# Search for Large ED in Monophoton Final State

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# OUTLINE

- Introduction to Signal
- Estimation of Z-gamma background
- Estimation of Cosmics background
- Summary & Future Plans

Note: CMS preliminary study. “NOT PUBLIC” yet.

# Introduction

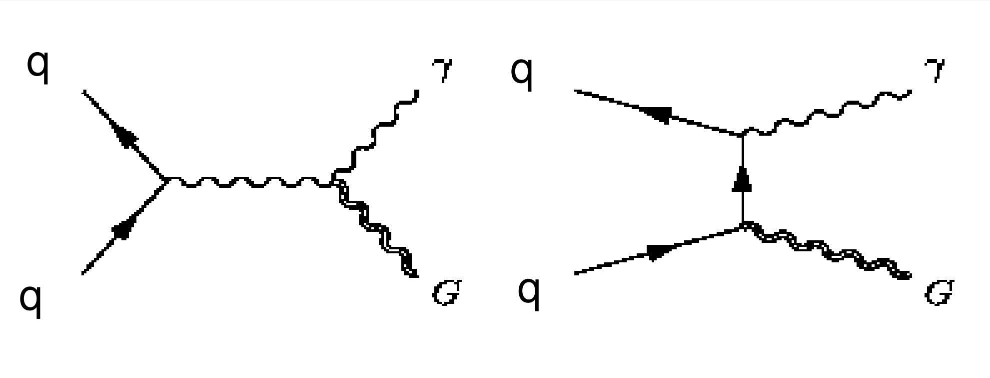
- In 1998, Large extra dimension (LED) were proposed as a solution to hierarchy problem by ADD.
  - It builds up saying that gravity can propagate in extra dimensions giving rise to a relation given as,

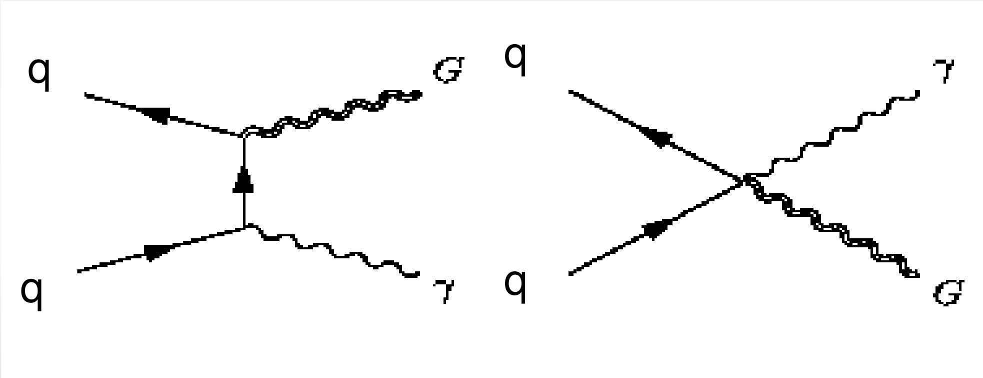
$$Mpl^2 = Md^{(n+2)} R^n$$

where, R is the size of compactified Extra-Dimension,

***Md and n are the parameters of the theory.***

- Gravitational field is carried by a particle called graviton whose signatures can be found at LHC.
- For a direct graviton production, MET becomes a signature.
- **Signal**: I am interested in looking for **$\gamma$ + MET** as the signal for the direct graviton production at LHC.



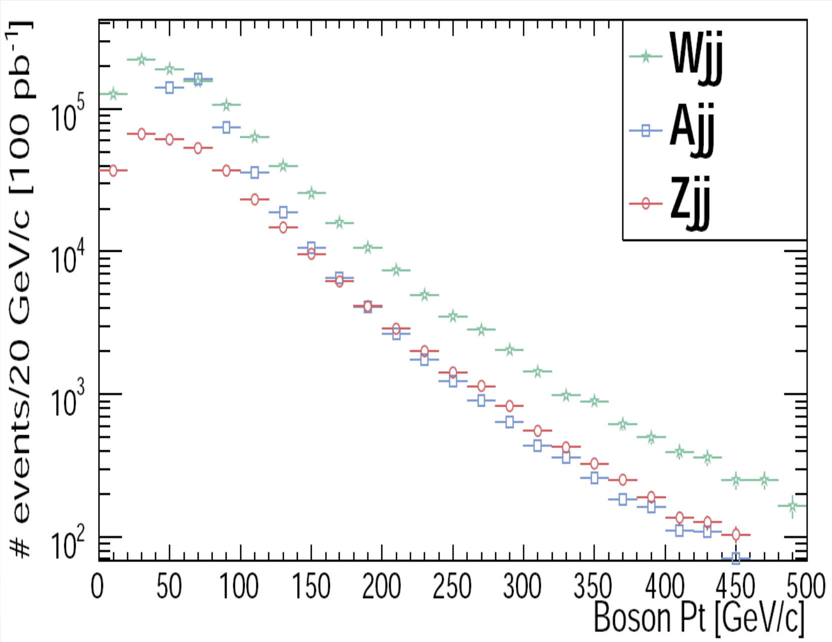



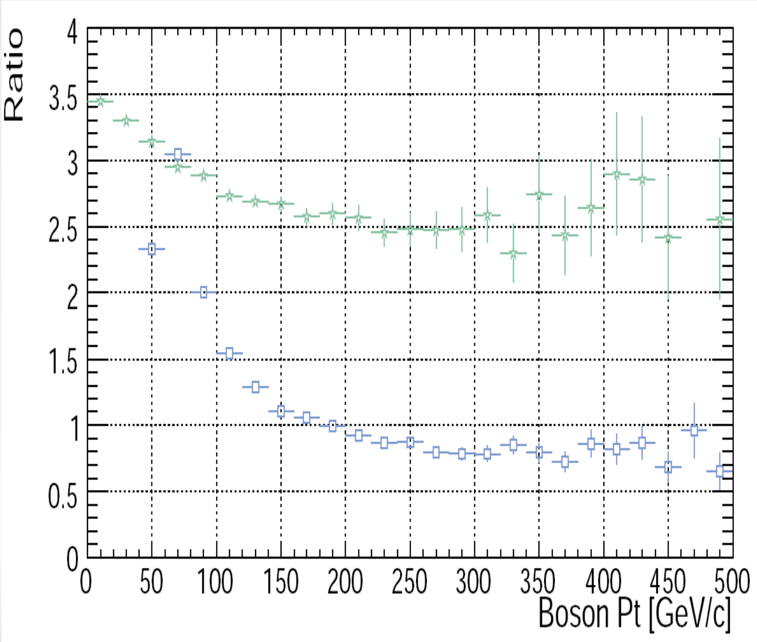
# $Z(\nu\nu)\ \gamma$ – SM background

- After all the analysis cuts being put, this background gives the maximum contribution among all other backgrounds. So, this irreducible background needs to be studied in detail.
- To estimate this background in data, in principle one can use $Z\text{->}\ (l^+ l^-)\ \gamma$ but number of expected $Z\text{->}\ (l^+ l^-)\ \gamma$ events after all the cuts comes out to be < **2** events (very small).
- So, we take up diphoton sample to estimate Z $(\nu\nu)\gamma$ based on the data driven technique introduced in AN-2008/036.

# Introduction to Data driven technique

- Reference: AN-2008/036, **gamma + jets** & **W + jets** was used to estimate **Z( inv) + jets**, which is a irreducible backgroung to SUSY Met+ jets search.
- In left plot, comparison of the pt distribution of gamma (from gamma + jets) and W(from W + jets) with Z(Z  + jets)
- In the right plot, ratio of W/A pt with Z pt is plotted.
- So, estimation of Z(inv) + jets is done from W/A + jets by defining here a Met like quantity defined as, System Met + W/A pt, which corresponds to Met in Z(inv) + jets sample.



