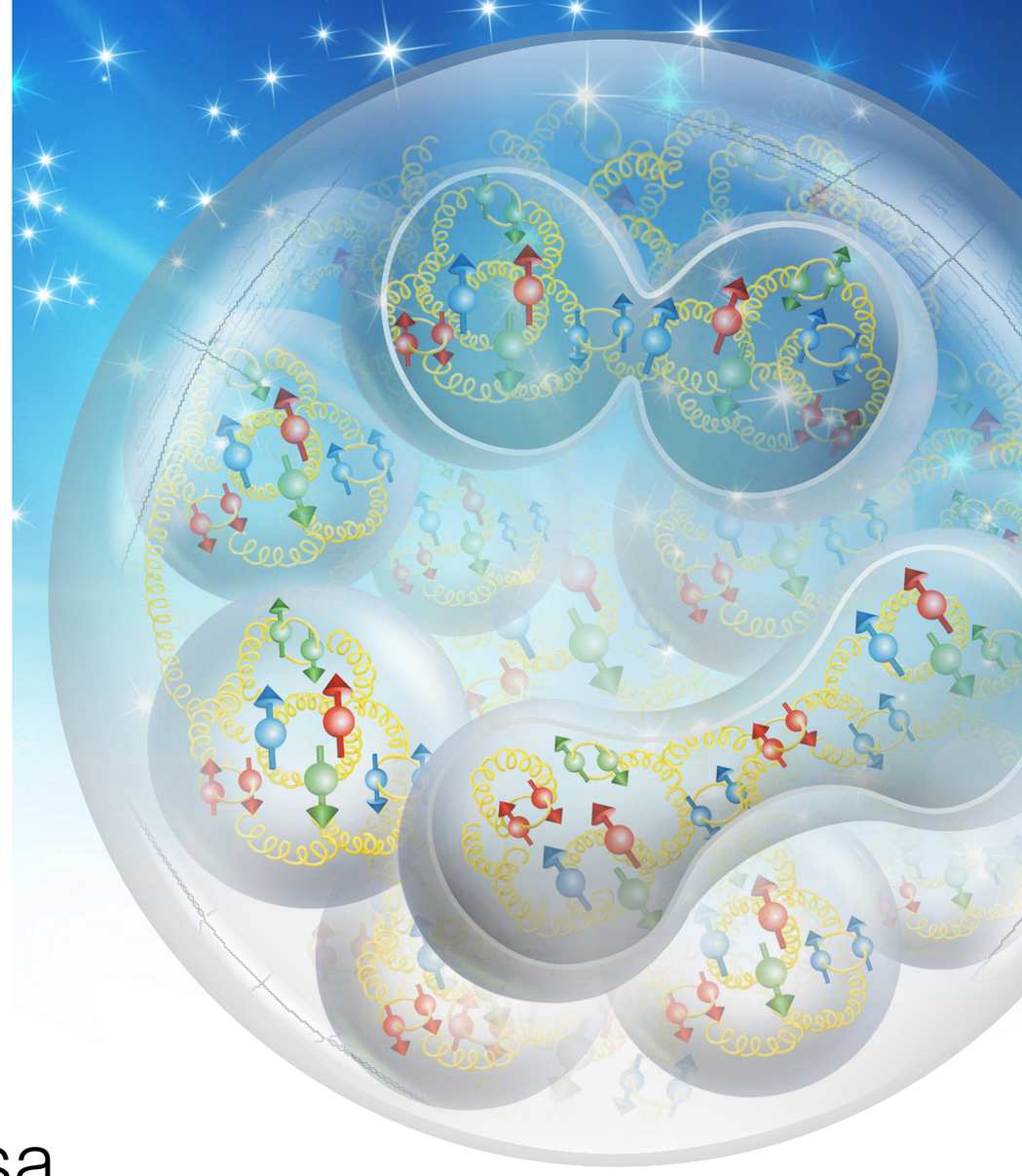
Progress in hard probes of small collision systems



Dennis V. Perepelitsa
University of Colorado Boulder

8th Workshop of the APS Topical Group on Hadronic Physics
Denver, CO
12 April 2019

material from:
Hard Probes '18 Student Day Lecture
Electron Ion Collider Users Group Mtg '18 Plenary

universal nPDF picture

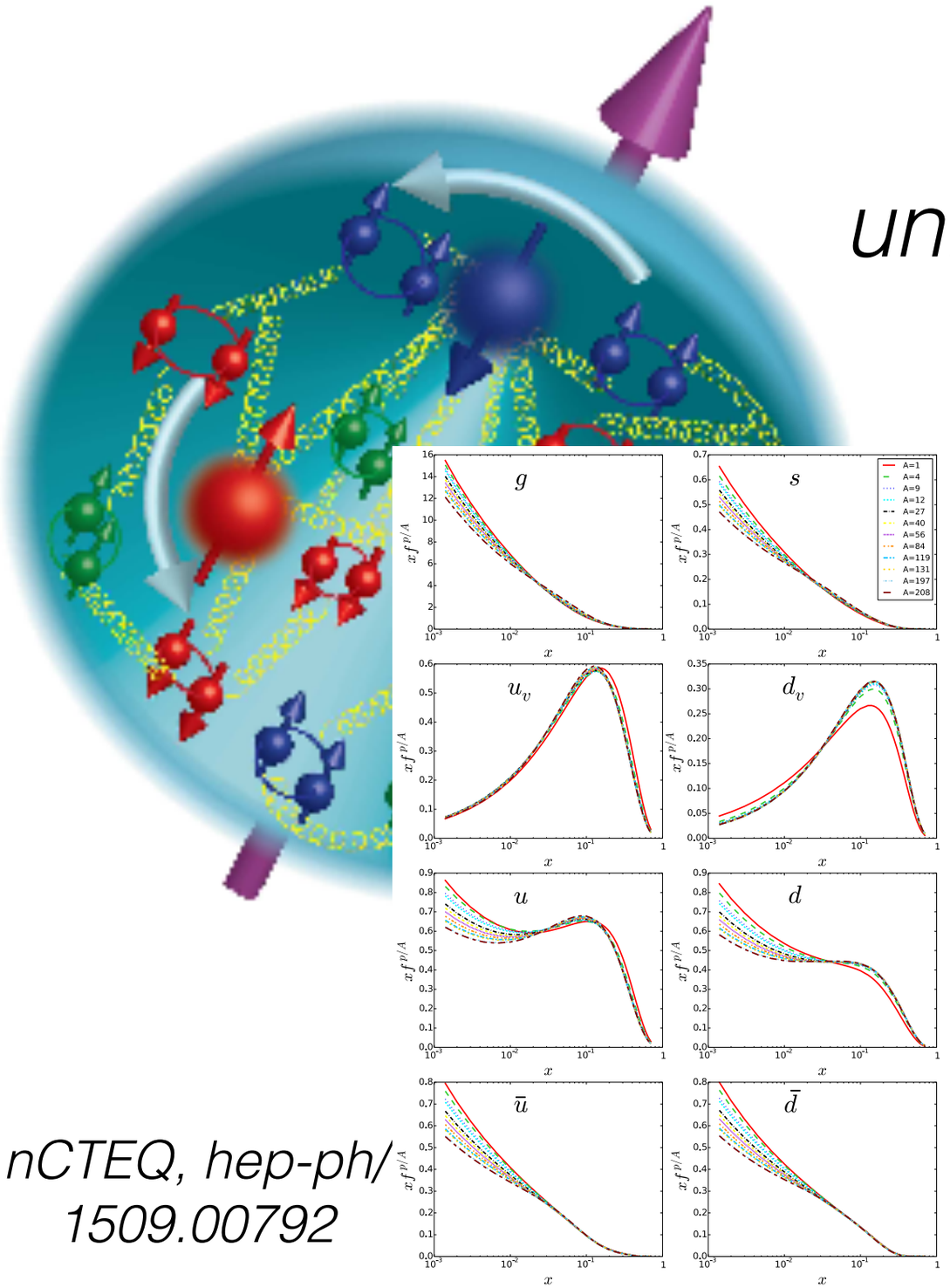
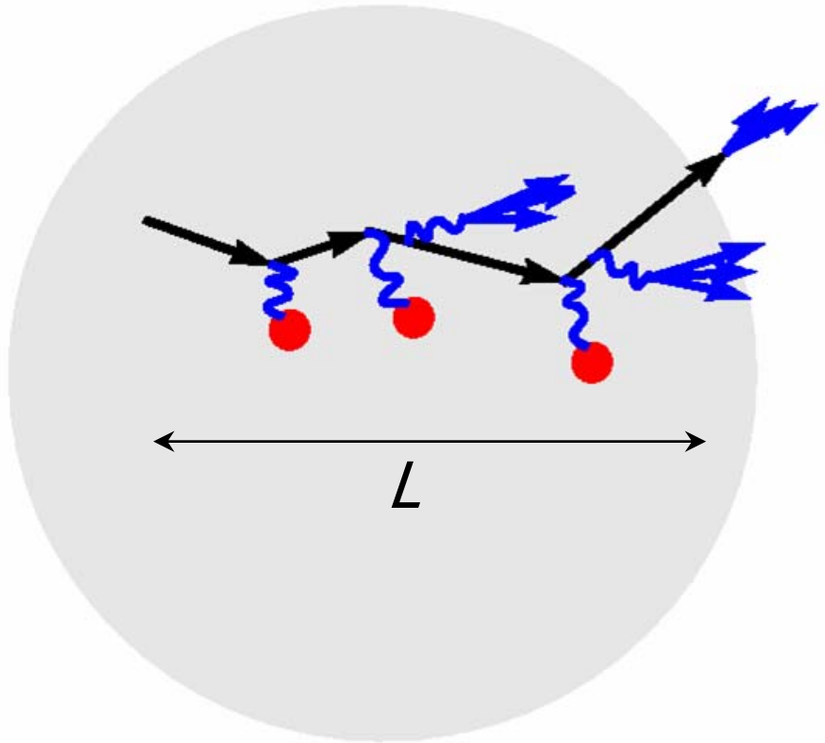


Figure 6: `nCTEQ15` bound proton PDFs at the scale $Q = 10$ GeV for a range of nuclei from the free proton ($A = 1$) to lead ($A = 208$).

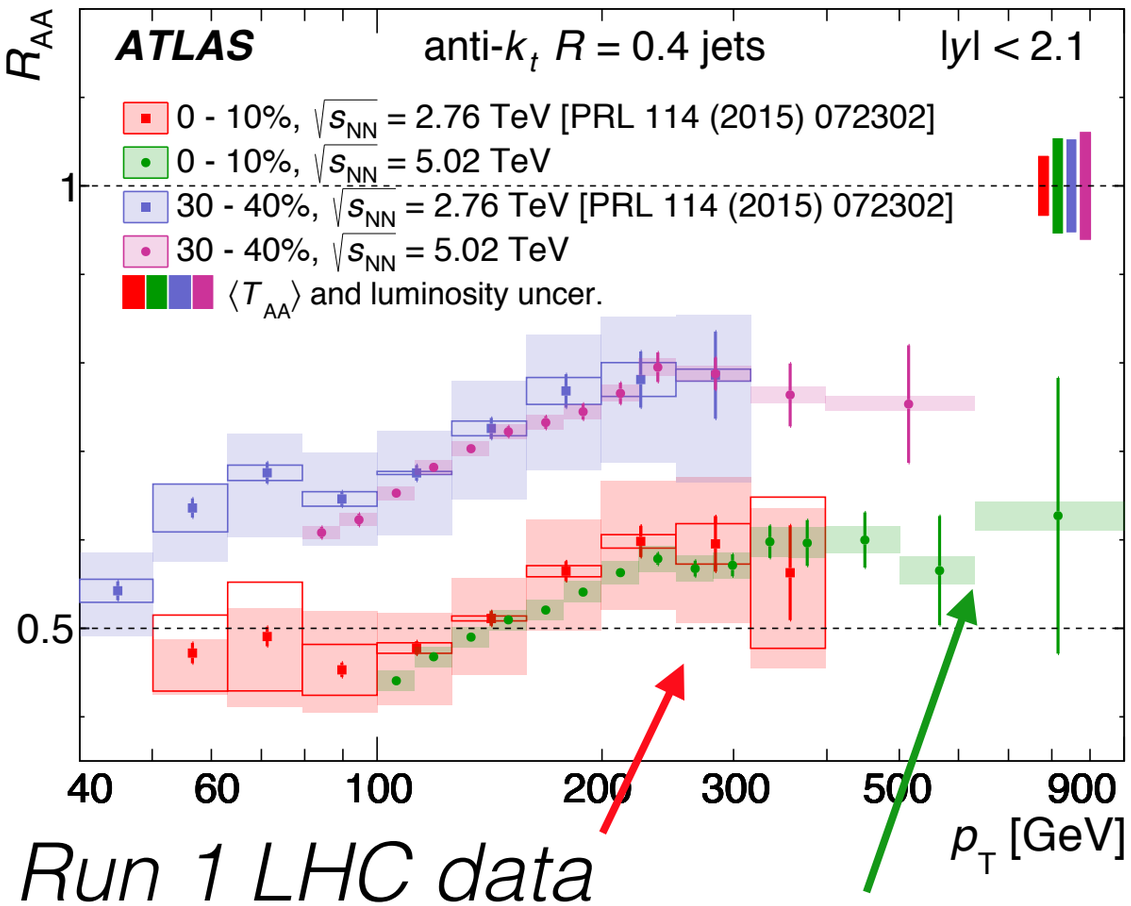
nCTEQ, hep-ph/1509.00792



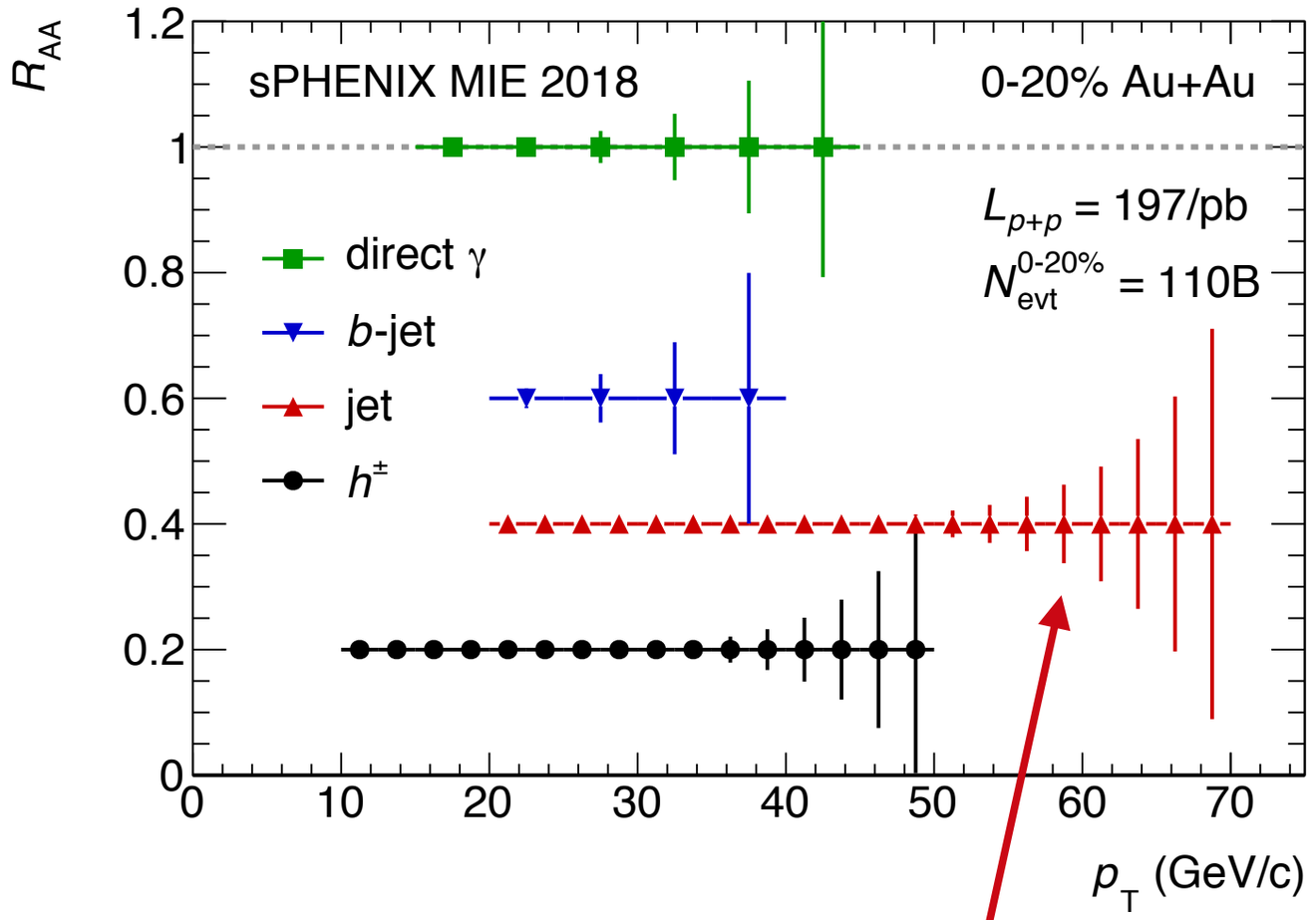
dynamical pictures of "cold nuclear matter" effects

context for A+A program

arXiv:1805.05635



Run 1 LHC data



2015 LHC data

(3x-4x more in 2018?)

E_{jet} = 1 TeV at y~0

x_A ~ 0.4 (EMC region!)

