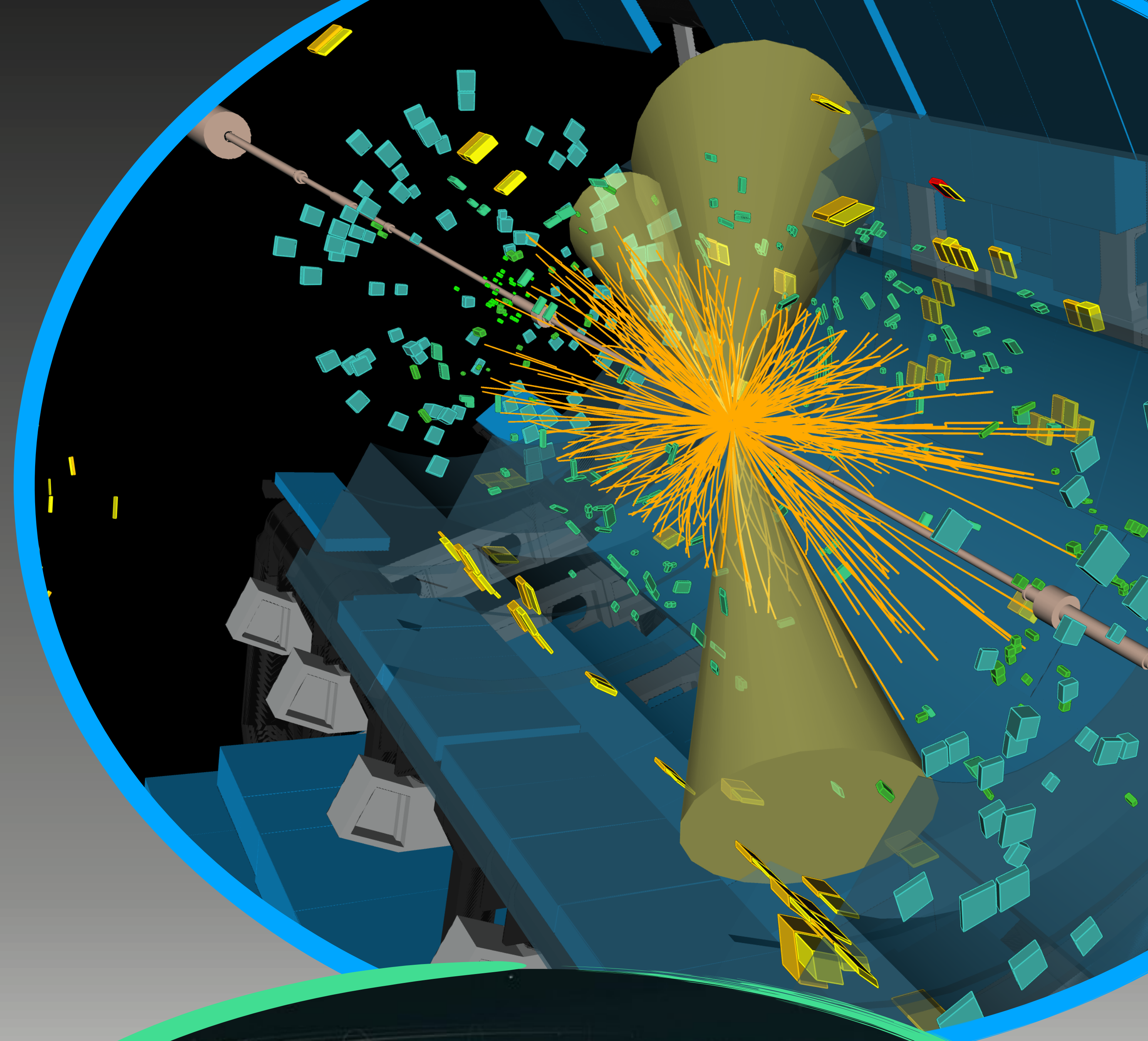
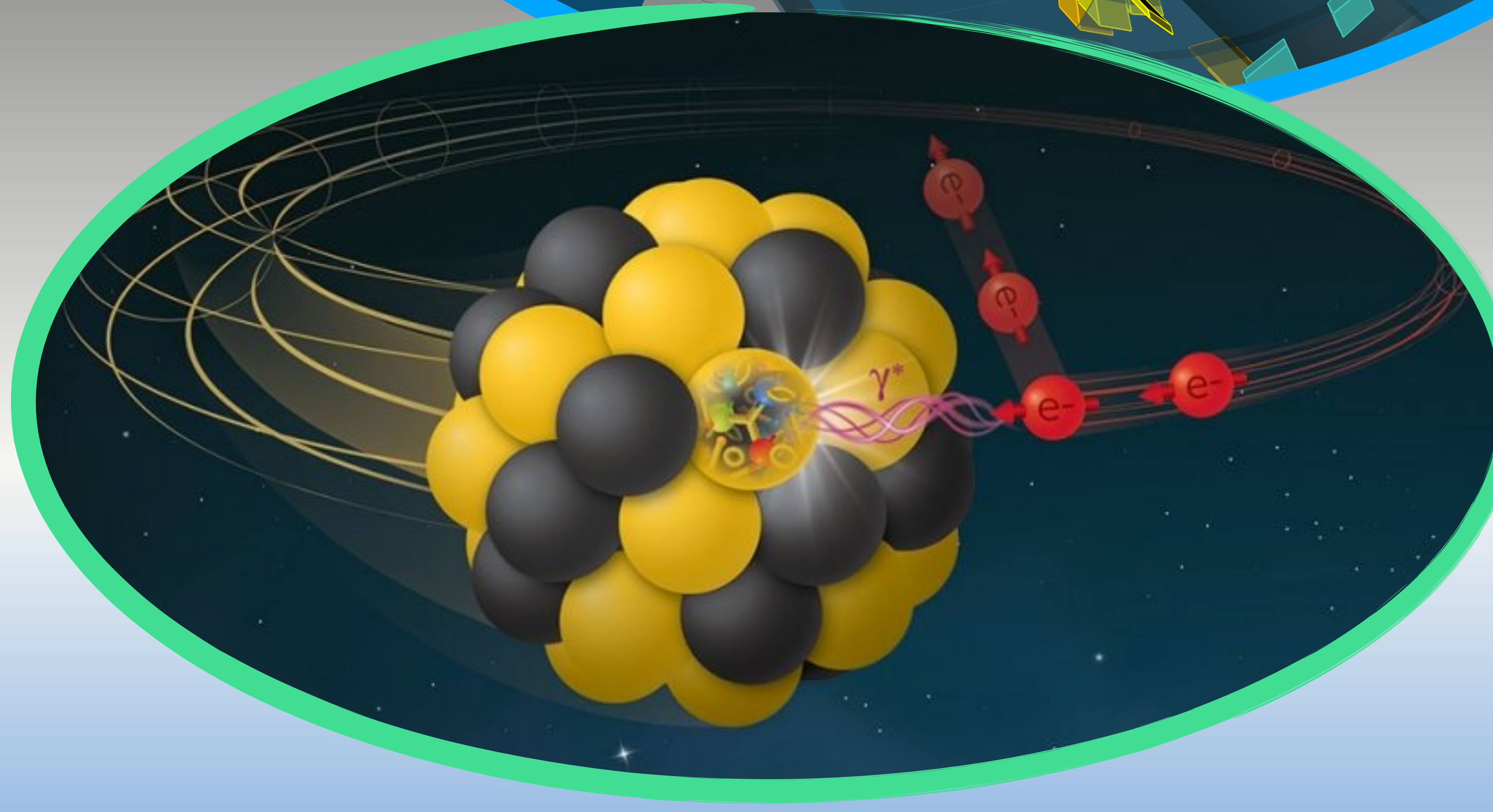
Opportunities for Heavy Ion at ATLAS with Phase-II upgrades and synergies with the EIC





Riccardo Longo

On behalf of the ATLAS Collaboration

September 22nd 2025

Joint ECFA-NuPECC-APPEC Workshop
“Synergies between the EIC and the LHC”

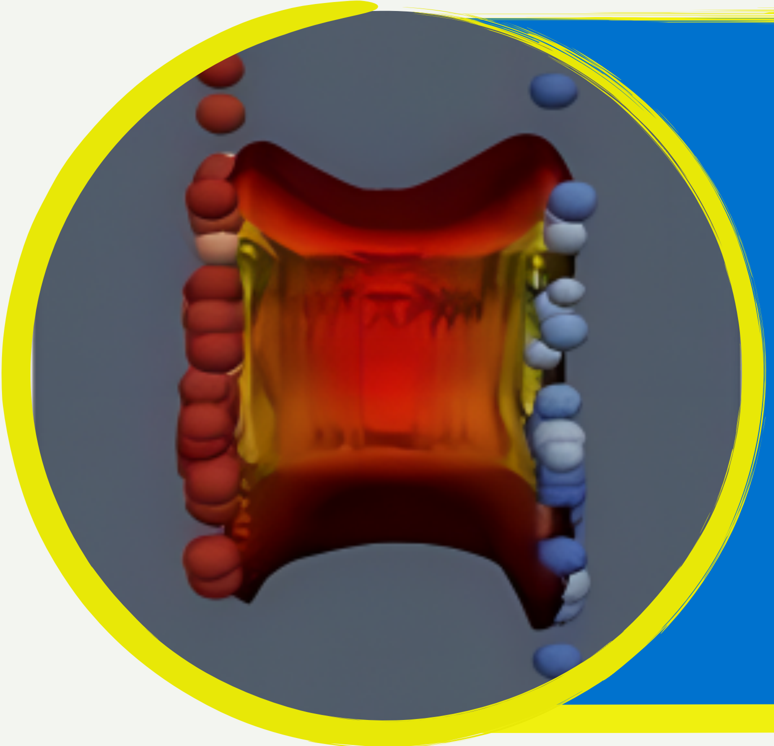
UNIVERSITÀ DI TORINO

MUR
Ministero dell'Università e della Ricerca

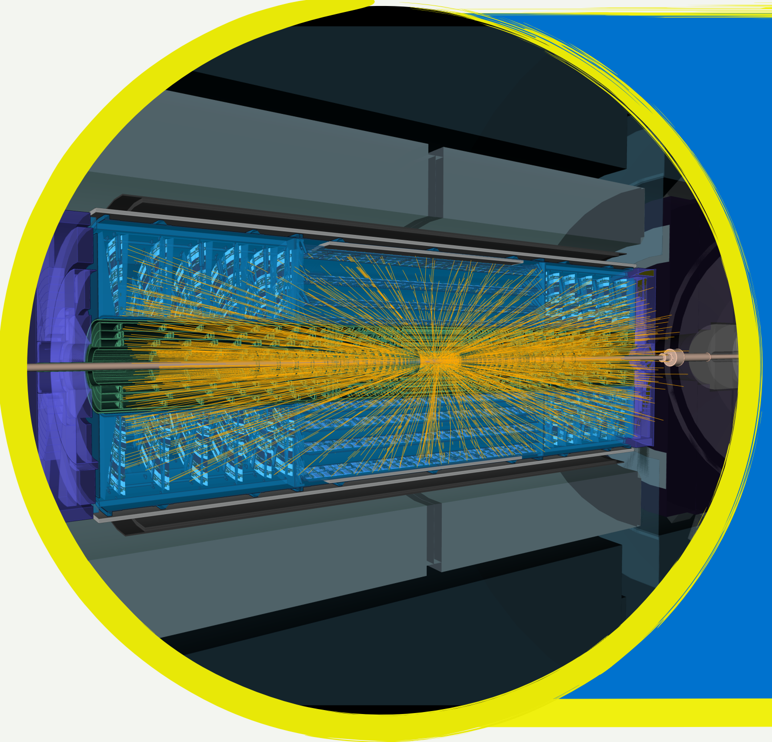
ATLAS EXPERIMENT

INFN TORINO

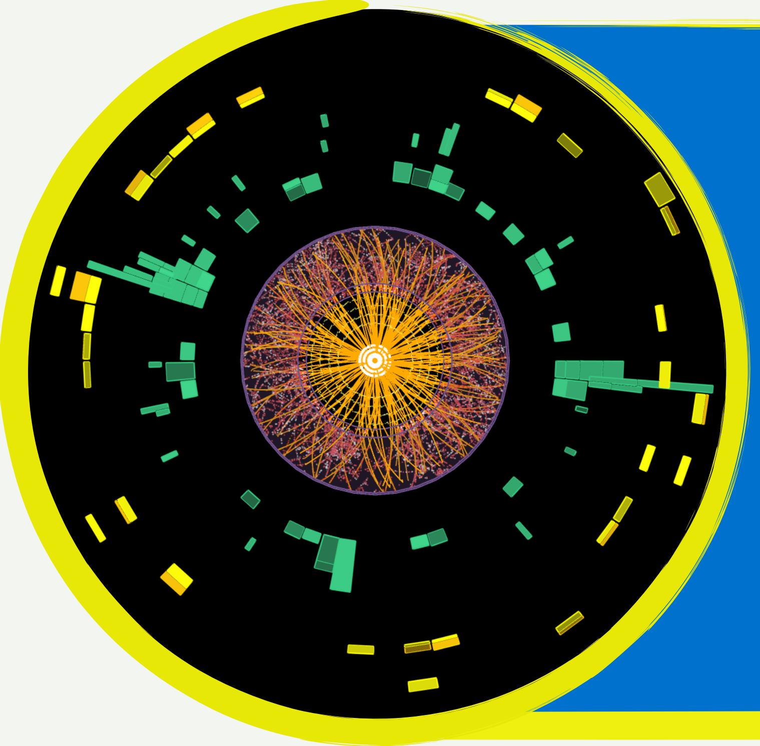
Outline



Introduction

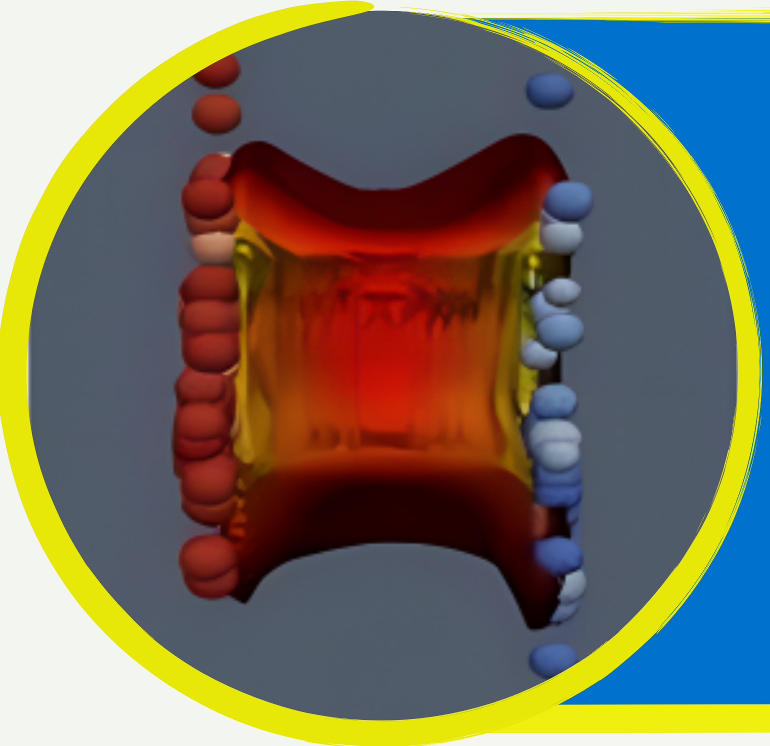


ATLAS Phase-II upgrades



Synergies between the ATLAS HI program & the EIC

Outline



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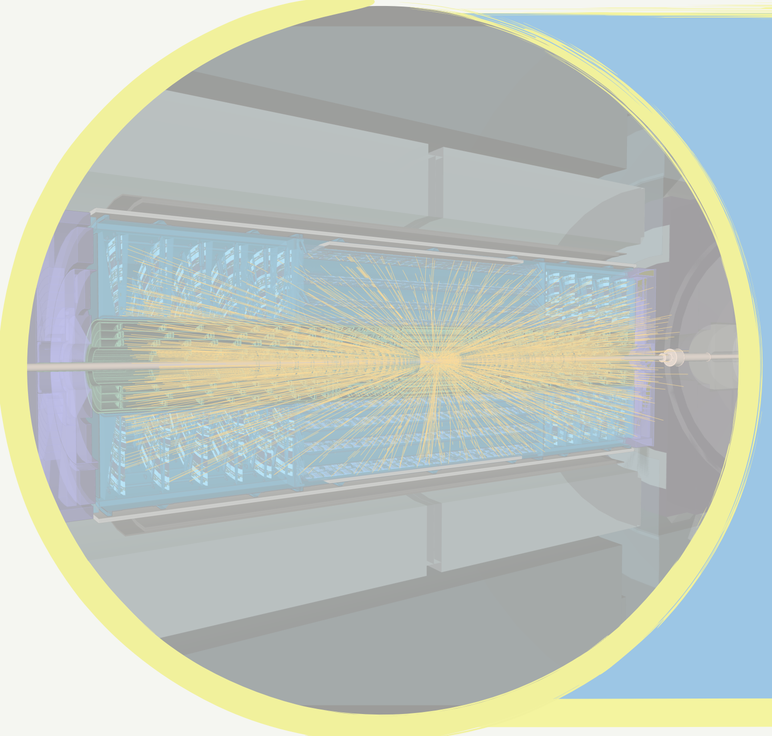

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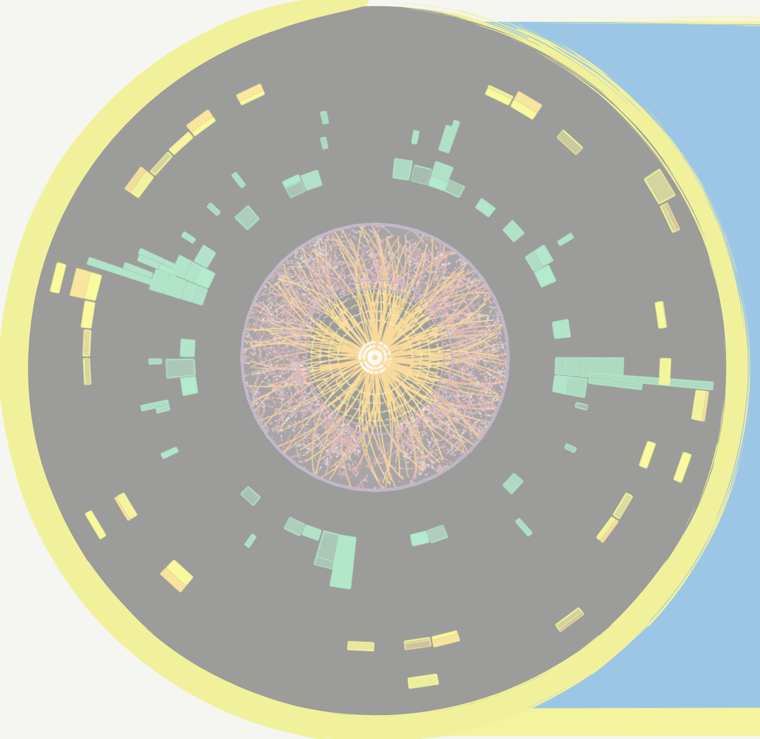
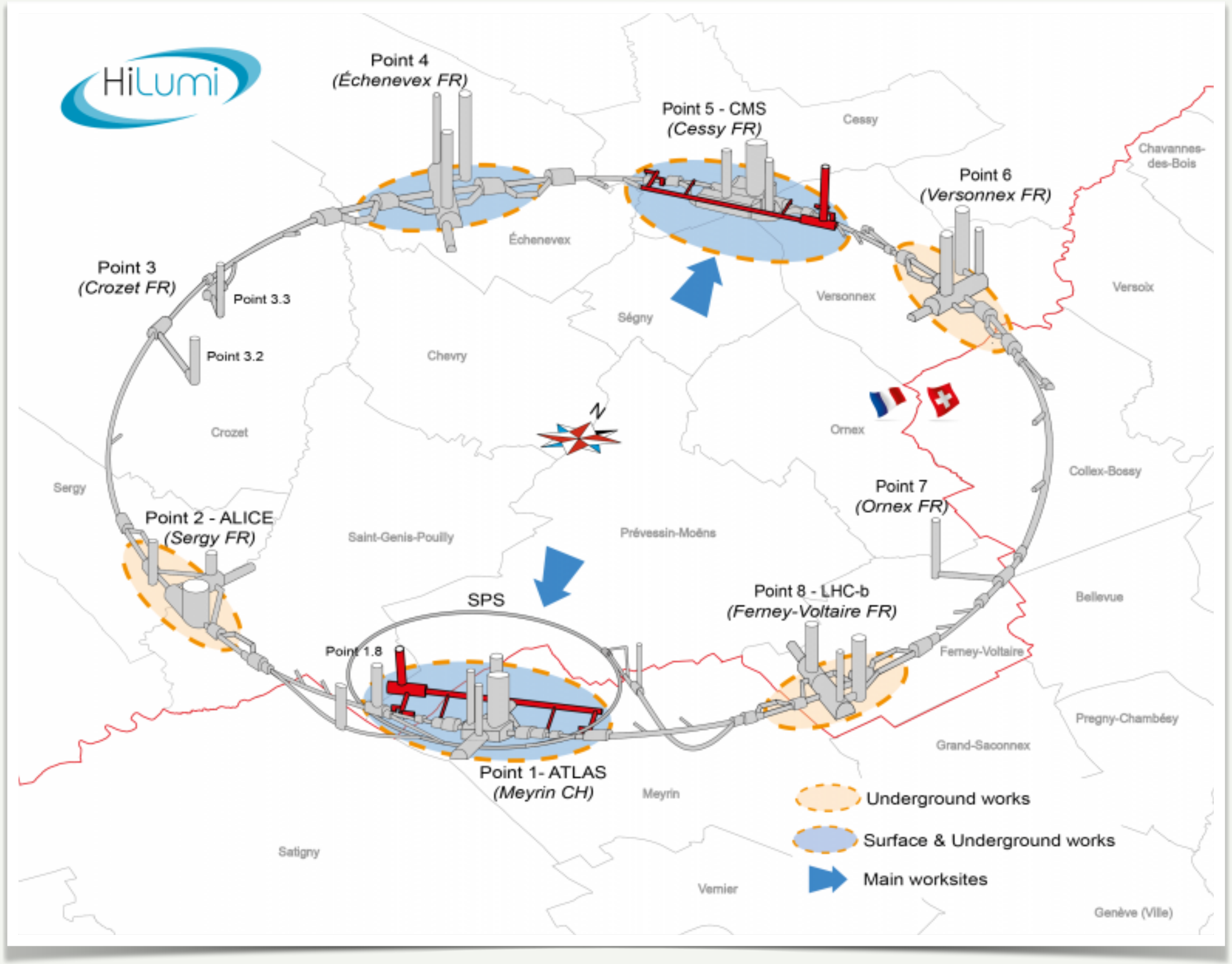


Synergies between the ATLAS HI program & the EIC

HL-LHC



LHC: until mid 2026

Pb+Pb runs in 2023 and 2024. Very successful light-ion run in 2025!

More Pb+Pb to come this year, next year still TBD

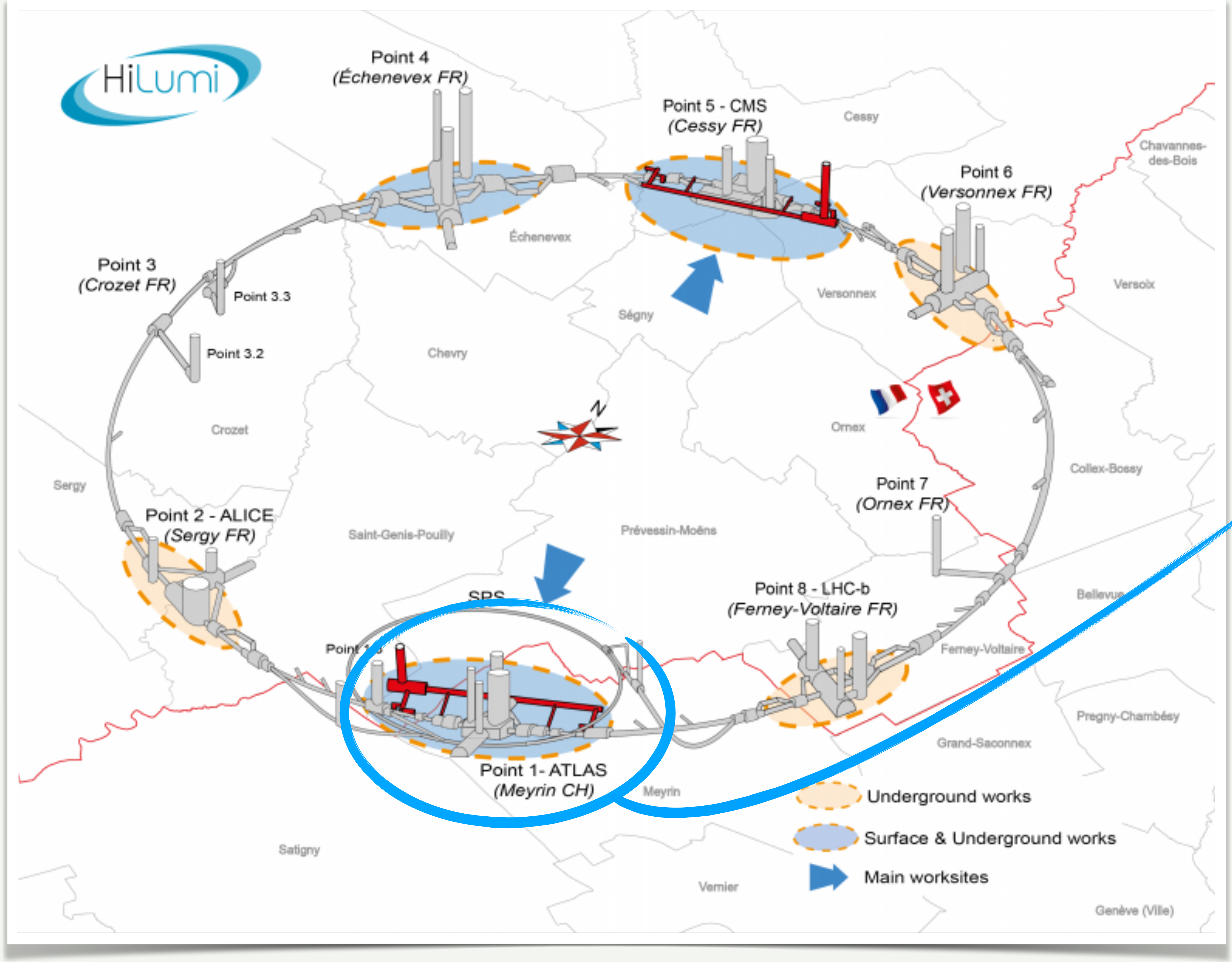
HL-LHC: starting 2030++

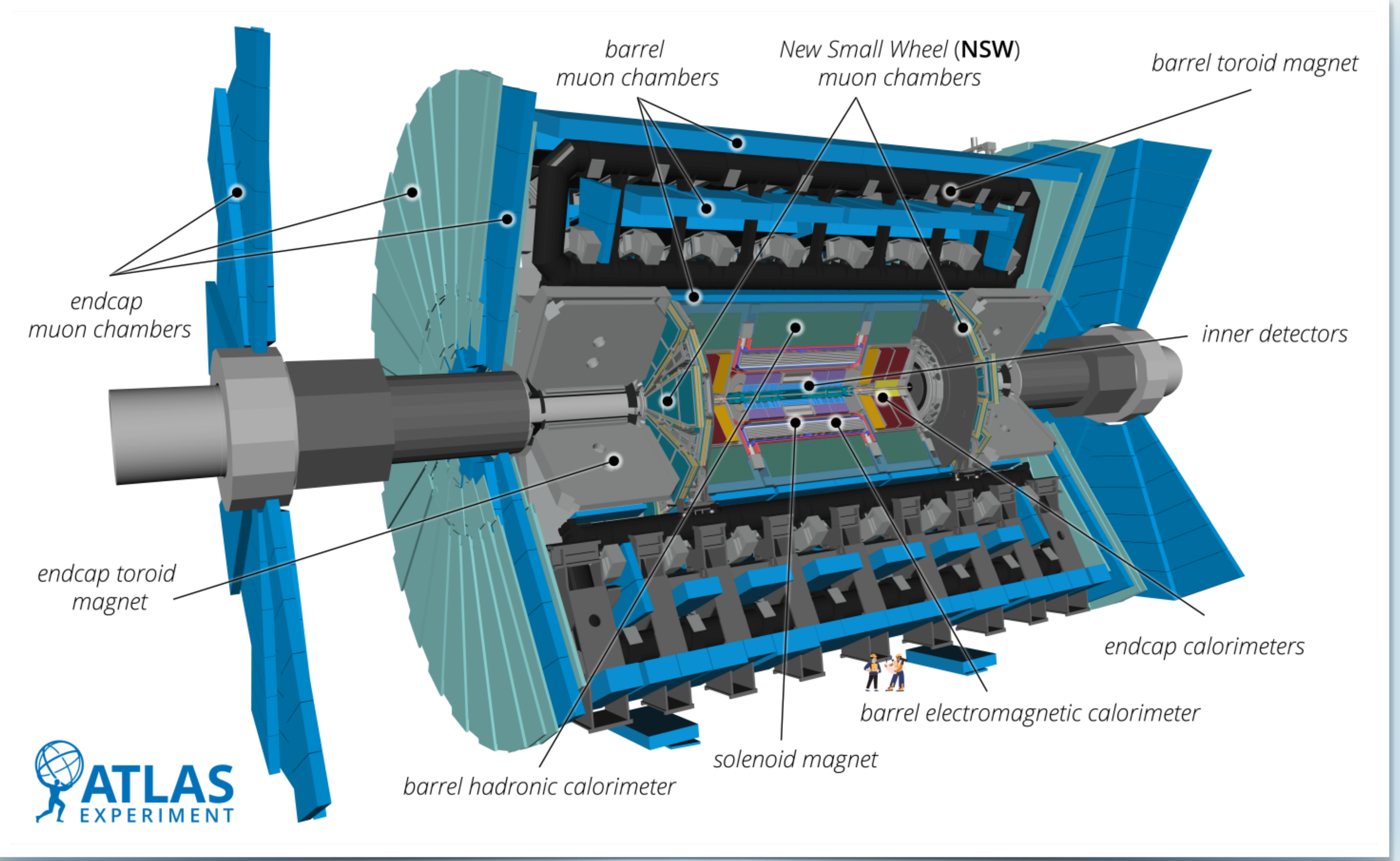
Will be the **only high-energy p+A/A+A collider after RHIC shutdown** and transition to the EIC.

