

# $HH \rightarrow bb\gamma\gamma$

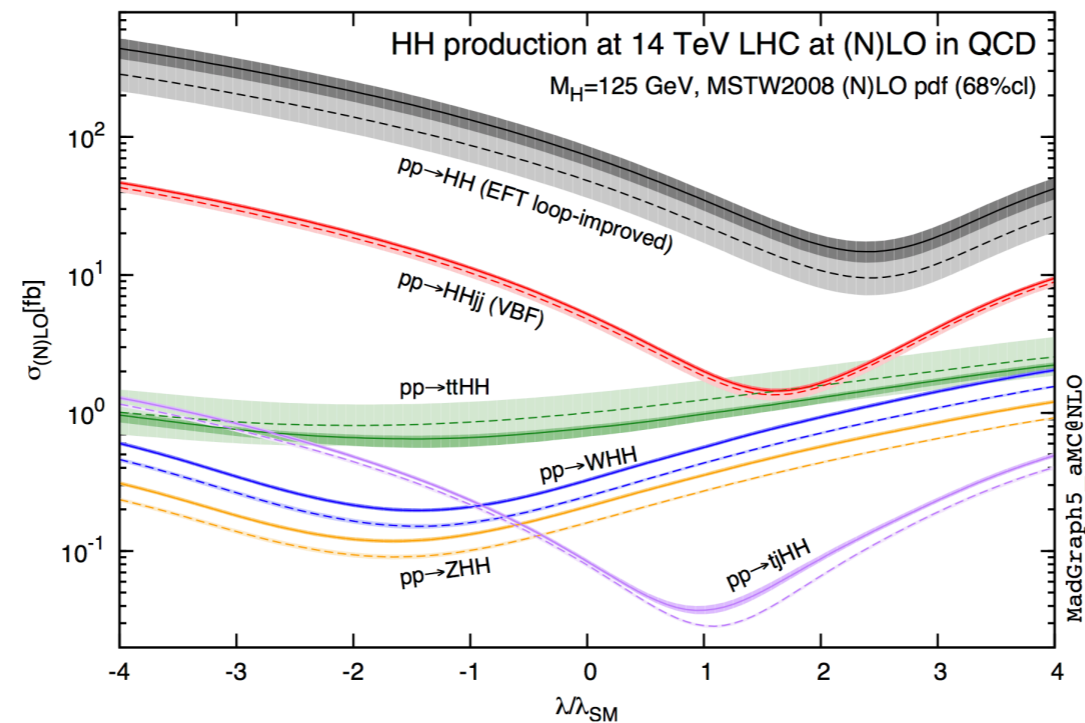
# Status Report

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# Strategy

- extract signal strength  $\mu = \sigma/\sigma_{\text{SM}}$
- derive sensitivity on the self-coupling  $\Delta\lambda = \left|\frac{1}{\alpha}\right|\Delta\mu$



- dependence on  $\lambda$  is different in for  $\sigma_{\text{fid}}$  and  $\sigma_{\text{inc}}$
- need to study the dependence in fiducial region

# Context

- Detailed study performed already in 2016

- results obtained with *Contino, Panico, Papaefstathiou, Son* are summarised in the 100 TeV report
- cut-based analysis using statistical uncertainty (no systematics)
- reported sensitivity on  $\lambda$  after  $30 \text{ ab}^{-1}$  at 100 TeV

	$\Delta_S = 0.00$	$\Delta_S = 0.01$	$\Delta_S = 0.015$	$\Delta_S = 0.02$	$\Delta_S = 0.025$
$r_B = 0.5$	2.7%	3.4%	4.1%	4.9%	5.8%
$r_B = 1.0$	3.4%	3.9%	4.6%	5.3%	6.1%
$r_B = 1.5$	3.9%	4.4%	5.0%	5.7%	6.4%
$r_B = 2.0$	4.4%	4.8%	5.4%	6.0%	6.8%
$r_B = 3.0$	5.2%	5.6%	6.0%	6.6%	7.3%

- Perform the analysis:

- with latest detector description (4T vs 6T)
  - better in terms of jet energy resolution
- shape analysis instead of cut-based
- include discussion on systematics

# Samples

- **Pythia8 shower default for FCC-hh studies**

- Py6 tune as default is off already at LHC, plus no vacuum  $\gamma$ -splitting

- **Signal**

- LO MG5, rescaled to NNLO/NNLL calculation using a global K-factor (from 100 TeV report)

- **Backgrounds**

- All generated with MG5,  $\sim 10$  M events/process

- 4 flavor generation (as in report analysis):

