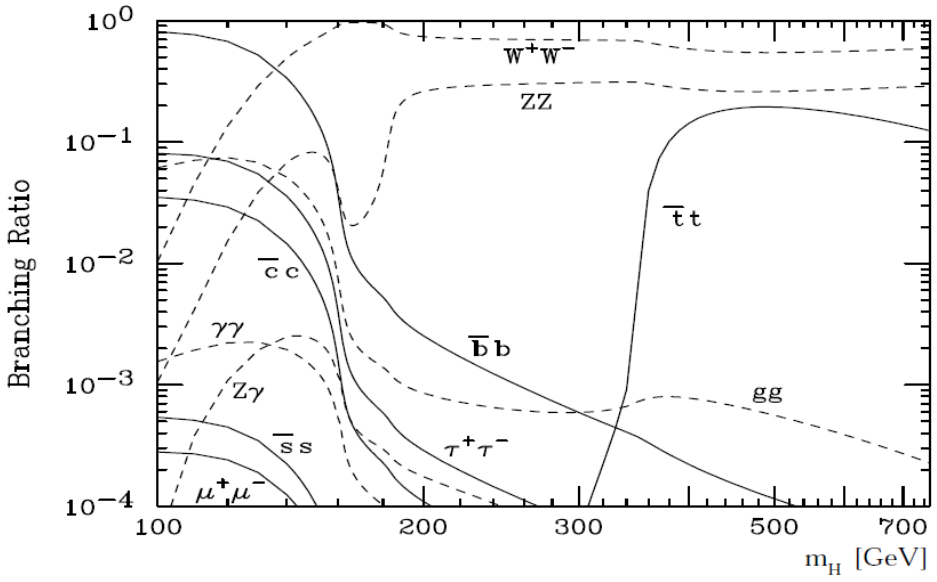
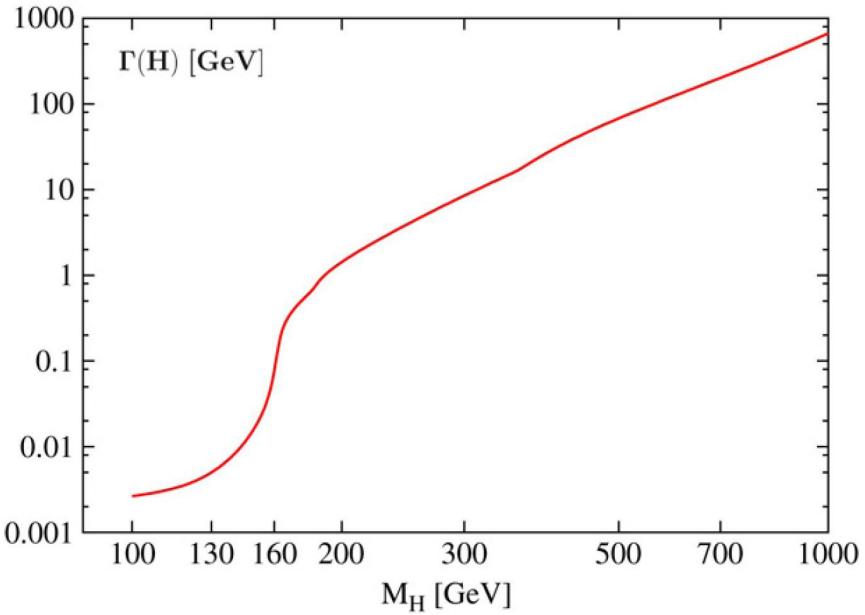
Inclusive Search for the $H \rightarrow \gamma\gamma$

- Why $H \rightarrow \gamma\gamma$?
- Ongoing work

Why $H \rightarrow \gamma\gamma$?



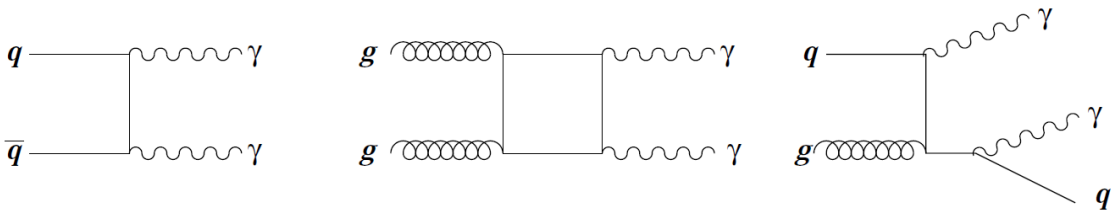
- Below $2M_W$ we cannot produce heavy on-shell particles
- $H \rightarrow \gamma\gamma$
  - Probability peaks at about 120 GeV and decreases rapidly because of the strong competition from direct decay of Higgs to W boson pairs, which at high mass becomes most frequent mode of disintegration
- For light Higgs this is an important channel



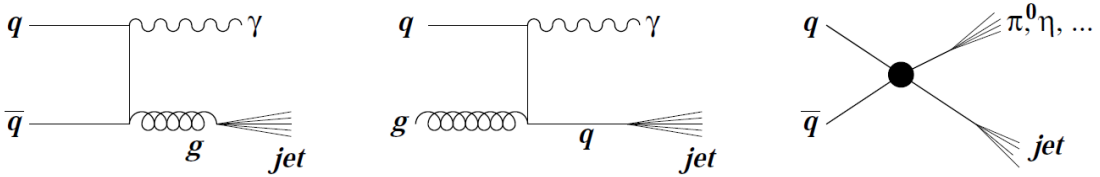
- CMS calorimetry allow excellent narrow peak reconstruction for $H \rightarrow \gamma\gamma$
  - Search for two isolated energetic photons