HI program officially in the schedule for Run 4

Discussion about HI in Run 5 and beyond to ramp up soon

ATLAS @ the LHC





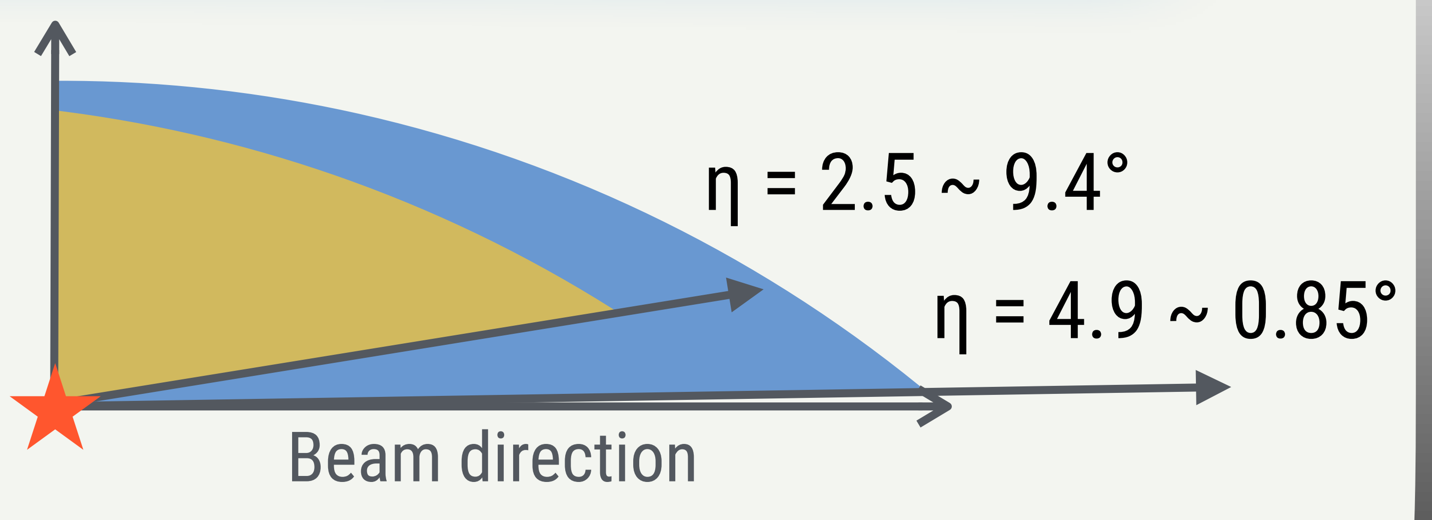
Hermetic detector

Tracker acceptance:

|η| < 2.5

Calorimeter acceptance:

|η| < 4.9



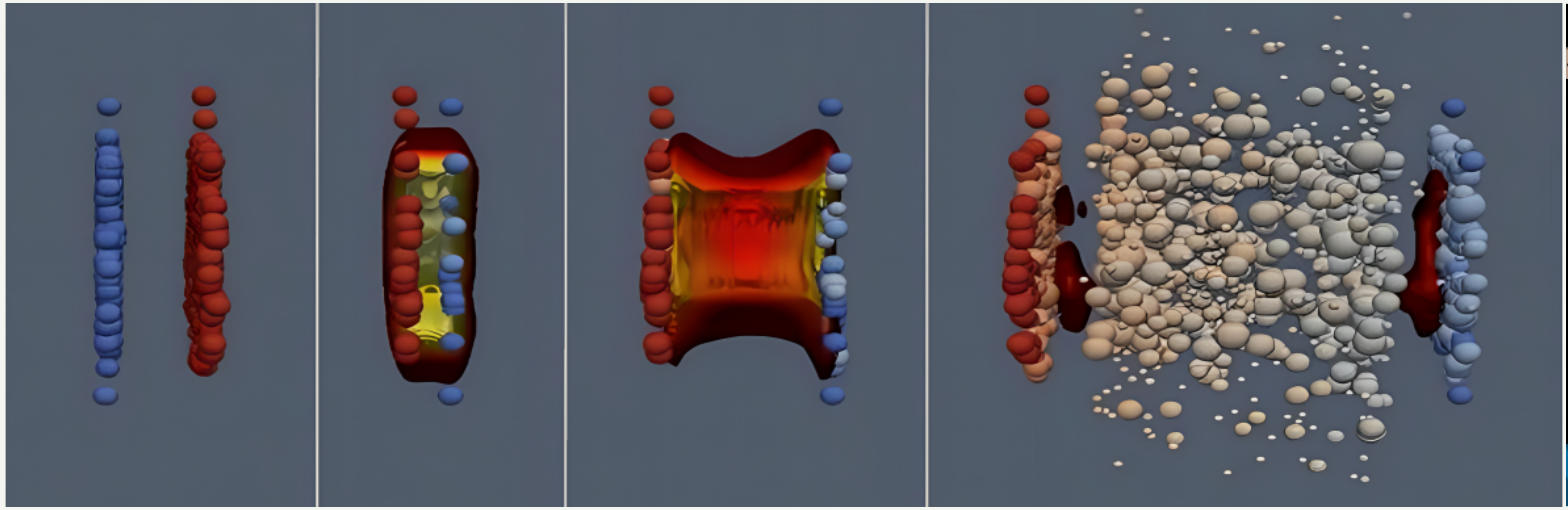
High-performance multi-purpose detector: can detect with high efficiency both p+p and heayv-ion collisions

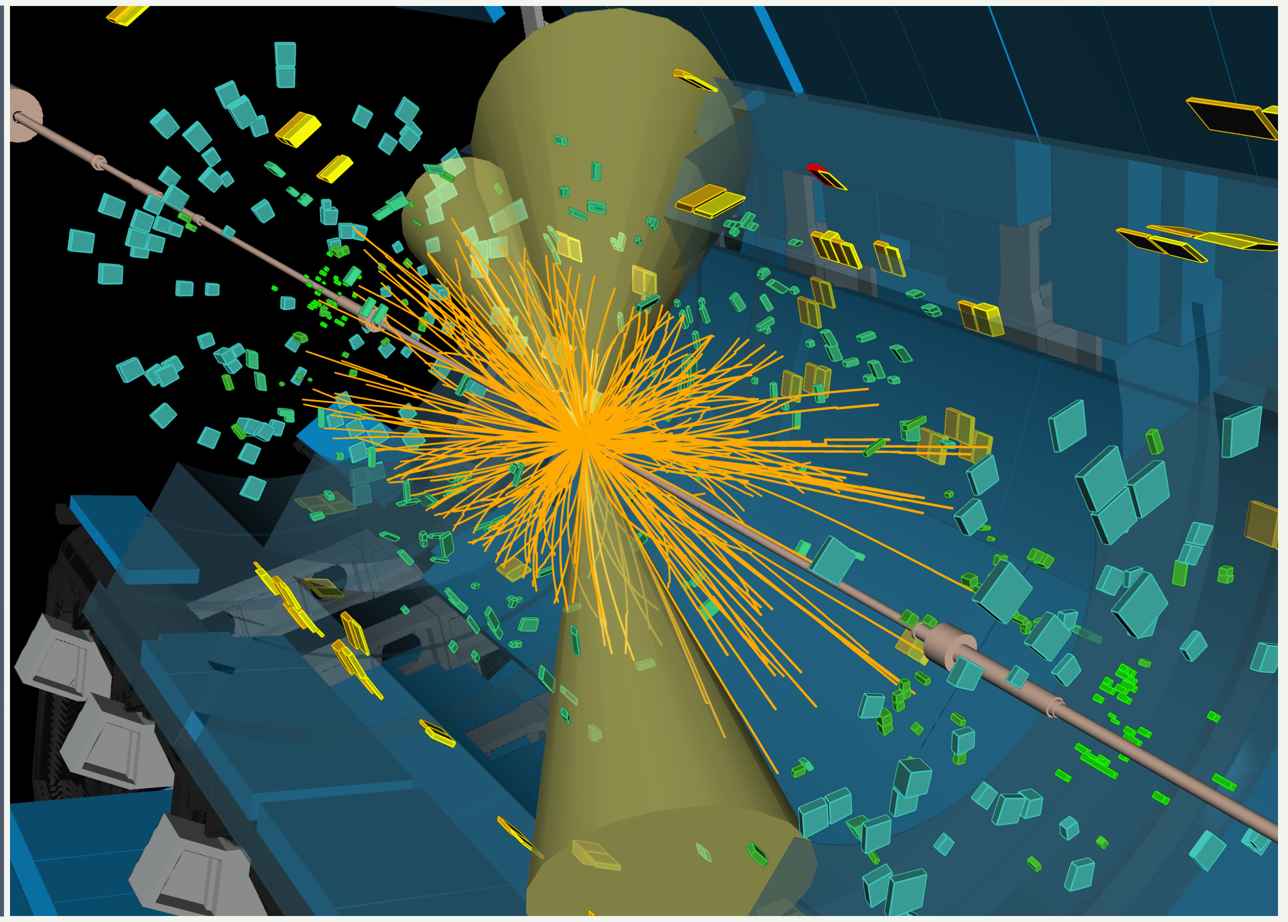
A brief reminder: ATLAS HI program goals

ATLAS EXPERIMENT

Time $\tau = 0$ $\tau \sim 1$ fm/c $\sim 10^{-23}$ s $\tau \sim 10$ fm/c $\sim 10^{-22}$ s $\tau > 10$ cm/c $\sim 10^{-11}$ s

Collision evolution sketch from MADAI collaboration





Initial state	Parton Scatterings	QGP formation & hydrodynamic expansion	Hadronization	Particle detection

Our main goal is to understand the properties of the QGP at different length scales

➡ This requires a detail understanding each stage of the collision

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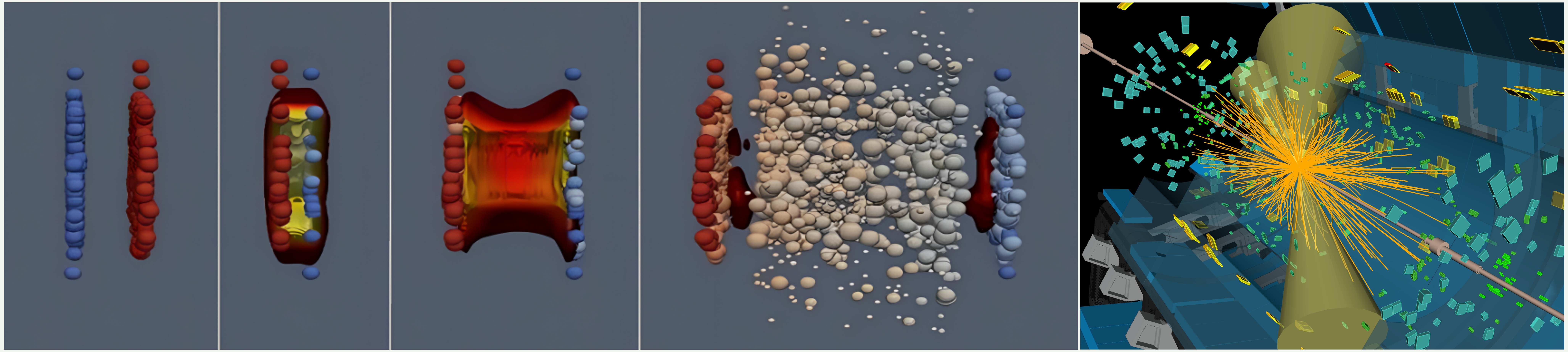

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Initial state | Parton Scatterings | QGP formation & hydrodynamic expansion | Hadronization | Particle detection

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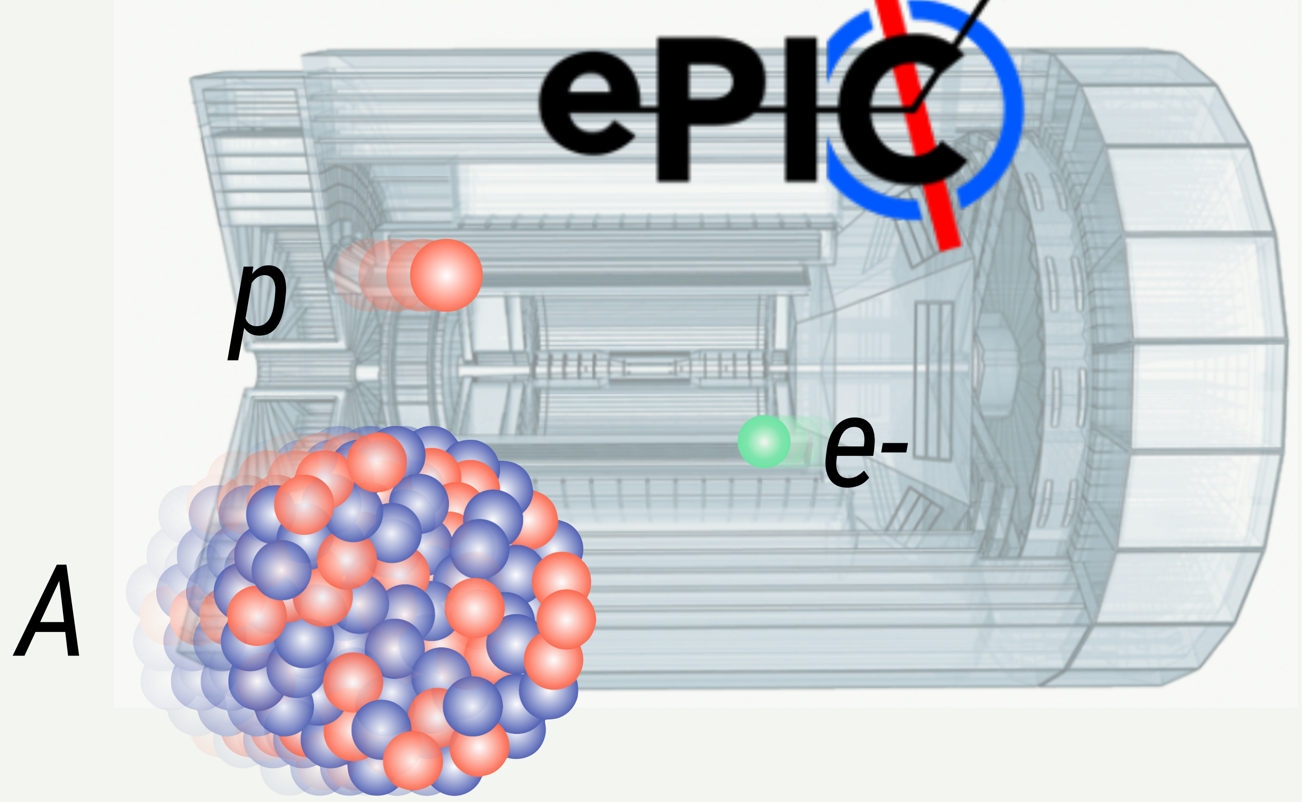
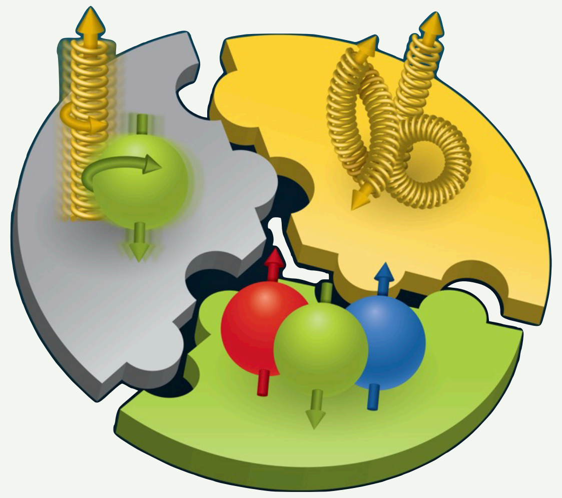
EIC physics pillars...

NAS report on EIC (2018) R.Ent – Monday

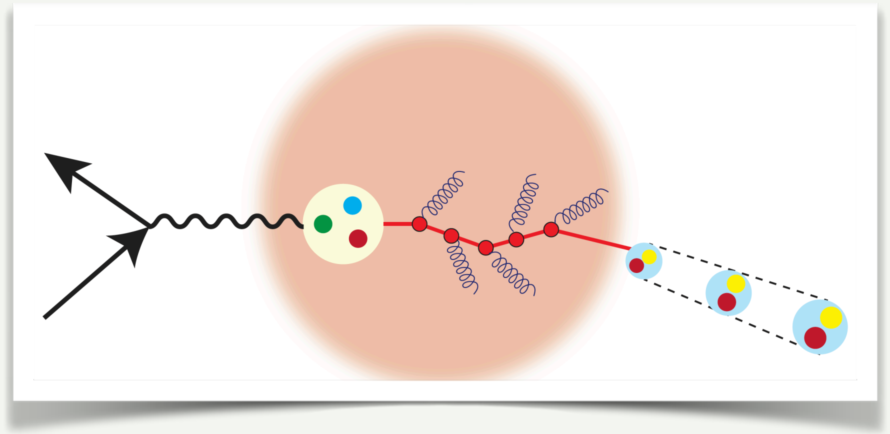


Origin of nucleon spin

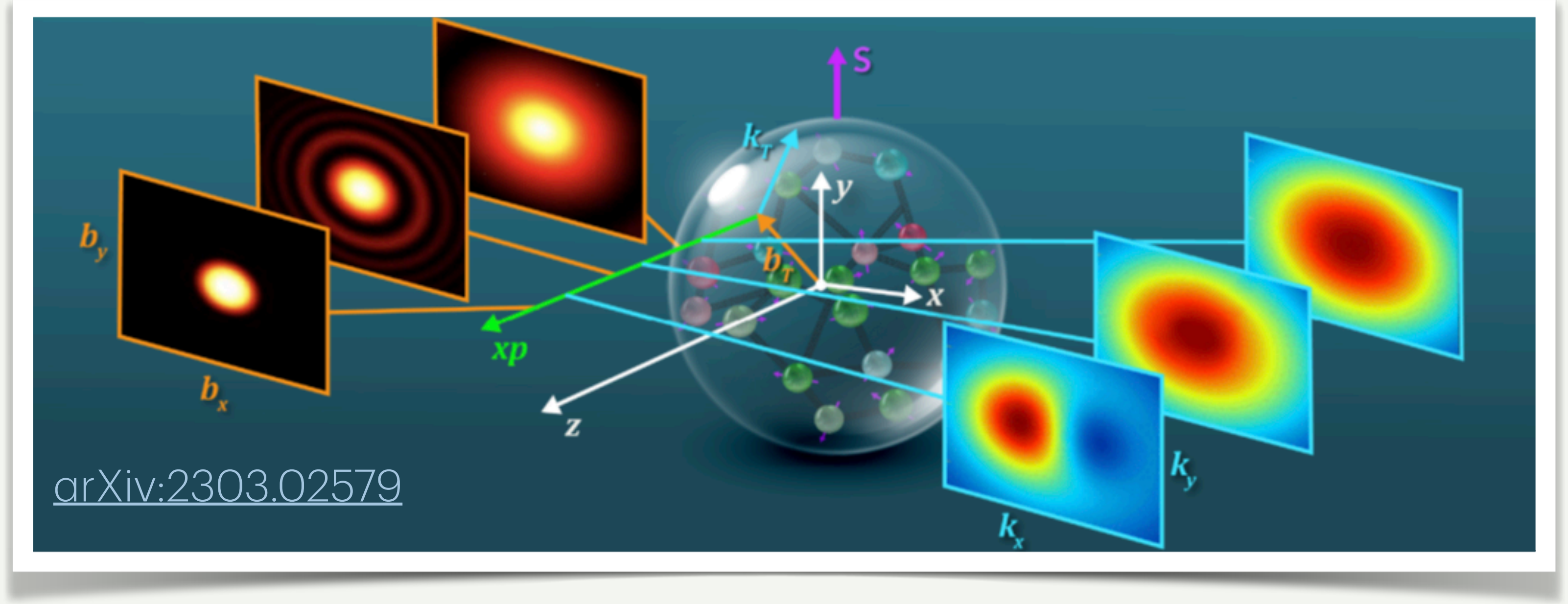


Origin of nucleon mass

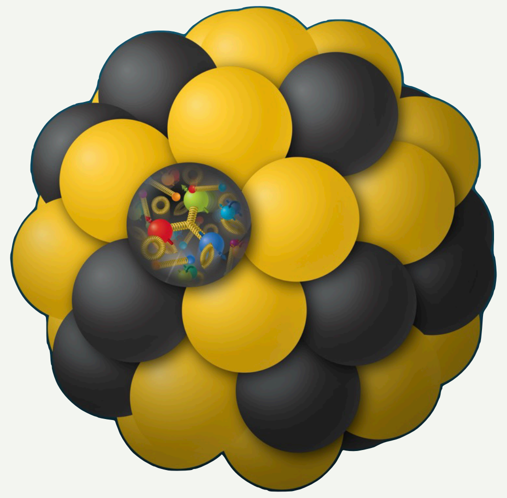
Passage of color charge through cold nuclear matter



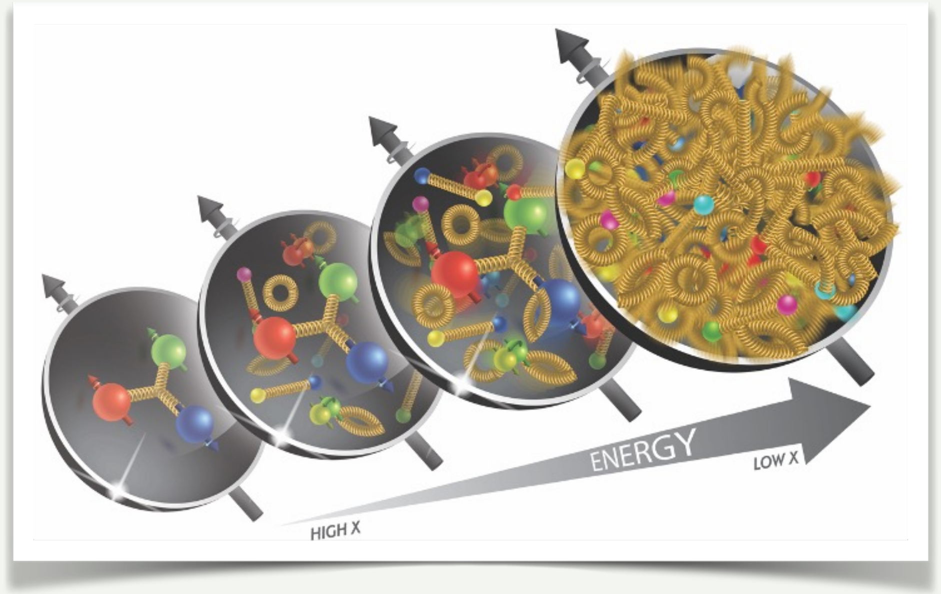
Multi-dimensional imaging of the nucleon in momentum and impact parameter space



