



# ATLAS@LPNHE: Higgs boson & New Physics with photons - status and plans

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G. Marchiori  
ATLAS group

Biennale du LPNHE  
04 October 2016

# Group composition

- 6 permanents:

Name	Position	HDR	fraction of research time
Bertrand LAFORGE	PR	Yes	90%
Sandrine LAPLACE	CR	Yes	100%
Giovanni MARCHIORI	CR	Yes	40%
Irena NIKOLIC	MdC	Not yet	100%
Jose OCARIZ	PR	Yes	100%
Lydia ROOS	DR	Yes	100%

- 1 post-doc:

Name	Funding	Dates	fraction of research time
Renjie WANG	ILP	04/2016-05/2019	100%

- 5 students:

Name	Year	Subject	Supervisor	Funding	Dates	Fraction
Yee YAP	3	high-mass $\gamma\gamma$ resonances	L. ROOS	ED STEP-UP	12/2013 12/2016	100%
Alvaro LOPEZ SOLIS	3	dark matter search in $H(\gamma\gamma)$ +MET	B. LAFORGE	ED STEP-UP	10/2014 10/2017	100%
Stefano MANZONI	3	new physics in $\gamma\gamma$ +MET	G. MARCHIORI	ITALIE (co-tutelle)	10/2014 10/2017	100%
Pierre LUZI	3	Higgs CP	J. OCARIZ	ED STEP-UP	12/2014 ?	100%
Ahmed TAREK	1	$H \rightarrow \gamma\gamma$ xsection measurements	S. LAPLACE	ED STEP-UP	10/2016 10/2019	100%

+1 thesis defended in 07/2014 (K. LIU, co-supervised by GM, winner of the ATLAS and FCPPL thesis awards, on *Photon identification efficiency measurements and searches of  $H \rightarrow \gamma\gamma$  and  $H \rightarrow Z\gamma$* )

- + some contributions also from Bogdan, Paolo, Ilaria

# Group “trombinoscope”

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***Yee***



***Alvaro***



***Stefano***



***Pierre***



***Ahmed***



***Ren-Jie***



***Sandrine***



***Giovanni***



***Irena***



***Bertrand***



***Lydia***

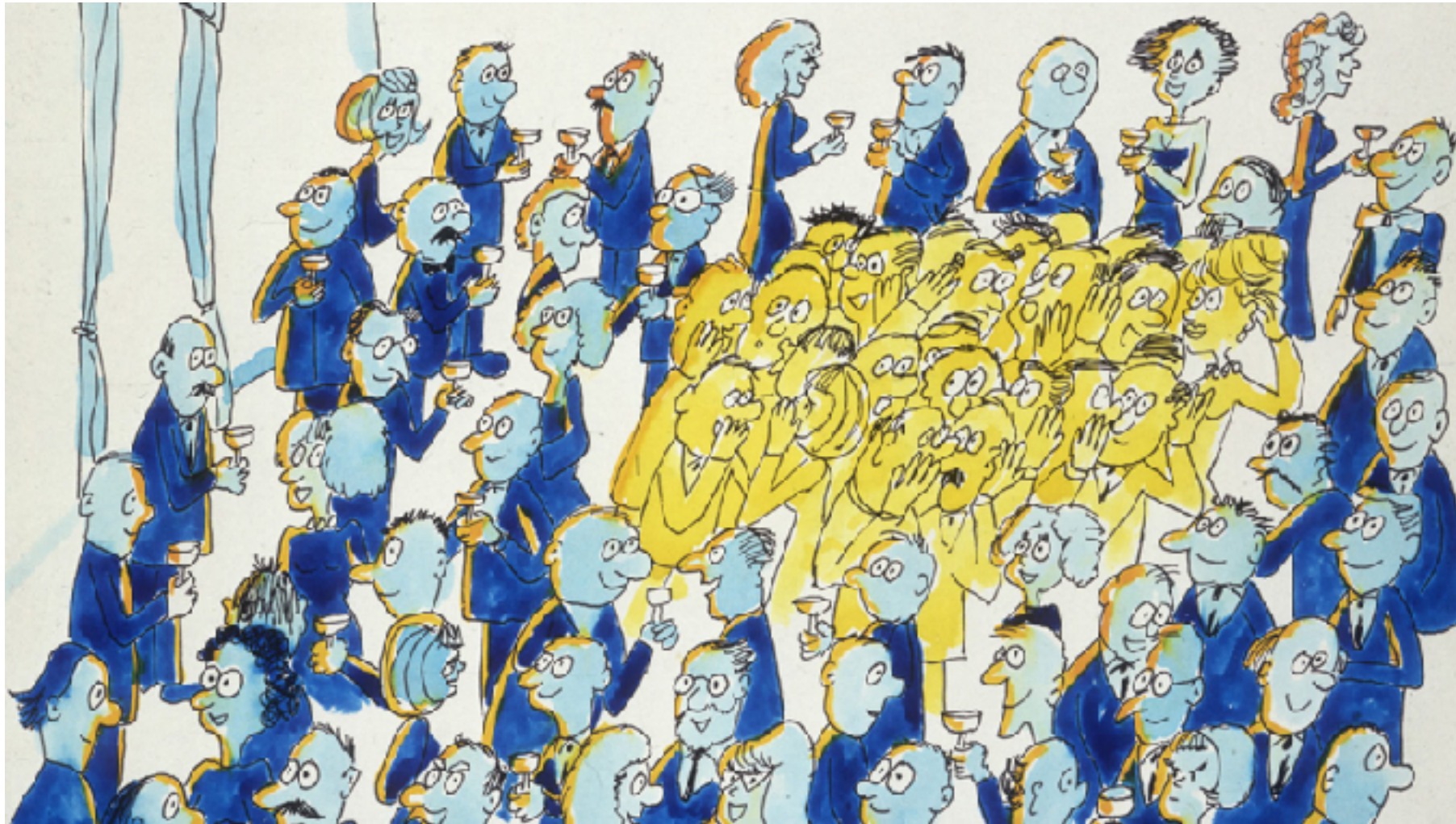


***Jose***



# Why studying the Higgs boson?

- Without the Higgs mechanism (or some alternative), particles are predicted to be massless by SM; weak and electromagnetic force are unified
- Particles acquire a mass through their interaction with the Higgs field

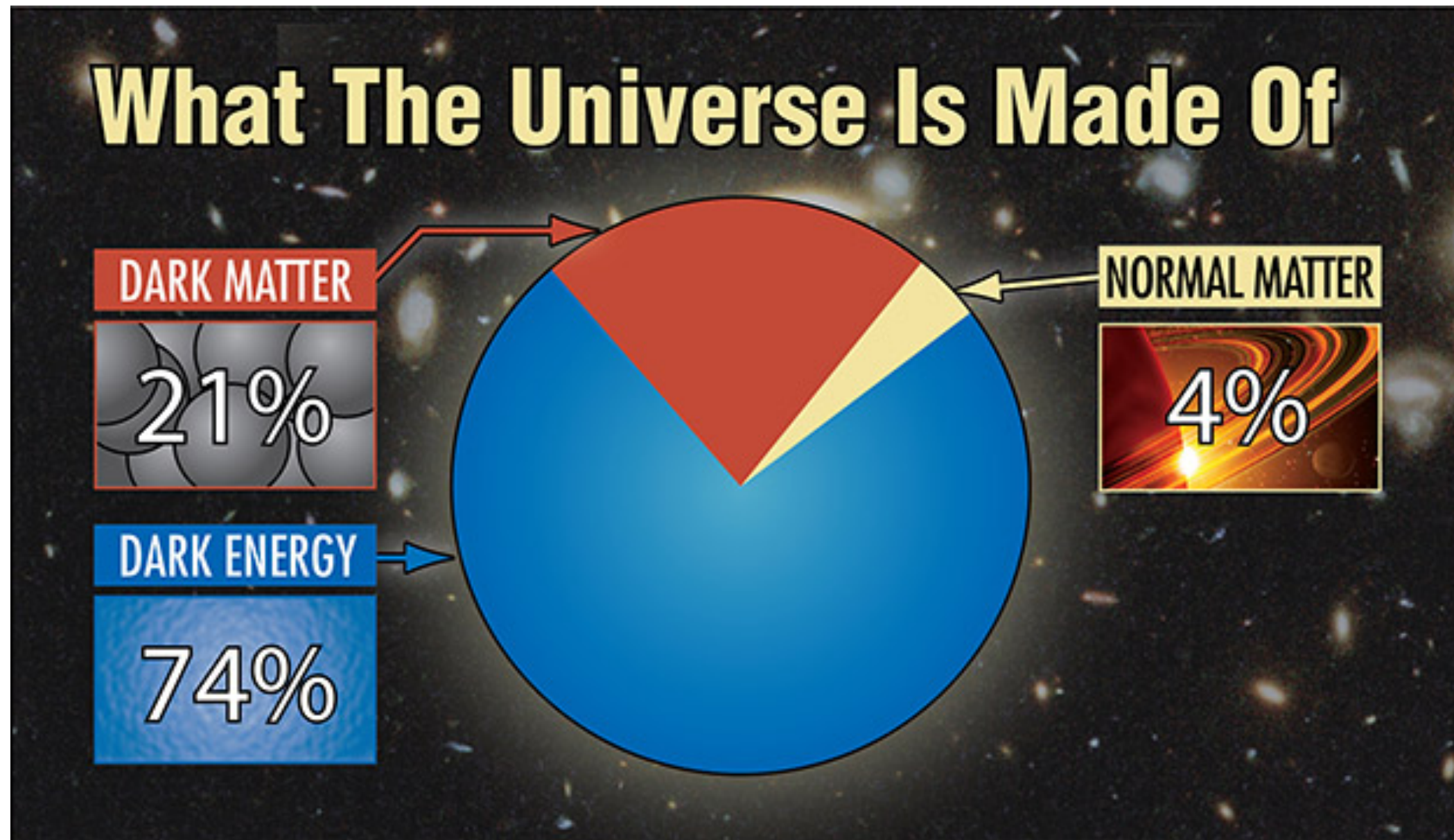


- In SM, once the Higgs boson mass is fixed, all other properties of the Higgs boson are well determined => can make accurate theory predictions and compare to experiment
- Outside of SM Higgs boson may have different production/decay properties or there may be multiple Higgs bosons



# Why searching for beyond SM physics (BSM)?

- No dark matter candidate in Standard Model

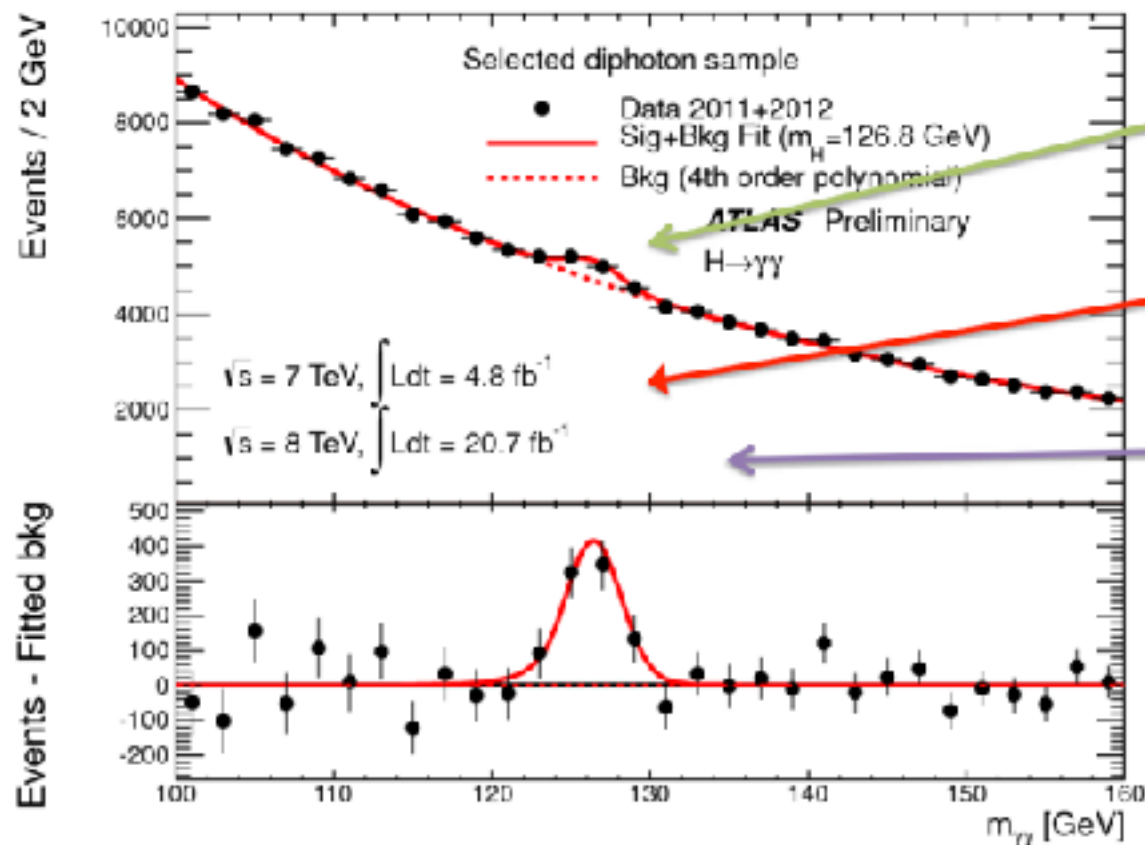


- Insufficient sources of CP violation (baryonic asymmetry)
- ..
- One possible solution (not the only one!): SuperSYmmetry (see Stefano's talk)

