much higher mass reach

Interesting experimental detail: top mass small compared to 7 TeV

→ top decay products in single jet → t-tagging!





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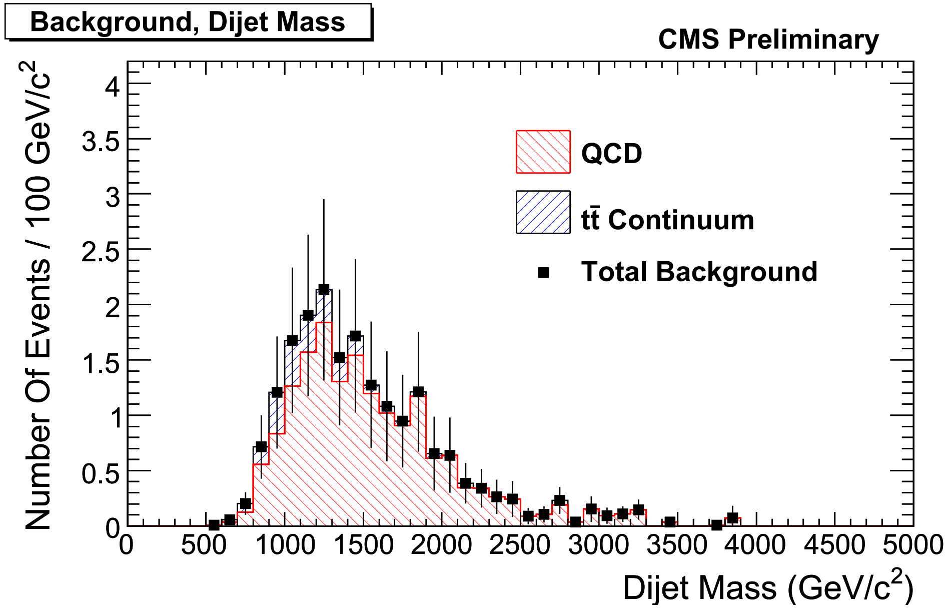
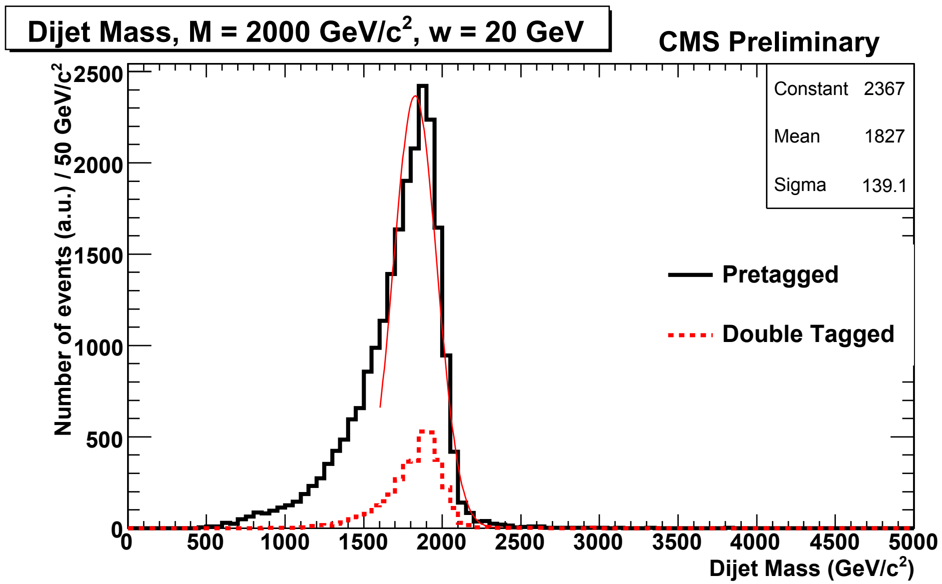


