$H \to \gamma\gamma$ in CMS

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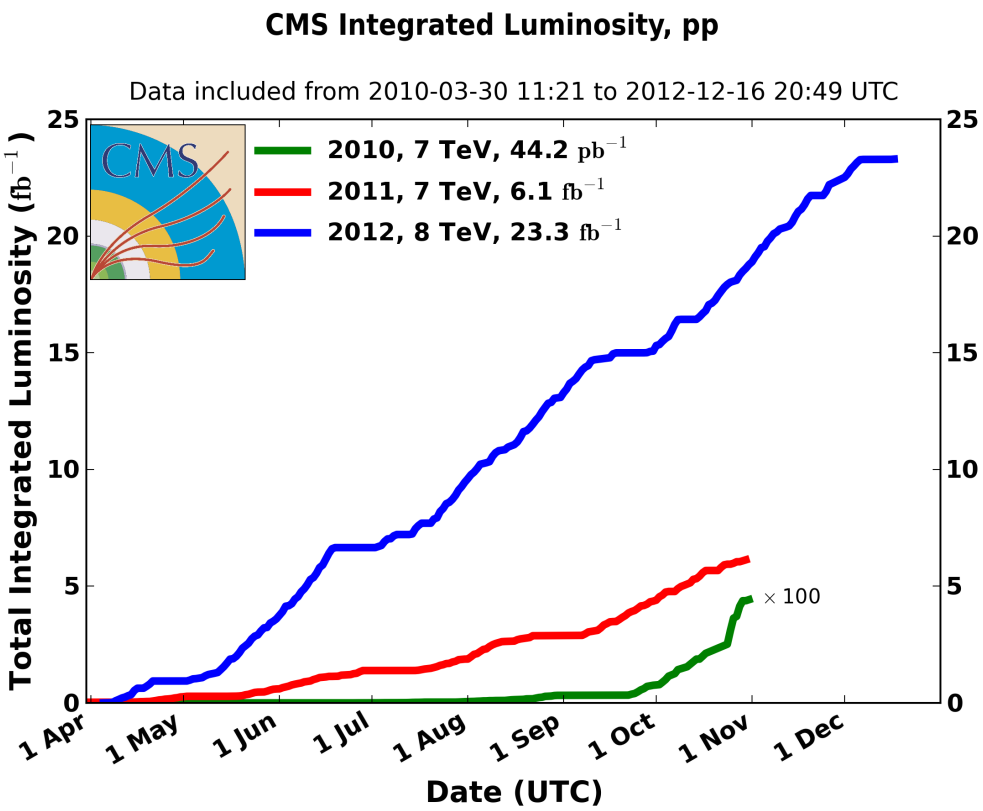
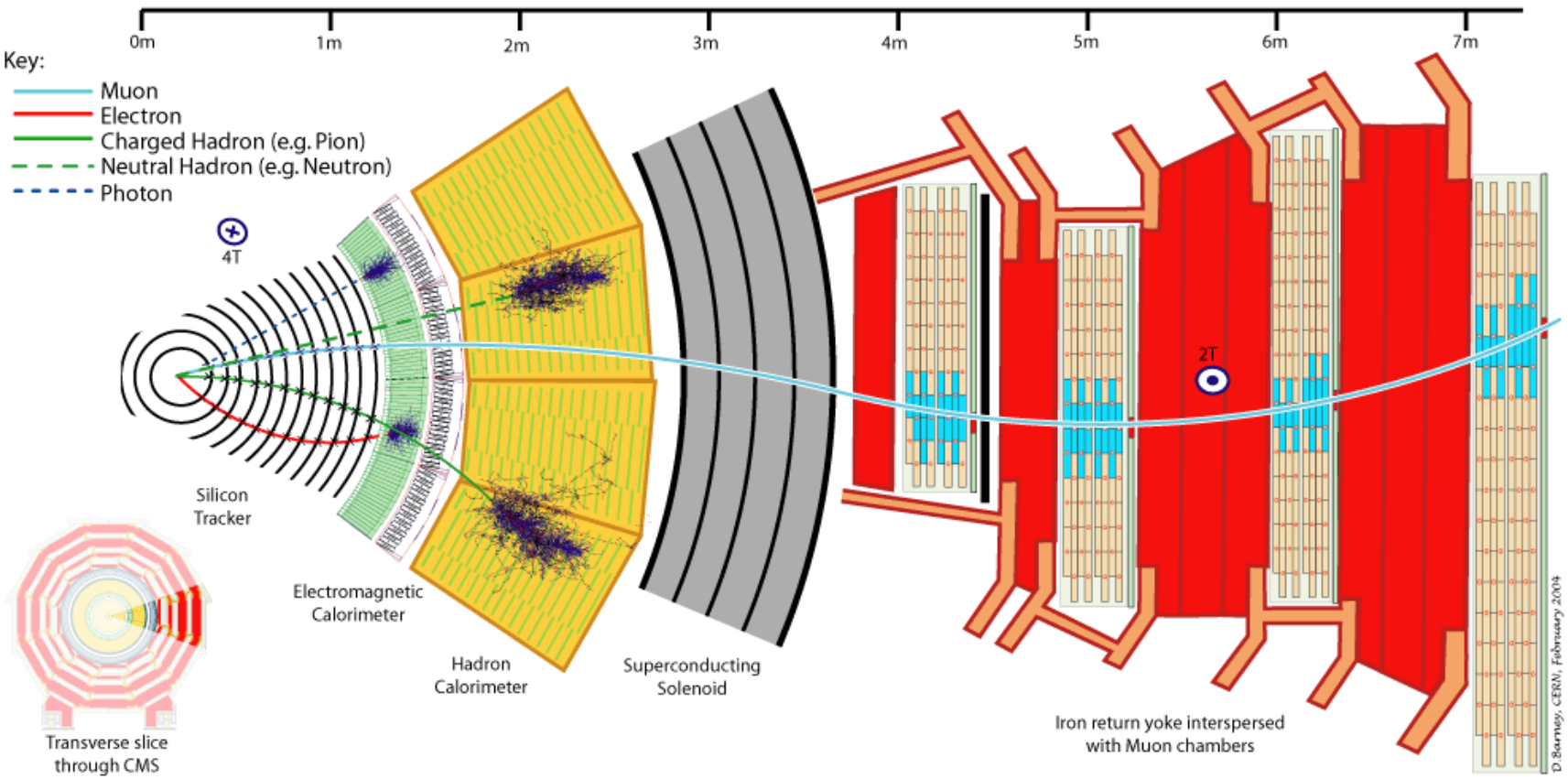
Data: pp collisions at $\sqrt{s} = 7\,\text{TeV}$ and $\sqrt{s} = 8\,\text{TeV}$.



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

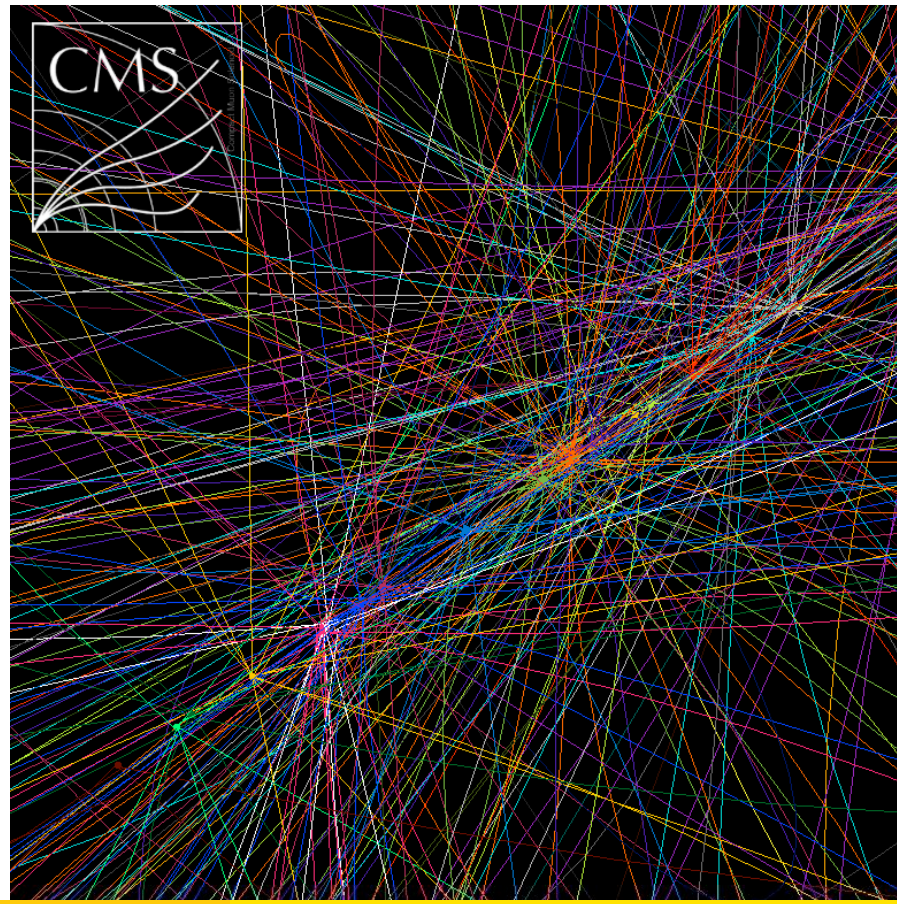
CMS

- Multi purpose experiment
- Data efficiency recording (used for analysis) > 90%
- Robust Muon system, lead tungstate crystals used in the CMS ECAL.
- Global Event Description with Particle Flow Algorithm



Pile Up (PU)

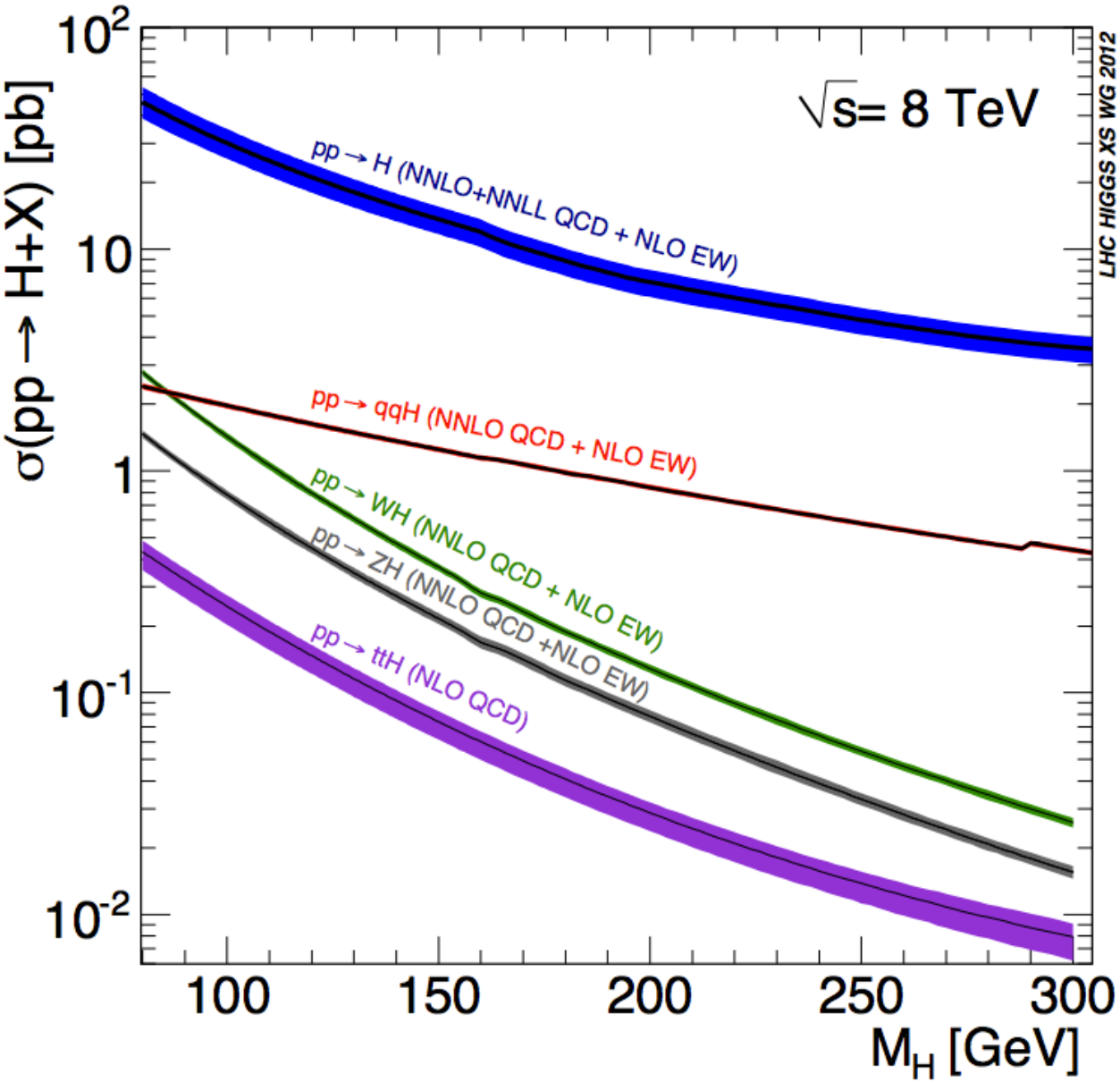
- Due to the increase in luminosity, more than one collision happen during a bunch-crossing in the LHC, this is pile up (PU).
- 2011 average PU $\approx$ **10**, for 2012 average PU $\approx$ **20**.
- Particle flow algorithm helps a lot in high PU events.



