Searches for new physics in diphoton events with ATLAS

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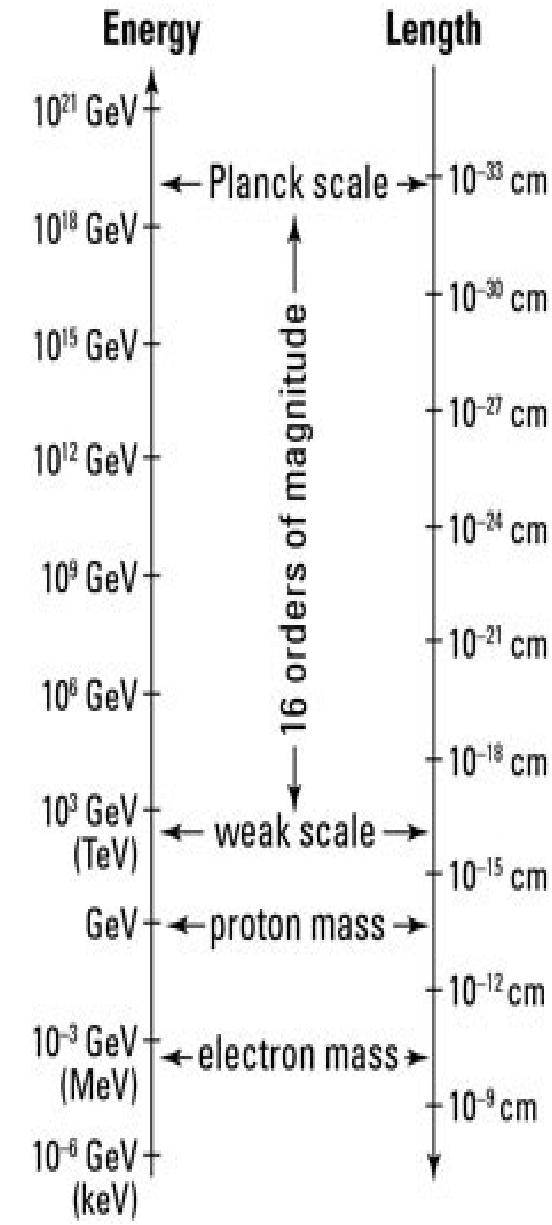
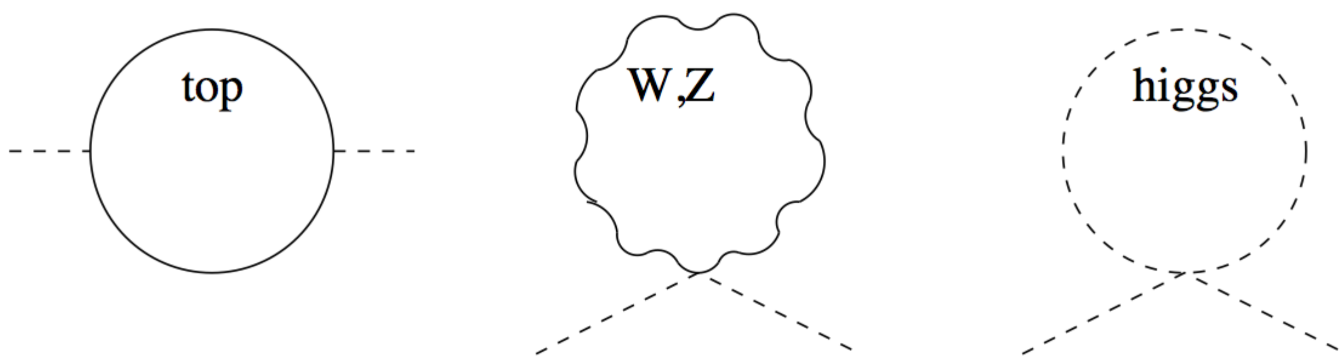
✴New physics in diphoton events means high mass events. Not the 125 GeV bump.

The hierarchy problem



- The hierarchy problem: $M_{ew} \sim 10^{-16} M_{Pl}$.

- In the context of SM: Higgs mass stability issue.
  - Radiative corrections:



$$-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \qquad \frac{9}{64\pi^2}g^2\Lambda^2 \qquad \frac{1}{16\pi^2}\lambda^2\Lambda^2$$

  - If $\Lambda \sim M_{Pl}$: to get $m_h \sim 125$ GeV, the bare Higgs mass and the radiative corrections need to cancel out with a precision of 10^{-32} !

Extra Dimensions models (1/2)

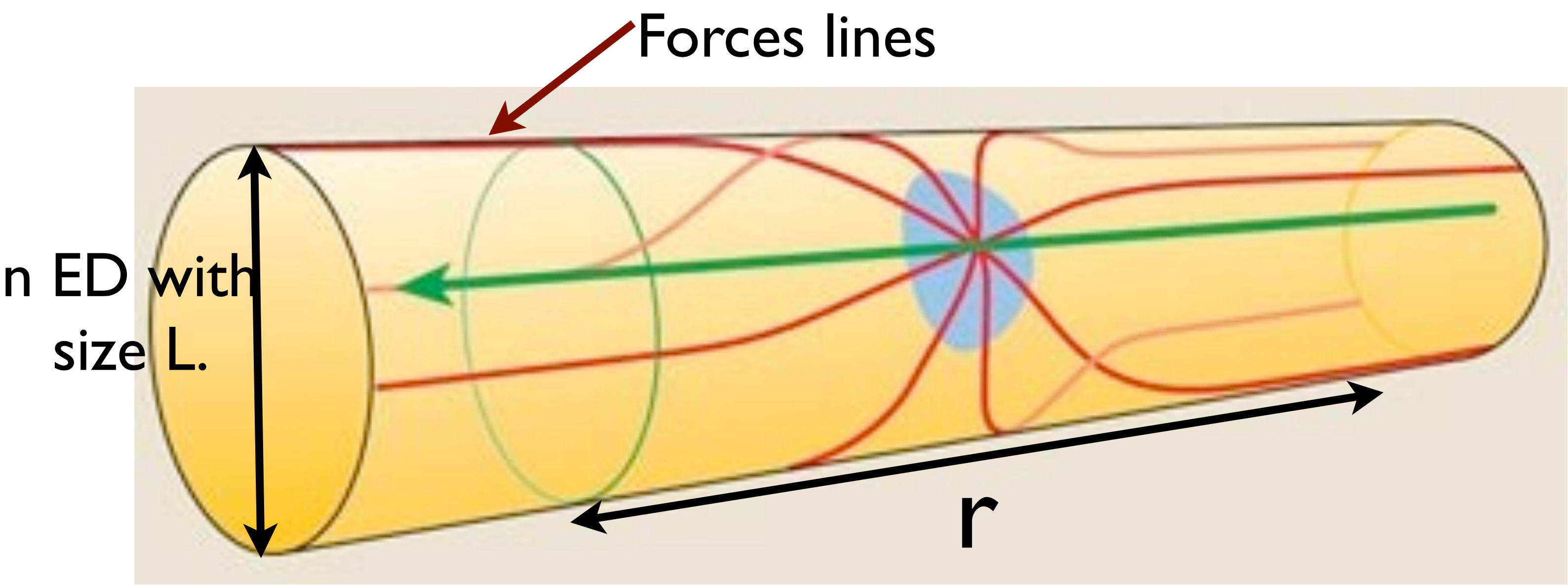
Extra-Dimensions paradigm:

- The fundamental M_{Pl} is close to M_{ew} but gravity is diluted by the presence of extra-dimensions (ED) and M_{Pl} appears much weaker.

- But precision measurements forbid the presence of ED at a size $R \gtrsim 1\ \text{TeV}^{-1}$.
  - ED have to be smaller or not accessible to SM fields.

Large Extra Dimensions:

Postulated by Arkani-Hamed, Dimopoulos, Dvali (ADD): Phys. Lett. B 429 (1998) 263



$$\Rightarrow M^2_{pl(4)} \sim M^{n+2}_{pl(4+n)} L^n$$

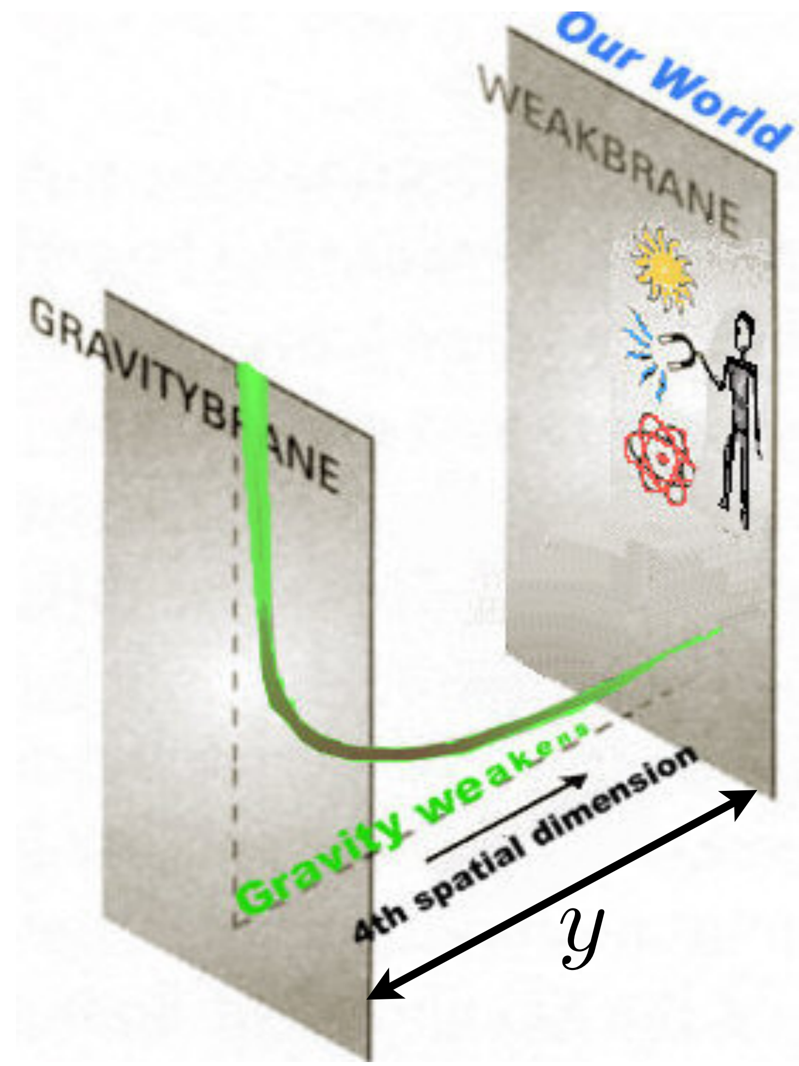
- Gravity is the only field allowed to propagate into the 5D space.
- Compactification leads to an infinite set of KK particles with a very small modal spacing.
- Divergence in the number of modes imposes an UV cutoff **M_s**.

Warped Extra Dimensions:

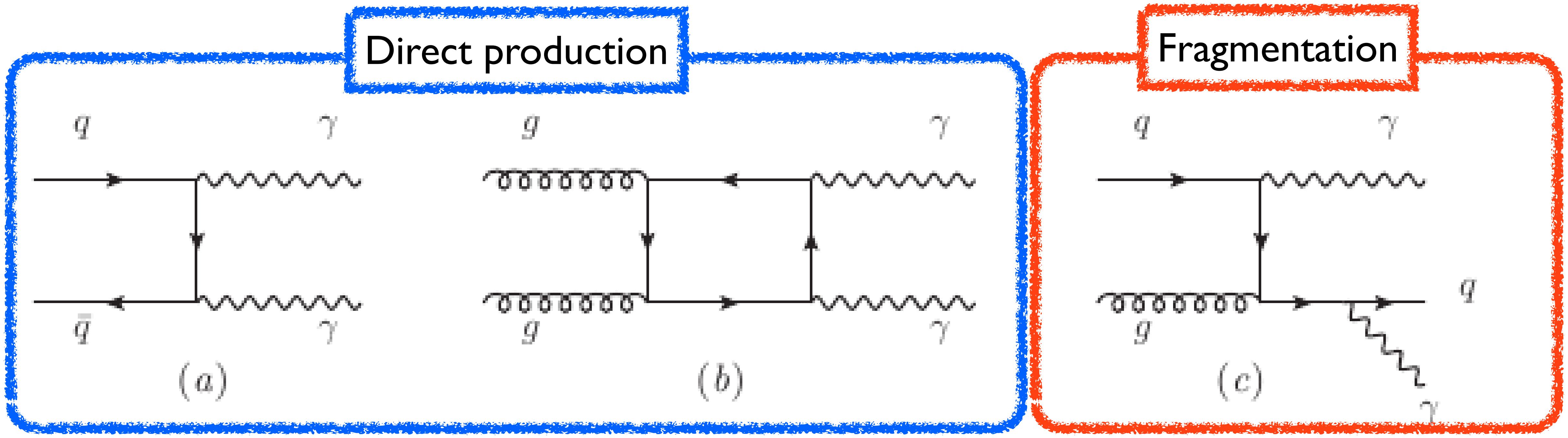
Postulated by Randall and Sundrum (RS): Phys. Rev. Lett. 83 (1999) 3370

- 5D space-time with two branes.
- Gravity is the only field allowed to propagate into the 5D space.
- The strength of gravity is diluted through a warp factor k.
- The compactification leads to a series of narrow resonances.

$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$



SM γγ production

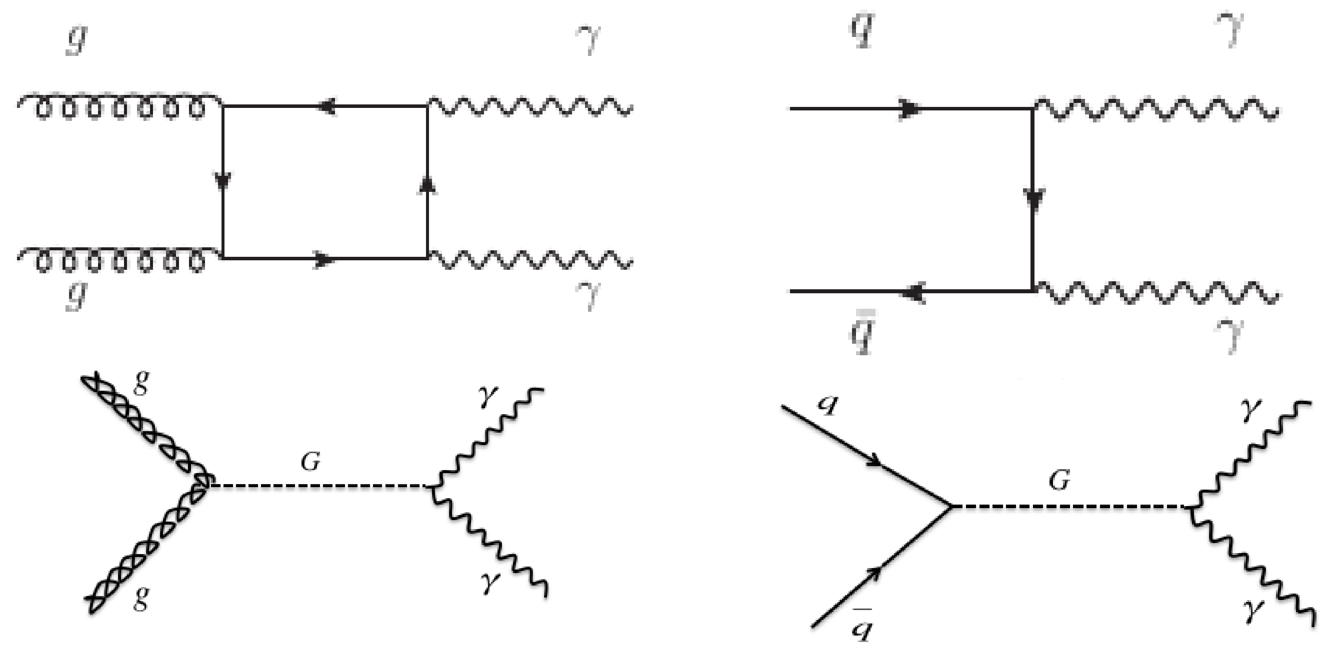


- Dominant background in this search.
- LO prediction and fragmentation model available in standard MC generators:
  - PYTHIA+PHOTOS, SHERPA
- Parton-level calculation for higher order terms and precise fragmentation calculation:
  - DIPHOX, MCFM, 2gNNLO