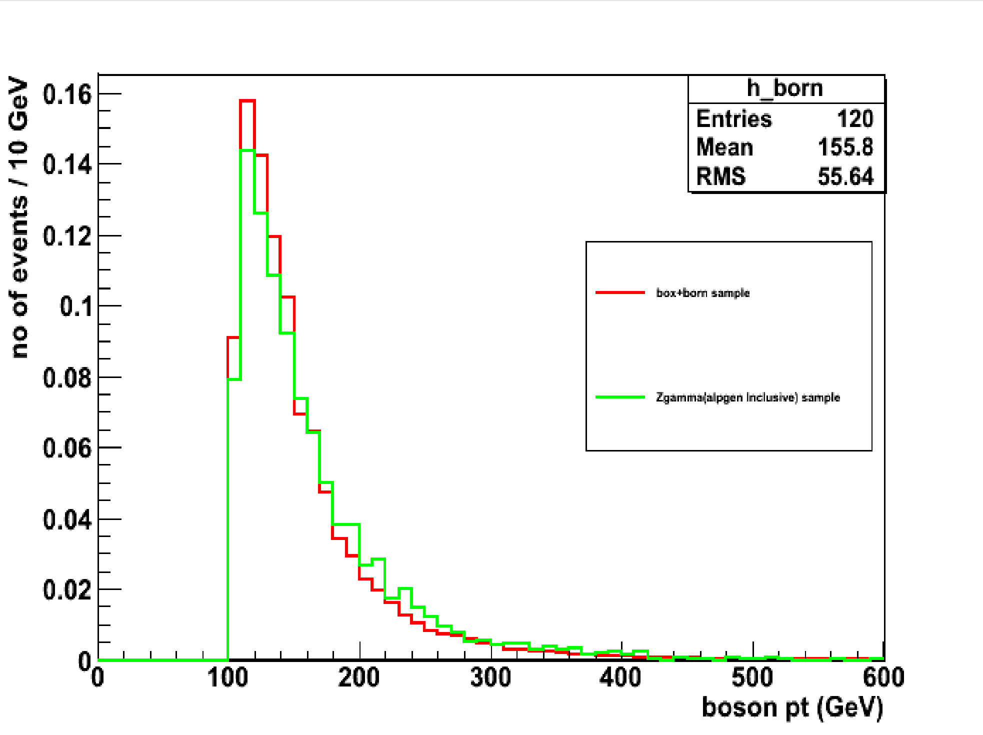



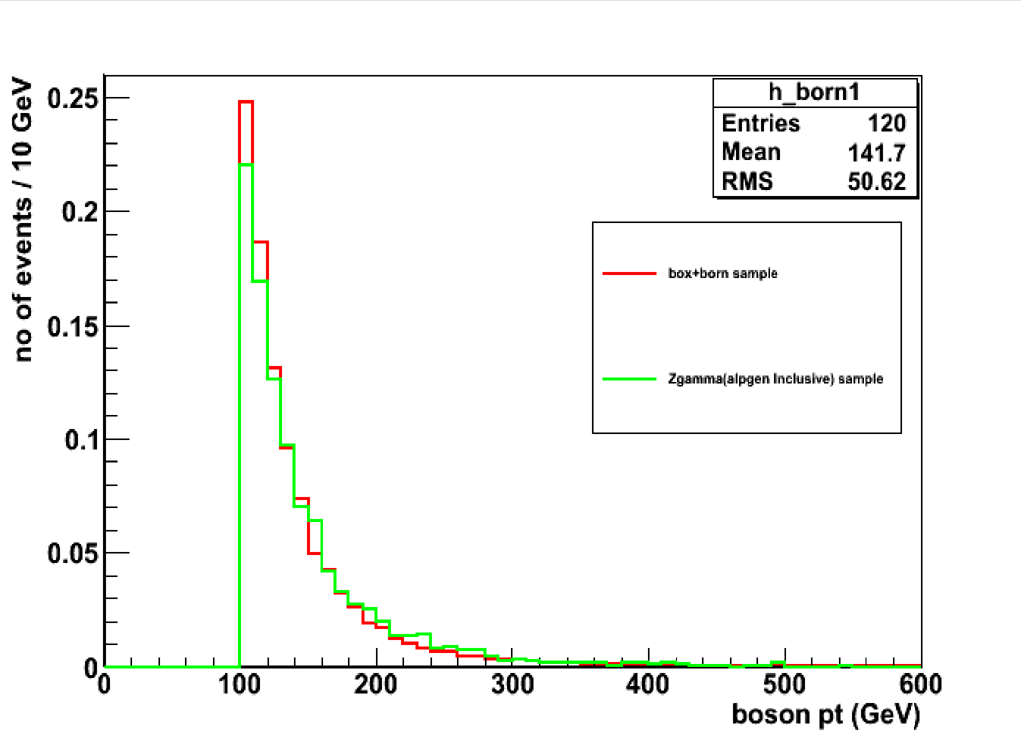
# Estimation of Z(inv) +γ from diphoton sample

- Question: which gamma from diphoton sample will mimic the gamma in Z(inv) ?

  If Z is boosted along the direction of boost of Zγ system i.e. $p_t^z > p_t^\gamma$ , then Z can be compared with a leading γ from the diphoton sample.

Comparison at GEN level



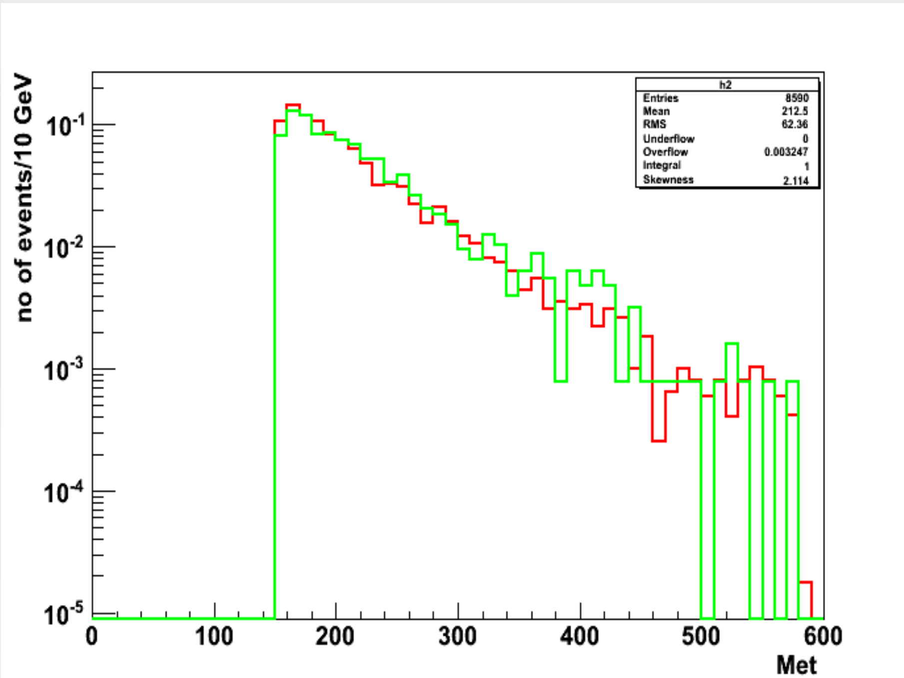



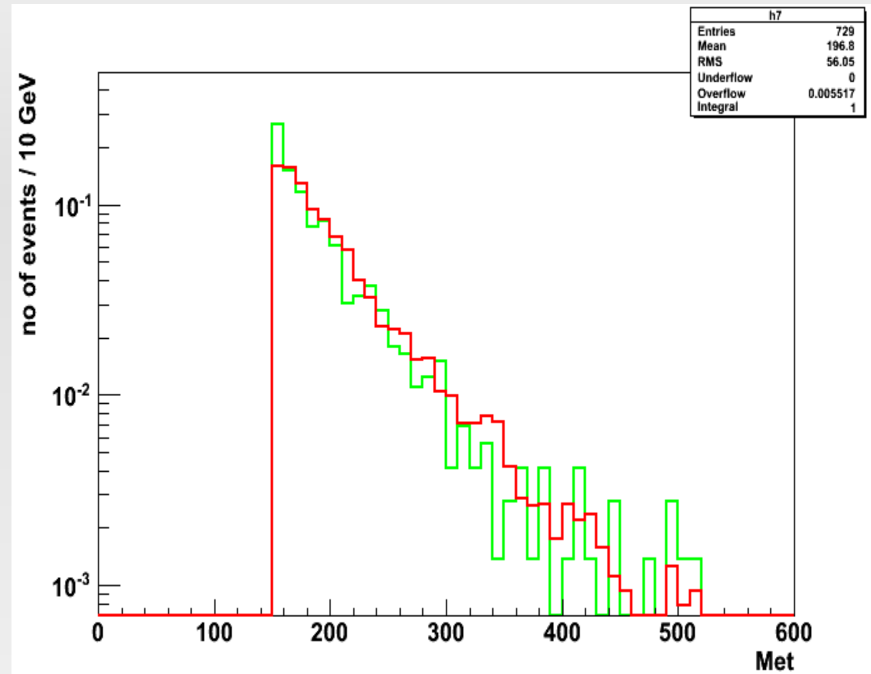

$p_T^Z > p_T^\gamma$ in the Z+γ sample and it is compared with the **leading** photon of the di-photon sample

$p_T^Z < p_T^\gamma$ in the Z+γ sample and it is compared with the **next to leading** photon of the di-photon sample

