RS-1 Graviton Diphoton Decay Study and Results

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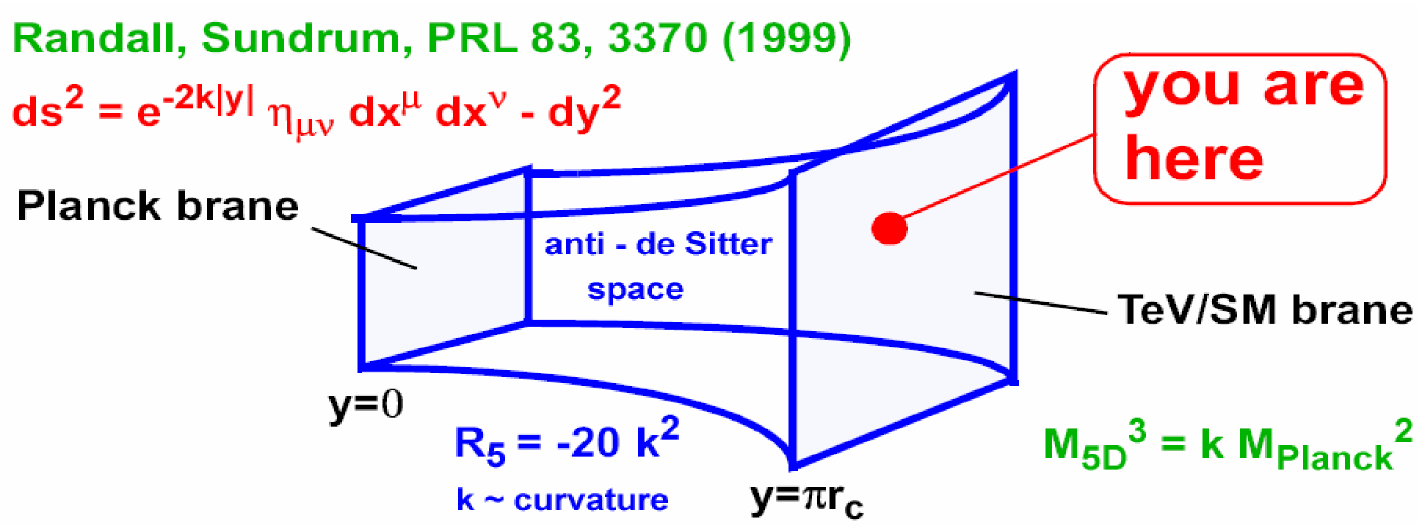
Randall –Sundrum model



Gravity scale $\Lambda_\pi = M_{Planck} \exp(-k\pi r_c)$ ~TeV for kr_c ~11-12 no hierarchy

Graviton resonances $m_n = x_n k \exp(-k\pi r_c)$, $J_1(x_n)=0$

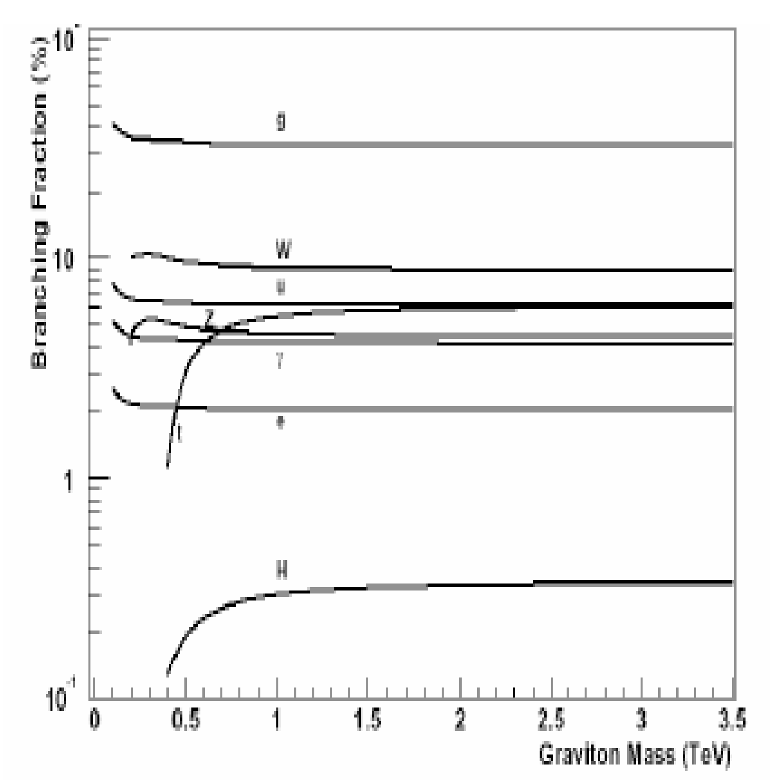
Two parameters control the properties of the RS model: the mass of the graviton m_G and the constant $c=k/M_{Planck}$ determining the graviton couplings and widths

$$\Gamma_n = \rho\, m_n x_n^2 (k/M_{Planck})^2$$

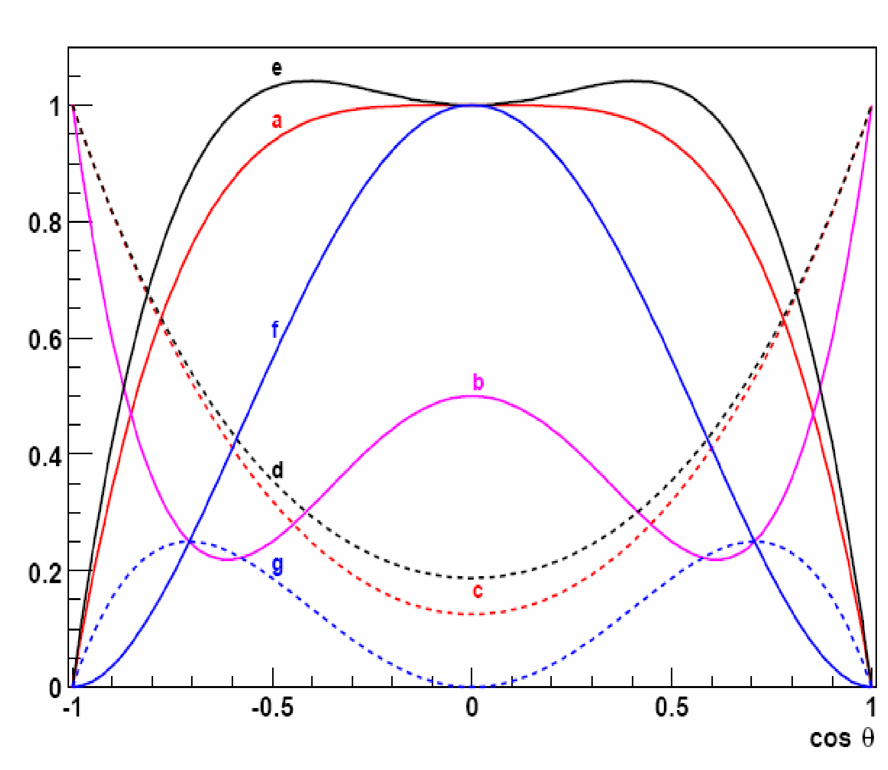
Stabilization needs to introduce a scalar field, the radion which generally mixes with the Higgs

Randall-Sundrum Graviton properties

Branching Ratios



Angular Distributions

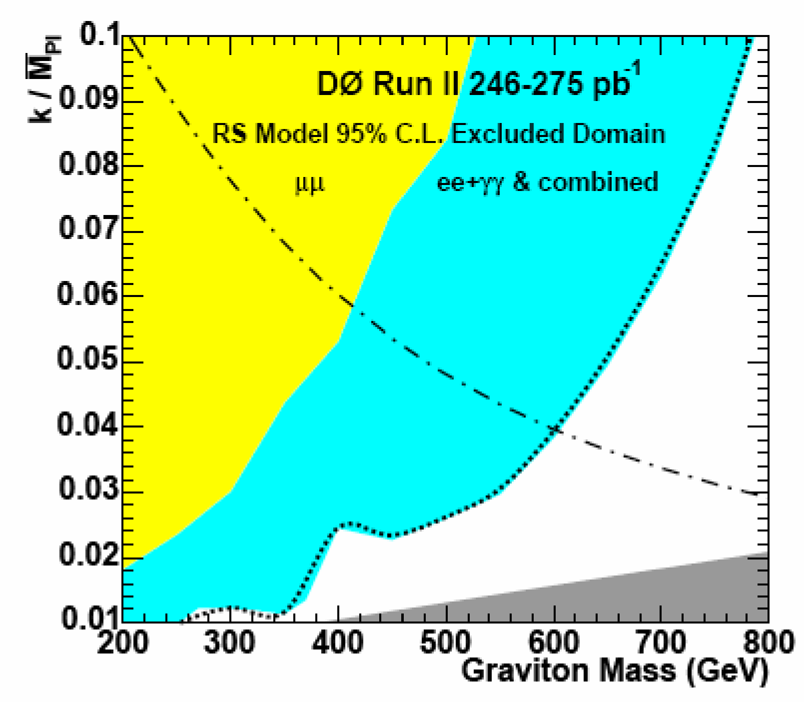


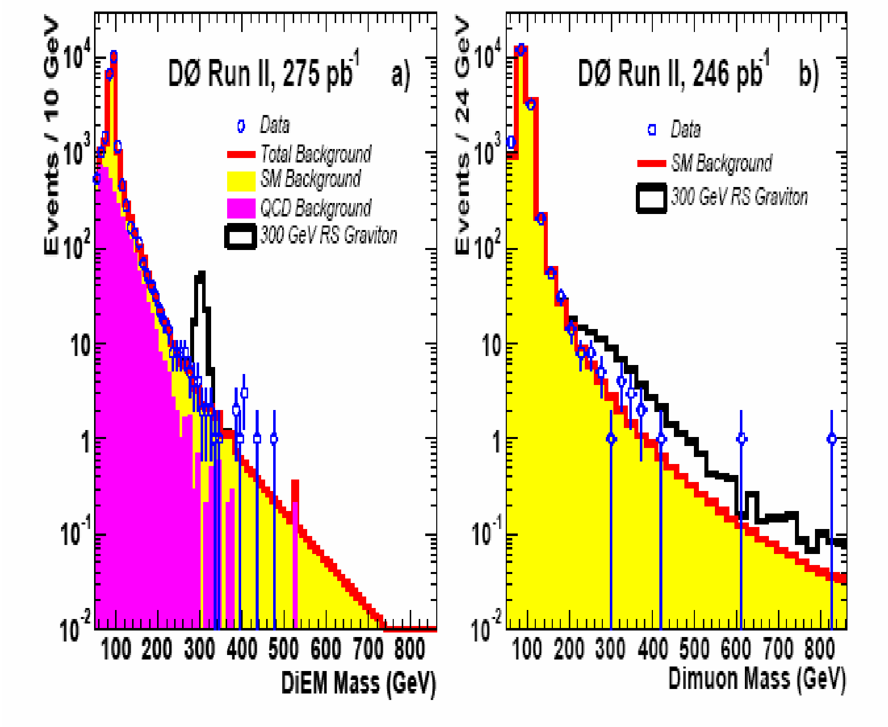
$gg \rightarrow G \rightarrow \gamma\gamma, gg$ (c)

