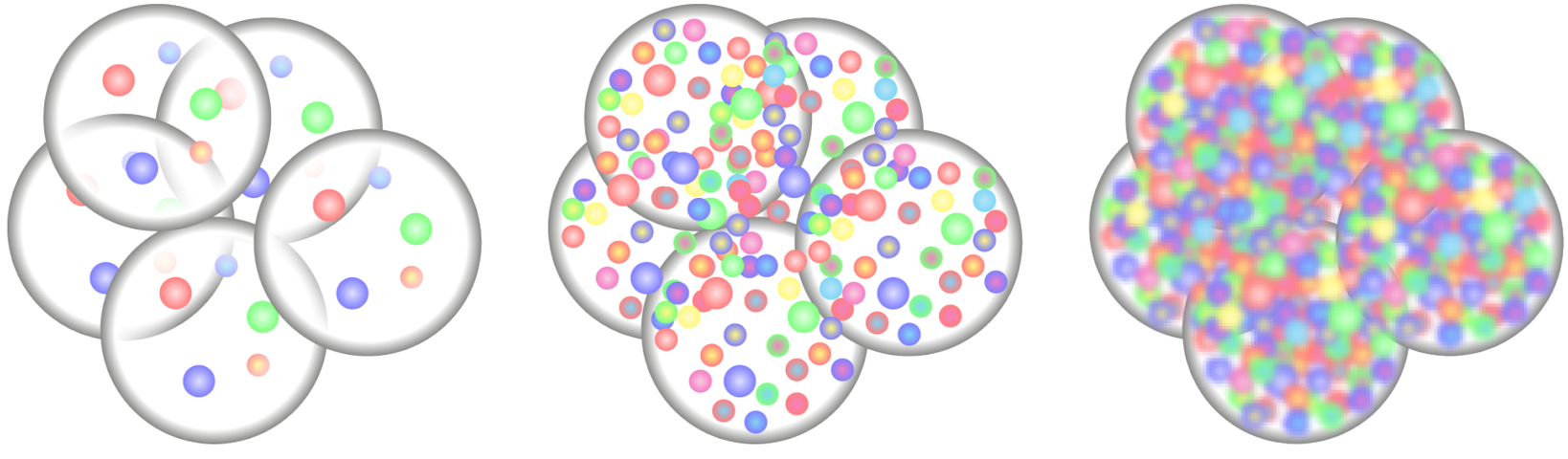
FoCal Physics Case I: Studies of the Initial State in pp and p–A



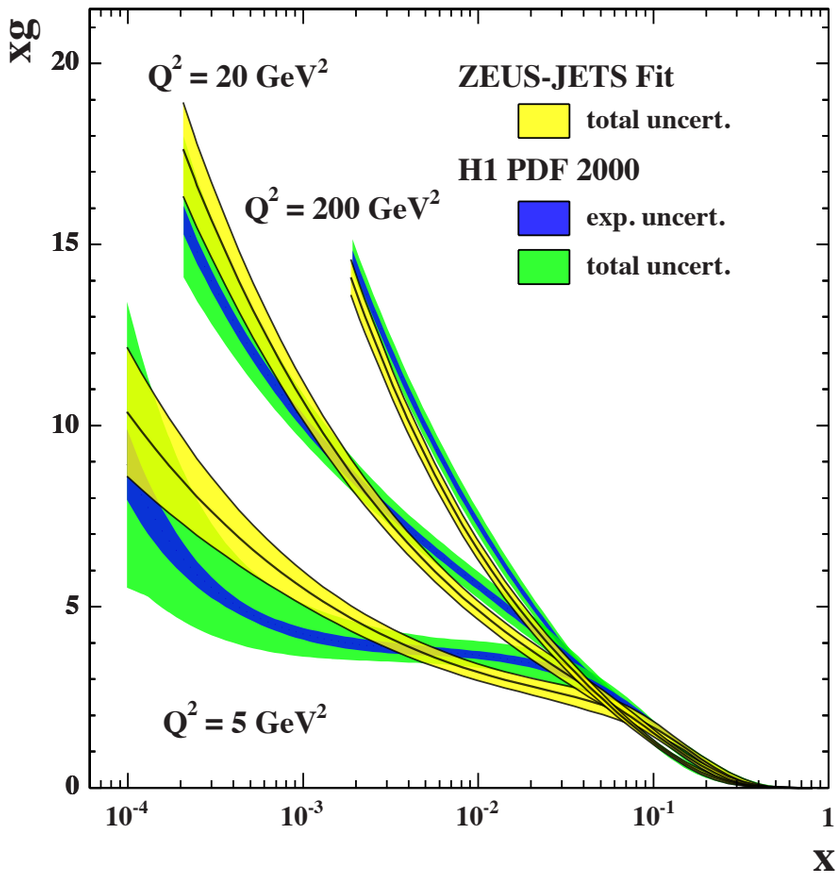
T. Peitzmann (Utrecht University/Nikhef)

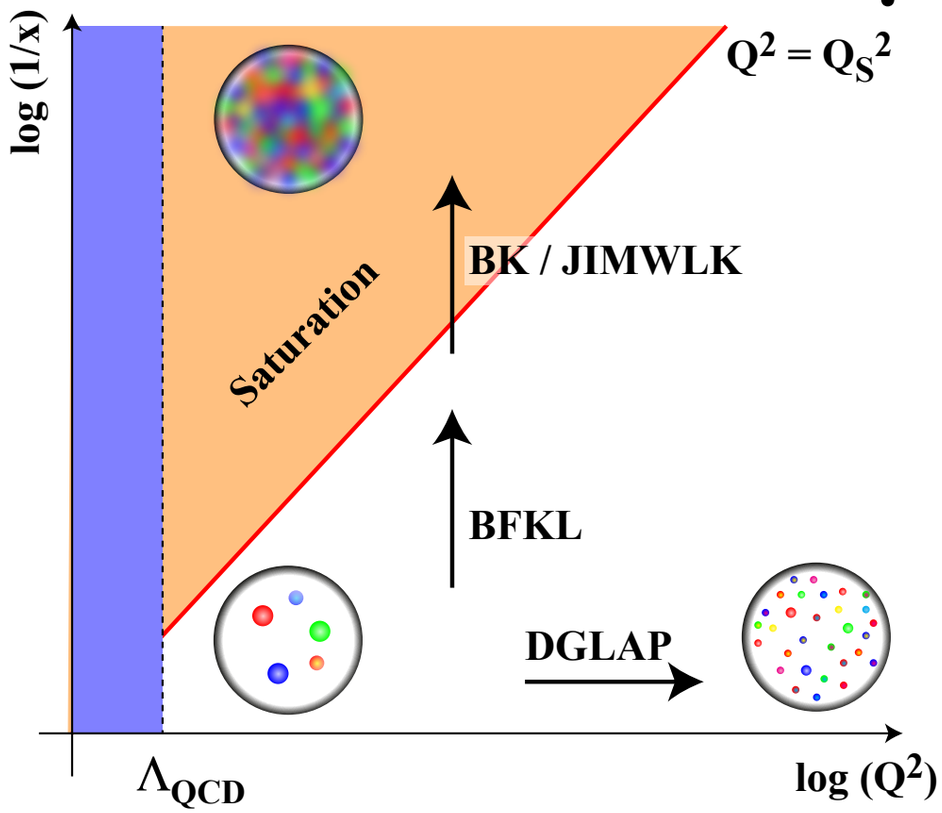
International Workshop on Forward Physics and Forward Calorimeter Upgrade in ALICE, Tsukuba, 07.03.2019

Outline

- Introduction: low-*x* PDFs and gluon saturation
- PDF studies in pA with photons
  - *x*-sensitivity: photons and competitors
  - FoCal perfomance
- Other physics studies
  - correlations
  - PDFs in pp, large *x*

PDFs and Gluon Saturation

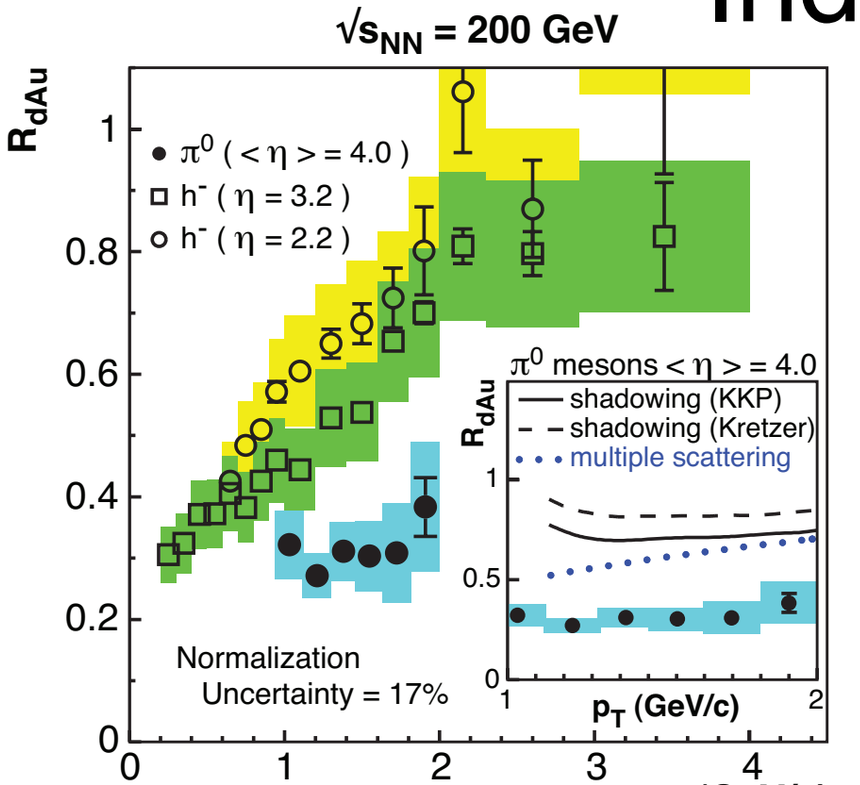




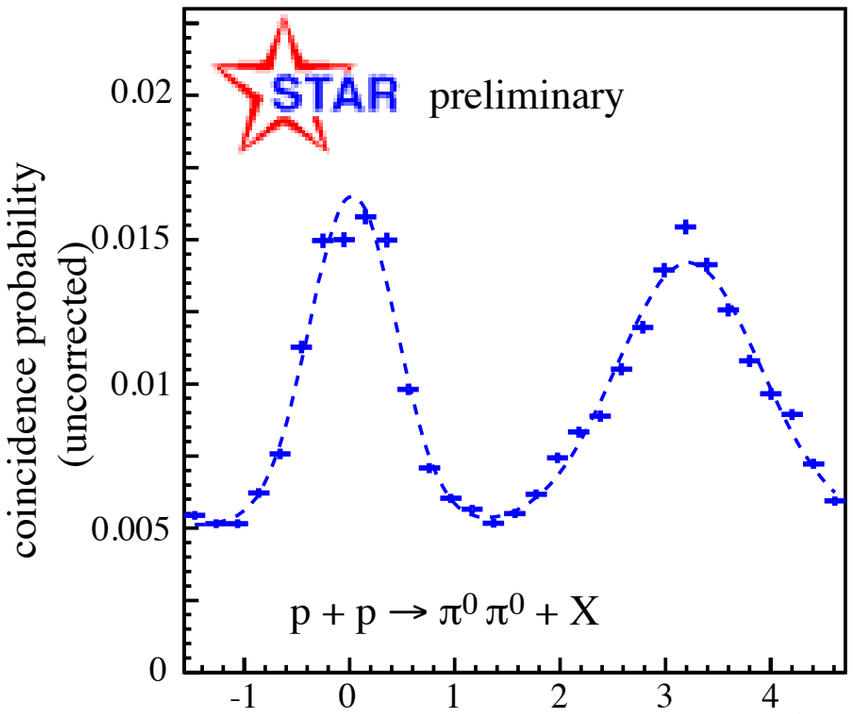
- from evolution equations (DGLAP, BFKL):
  - gluon density increases with Q^2 and 1/x
    - leads to very high gluon density
    - problems with unitarity
- for high density non-linear processes become important
- gluon saturation below saturation scale
  - enhanced in nuclei

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

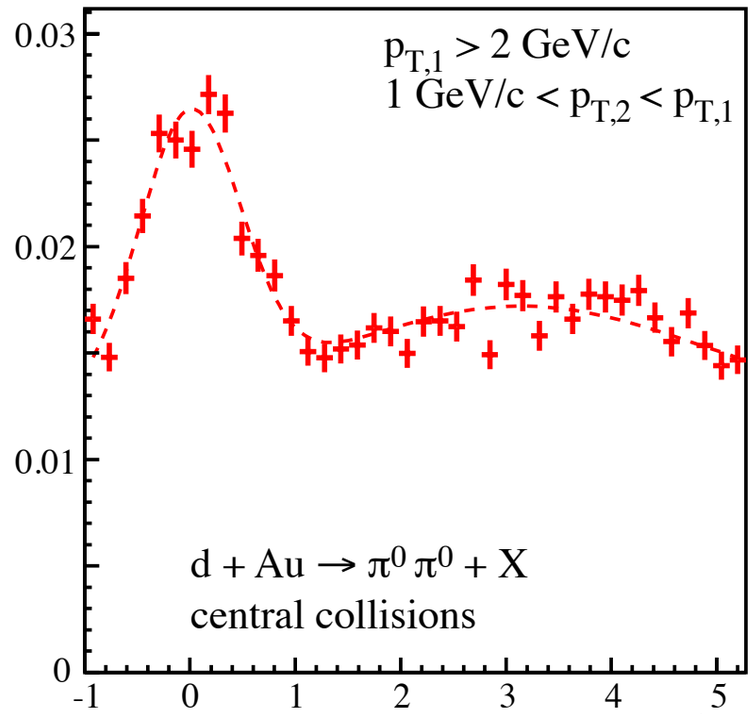
Indications from RHIC



STAR, PRL97, 152302



STAR, Braidot, Ogawa et al.