- $ttH, bbH, jj\gamma\gamma, bbj\gamma$

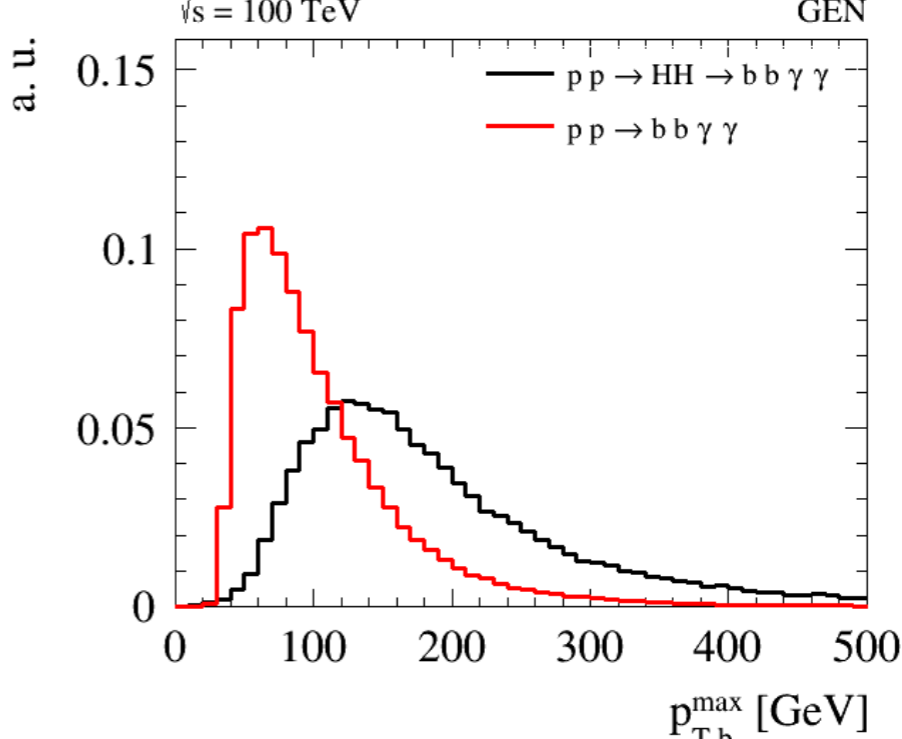
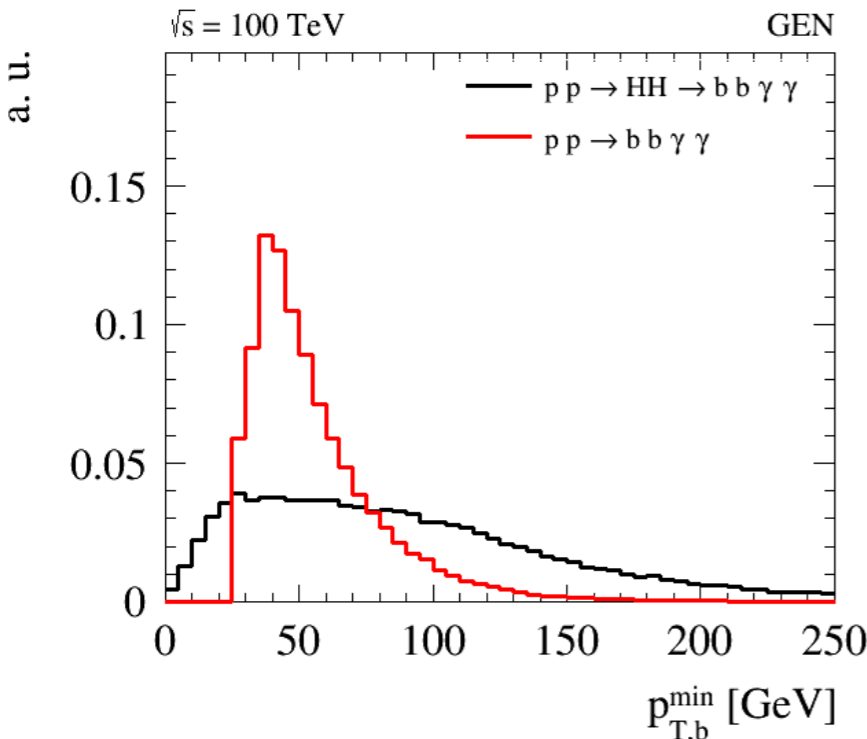
- $bb\gamma\gamma, bj\gamma\gamma + 0/1$  jets merged

- 5 flavor + 0/1 jets merged

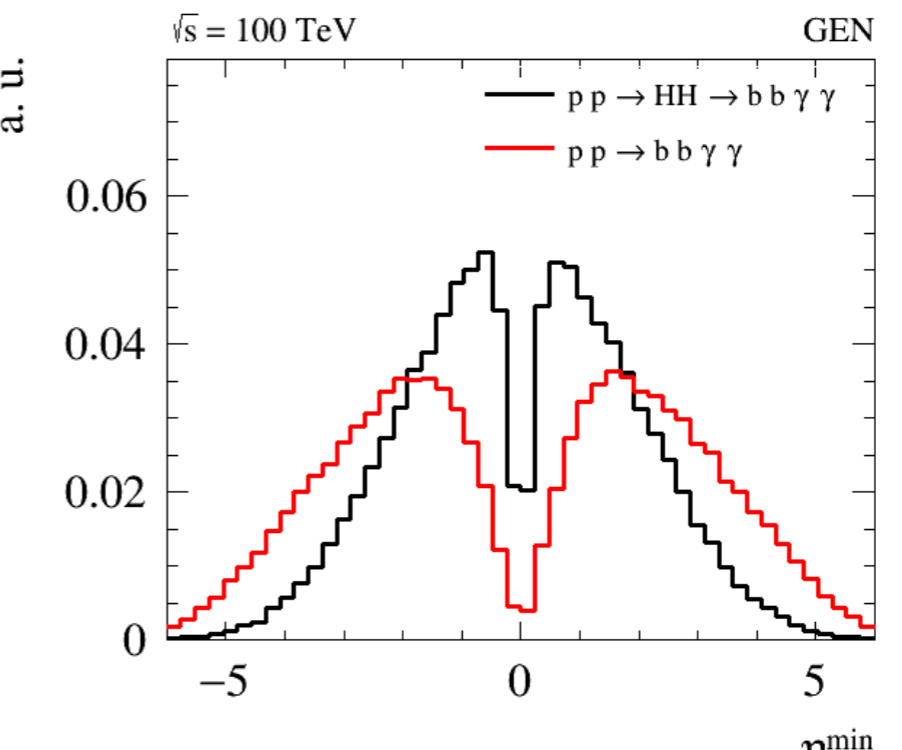
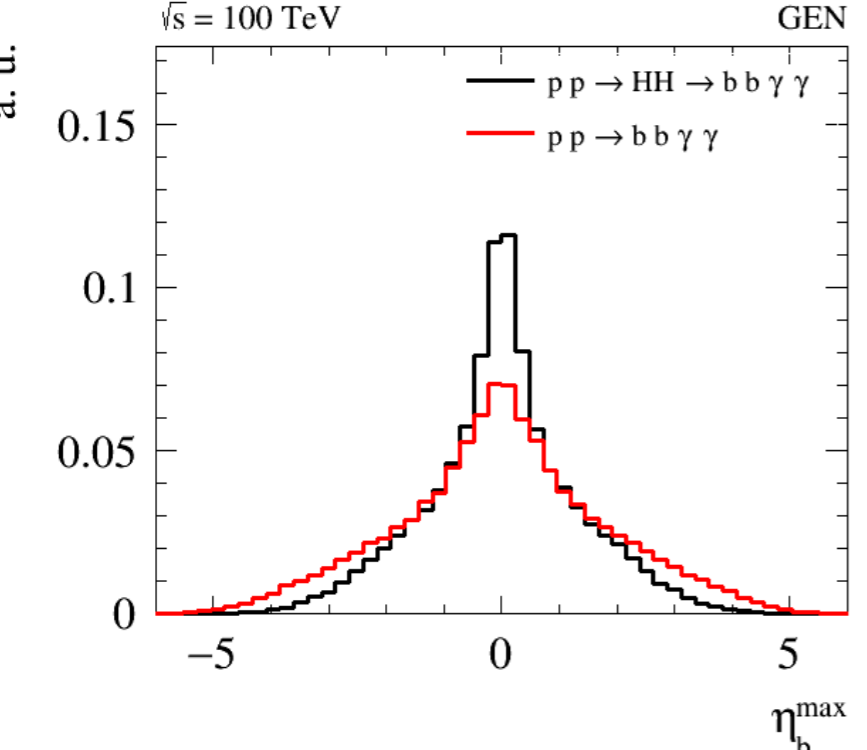
- $jjj\gamma, jj\gamma\gamma$

