# Search for Extra Dimensions in diphotons at CMS

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# Outline of the talk

- Introduction
- Photon commissioning
- MC study: expected limits and discovery potential
- Work in progress with 7 TeV data

# Hierarchy Problem and Extra Dimensions

- Hierarchy problem of SM
  - $M_{Pl}/M_{EWSB} \sim 10^{16}$
  - Large difference in scale → high degree of fine-tuning in fermion masses radiative correction ($\sim 10^{-34}$) to Higgs mass
- Large Extra Dimensions, ADD (Arkani-Hamed, Dimopoulos, Dvali) model [*Phys. Lett. B* ***429*** *(1998) 263*].
  - SM is constrained in 3+1 dimensions
  - Gravity propagates through entire multidimensional space and its strength is diluted -> effective Planck scale is observed

$$M_D^{(n_{ED}+2)} \sim \frac{M_{Pl}^2}{R^{n_{ED}}},$$

R and $n_{ED}$ are the size and number of ED, respectively

- Warped Extra Dimensions, RS (Randall-Sundrum) model [*Phys. Lett.* ***83*** *(1999) 3370 and ibid (1999) 4690*].
  - Extra dimension has finite size with Planck and SM branes at each end
  - Gravity is strong at Planck brane but graviton wave function is exponential suppressed when away from Planck brane.
  - Effective Planck scale at TeV brane:

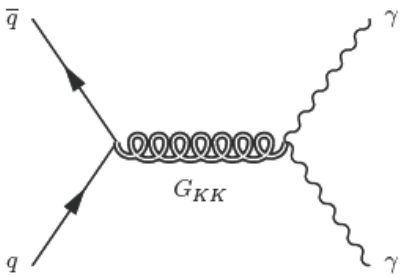
$$\Lambda_\pi = \overline{M}_{Pl} e^{-kr\pi} \quad kr \sim 10 \rightarrow \Lambda_\pi \sim 1TeV$$

k: warp factor

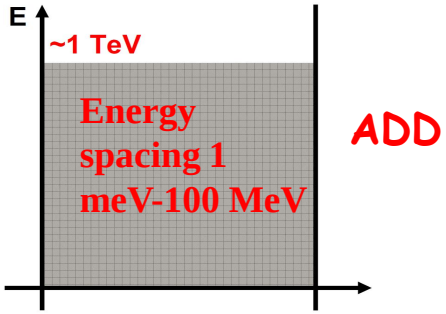
r: compactification radius

# Extra Dimensions (ED) at LHC

- Drell-Yan like virtual graviton production decaying to diphotons or difermions.
- Difermion channels are suppressed in the s-wave mode




- ADD signal:
  - Winding KK modes with small energy spacing ~1 meV-100 MeV -> continuous spectrum above SM expectation.
  - Define an ultraviolet (UV) cutoff, $M_s$, to avoid UV divergence of KK modes.

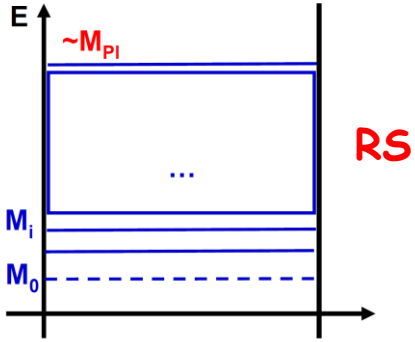



- RS signal:
  - First KK mode, $M_0$
  - Dimensionless coupling, $k/\overline{M}_{Pl}$ defines the graviton width
  - Coupling is constrained by EW data and model perturbation requirement.

$$0.01 < k/\overline{M}_{Pl} < 0.1$$

->Narrow resonances

$$M_i = M_0\, x_i / x_0 \approx M_0, 1.83 M_0, 2.66 M_0, 3.48 M_0, 4.30 M_0, \ldots$$




