Searches for Z' and Extra Dimensions in CDF

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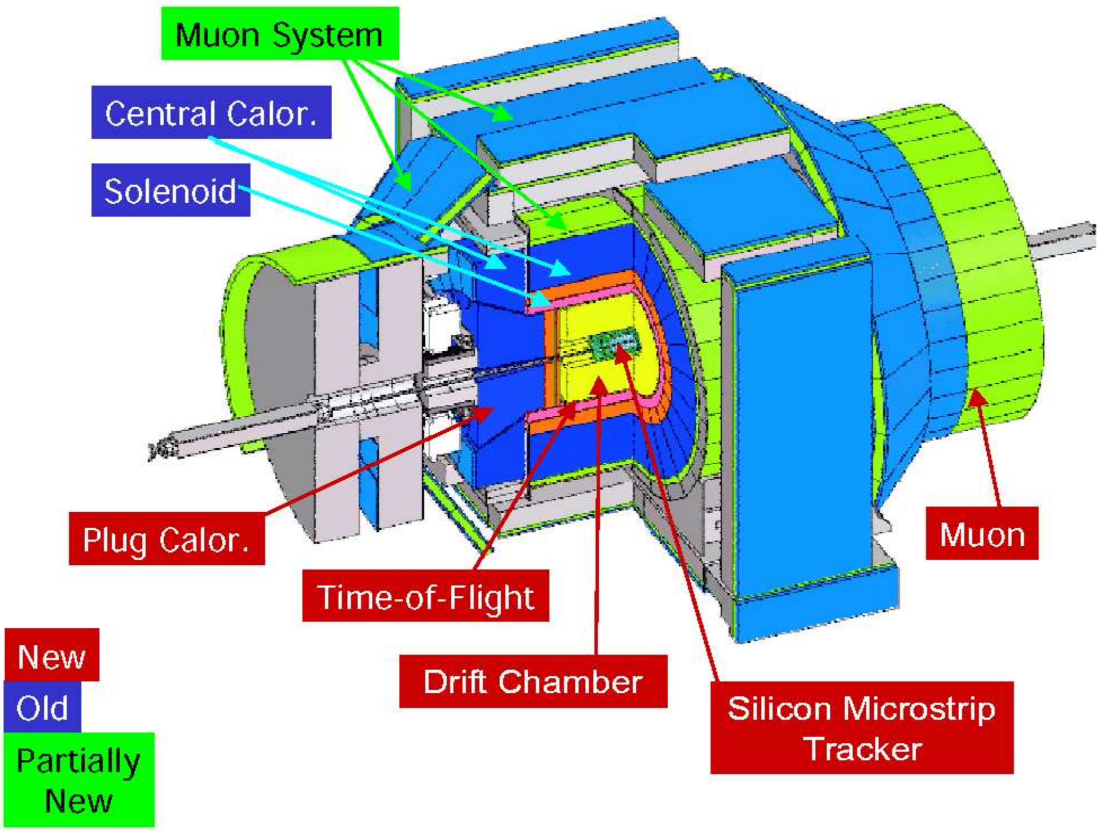
Outline

1. **Tevatron & CDF Detector**
2. $Z^{'}$ **Searches**
   – **Run I & Run II Results and Future Prospects**
3. **Extra Dimensions Searches**
   – **Run I & Run II Results and Future Prospects**
4. **Summary**

† **All Run II results are preliminary**

Tevatron & CDF Detector

- Tevatron Run II
  - Data taking period started in spring 2001
  - $\sqrt{s} = 1.8 \rightarrow 1.96$ TeV
  - Current instantaneous luminosity $\sim 4 \times 10^{31}$ cm^{-2} s^{-1}
- CDF Detector Upgrades
  - New silicon, drift chamber, TOF
  - New scintillating plug calorimeter
    $\rightarrow$Extends to $|\eta| = 3.6$



$Z^{'}$ Boson Review

- Additional heavy gauge boson predicted by many theories

$$\mathcal{L}_{NC} = eJ^{\mu}_{EM}A_{\mu} + gJ^{\mu}_{Z^0}Z^0_{\mu} + g^{'}J^{\mu}_{Z^{0'}}Z^{0'}_{\mu}$$

◇ **Standard Model $Z^{'}$**

- $Z^{'}$ with same SM couplings ($g^{'} = g$)

◇ **E_6 GUT Model**

- SM embedded in $E(6)$ group
  $Z^{'} = Z_{\psi} \sin\theta_{E6} + Z_{\chi} \cos\theta_{E6}$

Model	θ_{E6}
χ	0
ψ	$-\pi/2$
η	$\sin^{-1}\sqrt{3/8}$
I	$\sin^{-1}\sqrt{5/8}$

◇ **Left-Right Symmetric Model (LR)**

- Introduce symmetry group $SU(2)_R$
- 3 vector bosons couple to right-handed fermions

◇ **Alternative Left-Right Symmetric Model (ALRM)**

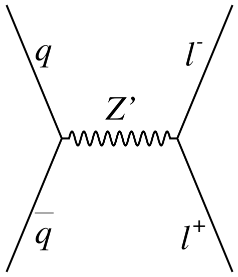
- Different interactions by $SU(2)_R$ gauge from those in LR

◇ **Leptophobic Topcolor $Z^{'}$**

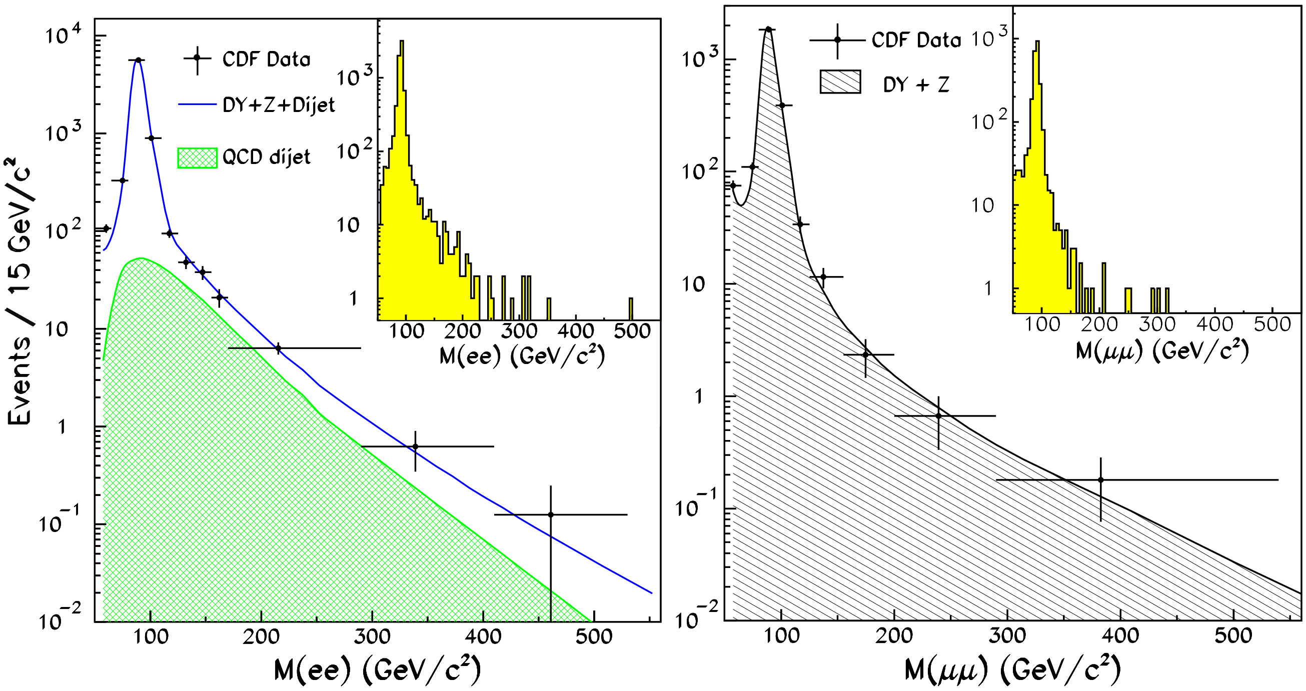
- Predicted by top-color-assisted technicolor : large cross section for $Z^{'} \rightarrow t\bar{t}$