$q\,qbar \rightarrow G \rightarrow \gamma\gamma, gg$ (a)

D0 results on Search for Randall-Sundrum Gravitons in Dilepton and Diphoton Final State

hep-ex/05050189 May 2005



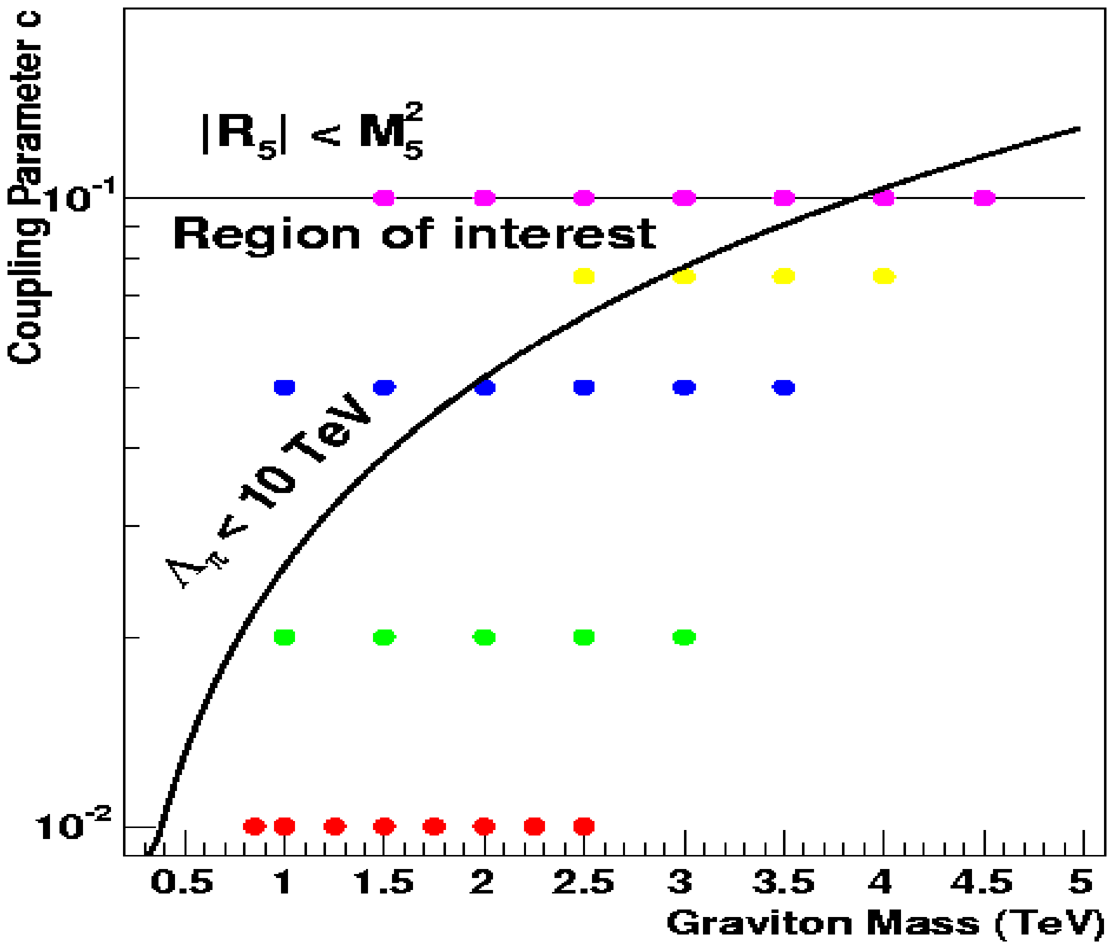


RS-1 Graviton masses up to 785 (250) GeV for c = 0.01 (0.1)

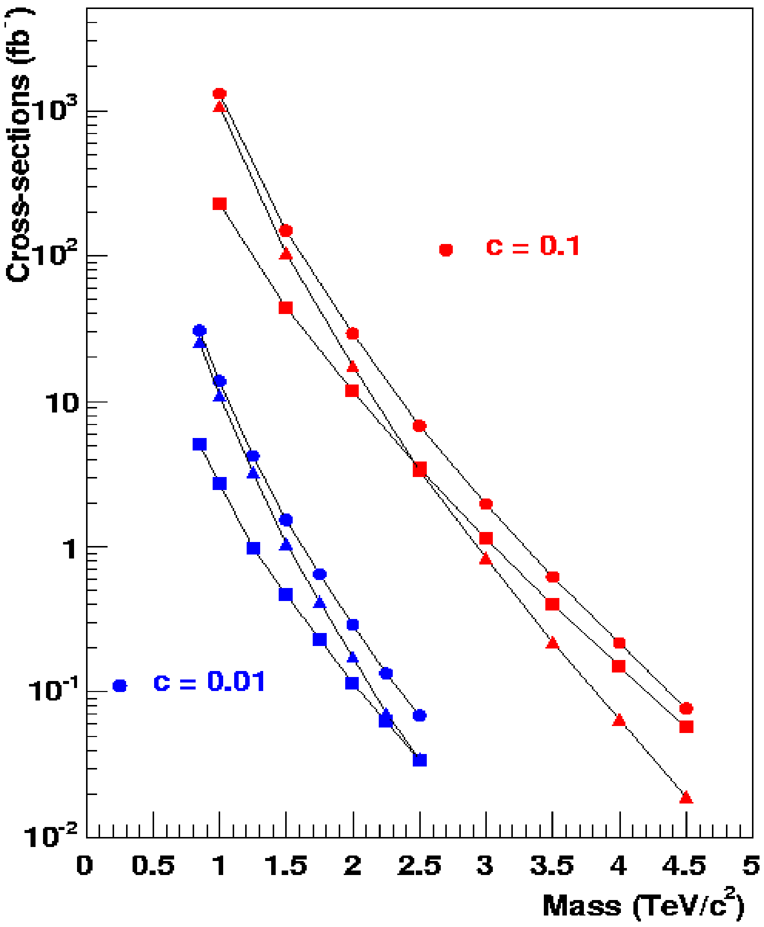
Requested Datasets

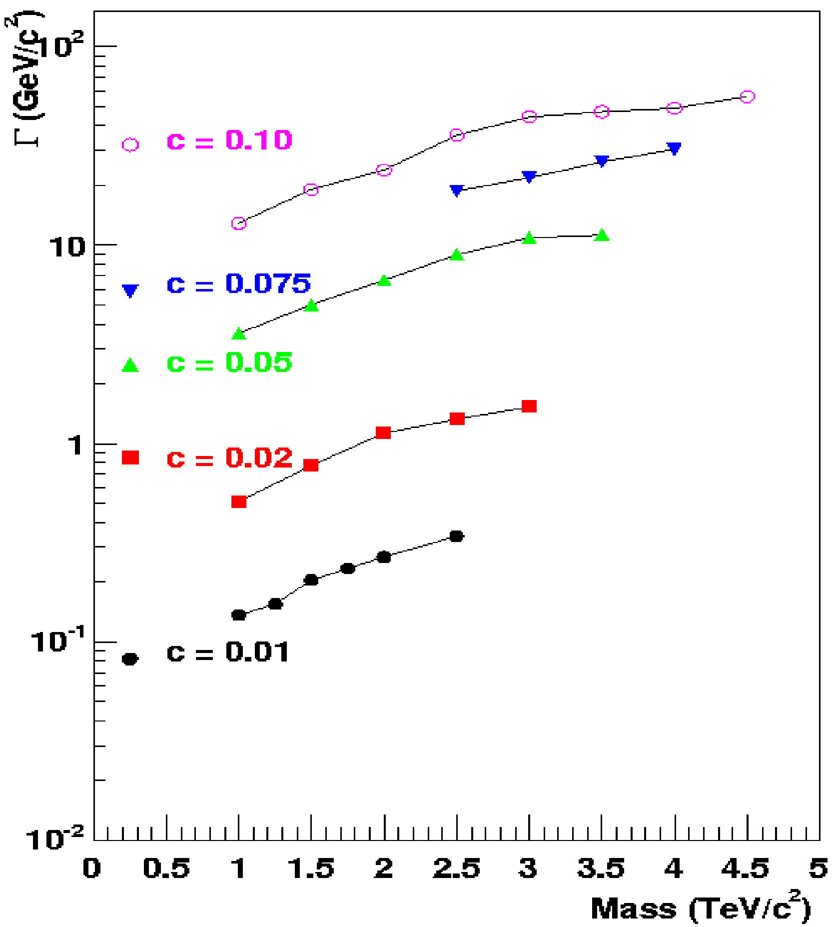
- **We have used next datasets for analysis:**
  - **- CMKIN_4_3_0, OSCAR 3_6_5 and ORCA_8_7_1**
  - **Signal (see plot on the next slide)**
    - **c=0.01 M=1.0, 1.25, 1.5, 1.75, 2.0, 2.25, 2.5 TeV/c^2 1k each**
    - **c=0.02 M=1.0, 1.5, 2.0, 2.5, 3.0 TeV/c^2 1k each**
    - **c=0.05 M=1.0, 1.5, 2.0, 2.5, 3.0, 3.5 TeV/c^2 1k each**
    - **c=0.075 M=2.5, 3.0, 3.5, 4.0 TeV/c^2 1k each**
    - **c=0.1 M=1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 TeV/c^2 1k each**
  - **There are five backgrounds we need to study:**
    - **born (MSEL = 0, MSUB = 18)**
    - **box (MSEL = 0, MSUB = 114)**
    - **brem (MSEL = 0, MSUB = 14,29,115)**
    - **QCD (MSEL = 1)**
    - **DY (MSEL = 0, MSUB = 1, MSTP 43 = 3). We are using PHOTOS radiation for Z boson decay - MSTJ 41 = 1 was added.**
- **Reconstruction with ORCA_8_7_1**
- **Hybrid algorithm in barrel and Island in endcap (see CMS Note 2001/034)**