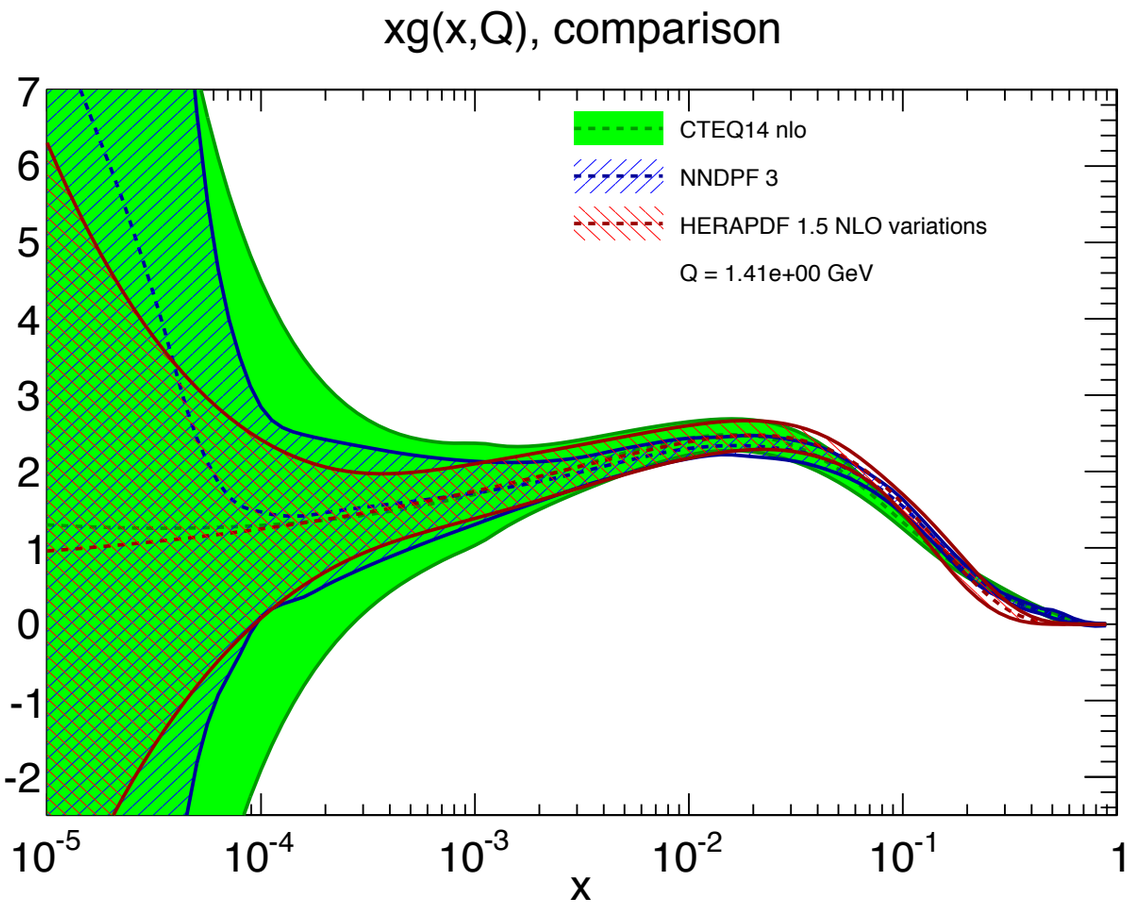
R_{dA}: strong suppression of hadron yield at forward rapidity

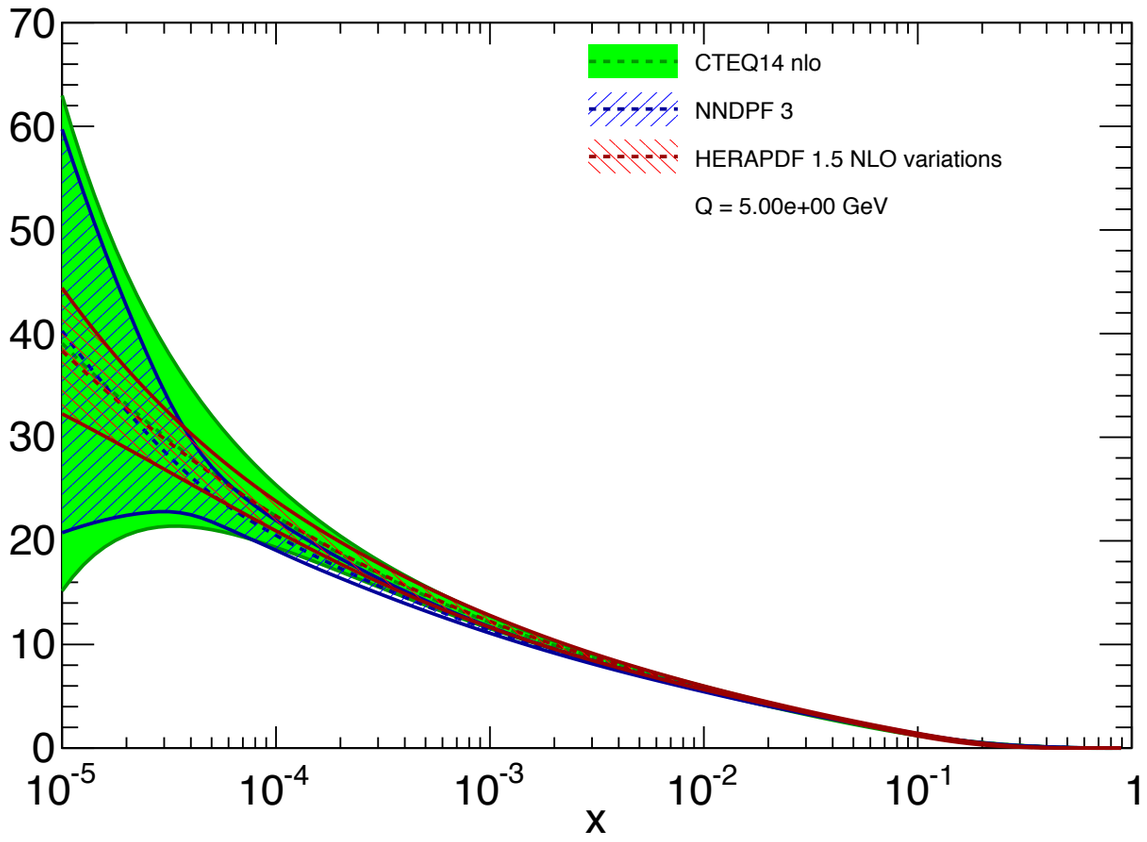
di-hadron correlations: broadening/suppression of away-side peak in dAu

$$R_{\mathrm{dA}} = \frac{dN/dp_{\mathrm{T}}(dA)}{\langle N_{\mathrm{coll}}(dA)\rangle\, dN/dp_{\mathrm{T}}(pp)}$$

- 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)

Uncertainties in Proton PDFs

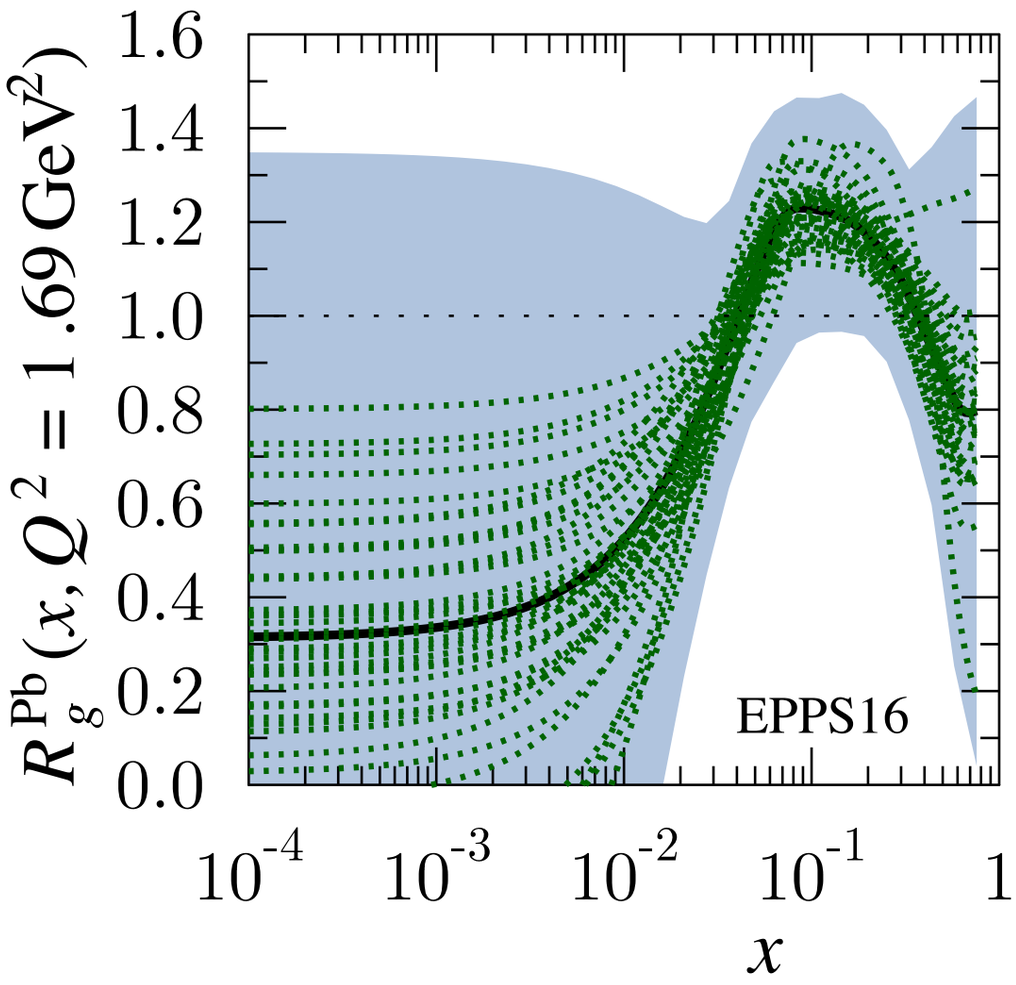


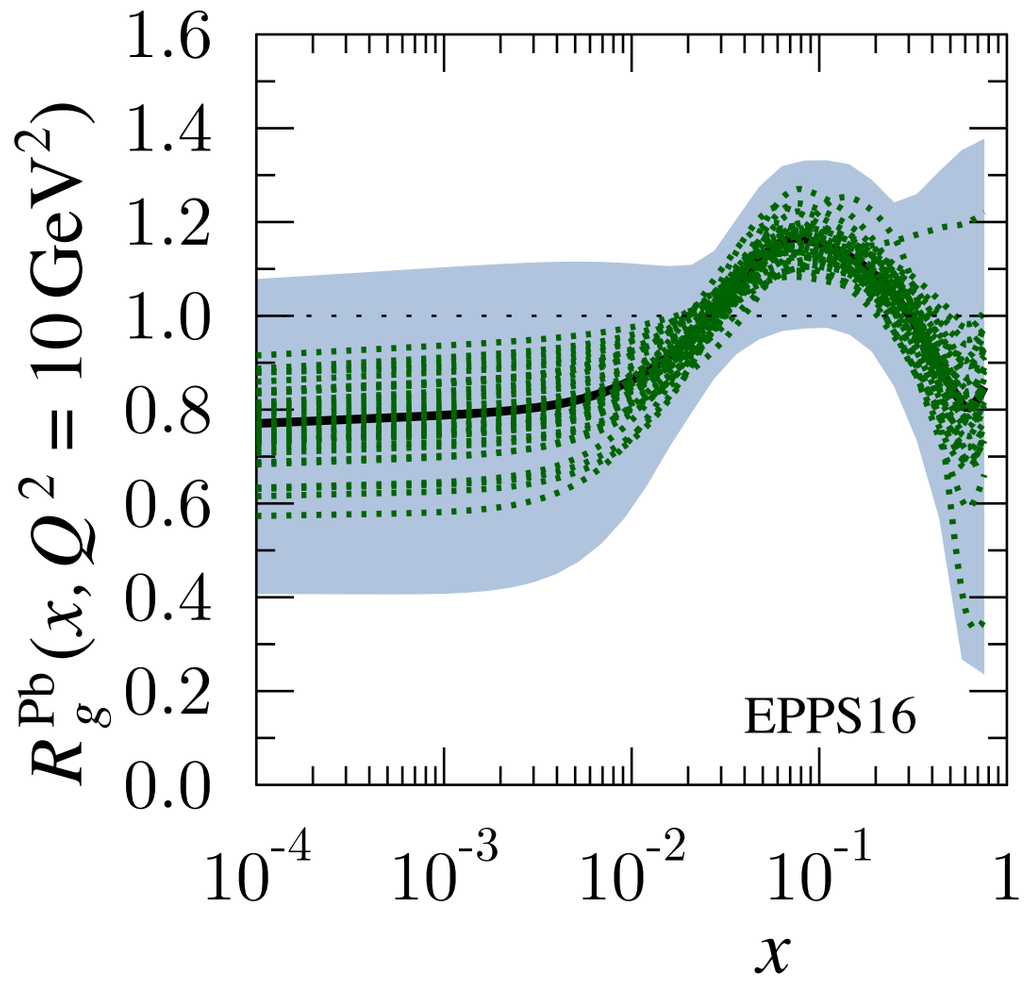


- large uncertainties of gluon PDFs for $x < 10^{-4}$
- relative uncertainty reduces for larger Q^2
  - contribution of “gluon radiation” off better constrained medium-x partons
  - relies on linear evolution (DGLAP)

