

# Measuring prompt photon production with the ALICE Forward Calorimeter (FoCal) upgrade

Florian Jonas for the ALICE collaboration



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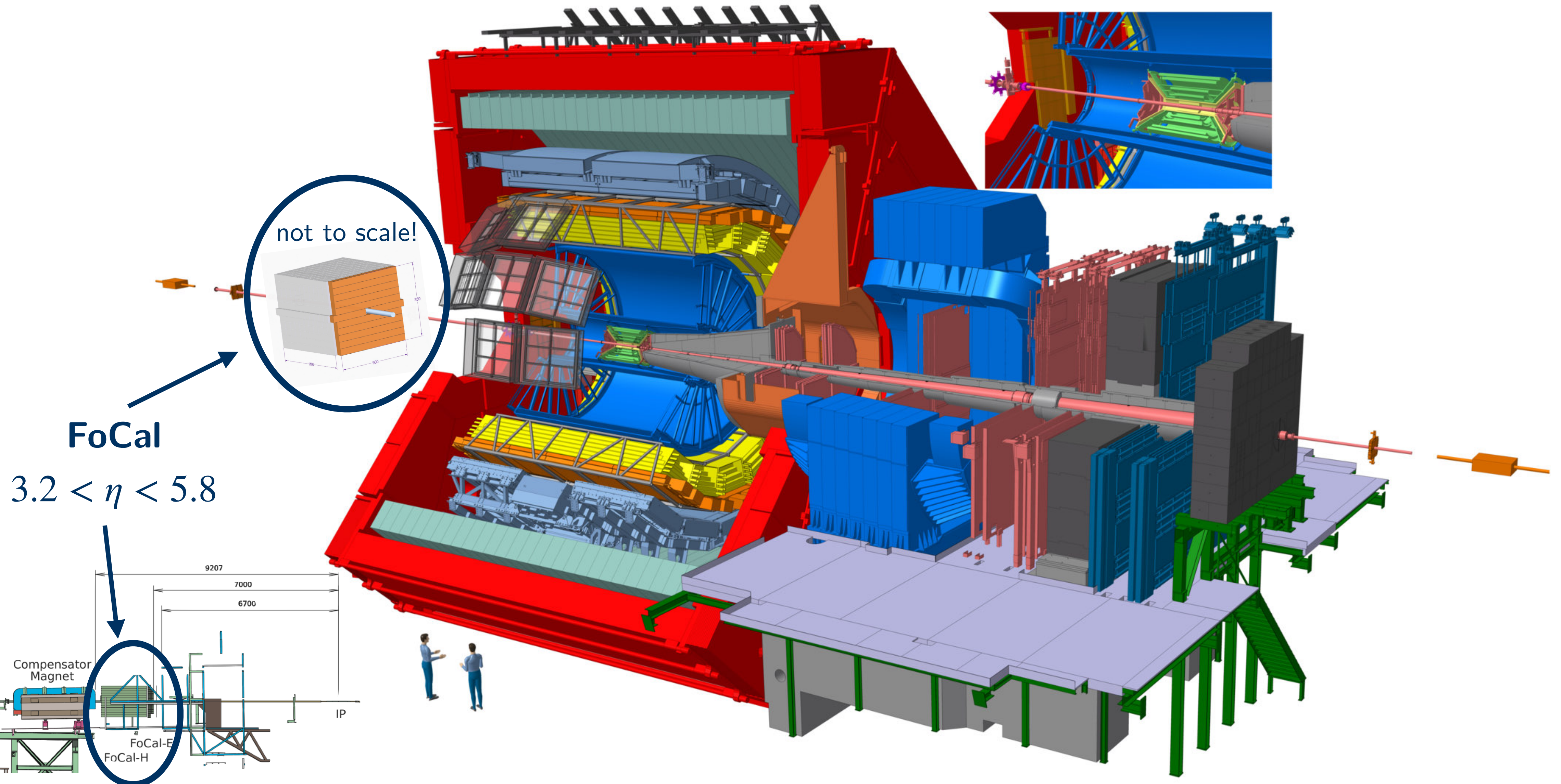