# The situation at the last biennale (May 2014)

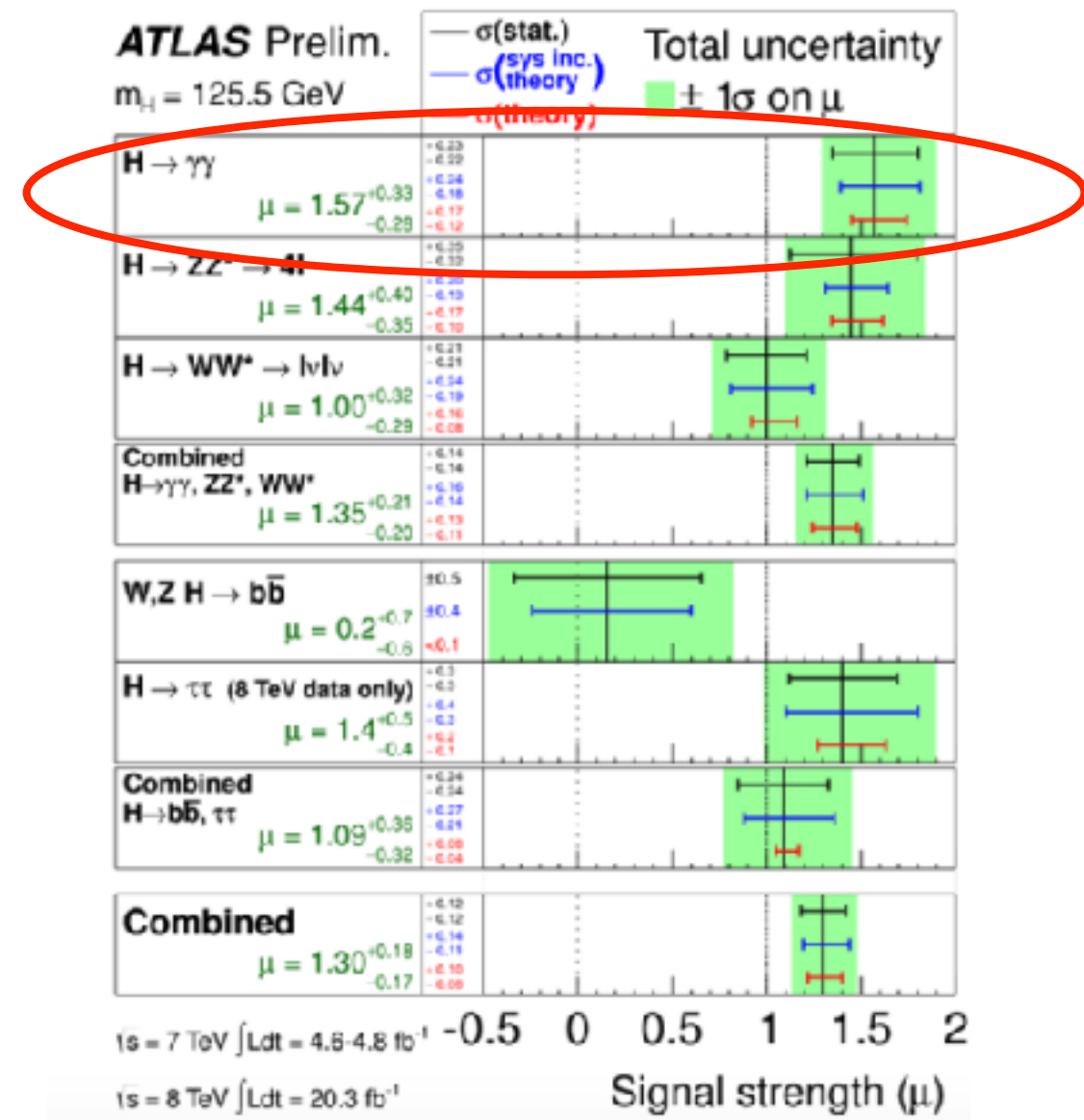
- Higgs boson discovered in Run1, properties (couplings,  $J^P$ ) consistent with SM

$$\mu = (\sigma \cdot \text{BR})_{\text{obs}} / (\sigma \cdot \text{BR})_{\text{SM}}$$



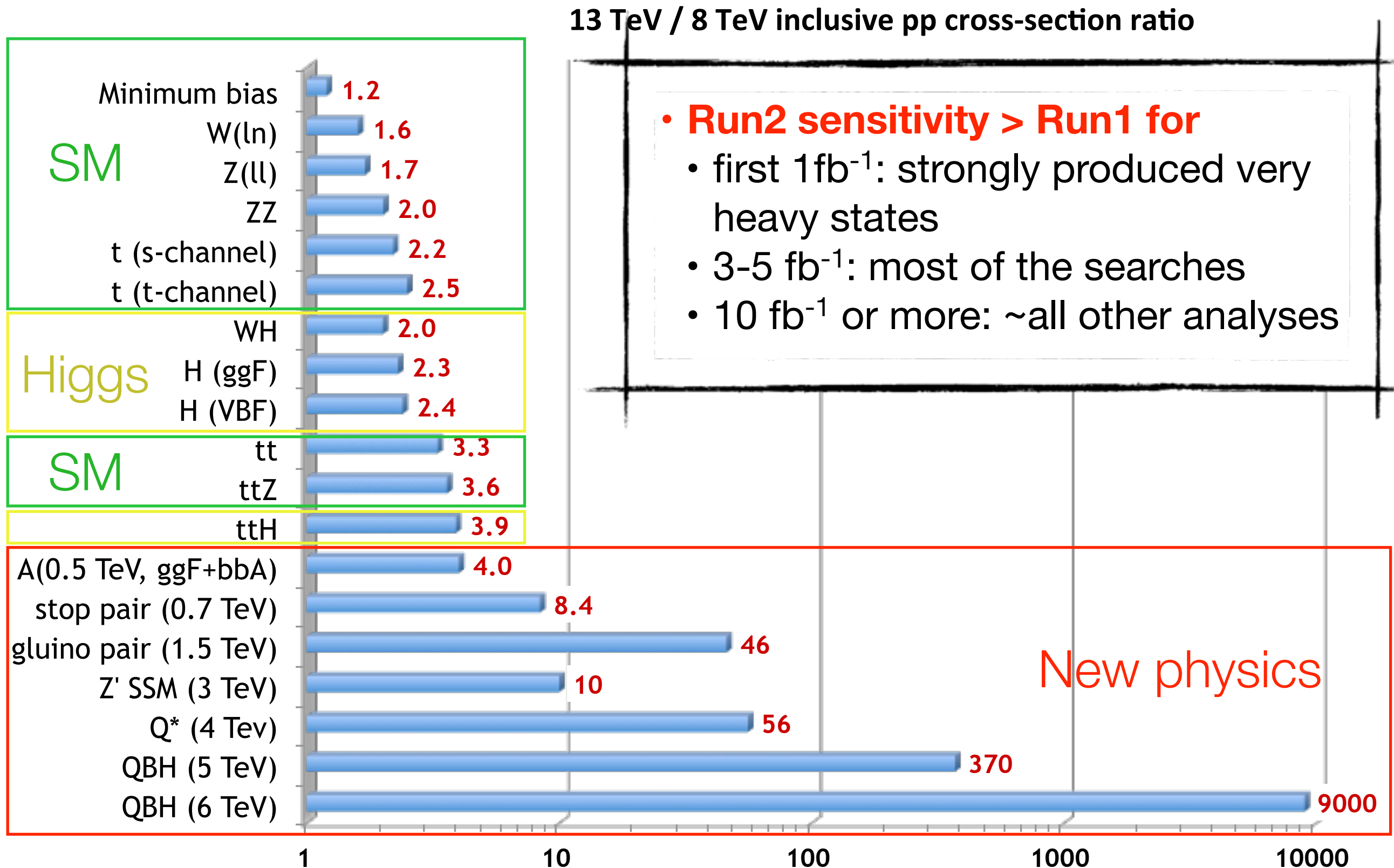
Masse combinée multi-canaux :  
 $m_H = 125.5 \pm 0.2 \text{ (stat.)} \pm 0.6 \text{ (syst.) GeV}$

29



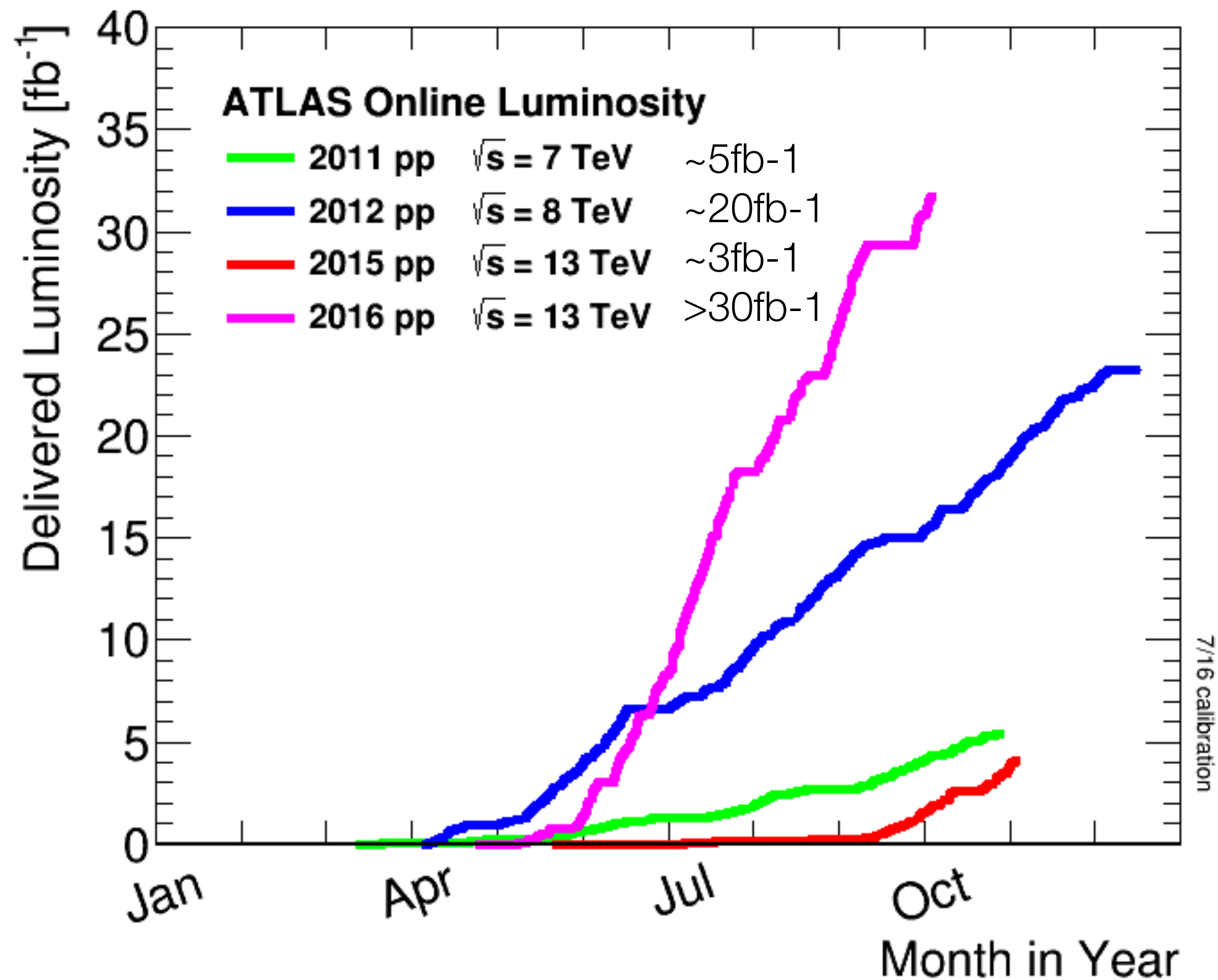
- LHC off since beginning of 2013 for 2 years of consolidation activities on accelerator and detectors.
- Main goals for Run2: higher energy and luminosity

