A Search for the Higgs Boson in the $H \to \gamma\gamma$ Channel with CMS

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on behalf of the CMS Collaboration

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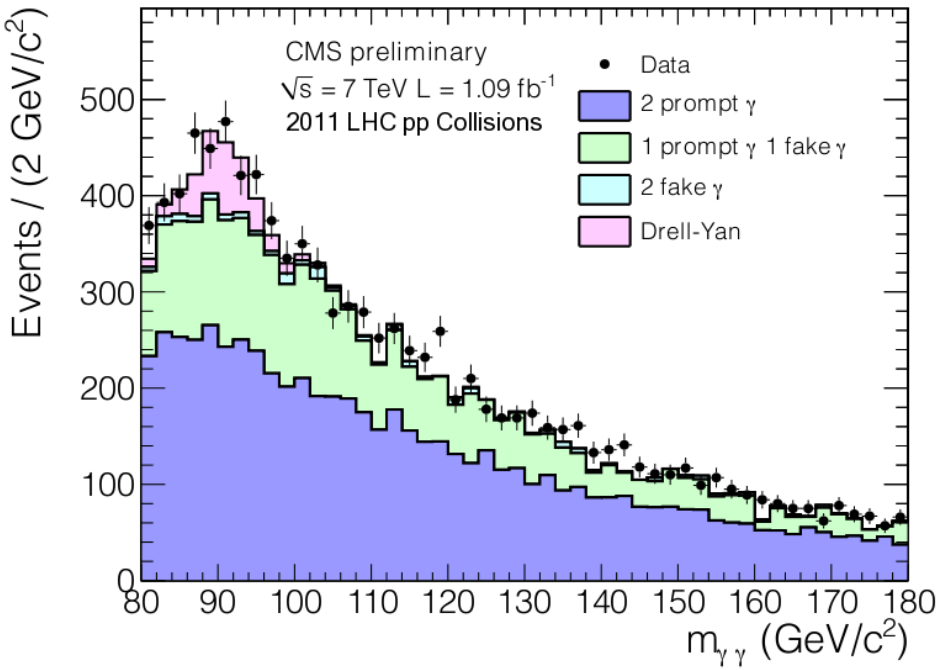
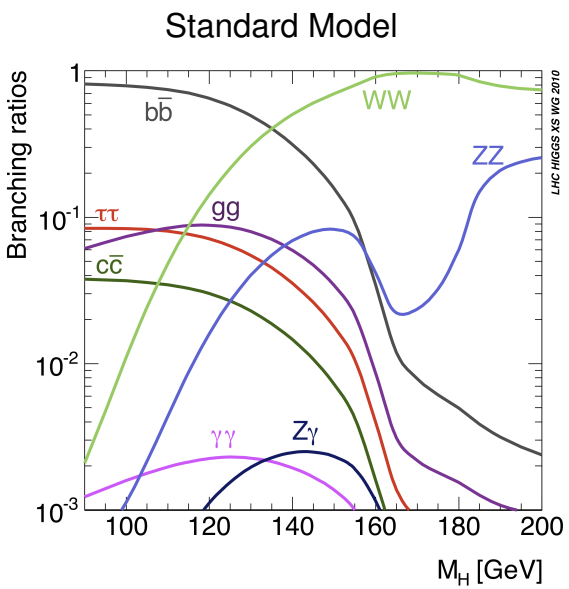
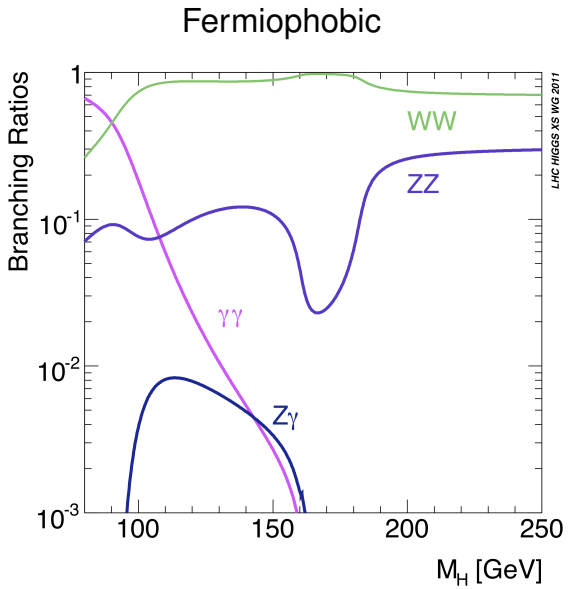
$H \to \gamma\gamma$ in a Nutshell

- Sharp signal peak
  need great resolution
- Smoothly declining background
  - Irreducible - 2 real γ's
  - Reducible - 1,2 fake γ's
    - Electrons faking γ's ($Z \to e^+e^-$)
    - Jets faking γ's ($\pi_0 \to \gamma\gamma$)

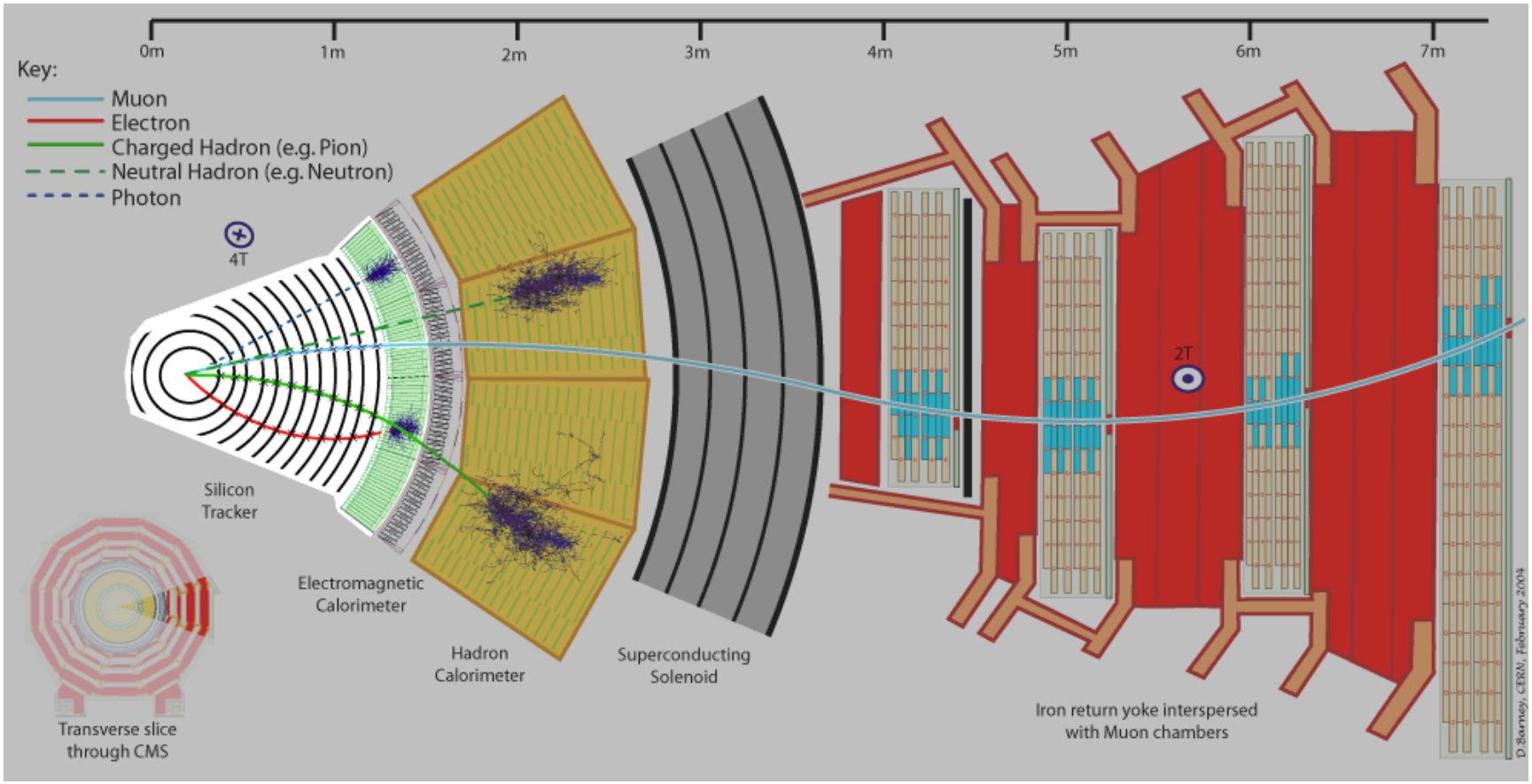






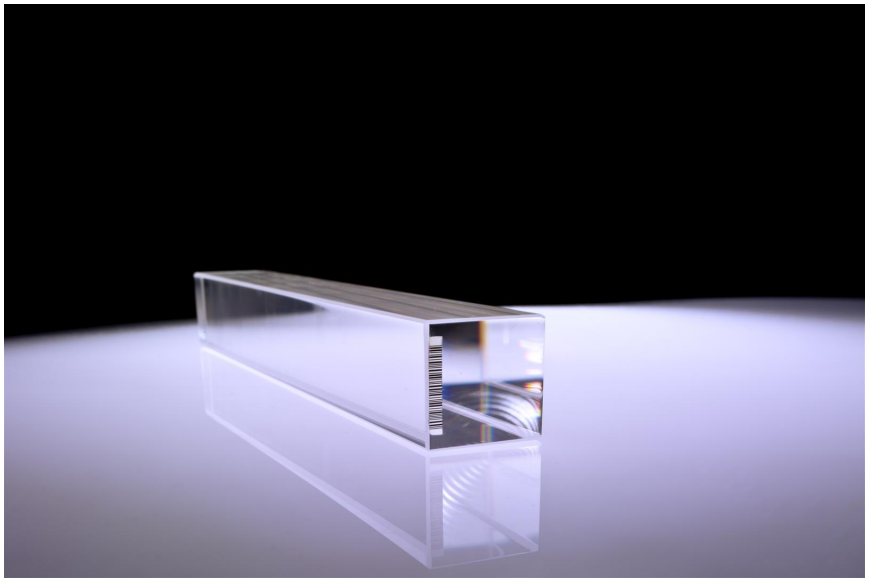
CMS

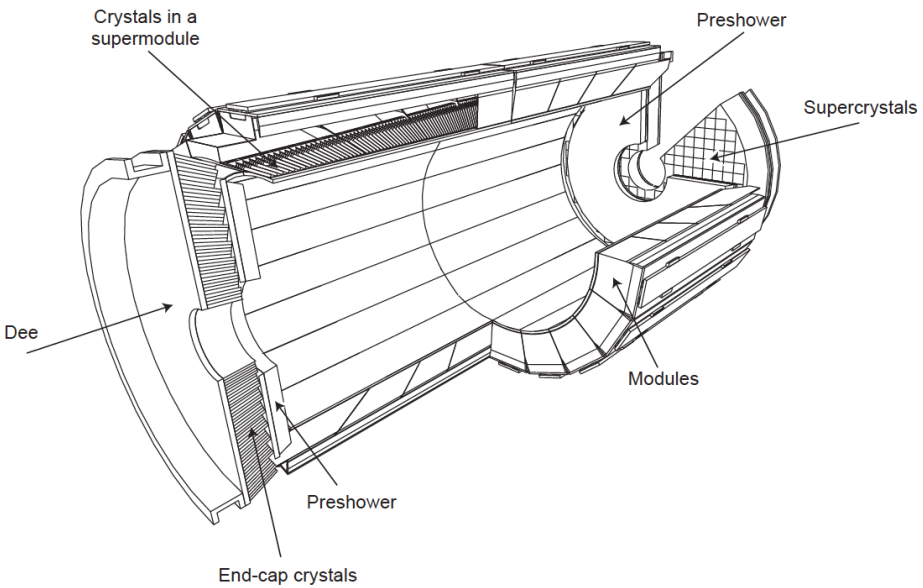
General purpose detector
Searching for Higgs, SUSY and more
Reconstructing photons (γ's), electrons, hadronic jets and muons (μ's)