Analysis Challenges

Irreducible backgrounds



Reducible bakgrounds



- Born, Box and isolated bremsstrahlung
- $d\sigma/dm_{\gamma\gamma} \sim 100$ fb/(GeV/c^2)
- Require very good mass resolution: ~1 GeV/c^2

- QCD high p_T jet processes
- Fake γ from π^0 and η hadrons
- Need jet suppression: $\varepsilon \sim 10^{-3}$

Process	p_T (GeV/c)	σ_{LO} (pb)
$H \rightarrow \gamma\gamma$ (120 GeV/c^2)	–	0.057 (NLO)
pp$\rightarrow \gamma\gamma$ (born)	> 25	32
pp$\rightarrow \gamma\gamma$ (box)	> 25	22
pp$\rightarrow \gamma$+jet	> 40	4×10^4
pp$\rightarrow$jets	> 60	6.6×10^6

Signal and Background Data Samples and Cross Sections

Summer08/Fall08 Signal Samples at $\sqrt{s} = 10$ TeV

Process	Generator	#Events	σ^{gen}	σ^{sim}	$\int Ldt$, (fb^{-1})
H120 (gluonfusion)	MCatNLO	20k	40.8±0.7 fb	40.8 fb	490
H120 (all)	PYTHIA (LO)	20k	38 fb	38 fb	526

PYTHIA Signal Cross Section for $M(H) = 120\,\mathrm{GeV}/c^2$

$\sqrt{s}$	gg fusion	WW fusion	ZZ fusion	WH	ZH	ttH
14 TeV	49 fb	9 fb	3.4 fb	3.7 fb	2.1 fb	1.5 fb
10 TeV	27 fb	4.9 fb	1.8 fb	2.5 fb	1.2 fb	0.6 fb

NLO Cross Sections

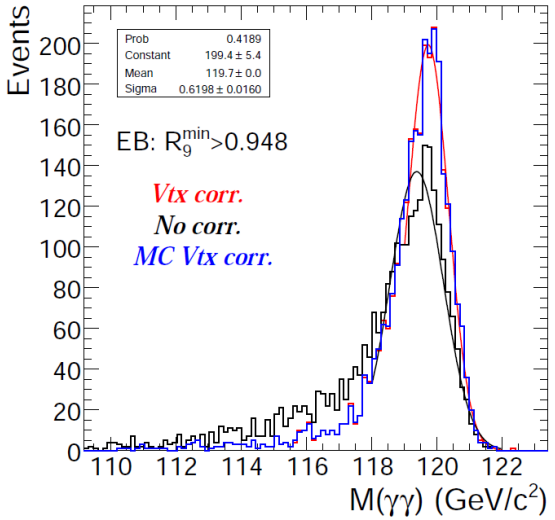
$M(H)$	σ (fb)
120 GeV	57.4
130 GeV	49.9
150 GeV	23.2

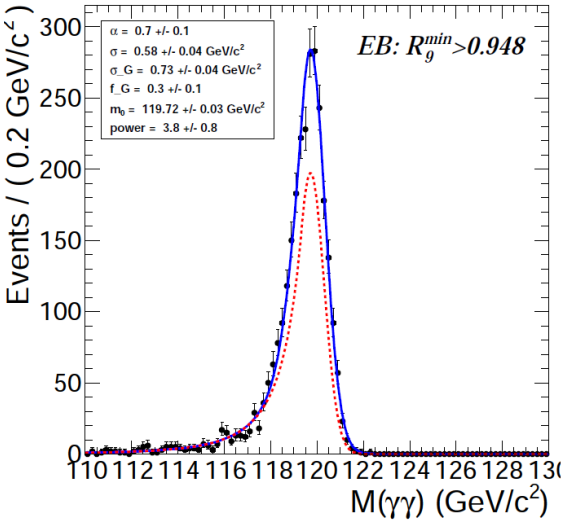
Summer08/Fall08 Background Samples at $\sqrt{s} = 10$ TeV

Process	Generator	$\sqrt{s}$	$\hat{p}_T(H_t)$	#Events	σ^{gen}	σ^{sim}	Lum (fb^{-1})
$gg \to \gamma\gamma$ (box)	PYTHIA	10 TeV	25	500k	22 pb	22 pb	22.7
$gg \to \gamma\gamma$ (box)	PYTHIA	10 TeV	$10 \div 25$	500k	580 pb	580 pb	0.86
$qq \to \gamma\gamma$ (born)	MADGRAPH	10 TeV	10	1M	210 pb	210 pb	4.8
$pp \to \gamma + jets$	MADGRAPH	10 TeV	$40 \div 100$	1.96M	40.6 nb	40.6 nb	0.0483
$pp \to \gamma + jets$	MADGRAPH	10 TeV	$100 \div 200$	730k	8.3 nb	8.3 nb	0.0877
$pp \to \gamma + jets$	MADGRAPH	10 TeV	$200 \div$ Inf	2.18M	0.99 nb	0.99 nb	2.2
QCD Jets	PYTHIA	10 TeV	60	245k	6.6 ub	6.6 nb	0.037
$gg \to \gamma\gamma$ (box)	PYTHIA	14 TeV	25	500k	36 pb	36 pb	13.9
$qq \to \gamma\gamma$ (born)	PYTHIA	14 TeV	25	-	45 pb	-	-
$qq \to \gamma\gamma$ (born)	PYTHIA	10 TeV	25	-	32 pb	32 pb	-
QCD Jets	PYTHIA	14 TeV	60	245k	12.2 ub	12 nb	0.02

