Physics with photons in ATLAS

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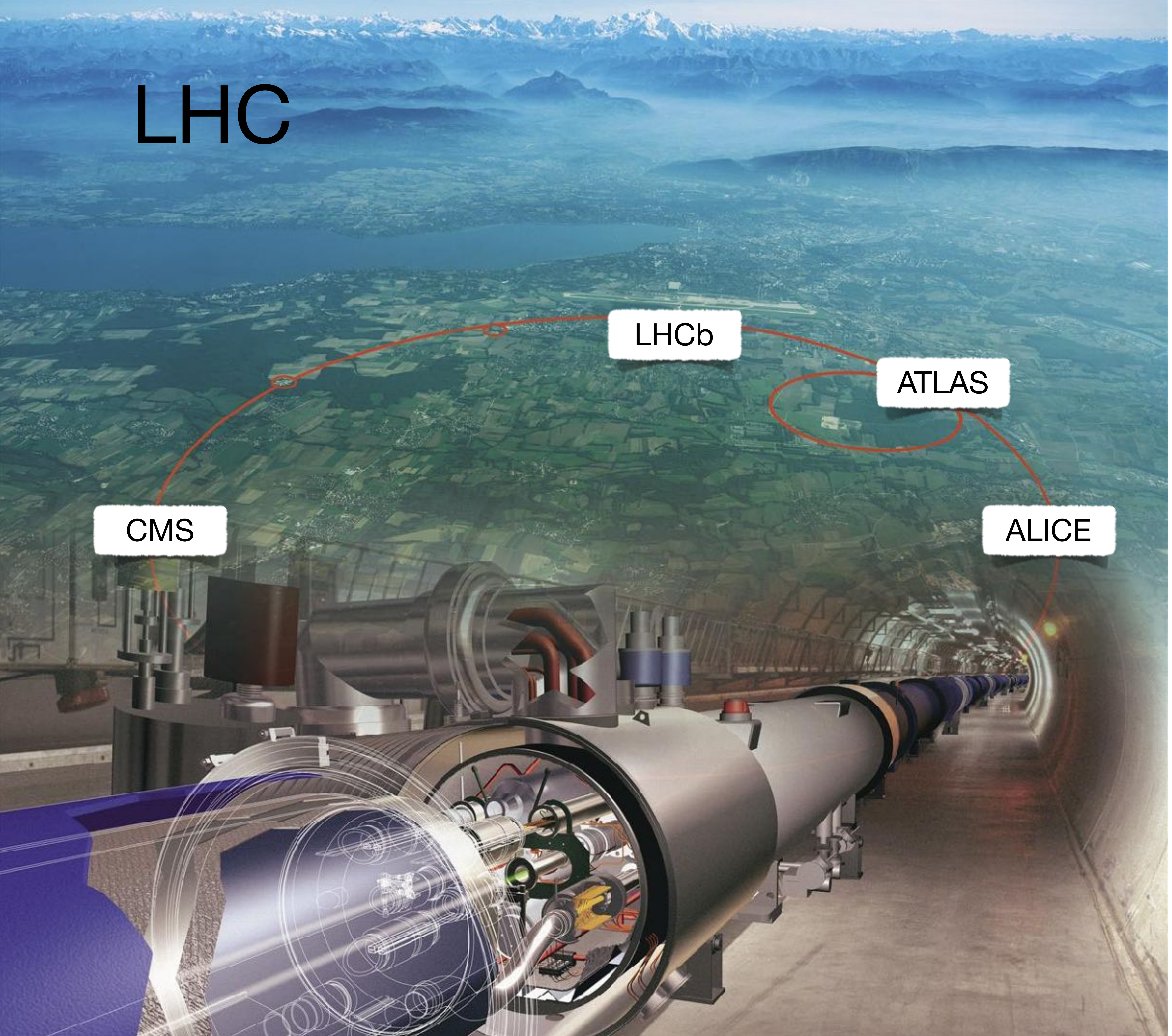
TECHNISCHE UNIVERSITÄT DRESDEN

Physics & games: Das Weihnachtsevent für Fellows
December 18th, 2020

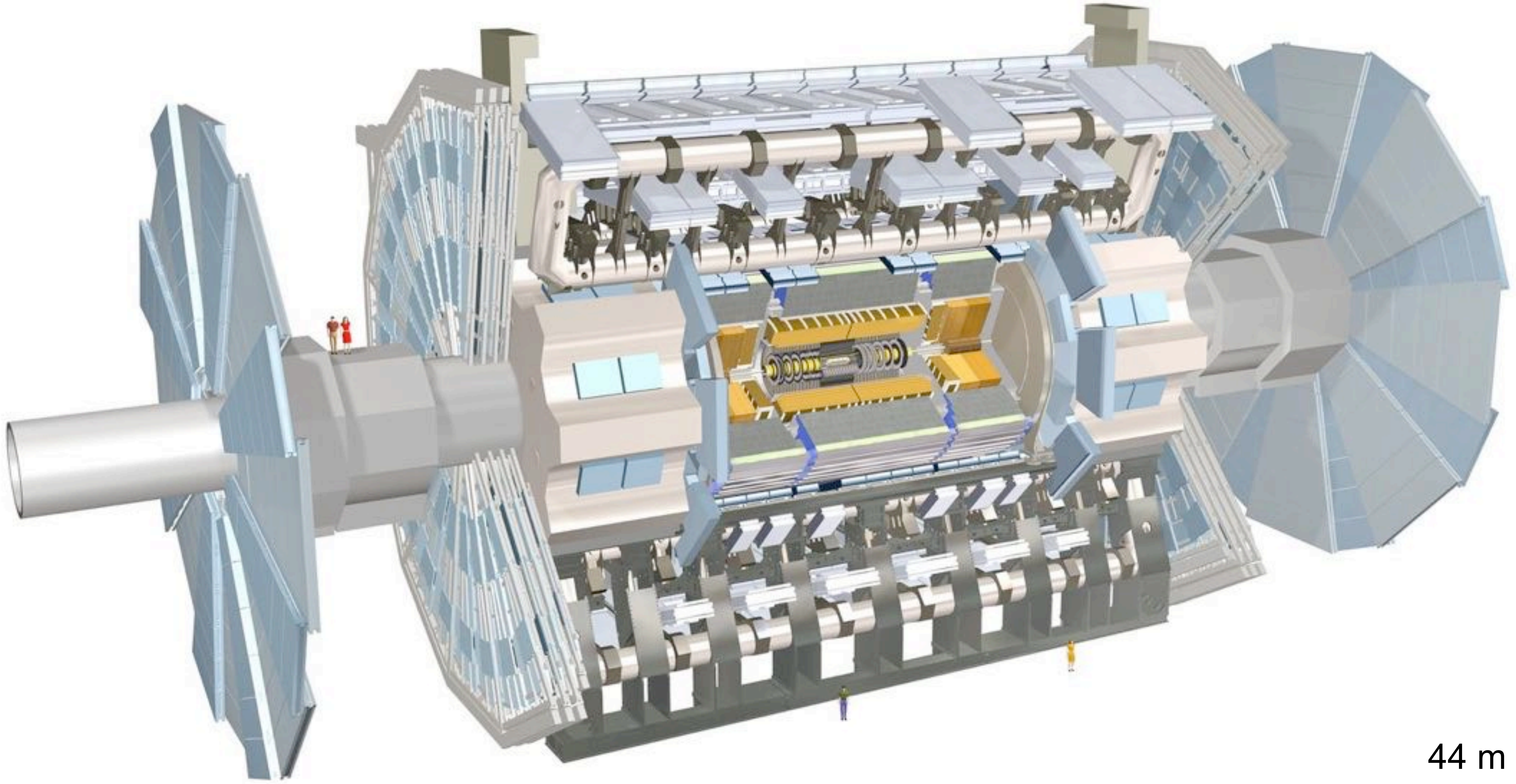
LHC



ATLAS and CMS detectors built with three main purposes:

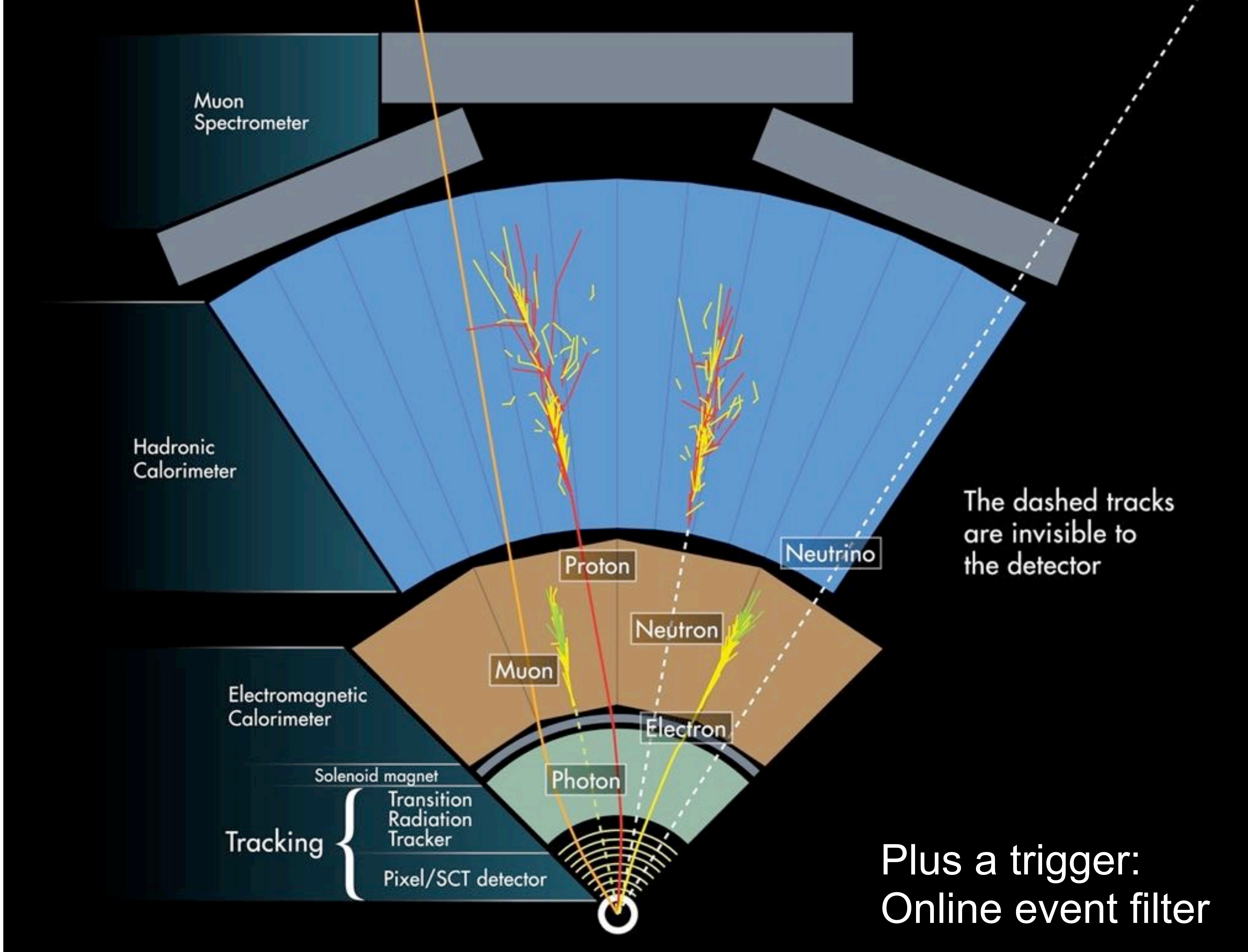
- Observing or excluding the Higgs boson,
- Searching for physics beyond the Standard Model,
- Precision measurements of Standard Model physics processes