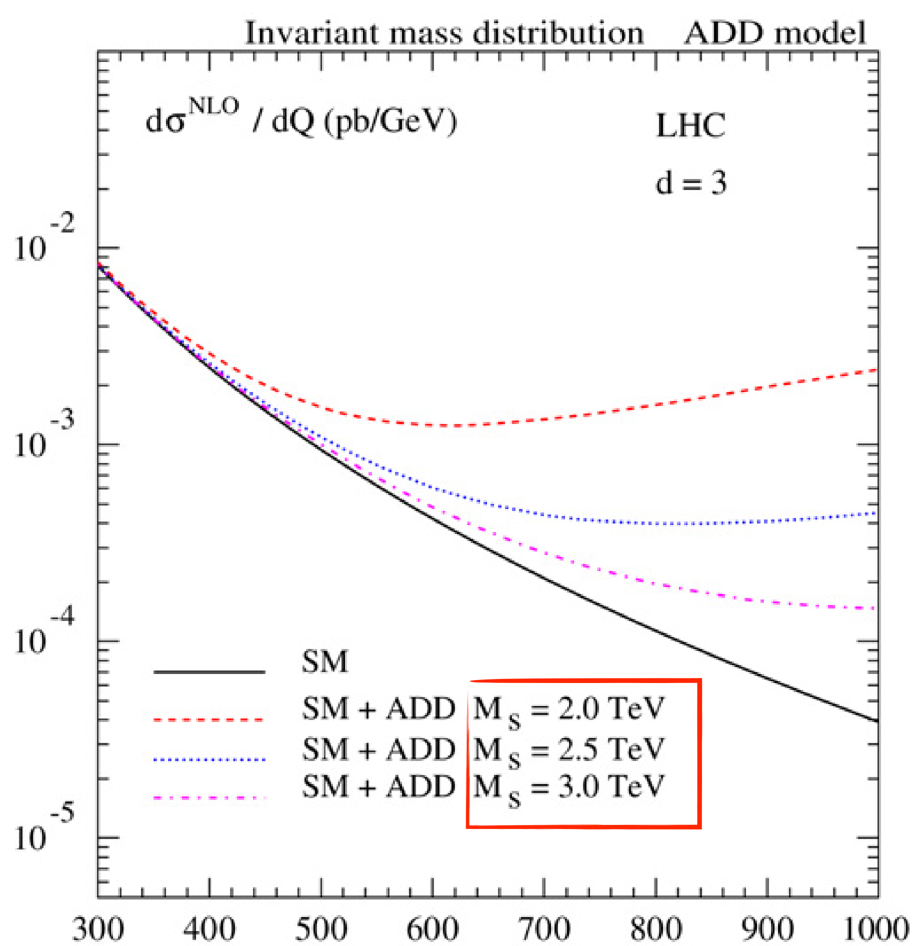
Extra Dimensions in the γγ final state

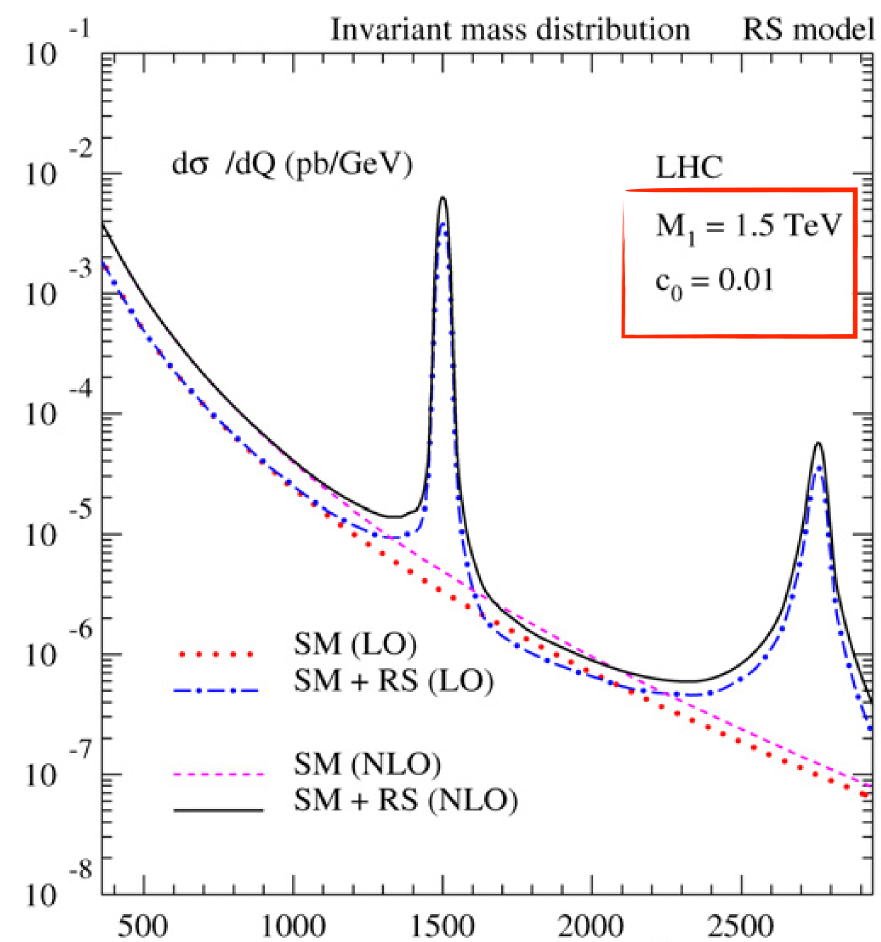
SM

ED



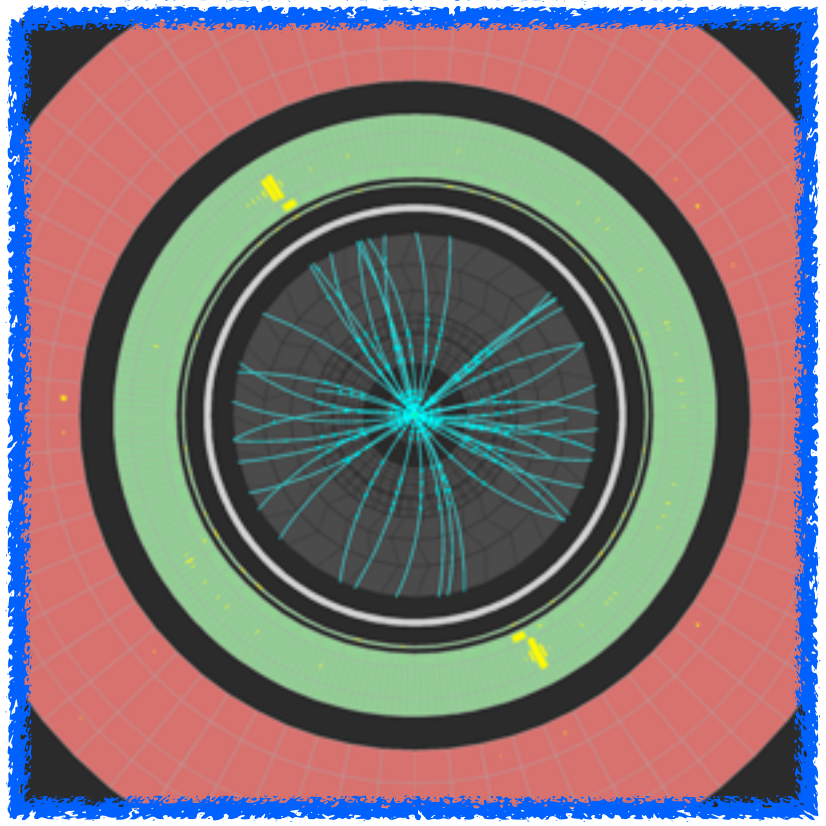
M.C Kumar et al: Nucl. Phys. B818 28-51 (2009)



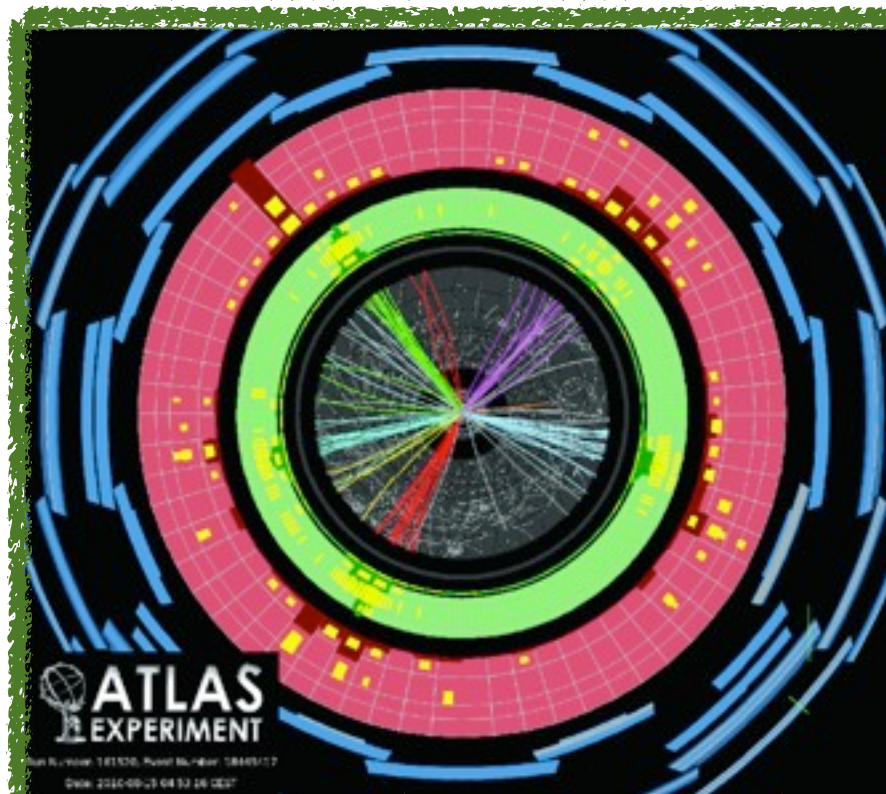


Detecting diphoton events

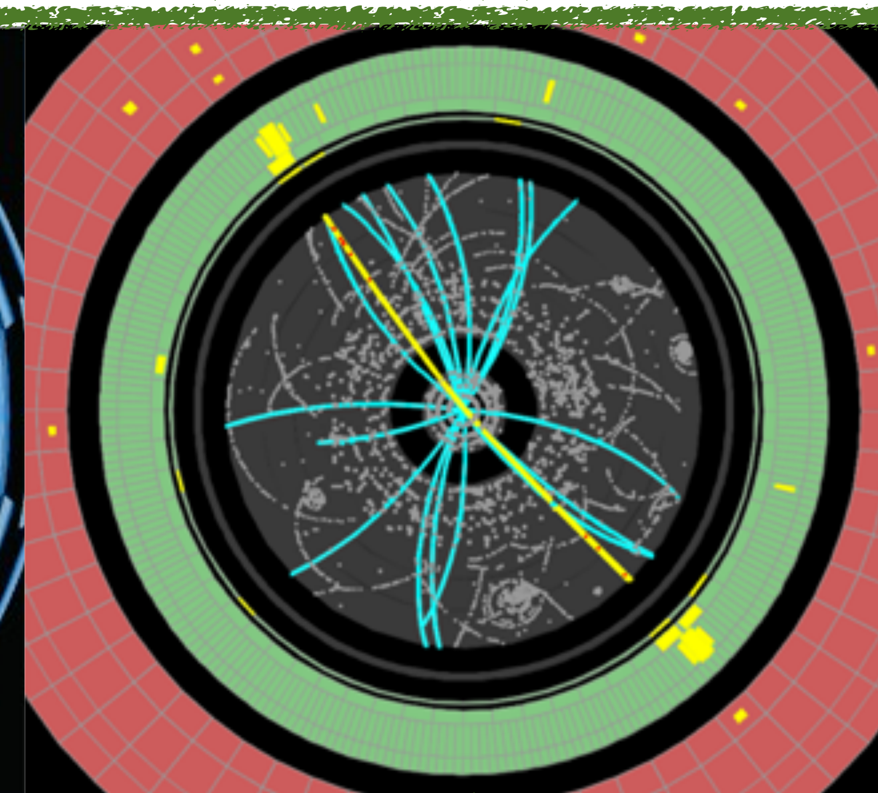
Diphoton candidate



Multi-jets candidate



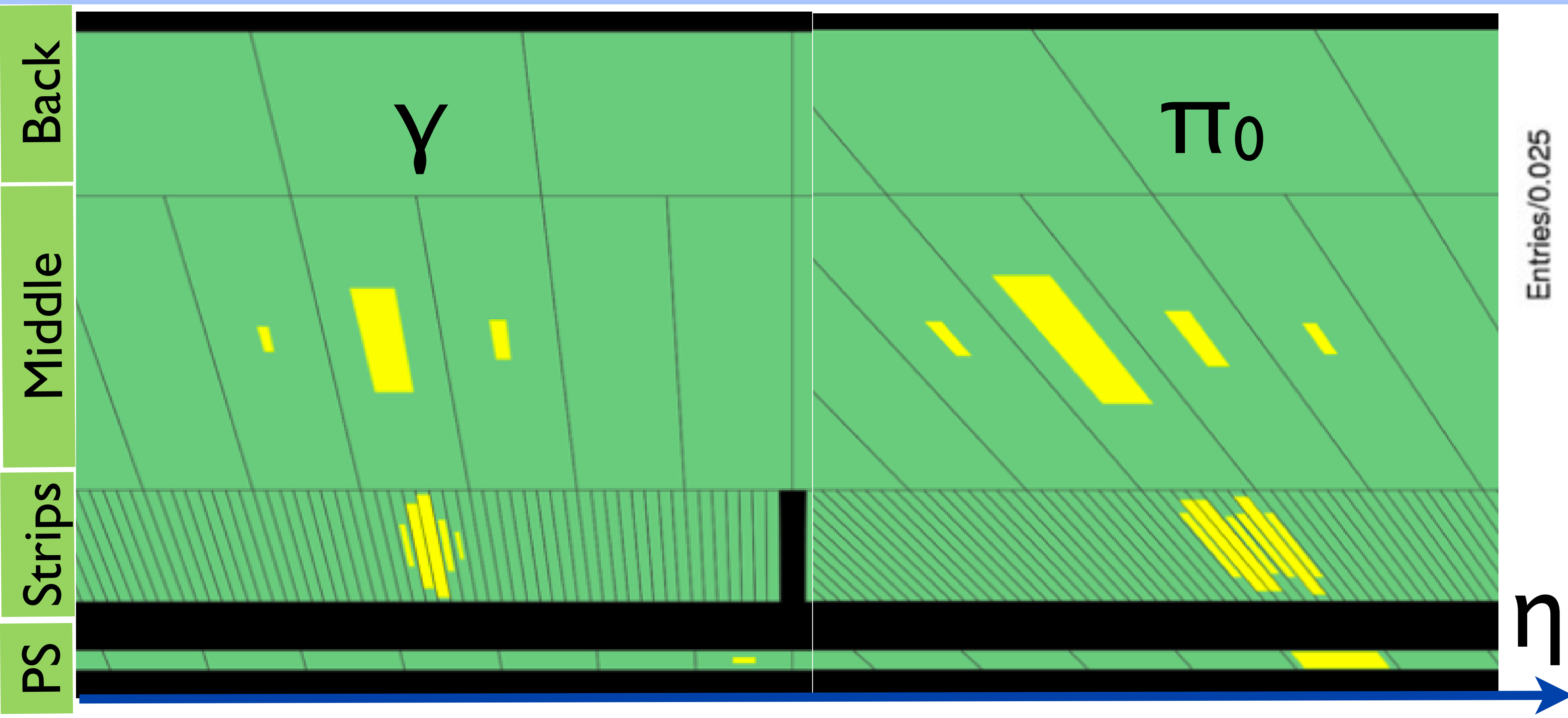
$Z \rightarrow e^+e^-$ candidate

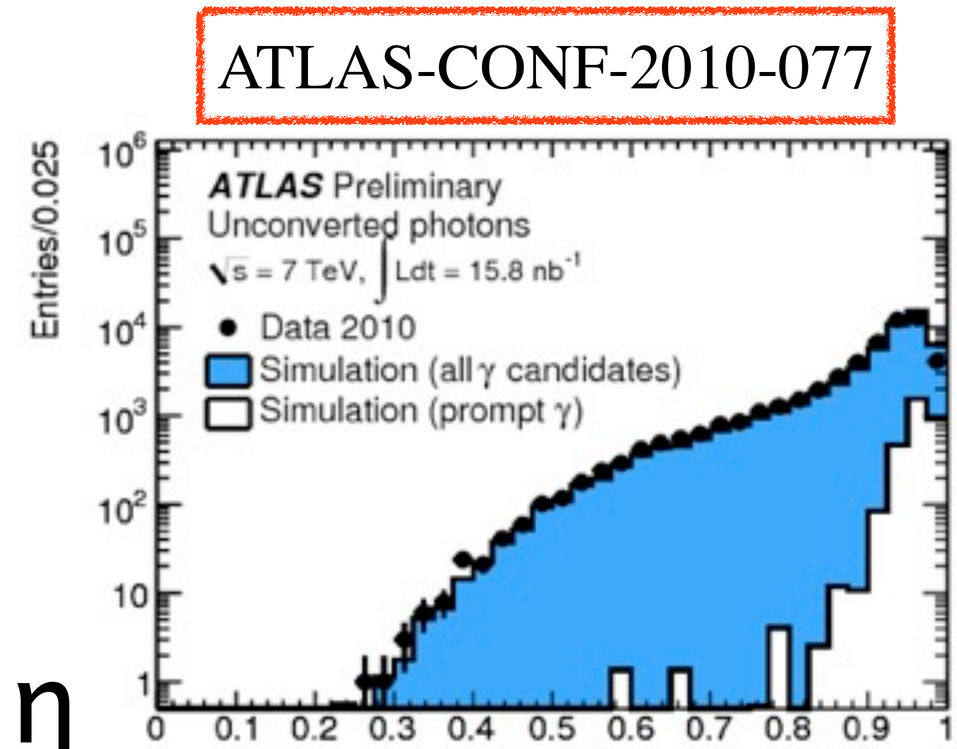


Process	Diphoton	HardQCD	$Z \rightarrow e^+e^-$
XS (mb) for $\sqrt{\hat{s}}$ > 140 GeV (from Pythia8)	$4.49.10^{-9}$	$8.29.10^{-2}$	$4.36.10^{-9}$
Ratio to Diphoton XS	1	**~2.10^7**	~1

• photons/jets separation needs specific tools: identification and isolation.
• electrons/photons separation is ensured by the tracker (special care is taken for the 30% of converted photons).