# Why higher pp collision energy?





# Integrated luminosity in Run2





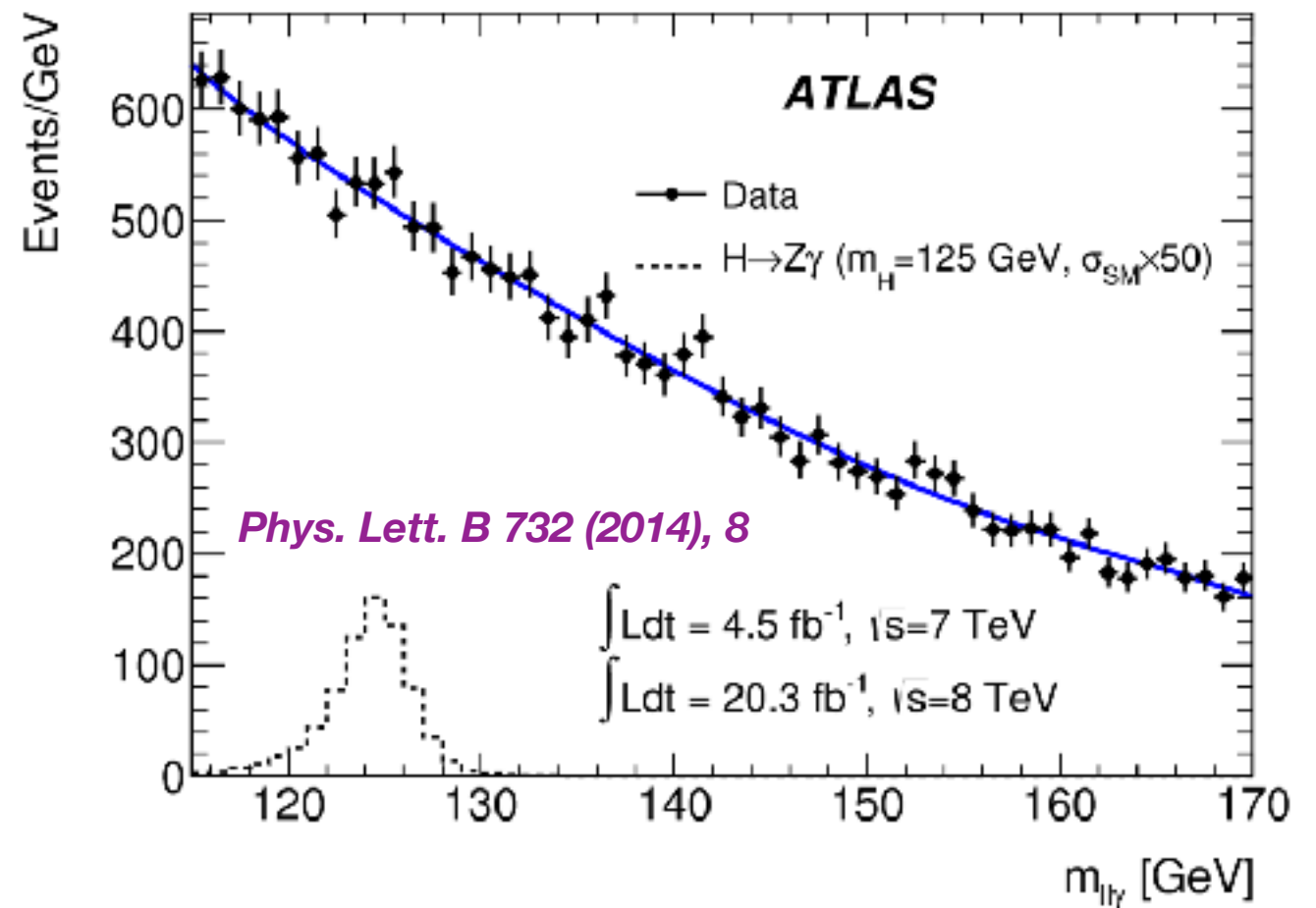
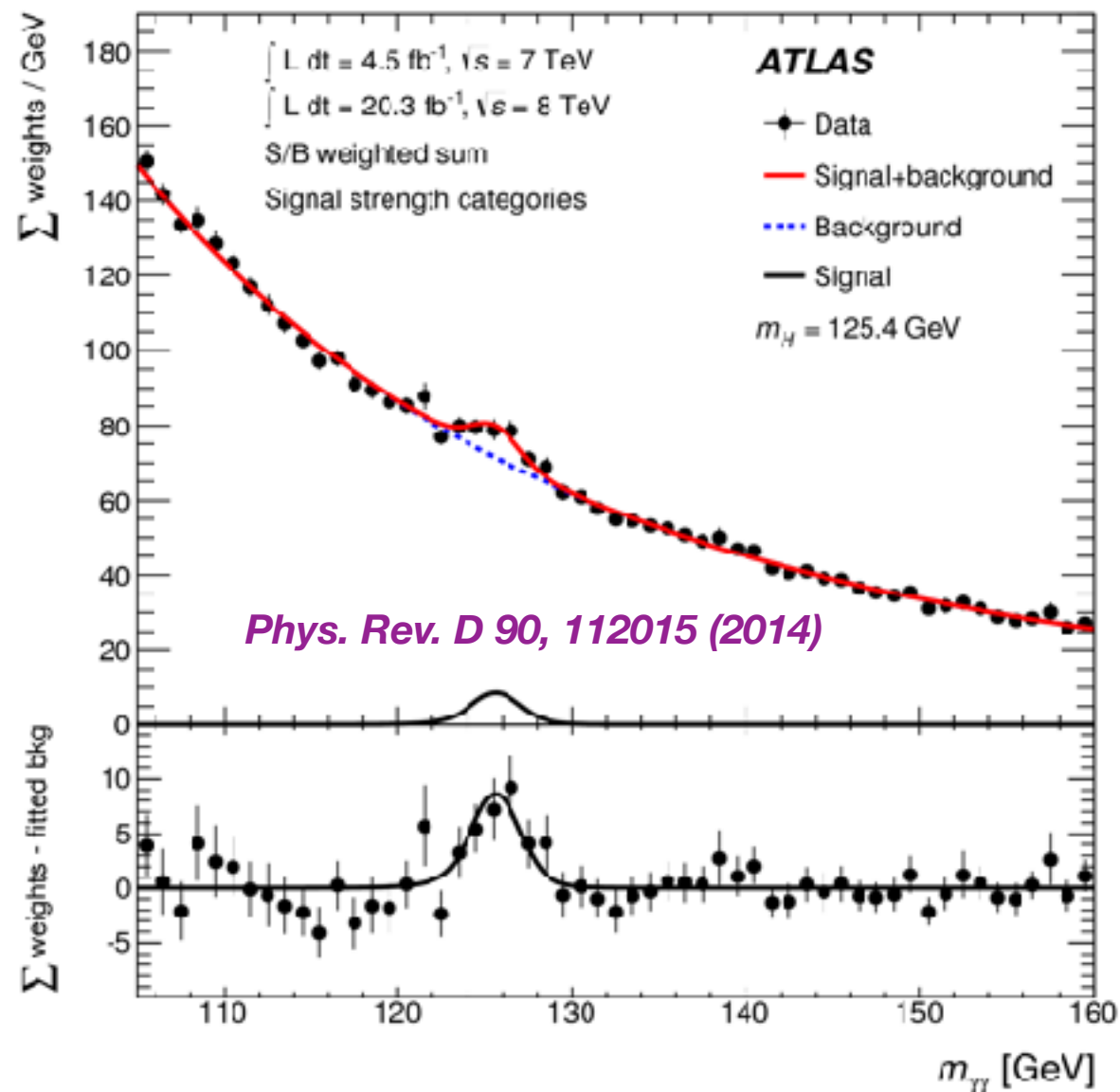
# Activities of the past 2.5 years

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- Consolidation/conclusion/publication of Run1 Higgs boson measurements, (including combination with CMS - not done by our group)
- Preparation of Run2 analyses with photons ( $H \rightarrow \gamma\gamma$  and more)
  - optimisation of photon reconstruction, identification and isolation algorithms
  - preparation of analysis tools, MC samples, optimisation of analysis strategy..
- Analysis of the first  $\sqrt{s}=13$  TeV LHC data for winter and summer '16 conferences
  - measurement of photon performance (identification and isolation efficiency, electron $\rightarrow$ photon fake rate)
  - search for BSM resonances: photon+jet, diphoton and photon+Z
  - search for new physics in final states with two photons and large transverse missing energy (from non-interacting particles)
  - measurement of H(125) properties combining  $H \rightarrow \gamma\gamma$  and  $H \rightarrow ZZ^* \rightarrow 4l$

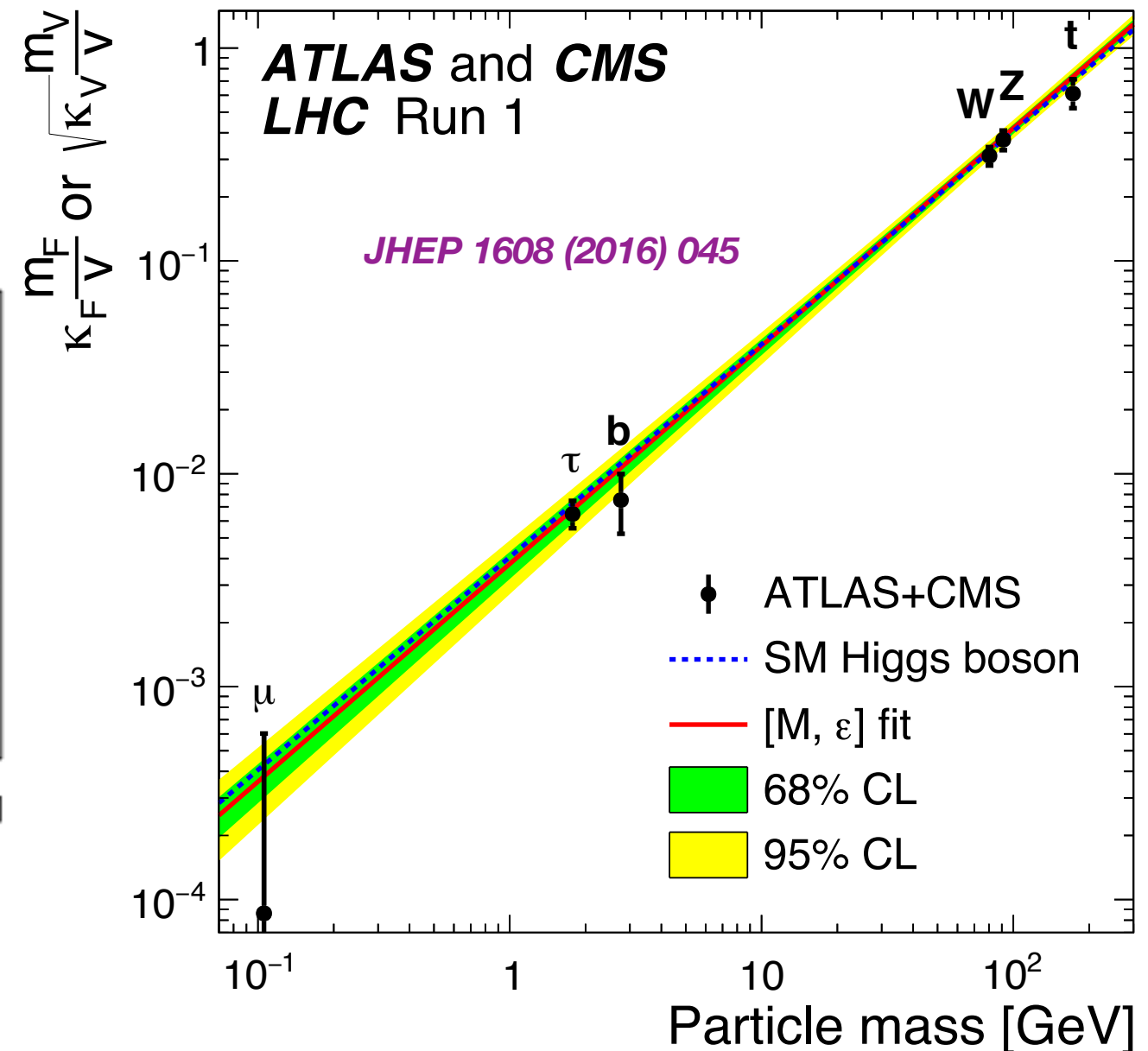
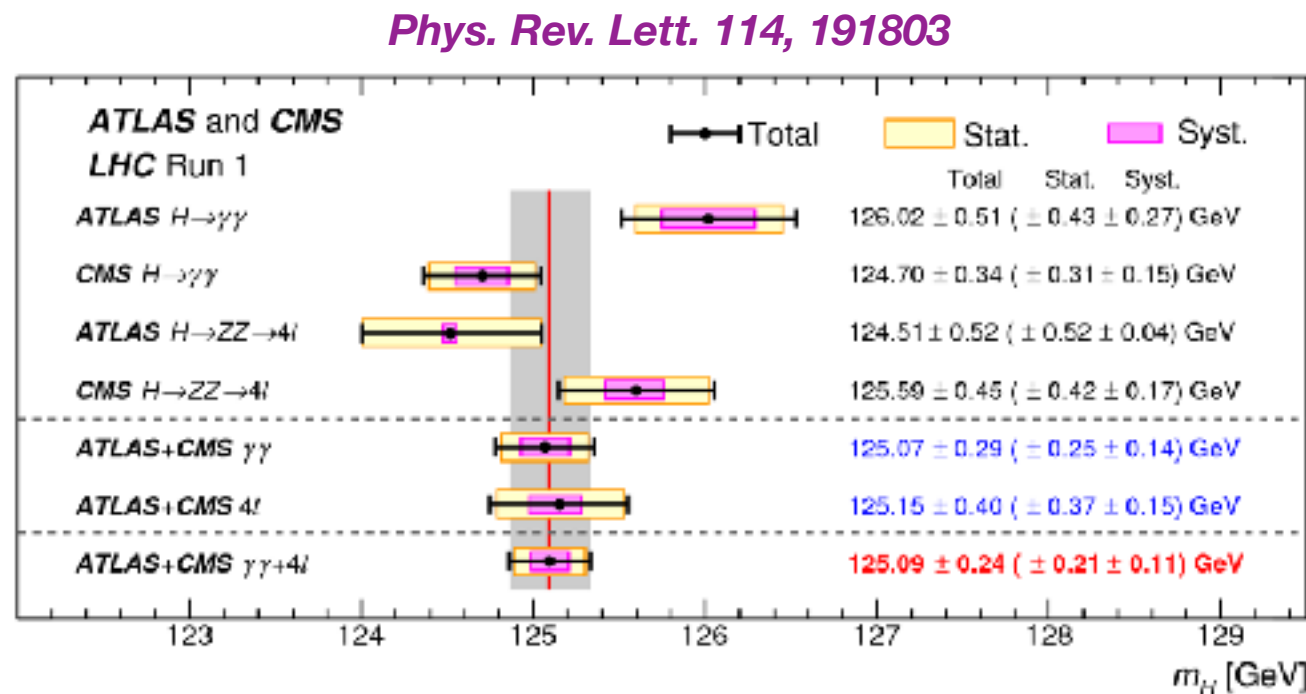
# Consolidation of the Run1 discovery