Background



Z' Signal

Going beyond 1 TeV at the Tevatron

arXiv.org:0906.4819

Dijet production has large cross section

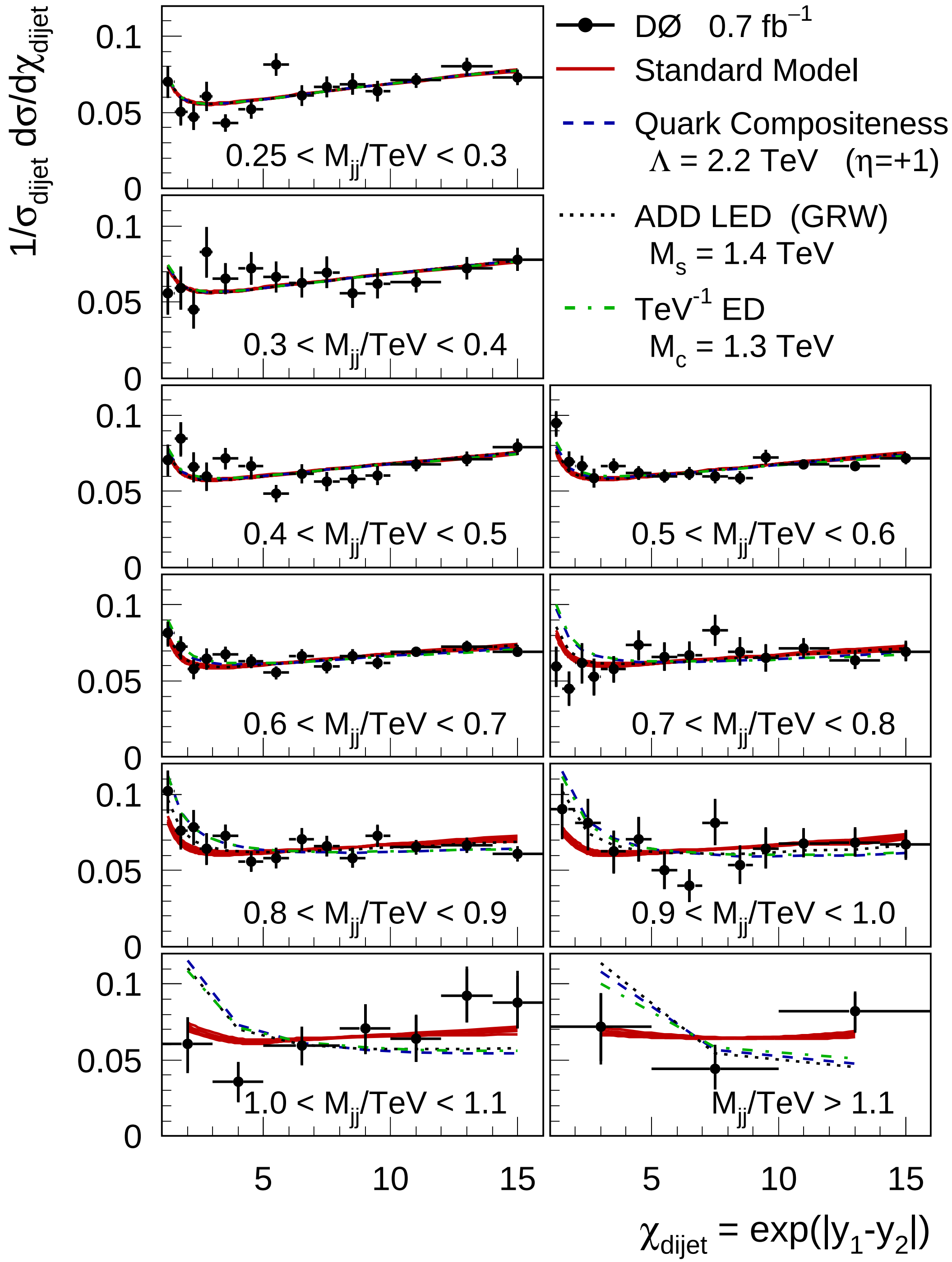
$\longrightarrow$ **can probe for deviations at very high energy scales**

Observable: $\chi_{dijet} = \exp(|y_1 - y_2|)$

- **roughly flat in QCD**
- **new physics detectable as deformation at high dijet mass**

Models tested:

- **composite quarks:** $\Lambda_C > 2.9$ **TeV**
- **Large extra dimensions (ADD):** $M_S > 1.66$ **TeV (GRW)**



Exotic Signatures

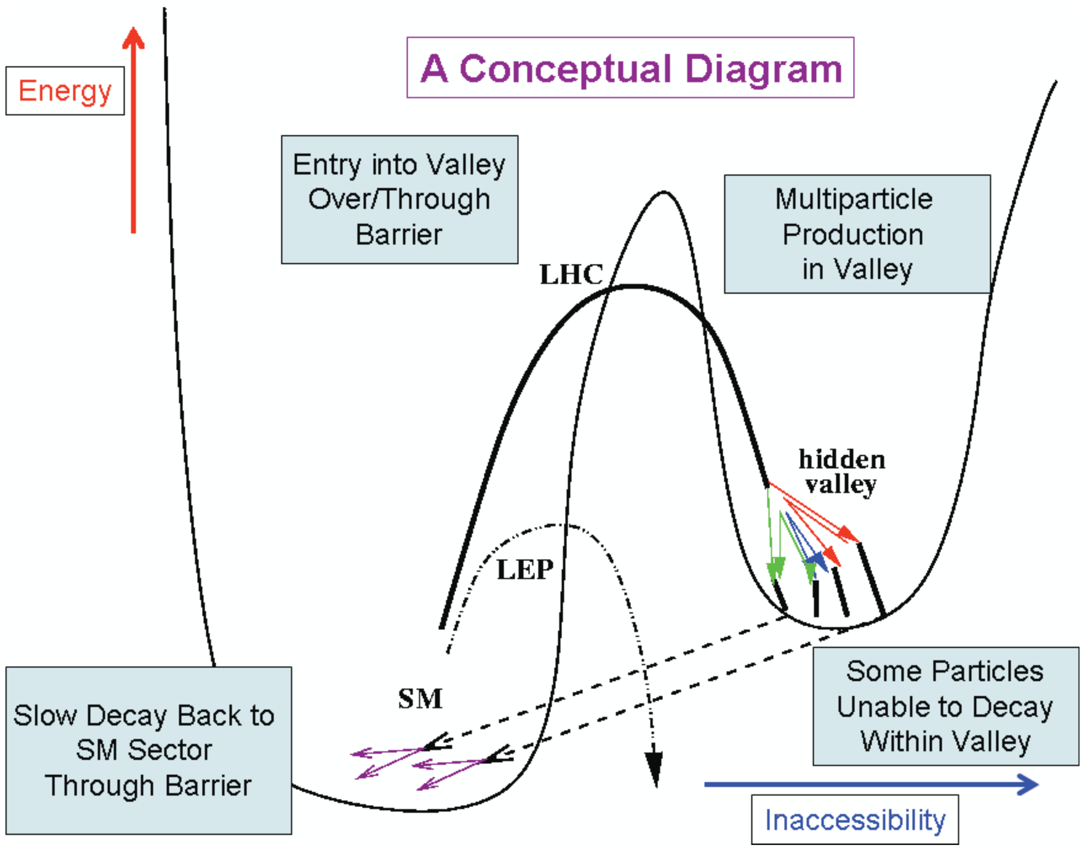
“Actually, did you ever search for ...?”