Run I Z' Summary - Dilepton Channel

Phys. Rev. Lett. 79, 2191 (1997)



- Dilepton invariant mass for ee & $\mu\mu$ (110 pb^{-1})



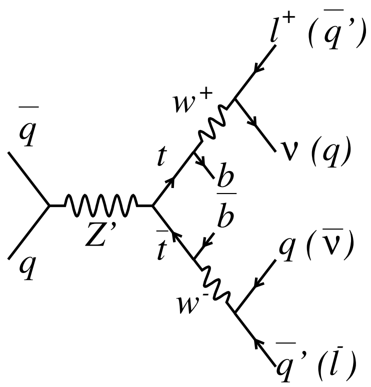
- 95% C.L. lower limit on $M_{Z'}$ (GeV$/c^2$)

	ee	$\mu\mu$	$ee + \mu\mu$
SM	655	590	690
χ	530	500	595
ψ	520	495	590
η	550	520	620
I	505	480	565
LR	565	530	630
ALRM	525	500	600

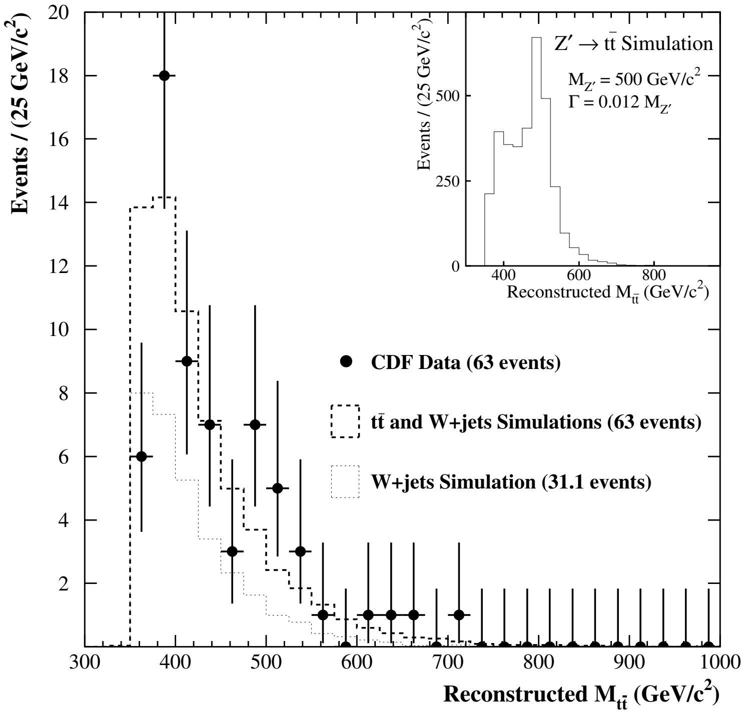
† Current best limits of direct searches

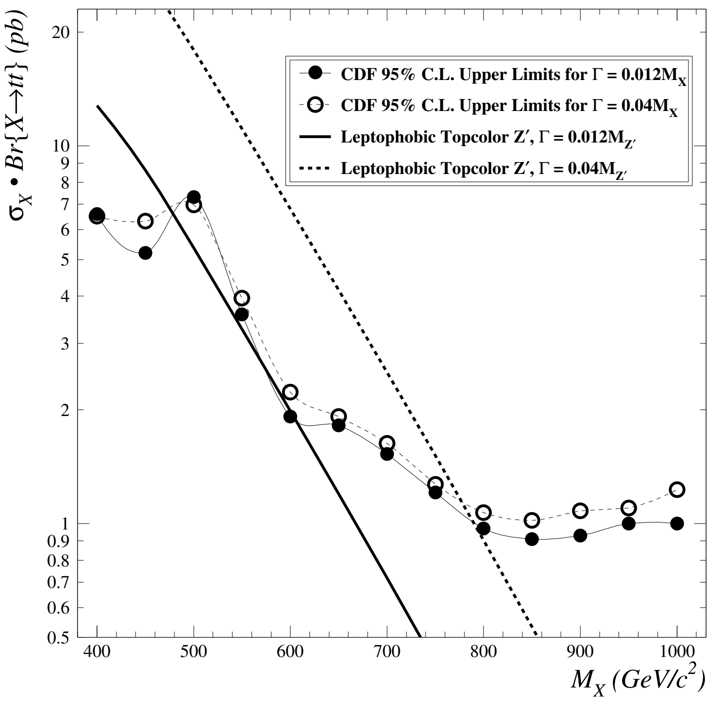
Run I Z' Summary - $t\bar{t}$ Channel

Phys. Rev. Lett. 85, 2062 (2000)



- $t\bar{t}$ invariant mass in lepton + 4jets and cross section limit (106pb^{-1})



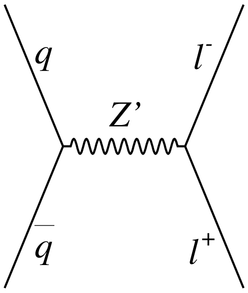


- 95% C.L. lower limit on $M_{Z'}$ (GeV$/c^2$)

$\Gamma = 0.0012 M_{Z'}$	480
$\Gamma = 0.04 M_{Z'}$	780

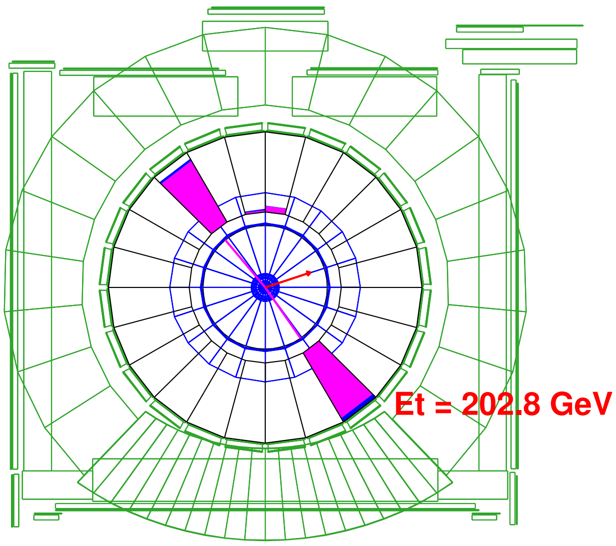
† Limits for Leptophobic Topcolor Z'

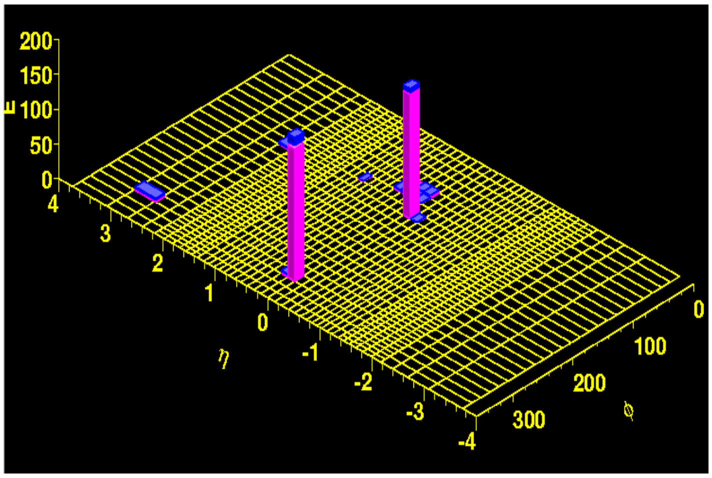
Run II Z' - Dilepton



- Selection criteria
  - ee
    - One good Central electron $E_T > 25$ GeV
    - Second good Central electron or good Plug electron $E_T > 25$ GeV
    - $\not{E}_T/\sqrt{\Sigma E_T} < 2.5$
  - $\mu\mu$
    - Two good muons
    - Cosmic ray rejection by vertex, impact parameter and timing cuts

