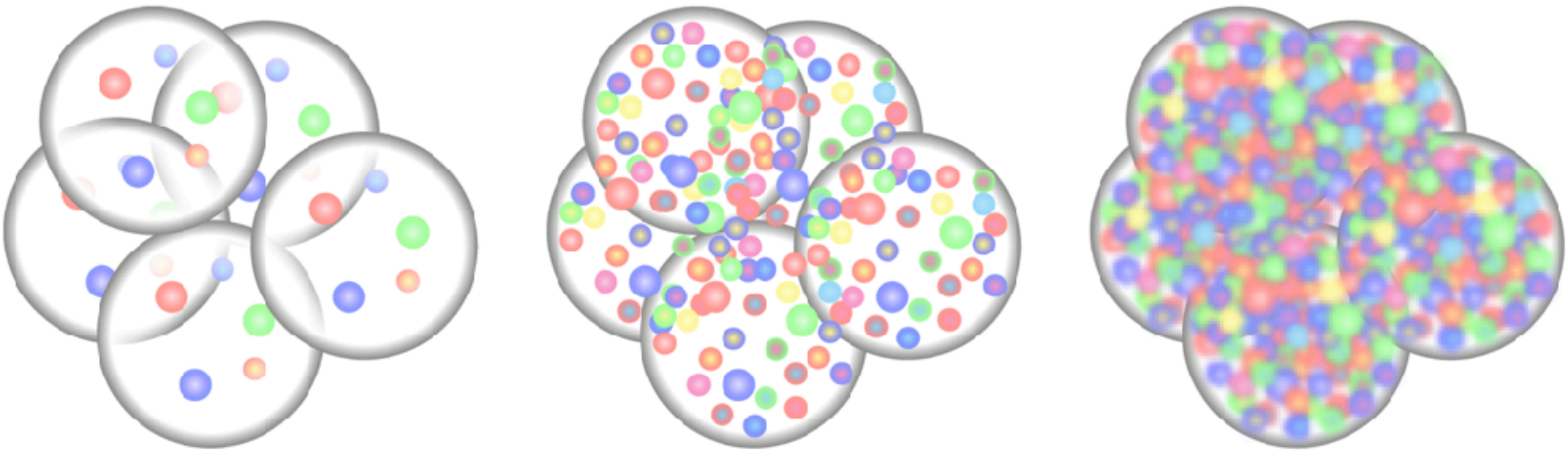
FoCal:
A Forward Calorimeter for ALICE in Run 4



Constantin Loizides (ORNL)
on behalf of the FoCal collaboration

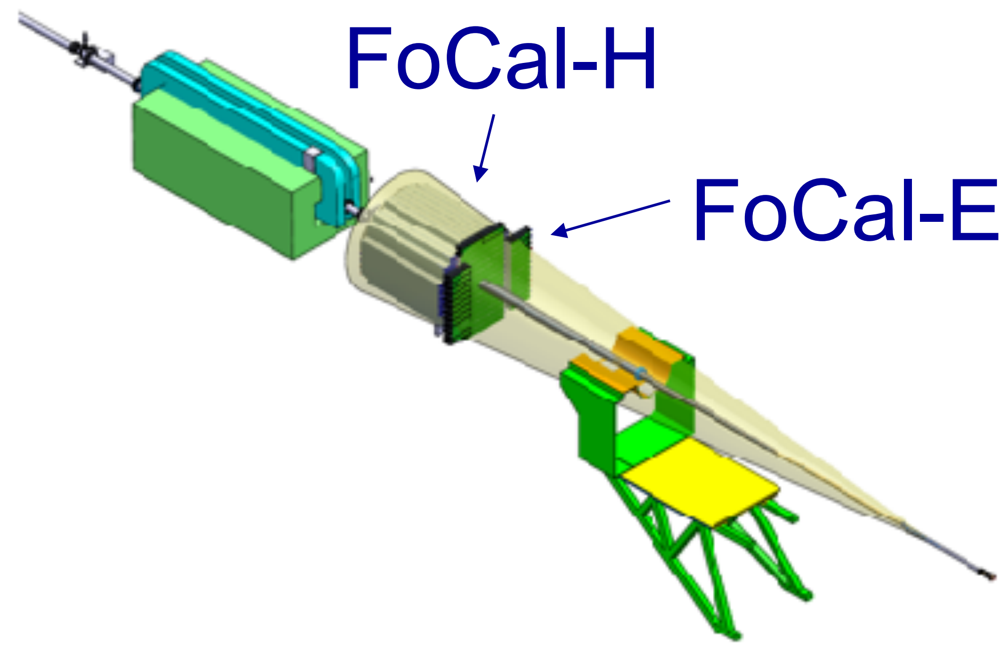
15.11.2019

LPC workshop on Physics connection between the LHC and EIC

The FoCal proposal

$3.2 < \eta < 5.8$
(baseline design @ 7m)

FoCal-E: high-granularity Si-W sampling calorimeter for photons and π^0
FoCal-H: conventional Cu-Sc sampling calorimeter for photon isolation and jets



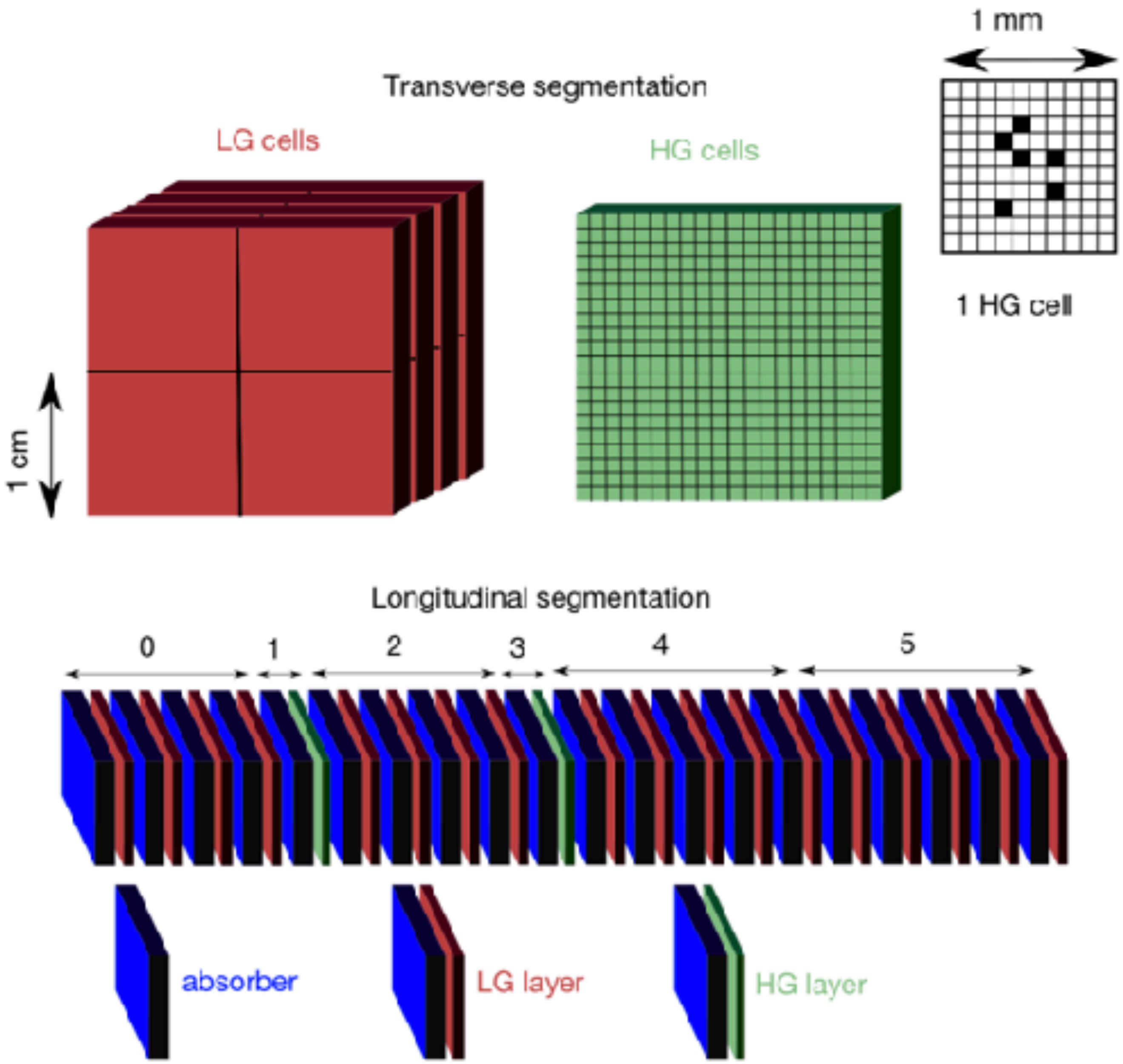
Observables:
- π^0 (and other neutral mesons*)
- Isolated photons
- Jets (and di-jets*)
- J/ψ (Υ*) in UPC
- W, Z maybe possible*
- Event plane and centrality*

(* not yet studied)

Advantage in ALICE:
forward region almost not instrumented;
'unobstructed' view of interaction point

See ALICE-PUBLIC-2019-005

FoCal-E design



Studied in simulations 20 layers:
W(3.5 mm $\approx 1X_0$) + silicon sensors
Two types: Pads (LG) and Pixels (HG)

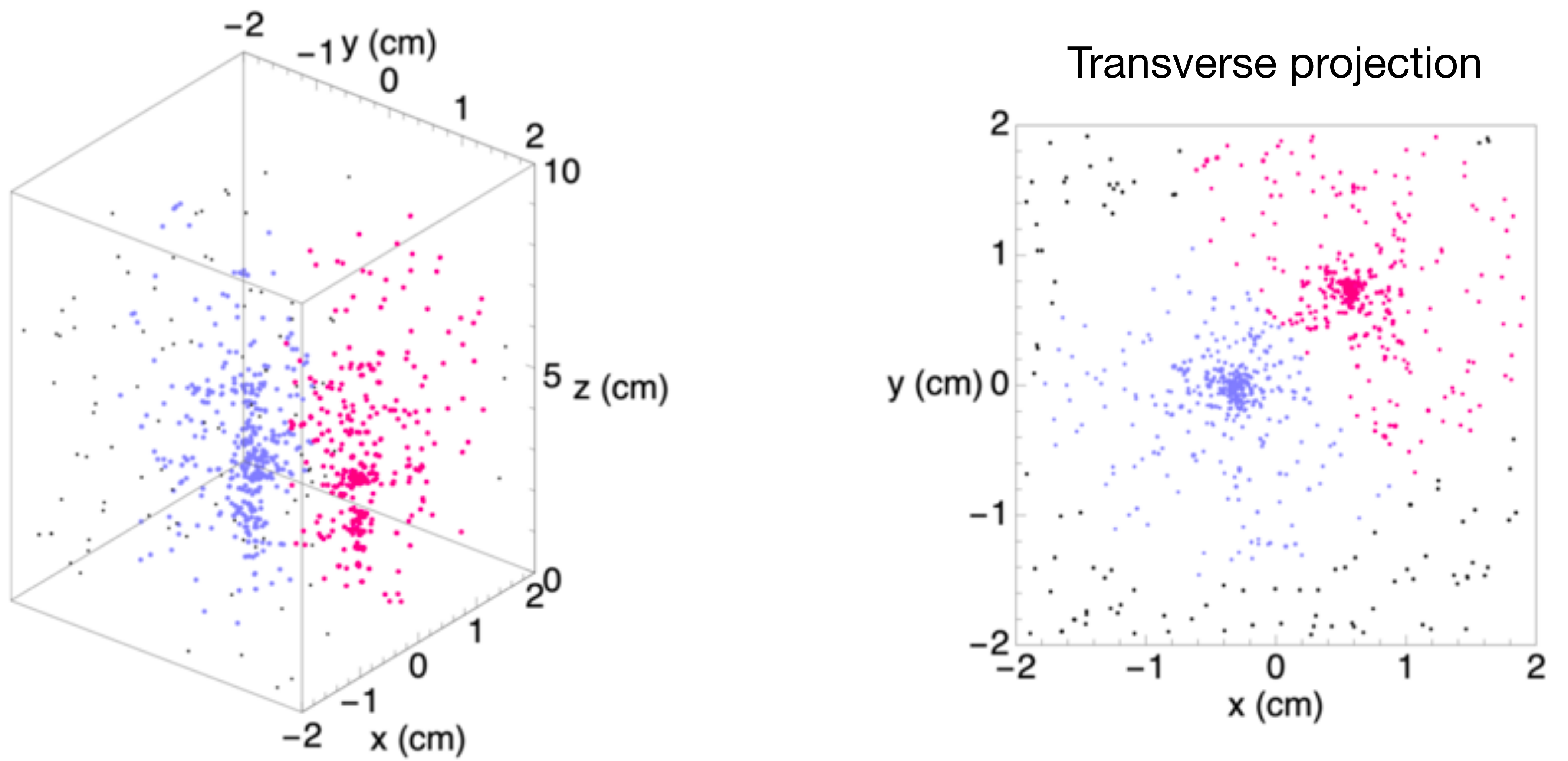
- Pad layers provide shower profile
- Pixel layers provide position resolution to resolve shower overlaps

Main optimization (TBD):

- Number of pixel layers and location
- Number of pad layers
- Maximum separation between layers

- Main challenge: Separate γ/π^0 at high energy
  - Two photon separation from π^0 decay (10 GeV, η=4.5) ~0.5mm
  - Needs small Molière radius and high granularity readout
  - Si-W calorimeter with effective granularity $\approx 1mm^2$

3d image of shower



Showers of two 5.4 GeV test beam electrons in a all-pixel layer prototype

Extensive R&D, see recent detector seminar at CERN:
https://indico.cern.ch/event/856365/

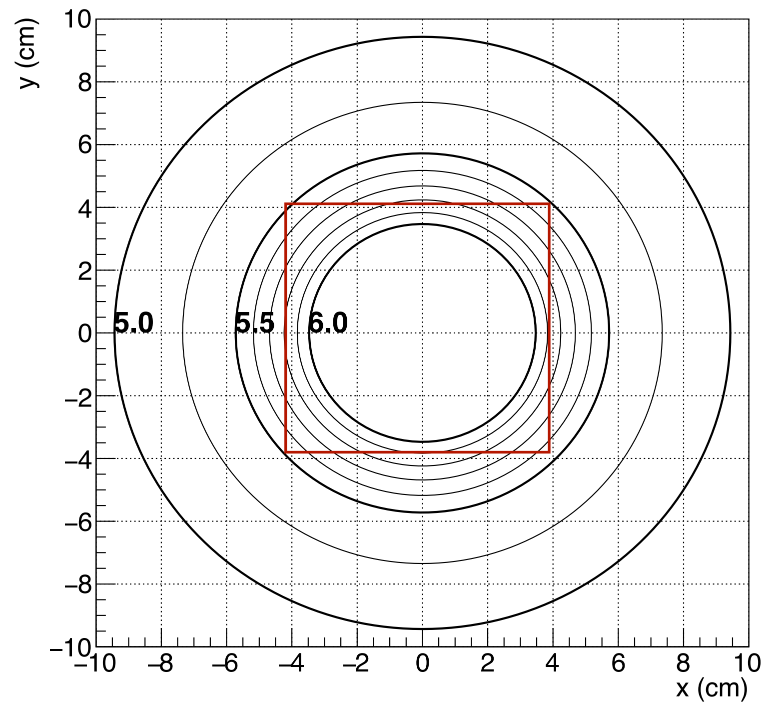
Rapidity coverage and efficiency

position z = 7m
beam pipe radius 3.5cm

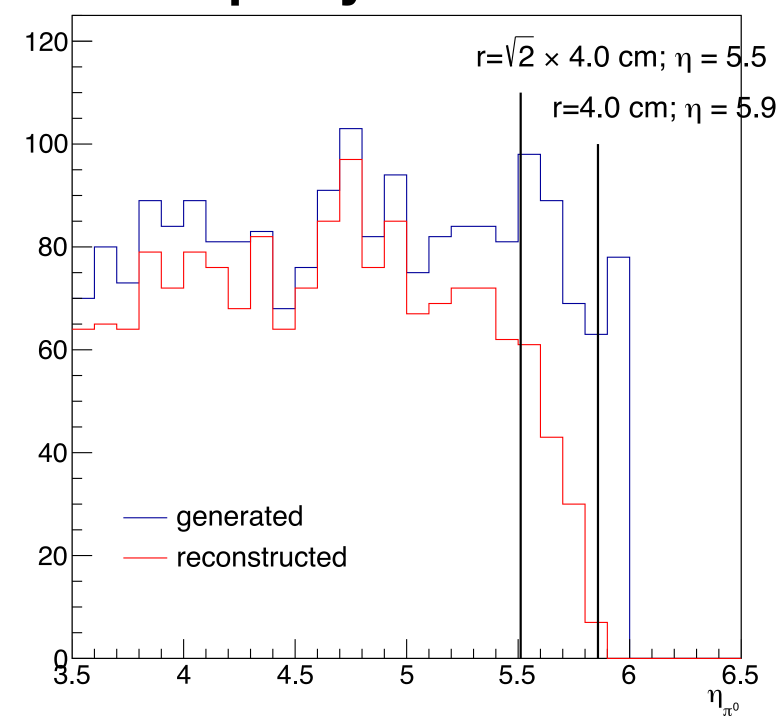
8x8cm square around beam:
maximum rapidity 5.5-5.8

