ALICE FoCal Upgrade
The physics and performance of
Forward calorimeter

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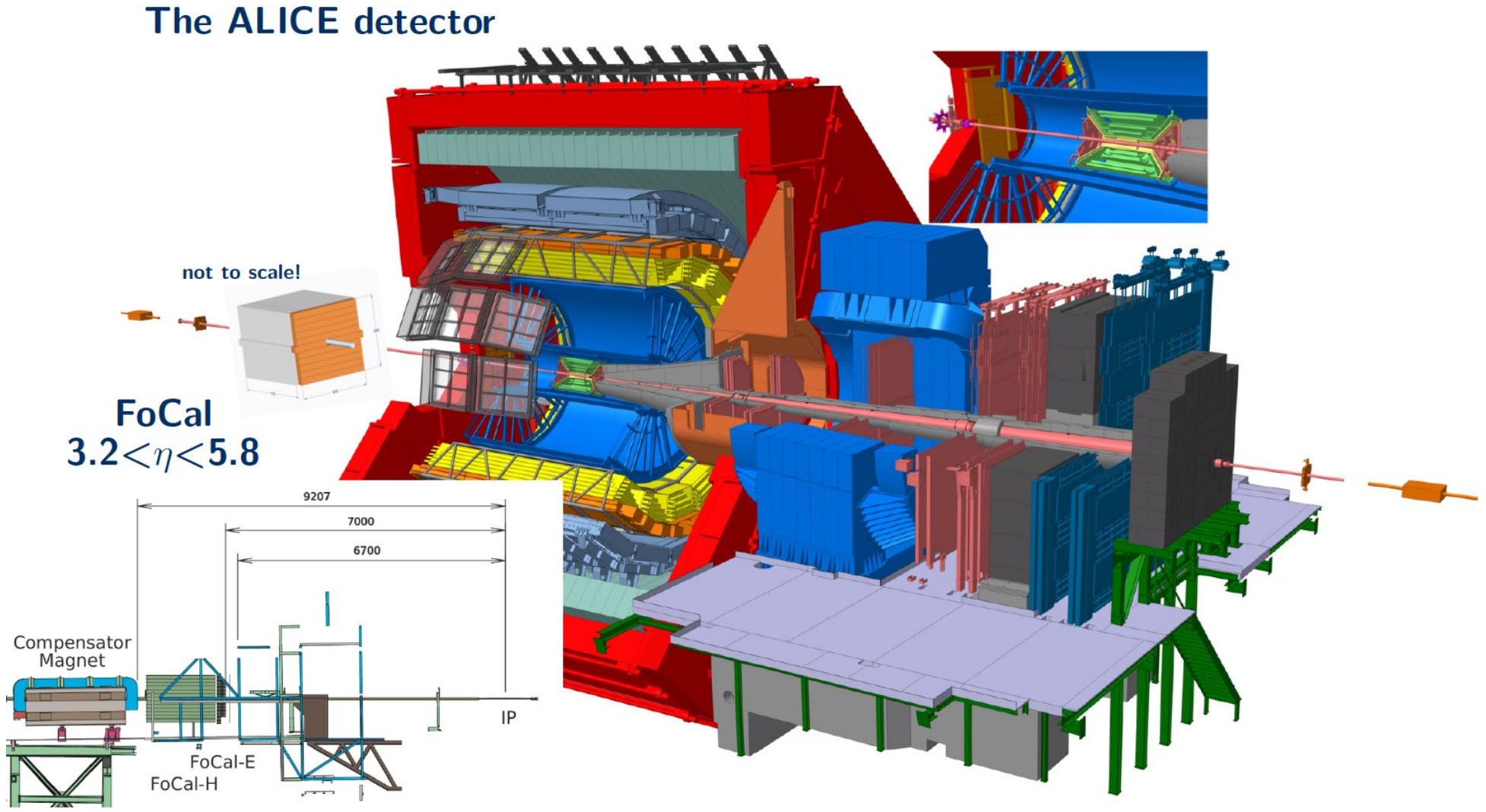
Hua Pei for the ALICE collaboration

The Forward calorimeter in ALICE for Run 4



Main design of FoCal

Operation expect at Run 4 (2029-)
Further info: FoCal-LoI

- A very forward calorimeter consisting of two parts (FoCal-E and FoCal-H) located ~ 7m from IP of ALICE
- Measure isolated photon, π^0, jet energy, etc.
- **FoCal-E (electromagnetic):**

· high-granularity Si-W sampling calorimeter combining two readout granularities:

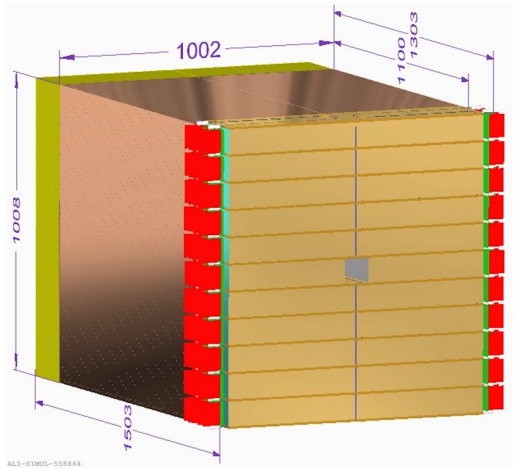
  - 18 pad layers with silicon pads (1 X 1 cm^2)
  - two pixel layers with digital readout (30 X 30 μm^2)

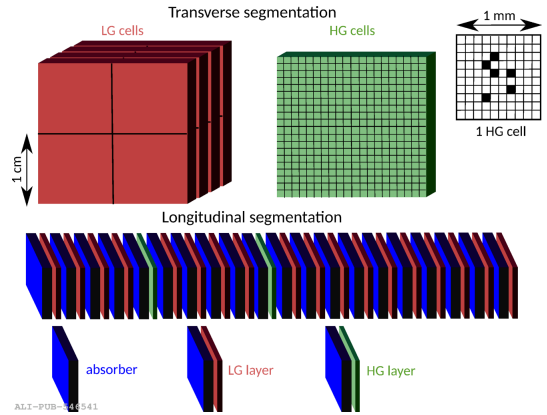
· 40 μm position res, ability to "track" longitudinal component of shower

- **FoCal-H (hadronic):**

· conventional metal-scintillator hadronic calorimeter behind FoCal-E

· design using scintillation fibers embedded in Cu tubes





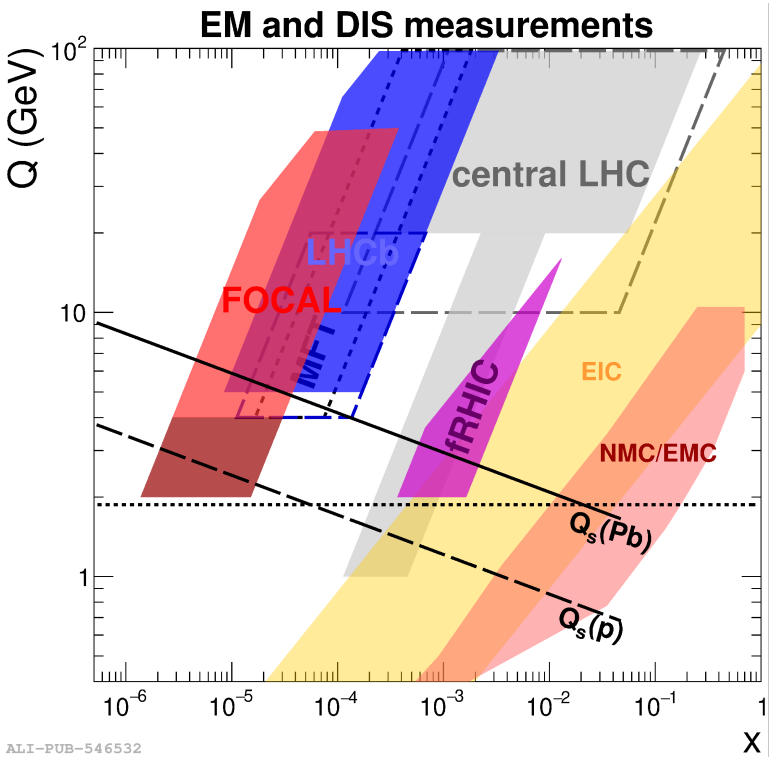
Physics goal of FoCal

Explore non-linear QCD in regime of saturated gluons at low Bjorken-x + constrain nPDFs

using a multi-messenger approach:

- ✓ prompt photon (isolated)
- ✓ γ-hadron correlations
- ✓ production of π^0, η, and many more vector mesons
- ✓ jet measurements (e.g. dijet production)
- ✓ J/ψ, Υ, Z, W, and more ...
- ✓ Uniquely forward Ultra-Peripheral Collisions **(UPC)**

ALICE-PUBLIC-2023-004



✓FoCal acceptance allows to reach down to x ~ 10^{-6}, complementing searches for gluon saturation at current and future facilities

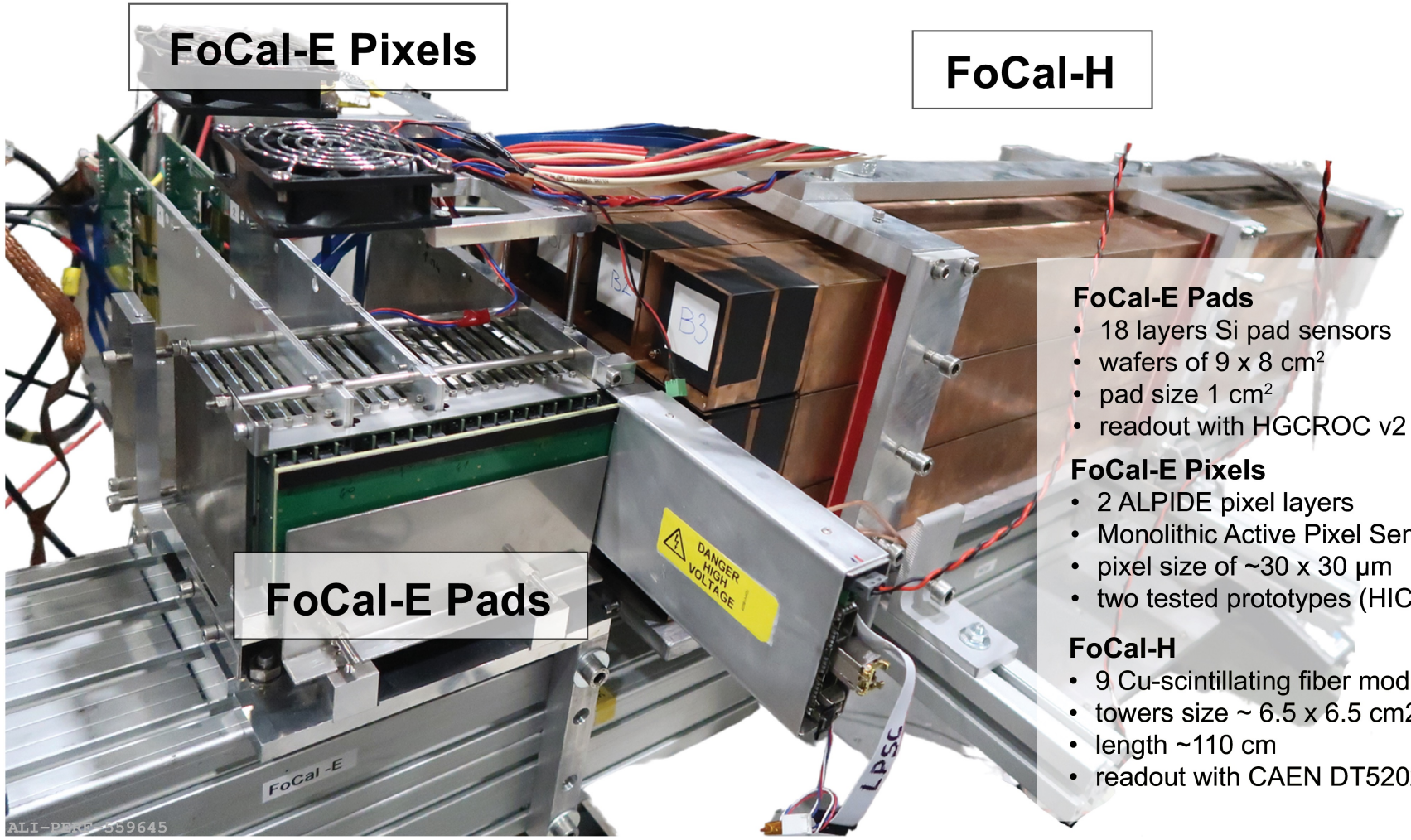
✓deep theoretical connection to EIC

FoCal prototype test beam: setup

FoCal prototype:
- FoCal-E Piexels
- FoCal-E Pads
- FoCal-H

Test beam at SPS
✓ Nov 2022
✓ May 2023

With electron and hadron beams

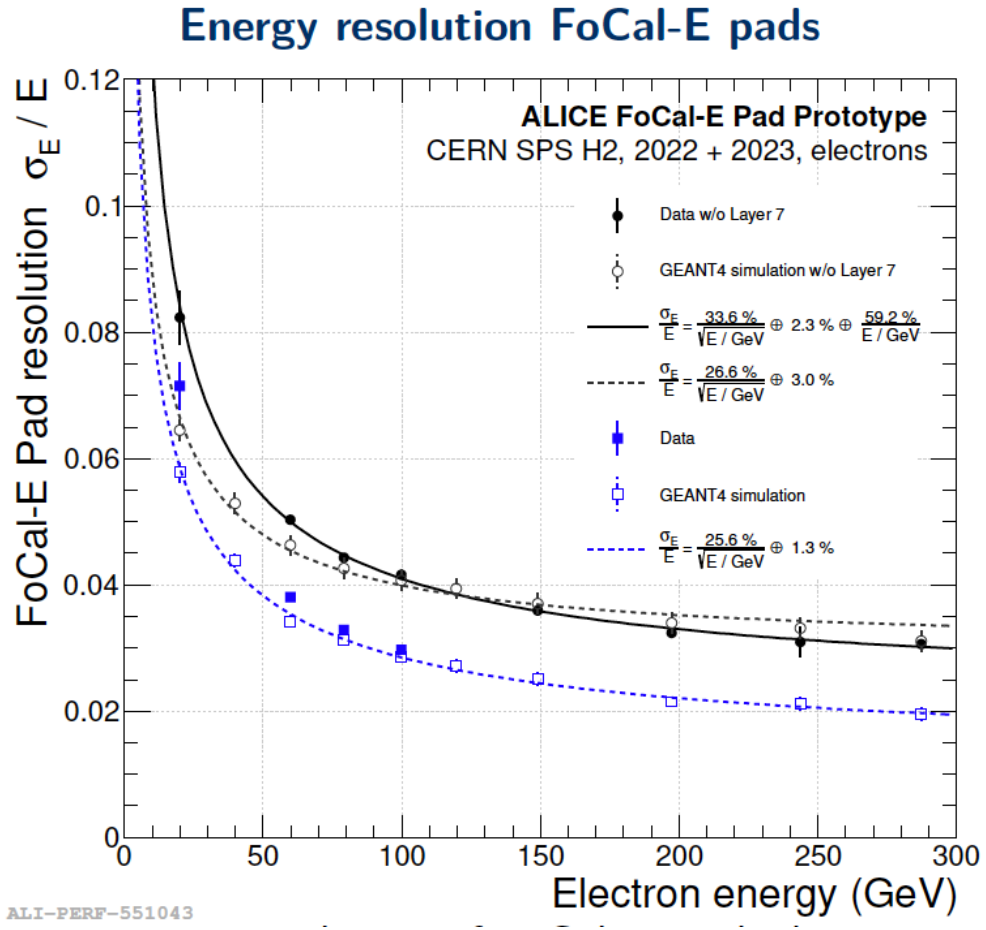


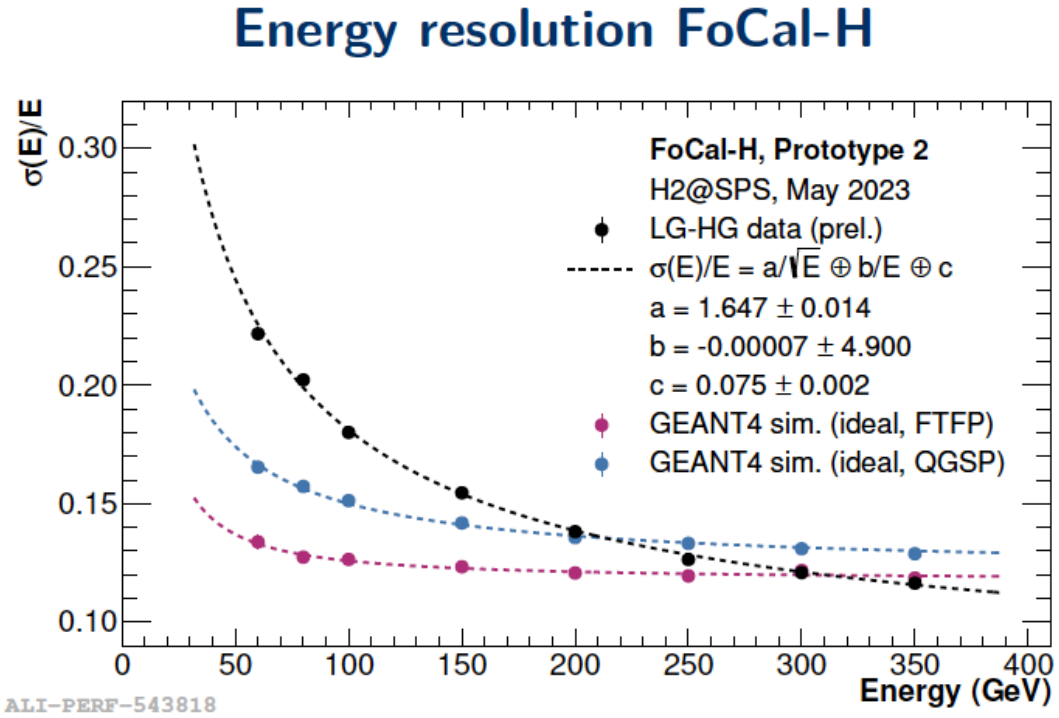
