Search for Randall-Sundrum gravitons at CDF

John Strologas

University of New Mexico

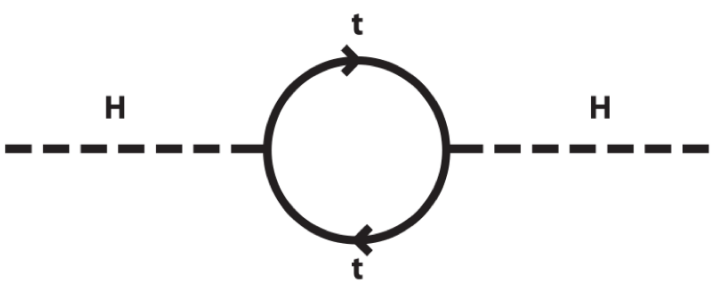
For the CDF Collaboration

XIX International Workshop on Deep-Inelastic Scattering and Related Subjects
April 11-15, 2011, Newport News, Virginia, USA

The "Hierarchy" problem

- The electroweak and Planck scales are 16 orders of magnitude apart

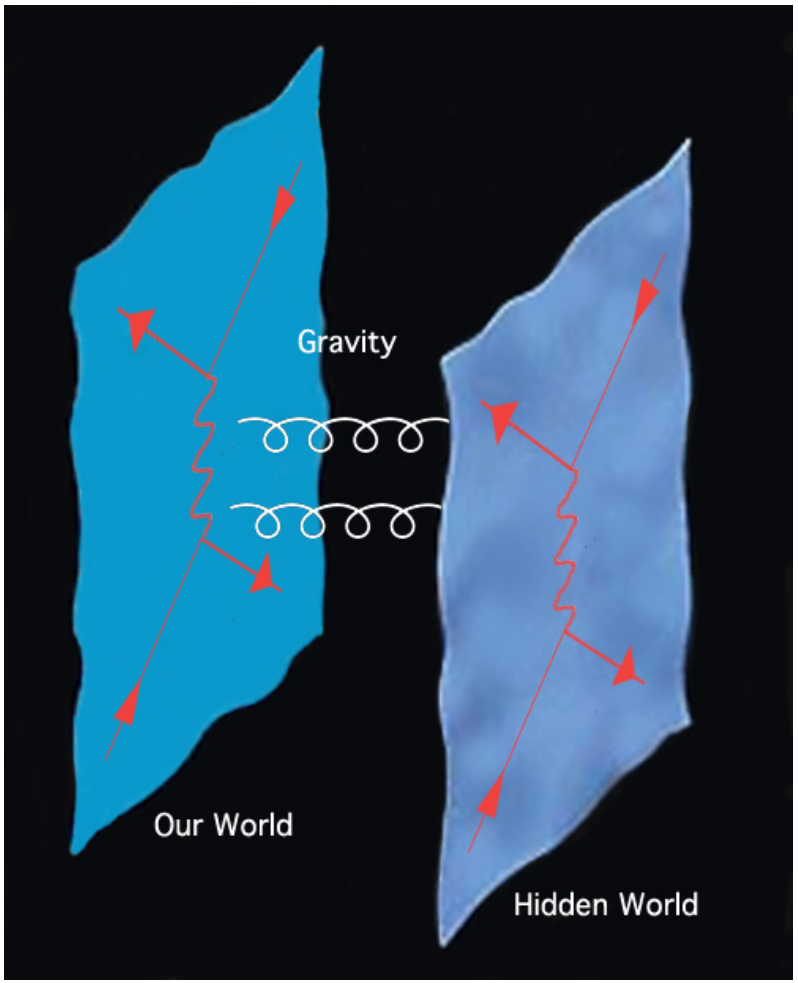
- The Lagrangian Higgs mass parameter m^2_H has to be fine-tuned to 1 part in 10^{26} to provide the needed cancelation that will maintain a <u>physical Higgs mass</u> below its unitarity limit



$$m^2_H(\text{phys}) = m^2_H + c/(16\pi^2)\Lambda^2$$

- This makes the theory not robust (or only an effective one) in case there are no new particles/phenomena between the electroweak scale and the Planck scale

Randall-Sundrum model

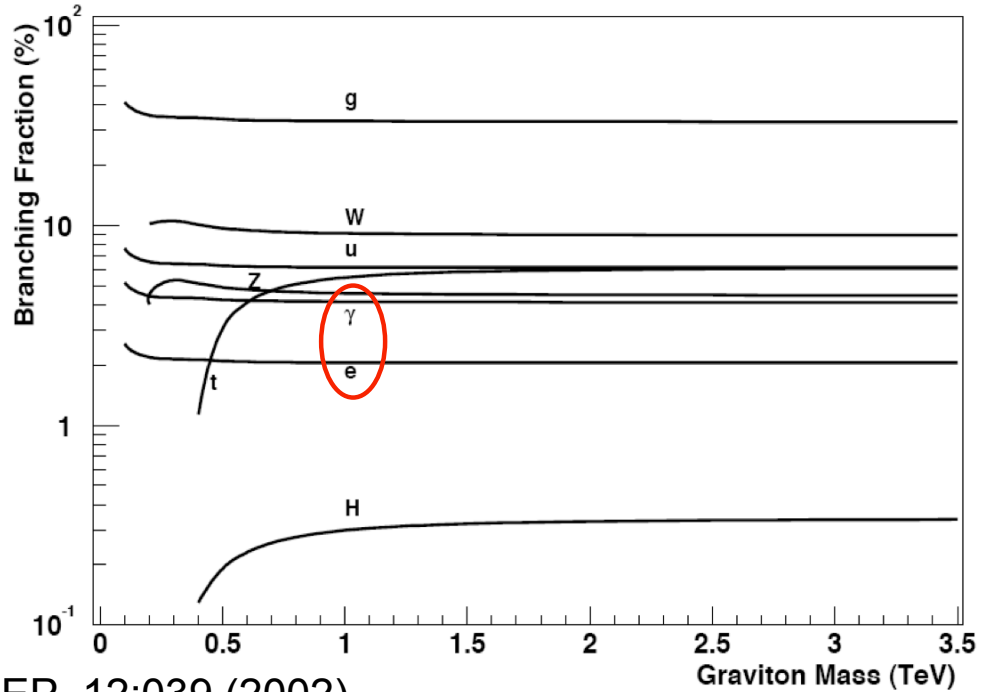


- Minimally 5 dimensions and 2 branes
- SM localized in one brane; only gravity propagates between the branes
- Mass parameter m_0 in the fundamental high-dimension corresponds to a physical mass $m = m_0 \exp(-kr_c/\pi)$
  - r_c is the compactificaton radius
  - k is the curvature scale (~ Planck scale)
  - Hierarchy problem is solved
- Compactificaton generates a Kaluza-Klein tower of states (spin-2 gravitons)
  - They decay to all possible pair of SM particles with equal coupling

L. Randall, R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999)

What we are looking for

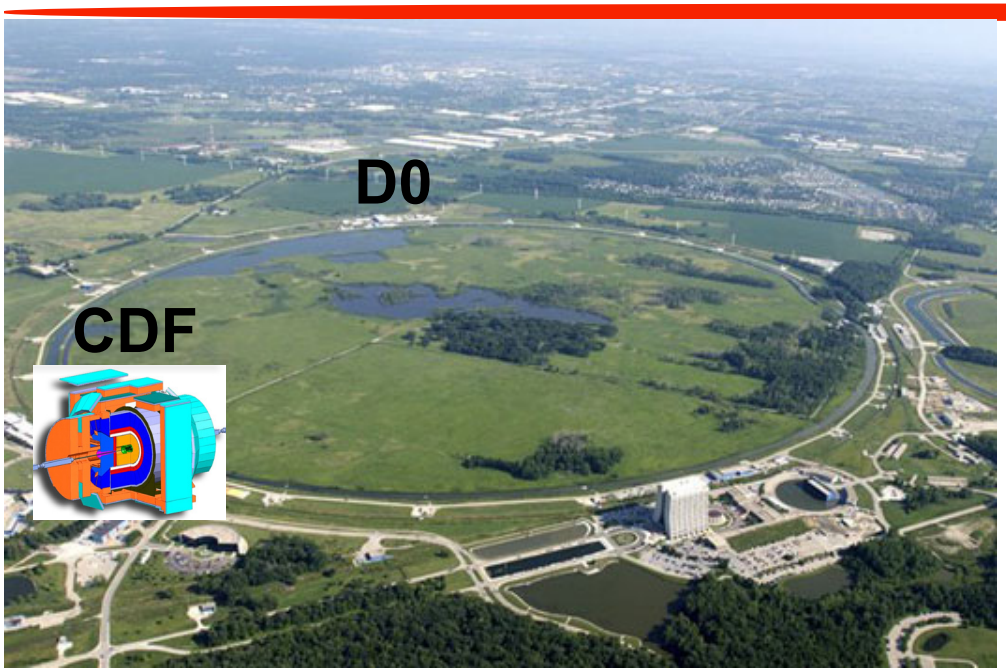
- We do not limit ourselves to just the RS model
- We are looking for a heavy particle that
  - Has spin 2
  - Has zero charge
  - Universal coupling to all known particles
- Given the conservation laws, the masses of the SM particles and their multiplicities due to flavor, color etc. we expect the following decay branching ratios for this particle:

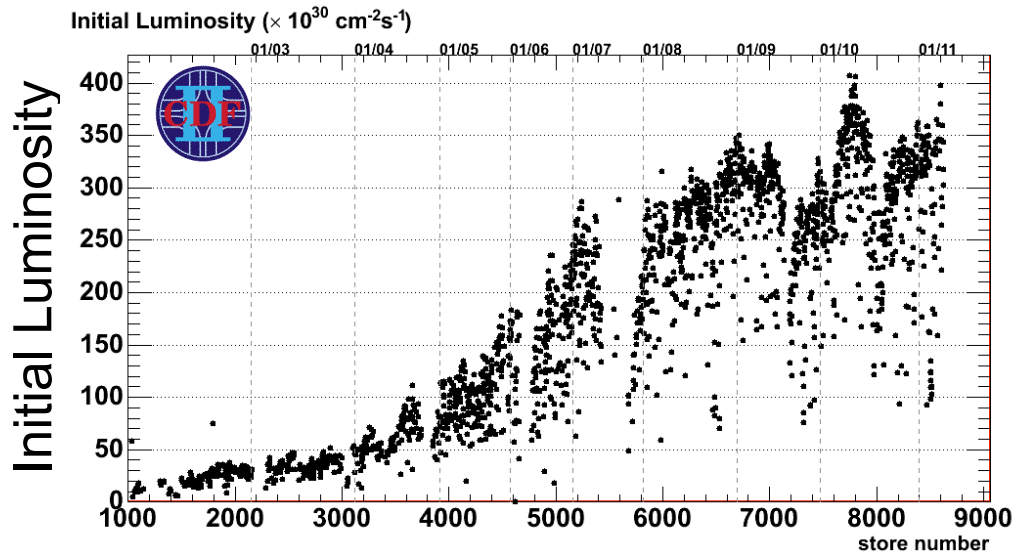


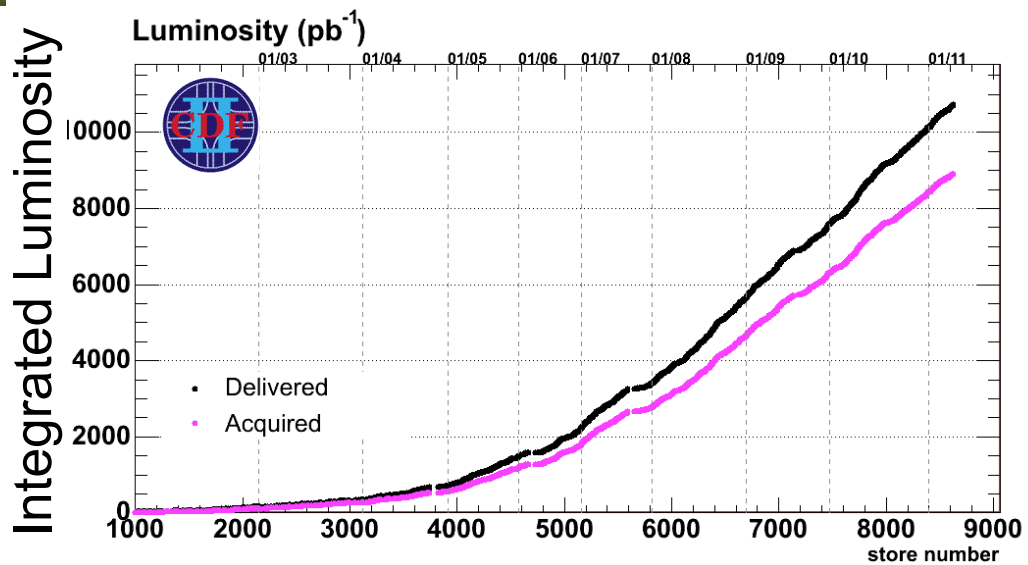
We are investigating here the γγ, ee, μμ decays, due to low hadronic and well-understood electroweak backgrounds

Allanach et al, JHEP, 12:039 (2002)

The Tevatron



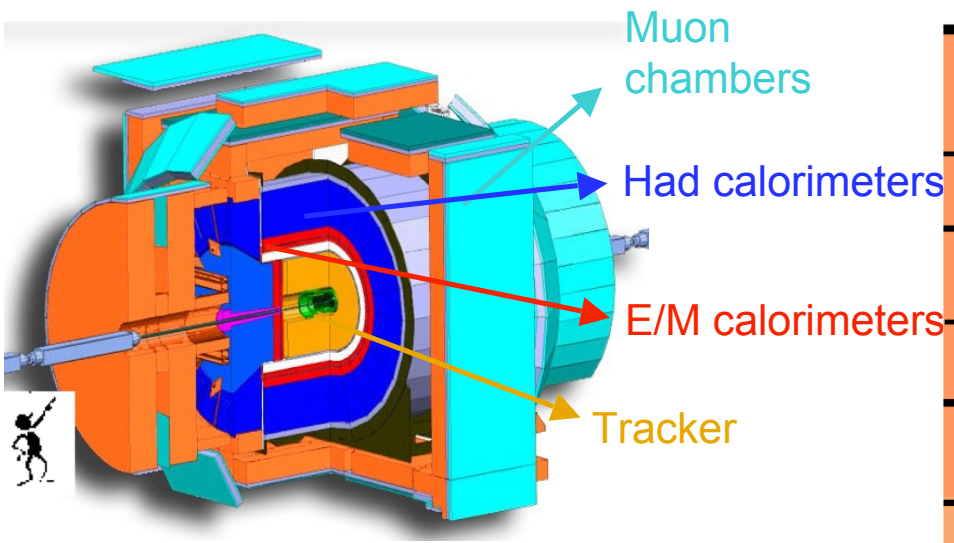




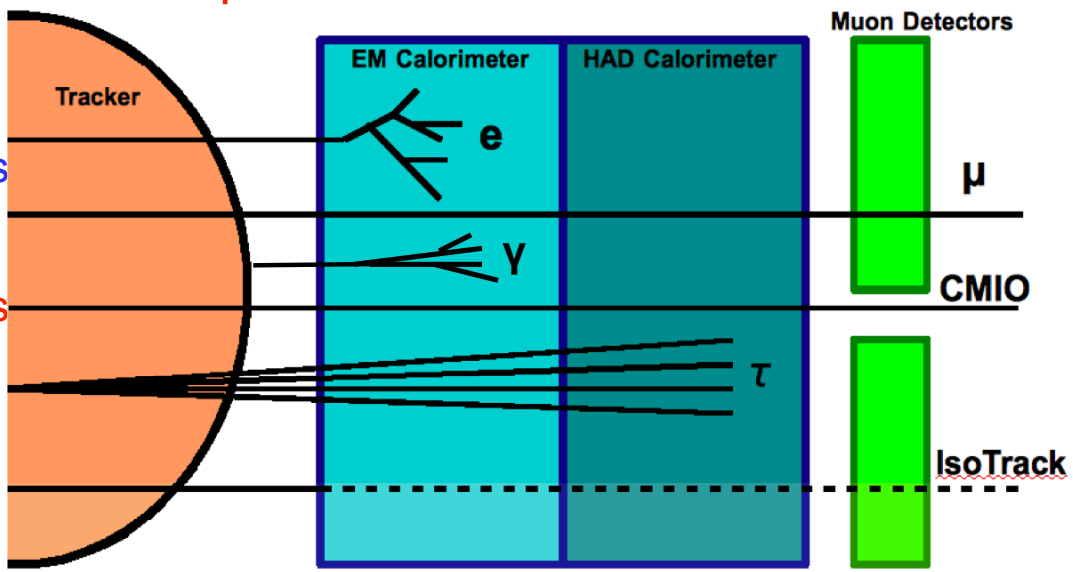
- Tevatron collides protons with antiprotons at 1.96 TeV center-of-mass energy
- Instantaneous luminosity:

  350-400 x 10^{30} cm^{-2} s^{-1}
- Delivered luminosity ~ 11 fb^{-1}
- Recorded luminosity: ~ 9 fb^{-1}
- **Presented in this talk up to 5.7 fb^{-1}**

The CDF II detector and lepton/photon identification



Leptons and Photons definitions

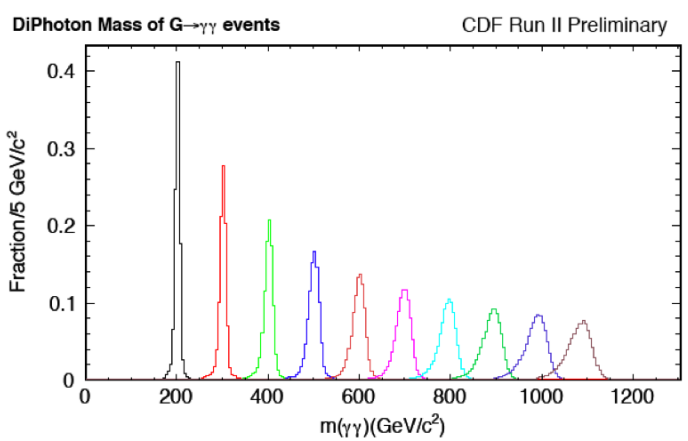


- Central tracker measures charged particle trajectories
- These trajectories are matched to calorimeter energy depositions and hits in muon chambers to reconstruct electrons and muons
- Photons deposit energy in the calorimeters without leaving signal in the tracker

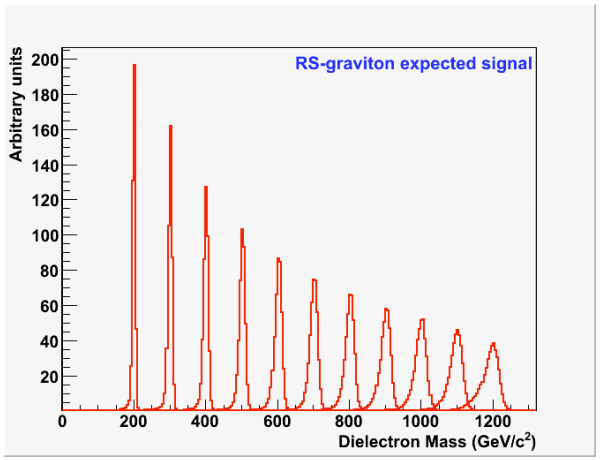
Graviton signal

- Graviton Monte-Carlo signal is generated with Pythia
- Production cross section is multiplied by K factors to account for next-to-leading order effects
  - K-factors are graviton-mass-dependent and calculated specifically for CDF by P. Mathews, V. Ravindran, and K. Sridhar
- The graviton diphoton or dilepton graviton spectrum will be smeared due to the detector resolution

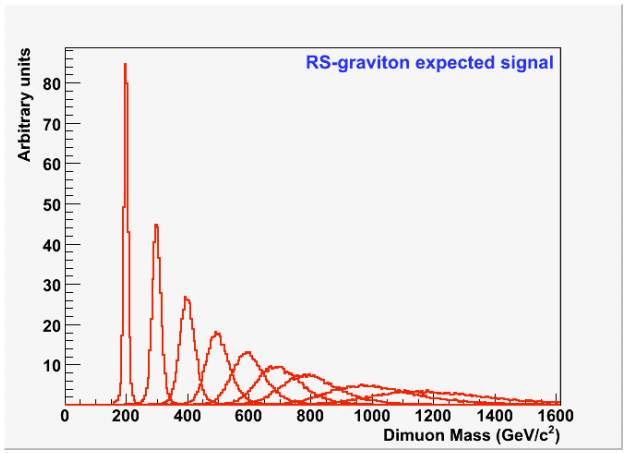
G → γγ



G → ee



G → μμ



Analysis strategy

- Confirm good understanding of γγ, ee and μμ mass spectra at low masses (<200 GeV/c^2)
- Study the tail of the above mass distributions (>200 GeV/c^2)
- If there is no evidence of new physics, set cross-section and graviton-mass limits for the three analyses
- Combine the 3 analyses to set the strongest RS-graviton limit

Setting limits

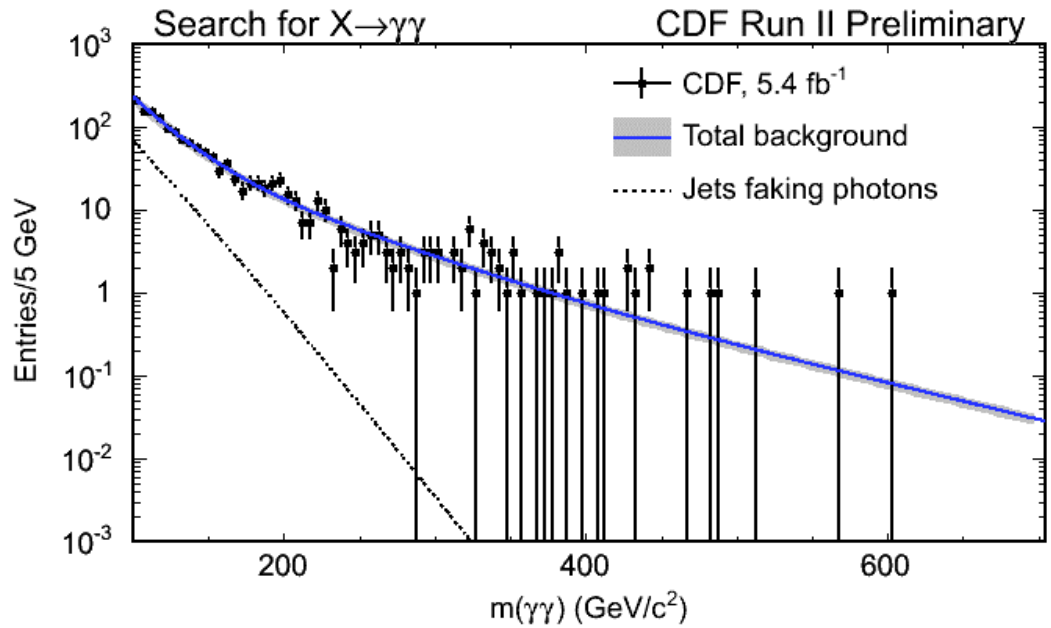
- We set cross-section limits as a function of graviton mass
  - Intersections with theoretical cross sections give us graviton-mass limits for different theory parameters

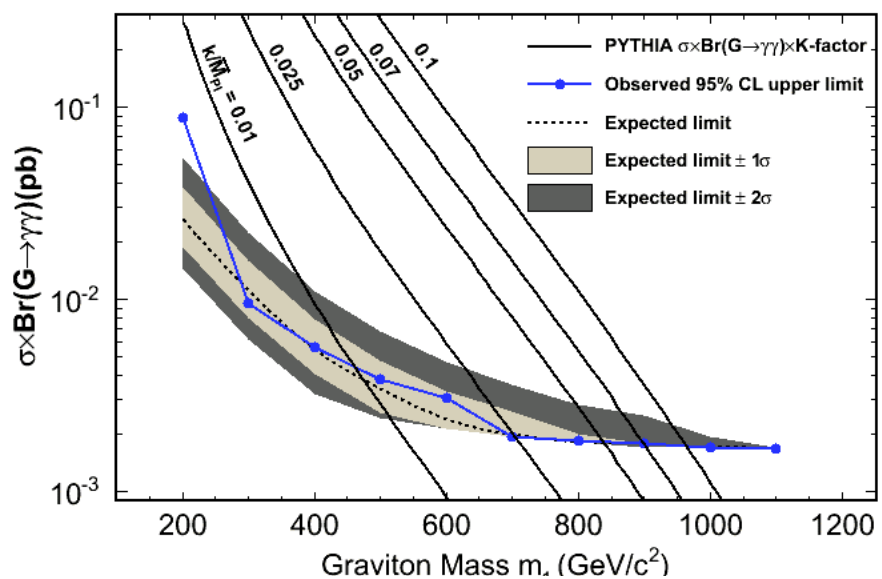
- The 95% CL cross section limit for each analysis is the signal cross section that gives CL_S=0.05, where $CL_S = P_{S+B}(\Delta\chi^2 \geq \Delta\chi^2_{obs}) / P_B(\Delta\chi^2 \geq \Delta\chi^2_{obs})$, and where the probabilities P_{S+B} and P_B are determined with pseudoexperiments for the background+signal and background hypotheses respectively (T. Junk, NIM A **434**, 435 (1999))