γ/jet separation: identification





$$R_\eta = E_{3\times7}/E_{7\times7}$$

- Exploit the granularity of the ECAL to describe the EM showers shape.
- Two working points: loose and tight.

Loose

- Veto energy deposit in the HCAL.
- Narrow shower in the middle layer.

▸ Very good signal efficiency (~95%) but modest jet rejection.

▸ Deployed at trigger level.

▸ Used as photon pre-selection in the analysis.

Tight

- Tighter cut in the middle layer.
- Requirement on the first layer (reject $\pi_0 \rightarrow \gamma\gamma$).

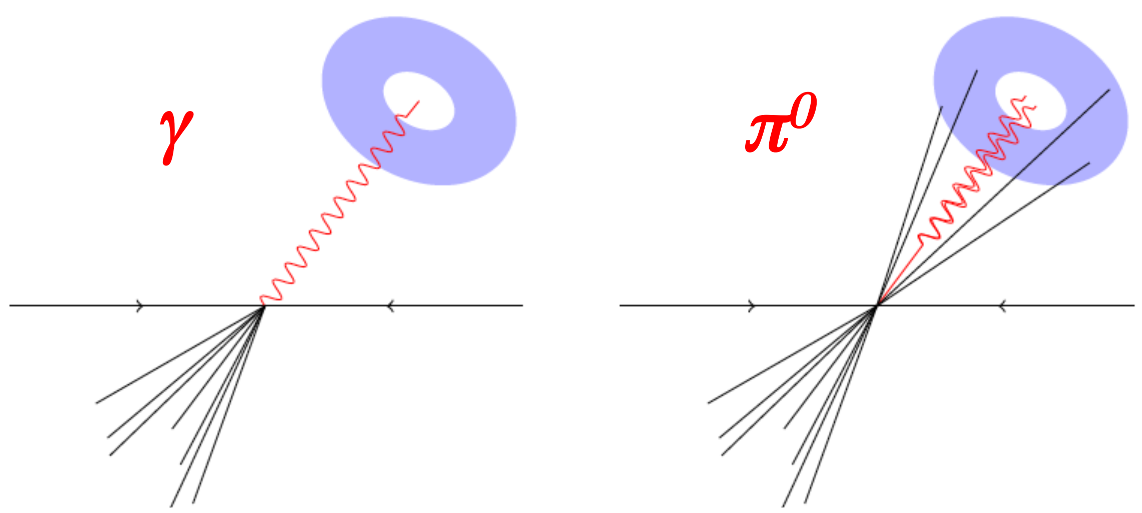
▸ Good signal efficiency (~90%). jet rejection ~5X better than loose.

▸ Used as photon identification in the analysis.

▸ Reverting Tight provides a large control region to study fakes.

γ/jet separation: isolation

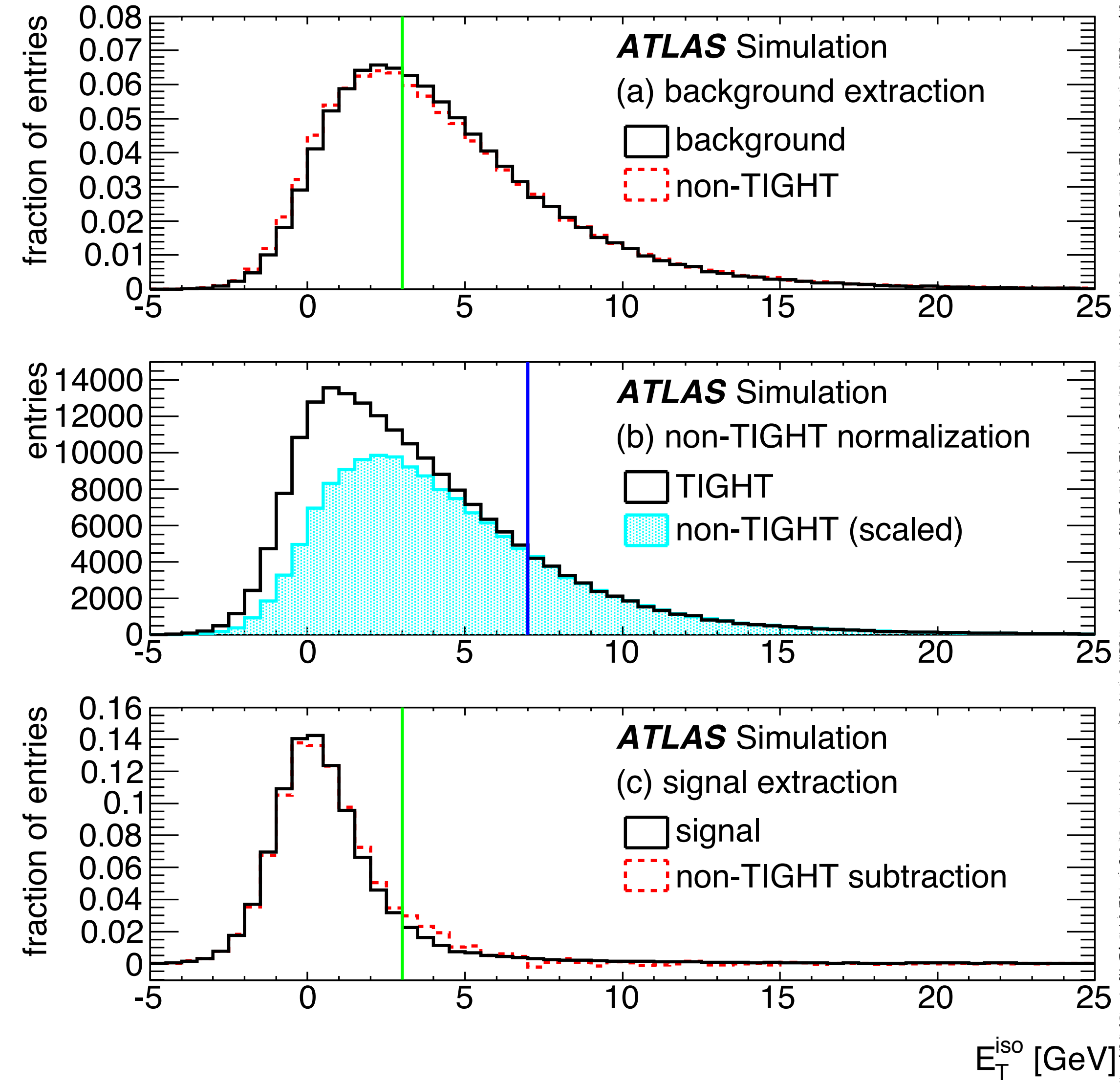
Calorimetric Isolation



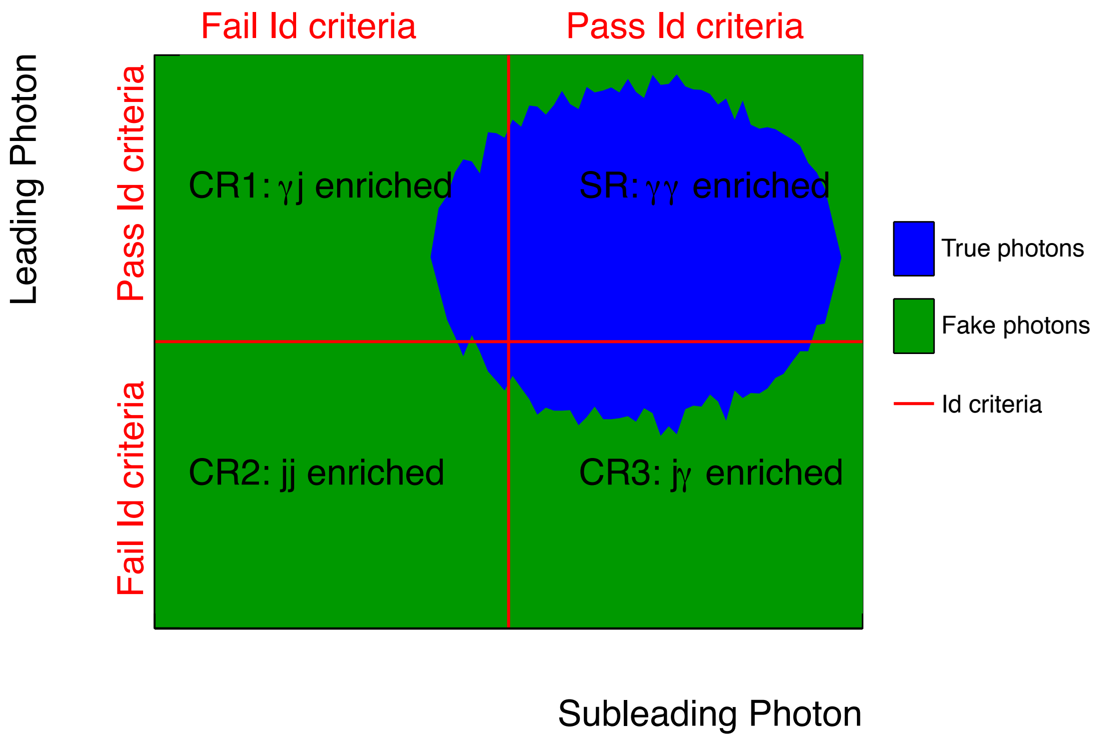
$$\sum_{cells} E_T^{iso}\; in\; \Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$$

subtracting:
- The energy of the candidate itself.
- The out-of-cluster leakage.
- The soft-jet contribution from pileup and underlying event.

Data Driven Techniques



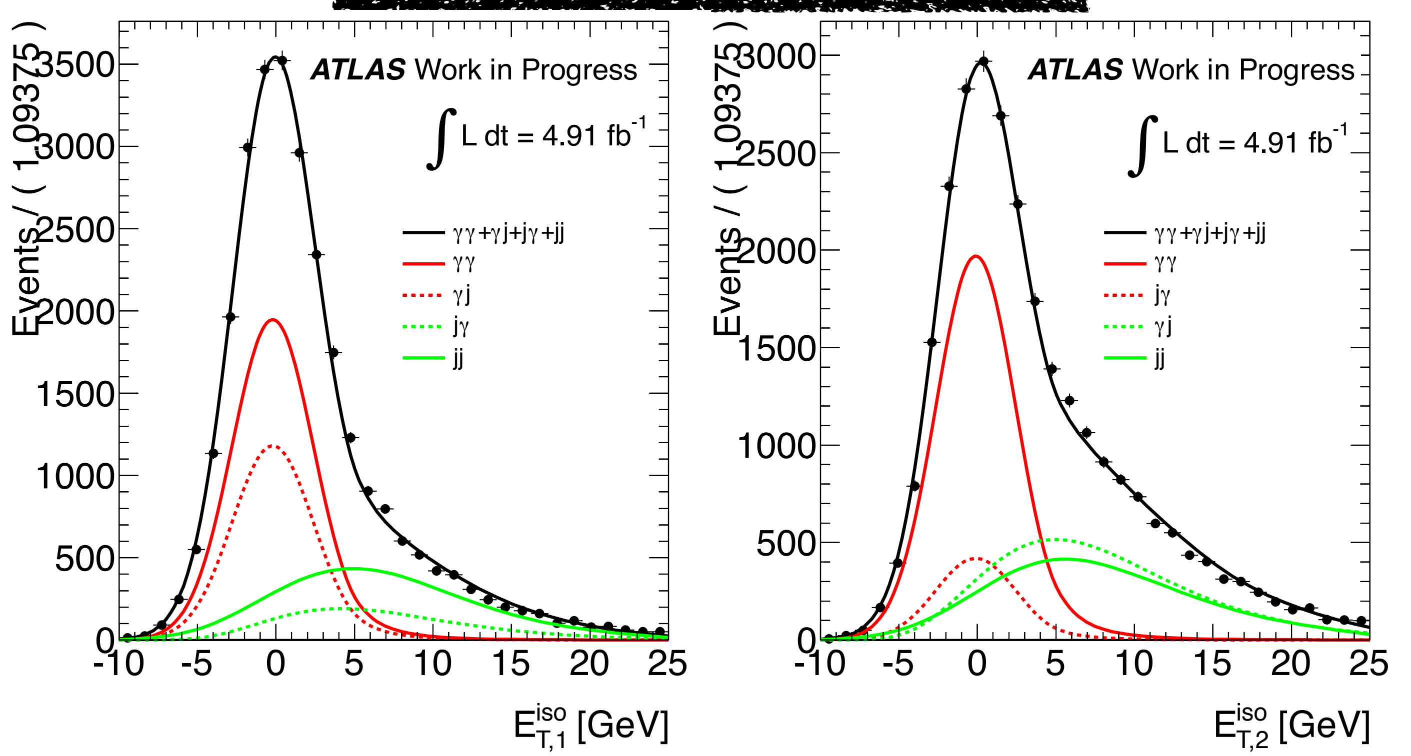
Isolation to determine the sample composition



2D template fit of the isolations

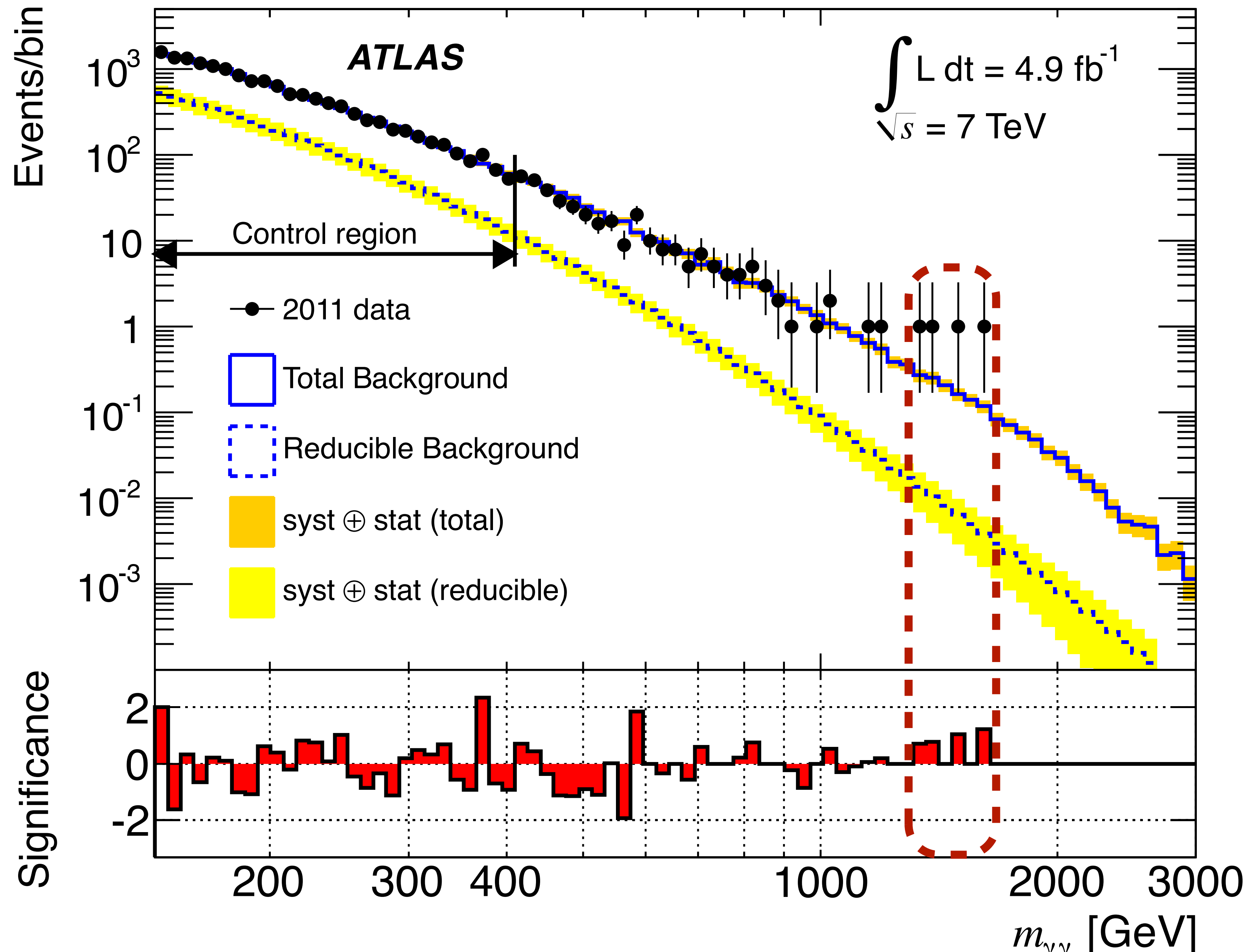
- 4 contributions: γγ, γj, jγ, jj.
- Extract the fake templates in the CRs.
- Extract the photon templates in the SR after bkg subtraction (as described in slide 9).
- Build the 2D templates as product of 1DX1D.
- ▸ Fit the 4 yields in the SR.

