Probing Extra Space-Time Dimensions at the Tevatron

Laurent Duflot

LAL, Orsay

Marumi Kado

LBL, Berkeley

Tevatron Experimental Protocol

Proton-anti-proton collisions at Tevatron Run I:

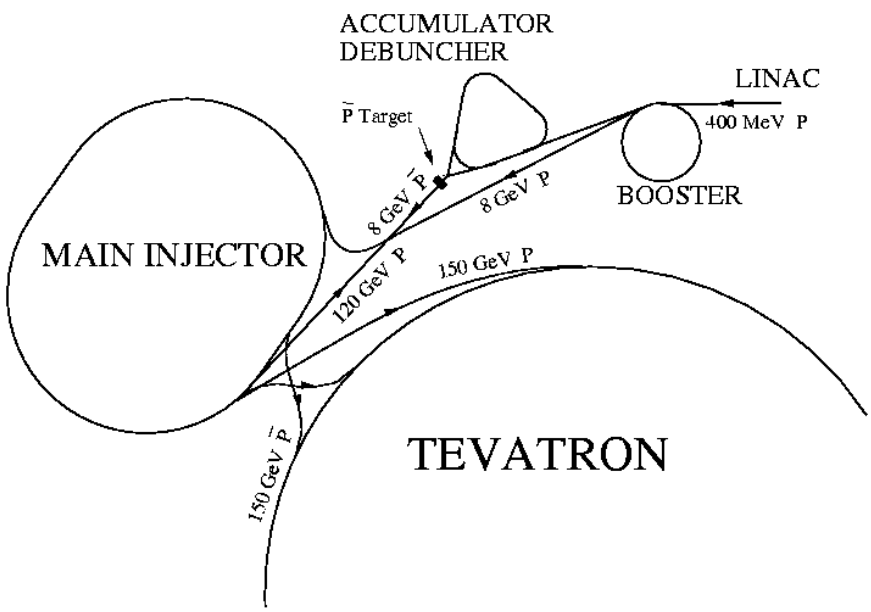
- Data taking period from 1992-1996
- $\sqrt{s} = 1.8 TeV$
- Average Peak Luminosity ~2.10^{31} $cm^{-2}s^{-1}$
- Collected Luminosity ~0.1 fb^{-1}

Run IIa and Run IIb upgrades:

- Data taking period started in spring 2001
- $\sqrt{s}=1.96TeV$
- Design average peak Luminosity:

  Run IIa ~9.10^{31} $cm^{-2}s^{-1}$ Run IIb ~5.10^{32} $cm^{-2}s^{-1}$
- Integrated Luminosities expected/Experiment:

  Run IIa $2fb^{-1}$, Run IIb $15fb^{-1}$



Upgrades:

- Booster
- Accumulator
- Cooling (use electron cooling at high intensities)
- Main injector
- Antiproton recycling

Tevatron Probes of Large Extra Spatial Dimensions (ADD)

Notations used (introduction by S. Riemann):

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

M_{Pl} (Plank mass), M_S (effective Planck mass),
R (compactification radius)

Similarly to LEP experiments (S. Riemann) Kaluza-Klein gravitons G_{KK} in ADD models can be probed either by:

1) direct G_{KK} emission in association with a Vector-boson

- EW-Gauge boson and missing Et. Similar to the LEP topology without the total missing energy constraint. Larger $\sqrt{s}$ but also larger backgrounds.

- Mono-jet topology, specific to Tevatron

or by

2) its virtual contribution to scattering processes resulting in (probing essentially $\sqrt{s}<M_S$):

- deviations in cross sections and asymmetries of standard model processes such as: $q\bar{q}' \rightarrow \ell^+\ell^-, \gamma\gamma$

- new processes such as: $gg \rightarrow \ell^+\ell^-$

CDF and DØ Experiments

Run I Detectors and Performances

CDF

Large Central Tracking Volume

$$\frac{\Delta p_T}{p_T} \approx (0.1\%) \times p_T \; (SVX + CTC)$$

Forward Muon spectrometer

Non-Spectrometric Central Muon

EM Calorimeter

$$\frac{\sigma_{EM}}{E} = \sqrt{\left(\frac{13.5\%}{\sqrt{E_T}}\right)^2 + (2\%)^2}$$

