$H \to \gamma\gamma$ results at $\sqrt{s} = 13$TeV

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30/03/2016

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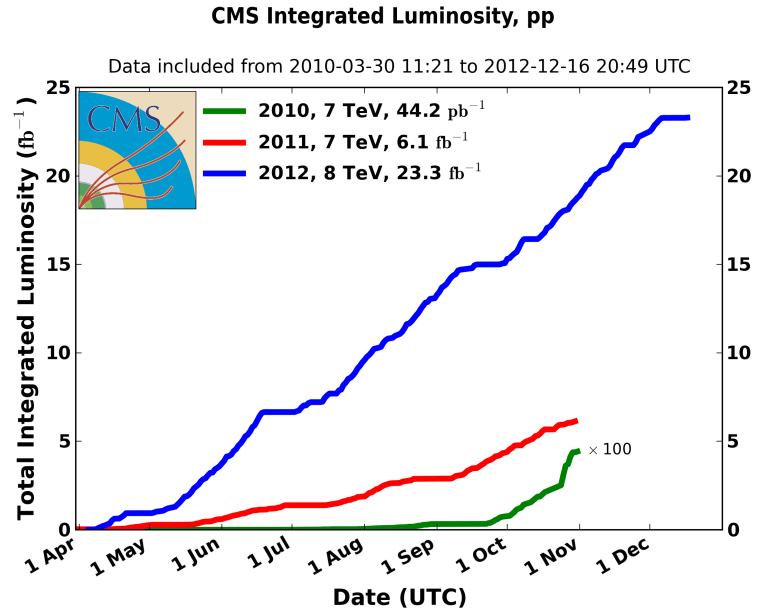
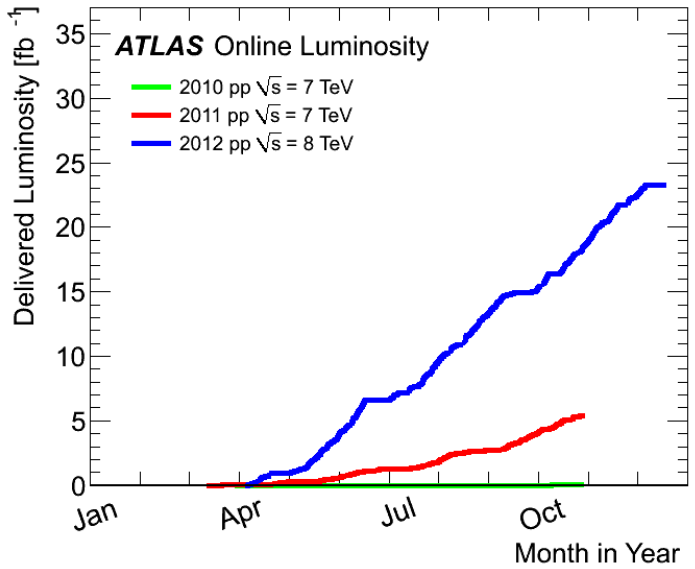
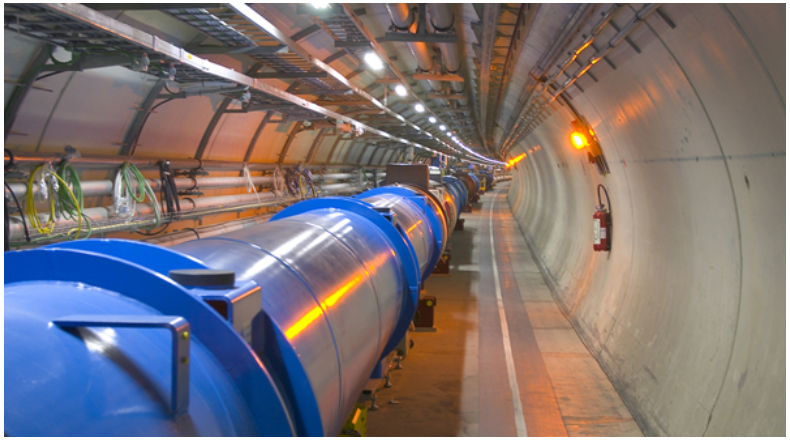
The Large Hadron Collider Run-I, pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV



- LHC excellent performance in 2011 and 2012
- $\int L\,dt \approx 25\,fb^{-1}$ at $\sqrt{s} = 7$ and 8 TeV
- Peak Instant Luminosity: $L = 7.7 \times 10^{-33}\,cm^{-2}s^{-1}$



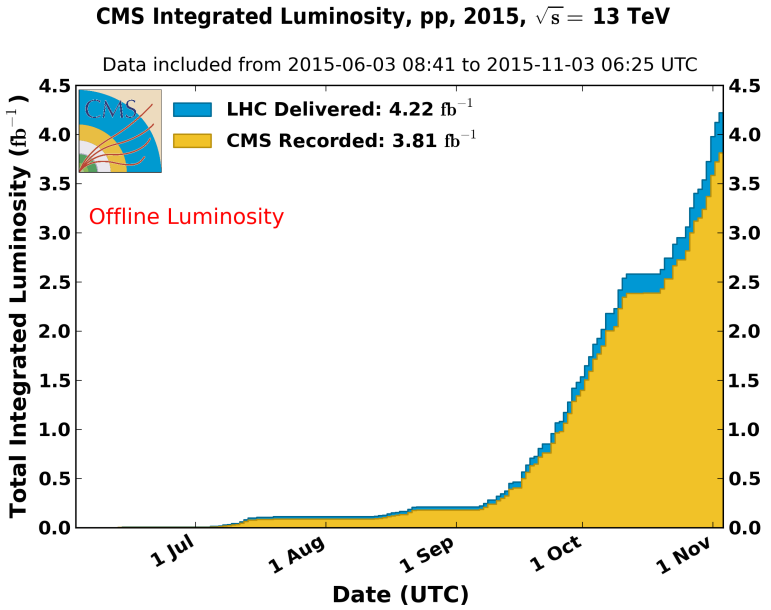
The Large Hadron Collider Run-II, pp collisions at $\sqrt{s} = 13$ TeV

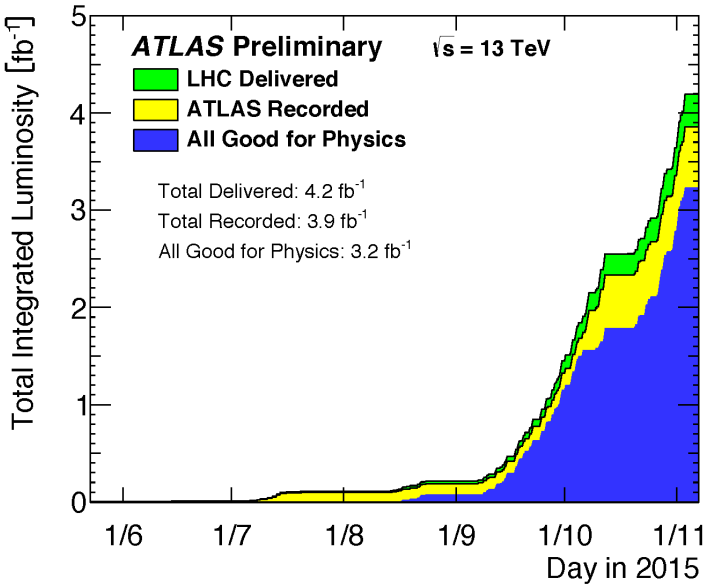


- LHC 2015 in two lines:

$$\approx 2 \times \sqrt{s}_{run-I}$$
$$\approx 0.2 \times \int L\,dt_{run-I}$$

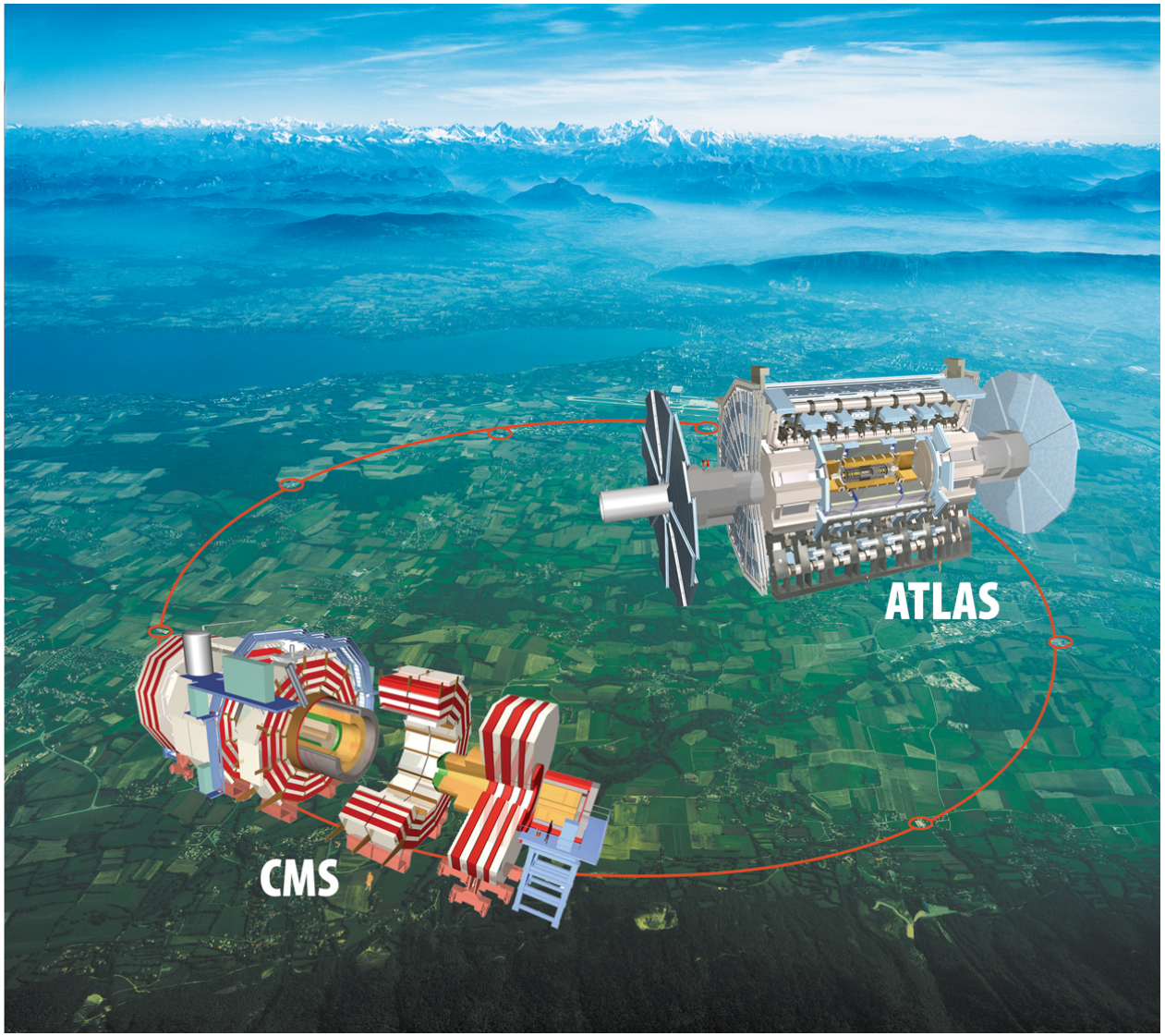
- $\int L\,dt \approx 4\,fb^{-1}$ at $\sqrt{s} = 13$ TeV
- Max Instant Luminosity: L = 5.13 Hz/nb
- Not all CMS collected lumi with B=3.8 Tesla





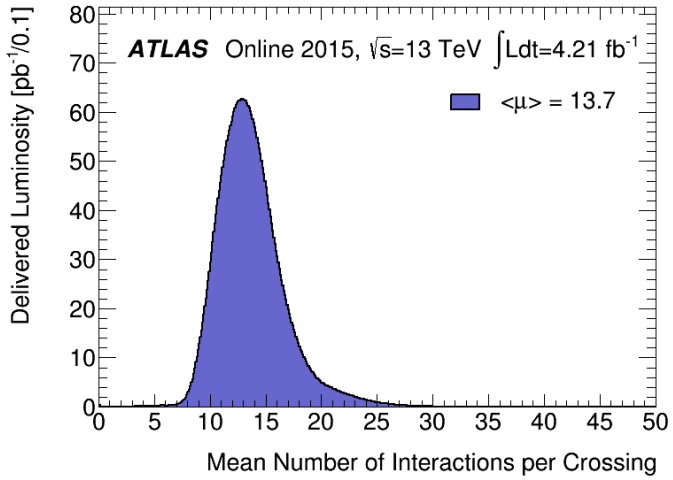
The experiment

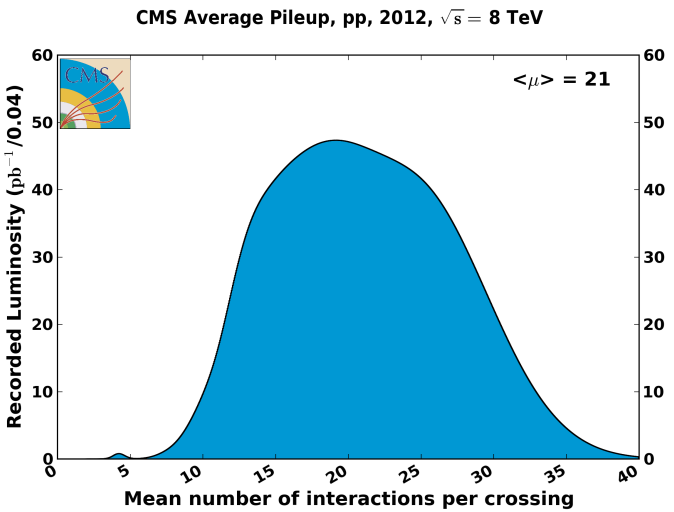
- Big collaborations (≈4000/experiment)
- Multi purpose experiments
- LHC data efficiency recording (used for analysis) > 90% during Run-I.
- Robust Muon systems and $e\gamma$-calorimeters (crystals(CMS) and liquid argon(ATLAS)).