Lawrence Berkeley  
National Laboratory



**ALICE**

# The Forward Calorimeter (FoCal)



**Acceptance:**  
 $3.2 < \eta < 5.8$

## General:

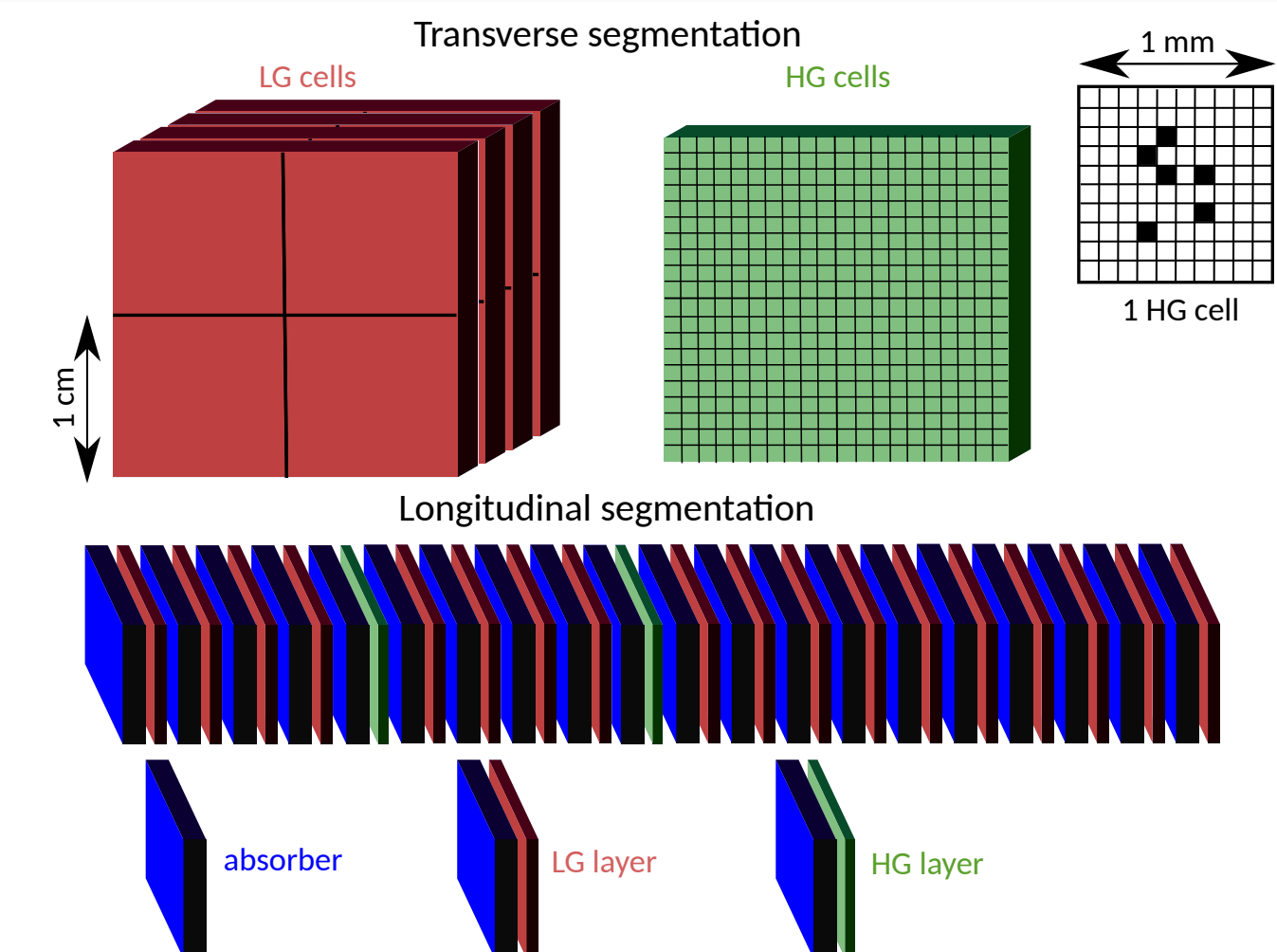
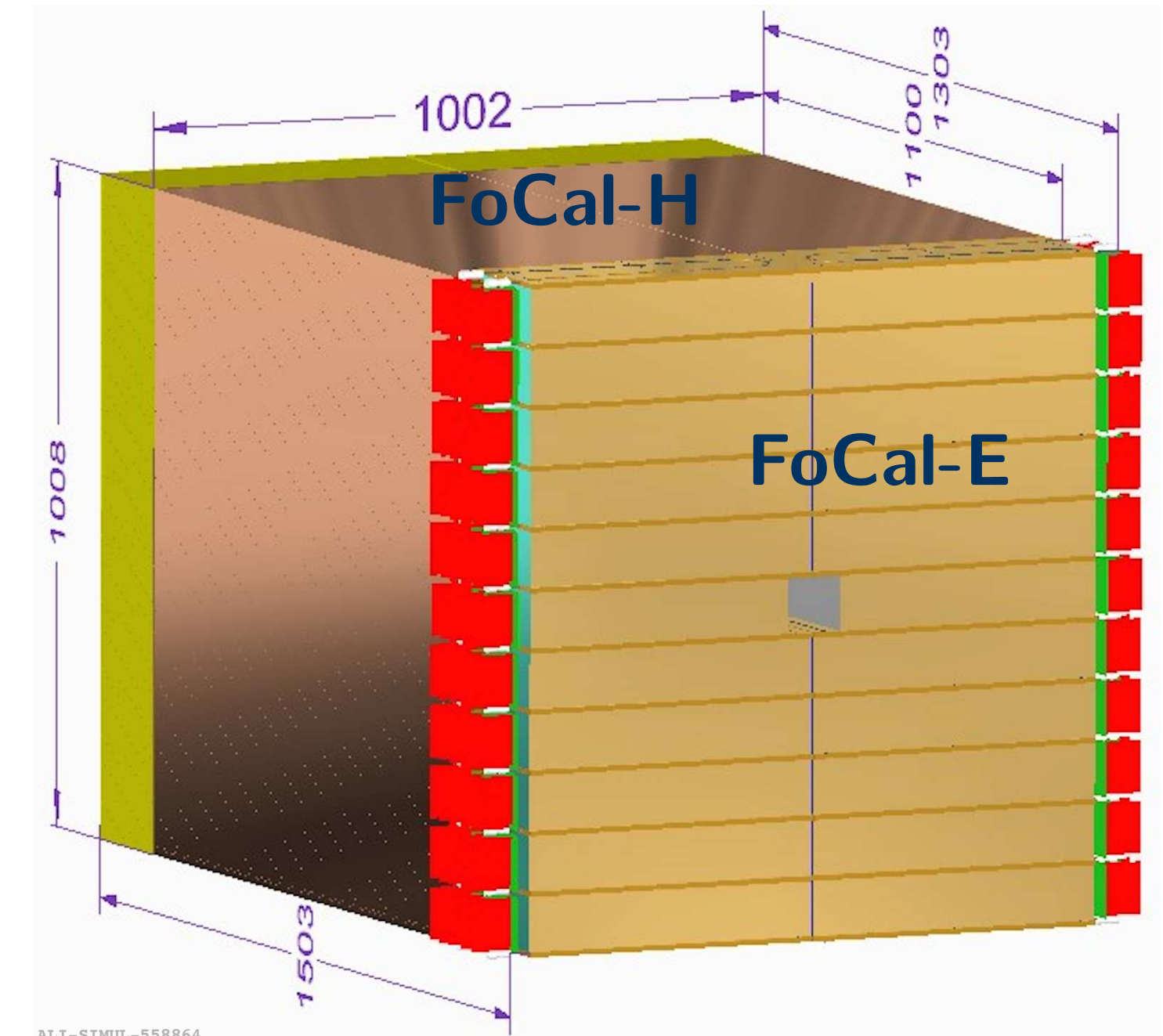
- Very forward calorimeter consisting of two parts (FoCal-E and FoCal-H) located  $\approx 7\text{m}$  from IP of ALICE

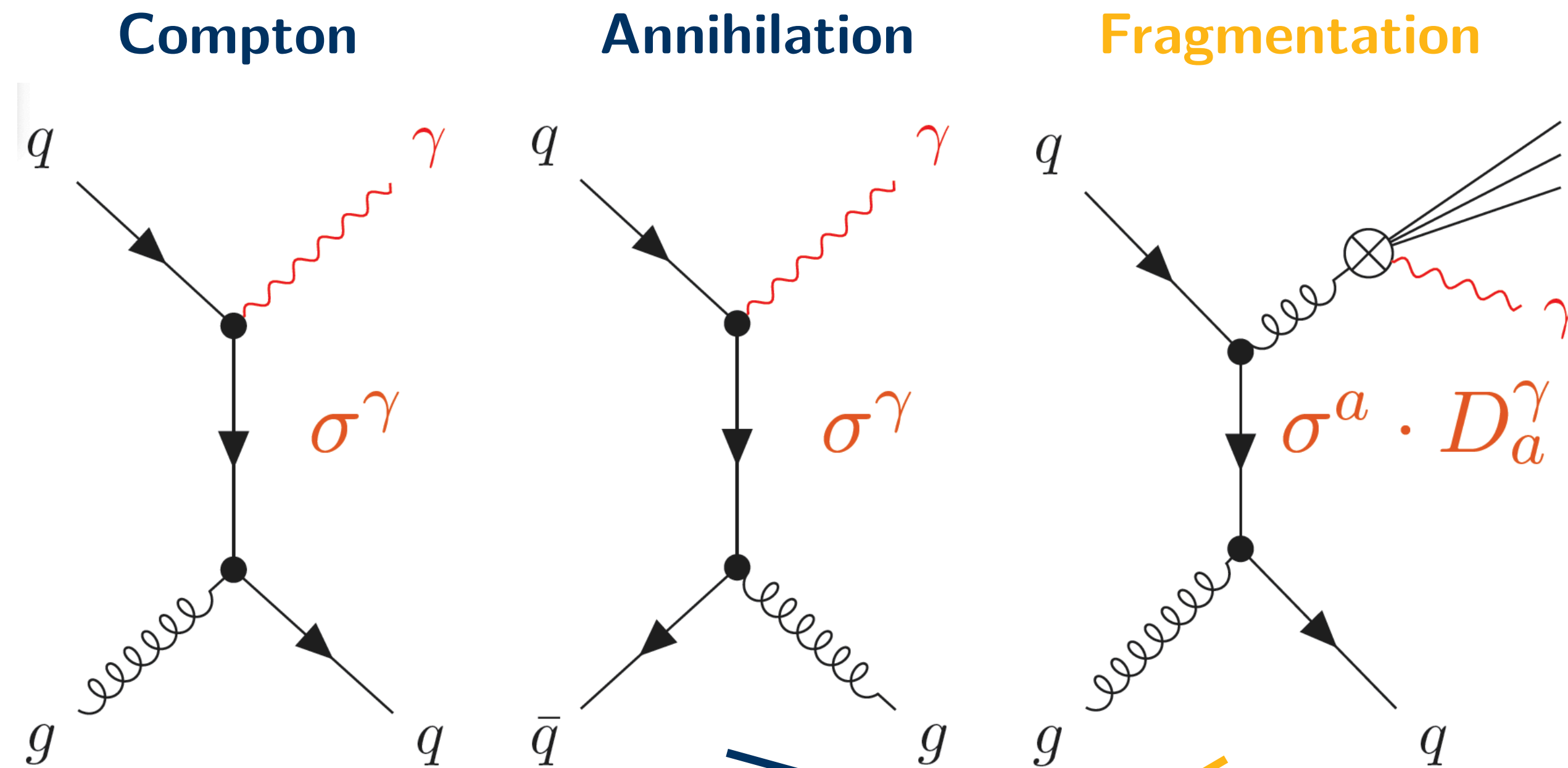
## FoCal-E (electromagnetic):

- High-granularity Si-W sampling calorimeter combining two sensor granularities
  - 18 pad layers with silicon pads ( $1 \times 1\text{cm}^2$ )
  - Two pixel layers with digital readout ( $30 \times 30\mu\text{m}^2$ )
- Ability to “track” longitudinal component of shower!
- Used to measure photons and  $\pi^0$  ( $40\mu\text{m}$  position rec.)