# MET distributions

Comparison at RECO level

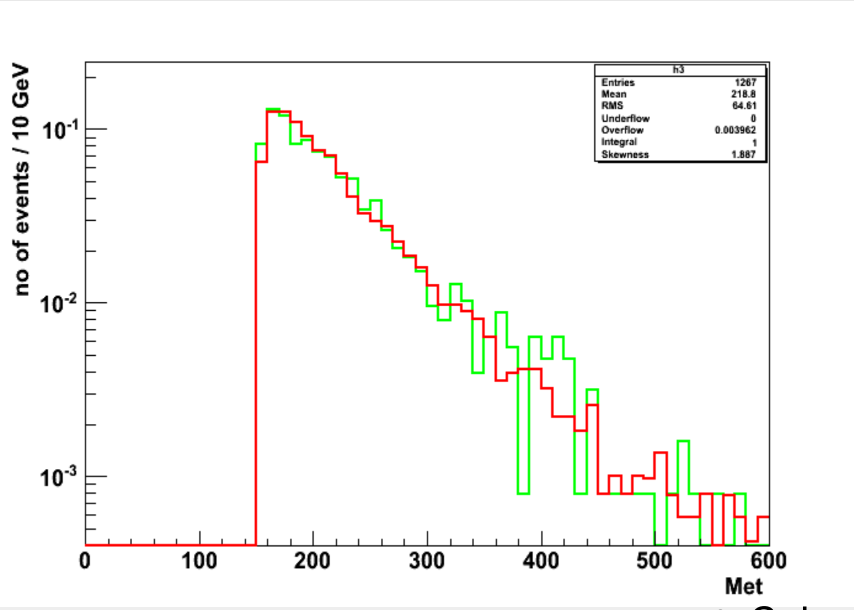


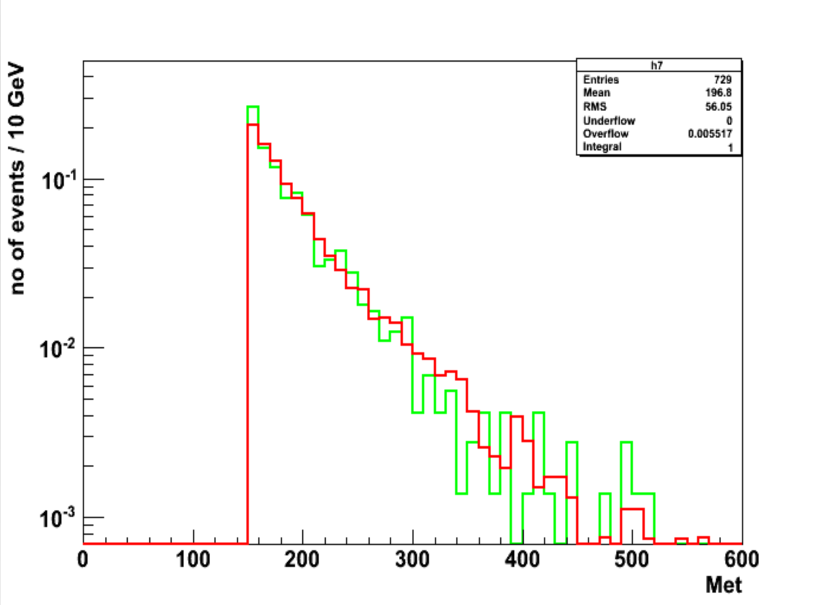

- **Met like quantity, leading** $p_t^{\gamma}$ + CaloMet from diphoton sample plotted with **CaloMet** from Zgamma sample ($p_T^Z > p_T^{\gamma}$ )
- Cuts on photon in analysis become the cuts on next to leading photon from diphoton sample.
- Diphoton Statistics : 19.38
- Z gamma : 5.22 ( with an additional cut of selecting events with CaloMet > $p_T^{\gamma}$ )

- **Met like quantity, next leading** $p_t^{\gamma}$ + CaloMet from diphoton sample plotted with **CaloMet** from Zgamma sample($p_T^Z < p_T^{\gamma}$ )
- Cuts on leading photon in the analysis, become the cuts on leading photon in diphoton sample.
- Diphoton Statistics: 24.88
- Z gamma: 3.00 ( CaloMet < $p_T^{\gamma}$ )

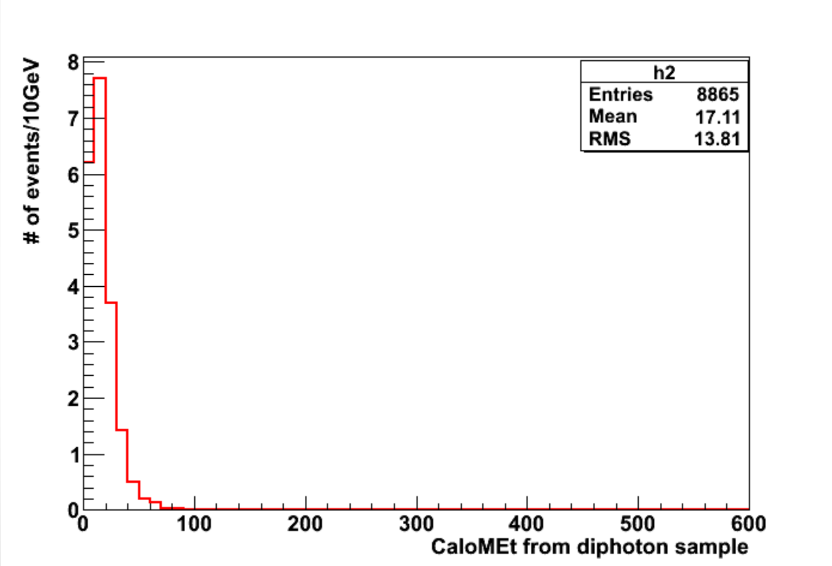
- Leading photon pt only from diphoton sample with calomet from zgamma




- Next leading photon pt from diphoton sample with calomet from Zgamma sample.




- Calomet from Diphoton sample



# Purity of Diphoton Sample

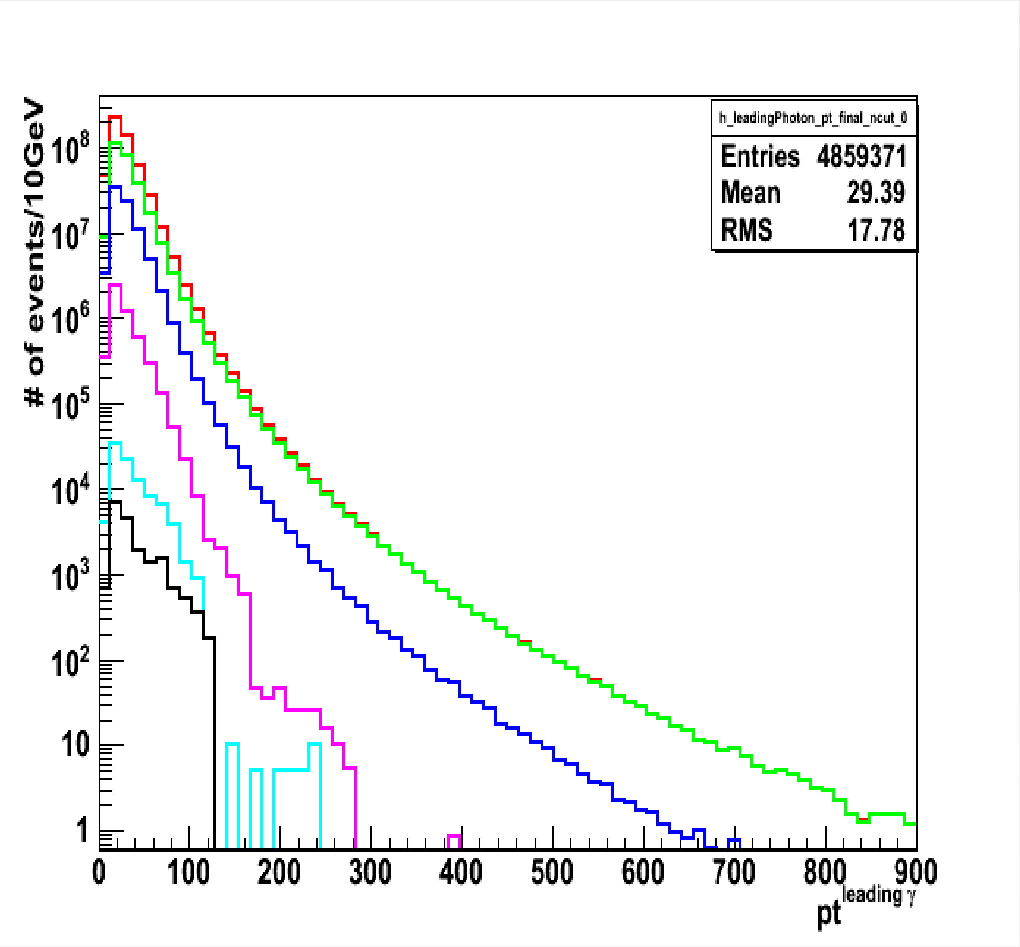
- In reality, diphoton sample collected from experiment will have contribution from $\gamma$ + jets and QCD where jets will fake photons.
- So, to have a minimum contribution from these in pure diphoton sample, we put a selection criteria.

- Trigger : is_HLT_Photon25_event
- P_T : Both photons are required to have pt > 150 GeV
- Fiducial range : Both photons are required to be in eta range $|\eta| < 2.5$
- Isolation : Both photons should be isolated.
- Ecal pt sum in the hollow cone ( 0.04 < dr < 0.4) < 10 GeV.
- Hcal pt sum in the hollow cone ( 0.04 < dr < 0.4) < 5 GeV
- Track pt sum in hollow cone ( 0.1 < dr < 0.4) < 5 GeV.
- Track pt cut : Leading track pt < 10 GeV.