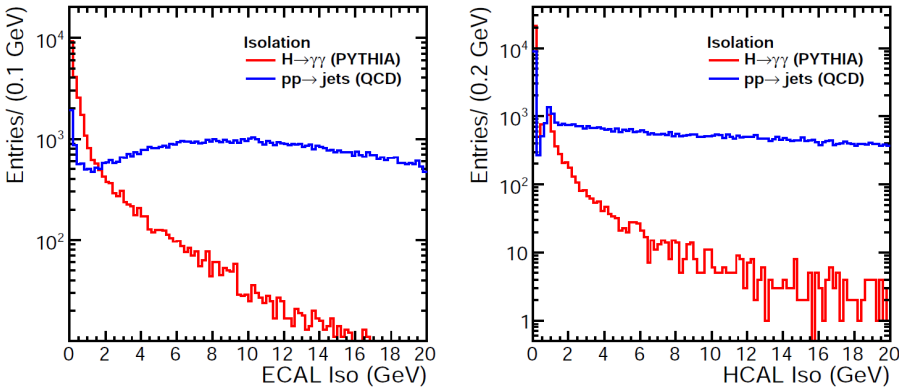
Event Selection

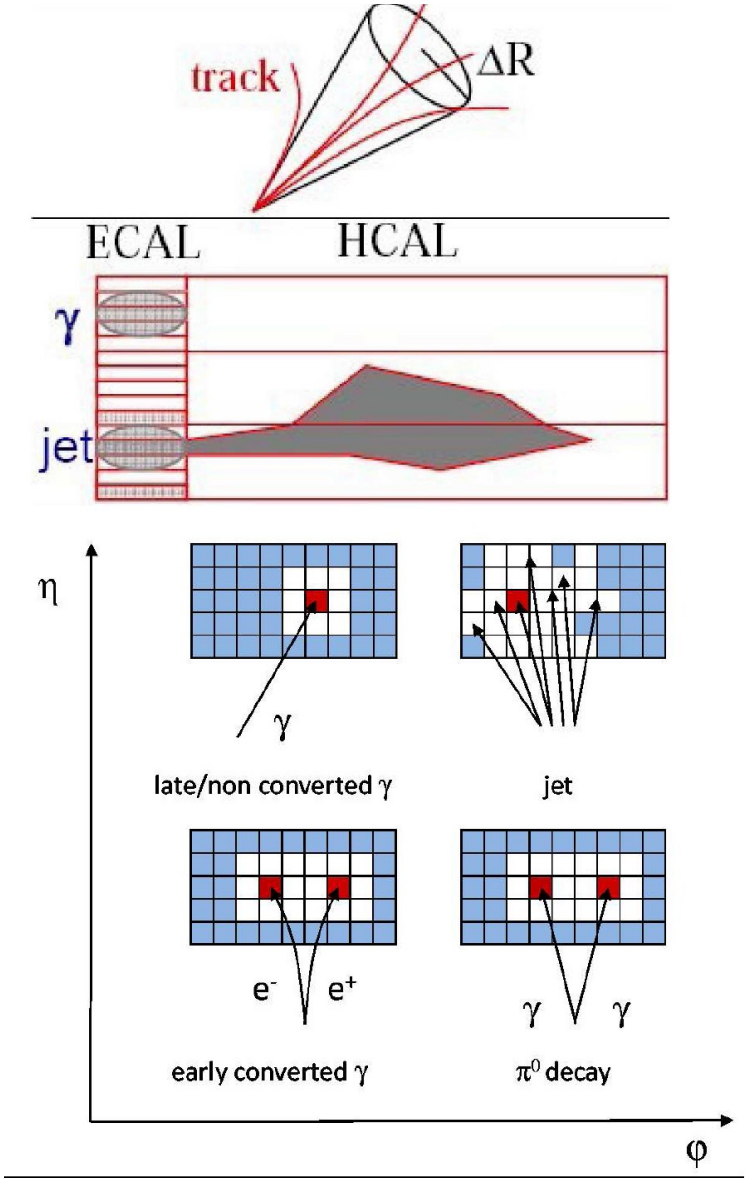
- Combine two highest p_T photons in the event to form the Higgs candidate (DoublePhoton HLT path)
  - Negligible effect on vertex resolution
  - Efficiency of finding two photon vertex (no pile-up samples)
- Best obtained resolution for EB non-converted di-photon events





Isolation and γ conversions

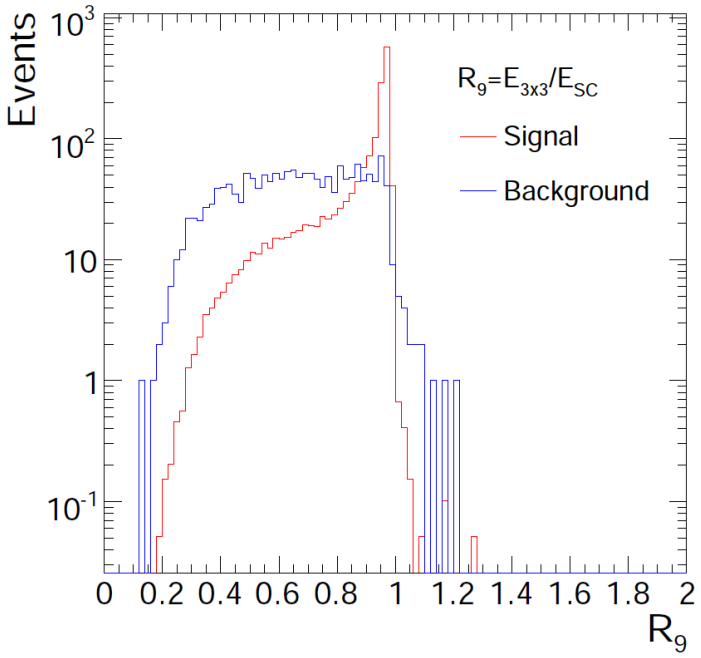




- Neutral hadrons (π^0, η) from fragmentation processes fake photons
- Isolation exploit 3 subdetectors variables computed inside a cone
- High value of R_9 identifies non-converted photons