## FoCal-H (hadronic):

- Conventional metal-scintillator hadronic calorimeter behind FoCal-E
- Design using scintillating fibres embedded in Cu tubes
- Used to measure photon isolation, jet energy etc.





$$\sigma(p_\gamma) = \sum_{a=q,\bar{q},g} \int_0^1 \frac{dz}{z} \hat{\sigma}^a\left(\frac{p_\gamma}{z}; \mu_r, \mu, \mu_f\right) \cdot D_a^\gamma(z; \mu_f) + \hat{\sigma}^\gamma(p_\gamma; \mu_r, \mu, \mu_f)$$

$\mu_r$ : renormalisation scale,  $\mu$ : factorisation scale,  $\mu_f$  fragmentation scale

- Prompt photons produced in hard scattering via two mechanisms:

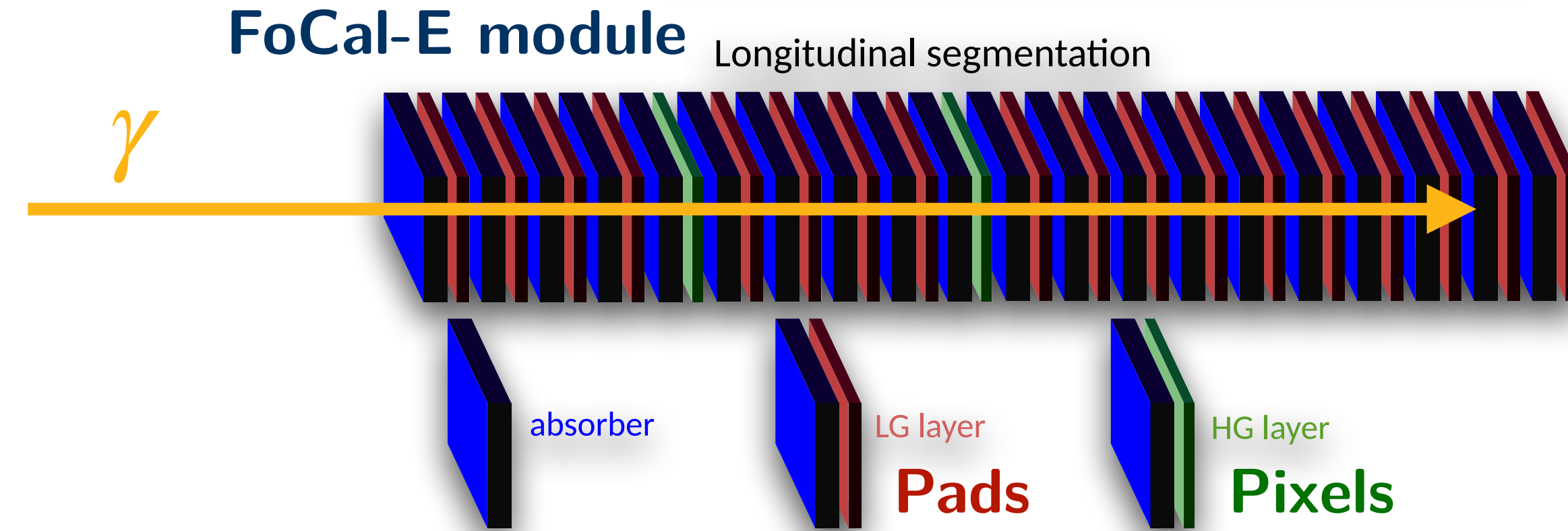
(1) **Direct production** (direct access to incoming parton, e.g. gluon)

(2) **Fragmentation** of outgoing parton (requires inclusion of non-perturbative objects)

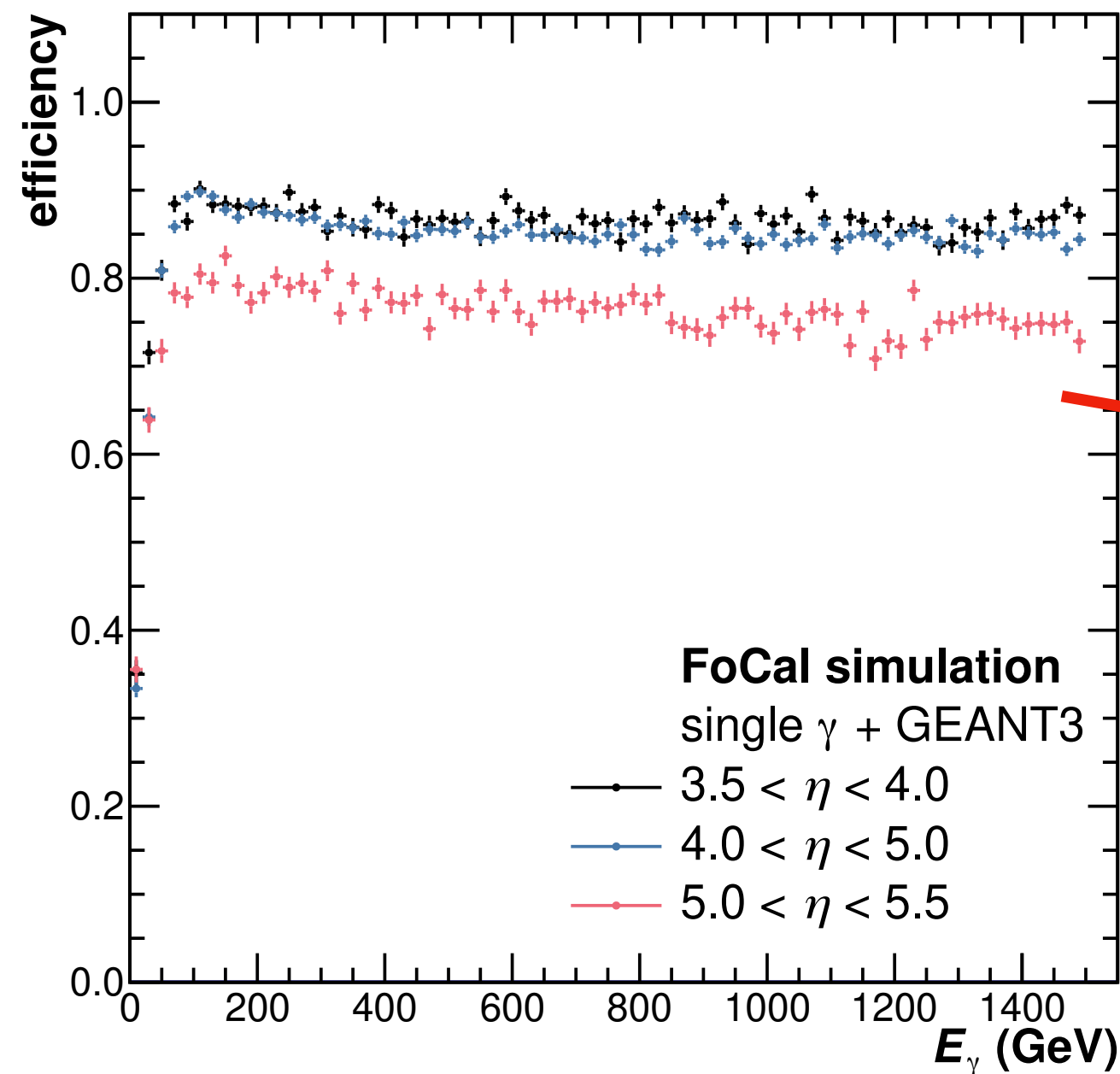
- Prompt photons sensitive to gluon (n)PDF
- No strong interaction in final state
- Exploration of low- $x$  gluons especially interesting
  - Shadowing?
  - Non-linear QCD effects (saturation)
- Validity of factorization?