Discovery plane for RS-1 graviton



RS-1 graviton cross-sections and lorentzian widths





RS-1 graviton cross-sections (left) and lorentzian widths (right). Square markers for the cross-sections are for qq production, triangle markers are for gg and circles are for the total cross-section

Table of background datasets

dataset	600-800	800-1300	1300-1900	1900-3200	3200-5250	5250-inf	Total
Box	1k	1k	1k	1k	1k	--	5k
Born	2.5k	4k	2k	1k	1k	--	10.5k
Brem	5k	5k	5k	5k	5k	5k	30k
QCD	20k	20k	20k	20k	10k	5k	95k
DY	1k	2.5k	1.5k	2.5k	1k	--	8.5k

Photon Reconstruction

Energy resolution: mean μ, sigma σ of gaussian fit and σ_{eff} (Barrel)

P_T, TeV/c	E_{SC}/E_{true} μ	E_{SC}/E_{true} σ	E_{SC}/E_{true} σ_{eff}	E_{25}/E_{true} μ	E_{25}/E_{true} σ	E_{25}/E_{true} σ_{eff}
0.25	0.995	0.57%	0.89%	0.996	0.57%	0.81%
0.75	1.00	0.59%	0.89%	1.00	0.62%	1.0%
1.8	0.991	0.63%	1.24%	0.999	0.67%	1.27%

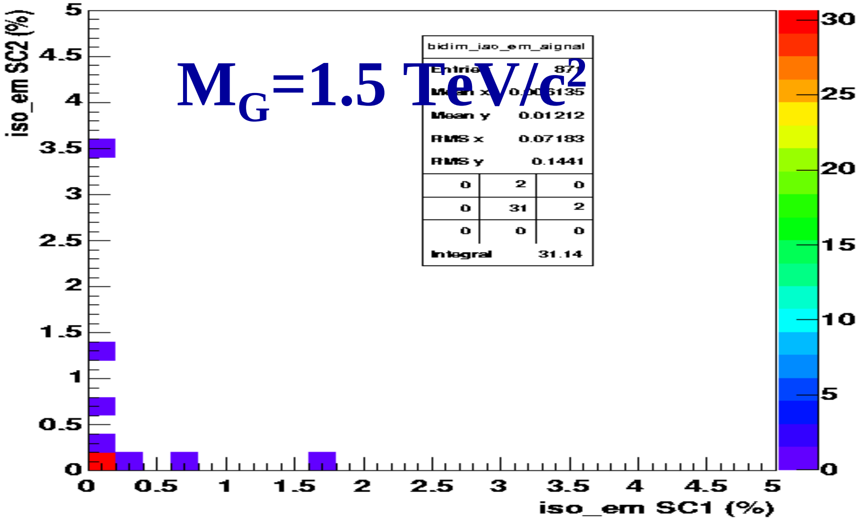
Energy resolution: mean μ, sigma σ of gaussian fit and σ_{eff} (Endcap)

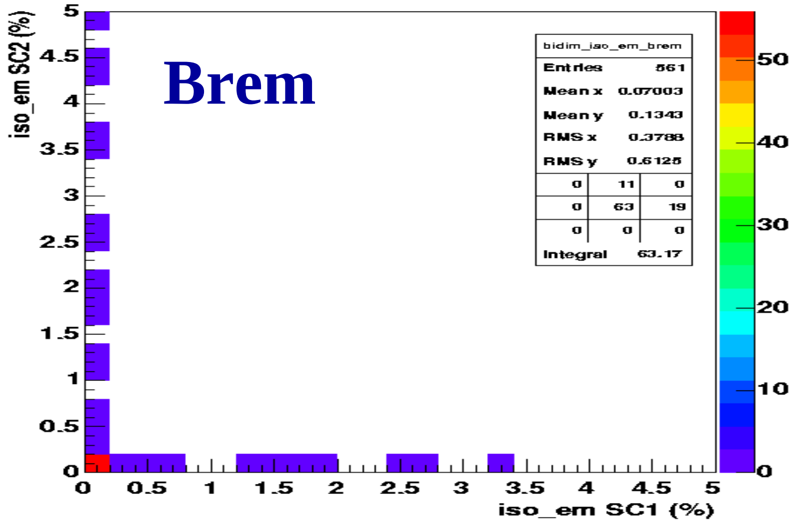
P_T, TeV/c	E_{SC}/E_{true} μ	E_{SC}/E_{true} σ	E_{SC}/E_{true} σ_{eff}	E_{25}/E_{true} μ	E_{25}/E_{true} σ	E_{25}/E_{true} σ_{eff}
0.25	1.00	0.82%	1.15%	0.994	0.96%	1.2%
0.75	1.00	0.75%	1.20%	1.00	0.79%	1.4%
1.8	0.993	1.04%	1.76%	0.985	1.33%	2.26%

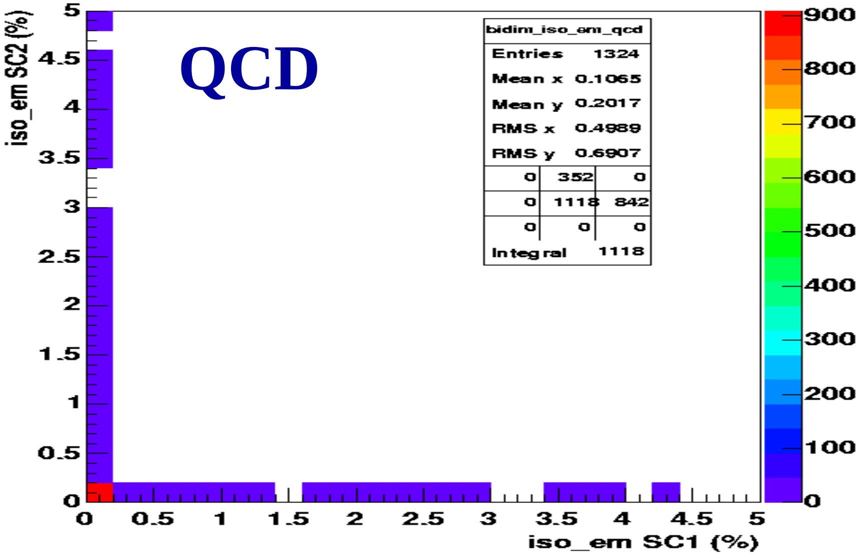
Simple Analysis

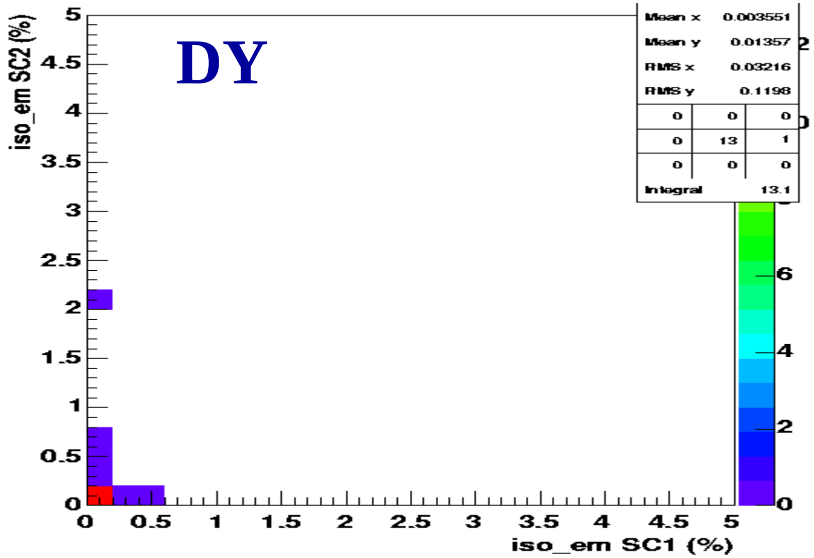
1. 2 Super-Clusters (SCs) with Et > 150 GeV,
   trig_hlt_2p = =1 || trig_hlt_r2p==1
2. Calorimeter isolation criteria: For each SC, the energy in a cone of $\Delta R = 0.5$ (excluding the SC) should be < 0.02 E_T(SC)
3. E(HCAL)/ E(ECAL) < 0.05
4. Tracker isolation: the sum of the energy tracks in a cone $\Delta R = 0.5$ around the Super-Cluster should be < 0.01 E_T(SC)
5. Photon energy corrections are done in a simple way so far
   - For S1 energy < 1.7 TeV, only simple energy dependent part of correction is applied (just a shift of the peak in 10 different η bins)
   - For S1 energy > 1.7 TeV, the MGPA saturation correction was applied (see CMS NOTE 2004/024).