**fake rate:**  $p_{j \rightarrow \gamma} = \alpha \exp(-p_{T,j}/\beta)$

# Parton level observables

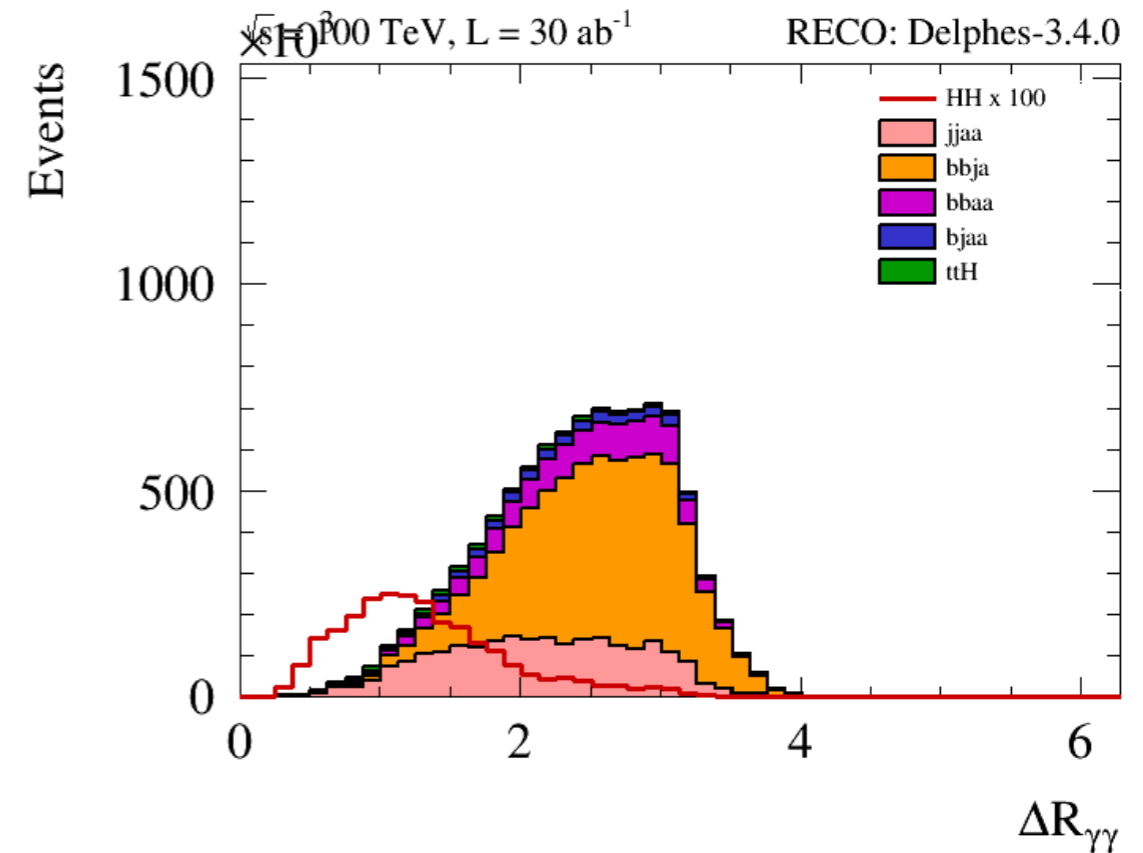
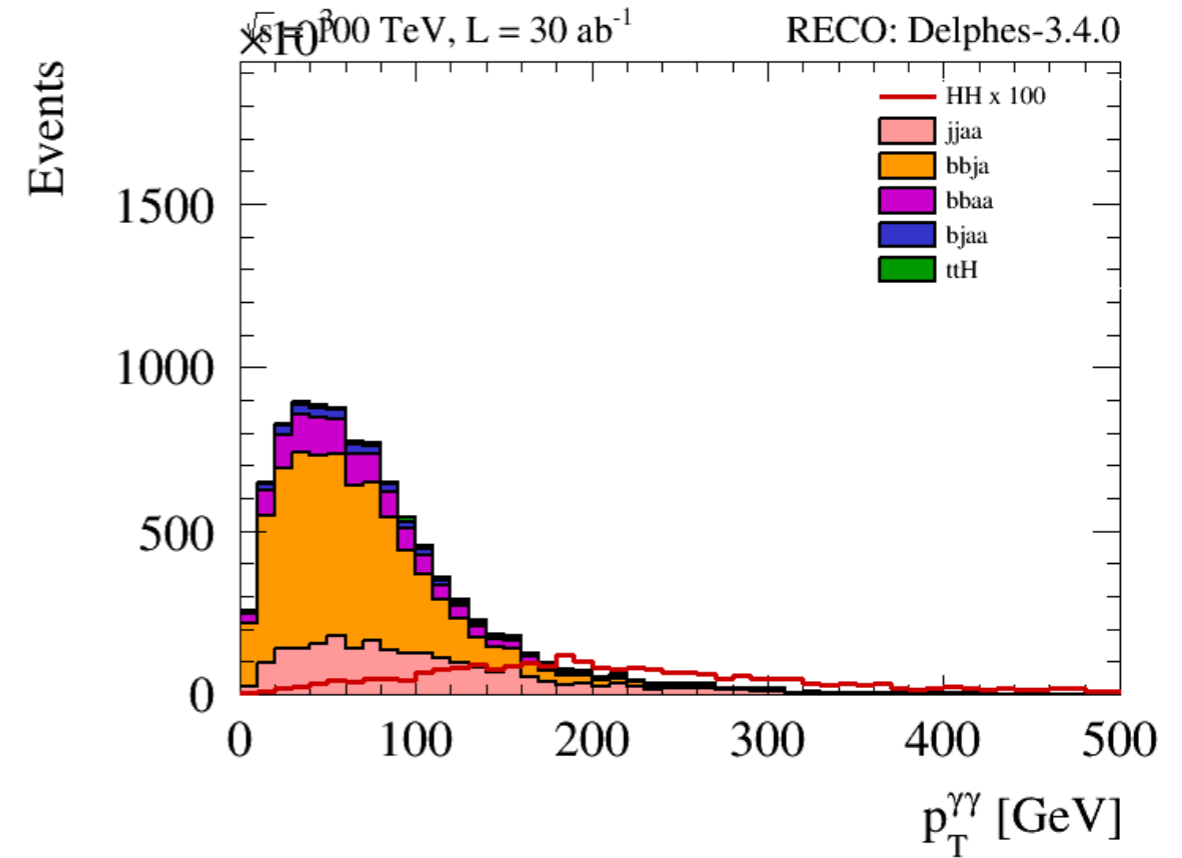


