ALICE Forward Calorimeter (FOCAL) Upgrade

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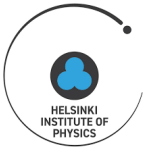
Centre of Excellence in Quark Matter



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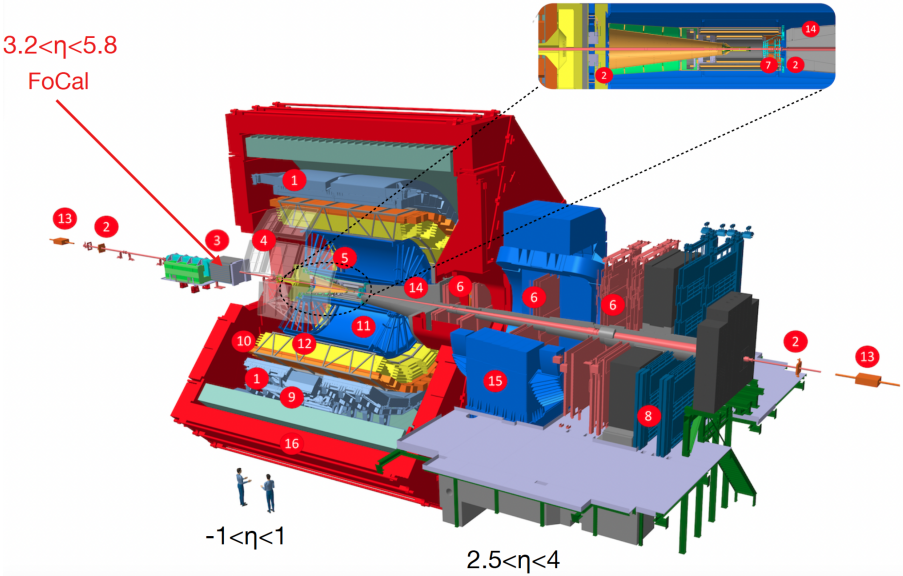
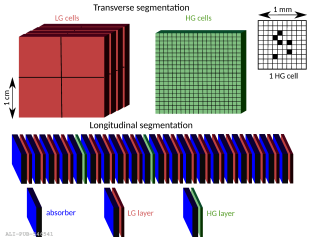
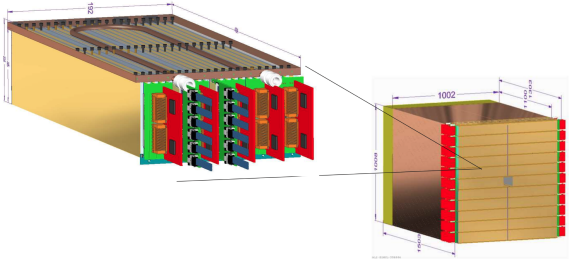


1. **EMCAL |** Electromagnetic Calorimeter
2. **FIT |** Fast Interaction Trigger
3. **FoCal |** Forward Calorimeter (in front of compensator magnet)
4. **HMPID|** High Momentum Particle Identification Detector
5. **ITS|** Inner Tracking System
6. **MCH|** Muon Tracking Chambers
7. **MFT|** Muon Forward Tracker
8. **MID|** Muon Identifier
9. **PHOS/CPV|** Photon Spectrometer
10. **TOF|** Time Of Flight
11. **TPC|** Time Projection Chamber
12. **TRD|** Transition Radiation Detector
13. **ZDC|** Zero Degree Calorimeter
14. **Absorber**
15. **Dipole Magnet**
16. **L3 Magnet**

Electromagnetic calorimeter (FOCAL-E)

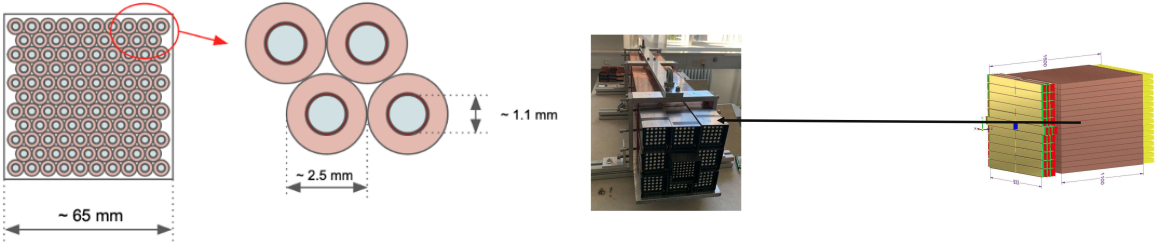
- The electromagnetic calorimeter is a Si+W sampling calorimeter with high granularity.
- It has 18 layers W+Si pads, and 2 W+Si pixels, with total length of $\approx$ 20cm.
- Silicon sensor with pad size of 1 cm $\times$ 1 cm with 8 $\times$ 9 pads per sensor.
- Si pixels: ALPIDE pixel sensor (ALICE ITS vertex detector pixel sensor) with pixel size of 30 μm $\times$ 30 μm
- 1024 x 512 pixels per chip of size 30 mm $\times$ 15 mm.
- Main goal of pixel layers is shower separation.





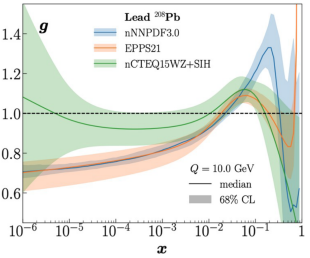
Hadronic Calorimeter (FOCAL-H)

- The hadronic calorimeter will be used for photon isolation and jet measurements.
- It has a length of 110 cm.
- It consists of Copper tubes parallel to beam pipe (diameter 2.5 mm), filled with scintillating fibers (diameter 1 mm).



Physics of Forward Calorimeter (FOCAL)

- Nuclear modification of the gluon density at small-x
  - isolated photons in pp and pPb collisions.



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- Nuclear modification of the gluon density at small-x
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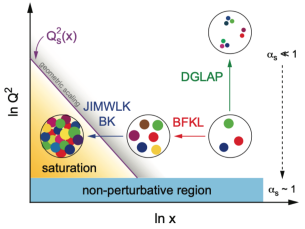
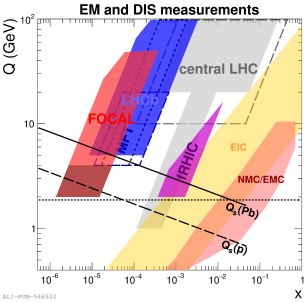
- Explore non-linear QCD evolution in regime of saturated gluons.





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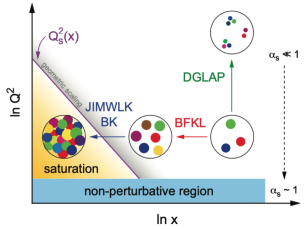

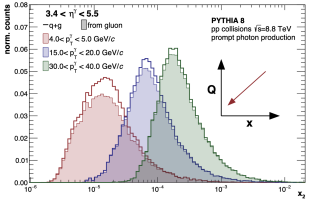

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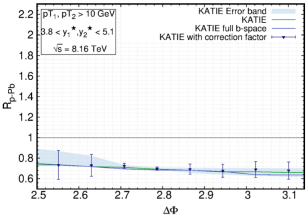
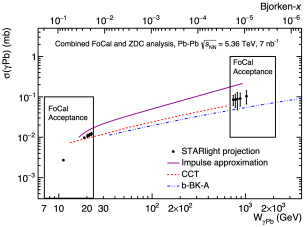
  - measurements of forward azimuthal correlations: $(\pi^0, \gamma_{iso}$, jet$)_{trigg}$ x $(\pi^0$, jet$)_{assoc}$.
  - Quarkonia in UPC.





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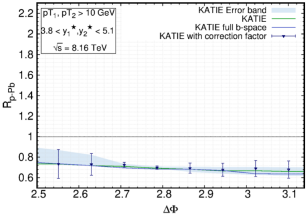
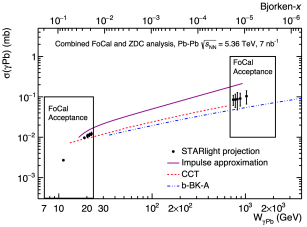
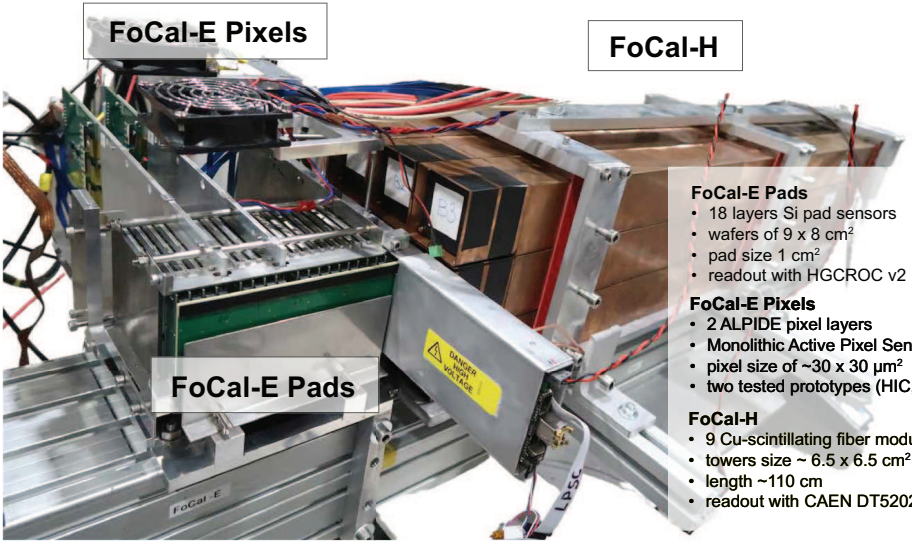
  - Quarkonia in UPC.
- More details on the FOCAL physics case can be found here:
  Physics of the ALICE Forward Calorimeter upgrade.





Testbeam performance



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

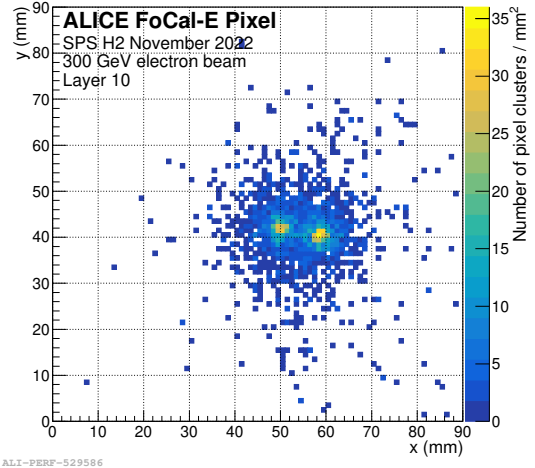
FoCal-E Pixels
- 2 ALPIDE pixel layers
- Monolithic Active Pixel Sensors
- pixel size of ~30 x 30 μm^2
- two tested prototypes (HIC,pCT)

FoCal-H
- 9 Cu-scintillating fiber modules
- towers size ~ 6.5 x 6.5 cm^2
- length ~110 cm
- readout with CAEN DT5202

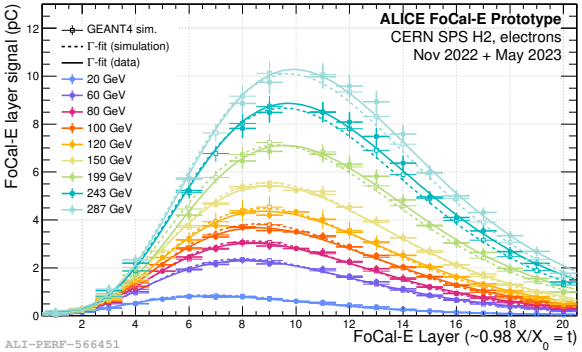
ALI-PERF-569144

Testbeam performance FOCAL-E

Shower separation in FoCal-E pixels

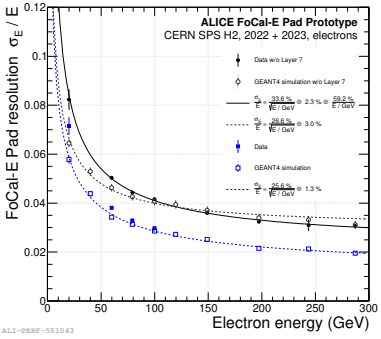


Longitudinal shower profile in FoCal-E



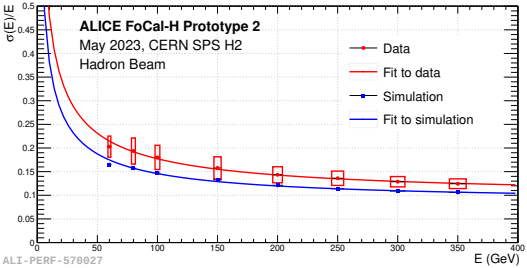
Testbeam performance

Energy resolution FoCal-E



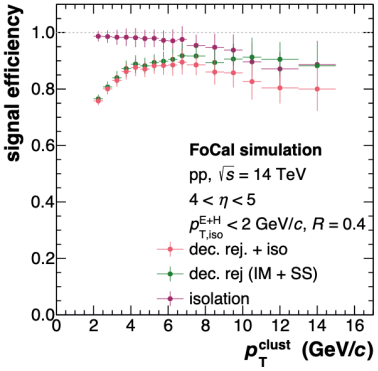
- Energy resolution of FoCal-E studied using electron beam from SPS.
- energy resolution $< 4\%$ for high energies and described by sim.

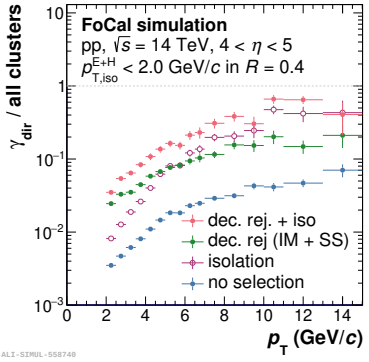
Energy resolution FoCal-H



- energy resolution $\approx 10\%$ at high energies.

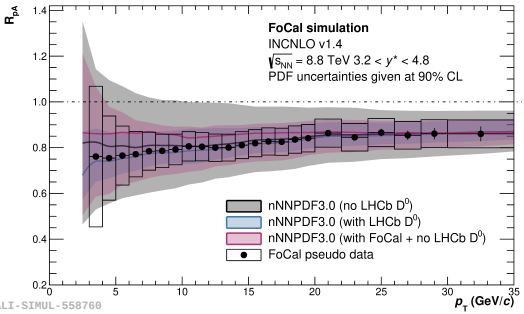
Isolated photons performance

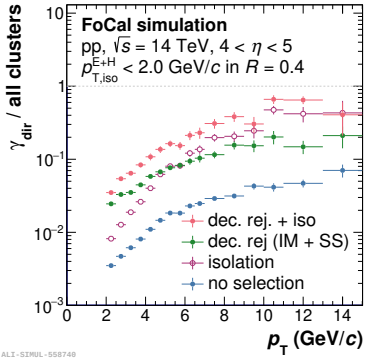




- Cluster selection on isolation, invariant mass, and shower shape, decreases the efficiency but allows for a purity of 70% at high p_T .

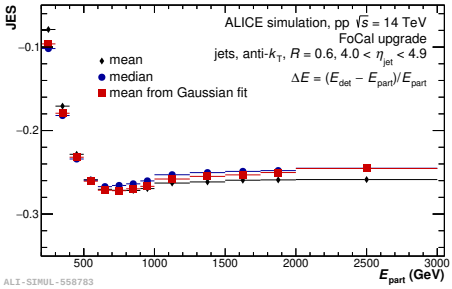
Isolated photons performance

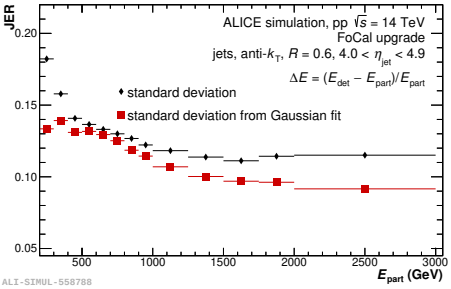




- Cluster selection on isolation, invariant mass, and shower shape, decreases the efficiency but allows for a purity of 70% at high p_T .
- FOCAL photon R_{pPb} significantly improves the NNPDF3 gluon PDF (without LHCb charm) by a factor 2.

Jet reconstruction performance

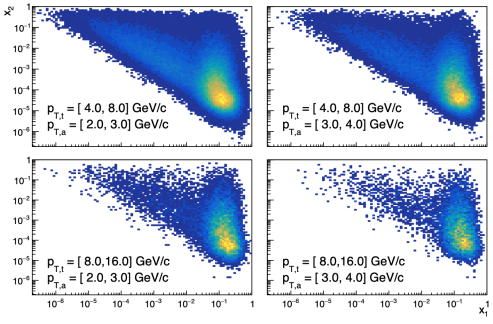


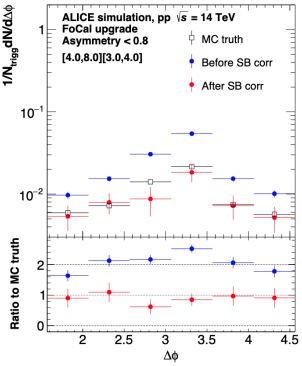


- Jets in FOCAL are reconstructed from showers in FOCAL-E and FOCAL-H.
- The jet performance is studied through JES and JER which are the mean and standard deviation of ΔE.
- Very good performance of jet reconstruction.

π^0-π^0 correlations

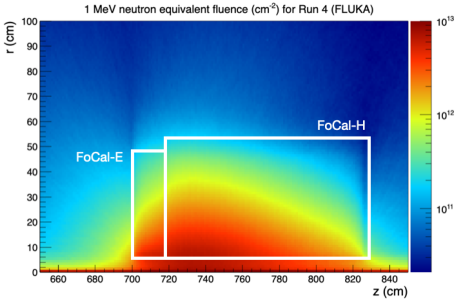
- Study of correlations in forward region can probe saturation effect and can help understand the low-x.
- π^0 candidates are reconstructed from clusters pairs in FOCAL-E with $m_{\gamma\gamma} = m_{\pi^0}$.
- Untrivial and significant correlated background subtracted using side-band method.





Hardware study

- Construct the FOCAL-H with off-the shelf hardware components with SiPM-based photon readout.
- Harsh running conditions impose strict limitations on the choice of photosensors.
- The SiPMs will not survive these conditions:
  - Redesign frontend such that SiPMs are moved away from region of highest radiation.
  - Cool the SiPMs to -40°C



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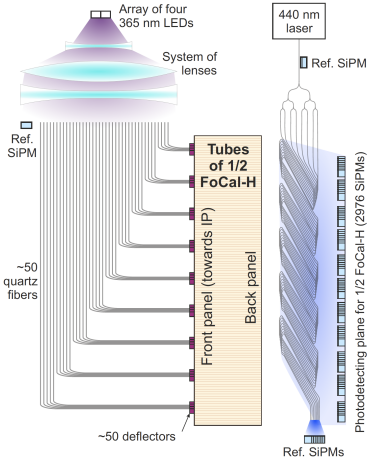
  - Cool the SiPMs to -40°C
- Development of the concept for the FoCal-H photo calibration system and specific characterization of fibers.



Summary

- The FoCal detector is a planned calorimeter for the ALICE experiment for Run 4, covering forward rapidities $3.2 < \eta < 5.8$.
- FOCAL can measure several observables: photons, neutral hadrons, jets, and their correlations
- The focus of the FoCal physics program is the study of the low-x structure of matter and the search for evidence of non-linear QCD evolution.

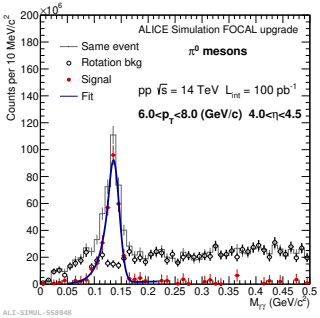
More details can be found:

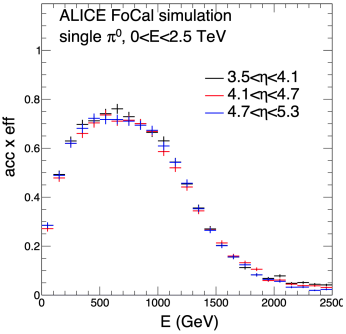
- FOCAL Letter of Intent: CERN-LHCC-2020-009
- Physics of the ALICE Forward Calorimeter upgrade: ALICE-PUBLIC-2023-001
- FoCal performance public note: ALICE-PUBLIC-2023-004
- Test beam paper of FoCal prototypes arXiv:2311.07413
- Technical Design Report: CERN-LHCC-2024-004

