ALICE upgrade with Forward Calorimeter - exploring CGC and ultimately low-x region

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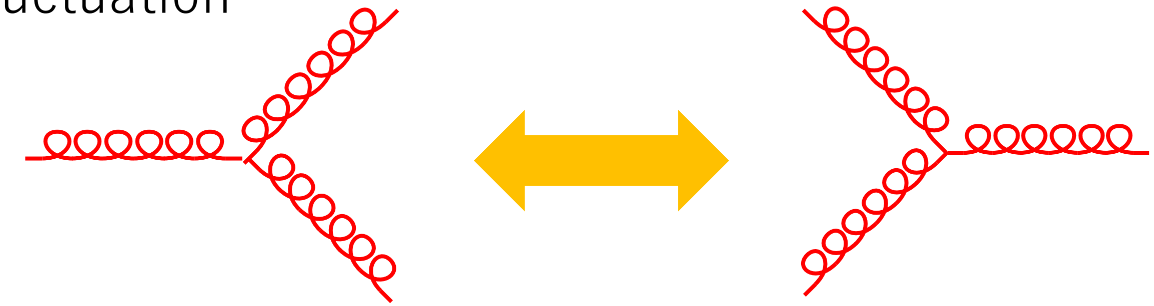
Outline

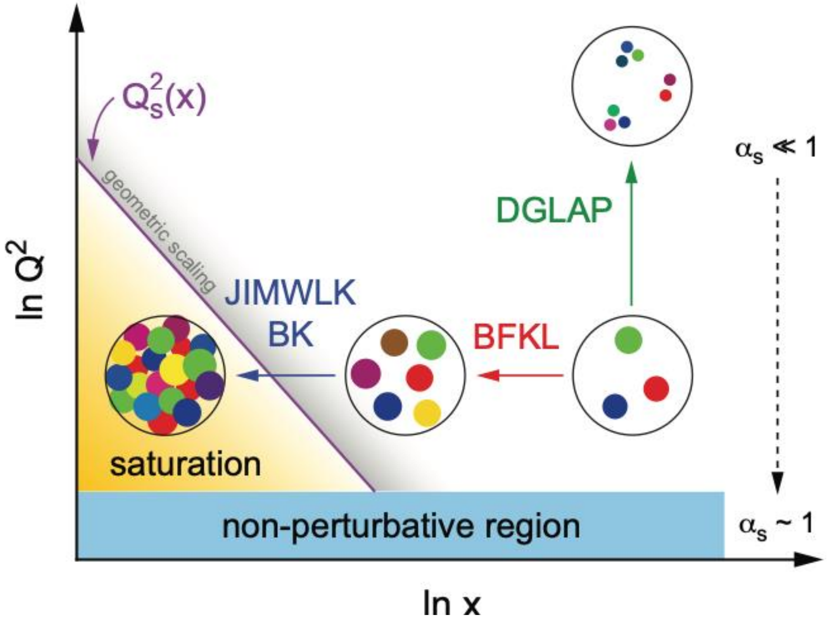
1. Physics motivations - forward physics and its relation to Quark Gluon Plasma physics
2. ALICE plan with FoCal detector and its system
3. FoCal performance
4. Summary

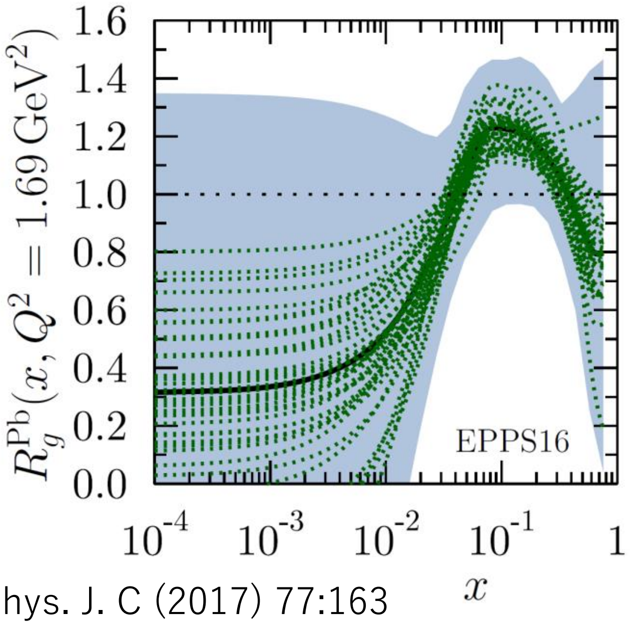
Gluon saturation and CGC

- Gluon self interaction (three-point interactions)
  → gluon fluctuation



- small-x gluons exist longer at high energy → further fluctuation
- gluon fusion and generation → equilibrate
  → small-x gluon saturation → Color Glass Condensation (CGC)
- Saturation scale depends on x and A: $Q_{sat}^2 \approx \frac{xg_A(x,Q^2)}{\pi R_A^2} \propto A^{1/3}x^{-\lambda}$
- also there is large uncertainty in nPDF at small-x
- our main goal: exploring and finding proof of gluon saturation

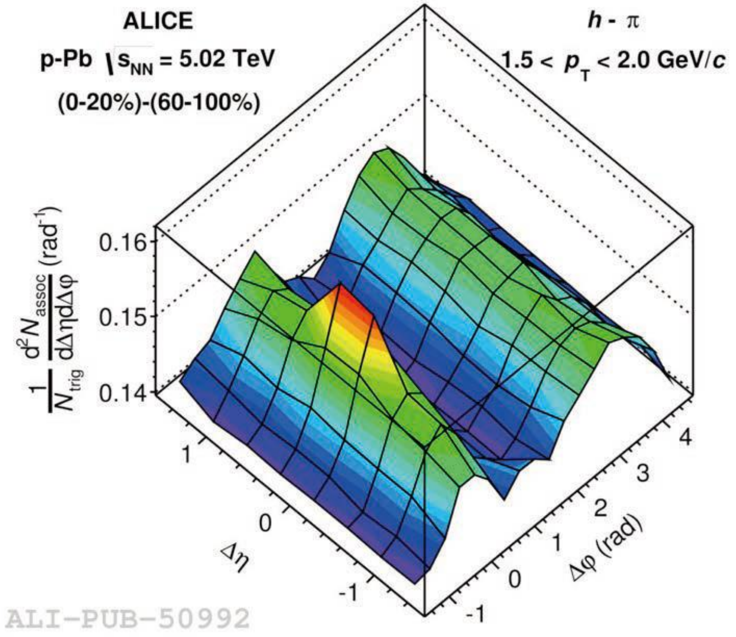




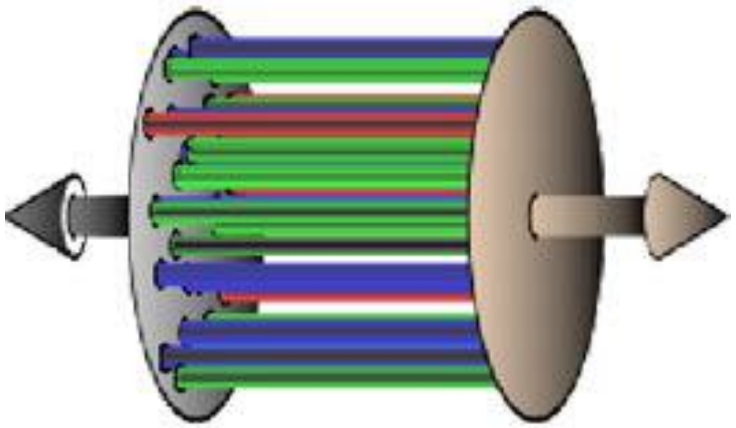
EPPS16 nuclear modifications for Pb Eur. Phys. J. C (2017) 77:163

Quark Gluon Plasma and CGC

CGC? | initial collision | GLASMA? | QGP (thermalized strongly interacting medium)



- Gluon saturation may play important role in quark gluon plasma formation and essential for systematic studies of hot and dense matter (AA)
- Long range η correlations (ridge) at RHIC and LHC observed
  - Au-Au, d-Au, p-Pb, and even in pp (high multiplicity)
  - CGC, Initial-state correlation to the final state?