# QCD background with looser cuts

| Cuts | No of events |
|---|---|
| Initially started with | 4.86 M |
| Eta Cut on both photons | 2.95 M |
| Ecal Isolation | 0.58 M |
| Hcal Isolation | 28 K |
| Track pt isolation | 557 |
| Track pt | 108 |

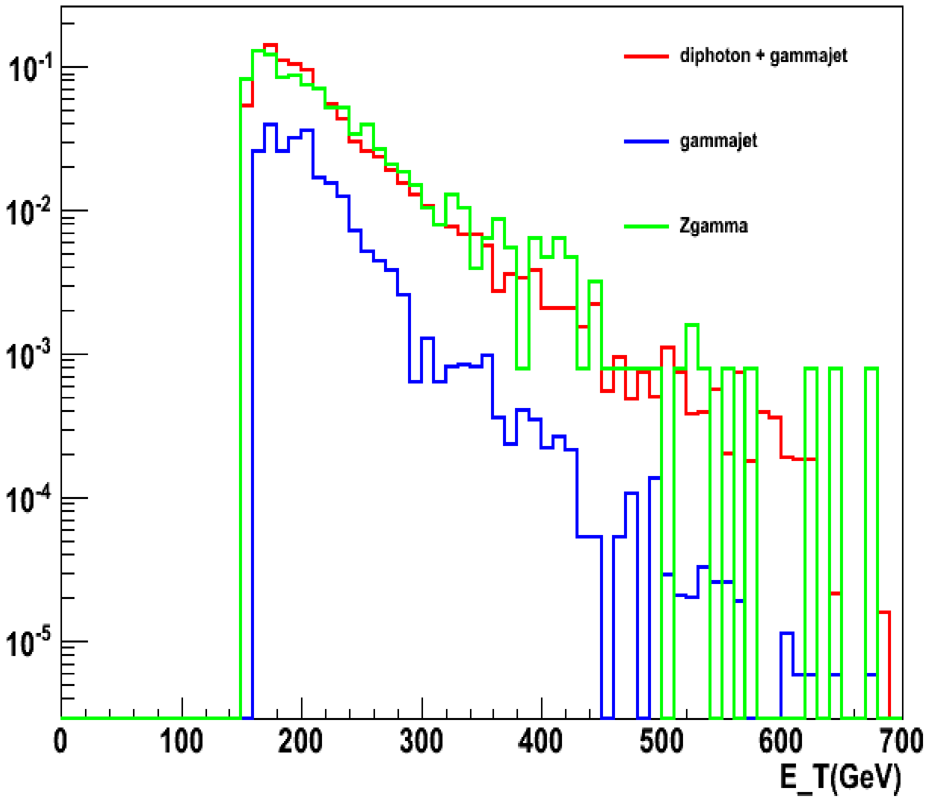
- No HLT & Pt cuts here.




| Cuts | No of events |
|---|---|
| Initially started with | 4.86 M |
| HLT Cut | 1.1 M |
| Pt cut on both photons | 48793 |
| Eta Cut | 48635 |
| Isolation cuts on both photons | 1 |
| Track pt cut | 0 |

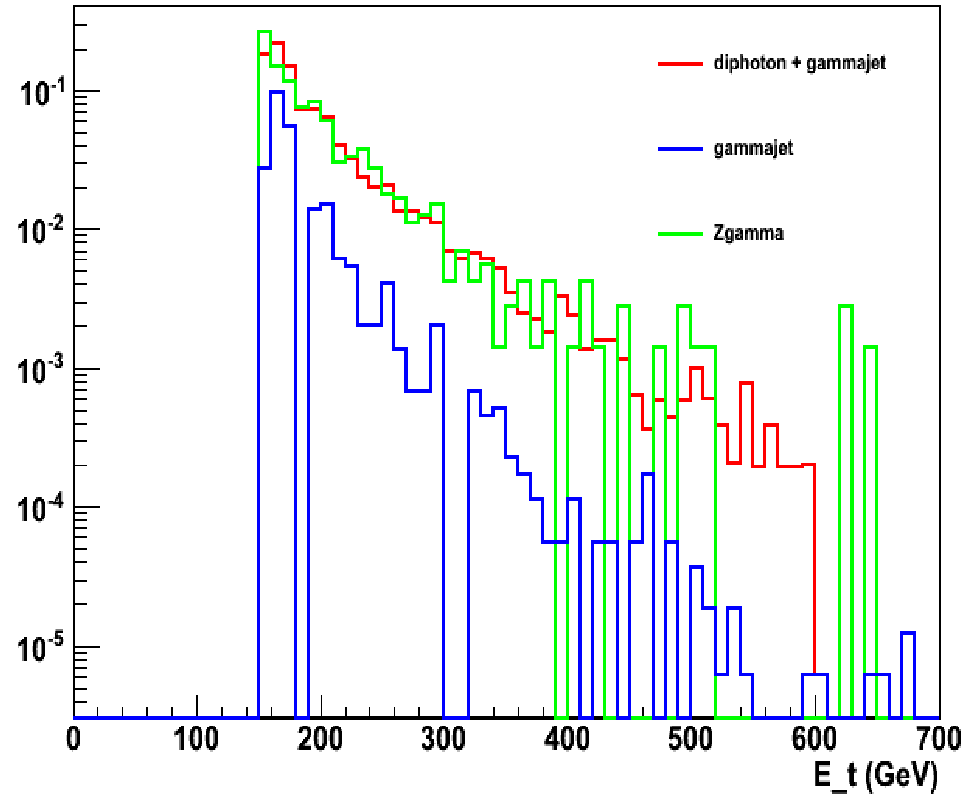
- No QCD events are left if we apply selection criteria