2-gamma distance gets small beyond η=5.5:
→ sharp drop at R_{min} plus effect of circle vs square

z = 700 cm

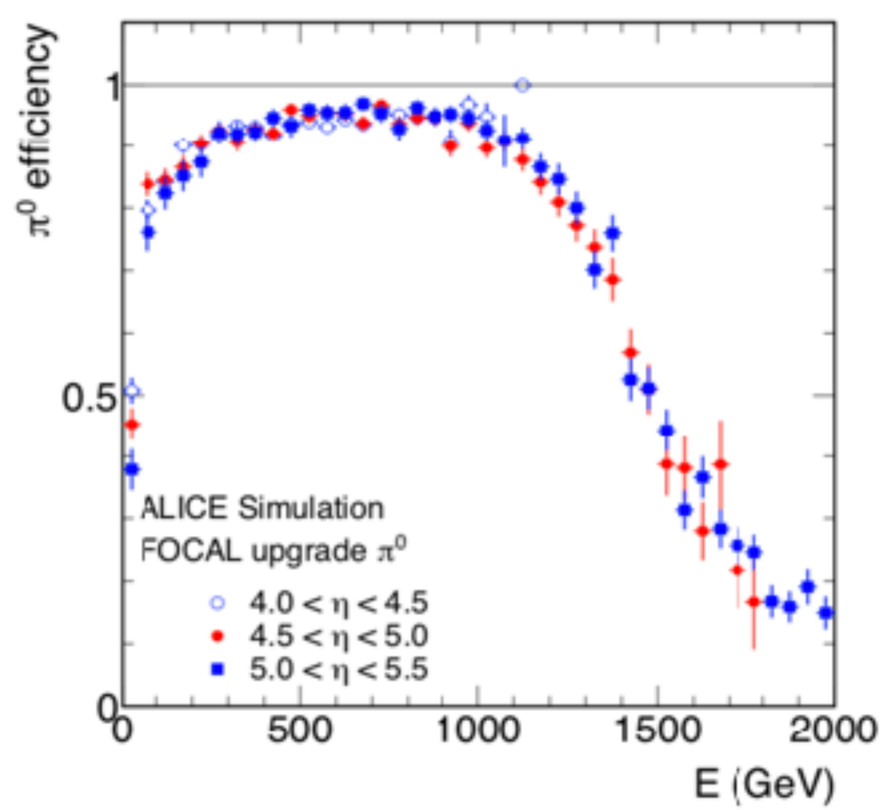


π^0 rapidity distribution

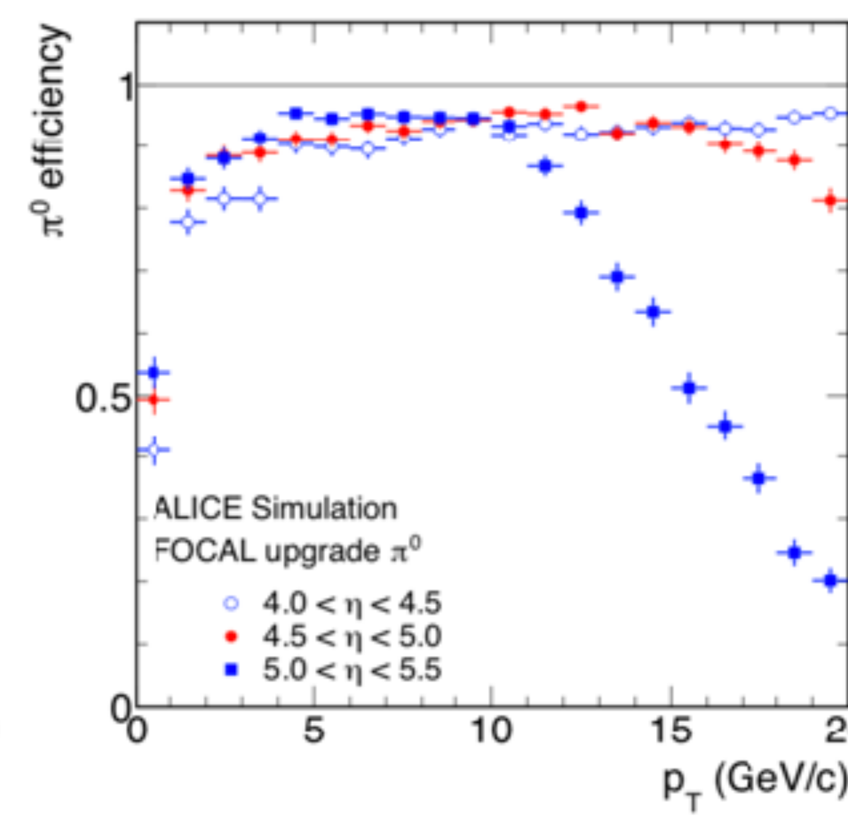


Very good π^0 efficiency up to η = 5.5
(falls off above p_T = 10 GeV due to 2-gamma distance)

π^0 efficiency vs E

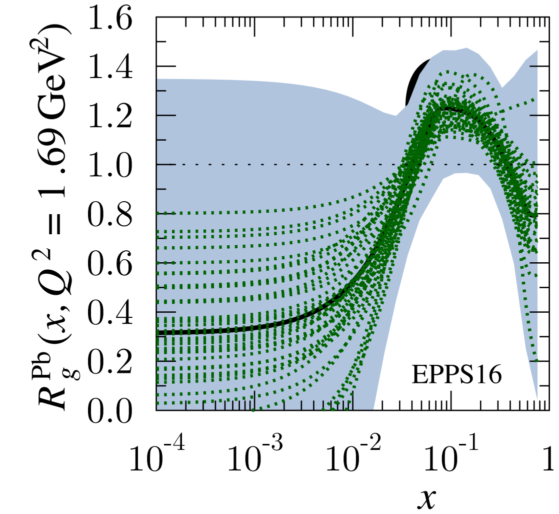


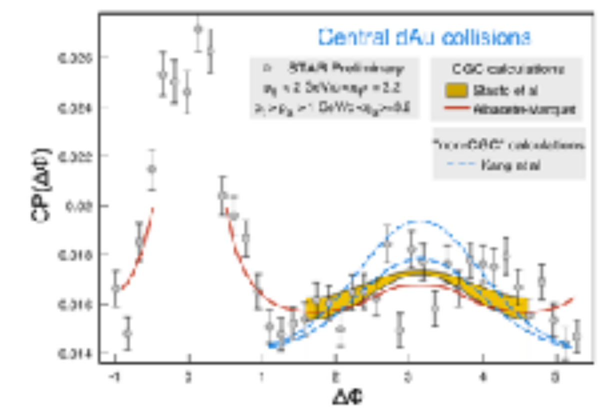
π^0 efficiency vs p_T

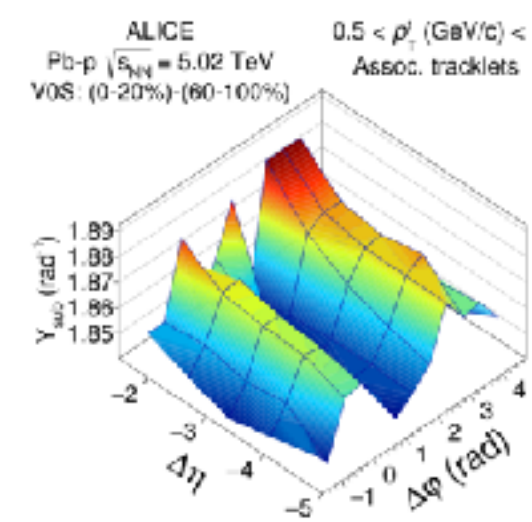


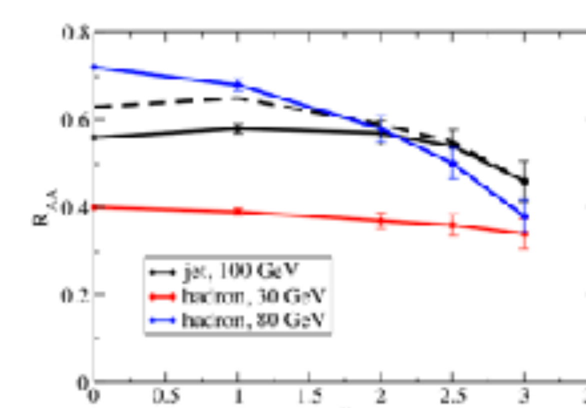
Physics goals

- Quantify nuclear modification of the gluon density at small-x
  - Isolated photons in pp and pPb collisions
- Explore non-linear QCD evolution
  - Azimuthal π^0-π^0 and isolated photon-π^0 (or jet) correlations in pp and pPb collisions
- Investigate the origin of long range flow-like correlations
  - Azimuthal π^0-h correlations using FoCal and central ALICE (and muon arm?) in pp and pPb collisions
- Explore jet quenching at forward rapidity
  - Measure high p_T neutral pion production in PbPb
- Other measurements need (more) study
  - Jets and dijets in pp/pPb and UPC
  - Quarkonia in UPC (and pp?)
  - Photon and pion HBT
  - W,Z in pp/pPb?
  - Measurements at 14 TeV
    - Universality at small-x
    - Saturation in pp
    - High-x (>0.1) gluon constraints?



