Non-SUSY Exotics Searches at the Tevatron

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for the **CDF and D0 Collaborations**

Introduction

- Despite the tremendous success of the Standard Model, many open questions remain:
  - What is the origin of mass?
  - Why are there (only?) three generations?
  - Why the large difference between Planck and EWK scales?
  - How can we incorporate gravity?
  - Are fermions point-like or do they have substructure?
  - What is the source of dark matter?

- SUSY is most commonly invoked to address these, but there are many other models that seek to answer some or all of these questions

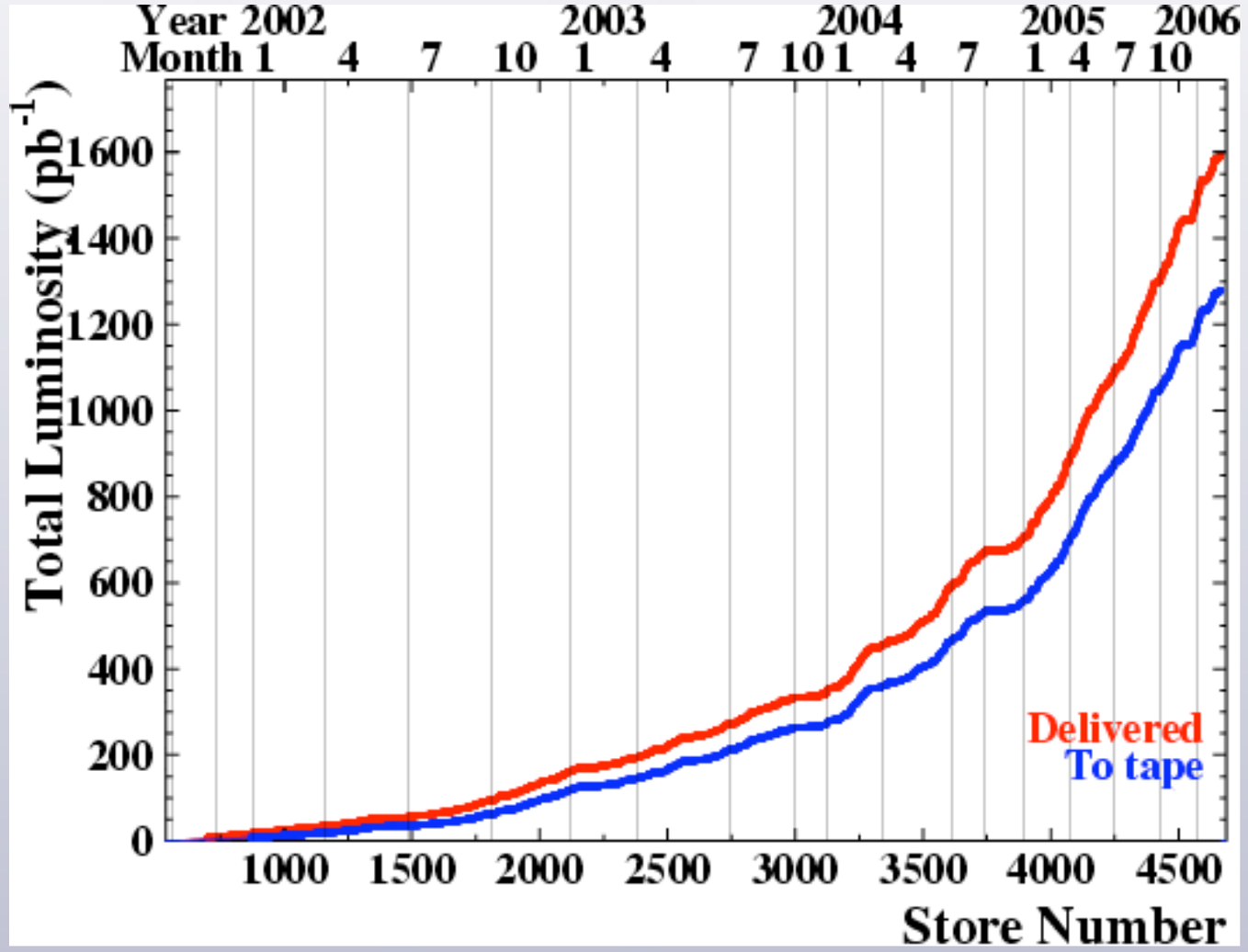
Introduction

- In today's talk, consider a few of the models that try to address some of these unanswered questions:
  - Extra Dimensions
  - New Heavy Quarks
  - New Gauge Bosons
- The same signature may be used to study multiple models
  - Signature-based searches look to compare how well the data agrees with the Standard Model, without applying any particular model

Tevatron Performance in RunII

Tevatron operation has been excellent

- Highest Initial Luminosity
  - 1.8×10^{32} $cm^{-2}s^{-1}$
- Integrated lum. in a week
  - 26.1 pb^{-1}



- 1.6 fb^{-1} delivered to the experiments, with ~1.2 fb^{-1} to tape
- Analyses shown today use samples of 0.3-1.0 fb^{-1}

Models of Extra Dimensions

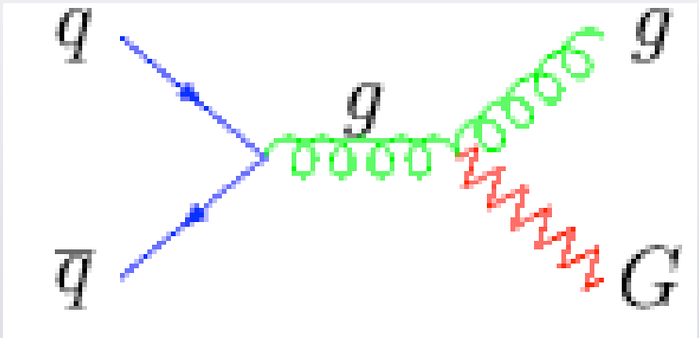
Extra Dimensions proposed as a new solution to the hierarchy problem. Two of the most prominent models:

- Arkani-Hamed, Dimopoulos, Dvali (ADD):
  - *n* extra dimensions, compactified at radius *R*, $(M_{PL})^2 \sim R^n (M_D)^{2+n}$
  - SM confined to brane in higher dimensional space
  - Only gravity can access extra dimensions
  - Signatures: Jet+MET, γ+MET, lepton pairs
- Randall-Sundrum Model:
  - One warped extra dimension
  - Two branes, gravity localized on one, SM on second
  - Signatures: Narrow, high mass resonances

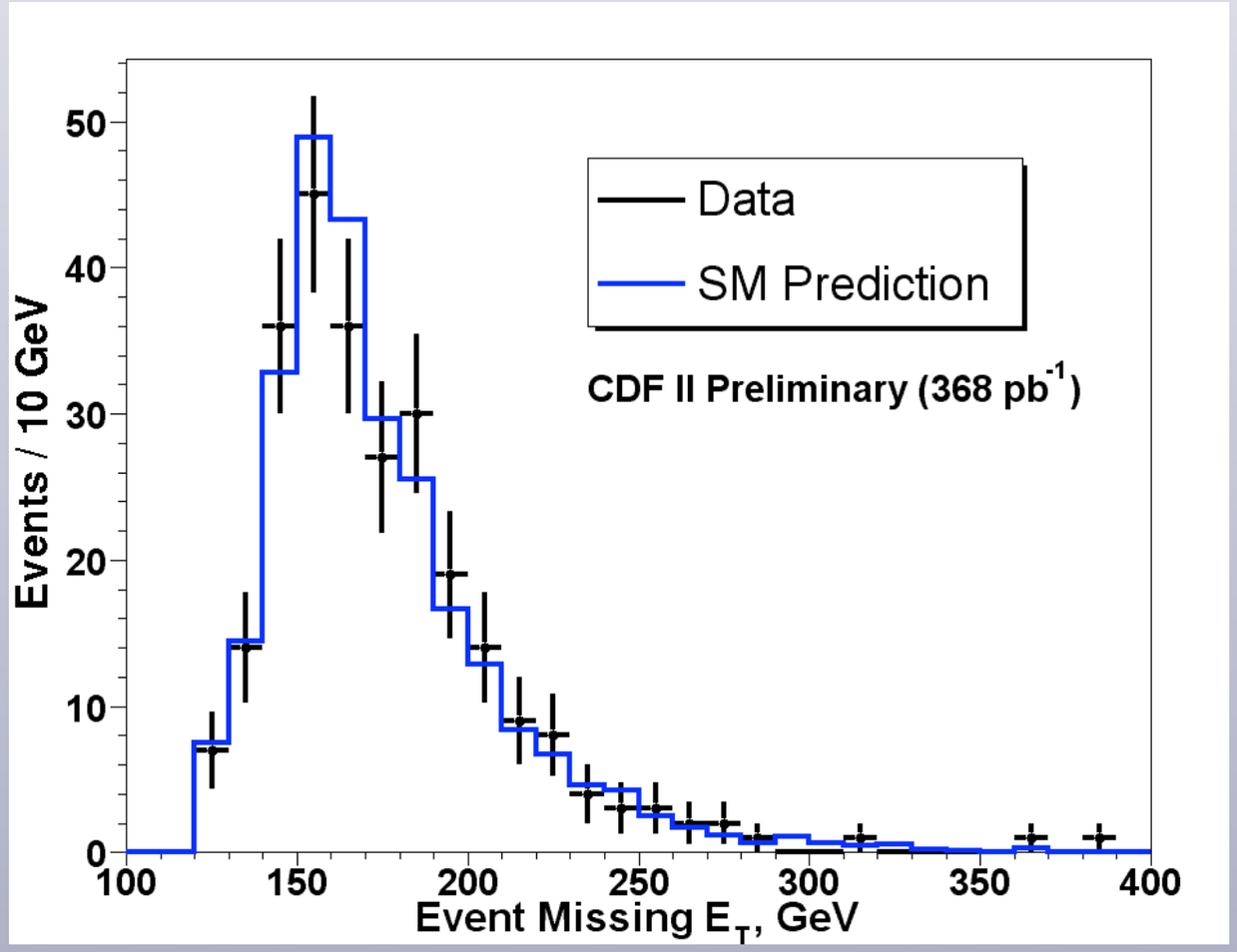
Monojet Search for LED (ADD)

- Single high E_T jet+MET
  - E_T>150 GeV, MET>120 GeV
  - SM Backgrounds:
  - *$Z \rightarrow \nu\nu$+jets (irreducible)*
  - *$W \rightarrow l\nu$+jets, QCD Dijets*

