A Forward Calorimeter in ALICE

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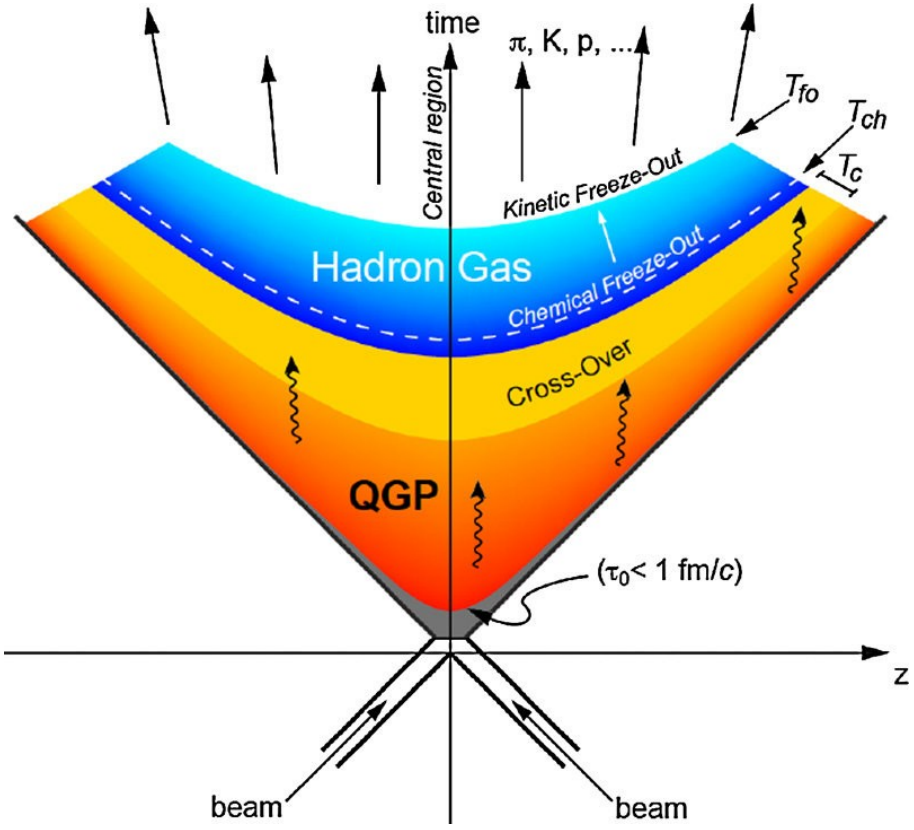
Contents

- Physics program of a forward calorimeter at the LHC
- FoCal detector upgrade in ALICE
  - Design
  - Projected performance
- Prototype tests with beam
- Summary and outlook

Heavy-Ion Collisions and the QGP



P.A.Steinberg, Plenary 1
L.Apolinario, Plenary 3

- Mission: study of the deconfined state of nuclear matter, QGP, using relativistic heavy-ion collisions (HIC)
- Need to disentangle effects originating in all the other stages of the collision: initial state, hadronization

Initial state and parton PDFs

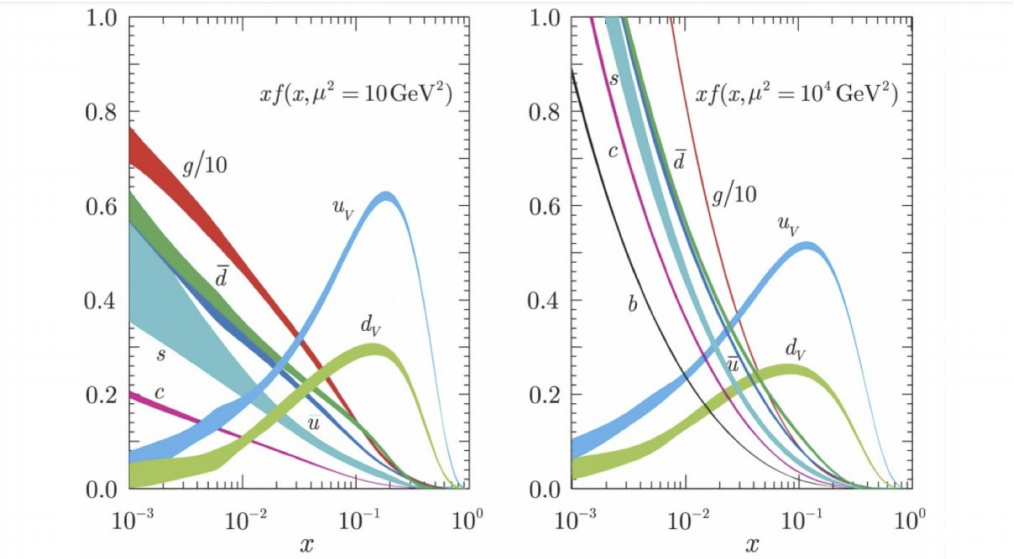


Figure 5.26 Parton distribution functions from a global analysis of data at two different energy scales $\mu^2 = Q^2$. Source: Adapted from Foster et al. (2018).

- Parton PDFs in free nucleons already part of textbooks, legacy of DESY experiments

Initial state and parton PDFs

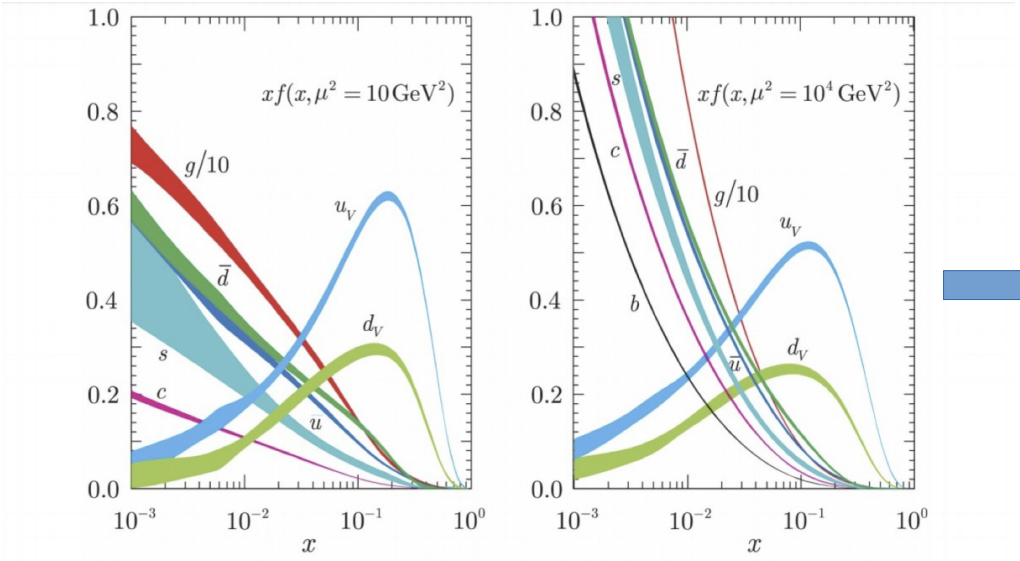
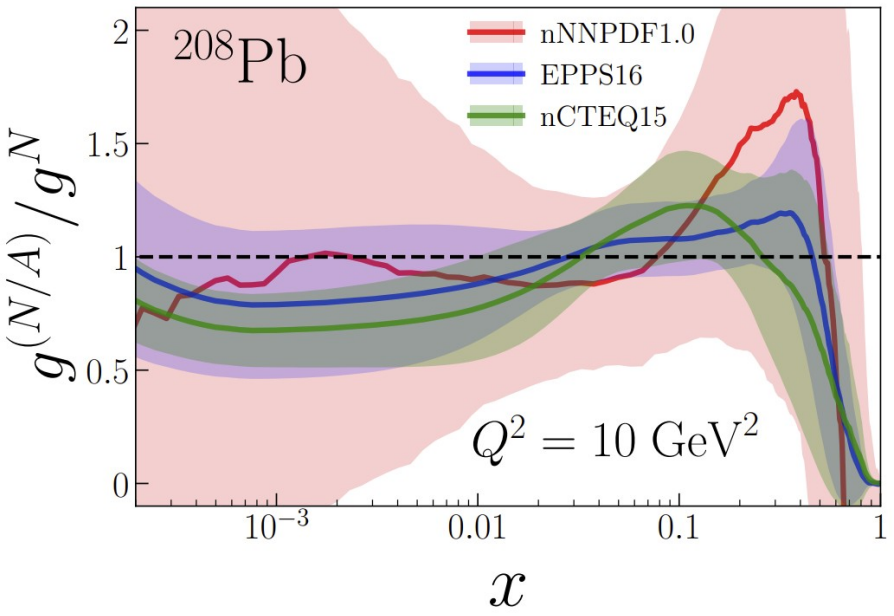
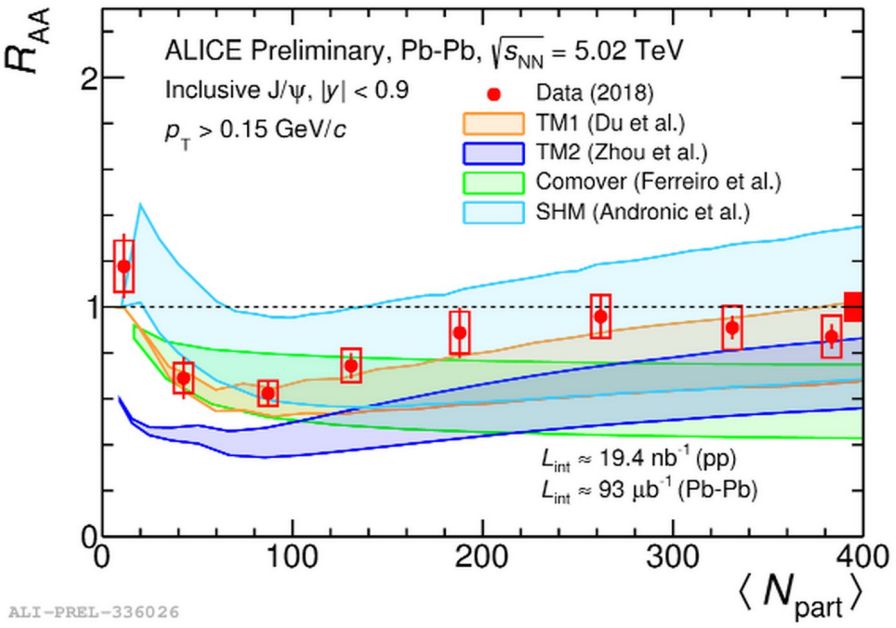