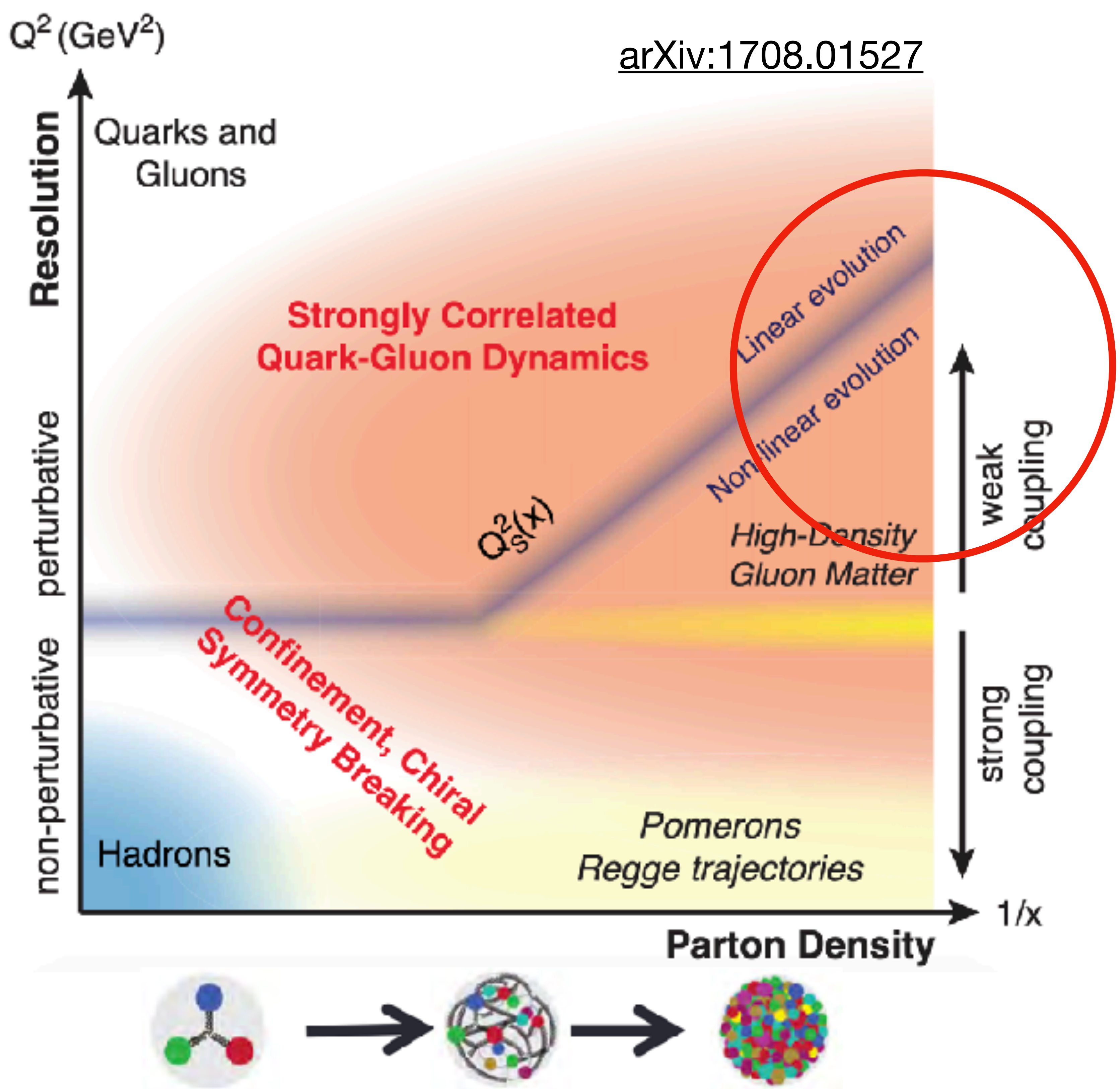




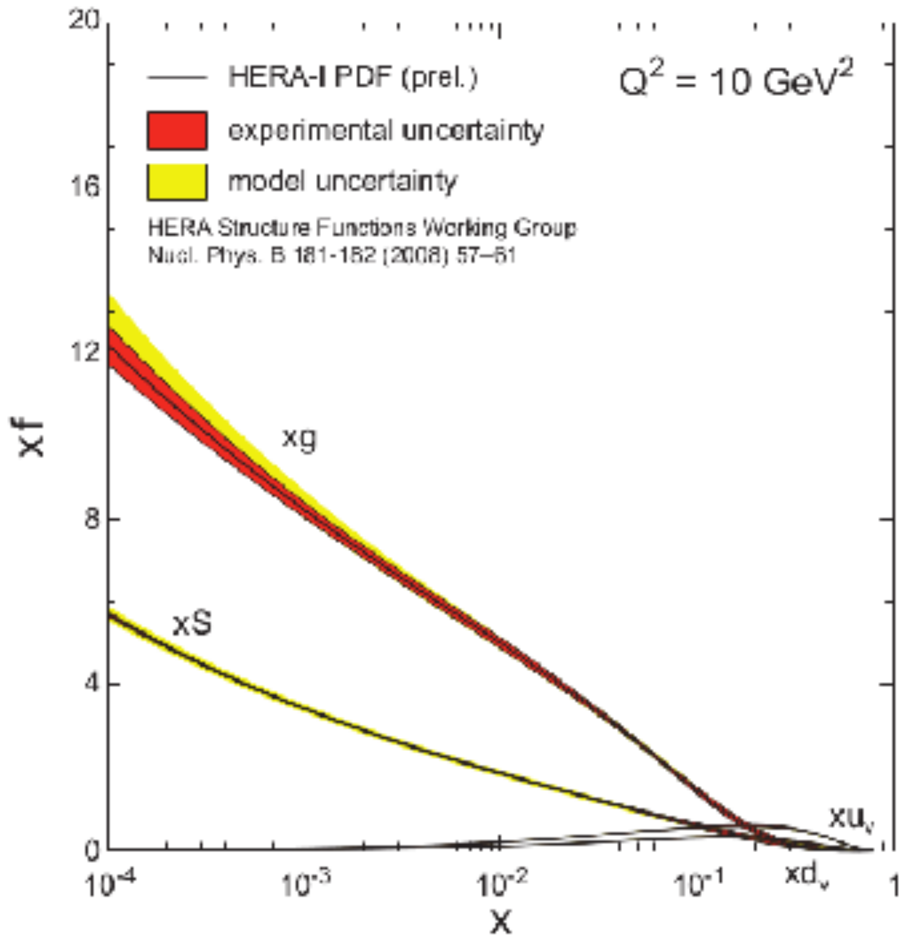


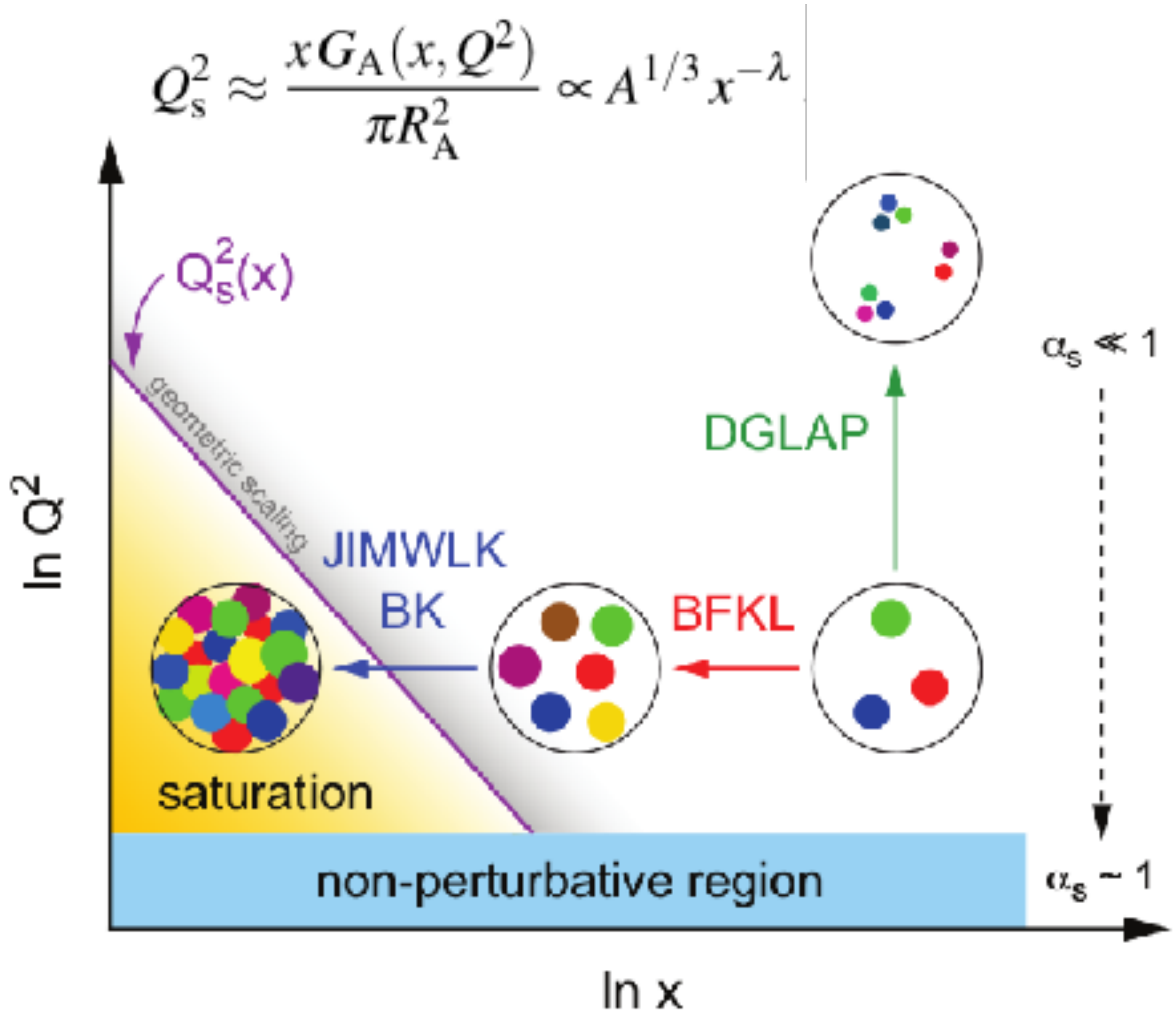
Physics goals

- Quantify nuclear modification of the gluon density at small-x
  - Isolated photons in pp and pPb collisions

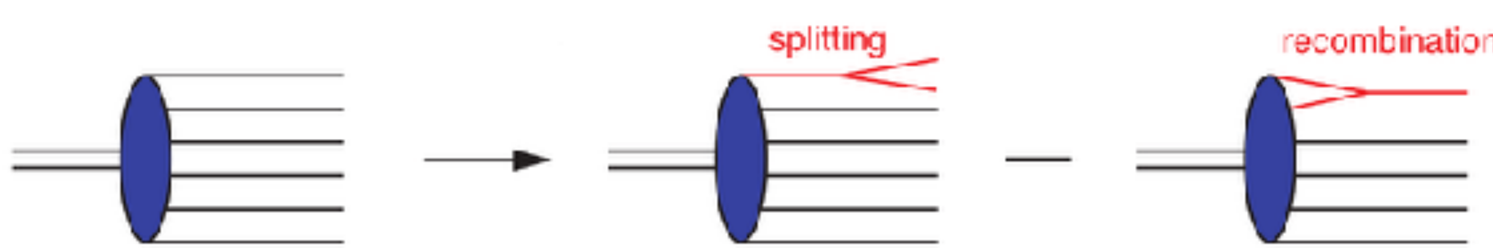


Physics motivation: Gluon PDF at small x

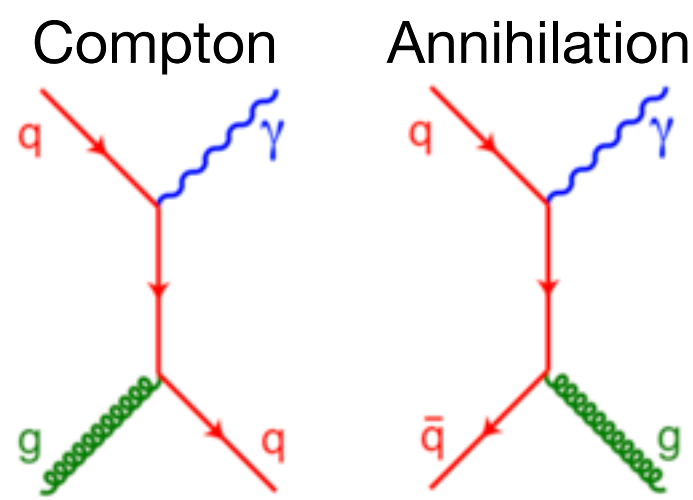




- Rise of gluon density natural for linear QCD evolution describing parton splitting
- Tamed by non-linear QCD evolution functions describing parton recombination, perhaps leading to saturation at the saturation scale Q_s

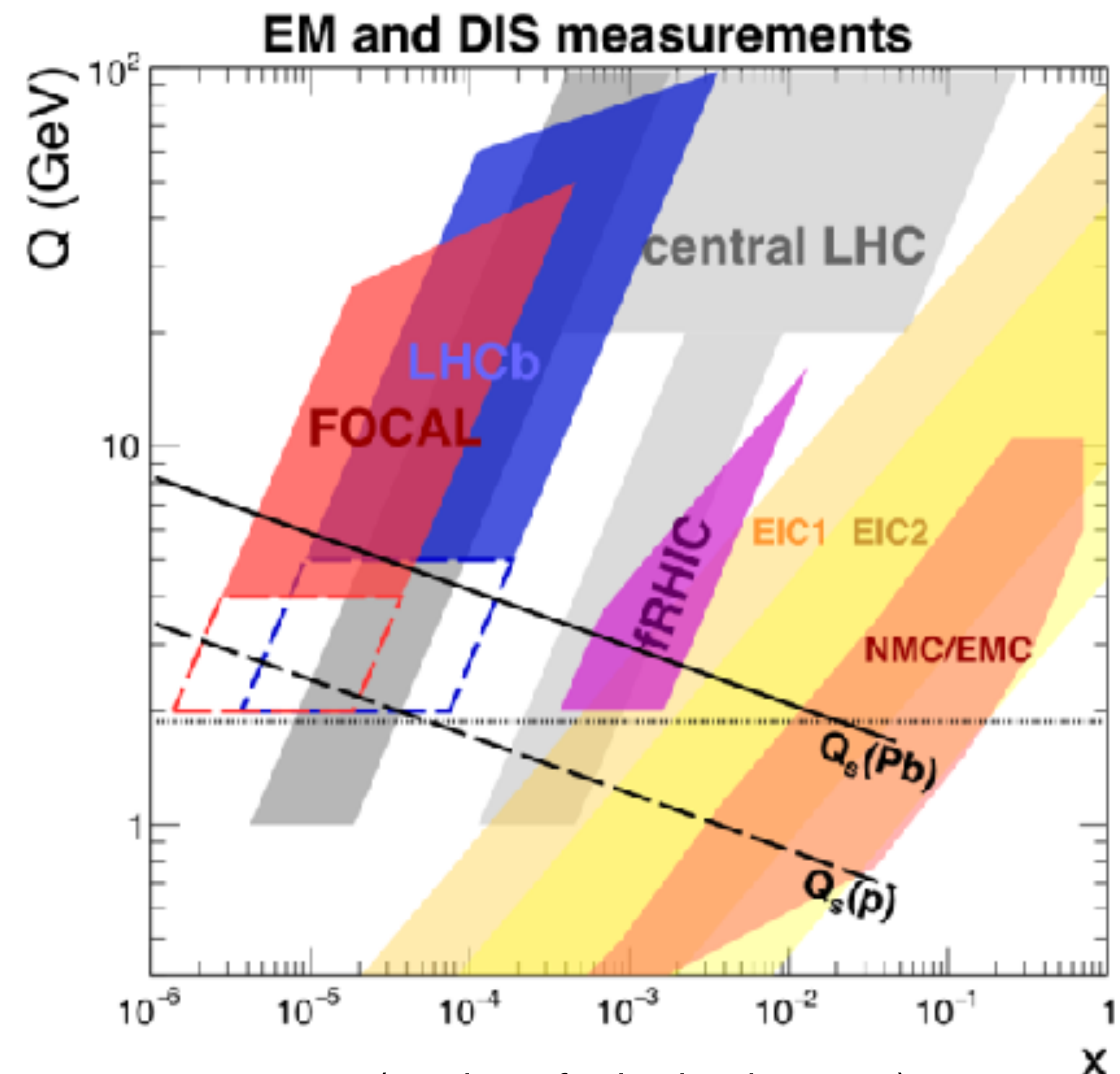


Isolated photons and the LHC small-x program



- Measure isolated photons forward
  - At LO more than 70% from Compton with direct sensitivity to gluon density
  - Not affected by final state effects nor hadronization
  - Uniquely low coverage at LHC (similar to LHeC)

- Hierarchy of goals
  - Prove or refute gluon saturation
  - Explore non-linear QCD evolution at small x
  - Constrain nuclear PDFs at small x

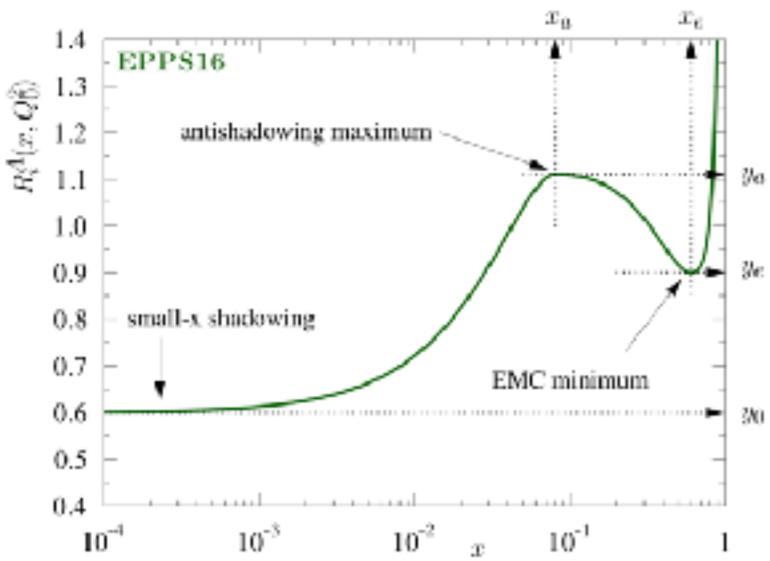


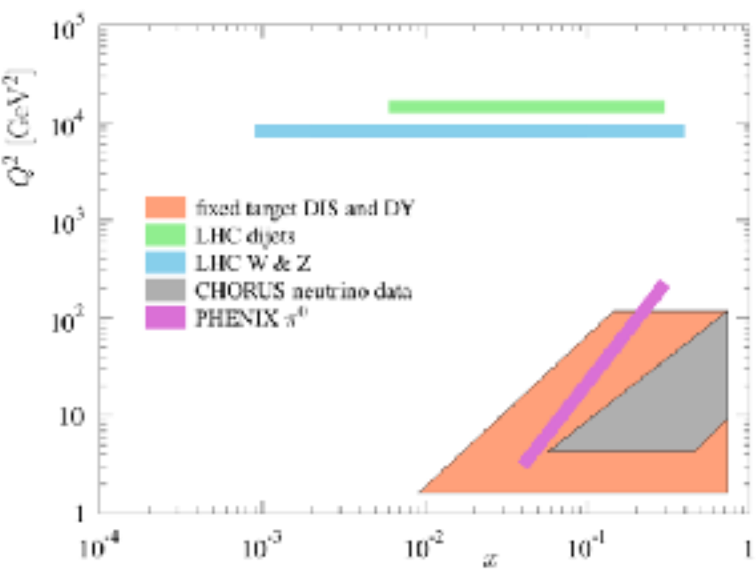
(see here for hadronic cases)

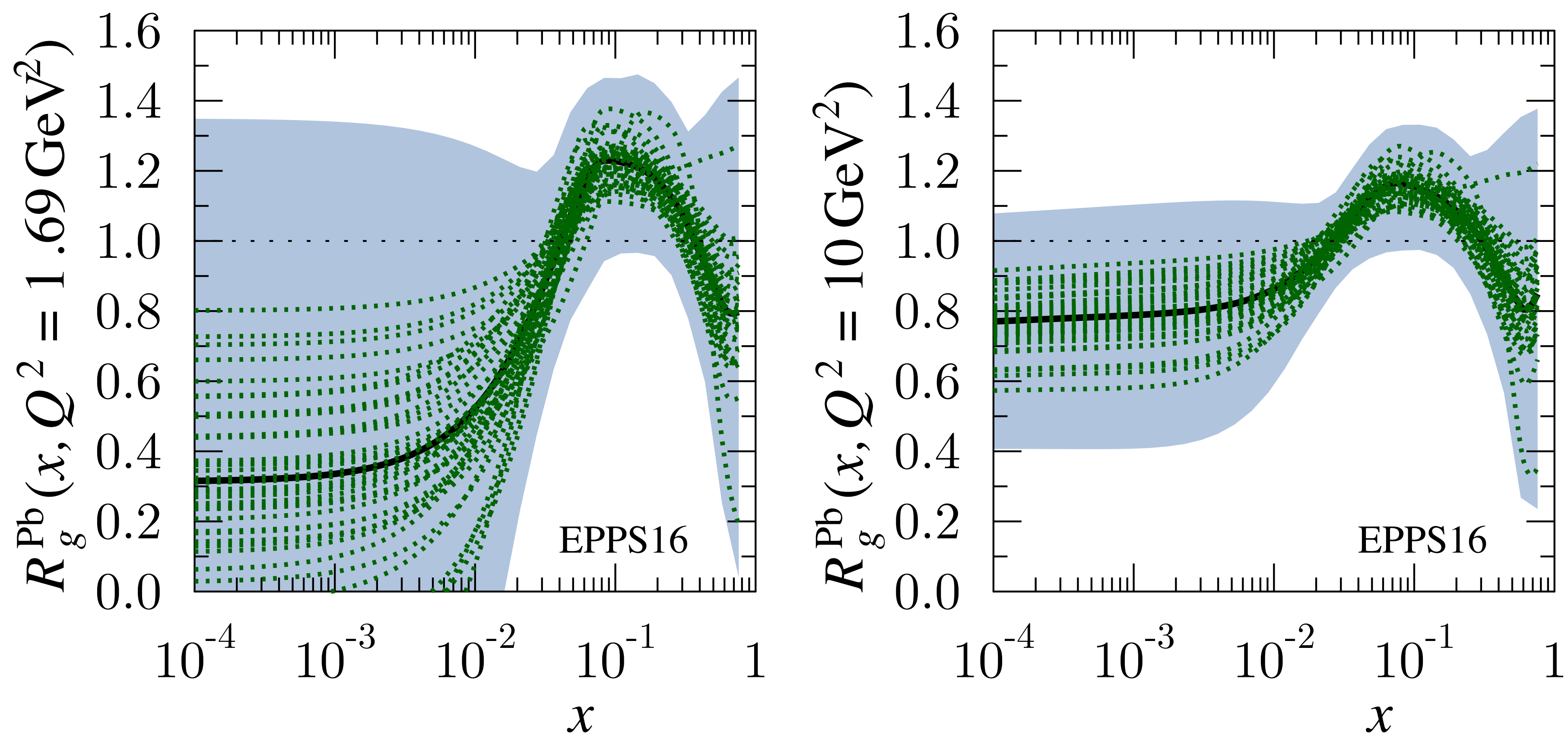
Strong LHC small-x program
- Various experiments/measurements including γ, DY, open charm +UPC
- Important to test factorization/ universality
- Synergy with fRHIC + EIC/LHeC

