Searches with γ and jets at the Tevatron

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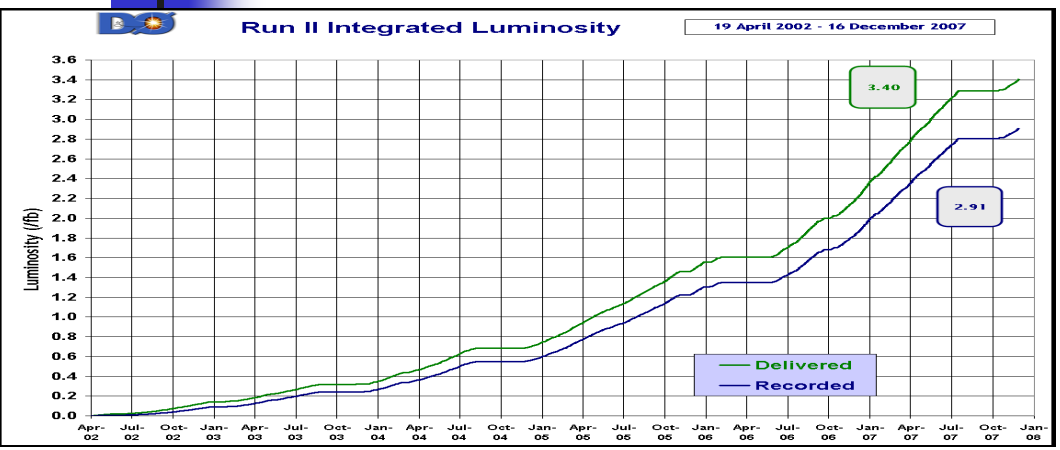
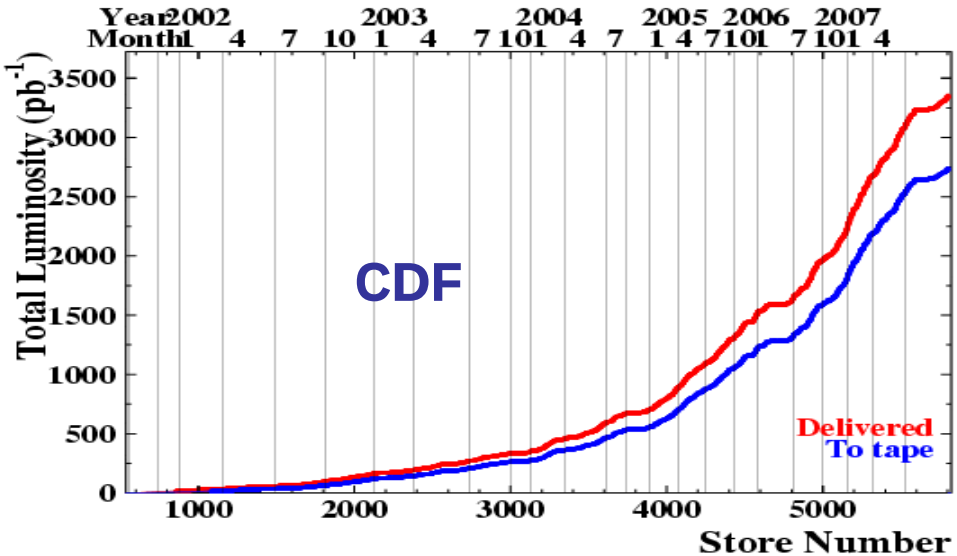
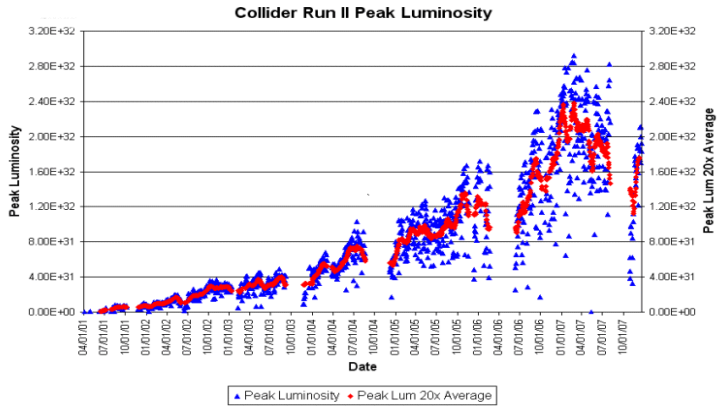
On behalf of the CDF and D0 Collaborations

Aspen CO, Jan 14, 2008

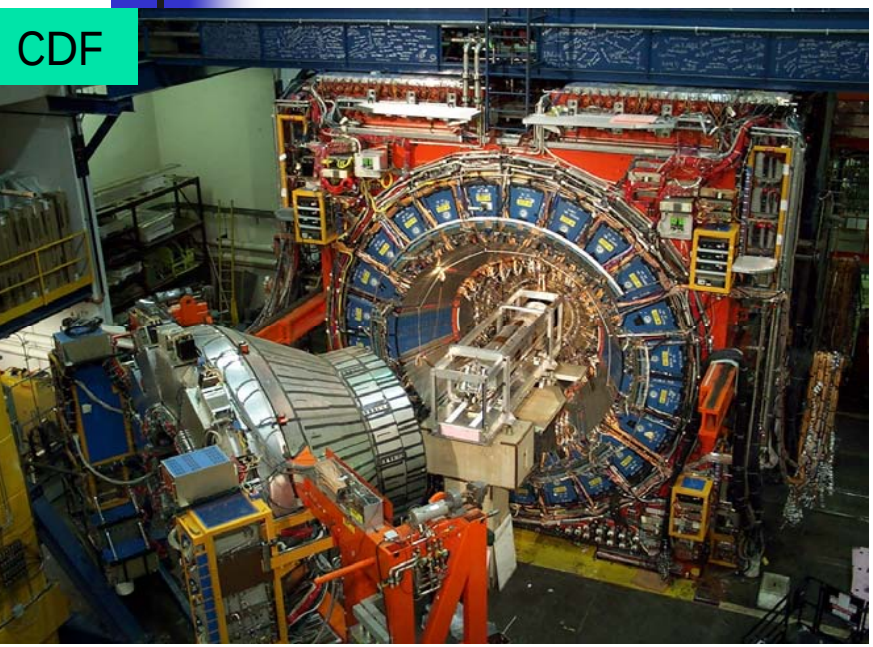
Tevatron has a lot of data!







CDF and D0 detectors



1.4 T, R=1.5m L=4.8m

Silicon microstrip, open-cell drift chamber

Sampling calorimeter, preshower(CPR), showermax detector (CES)

muon system

2T, R=0.7m L=2.7m

Silicon microstrip, central fiber tracker

Sampling calorimeter, preshower(CPS), finer granularity at 3rd layer of EM,

muon system

Recent results with ⩾ 1/fb only

Outline:

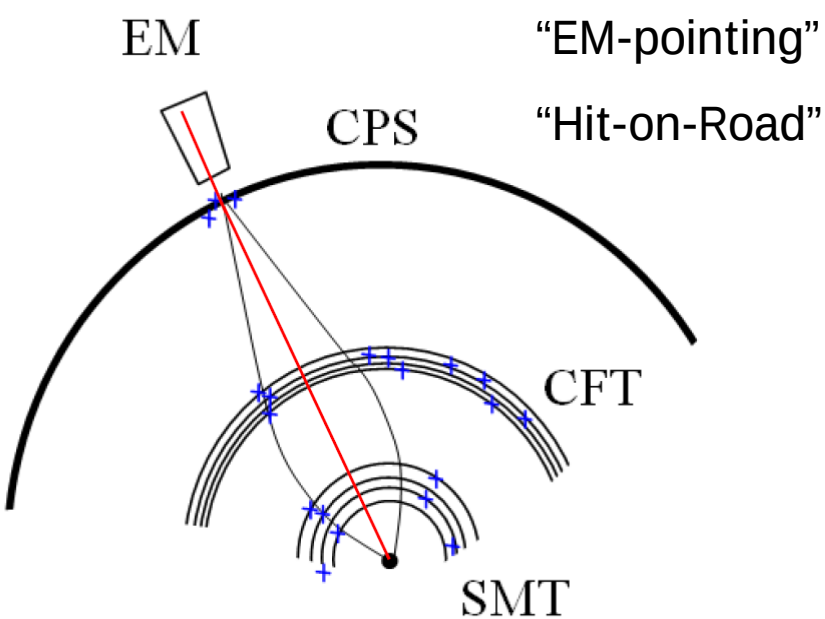
- $\gamma\gamma$+MET D0 1.1/fb, accepted (PLB)
- $\gamma\gamma$+MET CDF 1.2/fb signature-based
- Graviton$\rightarrow\gamma\gamma$ CDF 1.2/fb published (PRL)
- Graviton$\rightarrow\gamma\gamma$/ee D0 1/fb submitted (PRL)
- Graviton+γ CDF 2/fb preliminary
- $\gamma\gamma\tau$ CDF 2/fb signature-based
- jets+MET D0 2.1/fb submitted (PLB)
- jets+MET CDF 1.4/fb preliminary
- cc+MET D0 1/fb preliminary
- MIS CDF 0.9/fb submitted (PRL+PRD)

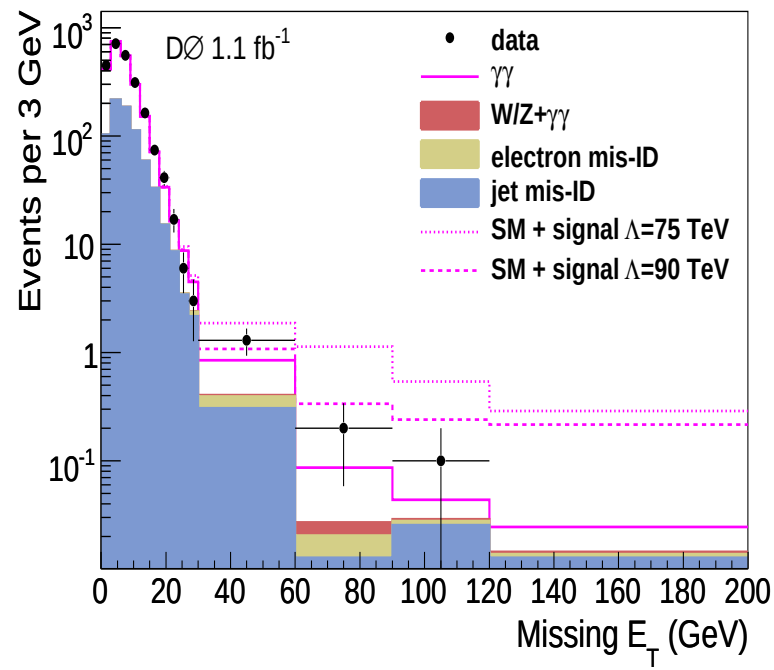
arXiv:0710.3946 [hep-ex], accepted by PLB,1.1/fb

$\tilde{\chi}_1^0 = \text{NLSP},$
$\tilde{G} = \text{LSP}$
$\tilde{\chi}_1^0 \to \gamma\tilde{G}$ prompt decay

Search for SUSY in $\gamma\gamma$+MET (I)

- GMSB, R-parity conserved,
- $\gamma\gamma$ final states
- 2x ET>25 GeV, $|\eta|<1.1$, at least one CPS.
- No jet with $\Delta\varphi(\text{MET},j)>2.5$