Uncertainties in Nuclear PDFs

EPPS16, EPJC 77, 163



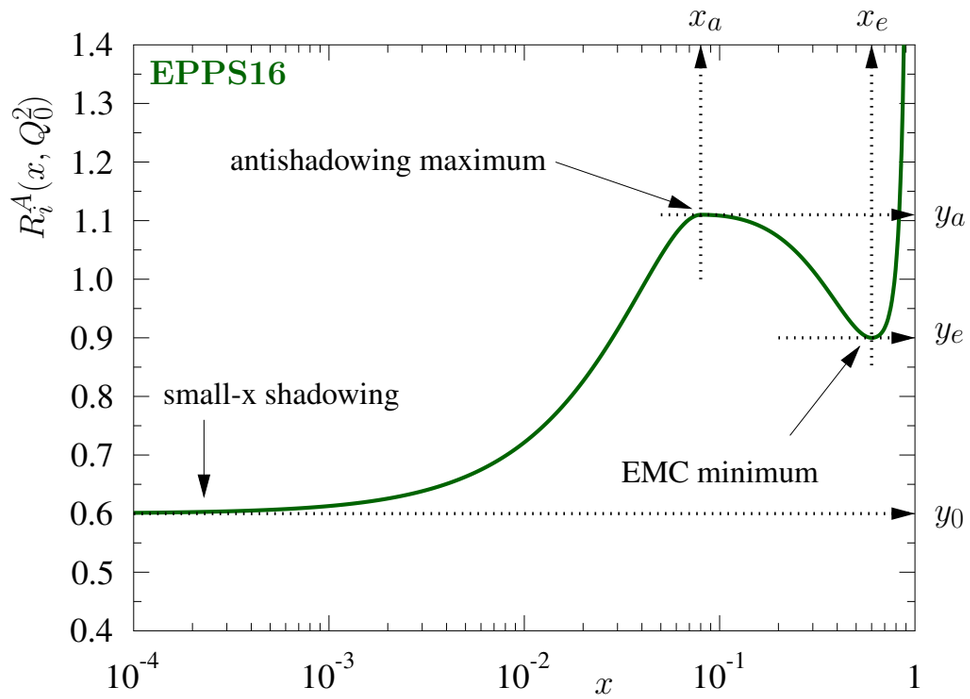


- large uncertainties of nPDFs
  - parameterised nuclear modification
  - recently updated to allow more freedom (e.g. flavour dependence)
- x-dependence?
  - very little dependence for $x < 10^{-2}$

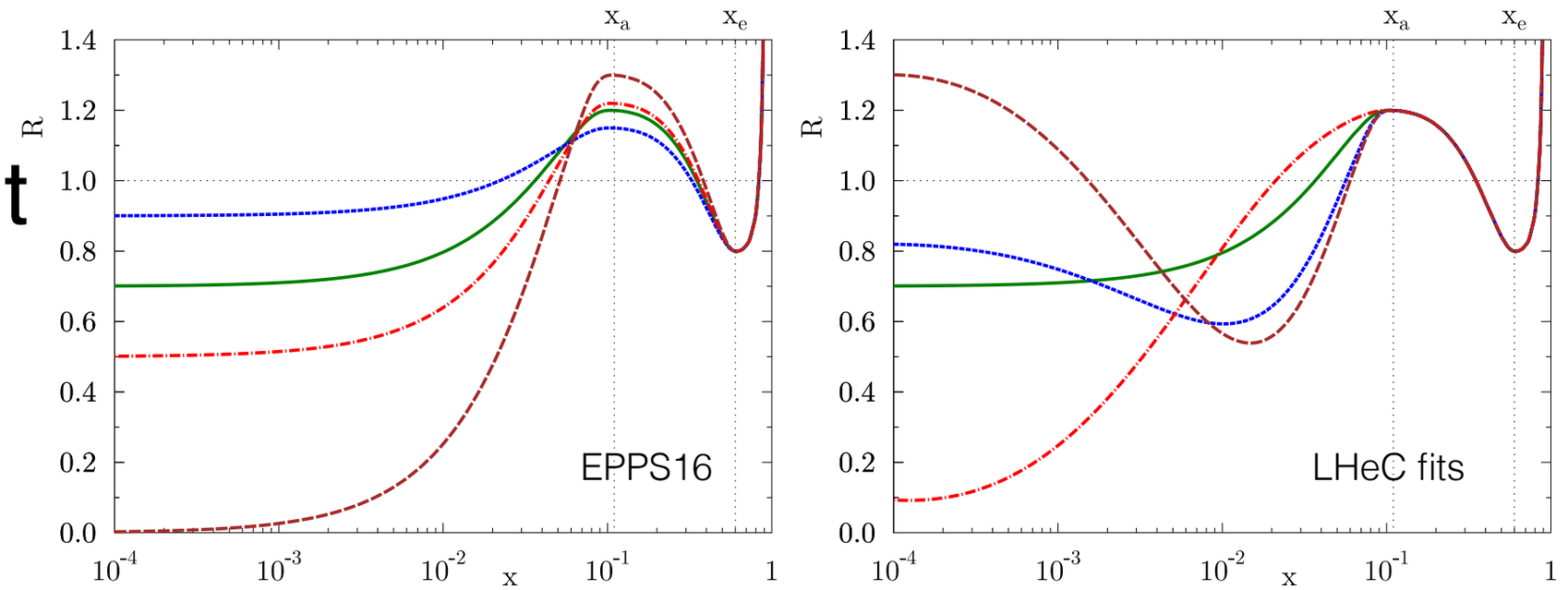
x-Dependence of PDF modification

EPPS16, EPJC 77, 163

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



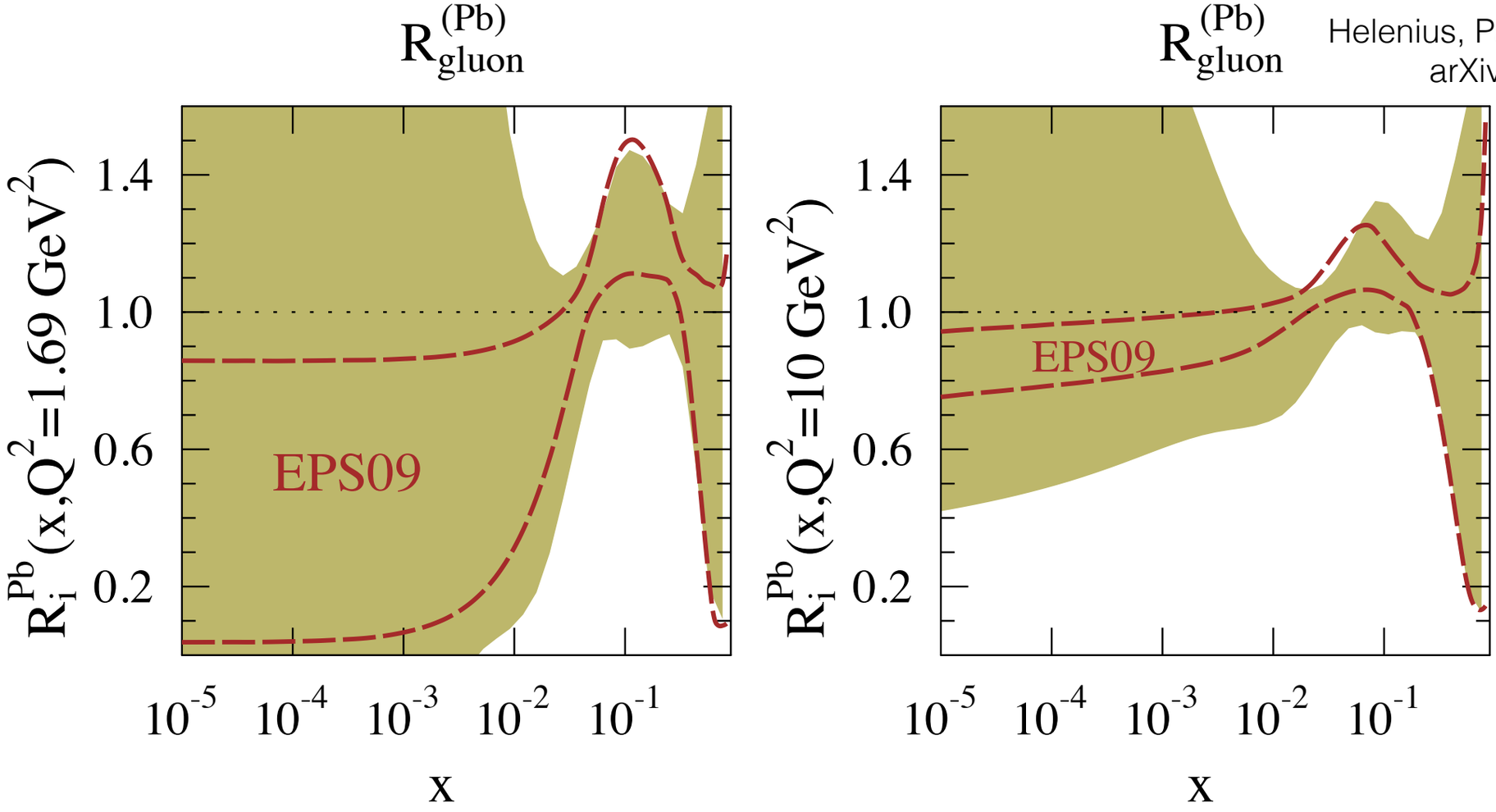
- parameterisation of R_A
  - shape similar to EPS09
  - at low x leads to “plateau” in log(x)
- likely not sufficient
  - more flexible PDF used for LHeC estimates



Helenius, Paukkunen, Armesto, arXiv:1606.09003

Uncertainties in Nuclear PDFs

Helenius, Paukkunen, Armesto, arXiv:1606.09003



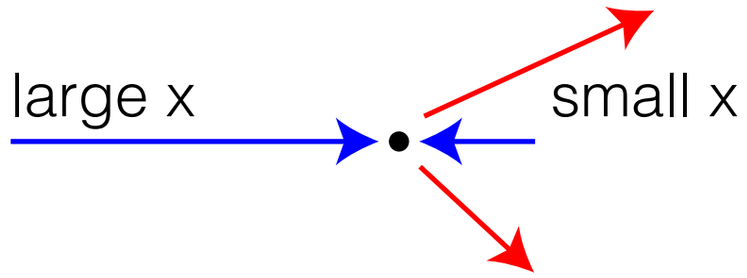
- still larger uncertainties (also compared to EPPS16)
  - due to larger shape flexibility of parameterisation
- likely a more reasonable assumption
  - last words?

Accessing small x – Kinematics

- for 2 → 2 process (LO on parton level):

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp\left(\pm\frac{y_3 + y_4}{2}\right)$$

  - forward rapidity selects small x
  - advantage for exclusive measurement



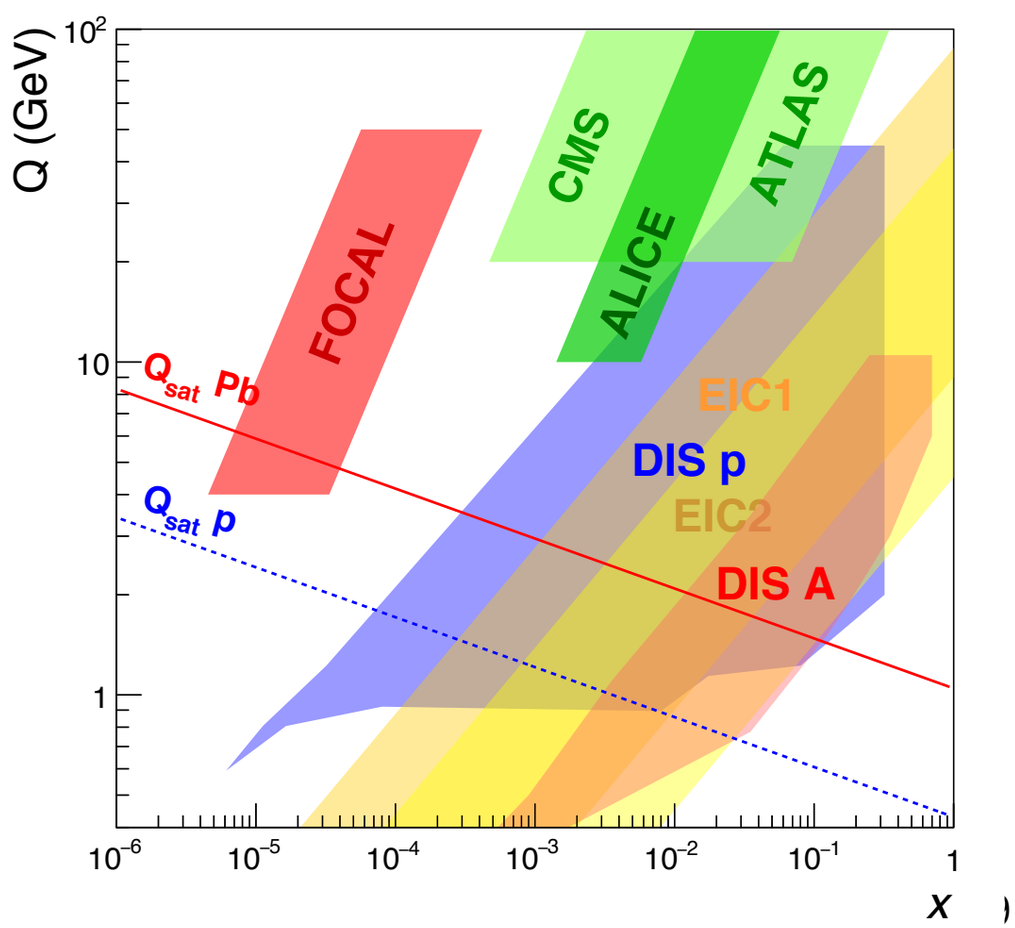
- for singles assume:

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

  - valid for jets (large m_T) and photons
  - for hadrons take fragmentation into account!

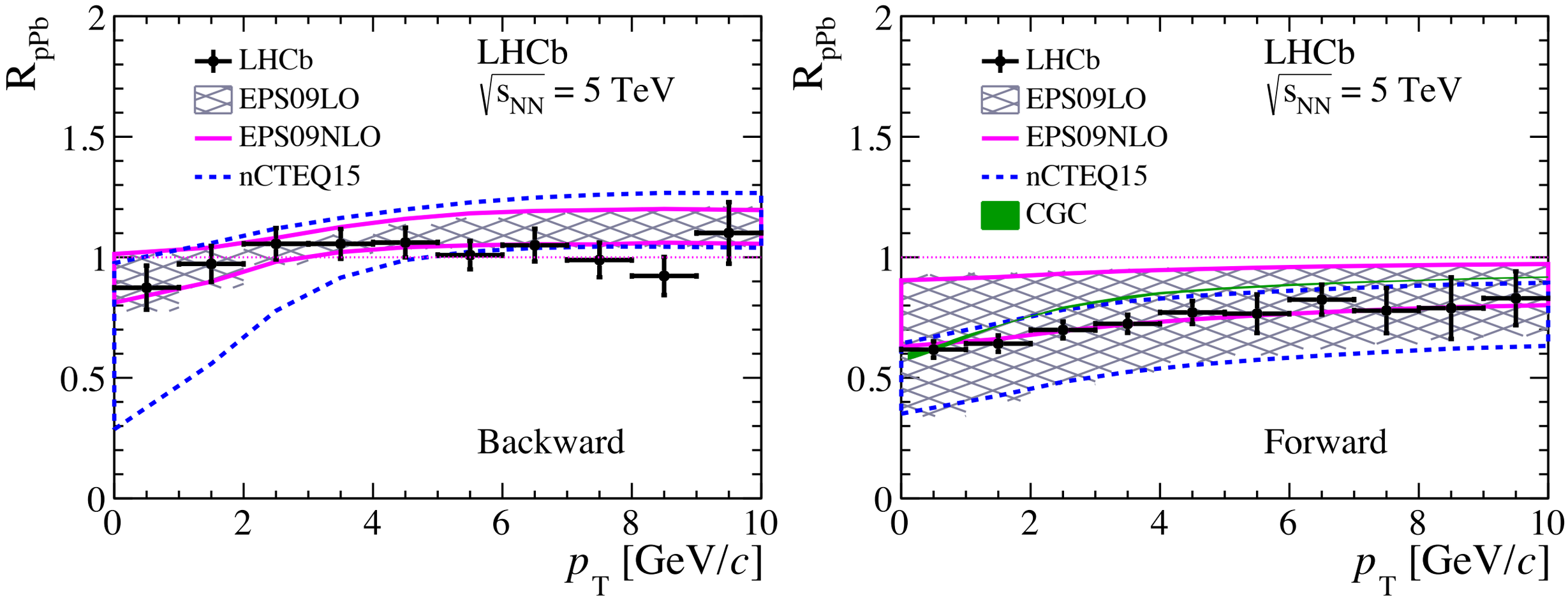
- further modification via higher order contributions
  - significant at LHC
- limited data so far!