Nuclear PDFs (EPPS16)

Eskola et al., EPJC 77 (2016) 163





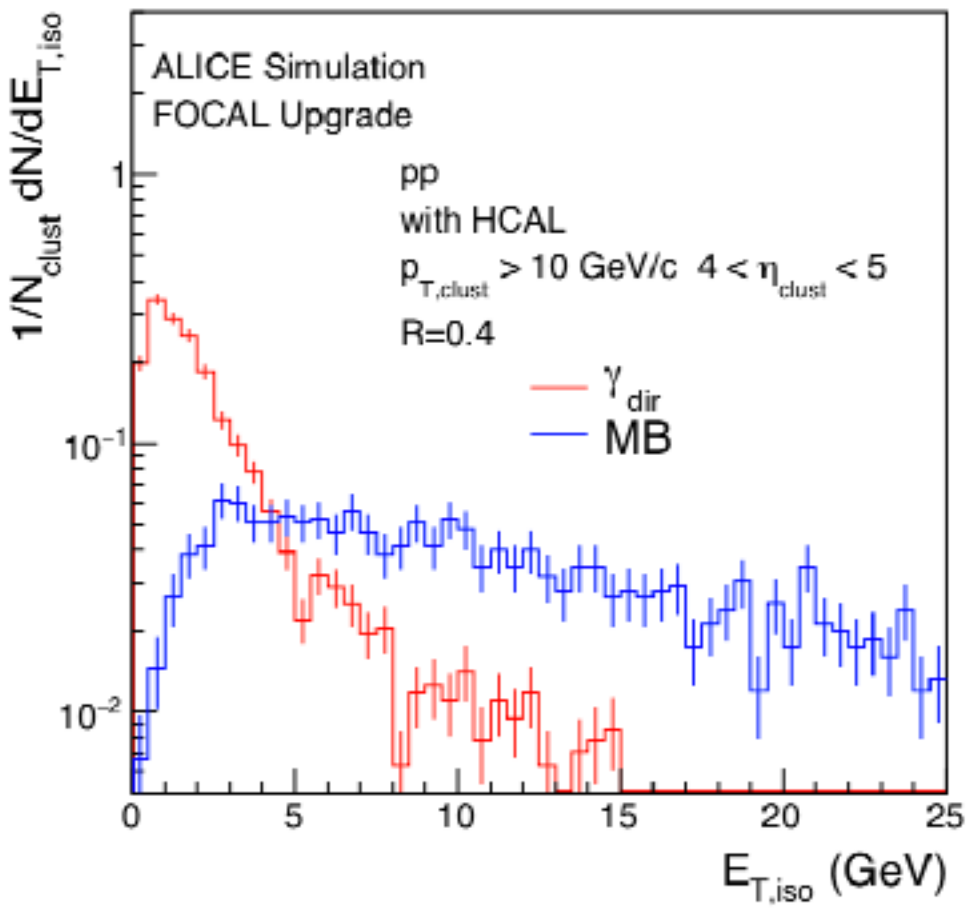


- Large uncertainties on the gluon content of the nucleus at small x
- Very few (DIS) measurements available
  - And they only probe the gluon density via the (DGLAP) evolution

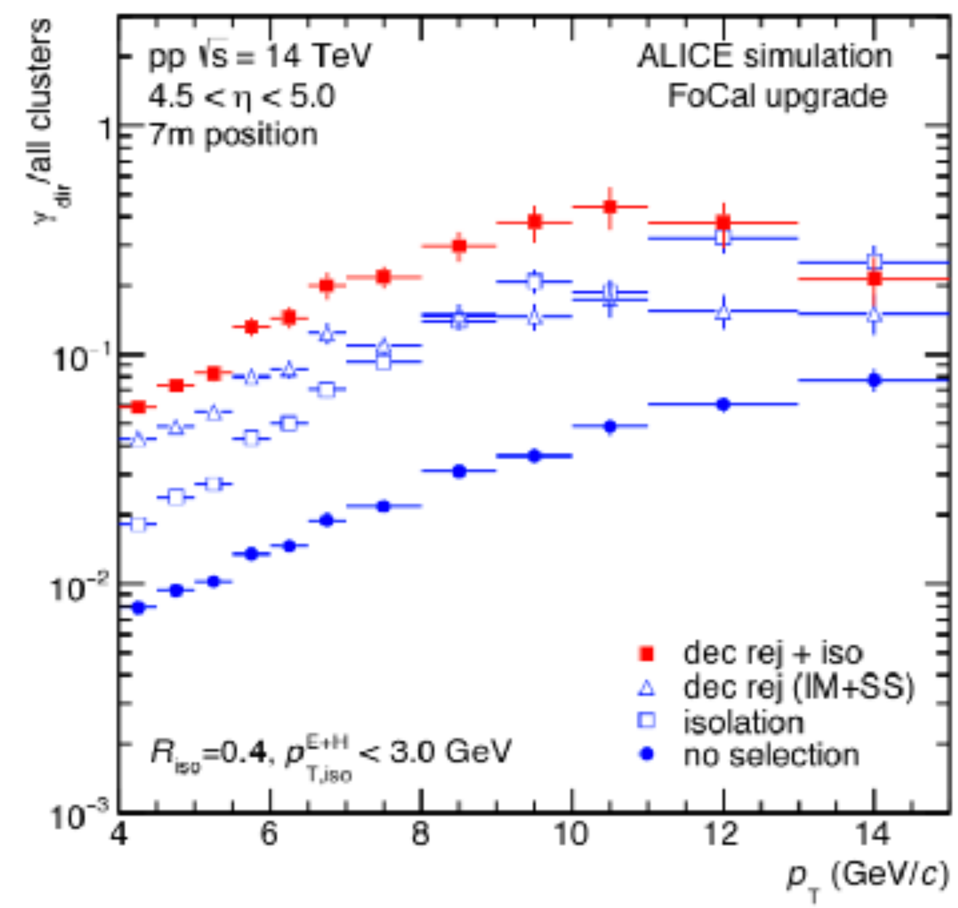
- Low-x especially accessible at forward rapidity $x_{1,2} \approx \frac{2m_T}{\sqrt{s}} \exp(\pm y)$
  - Photons are a excellent probe, not affected by final state nor hadronization

Key ingredients for isolated photon measurement

Isolation distribution



Direct γ/all cluster ratio

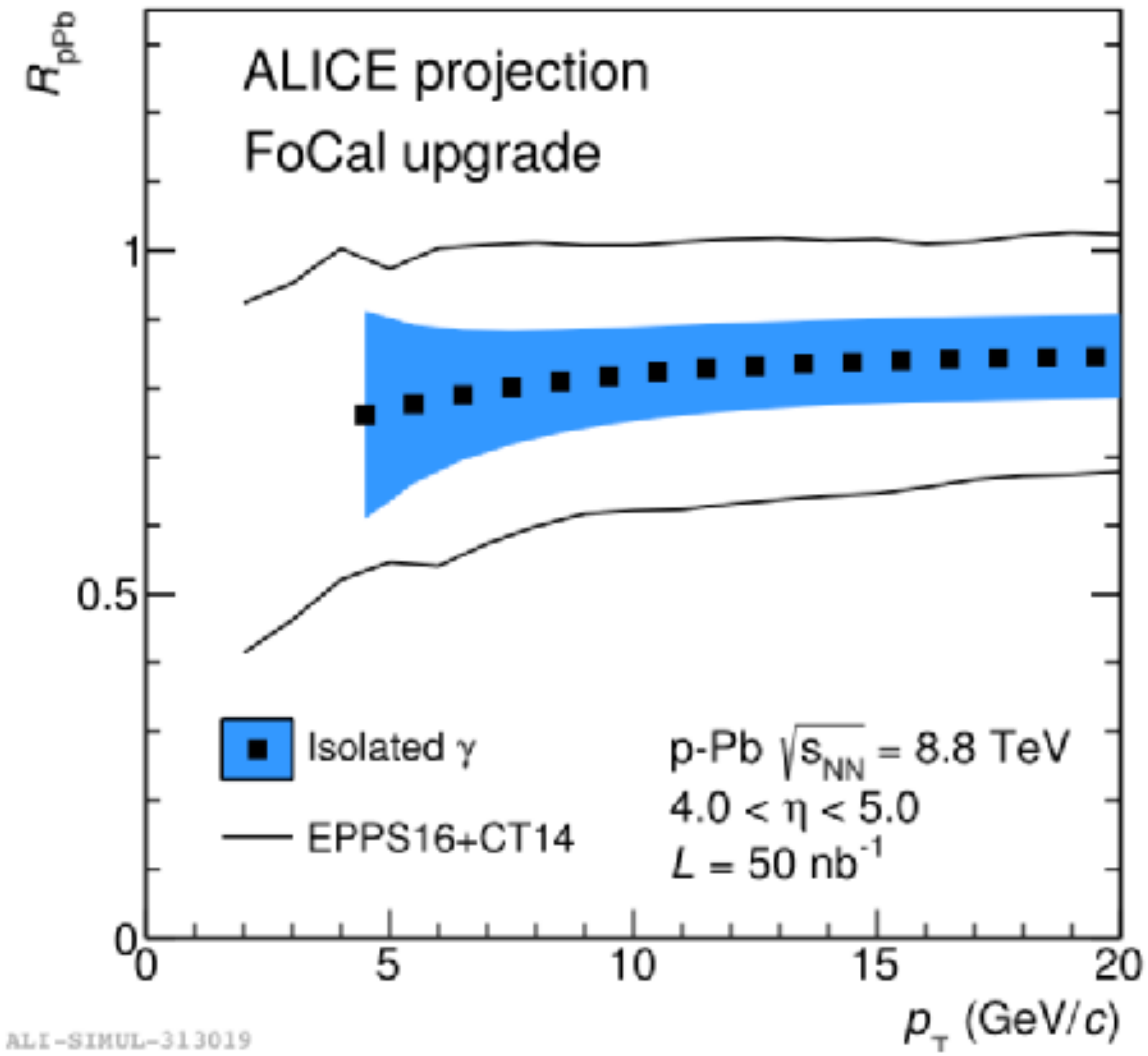


Main ingredients for direct photon identification

- Isolation cut (EmCal + HCal)
- Rejection of decays by invariant mass reconstruction

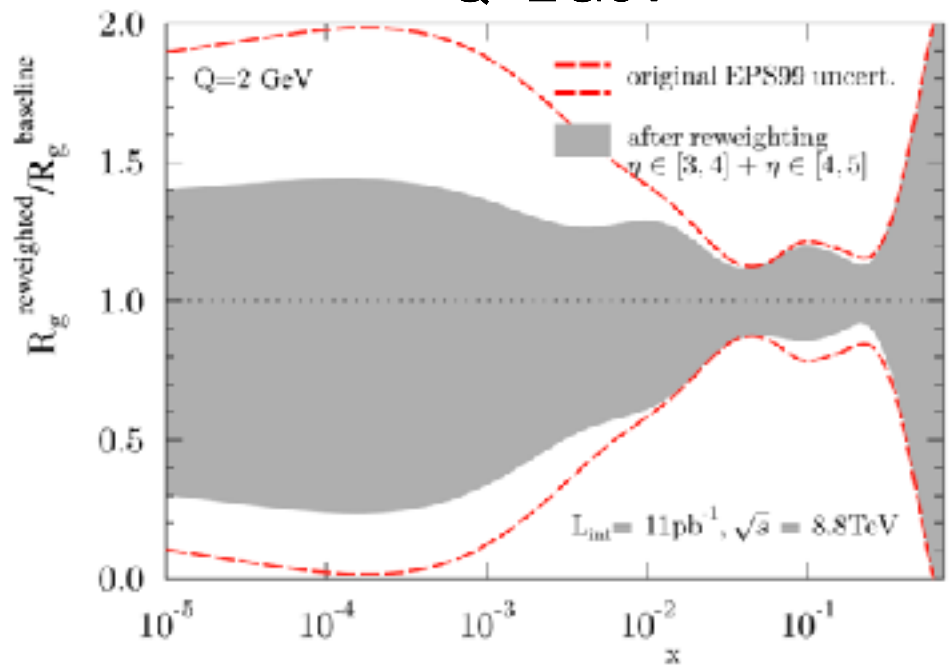
Improvement in signal fraction by factor 10 or more, from ~0.01 to ~0.1-0.6

Expected performance and impact on EPPS16 nPDF

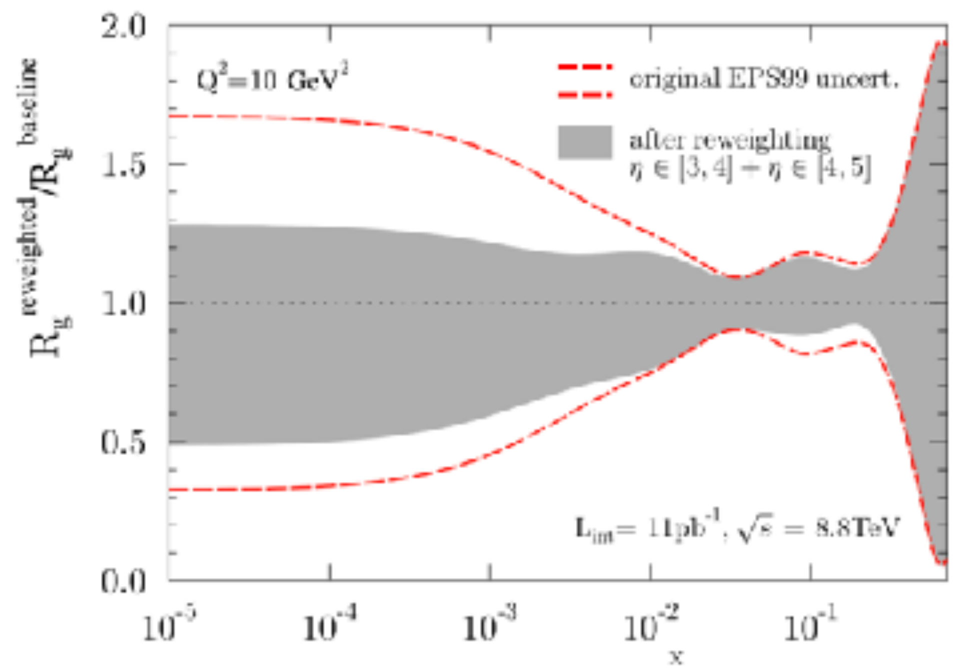


- Systematic uncertainty <20% above 6 GeV
- Below ~6 GeV, uncertainty rises due to background subtraction
- Significant improvement (up to factor 2) on EPPS16 gluon PDF
- Similar improvement as from open charm
  - Test factorization/universality

