New Physics Results with Photons at ATLAS and CMS

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May 23, 2011

Southern Methodist University

Photon 2011 Spa, Belgium

OUTLINE

- LHC and the ATLAS and CMS Detectors
- Calorimetry in ATLAS and CMS
- Calorimeter Performance
- $H \rightarrow \gamma\gamma$
- Randall-Sundrum Gravitons - $\gamma\gamma$
- Large Extra Dimension(ED) ADD models - $\gamma\gamma$+Missing E_T
- Universal ED/SUSY (GGM) Photons - $\gamma\gamma$+Missing E_T

The LHC

- pp collisions 3.5+3.5TeV$\Rightarrow\sqrt{s}$ = 7 TeV

1232 super-conducting dipoles B=8.3 T

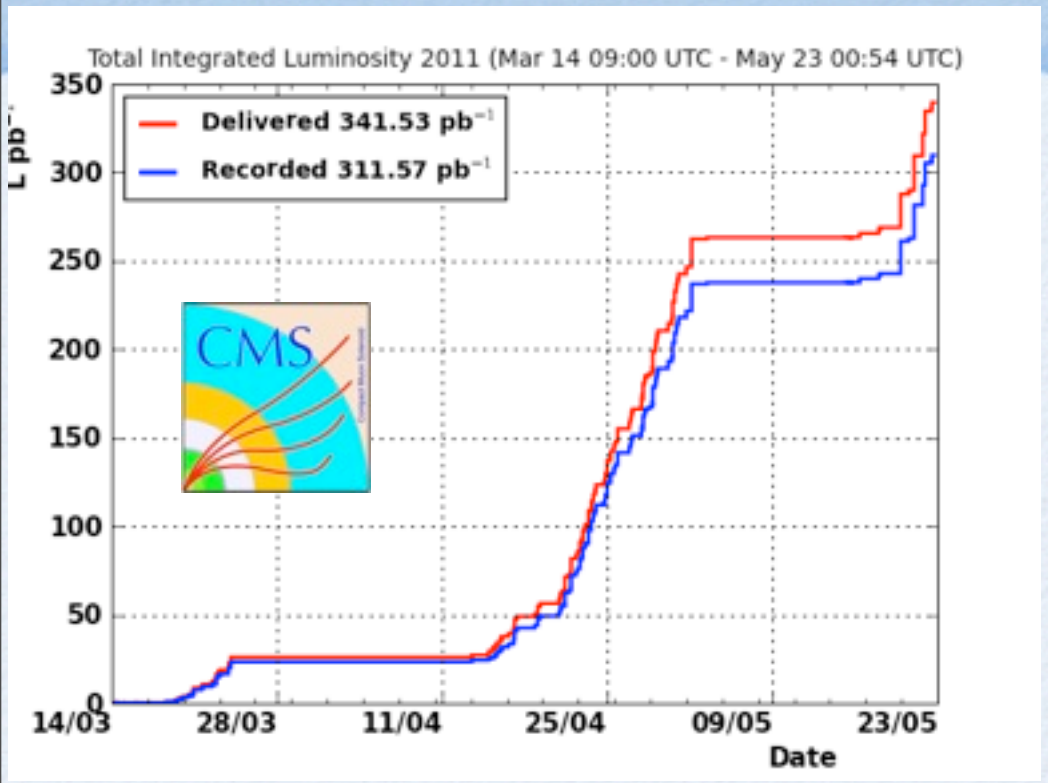
27 km

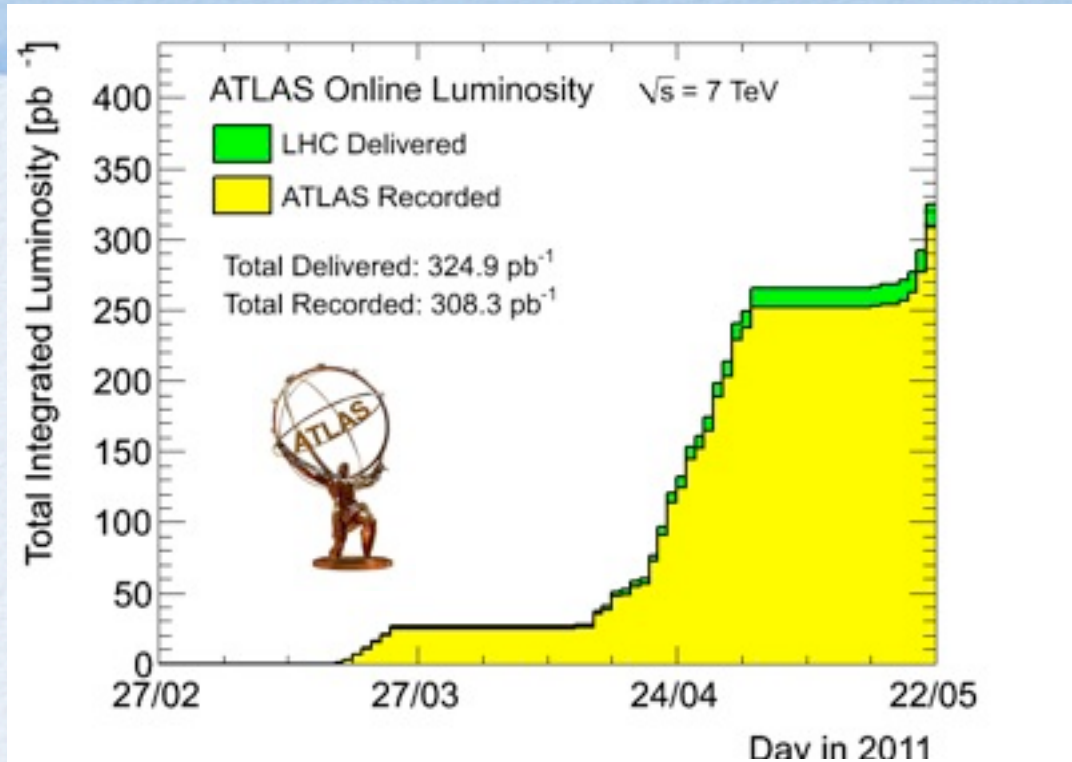
6400 other correctors

2835 Bunches, 10^{11} protons/bunch:

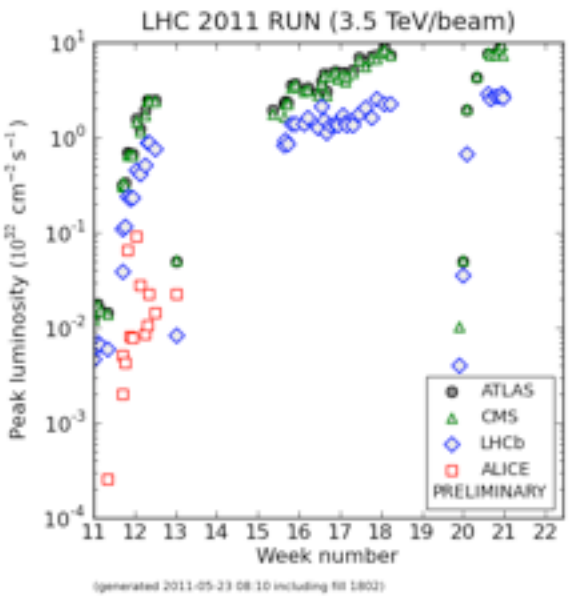
- $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$
- $L_{initial} \leq$ few x $10^{32}\ cm^{-2}\ s^{-1}$

LHC PERFORMANCE

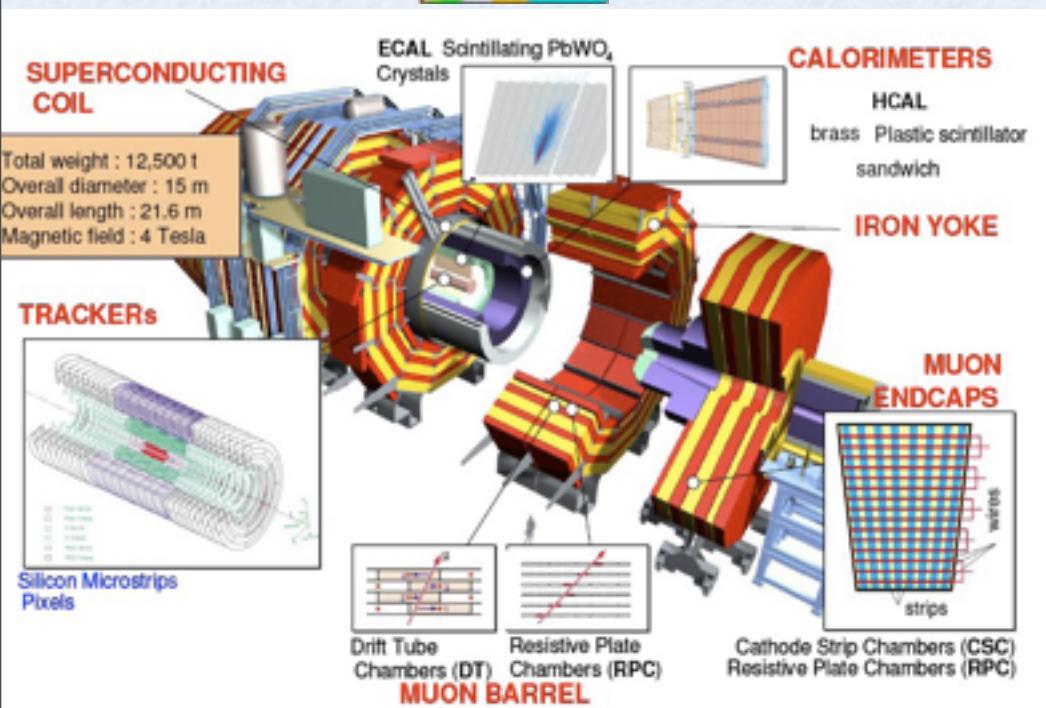


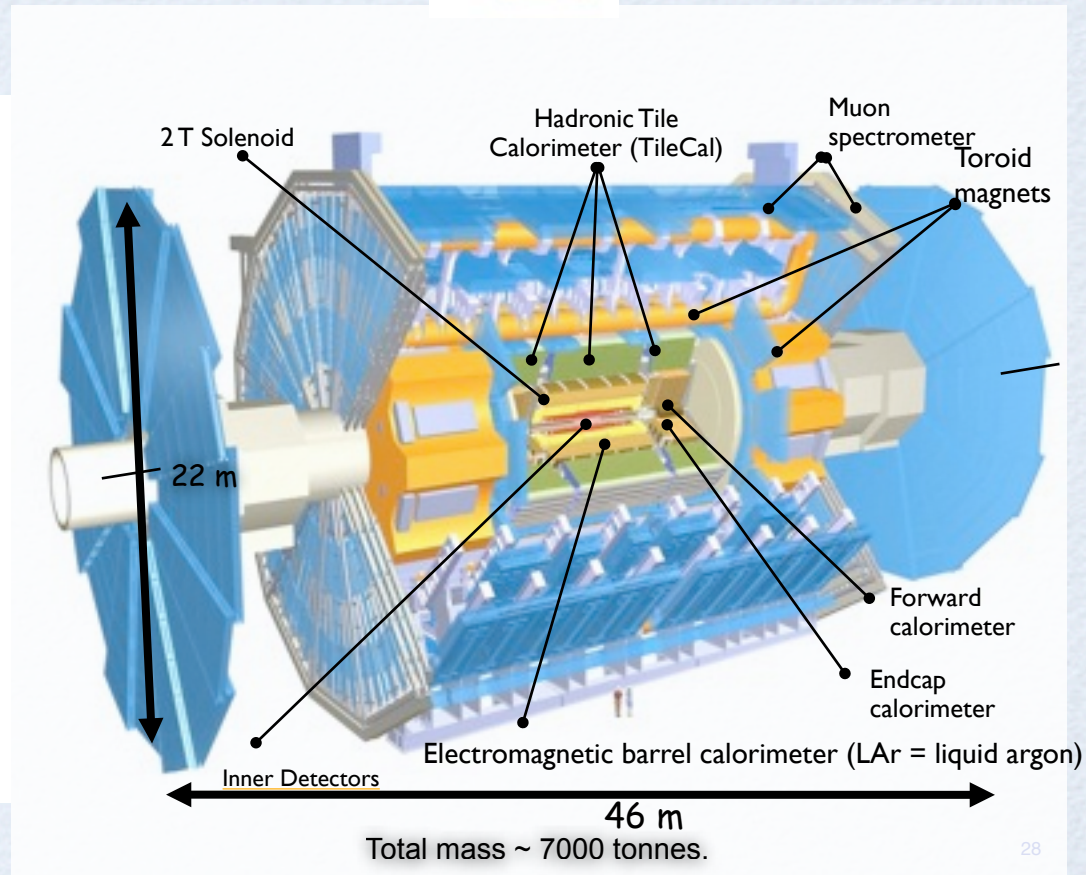


- LHC delivering steadily increasing luminosity
  - peak luminosity of ~ 1.1×10^{33} cm^{-2}/s
  - Detectors recording with > 90% efficiency