2D plots of the electromagnetic isolation

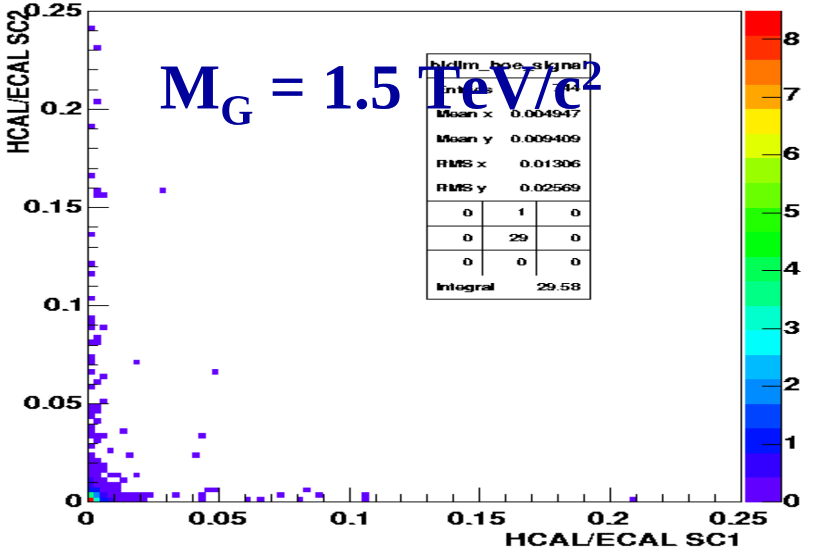


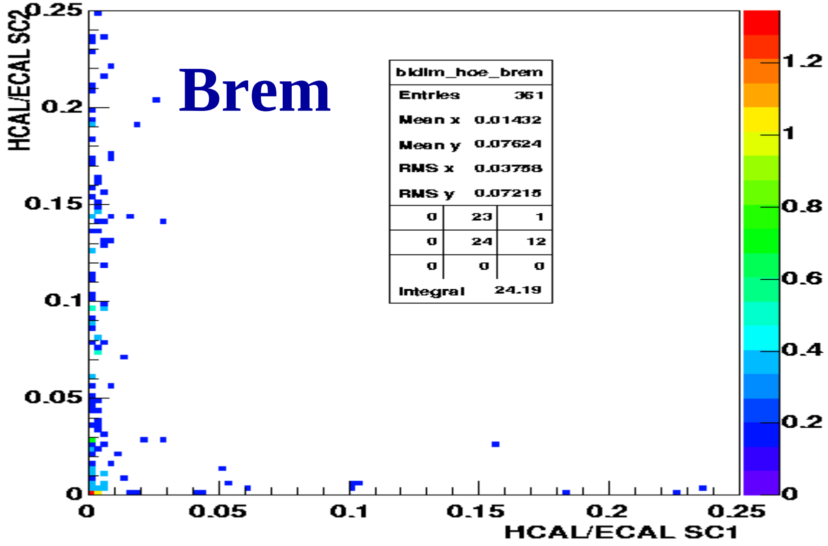


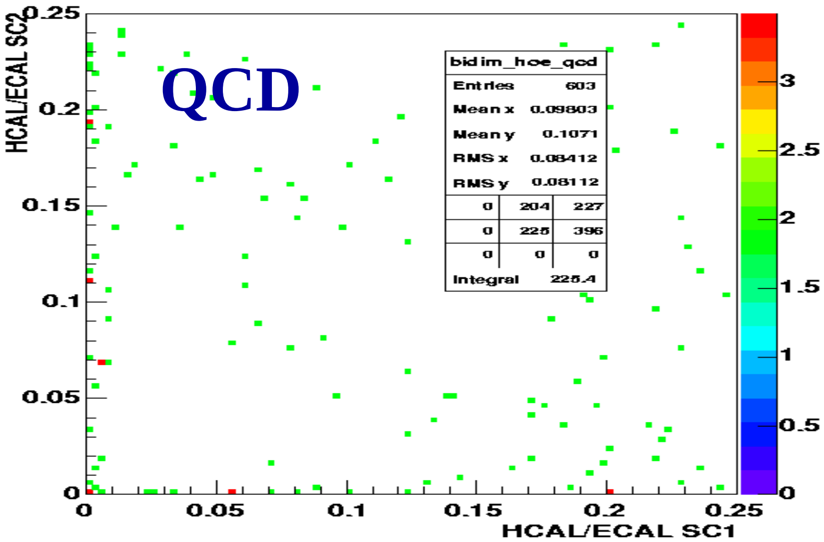


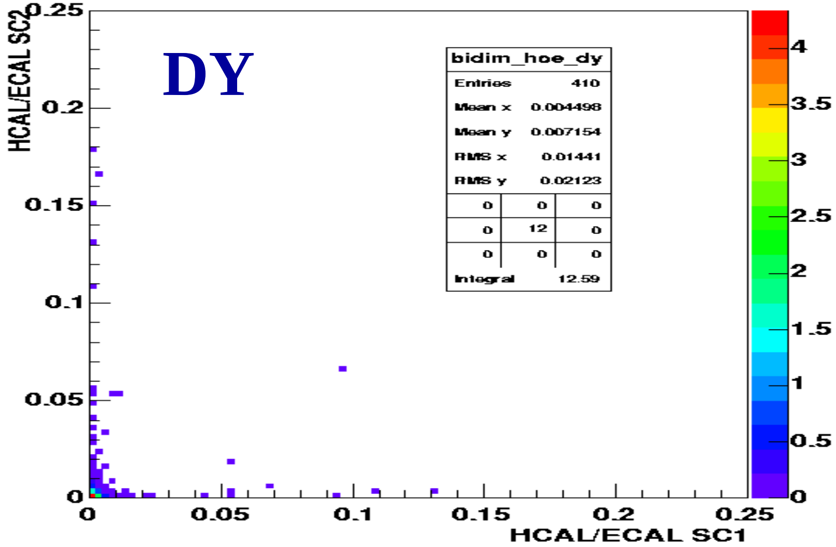


2D plots of E_{HCAL}/E_{ECAL}

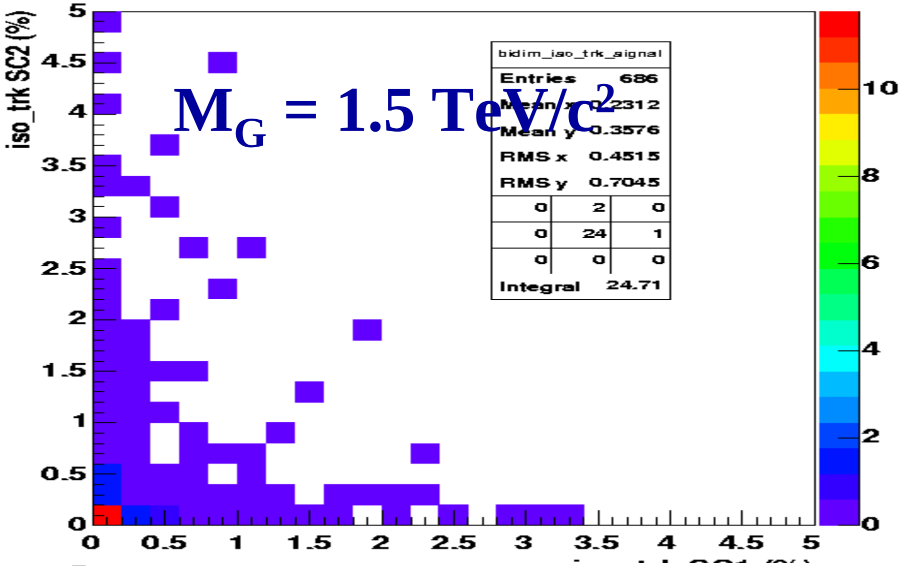


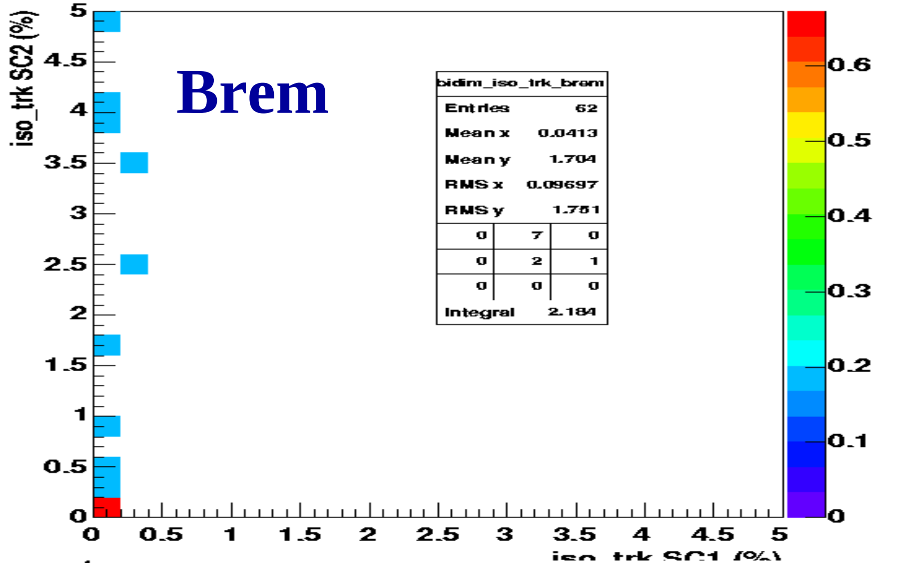


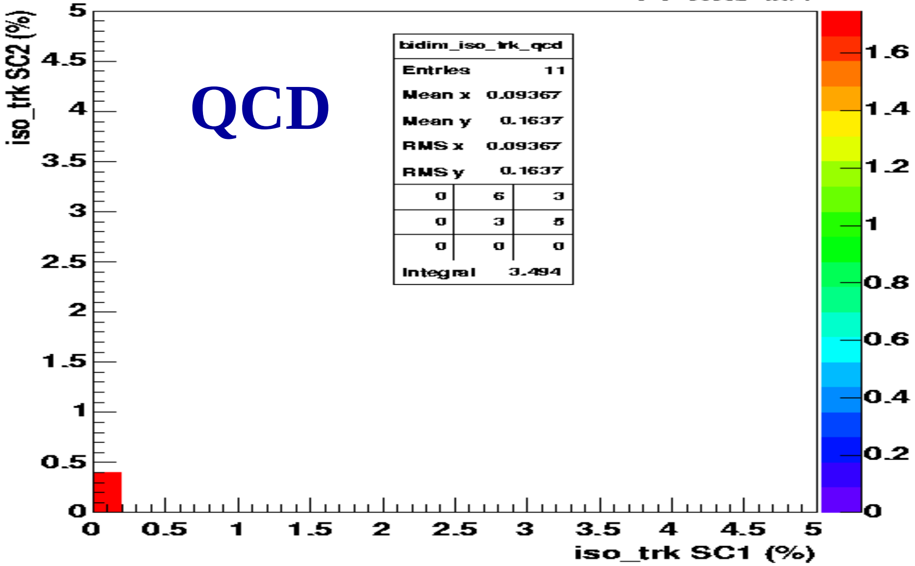


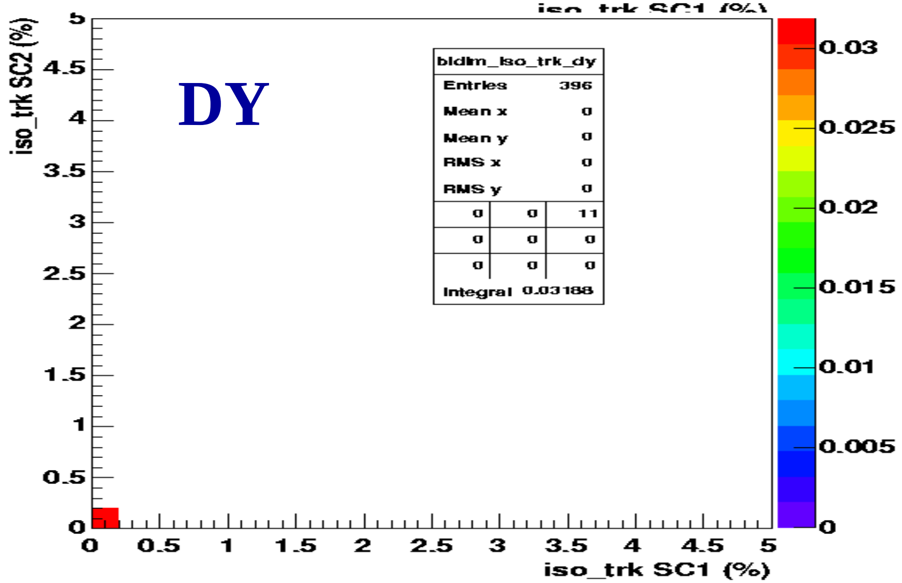


2D plots of the tracker isolation









M_G= 1500 GeV and c=0.01

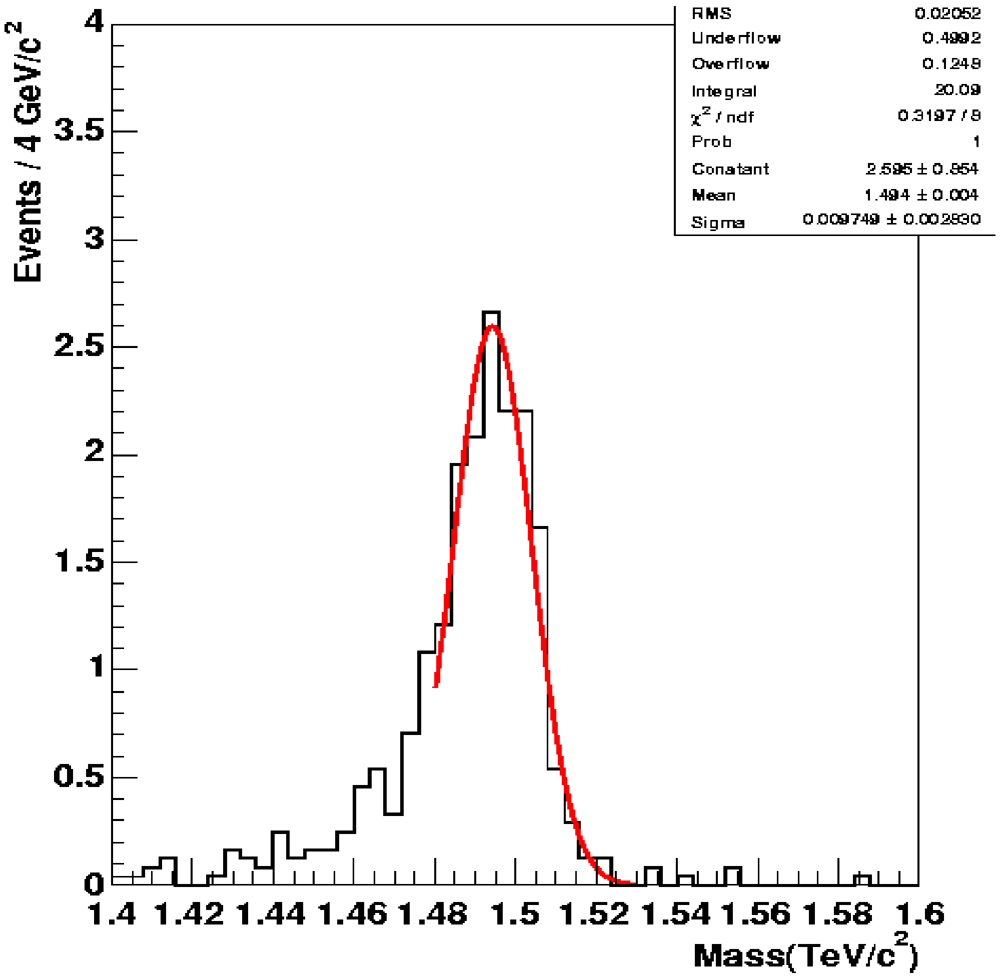
Number of events for L = 30 fb^{-1}

	Signal	Born(1.5)	Box(1.2)	Brem(1)	QCD(1)	DY(1)
Trig +2SC	28.9	8.6	0.10	29.2	798.7	4.3
+ EM Isolation	24.5	5.5	0.08	20.3	361.8	3.5
$+E_{HCAL}/E_{ECAL}$	24.3	5.4	0.08	4.4	12.8	3.5