Q=2GeV



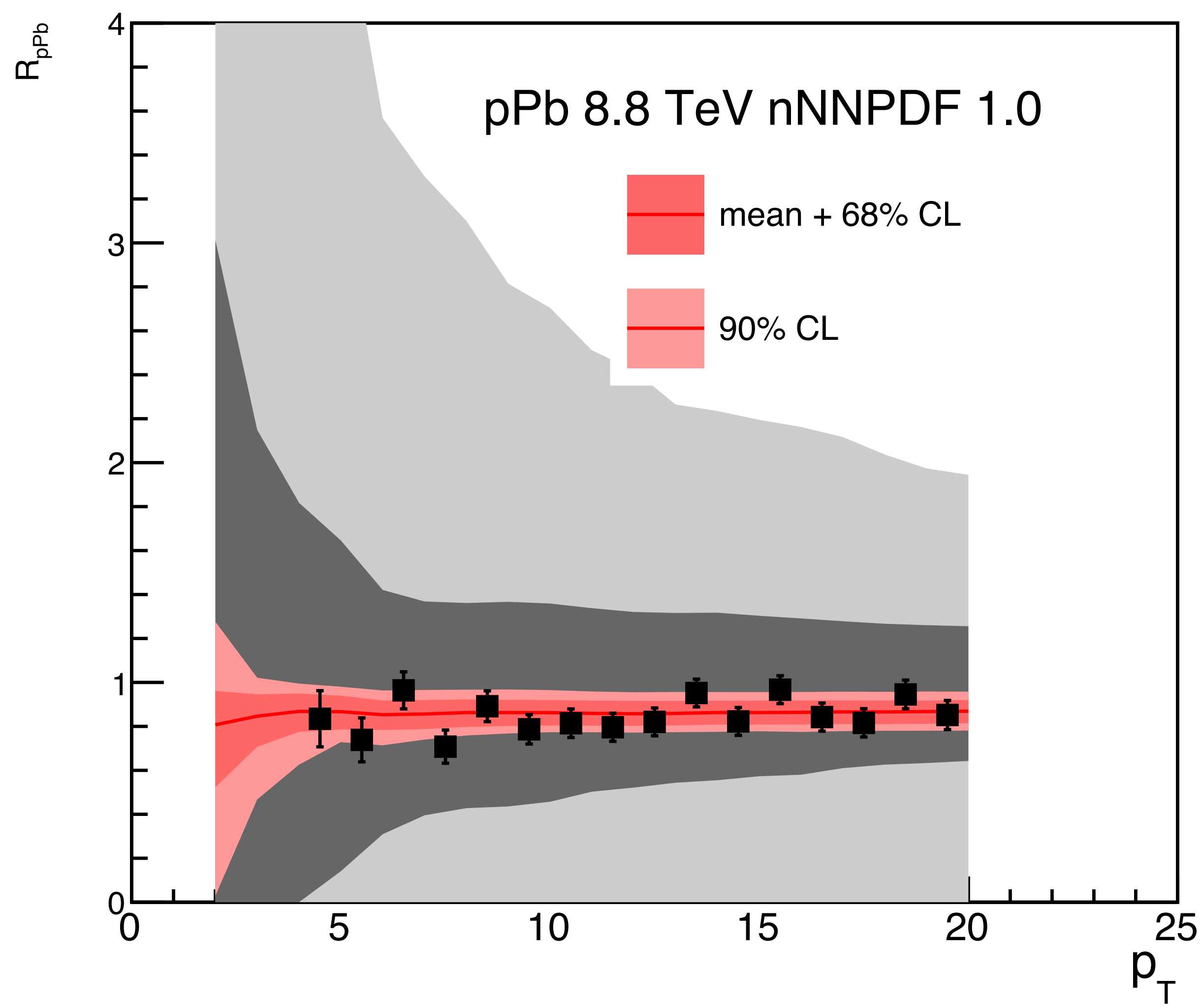
Q=10GeV



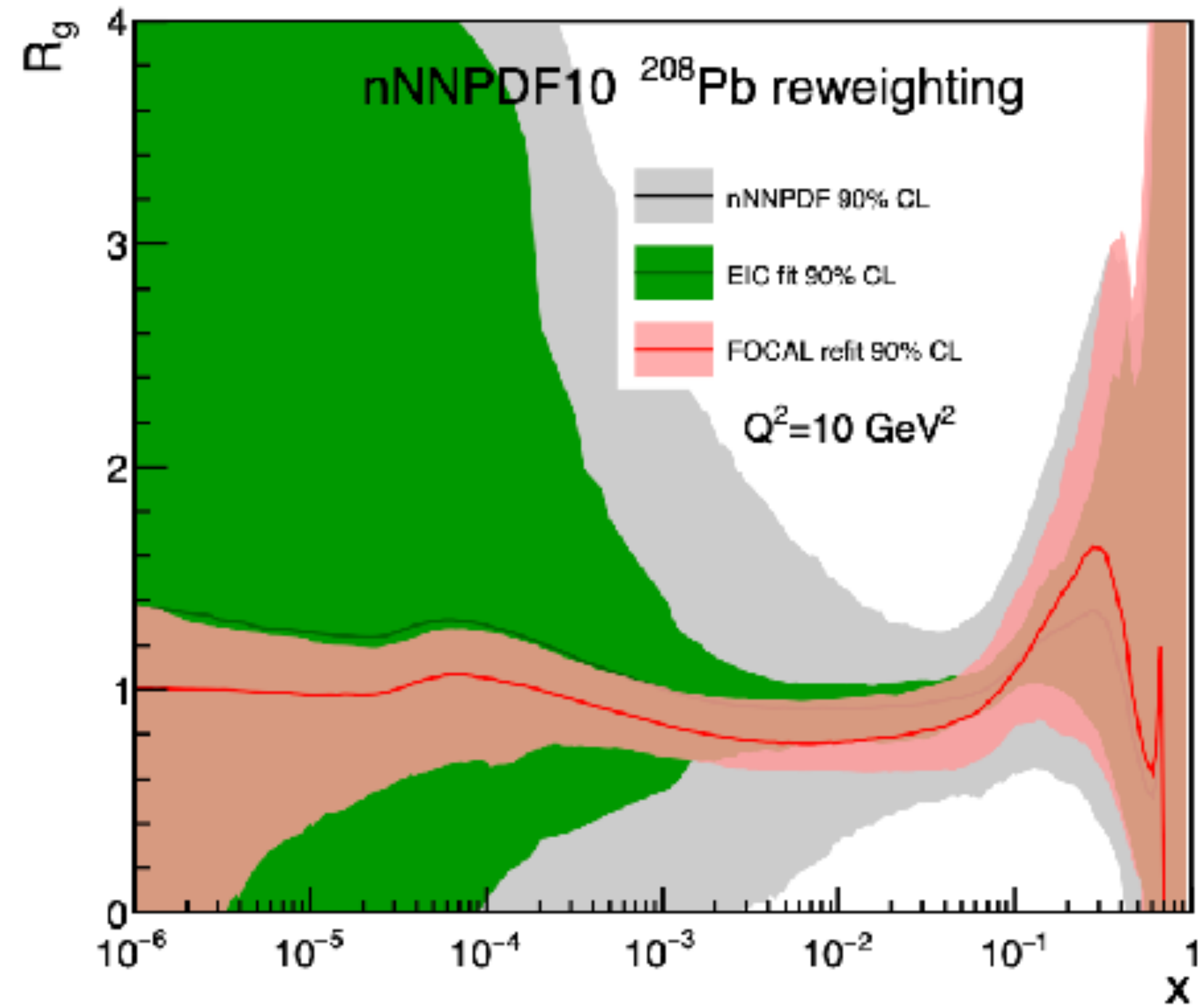
Impact on recent nNNPDF

R. Khalek et al., arXiv:1904.00018

FoCal pseudodata with nNNPDF



Impact of FoCal refit on nNNPDF



Recent nuclear PDFs: nNNPDF from DIS and minimal theoretical assumptions

- No constraints for $x < 10^{-2}$ from DIS
- FOCAL provides significant constraints over a broad range: ~10^{-5} - 10^{-2}
- Outperforming significantly the EIC in this aspect

Summary

- FoCal is highly granular Si+W-calorimeter complemented by a conventional sampling hadronic calorimeter

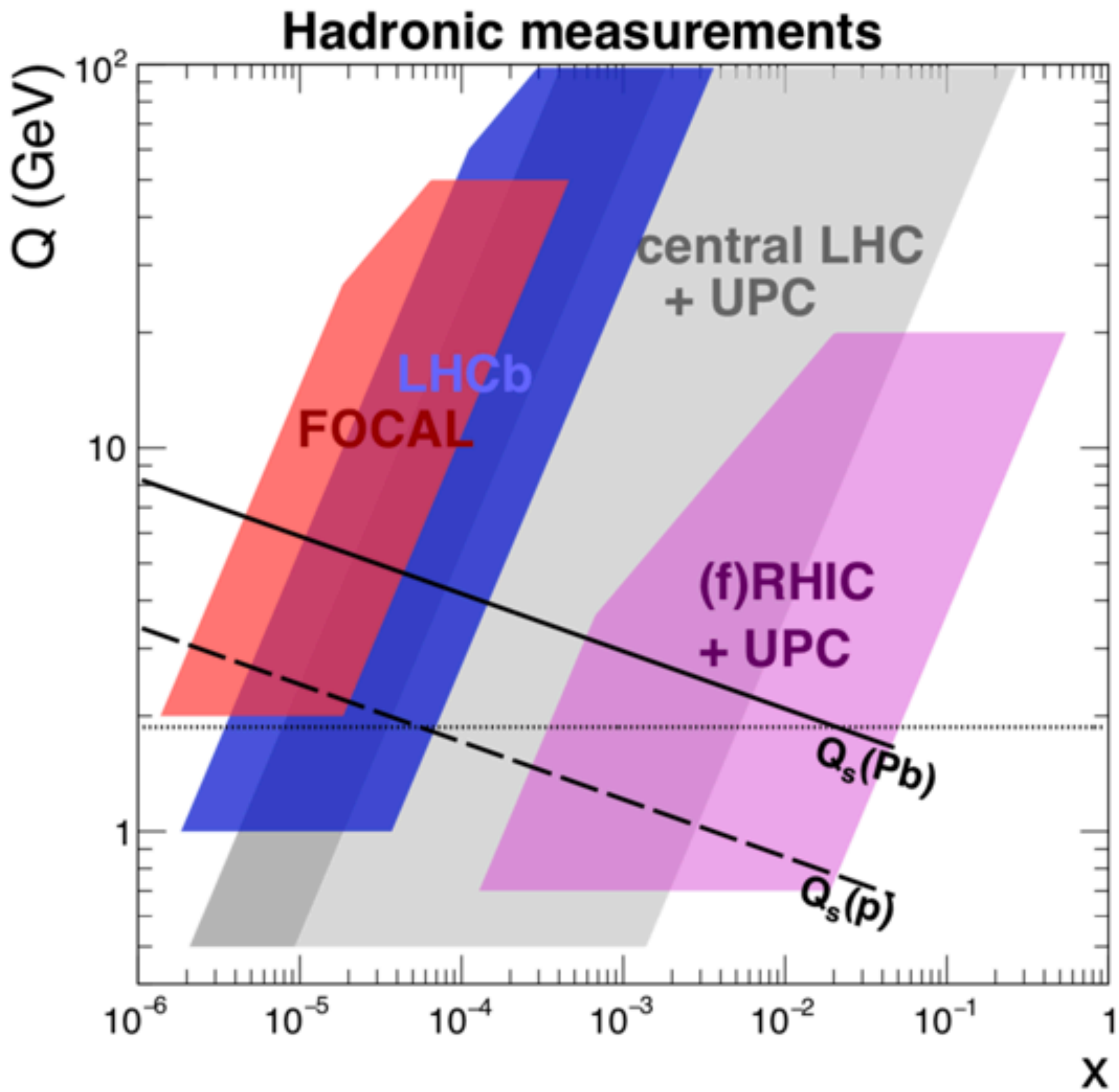
- Main physics goals
  - quantify gluon density in proton and nuclei at small-x
  - explore non-linear QCD evolution
  - establishes strong small-x program at LHC together with LHCb and UPC measurements; complementary to fRHIC and EIC

- Conceptual detector design available
  - Focus now mainly on implementation and integration
  - LoI draft available for discussion
    - See public note: ALICE-PUBLIC-2019-005
  - Discussions on national and institutional contributions ongoing

We very much welcome groups to join the project

Extra

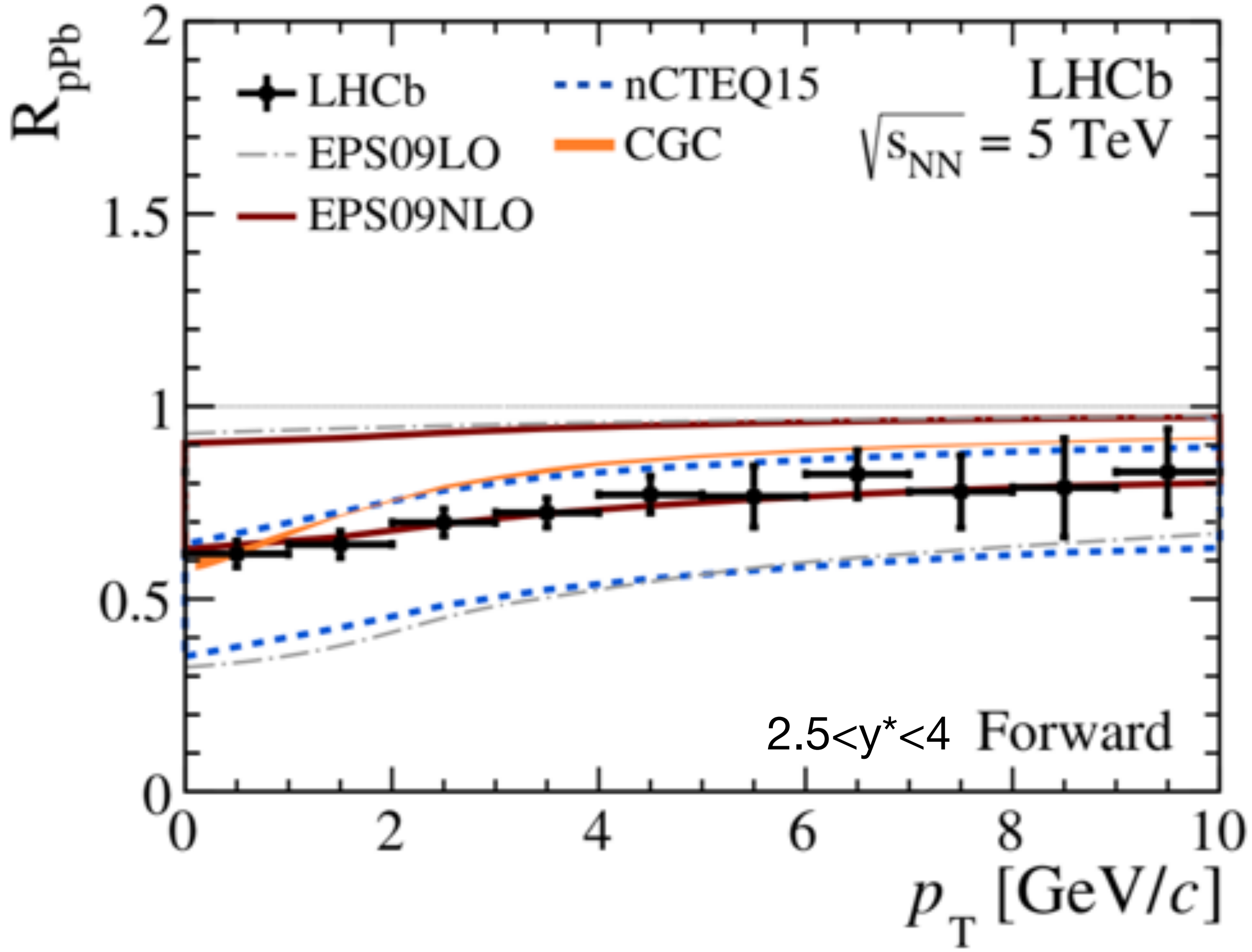
Kinematic reach at LHC



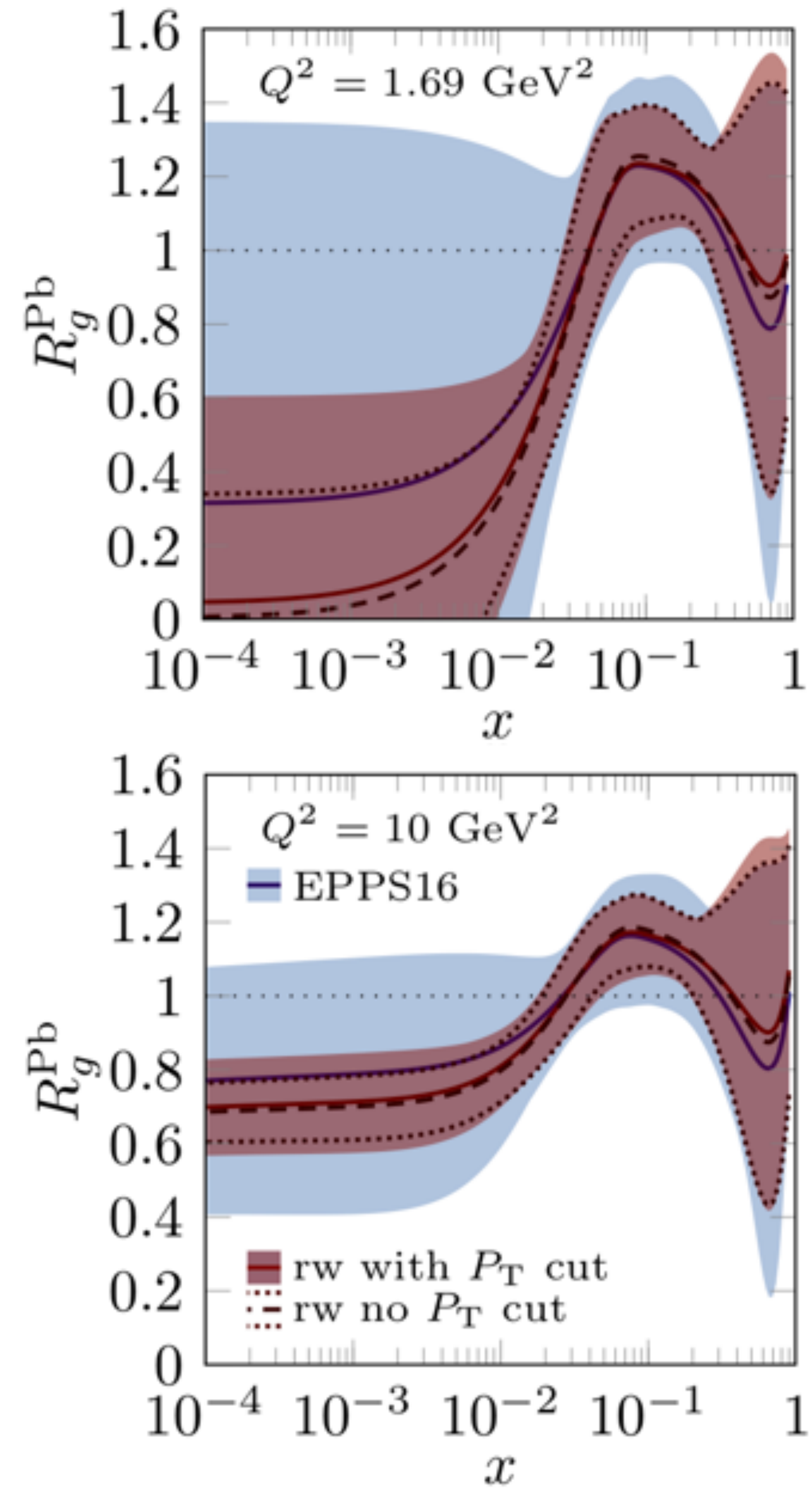
FoCal also extends the kinematic reach for hadrons and UPC

