Search for Higgs decay into a photon and a massless dark photon (ggF) in Run 3

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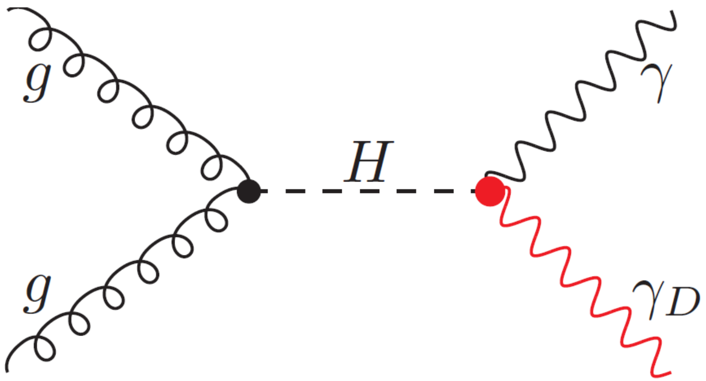
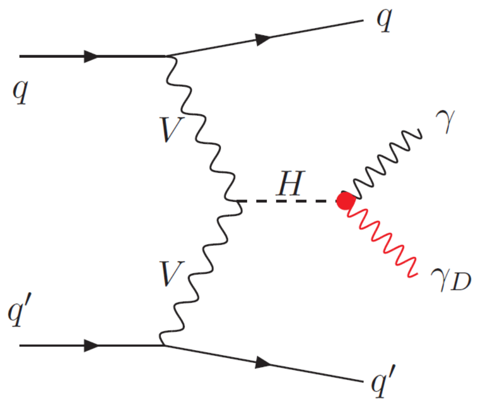
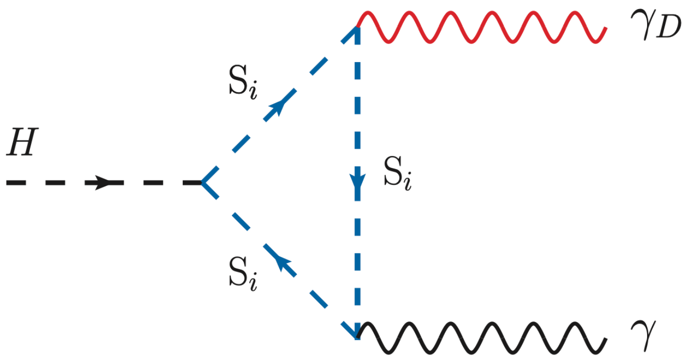




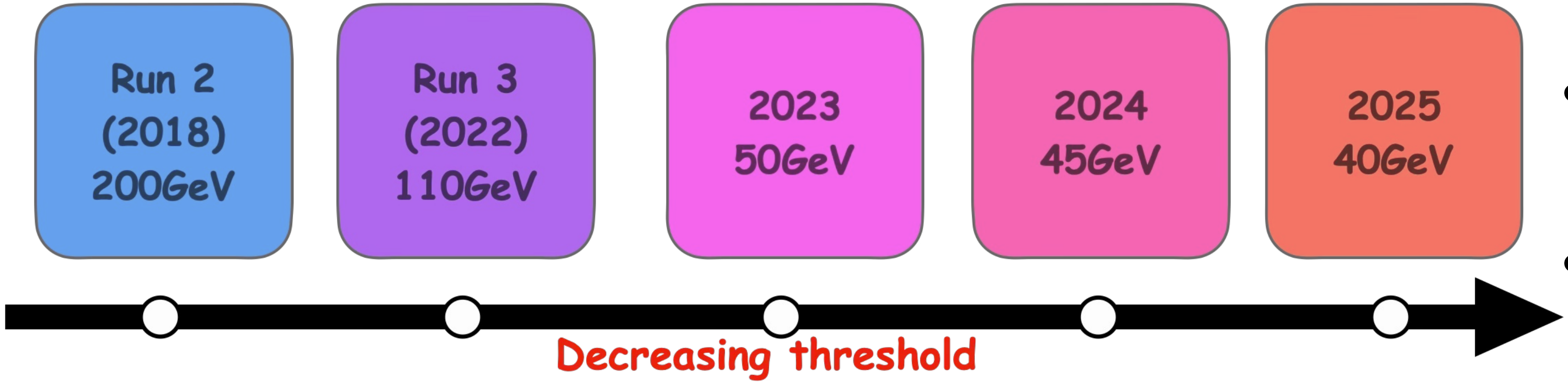
Motivation for $H \rightarrow \gamma\gamma_D$

- $H \rightarrow \gamma\gamma_D$, where the massless dark photon is invisible
- Experimental signature: one isolated photon recoiling against MET
- Exotic Higgs decays provide sensitivity to weakly coupled dark sectors
- Targeting the dominant ggF production provides access to a phase space complementary to previous CMS ZH and VBF searches
- Latest ATLAS results show improvement from ggF
- Previous talk at the CMS NPS Workshop 2026
- A first draft of the analysis note (AN-26-115) is now in place.

