Searches for New Physics at the Tevatron*

- Introduction
- Signature based searches for
  - ~~Compositeness and Leptoquarks~~
  - Extra Gauge Bosons
  - Extra Dimensions
- Supersymmetry
  - Squarks / Gluinos – Charginos / Neutralinos
  - "Exotic" SUSY – long-lived particles, hidden valley
- Model Independent Searches
- Conclusions

* A selection of recent results

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Arnd Meyer

PASCOS 2009, Hamburg

July 6, 2009

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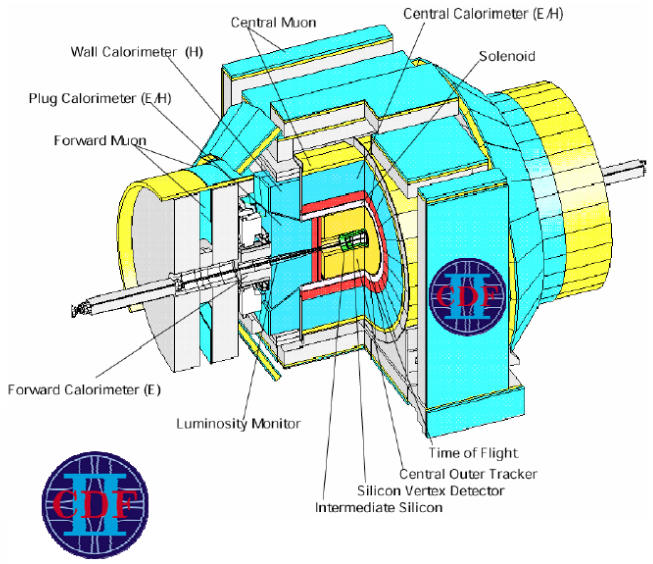
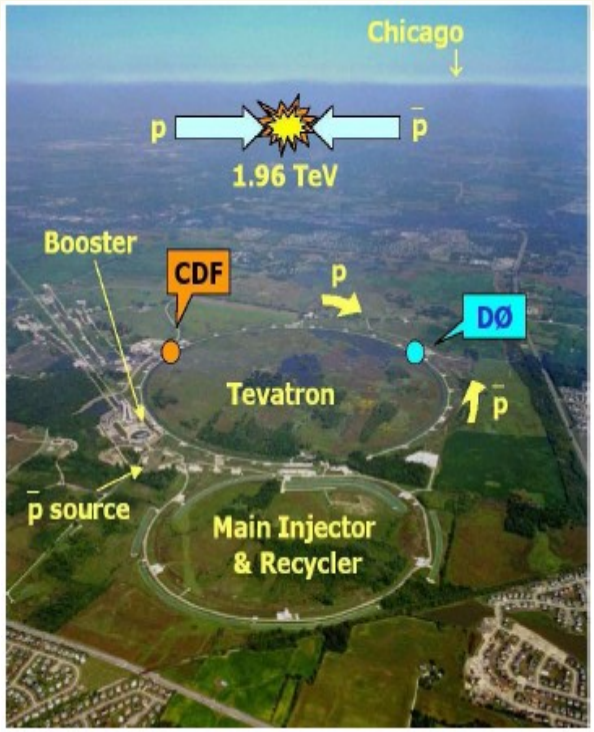
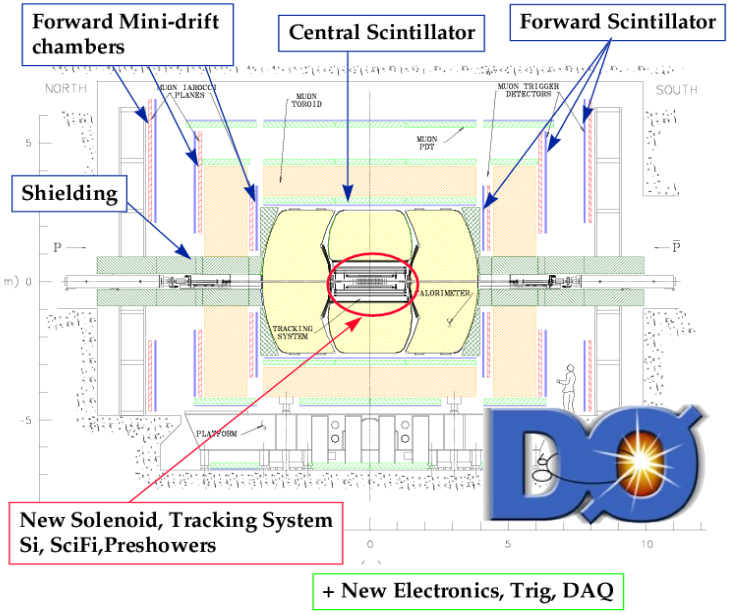
III. Physikalisches Institut A

Tevatron: DØ and CDF Experiments



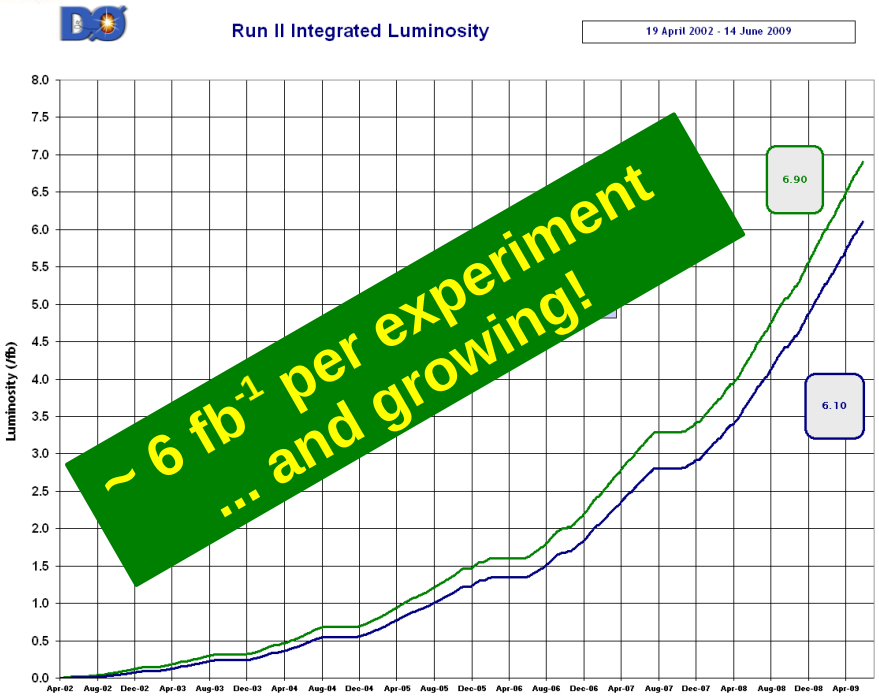




Typically:

Electron acceptance	$\|\eta\| < 2.0 – 3.0$
Muon acceptance	$\|\eta\| < 1.0 – 2.0$
Precision tracking (Si)	$\|\eta\| < 2.0 – 3.0$

Detectors are well understood and take data with ~80-95% efficiency



Extra Gauge Bosons: Z'

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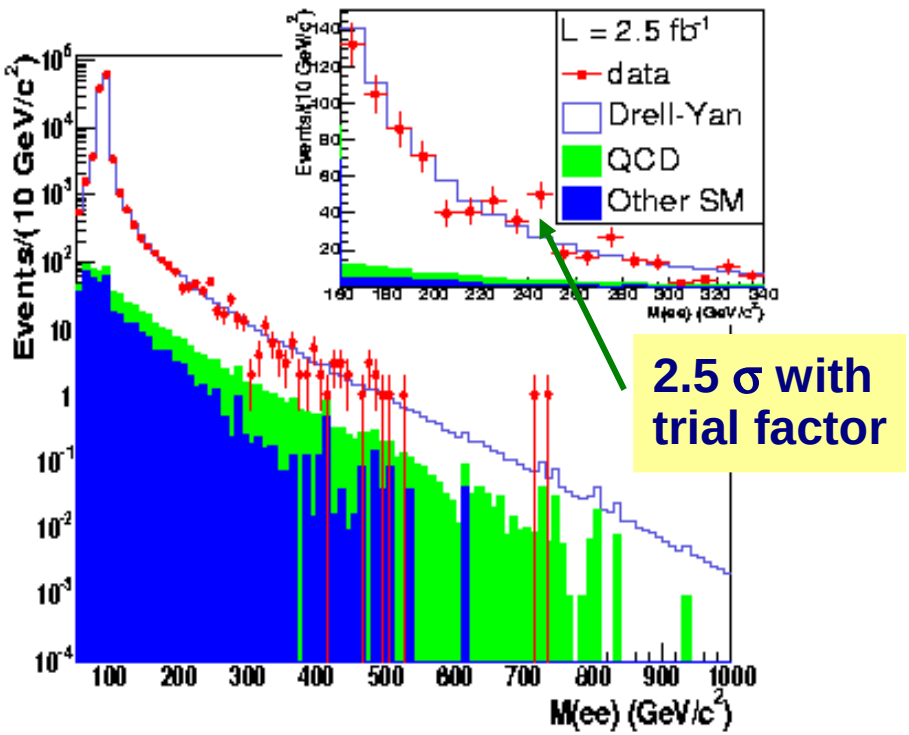
Z' → ee

CDF Run II Preliminary

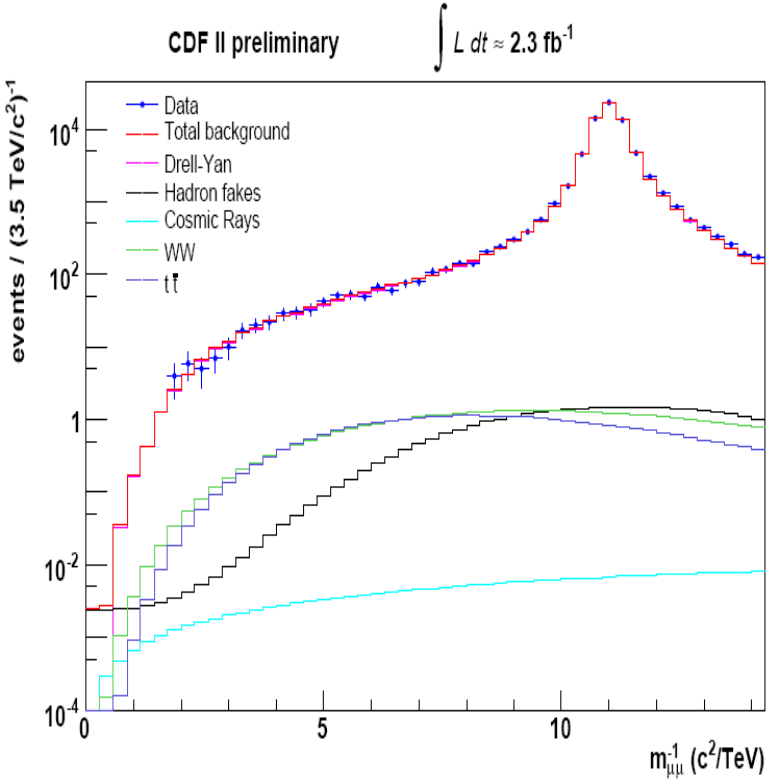


2.5 σ with trial factor

arXiv:0810.2059

Z'→μμ

arXiv:0811.0053



Plot in $1/m_{\mu\mu}$ (consistent with Gaussian resolution in $1/p_T$)

M(Z') > 966 GeV

M(Z') > 1030 GeV

(Sequential Z')

Extra Gauge Bosons: Z'

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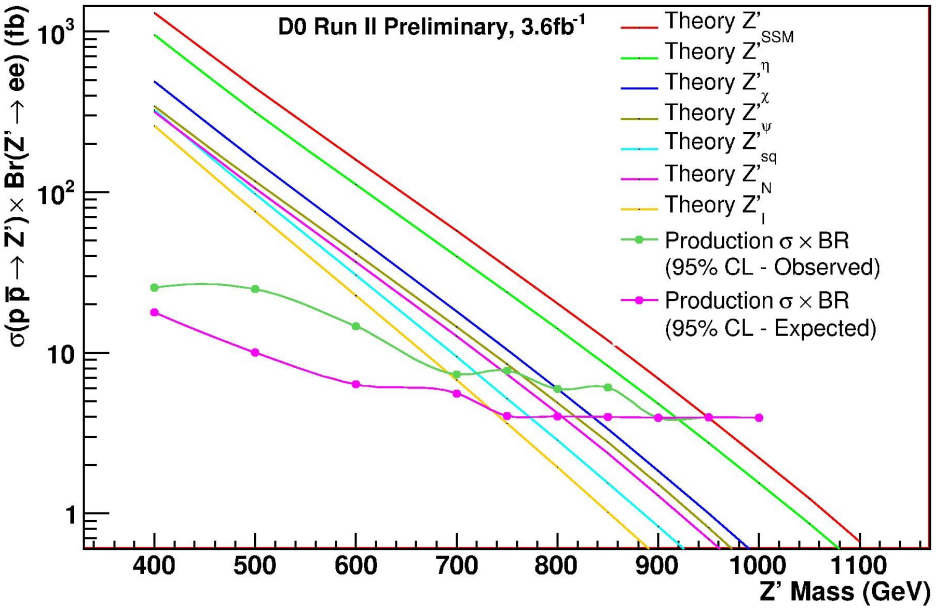
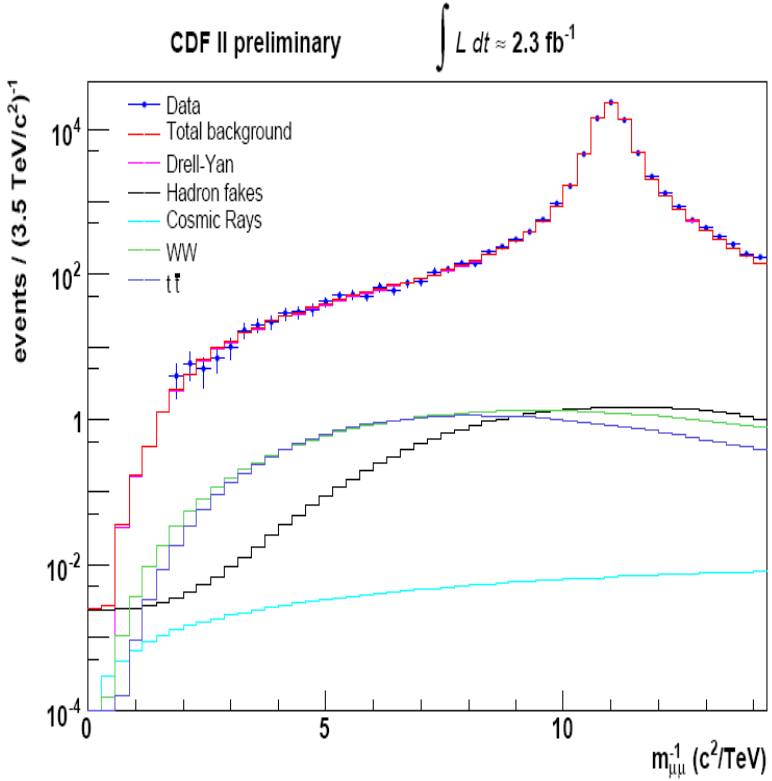
Z' → ee