- ee highest mass event in central ($M_{ee} = 371$ GeV)



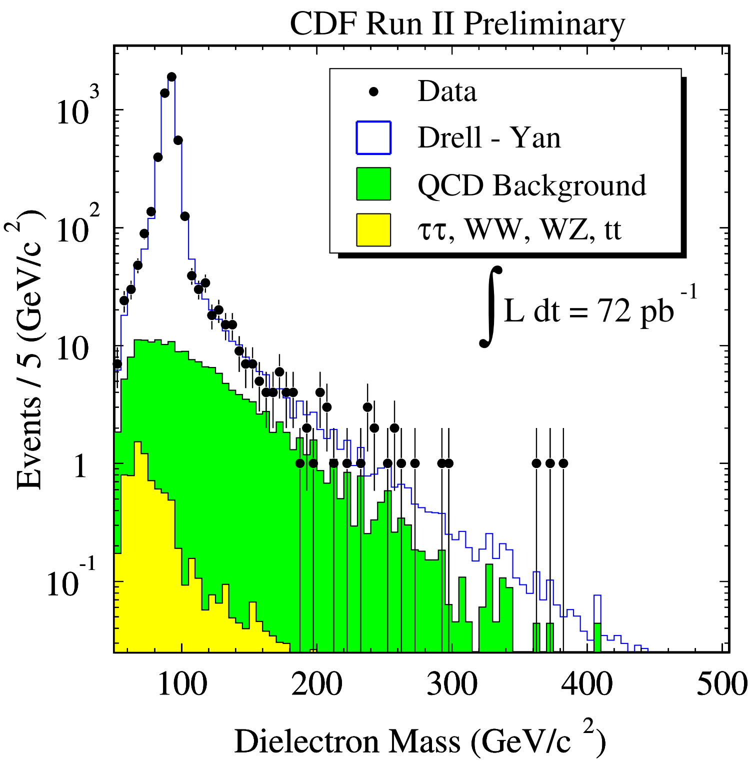


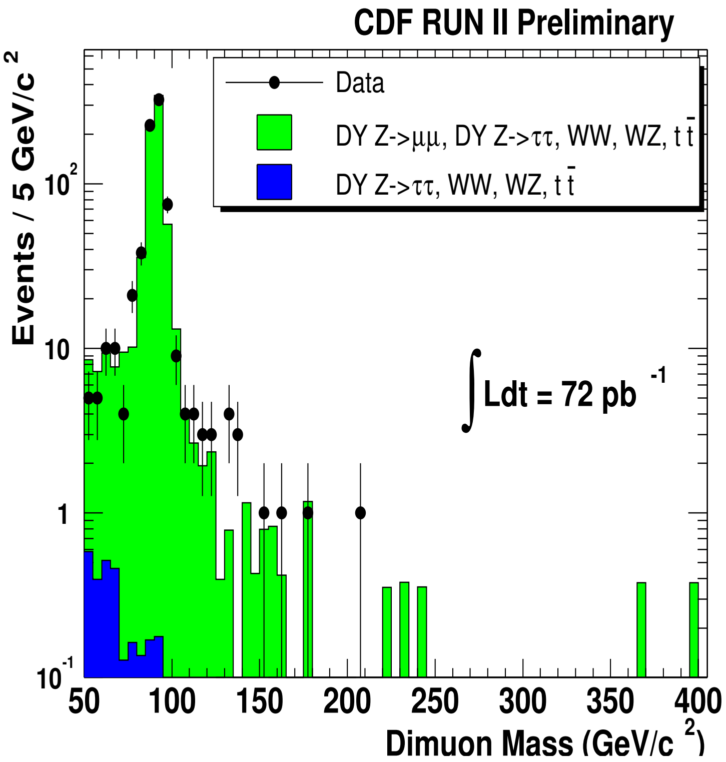
$E_T = 203$ & 180 GeV

Run II Z' - Dilepton (cont.)

- **Comparison of data with SM background (72pb^{-1})**

ee | $\mu\mu$





	Mass (GeV$/c^2$)	observed	expected
ee	150 ± 20	69	66.1 ± 23.9
$\mu\mu$	> 150	4	5.16 ± 0.34

No significant excess

- **Setting limits by Bayesian approach**

$$\sigma_{95} \cdot Br(Z' \to \ell^+\ell^-) = \frac{N_{95}}{\mathcal{L} \cdot \varepsilon_{tot}(M_{Z'})}$$

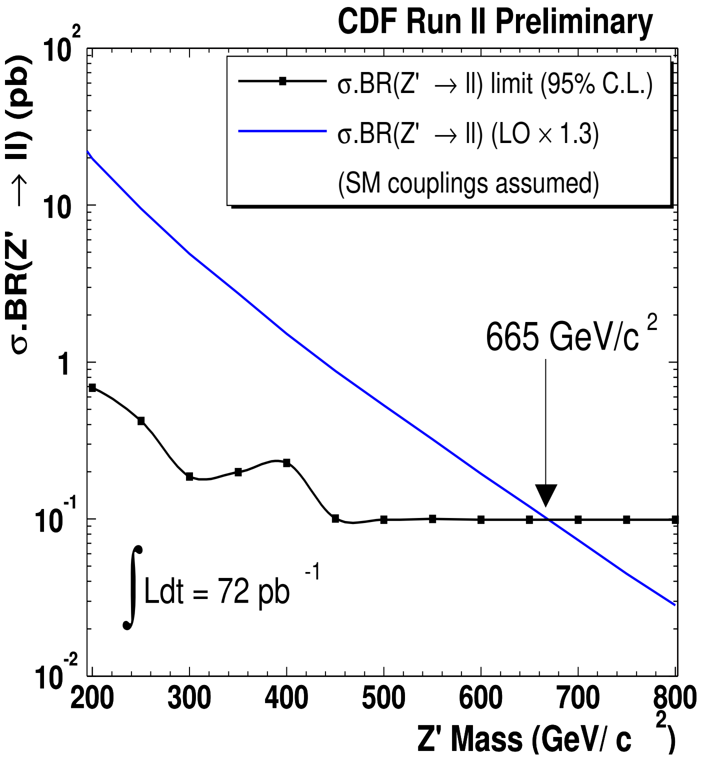
◇ **Mass window**

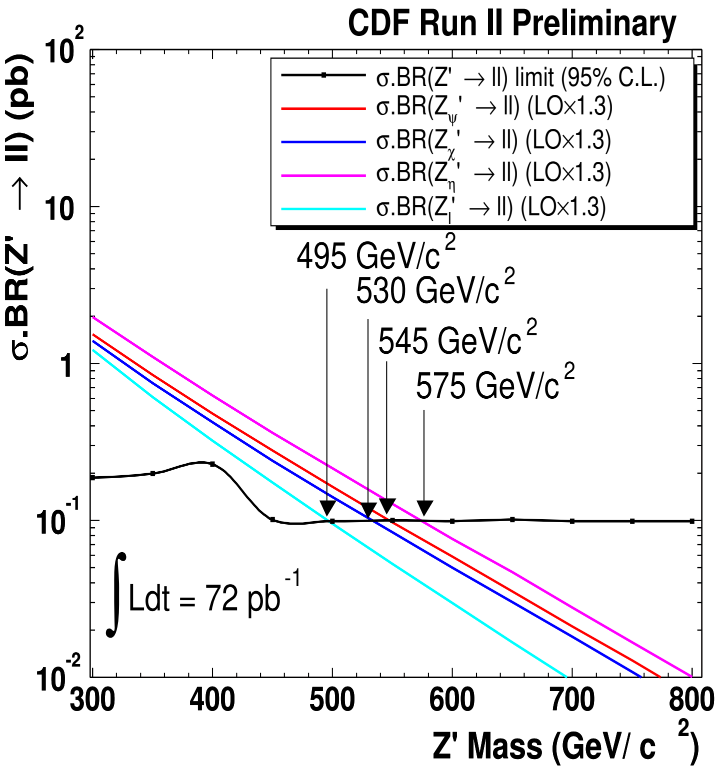
- **Electron $\to 3\sigma$ for each mass point**
- **Muon $\to M > 150$ GeV**

Run II Z' - Dilepton (cont.)