Nuclear modification of parton distribution functions

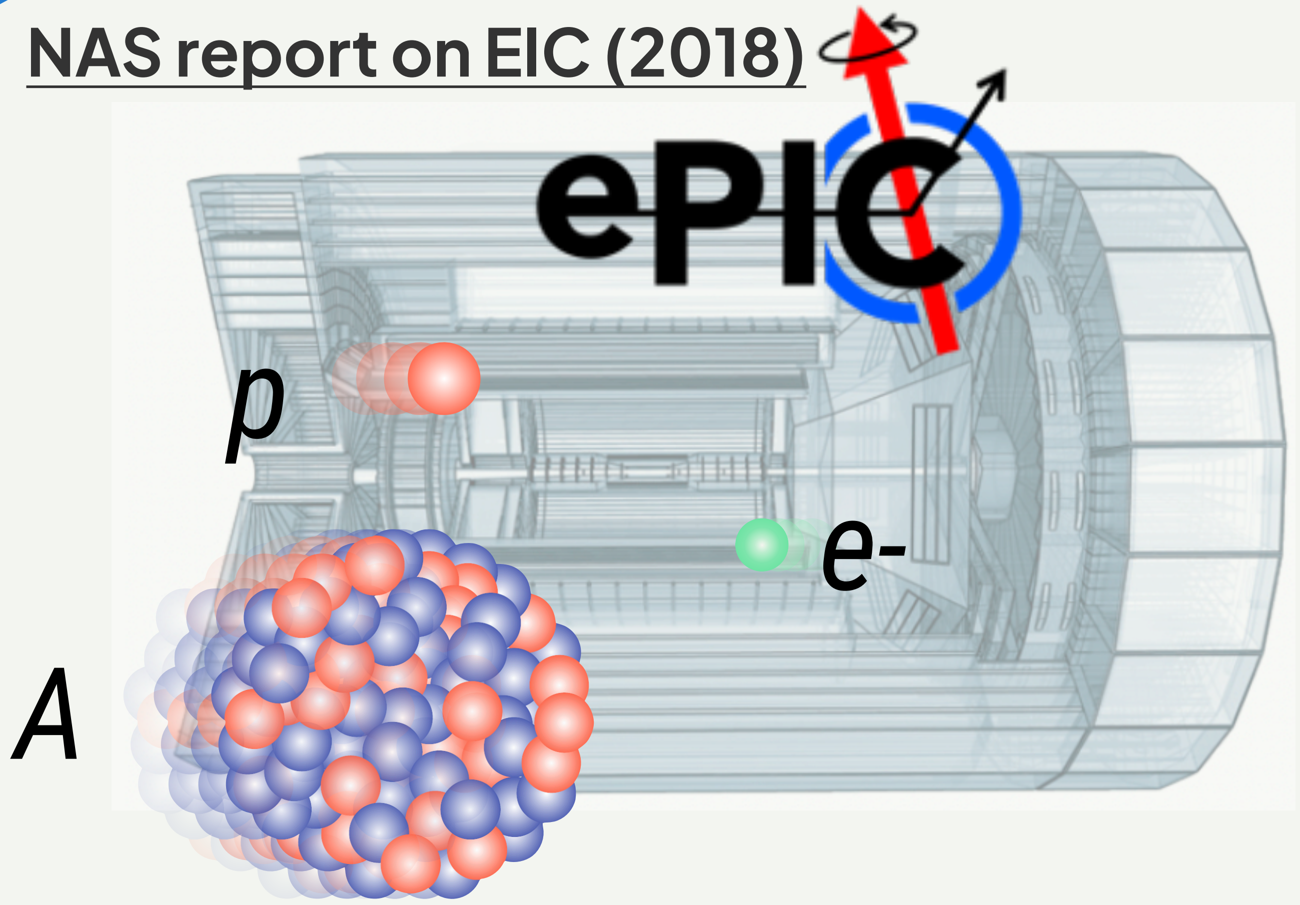


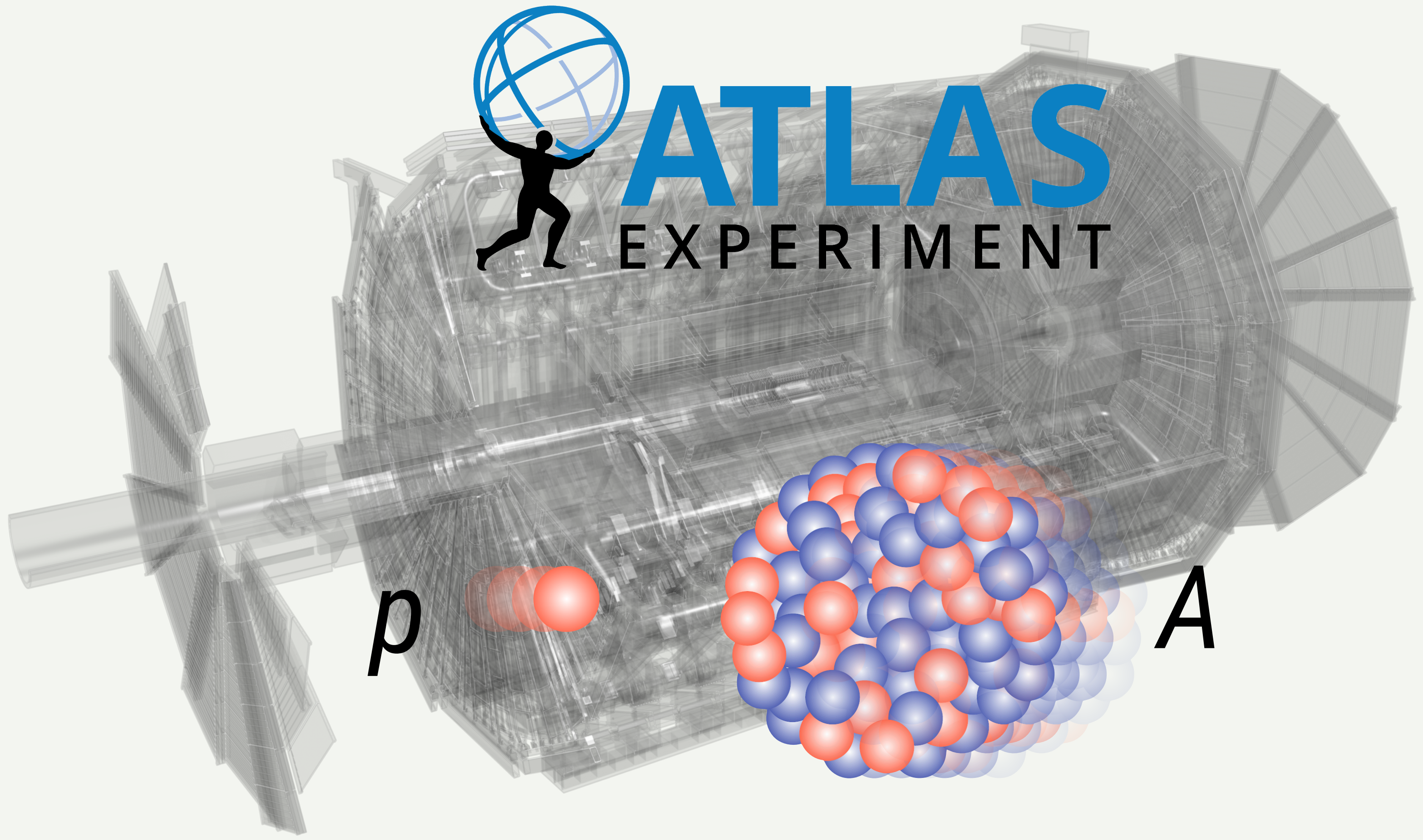
Search for saturation onset



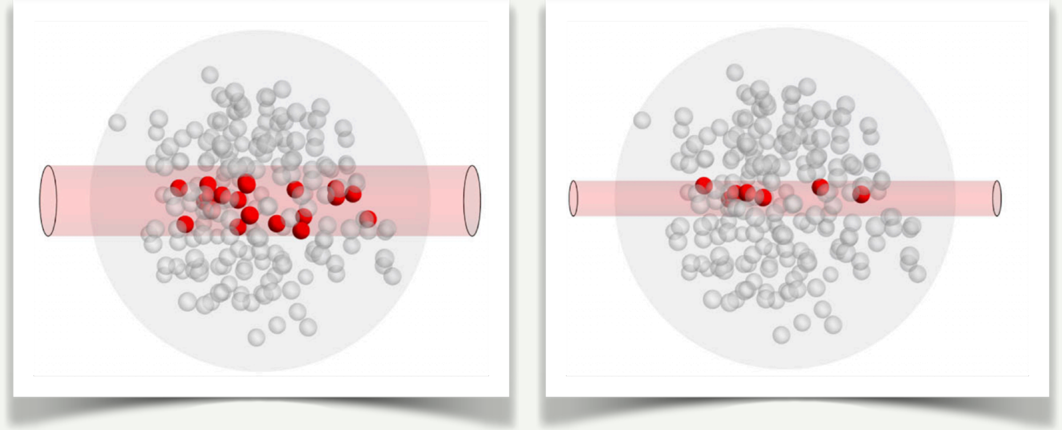
… and synergies with the ATLAS HI program

NAS report on EIC (2018)

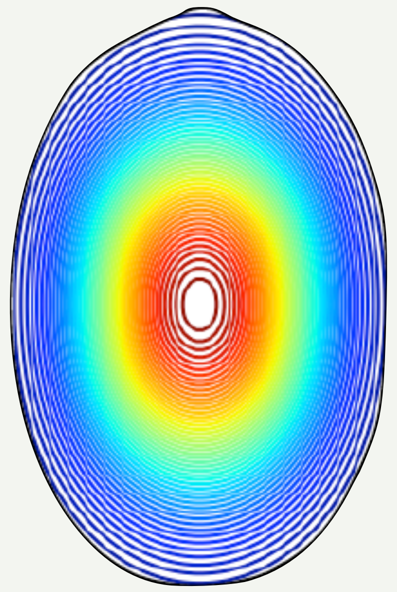




Passage of color charge through cold nuclear matter & color fluctuations (and/or GPD)



Study of collectivity in small system



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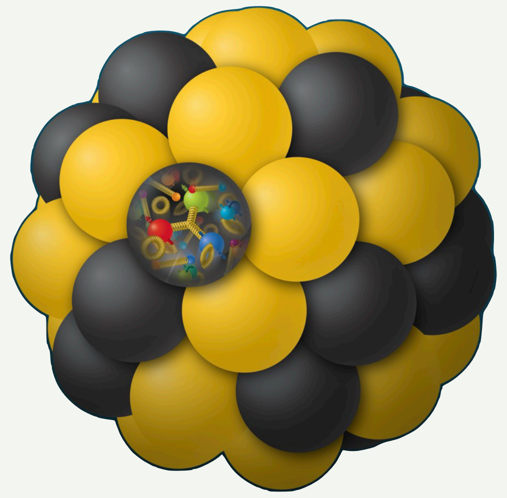

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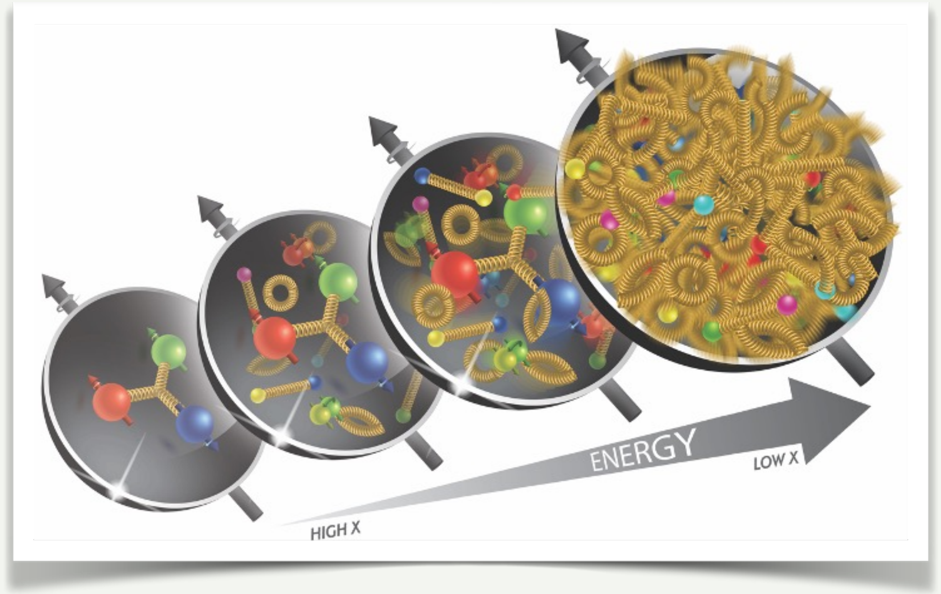
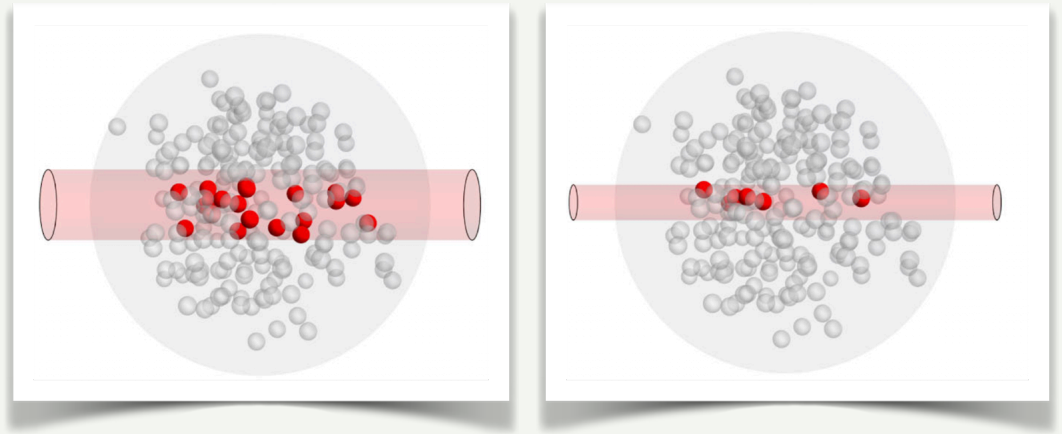
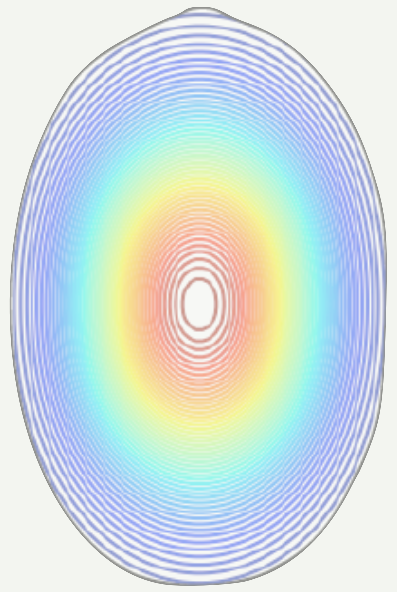


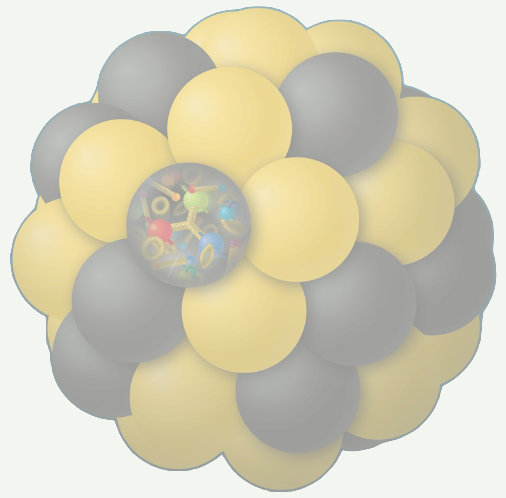
ATLAS synergies with EIC: this talk

I will be highlighting a few selected ideas using only **hadronic probes at ATLAS**.
For EM-probes, see **talk by K.Maj**!

Passage of color charge through cold nuclear matter & color fluctuations (and/or GPD)







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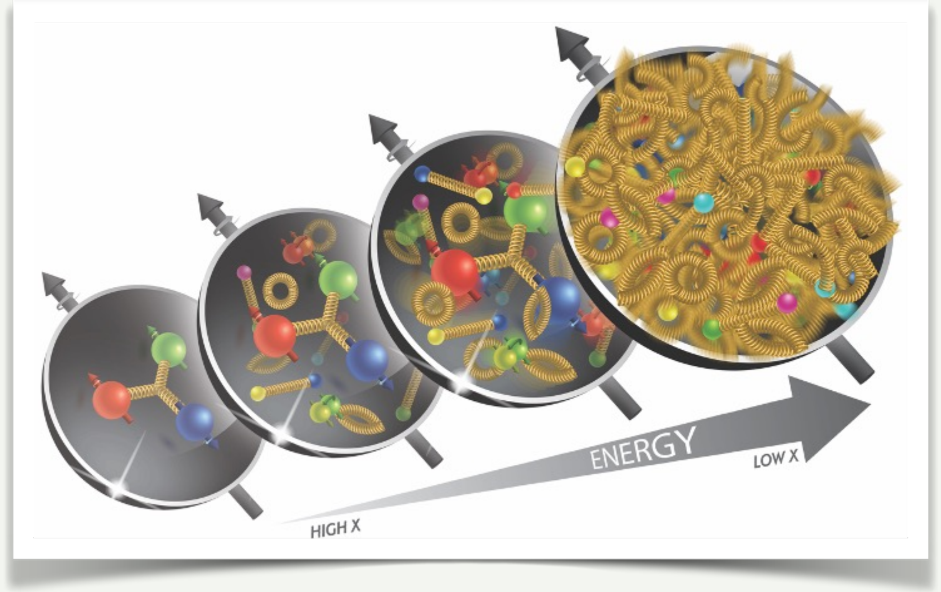
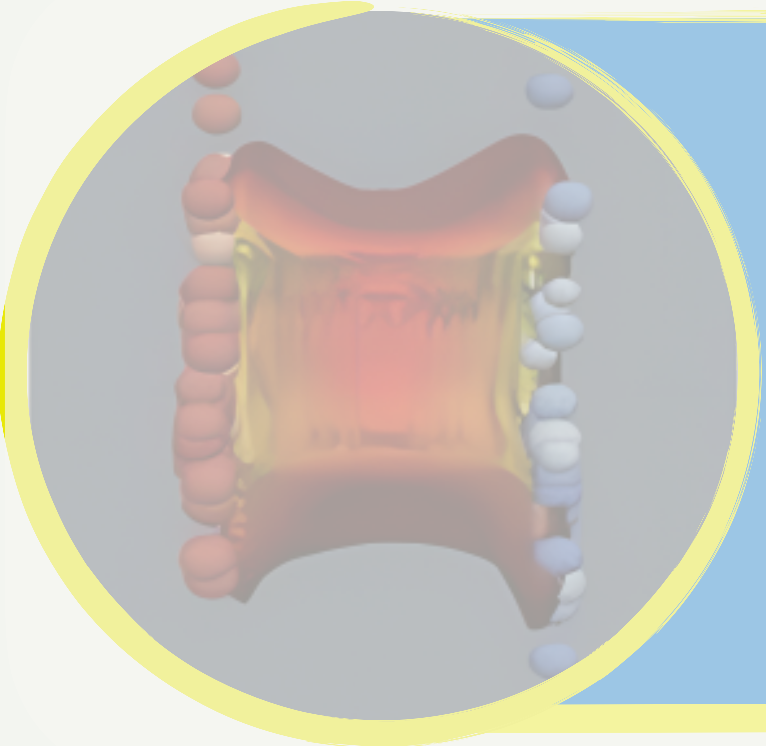


Outline

ATLAS
EXPERIMENT



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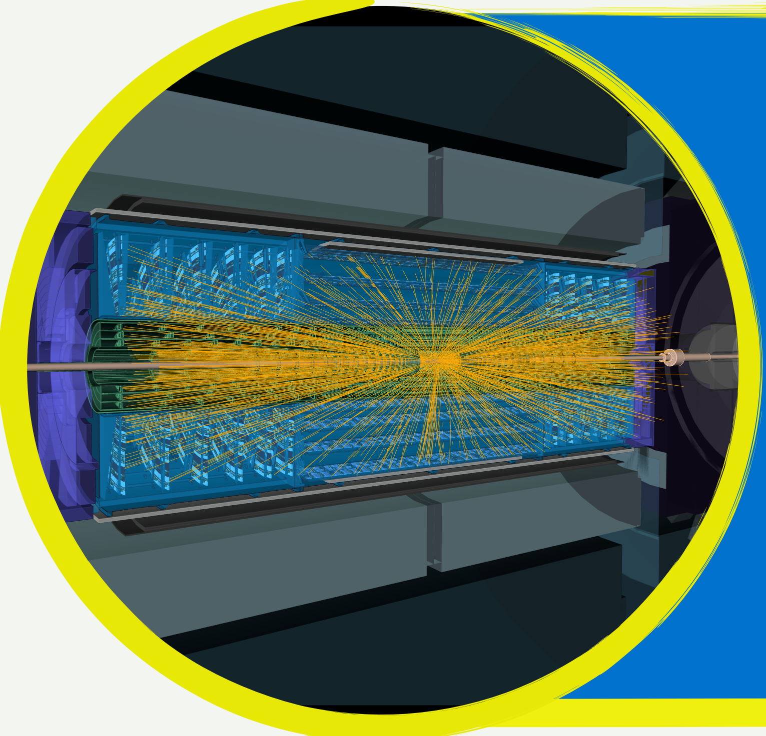
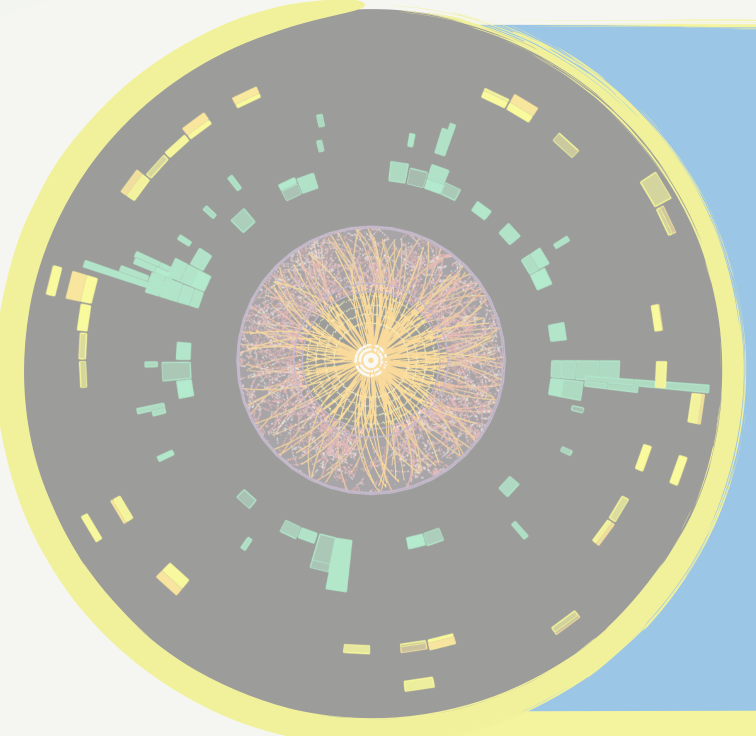


ATLAS Phase-II
upgrades



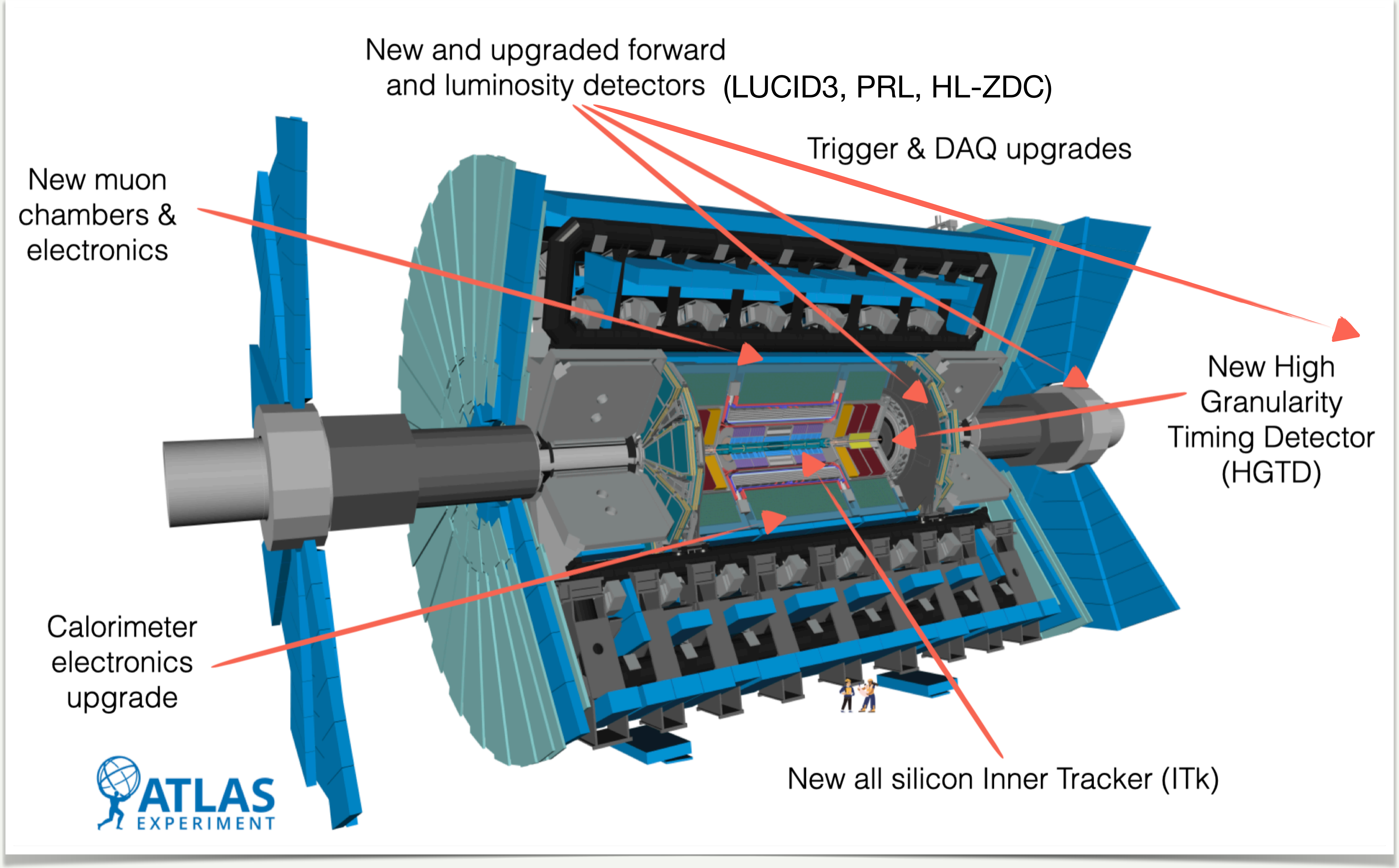
Synergies between the
ATLAS HI program & the EIC

ATLAS: upgrade overview

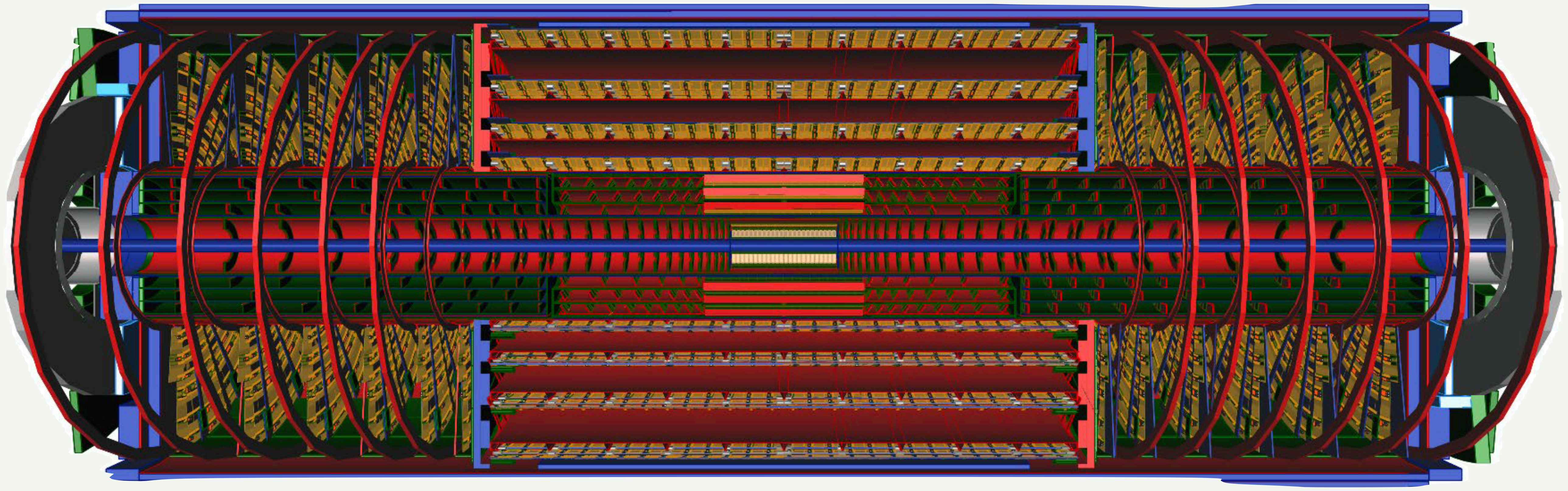
ATLAS EXPERIMENT

Several Upgrades to get ATLAS ready for the HL era!

