E/gamma energy calibration for Higgs mass measurement

ATLAS week - Berlin 2019

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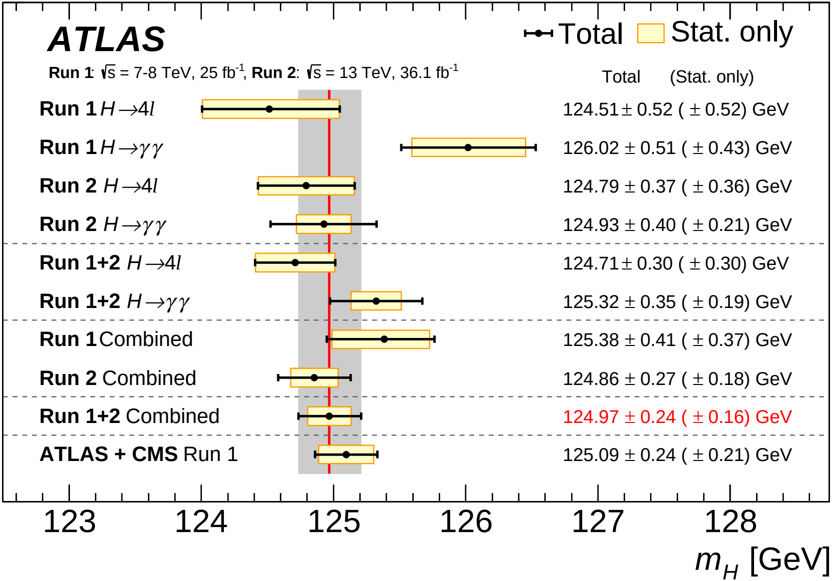
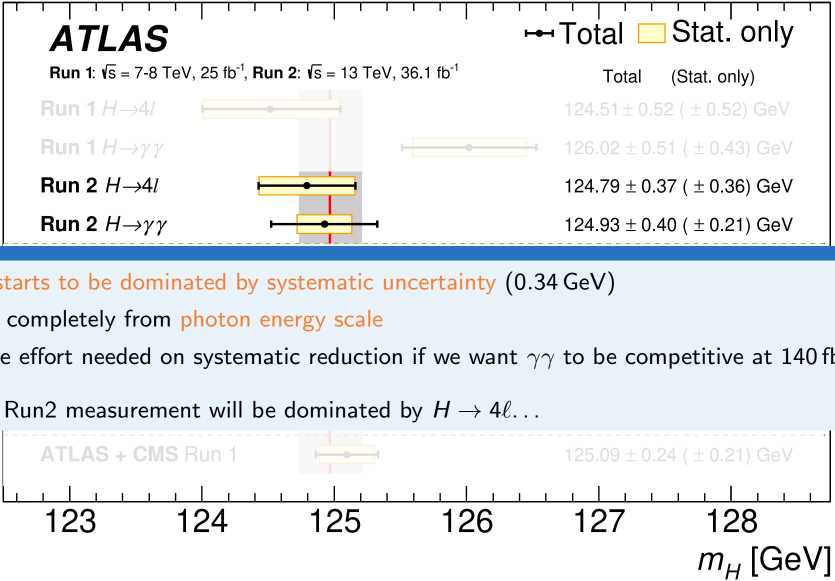
on behalf of the e/gamma calibration and the Higgs groups

INFN Milano

8 Oct 2019


ATLAS
Total
Stat. only
Run 1: √s = 7-8 TeV, 25 fb-1, Run 2: √s = 13 TeV, 36.1 fb-1
Total (Stat. only)
Run 1 H→4l
124.51 ± 0.52 (± 0.52) GeV
Run 1 H→γγ
126.02 ± 0.51 (± 0.43) GeV
Run 2 H→4l
124.79 ± 0.37 (± 0.36) GeV
Run 2 H→γγ
124.93 ± 0.40 (± 0.21) GeV
Run 1+2 H→4l
124.71 ± 0.30 (± 0.30) GeV
Run 1+2 H→γγ
125.32 ± 0.35 (± 0.19) GeV
Run 1 Combined
125.38 ± 0.41 (± 0.37) GeV
Run 2 Combined
124.86 ± 0.27 (± 0.18) GeV
Run 1+2 Combined
124.97 ± 0.24 (± 0.16) GeV
ATLAS + CMS Run 1
125.09 ± 0.24 (± 0.21) GeV
123
124
125
126
127
128
m_H [GeV]