Direct Graviton Emission



- Results:
  - 265±30 events predicted
  - 263 events observed

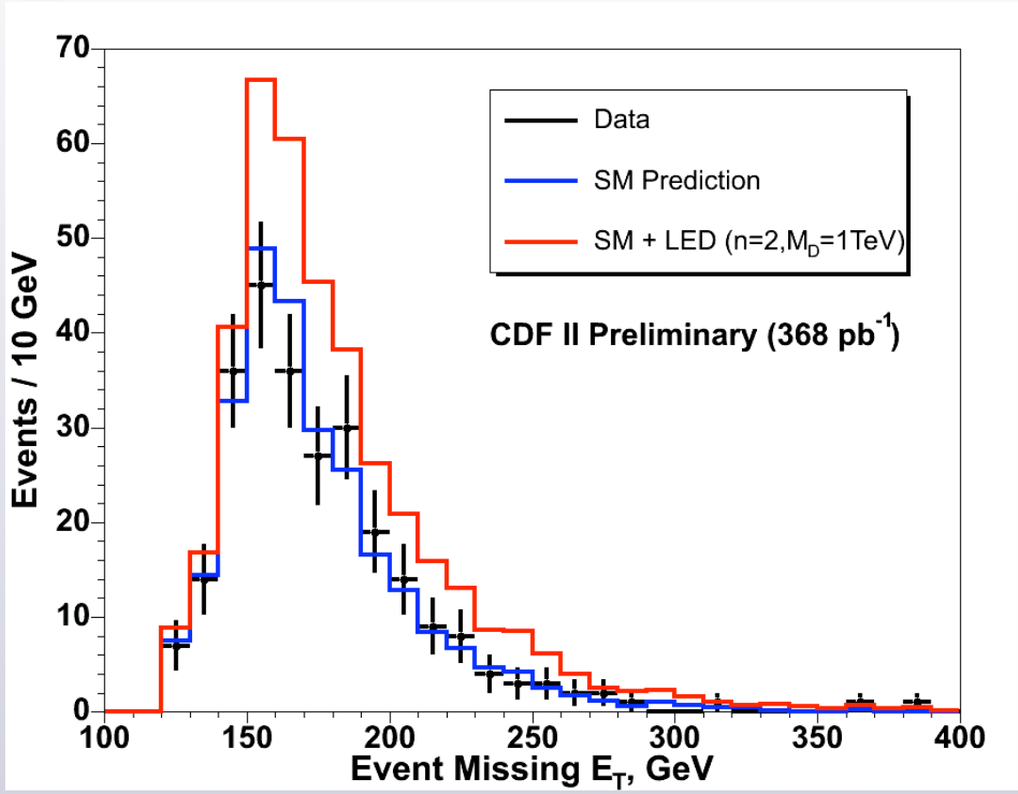


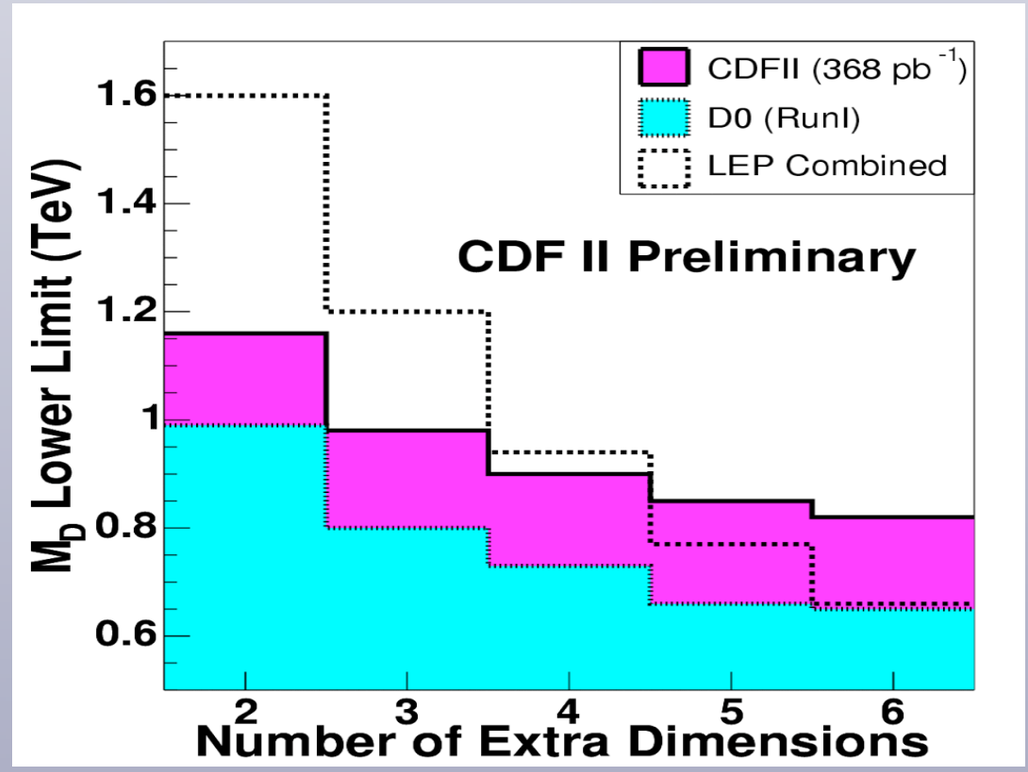
Monojet Search for LED (ADD)

- Based on ADD Model, convert to limits on M_D, R

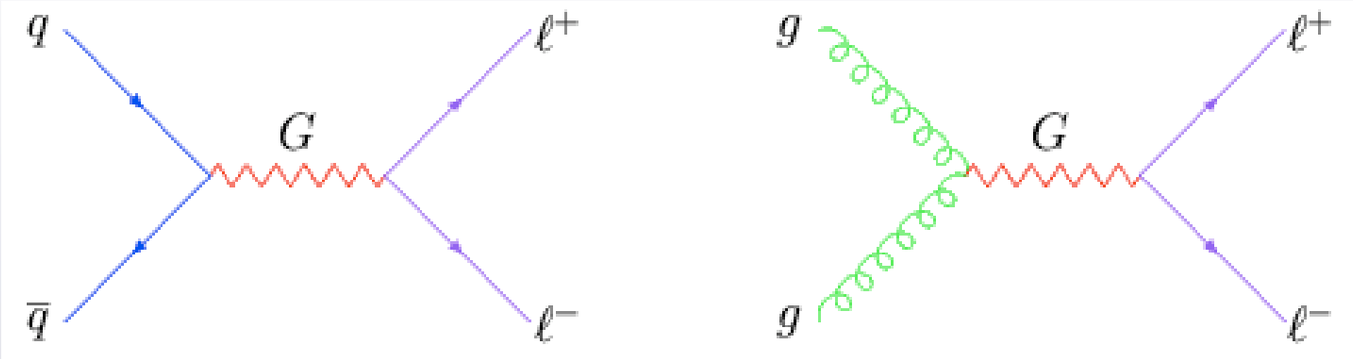
$$R^n = \frac{1}{8\pi}\left(\frac{M_{PL}}{M_D}\right)^2 \frac{1}{M_D^n}$$

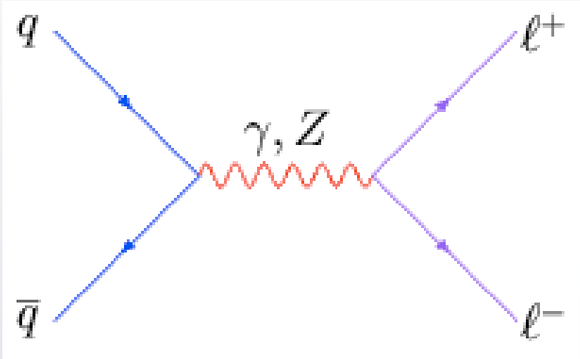
n	M_D(TeV/c^2)	R(mm)
2	> 1.16	< 3.6×10^{-1}
3	> 0.98	< 3.7×10^{-6}
4	> 0.90	< 1.1×10^{-8}
5	> 0.85	< 3.5×10^{-10}
6	> 0.83	< 3.4×10^{-11}





Search for LED - Graviton Exchange





Three terms in cross-section: SM, interference, graviton:

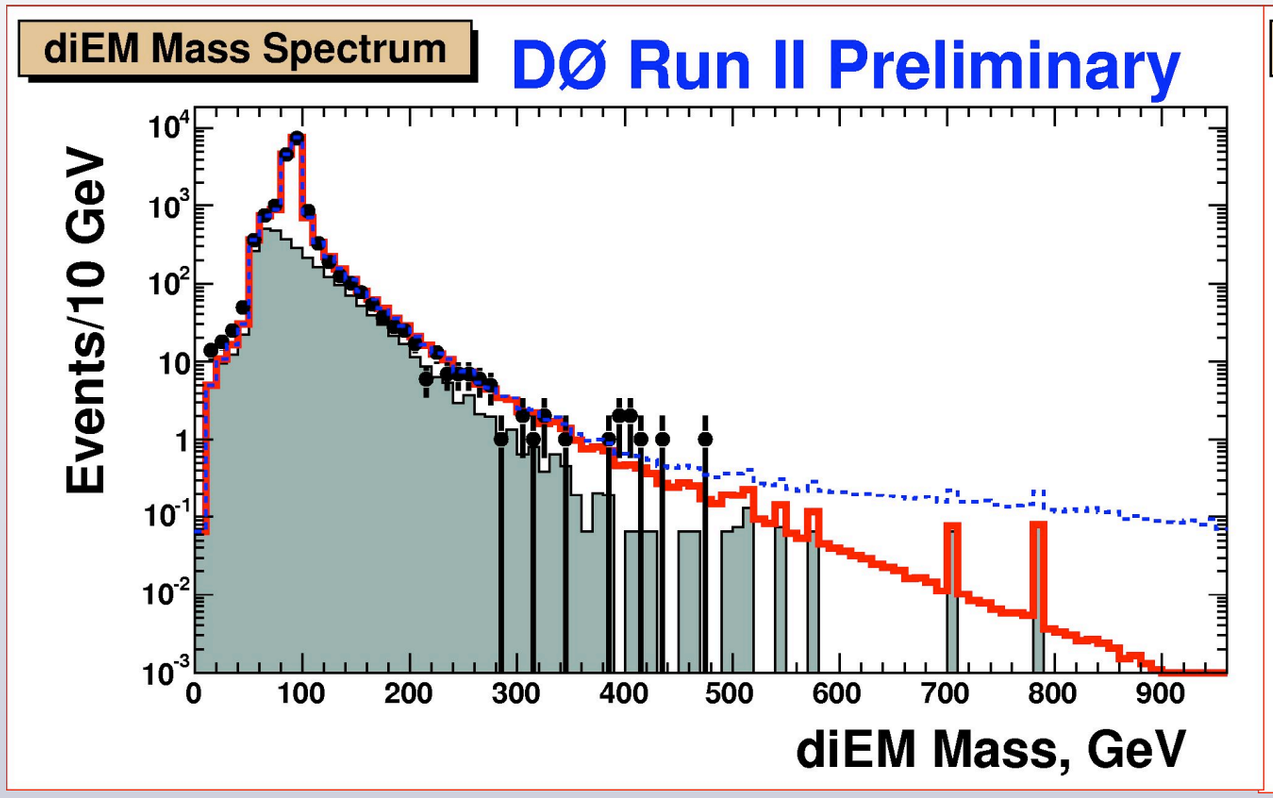
$\sigma_{TOT} = \sigma_{SM} + \eta\sigma_{INT} + \eta^2\sigma_{GRV}$ $(\eta = F/M_S^4)$

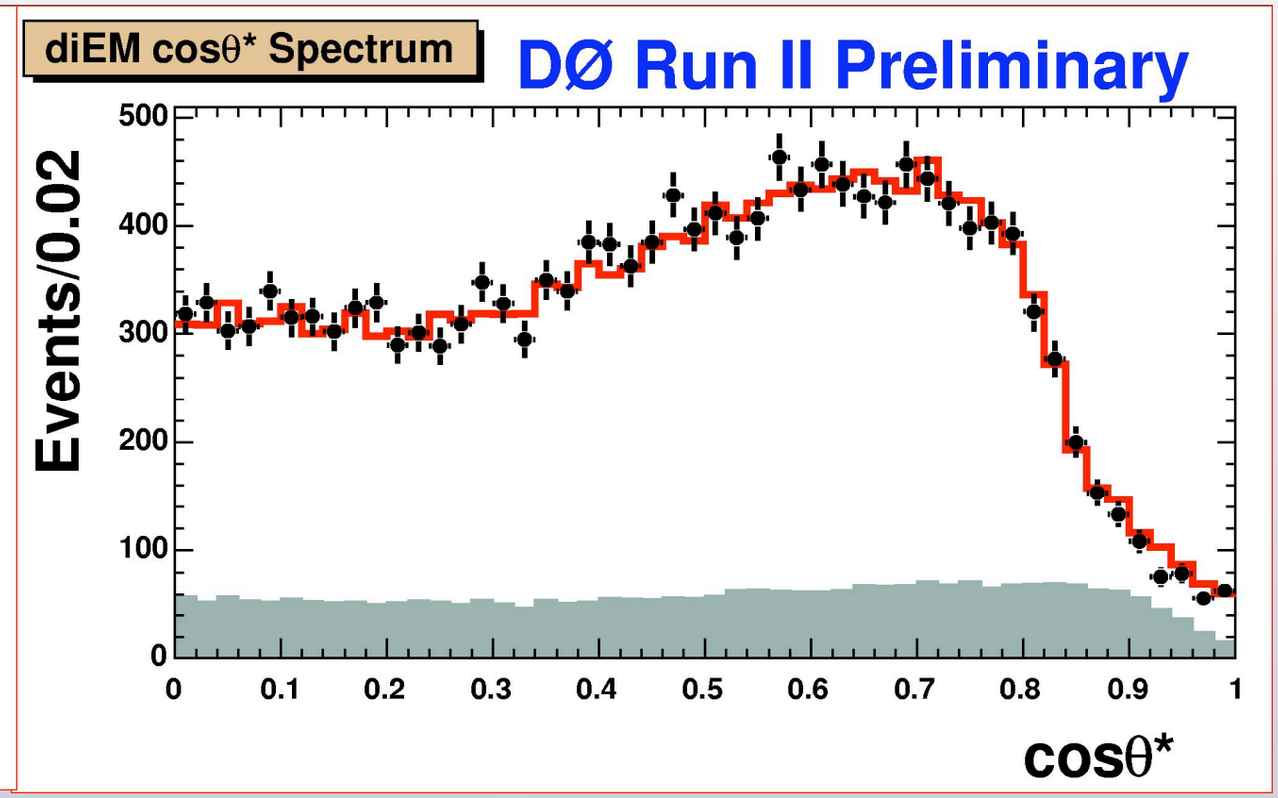
D0 Analysis Strategy:

- Use di-EM objects (ee+γγ)
- 2D Fit to M and cosθ*
- Set Limits on η and convert to limits on model

Conventions for *F*	
GRW	1
HLZ (n=2)	$\log(M_S^2/M)$
HLZ (n>2)	2/(n-2)
Hewett	2λ/π