Figure 5.26 Parton distribution functions from a global analysis of data at two different energy scales $\mu^2 = Q^2$. Source: Adapted from Foster et al. (2018).



- Parton PDFs in free nucleons already part of textbooks, legacy of DESY experiments
- PDFs of nucleons embedded in nuclei (nPDFs) are modified, as shown initially by the EMC Collaboration
- Large uncertainties on the nPDFs, in particular for gluons at low Bjorken-*x*

Initial state and parton PDFs

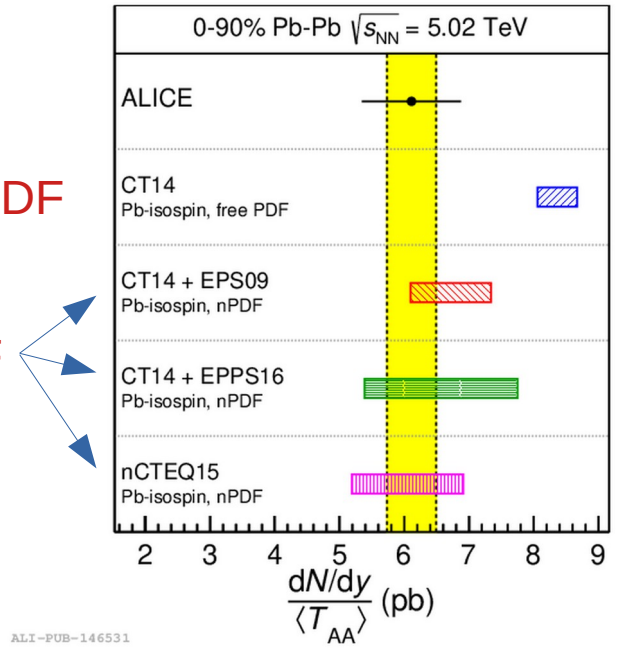


J/ψ nuclear suppression:
sensitive to gluon nPDFs

ALICE, JHEP 2009 (2020) 076

free PDF

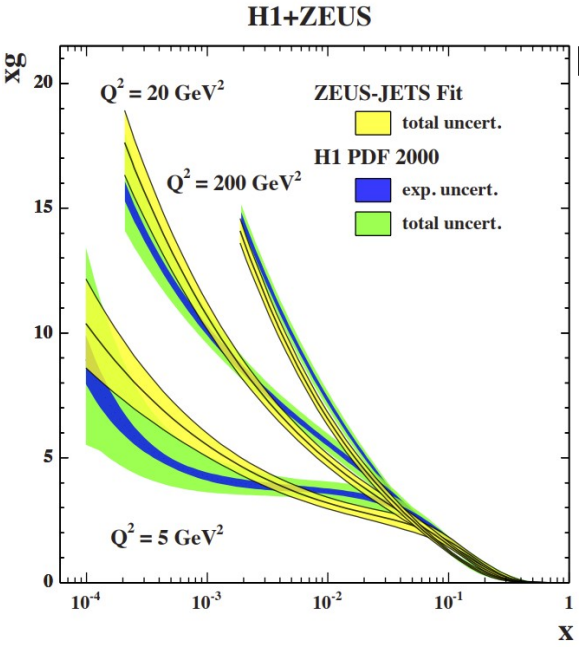
nPDF



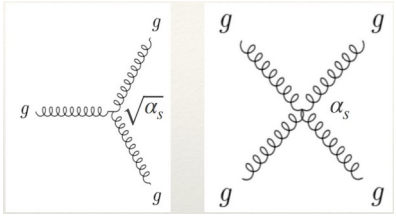
Z^0 production at 2.5<y<4:
sensitive to quark nPDFs

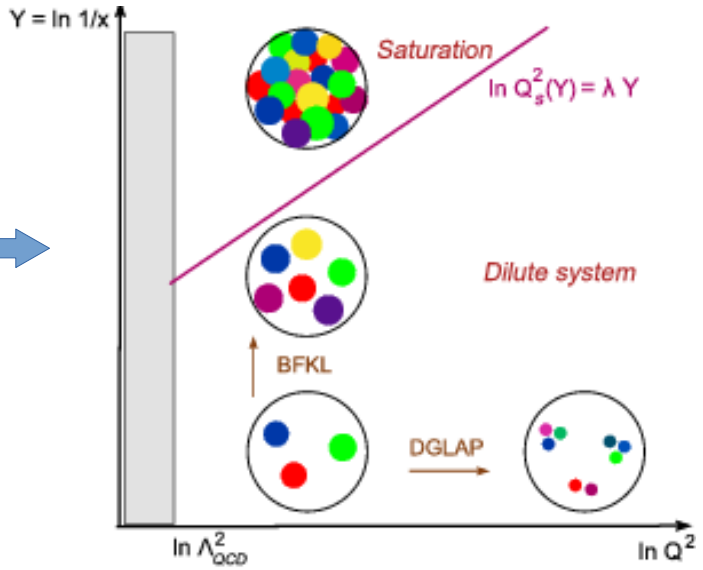
- Uncertainty on nPDFs directly impacts on the interpretation of observables in heavy-ion collisions

Gluon saturation



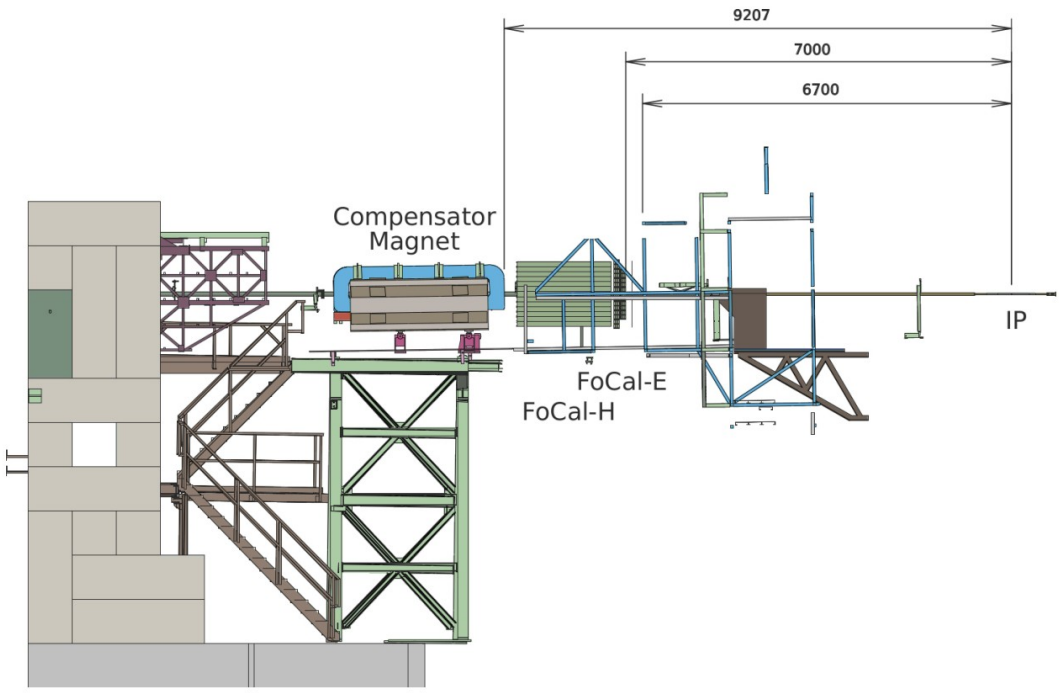
B.Xiao, Plenary 1





- Gluon density increases with Q^2 and 1/x
- At high density, gluon fusion processes become important, possibly leading to a saturation density at an energy scale $Q_s(x)$
  - Fundamentally new regime, also known as Color Glass Condensate (CGC)
  - Higher density in nuclei → CGC effects expected at larger *x*
- Some hints from p-Pb collisions: long range correlations, azimuthal anisotropy, ...

