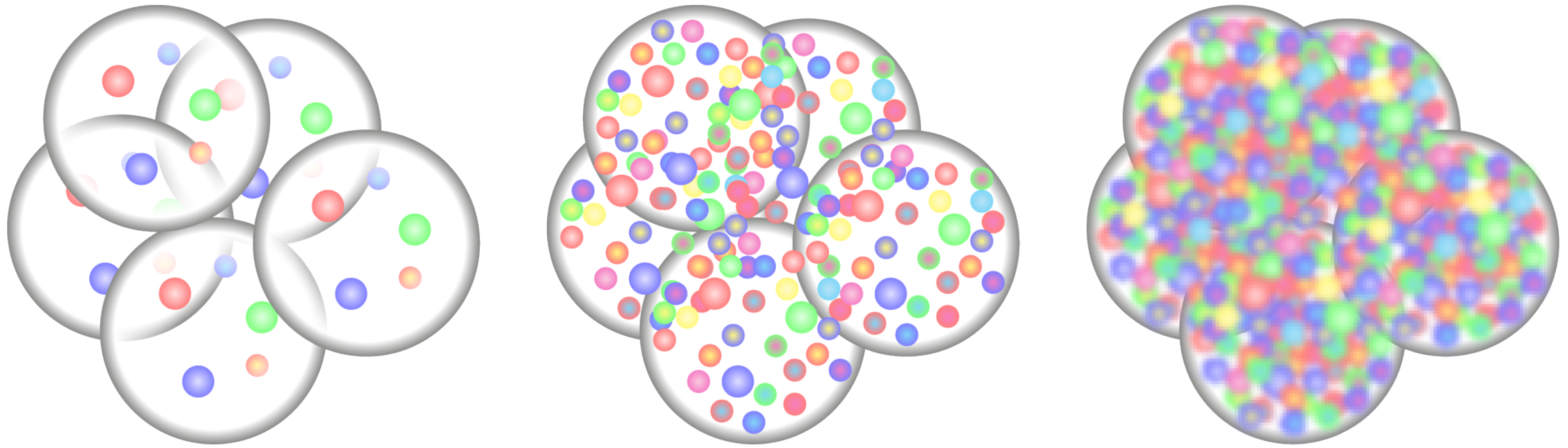
Forward Photon Measurements in ALICE at the LHC as a Probe for Low-x Gluons



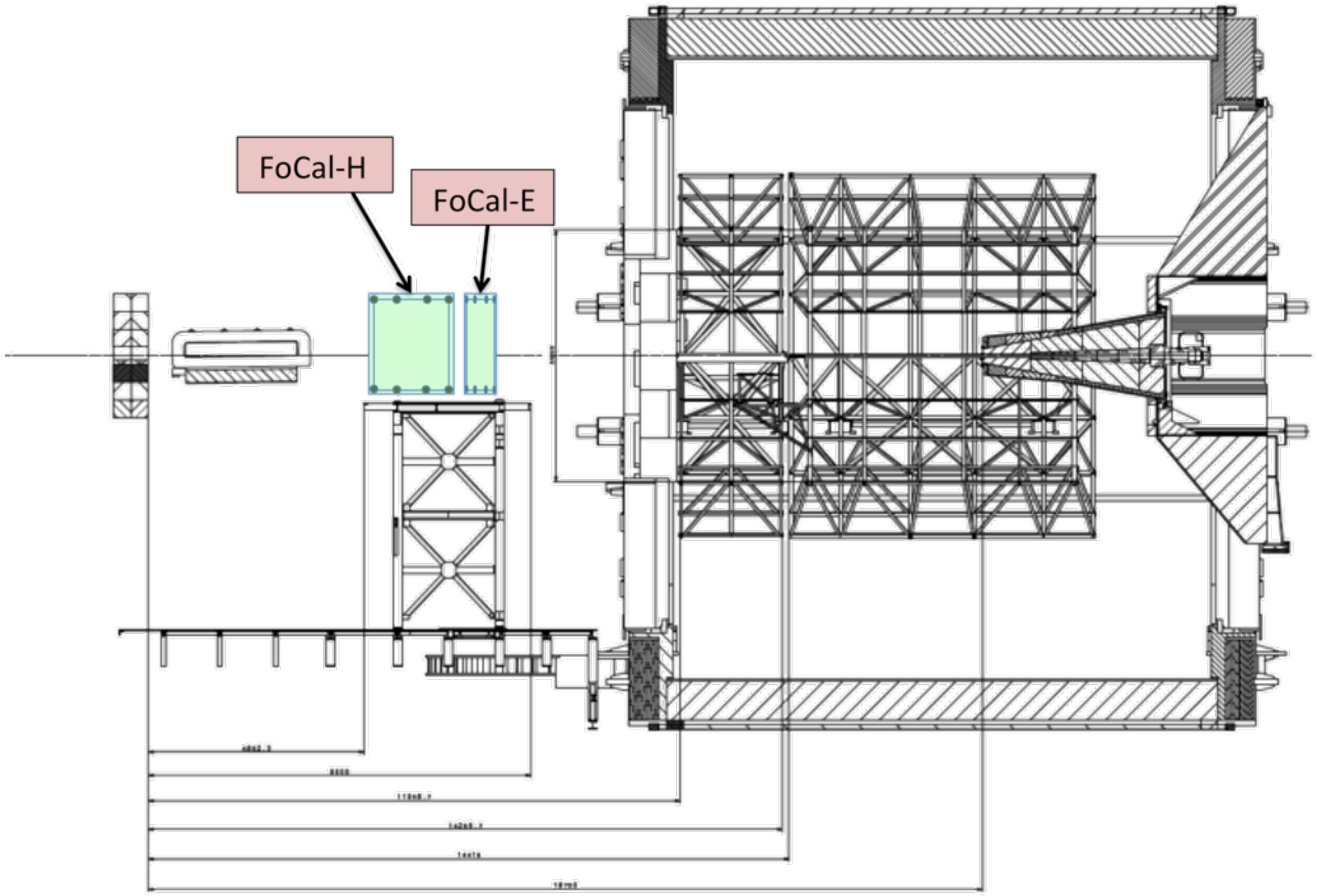
T. Peitzmann (Utrecht University/Nikhef)
for the ALICE Collaboration

Hard Probes 2018, Aix les Bains, 02.10.2018

Outline

- Physics case
  - PDF uncertainty (and gluon saturation)
  - photons as probes of PDFs
- FoCal - an ALICE upgrade proposal
  - baseline design, performance
- Research and development
  - high-granularity EM calorimeter
- Summary

FoCal in ALICE



electromagnetic calorimeter (FoCal-E) for γ and π^0 measurement

preferred scenario:

- at z ≈ 7m (outside solenoid magnet) $3.3 < \eta < 5.3$
- add hadronic calorimeter (FoCal-H)

under internal discussion
possible installation in LS3

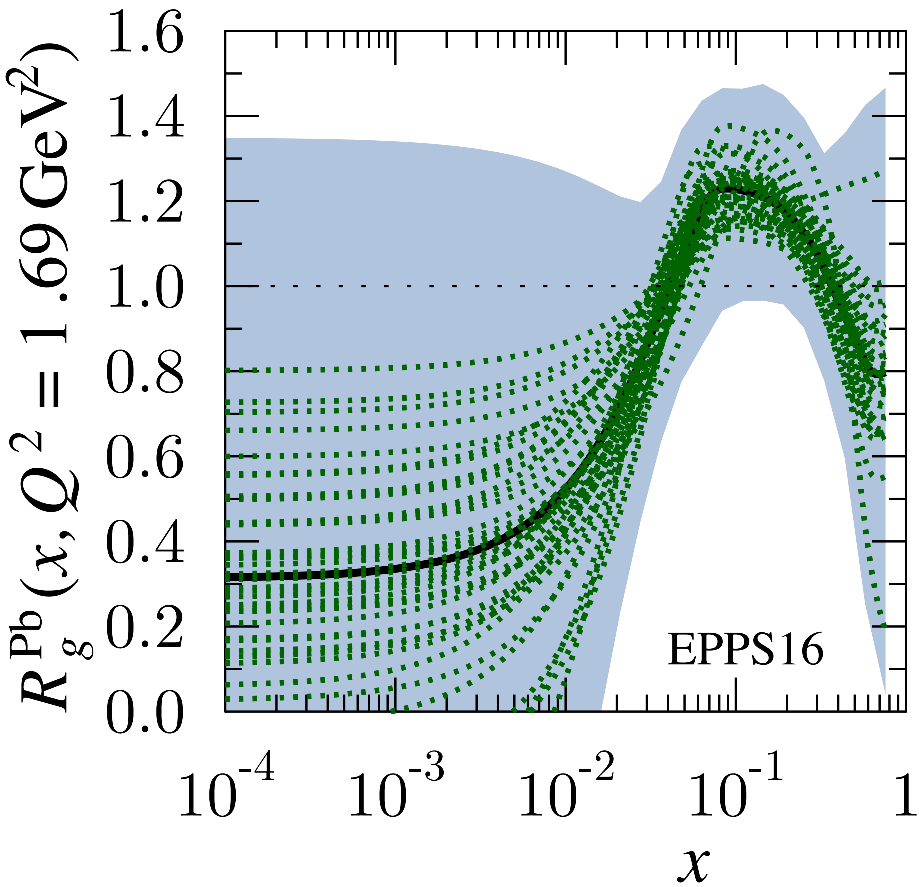
advantage in ALICE: forward region not instrumented, “unobstructed view”

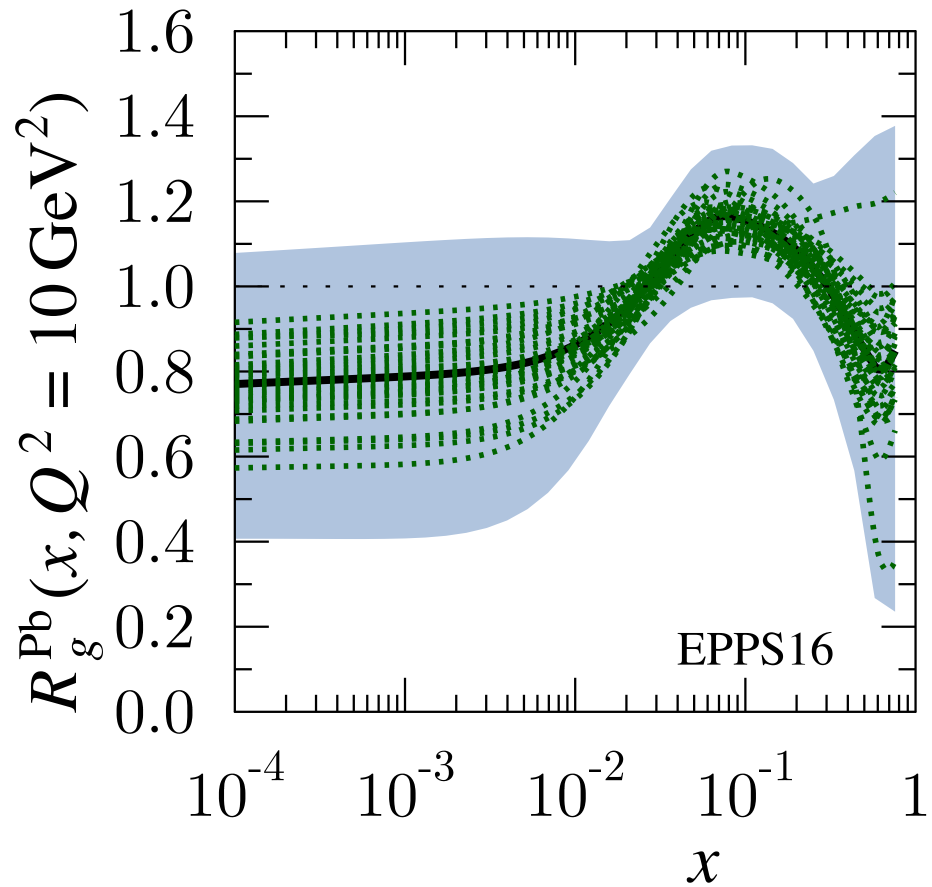
- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, effective granularity ≈ 1mm^2

note: two-photon separation from π^0 decay (p_T = 10 GeV/c, y = 4.5, α = 0.5) is d = 2 mm!