Z'→μμ

arXiv:0811.0053



Plot in $1/m_{\mu\mu}$ (consistent with Gaussian resolution in $1/p_T$)

M(Z') > 950 GeV

M(Z') > 1030 GeV

(Sequential Z')

Extra Gauge Bosons: Z' and W'

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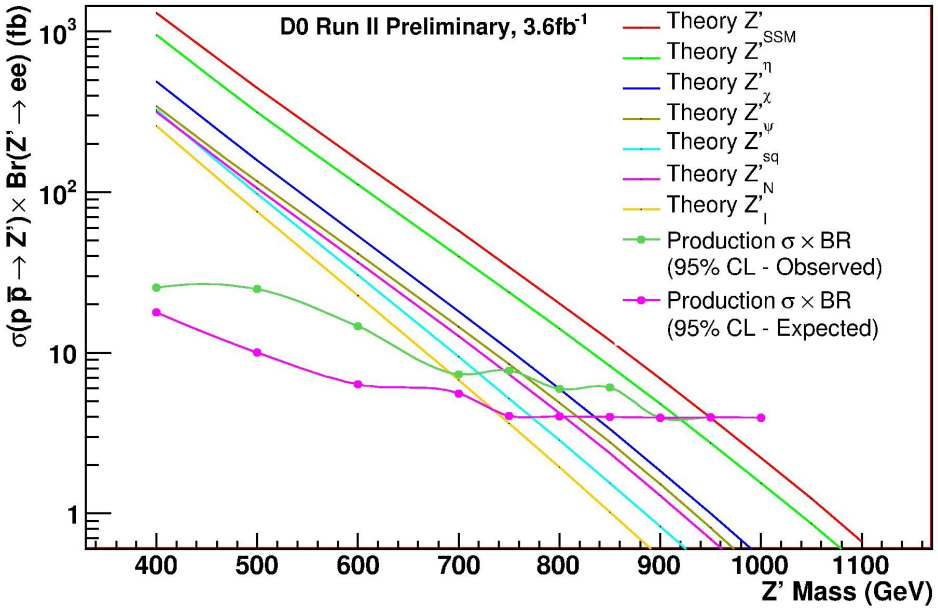
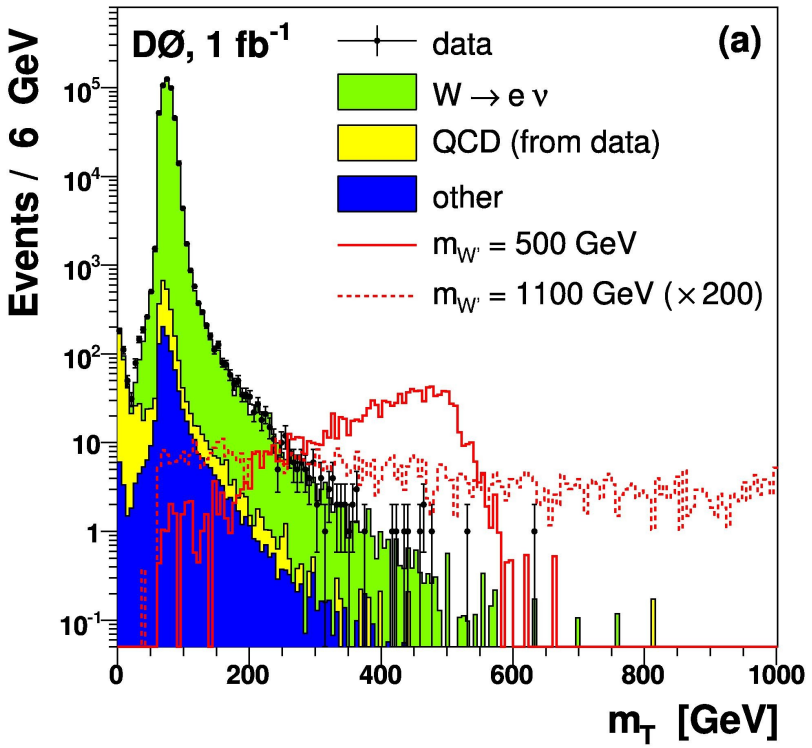
Z' → ee



W'→ eν

Use M_T distribution to derive limits



arXiv:0710.2966

M(Z') > 950 GeV

M(W') > 1.00 TeV

First direct search with sensitivity beyond 1 TeV

Randall-Sundrum Gravitons

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Use extra dimensions to address hierarchy problem

arXiv:0710.3338

RS model:

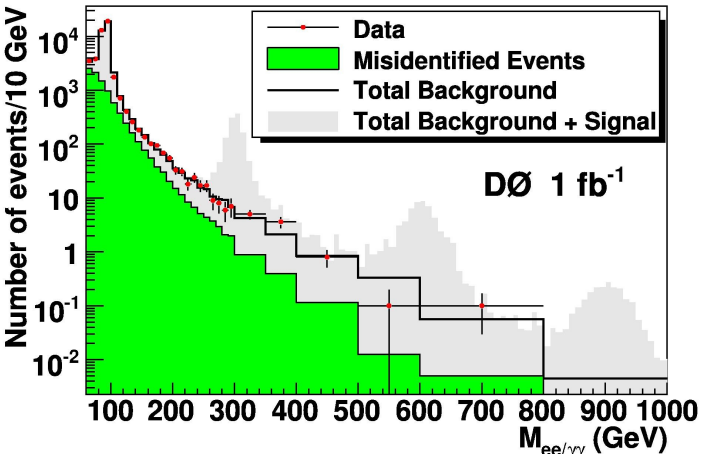
One 5th (infinite) ED with warped geometry

Gravity is localized on a brane other than the SM

KK excitations have spacings of order TeV

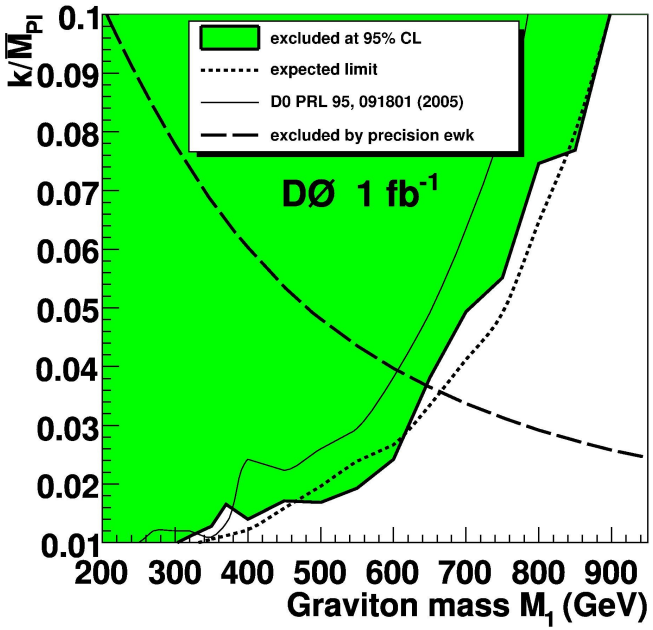
Signature: **narrow, high mass resonances**

Two model parameters: **Mass and coupling (κ/M_{Pl})**



Combined ee + γγ:

BF(γγ) = 2 BF(ee)



CDF in μμ with 2.3 fb^{-1}:

M > 921 GeV for κ/M_{Pl} = 0.1

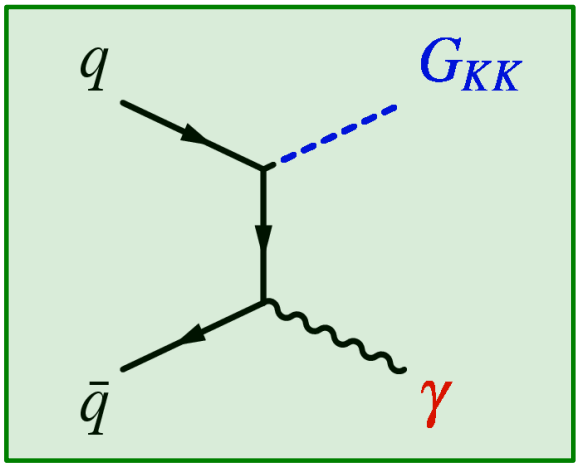
arXiv:0811.0053

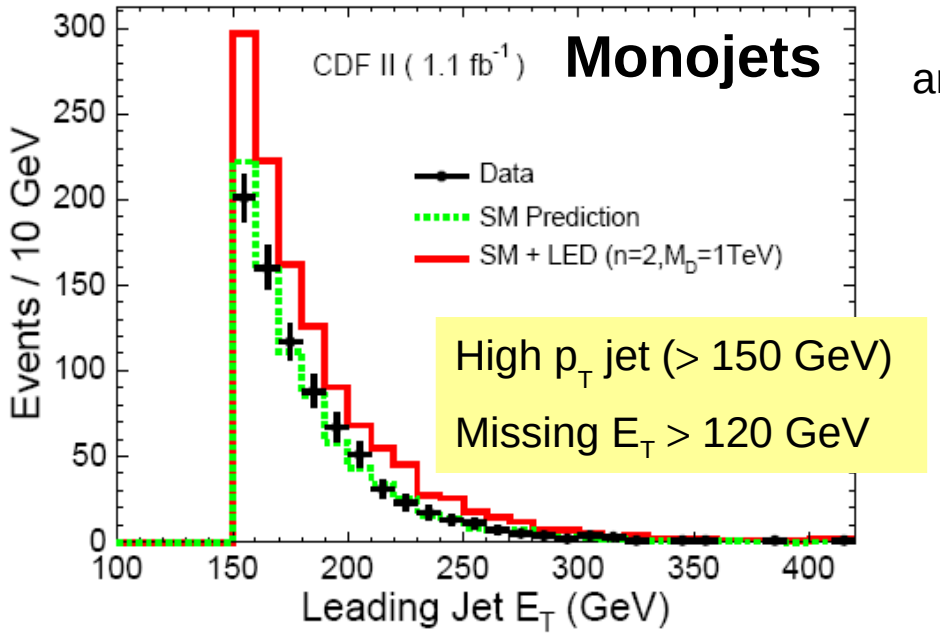
Comparable limits from CDF (ee, γγ) and DØ (ee)

For κ/M_{Pl} = 0.1: M > 900 GeV

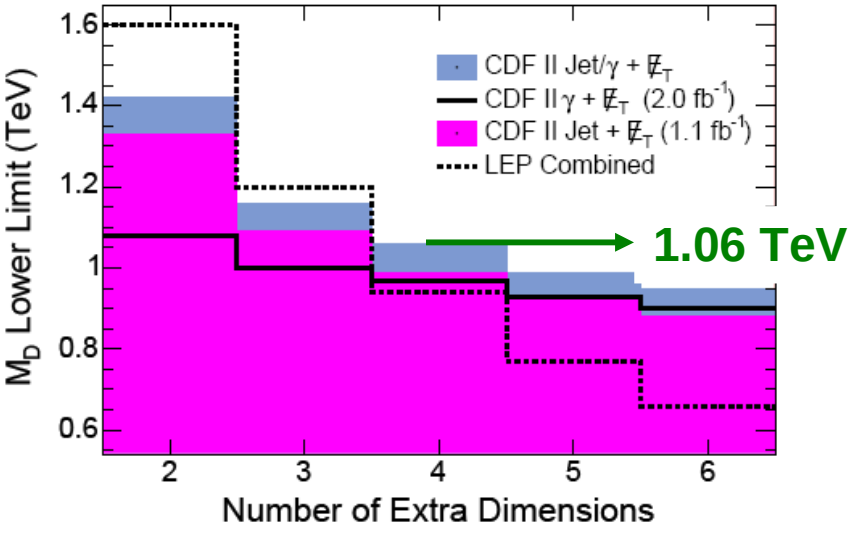
Large Extra Dimensions: γ/jet + MET

- LED can explain why gravity is weak: $1/G \sim M^2_{Pl} \sim M_D^{n+2} R^n$
- Can solve the hierarchy problem: $M_D \sim M_W$
- Search in **monophoton and monojet** final states





arXiv:0807.3132



CDF jet & γ combination

Main background: $(Z \rightarrow \nu\nu)$ +jet
Calibrated with $(Z \rightarrow ll$ and $W \rightarrow l\nu)$ + jet
QCD is negligible