ATLAS-PHOTO-2022-055

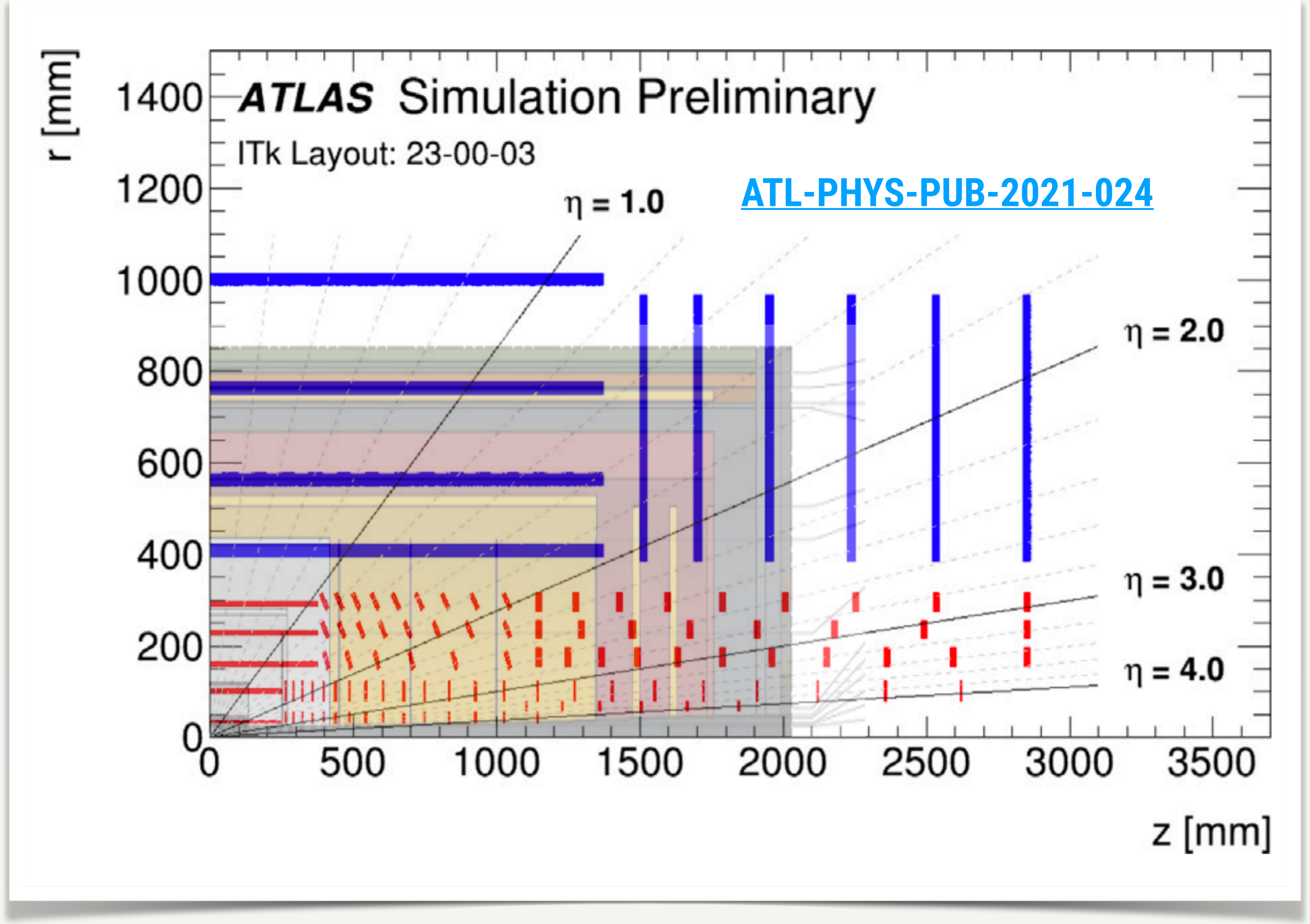


ATLAS Phase-II upgrades: ITK & TDAQ



Rates	Phase I	Phase II
Trigger input	40 MHz	
L0/L1 trigger	100 kHz	1 MHz
Event Farm	1 kHz	10 kHz

ATLAS ITK upgrade setup (overlaid w/ ePIC tracker)



Sketch courtesy of P.Steinberg

New extended tracking coverage ($|\eta| < 4$) and trigger capabilities will further boost ATLAS capabilities in reconstructing and analyzing HI events!

ATLAS Phase-II upgrades: LUCID 3

LUCID in Run 2 achieved a remarkable 0.8% precision (**Eur. Phys. J. C 83 (2023) 982**)

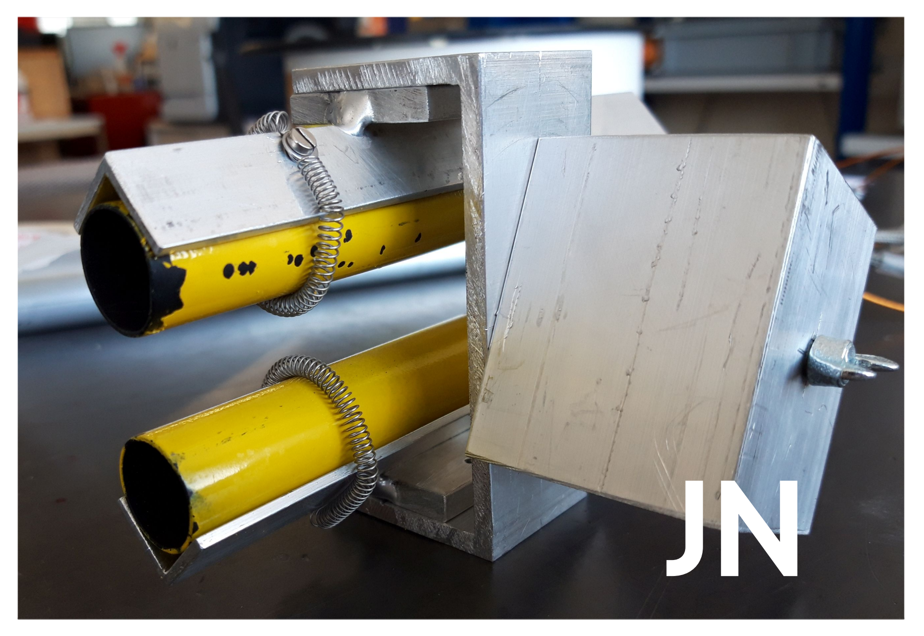
Precise determination of the luminosity is a key for HEP precision but also for HI analyses (to reduce normalization uncertainties in $R_{AA/pA}$, or in cross-section measurements)

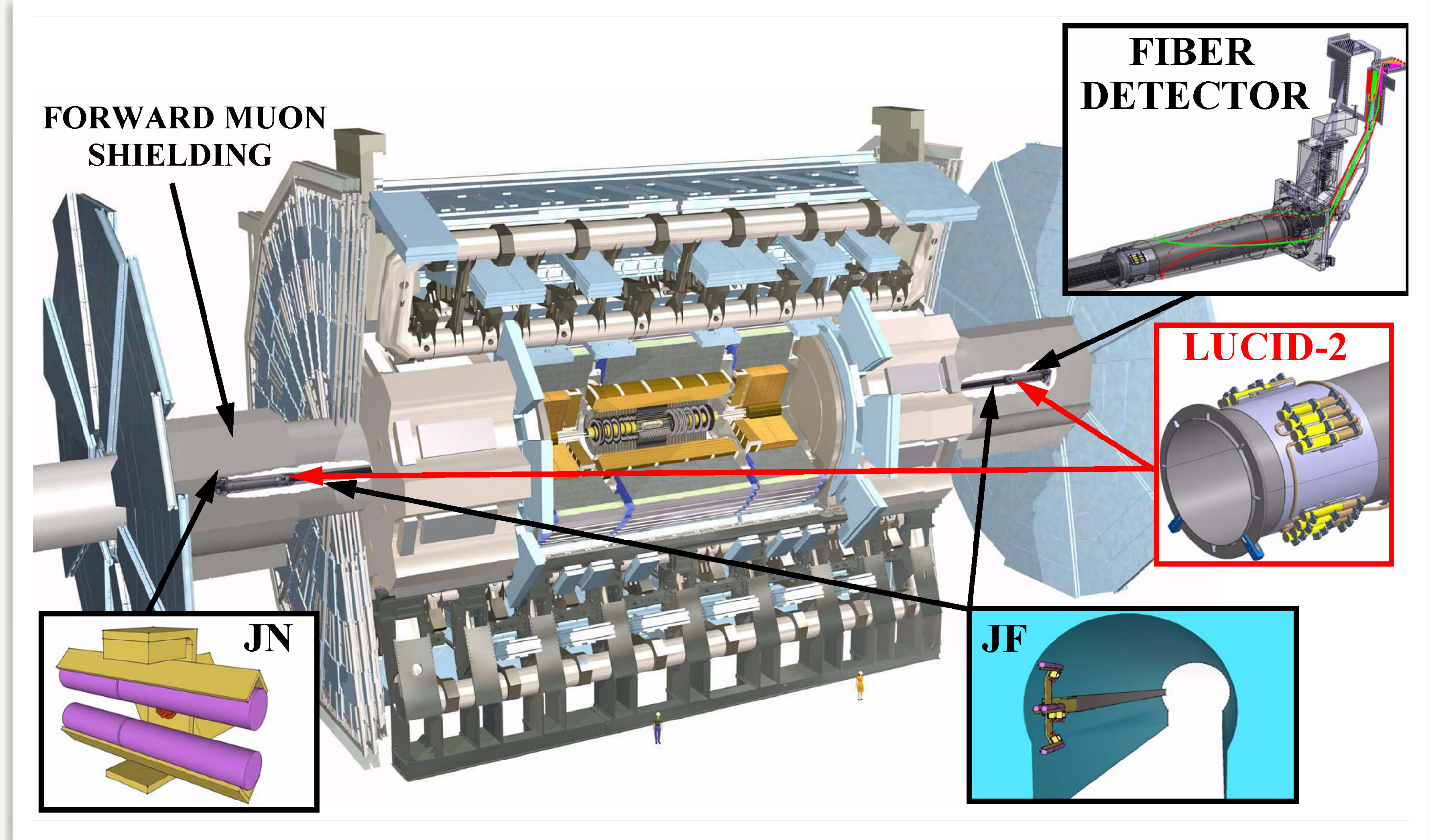
➡The goal is to do equal or better in Run 4, with way more challenging conditions

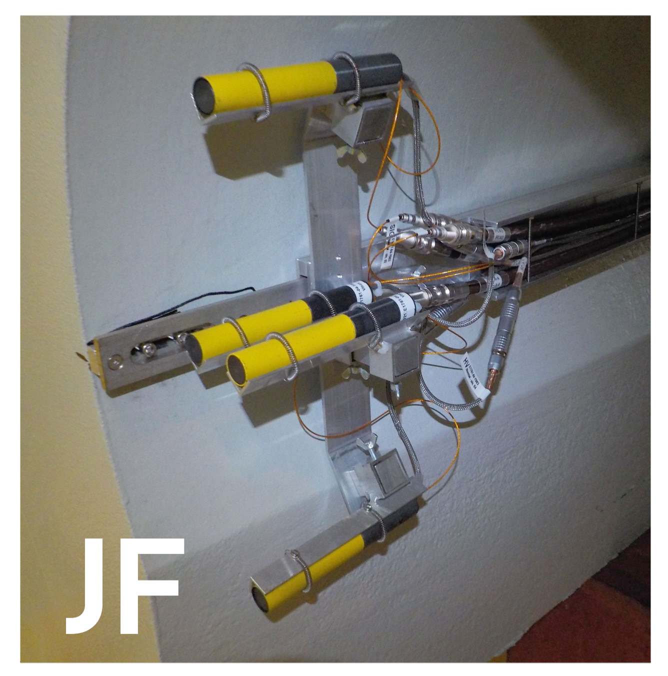
- Pile-up increases, large radiation dose/year impacting detector aging, demand of linearity over a large luminosity range between vdM and physics production

Any detector used in Run-2/3 (including LUCID) not able to ensure the needed precision in HL-LHC
➡ Upgrade of LUCID-2 to LUCID-3 for the HL-LHC era + HGTD + Pixel Ring for Luminosity

➡ Different LUCID-3 prototypes installed in ATLAS during Run 3



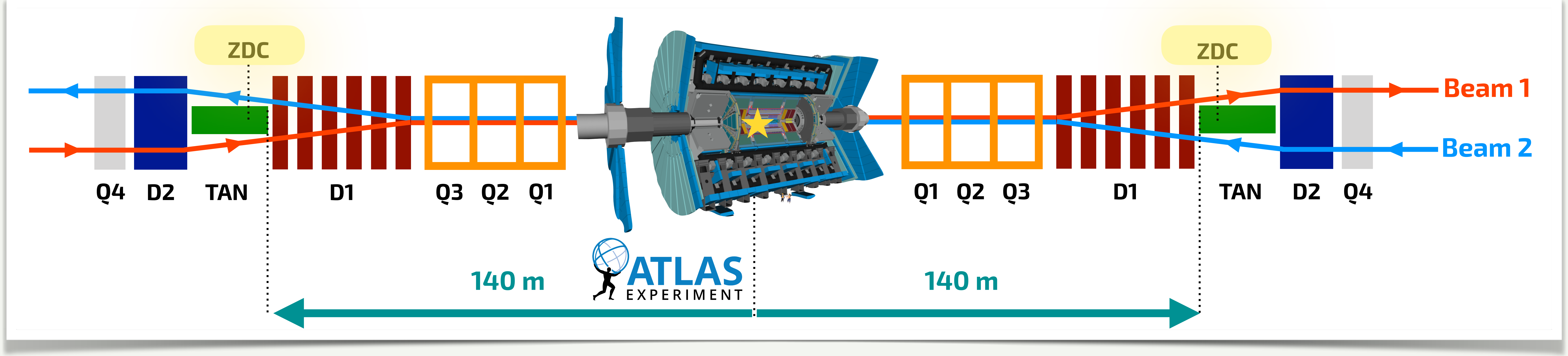


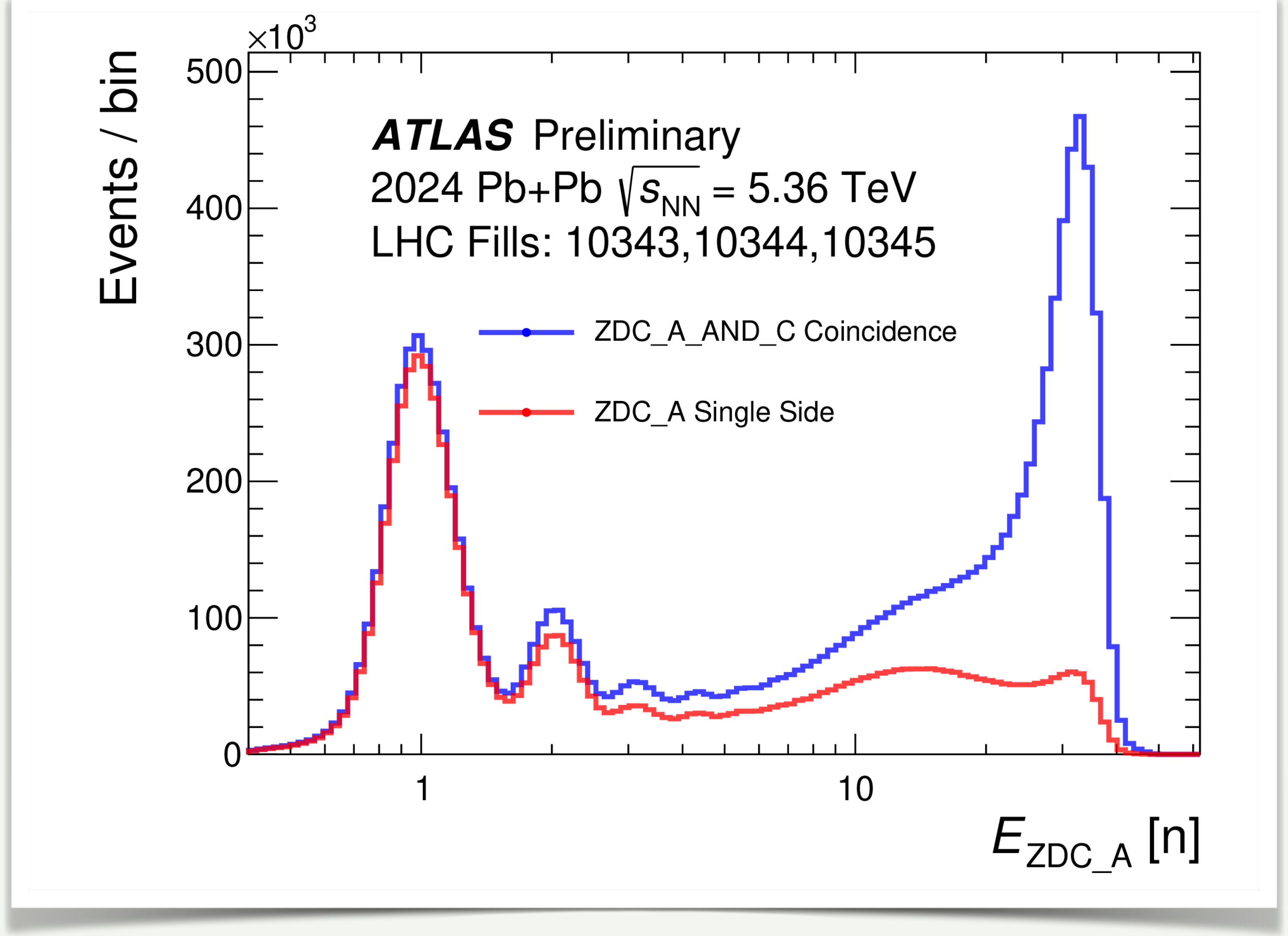


ATLAS Phase-II upgrades: HL-ZDC

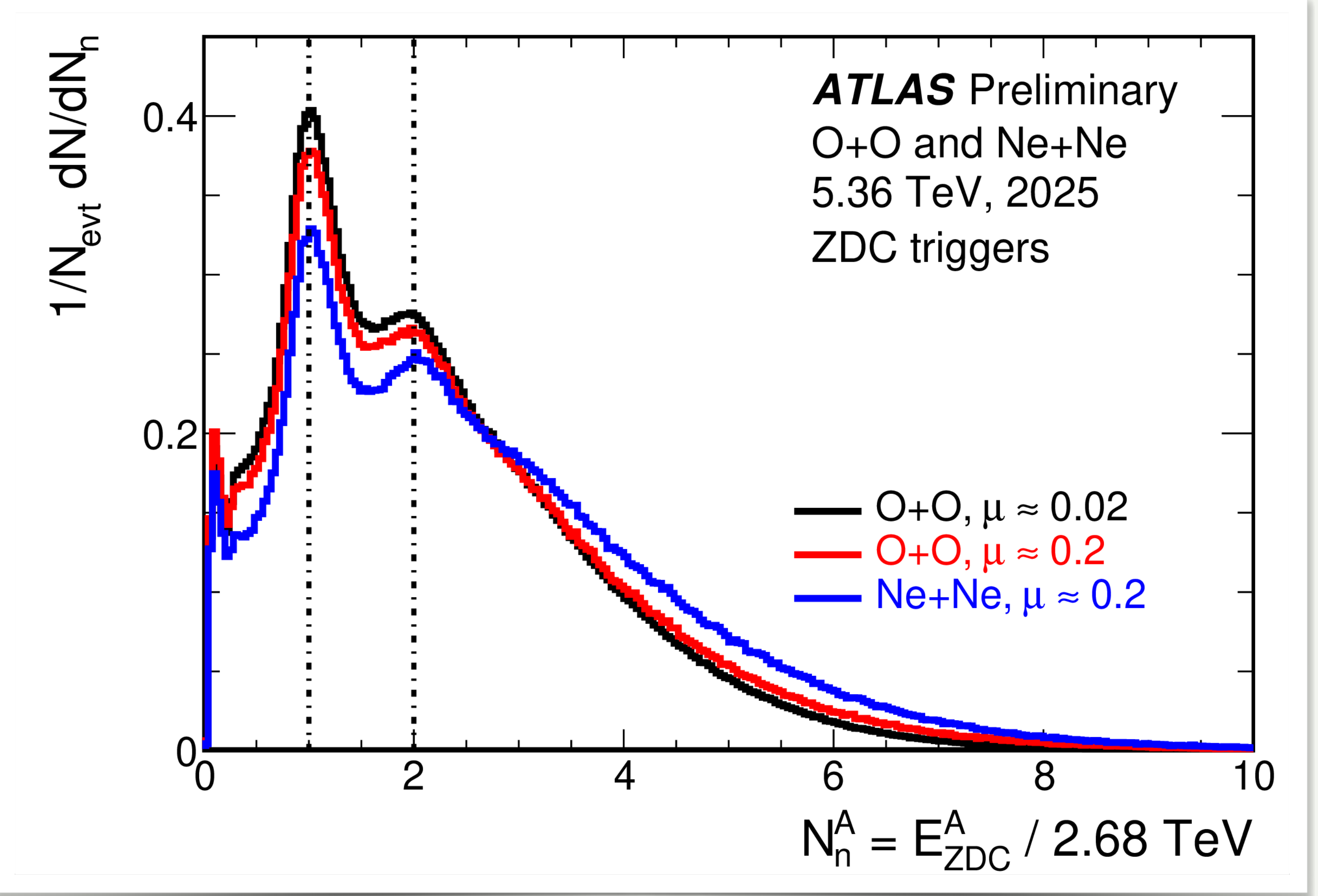
- Zero Degree Calorimeters (ZDCs) are essential to take advantage of the full potential of HI collisions (see **talk by K.Maj** for multiple examples)
- Starting from Run 3, ATLAS ZDCs are used also in luminosity measurement for HI

➡ **High-performance ZDCs are needed at the HL-LHC to continue capitalizing on the unique ion datasets delivered by the machine**





Heavy Ions – 2024



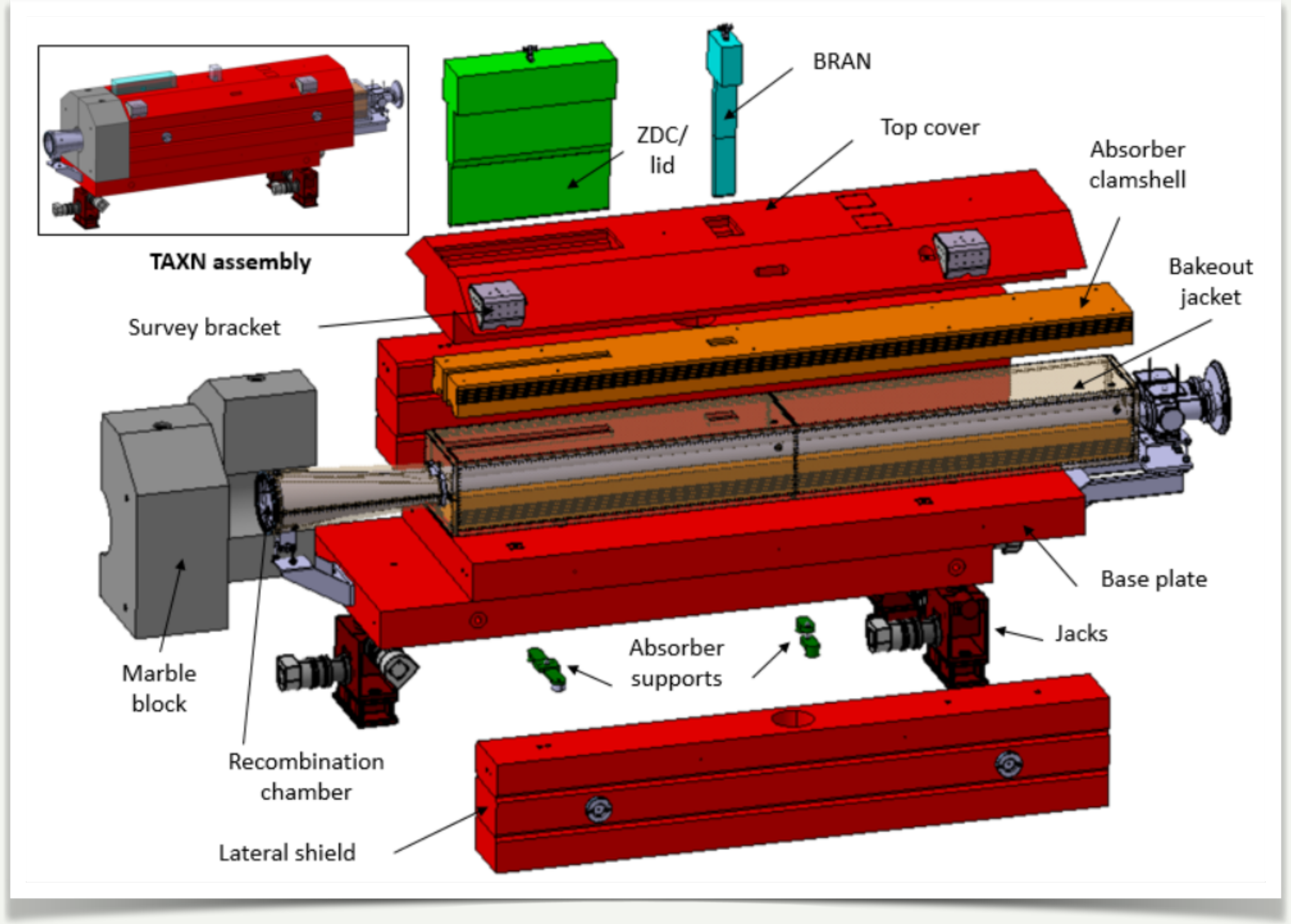
Light Ions – 2025

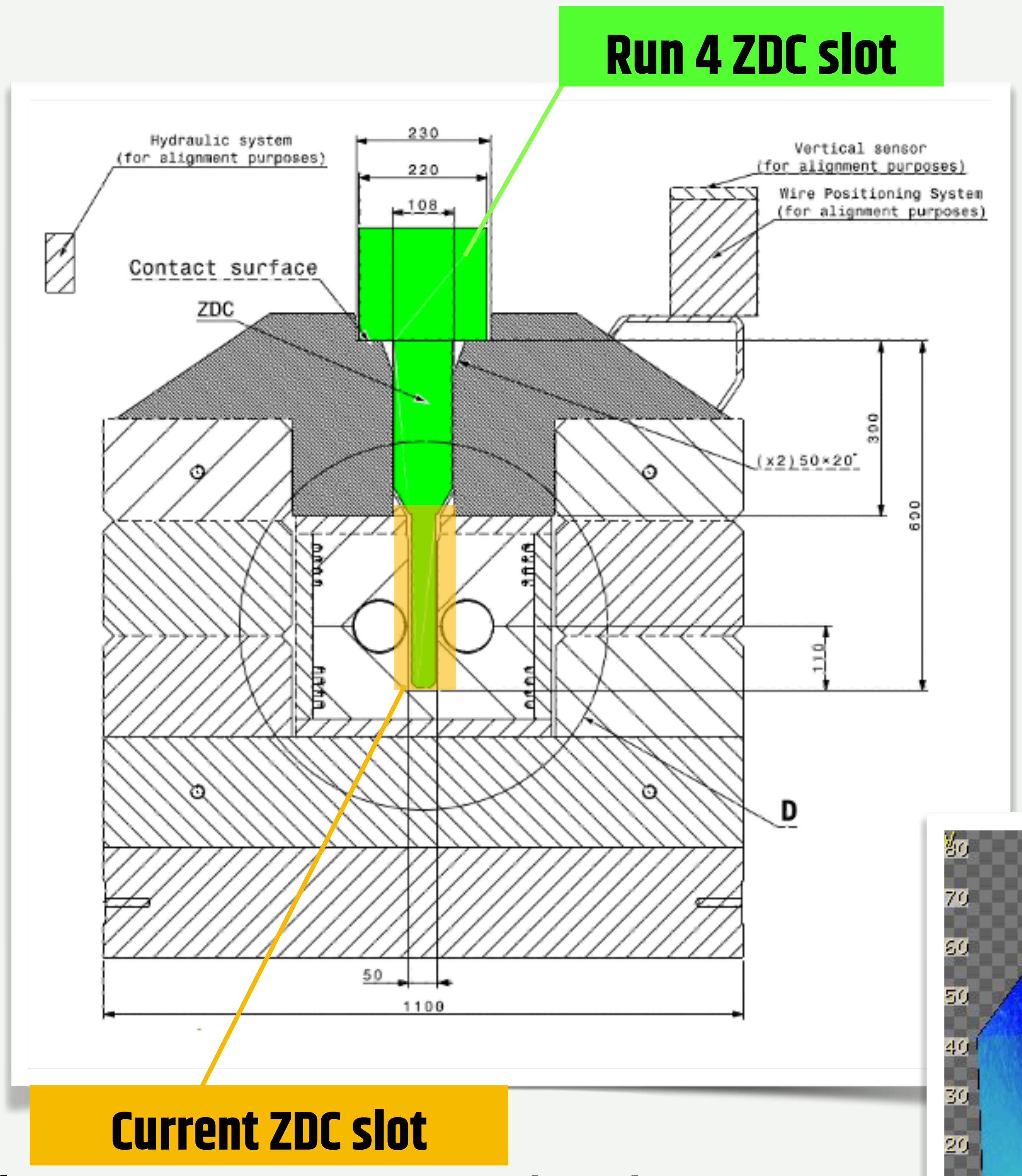
ATLAS ZDC in Run 3: **arXiv:2509.05948**