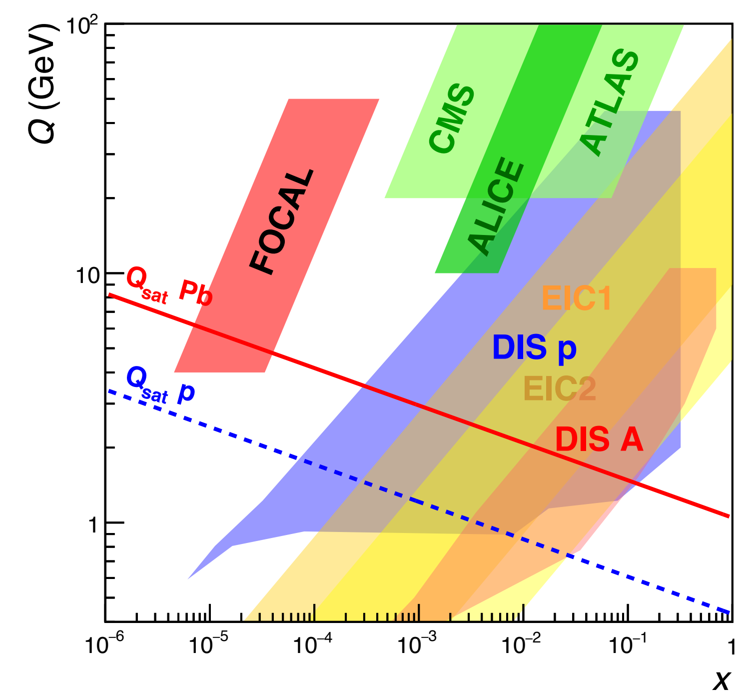
EPPS16, EPJC 77, 163

PDF Uncertainties and Saturation

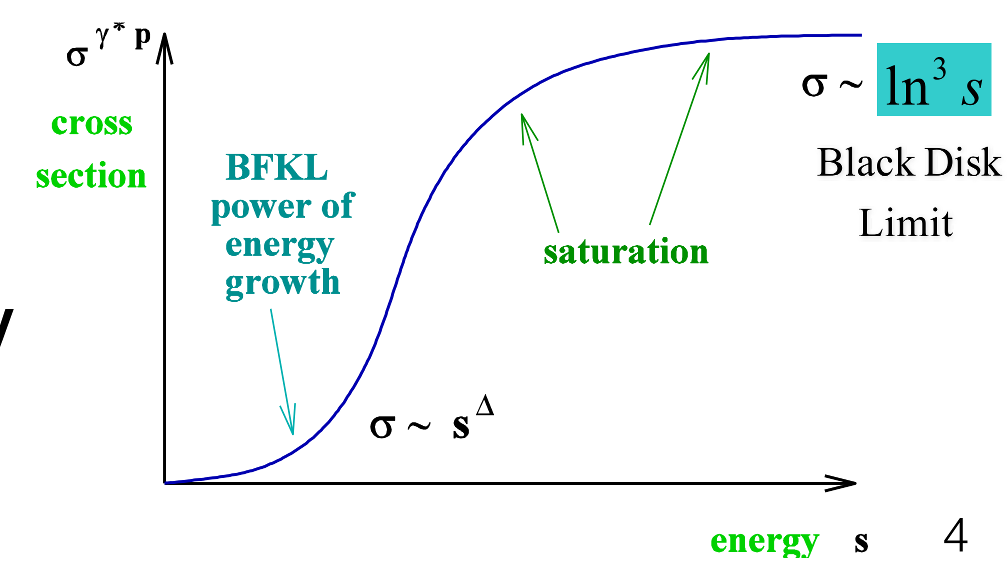




EM probes - kinematic coverage

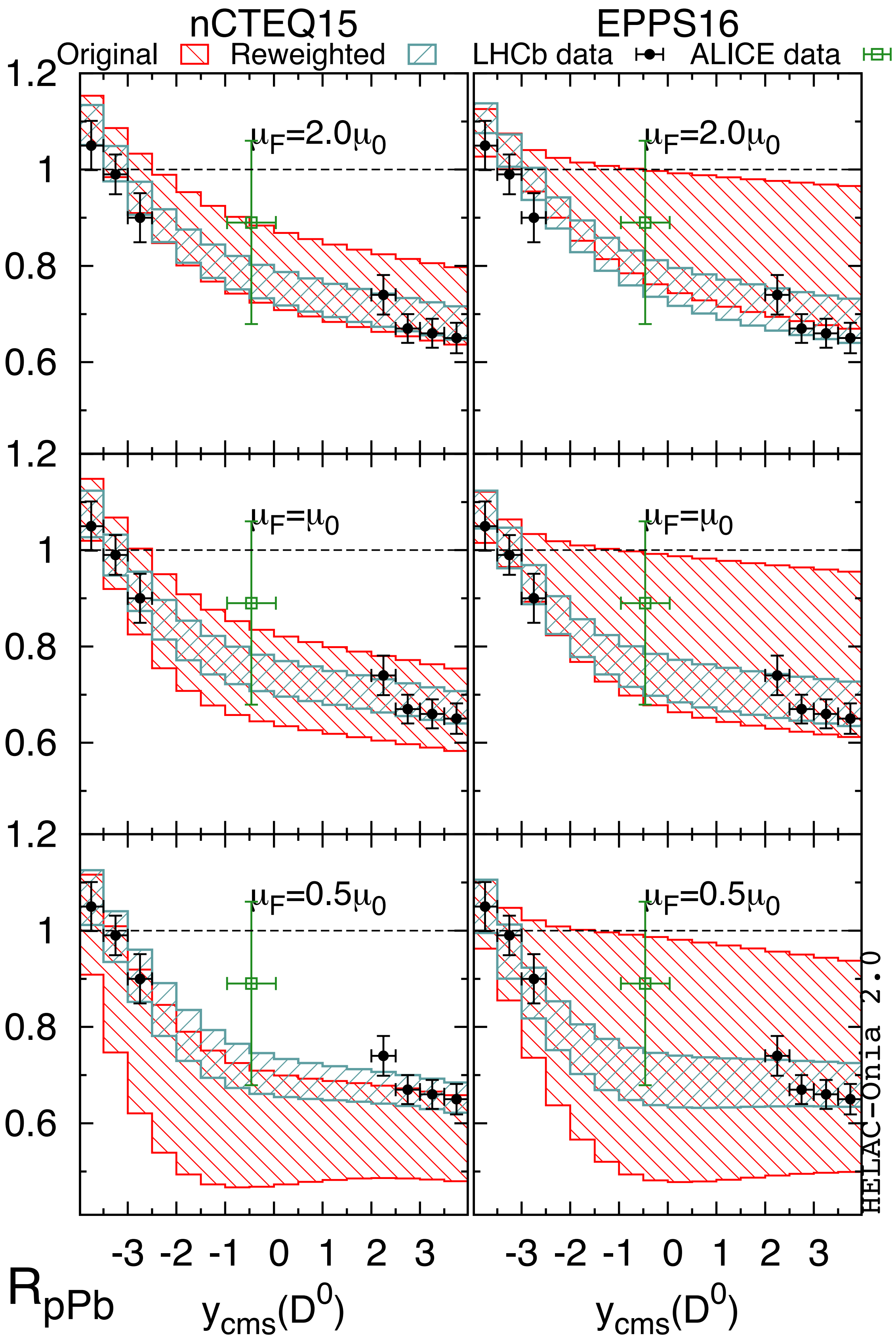


- large uncertainties of nPDFs
  - parameterised nuclear modification
  - recently updated to allow more freedom (e.g. flavour dependence)
- *x*-dependence?
  - very little dependence for $x < 10^{-2}$
- non-linear effects from high gluon density
- gluon saturation?

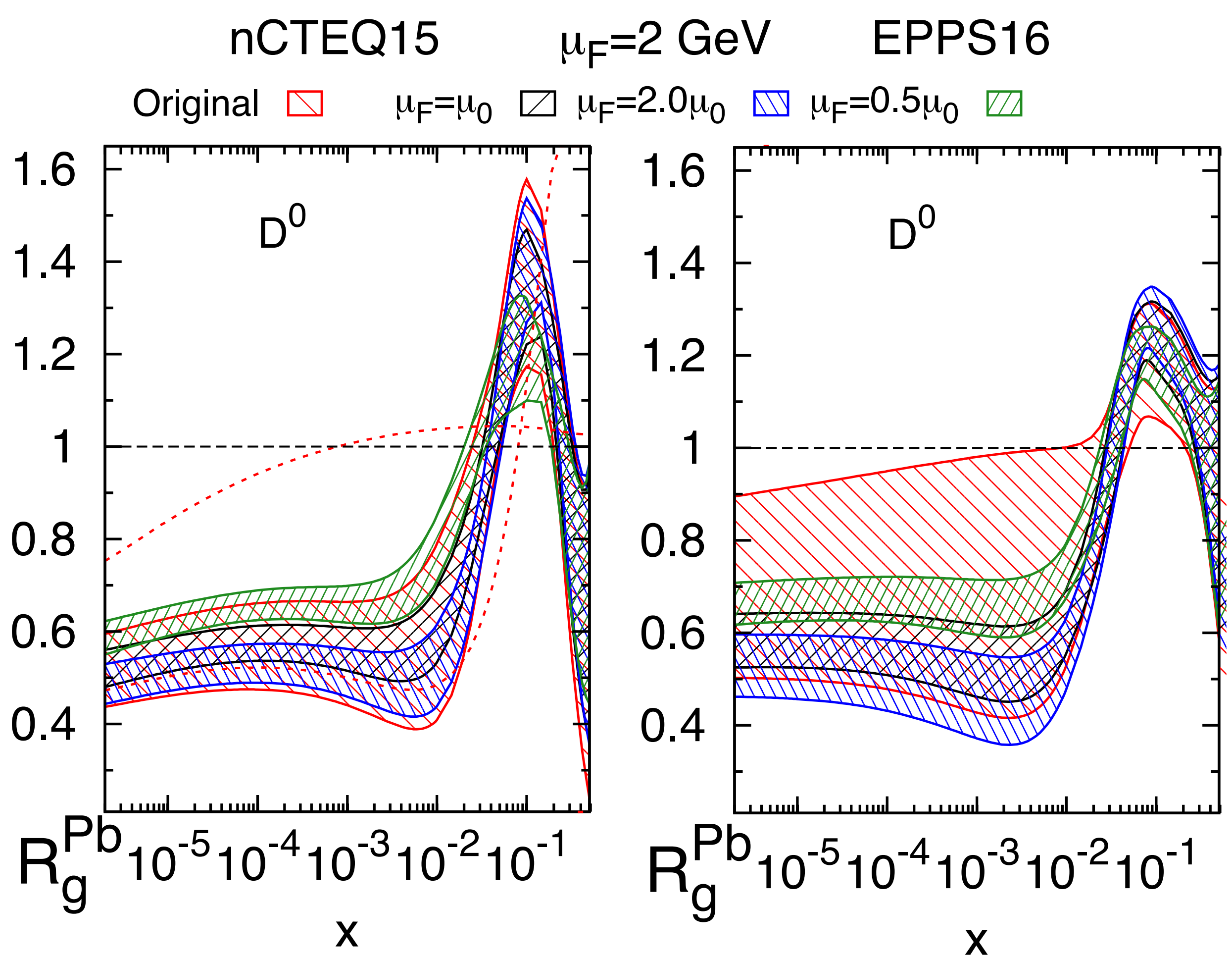


Recent: PDF Fits Using Charm

Kusina et al., arXiv:1712.07024



- open charm used in re-weighting
  - significant reduction of uncertainties
  - significant suppression – on the low side of current PDFs
  - significant pQCD uncertainties (scale, fragmentation)
  - relies on shape of parameterisation: very little *x*-dependence at low *x*!



True x-Sensitivity?

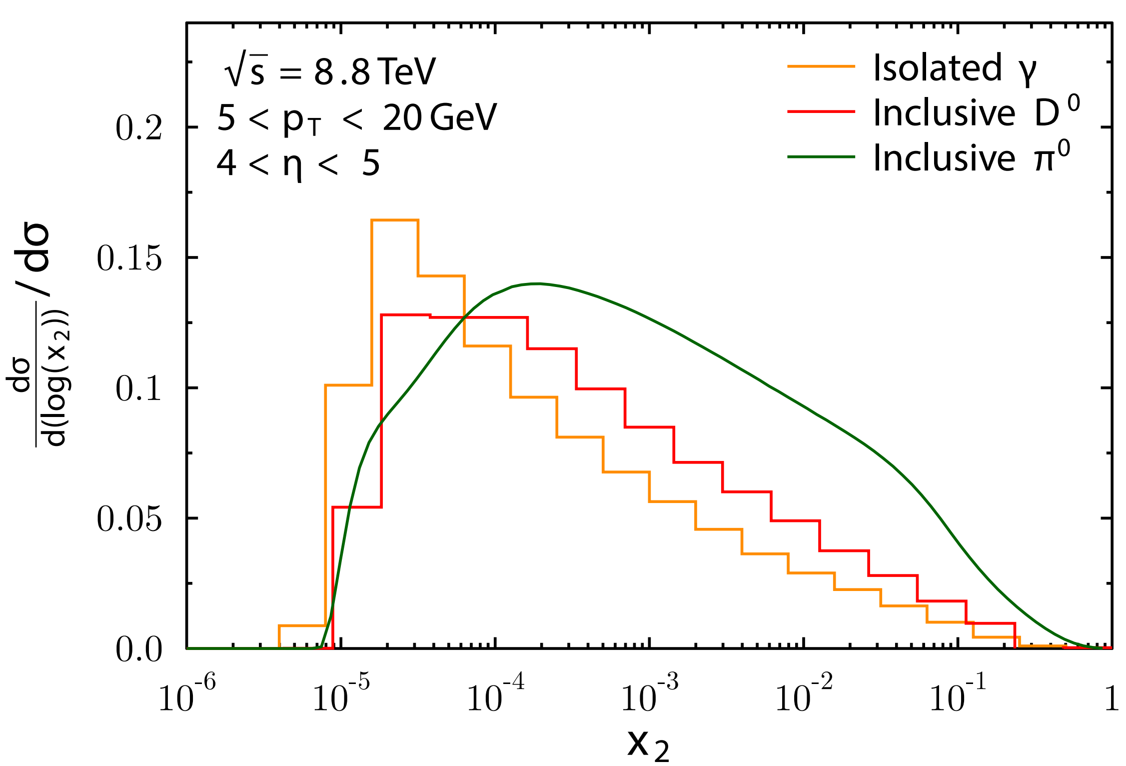
	$\sqrt{s}$ (TeV)	y	p_T (GeV/c)	z	x_2
π	0.2	4	2	0.3	$1.2 \cdot 10^{-3}$
π	8.8	0	2	0.3	$1.5 \cdot 10^{-3}$
jet	8.8	4	20	1	$8.3 \cdot 10^{-5}$
π	8.8	4	2	0.3	$2.8 \cdot 10^{-5}$
D	8.8	4	0	0.5	$1.5 \cdot 10^{-5}$
γ	8.8	4	4	1	$1.7 \cdot 10^{-5}$
γ	8.8	4.5	4	1	$1.0 \cdot 10^{-5}$

$$x_{1,2} \approx \frac{2m_T}{\sqrt{s}} \exp(\pm y)$$

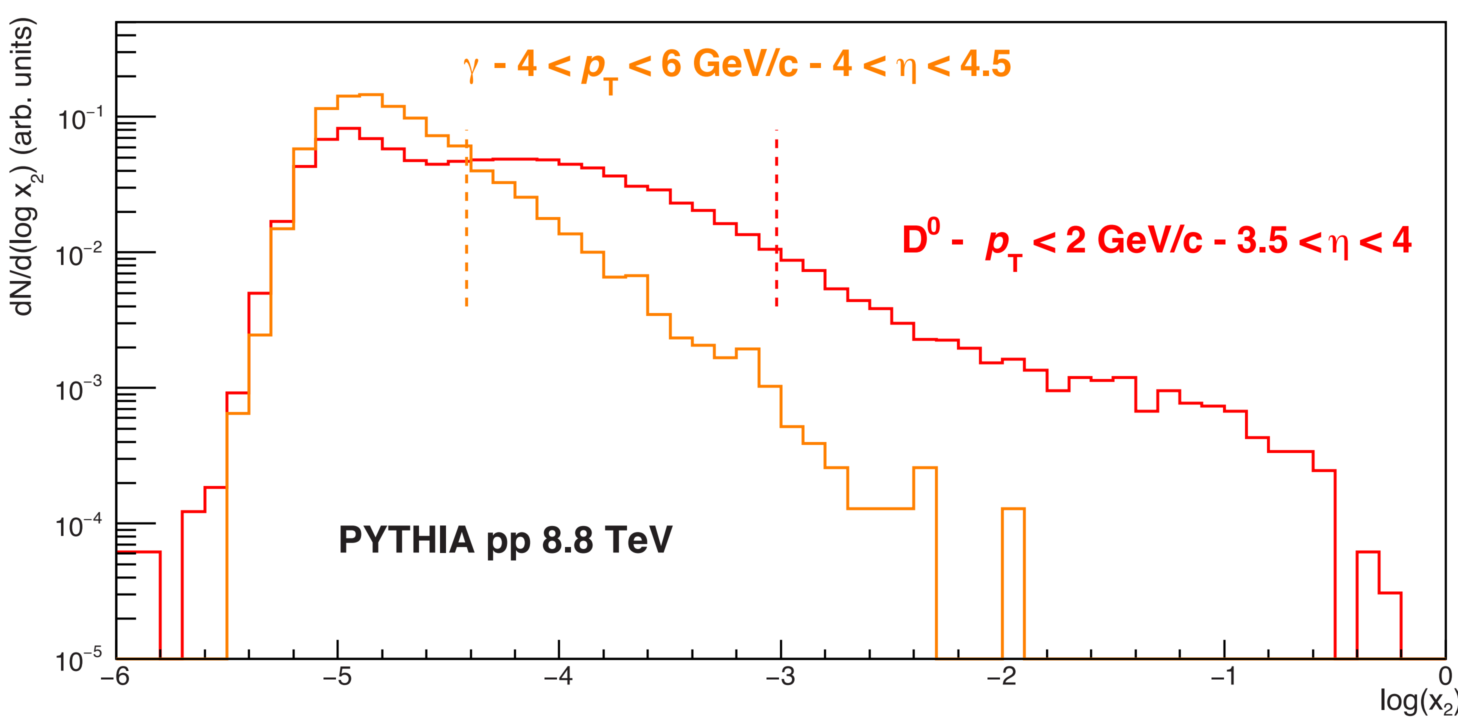
- LO kinematics estimates provide rather lower limit for x_2
- but: higher orders contribute significant tail towards large x_2

