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

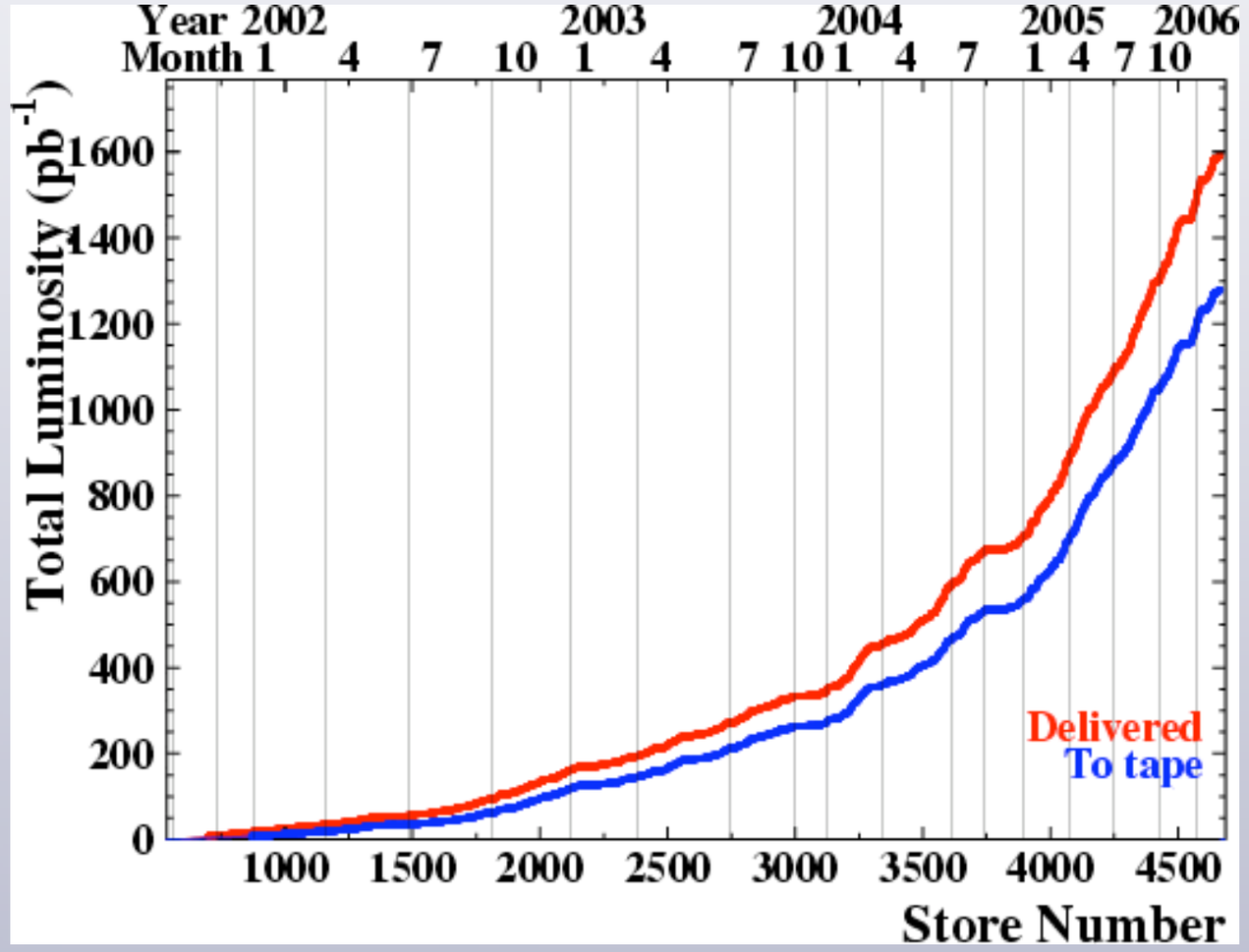
Introduction

- 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, ~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:

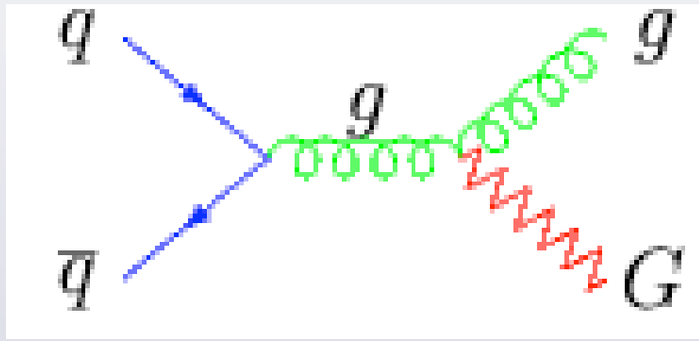
- Arkani-Hamed, Dimopoulos, Dvali (ADD):
  - *n* extra dimensions, compactified at radius *R*, $(M_{PL})^2 \sim R^n (M_D)^{2+n}$
  - SM confined to brane in higher dimensional space
  - Only gravity can access extra dimensions
  - Signatures: Jet+MET, γ+MET, lepton pairs
- Randall-Sundrum (RS) Model: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

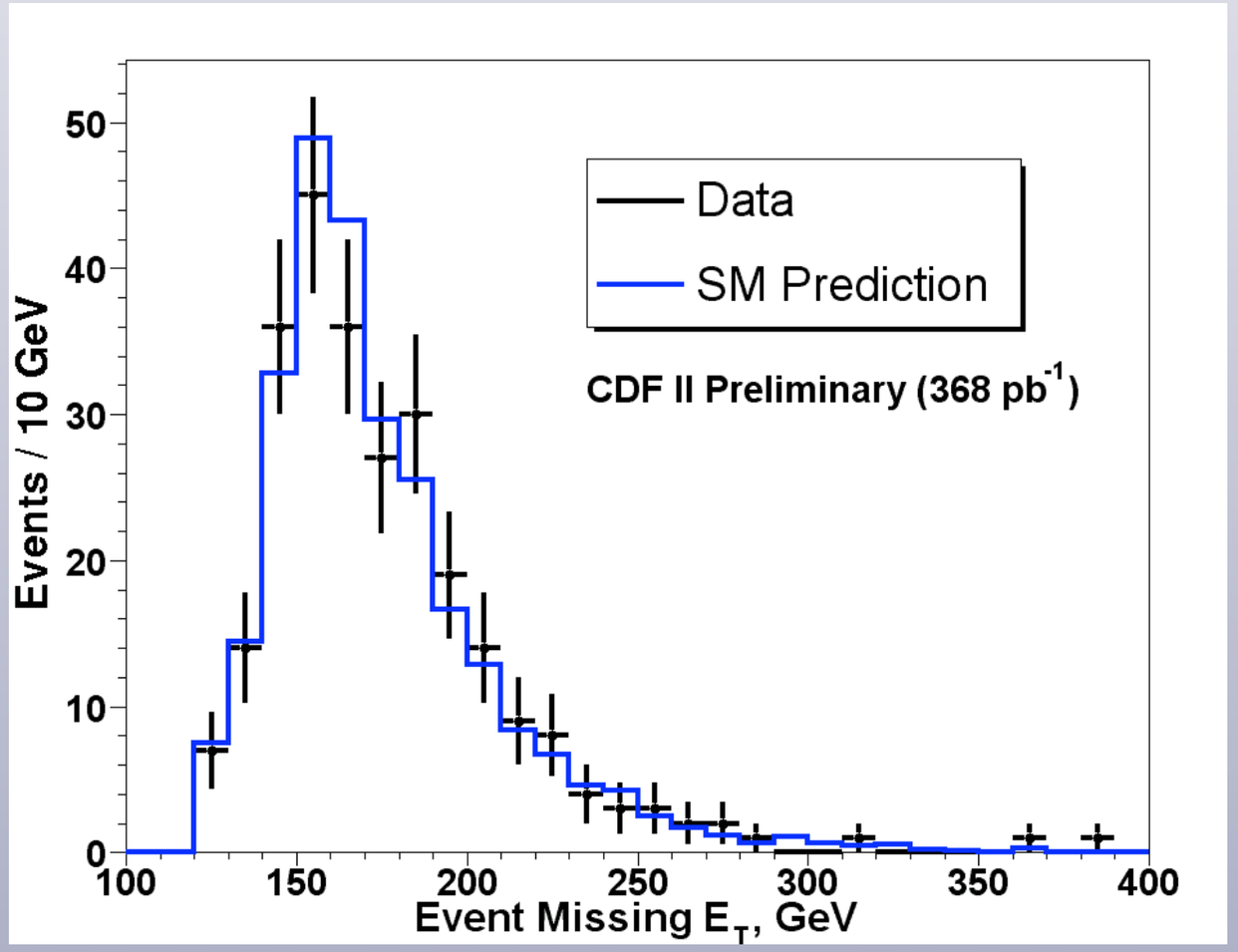
Monojet Search for LED (ADD)

- 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*

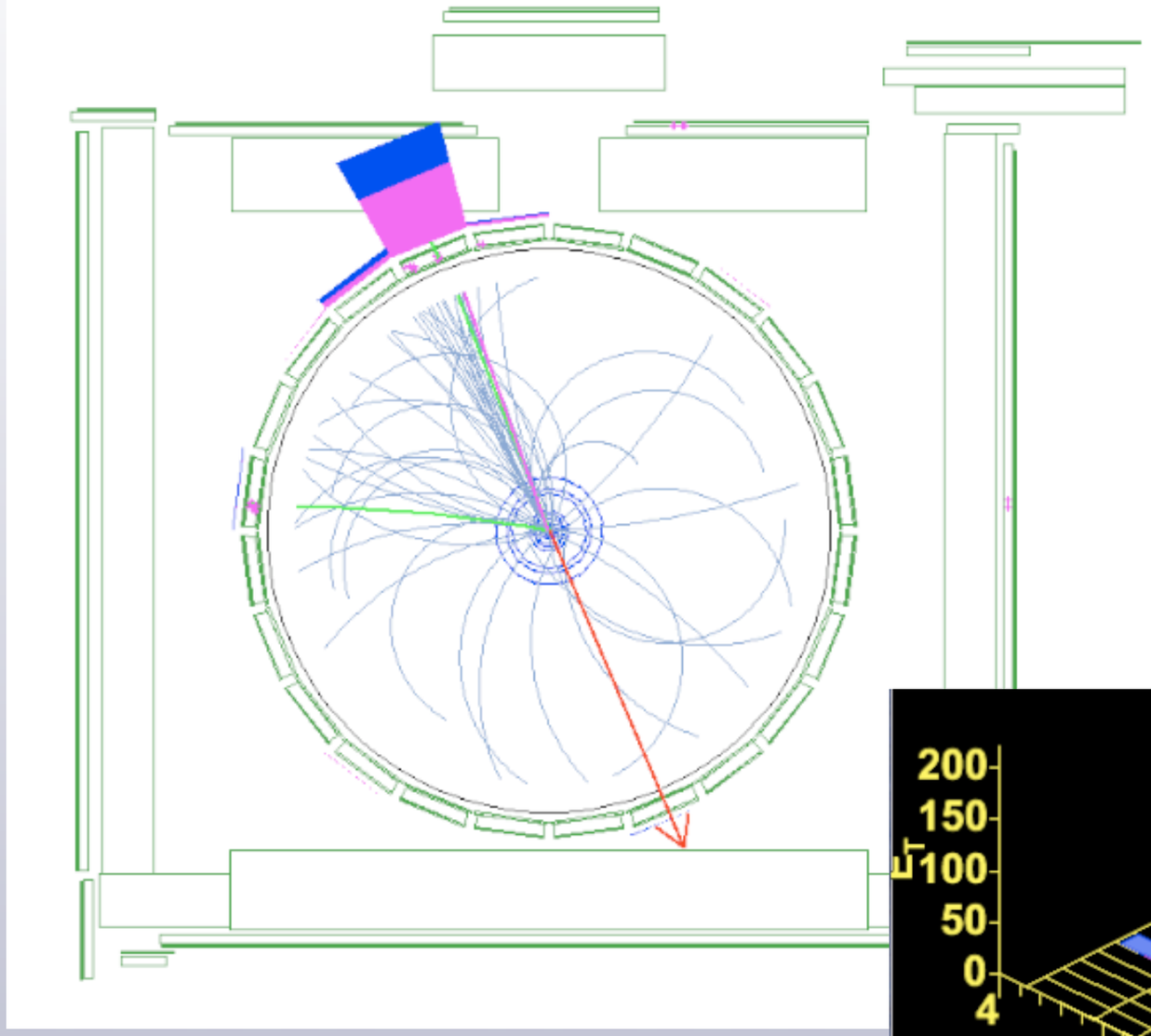
- Results:
  - 265±30 events predicted
    - 130±14 $Z \rightarrow \nu\nu$
    - 113±13 $W \rightarrow l\nu$
  - 263 events observed