- The three analyses ($\gamma\gamma$, ee, $\mu\mu$) are combined as independent channels bound by a common Graviton signal production

Diphoton analysis

- **L = 5.4 fb^{-1}**
- Selection:
  - 2 photons E_T>15 GeV, |η|<1.1
  - Calorimeter and track isolation applied
- Main backgrounds:
  - Standard-Model diphotons
  - QCD: photon+jet(fake γ) and jet(fake γ) + jet(fake γ)
- Results:
  - Excellent agreement in diphoton mass spectrum
  - M_G>963 GeV/c^2 at 95% CL, for k/M_{PL} =0.1

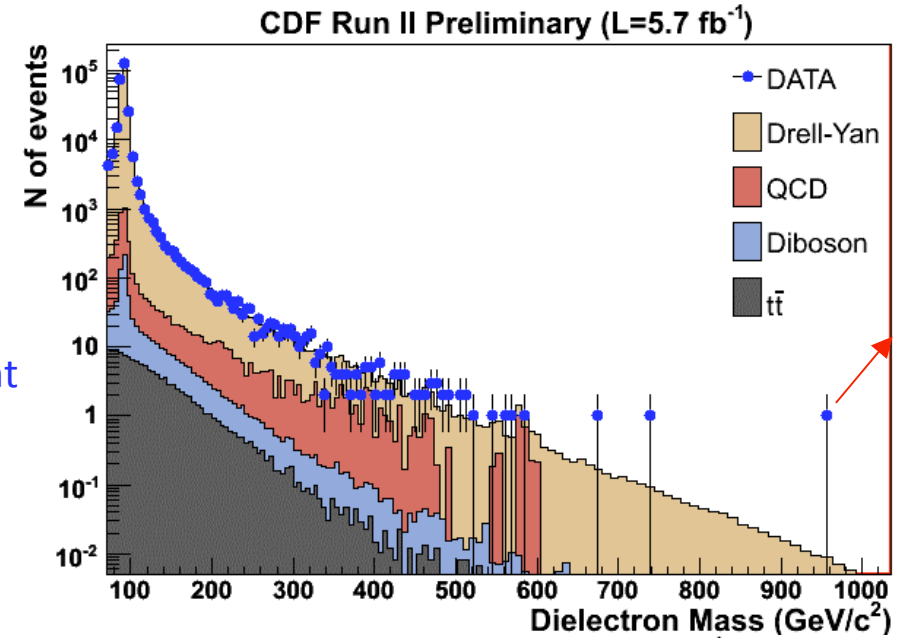




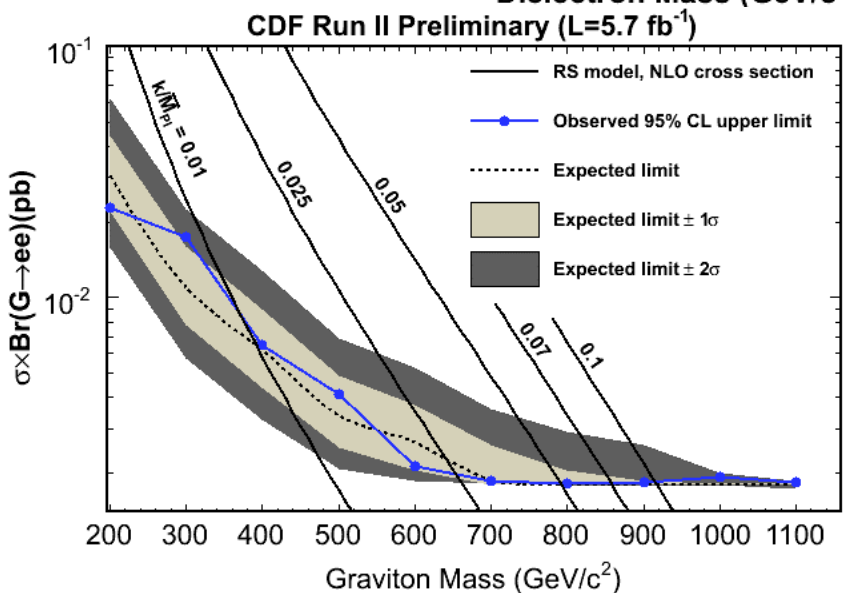
Phys.Rev.D **83**, 011102 (2011)

Dielectron analysis

- **L = 5.7 fb^{-1}**
- Selection:
  - 2 electrons (one $|\eta|<1$ $E_T > 20$ GeV)
  - Isolation and impact parameter applied
  - No opposite charge requirement
- Main backgrounds:
  - Drell-Yan to dielectrons
  - QCD: electron+jet(fake e)
  - Minor diboson, top
- Results:
  - Excellent agreement in dielectron mass spectrum
  - Observed the highest mass dielectron ever detected (probability to see ≥1 event with mass ≥ 960 GeV/c^2 is 4%)
  - M_G>914 GeV/c^2 at 95% CL, for k/M_{PL} =0.1

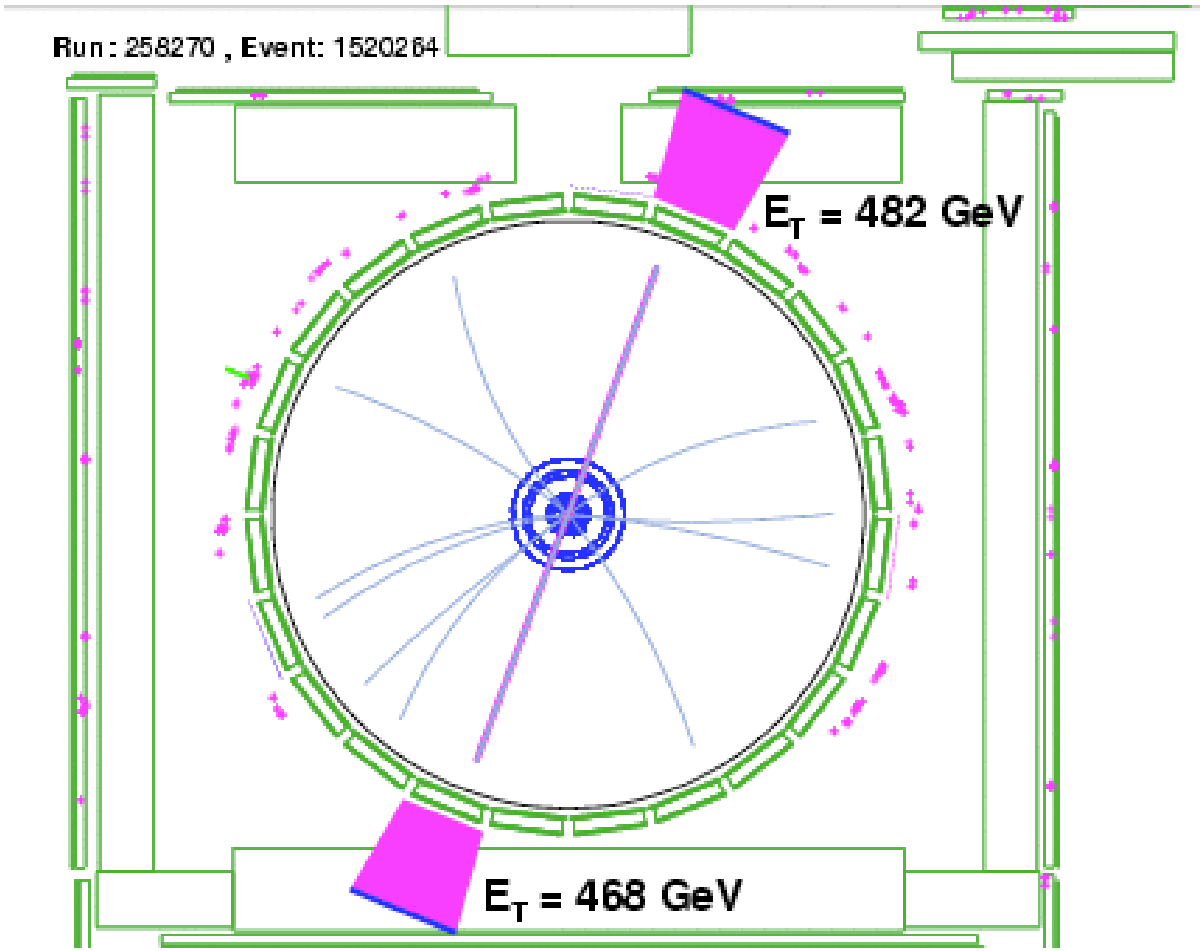


960 GeV/c^2 highest M_{ee} ever observed



arXiv:1103.4650 (submitted to PRL)