very similar plots for photons

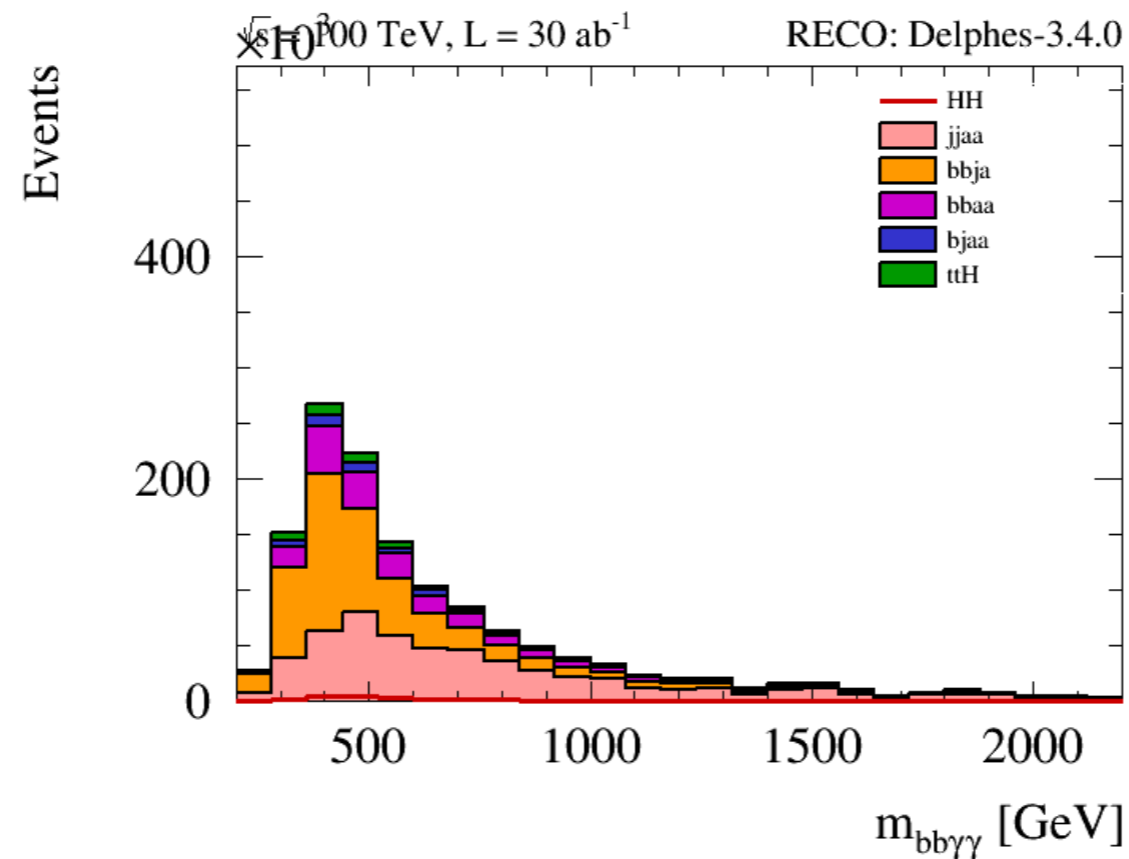