CMS - Electromagnetic Calorimeter (ECAL)

- $\sim$76K $PbWO_4$ crystals in barrel ($|\eta| < 1.48$) and endcap ($1.48 < |\eta| < 3.$)
- Design resolution $\sim$0.5% for unconverted γ's with energy > 100 GeV
- Critical resolution issues
  - Calibration
    - Crystal inter-calibration - $\pi_0 \to \gamma\gamma$
    - Energy scale calibration - $Z \to e^+e^-$
  - Transparency corrections for radition damage
    - An integrated laser system measures the transparency of crystals



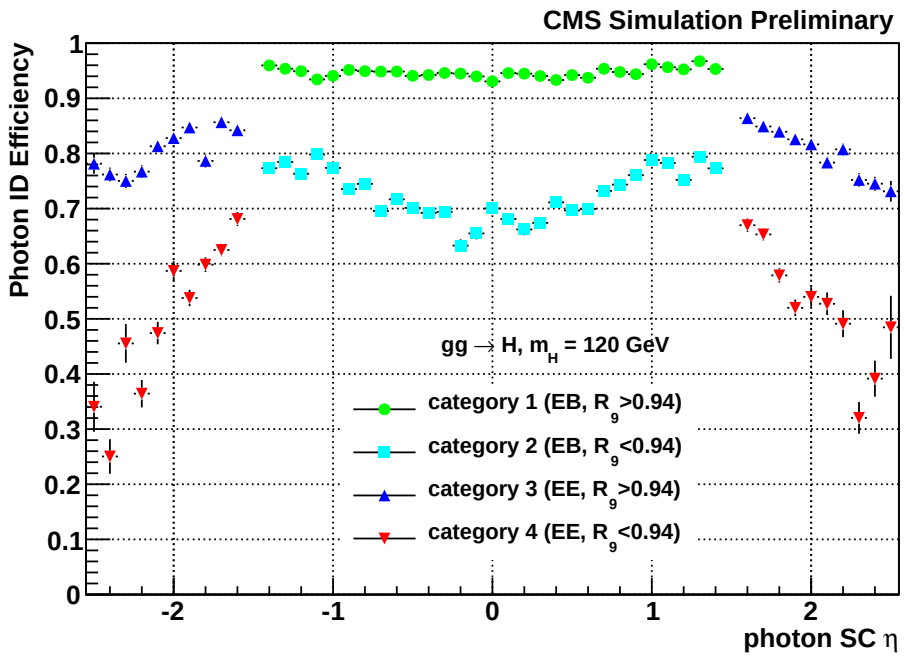


Photon Selection in Categories

- Photon Identification
  - Isolation
    - $\Sigma P_{T,Tracks}$ + ECAL energy + HCAL energy in hollow cone around γ
  - Cluster shape
    - Spread in η rejects $\pi_0 \rightarrow \gamma\gamma$
  - Electron veto
- Cuts are optimized in 4 photon categories
  - Barrels/endcap
  - Unconverted/converted
    - Indicated by a measure of the spread of γ's shower

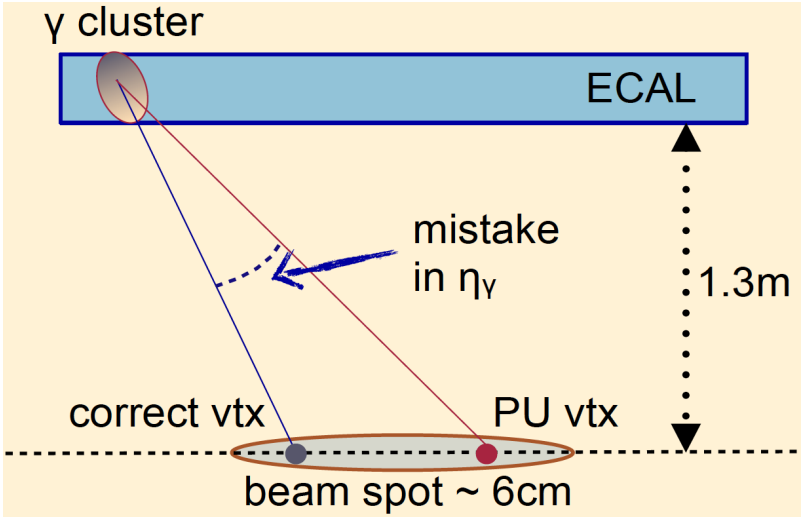
- Photon Transverse Momentum (P_T)
  - $P_T^{\gamma 1} > 40$ GeV/c
  - $P_T^{\gamma 2} > 30$ GeV/c

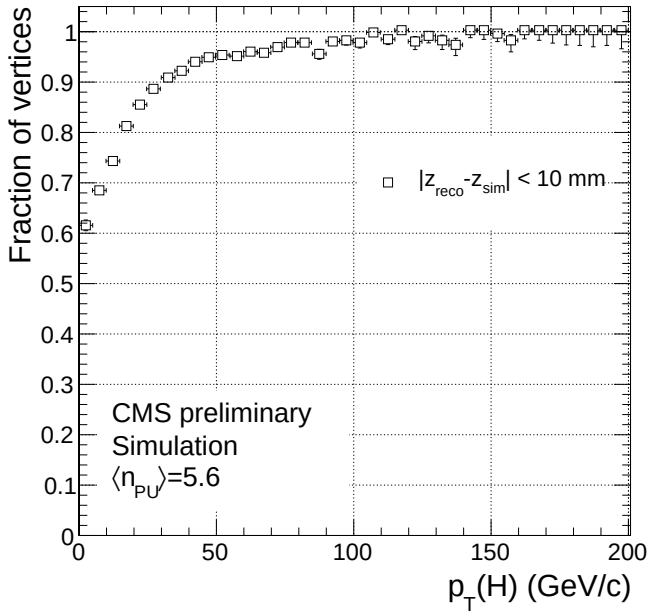
Efficiencies vs. η_γ



Vertex Selection

- The Pile-Up (PU) problem
  - $< N_{PU} > \sim$ 5.6 vertices in our 1.09 fb^{-1}
  - Wrong vertex, wrong $\gamma\gamma$ invariant mass $\rightarrow$ resolution loss
- Determine vertex using
  - $\sum_{Tracks} P_T^2$
  - Projection of tracks onto $\gamma\gamma$
  - Balance between $\gamma\gamma$ and vertex's tracks
  - For converted γ's use conversion-tracks to point back to vertex
- Efficiency of correct selection (within 1 cm) $\sim$83% with nearly 100% efficiency at high $P_T^{\gamma\gamma}$
- From just using beamspot resolution improves by $\sim$16% overall





Selection Efficiency in Data

$Z \to e^+e^-$ Tag and Probe

- Assume that electrons and photons have similar shower properties
- Tag with tight electron ID
- Probe with high E_T reconstructed electron
- Use associated reconstructed γ and apply γ selection

$Z \to \mu\mu\gamma$

- Select μ's and γ that make Z-mass
- Use to measure electron veto efficiency

Trigger Efficiencies from $Z \to e^+e^-$

Both photons in barrel	
2 Unconverted	1,2 Converted
$100.00^{+0.00}_{-0.01}$ %	99.53±0.04%

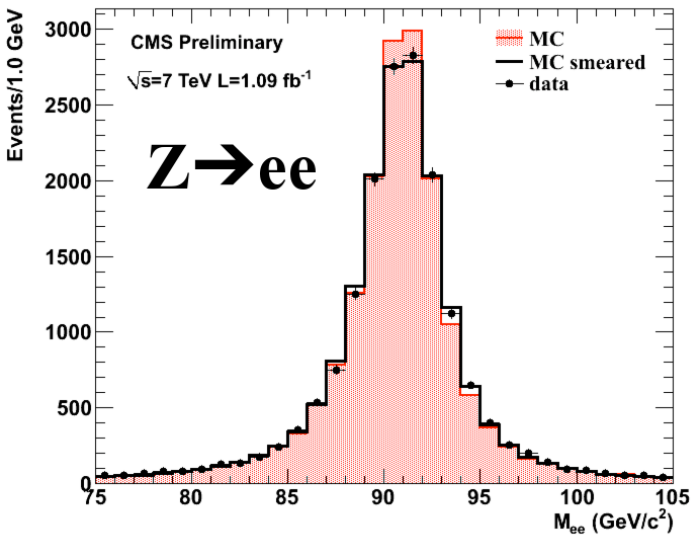
One or more in endcap	
2 Unconverted	1,2 Converted
$100.00^{+0.00}_{-0.02}$ %	98.86±0.07%

