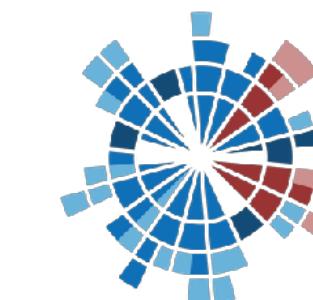


Physics with photons in the final state in ATLAS

Heberth Torres

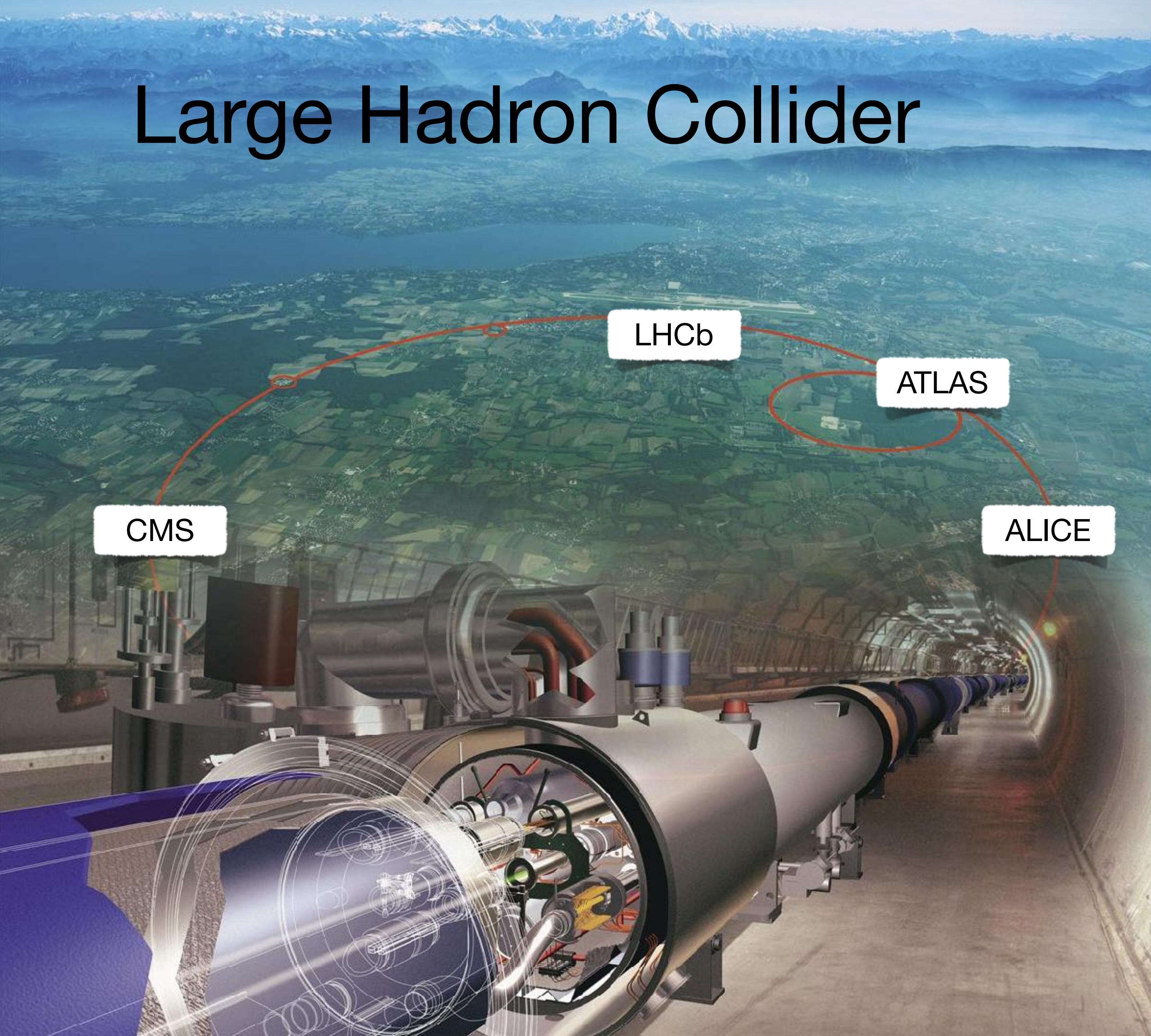


INSTITUTE OF
NUCLEAR AND
PARTICLE PHYSICS



IKTP institute seminar
January 28th, 2021

Large Hadron Collider



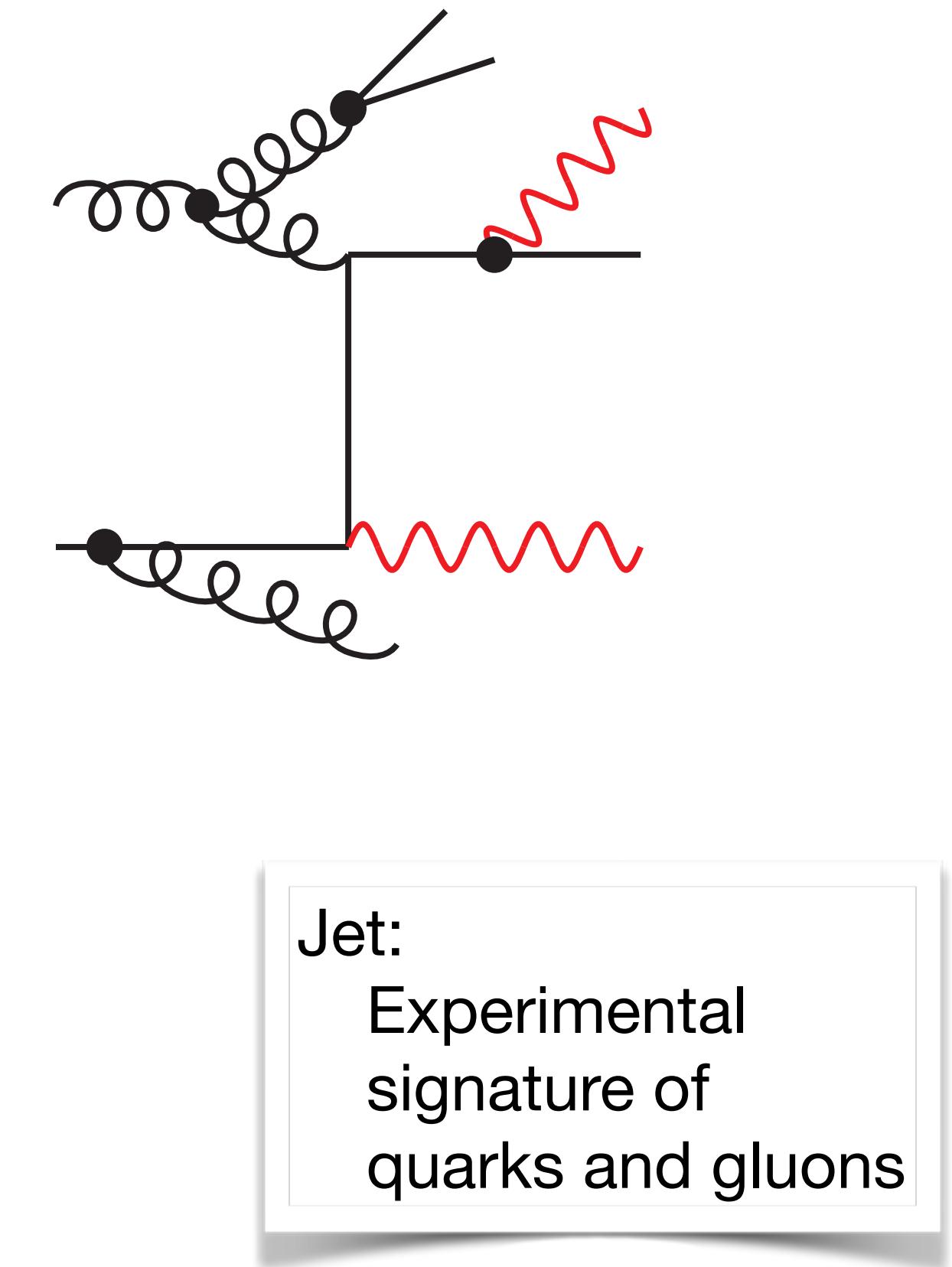
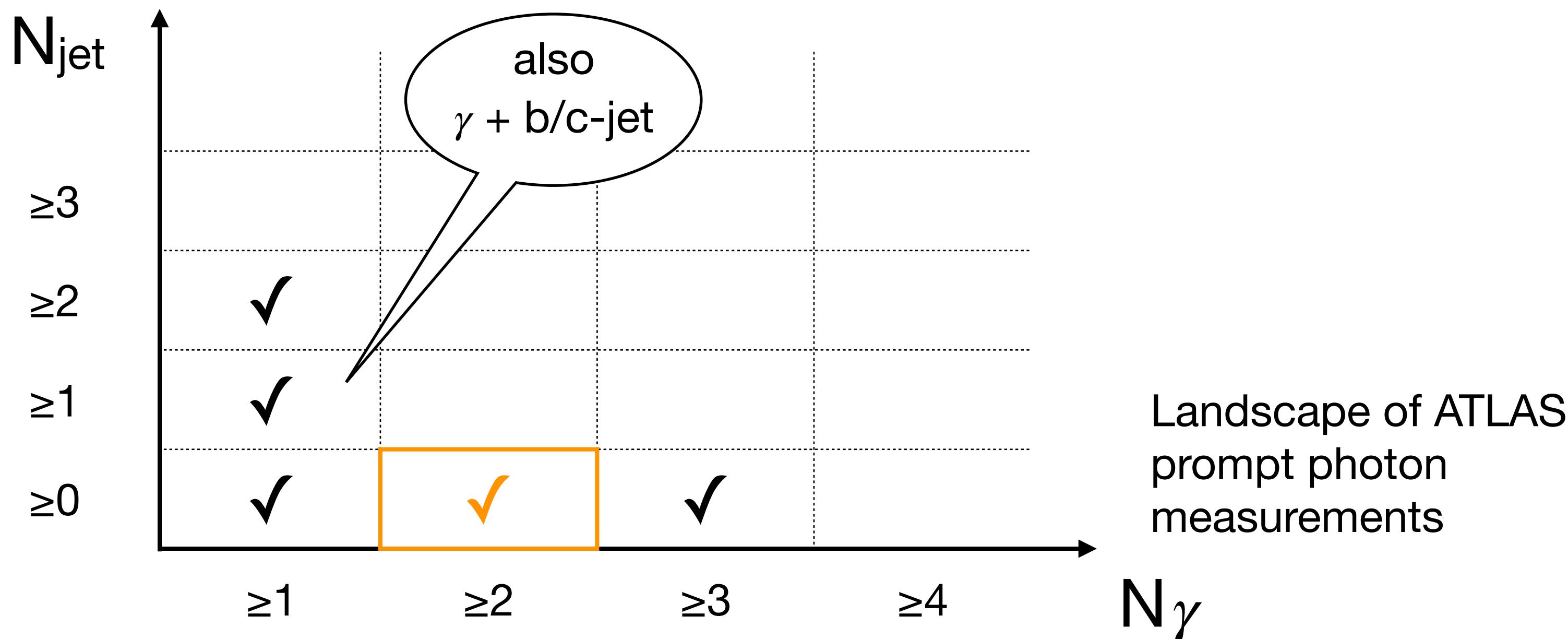
ATLAS and CMS detectors built with three main purposes:

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

Physics with photons γ in the final state

Good coupling
to quarks + Clean experimental
signature = QCD probe

to test / understand perturbative QCD,
Parton Distribution Functions, photon fragmentation...

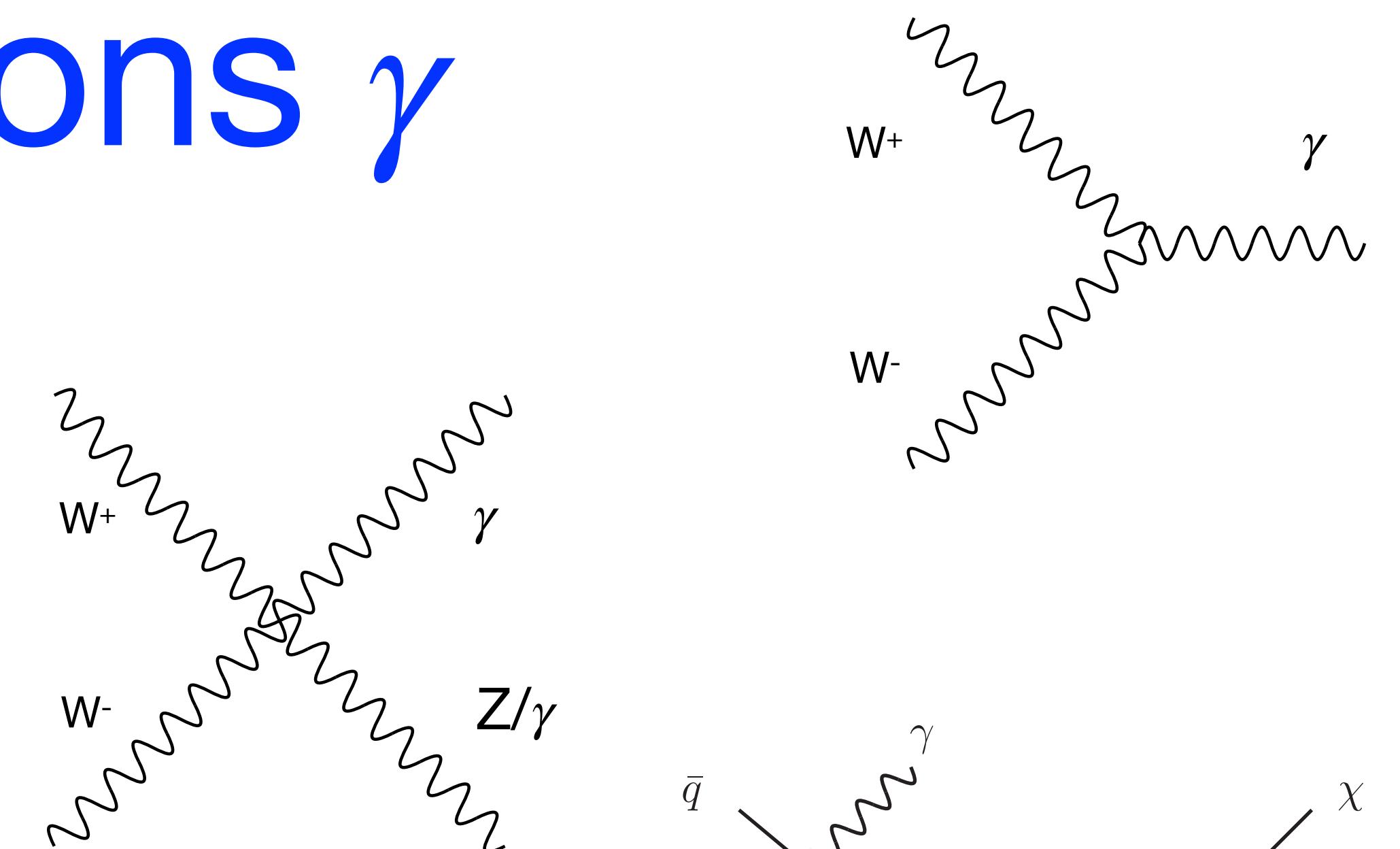


Physics with photons γ

- Electroweak physics

Measurements of $W\gamma$, $Z\gamma$, $V_{\gamma\gamma}$, $W\gamma\gamma$, $Z\gamma jj$