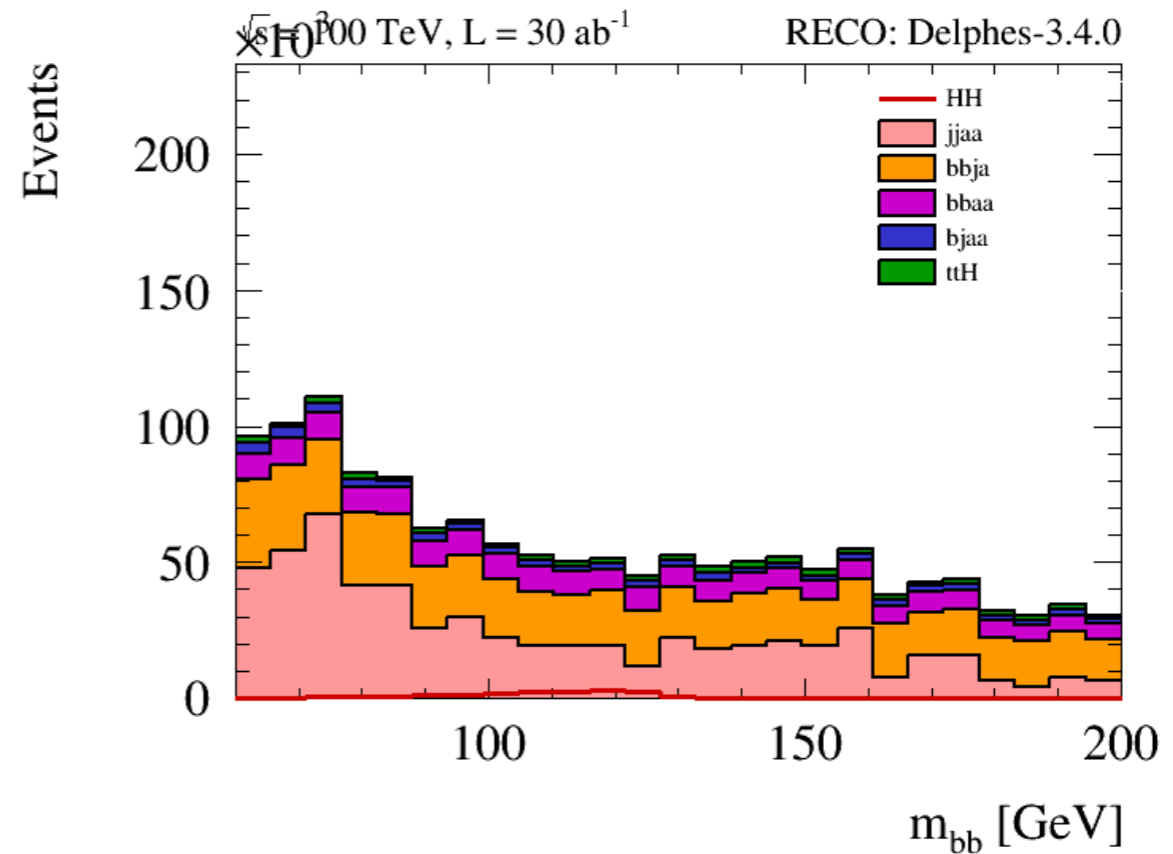
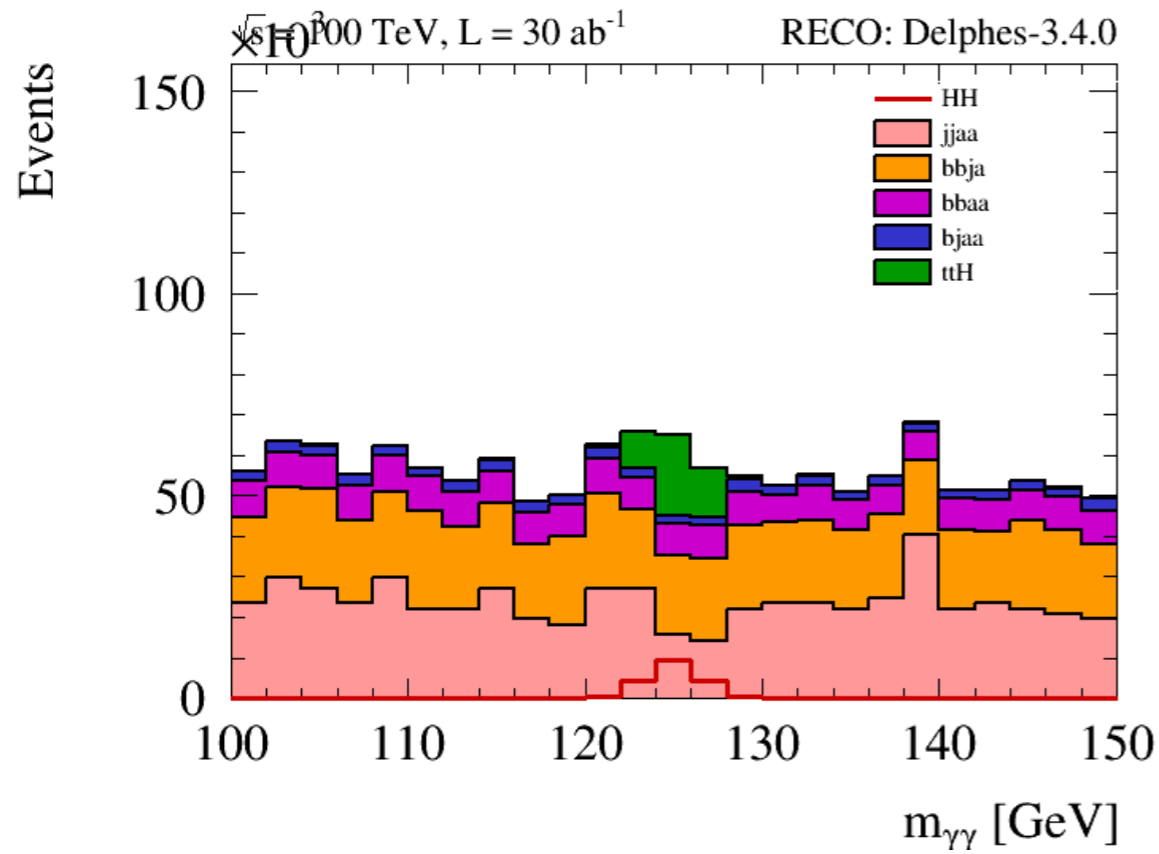