Categories

- Divide events according to signal purity
  - S/B varies with η;
  - different resolution for EB and EE;
  - conversion degrades resolution and raises bkg.



4 categories

	$\lvert\eta^{max}\rvert < 1.479$	$\lvert\eta^{max}\rvert > 1.479$
$R_9^{min} > 0.93$	25.4%	25.5%
$R_9^{min} < 0.93$	26.6%	22.5%

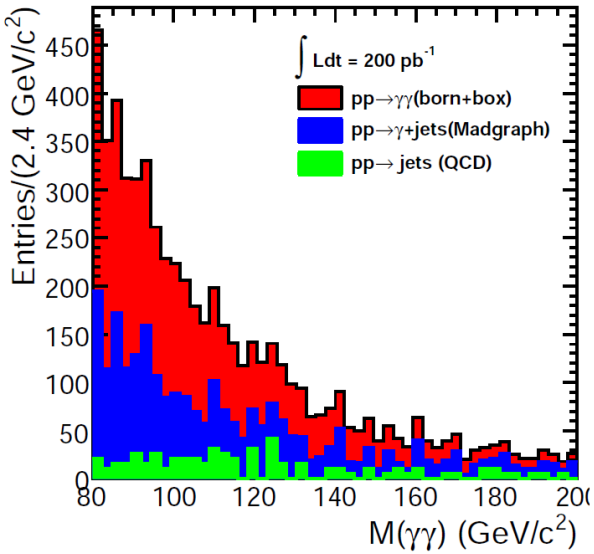
6 categories

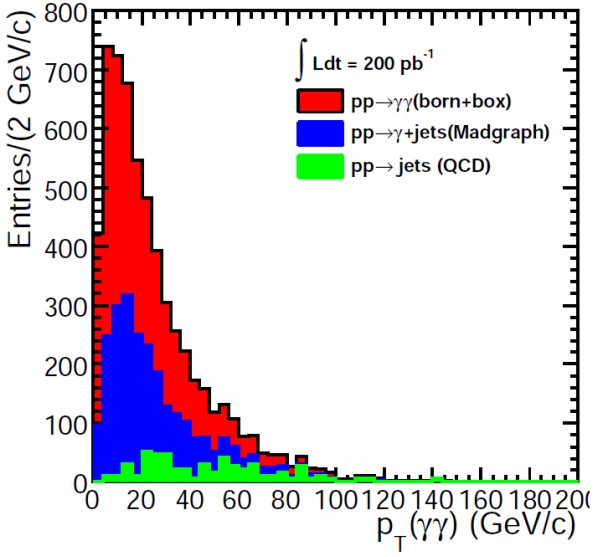
	$\lvert\eta^{max}\rvert < 1.479$	$\lvert\eta^{max}\rvert > 1.479$
$R_9^{min} > 0.948$	19.0%	21.7%
$0.9 < R_9^{min} < 0.948$	9.7%	7.0%
$R_9^{min} < 0.9$	23.3%	19.3%

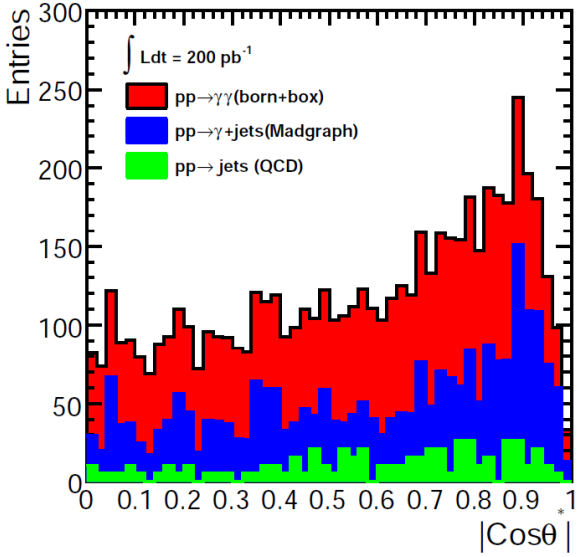
12 categories

	$\lvert\eta^{max}\rvert < 0.9$	$0.9 < \lvert\eta^{max}\rvert < 1.479$	$1.479 < \lvert\eta^{max}\rvert < 2.1$	$\lvert\eta^{max}\rvert > 2.1$
$R_9^{min} > 0.948$	10.7%	8.3%	9.0%	12.7%
$0.9 < R_9^{min} < 0.948$	5.1%	4.7%	4.0%	2.9%
$R_9^{min} < 0.9$	8.2%	15.1%	12.0%	7.3%

Di-Photon Yield







- Signal assumption
  - apply k-factor 1.2 for box (Pythia);
  - no k-factor for the born (Madgraph);
- Limited statistics to estimate background yields per categories
- Isolation cuts are included