Search for LED - Graviton Exchange





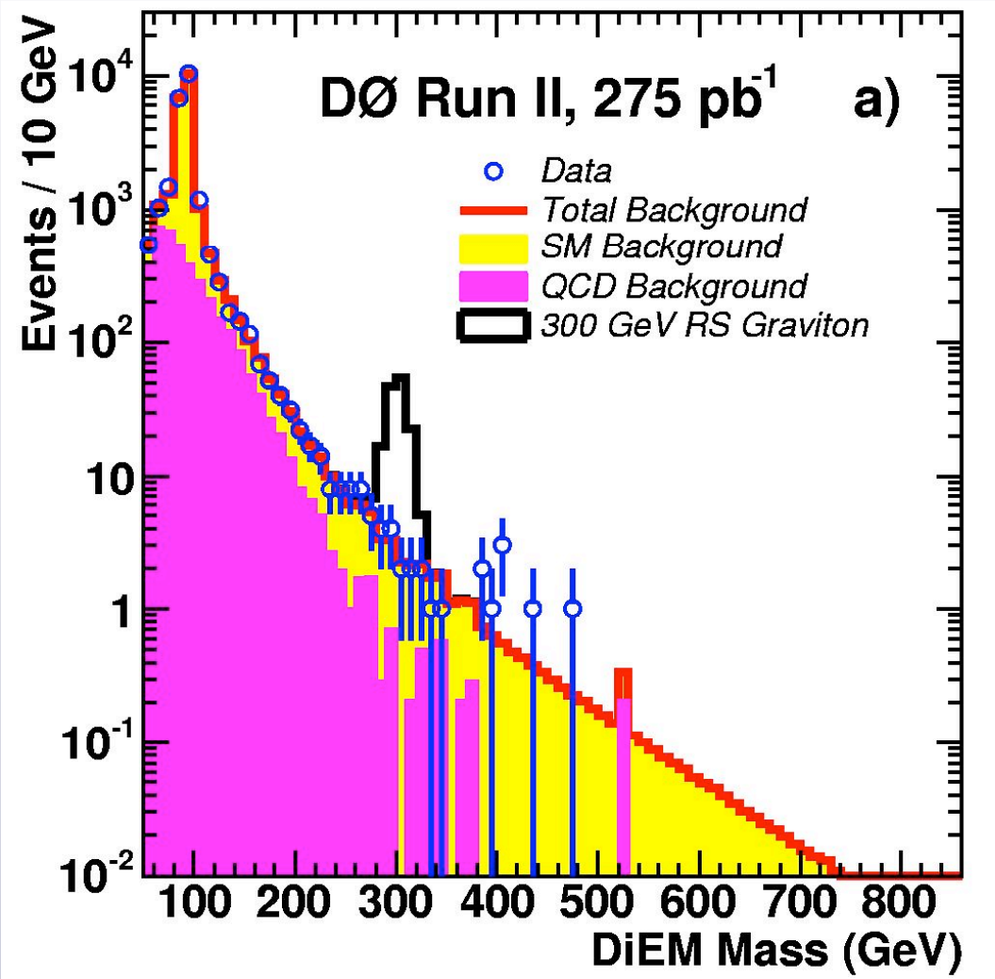
M_S Limit(TeV)	D0 (RunII)	D0(Run I+II)	CDF	LEP
$\lambda=+1$	1.22	1.28	0.96	1.1
$\lambda=-1$	1.10	1.16	0.99	1.2

D0 Limits in μμ (RunII only): 0.96,0.93 TeV (λ=+1,-1)

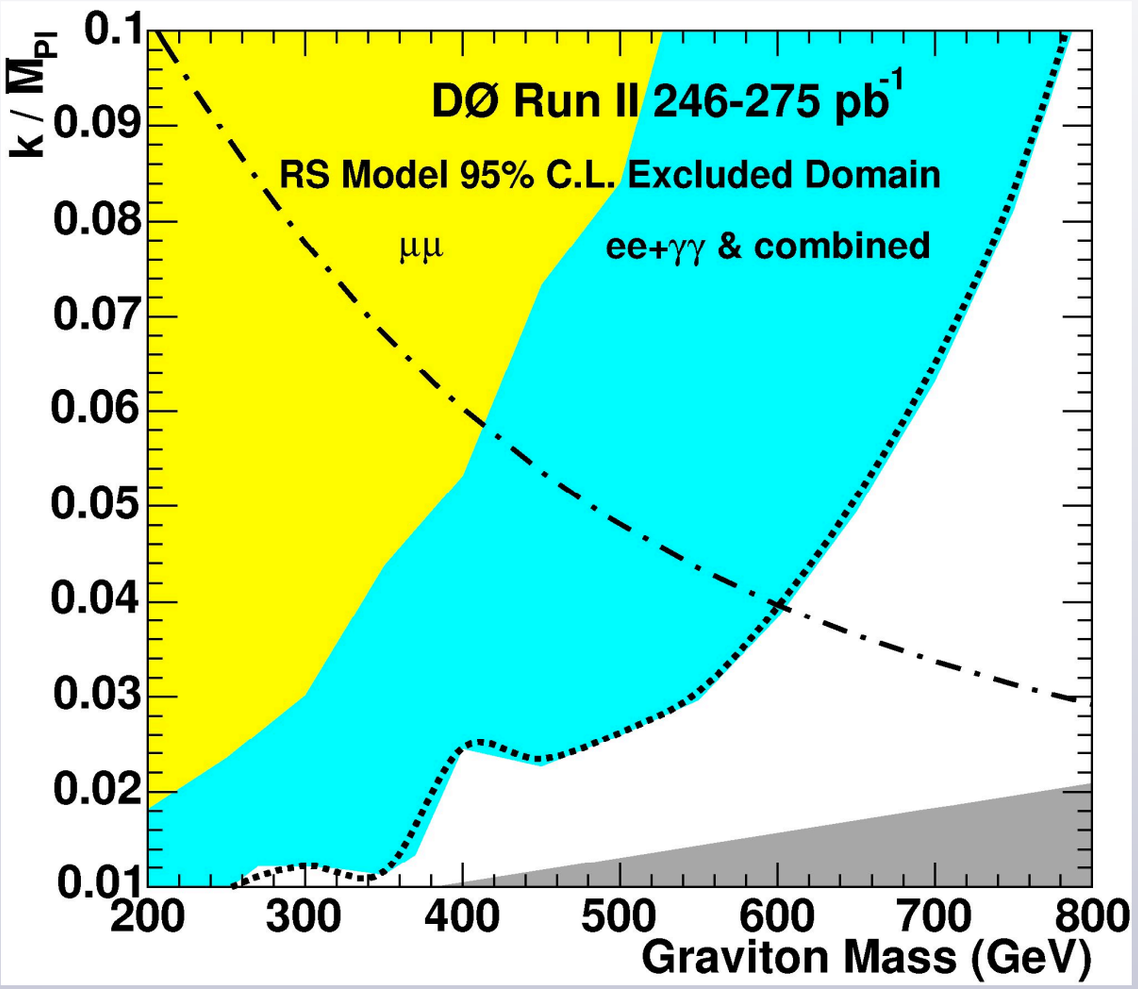
Search for ED - RS Gravitons

- In RS Model, two branes in one curved ED, with gravity on a different brane from SM
- Effects of gravity on SM brane have scale
  - $\Lambda_\pi = \overline{M}_{PL} \exp(-k\pi R)$ (k= curvature, $\overline{M}_{PL} = M_{PL}/\sqrt{8\pi}$)
  - Expect $k/\overline{M}_{PL}$ in the range 0.01-0.1
- Analysis looks for resonances in dilepton and diphoton mass distributions
- In absence of resonance, set limits on mass of first KK mode of graviton, as a function of $k/\overline{M}_{PL}$

Search for ED - RS Gravitons



Di-EM Mass Distribution

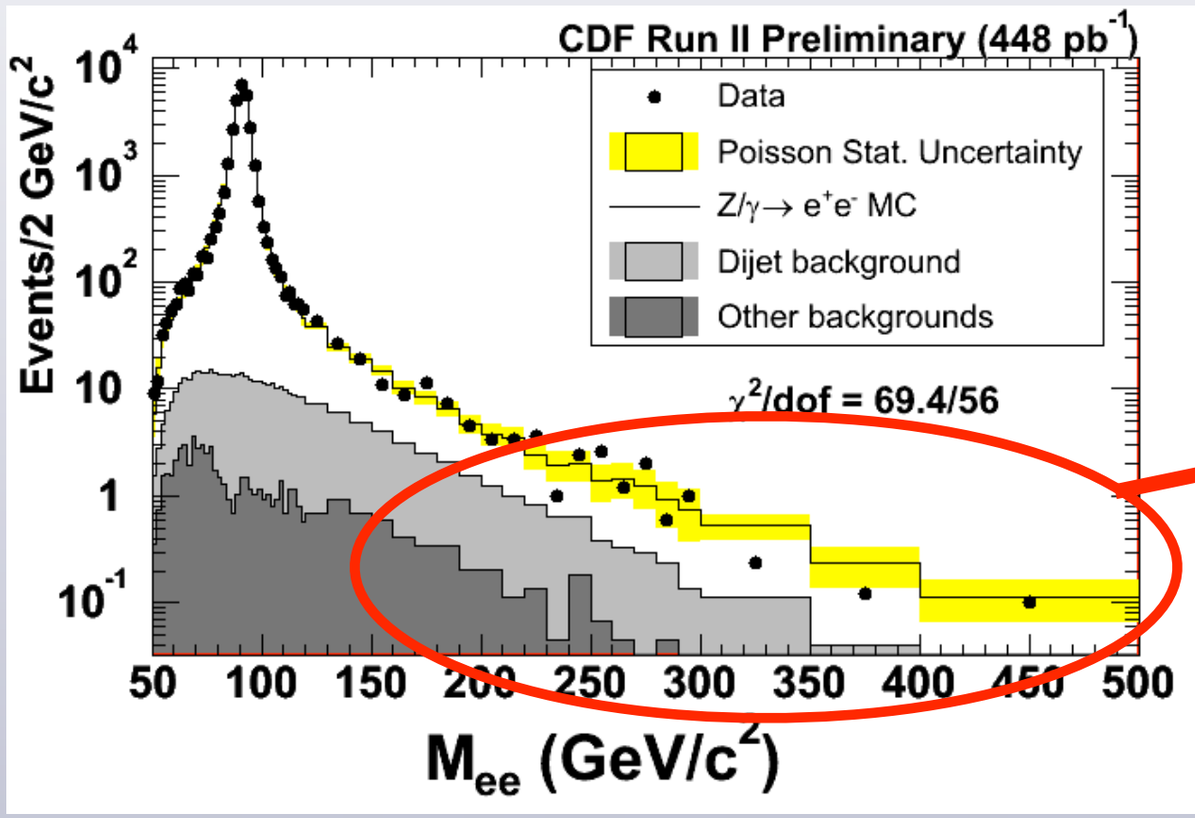


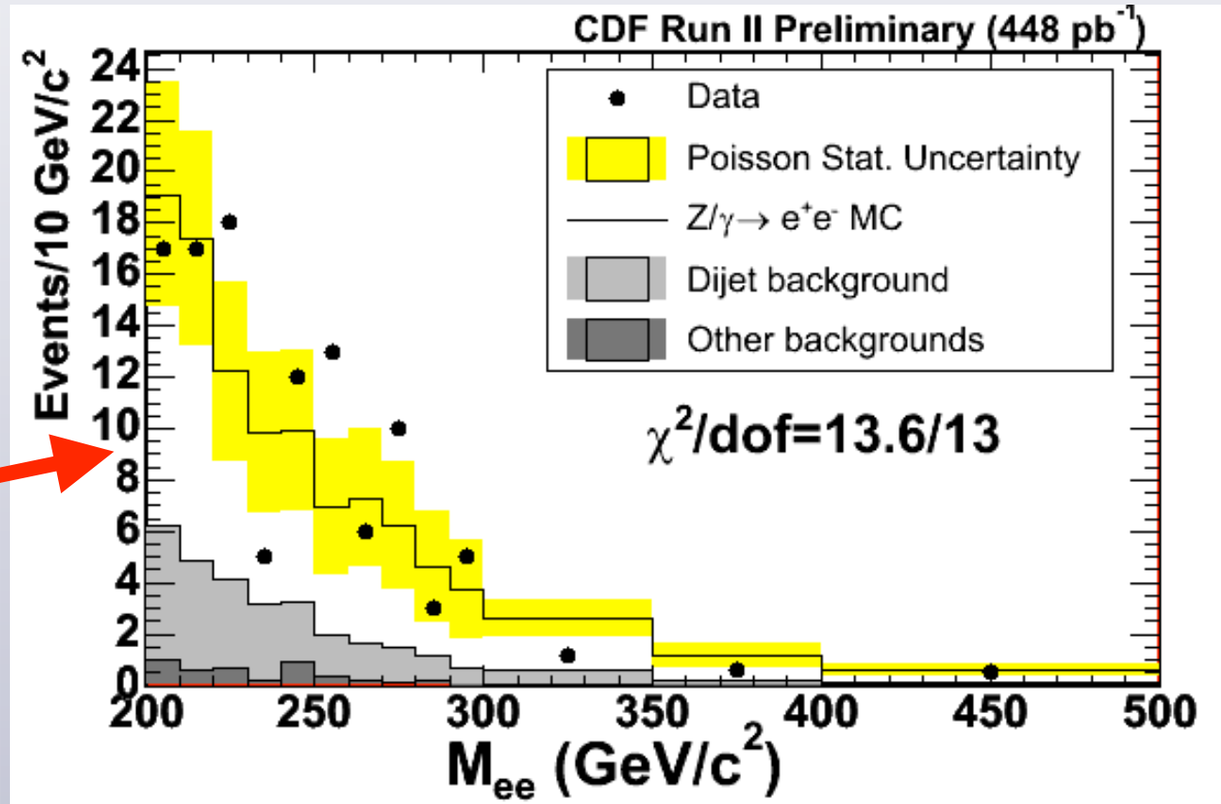
Mass Limit vs. $k/\overline{M}_{PL}$

Graviton masses excluded up to 785(250) GeV
for $k/\overline{M}_{PL}$ = 0.1(0.01)

Search for $Z' \rightarrow e^+e^-$

- Looking for new physics in e^+e^-, using M_{ee} and $\cos\theta^*$





- Use M_{ee}>200 GeV region for search:
  - 115 +16/-19 Events Expected (Z/γ^*, dijets)
  - 120 Events Observed

Search for $Z' \rightarrow e^+e^-$

- If Z' exisits, it will interfere with SM Z^*/γ
- Do the M_{ee} and $\cos\theta^*$ data distributions fit better to the SM Z^*/γ or to $Z'/Z^*/\gamma$?
- Test $Z'/Z^*/\gamma$ fit for different models and extract limits for sequential Z' and multiple E6 models