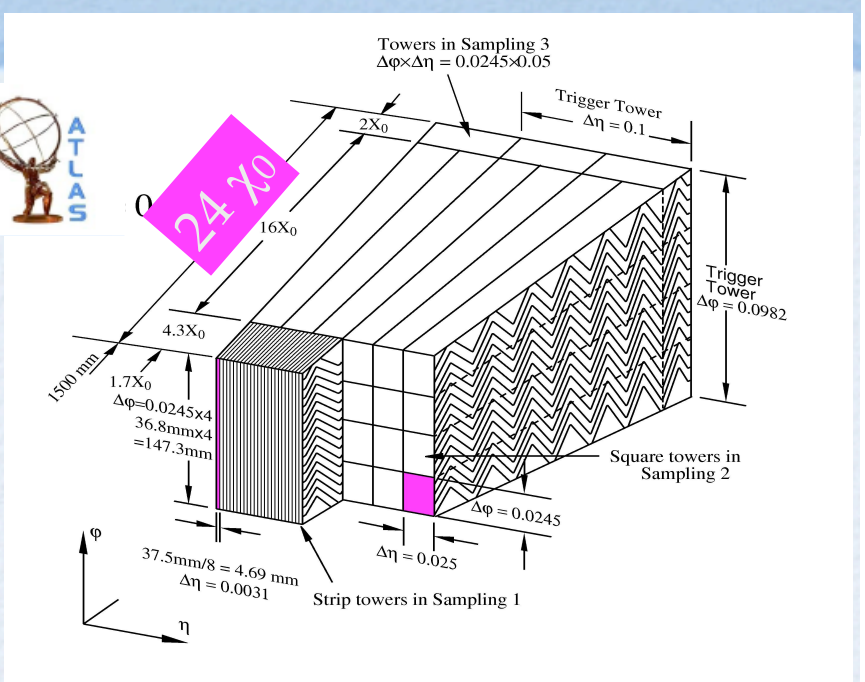


ATLAS/CMS DETECTORS

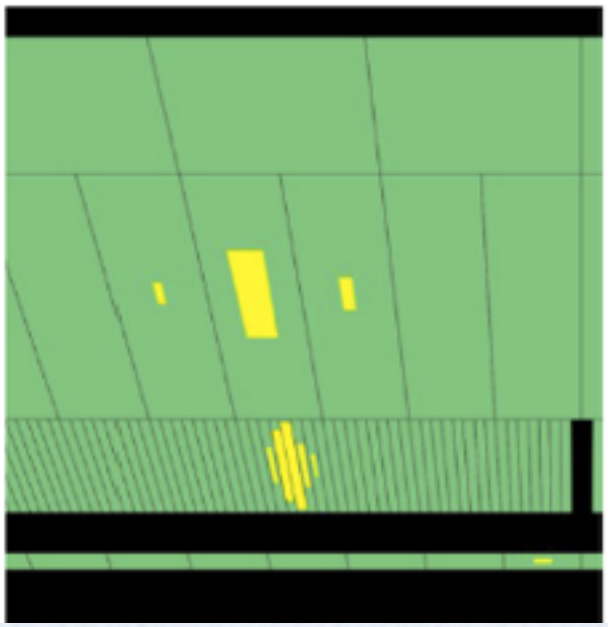




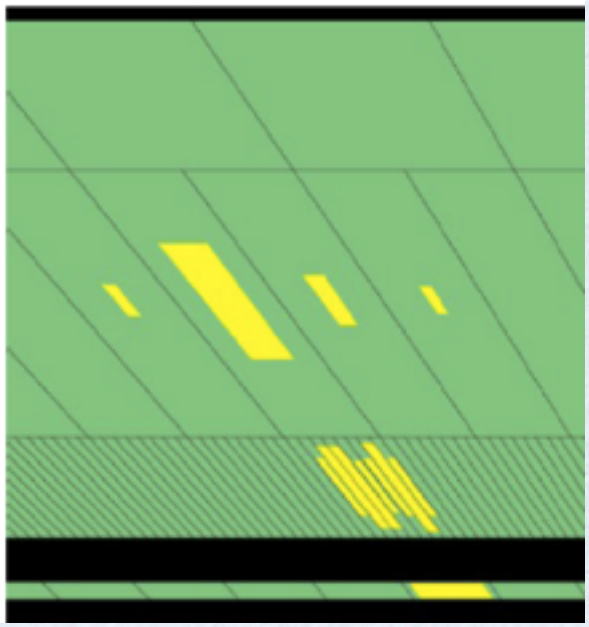
ATLAS EM CALORIMETER



prompt γ



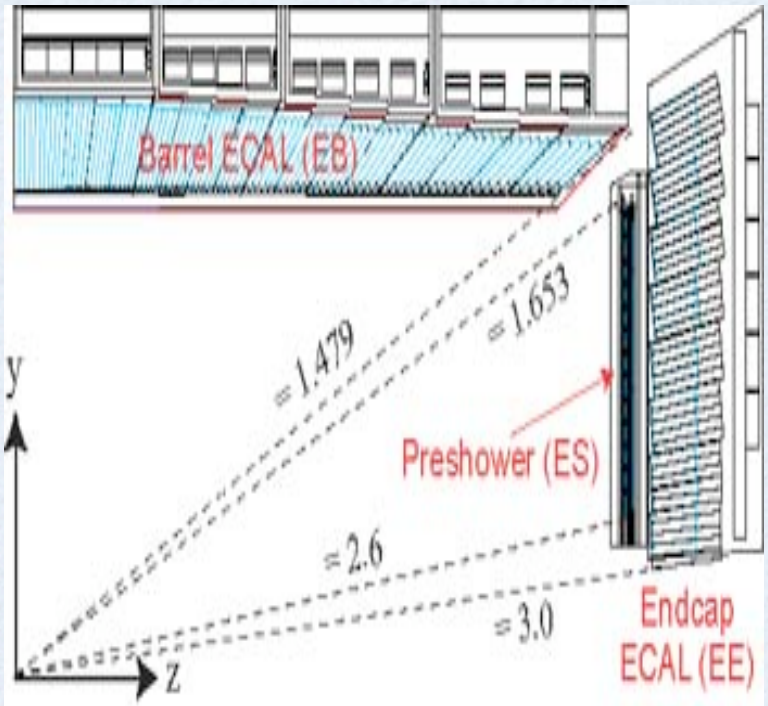
pi0



- lead/LAr accordion shaped sampling calorimeter
  - divided into three longitudinal layers and three segments (barrel and two endcaps)
  - fine granularity in first layer helps with pi0 rejection

	$\lvert\eta\rvert$ range	Cell η size	
		Layer 1	Layer 2
Barrel	0–1.4	0.025/8	0.025
	1.4–1.475	0.025	0.075
end-cap	1.375–1.425	0.05	0.05
	1.425–1.5	0.025	0.025
	1.5–1.8	0.025/8	0.025
	1.8–2.0	0.025/6	0.025
	2.0–2.4	0.025/4	0.025
	2.4–2.5	0.025	0.025

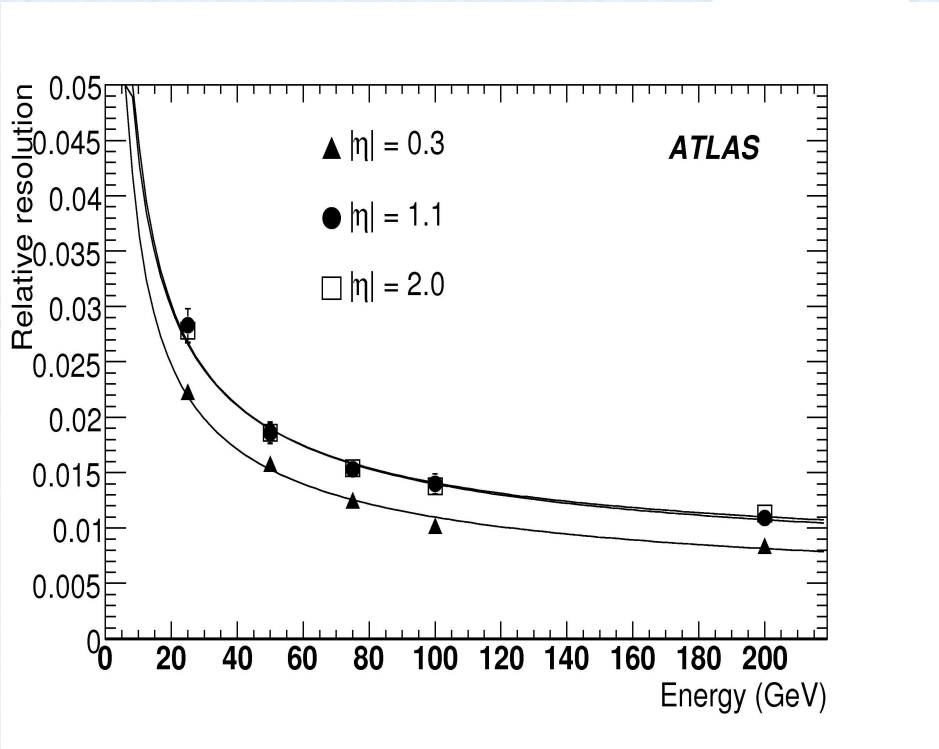
CMS CALORIMETER

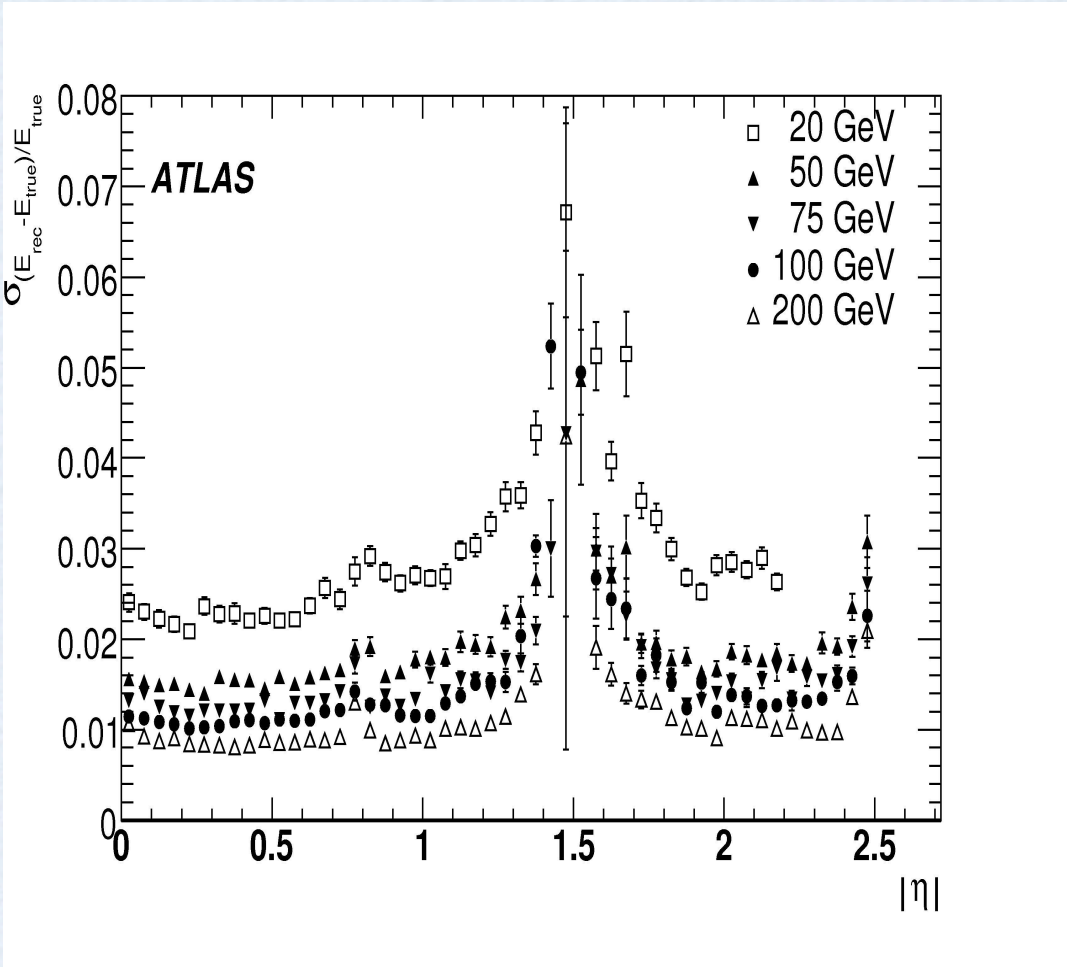


- ECAL made of 80k lead Tungstate crystals with photodiodes to read out emitted light
- $\Delta\eta \times \Delta\phi = 0.0175 \times 0.0175$ for barrel
- 26 χ_0 longitudinal