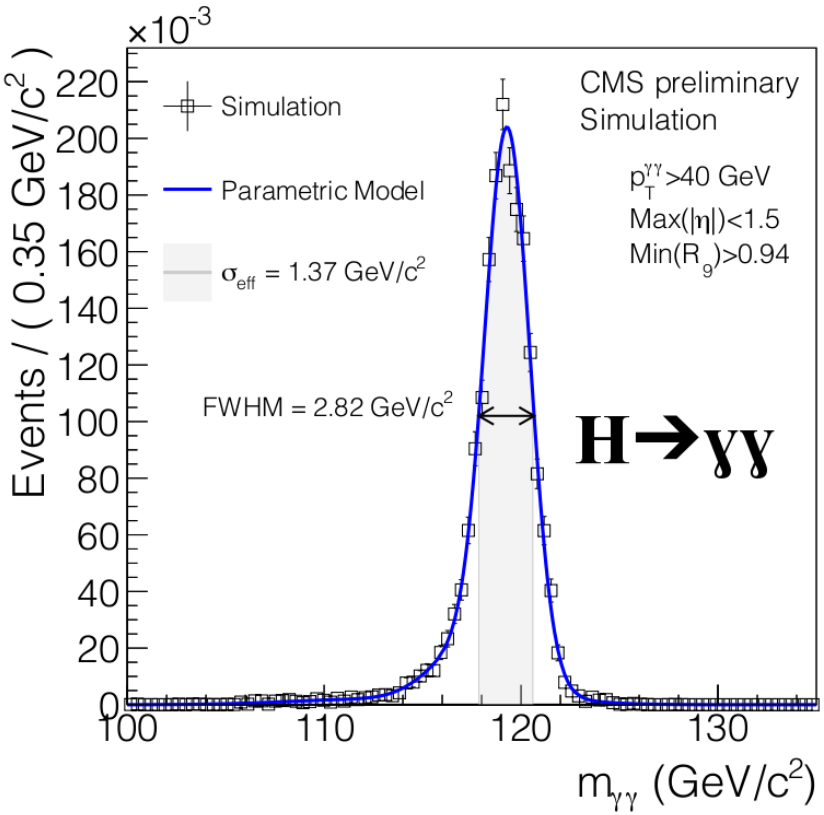
Selection Efficiencies from Data

Category	ϵ_{data} (%)	ϵ_{MC} (%)	$\epsilon_{data}/\epsilon_{MC}$
All cuts except electron rejection (from $Z \to e^+e^-$)			
1	91.77±0.14	92.43±0.07	0.993±0.002
2	72.67±0.43	71.89±0.08	1.011±0.007
3	80.33±0.47	80.04±0.18	1.004±0.008
4	57.80±1.26	55.09±0.15	1.049±0.025
Electron rejection cut (from $Z \to \mu\mu\gamma$)			
1	$99.78^{+0.13}_{-0.16}$	$99.59^{+0.13}_{-0.17}$	$1.002^{+0.002}_{-0.002}$
2	$98.77^{+0.59}_{-0.73}$	$97.70^{+0.32}_{-0.37}$	$1.011^{+0.007}_{-0.008}$
3	$99.32^{+0.51}_{-1.02}$	$99.29^{+0.30}_{-0.42}$	$1.000^{+0.006}_{-0.011}$
4	$93.0^{+2.1}_{-2.3}$	$93.34^{+0.79}_{-0.86}$	$0.996^{+0.024}_{-0.027}$

Resolution from $Z \to e^+e^-$

- ECAL resolution measured from $Z \to e^+e^-$ is applied to simulated Higgs' γ's.
- The simulated Higgs' γ's with data resolution are used in signal modeling for CL limits.





Suboptimal transparency loss corrections are primarily responsible for degraded resolution.

Event Classes Used for CL Evaluation

2 η Classes

- 2 γ's in the barrel
- 1 or 2 γ's in the endcap

2 Conversion Classes

- 2 Unconverted γ's ($R_9 > 0.94$)
- 1 or 2 Converted γ's ($R_9 < 0.94$)

2 $P_T^{\gamma\gamma}$ Classes

- $P_T^{\gamma\gamma} > 40$ GeV/c
- $P_T^{\gamma\gamma} < 40$ GeV/c

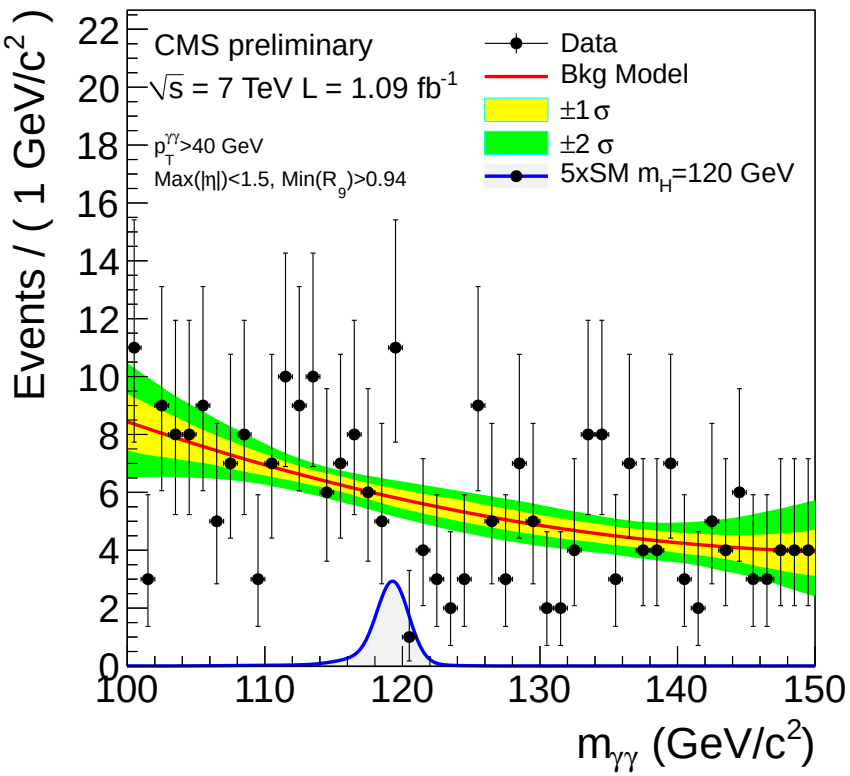
Fraction of selected signal and background expected in each event class.

	Both γ's in barrel		One or more in endcap	
	2 Unconverted	1,2 Converted	2 Unconverted	1,2 Converted
$P_T^{\gamma\gamma} < 40$ GeV/c				
Signal	0.209	0.271	0.094	0.116
Background	0.167	0.263	0.129	0.203
Signal $\sigma_{effective}$ (GeV/c^2)	1.58	2.33	3.14	3.60
$P_T^{\gamma\gamma} > 40$ GeV/c				
Signal	0.102	0.122	0.035	0.051
Background	0.043	0.079	0.043	0.074
Signal $\sigma_{effective}$ (GeV/c^2)	1.37	2.12	2.95	3.26

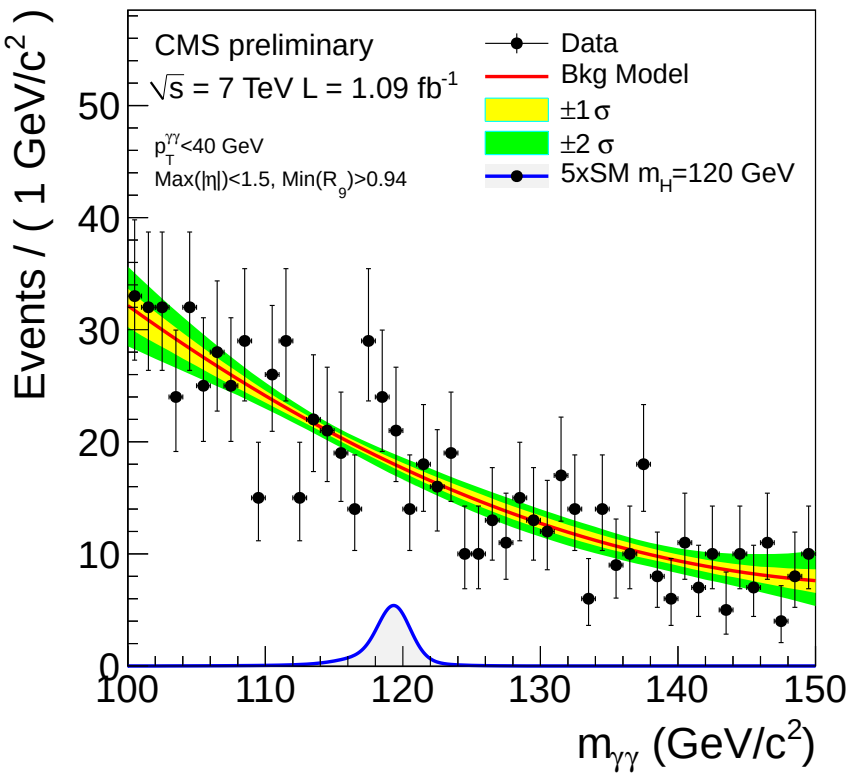
Background Modeling

Background from data fit to 2^{nd} order polynomial ($100 < M_{\gamma\gamma} < 150$ GeV/c^2)