DØ

Hermetic Compensated Uranium Calorimeter

$$\frac{\sigma_{EM}}{E} = \frac{15\%}{\sqrt{E}} + 0.3\%$$

Iron Toroid Muon Spectrometer with Large Acceptance

$$\frac{\Delta p}{p} = 0.2 \oplus 0.003\, p$$

Non-Magnetic Tracking

Run II Upgrades

CDF

New inner tracking

New plug calorimeter

Upgraded muon detectors

New trigger and DAQ

DØ

New inner tracking with 2T superconducting solenoid

New preshowers

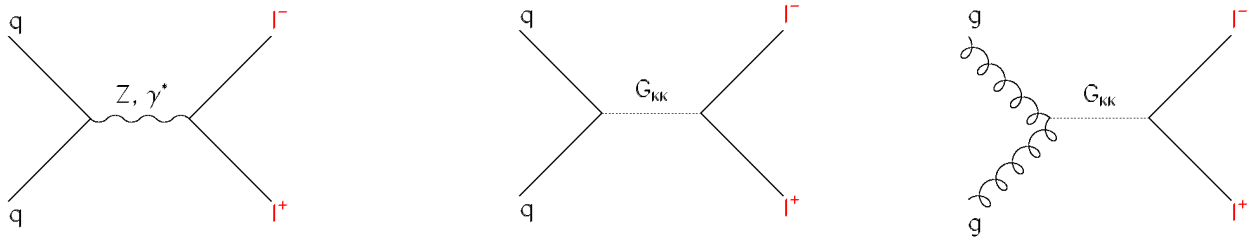
New trigger and DAQ

Virtual Kaluza-Klein Graviton Exchange

The case of di-lepton production:

- Standard model annihilation process interferes with the G_{KK} exchange additional process

- Production process through gluon fusion specific to KK Graviton exchange in the s-channel at hadron colliders

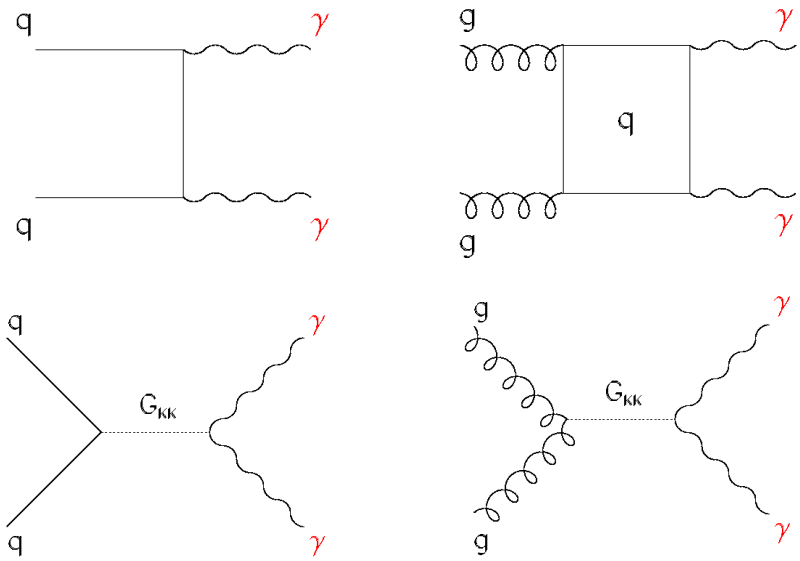


Standard model

Extra Dimension terms

The case of di-photon production:

- Standard model annihilation process interferes with the G_{KK} exchange additional process



Standard model

Extra Dimension terms

In both cases the calculation of the effective differential cross section requires an explicit cutoff (due to the divergence of the sum over KK states), naturally at M_S.

The effective cross section can be written:

$$\frac{\partial^2\sigma}{\partial\cos\theta^*\partial M_{\ell\ell,\gamma\gamma}} = \frac{\partial^2}{\partial\cos\theta^*\partial M_{\ell\ell,\gamma\gamma}}\left(\sigma_{SM} + \sigma_4\eta + \sigma_8\eta^2\right)$$

Where

$$\eta \equiv \frac{F}{M_S^4} \quad \text{and} \quad \begin{cases} \sigma_{SM} \equiv & \text{Standard model} \\ \sigma_4 \equiv & \text{Interference} \\ \sigma_8 \equiv & \text{Kaluza Klein} \end{cases}$$

Formalisms

Hewett: Neither interference sign (~λ) nor dependence on n_{ED}

$$F = \frac{2}{\pi}\lambda$$

GRW (Giudice-Rattazzi-Wells): interference sign specified, not the n_{ED} dependence

$$F \approx 1$$

HLZ (Han-Lykken-Zhang): Both interference sign of the I and the dependence on n_{ED} are accounted for

$$F = \begin{cases} \log\frac{M_S^2}{s} & \text{for } n = 2 \\ \frac{2}{n-2} & \text{for } n > 2 \end{cases}$$