Forward open charm by LHCb

LHCb, arXiv:1707.02750



Eskola et al., arXiv:1906.02512

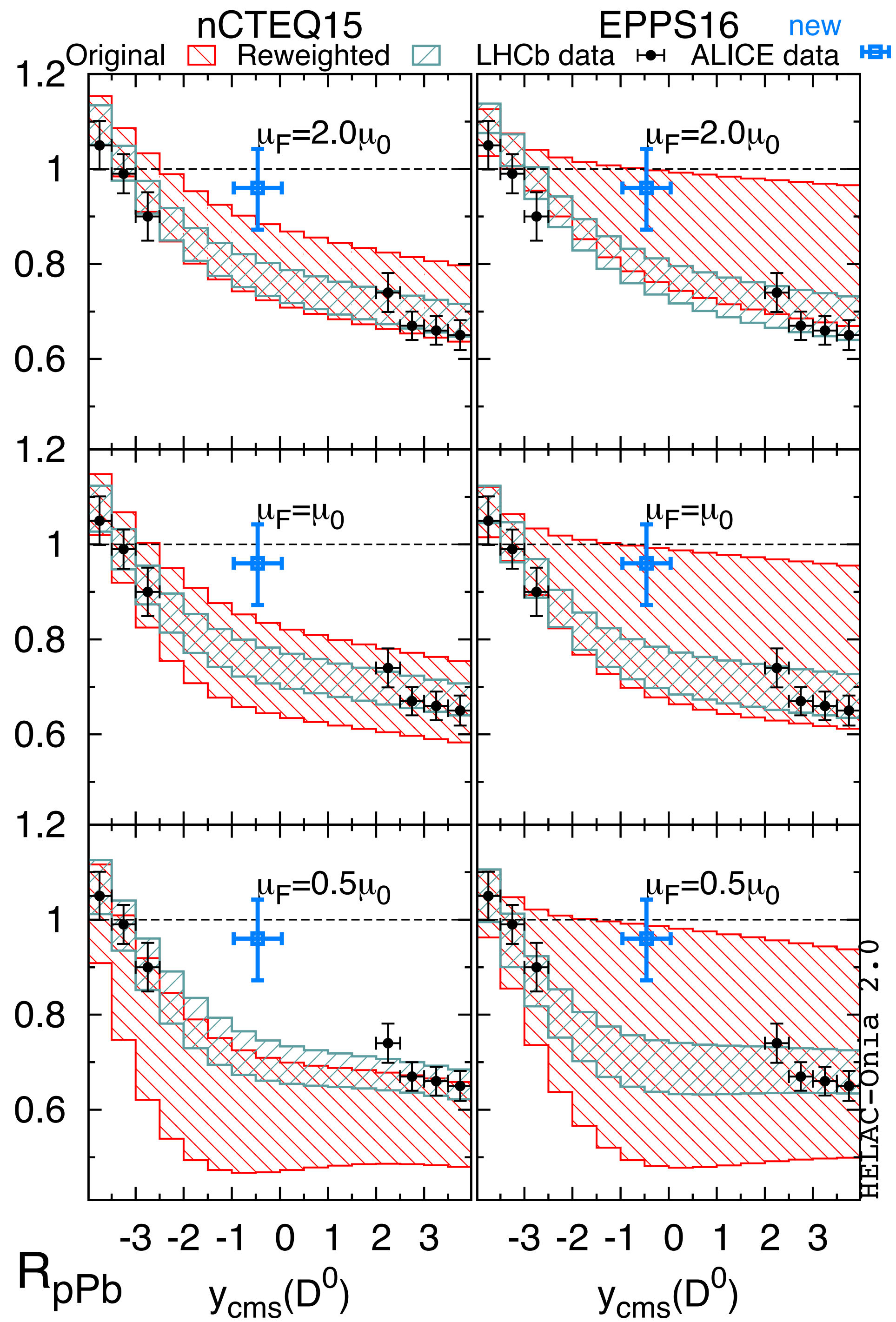


- Forward D^0 suppression observed by LHCb
- Consistent description with nuclear PDFs, with a large contribution from high x from fragmentation
  - Potential final state effects ignored
- Data constrain nPDF uncertainties by ~factor 2
  - Tension with ALICE mid-rap point (goto p29)
- Measurements with photons needed to verify factorization and universality

Reweighted nPDFs

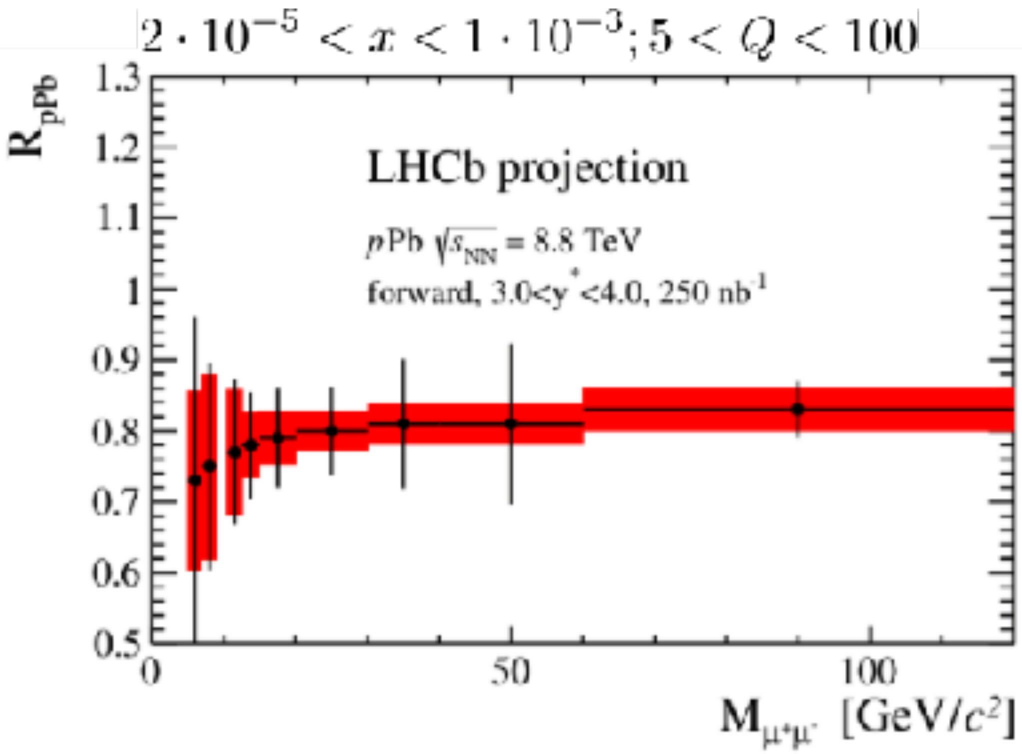
Kusina et al., PRL121 (2018) 052004

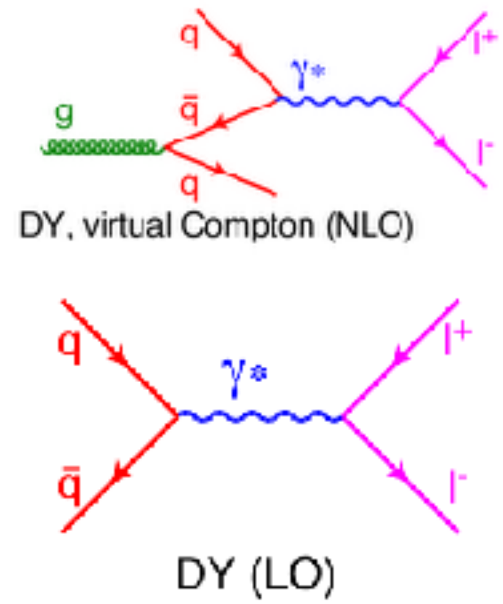
ALICE, arXiv:1906.03425

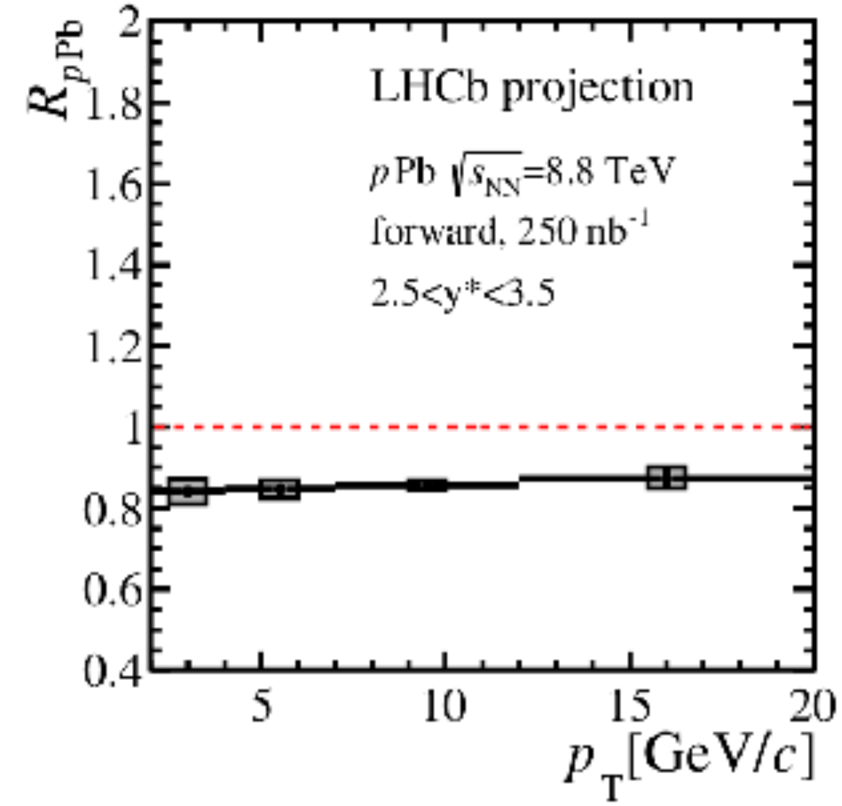


Reweighted nPDFs are in tension with the new ALICE mid-rapidity results

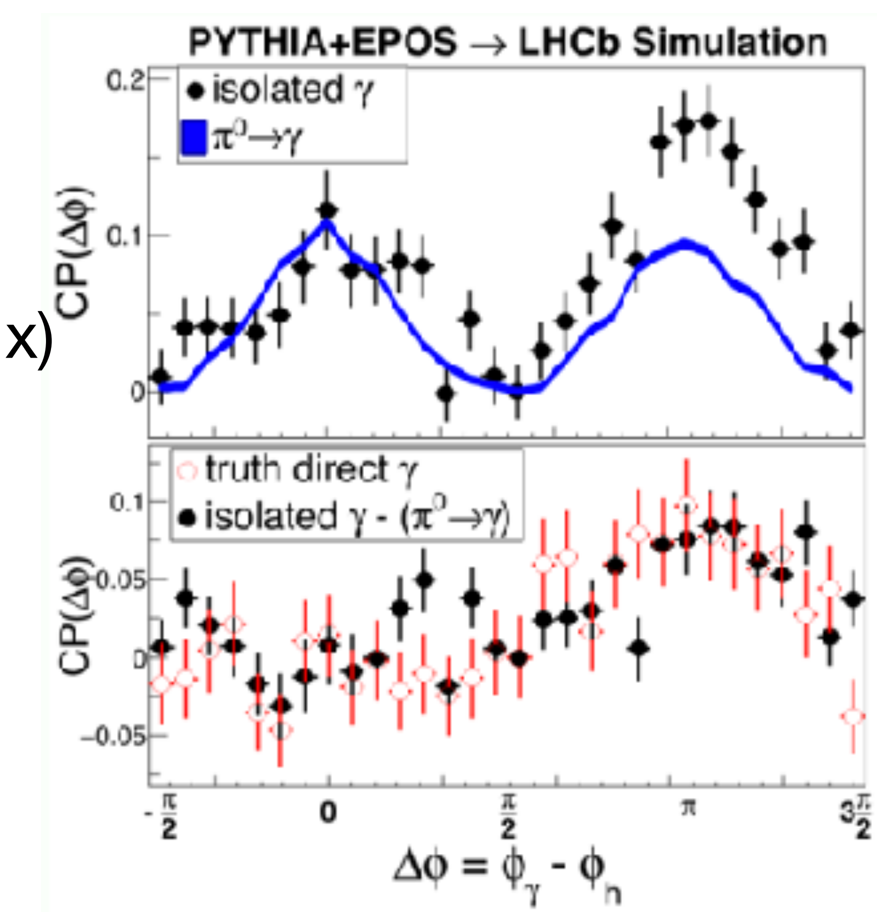
LHCb projections





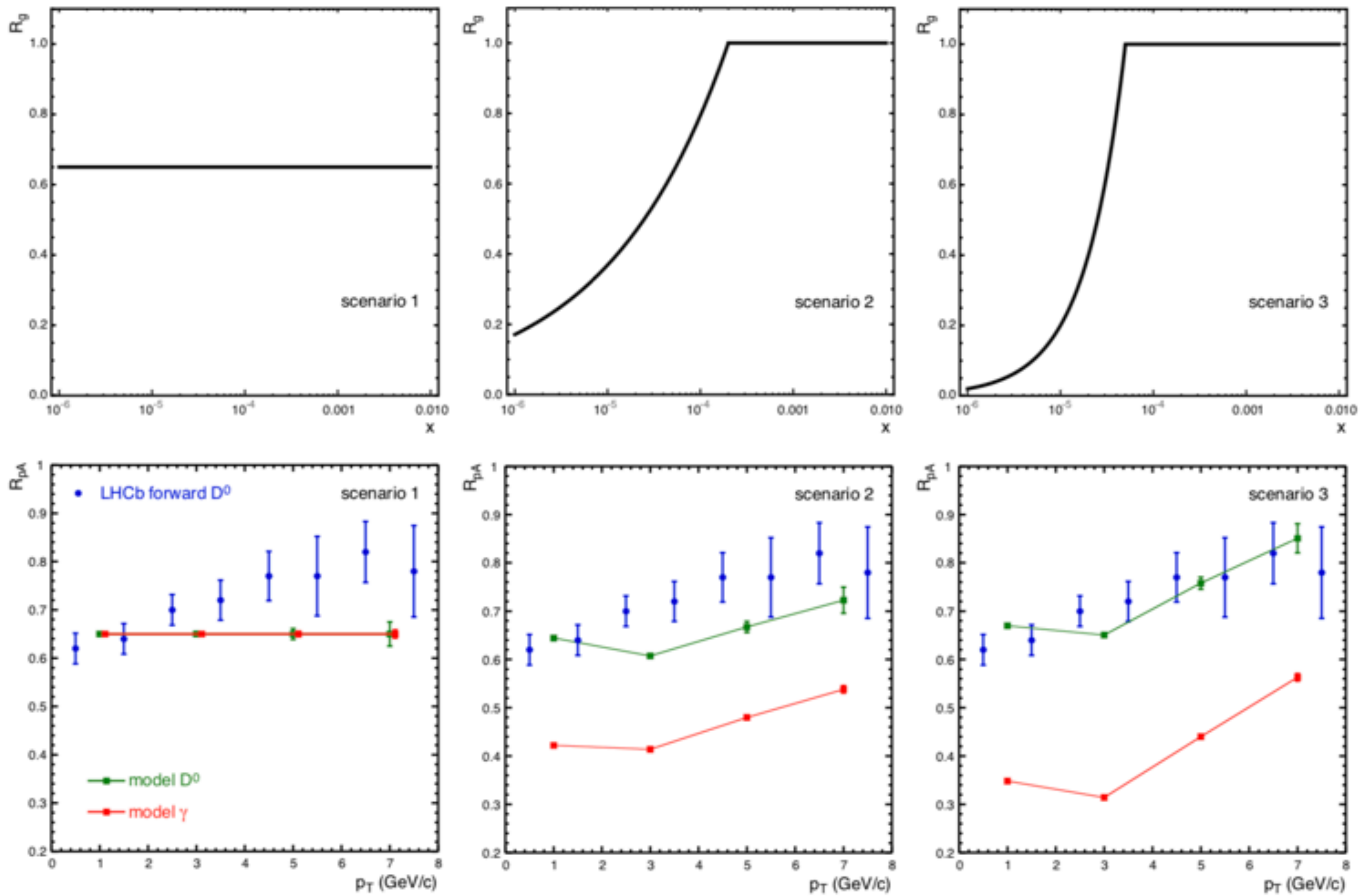


- DY forward (and backward)
  - Sensitive to gluons only at NLO
- D^0 production and D^0-D^0 correlations
- Measurements of B^+ production
  - Advantage higher scale for calculation (but also higher x)
- Isolated photon production and correlations with hadrons
  - Measure photon from conversions
  - Improve low p_T tracking for Run-4 with tracking stations inside the magnet



More info, see talk

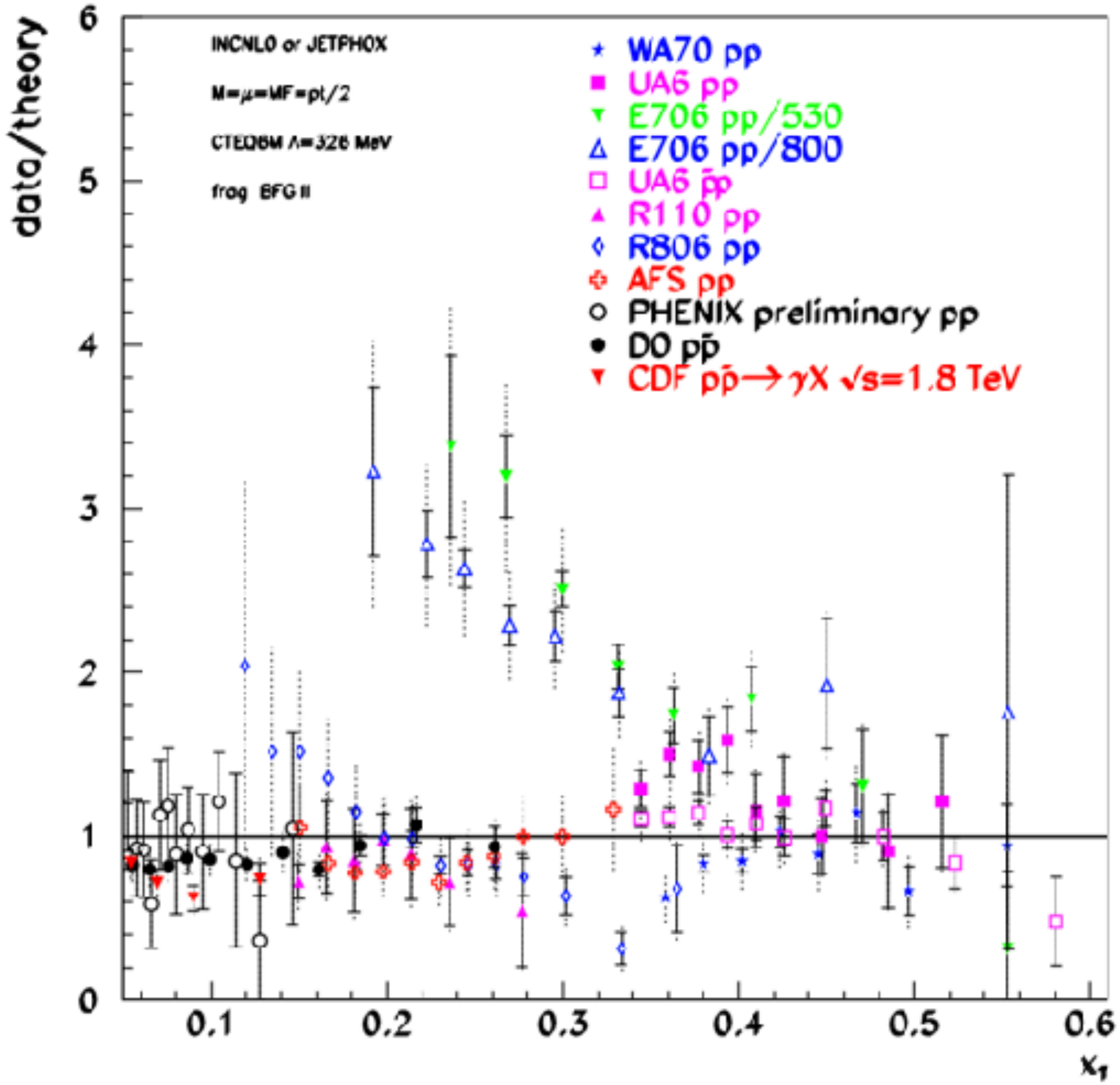
Charm vs photon sensitivity



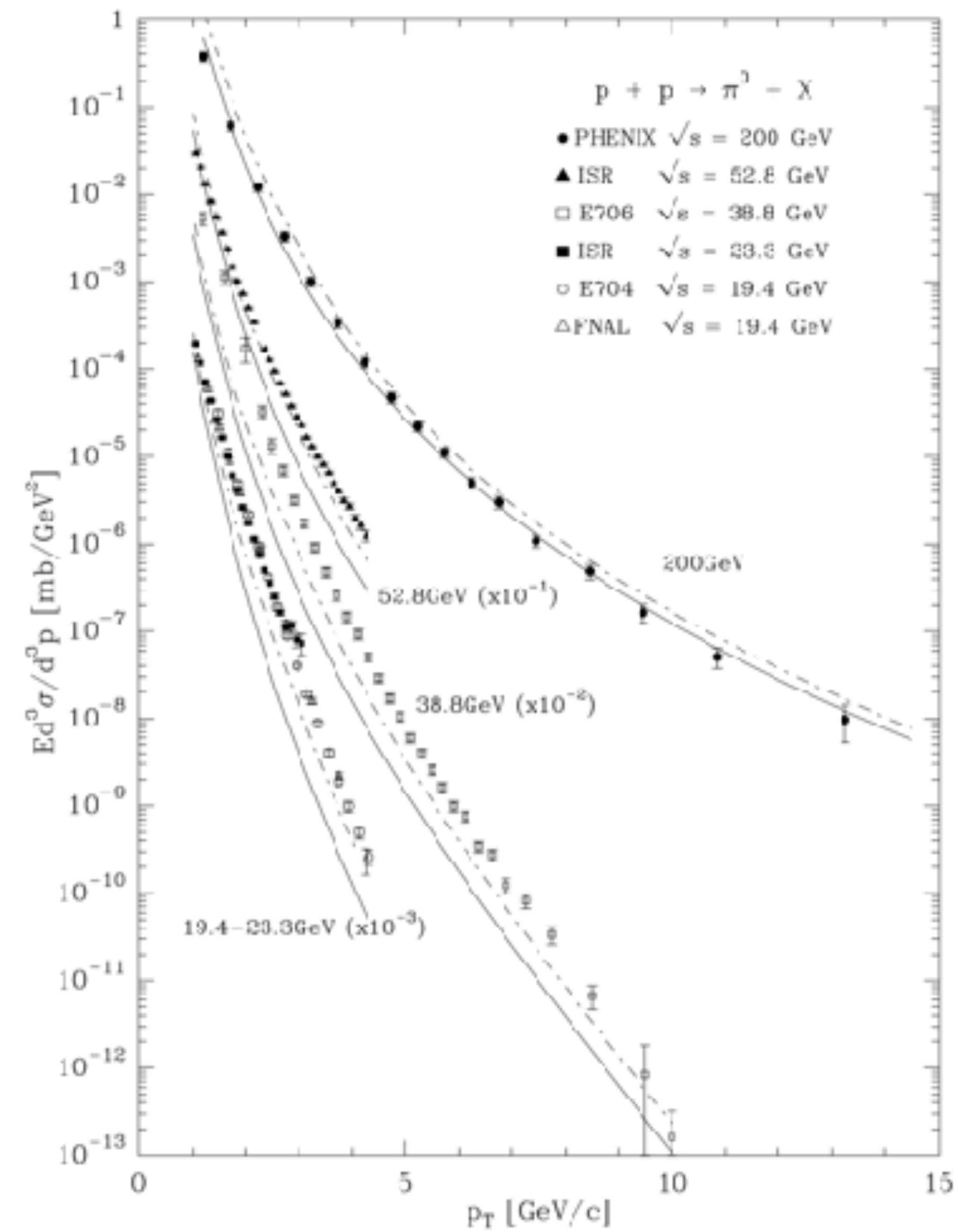
Toy study: Photons are more sensitive to shape of Rg than charm