FoCal-E Pads
- 18 layers Si pad sensors
- wafers of 9 x 8 cm^2
- pad size 1 cm^2
- readout with HGCROC v2

FoCal-E Pixels
- 2 ALPIDE pixel layers
- Monolithic Active Pixel Sensors
- pixel size of ~30 x 30 µm
- two tested prototypes (HIC,pCT)

FoCal-H
- 9 Cu-scintillating fiber modules
- towers size ~ 6.5 x 6.5 cm2
- length ~110 cm
- readout with CAEN DT5202

FoCal prototype test beam: energy resolution



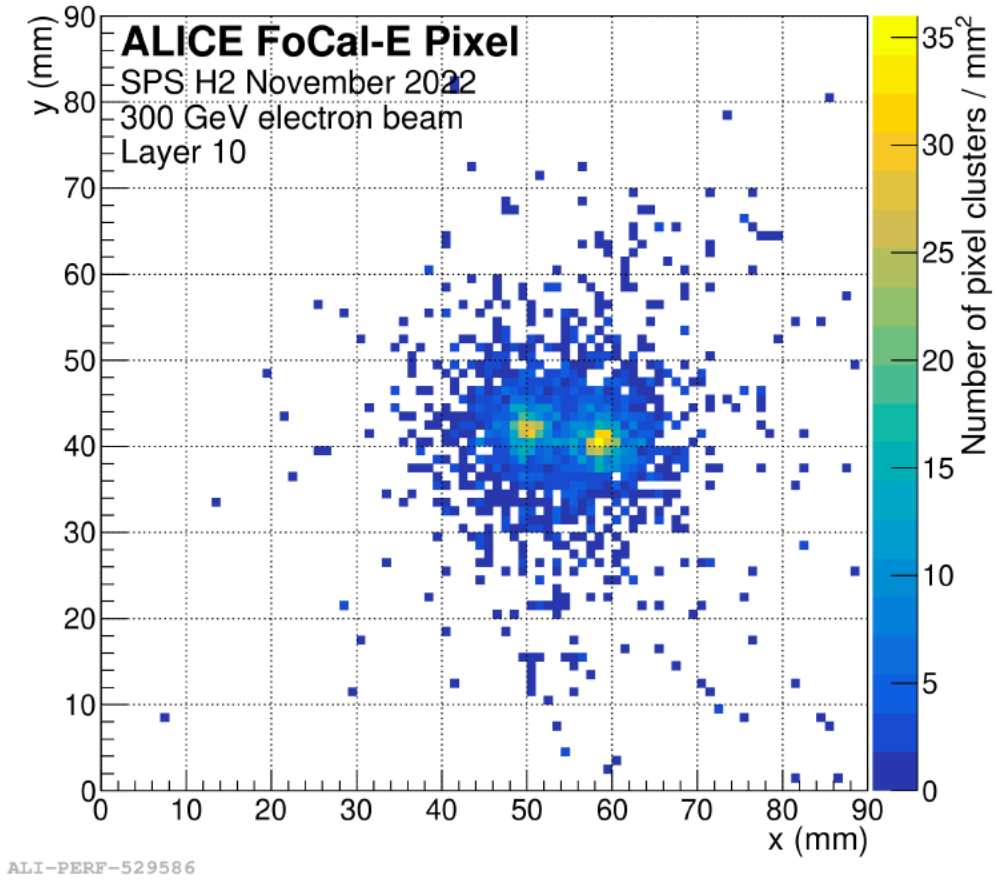


FoCal-E: energy resolution via electron beam,
< 4% at high energy regime,
within physics requirement and described by simulation

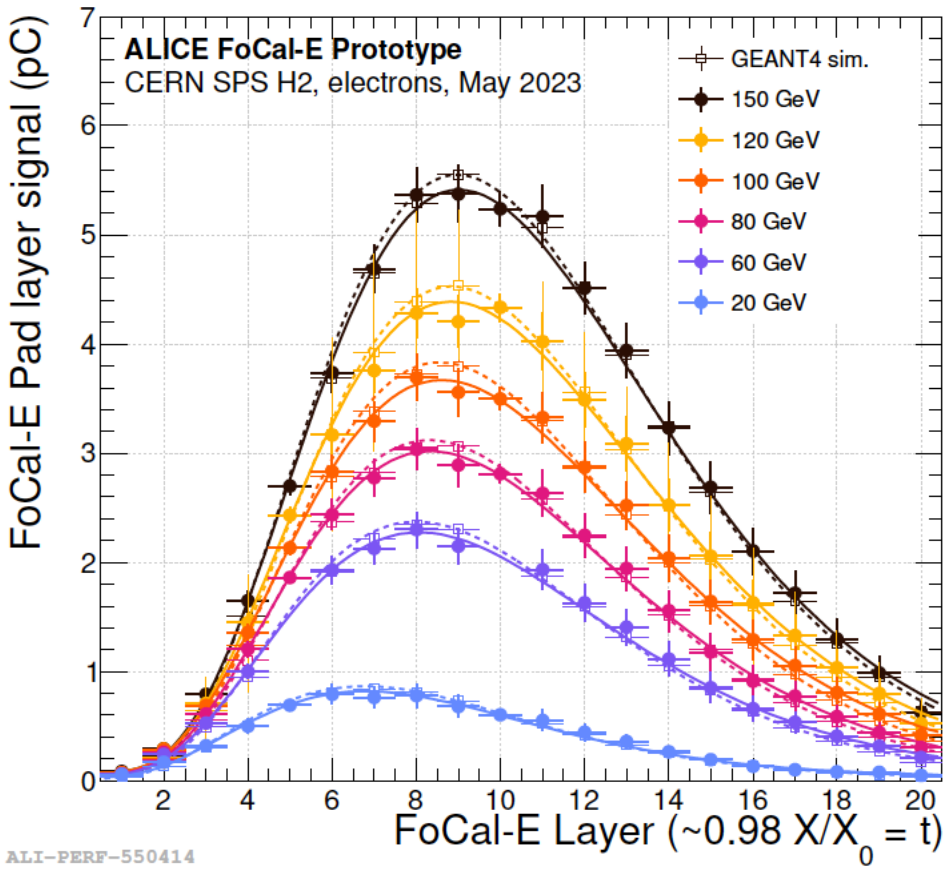
FoCal-H: energy resolution via proton beam,
< 8% at high energy regime,
disagreement with MC, under investigation