Direct Graviton Emission

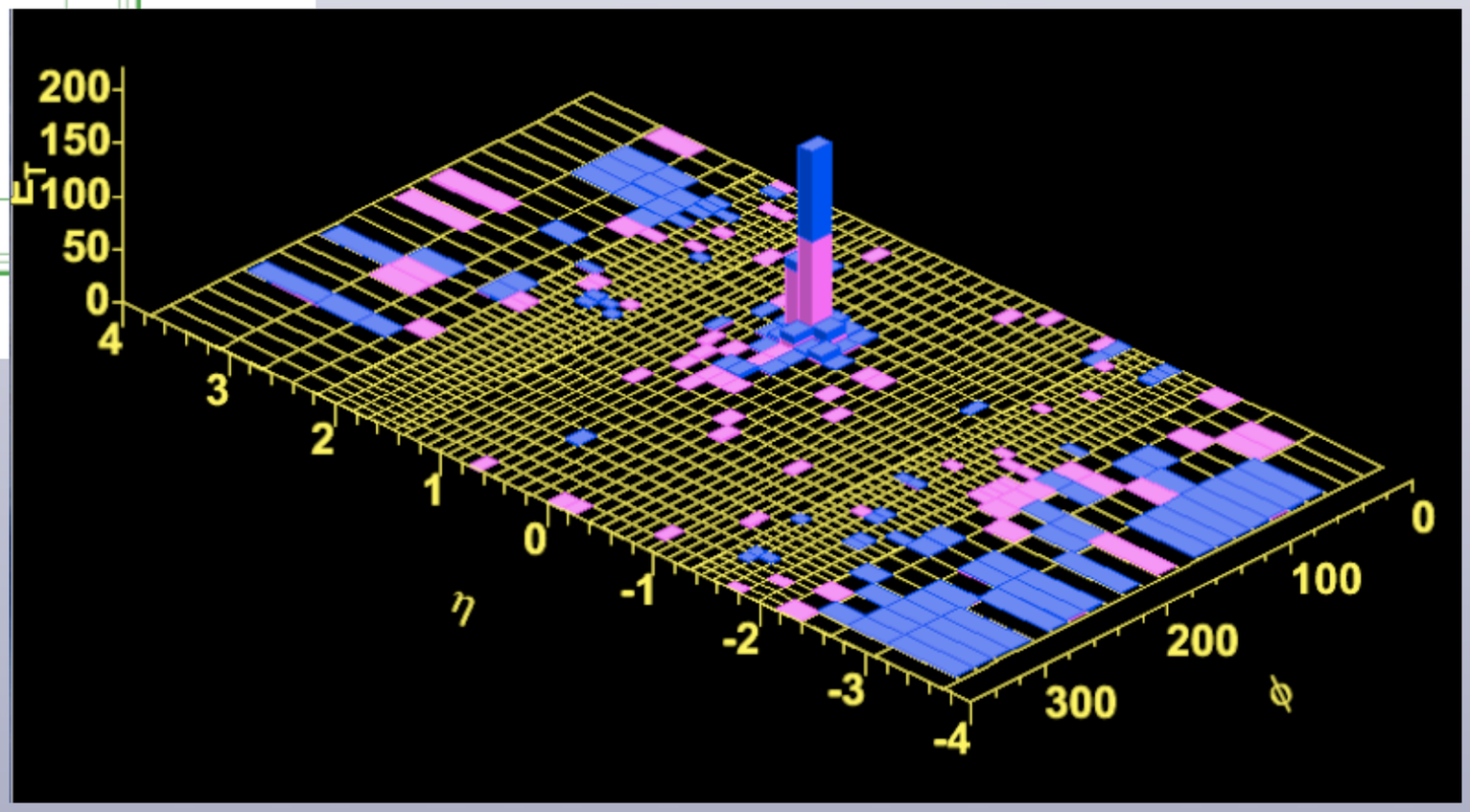




Example Candidate Event



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

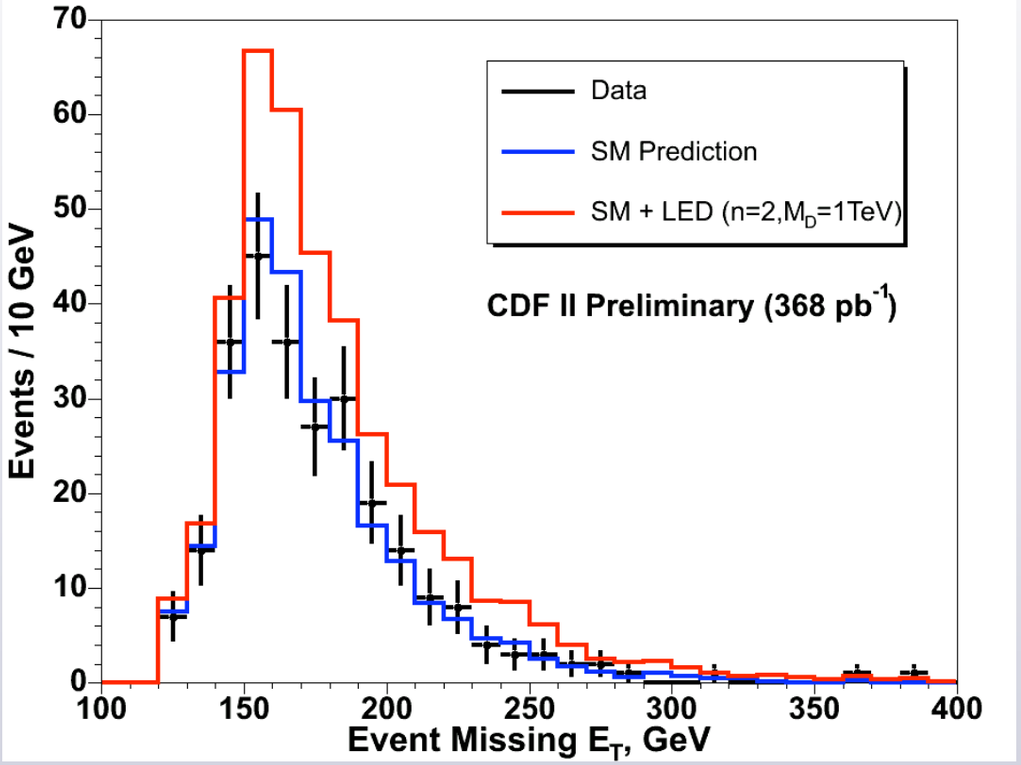


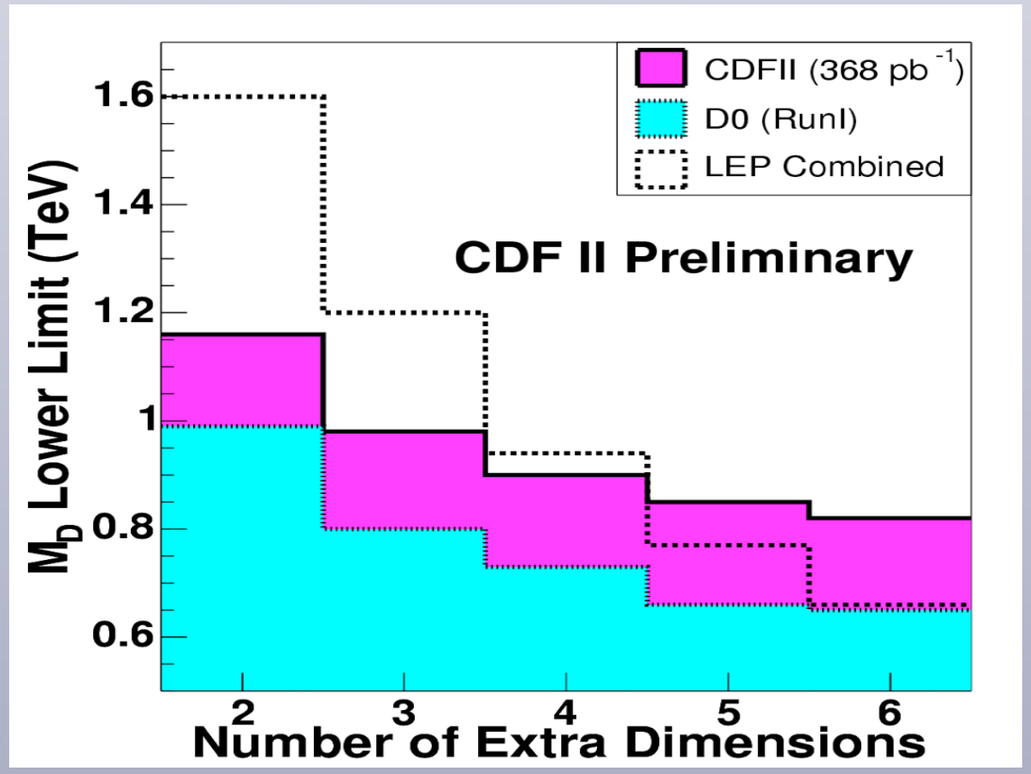
Monojet Search for LED (ADD)

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

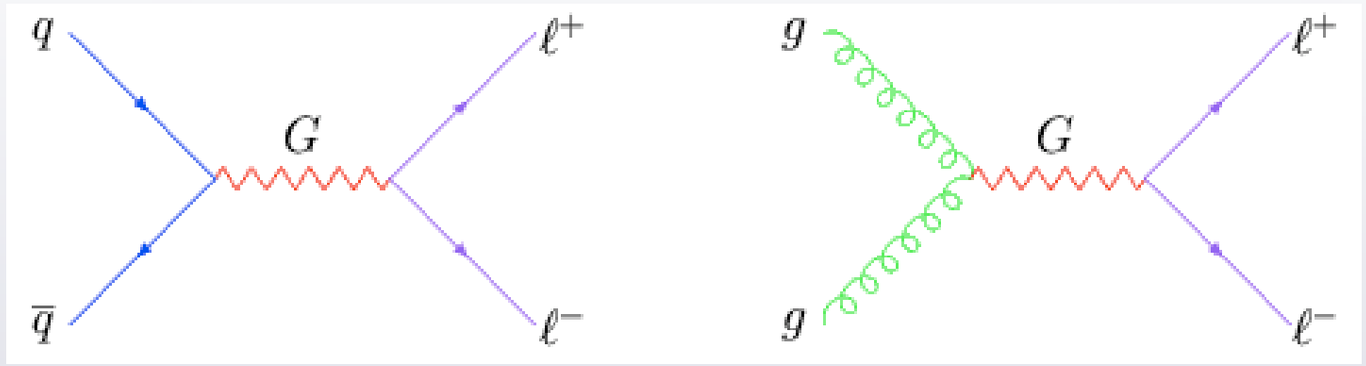
$$R^n = \frac{1}{8\pi}\left(\frac{M_{PL}}{M_D}\right)^2 \frac{1}{M_D^n}$$

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:

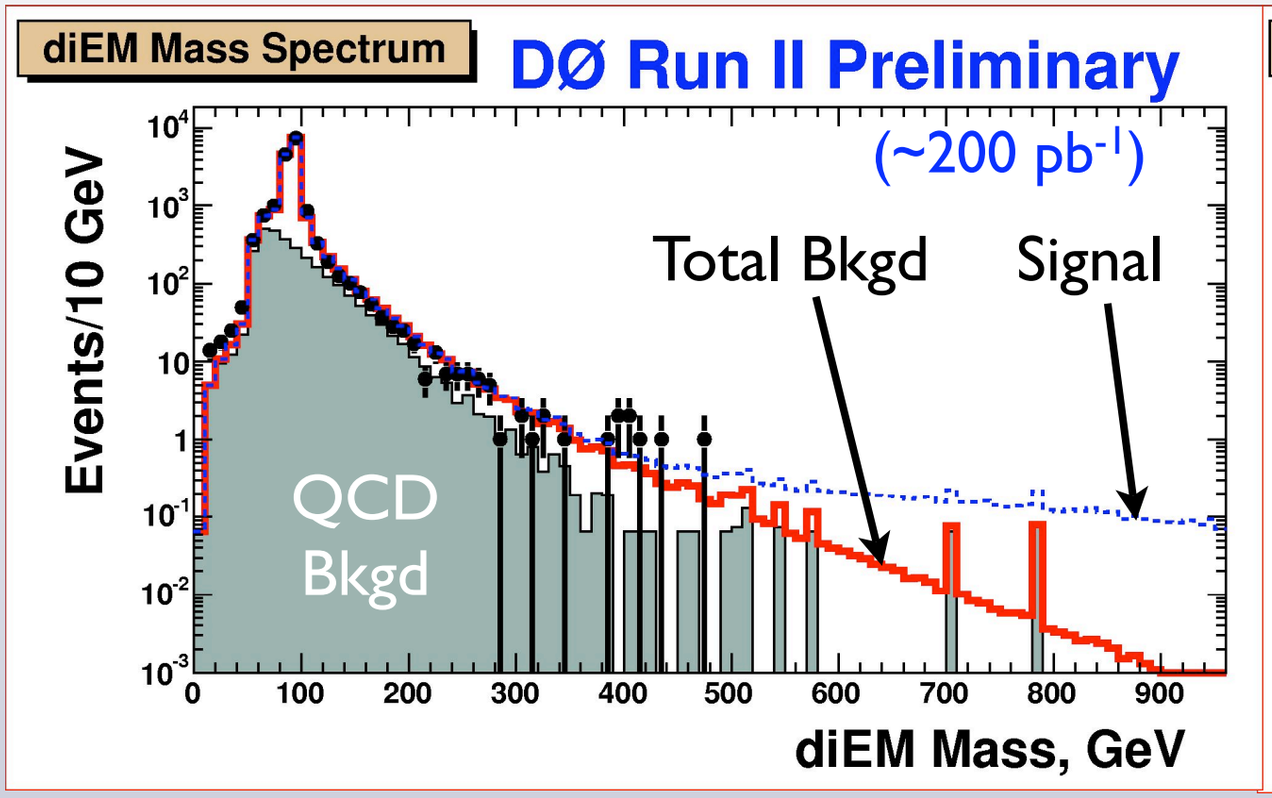
$\sigma_{TOT} = \sigma_{SM} + \eta\sigma_{INT} + \eta^2\sigma_{GRV}$ $(\eta = F/M_S^4)$