Search in Inclusive Dielectron/Diphoton Production at DØ

Phys. Rev. Lett. ***86*** *1156 (2001)*

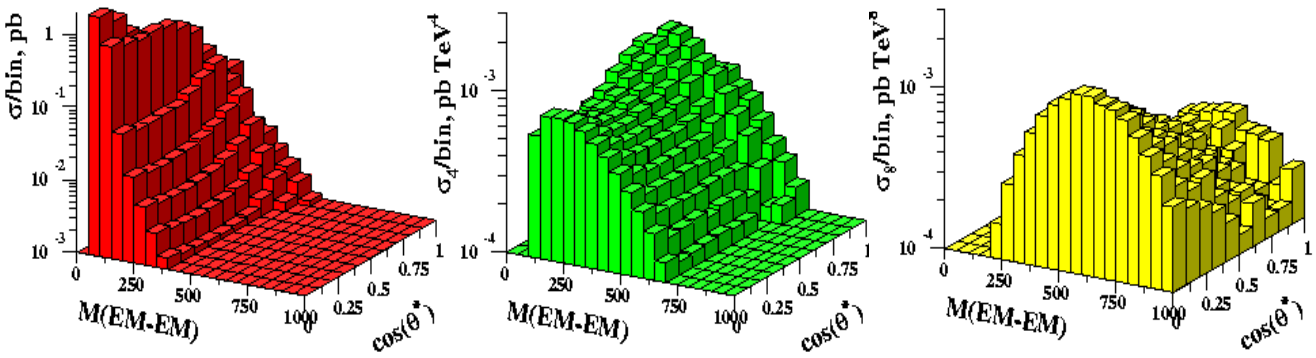
First search for Extra Dimensions at Tevatron

Why an inclusive Di-EM signature?

- Poor dimuon mass resolution at high mass
- Combining dielectrons and diphoton signatures maximizes the discovery potential

Signal simulation

- Cheung-Landsberg LO parton level generator
- CTEQ4-LO parton distribution functions
- NLO effects:
  - ISR effect simulation from Drell-Yan measurement
  - Use Drell-Yan K factor (1.3) for both SM and signal processes



Standard model Interference KK Graviton

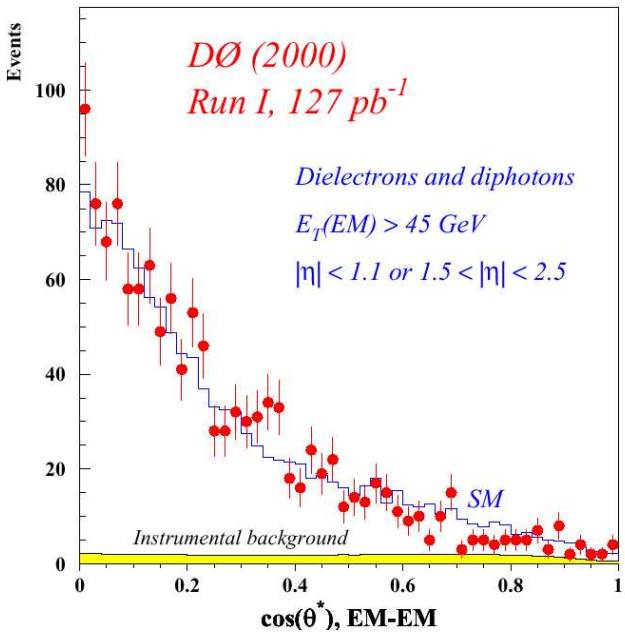
Main Backgrounds

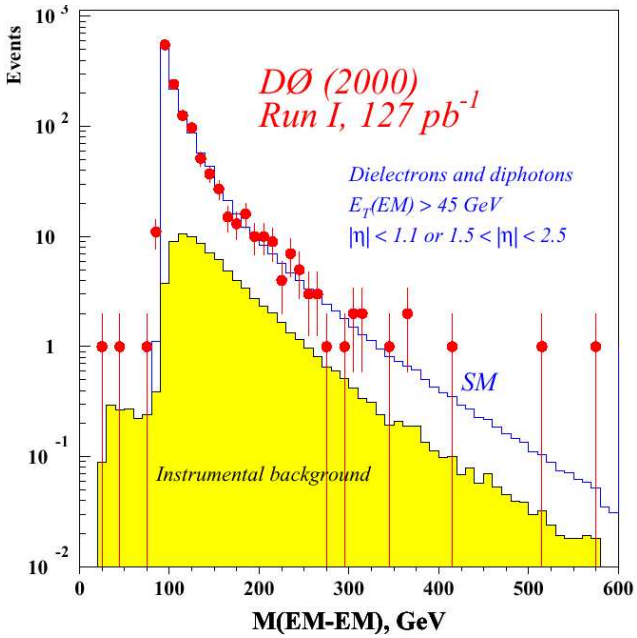
- Drell-Yan (determined from Monte Carlo)
- Instrumental Background from QCD and Compton-QCD events with jet fragmentation to leading π^o (determined from data)

Other Backgrounds (negligible)