- Cross section limits in $ee + \mu\mu$ combination

SM coupling | **E_6 Models**





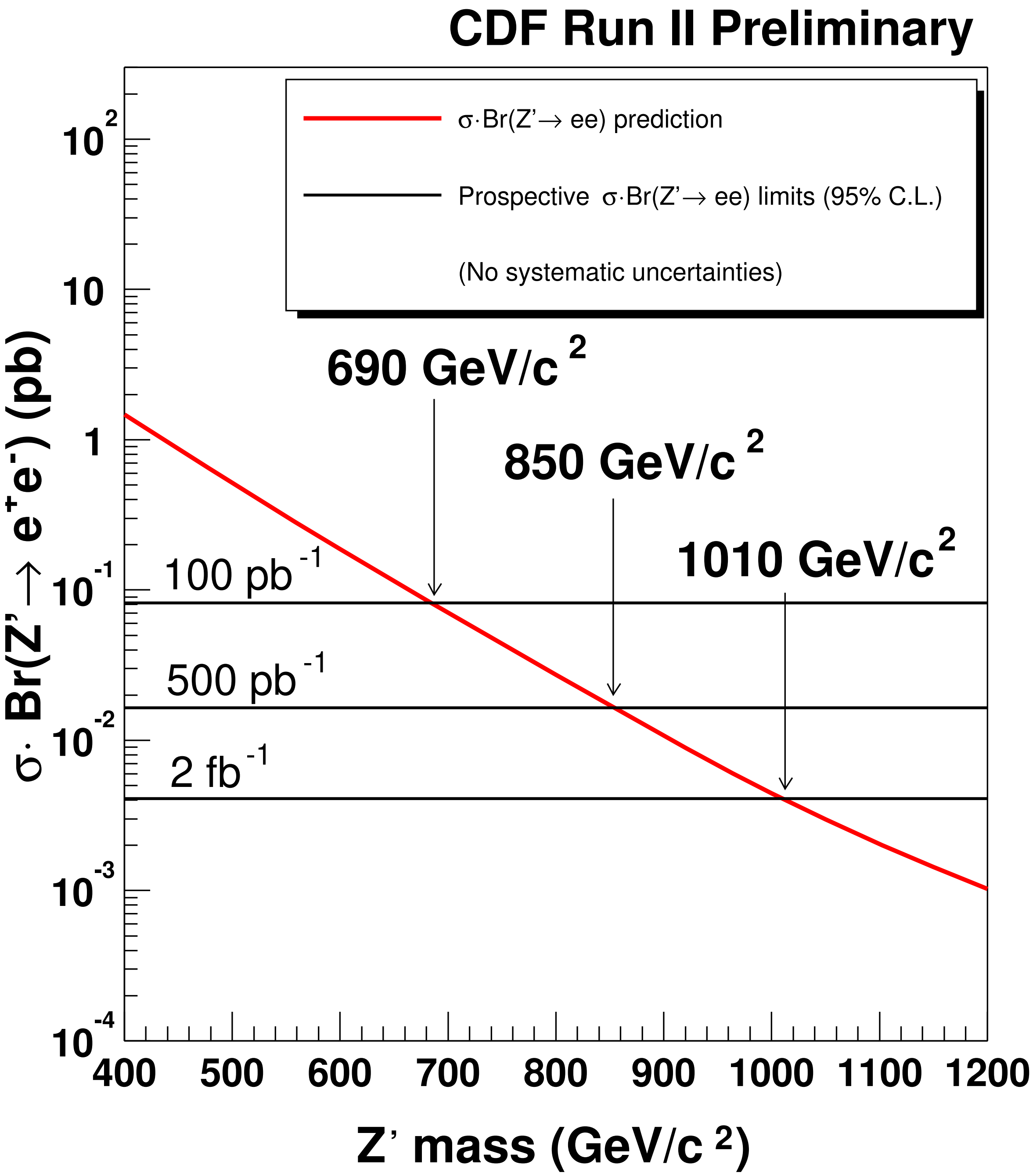
- 95% C.L. lower limit on $M_{Z'}$ (GeV$/c^2$)

	ee	$\mu\mu$	$ee+\mu\mu$
SM	650	455	665
χ	525	330	530
ψ	540	340	545
η	565	365	575
I	490	315	495

† Limits for other models (LR & ALRM) in progress

Run II Z' Prospect

- Future prospect of Z' mass limit (for same SM coupling) in ee channel
  - Null signal is assumed
  - No systematic uncertainties



Extra Dimensions Review

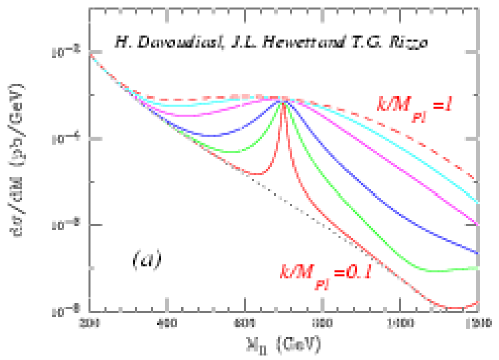
ADD Model (Arkani-Hamed, Dimopoulos, Dvali)

- Low-scale gravity in extra dimensions solves the hierarchy problem
  - ◇ World confined to 4 dimensions
  - ◇ Gravity propagates in extra dimensions
- (4+n)D Planck scale related to 4D Planck scale

$$M_{Pl}^2 \sim R^n M_S^{n+2}$$

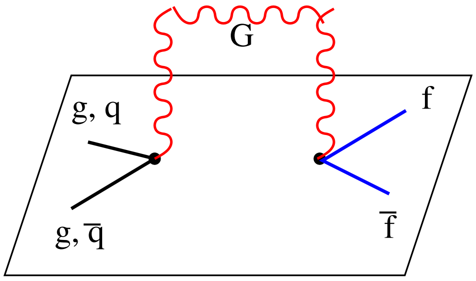
Randall-Sundrum Model

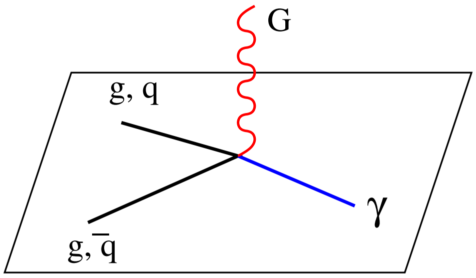
- Adds 1 extra dimension and warps space-time by $e^{-2kr_c\pi}$: predicts massive spin-2 graviton
- Two free parameters
  - ◇ Graviton mass
  - ◇ Coupling parameter : k/M_{Pl}



Experimental Signatures

- Virtual graviton exchange
  - ◇ Dileptons
  - ◇ Diphotons
- Direct graviton emission
  - ◇ Jets + $\not{E}_T$
  - ◇ Photon + $\not{E}_T$