- compare D^0 (LHCb) and prompt γ (FoCal)
- expect better sensitivity for photons

- *x*-distributions from NLO pQCD

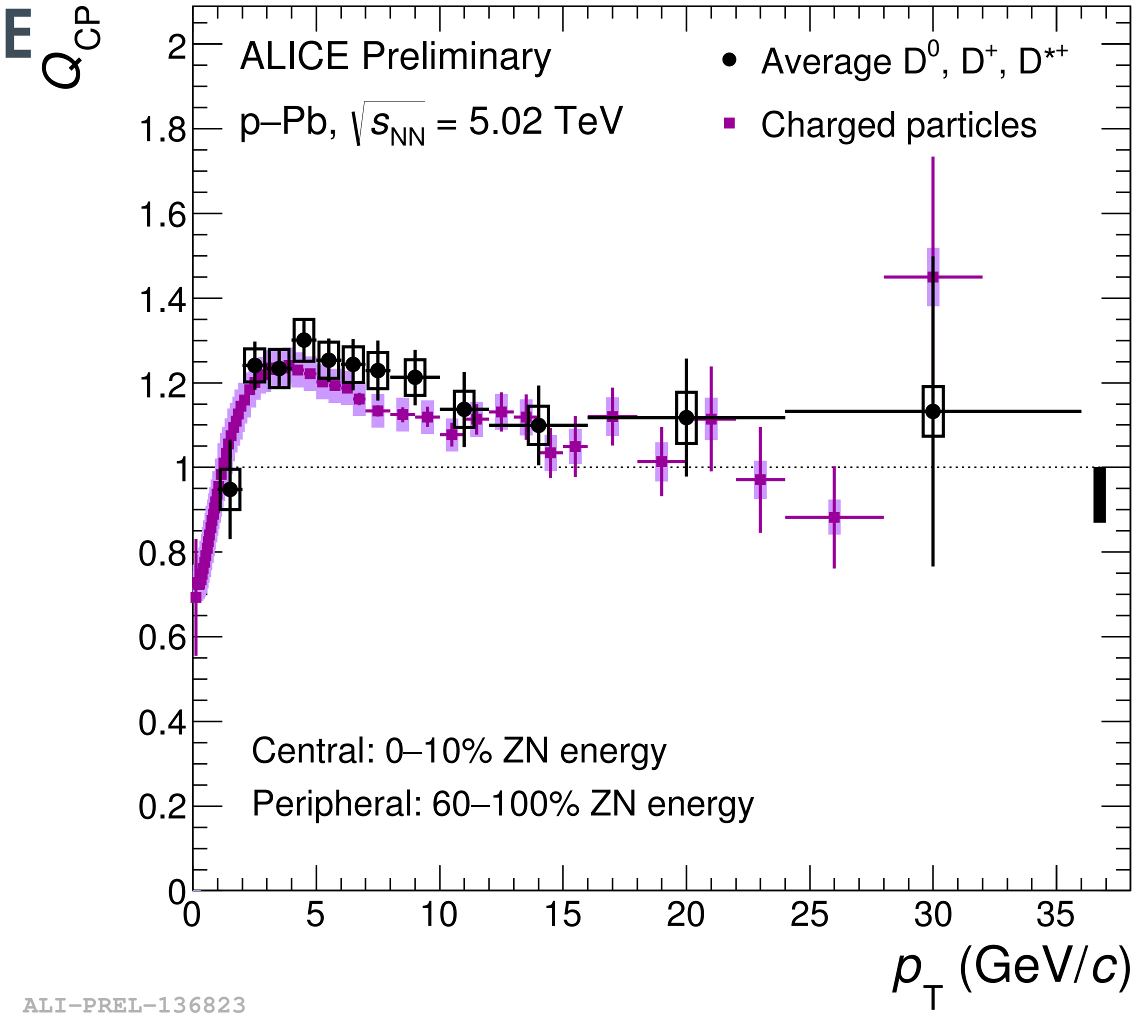


- *x*-distributions from PYTHIA



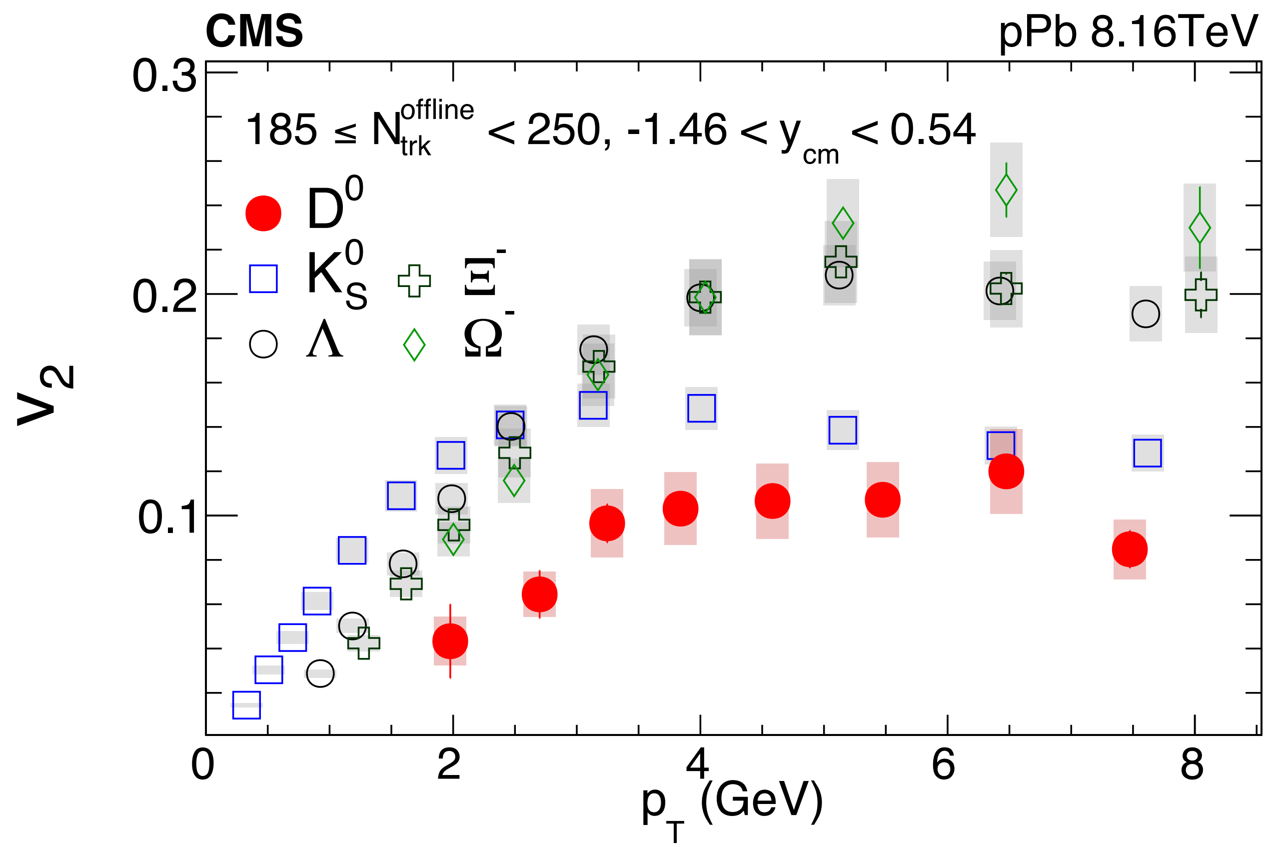
no analytical approximation, taking into account η of recoil parton

Final-State Modification of Open Charm in p–A?



nuclear modification for D mesons similar to charged hadrons, deviation from N_{coll} scaling at low p_T

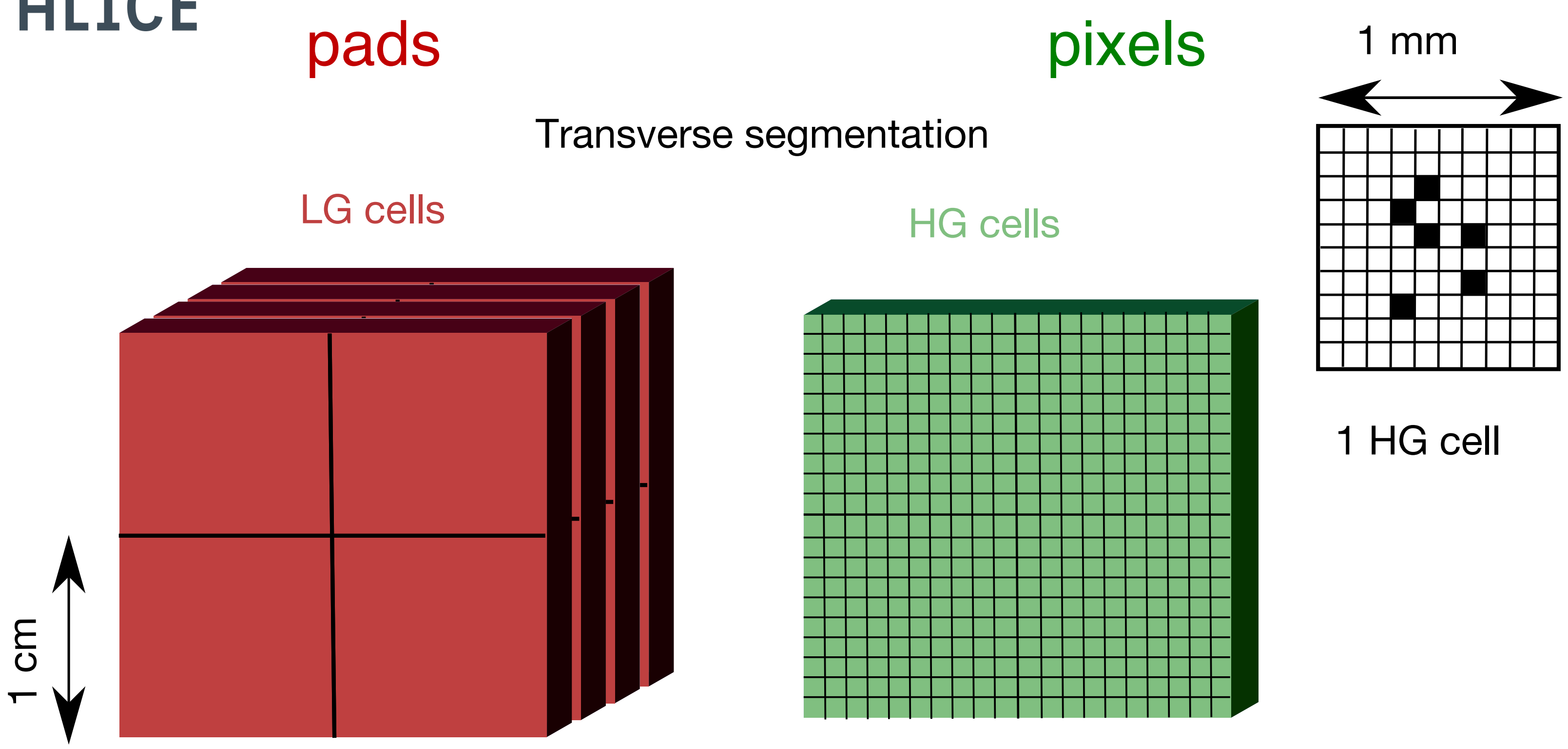
CMS Collaboration, CERN-EP-2018-076

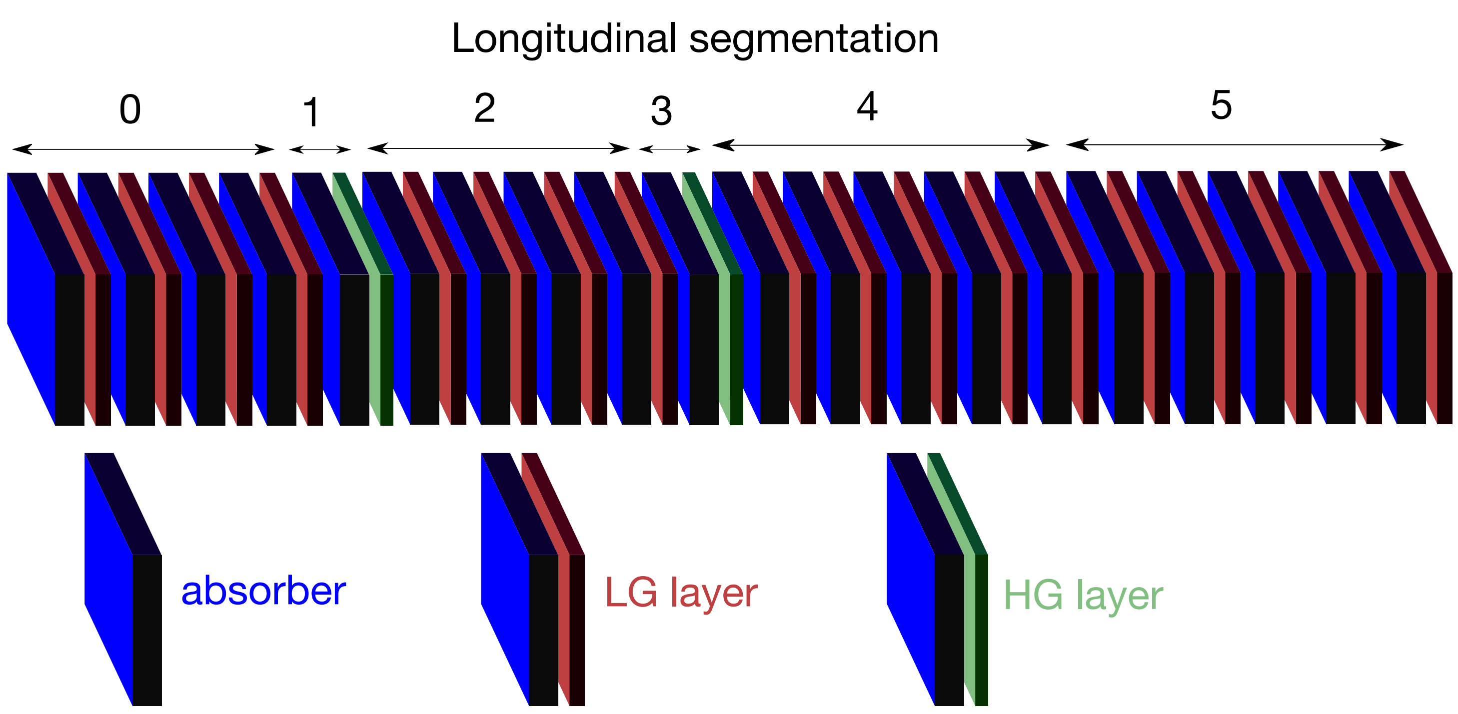


significant v_2 for D mesons, similar results for HF-decay leptons

- mechanism for modifications still unclear, possibly final-state interaction!
- relation between initial- and final-state kinematics may be obscured
- introduces additional systematic uncertainty

The FoCal Detector – Strawman Design





studied in performance simulations:

20 layers:
W (3.5mm ≈ 1 X_0) + Si-sensors

hybrid design (2 types of sensors)
- **Si-pads** (≈ 1 cm^2): energy measurement, timing(?)
- **CMOS pixels** (≈ 30x30 μm^2): two-shower separation, position resolution