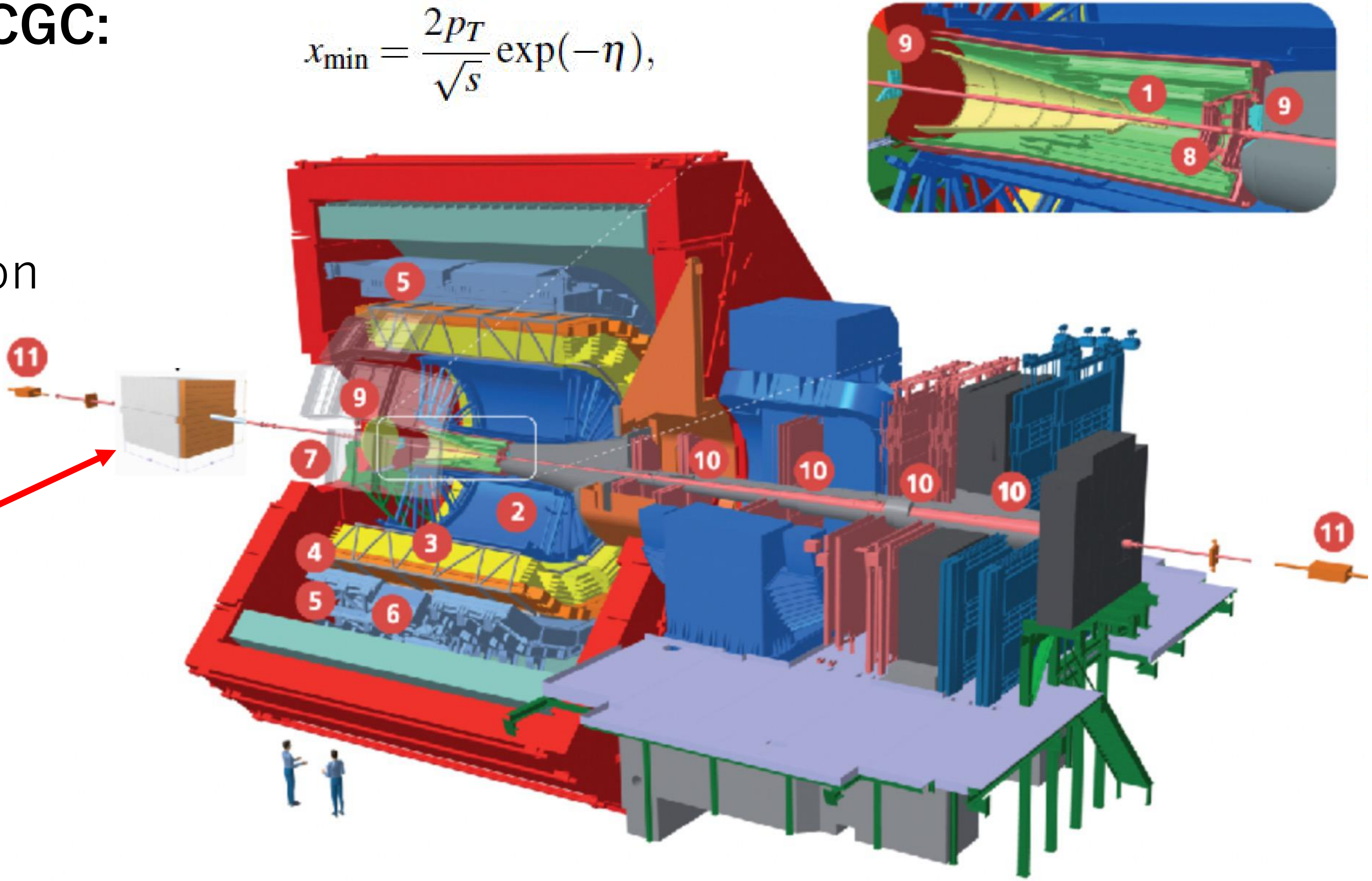


ALICE upgrade with a new forward calorimeter

To explore and test the CGC:

- go very forward
- go low-p_T
- go higher energy
- nucleus instead of proton
- direct γ (clean signal) as well as hadrons

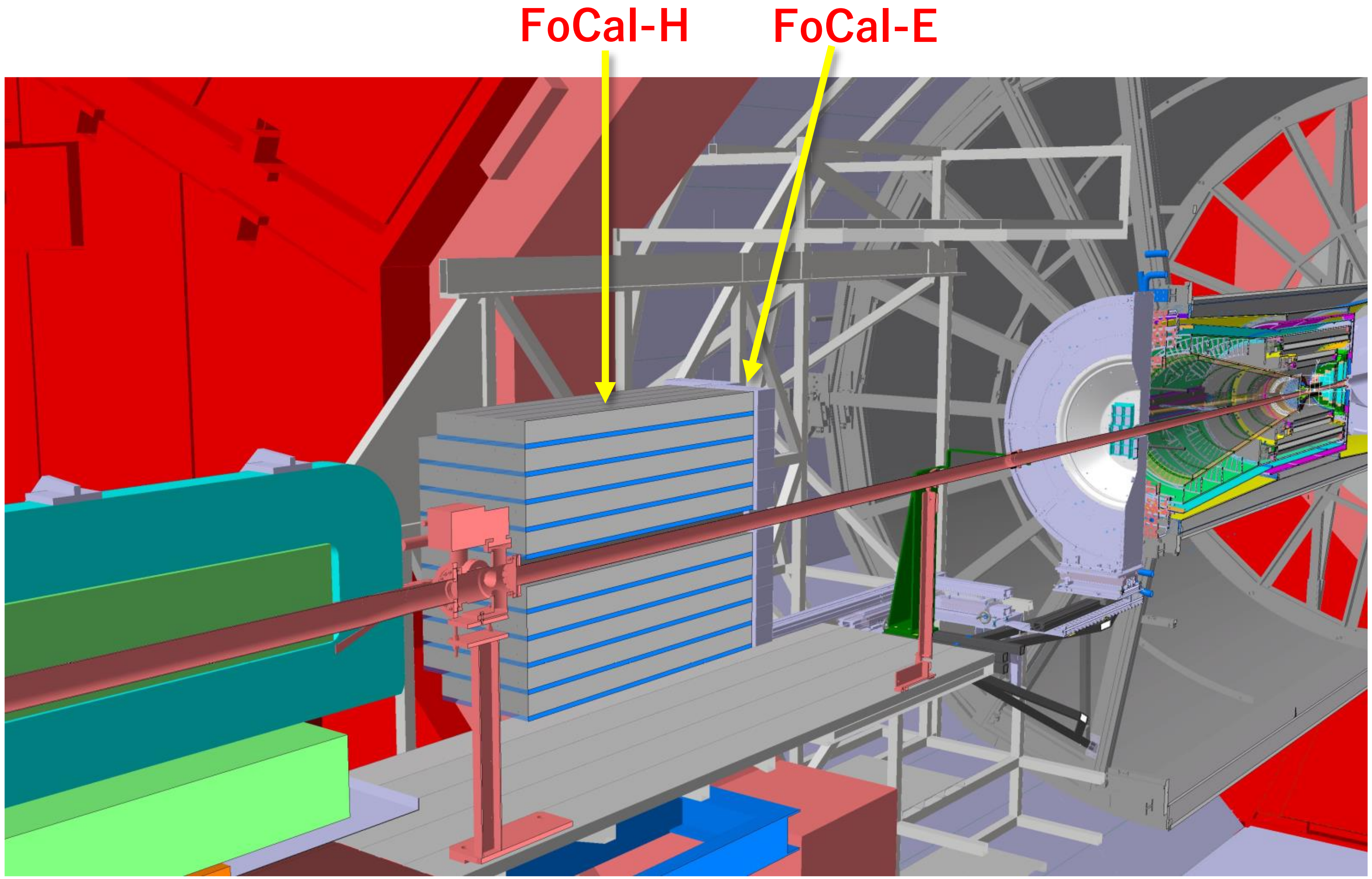
$$x_{\min} = \frac{2p_T}{\sqrt{s}} \exp(-\eta),$$