Dielectrons and Diphotons

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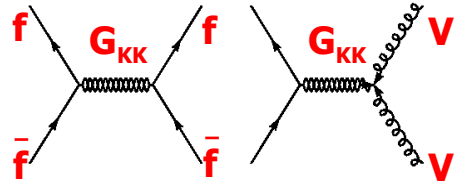
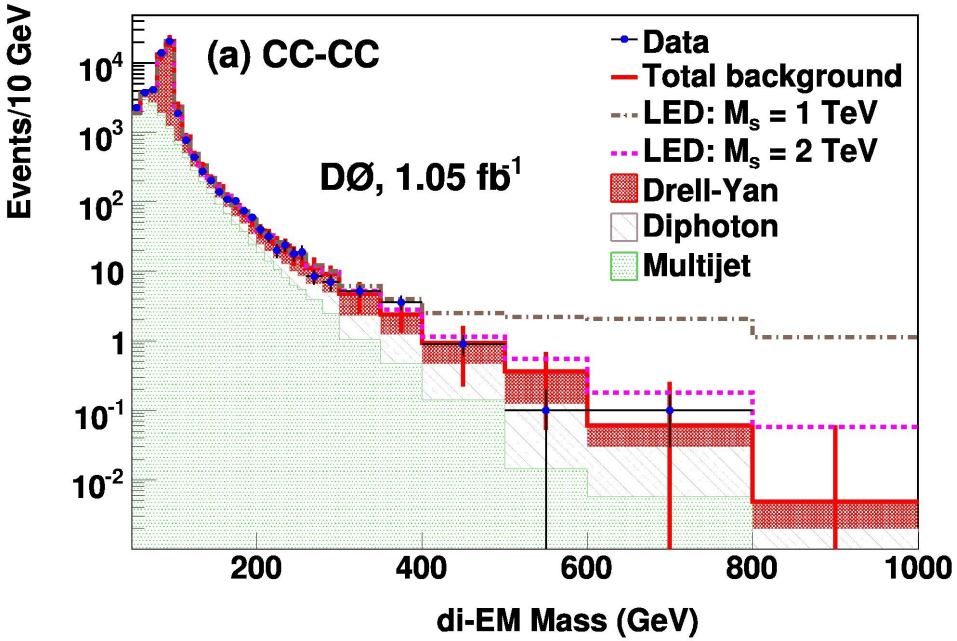
DØ search in 1.1 fb^{-1}:

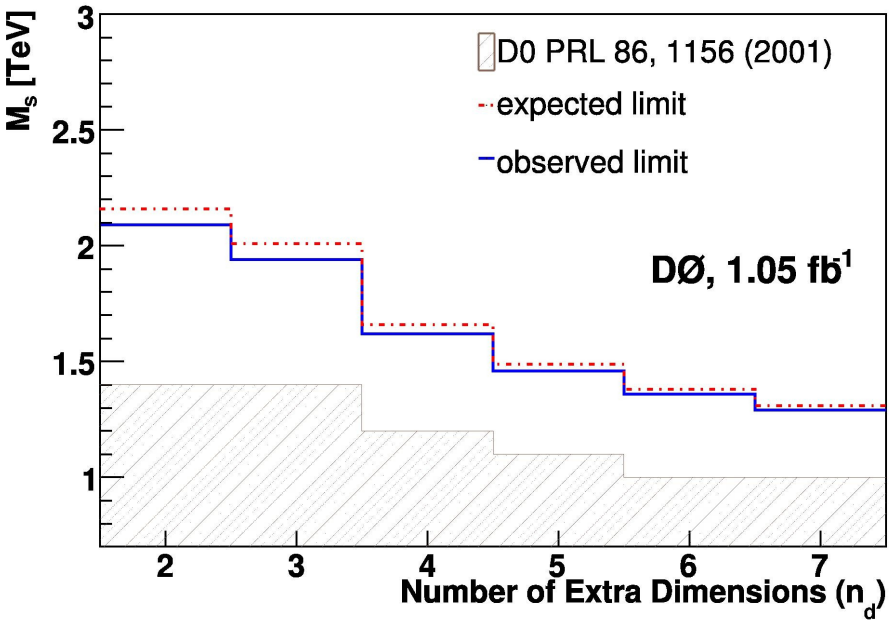
BF(γγ) = 2 BF(ee)

Combine ee and γγ to maximize sensitivity

2D-fit in mass and cos θ*

$\sum$ 





M_S > 1.62 TeV (GRW)

(HLZ formalism)

arXiv:0809.2813

LED in high p_T dijets

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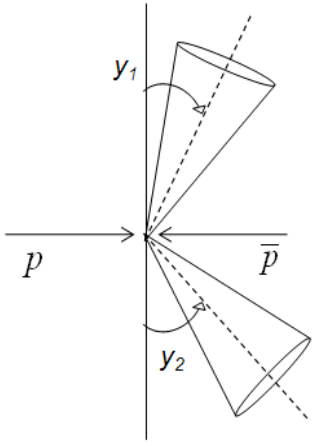
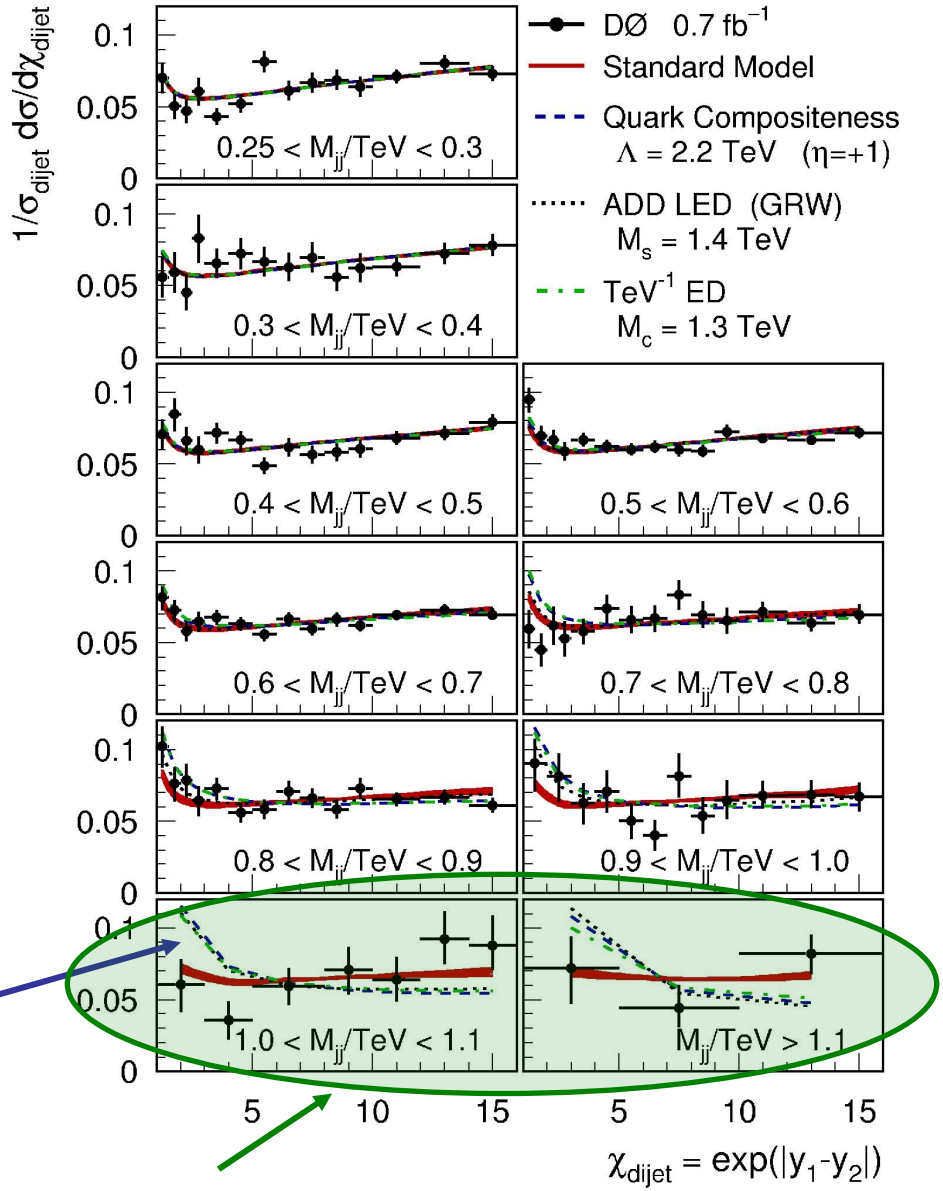
Dijet angular distribution is sensitive to new physics contributions, but fairly insensitive to theoretical and experimental uncertainties.



$$\chi_{dijet} = \exp(|y_1 - y_2|) \approx \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

Analyzed as a function of the dijet mass in 0.7 fb^{-1} of DØ data

arXiv:0906.4819



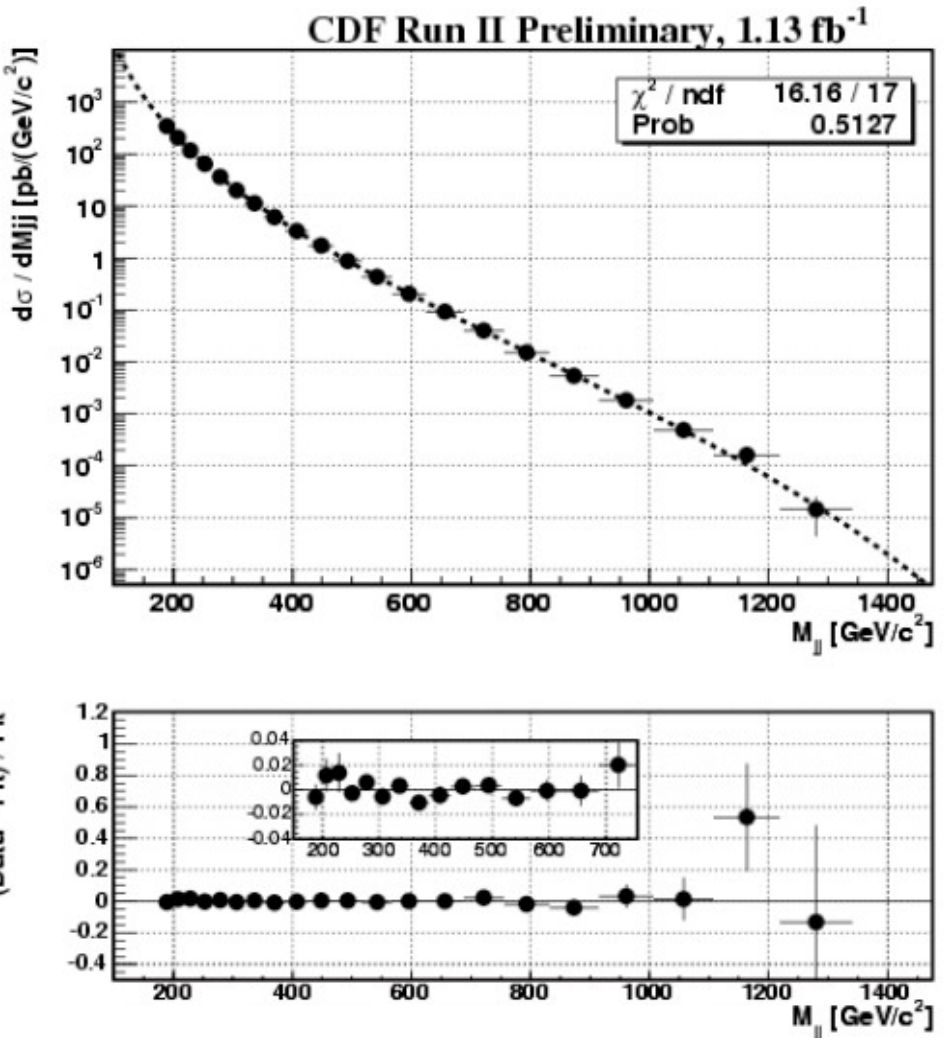
Sensitivity to new physics

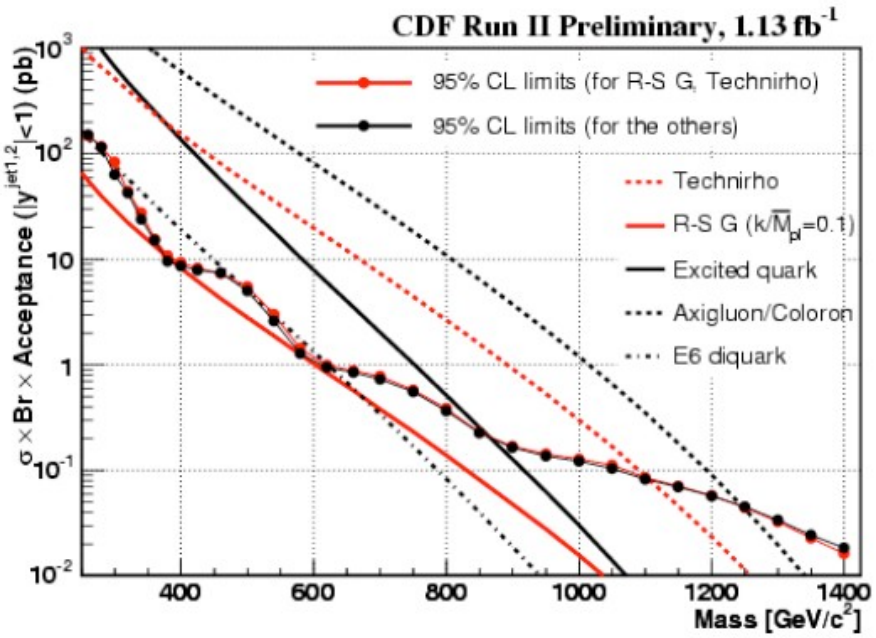
M_S > 1.48 TeV (GRW)

> 1 TeV

More dijets

- Mass bump search in events with two high p_T jets and rapidity less than 1.0
- Excludes
  - q* from 260 to 870 GeV
  - W' from 280 to 840 GeV,
  - Z' from 320 to 740 GeV





arXiv:0812.4036

Supersymmetry – Search Strategies

- Generic sparticle production
  - Probe large regions of parameter space
- Specific sparticle decays / decay chains
- Search for sparticles with unusual properties
  - Small mass differences or couplings, i.e. large lifetimes
  - Also: different SUSY breaking mechanisms
- SUSY Higgs, rare decays, ...