Sensitive to triple and quartic gauge boson couplings

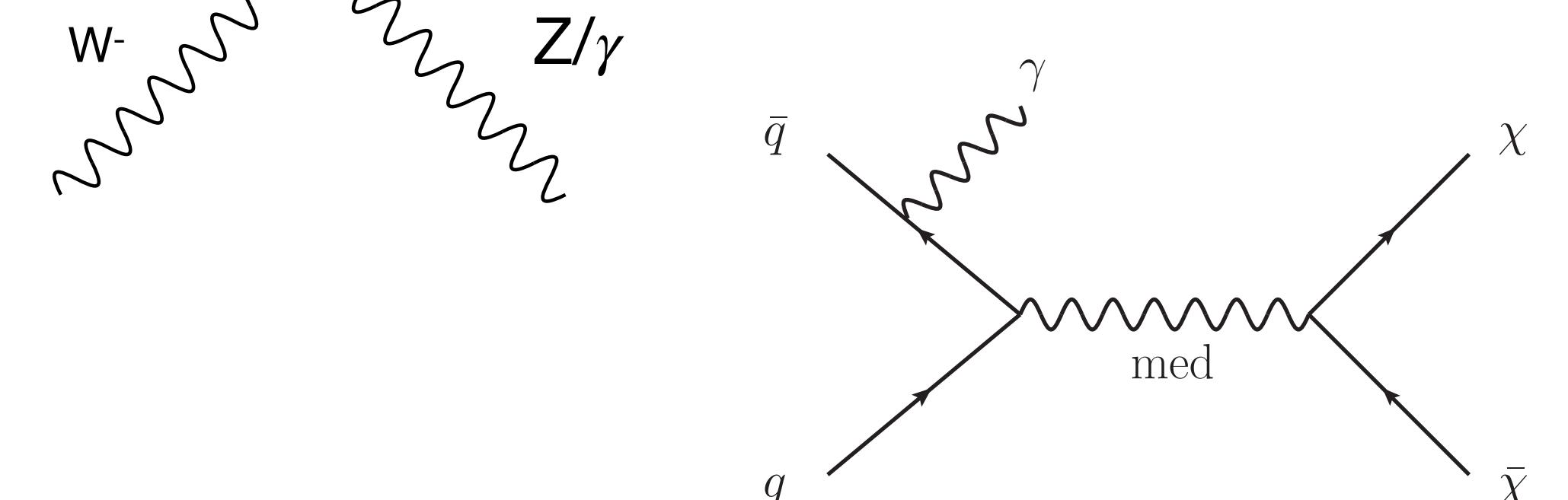


- Higgs boson physics

$H \rightarrow \gamma\gamma$ (among leading channels for Higgs studies / discovery)

$H \rightarrow Z\gamma$, $HH \rightarrow bb\gamma\gamma$, $HH \rightarrow WW\gamma\gamma$

Evidence of $H \rightarrow \gamma\gamma^* \rightarrow \gamma/\gamma$ next Tuesday's CERN seminar



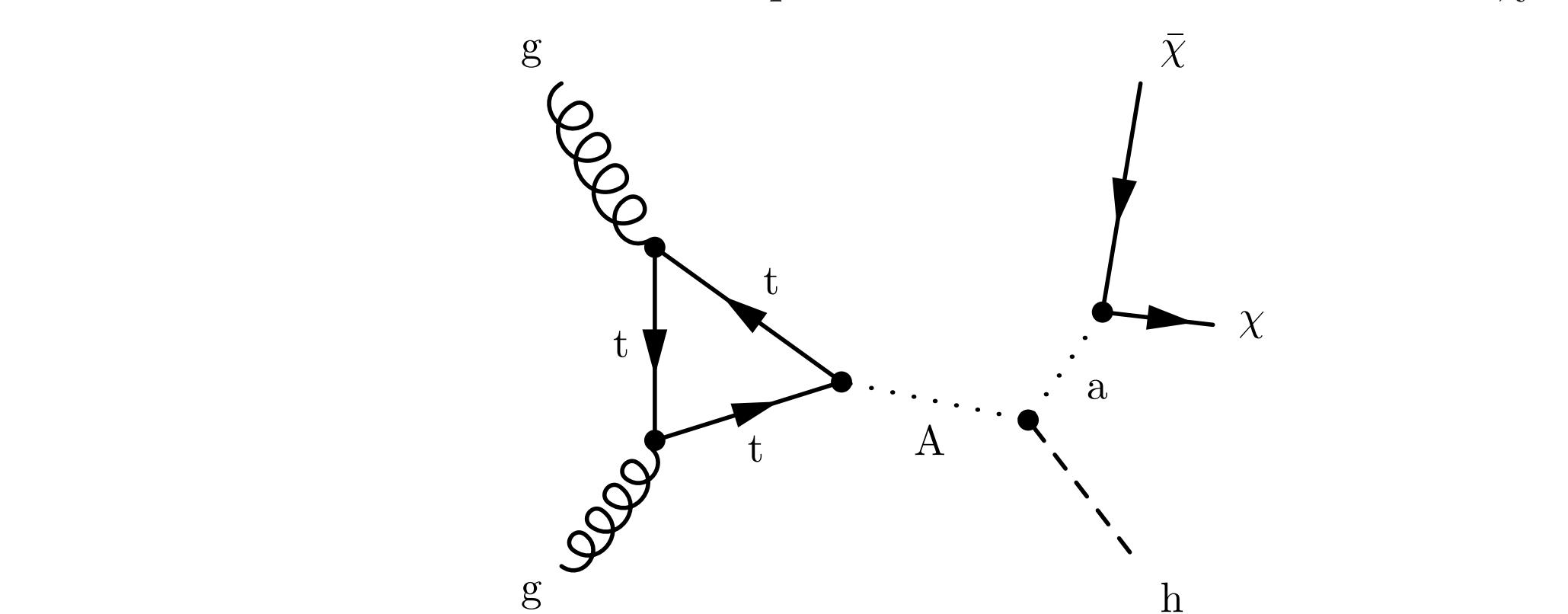
- Beyond Standard Model searches

$X \rightarrow \gamma\gamma$ (example spin 2 graviton), $H \rightarrow aa \rightarrow \gamma\gamma + \gamma\gamma$ (MSSM)

$\gamma + \text{Missing ET}$ or $H(\rightarrow \gamma\gamma) + \text{MET}$ (Dark matter search)

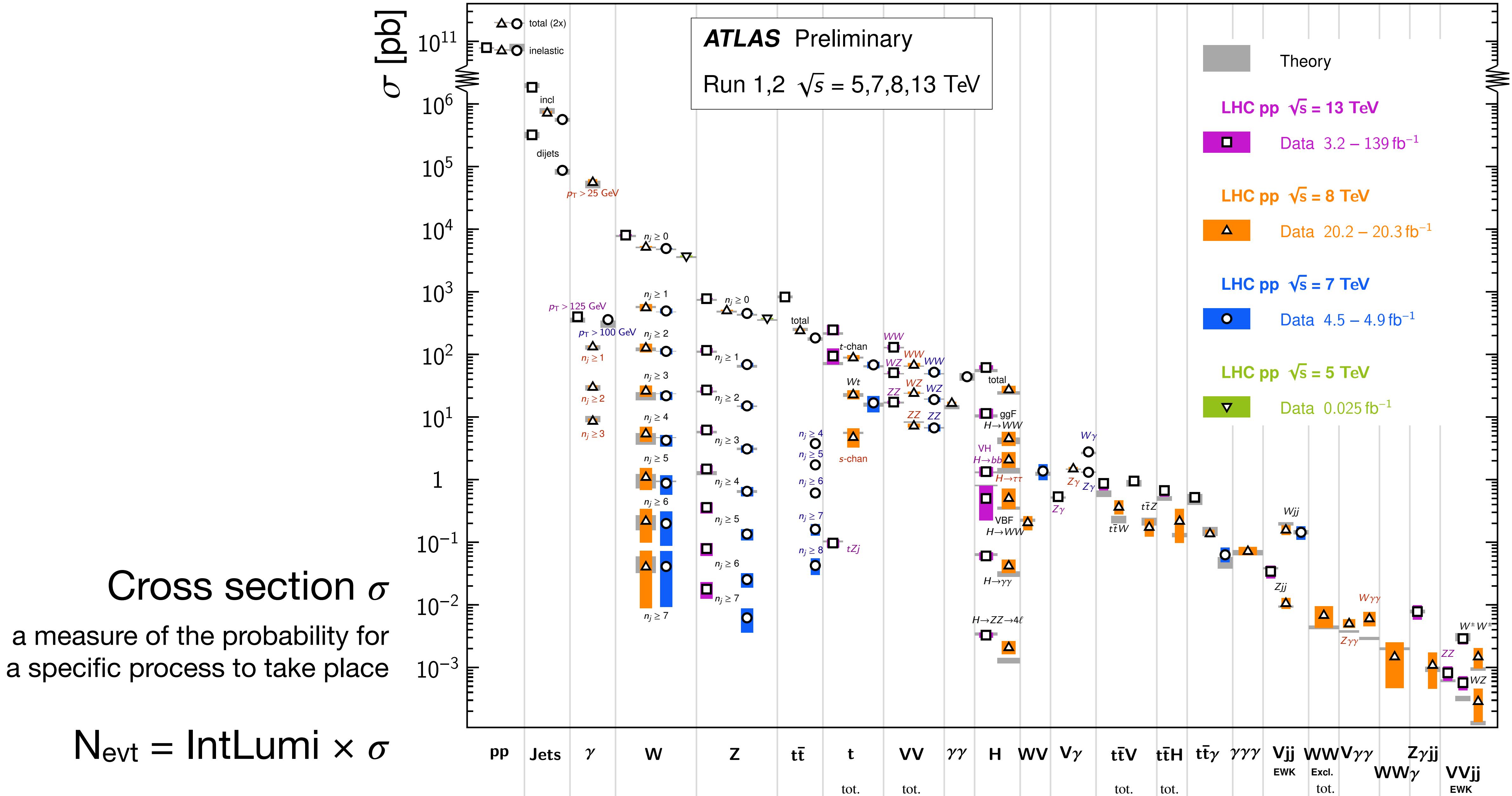
...

(to do this at LHC, very important to understand and model well the leading prompt photon production processes)



Standard Model Production Cross Section Measurements

Status: May 2020

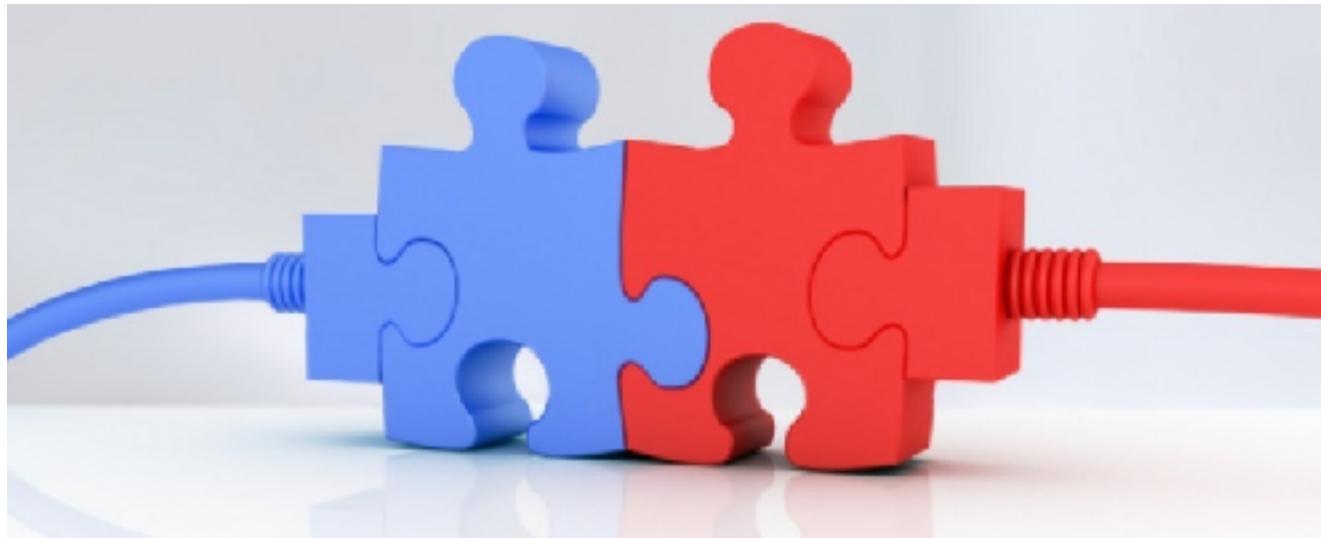


Emmy Noether junior research group

Precision Monte Carlo generators and LHC measurements

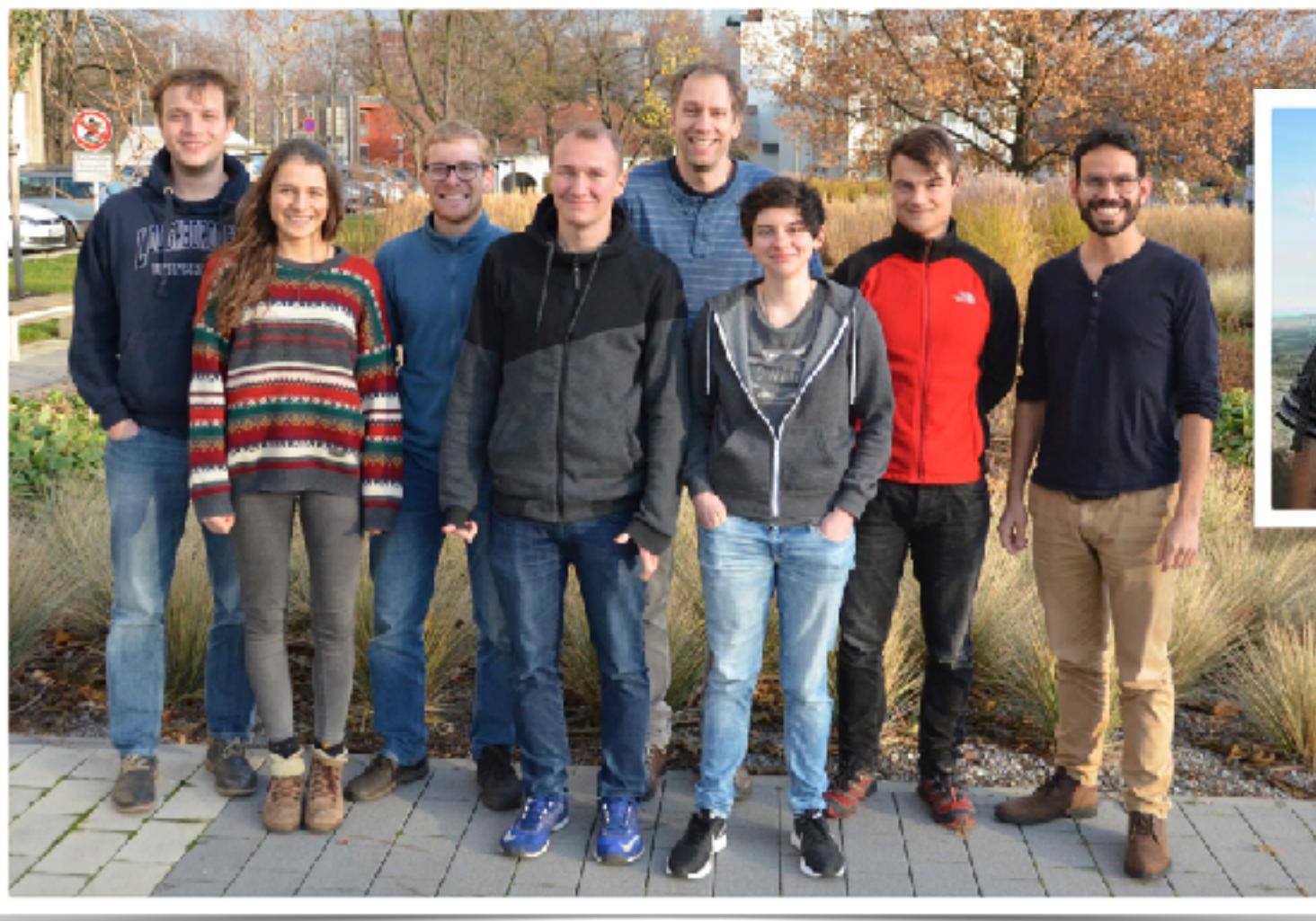
Group leader: Frank Siegert

Theory



Experiment

at the interface between experiment and theory for LHC physics,
with particular focus on QCD Monte Carlo simulations and ATLAS measurements sensitive to their modelling



Today: presenting an experimental study

Diphoton $\gamma\gamma$ production measurement

Done by: Ken Kreul, Frank Siegert, Heberth Torres, Christian Wiel

Previous theory photon studies

Isolation studies, Johannes Krause (PhD thesis)
Diphoton production, Valentin Boettcher (bachelor thesis)

...