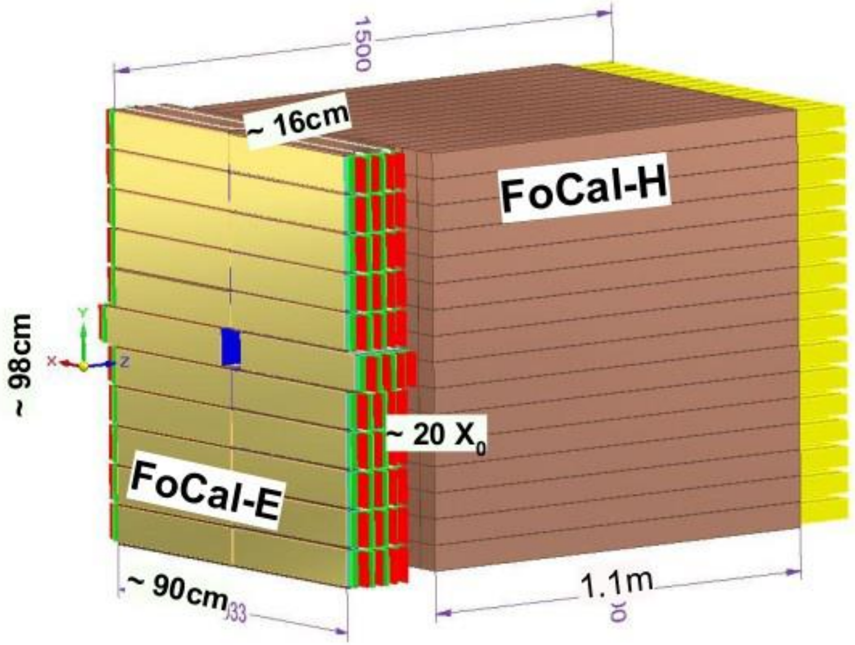


a new FoCal
$3.4 < \eta < 5.8$, $\Delta\phi = 2\pi$
7 m from I.P.

ALICE FoCal detector project

- Combination of electromagnetic calorimeter (FoCal-E) on front of hadronic calorimeter (FoCal-H)