HL-ZDC: challenges

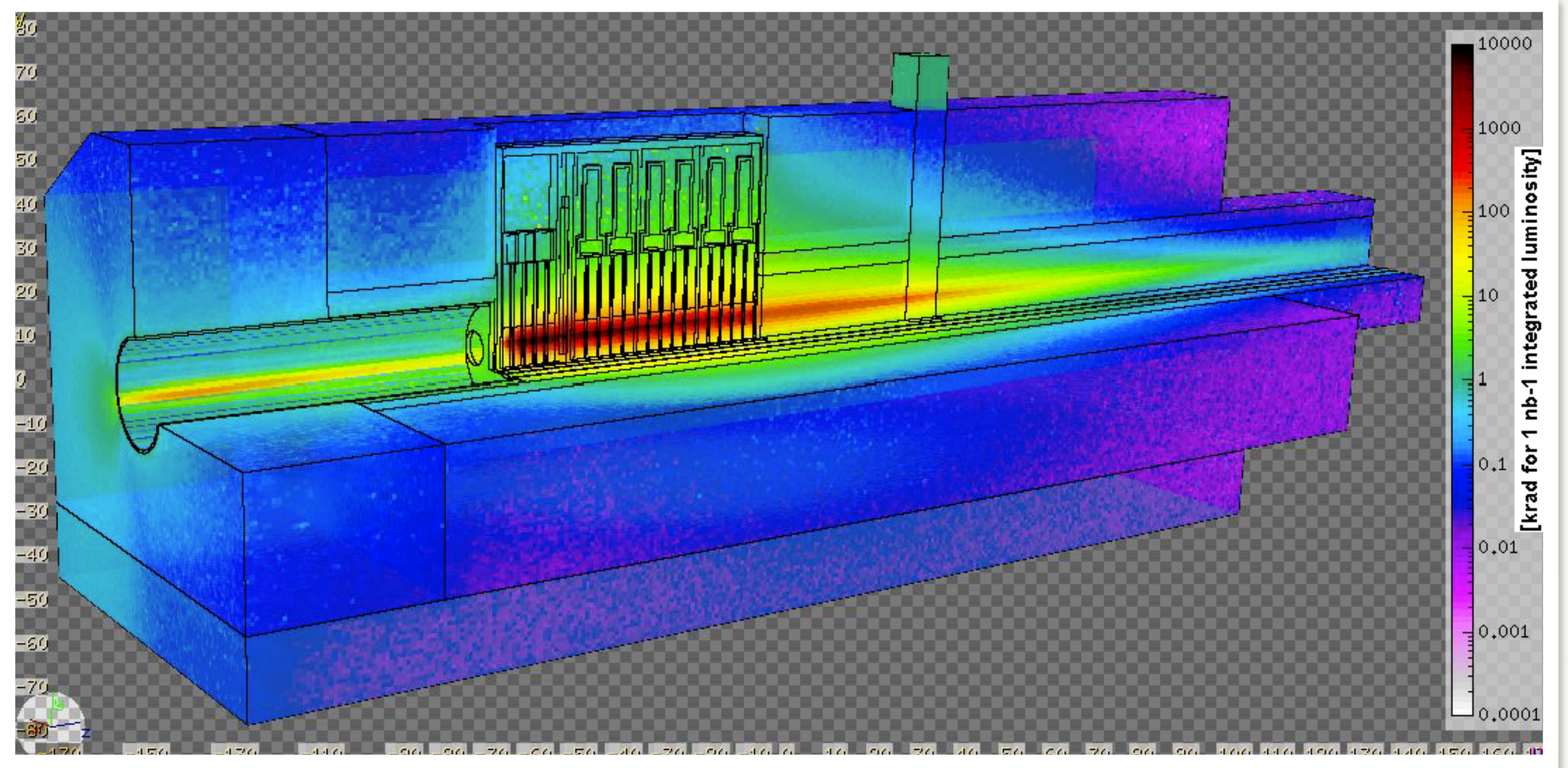
ATLAS EXPERIMENT

- Reduced space: new beam optics and new absorber (TAXN - see **PRAB 25,053001**)



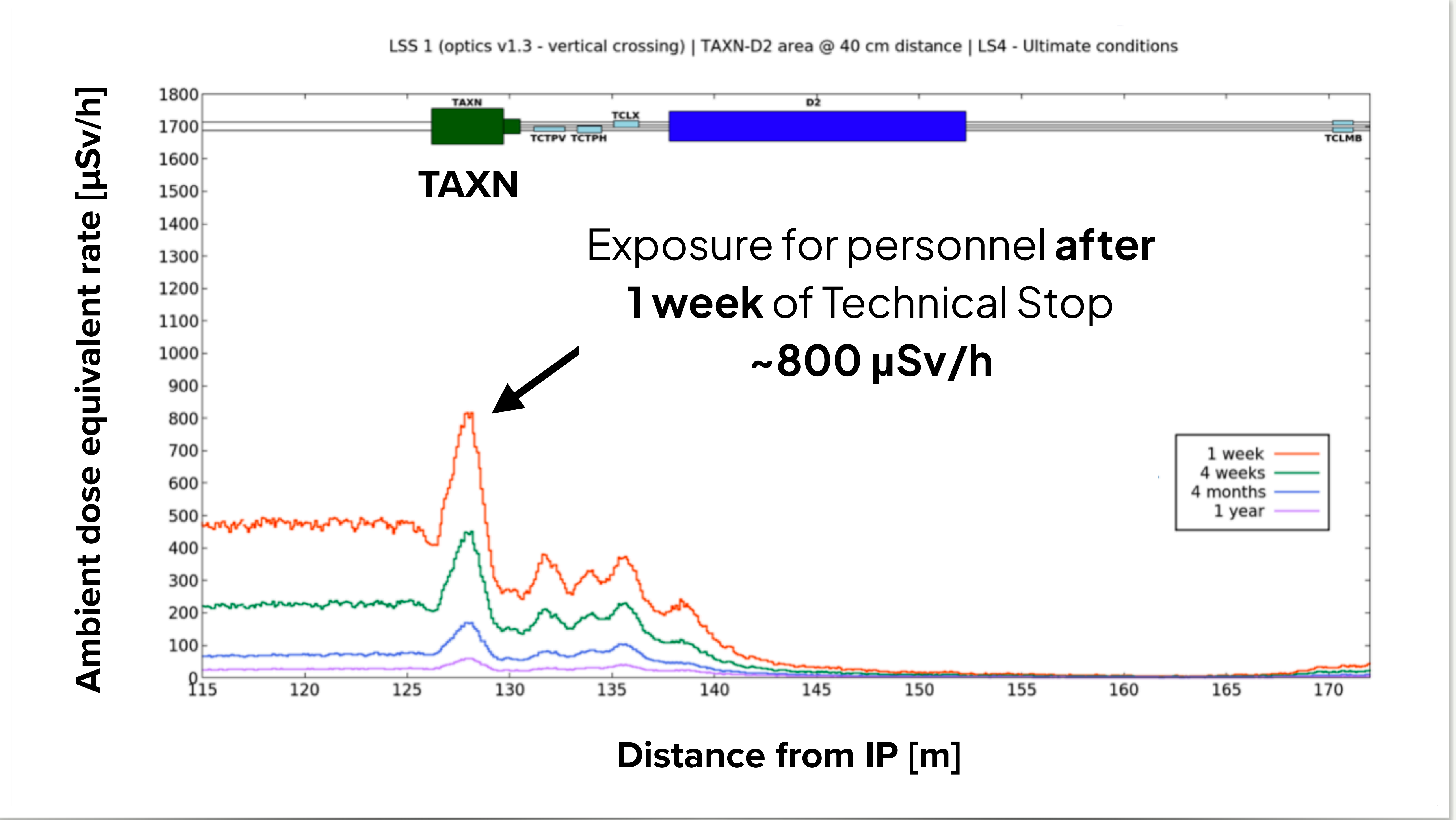


- Slot for Forward detectors (ZDC, BRAN) narrowed to 5 cm (currently 10 cm)
- Brand-new detectors need to be built



- **Radiation levels** on the ZDC will increase with the HL upgrade of the accelerator
- CERN **FLUKA** group provides detailed simulations of the radiation environment in the TA(X)N region
  ➡ **For Run4 HI program** (Pb+Pb, p+Pb, low µ p+p) expected **~4.5 MGy in total**

HL-ZDC: challenges…



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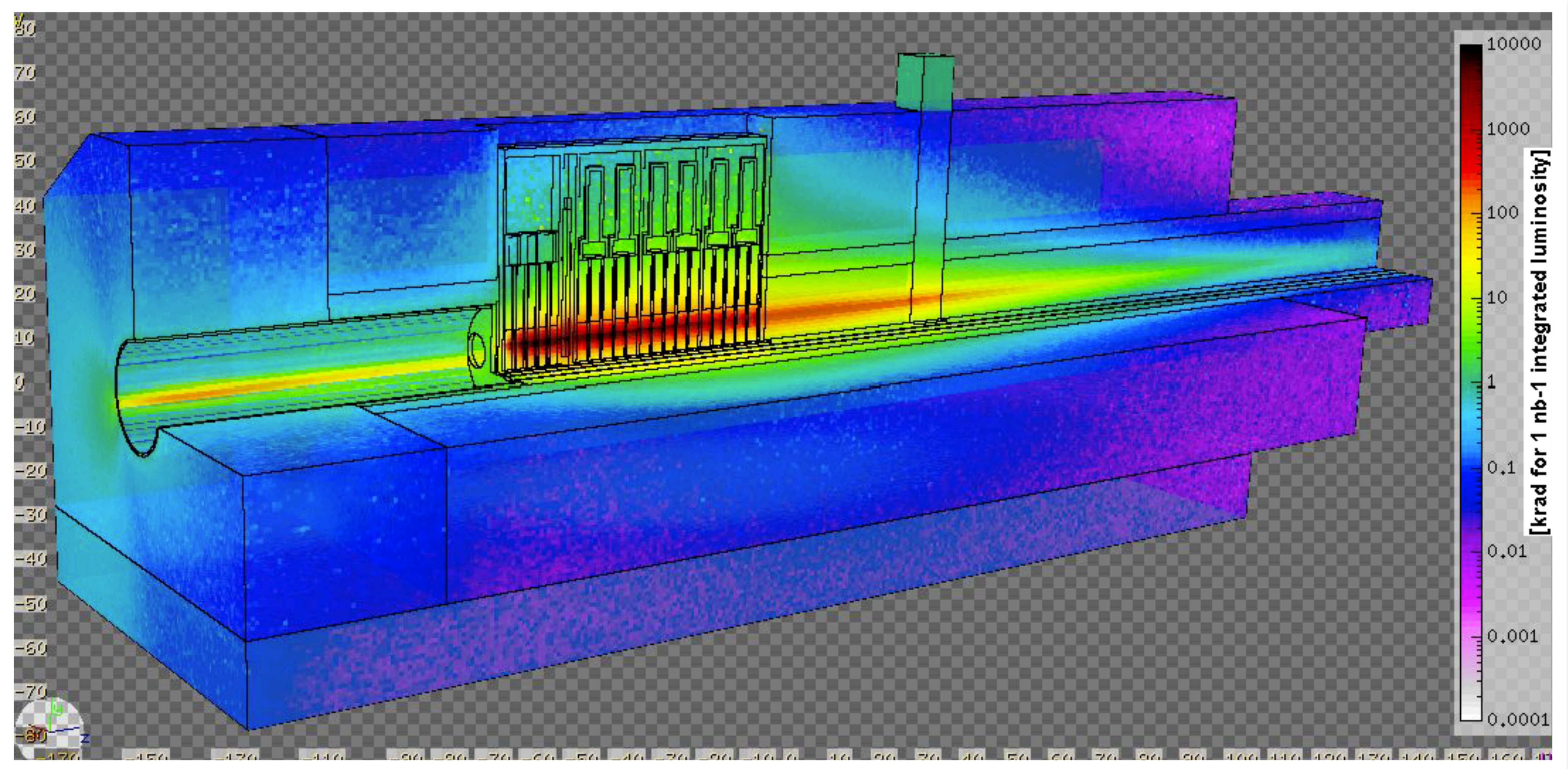
- Also, ~5× more in activation of the absorber at the time of installation!
  ➨Need a **easy-to-connect** detector after craning into TAXN to **reduce exposure for personnel**



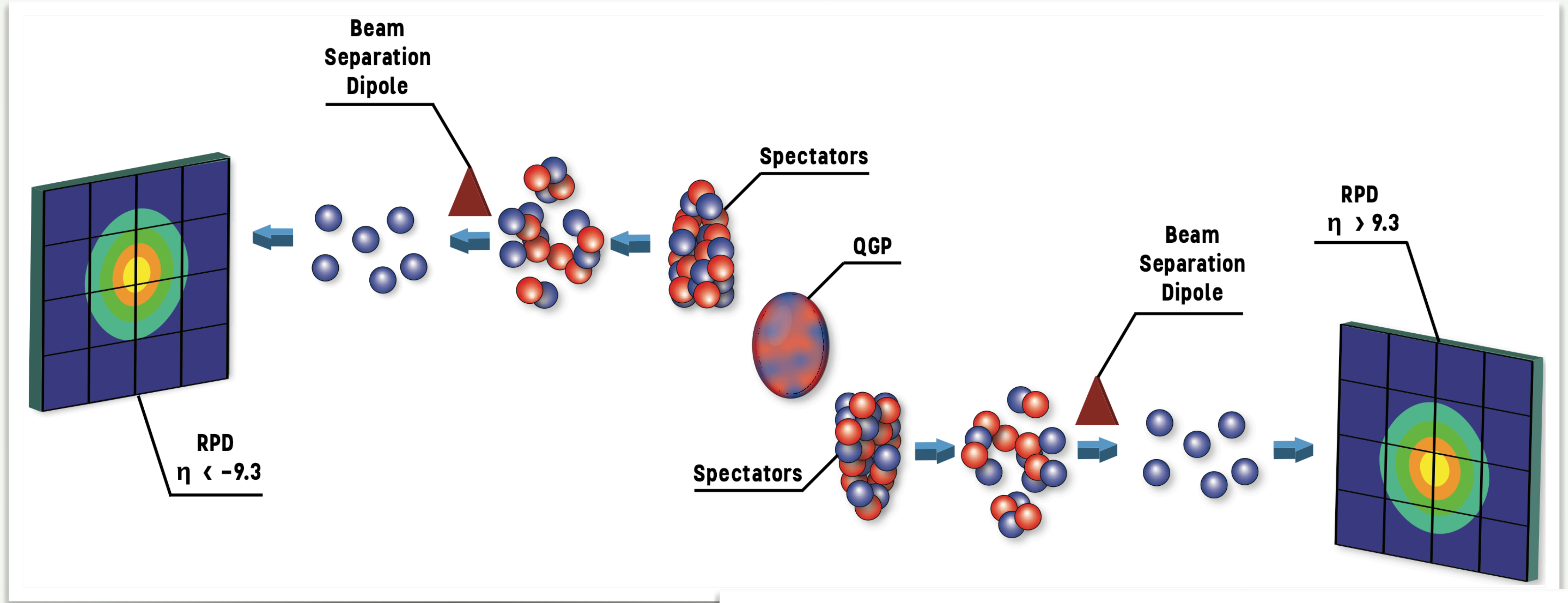
HL-ZDC: … and opportunities

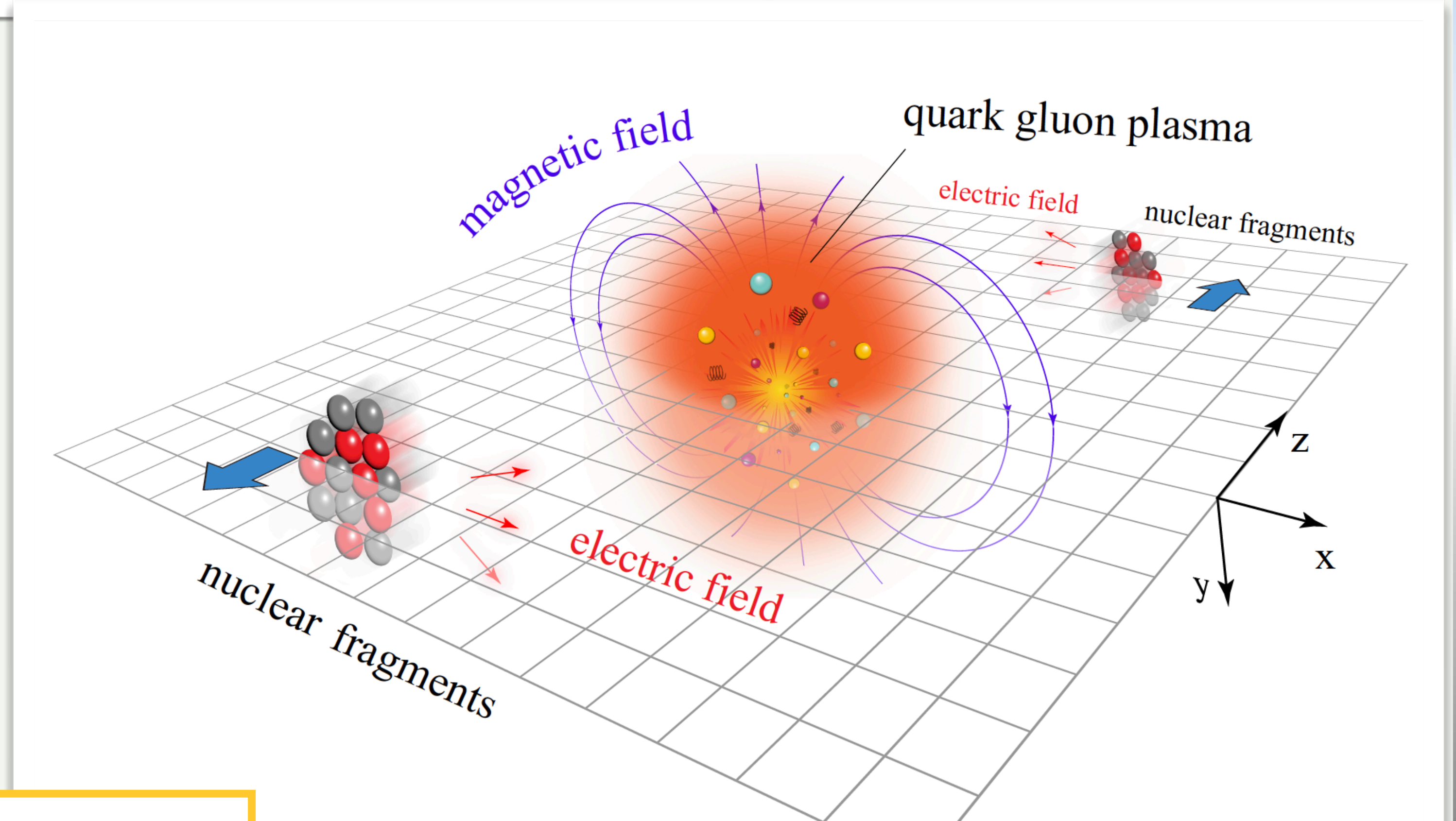
- Also, an opportunity to expand the physics capabilities of the ZDC:
  ➨ Implementation of a **Reaction Plane Detector (RPD)** to measure correlated deflection of forward neutrons in the direction of the reaction plane

- Enables direct access to v_1, "directed flow", through correlations with particles detected in the central region

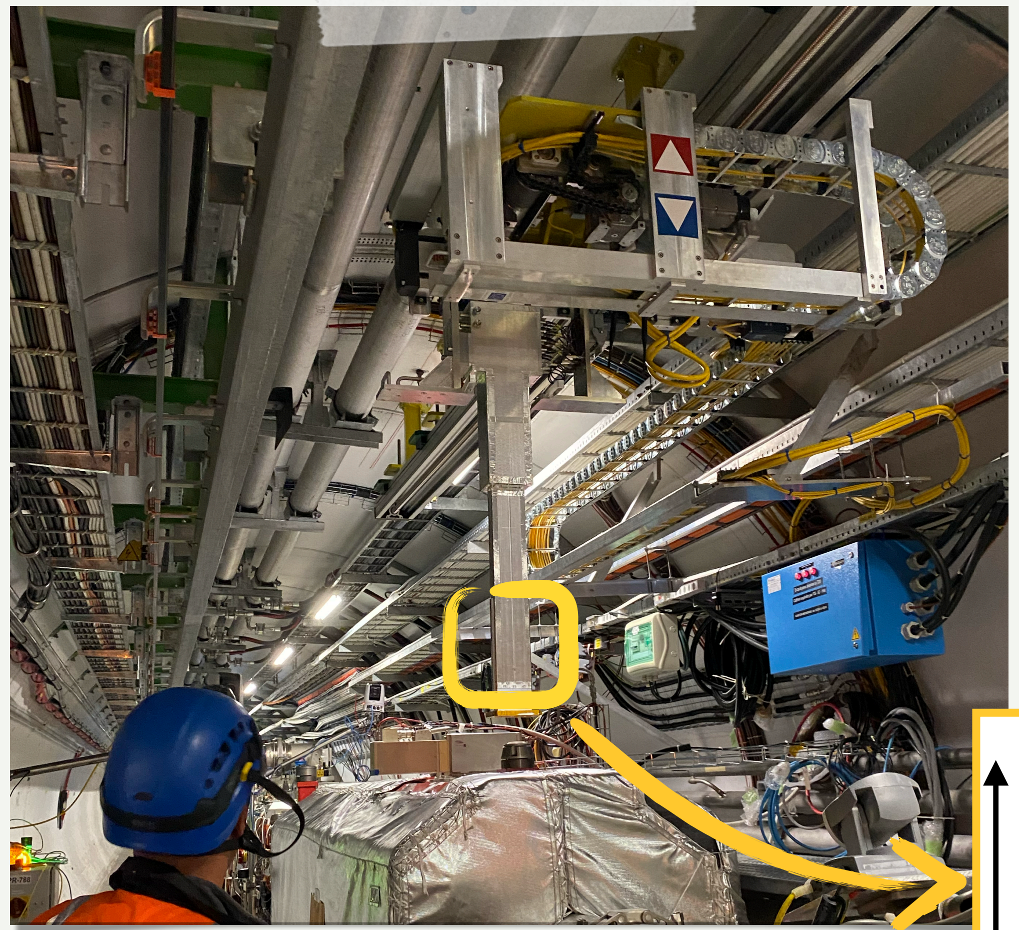
- Sensitive to the EM fields in the initial stages of the collisions

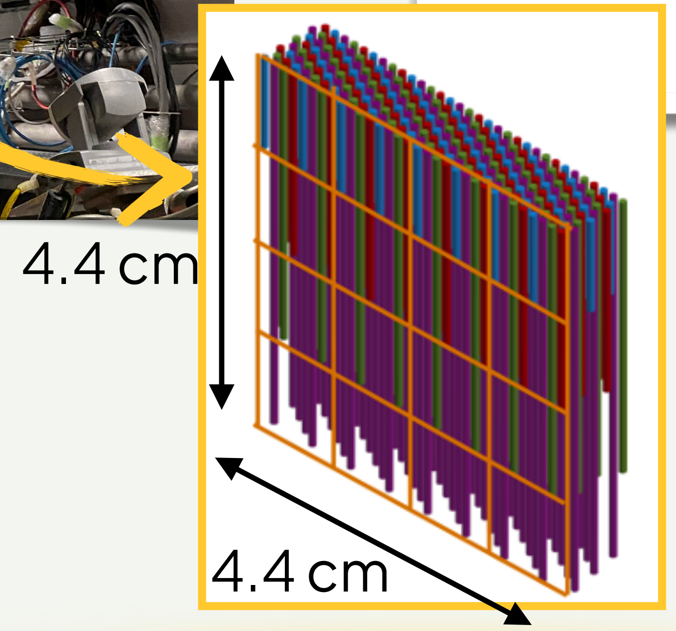
- ATLAS has implemented a Run 4–like version of the RPD already in Run 3 - to test in view of Run 4 (**see arXiv:2509.05948**)