Multiple collisions per bunch crossing, a challenge for the experiments

- Due to the increase in luminosity, more than one collision happen during a bunch-crossing in the LHC, this is called pile up (PU).
- 2011 average PU $\approx$ **10**, for 2012 average PU $\approx$ **20**.
- Particle flow algorithm helps a lot in high PU events.
- Less energy resolution for e and γ
- Central jet veto and VBF jet tagging affected.
- **At peak lumi for LHC Run-II at $\sqrt{s} = 13\,TeV$ we expected PU $\approx$ 40**

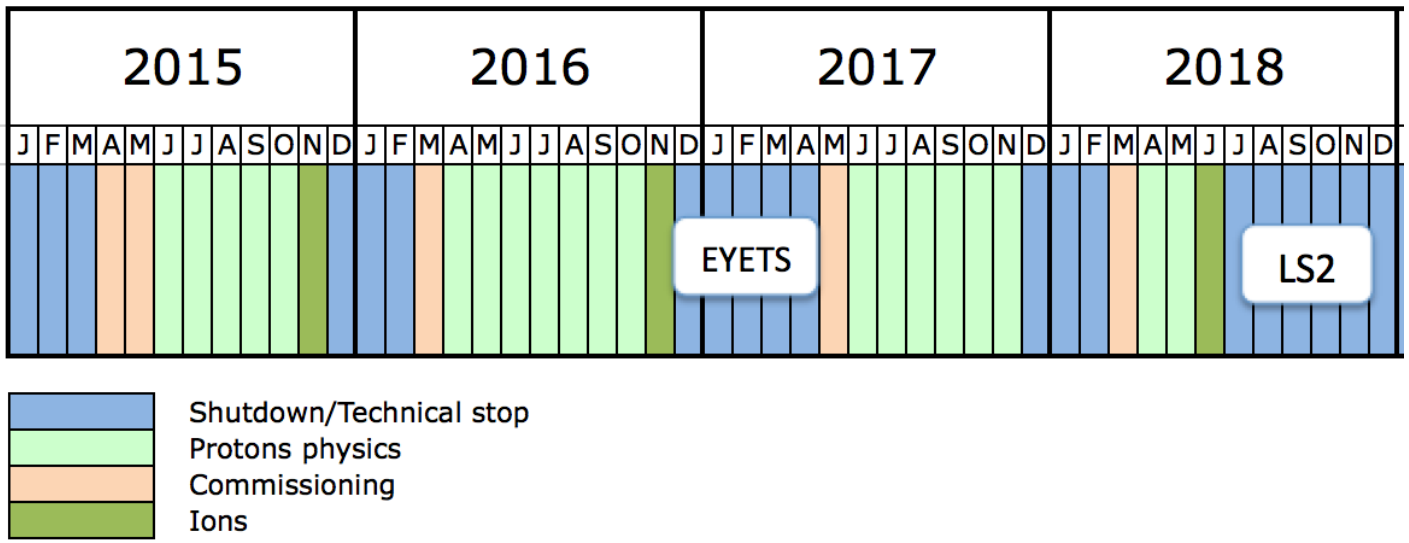




However... Slide from 8th FCPPL @ HEFEI 2015 by C. Carrillo
Expected Integrated luminosity for run-II 2015 $\approx$ 10 fb^{-1}

- Conservative β^* to start
- Conservative bunch population
- Assuming same machine availability as 2012

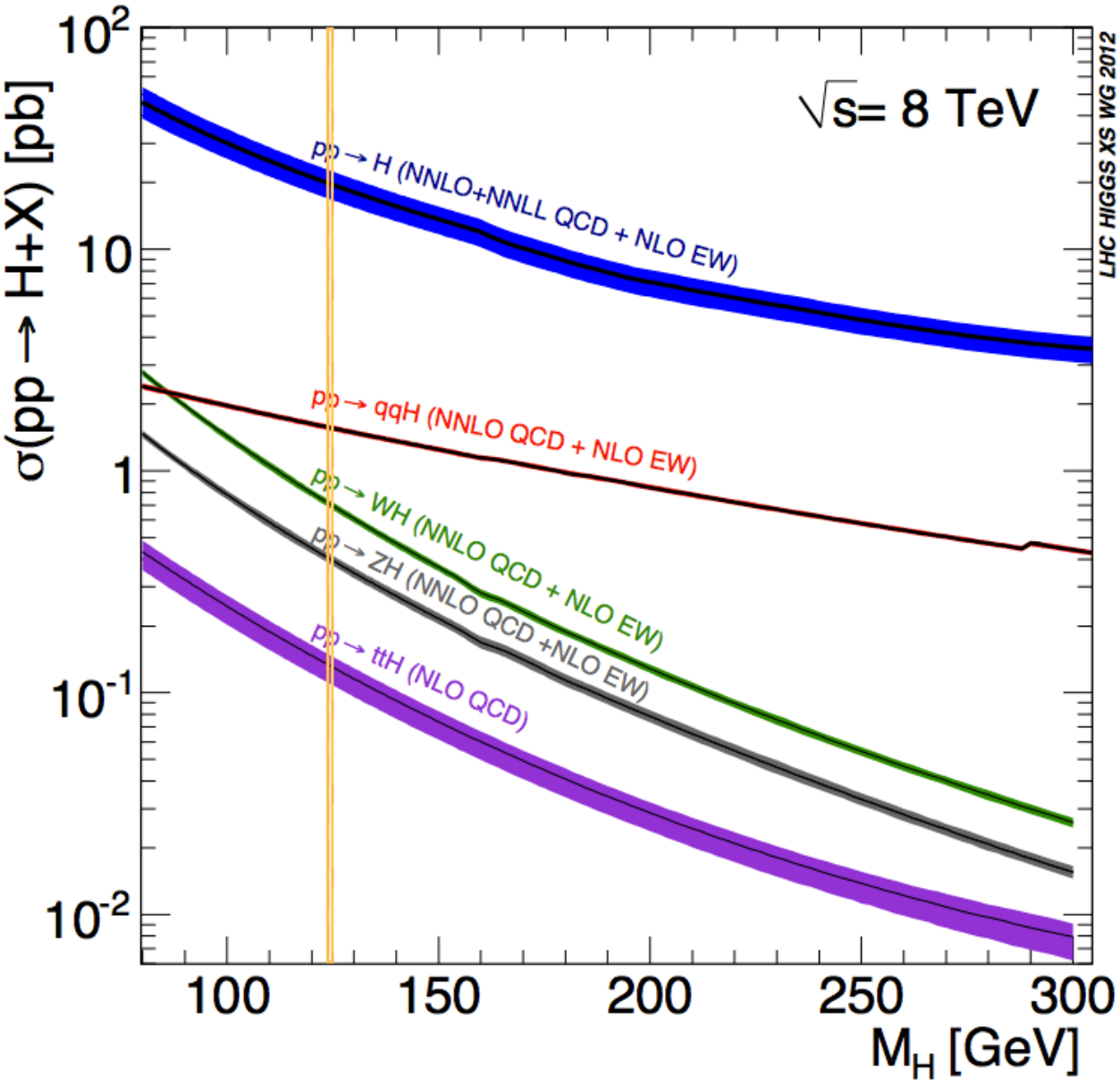
	Nc	Beta *	ppb	EmitN	Lumi [cm^{-2}s^{-1}]	Days (approx)	Int lumi	Pileup
50 ns	1300	80	1.2e11	2.5	4.8e33	21	~1 fb^{-1}	25
2015.1	2592	80	1.1e11	2.5	7.6e33	30	3 fb^{-1}	21
2015.2	2592	40	1.1e11	2.5	1.2e34	48	8 fb^{-1}	34



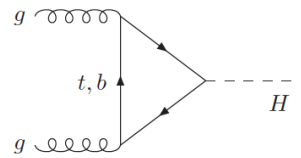
The BEH Boson

Production, decay, and what we have learned form run-I

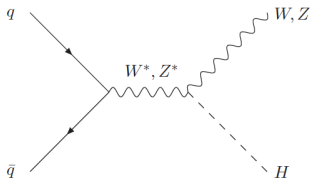
Higgs production modes



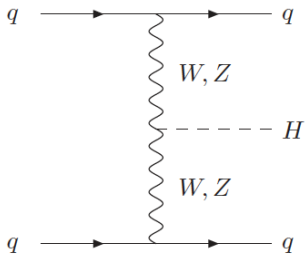
pp→H (ggh)



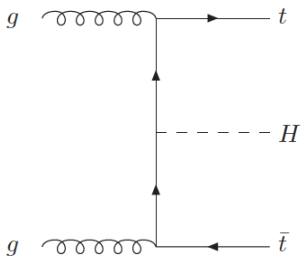
pp→W,Z H



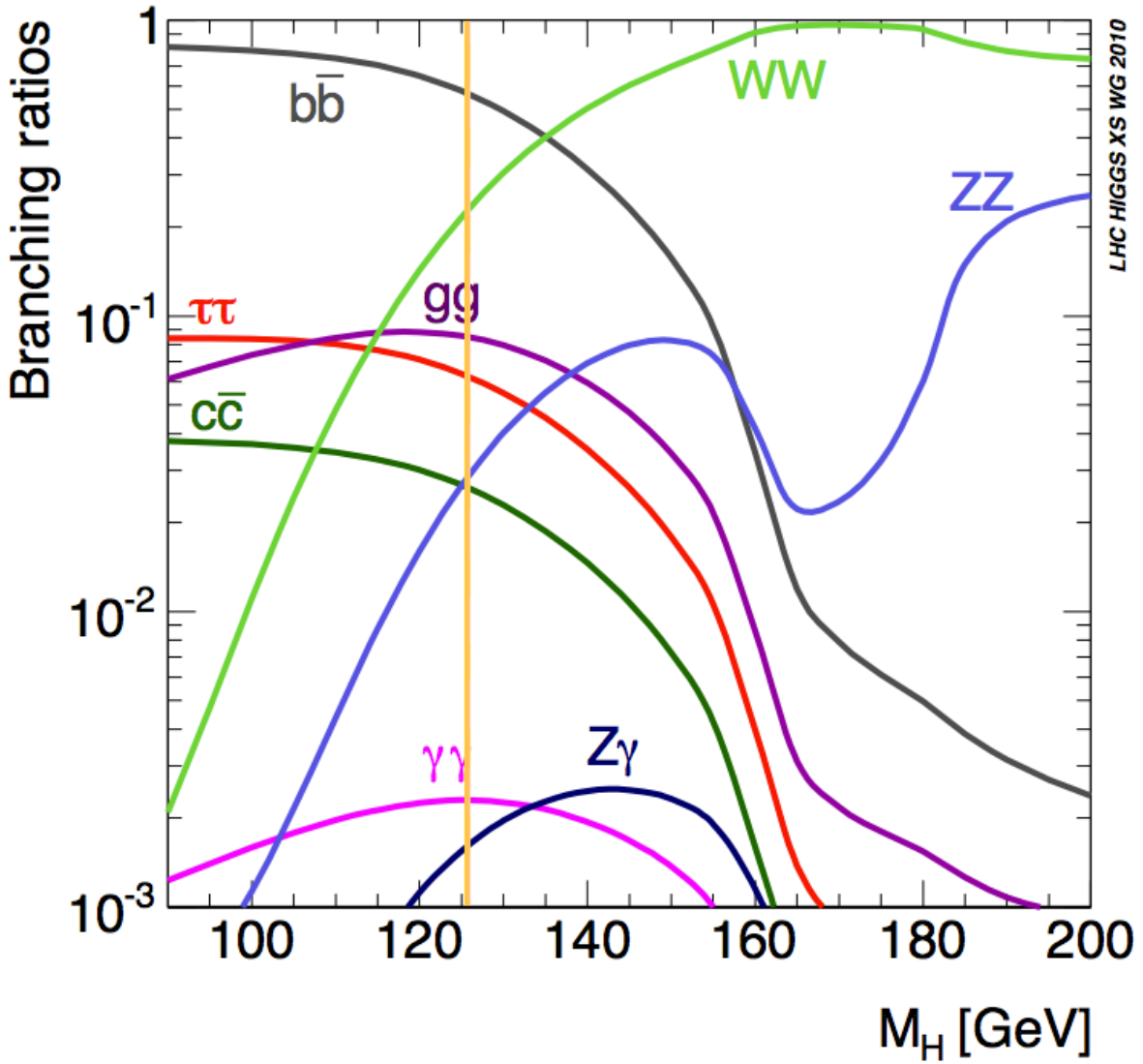
pp→qq H



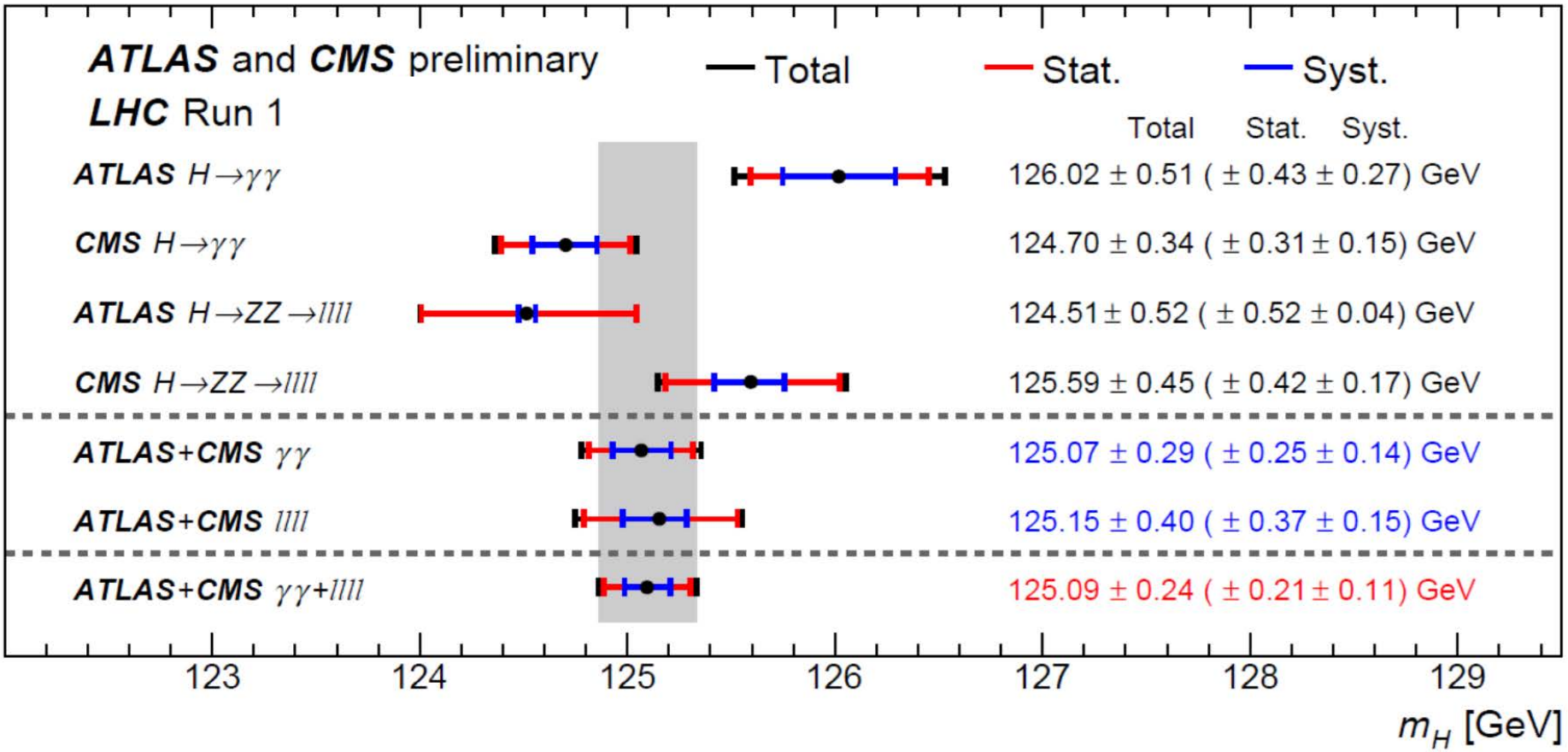
pp→ $t\bar{t}$ H



Higgs Decays, branching ratios



A detailed view for the mass measurements, run-I

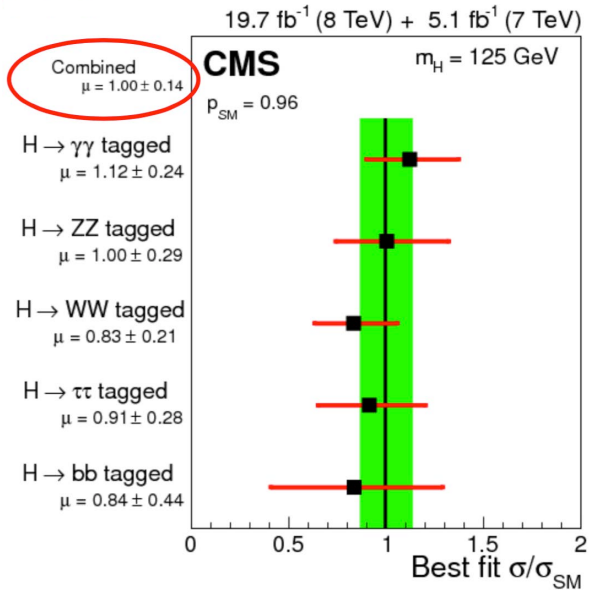


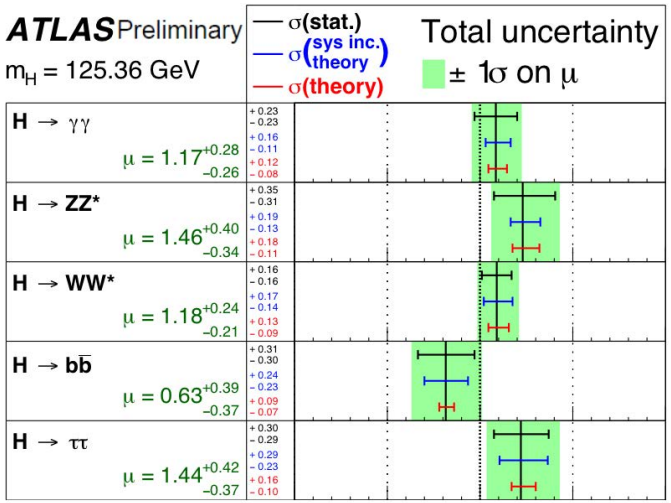
Combined ATLAS+CMS measurement of the Higgs boson mass:

m_H = 125.09 $\pm$ 0.24GeV

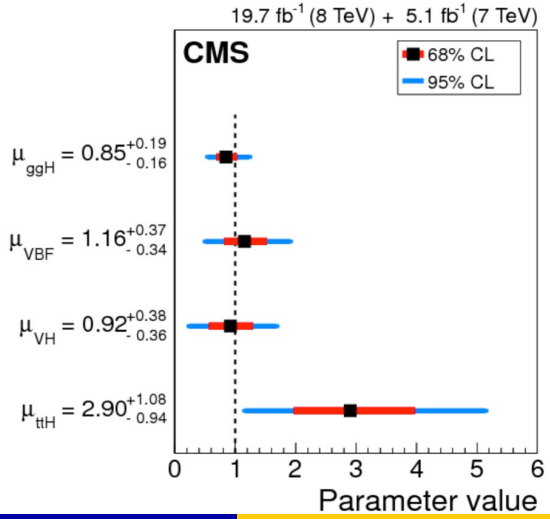
Higgs Signal Strength, from run-I

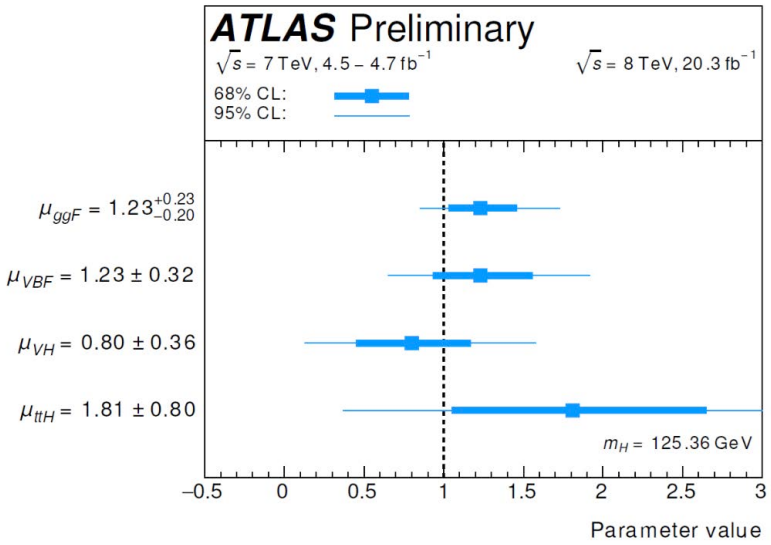
Signal Strength decay





Signal Strength production





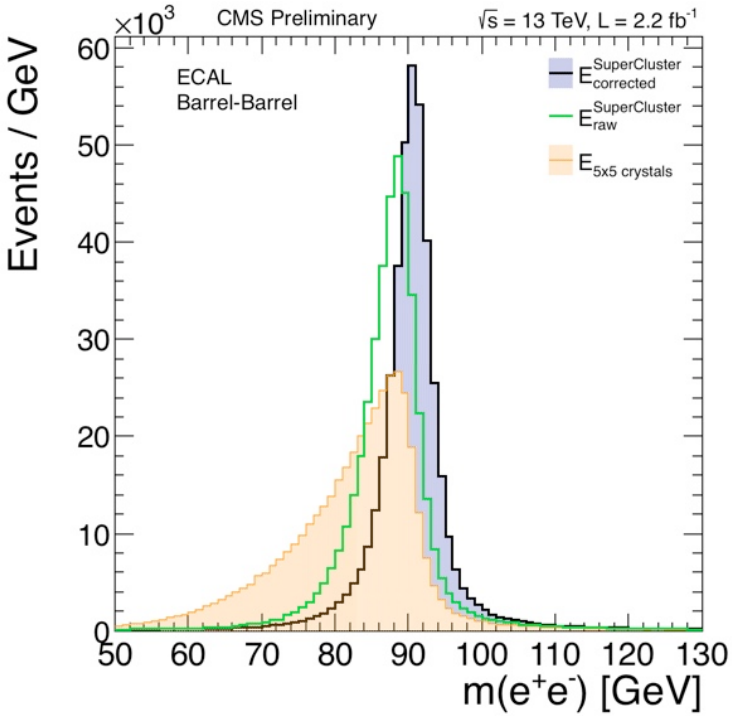
CMS $H \rightarrow \gamma\gamma$ results (Run-II)

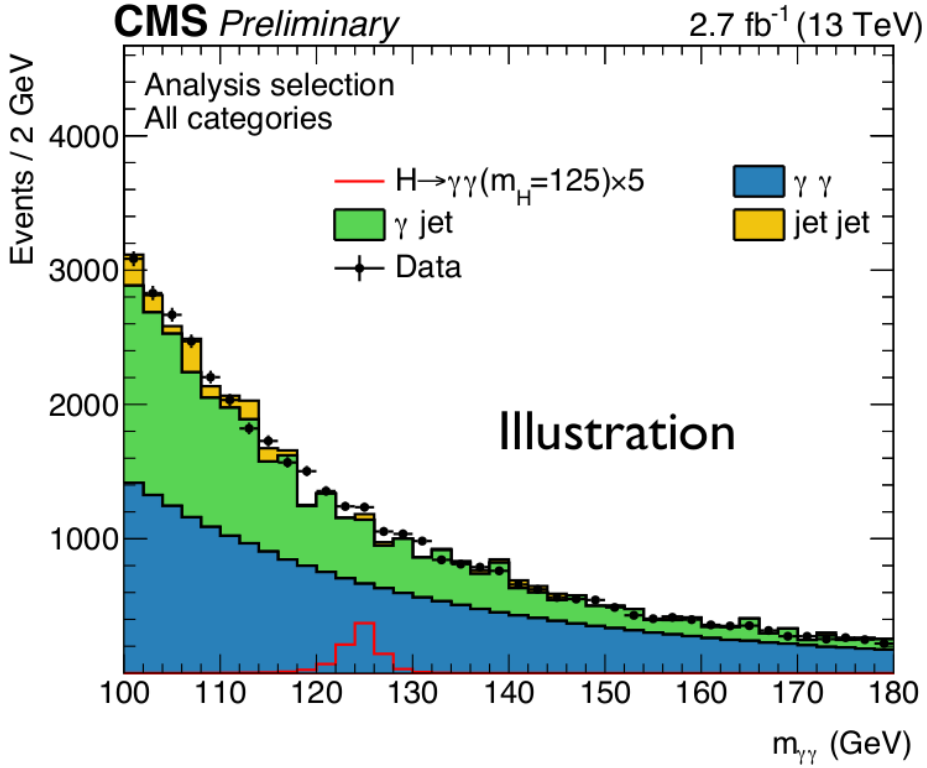
CMS-HIG-15-005

The overview CMS analysis

- Photon Energy resolution
- Correct Vertex identification
- Maximize S/B using

$$m_{\gamma\gamma} = \sqrt{2p_1p_2(1 - cos\Delta\alpha)}$$

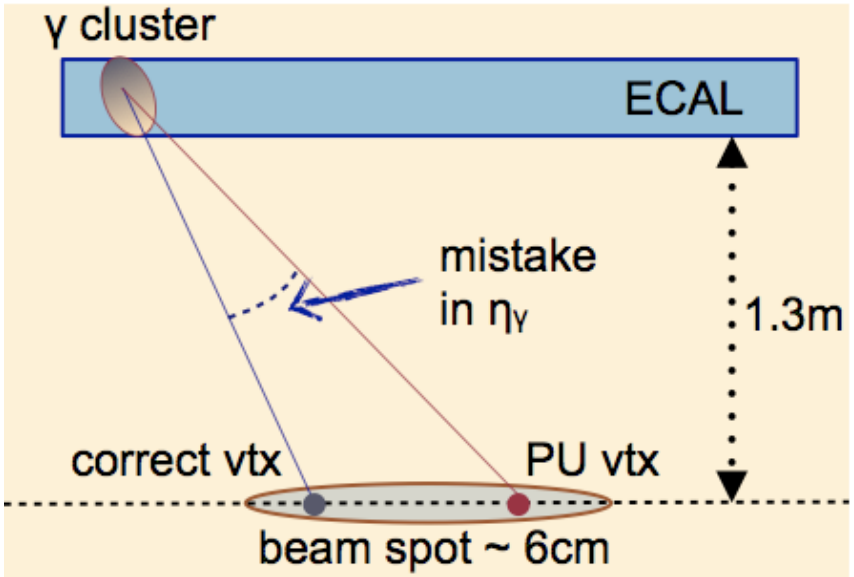


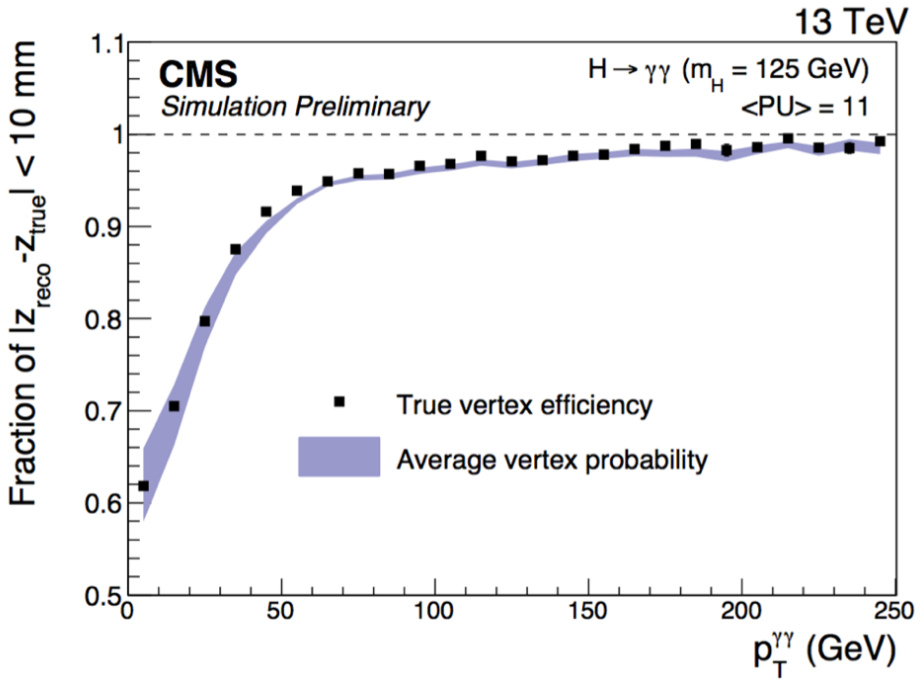


Vertex Identification

- MVA using Σp_T^2, Σp_T of vertex tracks
- Diphoton balancing with vertex tracks
- **Estimator of correct ID probability propagated to photon categorization**

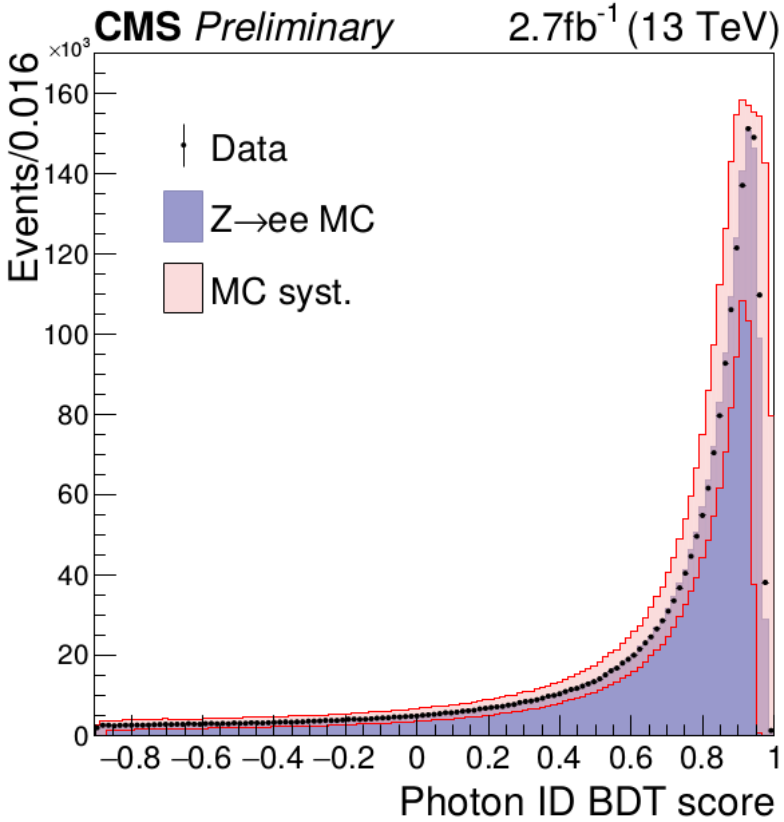
$\sum_i |\vec{p_T^i}|^2$, $-\sum_i (\vec{p}_T^i \cdot \frac{\vec{p}_T^{\gamma\gamma}}{|\vec{p}_T^{\gamma\gamma}|})$ and $(|\sum_i \vec{p}_T^i| - p_T^{\gamma\gamma})/(|\sum_i \vec{p}_T^i| + p_T^{\gamma\gamma})$

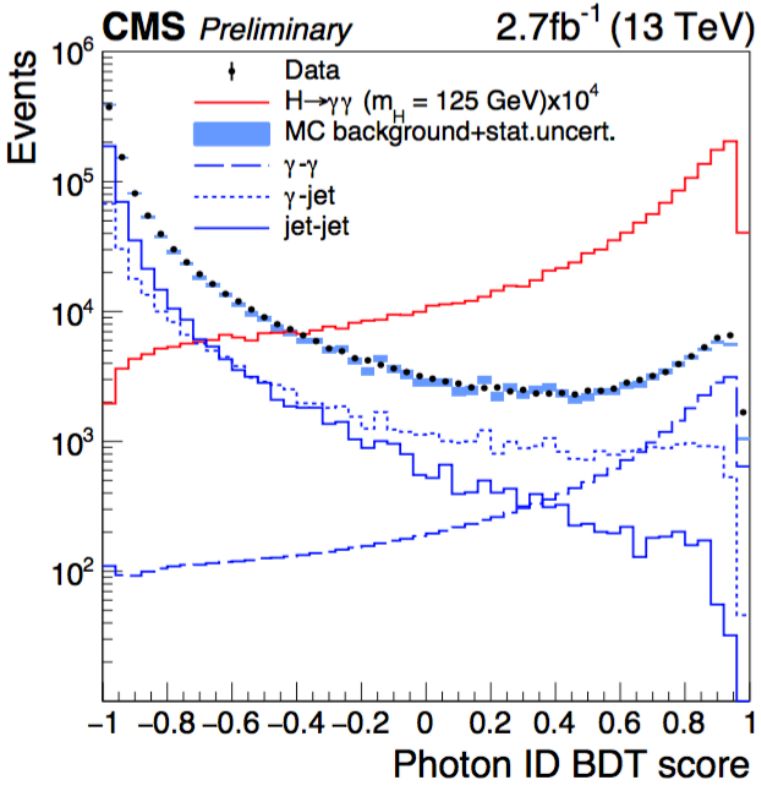




- Validated using $Z \to \mu^+\mu^-$ events where the vertices are refitted ignoring the muon tracks to mimic a diphoton system.
- In addition, γ + jet events are used to validate the use of tracks from converted photons to locate the vertex.