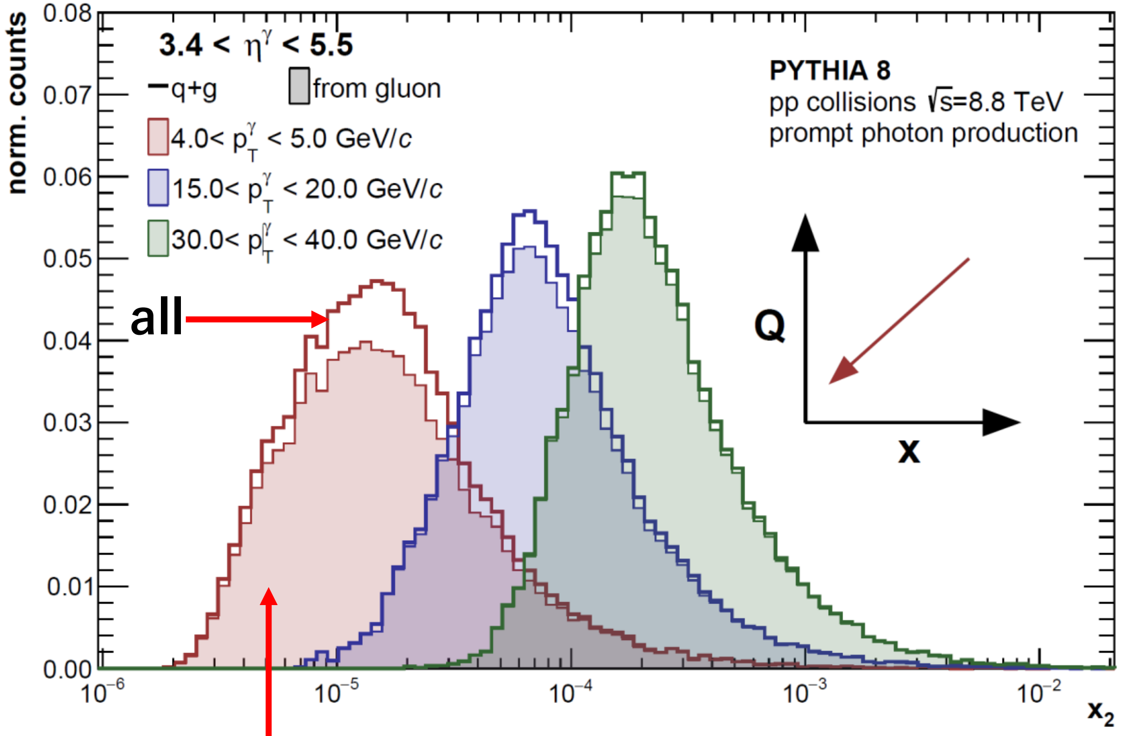


Observables

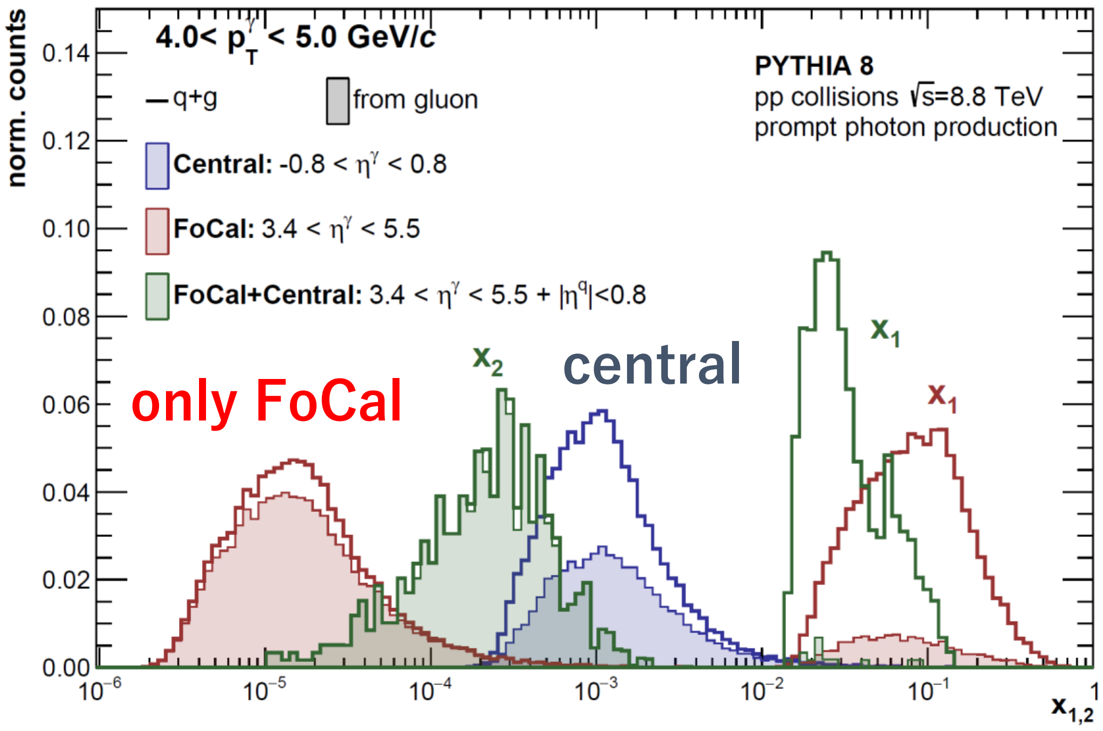
- isolated γ
- identified π^0, η
- inclusive jets, di-jets
- J/ψ, Υ (in ultraperipheral)
- W, Z
- event plane, centrality
- correlations (jet-other, etc)

FoCal kinematic coverage

gluon x distribution measured with prompt photons in FoCal kinematics (also with other ALICE detectors)



prompt photon is from gluon (qg→γq)



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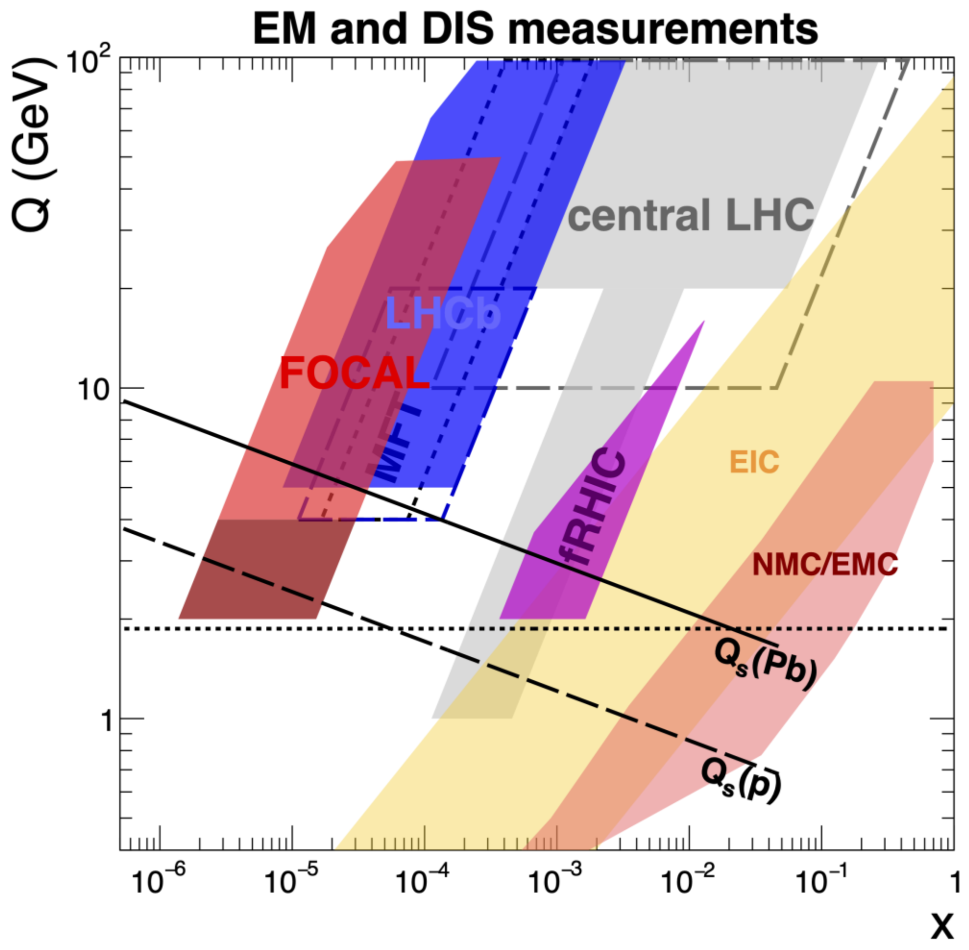
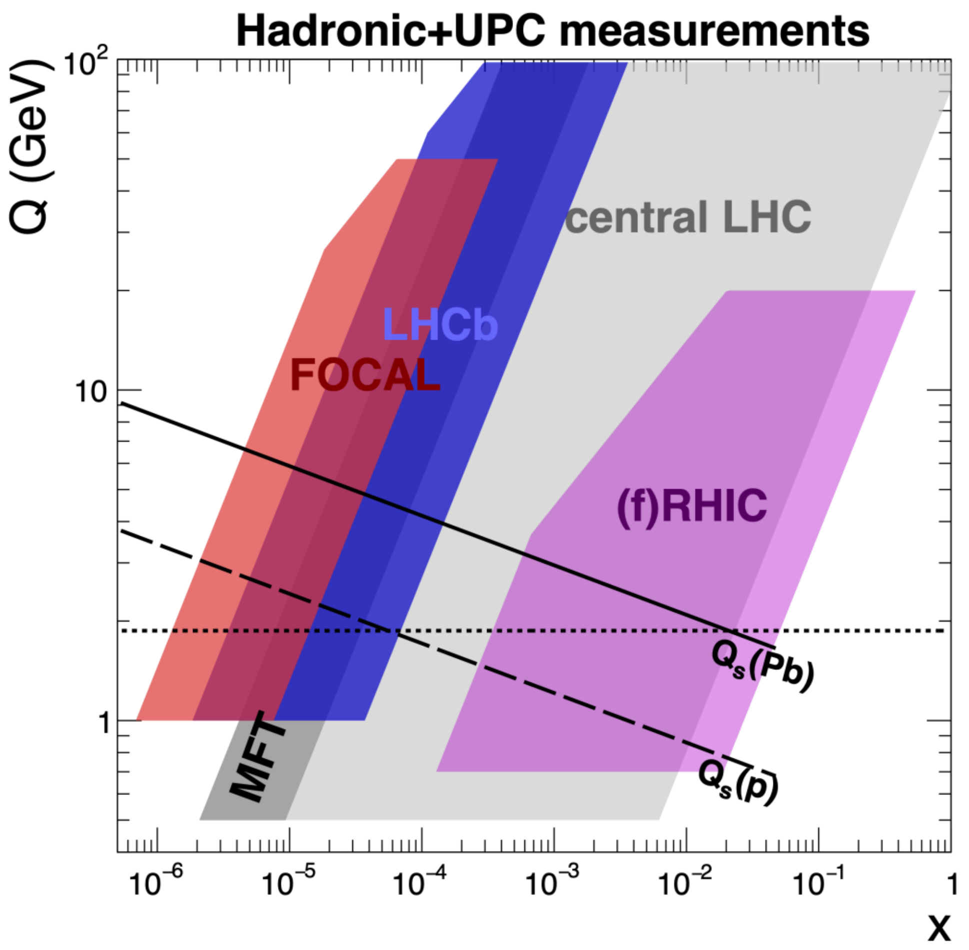
- FoCal probes almost only gluons at small x
- Together with existing detectors, FoCal significantly enhance kinematic coverage