A Forward Calorimeter in ALICE (FOCAL)



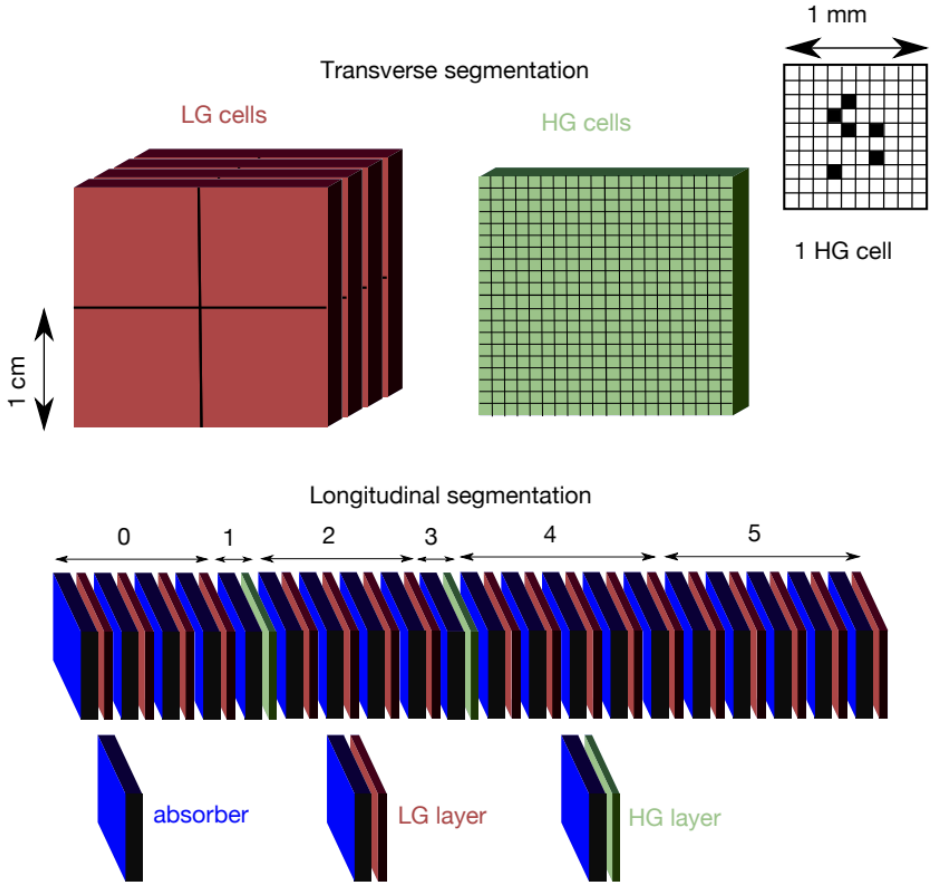
ALICE, LHCC-I-036 (2020)

- Detector of choice: forward calorimeter (3.4<η<5.8)
  - Electromagnetic: FoCal-E
  - Hadronic: FoCal-H
- Main observable: direct photons
- Complementary observables:
  - π^0
  - Jets
  - Quarkonia
  - Z^0 and $W^{\pm}$

Aims:

- Explore the small-x structure of nucleons inside nuclei down to Bjorken-x of ~10^{-6}
- Study the longitudinal dependence of particle production in HICs using π^0, jets and long range correlations

High granularity EM calorimeter: FoCal-E



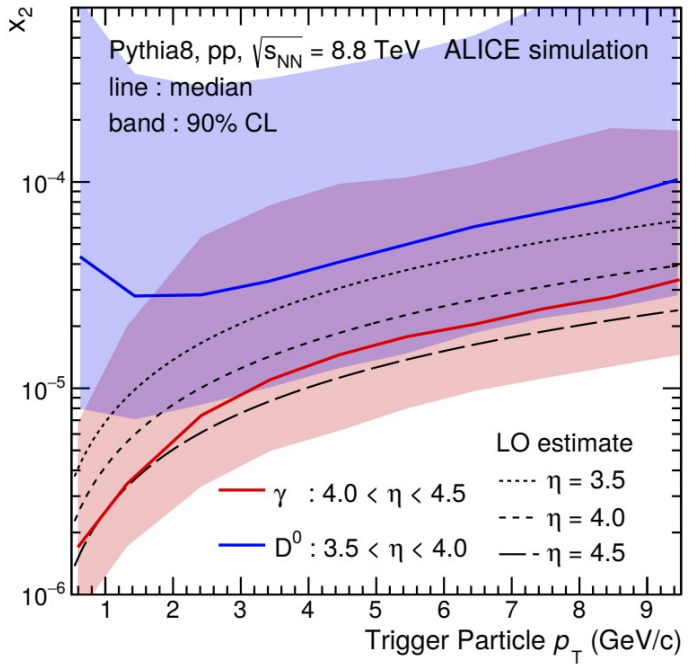
ALICE, LHCC-I-036 (2020)

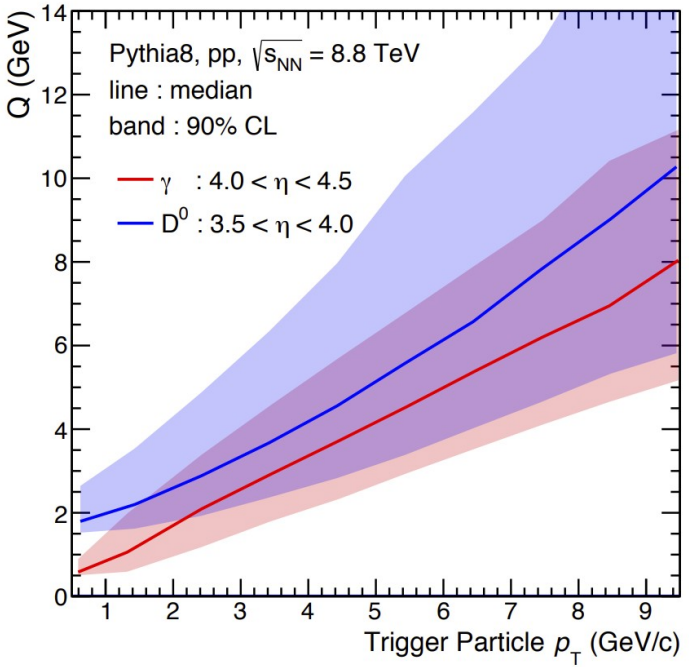
20 layers, each including
- 3.5 mm tungsten (~ 1 X_0)
- Silicon sensors

Hybrid readout design:
- Silicon pads: ~ 1x1 cm^2
  - Energy measurement, timing
- CMOS pixels: ~ 30 x 30 μm^2
  - Two-shower separation, position resolution

- Challenge: separate photons from π^0 at large momentum
- Requirements:
  - Small Molière radius
  - High granularity read-out

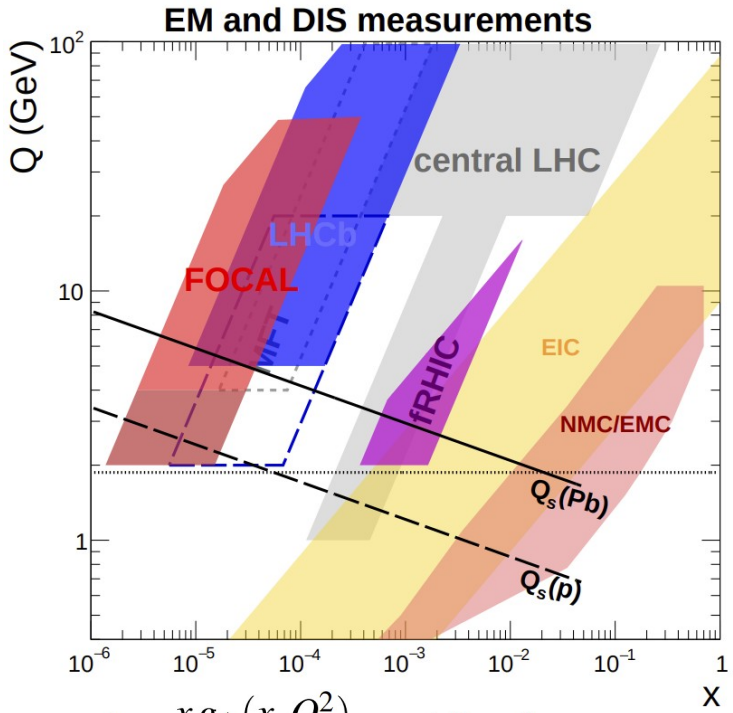
Sensitivity to gluon PDFs

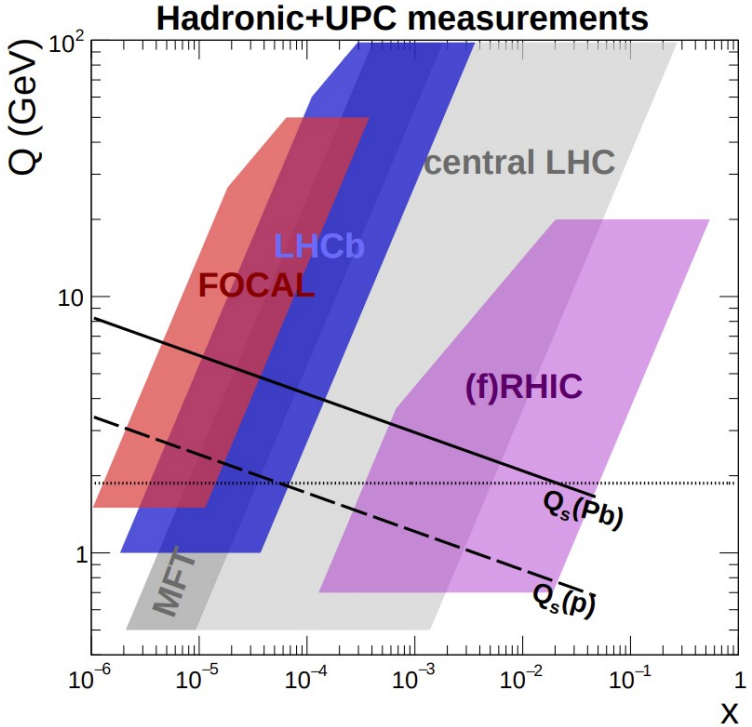




- PYTHIA pp 8.8 TeV simulations
- Both direct photons and D^0 mesons are sensitive to gluon PDFs
- Compare expected performance of LHCb D^0 and FoCal photons
- Overall better coverage at low-x expected with FoCal

Sensitivity to gluon PDFs

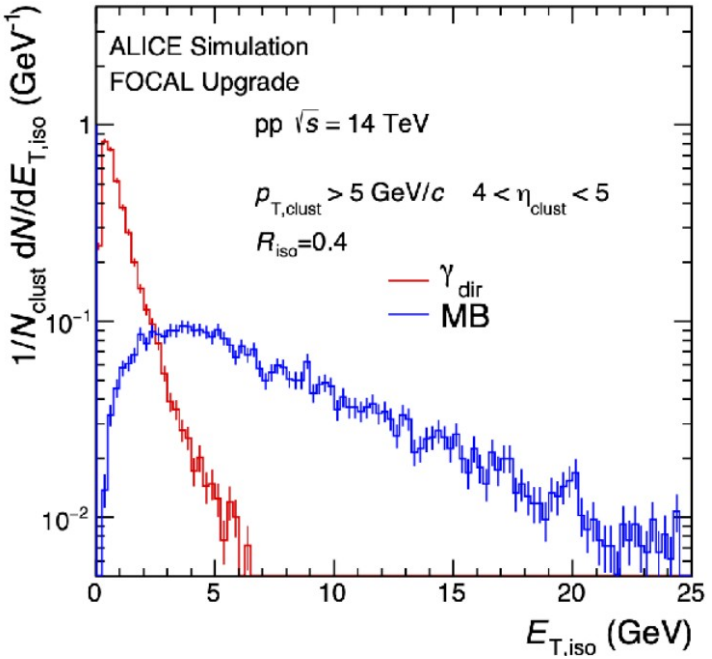


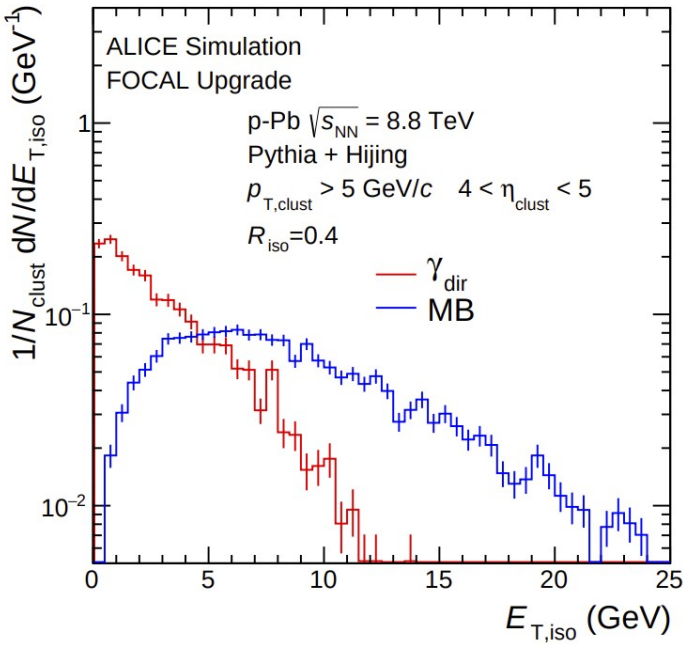


$$Q_s^2 \approx \frac{x g_A(x,Q^2)}{\pi R_A^2} \propto A^{1/3} x^{-\lambda}$$

- Kinematic reach of various DIS measurements and future electromagnetic (left) and hadronic (right) measurements
- FoCal uniquely placed to explore low-x physics over a broad range in Q^2

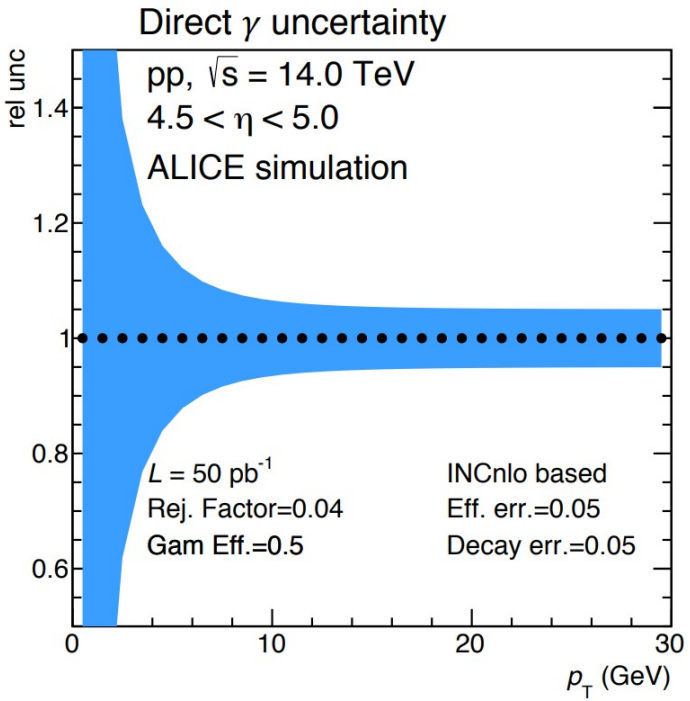
Direct photon reconstruction performance

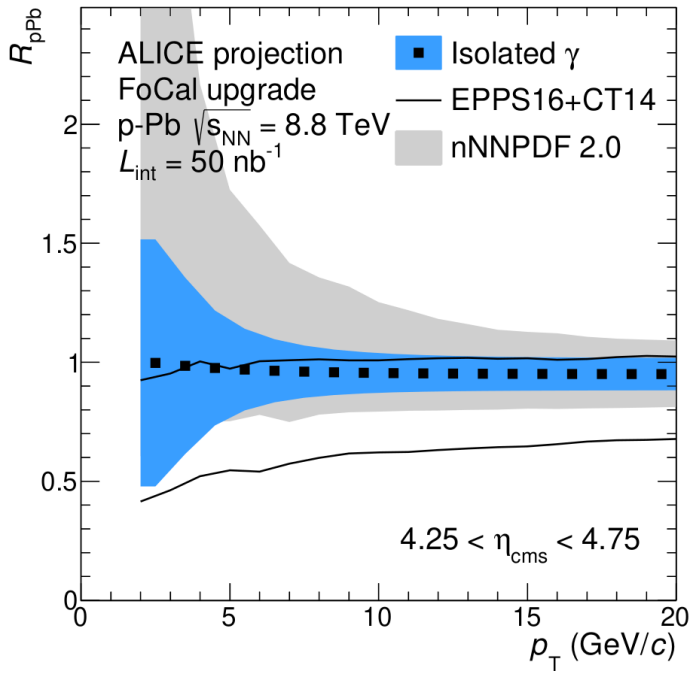




- Rejection of decay photons performed using selections on invariant mass, cluster shape and isolation energy veto
- Very good separation power for direct photons in pp and p-Pb collisions

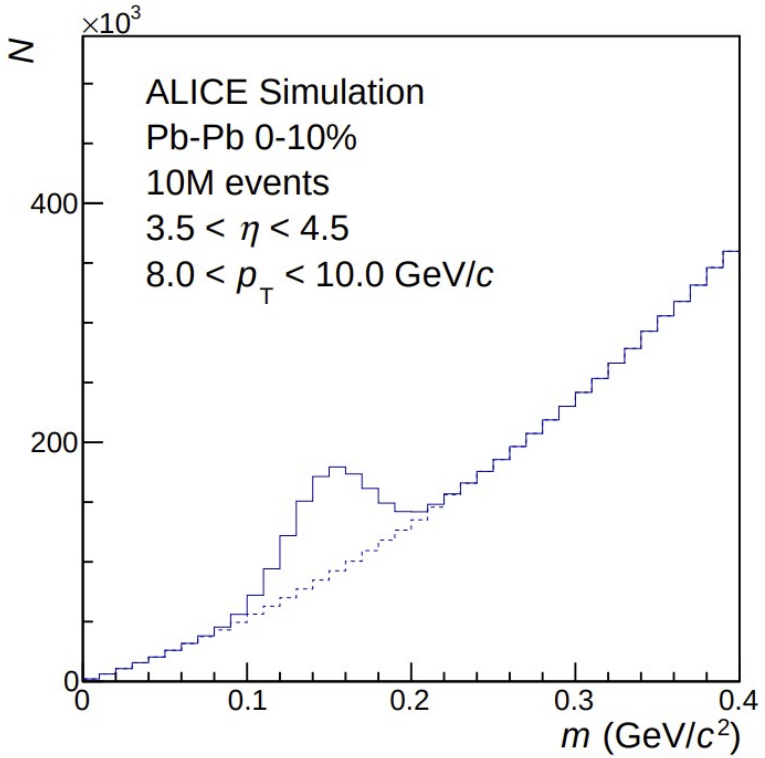
Direct photon reconstruction performance

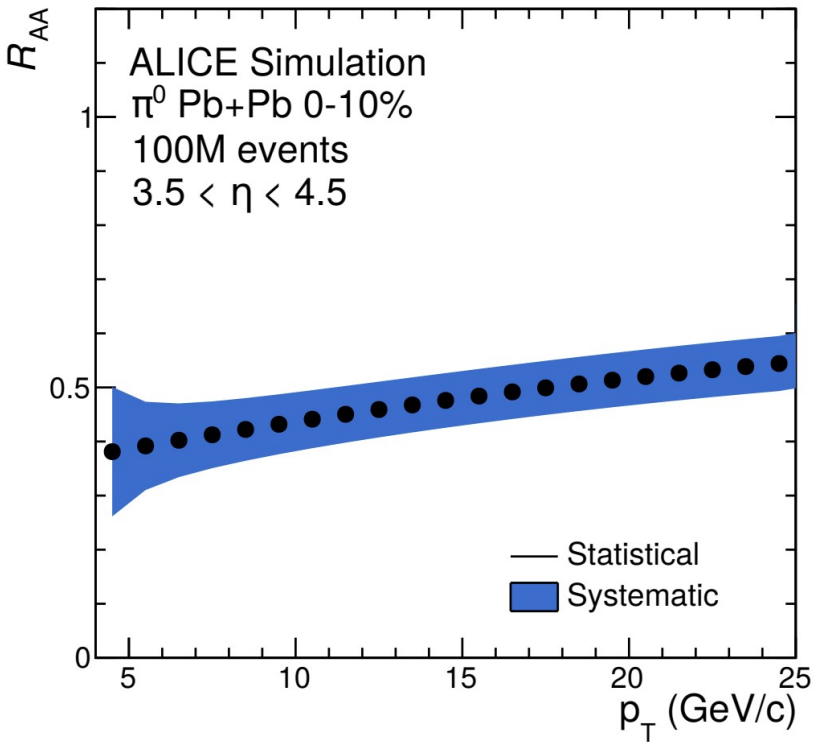




- Uncertainty on direct photon measurements < 10% for p_T>5 GeV/c
- Significantly constrains state of the art nPDFs such as EPPS16 and nNNPDF

π^0 measurements in Pb-Pb

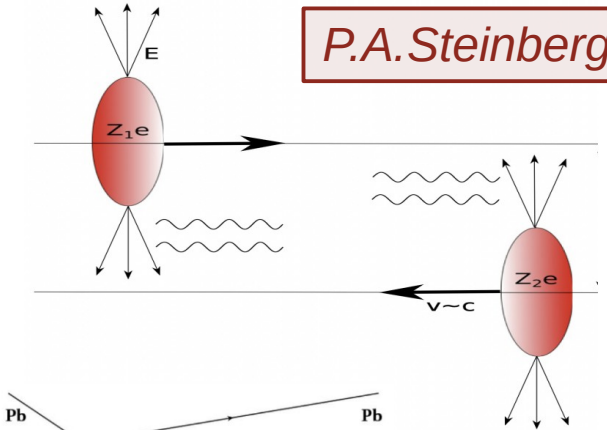




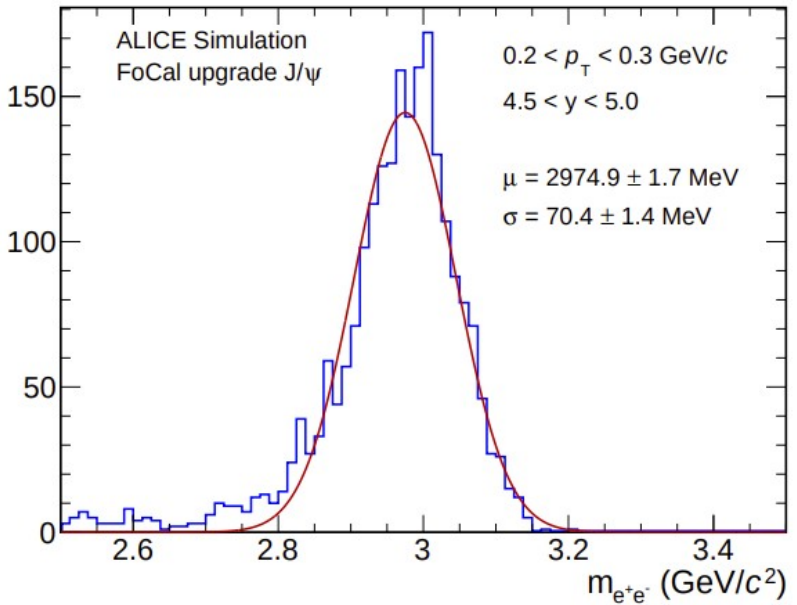
- Precise neutral pion measurements in central Pb-Pb collisions
- Explore longitudinal dependence of nuclear suppression, long range correlations, etc.

nPDFs using UPCs (p-Pb and PbPb)

P.A.Steinberg, Plenary 1

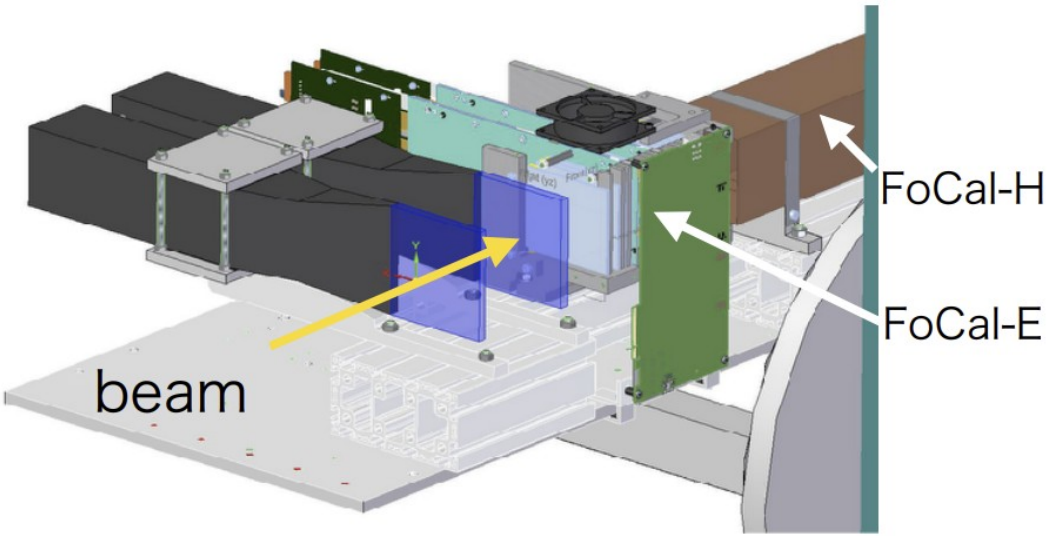


$$x = \frac{m_{J/\psi}}{\sqrt{s}} e^{\pm y}$$



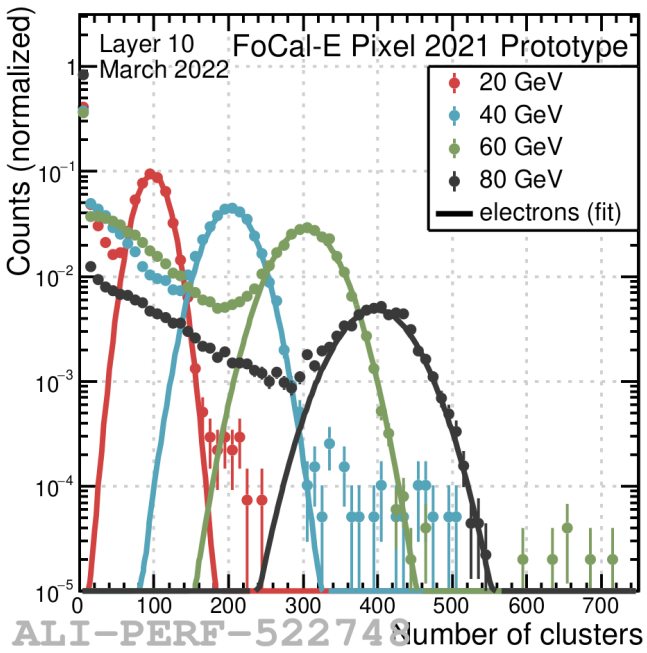
- Ultra-Peripheral Collisions (UPC) allow the study of vector meson photo-production in photo-nuclear processes
- Photo-nuclear production sensitive to nuclear gluon PDFs
- Very good reconstruction performance for J/ψ in the relevant kinematic range

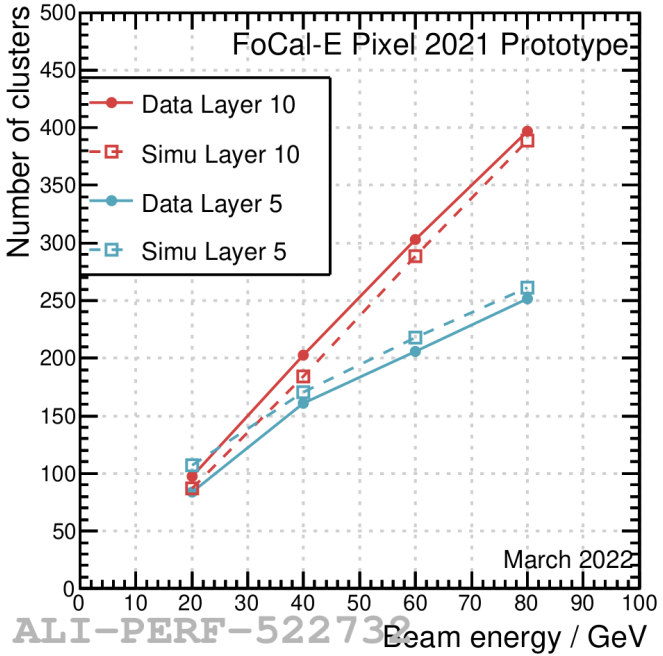
FoCal beam test at the SPS (2021)

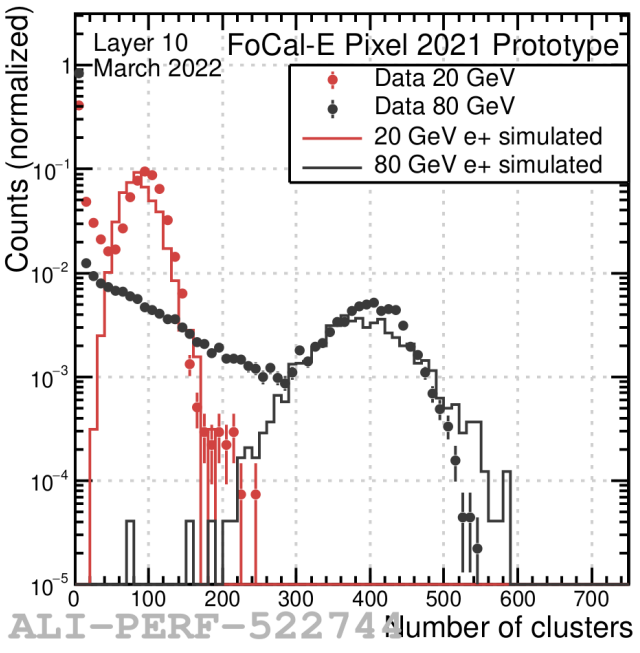


- Use H6 beam line, up to ~120 GeV
- FoCal-E:
  - 20 tungsten plates
  - 1 pad layer of a single Hamamatsu sensor
  - 2 pixel layers of 18 ALPIDE chips each, placed after 5 and 10 X_0, respectively

FoCal-E pixel layers (preliminary results)

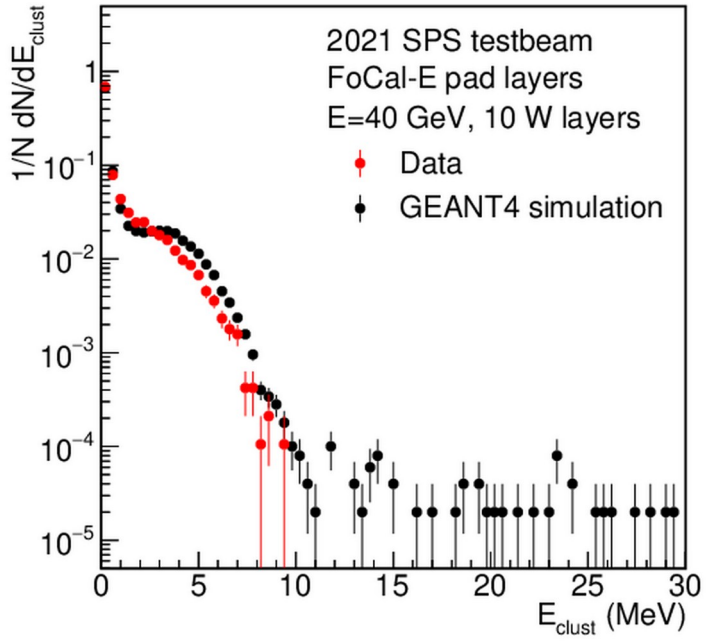


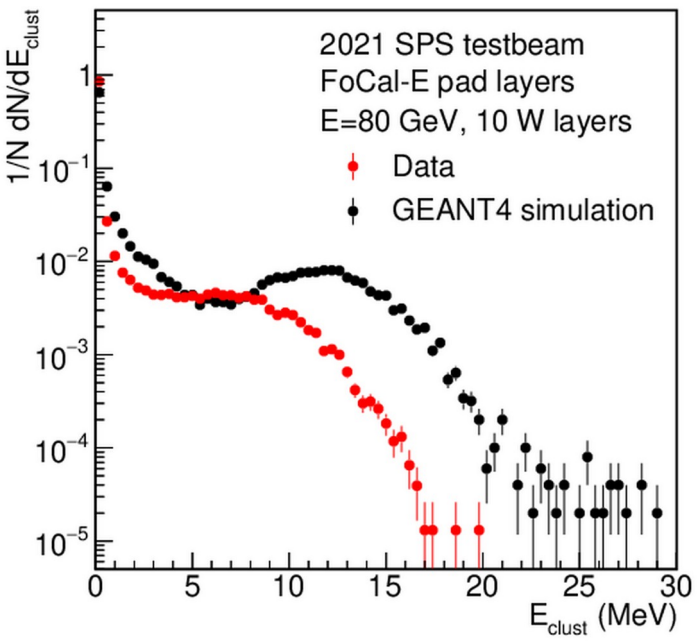




- Four beam energies tested: 20, 40, 60 and 80 GeV
- Work in progress for detailed understanding of data
  - Mean of electromagnetic component extracted using a gauss fit
  - Reasonable agreement with electrons simulated with GEANT4