Supersymmetry – Search Strategies

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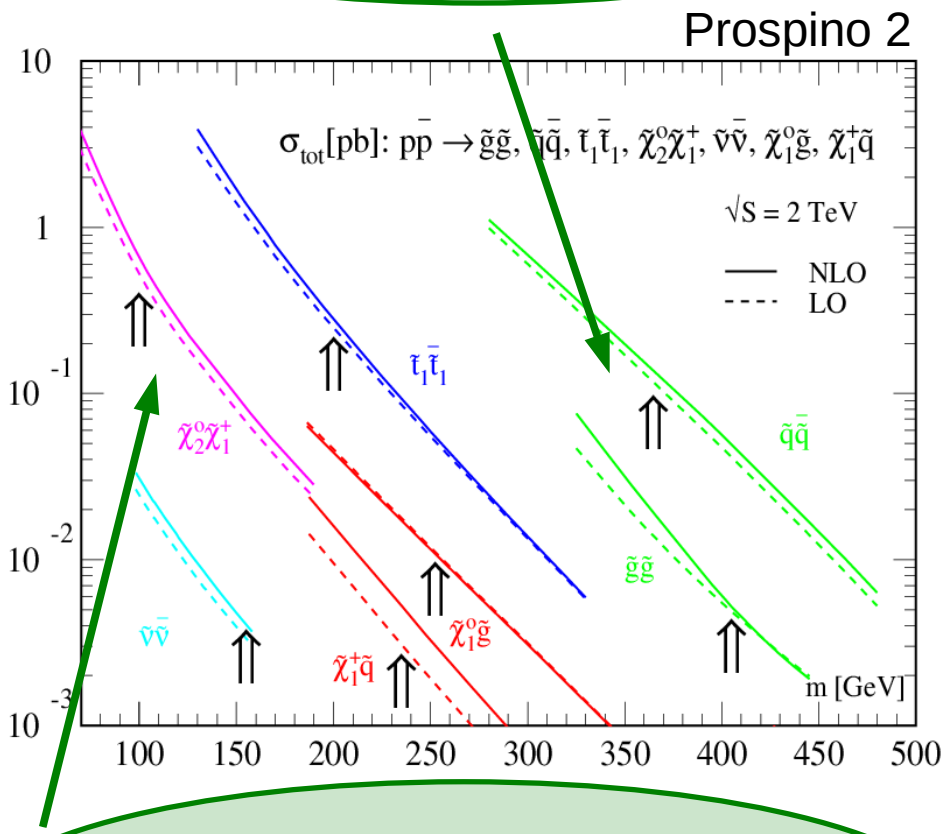
Generic squarks and gluinos
⇒ Multijets + missing E_T



Gauginos with leptonic decays
⇒ Trileptons

Supersymmetry: Squarks and Gluinos

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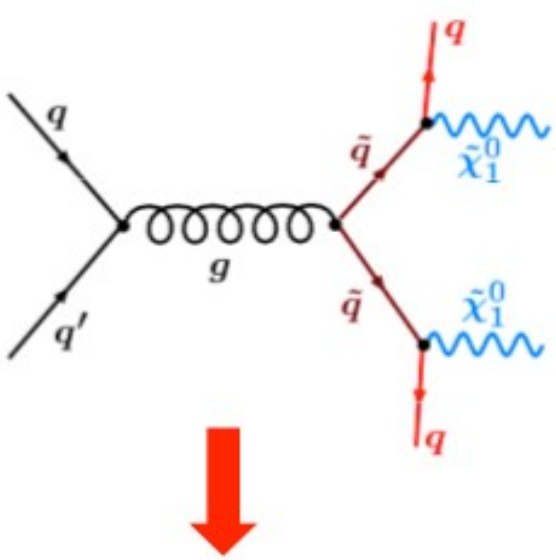
LSP assumed stable (R_p conserved)

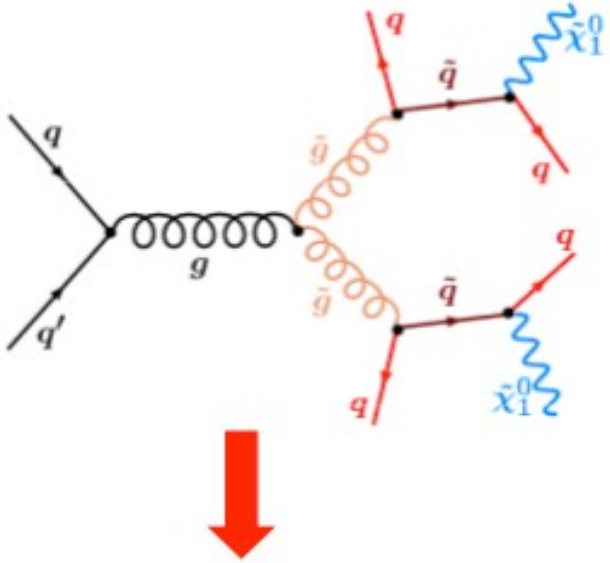
$$R_P = (-1)^{3B+L+2S}$$ + 1 SM, 1 SUSY



Result: 2 jets and MET

Low m_0

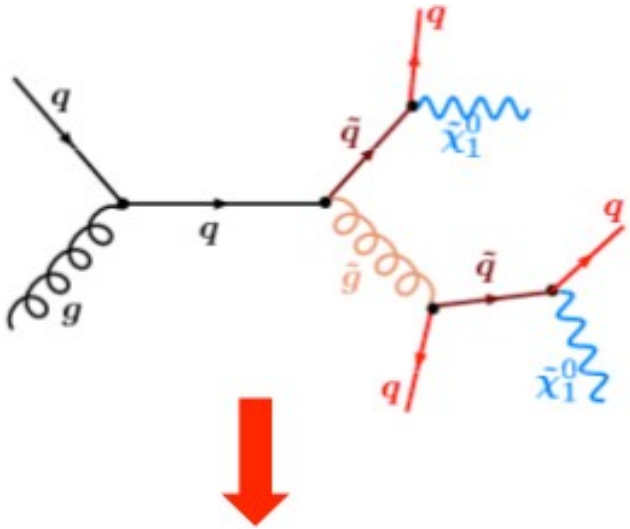
m(squark) < m(gluino)



Result: 4 jets and MET

High m_0

m(squark) > m(gluino)



Result: 3 jets and MET

Medium m_0

m(squark) ~ m(gluino)

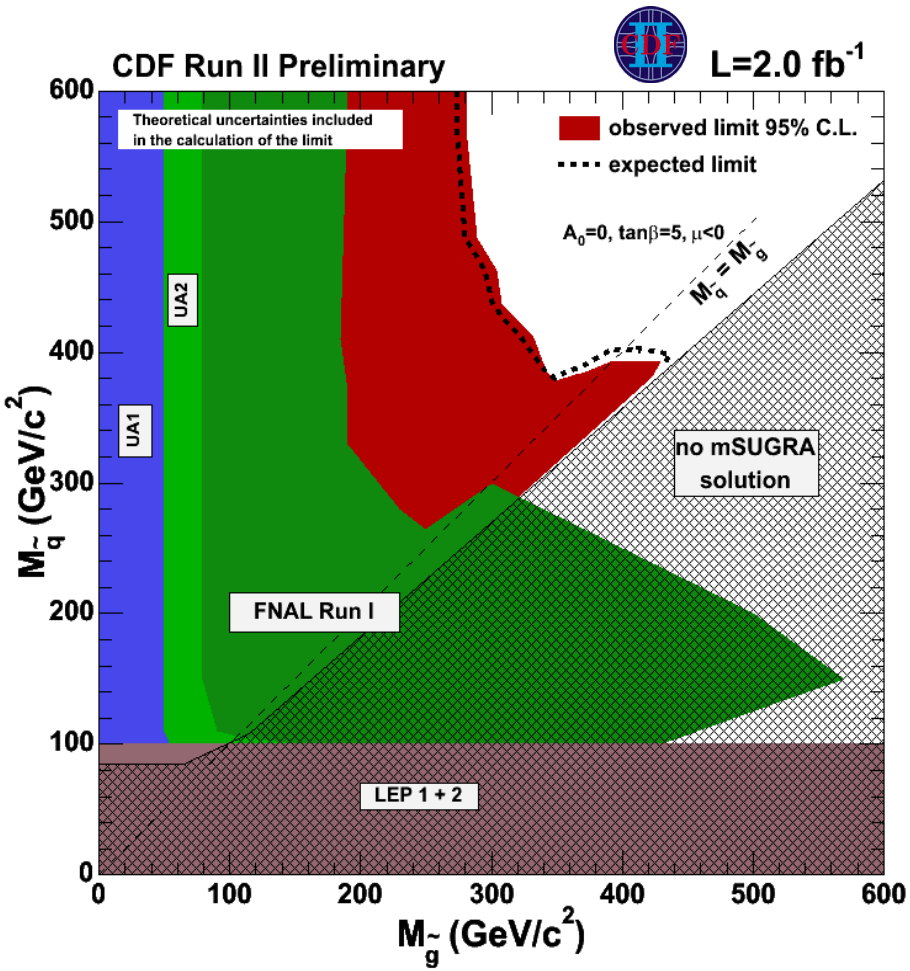
arXiv:0712.3805

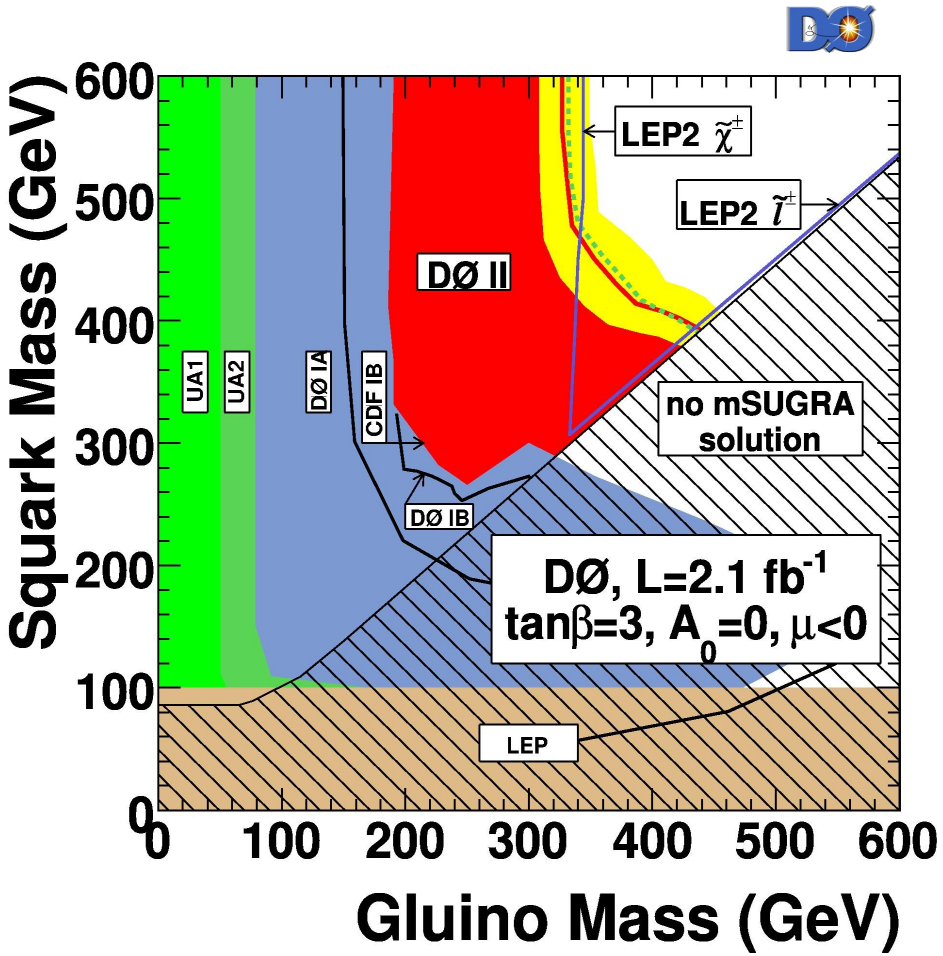
Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA
Dijet	325	225	35,35	11 ± 1 +3/-2	11
Trijet	375	175	35,35,35	11 ± 1 +3/-2	9
4-jet	400	100	35,35,35,20	18± 1 +6/-3	20

arXiv:0811.2512

Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA
Dijet	330	180	165,100	16 ± 5	18
Trijet	330	120	140,100,25	37± 12	38
4-jet	280	90	95,55,55,25	48 ± 17	45

Squarks and Gluinos: Mass Limits





M > 392 GeV [M($\tilde{q}$)=M($\tilde{g}$)]
M($\tilde{g}$) > 280 GeV

M($\tilde{q}$) > 392 GeV
M($\tilde{g}$) > 327 GeV

Charginos / Neutralinos: Trileptons

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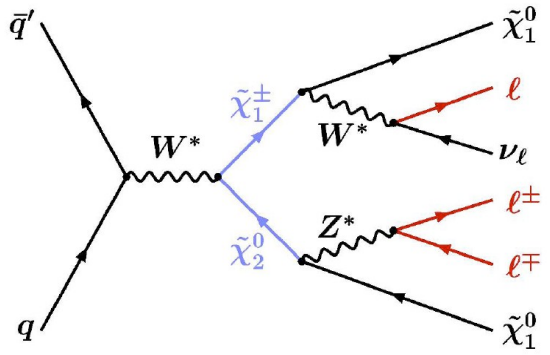
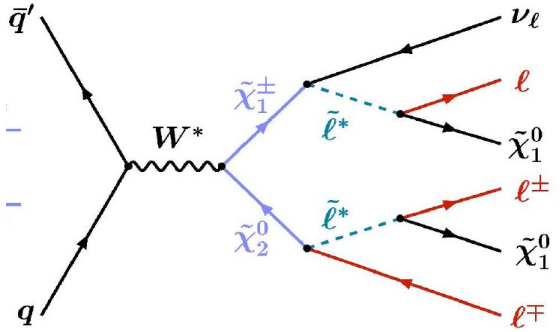
Heavy sleptons:



Light sleptons:

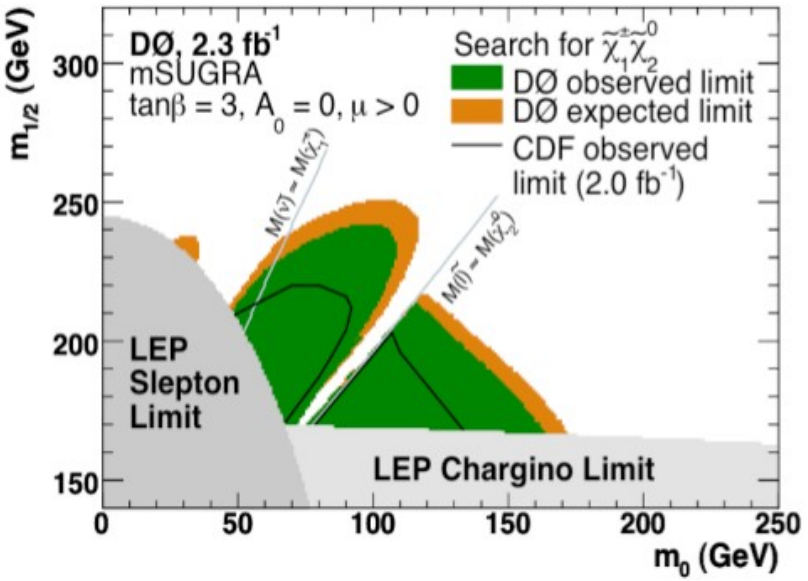


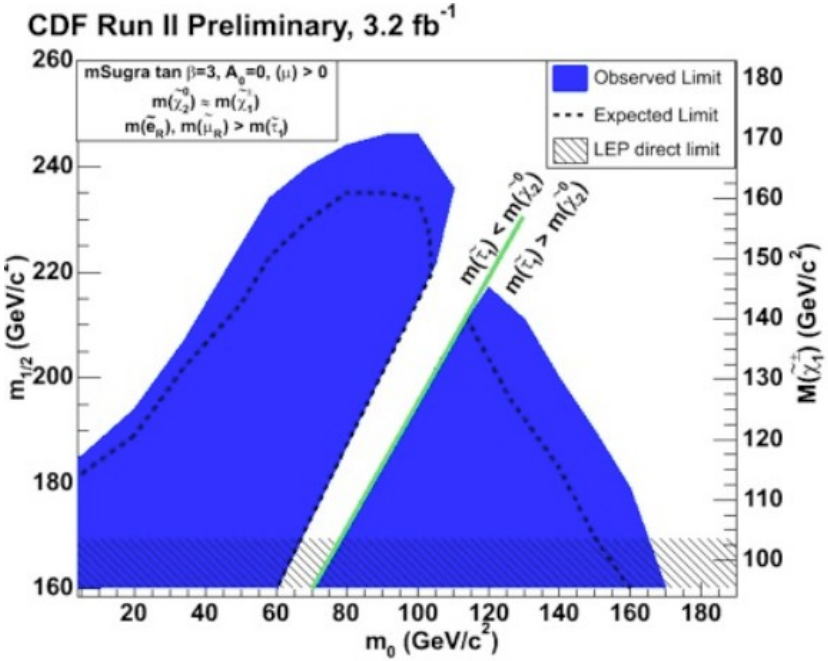
- Gaugino pair production via EW interaction
  - Small cross sections, ~0.1 – 0.5 pb
- Charginos and neutralinos decay via gauge bosons or sfermions to LSP and SM particles
- Clean SUSY signature:
  - 2 identified leptons (e or μ, DØ also τ)
  - Third lepton (or isolated track)
  - Large missing E_T

DØ $\int \mathcal{L}dt = 2.3\ \mathrm{fb}^{-1}$			CDF $\int \mathcal{L}dt = 3.2\ \mathrm{fb}^{-1}$		
	Background	Data		Background	Data
low p_T	5.4±0.6	9	Trilepton	1.5 ± 0.2	1
high p_T	3.3±0.4	4	Lepton+track	9.4 ± 1.4	6

Charginos / Neutralinos: Limits

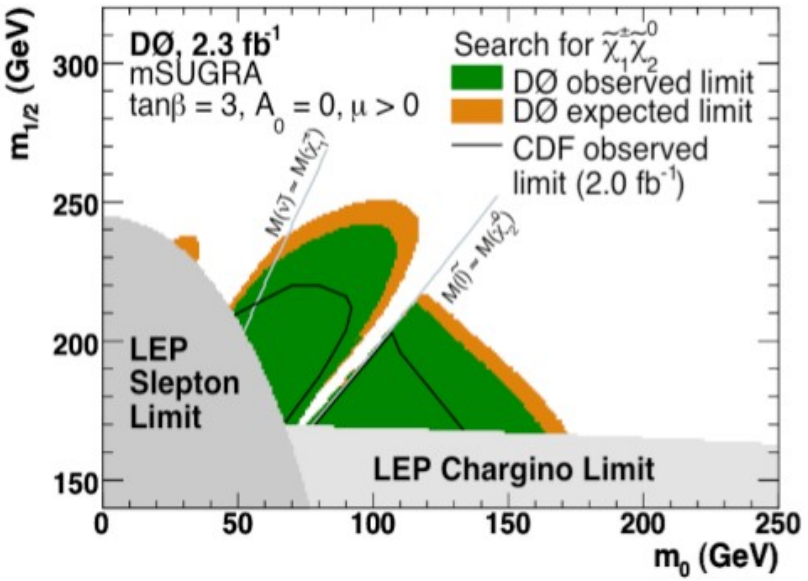
arXiv:0901.0646

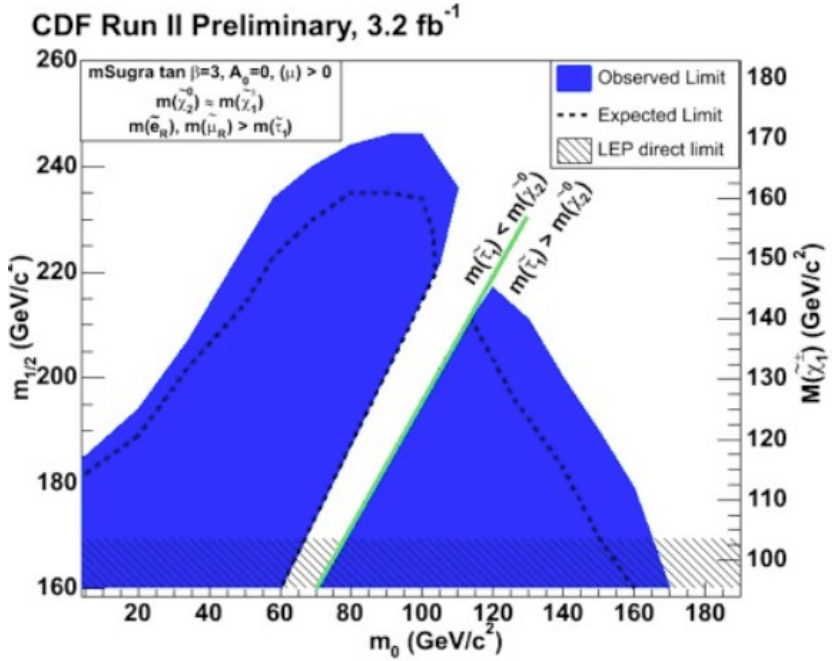




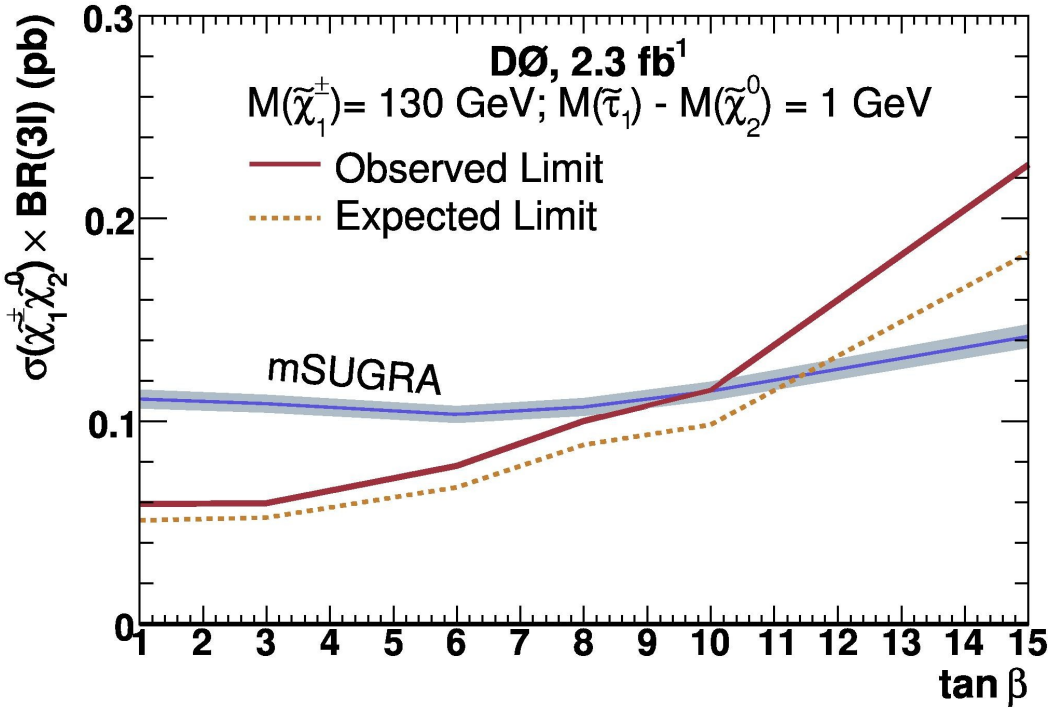
Charginos / Neutralinos: Limits

arXiv:0901.0646





Good limits also for increasing tan β (large BF into τ's)

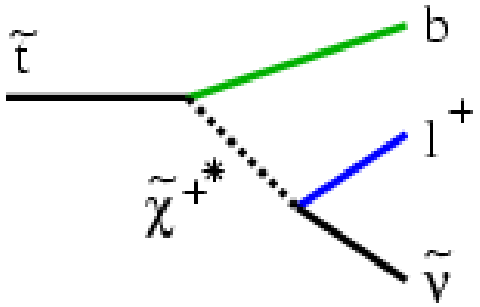


$M(\tilde{\chi}_1^{\pm}) > 130$ GeV

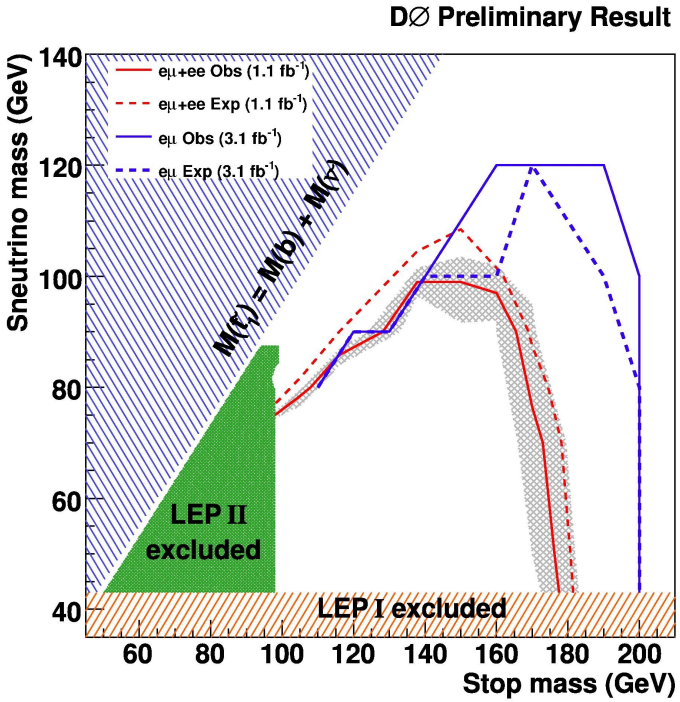
for $\tan\beta < 9.6$

Stop

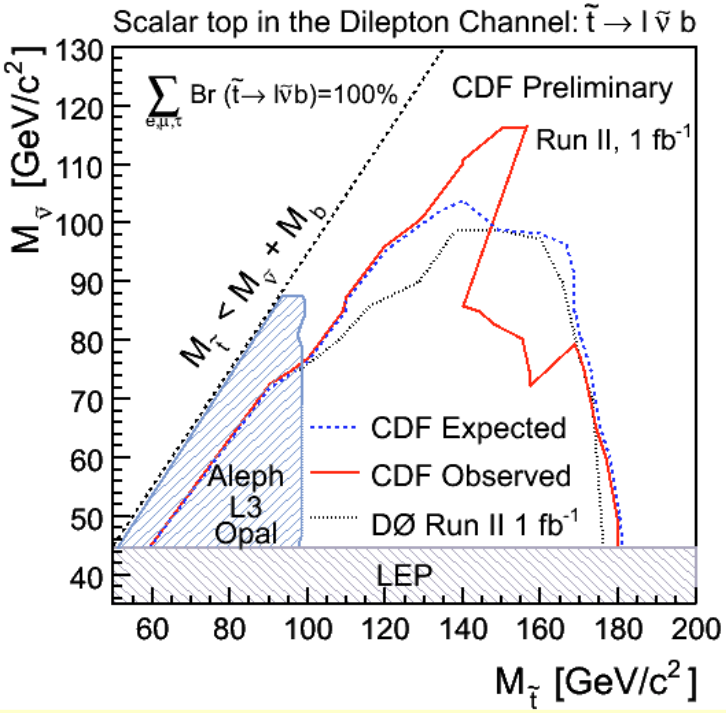
- Lightest stop might be lighter than the top quark, opening up interesting decay modes
- Example with sneutrino NLSP, leading to
  2 leptons + 2 b-jets + MET:
- Challenge can be potentially soft jets (and leptons)