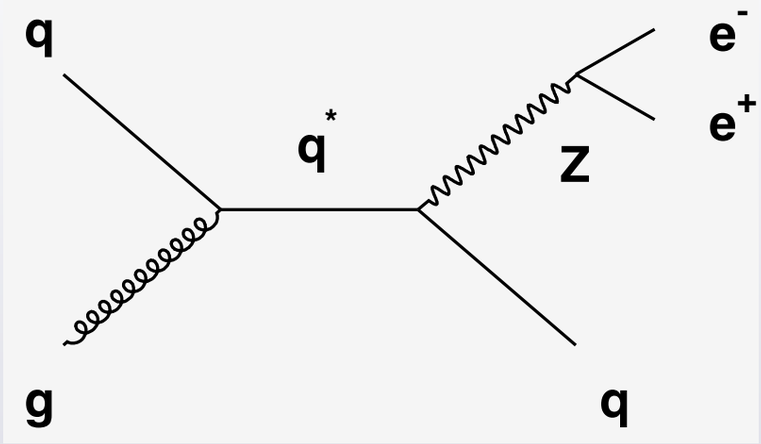
Z' Model	Z_{SM}	Z_χ	Z_ψ	Z_η	Z_I	Z_N	Z_{sec}
Limit (GeV/c^2)	850	740	725	745	650	710	680

- Can also test for contact interactions:

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

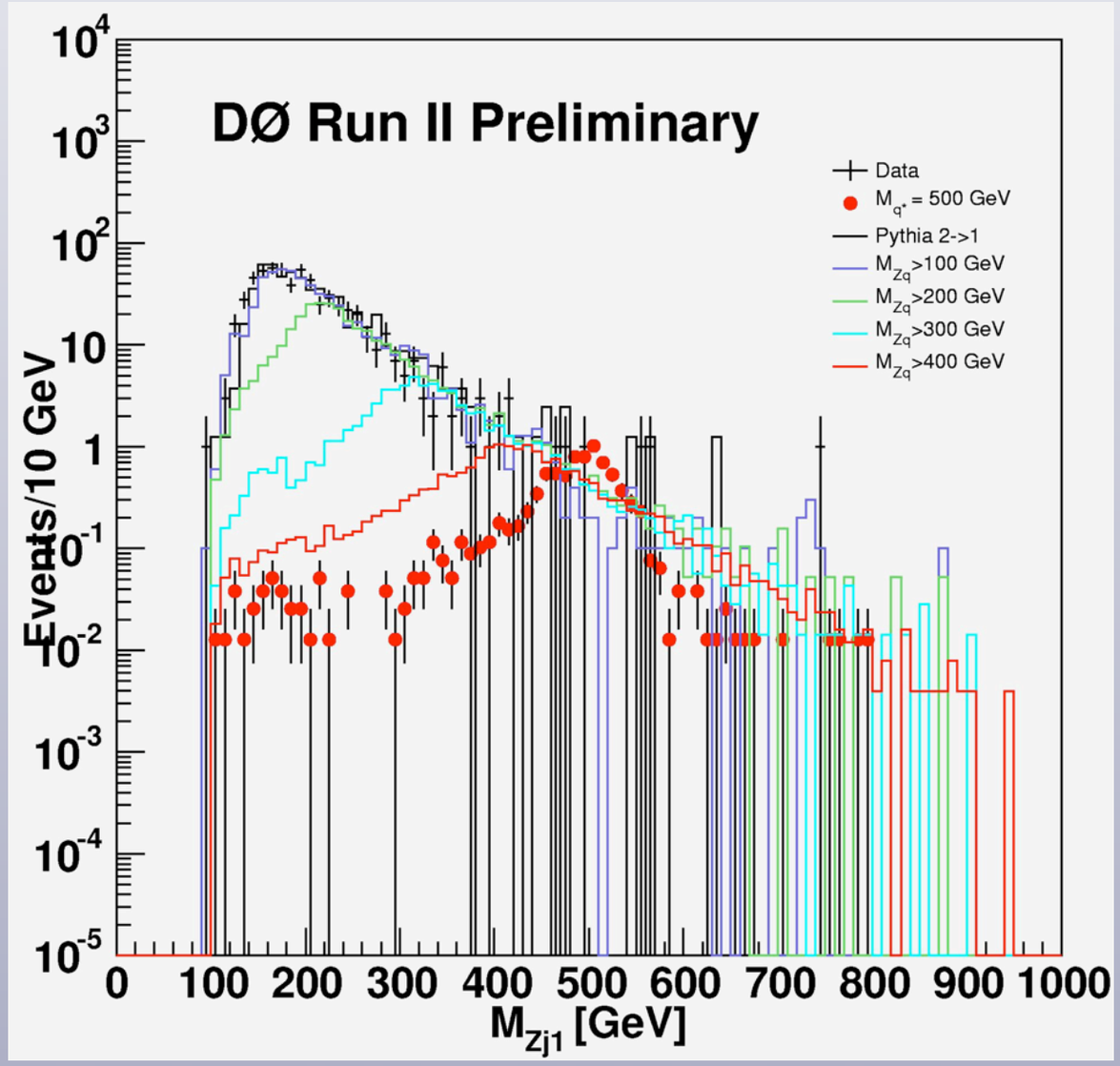
Search for Resonances in Z+jets

- Heavy resonances decaying into W/Z+*q* could signal quark substructure (Baur, Spira, Zerwas)

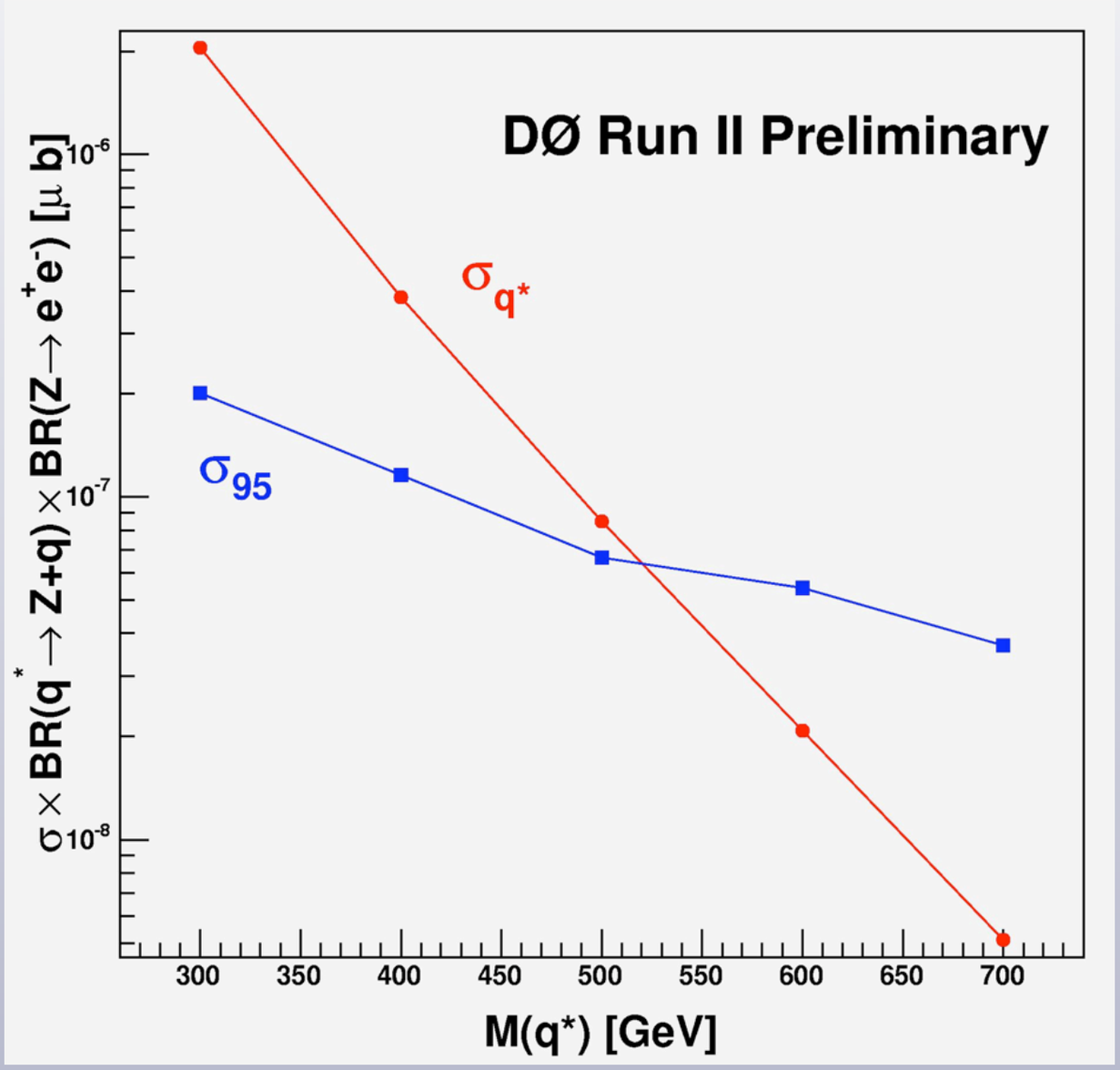


- Study *Z+jets* ($Z \rightarrow e^+e^-$)
  - essentially background free
  - P_T(jet)>10 GeV, |η|<2.5

- For SM expectation, generate Monte Carlo with different thresholds for M(*Zq*)



Search for Resonances in Z+jets

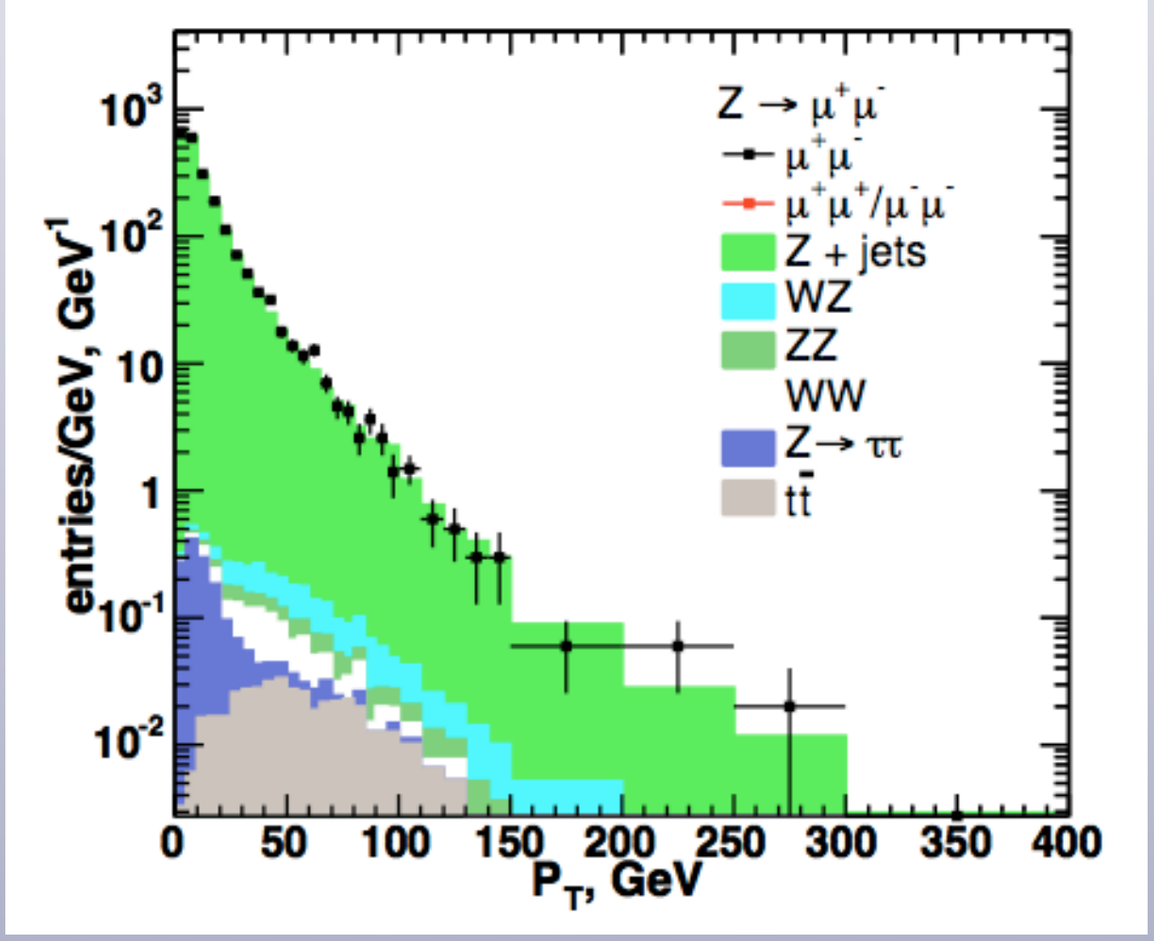


M(GeV)	*SM Bkgd*	*Data*	σ_{95}*(pb)*
300	41.59 + 4.65	35	0.201
400	35.66 + 3.59	30	0.111
500	10.94 + 1.42	7	0.066
600	7.06 + 0.75	5	0.054
700	0.71 + 0.10	0	0.037

M(*q**)>520 GeV (95%CL)

Signature-Based Search: High P_T Zs

- Look for Z from heavier particles decaying weakly
  - Open to many different models (SUSY, ED, etc.)
  - Start with heavy quark model of Bjorken, Paksava, Tuan
    - 3 down-type quarks, Q_i , decaying $Q \rightarrow Z/H+d$ or $Q \rightarrow W+u$
    - Would create high P_T Z's
- Study $P_T(Z)$ for Inclusive, P_T>60, 120 GeV
- Good agreement between data and SM backgrounds