ATLAS ECAL RESOLUTION

$$\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 0.7\%$$

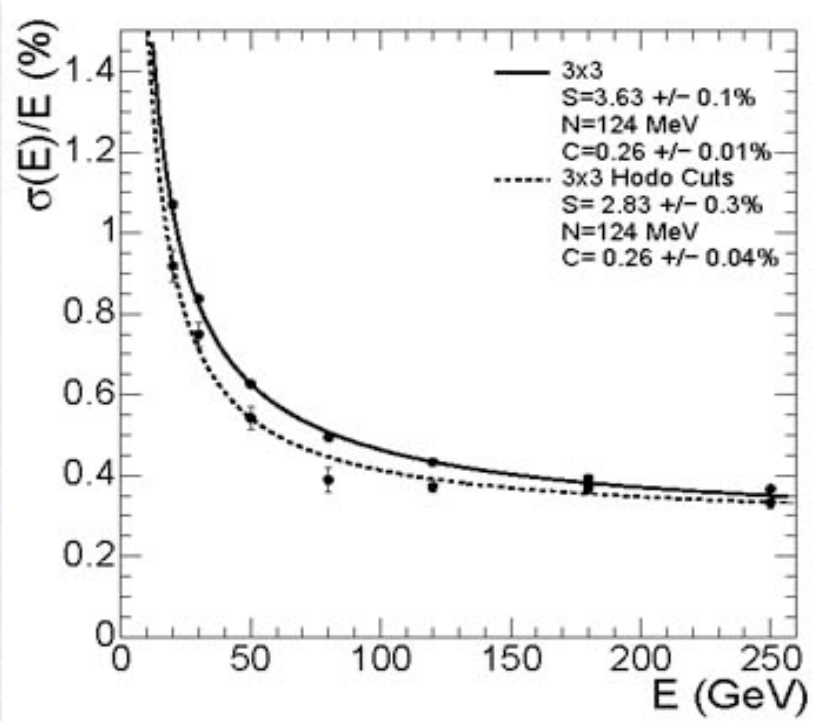


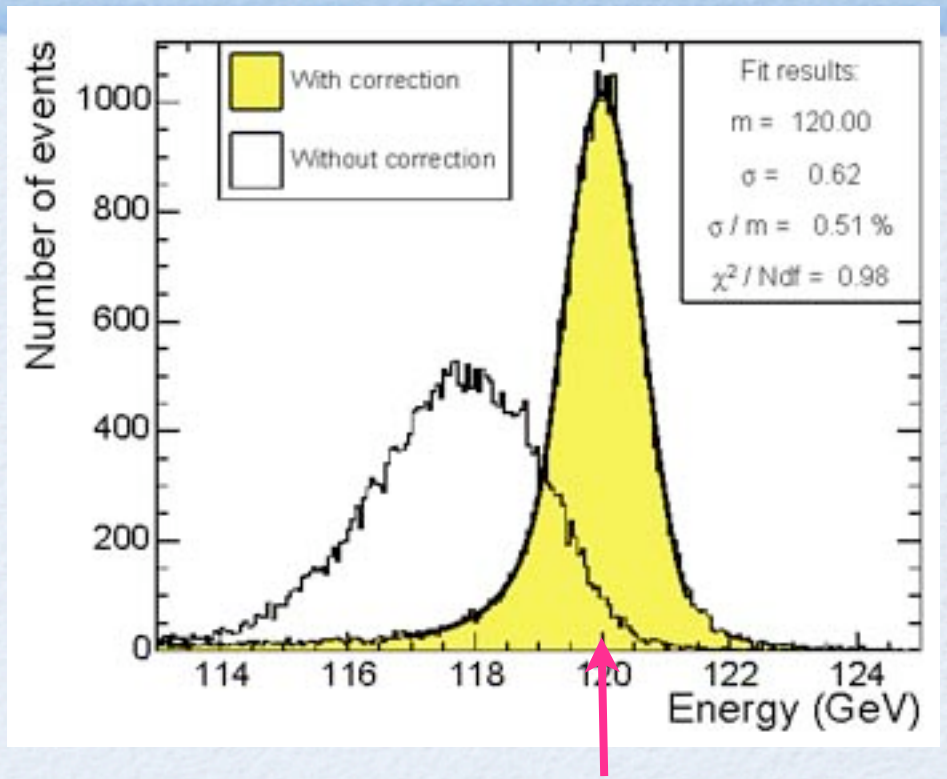


- Energy resolution worsens around η=1.5 due to gap between barrel and endcap

CMS ECAL RESOLUTION

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.9\%}{\sqrt{E}}\right)^2 + \left(\frac{125(MeV)}{E}\right)^2 + (0.30\%)^2$$

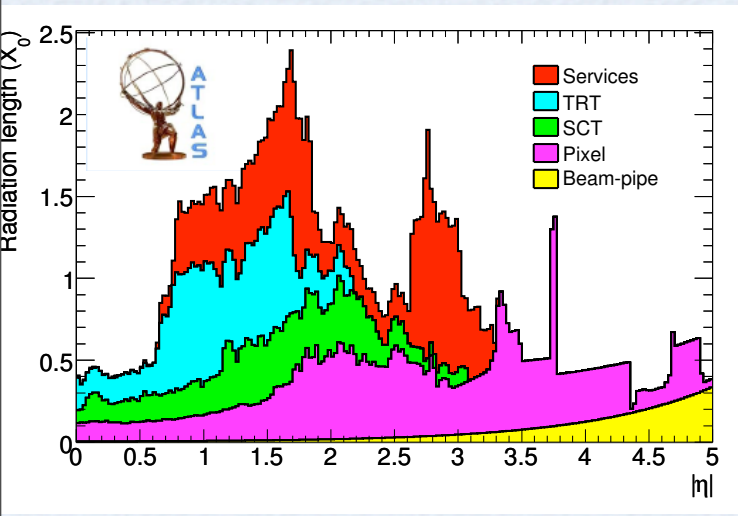


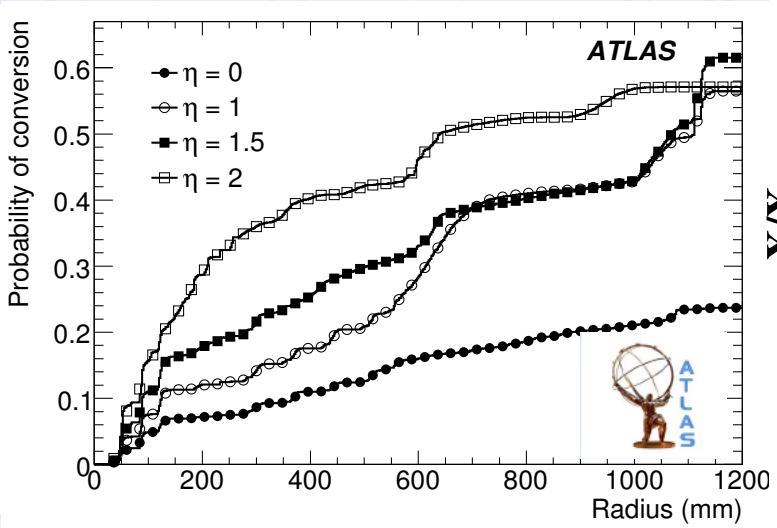


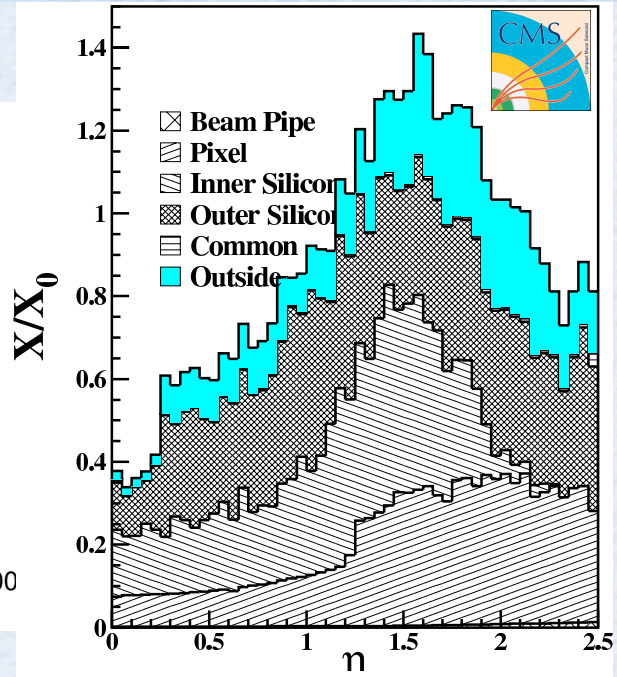
Test Beam: electron beam of 120 GeV

- event-by-event universal correction factor applied
  - determined by energy sharing between crystals
- Shown resolution achieved after summing over matrix of 3x3 crystals

MATERIAL IN TRACKER



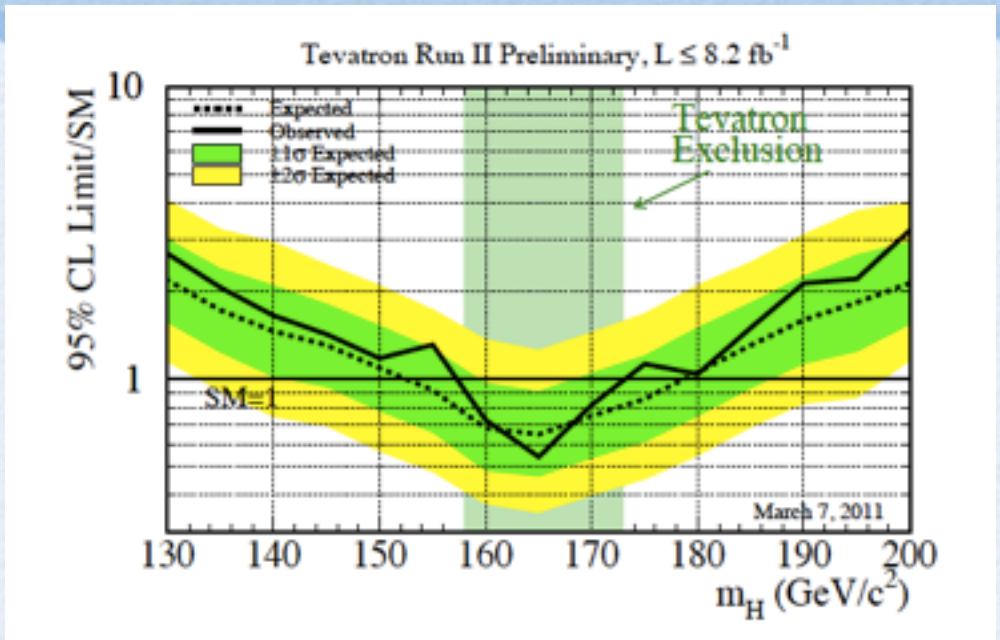


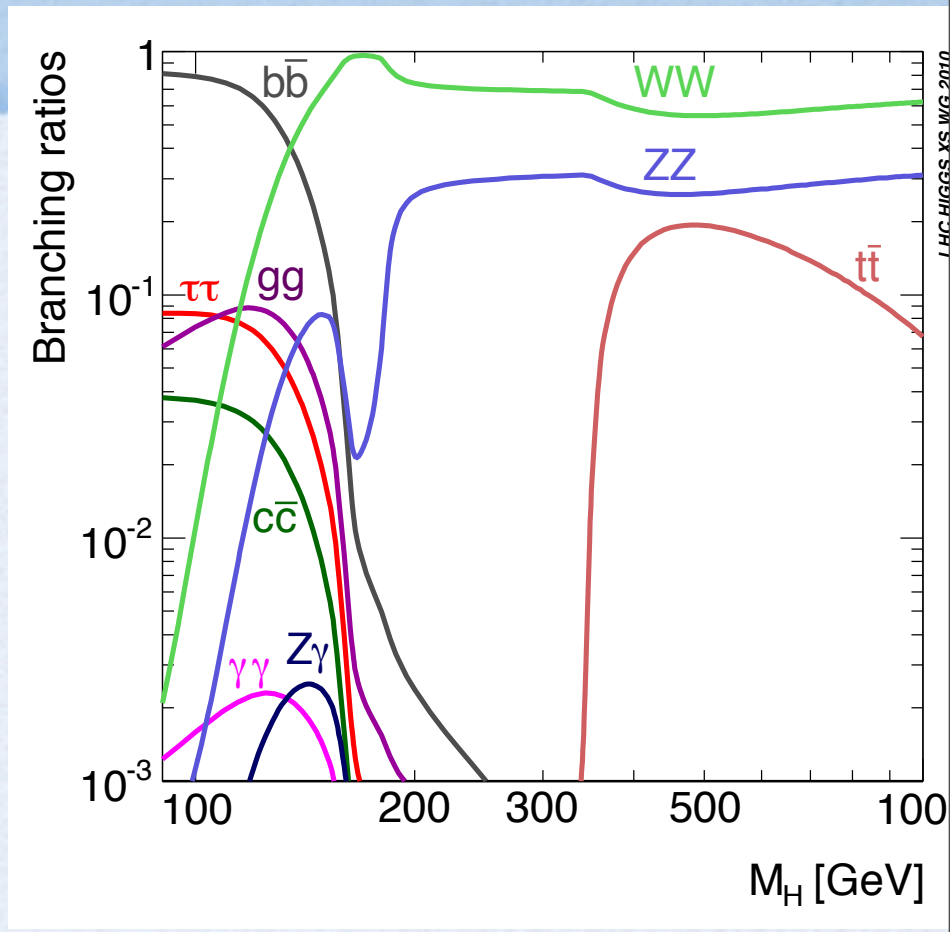


- ATLAS tracker in B field of 2 T as opposed to 4 T for CMS
  - CMS: momentum resolution of signal tracks better by factor of 3
- CMS: 20%-60% of photons in the barrel calorimeter acceptance convert before reaching the front face of the crystals