- $5.2\sigma$  excess observed in  $\gamma\gamma$  by ATLAS, agrees with SM ( $\mu=1$ ):  $\mu=1.17\pm0.27$
- no evidence of rare decay to  $Z\gamma$  ( $\mu<11$ )



# Consolidation of the Run1 discovery (II)

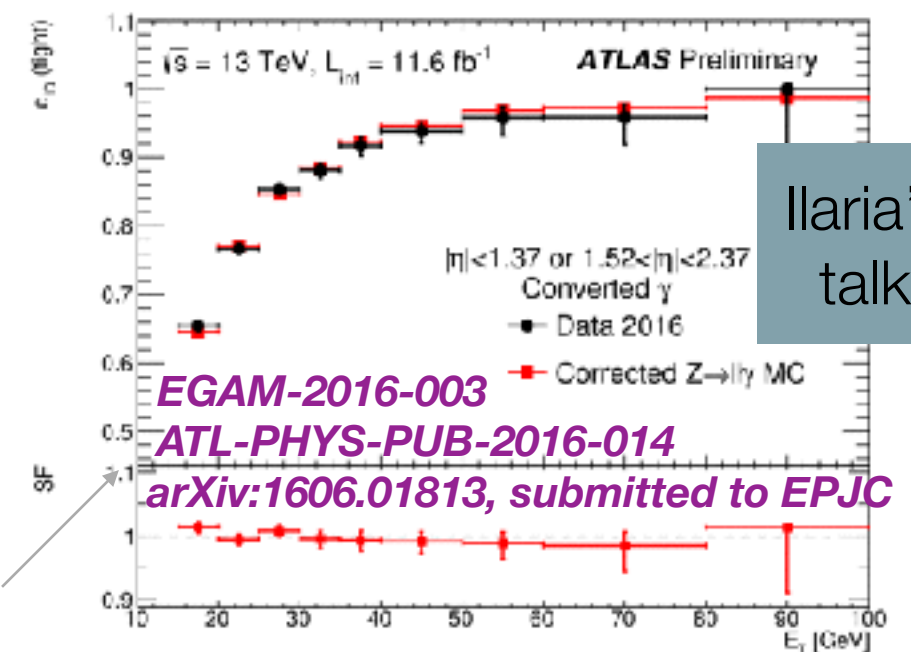
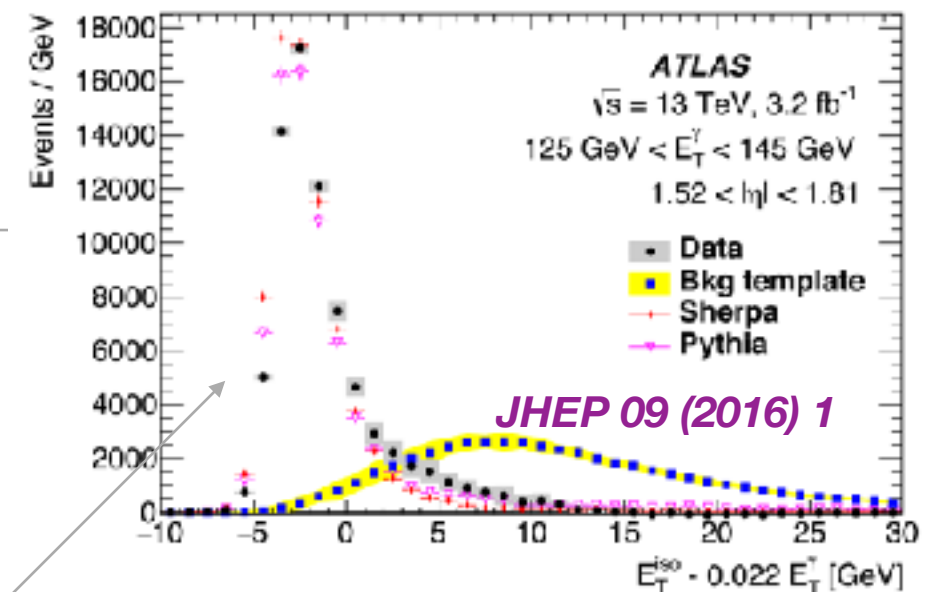
- mass measured to 0.2% by ATLAS+CMS ( $H \rightarrow \gamma\gamma + H \rightarrow ZZ^* \rightarrow 4l$ )
- couplings to SM particles in good agreement with SM predictions (10% precision for W, Z; worse for others)



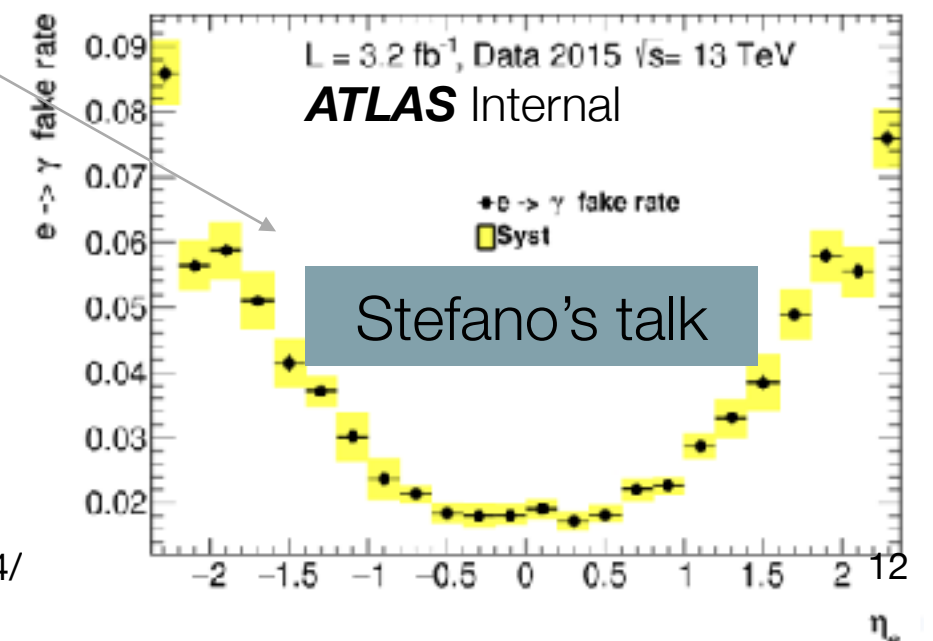


# Photon performance in Run2 (I)

- $e/\gamma$  isolation (discriminate photons from hadronic jets looking at energy around the photon):
  - ATLAS-wide harmonisation effort between analyses before start of Run2
  - measured data-MC corrections and data/MC efficiency scale factors with inclusive prompt photons ( $+Z \rightarrow l l \gamma$  and  $Z \rightarrow e e$ ) in Run2 data
- photon identification (discriminate photons from hadronic jets looking at shower shape):
  - retuned criteria for Run2 data-taking
  - measured data/MC photon efficiency scale factors ( $Z \rightarrow l l \gamma$ ,  $Z \rightarrow e e$ , prompt photons) in Run2 data
  - measured  $e \rightarrow \gamma$  misidentification rate in data with  $Z \rightarrow e e$
- $e/\gamma$  energy calibration:
  - performed training of MVA regression on MC



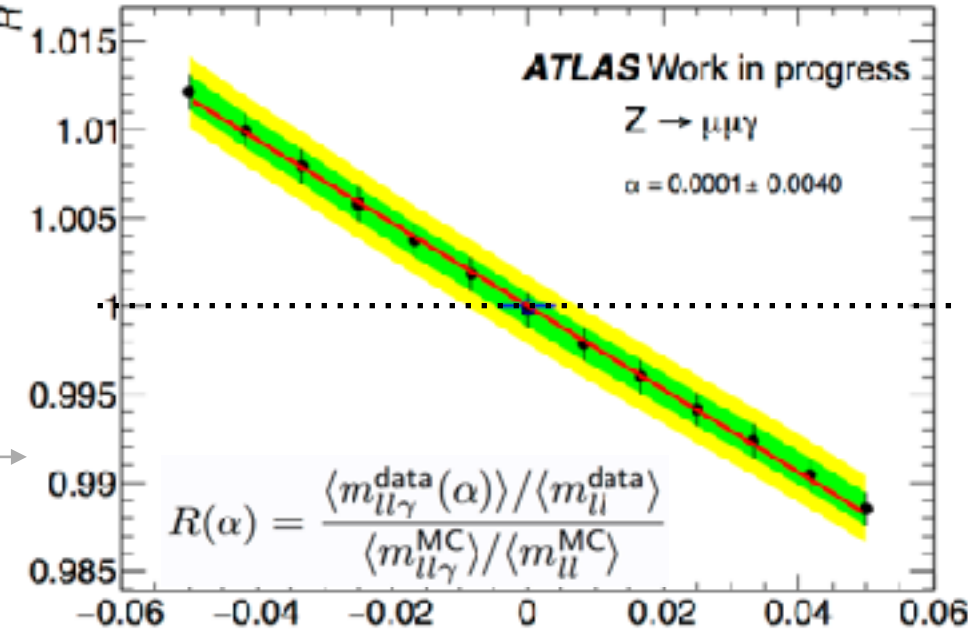
Ilaria's talk



# Photon performance in Run2 (II)

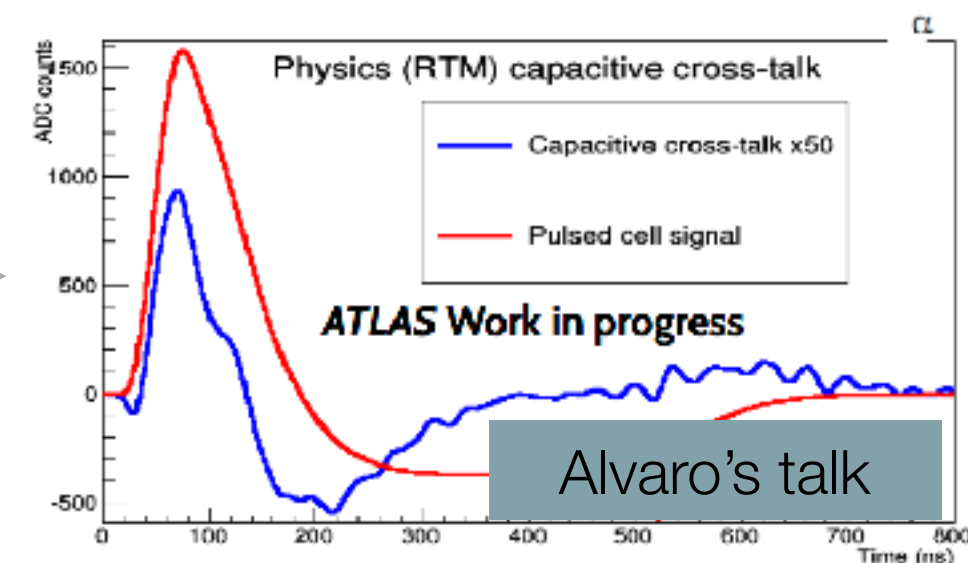
- **photon energy scale:**

- measured photon energy scale with  $Z \rightarrow l l \gamma$  decays in full 2015 data; uncertainties ~few per mil



- **cross-talk in LAr calorimeter:**

- used special calibration runs to extract maps of cross-talk corrections
- subtract x-talk contribution from measured cell energies to improve photon energy, timing and shower shape information (quantification of improvements in progress)