- Major backgrounds: dijets, photon+jet, diphotons and Drell-Yan dielectrons

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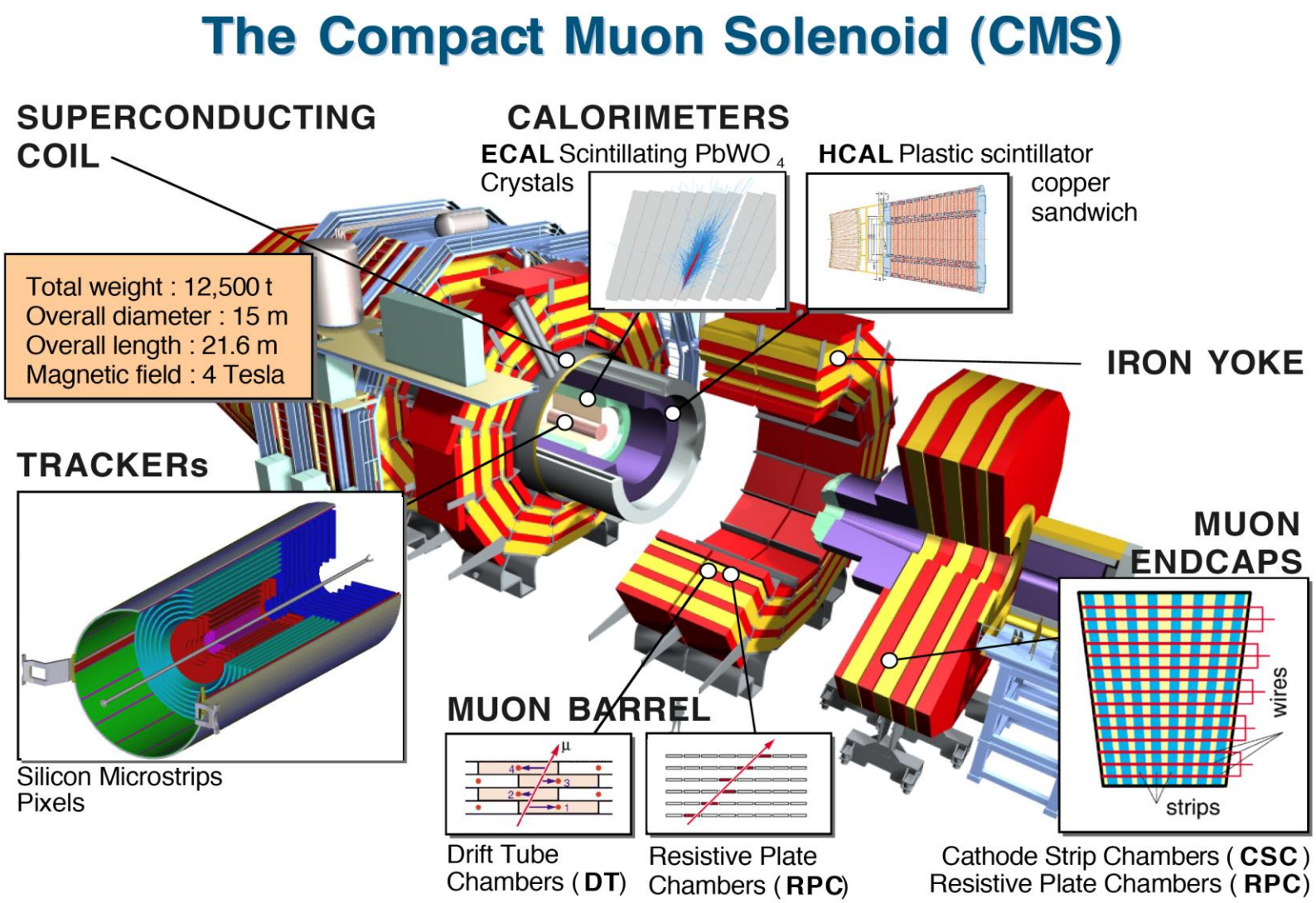
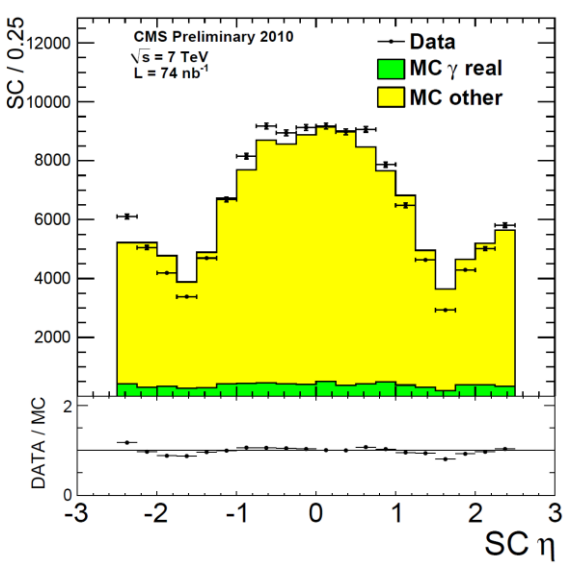
# CMS Detector



# Photon reconstruction

- Superclusters are used to reconstruct photons and electrons
  - Energy deposits in ECAL crystals are clustered
  - In order to recover energy spread due to bremsstrahlung, clusters are grouped into supperclusters extending in φ.
  - Small energy correction is applied to raw energy sum of superclusters
- Compare supercluster observables using data and Monte Carlo simulation.

**EGM-10-005**

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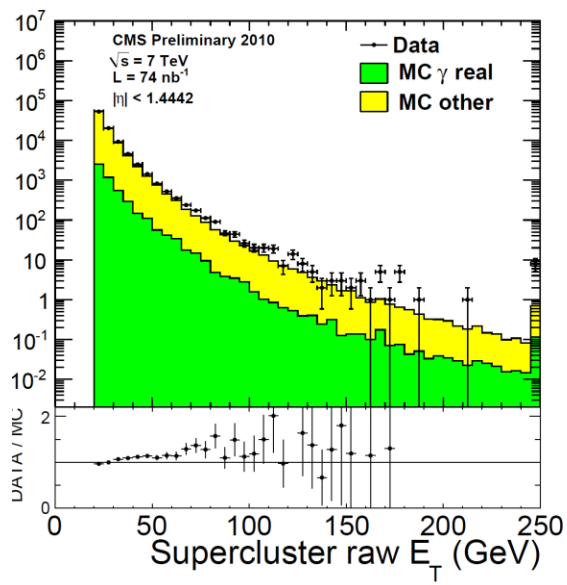


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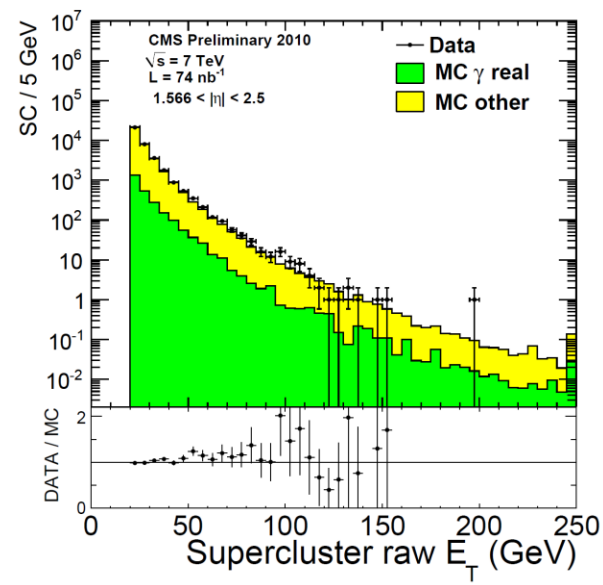
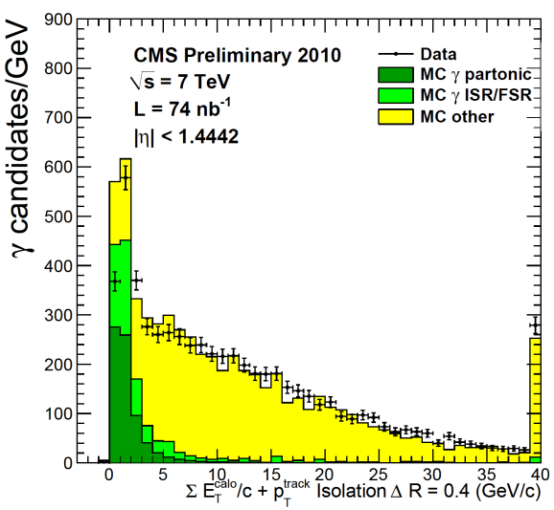