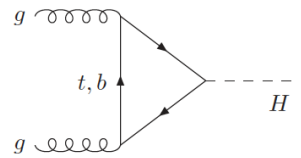
Challenges for event reconstruction with high PU.

- Less energy resolution for e and γ
- Energy from underlying events added to isolation cones.
- Central jet veto and VBF jet tagging affected.
- For LHC Run-II at $\sqrt{s} = 13\,TeV$ in 2015 are expected PU ≈ 40.

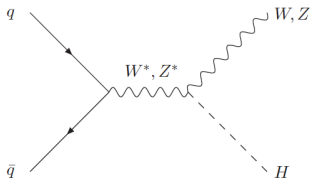
Higgs production modes



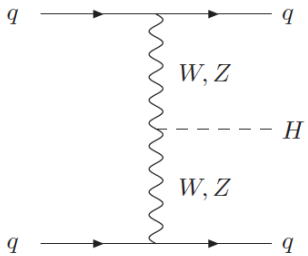
pp→H (ggh)



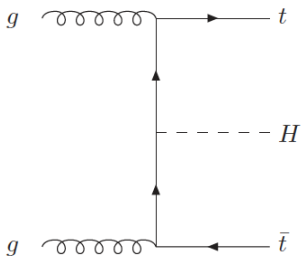
pp→W,Z H



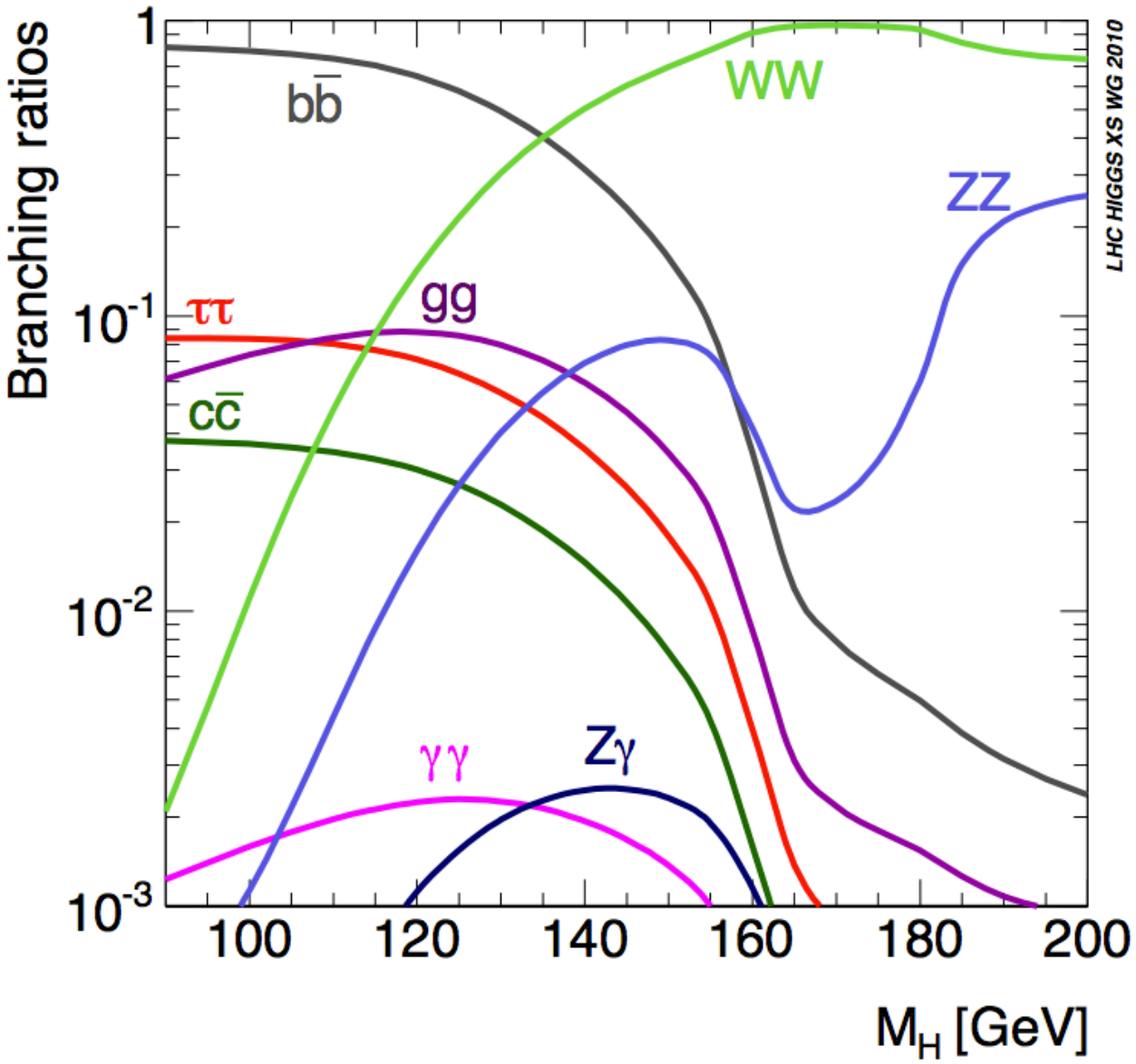
pp→qq H



pp→ $t\bar{t}$ H

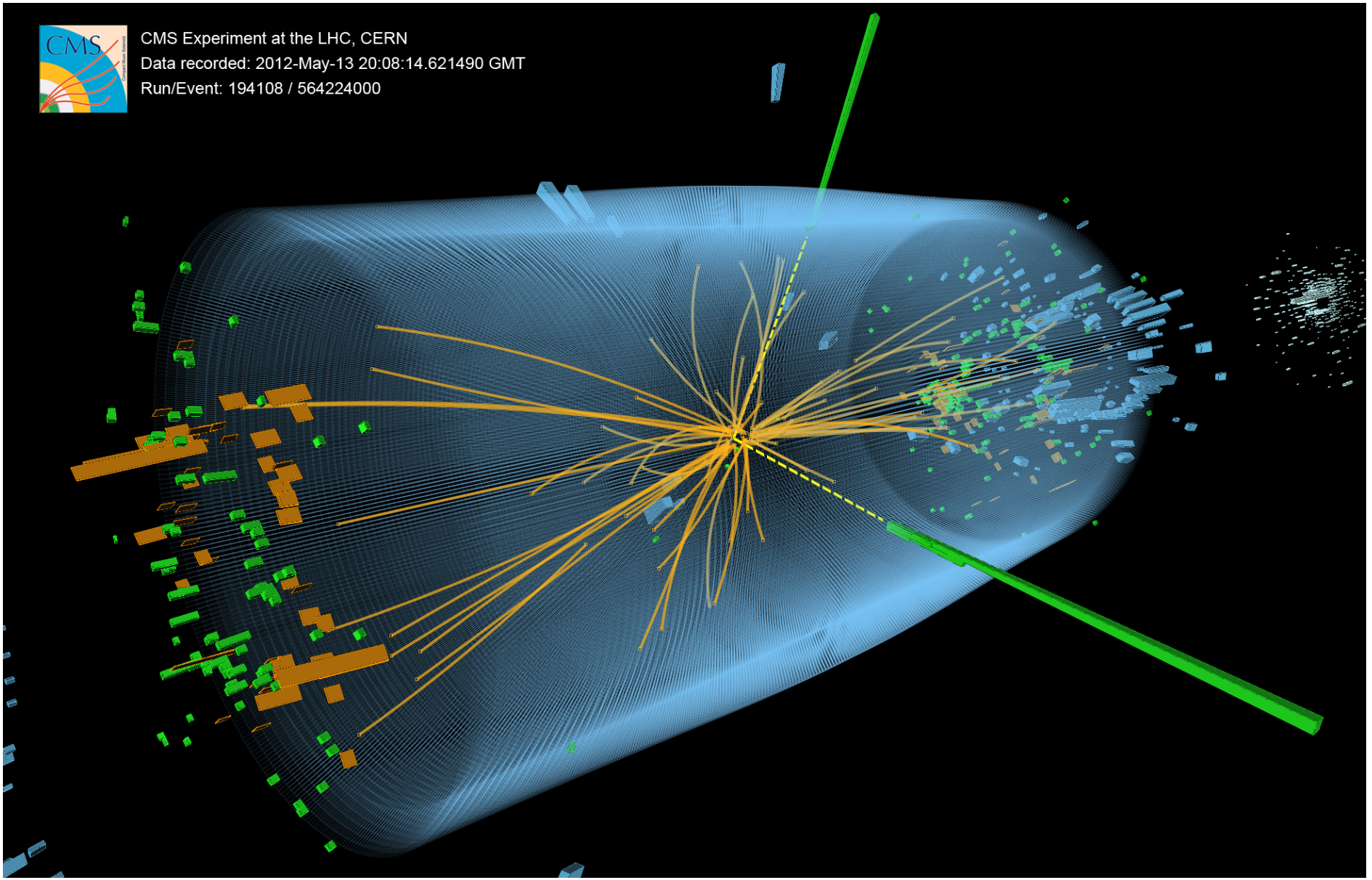


Higgs Decays, branching ratios



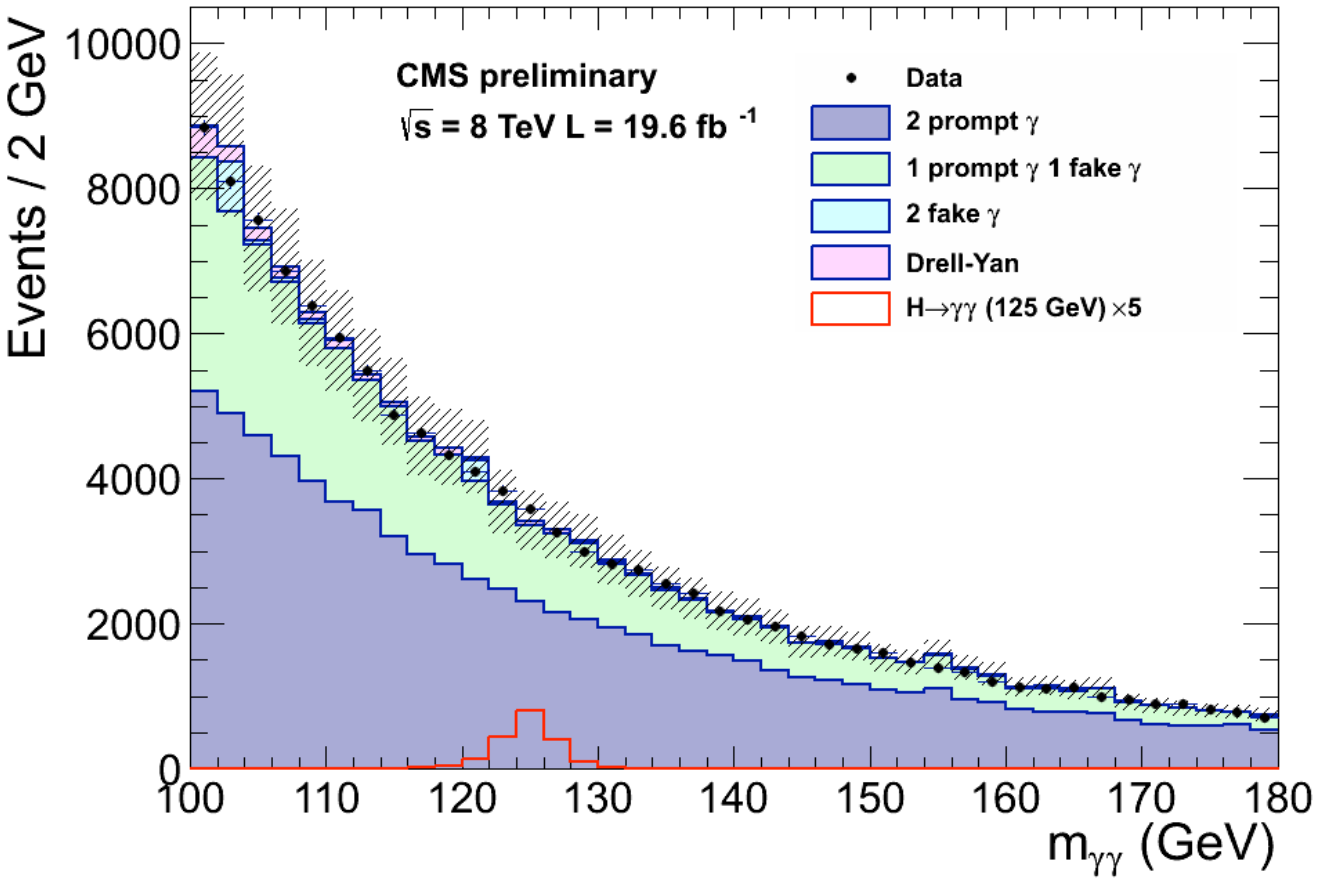
Branching ratios, Higgs $\rightarrow \gamma\gamma$ is a small part, $\approx 2\times10^{-3}$, however is the channel with the best mass resolution and one with the highest sensitivities.

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



The Background

- **Irreducible:**
  $\gamma\gamma$ from QCD
- **Reducible:**
  γ+jet with 1 + fake γ.
  QCD, 2 fake γ's.
  DY, electrons faking γ.



The event selection

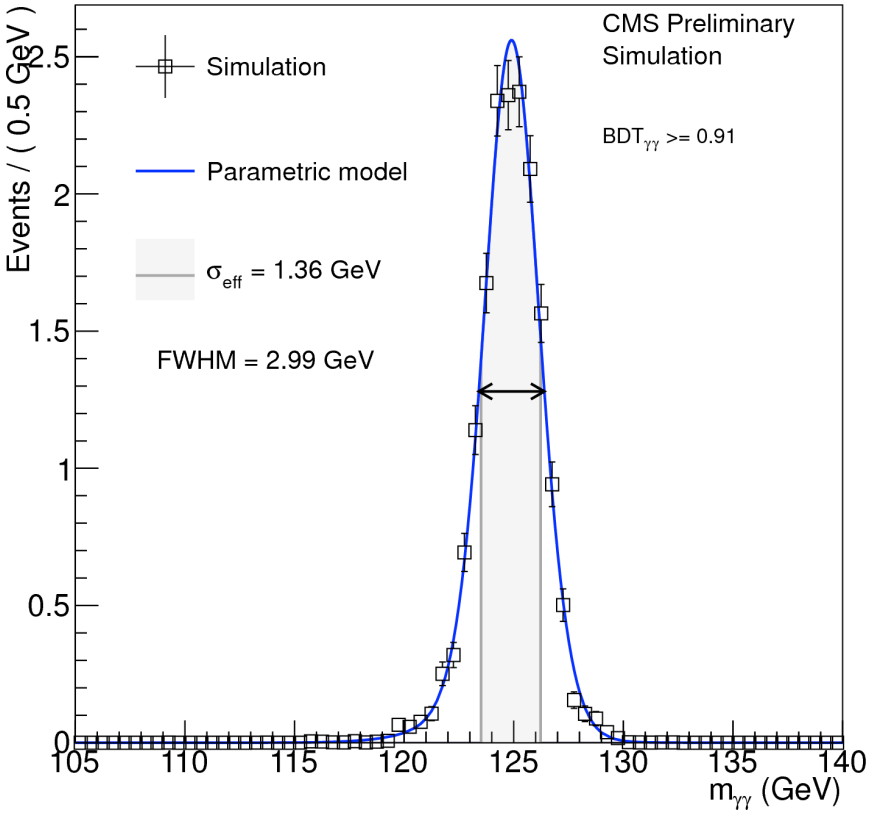