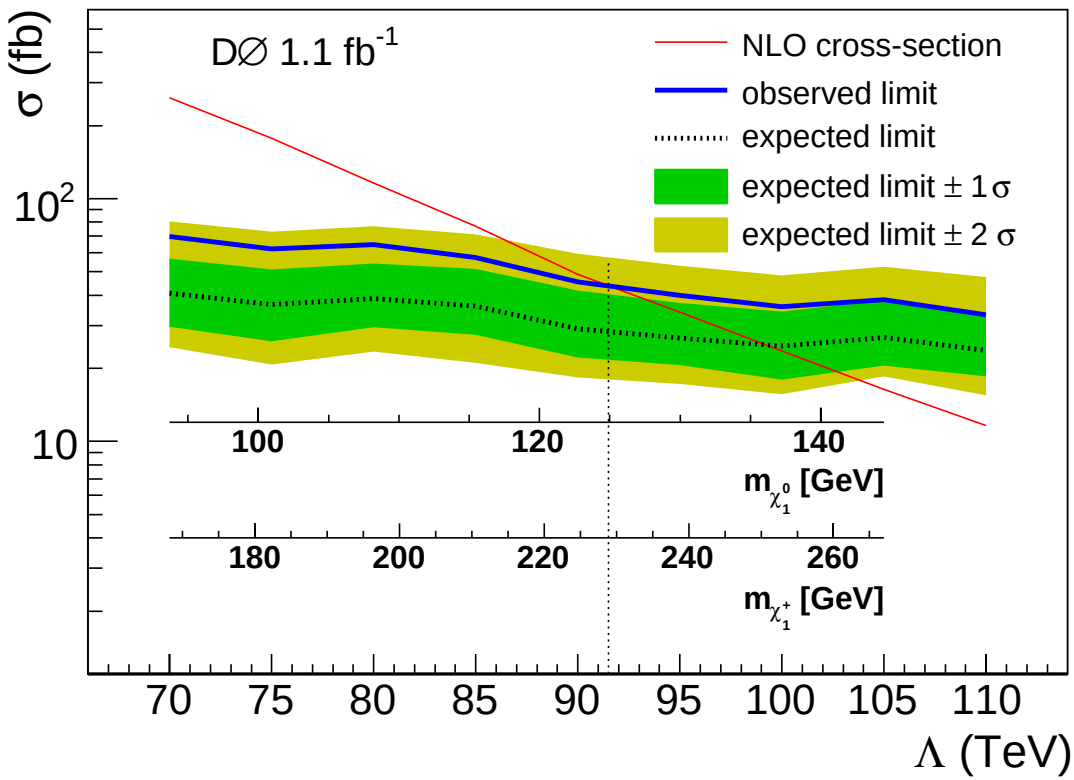




For MET>60 GeV, Nobs=3, Nexp = 1.6 +-0.4

Benchmark signal model:
Snow mass Slope SPS 8 [reference]
$\tan\beta$ = 15, $\mu>0$,N5=1,Mm=2Λ(slope)

Search for SUSY in $\gamma\gamma$+MET(II)



Consider all GMSB production channels.

Limit from MET distribution

Systematic dominated by photon identification efficiency (10%).

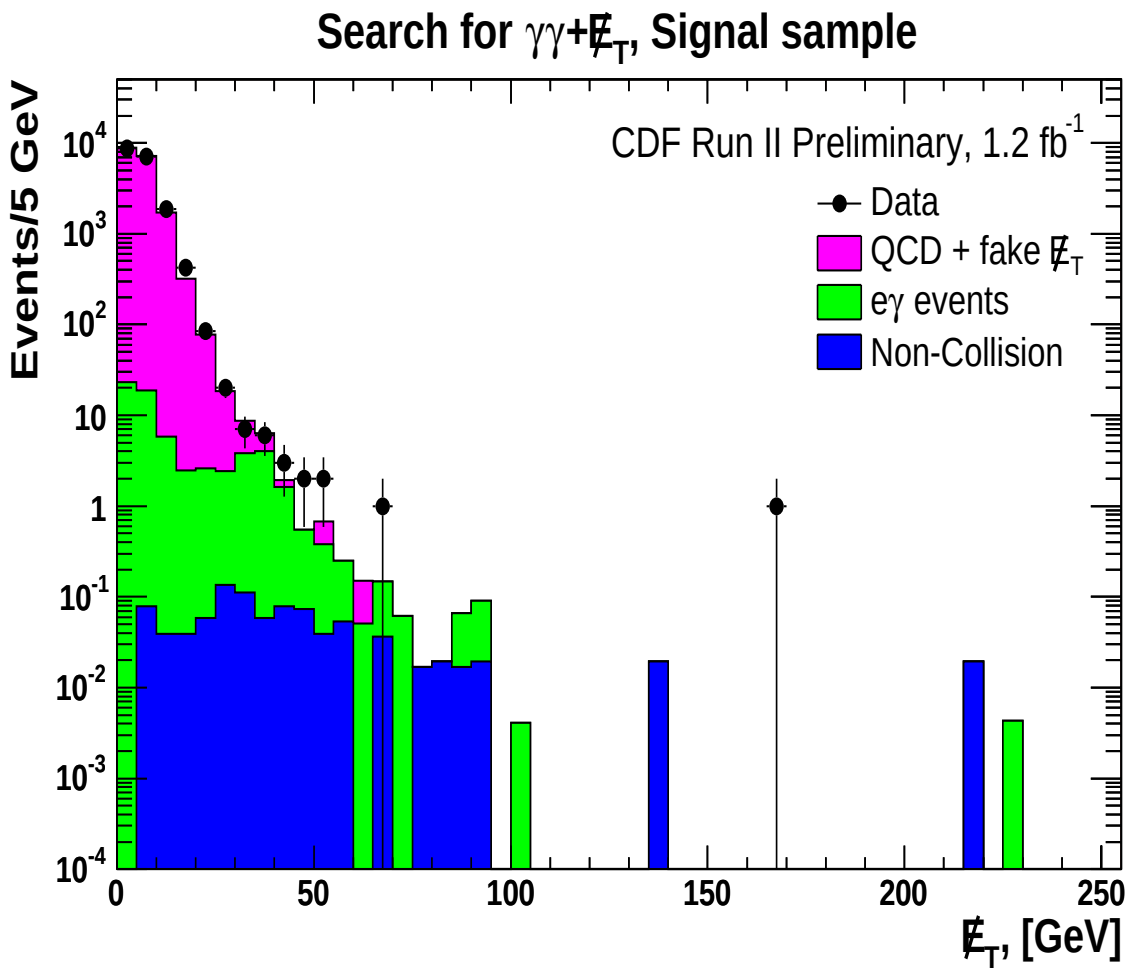
Λ>91.5 TeV at 95% C.L.

Previously CDF/D0 (260/200 pb-1) commined : Λ>84.6TeV at 95% CL

$$m_{\tilde{\chi}_1^0} > 125\,\mathrm{GeV}$$
$$m_{\tilde{\chi}_1^+} > 229\,\mathrm{GeV}$$

1.2/fb

Search in $\gamma\gamma$+MET



2X ET>13 GeV
$|\eta|<1$
Shower shape
Isolated in calorimeter
Isolated in tracker
|vertex z|<60 cm

For MET>50 GeV

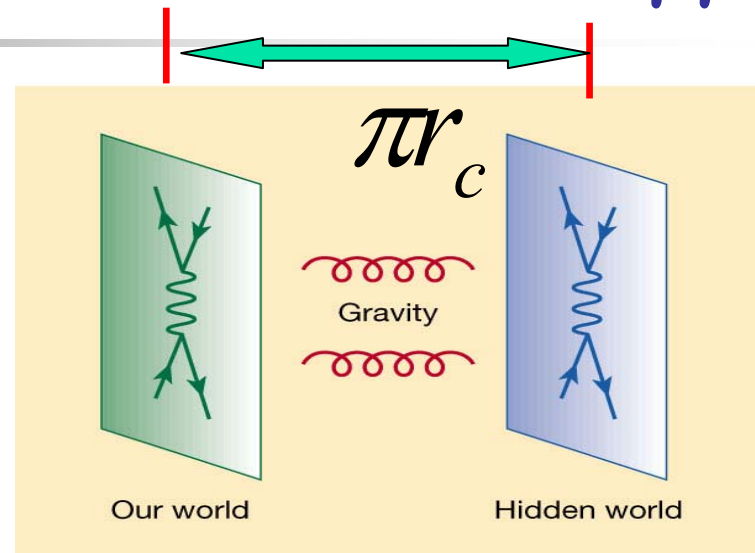
Nobs=4

Nexp = 1.6+-0.3+-0.2

p-value = 9%

Cannot rule out the SM.

Search for RS Gravitons in $\gamma\gamma$



$\varphi=\pi$ $\varphi=0$

$$ds^2 = e^{-2kr_c\phi}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^{\,2}d\phi^2$$

$$0 \le \phi \le \pi$$

scale of physical phenomena on the Tev Brane $(\phi = \pi)$ is

$$\Lambda_\pi \equiv \overline{M}_{pl}e^{-kr_c\pi}, (\overline{M}_{pl} = M_{pl}/\sqrt{8\pi})$$

$$kr_c \approx 11-12 \text{ for } \Lambda_\pi \approx \text{TeV}$$

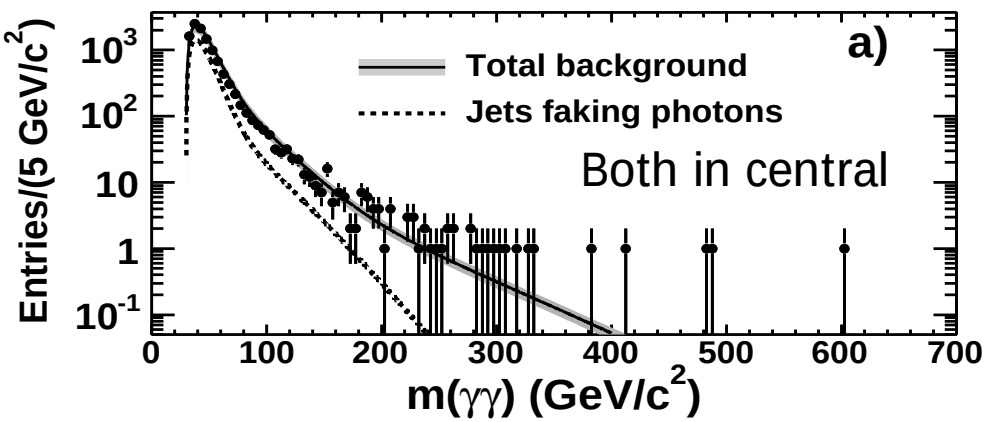
$$0.01 < k/\overline{M}_{pl} < 0.1 \text{ currently being tested}$$

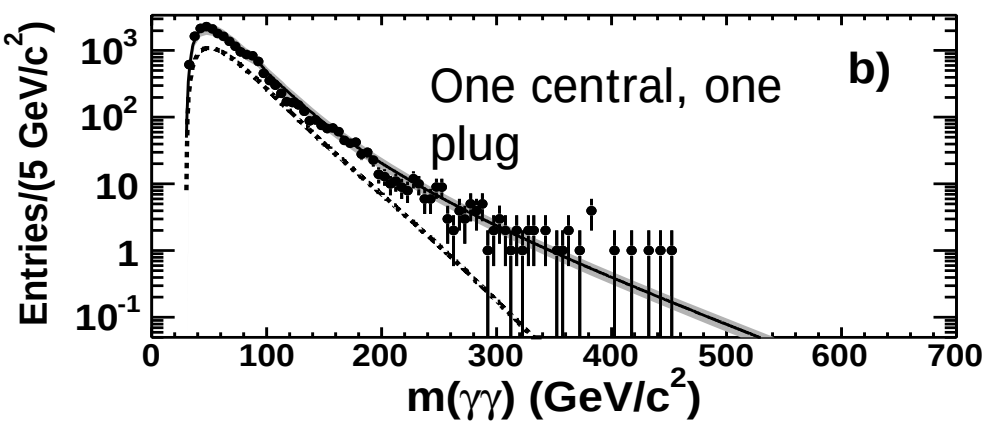
Small overlap of gravitation waves function with TeV brane =>

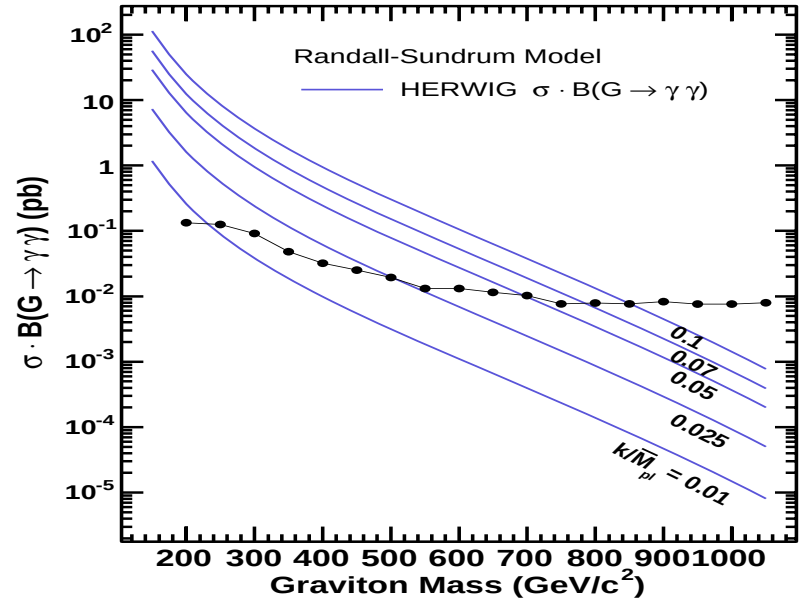
Kaluza Klein tower of Graviton states that can decay to photon pairs.