# Gamma + jet Contribution




For the leading case

- Diphoton Integral : 16.6
- γ+ jet Integral : 5.1
- Z γ Integral : 5.24

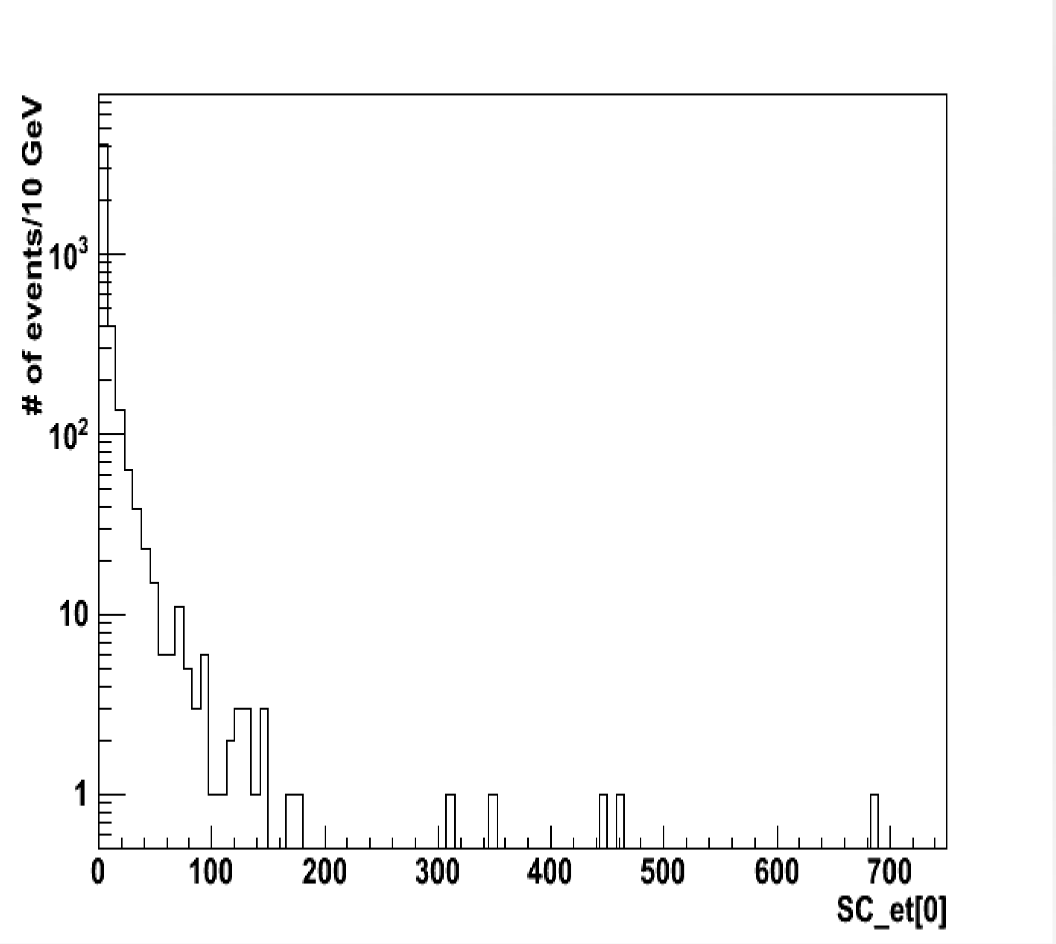



For next to leading case

- Diphoton Integral : 15.5
- γ+ jet Integral : 4.8
- Z γ Integral : 3.01

# Non beam background - Cosmics

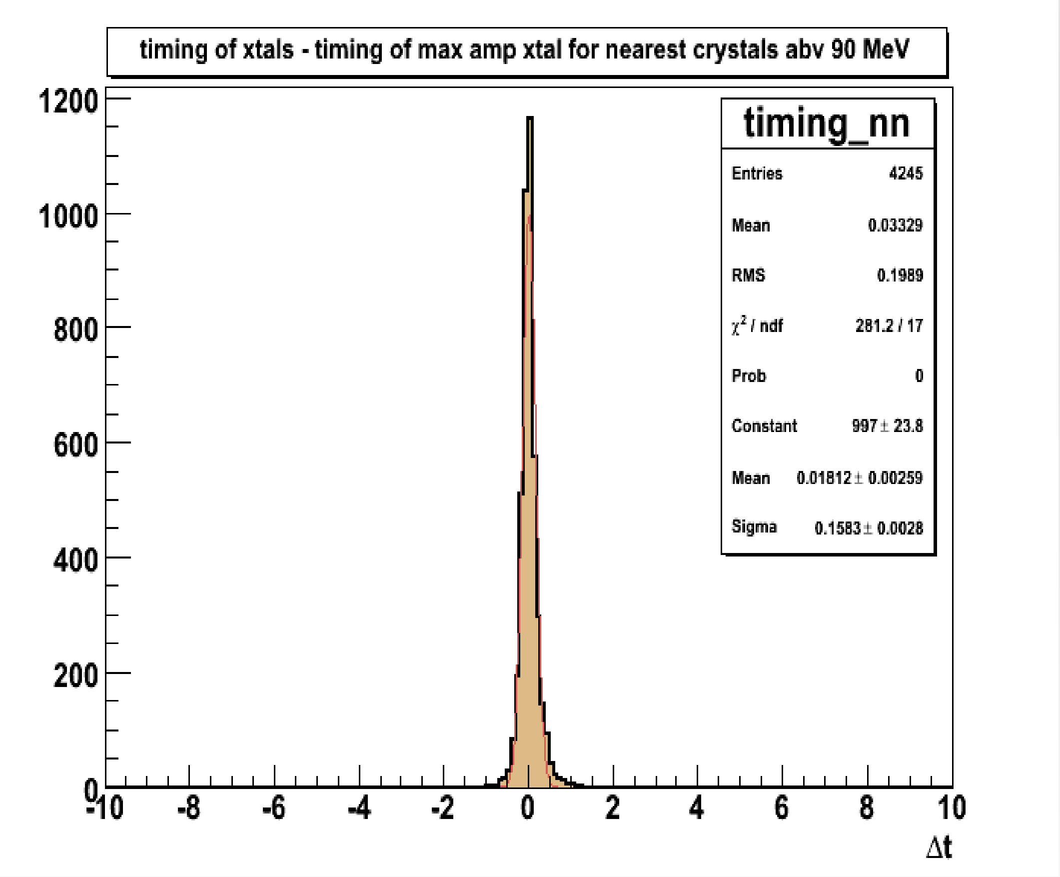
- This shows the energy deposit by superpointing muons in ECAL, which goes till 700 GeV.
- Though the statistics is less, but we need to know the rate of these cosmic muons so that once we have data over some interval of time, then we know how many such events we expect  from the data.




Only “Barrel” Muons

# Timing Resolution

- Asking >90 MeV for each crystal in 3x3 around seed we get fitted sigma = 3.96 ns ( from CRUZET-2)
- More recent study shows as energy deposit in ECAL increases, resolution becomes better(~100ps for large energy deposit in ECAL)

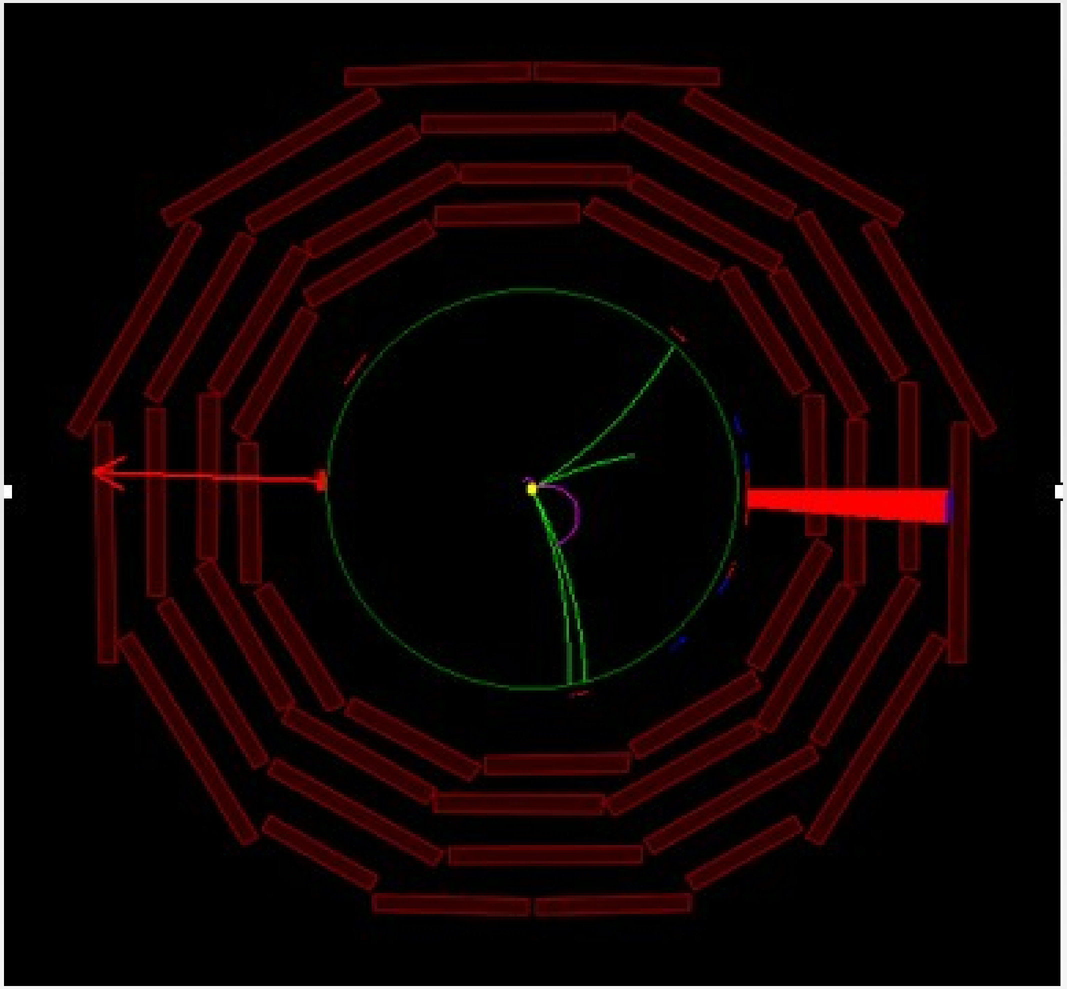


# Cosmic rate calculation

- 1 second of collision means $4 \times 10^7$ collisions.
- For a window of 100 ps around the collision, cosmics will be accepted for $2 \times 100 \times 4 \times 10^7$ ps = $8.0 \times 10^{10}$ ps = $8.0 \times 10^{-2}$s
- If the rate of Cosmics is R Hz, then total cosmics collected in 1s for a window of 100ps around the collision = $R \times 8.0 \times 10^{-2}$.
- Then further from this timing window, total cosmics faking photons = $\varepsilon\,(R \times 8.0 \times 10^{-2})$, where $\varepsilon$ is the efficiency of cosmics which passes the selection criteria.
- $\varepsilon R = 1.414 \times 10^{-5}$ Hz ( for pointing muons above 150GeV) .
- This means we will have ~1 muon in a year corresponding to 2808 bunches.

# Summary & Plans

- We can estimate Z ( Inv) $\gamma$ background using diphoton sample.
- We can estimate cosmics using the rate and try to reduce it further having track matching or doing extrapolation to muon chambers.
- We will consider beam halo too in the studies.
- We will incorporate better estimation of QCD in data driven method.