Dark Photons at DØ

arXiv.org:0905.1478

Supersymmetric hidden valley model motivated by various hints of dark matter signals

- Photon in hidden sector: dark photon γ_D with SUSY partner darkino $\tilde{X}$
- Dark Photon mass $\lesssim$ O(1) GeV to explain Pamela positron excess

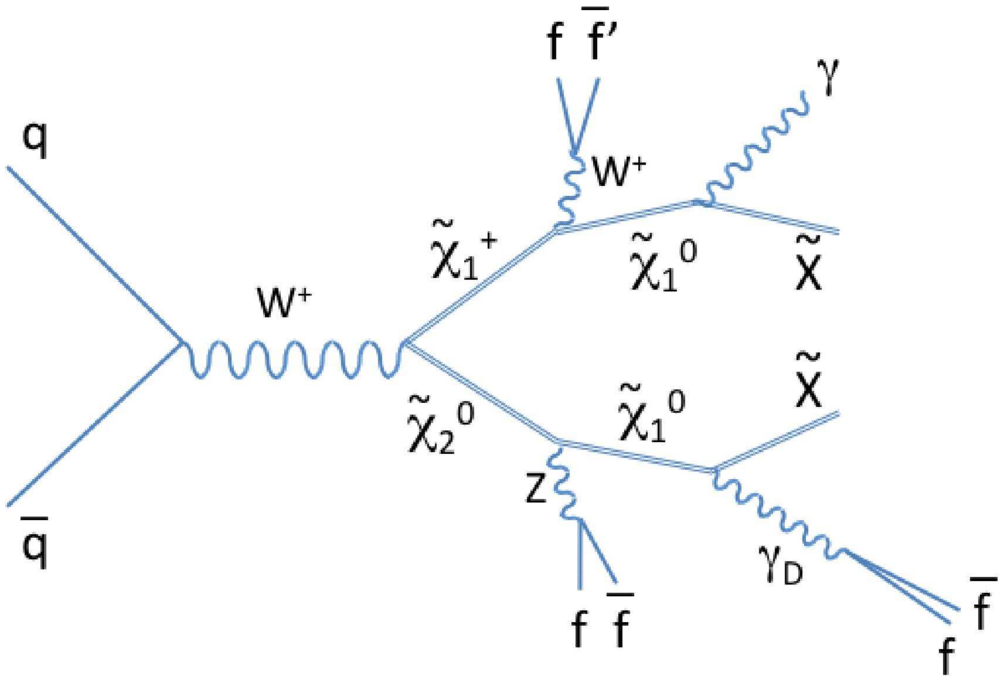


Dark Photons at DØ

arXiv.org:0905.1478

Production of supersymmetric particles results in decays $\tilde{\chi}_1^0 \to \gamma_D \tilde{X}$ or $\tilde{\chi}_1^0 \to \gamma \tilde{X}$

$\to$ **look for events with γ+γ_D+$\not{E}_T$ with γ_D $\to$ee,$\mu\mu$ (small lepton opening angle)**



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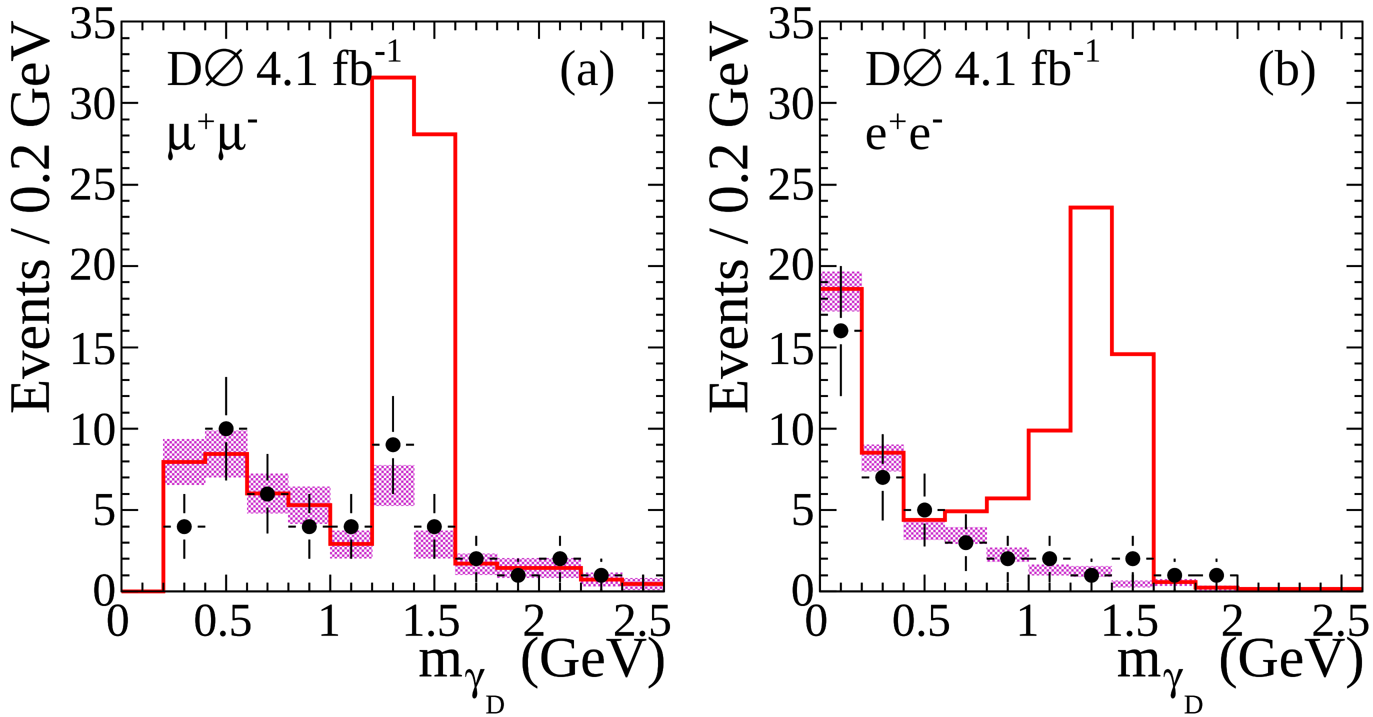