Au+Au @ RHIC-sPHENIX,

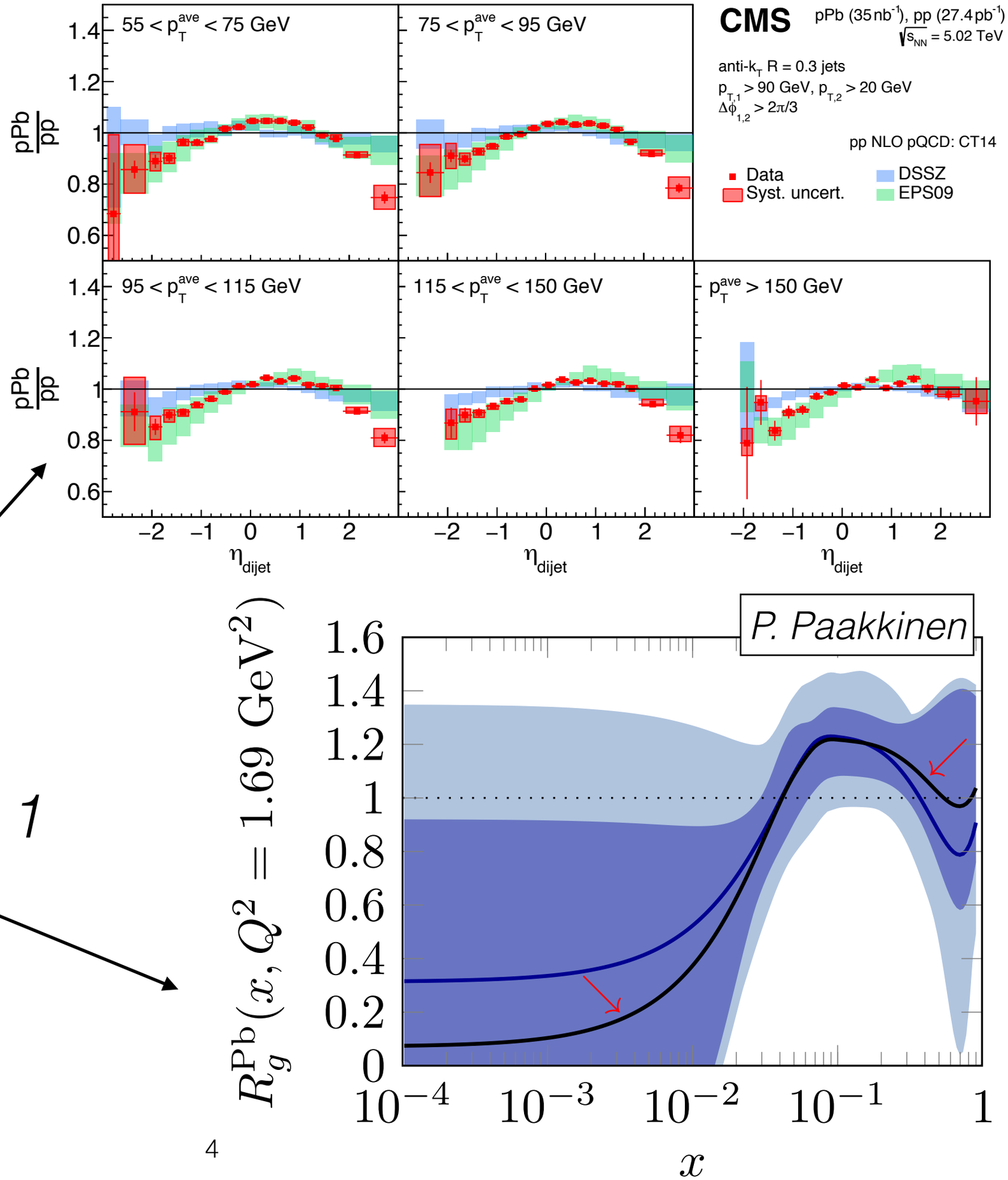
E_{jet} = 60 GeV at y~+0, x_A ~ 0.6

need <u>precise</u> constraints from p+A… (also for HF…)

hard probes data in a global nPDF picture

broad (p_T, η)-dep. measurements in p+Pb/pp

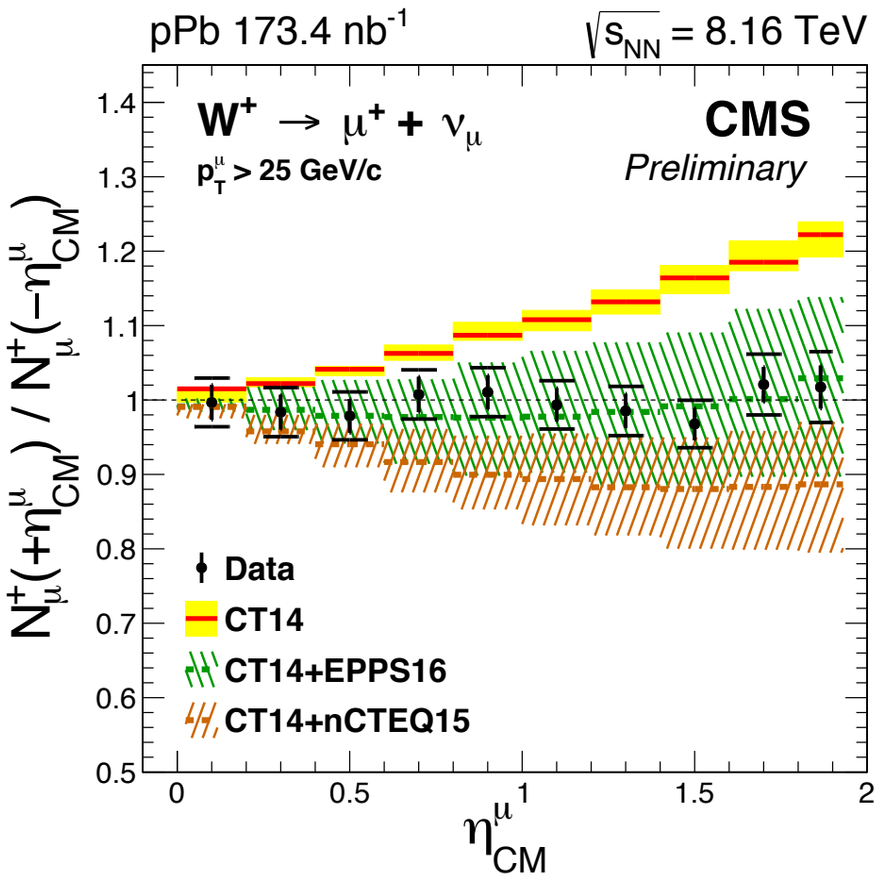
impact of LHC Run 1 data on nPDF constraints

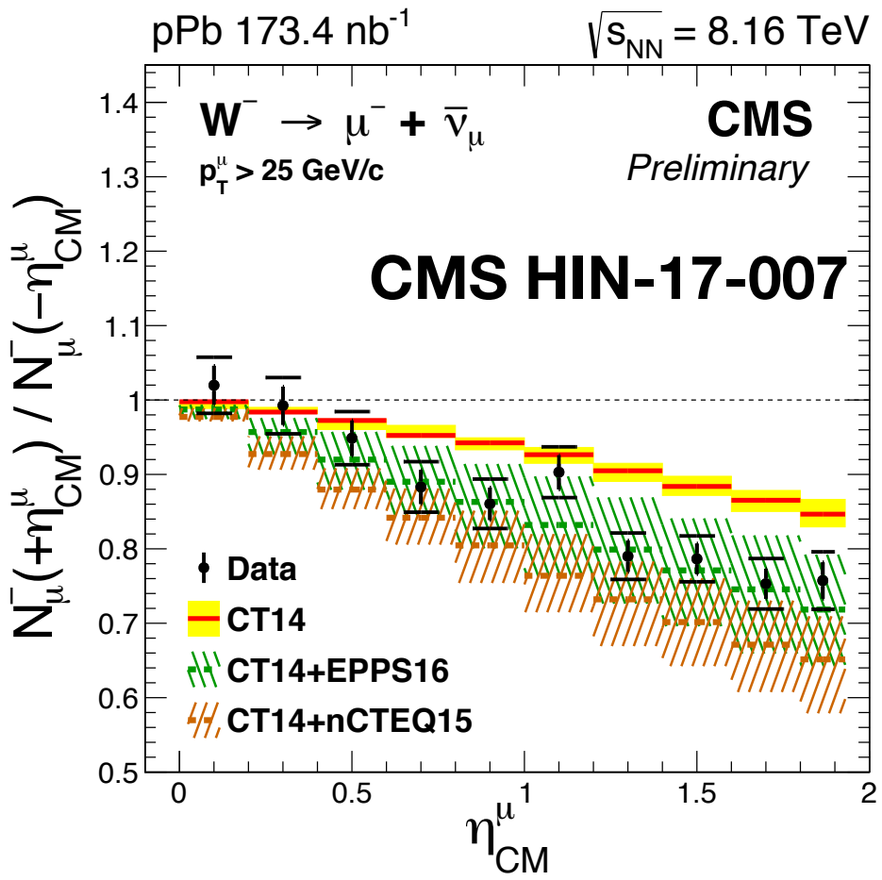


EW probes in (Run 2, @ 8.16 TeV) *p*+Pb

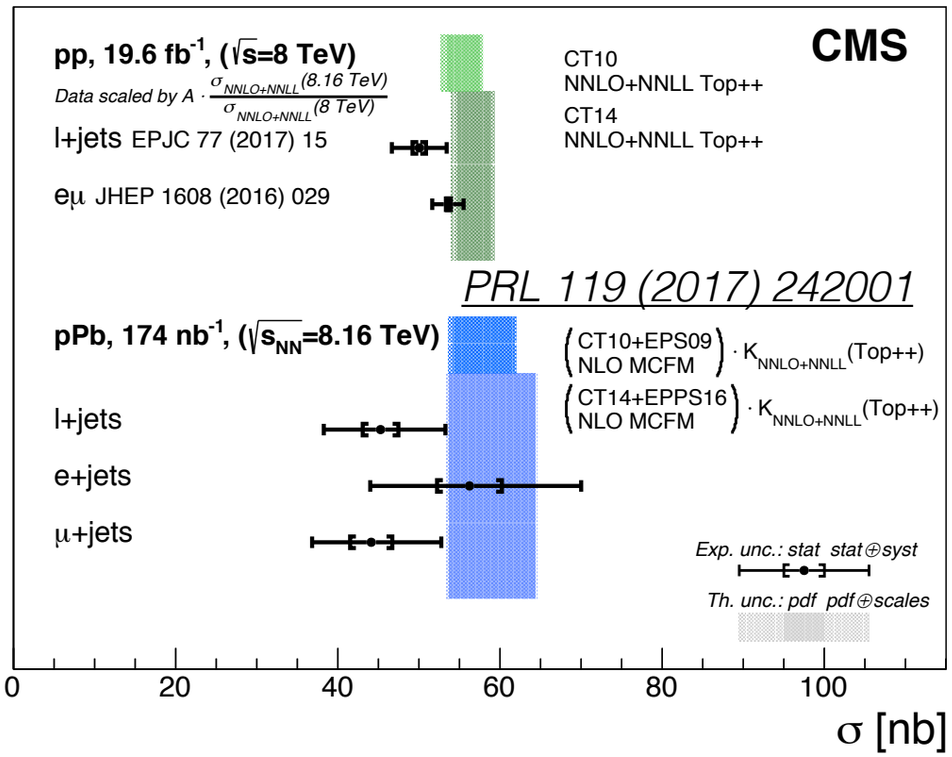
Forward/ backward ratios of W production