Signature-Based Search: Dilepton+X

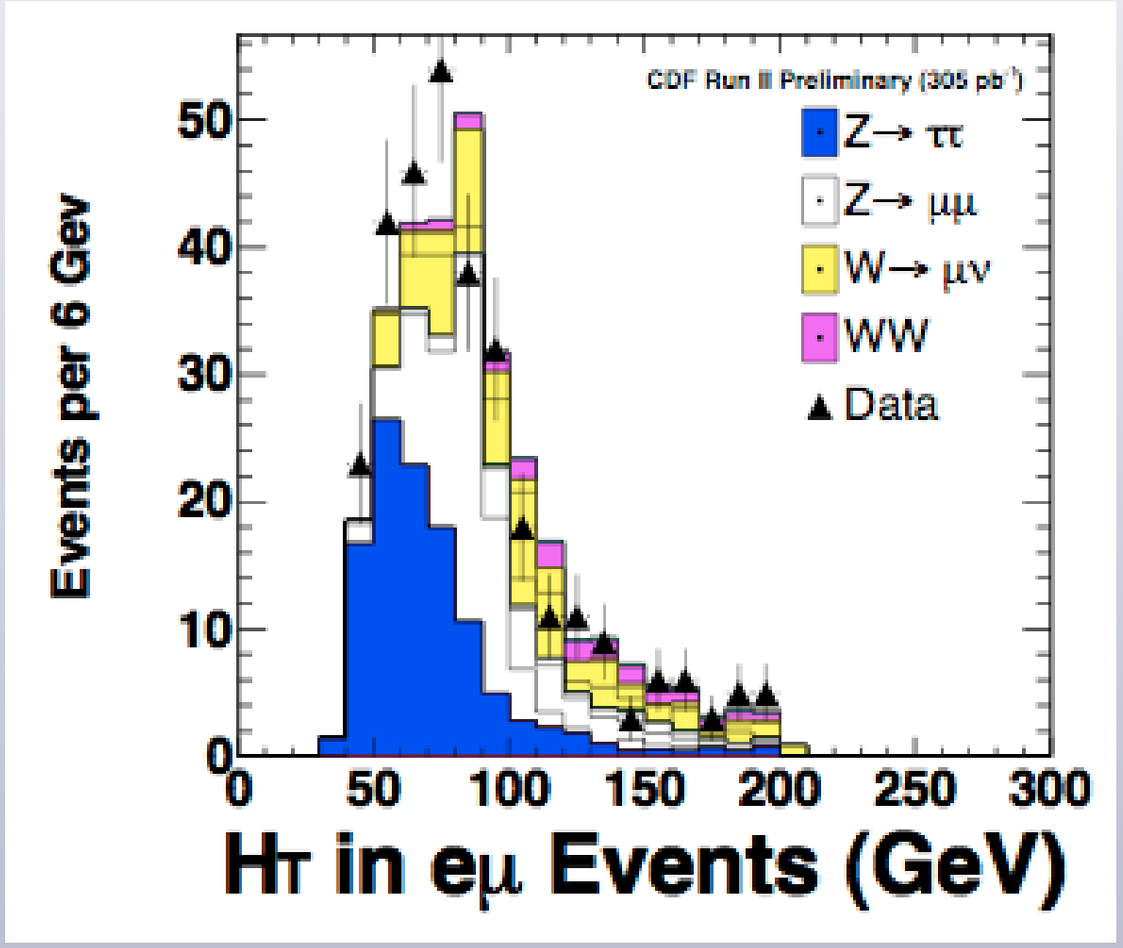
- Looking for anomalous Dilepton+X events
  - X = Large H_T, Large MET, b tags, high E_T jets, 3rd leptons

$H_T = E_T(e)+E_T(jet)+P_T(\mu)+MET$

Control Region: H_T<200 GeV

Signal Region: H_T>400 GeV

2 jets E_T>50 GeV



Expect:

0.802+0.440 SM

0.526+0.058 QQ

Observe: 0

$\sigma < 4.49*\sigma_Q$ (90%CL)

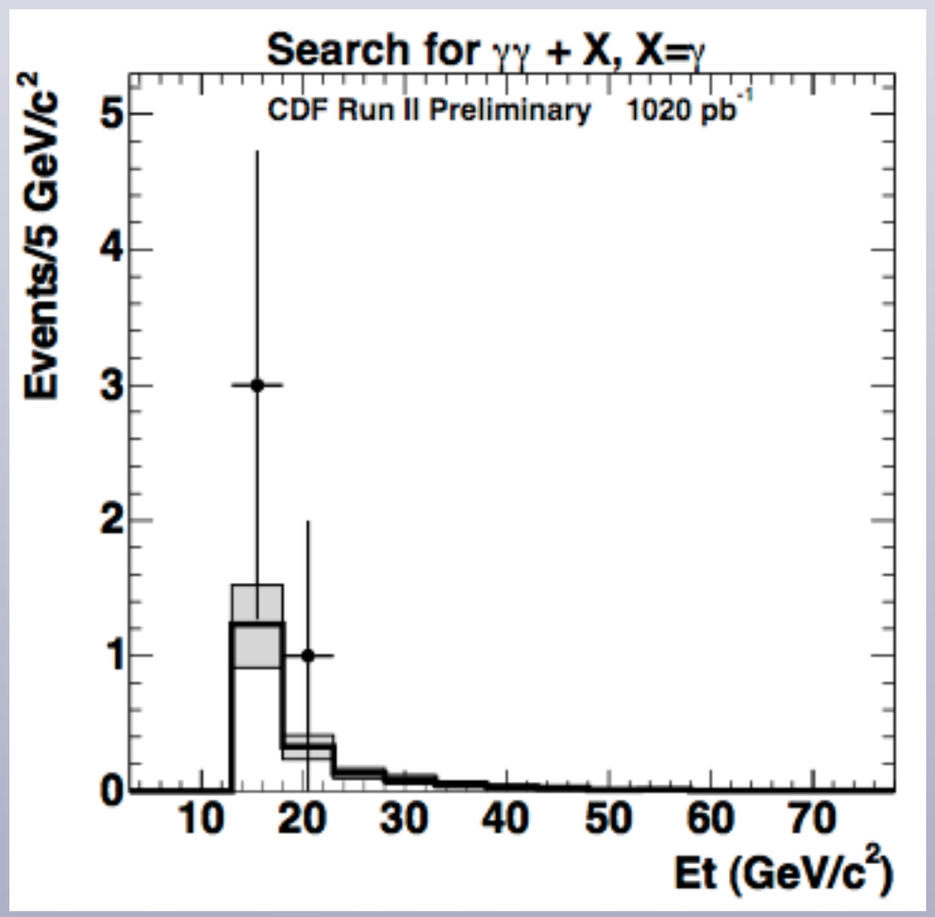
(σ_Q=0.289pb m_Q=300 GeV)

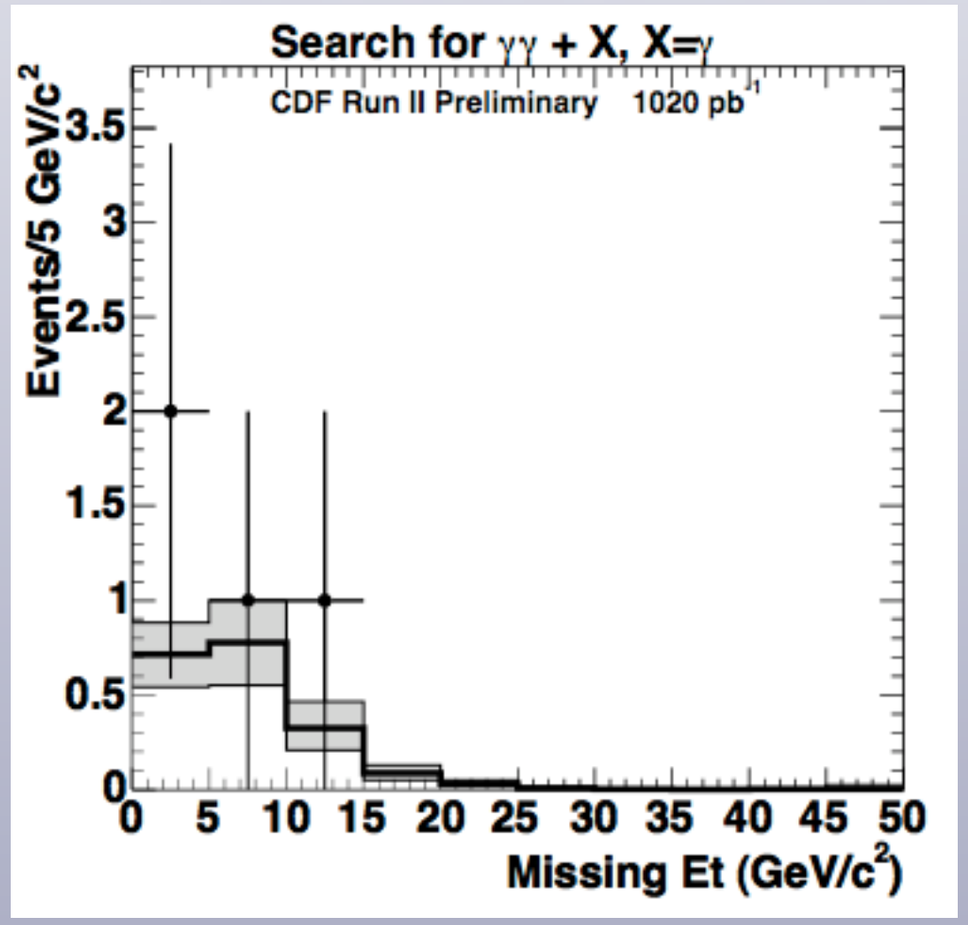
Signature-Based Search: ϒϒ+ϒ/e/μ

Motivated by e^+e^-ϒϒ+MET Event in RunI, study events with 2 photons plus another object

First analysis looks at ϒϒ+ϒ (All E_T>13 GeV)

- Expect 1.9 + 0.6 events (real tri-ϒ, fakes)
- Observe 4 Events





Signature-Based Search: ϒϒ+ϒ/e/μ

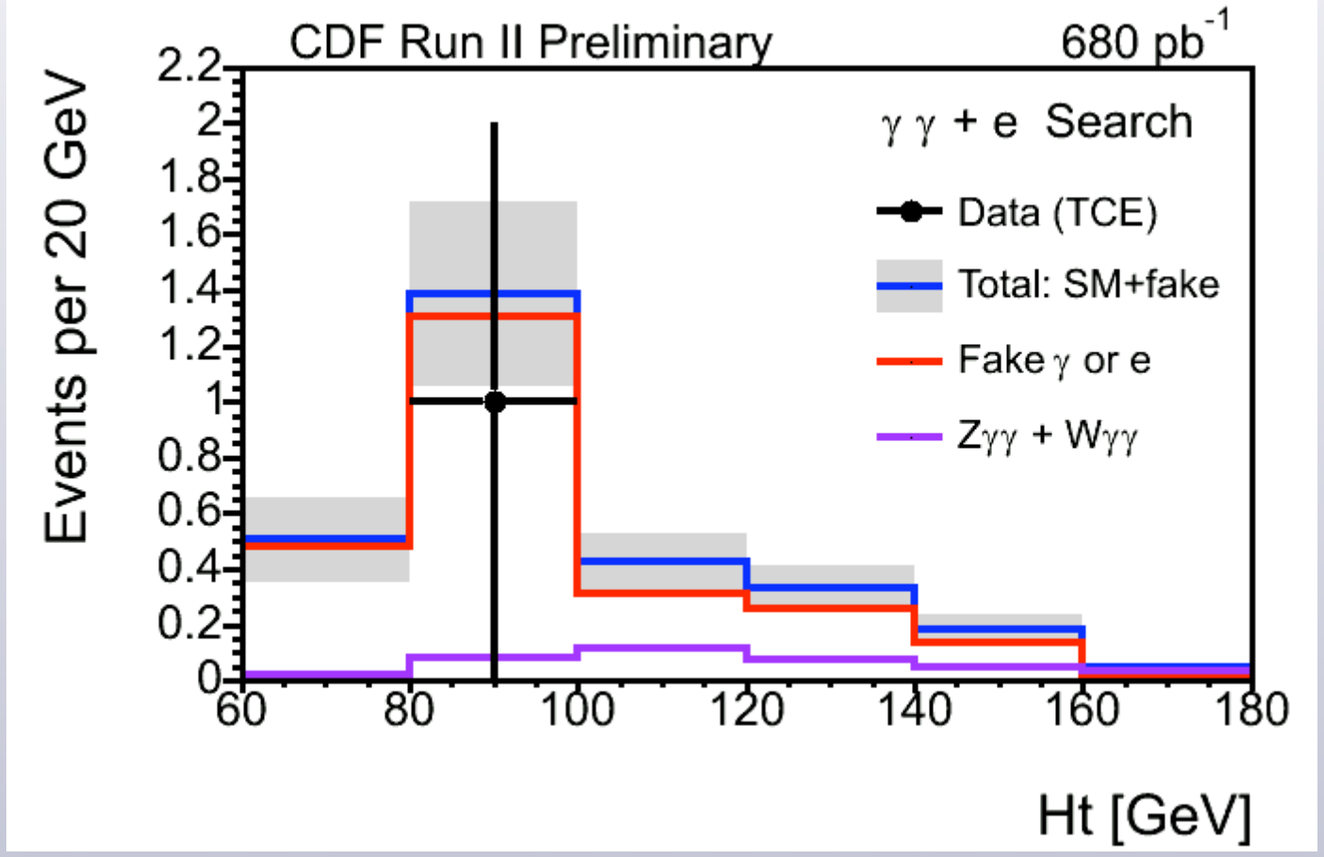
Also look for ϒϒ+e,μ - Same photon selection

ϒϒ+e: $E_T(e)>20GeV$

- Expect 3.16+0.62 events (real tri-ϒ, fakes)
- Observe 1 Event

ϒϒ+μ: $p_T(\mu)>20GeV$

- Expect 0.32+0.08 events (Zϒϒ, fakes)
- Observe 0 Events



- Good agreement between data and SM predictions
- Plan to continue to add objects in ϒϒ+X Search

Signature-Based Search: Same-Sign Dileptons

Events with 2 like-sign leptons (e or μ) have few SM sources, but can signal many types of new physics

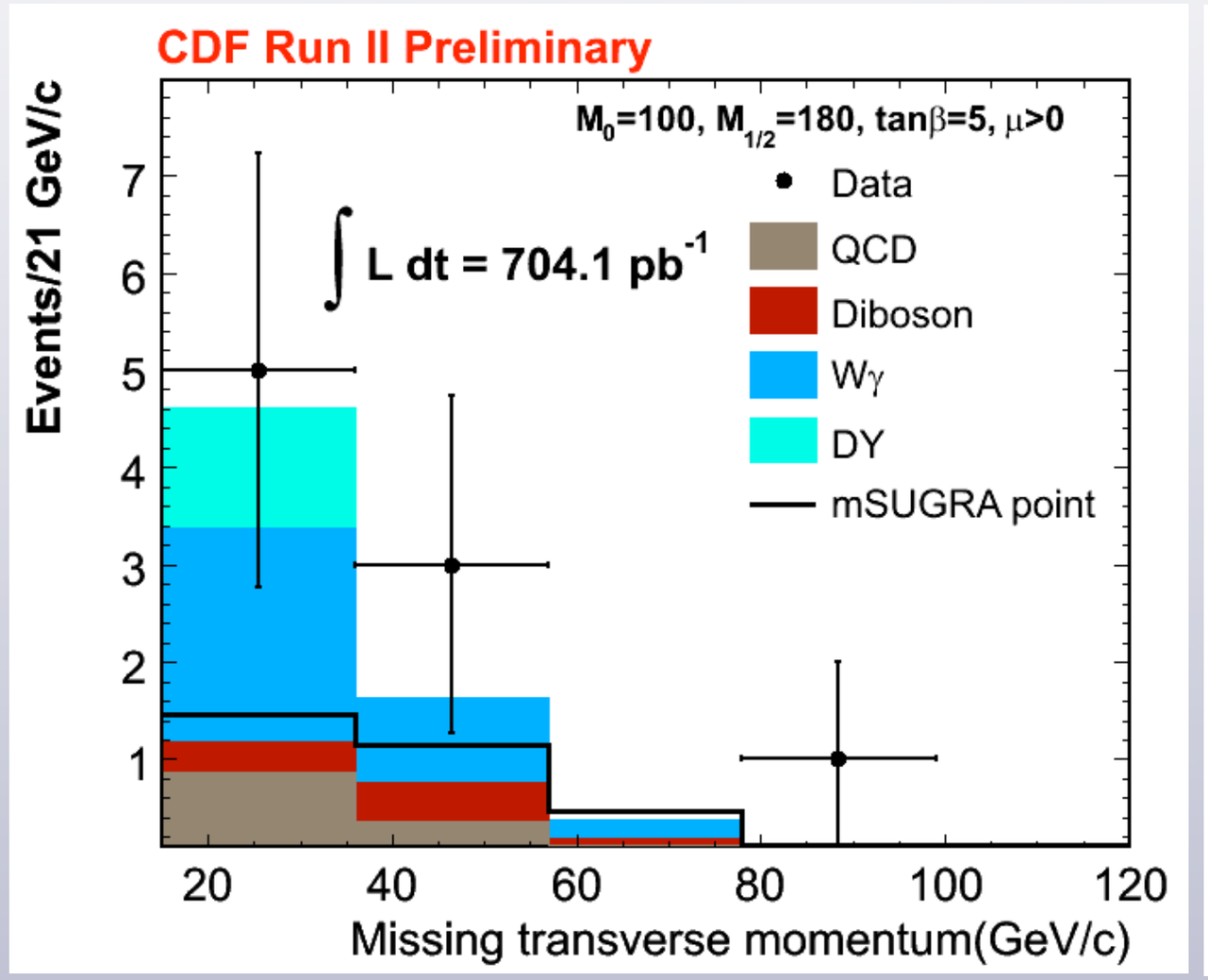
- Select events with 2 leptons:
  - 1st: $E_T(P_T) > 20$ GeV, 2nd : $E_T(P_T) > 10$ GeV
- Background estimates checked in multiple control regions
- Background dominated by asymmetric conversions

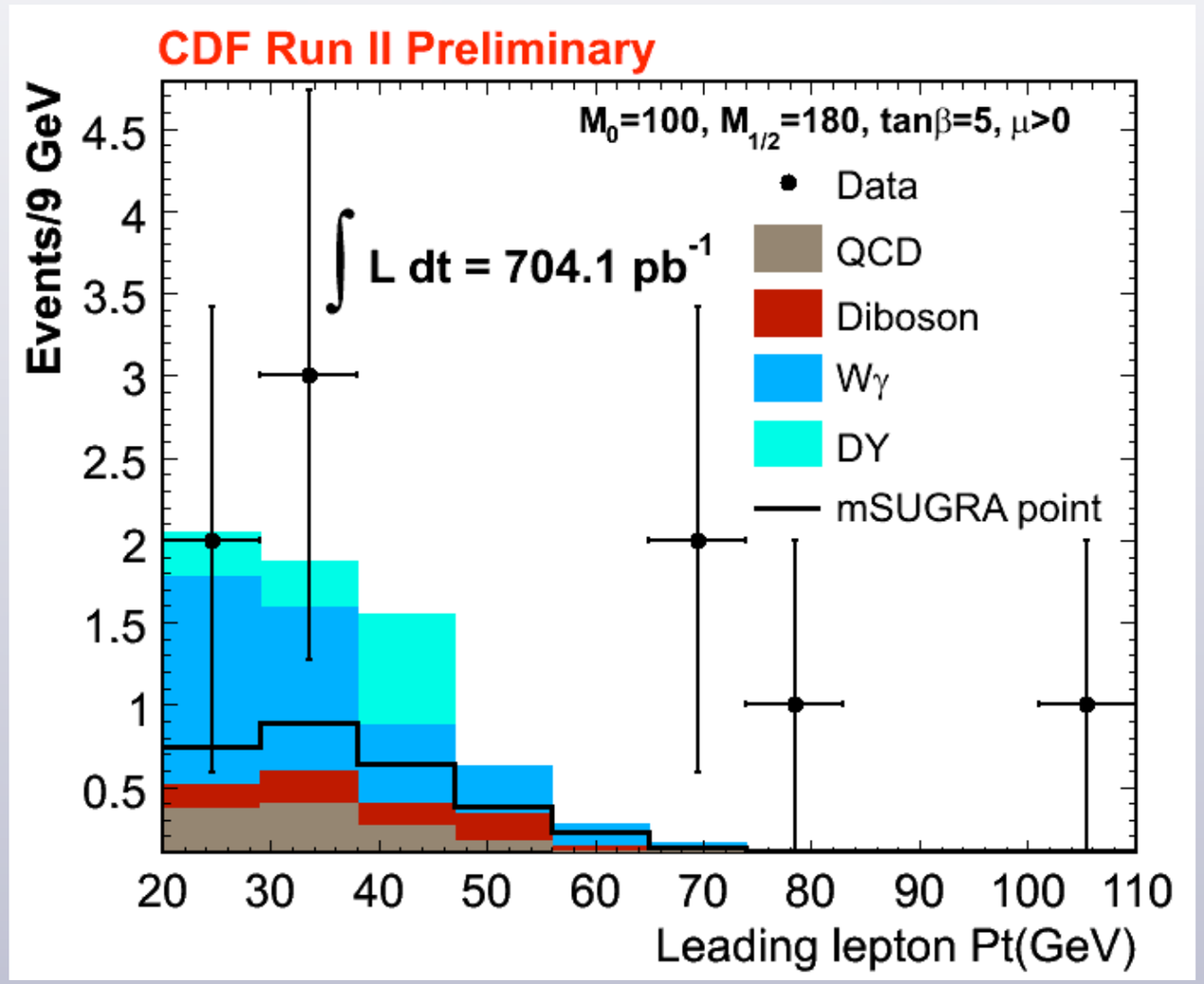
Results from Signal Region

Category	*Predicted Events*	*Observed Events*
ee	2.6 ± 0.4	4
eμ	3.5 ± 0.6	5
μμ	0 ± 0.7	0
Combined	6.8 ± 1.0	9

Signature-Based Search: Same-Sign Dileptons

What do the events look like?