+ Tracker Isolation	17.6	4.2(+0.2)	0.05	0.17	0.0	0.0

All saturated events, passed through the analysis were added in brackets, where applied

Randall-Sundrum Graviton
M_G = 1.5 TeV and c=0.01

L = 30 fb^{-1}



μ = 1.50
σ= 0.01

Resolution due to detector

M = [1.467-1.525] TeV/c^2
N_s = 17.6 evts

M_G= 3500 GeV and c=0.1

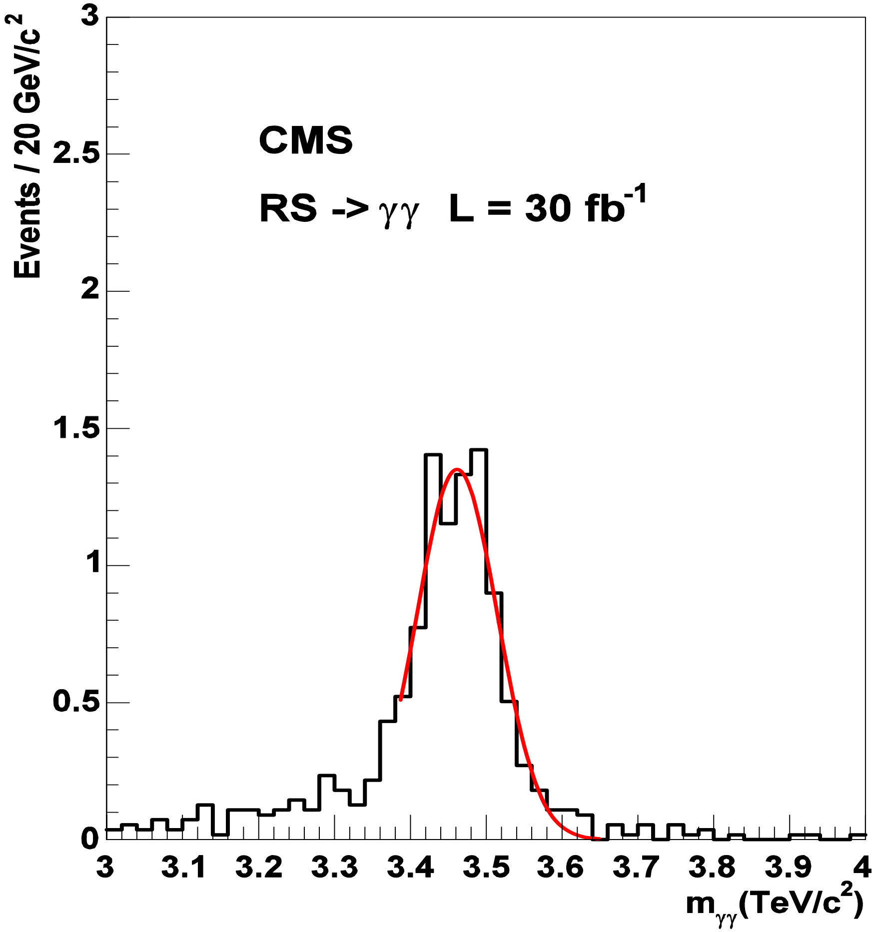
Number of events for L = 30 fb^{-1}

	Signal	Born(1.5)	Box(1.2)	Brem(1)	QCD(1)	DY(1)
Trig +2SC	11.6	0.20	$4.4*10^{-4}$	0.78	821.9	0.10
+ EM Isolation	10.8	0.14	$3.6*10^{-4}$	0.32	164.4	0.095
$+E_{HCAL}/E_{ECAL}$	10.6	0.13	$3.4*10^{-4}$	0.016	0.0	0.095
+ Tracker Isolation	8.9(+1.0)	0.10(+0.02)	$2.7(+0.24)*10^{-4}$	0.0017	0.0	$7.2*10^{-4}$

All saturated events, passed through the analysis were added in brackets, where applied