EM probes - kinematic coverage



LHCB, JHEP 10 (2017) 090

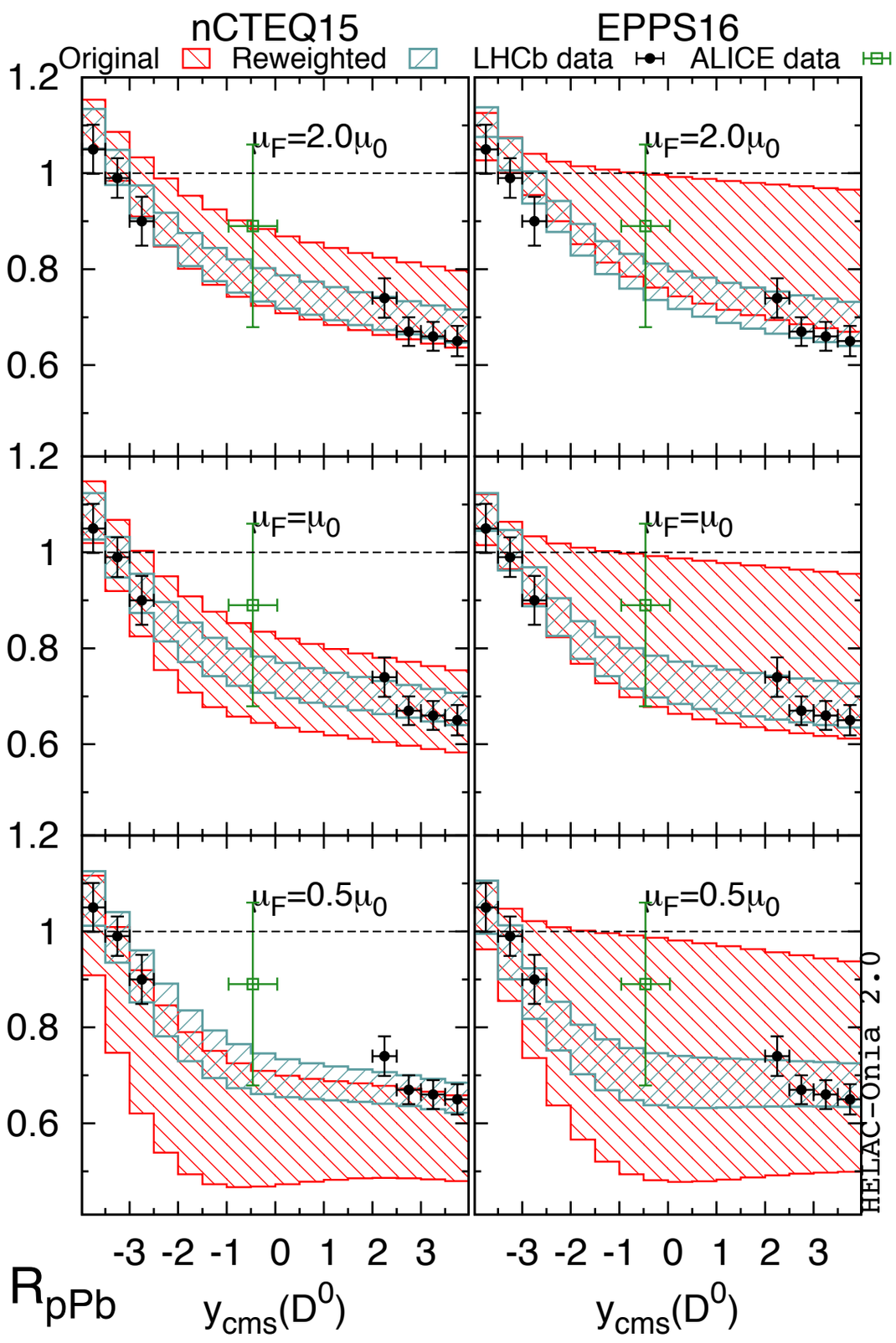
Results from p-Pb at LHC (2)



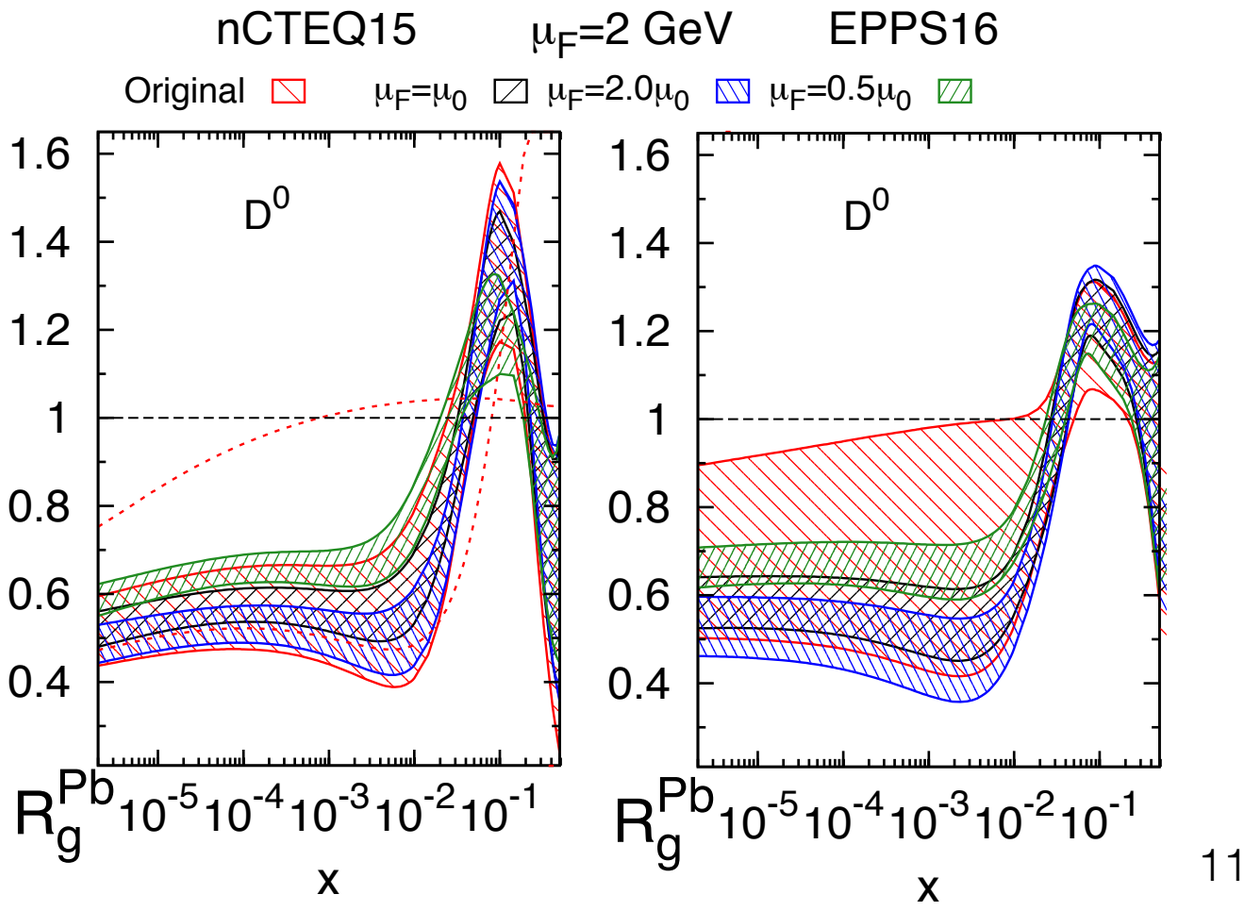
- prompt D^0 suppressed at forward rapidity
  - consistent with pQCD + shadowing (EPS09)
  - also consistent with CGC calculation

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?

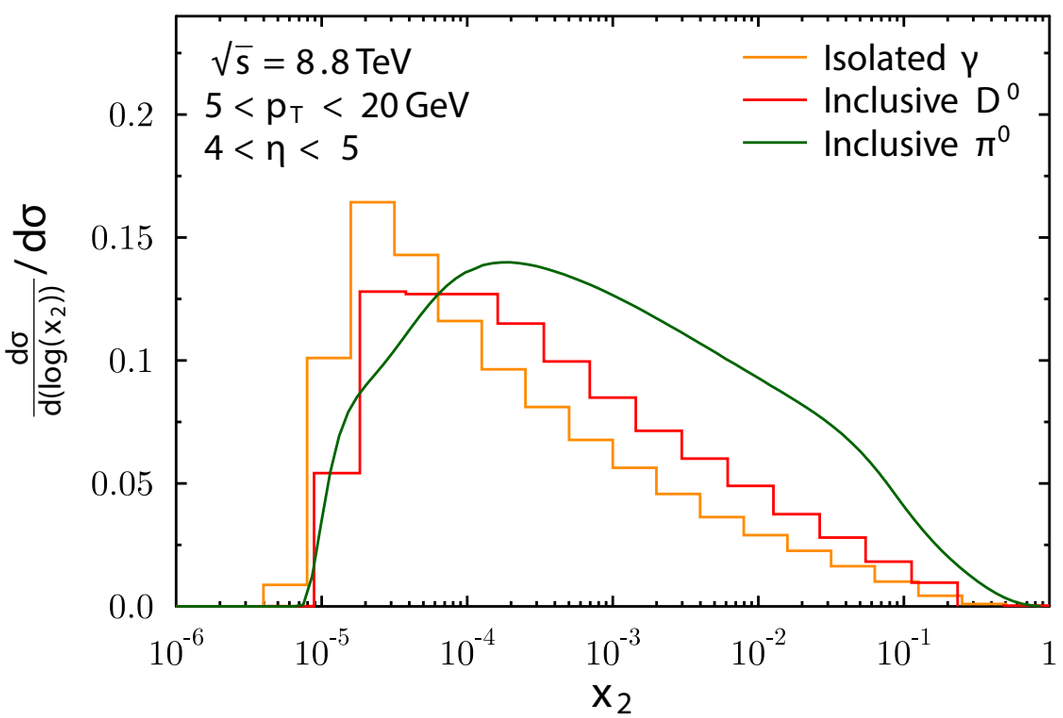
	$\sqrt{s}\,(\mathrm{TeV})$	y	$p_T\,(\mathrm{GeV}/c)$	z	x_2
π	0.2	4	2	0.3	$1.2 \cdot 10^{-3}$
π	8.8	0	2	0.3	$1.5 \cdot 10^{-3}$
jet	8.8	4	20	1	$8.3 \cdot 10^{-5}$
π	8.8	4	2	0.3	$2.8 \cdot 10^{-5}$
D	8.8	4	0	0.5	$1.5 \cdot 10^{-5}$
γ	8.8	4	4	1	$1.7 \cdot 10^{-5}$
γ	8.8	4.5	4	1	$1.0 \cdot 10^{-5}$

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

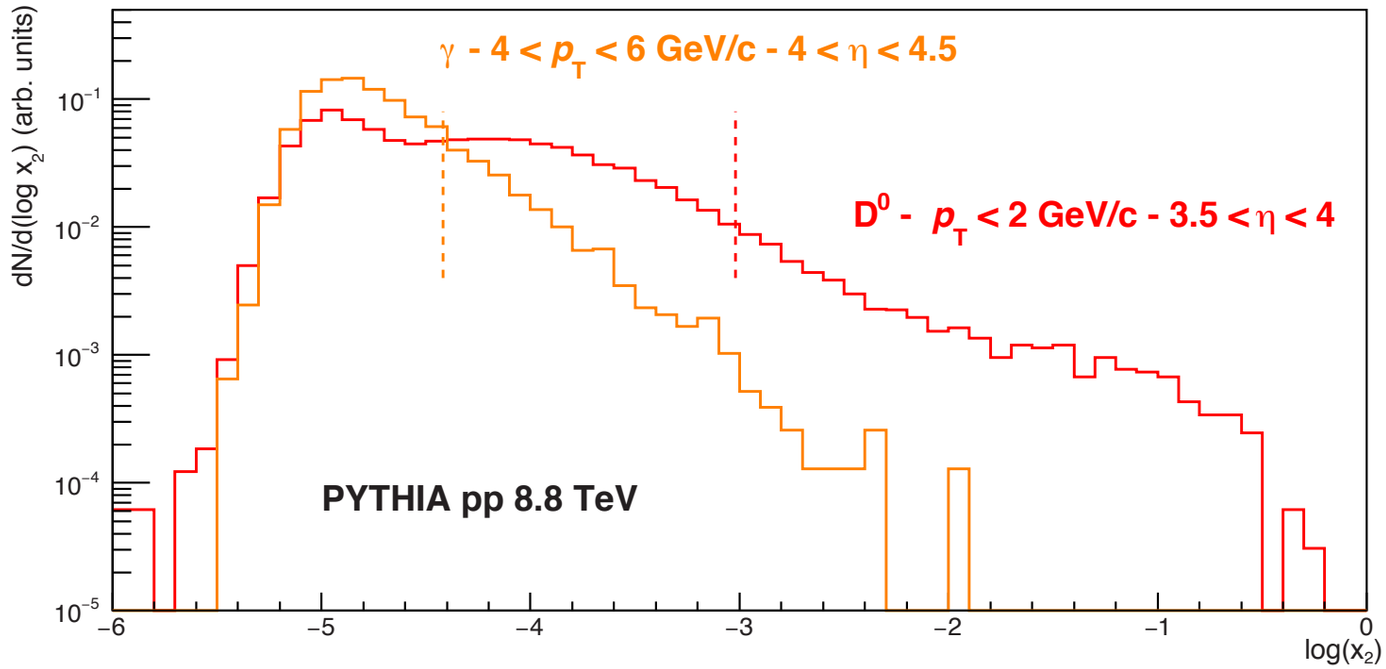
- LO kinematics estimates provide rather lower limit for x_2
- but: higher orders contribute significant tail towards large x_2