1.2/fb PRL99,171801(2007)

The $\gamma\gamma$ data

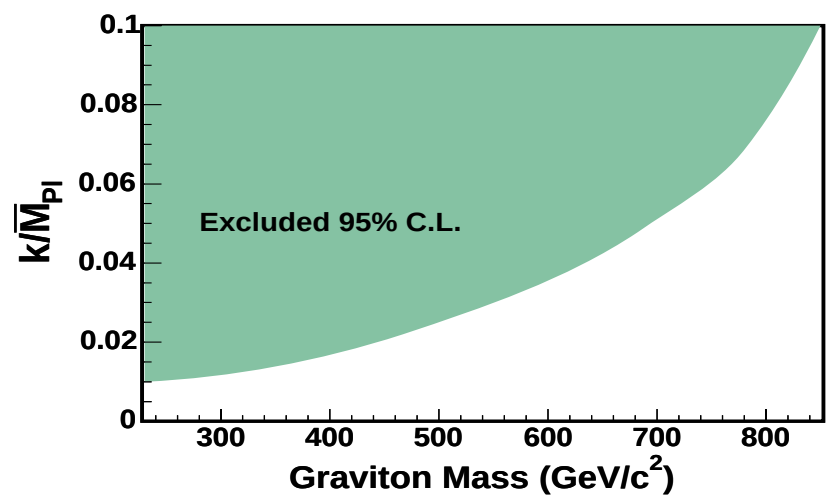






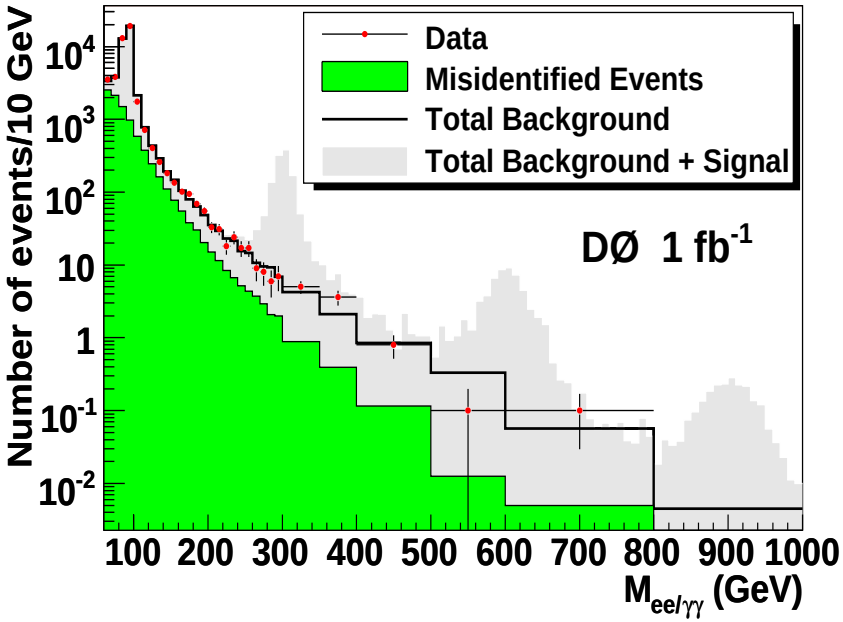
$\gamma\gamma$ estimated with **DIPHOX** (20%uncertainty)

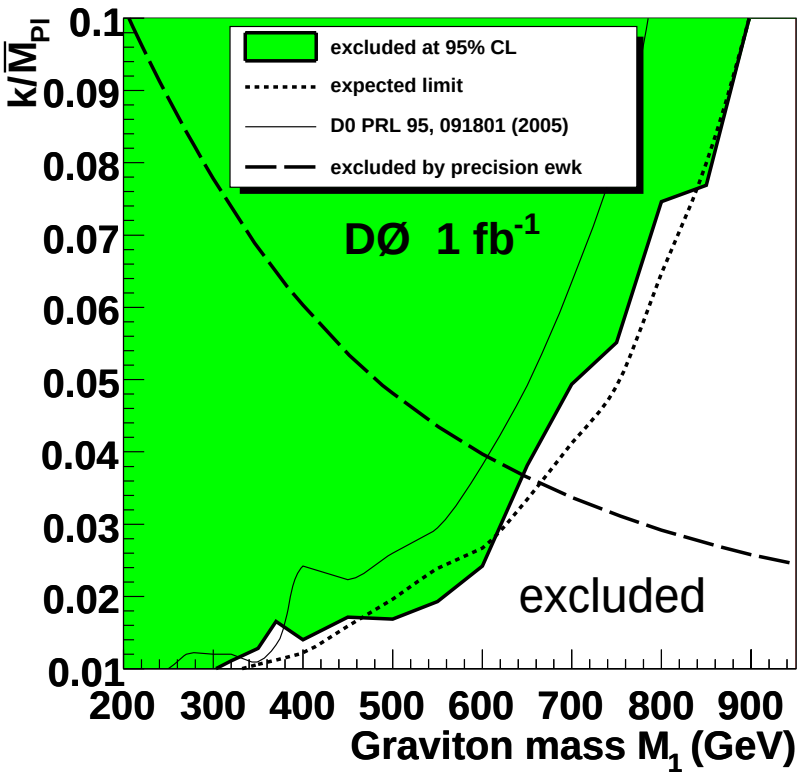
Mass shape of "photon-like" jets from data(20% uncertainty), normalized with 30-100 GeV.



D0, 1/fb, arXiv:0710.3338 [hep-ex] submitted to PRL

$\gamma\gamma$/ee data





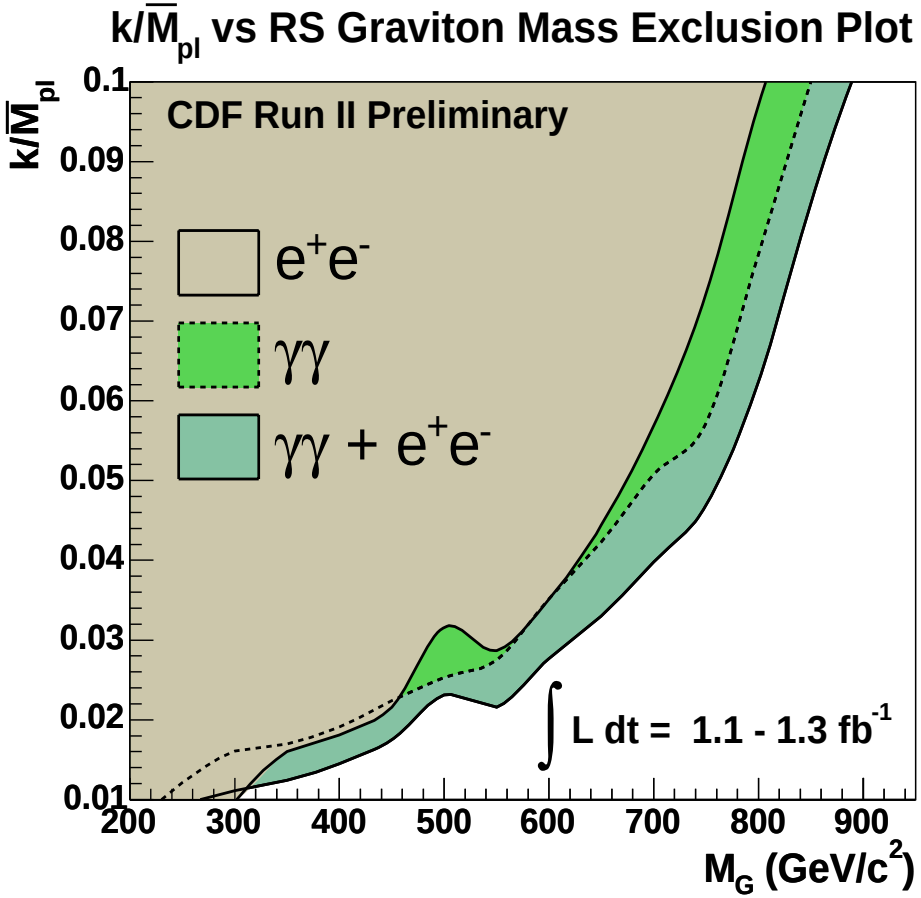
BR(G→$\gamma\gamma$)/BR(G→ee) = 2

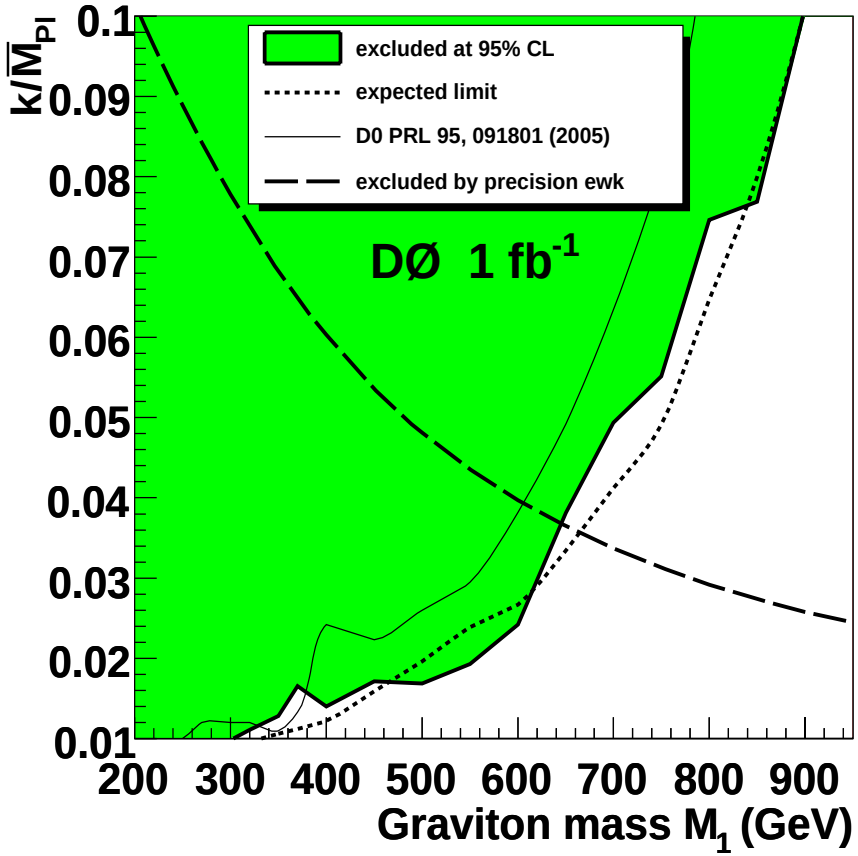
e/γ with pT>25 GeV |η|<1.1

$\gamma\gamma$/ee from MC simulations.

Multi-jet contribution from data.

CDF and D0


k/M̄pl vs RS Graviton Mass Exclusion Plot
CDF Run II Preliminary
e+e-
γγ
γγ + e+e-
∫ L dt = 1.1 - 1.3 fb-1
k/M̄pl
MG (GeV/c2)


excluded at 95% CL
expected limit
D0 PRL 95, 091801 (2005)
excluded by precision ewk
DØ 1 fb-1
k/M̄Pl
Graviton mass M1 (GeV)

Trading energy with space. But impressive experimental consequences.