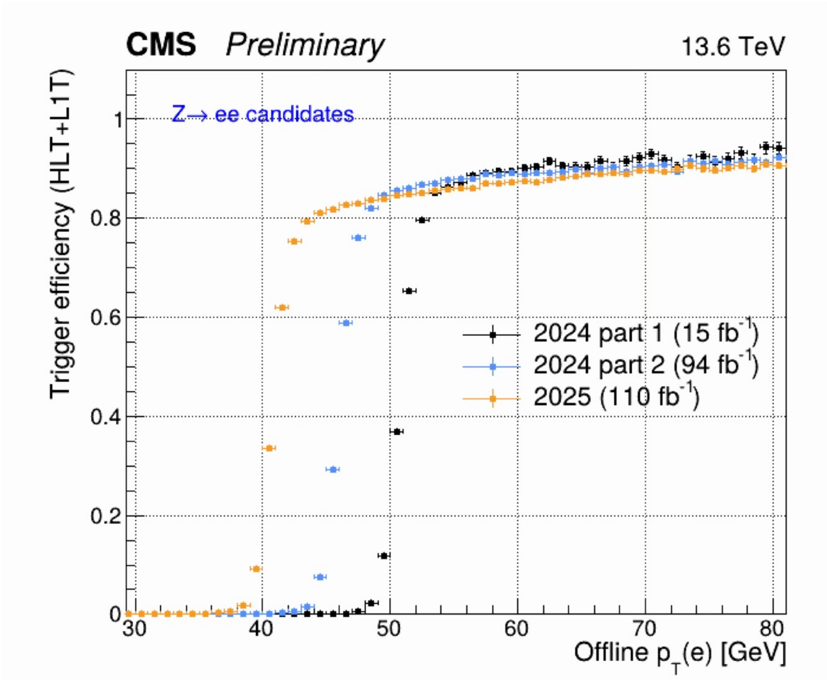


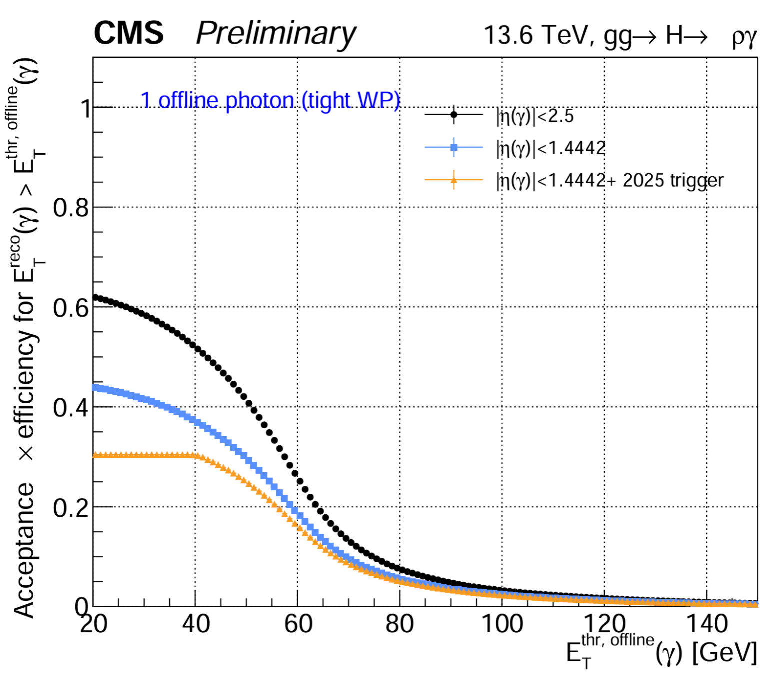
arXiv:2206.05297

A New ggF Opportunity in Run 3



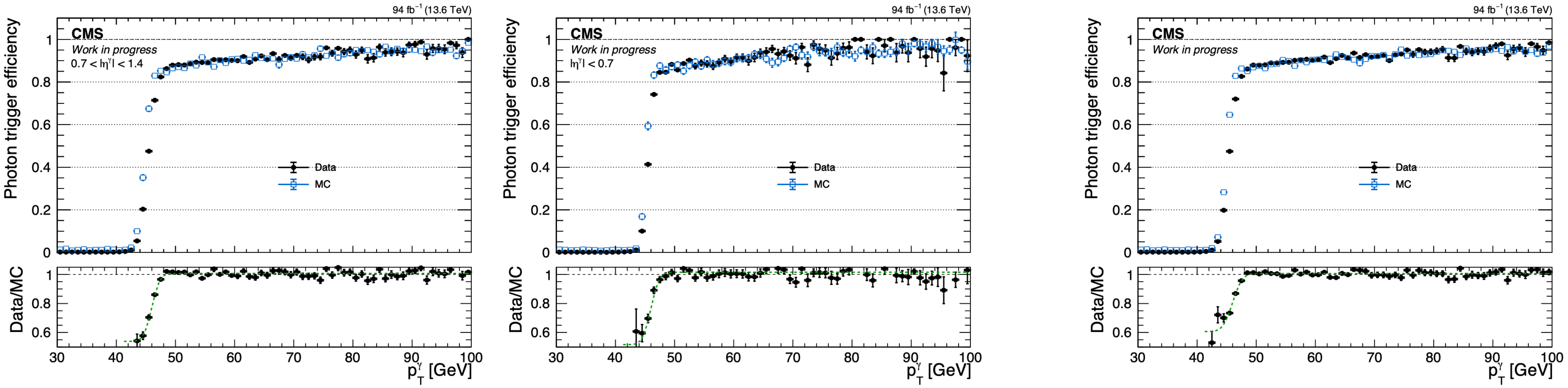
- CMS-DP-2025/086
- Low p_T single photon triggers deployed with high efficiency
- Signal acceptance falls rapidly at high photon E_T
- This analysis currently focuses on the 45 GeV trigger





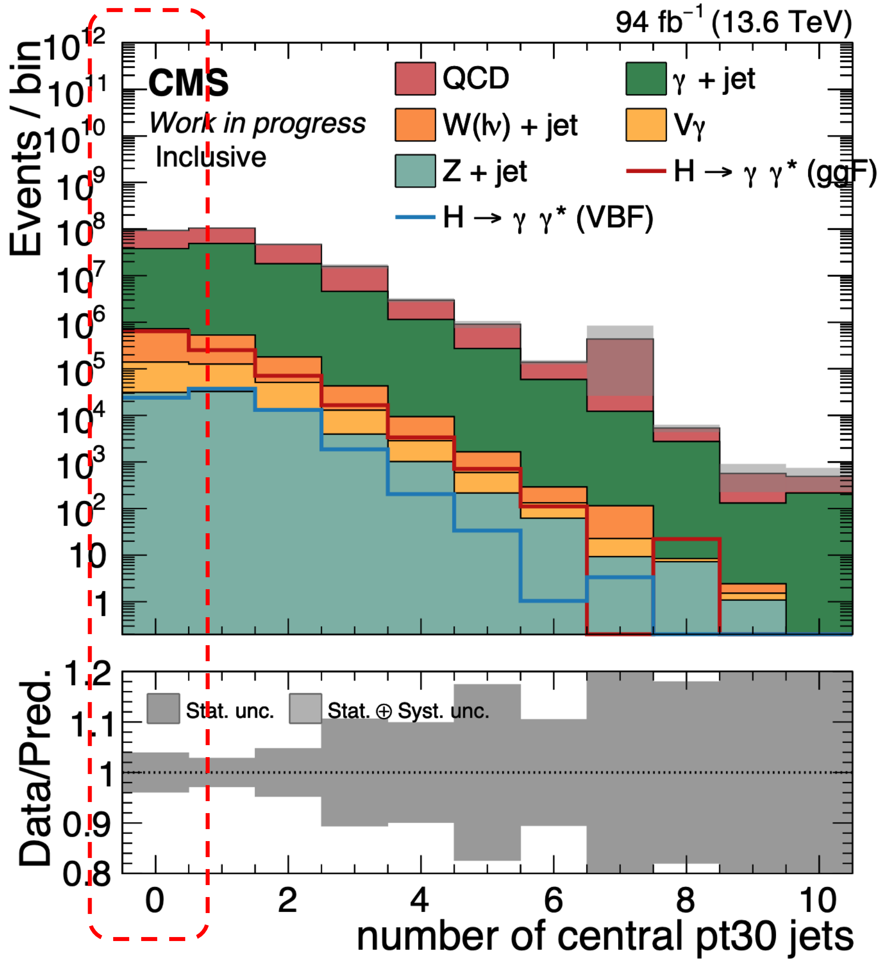
CMS-DP-2025/086

- **Dataset**
  - 2024 EGamma0/EGamma1
  - Eras E–I
  - 93.6 fb^{-1}
  - HLT_Photon45EB_TightID_TightIso
  - Barrel photon: $|\eta^{\gamma}|<1.4442$
- **Trigger performance**
  - $Z \rightarrow ee$ tag-and-probe
  - Endcap electron tag
    - $p_T \geq 32\mathrm{GeV}$, $1.566 < |\eta| < 2.5$
  - Barrel photon probe
    - $p_T \geq 20\mathrm{GeV}$, $|\eta| < 1.4442$
  - $50 \leq m(e, \gamma) \leq 130$ GeV



MET tails in inclusive jets category

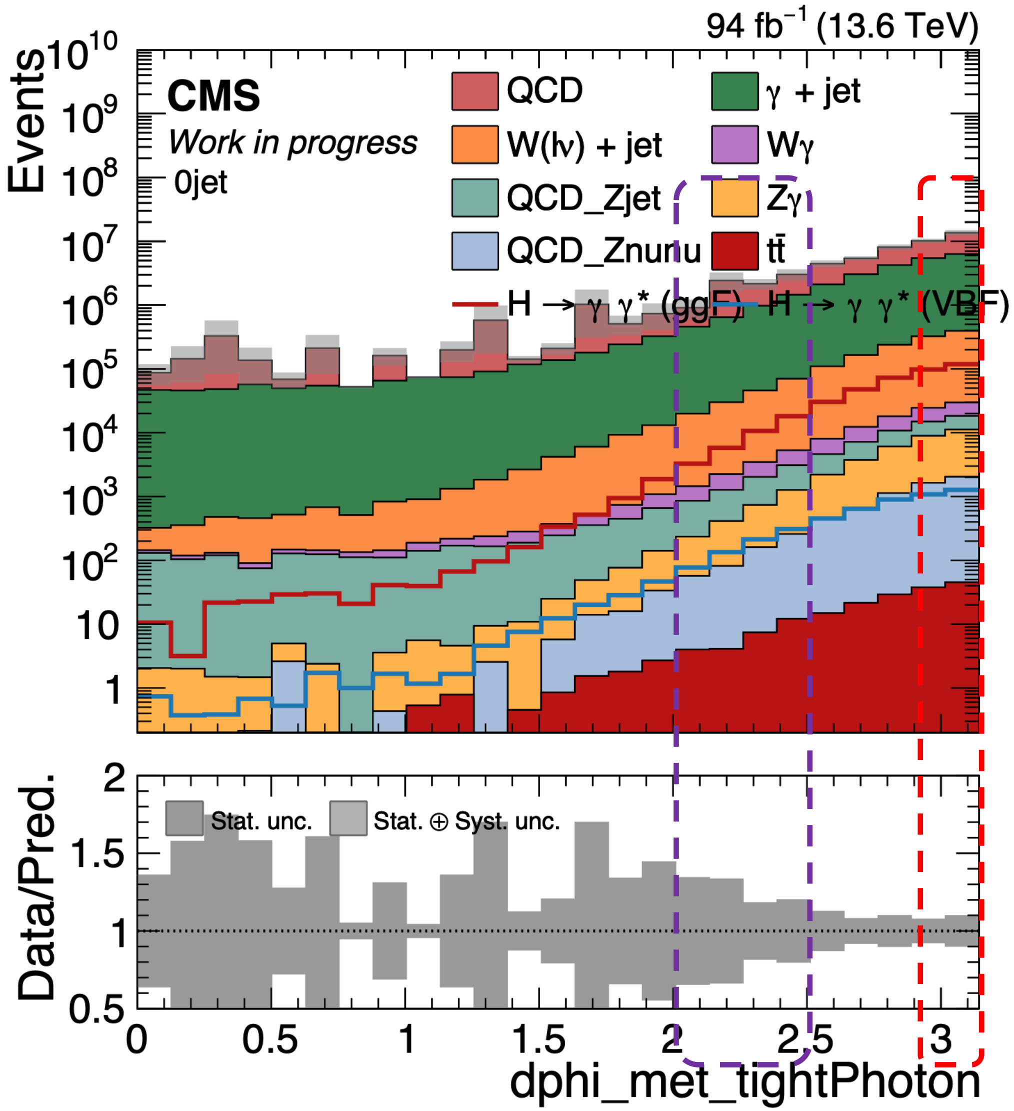
Event Selection and the 0-Jet Category



Process	N(0 jet)/N(inclusive)
ggF signal	65.0%
QCD multijets	35.8%
γ+jets	34.1%

Selection	Signal region	Low-$\Delta\phi$ validation region
Trigger	`HLT_Photon45EB_TightID_TightIso`	
Photon multiplicity	Exactly one tight photon in the ECAL barrel	
Photon kinematics and ID	$p_T^\gamma > 45\,\mathrm{GeV}$, $\lvert\eta^\gamma\rvert < 1.4442$, tight photon ID	
MET	Type-1 corrected PUPPI $40 < p_T^{miss} < 100\,\mathrm{GeV}$	
Lepton veto	No loose electron, muon, or hadronically decaying tau candidate	
b-jet veto	No b-tagged central AK4 jet with $p_T > 15\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$	
Fake-jet veto	No AK4 jet with $p_T > 50\,\mathrm{GeV}$ and $\lvert\eta\rvert < 4.7$ failing the “Tight” jet ID	
N_{jet} selection	No inclusive AK4 jet with $p_T > 30\,\mathrm{GeV}$ passing the jet selection	
$\Delta\phi(\gamma, \vec{p}_T^{miss})$	> 2.9	$2.0 < \Delta\phi(\gamma, \vec{p}_T^{miss}) < 2.5$