Event yields for $\int Ldt = 200\,\mathrm{pb}^{-1}$ and $\sqrt{s} = 10$ TeV

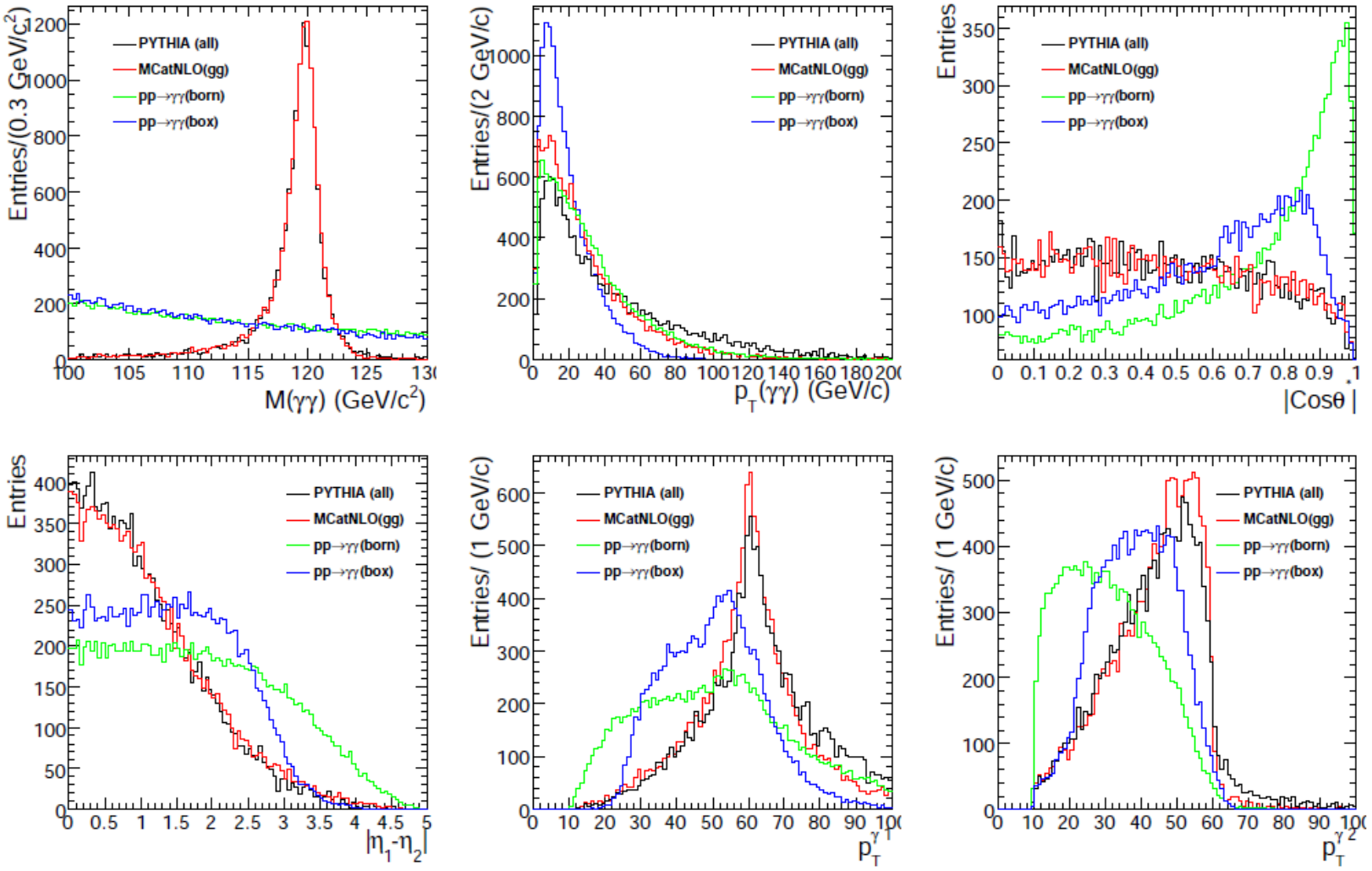
Process	$\lvert\Delta m\rvert < 5$	$[100, 150]$	> 80
H$\longrightarrow \gamma\gamma$	4.6	5.0	5.0
pp$\longrightarrow \gamma\gamma$(born)	266	1291	3327
pp$\longrightarrow \gamma\gamma$(box)	74	353	963
pp$\longrightarrow \gamma$+jets	165	825	2297
pp$\longrightarrow$ QCD	70	281	670

Observables and Correlations

lin. corr. coef. (%)		| cos θ* |	PT (H)	| Δη (γ) |	PT (γ1)	PT (γ2)
Signal	m (H)	3	0	3	2	2
Box		3	4	5	12	13
Born		2	5	5	10	10
γ+jets		4	5	9	7	7
QCD γγ		6	2	9	5	8
Signal	PT (γ2)	-53	35	-57	29	
Box		-72	7	-90	66	
Born		-59	-11	-70	15	
γ+jets		-46	-6	-64	15	
QCD γγ		-80	-3	-83	45	
Signal	PT (γ1)	-6	87	-43		
Box		-59	63	-87		
Born		-21	81	-71		
γ+jets		-15	87	-78		
QCD γγ		-57	63	-80		
Signal	| Δη (γ) |	53	-14			
Box		74	-30			
Born		54	-30			
γ+jets		39	-48			
QCD γγ		84	-21			
Signal	PT (H)	-1				
Box		-19				
Born		-2				
γ+jets		-3				
QCD γγ		-7				