# Pre-Selection

Acceptance cuts	Final selection
$\gamma$ isolation $R = 0.4$ $(p_T(\text{had})/p_T(\gamma) < 0.15)$ jets: anti- $k_T$ , parameter $R = 0.4$ $ \eta_{b,\gamma,j}  < 6$ $p_T(b), p_T(\gamma), p_T(j) > 35$ GeV	$\gamma$ isolation $R = 0.4$ $(p_T(\text{had})/p_T(\gamma) < 0.15)$ jets: anti- $k_T$ , parameter $R = 0.4$ $ \eta_{b,\gamma}  < 4.5$ $p_T(b_1), p_T(\gamma_1) > 60$ GeV $p_T(b_2), p_T(\gamma_2) > 35$ GeV
$m_{bb} \in [60, 200]$ GeV $m_{\gamma\gamma} \in [100, 150]$ GeV	$m_{bb} \in [100, 150]$ GeV $ m_{\gamma\gamma} - m_h  < 2.0, 2.5, 4.5$ GeV
	$p_T(bb), p_T(\gamma\gamma) > 100$ GeV $\Delta R(bb), \Delta R(\gamma\gamma) < 3.5$ no isolated leptons with $p_T > 25$ GeV



# After Pre-Selection cuts



Selvaggi -  $HH \rightarrow b\bar{b}\gamma\gamma$

# Cut and count analysis

Further apply:

$$m_{bb} \in [100, 150] \text{ GeV}$$

$$|m_{\gamma\gamma} - m_h| < 2.0, 2.5, 4.5 \text{ GeV}$$

Process	Acceptance cuts [fb]	Final selection [fb]	Events ( $L = 30 \text{ ab}^{-1}$ )
$h(b\bar{b})h(\gamma\gamma)$ (SM)	0.73	0.40	12061
$bbj\gamma$	132	0.467	13996
$jj\gamma\gamma$	30.1	0.164	4909
$t\bar{t}h(\gamma\gamma)$	1.85	0.163	4883
$b\bar{b}\gamma\gamma$	47.6	0.098	2947
$b\bar{b}h(\gamma\gamma)$	0.098	$7.6 \times 10^{-3}$	227
$bj\gamma\gamma$	3.14	$5.2 \times 10^{-3}$	155
Total background	212	1.30	27118

Old

HH : 0.848 +/- 0.012  
tth : 6.424 +/- 0.146

jjaa : 86.149 +/- 0.542  
jjja : 184.513 +/- 2.431

jjaa : 77.374 +/- 1.829  
bbja : 187.706 +/- 0.794  
bbaa : 39.57 +/- 0.153  
bjaa : 11.826 +/- 0.141

New

← 5f →

← 4f →

HH : 12300.903 +/- 254.507  
tth : 14213.855 +/- 1188.622

jjaa : 45334.416 +/- 2153.903  
jjja : 22810.698 +/- 4376.07

jjaa : 14272.417 +/- 4303.296  
bbja : 16697.744 +/- 1214.665  
bbaa : 7078.155 +/- 354.351  
bjaa : 1873.356 +/- 307.978



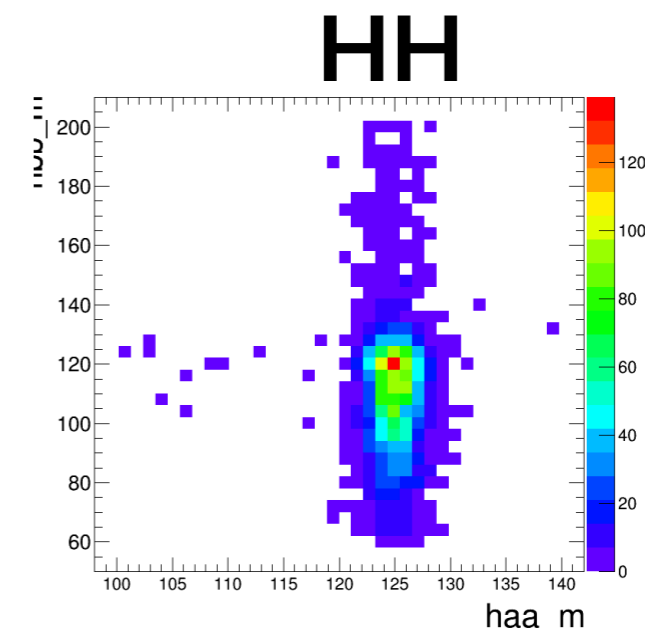
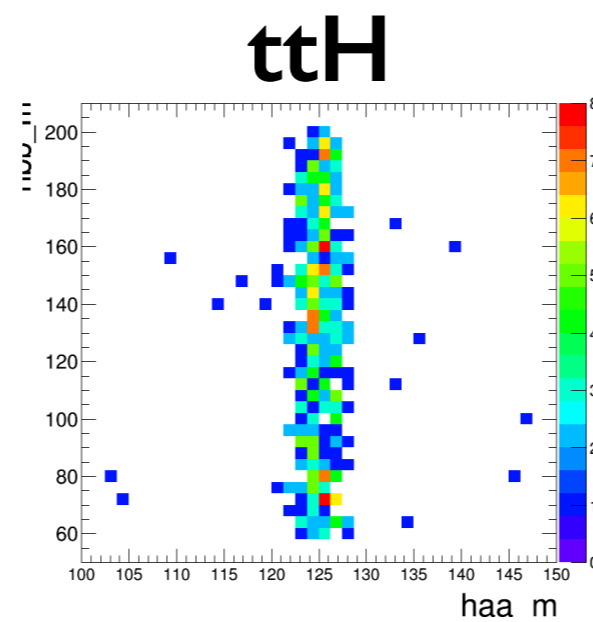
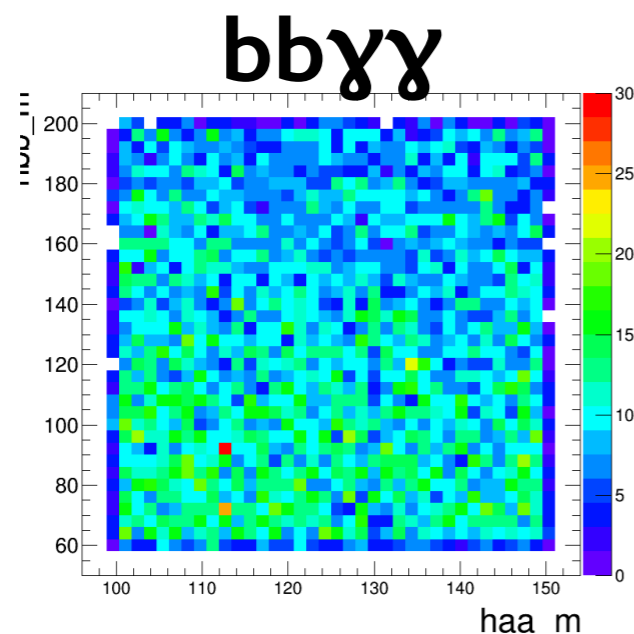
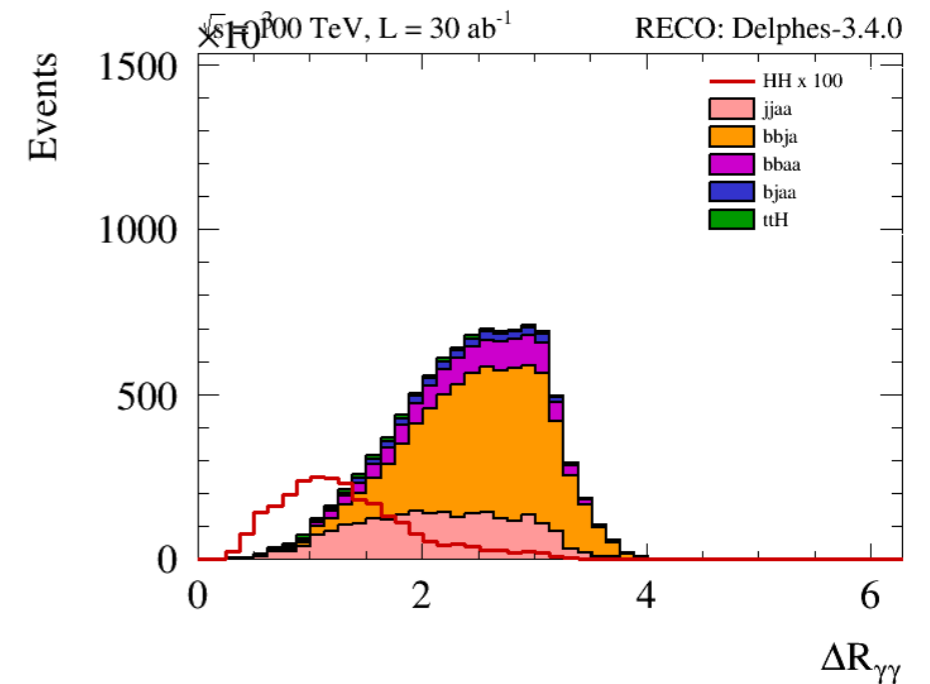
# Cut and Count