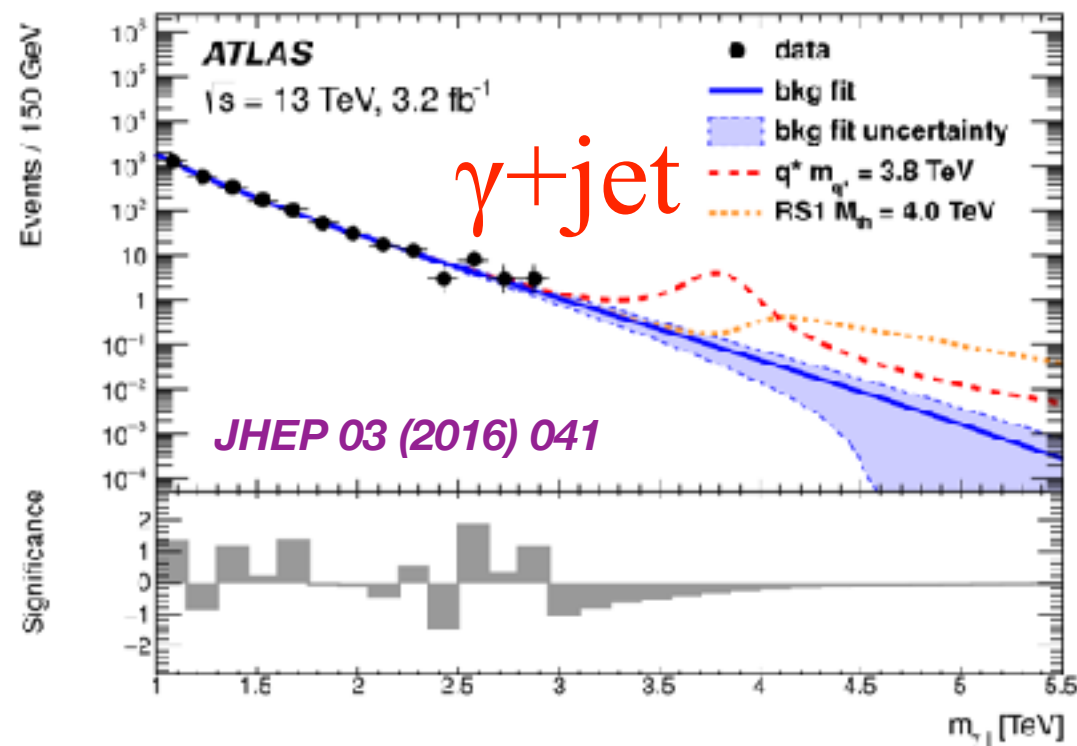
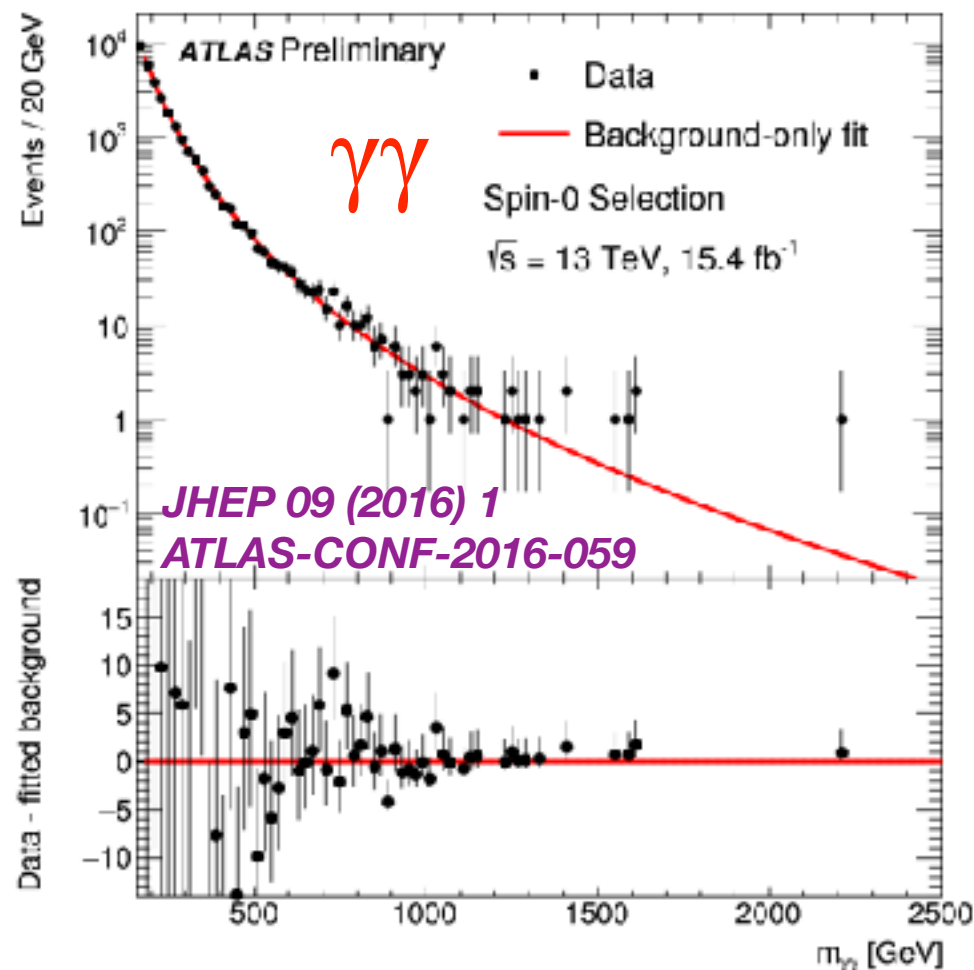
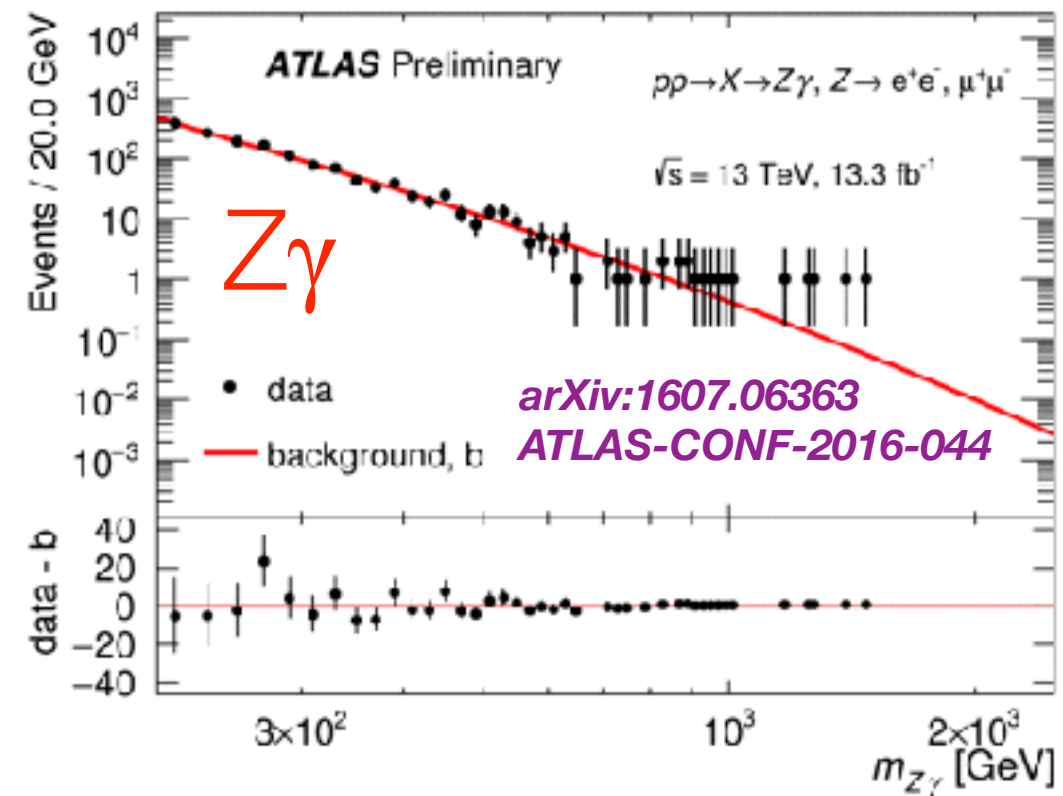
- **photon conversion reconstruction efficiency:**

- technique developed and efficiency measured with Run1 data (fit data shower shapes of reco-converted and reco-unconverted photons with templates from truth), study on Run2 ongoing

$\eta$	$E_1/E_2$		BDTG ( $E_1/E_2 + R_\Phi$ )	
	fFake	fReco	fFake	fReco
$ \eta  < 0.6$	$0.013 \pm 0.006$	$0.921 \pm 0.047$	$0.015 \pm 0.003$	$0.890 \pm 0.013$
$0.6 <  \eta  < 1.37$	$0.029 \pm 0.005$	$0.801 \pm 0.023$	$0.027 \pm 0.005$	$0.804 \pm 0.009$
$1.52 <  \eta  < 1.8$	$0.009 \pm 0.015$	$0.918 \pm 0.030$	$0.015 \pm 0.018$	$0.906 \pm 0.019$
$1.8 <  \eta  < 2.37$	$0.006 \pm 0.007$	$0.568 \pm 0.014$	$0.013 \pm 0.009$	$0.565 \pm 0.013$

# Exotic resonance searches with 13 TeV data

- $\gamma\gamma$  and  $Z\gamma$  resonances can be produced for instance in models with **extra Higgs bosons** (like SUSY, 2HDM, ...) or with **extra dimensions** (Randall-Sundrum graviton ..)
- $\gamma$ +jet resonances can be produced for instance from **excited quarks** ( $q^* \rightarrow q\gamma$ ) or **microscopic quantum black holes** predicted by extra-dimension models
- Unfortunately, we saw nothing like that in 13 TeV data so far :(

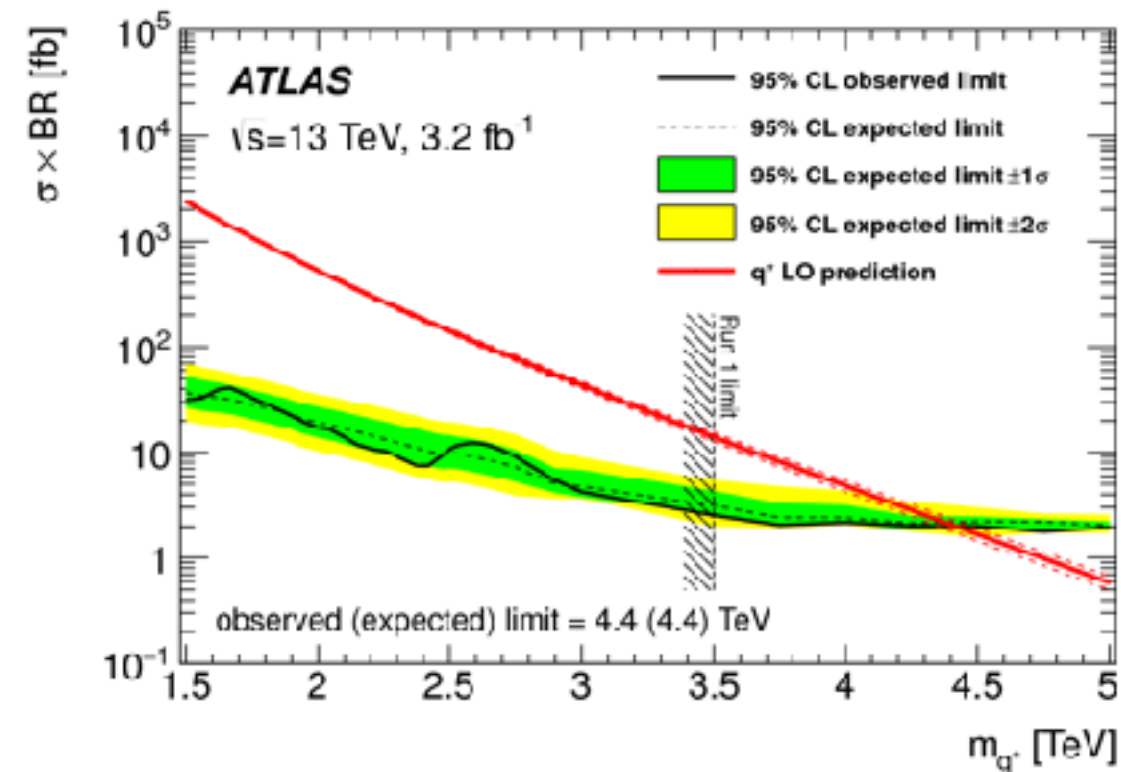
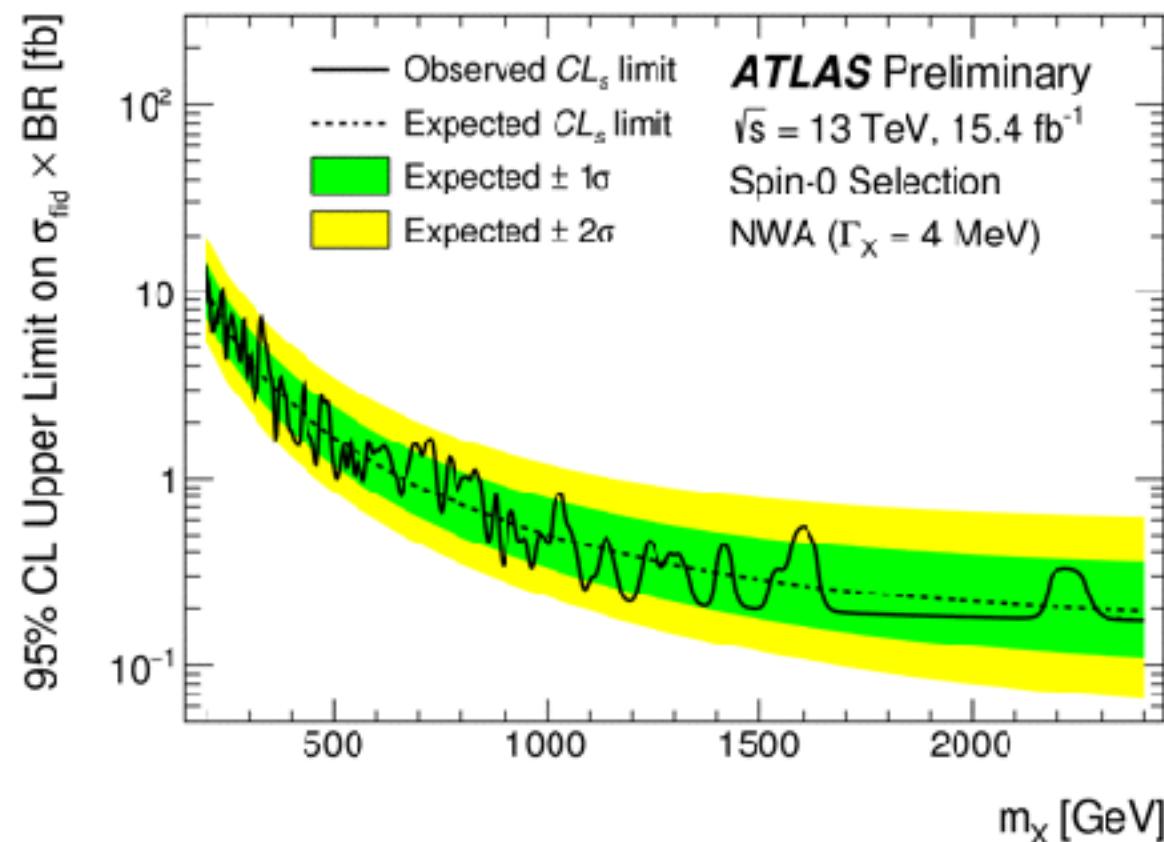
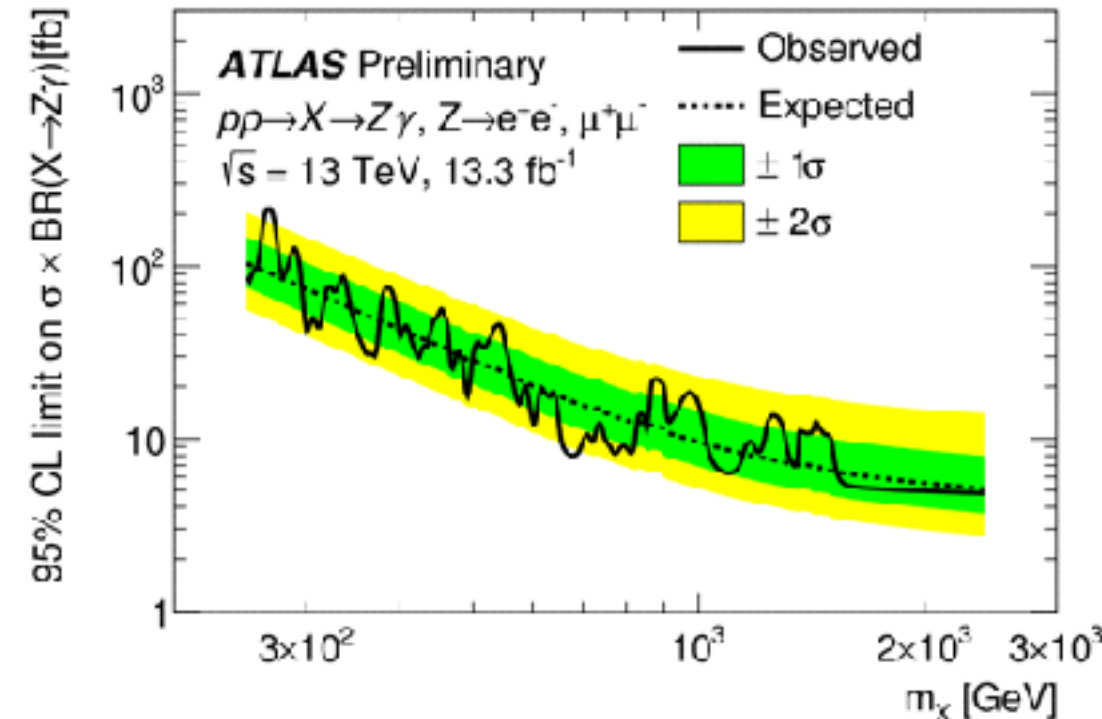