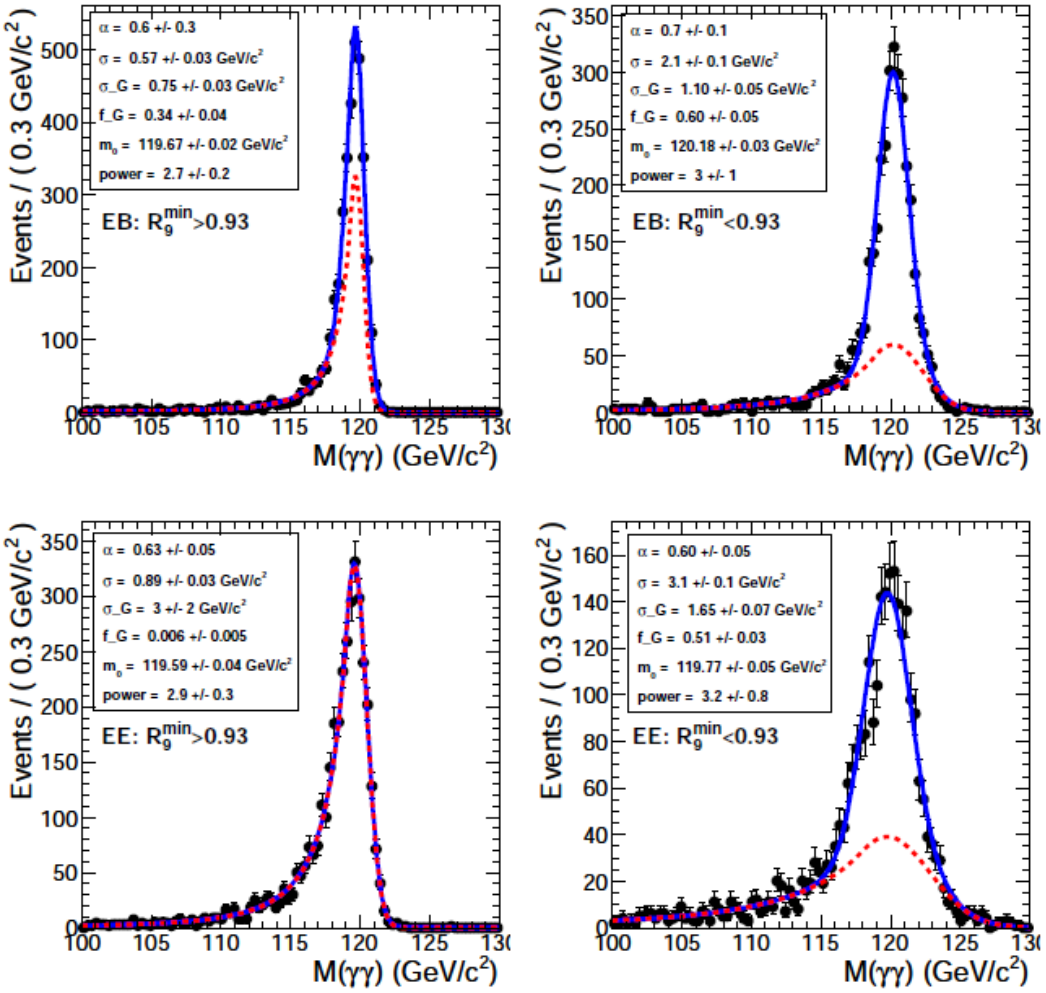
- Correlations of $m_{\gamma\gamma}$ with others ≤ 5% (15%) for signal (background: 4 event types)

Discriminating variables

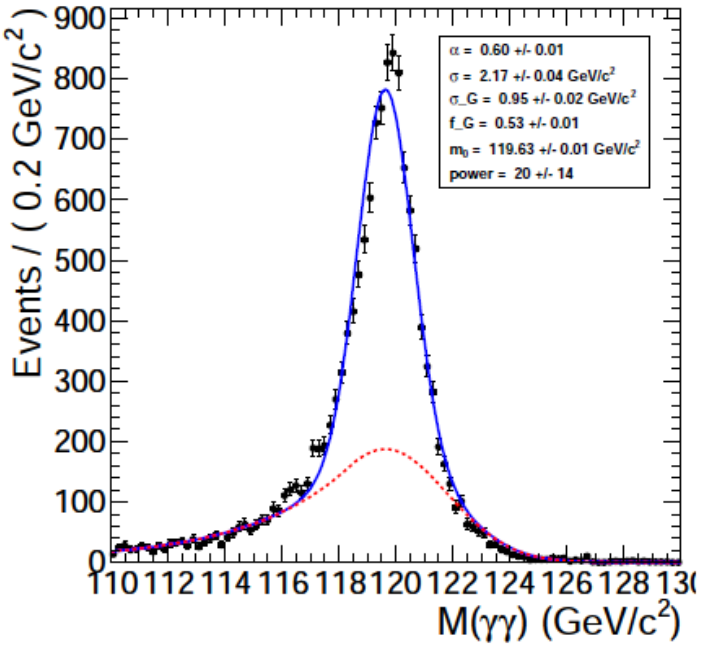


Signal Resolution Model

Model: Crystal Ball + Gaussian



Fit of all categories



	Barrel	Endcap
$R_9^{min} > 0.93$	25.4%	25.5%
$R_9^{min} < 0.93$	26.6%	22.5%

$\Delta M_{\gamma\gamma} \sim 0.6 \div 2.2\,\mathrm{GeV}/c^2$

Model Optimization

- Test different models
  - Extended unbinned ML fit
  - Estimate significance (Profile Likelihood)