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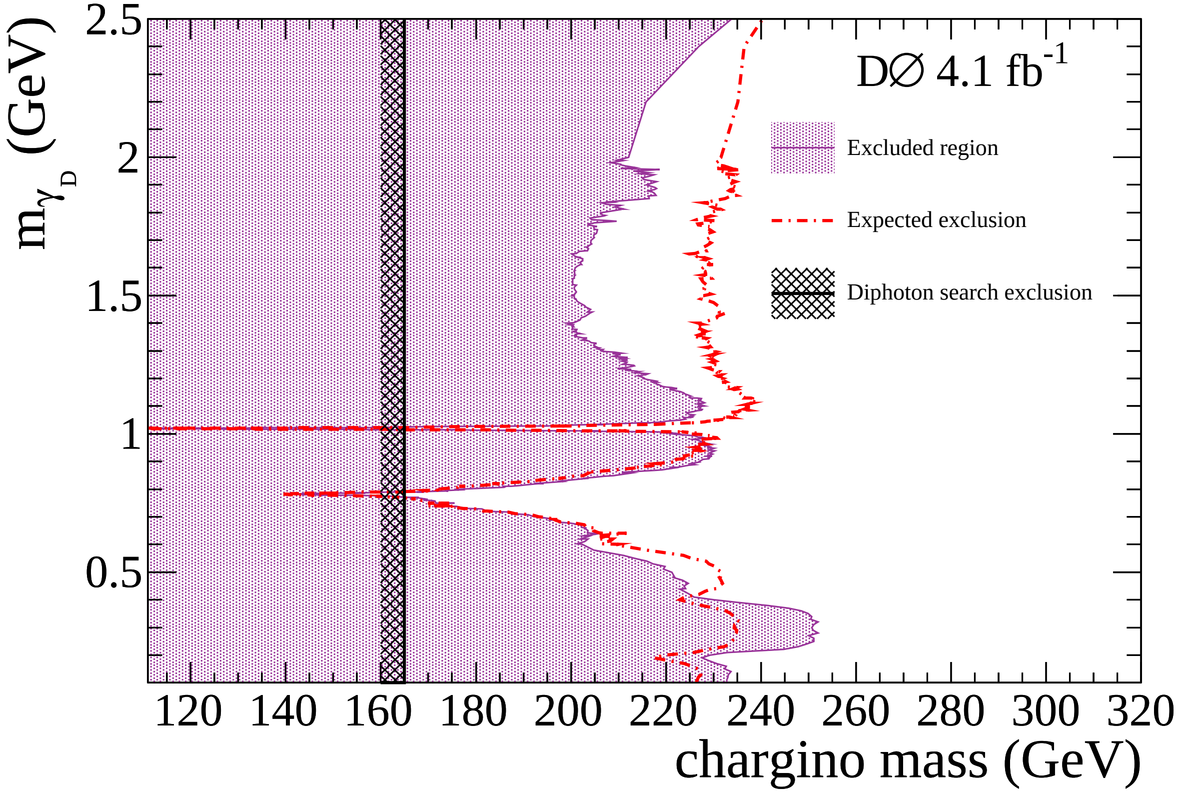