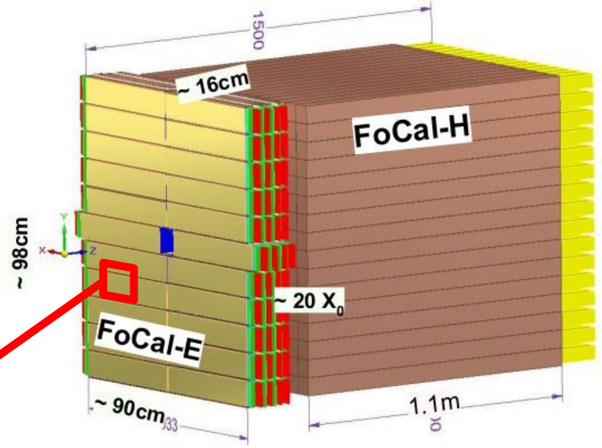
FoCal kinematic coverage (cont.)

- FoCal has very unique kinematic coverage
- Measure direct photons, π^0 jets, quarkonia addition to hadronic probes

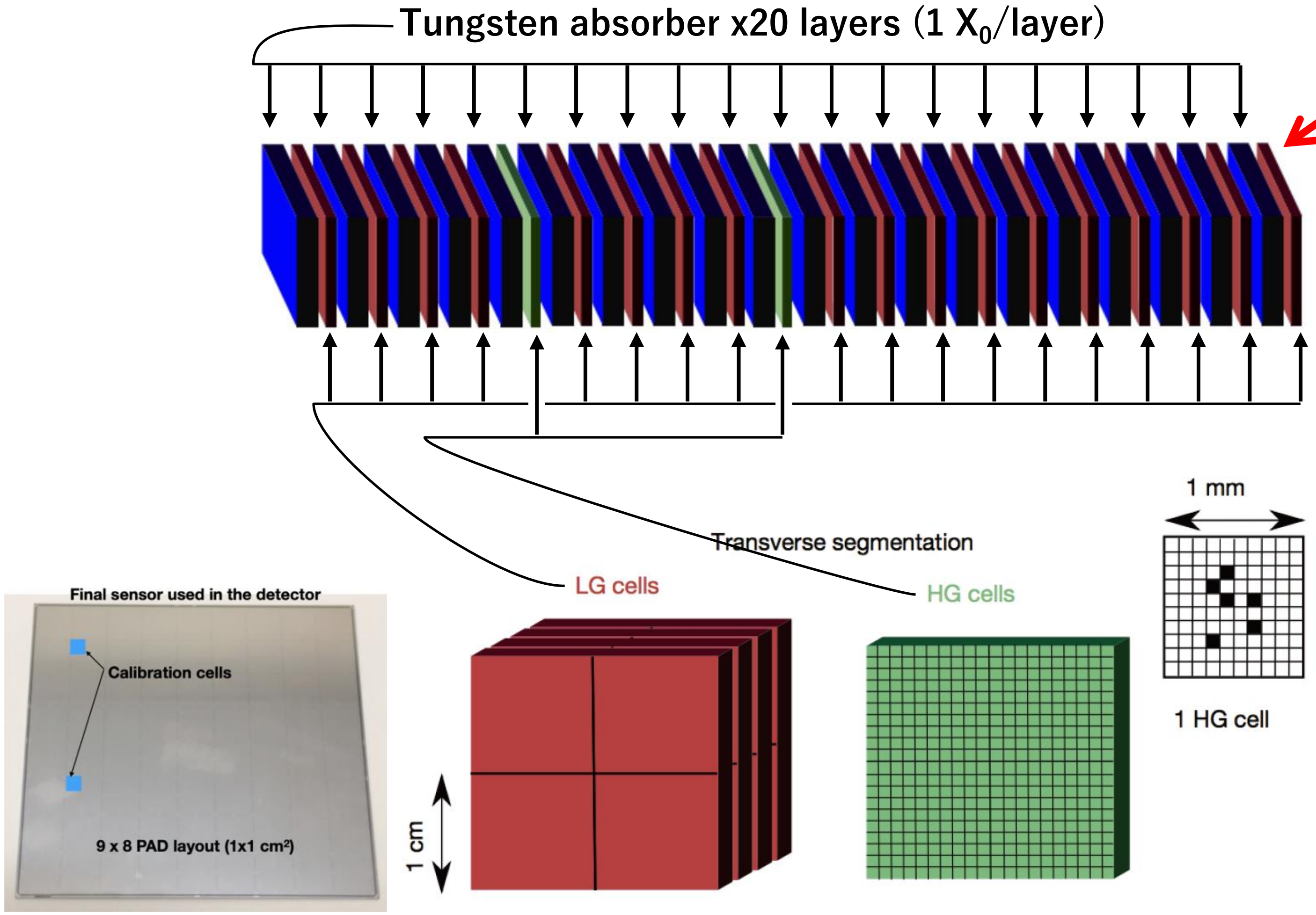




FoCal-E



FoCal-E tower cross section ~9 x 9 cm² (1/110 of total)

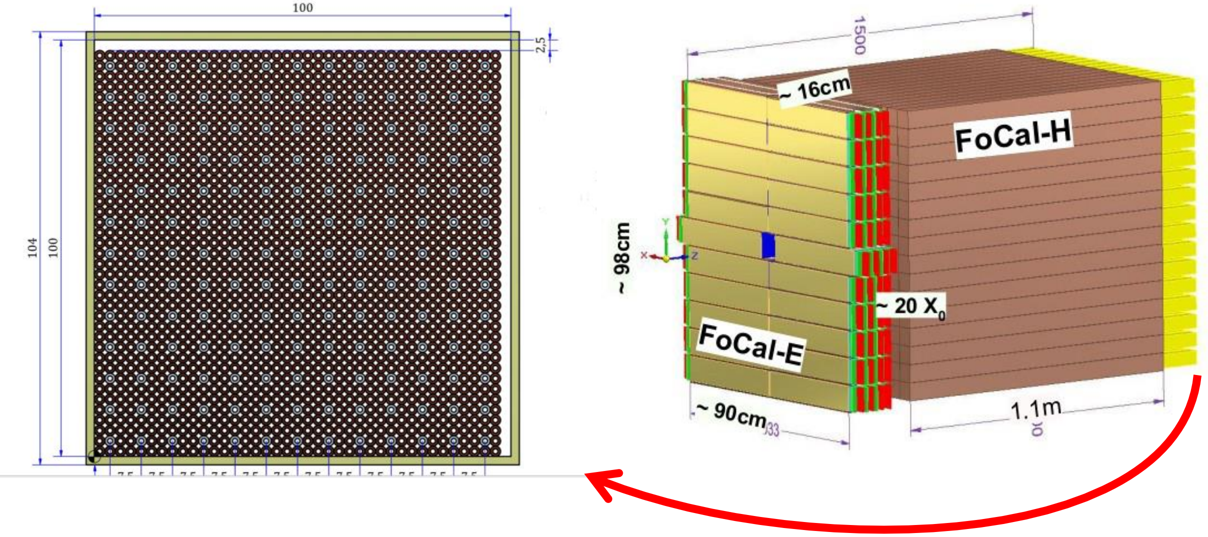


- Si+W electromagnetic calorimeter
- LG: 20 PAD layers (analog)
  - 20 layers, 1 X_0/layer
  - cell size 1 x 1 cm²
  - Si-pad with analog readout ASIC (CMS HGCROC)
- HG: 2 PIXEL layers (digital)
  - CMOS-pixel
  - pixel size 30 x 30 μm²
  - ALICE ITS ALPIDE (MAPS: Monolithic Active Pixel Sensors)

FoCal-H

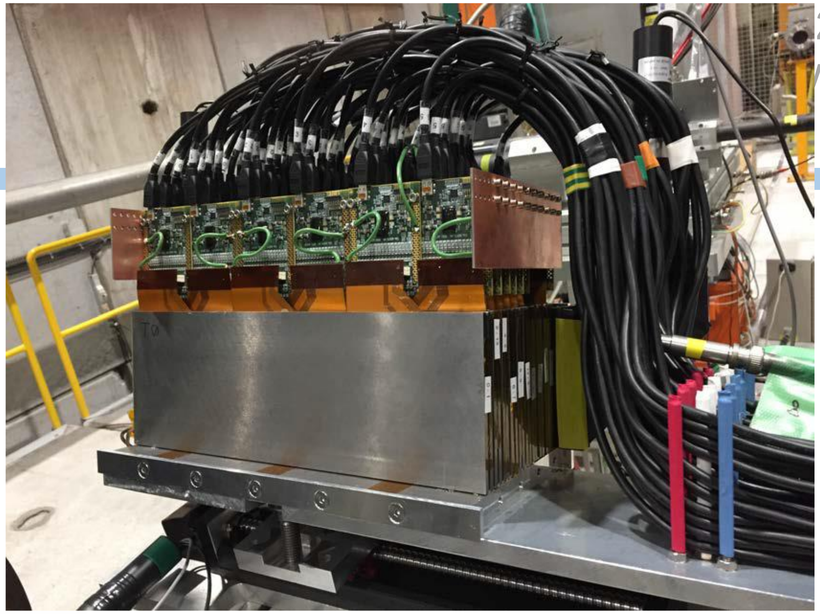
Copper rods
outer diameter: 2.4 mm,
inner diameter: 1.2 mm

Prototype calorimeter tower
10x10x55 cm^3 built from copper rods equipped with scintillating fibers

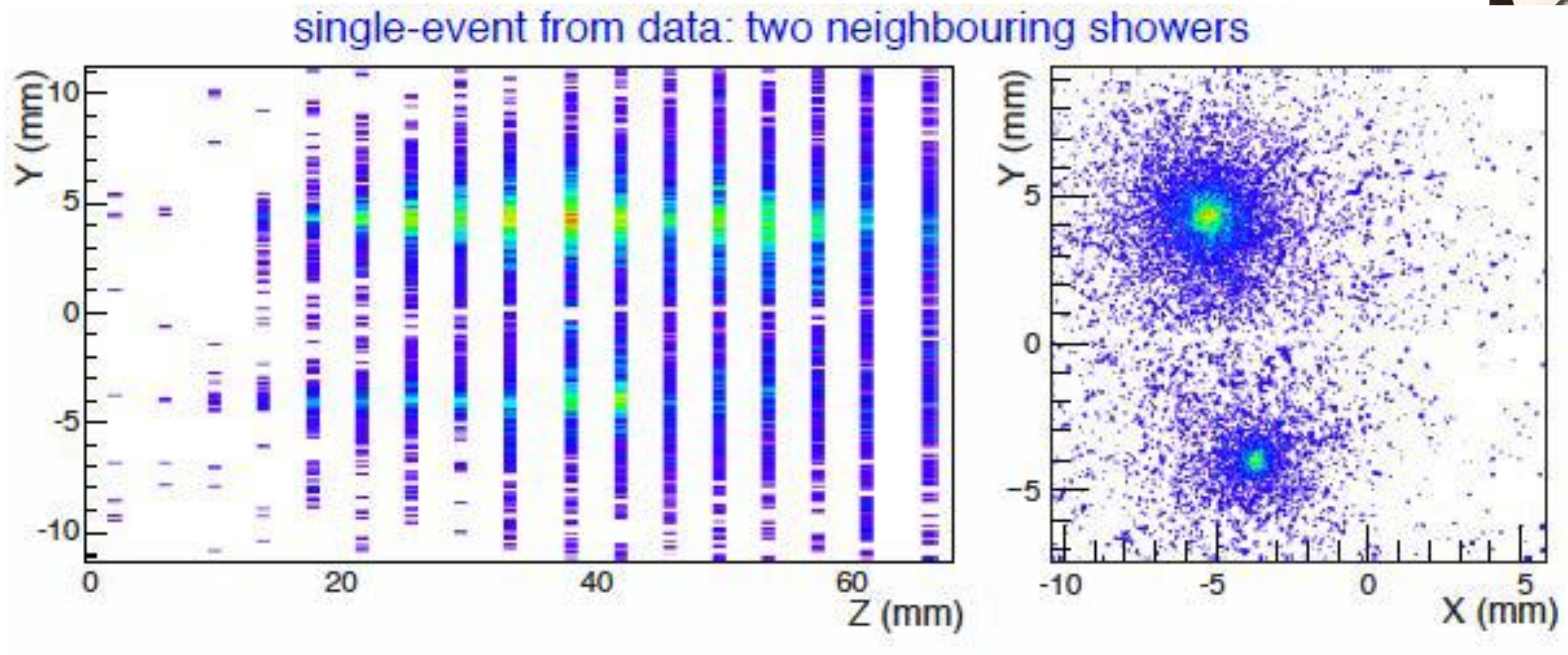


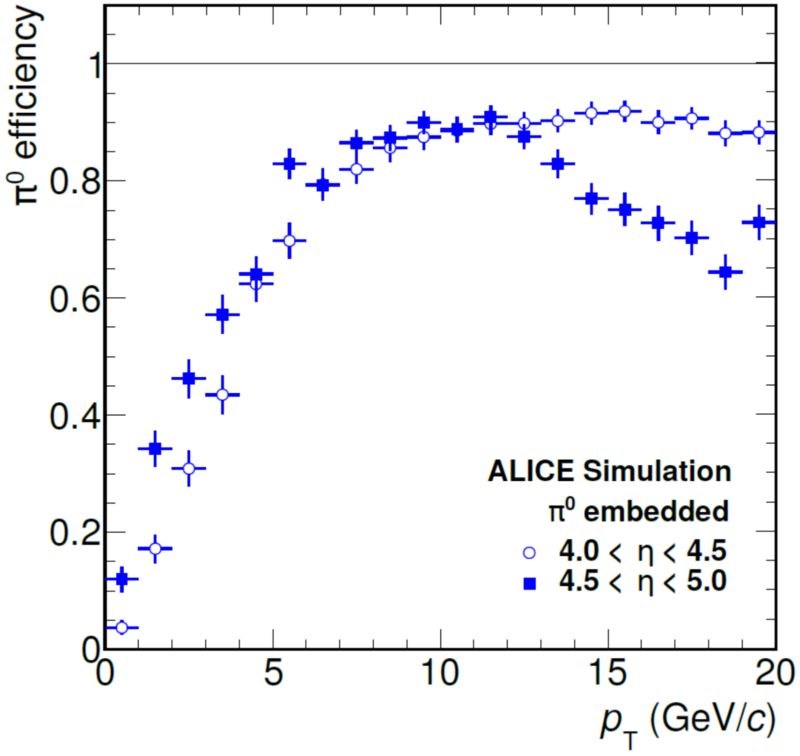
- hadronic calorimeter
- scintillating fibers enclosed in Cu capillary-tubes
- readout by SiPMs and CMS HGCROC ASICs
- designed to study the dynamics of hadronic matter and provides good Jet isolation capabilities

FoCal performance(1)



- Excellent two-gamma separation achieved in test beam (using MIMOSA instead of ALPIDE which is final choice)
- Enough good γ- γ mass resolution and π^0 reconstruction efficiency (simulation)





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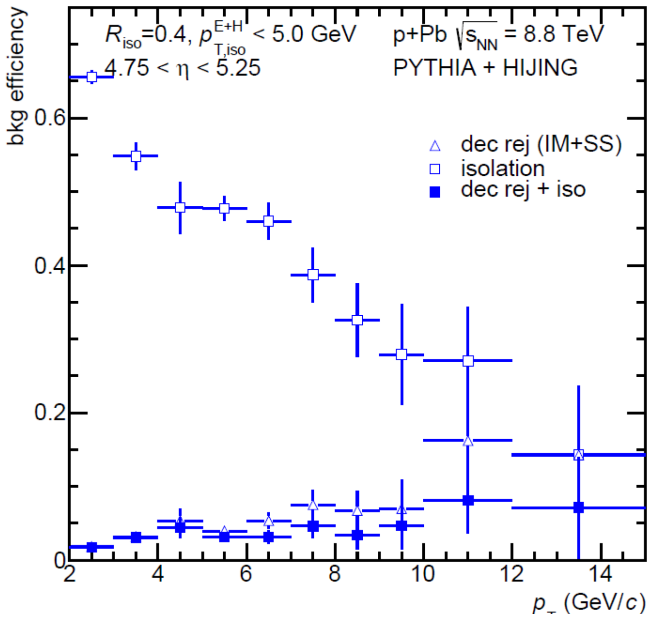
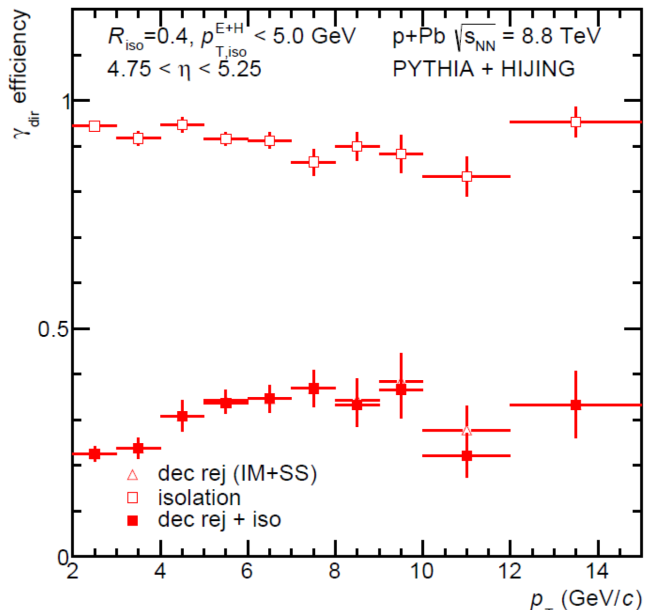
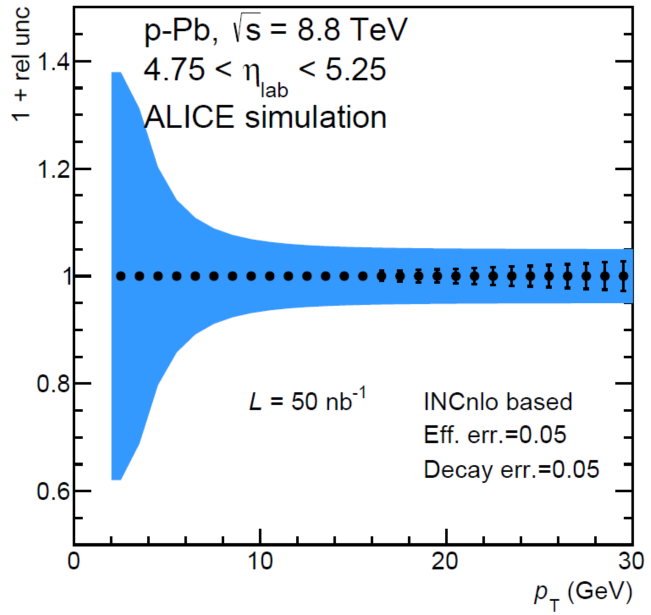
FoCal performance (2)

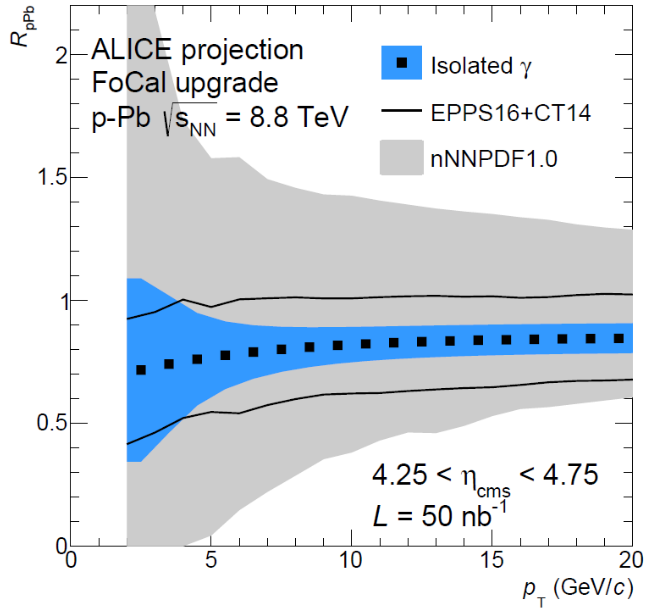
- Simulation at $\sqrt{s_{NN}}$=8.8 TeV p-Pb collisions (PHYTHIA signal with HIJING background)
  - isolation + decay rejection works well
  - >80% background rejection while 20-40% signal efficiency achieved
  - low-p_T is still challenging and we are studying isolation cuts and so on

- Expected relative uncertainty on isolated photon measurement (left) and R_{pPb} (right) expected by FoCal
  - FoCal will provide strong limitation on uncertainty of present nPDF