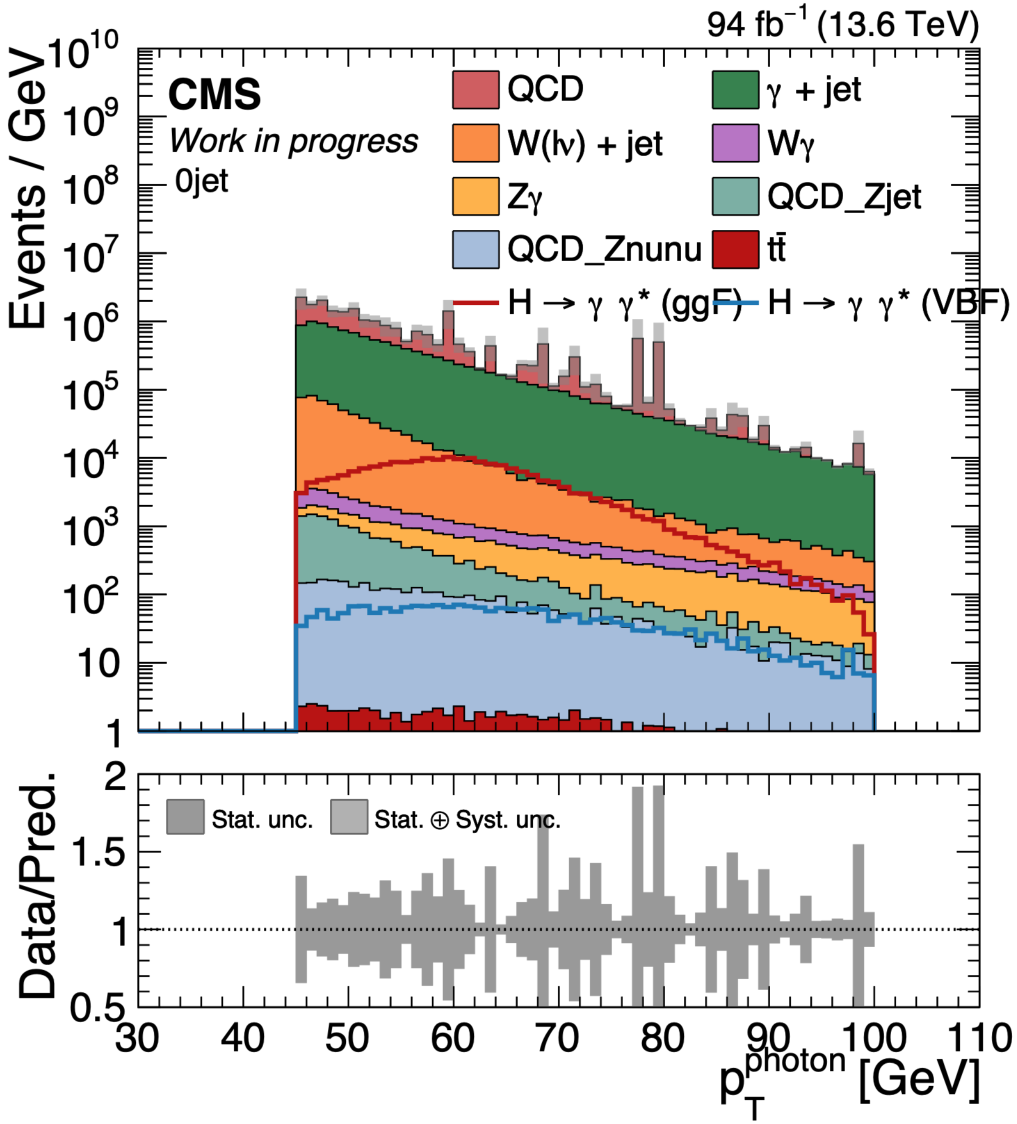
Signal and Validation Regions



<table>
<tr><th rowspan="2">Region</th><th colspan="2">N(region) / N(full selected)</th></tr>
<tr><th>ggF signal</th><th>γ+jets & QCD</th></tr>
<tr><td>VR $2.0 < \Delta\phi < 2.5$</td><td>8.7%</td><td>15.0%</td></tr>
<tr><td>SR $\Delta\phi > 2.9$</td><td>51.2%</td><td>42.2%</td></tr>
</table>

- $\Delta\phi(\gamma,\text{MET})$ is used to define the analysis regions
- Low $\Delta\phi$ region: background model validation region (VR)
- High $\Delta\phi$ region: signal region

Signal Extraction and Statistical Model



- **Observable**
  - Binned fit to the p_T^{γ} spectrum
  - Fit range: $49 < p_T^{\gamma} < 100$ GeV
  - Signal feature near $p_T^{\gamma} \approx m_H/2$
- **Model**
  - ggF: double-Gaussian function
  - VBF: fourth-order Bernstein polynomial
  - Background: three-order exponential
- **Inference**
  - Binned profile likelihood with Combine
  - Common branching fraction for ggF and VBF

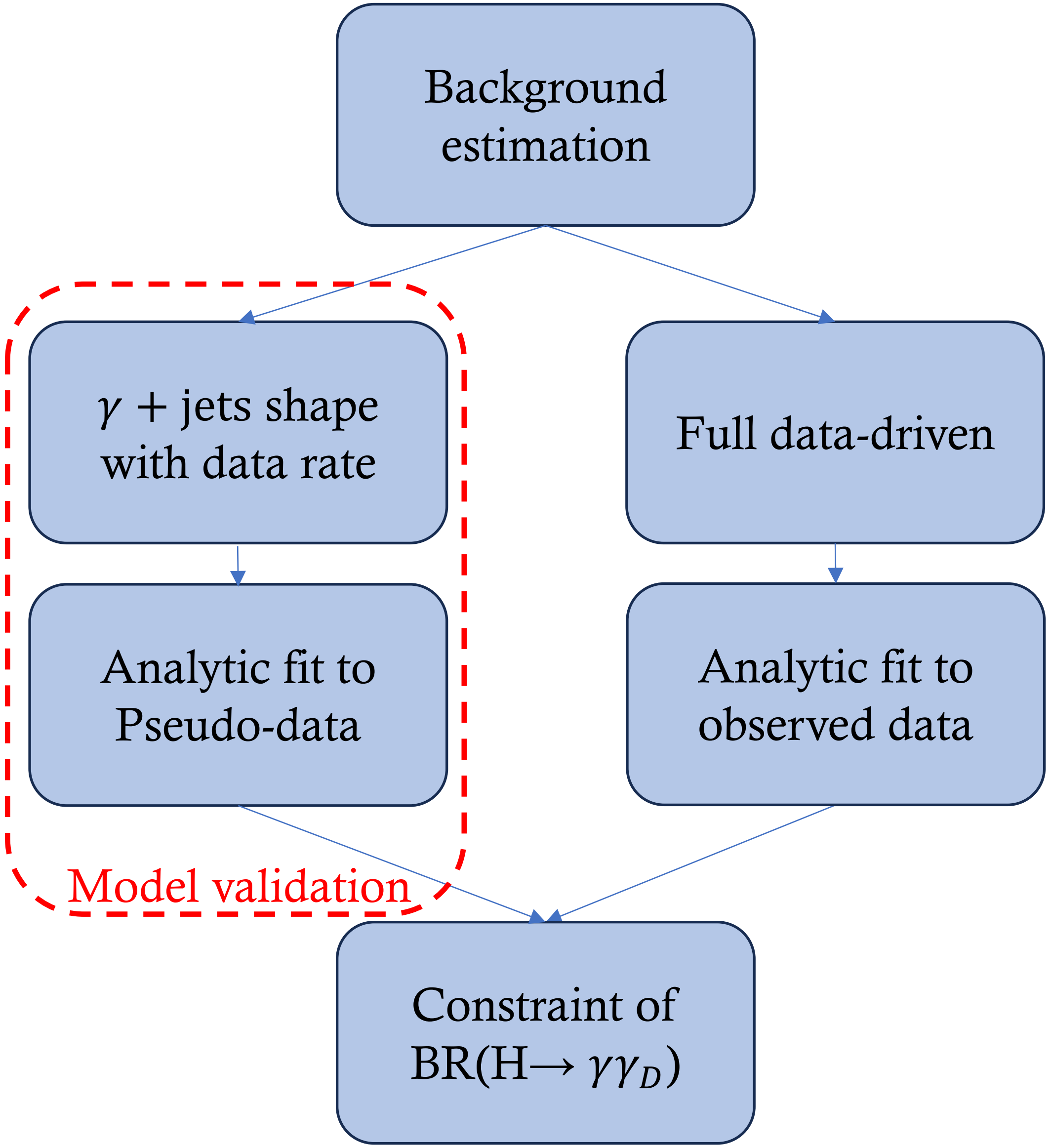
Background Estimation

Process	SR yield	SR fraction
QCD multijet	8,019,464	51.1%
γ + jets	7,256,605	46.3%
$W(\ell\nu)$ + jets	364,789	2.3%
$W\gamma$	14,285	0.1%
$Z\gamma$	13,200	0.1%
$Z(\ell\ell)$ + jets	7,664	$< 0.1\%$
$Z(\nu\nu)$ + jets	2,813	$< 0.1\%$
Top quark	66	$< 0.1\%$
Total simulated background	15,678,886	100%
ggF $H \rightarrow \gamma\gamma_D$	192,019	–
VBF $H \rightarrow \gamma\gamma_D$	2,018	–