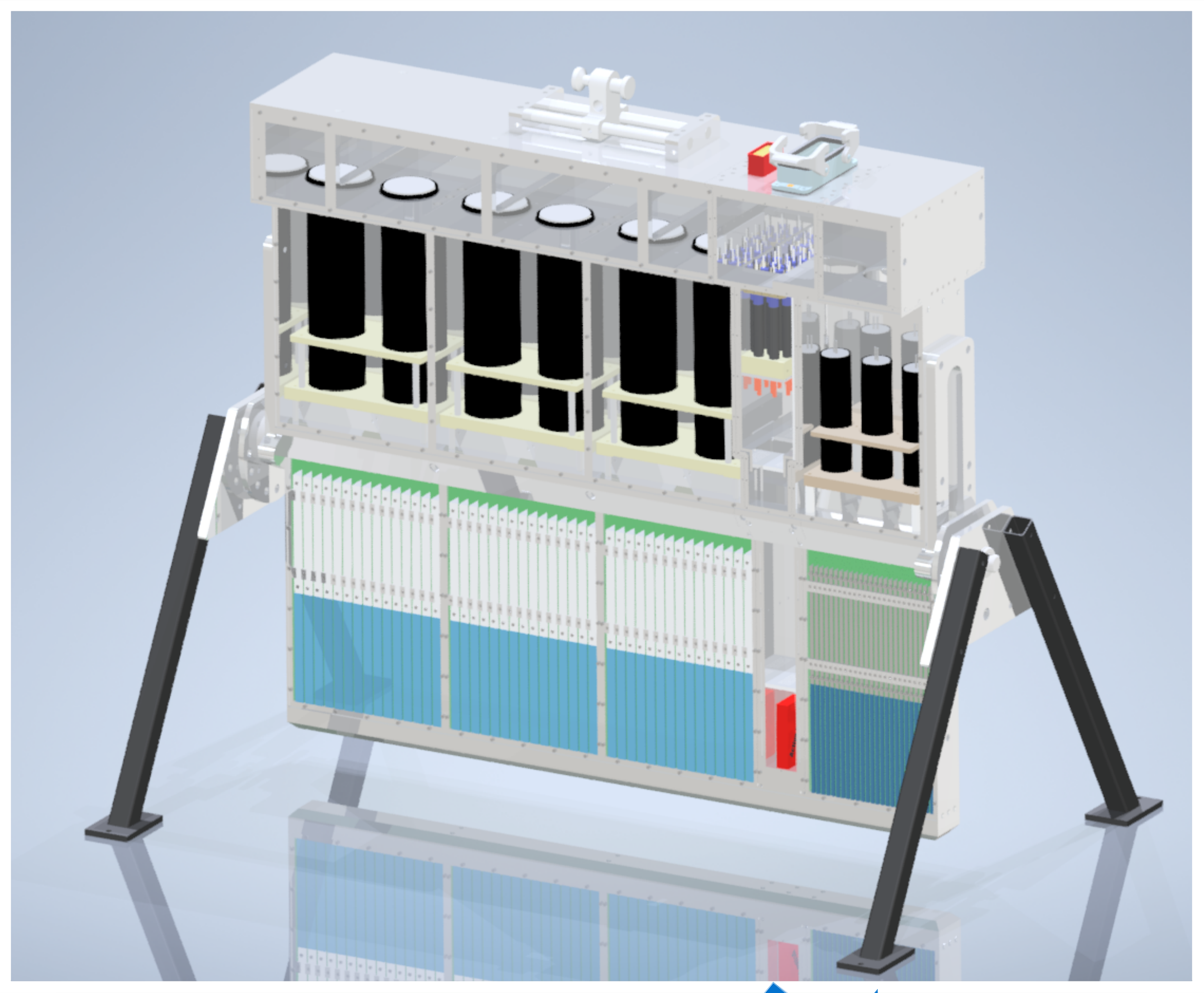


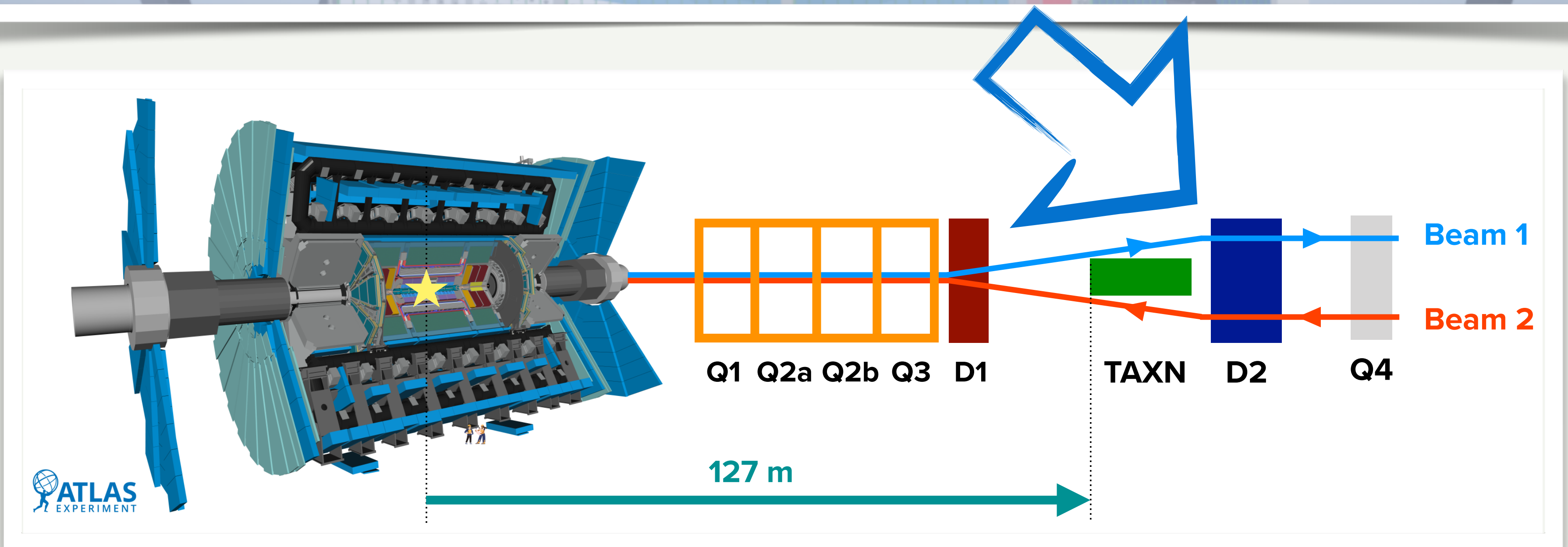
arXiv:2304.03430





HL-ZDC: targets for the detector



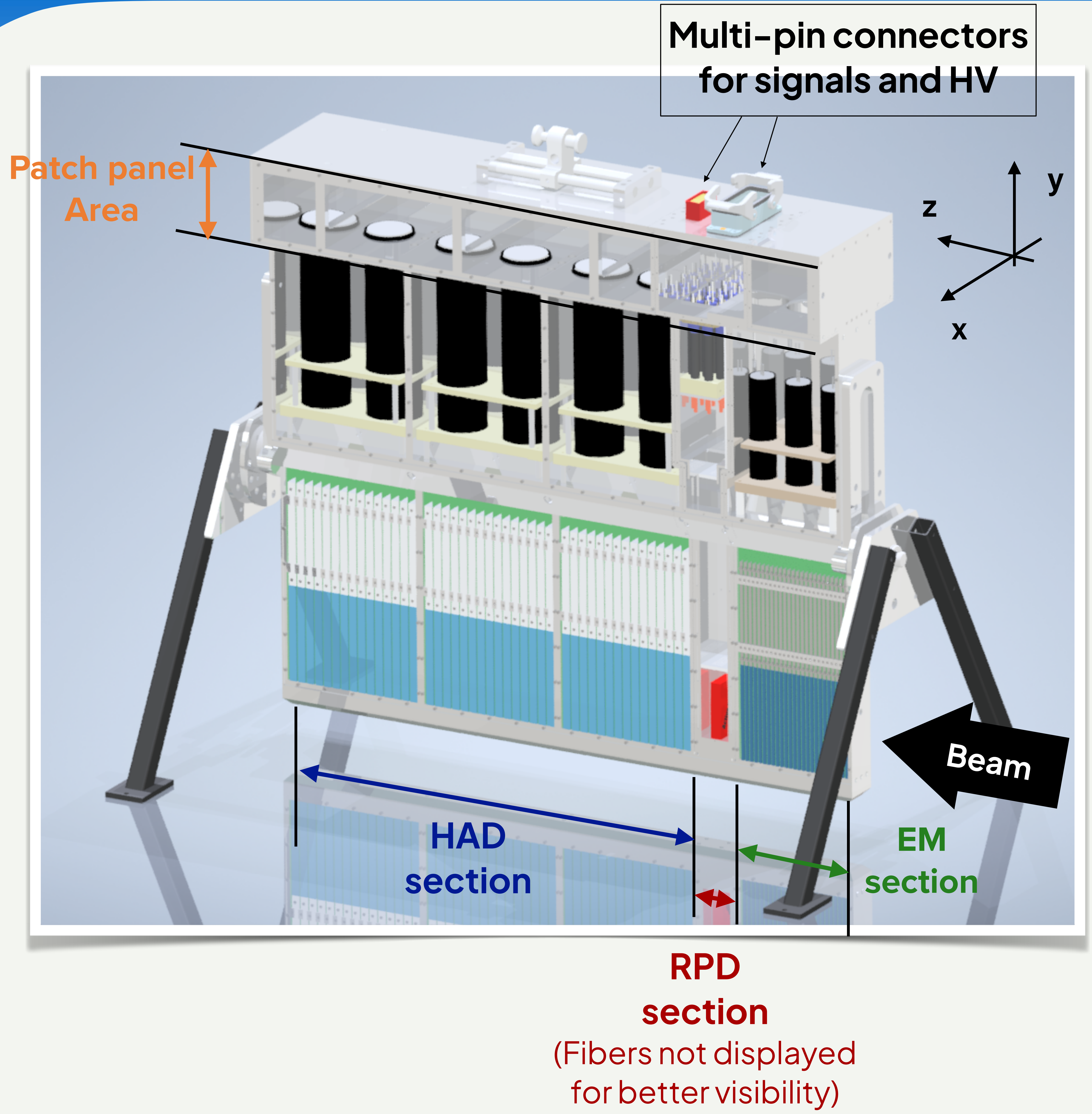


- Rad-hard detector: stable performance during the running period
- Well-controlled energy scale (via good 1n, 2n and 3n resolution)
- Good γ/n separation using segmented EM module
- Reaction Plane Detector
- Compatible with TAXN slot constraints and fully integrated with the machine
- Simplified connection procedures to reduce radiation exposure

CMS has similar challenges and physics goals

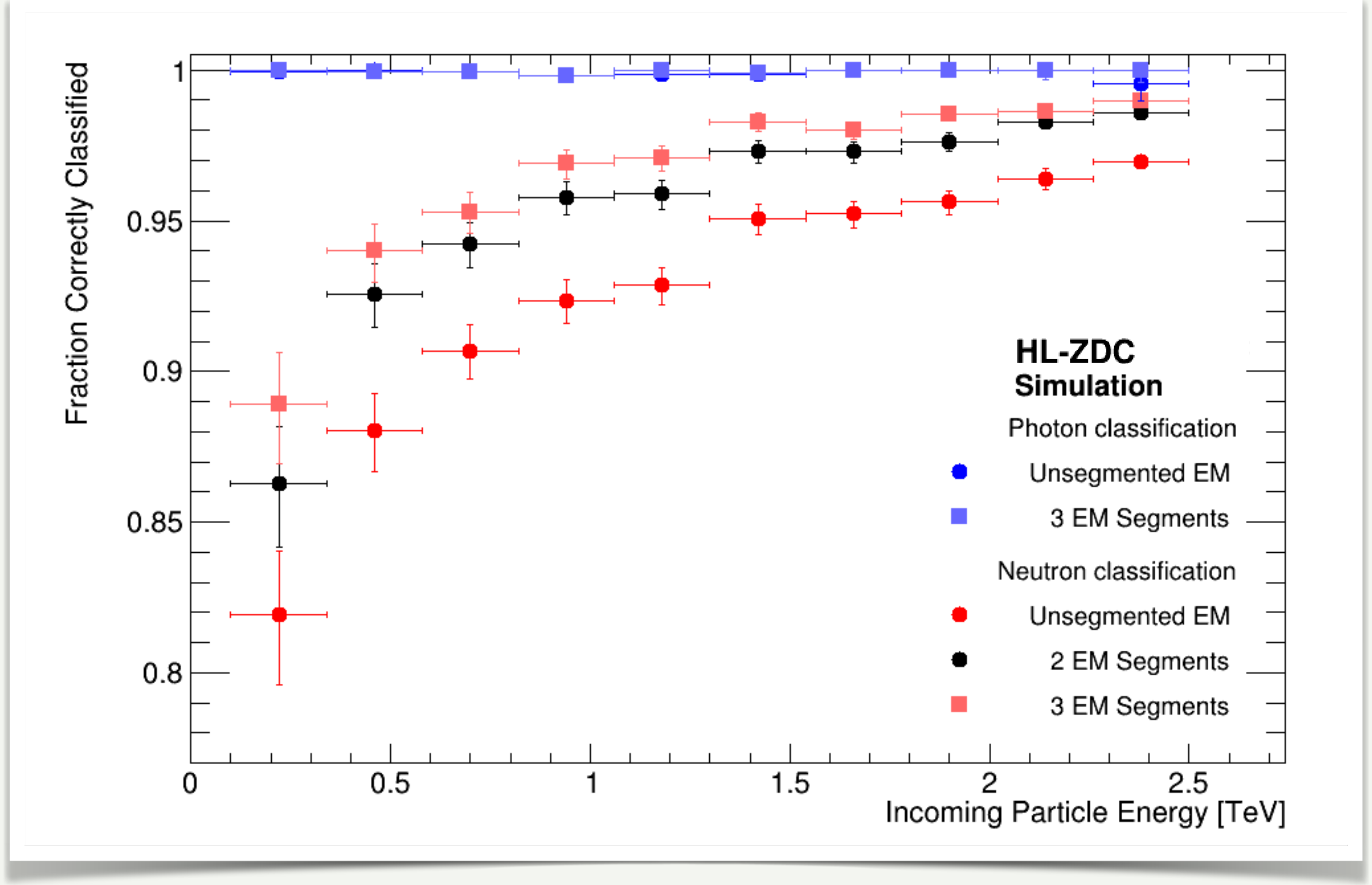
➡First joint hardware project between the two experiments!

HL-ZDC design



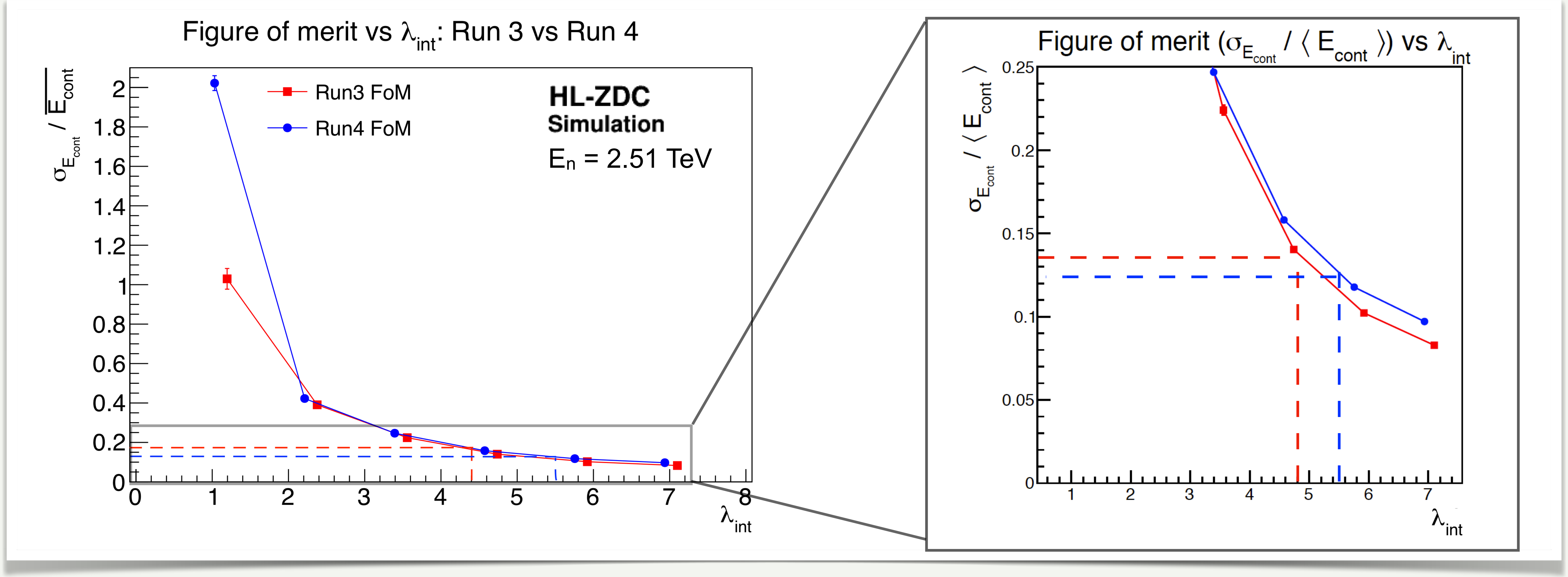
- Tungsten - fused silica sampling calorimeter
- Three sections:
  - ➡ Electromagnetic (EM)
    - ➡ z-segmentation w/ 3× channels
  - ➡ Reaction Plane Detector (RPD)
    - ➡ 4×4 x-y segmentation, 16× channels
  - ➡ Hadronic (HAD)
    - ➡ z-segmentation w/ 6× channels
- Time-efficient installation in a high radiation environment
  - ➡ Single module structure
  - ➡ Patch panels for rapid cabling

HL-ZDC: expected calorimeter performance



γ/n discrimination

- Very good photon/neutron achievable with basic algorithms, thanks to 3-fold EM segmentation



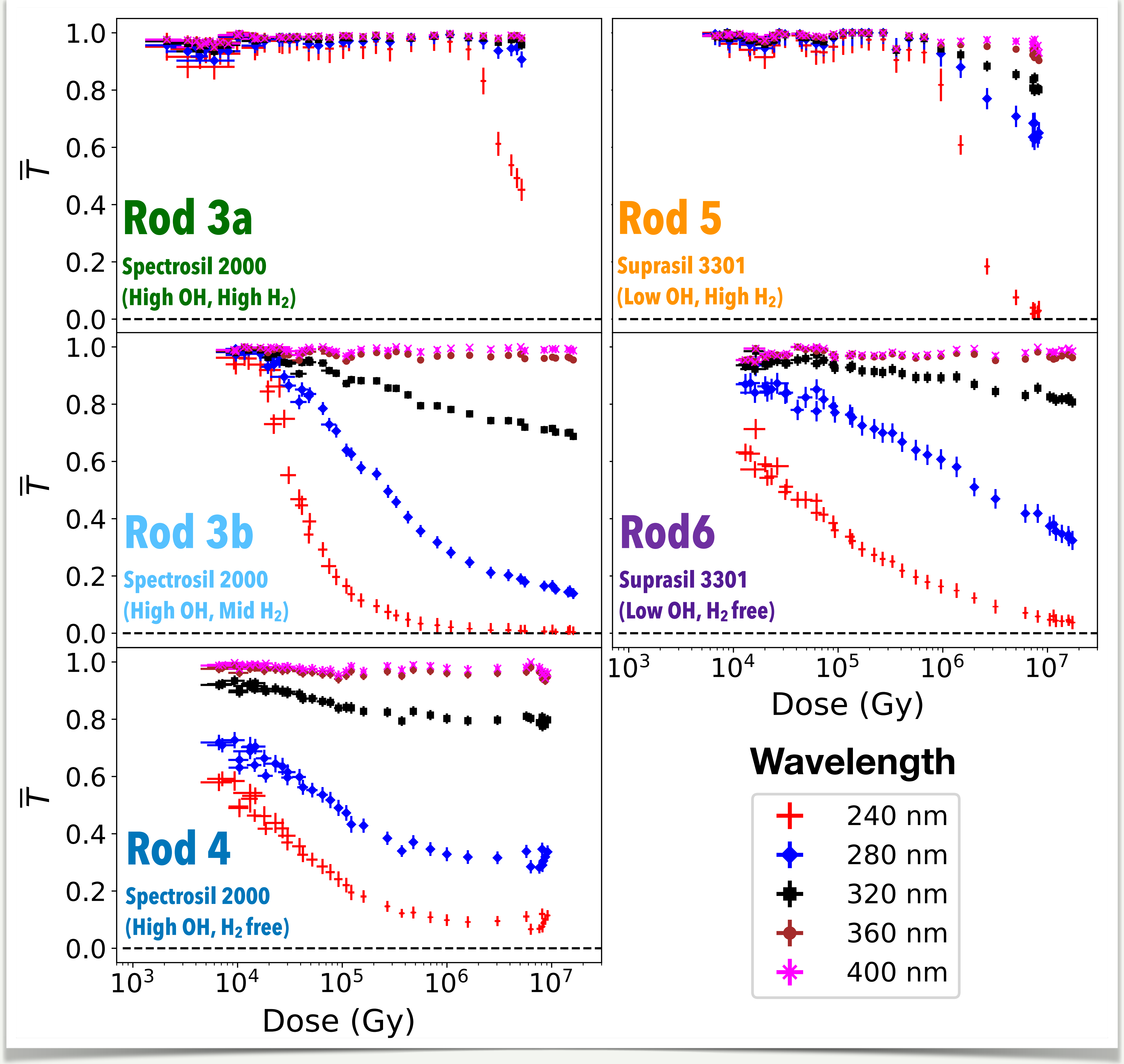
Shower containment

- HL-ZDC will have reduced transverse acceptance but a total of 5.5 λ_{int} (vs 4.4) and no BRAN detector in between
- Similar containment, but **HL-ZDC has better resolution**

HL-ZDC: radiation hardness

ATLAS EXPERIMENT

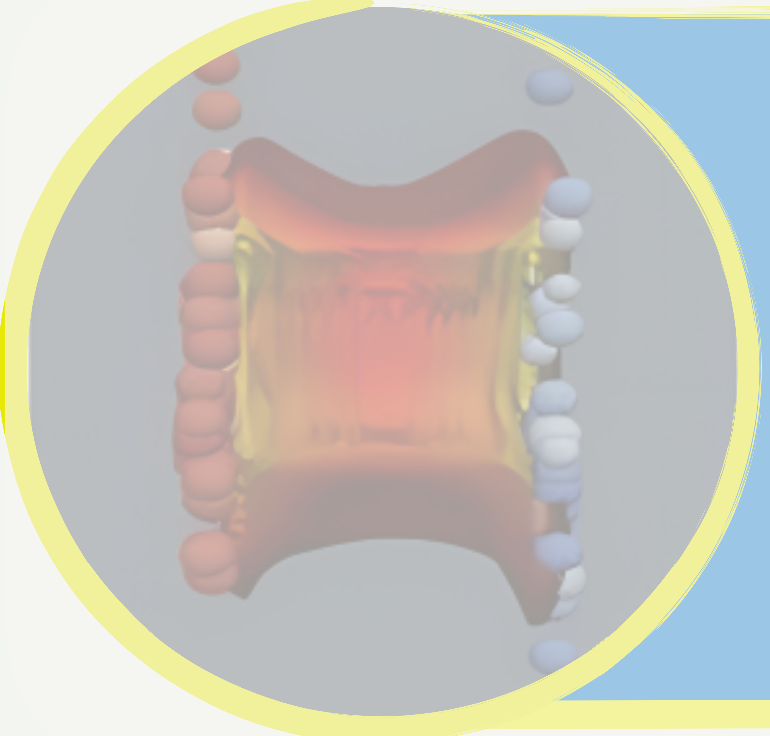
NIM-A, 1055 (2023) 168523



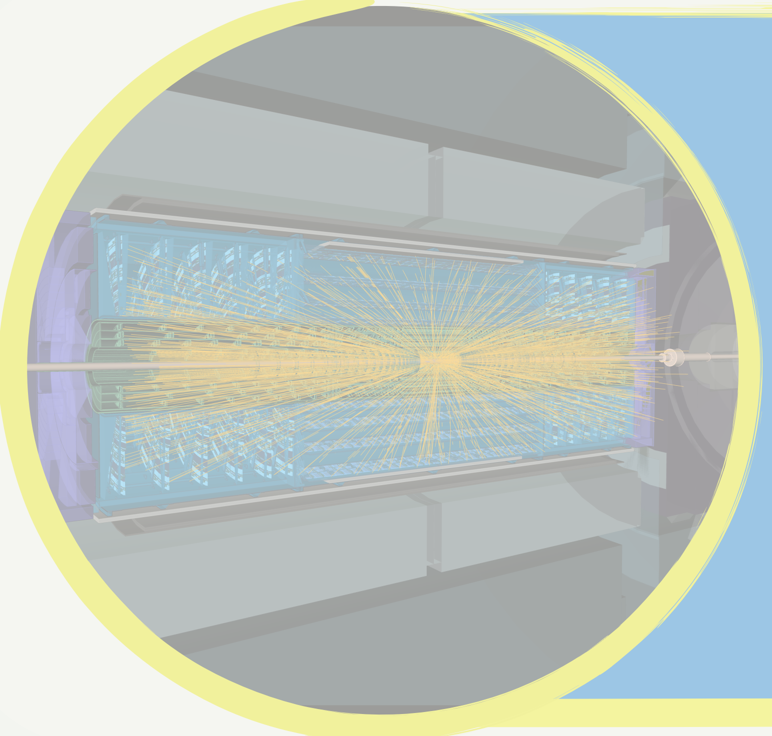
- Analysis using samples irradiated in the BRAN in Run 2. It correlates wavelength, transmittance, dose received, and material composition
- Results informed the choice of the **new material (Spectrosil 2000, High OH, High H_2)** for **ATLAS Run 3 ZDC refurbishment**
  - ➡No relevant losses in the irradiation range expected on the ZDC in Run 3 (~1.5 MGy)
  - ➡So far - expectation confirmed by performance during data taking!
- **New campaign in Run 3,** will extend the irradiation range of ~1 order of magnitude

In memoriam of S.Mazzoni 1978–2025

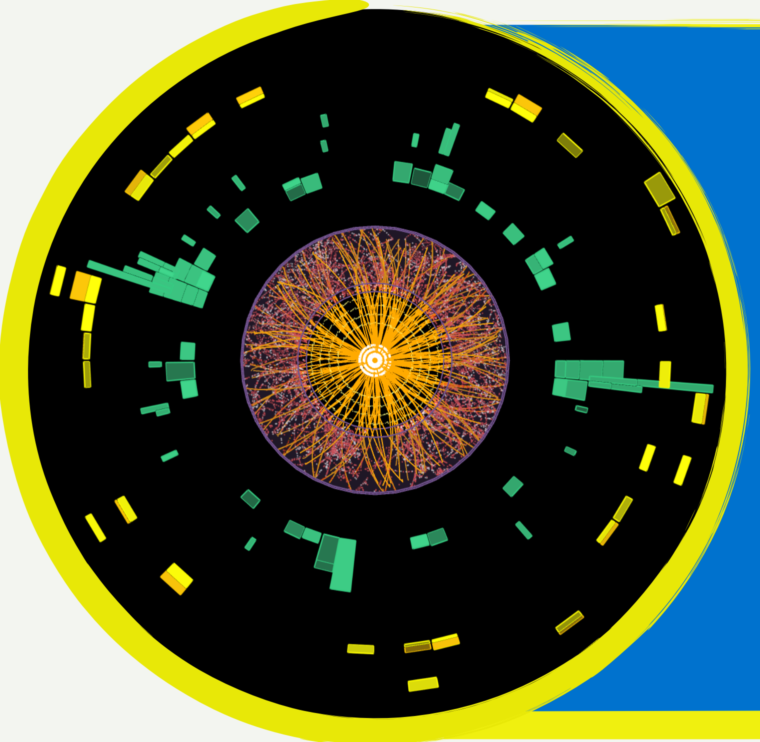
Outline



Introduction

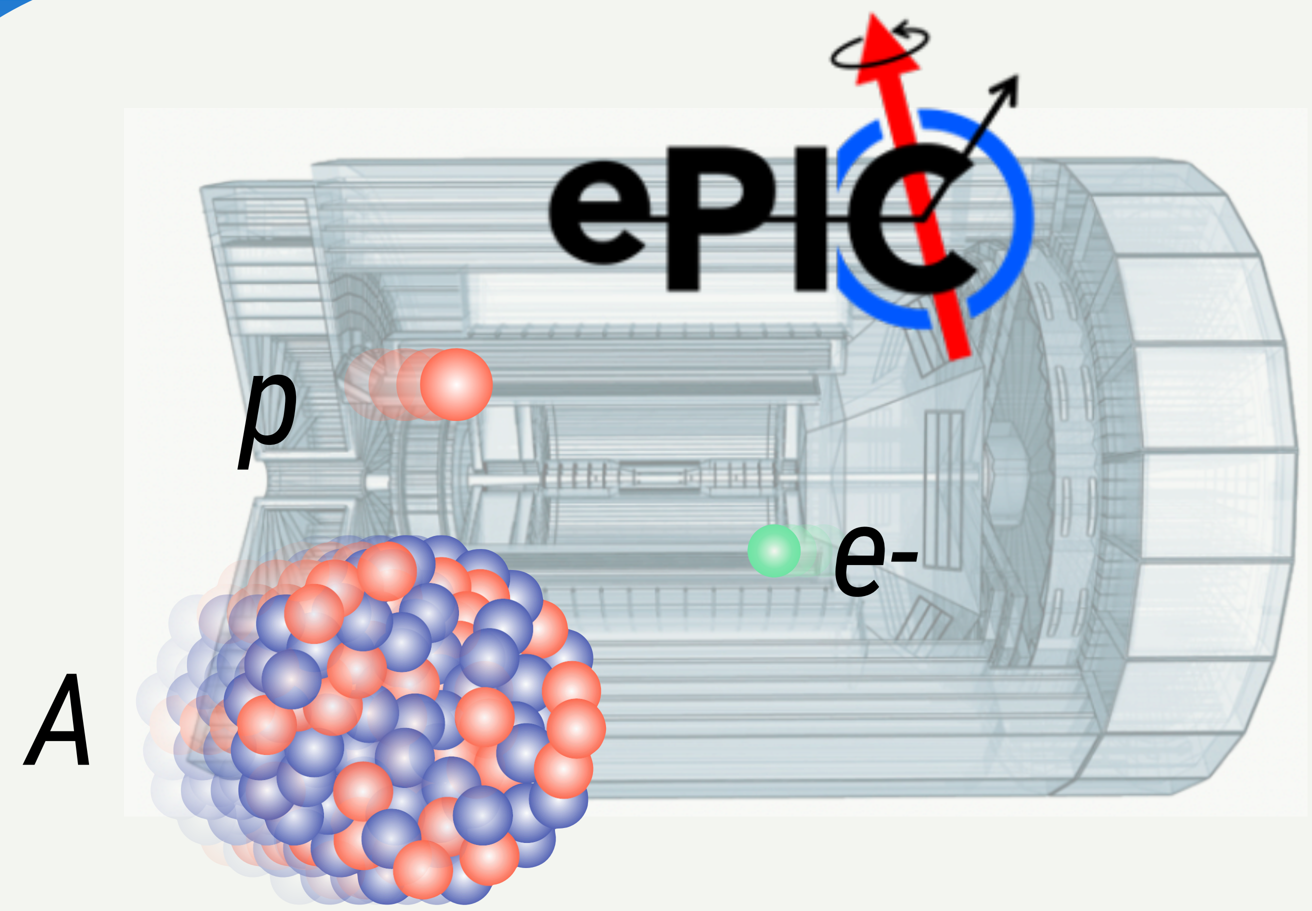


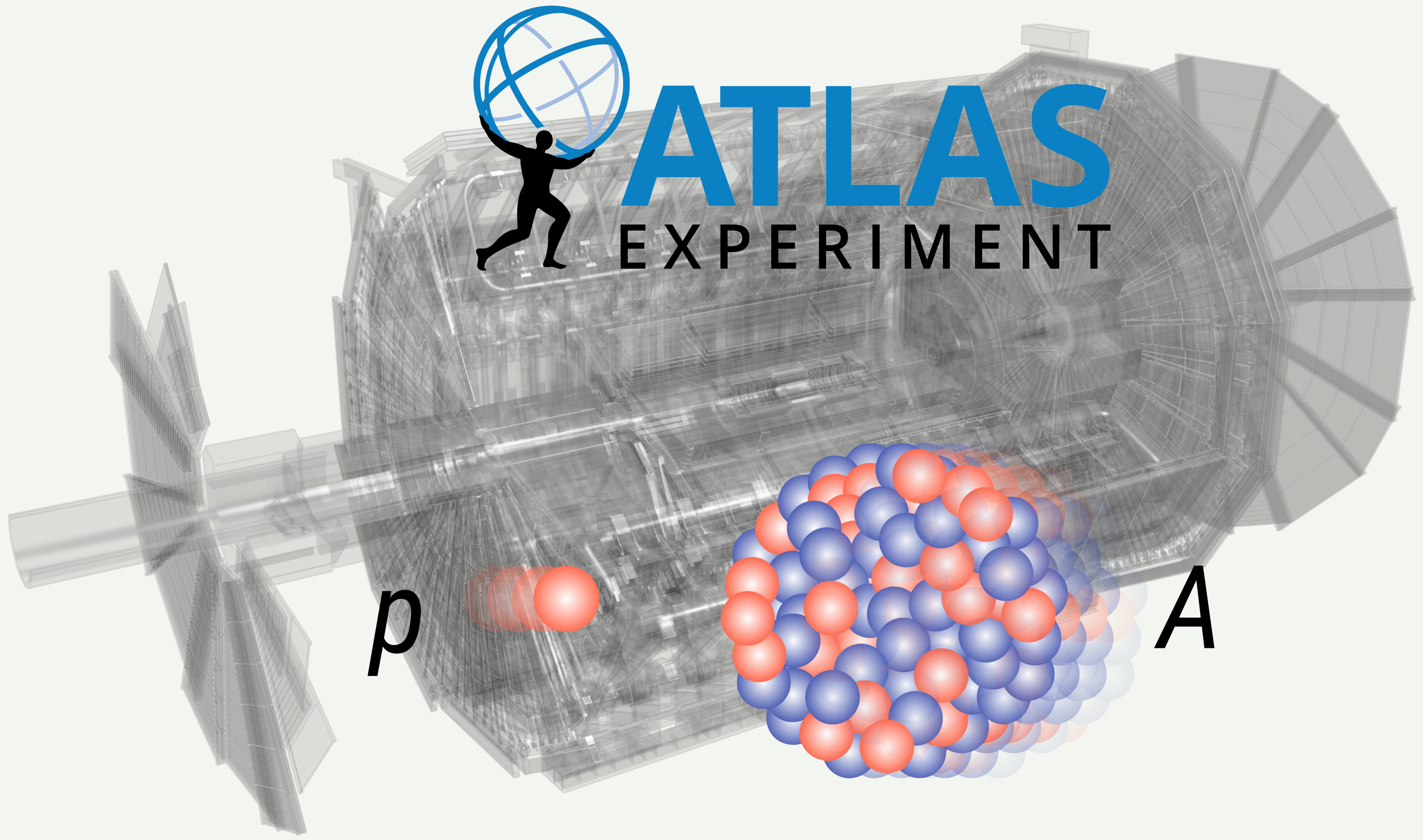
ATLAS Phase-II upgrades



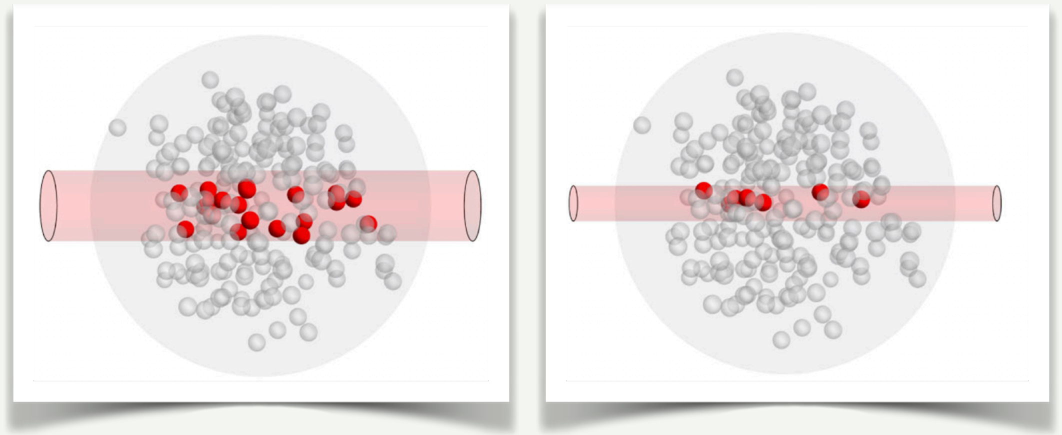
Synergies between the ATLAS HI program & the EIC

