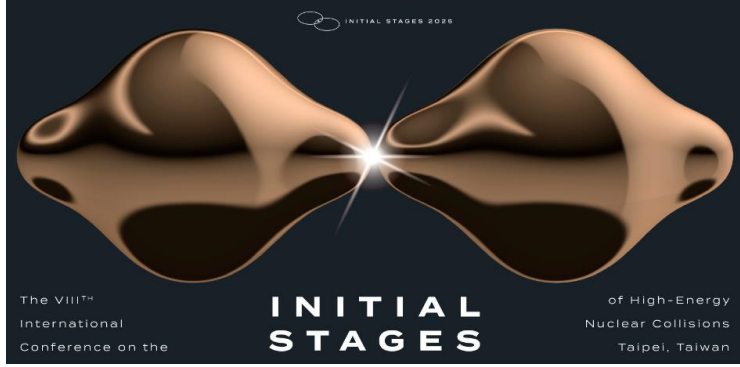
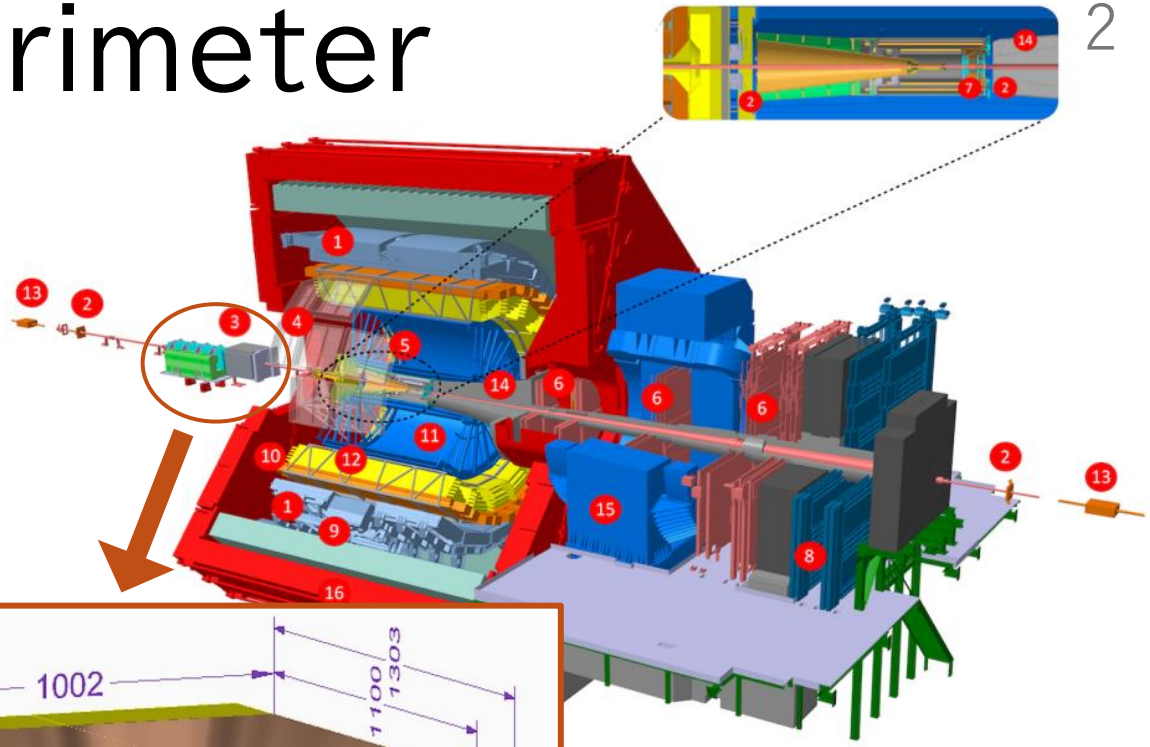


FoCal
Forward Calorimeter Upgrade for ALICE

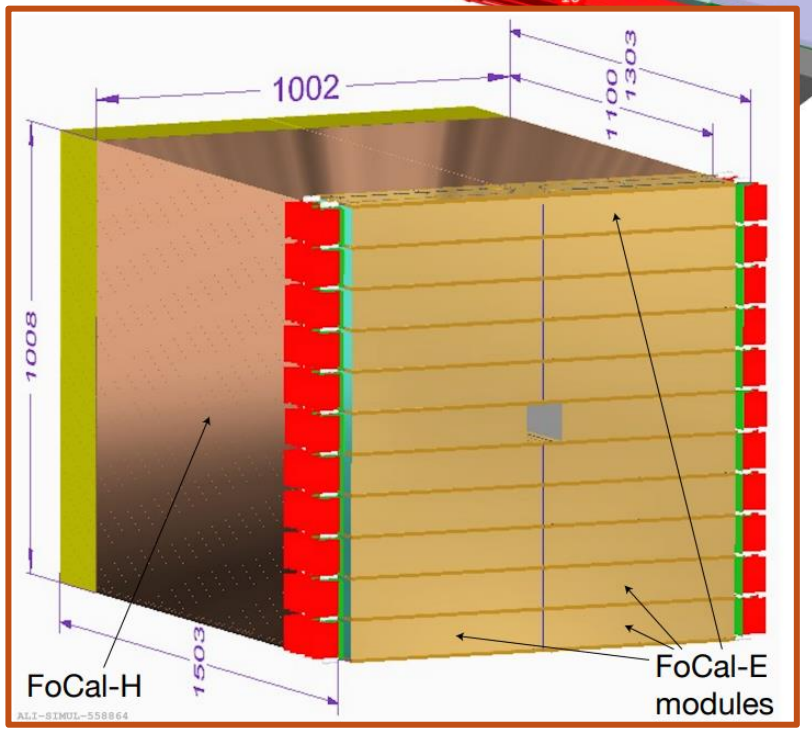
Takashi Hachiya
Nara Women's University
for the ALICE collaboration

FoCal - Forward Calorimeter



- FoCal is new Forward Calorimeter as an upgrade of ALICE for Run 4 (2030-2034)
  - Approved by the LHCC in 2024
  - Installation during LS3 (2026-2030)

LOI CERN-LHCC-2020-009
TDR CERN-LHCC-2024-004

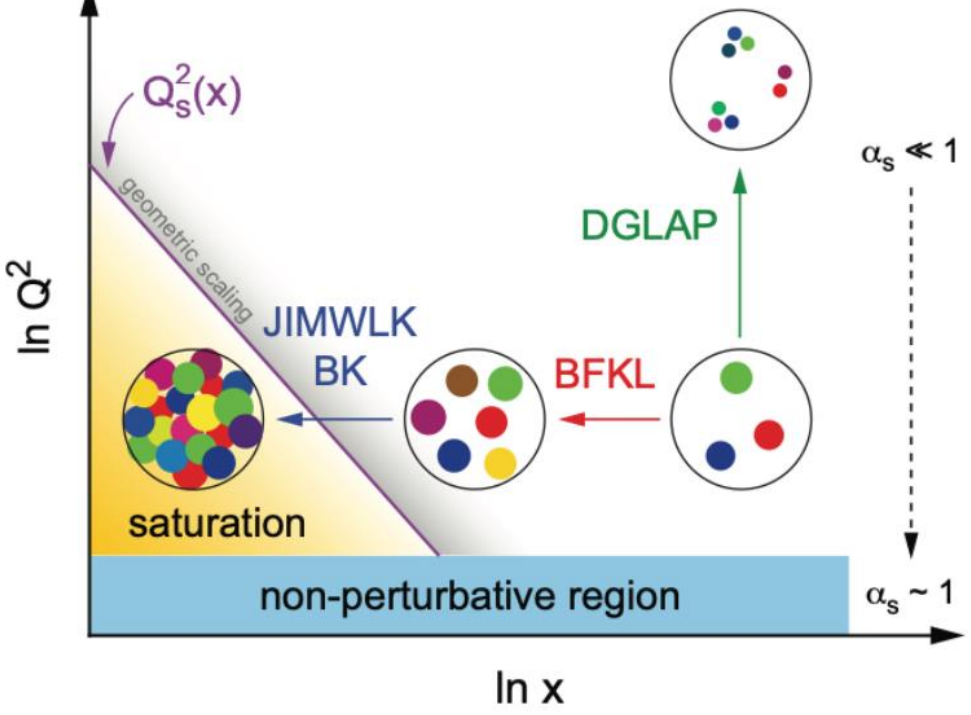


- FoCal consists of EM and Hadronic calorimeter
  - **7m from IP**
  - **Full azimuth coverage for $3.4<\eta<5.5$**
    - η : 3.2-3.4 & 5.5-5.8 with partial azimuth

FoCal Physics

- Explore non-linear QCD evolution at extremely small-x region
  - Gluon saturation expected due to balance between split and recombination of gluons
  - Saturation Scale; $Q_s^2 \propto A^{1/3}$
    - p+A is preferable for saturation study
    - Both p+p and p+A are necessary

$$Q_s^2(x) \approx \frac{xG_A(x,Q^2)}{\pi R_A^2} \propto A^{1/3}x^{-\lambda}$$



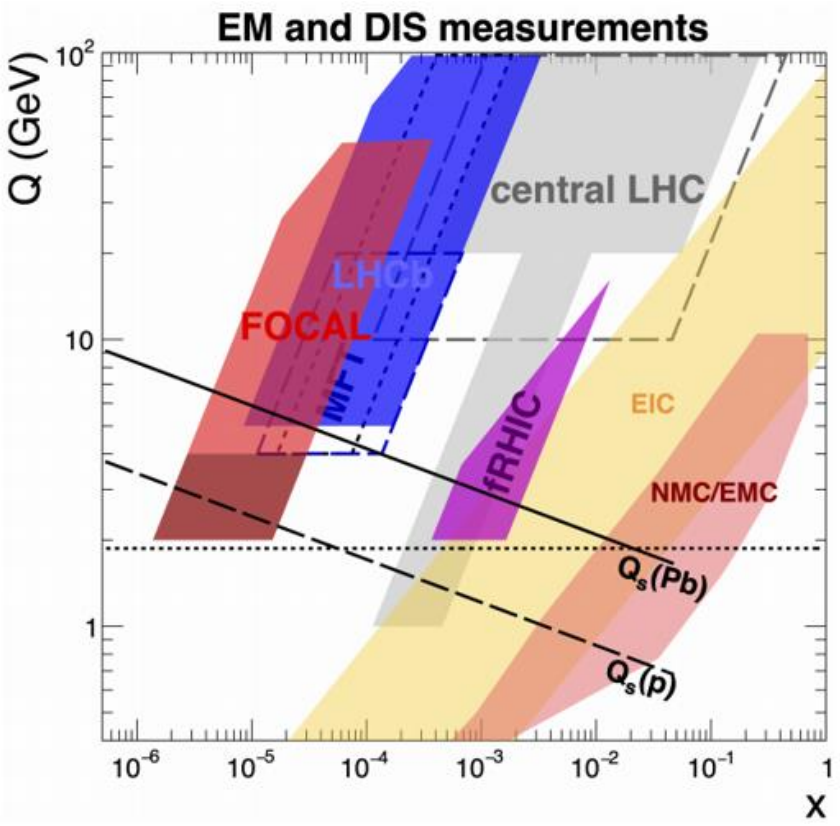
- Understanding the initial conditions of QGP physics
  - Origin of long-range correlations in small system
  - Early thermalization puzzle

FoCal Capabilities

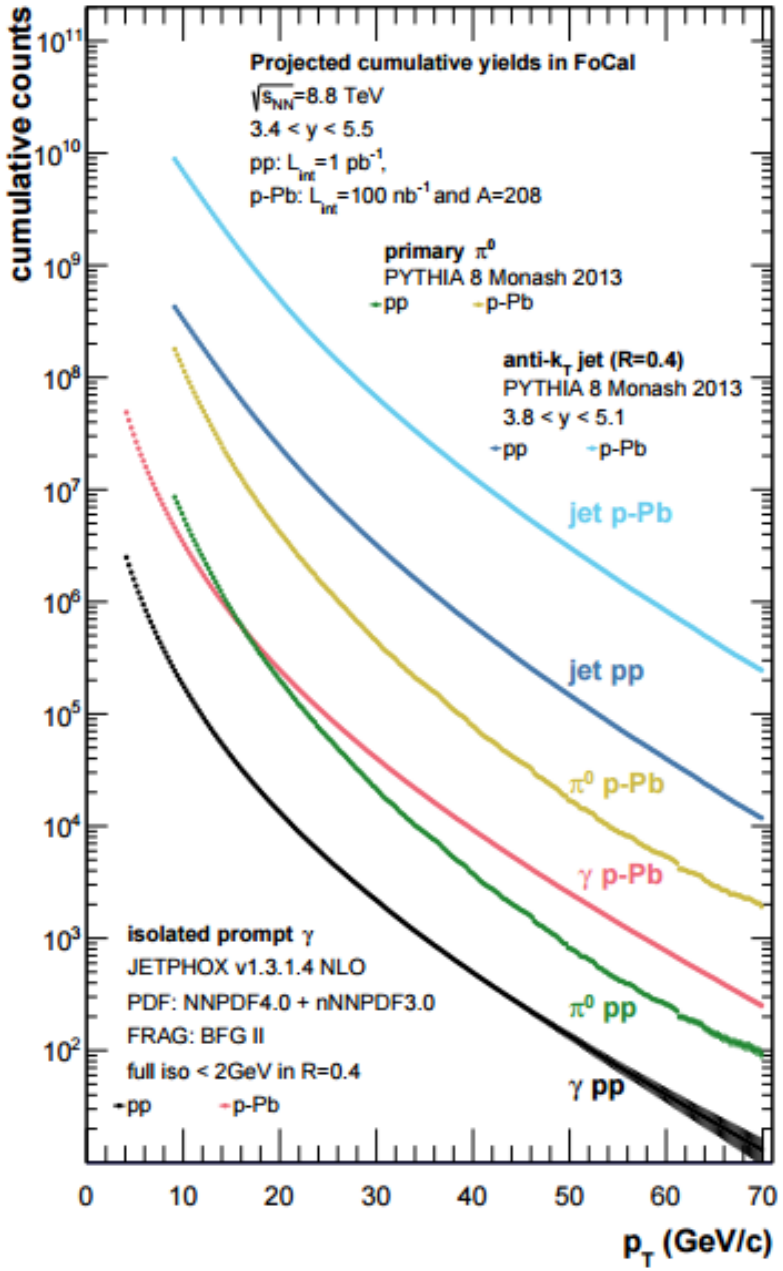
- FoCal covers small-x region (~10^{-6})
  - Complementary to LHCb and EIC

- Observables
  - Prompt photons
  - π^0, η,
  - Jet, γ +jet,
  - J/ψ, ψ(2s) in UPC

  and more …



Expected statistics

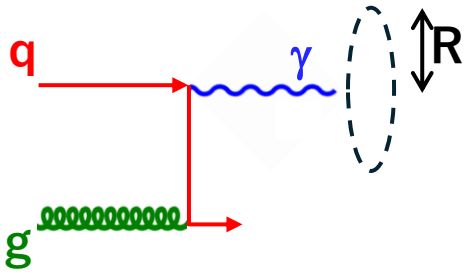


Multi-messenger approach

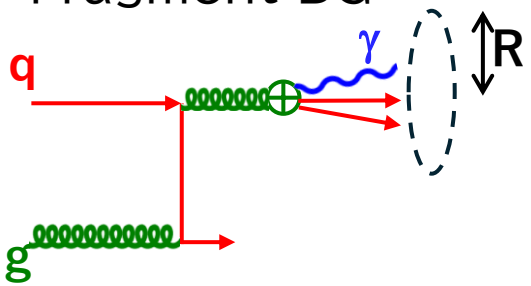
Prompt photons with isolation

- Theoretically clean probe of the gluon PDF in p & A
  - **Isolation** significantly improve S/N

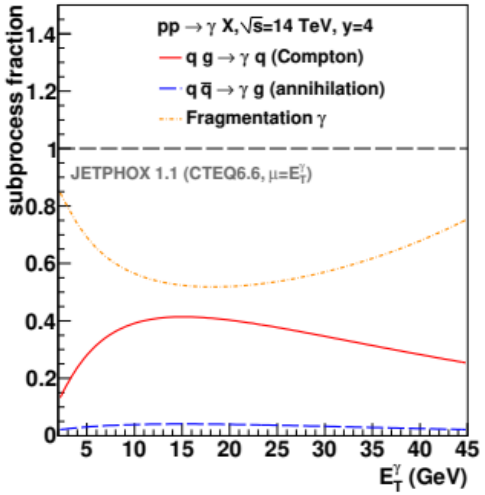
Compton

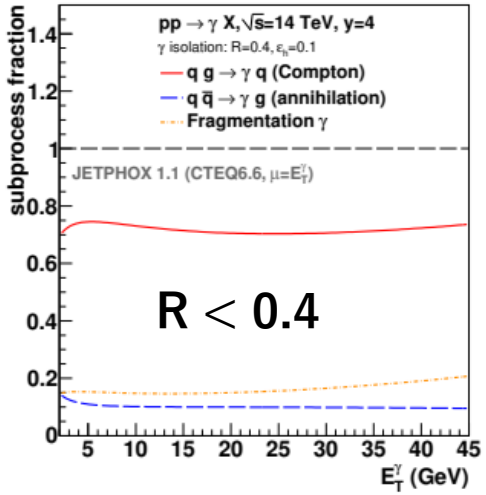


Fragment BG



Phys.Rev.D82:014015,2010





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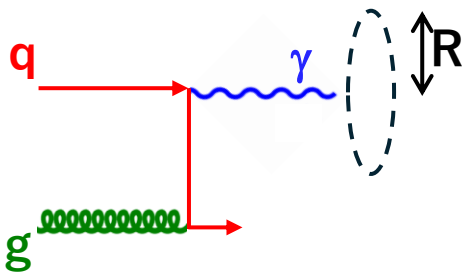
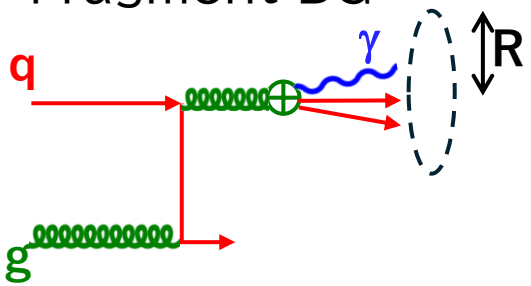


Fragment BG



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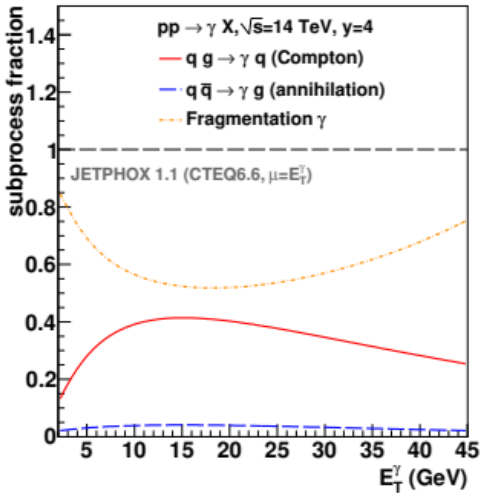
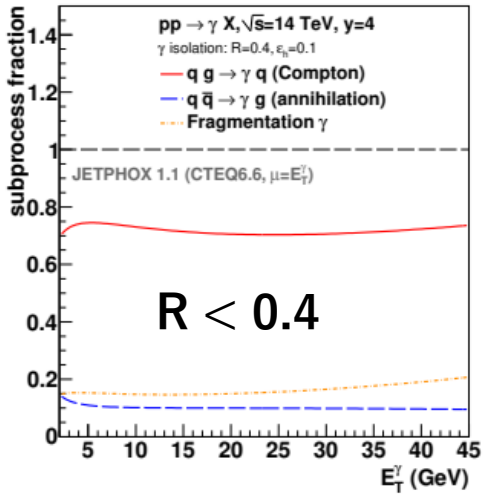
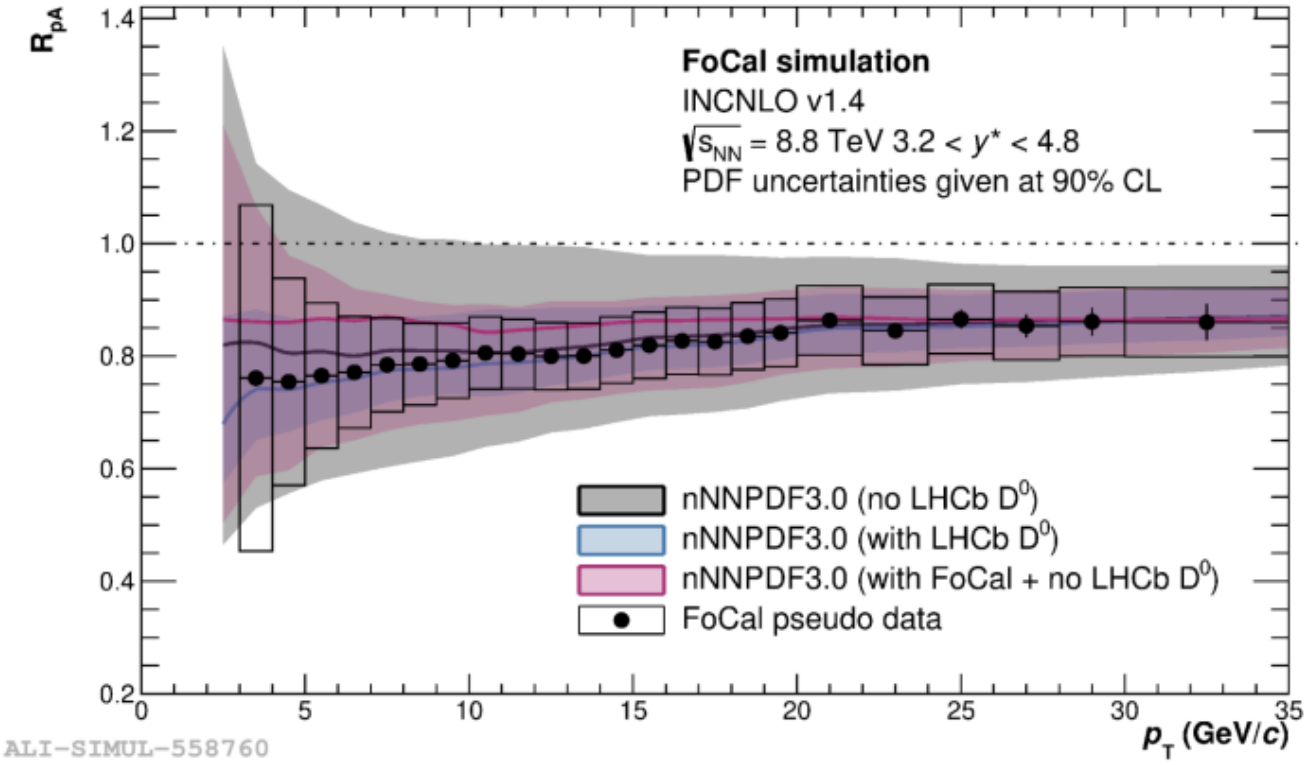




- FoCal can constrain (n)PDF
  - No strong interaction at final state
  - Comparable with LHCb D^0

Physics performance of FoCal, ALICE-PUBLIC-2023-004

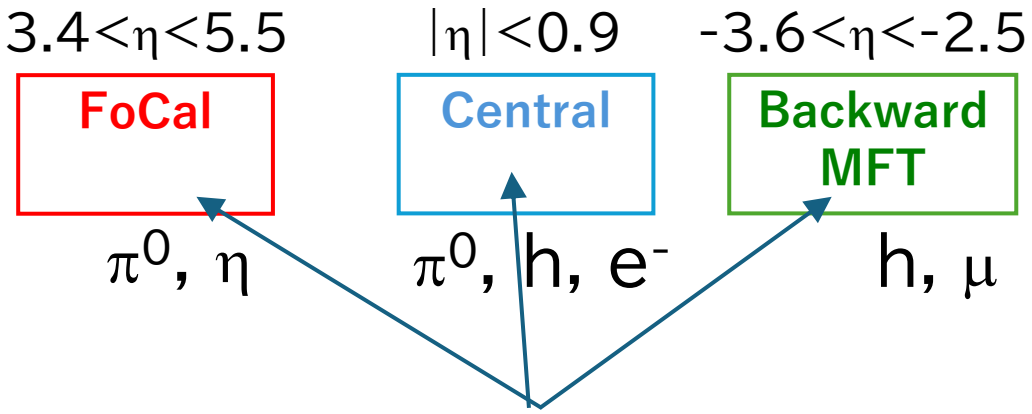


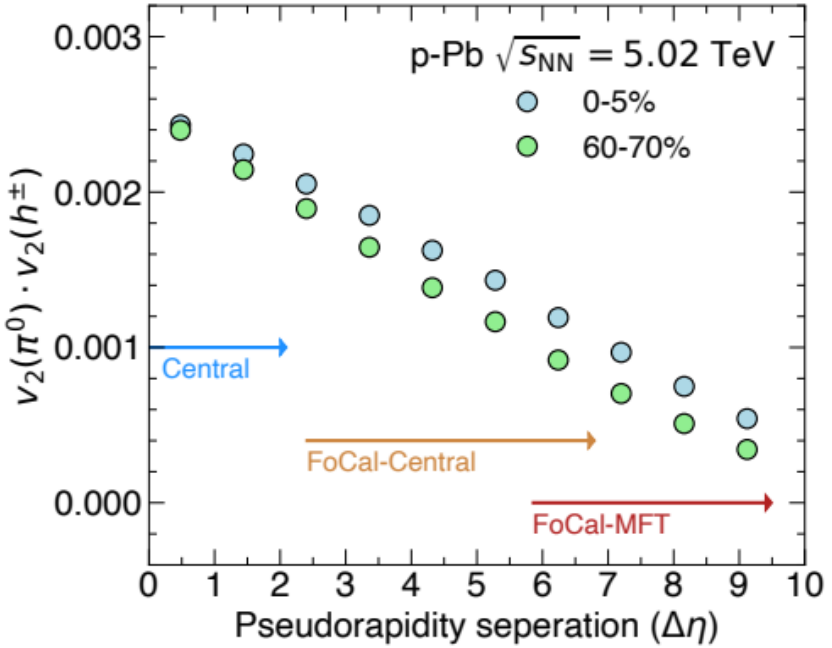
Key observable to explore gluons at the small-x

Long range correlations

- Initial state vs final state anisotropy in small systems

- FoCal extend the rapidity gap up to 9 with the ALICE Central and Backward(MFT)
  - Large rapidity gap gives early-stage correlation





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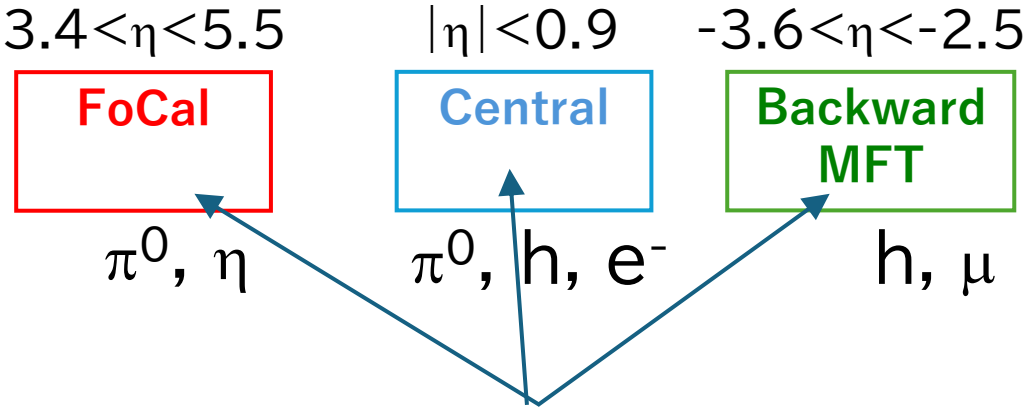
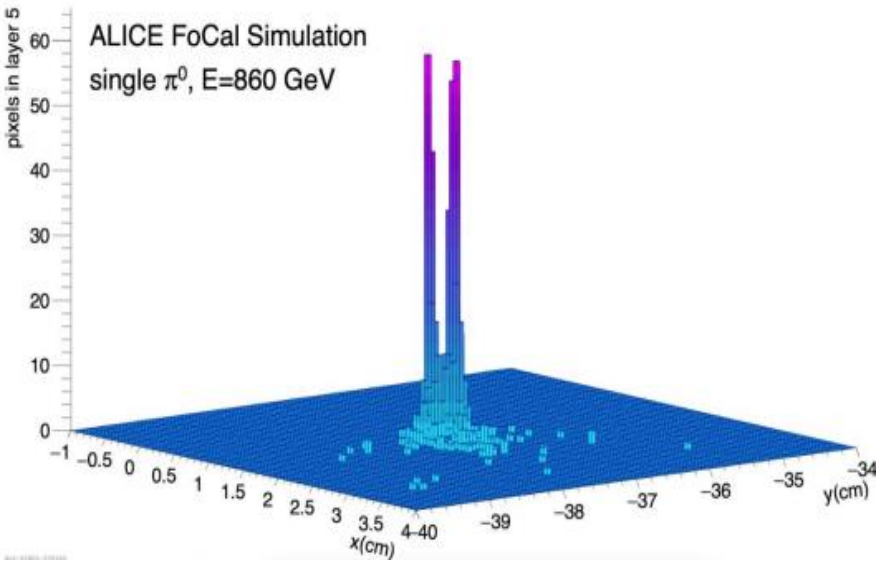
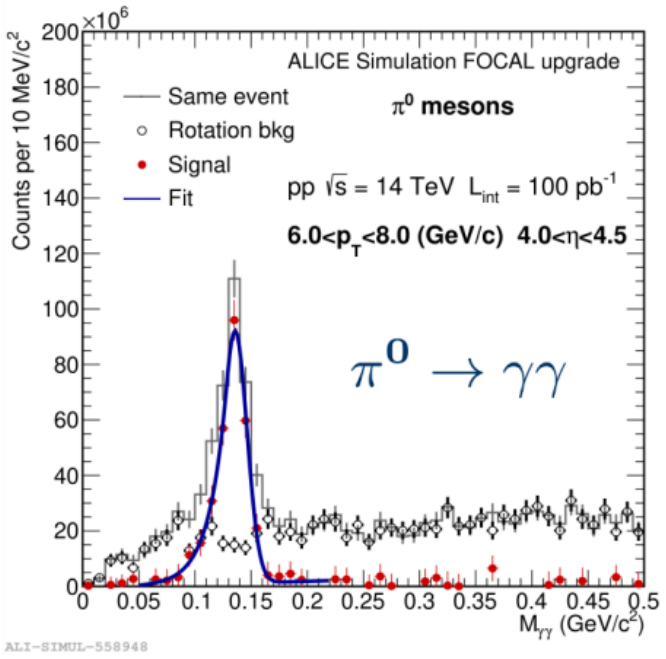
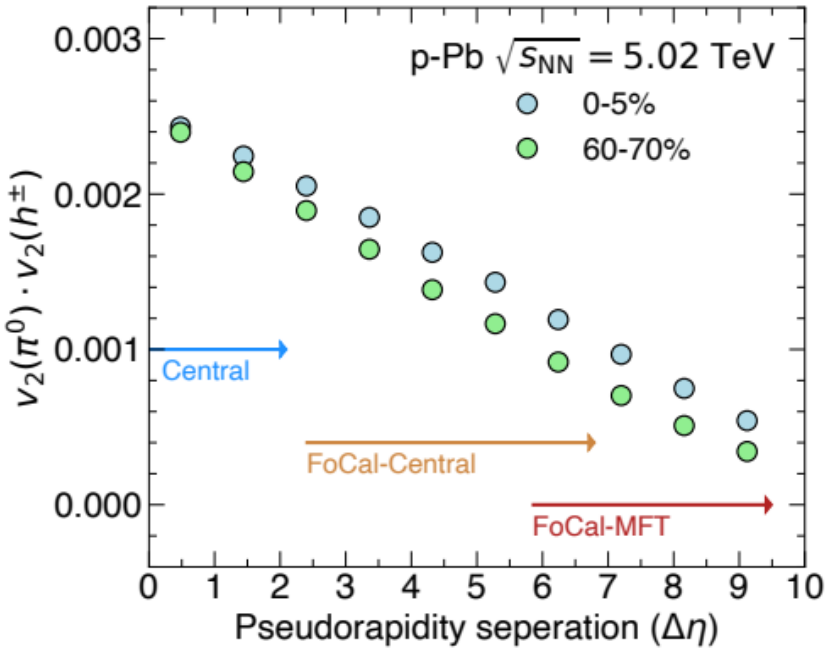






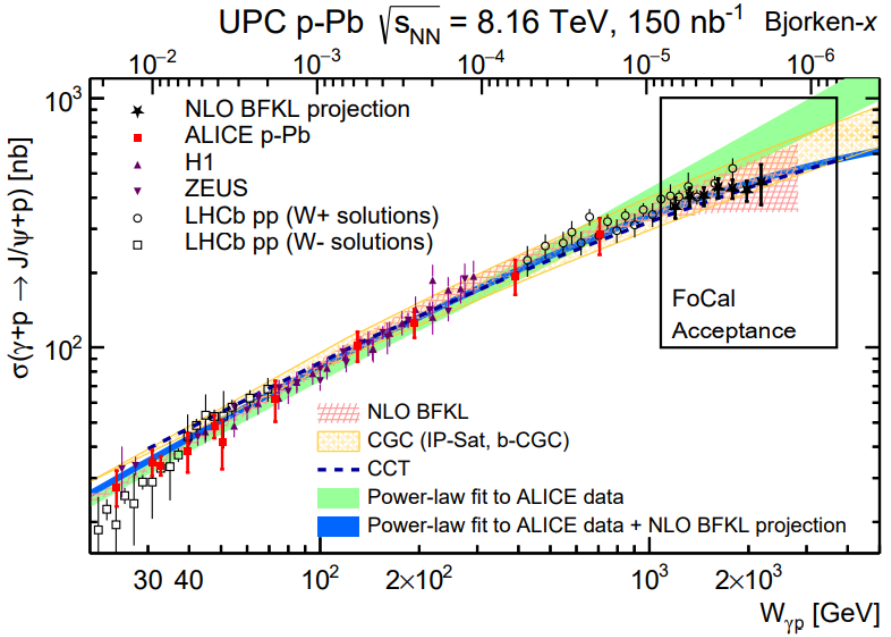


Physics of FoCal, ALICE-PUBLIC-2023-001

Physics Performance, ALICE-PUBLIC-2023-004

J/ψ photo-production in UPC

- Sensitive to the non-linear behavior in small-x in p and A
  - Photo-production is proportional to the gluon density at LO-pQCD calculation
- Accessible to small-x with $W_{\gamma p} \sim 2$ TeV
- $\psi(2s)/J/\psi$ ratio can provide a clearer signal



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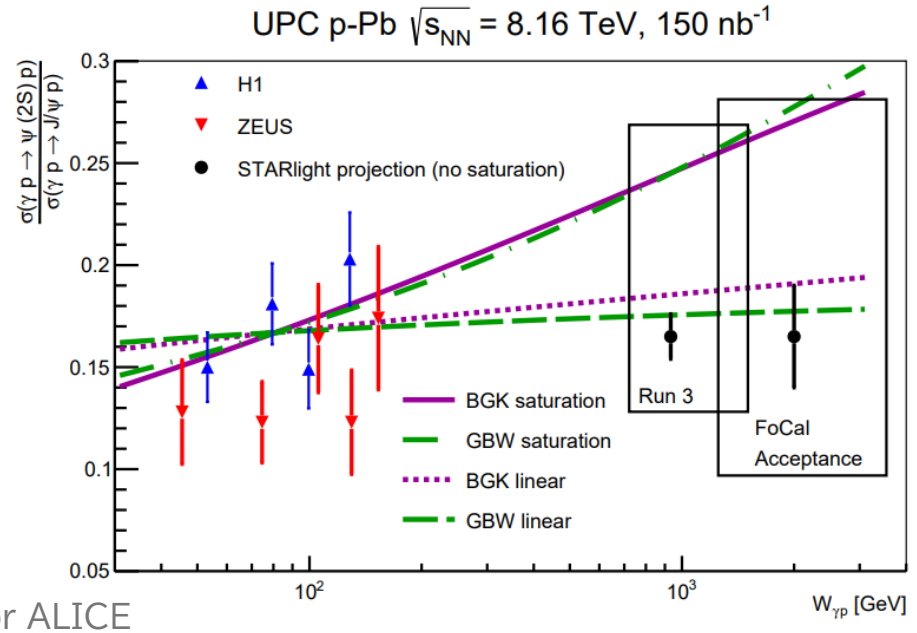

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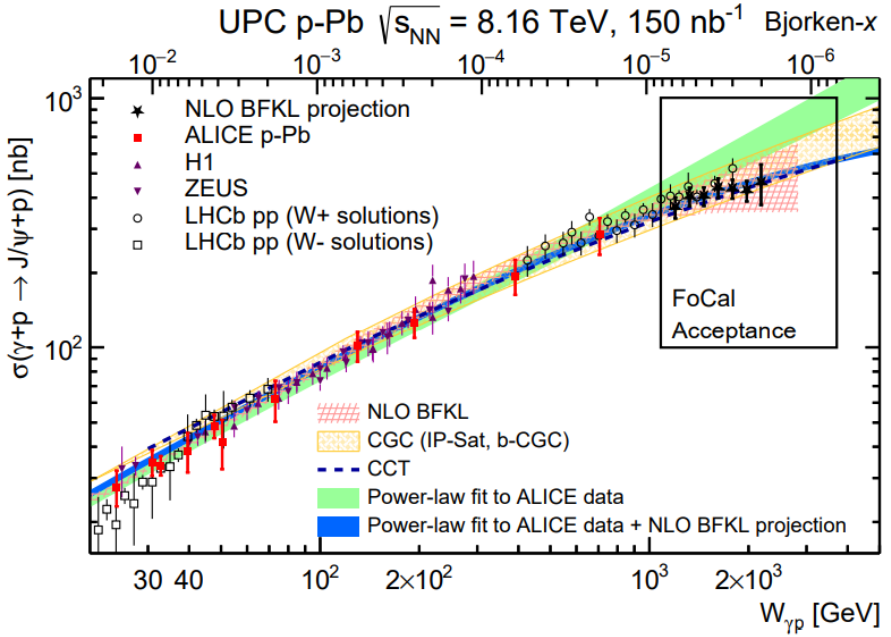
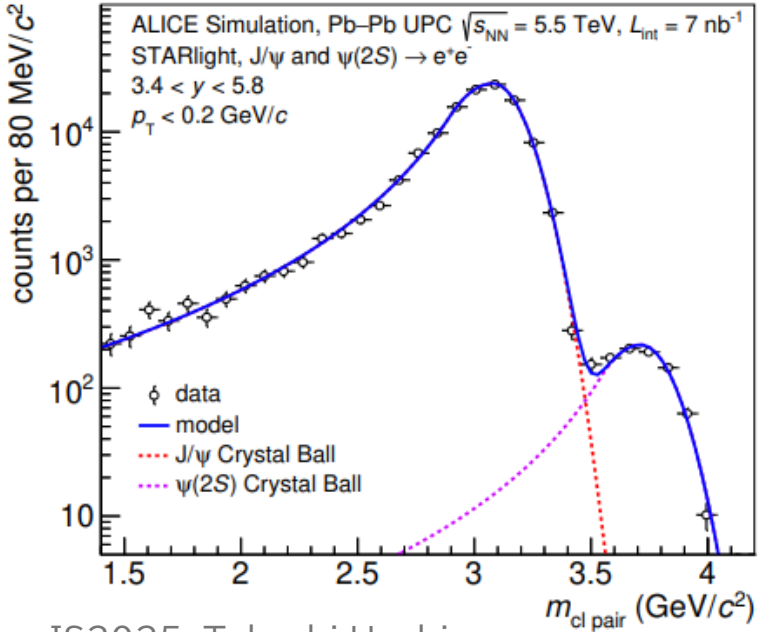
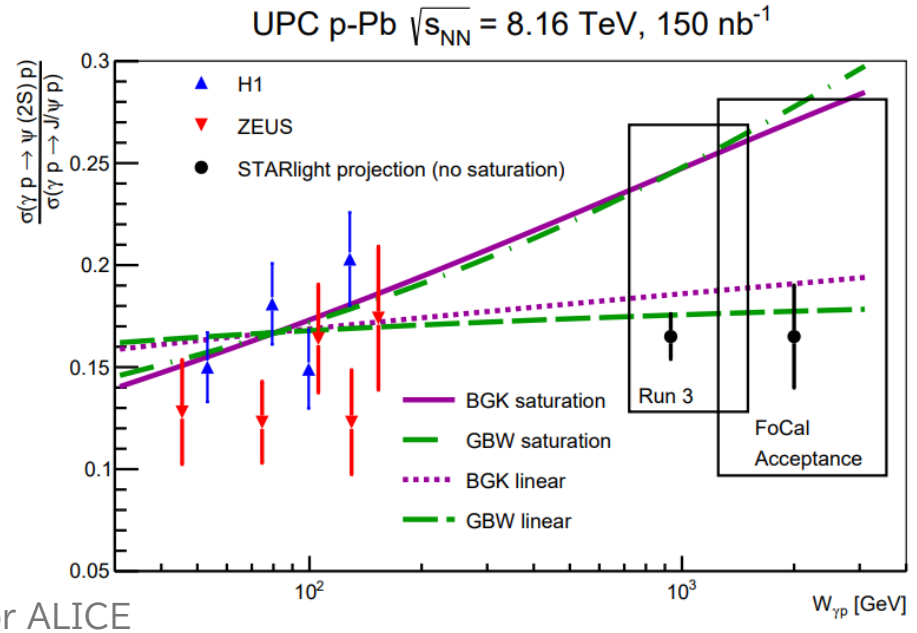


Mass from simulated FoCal cluster-pairs



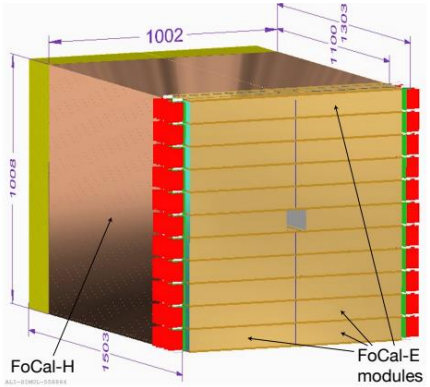
Physics of FoCal, ALICE-PUBLIC-2023-001

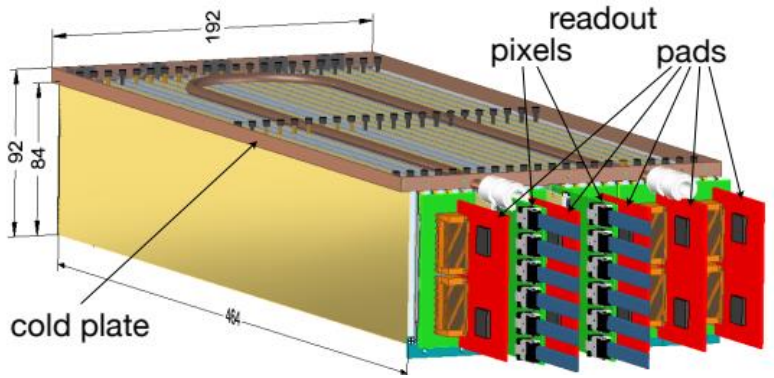
Physics performance of FoCal, ALICE-PUBLIC-2023-004



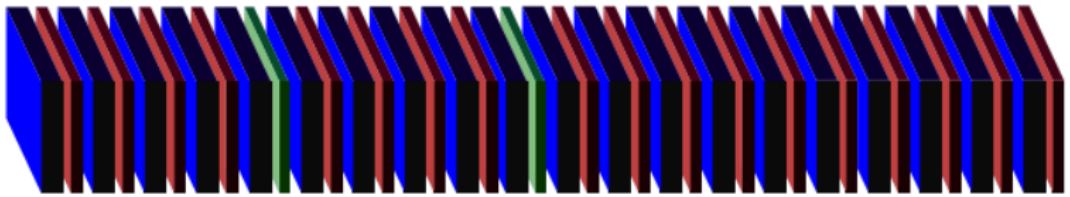
FoCal–E : EM Calorimeter

- High-granularity EM Calorimeter w/ Pixel & Pad Si sensors
  - 22 modules (93 x 101 cm^2)
  - Photon Energy up to ~2 TeV
- 20 X_0 : 20 W absorber
  - W : X_0 ~ 3.5mm, R_m ~ 9mm
- 18 Pad layers (1 x 1 cm^2)
  - Energy measurements by ADC & TOT
  - Timing (HGCROC)
  - P-type Si sensor (radiation hardness)
- 2 Pixel layers (27 x 29 μm^2)
  - Shower position for two photon separation
  - ALPIDE MAPS chips (from ITS2 and MFT)
- 3D imaging of EM-shower by reading individual layer and channels



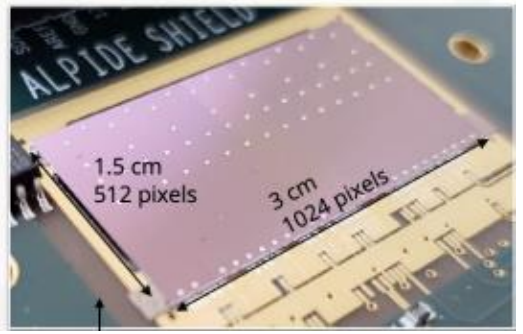


Longitudinal segmentation



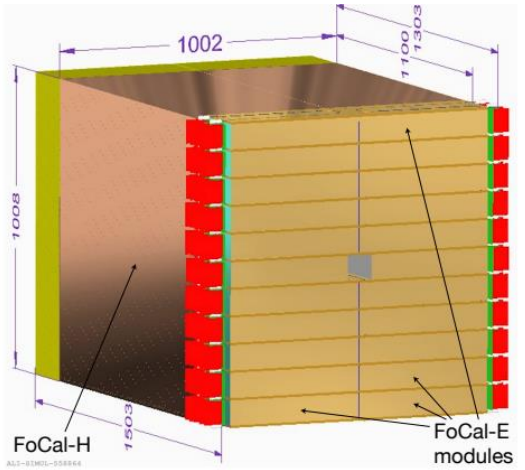
Pad Sensor

Pixel Sensor



TDR CERN-LHCC-2024-004

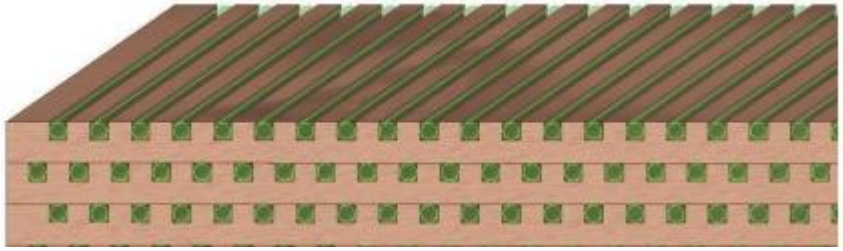
FoCal-H : Hadron Calorimeter



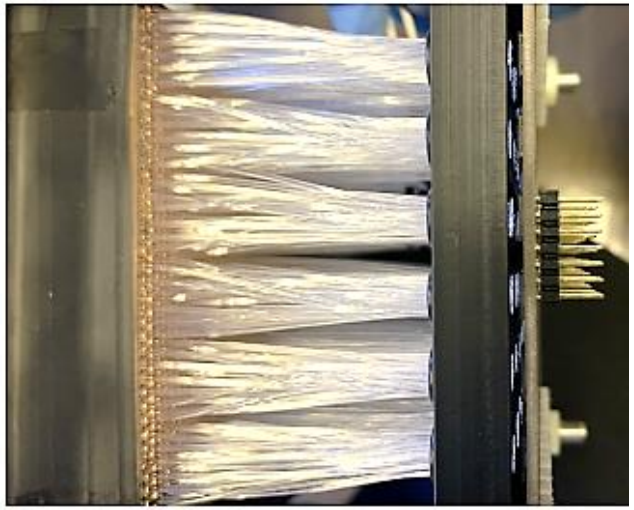
- Cu + SciFi hadronic calorimeter
  - 90 x 90 x 110 cm^3 depth ~ 6 λ_{had}
  - SiPM readout + H2GCROC (HGCROC for SiPM)

- Final design in progress
  - Cu sheet w/ grooves for SciFi
  - 5 x 50 x 110 cm^3
  - New design to be tested in 2025

Cu sheet w/ grooves



SciFi connected to SiPM



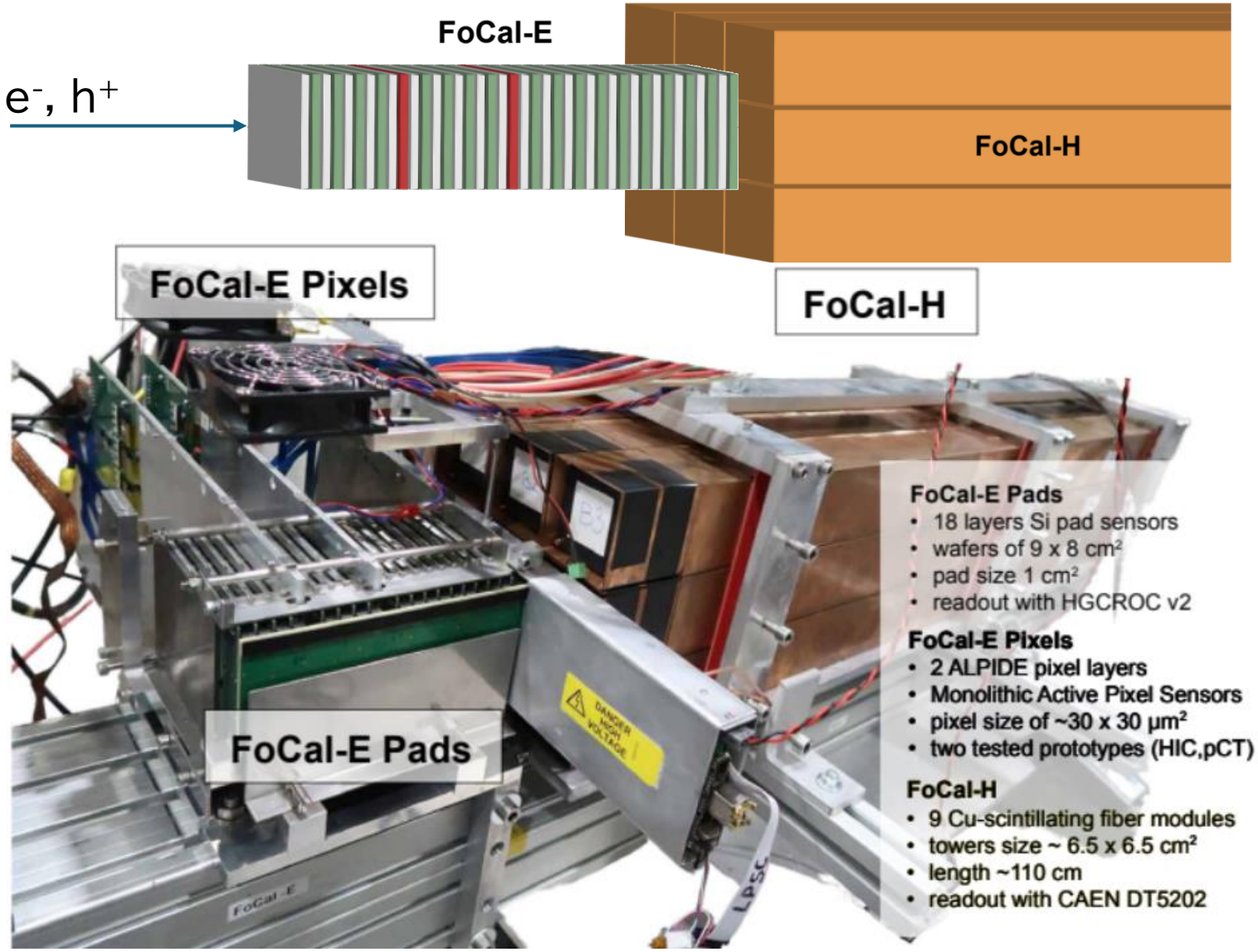
SiPM

TDR CERN-LHCC-2024-004

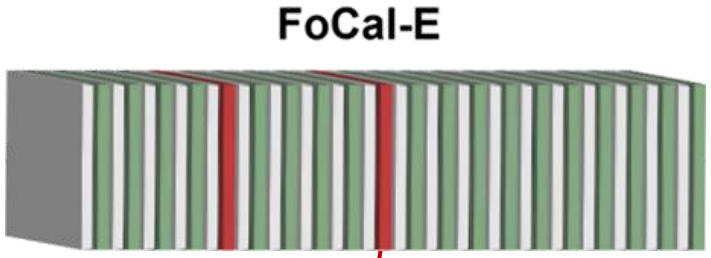
Performance at Beam Test

Test beam paper JINST 19 P07006

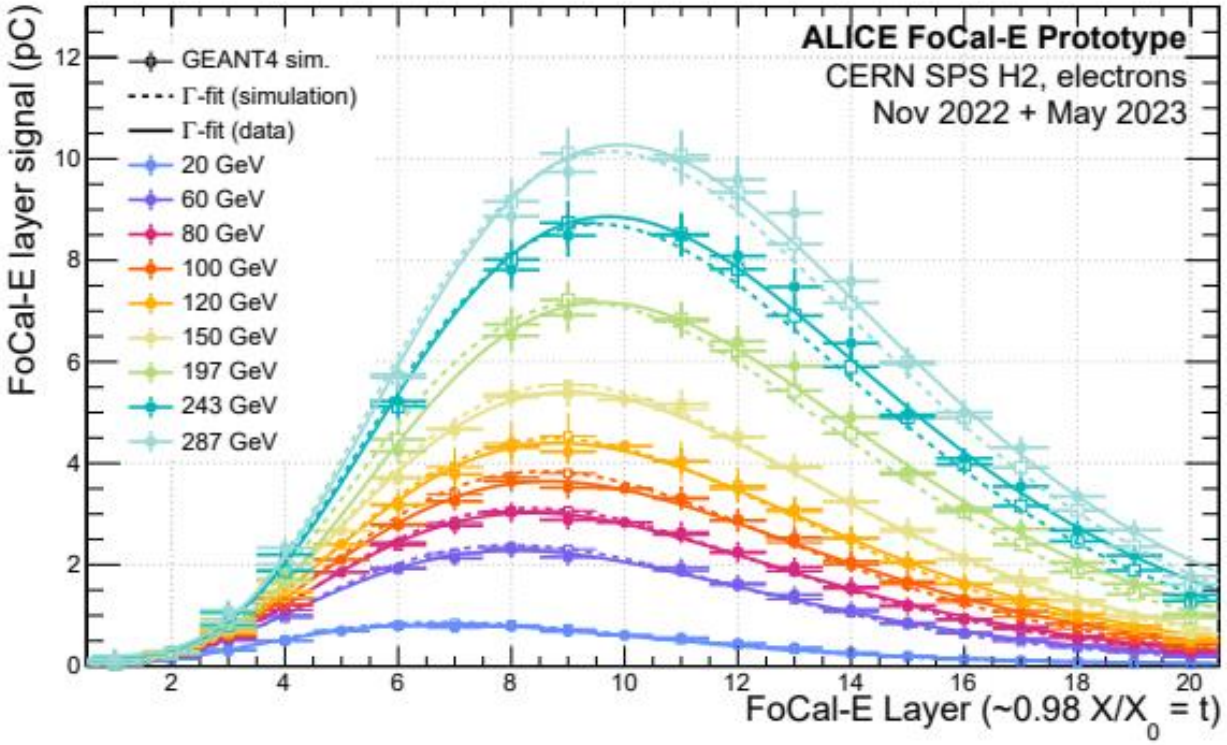
- Test Beam at CERN PS & SPS (2022 & 2023)
  - Electron beam < 300 GeV
  - Hadron beam < 350 GeV
- FoCal E & H Prototype
  - Full stack of modules in longitudinal configuration
  - EM calorimeter
    - 18 Si Pad layers
    - 2 Si Pixel layers
  - Hadronic calorimeter
    - 110cm Cu capillary tube



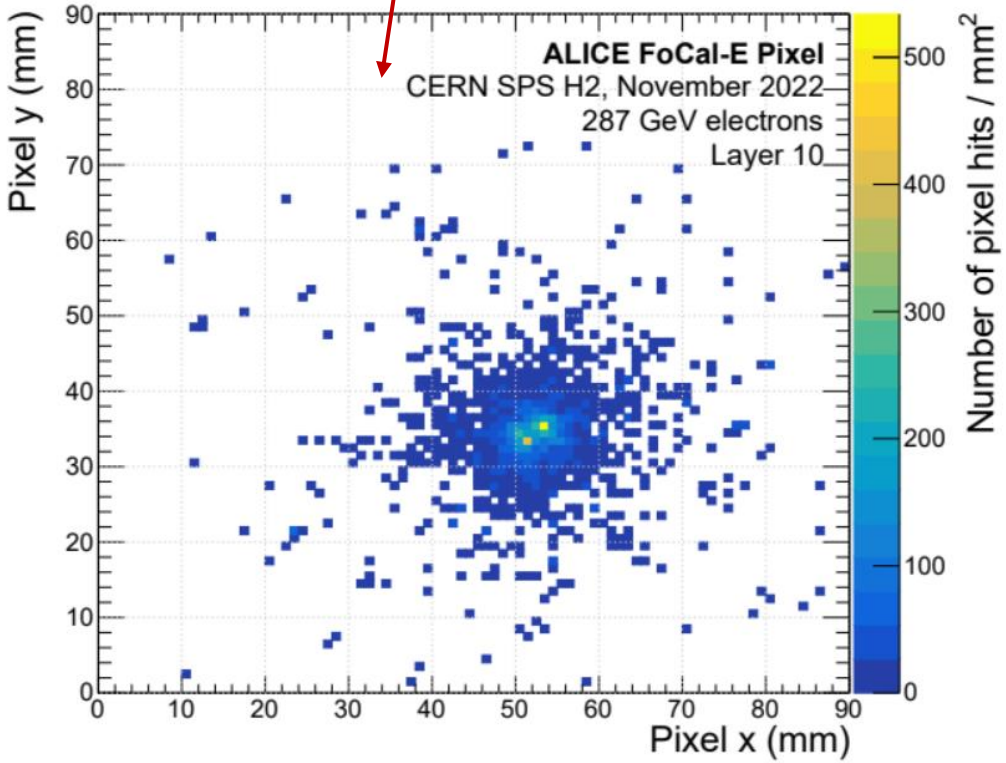
FoCal-E EM-shower



Longitudinal shower profile in FoCal-E



Two electron separation in pixel

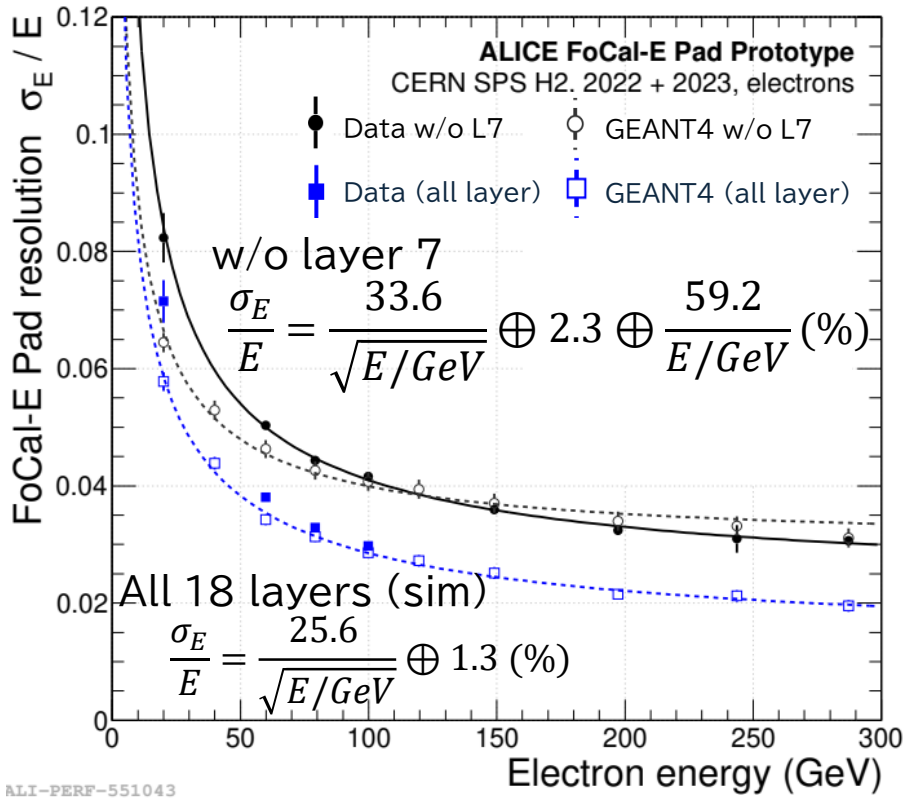


- Shower profile is good agreement w/ simulations : 20 – 287 GeV
- A clear two electron separation
  - Good for isolated photon