Large extra dimensions

D - dimensional space, $z = (z_{1,} ..., z_D) = (x_{0,} x_1, x_2, x_3, y_{1,} ..., y_\delta)$

$\delta = D - 4$

Every of the extra dimension is compactified. Imposing periodicity :

$y_j \to y_j + 2\pi R, j = 1,..., \delta.$

$\overline{M}_P = R^{\delta/2} M_D^{1+\delta/2}$

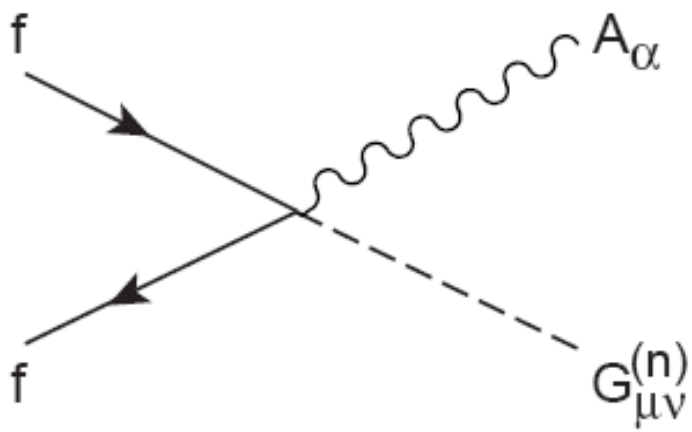
D - dimensional Plank scale can be natural (~TeV).

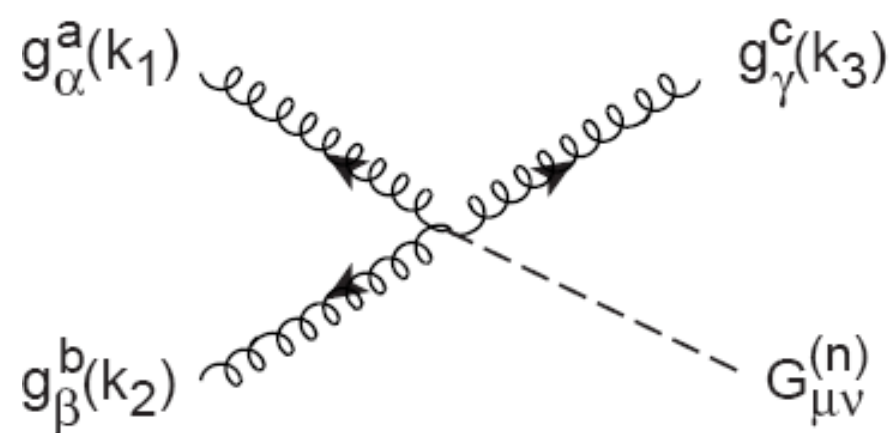
Graviton production cross section, suppressed by $(1/\overline{M}_P)^2$,

can be significant due to the compensation D - dimensional phase - space factor.

Graviton production associated with photon or jet

leaves photon or jet +MET signature.





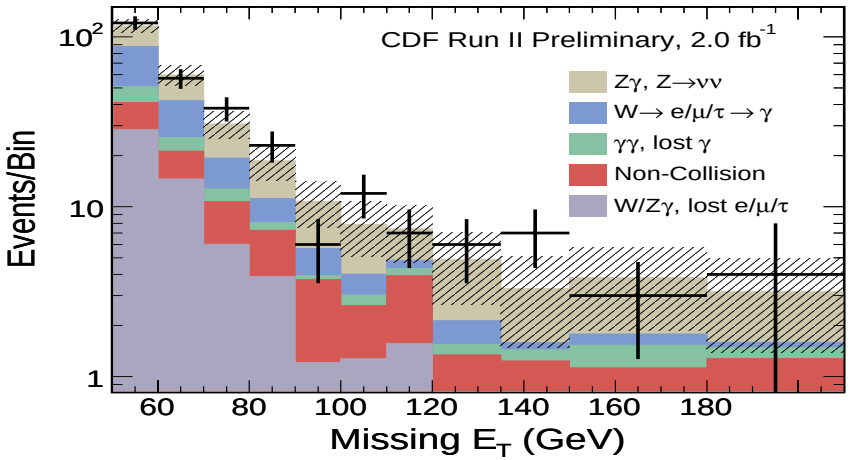
2/fb

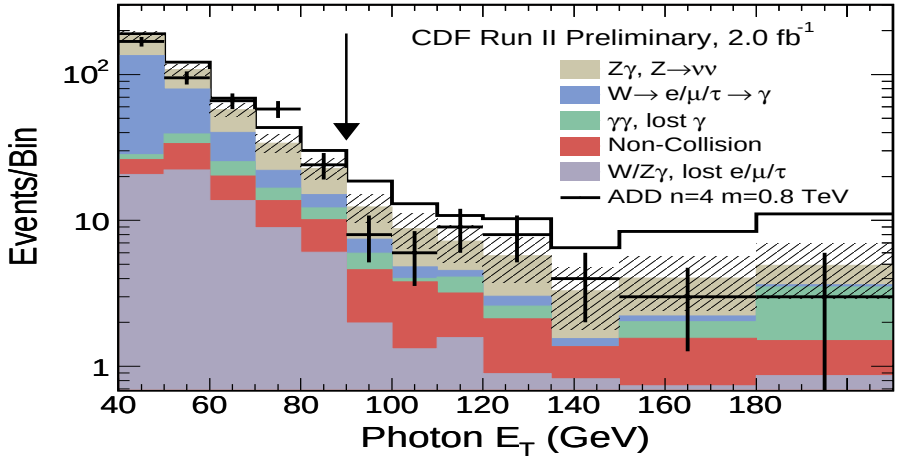
Only a photon (+ remnants) in detector

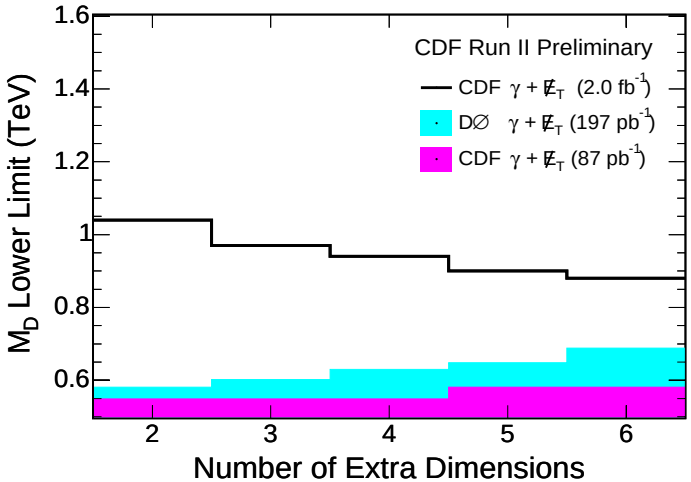
Varieties of the background!

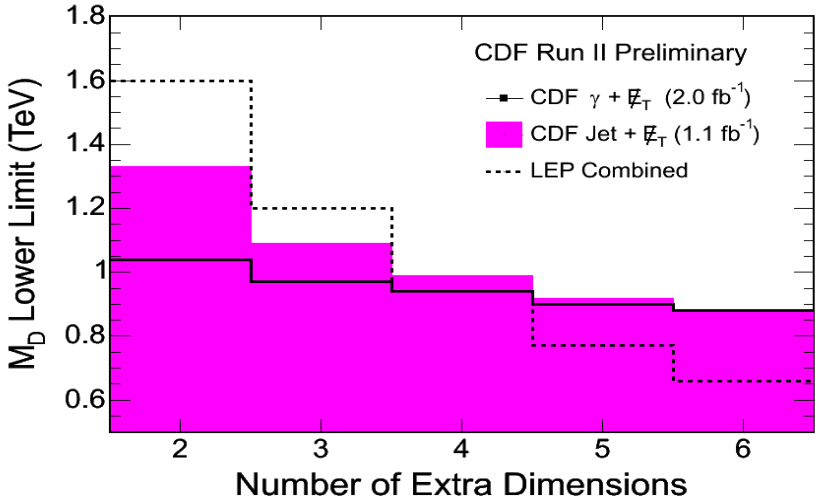
Significantly improved the exclusion limits.

Photon + MET search









2/fb

$\gamma\gamma+\tau$

Tau id

Seed track pT>4.5 GeV

Fiducial to shower max detector

Electron veto (EM fraction)

Visible mass < 1.8 GeV

Track isolation

1 or 3 tracks in 10 deg cone

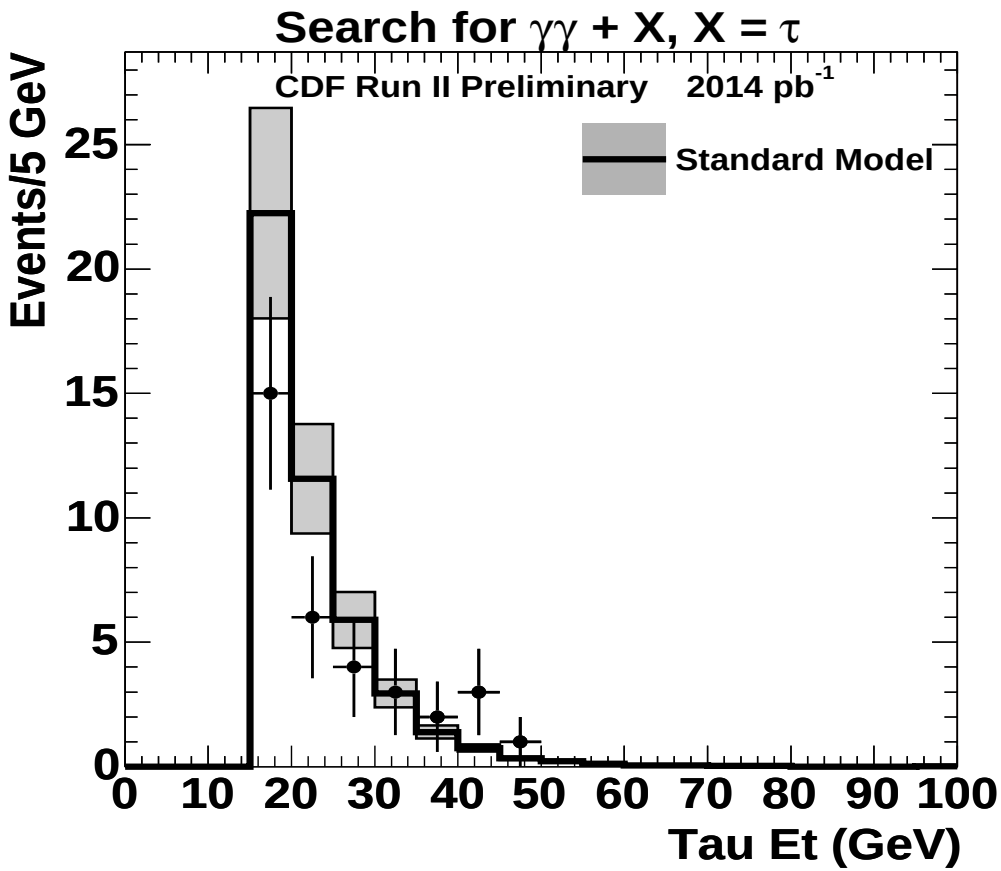
total charge +-1

$\pi 0$ pT<0.6 GeV

20% uncertainty on fake rate

Dominant background from jets faking τ

MC: quark jet 3x more likely to fake τ



Source	Number
Fakes	44+-10
Wγ	1.2+-0.7
Zγ	1.0+-0.3
Total	46+-10
Observed	34

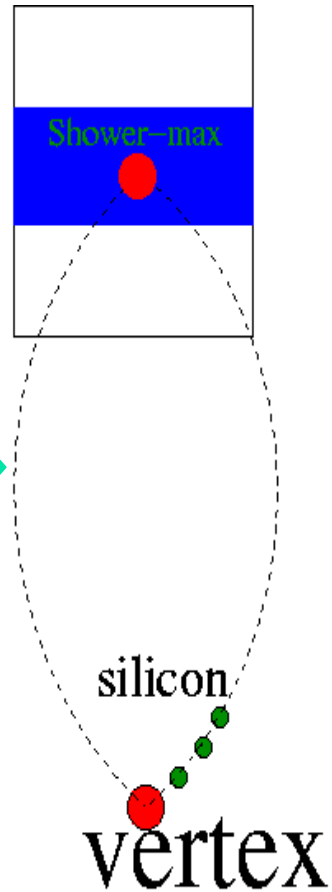
, 1/fb

$\gamma\gamma e$, $\gamma\gamma\mu$

Before applying Phoenix rejection		
Source	electron	muon
$Z\gamma\gamma$	$0.904 \pm 0.023 \pm 0.083$	$0.552 \pm 0.017 \pm 0.050$
$W\gamma\gamma$	$0.170 \pm 0.012 \pm 0.016$	$0.086 \pm 0.008 \pm 0.008$
Fake $l+\gamma\gamma$	$0.131 \pm 0.004 \pm 0.053$	$0.004 \pm 0.003 \pm 0.002$
$l\gamma + \text{jet} \rightarrow \gamma$	$0.475 \pm 0.025 \pm 0.312$	$0.133 \pm 0.013 \pm 0.090$
$l\gamma + e \rightarrow \gamma$	$5.140 \pm 0.340 \pm 0.584$	$0.017 \pm 0.017 \pm 0.002$
Total	6.82 ± 0.75	0.79 ± 0.11
Data	3	0