Signal M_G=3.5 TeV c=0.1

L= 30 fb^{-1}



μ = 3.46

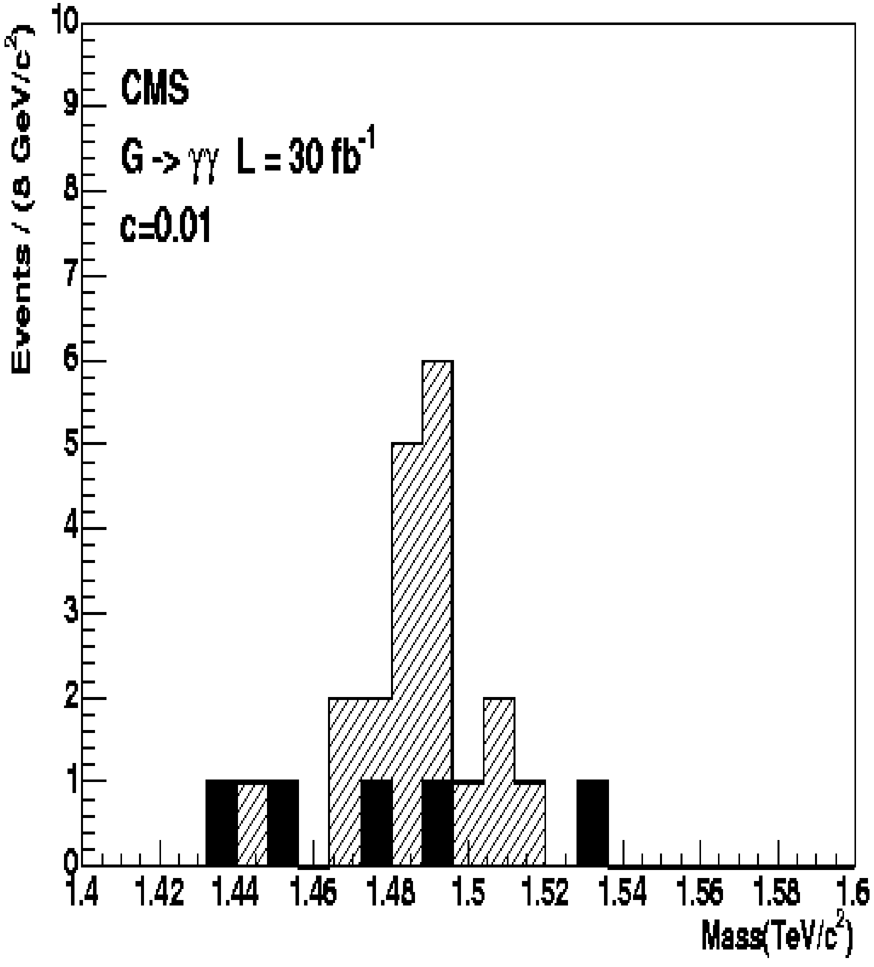
σ= 0.053

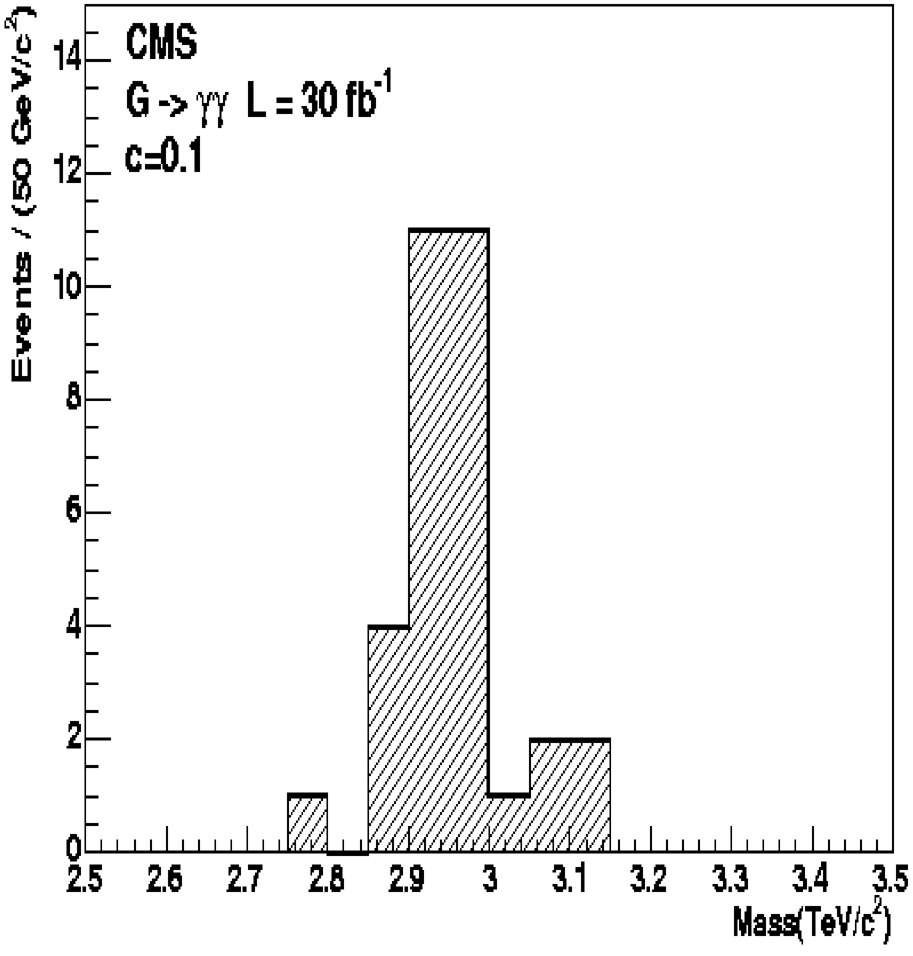
Resolution is mainly due to natural width of the resonance (0.047 GeV/c^2) with small contribution from detector resolution

In mass window 3.30-3.62 TeV/c^2

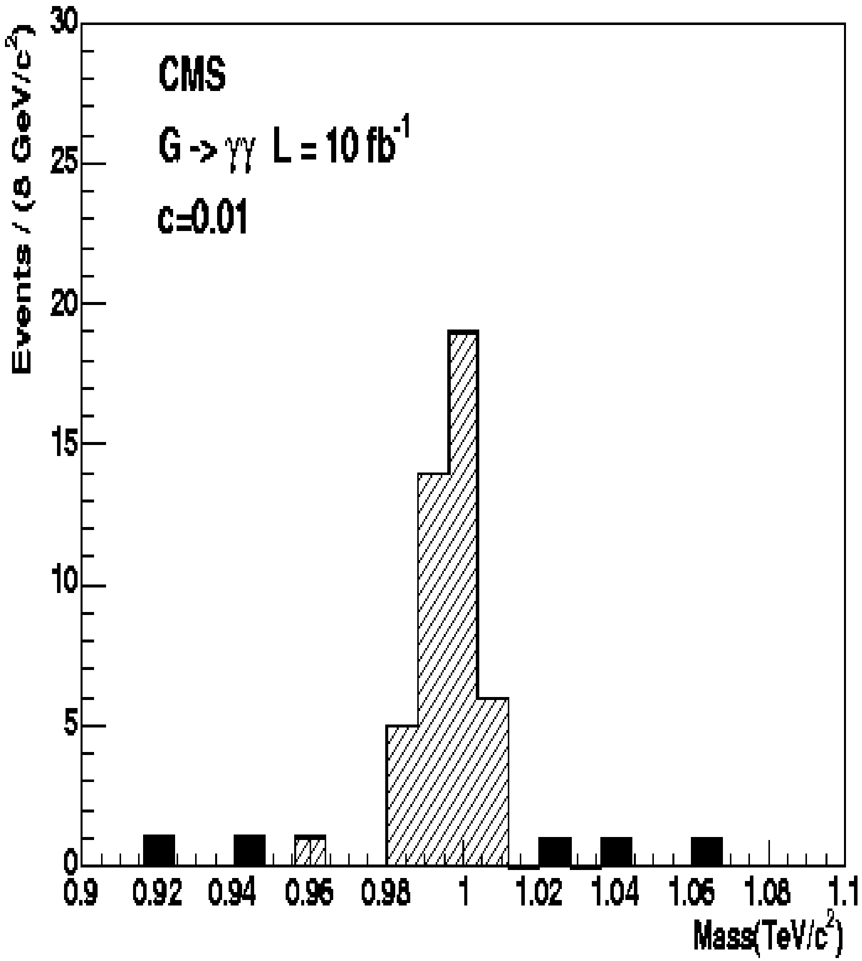
N_s = 9.9 evts

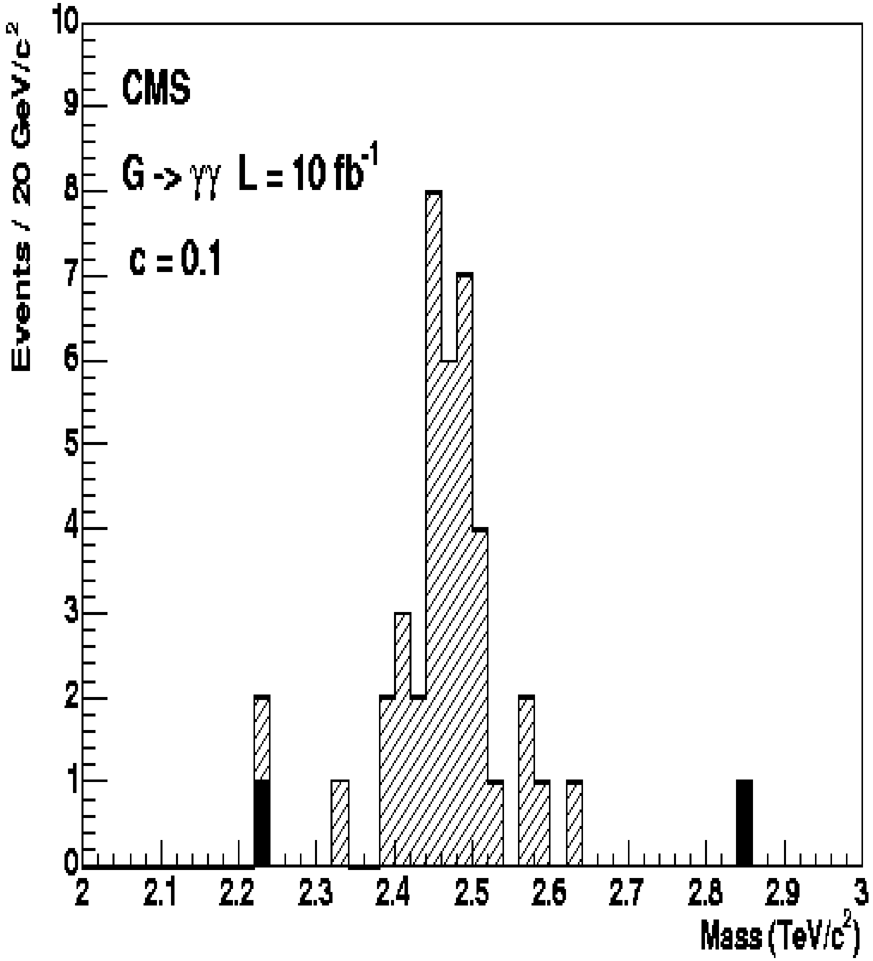
Signal + backgrounds vs invariant mass: 30 fb^{-1}