Photon Identification

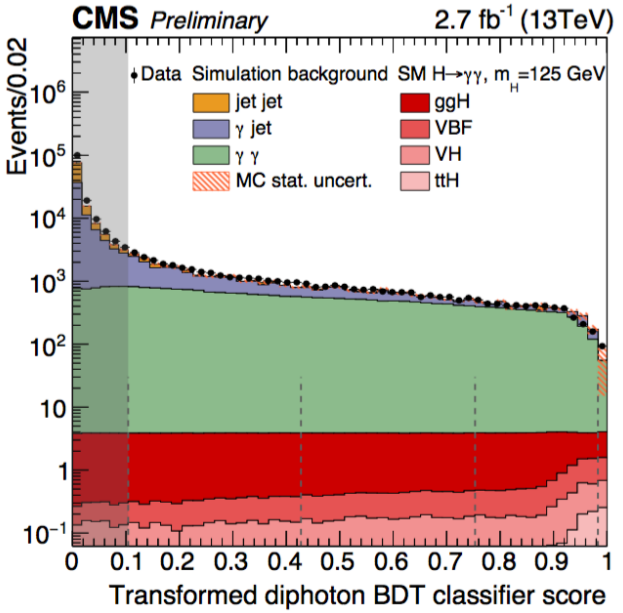


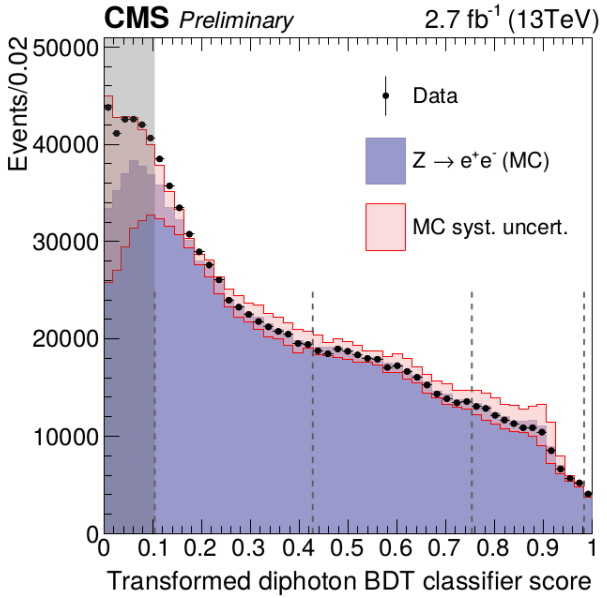


- Shower shape observables
- Isolation variables based on the sums of the p_T of photons, and of charged hadrons, within regions of $\Delta R \leq 0.3$
- The energy median density per unit area in the event, ρ, makes the BDT independent of pileup
- Photon kinematic observables (pseudorapidity and energy)

Di-Photon Identification

- Use vertexing, photon information, kinematics to produce classifier that indicates the expected diphoton resolution
- Divide events into 4 categories based on output of classifier $\rightarrow$
- Other categories:
  - TTH events require a b-tag AND (lepton+$\geq$2j OR $\geq$ 4j)
  - VBF events tagged additional,similar multivariate discriminator (2 categories)





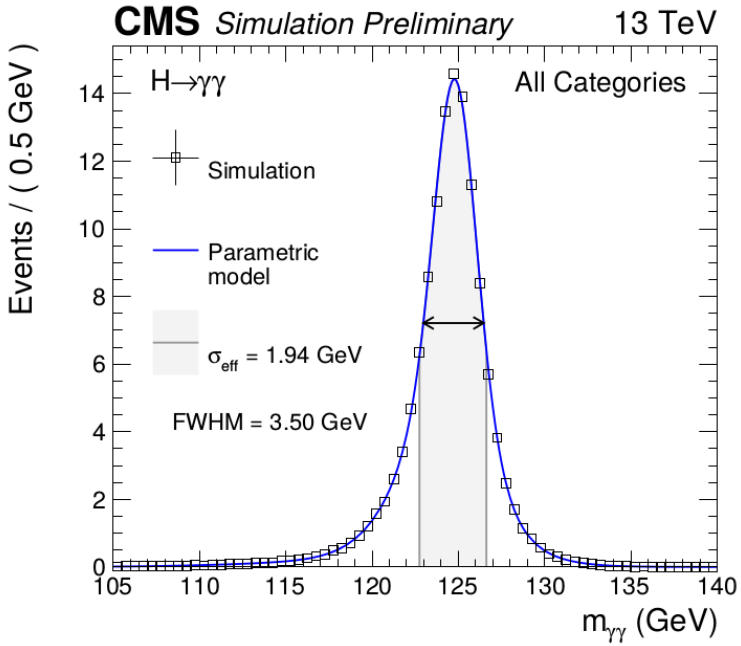
Signal/Background Model

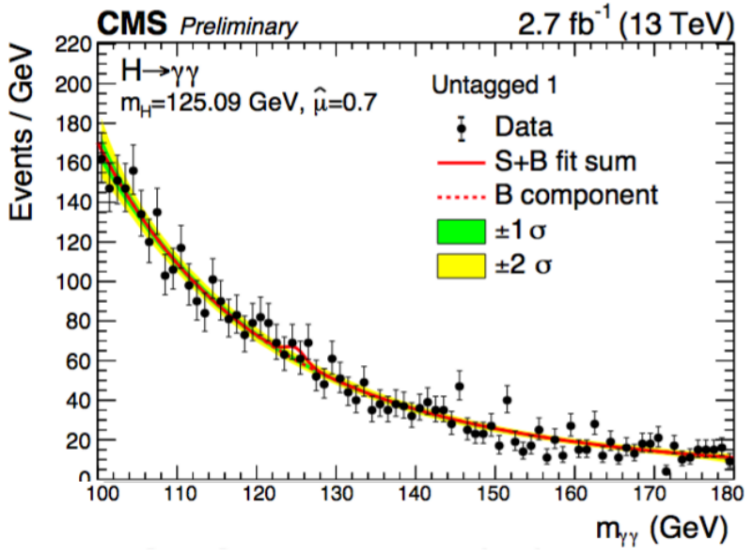
Signal:

- The $m_{\gamma\gamma}$ distributions are fitted using a sum of at most five Gaussians.
- The model is constructed by interpolating with a spline each parameter between individual mass points.
- The analytic functions for each production mode are summed together and weighted to obtain the final function in each category.

Background:

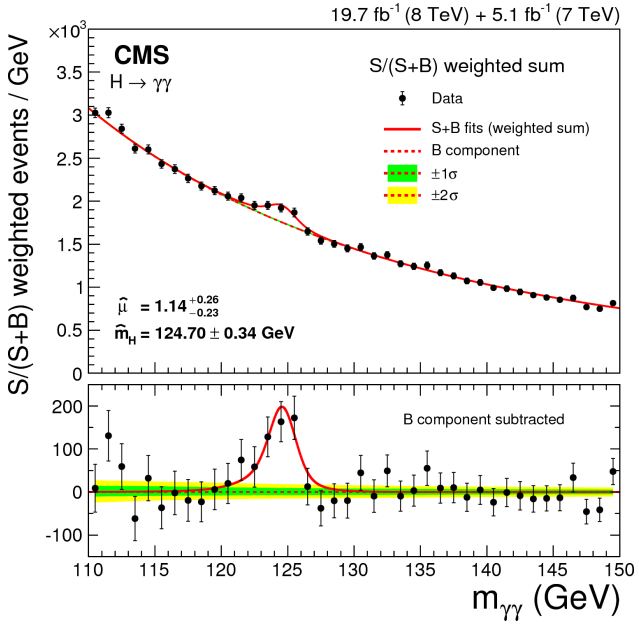
- Discrete profiling or "envelope" method (Bernstein polynomials, Laurent series and power-laws)
- Range of functions considered that fit bkg.

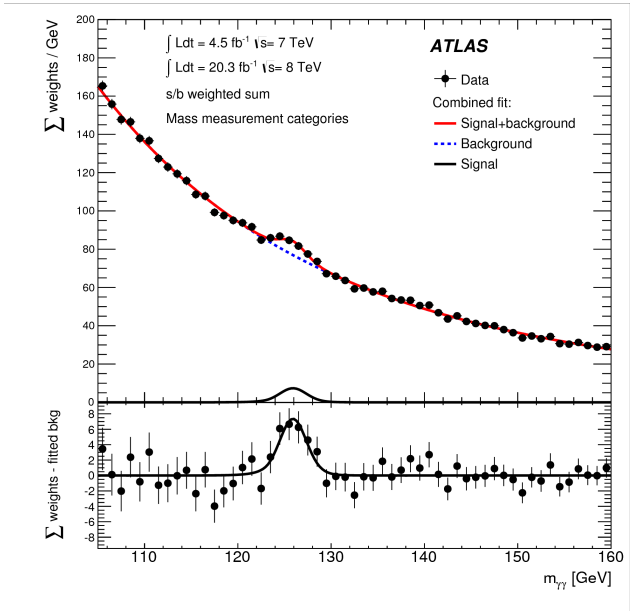




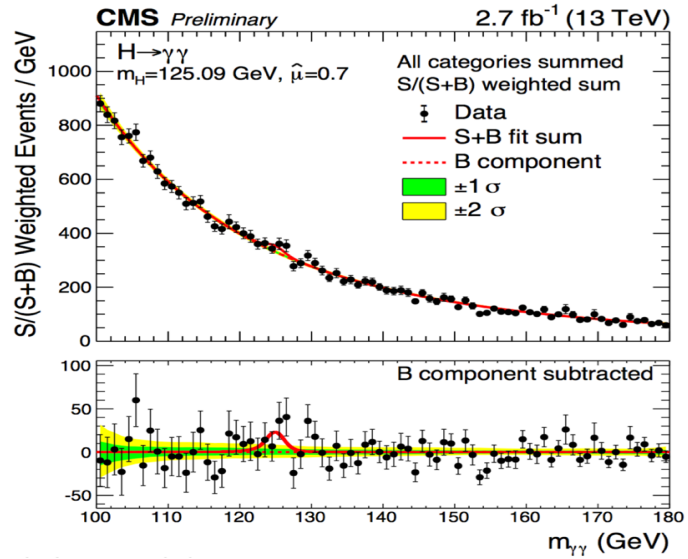
$\gamma\gamma$ spectrum, run-I & run-II CMS-ATLAS

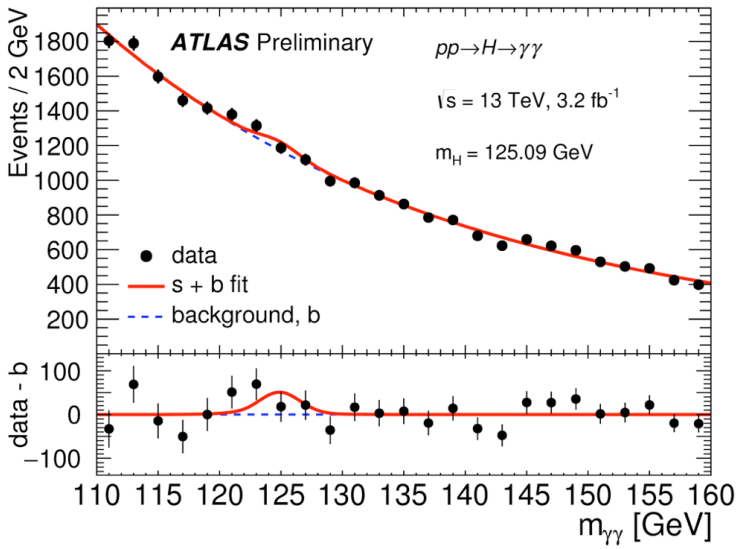
$H \to \gamma\gamma$
run-I



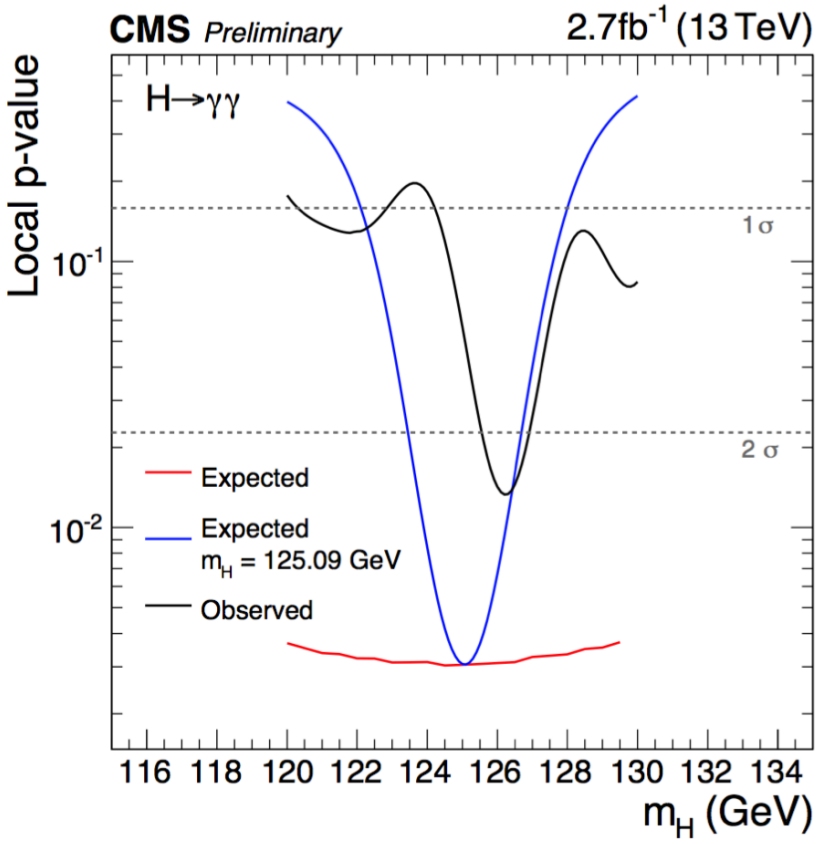


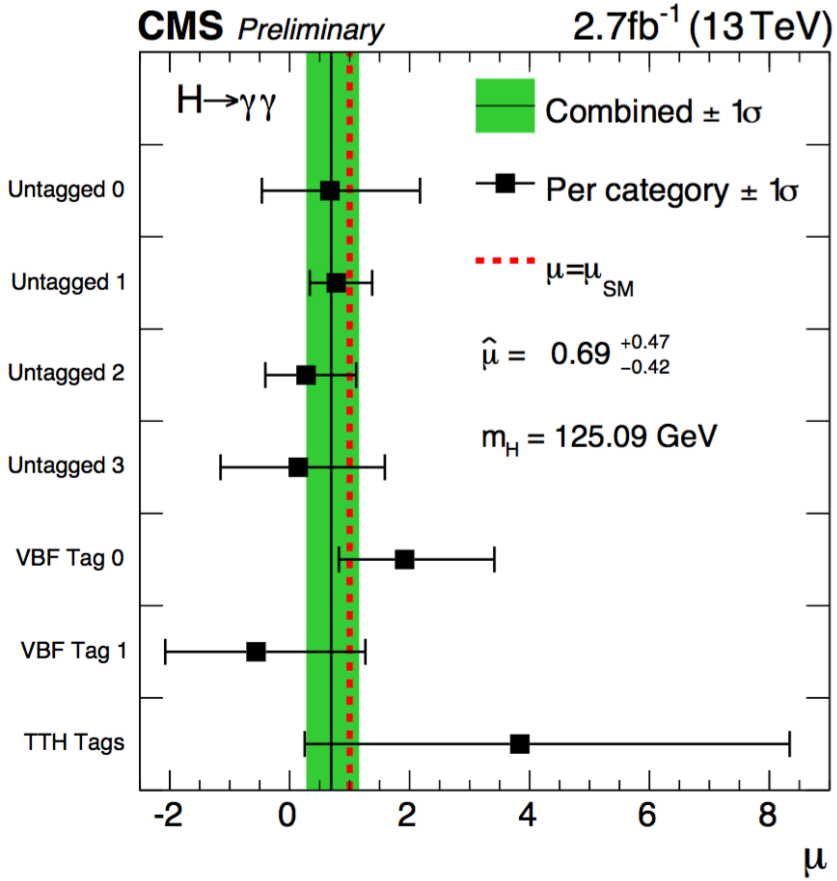
$H \to \gamma\gamma$
run-II





CMS Signal Strenght, split by categories





Significance:

- Observed : 1.7σ
- Expected (at 125.09 GeV): 2.7σ

$\hat{\mu} = 0.69^{+0.47}_{-0.42}$
at fixed m_H=125.09GeV

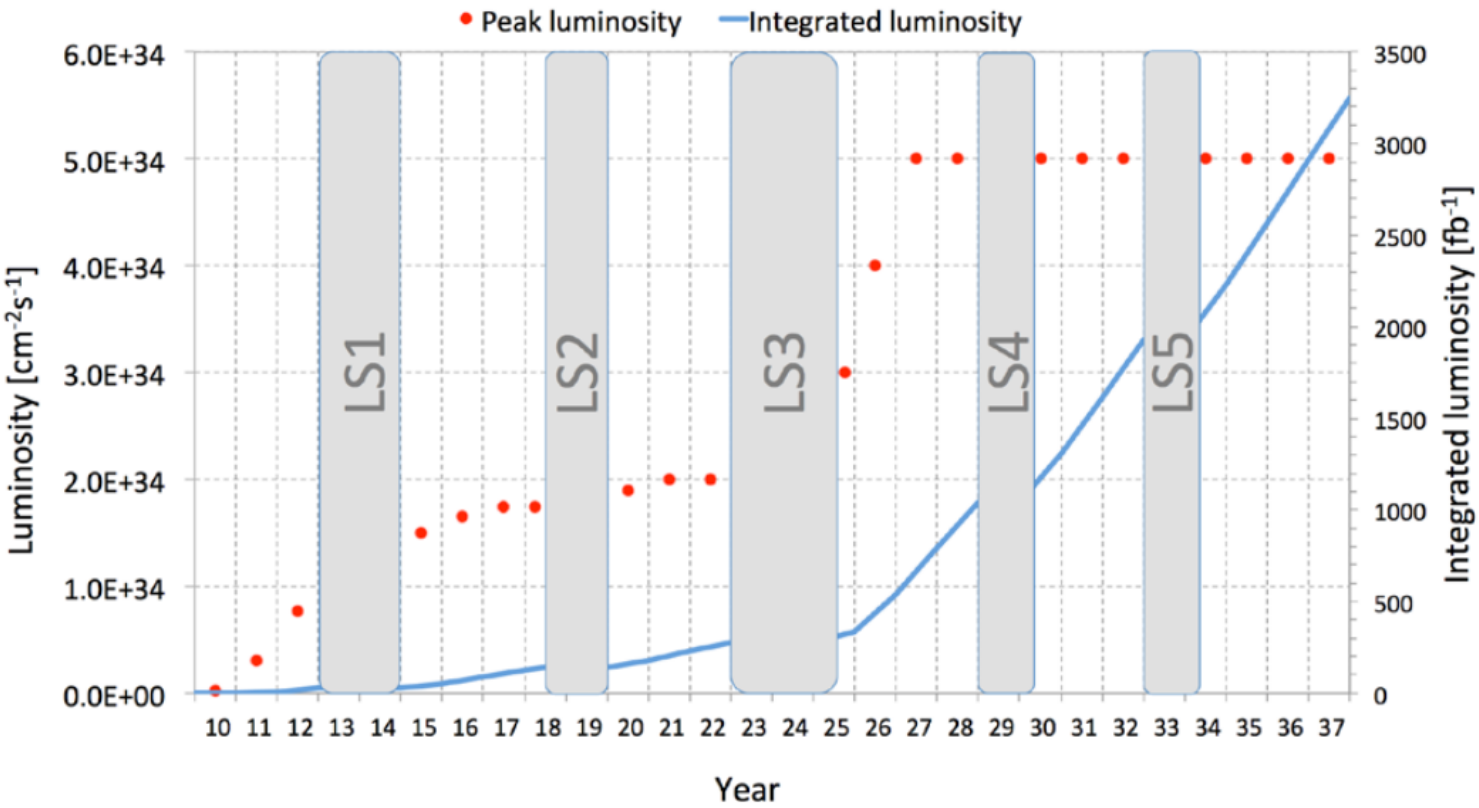
Conclusions

- Run-II 2015 is a low statistics sample when compared to run-I, $\approx 2 \times \sqrt{s}_{run-I}$, $\approx 0.2 \times \int L\,dt_{run-I}$
- First 13 TeV measurements of scalar decays to $\gamma\gamma$
- Both experiments: fix mass to run 1 measurement $\mathbf{m_H = 125.09 \pm 0.24GeV}$, much more precise than constraints from Run 2 data.
- Extensive search for deviations from the SM prediction in:
  - Higgs production kinematics
  - Signal strength in all categories of all observable final states and Higgs coupling strength
- All results show consistent within errors with the Standard Model Hypothesis
- **Looking forward for the rest of run-II**

Backup

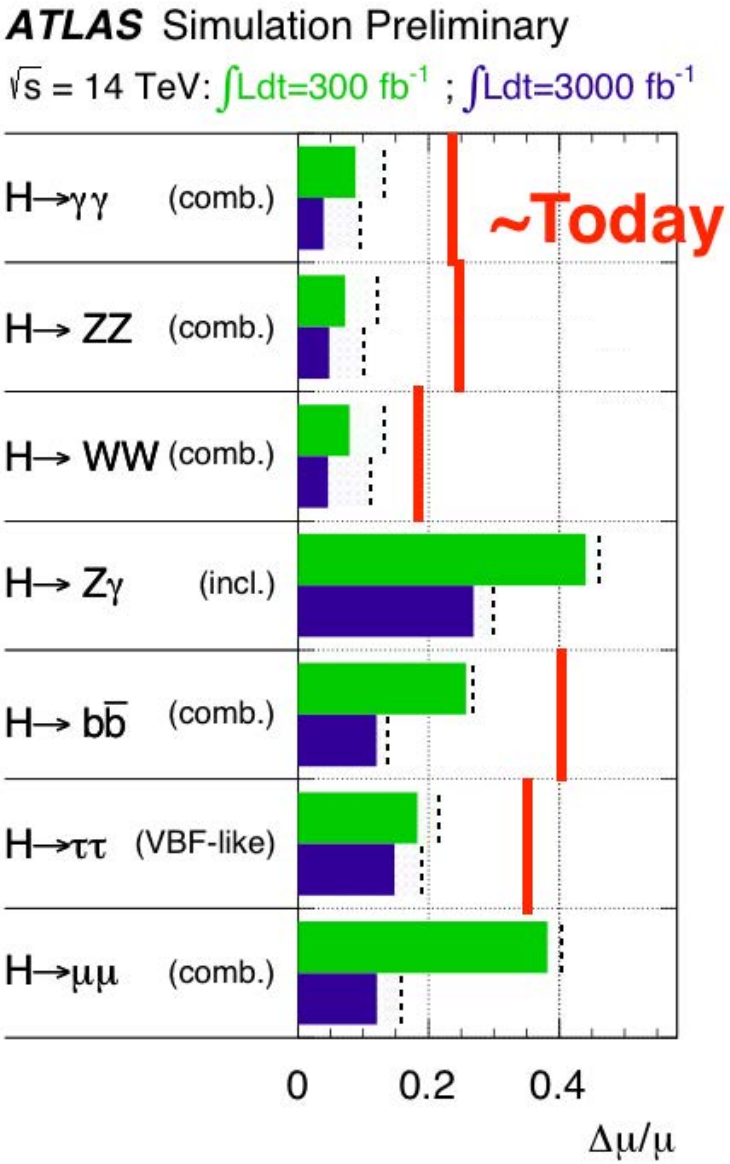
BACKUP

Perspective for the LHC during the next 10 years



- Run-I center of mass energy is just $\approx \frac{1}{2}$ of the designed for the LHC
- Run-I is a small portion of the expected integrated luminosity for the life-time of the LHC.
- Nevertheless we have a discovery!

A little bit further into the future



- This could be the window to new physics.
- Reducing $\frac{\Delta\mu}{\mu}$ could show as a deviations from the SM

Run-II year by year ($\approx 100 fb^{-1}$)

	Peak lumi E34 $cm^{-2}s^{-1}$	Days proton physics	Approx. int lumi [fb^{-1}]
2015	1.3	100	10
2016	1.5	160	35
2017	1.7	160	45
2018	1.7	40	10

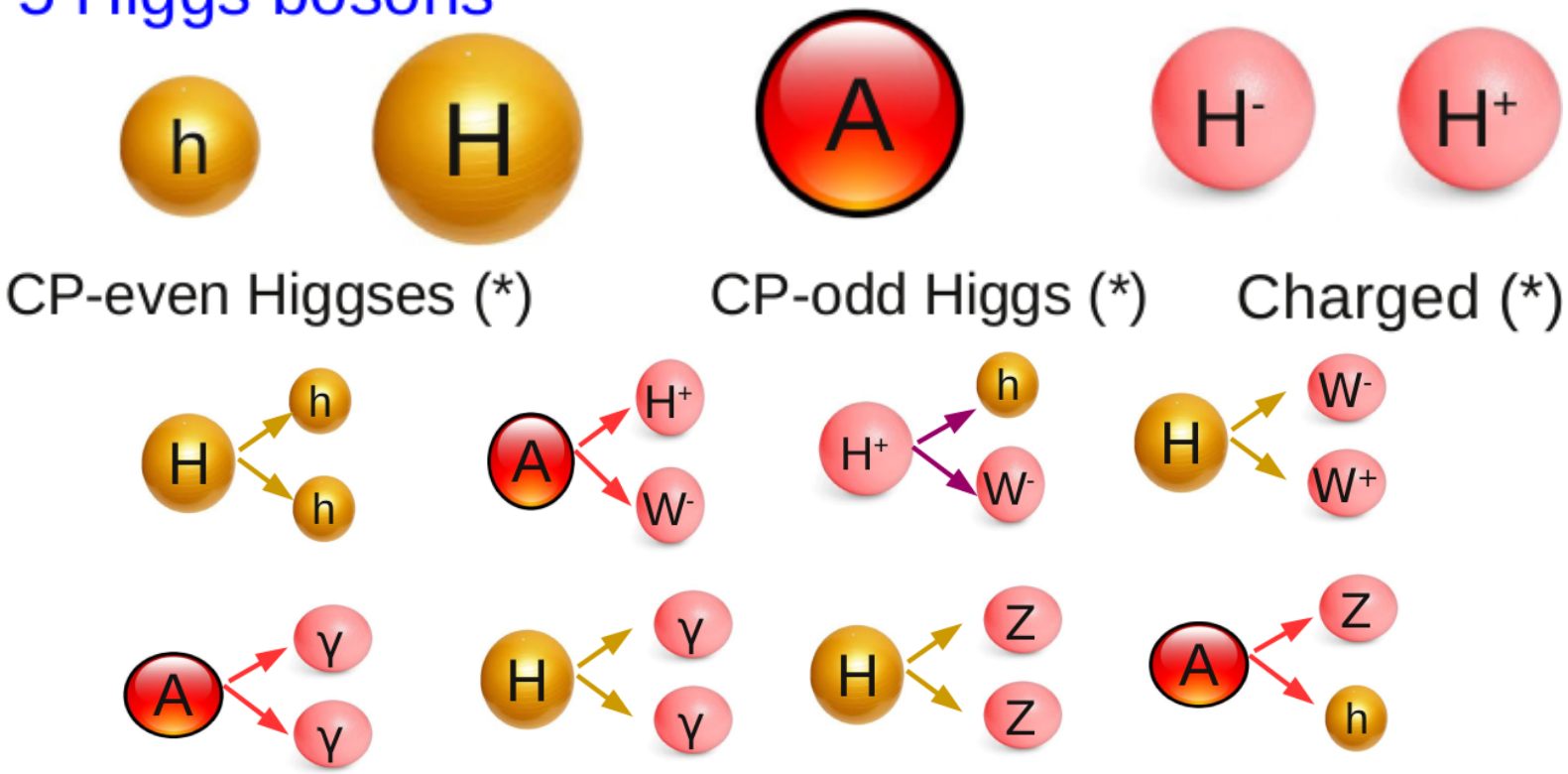
Analysis Overview

	H→γγ	H→ZZ	H→WW	H→ττ	H→bb	H→Zγ	H→μμ
gg→H	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VBF	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		ATLAS CMS	ATLAS CMS
VH	ATLAS CMS	ATLAS CMS	ATLAS CMS	- CMS	ATLAS CMS	ATLAS CMS	- CMS
ttH	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		

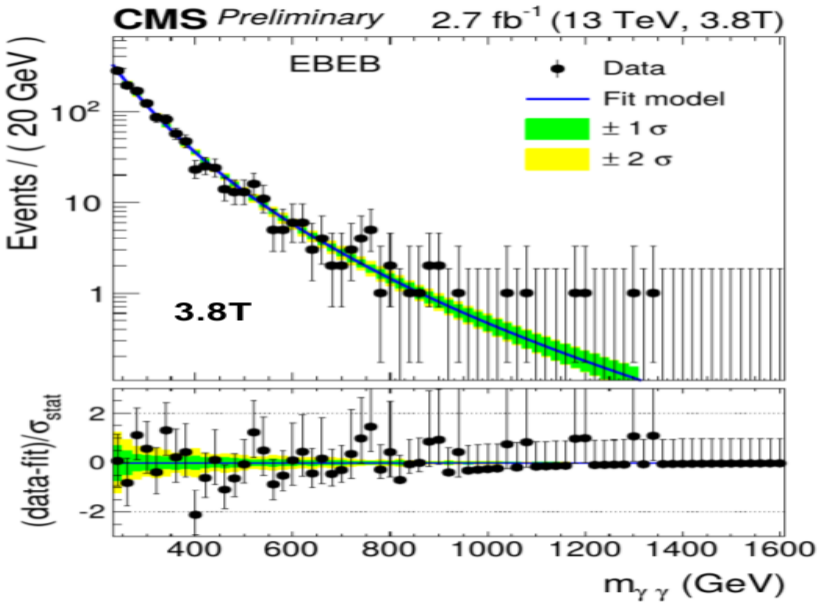
A comprehensive coverage of all Higgs/SM physics cases