Ahmed's  
talk



# Exotic resonance searches with 13 TeV data

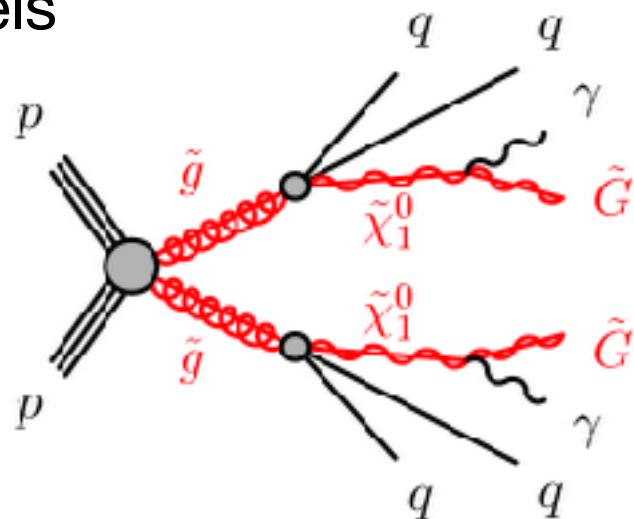
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# BSM physics searches in $\gamma\gamma$ +MET with 13 TeV data

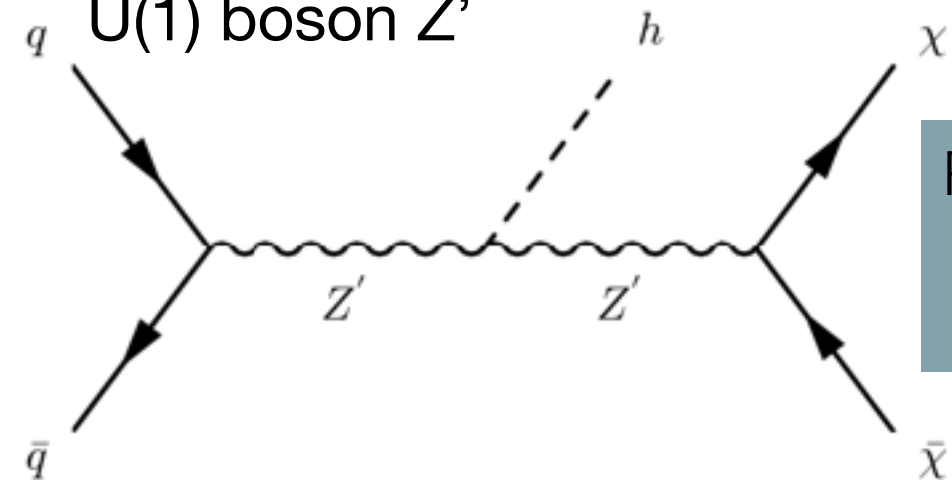
- Searches for two photons and large transverse momentum imbalance from:

- gauge-mediated **supersymmetry** models



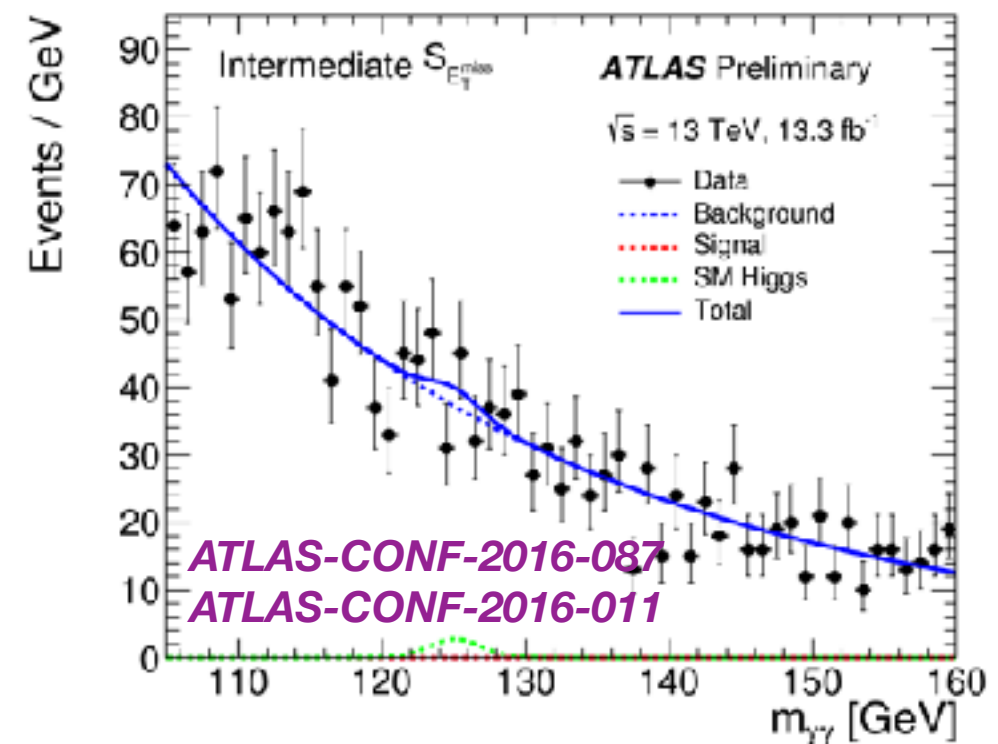
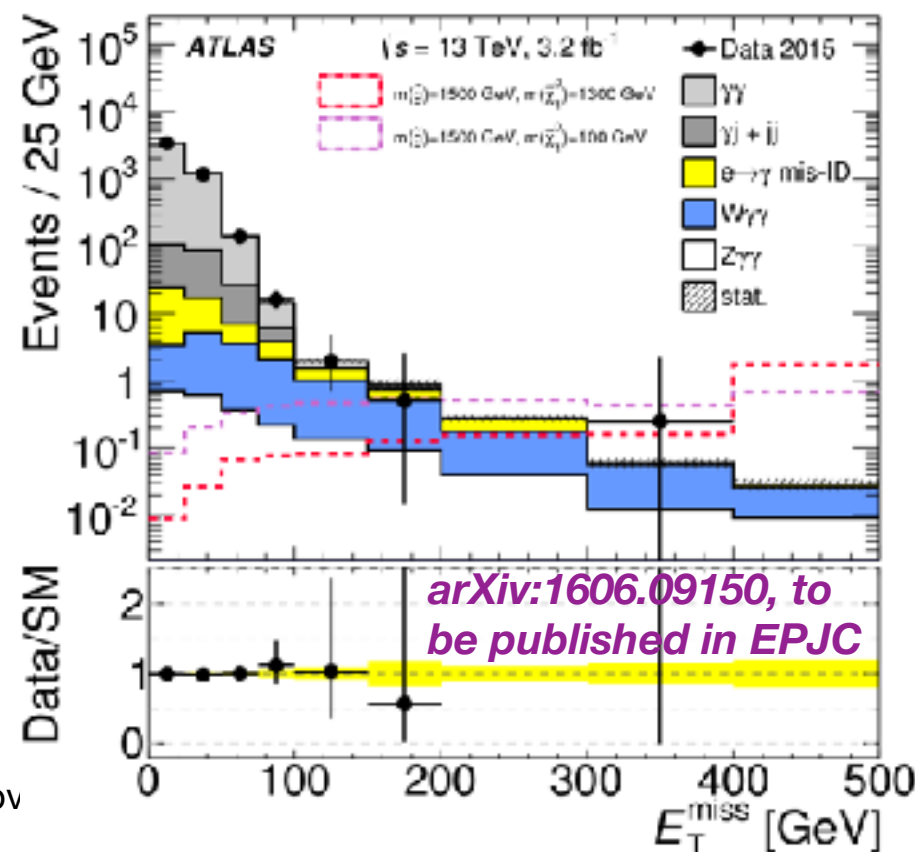
Stefano's talk

- dark-matter** particles produced with a Higgs boson from a dark U(1) boson  $Z'$