The ATLAS detector



44 m long
25 m of diameter

Detector components



Plus a trigger:
Online event filter

ATLAS CONF Note

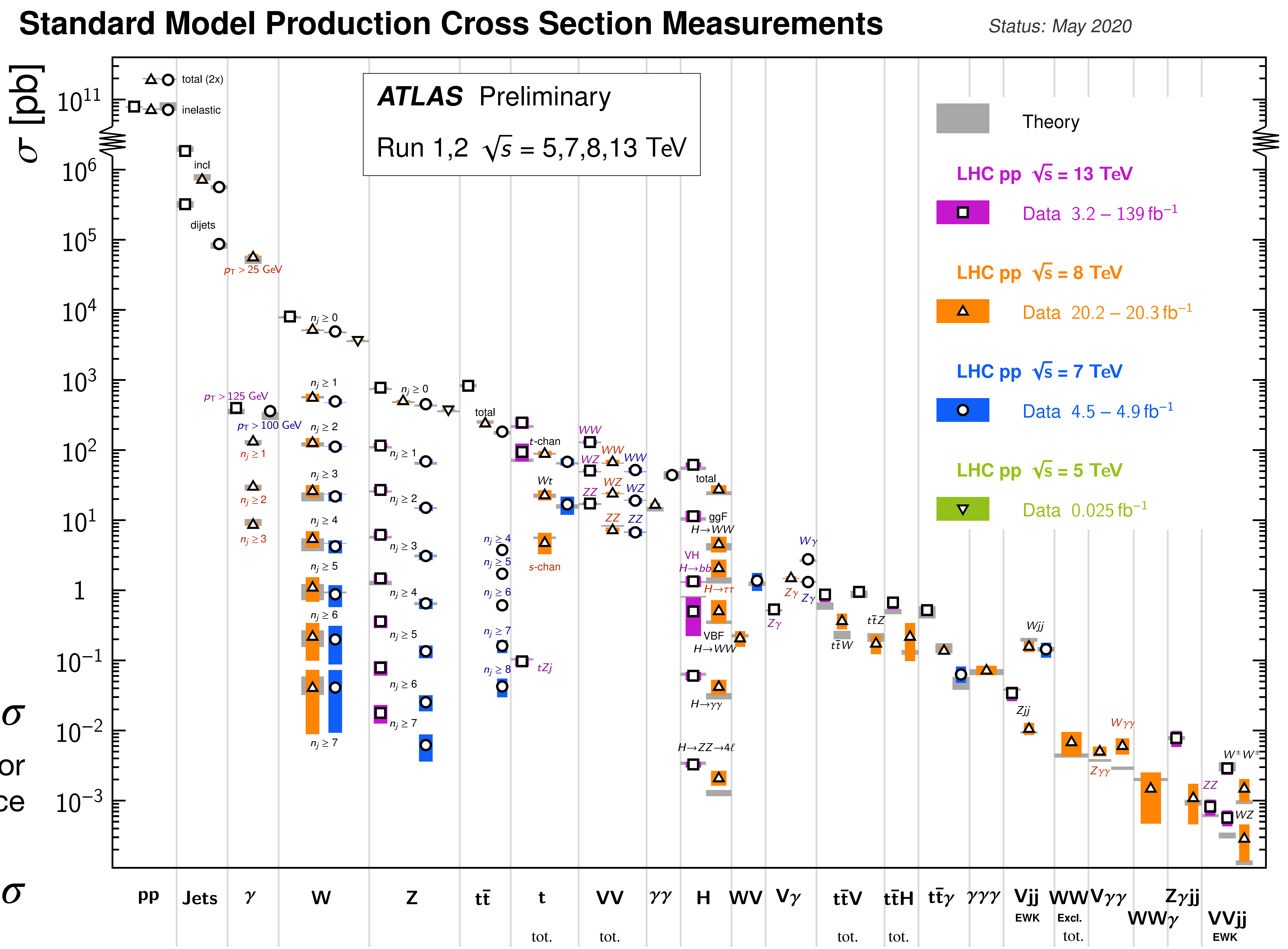
ATLAS-CONF-2020-024

28th July 2020

Measurement of the production cross section of isolated photon pairs in pp collisions at 13 TeV with the ATLAS detector

The ATLAS Collaboration

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2020-024/



Cross section σ

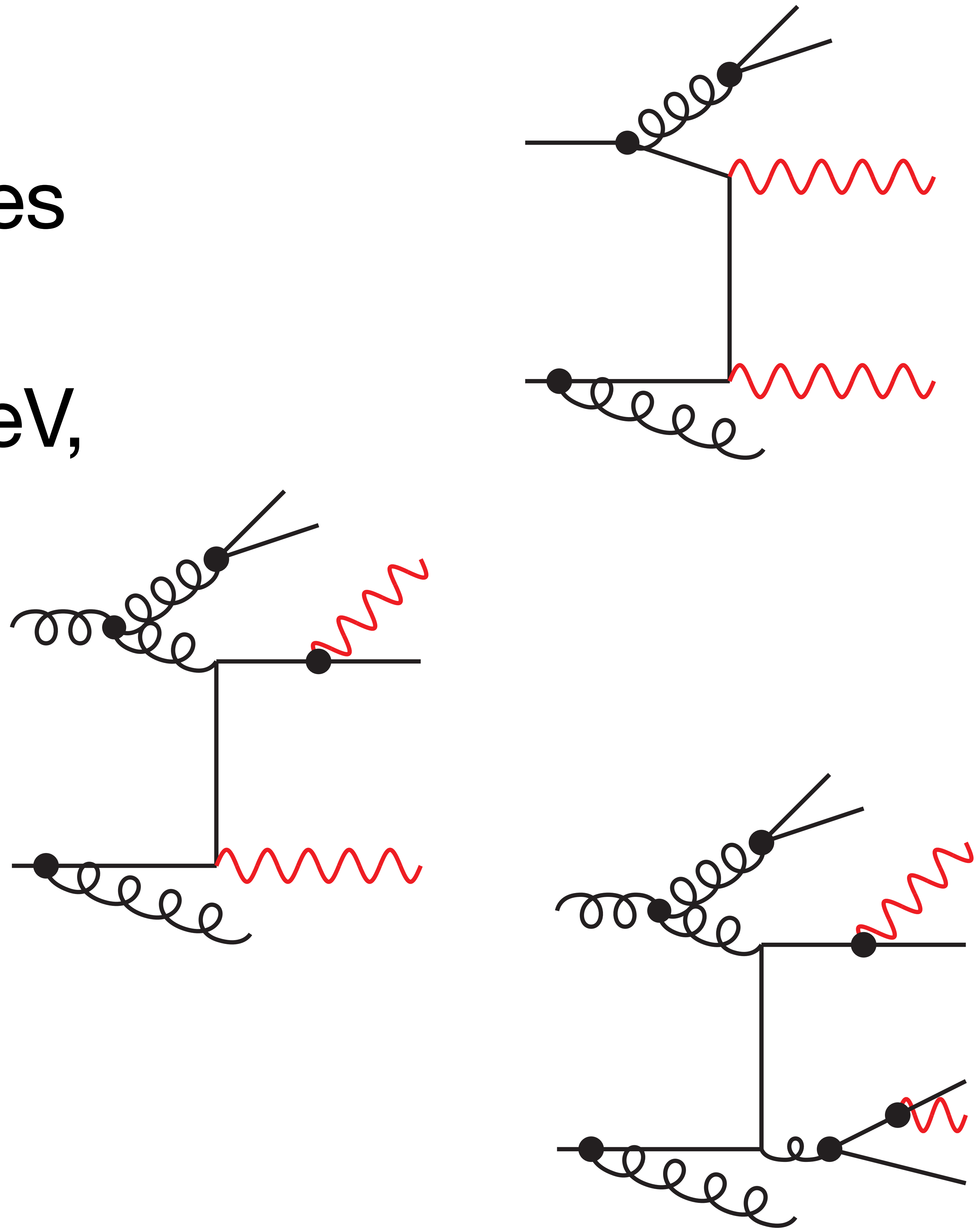
a measure of the probability for a specific process to take place

$$N_{evt} = \text{IntLumi} \times \sigma$$

Physics goal: $\gamma\gamma$ production measurement

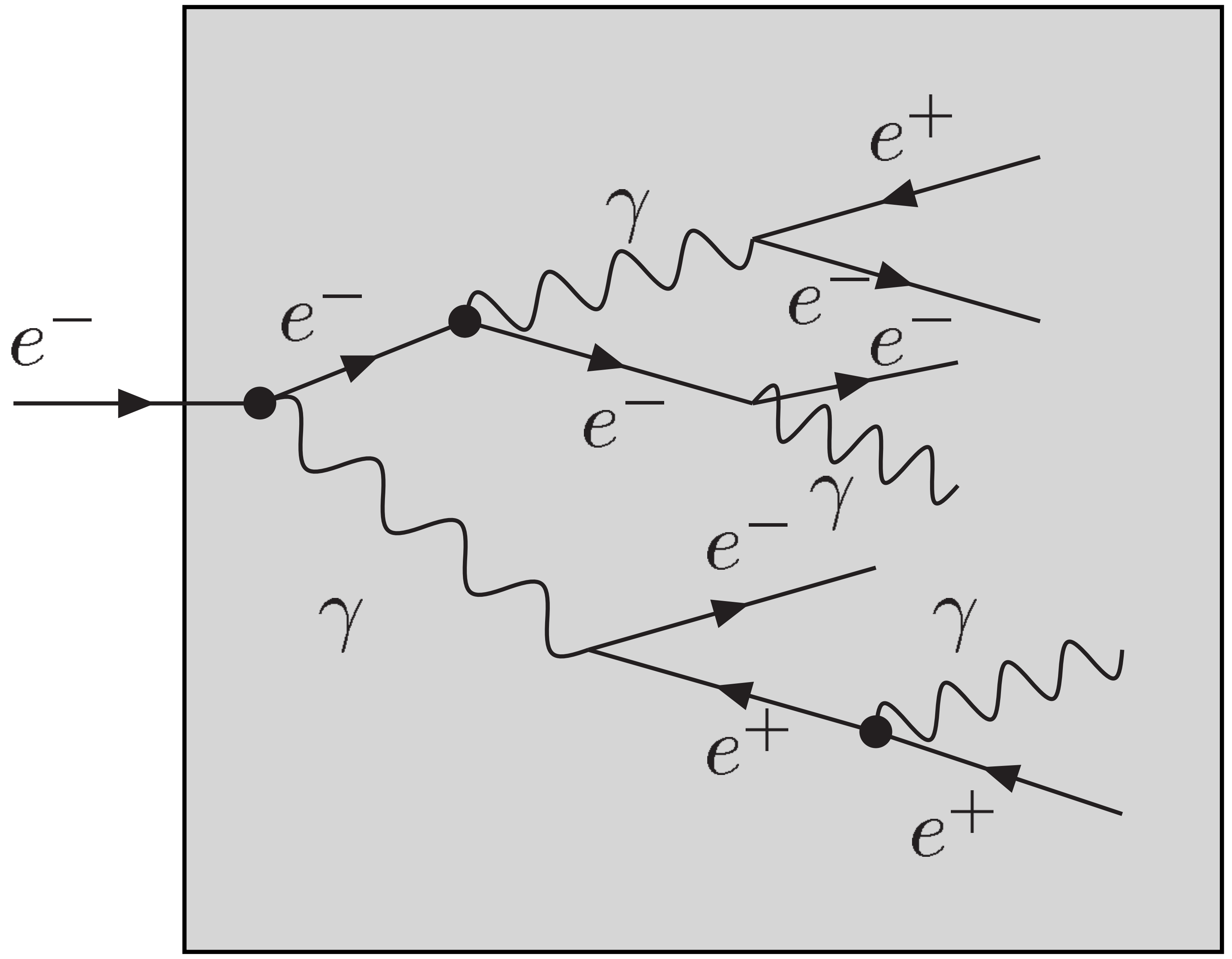
- Helps understanding QCD,
  background process for $H \rightarrow \gamma\gamma$ and BSM searches