L1 Trigger: L1 DoubleEG 13 7 OR L1 SingleEG 22
High Level Trigger selection:

- **194** HLT Photon26 R9Id85 OR CaloId10 Iso50 Photon18 R9Id85 OR CaloId10 Iso50 Mass60 v5 OR
- **195** HLT Photon26 R9Id85 OR CaloId10 Iso50 Photon18 R9Id85 OR CaloId10 Iso50 Mass70 v1 OR
- **205** HLT Photon36 R9Id85 OR CaloId10 Iso50 Photon22 R9Id85 OR CaloId10 Iso50 v5

There are two independent offline event selections in $H \rightarrow \gamma\gamma$

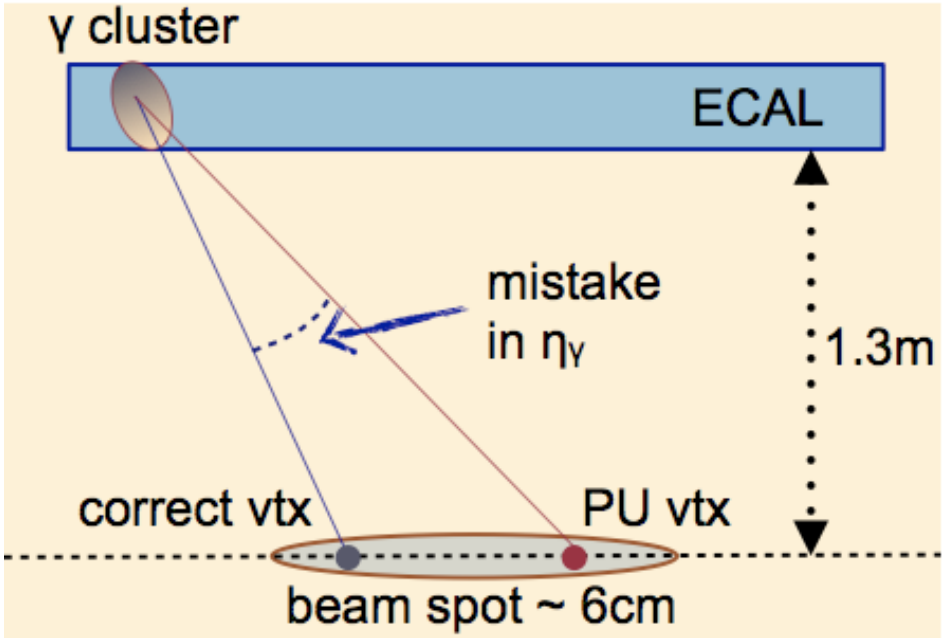
- **MVA**:**M**ulti**v**ariate **a**nalysis. based on isolation, shower shape and electron rejection.
- **CiC**: **C**ut base optimization **i**n different **C**ategories with different background levels, barrel/endcap and converted/unconverted identified with shower shape in ECAL.

Mass resolution and vertex id



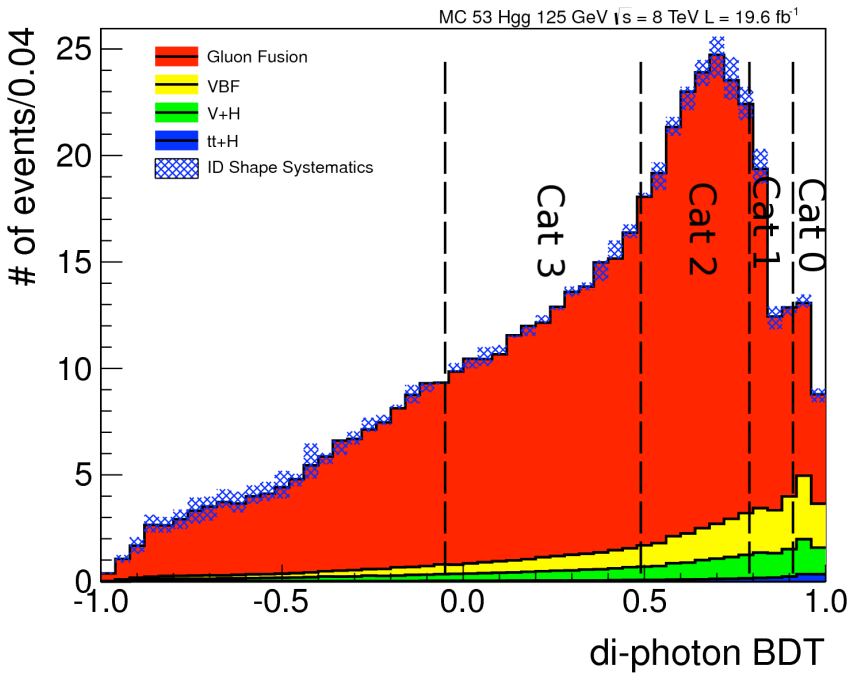
Calibration done with:

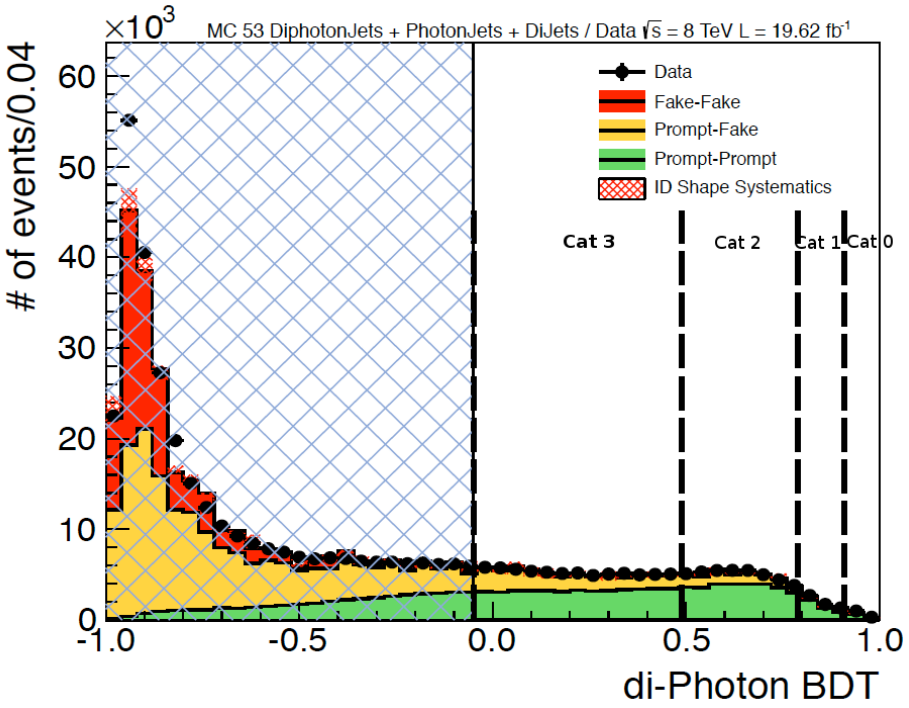
- $Z \to ee$ and $\pi^0 \to \gamma\gamma$
- $W \to e\nu$ $\left(\frac{E}{p}\right)$
- Laser corrections (transparency)



- Primary vertex identified with tracks from recoiling jets and underlying events.
- 80% good identifications with high PU.