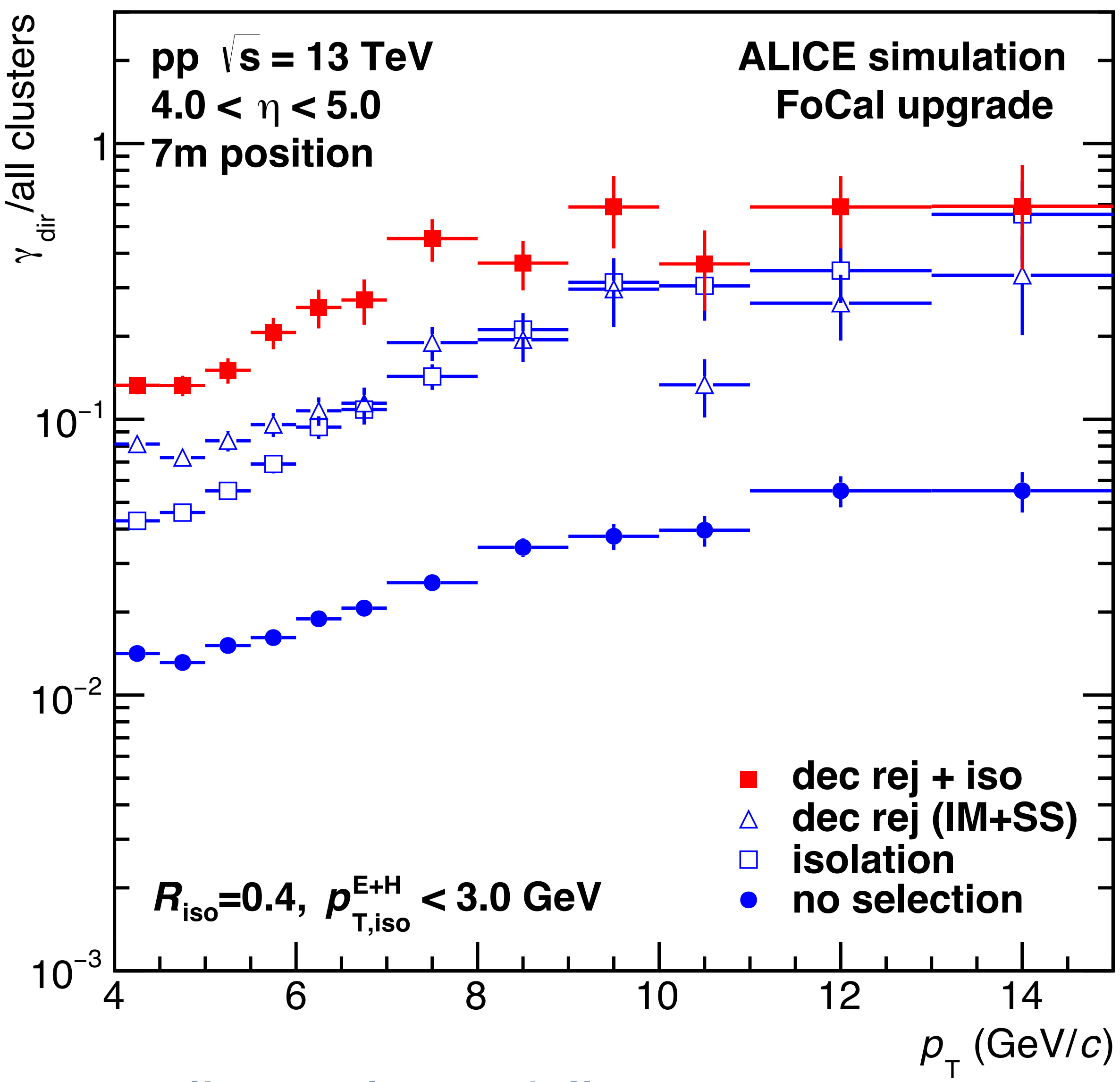
	Si-pads	Si-pixels
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9
readout channels	≈ 5 x 10^4	≈ 2 x 10^6

assuming ≈ 1m^2 detector surface

Direct γ Performance in pp

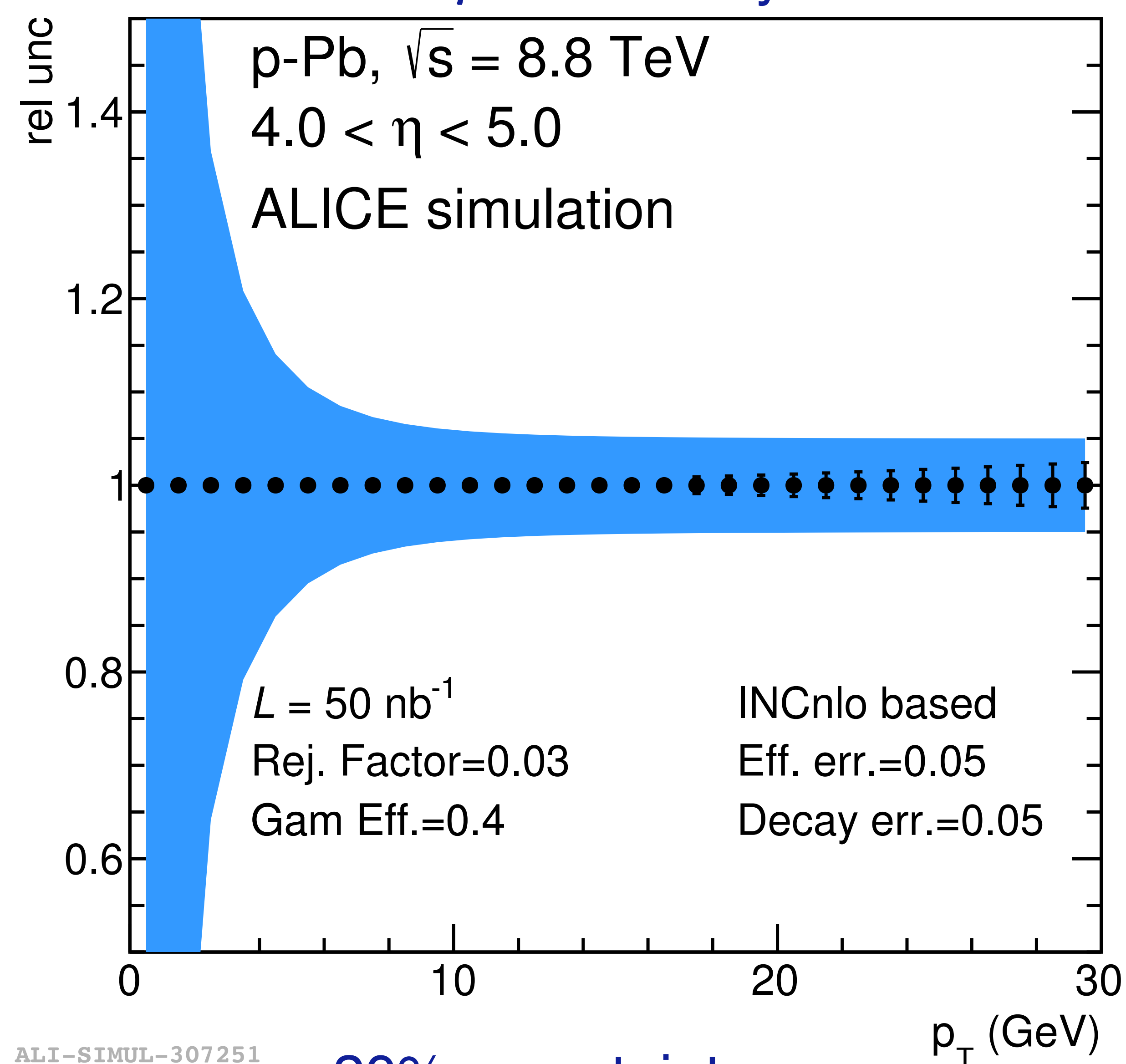
- combined rejection (invariant mass + shower shape, isolation)
- combined suppression of background relative to signal: factor ≈ 10
  - largely p_T-independent

Direct γ/all cluster ratio



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

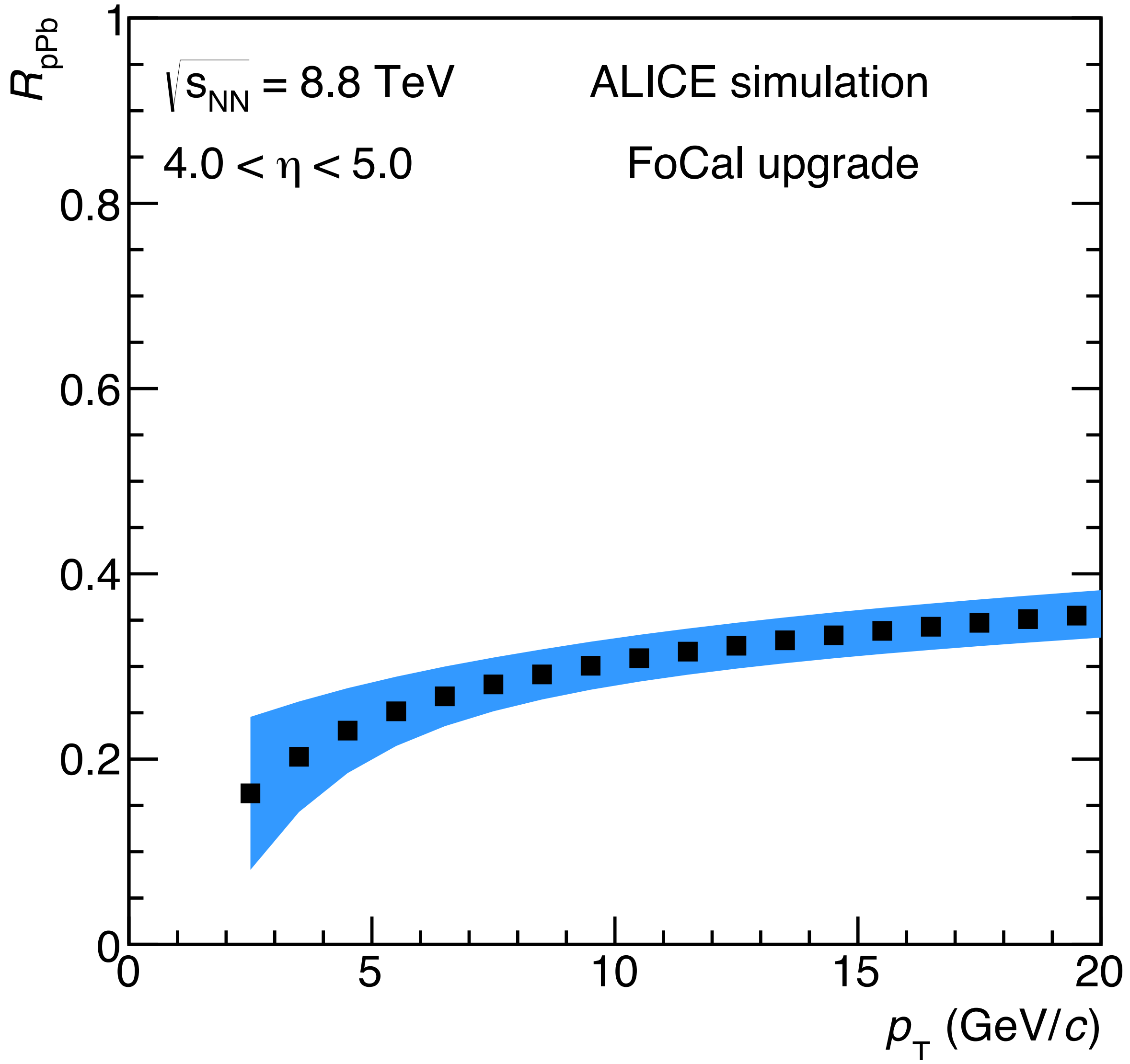
Direct γ uncertainty



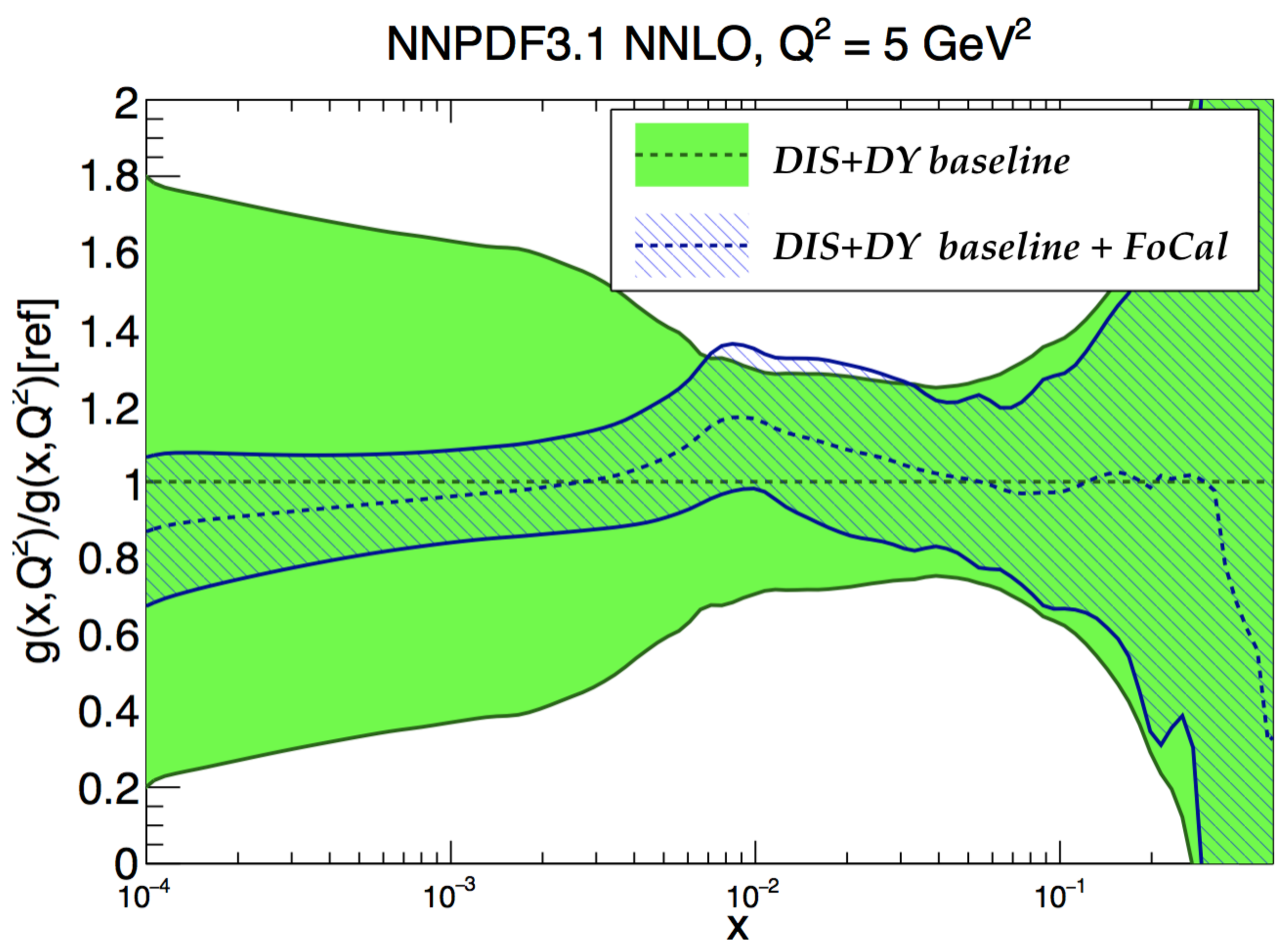
≈ 20% uncertainty
at p_T = 4 GeV/c
decreases with increasing p_T