FoCal prototype test beam: space profile

Shower separation in FoCal-E pixels

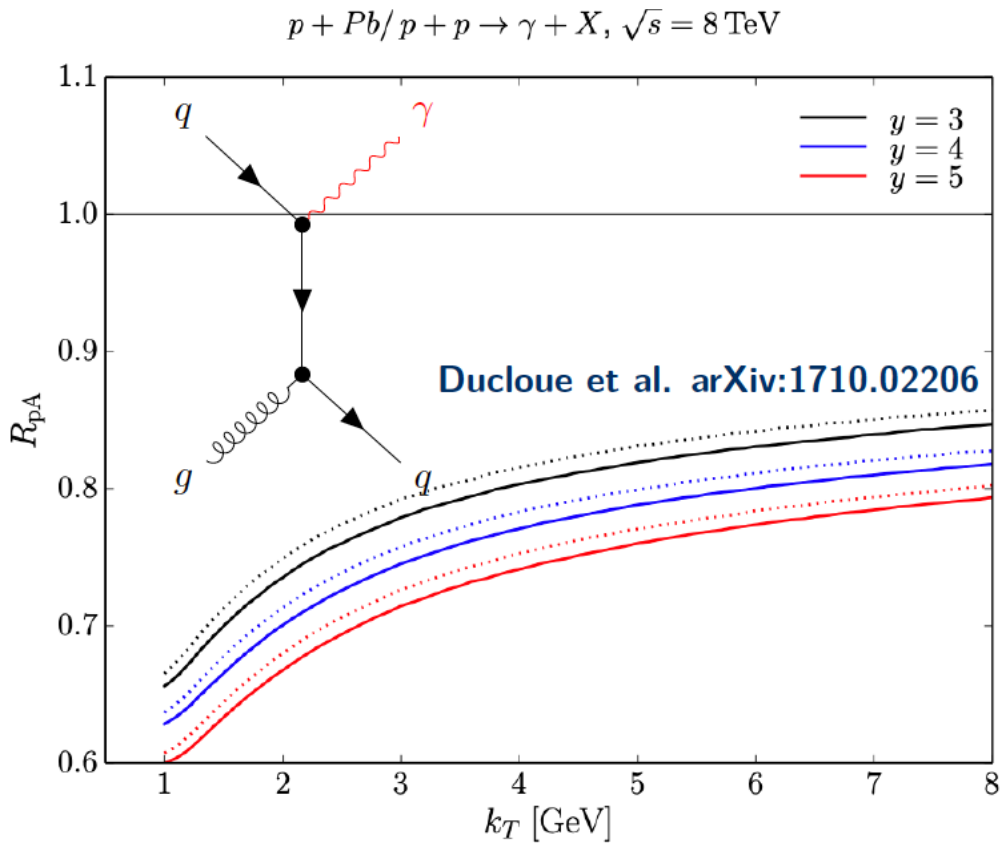


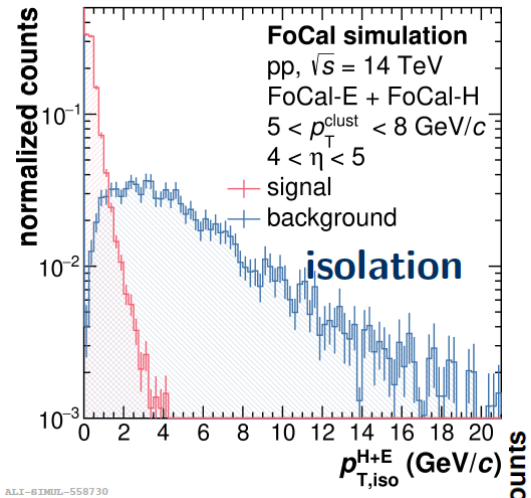
Longitudinal shower profile in FoCal-E

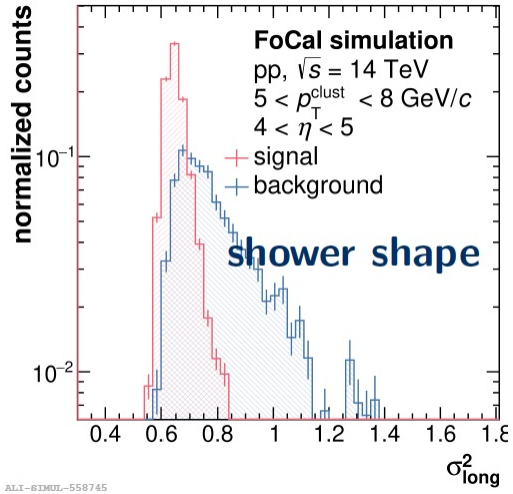


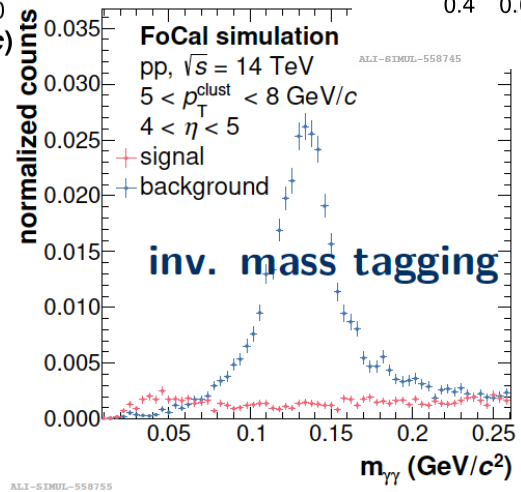
FoCal-E: combination of pixel and pad layers to reconstructe transverse and longitudinal profiles, so as to measure isolated photons and jet sub-structure

FoCal physics prospect: prompt photon









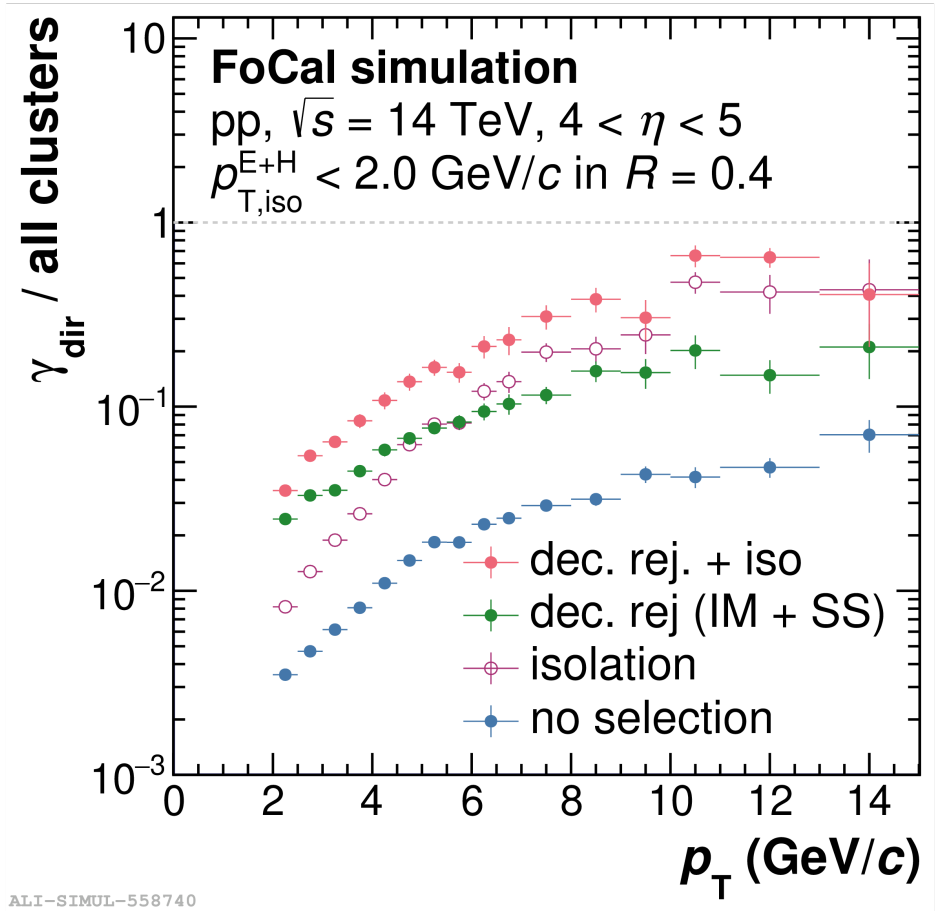
Theory:

- Prompt photons produced in hard scatterings
- Sensitivity of gluon: No strong interaction in final state
- Measurement at forward *y* in e.g. p-Pb collisions

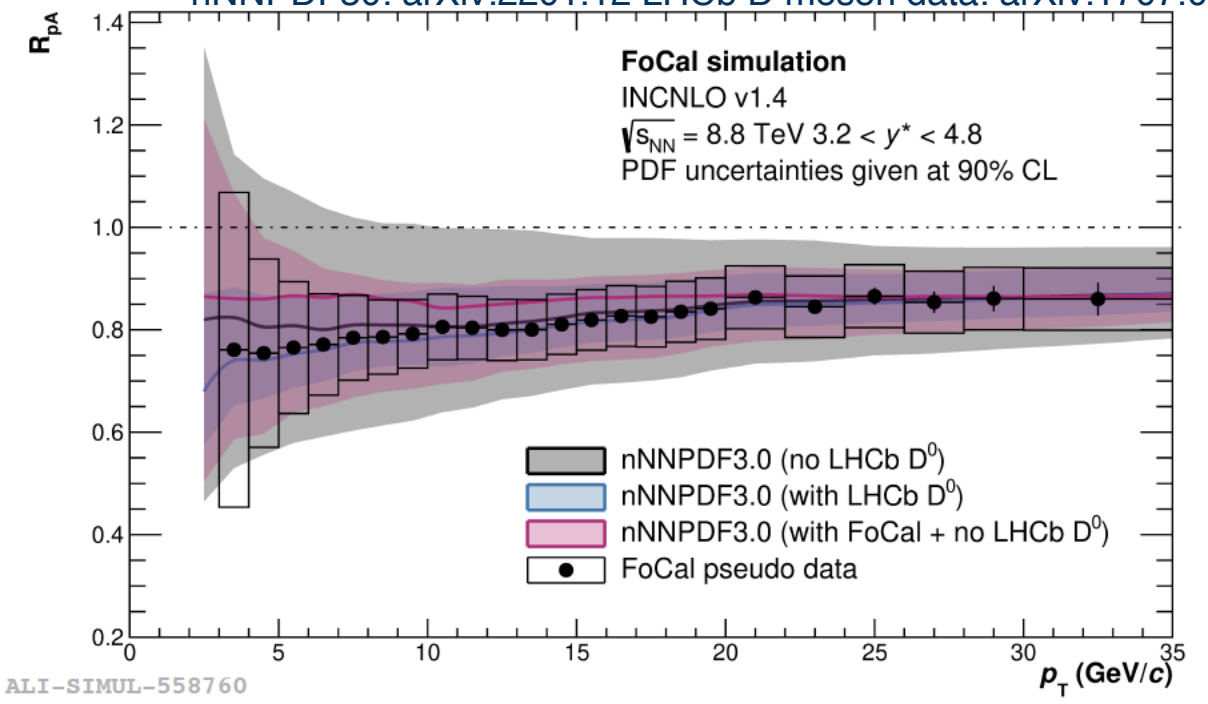
Experiment:

- FoCal measure photon energy in FoCal-E & FoCal-H
- EM shower shape in 20 layers
- Well suited to sperate decayed π^0, η -> $\gamma\gamma$ background

FoCal physics prospect: prompt photon



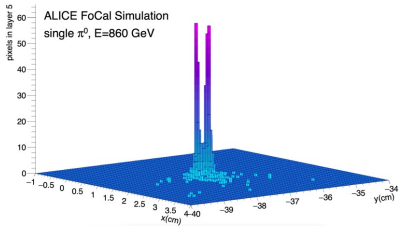
nNNPDF30: arXiv:2201.12 LHCb D meson data: arXiv:1707.02750

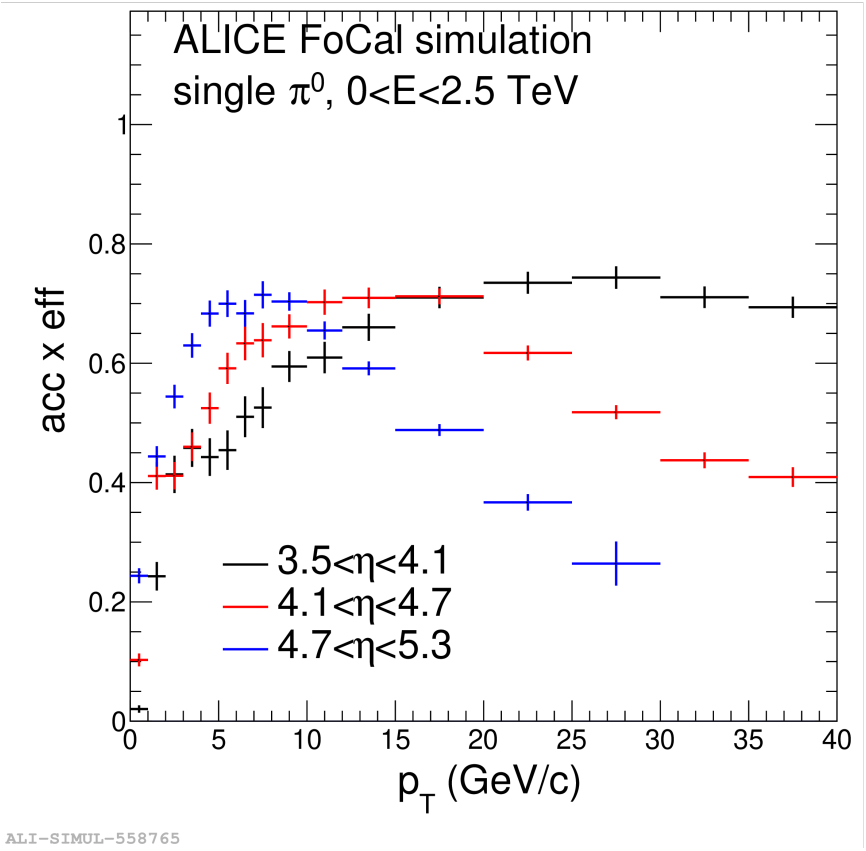


- Combine isolation / shower shape / invariant mass
- Increase signal fraction by about factor 11 at p_T ~ 14 TeV
- 3D showers, machine learning, etc.