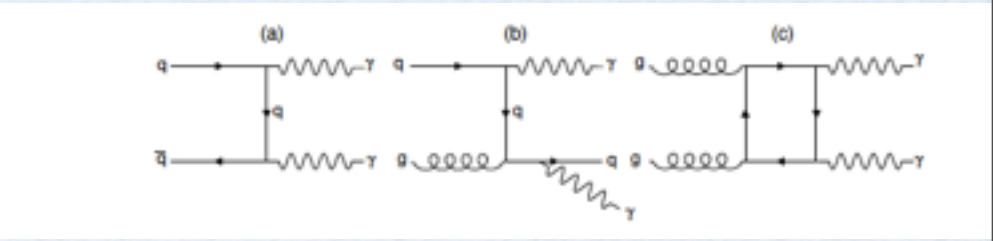
Current Combined Tevatron Limit

HIGGS SM





- $\gamma\gamma$ final state experimentally clean signature
- QCD diphoton background processes to $H \rightarrow \gamma\gamma$ a) Born b) FSR c) Box
- Other background instrumental coming from γ+jet and jet-jet



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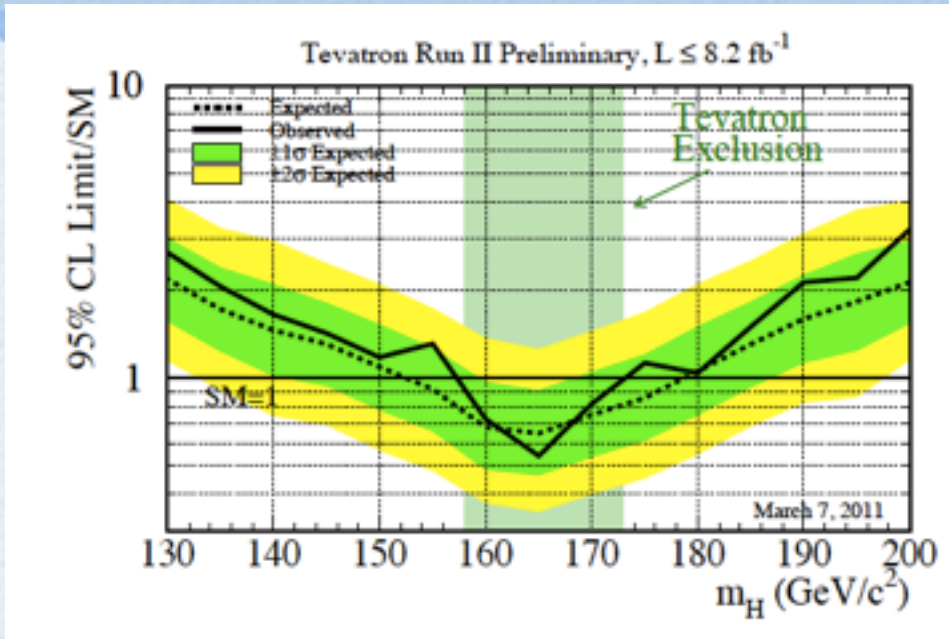

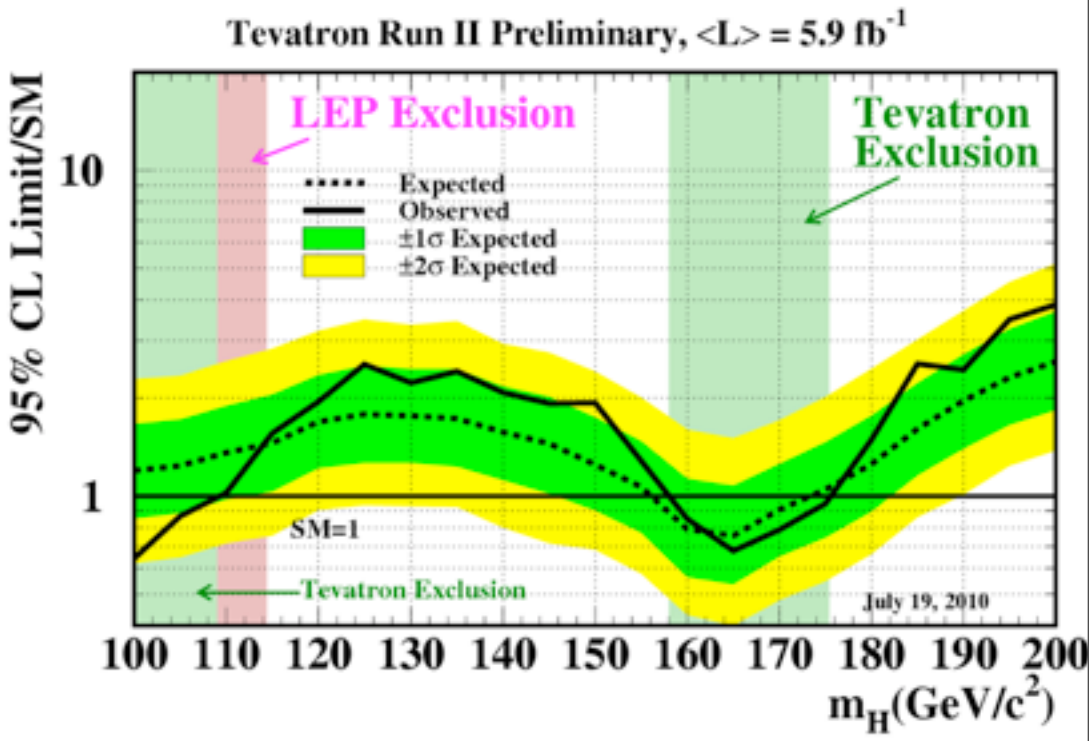

- γγ final state experimentally clean signature
- QCD diphoton background processes to H→γγ a) Born b) FSR c) Box
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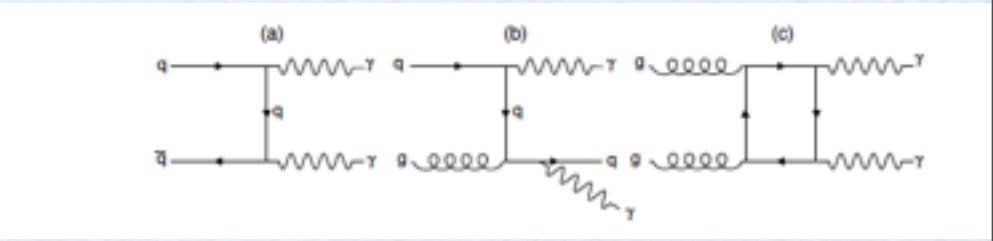
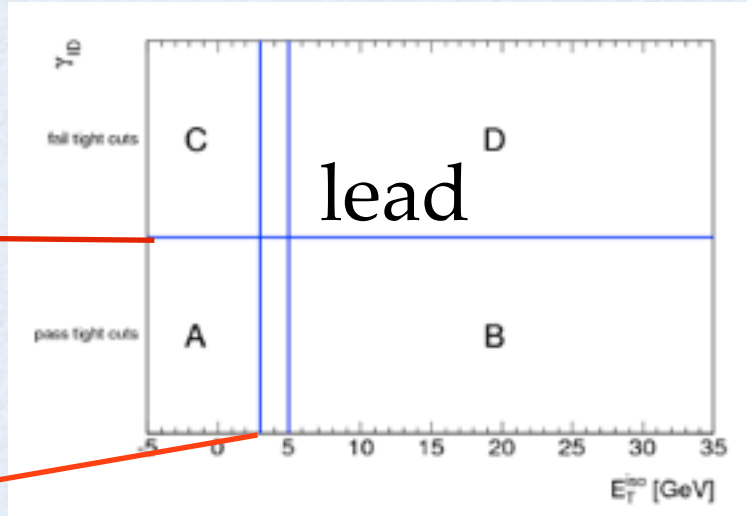
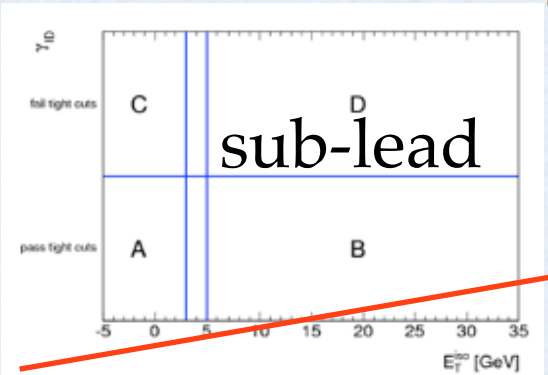


2X2D SIDEBAND METHOD

$$N_A^{yield} = N_A - N_A^{bkg} = N_A - R^{bkg}\frac{(N_B^{obs}-N_B^{sig})(N_C^{obs}-N_C^{sig})}{N_D^{obs}-N_D^{sig}}$$

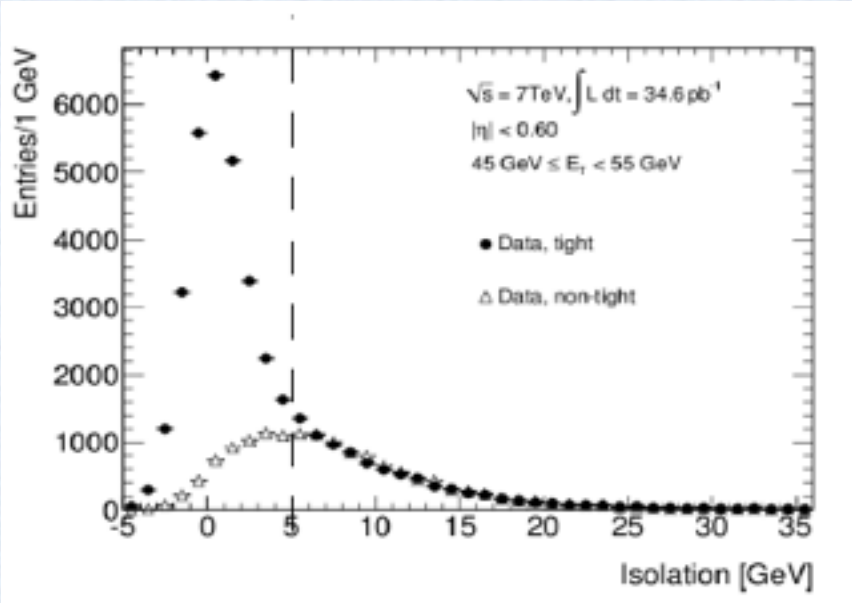
$$R^{bkg} = \frac{N_A^{bkg}\,N_D^{bkg}}{N_C^{bkg}\,N_B^{bkg}} \qquad c_x = \frac{N_x^{sig}}{N_A^{sig}}$$ from MC





See **Measurements of isolated prompt photons by** M. Stockton

- Leading Photon in Signal region ie isolation of 3 GeV and pass Tight photon requirements
- Determine purity of sub-lead photon in same way



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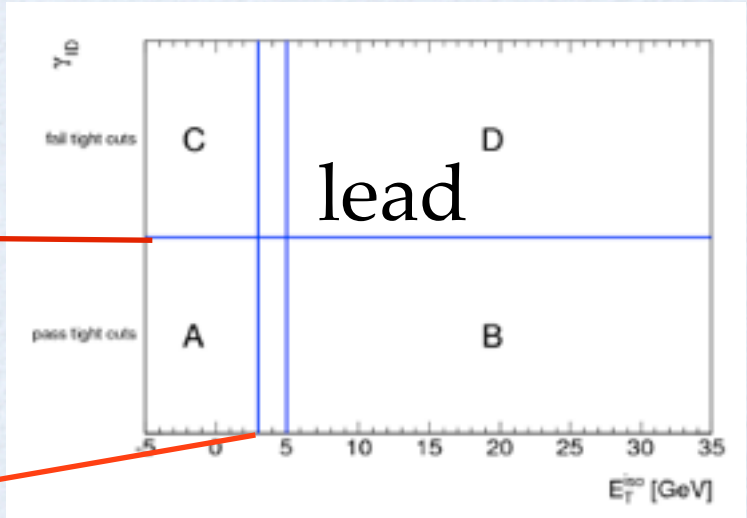