Fit results: 1D Projections



Data/background comparison

New J. Phys. **15** 043007, http://arxiv.org/abs/1210.8389. Plot available here.

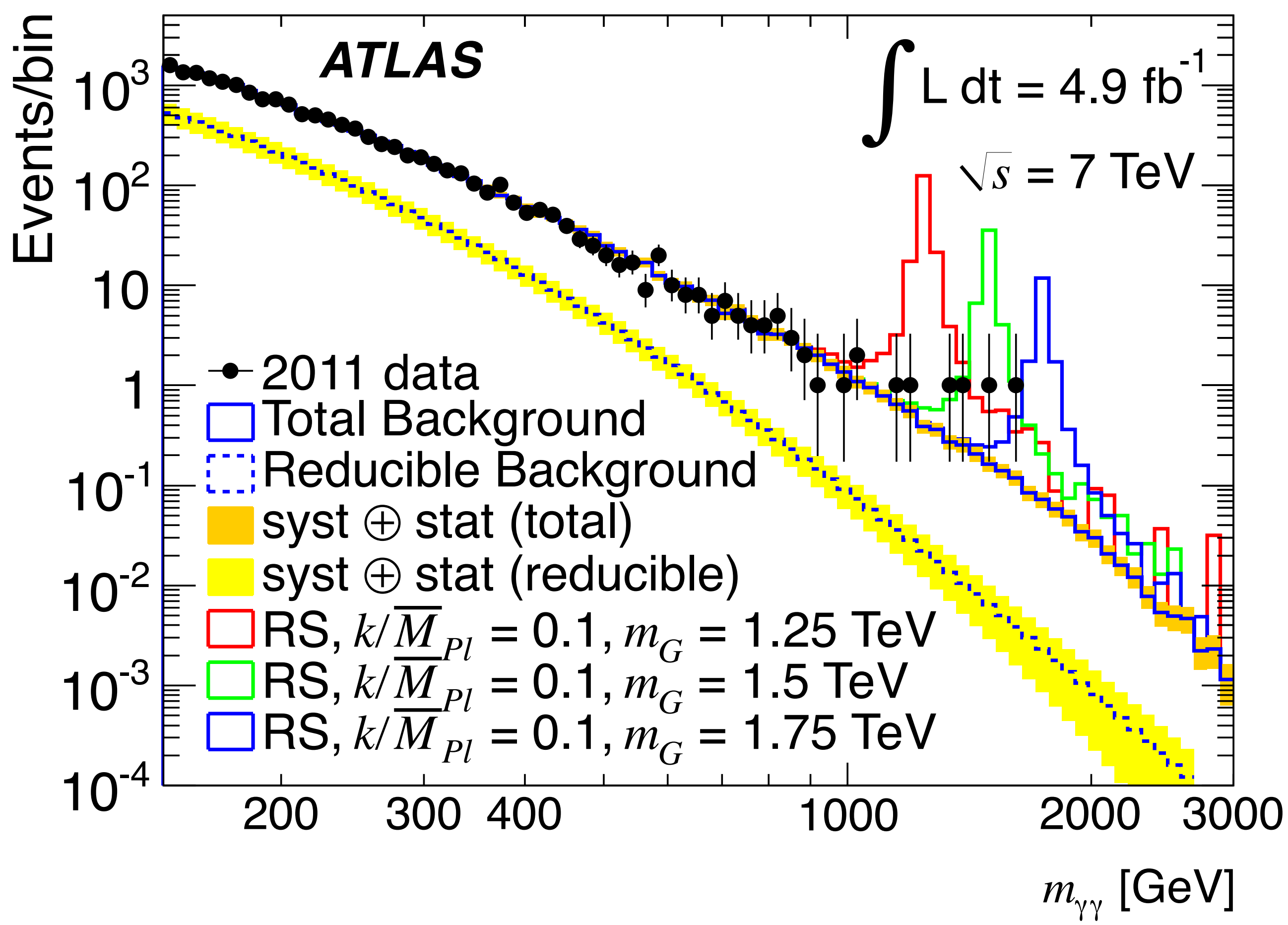


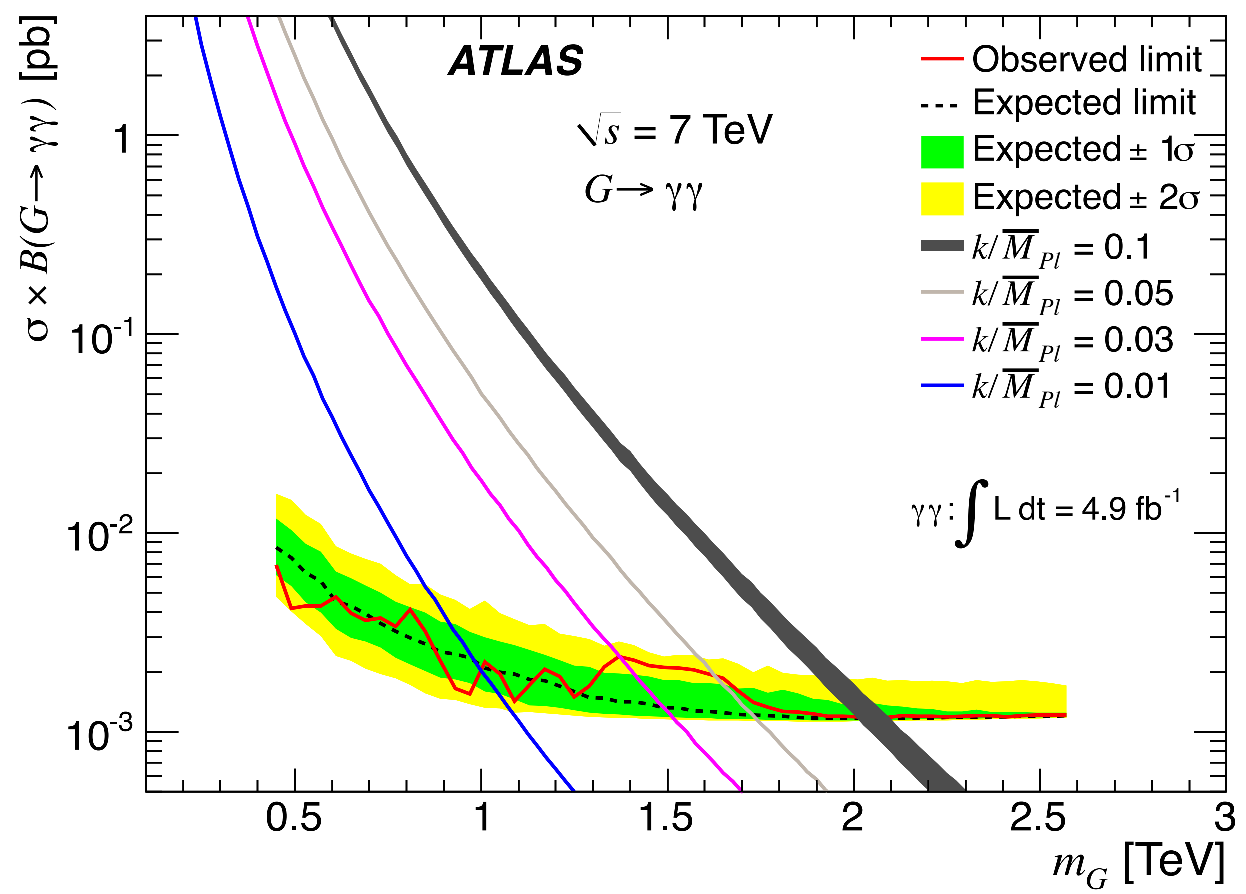
Bump Hunting

The most significant deviation is found for 1.3 TeV < $m_{\gamma\gamma}$ < 1.6 TeV.
Global p-value : 0.86

Constraints on Warped Extra Dimensions

New J. Phys. **15** 043007. Plots available here.

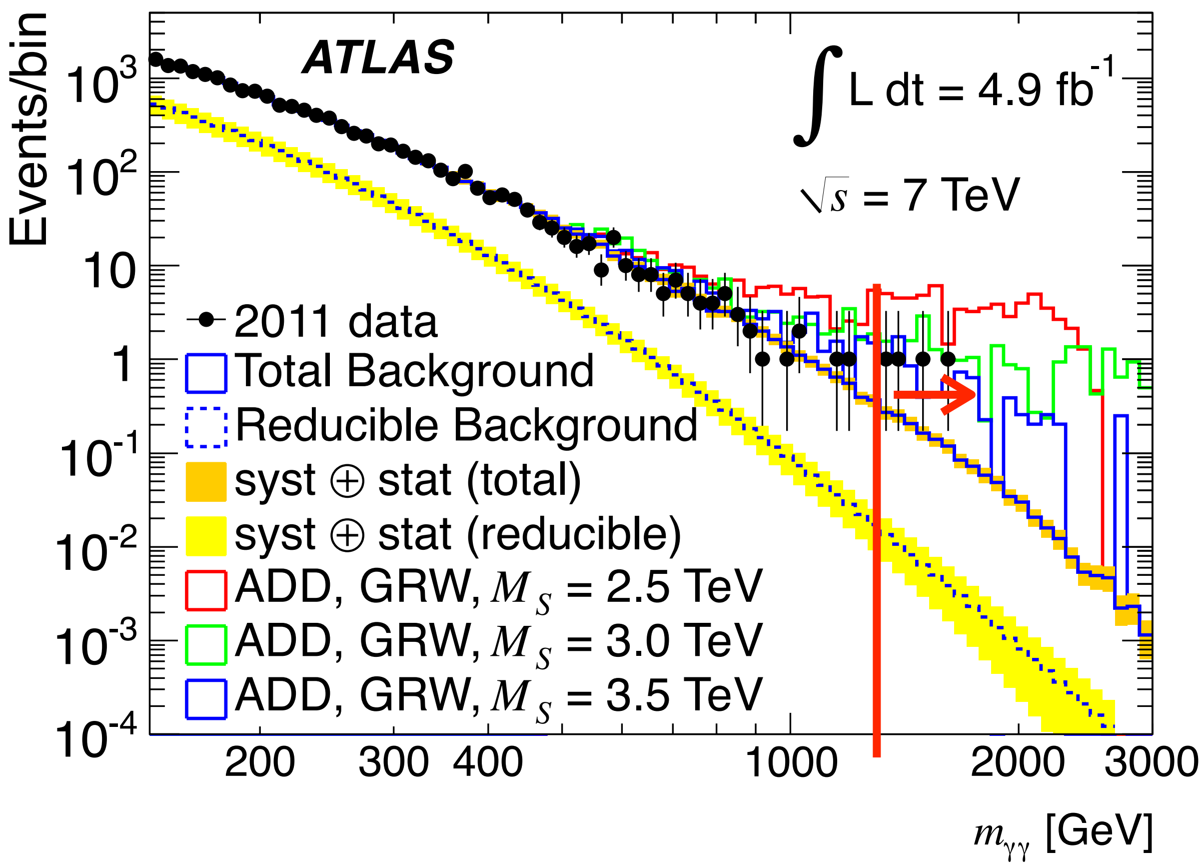




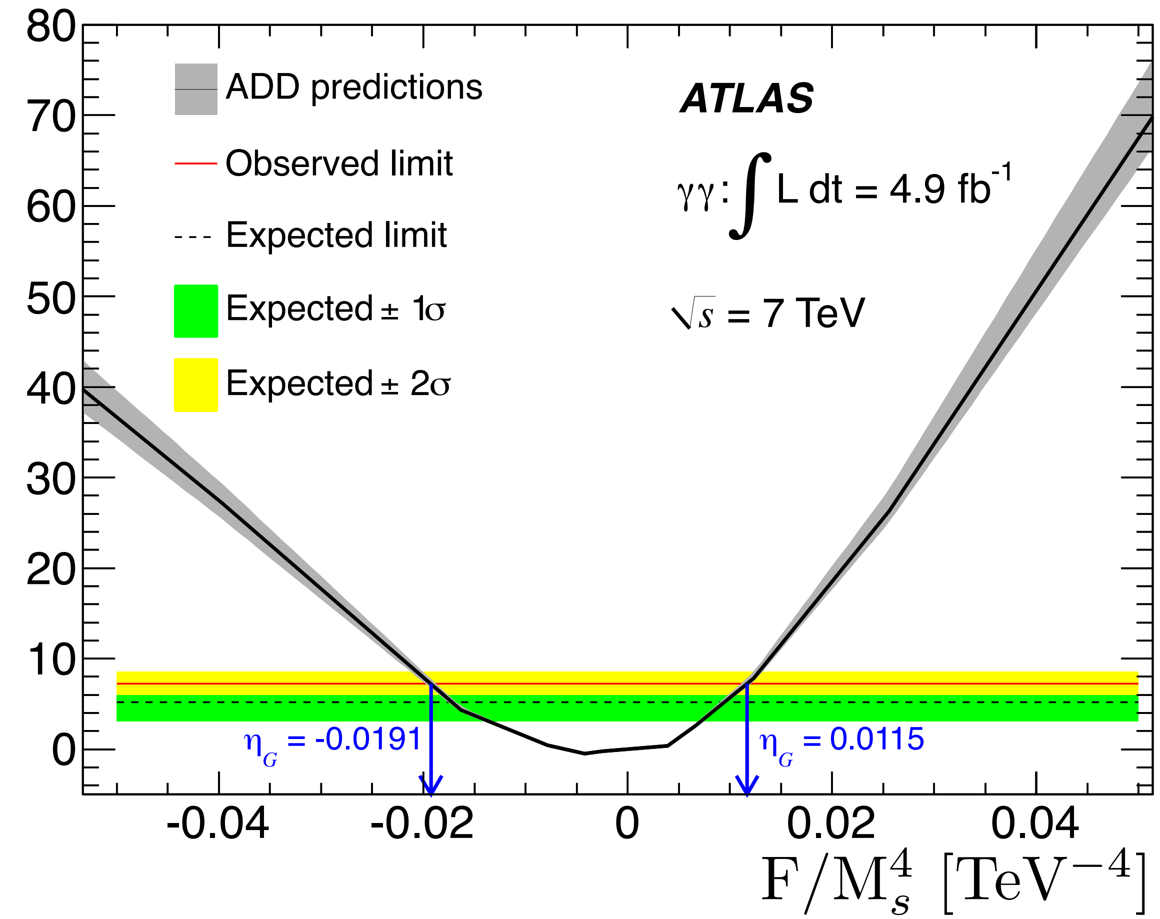
- Coupling k/M$_{Pl}$=0.1: Observed limit@95% CL on m$_G$ = 2.06 TeV.
- Combination with dilepton result JHEP 1211 (2012) 138 improves m$_G$ limit to 2.23TeV.