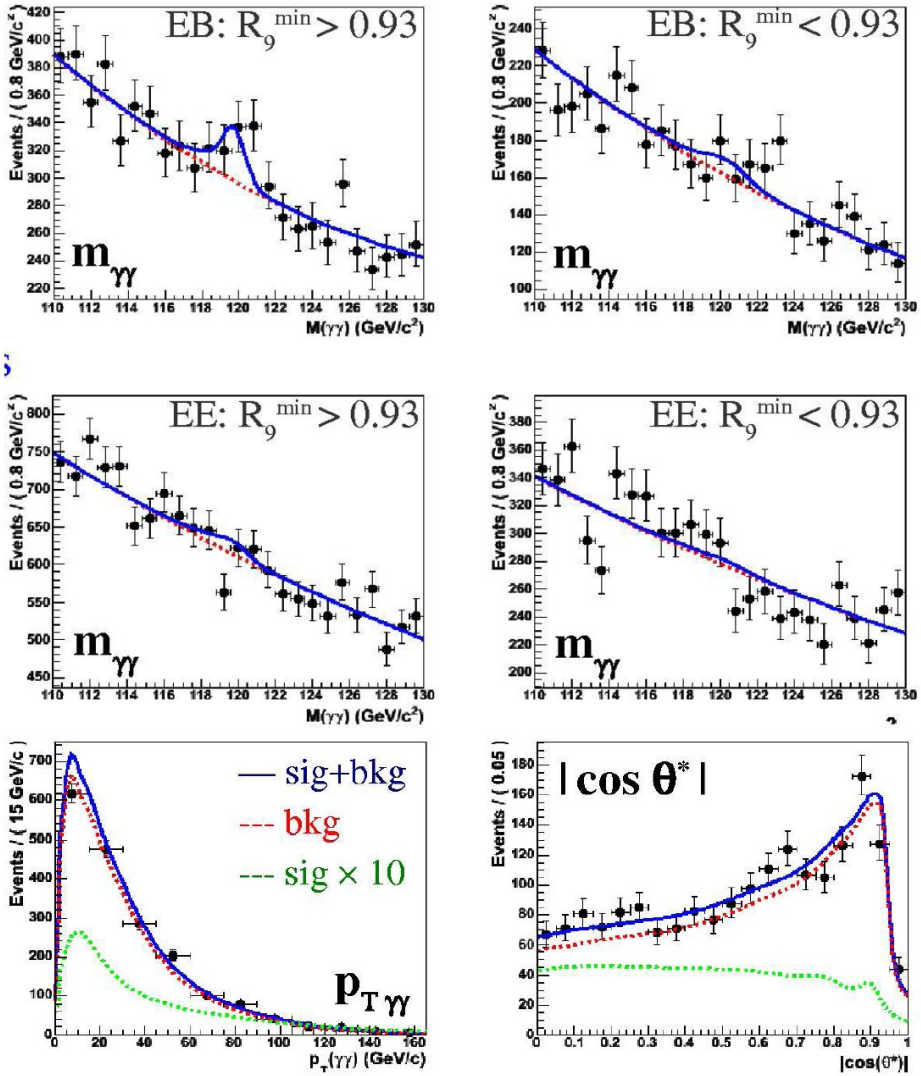
$10\,\mathrm{fb}^{-1}$ and $\sqrt{s} = 10$ TeV

Model	$\langle S_L \rangle$
$\mathcal{L}(m_{\gamma\gamma})$	2.14±0.03
$\mathcal{L}(m_{\gamma\gamma}, p_T)$	2.66±0.03
$\mathcal{L}(m_{\gamma\gamma}, \cos\theta^*)$	2.47±0.03
$\mathcal{L}(m_{\gamma\gamma}, {p_T}^{\gamma\gamma}, \cos\theta^*)$	3.00±0.03
$\mathcal{L}(m_{\gamma\gamma}, {p_T}^{\gamma\gamma}, \cos\theta^*, cat4)$	3.60±0.06

Best performance: Likelihood model based on event topology + 3 discriminating variables