ATLAS CONF Note

ATLAS-CONF-2020-024

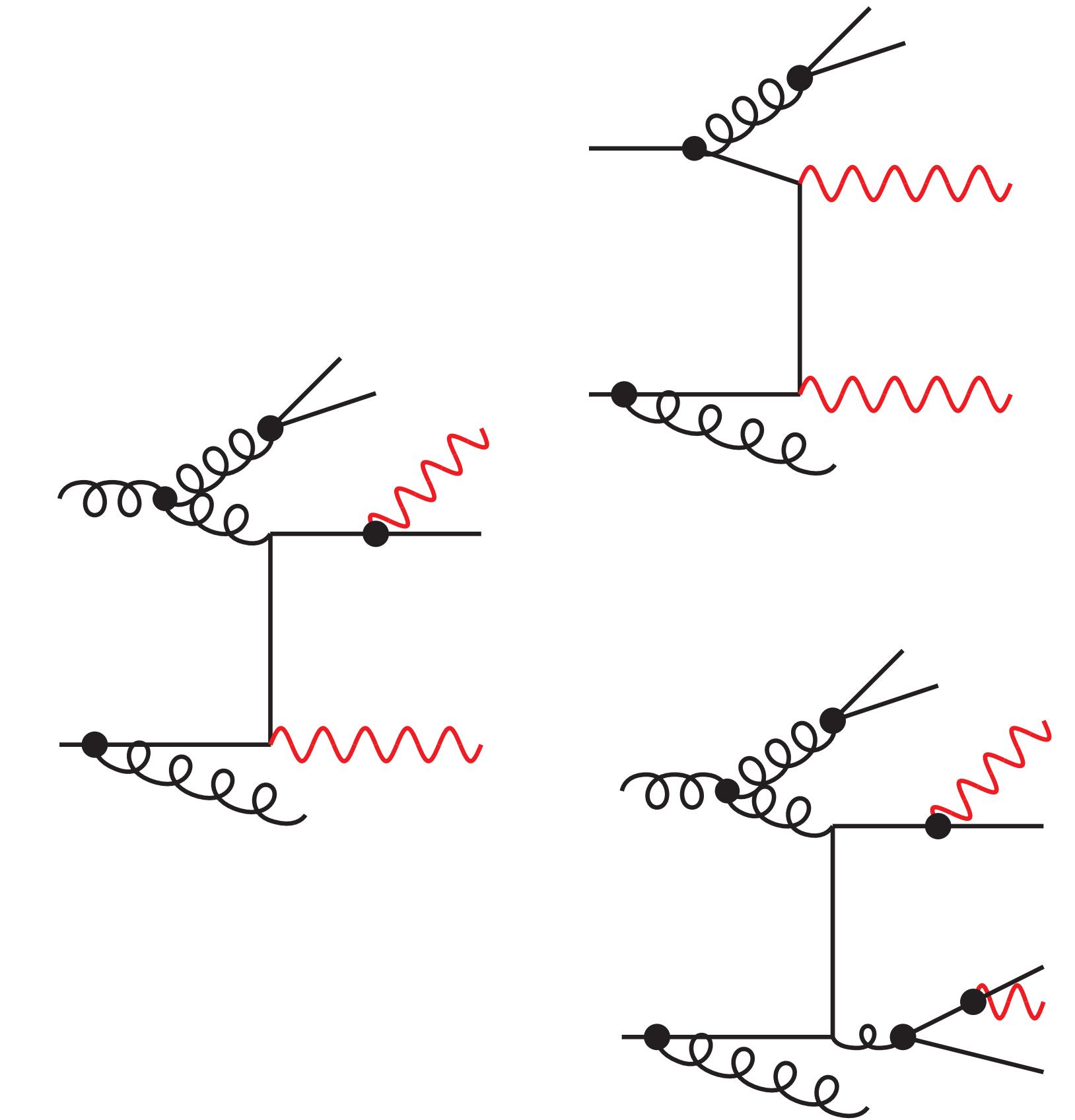
28th July 2020



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

The ATLAS Collaboration

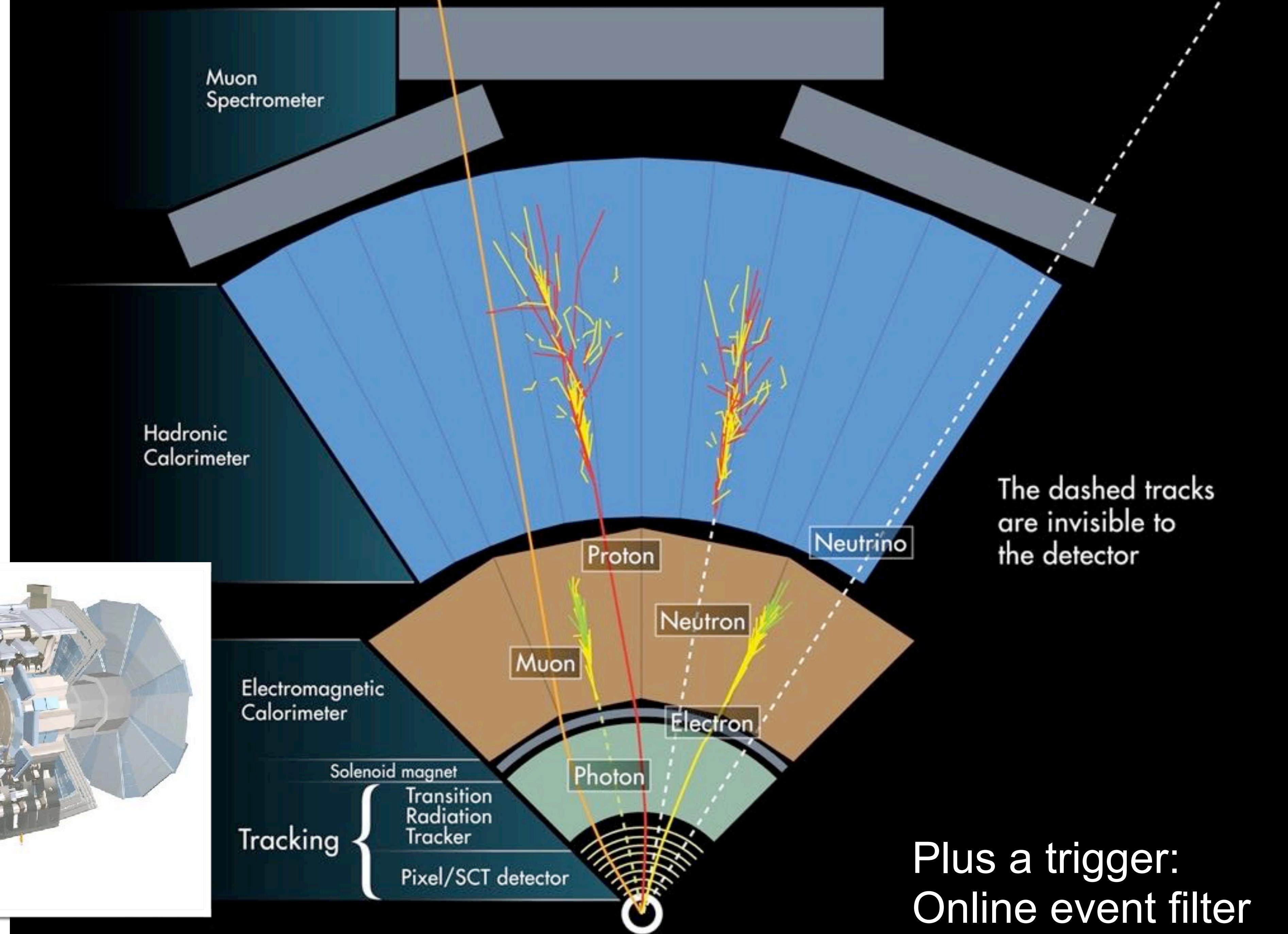
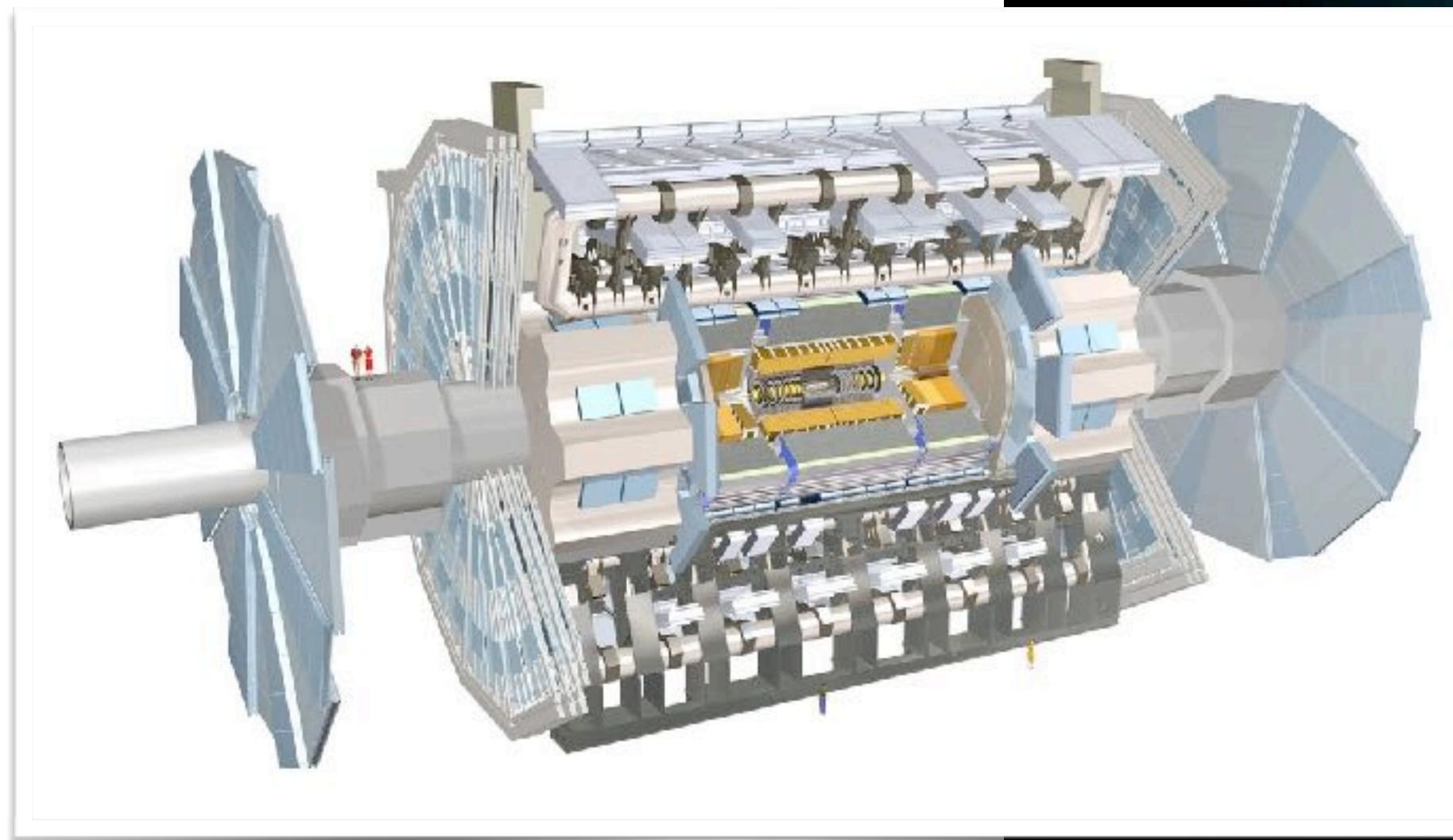
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2020-024/>



Differential cross-sections measurement, with the Run 2 dataset,
139 fb^{-1} of pp collisions at 13 TeV

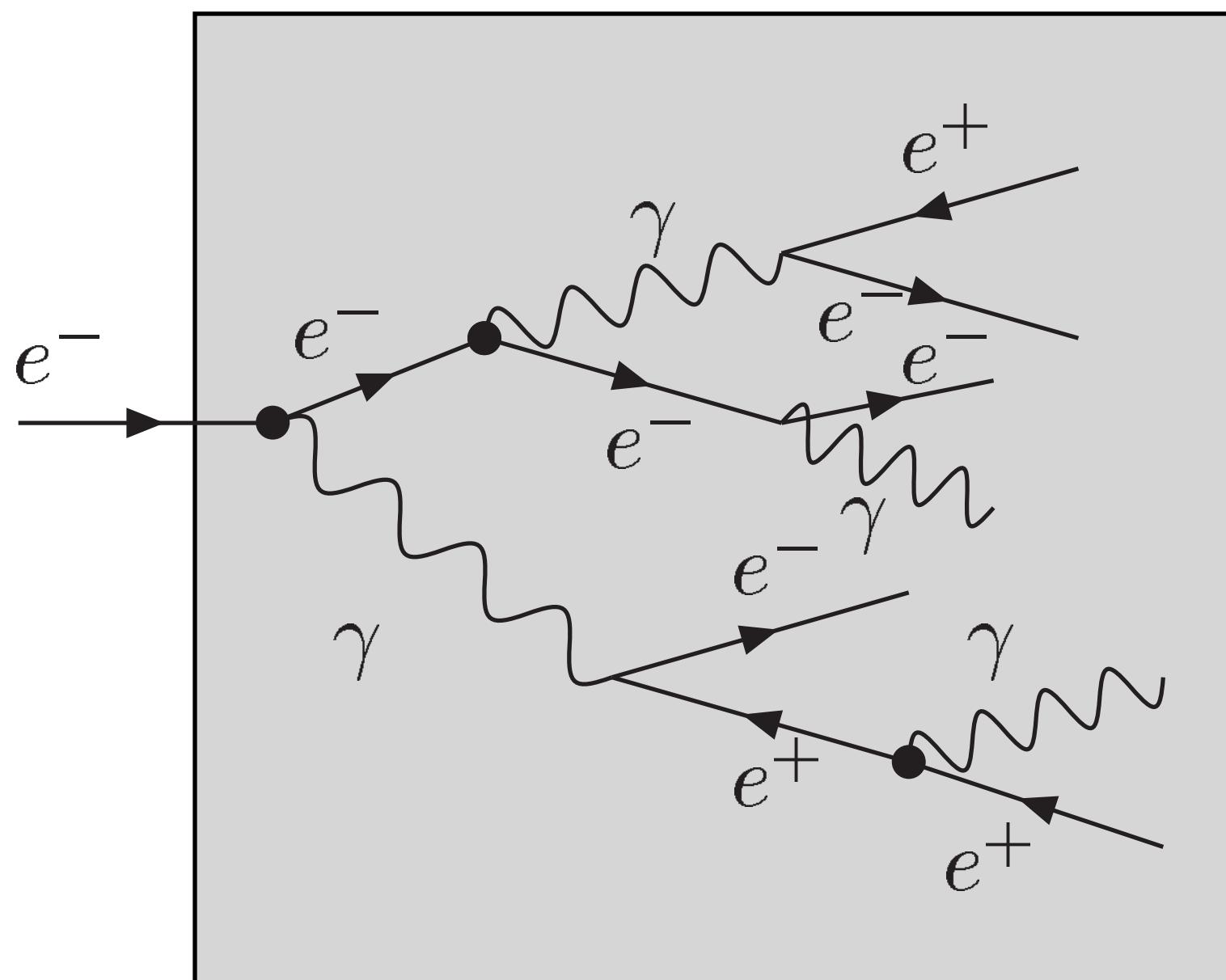
Studied 8 observables: Individual photon p_{T}^{γ} , $m_{\gamma\gamma}$, $p_{\text{T}}^{\gamma\gamma}$, $a_{\gamma\gamma}$, $\phi^{*\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, $\cos\theta^{*\gamma\gamma}$