# Photon identification

- Require isolated photons with narrow shower shape
  - Isolation variables: energy deposits in ECAL, HCAL and transverse momentum sum of tracks inside a hollow cone around SC position.
  - Shower shape variables: widths of the EM showers in η. It can be used as a template to estimate photon purity.
- Pixel seed veto:
  - Hits in a search window consistent with a track
  - Distinguish photons from electrons

**EGM-10-005**

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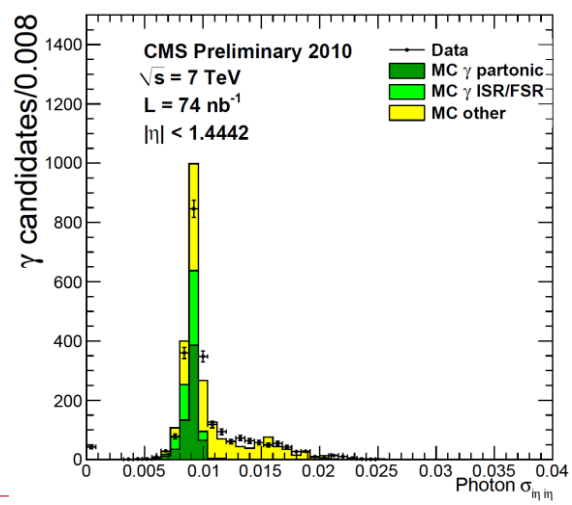


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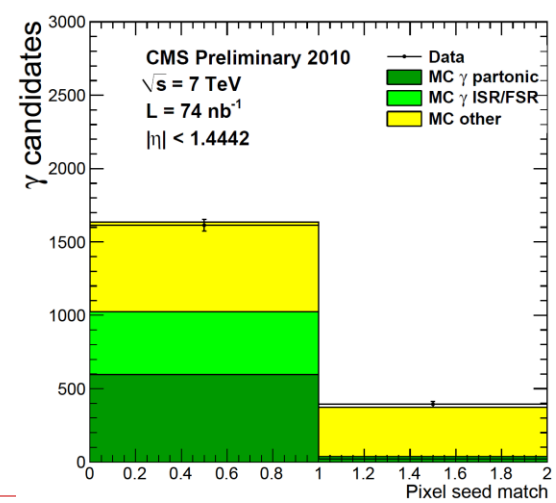


# Event selections

- Two isolated high pT photons (pT > 50 GeV)
- Optimized acceptance cuts:

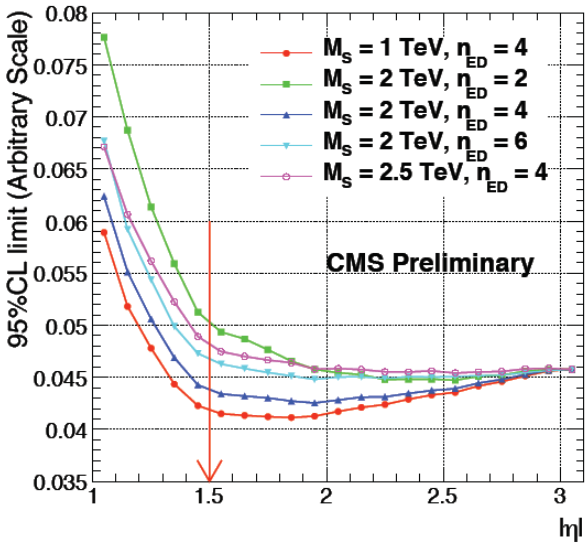
$$|\eta| < 1.5,\ m_{\gamma\gamma} > 700\text{GeV}$$

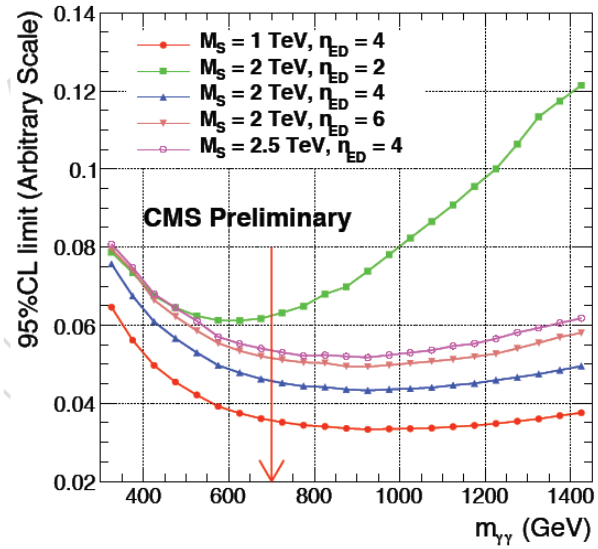
- Control region to normalize diphoton background

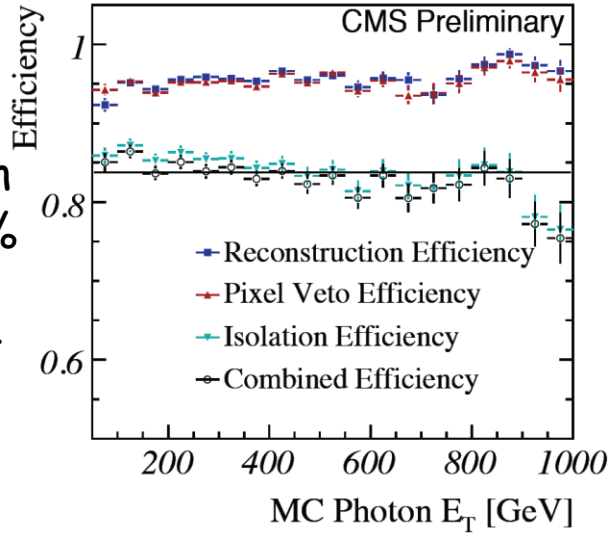
$$200 < m_{\gamma\gamma} < 500\text{GeV}$$

