

# ALICE Forward Calorimeter (FoCal): Physics program and performance

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**Abstract.** This contribution outlines the physics program and performance of the Forward Calorimeter (FoCal), which is a planned new detector subsystem for the ALICE experiment in Run 4. The forward pseudorapidity coverage of  $3.2 < \eta < 5.8$  allows to study the gluon density in hadronic matter down to  $x \sim 10^{-6}$  and enables the search for gluon saturation at the LHC.

## 1 Introduction

The gluon density in hadronic matter grows rapidly with decreasing Bjorken- $x$ . However, due to the non-Abelian nature of Quantum Chromodynamics (QCD), this growth is expected to be limited, resulting in a new state of gluon-saturated matter at low  $x$ . The ALICE experiment at the LHC proposes a new device – the Forward Calorimeter (FoCal) – to explore gluon saturation through precise measurements of multiple electromagnetic and hadronic observables at forward rapidities, which probe nuclear matter at unprecedentedly low values of  $x \sim 10^{-6}$ .

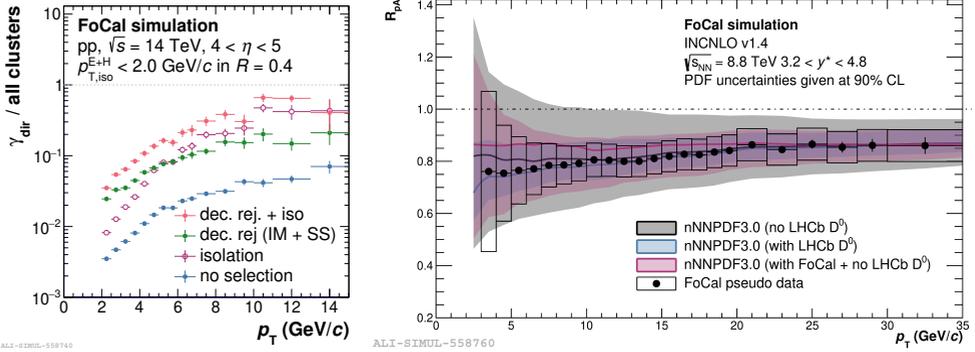
The FoCal calorimeter [1] will be installed in the ALICE cavern during LS3 and be ready for Run 4, beginning of 2029. FoCal consists of a highly granular Si+W electromagnetic calorimeter (FoCal-E) and a conventional sampling hadronic calorimeter (FoCal-H), positioned about 7 m from the ALICE interaction point and covering a pseudorapidity range  $3.2 < \eta < 5.8$ . FoCal-E employs a hybrid design combining multiple silicon readout technologies, with 18 layers of silicon pad sensor with transverse cell size of  $1 \text{ cm}^2$ , combined with two digital-readout pixel layers with cell size of  $\approx 30 \times 30 \mu\text{m}^2$ . FoCal-H is a sampling hadronic calorimeter positioned behind the FoCal-E, with a "spaghetti-type" structure consisting of scintillation fibers in copper tubes. This contribution outlines the FoCal physics program [2] and performance [3] for measurements in pp, p–Pb and Pb–Pb collisions. It also presents FoCal prototype measurements using test beams at the CERN PS and SPS [4].

## 2 Physics performance

The FoCal physics performance is studied using simulated pp and p–Pb collision events at  $\sqrt{s_{\text{NN}}} = 14 \text{ TeV}$  and  $8.8 \text{ TeV}$ , respectively using PYTHIA8 [5] and HIJING [6], and an idealized FoCal geometry implemented in GEANT3 [7] within the AliRoot framework. Furthermore, the performance for measurements in Ultra-Peripheral Collisions (UPCs) is assessed using STARlight simulations [13]. We focus here on observables sensitive to saturation effects which are theoretically robust and well-motivated [2].

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**Figure 1. Left:** Prompt photon signal fraction in simulated pp collision events for various selection criteria. **Right:** FoCal pseudodata of the nuclear modification factor  $R_{pA}$  and impact on current nuclear PDFs. Vertical lines and boxes denote estimated statistical and systematic uncertainties, respectively [3].