ATLAS detector components

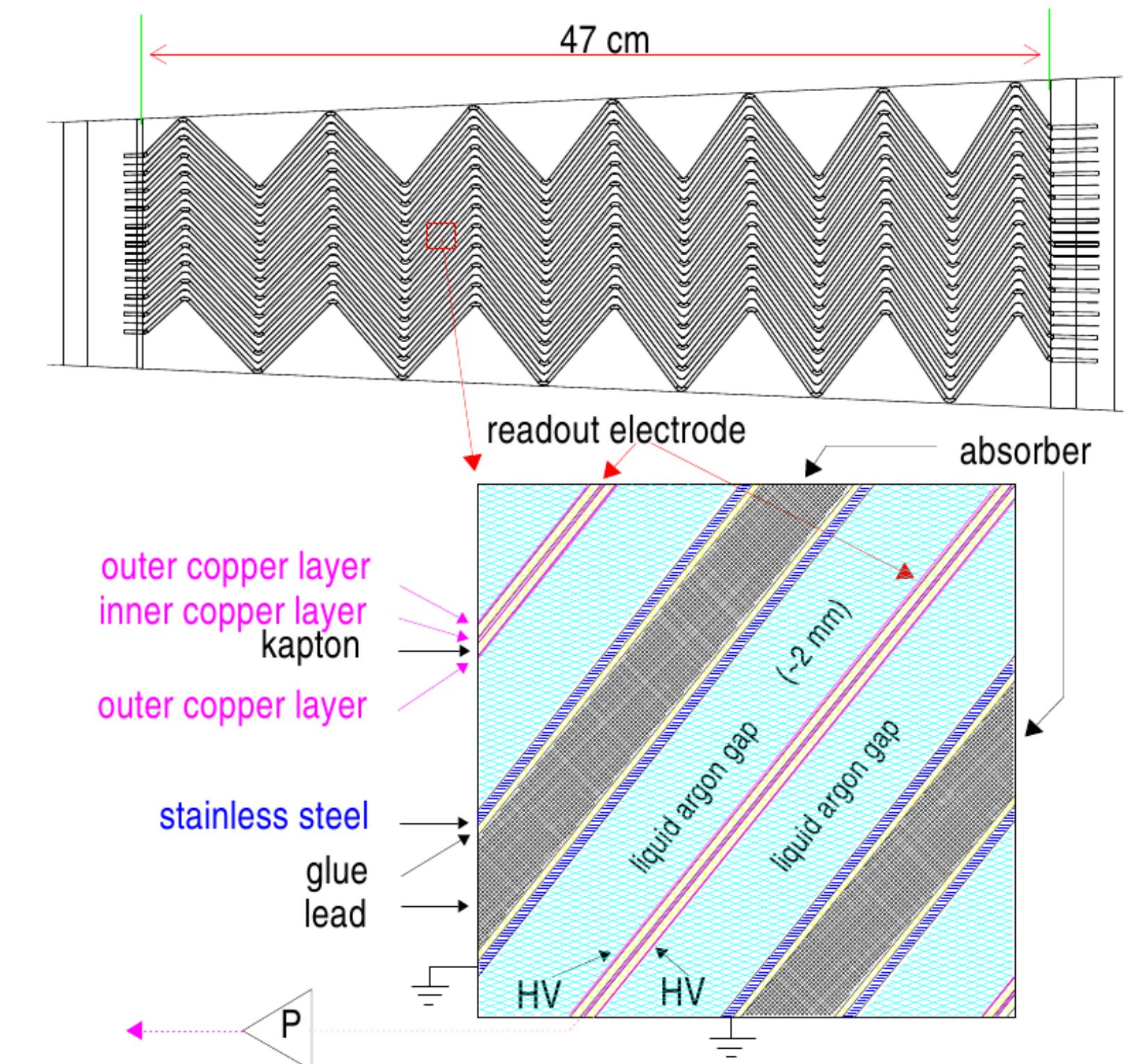


γ reconstruction in the EM calorimeter

Number of secondary particles
proportional to the particle energy

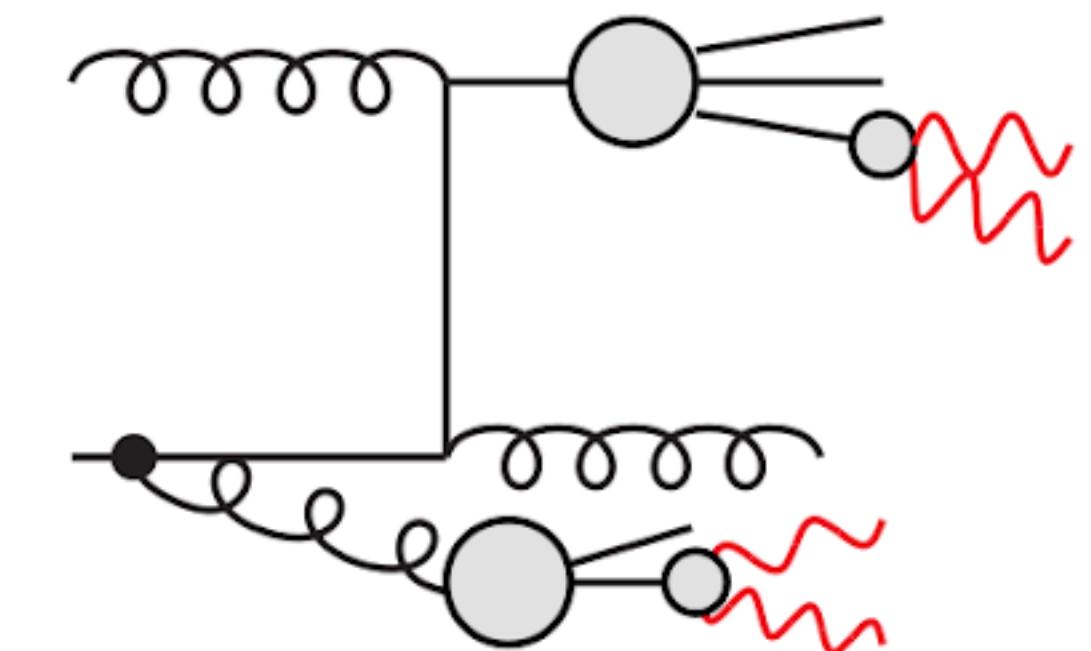


A lead - liquid argon accordion



Photon identification

- Prompt photon / signal photon:
Photons not coming from hadron decays
- A photon from hadron decays (e.g. $\pi^0 \rightarrow \gamma\gamma$)
→ background
The hadrons come inside jets
(the experimental signature of quarks and gluons)
Will call these background “photons” jets or fake photons



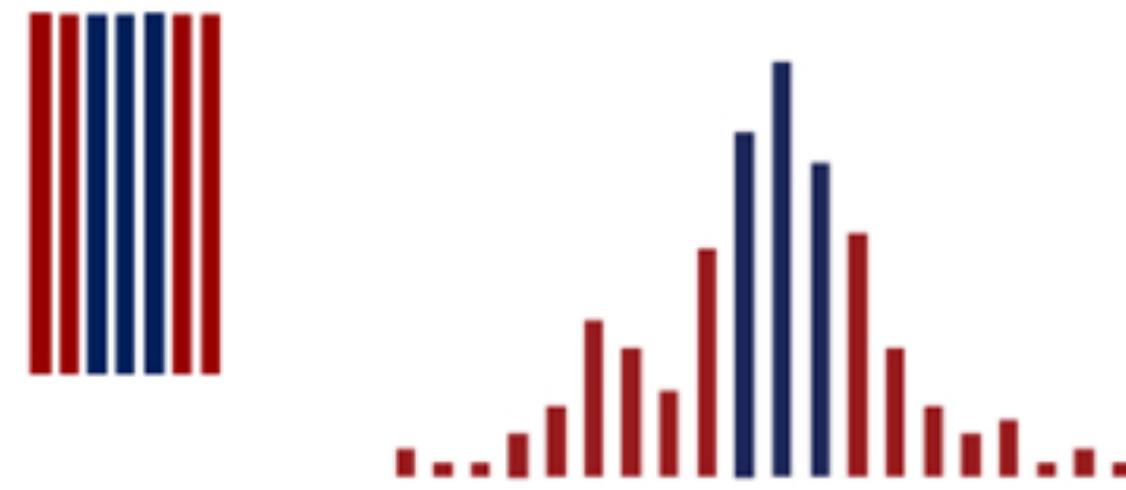
γ identification

Photon ID based on longitudinal
and lateral shower shape

Using 9 discriminant variables

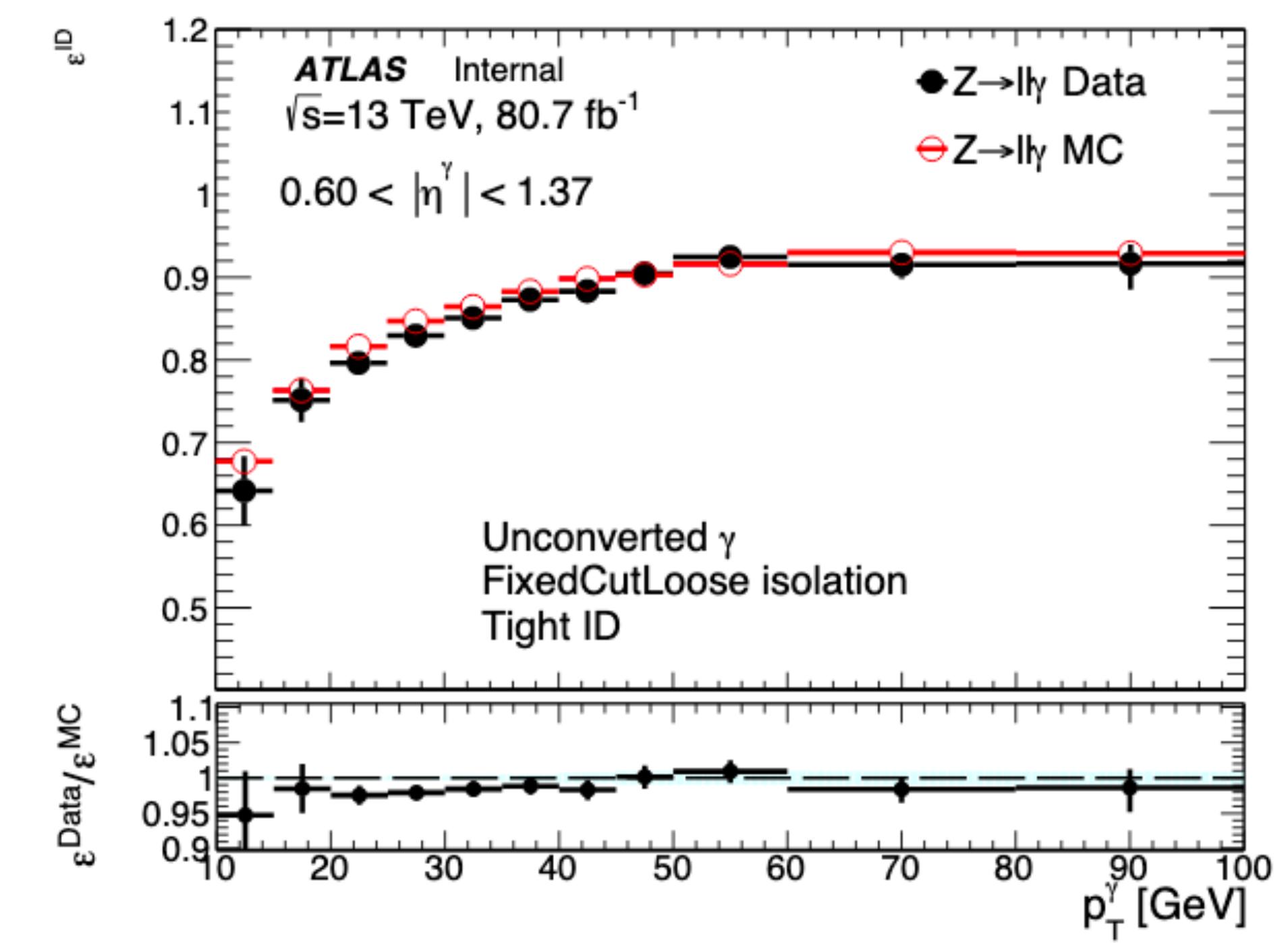
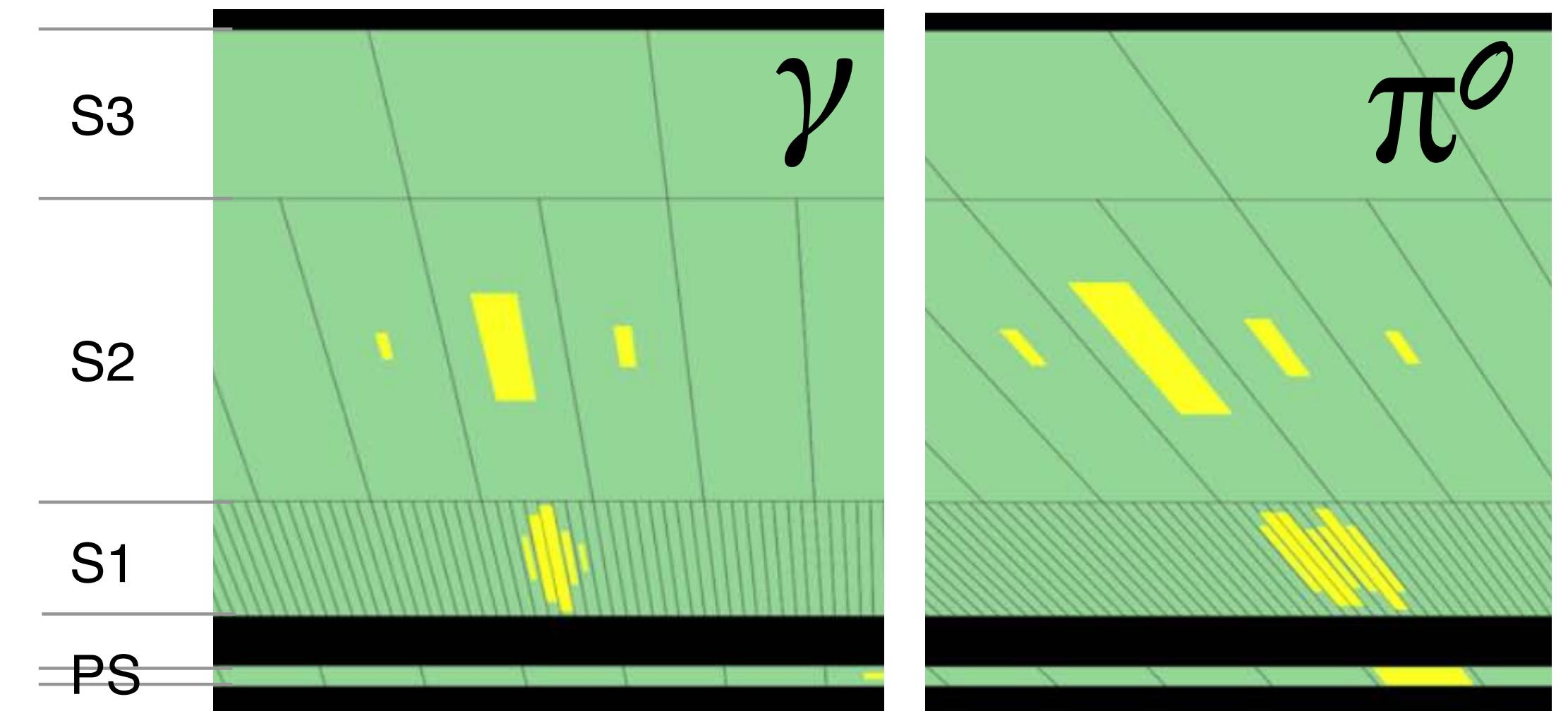
Example:

$$f_{\text{side}} = \frac{E_7^{S_1} - E_3^{S_1}}{E_3^{S_1}}$$



This identification is optimized using
simulated events

The efficiency is also studies with simulation
and corrected based real data information