- Differential cross-sections measurement at 13 TeV,
  as a function of several observables:
  - Individual photon p_T^{γ}
  - $m_{\gamma\gamma}$, $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$
  - $a_T^{\gamma\gamma}$, $\phi^{*\gamma\gamma}$, $\cos\theta^{*}_{\gamma\gamma}$

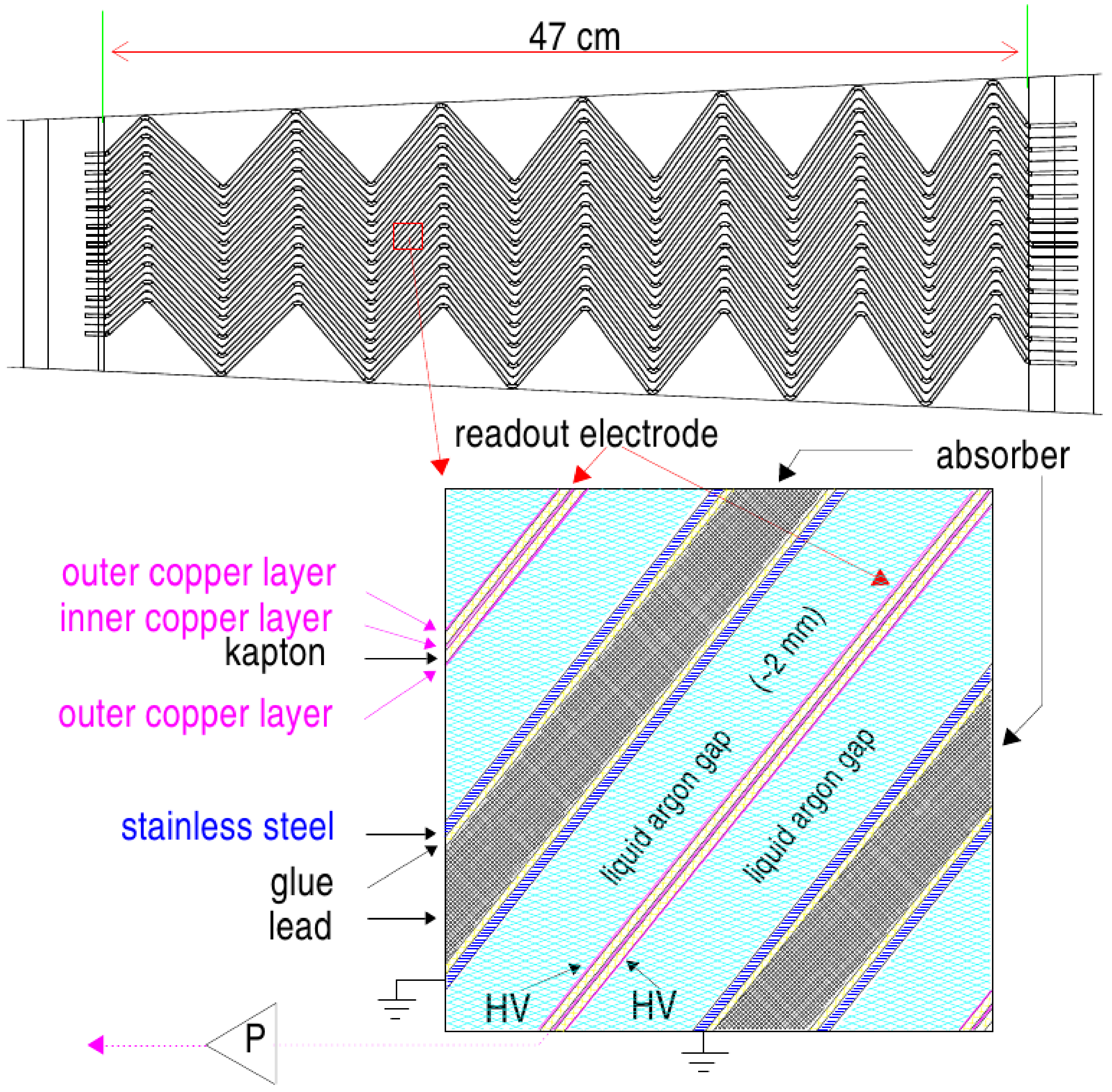


γ reconstruction in the EM calorimeter

Number of secondary particles proportional to the particle energy



A lead - liquid argon accordion

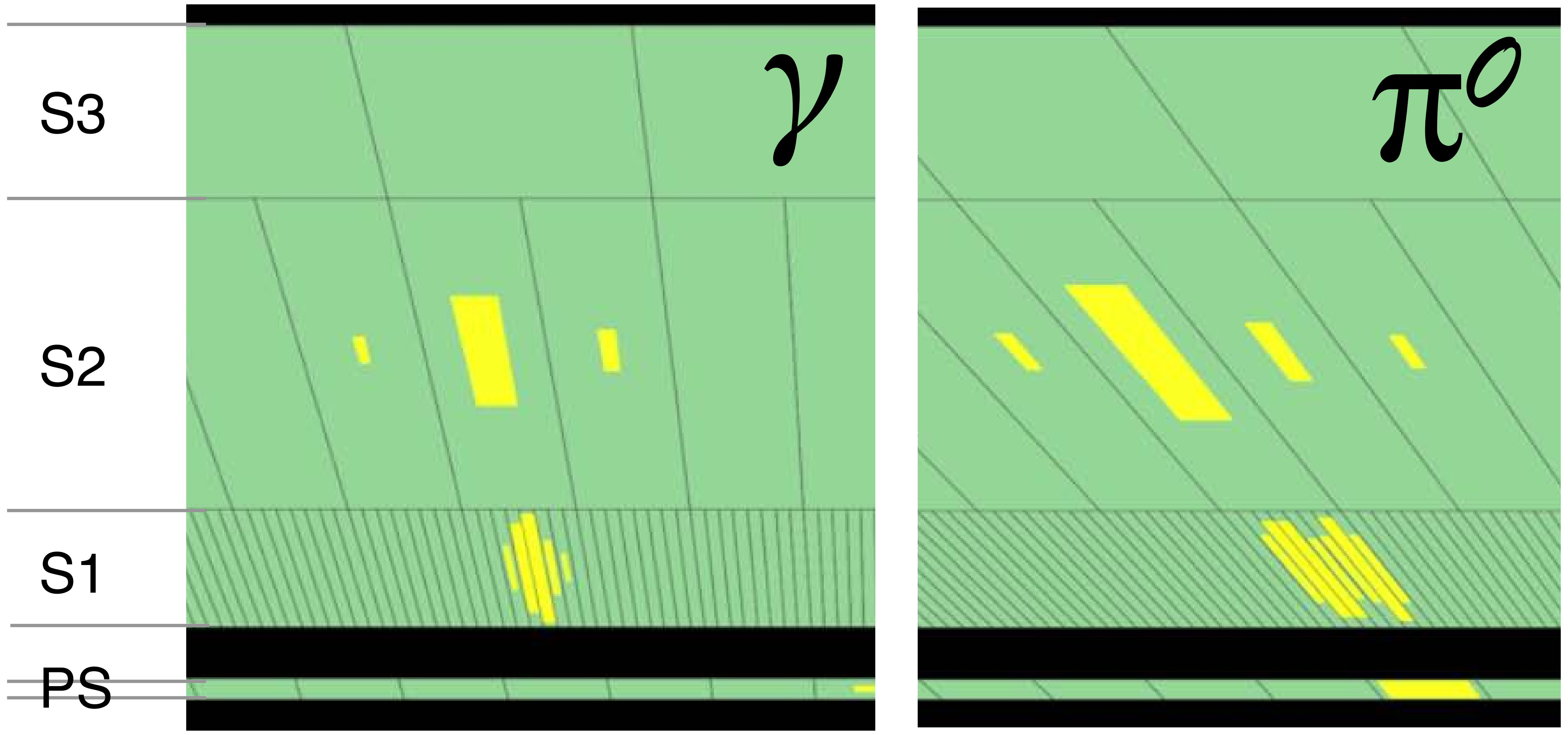


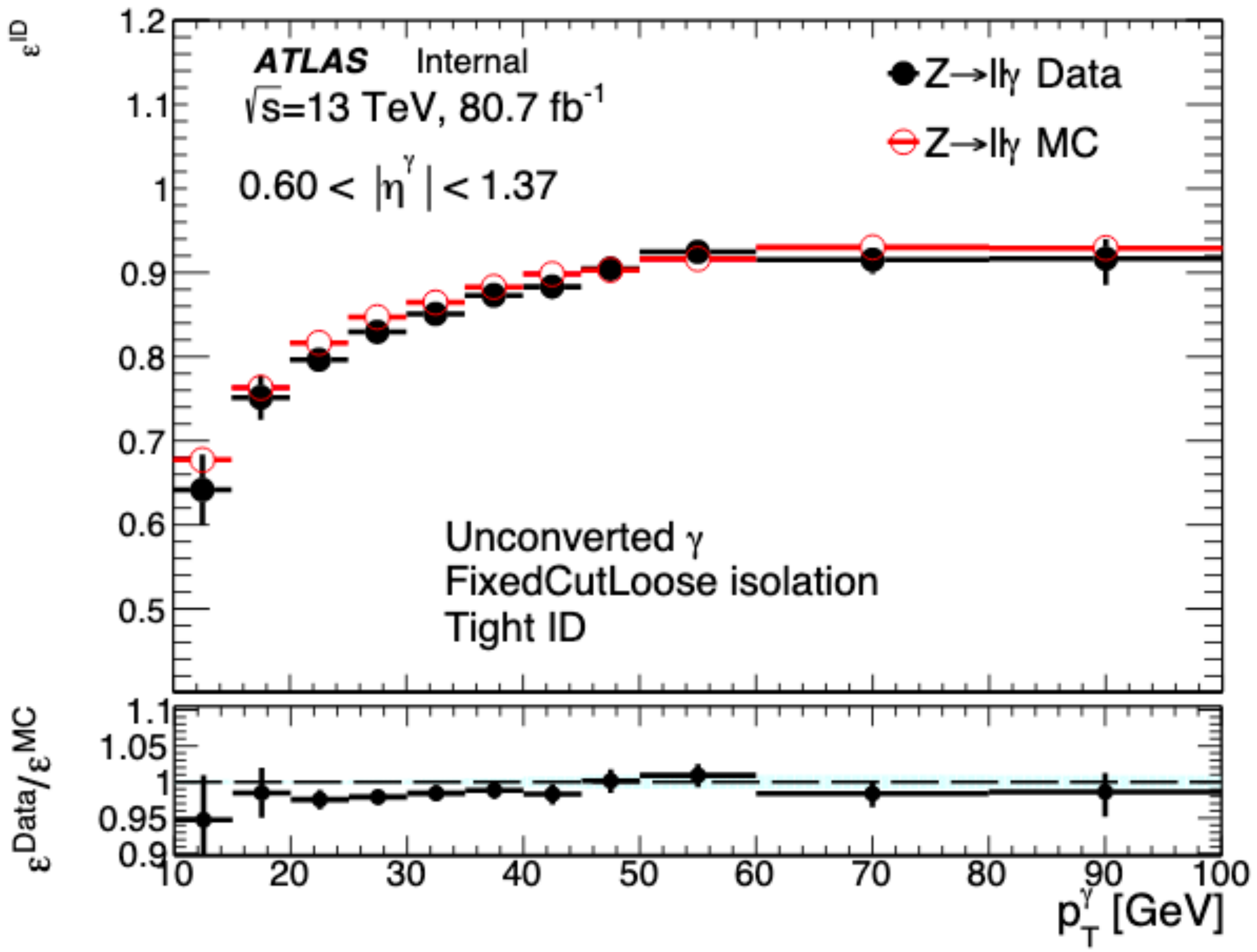
γ identification

Photon ID based on longitudinal and lateral shower shape