BDT Tree

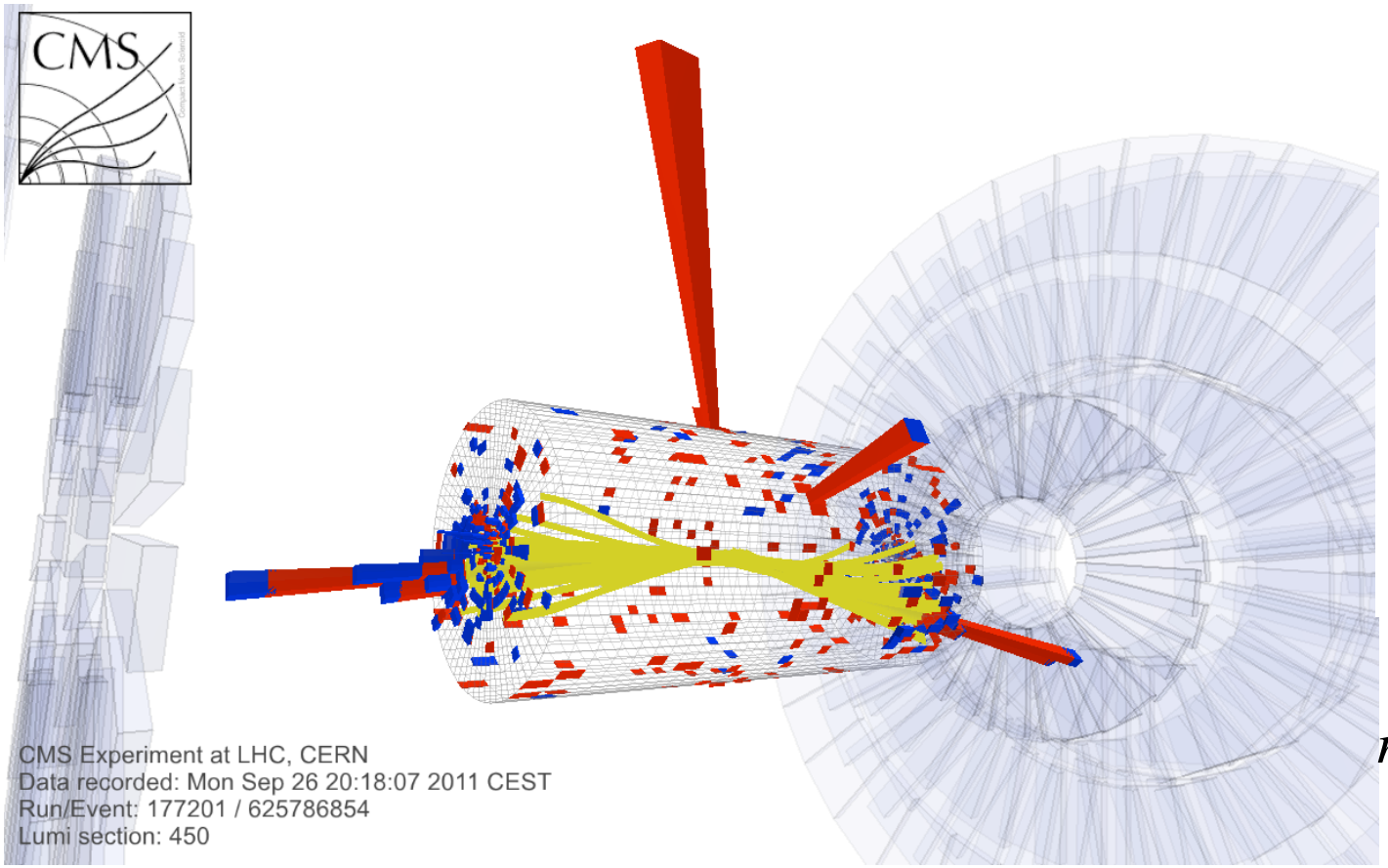


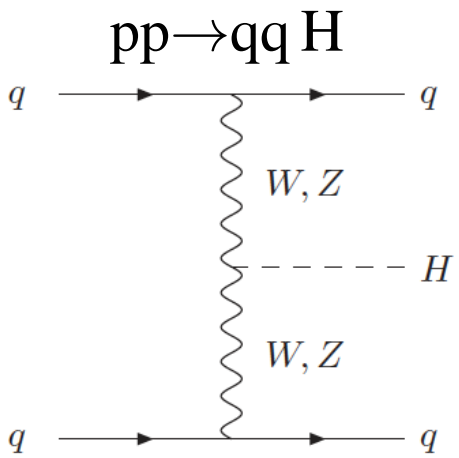


- 4 categories.
- The input for the BDT: Kinematic information, Photon Id classifier, estimated mass resolution.
- Additional categories for vector boson fusion and and associated W,Z production.

$H \to \gamma\gamma$ exclusive channels VBF

In order to profit specific production processes the background could be reduced by putting stronger cuts in the event selection.





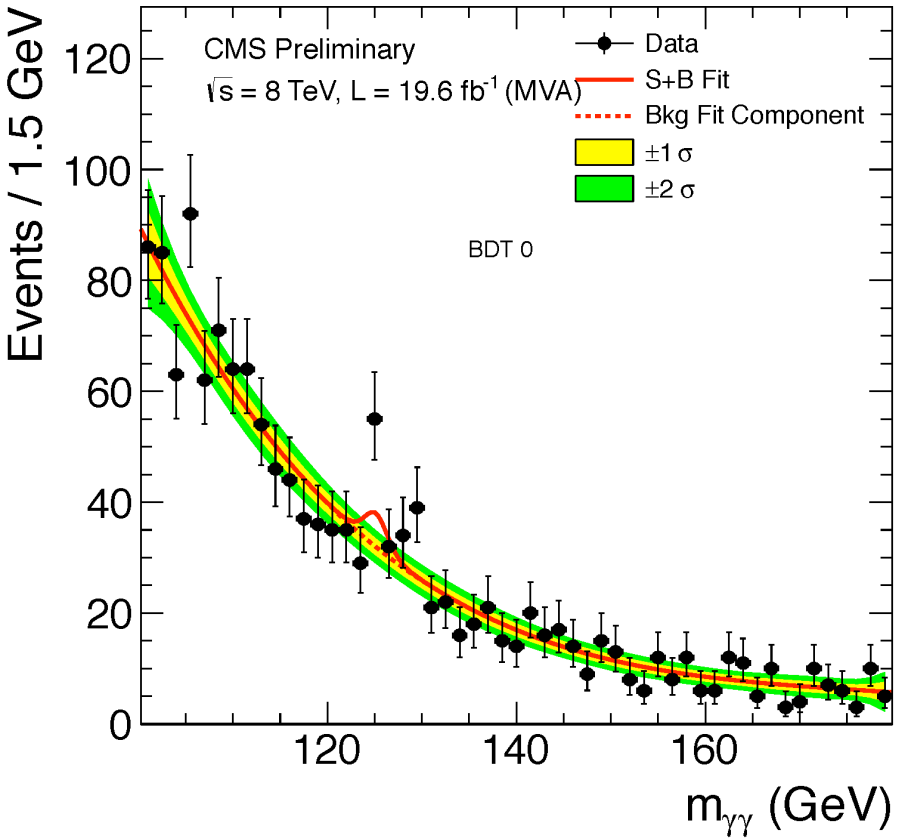
$m_{\gamma\gamma} = 121.9\,GeV$

$m_{jet\,jet} = 1460\,GeV$

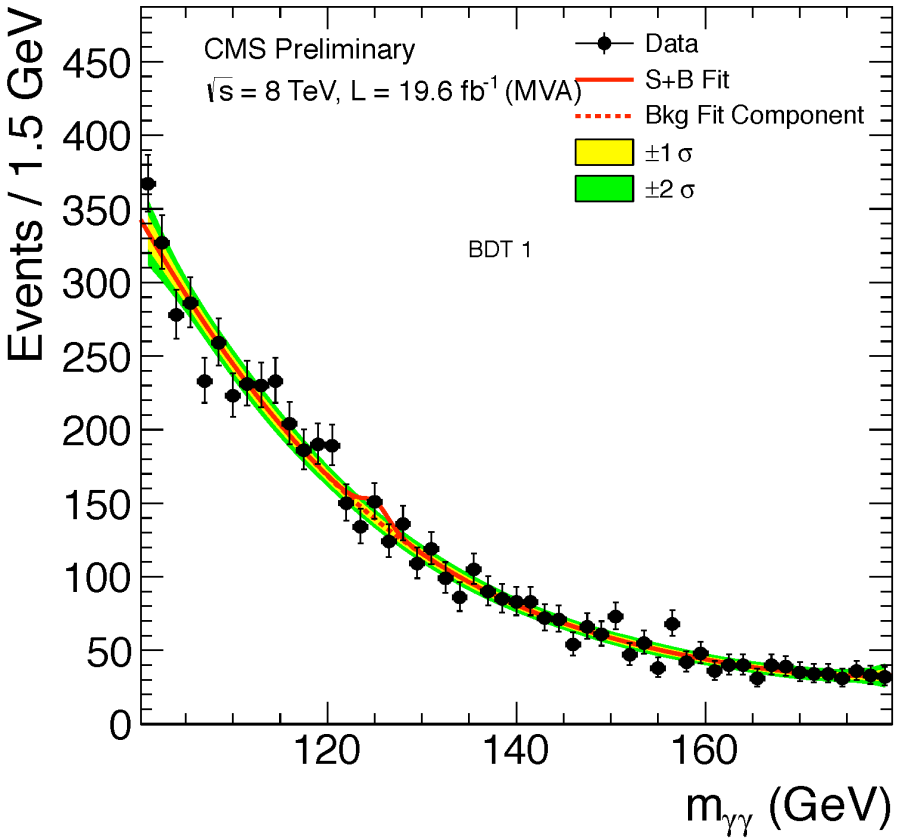
- For VBF two energetic jets.
- For W,Z H l+MET tag to address: $W \to l\nu$,$Z \to \nu\nu$ and $Z \to ll$.