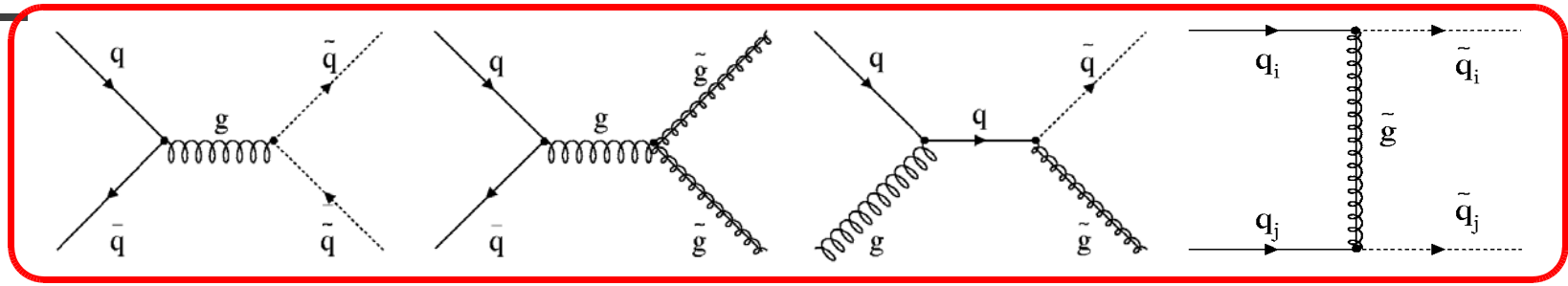
“phoenix tracking”

After applying Phoenix rejection		
Source	electron	muon
$Z\gamma\gamma$	$0.816 \pm 0.021 \pm 0.074$	$0.498 \pm 0.016 \pm 0.045$
$W\gamma\gamma$	$0.153 \pm 0.011 \pm 0.014$	$0.078 \pm 0.008 \pm 0.007$
Fake $l+\gamma\gamma$	$0.118 \pm 0.004 \pm 0.049$	$0.004 \pm 0.003 \pm 0.002$
$l\gamma + \text{jet} \rightarrow \gamma$	$0.439 \pm 0.023 \pm 0.263$	$0.123 \pm 0.012 \pm 0.083$
$l\gamma + e \rightarrow \gamma$	$2.261 \pm 0.211 \pm 0.411$	$0.004 \pm 0.004 \pm 0.001$
Total	3.79 ± 0.54	0.71 ± 0.10
Data	1	0



Not to scale – for illustration purpose only

Search for squarks and gluinos with jets and MET



Assumptions: R-parity is conserved

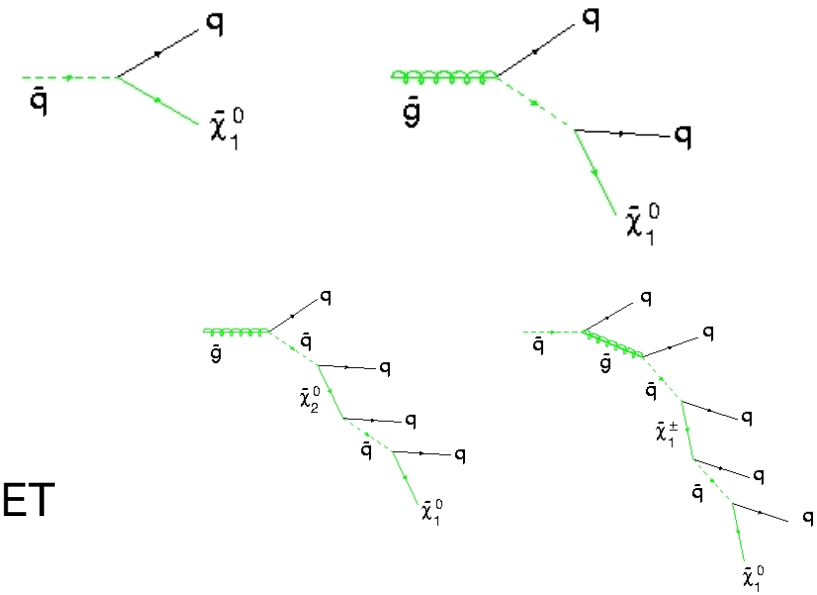
mSUGRA, LSP is neutralino

Ignore stop. A0=0,tanβ = 3, μ < 0.

<u>3 channels:</u>

at least 2-jet, 3-jet, “gluinos (4 jets)”

Events collected with di-jet and multi-jet + MET triggers, average 97% efficient.



Jets and MET selection

2 leading jets:

|detector η|<0.8

⩾ 5% energy in HCAL

⩾75% track pT from tracks associated to the event primary vertex

3rd, 4th jet:

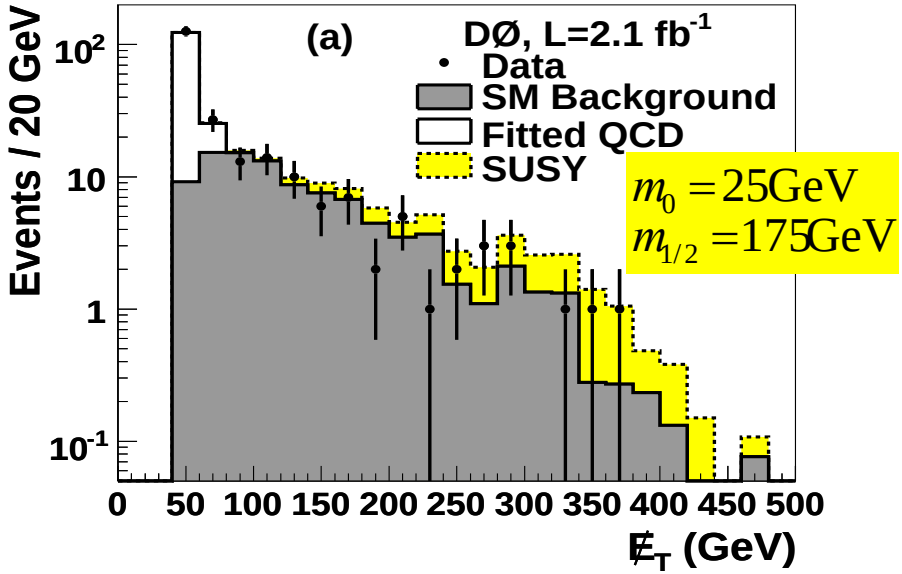
|detector η|<2.5

HT=Σ(all jets)pT, MET cuts optimized for best expected limits.

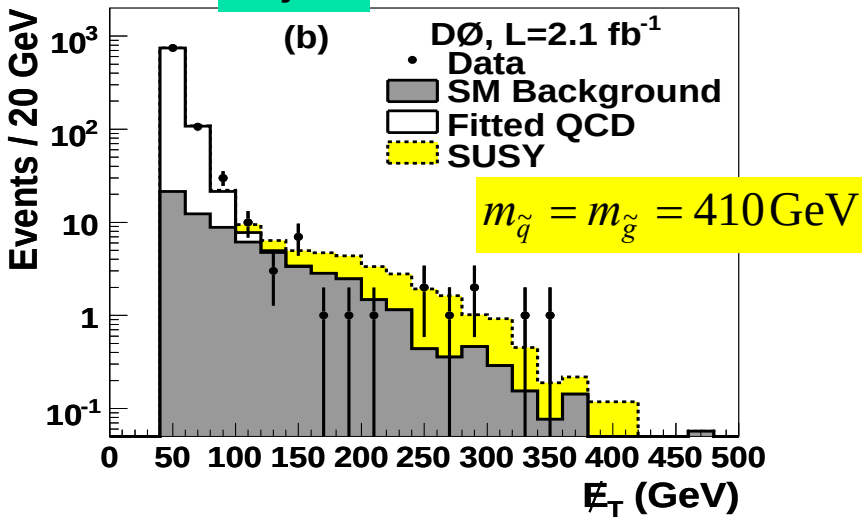
Preselection Cut	All Analyses		
$\not\!\!E_T$	≥ 40		
|Vertex z pos.|	< 60 cm		
Acoplanarity	$< 165°$		
Selection Cut	"dijet"	"3-jets"	"gluino"
Trigger	dijet	multijet	multijet
jet$_1$ $p_T{}^a$	≥ 35	≥ 35	≥ 35
jet$_2$ $p_T{}^a$	≥ 35	≥ 35	≥ 35
jet$_3$ $p_T{}^b$	–	≥ 35	≥ 35
jet$_4$ $p_T{}^b$	–	–	≥ 20
Electron veto	yes	yes	yes
Muon veto	yes	yes	yes
$\Delta\phi(\not\!\!E_T, \text{jet}_1)$	$\geq 90°$	$\geq 90°$	$\geq 90°$
$\Delta\phi(\not\!\!E_T, \text{jet}_2)$	$\geq 50°$	$\geq 50°$	$\geq 50°$
$\Delta\phi_{\min}(\not\!\!E_T, \text{any jet})$	$\geq 40°$	–	–
H_T	≥ 325	≥ 375	≥ 400
$\not\!\!E_T$	≥ 225	≥ 175	≥ 100

Jets & MET: MET distribution

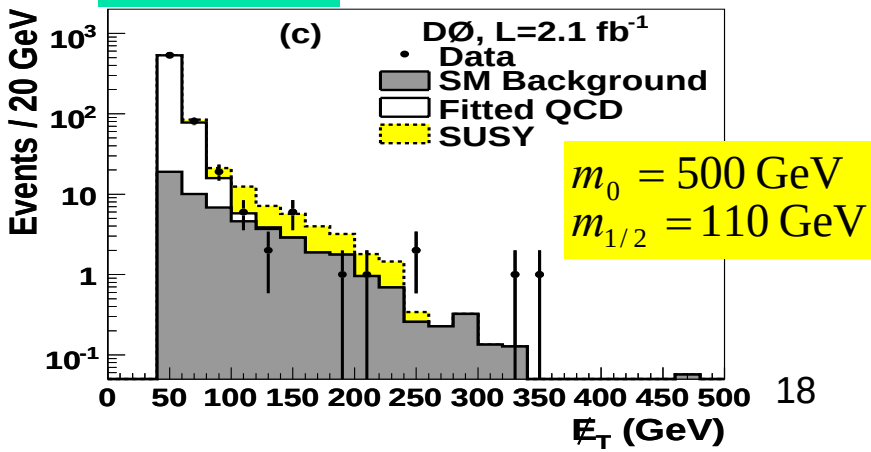
Dijet



3-jet



"gluino"



