Searches for New Physics in High Mass Dileptons at CDFII

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for the CDF Collaboration

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Outline:

- Motivation and Model Introduction
- Dilepton (ee + $\mu\mu$) Event Selection
- Comparison of Background Expectation to Data
- Model Acceptances
- Preliminary Results
- Summary and Conclusions

Motivation: New Physics Searches

- Standard Model survived many stringent tests up to now. However, ...
  - Indications of possible new physics exist
  - Questions like "hierarchy problems" are unanswered

➡ Numerous attempts (models) to understand beyond SM!

Strategy: Analyze (Inclusive) High Mass Dileptons

- Dileptons serve as clean data samples with manageable backgrounds
- Many predicted particles produce dilepton signatures!

☞ Use dilepton signatures for searches on below categories:

Resonance Production

- **Spin-0**: SUSY ($\not{R}_P$ $\tilde{\nu}$)
- **Spin-1**: Z' (E6, little Higgs), Technicolor (ρ_T, ω_T)
- **Spin-2**: Randall-Sundrum G

Continuous mass spectrum

- Large Extra Dimensions (ADD)

Heavy Neutral Spin-1 Particles:

Sequential Z':

- Reference model with SM-like couplings to fermions
- $M(Z'_{SM})$ sole free parameter

E6 Model Z':

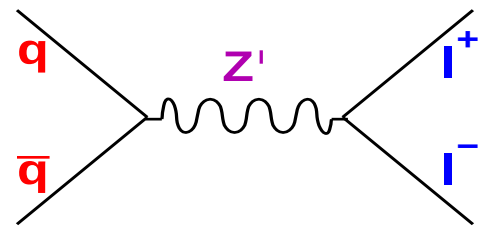
del Aguila et al., Nuc Phys B287 (87)

- Unification of strong and EWK forces at GUT
- $E6 \rightarrow (SO(10) \rightarrow SU(5) \times U(1)_\chi) \times U(1)_\psi$
- $Z' = Z_\psi \sin\theta_{E6} + Z_\chi \cos\theta_{E6}$
- $Z_\eta, Z_I \leftrightarrow \theta_{E6} = \sin^{-1}\sqrt{3/8}, \sin^{-1}\sqrt{5/8}$

Littlest Higgs Z':

Han et al., Phys Rev D67 (03)

- Solve fine-tuning and hierarchy by canceling divergences of Higgs mass
- SU(2) Z_H coupling parameter: **cotθ**



Technicolor ρ_T, ω_T:

Lane and Mrenna, Phys Rev D67 (99)

- Alternative to Higgs mechanism using strong dynamics
- TCStraw-Man Model: phenomenology of vector and pseudoscalar T-mesons
- Parameter for T-vector decays: $\mathbf{M_T}$

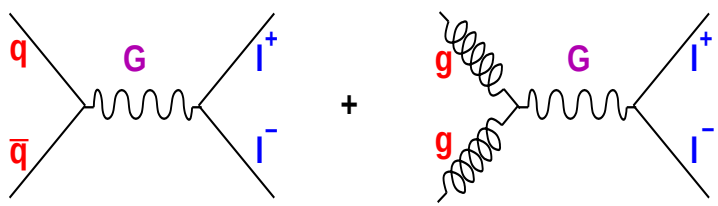
Müge Karagöz Ünel, CDF / Northwestern University

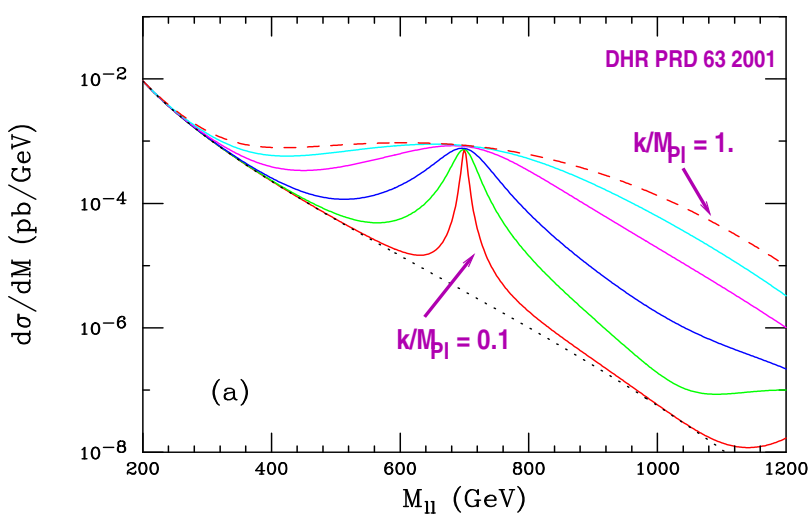
Gravitons in Extra Dimensions:

Randall-Sundrum G:

Randall and Sundrum, Phys Rev Lett 83 (99)

- 5-D warped space-time via an $\exp(-kr_c\pi)$ factor predicts graviton resonances
- dimensionless coupling parameter: k/M_{Pl}





Large Extra Dimensions (ADD):

ADD, Phys Lett B429 (98)

- ***n*** extra dimensions to solve hierarchy problem: $M^2_{Pl} \sim R^n M_s^{n+2}$, M_s: string scale
- Graviton: sum of many excited states, Kaluza-Klein (KK) modes
- virtual G exchange effective σ:

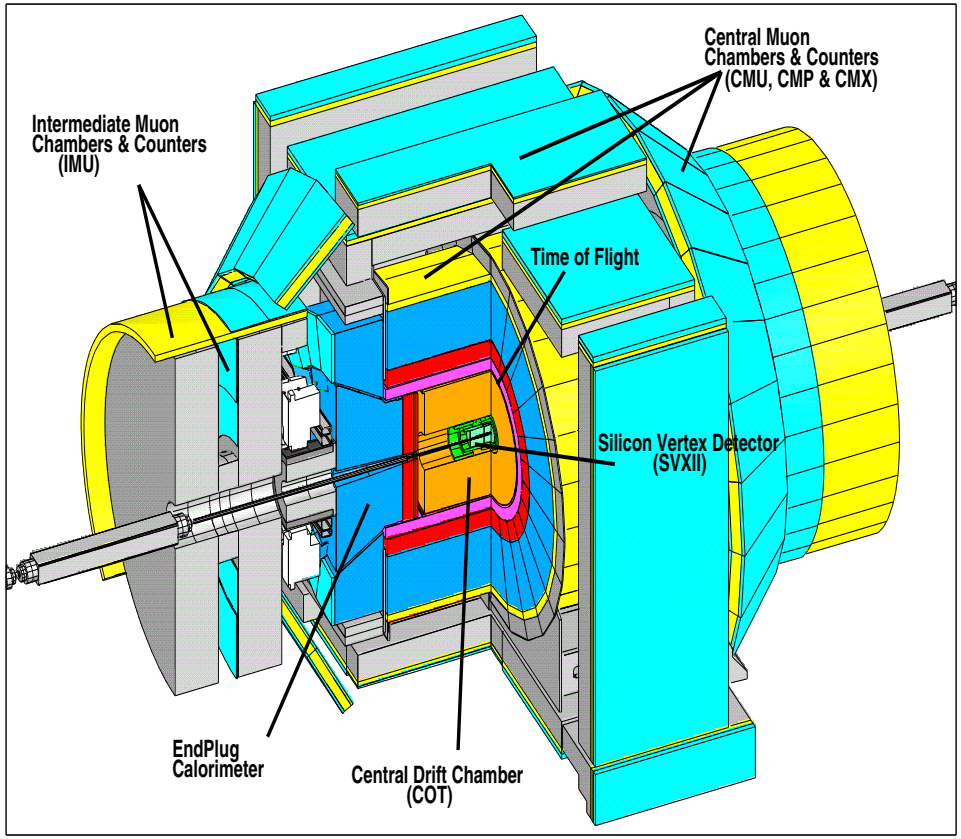
$$\sigma = \sigma_{SM} + \eta\sigma_{int} + \eta^2\sigma_{KK}$$
$$\eta = \lambda / M_s^4, \quad \lambda_{Hewett} = \pm 1$$

RPV sneutrino:

Choudhury et al., Nuc Phys B660 (03)

- SUSY theories may include interactions with R-parity violation
- $\sigma \propto \lambda'^2 \times \mathbf{BR}$, $\tilde{\nu}$'s Yukawa coupling to quarks $\times$ leptonic branching fraction

Selection Criteria for High Mass Dileptons:



- Require two isolated *e*, E_T> **25 GeV**

Central: $|\eta|< 1$	Plug: $1< |\eta|< 3.0$

⇓

CC CP PP

categories

- at least one *e* with track required for electron pair

- Require two isolated μ, p_T> **20 GeV**

μ_1: Central	μ_2: $|\eta|< 1.5$

- μ_2 may include tracks w/o μ-chamber information

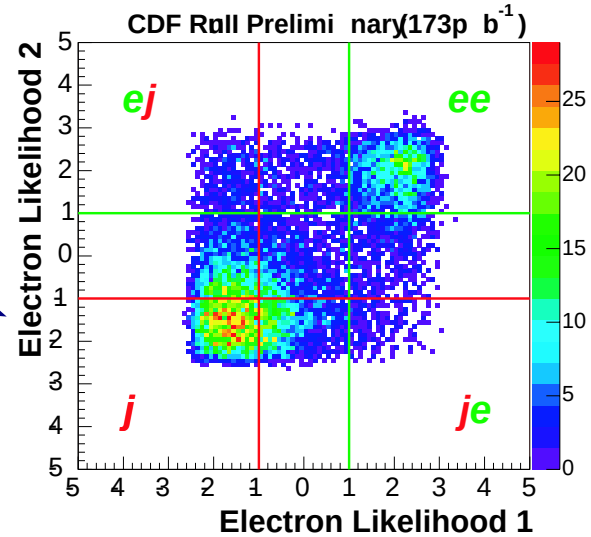
➥ Will show results from **~200** pb^{-1} ($\mu\mu$, CC+CP *ee*) and **~175** pb^{-1} (PP *ee*) CDF data taken at 1.96 TeV during March 2002 – September 2003.

Background Contributions:

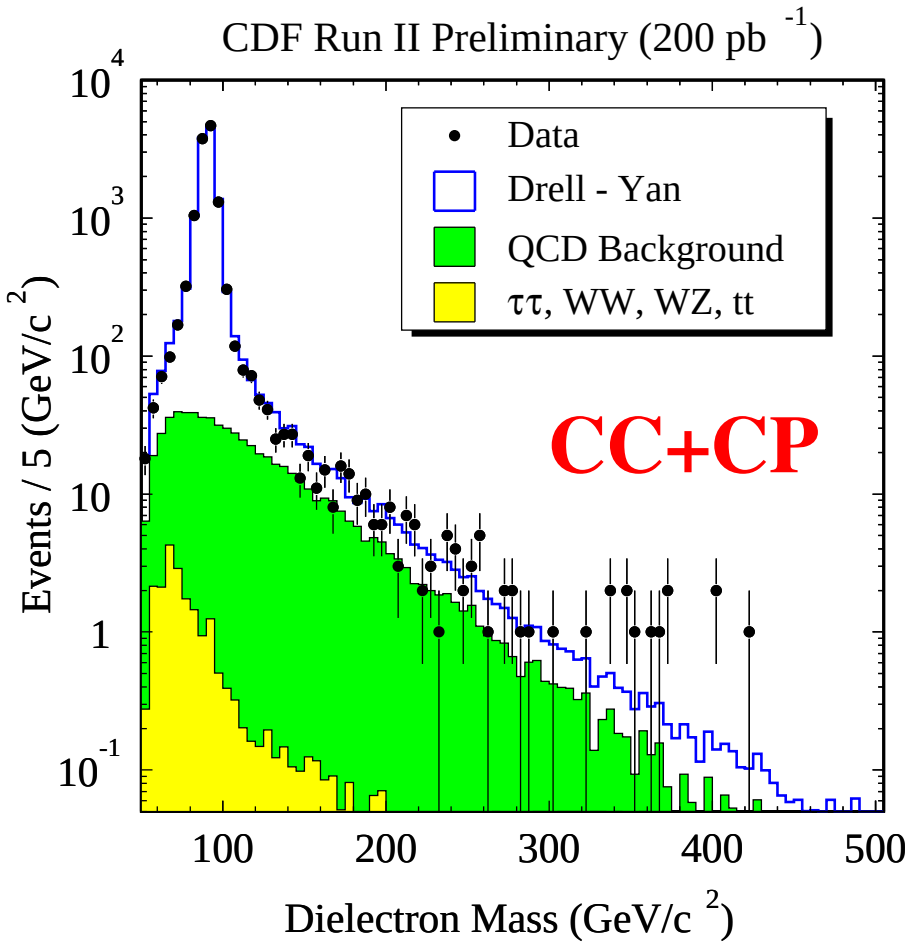
- Use data to estimate backgrounds and efficiencies as much as possible
- Veto fakes/cosmics mainly by $\not{E}_T$ significance and track-timing cuts

		ee	μμ	Estimation
Direct	Drell-Yan/Z	✓	✓	MC
	WW,WZ, ZZ, Z→ττ, $t\bar{t}$	✓	✓	MC
Fakes	W+n jets, dijets	✓	✓	MC/Data
	cosmic rays		✓	Data

QCD bgrnd estimation for plug electrons



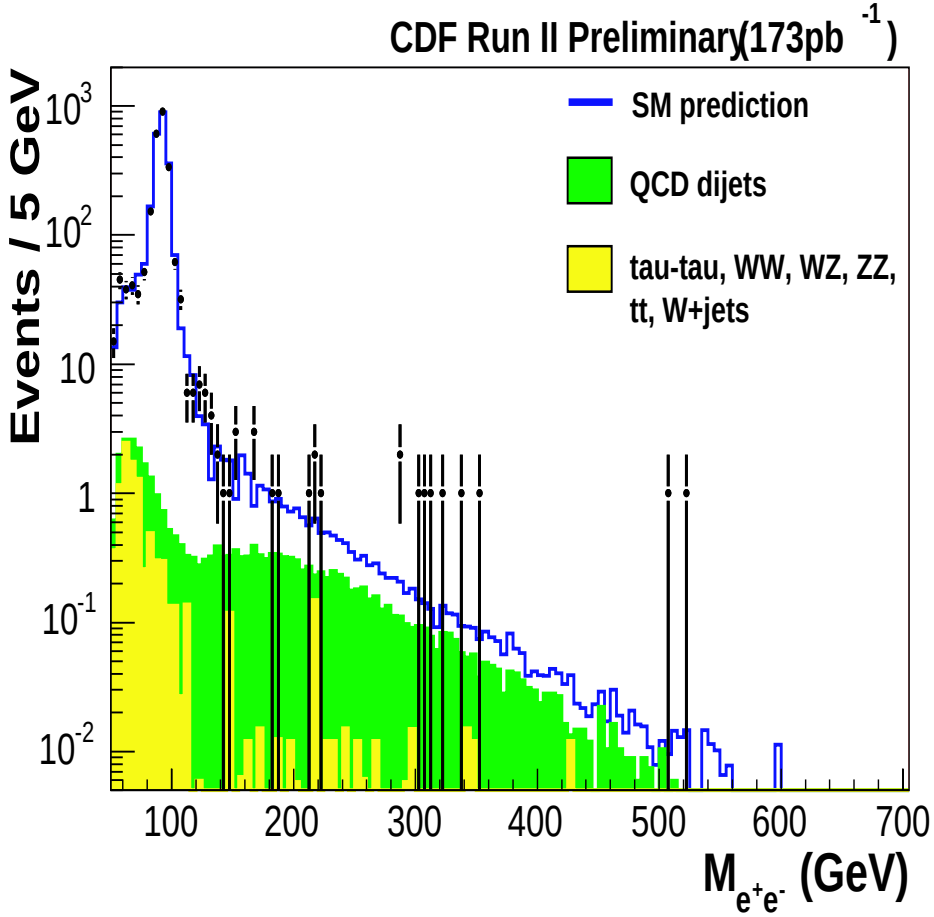
Comparison to Expectation (CC+CP *ee*):



Mass >(GeV/c^2)	N_{exp}	N_{obs}
200	66.9	70
250	25.1	29
300	10.4	14
350	4.7	8
400	2.4	3
450	1.4	0

Total of ~12500 CC+CP candidates in 200 pb^{-1} data

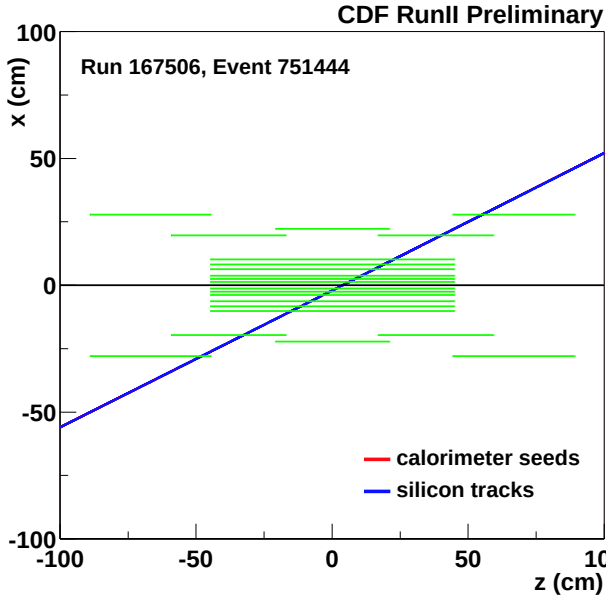
Comparison to Expectation (Plug-Plug *ee*):



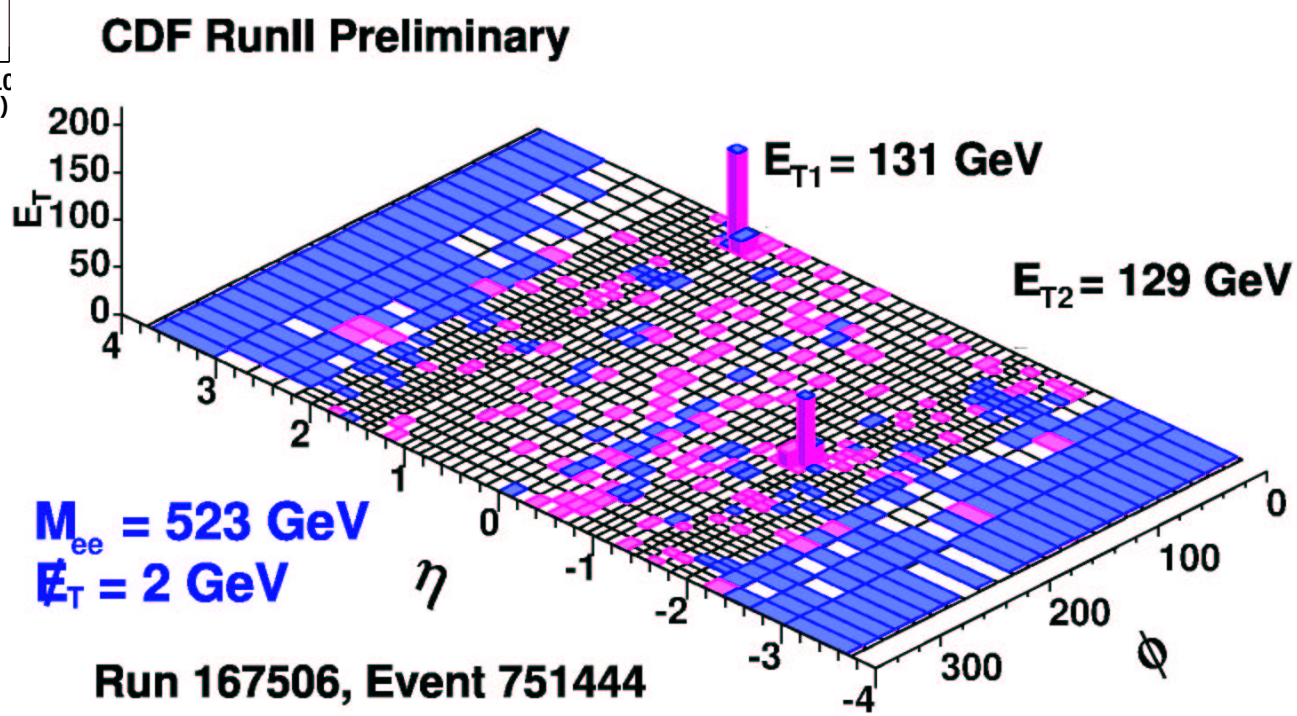
Mass Cut	N_{PRED}	N_{DATA}
0	2414 ± 58	2387
50	2410 ± 58	2381
100	144 ± 6.7	149
150	20.8 ± 3.7	22
200	10.2 ± 2.2	14
250	5.0 ± 1.2	10
300	2.5 ± 0.7	8
350	1.4 ± 0.33	3
400	0.71 ± 0.17	2
450	0.39 ± 0.09	2
500	0.21 ± 0.04	2
550	0.10 ± 0.03	0

✔ **New for Run II: Plug dielectrons to increase the acceptance!**

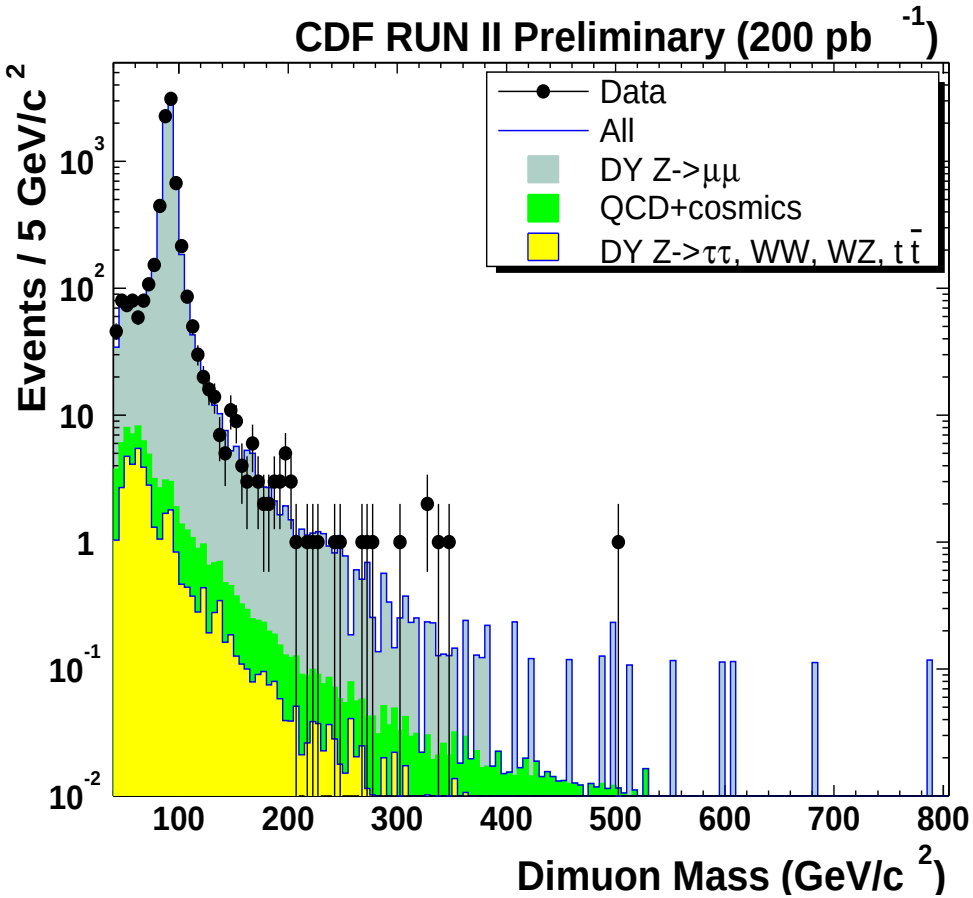
Highest mass Dielectron Event in CDF Plug Region:



- Two electrons with tracks in plug (forward) region.



Comparison to Expectation (μμ):

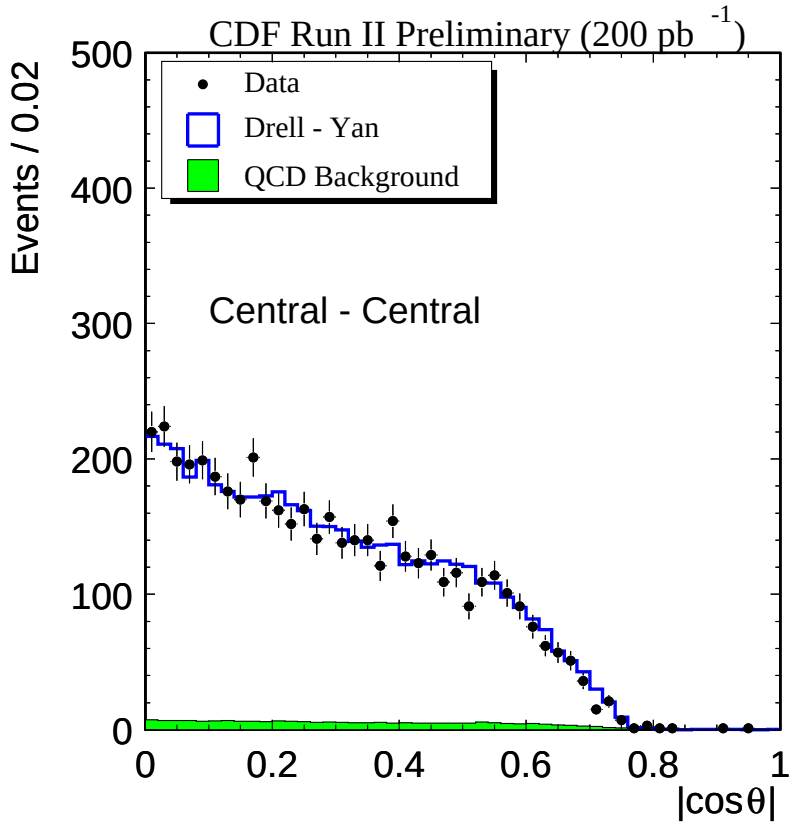


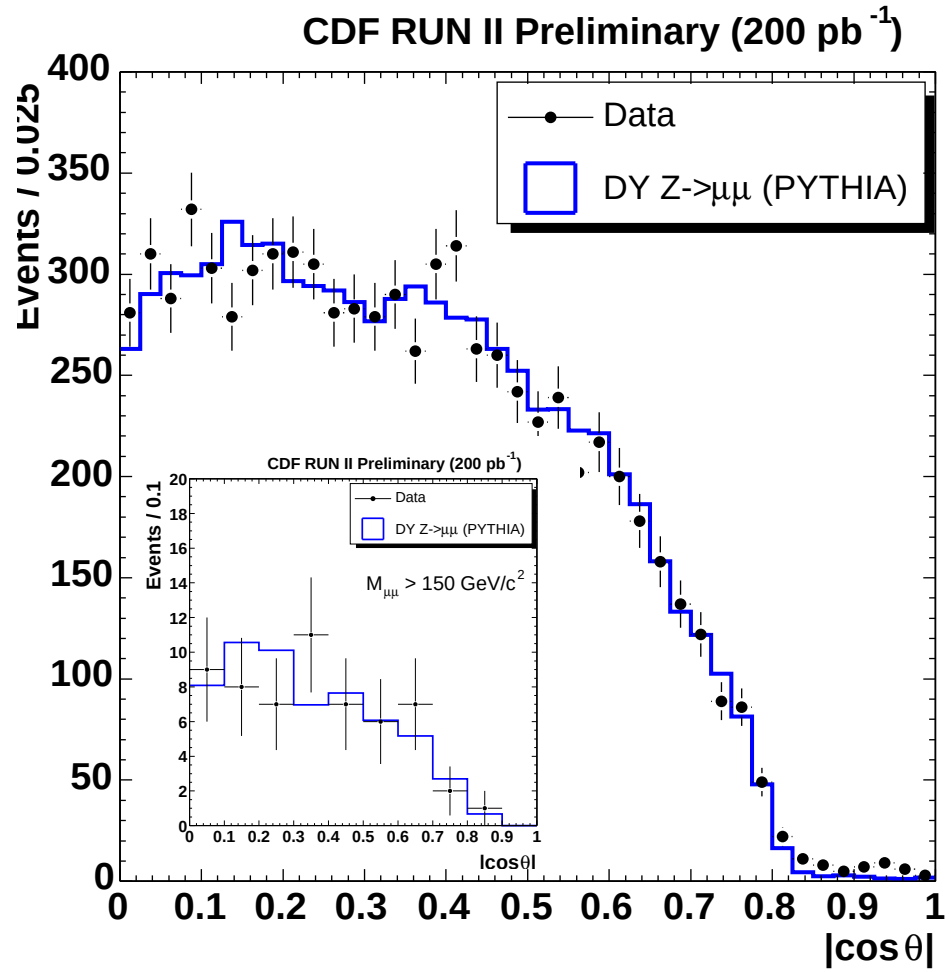
Mass > (GeV/c^2)	N_{exp}	N_{obs}
150	55.25±2.50	58
200	20.88±0.97	18
250	9.44±0.49	9
300	5.22±0.32	6
350	3.23±0.24	1
400	2.28±0.19	1
450	1.79±0.16	1
500	1.24±0.13	1
550	1.03±0.11	0

Total of ~ 7500 dimuon candidates in 200 pb^{-1} data

- **High mass dilepton spectra is consistent with background prediction**

Comparison to Expectation (*ee* + μμ): cosθ distributions



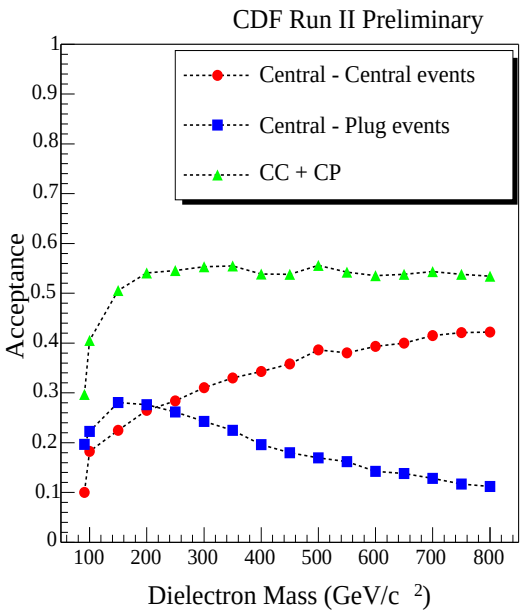


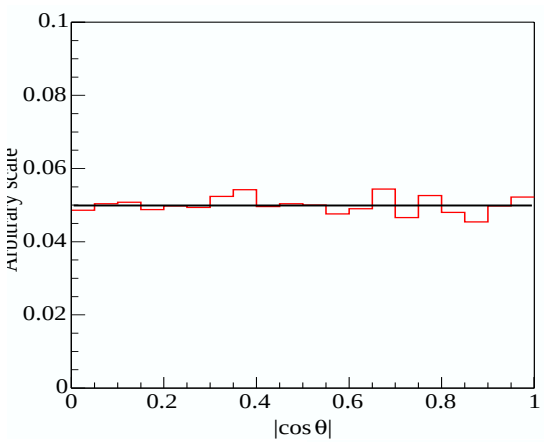
*cosθ in Collins-Soper frame

Acceptance for the Models:

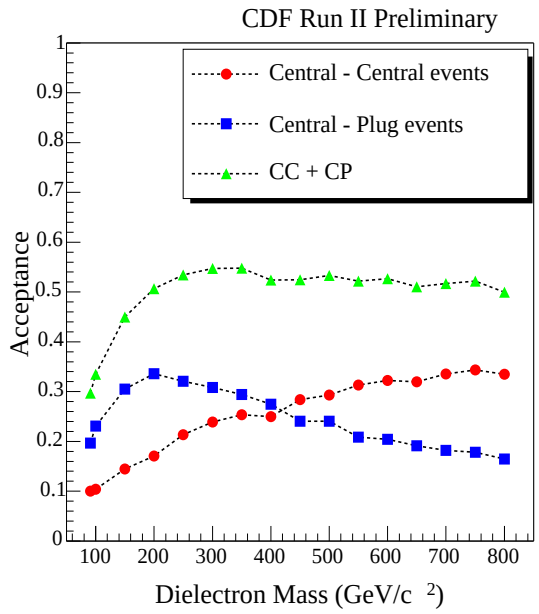
➡ Angular dependence ➜ Variations in Acceptance

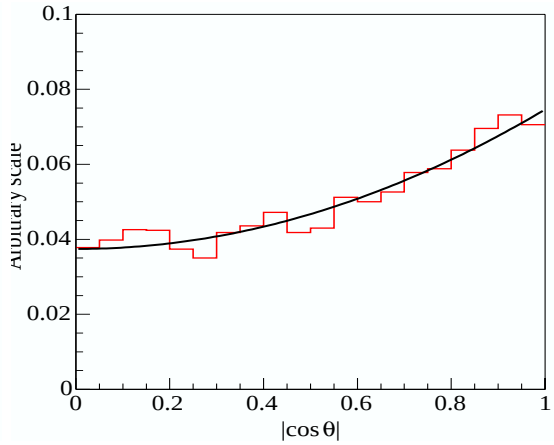
Spin-0 (Higgs)



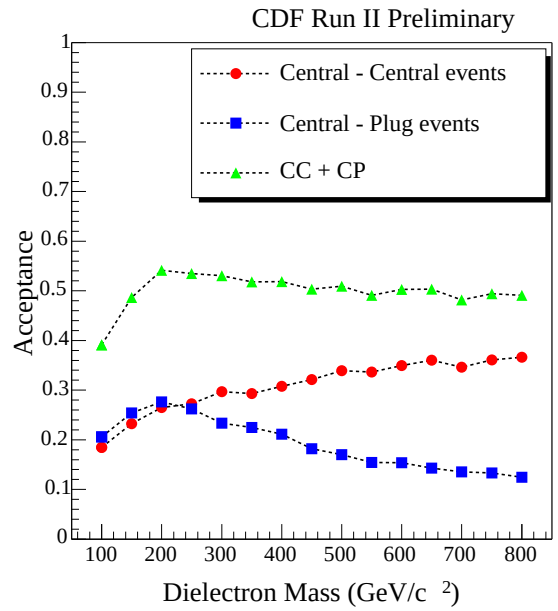


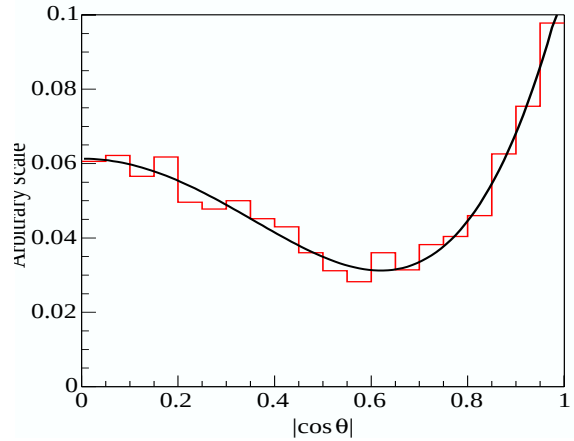
Spin-1 (Z'_{SM})





Spin-2 (RS G)





Limits on New Physics (CC+CP *ee* + μμ):

- 95%CL upper limits on σ•BR($X \rightarrow \ell\ell$) for spin-**0,1,2** and lower limits on string scale for LED are placed using binned likelihood method.

$$L(\alpha/\eta) = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$$

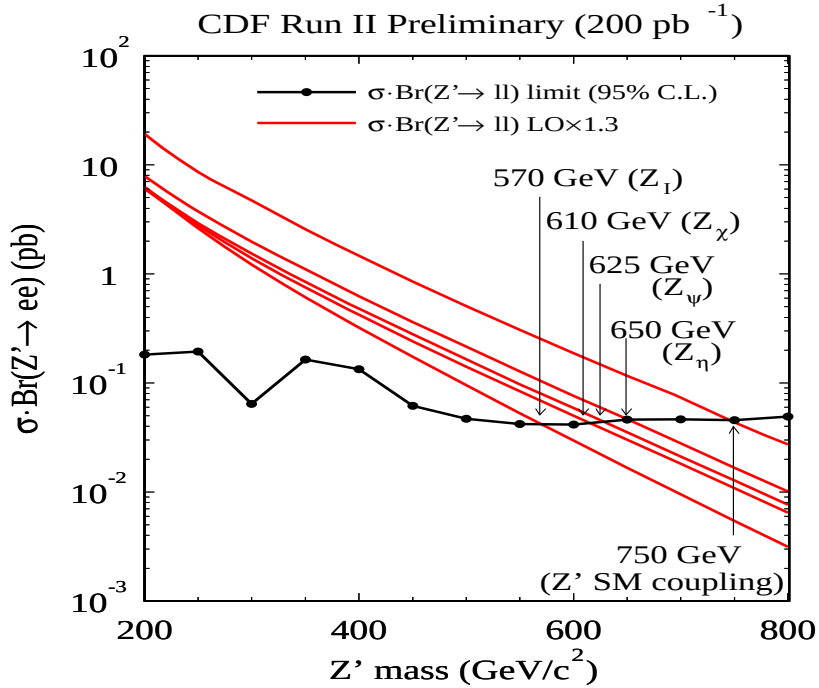
- n_i: observed events
- $\mu_i = \alpha N_i^{sig} + N_i^{bgrd}$ *(resonant particles)*
- $\mu_i = N_i^{sig}(\eta) + N_i^{bgrd}$ *(LED spectrum)*

- Likelihoods are integrated to give the final limits, taking into account the signal and background systematic uncertainties.

Sources of systematic uncertainties:

- Luminosity (6%)
- Acceptance (PDF, MC statistics, detector description, ..)
- Energy/Momentum scale/resolution
- Selection efficiencies
- Background statistics and normalization

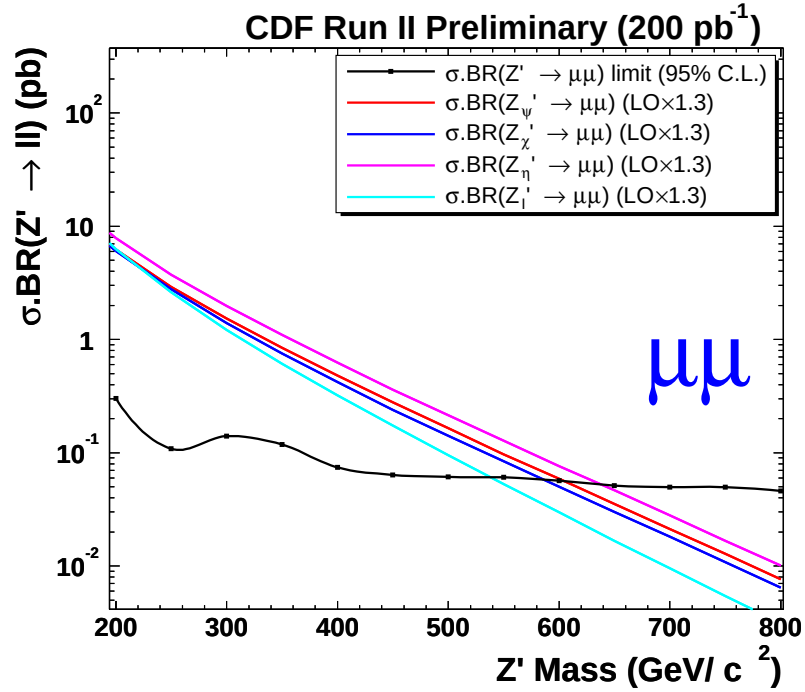
Results for Z' (E6 and Sequential):



CDF Run II Preliminary

μμ Z' Mass limit @95%CL (GeV/c²)

Model	Run I	Run II (winter '04)
Z'_{SM}	590	735
Z_ψ	495	600
Z_χ	500	580
Z_η	520	635
Z_I	480	530



***ee* Z'_{SM}**

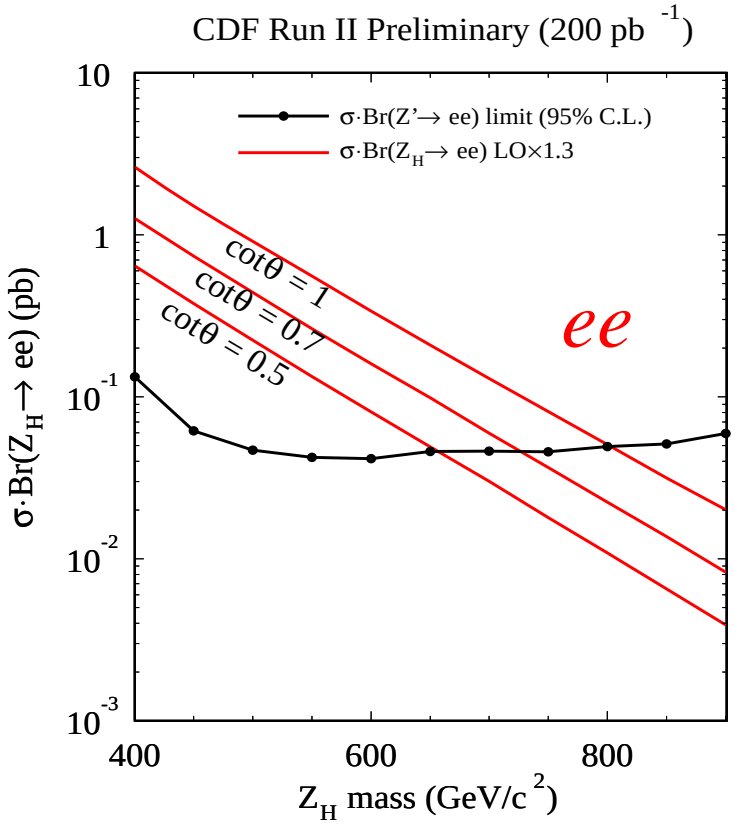
CDF Run II Preliminary

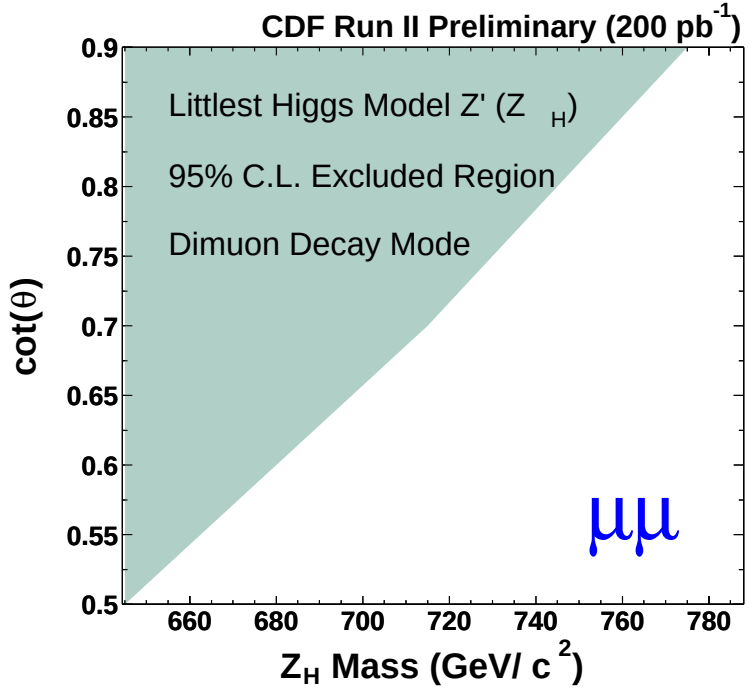
CDF Run	L(pb^{-1})	Mass limit @95%CL
IA ('92-'93)	20	**505**
IB (('94-'95)	90	**640**
IIA (winter '04)	200	**750**

(D0 Run II limit: 780 GeV/c²)

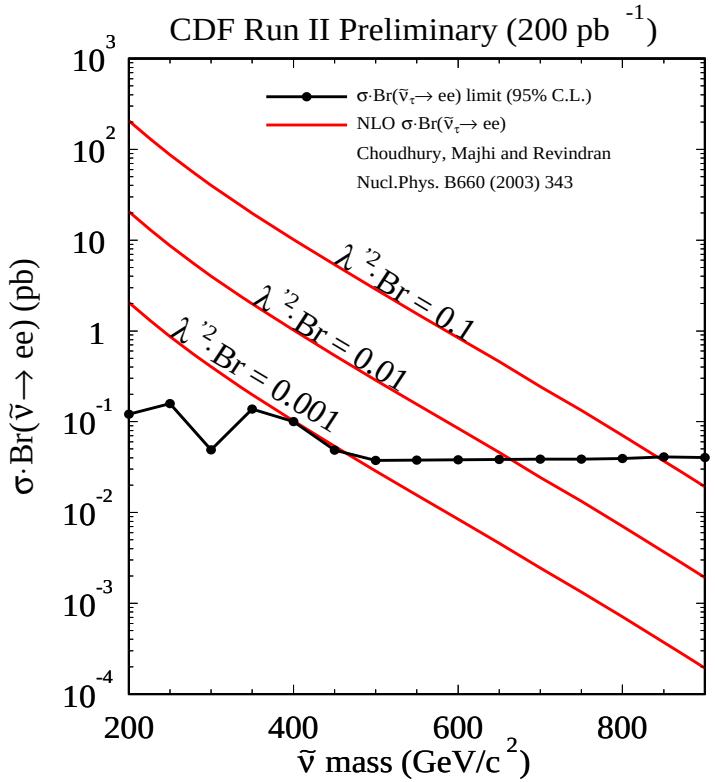
Results for Z' (Littlest Higgs Z_H):

- *ee:* $M(Z_H) > 800$ GeV/c^2 for $\cot\theta = 1.0$
- μμ: $M(Z_H) > 755$ GeV/c^2 for $\cot\theta = 0.9$

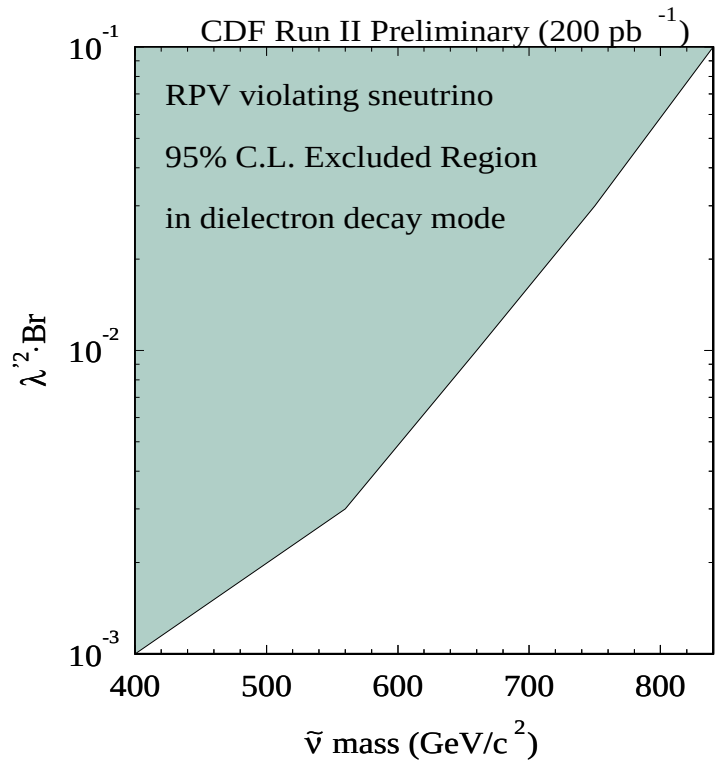




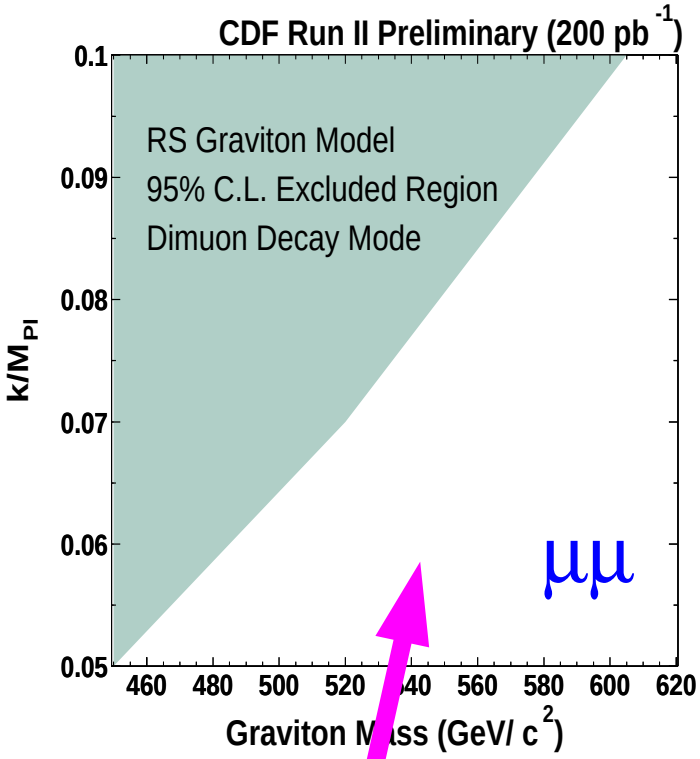
Results for $\not{R}_P$ sneutrino: (ee)

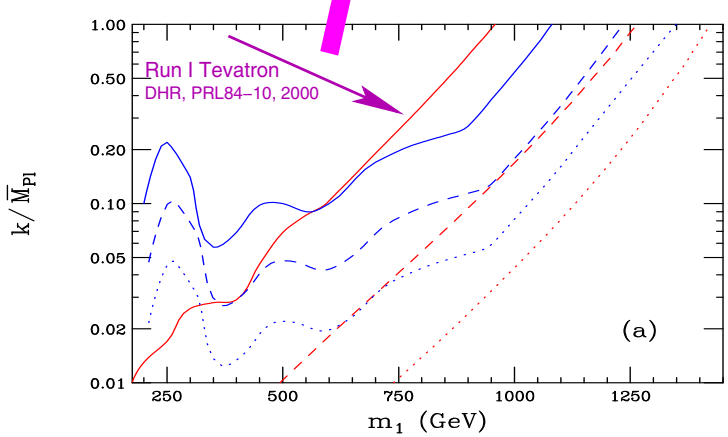


	CC (GeV)	CP (GeV)	CC+CP (GeV)
$\lambda'^2 \cdot Br = 0.1$	830	710	840
$\lambda'^2 \cdot Br = 0.01$	650	550	660
$\lambda'^2 \cdot Br = 0.001$	400	340	400



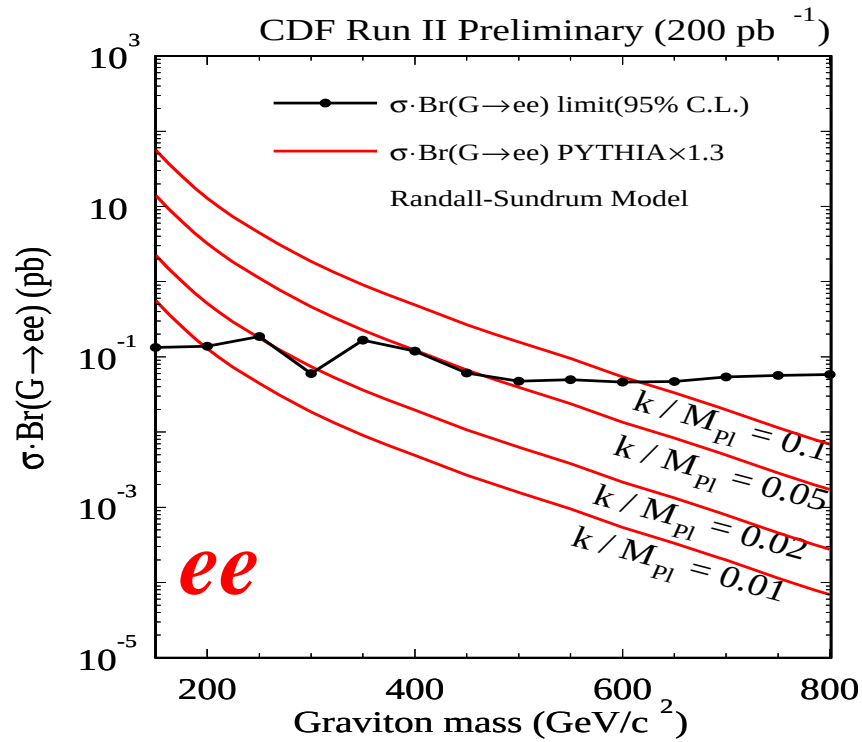
Results for RS Graviton:





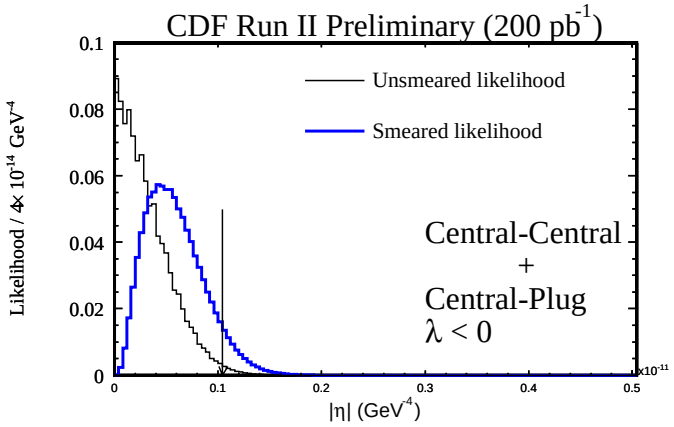
CDF Run II Preliminary

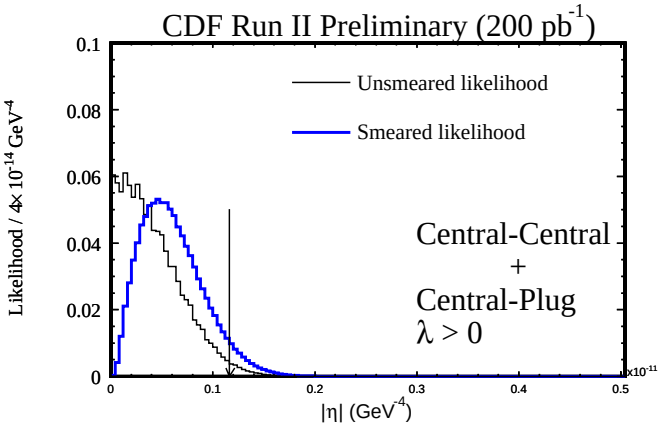
CDF Run	L(pb^{-1})	M_G @95%CL (k/M_{Pl}=0.1)	
		ee	μμ
IIA (winter '04)	200	**620**	**605**



Results for ADD Model: (ee)

- λ conventions : $\frac{2}{\pi}\lambda_{Hewett} = F_{GRW} = F_{HLZ}$, $F_{GRW} = 1$, $F_{HLZ} = \frac{2}{n-2}(n > 2)$





CDF Run II Preliminary (200 pb^{-1})

	η_{95} (10^{-12}GeV^{-4})		Hewett (GeV)		HLZ (GeV)					GRW (GeV)
	$\lambda = -1$	$\lambda = +1$	$\lambda = -1$	$\lambda = +1$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	
Central-Central	1.05	1.18	987	959	1174	987	892	830	785	1105
Central-Plug	2.23	2.47	818	797	973	818	739	688	650	916
Combined	1.05	1.17	987	961	1174	987	892	830	785	1105

CDF Run I: 780 768

Summary and Conclusions:

- We set preliminary σ•BR upper and mass lower limits on various predictions @95%CL using L~200 pb^{-1} of CDF II high mass *ee*+μμ data.

- We have surpassed the sensitivity and results of Run I high mass dilepton searches!

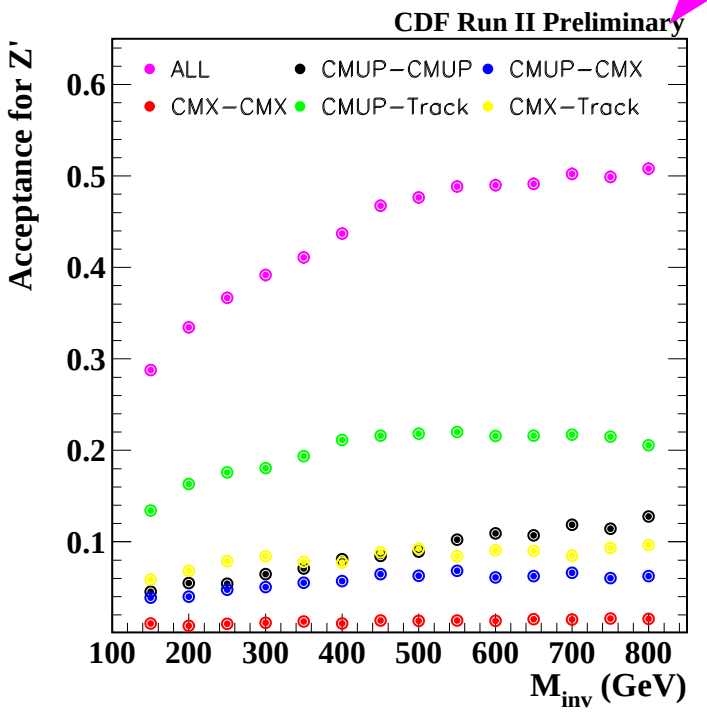
- All the limits shown either exceed any published results of direct searches or are the first limits ever!

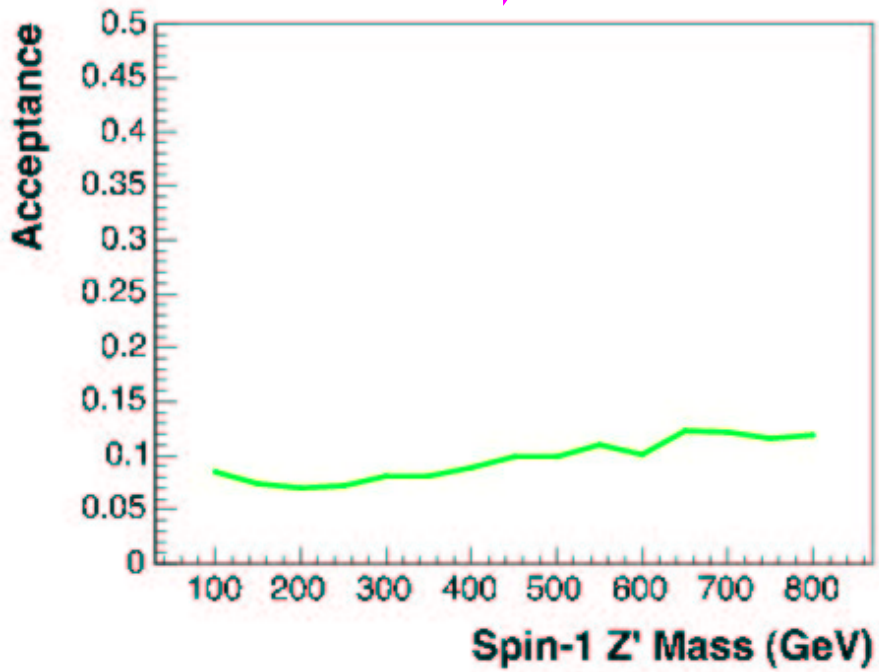
- Combined dilepton results are right around the corner!

(*) For more CDF search results, see talks by G. Veramendi (*ee* FB asymmetry), H. Gerberich (excited *e*) this afternoon.