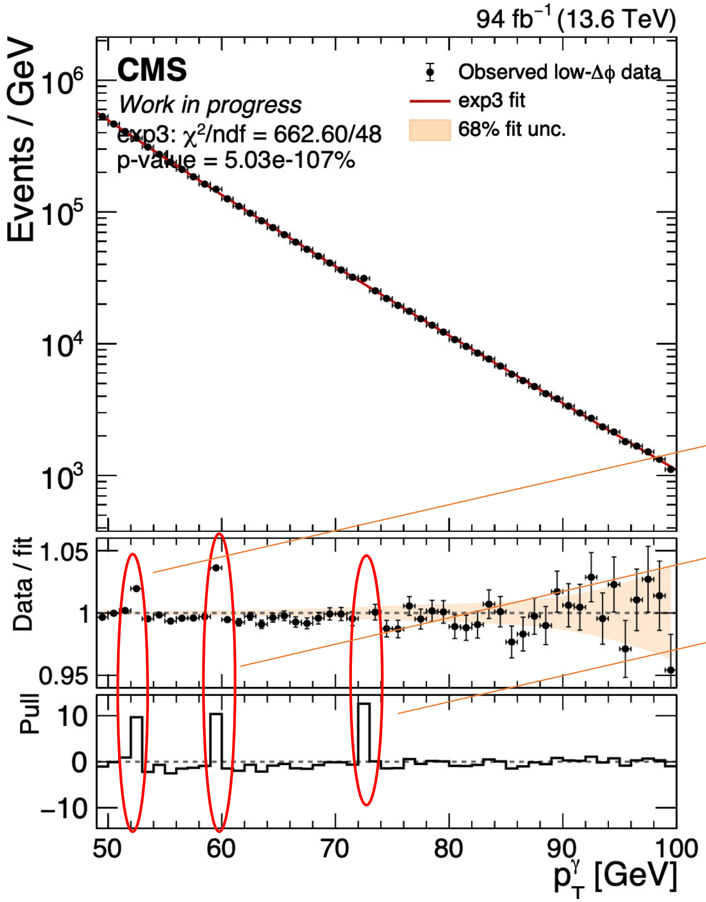
- QCD multijet
  jet → photon misidentification and instrumental MET

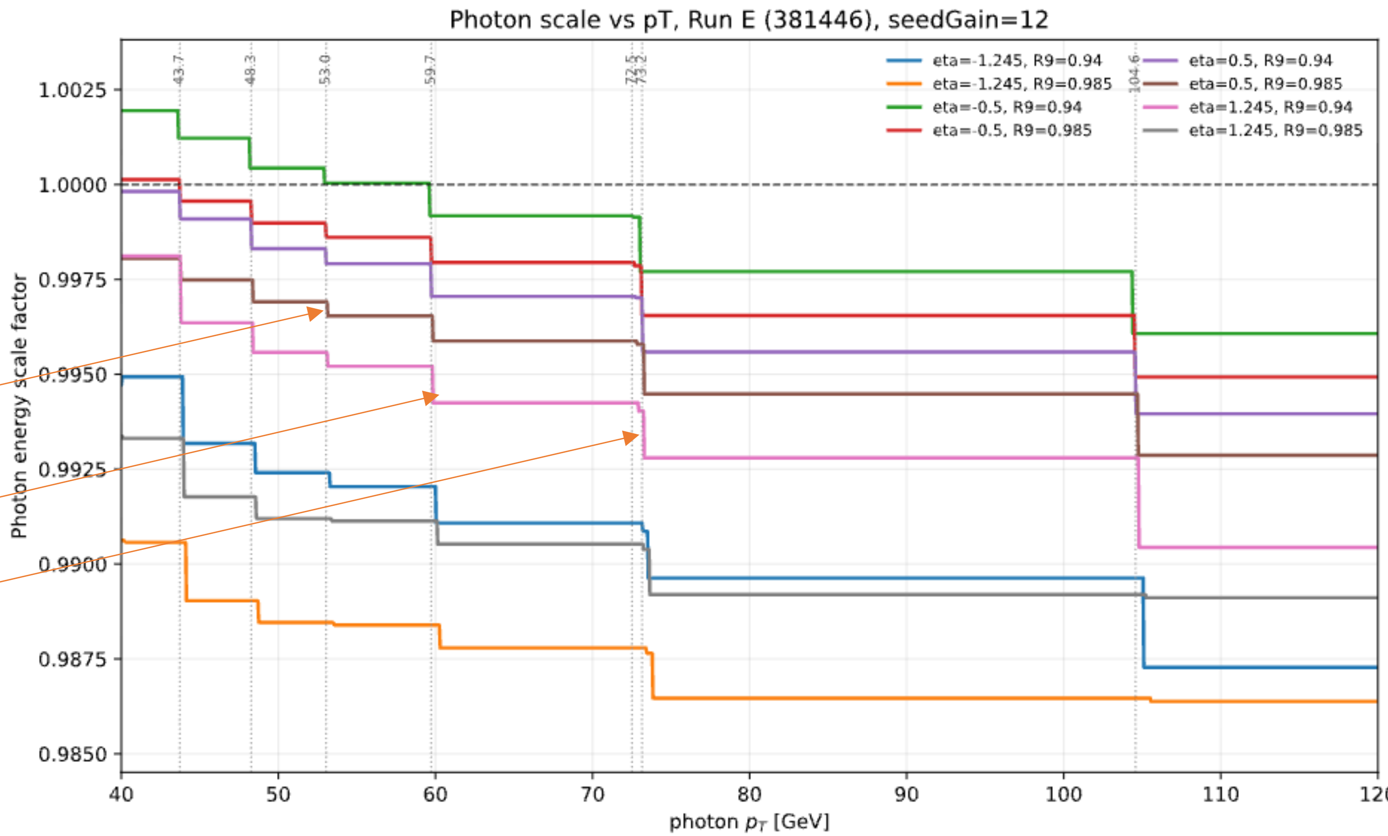
- γ+jets
  prompt photon with instrumental MET