DØ: update in eμ



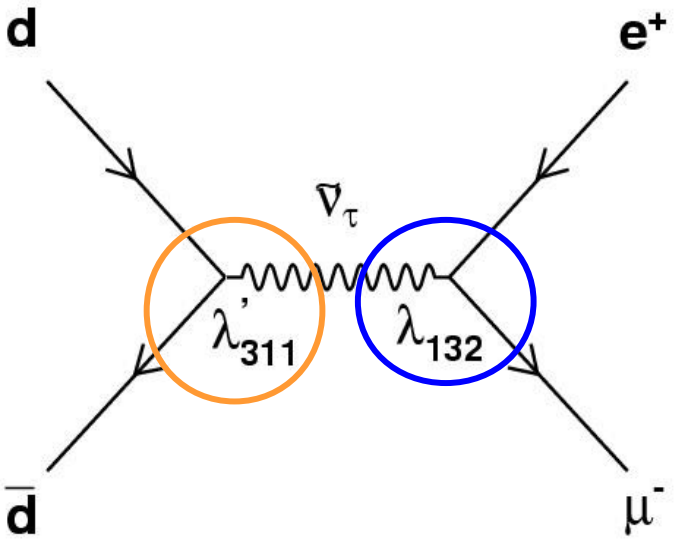
CDF: eμ, μμ, and ee

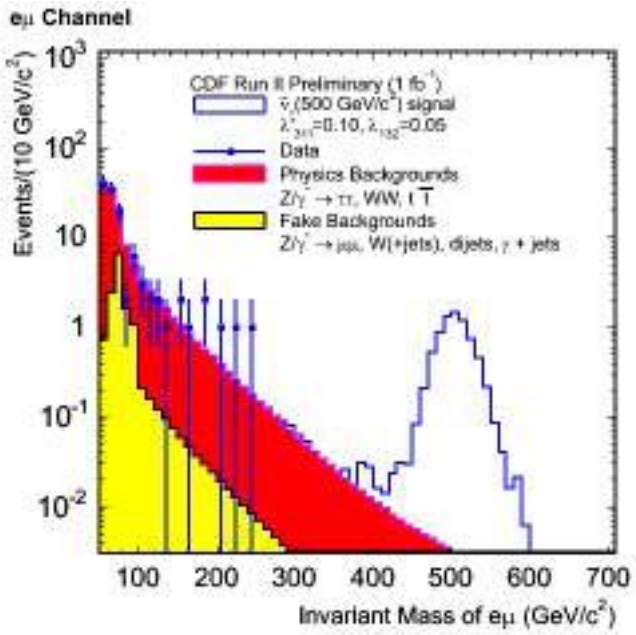


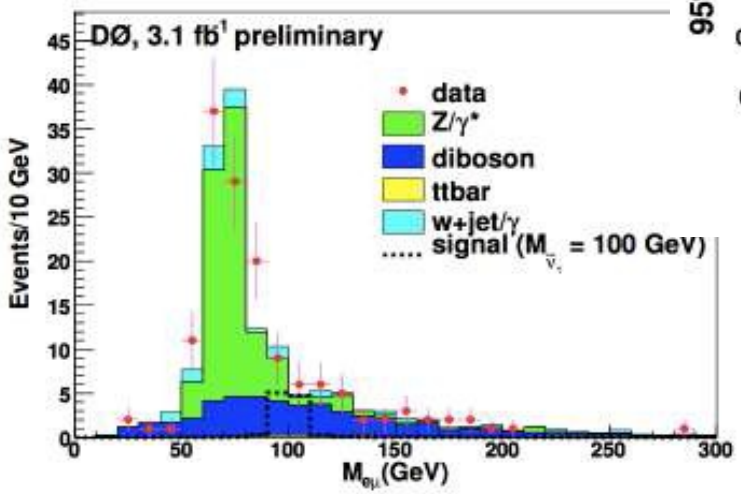
Also updates in other channels, and new sbottom results

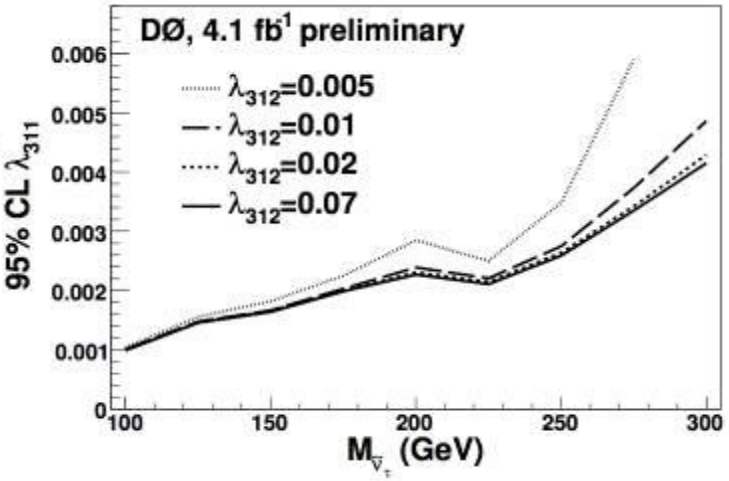
RPV SUSY: Sneutrino

- R-parity violation allows for resonant production of SUSY particles
- Single tau sneutrino production and decay
  - CDF: eμ, μτ, eτ 1.0 fb^{-1}
  - DØ: eμ (1.0 + 3.1) fb^{-1}









Limits on couplings and/or masses

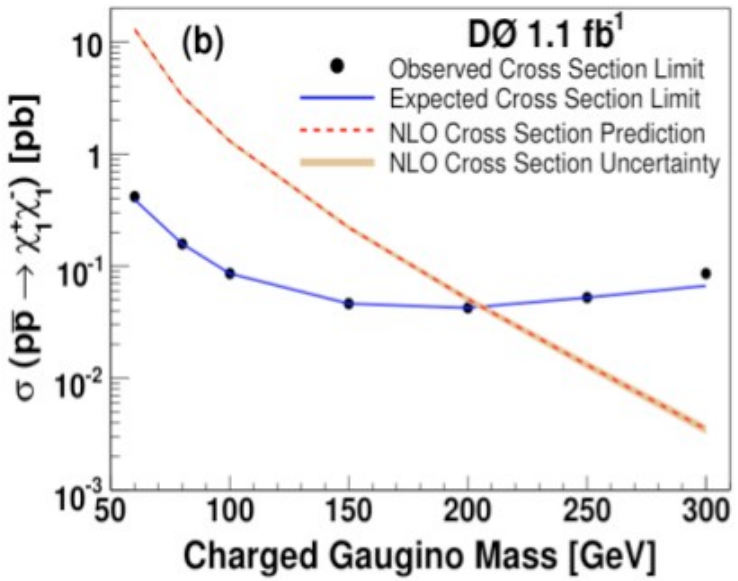
Long-lived particles

- Could be stau, chargino, stop, …
- May appear as “slow” moving highly ionizing and highly penetrating particles (muons).
- Striking signature: isolated high p_T muons, with possible calorimeter deposition
- DØ (1.1 fb^{-1}) uses timing in the muon system to measure the speed while the dimuon mass provides discrimination
- CDF (1.0 fb^{-1}) uses the TOF detector to measure the mass and sets a limit on the stop mass – long TOF and large dE/dx

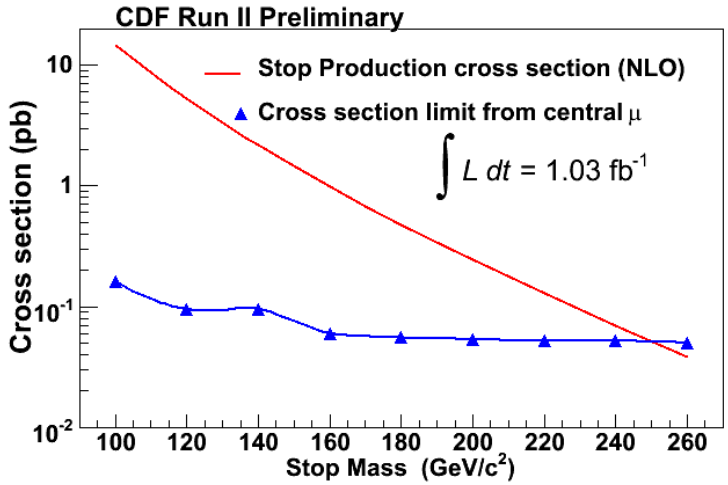
arXiv:0809.4472

Limits:

- $\tilde{\tau}$: no sensitivity
- $\tilde{\chi}_1^+$, $\tilde{h}$-like
  $m_{\tilde{\chi}_1^+} > 171\ GeV$
- $\tilde{\chi}_1^+$, gaugino-like
  $m_{\tilde{\chi}_1^+} > 206\ GeV$



arXiv:0902.1266

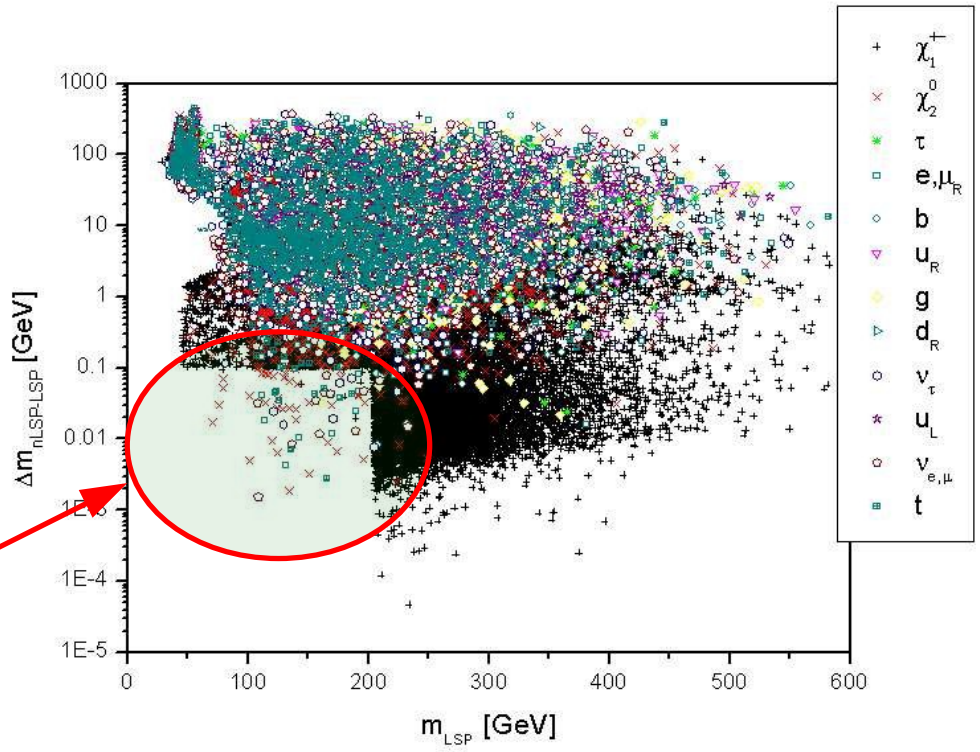


$m_{\tilde{t}} > 249\ GeV$

Long-lived particles

- Could be stau, chargino, stop, …
- May appear as “slow” moving highly ionizing and highly penetrating particles (muons).
- Striking signature: isolated high p_T muons, with possible calorimeter deposition
- DØ (1.1 fb^{-1}) uses timing in the muon system to measure the speed while the dimuon mass provides discrimination
- CDF (1.0 fb^{-1}) uses the TOF detector to measure the mass and sets a limit on the stop mass – long TOF and large dE/dx

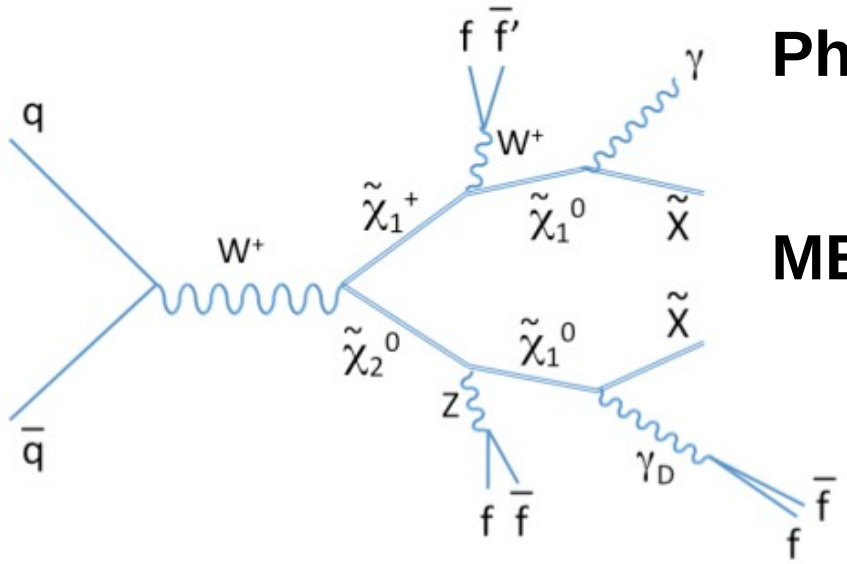
Ruled out by DØ CMSP search

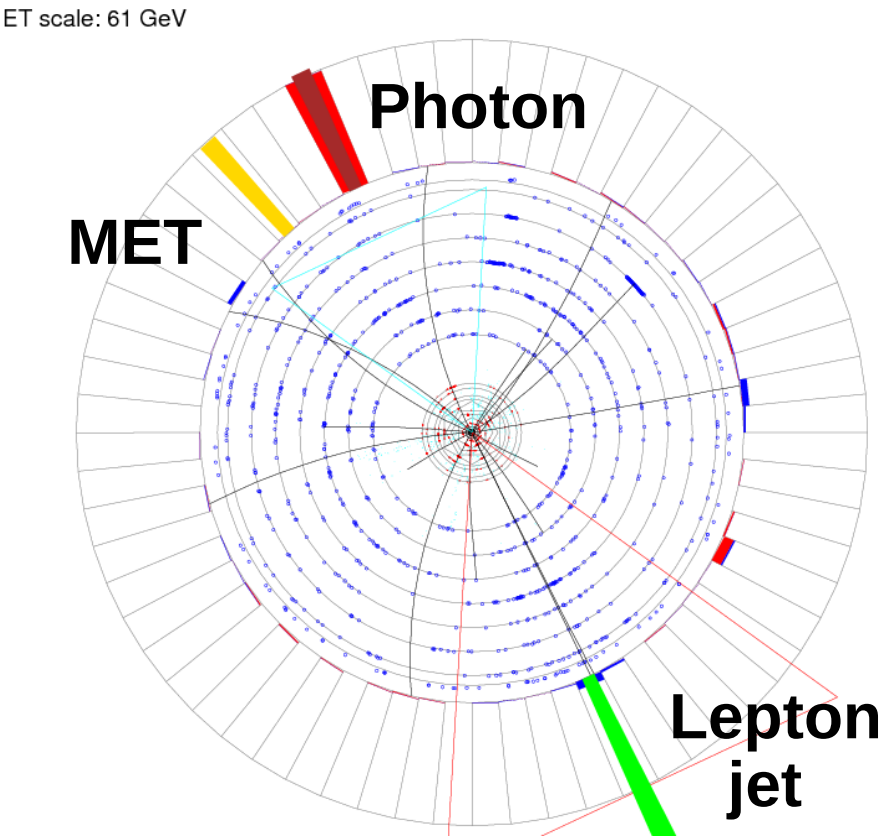


T. Rizzo et al. SUSY without prejudice arXiv:0812.0980

SUSY Hidden Valley: dark photons

- In Hidden Valley SUSY, neutralino can decay into dark photon
- Dark photon decays into photon or “lepton jet”
  - Large boost due to low mass