$\sqrt{s}$ =8 TeV categories

BDT cat 0

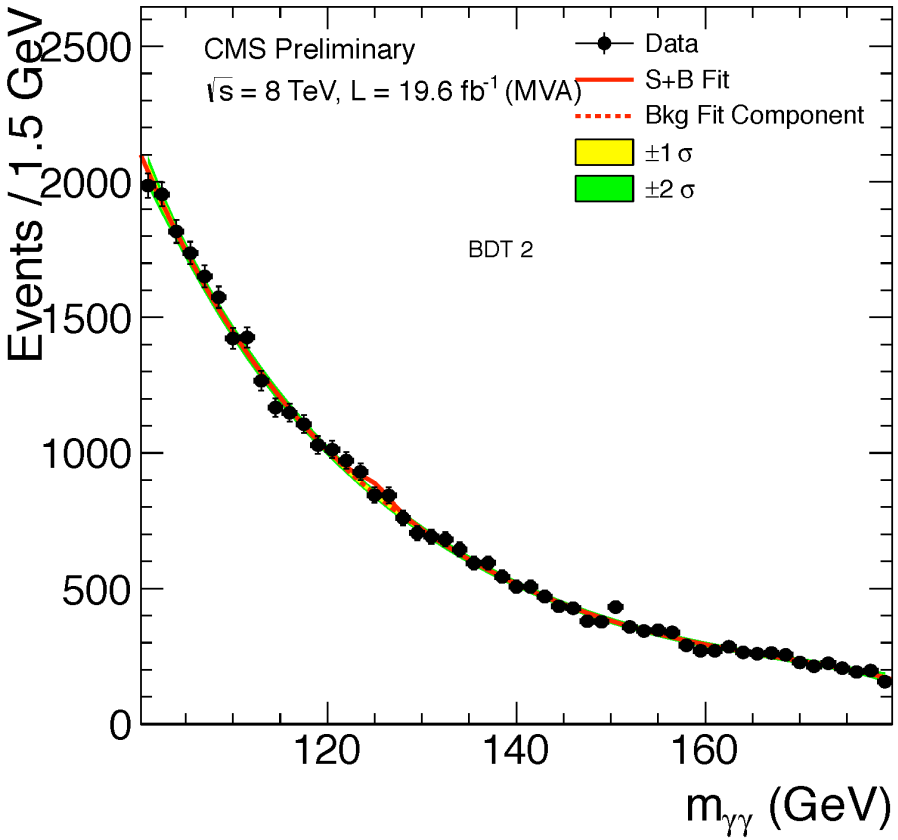


BDT cat 1

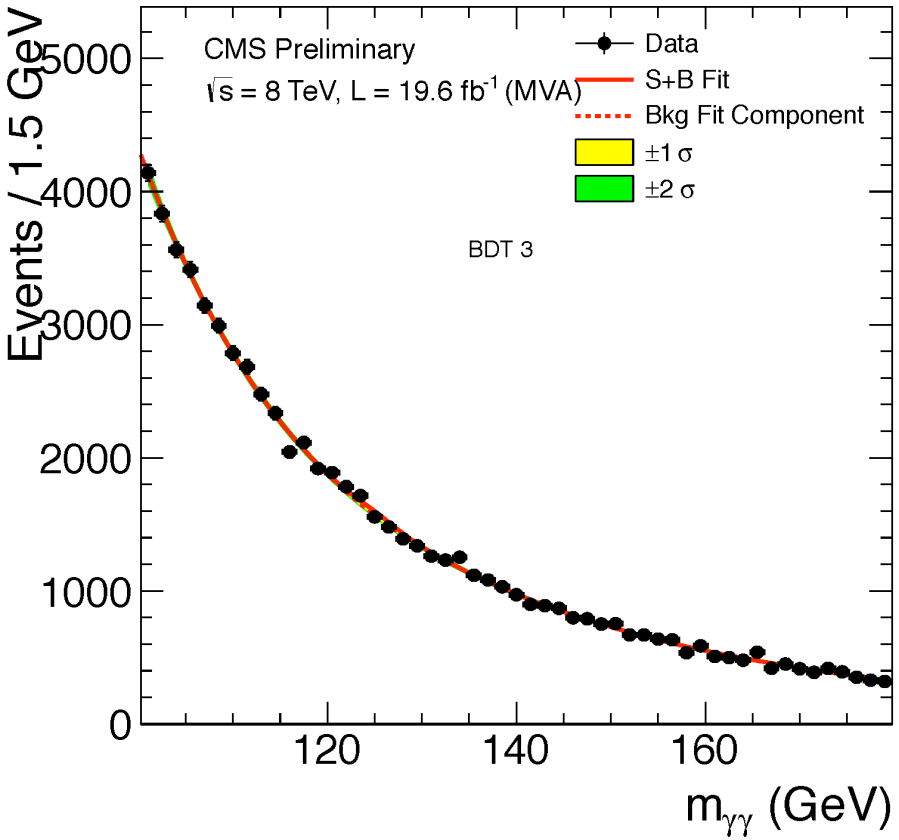


$\sqrt{s}$ =8 TeV categories

BDT cat 2

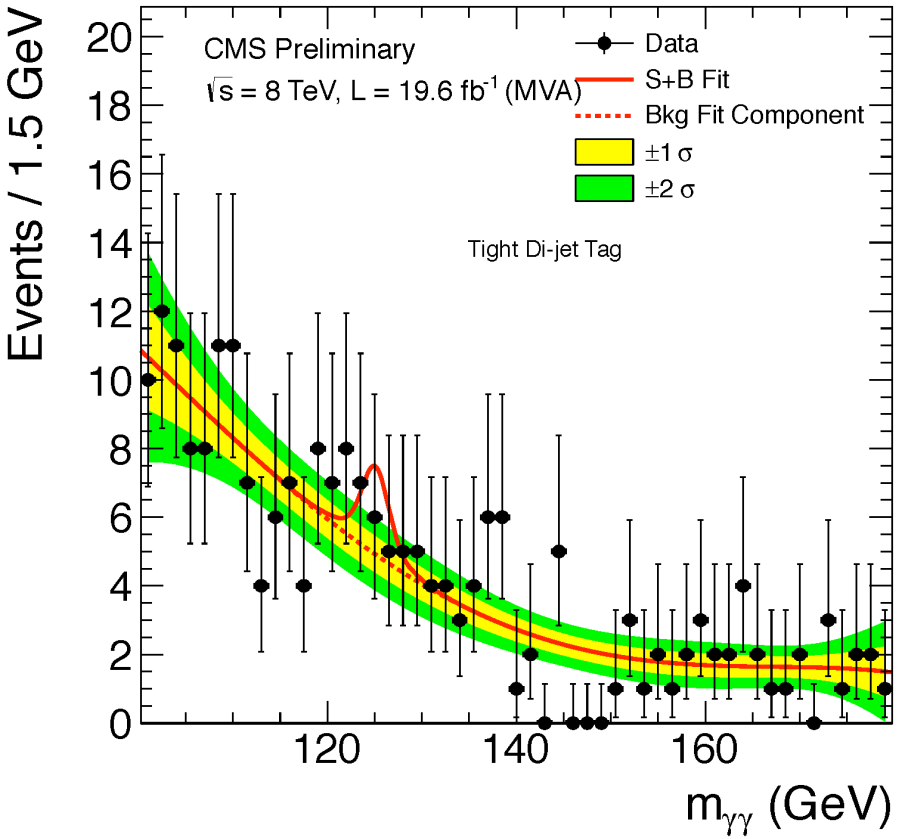


BDT cat 3

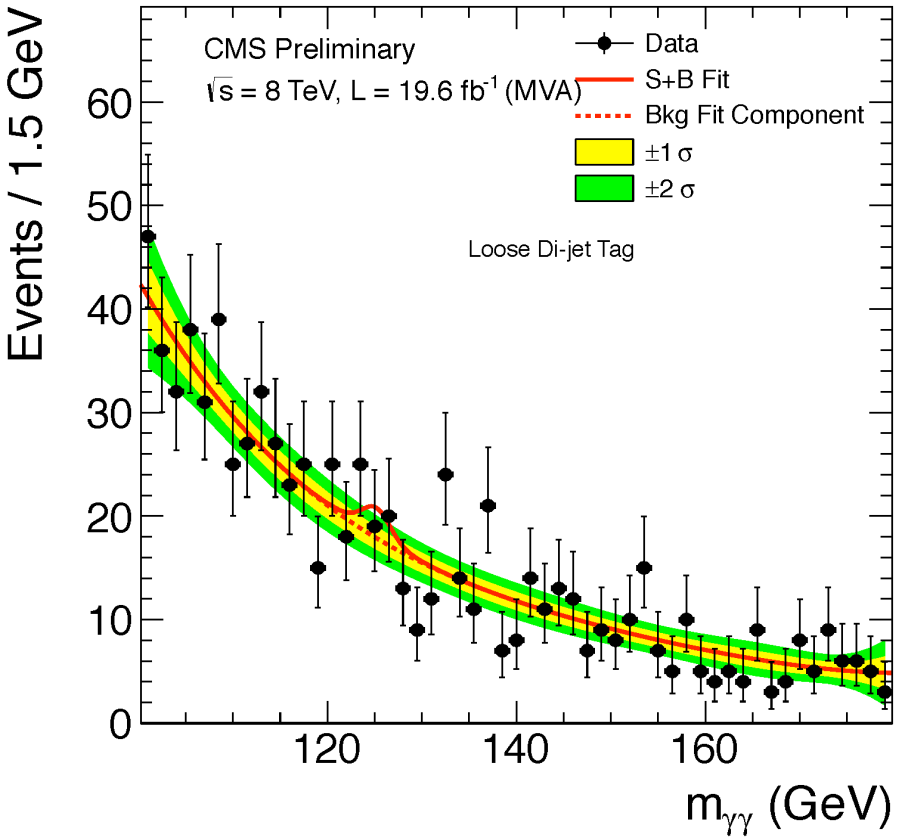


$\sqrt{s}$ =8 TeV categories

Tight Di-jet Tag

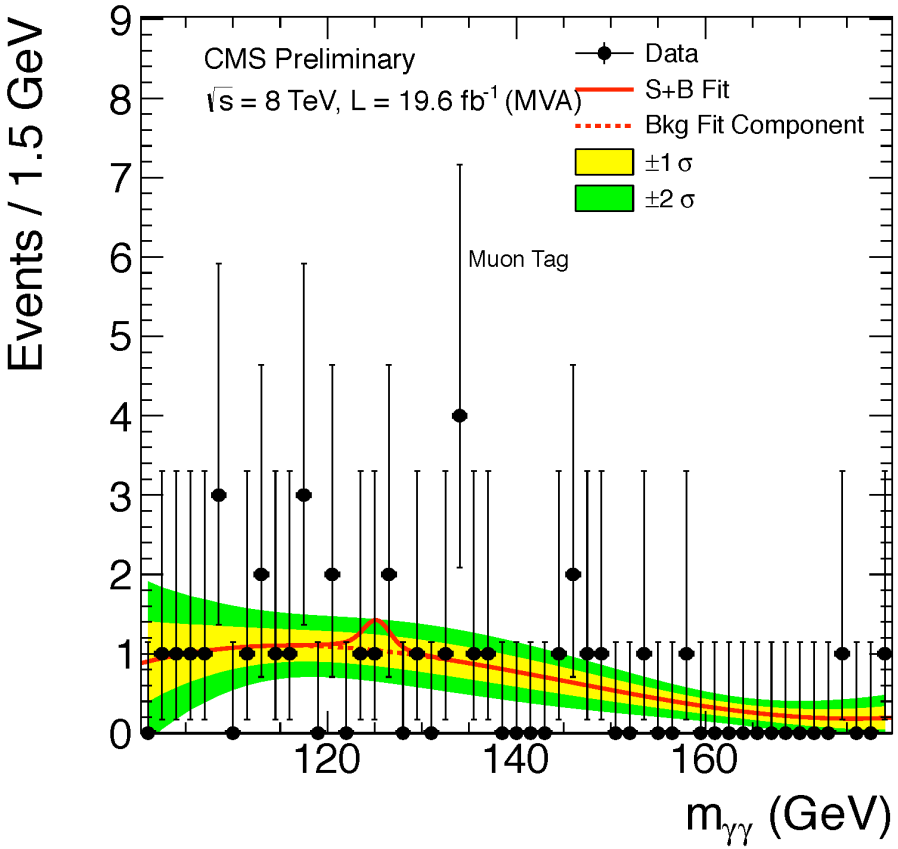


Loose Di-jet Tag

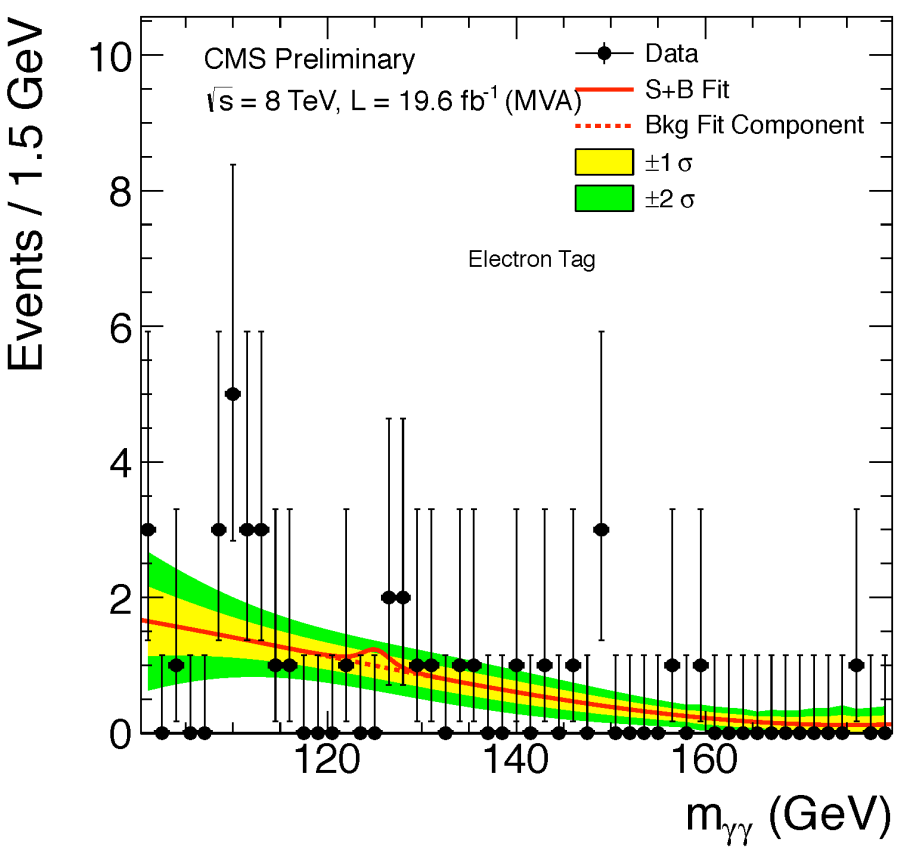


$\sqrt{s}$ =8 TeV categories

μ Tag

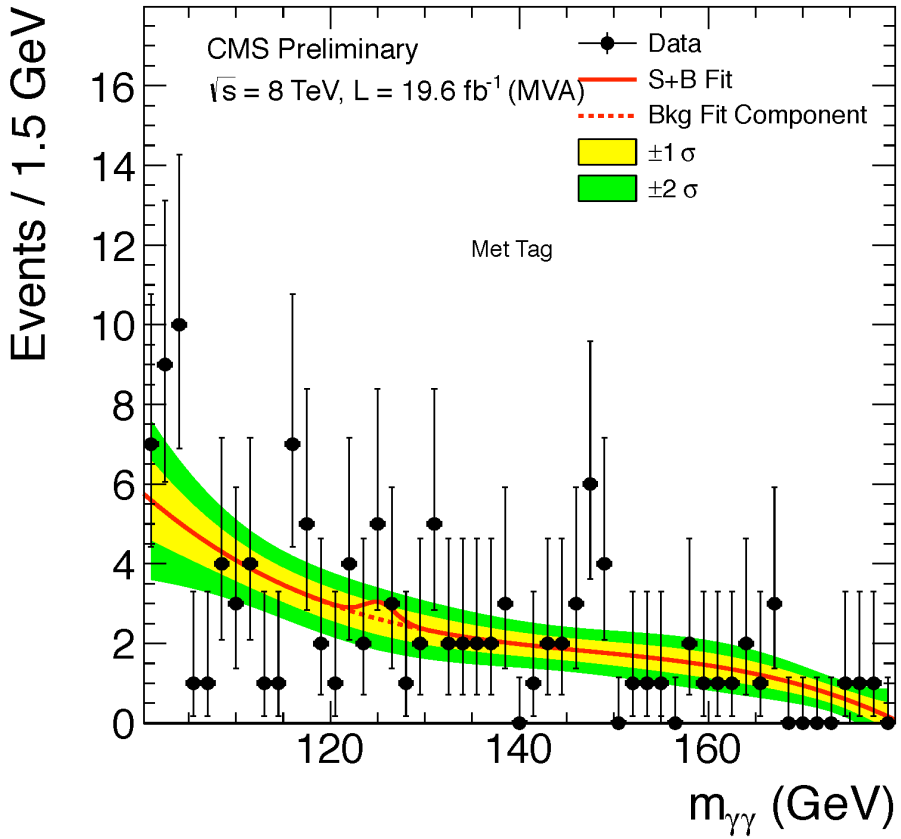