Using 9 discriminant variables

This identification is optimized using simulated events.
The efficiency is also studies with simulation and corrected based real data information



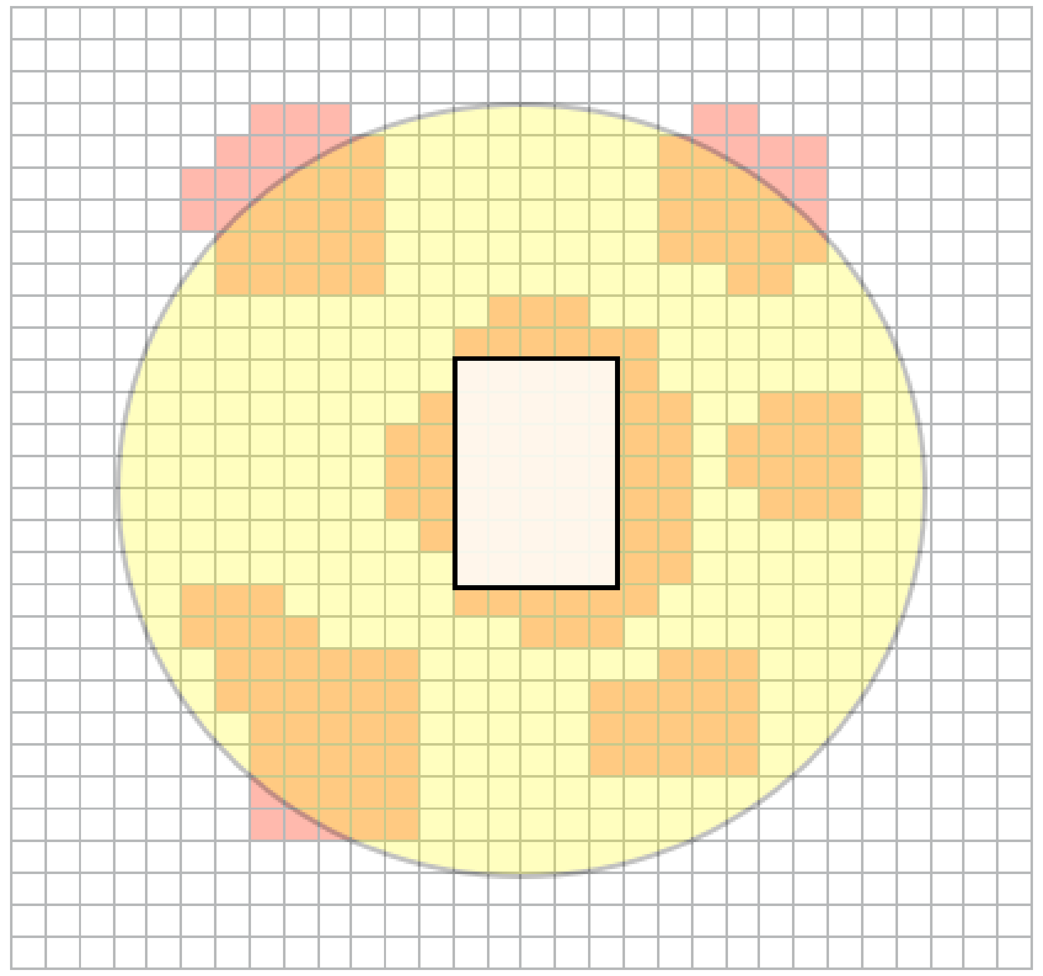


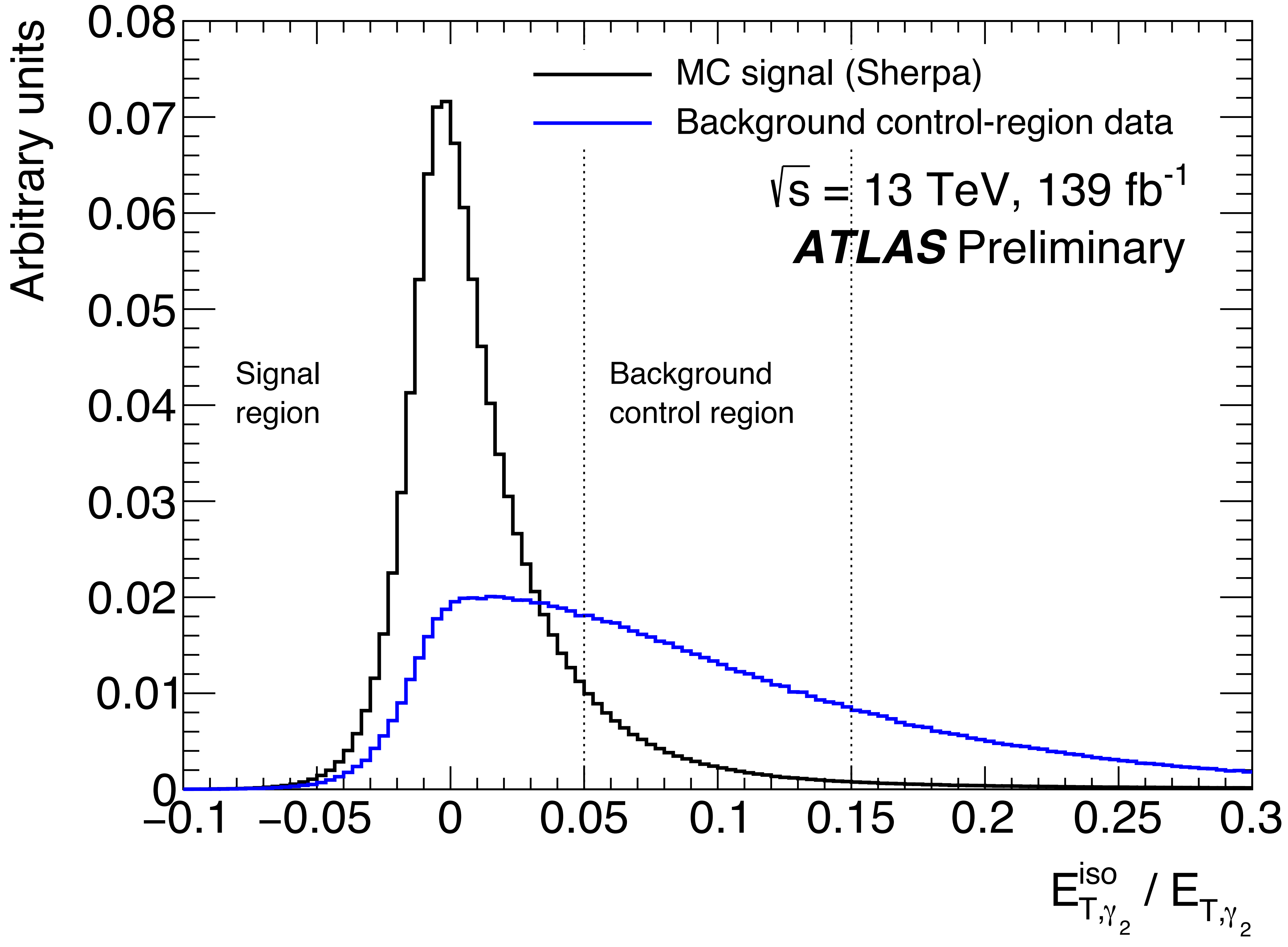
γ isolation

Fake photons from jets have hadronic activity around them

Calorimetric isolation:

- Sum of E_T of calorimetric clusters in a cone ΔR<0.4, excluding the photon cells.
- Out-of-core energy leakage corrections.
- Ambient energy correction event per event (to reduce the effects of underlying event and pile-up).