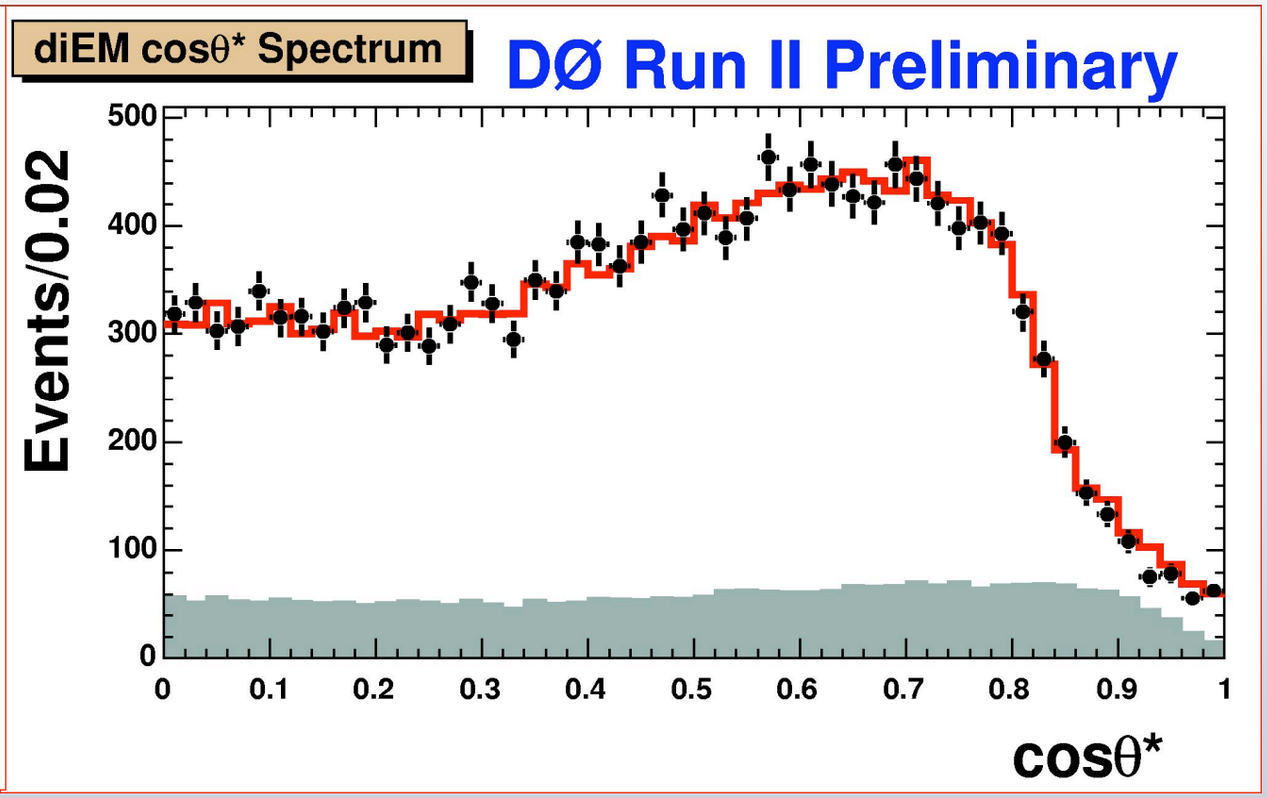
D0 Analysis Strategy:

- 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	$2\lambda/\pi$

Search for LED - Graviton Exchange





M_S Limit(TeV)	D0 (RunII)	D0(Run1+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 ($\lambda=+1,-1$)

Search for ED - RS Gravitons

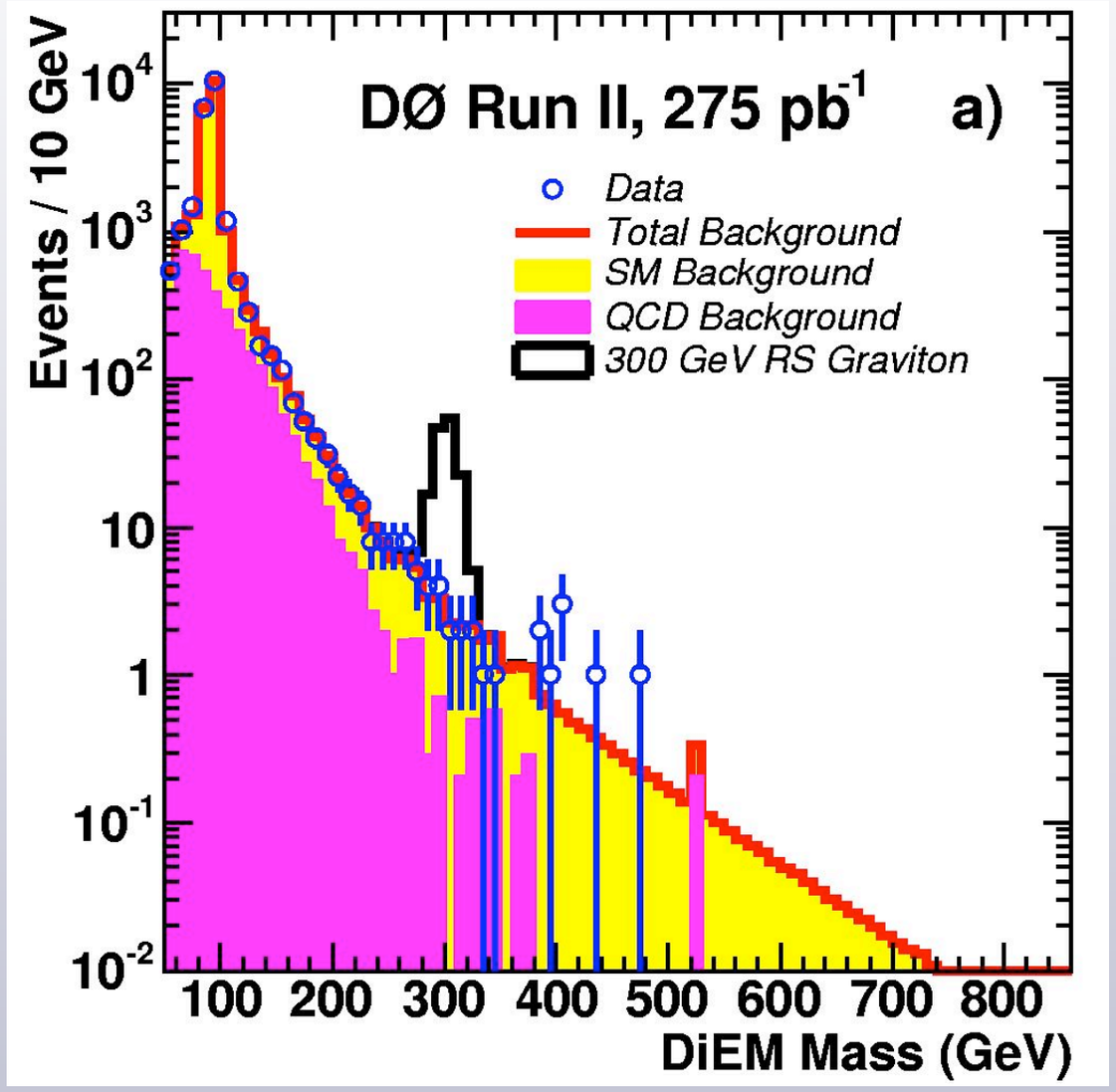
- In RS Model, two branes in one curved ED, with gravity on a different brane from SM
- Effects of gravity on SM brane have scale

  $\Lambda_\pi = \overline{M}_{PL}\, exp(-k\pi R)$ (k= curvature, $\overline{M}_{PL} = M_{PL}/\sqrt{8\pi}$)

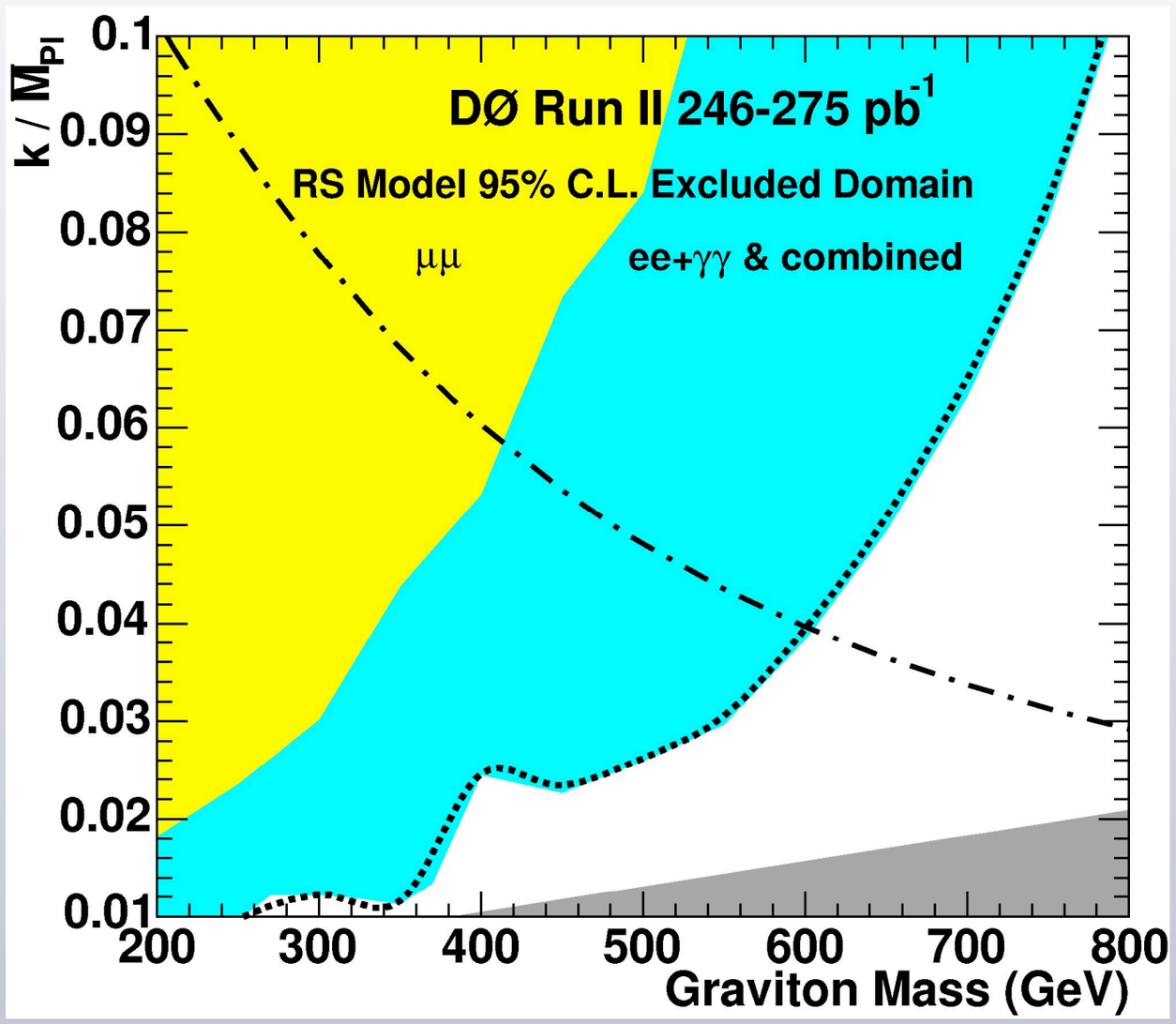
  - Expect k/M_{PL} in the range 0.01-0.1