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

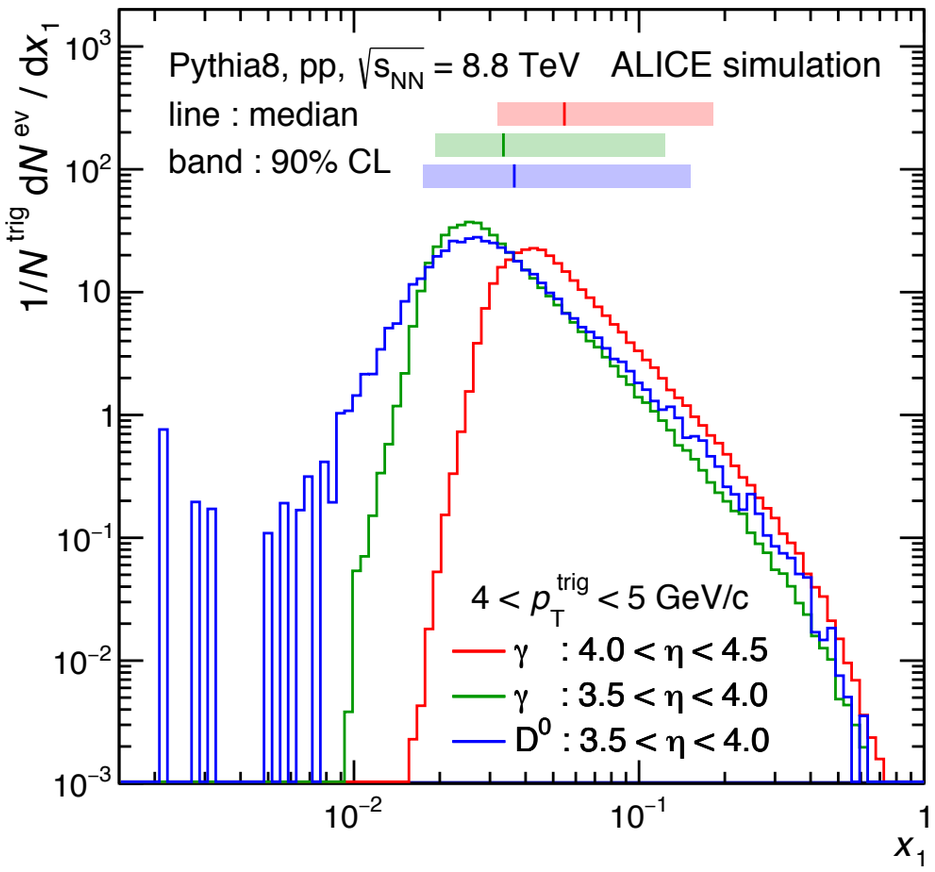
- *x*-distributions from NLO pQCD



- *x*-distributions from PYTHIA



no analytical approximation, taking into account η of recoil parton

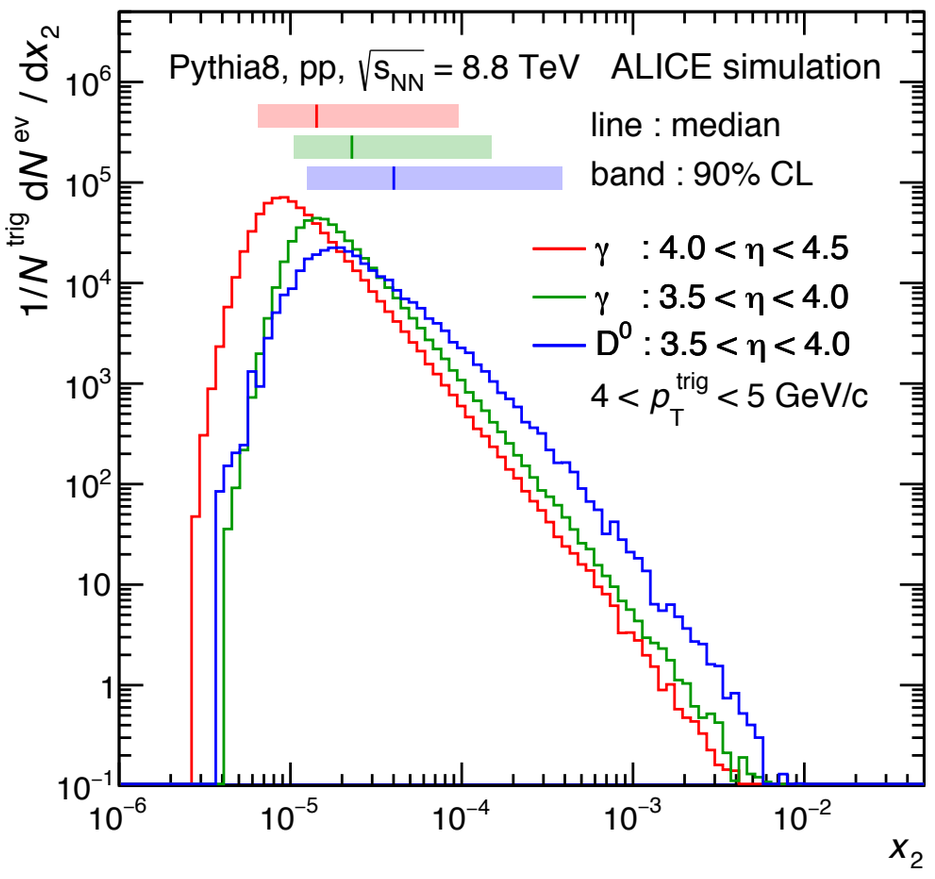


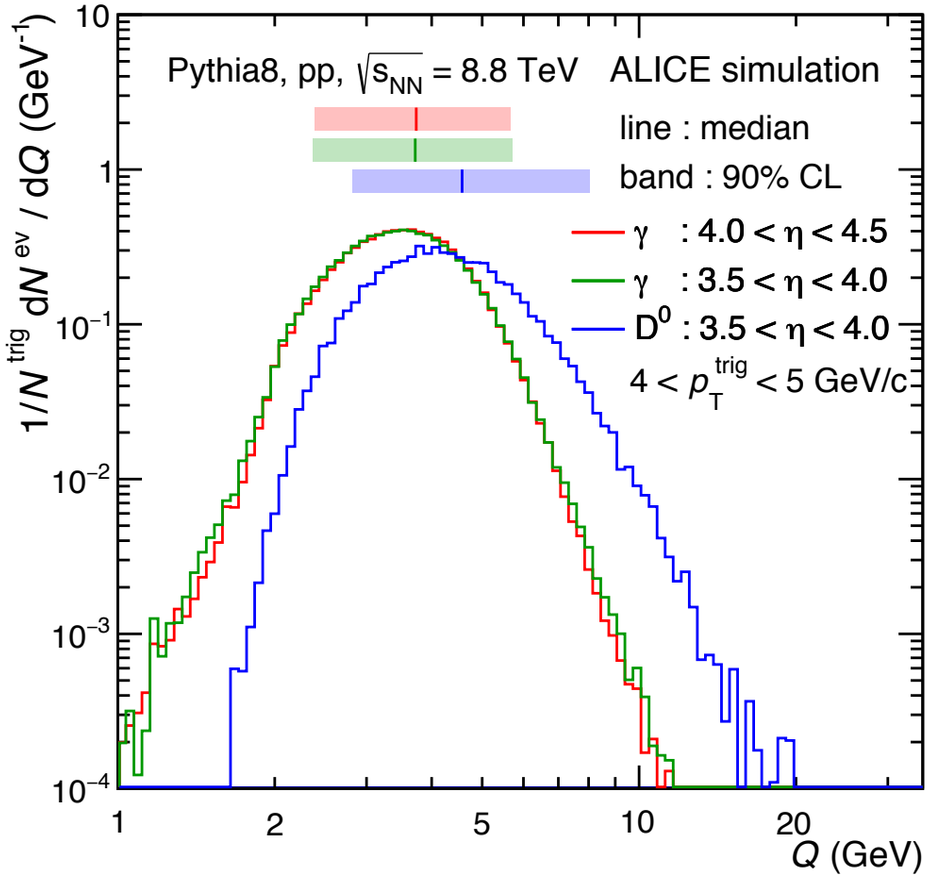
x-Q^2-Sensitivity

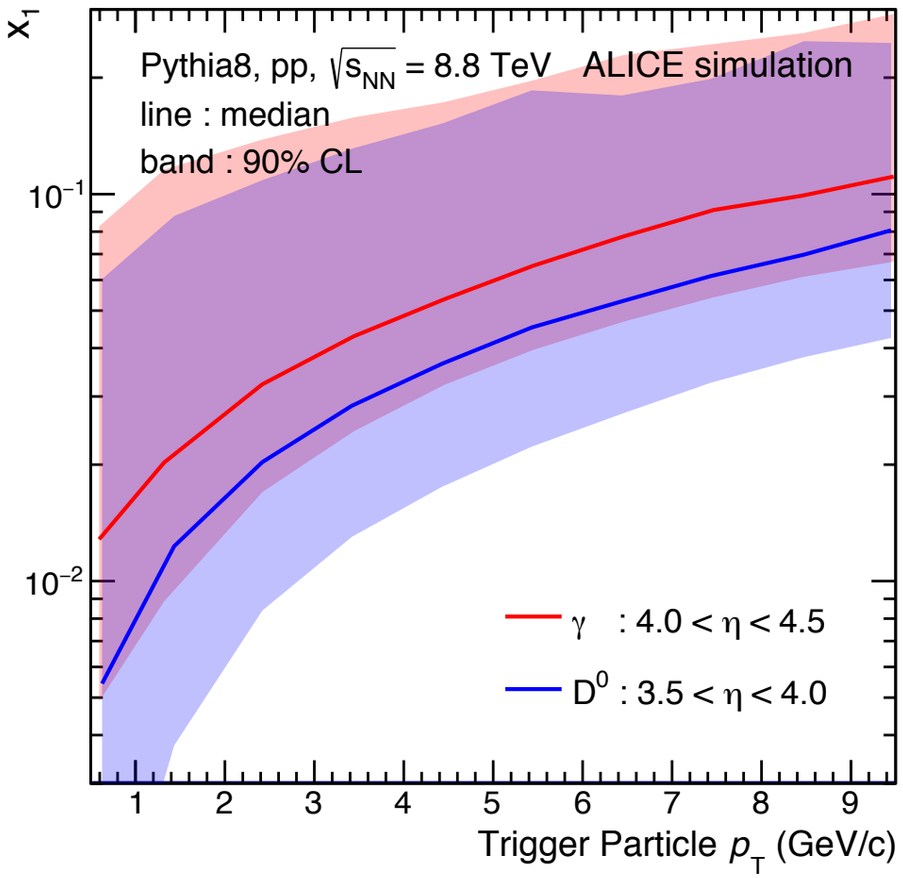
PYTHIA pp 8.8TeV
forward measurements

LHCb D0 vs FoCal photons

study median of distribution and
90% confidence level limits







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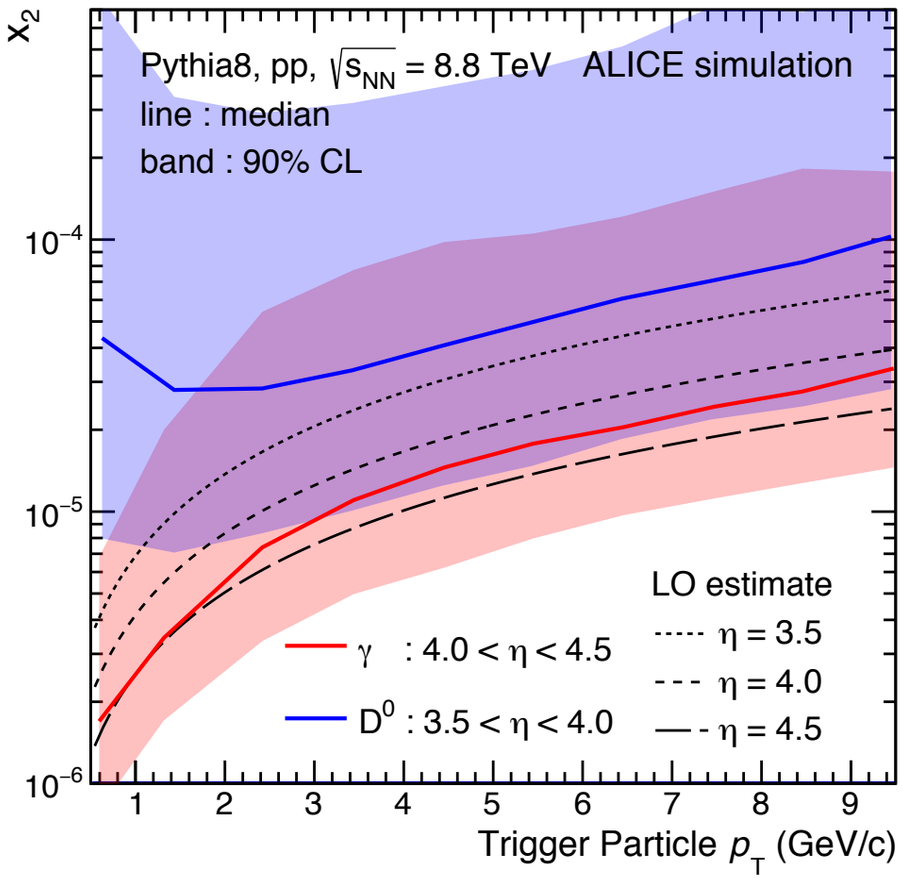
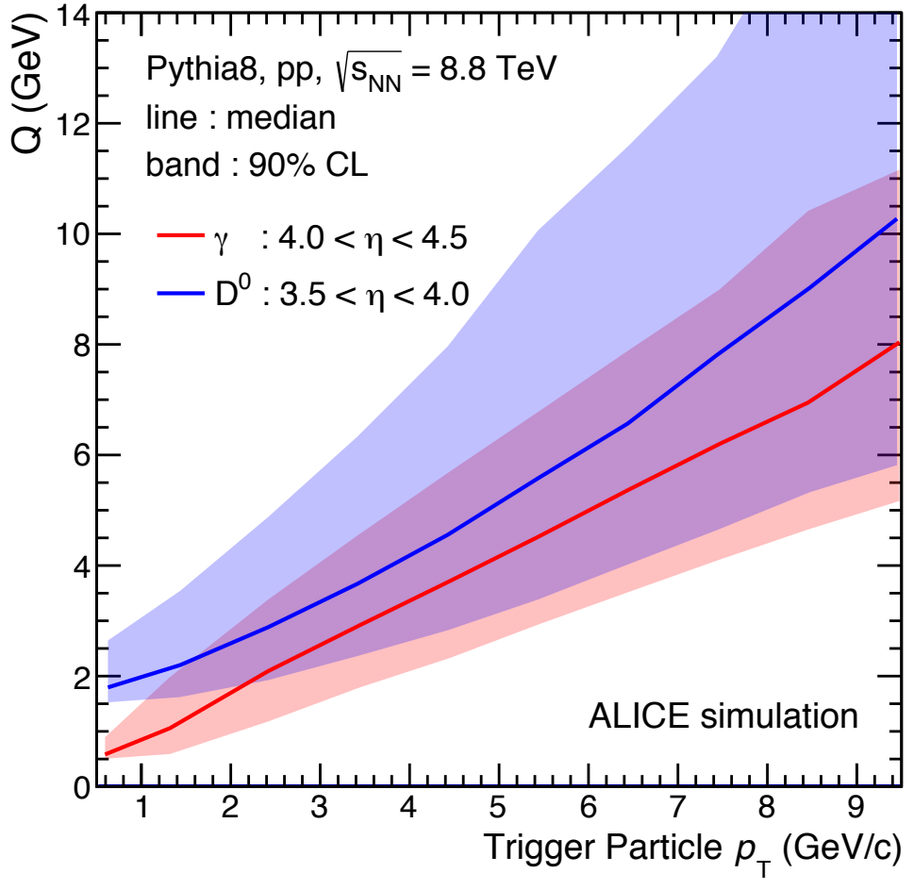
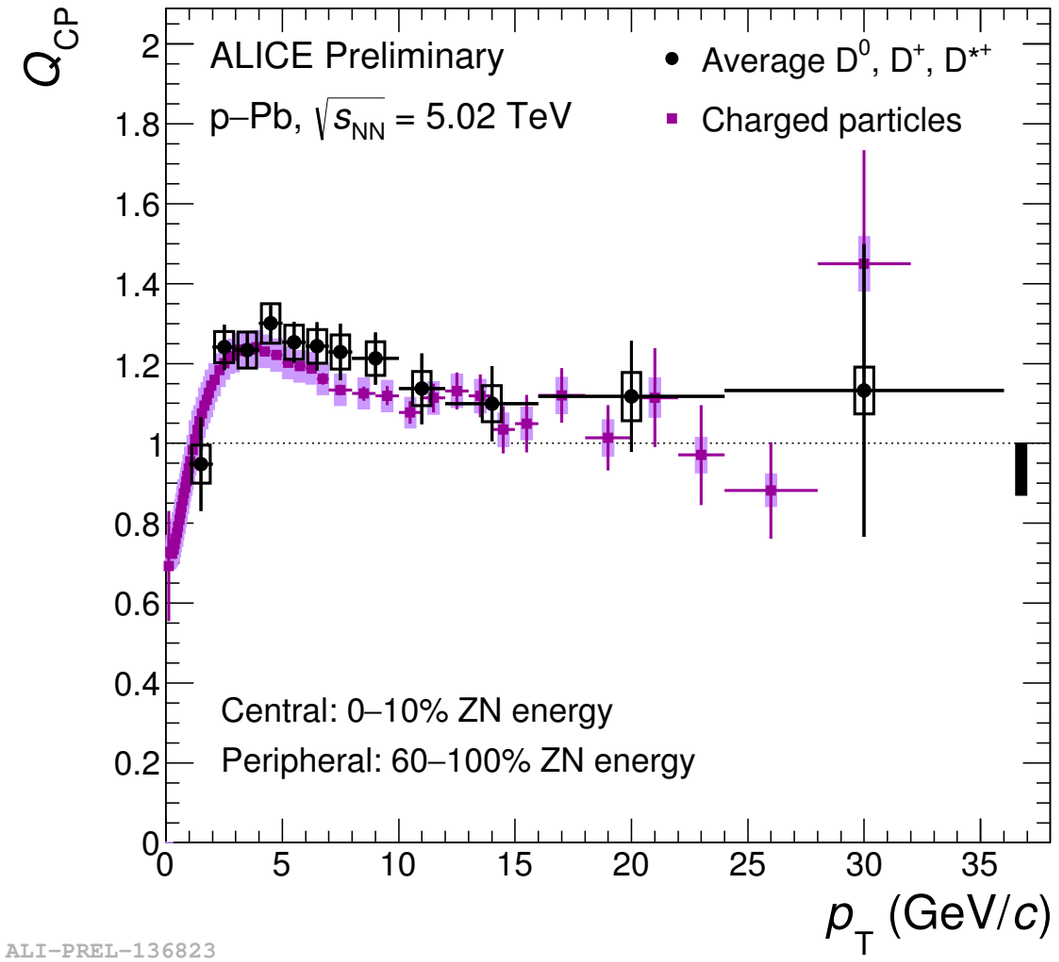


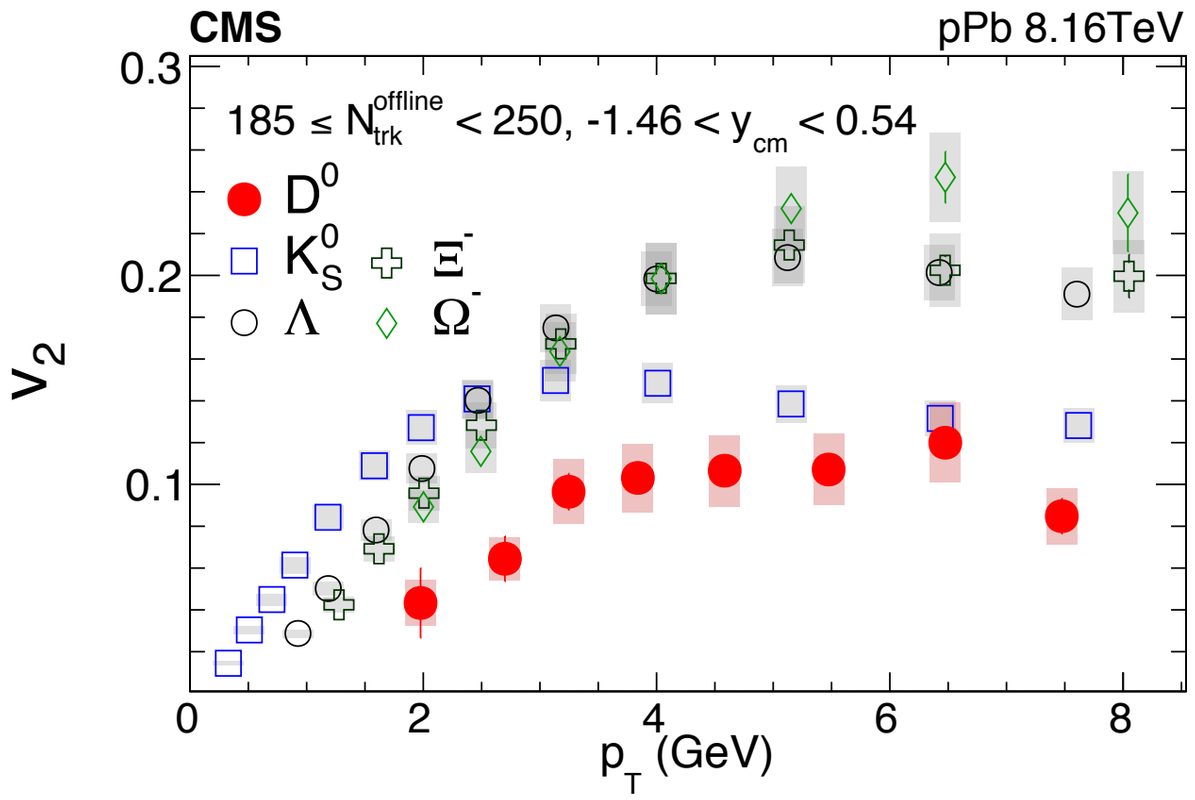