⇒ key observable for the FoCal physics program and exploration of the saturation regime!

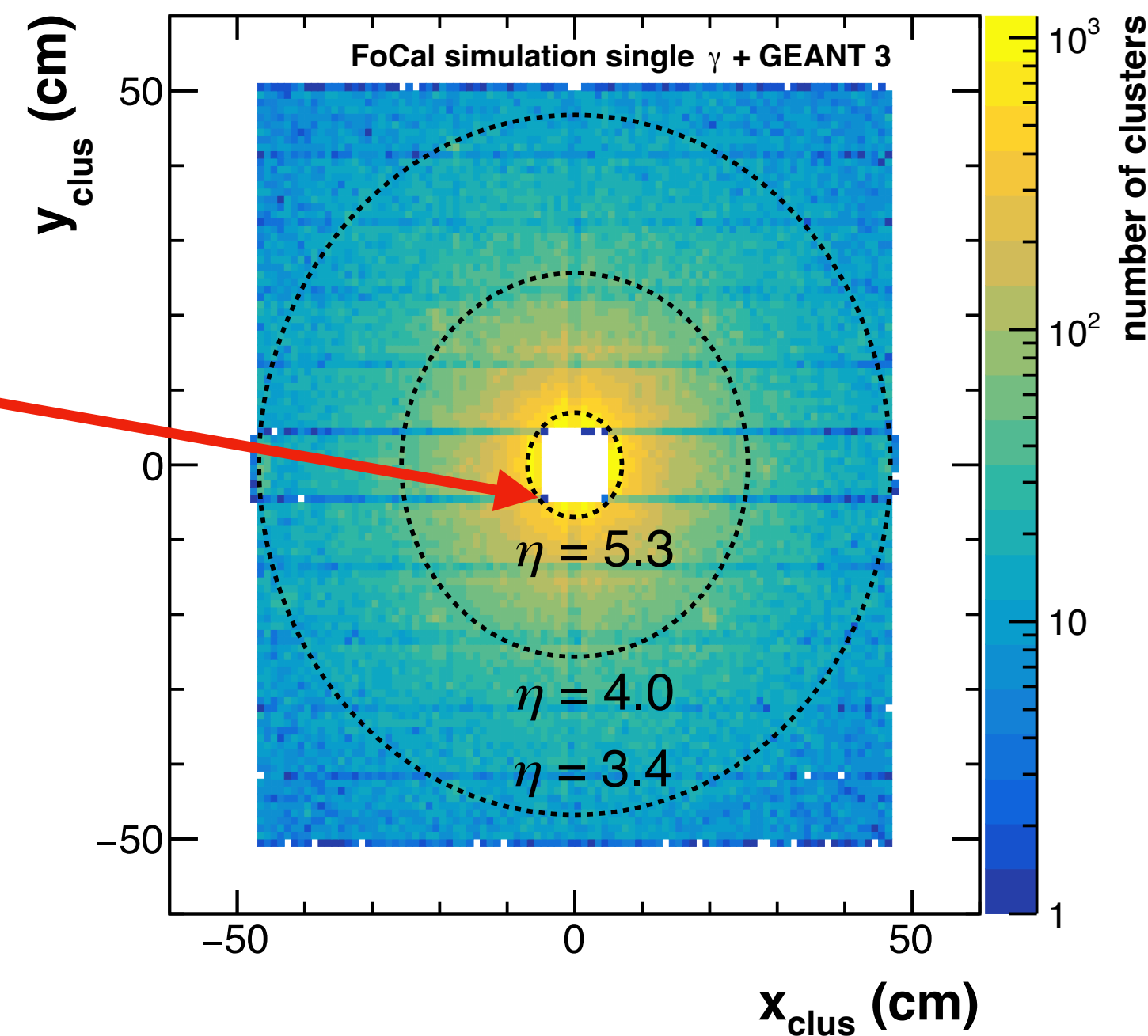
- Detector response to single photons estimated using full description of FoCal-E and FoCal-H in GEANT3
- High photon reconstruction efficiency of about 90%; reduction to about 80% for  $\eta \gtrsim 5.3$  due to reduced azimuthal coverage
- High precision measurements with energy resolution of less than 5% for photons up to high energies of 1.5 TeV



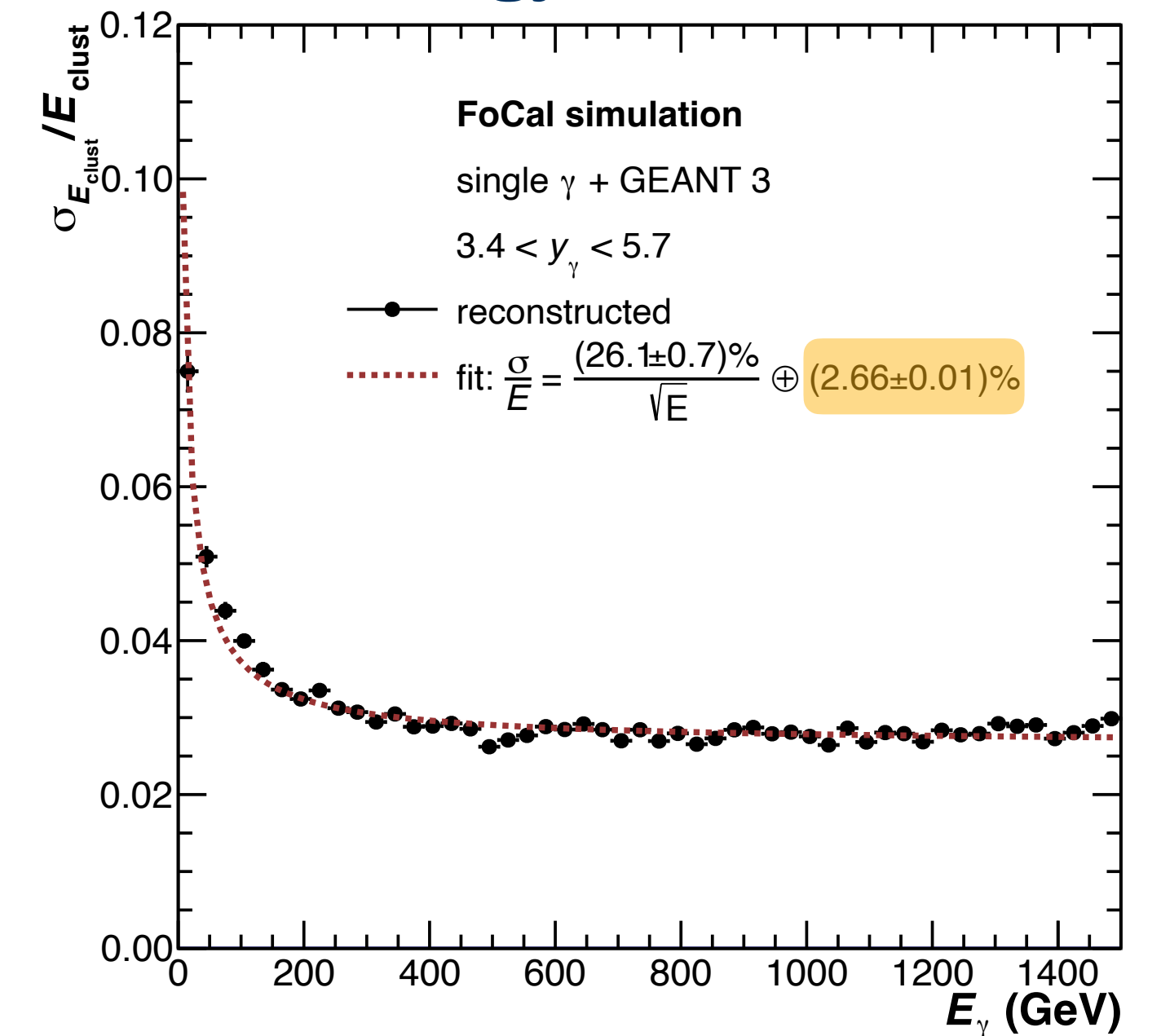
Reconstruction efficiency:



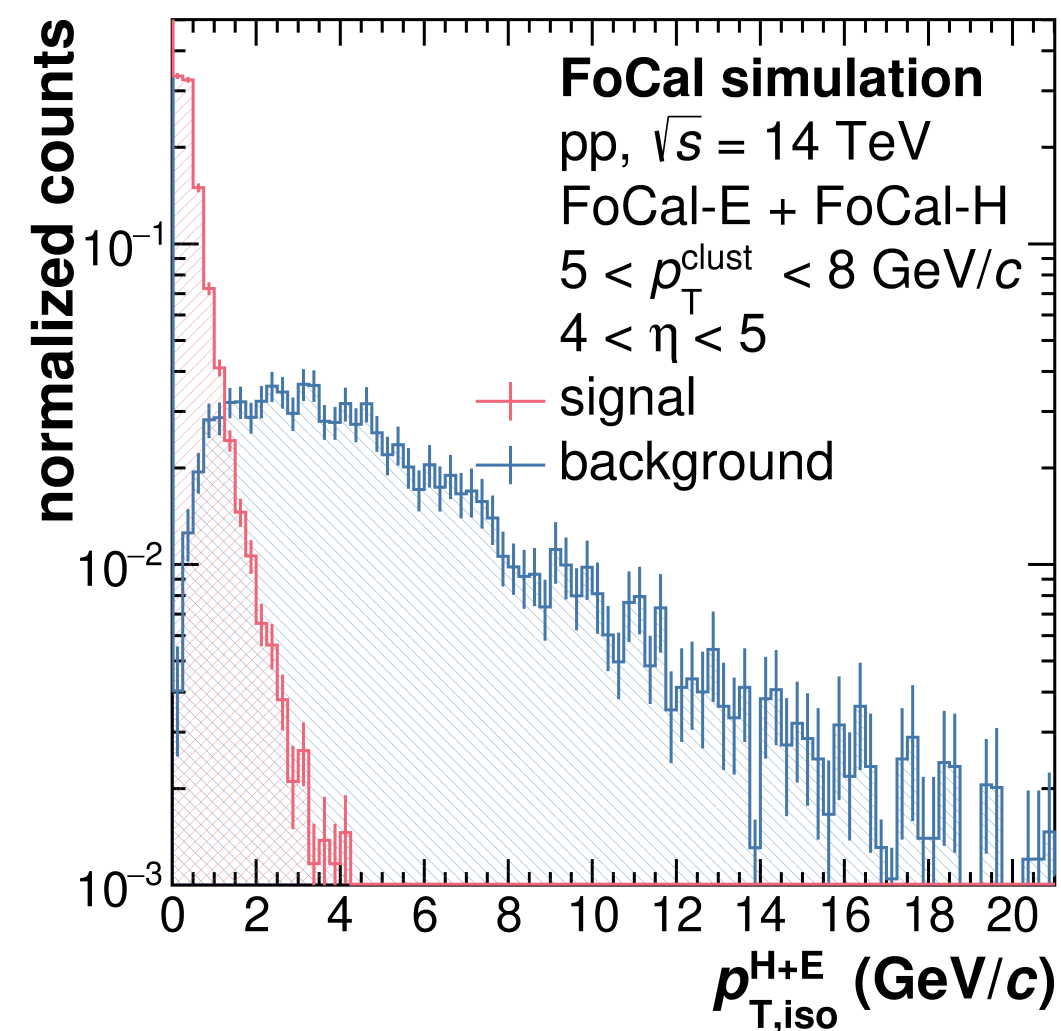
Cluster x-y position:



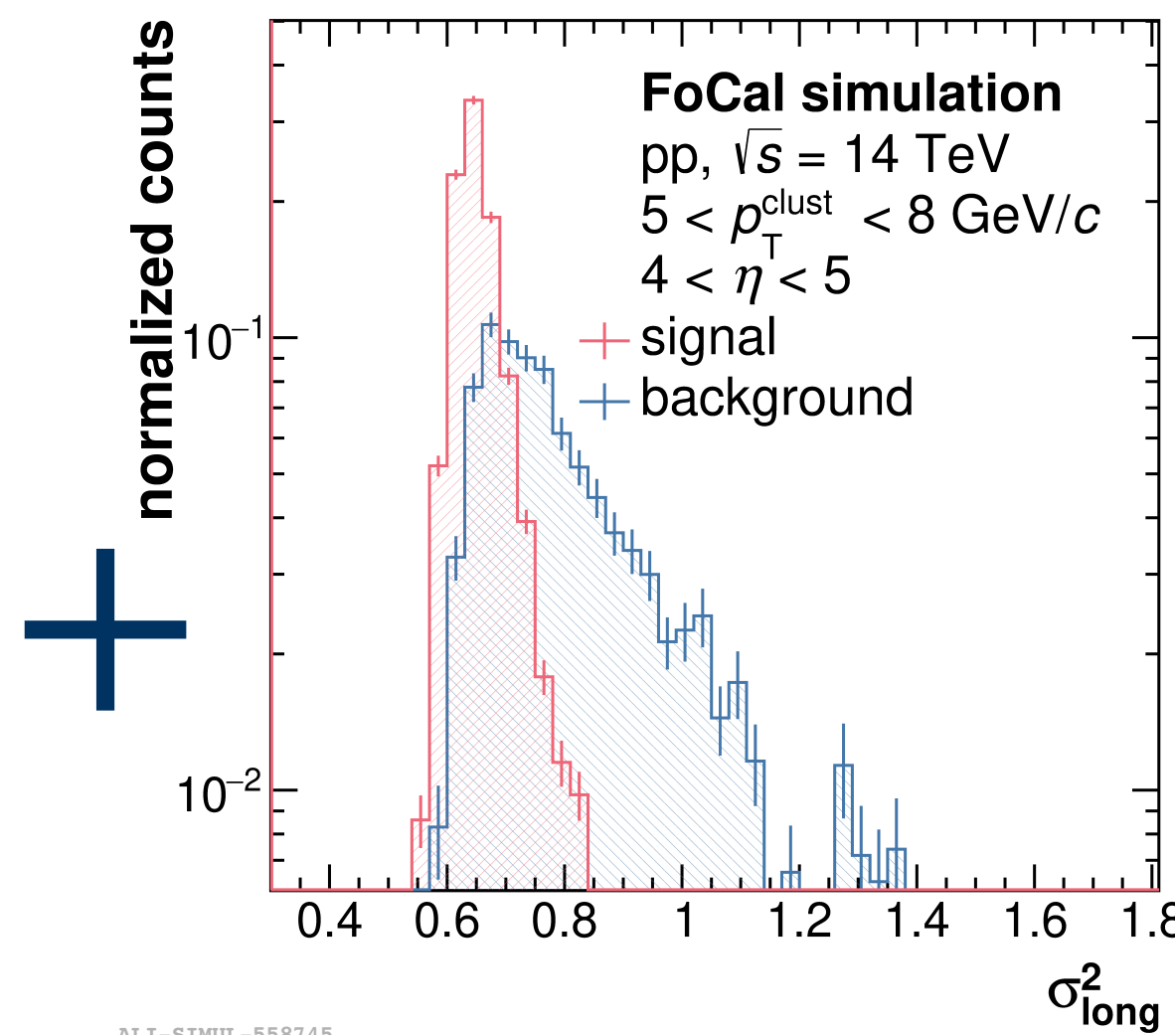
Energy resolution



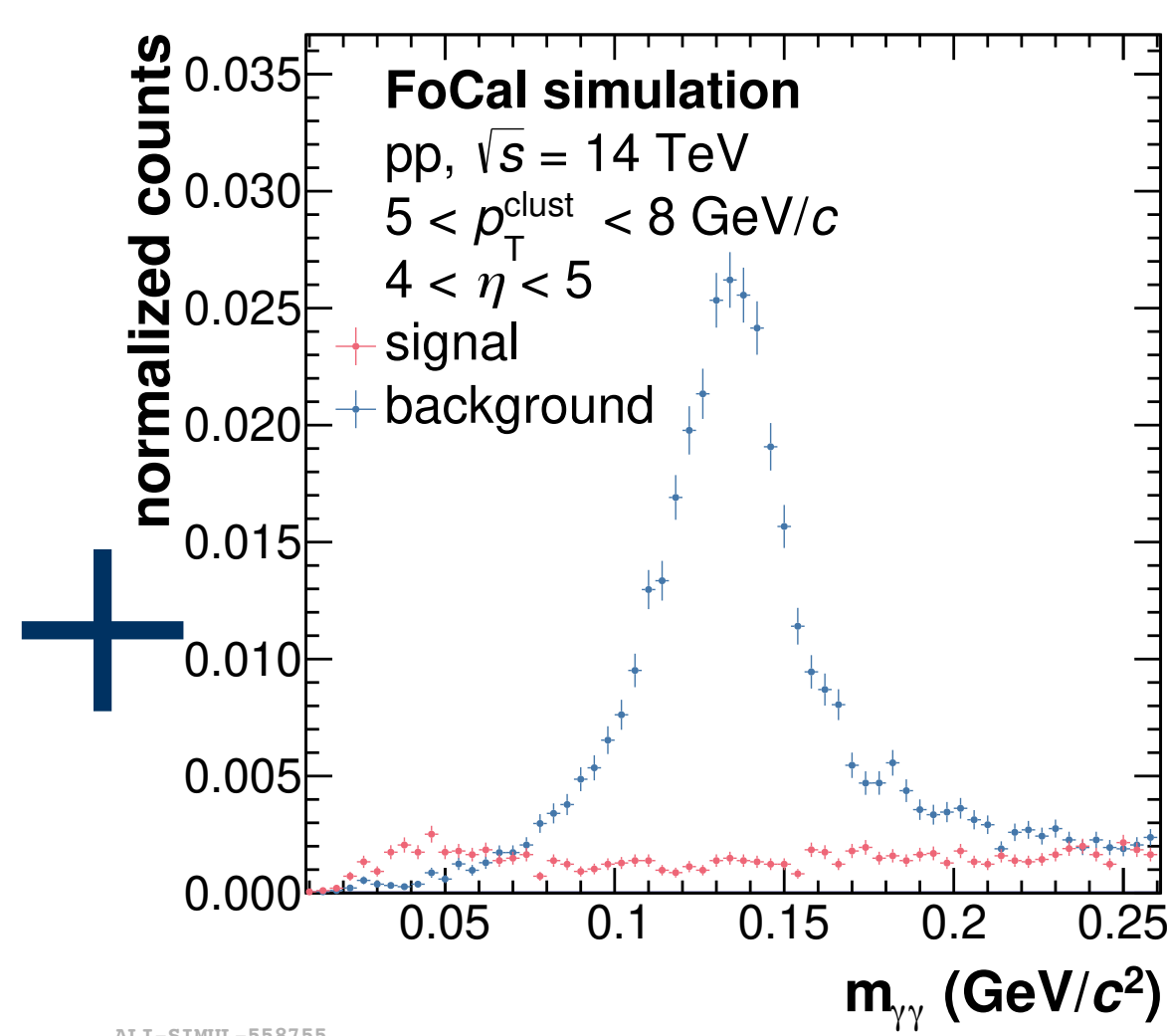
## Isolation



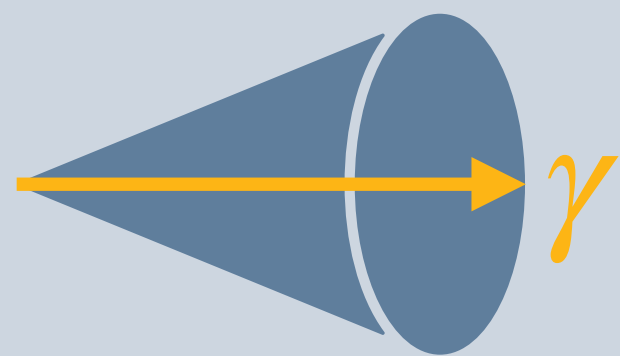
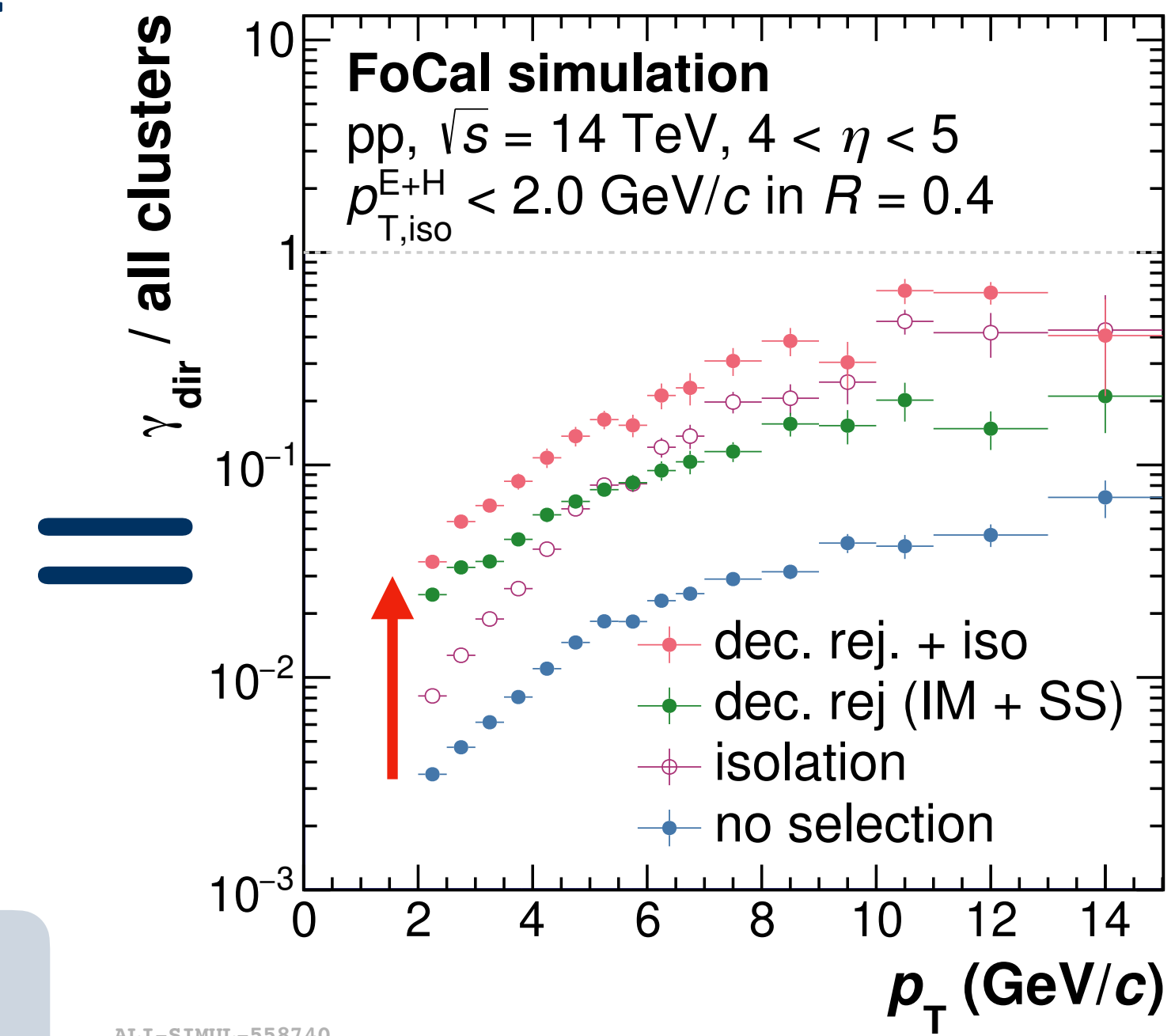
## Shower shape