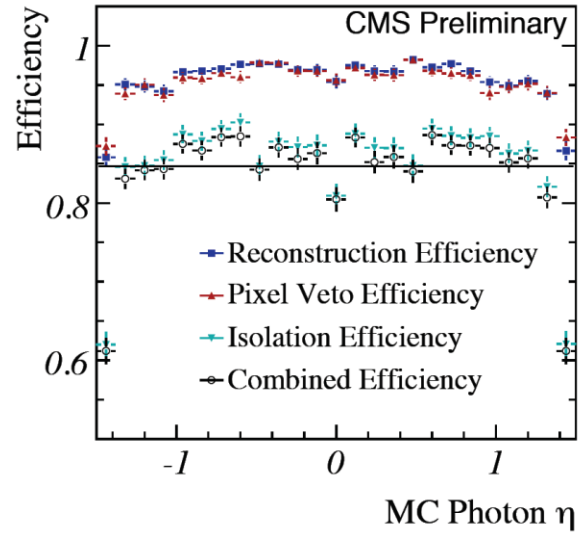
- Efficiency of finding an isolated photon is ~85%
- The jet-faking-photon rate is ~$10^{-4}$ at high pT (>200 GeV)

EXO-09-004



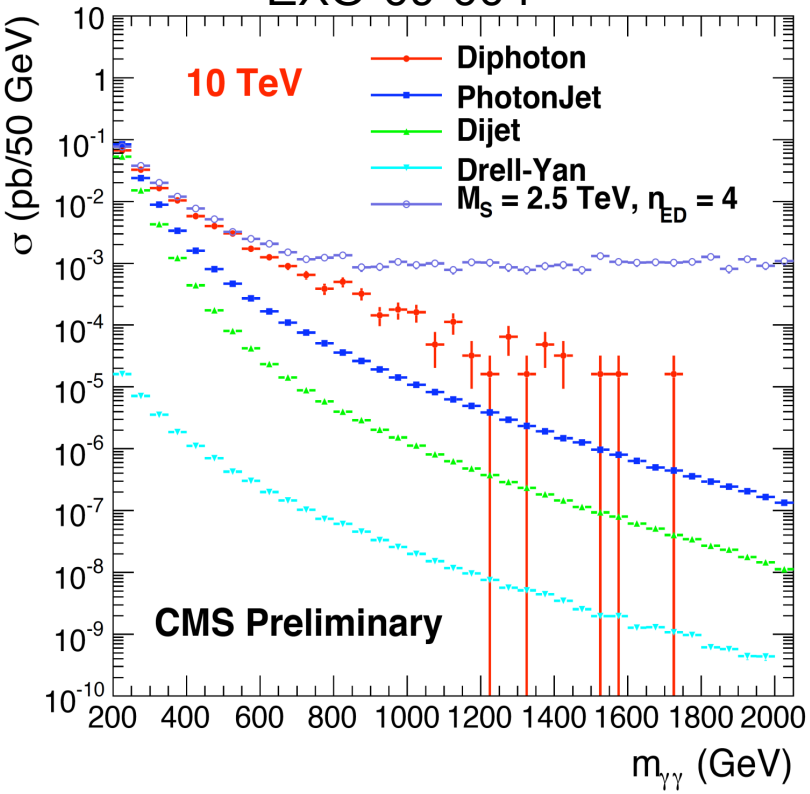



# SM backgrounds and ED signals at 10 TeV

EXO-09-004

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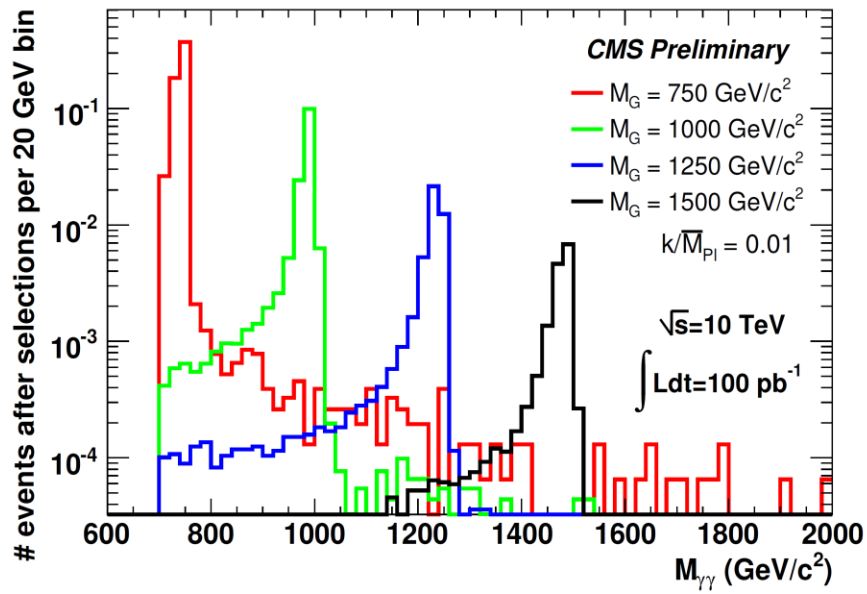



RS signal after selections

- Dominant background is irreducible QCD diphotons
- Other backgrounds: dijet, photon+jet, high mass Drell-Yan ($e^+e^-$)
- Total background (10 TeV): 0.4 at 100 $pb^{-1}$
- Background uncertainty: ~35% at 100 $pb^{-1}$

# LHC reach in ADD model at 7 TeV

- 10 TeV results (above slide) are scaled to 7 TeV by using parton luminosity ratios for gg and qqbar as a function of the invariant mass.