e Tag

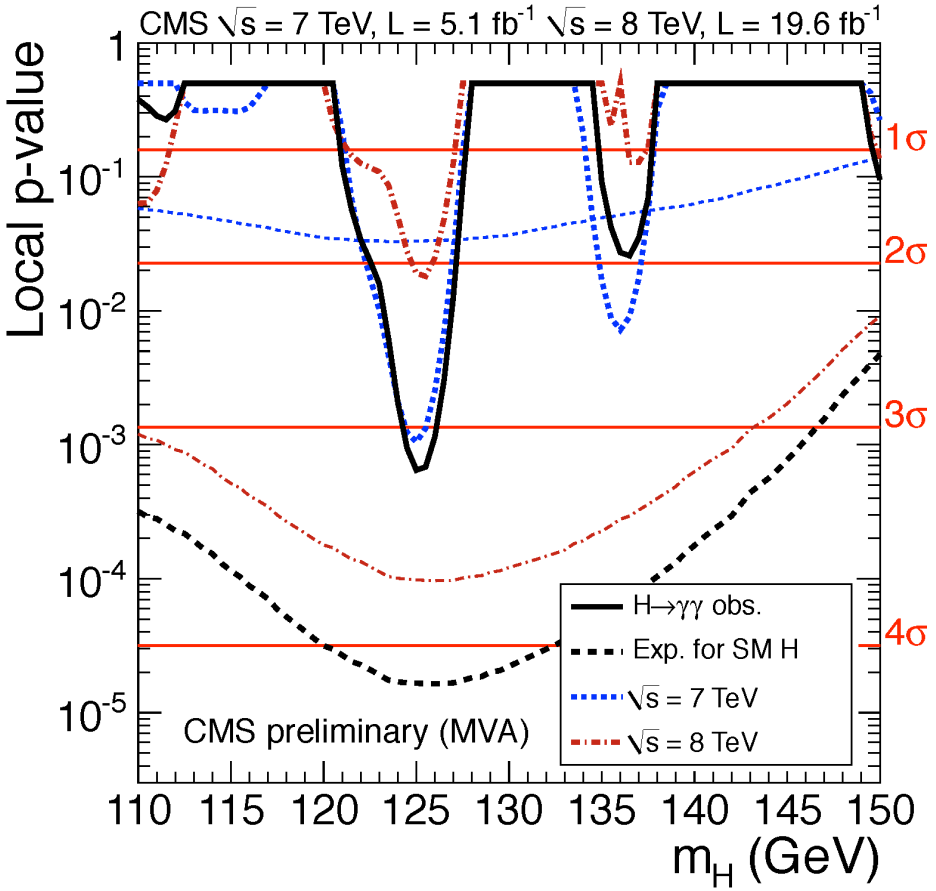


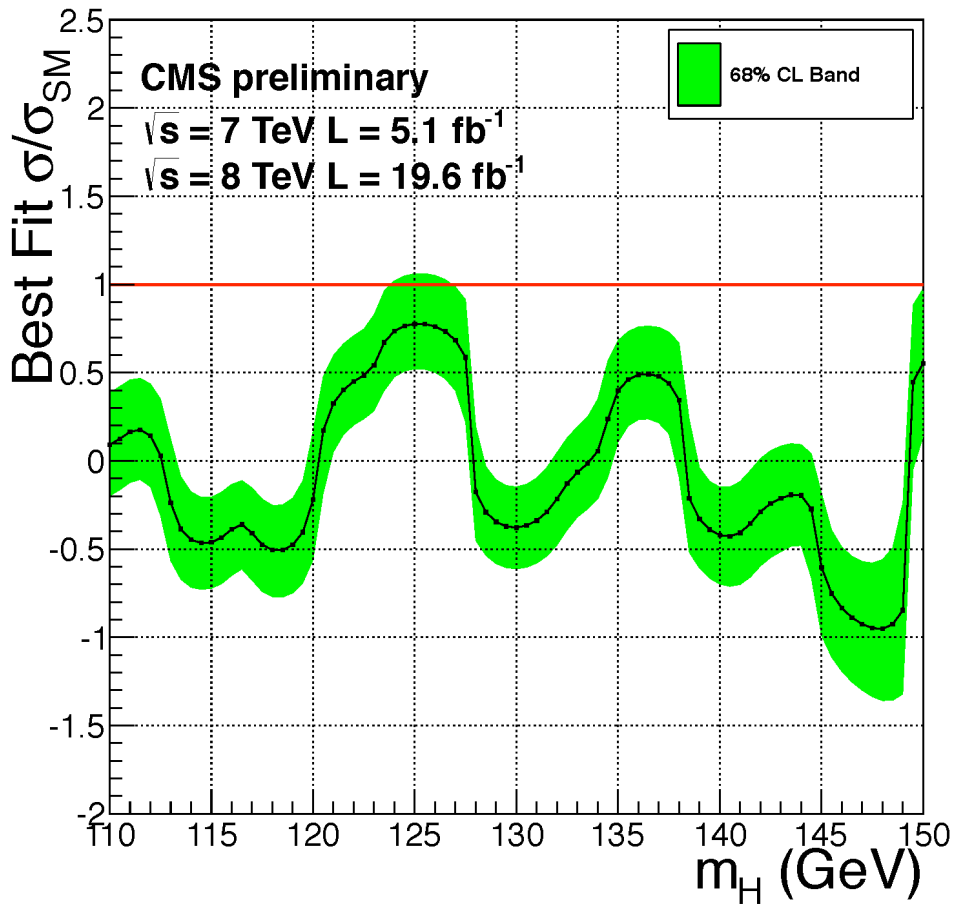
$\sqrt{s}$ =8 TeV categories

MET Tag



$H \to \gamma\gamma$ results, p-value



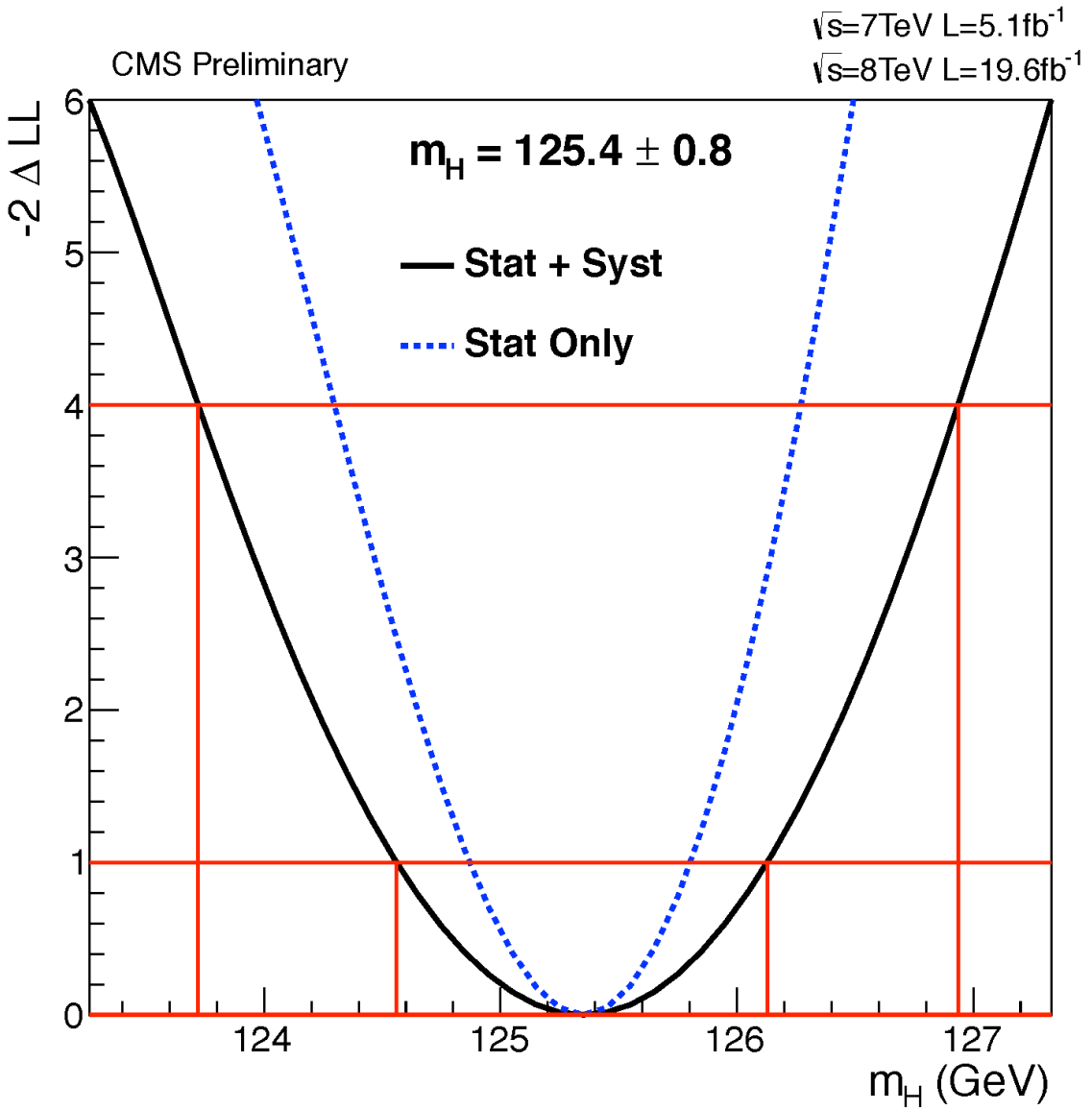


- Largest excess at $m_H \approx 125\,\text{GeV}$
- signif. $\to 3.2\sigma$
- expect. $\to 4.2\sigma$

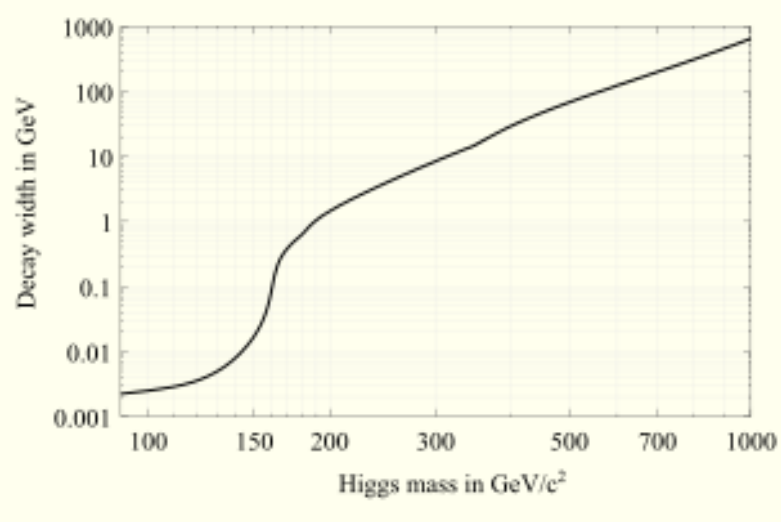
- Consistent results with CiC.
- The Higgs is still there!

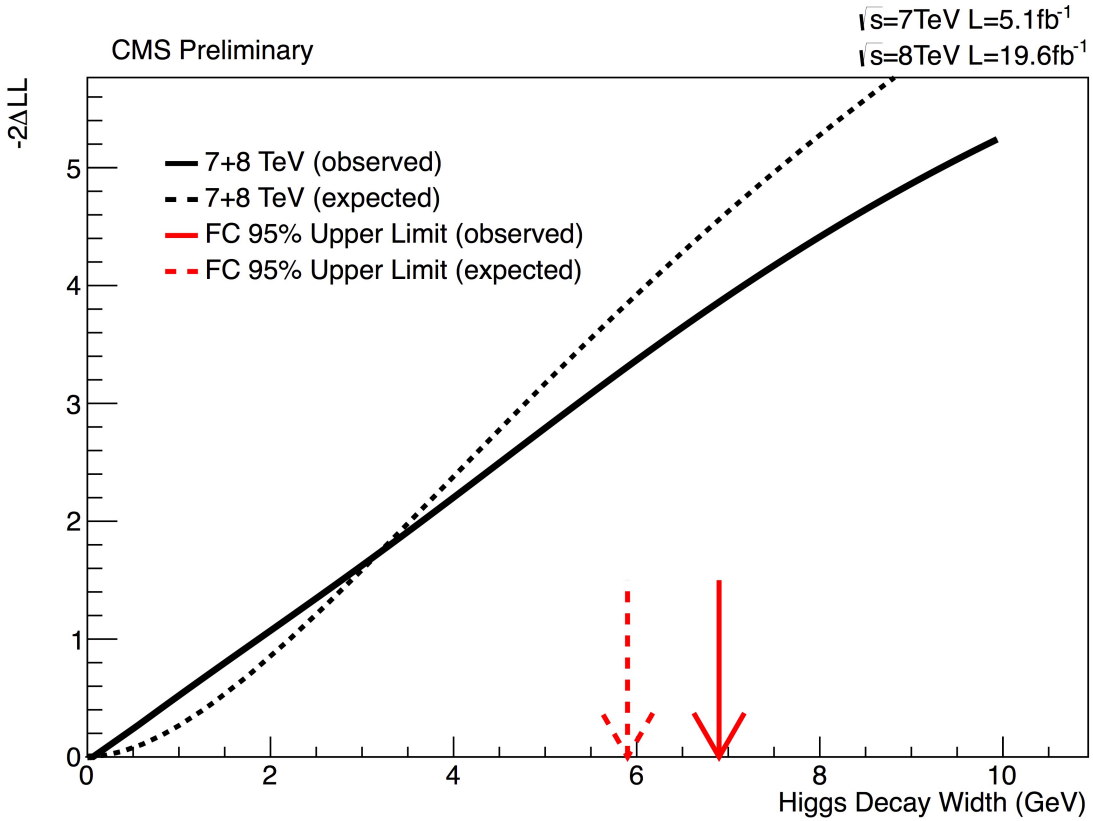
$H \to \gamma\gamma$ results, mass