note: probe $Q^2 > m_W^2$, $q/\bar{q}$ nPDFs

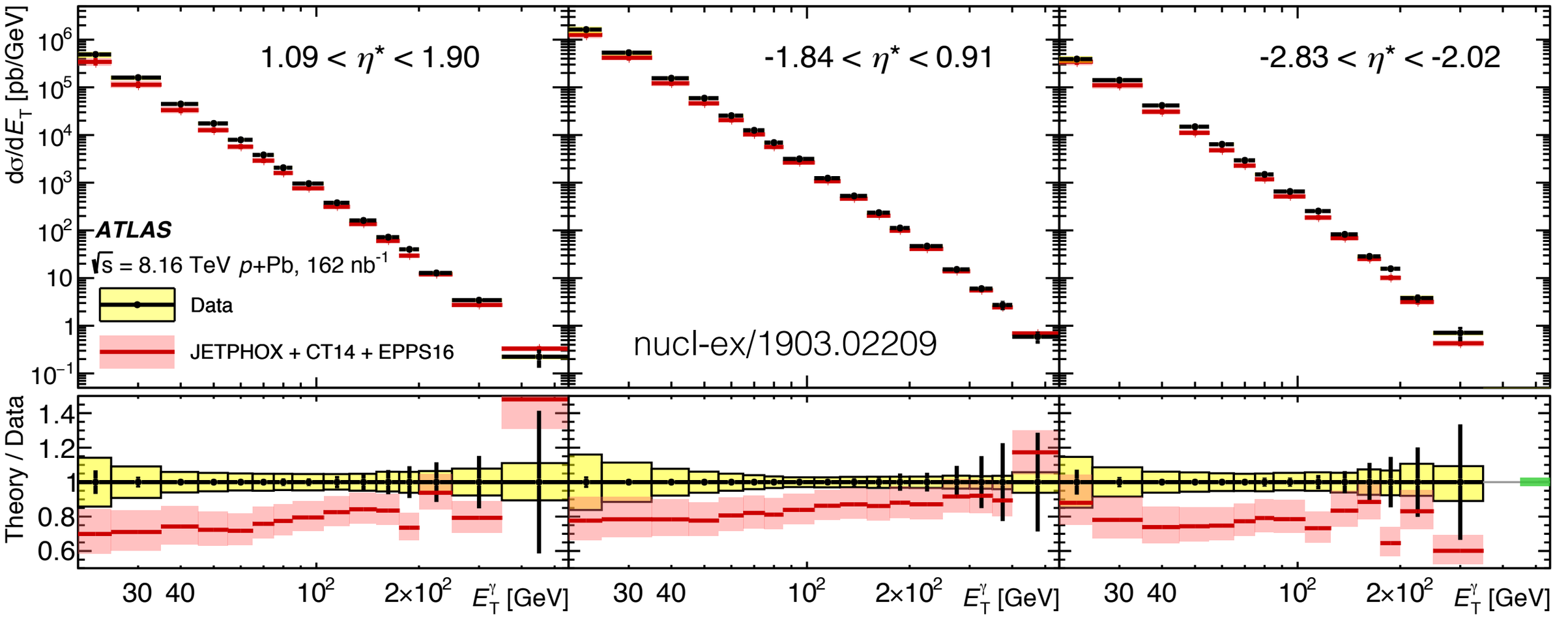




ttbar in p+Pb:… modest impact for large-x gluon PDFs



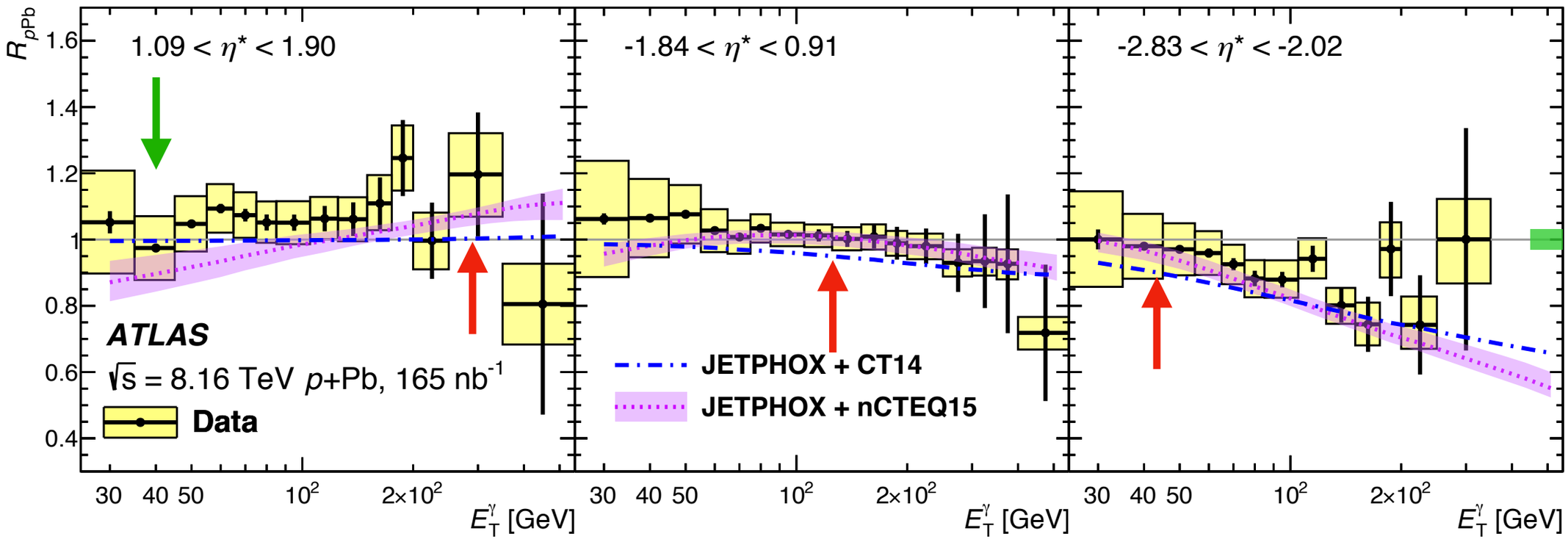
Isolated photon cross-section in *p*+Pb



forward (p-going) ⟵ ⟶ *backward (Pb-going)*

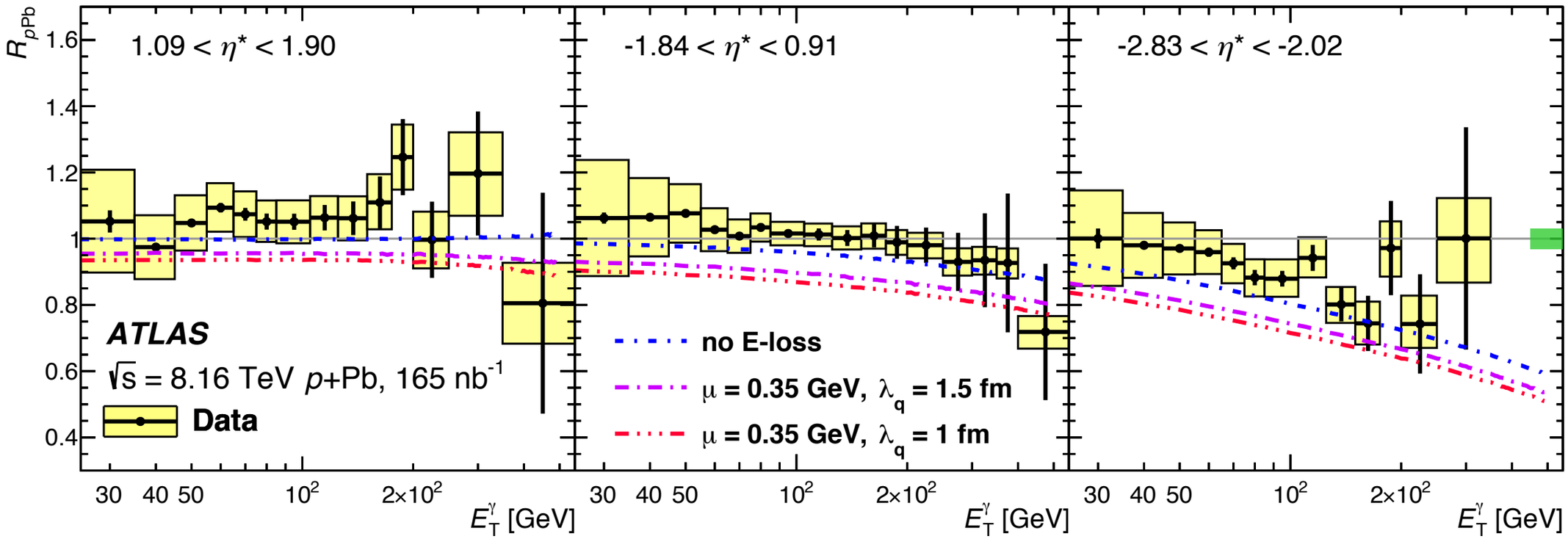
- Broad measurement (p_T = 20-500 GeV) of isolated photon production
  - ➡ as in *pp*, under-prediction by NLO calculations (w/ nuclear effects)
- Total uncertainty as low as ~3% (!)

R_{pPb}



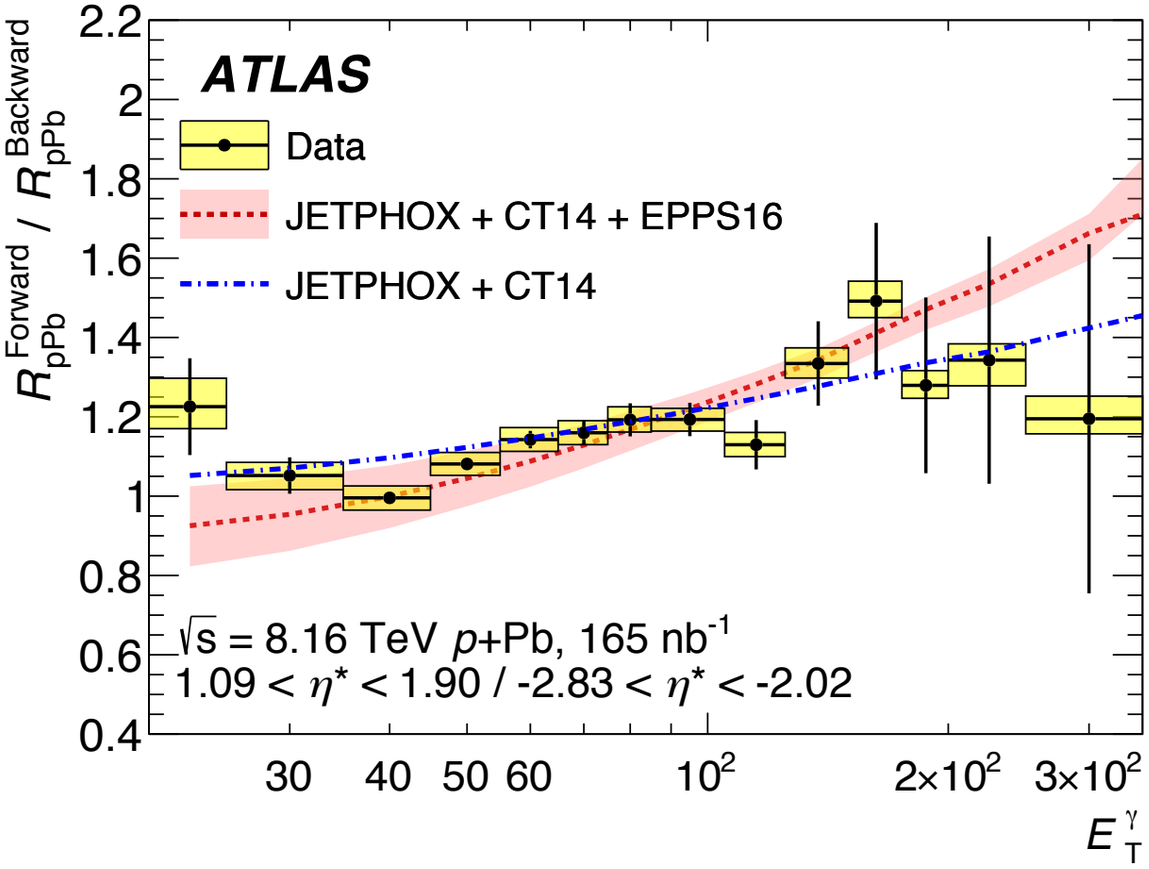
- Data favors **anti-shadowing** modification in line with global nPDF fits, less obvious in **shadowing** region

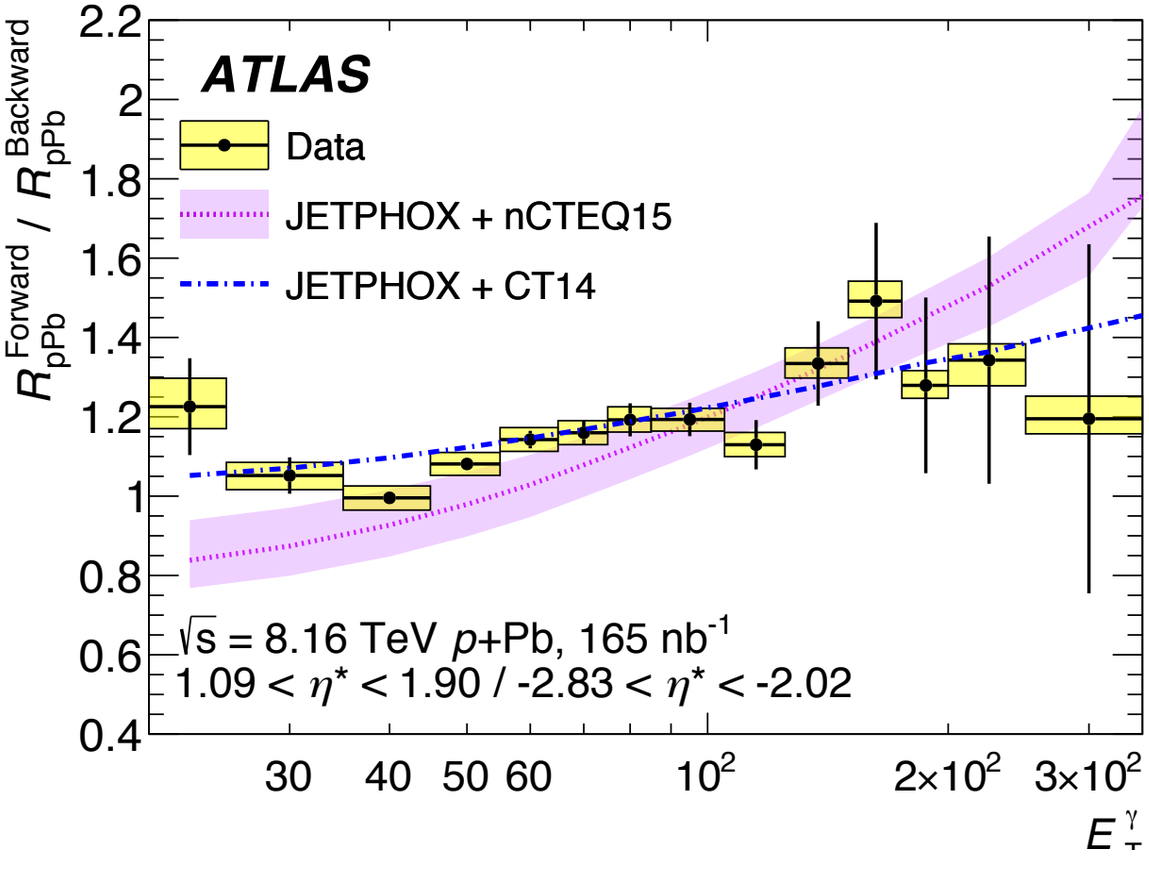
R_{pPb}



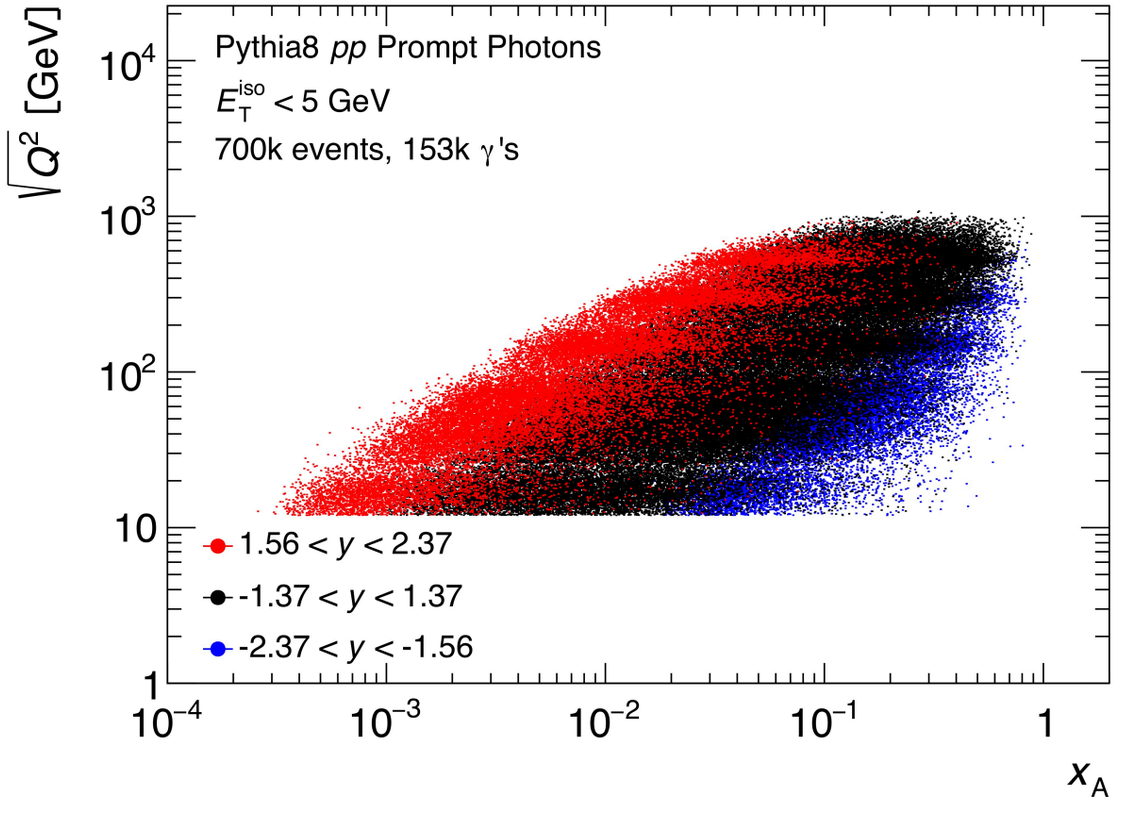
- Disfavors large initial state energy loss

Forward / backward $R_{p\mathrm{Pb}}$ ratio vs. p_{T}



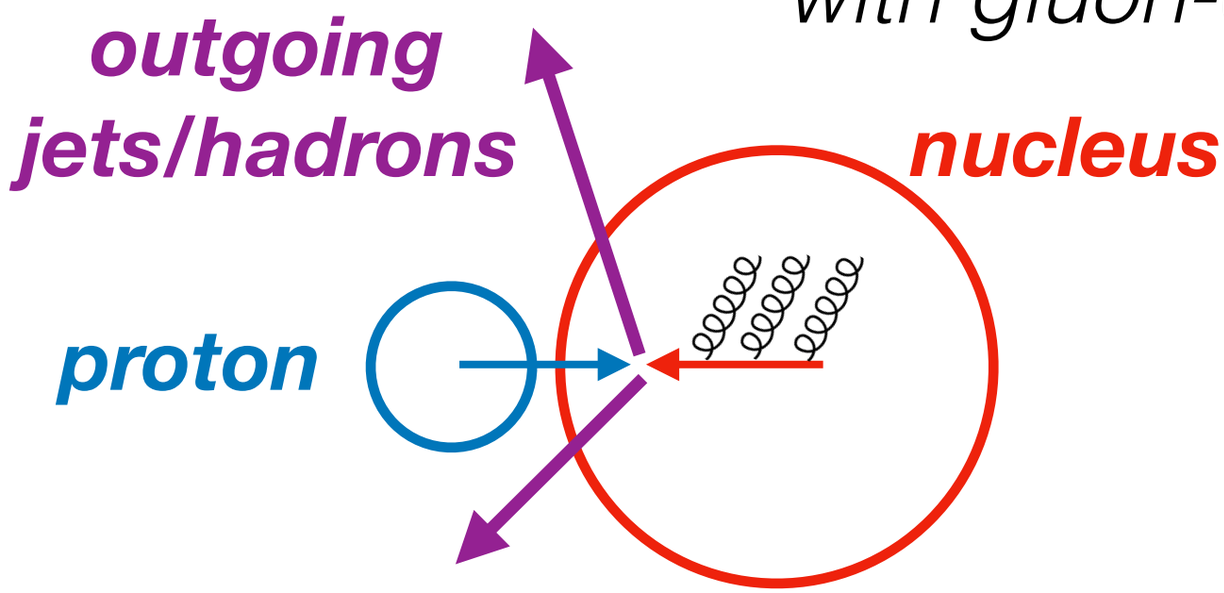


- At low-E_{T}, data almost compatible with free nucleon PDFs
  - ➡ can't probe this region with W/Z!
  - ➡ more generally, information for global nPDF fits

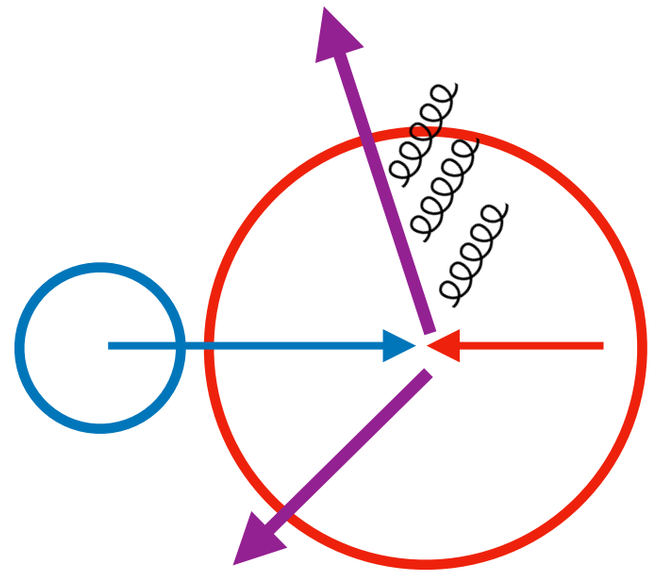


“cold nuclear matter” dynamics

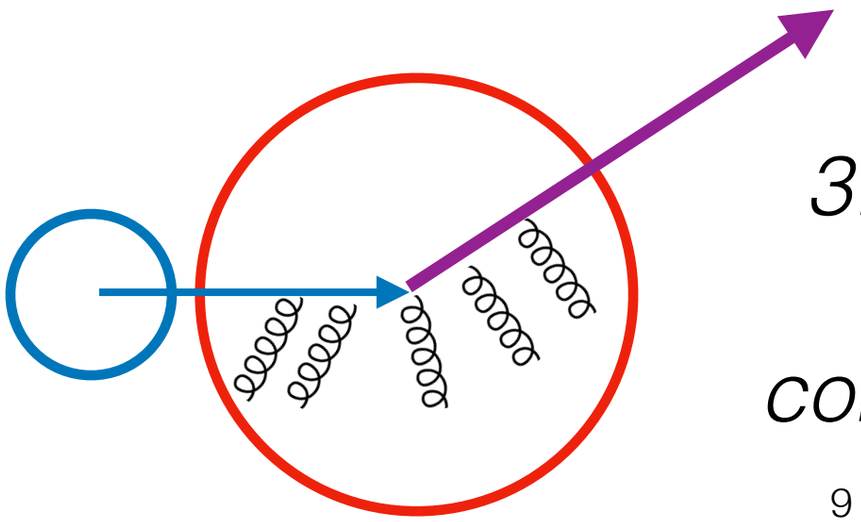
partons before and/or after hard scattering interacting with gluon-dense nucleus