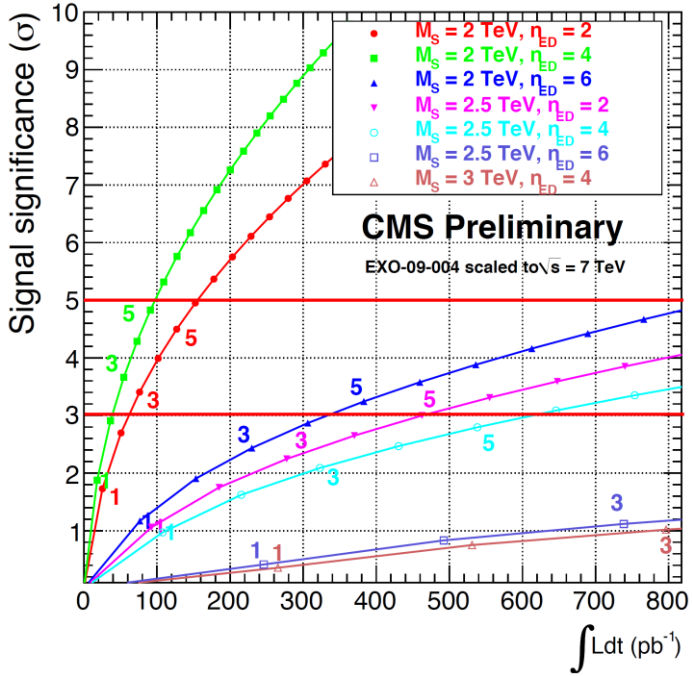
CMS NOTE-2010/008

Limits

| $n_{ED}$ | 95% C.L. Lower Limits on $M_S$ | | |
|---|---|---|---|
| | 50 pb$^{-1}$ | 100 pb$^{-1}$ | 200 pb$^{-1}$ |
| 2 | 2.0 TeV | 2.2 TeV | 2.4 TeV |
| 3 | 2.5 TeV | 2.7 TeV | 2.9 TeV |
| 4 | 2.1 TeV | 2.2 TeV | 2.4 TeV |
| 5 | 1.9 TeV | 2.0 TeV | 2.2 TeV |
| 6 | 1.7 TeV | 1.9 TeV | 2.0 TeV |
| 7 | 1.6 TeV | 1.8 TeV | 1.9 TeV |

CMS NOTE-2010/008

Discovery potential

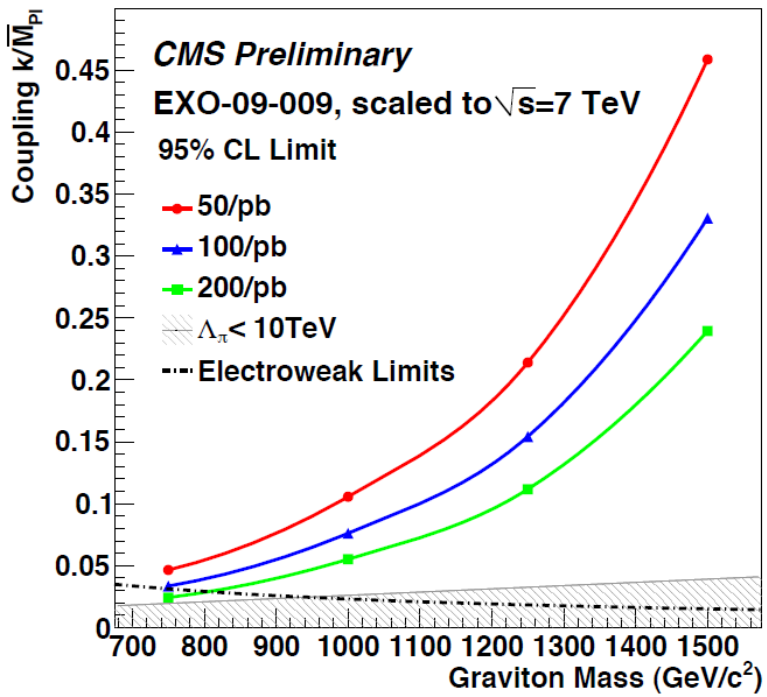



- At 50 pb$^{-1}$, comparable limits with Tevatron limits, 1-2 TeV
- Observe and discover large region of the parameter space

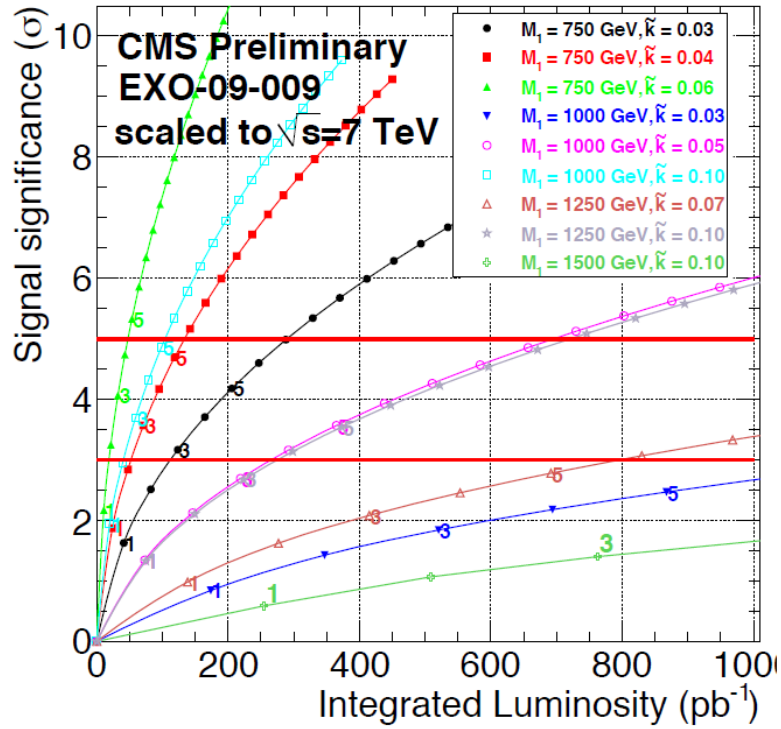
# LHC reach in RS model at 7 TeV

CMS NOTE-2010/008

Limits




Discovery potential




- 95% limit on graviton mass ~1 TeV at 50 pb$^{-1}$ with $\tilde{k} \sim 0.1 (\tilde{k} = k / \bar{M}_{Pl})$
- 5 sigma discovery for 750 GeV/c$^2$ graviton at ~125 pb$^{-1}$ with $\tilde{k} \sim 0.04$

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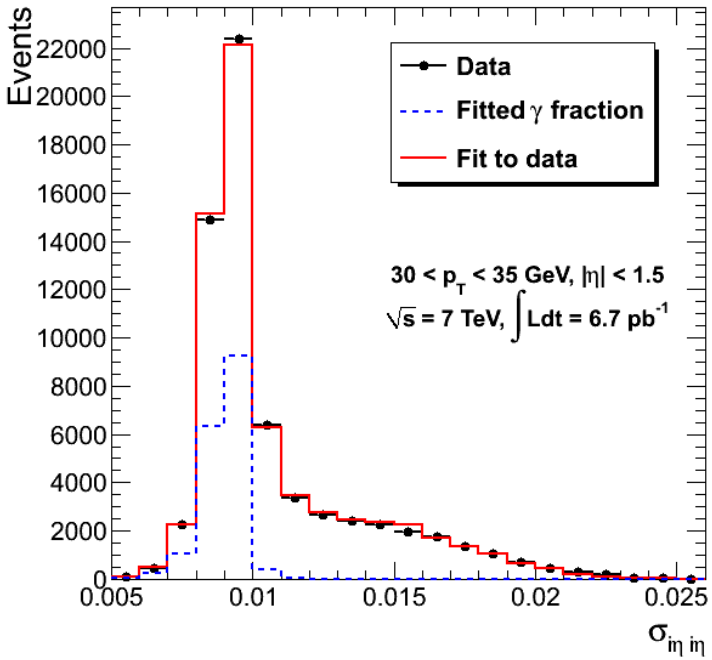
# Background estimation

- QCD processes are not well-modeled by MC simulation->need a data-drive method to estimate dijet and photon+jet backgrounds
  - Define photon fake rate as the fraction of tight photons (passing tight selection for selecting signal) over loose photons (passing preselection and not a tight photon).
  - Convolute numbers of loose-loose and loose-tight diphoton observed in data by photon fake rate
- Diphoton background is estimated using MC simulation
- Drell-Yan dielectron background is small and can be estimated using electron-faking-photon fake rate

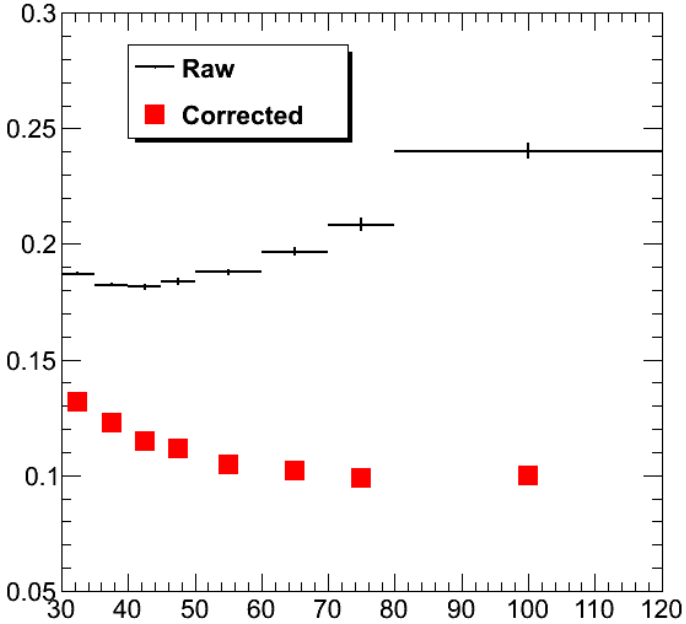
# Photon fake rate estimation

- Need to subtract photon contamination -> use photon purity
- Estimate photon purity by template fitting
  - Template: shower shape, isolation sum or E/p of converted photons