Ren-Jie & Alvaro's talks

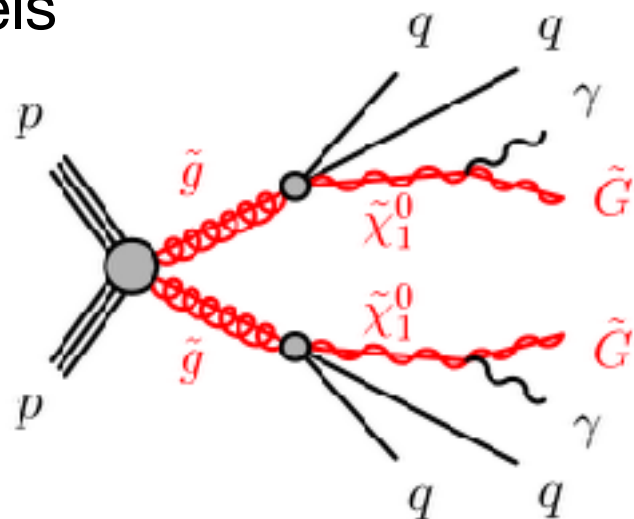
- No signal found in both cases :(



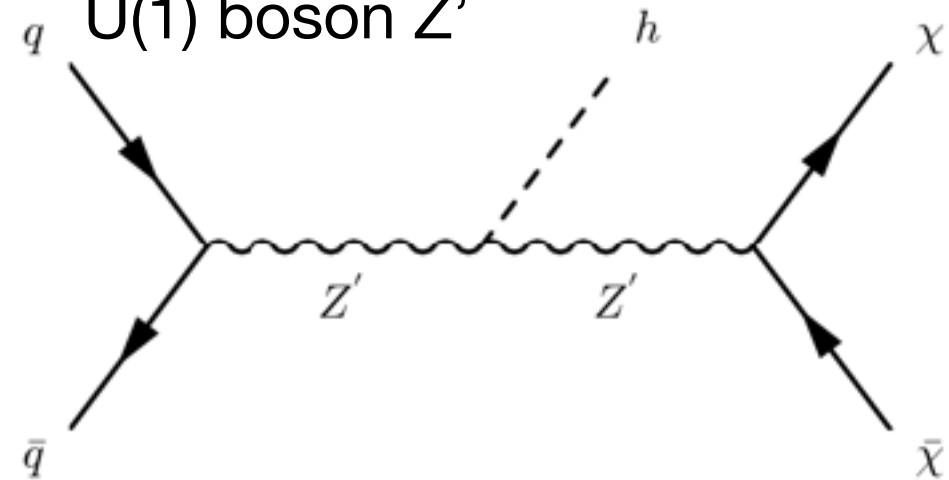
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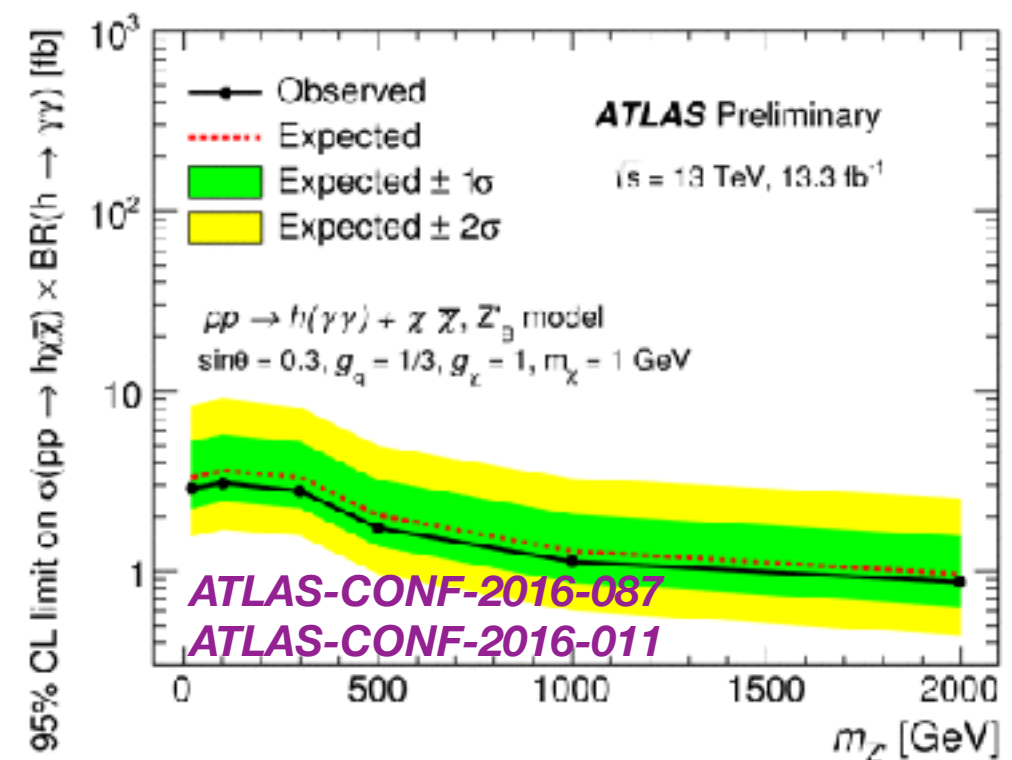
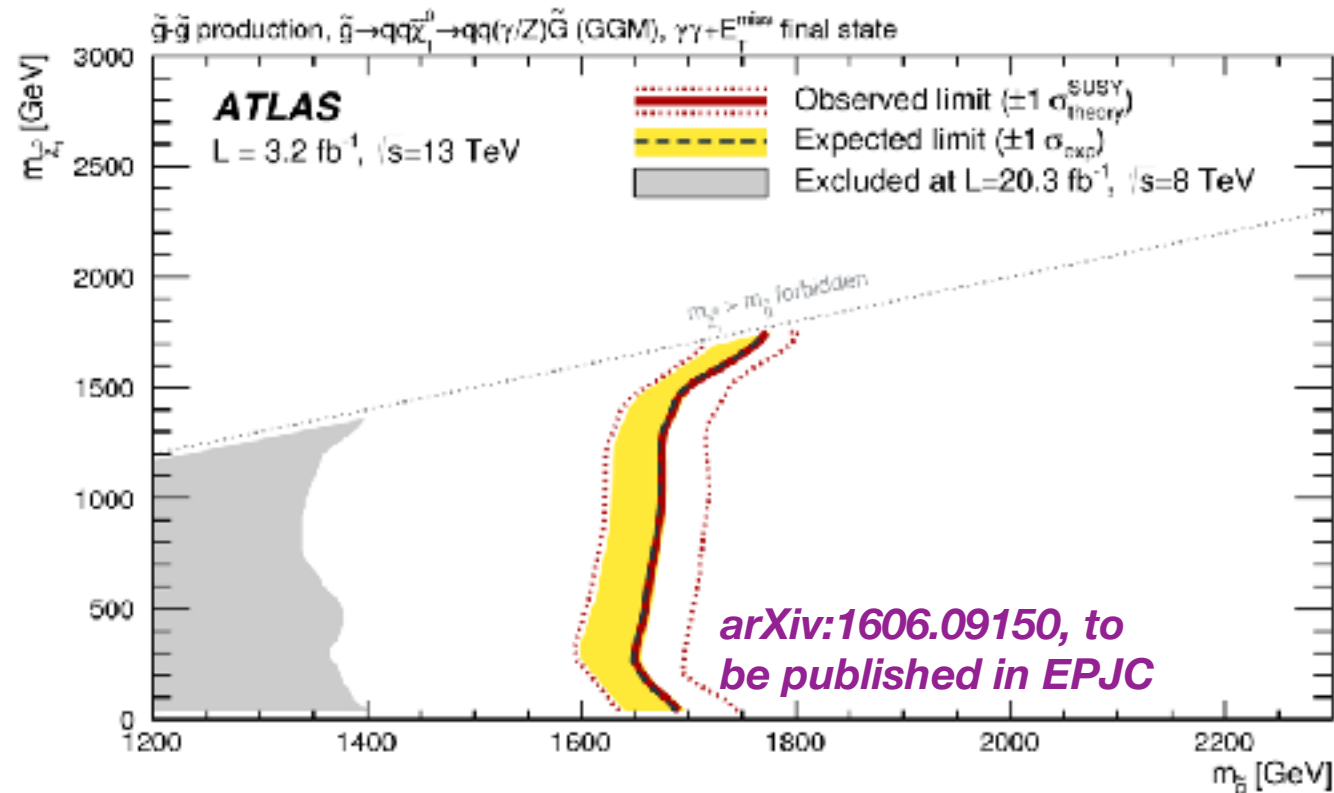
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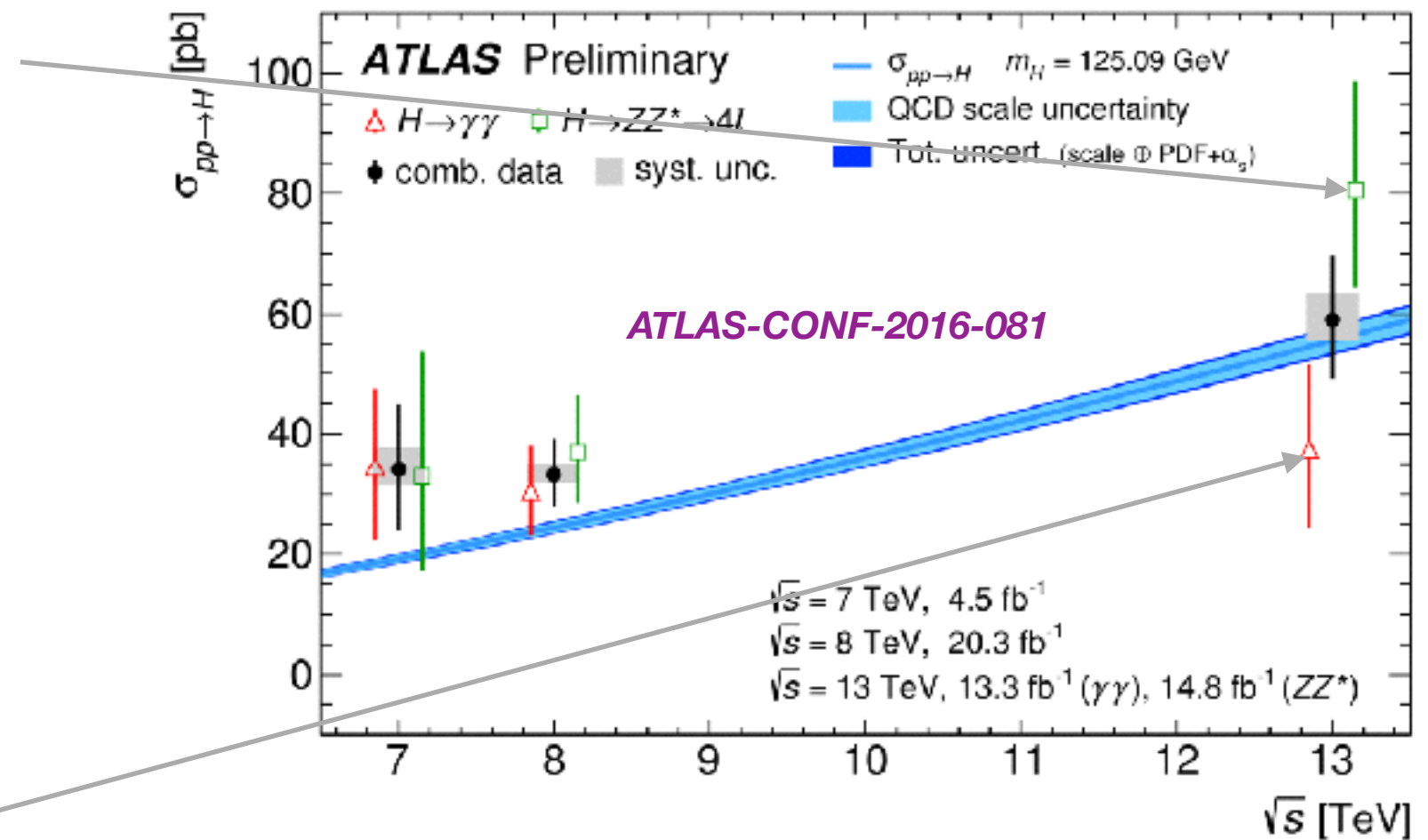
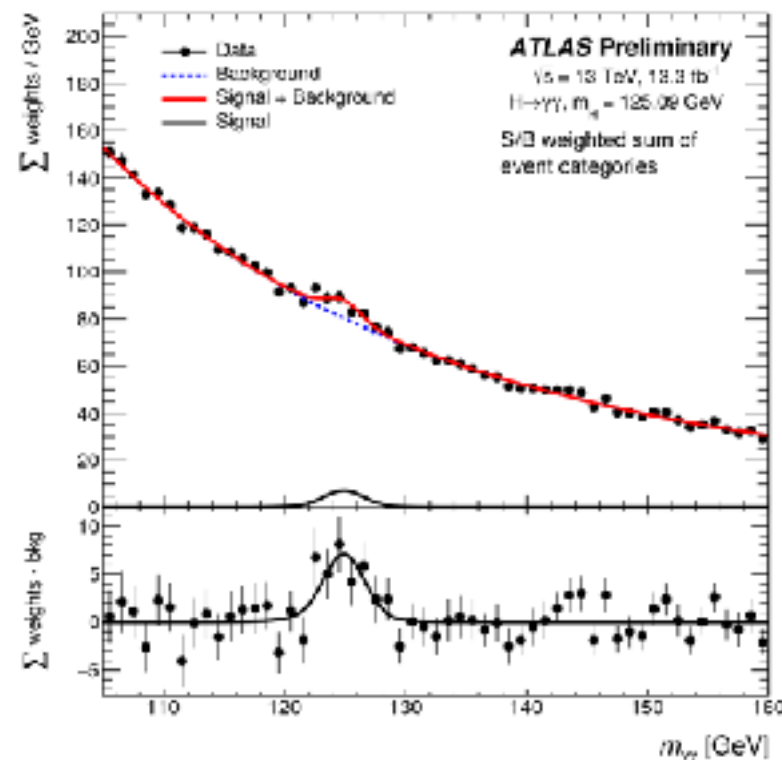
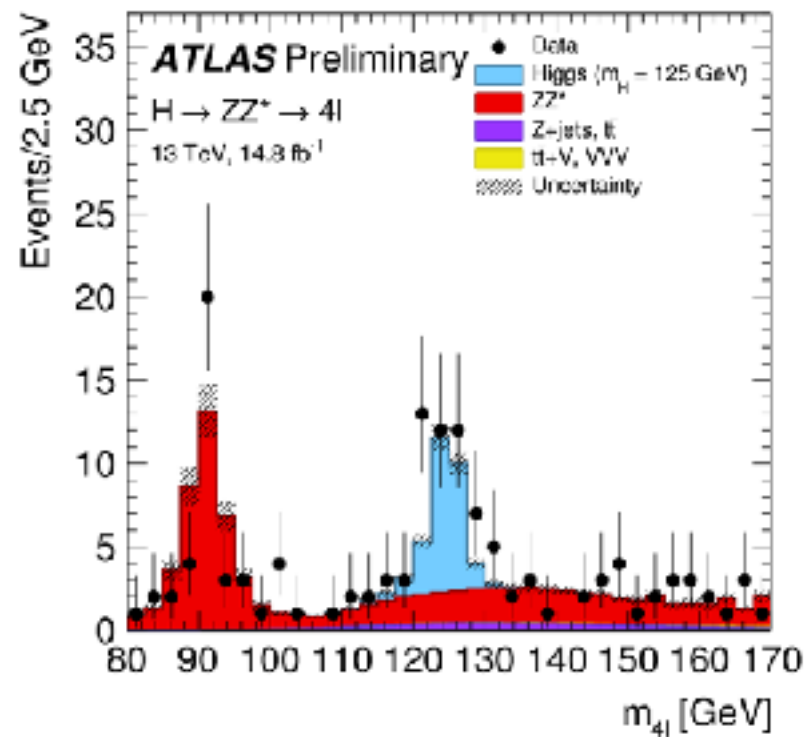
- No signal found in both cases :(