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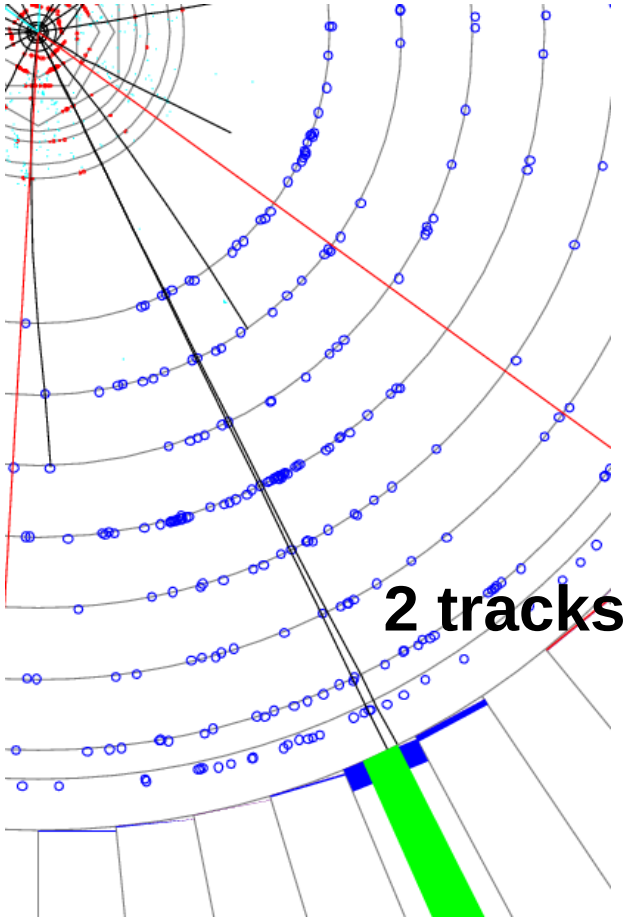
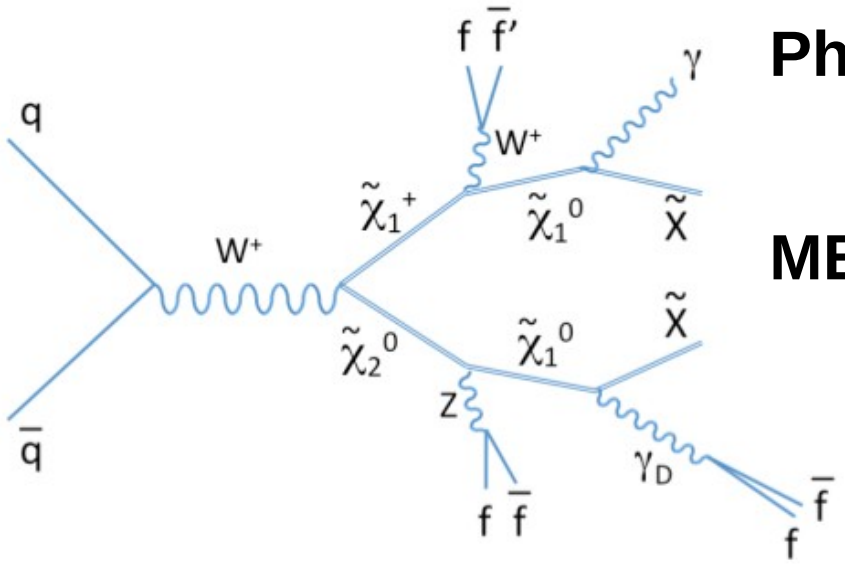




Photon

MET

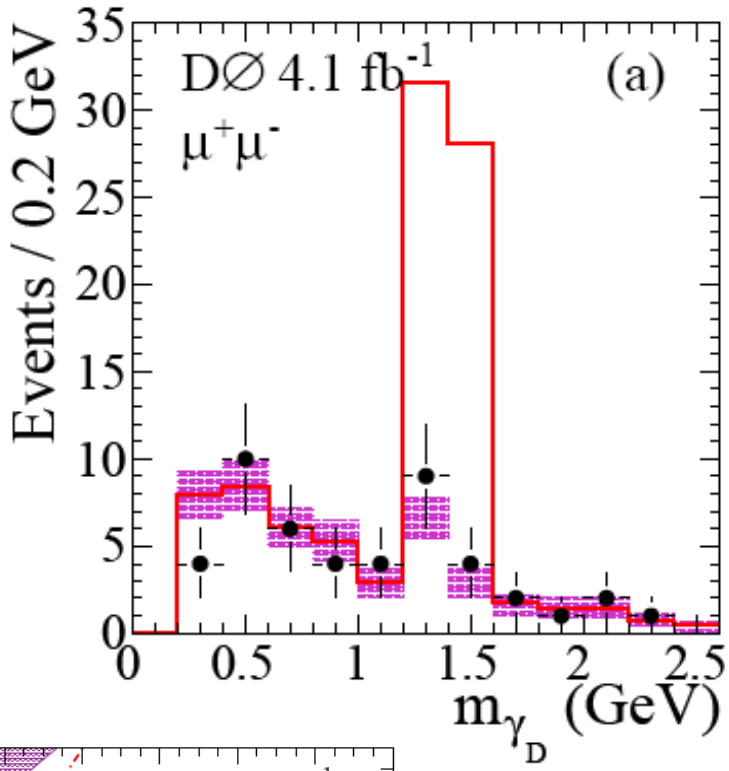
Lepton jet

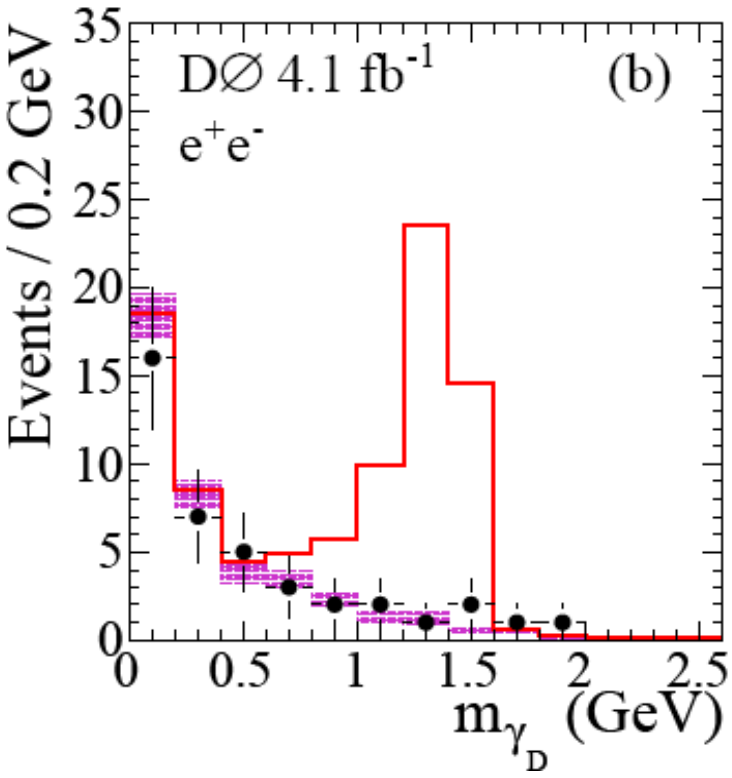
First search for lepton jets!

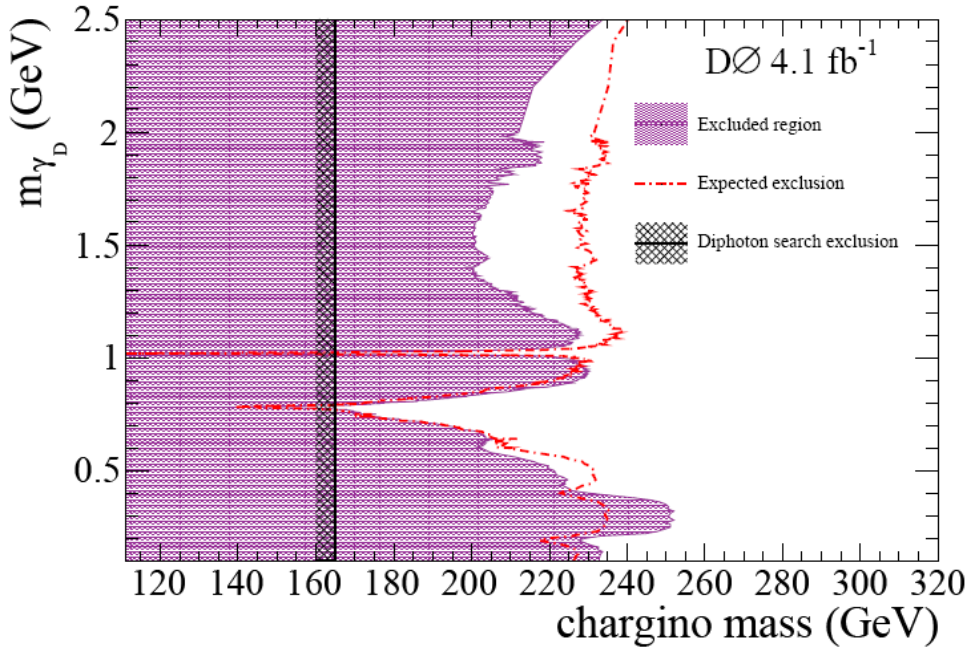
SUSY Hidden Valley: dark photons

RWTH AACHEN UNIVERSITY

Search for peak in dilepton mass





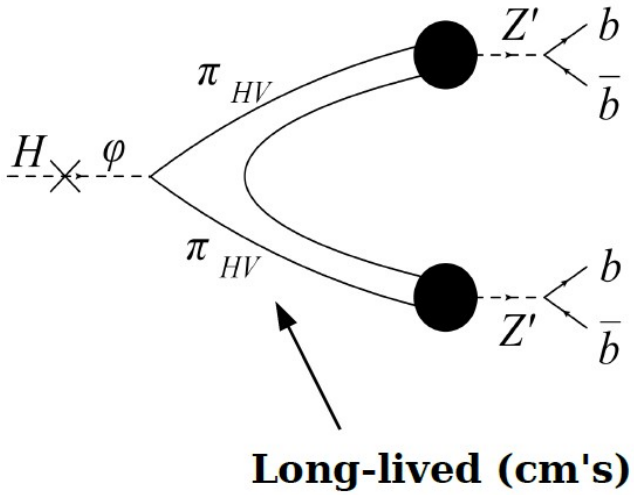


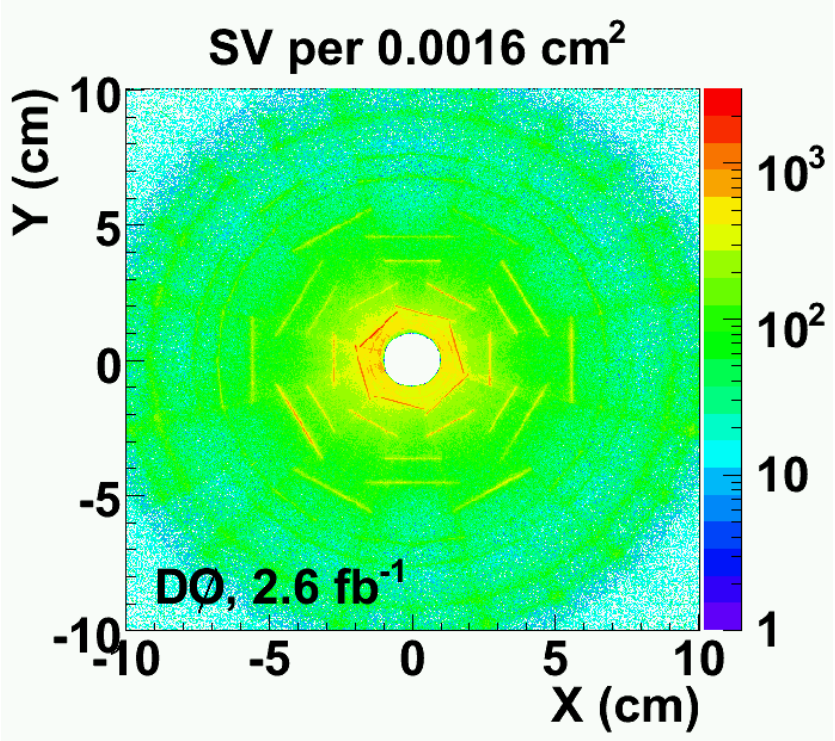
Set limits as function of chargino and dark photon mass

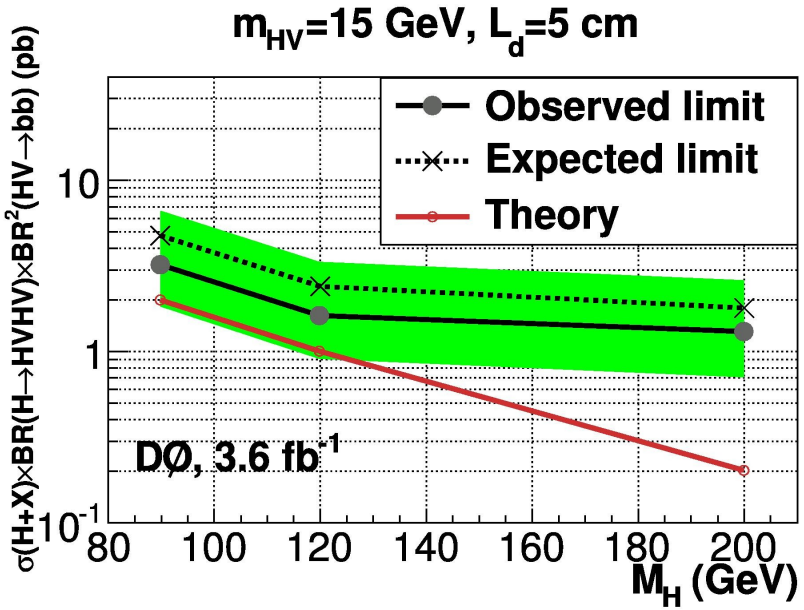
arXiv:0905.1478

Neutral long-lived particles in $b\bar{b}$

- Search for pair production of neutral particles decaying into $b\bar{b}$, within decay radius between 1.6cm and 20cm
- Benchmark model: Higgs boson in hidden valley
  - Higgs decays into a pair of v-hadrons
  - v-hadrons decay preferentially to $b\bar{b}$
- Require two secondary vertices, apply additional kinematic and topological cuts to enhance signal