High $P_T^{\gamma\gamma}$, both high R_9, barrel-barrel



Low $P_T^{\gamma\gamma}$, both high R_9, barrel-barrel

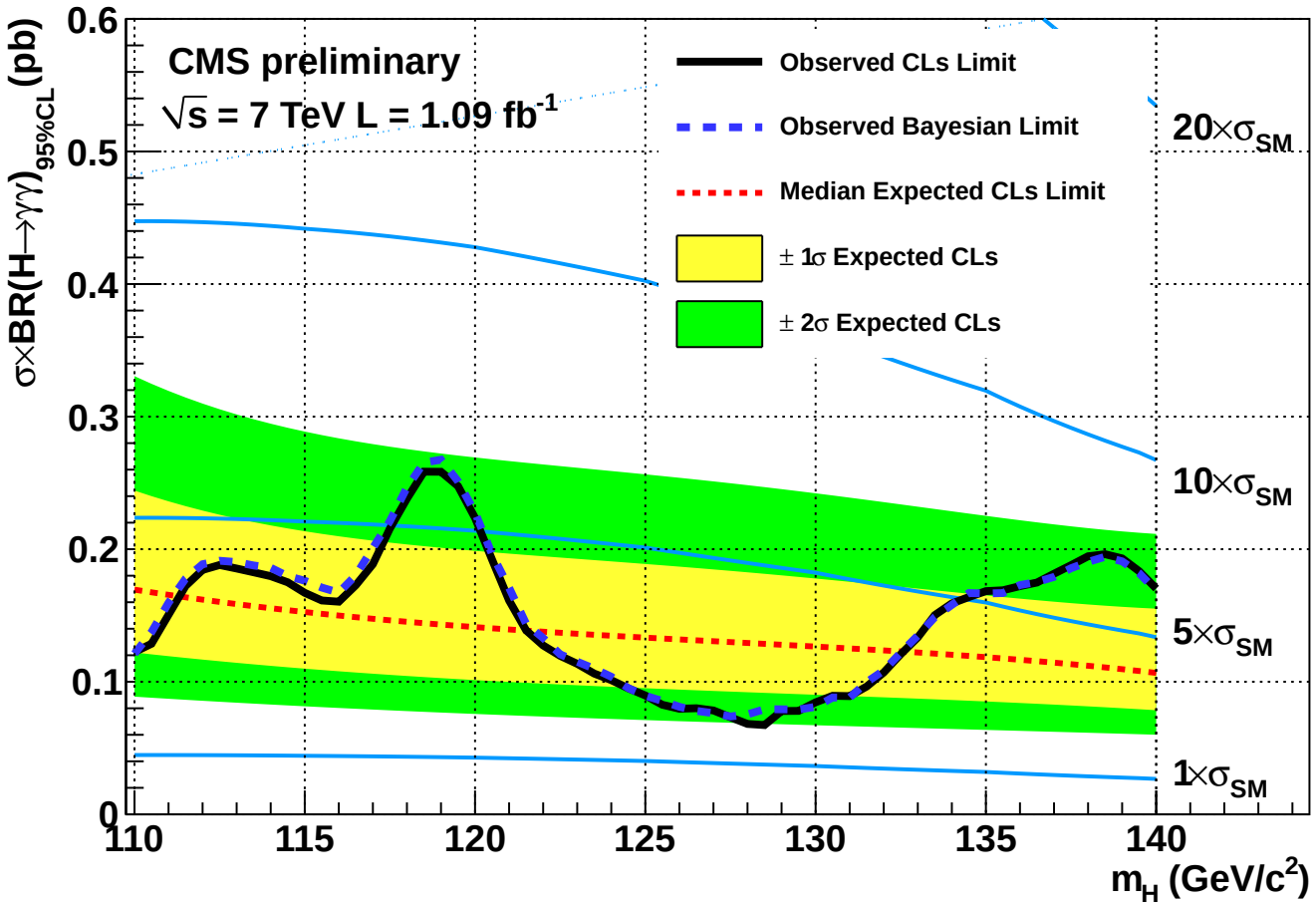


Systematic Errors on the Signal

Source	Systematics
applicable to individual photons	
Photon identification efficiency	1.0% ÷ 4.0%
R9 cut efficiency	4.0% ÷ 6.5%
Energy resolution	0.2% ÷ 0.5%
Energy scale	0.05% ÷ 0.34%
applicable to di-photons	
Integrated luminosity	6.0%
Trigger efficiency	1.0%
Vertex finding efficiency	0.5%
pT>40GeV cut efficiency	6.0%
cross sections and branching ratios	
Gluon-gluon cross section	12.5%(scale) 7.9%(PDF)
Fermiophobic: scale	0.5%(VBF) 0.8%(WH) 1.6%(ZH)
Fermiophobic: PDF	3.1%
Fermiophobic: BR	5.0%

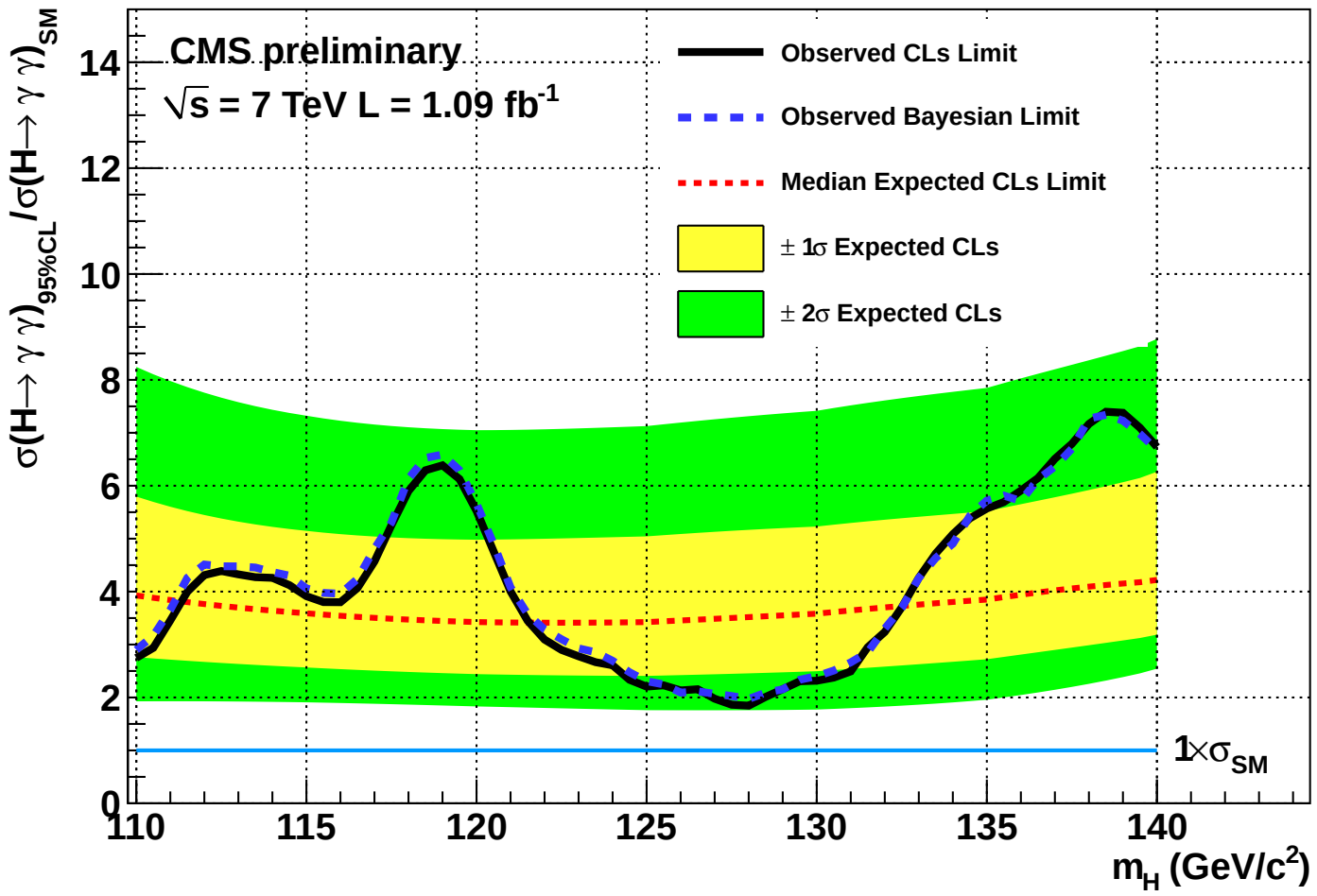
SM Exclusion at 95% CL

- Limits determined in two ways with consistent results
  - Modified frequentist approach (CLs) using profile likelihood
  - Bayesian method with flat prior
- **Excluding between 0.06 and 0.26 pb**



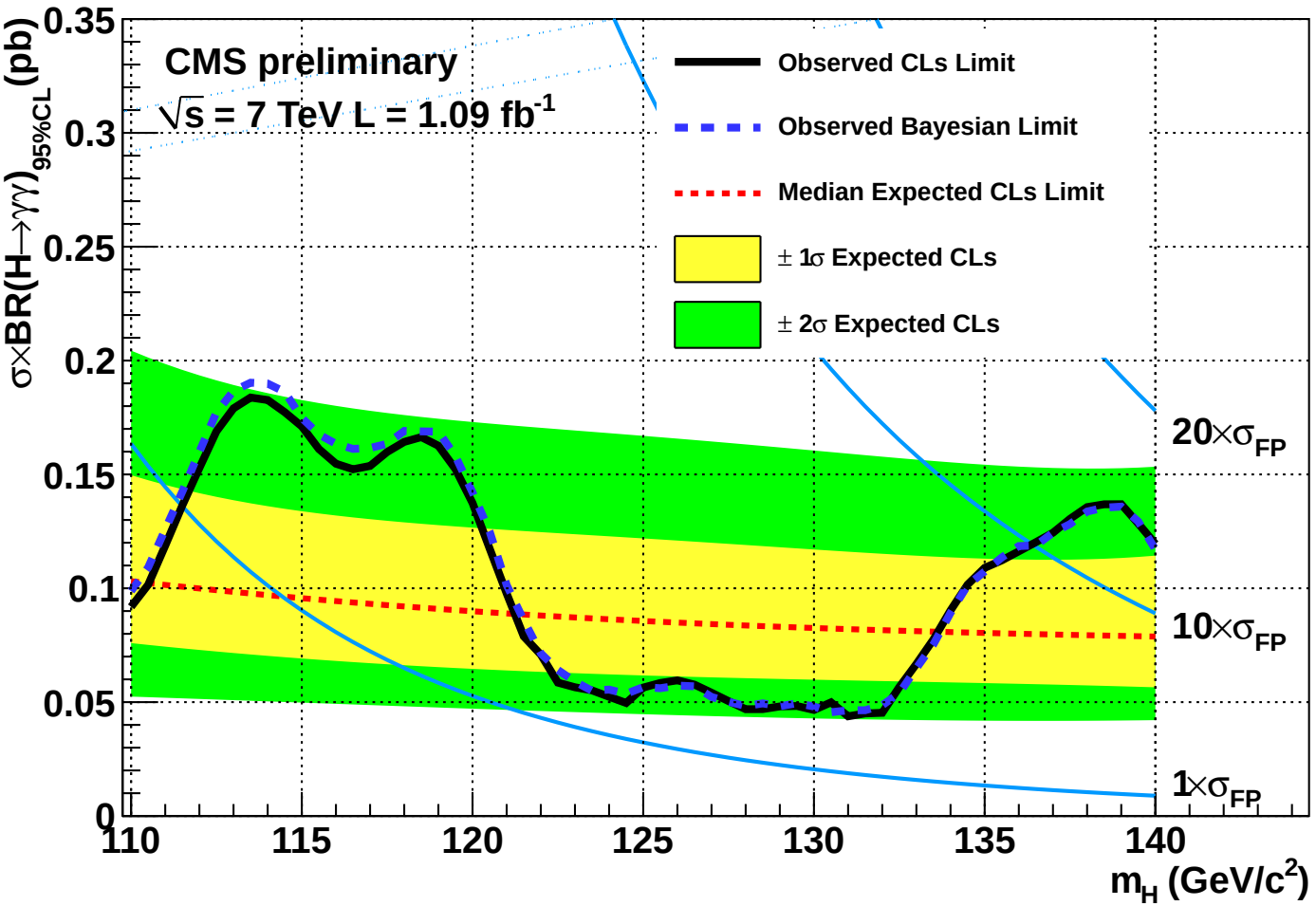
SM Exclusion Relative to σ_{SM}

- Excluding between 1.9 and 7.0 $*\sigma_{SM}$



Fermiophobic Exclusion at 95% CL

- Excluding between 0.04 and 0.18 pb
- Constraining $M_{Fermiophobic} > 111$ GeV/c^2