Backup Slides

Acceptances for Spin-1 dimuons and plug dielectrons:

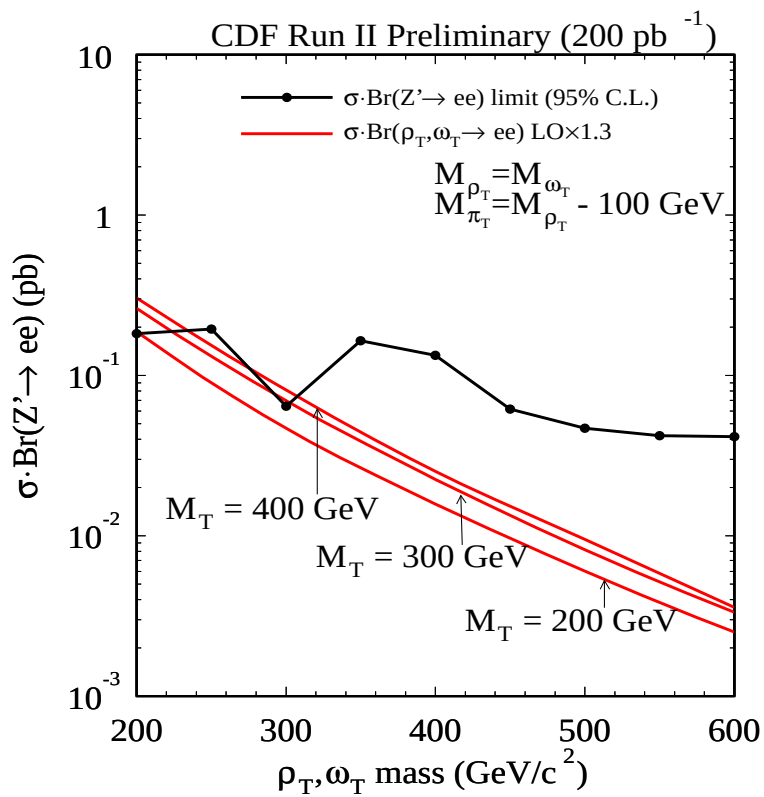




Spin-1 experimental limit:

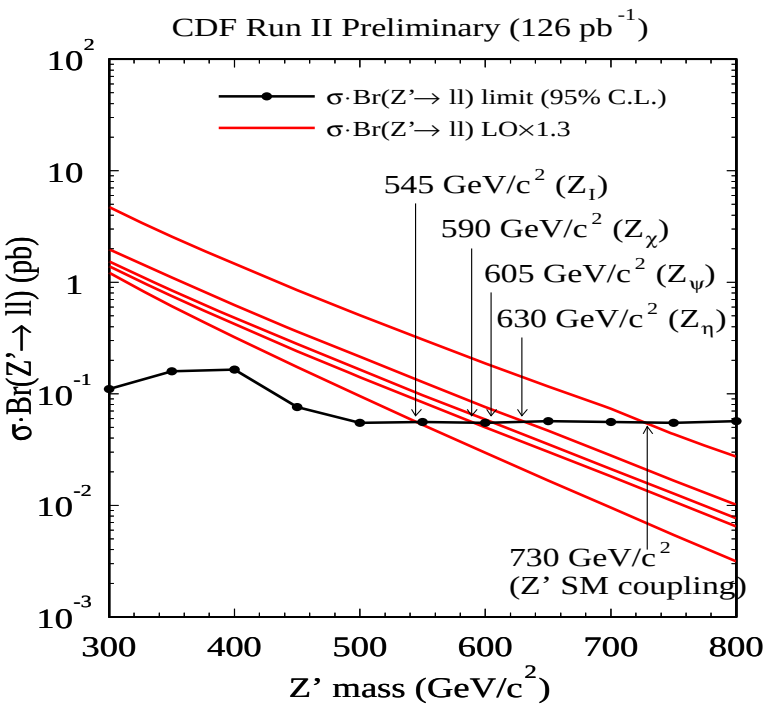
Comparison with techni-ρ and techni-ω production

★ TCSM model



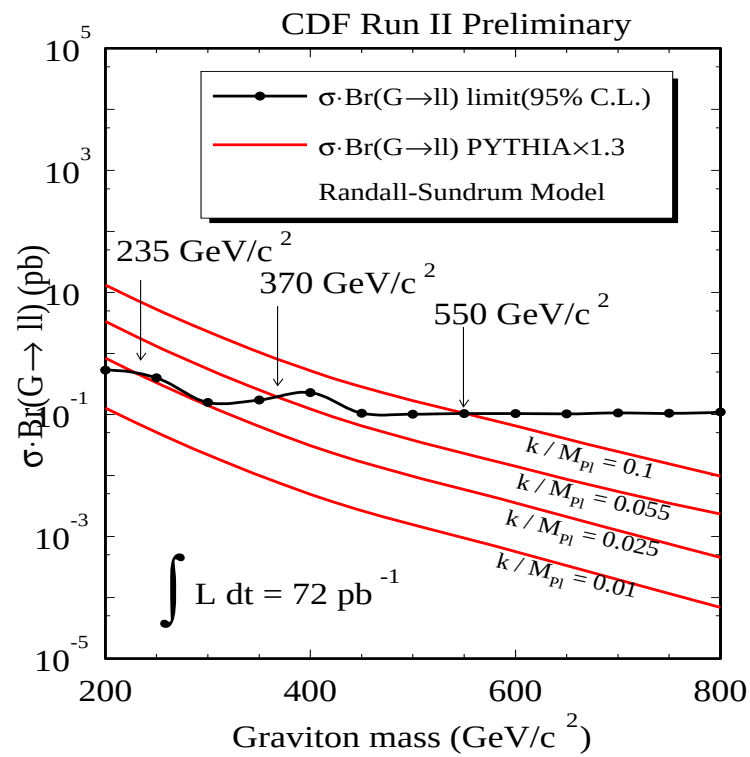
Combined dilepton limits (Summer '03, 126 pb^{-1}):

➡ Obtained using counting experiment results at high mass region



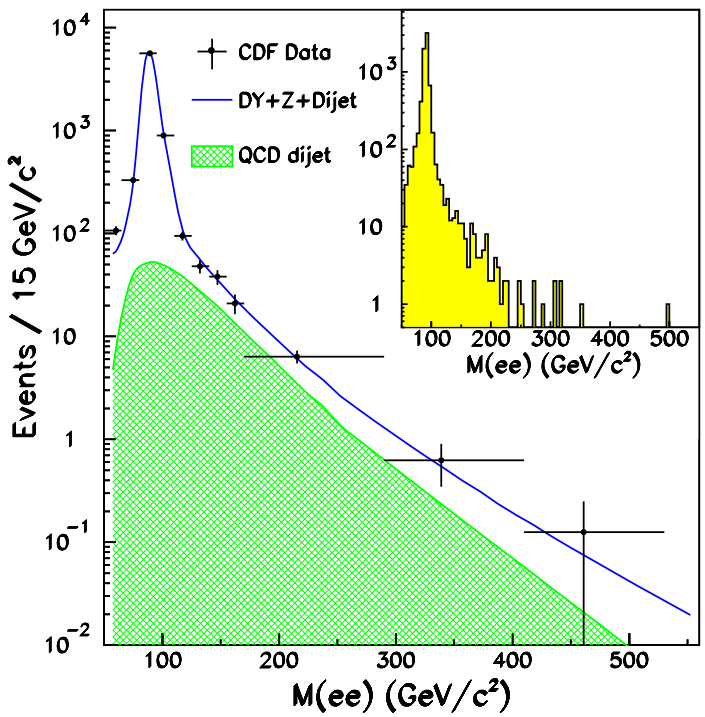
Spin-1

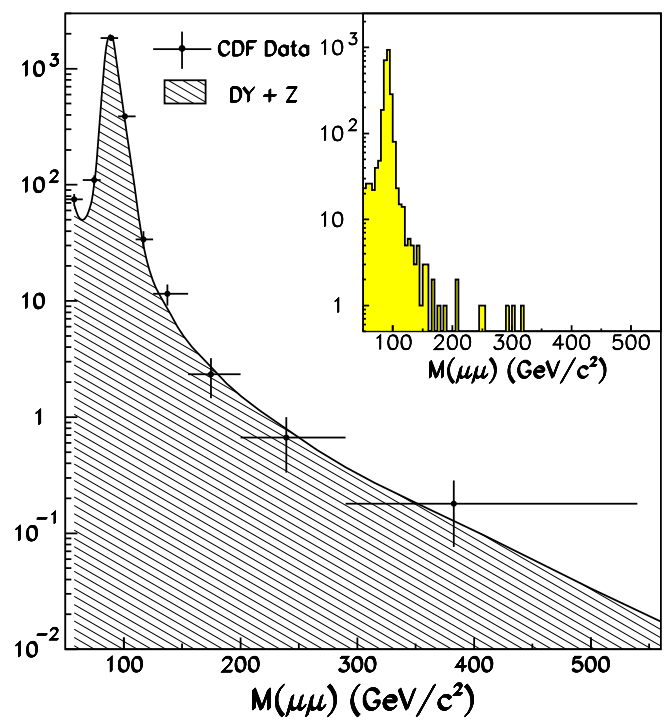
Spin-2



CDF Run I high mass spectra limits:

- Used to set Run I Z' limits



ee

μμ