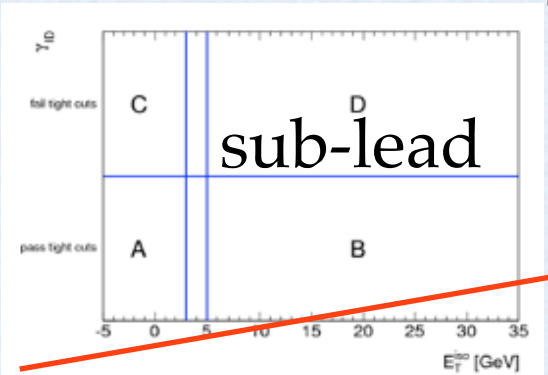

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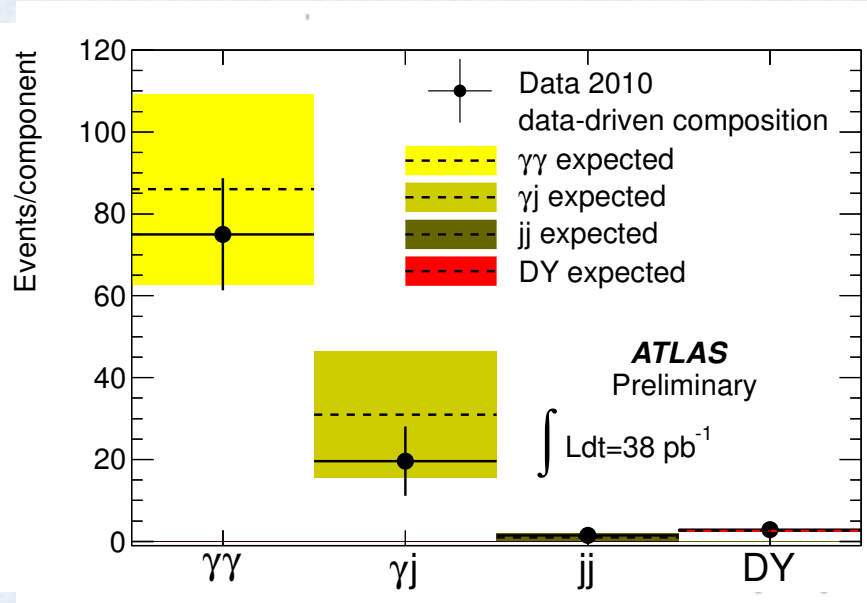
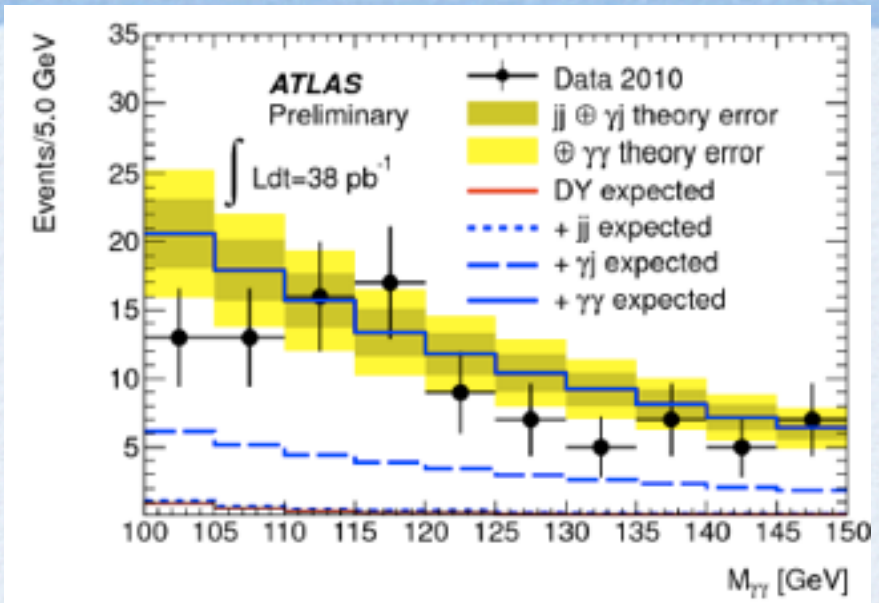
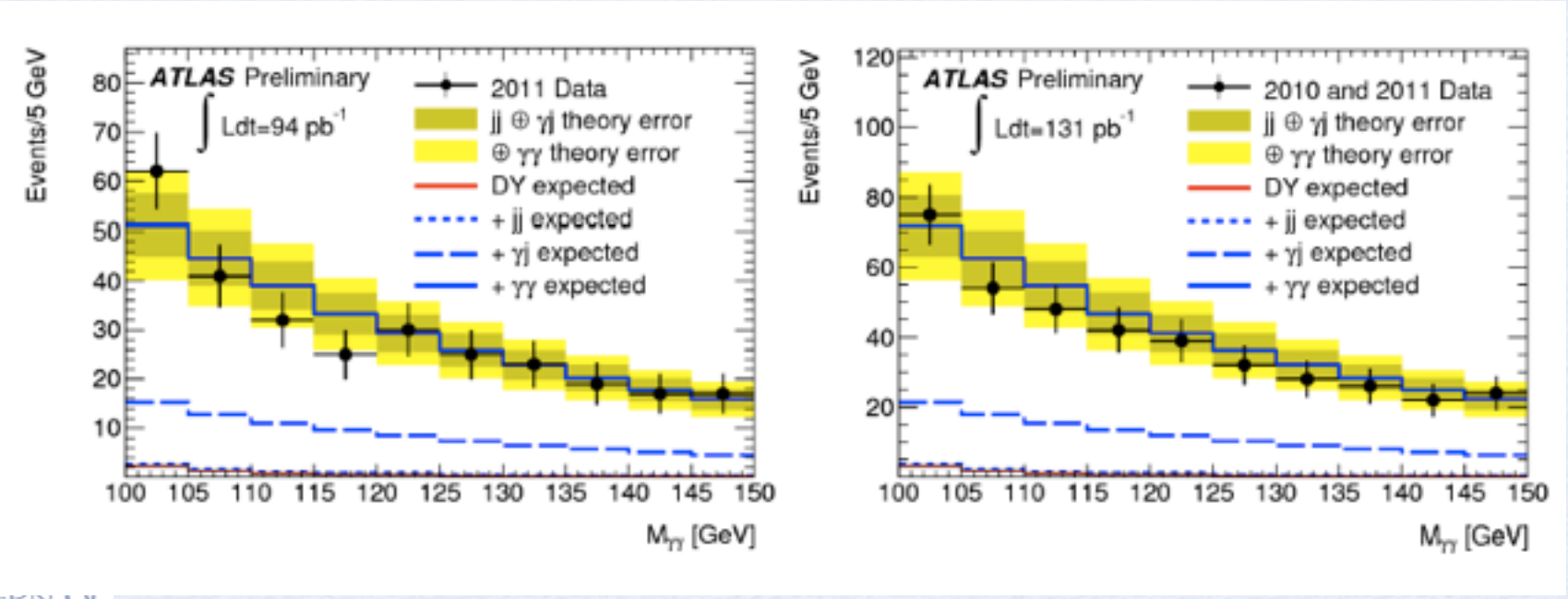


$M_{\gamma\gamma}$ SPECTRUM

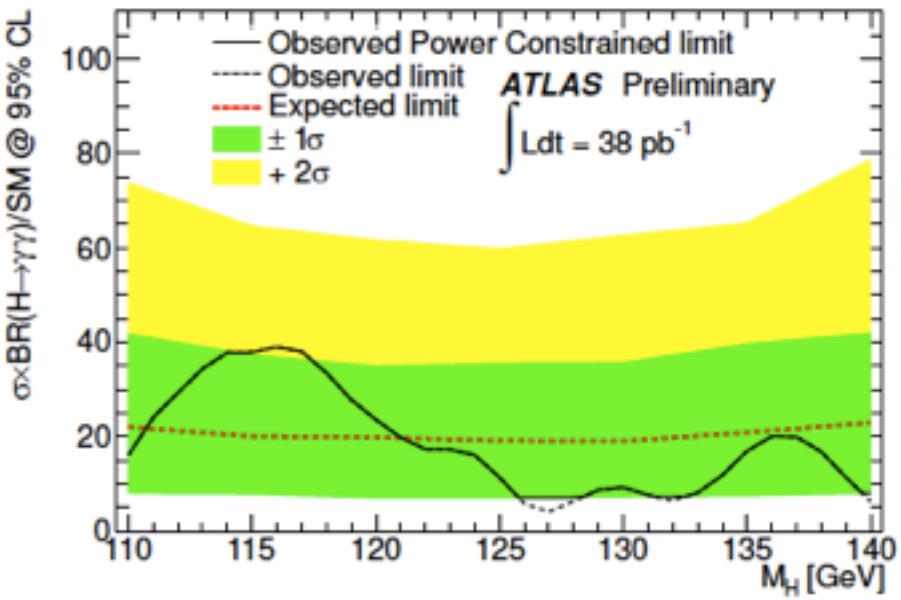


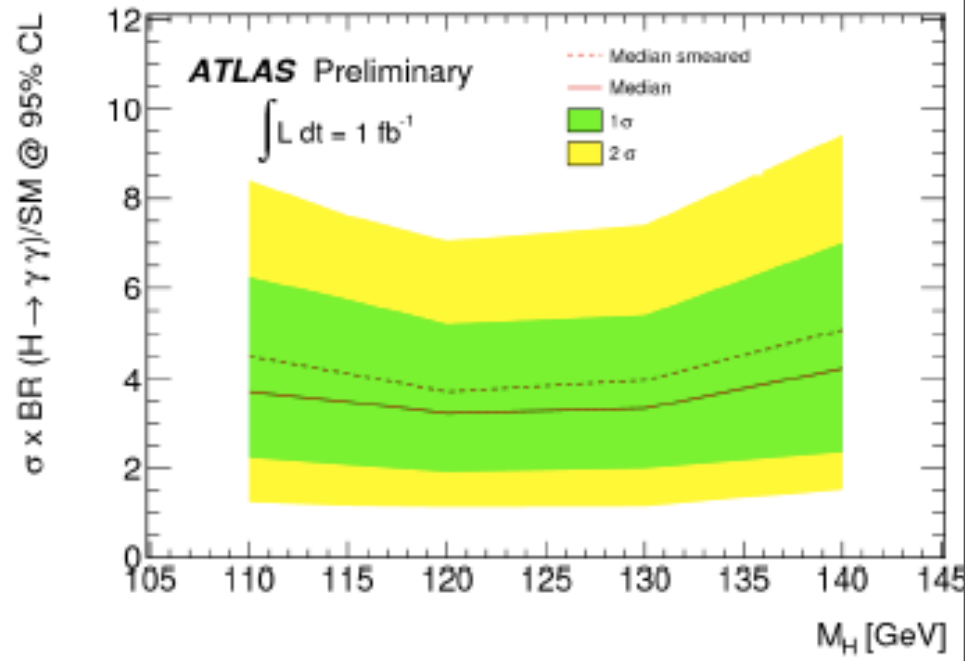
- Background composition known from 2D sideband method
  - In good agreement with MC
- Slight excess ~ 115 GeV in 2010 data
  - Not seen in 2011 data and combination



HIGGS LIMIT

http://cdsweb.cern.ch/record/1336758/





- 110< *mH* <140 GeV expected upper limit is ~ 20 times larger than the Standard Model prediction.
- Observed exclusions range from 8 times the Standard Model prediction at 127 GeV, to 38 times at 116 GeV
- With 1 fb^{-1} limits of about 4 times the SM prediction

m_H [GeV]	Expected limit		Observed limit	
	CL_{s+b}	CL_s	PCL_{s+b}	CL_s
110	22.1	27.9	16.1	24.0
115	20.1	25.5	37.9	39.7
120	19.9	24.4	23.6	27.2
130	19.1	24.0	9.3	18.3
140	23.0	29.9	8.0	20.7

See **Search for Higgs to gamma +gamma at ATLAS** by J. Ocariz

Extra Dimension Models

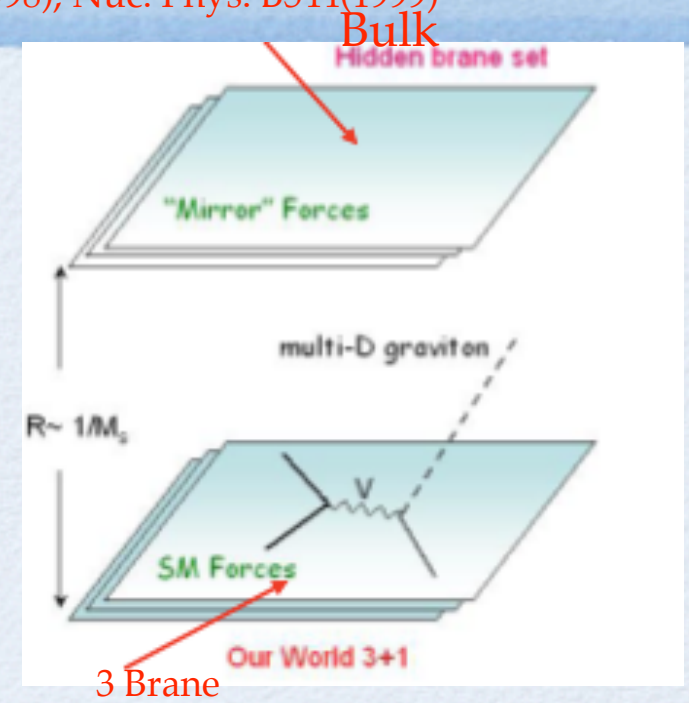
- A class of theories including extra dimensions was introduced in 1999 N. Arkani-Hamed, S. Dimopoulos, G. Dvali
- These theories incorporate Gravity in the theory and have an explanation for its weakness in the brane that we live on
- Several of these theories will be described:

1. LED (ADD)
2. Randall-Sundrum
3. Universal Extra Dimension (SUSY as well)

LED ADD MODEL

N. Arkani-Hamed, S. Dimopoulos, G. Dvali Phys. Lett. B429 (1998), Nuc. Phys. B544(1999)

- SM forces live on 3-brane and there exists a parallel universe with hidden branes
- n flat Euclidean dimension with maximal dimension =3(our world) + 6 (extra)=9
- Only gravitons can escape to the extra dimensions
- Gravity scale on in 4+N dimensions M_D~TeV $M_{Pl}=8\pi M_D^{n+2}R^n$
  - n=2 R~mm; gravity not tested for scales << mm
- Physics signature
  - diphoton production in virtual KK exchange with SM interference
  - small separation of KK mass states $m_n^2=m_0^2+(n/R)^2$ since R is large ~eV spacing
  - Show up as tails in invariant mass spectrum
  - Ms → UV cutoff scale- avoid divergence in CS



$$\sigma = \sigma_{SM} + \eta_G \sigma_{int} + \eta_G^2 \sigma_{KK} \qquad \eta_G = F / M_s^4$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{\hat{s}}\right) & \text{if } n_{ED} = 2 \\ \frac{2}{(n_{ED}-2)} & \text{if } n_{ED} > 2 \end{cases}$$ HLZ

$$\mathcal{F} = 1$$ GRW

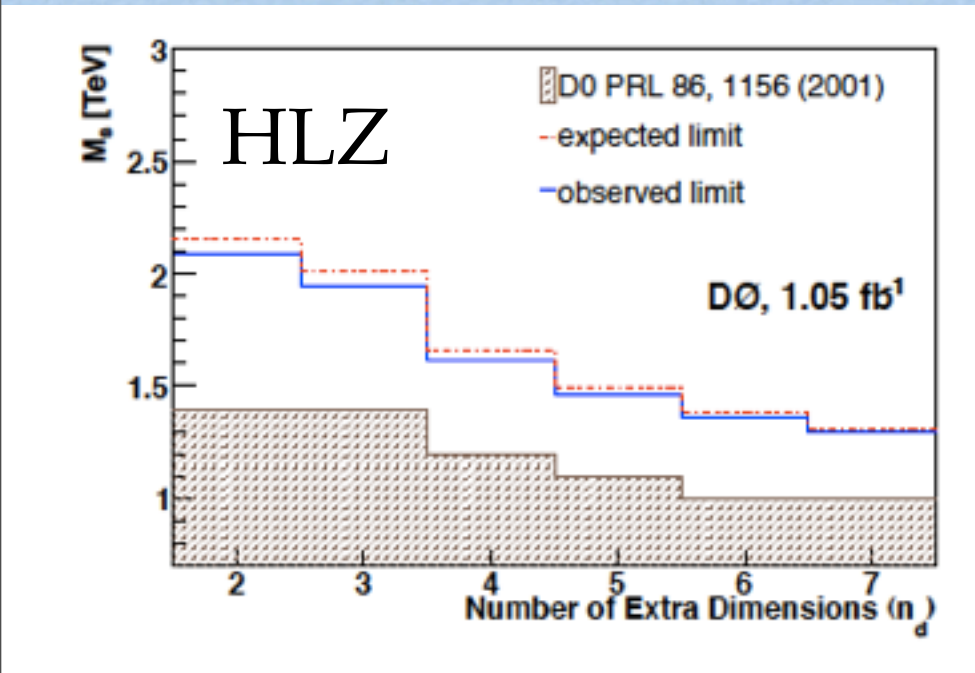
$$\mathcal{F} = \pm\frac{2}{\pi}$$ Hewett

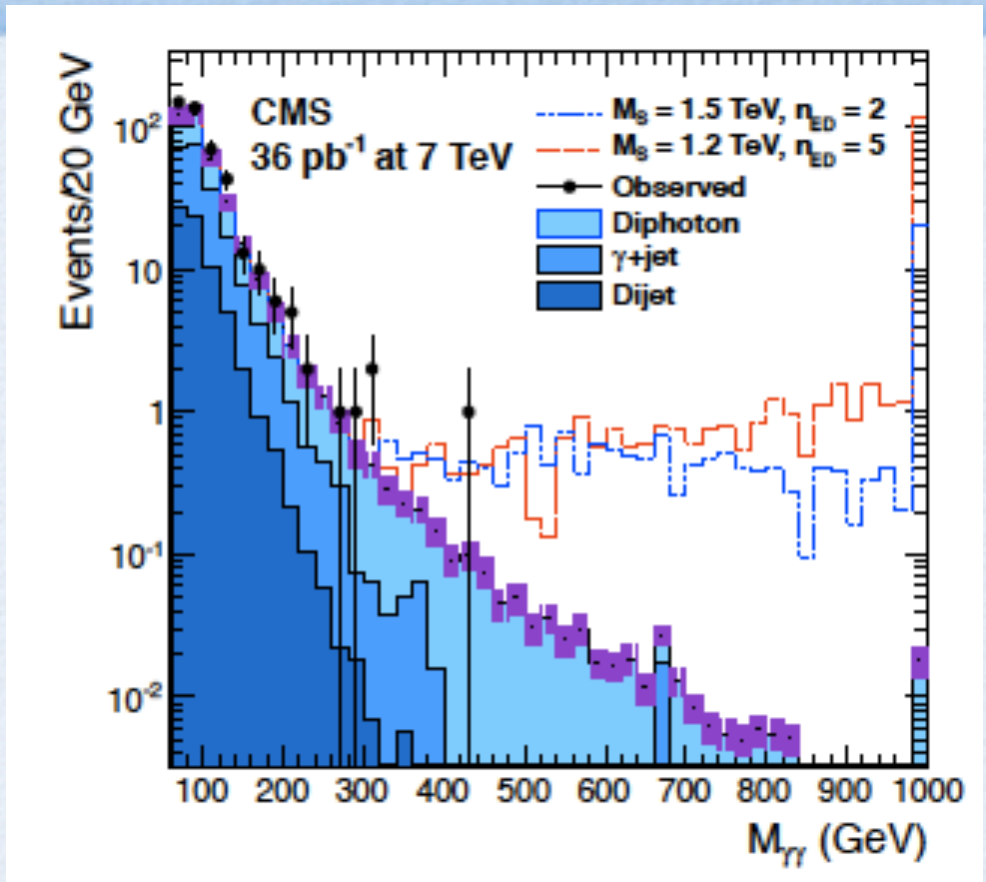
ADD LIMITS

D0

arXiv:0809.2813v1 Phys.Rev.Lett.102:051601,2009

arXiv:1103.4279v1





	GRW	HLZ					
		n_d	2	3	4	5	6	7
Obs.	1.62		2.09	1.94	1.62	1.46	1.36	1.29
Exp.	1.66		2.16	2.01	1.66	1.49	1.38	1.31

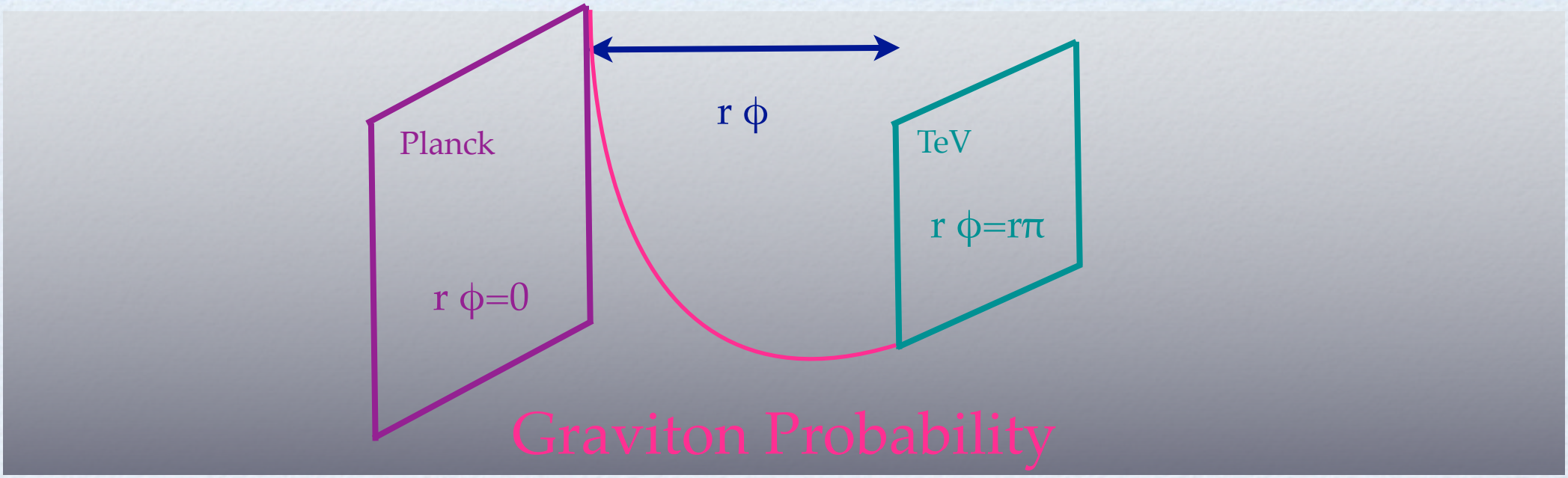
new results from CMS extend limits on M_S from D0 limits for all but n=2

Table 3: 95% CL limits on M_S (TeV), as a function of the convention and number of ED. A comparison of the limits with a truncation of the production cross section above $\sqrt{\hat{s}} > M_S$ is also shown. The two limits for the Hewett convention correspond to positive and negative interference effects.

	GRW	Hewett		HLZ					
		Pos.	Neg.	$n_{ED} = 2$	$n_{ED} = 3$	$n_{ED} = 4$	$n_{ED} = 5$	$n_{ED} = 6$	$n_{ED} = 7$
Full	1.94	1.74	1.71	1.89	2.31	1.94	1.76	1.63	1.55
Trunc.	1.84	1.60	1.50	1.80	2.23	1.84	1.63	1.46	1.31

RS MODEL

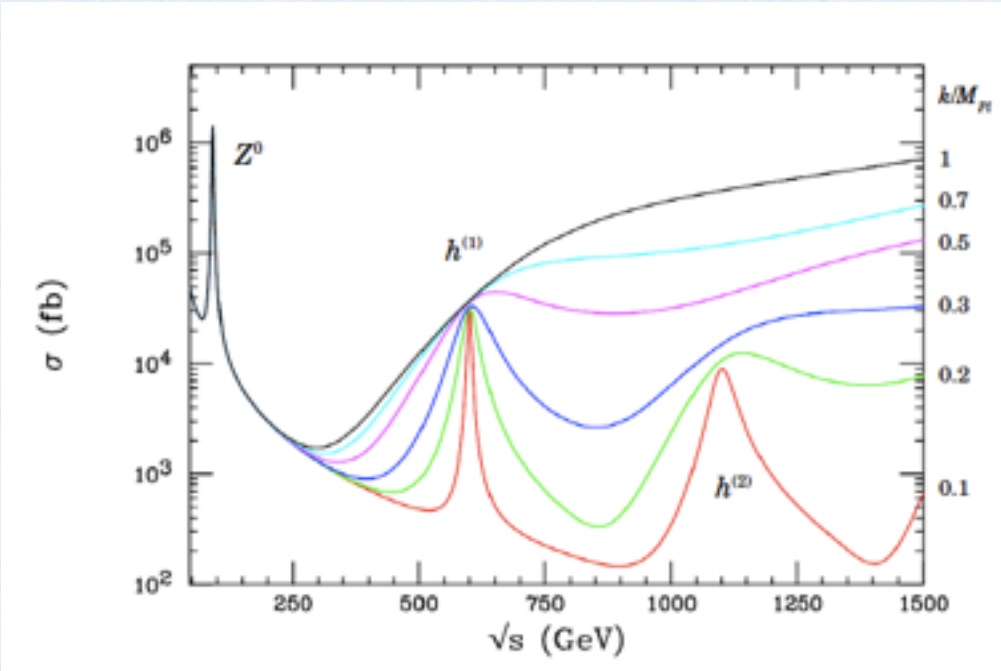
L. Randall, R. Sundrum (RS1 scenario), PRL 83 3370 (1999).



- 5 D curved or warped extra dimension
- Model Parameters:
  - Coupling constant: $c=k/M_{pl}$
    - k curvature of space
  - Gravity Scale $\Lambda_\pi=M_{pl}e^{-kr\pi}$ ~TeV
    - r is compactification radius
    - kr ~ 11-12

KK Modes

H. Davoudiasl, J.L. Hewett, T.G. Rizzo,Phys.Rev.Lett. 84 (2000) 2080



Quantized in modes of order TeV

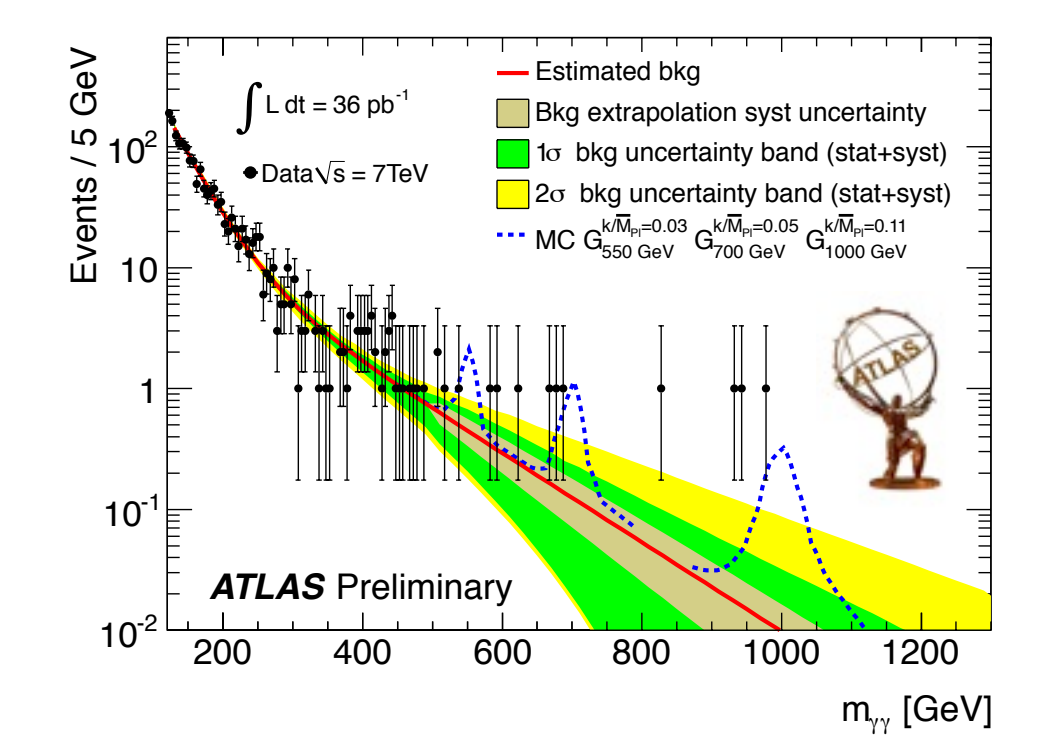
Width of KK resonance proportional to c^2