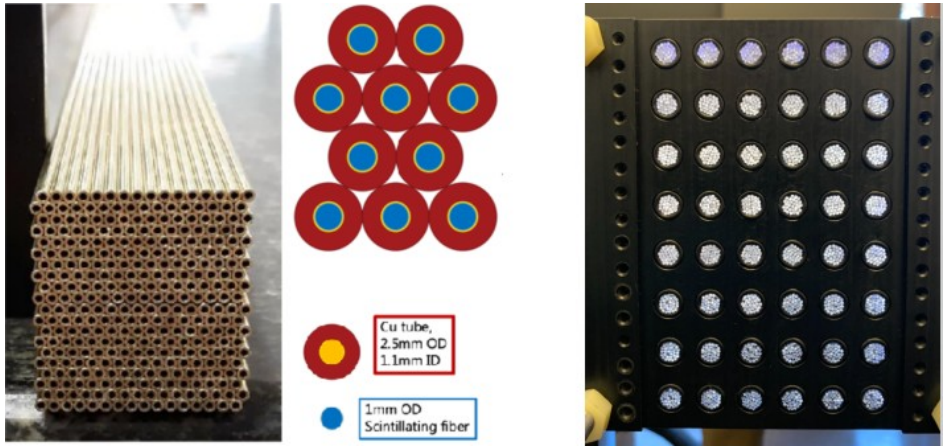
FoCal-E pad layer (preliminary results)

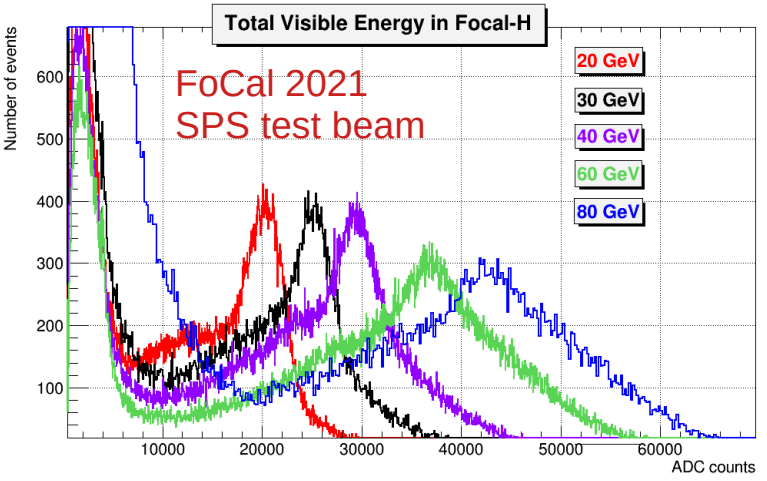


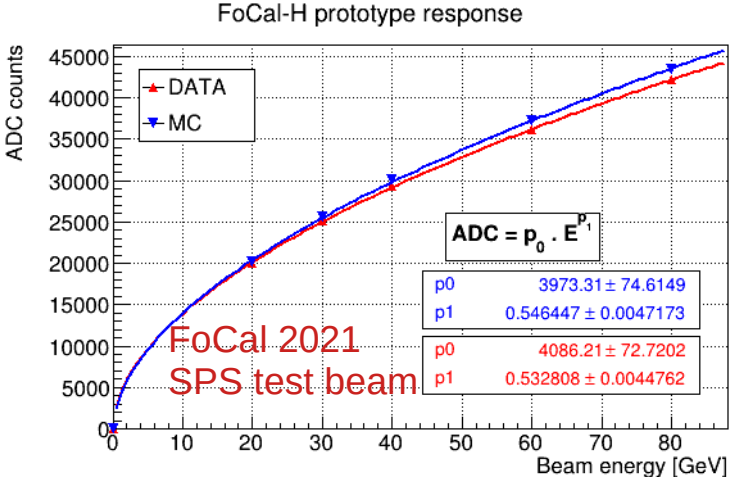


- Four beam energies tested: 20, 40, 60 and 80 GeV
- Work in progress for detailed understanding of data
  - Mean of electromagnetic component extracted using a gauss fit
  - Reasonable agreement with electrons simulated with GEANT4

FoCal-H (preliminary results)



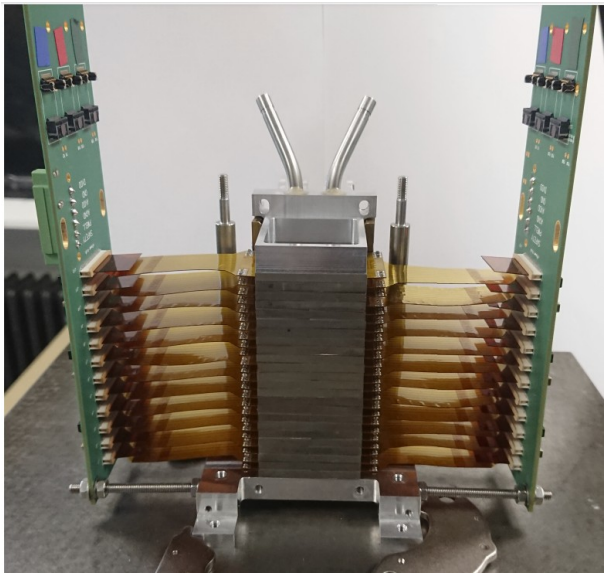


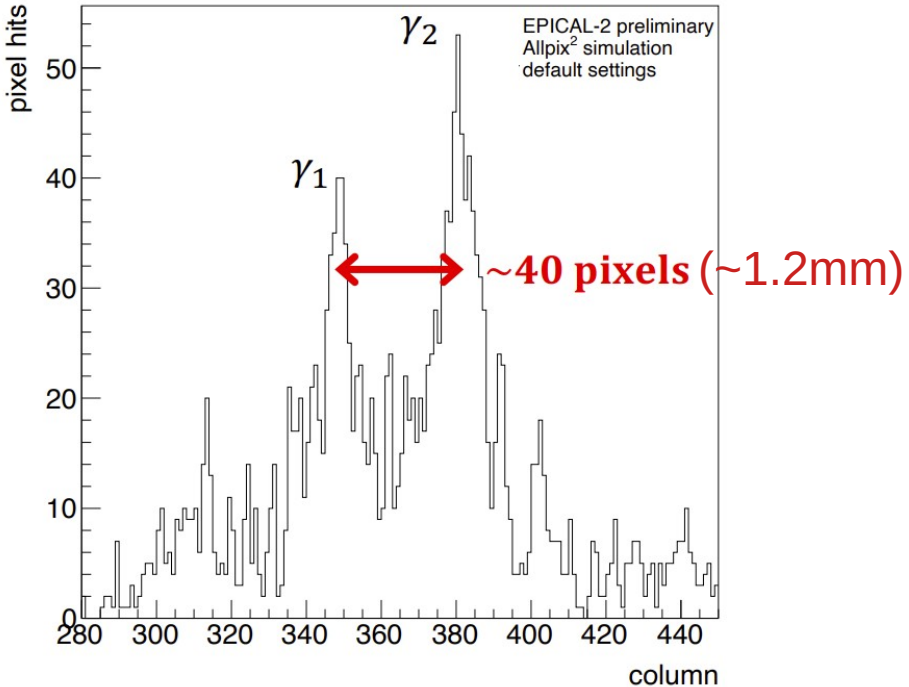


- Spaghetti-type calorimeter
- Geometry: 95 x 95 x 550 mm
  - 36x40 copper tubes filled with scintillating fibers
  - 48 SiPMs, readout by two CAEN boards