- W-plus-jets (jet $\rightarrow$ leading π^o)	$< 0.4\%$
- WW	$< 0.1\%$
- top	$< 0.1\%$
- $Z \rightarrow \tau\tau$	$< 0.01\%$
- $Z\gamma$	$< 0.01\%$

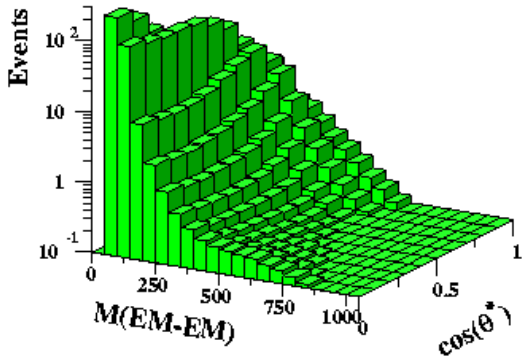
Good agreement Data/Monte Carlo…



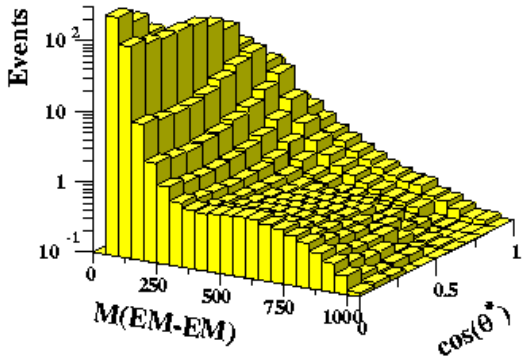


... No deviations observed.

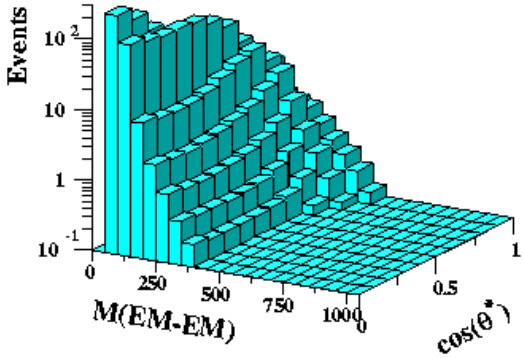
Two-dimensional Data-Monte Carlo comparison:



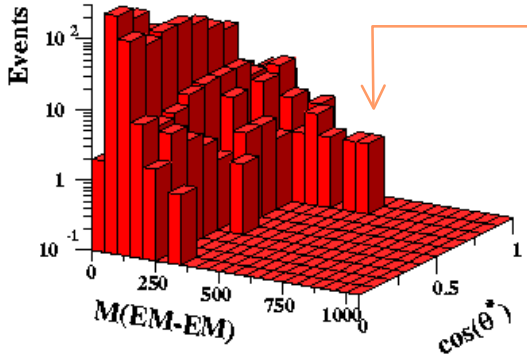
SM+ED signal, $M_S = 1$ TeV, $n = 4$



SM+ED signal, $M_S = 1$ TeV, $n = 3$



Total background



Data

Two interesting events, likely due to QCD background

Systematic uncertainties taken into account:

Source	K-Factor	PDF	⇩Ldt	Efficiency	Overall
Uncertainty	10%	5%	4%	3%	12%

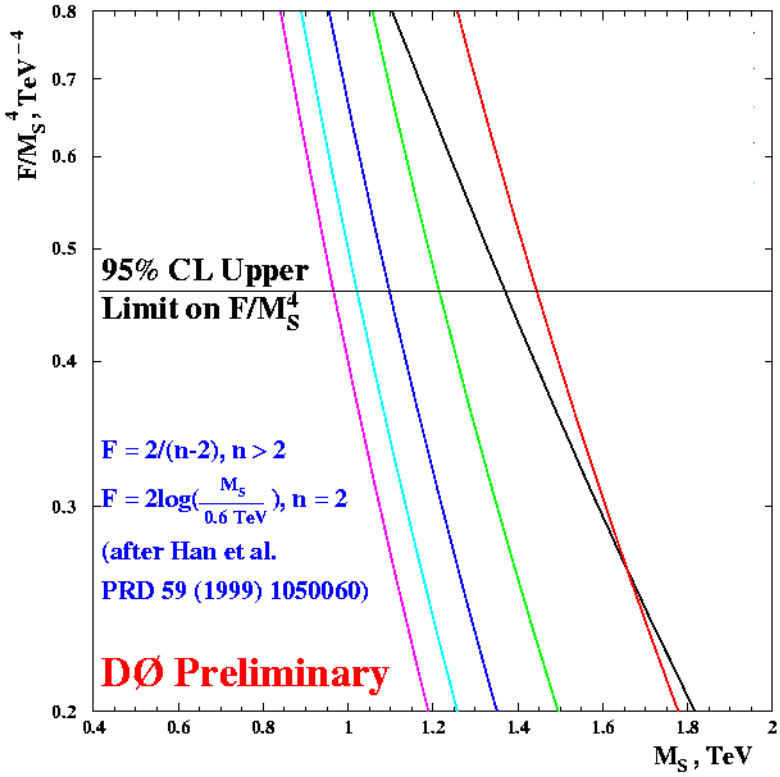
Interpretation of the Result

Combine the information from the $\cos\theta^*$ and invariant mass distributions in a two-dimensional binned likelihood taking systematic uncertainties into account