- Minor backgrounds
  W/Z+jets, Vγ, and top-quark processes



Current status of the low-Δϕ validation

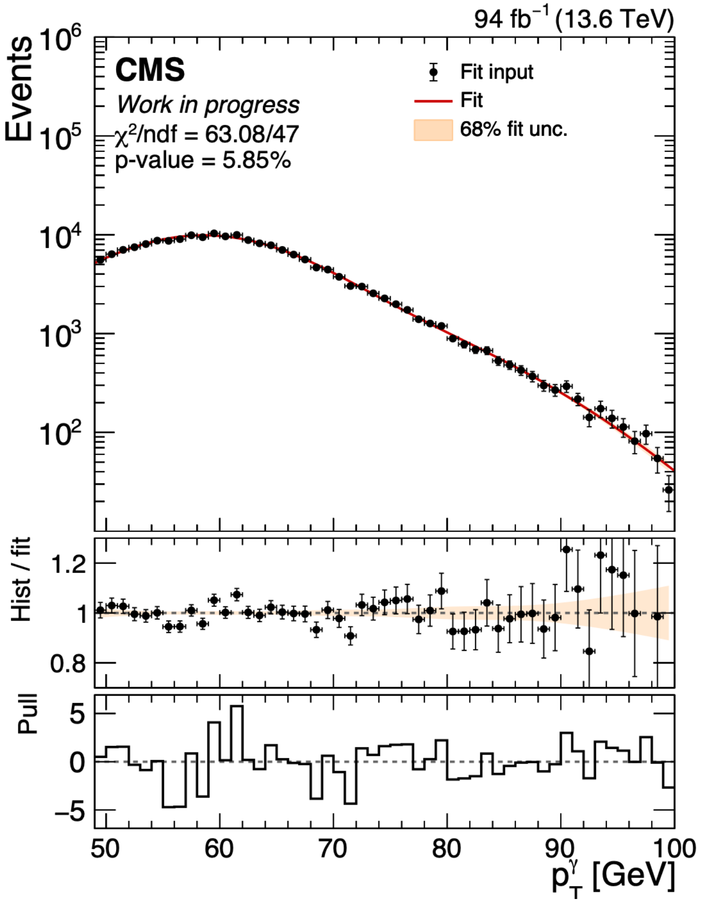




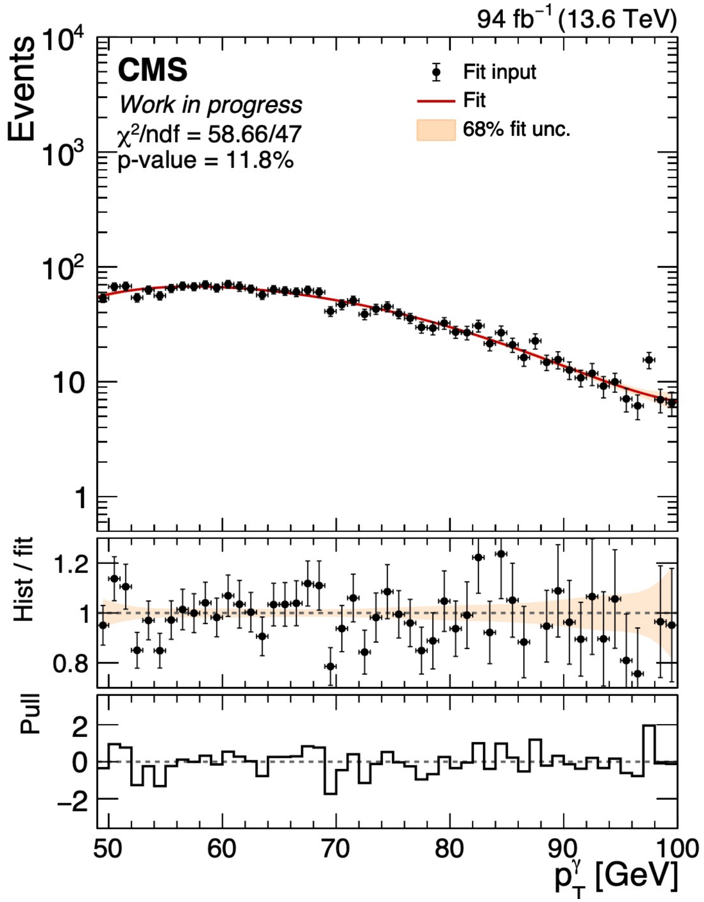
- The nominal exp3 model describe the current low-Δϕ data well except several points
- Localized residuals are aligned with discontinuities in the piecewise photon energy-scale correction
- A smooth EGM correction parameterization is being implemented before repeating the final background-model validation

Signal and background model

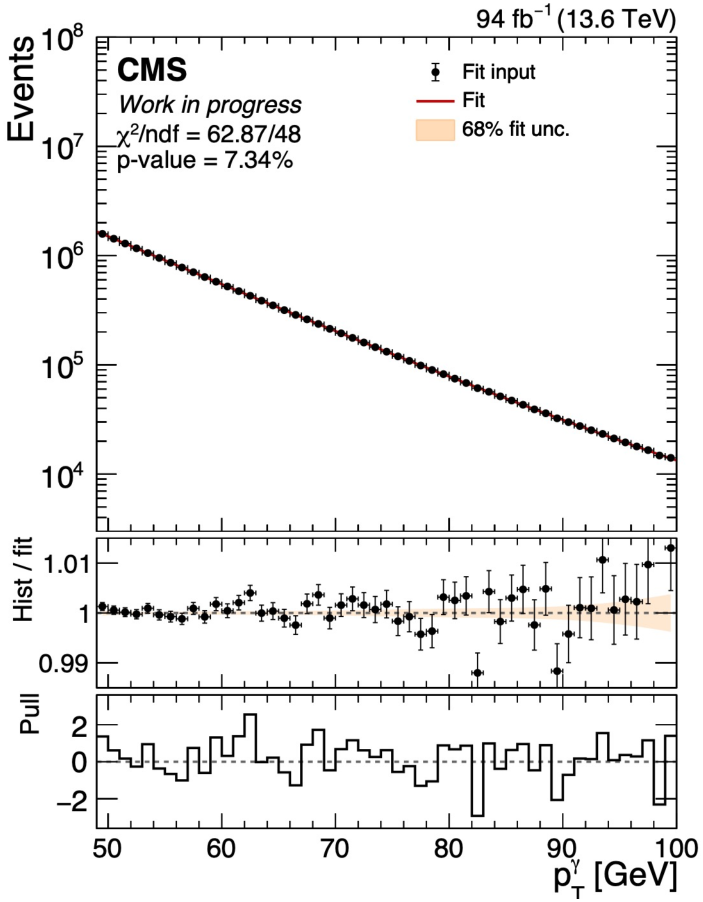
ggF signal — double Gaussian



VBF signal — Bernstein polynomial



Background — exp3



Fits to the signal templates and the background validate the chosen parameterizations and provide initial values for the likelihood fit.

Background model workflow

γ + jets MC

↓

Fit smooth RooGenericPdf

↓

Generate Poisson pseudo-data

↓

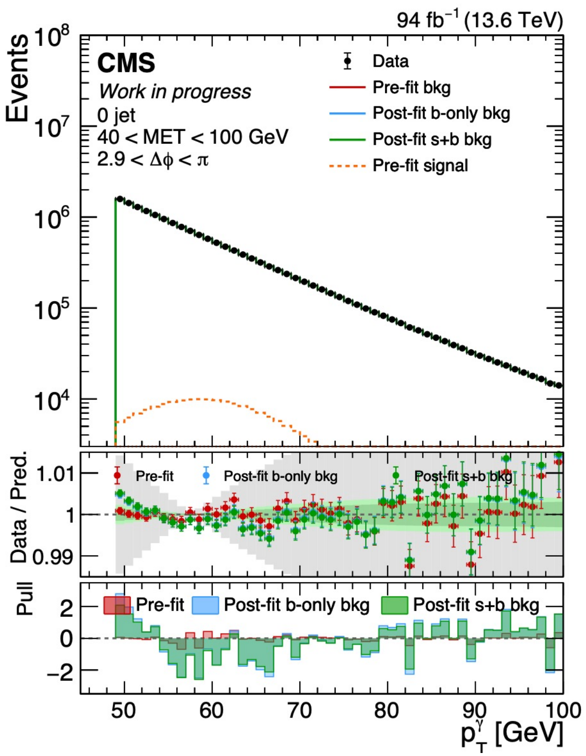
Refit the pseudo-data

↓

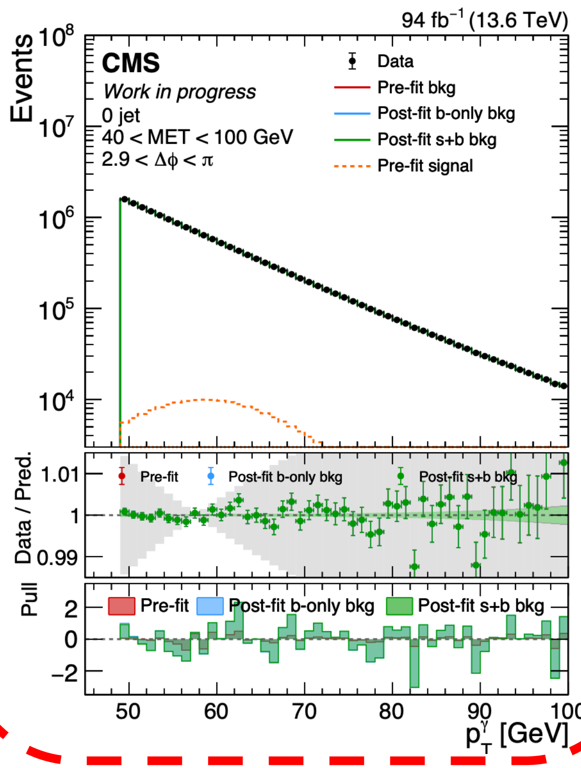
Normal card	ShapeBin card
↓	↓
Direct RooGenericPdf	Wrap same pdf function with RooParametricShapeBinPdf
↓	↓
Bin-central approximation $f(x_i)\Delta x_i$	Bin-integrated implement $\int f(x)\,dx$