1. parton-gluon interactions before hard scattering (initial state E-loss)

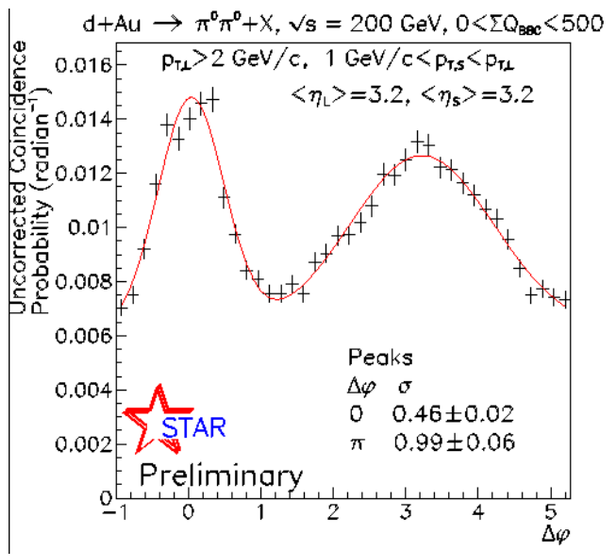


2. interactions after scattering (k_T broadening, $\Delta\phi$ decorrelation)

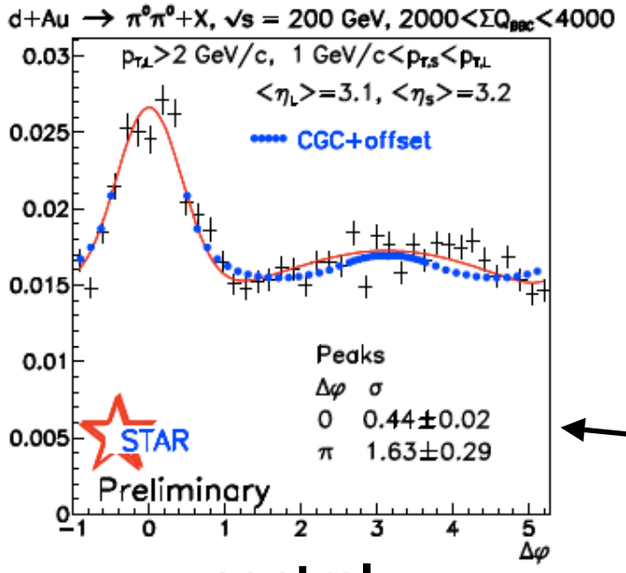


3. forward mono-jet production (parton in proton interacts coherently with saturated gluons)

forward “mono-jet” production



peripheral

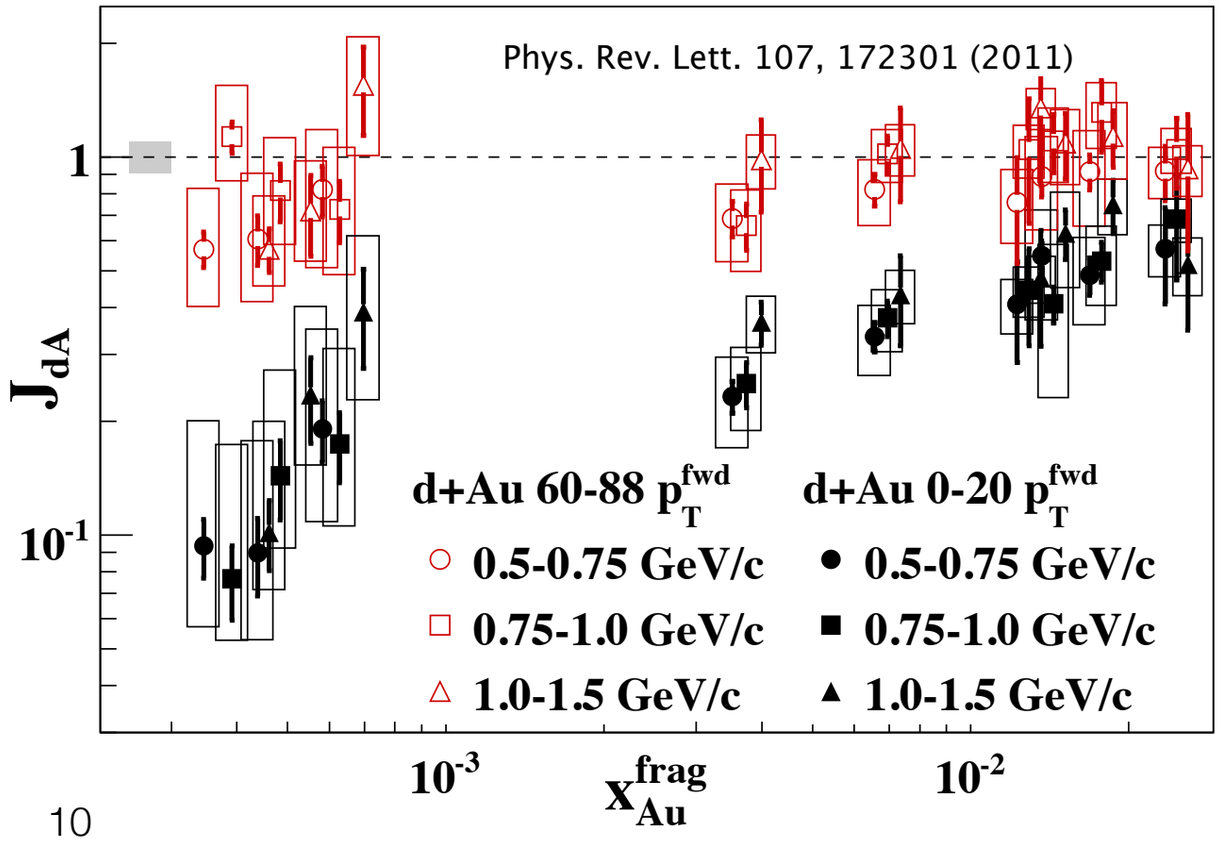


central

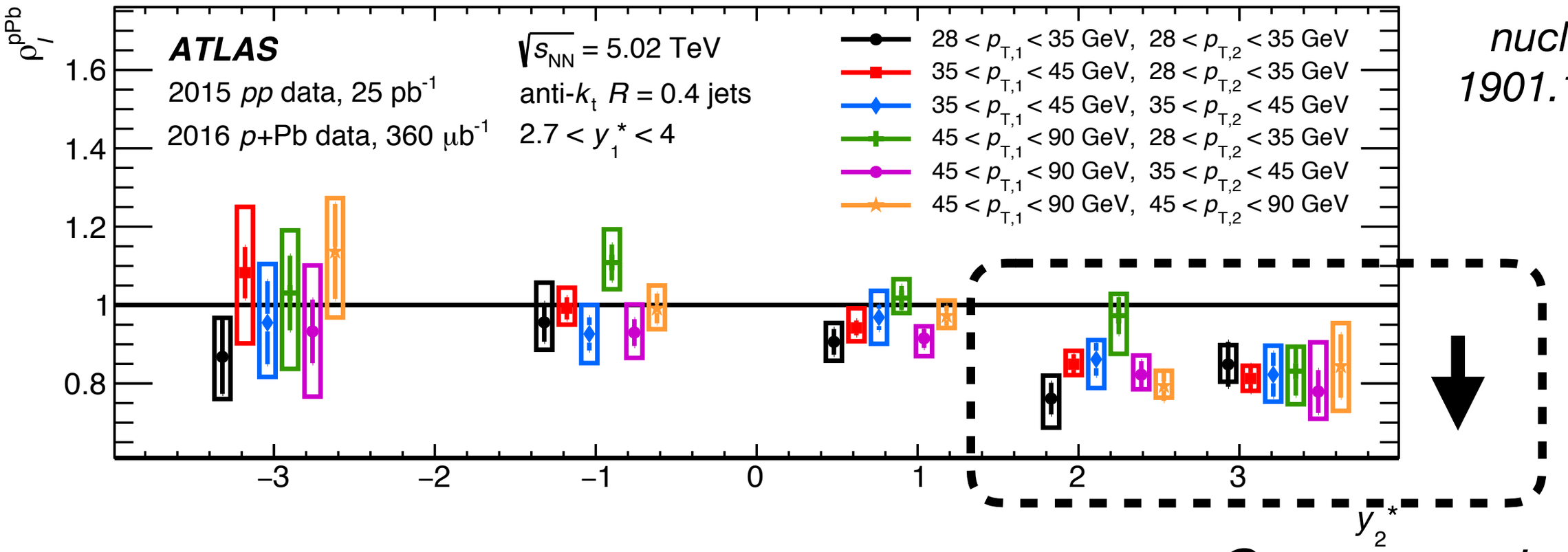
dramatic effects in d+Au at RHIC:

← *STAR forward di-hadron Δϕ*

PHENIX ratio of central-forward per-trigger hadron yields →

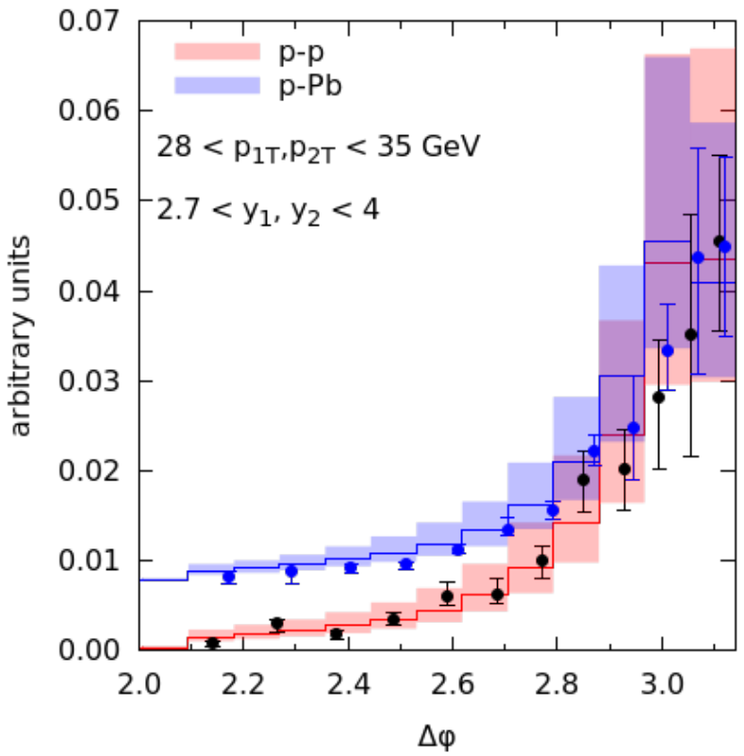


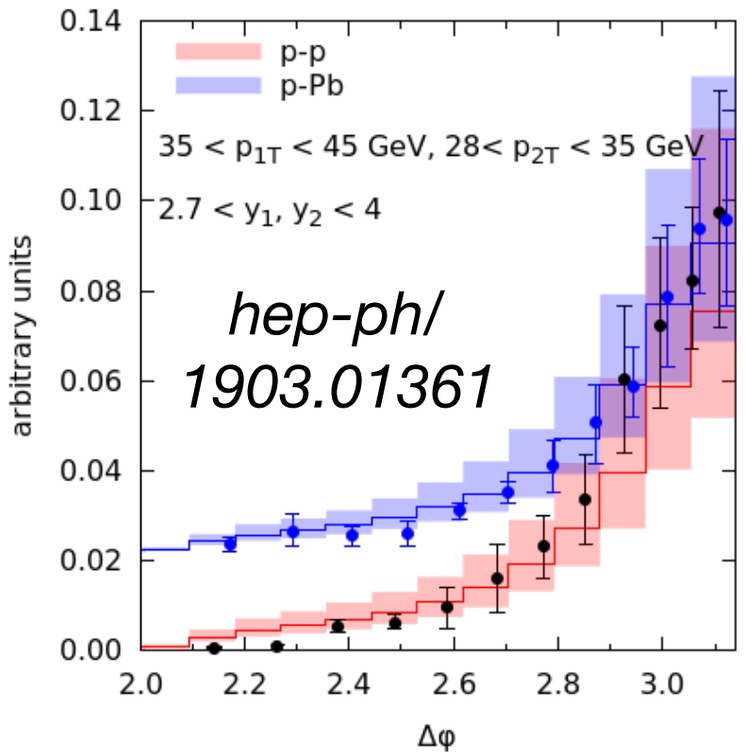
forward di-jets at LHC



nucl-ex/ 1901.10440

Suppression of conditional yield

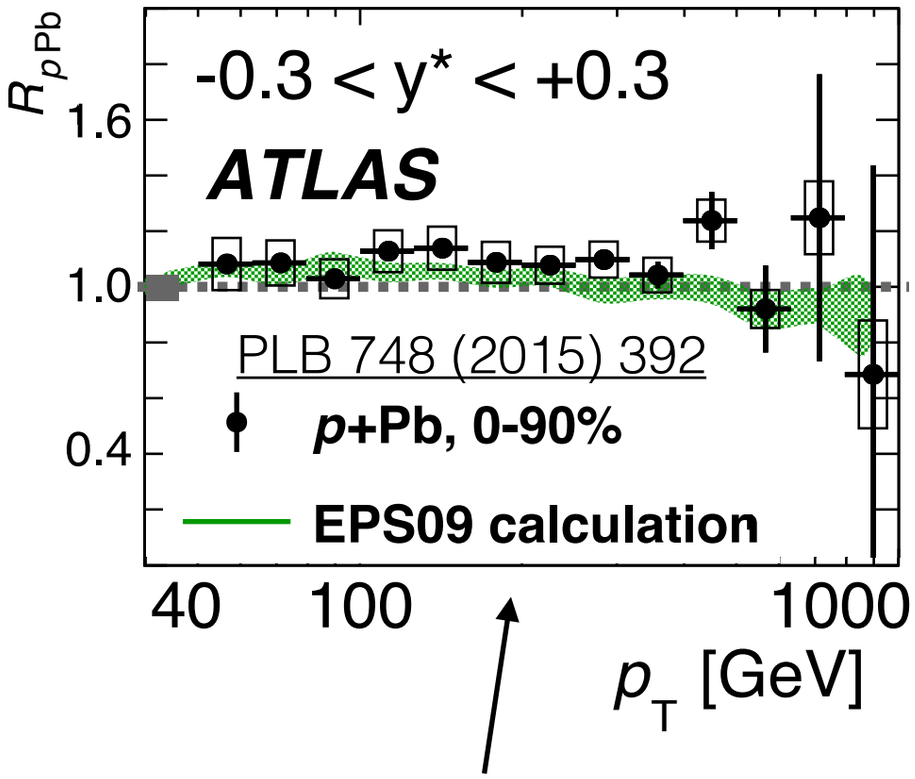




hep-ph/ 1903.01361

Δϕ matched to theory calcs. which include saturation

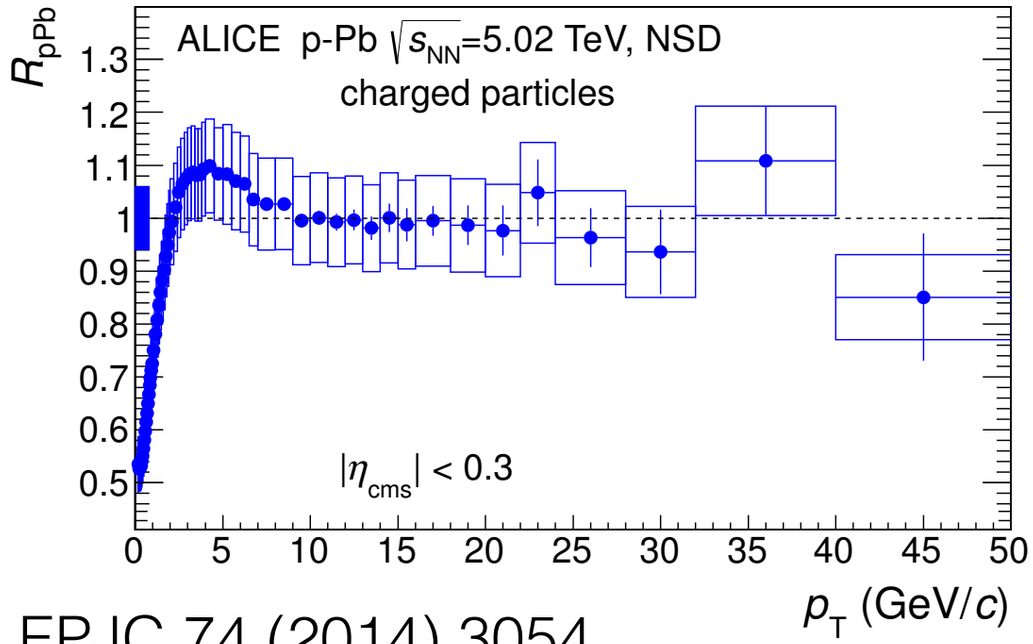
how can we explore saturation region?