Conclusions

- $H \to \gamma\gamma$ Analysis
  - Photon selection in categories
  - Vertex selection (from conversions and event topology) improves resolution
  - Resolution measured from $Z \to e^+e^-$
- Limits
  - CL evaluation in event classes $\to$ greater sensitivity
  - Becoming sensitive to SM Higgs (2-6 times σ_{SM}*BR in 110-135 GeV range)
  - Already quite sensitive to Fermiophobic Higgs ($M_{Fermiophobic} > 111$ GeV)
- Outlook
  - More data!
  - Improved CMS $\gamma\gamma$ resolution

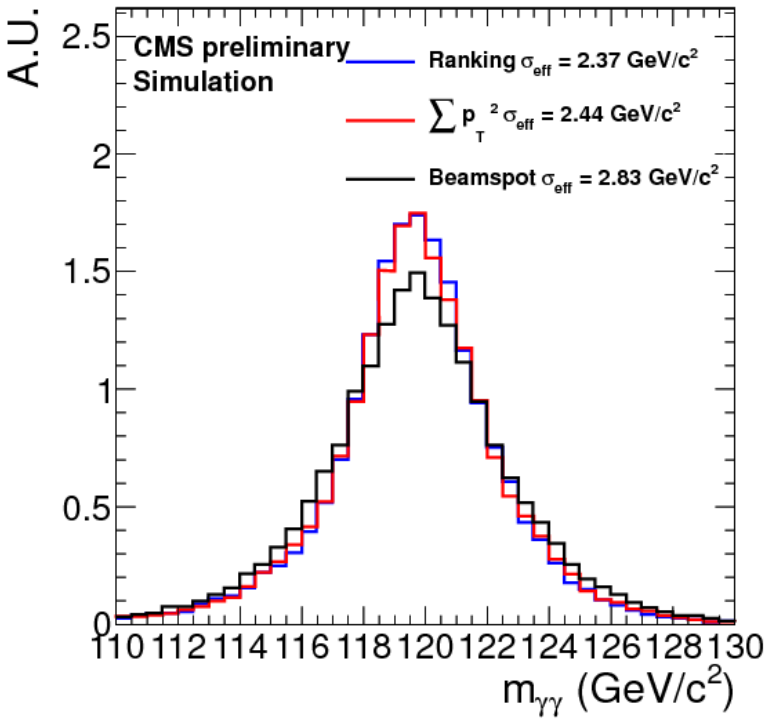
BACKUP

Vertex ID: P_T^{Asym} and P_T^{Bal}

- $$P_T^{Asym} = \frac{\left(\sum_{Tracks} P_T - P_T^{\gamma\gamma} \right)}{\left(\sum_{Tracks} P_T + P_T^{\gamma\gamma} \right)}$$

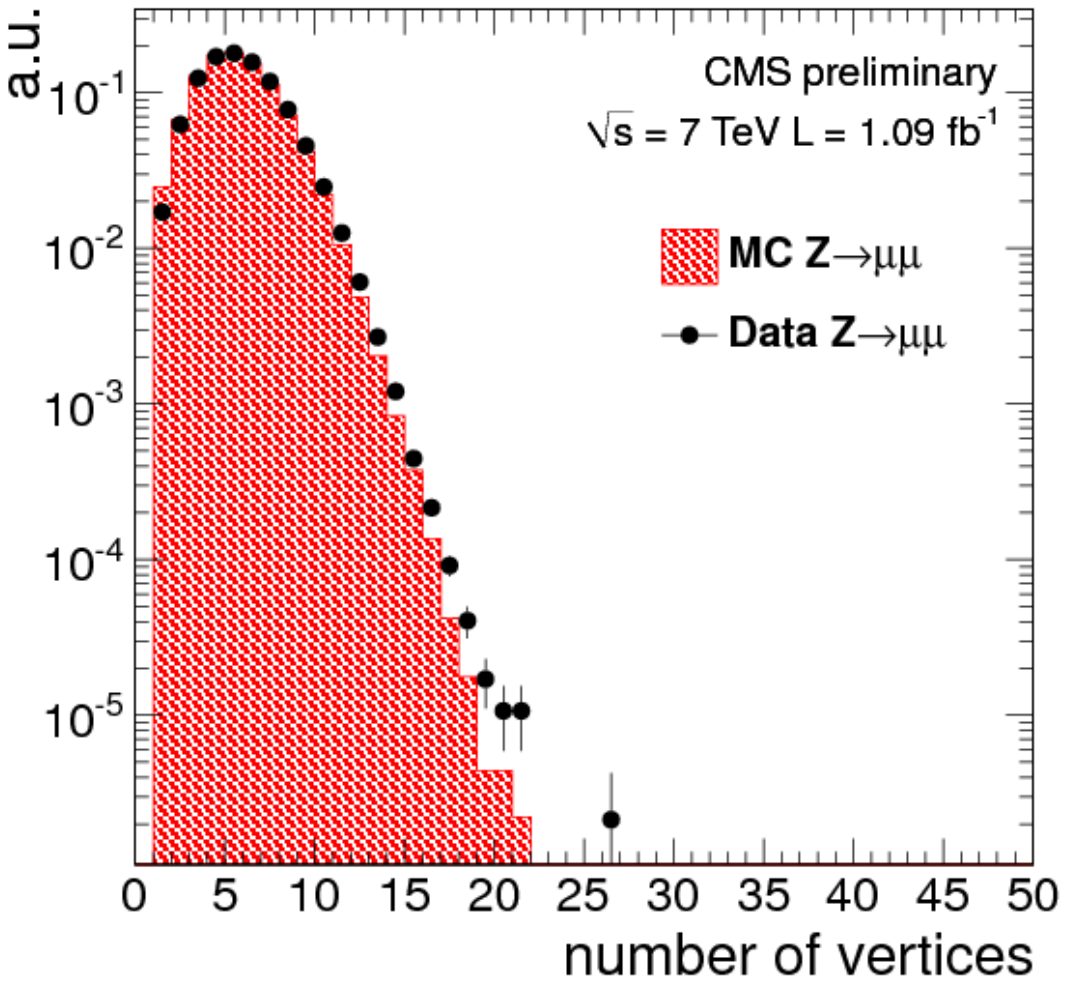
- $$P_T^{Bal} = -\left(\sum_{Tracks} P_T \cdot \frac{\bar{P}_T^{\gamma\gamma}}{|\bar{P}_T^{\gamma\gamma}|} \right)$$

Simulated Mass Resoluiton



Vertex Re-weighting Validation

Re-weighting applied on the number of in-time pile-up events according to the number of expected number of interactions in data.

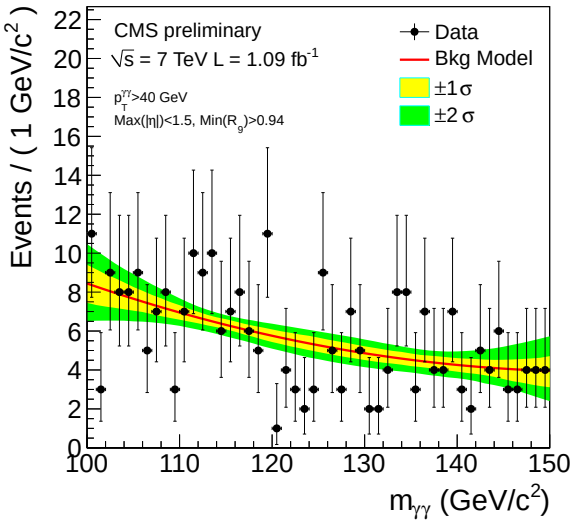


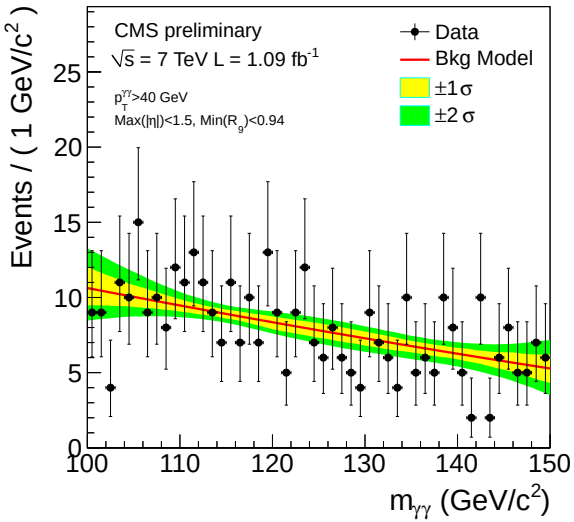
$P_T^{\gamma\gamma} > 40$ Fits in Data

2 high R_9 γ's

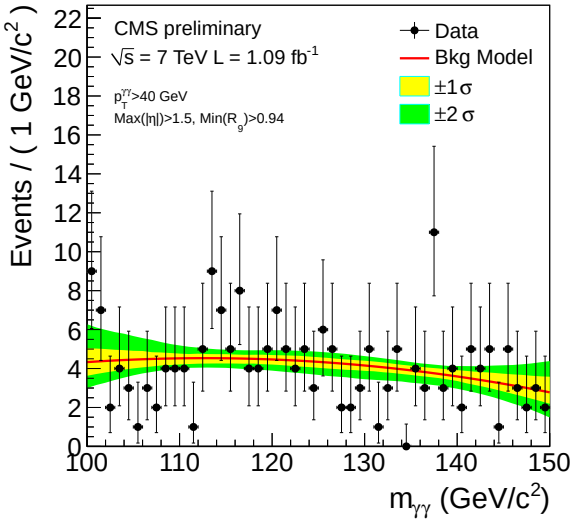
1 or 2 low R_9 γ's

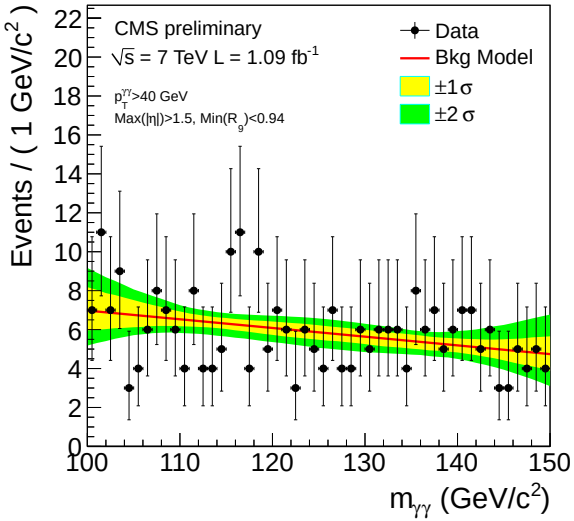
2 barrel γ's





1 or 2 endcap γ's





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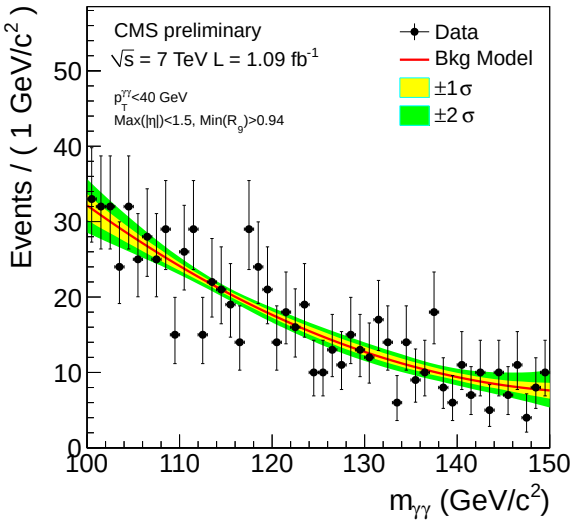