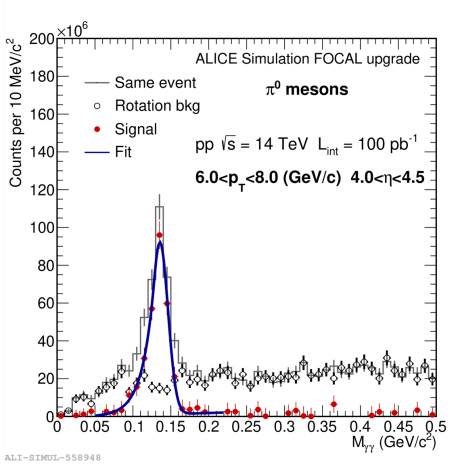
- nPDF+NLO R_{pA} reweighted using FoCal pseudo-data
- FoCal photons: reduction of nNNPDF30 uncertainties
- Strong nPDF constrains, similar to LHCb D mesons
- Multi messenger approach: differing sensitivity to final state effects

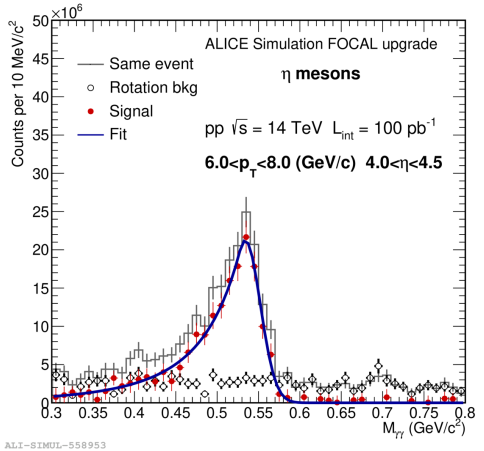
FoCal physics prospect: vector mesons π^0, η, …

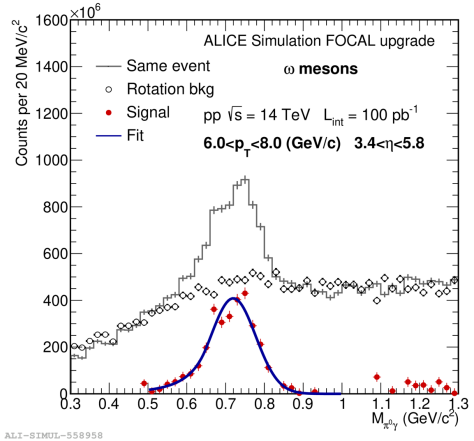




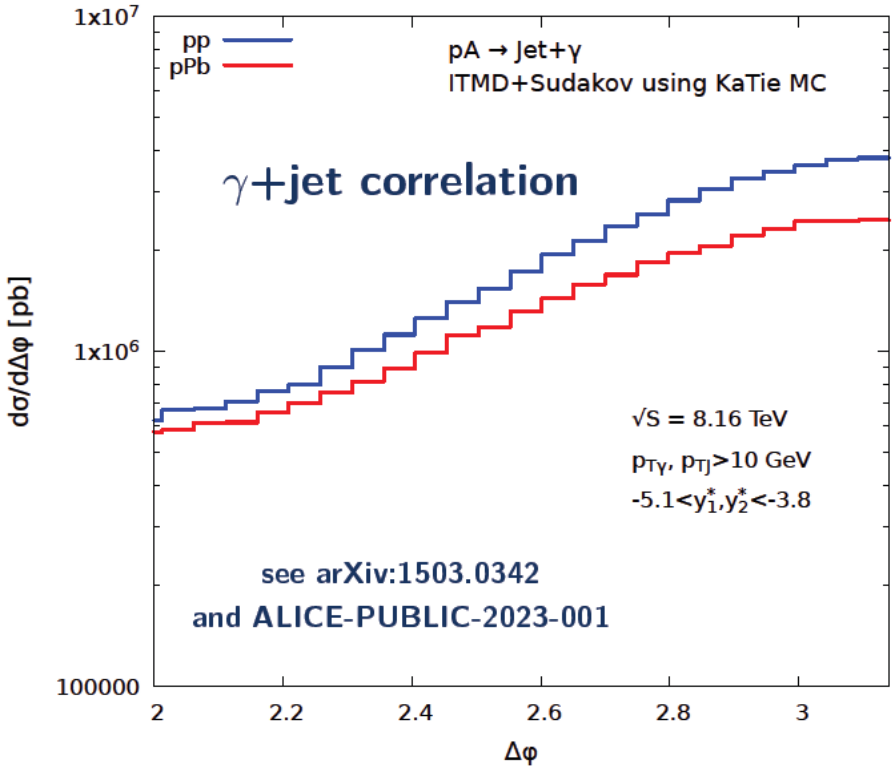
- GEANT simulation demonstrates the FoCal capabilities to measure e.g. $\pi 0$, η, and ω mesons
- Highly granular pixel layers allow for efficiencies of up to 80%, even for boosted photon separation of < 5mm
- Energy up to 2 TeV measurable with Run 4 luminosity
- Also differentially in rapidity

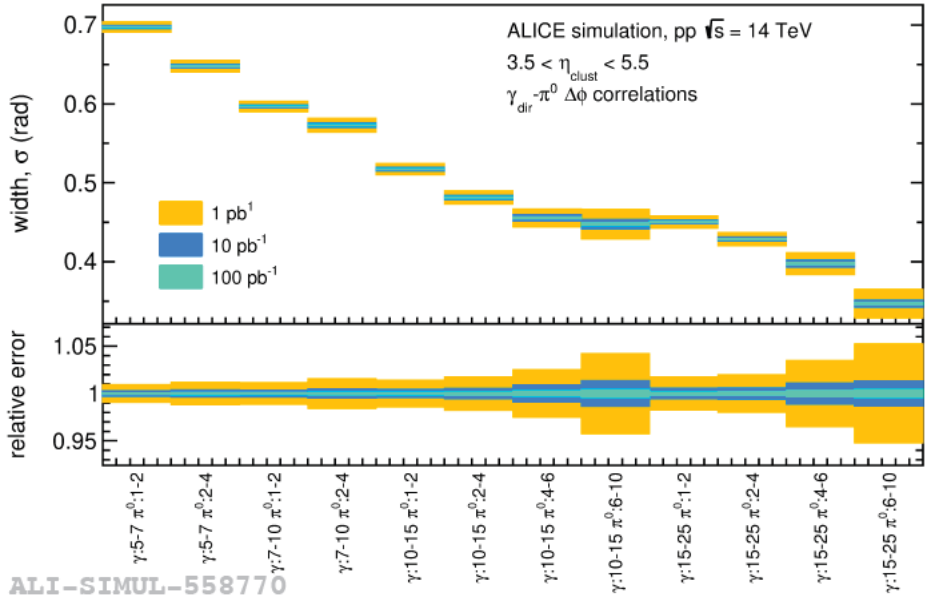






FoCal physics prospect: γ-hadron correlation





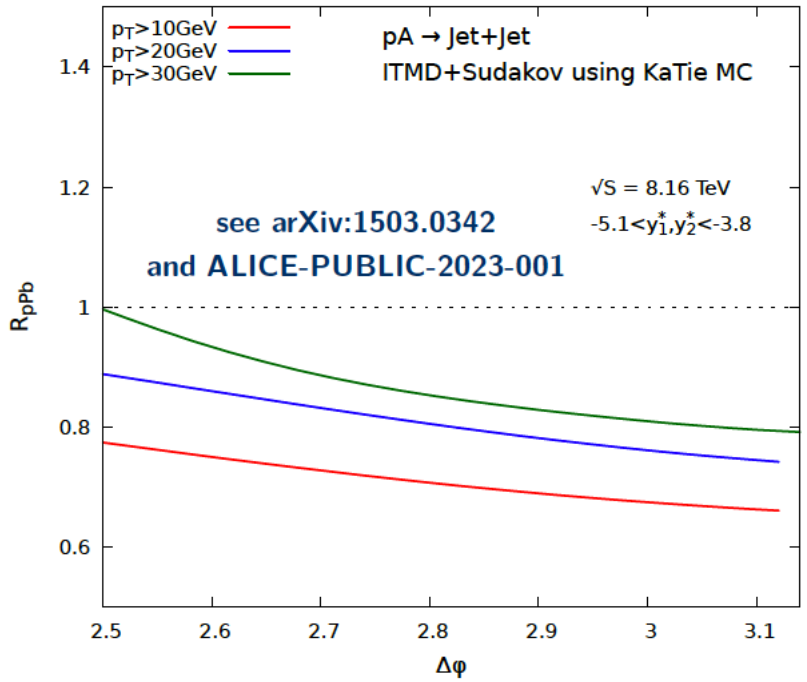
Theory:

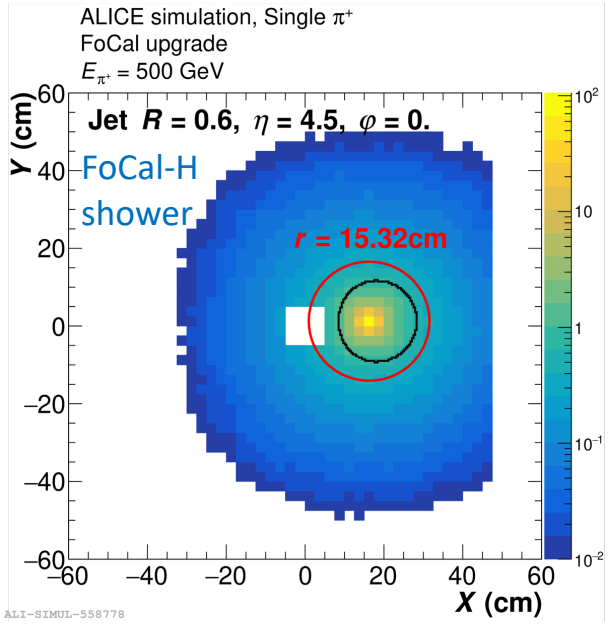
- Prompt photons (leading order) good proxy of parton energy
- γ-hadron correlation provides sensitivity to low-x dynamics
- And saturation cause yield suppression and de-correlation

Experiment:

- Simulated pp events into FoCal with detector smearing
- Correlation peak of γ-h and meson-h compared in details: yields, width, …
- Differential measurement feasible in multiple trigger bins: energy, rapidity

FoCal physics prospect: jets





Theory:

- Forward inclusive jet, g+jet, dijet share and differ in sensitivity to gluon saturation
- Away-side jet tells momentum imbalance k_T to probe Q_{sat}

Experiment:

- Jet with resolution R will be squeezed into smaller geometrical space at forward rapidity
- Effective Moliere radius FoCal-E ~ 1-2 cm, interaction length FoCal-H ~ 15-20 cm

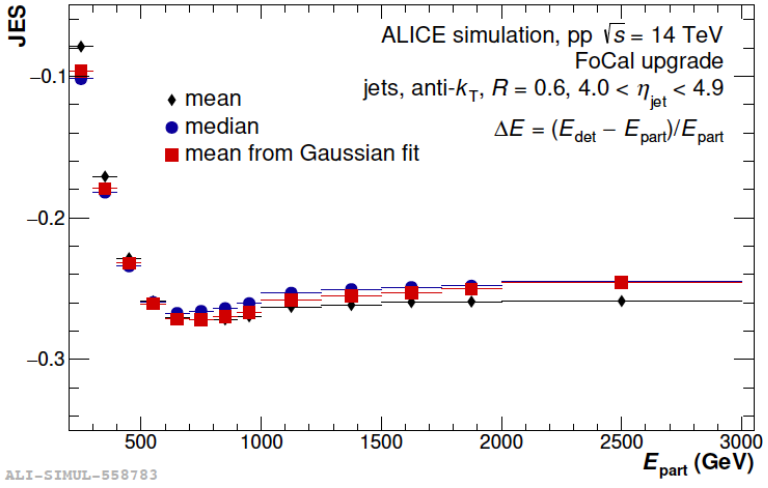
FoCal physics prospect: jets

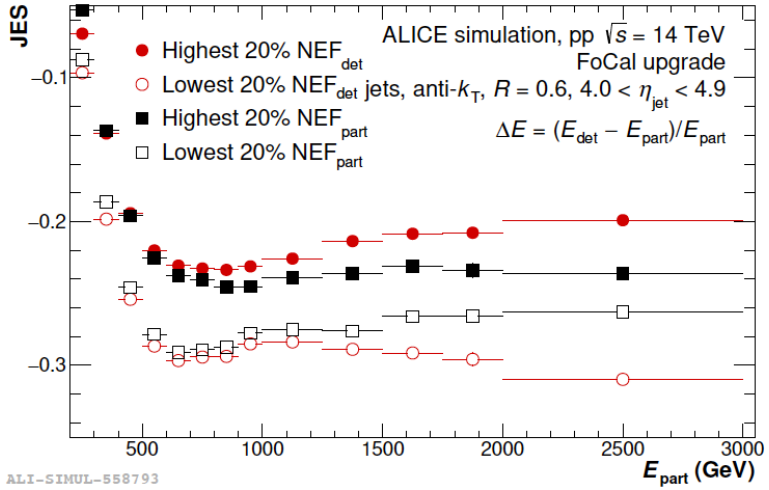
Jet performance study: Pythia (particle level) vs. GEANT (detector level) to quantify the energy difference

- $\Delta E = (E_{det} - E_{part}) / E_{part}$

JES: the Jet Energy Scale = mean of ΔE

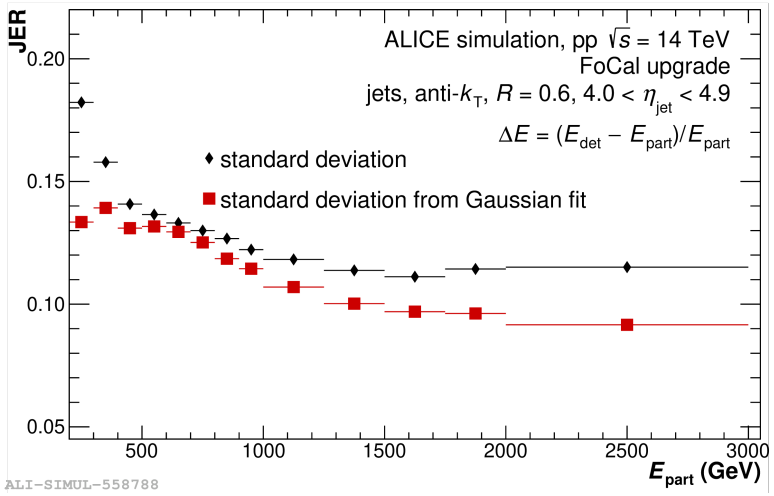
- depends on kinetic thresholds and neutral energy fraction