jets: *minimum p_T, effects evolve away with high Q^2…*

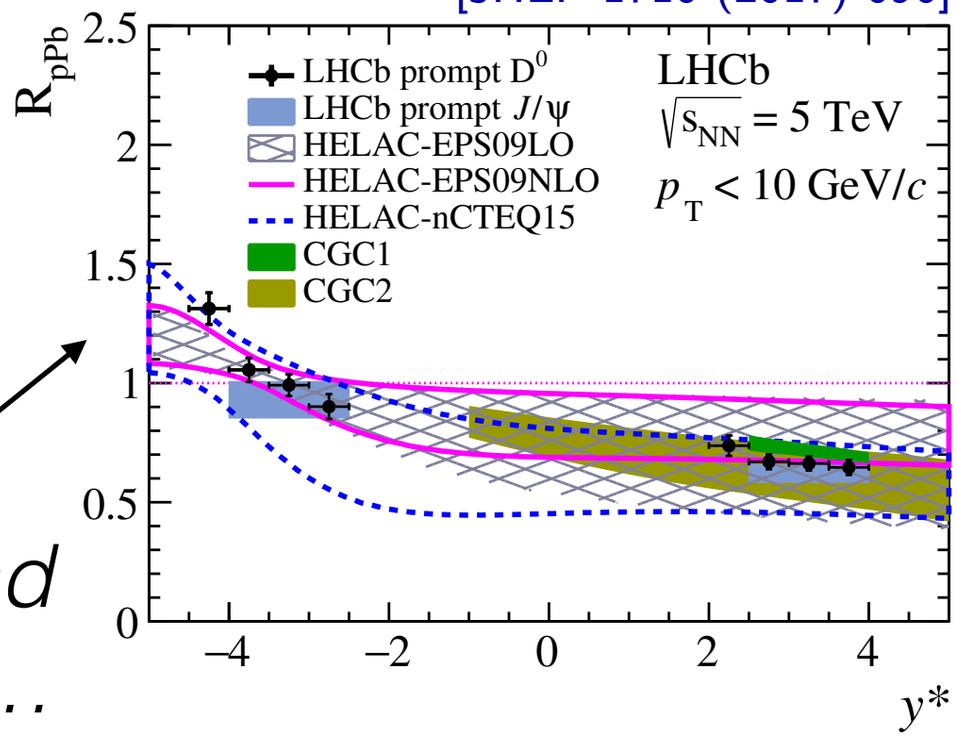
hadrons: *indirect access to parton kinematics, soft / semi-hard contribution…*

J/Ψ: *don't understand production mechanisms…*

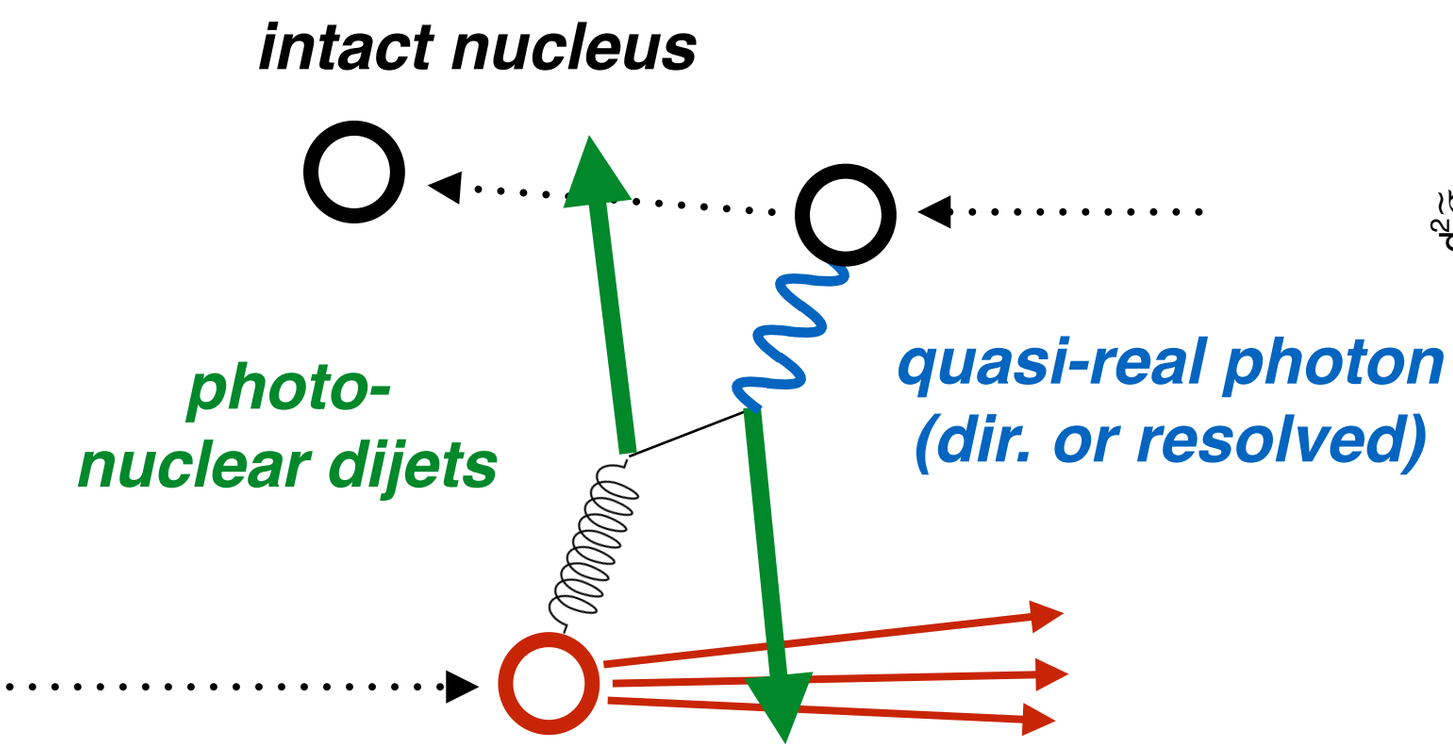


EPJC 74 (2014) 3054

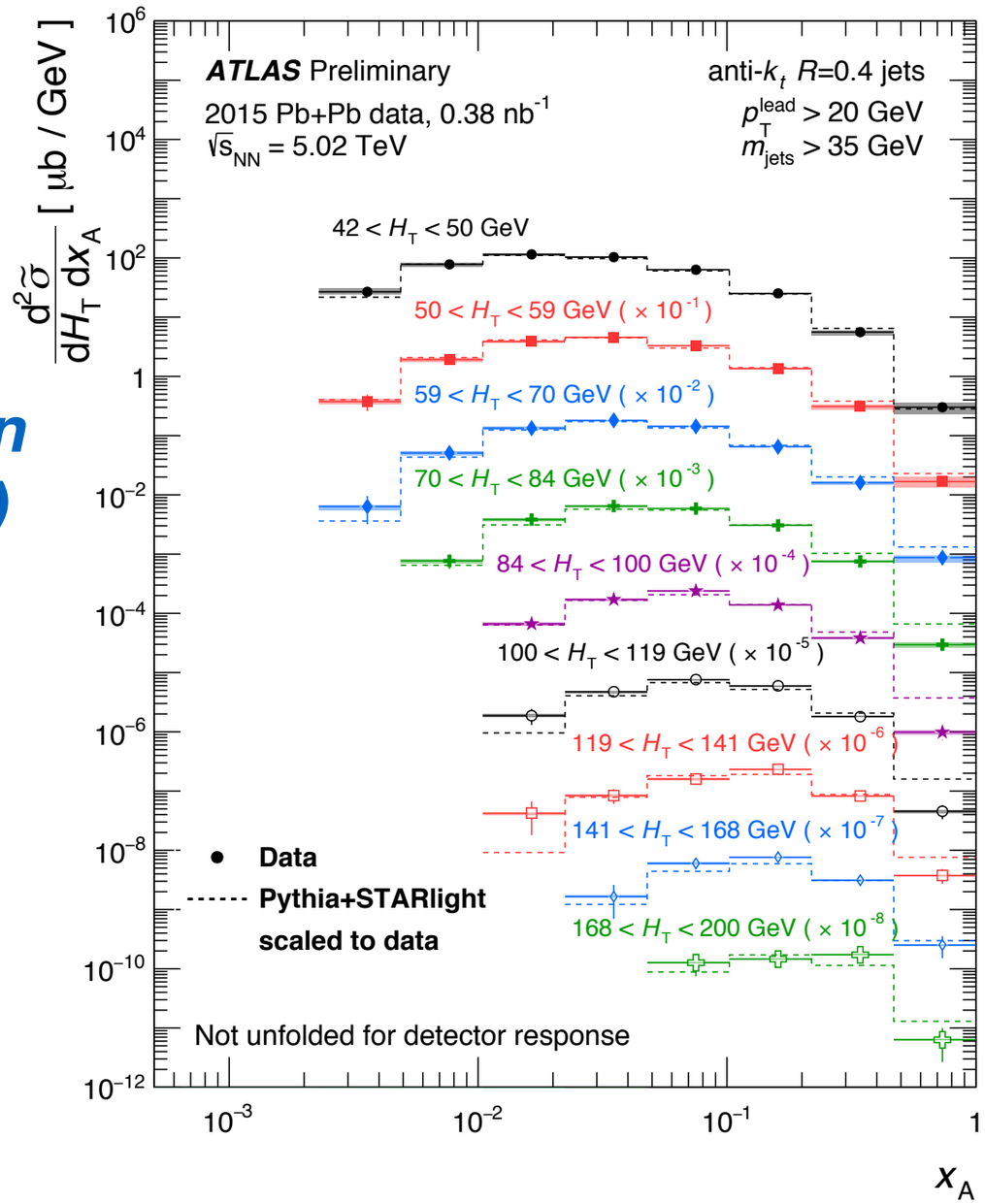
[JHEP 1710 (2017) 090]



New processes: photo-nuclear dijets in Pb+Pb w/ ATLAS

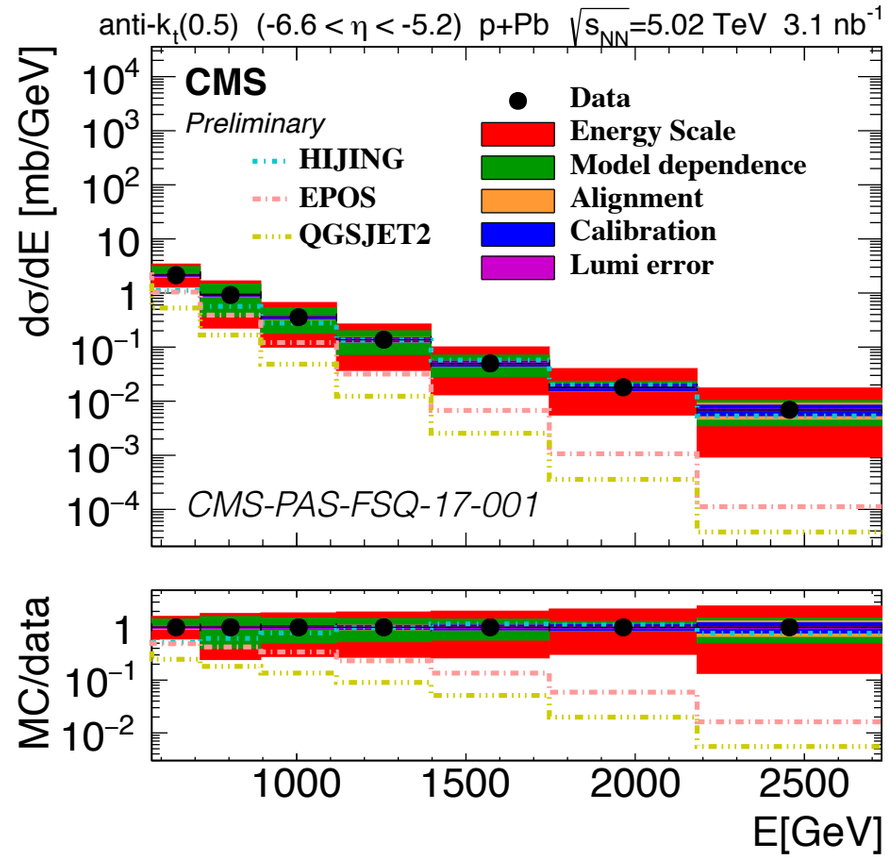


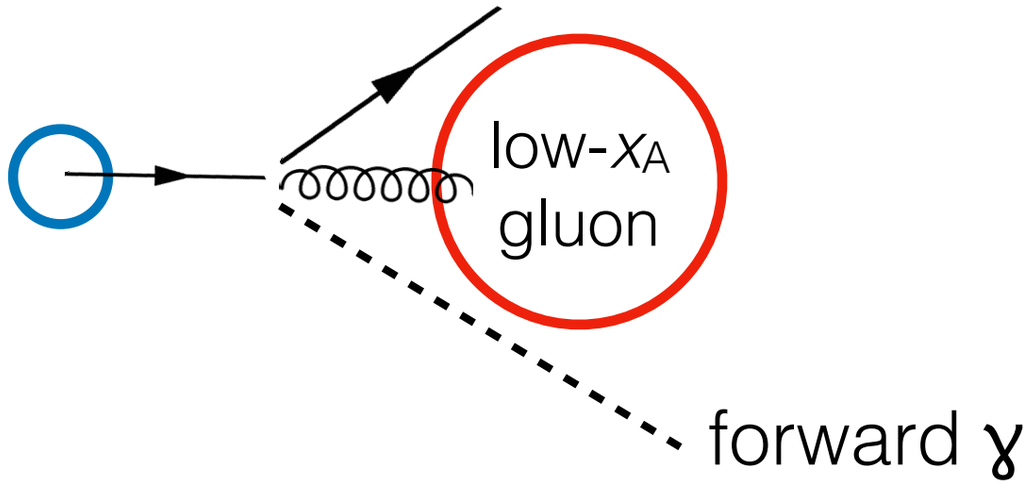
("DIS-like", measure to lower-p_T)

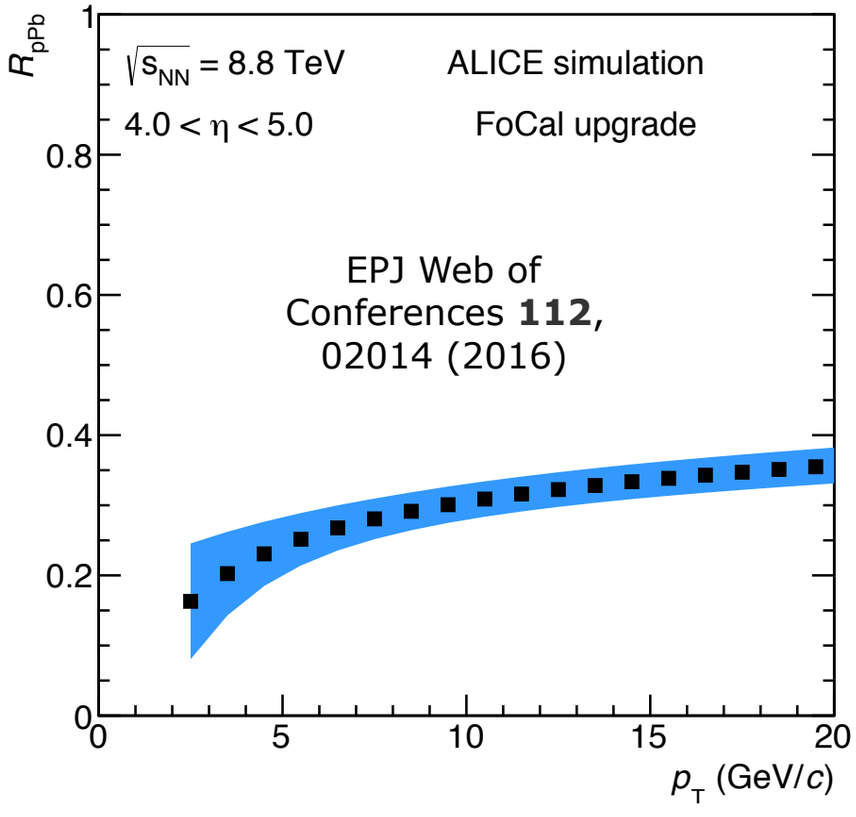


New kinematic regions: far forward probes

Very forward (y=5.2-6.6) jets in p+Pb w/ CASTOR



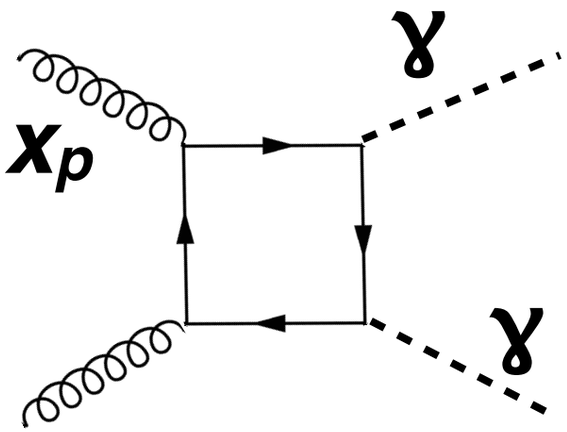




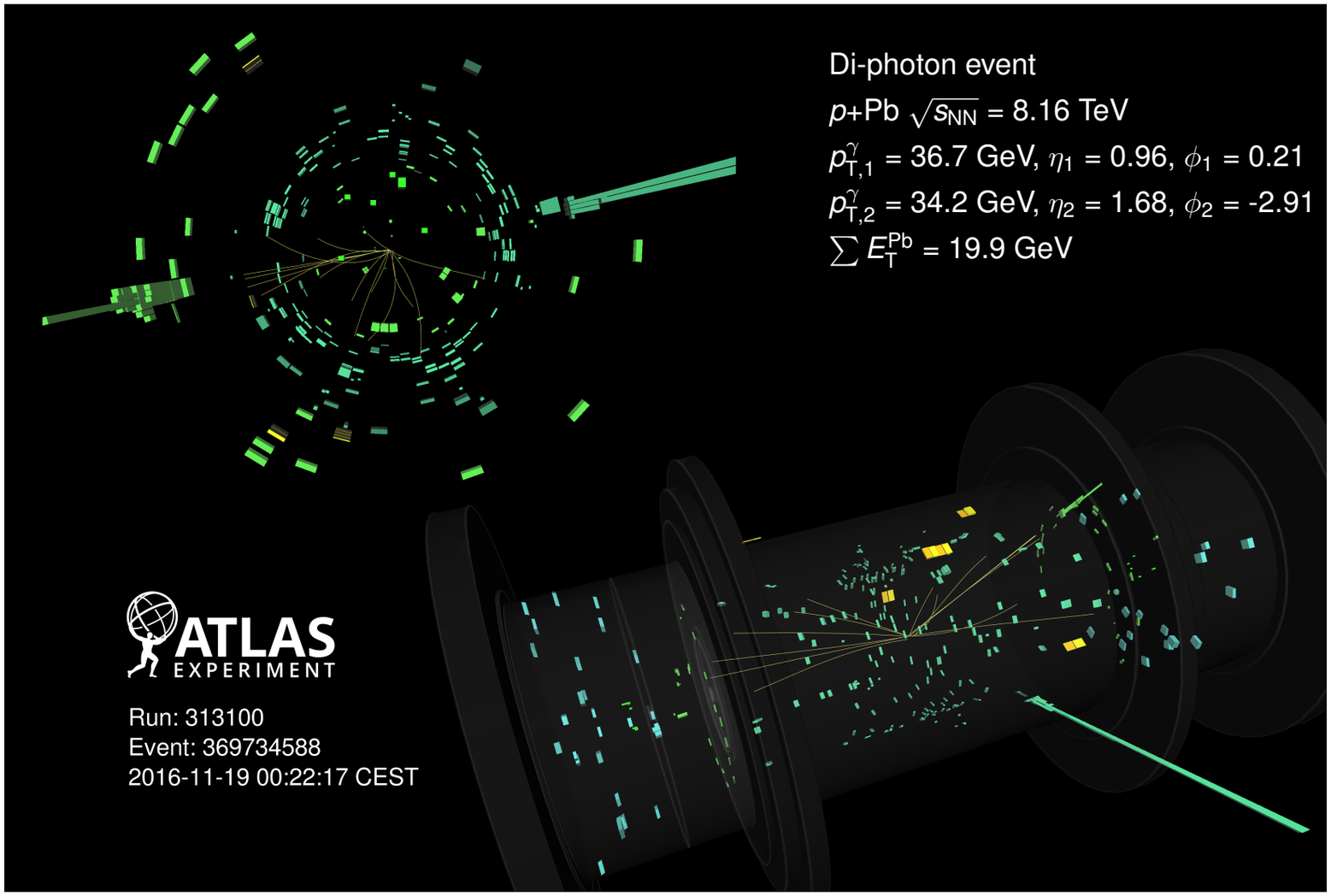
y=4-5 (ALICE FoCal upgrade)

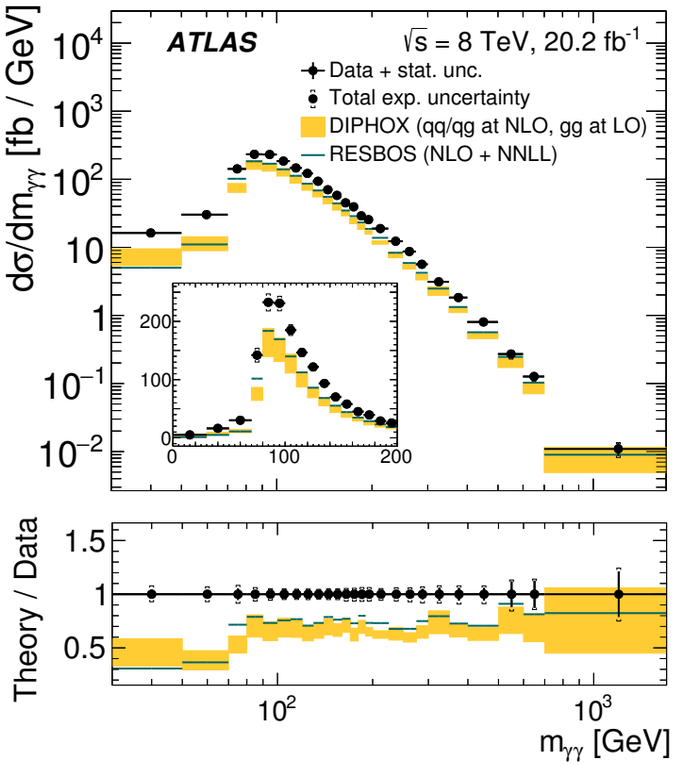
see also LHCb & PHENIX MPC-EX

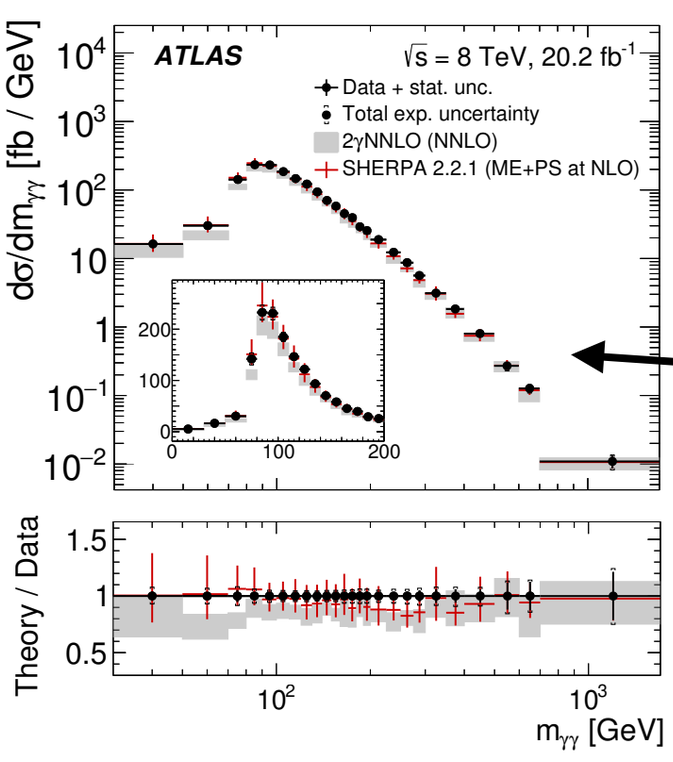
di-photon production @ LHC



low-x_A







- Detailed reference measurements at 8 TeV
- $m_{\gamma\gamma}$ compared to DIPHOX, RESBOX, NNLO, Sherpa

➡ should estimate nPDF effects!

Phys. Rev. D 95 (2017) 112005

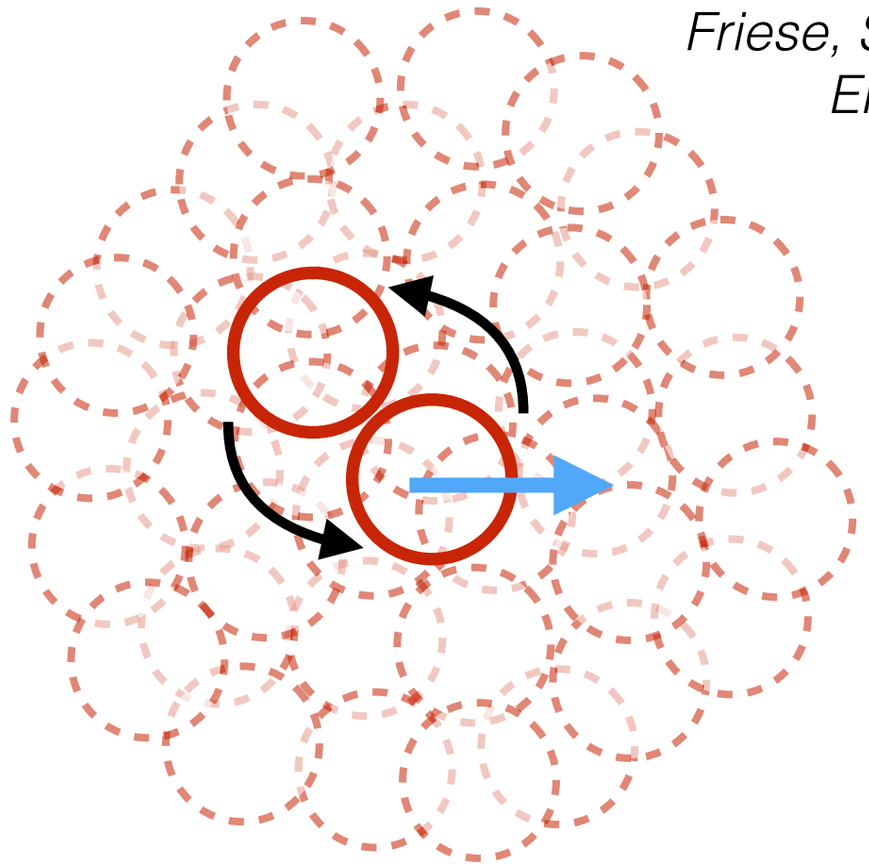
nuclear effects at large-x_A

At large-x_A, Fermi motion of nucleons in nucleus:
*… but also, short-range **p-n** correlations!*

Friese, Sargsian, Strikman
EPJC 75 (2015) 534

nucleus has total momentum p_A

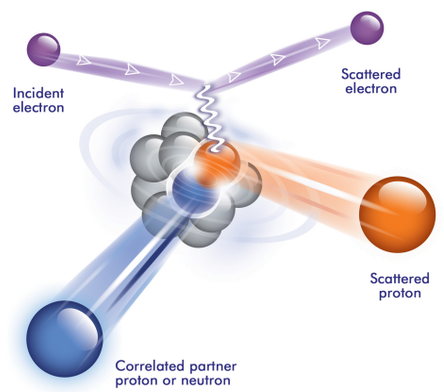
quark with p_q such that
$x_A = p_q/(p_A/A) > 1$



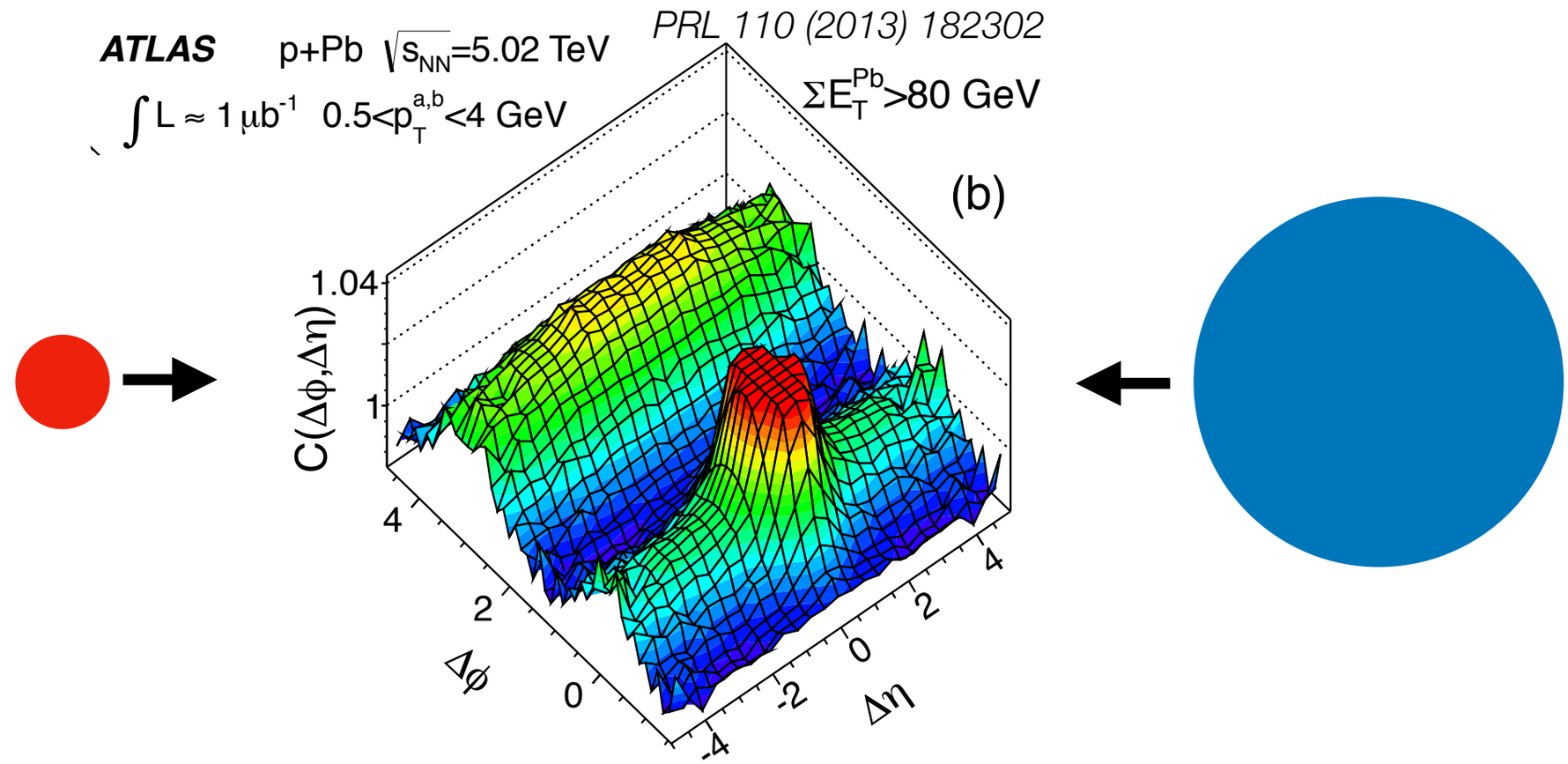
Possibility to observe $x_A > 1$ configurations!

➡ *rates are sensitive to Short-Range Correlations (SRCs) in nuclei ("medium energy" physics)*

JLab experiments

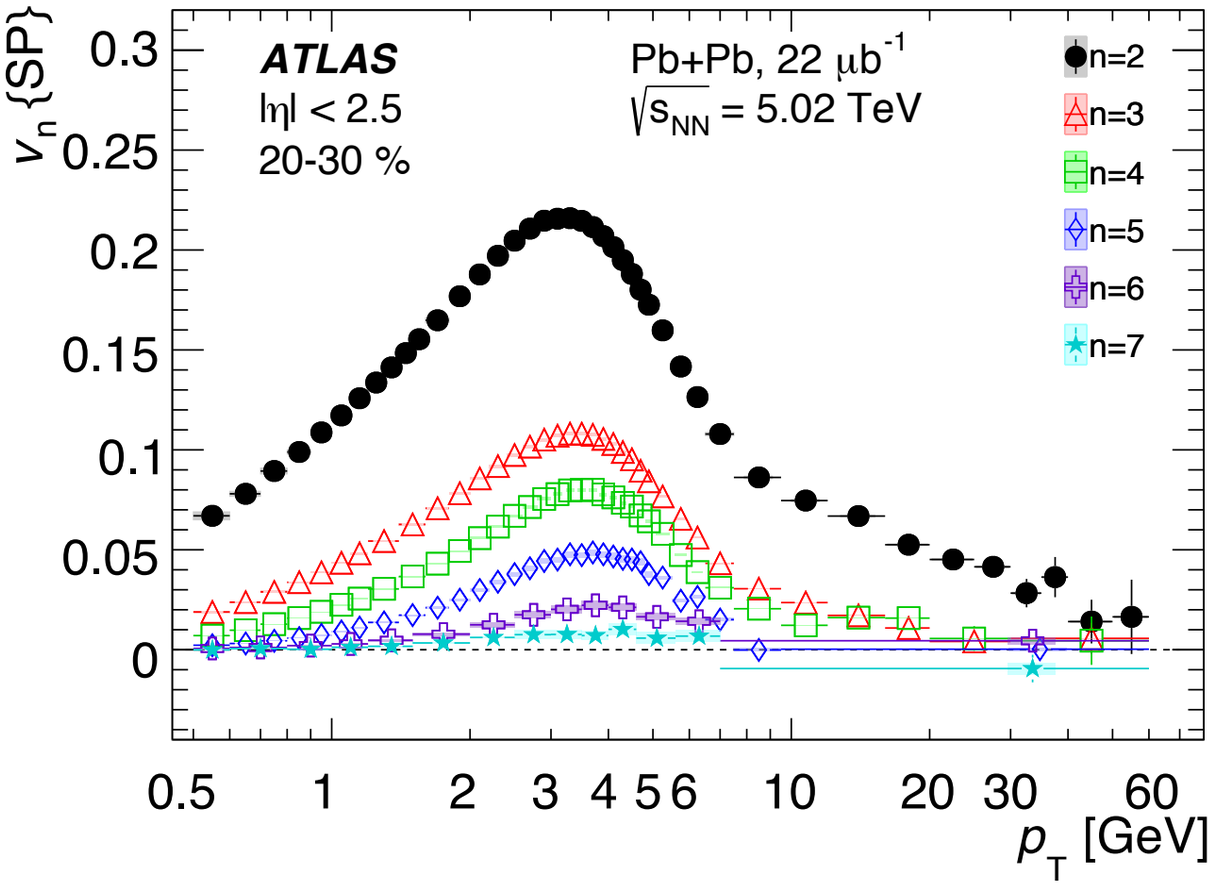


QGP in small systems?



high-p_T v_2 in ultra-central p+A?