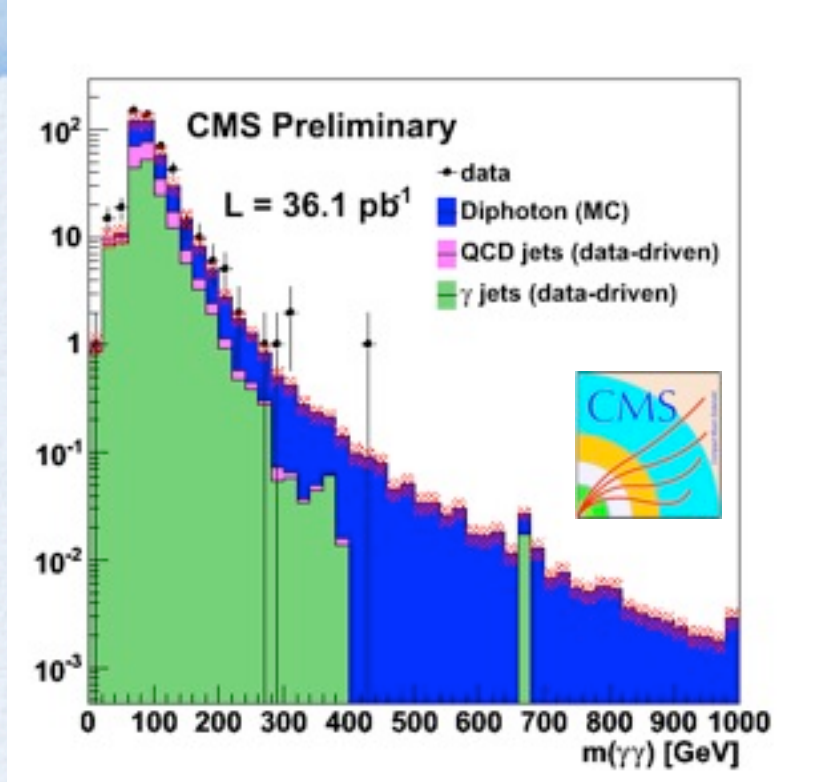
$$q\bar{q}, gg \rightarrow G_{KK} \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma, jet + jet$$

- KK particles carry momentum on extra dimension
- Looks like mass in 4 dimensions
- KK modes of Graviton visible on TeV brane
- Narrow high mass resonances
  - Separation of ~TeV

Value of $k/\overline{M}_{Pl}$	95% CL Mass Limit (GeV)	
	D0 Expt	CDF Expt
0.01	560	472
0.1	1050	976

$M_{\gamma\gamma}$ DISTRIBUTION





Use control region 120-500 GeV to determine background shape

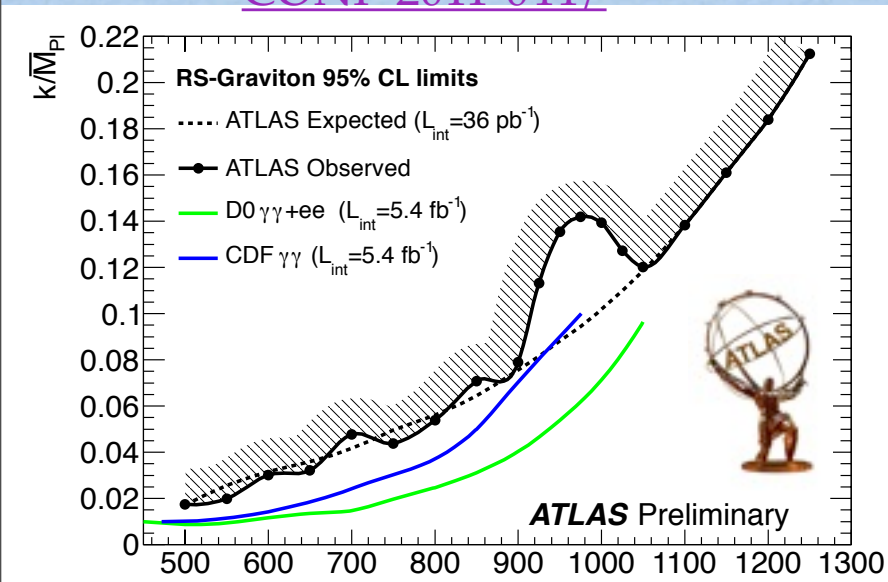
Use shape from MC in region 220-1000 GeV
Normalization from data in 100-220 GeV

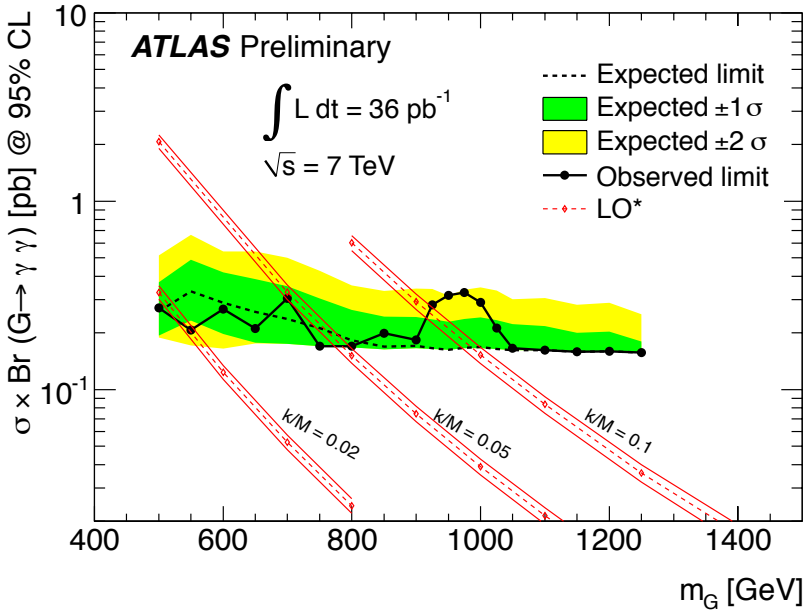
- Statistical band includes background systematic error
- Some excess of events - will push limit lower

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-044/

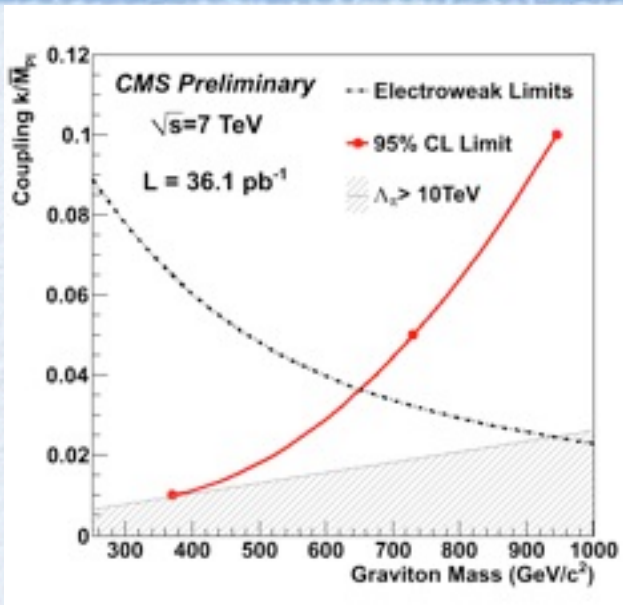
RS LIMITS

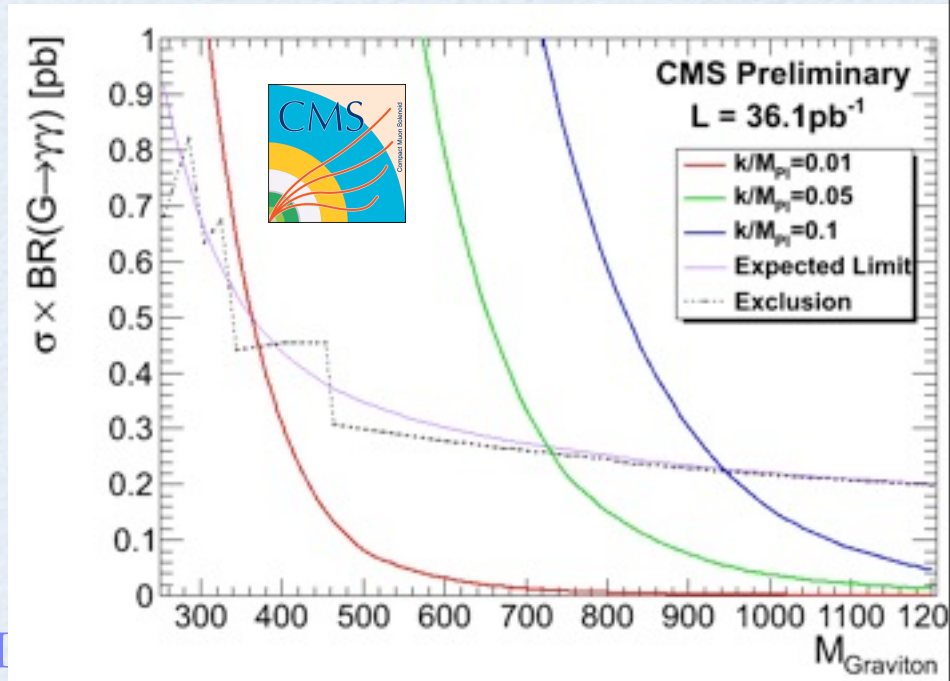
http://cdsweb.cern.ch/record/1350261/





k/ M_{pl}	0.01 (0.02)	0.1
ATLAS	545	920
CMS	368	952





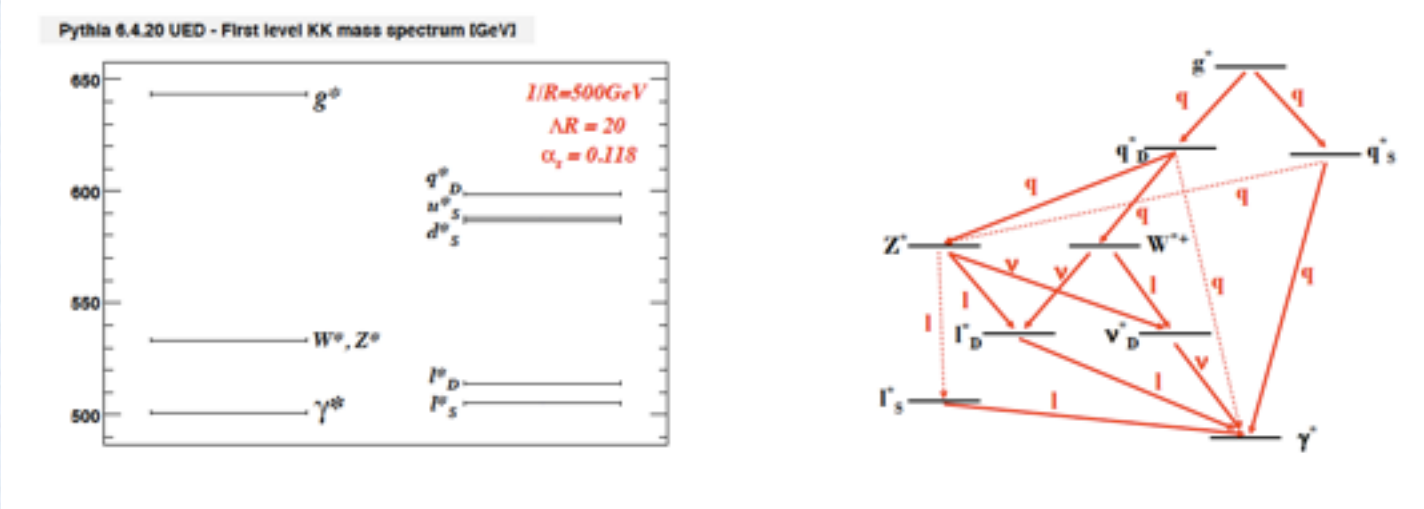
See **A Search for High Mass Diphoton Resonances in the Context of the Randall-Sundrum Model in ATLAS** by M. Kataoka

Haleh Hadavand-SM

UED MODEL

- Model with one Universal Extra Dimension
- Universal== All SM particles propagate into extra dimension n=1,2,3 are KK excitations for each SM particle n=0 $m_n^2=m_{SM}^2+(n/R)^2$
- R== compatification scale of 1/R ~ 1 TeV