# The rediscovery of an old friend

- $H \rightarrow \gamma\gamma + H \rightarrow ZZ^* \rightarrow 4l$ :  $10\sigma$  observed excess at 13 TeV, xsection consistent with SM



# Short-term plans

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- Main goals for **winter 2017**:
  - “**physics**”-wise: convert ICHEP conf notes (high-mass  $\gamma\gamma$  and  $Z\gamma$ ,  $H(\gamma\gamma)+\text{MET}$ ) into papers based on full 2016 dataset (>2x larger dataset)
    - $\gamma\gamma$ : test also spin-2 signals
    - $Z\gamma$ : also include low-mass search (i.e. rare BR of 125 GeV Higgs)
    - extend probed mass range to >2.4 TeV thanks to larger dataset
  - “**performance**”-wise:
    - use full 2016 data to measure photons isolation and identification efficiency scale factors for all ATLAS photon-based analyses
    - provide some initial in situ  $e/\gamma$  energy calibration based on full 2016 data; final calibration to be available later in 2017
    - first results on the calibration with x-talk corrections

# Longer-term plans

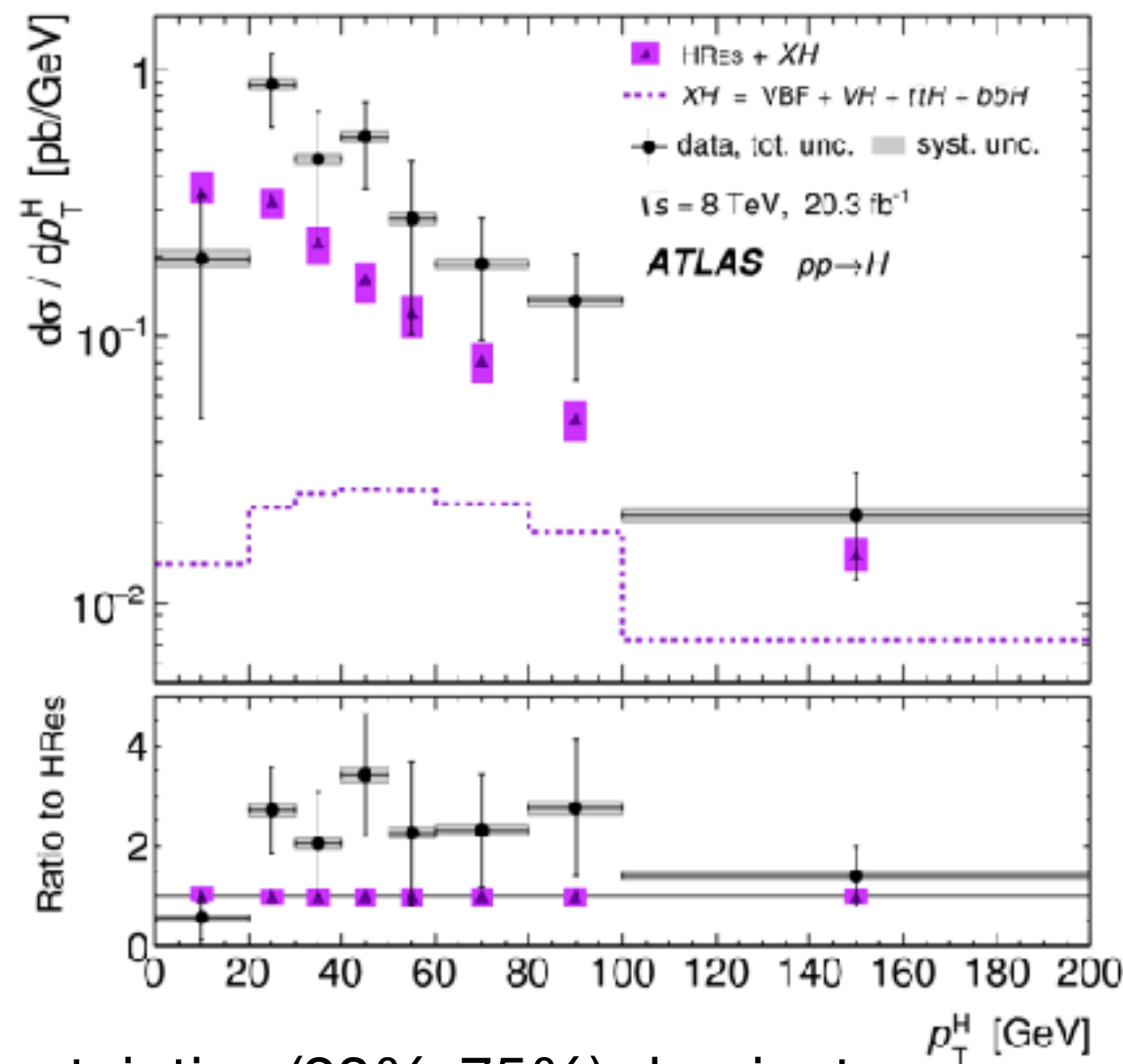
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- [Exploit full Run2 dataset](#) ( $\sim 10\times$  larger than in summer 2016, data-taking stops end of 2018) and prepare Run3 analysis
  - [searches of BSM physics](#) (high-mass resonances, dark matter in  $H(\gamma\gamma)+\text{MET}$ ) [or rare decays \( \$Z\gamma\$ \)](#): probe  $\sim 10\times$  smaller xsections; get close to  $H\rightarrow Z\gamma$  observation
  - measure [Higgs boson properties](#)
    - mass (w/ 2016 data at least): aim for  $\sim 0.1\%$  uncertainty (combined)
    - simplified & differential cross section measurements
  - plus usual involvement in [e/ \$\gamma\$  performance activities](#)
    - e/ $\gamma$  calibration: study of various systematic uncertainties
    - x-talk: implementation in ATLAS reconstruction code
    - photon ID and isolation efficiency measurements
- Within the framework of a [4-year ANR project “photonportal”](#) starting 01/2017
  - 3 partners (LAPP, LAL, LPNHE)
  - 3rd ANR obtained by the group on these activities in past  $\sim 10$  years



# Differential cross-sections from $H \rightarrow \gamma\gamma$ (and $H \rightarrow 4\ell$ )

- Several distributions sensitive to various theoretical effects have been measured in Run1 (and in early Run2): QCD modelling in ggF production ( $p_T^H$ ,  $y^H$ ), ratios of different production mechanisms ( $N_{\text{jets}}$ ), modelling of partonic radiation in ggF and of jets in VBF and VH events ( $p_T$  of leading jet,  $p_T^{j1}$ )
- Current results:  $p_T(H)$  spectrum somewhat harder than predicted



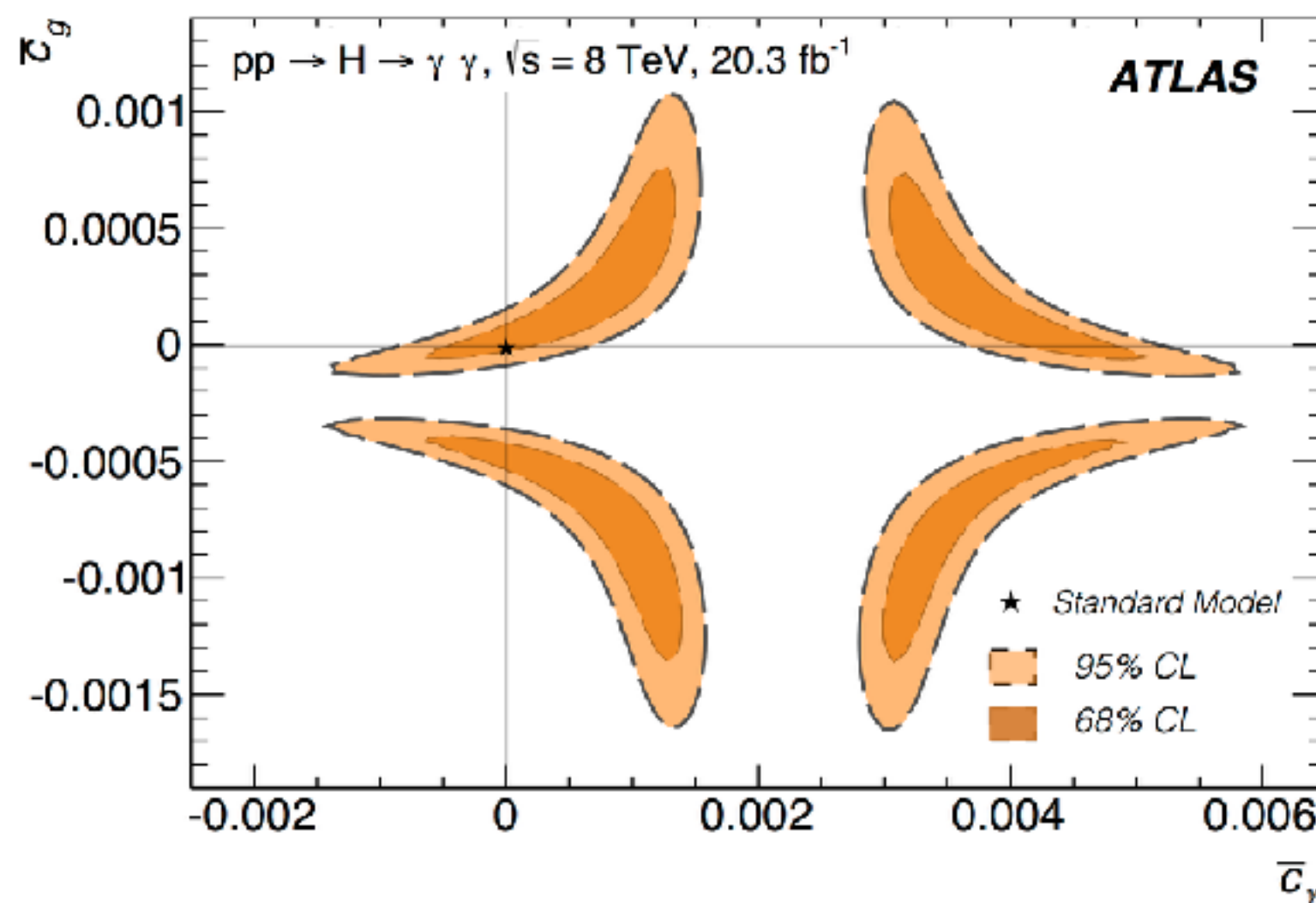
- statistical uncertainties (23%-75%) dominate
- Exploit full Run2 to better investigate this small discrepancy

# Constraints on BSM in EFT using differential xsections in $\gamma\gamma$

- SM lagrangian augmented with dim-6 operators. Differential xsections in  $H \rightarrow \gamma\gamma$  mainly sensitive to CP-even and CP-odd operators affecting interactions with: photons ( $c_\gamma$ ); gluons, via gluon fusion production ( $c_g$ ); WW and ZZ via VBF and associated production ( $c_{HW}$ ,  $c_{HB}$ ). Other operators have very small impact

$$\mathcal{L} = \bar{c}_\gamma O_\gamma + \bar{c}_g O_g + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_g \tilde{O}_g + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB},$$

- 2D limits on pairs of coefficients after setting other coefficients to SM ( $c=0$ )



# Longer-term plans: manpower @ LPNHE

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- 1 post-doc to be recruited in fall 2017 (ANR), to work on analysis of full Run2 data (publications during 2019)
- PhD theses:
  - fall 2016 (now): Ahmed starting on  $e/\gamma$  calibration + Higgs x-sections
  - fall 2017:
    - Lydia (cotutelle w/ USTC): calibration + low/high-mass  $\gamma\gamma$  resonances
    - Bertrand (maybe cotutelle w/ WITS): calibration/x-talk + dark-matter search
    - Jose: Higgs boson properties
    - if cotutelle w/ WITS doesn't work and if only 1 NPAC bourse, consider postponing one of the last two to 2018
  - fall 2019:
    - Sandrine: Run3 preparation & analysis of first  $\sim 1.5$  years of Run3 ( $\sim 100 \text{ fb}^{-1}$ ). Could be 2 with the usual strategy of cotutelles