Impact of Forward Photons on nPDFs

Performance estimate of FoCal measurement



uncertainty of nPDFs without/with FoCal
J. Rojo et al, priv. comm.,
arXiv 1610.09373,1706.00428,1802.03021



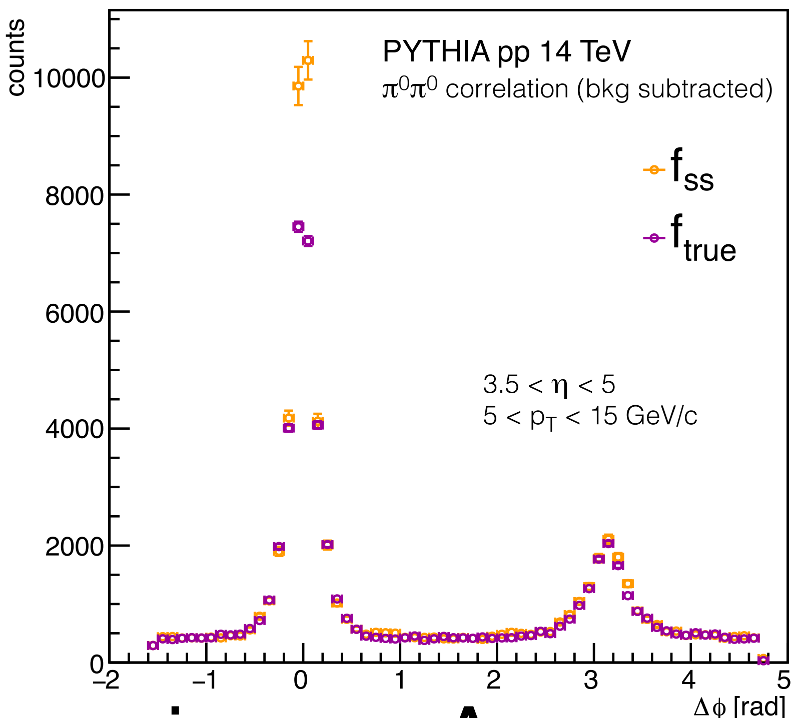
Uncertainties can be improved significantly

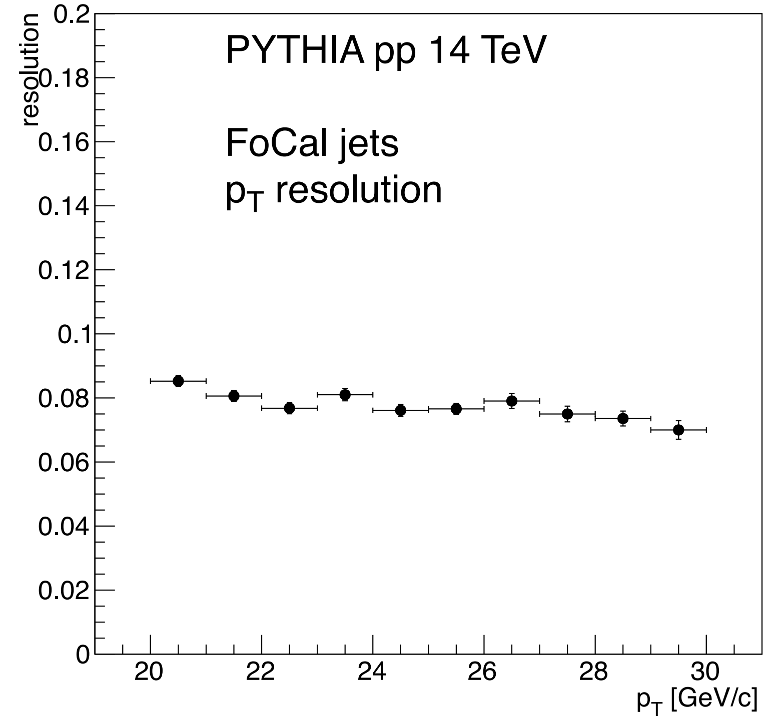
Still some discussion ongoing:
choice of $\Delta\chi^2$, effect of DGLAP evolution, shape of parameterisation

Work in progress!

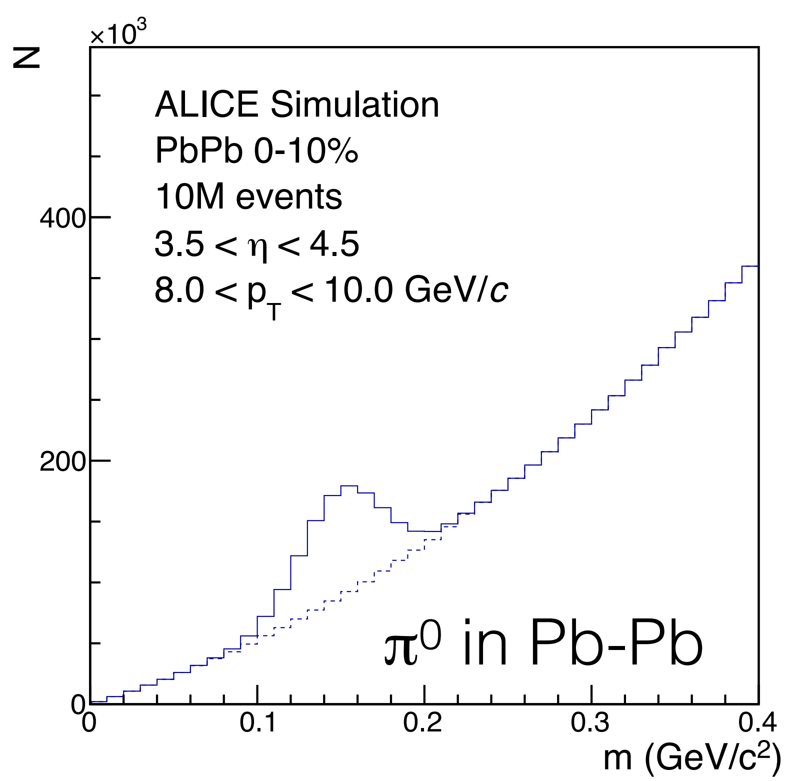
More FoCal Physics Topics

- low-x gluons (n)PDFs, saturation
  - direct photon R_{pA}
  - π^0-π^0 correlations
  - dijet correlations





- ridge/flow-like phenomena in pp, pA
  - correlations: forward photon – mid-rapidity hadron

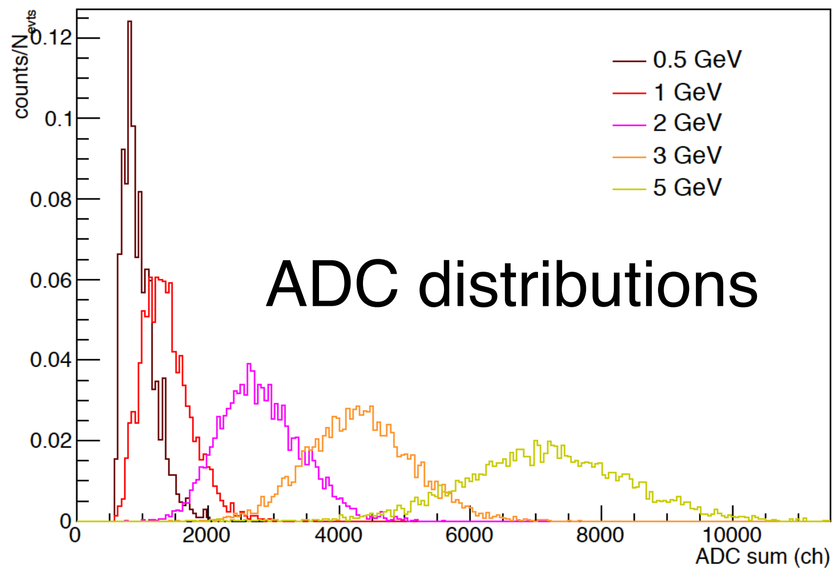


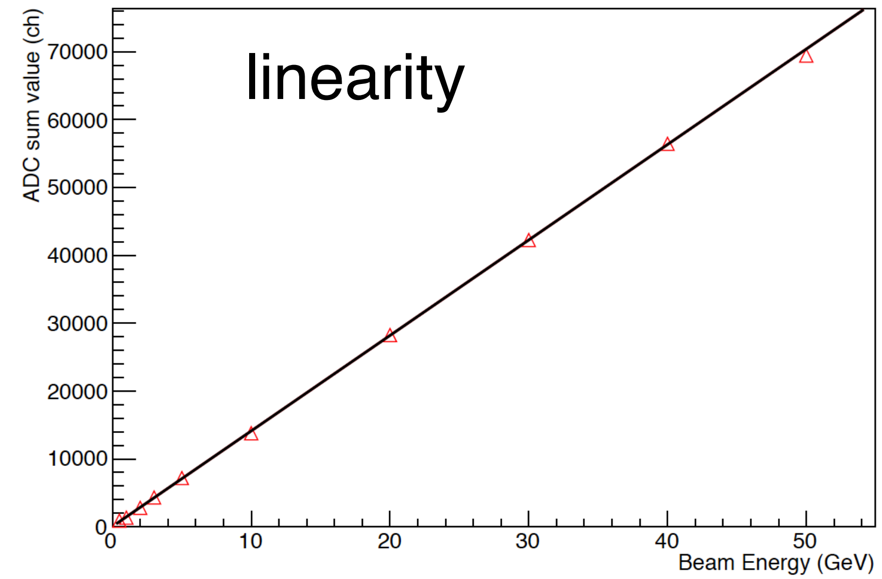
- jet quenching at large y
  - neutral pion R_{AA}
- miscellaneous
  - reaction plane in Pb–Pb

Extensive R&D Program Ongoing

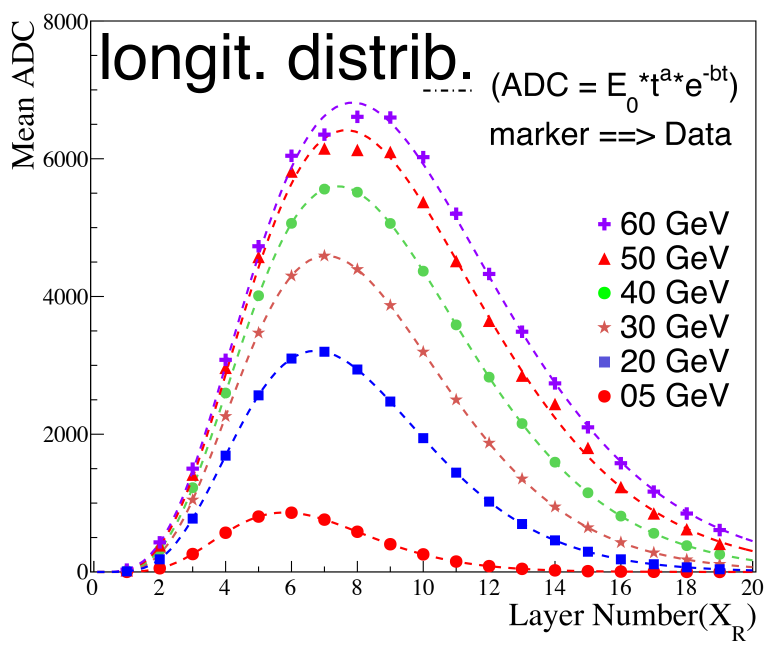
- requires to go beyond state of the art
  - pixel sensors needed for pion rejection (two-shower separation)
  - Si-pads needed for energy resolution and timing
- proof of principle demonstrated
  - successful test of first digital pixel calorimeter (JINST 13 (2018) P01014)
  - investigating several options for pad sensor readout
  - ongoing test-beam program
    - test setup with pads currently in ALICE cavern
- still significant R&D steps necessary
  - modifications to ALPIDE sensor
  - optimisation of pad readout
  - general design (minimisation of Molière radius, etc.)

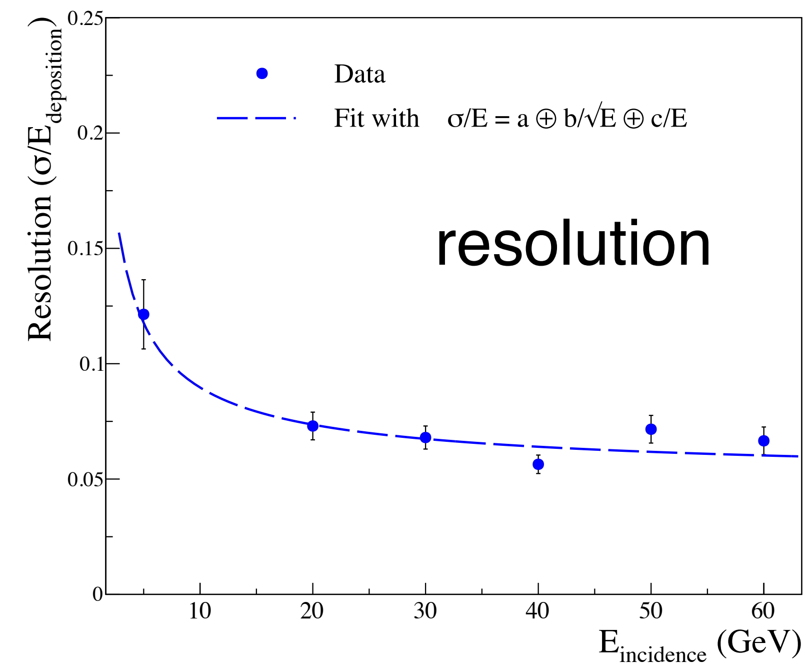
W/Si-Pad Test-Beam Performance





ORNL/Japan Pad prototype with APV/SRS readout



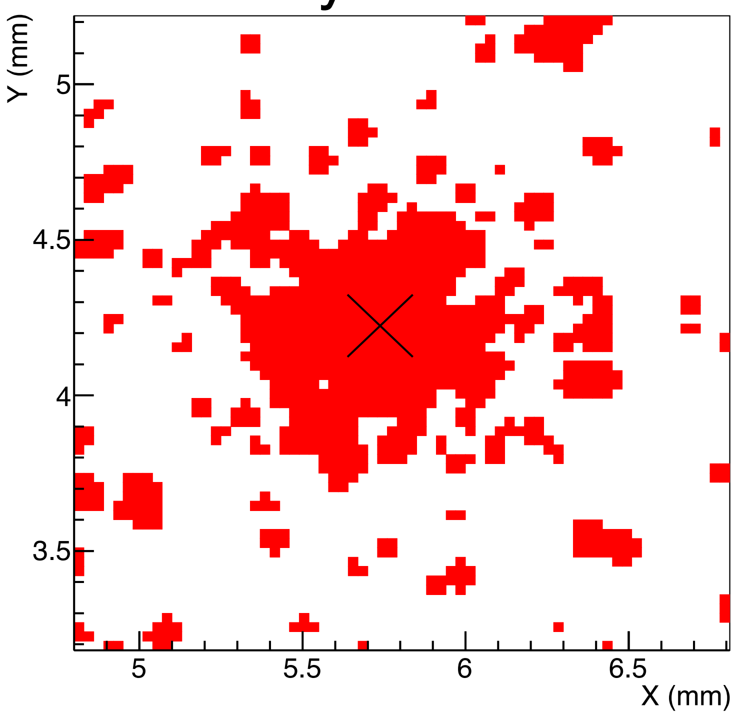


India Pad prototype with custom chip (MANAS/ANUSANSKAR)