- 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



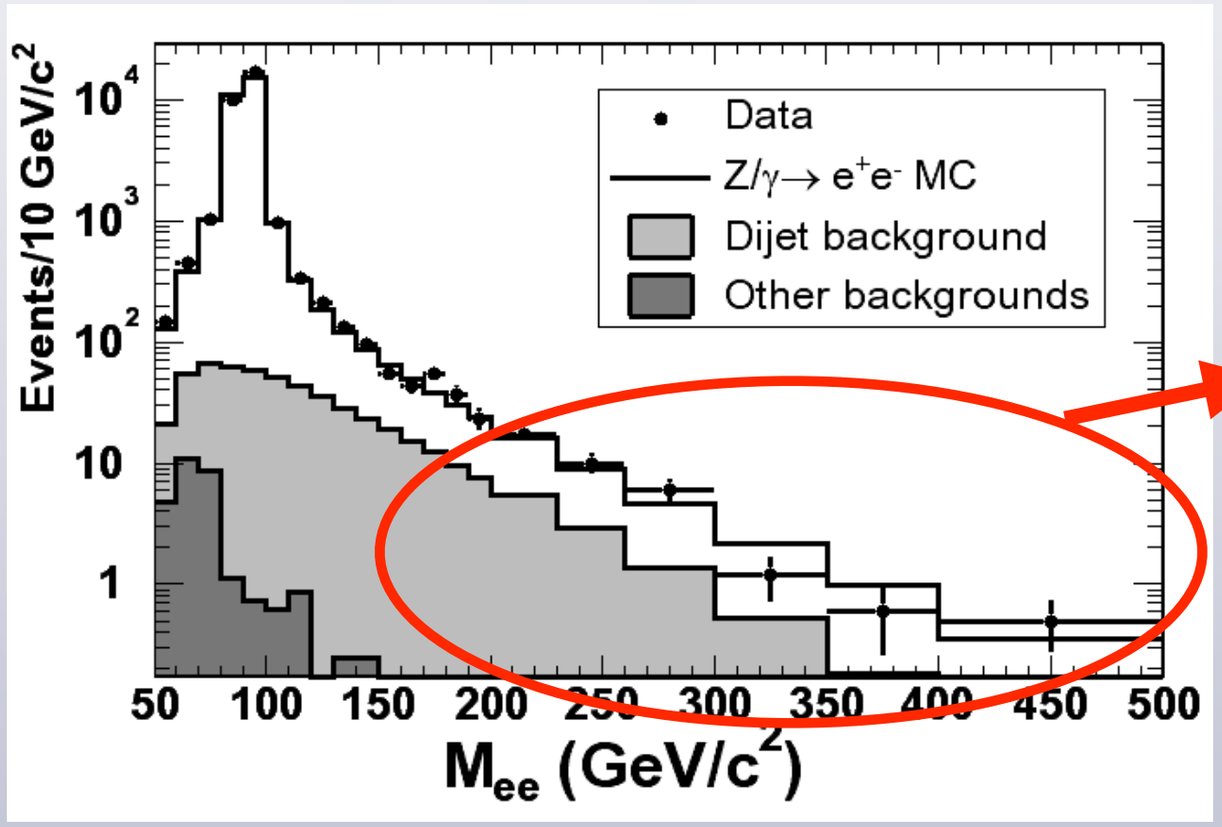
Mass Limit vs. $k/\overline{M}_{PL}$

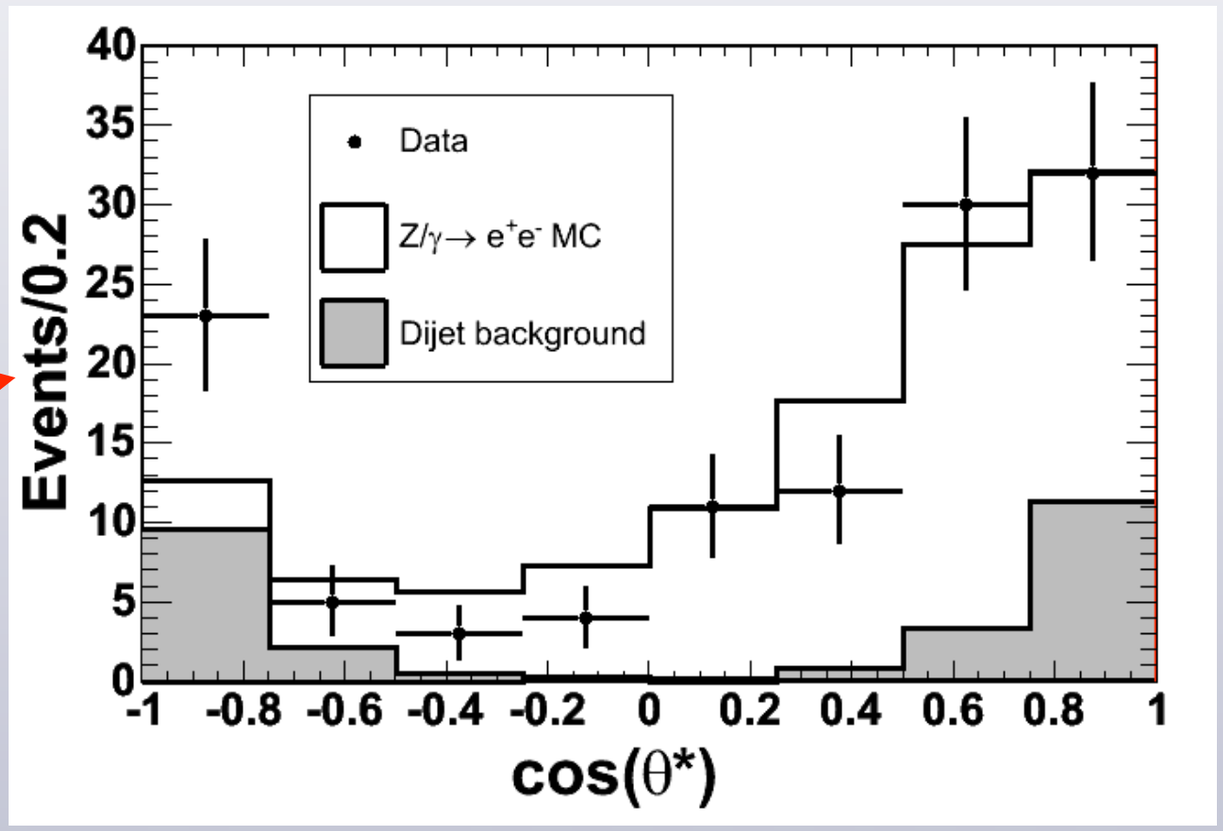
Graviton masses excluded up to 785(250) GeV
for $k/\overline{M}_{PL}$ = 0.1(0.01)

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

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

(Recently submitted, hep-ex/0602045)





- Use M_{ee}>200 GeV region for search (448 pb^{-1}):

Source	$Z/\gamma^* \rightarrow e^+e^-$	Dijet	Diboson	Total SM	Observed
Events	80.0 ± 8.0	28^{+14}_{-17}	6.8 ± 1.4	115^{+16}_{-19}	120

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

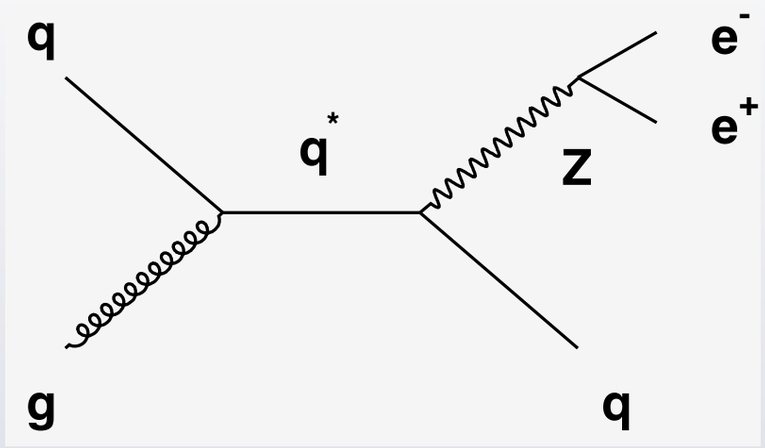
- If Z' exisits, it will interfere with SM Z/γ^*
- Do the M_{ee} and $\cos\theta^*$ data distributions fit better to the SM Z/γ^* or to $Z'/Z/\gamma^*$?
- Test $Z'/Z^*/\gamma$ fit for different models and extract limits for sequential Z' and multiple E6 models

Z' Model	Z_{SM}	Z_χ	Z_ψ	Z_η	Z_I
CDF Limit (GeV/c^2)	850	740	725	745	650
D0 Limit [200 pb^{-1}]	780	640	650	680	575

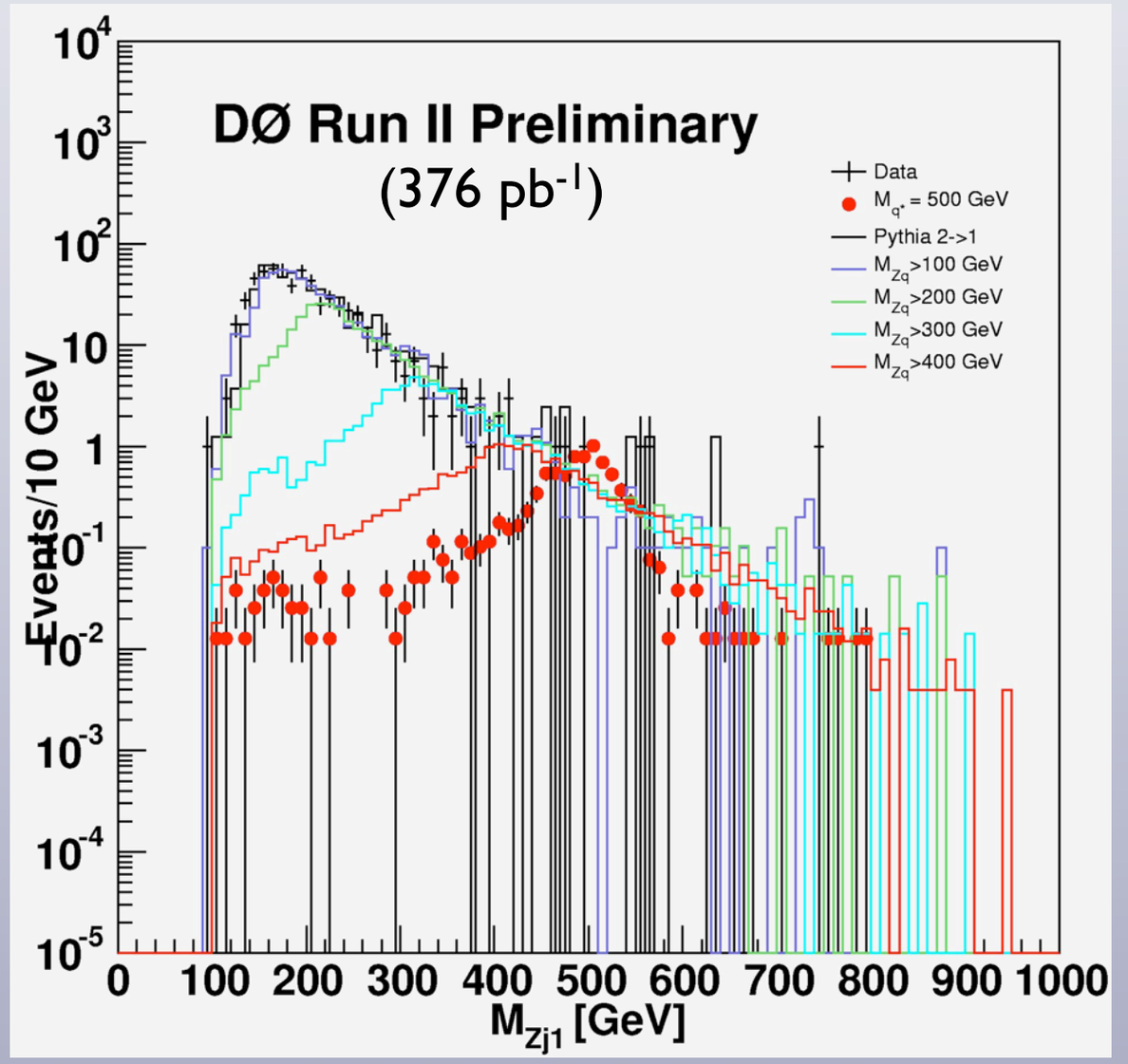
- Can also test for contact interactions:
  - See hep-ex/0602045 for details