Constraints on Large Extra Dimensions

New J. Phys. **15** 043007. Plots available here.



Number of signal events



$$\sigma_{tot} = \sigma_{SM} + \boxed{\left(\frac{F}{M_s^4}\right)\sigma_{int} + \left(\frac{F}{M_s^4}\right)^2 \sigma_{ED}}$$

- Several values for F in the litterature.
- GRW: F=1. Observed limit@ 95% C.L: F/M_S^4= 0.0085, M_S= 3.29 TeV.
- Combination with dilepton result Phys. Rev. D 87, 015010 (2013) improves M_S limit to 3.51 TeV.

Conclusions

- **With the full dataset of $\sqrt{s}$ = 7 TeV pp collisions:**

  - The presence of new phenomena in diphoton events has been tested.
  - Resonant and non-resonant scenario have been constrained.
  - The result has been published by NJP: *New J. Phys.* **15** 043007.

- **~20 fb^{-1} of data with $\sqrt{s}$ = 8 TeV pp collisions:**

  - Expect large improvement on the limits (~0.5 TeV).
  - Dilepton preliminary result with 8 TeV data already there:
    - ✳ m_G limit = 2.47 TeV for k/M_{Pl}=0.1(ATL-CONF-2013-017).

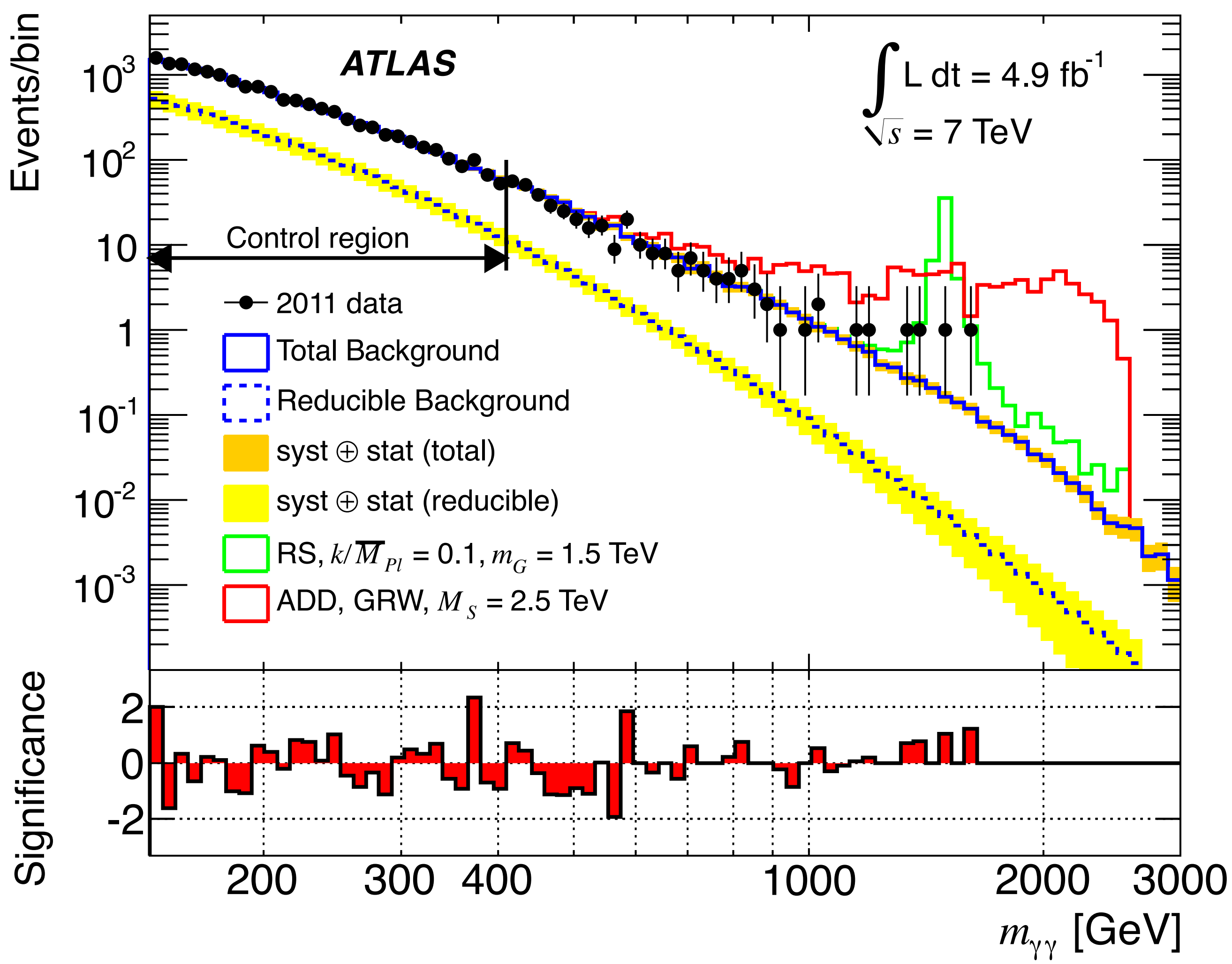
- **Waiting for the LHC nominal energy !**

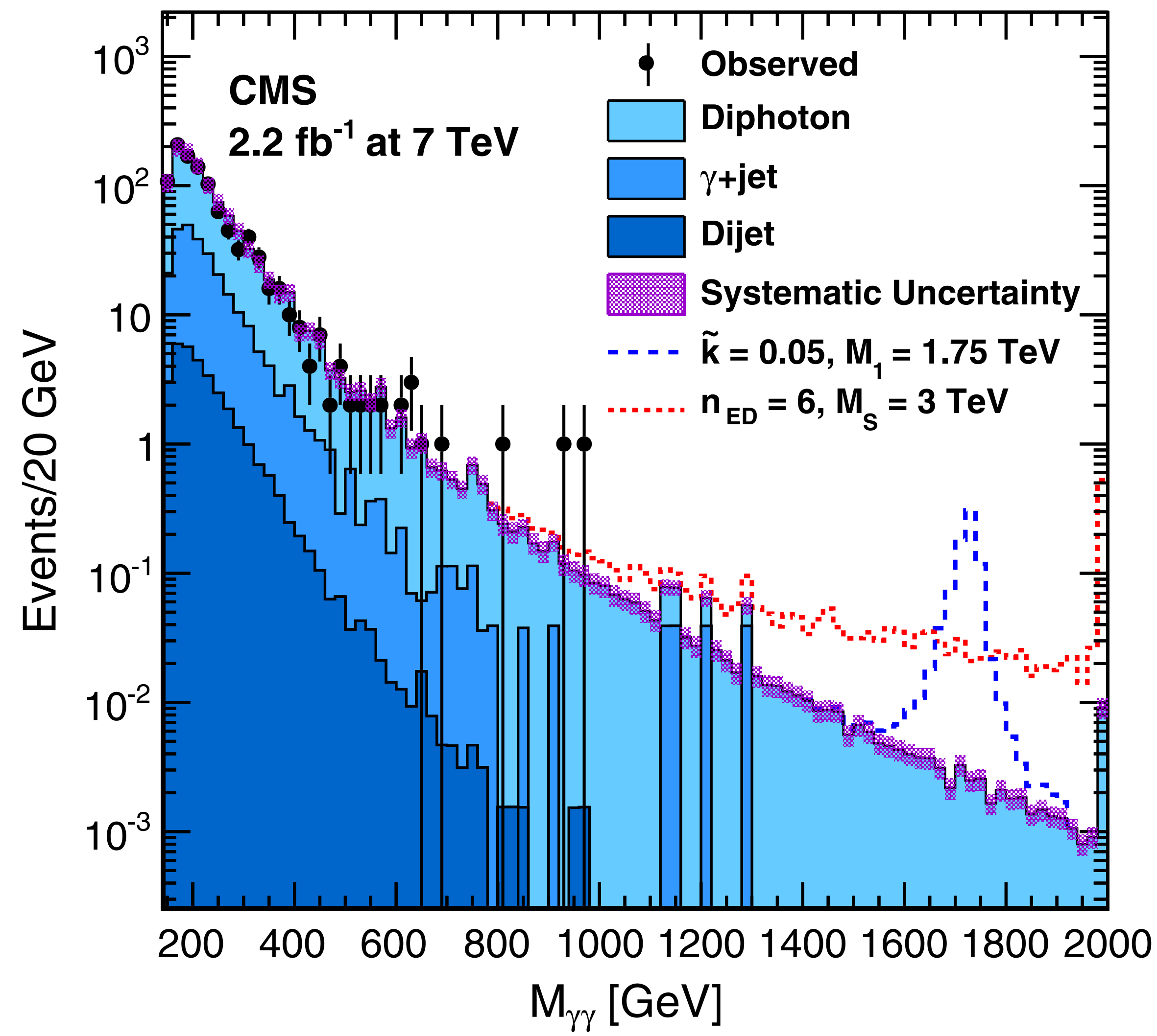
- **Related CMS searches:**

  - Resonant: dilepton PAS EXO12015, diphoton Phys. Rev. Lett.108(2012) 11180.
  - Non-resonant: dielectron PAS EXO12031, dimuon PAS EXO12027, Diphoton Phys. Rev. Lett.108(2012) 111801.

Backup

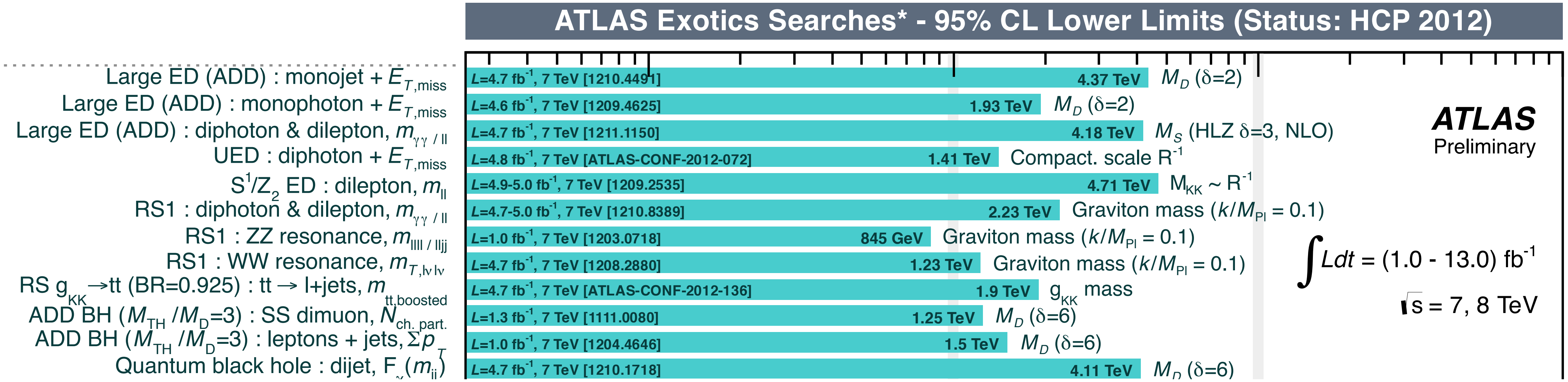
ATLAS/CMS comparison





- Similar strategy:
  - jet faking photon estimated by data-driven techniques (reverting id/isolation criteria)
  - SM diphoton estimated by simulations+NLO cross-section computations
  - $m_{\gamma\gamma}$ shape analysis for RS and counting experiment for ADD.
- ATLAS uses the full dataset, CMS only half of it:
  - ATLAS limits are more stringents.

ATLAS ED Searches



Update since HCP

★ATLAS-CONF-2012-147

★ATLAS-CONF-2013-017

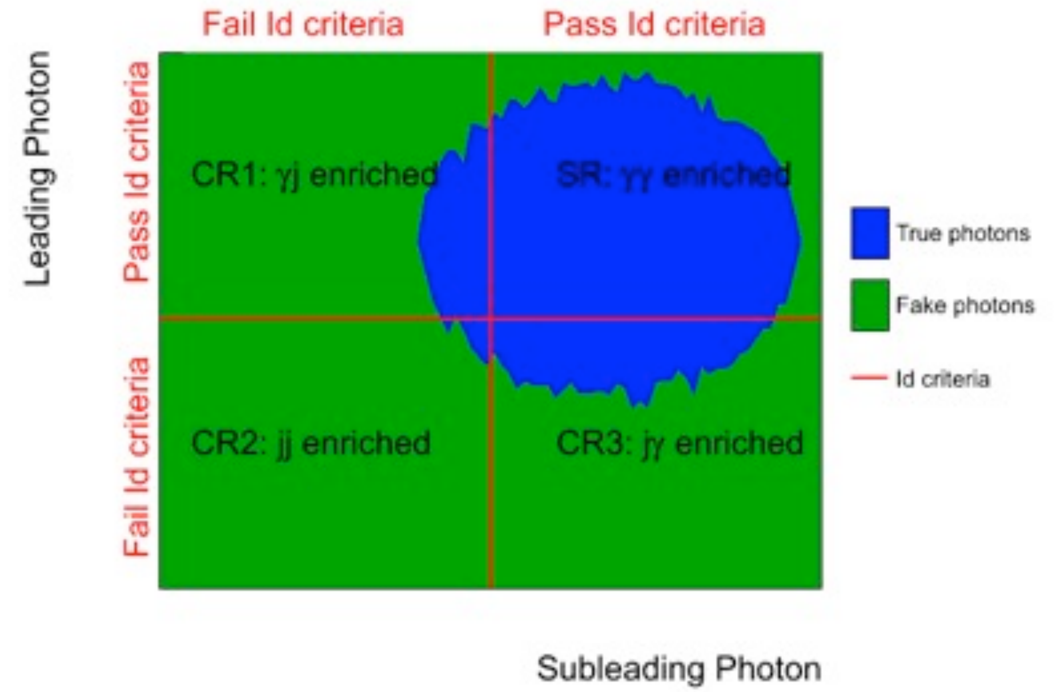
★ATLAS-CONF-2012-150

Background composition

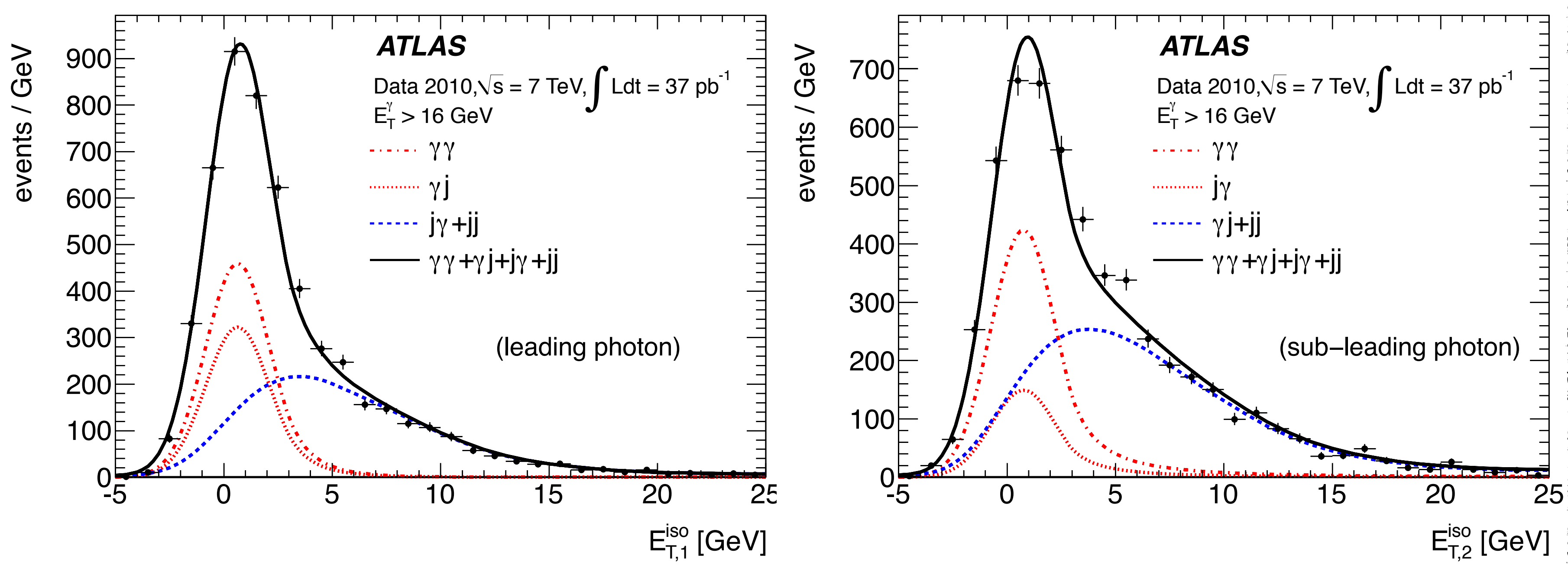
Method: 2D template fit of the isolations

- Consider 4 contributions: γγ, γj, jγ, jj.
- Extract the fake templates in the CRs.
- Extract the photon templates in the SR after bkg substraction (as introduced on slide4).
- Build the 2D templates as product of 1DX1D (except for jj).
- ▸ Fit the 4 yields in the SR.