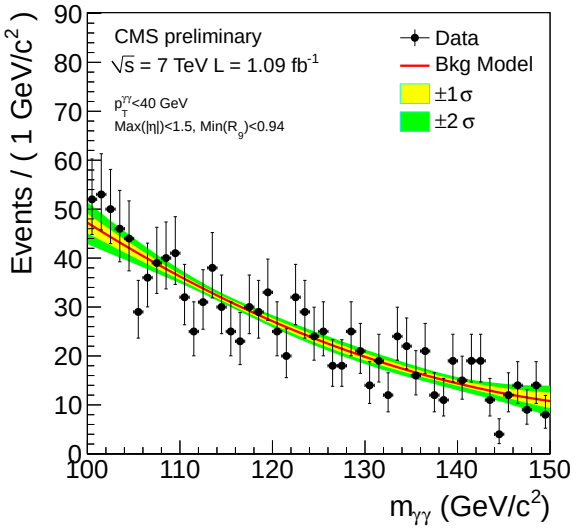

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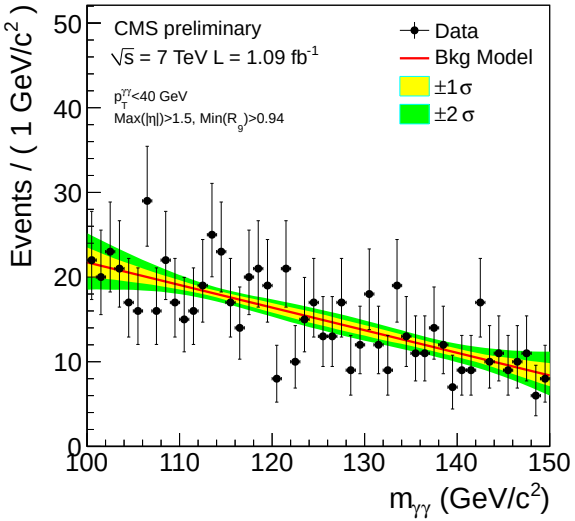
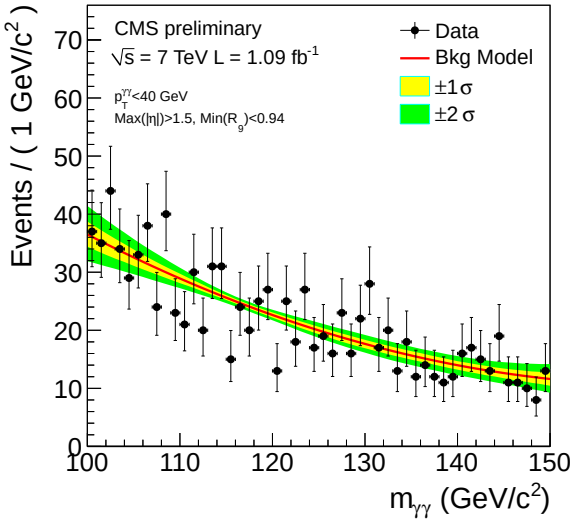
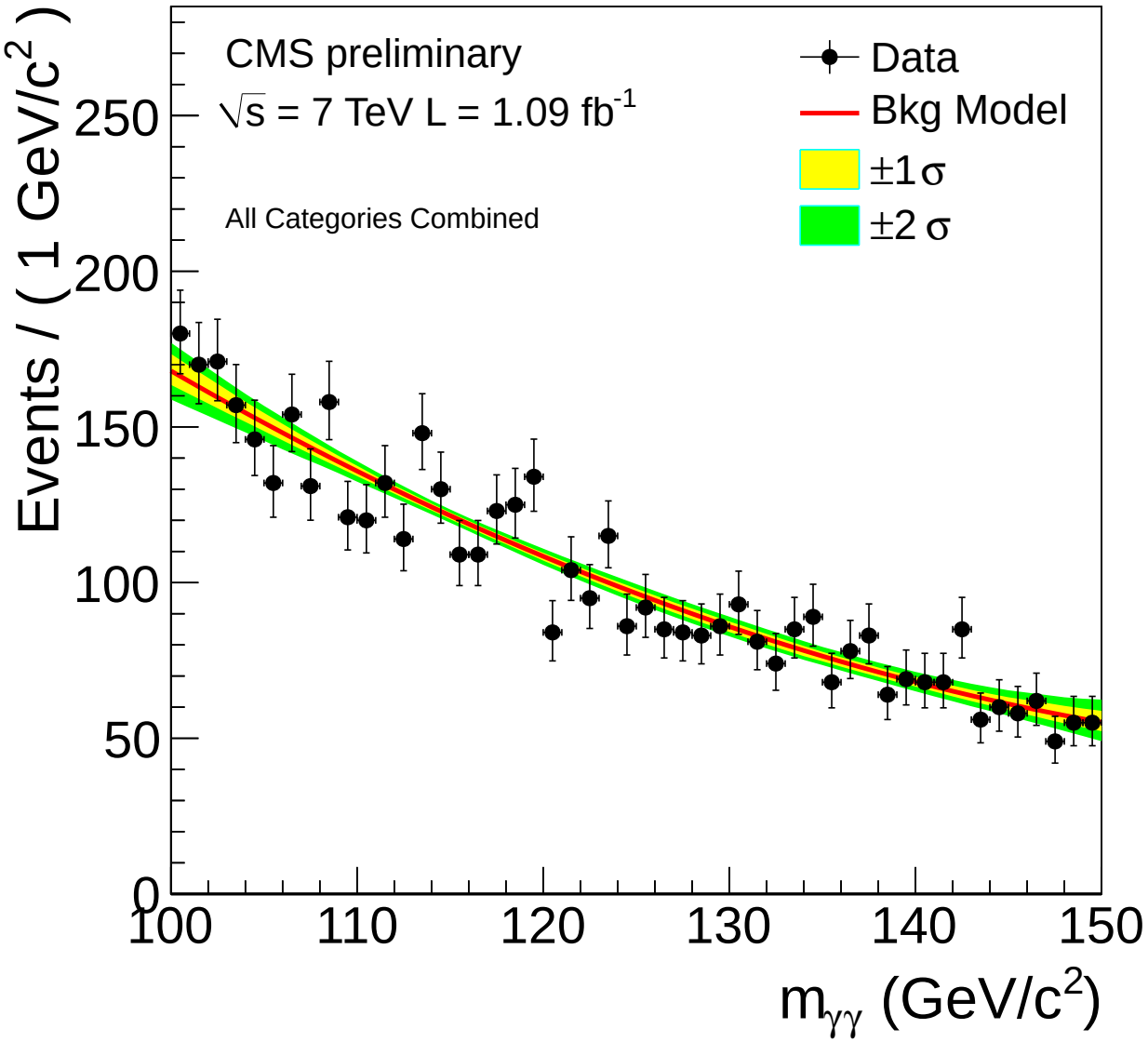




Combined Fits from Data

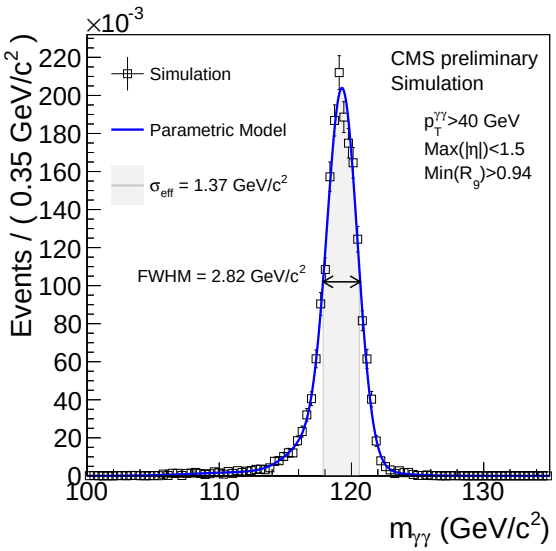


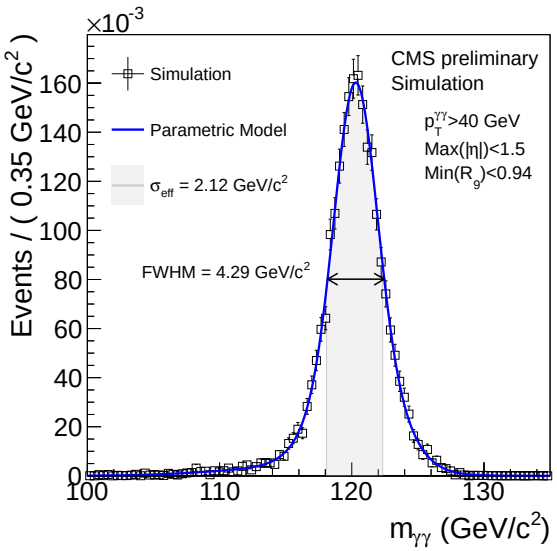
$P_T^{\gamma\gamma} > 40$ Resolution with Smearing