The highest dielectron mass

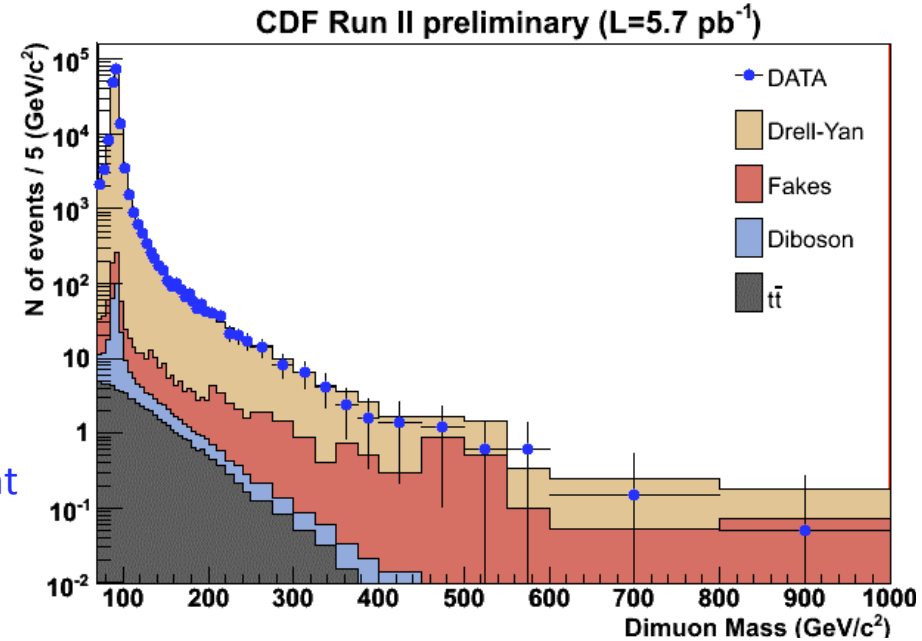


Tracks > 1 GeV/c shown

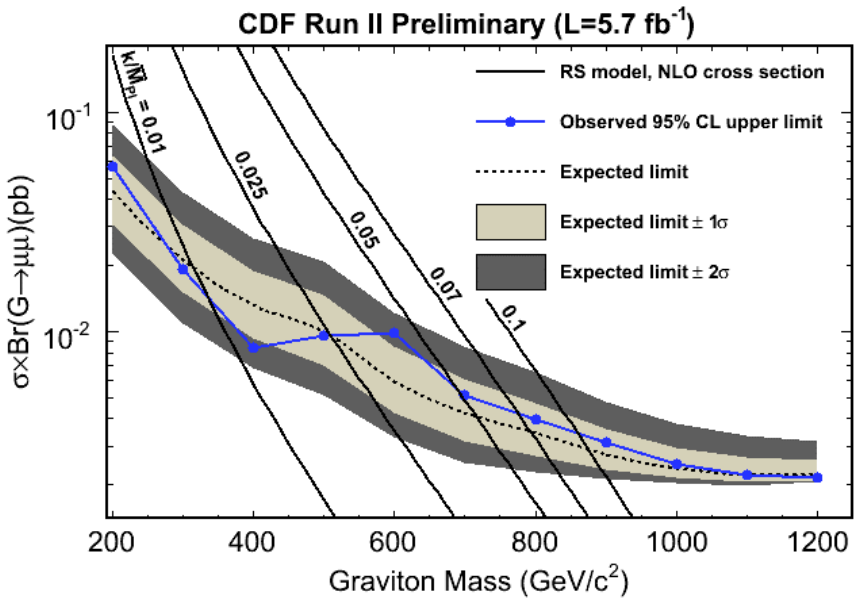
- Electrons oppositely charged
- Minimal missing transverse energy (17 GeV) 23 degrees away from the 468 GeV electron
- No jet activity

Dimuon analysis

- L = 5.7 fb^{-1}
- Selection:
  - 2 muons (one $|\eta|<1$) $p_T > 20$ GeV)
  - Isolation and impact parameter applied
  - Cosmic muons filter
  - No opposite charge requirement
- Main backgrounds:
  - Drell-Yan to dimuons
  - QCD: muon+track(fake μ)
  - Minor diboson, top
- Results:
  - Excellent agreement in dimuon mass spectrum
  - M_G>859 GeV/c^2 at 95% CL, for k/M_{PL} =0.1

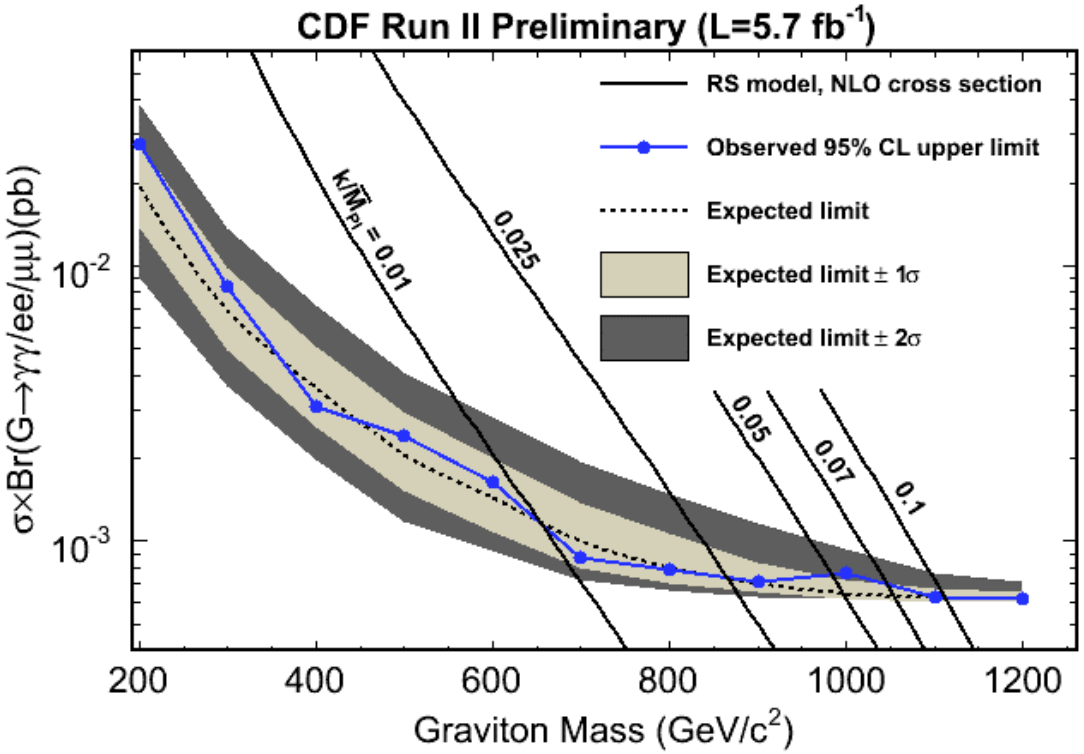


New



CDF public note 10479

Combined γγ+ee+μμ RS-graviton limit



New

CDF Run II Preliminary

$k/\overline{M}_{PL}$	Graviton Mass (GeV/c^2)
0.01	642
0.025	865
0.05	984
0.07	1046
0.1	1111

- M_G>1111 GeV/c^2 at 95% CL, for k/M_{PL} =0.1
- Currently the best RS-graviton limit in the world

CDF public note 10479

CMS: 1079 GeV/c^2
D0: 1050 GeV/c^2 (Phys. Rev. Lett **104**, 241802 (2010)

Conclusions

- We performed a search for Randall-Sundrum gravitons decaying to diphotons or dielectron or dimuons
- The γγ/ee/μμ mass spectra agree very well with Standard-Model prediction
- The combined γγ/ee/μμ analysis yields a 95% CL limit of M_G>1111 GeV/c^2
- We will continue updating the high-mass spectrum analyses to include more luminosity

Backup

Photon, electron selection cuts

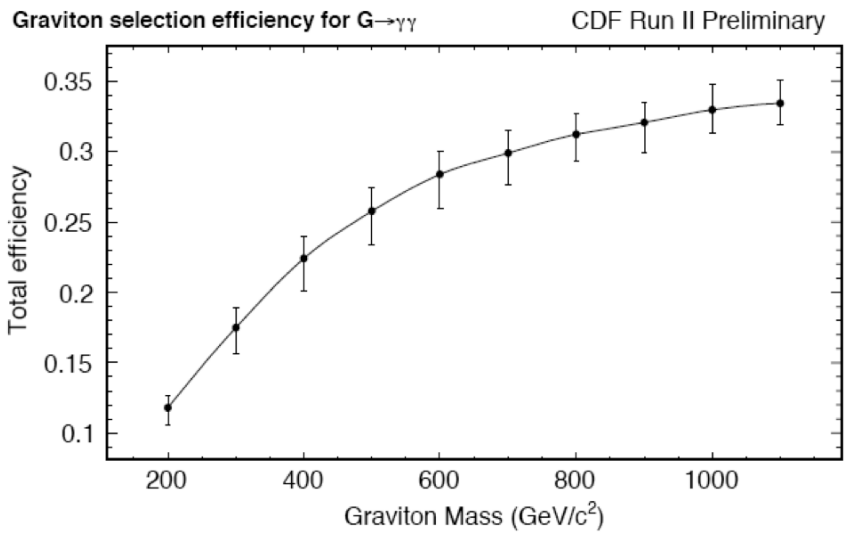
- PHOTON
  - Calorimeter fiduciality
  - Shower profile in calorimeter consistent with photon
  - HAD/EM < 0.055 +0.00045*E
  - Track veto: N of tracks in cluster ≤ 1
  - Calorimeter and track isolation <2 GeV

- ELECTRON
  - Calorimeter fiduciality
  - Shower profile in calorimeter consistent with electron
  - HAD/EM < 0.055 +0.00045*E
  - E/P <=2 for E<50 GeV
  - Tracking quality and matching with calorimeter
  - Impact parameter < 2(0.2) cm without (with) silicon tracking signals
  - Calorimeter isolation < 10%*E_T

Muon selection cuts

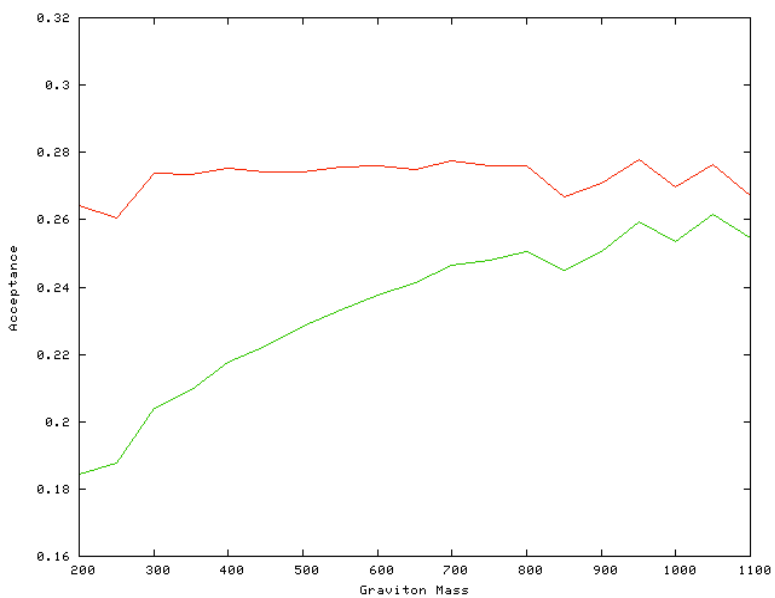
- MUON
  - Muon chamber fiduciality (although non-fiducial muons are used)
  - Electromagnetic calorimeter energy < 2 GeV (sliding)
  - Hadronic calorimeter energy < 6 GeV (sliding)
  - Tracking quality and matching with muon chambers (for fiducial muons)
  - Impact parameter < 2(0.2) cm without (with) silicon tracking signals
  - Calorimeter isolation < 10%*p_T

RS-graviton efficiency



→ **RS → γγ**

Only central photons



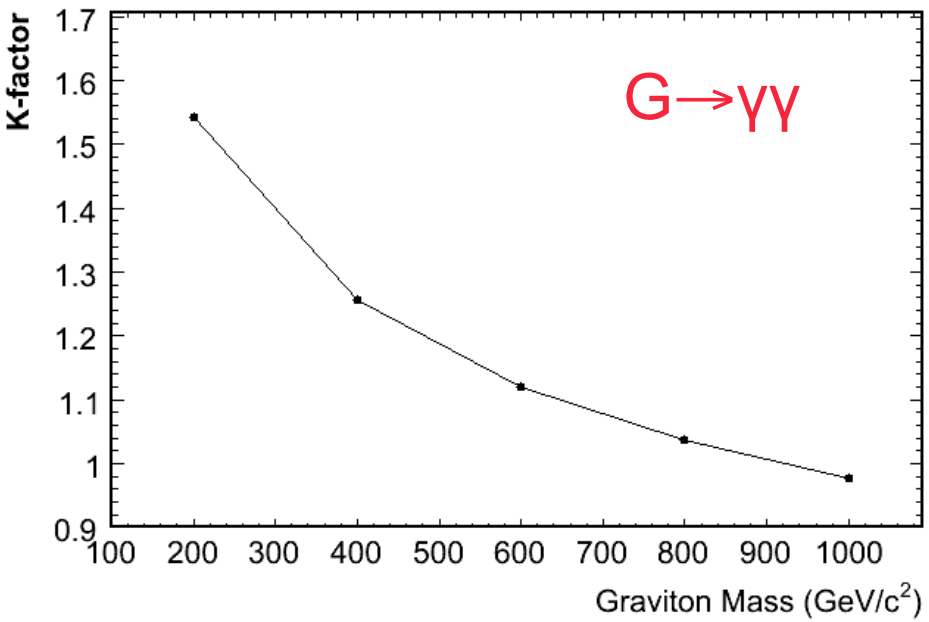
→ **RS → ee**

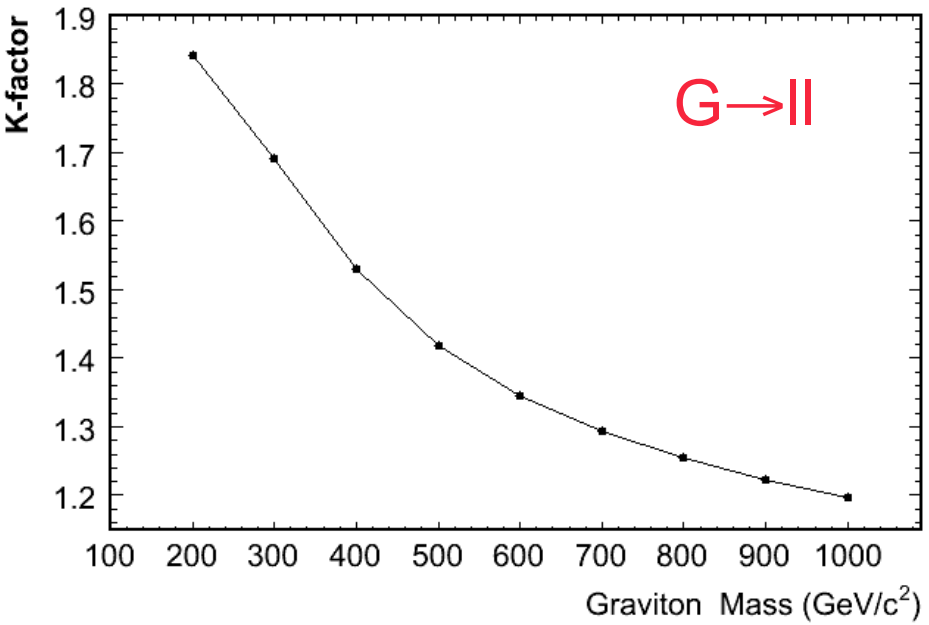
Red: central+forward objects

Green: Only central objects

- Using forward (|η|>1) objects improves the acceptance and makes it flat

K-factors





- Next-to-leading order K-factors strongly depend on Graviton mass
- P. Mathews, V. Ravindran, and K. Sridhar calculated the values for our parton distribution functions (CTEQ5L)

Fake leptons

- Due to the imperfect simulation of QCD processes (generation rates, isolation in hadronic environment etc.) we use CDF data for the determination of the QCD-induced background (fake dielectrons and fake dimuons)

- The determination of Fake dileptons takes place in two steps:
  - **Fake-rate measurement** (i.e., measurement of the probability that a jet fakes an electron or a track fakes an muon)
  - **Fake-rate application** (i.e., application of this probability to all fakeable jets and tracks in true CDF single-electron and single-muon events respectively)
  - Our denominators are isolated objects

- Due to the low values of the fake-rates (of the order of 10^{-2}), for us, dilepton fakes are events with one "real" identified lepton and one fakeable object (i.e., di-fakes are ignored)

Main systematic uncertainties

Dilepton analyses

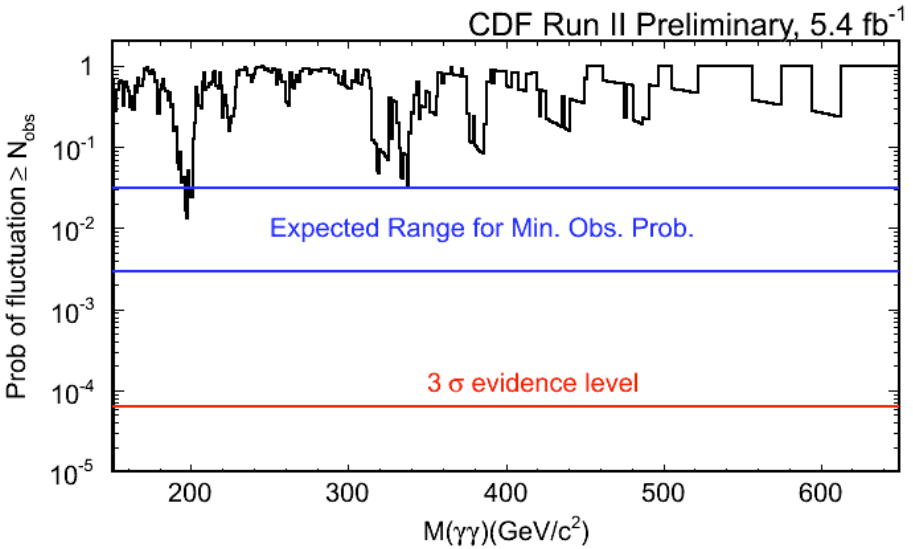
- PDF and Q^2
  - 3%
- Theoretical cross sections
  - 8%
- Luminosity
  - 6%
- Fake rates
  - 50% (for p_T>20 GeV/c)

Diphoton analysis

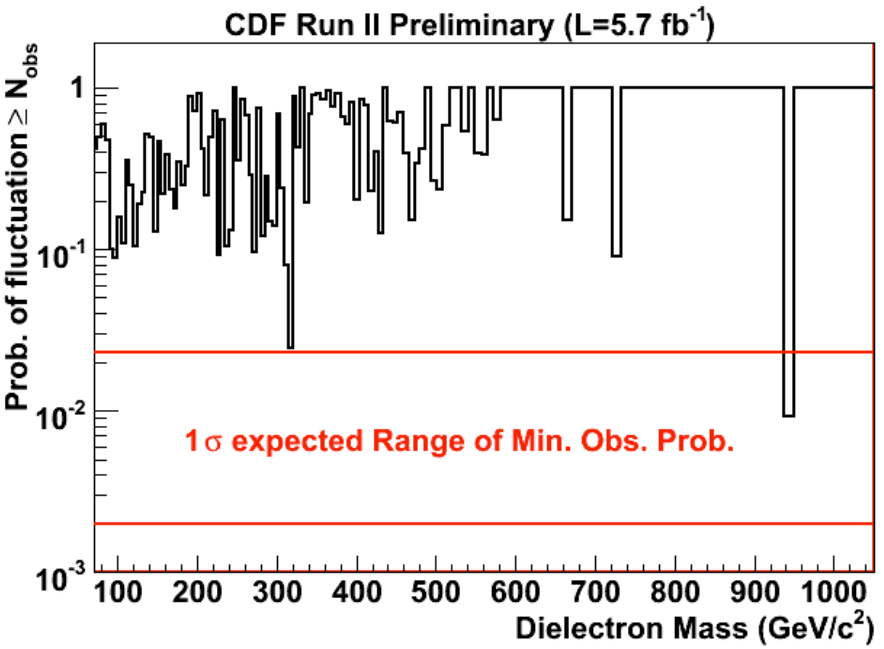
- PDF and Q^2
  - 5%-20% (low-high mass)
- ISR/FSR
  - 8-4% (low-high mass)
- Luminosity
  - 6%

p-values for γγ and ee analyses

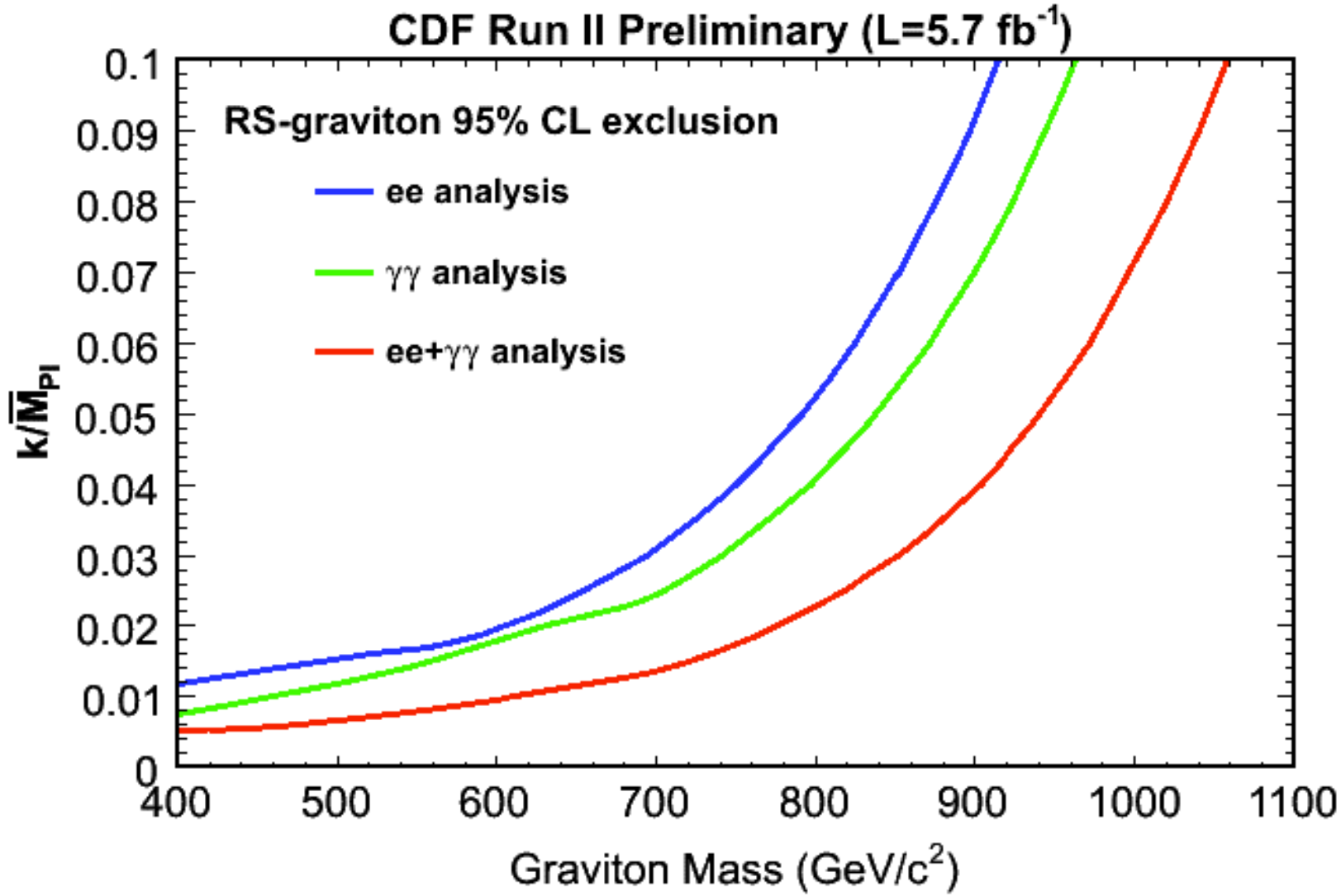
Diphoton



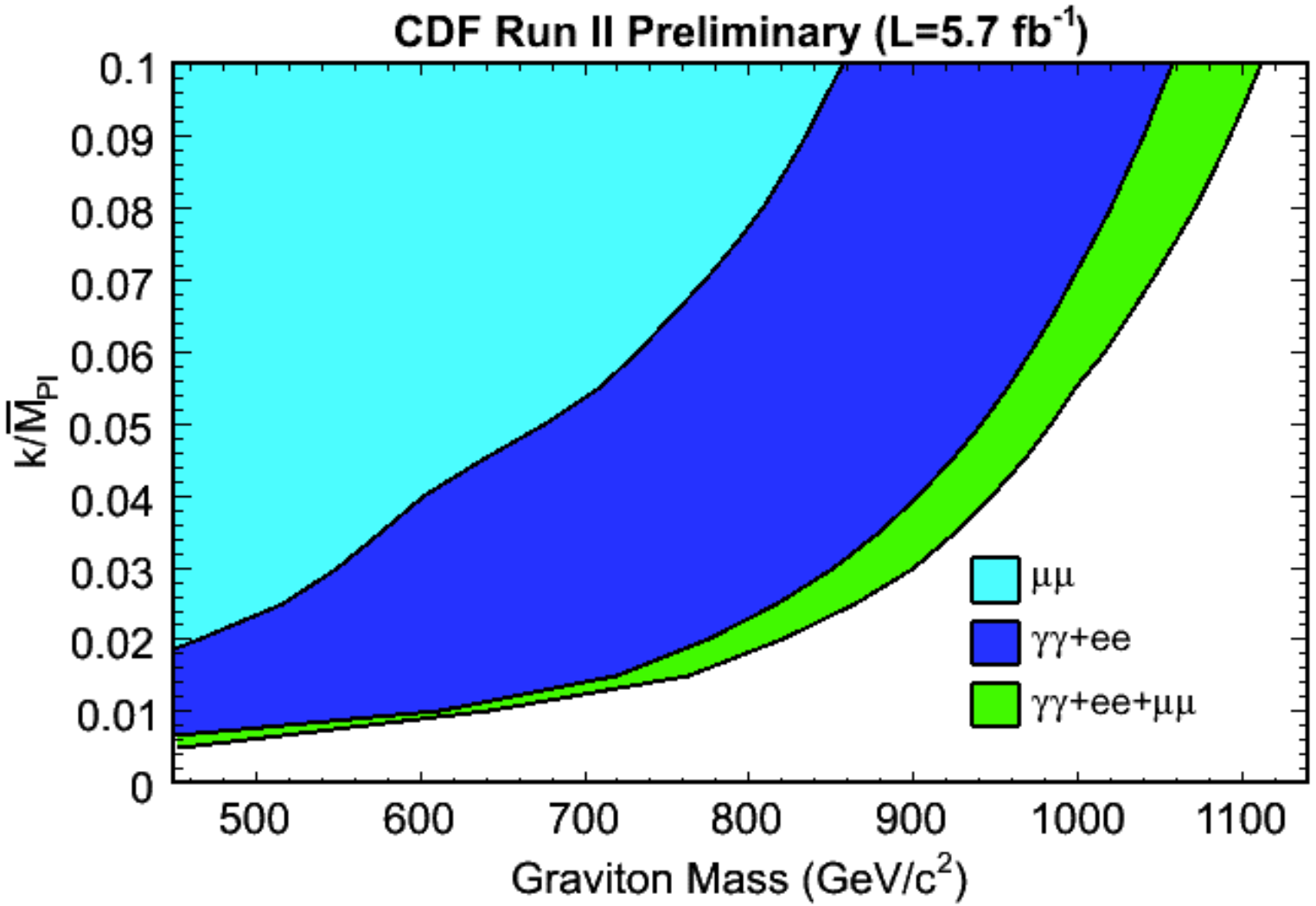
Dielectron



Improvement adding ee to γγ



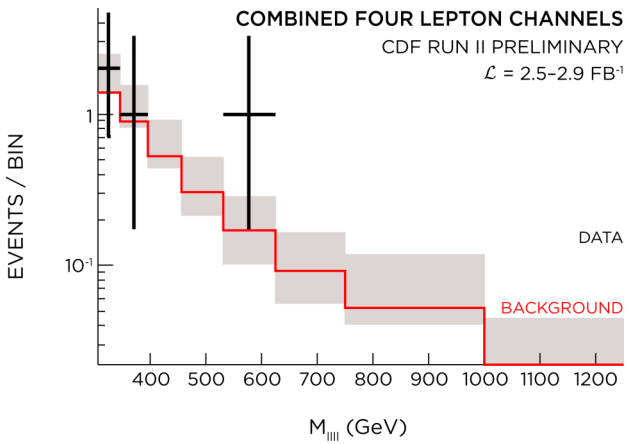
Improvement adding μμ to γγ+ee



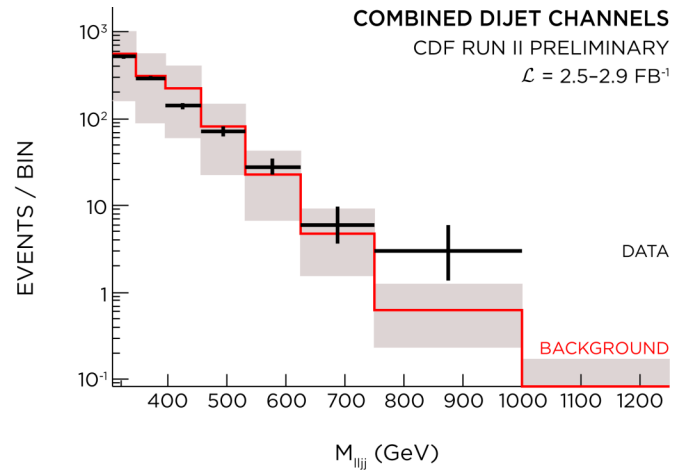
Search for gravitons in the ZZ channel

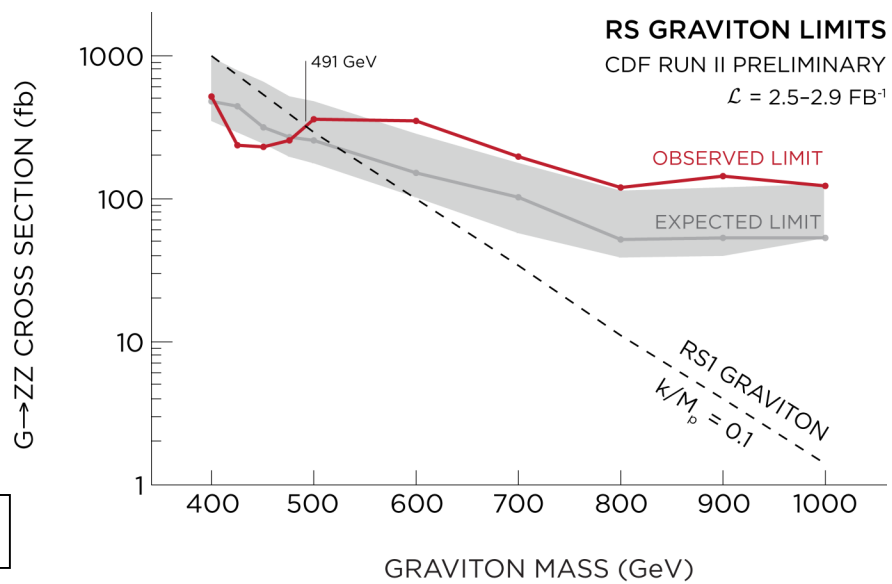
- $L = 3\ fb^{-1}$

4 leptons



2 leptons + 2 jets





M_G >491 GeV/c^2
for k/M_{PL} =0.1

CDF public note 9640