Preselected data sample with 140<$m_{\gamma\gamma}$ (GeV)<400.



Fit results: 1D Projections



Analysis strategy

Background estimate

- Irreducible: SM $\gamma\gamma \rightarrow$ MC predictions.
- Reducible: Jets faking photons $\rightarrow$ Data driven.
- Electrons faking photons: negligible.
- Composition determined in the mass control region: [140,400] GeV.

▸ Total prediction normalised to the data in the mass control region.

$m_{\gamma\gamma}$ modeling

- Obtain the $m_{\gamma\gamma}$ lineshapes for each bkg component.
- Weight them according to the composition of the mass control region.

Interpretation

- Test the agreement between the data and the expectation.
- Set limits in the context of two ED models.

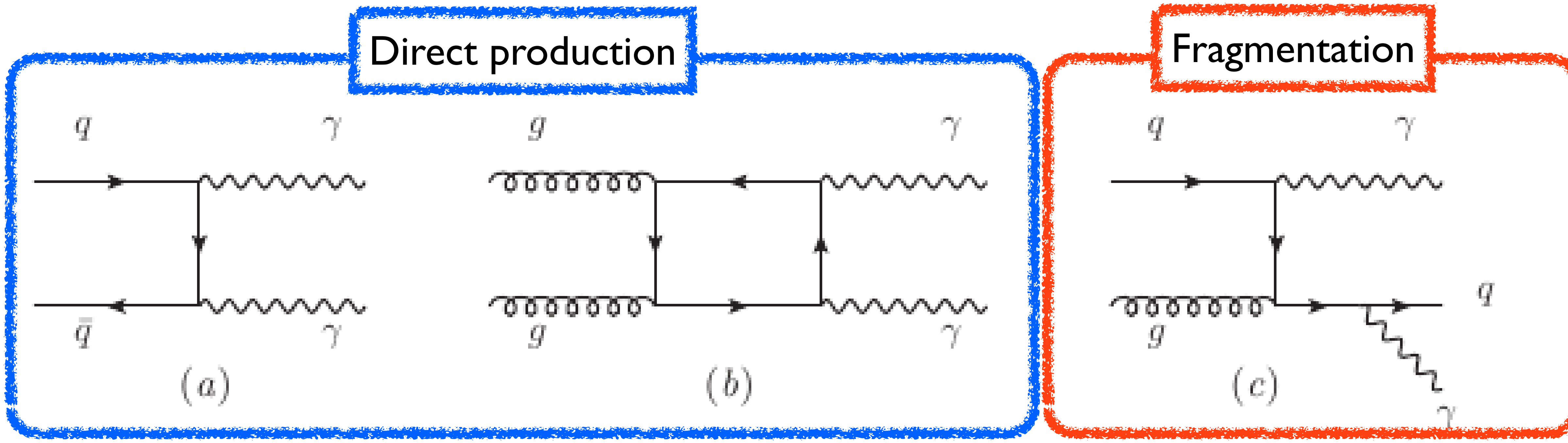
Data selection

Data selection

- Preselection - At least two photons with:
  - E_T>25 GeV
  - In the acceptance of the ECAL
  - Pass loose ID criteria
- Final selection - The two highest-E_T candidates:
  - Pass tight ID criteria
  - $E_T^{iso} < 5$ GeV
- Mass selection - $m_{\gamma\gamma} > 140$ GeV

$m_{\gamma\gamma}$ modeling

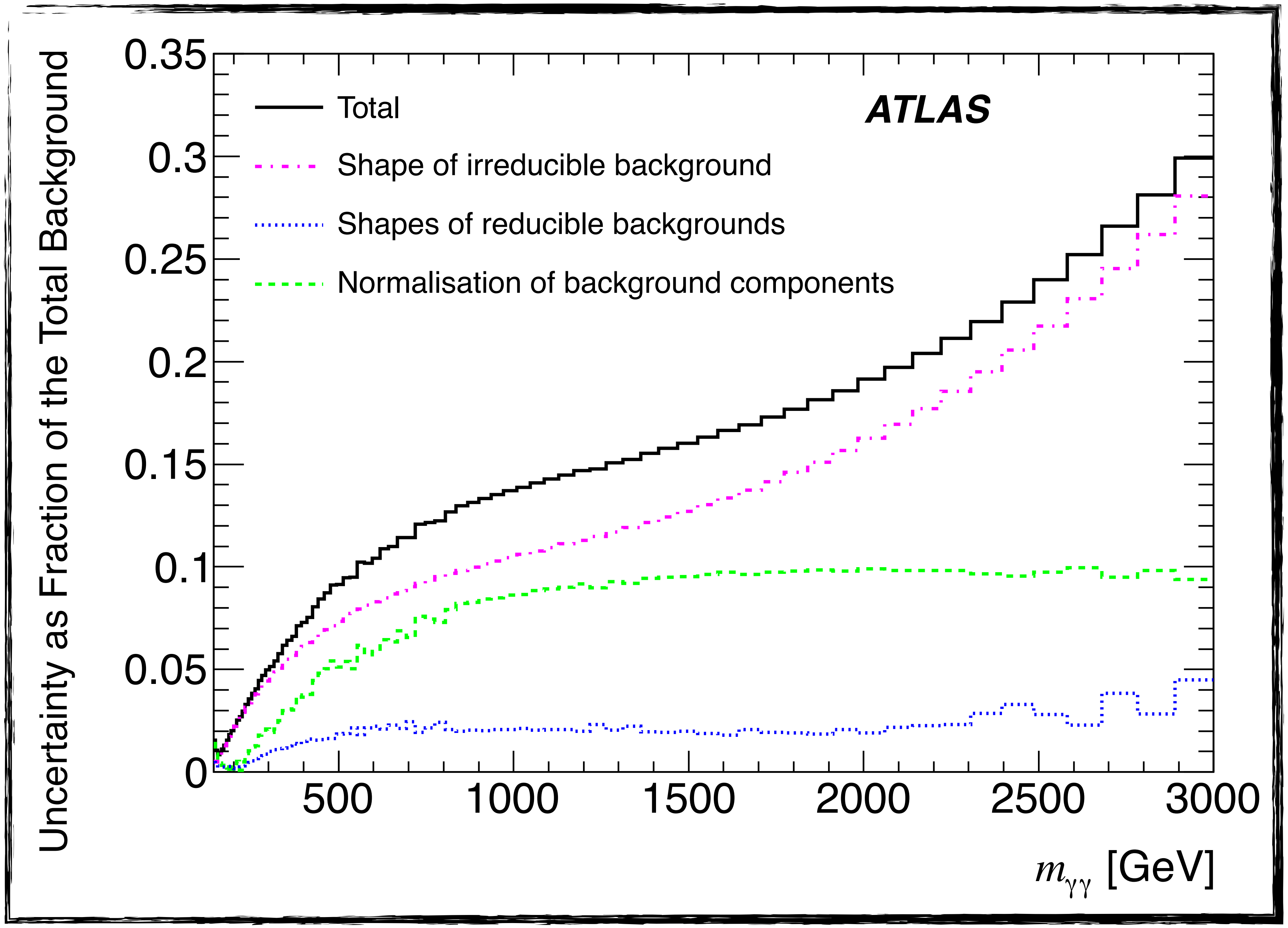
- Irreducible



  - Direct production (a),(b) generated with PYTHIA.
  - NLO+fragmentation calculation with DIPHOX:
    - NLO/LO $m_{\gamma\gamma}$-dependent kfactor.
    - 20%-25% $m_{\gamma\gamma}$-dependent uncertainties due to PDFs and scales

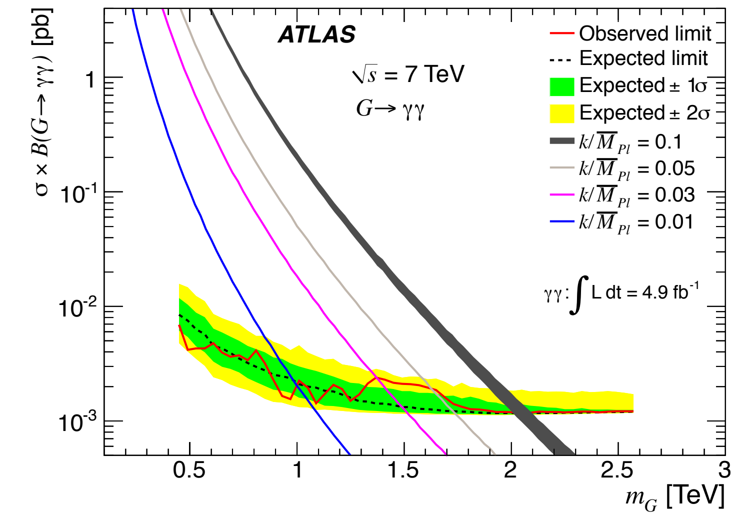
- Reducible
  - Select events passing the data selection but with reverse-id criteria.
  - Fit the $m_{\gamma\gamma}$ lineshape and extrapolate to higher masses

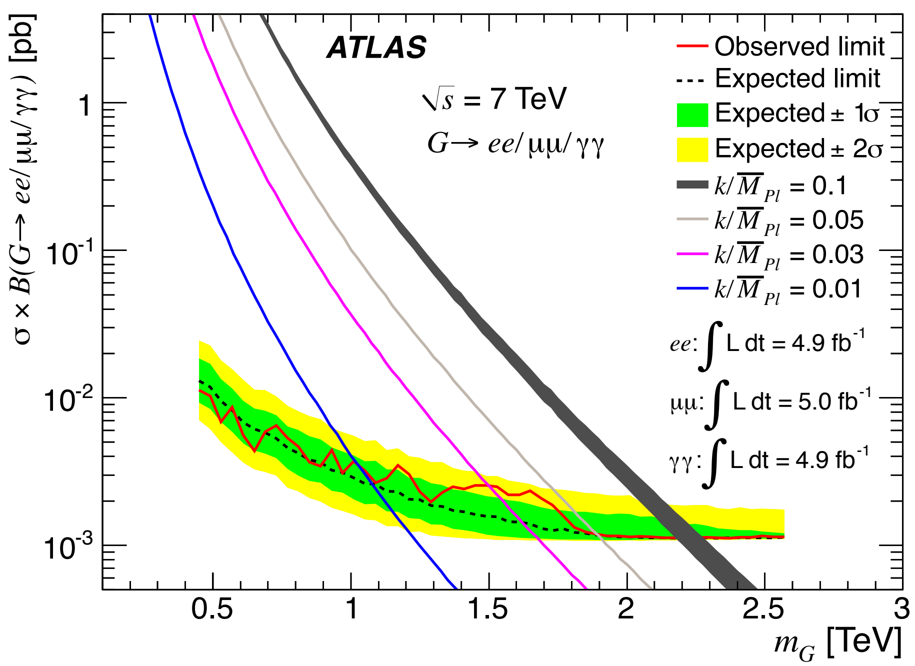
Background systematic uncertainties



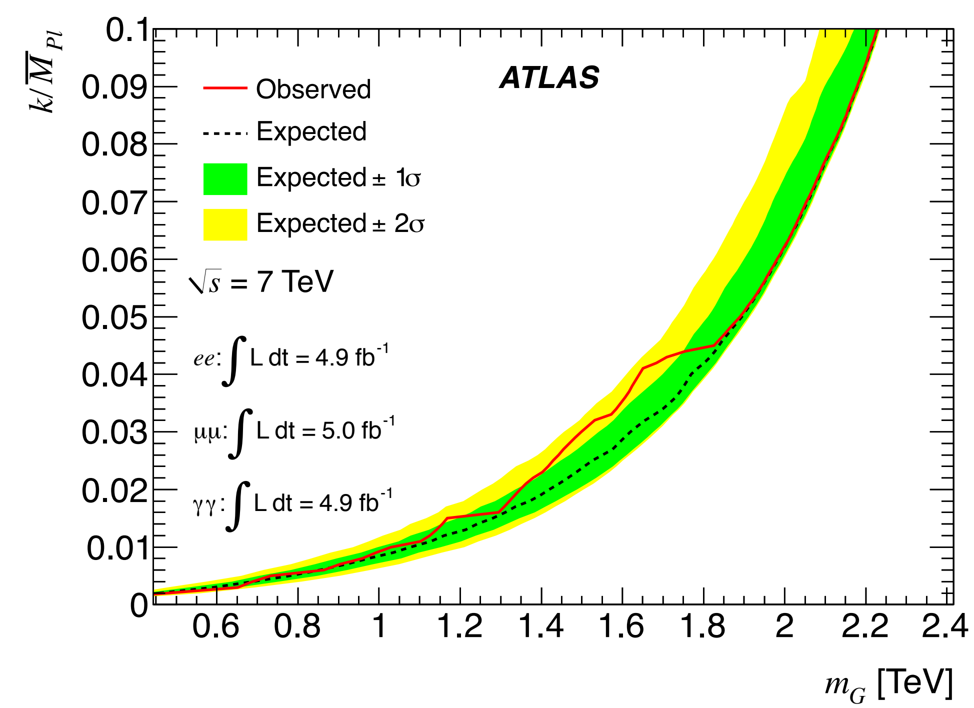
Warped Extra Dimensions

- Signal generated with Pythia6.
- Xsec corrected @NLO: kfactor = 1.75 .
- Setting limit on σ.B:
  - Binned likelihood fit of the $m_{\gamma\gamma}$ shape.
  - Bayesian approach with flat prior on the production cross-section.
- Combined with Dilepton 7TeV result ([Phys. Lett. B 719 (2013) 242-260]())





$$\sigma \times B = f(m_G, k/\overline{M}_{Pl})$$



Channel(s) Used	95% CL Observed (Expected) Limit [TeV]			
	$k/\overline{M}_{Pl}$ Value			
	0.01	0.03	0.05	0.1
$G\rightarrow\gamma\gamma$	1.00 (0.98)	1.37 (1.49)	1.63 (1.73)	2.06 (2.05)
$G\rightarrow ee/\mu\mu$	0.92 (1.02)	1.49 (1.53)	1.72 (1.81)	2.16 (2.17)
$G\rightarrow\gamma\gamma/ee/\mu\mu$	1.03 (1.08)	1.50 (1.63)	1.89 (1.90)	2.23 (2.23)