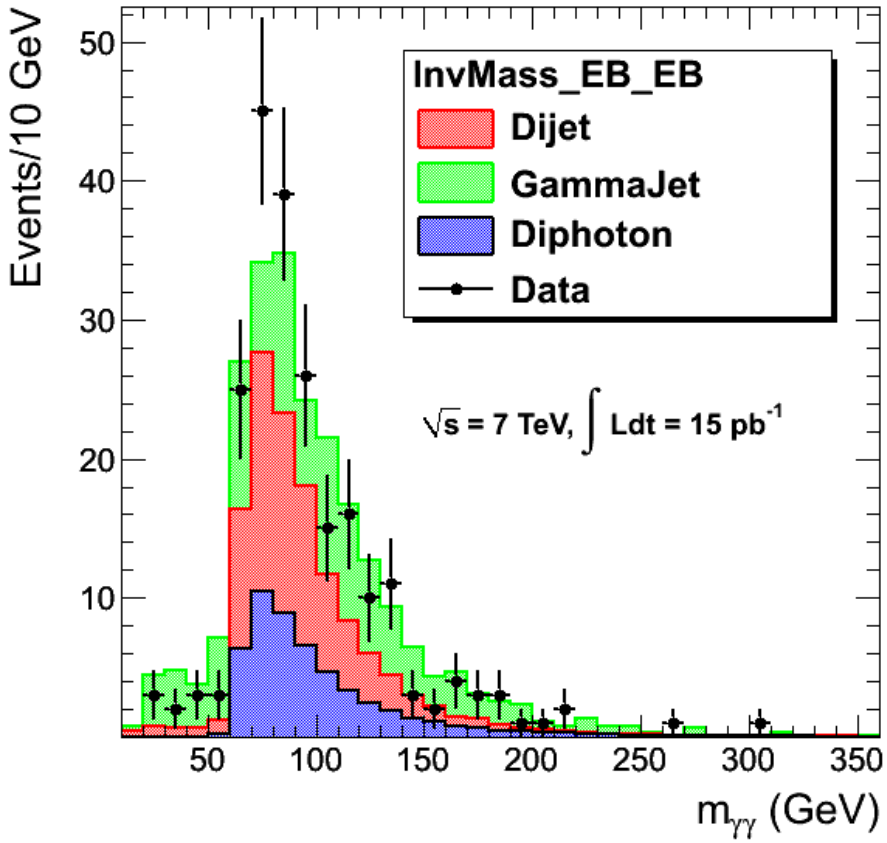
Work in progress




Work in progress



# Diphoton invariant mass from data



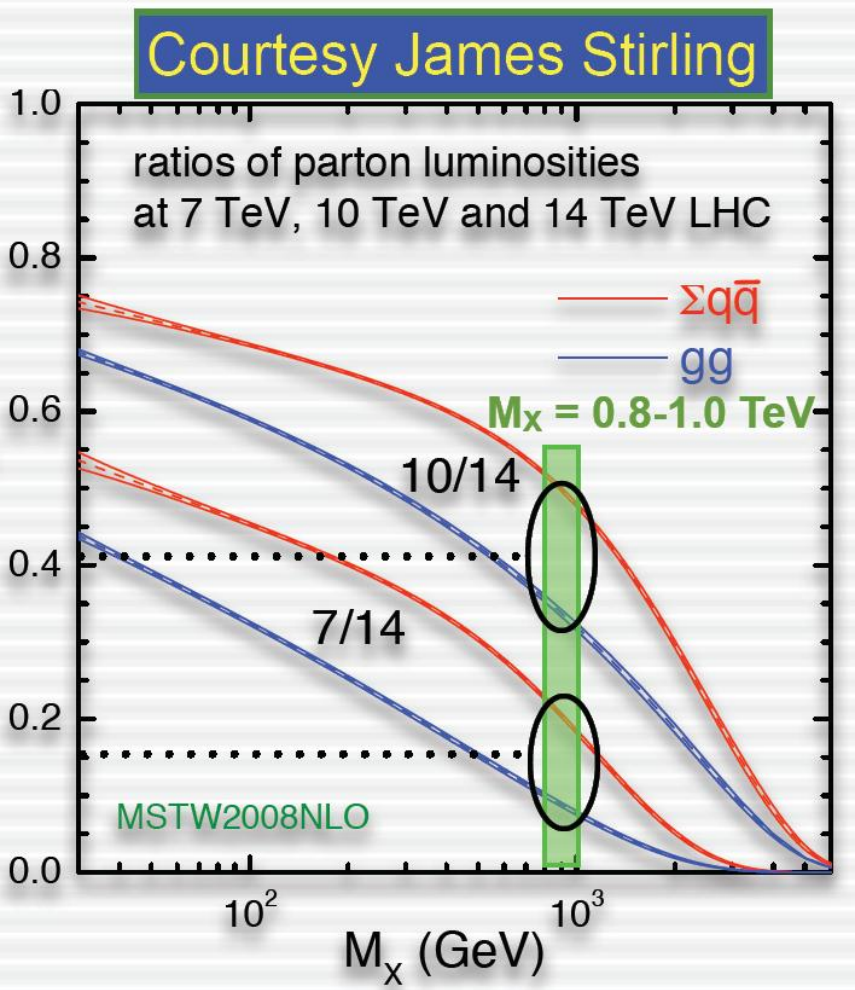

Work in progress

- Data-driven estimation of dijet and photon+jet background using photon fake rate
- Good agreement between data and total backgrounds.

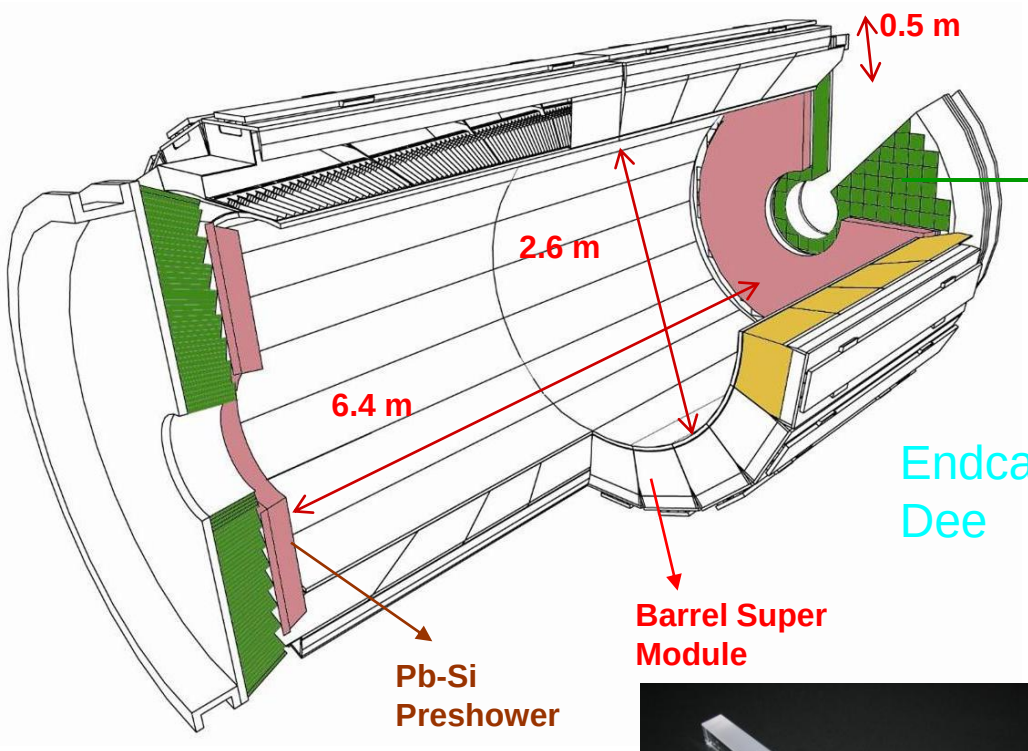
# Conclusions

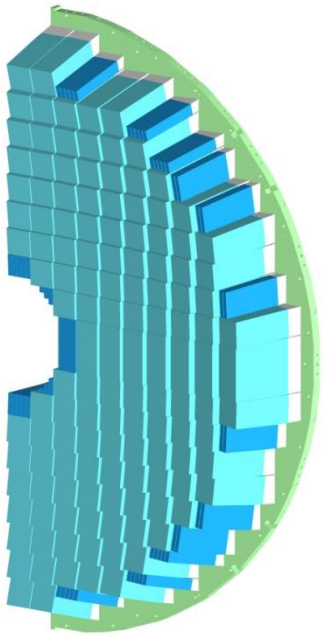
- The photon reconstruction is fully commissioned and ready for physics analysis.
- Diphoton channel has high sensitivity for probing extra dimension effect.
- With ~100 $pb^{-1}$ of data, the most stringent 95% CL limits can be set for the extra dimension model parameters.