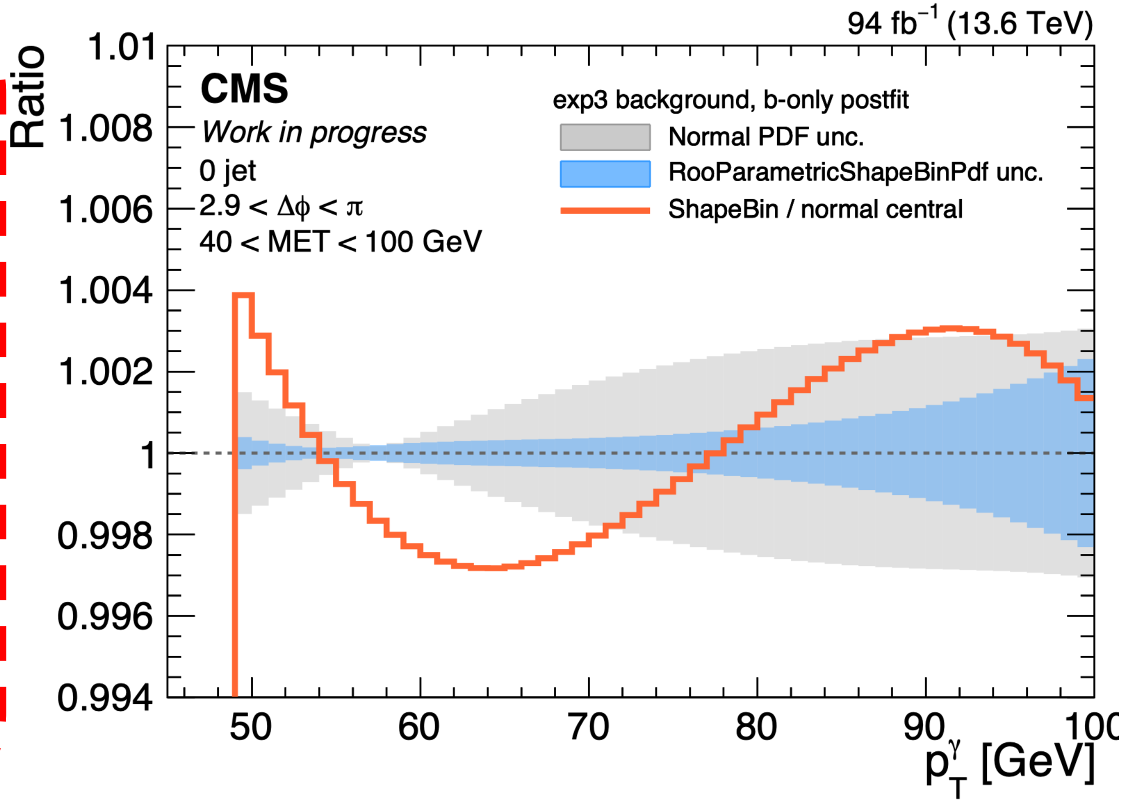
Prefit and Postfit

RooGenericPdf



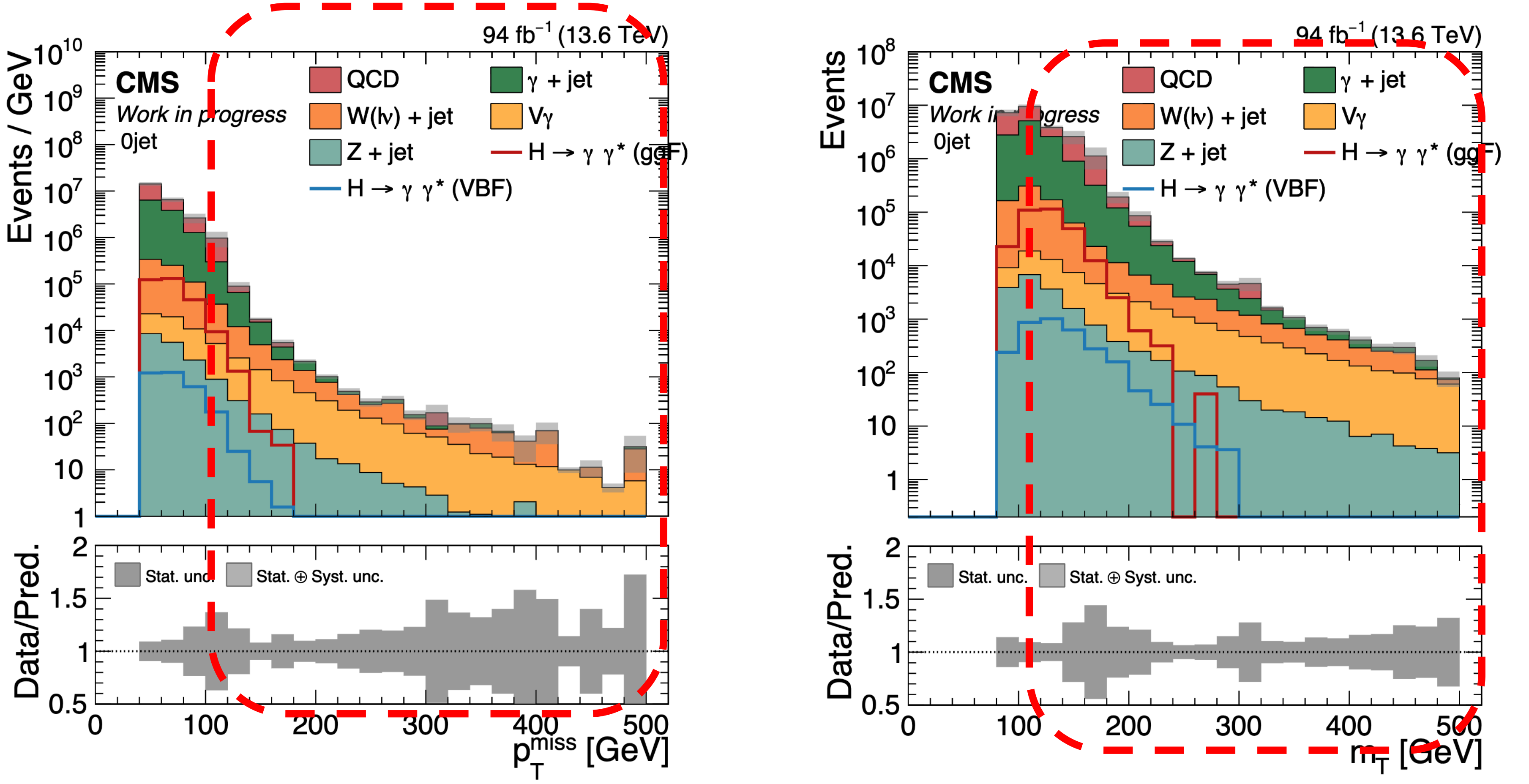
RooParametricShapeBinPdf





- Both models use the same exp3 function and the same dataset; only the bin prediction differs.
- This changes the profiled background parameters and the propagated bin uncertainty. The central predictions differ by at most ±0.4%.

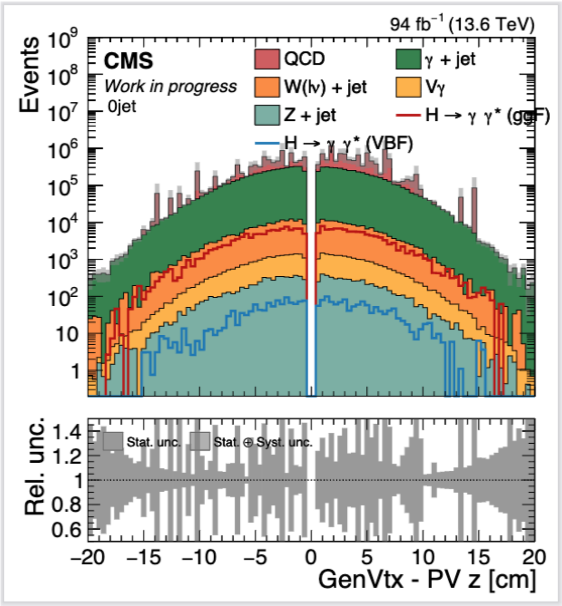
MET Tails in current 0-jet category



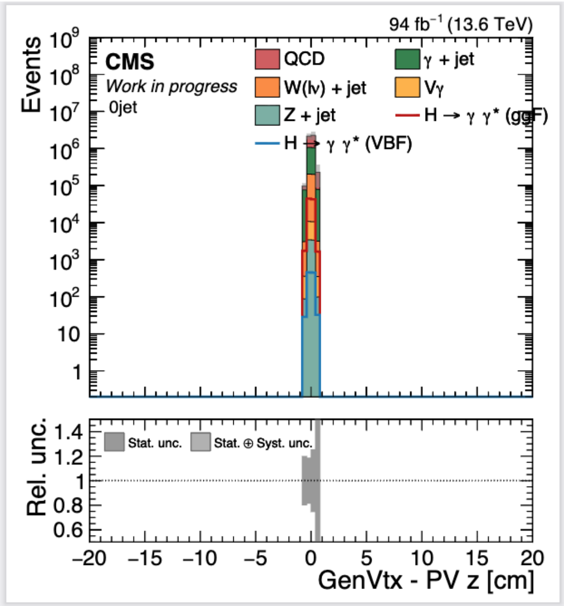
- MET>40
- The current 0-jet MC prediction shows harder high-MET and high-m_T tails than the ATLAS, driven mainly by γ+jets.