Search for Resonances in Z+jets

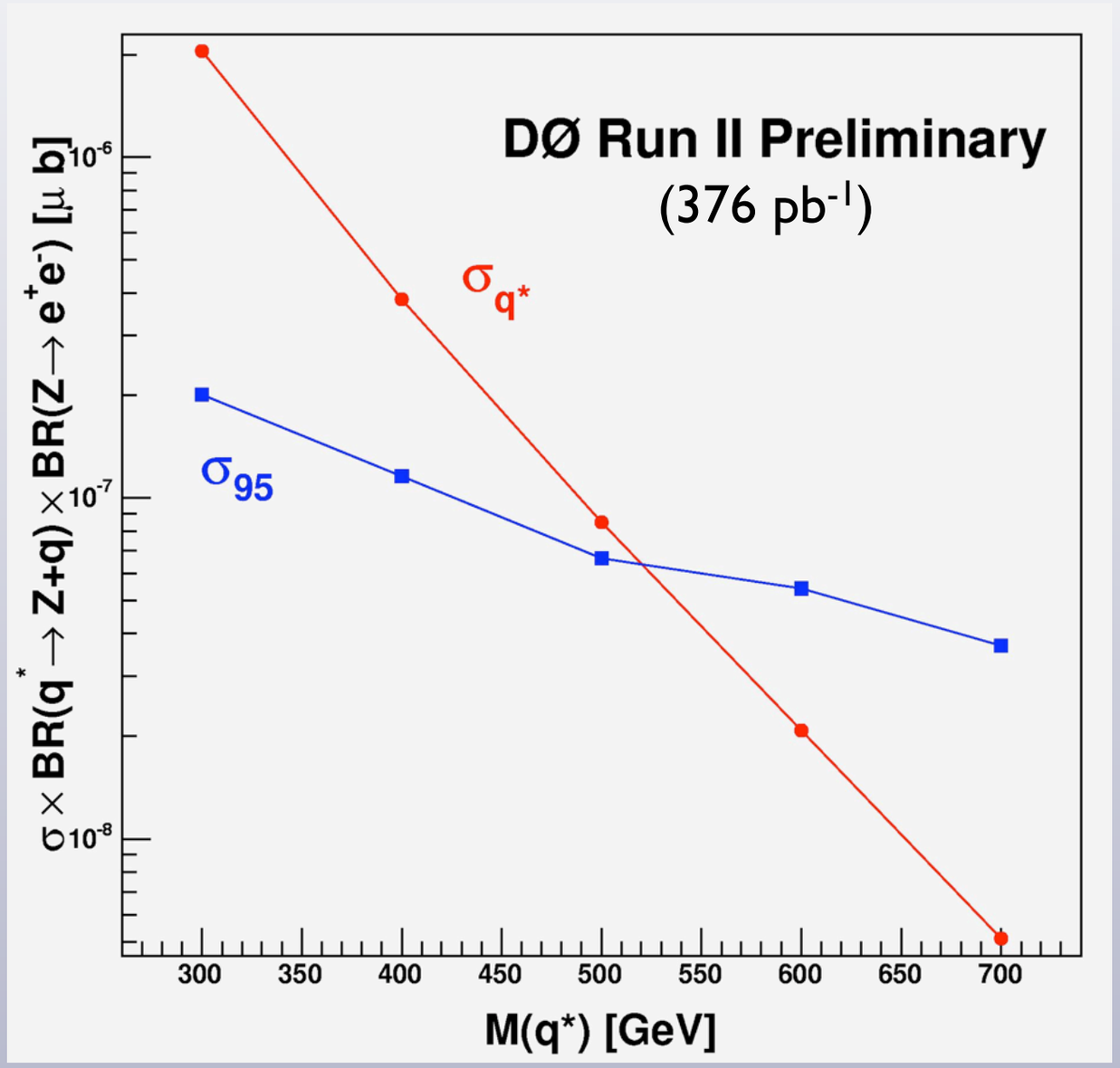
- Heavy resonances decaying into $W/Z+q$ could signal quark substructure (Baur, Spira, Zerwas PRD42,8158)



- Study $Z+jets$ ($Z \rightarrow e^+e^-$)
  - essentially background free
- For SM expectation, generate Monte Carlo with different thresholds for M(Zq)



Search for Resonances in Z+jets



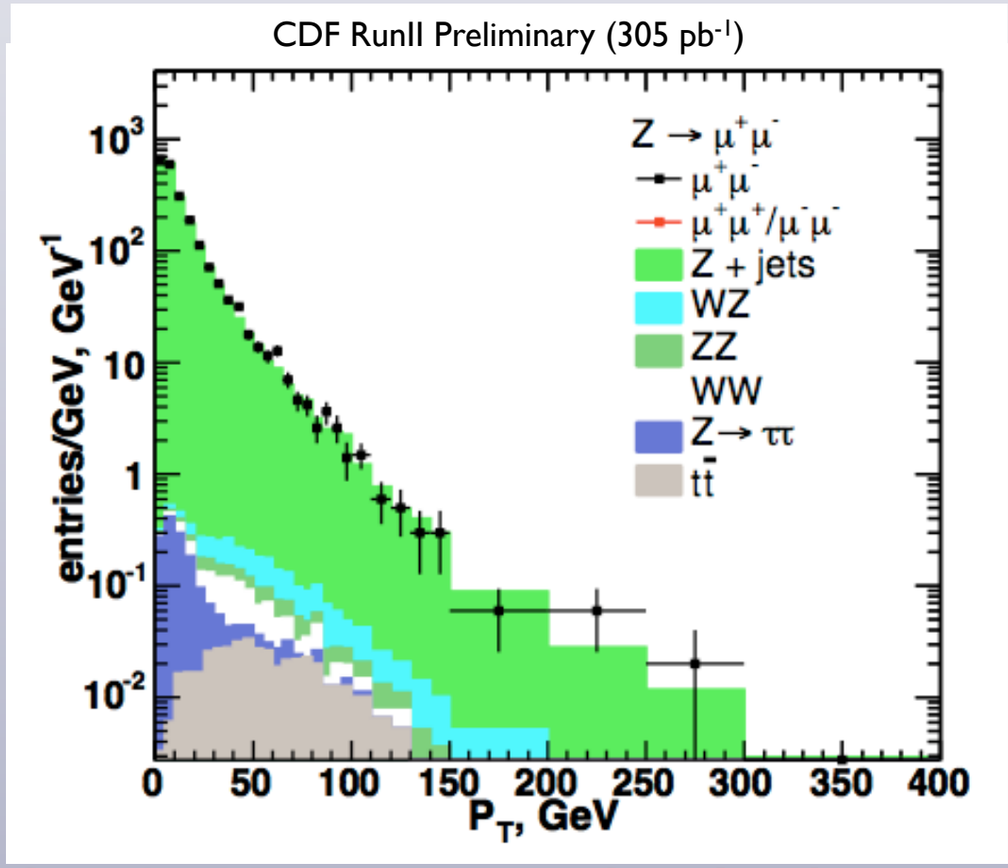
M(GeV)	*SM Bkgd*	*Data*	σ_{95}*(pb)*
300	41.59 ± 4.65	35	0.201
400	35.66 ± 3.59	30	0.111
500	10.94 ± 1.42	7	0.066
600	7.06 ± 0.75	5	0.054
700	0.71 ± 0.10	0	0.037

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

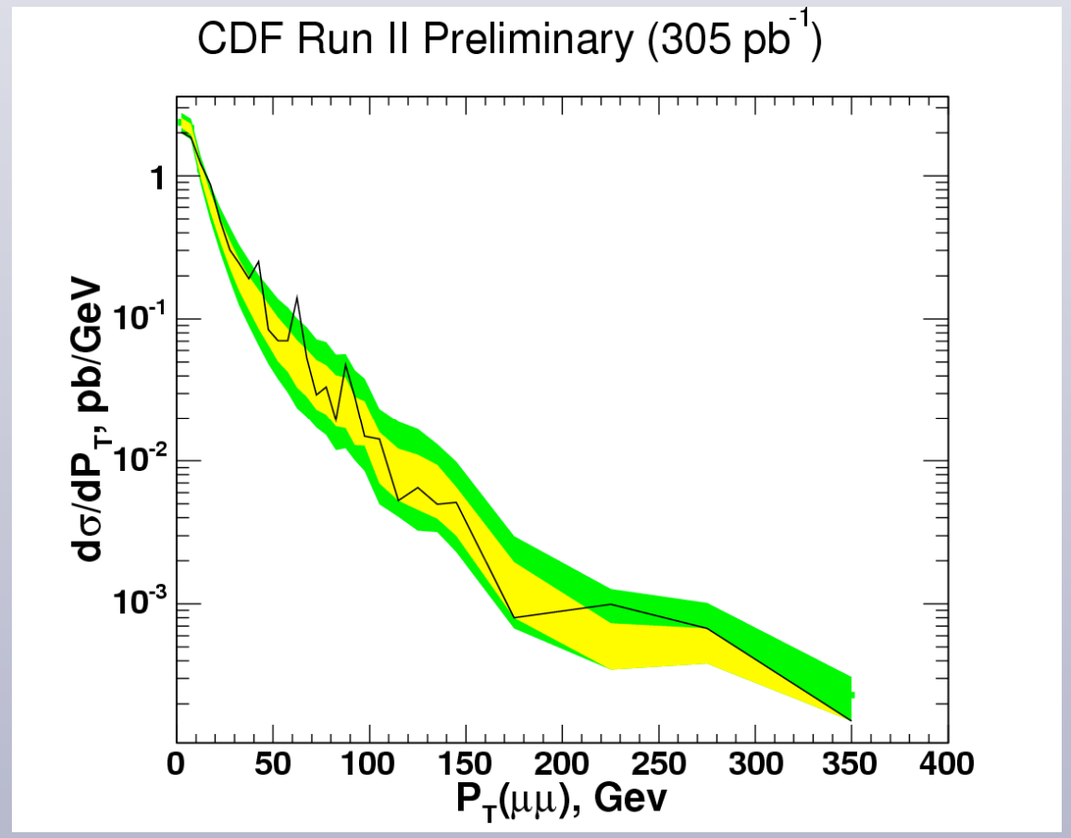
Signature-Based Search: High P_T Zs

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 Kinematics for Inclusive, $P_T(Z)>60$, 120 GeV



Set Limit on anomalous Z Production

Signature-Based Search: Dilepton+X

Looking for anomalous Dilepton+X events

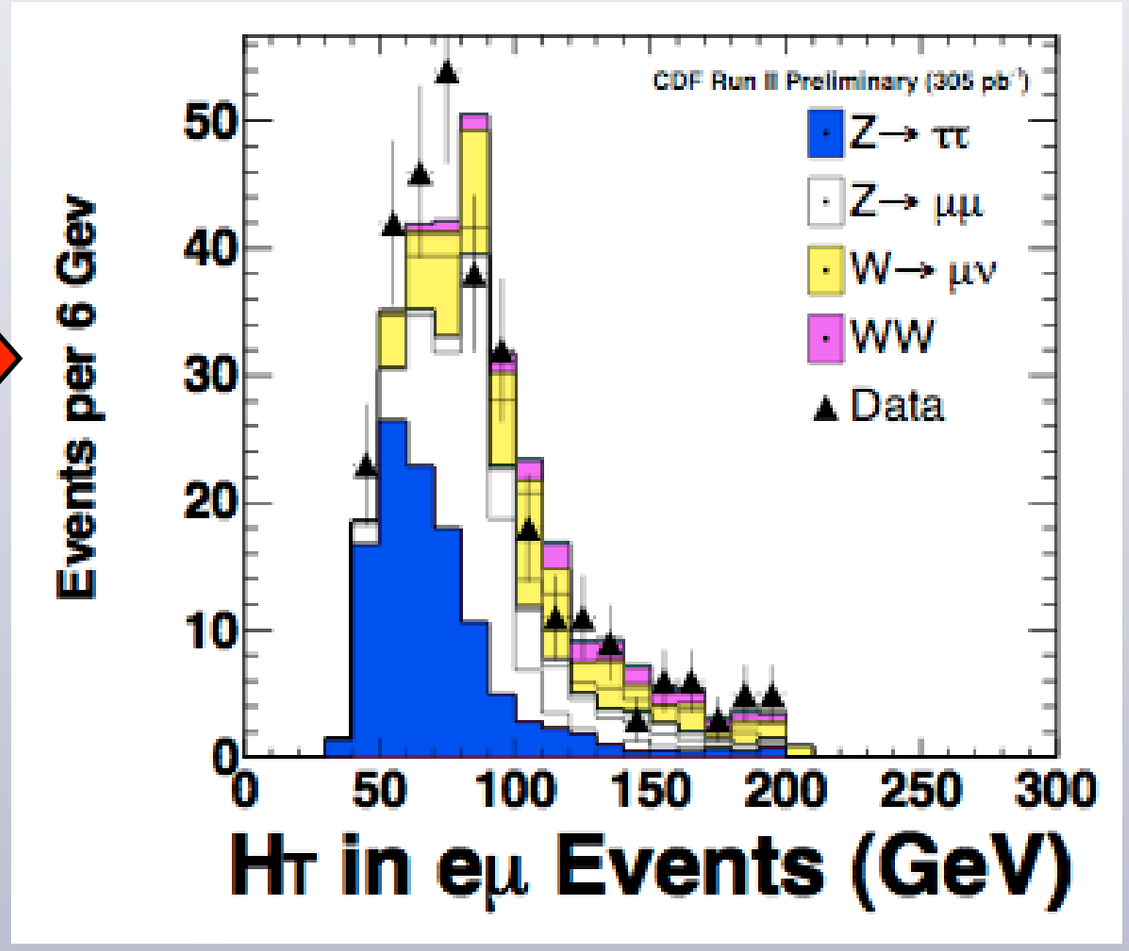
- X = Large H_T, Large MET, b tags, high E_T jets, 3rd leptons