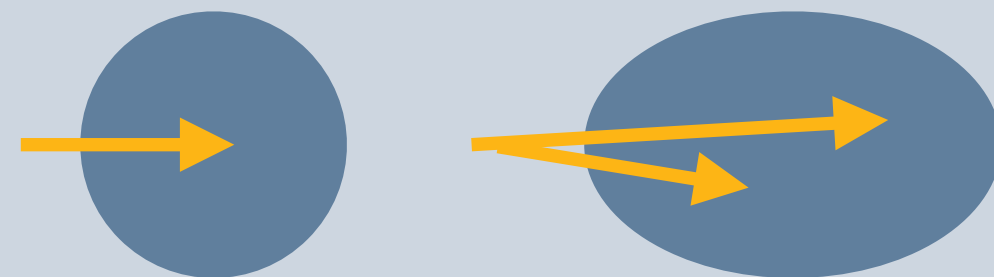
## Invariant mass tagging:



## Signal fraction:



$E_T$  sum within cone with  $R = 0.4$  allows to discriminate sig. and bck.



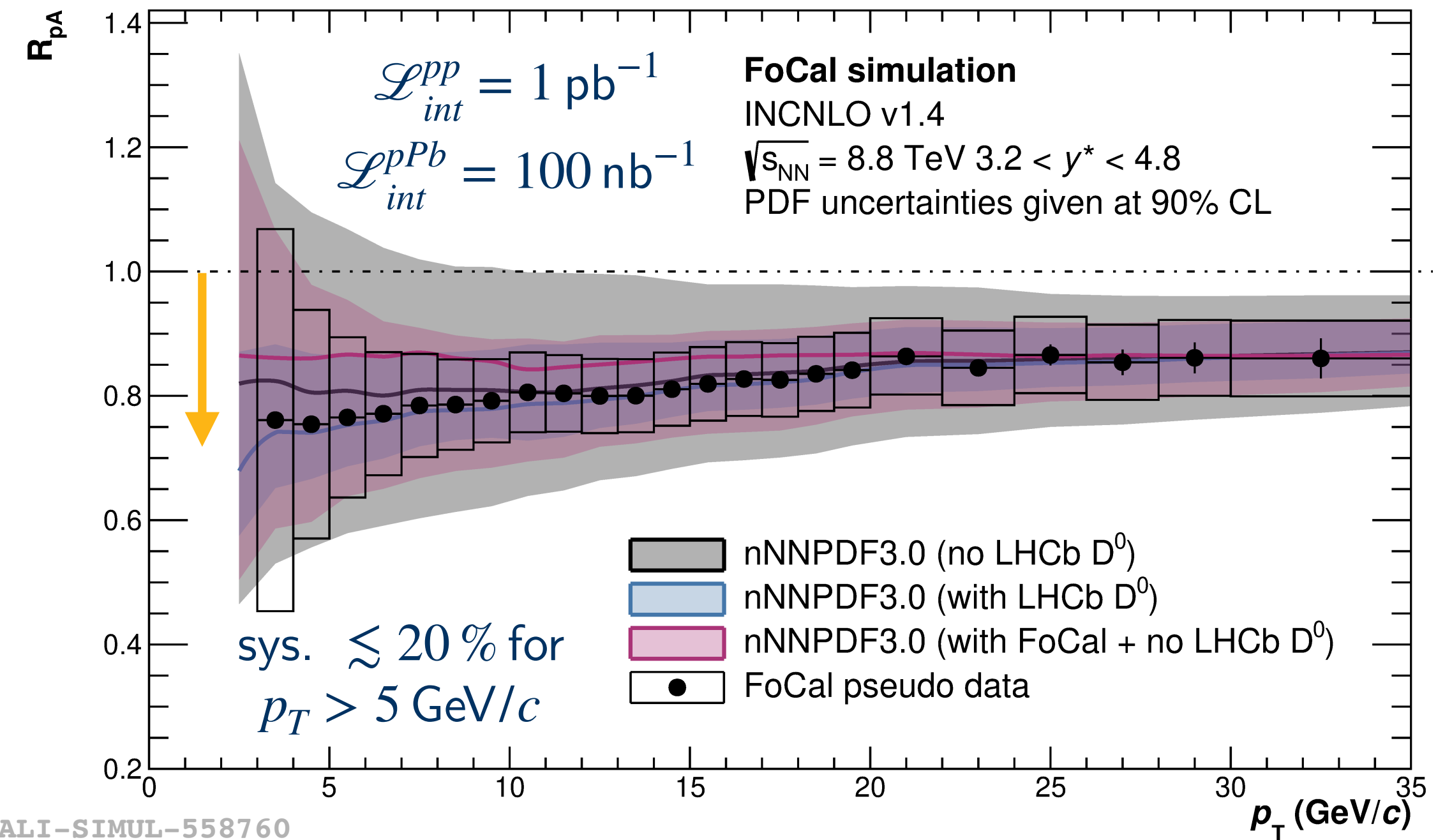
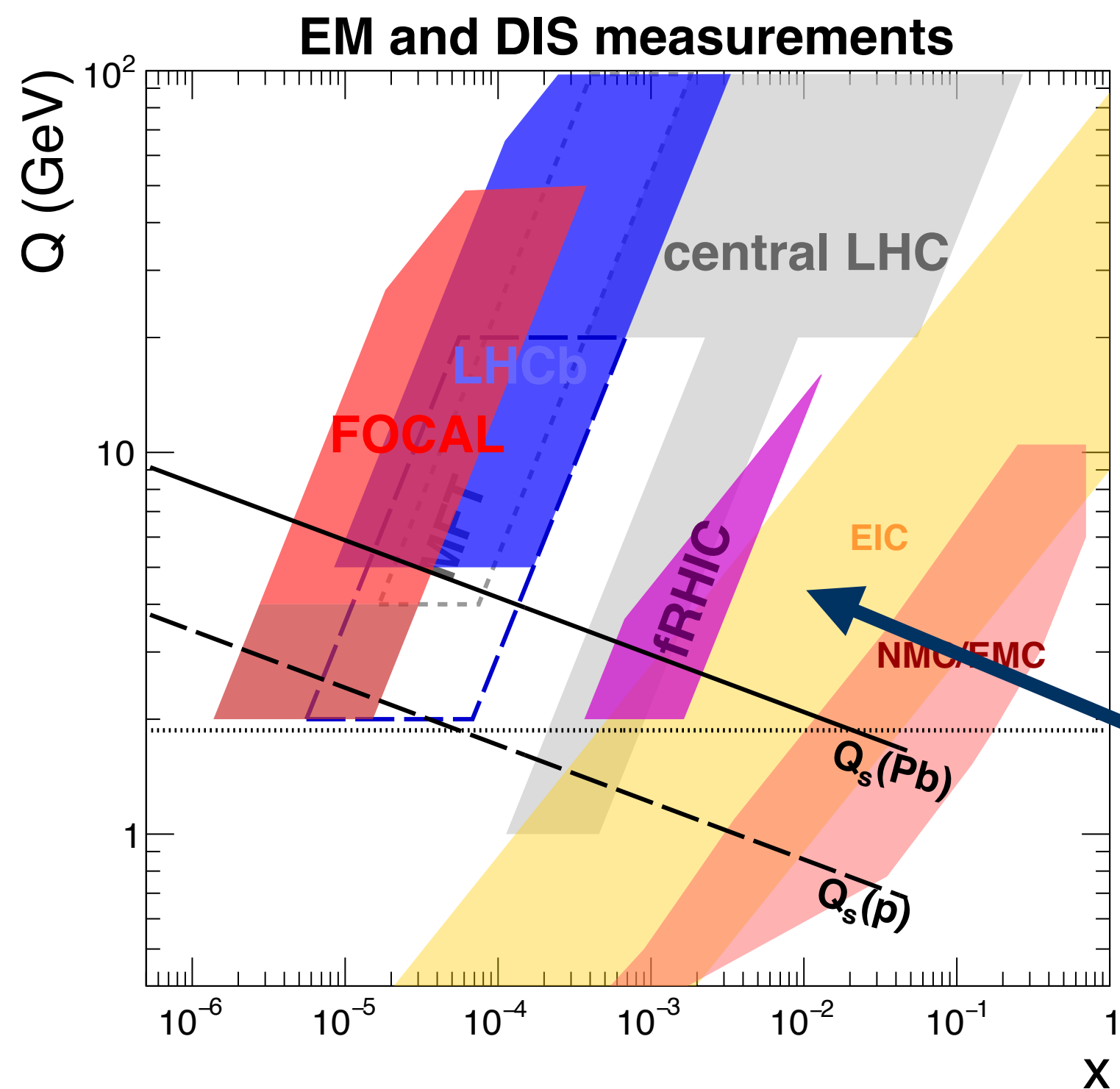
Decay photons may produce elongated showers in pad layers due to shower overlaps