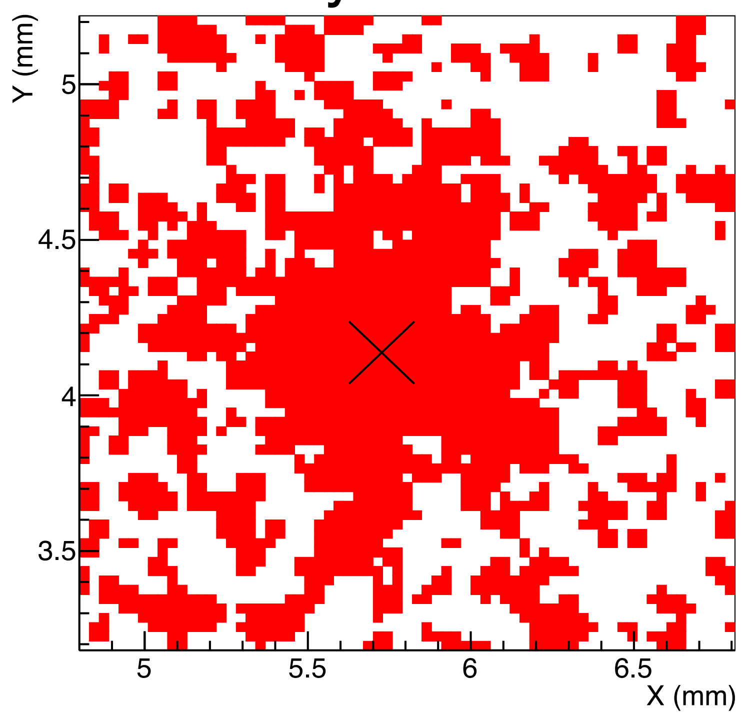
test beam performance agrees with simulations
papers on instrumentation in preparation

Digital Pixel Test-Beam Results

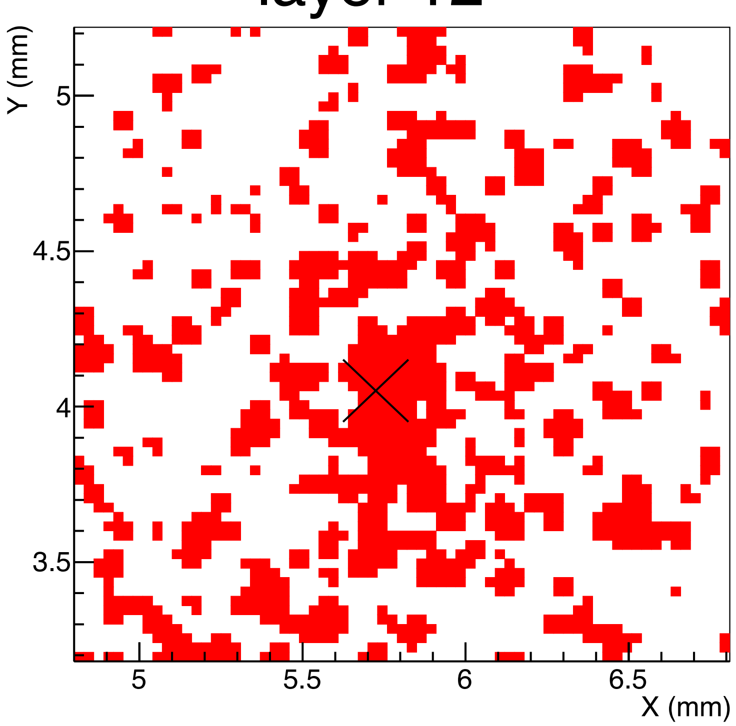
layer 4



layer 8



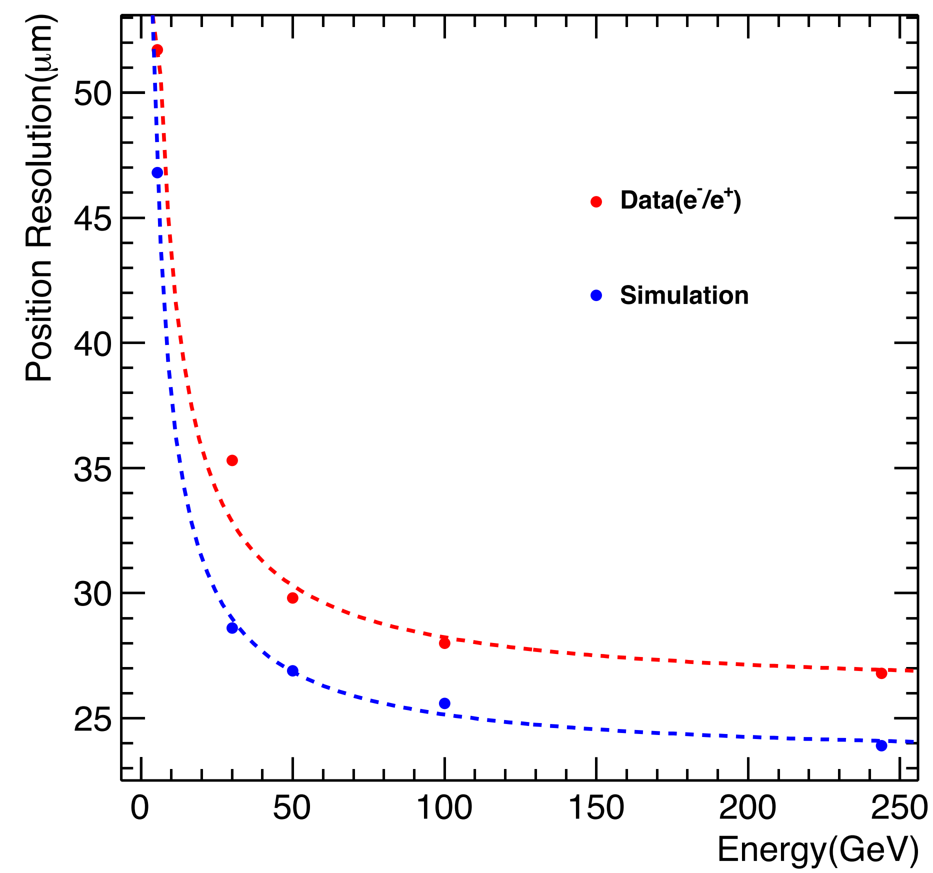
layer 12



244 GeV e^- (@ SPS)
single-event display
in pixel calorimeter

detailed reconstruction
of em showers possible

shower-position resolution



can also provide excellent
two-shower separation

Summary

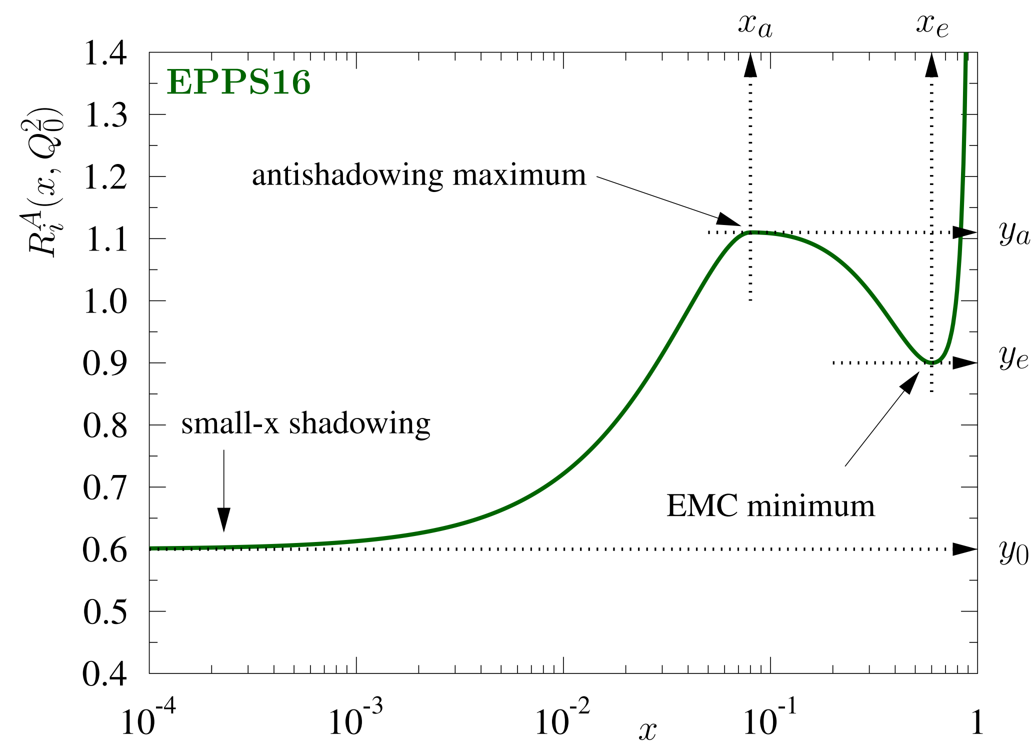
- Forward photon measurements at LHC provide unique opportunity for low-x physics
  - complementarity with open charm: some advantages for photons
  - needs detector upgrade: proposed FoCal detector in ALICE
  - more physics opportunities with FoCal
- Extensive R&D with prototypes
  - FoCal will be a significant step beyond state of the art in calorimetry

Backup Slides

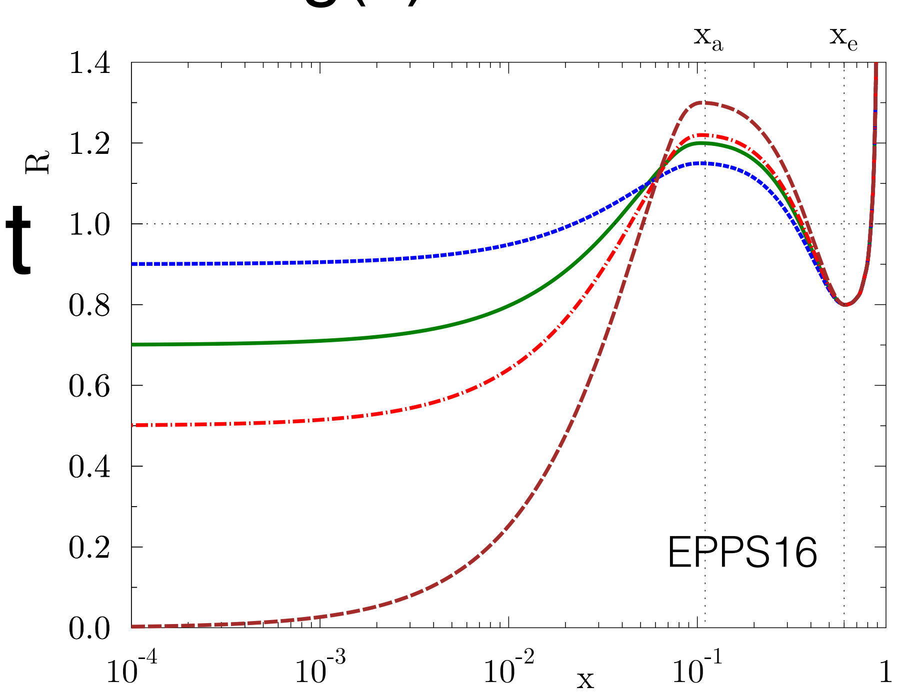
x-Dependence of PDF modification

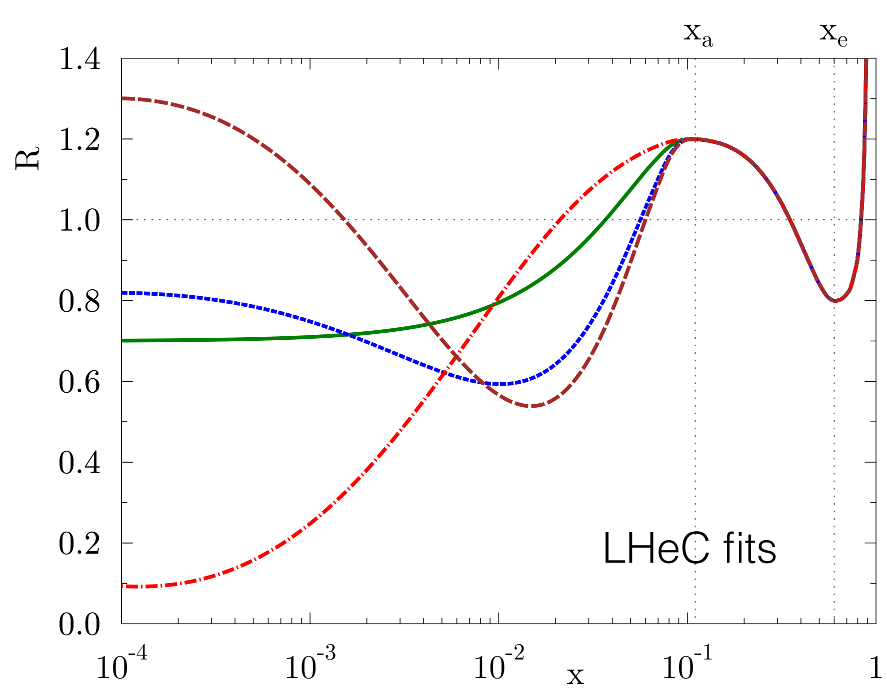
EPPS16, EPJC 77, 163

$$R_i^A(x,Q^2) = \begin{cases} a_0 + a_1(x-x_a)^2 & x \le x_a \\ b_0 + b_1 x^{\alpha} + b_2 x^{2\alpha} + b_3 x^{3\alpha} & x_a \le x \le x_e \\ c_0 + (c_1 - c_2 x)(1-x)^{-\beta} & x_e \le x \le 1 \end{cases}$$



- parameterisation of R_A
  - shape similar to EPS09
  - at low x leads to “plateau” in log(x)
- likely not sufficient
  - more flexible PDF used for LHeC estimates



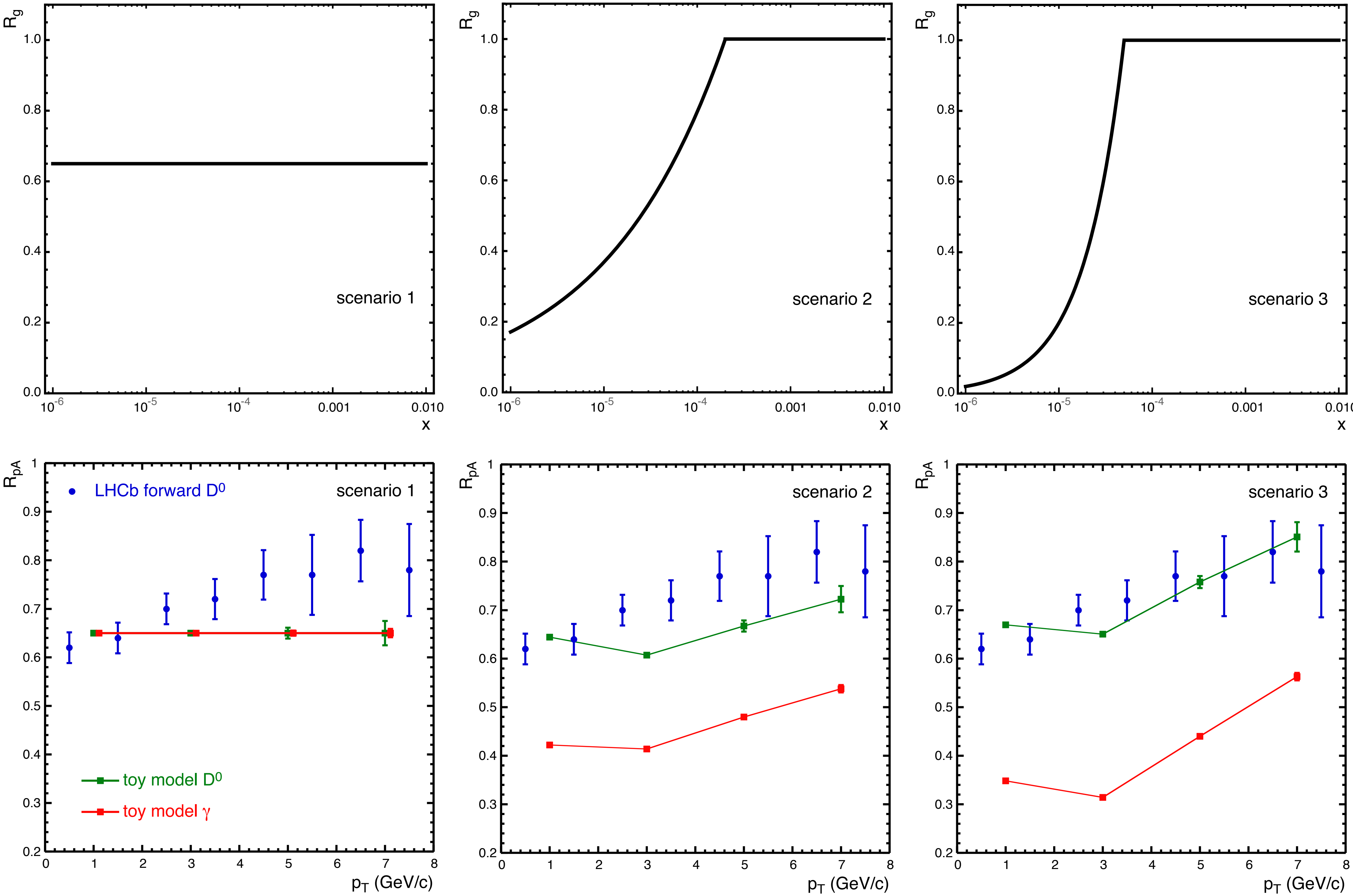


Helenius, Paukkunen, Armesto, arXiv:1606.09003

Influence of x Dependence

parameterise nuclear modification of gluon PDFs

Simple Model based on PYTHIA – no proper Q^2 dependence



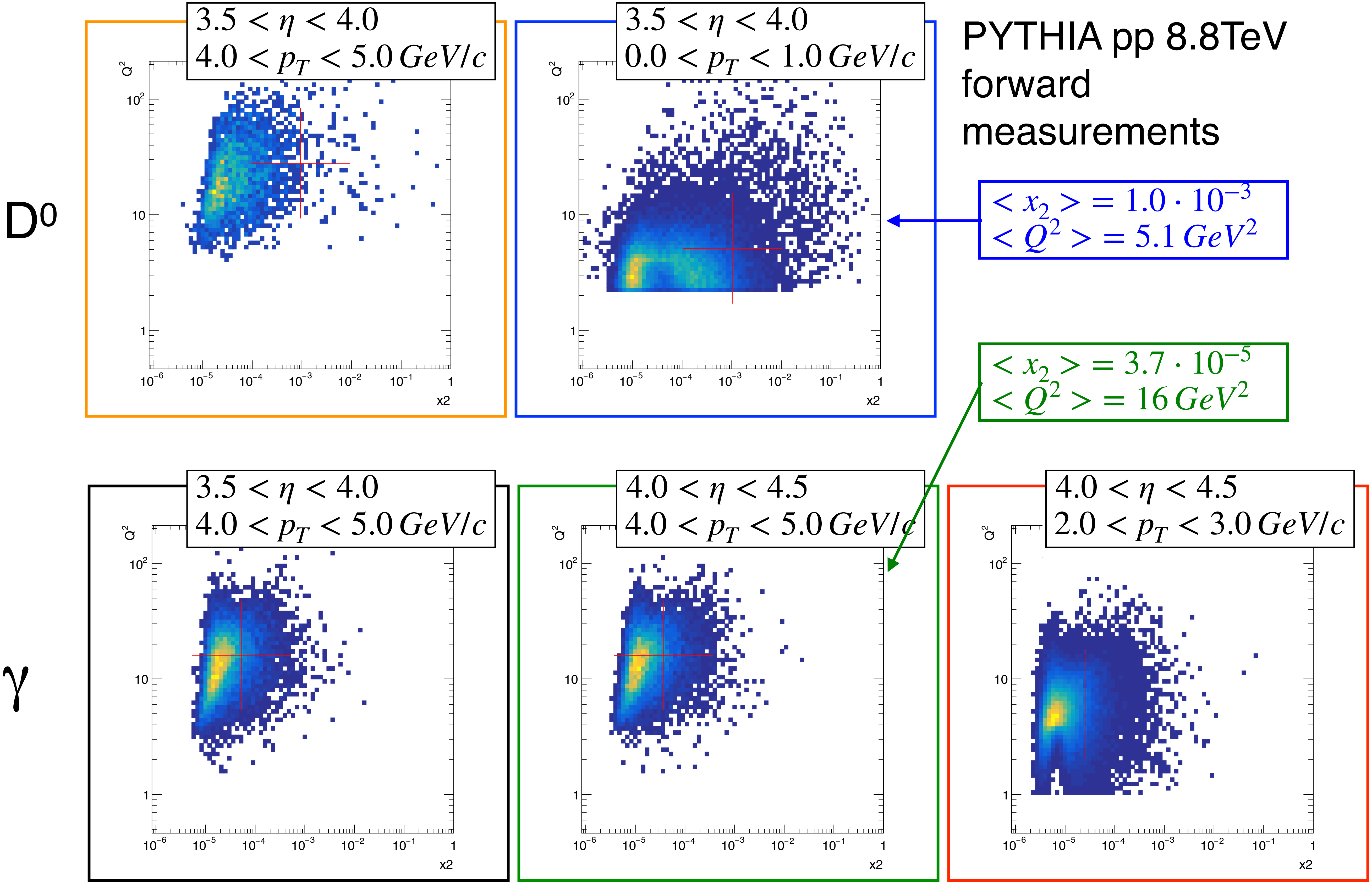
different x-sensitivity of probes

reflected in nuclear modification factor

$$R_{pA} = \frac{\int dx\ d\sigma/dx(p_T, y) \cdot R_g(x)}{\int dx\ d\sigma/dx(p_T, y)}$$

x-Q^2-Sensitivity

PYTHIA pp 8.8TeV
forward
measurements



Main Physics Motivation for FoCal (A Hierarchy)

1. prove or refute gluon saturation

- compare saturation models with linear QCD
- depends on saturation model implementation and flexibility of PDF analytical shape

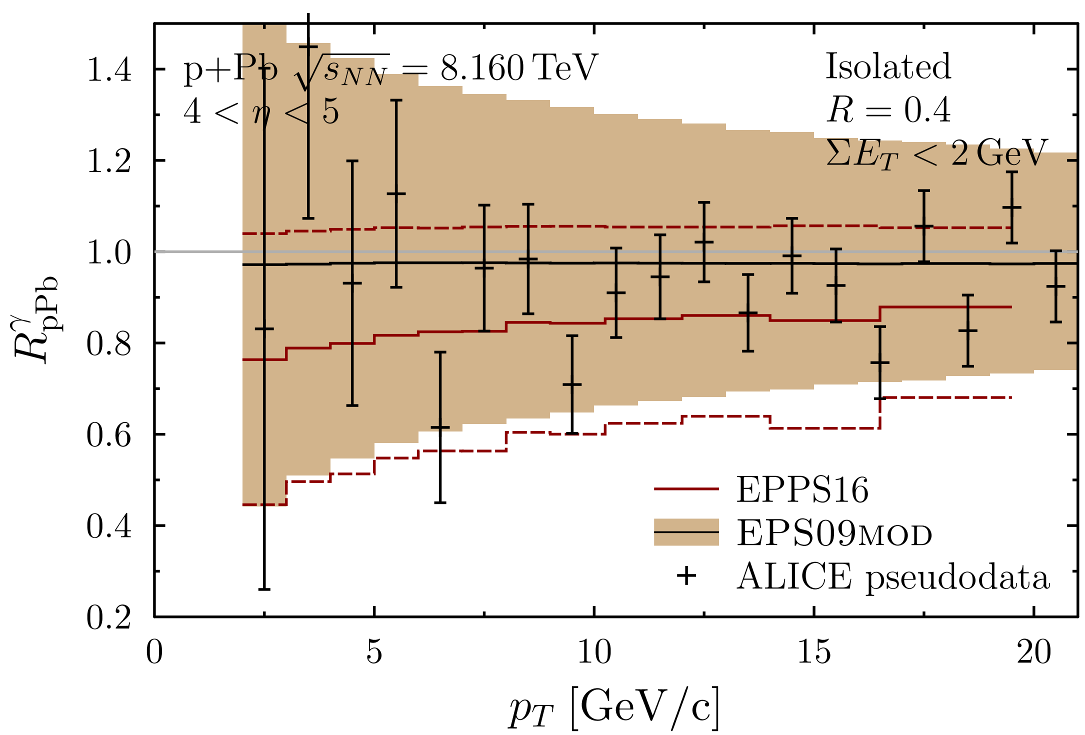
2. show invalidity of linear QCD at low *x*

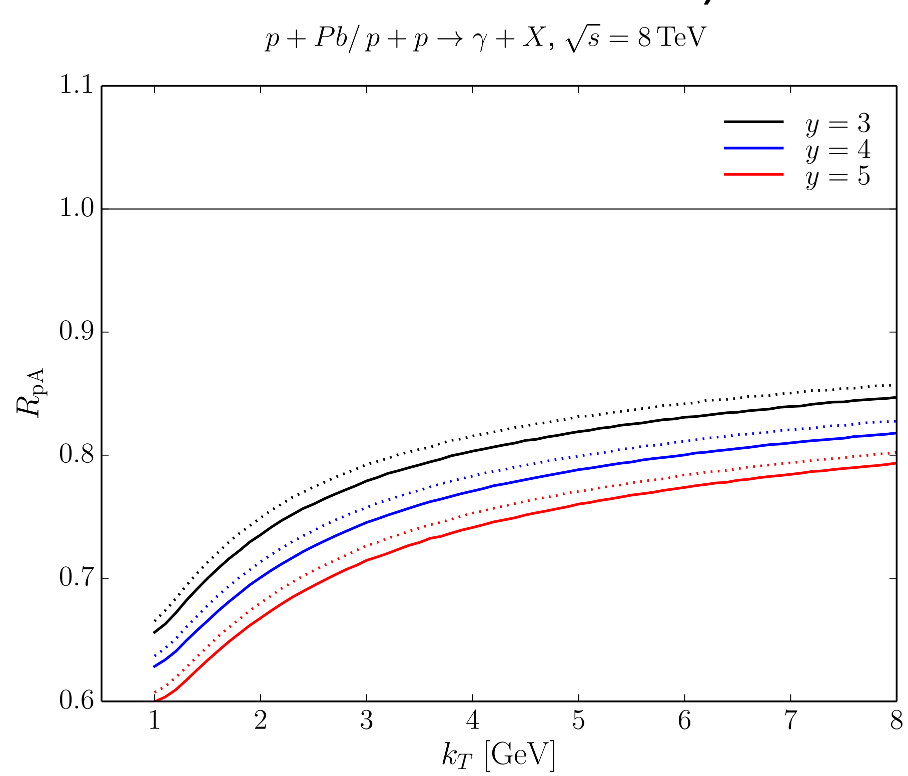
- can all potential measurement outcomes be absorbed in a modified PDF?

3. constrain the PDFs at low x

- nuclei, also protons

- main observable: nuclear modification factor R_{pA} of direct photons
  - saturation stronger in nuclei
  - possibly non-existent in protons (calculation of reference in models?)

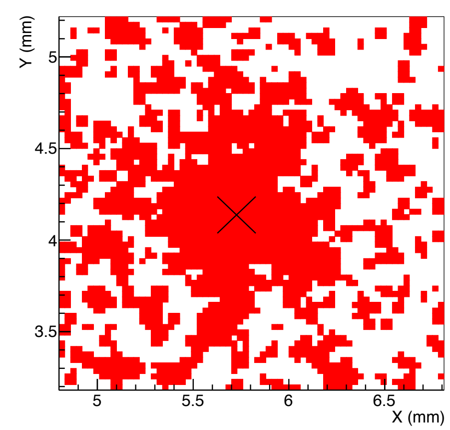




CGC Calculation:
Ducloué, Lappi, Mäntysaari, arXiv:1210.02206

R&D for FoCal
Developing an Extremely Granular Calorimeter

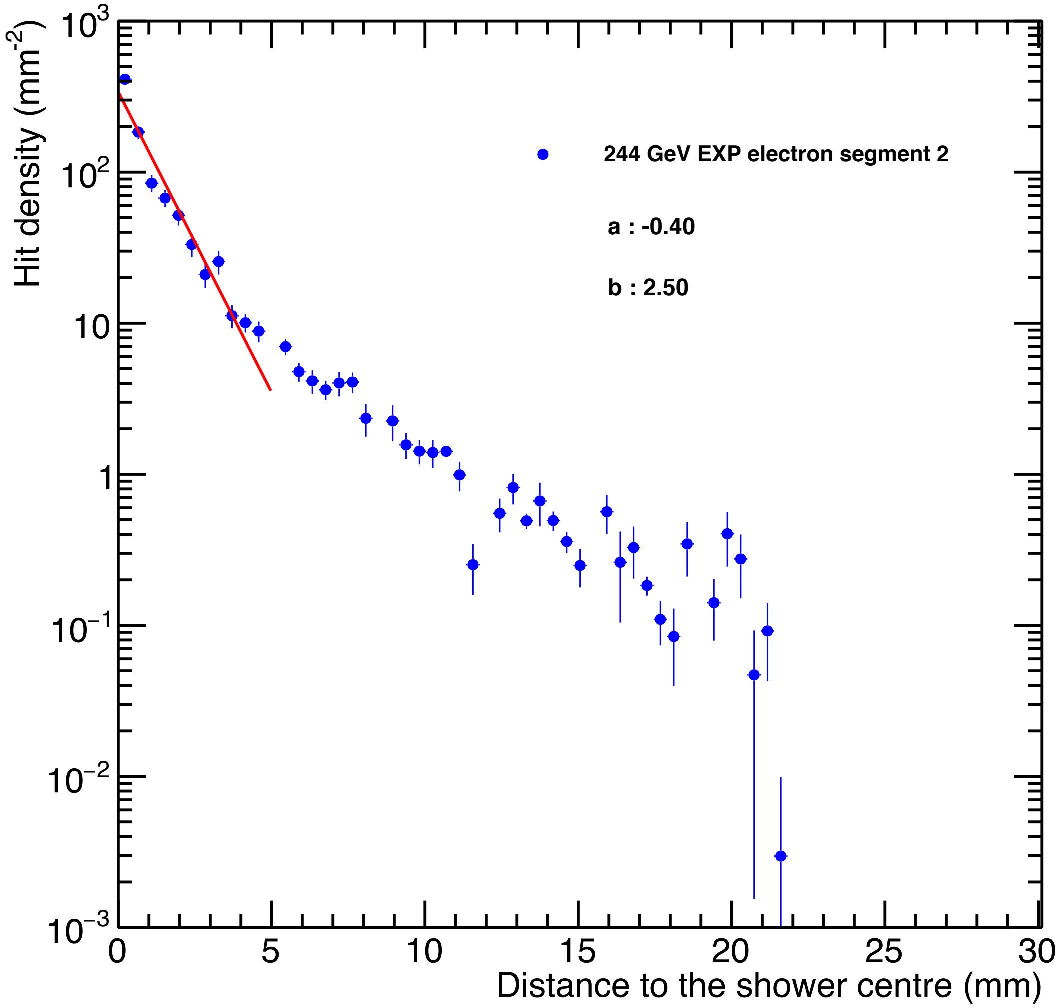
~ CMS-HGCAL
pad size ($0.5 cm^2$)