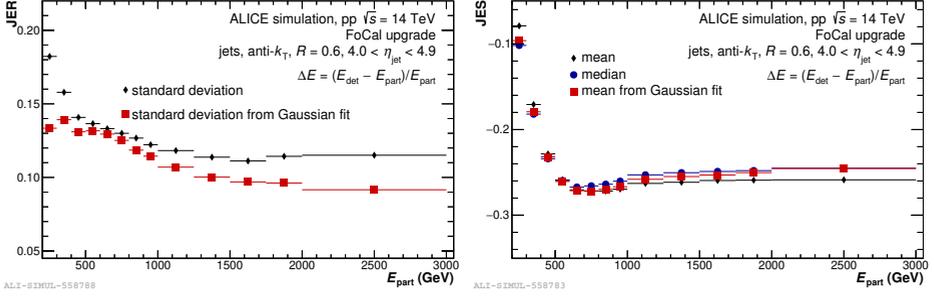
### Prompt photon production

Prompt photons are produced primarily via the Compton process,  $qg \rightarrow \gamma q$ , and therefore provide direct access to the gluon density, without being subject to final-state effects. The key challenge in their measurement is the large background of decay and fragmentation photons, which results in a low signal-to-background ratio of a few percent at LHC energies. FoCal is optimized to identify prompt photon candidates using three selection criteria: 1. isolation energy (sum of transverse momentum in a cone of a given radius around the photon) in FoCal-E and FoCal-H; 2. electromagnetic shower shape ellipse in the 18 FoCal-E pad layers; and 3. identification of decay photons from  $\pi^0 \rightarrow \gamma\gamma$  decays using an invariant mass tagging. Figure 1 (left) shows the prompt photon signal fraction in pp collisions at  $\sqrt{s} = 14$  TeV. Utilizing these three criteria increases the signal fraction by a factor  $\sim 11$ , with a value of about 70% at  $p_T \sim 14$  GeV/c.

The physics impact of FoCal prompt-photon measurements is estimated by generating pseudodata of the nuclear modification factor  $R_{pA}$  (Fig. 1, right), based on NLO calculations [8] using nuclear PDFs. Detector simulations are used to estimate systematic and statistical uncertainties [3]. The uncertainties are less than 20% for  $p_T \gtrsim 5$  GeV/c, which is smaller than the expected suppression of the isolated prompt photon cross section in p-Pb collisions of about 20% from the nPDF prediction. These pseudodata are used to reweight the  $R_{pA}$  distribution obtained using nNNPDF3.0 [9, 10]. Fig. 1 projects a significant reduction of nPDF uncertainties due to the inclusion of FoCal direct photon data, of similar magnitude to the gain in precision obtained by including recent LHCb measurements of  $D$  meson production [11]. We note that these two probes – prompt photons and  $D$  mesons – have different sensitivity to final state effects, making the inclusion and comparison of both observables in PDF fits essential to constrain the low- $x$  gluon density and test its universality.

### Jet measurements

Inclusive jet production, di-jet production, as well as  $\gamma$ -jet correlations are sensitive to saturation effects and part of the FoCal physics program [2]. The jet performance is evaluated in simulated pp collision events at  $\sqrt{s} = 14$  TeV generated by PYHIA8. Jets are reconstructed using the anti- $k_T$  clustering algorithm, taking into account energy deposits in both FoCal-E and FoCal-H. Two key performance metrics, the Jet Energy Resolution (JER) and Jet Energy

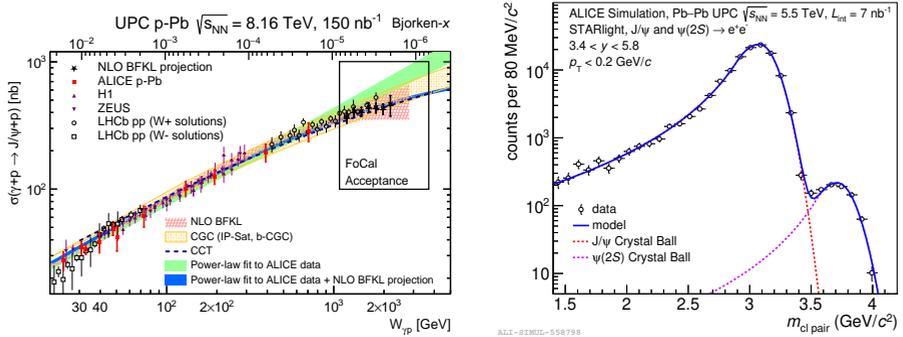


**Figure 2.** Jet Energy Resolution (left) and Jet Energy Scale (right) shown for anti- $k_T$  jets with  $R = 0.6$  in simulated pp collision events at  $\sqrt{s} = 14$  TeV [3].