MET Tails in current 0-jet category

|dz| > 0.5 (PV mismatched)



|dz| <= 0.5 (PV matched)



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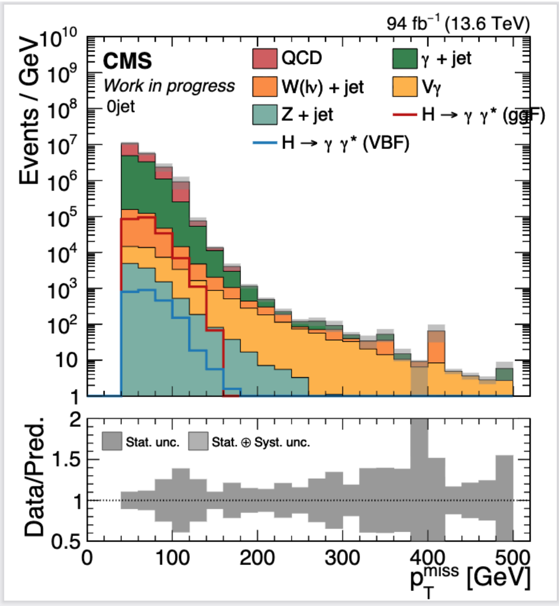
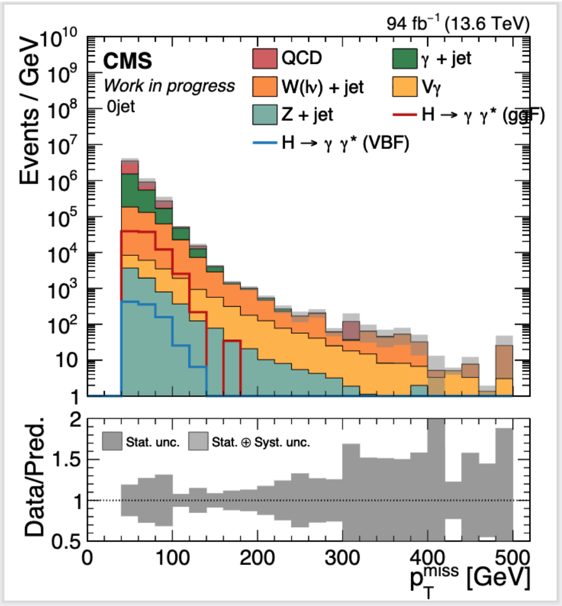


|dz| <= 0.5 (PV matched)



- Split MC by $|Z_{gen} - Z_{PV}| <= 0.5$ cm and > 0.5 cm.
- The selected MC sample shows a large contribution from events with $|Z_{gen} - Z_{PV}| > 0.5$.
- PV matching improves the high-tail to some extent, but does not remove it.

Summary and Outlook

- Run 3 low-threshold single photon triggers enable a new CMS search for $H \rightarrow \gamma\gamma_{\mathrm{D}}$ targeting the ggF topology.

- The current baseline uses 93.6 fb^{-1} of 2024 data and focuses on the 0-jet category with $40 < p_{\mathrm{T}}^{\mathrm{miss}} < 100\mathrm{GeV}$.

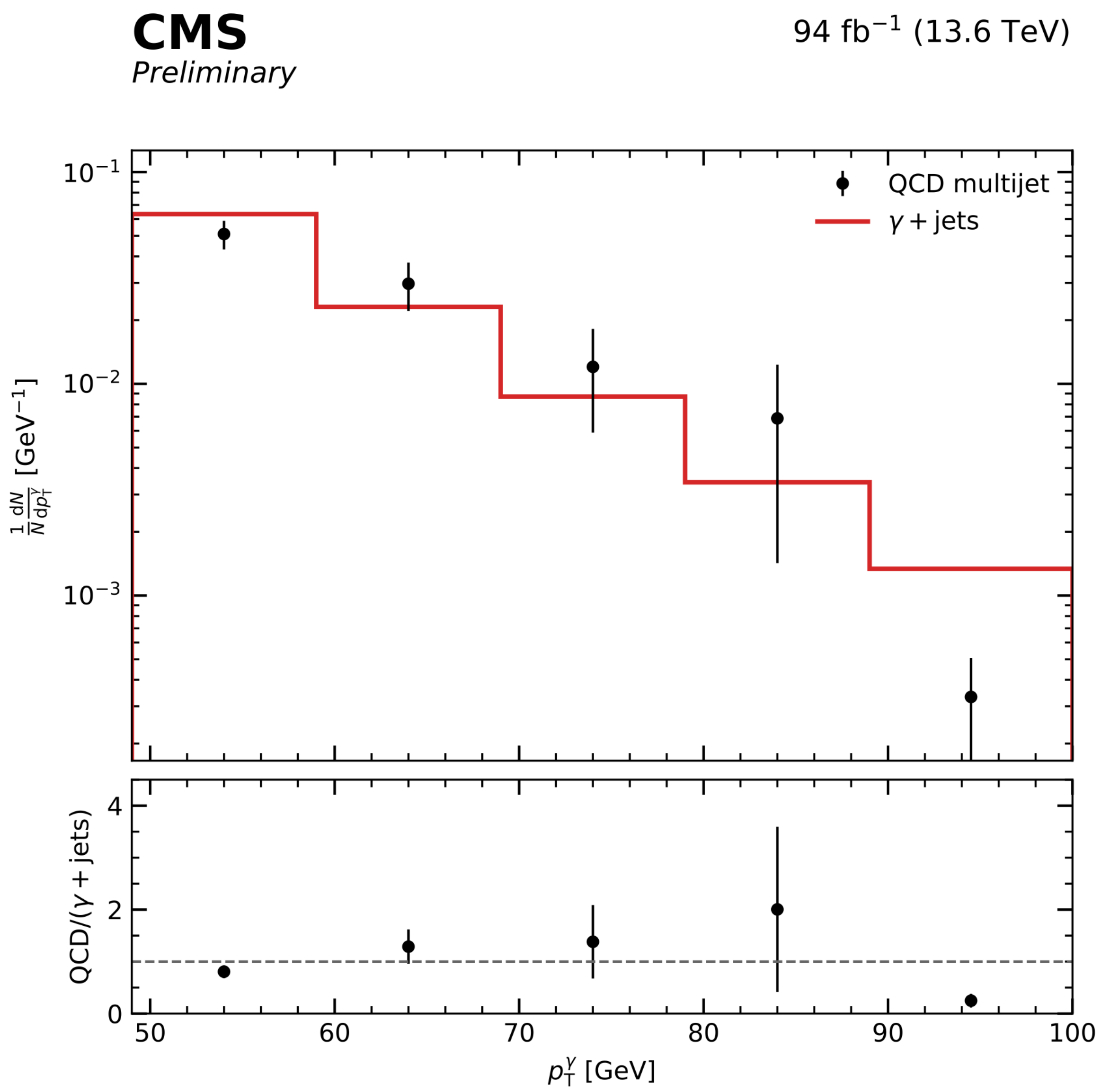
- The current blinded implementation uses pseudo-data for model development; the final total background will be determined directly from data.

- Next steps
  - Background-model bias tests;
  - instrumental MET tail studies;
  - Enable smooth EGM correction;
  - integration of the 2025 dataset.

- With the analysis note ready, we kindly request the opening of a CADI line to start the review after the summer.

Back up

Similarity between Gjets and QCD multijet



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Background model families

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1. Exponential polynomials of orders $n = 2, 3, 4$, and 5:

$$f_{\exp,n}(x) = \exp\left(\sum_{k=1}^{n} a_k \tilde{x}^k\right). \quad (3)$$

2. Bernstein polynomials of orders $n = 5, 6$, and 7:

$$f_{\mathrm{Bern},n}(x) = \sum_{k=0}^{n} c_k \binom{n}{k} t^k (1-t)^{n-k}, \quad (4)$$

   where c_0 is fixed to unity and the remaining coefficients are constrained to be positive.

3. Power-law functions multiplied by exponential polynomials, with $n = 2, 3, 4, 5$, and 6 free shape parameters:

$$f_{\mathrm{powexp},n}(x) = \left(\frac{x}{100\,\mathrm{GeV}}\right)^q \exp\left(\sum_{k=1}^{n-1} a_k \tilde{x}^k\right). \quad (5)$$

4. A sum of two exponential functions:

$$f_{2\exp}(x) = f \exp(a\tilde{x}) + (1-f)\exp(b\tilde{x}), \quad (6)$$

   where $0 \le f \le 1$.

Alternative background models

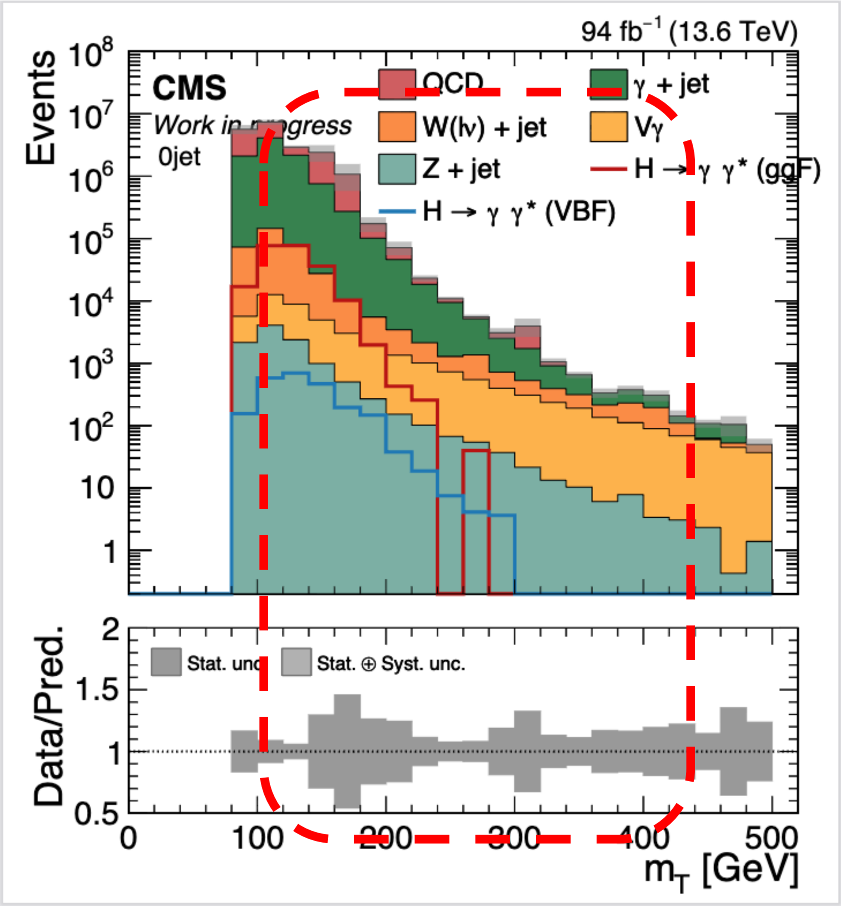
Signal and background model

- **Nominal analytic (RooGenericPdf):**
  data_obs
  γ + jets → fitted analytic PDF → Poisson pseudo-data
  background
  direct RooGenericPdf
  → bin-central approximation in the binned Combine model