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

Control Region: H_T<200 GeV

Signal Region: H_T>400 GeV

2 jets E_T>50 GeV



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

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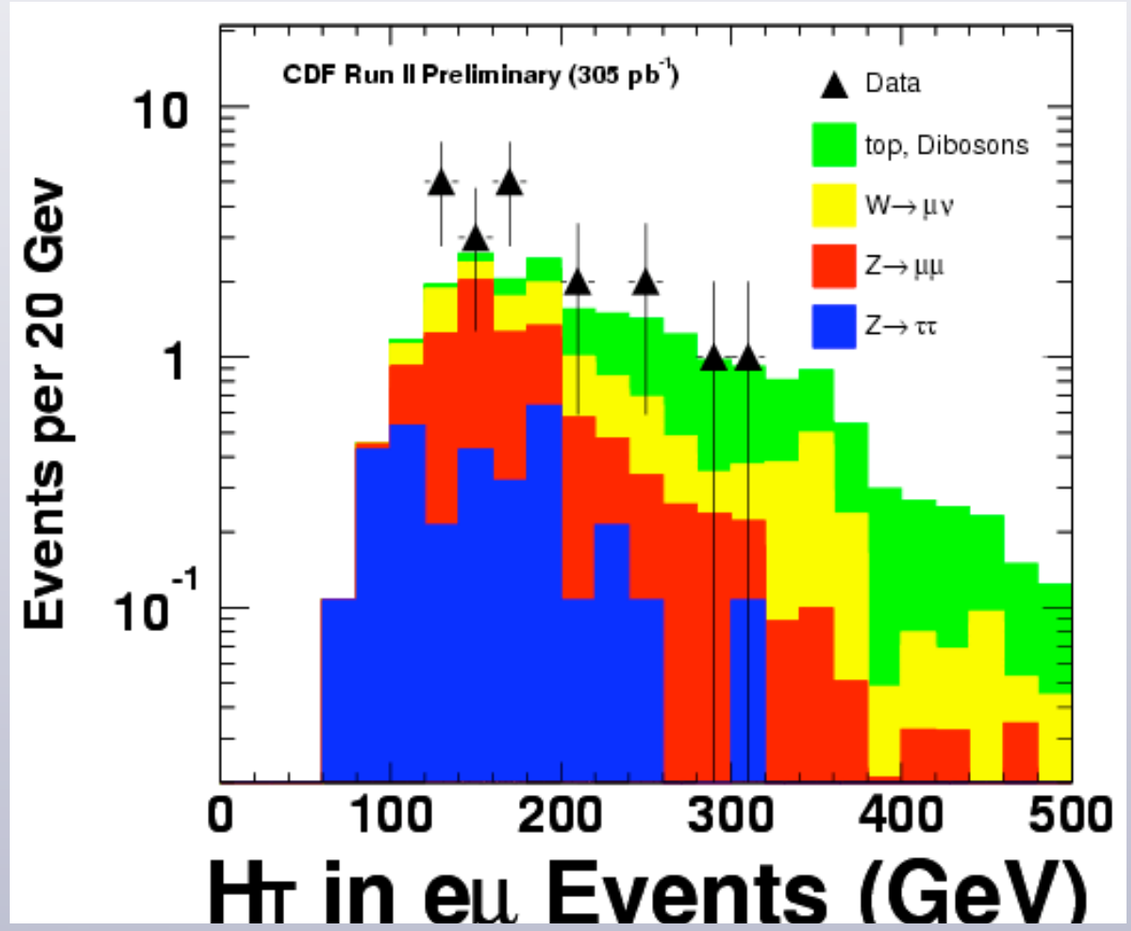


Expect:

0.802 ± 0.440 SM

0.526 ± 0.058 QQ

Observe: 0

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

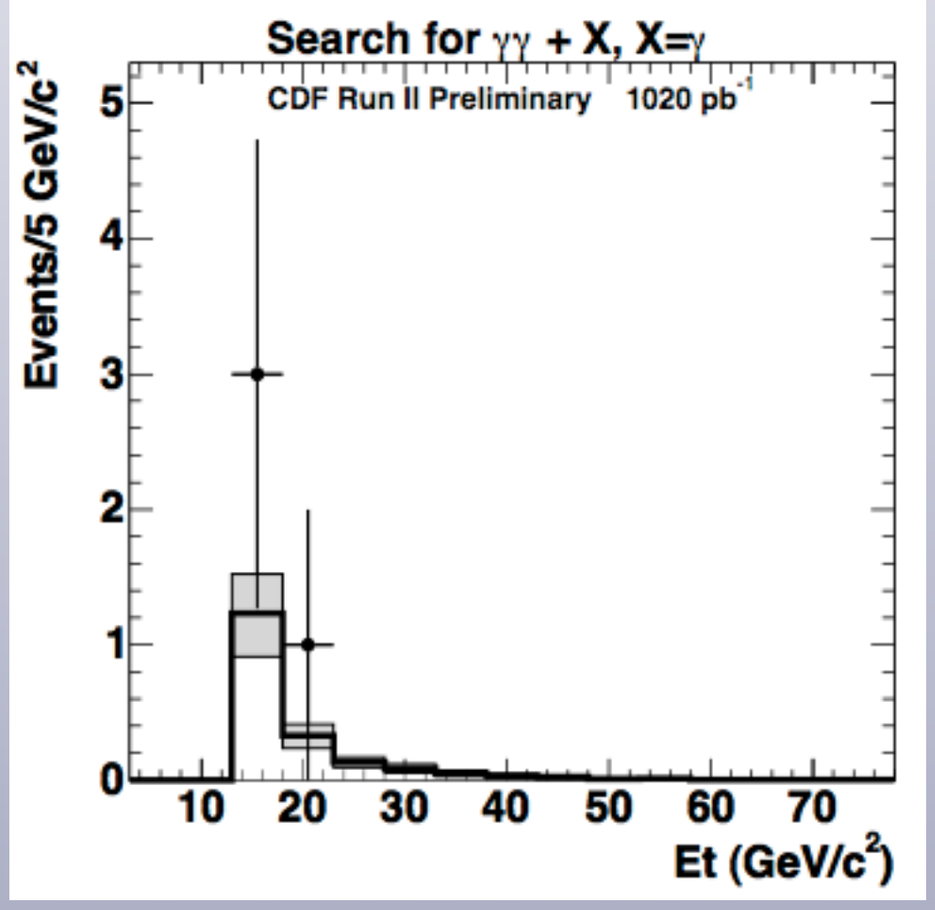
(σ_Q=0.289pb m_Q=300 GeV)

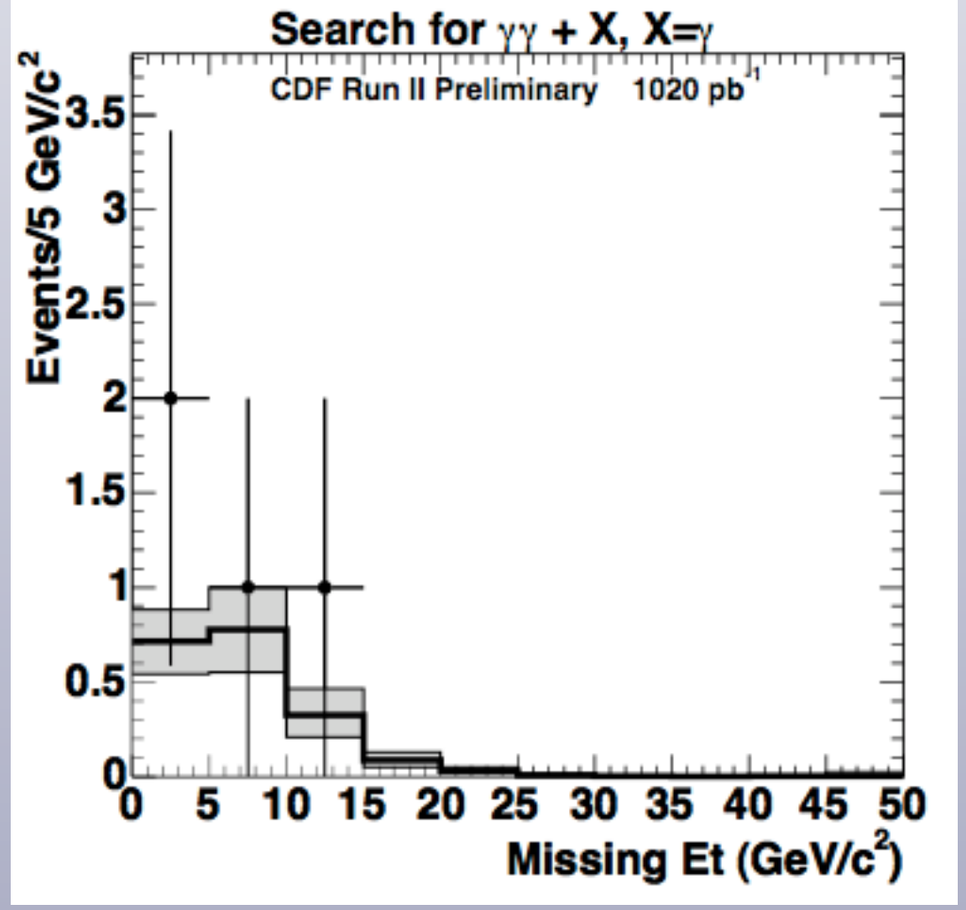
Signature-Based Search: γγ+γ/e/μ

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

First analysis looks at γγ+γ (All E_T>13 GeV)

- Expect 1.9 ± 0.6 events (real tri-γ, fakes)
- Observe 4 Events





Signature-Based Search: γγ+γ/e/μ

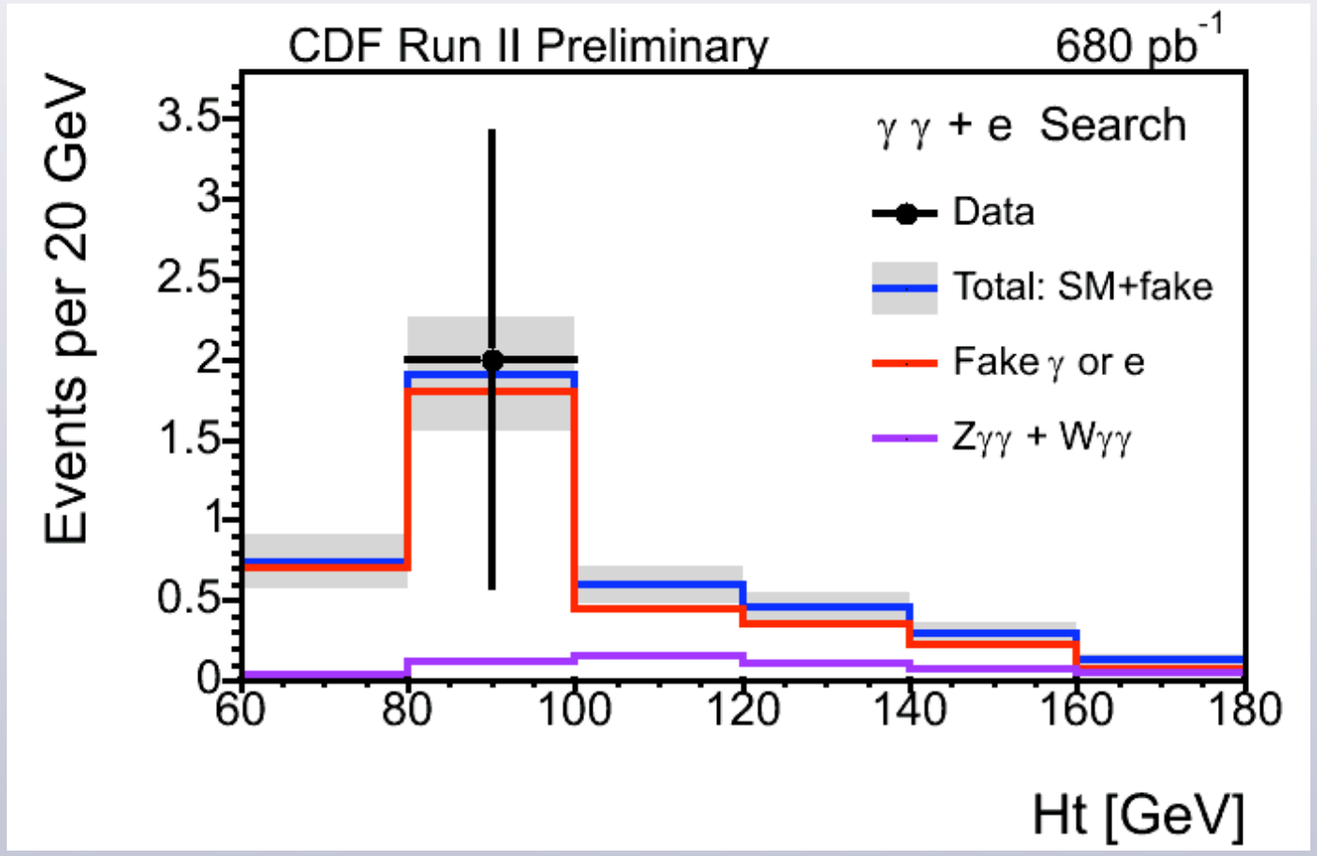
Also look for γγ+e,μ - Same photon selection

γγ+e: (E_T(e)>20 GeV)

- Expect 4.49±0.84 events (Zγγ, fakes)
- Observe 2 Events

γγ+μ: (p_T(μ)>20 GeV)