Present status, Run2 = 36 fb^{-1} Rel 20.7



$\gamma\gamma$ starts to be dominated by systematic uncertainty (0.34 GeV)

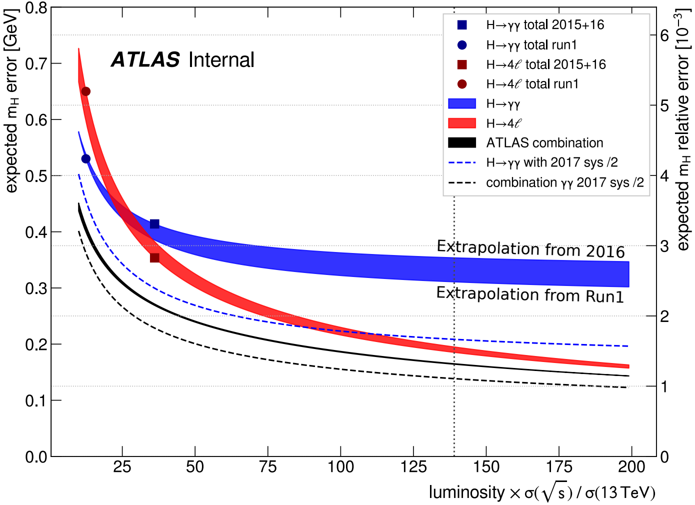
- completely from photon energy scale

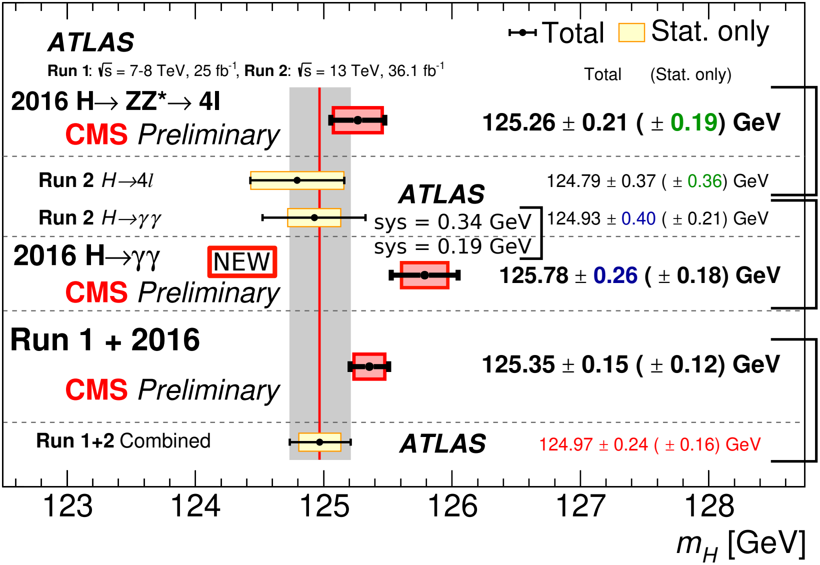
Huge effort needed on systematic reduction if we want $\gamma\gamma$ to be competitive at 140 fb^{-1}