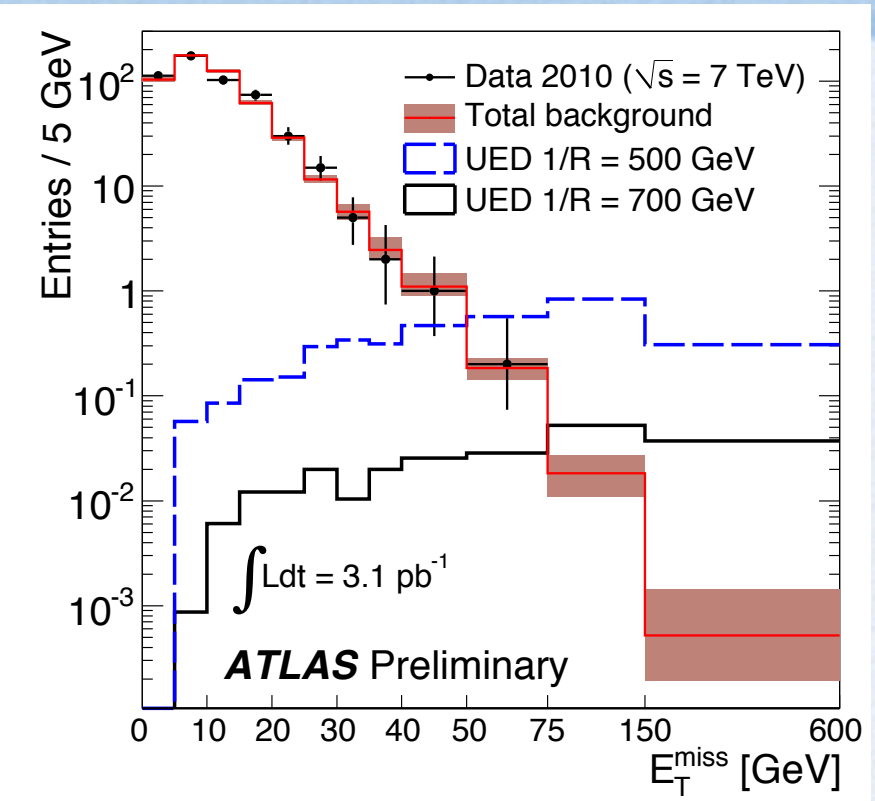
Strong production of pair of KK quarks/gluons which cascade down to LKP (γ^*)

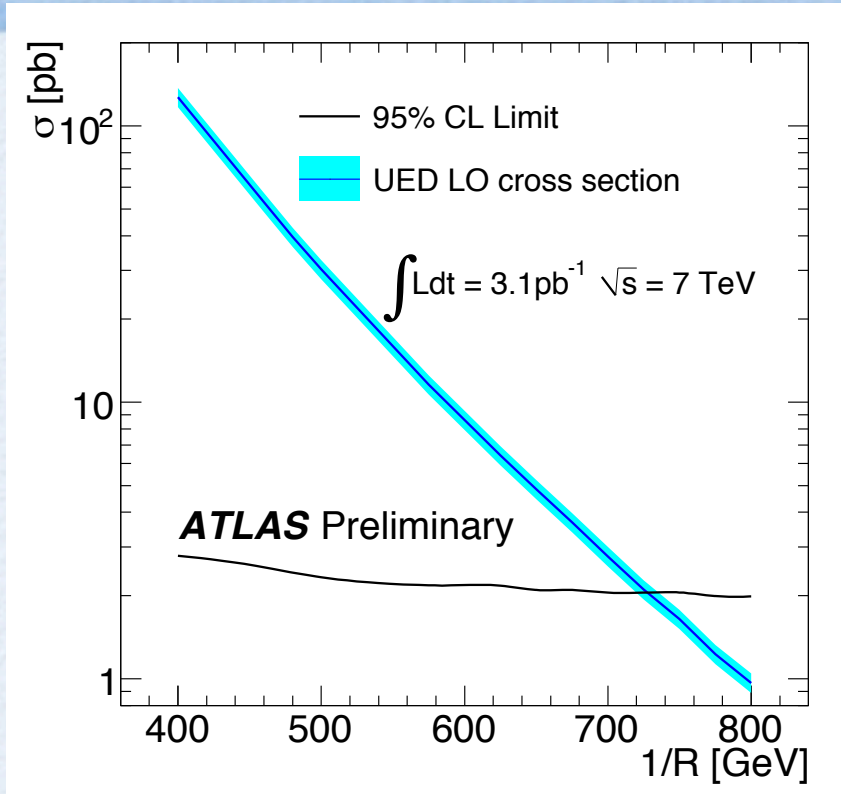


- Embedding UED in larger space with N large dimension of (of size^{-1} ~ev) where only graviton can propagate → Gravity mediated decays become possible $\gamma^* \rightarrow \gamma$+Graviton diphoton+MET

D0 excludes 1/R < 447 GeV @ 95% CL Phys.Rev.Lett.105:221802,2010

UED RESULTS



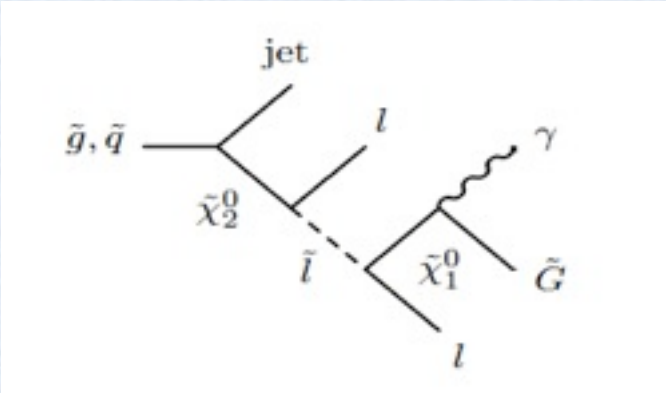


Phys. Rev. Lett. 106, 121803, 2011

- Background determined entirely from data, Z->ee, QCD sample, W+jets
- ΛR=20, M_D=5 GeV , and N=6
- Use Bayesian counting experiment
- No excess of events seen
  - Exclude 1/R values of > 728 GeV

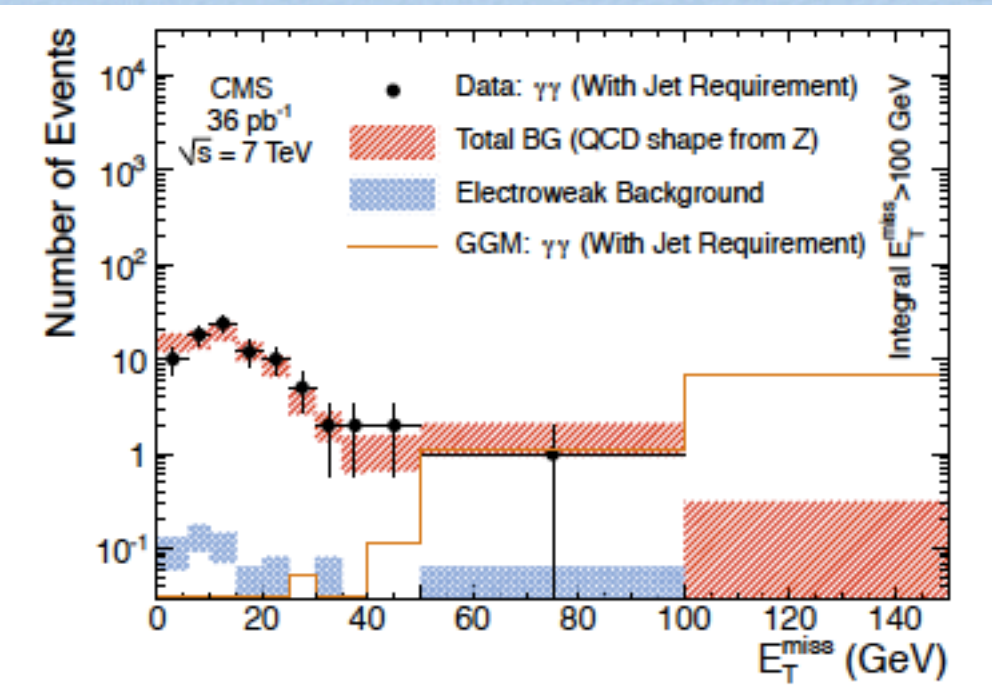
General Gauge Mediated (GGM) Photons

- Strongly-interacting SUSY particles are pair-produced (R-Parity Conserved)
- Gravitino LSP particle
- χ_1^0 NLSP decays to Gravitino and photon
- GGM allows for light gluino →high cross section at the LHC



- if NLSP lifetime is not too long C_{grav}~1
  - events with 2 high p_T photons are expected
  - Or if lifetime is large we could see only 1 photon and Missing E_T
- Look for two reconstructed photons with (E_T) (30 GeV), at least one isolated jet, and missing E_T (50 GeV)

GGM RESULTS CMS



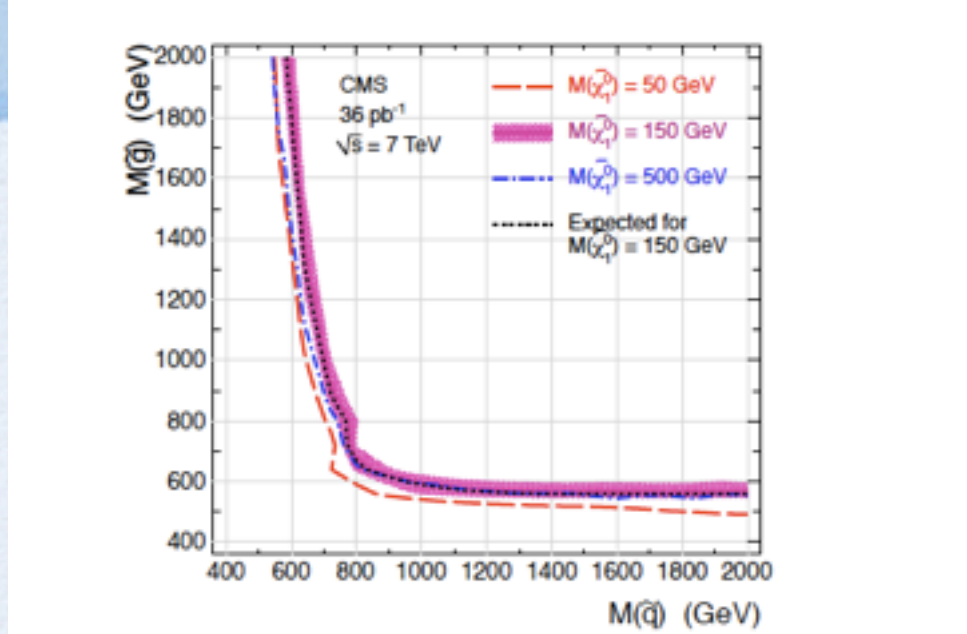


Figure 4: Lower 95% CL exclusion limits on the squark ($\tilde{q}$) and gluino ($\tilde{g}$) masses in the GGM benchmark model for 50, 150, and 500 GeV neutralino ($\tilde{\chi}_1^0$) masses. The areas below and to the left of the lines are excluded. The expected exclusion limit for 150 GeV neutralino mass is shown by the dashed line. The shaded band represents ±1 standard deviation of theoretical uncertainty on the GGM cross section.

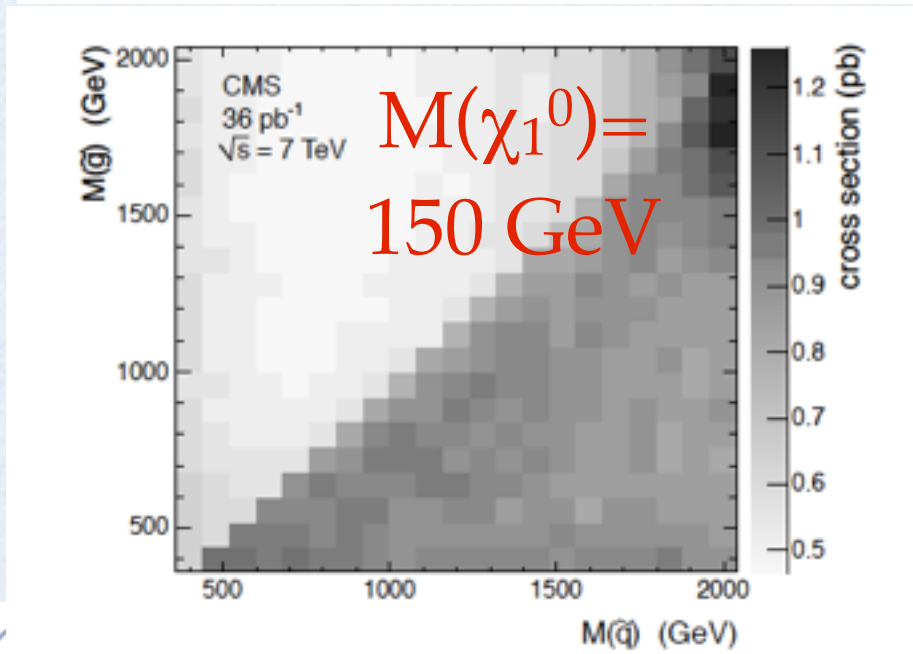


Figure 3: 95% CL upper limits for GGM production cross section as a function of squark ($\tilde{q}$) and gluino ($\tilde{g}$) masses for a neutralino mass of 150 GeV.

arXiv:1103.0953v2 [hep-ex]

- Backgrounds determined completely from data
  - Observe 1 event 1.2±0.8 background
- Limits in the GGM benchmark model of 0.3-1.1 pb^{-1}

CONCLUSIONS

- Many new exciting photon results from LHC both within SM and BSM
- Already 310 pb^{-1} of data recorded per experiment
  - New limits already set and more to be broken
- Expect SM Higgs limits of 4xSM with 1fb^{-1} of data in low mass region
- More public results listed:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults