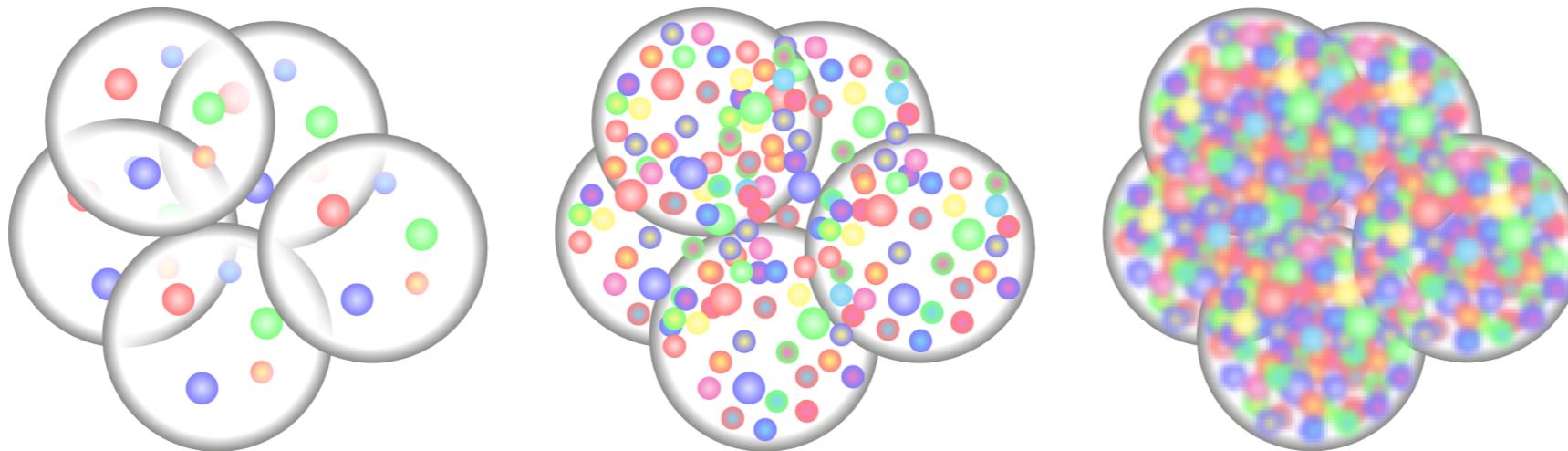




ALICE



Forward Direct Photons

Physics Motivation and the Status of R&D for FoCal in ALICE

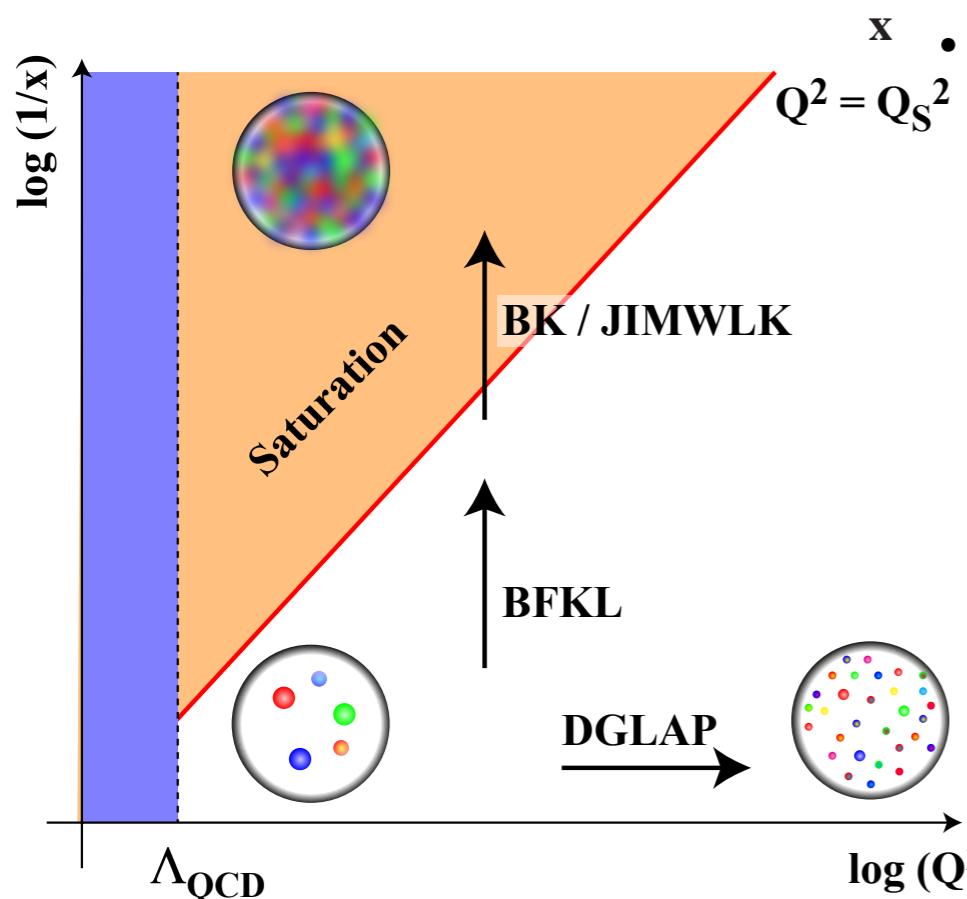
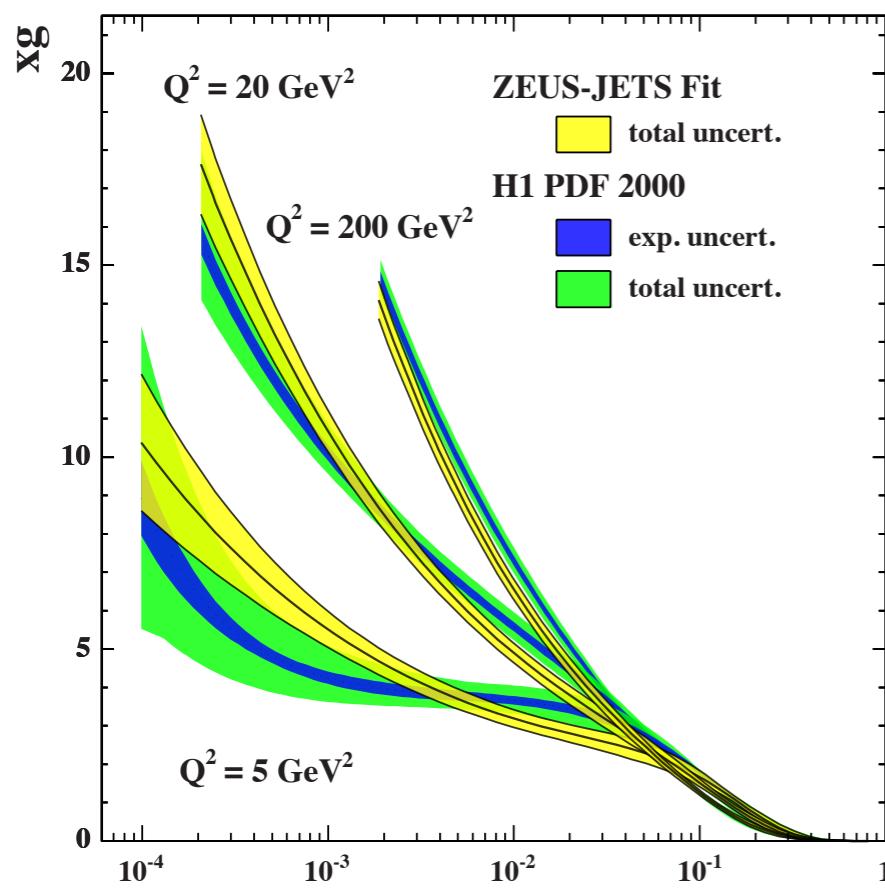
T. Peitzmann (Utrecht University/Nikhef)

Outline

- Introduction
 - low-x physics, gluon saturation
 - first results from LHC
- Saturation signals
 - PDF uncertainties
 - charm vs photons?
- FoCal - an ALICE upgrade proposal
 - baseline design: performance studies
 - progress on detector R&D
- Summary

Gluon Saturation

H1+ZEUS

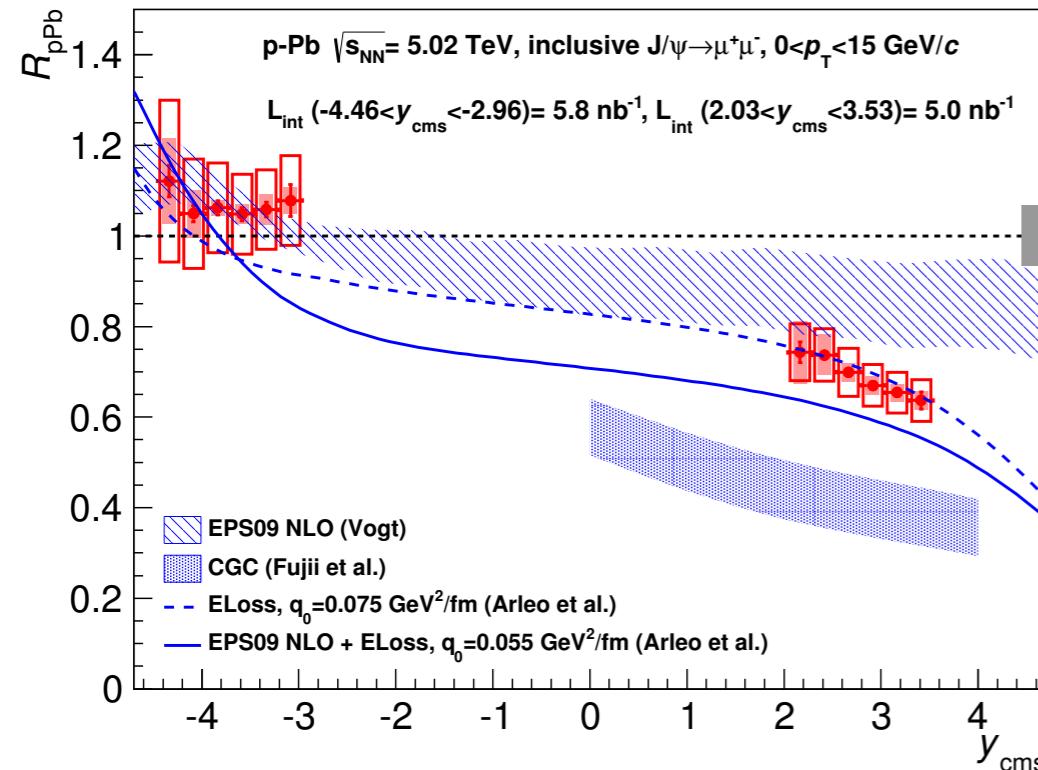


- from evolution equations (DGLAP, BFKL):
 - gluon density increases with Q^2 and $1/x$
 - leads to very high gluon density
 - problems with unitarity
 - for high density non-linear processes become important
- gluon saturation below saturation scale
 - enhanced in nuclei

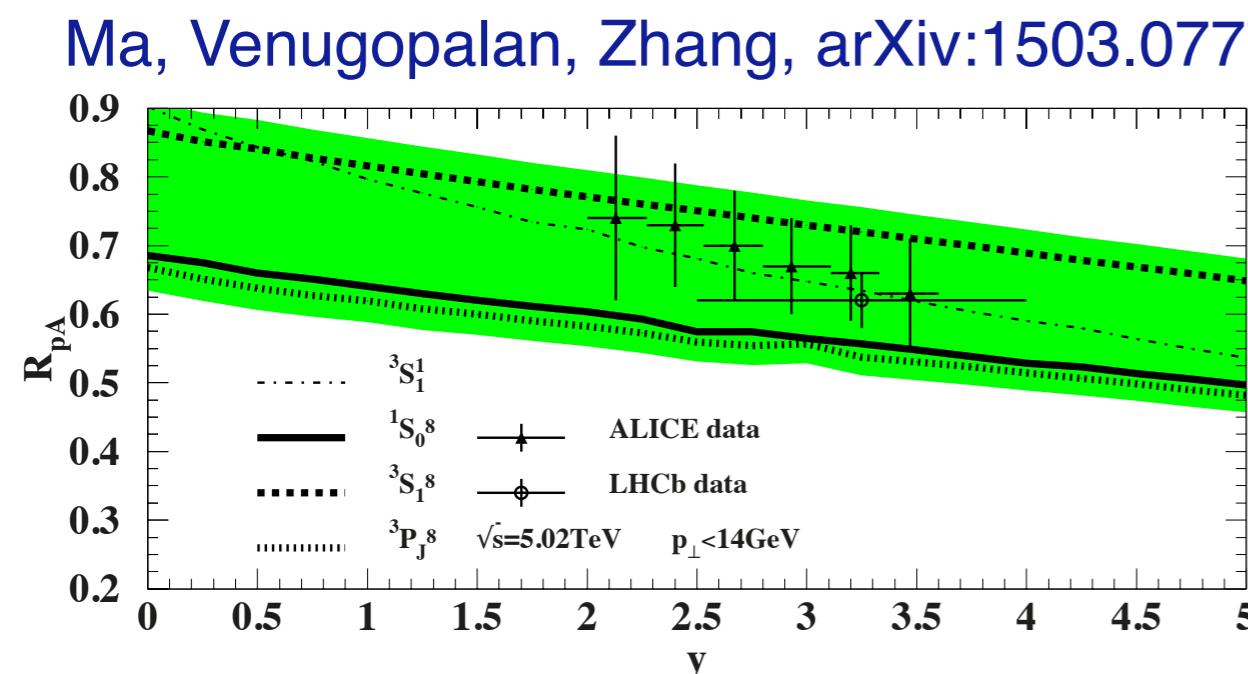
$$Q_s^2(x) \approx \frac{\alpha_S}{\pi R^2} x G(x, Q^2) \propto A^{1/3} \cdot x^{-\lambda}$$

Results from p-Pb at LHC (1)

ALICE, JHEP02 (2014) 073

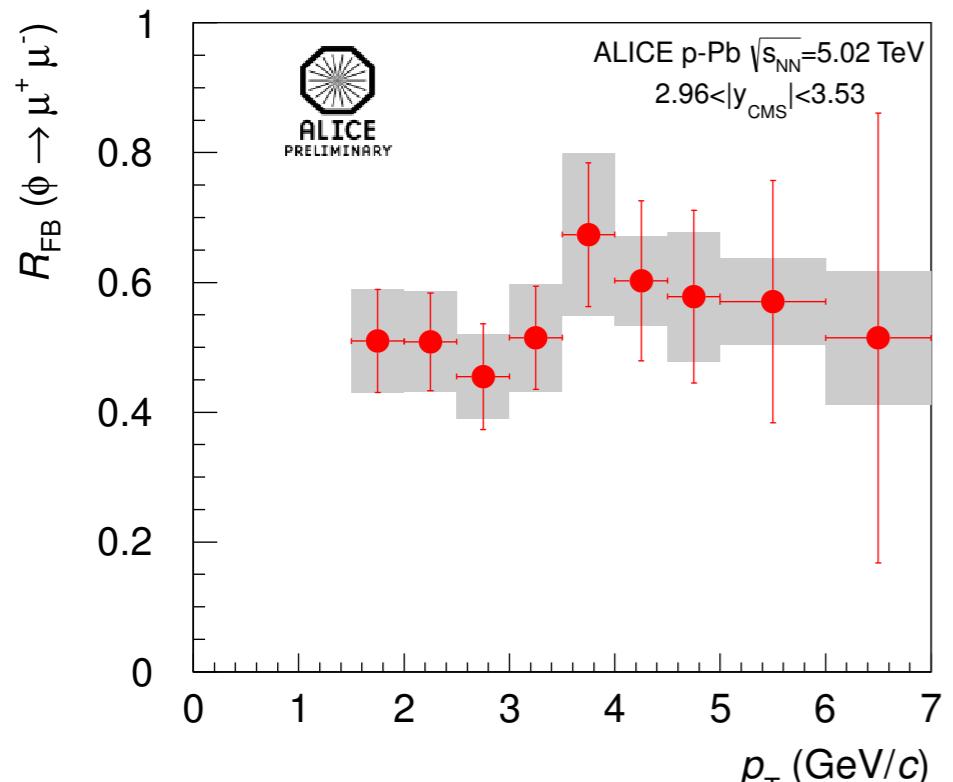


- nuclear modification factor R_{pPb} for charmonium
- J/ψ suppressed at forward rapidity
 - consistent with shadowing (EPS09)
 - not described by one CGC calculation (state of the art?)
- description by CGC
 - needs refined calculations
 - uncertainties due to population of different quantum states
- not conclusive



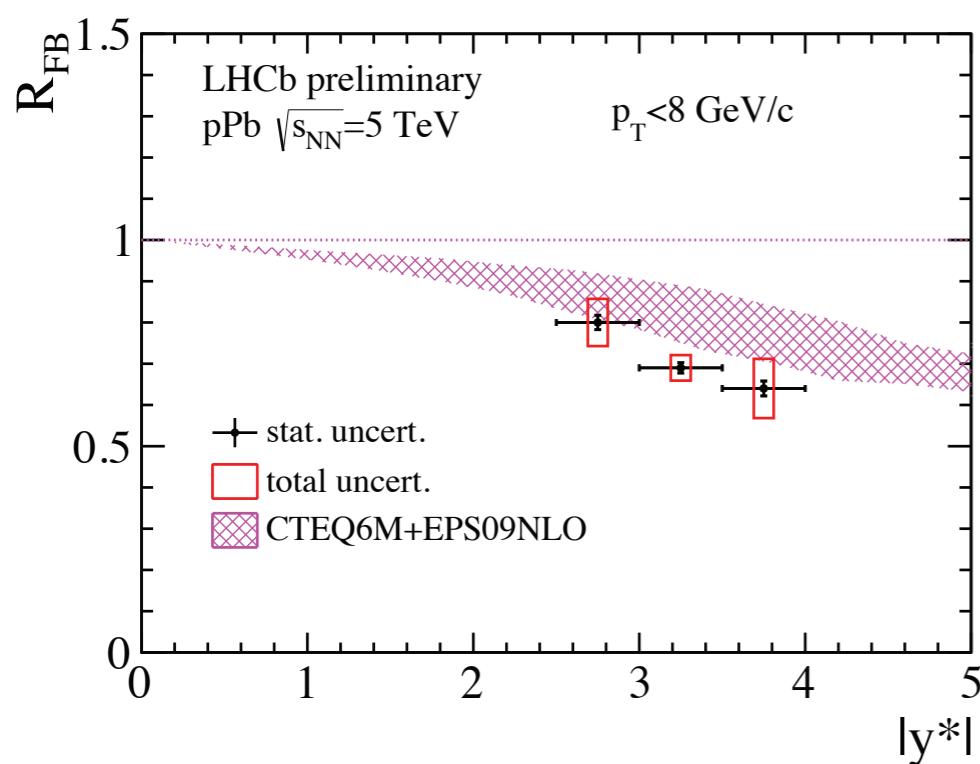
$$R_{pA} = \frac{dN/dp_T(pA)}{\langle N_{coll}(pA) \rangle dN/dp_T(pp)}$$

Results from p-Pb at LHC (2)



ALI-PREL-61845

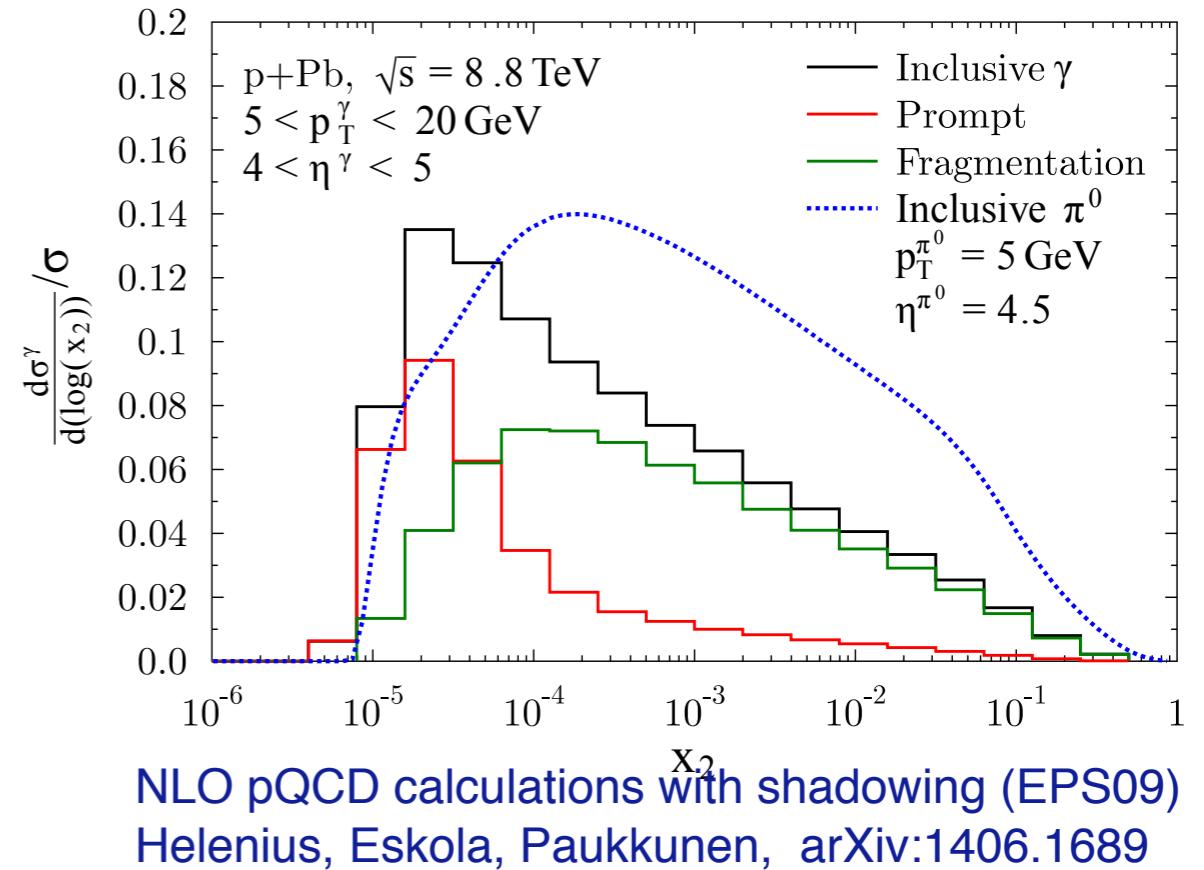
LHCb-CONF-2016-003



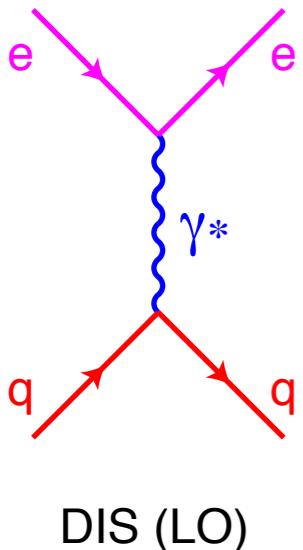
- forward/backward ratio R_{FB}
- $$R_{FB} = \frac{dN/dp_T(\text{p} - \text{going})}{dN/dp_T(\text{Pb} - \text{going})}$$
- for ϕ -mesons in ALICE (dimuons)
and for open charm in LHCb
- ϕ strongly suppressed at forward rapidity
 - interpretation unclear
 - prompt D^0 suppressed
 - comparison with shadowing (EPS09): consistent, but data slightly more suppressed

Signals of Saturation?

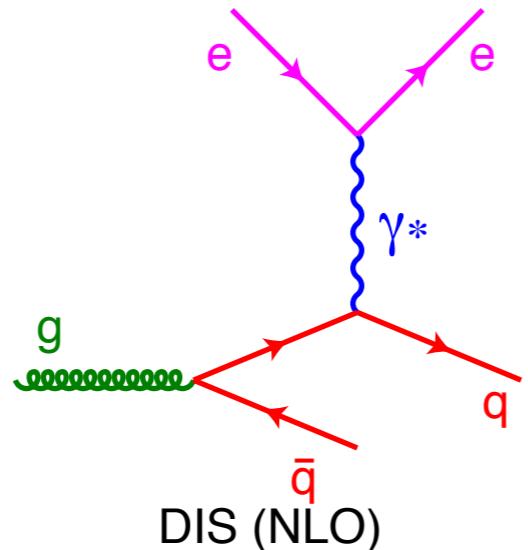
- cleaner observables: EM probes (direct photons, Drell-Yan)
 - no final state interaction
 - well-understood production process
 - well-defined kinematics
- advantage of direct photons:
large cross section
 - forward p–A measurement of DY likely not possible with expected luminosity
- interpretation of hadronic observables remains inconclusive
 - final state modifications in p–A collisions?
 - production process not fully understood for many hadrons
 - kinematic relation to Bjorken-x uncertain (e.g. fragmentation)
- best alternative candidate: open charm
 - direct sensitivity to gluons
 - final state interactions?



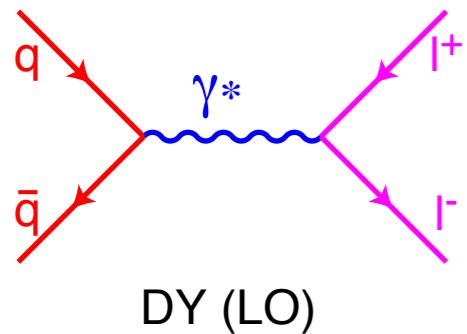
Electromagnetic Processes



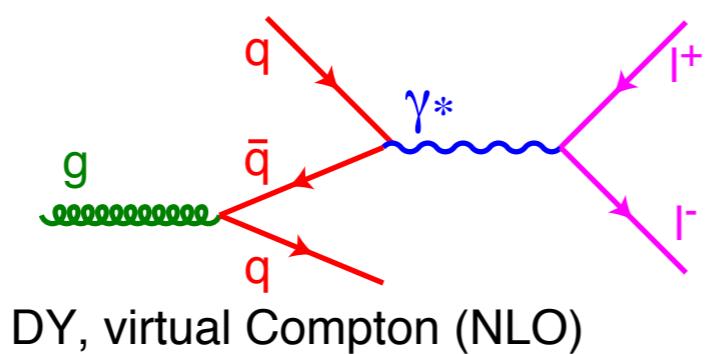
DIS (LO)



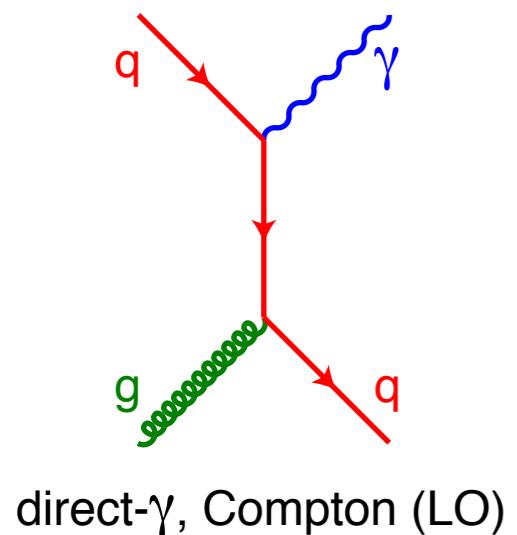
DIS (NLO)



DY (LO)



DY, virtual Compton (NLO)

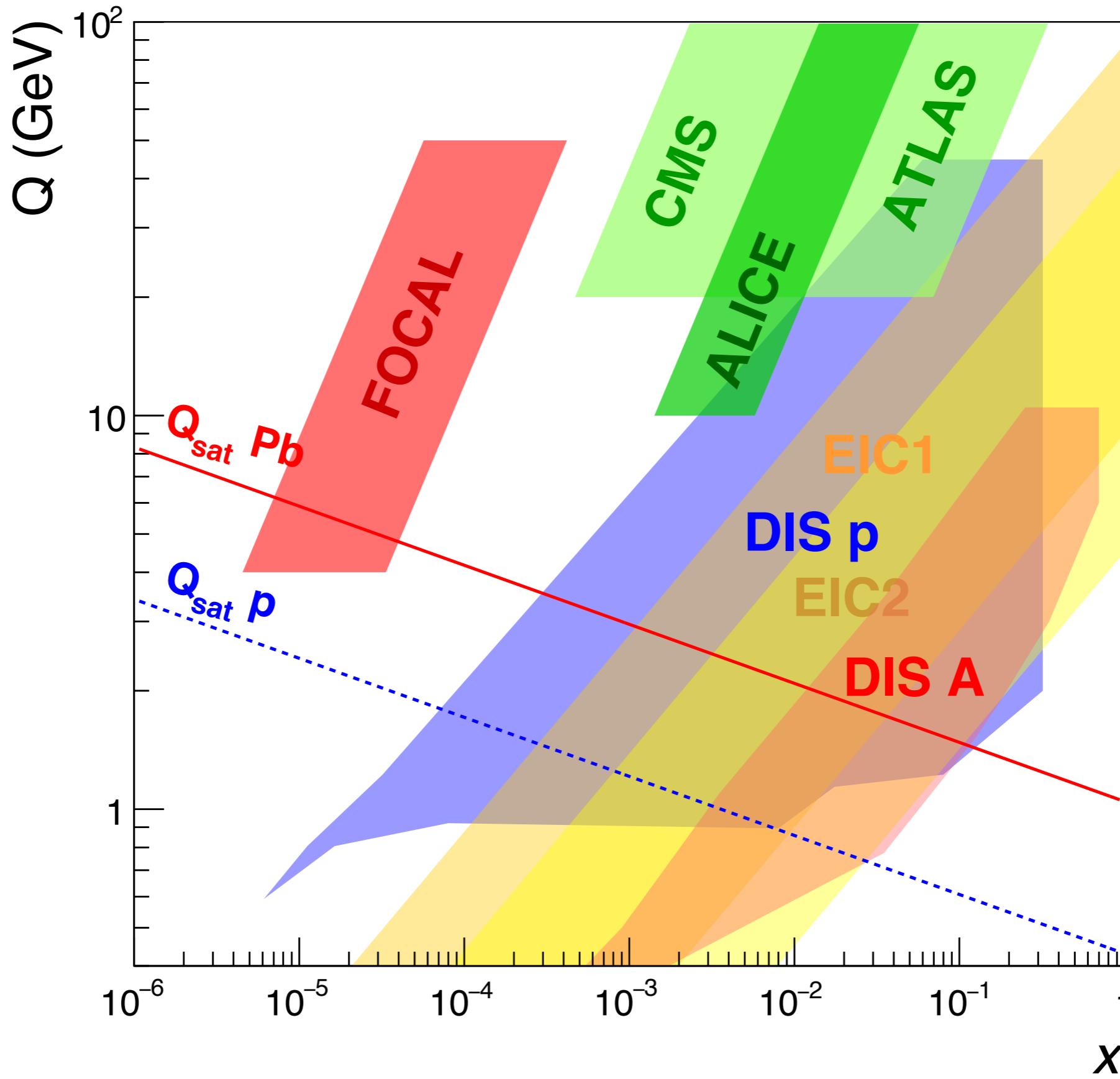


direct- γ , Compton (LO)

- DIS and Drell-Yan are equivalent processes
 - crossing symmetry
 - sensitivity to gluons only at NLO
 - e.g. virtual qg-Compton
- main disadvantage of DY: very low cross section
 - not accessible in pA

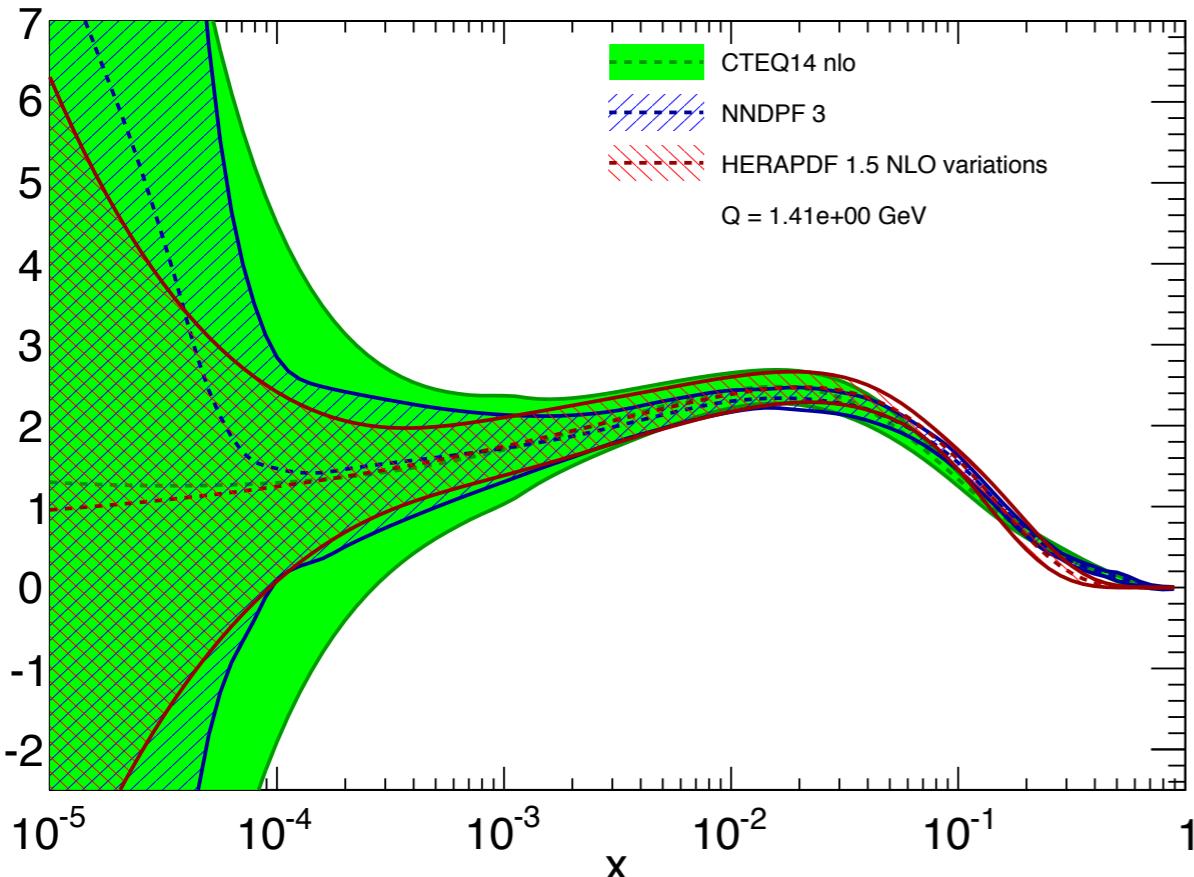
- real photons: sensitivity to gluons at LO, clear kinematic relation
 - higher order corrections?

EM Probes: Kinematic Coverage

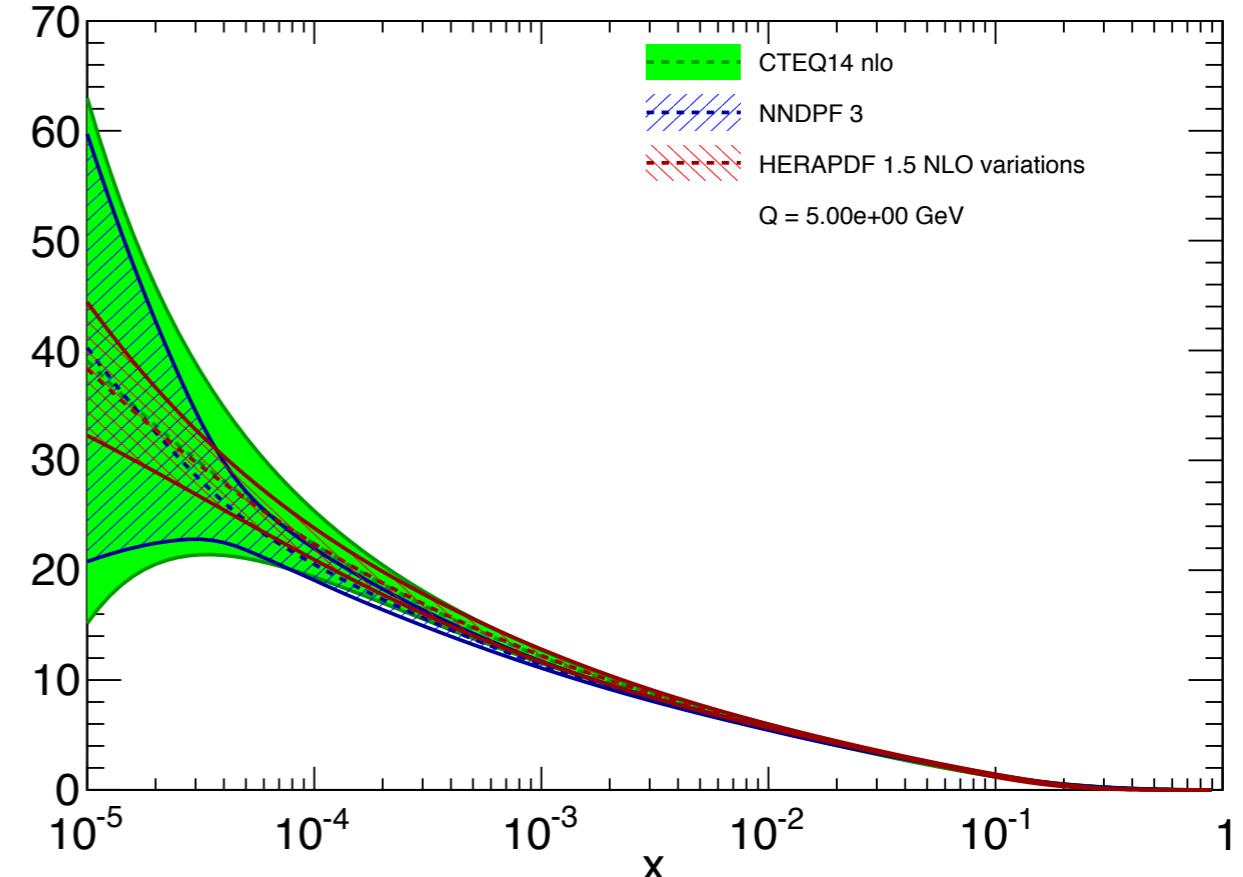


Gluon Densities at Low x (Protons)

$xg(x,Q)$, comparison



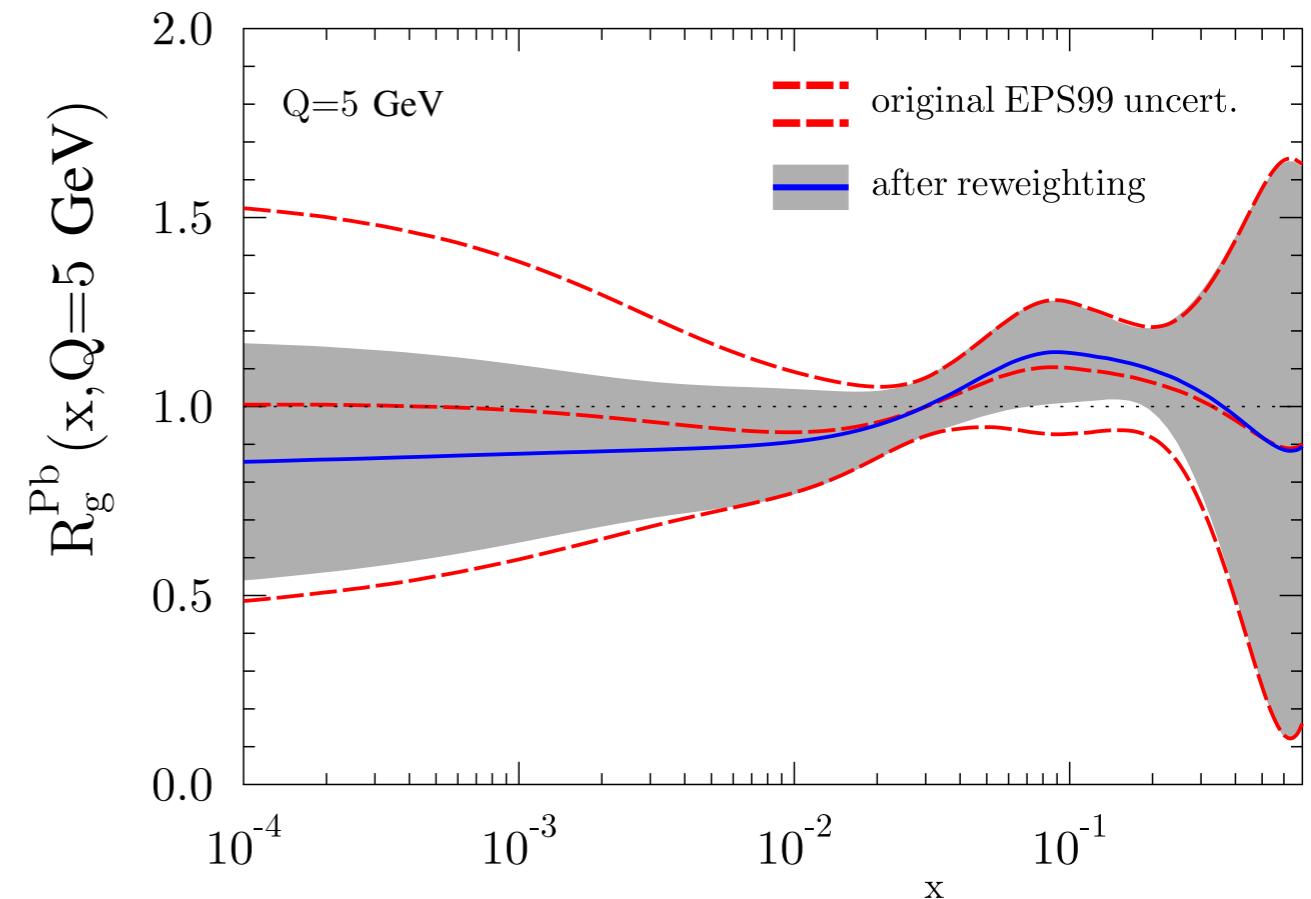
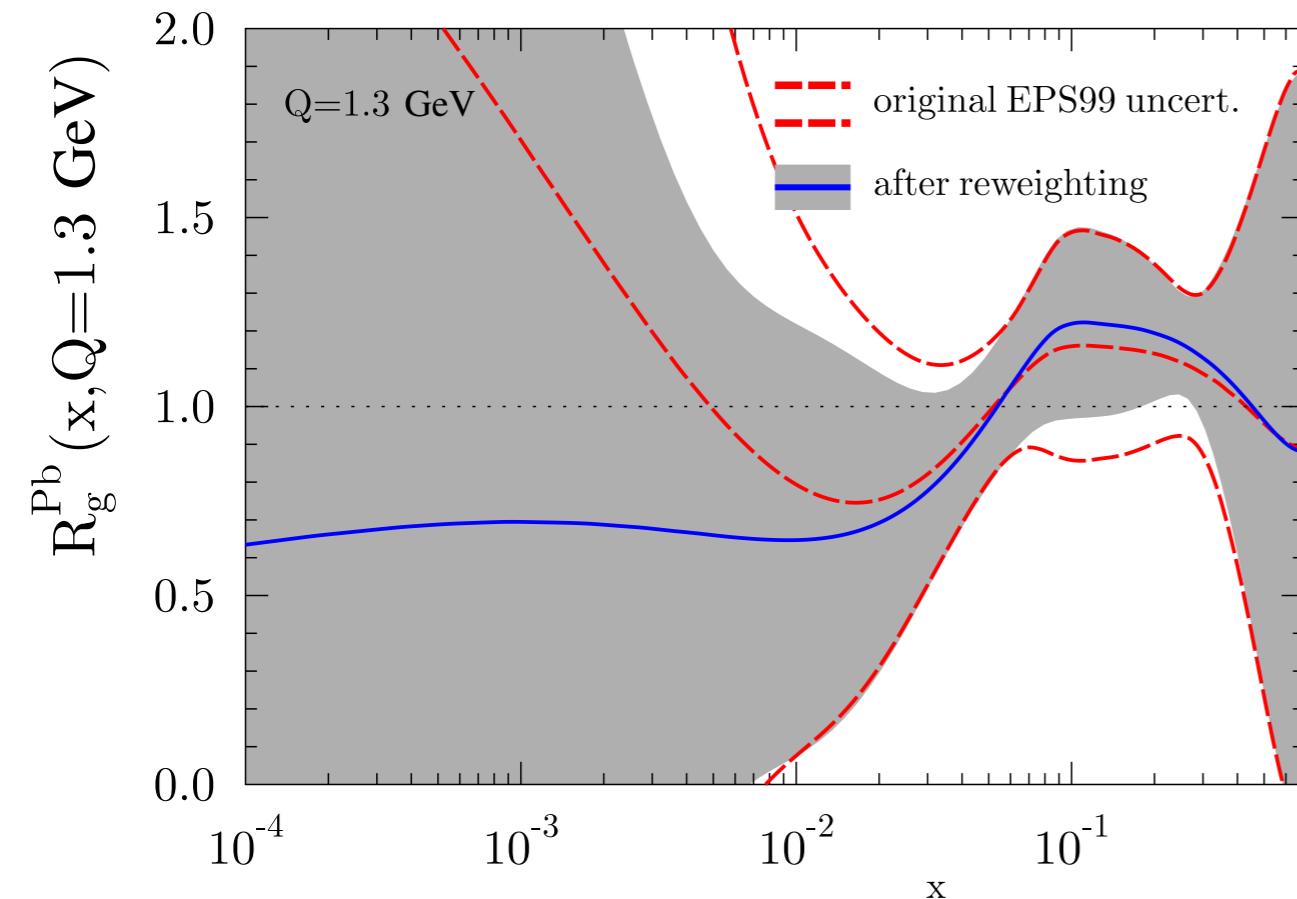
$xg(x,Q)$, comparison



Generated with APFEL 2.4.0 Web

- at $Q = 1.41 \text{ GeV}$, $g(x)$ essentially unconstrained for $x < 10^{-4}$
- apparent uncertainty significantly reduced at slightly larger Q (5 GeV)
 - not from more data constraints!
 - strong role of QCD evolution
- **careful: we want to test QCD evolution!**

Gluon Densities at Low x (Nuclei)

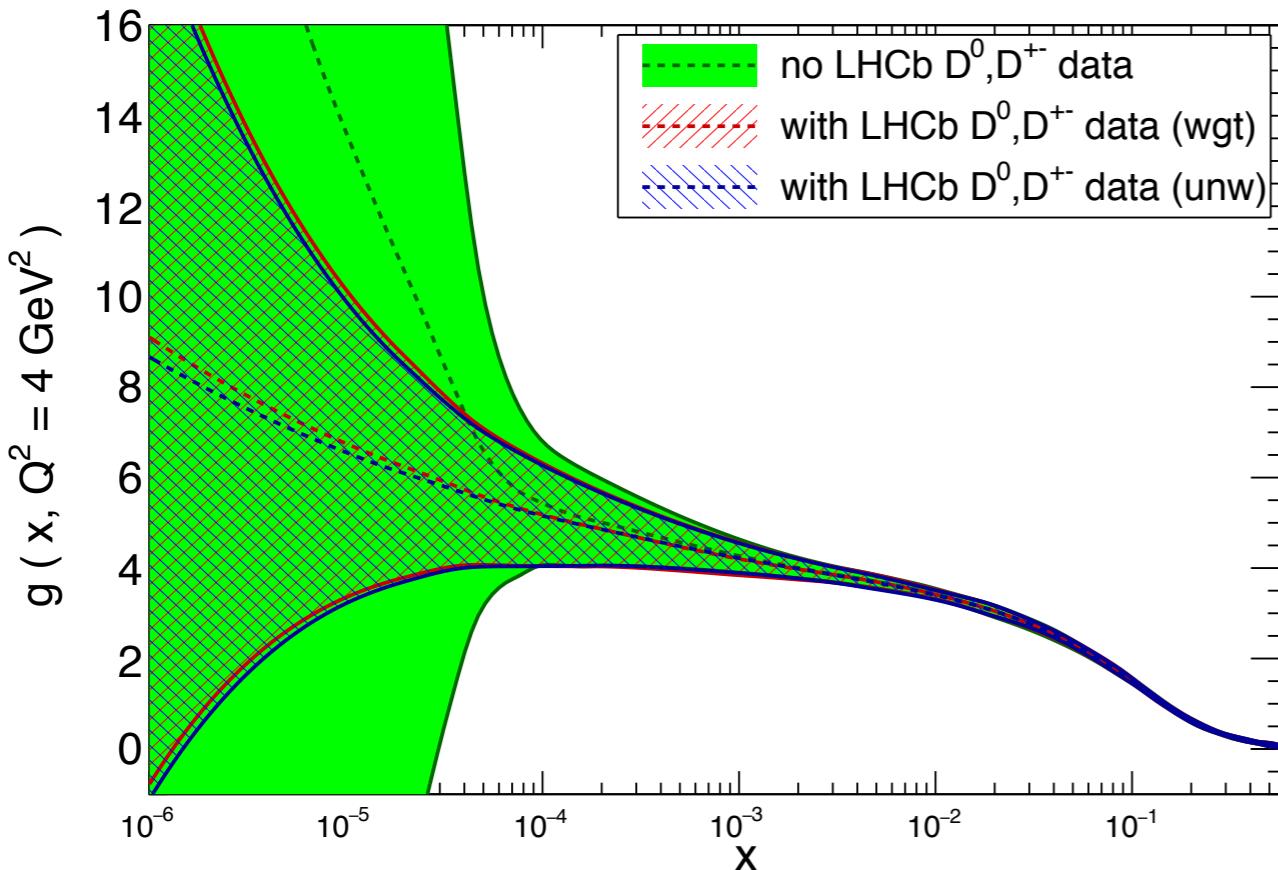


H. Paukkunen, I. Helenius, priv. communication

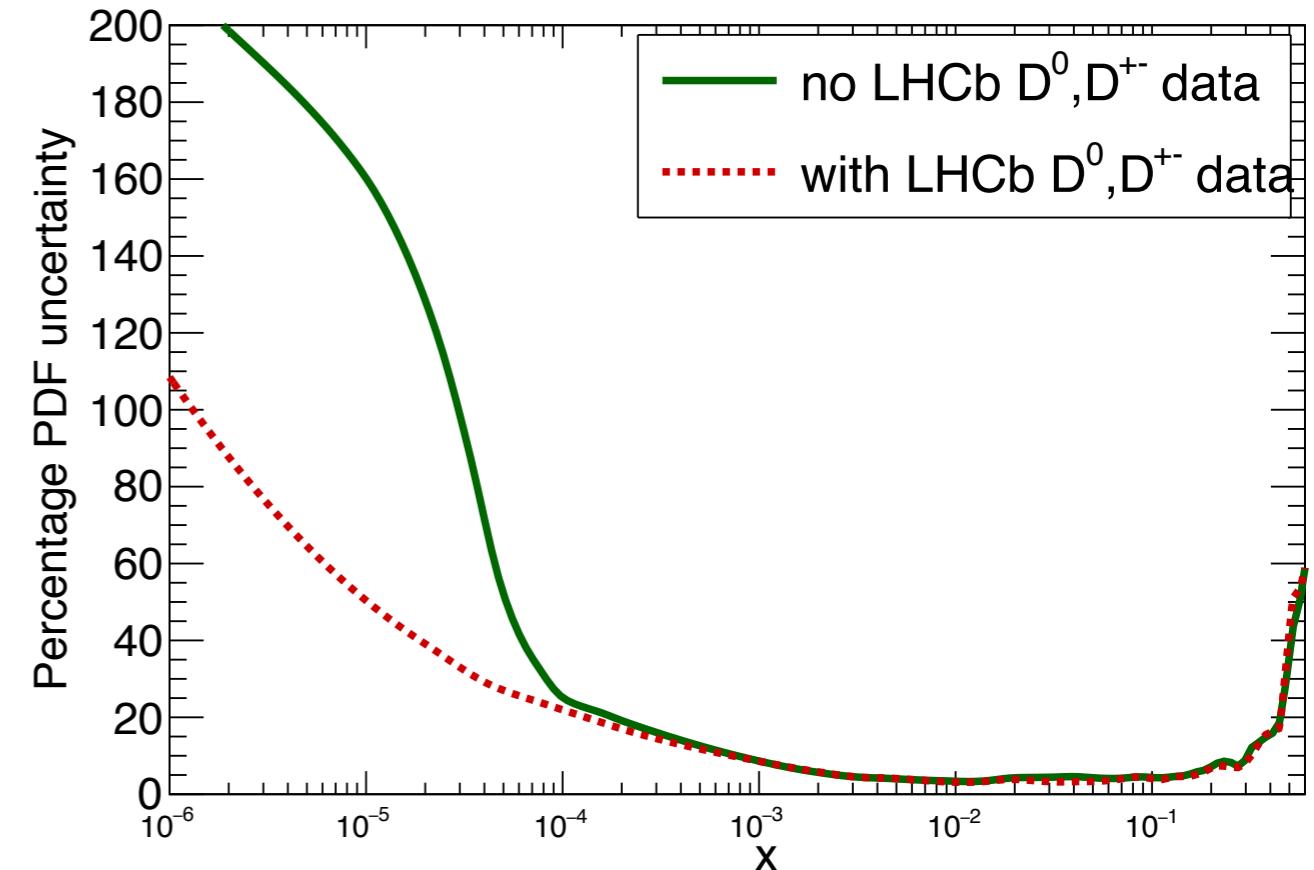
- at $Q = 1.3 \text{ GeV}$, $g(x)$ essentially unconstrained for $x < 10^{-2}$
 - old PDF sets in nuclei did not allow sufficient freedom
 - new parameterisations under way – still not equivalent flexibility as NNPDFs

Impact of Forward Open Charm

NNPDF3.0 NLO $\alpha_s=0.118$



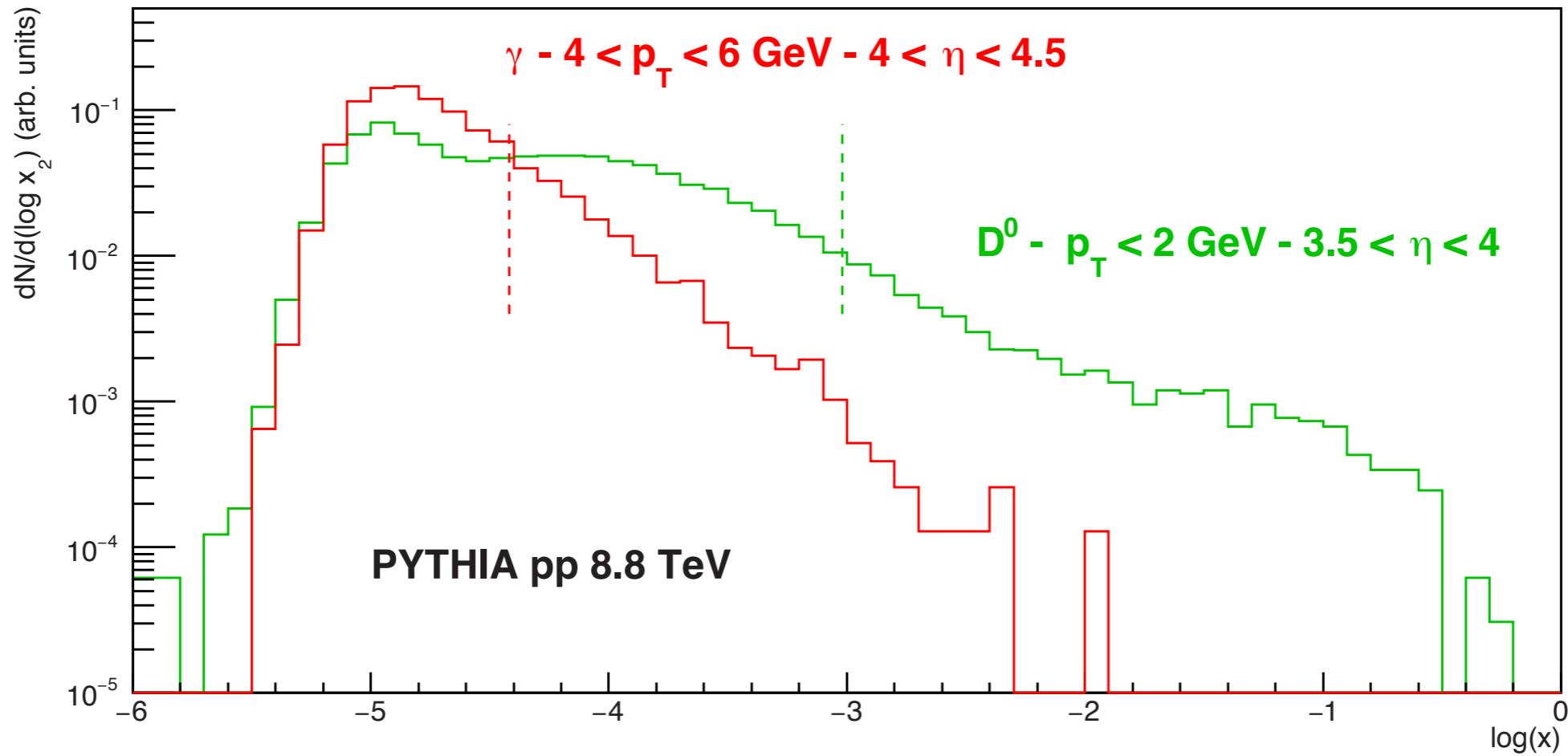
$\Delta(g(x, Q^2))$ for $Q^2=4 \text{ GeV}^2$, NNPDF3.0 NLO



R. Gauld et al., arXiv 1506.08025

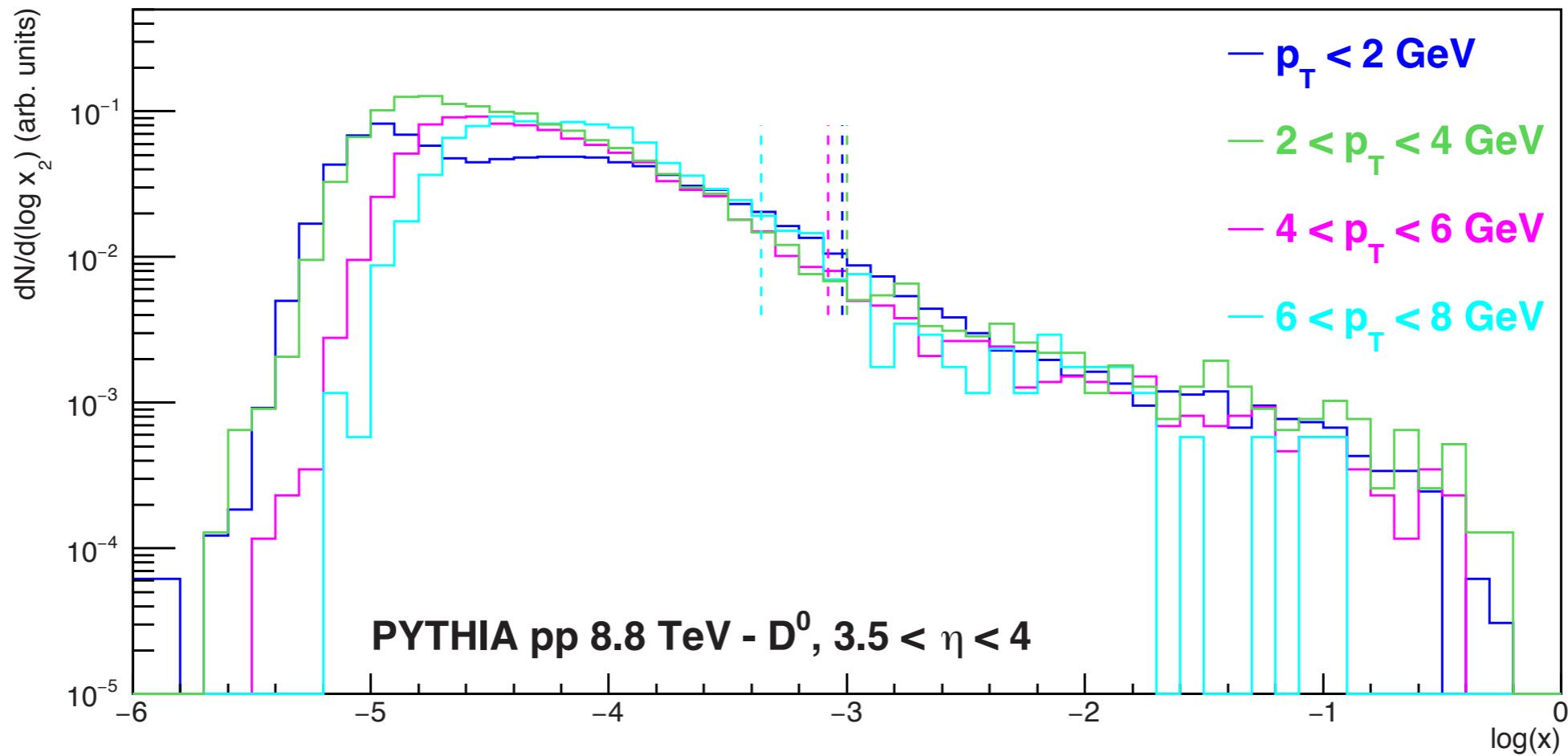
- usage of forward D measurements by LHCb can constrain gluon distribution
 - fit uses normalisation at low y , high p_T
- how much of the constraints due to data?

x-Sensitivity



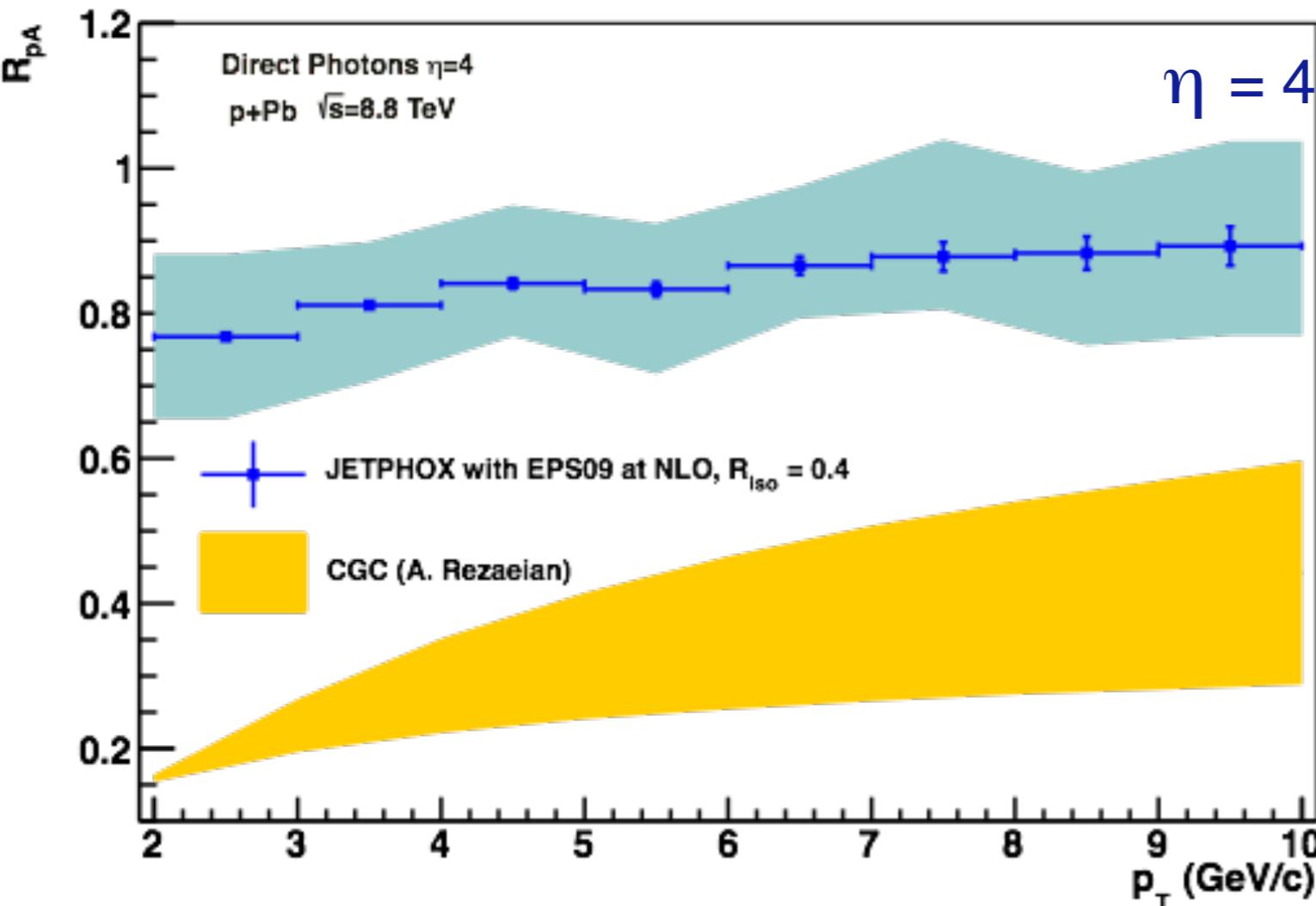
- x_2 distributions for forward production
 - LO production from PYTHIA
 - D^0 (LHCb) vs prompt γ (FoCal)
- apparent maximum at $x \approx 10^{-5}$
 - beware of $\log(x)$ scale!
 - significantly larger mean value
- significant advantage of proposed direct photon measurement relative to charm in LHCb

x-Sensitivity



- x_2 distributions for forward charm production
- weak p_T dependence

nPDF/DGLAP vs CGC



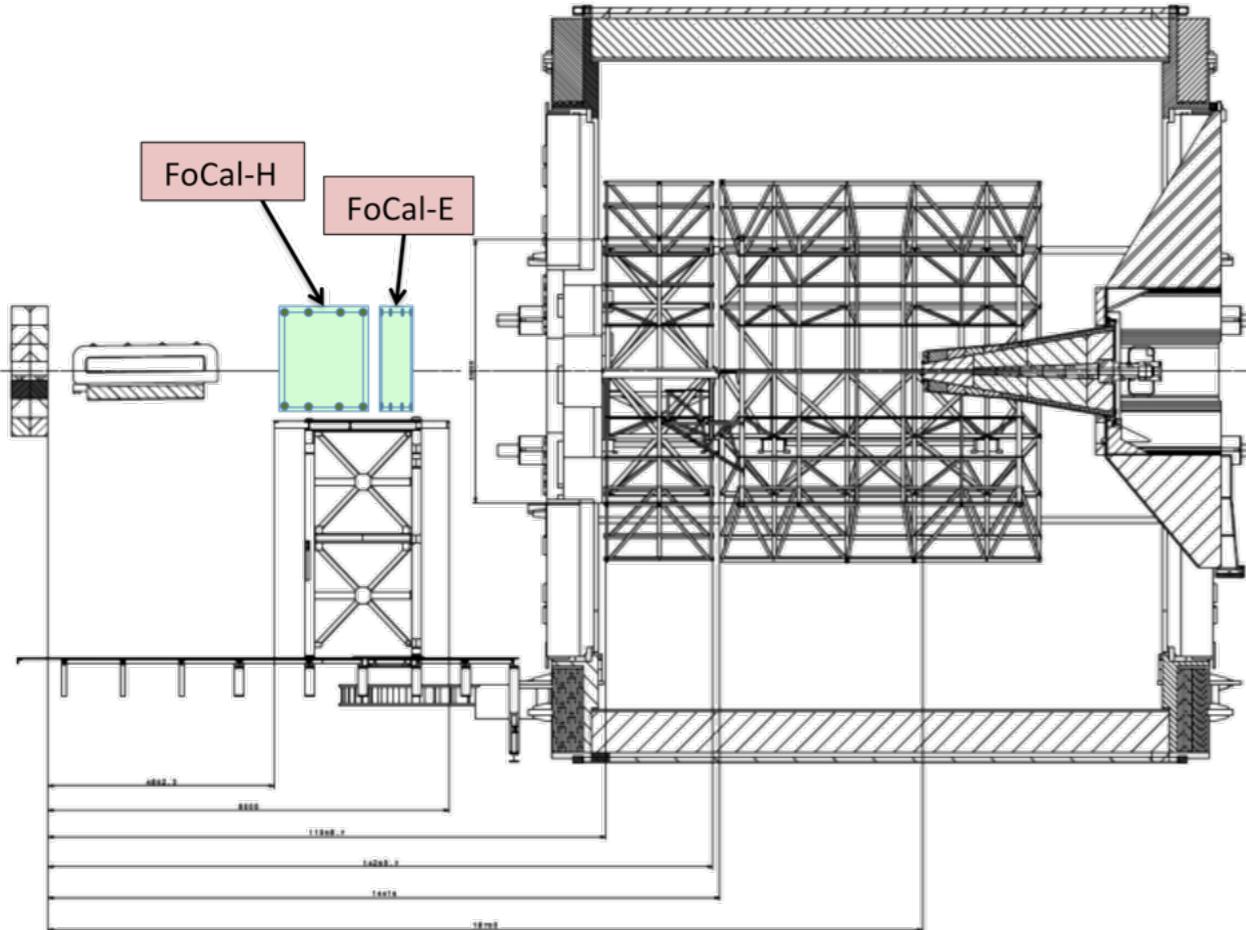
two scenarios for forward γ production in $p+A$ at LHC:

- normal nuclear effects
linear evolution, shadowing
- saturation/CGC
running coupling BK evolution

Rezaeian, PLB 718, 1058

- strong suppression in direct γR_{pA}
 - clean signal for isolated photons
 - signals expected at forward η , low-intermediate p_T

FoCal in ALICE



electromagnetic calorimeter for γ and π^0 measurement

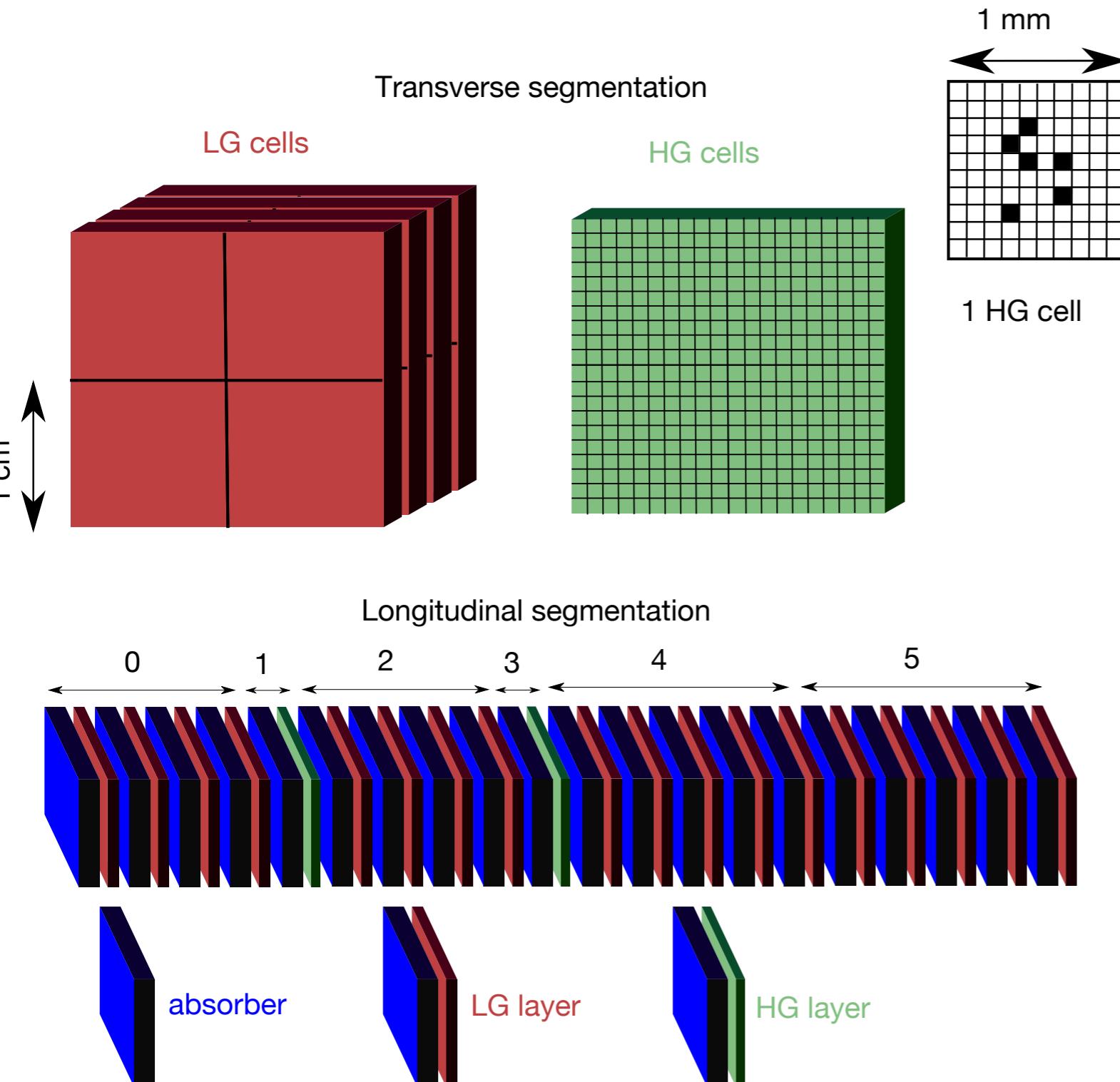
preferred scenario:

- at $z \approx 7\text{m}$ (outside magnet)
 $3.3 < \eta < 5.3$
(space to add hadr. calorimeter)

under internal discussion
possible installation in LS3

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
 - Si-W calorimeter, effective granularity $\approx 1\text{mm}^2$

FoCal Strawman Design



studied in performance simulations:

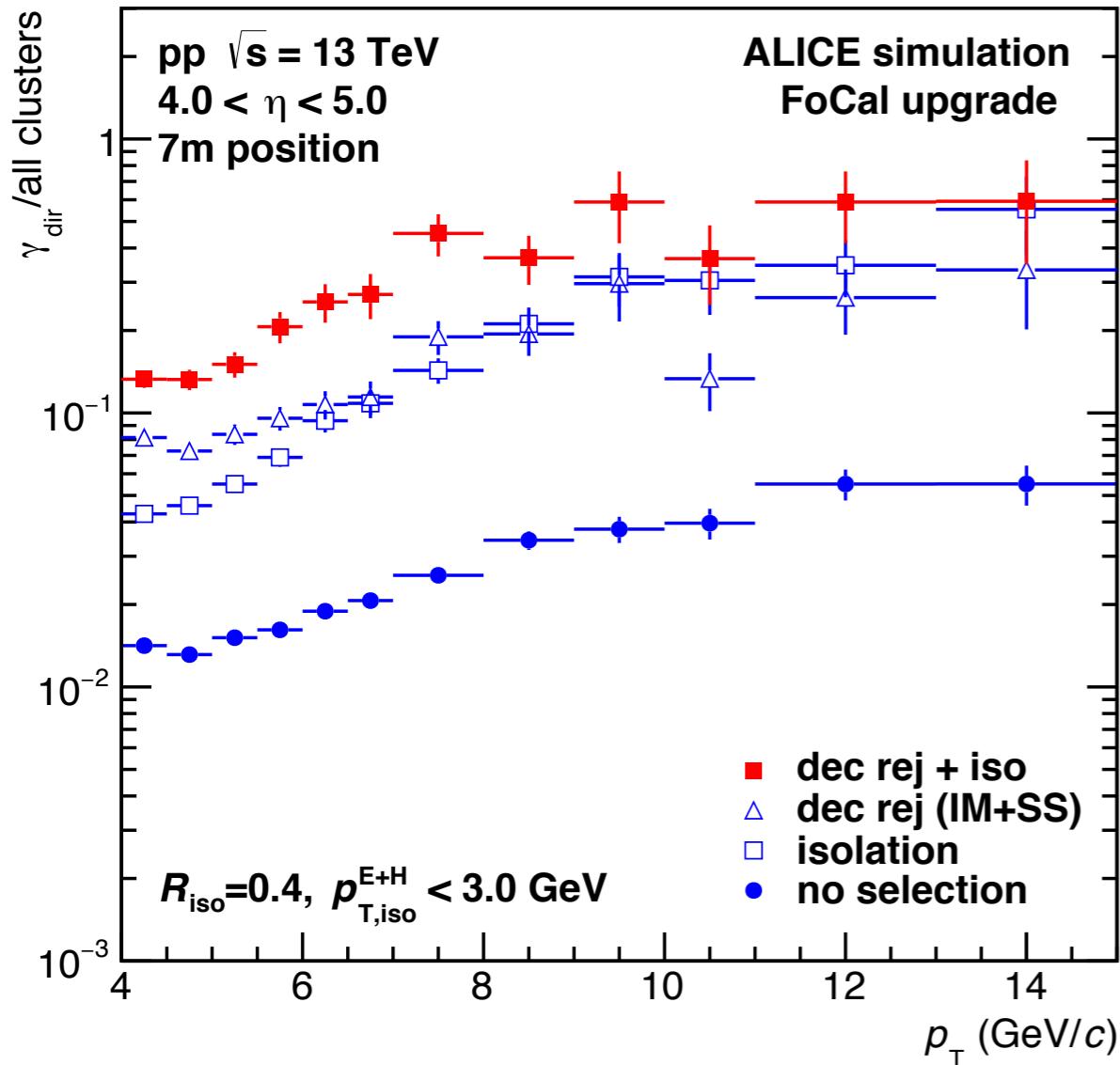
24 layers: W ($3.5\text{mm} \approx 1 \times 0$) +
Si-sensors (2 types)
low granularity (LG), Si-pads
high granularity (HG), pixels
(e.g. CMOS-MAPS)

	LG	HG
pixel/pad size	$\approx 1 \text{ cm}^2$	$\approx 30 \times 30 \mu\text{m}^2$
total # pixels/pads	$\approx 2.5 \times 10^5$	$\approx 2.5 \times 10^9$
readout channels	$\approx 5 \times 10^4$	$\approx 2 \times 10^6$

assuming $\approx 1\text{m}^2$ detector surface

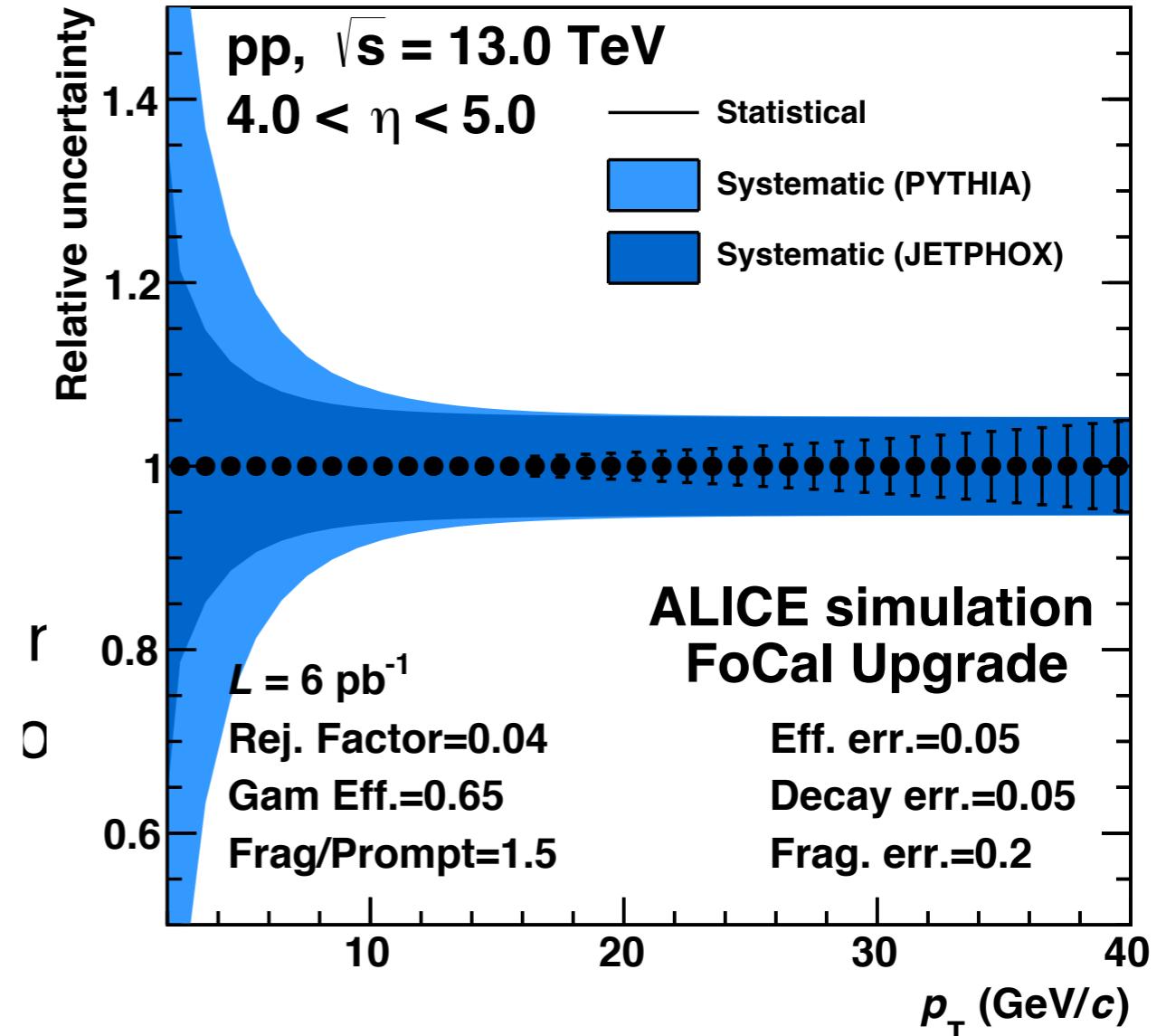
Direct γ Performance in pp

Direct γ /all cluster ratio



direct photon/all > 0.1
for $p_T > 4$ GeV/c

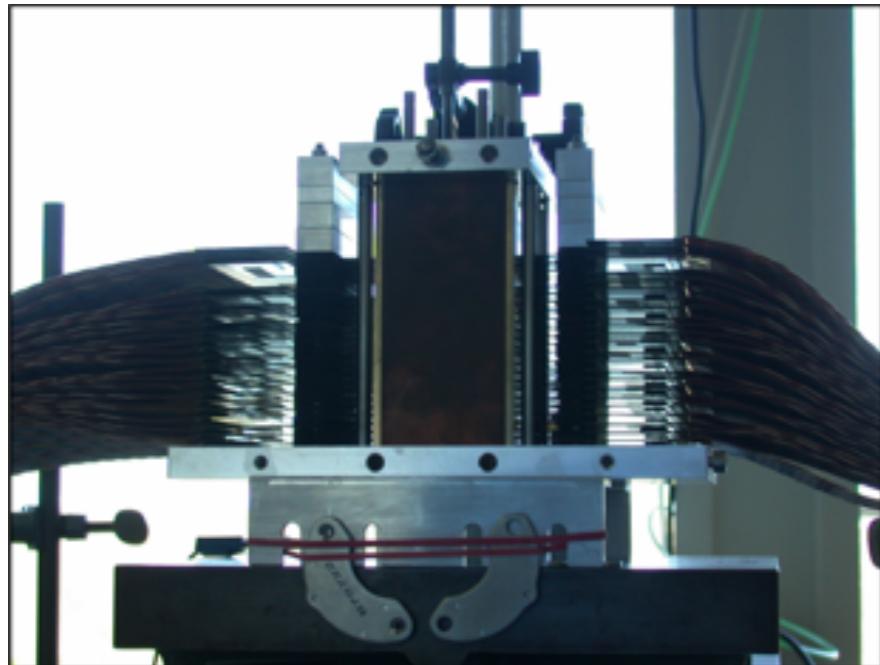
Direct γ uncertainty



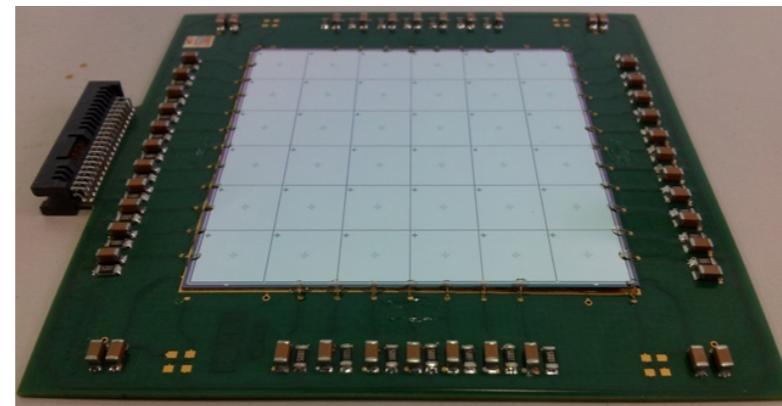
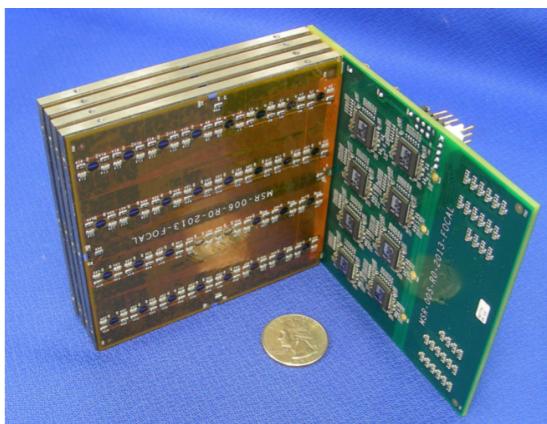
20-40% uncertainty
at $p_T = 4$ GeV/c
decreases with increasing p_T

FoCal R&D: Si-W pixel and pad readout

20 layer pixel detector



Pad layer integration



Several groups involved:

Full prototype with pixel detectors
CMOS (MIMOSA) 39M pixels,
30 μ m pitch

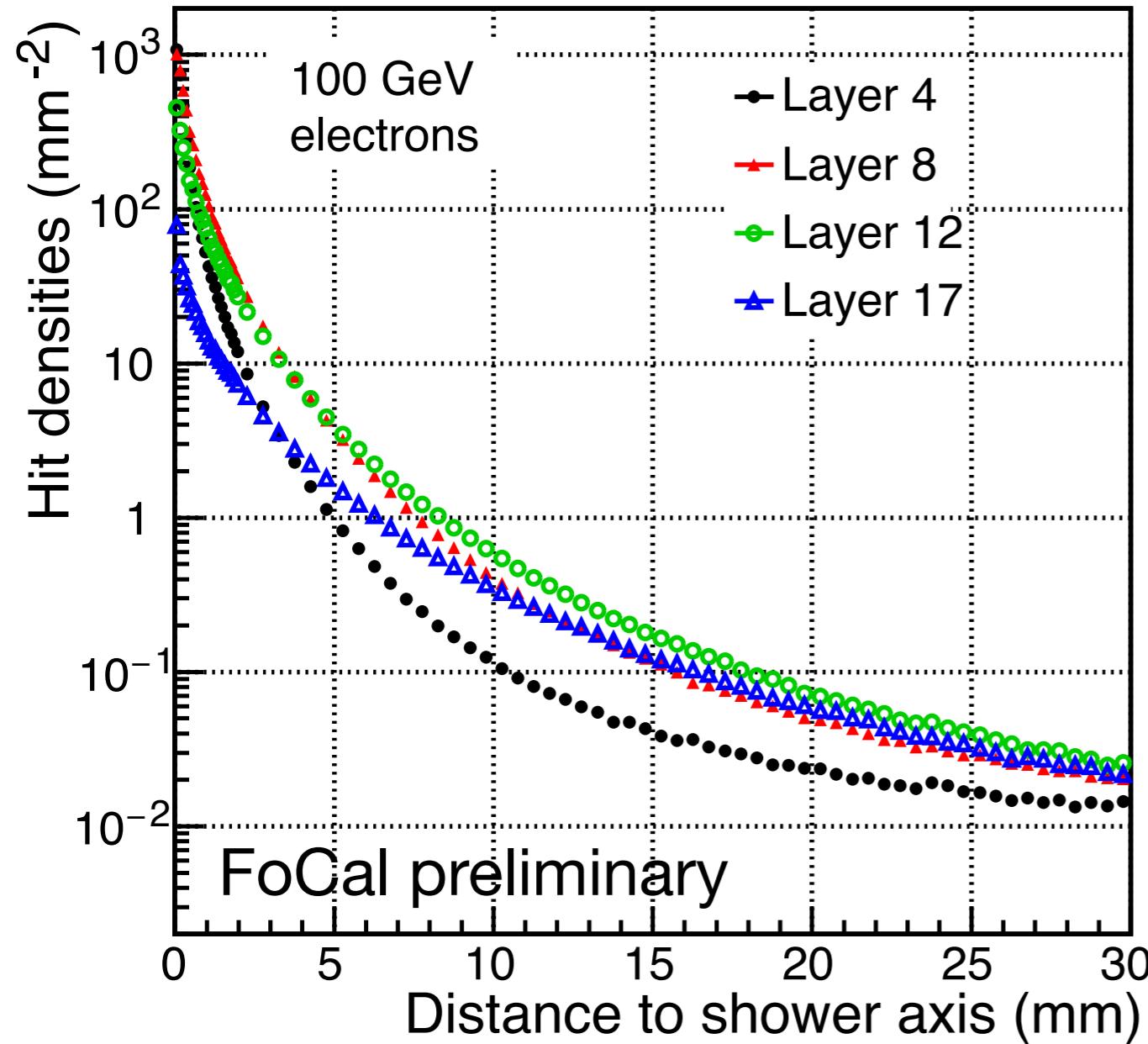
use synergy with R&D for ALICE ITS
upgrade

Full prototype with pad readout

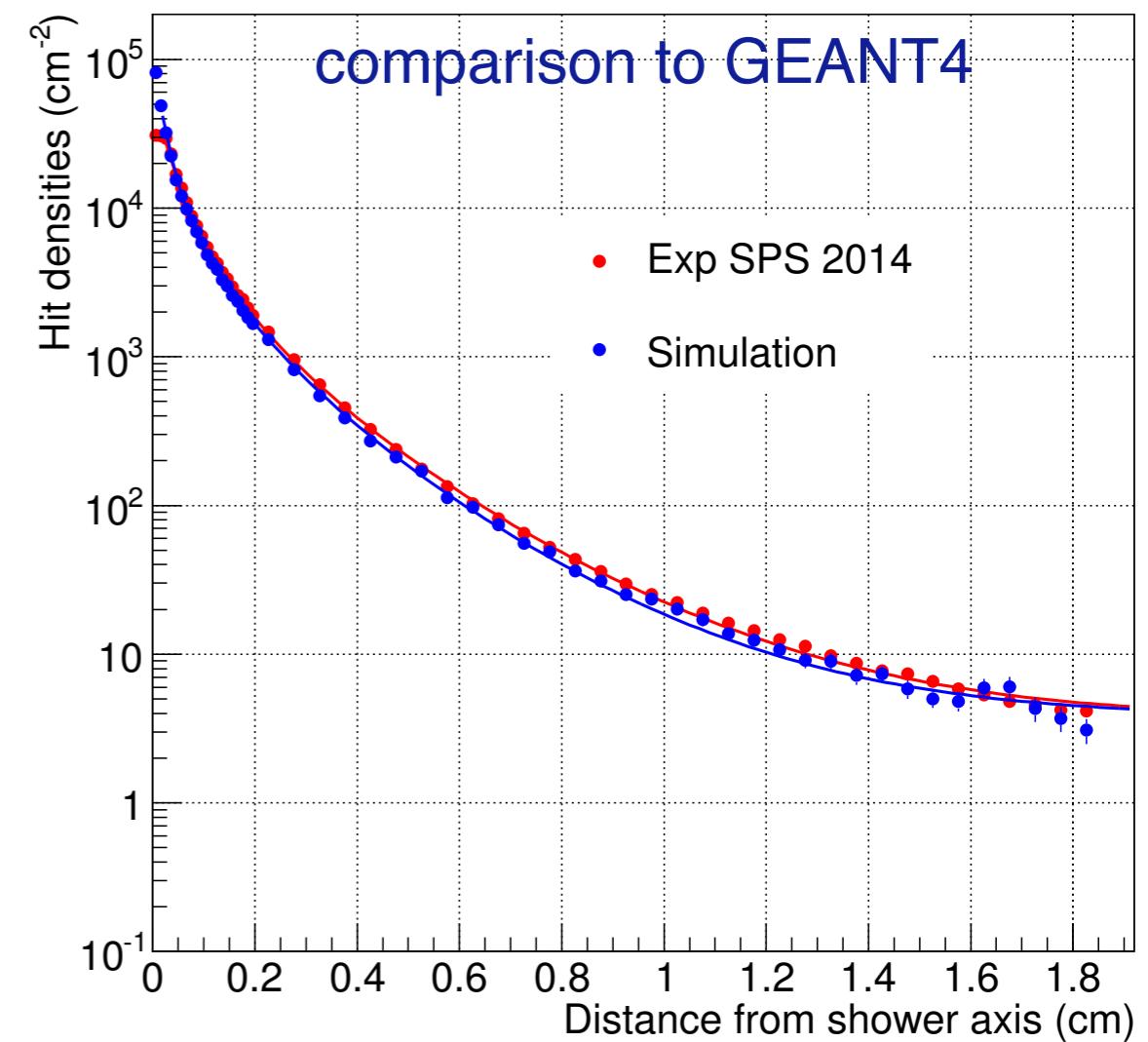
Performed systematic tests:

Test beam data from 2 to 250 GeV
(DESY, PS, SPS)
Cosmic muons

R&D Results: Lateral Profiles



allows precision measurements of
EM showers
 $R_M \approx 11\text{ mm}$ (as estimated from
cumulative distributions)

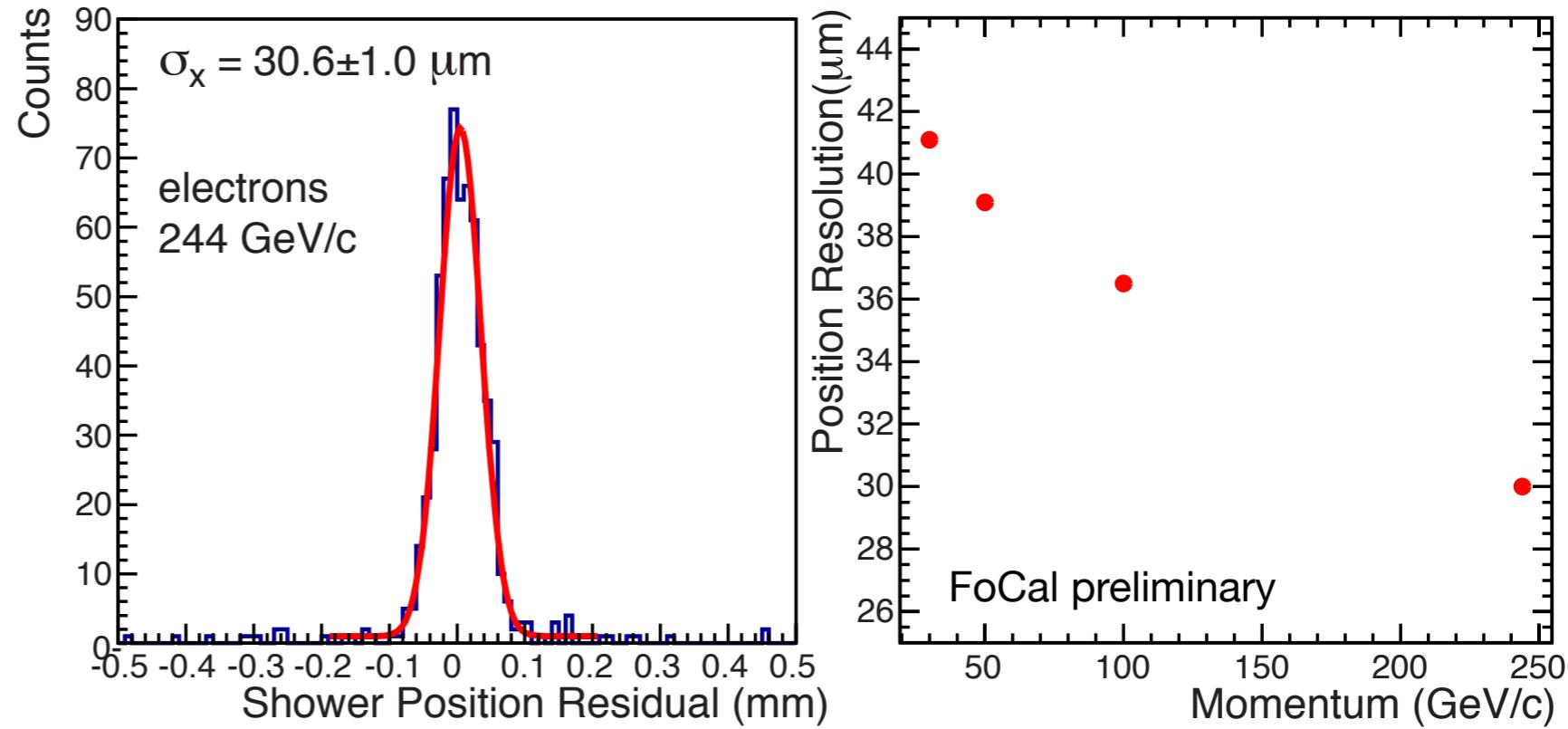


good agreement with simulations
using GEANT4 + charge diffusion

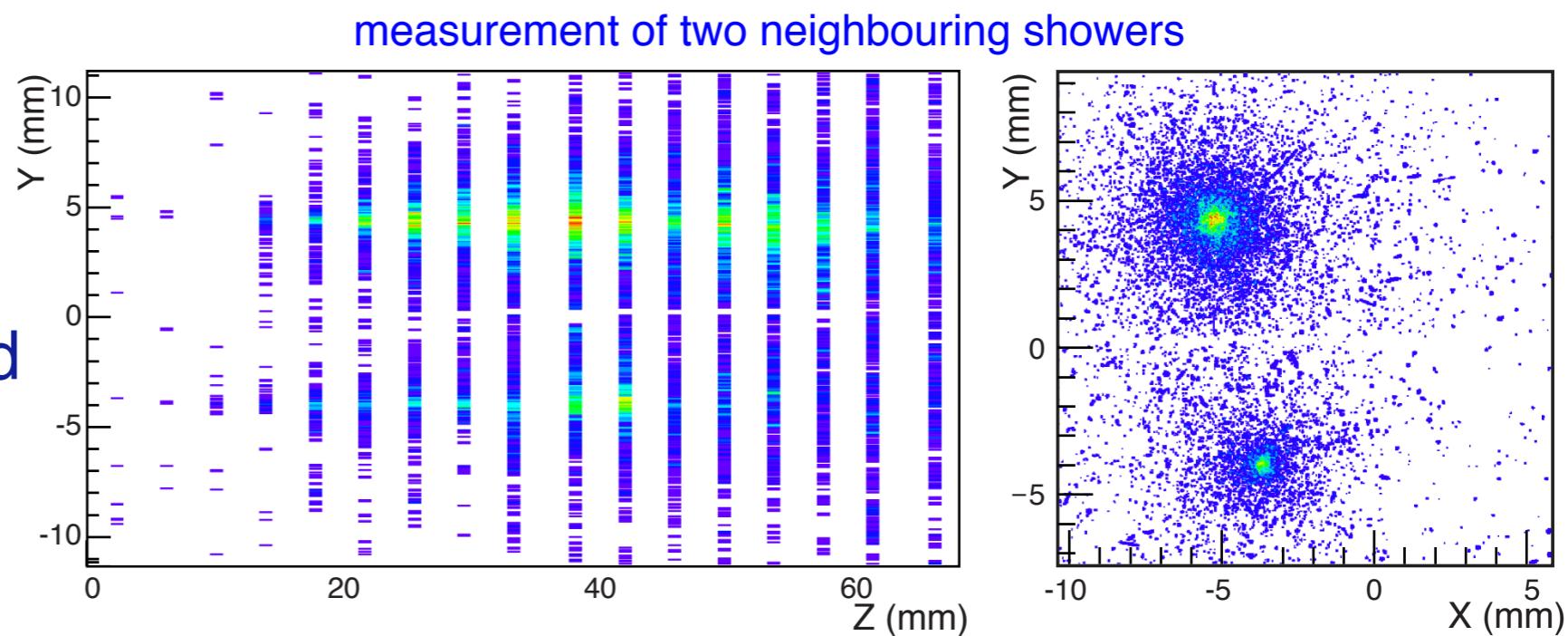
R&D: High-Granularity Calorimetry

unique single shower
position resolution

$$\sigma_x \approx 30 \mu\text{m}$$

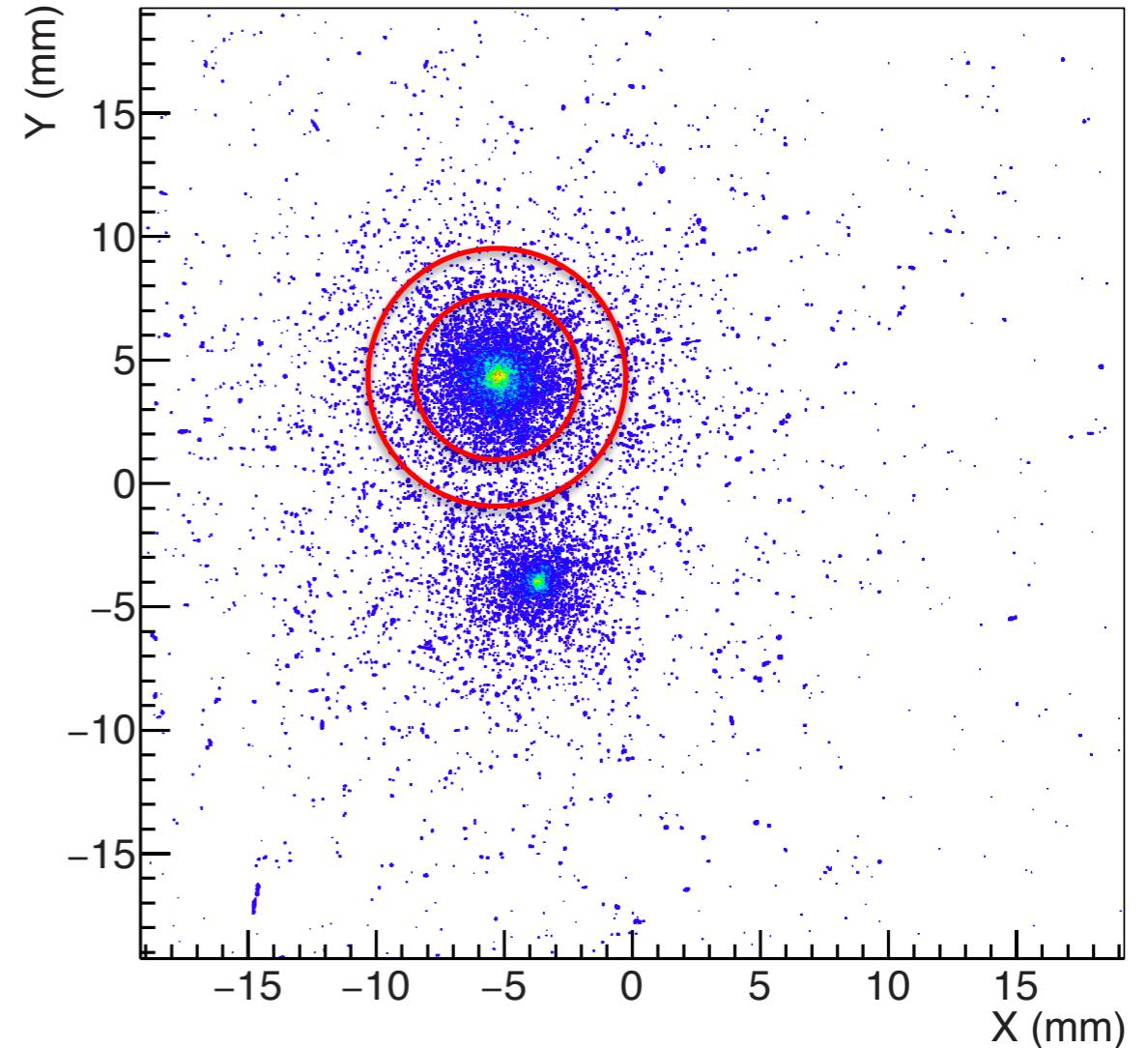
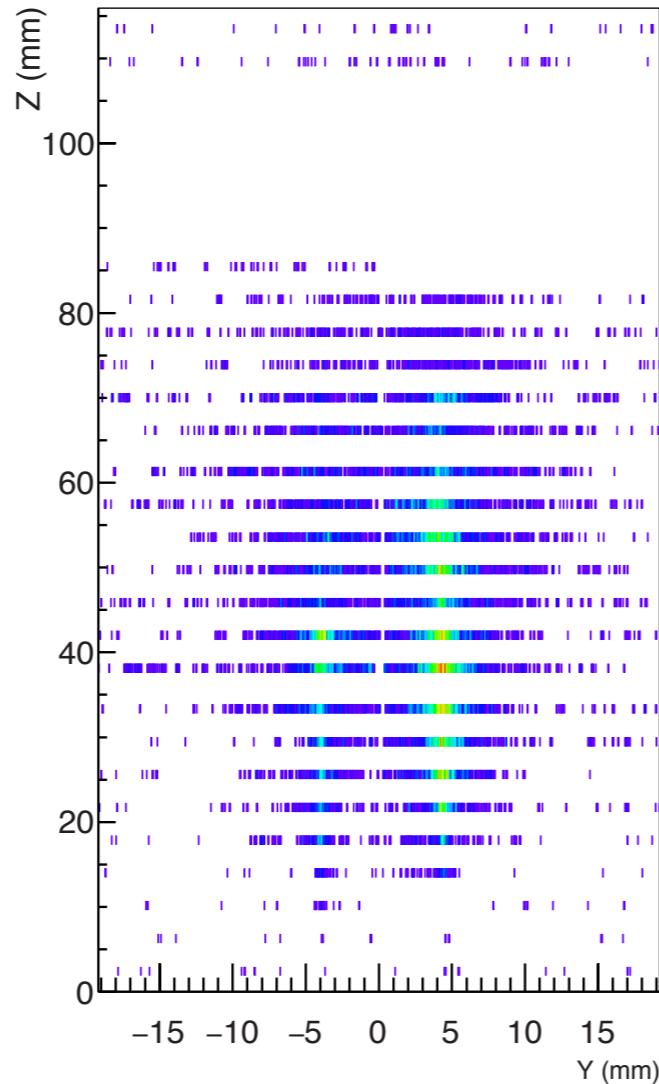
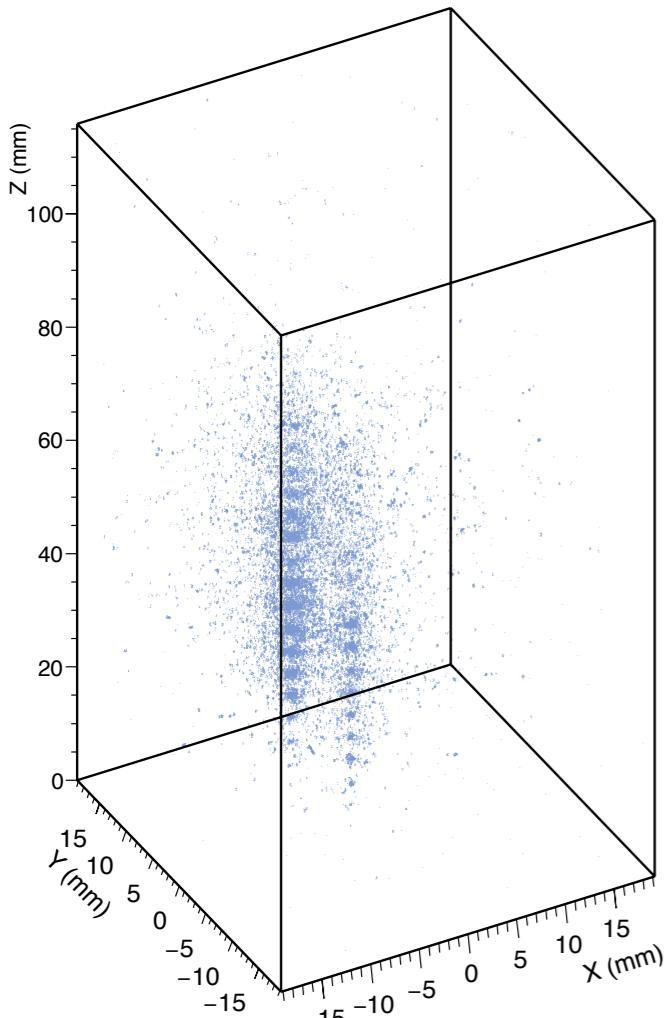


can provide unprecedented
two-shower separation



Two Shower Separation

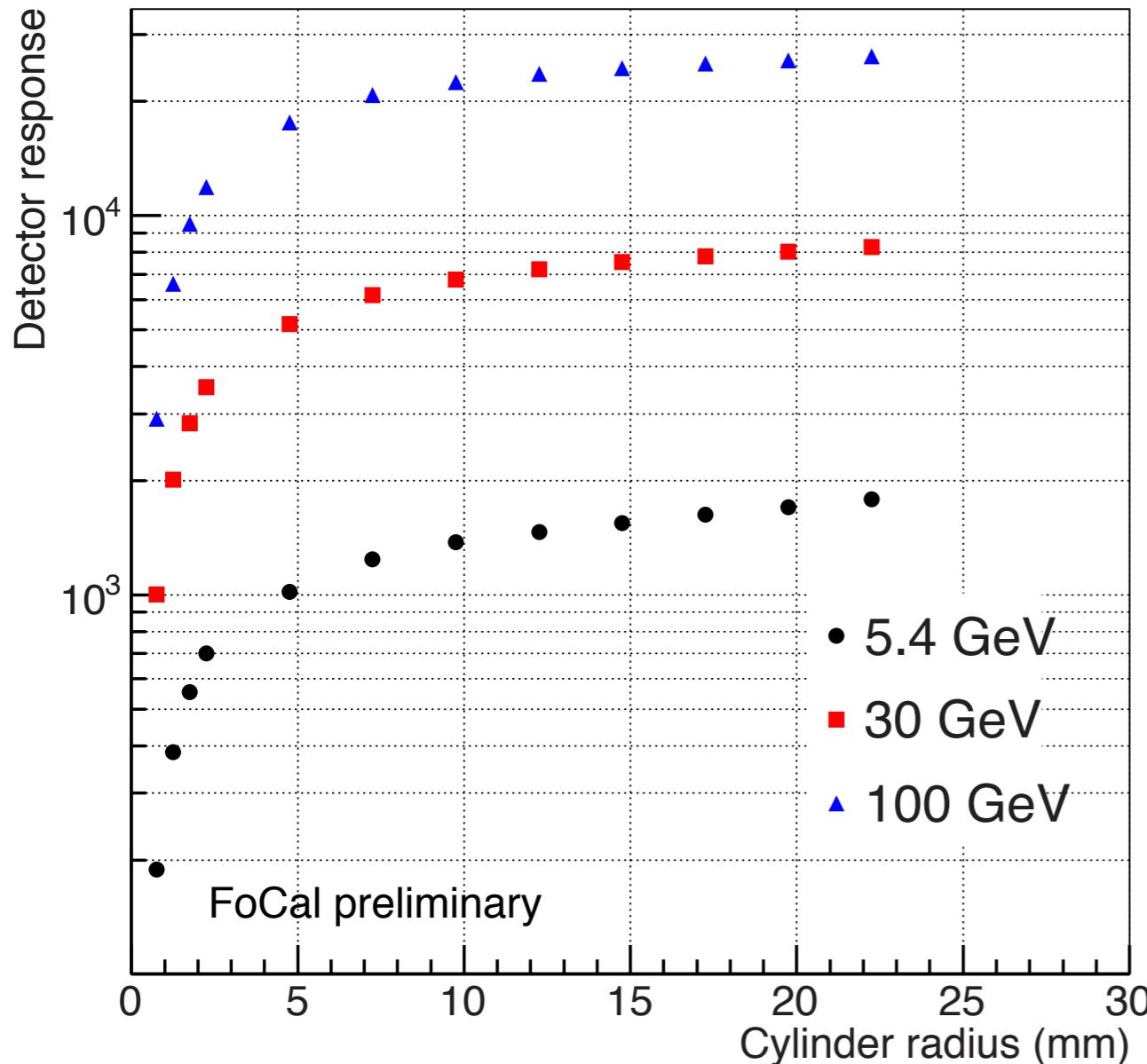
display of single event (with pile-up) from 244 GeV mixed beam



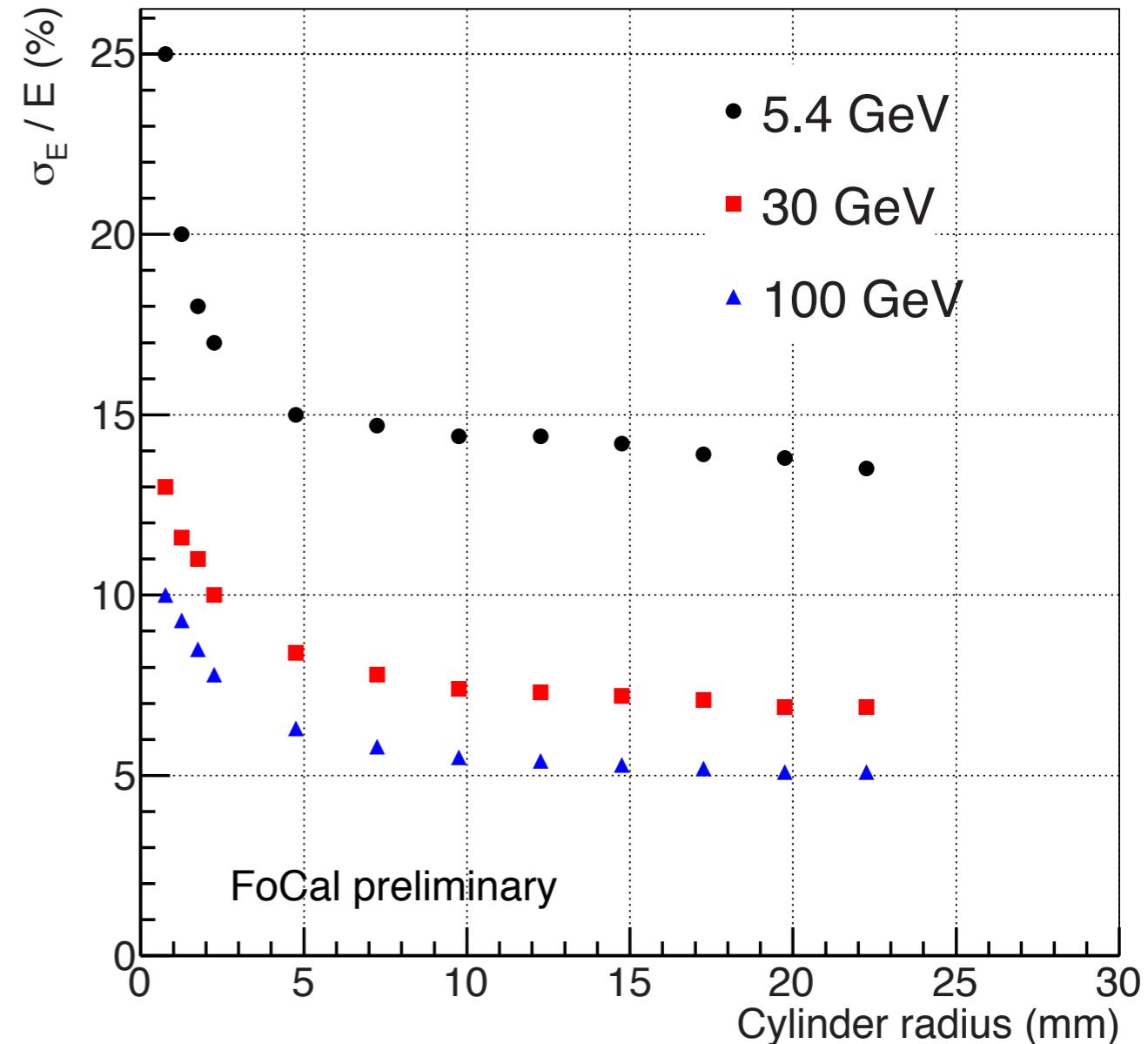
evaluate separation capability: core energy
calculate shower energy in cylinder of finite radius
study as function of radius

R&D Results: Core Energy

detector response (number of hits)



energy resolution



reasonable energy resolution of pixel calorimeter, sufficient for conceptual design

response and resolution for core energy hardly affected down to $r = 5\text{mm}$:
adequate for very high particle density

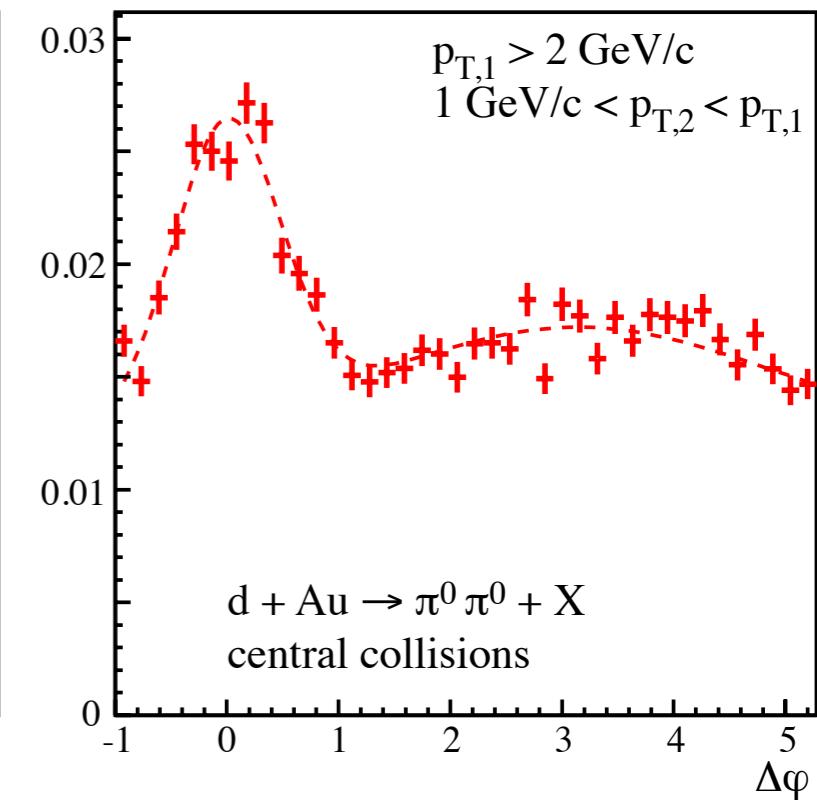
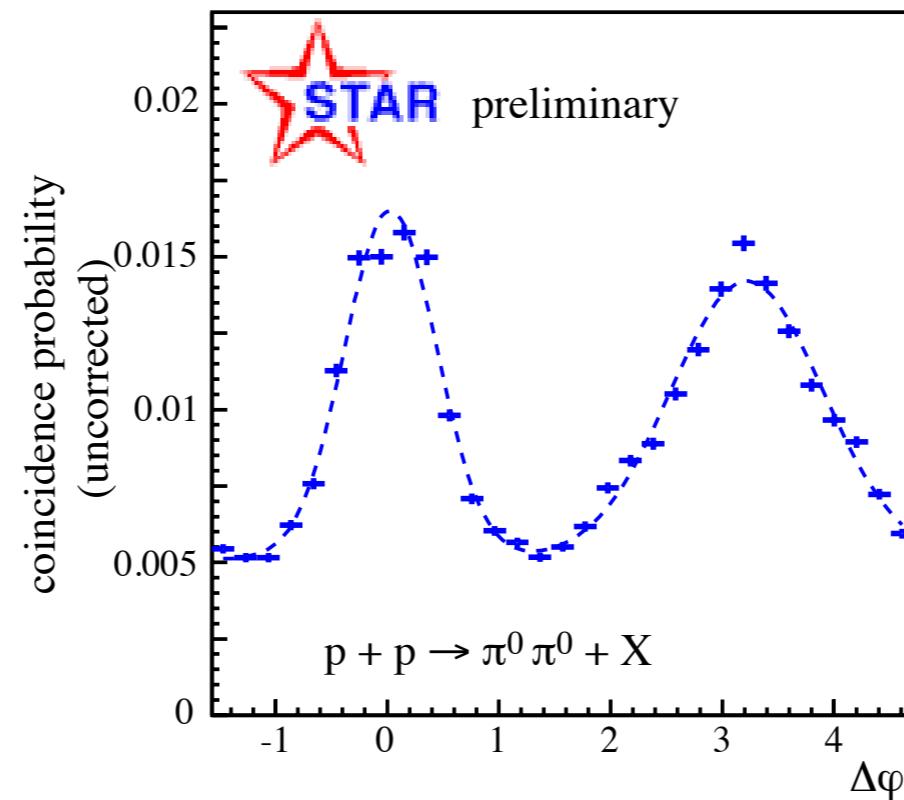
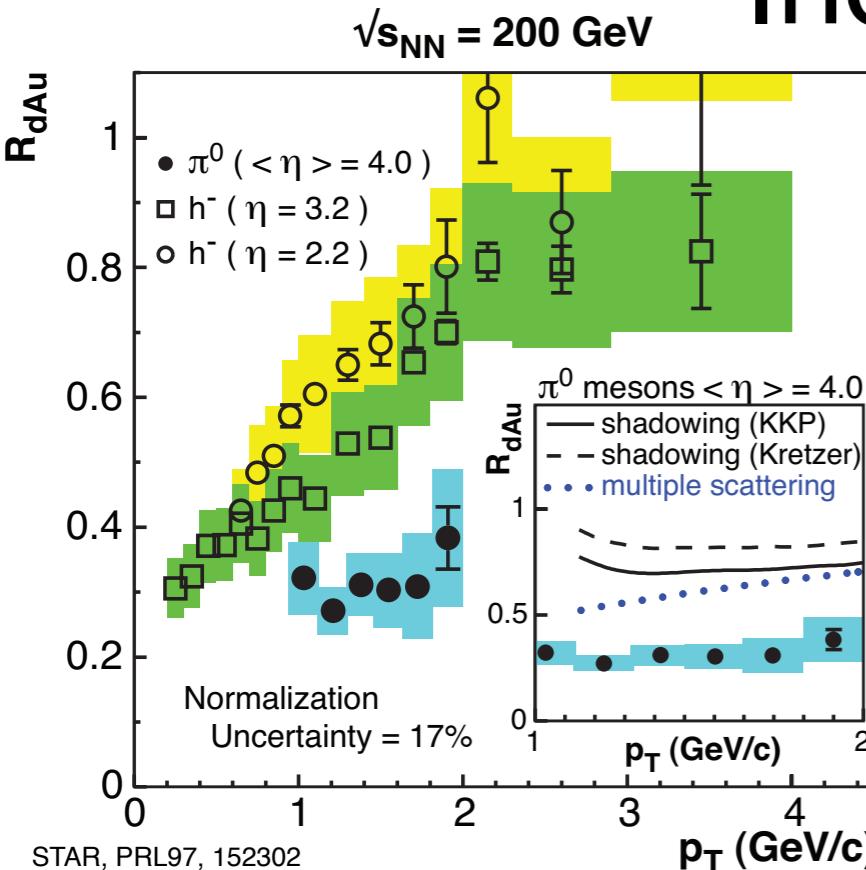
Summary

- LHC forward measurements provide unique opportunity for low- x physics
 - hadronic probes inconclusive
 - best bet: open charm
 - advantage of EM probes: sensitivity to initial state, clean production process
 - need better understanding of PDF uncertainties and role of QCD evolution
 - measurement needs detector upgrade at LHC
 - proposed FoCal detector in ALICE
 - opportunity for forward direct photon measurement
 - particle density/kinematics require extremely high granularity: feasible with SiW pixel calorimeter

Backup Slides

Indications from RHIC

STAR, Braidot, Ogawa et al.



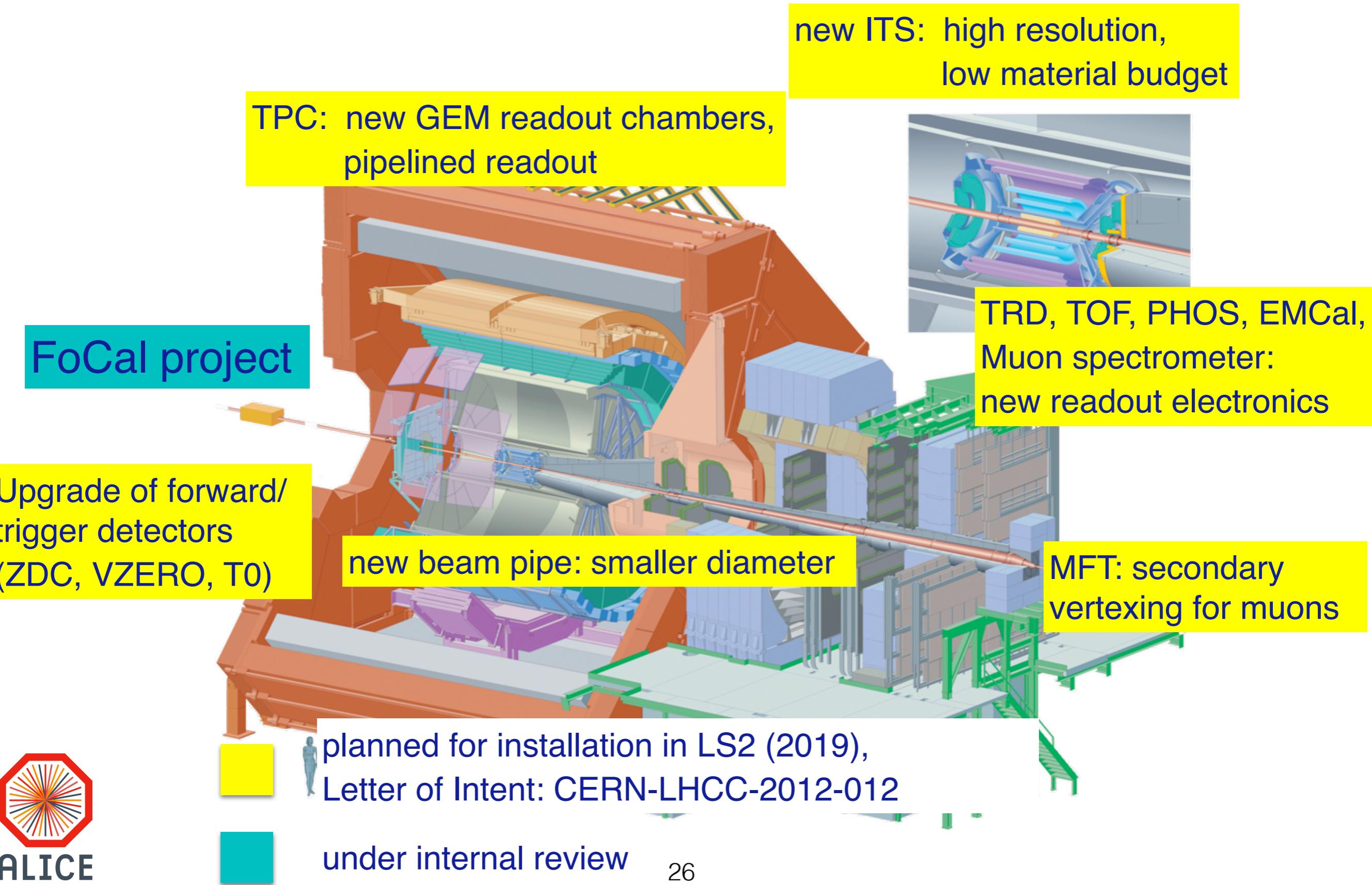
R_{dA} : strong suppression of hadron yield at forward rapidity

di-hadron correlations: broadening/suppression of away-side peak in dAu

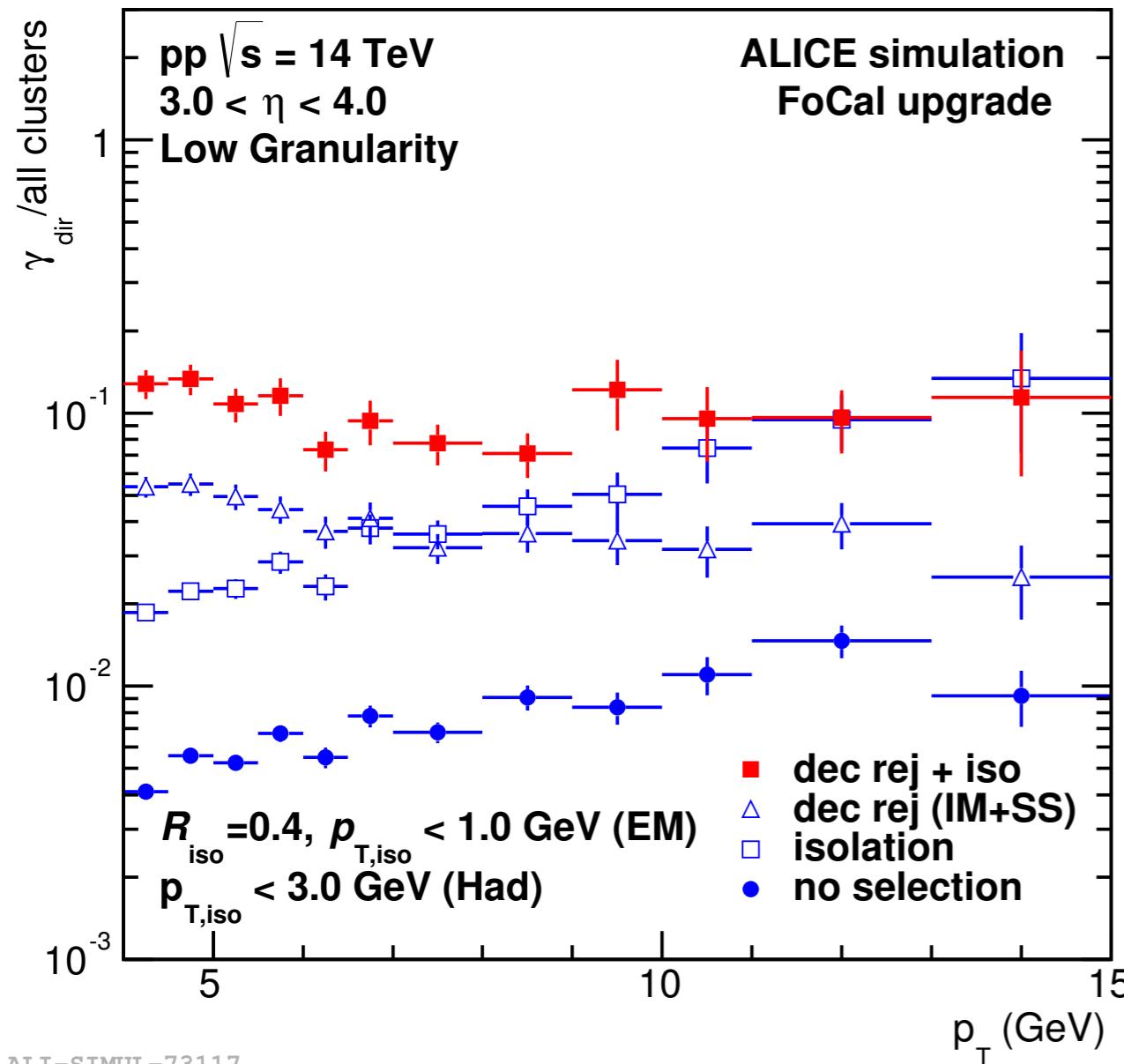
$$R_{dA} = \frac{dN/dp_T(dA)}{\langle N_{coll}(dA) \rangle dN/dp_T(pp)}$$

- qualitatively consistent with CGC, but ...
 - very low p_T , close to kinematic limit,
hadron observable (final state interactions)!
 - extend p_T and y range (not possible at RHIC)

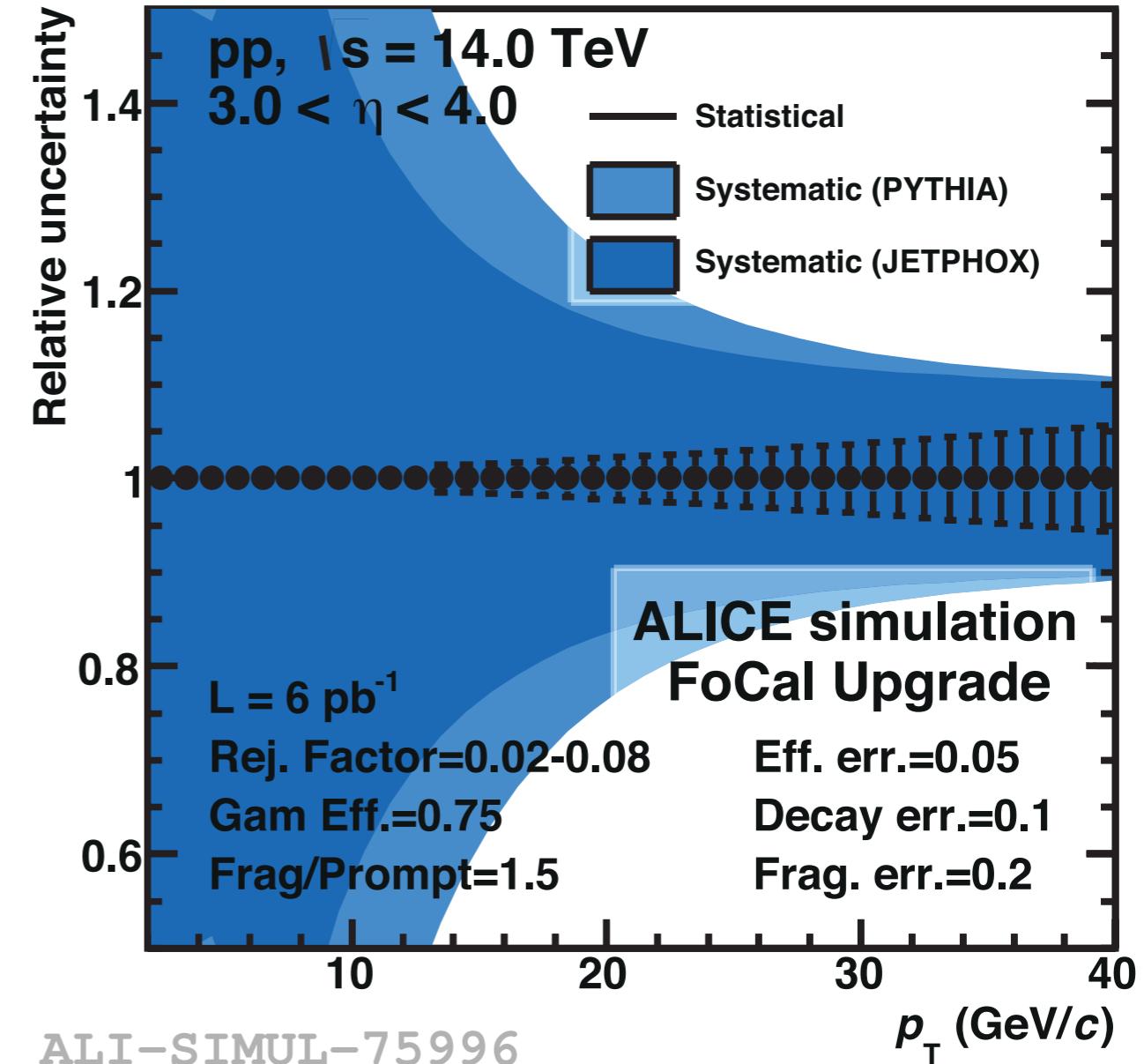
ALICE Detector & Upgrades



Low Granularity Measurement



low granularity (1cm²) does not allow efficient decay rejection
direct photon/all ≈ 0.1 for all pT



significant measurement not possible at low pT

NB: conditions similar to LHCb