Signal + backgrounds vs invariant mass: 10 fb^{-1}





Significance c=0.01 for L=30 fb^{-1}

Born k=1.5
Box k=1.2

$$S = \sqrt{2\ln Q} \quad \text{with} \quad Q = (1 + n_s/n_b)^{ns+nb} \exp(-n_s)$$

	M_G = 1.0 TeV/c^2	M_G =1.25 TeV/c^2	M_G = 1.5 TeV/c^2	M_G =1.75 TeV/c^2	M_G = 2.0 TeV/c^2
N_s	135.8	44.0	17.6	7.3	3.9
N_{bkg}	15.0	8.8	4.6	1.8	1.2
S	20.6	10.1	5.9	3.9	2.6

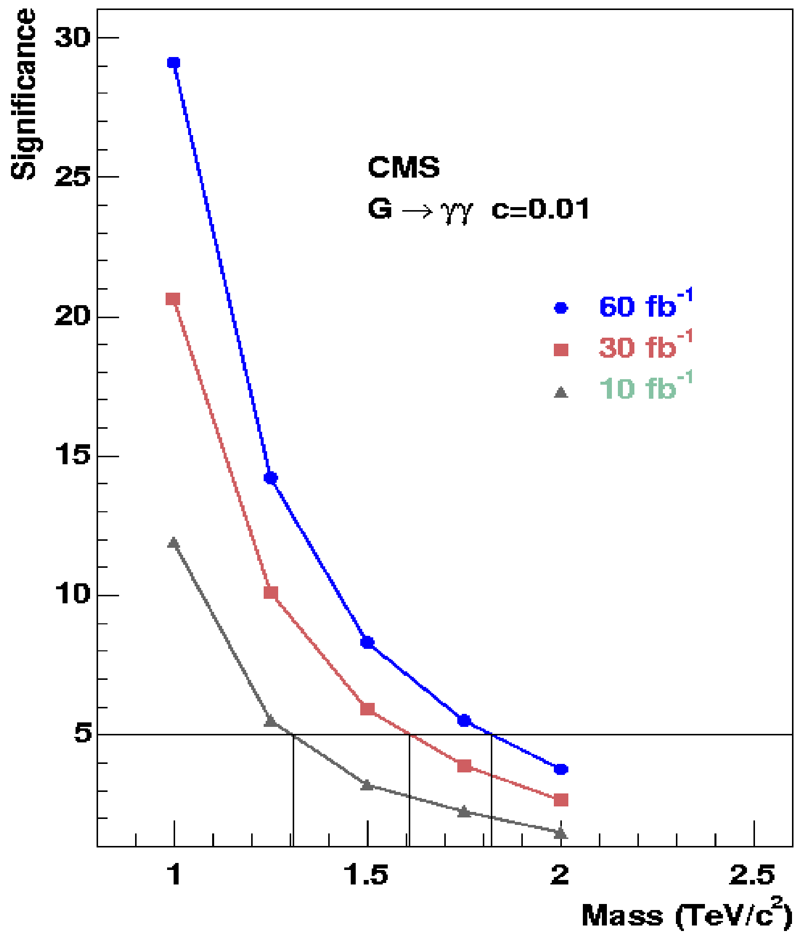
Significance c=0.1 for L= 30 fb^{-1}

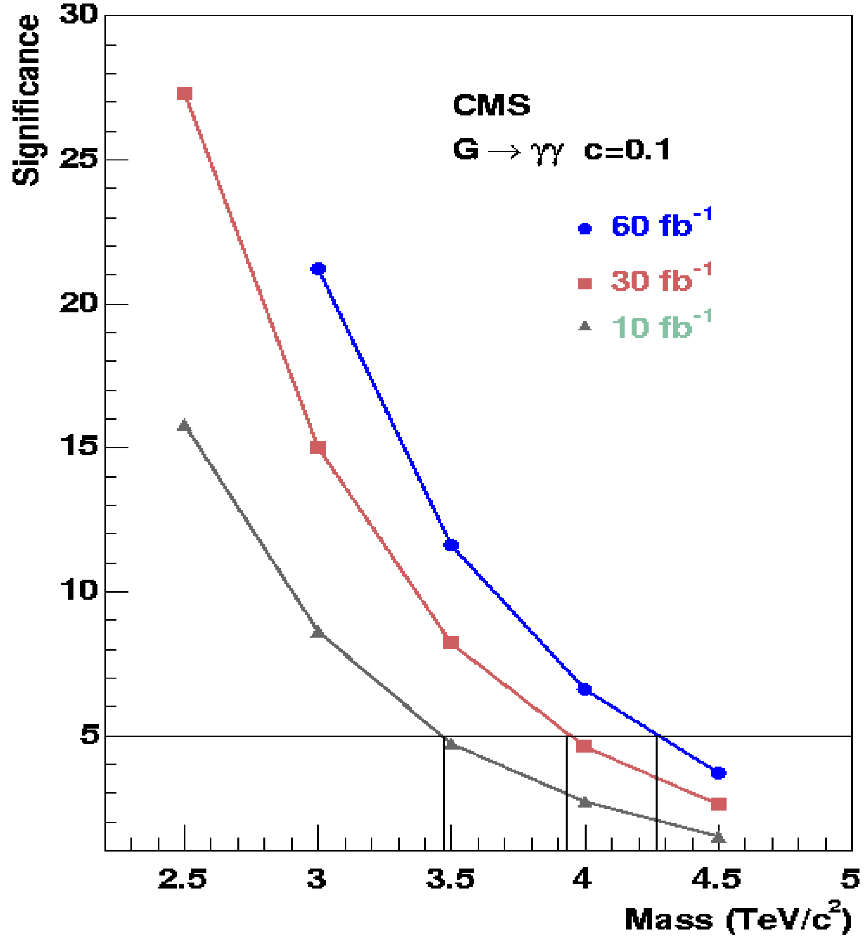
Born k=1.5
Box k=1.2

$$S = \sqrt{2 \ln Q} \quad \text{with} \quad Q = (1 + n_s/n_b)^{ns+nb} \exp(-n_s)$$

	M_G = 2.5 TeV/c^2	M_G =3.0 TeV/c^2	M_G = 3.5 TeV/c^2	M_G =4.0 TeV/c^2	M_G = 4.5 TeV/c^2
N_s	103.8	31.6	9.9	3.44	1.11
N_{bkg}	1.11	0.35	0.13	0.06	0.02
S	27.3	15.0	8.2	4.6	2.6

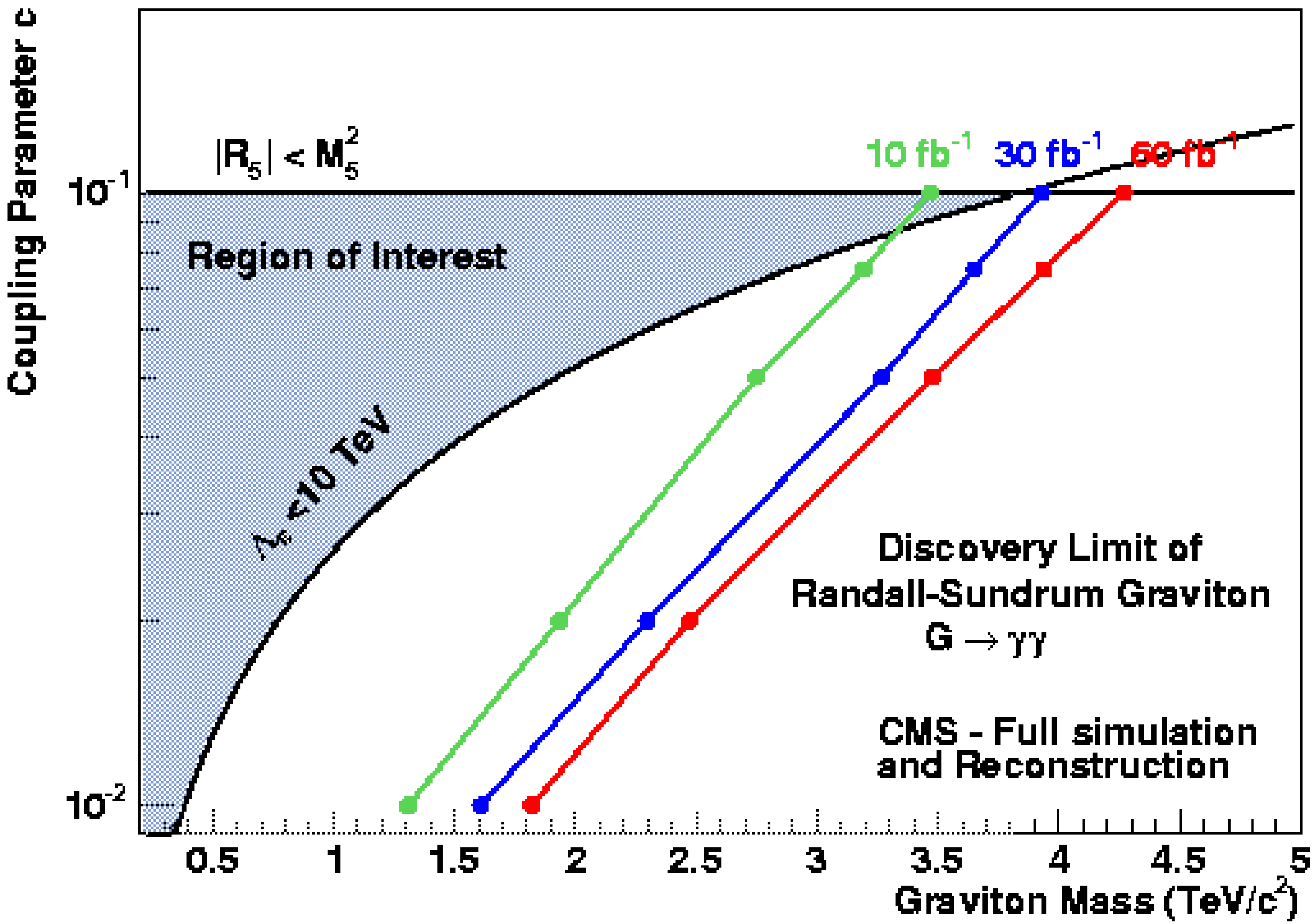
Significance vs RS-1 graviton invariant mass