Data sample and selection

- Full Run 2 data, 13 TeV 139 fb^{-1}, collected by triggers:
  - HLT_g35_loose_g25_loose for 2015+16
  - HLT_g35_medium_g25_medium_L12EM20VH for 2017+18
- Selection (signal region)

E_T	$E_{T,\gamma_1} > 40$ GeV, $E_{T,\gamma_2} > 30$ GeV
η	$\lvert\eta_{\gamma_{1(2)}}\rvert < 1.37$ or $1.52 < \lvert\eta_{\gamma_{1(2)}}\rvert < 2.37$
identification	both tight
isolation	$E^{\mathrm{iso},0.2}_{T,\gamma_{1(2)}} < 0.05 \cdot E_{T,\gamma_{1(2)}}$
ΔR	$\Delta R_{\gamma\gamma} > 0.4$

- 5M data events at signal region

Sample composition

- 60% → $\gamma\gamma$ signal
- 36% → γ-jet or jet-jet events with jets mis-identified as photons

  Data-driven estimation
- 2.6% → Drell-Yan Z→ee events with electrons mis-identified as photons

  Estimation based on simulation samples
- 0.6% → Pileup: Two gamma-jet events overlapping

  Data-driven estimation

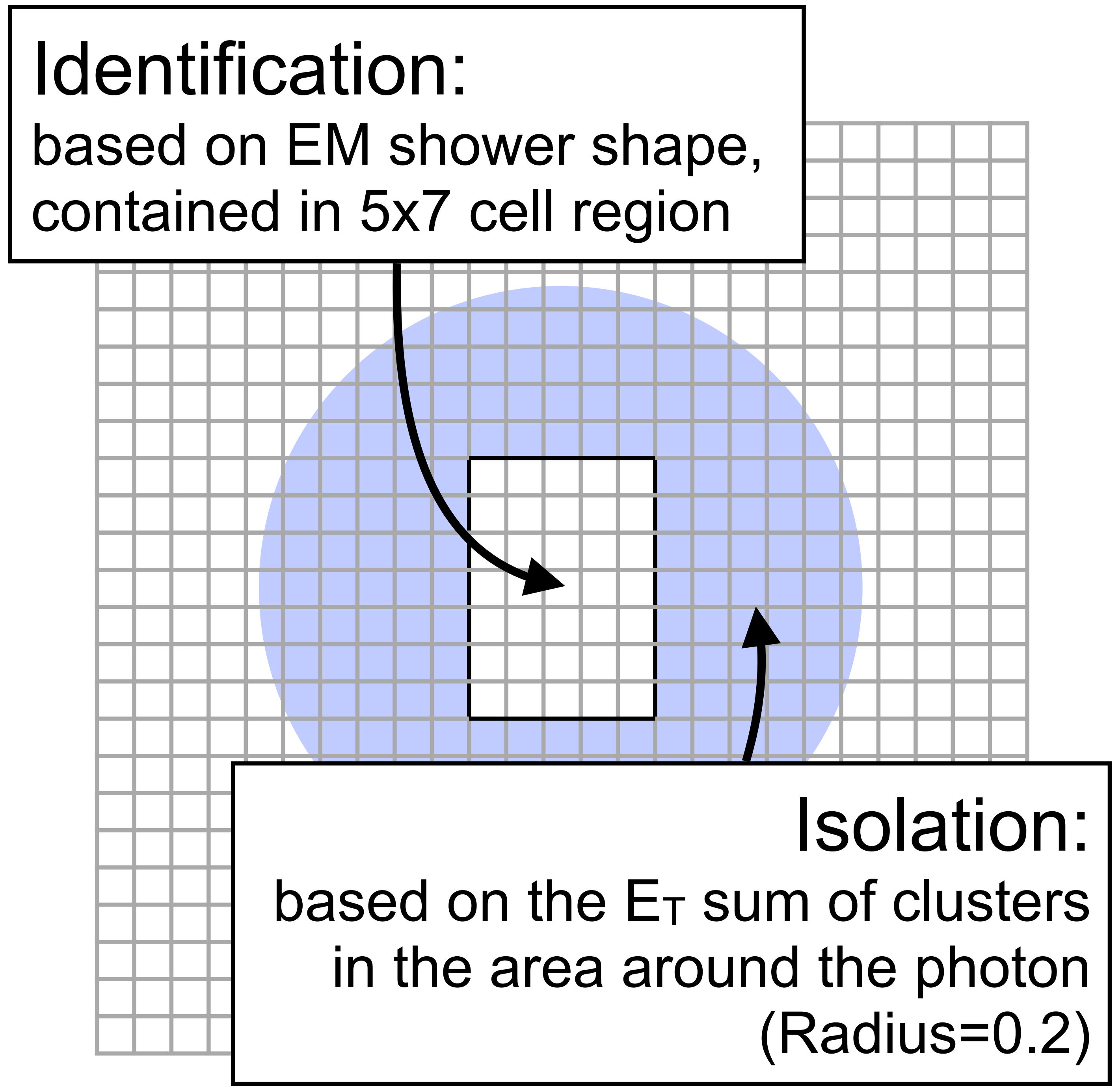
Jet background estimation

ABCD method, one photon example

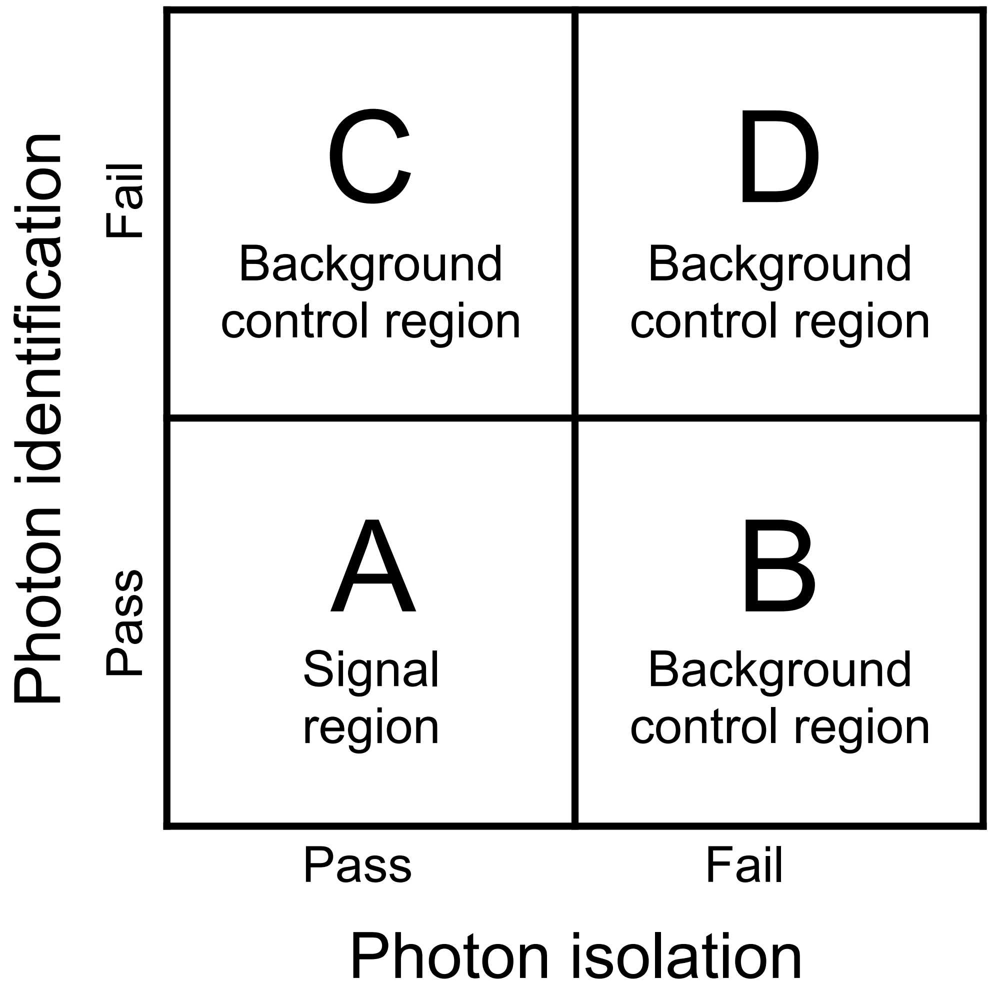
- Signal events mostly present in bin A, and boxes B, C & D dominated by background events
- Relies on isolation-ID non-correlation for the background fake-γ

  i.e. assuming $$\frac{n_{o,\,\mathrm{A}}}{n_{o,\,\mathrm{B}}} = \frac{n_{o,\,\mathrm{C}}}{n_{o,\,\mathrm{D}}},$$