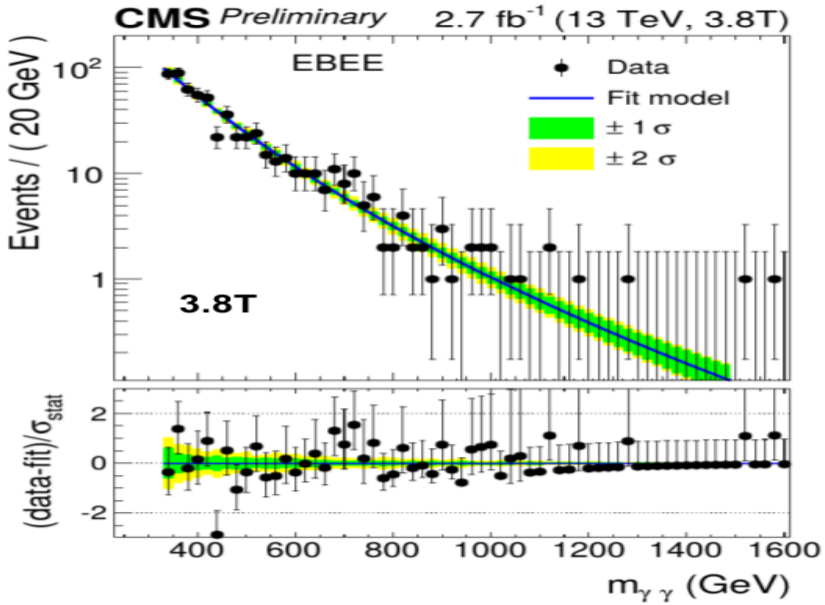
Search for additional Higgs Beyond the Standard Model (2HDM)

- The addition of doublet in the Higgs sector is one of the simplest possible extensions
- 2HDMs and the MSSM are fully compatible with a SM-like Higgs boson with mass ≈125 GeV
  - 5 Higgs bosons



X750GeV


CMS Preliminary
2.7 fb-1 (13 TeV, 3.8T)
EBEB
Data
Fit model
± 1 σ
± 2 σ
3.8T
Events / (20 GeV)
(data-fit)/σstat
mγ γ (GeV)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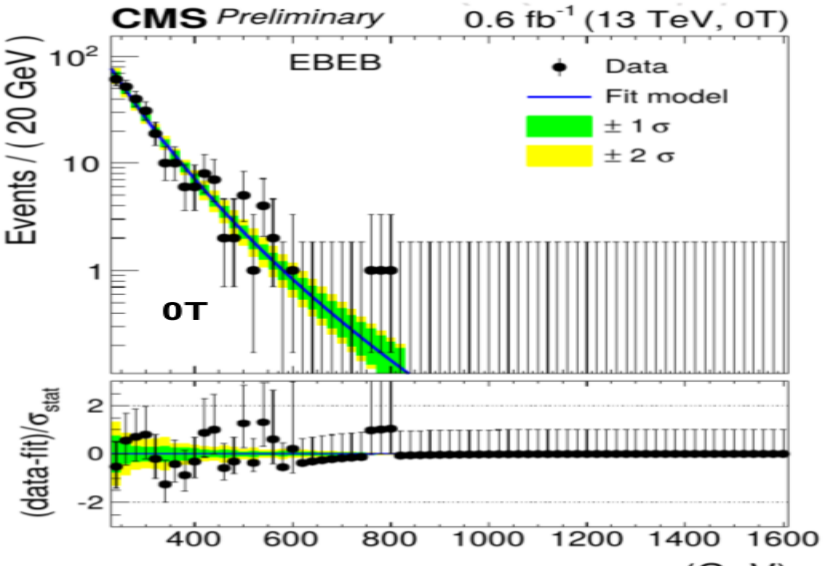
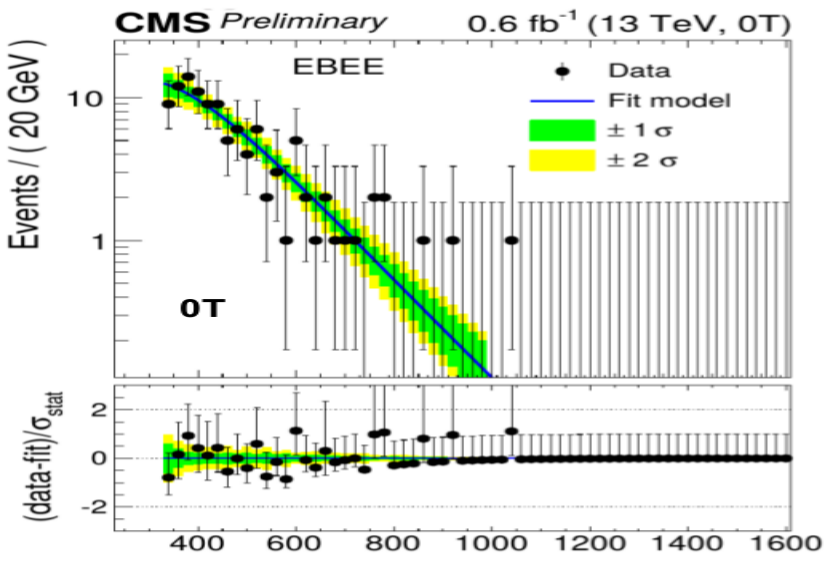

CMS Preliminary
0.6 fb-1 (13 TeV, 0T)
EBEB
Data
Fit model
± 1 σ
± 2 σ
0T
Events / (20 GeV)
(data-fit)/σstat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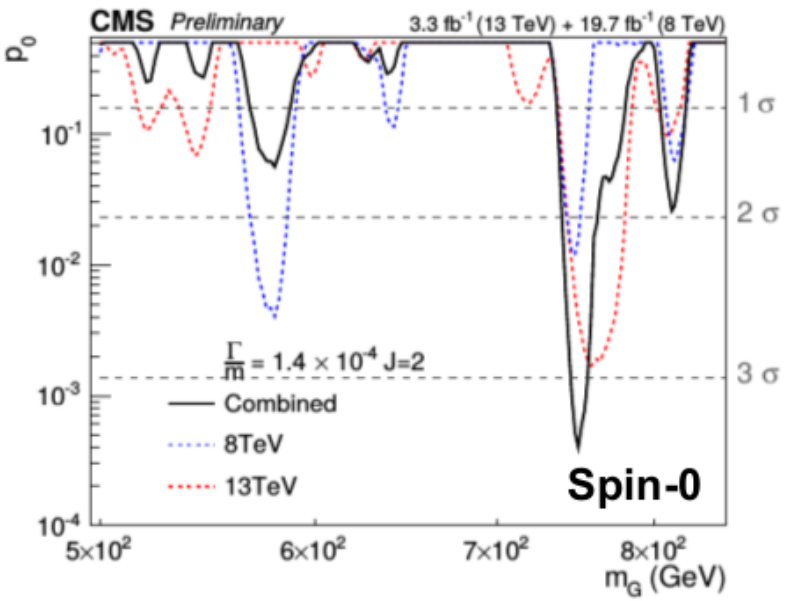
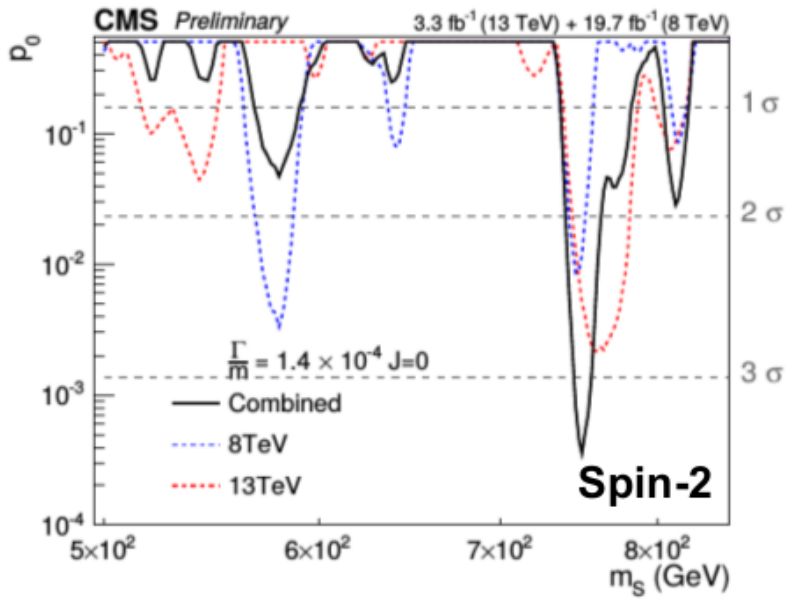
0.6 fb-1 (13 TeV, 0T)
EBEE
Data
Fit model
± 1 σ
± 2 σ
0T
Events / (20 GeV)
(data-fit)/σstat

X750GeV

- Largest excess observed at $\mathbf{m_x = 750GeV}$ and for **narrow** width.
  - **Local** significance: **3.4σ**
  - Taking into account mass range 500-3500GeV (and all signal hypotheses), "**global**" significance becomes **1.6σ**



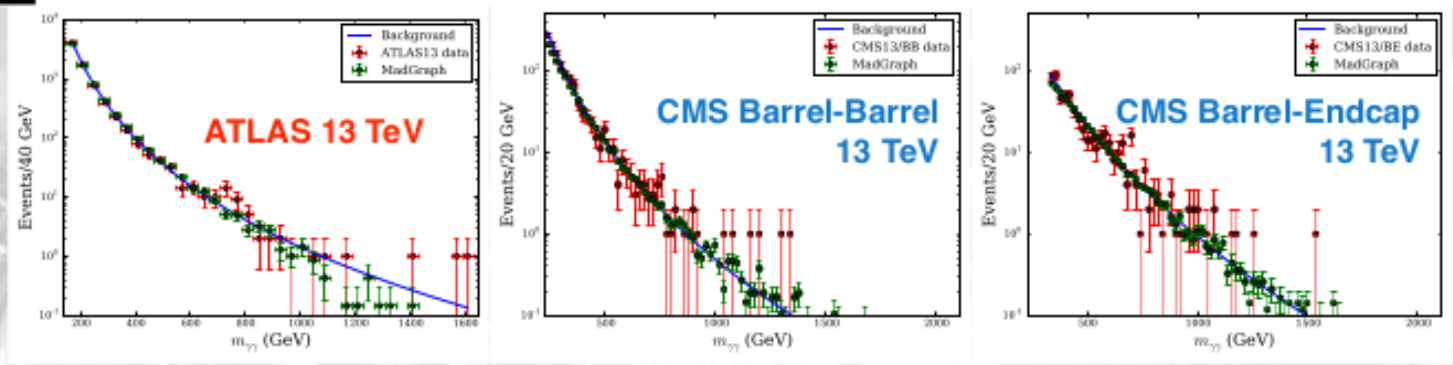


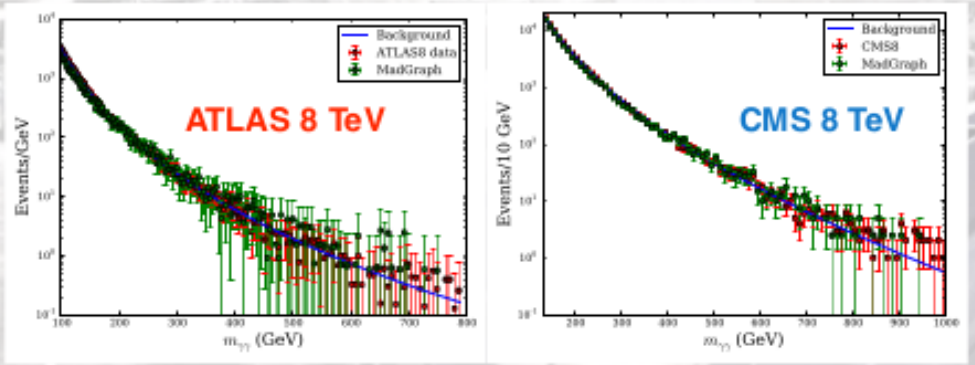
X750GeV Unofficial combination @ Moriond

PARENTAL ADVISORY UNOFFICIAL COMBINATION

A Private CMS+ATLAS Combination

PARENTAL ADVISORY UNOFFICIAL COMBINATION





- Repeat fits from digitised plots @13 TeV and @8TeV [Jamboree analyses]
- Compute significance vs experiment, energy, production mechanism, and width
  - in general, quoted significance smaller than what experiments quote

X750GeV Unoficial combination @ Moriond

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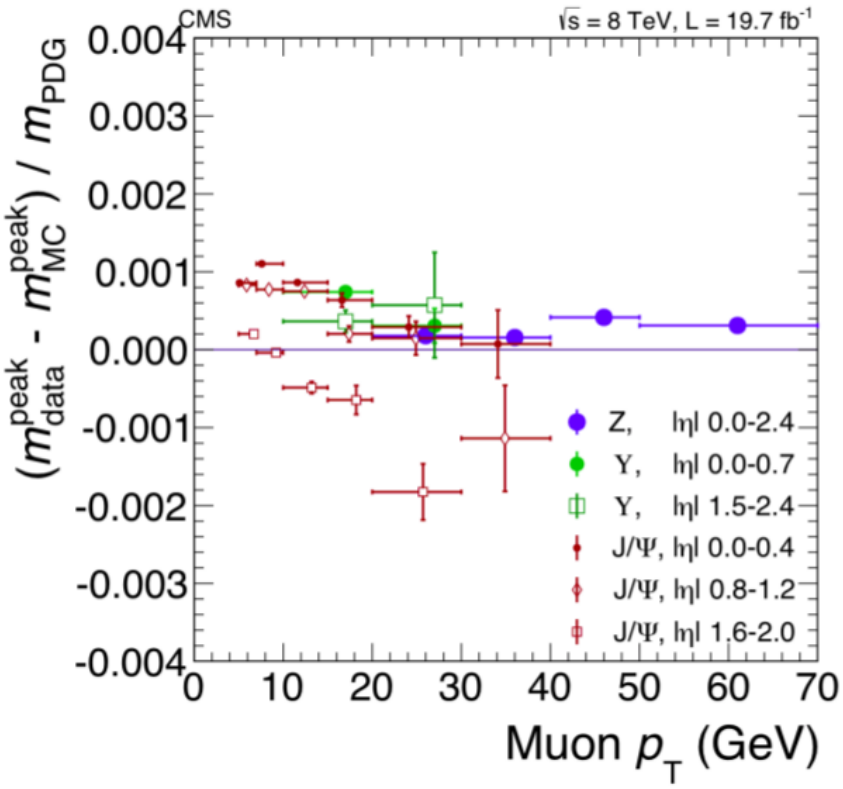
A Private CMS+ATLAS Combination

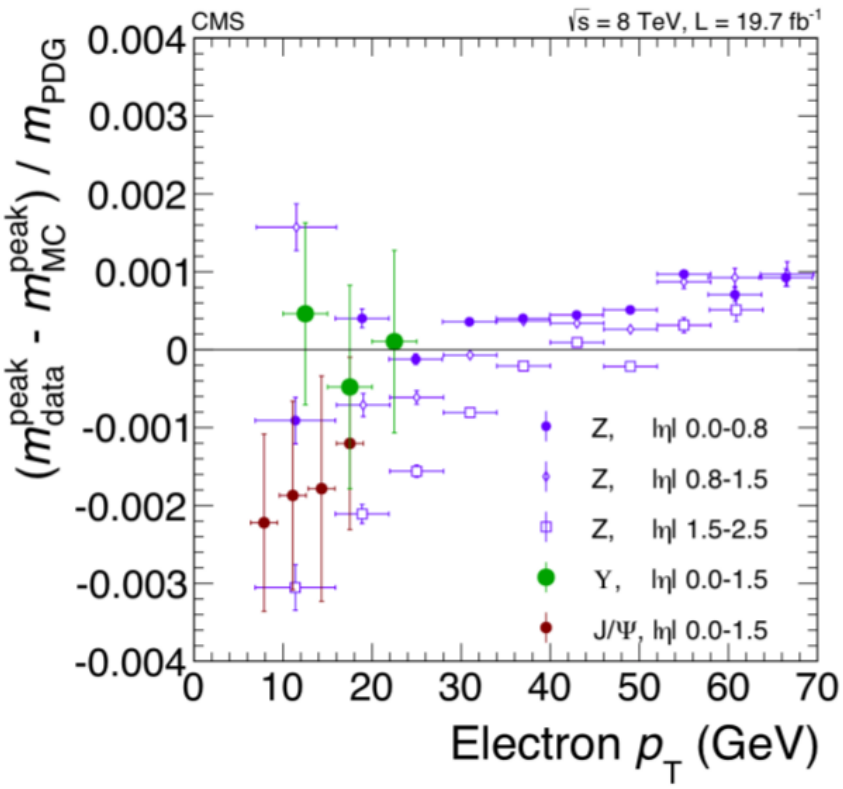
PARENTAL ADVISORY UNOFFICIAL COMBINATION