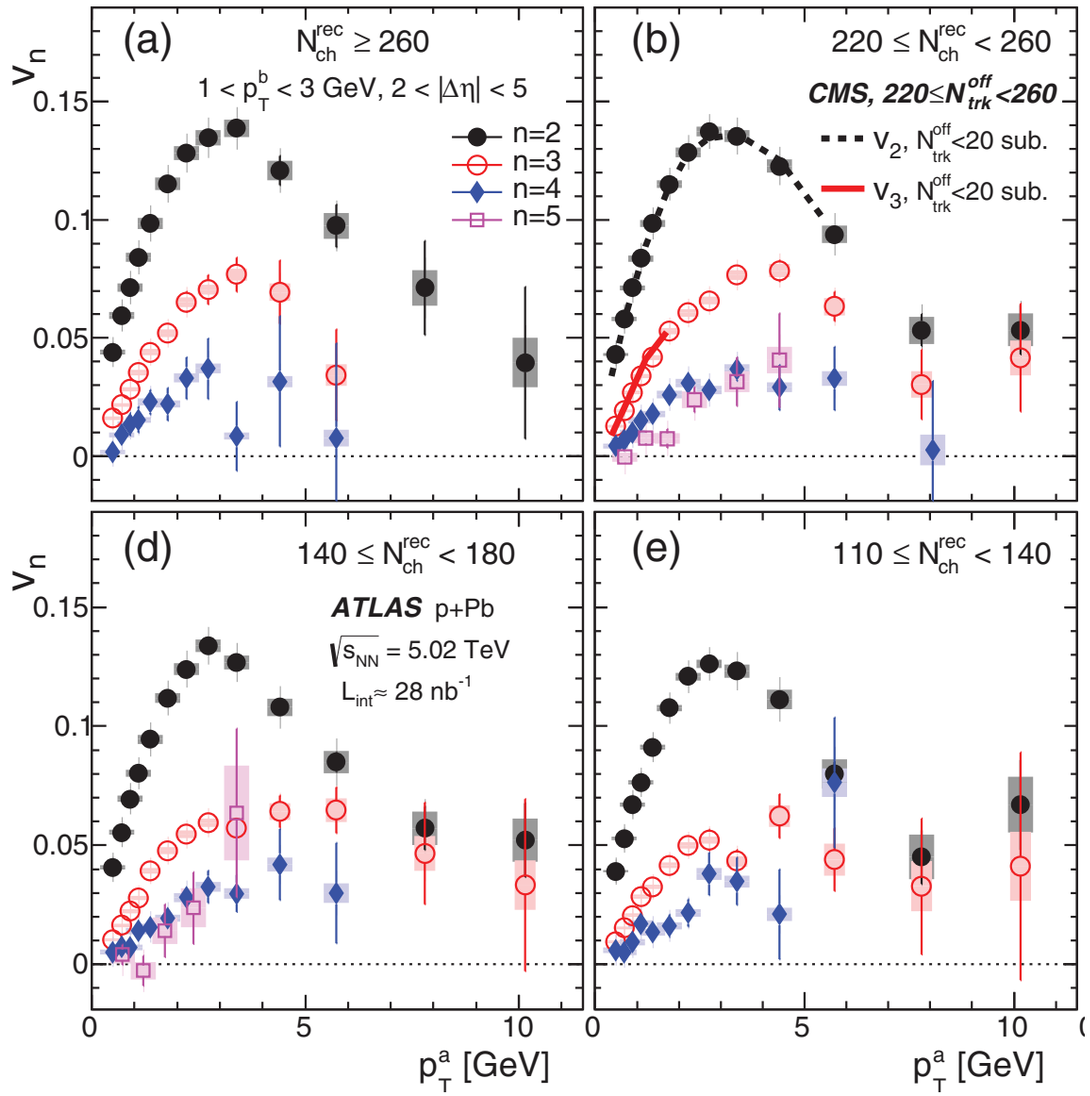
nucl-ex/1808.03951



in AA systems, high-p_T (> 10 GeV) v_2 understood as energy loss

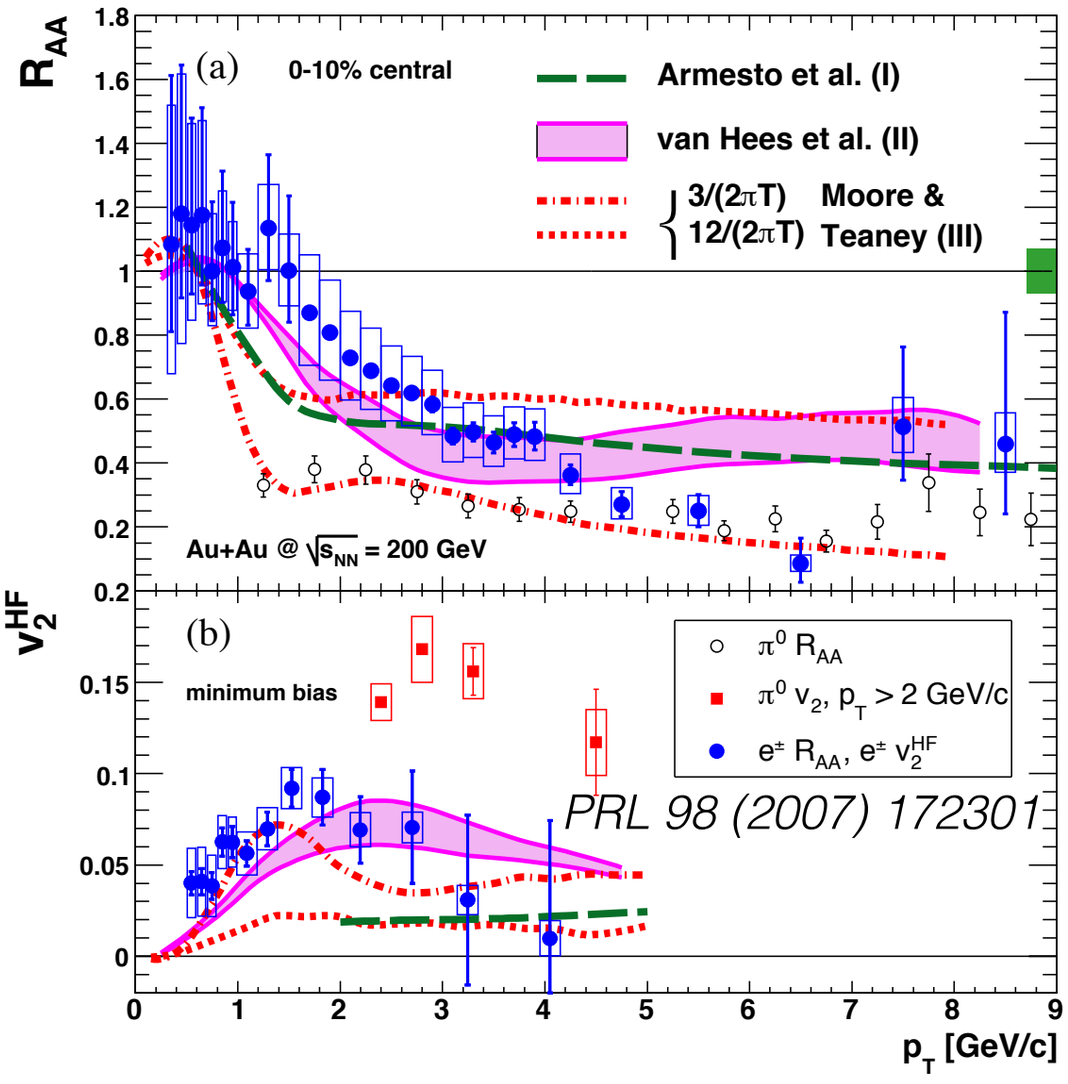
(diff. energy loss in vs. out of plane)

PRC 90 (2014) 044906



In 2013 p+Pb data, large v_2 @ p_T ~ 10 GeV in 0-1% p+Pb…

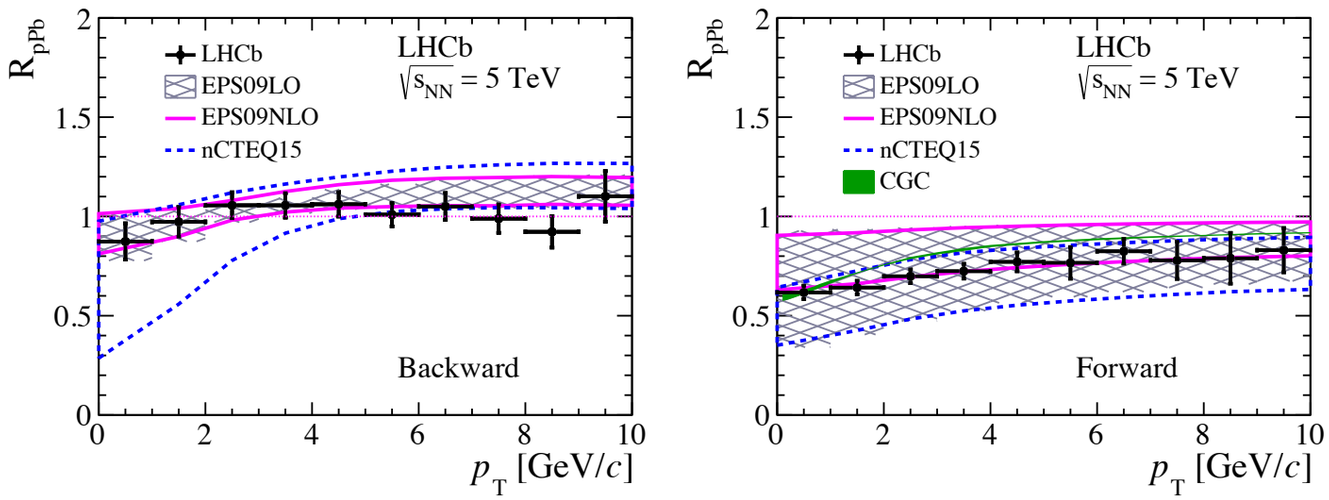
collective behavior of HF quarks



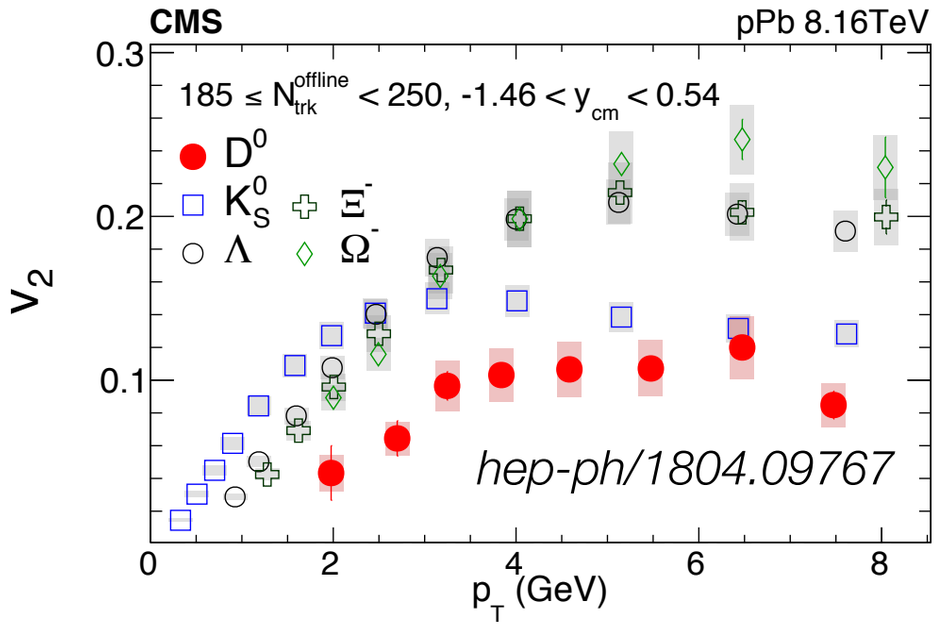
substantial E-loss & flow of HF electrons in RHIC Au+Au

➡ *η/s = 1/4π bound!*

JHEP 10 (2017) 090



R_{pA} compatible with only nPDF / saturation effects…



but very large "flow"(??)

➡ *how to understand soft & hard physics together?*

jet quenching in *p*+A?

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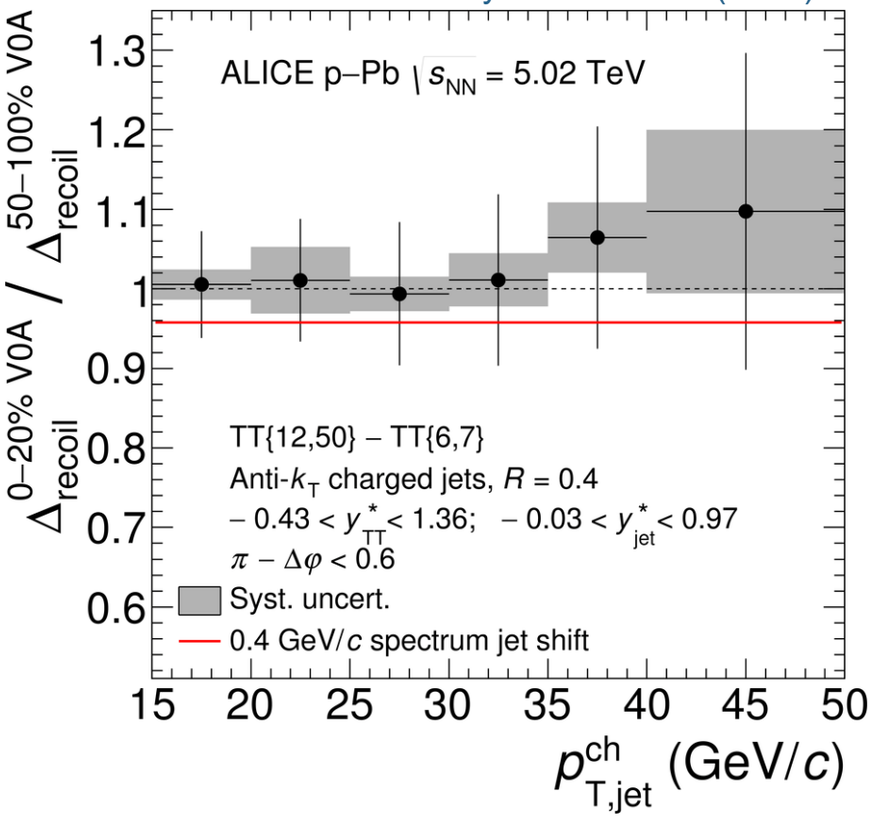
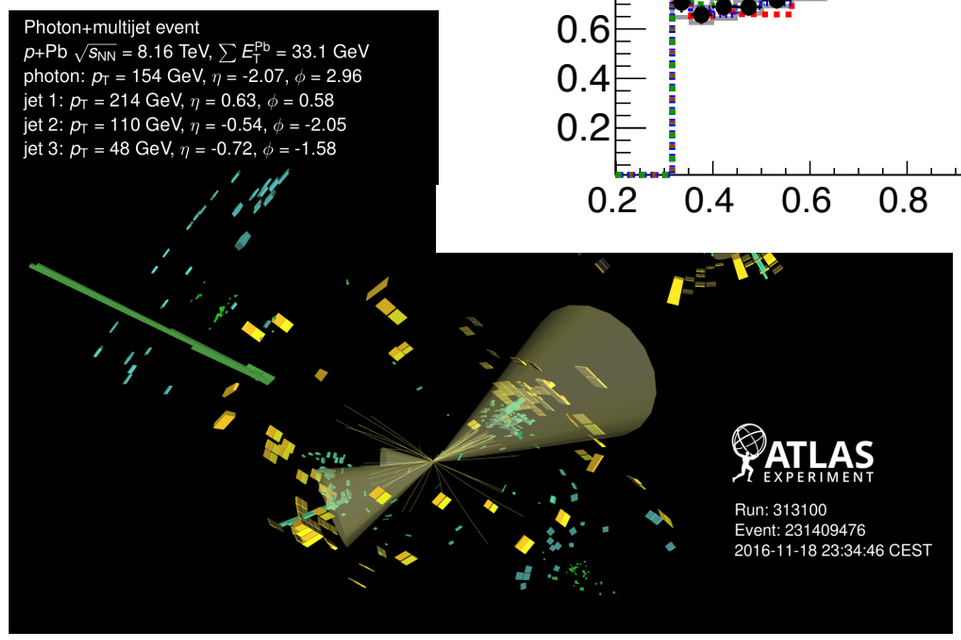
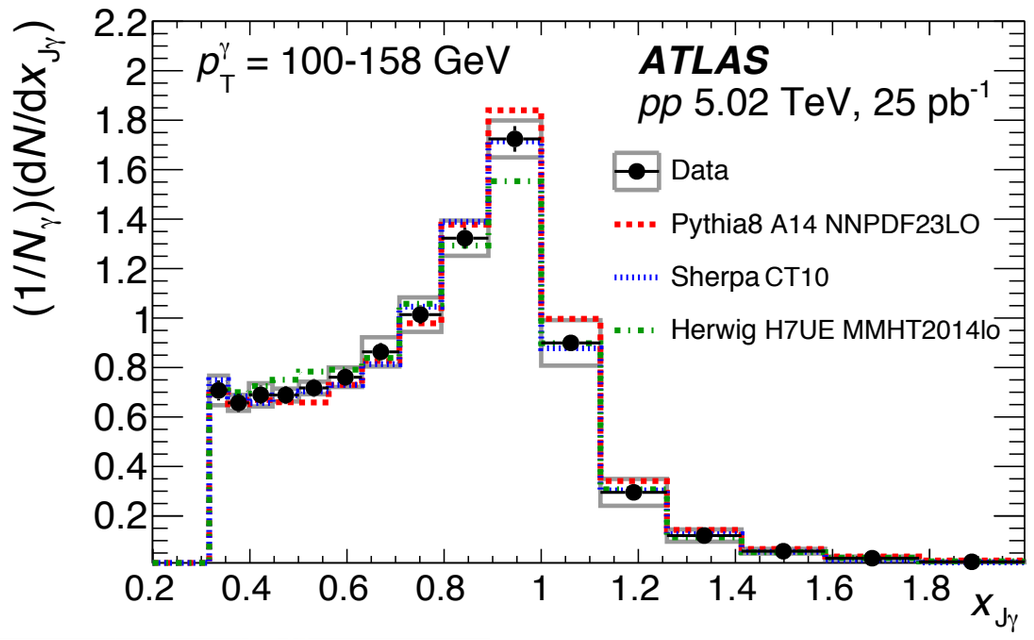