2 high R_9 γ's

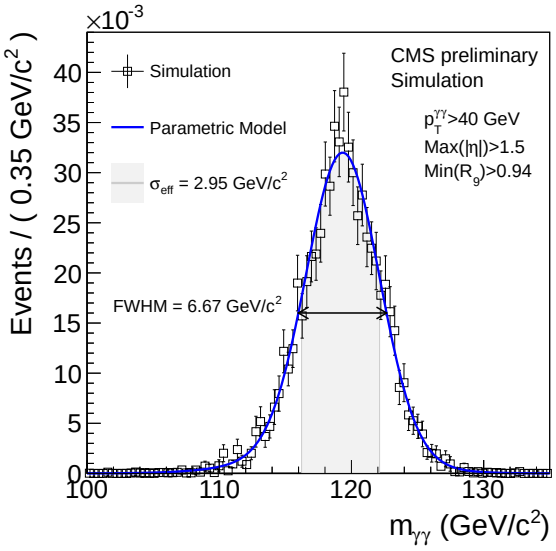
1 or 2 low R_9 γ's

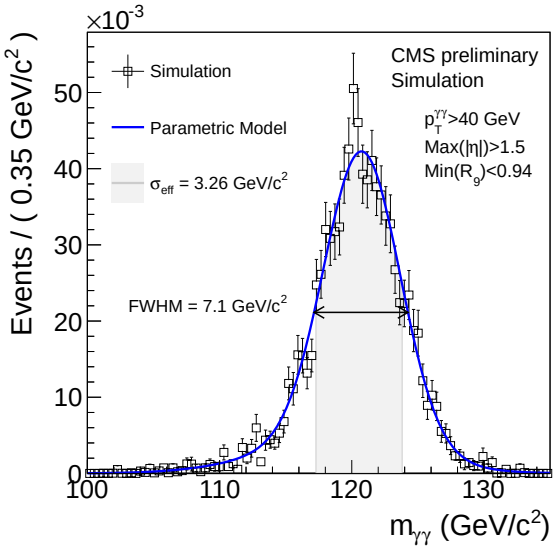
2 barrel γ's





1 or 2 endcap γ's





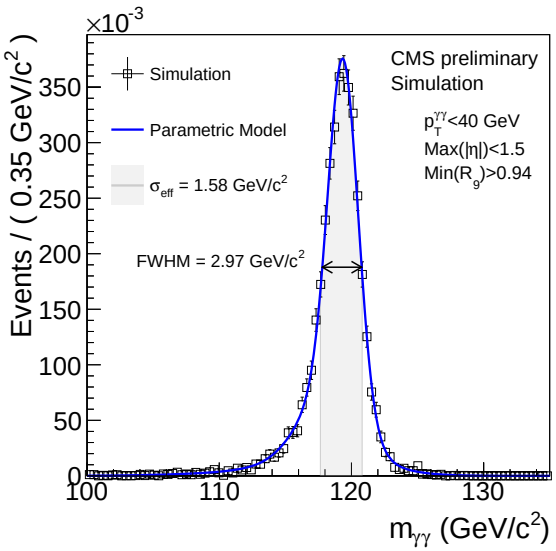
$P_T^{\gamma\gamma} < 40$ Resolution with Smearing