Final-State Modification of Open Charm in p–A?



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

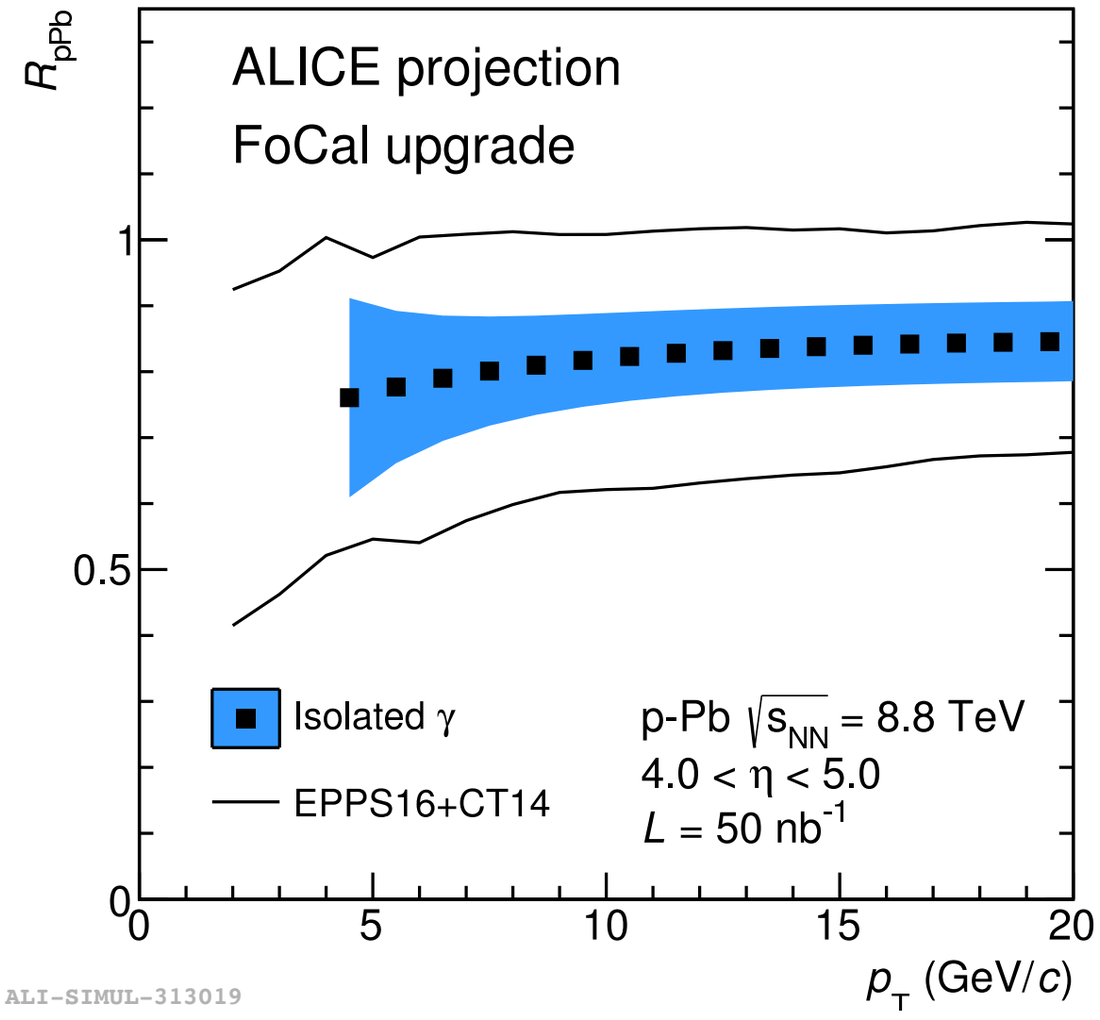
- mechanism for modifications still unclear, possibly final-state interaction!
- relation between initial- and final-state kinematics may be obscured
- introduces additional systematic uncertainty

Low-x Probes

- Open charm and photons apparently most sensitive probes
- Some advantages for photons
- Charm measurements possible with existing LHCb apparatus
- Photons provide complementary measurement
- Not possible with existing experiments
  - need new detector

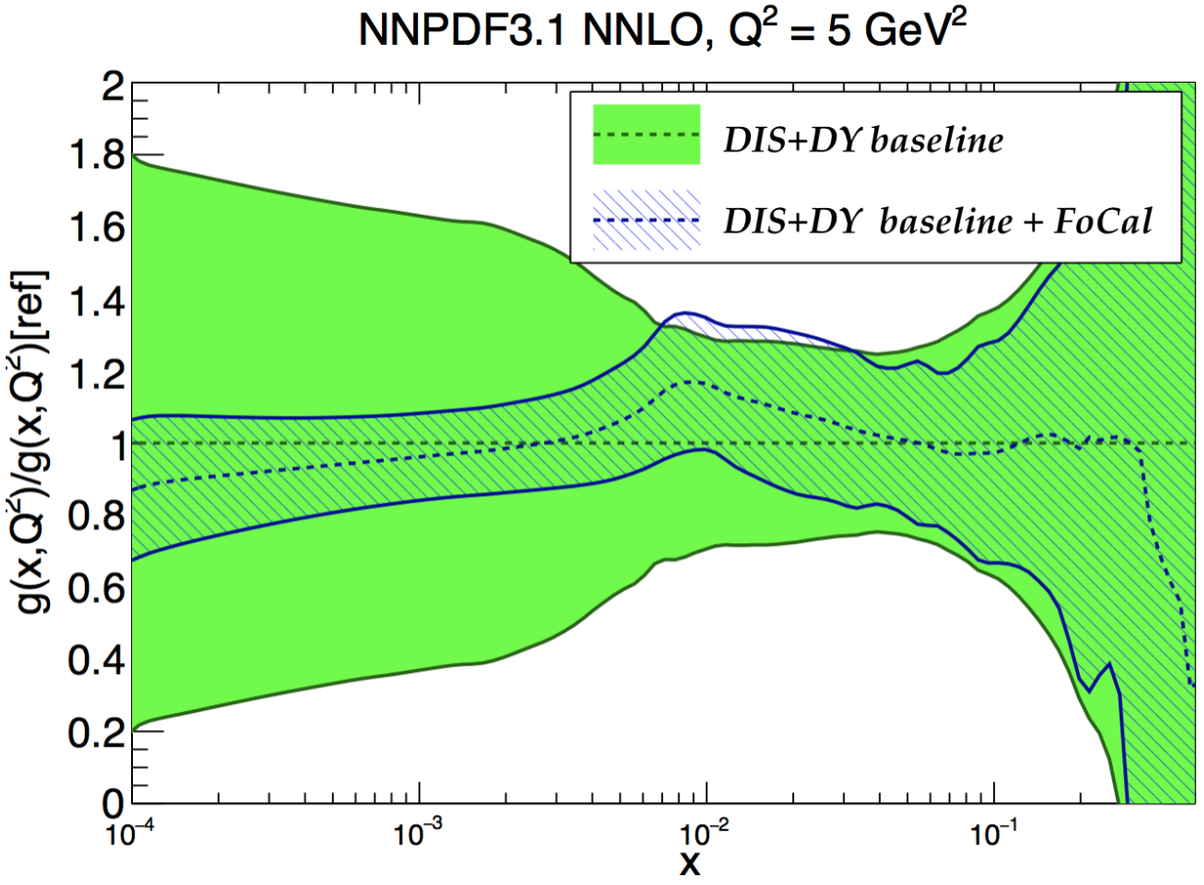
Impact of Forward Photons on nPDFs

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!

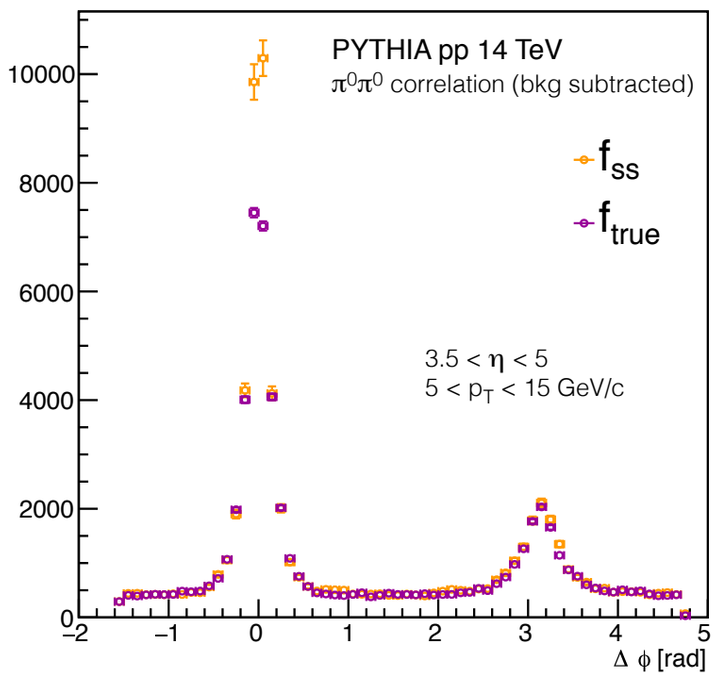
Other Probes of Saturation

- Suppression of single particles observed in R_{pA} tests gluon density
- Other probes: two-particle correlations
- Signal: Monojet production in place of dijets
  - sensitive to scattering off coherent gluon state
  - disappearance of away-side jet observed in pion azimuthal correlations d–Au at RHIC
  - also study $\pi^0\pi^0$ correlations in FoCal
  - more: photon-hadron correlations, jet-jet correlations

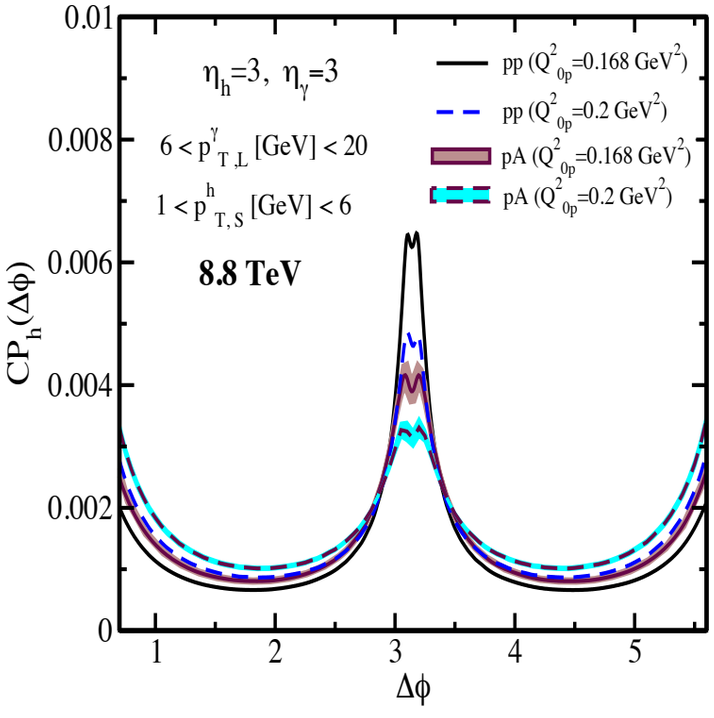
Azimuthal Correlations

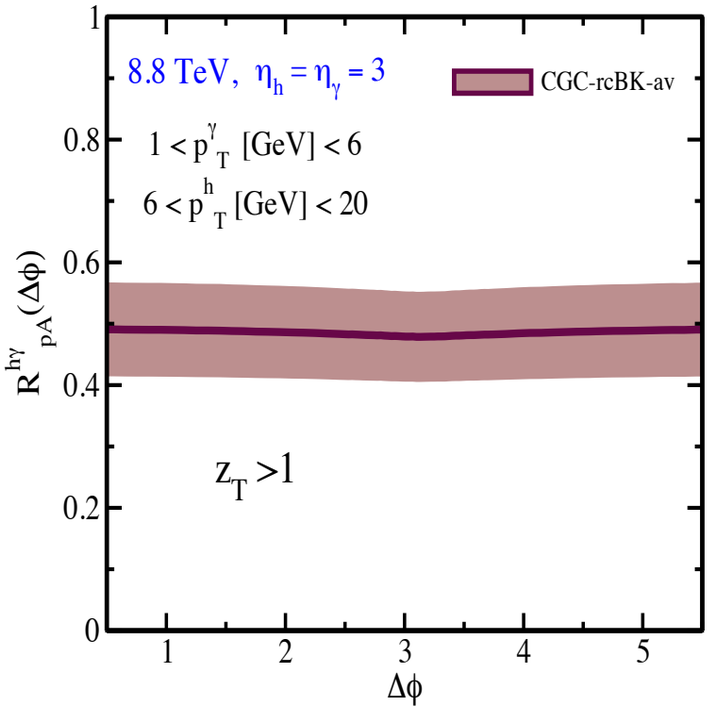
- first performance studies
  - π^0-π^0 correlations observable

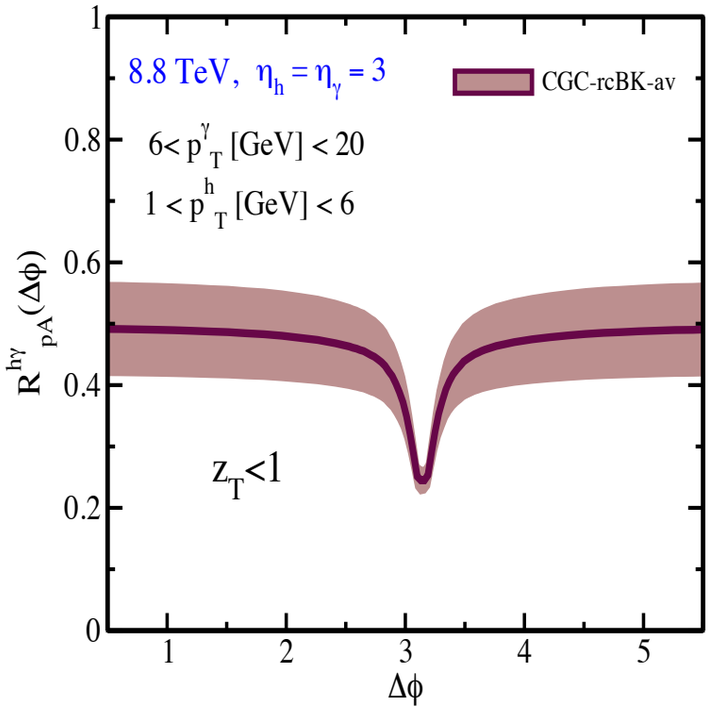
Tomoko Sakamoto



- more unique probe: photon-hadron correlations





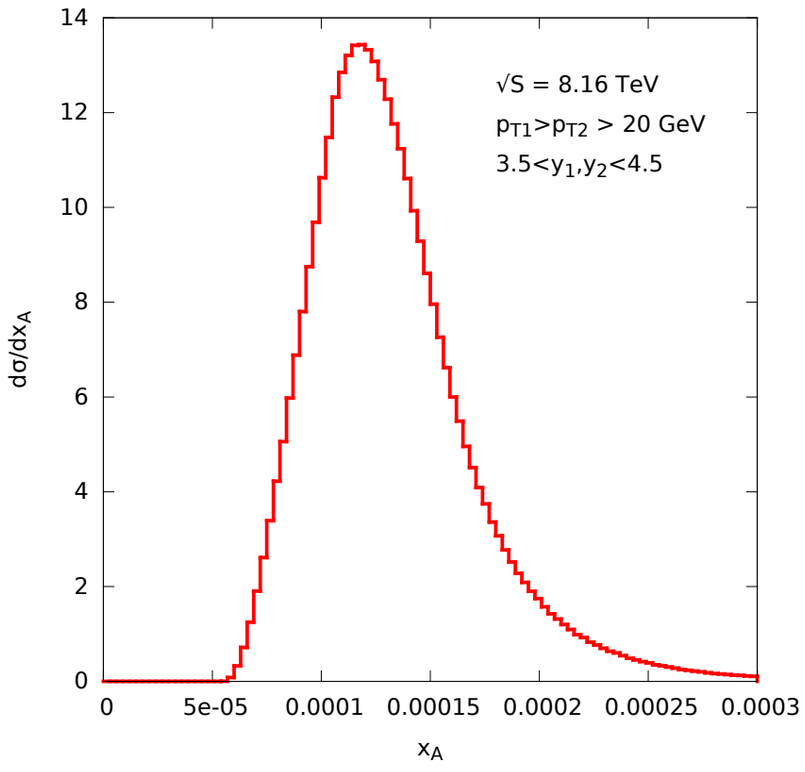


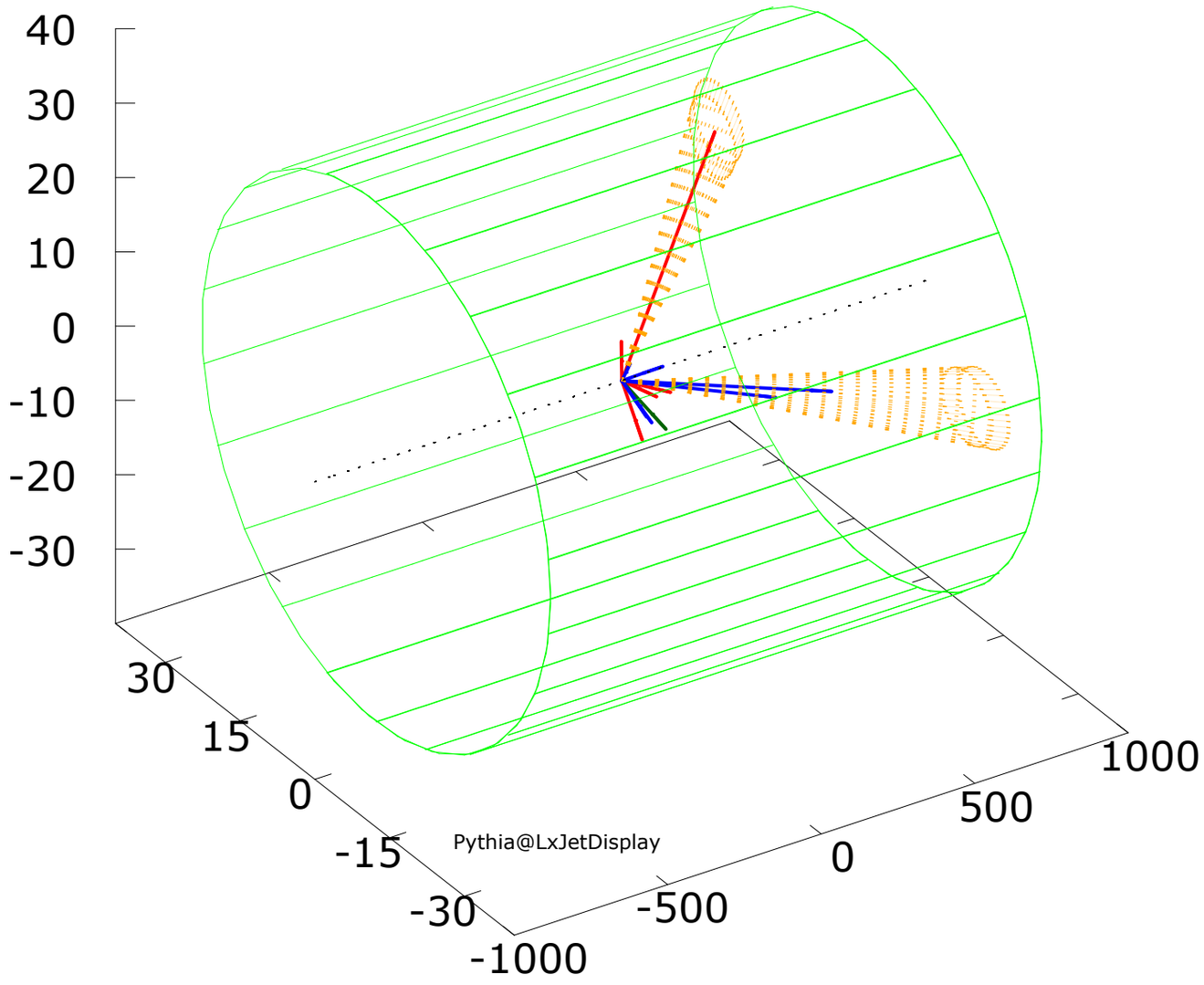
Results for dijet production in *p*Pb at LHC