- Expect 0.47±0.12 events (Zγγ, fakes)
- Observe 0 Events



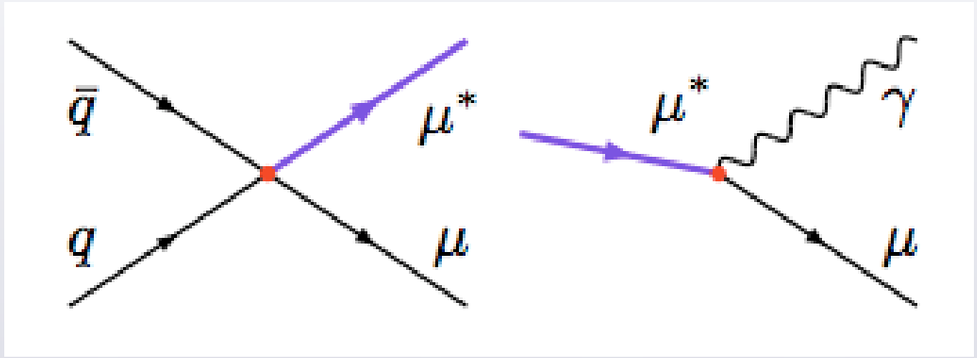
- Good agreement between data and SM predictions
- Continue to add objects in γγ+X Search

Search for Excited Muons

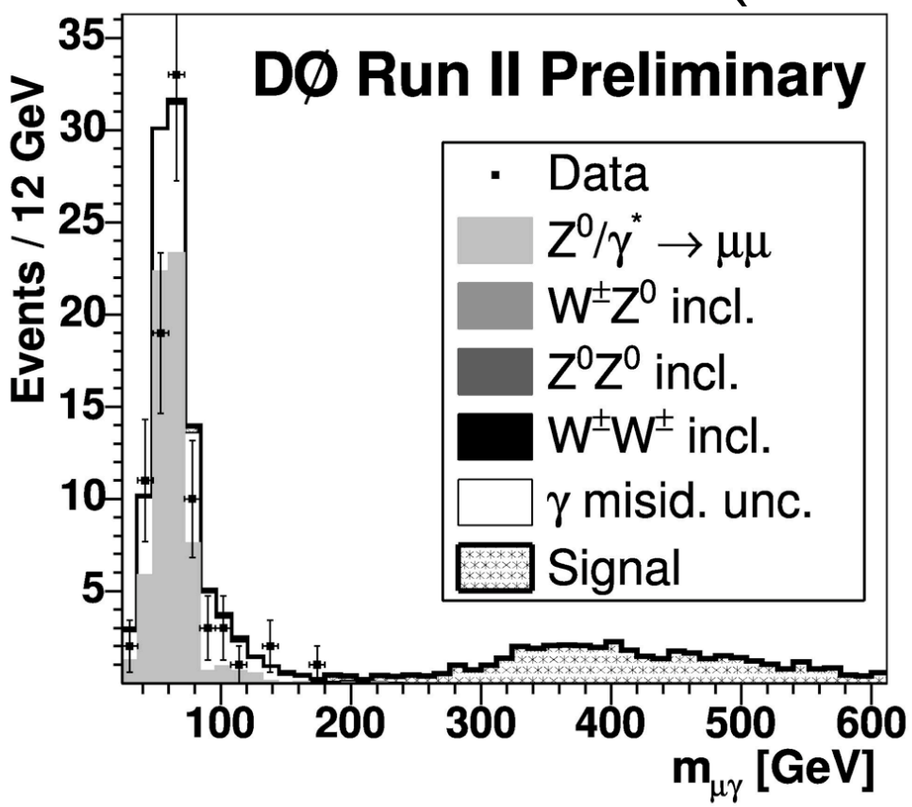
Excited leptons are a possible sign of compositeness

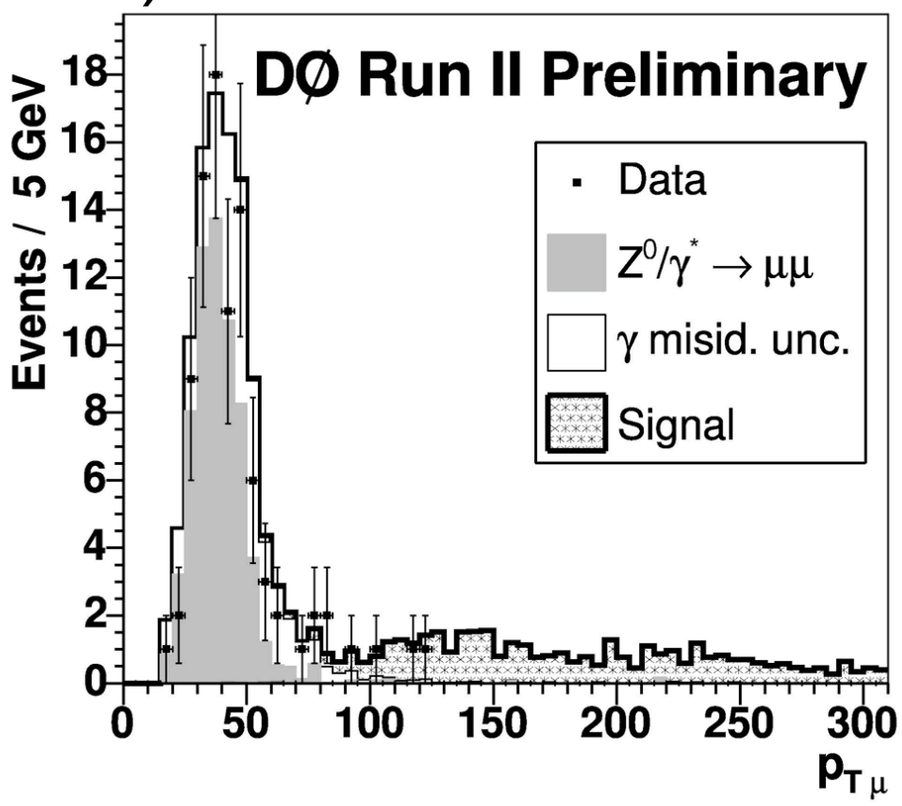
Search for $p\bar{p} \rightarrow \mu\mu^*$, $\mu^* \rightarrow \mu\gamma$

(Contact Interaction Model)



(380 pb^{-1})





Signal should have large $m_{\mu\gamma}$

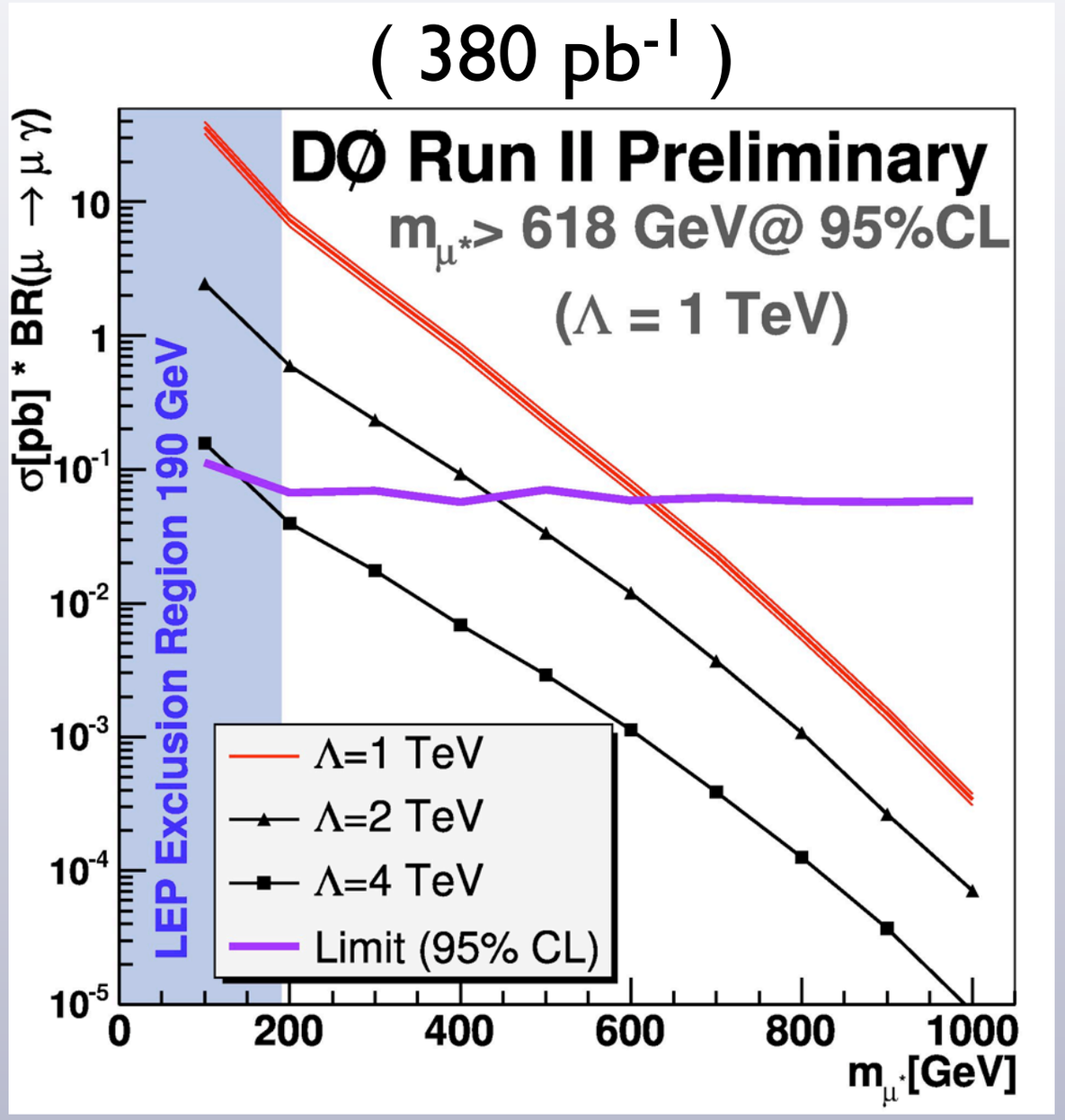
Search for Excited Muons

No events above $m_{\mu\gamma}$ cuts

Set limits on m_{μ^*} for different values of Λ (Compositeness Scale)

- $m_{\mu^*} > 618$ GeV ($\Lambda = 1$ TeV)
- $m_{\mu^*} > 688$ GeV ($\Lambda = m_{\mu^*}$)

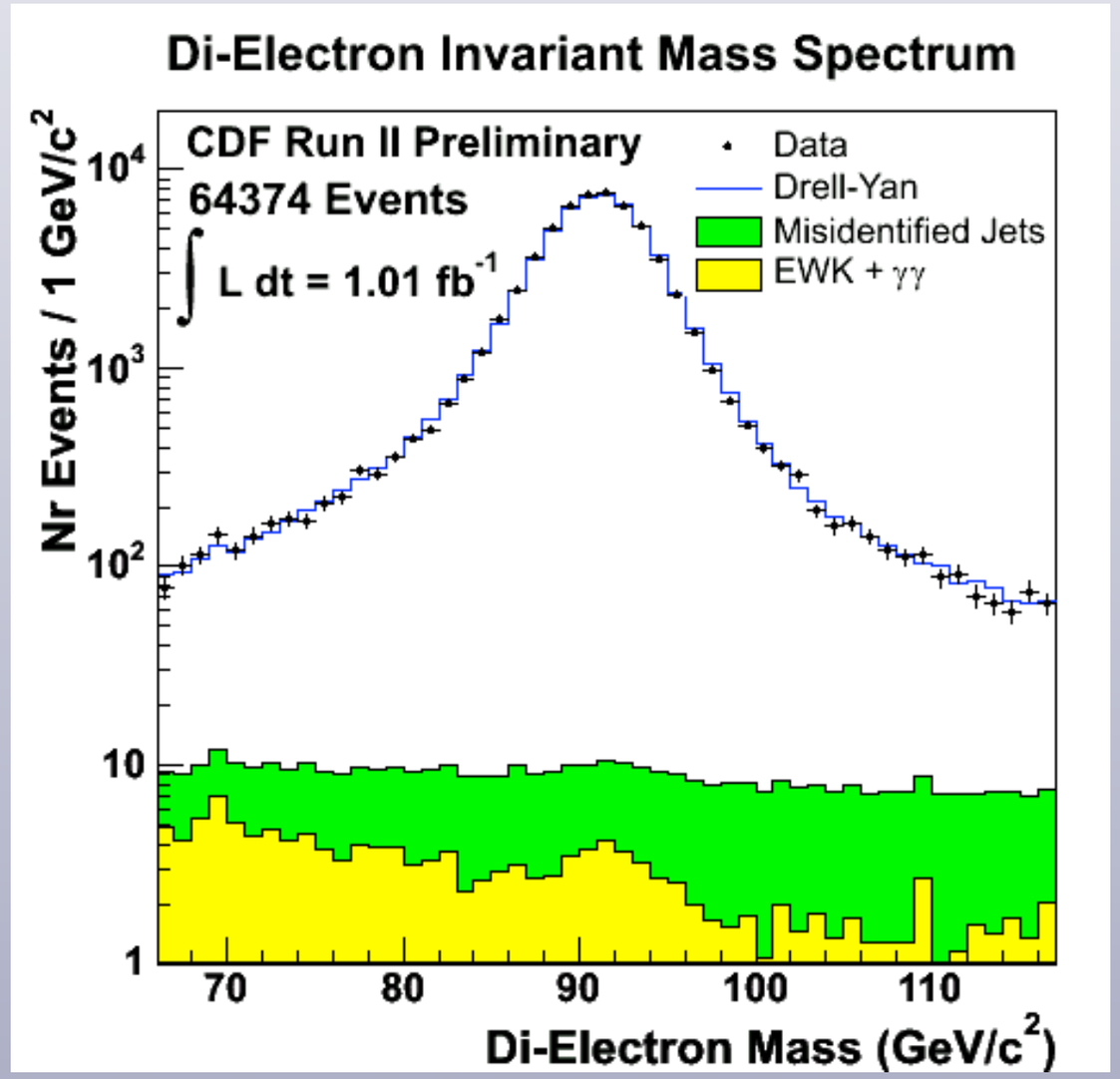
- Limits from CDF on both m_{e^*} and m_{μ^*} with similar sensitivity in slight different models