Limits as function of Higgs mass, v-hadron mass m_{HV} and its decay length

arXiv:0905.1478

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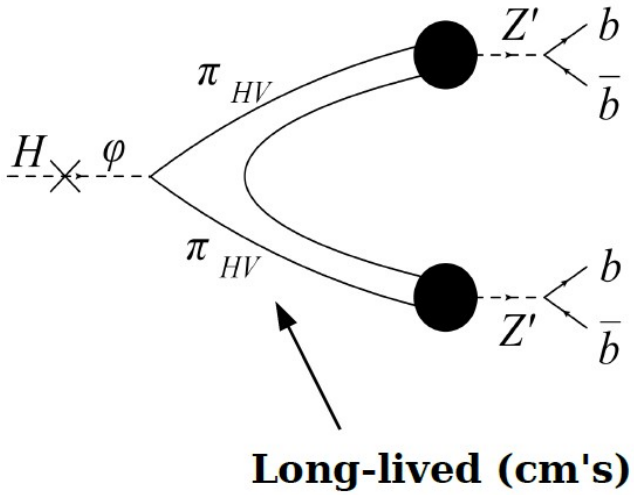
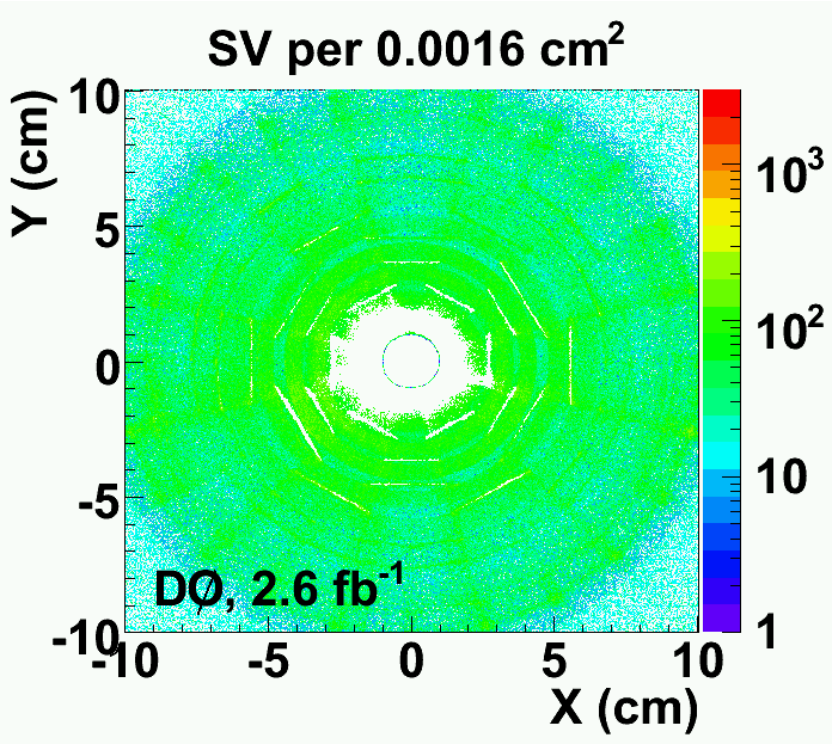
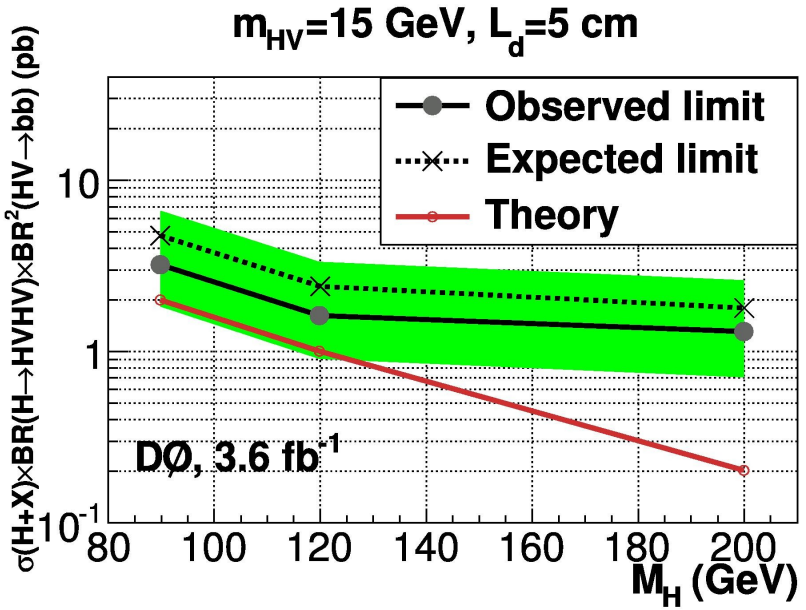


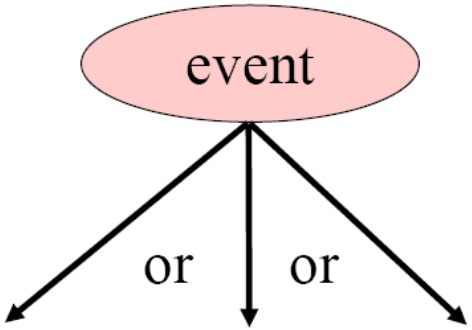


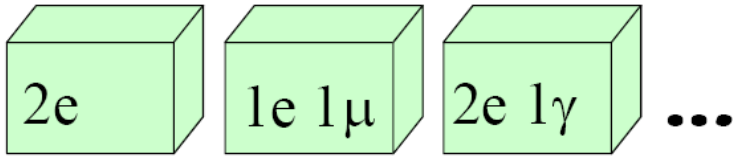


Limits as function of Higgs mass, v-hadron mass m_{HV} and its decay length

arXiv:0905.1478

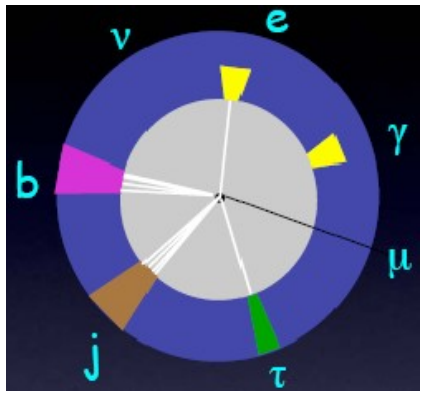
Global Analysis



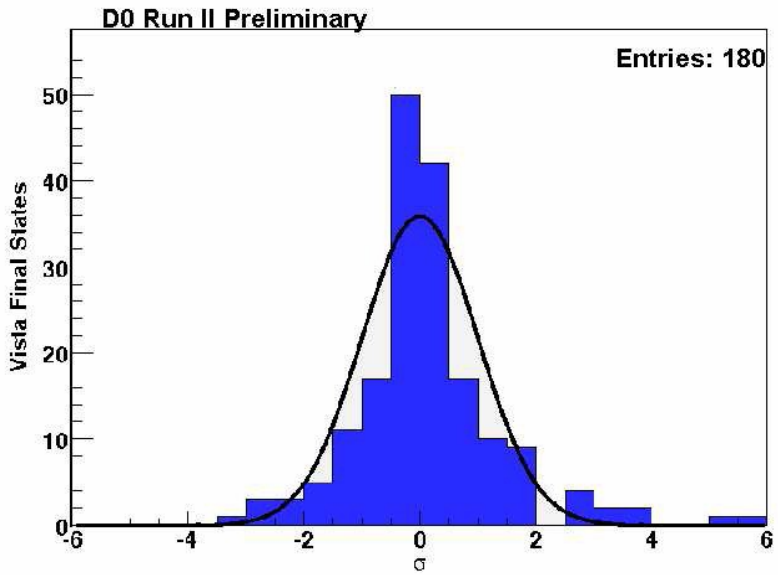


Categorize in terms of (high p_T!) physics objects

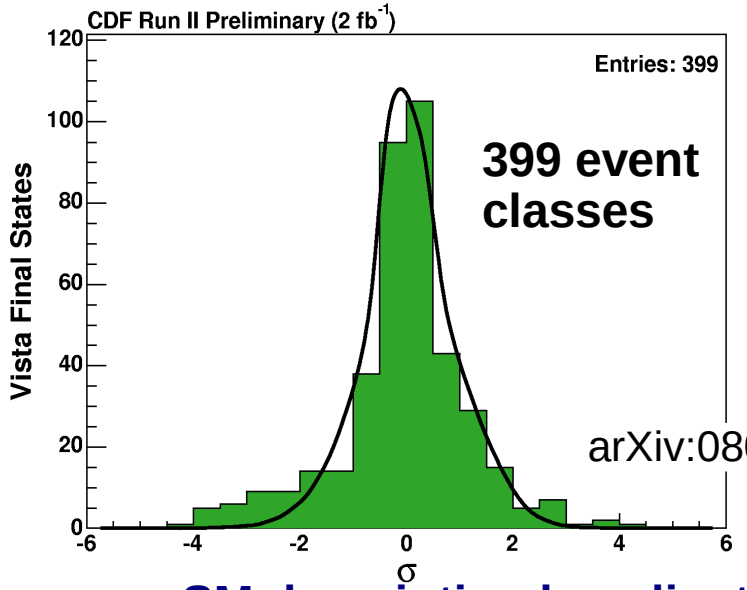
Put events in (e.g.) exclusive boxes
(ej, μjj, γγ+MET, bbj,…)



DØ



CDF: "Vista"

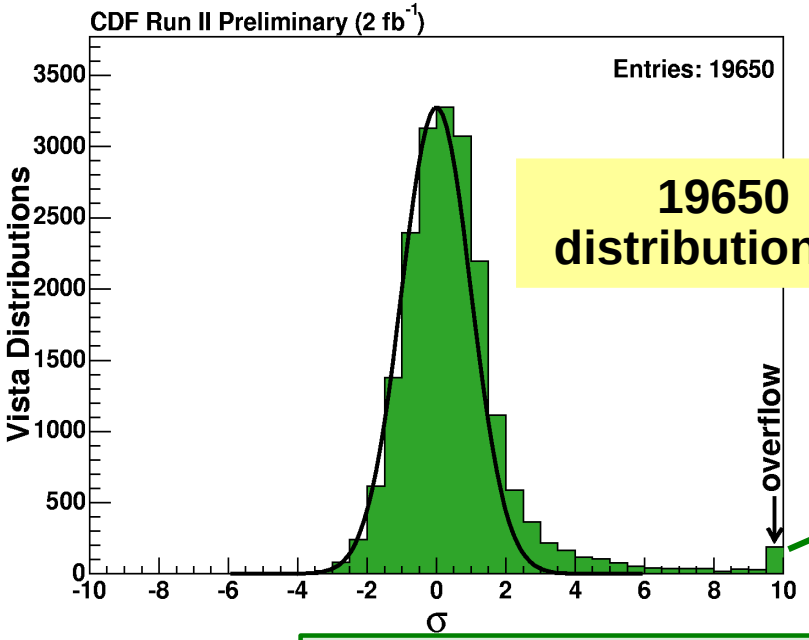


arXiv:0809.3781

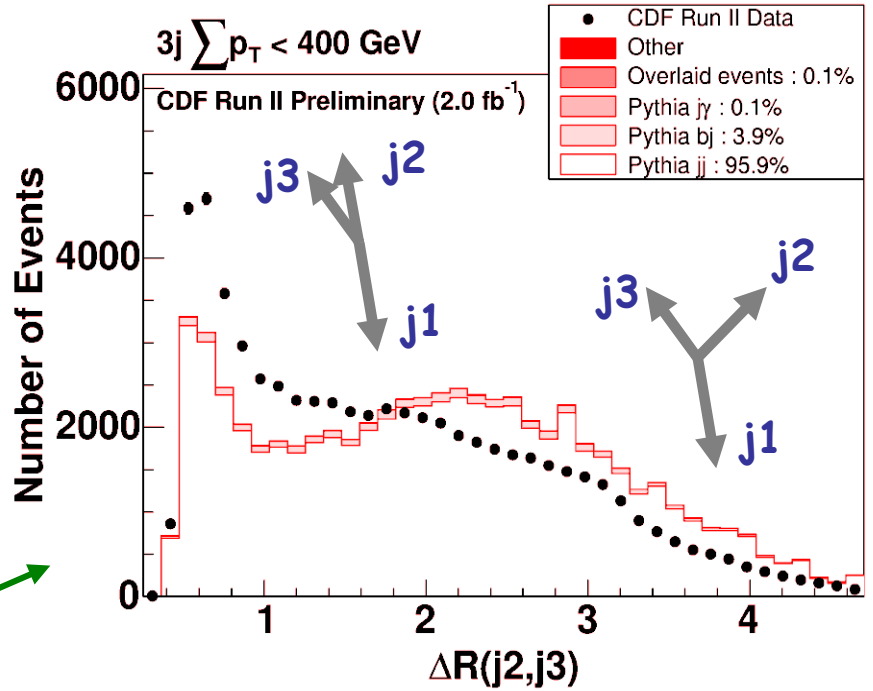
Also: improve SM description by adjusting a number of correction and normalization factors

Global Analysis

Look at a large number of distributions, and perform Kolmogorov-Smirnov tests to find possible discrepancies.



19650 distributions…



Found discrepancies are not suggestive of "new physics", rather of an inadequate modeling of soft QCD

Once the bulk of the distributions is under control, look specifically at the high $\sum p_T$ tails ("Sleuth"), and check for mass bumps (only CDF)

No more deviations than expected from statistics found in 2 fb^{-1} (CDF) / 1.1 fb^{-1} (D0) (taking into account the number of trials)

Conclusions

- A vibrant program searching for new phenomena continues – have shown a small selection of new(er) results in selected areas
- With 6 fb^{-1} of integrated luminosity collected at the Tevatron, updates promising
- All Tevatron results and more available at
  http://www-d0.fnal.gov/Run2Physics/WWW/results.htm
  http://www-cdf.fnal.gov/physics/exotic/exotic.html