Full Run2 measurement will be dominated by $H \to 4\ell \ldots$

Present status, Run2 = 36 fb^{-1} Rel 20.7

... unless we reduce energy scale systematic by a factor $\simeq 2$





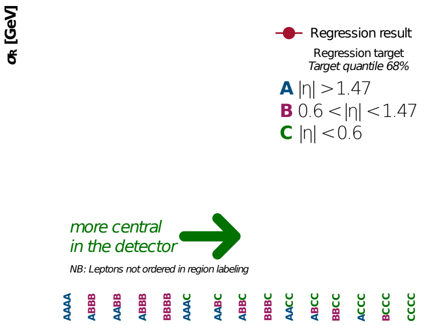
Total
Stat. only
ATLAS
Run 1: √s = 7-8 TeV, 25 fb-1, Run 2: √s = 13 TeV, 36.1 fb-1
Total (Stat. only)
2016 H→ ZZ*→ 4l
CMS Preliminary
125.26 ± 0.21 (± 0.19) GeV
Run 2 H→4l
124.79 ± 0.37 (± 0.36) GeV
ATLAS
sys = 0.34 GeV
sys = 0.19 GeV
Run 2 H→γγ
124.93 ± 0.40 (± 0.21) GeV
2016 H→γγ
NEW
CMS Preliminary
125.78 ± 0.26 (± 0.18) GeV
Run 1 + 2016
CMS Preliminary
125.35 ± 0.15 (± 0.12) GeV
Run 1+2 Combined
ATLAS
124.97 ± 0.24 (± 0.16) GeV
123
124
125
126
127
128
mH [GeV]

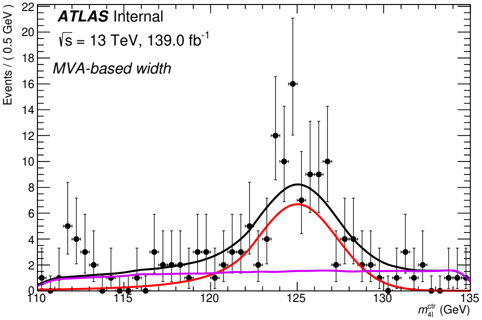
$H \to 4\ell$ ongoing analysis Full Run2

- Dominated by statistical error
- Category by lepton flavour
- Improve resolution modeling and purity: Z-mass constraint, FSR recovery, bkg BDT, per-event resolution
- 2D fit $m_{4\ell} \times BDT_{ZZ}$(signal vs ZZ):

$$P[m_{4\ell}, BDT_{ZZ}|m_H, \sigma_{4\ell}] = P[BDT_{ZZ}|m_{4\ell}]P[m_{4\ell}|m_H, \sigma_{4\ell}]$$

- NEW: resolution value from a NN regression: $\sigma_{4\ell} = NN[\text{kinematic}, \text{flavours}]$



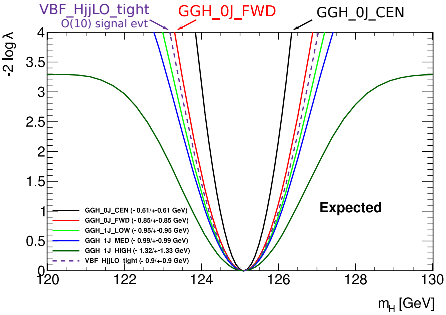


$H \to \gamma\gamma$ 36 fb^{-1} Rel 20.7

Same selection as other $H(125) \to \gamma\gamma$ analyses: $E_T^{\gamma}/m_{\gamma\gamma} > 0.25/0.35$, tight, isolated.

31 categories as in the STXS analysis: (`ggF_0J_CEN`, `ggF_0J_FWD`, ..., `ttH`):

- Separate events with different s/b (`VBF_HjjLO_tight` has s/b=1)
- Quite separate events with different resolution (`CEN`/`FWD`, high-pT (VBF) / low-pT (ggF))