Synergies between ATLAS HI and EIC programs

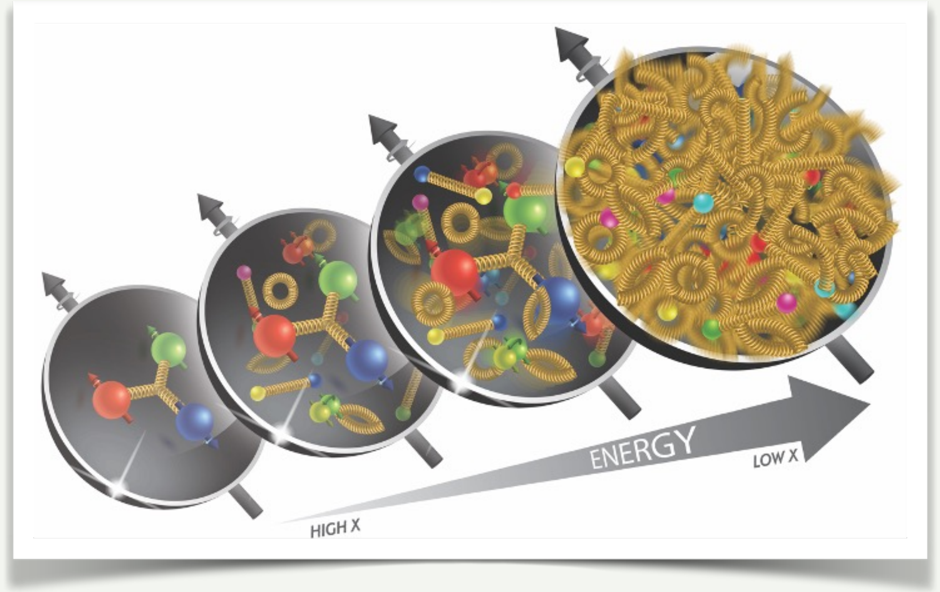




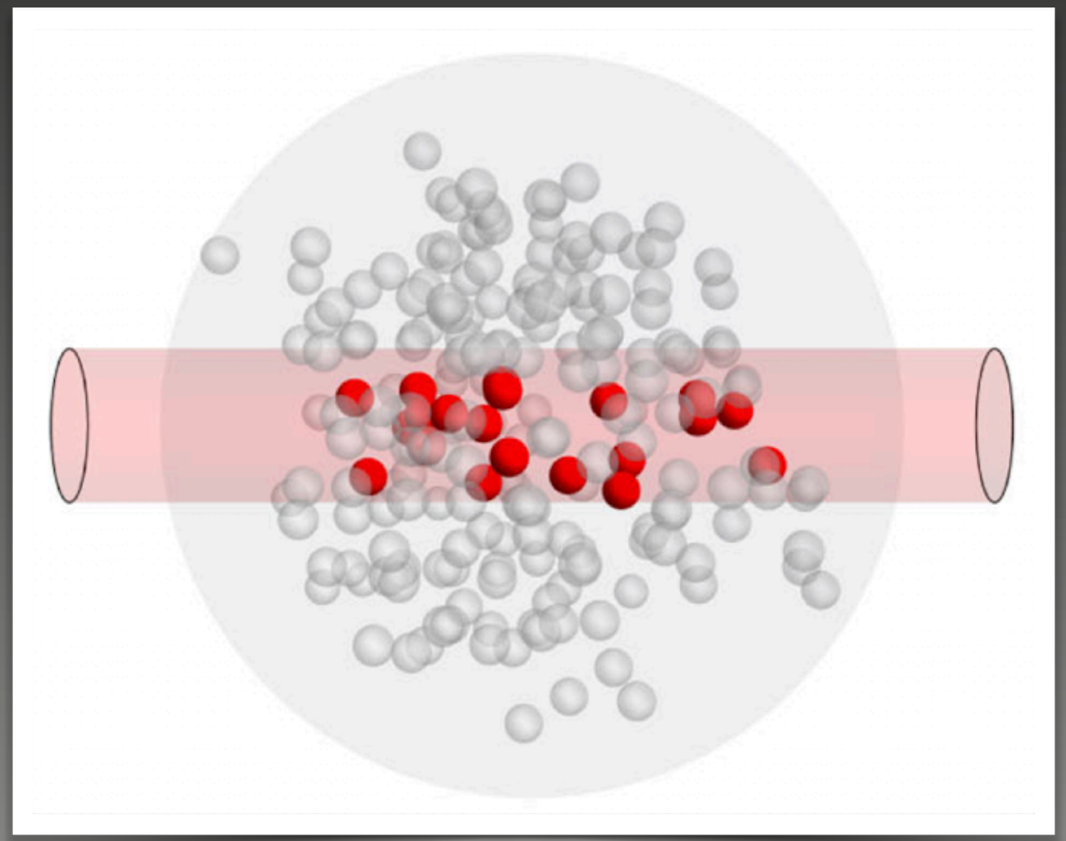
Passage of color charge through cold nuclear matter & color fluctuations (and/or GPD)

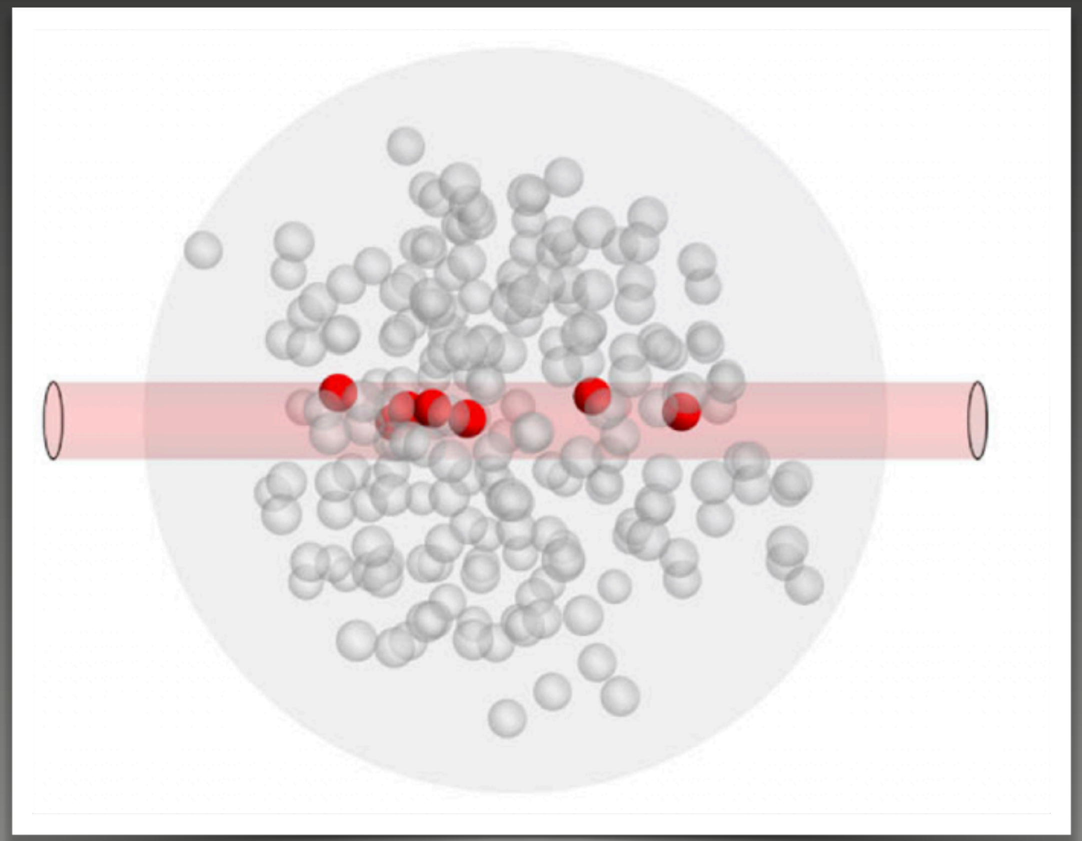


Search for saturation onset



nPDF and collectivity not covered for matter of time ➨☕



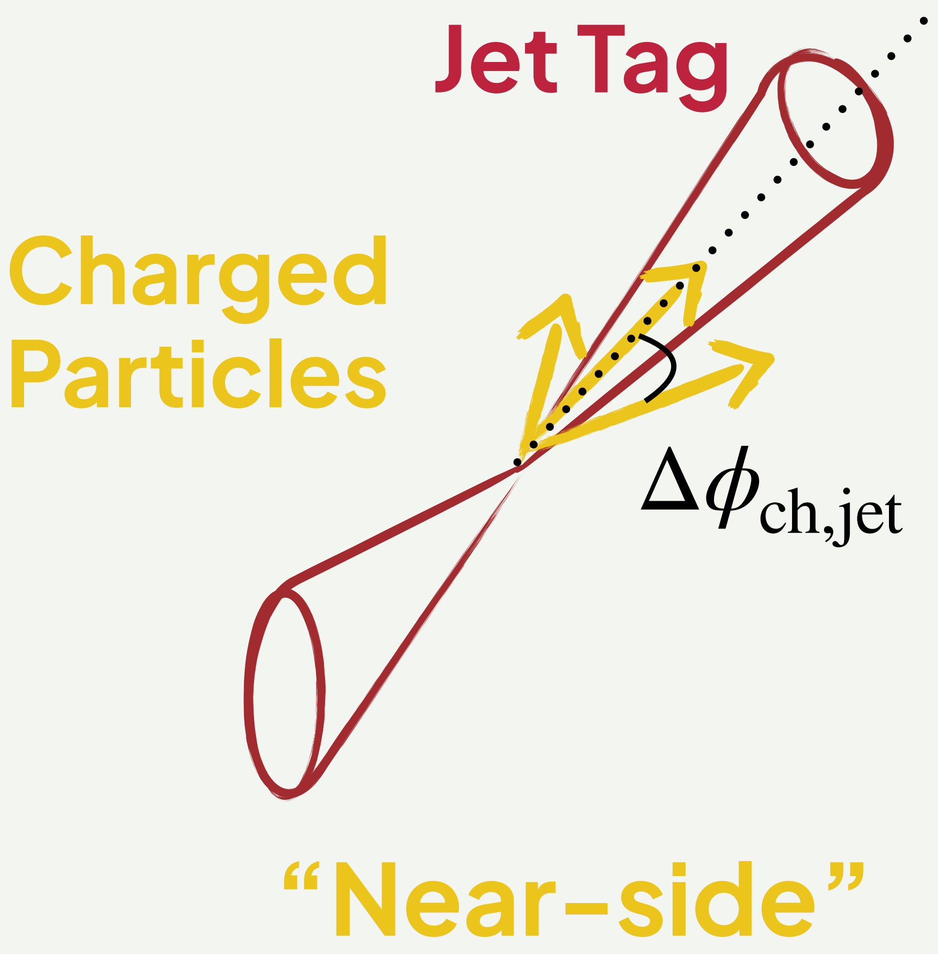


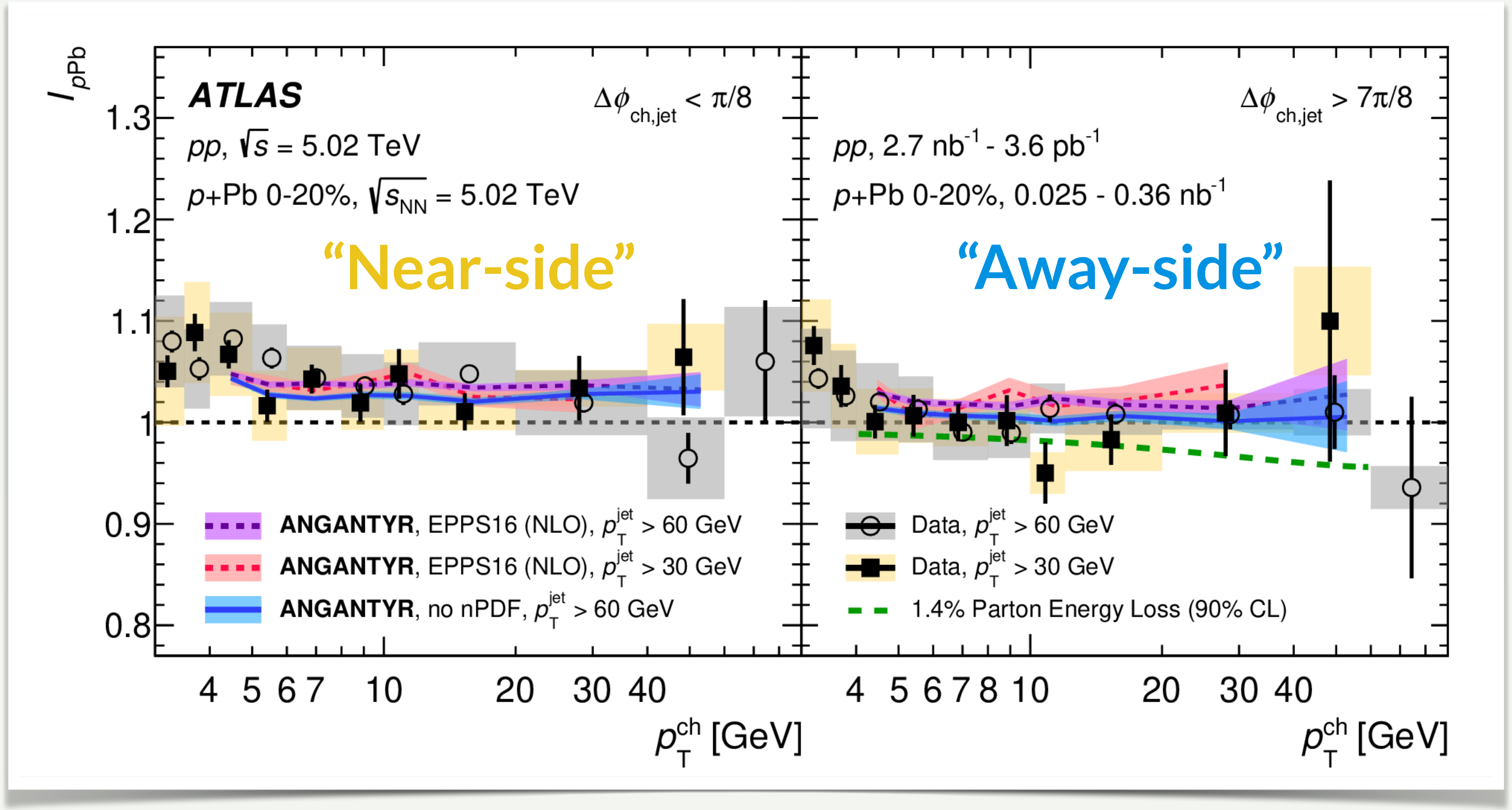
Passage of color charge through cold nuclear matter & color fluctuations (and/or GPD)

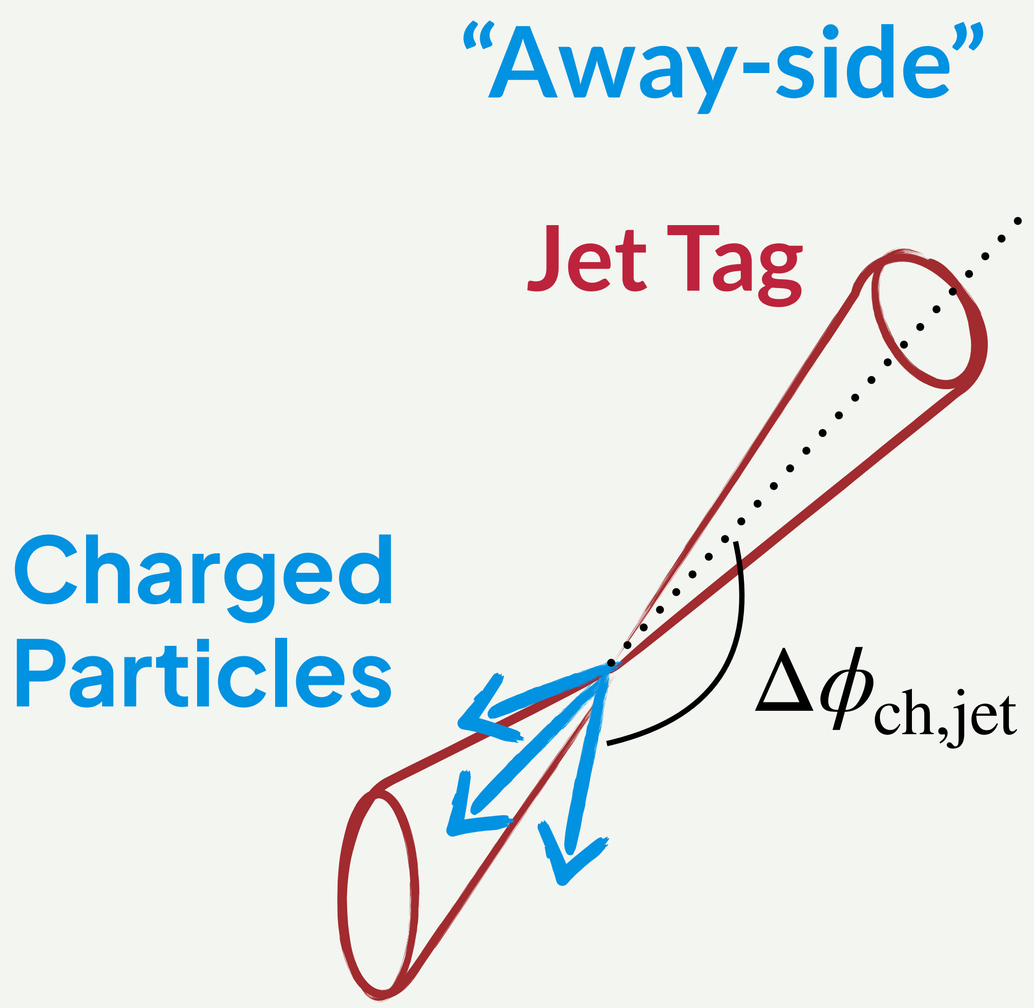
Jet probes in p+Pb: no (significant) E_{Loss}

Phys. Rev. Lett. 131 (2023) 072301

$$I_{pPb} = \left(\frac{1}{N_{\rm jet}} \frac{dN_{\rm ch}}{dp_{\rm T}^{\rm Ch}} \right)_{p+Pb} \Big/ \left(\frac{1}{N_{\rm jet}} \frac{dN_{\rm ch}}{dp_{\rm T}^{\rm Ch}} \right)_{p+p}$$







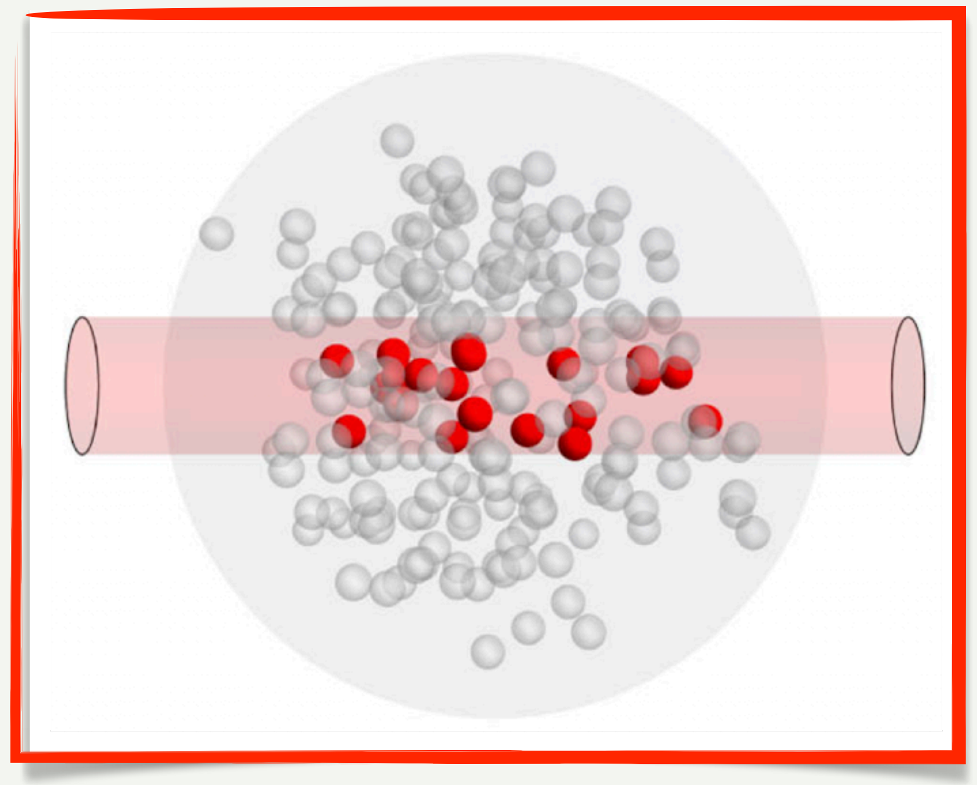
Reminder: No evidence of **jet quenching** in p+Pb

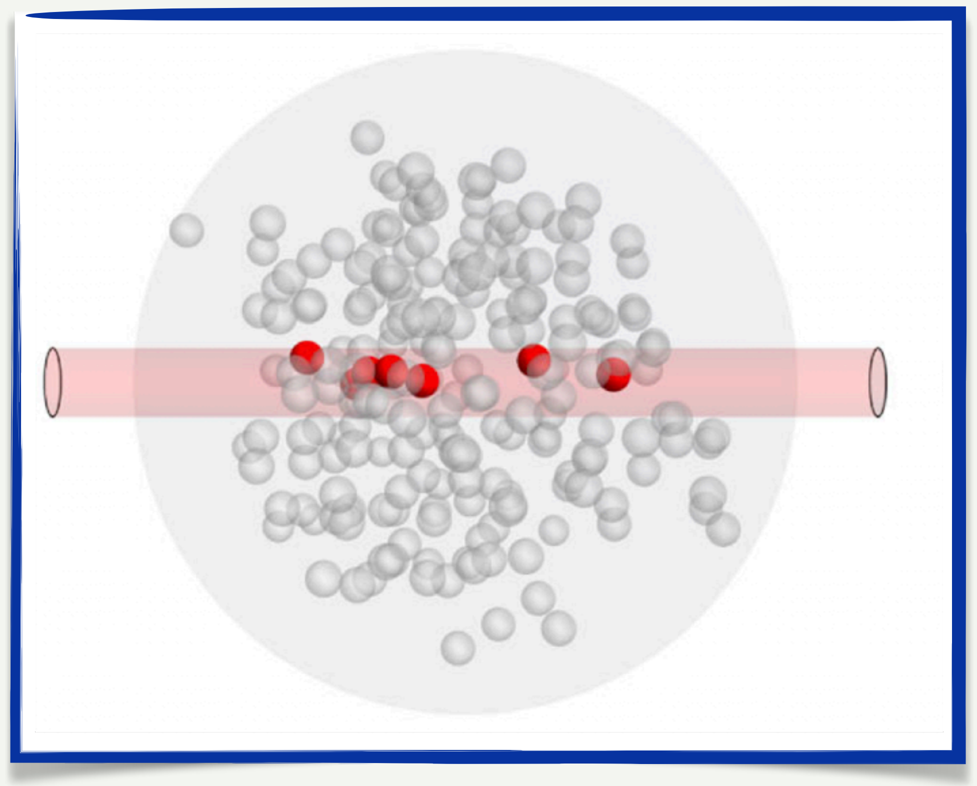
Parton energy loss constraint: 0.2 ± 0.5% and < 1.4% at 90% confidence level