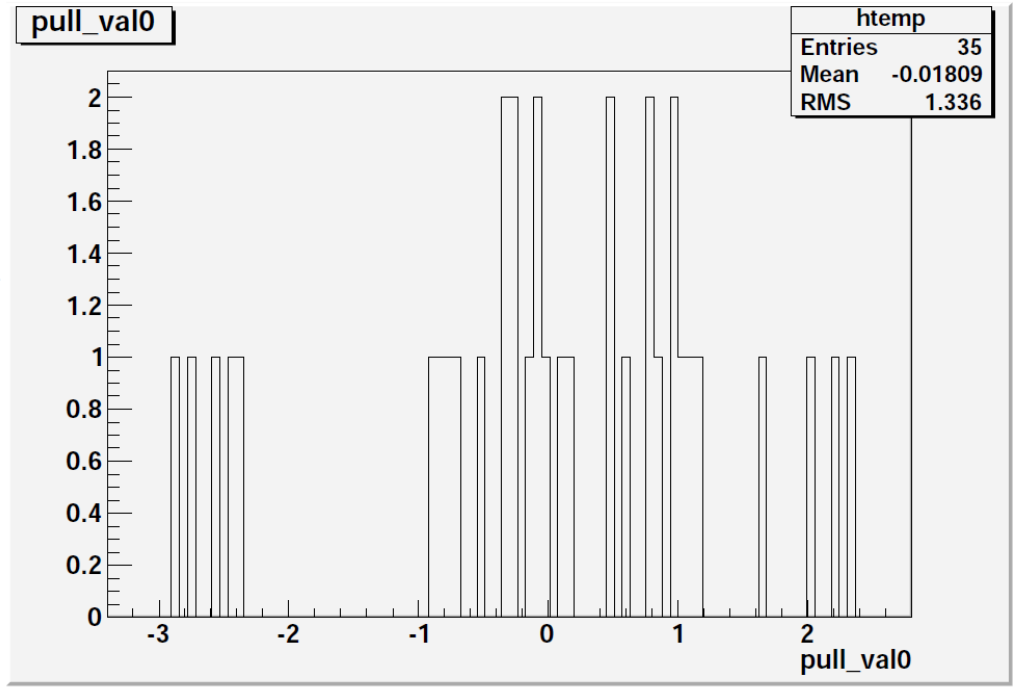
Model

- PDFs for each component are fixed
- Floated parameters N_s, N_b



Model Validation with Toy MC

- Produce 570 $H \rightarrow \gamma\gamma$ events per 10 fb^{-1}
- Divide 20k signal events into 35 independent samples
- Generate toy MC background
- Fit model signal + background

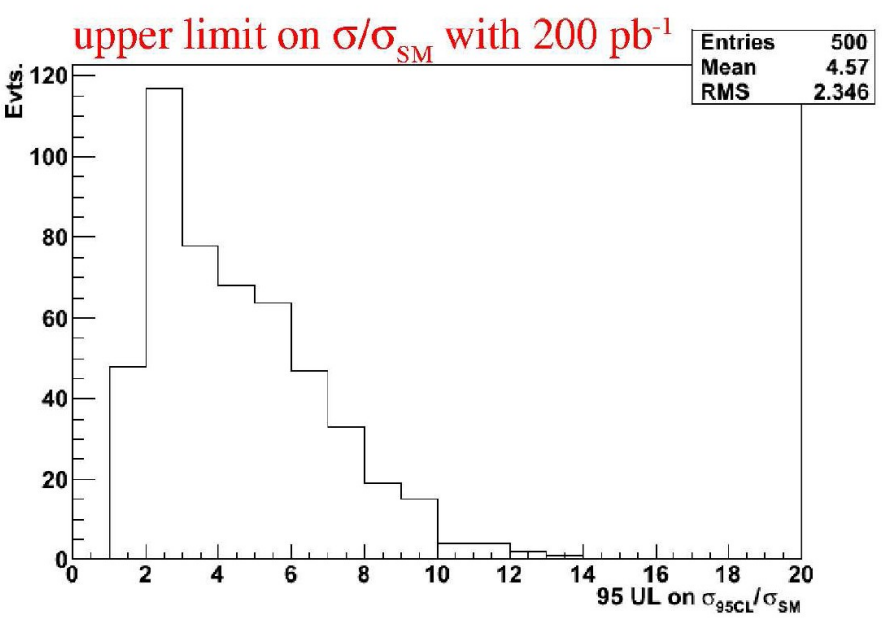


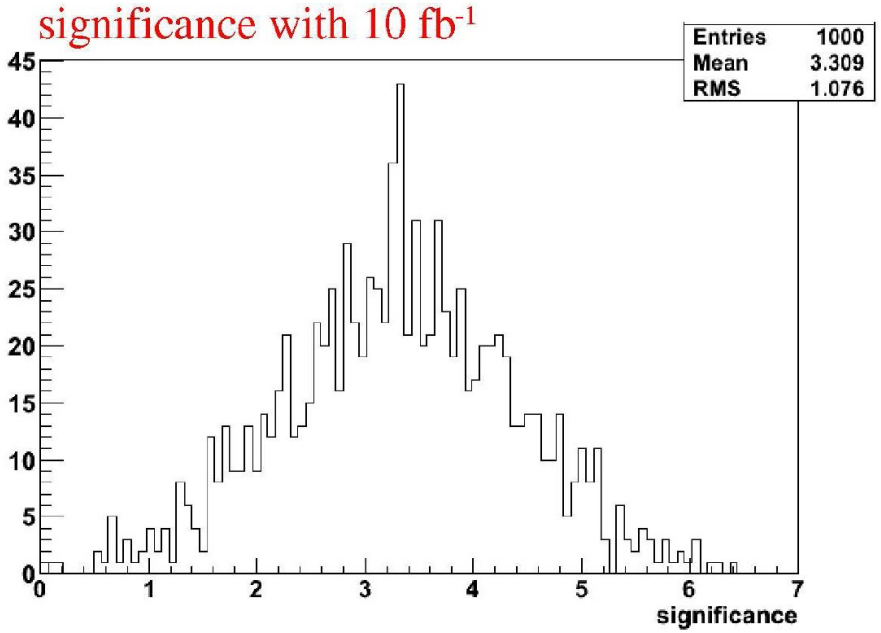
No bias observed in N_s pull distribution

Significance and Upper Limit

$\sigma/\sigma_{\mathrm{SM}} < 4.6$ at 95% CL ($200\,\mathrm{pb}^{-1}$), $\sqrt{s} = 10$ TeV

$S_L = \sqrt{-2\Delta \ln \mathcal{L}} = 3.3 \pm 1.1$ ($10\,\mathrm{fb}^{-1}$), $\sqrt{s} = 10$ TeV





ATLAS expects 3.6 σ with $10\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 14$ TeV