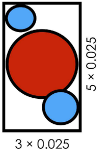


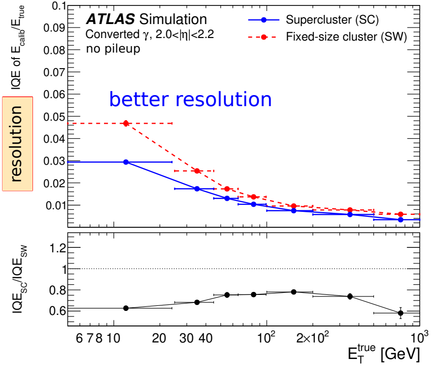
method	ADD		SUB	
	down	up	down	up
sys [MeV]				
Backgroup model	70	67	53	55
Conversion reconstruction	49	50	52	47
ID material	107	109	108	109
Lar cell non-linearity	193	190	182	178
Lateral shower shape	110	109	111	110
Layer calibration	178	177	170	169
Luminosity	1	0	18	0
Other material (not ID)	124	125	120	121
Resolution	20	0	20	22
Signal model	17	18	15	16
Primary vertex effect on mass scale	37	38	37	38
$Z \to ee$ calibration	76	78	76	76

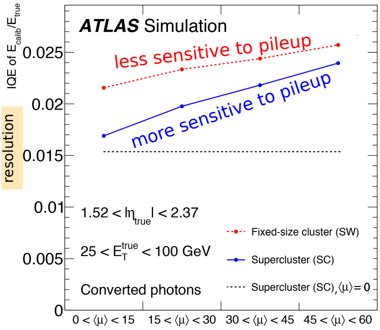
Calibration in Rel 21

Change in reconstruction: use super-cluster instead of sliding window

- Recover energy from satellite clusters (e.g. soft conversions)
- Better resolution, in particular for converted photons in the endcap
- More sensitive to pileup







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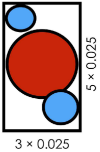
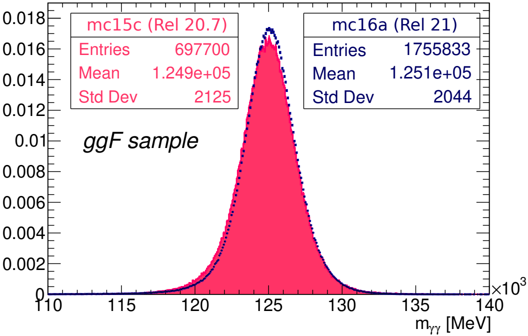
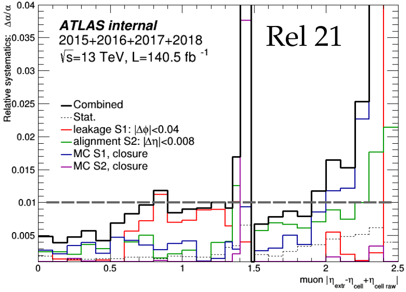


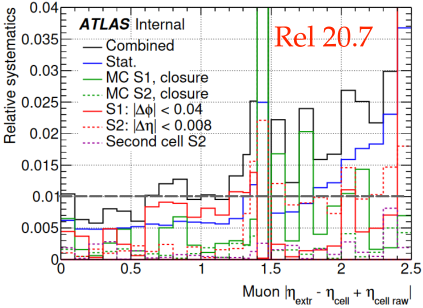


4% improvement in mc16a (2015+16 data) ggF resolution. Smaller at higher pileup

Layer calibration (ongoing)

- E_1/E_2 scale measured with muons (insensitive to material in front)
- Full Run2 data used: will enter in fall recommendation
- Overall uncertainty decreased (vs Rel 20.7 2015+16 data)