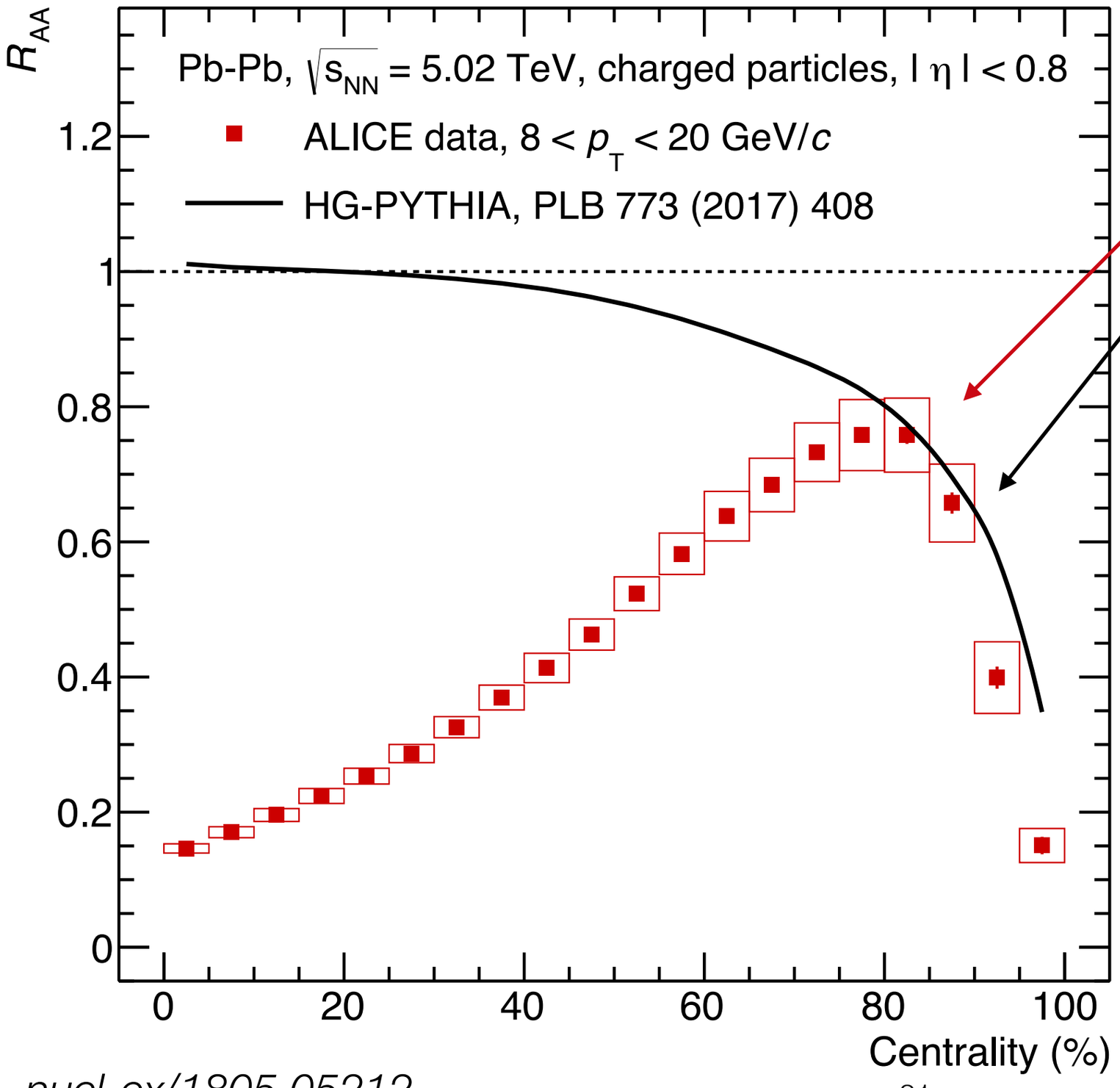
Phys. Lett. B 789 (2019) 167

unmodified recoil jet distributions in 0-20% events

explore with high-stats γ+jet in p+A…

is there an onset of jet quenching?
or do we mis-understand a high-p_T v2?

System size dependence of energy loss



Pb+Pb data

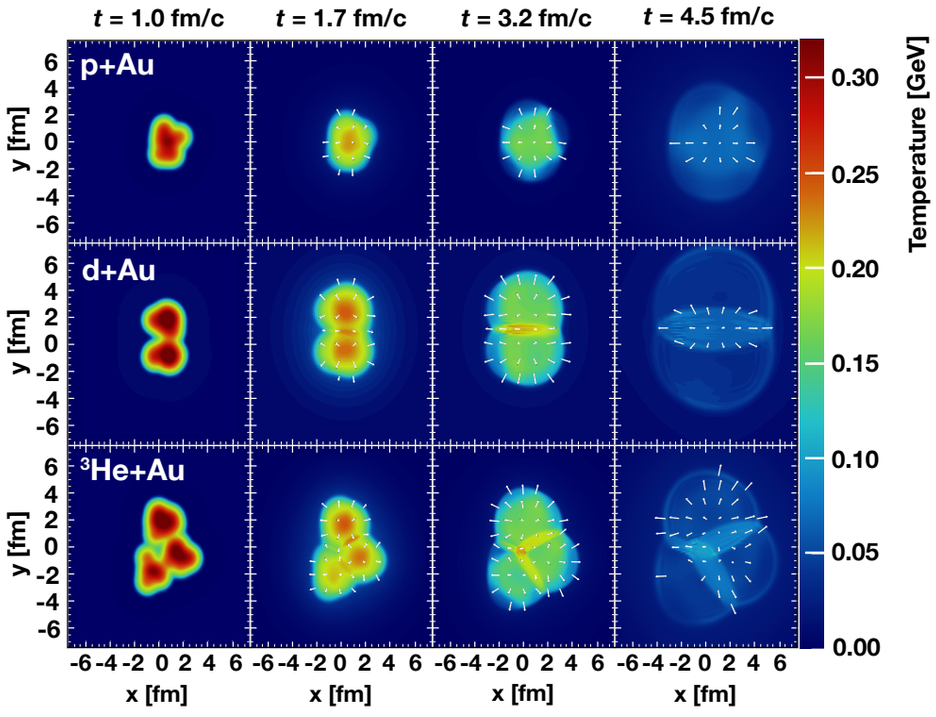
artificial effect *from bias in geometric classification*

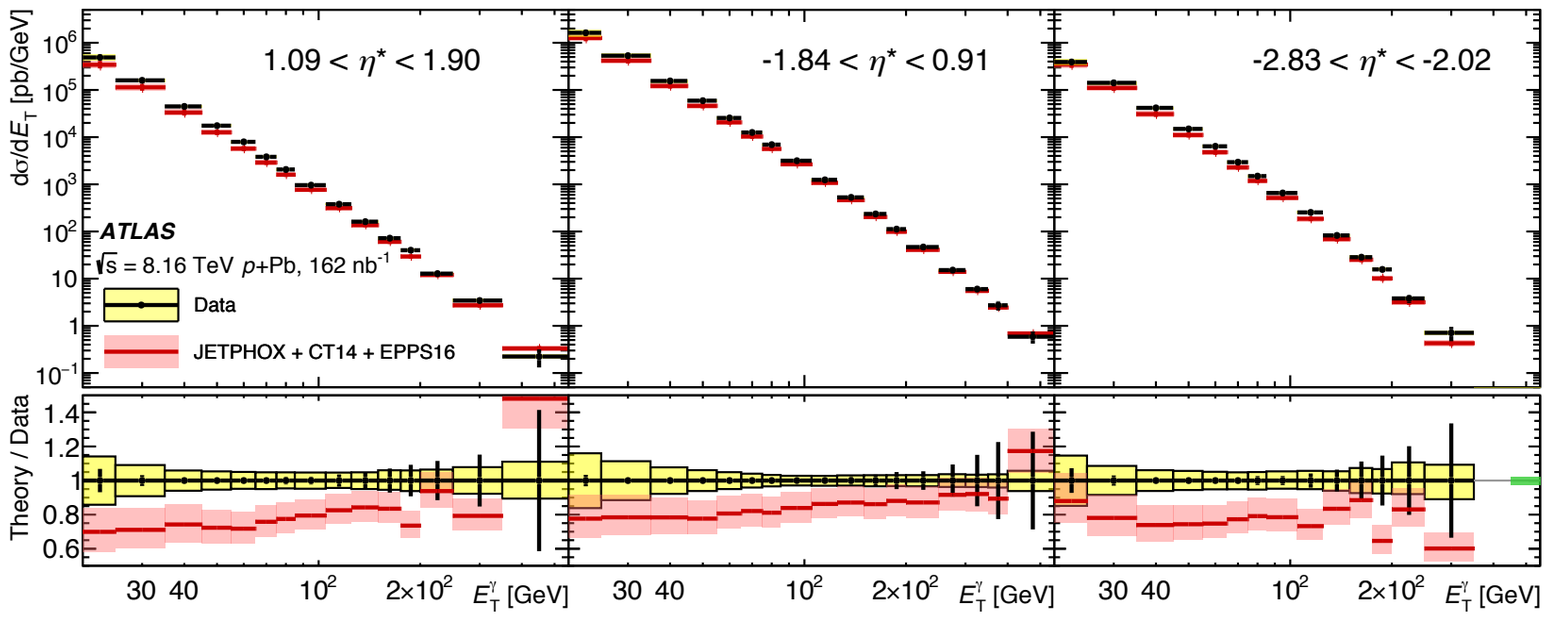
jet quenching may turn "off" much sooner than expected…

… very interesting to run O+O, Ar+Ar, etc. at LHC

nucl-ex/1805.05212

future *p*+A physics

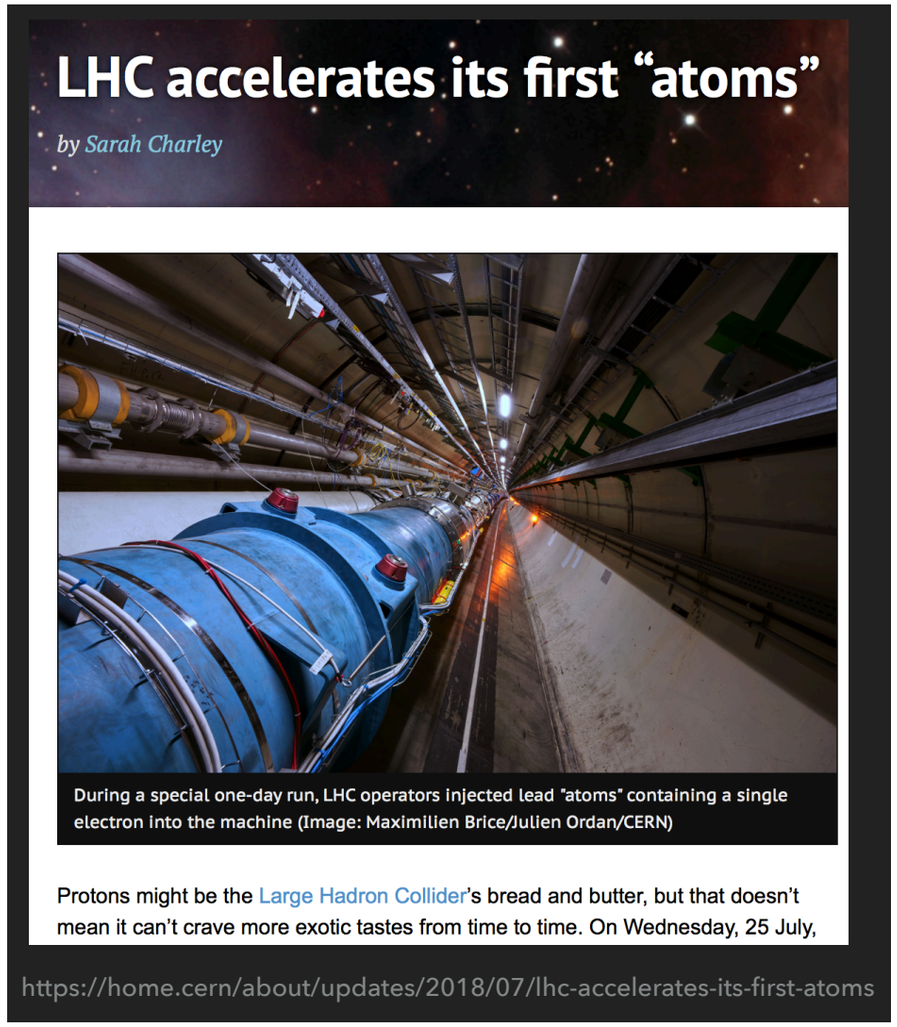


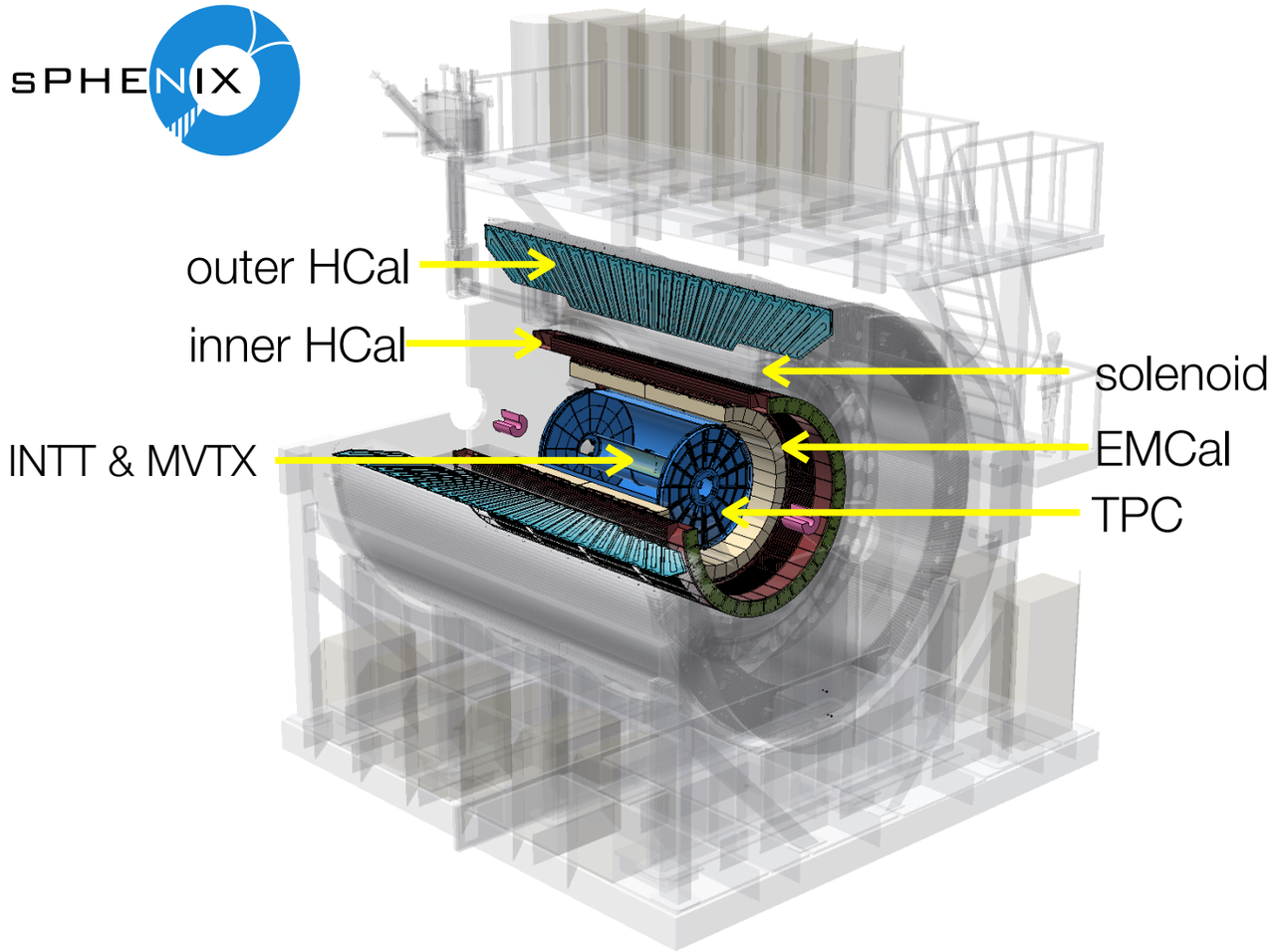


collision species versatility @ RHIC

large aperture & kinematic reach @ LHC

future *p*+A physics





collision species versatility @ ~~RHIC~~ **LHC**

large aperture & kinematic reach @ ~~LHC~~ **RHIC**

O+O, Ar+Ar, e+Pb(?)

sPHENIX detector