In the HLZ formalism:

- For n_{ED}>2, M_S limit directly derived from limit on η

- For n_{ED}=2 take an average s: $\langle s \rangle \approx 0.36\ TeV^2$



N_{ED}	M_S limit (TeV)
2	1.37
3	1.44
4	1.21
5	1.10
6	1.02
7	0.97

In the Hewett formalism:

$$\begin{cases} M_S > 1.1\,TeV\ (\lambda = +1) \\ M_S > 1.0\,TeV\ (\lambda = -1) \end{cases}$$

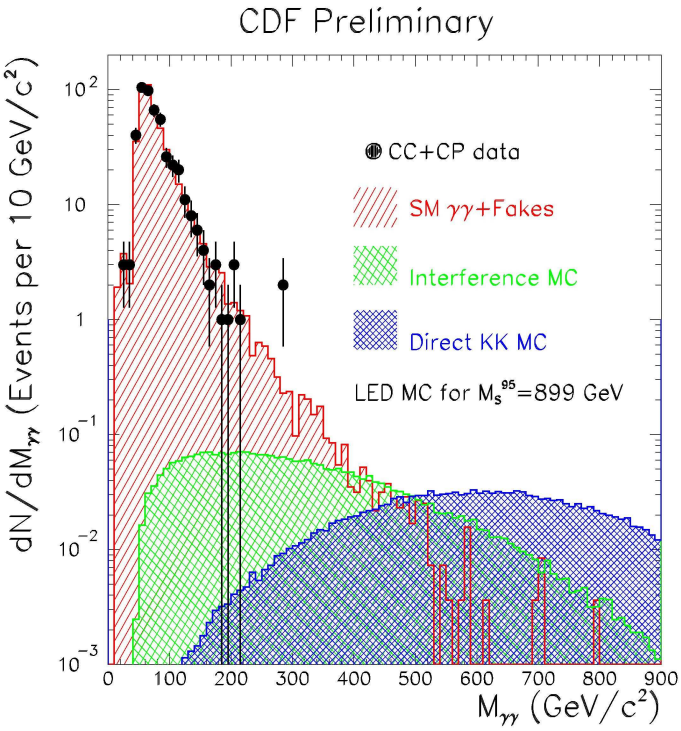
In the GRW formalism:

$$M_S > 1.2\,TeV$$

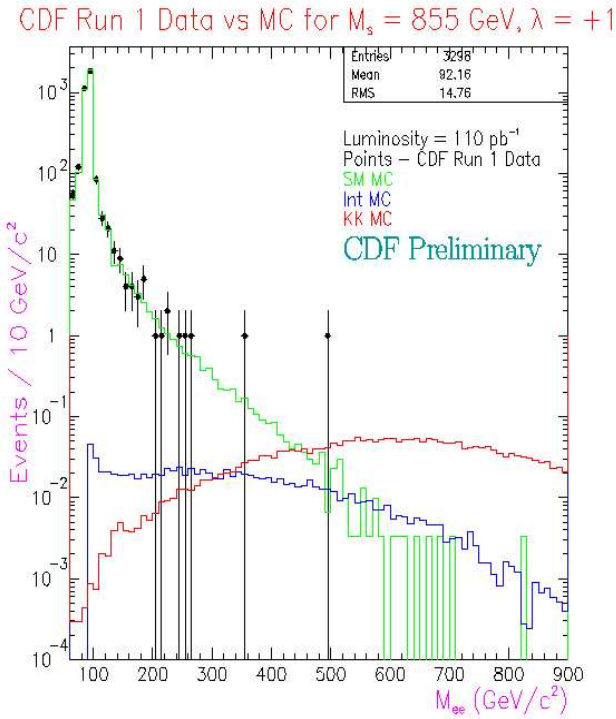
Search in Exclusive Dielectron/Diphoton Production at CDF

Taking advantage of the magnetic field information, to improve the purity of the Dielectron channel

Diphoton mass spectrum



Dielectron mass spectrum



Data in agreement with SM

Limits on M_S (Hewett formalism):

Unbinned likelihood fit to invariant mass distributions

Diphoton: M_S > 0.797 TeV (λ=-1), 0.899 TeV (λ=+1)

Dielectron: M_S > 0.808 TeV (λ=-1), 0.826 TeV (λ=+1)

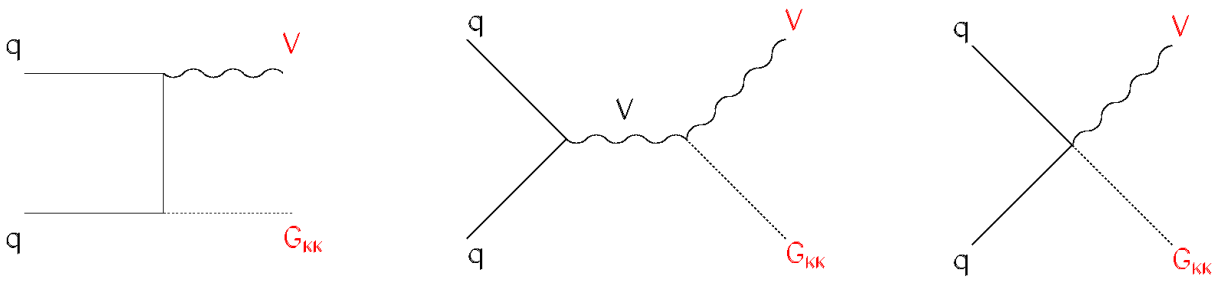
Combination:

***M_S > 0.853 TeV** (λ=-1) and **0.939 TeV** (λ=+1)*

Real Kaluza-Klein Graviton Emission

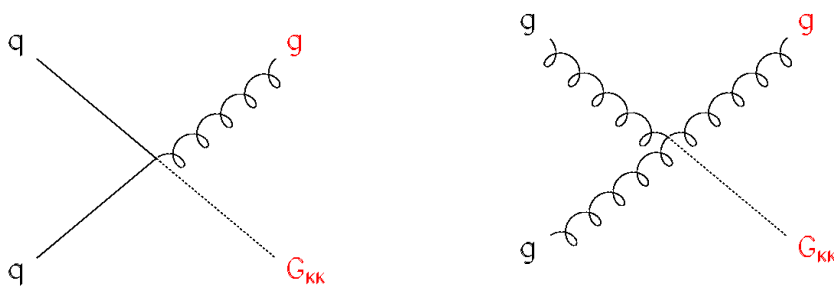
Real G_{KK} emission in association with a Vector-boson signatures :

- EW-Gauge boson (V) and missing Et. Similar to the LEP topology without the total missing energy constraint. Larger $\sqrt{s}$ but also larger backgrounds.



KK Graviton's signature: missing (transverse) energy

- Mono-jet topology: Topology specific to Tevatron, which takes advantage the two production processes:



KK Graviton's signature: missing (transverse) energy

The DØ mono Jet Search

Search Selection (performed on ~80pb^{-1})

One or two 0.5 cone jets

Missing $E_T > 150$ GeV

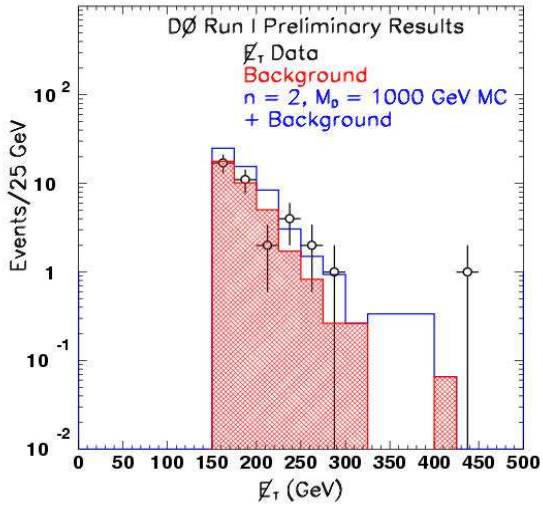
Leading Jet: $E_T > 150$ GeV, $|\eta| < 1.0$

Second Jet: $E_T < 50$ GeV, not pointing at missing E_T

to Suppress QCD background

Result

From Ws and Zs	$= 30 \pm 4$
From QCD & Cosmics	$= 8 \pm 7$
Total	$= 38 \pm 8$
Observed events	$= 38$