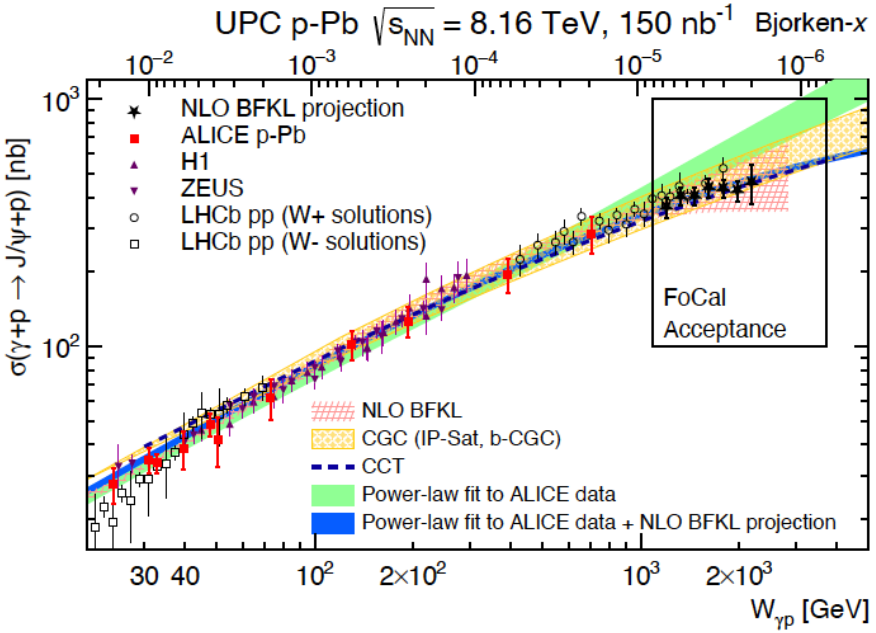


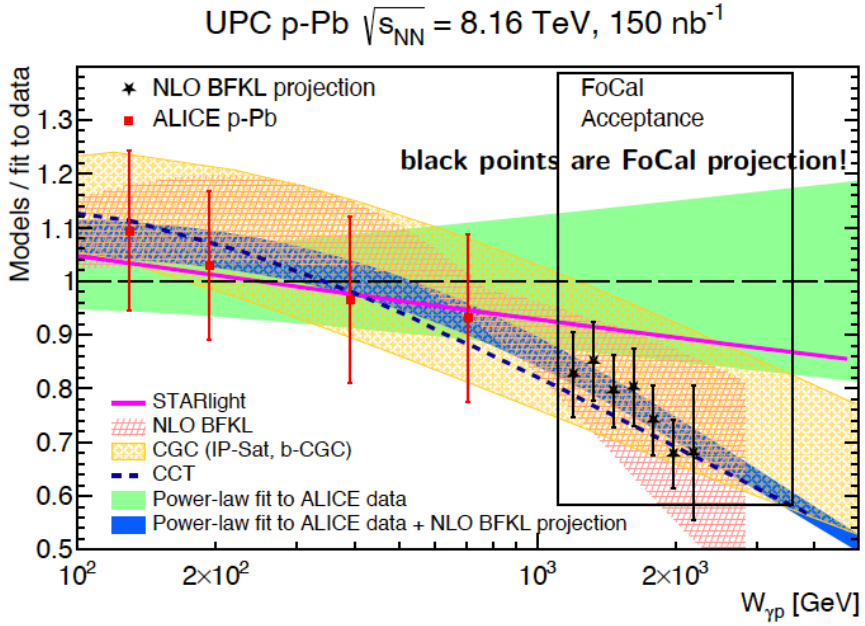
JER: the Jet Energy Resolution = width of ΔE

- depends on away-side jet decorrelation



FoCal physics prospect: UPC





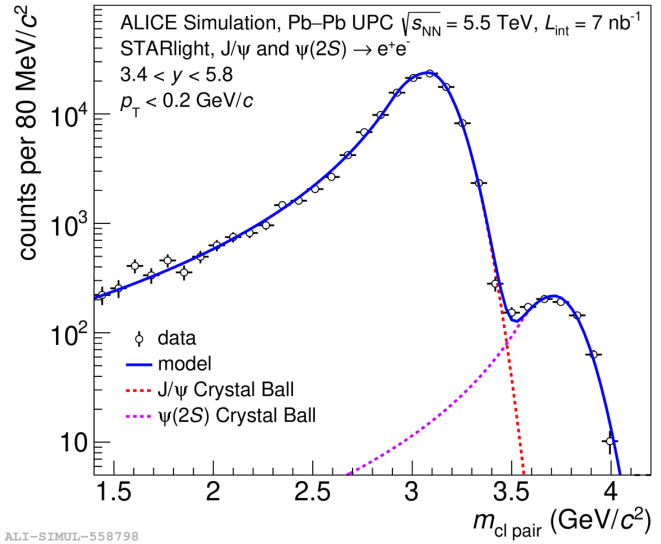


fig. taken from Bylinkin, Nystrand, Takaki arXiv:2211.16107

Theory:

- Cross section of vector mesons photo-production (e.g. J/ψ) in ultra-peripheral collisions (UPC) proportional to gluon density
- Deviation from power-law growth of cross section with increasing $W_{\gamma p}$ expected due to saturation effects

Experiment:

- FoCal allows to access unprecedented low-x to $W_{\gamma p}$ ~ 2 TeV (10 GeV) in p-Pb (Pb-p) collisions, plus Pb-Pb collisions
- Existing studies with STARLight + GEANT showsuccessful reconstruction of J/ψ and ψ(2S)

Summary

- **FoCal detector** is a planned calorimeter for the ALICE experiment for Run 4, covering forward rapidities $3.2 < \eta < 5.8$
- **Physics goal** to explore gluon saturation at low-x in multi-messenger approach, deep connection to EIC physics
- **Performance studies** using simulated collision events + detector smearing demonstrates FoCal capabilities to probe this regime using a variety of observables
- **Prototype of detector tested** in test beams at SPS in 2022 and 2023 show energy resolution meeting physics requirements

Read more:

- FoCal Letter-of-Intent (CERN-LHCC-2020-009)
- Physics of the ALICE Forward Calorimeter upgrade (ALICE-PUBLIC-2023-001)
- Physics performance of the ALICE Forward Calorimeter upgrade (ALICE-PUBLIC-2023-004)
- Technical Design Report (in preparation)
- Performance of the electromagnetic and hadronic prototype segments of the ALICE FoCal (paper in preparation)

Backup

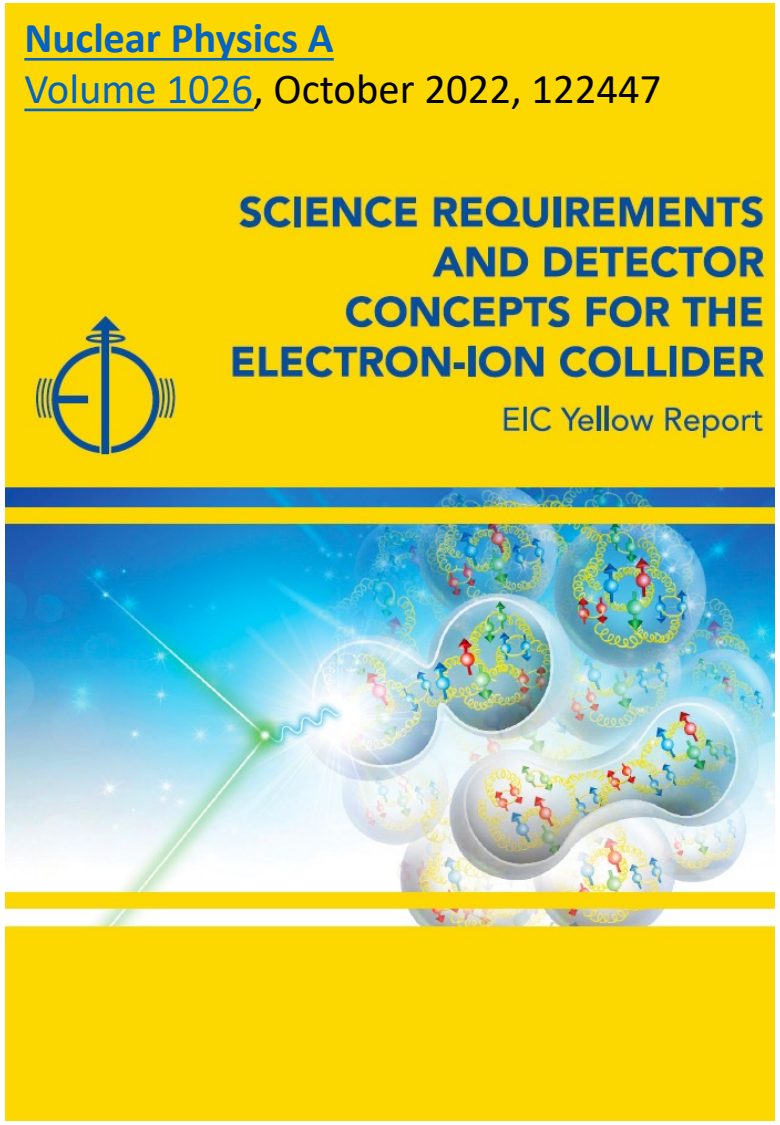
Connection to EIC

- EIC Yellow Report Sec. 7.5.4:

"Meanwhile, pA collisions can serve as a gateway to the EIC as far as saturation physics is concerned, and it also plays an important and complementary role in the study of these two fundamental gluon distributions."

	Inclusive DIS	SIDIS	DIS dijet	Inclusive in p+A	γ+jet in p+A	dijet in p+A
xG_{WW}	−	−	+	−	−	+
xG_{DP}	+	+	−	+	+	+

Table 7.2: The process dependence of two gluon distributions (i.e., the Weizsäcker-Williams (WW for short) and dipole (DP for short) distributions) in e+A(e+p) and p+Acollisions. Here the + and − signs indicate that the corresponding gluon distributions appear and do not appear in certain processes, respectively.



➢ EIC + Forward LHC/RHIC:

The whole game is bigger than simply adding up

Connection to EIC

- Yields for various observables in FoCal acceptance
- estimated using expected integrated luminosities at Run 4
- high rates for prompt photons, mesons, and jets