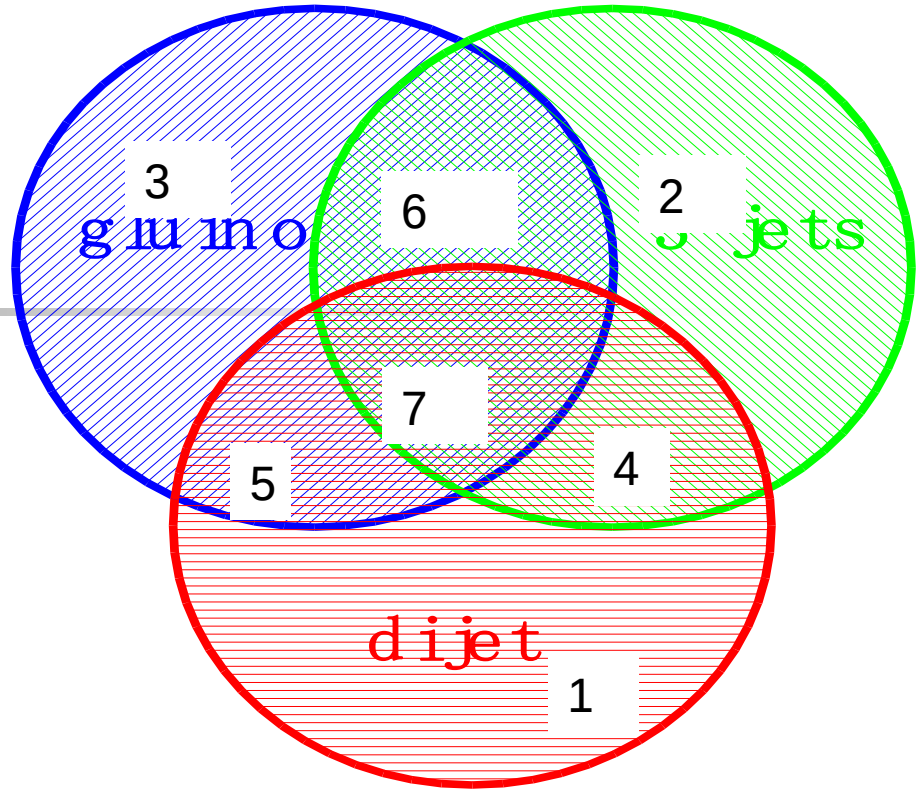
Background : W/Z + jets, WW/WZ/ZZ, ttbar, single top, from MC

Multi-jet, from data, fit MET<60 GeV, negligible after the final MET cut.

Combined, data:31 events background: 32.1,

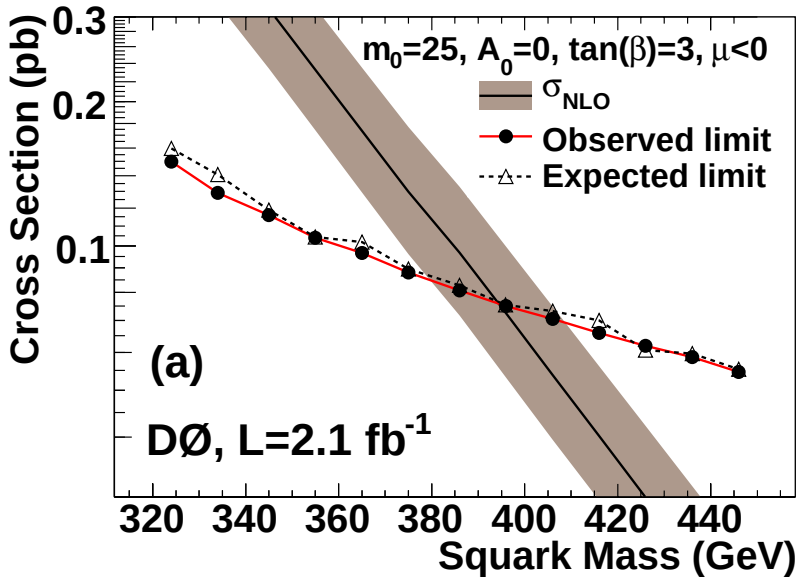
uncertainty~30%:JES,lumi,,NLO cross section...

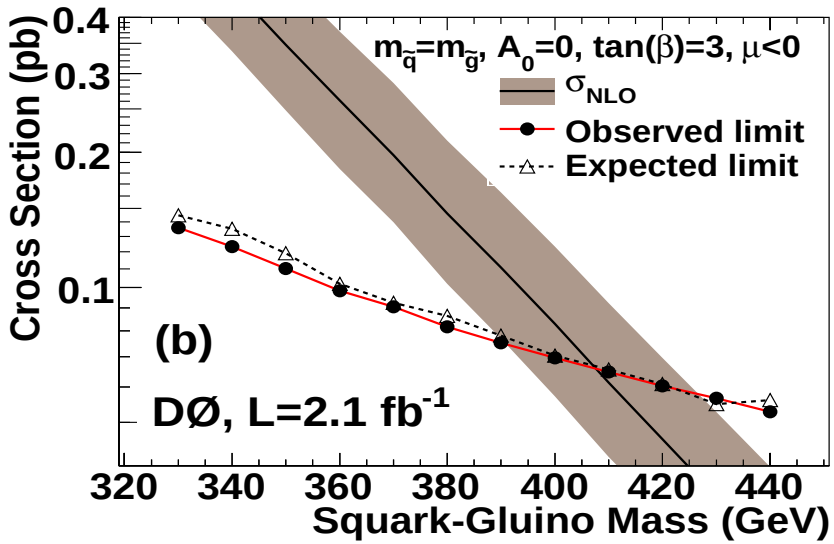
combination

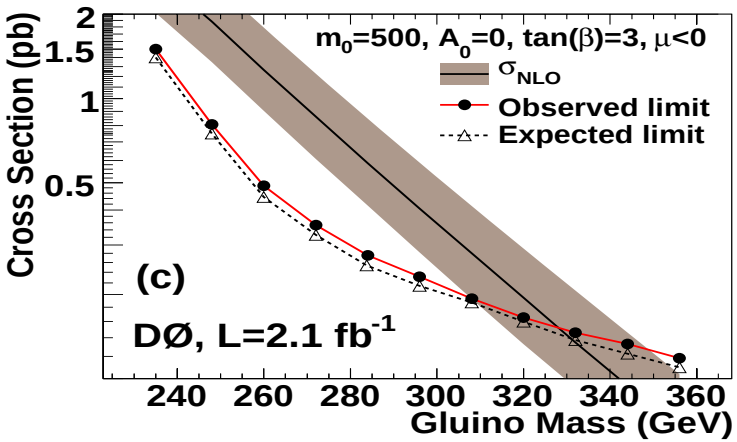


Selection	"dijet"	"3-jets"	"gluino"	$N_{\text{obs.}}$	$N_{\text{backgrd.}}$
Combination 1	yes	no	no	8	9.4 ± 1.2 (stat.) $^{+2.3}_{-1.8}$ (syst.)
Combination 2	no	yes	no	2	4.5 ± 0.6 (stat.) $^{+0.7}_{-0.5}$ (syst.)
Combination 3	no	no	yes	14	12.5 ± 0.9 (stat.) $^{+3.6}_{-1.9}$ (syst.)
Combination 4	yes	yes	no	1	1.1 ± 0.3 (stat.) $^{+0.5}_{-0.3}$ (syst.)
Combination 5	yes	no	yes		kinematically not allowed
Combination 6	no	yes	yes	4	4.5 ± 0.6 (stat.) $^{+1.8}_{-1.3}$ (syst.)
Combination 7	yes	yes	yes	2	0.6 ± 0.2 (stat.) $^{+0.1}_{-0.2}$ (syst.)
At least one selection				31	32.6 ± 1.7 (stat.) $^{+9.0}_{-5.8}$ (syst.)

Signal cross sections





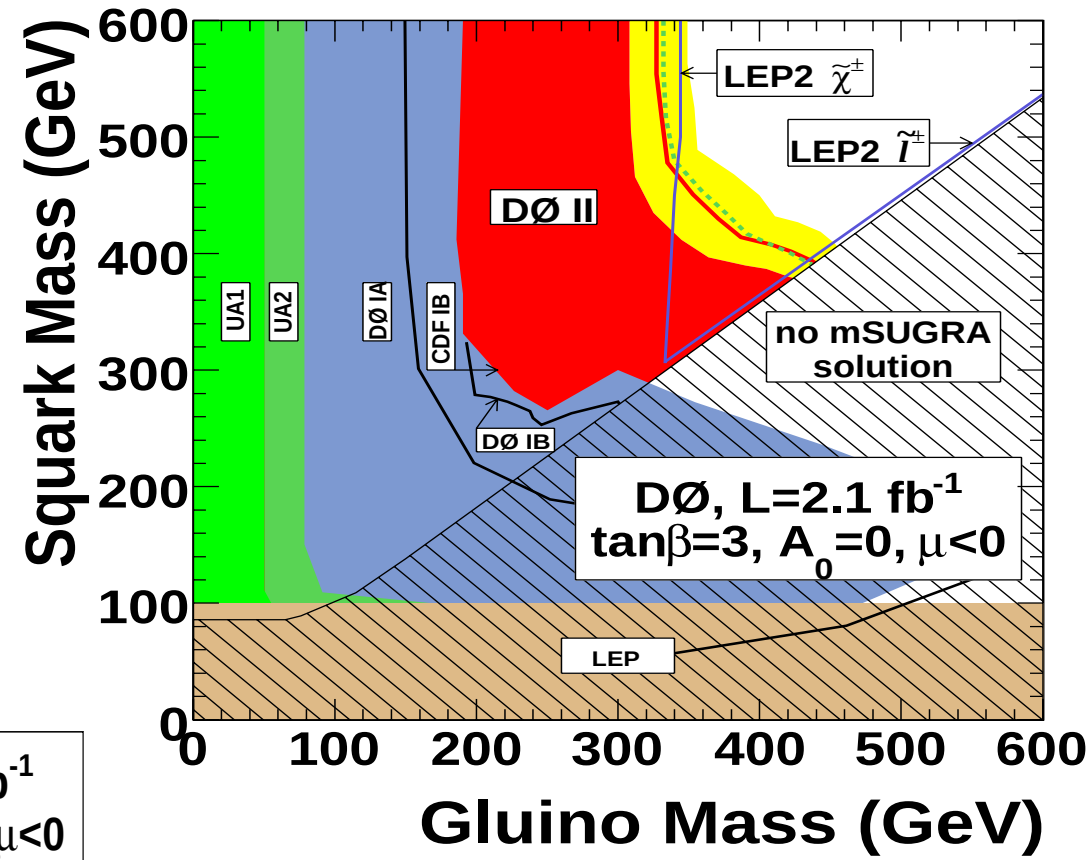


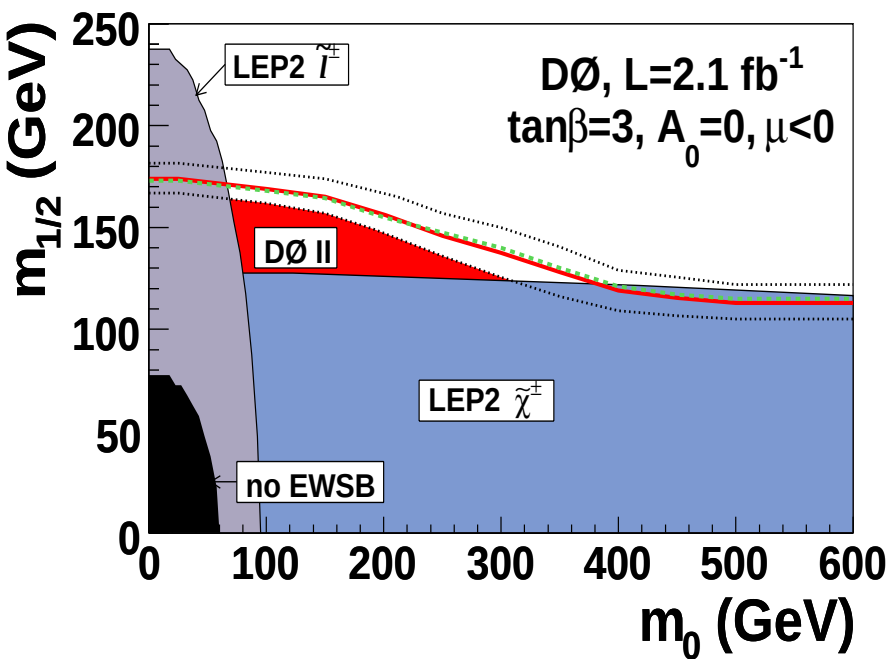
Signal cross section uncertainty from PDF: 15-60%, large for high-x gluons.