- Detector response well reproduced in GEANT4 simulations

EPICAL-2 prototype

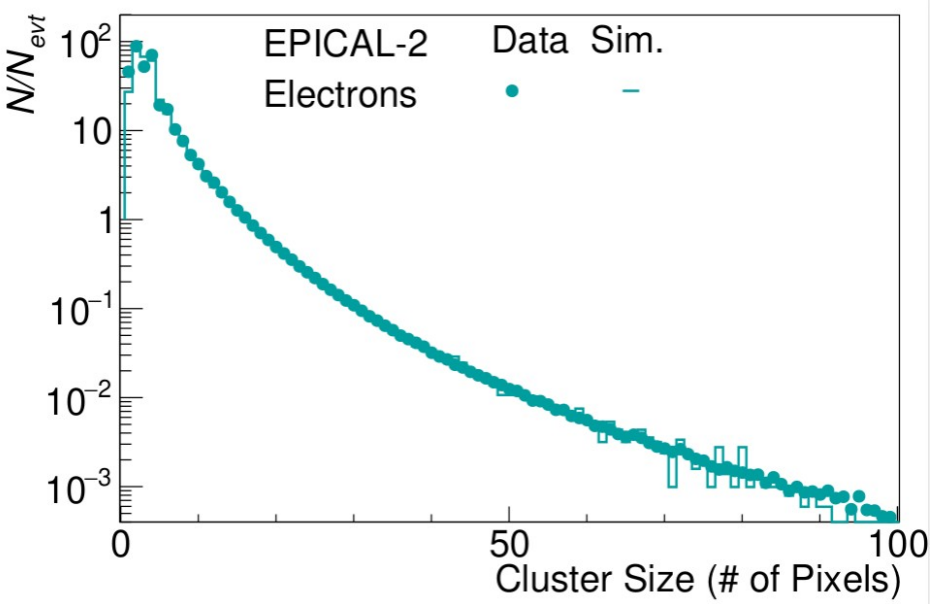


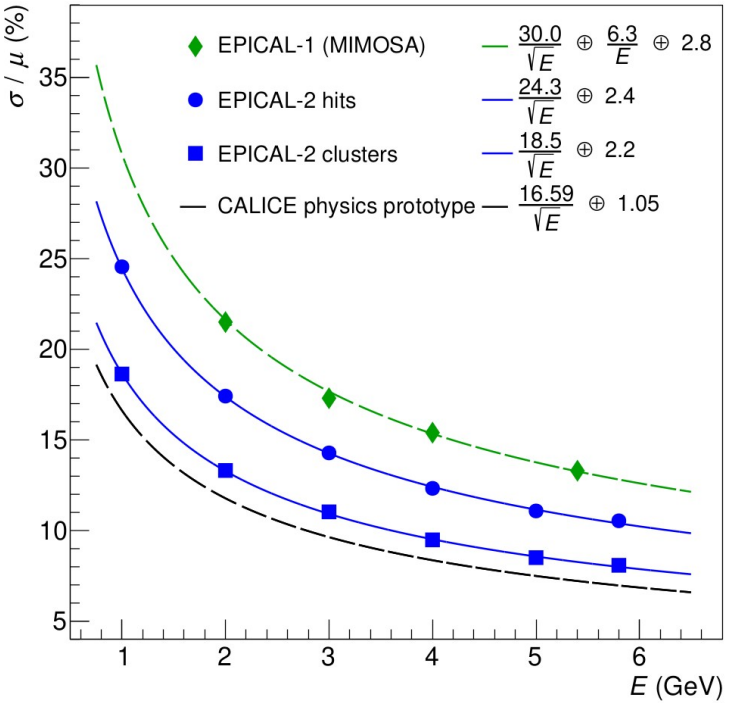


Fully digital calorimeter:

- 24 layers with 3mm tungsten each
- Readout using 2 ALPIDE sensor chips in each layer
- Transverse size: 30 x 30 mm, 1024 x 1024 pixels
- Two shower separation down to about 1 mm

EPICAL-2 beam test at DESY (2019)





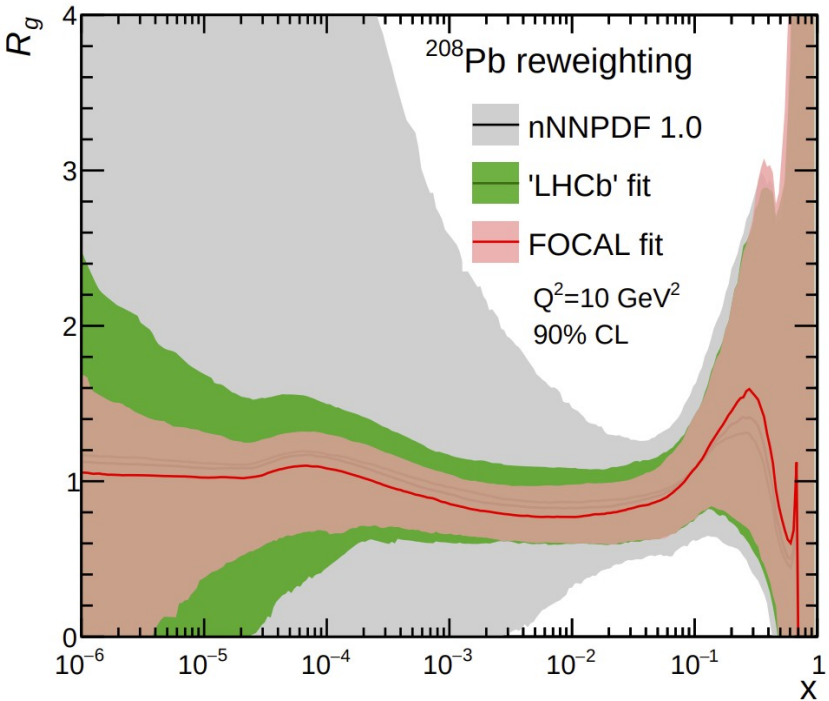
- Very good agreement between data and simulations
- Improvement on energy resolution wrt previous prototype based on MIMOSA sensors
- Ongoing analysis of the SPS test beam (2021)

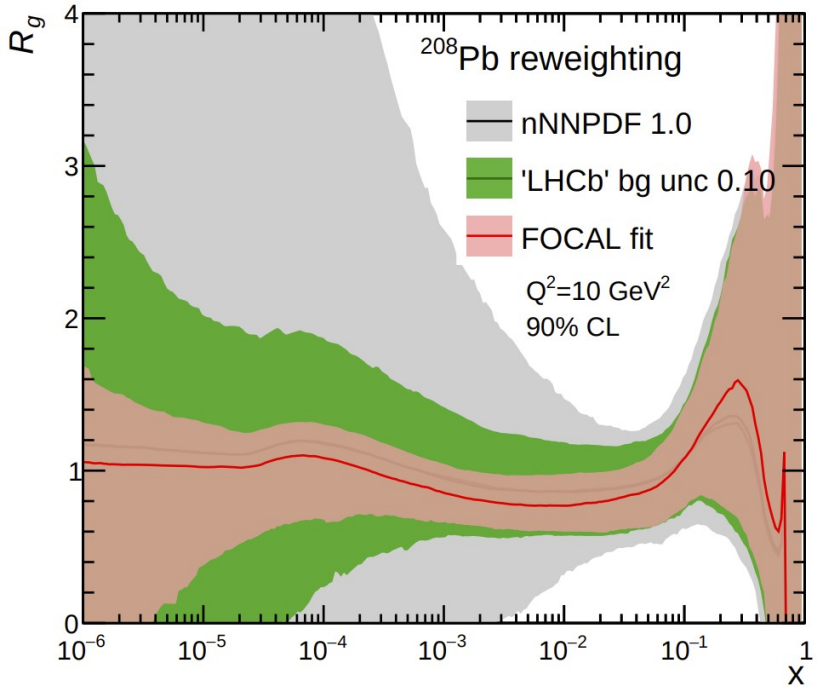
Summary

- Strong low-x programme enabled by the forward measurements with FoCal
  - Direct photons, π0, jets, quarkonia in UPC, electro-weak bosons
- Extensive R&D with prototypes
- Outlook
  - Two test beams in 2022:
    - June at CERN PS to test new pad electronics
    - Autumn at the SPS to test the demonstrator prototype
  - Summer 2023: finalization of R&D and Technical Design Report
  - LHC LS3 (2026-2028): FoCal installation and commissioning

Backup

FOCAL performance vs LHCb





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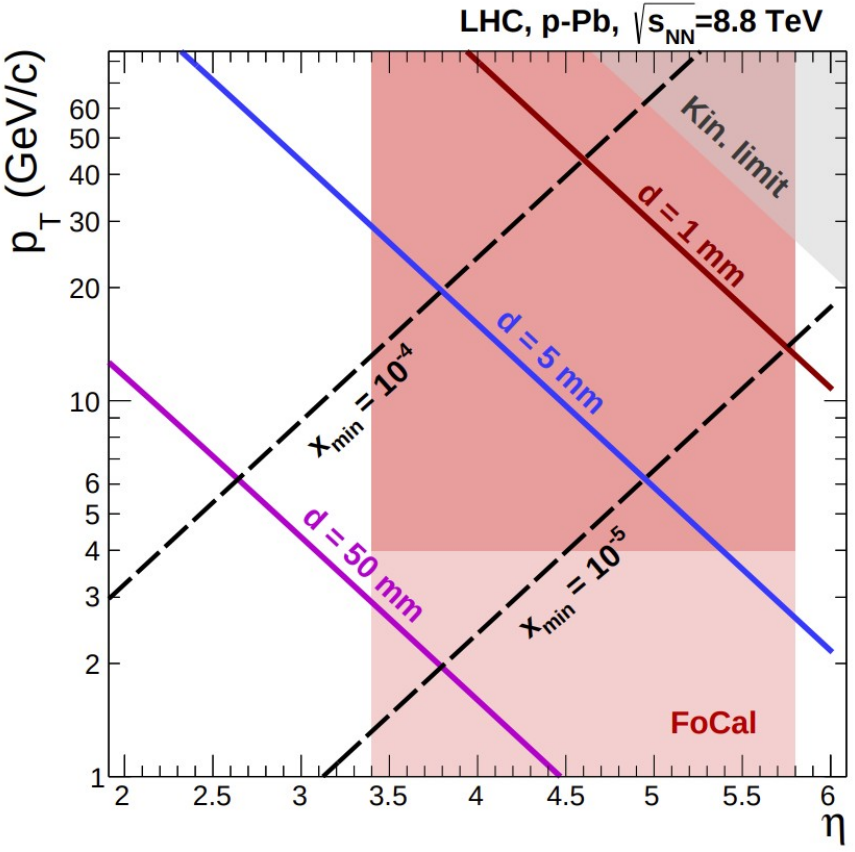

- Challenge: separate photons from π^0 at large momentum
- Requirements:
  - Small Molière radius
  - High granularity read-out