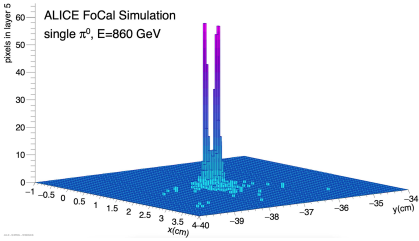
Backup

Meson reconstruction

- Neutral mesons decaying fully into photons or electrons can be reconstructed using EM showers in FoCal-E.
  - Most abundant: π^0, η, and ω
- Vector mesons decaying via di-electrons can also be reconstructed.







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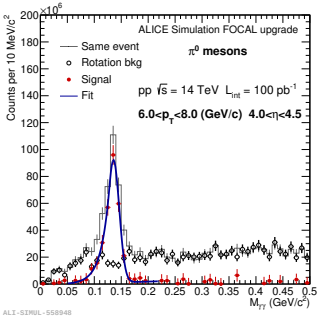

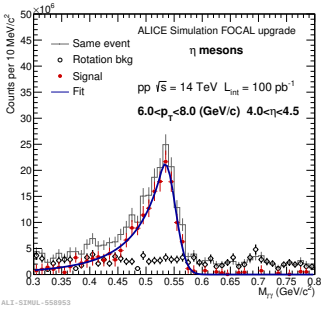

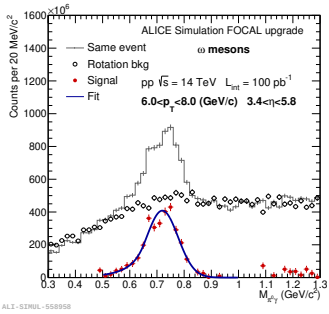

Meson reconstruction

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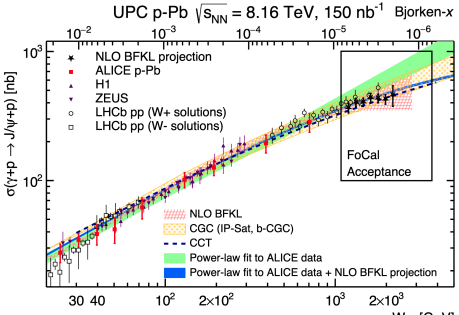
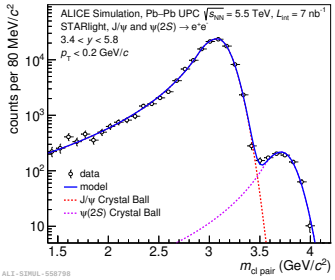
- In addition to J/ψ and $\psi(2S)$ reconstruction in UPC.

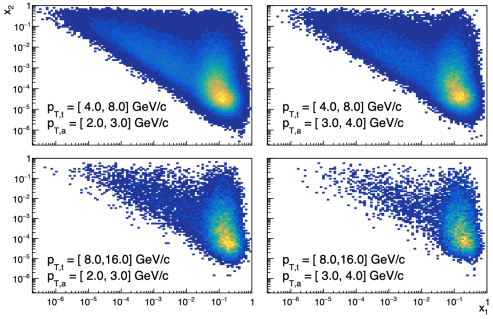


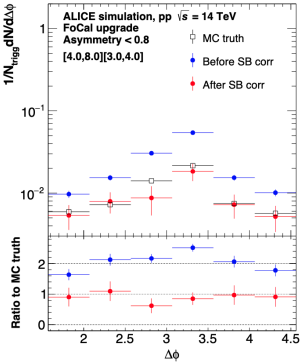
Bylinkin, Nystrand, Takaki arXiv:2211.16107



Correlation measurements

- Study of correlations in forward region can probe saturation effect and can help understand the low-x.
- π^0-π^0 correlations (Heidi Rytkönen):
  - π^0 candidates are reconstructed from clusters pairs in FOCAL-E with $m_{\gamma\gamma} = m_{\pi^0}$.
  - Untrivial and significant correlated background subtracted using side-band method.





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  - Untrivial and significant correlated background subtracted using side-band method.
- γ-π^0 correlations:
  - High precision in measuring the width of correlation functions as indicators of gluon density effects.