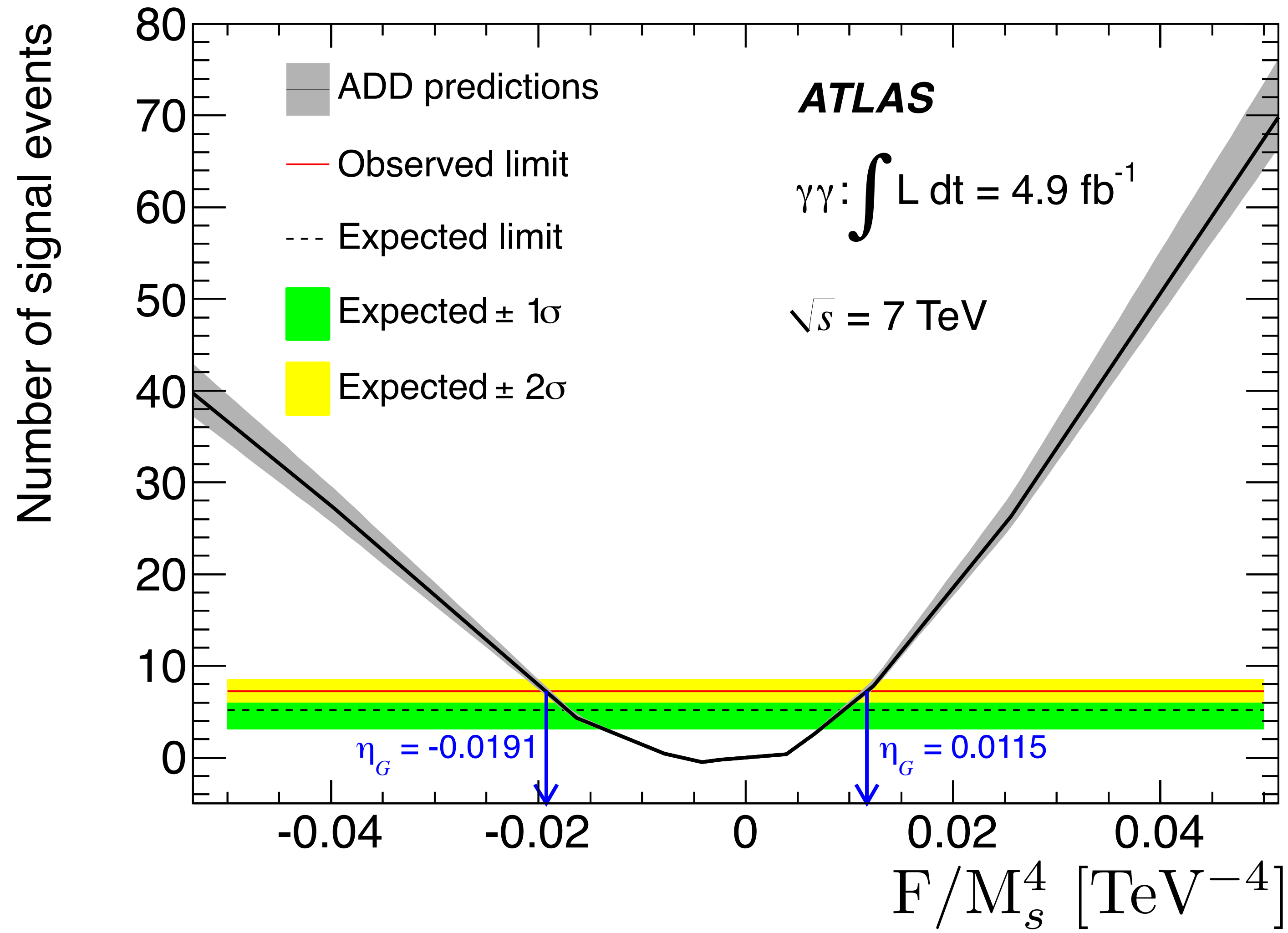
Large Extra Dimensions

- Signal generation (Sherpa):
  - Parameterization:

$$\sigma_{tot} = \sigma_{SM} + \left(\frac{F}{M_s^4}\right)\sigma_{int} + \left(\frac{F}{M_s^4}\right)^2 \sigma_{ED}$$

  - NLO/LO K-factor: 1.7

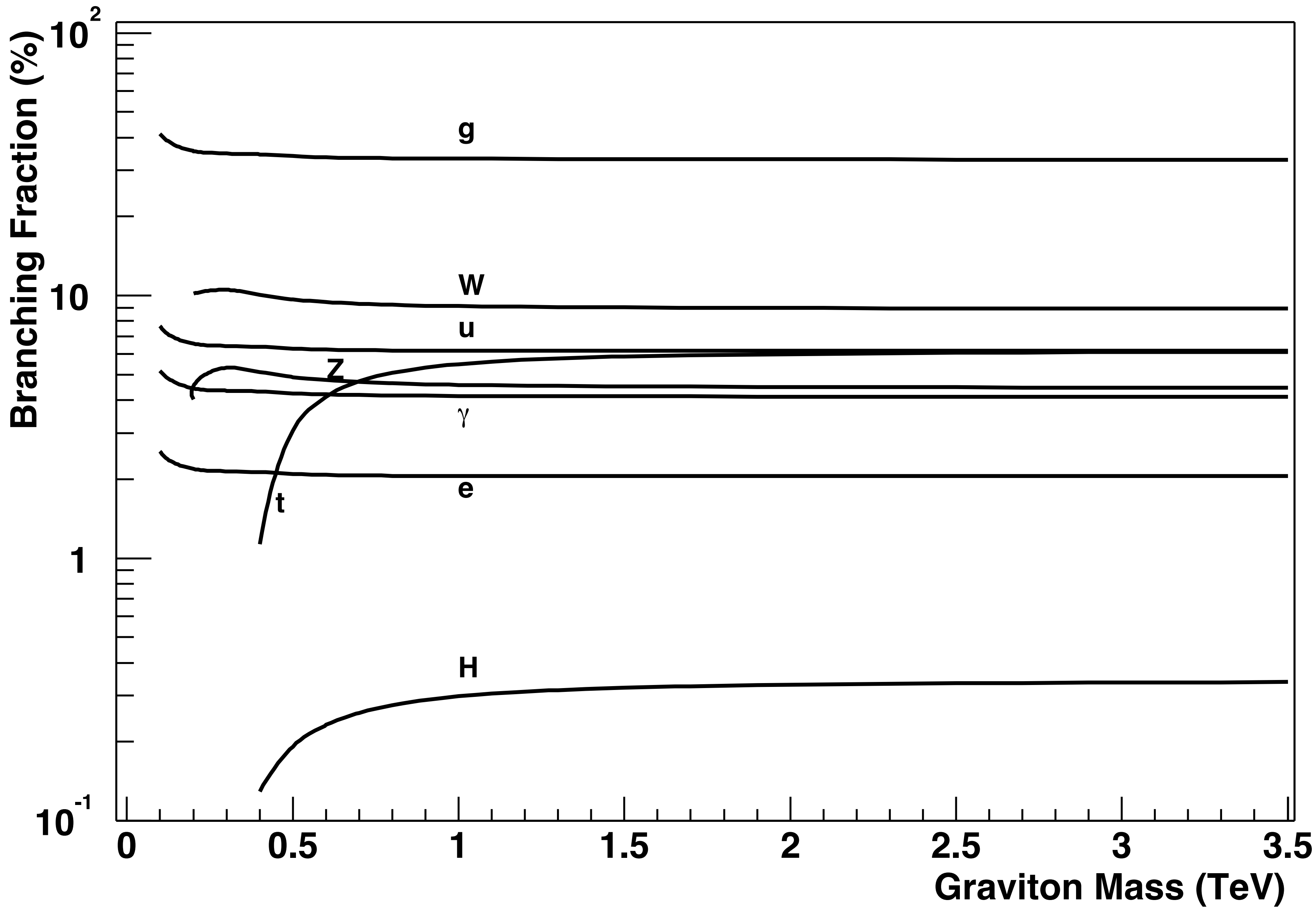
- Counting experiment:
  - Optimize expected limit for Ms= 2.5 TeV.
  - Search region: $m_{\gamma\gamma}$> 1.2 TeV.



ADD Parameter	GRW	Hewett Neg.	Hewett Pos.	HLZ $n=2$	HLZ $n=3$	HLZ $n=4$	HLZ $n=5$	HLZ $n=6$	HLZ $n=7$
F/M_s^4	0.0085	−0.0159	0.0085			0.0085			
M_s	3.29	2.52	2.94	3.55	3.92	3.29	2.98	2.77	2.62

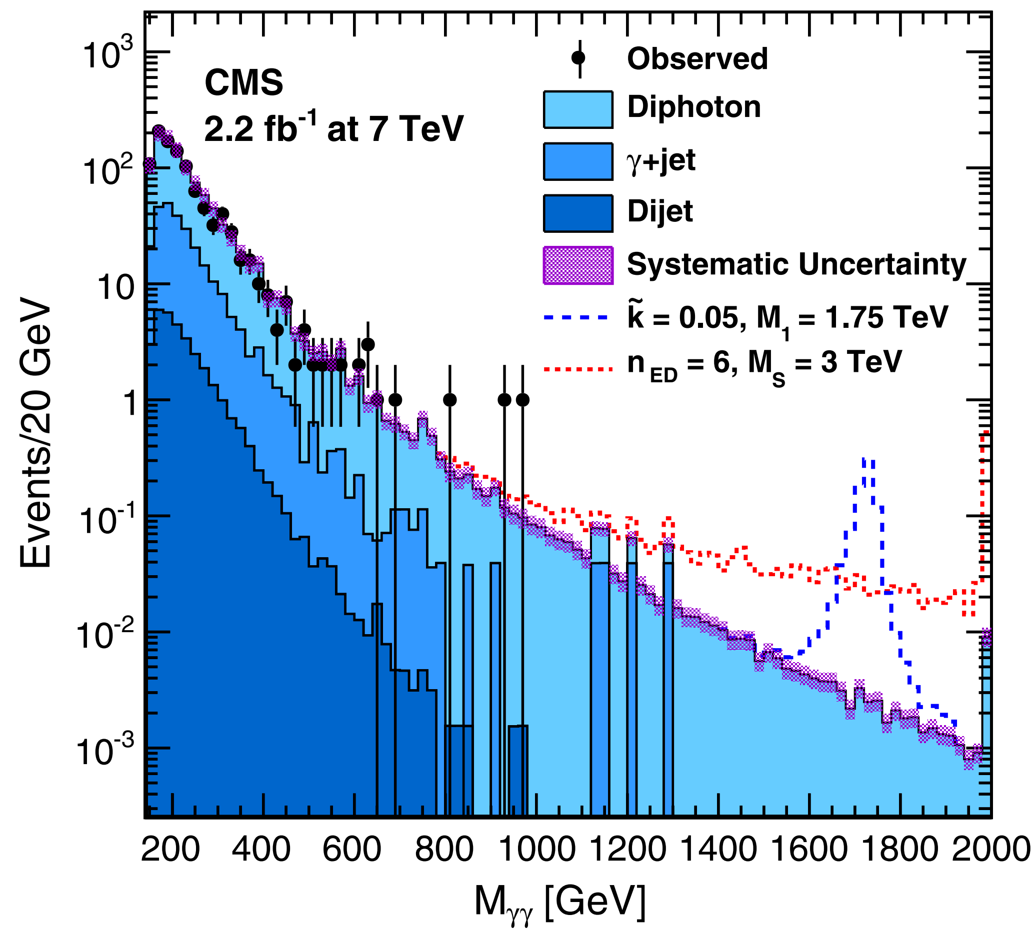
Combination with Dilepton results [Phys. Rev. D 87, 015010 (2013)]
improves limits from few hundreds of GeV.
ex: GRW limit improved to 3.51 TeV

RS BR



Branching Fraction (%)
10^2
10
1
10^{-1}
g
W
u
Z
γ
t
e
H
0
0.5
1
1.5
2
2.5
3
3.5
Graviton Mass (TeV)

CMS: Diphoton Phys. Rev. Lett.108(2012) 11180



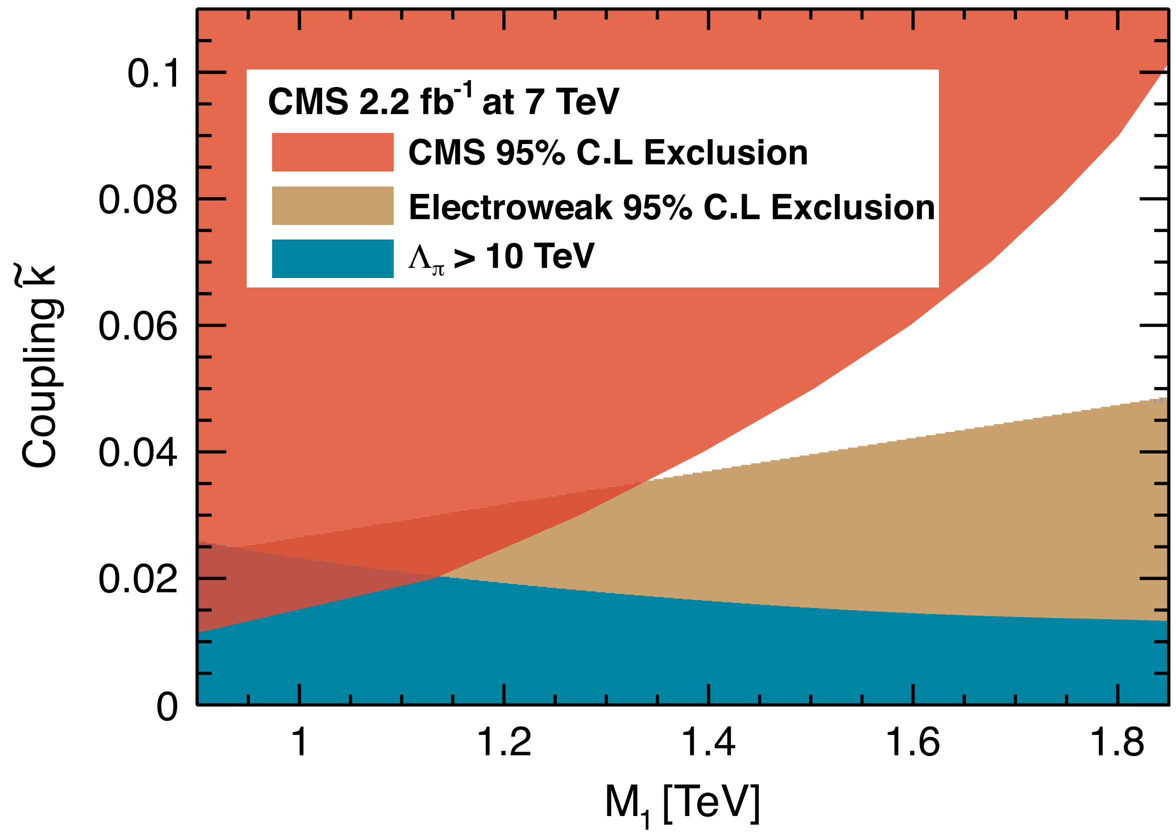
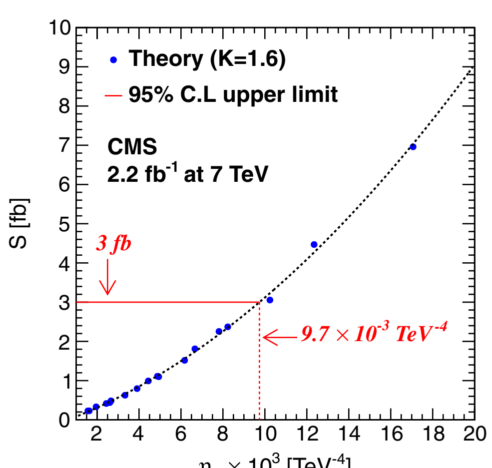


TABLE III. The 95% C.L. lower limits on M_1 for given values of the coupling parameter $\tilde{k}$. For $\tilde{k} < 0.03$, masses above the presented limits are excluded by electroweak and naturalness constraints. The median expected lower limits are numerically the same for the presented precision except for the $\tilde{k} = 0.01$ case, for which the expected lower limit on M_1 is 0.84 TeV.