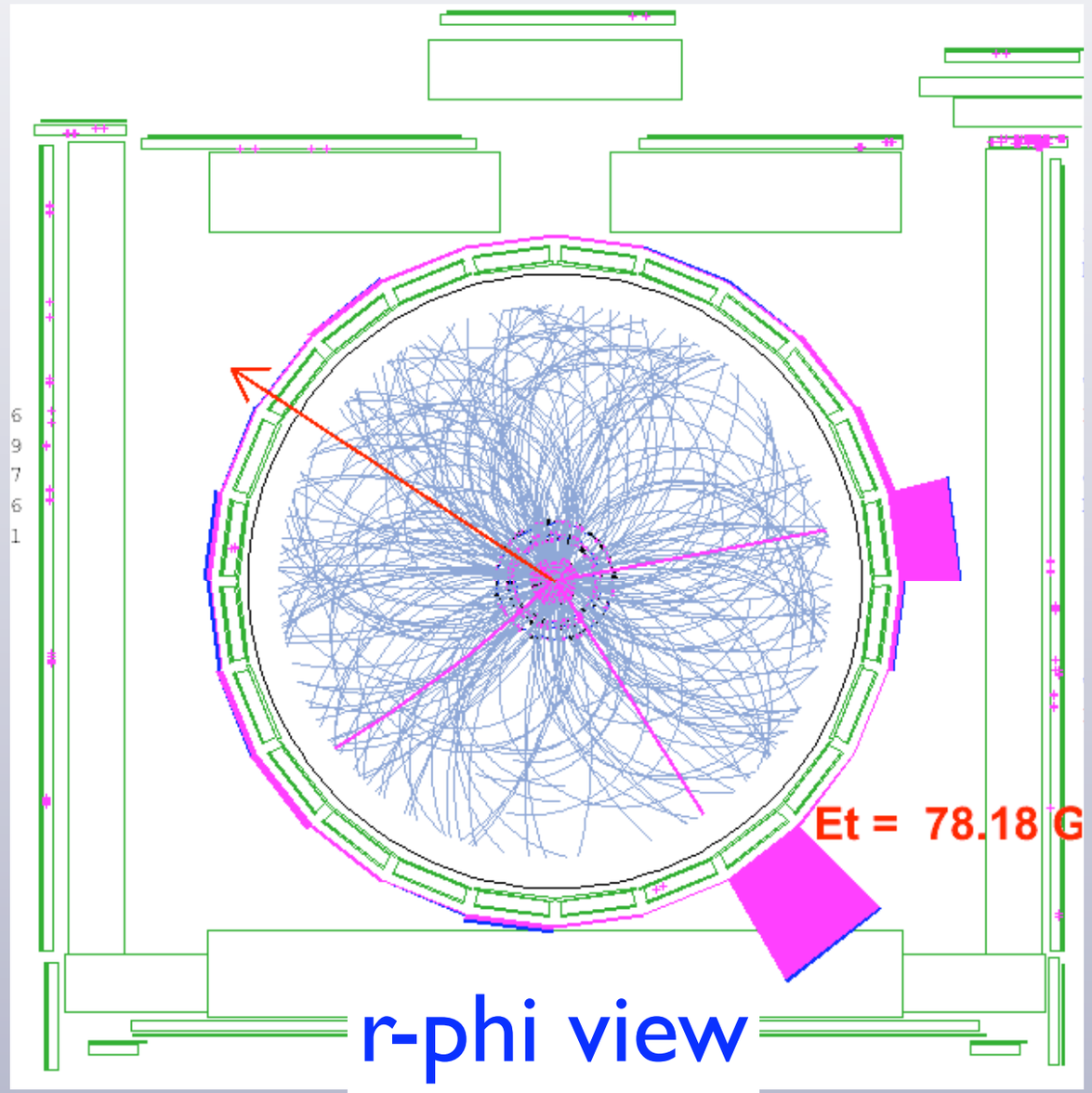


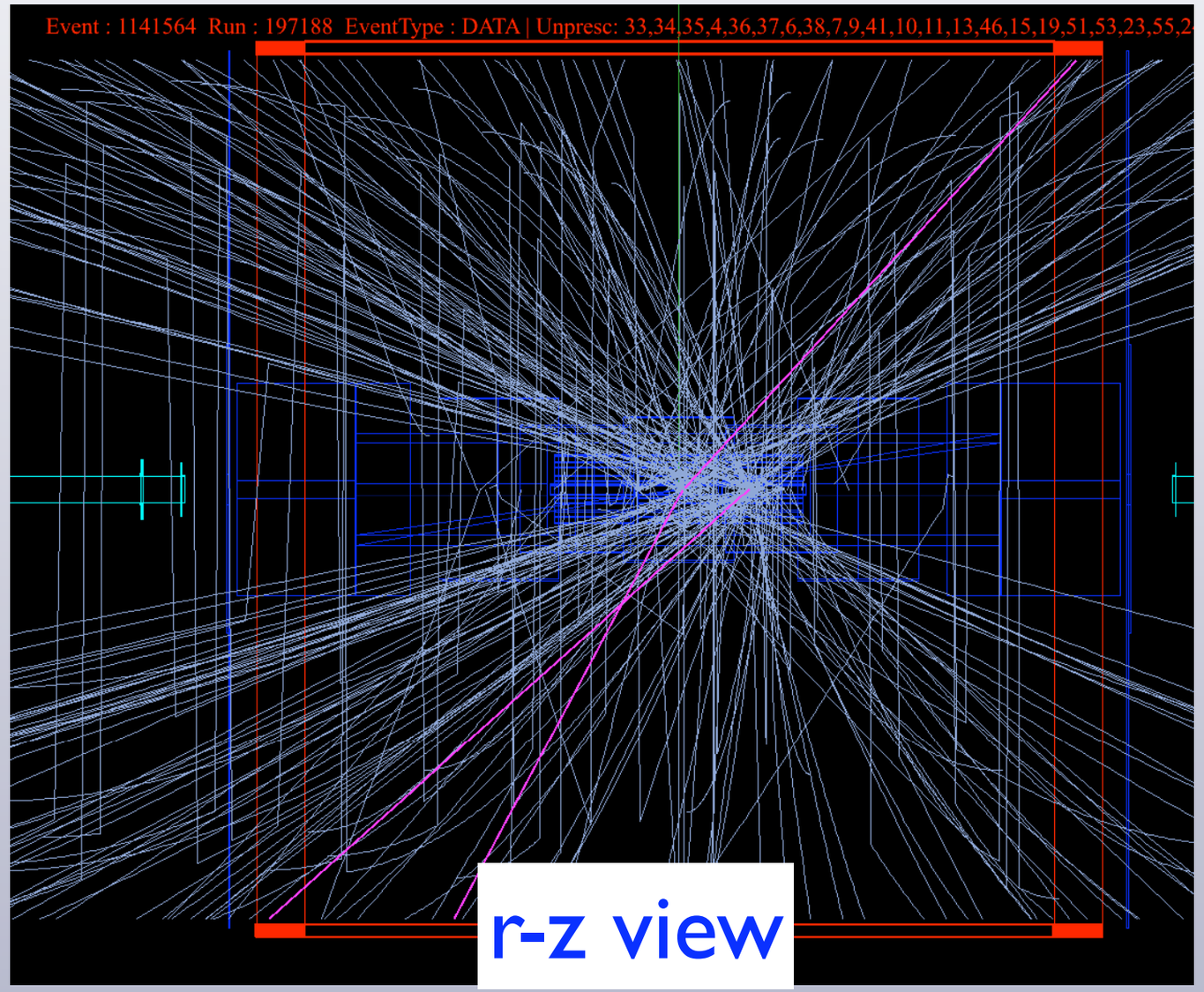


- Agreement in overall normalization, but some discrepancy in kinematic distributions

Signature-Based Search: Same-Sign Dileptons

Highest MET Event

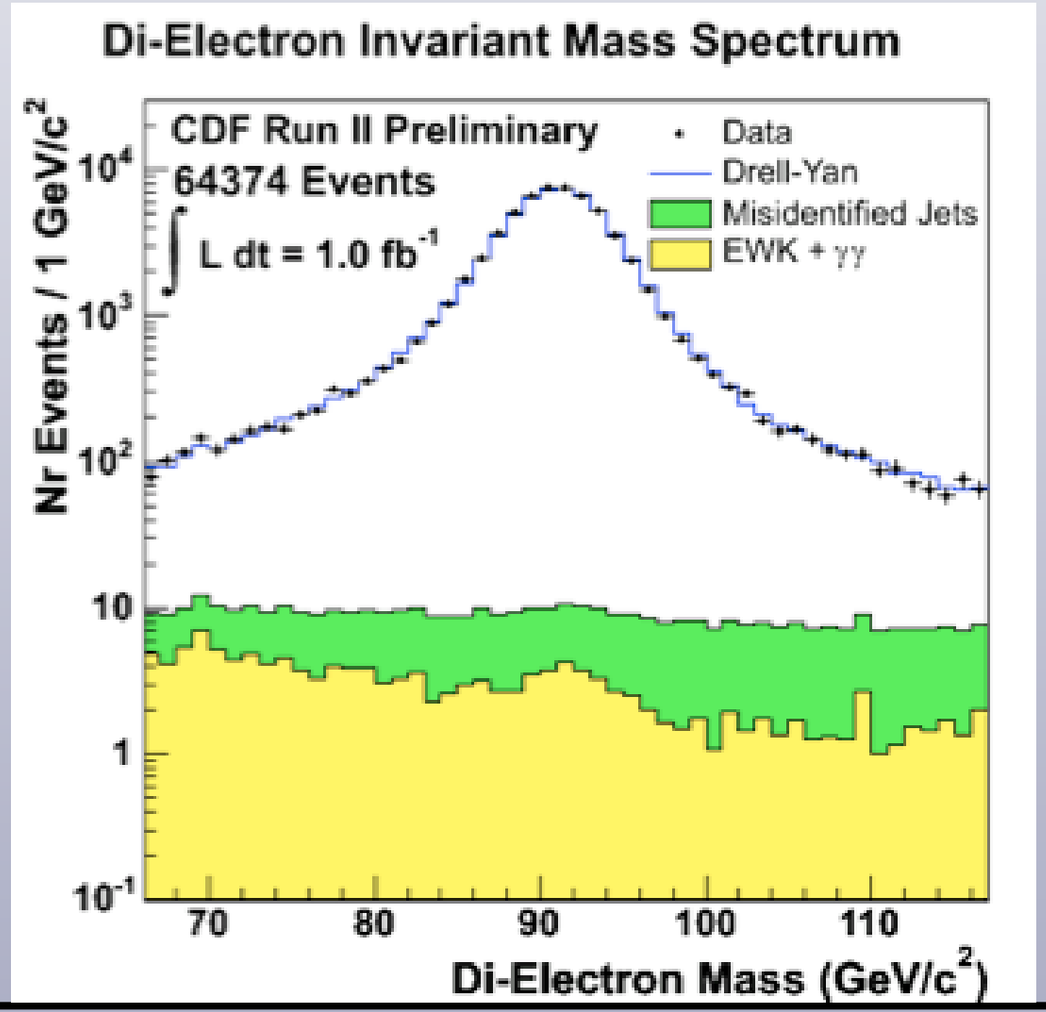




- 70, 40 GeV electrons
- 4 good vertices

Conclusions

- CDF and D0 are pursuing searches for evidence of many different models of new physics
  - Not shown today: leptoquarks, excited leptons, etc.
- No signals of NP observed in data yet
- Analyses of 1 fb^{-1} data samples just beginning
- Will provide stringent tests of many models
- Many exciting results still to come

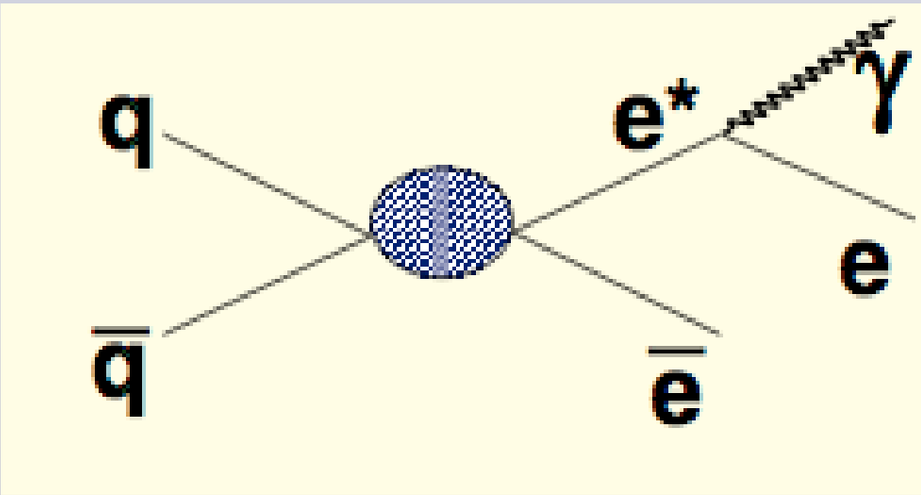


BACKUP SLIDES

Search for Excited Leptons

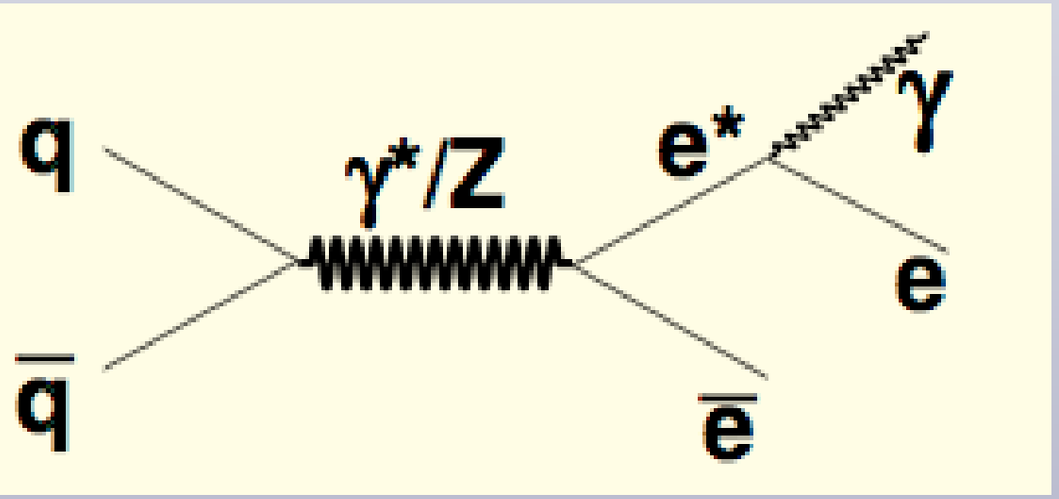
- Existence of excited states of leptons could indicate a possible substructure
- Looking for $p\bar{p} \rightarrow e^*e \rightarrow e\gamma e$
- 2 leptons + 1 γ , with resonance in lepton-γ mass