Highly granular pixel layers enable large  $\pi^0$  reconstruction efficiency  
→ tag decay photons according to inv. mass of clust. pairs

**Employed selections increase signal fraction by a factor 11!**

Comparable performance in p-Pb collisions at  $\sqrt{s_{\text{NN}}} = 8.8$  TeV

- FoCal pseudo-data** of nuclear modification factor  $R_{pA}$  constructed using input from NLO+nPDF and assumptions on stat. and sys. uncertainties from perf. studies
- Bayesian re-weighting of nNNPDF3.0** prediction showcases **significant reduction of nPDF uncertainties** when including FoCal data; comparable to  $D$  meson measurement by LHCb



- Isolated prompt photon measurements in pp and p-Pb collisions with FoCal allow to low Bjorken- $x \sim 10^{-6}$  in a regime where gluon saturation is expected
- Interesting synergies with future measurements at the EIC!**

	Inclusive DIS	SIDIS	DIS dijet	Inclusive in p+A	$\gamma$ +jet in p+A	dijet in p+A
$x_{G_{WW}}$	-	-	+	-	-	+
$x_{G_{DP}}$	+	+	-	+	+	+

- **The Forward Calorimeter (FoCal)** is a future calorimeter upgrade for the ALICE detector planned to be operational in **Run 4 (2029)** of LHC operation
- Acceptance of  $3.2 < \eta < 5.8$  allows to access low  $x \sim 10^{-6}$
- Measurement of **isolated prompt photon production** in pp and p-Pb collisions is a key measurement for **FoCal's physics goal of exploring gluon saturation & constrains for (n)PDFs**
- The shown simulation studies showcase **FoCal's capability to identify and measure this observable with high precision!**

Stay tuned for our upcoming TDR!

## Recent publications:

- ALICE Coll., *Letter of Intent: A Forward Calorimeter (FoCal) in the ALICE experiment*, CERN-LHCC-2020-009
- ALICE Coll., *Physics of the ALICE Forward Calorimeter upgrade*, ALICE-PUBLIC-2023-001
- ALICE Coll., *Physics performance of the ALICE Forward Calorimeter upgrade*, ALICE-PUBLIC-2023-004

Come and meet me at my poster!  
I am happy to discuss :-)

### Measuring prompt photon production with the ALICE Forward Calorimeter (FoCal) upgrade

Florian Jonas (UC Berkeley / LBNL)

**Summary:**

- FoCal is a planned calorimeter (2029) for the ALICE exp. covering very forward rapidities  $3.2 < \eta < 5.8$
- **Physics Goal:** explore gluon saturation & constrain nuclear Parton Distribution Functions (nPDFs)
- presented simulation studies demonstrate FoCal's capabilities to measure prompt photon production down to low Bjorken- $x \sim 10^{-6}$

#### The FoCal detector

- FoCal [1-3] is a calorimeter planned as an upgrade to the ALICE detector covering very forward rapidities  $3.2 < \eta < 5.8$
- consists of EM and hadronic calorimeter (FoCal-E & FoCal-H)
- FoCal-E is highly granular Si-W calorimeter combining two readout technologies:
  1. 18 silicon pad layers (1x1 cm<sup>2</sup>)
  2. Two pixel layers (30x30  $\mu$ m<sup>2</sup>)

#### Prompt photon production

- Prompt photons are produced directly in hard scattering process, mainly via Compton process ( $gq \rightarrow \gamma q$ )
- Measurement at forward rapidities sensitive to gluon (n)PDFs at  $x \sim 10^{-6}$
- Important observable to explore gluon saturation
- Photon does not interact strongly in final state
- Low signal-to-background ratio due to large decay photon background

#### Photon reconstruction

single  $\gamma$  + GEANT3

- Detector response to single photons estimated using full description of FoCal-E and FoCal-H in GEANT3
- High precision measurements with energy resolution of less than 5% for photons up to high energies of 1.5 TeV
- High photon reconstruction efficiency of about 90%; reduction to about 80% for  $\eta \geq 5.3$  due to reduced azimuthal coverage

#### Clusters in FoCal-E

#### Energy resolution

#### Reconstruction efficiency

#### Prompt photon identification

pp collisions at  $\sqrt{s} = 14$  TeV (PYTHIA8 + GEANT3)

##### Isolation in FoCal-E+H

##### Shower shape

##### $\pi^0$ invariant mass tagging

##### Impact on signal fraction

#### Physics impact

- nPDF+NLO nuclear modification factor ( $R_{pA}$ ) reweighted using FoCal pseudo-data
- Inclusion of FoCal photons: reduction of nNNPDF3.0 [4] uncertainties similar to LHCb  $D$  mesons data [5]
- Strong nPDF constrains at forward rapidities
- Multi messenger approach: differing sensitivity to final state effects for photons vs.  $D$  mesons
- FoCal probes phasespace where gluon saturation effects are expected to be sizable
- Interesting synergies with saturation searches at EIC

#### References

[1] ALICE Collaboration, Letter of Intent: A Forward Calorimeter (FoCal) in the ALICE experiment, CERN-LHCC-2020-009  
 [2] ALICE Collaboration, Physics of the ALICE Forward Calorimeter upgrade, ALICE-PUBLIC-2023-001  
 [3] ALICE Collaboration, Physics performance of the ALICE Forward Calorimeter upgrade, ALICE-PUBLIC-2023-004  
 [4] R. A. Khachatryan et al., nNNPDF3.0: evidence for a modified partonic structure in heavy nuclei, Eur. Phys. J. C 82 (2022) 6, 507  
 [5] LHCb Collaboration, Study of prompt  $D^0$  meson production in p-Pb collisions at  $\sqrt{s} = 5.76$  TeV, JHEP10 (2017) 090

#### FoCal pseudo-data of nuclear modification factor $R_{pA}$

#### Phasespace coverage