$\tilde{k}$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
M_1 [TeV]	0.86	1.13	1.27	1.39	1.50	1.59	1.67	1.74	1.80	1.84



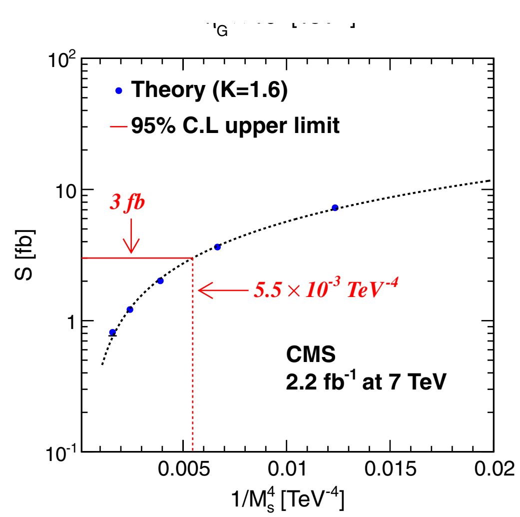
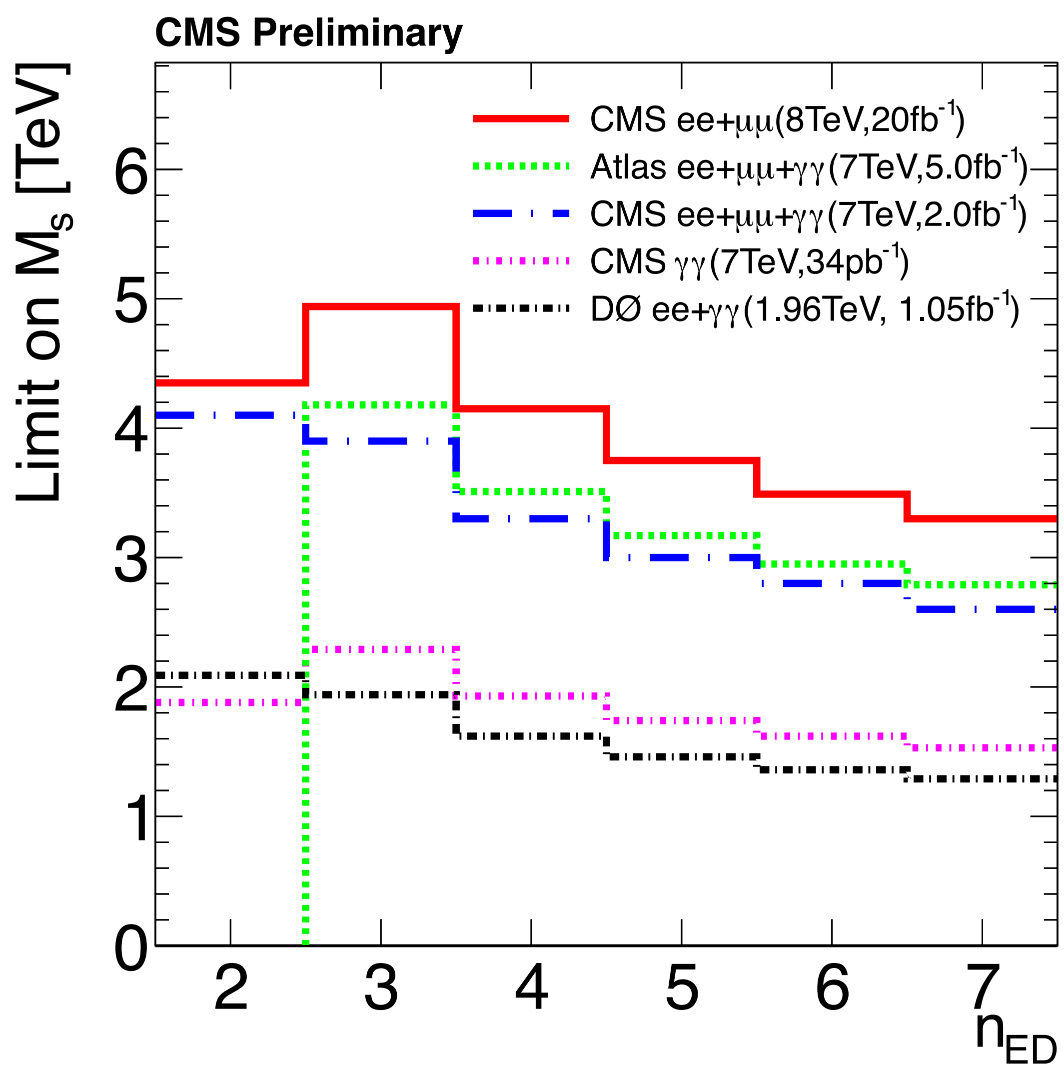
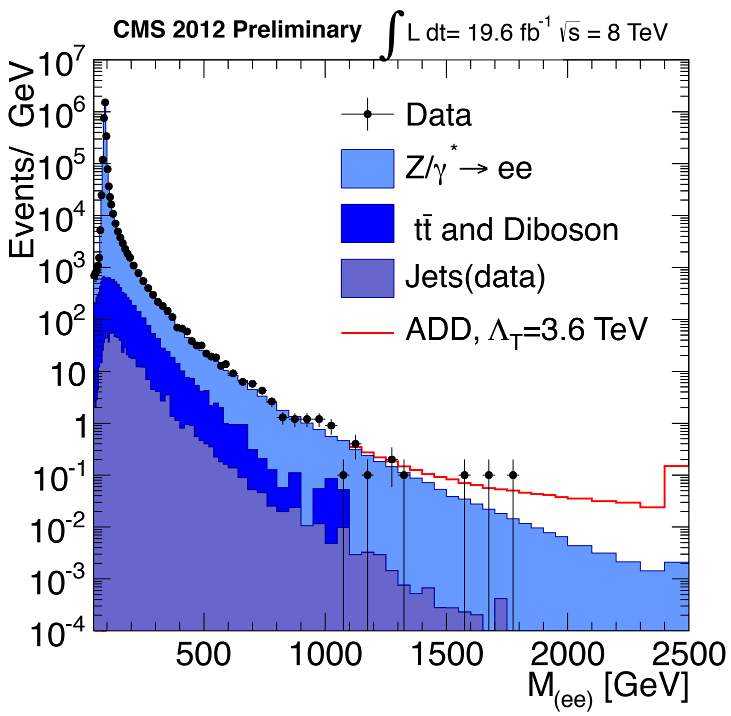


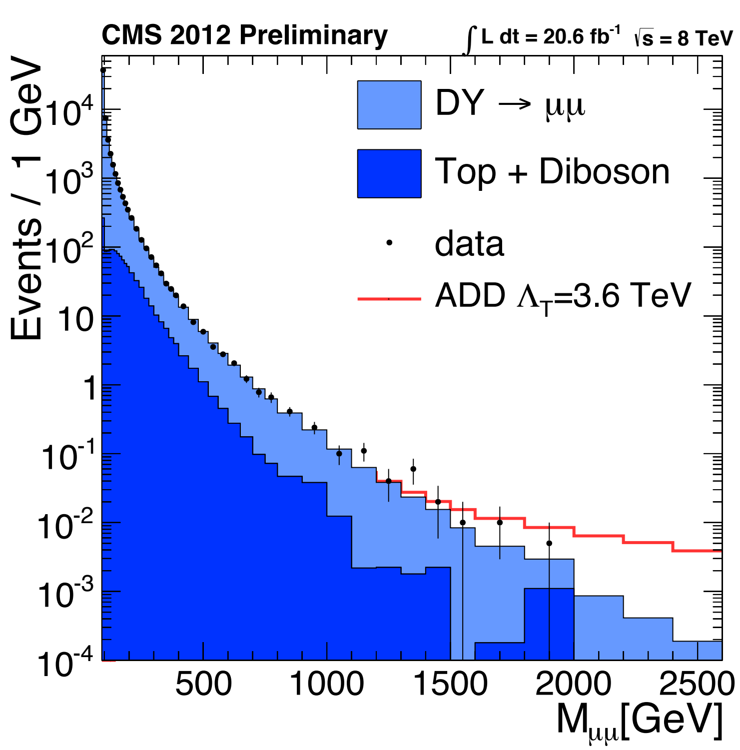
TABLE II. The 95% C.L. lower limits on M_S (in TeV) in the GRW, Hewett, and HLZ conventions for two values of the ADD signal K factor, 1.0 and 1.6 ± 0.1. All limits are computed with a signal cross section truncated to zero for $\sqrt{\hat{s}} > M_S$, where $\sqrt{\hat{s}}$ is the center-of-mass of the partonic collision. The limits are presented for both positive and negative interference in the Hewett convention and for $n_{ED} = 2$–7 in the HLZ convention. The median expected lower limits are given in parentheses.

		Hewett		HLZ					
K	GRW	Positive	Negative	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
1.0	2.94	2.63	2.28	3.29	3.50	2.94	2.66	2.47	2.34
	(2.99)	(2.67)	(2.31)	(3.37)	(3.56)	(2.99)	(2.71)	(2.52)	(2.38)
1.6 ± 0.1	3.18	2.84	2.41	3.68	3.79	3.18	2.88	2.68	2.53
	(3.24)	(2.90)	(2.44)	(3.77)	(3.85)	(3.24)	(2.93)	(2.73)	(2.58)

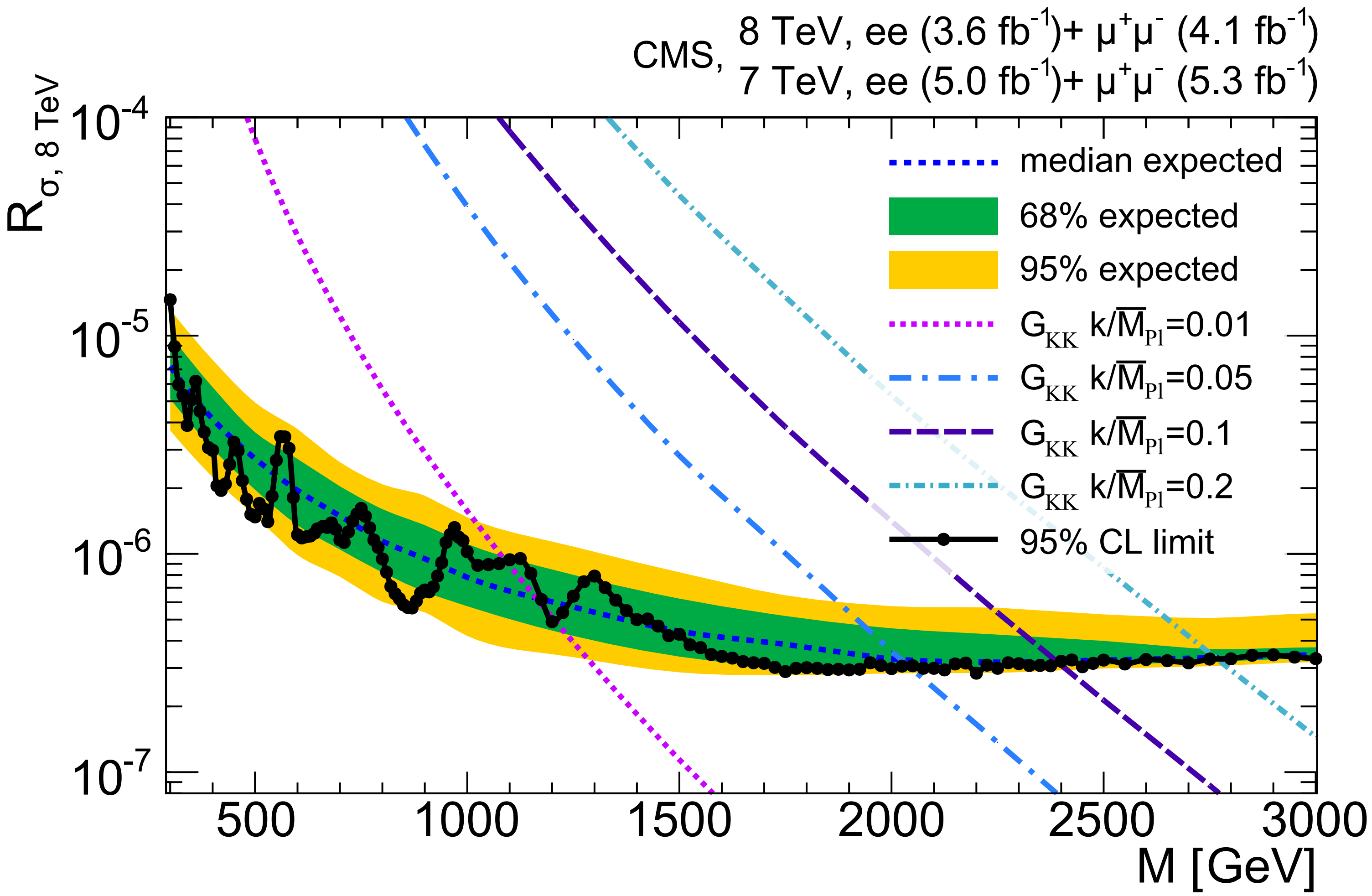
PAS EXO12031, PAS EXO12027

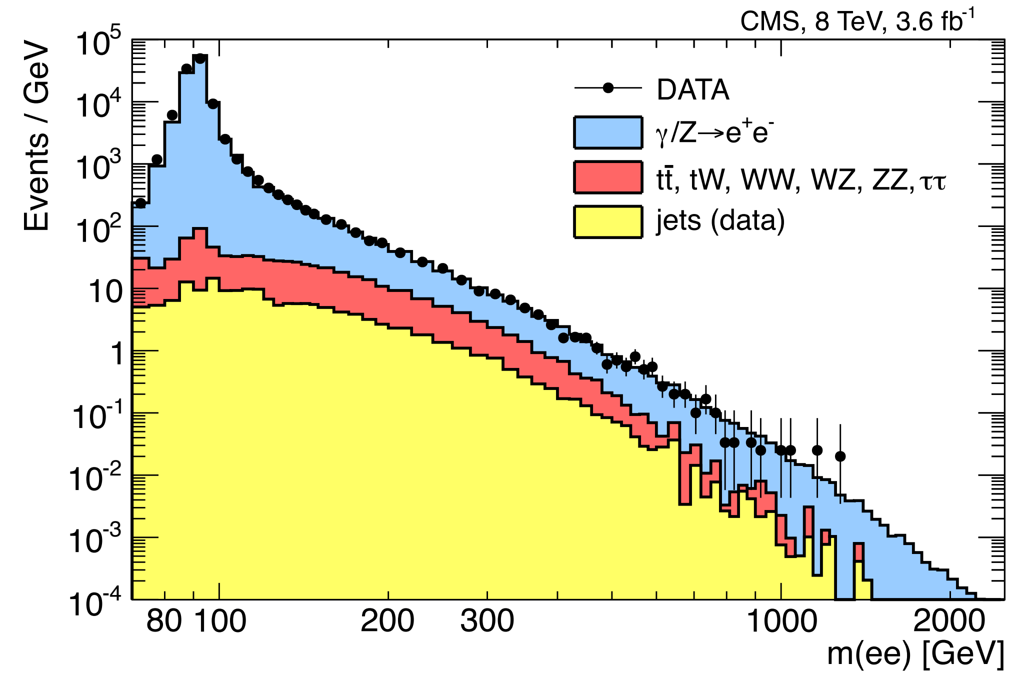


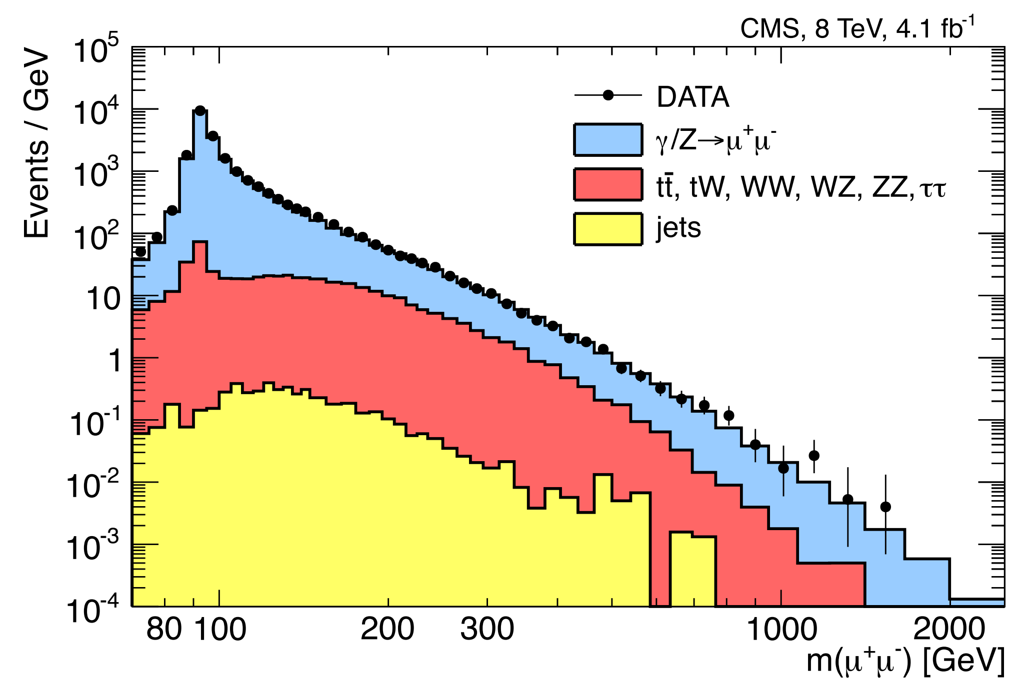




PAS EXO12015/arXiv:1212.6175







Model	Mass Limits (GeV)		
	7 TeV	8 TeV	7+8 TeV
Z'_{SSM}	2330	2440	2590
Z'_{ψ}	2000	2110	2270
G_{KK} $(k/\overline{M}_{Pl} = 0.1)$	2140	2260	2390
G_{KK} $(k/\overline{M}_{Pl} = 0.05)$	1810	1900	2030