Limits

$n=4$ $M_S>698$ GeV

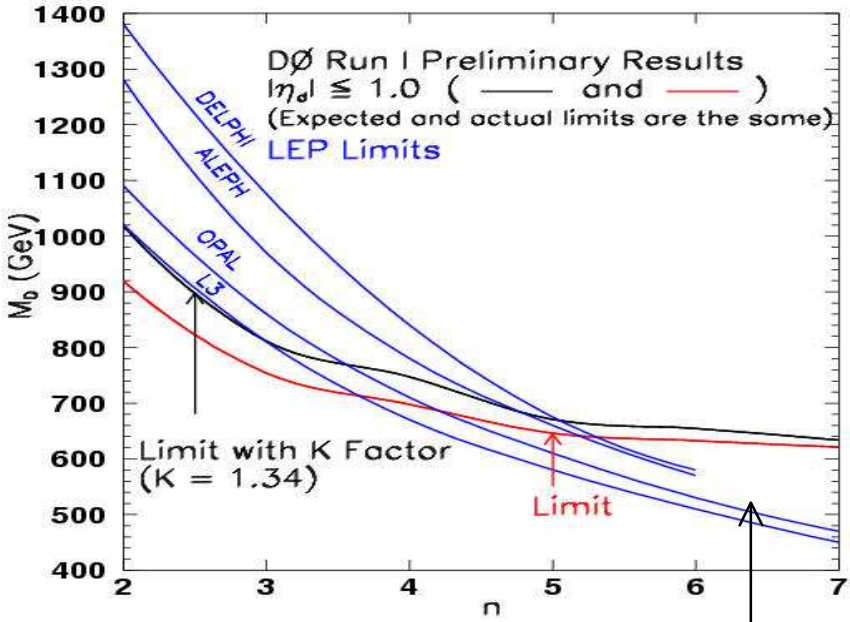
$n=6$ $M_S>632$ GeV

Delphi:

$n=4$ $M_S>840$ GeV

$n=6$ $M_S>580$ GeV

Improvement at large n



The CDF Single Photon-plus-Missing-Energy Search

hep-ex/0205057 submitted to Phys. Rev. Lett.

Search Selection (Performed on ~87pb^{-1})

One photon with Transverse energy in excess of 55 GeV and within the pseudo-rapidity range $|\eta^{\gamma}| < 1$

Missing $E_T > 45$ GeV

No jets with $E_T > 15$ GeV

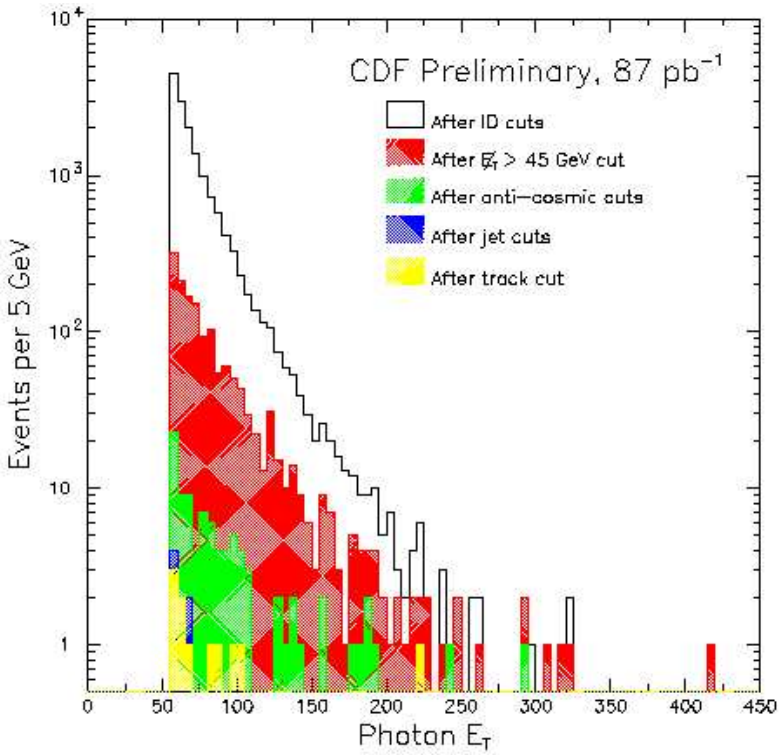
No tracks with $p_T > 5$ GeV

Result

- Background estimate = 11 ± 2
- Observed events = 11

Background dominated (~60%) by **Cosmic rays** where a muon undergoes a brehmsstrahlung in the CEM

Second most prolific background (30%) $Z\gamma \rightarrow \nu\nu\gamma$



Limits

$n=4$ $M_S > 550$ GeV

$n=6$ $M_S > 580$ GeV

$n=8$ $M_S > 600$ GeV

Warped Extra Dimension (RS)