**THANK YOU**

# Backup Slides

# Selection results - I

| $\sigma$ in *pb* ( ) = % | ADD MD1d2 | ADD MD2d2 | ADD MD3d2 | $Z(\nu\nu)+\gamma$ | $W+\gamma$ | $W\to e\nu$ | $W\to\mu\nu$ | $W\to\tau\nu$ | $Z(ll)+\gamma$ |
|---|---|---|---|---|---|---|---|---|---|
| **starting $\sigma$** | 0.1983 | 0.0384 | 0.0105 | 0.1381 | 36.6 | 11850 | 11850 | 11840 | 11 |
| **HLT** | 0.1957 (98.7) | 0.0379 (98.7) | 0.0104 (99.0) | 0.1359 (98.5) | 12.1127 (33.1) | 7549.22 (63.7) | 326.437 (2.8) | 532.310 (4.5) | 3.9397 (35.8) |
| **$P_T^{\gamma}$ >150 GeV** | 0.0866 (44.3) | 0.0205 (54.1) | 0.0059 (56.7) | 0.0394 (29.0) | 0.0564 (0.5) | 3.2418 (0.04) | 0.6825 (0.2) | 0.2728 (0.05) | 0.0243 (0.6) |
| **MET >150 GeV** | 0.0801 (92.5) | 0.0192 (93.7) | 0.0056 (94.9) | 0.0317 (80.5) | 0.0241 (42.7) | 0.2060 (6.4) | 0.5614 (82.3) | 0.0885 (32.4) | 0.0021 (8.8) |
| **$\Delta\phi$ >2.7** | 0.0773 (95.4) | 0.0186 (96.9) | 0.0054 (96.4) | 0.0297 (93.6) | 0.0238 (98.8) | 0.1951 (94.7) | 0.5284 (94.1) | 0.0885 (100) | 0.0021 (97.4) |
| **$\lvert\eta^{\gamma}\rvert$<2.5** | 0.0760 (98.3) | 0.0183 (98.4) | 0.0053 (98.1) | 0.0296 (99.6) | 0.0213 (89.5) | 0.1951 (100) | 0.5174 (97.9) | 0.0811 (91.6) | 0.0020 (97.4) |
| **$iso^{\gamma}$** | 0.0737 (97.0) | 0.0177 (96.7) | 0.0052 (98.1) | 0.0283 (95.3) | 0.0192 (90.1) | 0.0106 (5.4) | 0.1211 (23.4) | 0.0074 (9.1) | 0.0019 (95.0) |
| **Track veto** | 0.0730 (99.1) | 0.0175 (98.9) | 0.0052 (100) | 0.0272 (96.1) | 0.0050 (26.0) | 0.0106 (100) | 0 (0) | 0.0074 (100) | 0.0009 (47.4) |
| **Jet veto** | 0.0633 (86.7) | 0.0153 (87.4) | 0.0045 (86.5) | 0.0149 (54.8) | 0.0025 (50.0) | 0.0106 (100) | 0 (0) | 0 (0) | 0.0005 (55.6) |
| **final eff. (%)** | 31.9 | 39.9 | 42.6 | 10.8 | $6.8\ 10^{-3}$ | $8.95\ 10^{-5}$ | - | - | $4.5\ 10^{-3}$ |
| **# ev (300 $pb^{-1}$)** | **19.0** | **4.6** | **1.3** | **4.5** | **0.75** | **3.19** | **negl.** | **negl.** | **0.15** |

# Selection results - II

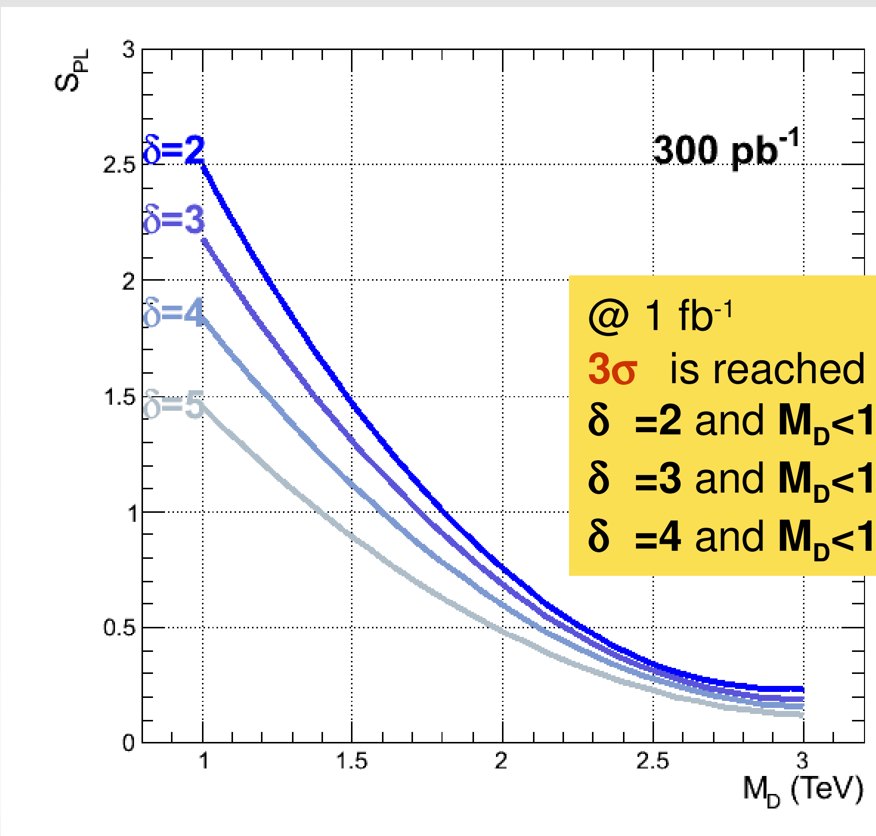
| $\sigma$ in *pb* ( ) = % | ADD MD1d2 | $Z(\nu\ \nu\ )$ +jet | $\gamma$ jet $p_T>80$ | $\gamma$ jet $p_T>170$ | $\gamma$ jet $p_T>300$ | $\gamma$ jet $p_T>470$ |
|---|---|---|---|---|---|---|
| **starting $\sigma$** | 0.1983 | 3700 | 1010 | 51.4 | 4.19 | 0.45 |
| **HLT** | 0.1957 (98.7) | 254.432 (6.9) | 854.845 (84.6) | 48.990 (95.3) | 4.012 (95.8) | 0.4333 (96.3) |
| **$P_T^\gamma$ >150 GeV** | 0.0866 (44.3) | 0.804 (0.3) | 79.250 (9.3) | 44.125 (90.1) | 3.844 (95.8) | 0.4189 (96.7) |
| **MET >150 GeV** | 0.0801 (92.5) | 0.487 (60.6) | 0.0898 (0.1) | 0.307 (0.7) | 0.0488 (1.3) | 0.0099 (2.4) |
| **$\Delta\ \phi$ >2.7** | 0.0773 (95.4) | 0.428 (87.9) | 0.0411 (45.8) | 0.0746 (24.3) | 0.0195 (40.0) | 0.0037 (37.4) |
| **$\vert\eta^{\gamma}\vert$<2.5** | 0.0760 (98.3) | 0.424 (99.1) | 0.0383 (93.2) | 0.0705 (94.5) | 0.0192 (98.5) | 0.0037 (100) |
| **iso$^\gamma$** | 0.0737 (97.0) | 0.007 (1.7) | 0.0327 (85.4) | 0.0633 (89.8) | 0.0170 (88.5) | 0.0033 (89.2) |
| **Track veto** | 0.0730 (99.1) | 0.007 (100) | 0.0065 (19.9) | 0.0059 (9.3) | 0.0012 (7.1) | 0.0001 (3.0) |
| **Jet veto** | 0.0633 (86.7) | 0 (0) | 0 (0) | 0.0008 (13.6) | $5.69\ 10^{-5}$ (4.7) | $4.94\ 10^{-6}$ (4.9) |
| **final eff. (%)** | 31.9 | - | - | $1.6\ 10^{-3}$ | $1.4\ 10^{-3}$ | $1.1\ 10^{-3}$ |
| **# ev (300 $pb^{-1}$)** | **19.0** | **negl.** | **negl.** | **0.24** | **0.02** | **0.001** |

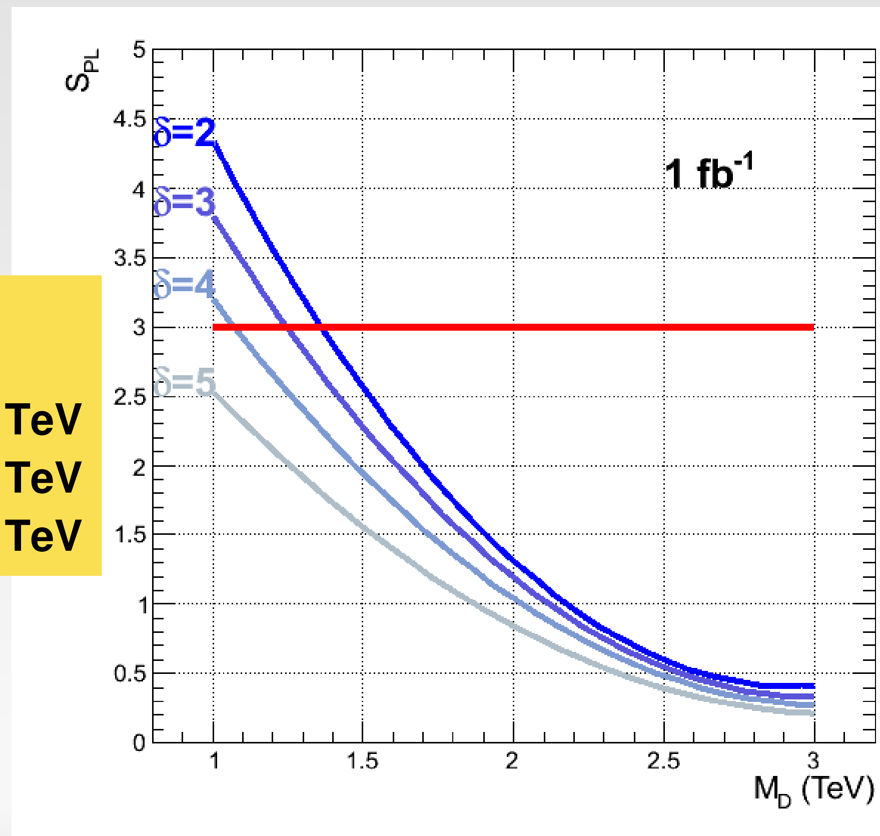
# Discovery potential

To compare signal and background we use the

Profile Likelihood Significance $S_{PL}$

The likelihood function is a Poisson distribution of $N_S+N_B$ multiplied by a Gaussian with $N_B$ as mean and $\Delta_B$ as sigma (*arXiv:physics/0702156)*