Conclusions

- CDF and D0 are pursuing searches for evidence of many different models of new physics
  - Not shown today: leptoquarks, compositeness, 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 $Z' \rightarrow e^+e^-$

- 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

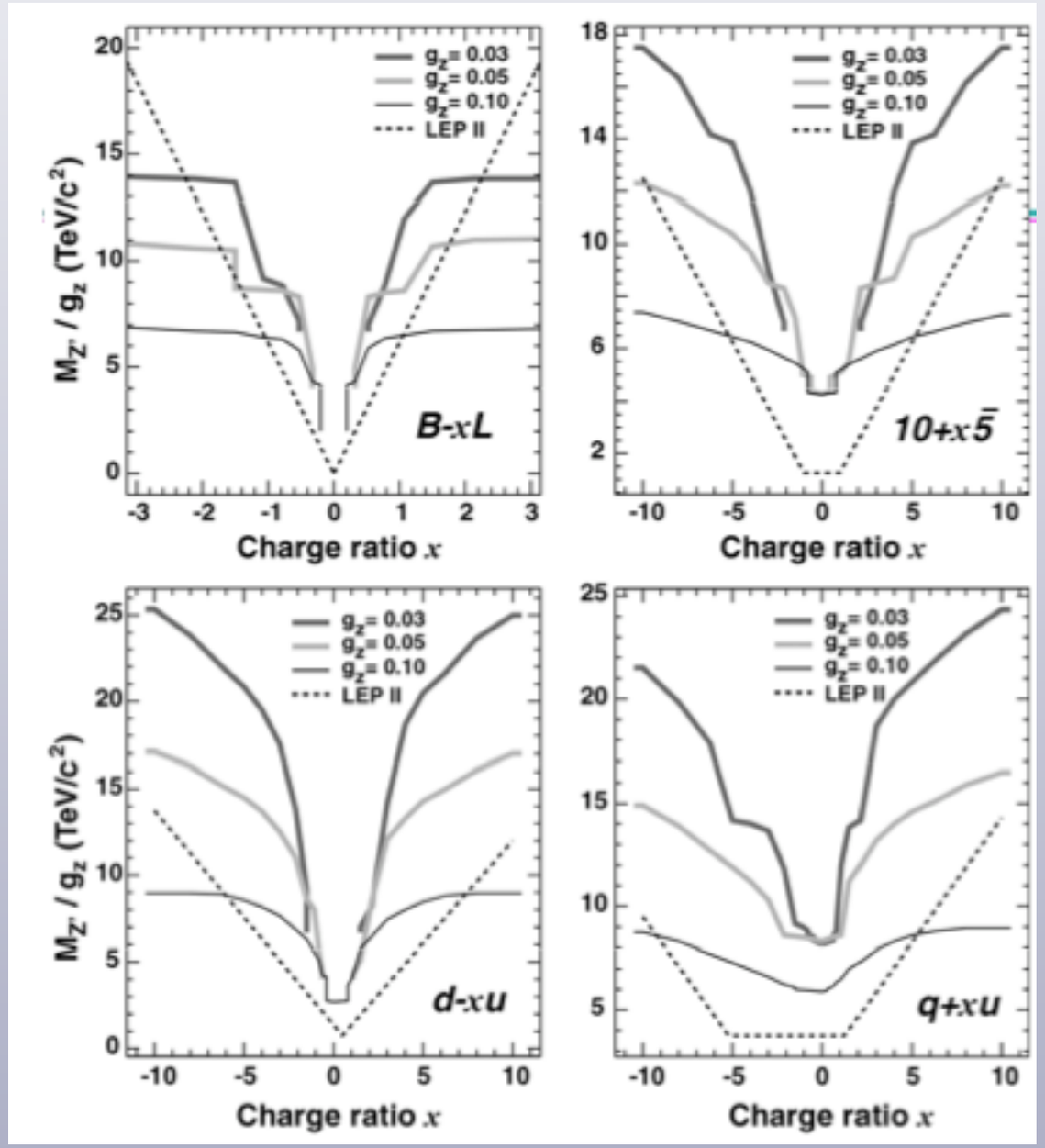
- Can also test for contact interactions:

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

General Z′ Formalism:

- Define 4 classes of models with 3 parameters (Carena et al) :
  - Mass $M_{Z'}$
  - Strength $g_{Z'}$
  - charge ratio x

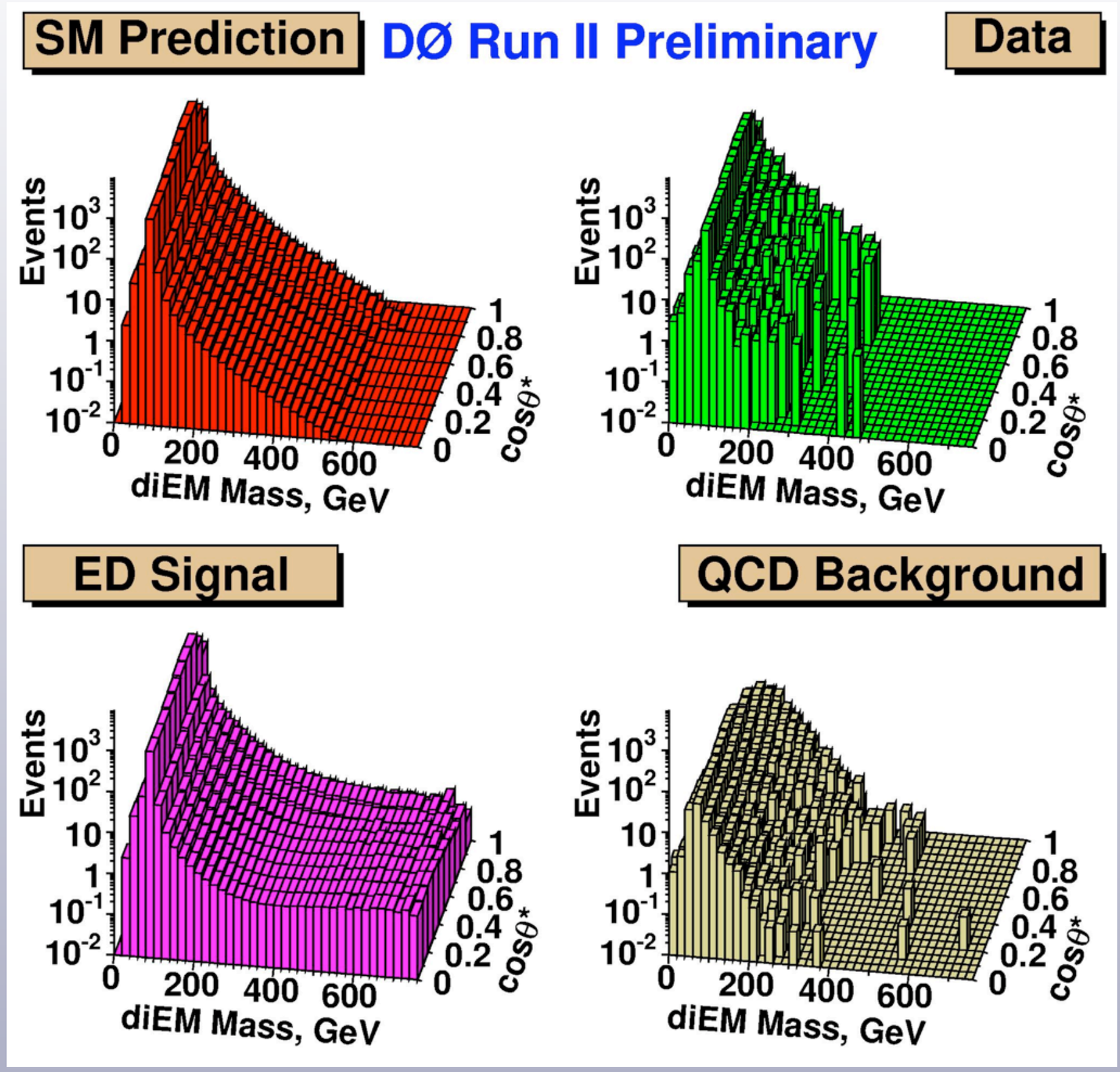


Expected Future Limits on M_D

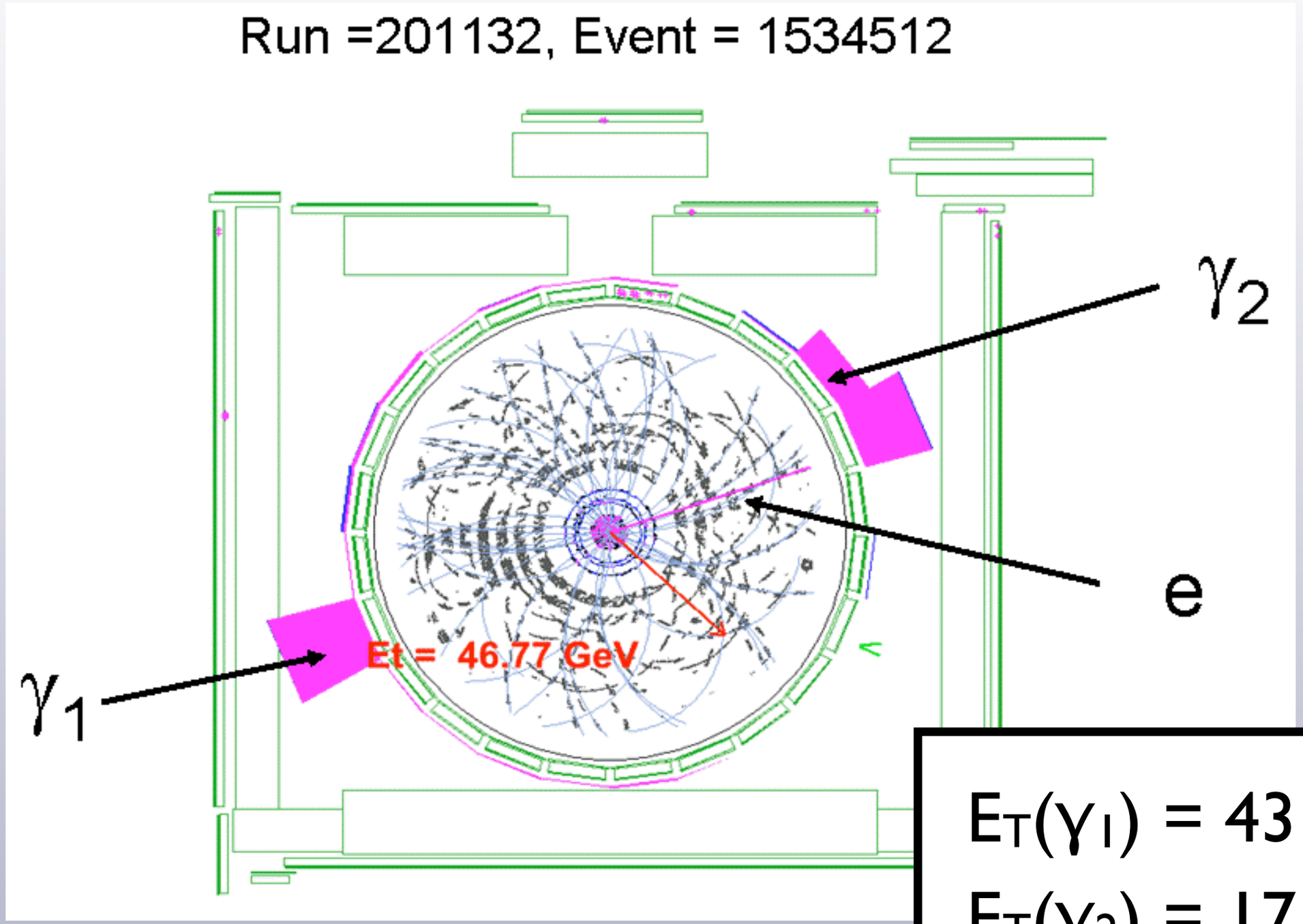
- Current analysis uses 368 pb^{-1} of data
- Because backgrounds are estimated from data, uncertainty will continue to improve with more data
  - Expect updated result with 1 fb^{-1} for summer
  - Additional gains using lower E_T cut and MET trigger
- Estimates of improved M_D limits with 1fb^{-1}

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

Virtual Graviton Signal/Bkgd Shapes



γγ+e Candidate Event



$E_T(\gamma_1) = 43$ GeV

$E_T(\gamma_2) = 17$ GeV

$E_T(e) = 34$ GeV