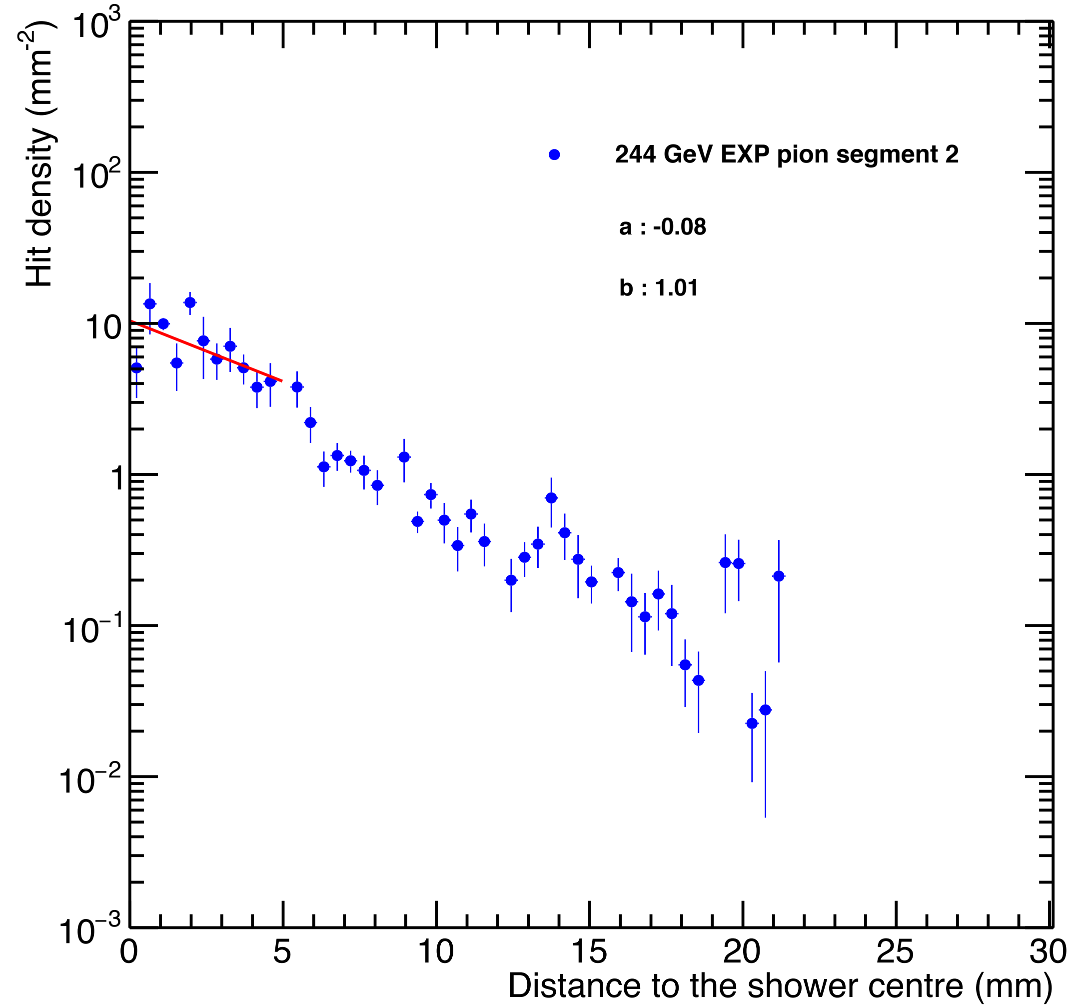
single electron shower
measurement (244 GeV)
in CMOS sensor

Pixel (HGL) R&D Results: Single Event Profiles

electron



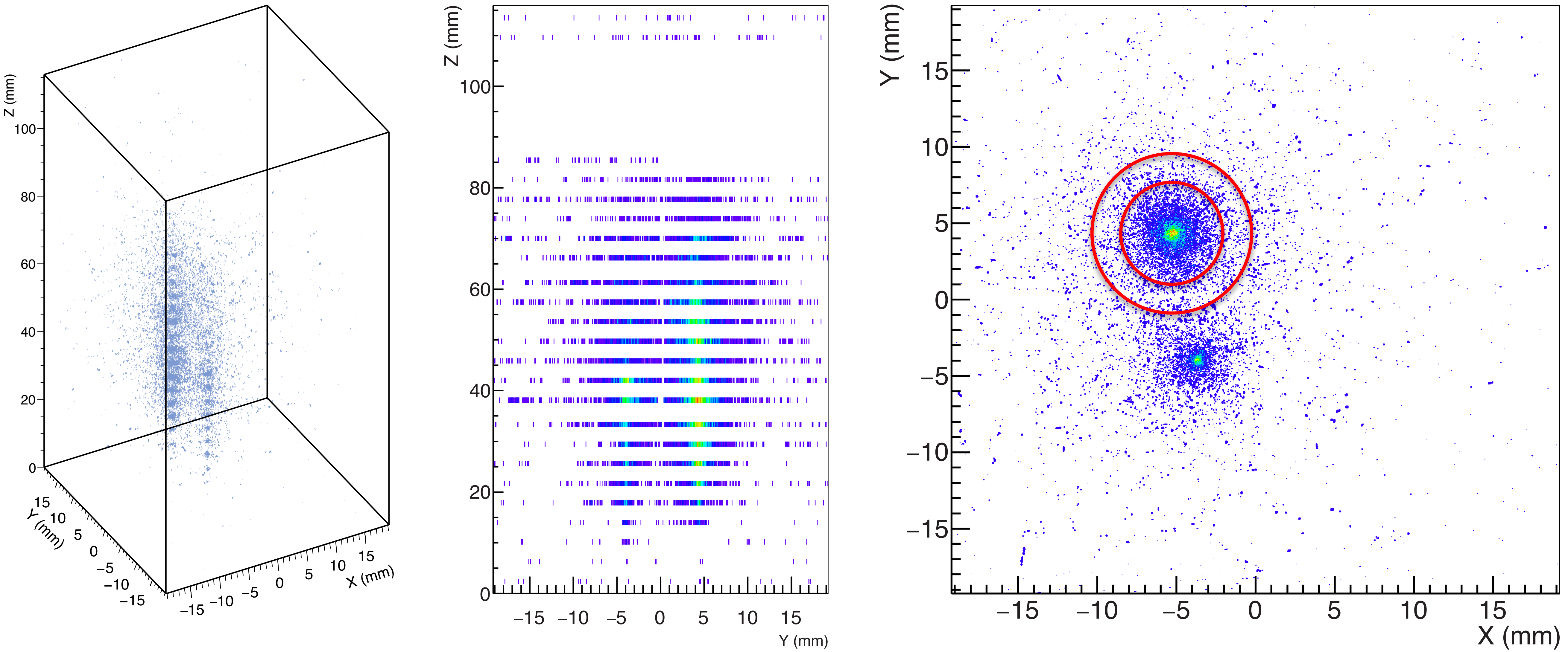
pion



electron showers have well defined profile, very narrow shower core
pion showers show much larger fluctuation, often much wider

Two Shower Separation

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



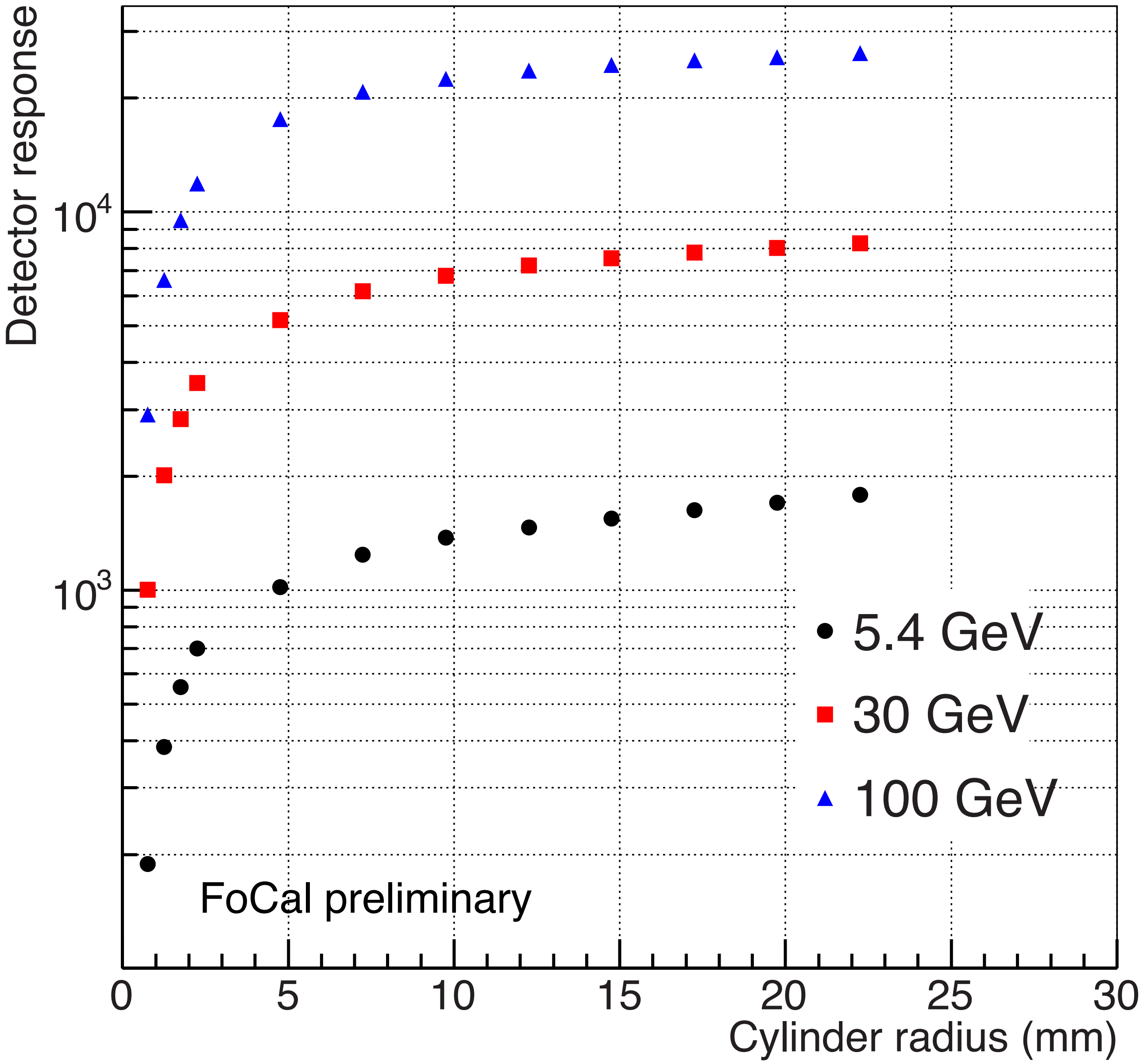
evaluate separation capability: core energy

calculate shower energy in cylinder of finite radius

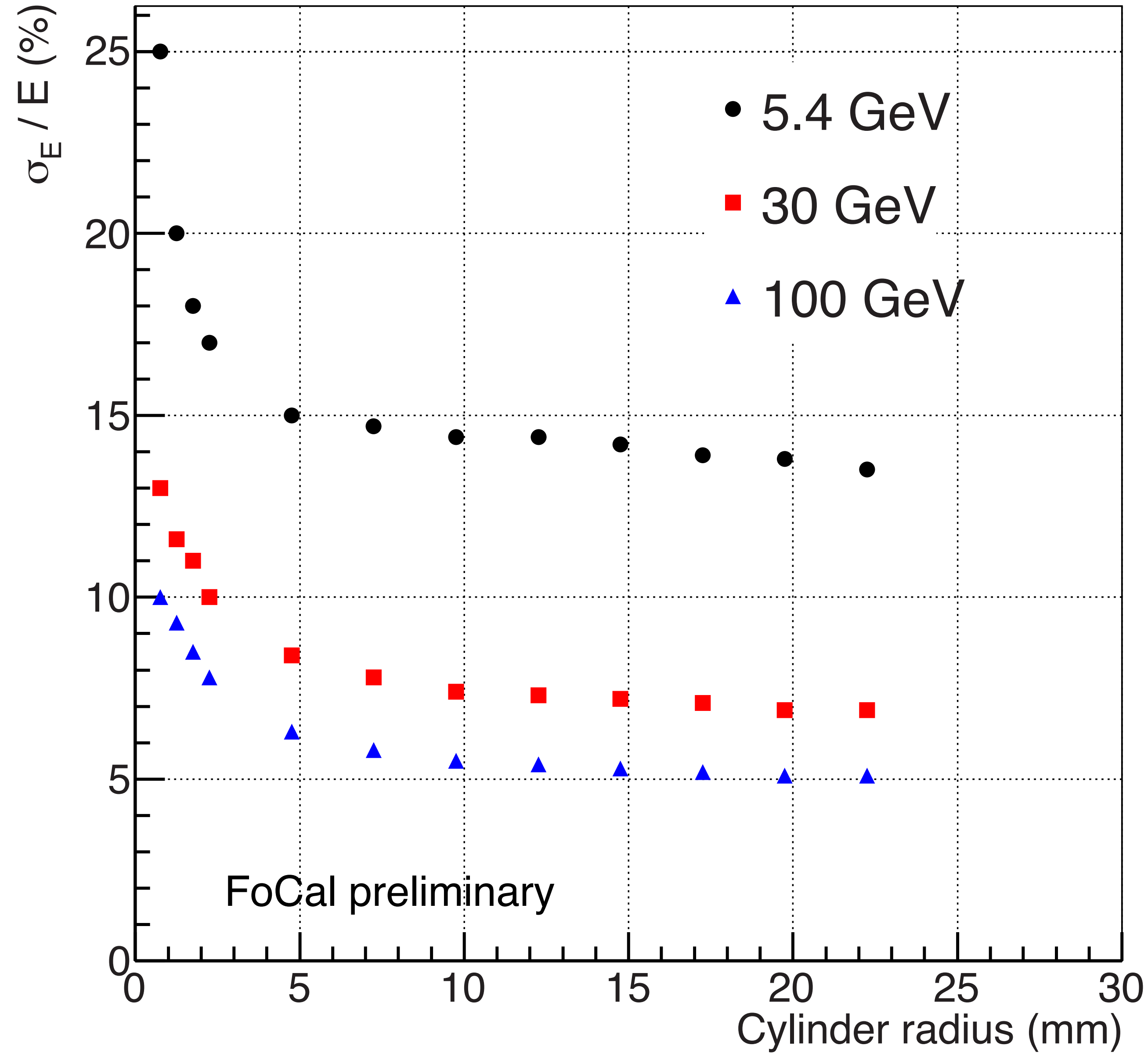
study as function of radius

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 = 5mm:
adequate for very high particle density