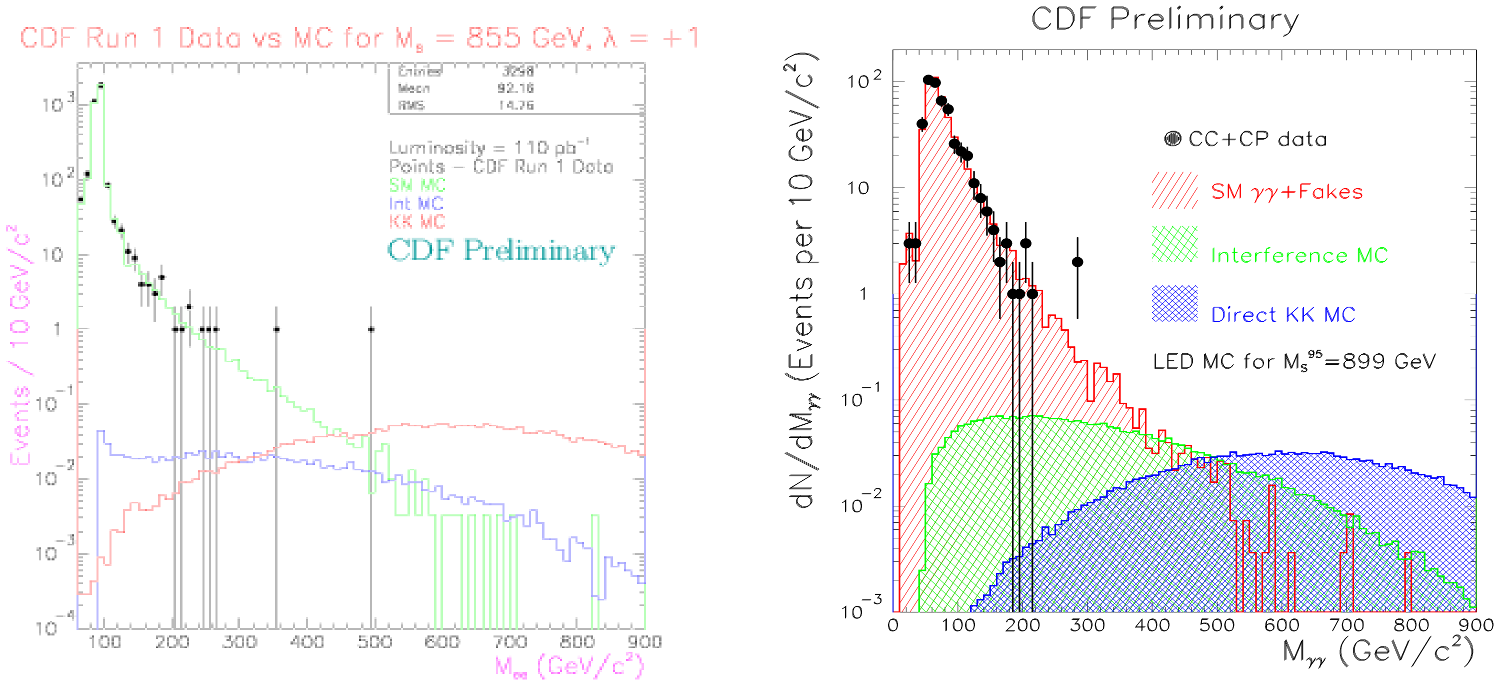




Run I Extra Dimensions Summary

ADD Model

- **Pair production in virtual graviton exchange (ee+$\gamma\gamma$)**



- **Effective cross section :**

$$\sigma = \sigma_{SM} + \eta\sigma_{Int} + \eta^2\sigma_{KK} \text{ where } \eta = \frac{F}{M_S^4}$$

$$F = \begin{cases} 1 & & \text{(GRW)} \\ \log\left(\frac{M_S^2}{s}\right) & n = 2 & \text{(HLZ)} \\ \frac{2}{n-2} & n > 2 & \text{(HLZ)} \\ \frac{2\lambda}{\pi} & & \text{(Hewett)} \end{cases}$$

- **95% C.L. lower limit on M_S (GeV$/c^2$)**

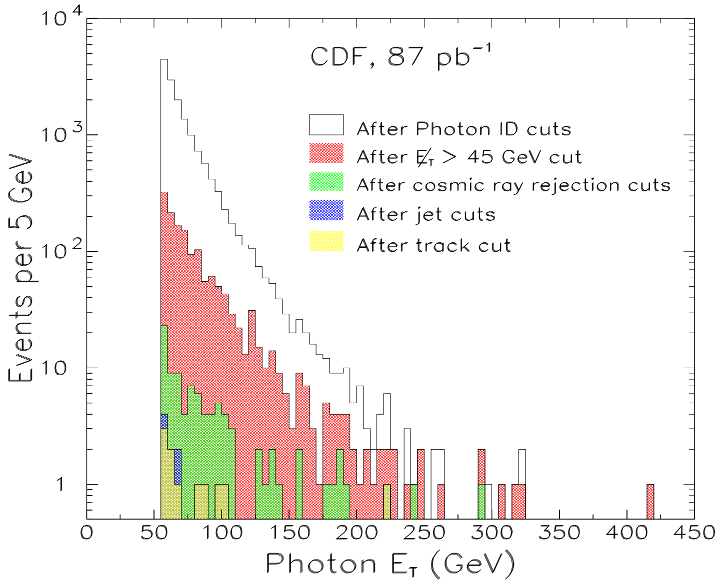
	$\lambda = -1$	$\lambda = 1$
ee	826	808
$\gamma\gamma$	899	797
$ee + \gamma\gamma$	939	853

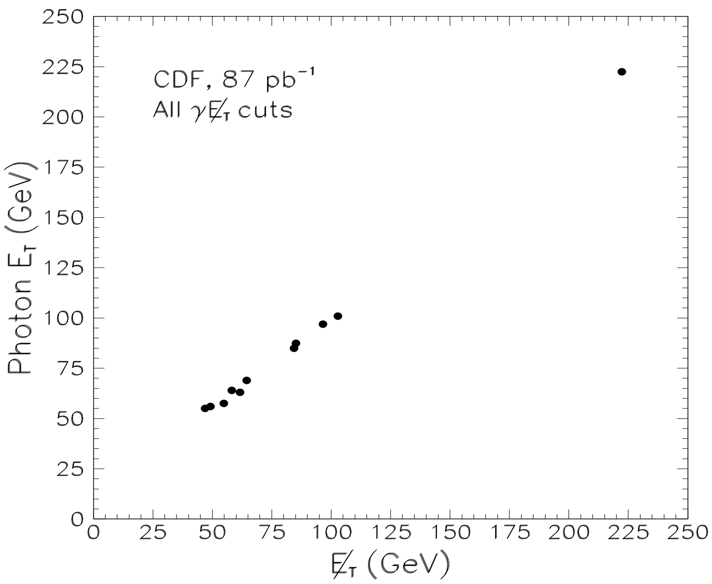
† In the normalization convention of Hewett

Run I Extra Dimensions Summary (cont.)

ADD Model

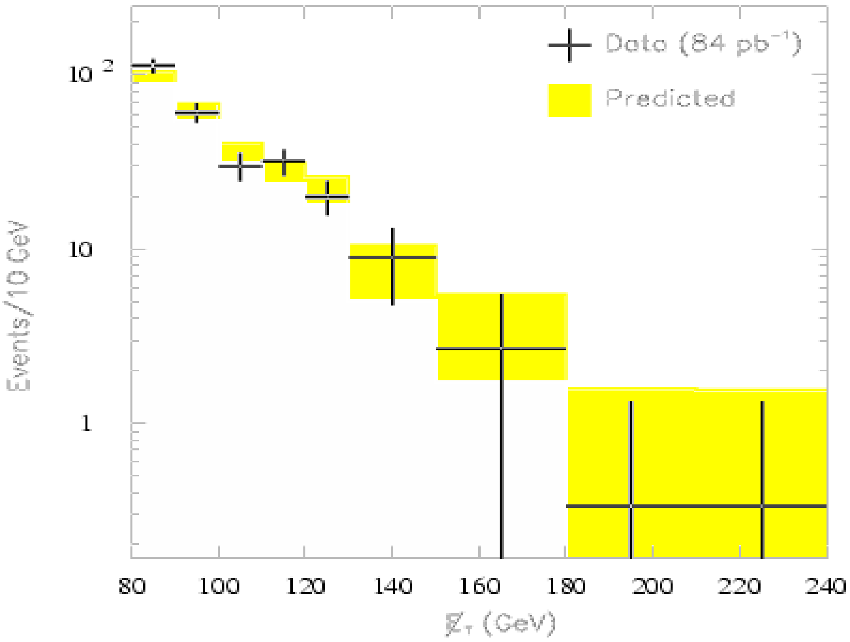
- **Graviton emission in γ + $\not{E}_T$ channel (87pb^{-1})**