- m_H is not predicted by theory
- All predictions for SM fully determined once the mass is know
- The first precision measurement of the properties of the new boson
- m_H=125.4 $\pm$ 0.5(stat) $\pm$ 0.6 (syst) GeV



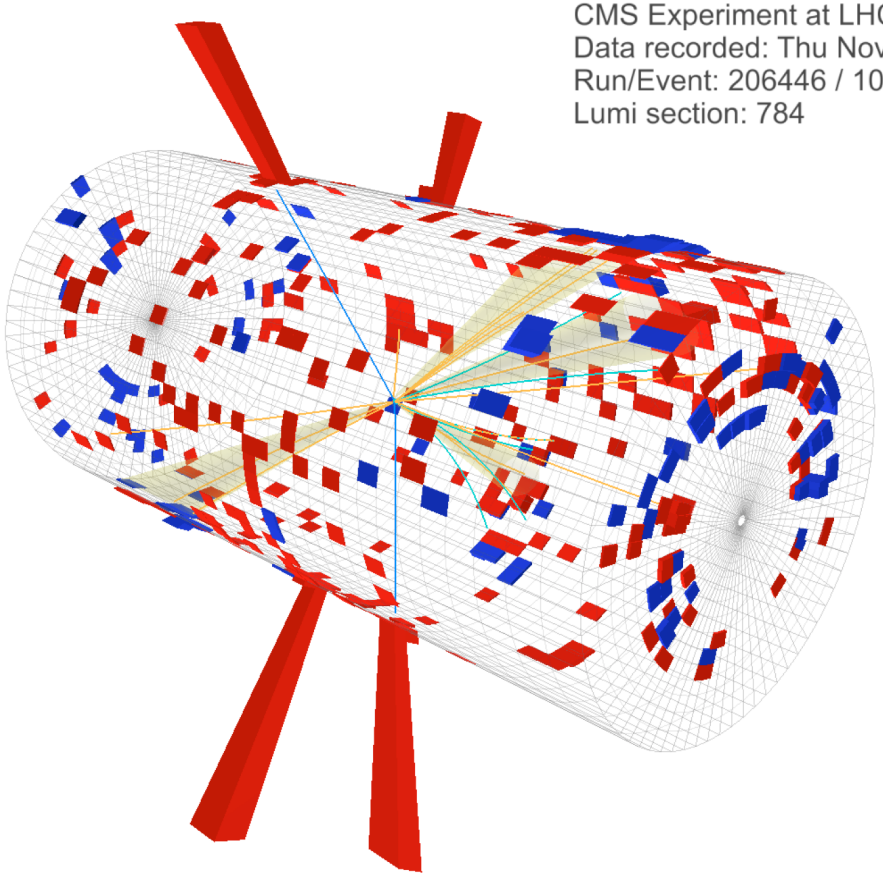
$H \to \gamma\gamma$ results, width

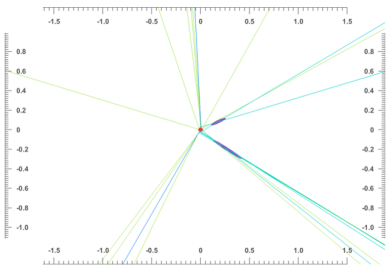




- SM prediction:
  $\Gamma_H \approx 4$ MeV,
  measurement limited by experimental resolution:
- $\Gamma_H < 6.9$ GeV, 95% C.L.
- (expected 5.9 GeV)