Preparing for exotic signals at the LHC

Many models predict long-lived charged or neutral particles

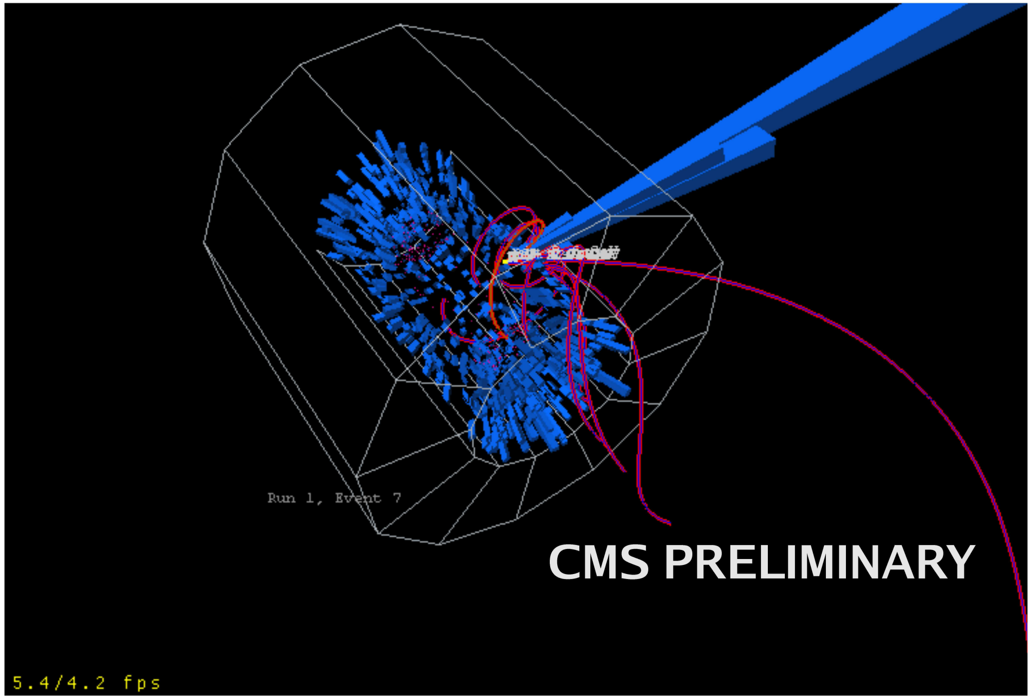
Many signatures to be explored: displaced vertices, kinks, disappearing tracks, high ionisation, non-pointing photons, out-of-time energy...

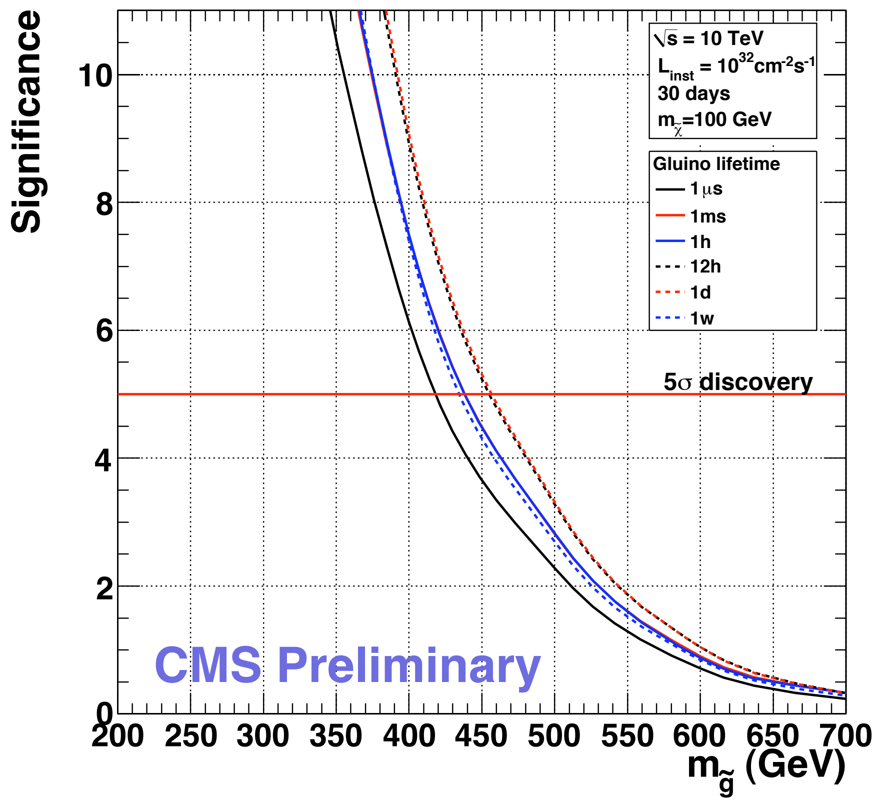
→ need to make sure none of them are discarded by ATLAS and CMS trigger systems