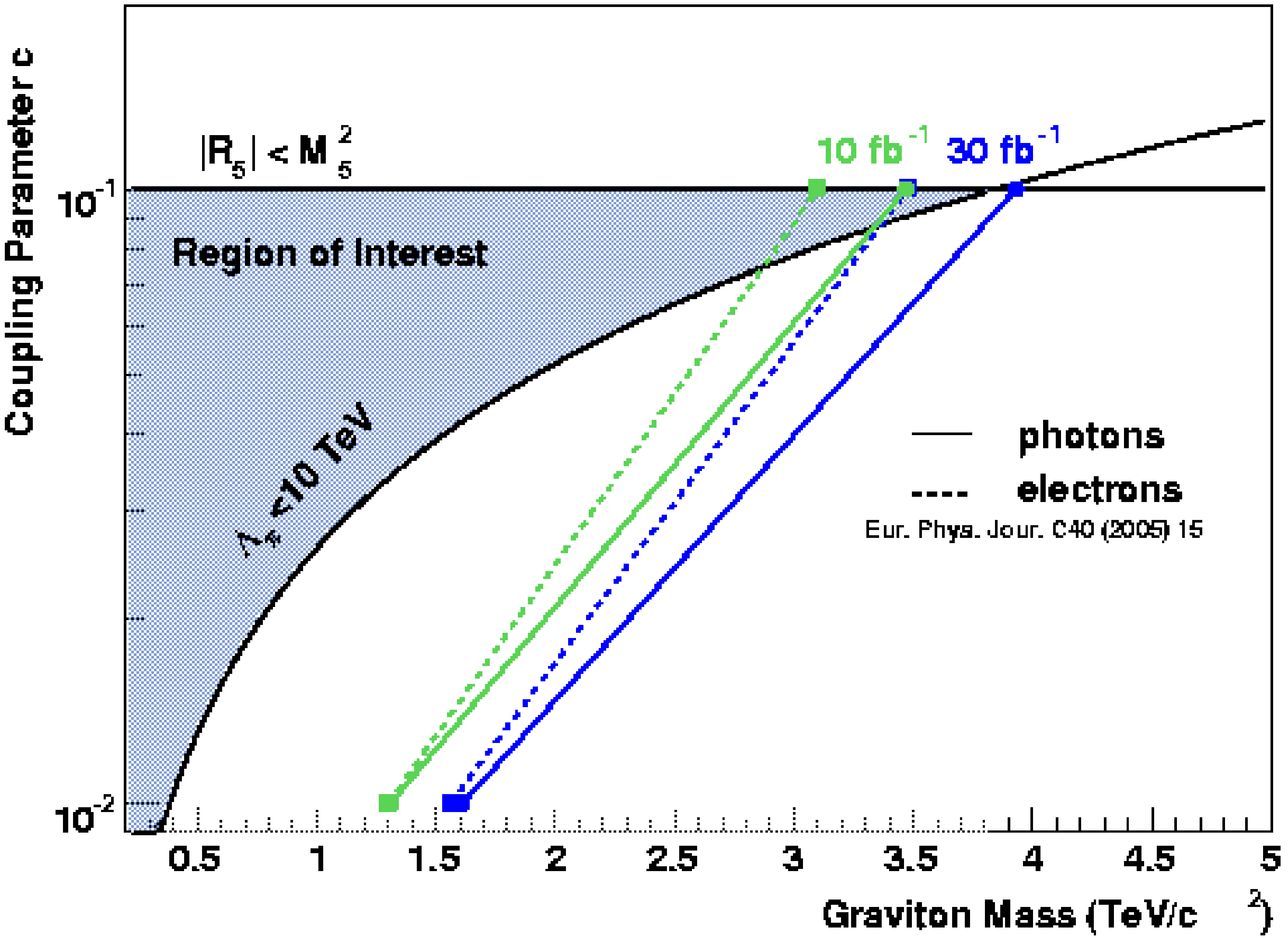


Significance plots are not taking systematic errors into account

Discovery potential



Electron and photon discovery potential



Hard process scale uncertainties

Hard process scale uncertainties were calculated based on the cross sections. Default value was s.

c=0.01	1.25 TeV/c^2	1.5 TeV/c^2	1.75 Tev/c^2
4s	-8.3%	-8.2%	-8.9%
0.25s	+8.7%	+10.7%	+10.3%
c=0.1	3.5 TeV/c^2	4.0 TeV/c^2	4.5 TeV/c^2
4s	-10.2%	-12.7%	-12.3%
0.25s	+12.5%	+13.9%	+14.2%
Born	1300-1900	1900-3200	3200-5250
4s	-0.26%	+0.59%	-0.49%
0.25s	+0.68%	+0.18%	+2.55%

PDF uncertainties

Master equations for calculating uncertainties

let $X(S)$ be any variable that depends on the PDF,
$X_0 = X(S_0)$ is evaluated with the 'best-fit' PDF, $X_k^{\pm} = X(S_k^{\pm})$

$$D_k = X_k^+ - X_k^-, \quad k = 1, ..., d \quad (D_k = (X_k^+ - X_0) - (X_k^- - X_0)$$

$$R_j,\ j = 1, 2, ..., (2d),\ R_1 = X_1^+ - X_0, R_2 = X_1^- - X_0,\ R_3 = X_2^+ - X_0,\ R_4 = X_2^- - X_0,$$

two **master** equations for calculating uncertainties

$$\Delta X = \sqrt{\sum_{k=1}^{d} D_k^2} \qquad \Delta X_C = \sqrt{\sum_{j=1}^{2d} R_j^2}$$

ΔX_C looks more "stable", because ΔX could vary from **zero** to $2\Delta X_C$

The talk by Sergey Slabospitsky

http://agenda.cern.ch/askArchive.php?base=agenda&categ=a055243&id=a055243s1t0/moreinfo

PDF uncertainties

CMKIN_6_0_0 and LHAPDF4.0

$$\Delta X = \frac{1}{2}\sqrt{\sum_{i=1}^{N_{PDF}}[X_{2i} - X_{2i-1}]^2} \qquad \Delta X_C = \frac{1}{2}\sqrt{\sum_{i=1}^{2N_{PDF}}[X_i - X_o]^2}$$

c=0.01	1.25 TeV/c^2	1.5 TeV/c^2	1.75 TeV/c^2
CTEQ6M,$\Delta X_C/X_0$	8.3%	8.6%	11.7%
c=0.1	3.5 TeV/c^2	4.0 TeV/c^2	4.5 TeV/c^2
CTEQ6M,$\Delta X_C/X_0$	23.3%	25.7%	30.8%
Born	1300-1900	1900-3200	3200-5250
CTEQ6M,$\Delta X_C/X_0$	6.15%	6.24%	11.44%

Note: uncertainties for c=0.1 are higher because we are saying about higher invariant masses – 3.5 TeV/c^2 – 4.5 TeV/c^2 instead of 1.25 TeV/c^2 - 1.75 TeV/c^2. In this case we have larger x's and , hence, higher uncertainties in PDF(x, Q^2)

Limits Uncertainties for 30fb^{-1}

- Hard scale uncertainties

	4s	0.25s
C=0.01	-62 GeV/c^2	+56 GeV/c^2
C=0.1	-47 GeV/c^2	+42 GeV/c^2

- LHApdf uncertainties
  - c=0.01 -55 GeV/c^2
  - c=0.1 -152 GeV/c^2
- Preselection uncertainty was calculated based on 2% (QCD) and 1% (brem) upper limit of inefficiencies (CMS IN 2005/018, “Selection A”). It propagates to 1-2% cross-section uncertainties and 0.1-0.15 uncertainty in the number of background events
  - c=0.01 -8 GeV/c^2
  - c=0.1 -5 GeV/c^2
- Keeping all K-factors equal 1 instead of K=1.5 for born and K=1.2 for box, results will be better:
  - c=0.01 +70 GeV/c^2
  - c=0.1 +40 GeV/c^2
- Uncertainty due to the fact, that Tevatron has a K- factor =2 for born instead of 1.5 (D. Acosta et al., CDF Collaboration, PRL 95(2005) 022003) as we have here
  - c=0.01 -50 GeV/c^2
  - c=0.1 -30 GeV/c^2

Conclusion

- We presented preliminary results on the discovery potential for RS-1 graviton in the diphoton decay mode.
- There is an opportunity to find a radion parameters based on the exact knowledge of the RS-1 graviton mass as well as natural width which might be found rather accurately for high graviton masses
- Various confidence limits systematic uncertainties have been estimated – hard process scale, LHApdf uncertainties for the signal as well as for the background. They are changing the results from 50 to 150 GeV.
  - Detector response uncertainties might affect our analysis as well – ECAL calibration and, probably, tracker/pixel misalignment are most important, but these effects are beyond the scope of this study.

- Confidence Limits for 30 fb^{-1} c=0.01 M_G= 1.61 TeV
  c=0.1 M_G= 3.95 TeV
- Confidence Limits for 10 fb^{-1} c=0.01 M_G= 1.31 TeV
  c=0.1 M_G= 3.47 TeV