Scale (JES) are presented in Fig. 2. The JER is observed to be better than 15% for the studied energies up to 3 TeV. The JES illustrates energy losses of up to 28%, which can be attributed to the transverse size of the hadronic shower in the FoCal-H being larger than the used jet resolution parameter  $R = 0.6$ . Additional studies show that the JES can be improved by introducing biases on the neutral energy fraction of the studied jet population [3].

### Vector meson photoproduction in ultra-peripheral collisions

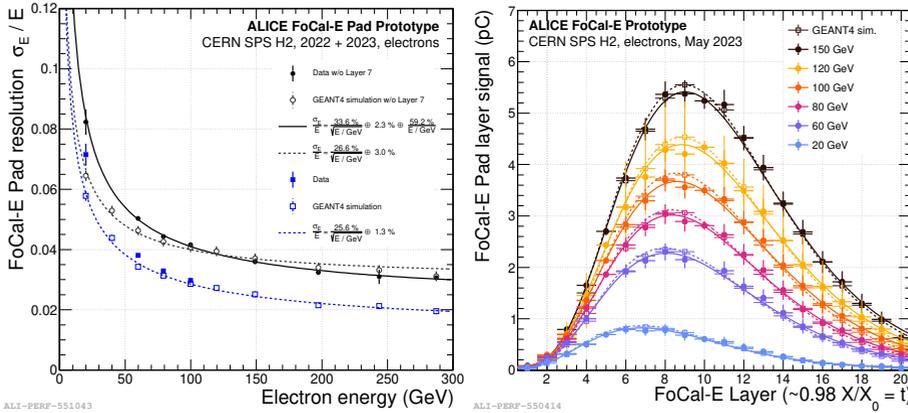
Photoproduction of vector mesons in ultra-peripheral collisions (UPCs) is sensitive to the gluon density in the target nucleon or nucleus and one expects the onset of non-linear behavior for high center-of-mass energies  $W_{\gamma p}$  of the emitted photon and the proton projectile. The kinematic coverage of the FoCal allows to significantly extend existing measurements of  $J/\psi$  and  $\psi(2S)$  photoproduction cross section in p–Pb collisions up to  $W_{\gamma p} = 2$  TeV [3]. The importance of this extension is illustrated in Fig. 3 (left), which showcases that FoCal data will contribute at high  $W_{\gamma p}$  where models including gluon saturation predict deviations from a power-law growth of the production cross section [12]. Fig. 3 (right) illustrates the successful extraction of  $J/\psi$  and  $\psi(2S)$  candidates in ultra-peripheral Pb–Pb collisions, where the UPC events are simulated using STARlight [13] subsequently propagated through the detector geometry in GEANT3 [7].



**Figure 3.** Left:  $J/\psi$  photoproduction cross section in ultra-peripheral p–Pb collisions shown for a selection of data, theoretical predictions and a FoCal projection [12]. Right: Invariant mass distribution of  $J/\psi$  and  $\psi(2S)$  candidates in FoCal acceptance based on STARlight simulations [3].

### 3 FoCal prototype & test beam results

The performance of a FoCal prototype has been studied extensively using electron and hadron beams at the PS and SPS and the results are reported in detail in Ref. [4]. Figure 4 (left) shows the energy resolution of the FoCal-E prototype for electron beams. A resolution of less than 3 % is observed for high energies, which is well within the physics requirement of about 5 %, and the measured results are well described by simulations. Figure 4 (right) showcases the capability of the FoCal detector to measure the longitudinal evolution of the shower in the pad and pixel layers. Good agreement with GEANT4 simulations are observed for all studied beam energies of up to 150 GeV.



**Figure 4. Left:** Energy resolution of the FoCal-E prototype. While all pad layers are included for the data denoted by blue markers, black markers denote a dataset where one of the pad layers had to be excluded from the analysis, leading to a slightly degraded performance. **Right:** Longitudinal shower profiles of the FoCal-E prototype. The profiles are fitted with  $\Gamma$ -distributions shown as solid and dashed lines, indicating a fit to the profiles from data and GEANT4 simulations, respectively.

### References

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