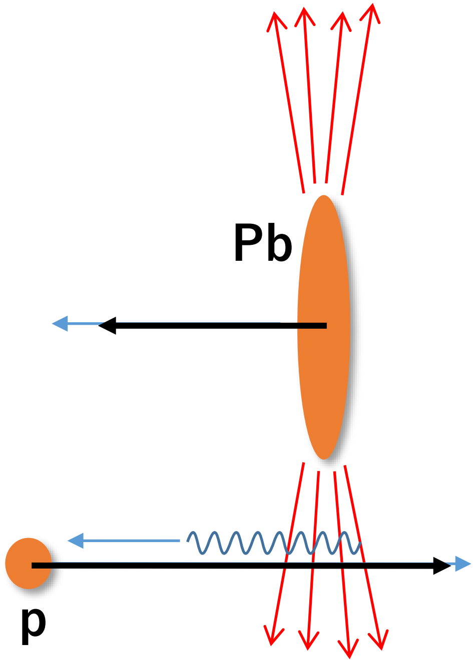


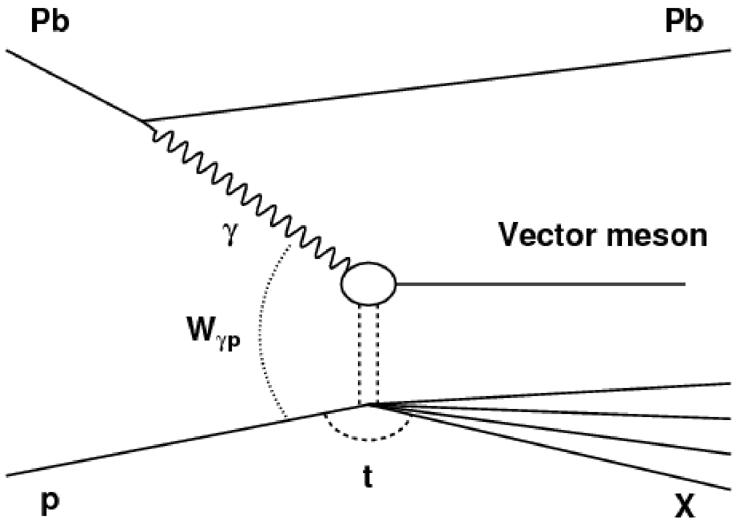




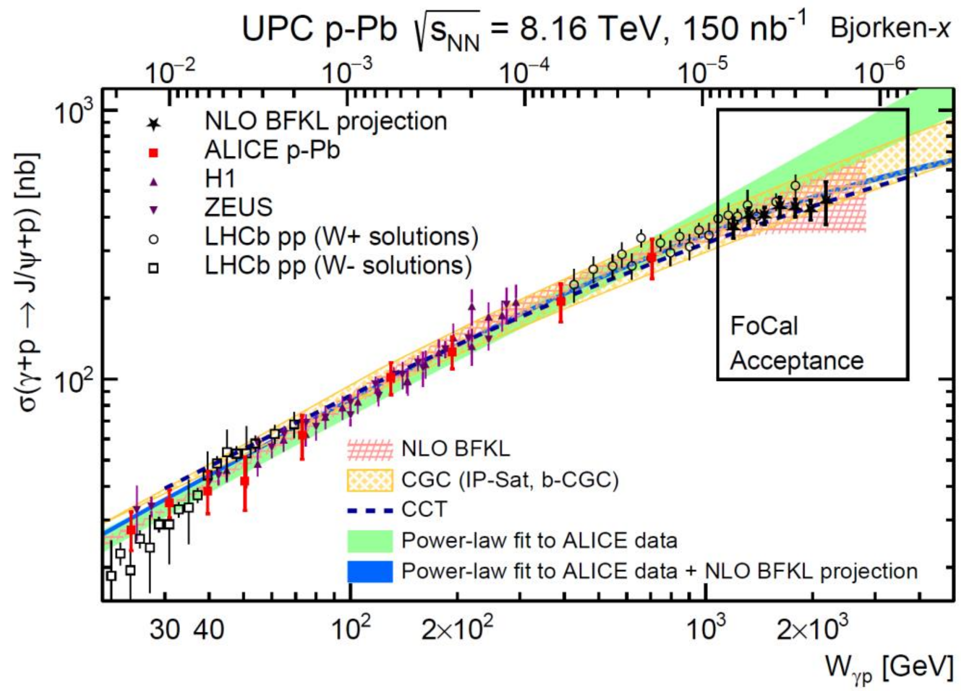
FoCal performance (3)

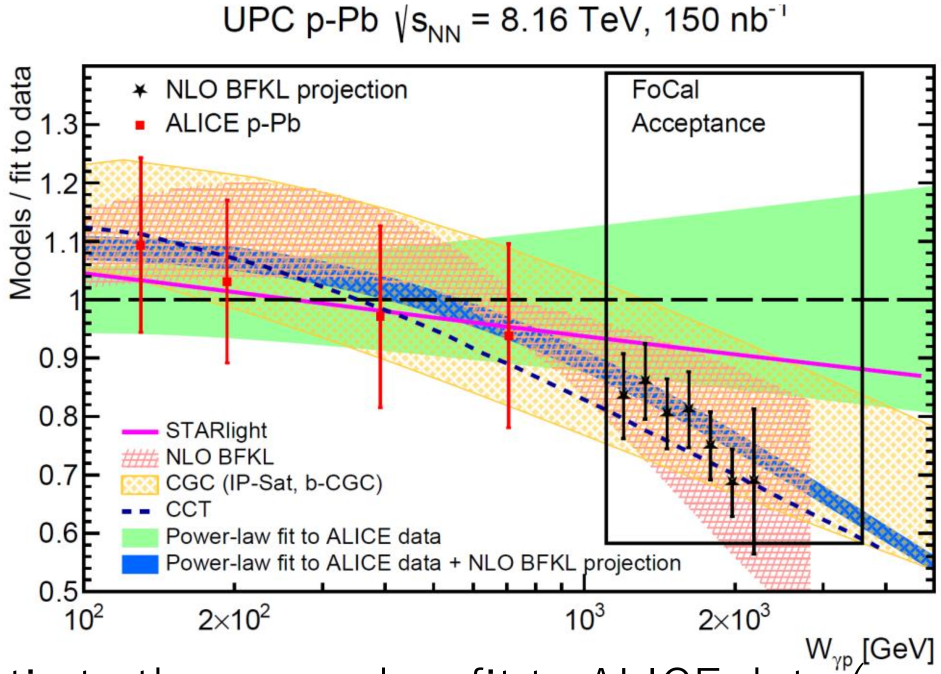
- Ultra peripheral collision (UPC) = pure γ-p collisions
- FoCal is ideal to measure (for example) $J/\psi \rightarrow e^{+}e^{-}$ to explore hadron structure
- can observe deviation from power law behavior (non-linear QCD dynamics)





c.m. energy: $W_{\gamma\mathrm{p}} = 2E_{\mathrm{p}}M_{\mathrm{J/\psi}}\exp(\pm y)$





ratio to the power-law fit to ALICE data (green)

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Summary and Plan

■ Summary

- a forward calorimeter (FoCal) is under development as a new ALICE detector
- studies gluon saturation and CGC at unprecedented area: $x < 10^{-6}$ with unique probes (direct photon, electromagnetic + hadrons, UPC, etc)
- it allows ALICE to explore further on quark matter initial state and its formation mechanism

■ FoCal project plan

- FoCal R&D will continue ~2024 (TDR this summer)
  - detector design & technologies are nearly fixed
  - electronics, trigger, and readout design ongoing
- Production: 2025-2026
- Installation: 2027-2028 (during LHC Long Shutdown)
- **Operation: 2029~ (LHC RUN 4)**
  - beam energy: Pb-Pb, p-Pb and p-p at 8.8 TeV per nucleon pair, p-p at 14 TeV