@ 1 $fb^{-1}$

**3σ** is reached if

**δ =2** and **$M_D$<1.4 TeV**

**δ =3** and **$M_D$<1.3 TeV**

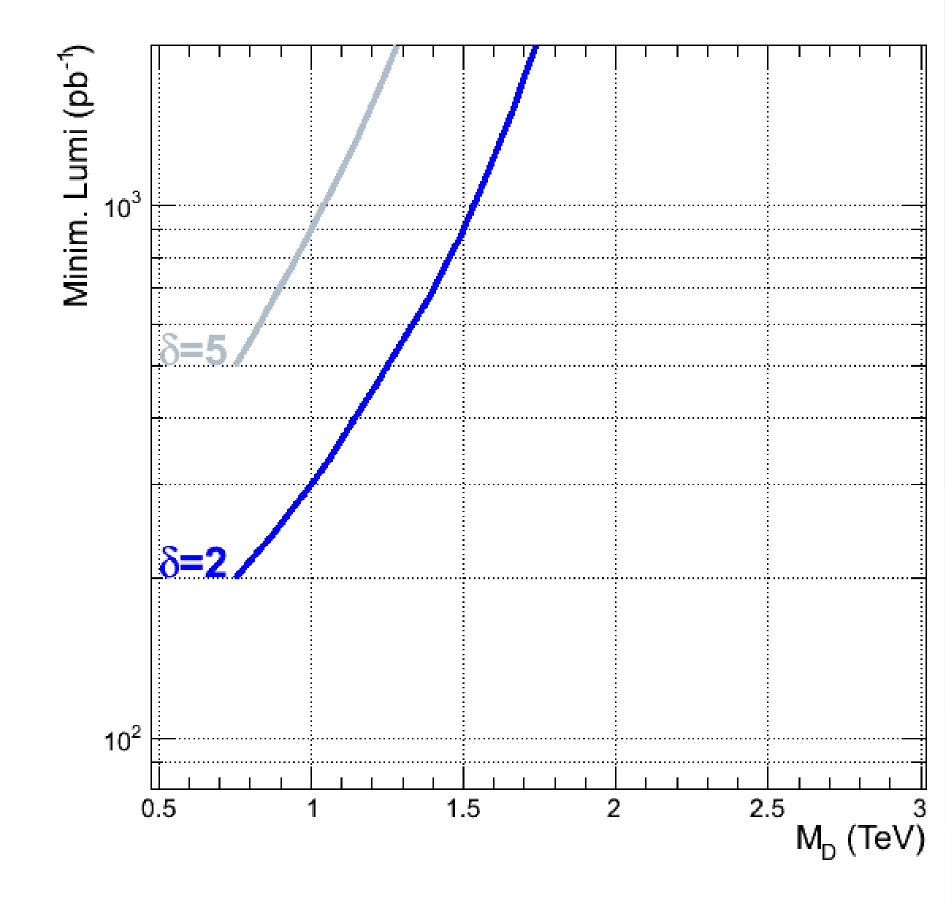
**δ =4** and **$M_D$<1.1 TeV**

# Exclusion limits

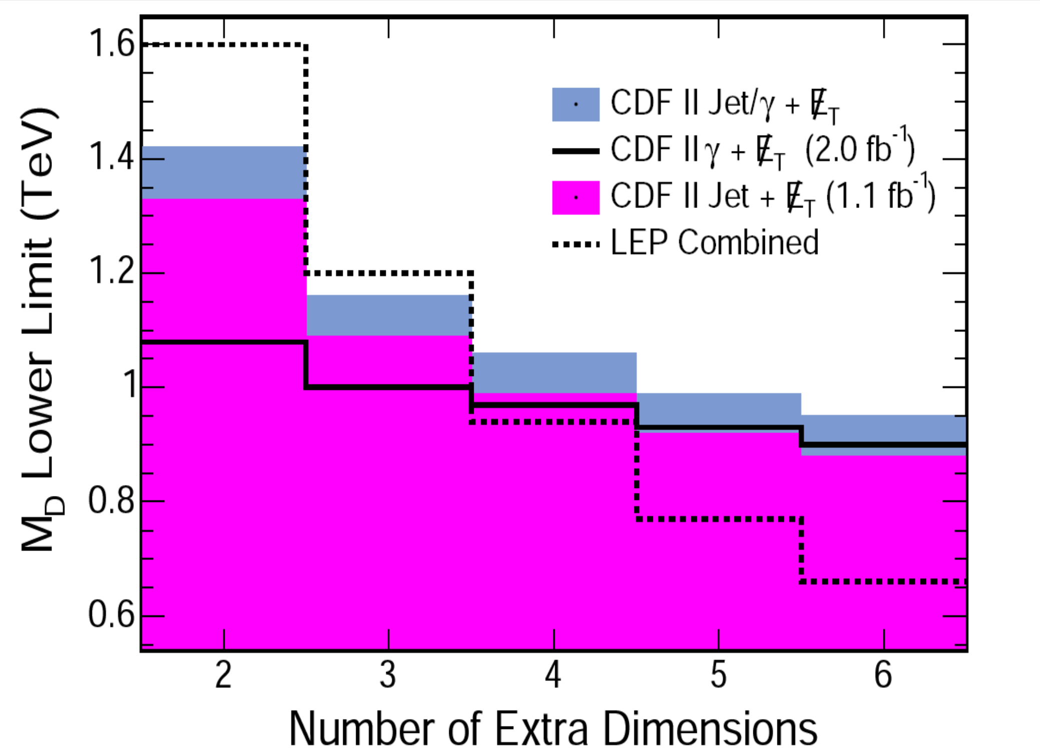
- Assumption of no signal
- Calculation of 95% C.L.
- Minimum luminosity to exclude a given $M_D$ value

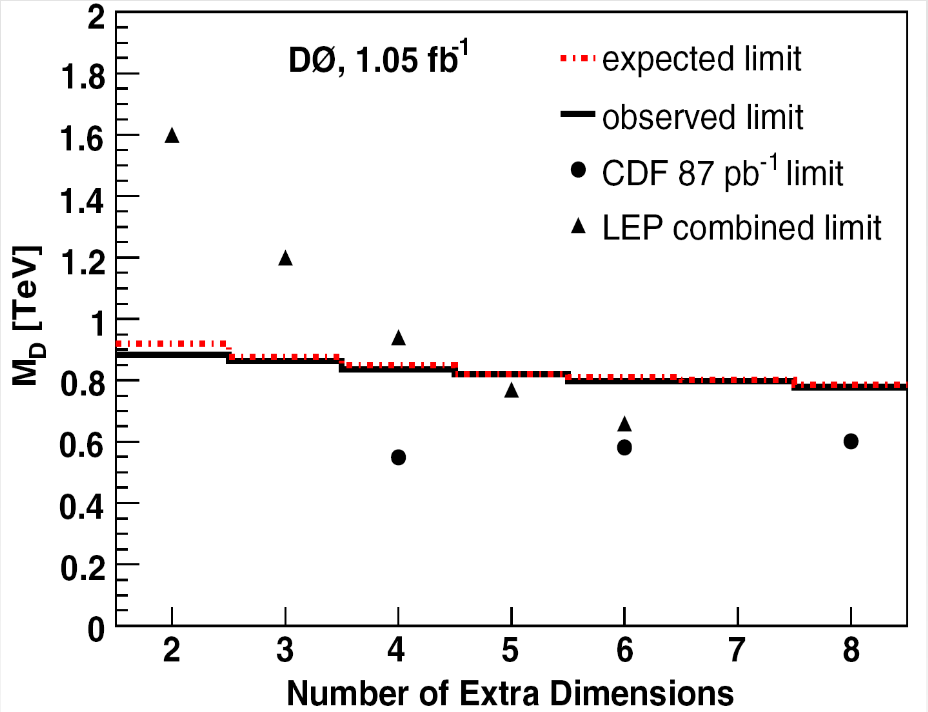
With 300 $pb^{-1}$ the exclusion limits are:
**$M_D$ = 1.15, δ = 2**

With 1 $fb^{-1}$ the exclusion limits are:
**$M_D$ = 1.55, δ = 2**
**$M_D$ = 1.05, δ = 5**