  → main source of uncertainty on final result

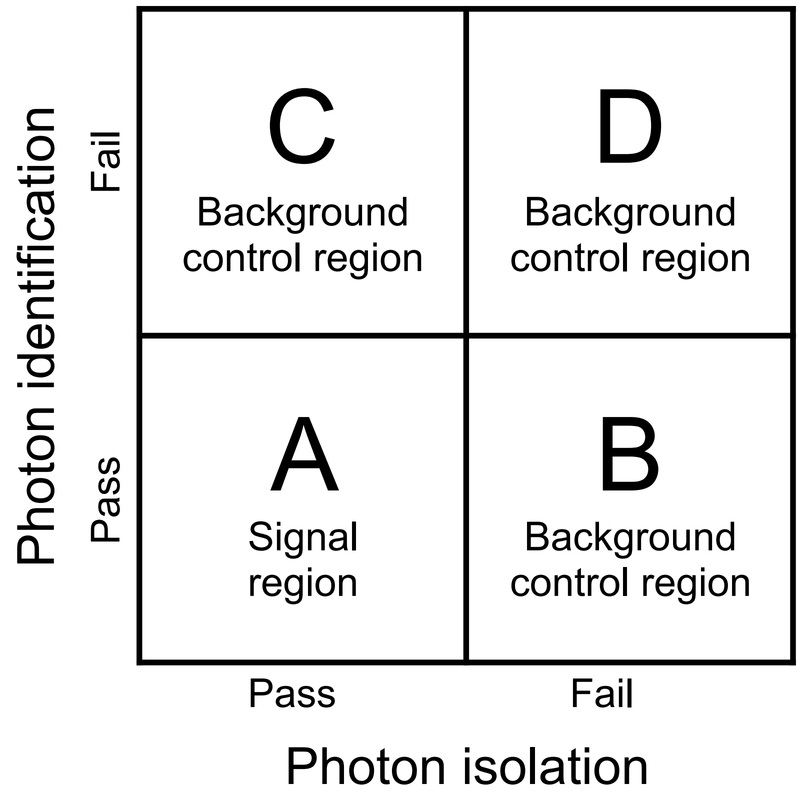


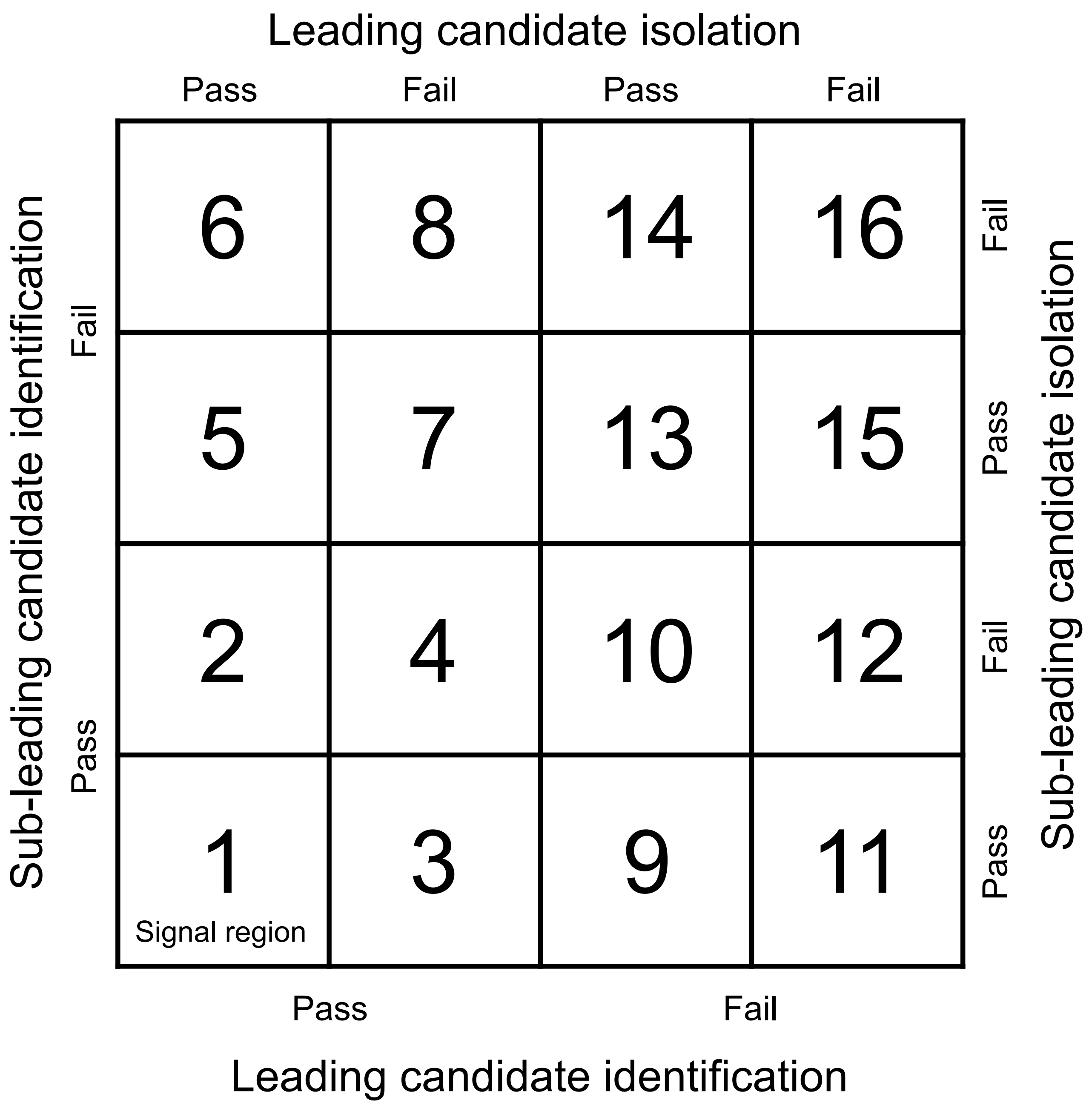
Cells at the 2nd layer of the EM calorimeter

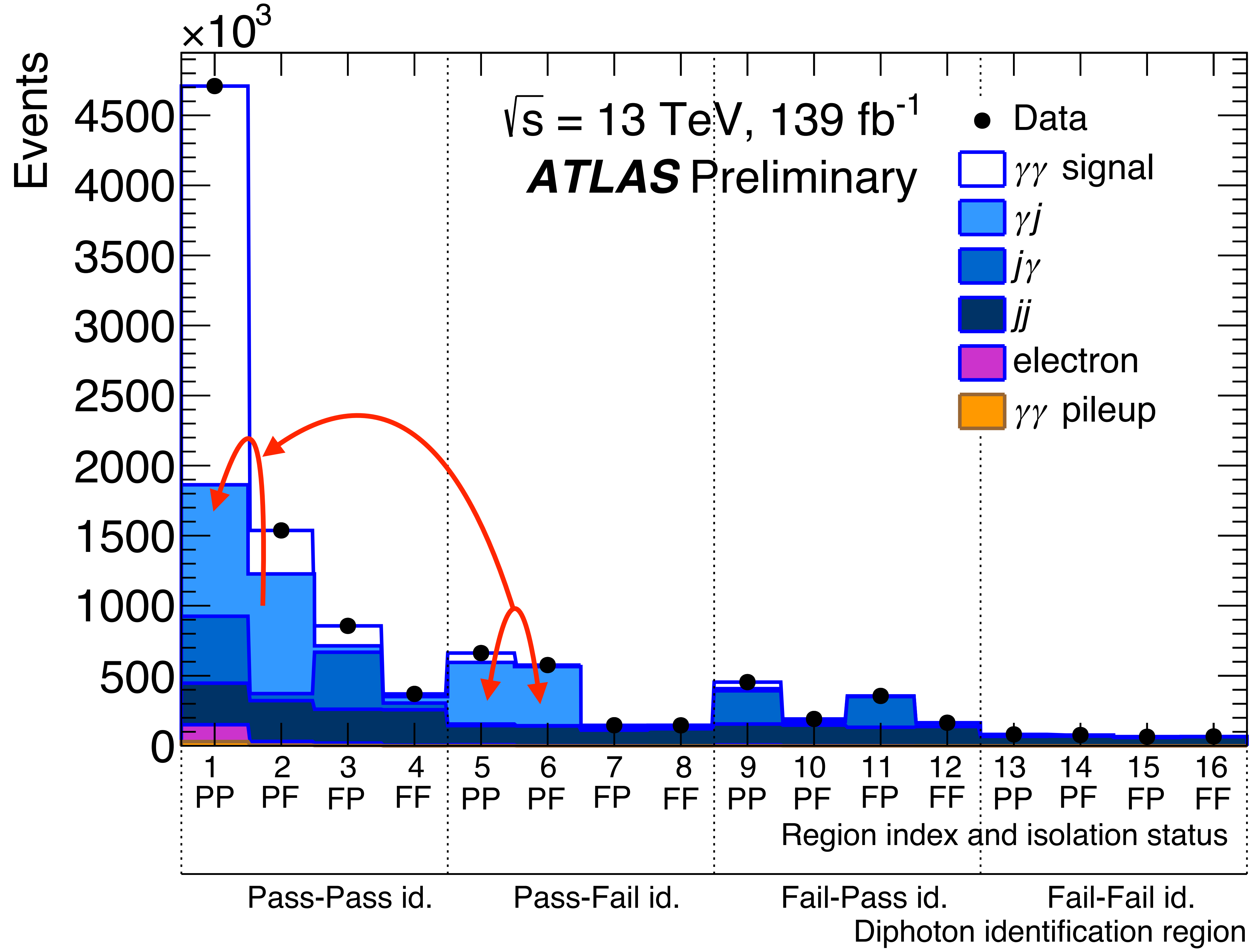


Jet background estimation

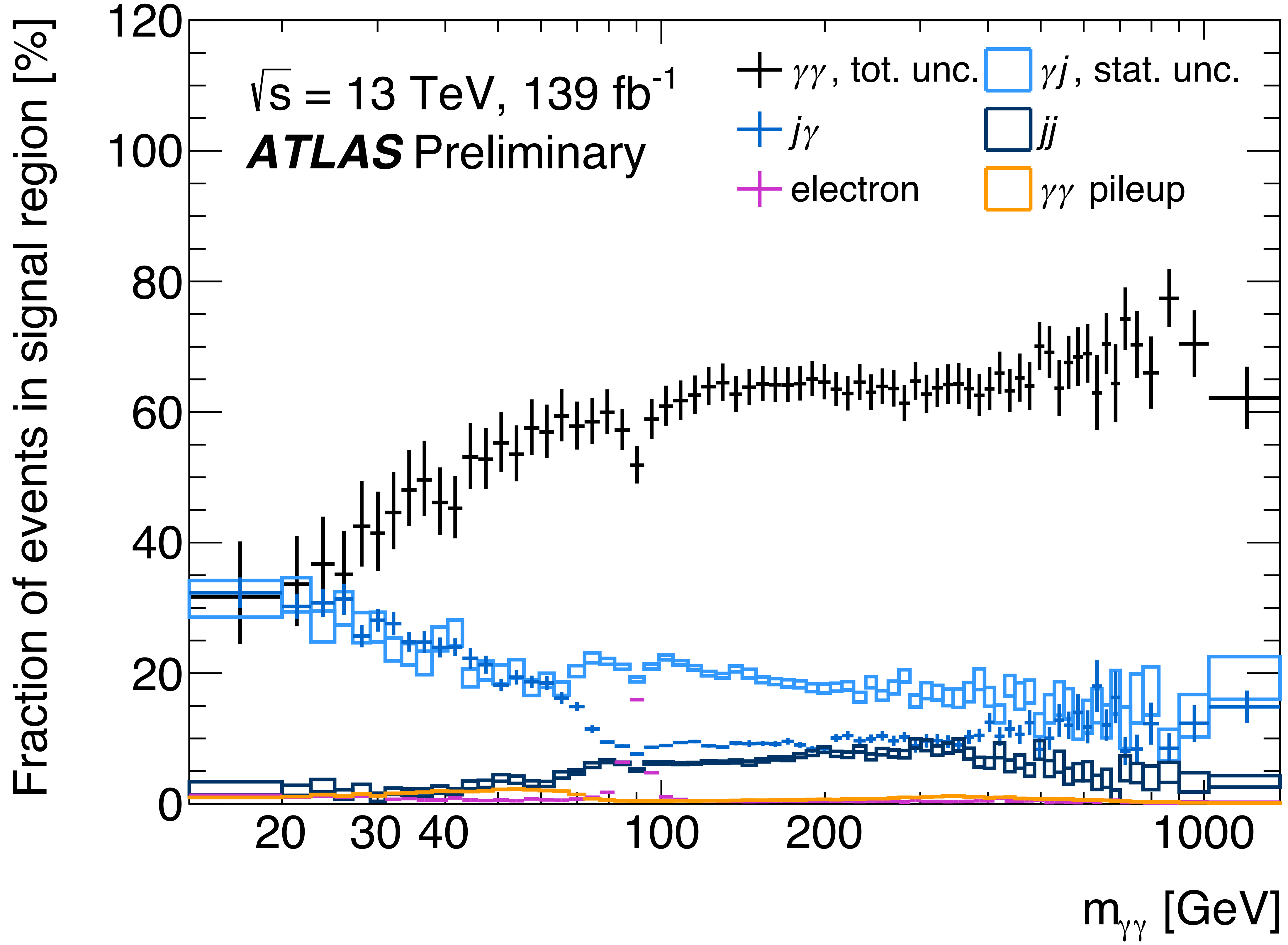
Two-photon case
ABCD method,
with a likelihood fit