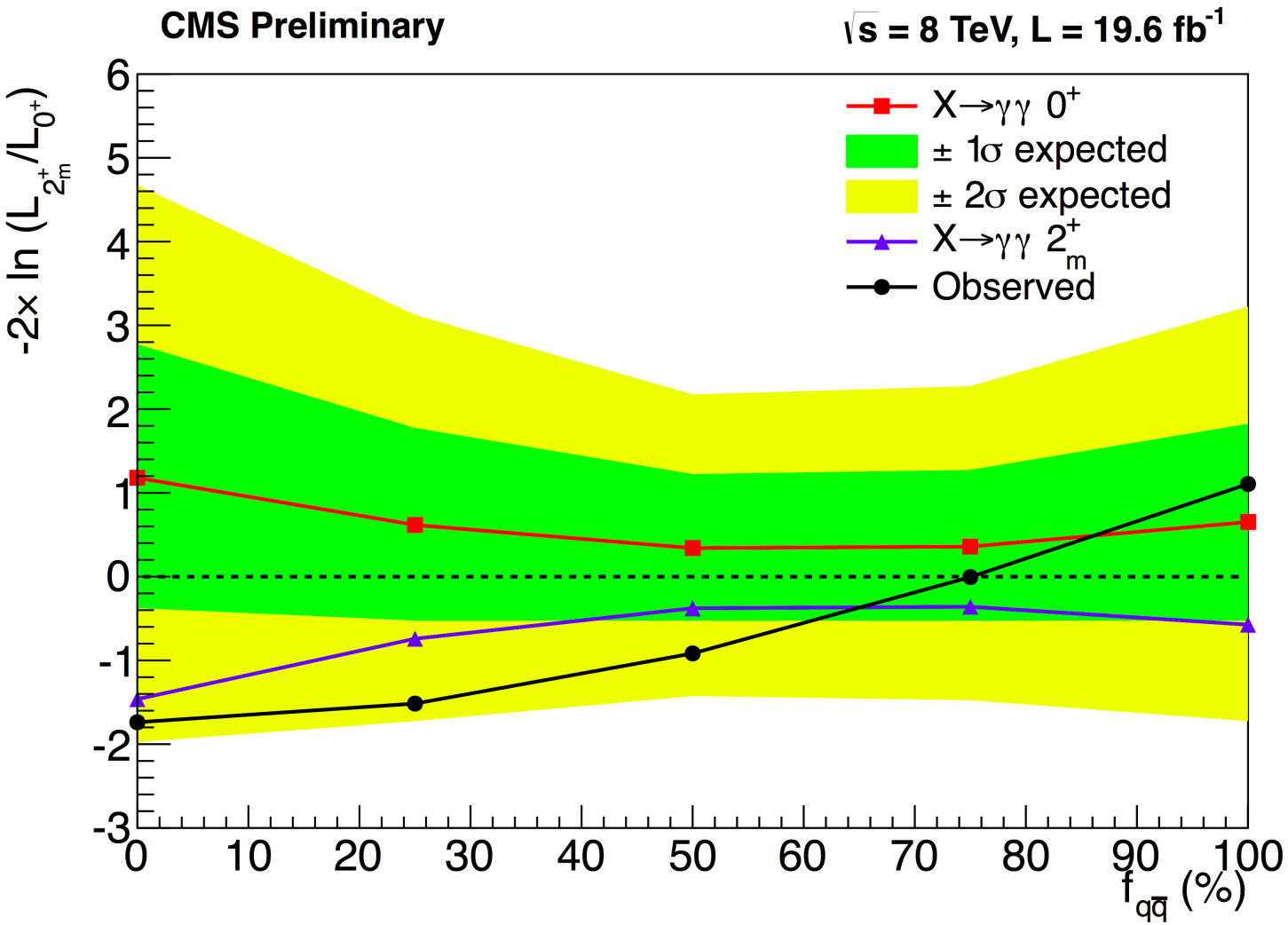
For the future, tt H





- Not yet part of the overall estimation
- Requires b-tagging and large jet multiplicity

Spin



- Clear prediction of the Standard Model: Higgs boson is a 0 spin state
- The spin is not yet measured, different hypothesis are being tested.

Conclusions

- The CMS $H \to \gamma\gamma$ strategy has been presented.
- Results with the full dataset 2011-2012 $\sqrt{s}$ 7 Tev and 8 TeV for the LHC Run-I:
  - **p-value:** 3.2 σ
  - **mass:** m_H=125.4 $\pm$ 0.5(stat) $\pm$ 0.6 (syst) GeV
  - **width:** $\Gamma_H < 6.9$ GeV, 95% C.L.
  - **spin:** (Compatible with spin 0^+ hypothesis)
- m_H is the first precision measurement
- Uncertainties mostly dominated by statistics.
- The tests for the SM predictions have begun.
- More to come for the next years.

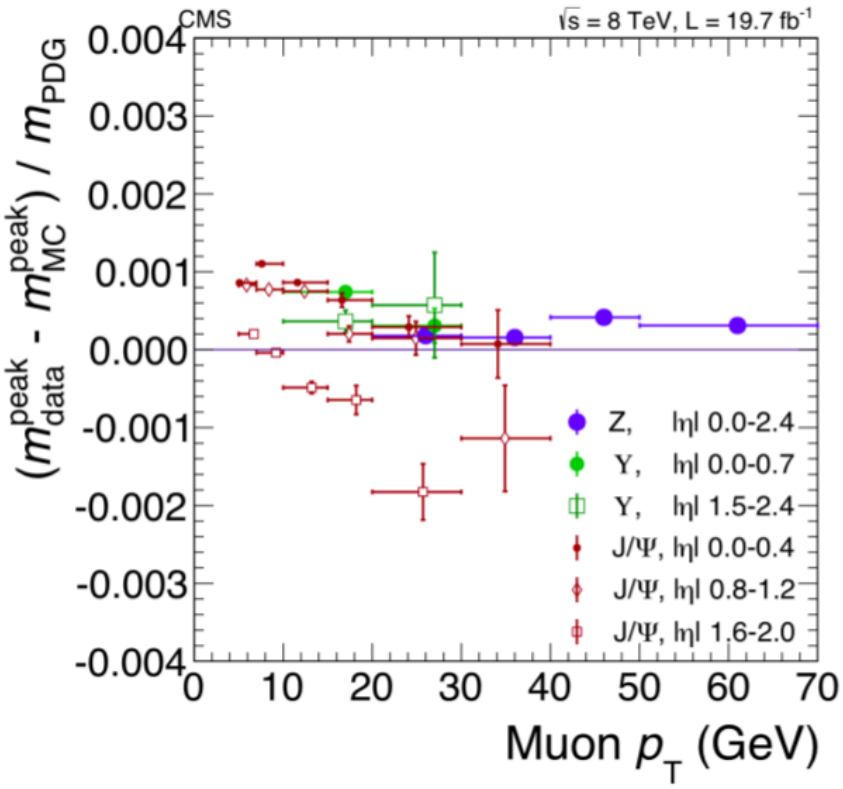
Web references

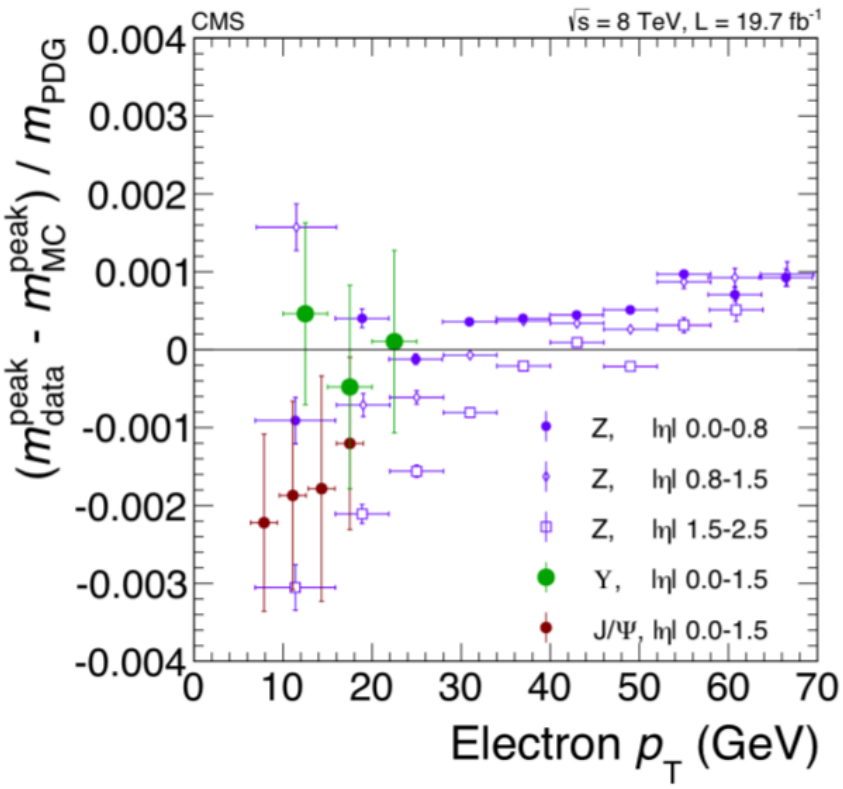
- All CMS Higgs Public results
  `https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG`

Backup

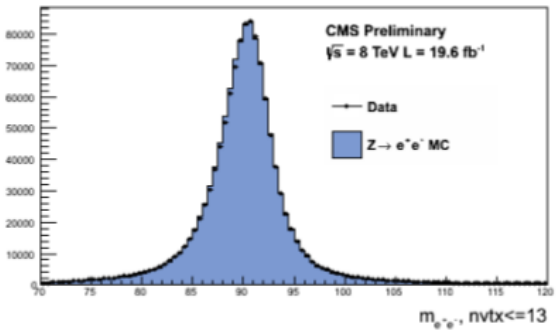
Backup

Lepton momentum scale

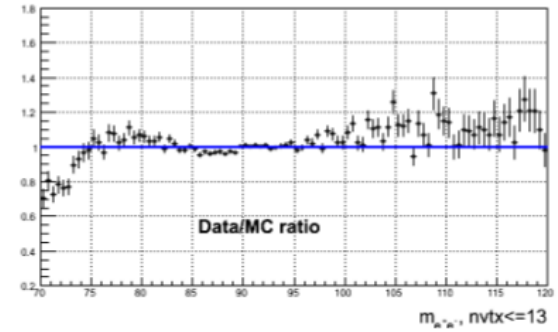




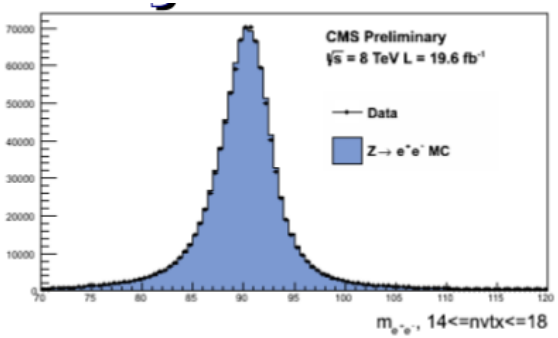
e γ energy reconstruction stability



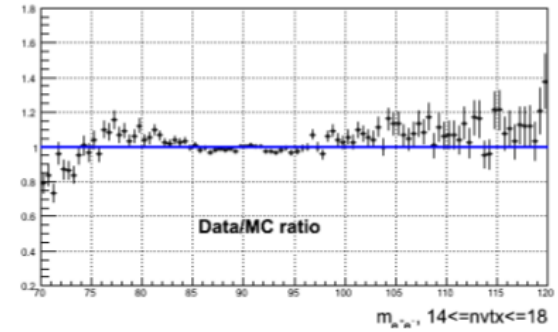
$m_{e^+e^-}$, nvtx<=13



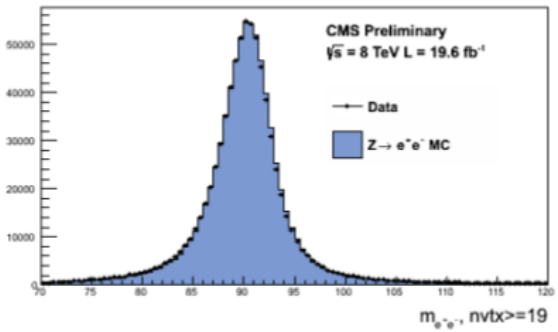
$m_{e^+e^-}$, nvtx<=13



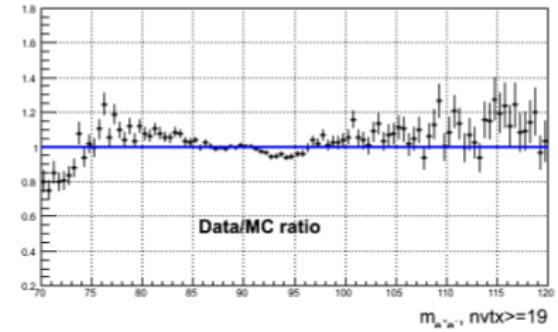
$m_{e^+e^-}$, 14<=nvtx<=18



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



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



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