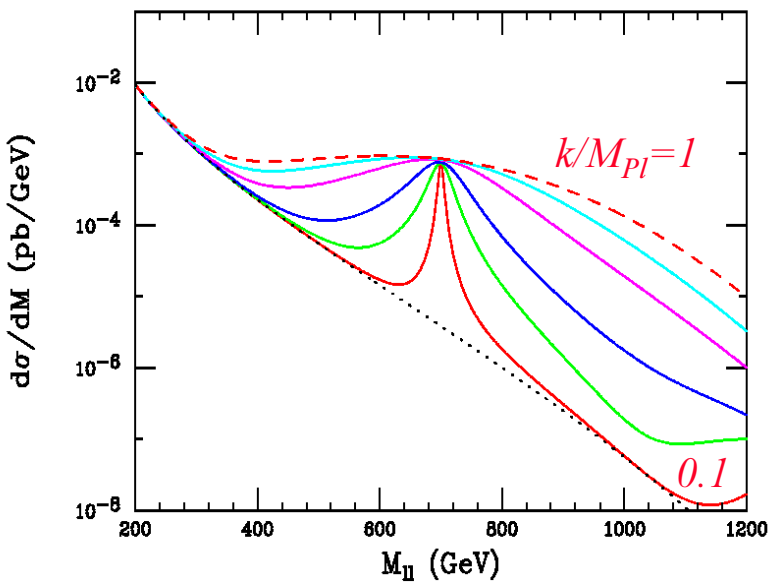
Davoudiasl, Hewett and Rizzo Phys.Rev.D63,2001

Hierarchy problem solved with a single extra dimension in a 5-dimensional Anti-de-Sitter space (AdS_5) with metric

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

Tevatron Phenomenology:

- *Resonant production of Kaluza-Klein gravitons*
- *All parameters of the model can be derived from the measurement of the width and location of the first Kaluza-Klein excitation with mass m_1*



Deviations to the dilepton Drell-Yan differential cross section due to a 700 GeV/c^2 KK graviton for different values of k/M_{Pl}

Using Tevatron Drell-Yan and dijet data from Run I exclude large values of k/M_{Pl} for values of m_1 within kinematic reach (e.g. for $k/M_{Pl} \sim 0.1$, $m_1 > 0.6$ TeV/c^2)

Run II Prospects

Current sensitivities are mostly limited by statistics

At Run II, with an increase in centre-of-mass energy from 1.8 TeV to 2 TeV and a significant increase in Luminosity, sensitivities improve:

Limits on the gravity scale in ADD models

Run IIa: M_S sensitivity ~doubles w.r.t. Run I

Run IIb: M_S sensitivity ~triples w.r.t. Run I

Other final states (e.g. with muons) may be searched for

Warped extra dimensions

With the Run IIa luminosity, the sensitivity to a first resonance is expected to reach up to $m_1 \sim 1.1$ TeV/c^2

Status of Run II

Status as of June 2002:

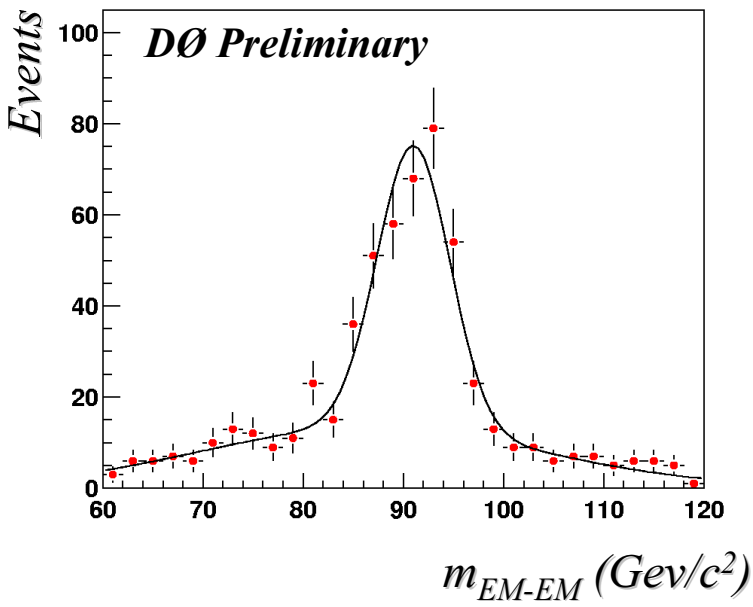
- Highest Peak Luminosity reached ~ 2.10^{31} $cm^{-2}s^{-1}$
- Luminosity delivered so far ~ 50 pb^{-1}/Experiment
- Luminosity for physics ~15 -35 pb^{-1}/Experiment

Status of the CDF and D0 detectors:

Detectors still in commission phase, mainly ready for physics

First PreliminaryResults

See talks by A. Goussiou, M. Wegner and C. Elvezio Pagliarone



Inclusive Di-EM invariant mass spectrum with the observation… of a well known resonance

Conclusions and Outlook

The CDF and DØ experiments at Tevatron Run I have performed searches for signs of extra spatial dimensions

In none of the channels searched for has any sign of a deviation from the background expectation been observed

Limits, of the same order of magnitude as those derived at LEP, on the gravity scale have been set ~O(800 GeV/c^2)

The Tevatron Run II program has successfully started with a promising observation potential

New exciting results should come soon