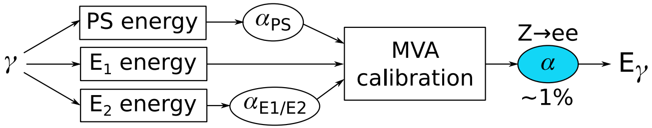


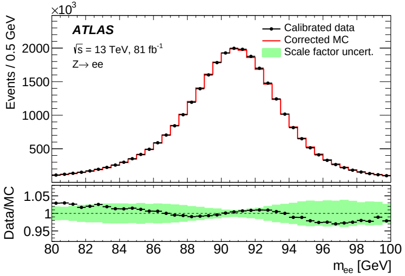
- PS scale study just started

Still quite large extrapolation uncertainty on muon → photons

The alternative is to study E_1/E_2 directly with electrons

Data/MC energy scale

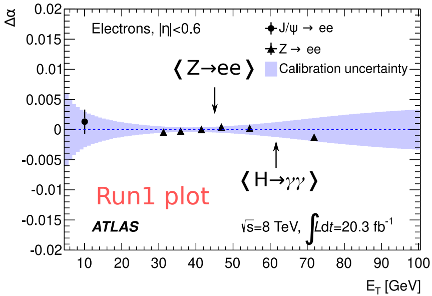


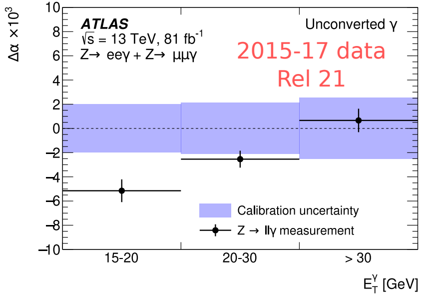


- Energy systematic dominated by extrapolation from $\simeq$ 45 GeV electrons $\rightarrow$ $\simeq$ 60 GeV photons
- Systematics split in $\sim$ 70 components with non-trivial correlation in η
- Most relevant for $m_H^{\gamma\gamma}$: high/medium gain, E_1/E_2 calibration, non-ID material

Scales as a function of p_T and from $Z \to \ell\ell\gamma$

- Presently used as cross checks: compute residual scale factors on top of the ones from $Z \to ee$
- Some tension between γ/e scales

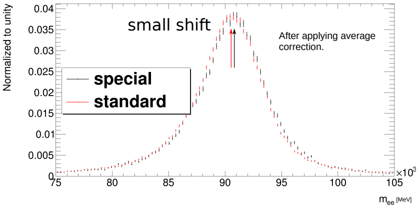


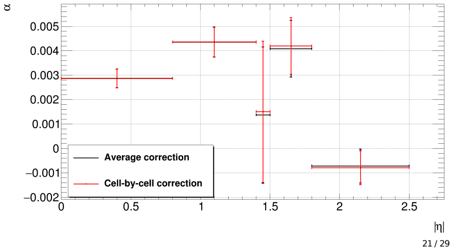


Can be used to reduce extrapolation uncertainties 45 GeV electrons → 60 GeV photons

Medium/High gain scale

- Calibrate medium / high-gain using special runs: lower DAC threshold to record most of Z decay events in MG (instead of HG)
- Derive scale factor between MG/HG from $Z \to ee$
- Presently: assume no correction, use the deviation as systematic (100%)
- May change in future: correct and use error from the measurement $\to$ strong reduction in systematic





Projection to 140 fb^{-1} $H \to \gamma\gamma$ (expected)

Use workspace from coupling 80/fb, try scenarios provided by egamma with different values of systematic

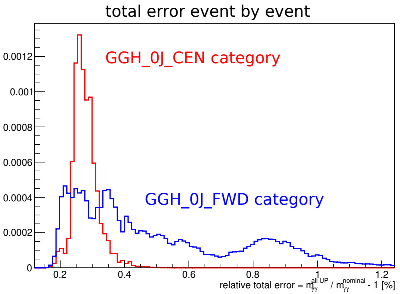
	total [GeV]	stat [GeV]	sys [GeV]
Latest result with 36 fb^{-1} Rel 20.7	0.40	0.25	0.31
...extrapolated at 140 fb^{-1}	0.35	0.13	0.31
Refit latest analysis Rel 21 with 140 fb^{-1}	0.26	0.10	0.24
...with reduced systematics[1]	0.20	0.10	0.18
Latest 4ℓ extrapolated at 140 fb^{-1}	0.18	0.18	~ 0
ATLAS Combination $\gamma\gamma + 4\ell$ 140 fb^{-1}	0.13		