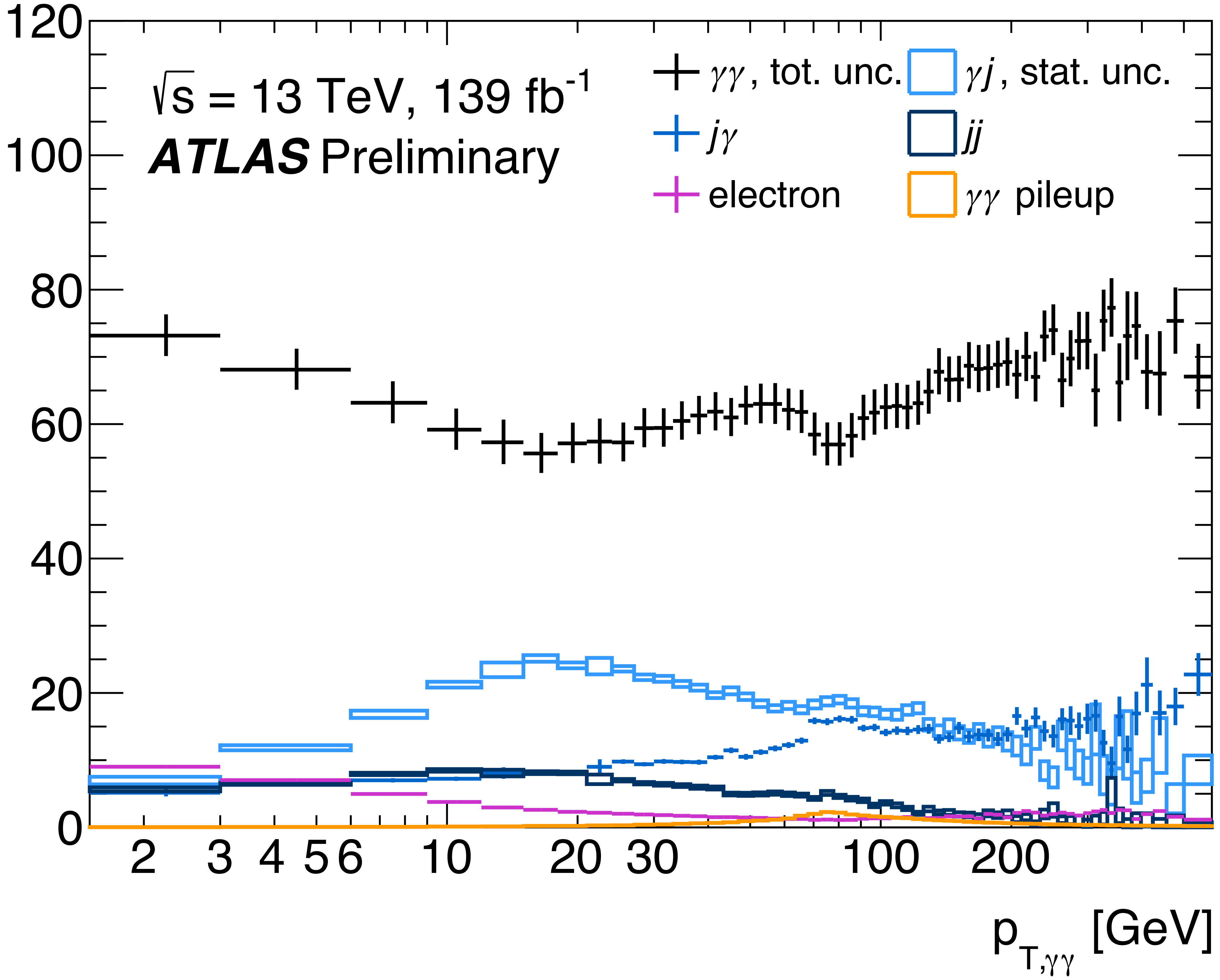






Sample composition result





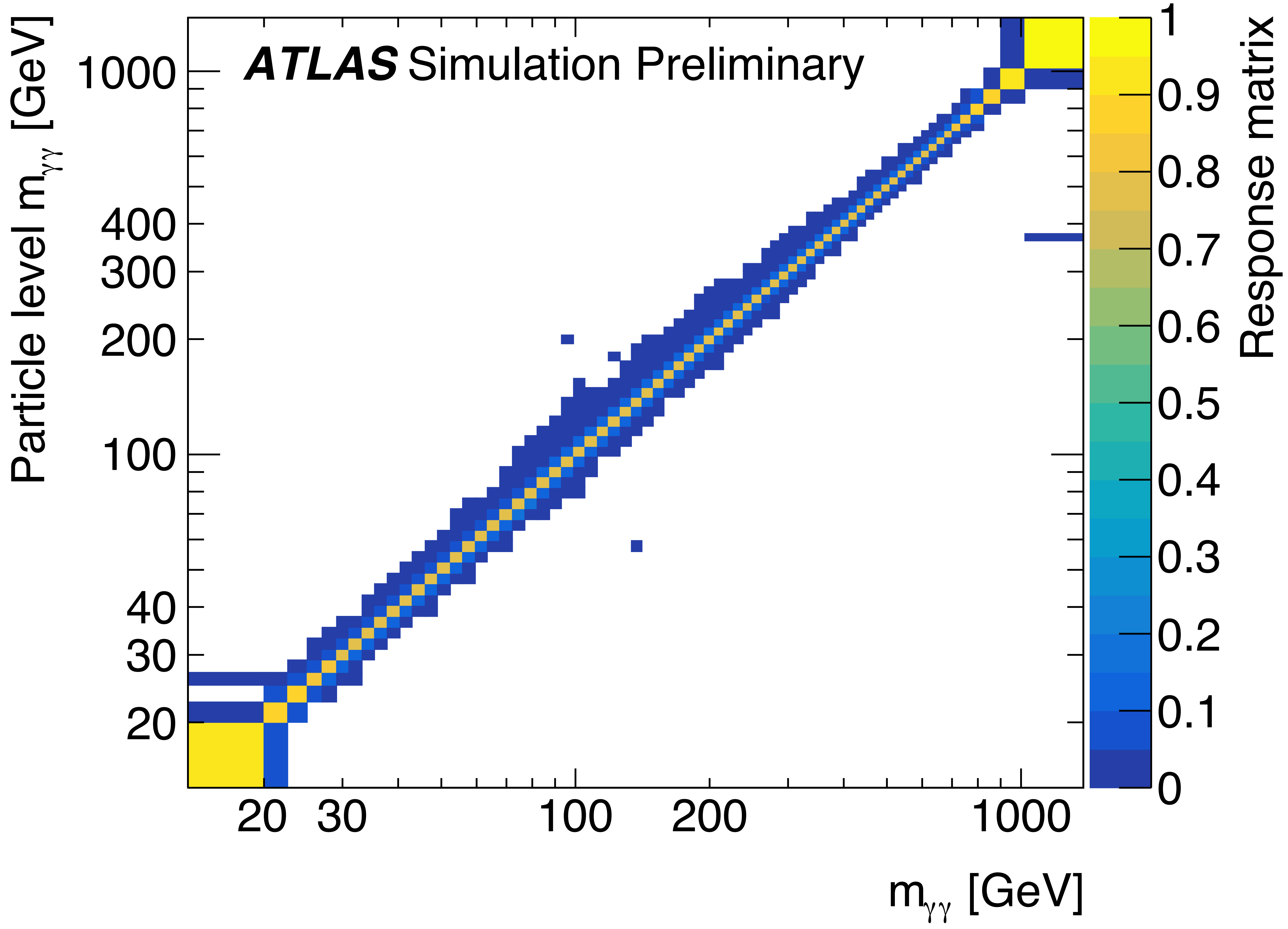
Unfolding

(Detector effect corrections)

- **Detector level**
  (experimental event counts)

- **“Truth” or particle level**
  (theory predictions)

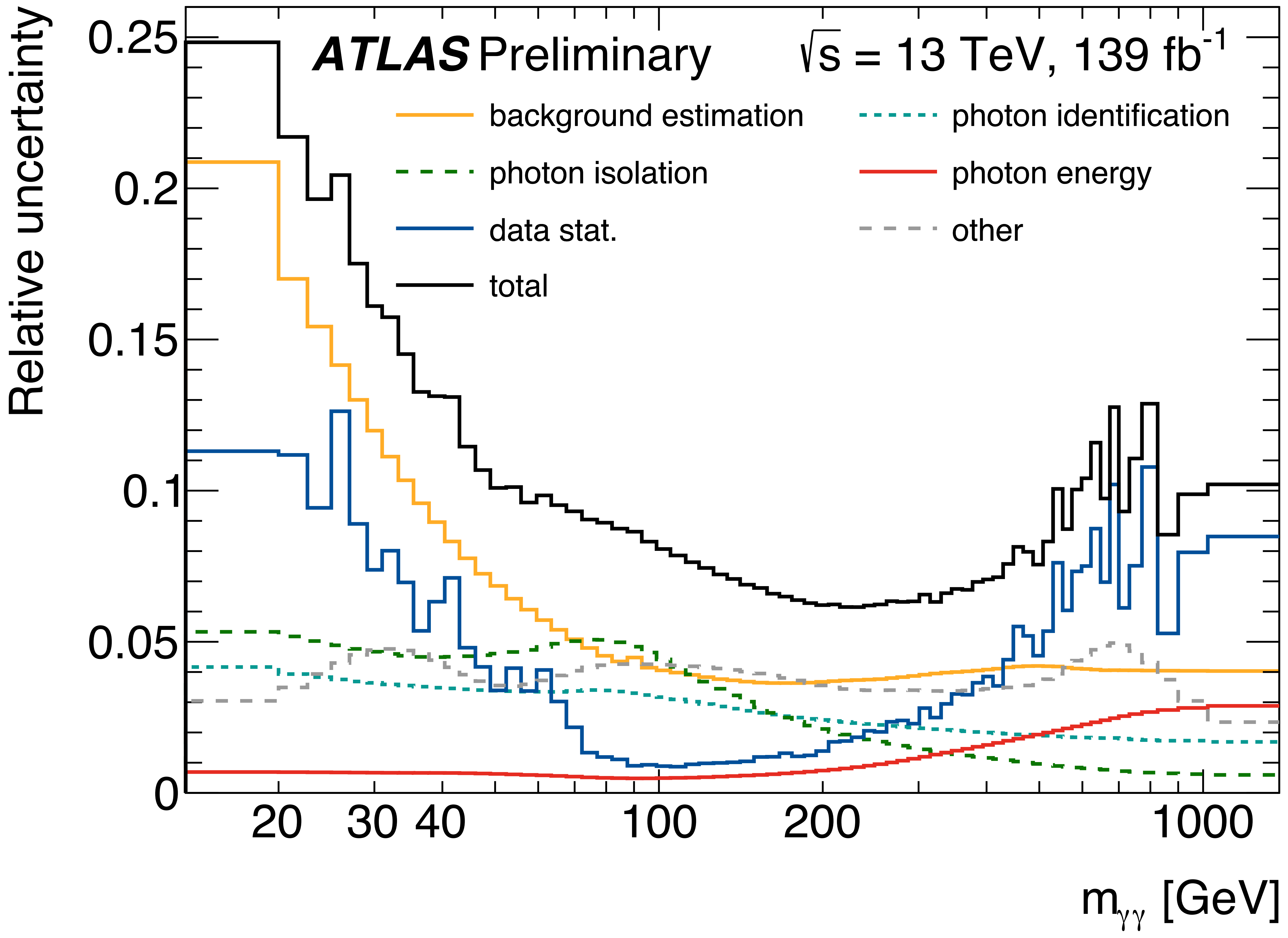
Reconstruction and identification efficiency are taken into account in this step