Number of extra dimensions	4	6	8
95% C.L. limit on M_S (GeV/c^2)	549	581	602

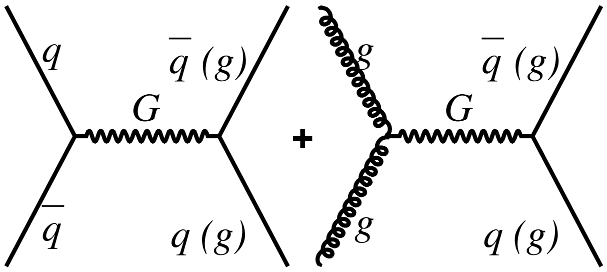
- **Graviton emission in Jets + $\not{E}_T$ channel (84pb^{-1})**



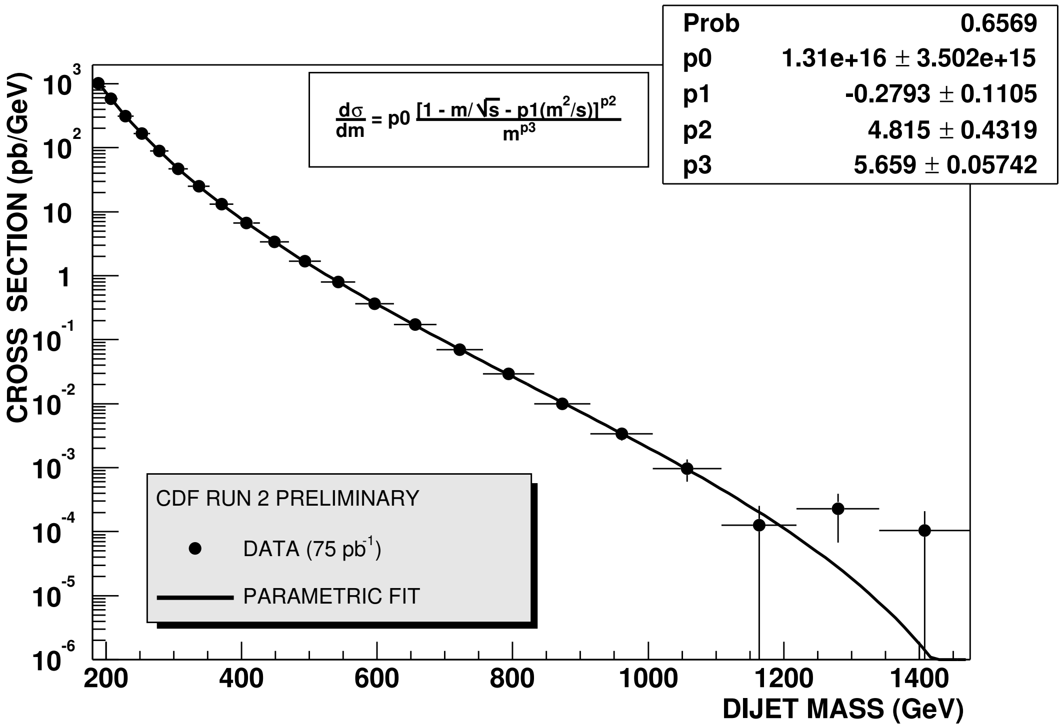
Number of extra dimensions	2	4	6
95% C.L. limit on M_S (GeV/c^2)	1000	770	710

Run II Extra Dimensions - Dijet

Randall-Sundrum Graviton



- **Event Selection**
  - $\dfrac{\not{E}_T}{\sqrt{\sum E_T}} < 6$ and $\sum E_T < 2.2$TeV
  - Two highest E_T jets with $|\eta| < 2$ and $|\cos\theta| < 2/3$
- **Dijet invariant mass distribution**
  - With background parameterization fit



No significant evidence for new particles

Run II Extra Dimensions - Dijet (cont.)

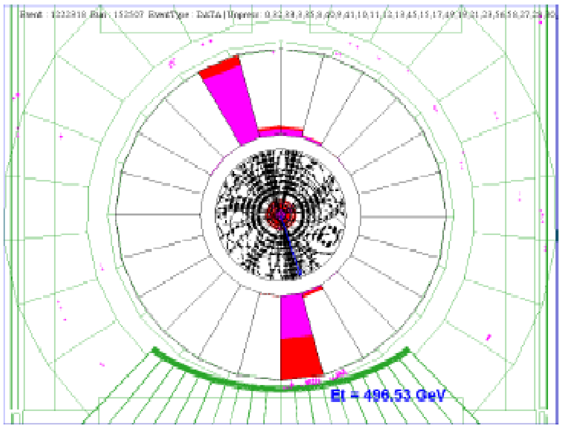
Randall-Sundrum Graviton

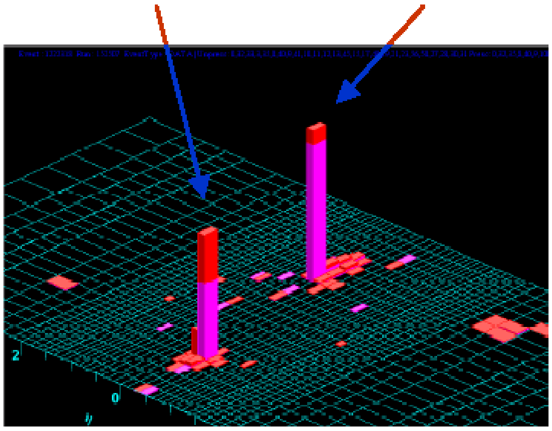
- **Dijet highest mass event ($M_{jj} = 1364$ GeV)**

Run 152507 event 1222318
Dijet Mass = 1364 GeV (corr)
cos θ^* = 0.30
z vertex = -25 cm

J2 E_T = 633 GeV (corr)
546 GeV (raw)
J2 η = -0.30 (detector)
= -0.19 (correct z)

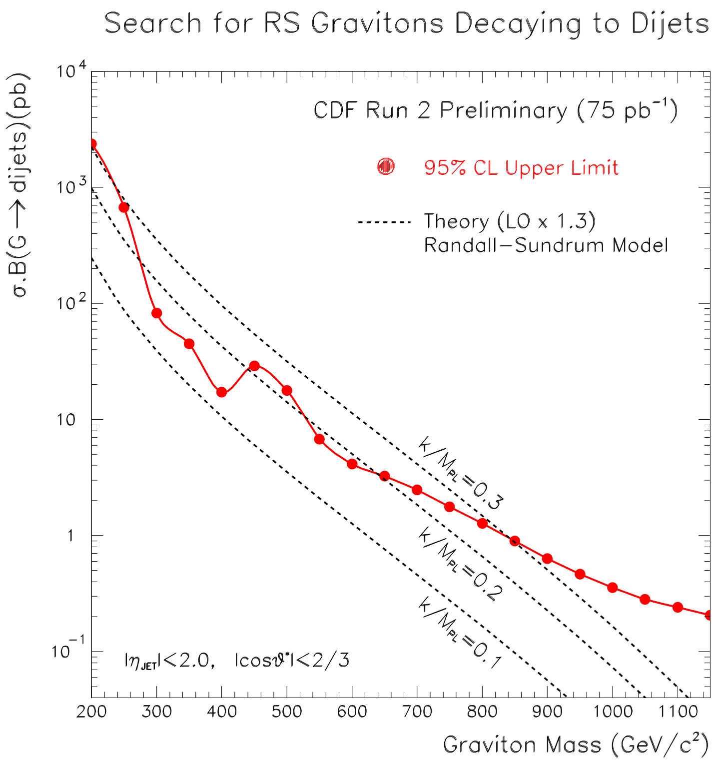
J1 E_T = 666 GeV (corr)
583 GeV (raw)
J1 η = 0.31 (detector)
= 0.43 (correct z)