Contact Interaction Model



Baur et al, PRD V42, 3

Gauge Mediated Model



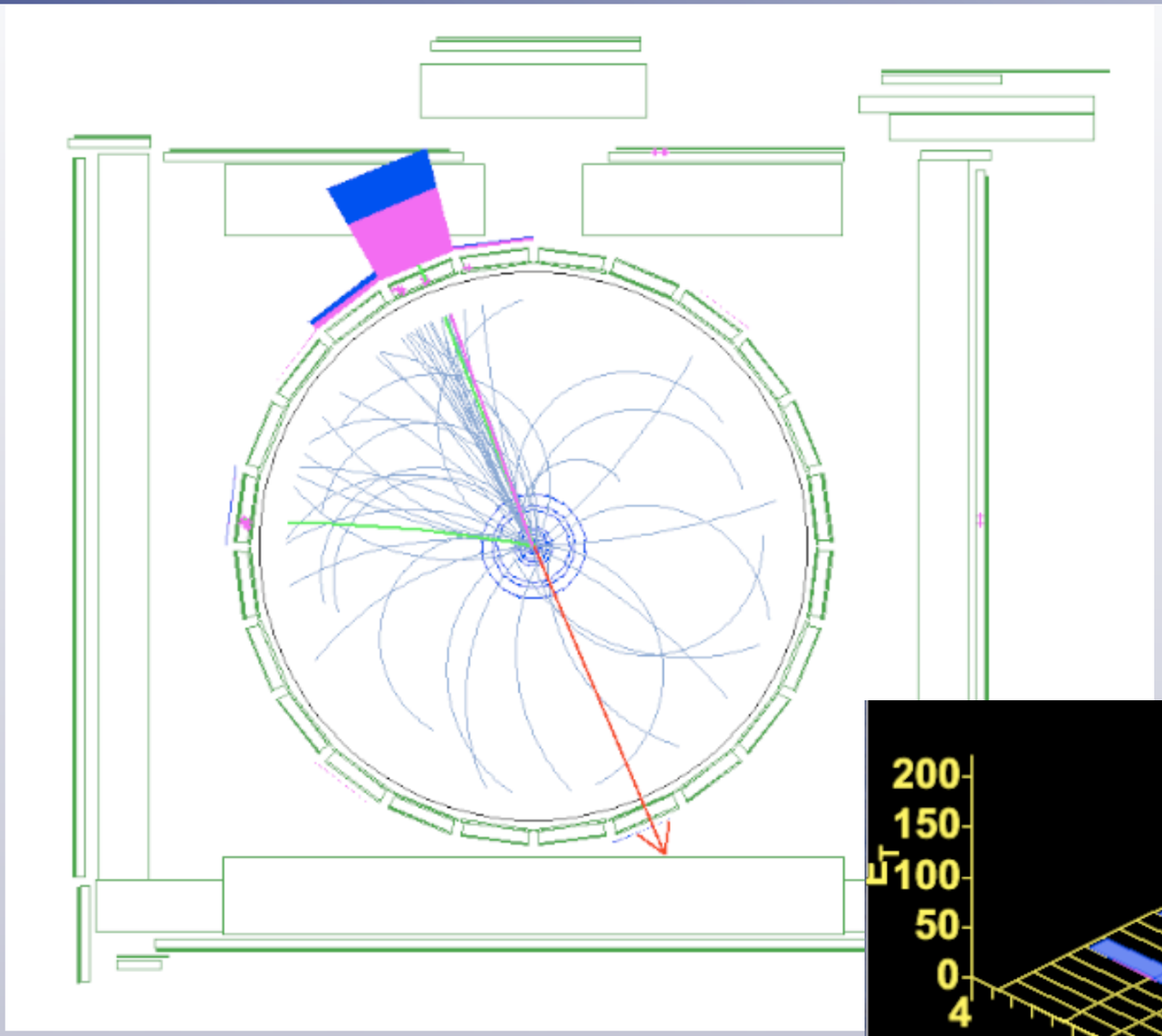
Hagiwara et al, Z Phys C29: 115

Looking Ahead

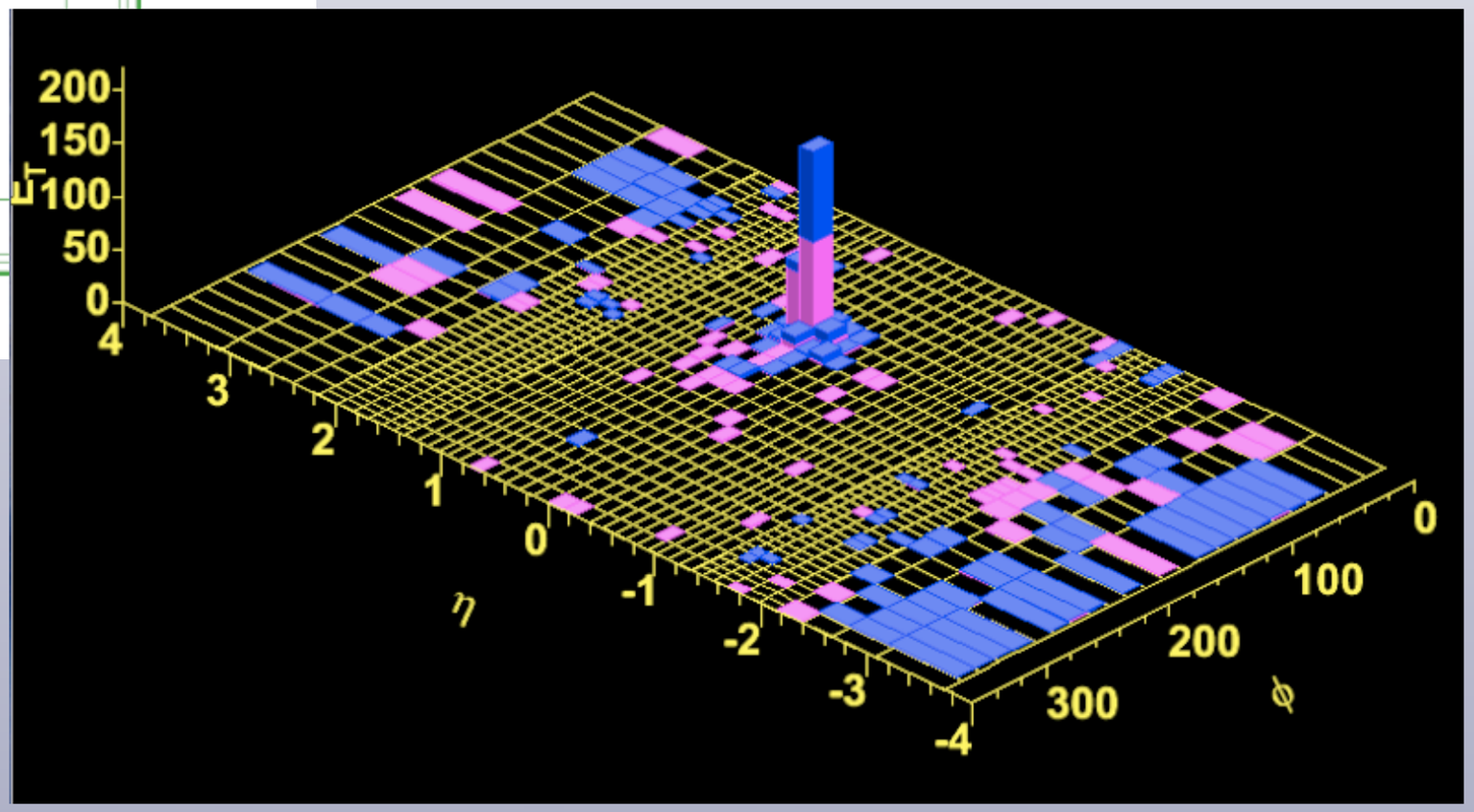
- Current analysis uses 368 pb^{-1} of data
- Because backgrounds are estimated from data, uncertainty will continue to improve with more data
  - Expect updated result with 1 fb^{-1} for summer
  - Additional gains using lower E_T cut and MET trigger
- Estimates of improved M_D limits with 1fb^{-1}

n	M_D (TeV)
2	1.40
3	1.14
4	1.03
5	0.95
6	0.91

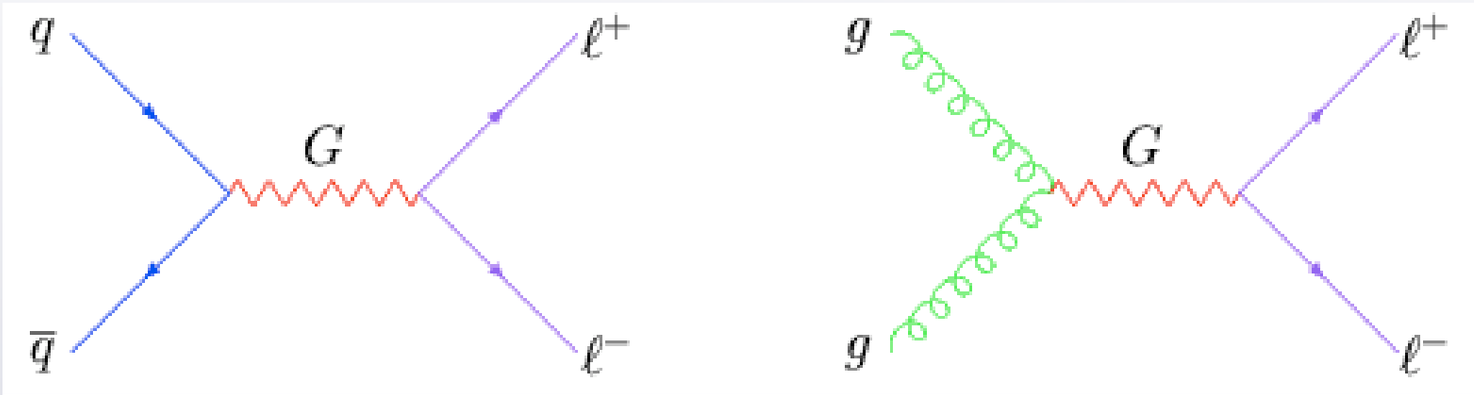
Example Candidate Event

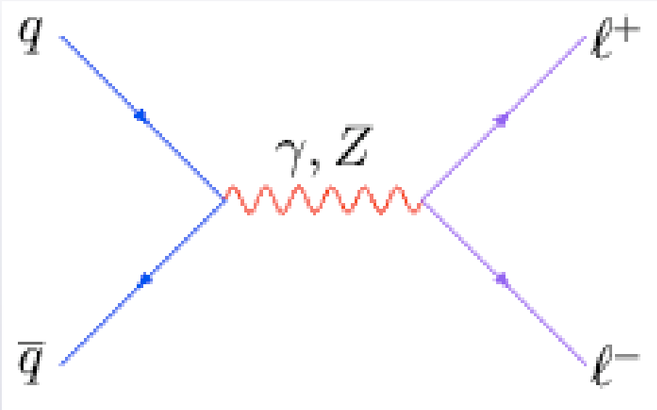


- E_T(Jet 1) = 361 GeV
- Missing E_T = 350 GeV



Virtual Graviton Results





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- Different conventions for *F* :

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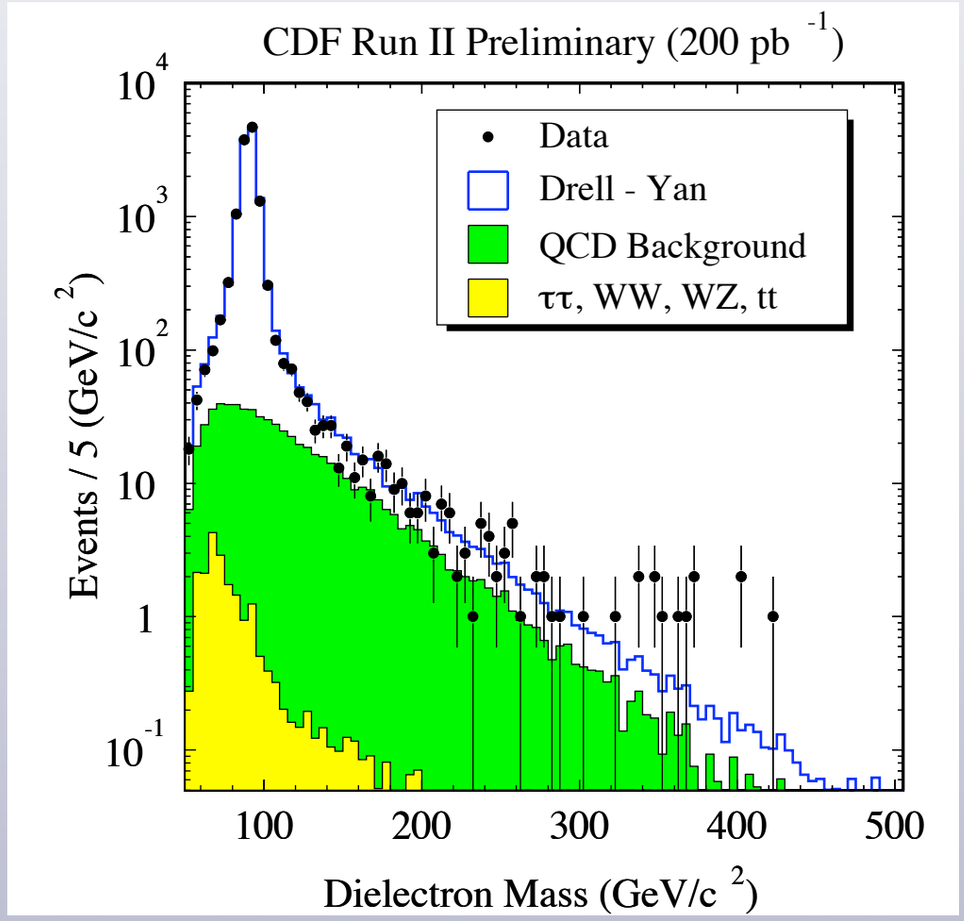
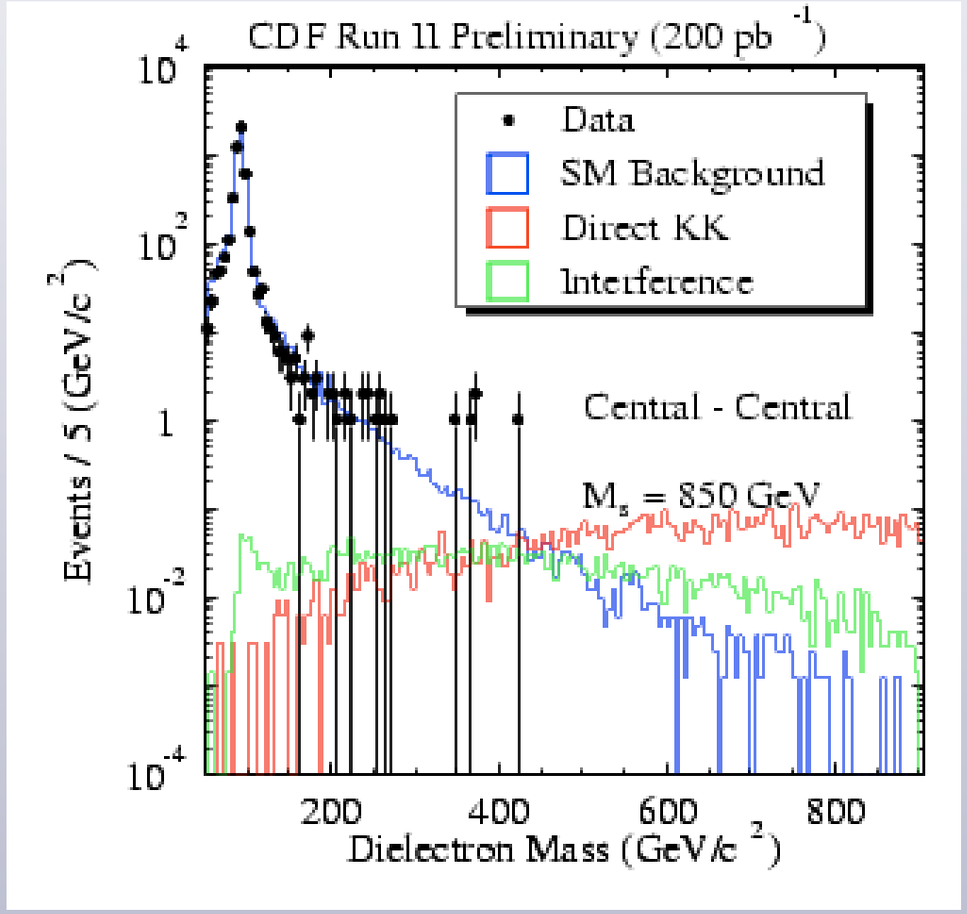
HLZ (n=2)	$\log(M_S^2/M)$
HLZ (n>2)	$2/(n-2)$
Hewett	$2\lambda/\pi$

Virtual Graviton Results

- CDF results in e^+e^- channel with 200 pb^{-1} of data
  - 1D Fit to invariant mass distribution





M_S Limit(TeV)	CDF	D0 (RunII)	D0(Run I+II)	LEP
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$\lambda=-1$	0.99	1.10	1.16	1.2