Selection	Detector level	Particle level
Photon kinematics	$E_{T,\gamma_{1(2)}} > 40(30)\ GeV$, $\|\eta_\gamma\| < 2.37$ excluding $1.37 < \|\eta_\gamma\| < 1.52$	
Photon identification	tight	stable, not from hadron decay
Photon isolation	$E_{T,\gamma}^{iso,0.2} < 0.05 \cdot E_{T,\gamma}$	$E_{T,\gamma}^{iso,0.2} < 0.09 \cdot E_{T,\gamma}$
Diphoton topology	$N_\gamma \geq 2, \quad \Delta R_{\gamma\gamma} > 0.4$	

Uncertainties

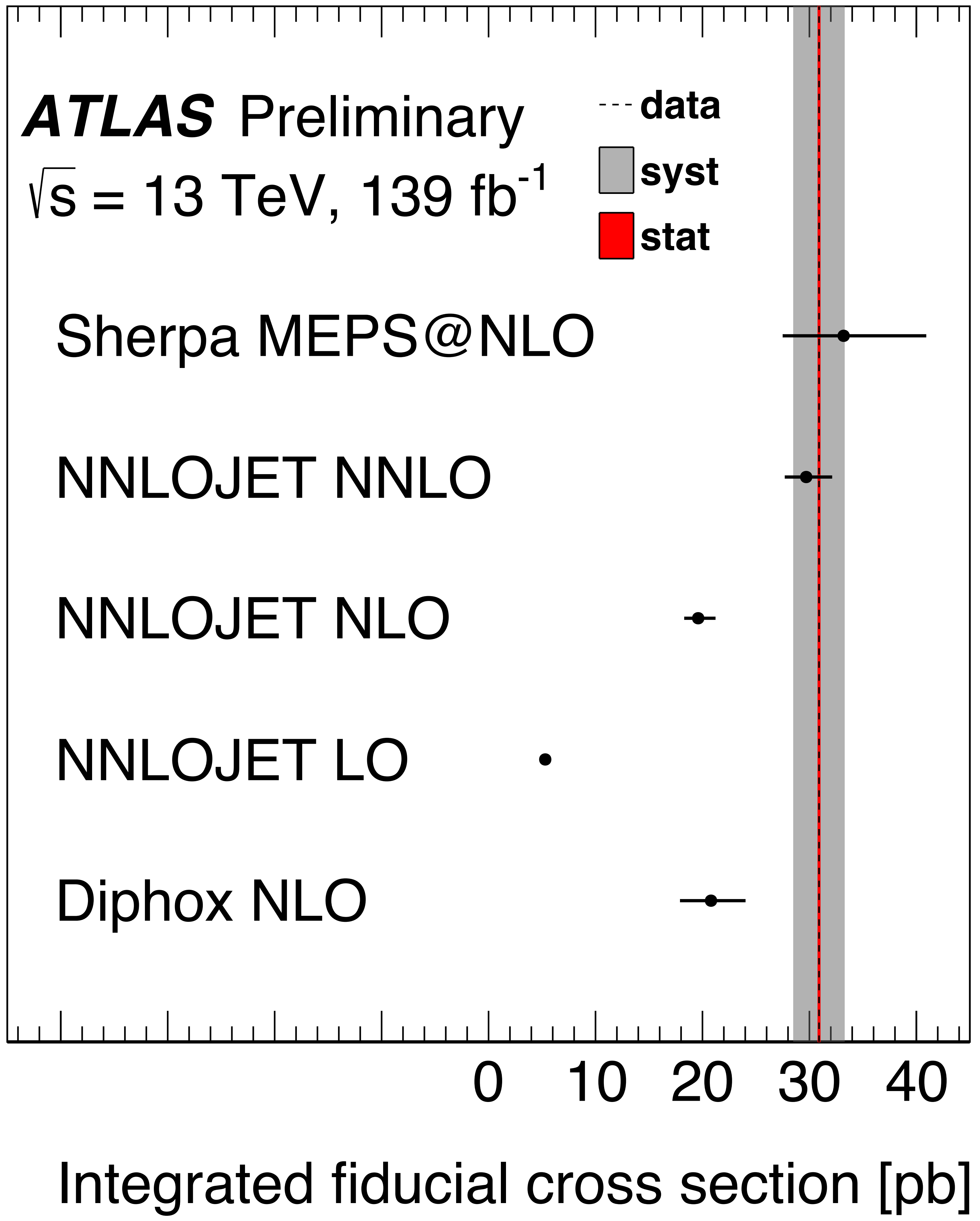
Source	Relative uncertainty [%]
Background estimation	4.3
$R_j^{\text{iso-id}}$	4.2
$\gamma\gamma$ pile-up background	0.6
$R_{\gamma j}^{\text{iso}}$	0.5
Electron background	0.2
Photon isolation	4.0
Pile-up reweighting	3.5
Photon isolation	1.9
Photon identification	3.0
Other	4.1
Data-period stability	3.6
Luminosity	1.7
Trigger efficiency	0.7
MC Sherpa/Pythia	0.6
Signal modelling of E_{T,γ_1}	0.2
MC statistical uncertainty	0.1
Unfolding method	<0.1
Photon energy	0.5
Total systematic uncertainty	7.8
Data statistical uncertainty	0.3



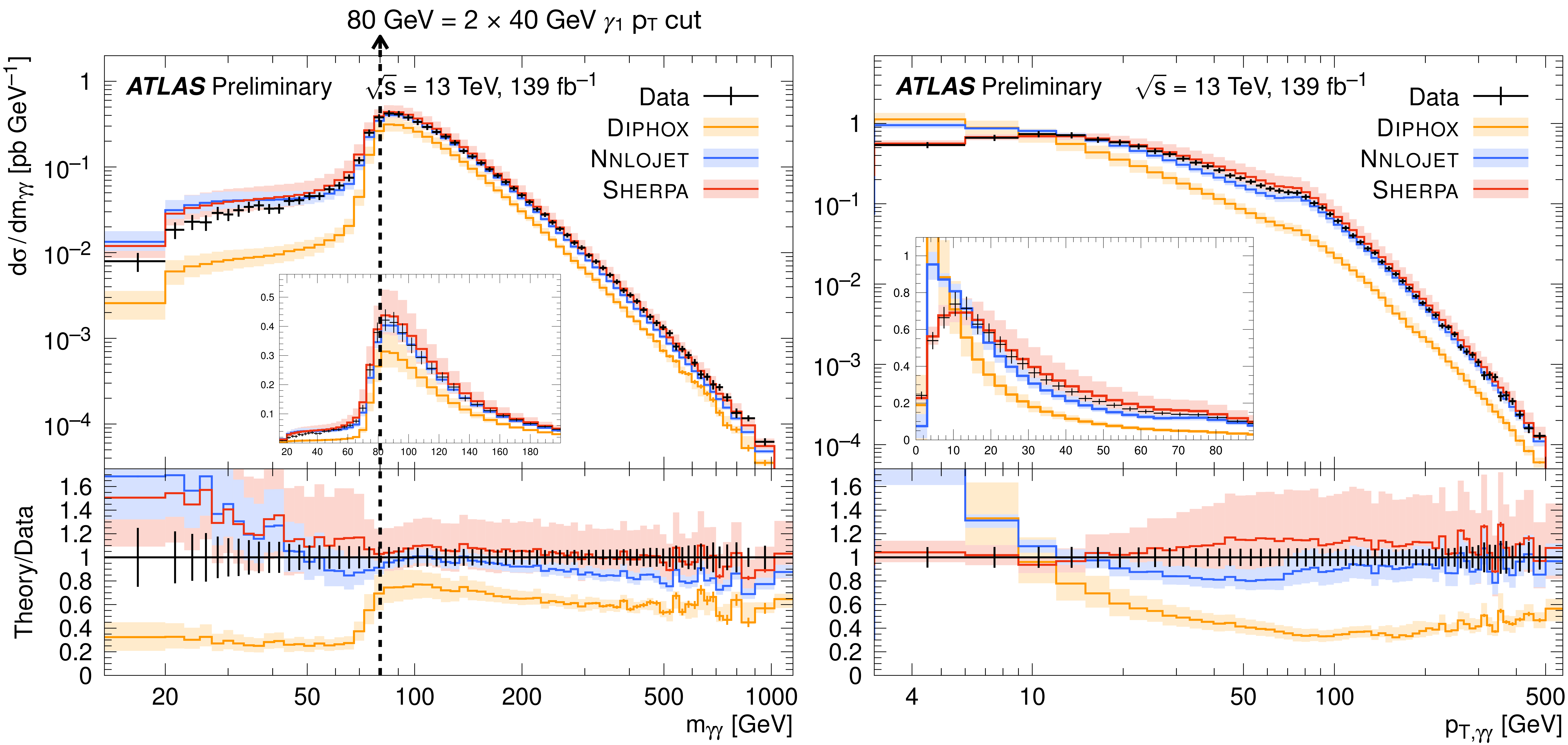
Results

Diphoton cross-section measurement

Integ. fid. cross section [pb]	$\sigma_{\gamma\gamma}$	$\pm$ syst	$\pm$stat
SHERPA MEPS@NLO	33.2	$^{+7.7}_{-5.6}$	<0.1
NNLOJET NNLO	29.7	$^{+2.4}_{-2.0}$	< 0.1
NLO	19.6	$^{+1.6}_{-1.3}$	< 0.1
LO	5.0	$^{+0.5}_{-0.5}$	< 0.1
DIPHOX NLO	20.8	$^{+3.2}_{-2.9}$	< 0.1
Data	30.9	2.4	0.1



Result


80 GeV = 2 × 40 GeV γ1 pT cut
ATLAS Preliminary
√s = 13 TeV, 139 fb−1
Data
DIPHOX
NNLOJET
SHERPA
dσ / dmγγ [pb GeV−1]
Theory/Data
mγγ [GeV]
pT,γγ [GeV]

Summary

$\gamma\gamma$ production at 13 TeV characterized with high precision

- At high energy beyond previous result, 1 TeV invariant mass
- At very low invariant mass → challenging to model by theory predictions
- Fine binning exploiting detector resolution
- Compared with state of the art predictions

Backup

Theory predictions

	fixed order accuracy						fragmentation		QCD	NP
	$\gamma\gamma$	$+1j$	$+2j$	$+3j$	$+\geq 4j$	$gg \to \gamma\gamma$	γj	jj	res.	eff.
DIPHOX	NLO	LO	-	-	-	LO	NLO		–	–
NNLOJET	NNLO	NLO	LO	-	-	LO	–	–	–	–
SHERPA	NLO		LO		PS	LO	ME+PS		PS	✓