Spin 0 Narrow	ATLAS narrow	CMS narrow	Combined narrow	ATLAS wide	CMS wide	Combined wide
8 TeV	-	1.2 σ	1.2 σ	-	1.7 σ	1.7 σ
13 TeV	3.2 σ	2.0 σ	3.4 σ	3.5 σ	2.0 σ	3.0 σ
Combined	n.a.	n.a.	3.4 σ	n.a.	n.a.	3.4 σ

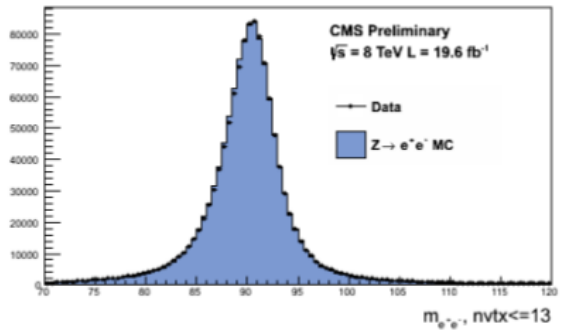
- Both for large and small width, the large ATLAS Run II excess is pushed down by CMS Run II + CMS/ATLAS Run I
- The average close to CMS central value, but with reduced uncertainty

Lepton momentum scale

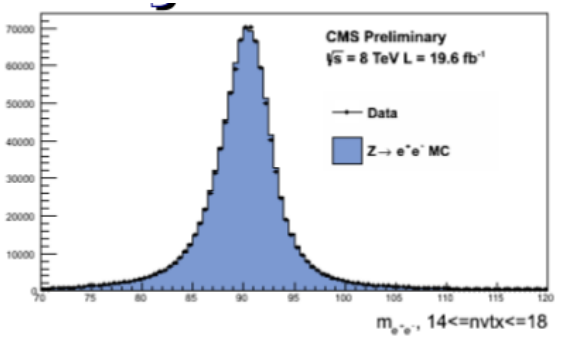




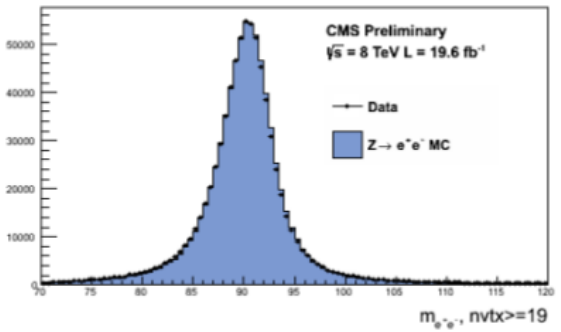
e γ energy reconstruction stability



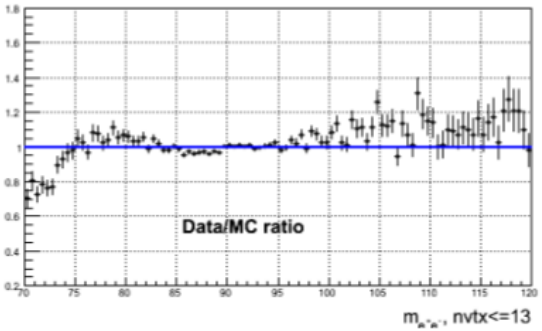
$m_{e^+e^-}$, nvtx<=13



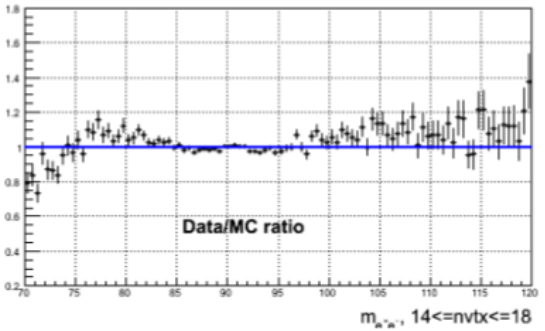
$m_{e^+e^-}$, 14<=nvtx<=18



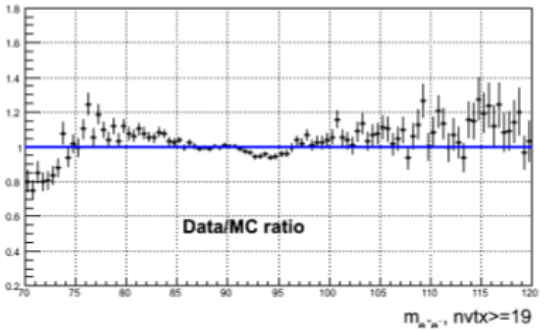
$m_{e^+e^-}$, nvtx>=19



$m_{e^+e^-}$, nvtx<=13

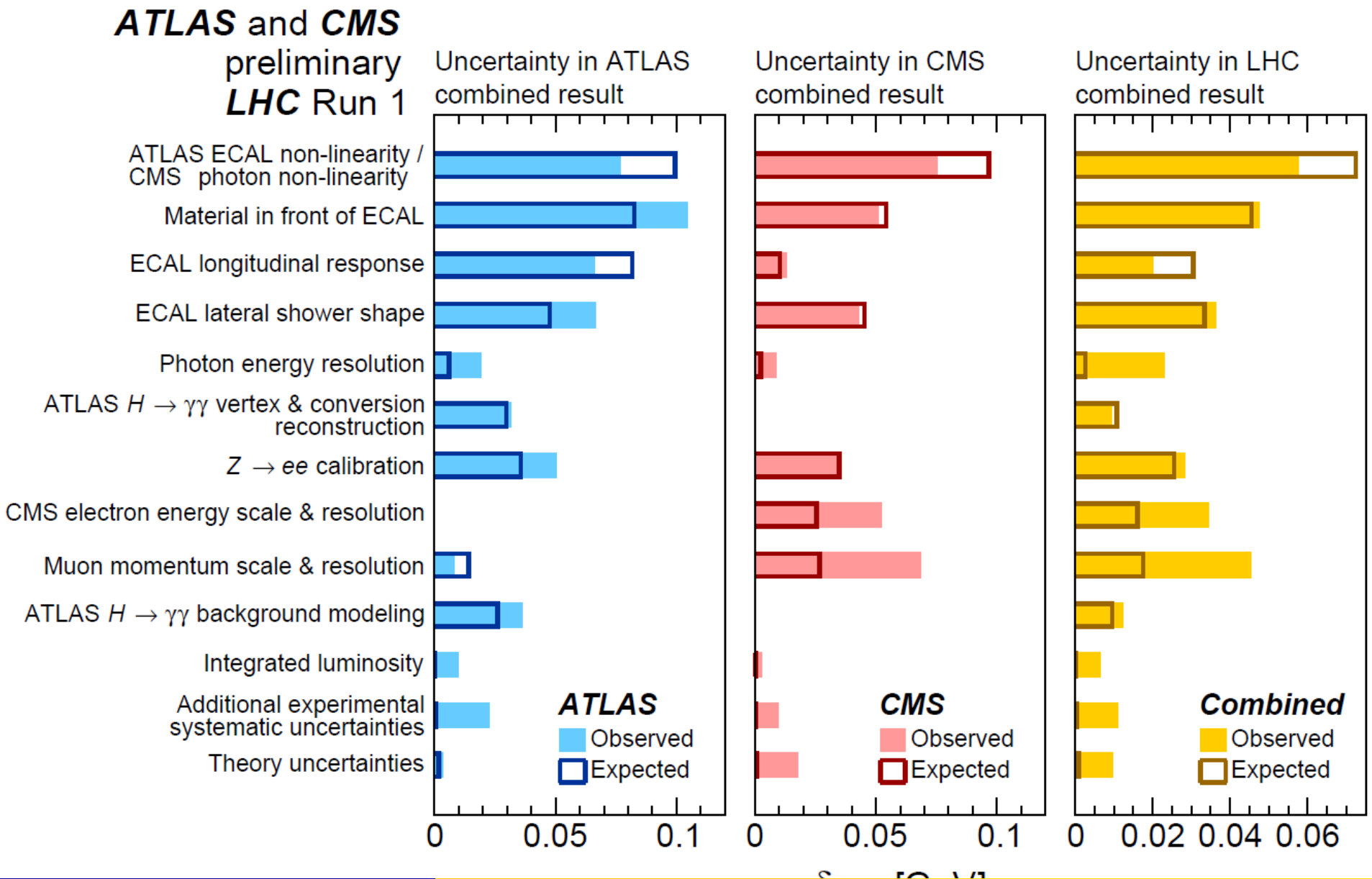


$m_{e^+e^-}$, 14<=nvtx<=18

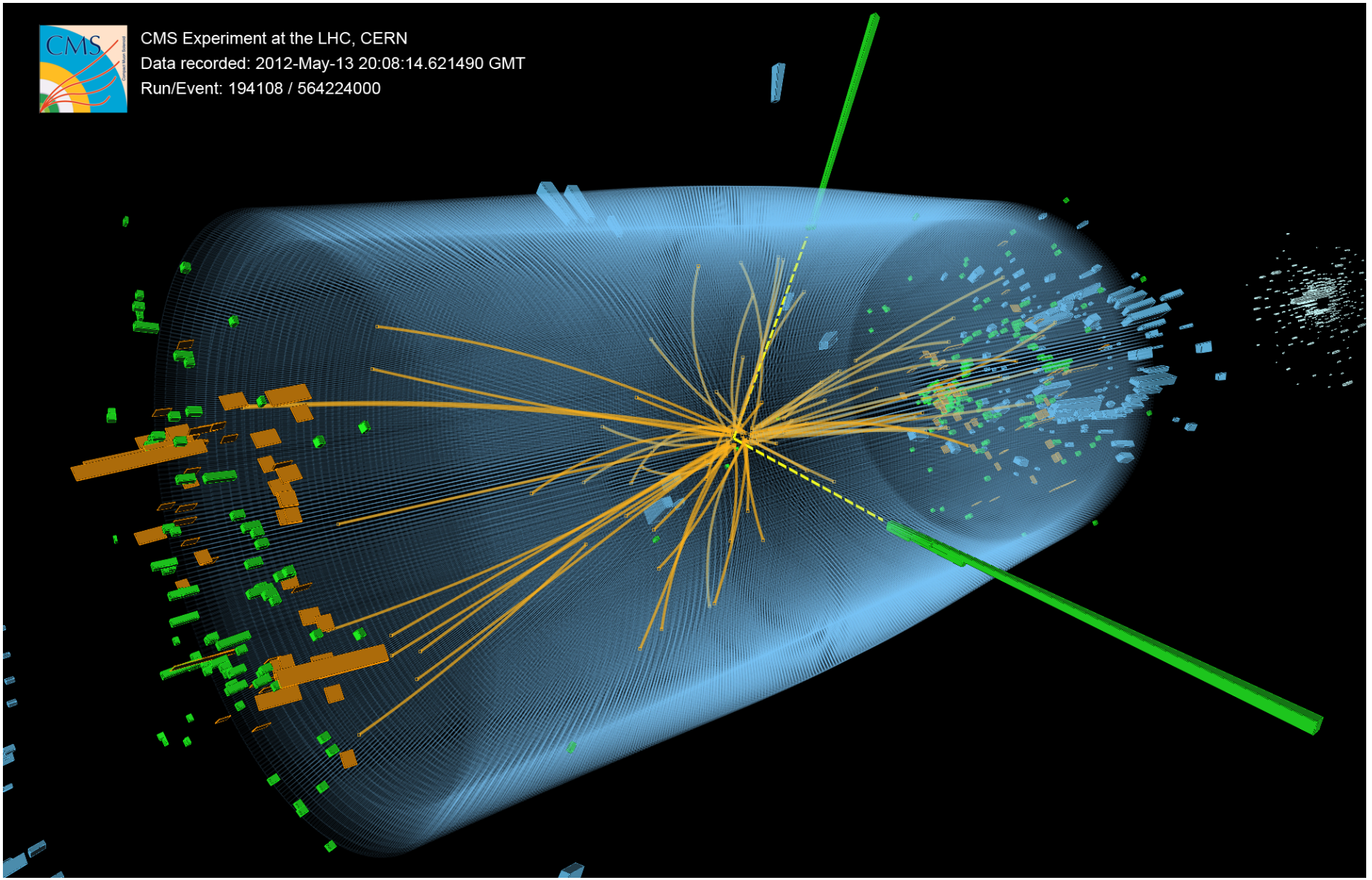


$m_{e^+e^-}$, nvtx>=19

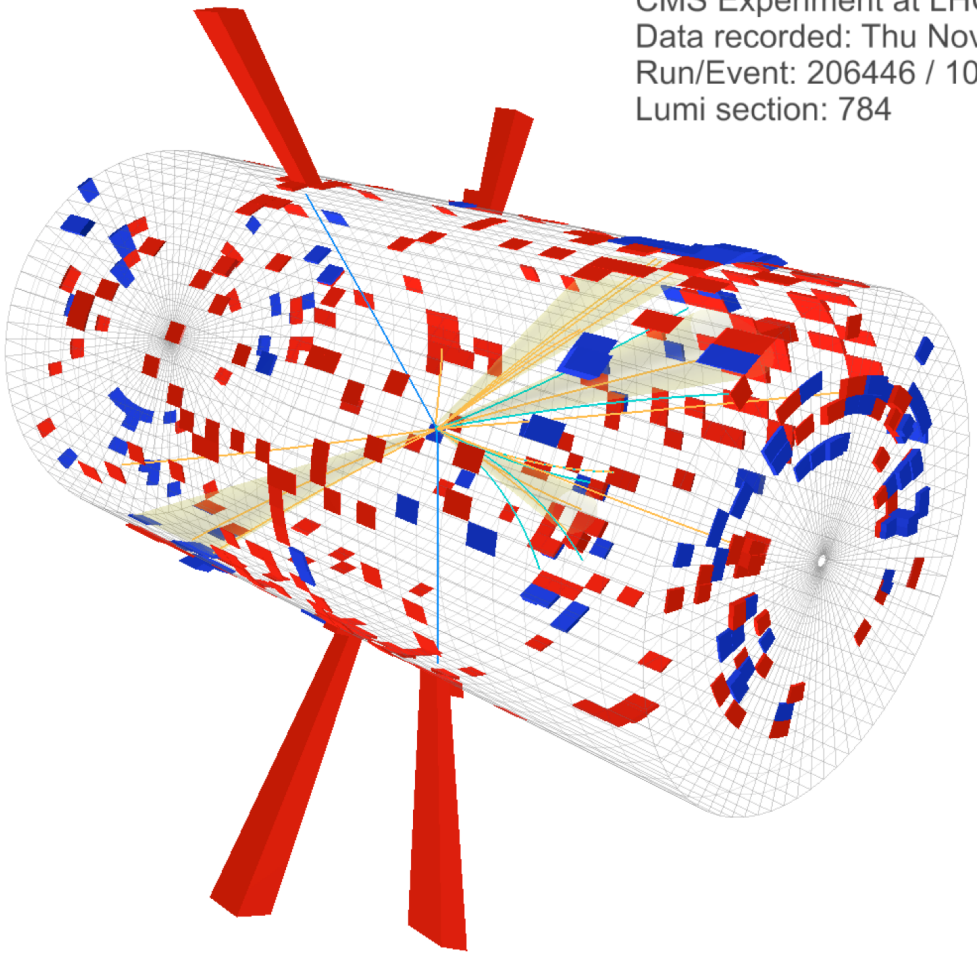
systematic errors $\gamma\gamma$

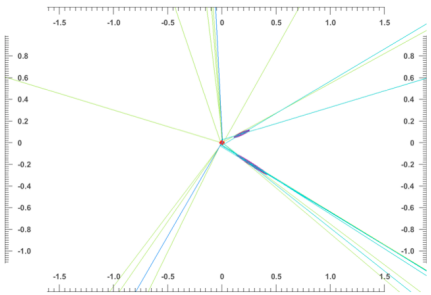