Scale dependence: 15-20%

Limits

For equal squark and gluino mass, M>390 GeV at 95% CL for lower σ





scenario	Gluino M(GeV)	Squark M(GeV)
lower σ	308	379
central σ	327	392
upper σ	349	406

1.4/fb. CDF note 9093

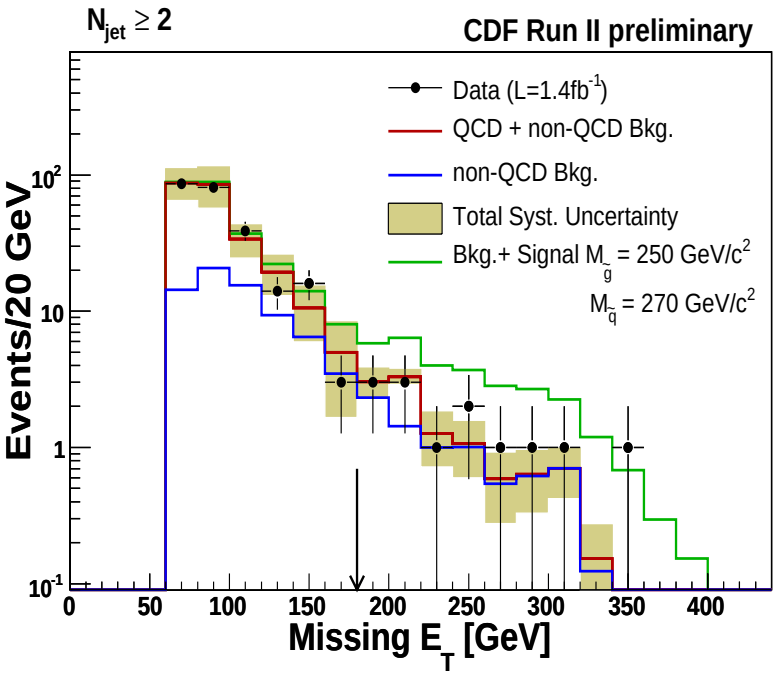
Searches in Jets+MET

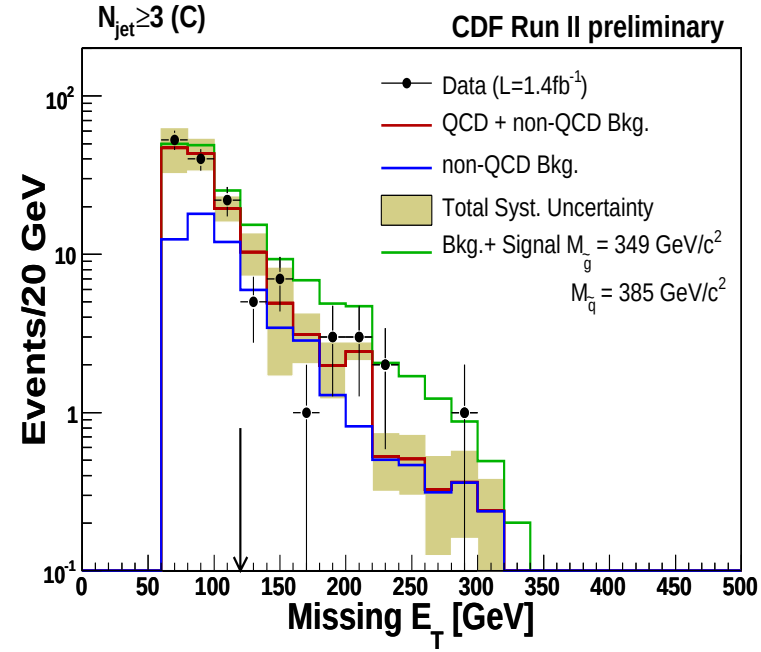
- Jets pT>25 GeV, |η|<2, one in |η|<1.
- Thresholds optimized for best S/sqrt(B)

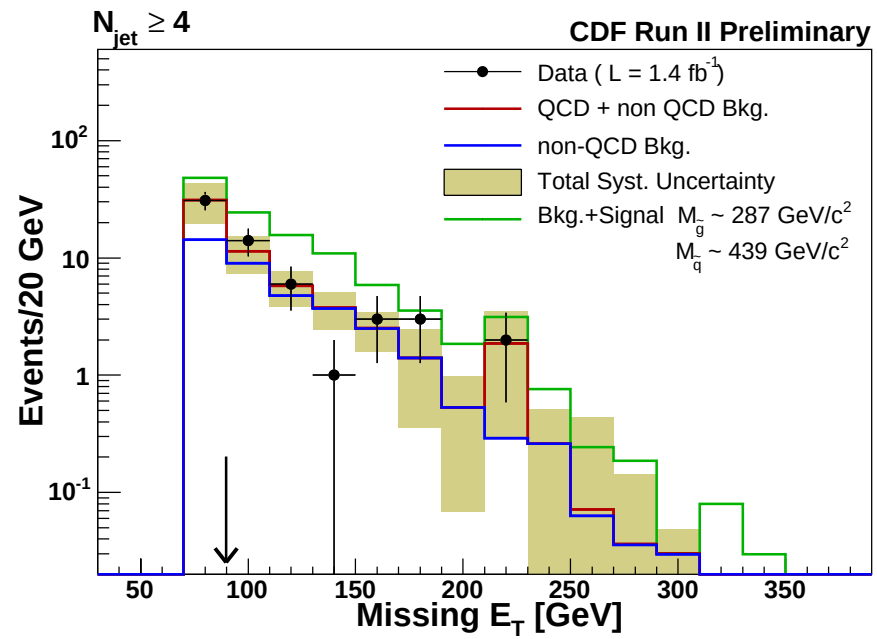
[GeV]	4-jet	3-jet(A)	3-jet(B)	3-jet(C)	2-jet
H_T	280	230	280	330	330
$\not{E}_T$	90	75	90	120	180
E_T^{jet1}	95	95	120	140	165
E_T^{jet2}	55	55	70	100	100
E_T^{jet3}	55	25	25	25	–
E_T^{jet4}	25	–	–	–	–

4-jets	29	$27 \pm 2 \pm 9$
3-jets(A)	616	$607 \pm 16 \pm 146$
3-jets(B)	166	$154 \pm 7 \pm 44$
3-jets(C)	22	$25 \pm 2 \pm 8$
2-jets	13	$11 \pm 2 \pm 3$

MET





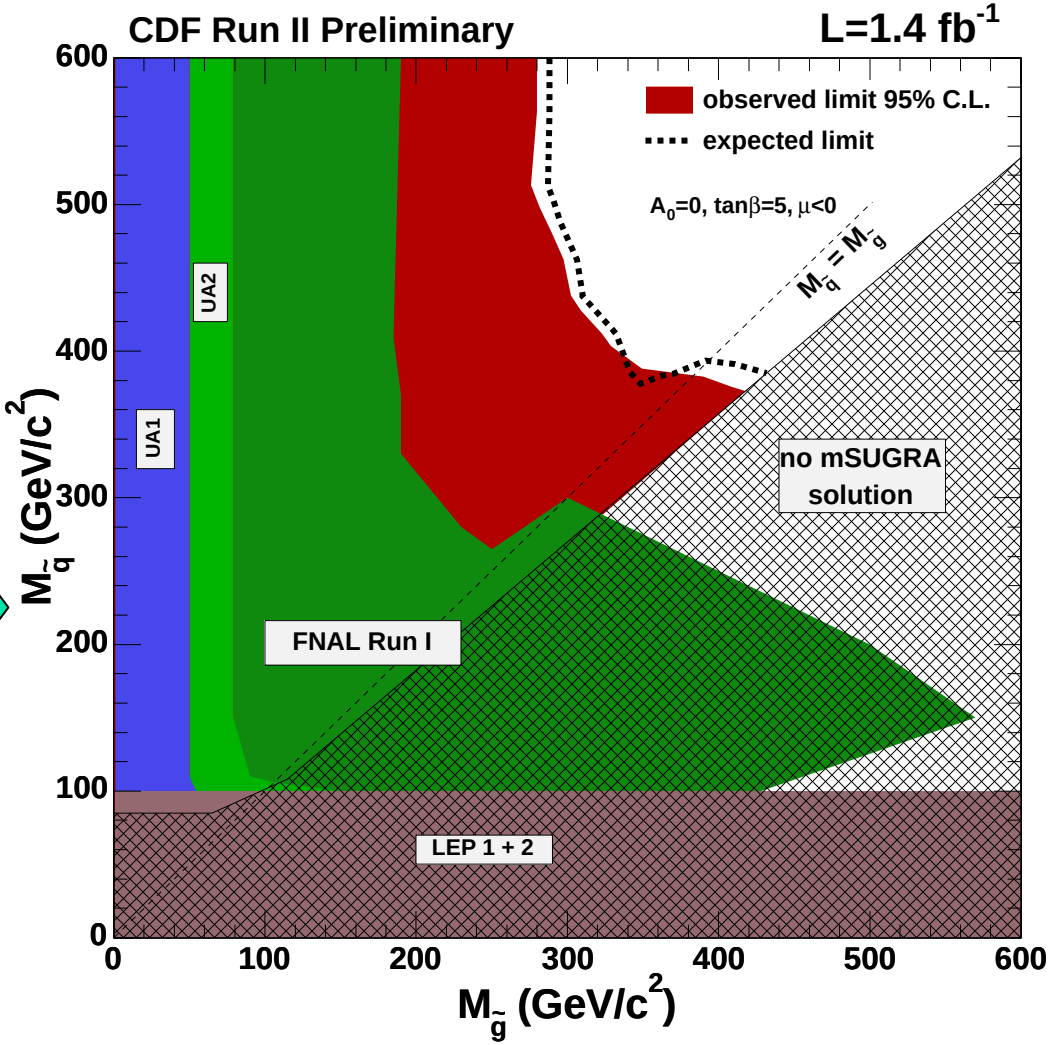


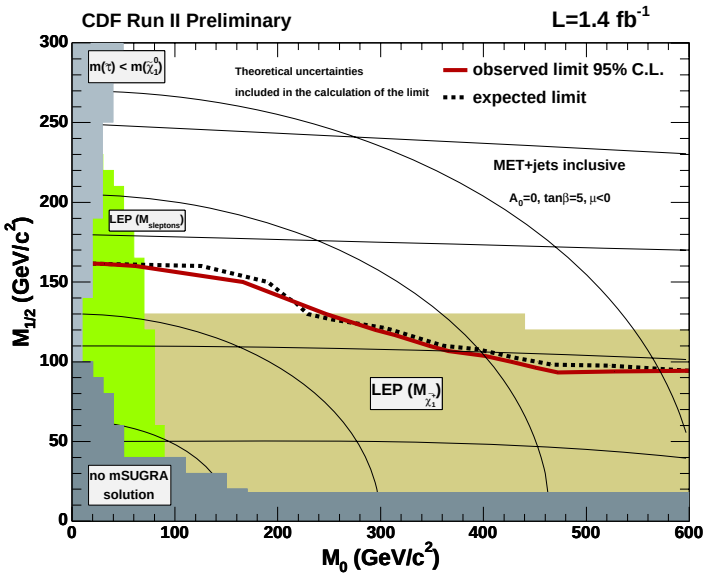
A0=0,μ<0,tanβ=5.

Squarks: ignore stop and sbottom, degenerate mass for others.