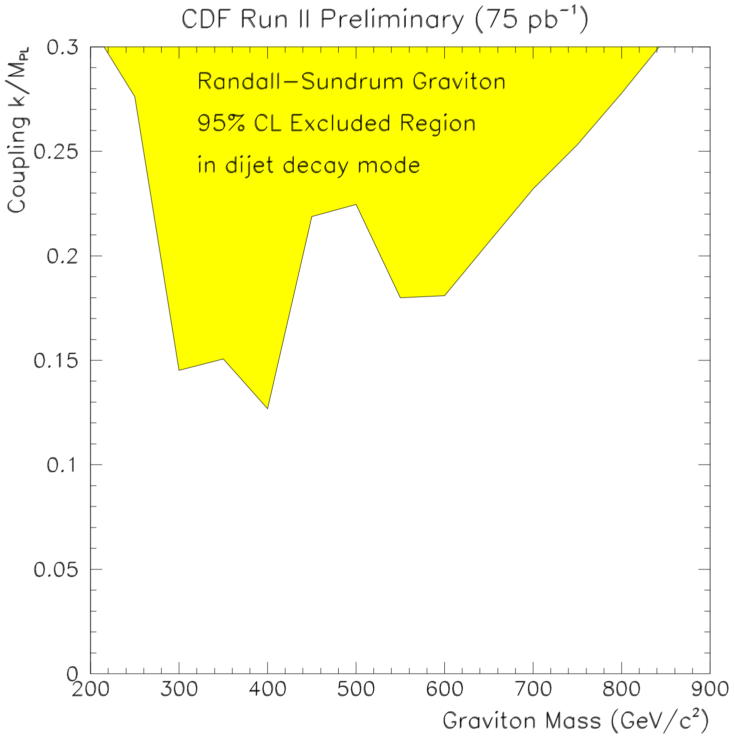




CDF Run 2 Preliminary

- **95% C. L. limit on cross section and excluded region in the k/M_{Pl} and mass plane (75pb^{-1})**

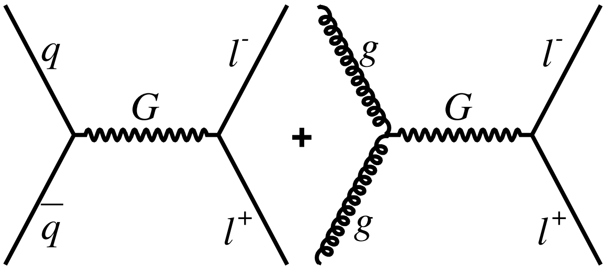




† **Limits for $0.1 < k/M_{Pl} < 0.3$**

Run II Extra Dimensions - Dilepton

Randall-Sundrum Graviton

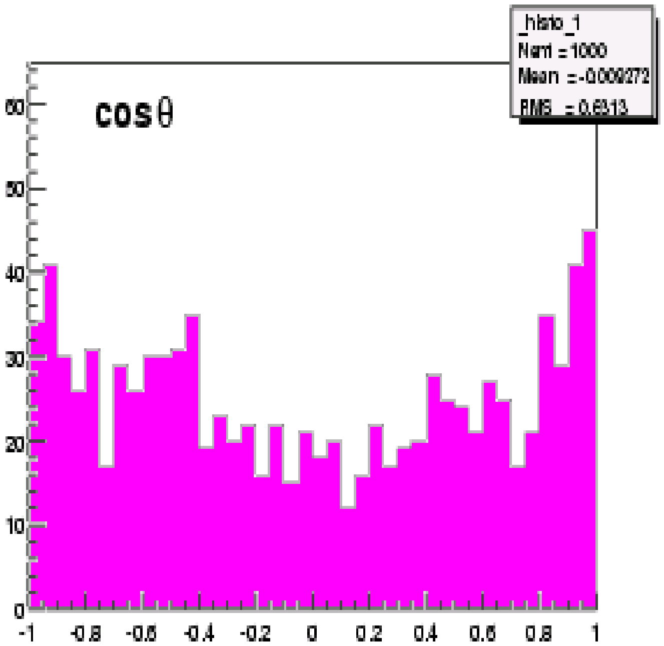


- Same selection criteria as $Z^{'} \rightarrow \ell\ell$ search
- Setting limits : same method as $Z^{'}$ search but different efficiency

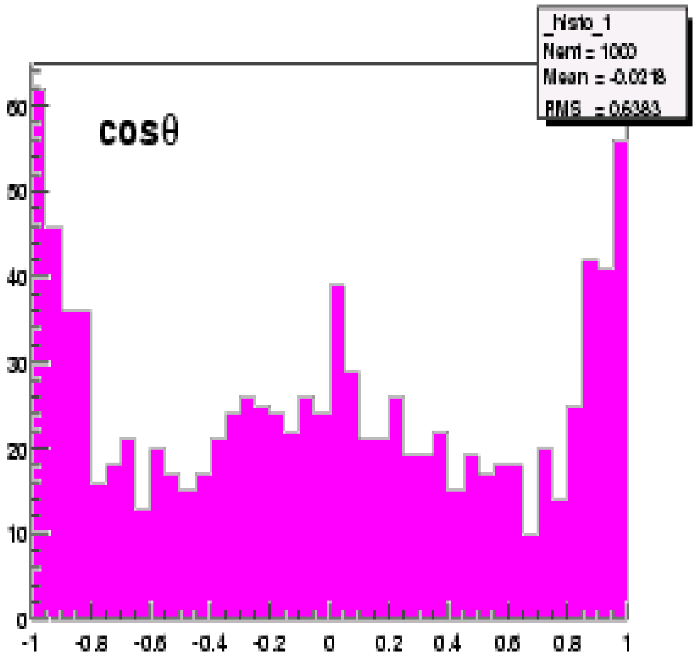
$$\sigma_{95} \cdot Br(G \rightarrow \ell^{+}\ell^{-}) = \frac{N_{95}}{\mathcal{L} \cdot \varepsilon_{tot}(M_G)}$$