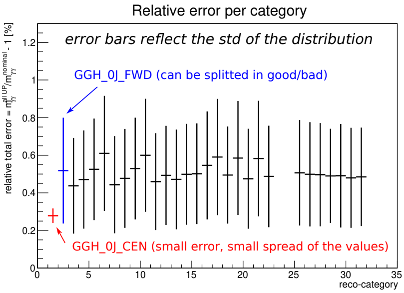
With reduced systematic scenario $\gamma\gamma$ is competitive with 4ℓ (CMS extrapolated $\sim$ 0.09 GeV)

[1] gain and leakage (now 100% uncertainty) by 3, layer by 2

Improvements at analysis level $\gamma\gamma$

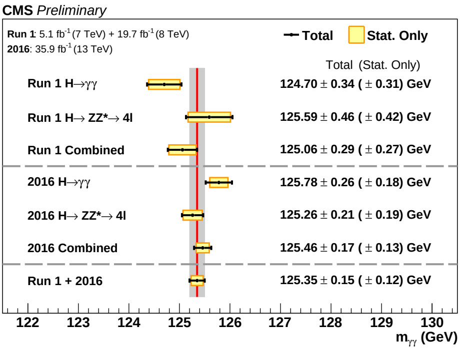
- Past strategy: separate events with good/bad resolution and high/low purity
- Need to focus also on the value of the systematics (e.g. separate by conv/unconv)
- Ideally one wants to use for each event its value of the systematic and not the value computed as average of the category $\rightarrow$ per-event systematic error
- Feedback from 4ℓ (which did similarly for the resolution): computationally too expesive
- Alternatively: split present categories in bad/good systematic





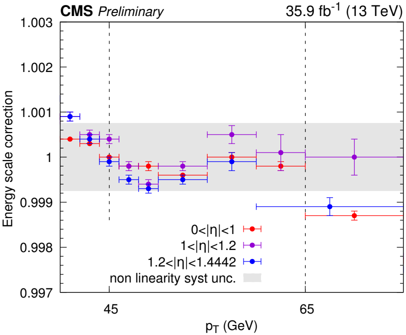
New $H \to \gamma\gamma$ CMS measurement with 36 fb^{-1}
CMS-PAS-HIG-19-004

- 3 VBF categories + 4 untagged (BDT) (STXS in ATLAS)
- MVA regression with shower shapes (R_9), pileup as inputs (no conv/unconv separated regression); regression of the expected resolution (no shower shapes in ATLAS, large mismodeling)
- Best resolution $\sigma_{eff} = 1.35$ GeV (ATLAS 1.59 GeV in GGH_0J_CEN)
- BDT photon identification (ATLAS: cut-based). Diphoton event BDT



Energy scale assumed to be uncorr. between measurements ⇒ inflate uncertainty by 5%

- Scales from $Z \to ee$ as a function of $|\eta| \otimes p_T \otimes R_9$.
- R_9 different from e/conv/unconv
- Systematic error from the non-linearity: non-closure of the p_T-dependent scale factors (0.075-0.15%)



Source	Contribution [GeV]	ATLAS
Electron energy scale and resolution corrections	0.10	0.08
Residual p_T dependence of the photon energy scale	0.11	
Modelling of the material budget	0.03	0.16
Non-uniformity of the light collection	0.11	
Statistical uncertainty	0.18	0.21
Total uncertainty	0.26	0.40
total systematic	0.18	0.34

Conclusions

- $H \to 4\ell$ almost systematic free
- $H \to \gamma\gamma$ will be dominated by systematics, not competitive $140\,\mathrm{fb}^{-1}$
- unless energy scale systematics reduced by a factor 2
- this is challenging, but within reach assuming we have the people to work on it (for the gain and for the leakage, we currently quote 100% uncertainty on the source of uncertainty)
- From the analysis point of view need to separate events with high/low-systematic value

Person power in e/gamma calibration

Timeline of e/gamma limited by person-power. Some tasks just started (PS scale, $Z \to \ell\ell\gamma$, lateral leakage, several are uncovered (see here):

- non-ID material
- $Z \to ee$ scales

Also W mass is affected.