Limits

Pick the one with the best expected limit out of the 5 channels for each point





For similar gluino and squark mass, M>380 GeV,

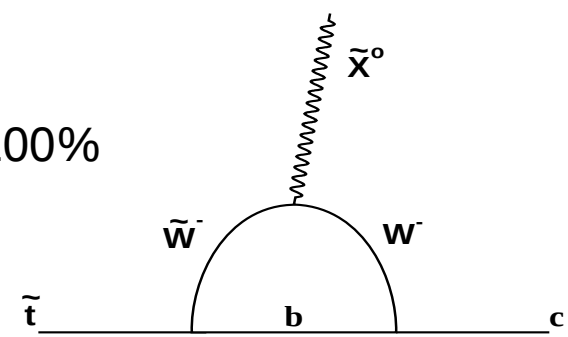
Gluino mass > 280 GeV

Search for stop with cc+MET

- 2 stops: left-,right-handed top quarks.
- Plausibly one of the two being light.

$$m_c + m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_W + m_b + m_{\tilde{\chi}_1^0}$$

100%



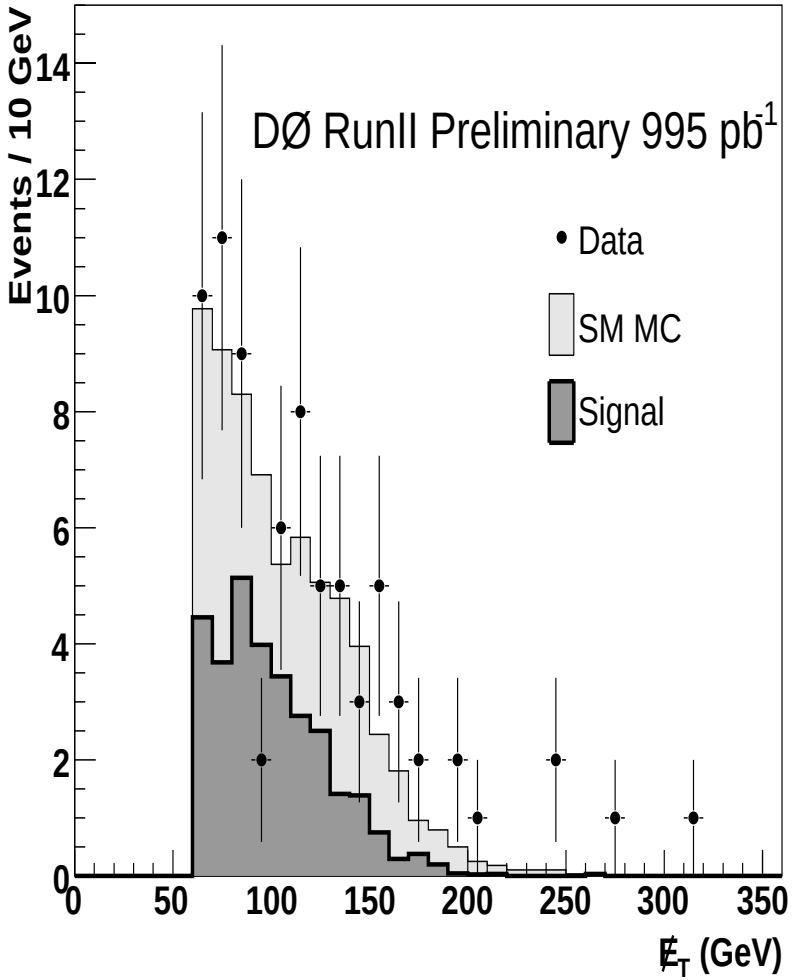
LSP is neutralino, R-parity conserved

Signature: acoplanar cc and MET.

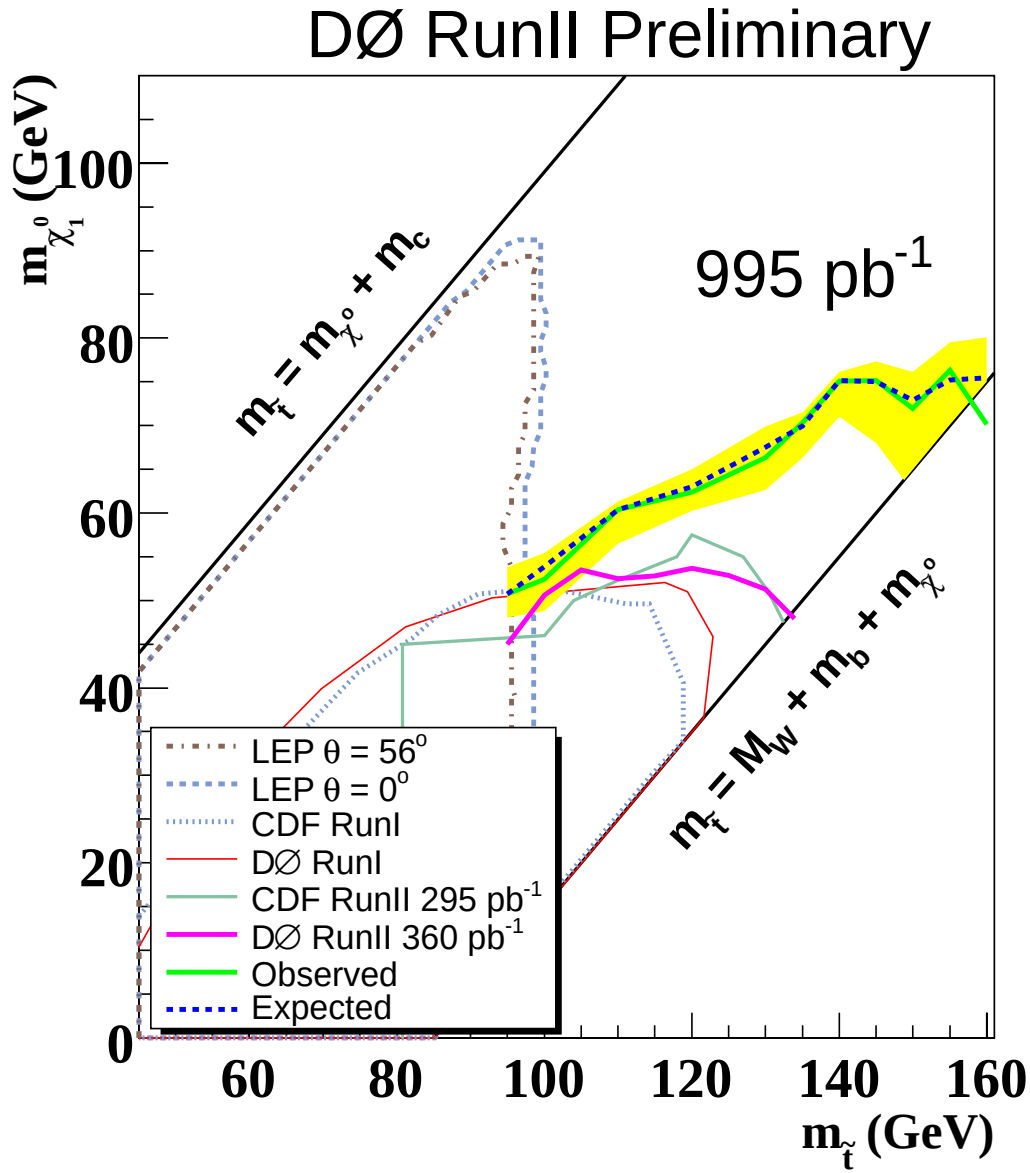
Largest background: W/Z + jets.

The analysis

- Z pT calibrated with Z→ee data
- pT(j1) > 40 GeV, pT(j2)>20 GeV;|η|<1.5, “confirm vertex”.
- MET > 60 GeV
- leptons or isolated tracks veto.
- Kinematical correlation of j1,j2, MET
- loose heavy flavor tag
- Optimized for better expected limits for different ranges of stop mass.



Limits



Stop mass > 149 GeV at 95 % CL for neutralino mass of 63 GeV – in the most conservative case

model-independent searches

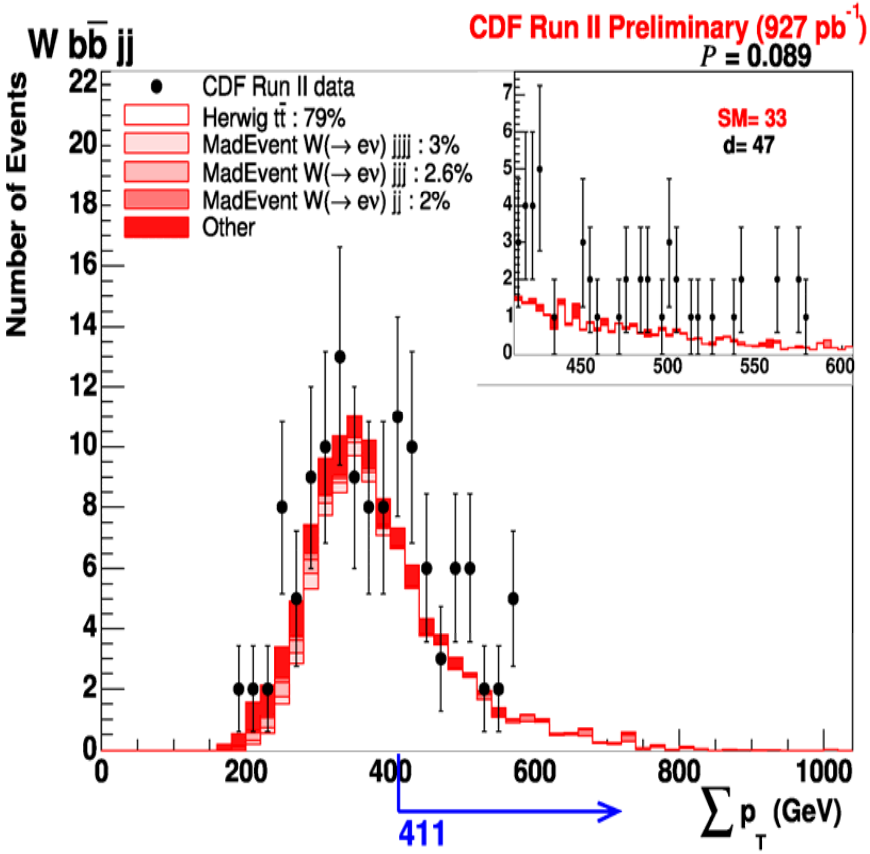
- But where will the first hint be?
- Systematically check events containing high pT e,μ,τ,γ, j,b or large MET and combinations of those.
- Evaluate p-values.
- CDF: examined 344 final states, no “interesting” discrepancy seen.

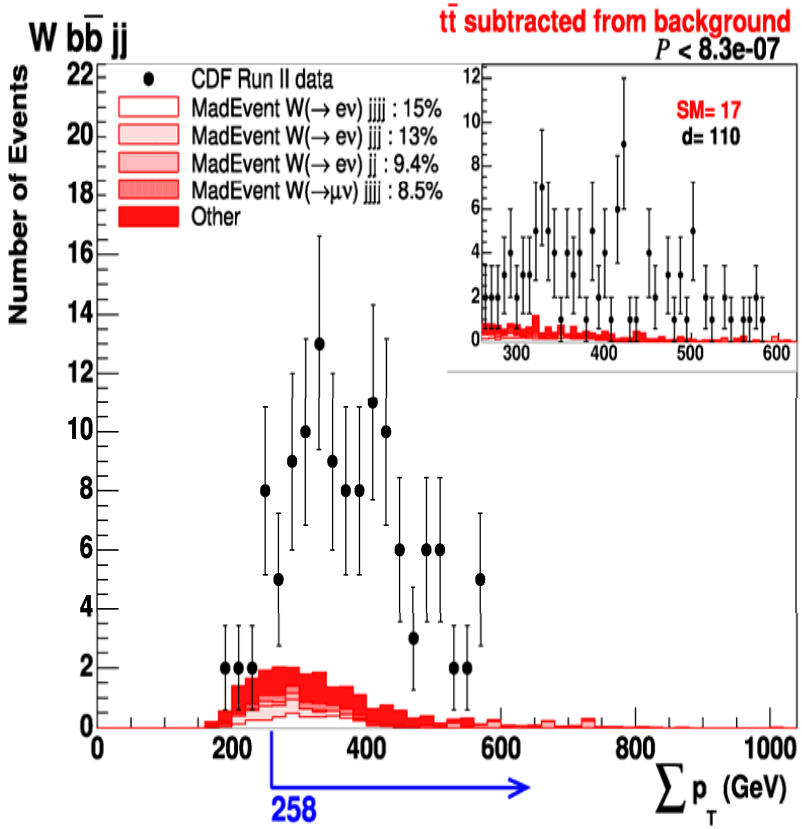
arXiv:0712.1311 [hep-ex]

arXiv:0712.2534 [hep-ex]

Need 80/pb for discovery

Re-discover ttbar





Lepton + jets(1-btag) final state. Pretend we are not aware of ttbar.

The Last Slide

- Both experiments have large datasets.
- Many limits updated, no surprises yet
- Data sample keeps growing, analysis tech keeps advancing…