Factorization

PRD 73 (2006) 094007

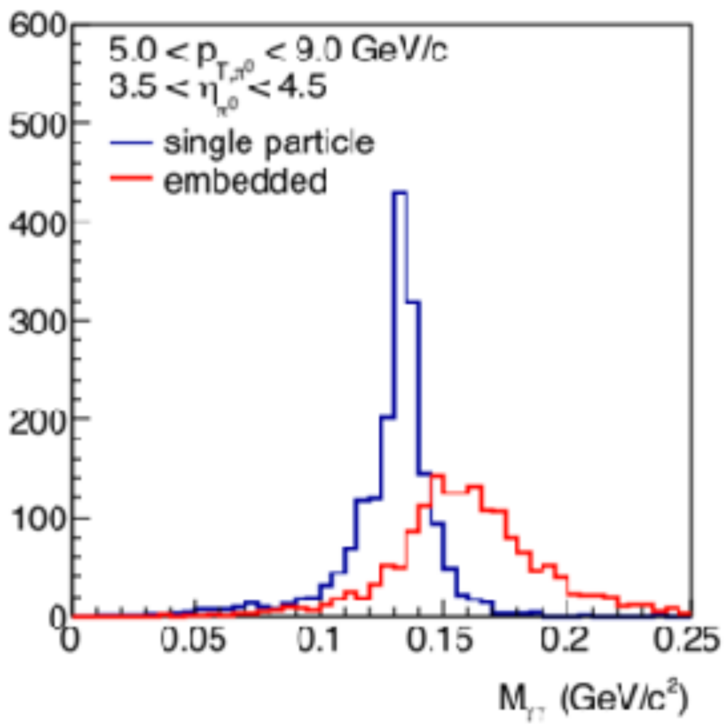


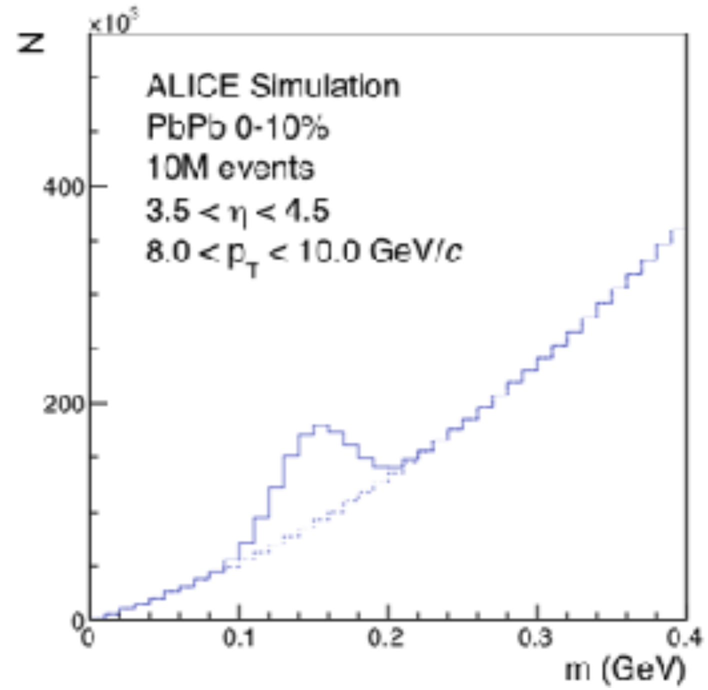
arXiv:hep-ph/0311110

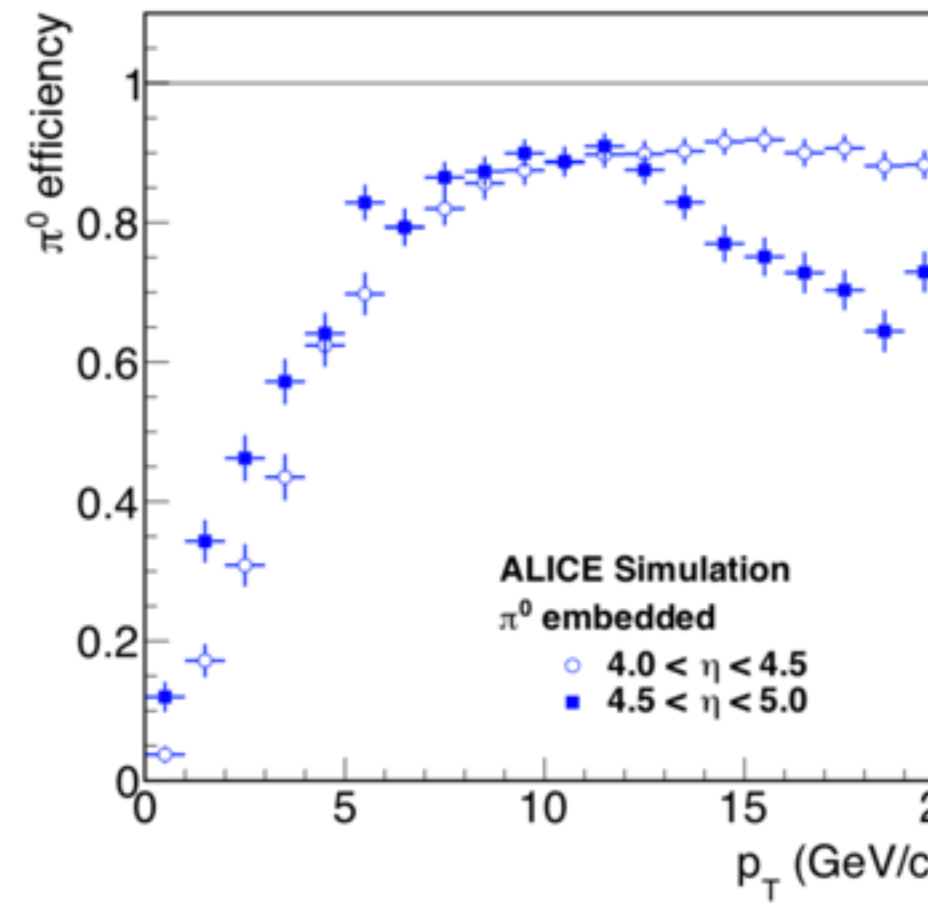


Breaking of factorization/universality, examples before D0/CDF/Phenix

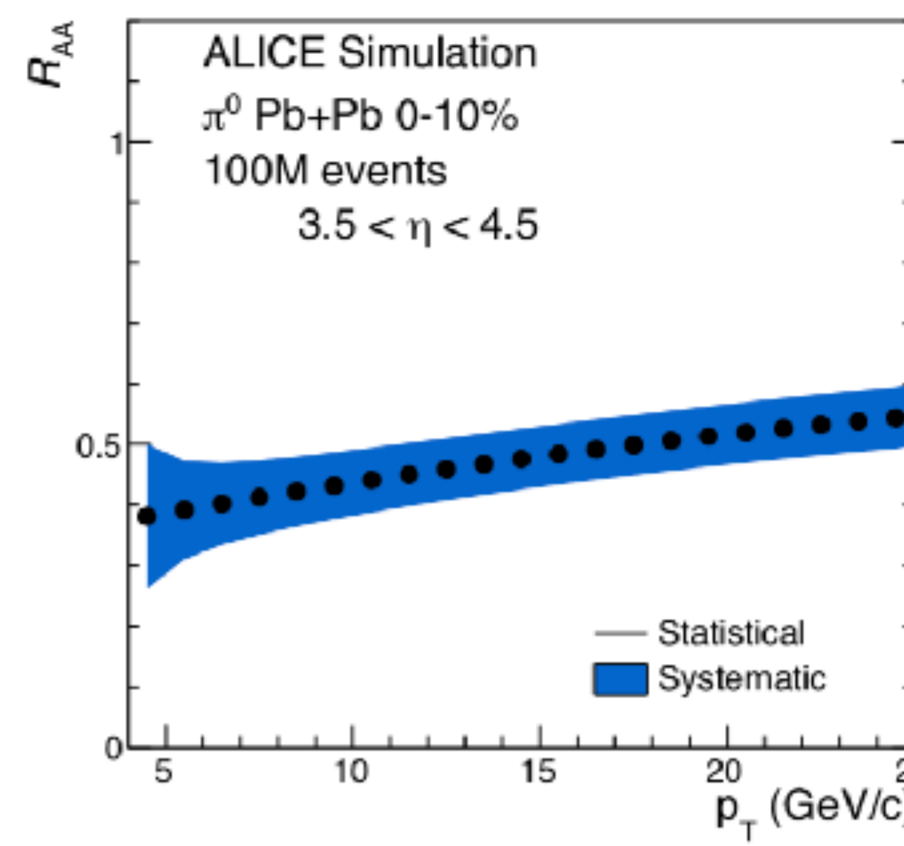
Performance in PbPb



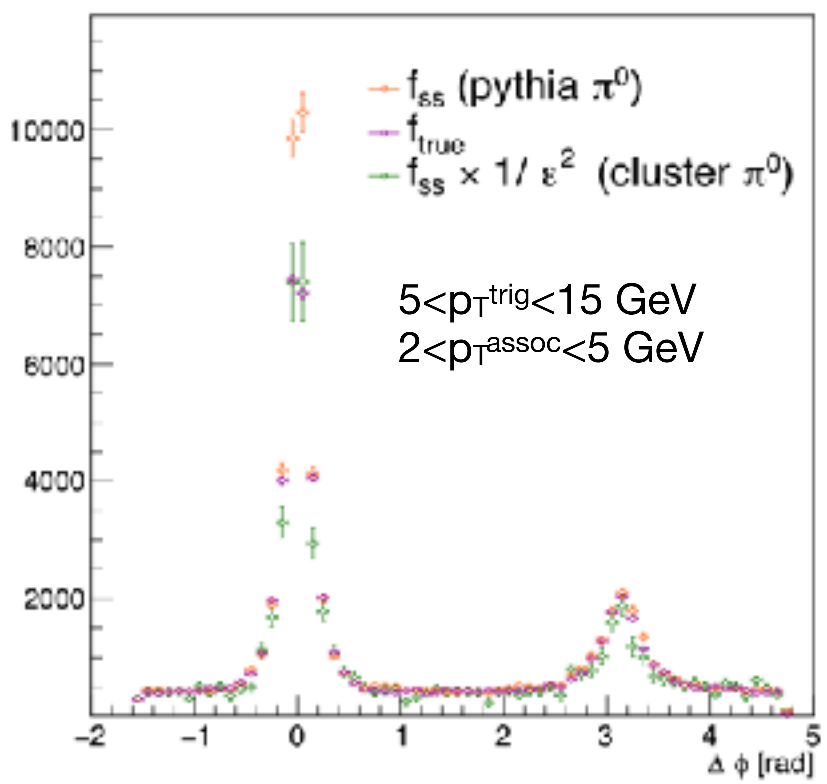




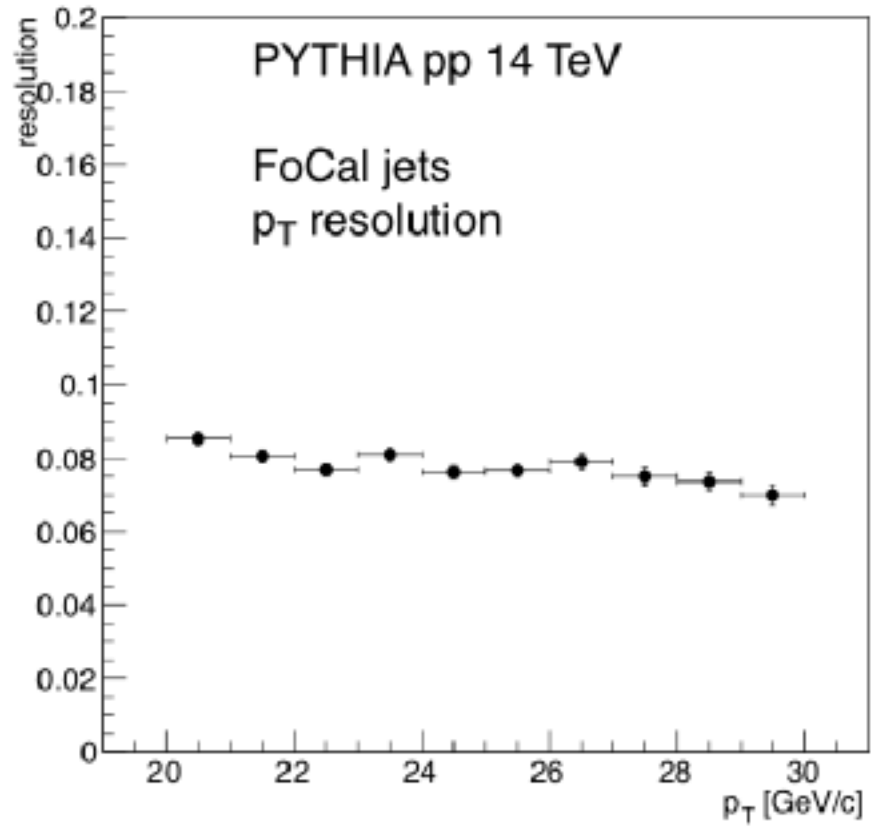
- Performance in PbPb affected by shower overlaps and combinatorial background
- Efficiency for high energy neutral pions nevertheless quite good
- Combinatorial background may prohibit low p_T reconstruction, but above 5 GeV can perform a precise R_{AA} measurement



Other observables

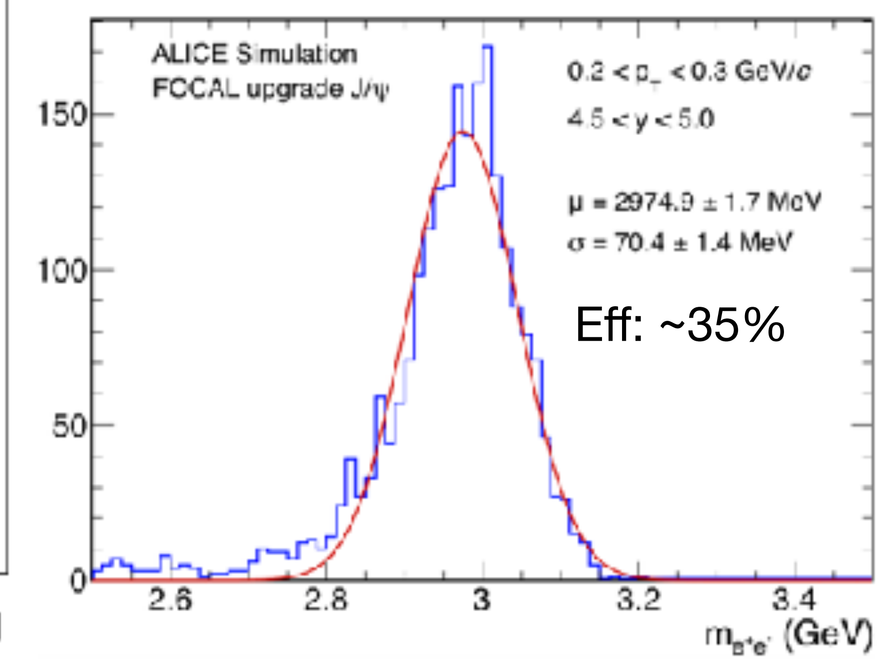


π^0-π^0 correlations in pp
(for decorrelation studies)



Jet resolution
(jet/dijets in pp/pPb/UPC)

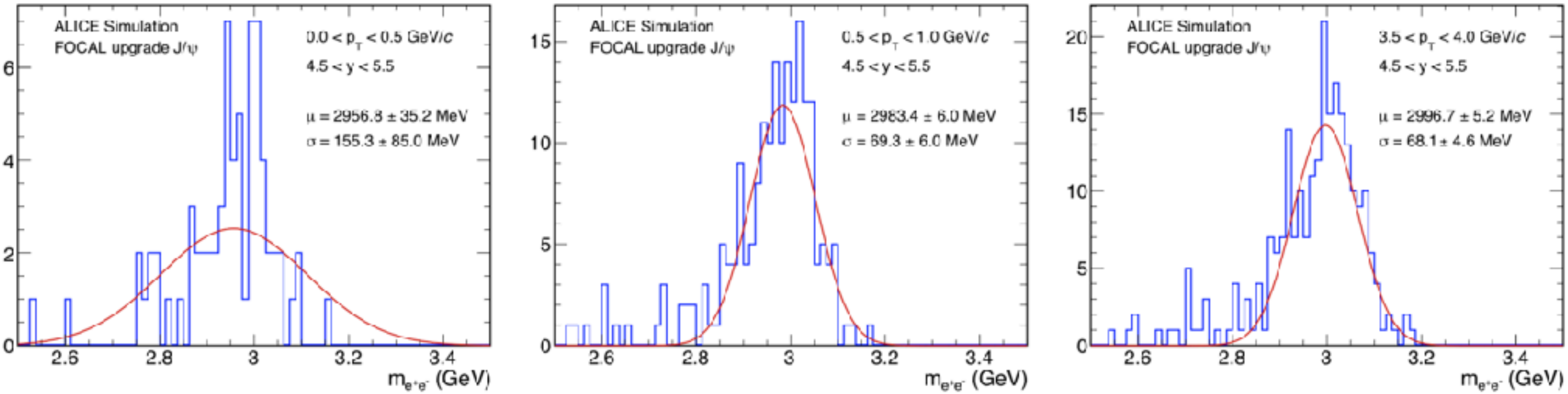
Single particle response

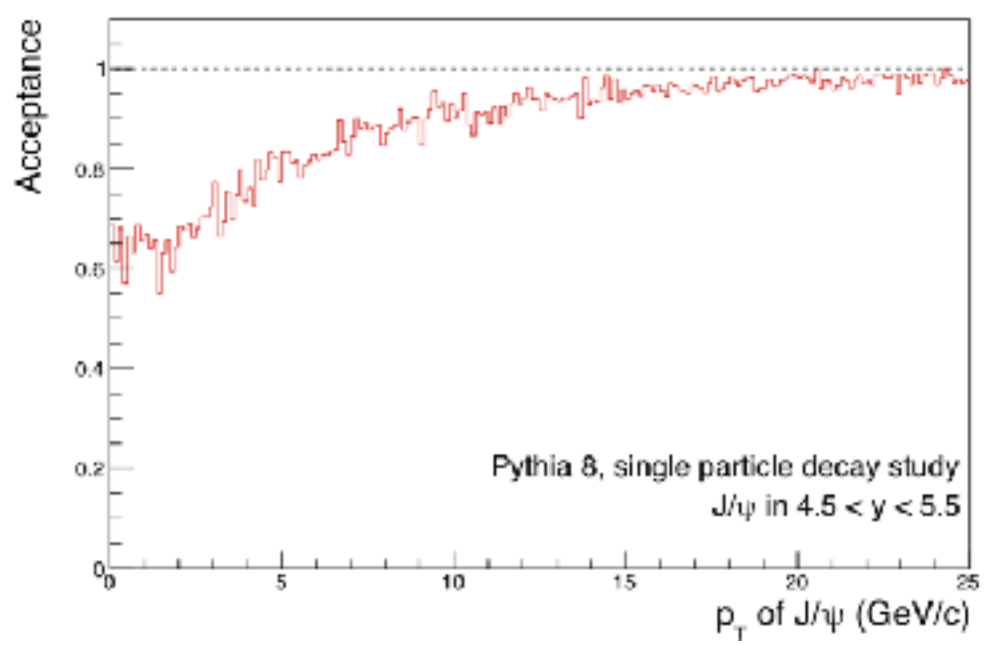


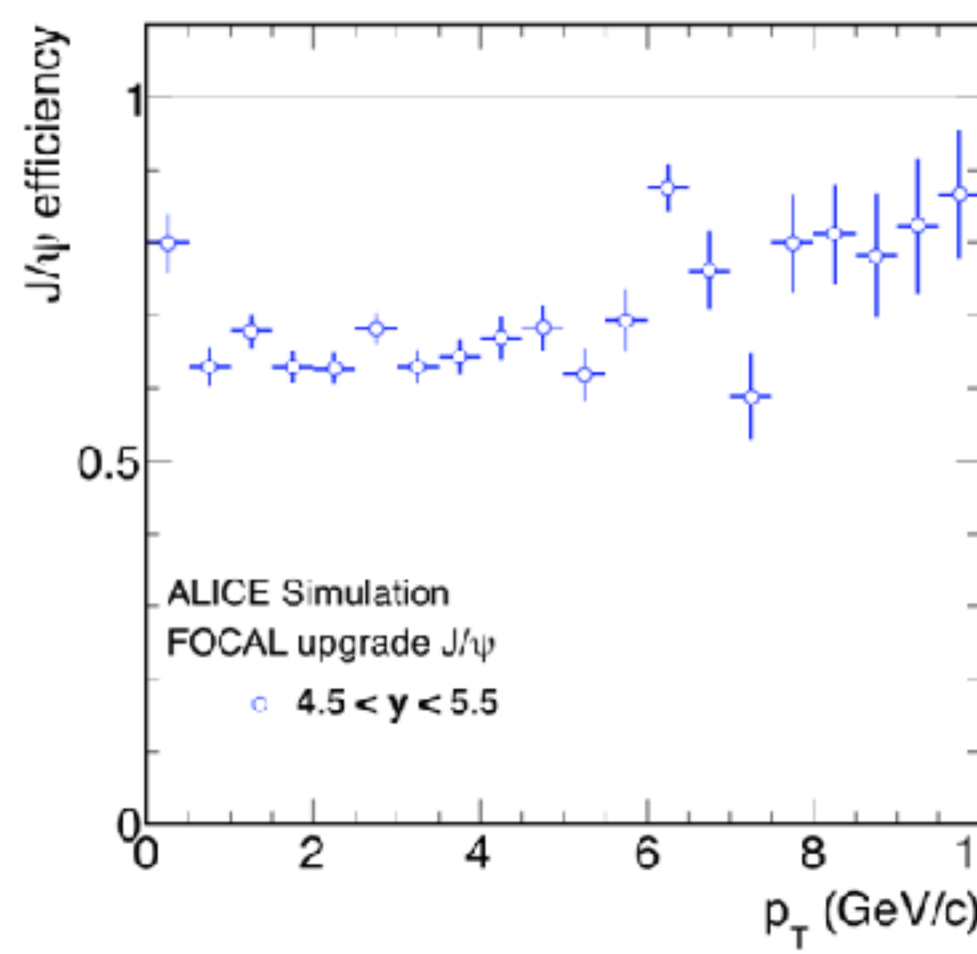
J/ψ reconstruction
(for UPC measurements)

Excellent performance for other observables
(complete case studies envisioned for TDR)

J/ψ in UPC (empty FoCol)







Feasibility of J/ψ at low p_T established