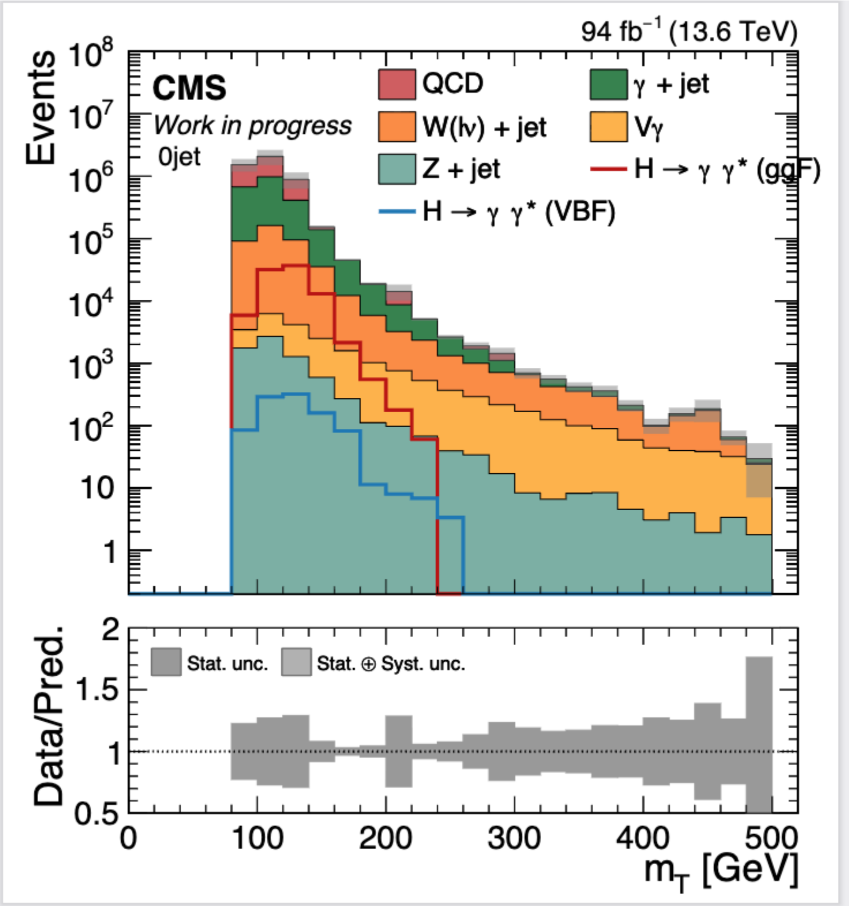
- **Shapebin analytic (RooParametricShapeBinPdf):**
  data_obs
  exactly the same pseudo-data as the corresponding normal card
  background
  same analytic function and the same fitted parameters
  → wrapped by RooParametricShapeBinPdf after the pseudo-data fit
  → exact bin-integrated prediction in the binned Combine model

MET Tails in current 0-jet category

|dz| > 0.5 (PV mismatched)

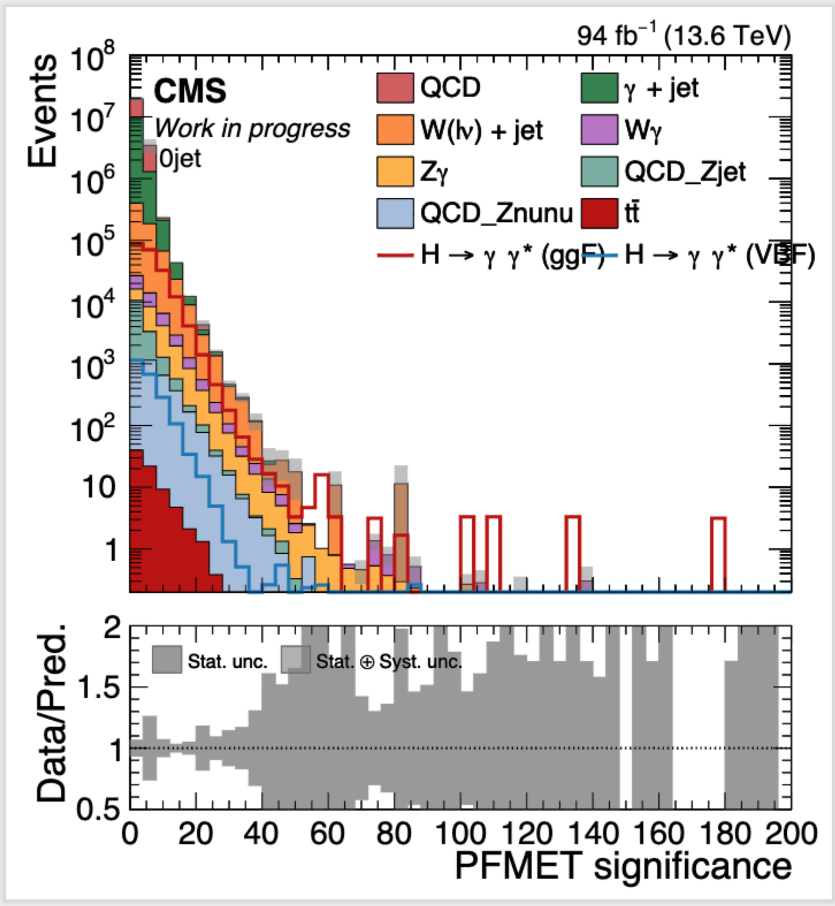


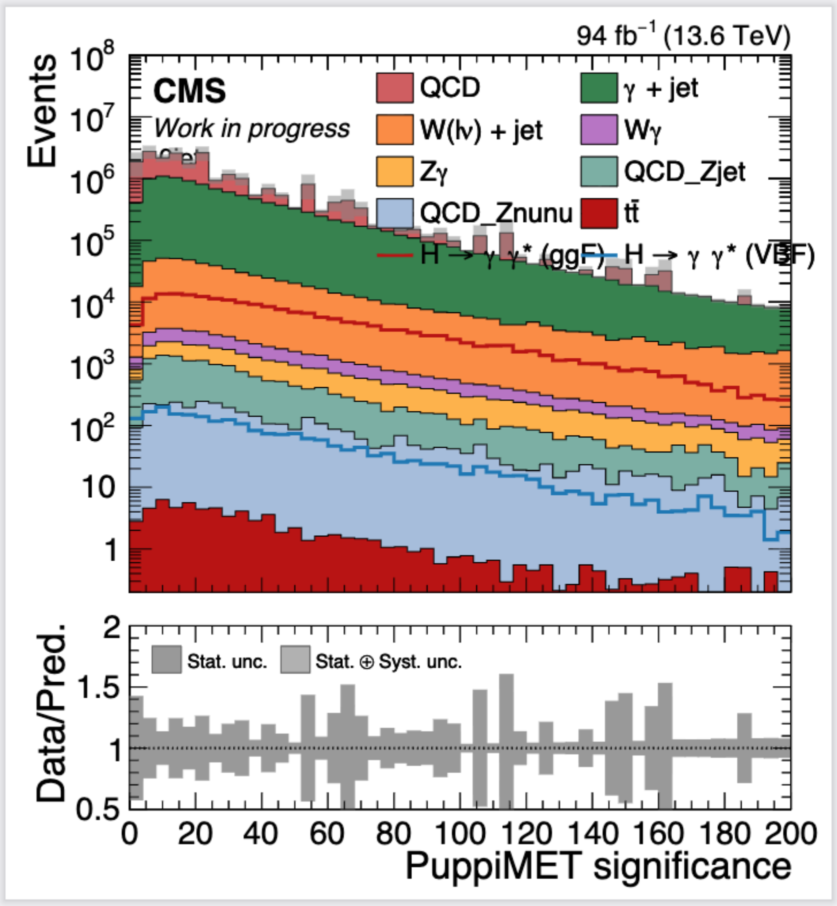
|dz| <= 0.5 (PV matched)



PV matching improves the high-tail to some extent, but does not remove it.

MET Tails in current 0-jet category





PF and PUPPI MET significance exhibit substantially different numerical ranges and shapes.