Test beam paper JINST 19 P07006

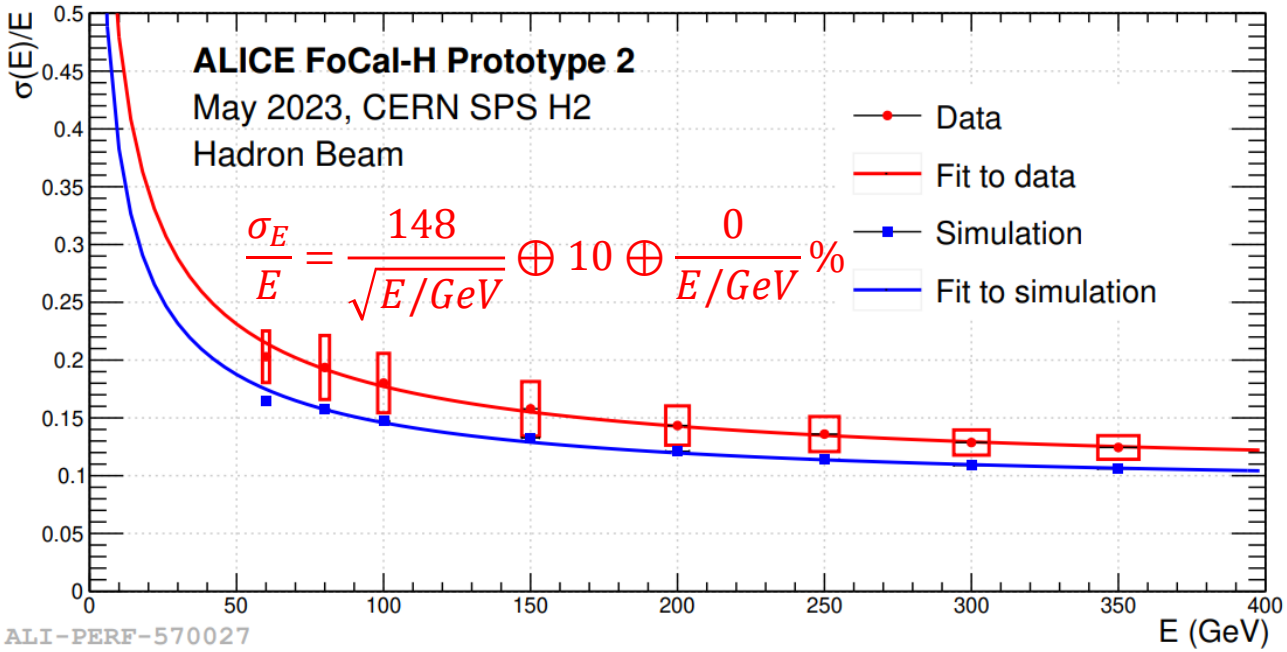
FoCal Energy resolution

FoCal-E resolution w/ electron beam



Test beam paper JINST 19 P07006

FoCal-H resolution w/ hadron beam



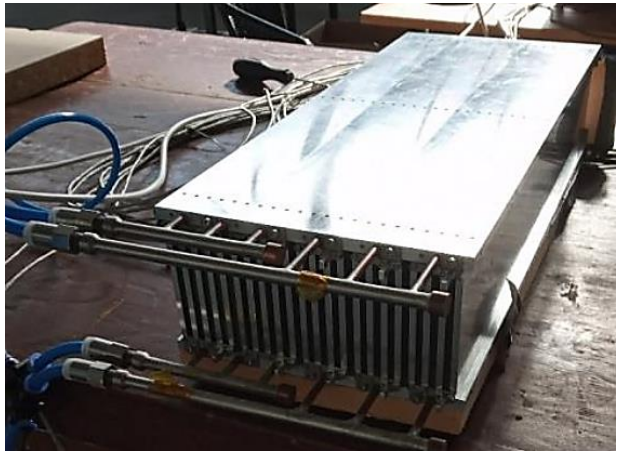
- FoCal-E Energy resolution 3% > 200 GeV
  - Simulation describes data well, but resolution degrades due to ADC/TOT noise at low energy
  - Performance can be further improved with 18-layer configuration
- FoCal-H Energy resolution 15% (>60 GeV)
  - Simulation doesn't reproduce data, light collection in data and/or need the simulation-tuning

Schedule and Mass-production

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
			Run3			LS3				Run4	
LOI				TDR							
		Beam Test@ PS, SPS	Beam Best@ PS, SPS	Final Design	Preproduction + Production			Installation commissioning			

- Final design & Mass production
  - Prototype shows good performance
- Procedure
  - Mechanical structure + Cooling test
  - Production
    - Pre-production + Beam Test
  - Installation & Commissioning

FoCal-E mockup for cooling test

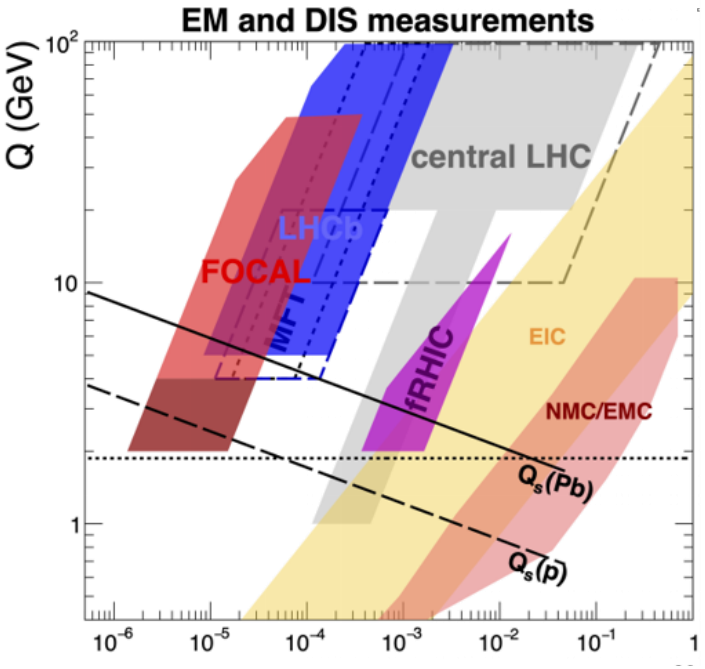


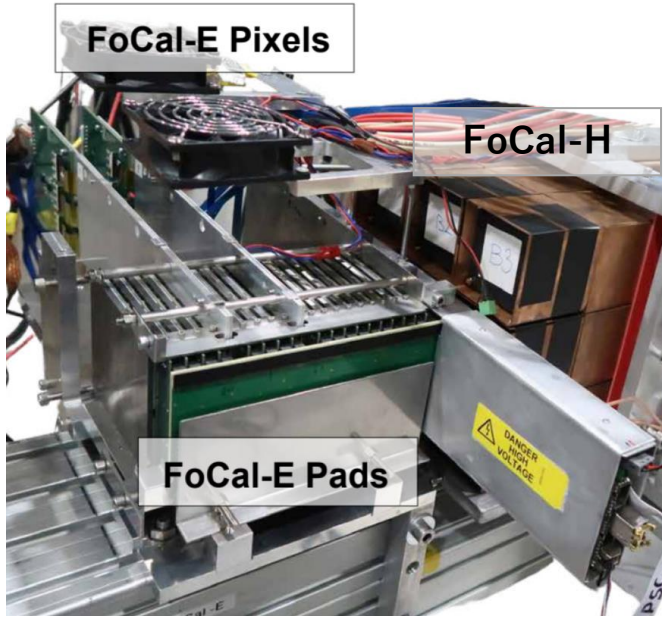
FoCal-E segment mockup w/ Tungsten

FoCal-H prototype

Summary

- **FoCal** is a new forward calorimeter for ALICE Run4
  - **High granularity EM + Hadronic calorimeters**
  - Broad phase space coverage ($3.4 < \eta < 5.5$)
  - Complimentary with EIC and LHCb
- Goal is **gluon saturation at small-x region** (~ 10^{-6}) with multi-messenger approach
  - **Prompt photons**, π^0, Jet, J/ψ in UPC
  - Simulation study demonstrates FoCal capabilities
- FoCal prototype shows **good energy resolutions** and **two cluster separation**
- Mass production is about to start !





Paper list

- FOCAL Letter of Intent CERN-LHCC-2020-009
- Physics of the ALICE Forward calorimeter upgrade, ALICE-PUBLIC-2023-001
- Physics performance of the ALICE FoCal upgrade, ALICE-PUBLIC-2023-004
- Test beam paper: Performance of the electromagnetic and hadronic prototype segments of the ALICE Forward Calorimeter, JINST 19 P07006
- Technical Design Report, CERN-LHCC-2024-004