# Results From Tevatron

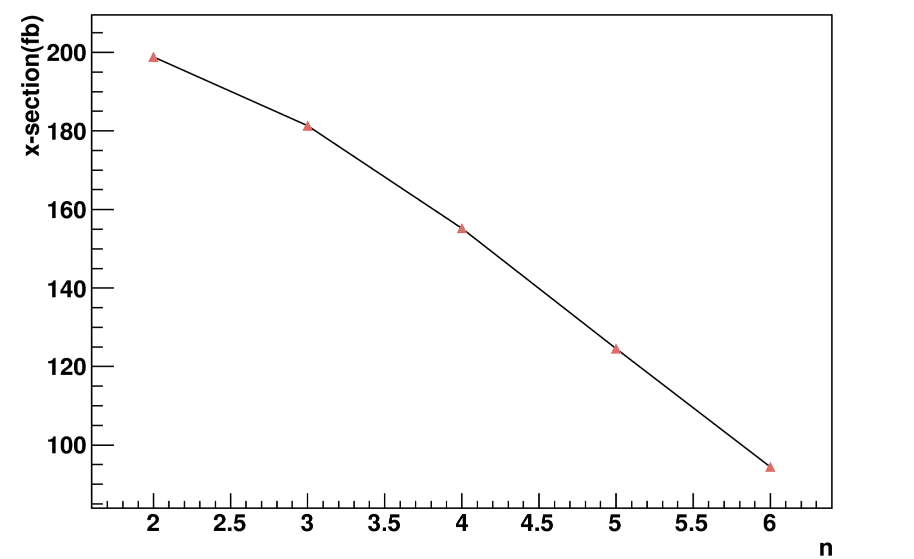


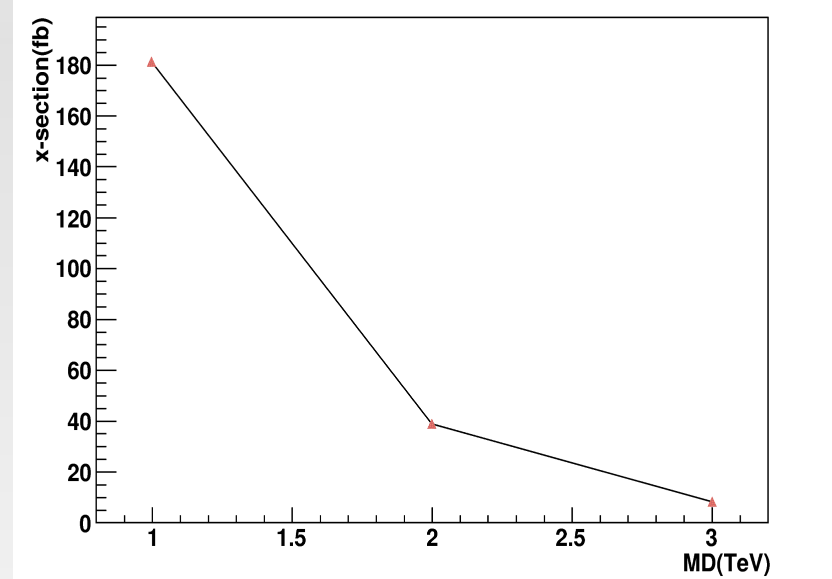

- 95 % C.L. lower limits on Md in ADD model as the function of number of extra dimensions.

# Cross-section variation with the parameters of the theory

- As n increases keeping Md fixed ( here Md = 2TeV), x-section decreases.




- As Md increases keeping n fixed ( here n = 3), x-section decreases.




| | Md= 1TeV | Md=2TeV | Md=3TeV |
|---|---|---|---|
| N=2 | 198.9 | 38.5 | 15.05 |
| N=3 | 181.3 | 34.4 | 8.28 |
| N=4 | 155.2 | 29.8 | 6.62 |
| N=5 | 124.7 | 24.7 | 5.21 |
| N=6 | 94.4 | 19.5 | 3.99 |

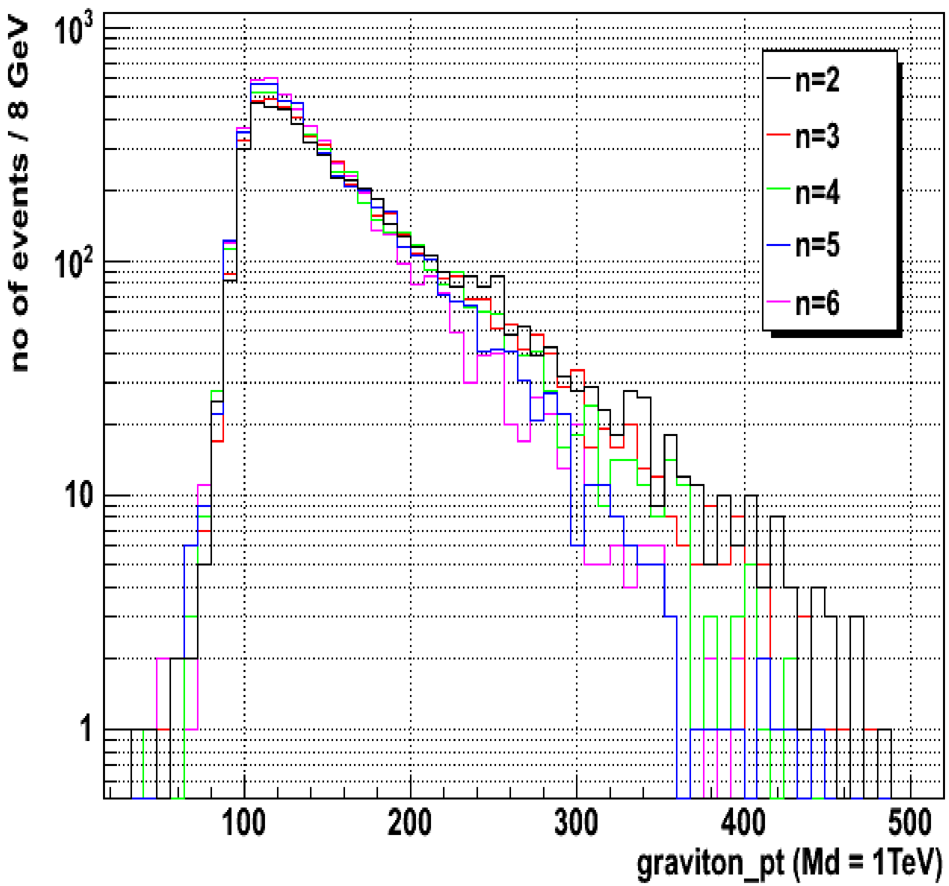
Signal cross section with the parameters of the theory

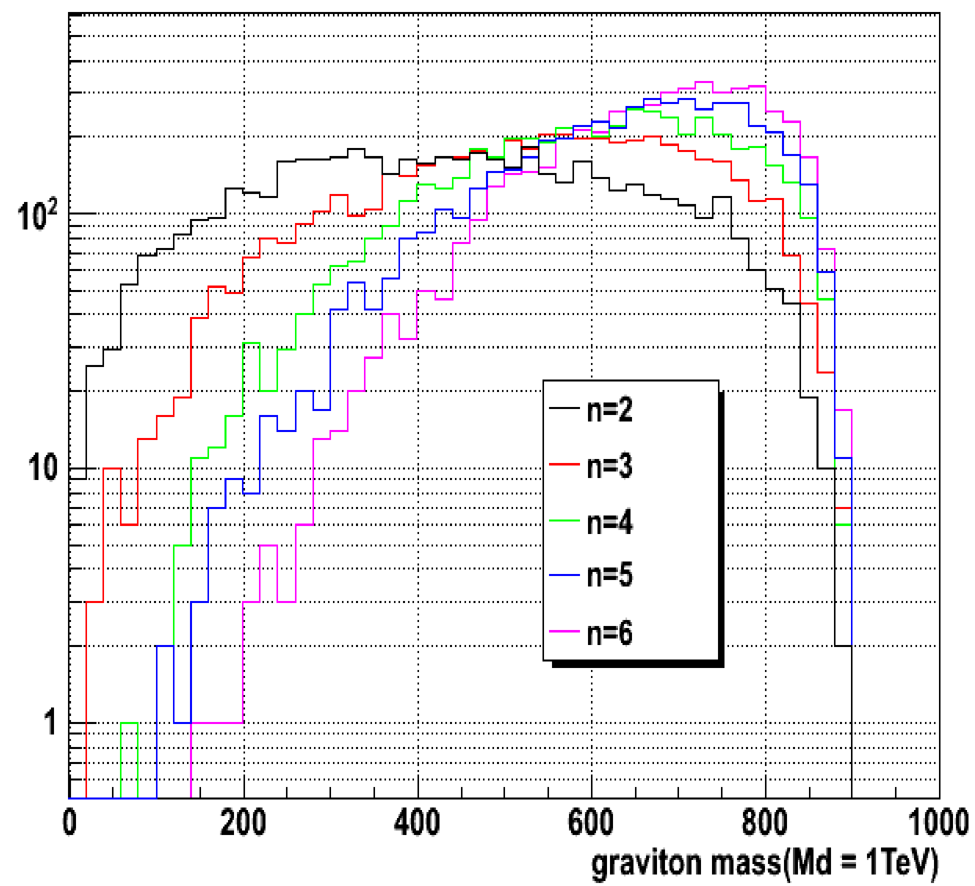
- Signal samples are produced at each of these points
- Pt cut on photon > 100GeV
- Generator : Sherpa
- Pdf: Cteq6ll.pdf
- n>6, difficult to probe at LHC, as cross sections are small.

**Previous Studies at CMS**

- Physics TDR
- CMS AN 2006/092

# GEN Level Plots – Graviton Kinematics



# Comics seen from Cruzet-2 data