An event display, $m_{\gamma\gamma} = 125.9\,GeV$

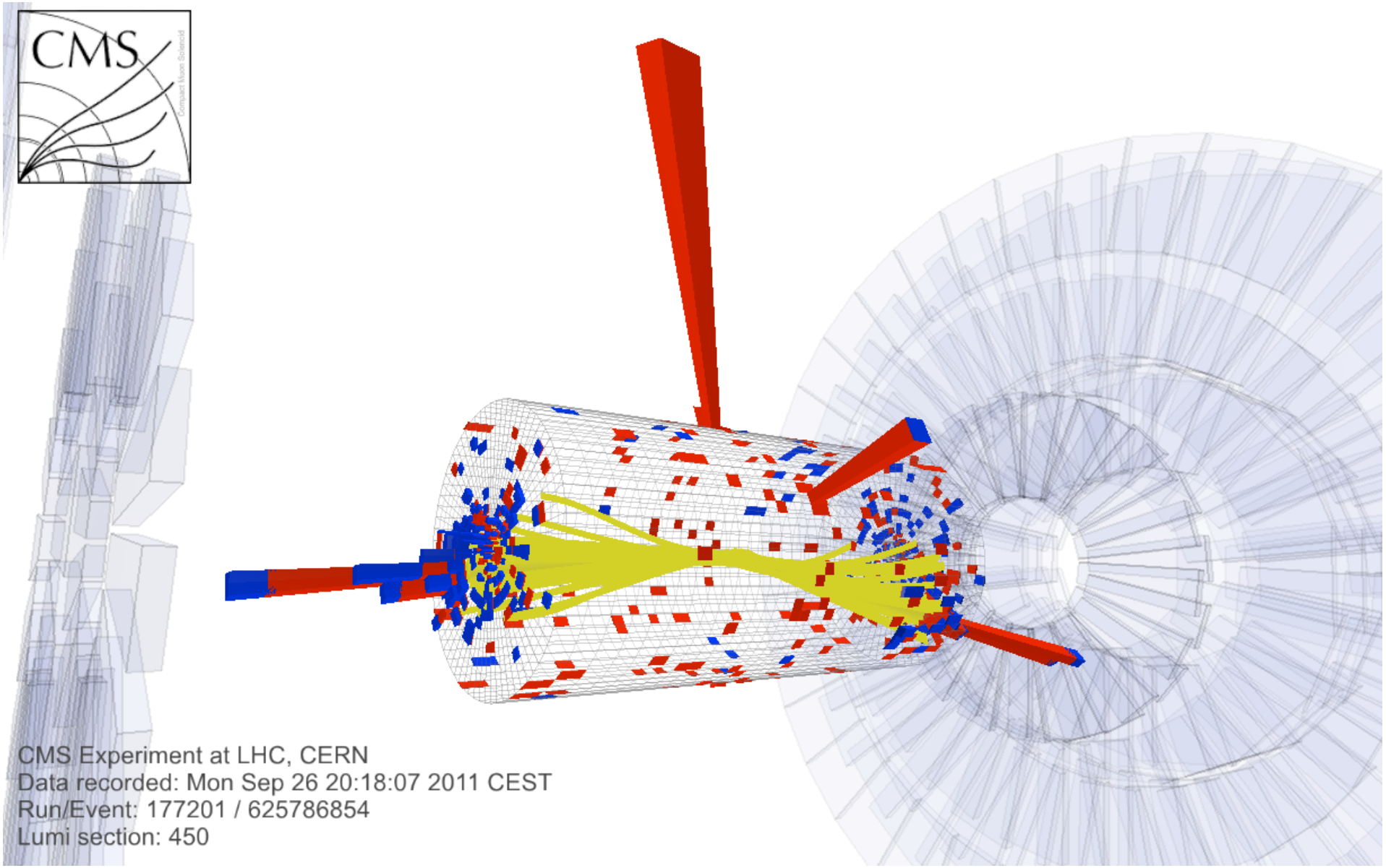


event display tth





event display vbf

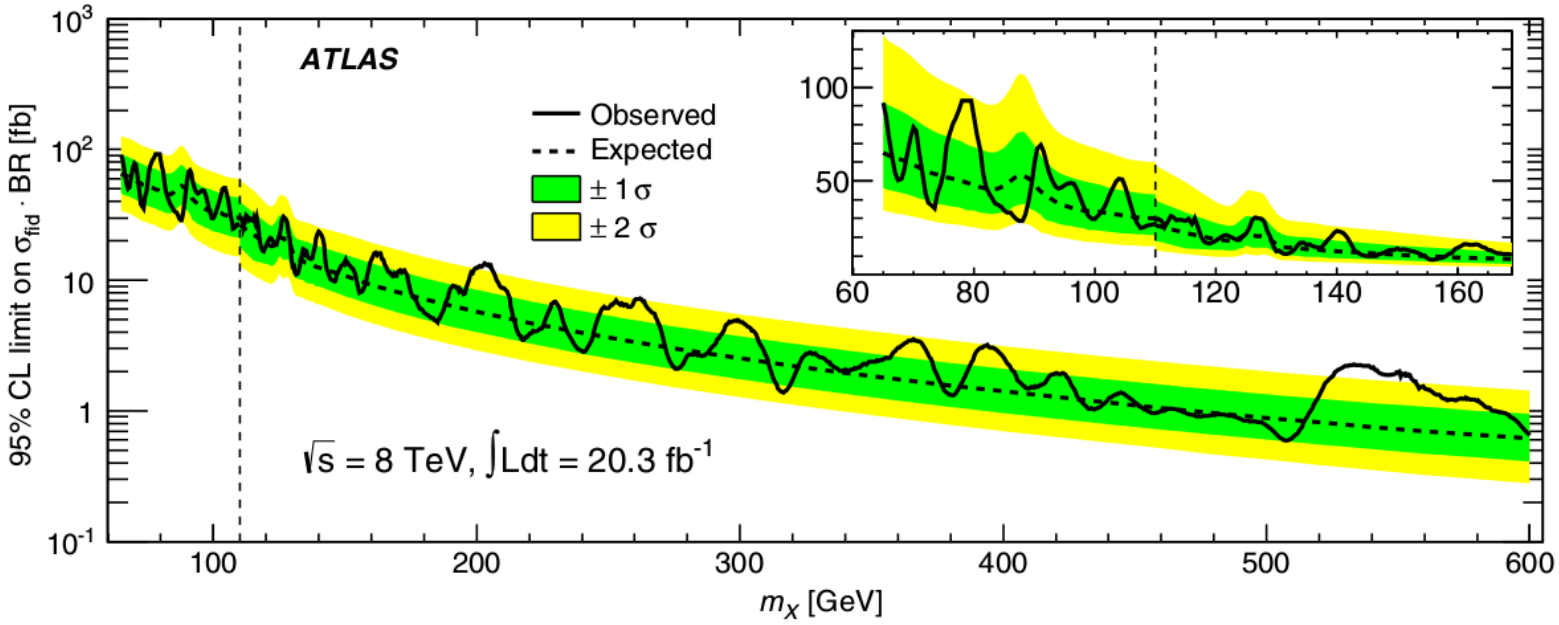


Low mass Higgs in $\gamma\gamma$ resonances

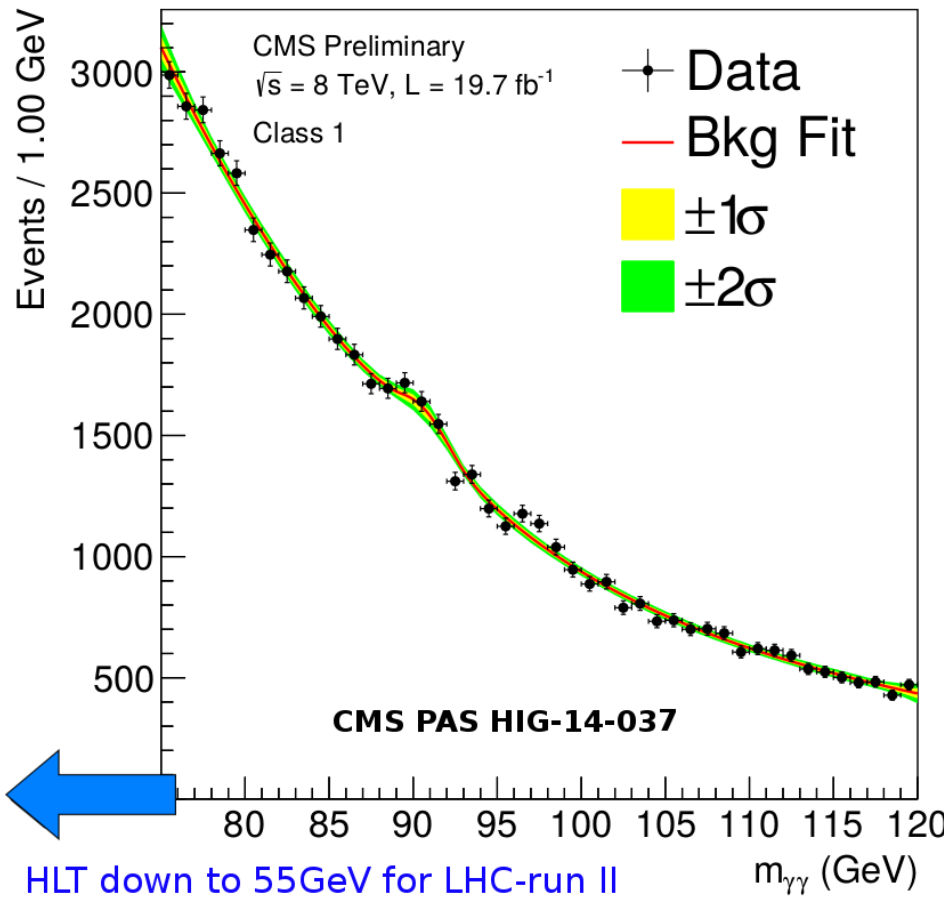
Additional Higgs at a lower mass (down to m_H=60 GeV for run-II)

- Few words about this search in this presentation.
- Presentation about Run-I Sijing Z. (IPNL/IHEP) today.
- For Run-II, a High Level Trigger selections were implemented in CMS to extend our search during run-II.

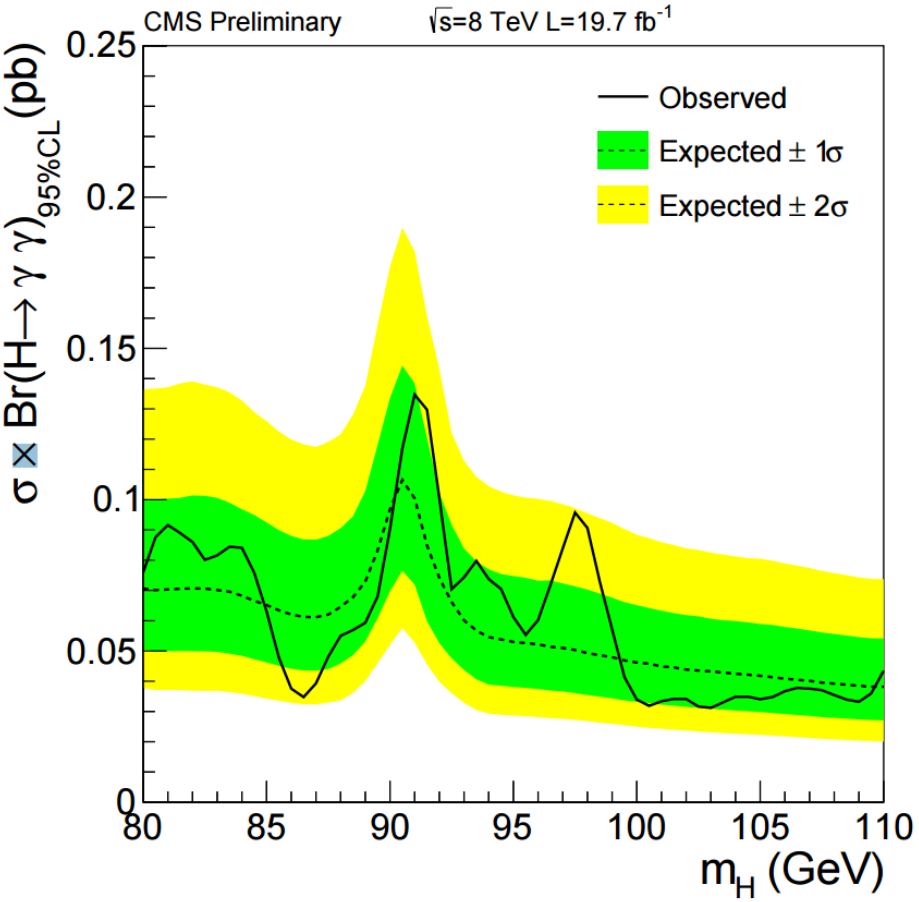
ATLAS:



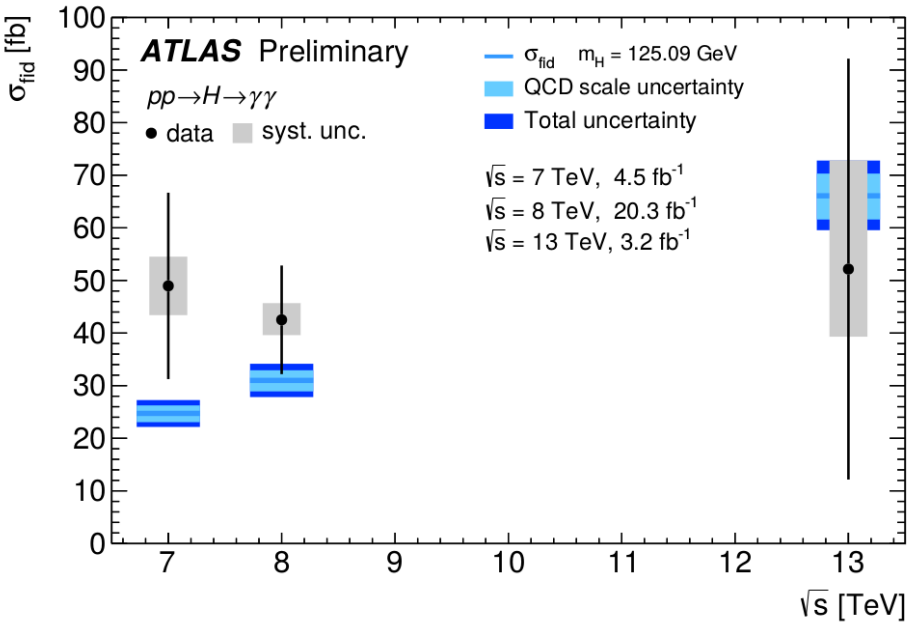
CMS low mass



HLT down to 55GeV for LHC-run II



ATLAS Cross section



No split by categories/production-mode public yet.

$\sqrt{s}$	Measured total cross section [pb]	LHC-XS prediction [pb]
7 TeV	35 ± 12 (stat.) ± 4 (syst.) ± 1 (lumi.)	17.5 ± 1.6
8 TeV	30.5 ± 7.1 (stat.) $^{+2.6}_{-2.5}$ (syst.) ± 0.9 (lumi.)	22.3 ± 2.0
13 TeV	40 ± 26 (stat.) $^{+16}_{-10}$ (syst.) ± 2 (lumi.)	$50.9\ ^{+4.5}_{-4.4}$