Example: stopped gluinos in CMS

– will run trigger on low-p_T jet in buckets/periods without beam

→ sensitivity to stopped gluinos for large range of gluino lifetime



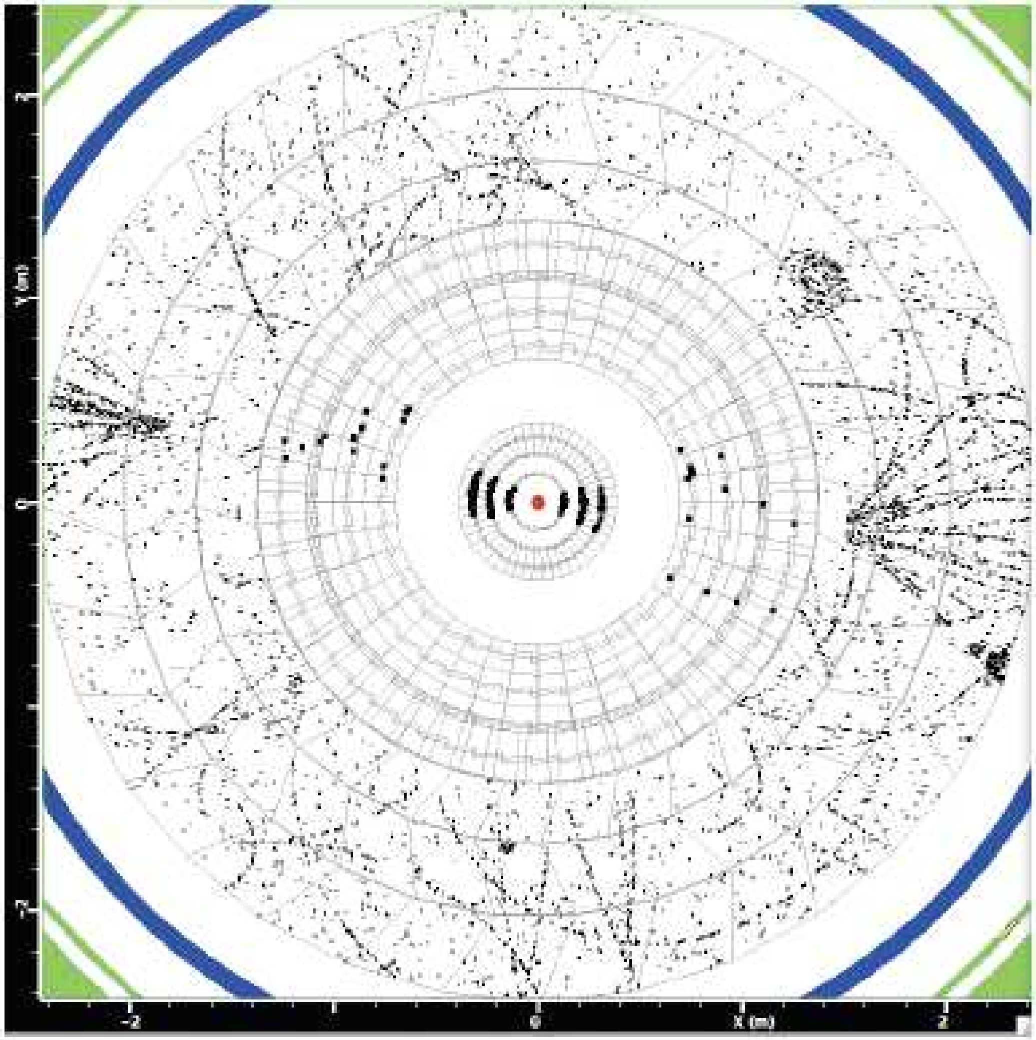


Preparing for exotic signals at the LHC

Example: Higgs h $\longrightarrow \pi_v^0 \pi_v^0$ with long-lived $\pi_v^0 \longrightarrow b\bar{b}$ in ATLAS

Implemented three dedicated triggers:

- **Decays in tracker: "trackless jets" with a muon**



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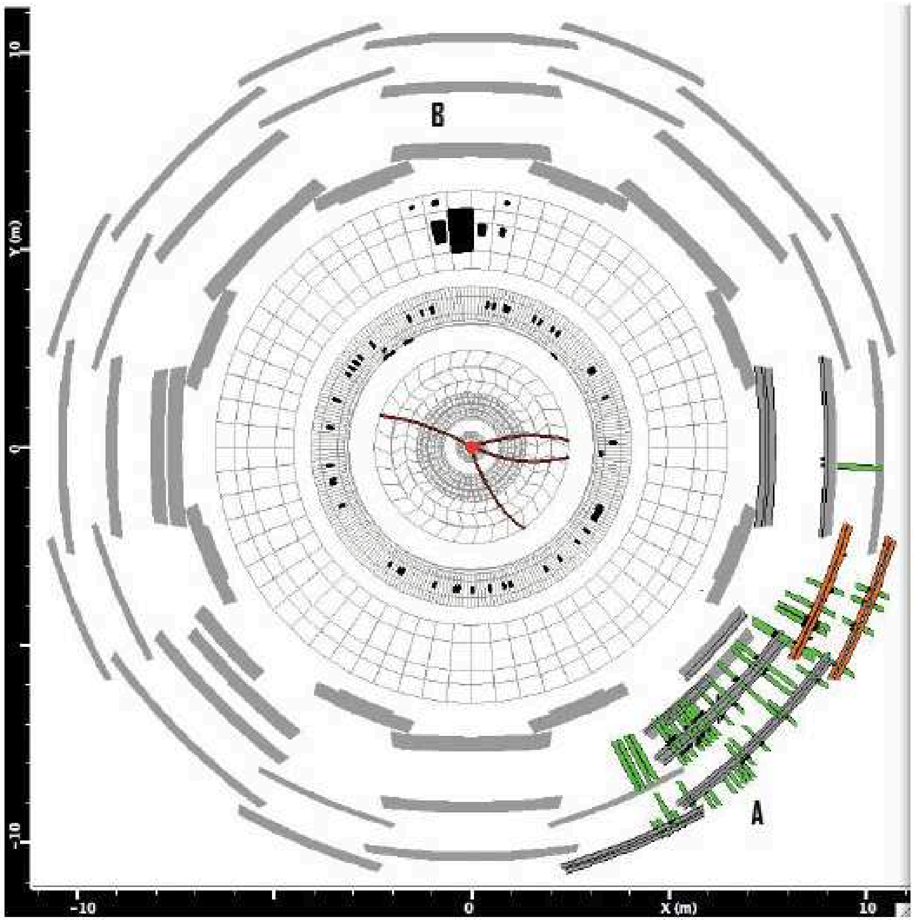
- Decays in calorimeter: tau-like jet, distorted longitudinal profile, no tracks
- Decays in the muon system: several muons without jets or tracks