Kinematic cuts

- CM energy: $\sqrt{S} = 8.16\,\mathrm{TeV}$
- require two jets with $(\Delta\phi)^2 + (\Delta\eta)^2 > R^2, R = 0.5$
- transverse momenta cuts: $p_{T1} > p_{T2} > 20\,\mathrm{GeV}$
- rapidity cuts: $3.5 < y_1, y_2 < 4.5$

x fractions probed





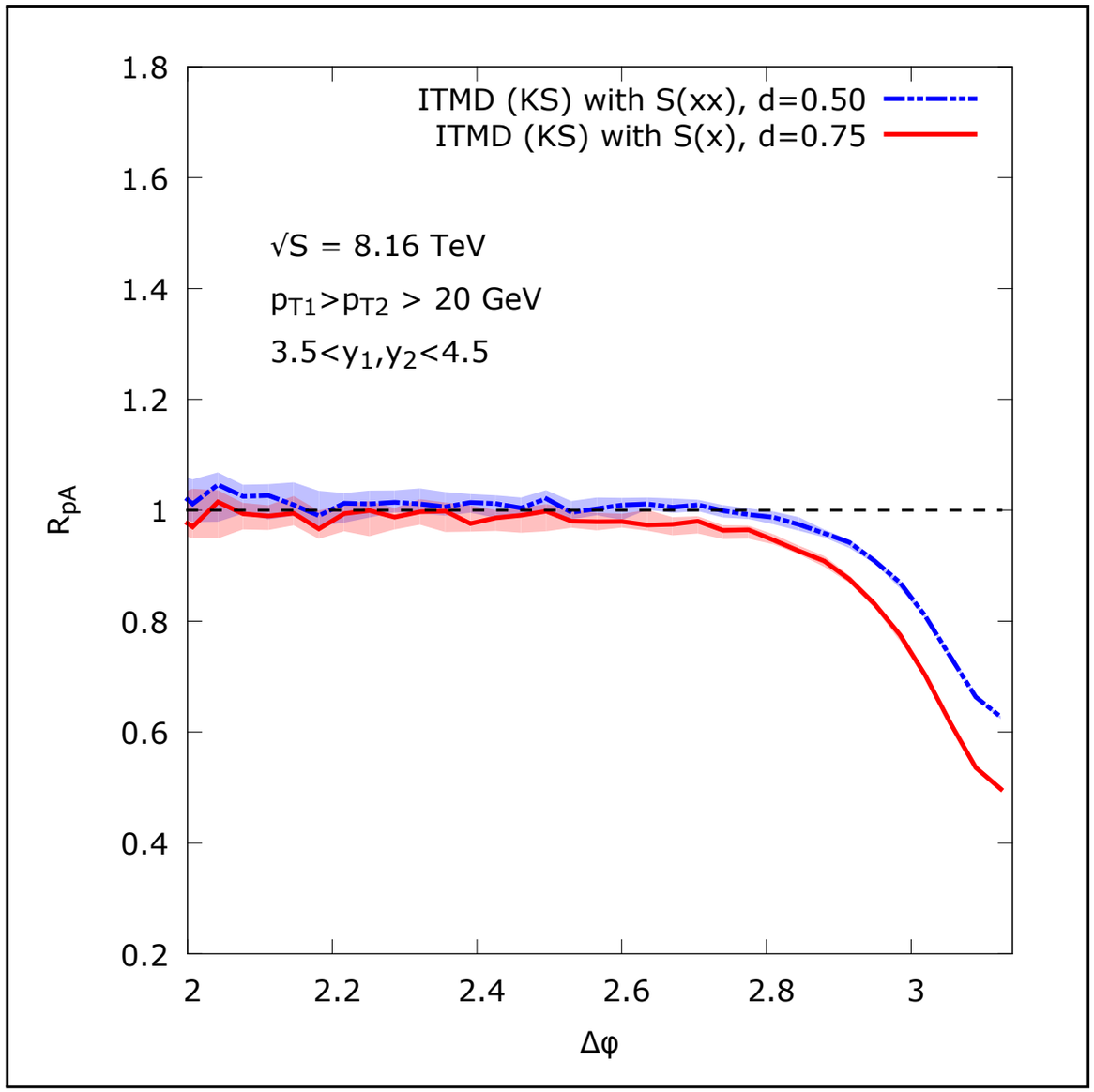
This particular PYTHIA event:

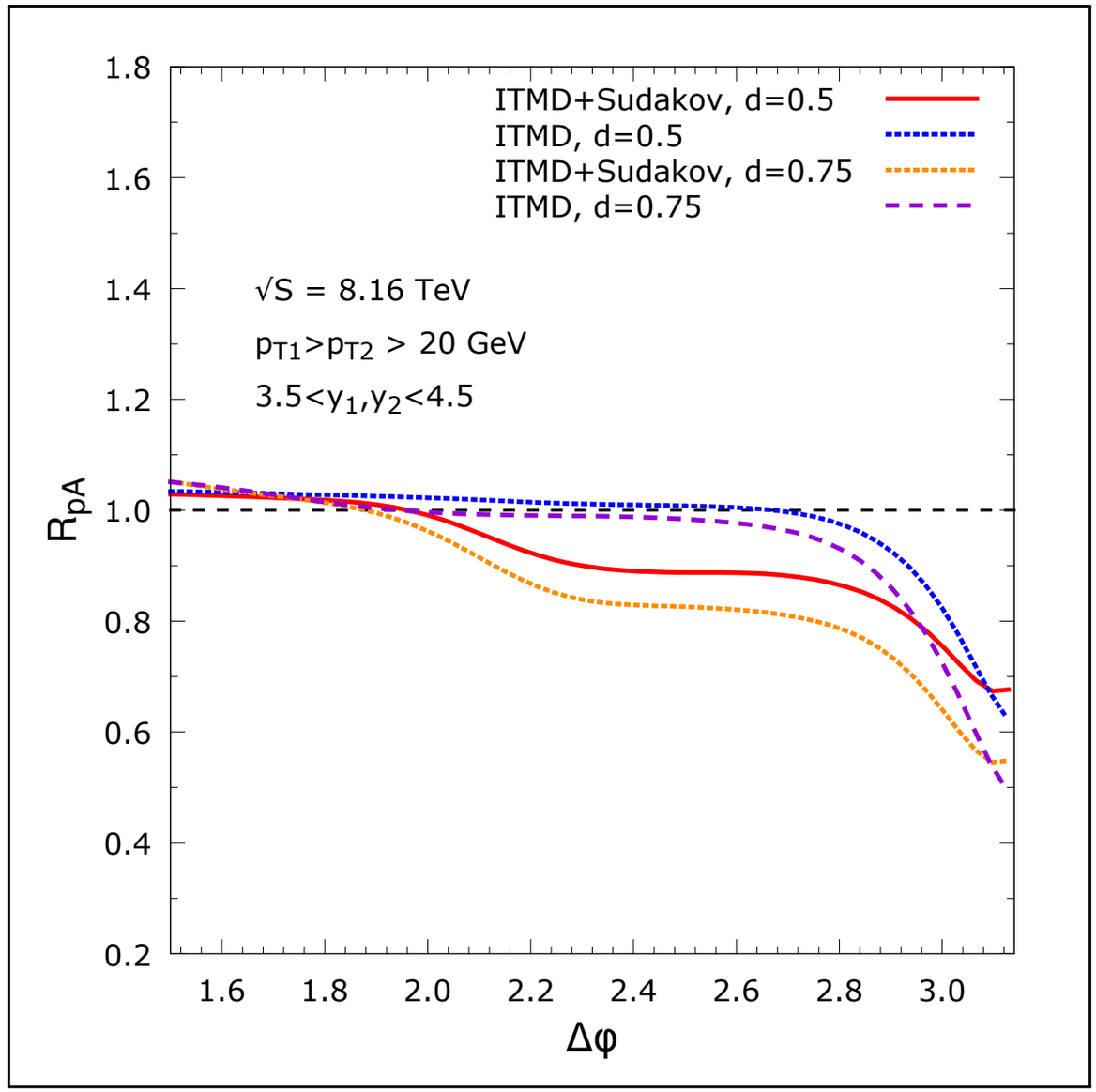
- jets with $p_{T1} \sim 27\,\mathrm{GeV}$, $p_{T2} \sim 30\,\mathrm{GeV}$
- $y > 3.5$
- 9 MPI events (not all visible; each in different color)
- jet imbalance $q_T \sim 10\,\mathrm{GeV}$

Results for dijet production in *p*Pb at LHC

Nuclear modification ratio for azimuthal decorrelations

[A. van Hameren, P.K., K. Kutak, C. Marquet, E. Petreska, S. Sapeta, JHEP 1612 (2016) 034]

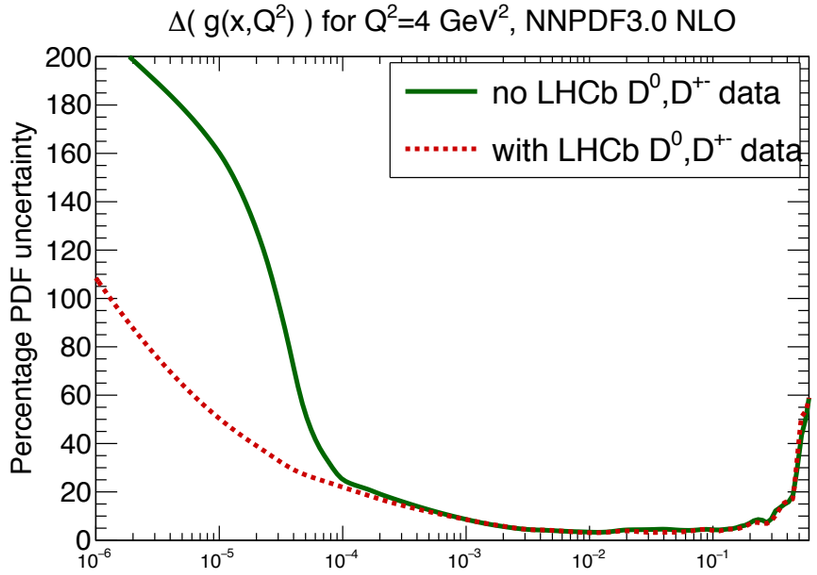




P. Kotko, Talk at RBRC workshop

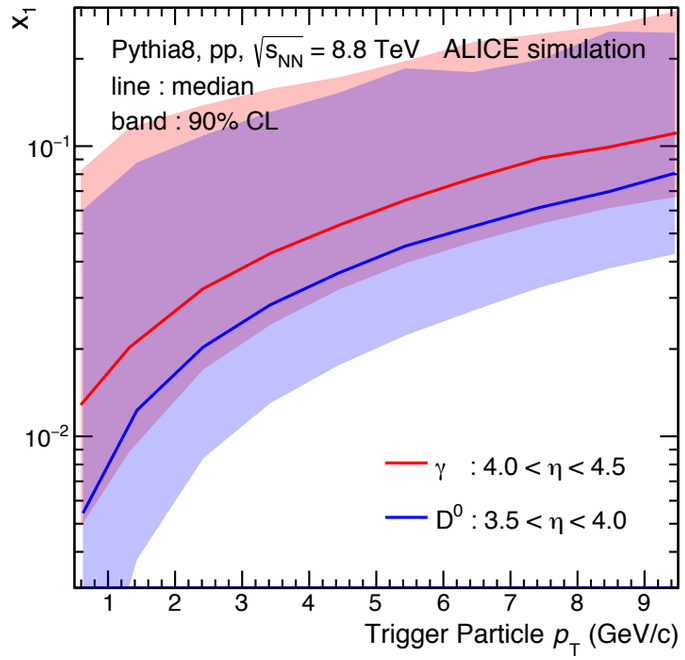
Other Physics Topics

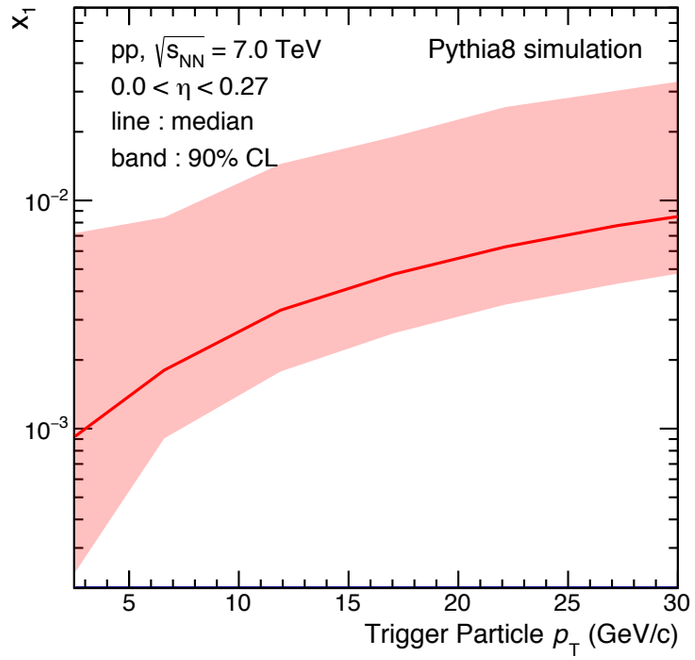
- Initial State
  - constrain proton PDF



Gauld, Rojo et al, arXiv:1506.08025

  - constrain large *x* partons





  - more topics in Pb–Pb …

Summary

- Large uncertainties in low-x parton density
  - also needs improvement in theory
  - hints for gluon saturation, no proof!
- Opportunity for forward photon measurement
  - complementary information to open charm
  - possibly cleaner signal
  - main observable: direct photon R_{pA}
  - study also correlations (needs more theory work)