† Different geometrical acceptance due to the difference of spin

$Z^{'}$: spin-1



Graviton : spin-2

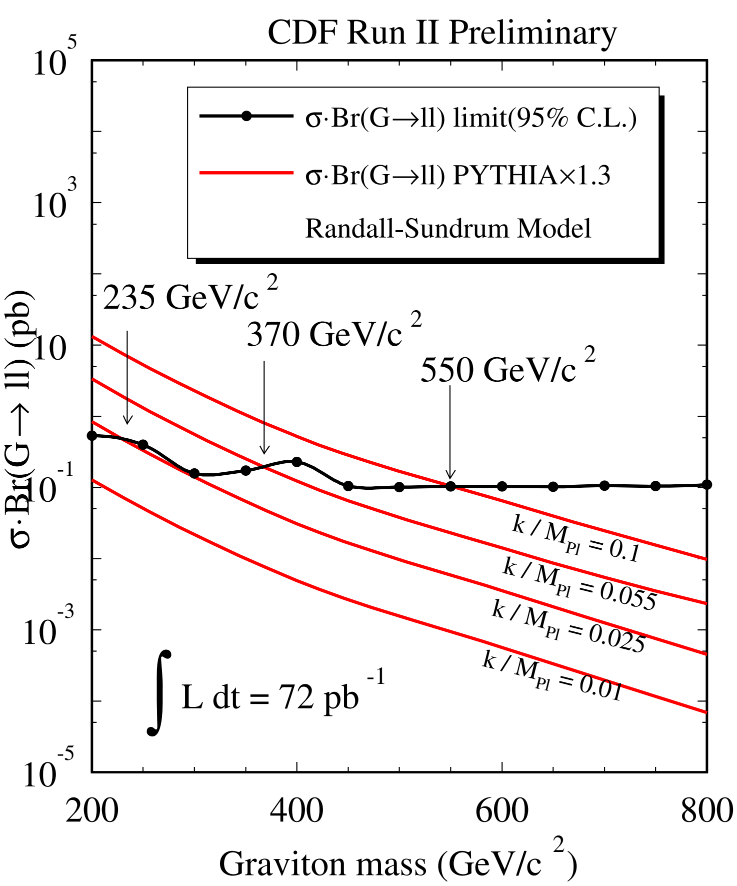


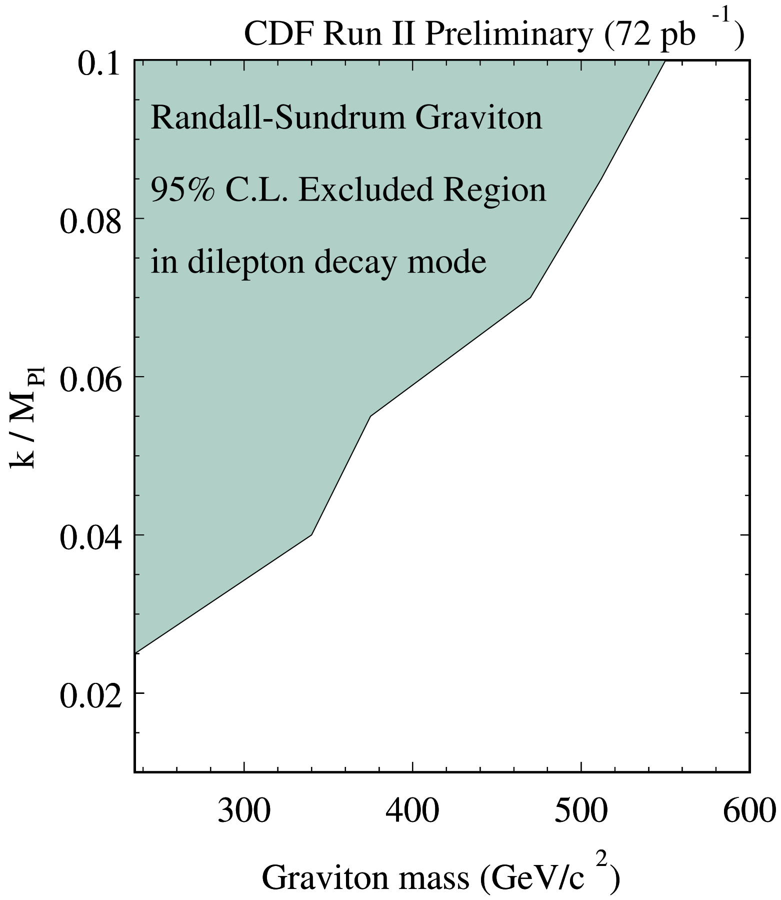
Angular distribution for the decay

Run II Extra Dimensions - Dilepton (cont.)

Randall-Sundrum Graviton

- 95% C. L. limit on $G \to \ell\ell$ cross section and excluded region in the k/M_{Pl} and mass plane in ee+$\mu\mu$ combined (72pb^{-1})



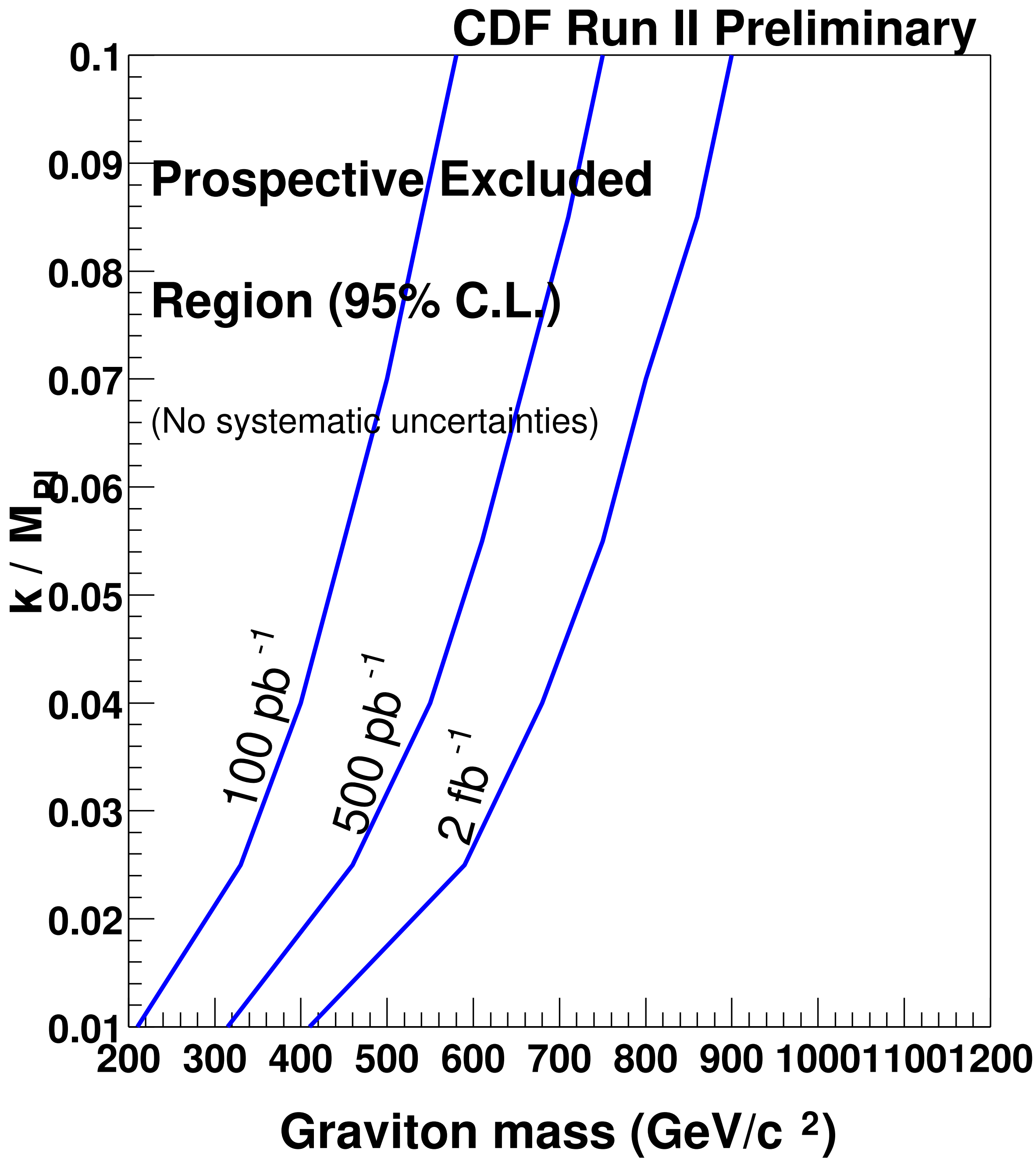


† Limits for $0.01 < k/M_{Pl} < 0.1$

Run II Extra Dimensions Prospect

Randall-Sundrum Graviton

- Future prospect of Randall-Sundrum Graviton in ee channel
  - Null signal is assumed
  - No systematic uncertainties



Summary

- Overview searches for $Z^{'}$ and extra dimensions in CDF Run I & Run II (past, present and future)
- CDF is taking data actively and producing first results on searches for new physics
- Some of the results are already better than Run I results
- New exciting results are coming soon...