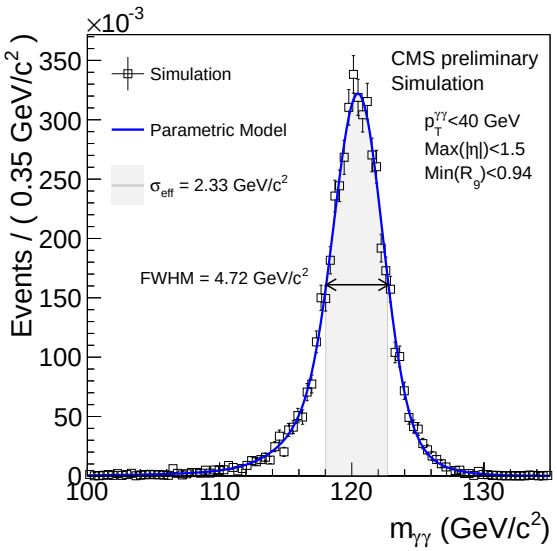
2 high $R_9\,\gamma$'s

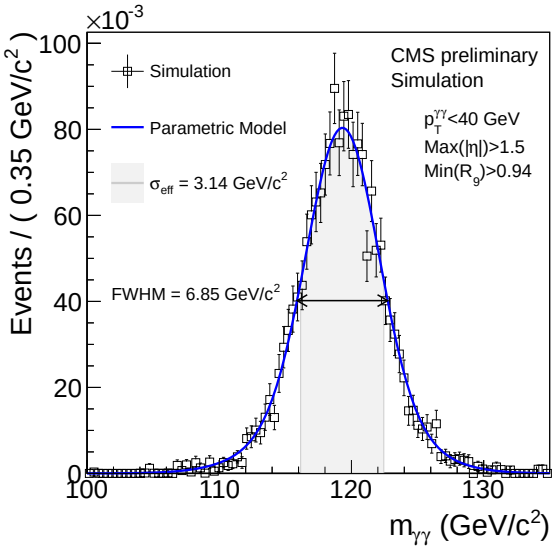
1 or 2 low $R_9\,\gamma$'s

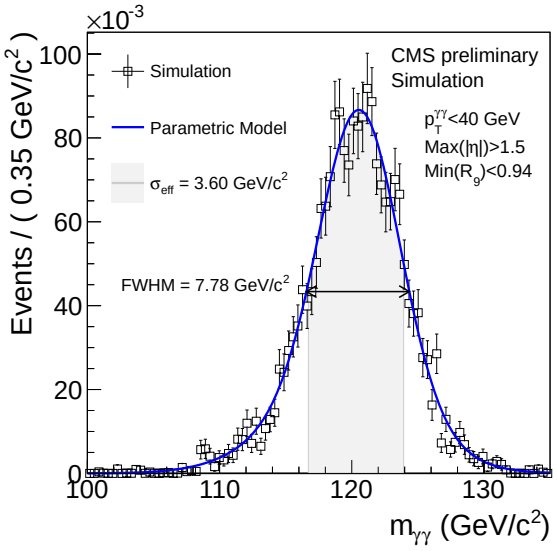
2 barrel γ's

1 or 2 endcap γ's

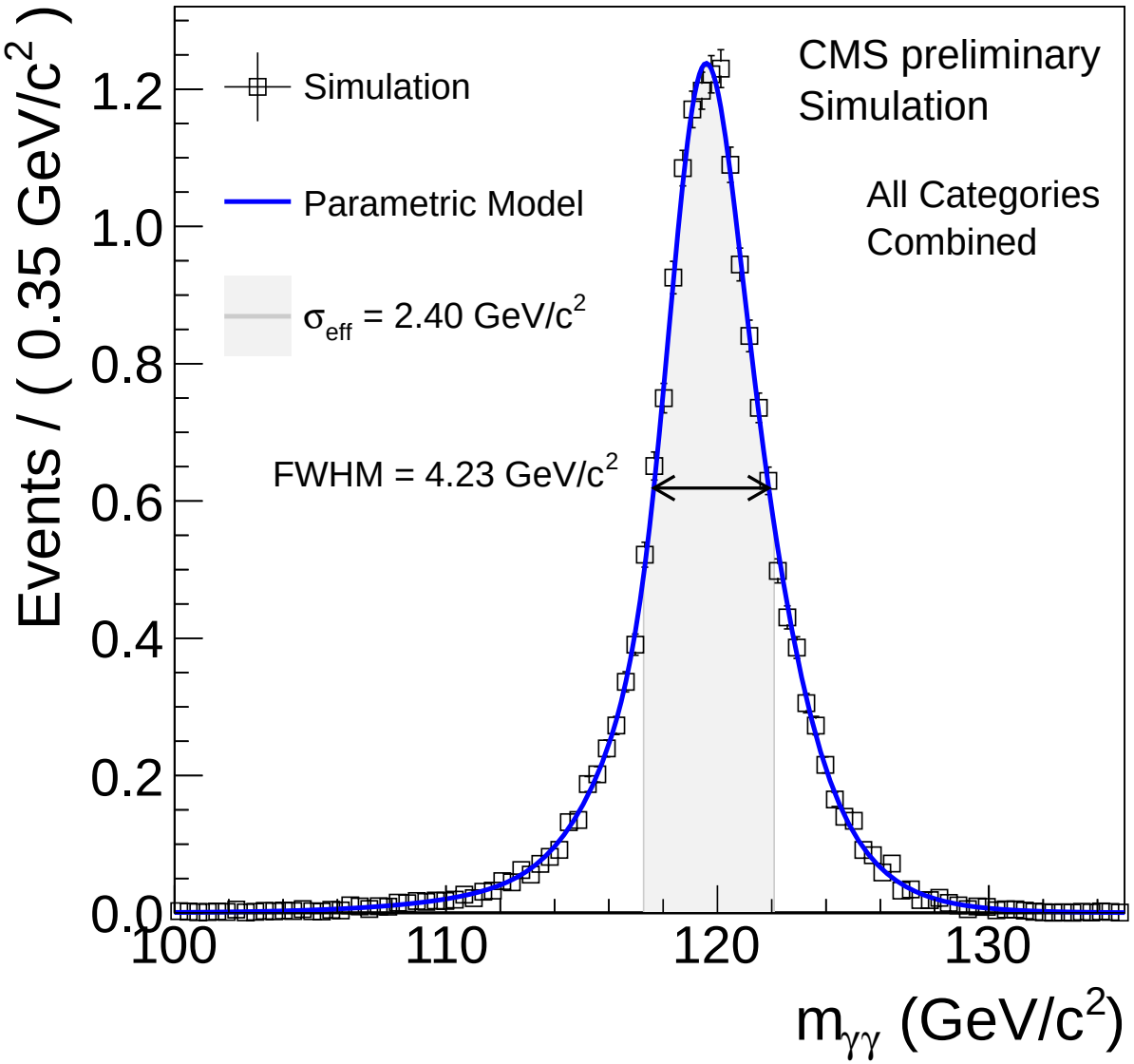




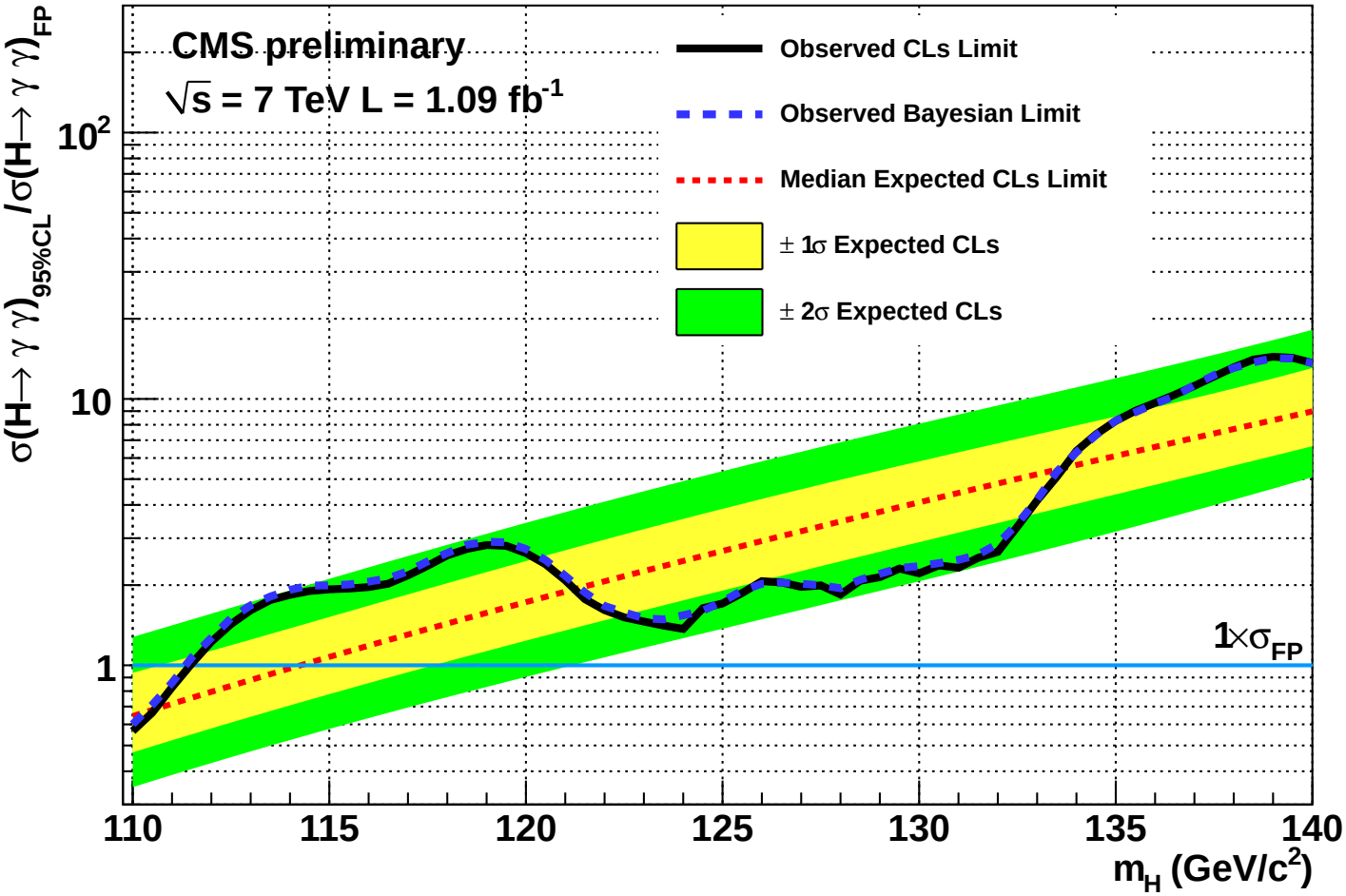




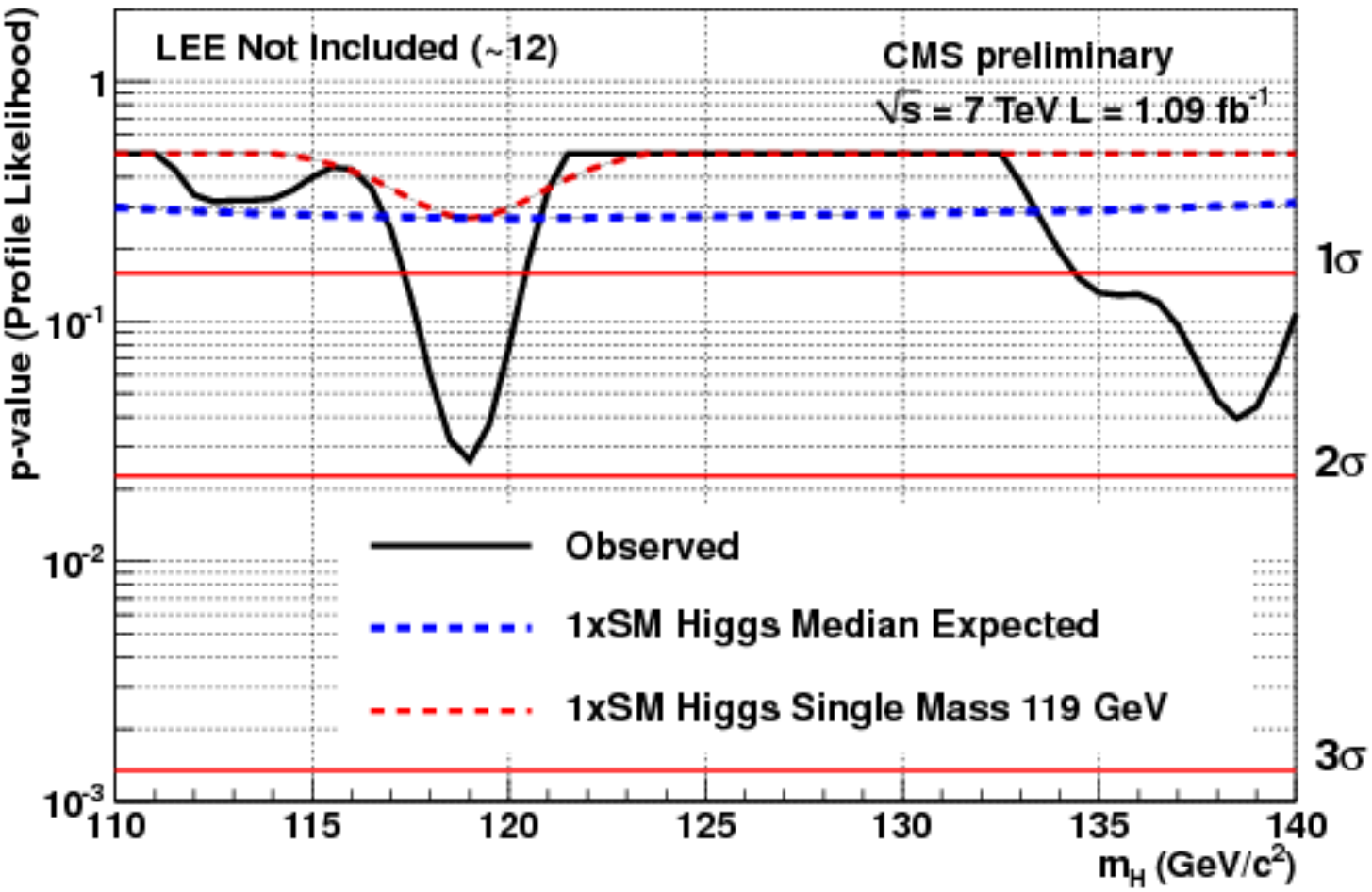
Combined Resolution with Smearing



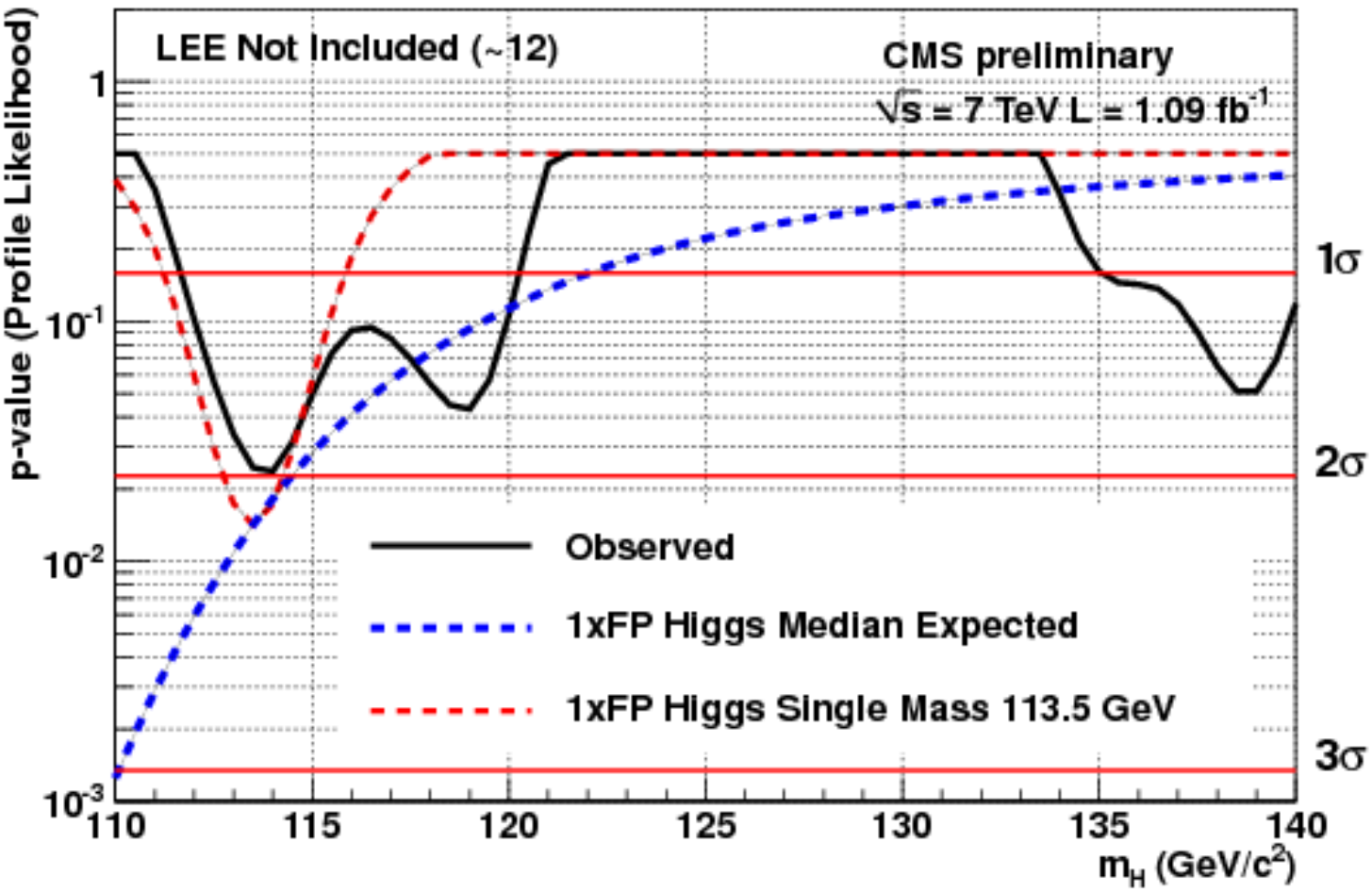
Limits Relative to Fermiophobic Cross Section



P-Values (SM)


LEE Not Included (~12)
CMS preliminary
√s = 7 TeV L = 1.09 fb-1
p-value (Profile Likelihood)
1
10-1
10-2
10-3
110
115
120
125
130
135
140
mH (GeV/c2)
Observed
1xSM Higgs Median Expected
1xSM Higgs Single Mass 119 GeV
1σ
2σ
3σ

P-Values (Fermiophobic)



Associated Public Documents

- CMS PAS HIG-11-010 ($H \to \gamma\gamma$ PAS)
  cdsweb.cern.ch/record/1369553/files/HIG-11-010-pas.pdf
- CMS PAS HIG-11-011 (Higgs combination PAS
  cdsweb.cern.ch/record/1370076/files/HIG-11-011-pas.pdf
- Other public plots
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig11010TWiki