# Back up


Courtesy James Stirling
ratios of parton luminosities
at 7 TeV, 10 TeV and 14 TeV LHC
Σqq̄
gg
M_X = 0.8-1.0 TeV
10/14
7/14
MSTW2008NLO
1.0
0.8
0.6
0.4
0.2
0.0
10^2
10^3
M_X (GeV)

# CMS Electromagnetic Calorimeter (ECAL)

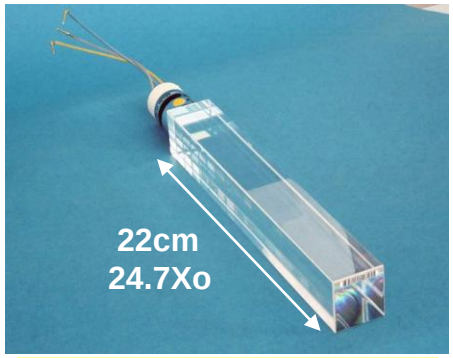



$PbWO_4$

Light emission: 80% in 25 ns
Radiation length: $X_0$ = 0.89 cm
Molière radius: $R_M$ = 2.10 cm
Emission peak: 425nm
Good radiation resistance to very high doses

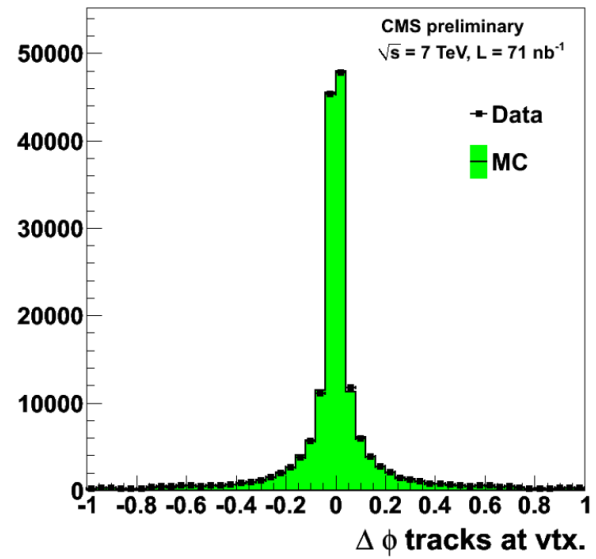

Barrel crystal, 34 types, ~2.6x2.6 $cm^2$ at rear

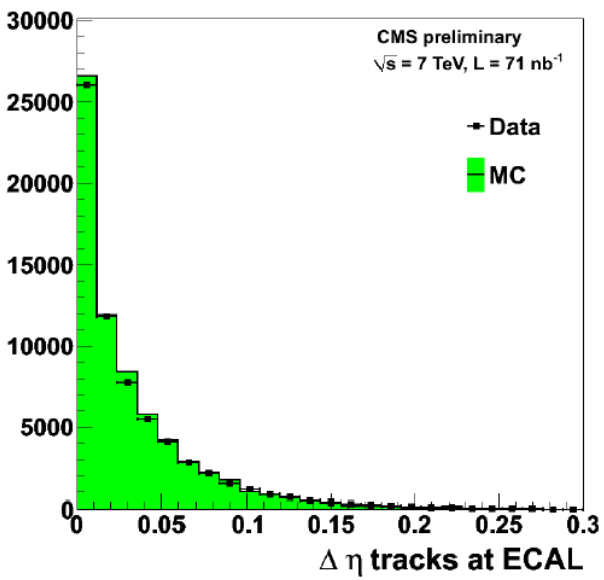


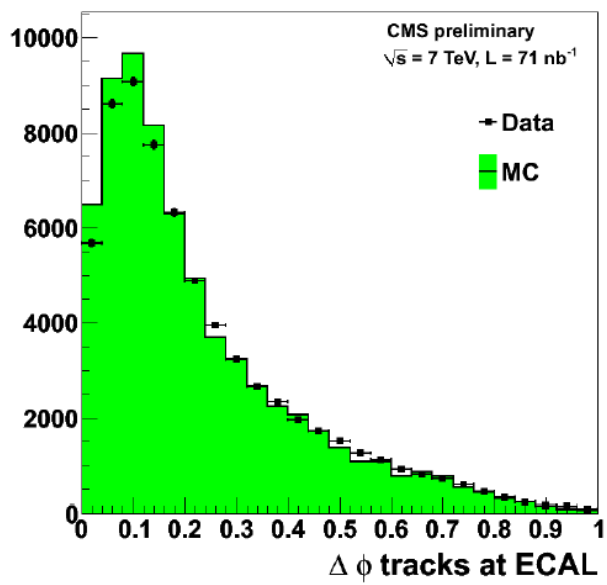

Endcap crystal, 1 type, 3x3 $cm^2$ at rear

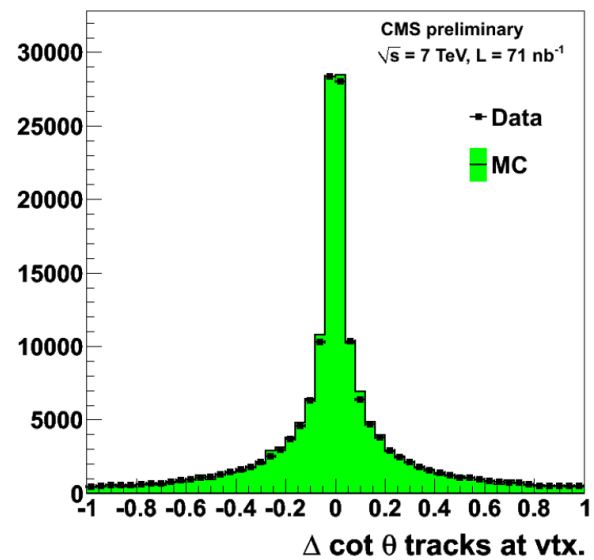
# Conversion finding

- Good chance that photons are converted because of about one radiation length material in front of ECAL.
- Conversion recognition based on separation at the closet approach and at the impact on ECAL of tracks



# Converted photons

- Selection:
  - $|\Delta\cot\theta| < 0.3$
  - $|\Delta\varphi| < 0.2$
  - P(vertex fit) > $5\times10^{-4}$
- Ratio of sum of momentum of tracks and energy of photons $p_{track}/E_{cand}$ used as template to extract photon purity.
- Clear indication of contribution from prompt photons