Section 1

Backup

Toys/BLUE vs on/off systematics

- Presently we compute the stat-only error fixing the NP-values to the best-fit and look to the width of $-2\log\frac{L(\mu,\hat{\hat{\theta}}_\mu)}{L(\hat{\mu},\hat{\theta})} \sim \chi^2$
- This correspond to assume that there are no systematics error
- The weight the various channels/categories receive is proportional only to the stat-error (and not the total error)
- Discussion about if this is what we want
- Another approach is to propagate the systematic error taking into account the weights from the total error (BLUE, toys, ...)

In this slides: check how much these two approaches differ withing the $\gamma\gamma$ analysis

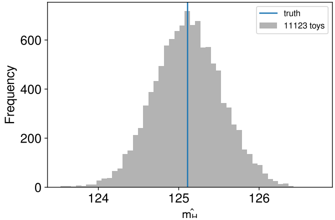
- $\simeq$ 6000 toys: much more than the needed ones, precision negligible wrt rounding (e.g. std of $\hat{m}_H = 0.424 \pm 0.006$)
- Systematic error always computed as quadrature difference: $\sqrt{\text{total}^2 - \text{stat-only}^2}$

Showing some results also for couplings: remember differences of workspaces

Toys

$$\text{Conf-note result:} \quad 125.11 \pm 0.42\,\text{GeV} = 125.11 \pm 0.21(\text{stat}) \pm 0.36(\text{sys})\,\text{GeV}$$
$$\text{Toys:} \quad 125.11 \pm 0.42\,\text{GeV} = 125.11 \pm 0.26(\text{stat}) \pm 0.33(\text{sys})\,\text{GeV}$$

- No bias to the central value
- Full error perfectly reproduced (it must be)
- Smaller sys-error with toy
  - make sense: if you weight with the full-error, categories with larger sys are weighted less



Run1 categorization (10 categories)

1. Both photon candidates are unconverted, and have $|\eta_{S2}| < 0.75$; the diphoton system has $p_{Tt} < 70\,\text{GeV}$.
2. Both photon candidates are unconverted, and have $|\eta_{S2}| < 0.75$; the diphoton system has $p_{Tt} > 70\,\text{GeV}$.
3. Both photon candidates are unconverted and at least one candidate has $|\eta_{S2}| > 0.75$; the diphoton system has $p_{Tt} < 70\,\text{GeV}$.
4. Both photon candidates are unconverted and at least one candidate has $|\eta_{S2}| > 0.75$; the diphoton system has $p_{Tt} > 70\,\text{GeV}$.
5. Both photon candidates are unconverted and at least one candidate is in the range $1.3 < |\eta_{S2}| < 1.37$ or $1.52 < |\eta_{S2}| < 1.75$.
6. At least one photon candidate is converted and both photon candidates have $|\eta_{S2}| < 0.75$; the diphoton system has $p_{Tt} < 70\,\text{GeV}$.
7. At least one photon candidate is converted and both photon candidates have $|\eta_{S2}| < 0.75$; the diphoton system has $p_{Tt} > 70\,\text{GeV}$.
8. At least one photon candidate is converted and both photon candidates have $|\eta_{S2}| < 1.3$ or $|\eta_{S2}| > 1.75$, but at least one photon candidate has $|\eta_{S2}| > 0.75$. The diphoton system has $p_{Tt} < 70\,\text{GeV}$.
9. At least one photon candidate is converted and both photon candidates have $|\eta_{S2}| < 1.3$ or $|\eta_{S2}| > 1.75$, but at least one photon candidate has $|\eta_{S2}| > 0.75$. The diphoton system has $p_{Tt} > 70\,\text{GeV}$.
10. At least one photon candidate is converted and at least one photon candidate is in the range $1.3 < |\eta_{S2}| < 1.37$ or $1.52 < |\eta_{S2}| < 1.75$.