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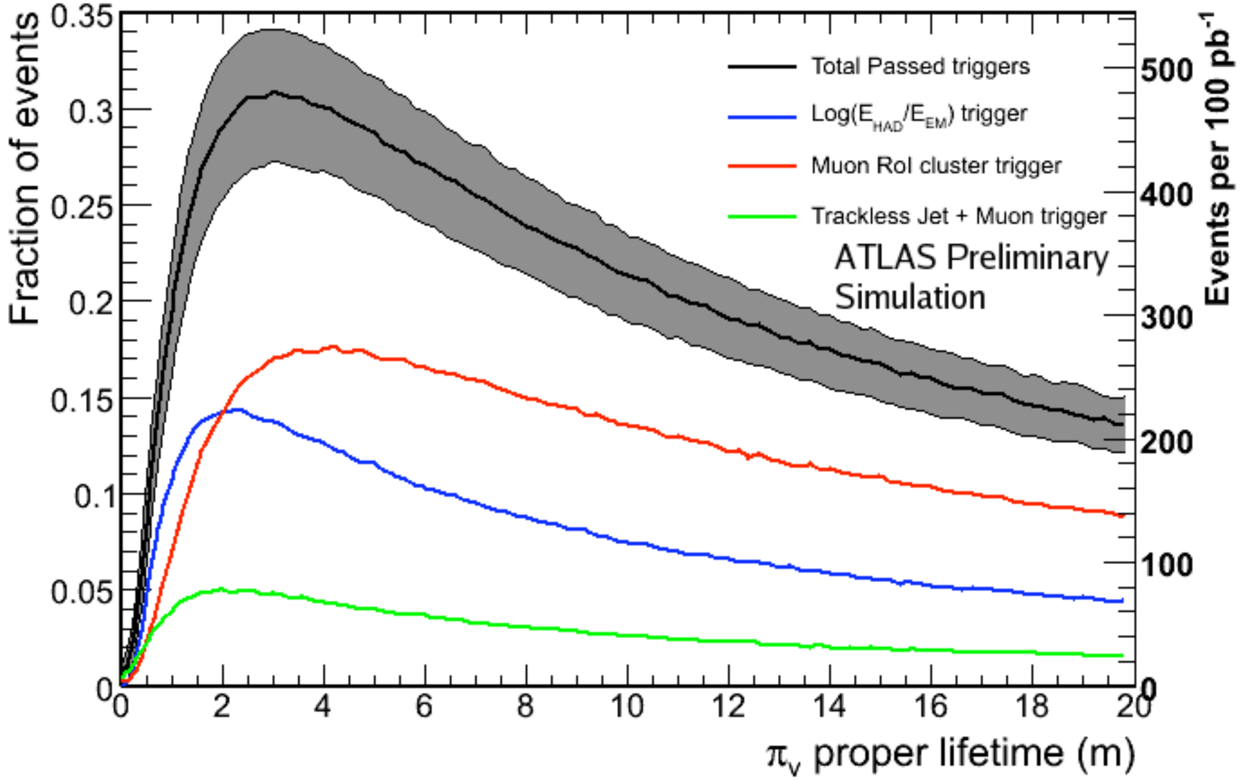
Combination of triggers: efficiency>15% for decay length 1-20 m



Conclusions

- Tevatron is running very well: 6 fb^{-1} on tape, good prospects for up to 12 fb^{-1} by 2011
- Huge number of signatures explored, still adding new ones
- ATLAS and CMS ready for analysis of first LHC data
- Excellent prospects for early discovery: no more limits, please!

Thanks to:

Todd Adams, Oliver Buchmüller, Arnaud Duperrin, Paul de Jong, Greg Landsberg, Monica D'Onofrio, Giacomo Polesello, Jeffrey Richman, Albert de Roeck, Eduardo Ros, Pierre Savard, Tom Wright

Full set of results available at:

http://www-cdf.fnal.gov/physics/physics.html

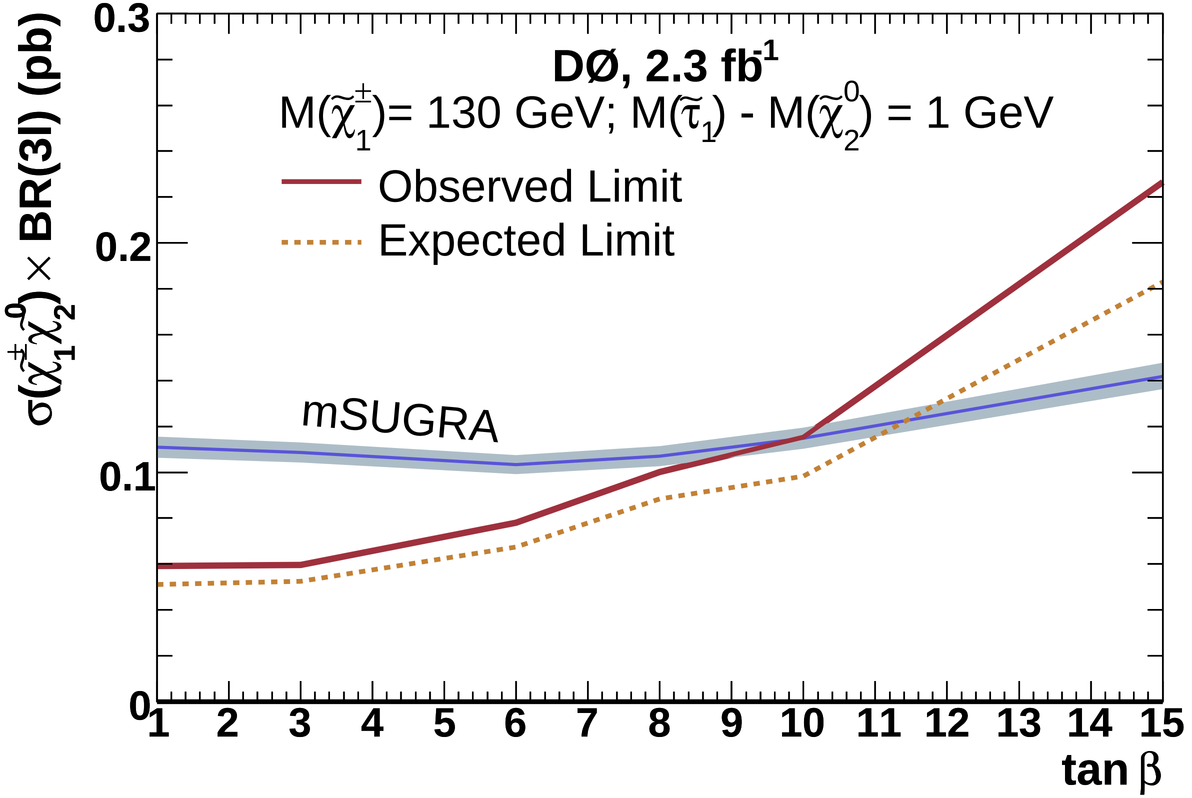
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults

https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

BACKUP

Search for Charginos and Neutralinos: Results



Probing chargino masses up to 176 GeV

Reach degrades with increasing tanβ

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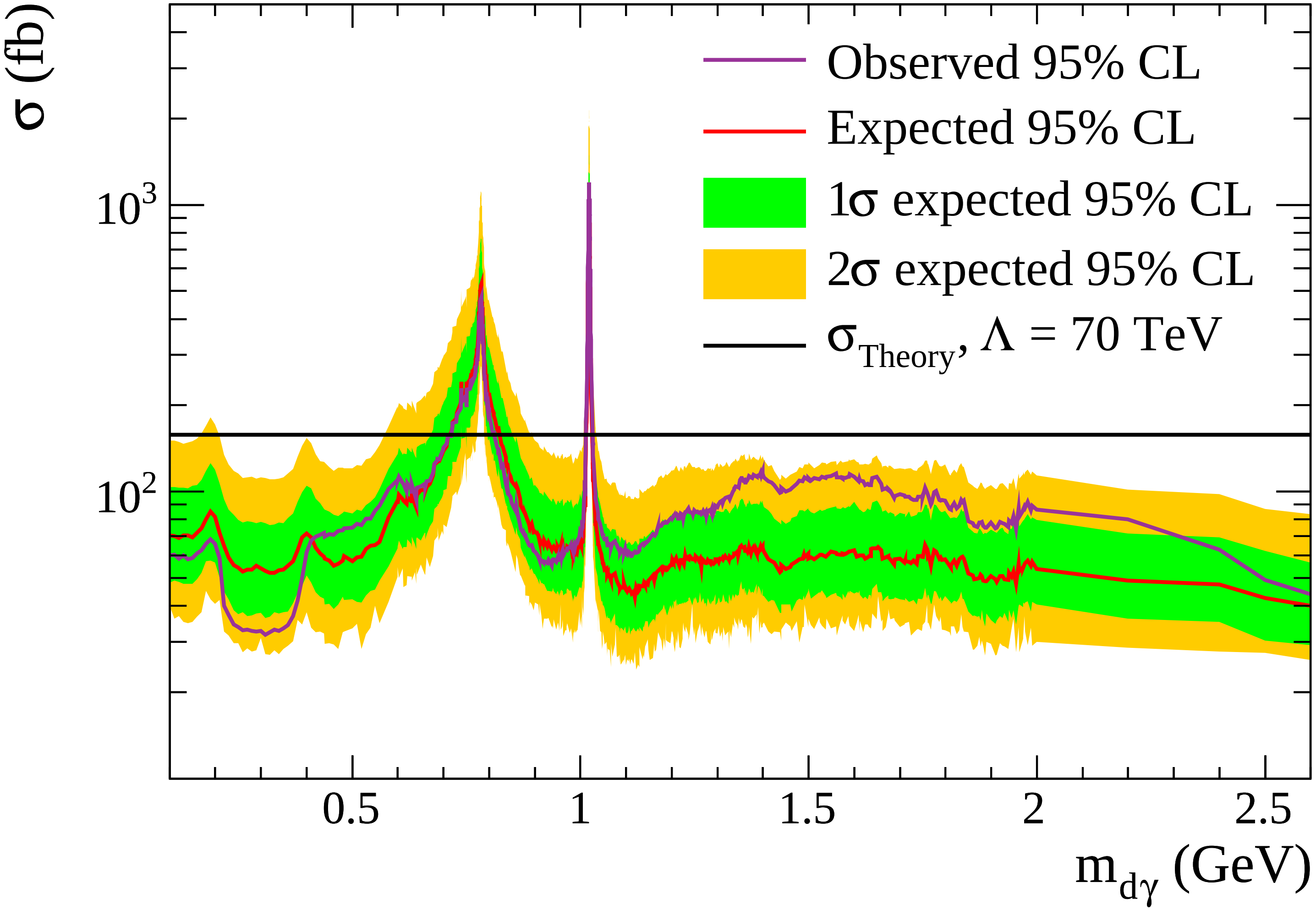

(chargino mass: 177 GeV)

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