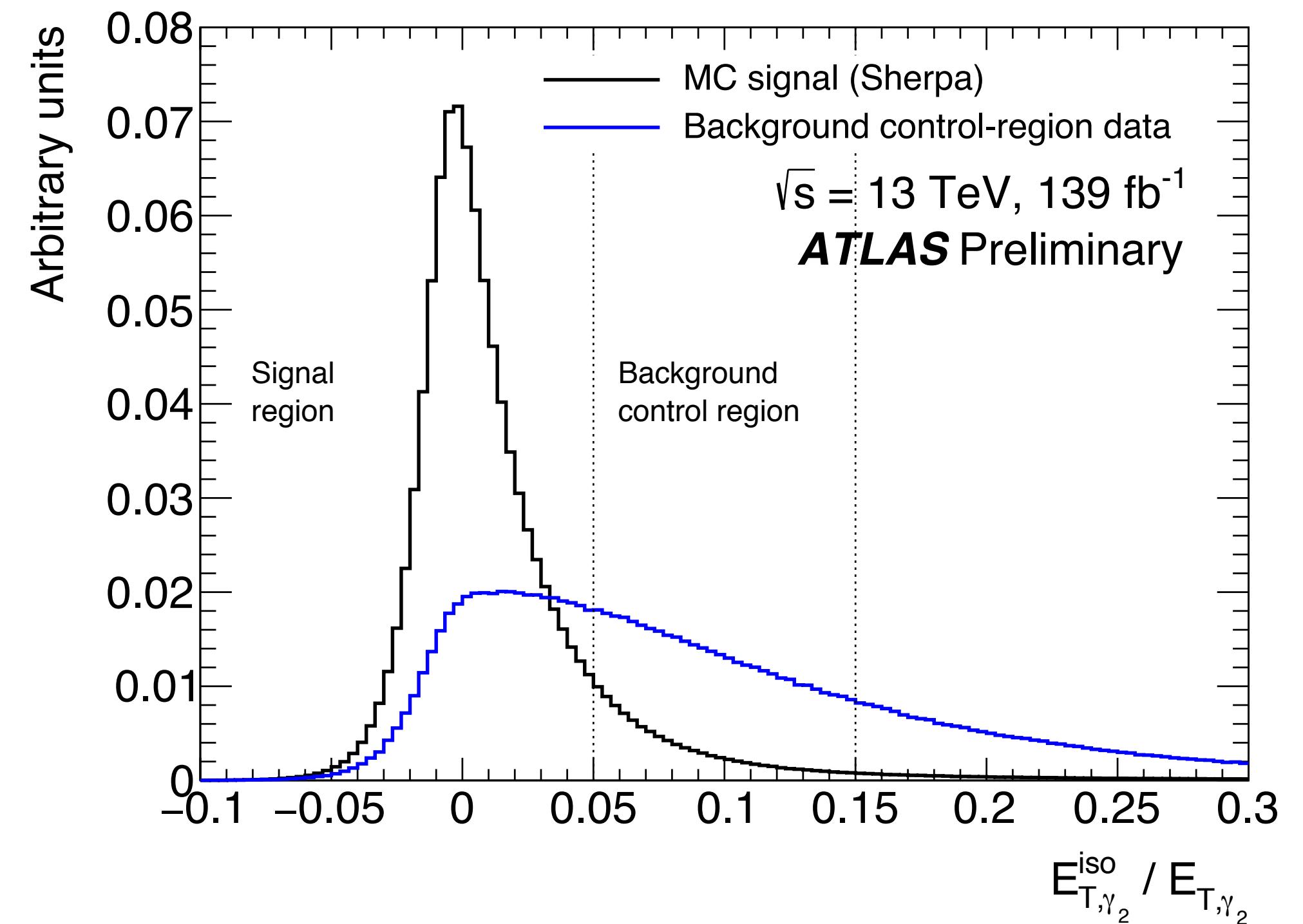
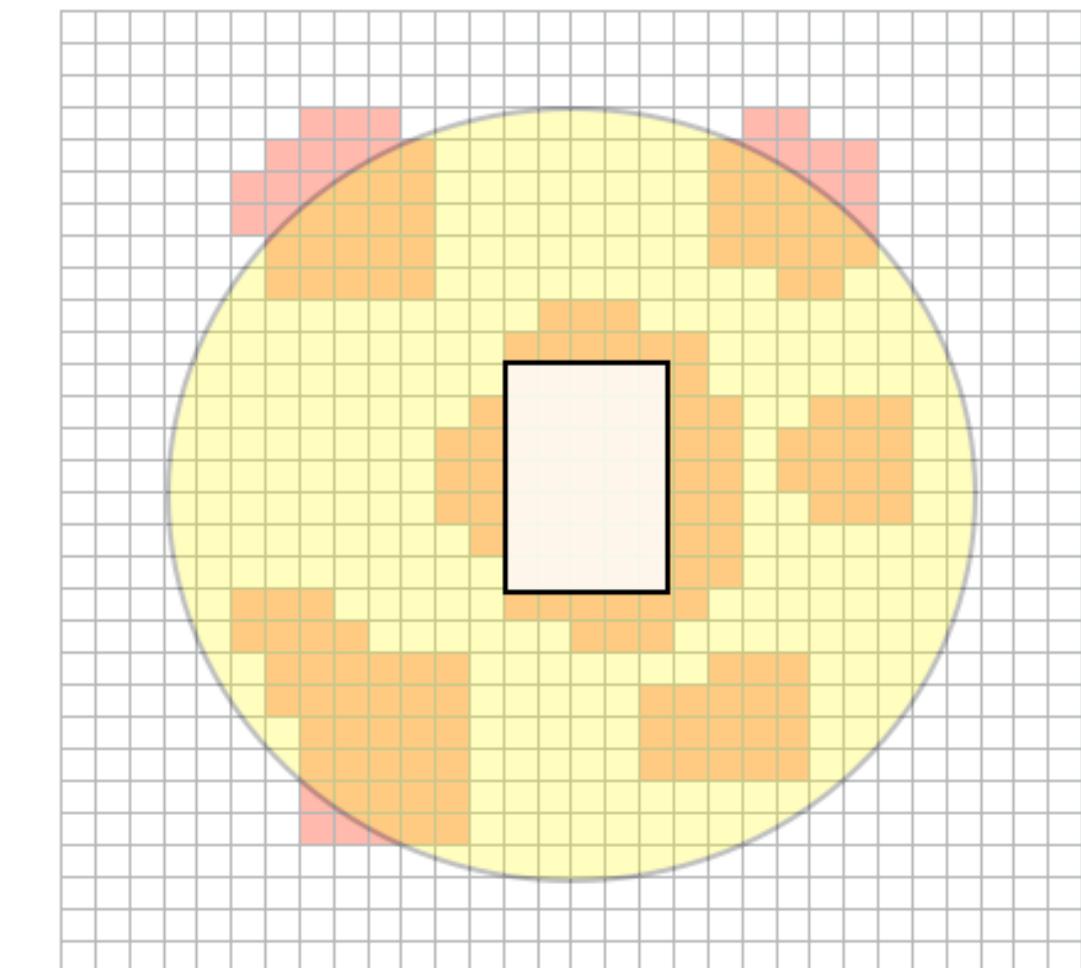


γ isolation

Fake photons from jets have hadronic activity around them

Calorimetric isolation:

- Sum of E_T of calorimetric clusters in a cone $\Delta R < 0.4$, 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	$E_{T,\gamma_1} > 40 \text{ GeV}, E_{T,\gamma_2} > 30 \text{ GeV}$
η	$ \eta_{\gamma_{1(2)}} < 1.37 \text{ or } 1.52 < \eta_{\gamma_{1(2)}} < 2.37$
identification	both tight
isolation	$E_{T,\gamma_{1(2)}}^{\text{iso},0.2} < 0.05 \cdot E_{T,\gamma_{1(2)}}$
ΔR	$\Delta R_{\gamma\gamma} > 0.4$

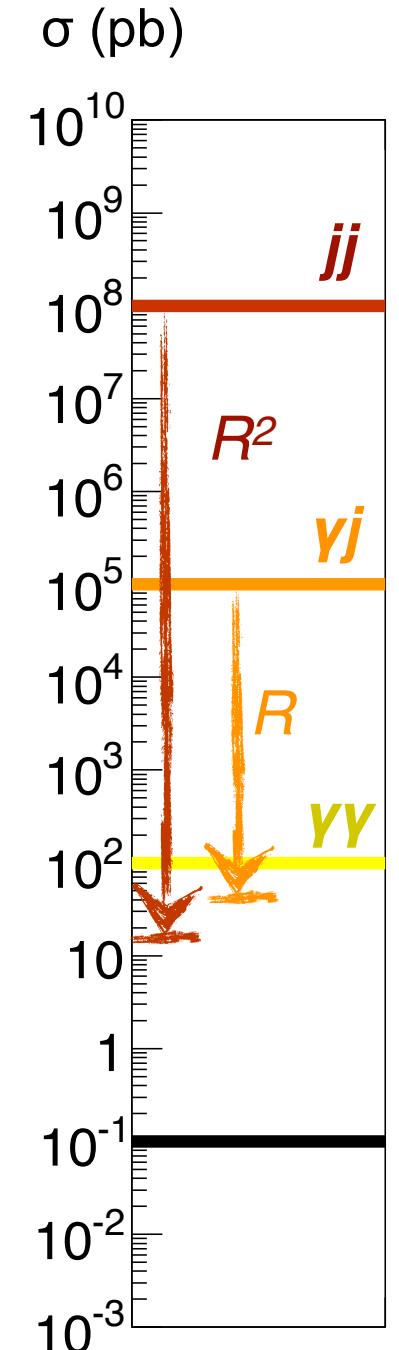
- 5M data events at signal region

Sample composition

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

Data-driven estimation

- 2.6% \rightarrow Drell-Yan $Z \rightarrow ee$ events with electrons mis-identified as photons
Estimation based on simulation samples
- 0.6% \rightarrow Pileup: Two gamma-jet events overlapping
Data-driven estimation



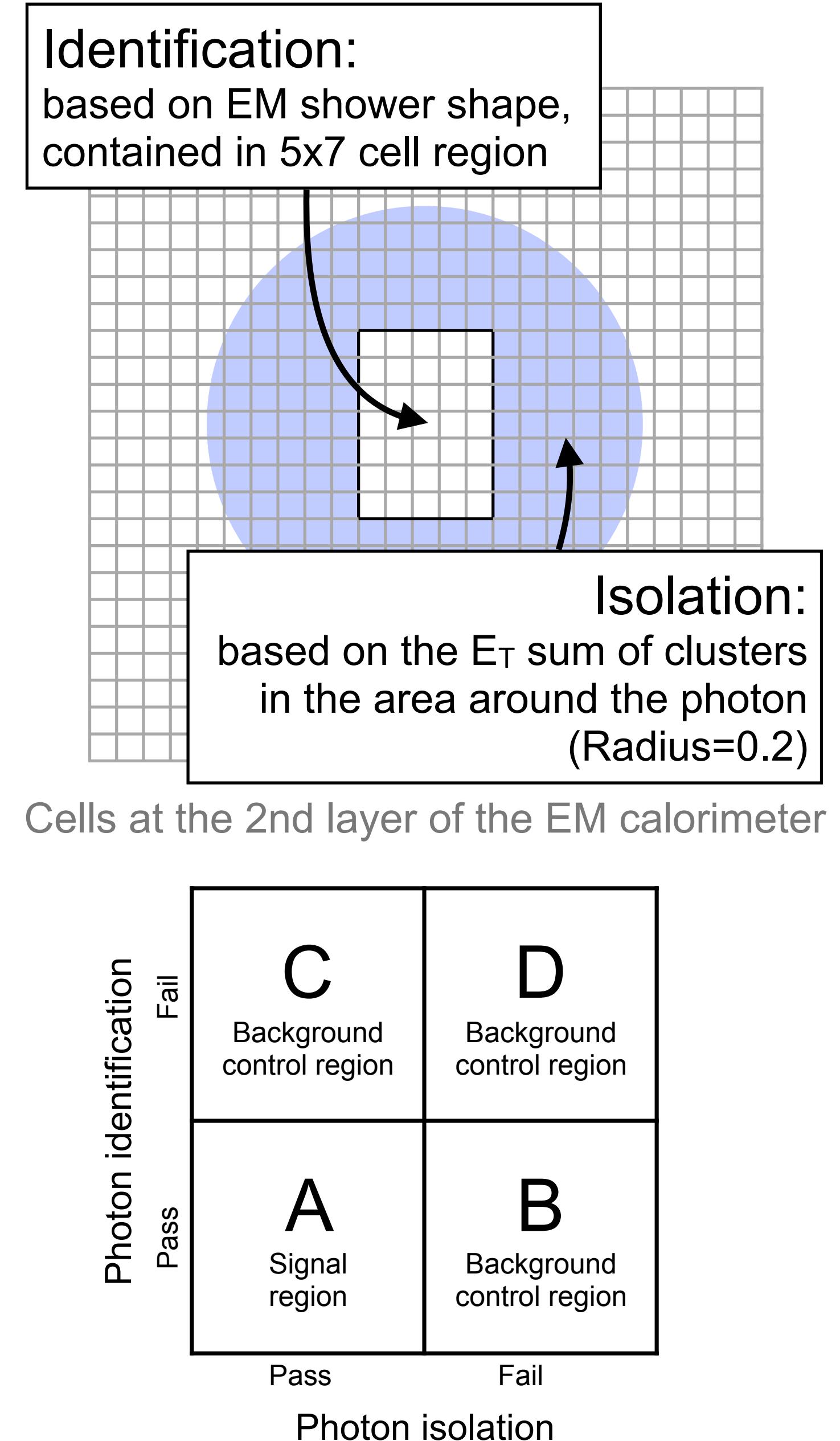
Jet background estimation

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

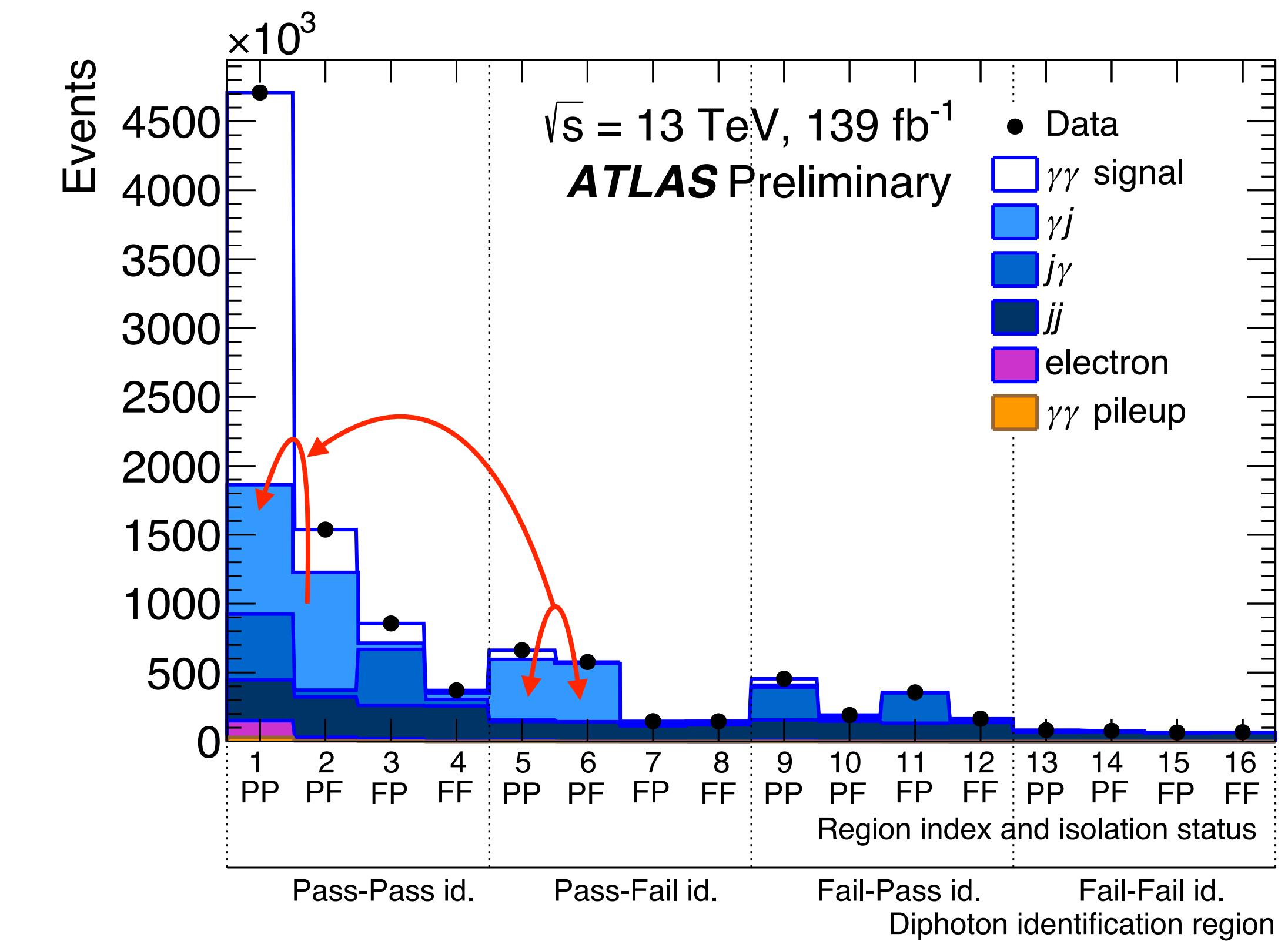
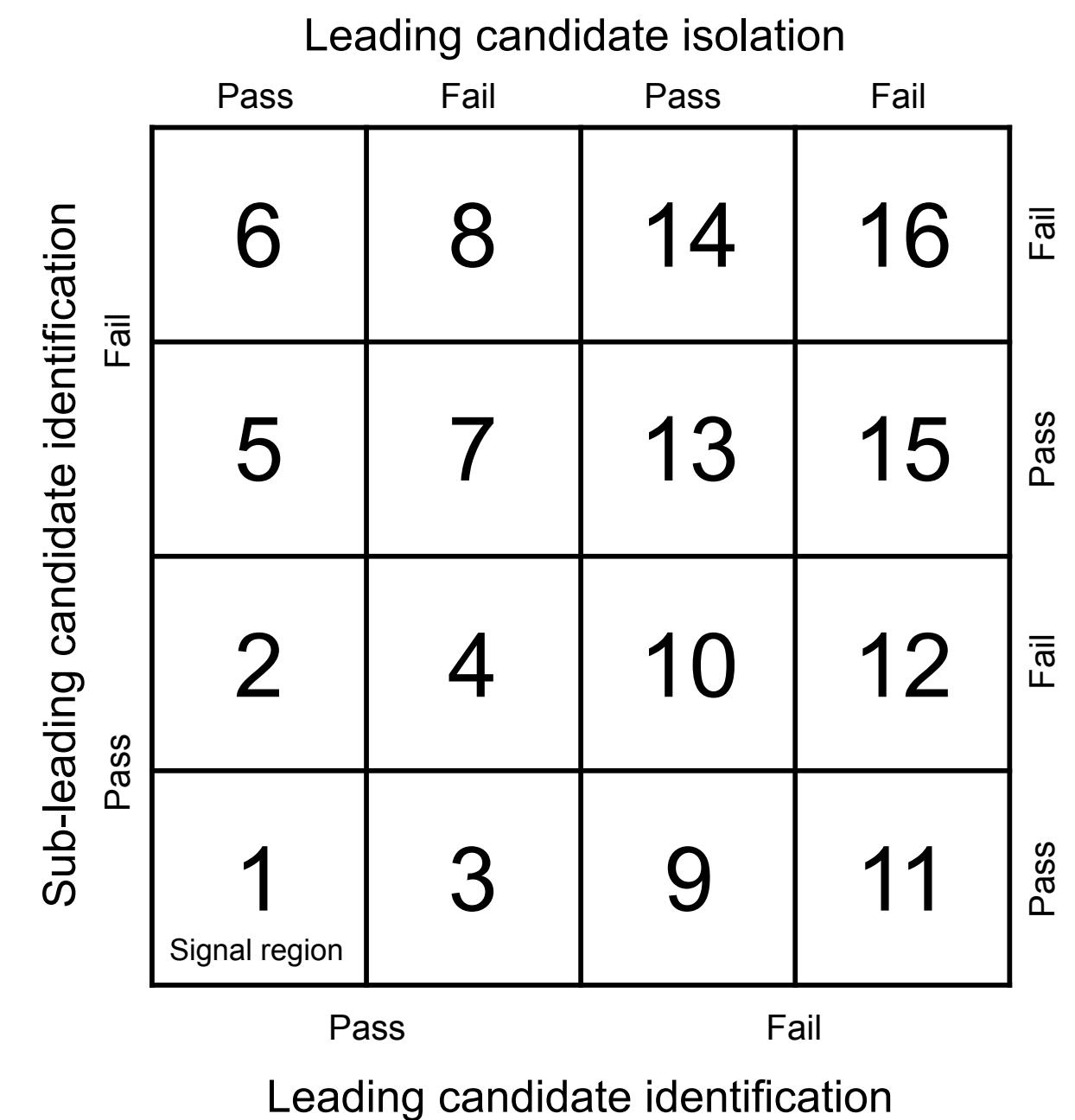
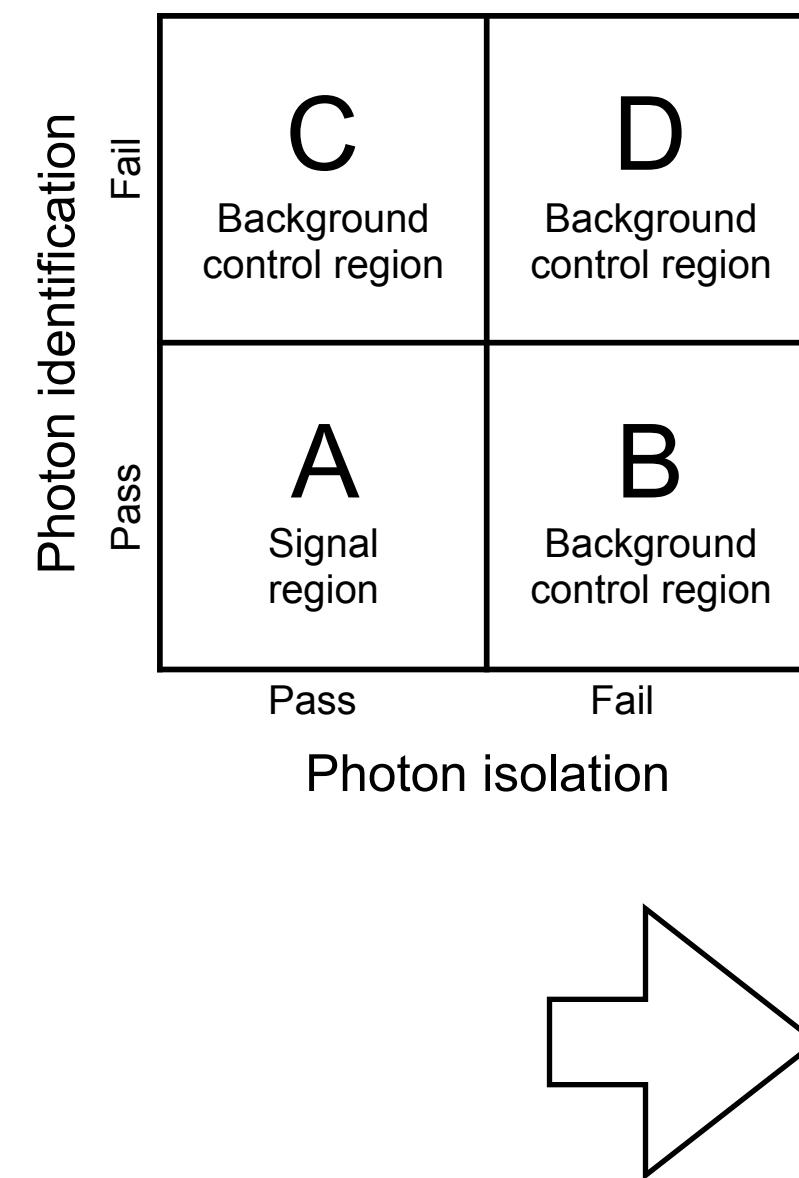
$$\frac{n_{o,A}}{n_{o,B}} = \frac{n_{o,C}}{n_{o,D}},$$

→ main source of uncertainty on final result



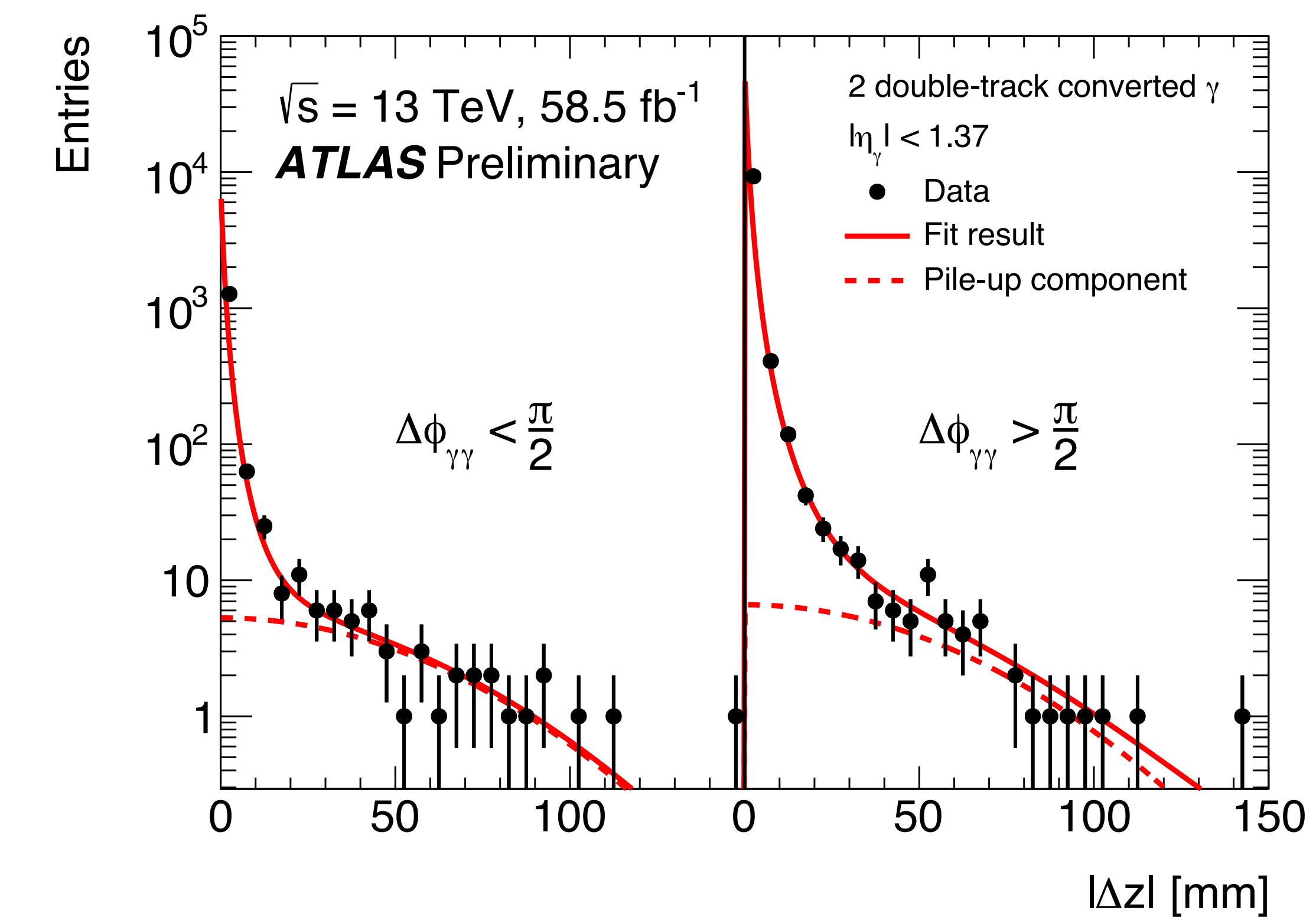
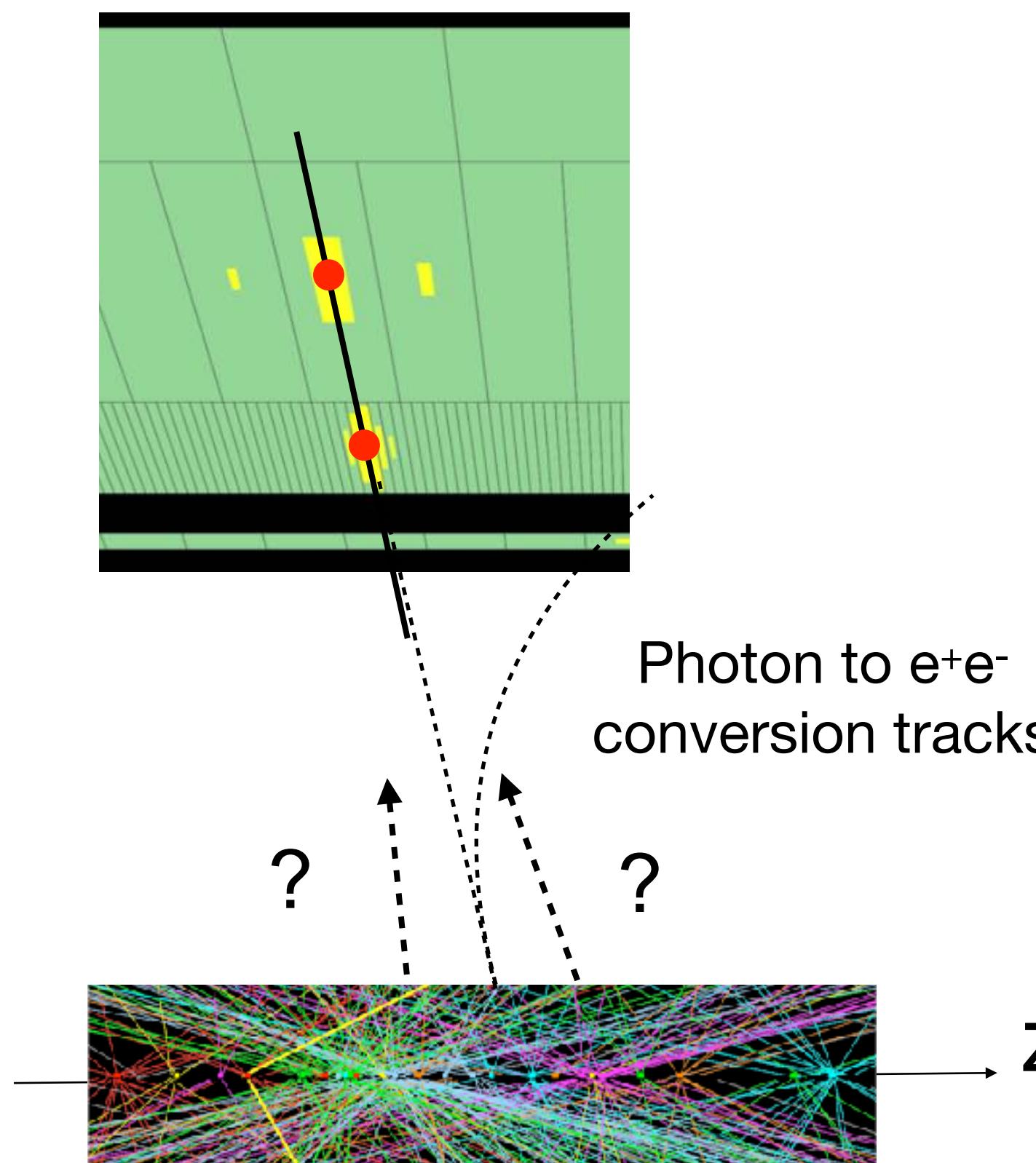
Jet background estimation

Two-photon case
 ABCD method,
 with a likelihood fit

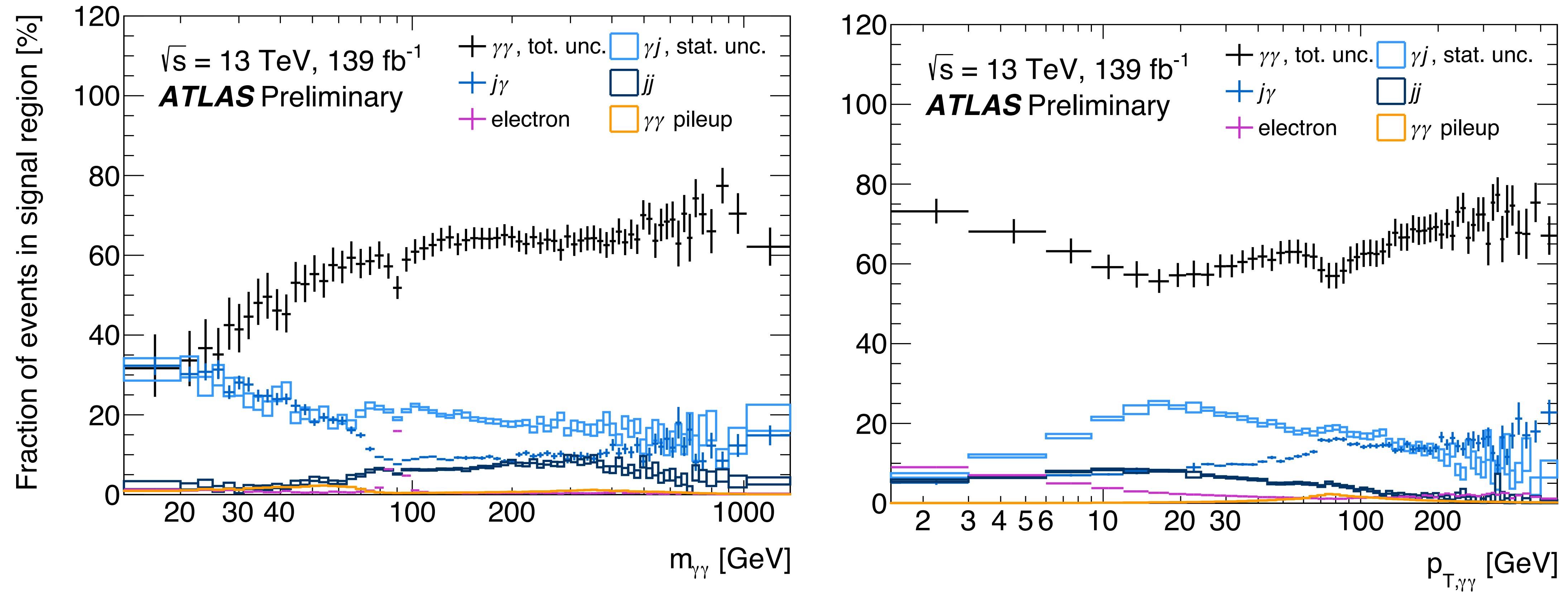


Pileup background estimation

Data-driven normalization from z-pointing info with both γ “converted”



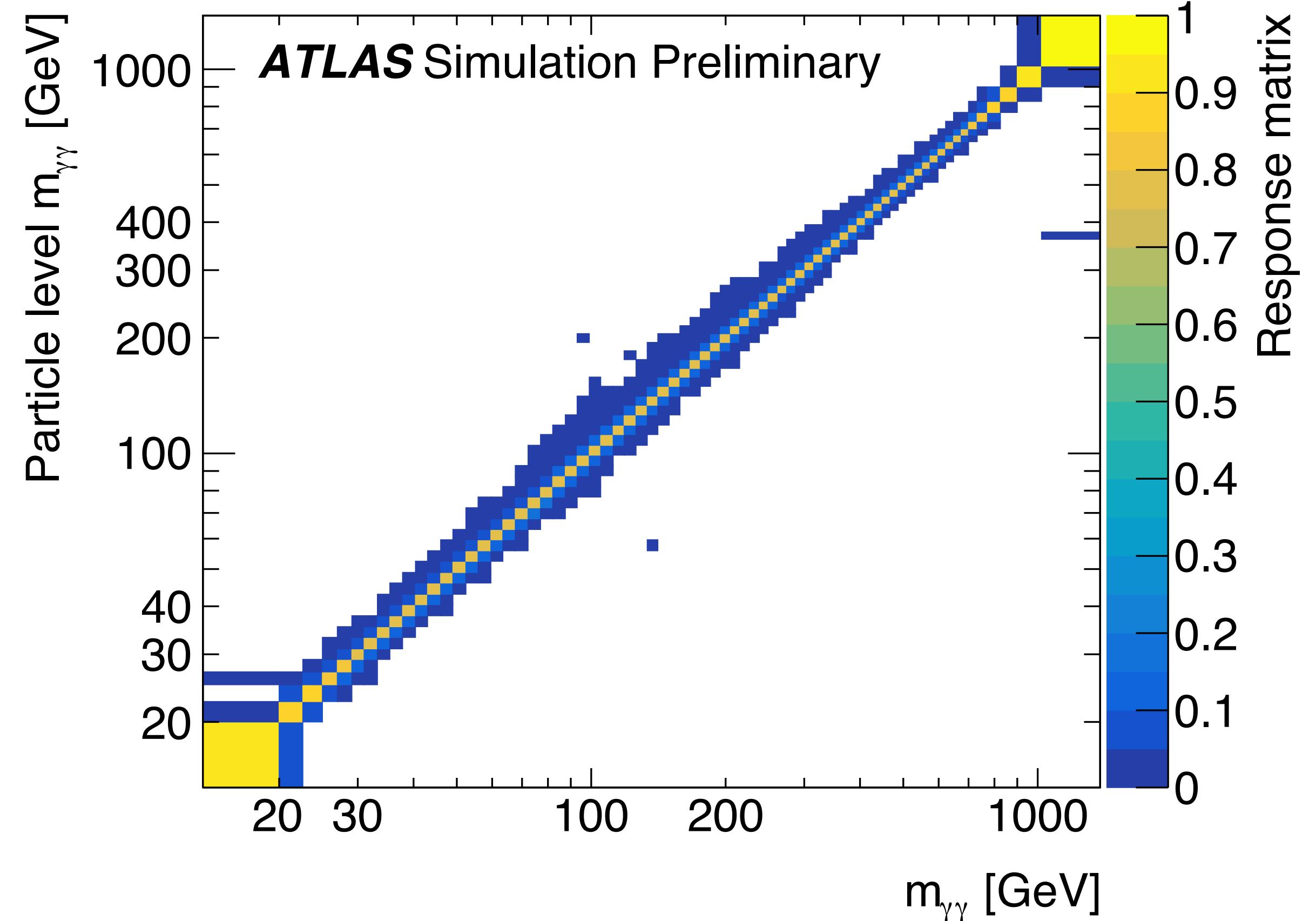
Sample composition result



Unfolding (Detector effect corrections)

- **Detector level**
(experimental event counts)
- **“Truth” or particle level**
(theory predictions)

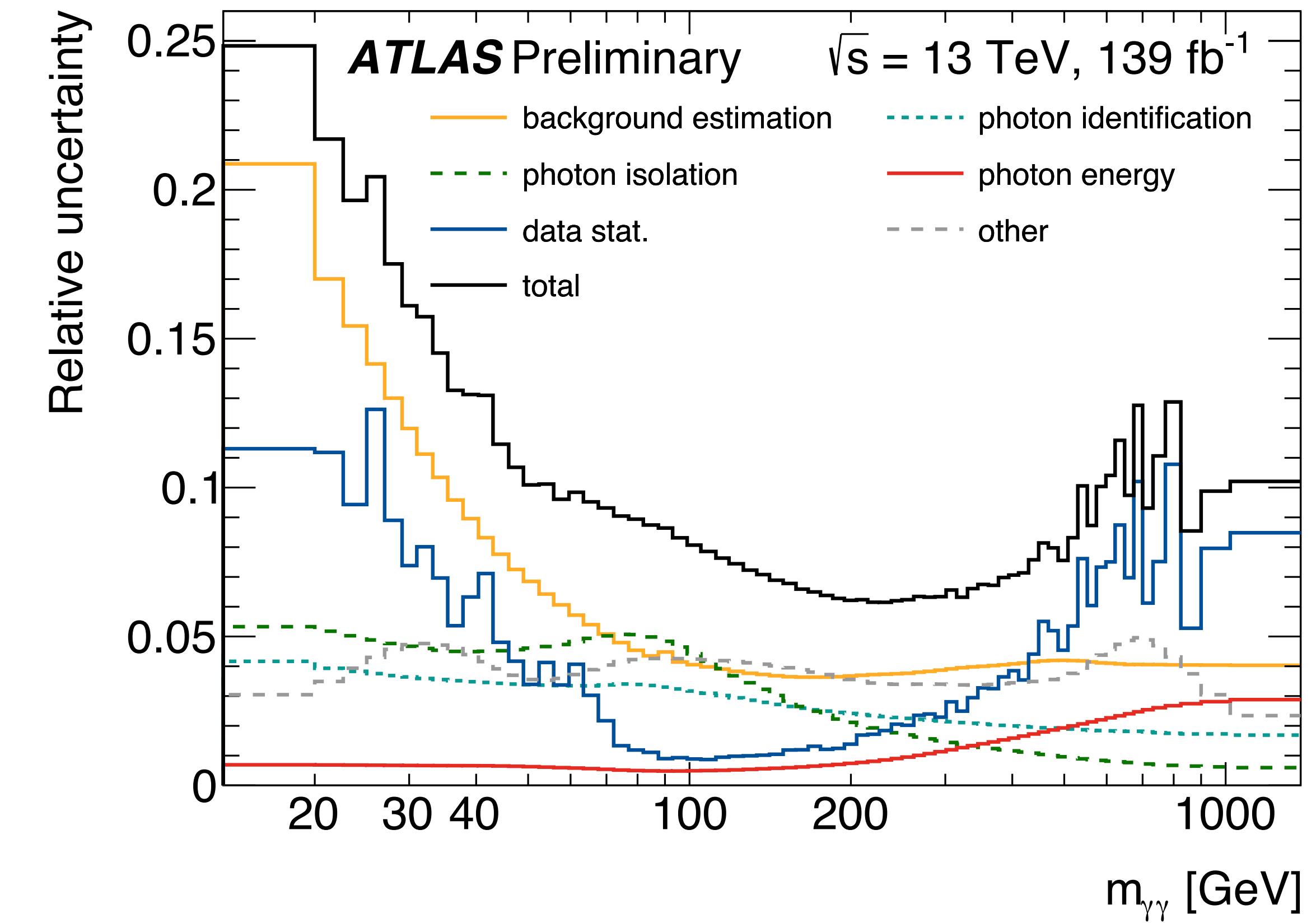
Reconstruction and identification efficiency are taken into account in this step



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

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



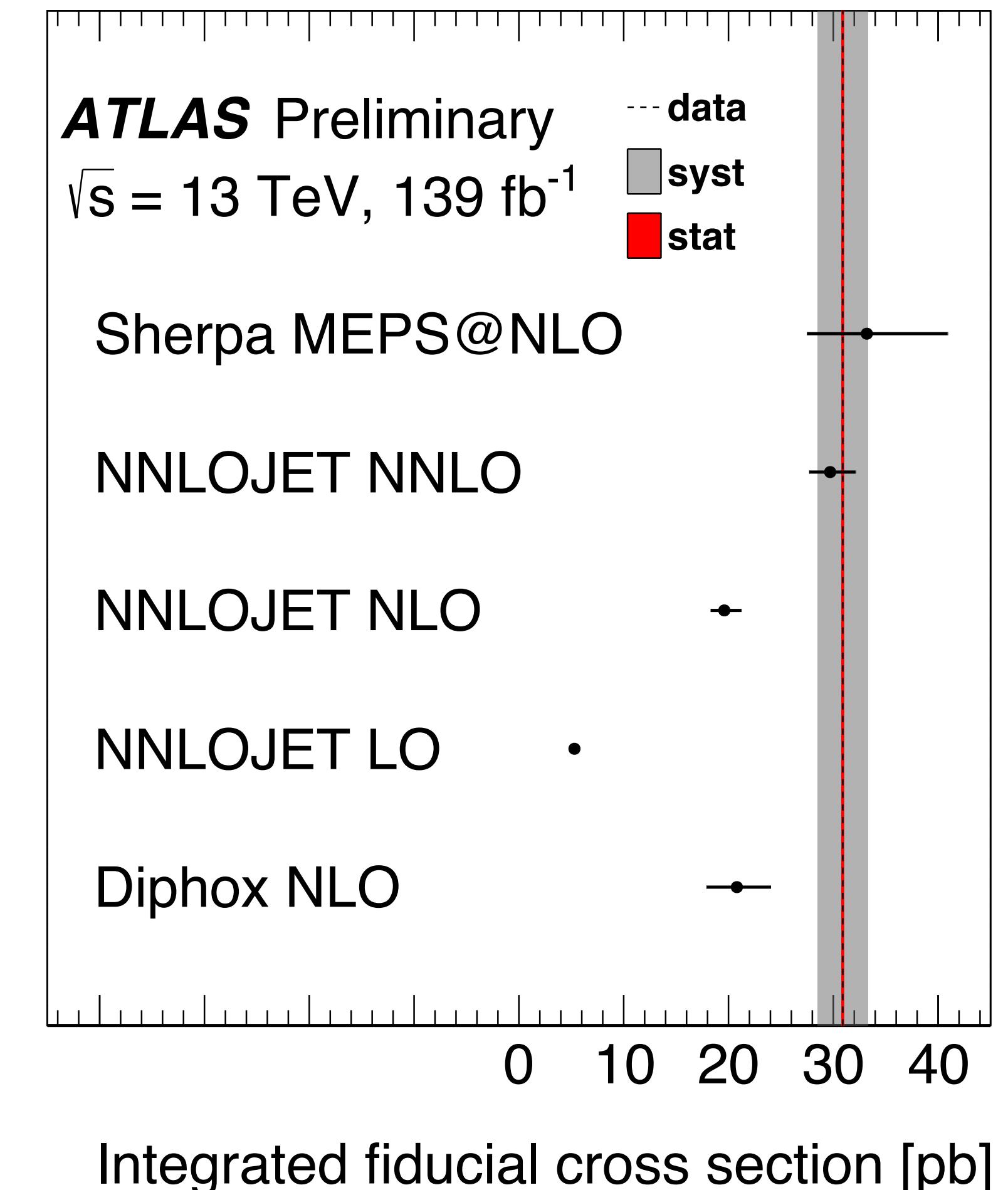
Theory predictions

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

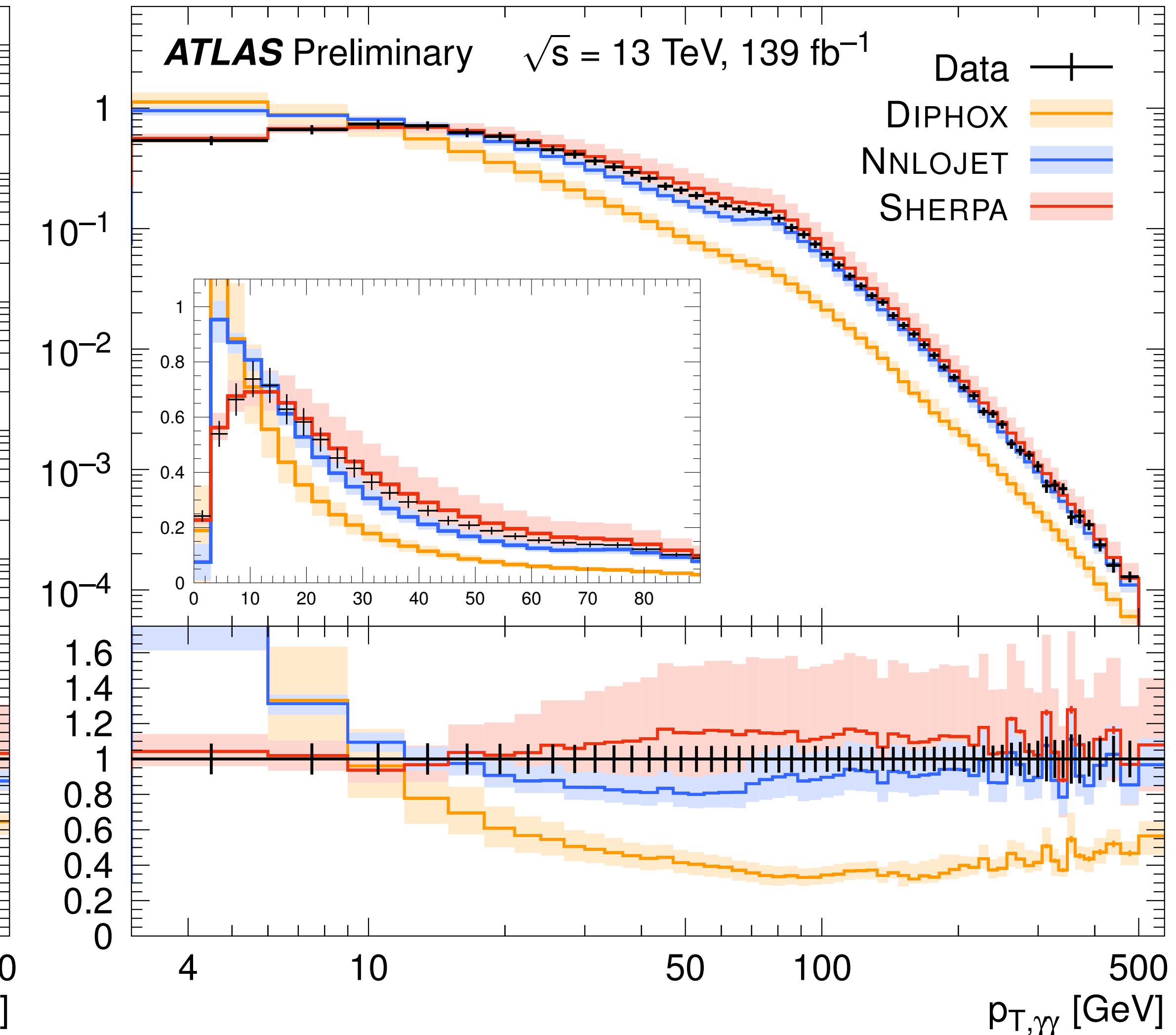
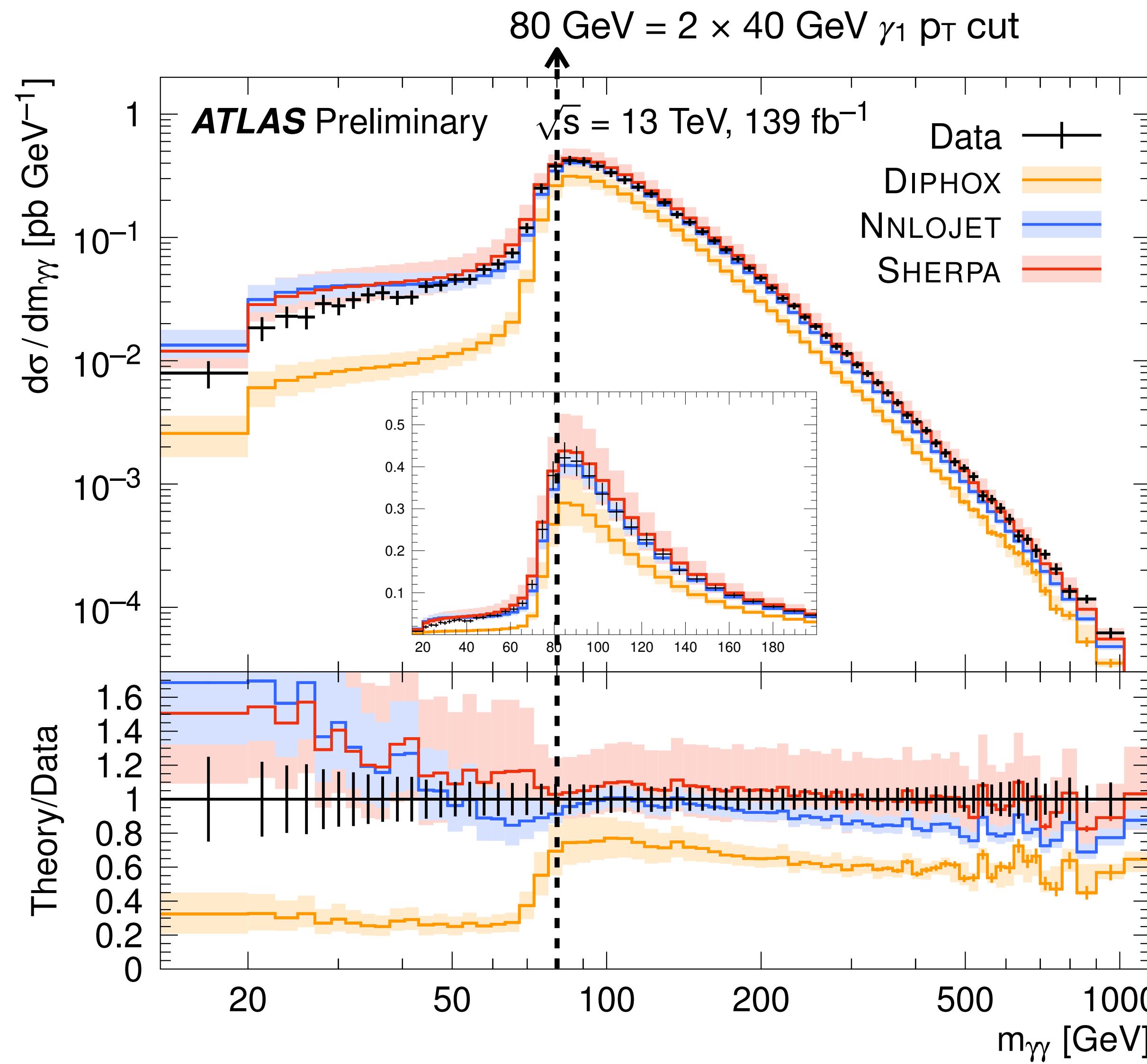
Results

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



Summary

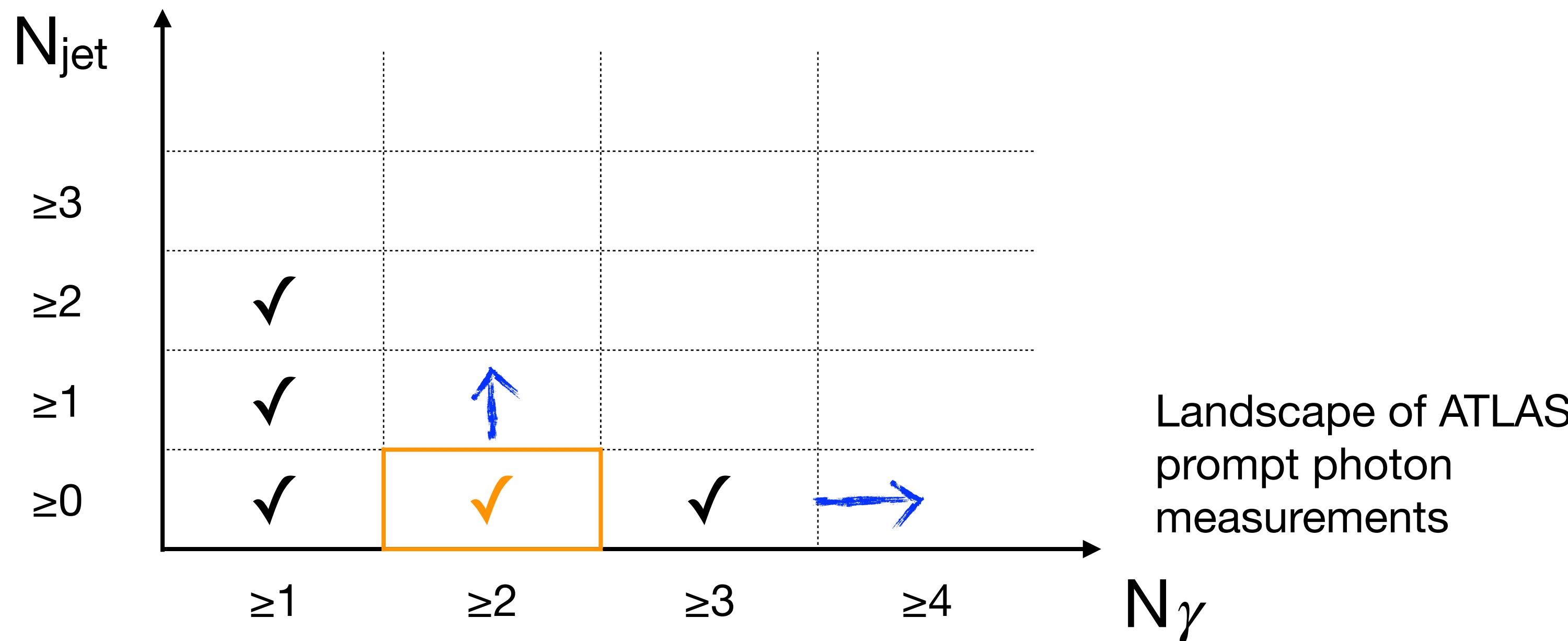
$\gamma\gamma$ production at 13 TeV characterized with high precision

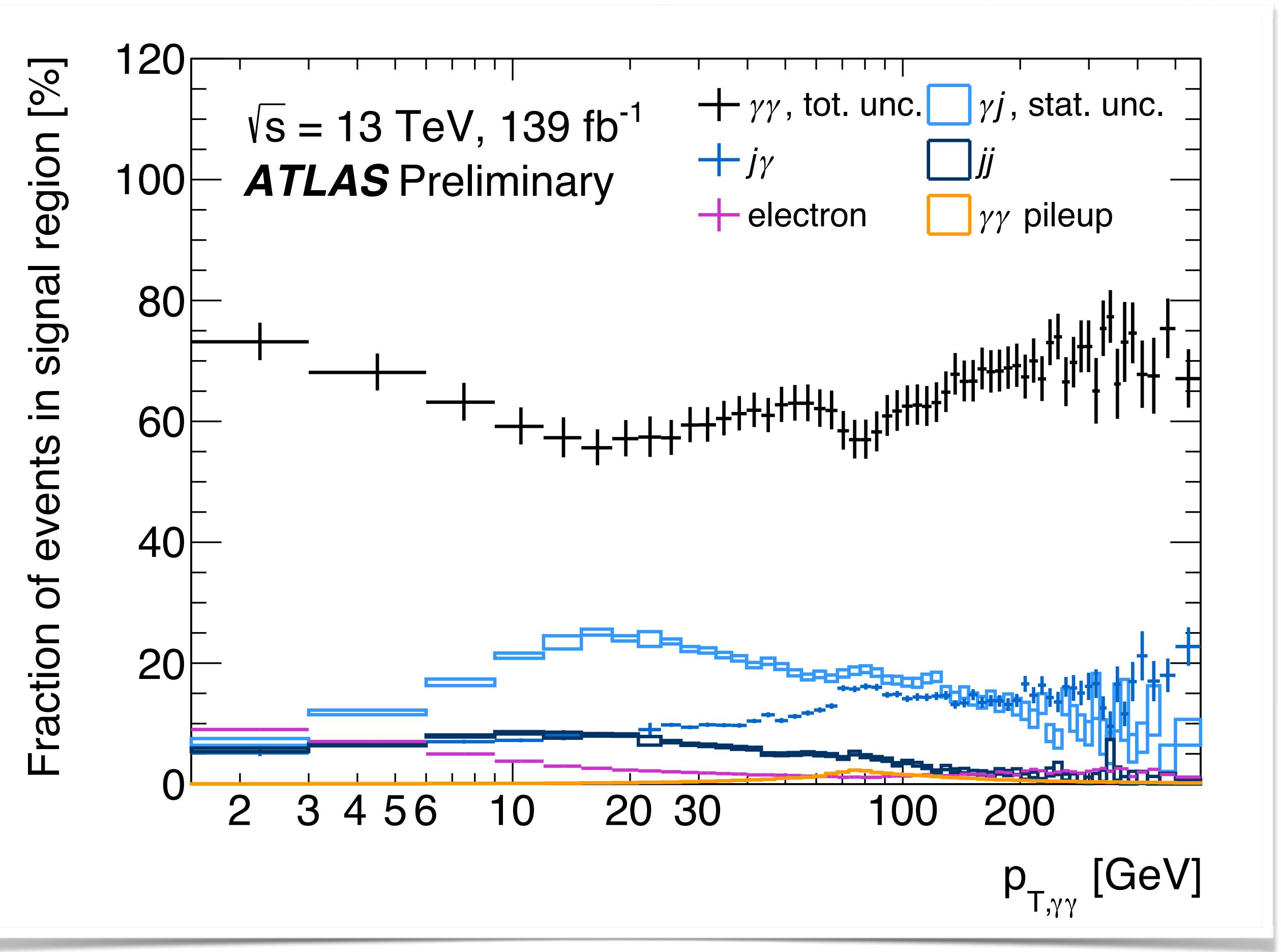
- At high energy beyond previous result, 1 TeV invariant mass
- At very low invariant mass → challenging to model by theory predictions
- Fine binning exploiting detector resolution
- Compared with state of the art predictions

Physics with photons γ – Outlook

Potential options for next studies

- $\gamma\gamma+\text{jets}$,
- $\gamma\gamma\gamma\gamma$,
- γ isolation distribution





Thanks for your attention!

Lucía's ATLAS event display
definitely wins

Experimental art pieces (during pandemic time)