- **Disclaimer: very preliminary!!**
  - Signal yield looks compatible
  - Background  $\sim$  x2 larger overall
- **(Statistical) Precision:**
  - Report:  $\Delta\mu/\mu = 1.6\%$  ( $\Delta\lambda/\lambda = 3.4\%$ )
  - Here:  $\Delta\mu/\mu = 2.1\%$  ( $\Delta\lambda/\lambda = 4.2\%$ )

**NO SYSTEMATICS !!**

# Possible improvements

- Optimize event selection
  - $\Delta R < 2$  (although probably very correlated with  $p_T^{\text{pair}}$ )
  - build categories based on jet multiplicities (non b-jet veto)
- Perform a shape analysis:
  - do not throw away precious events
  - exploit correlations, ex:  $m_{\gamma\gamma}$  vs  $m_{bb}$



# 2D binned shape analysis

- **Just a preliminary test, no systematics:**
  - 2D binned max likelihood fit
  - $\Delta\mu/\mu = 1.6\%$  ( $\Delta\lambda/\lambda = 3.4\%$ )
- **Can be improved by:**
  - background smoothening (now stat. limited despite several M events generated)
  - eventually parametric shape analysis

**NO SYSTEMATICS !!**

# Systematics

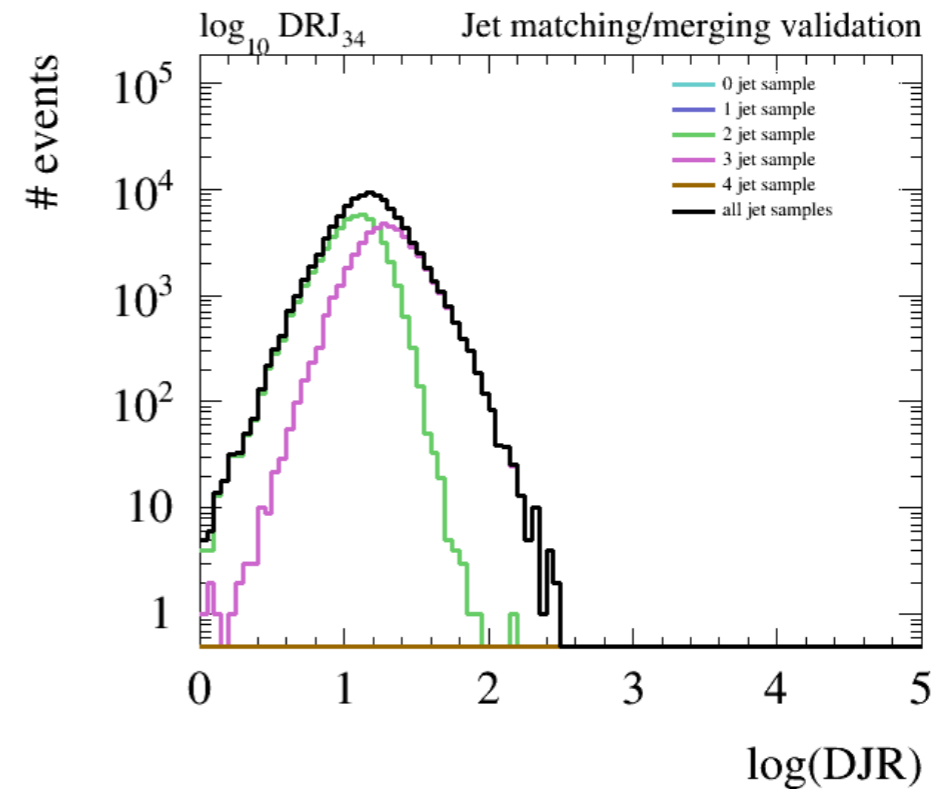
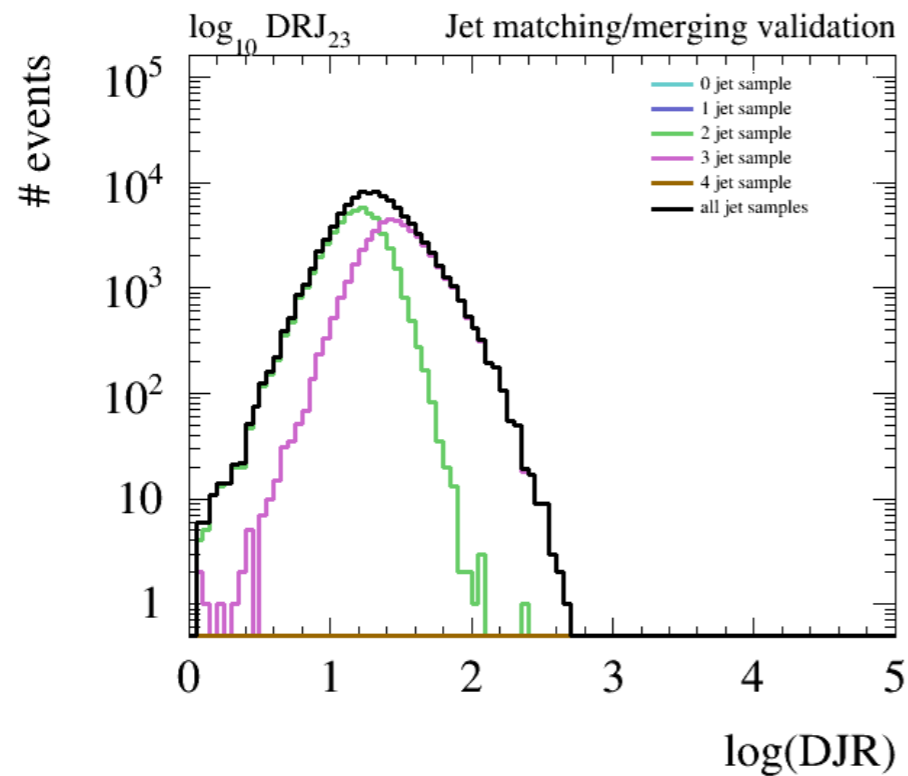
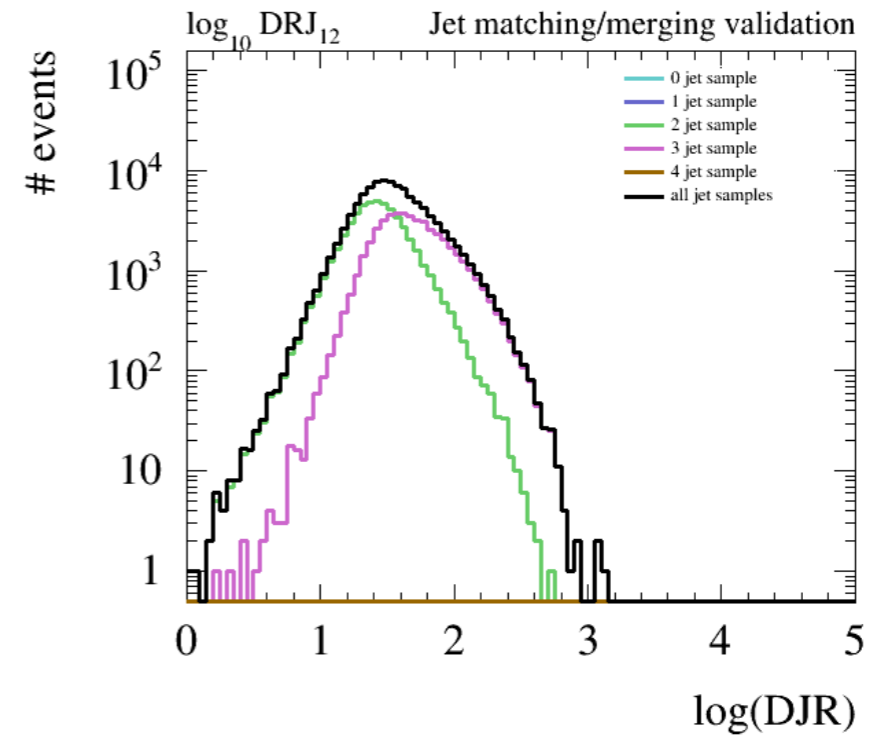
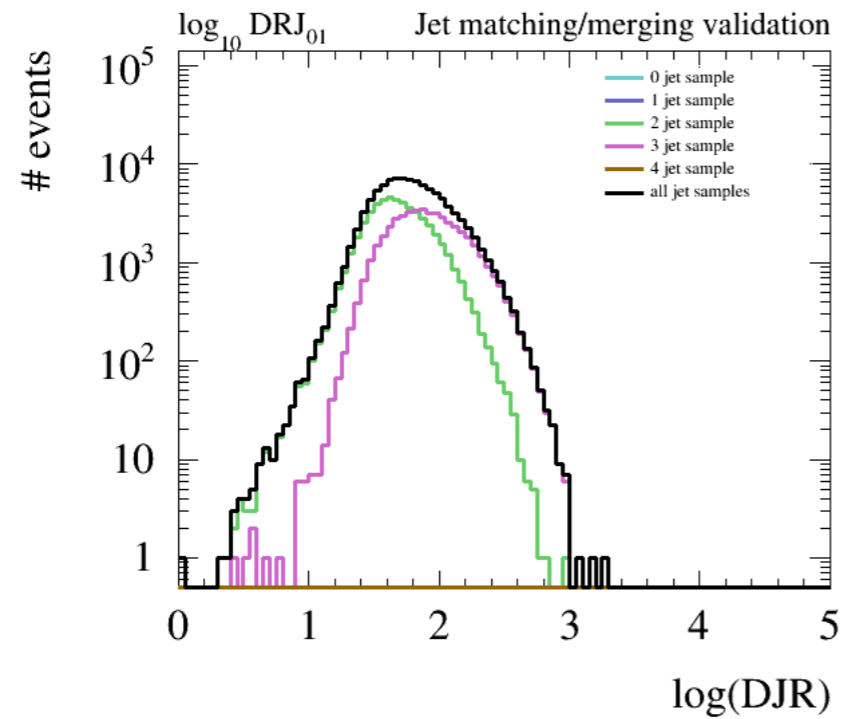
- **Dominant systematics are:**
  - Luminosity (2-3%) , affects mainly signal
  - Theory (finite top mass, PDFs), also mainly signal (5%)
    - eventually will go down to % level
  - Photon Energy Resolution, Energy Scale (shape 1 %)
    - affects both normalization (trigger, photonID) and shape
  - Jet Energy Scale (2%) / Resolution (5%)
    - impact both on event yield and shapes (TBS)
  - B-tagging efficiency (To be Studied) (2-3%)
    - normalization

# Conclusion

- Cross-check of the  $HH \rightarrow bb\gamma\gamma$  analysis @ 100 TeV has been performed
- Small differences have been observed but overall comparable sensitivity on the extraction of Higgs self coupling can be achieved
- Several ways to improve can be explored
- Understand how systematics impact sensitivity

# Backup

# jjaa\_0lj\_5f



# jjja\_0 | j\_5f