Proton configuration role in pA collisions

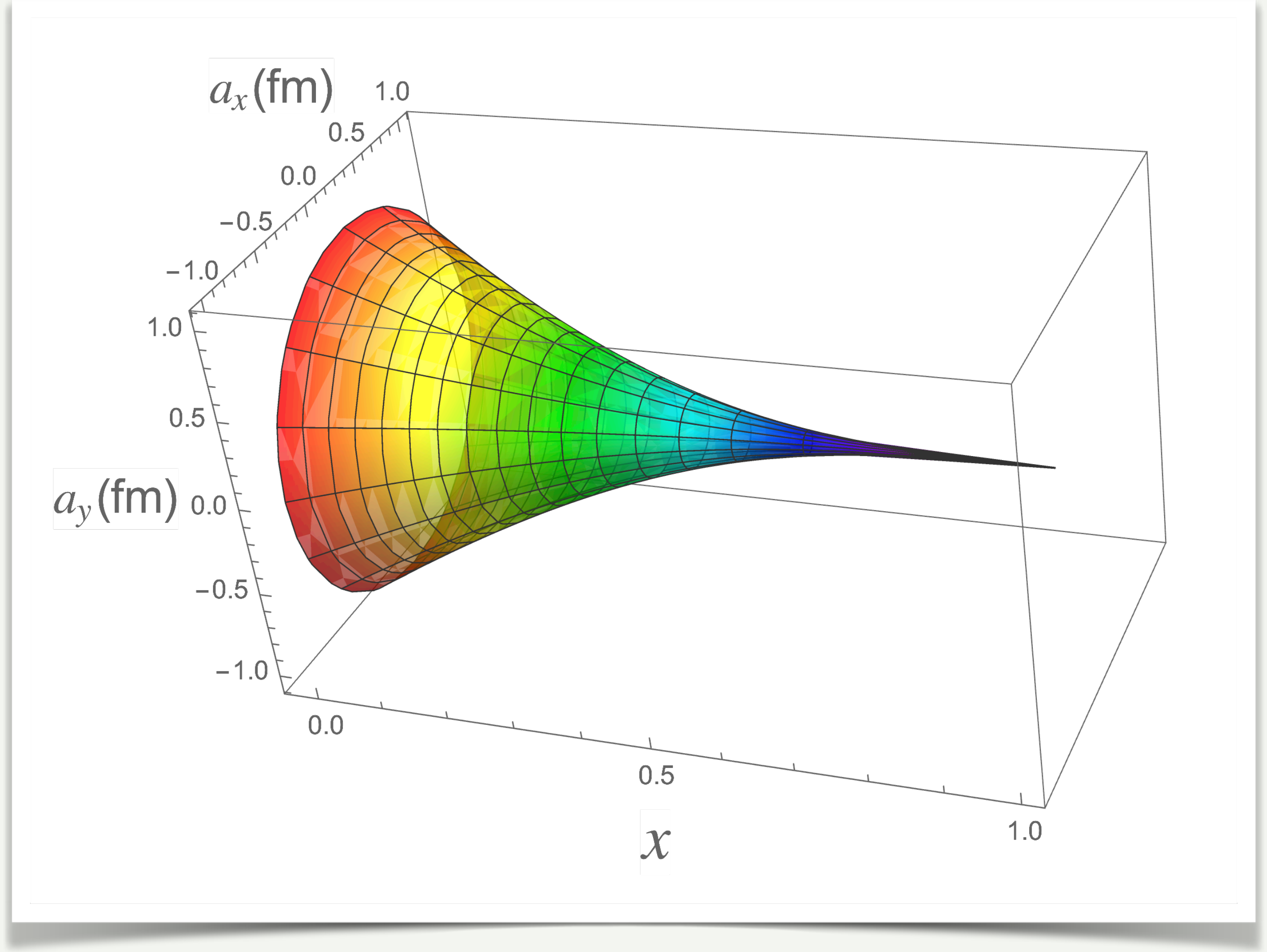
ATLAS EXPERIMENT

Color Fluctuations picture
Alvioli et al.
PRD 98 (2018) 071502





GPD & color transparency picture
Dupré et al., PRD95(2017)011501
Brodsky et al., Physics 2022, 4, 633–646



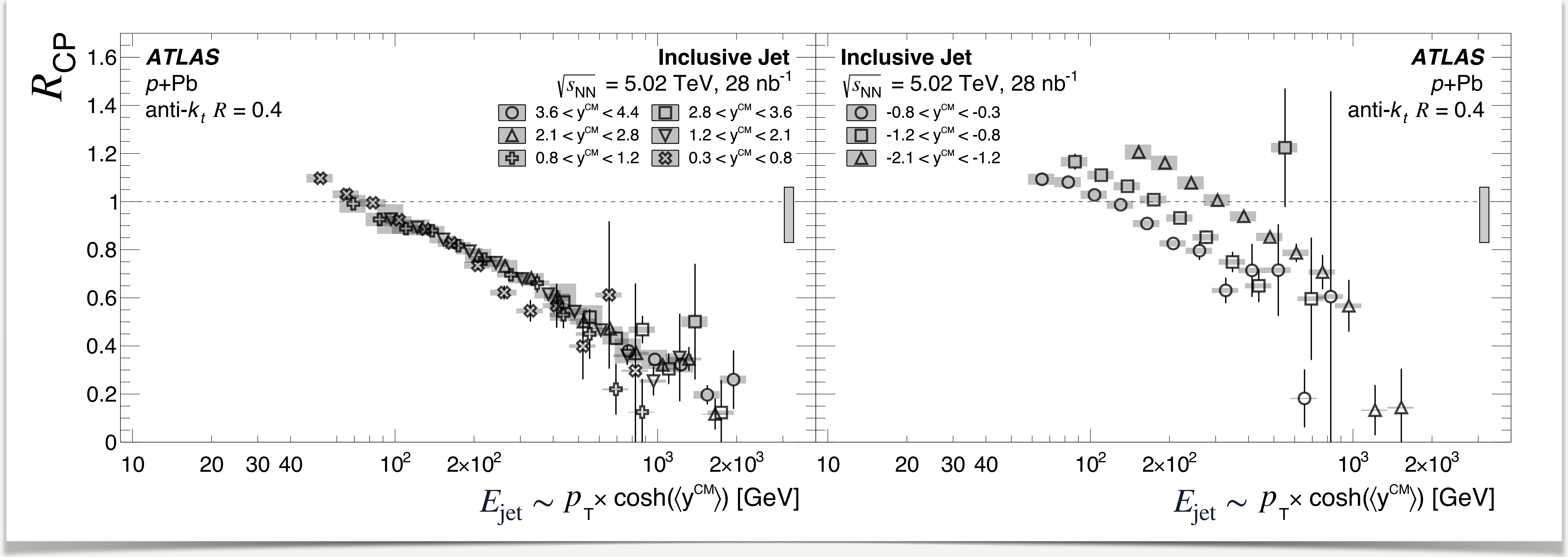
Proton size and interaction strength are closely related to the parton configuration

Protons containing higher-x partons are associated with more compact configurations, characterized by a lower-than-average interaction strenght

Nuclei can filter for different-sized proton configurations!

ATLAS input on small proton configurations

ATLAS EXPERIMENT



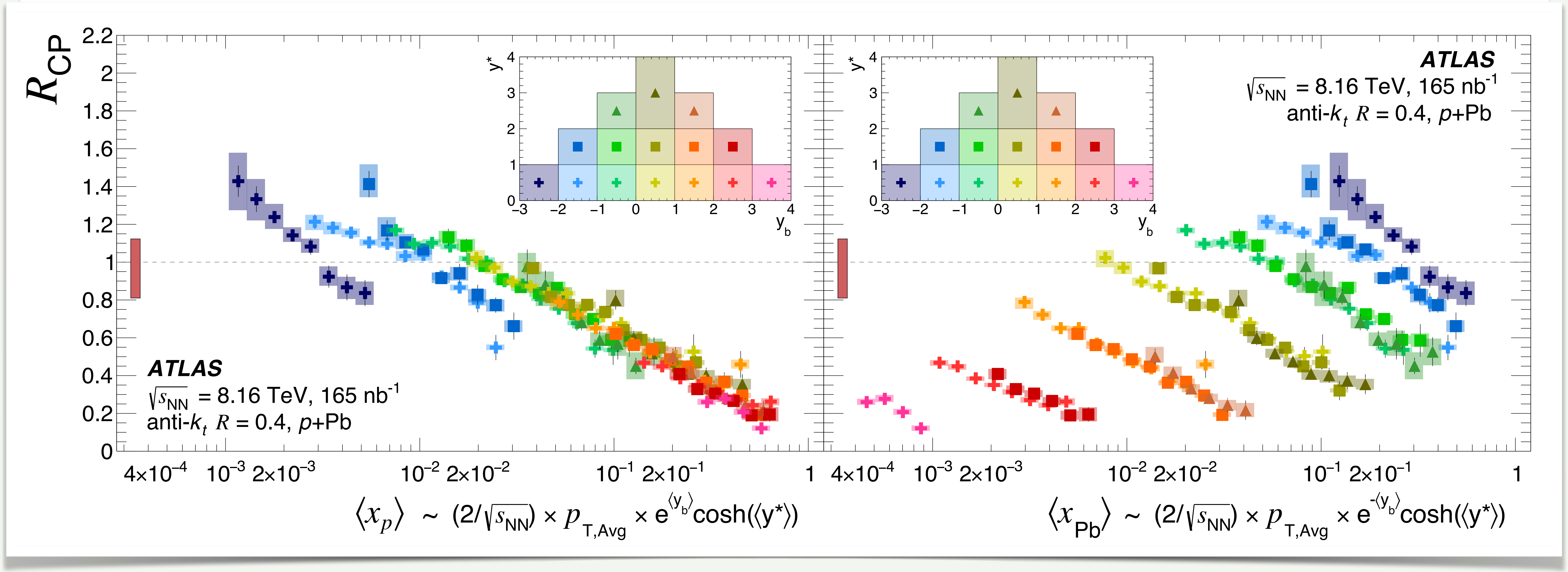
- **Inclusive jets R_{CP}:** suppression of central events compared to peripheral found to be function of the jet energy, suggesting direct link to initial state kinematics

2015

Evidence of event-activity bias in jet production in p+Pb at 5.02 TeV

PLB 748 (2015) 392–413

ATLAS input on small proton configurations



- **Dijets R_{CP}**: provides full access to the kinematics of the initial state. Confirms the event-activity bias is fully driven by the proton configuration

2015

Evidence of event-activity bias in jet production in p+Pb at 5.02 TeV

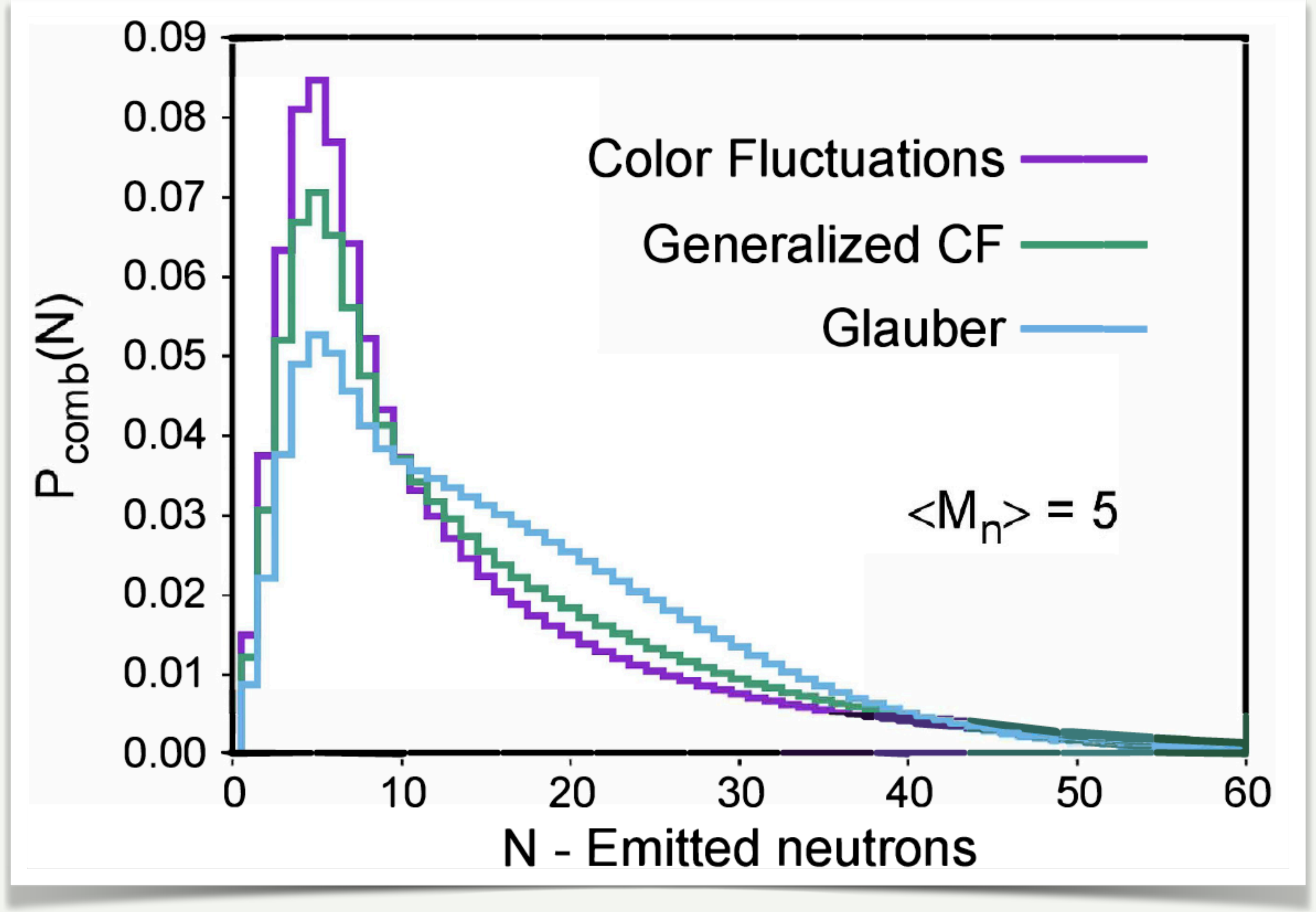
PLB 748 (2015) 392–413

2023

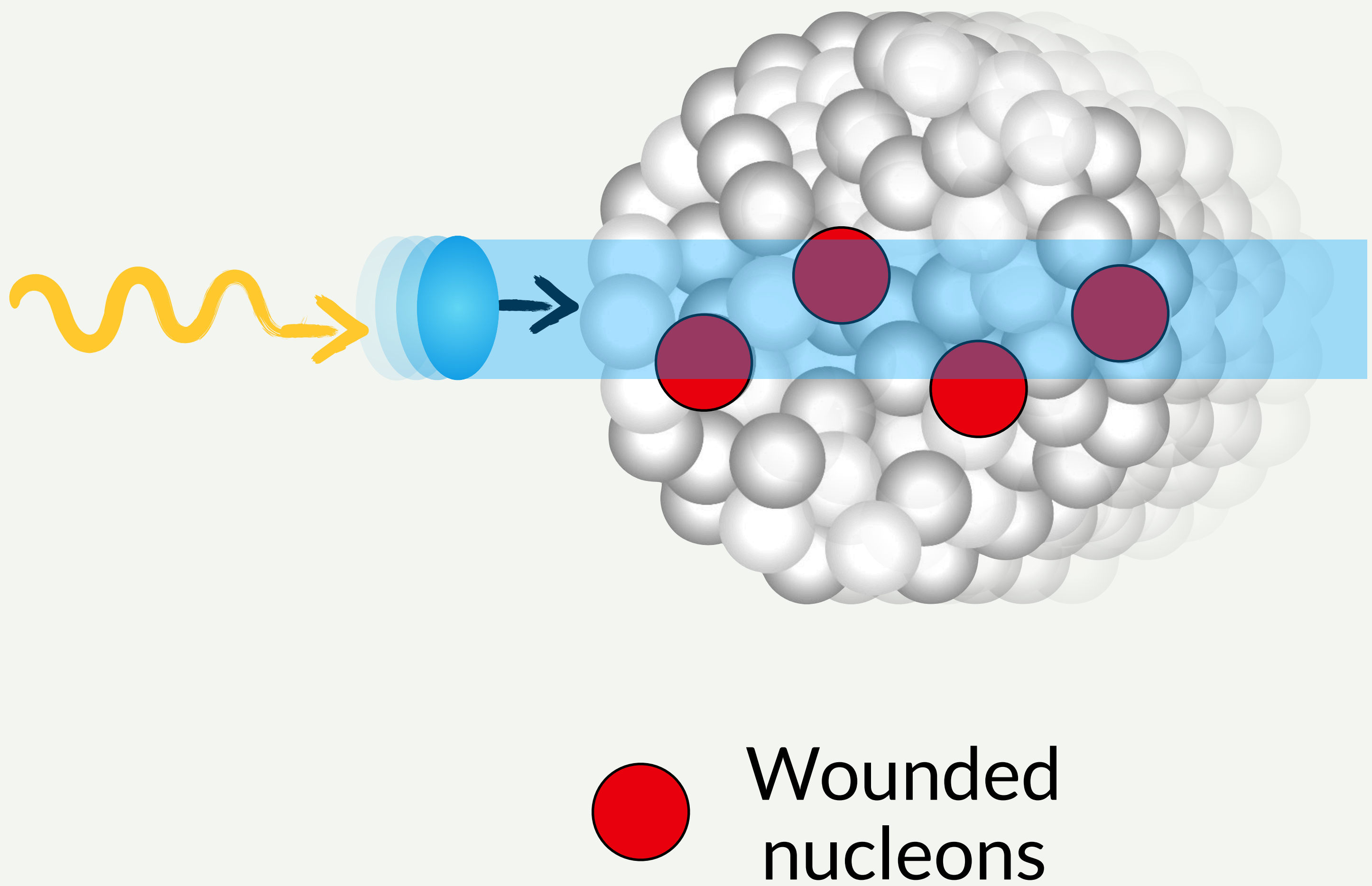
Mapping the event activity bias on the initial state kinematics using dijets

Phys. Rev. Lett. 132 (2024) 102301

Increasing attention on CF effects



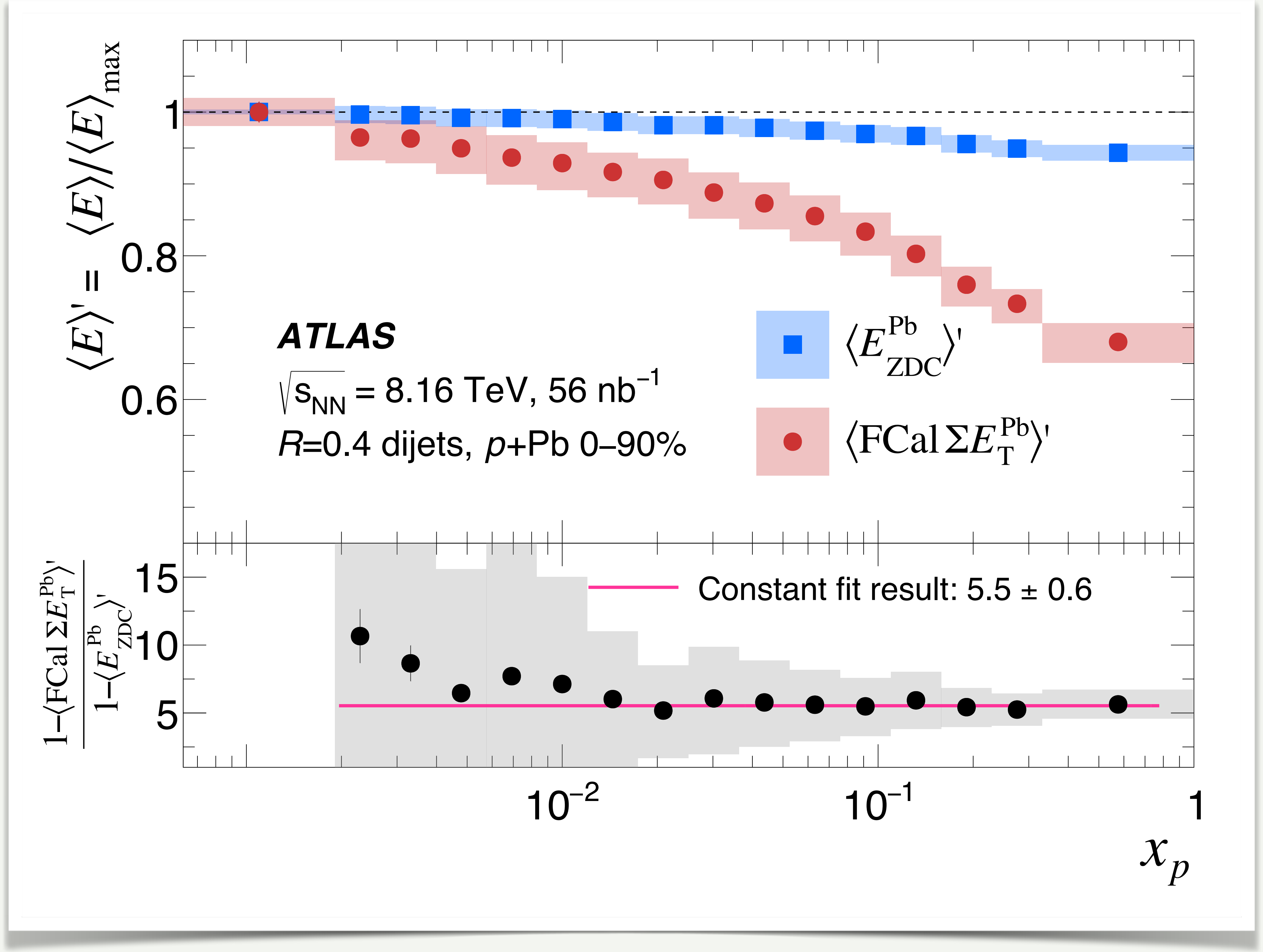
γA in $A + A$ collisions via **resolved photon**



Alvioli, Guzey and Strikman in [PRC 110, 025205 (2024)] show the **impact of CF on nuclear breakup** in resolved UPC collisions in Pb+Pb

- **Critical** to understand the role of these effects in resolved photon collisions **also for the EIC**, if one wants to rely on forward neutrons to characterize the **event geometry in e+A** collisions (approach proposed by Zheng et al, **Eur. Phys. J. A (2014) 50: 189**)
- **Are these effects relevant for centrality determination in p+Pb using the ZDC?**

ATLAS input++ on small proton configurations



2015

Evidence of event-activity bias in jet production in p+Pb at 5.02 TeV

PLB 748 (2015) 392–413

2023

Mapping the event activity bias on the initial state kinematics using dijets

Phys. Rev. Lett. 132 (2024) 102301

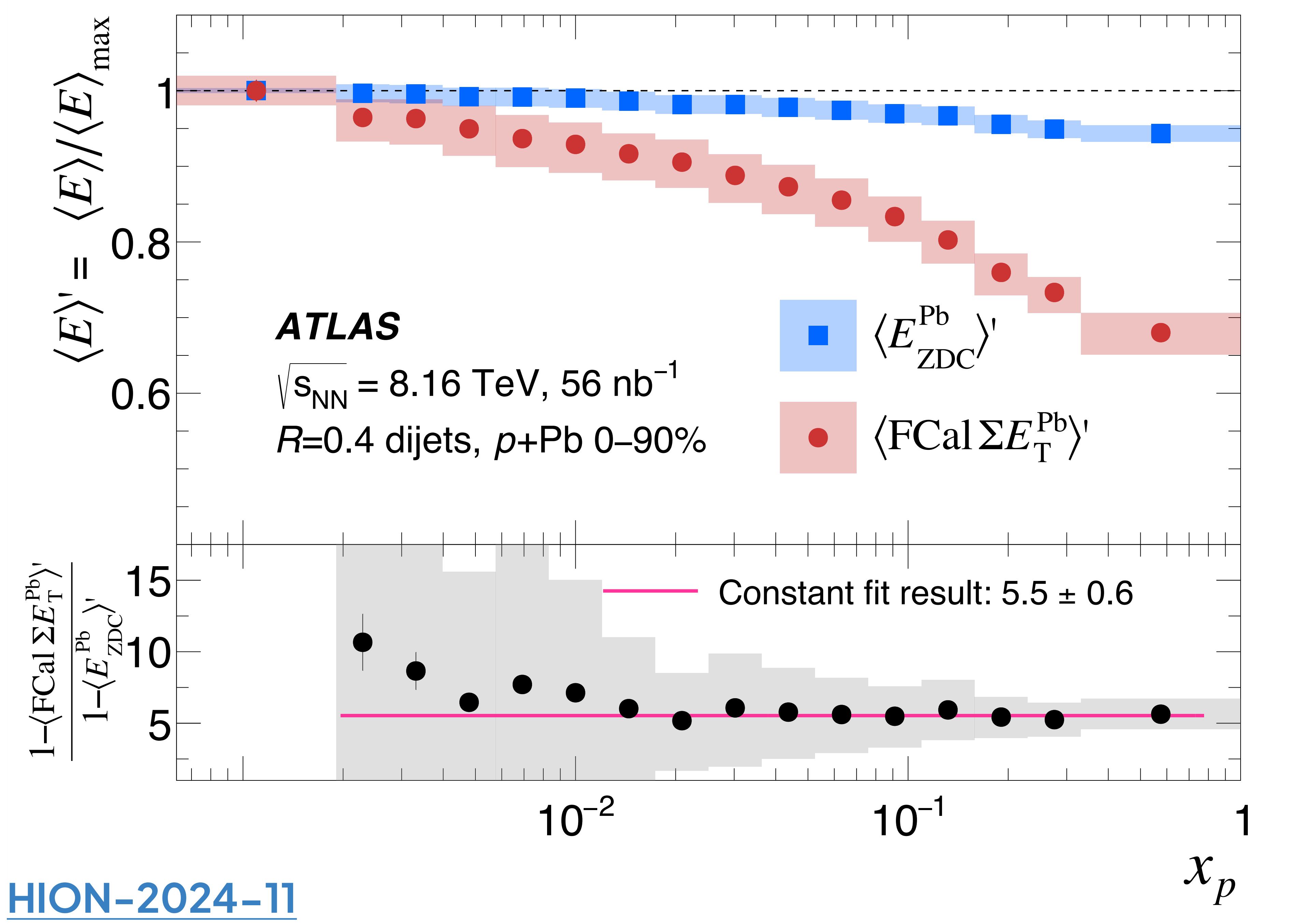
2025

Study of the robustness of event geometry estimators in p+Pb

HION-2024-11

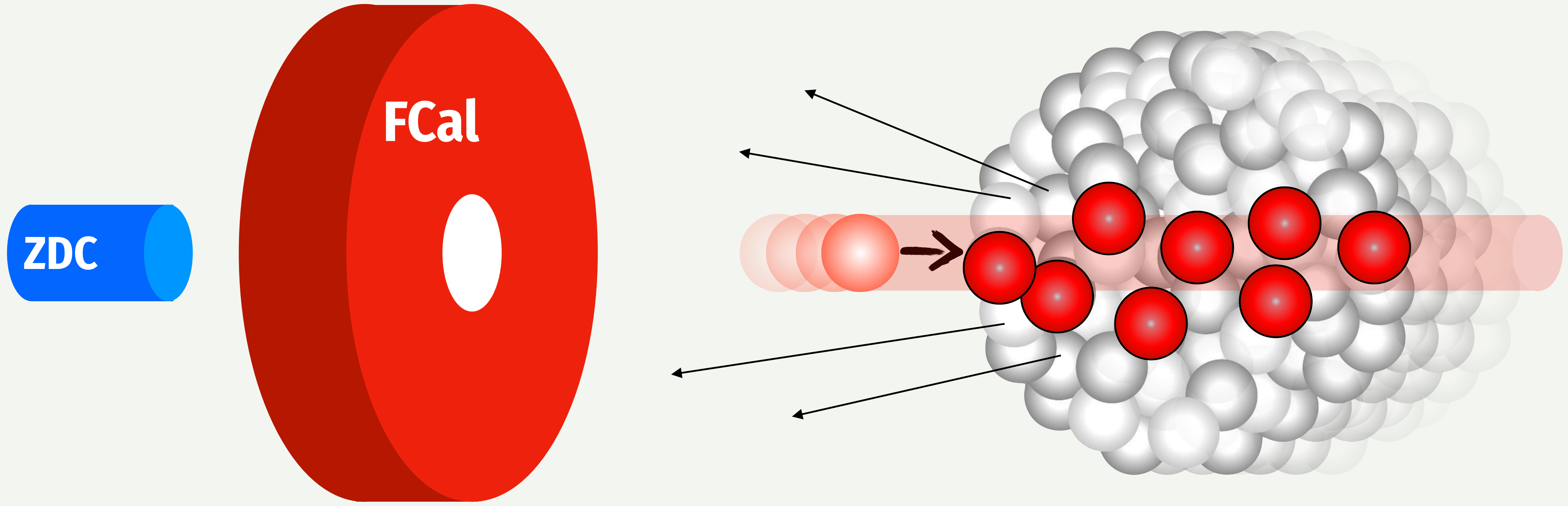
ATLAS input++ on small proton configurations

ATLAS EXPERIMENT

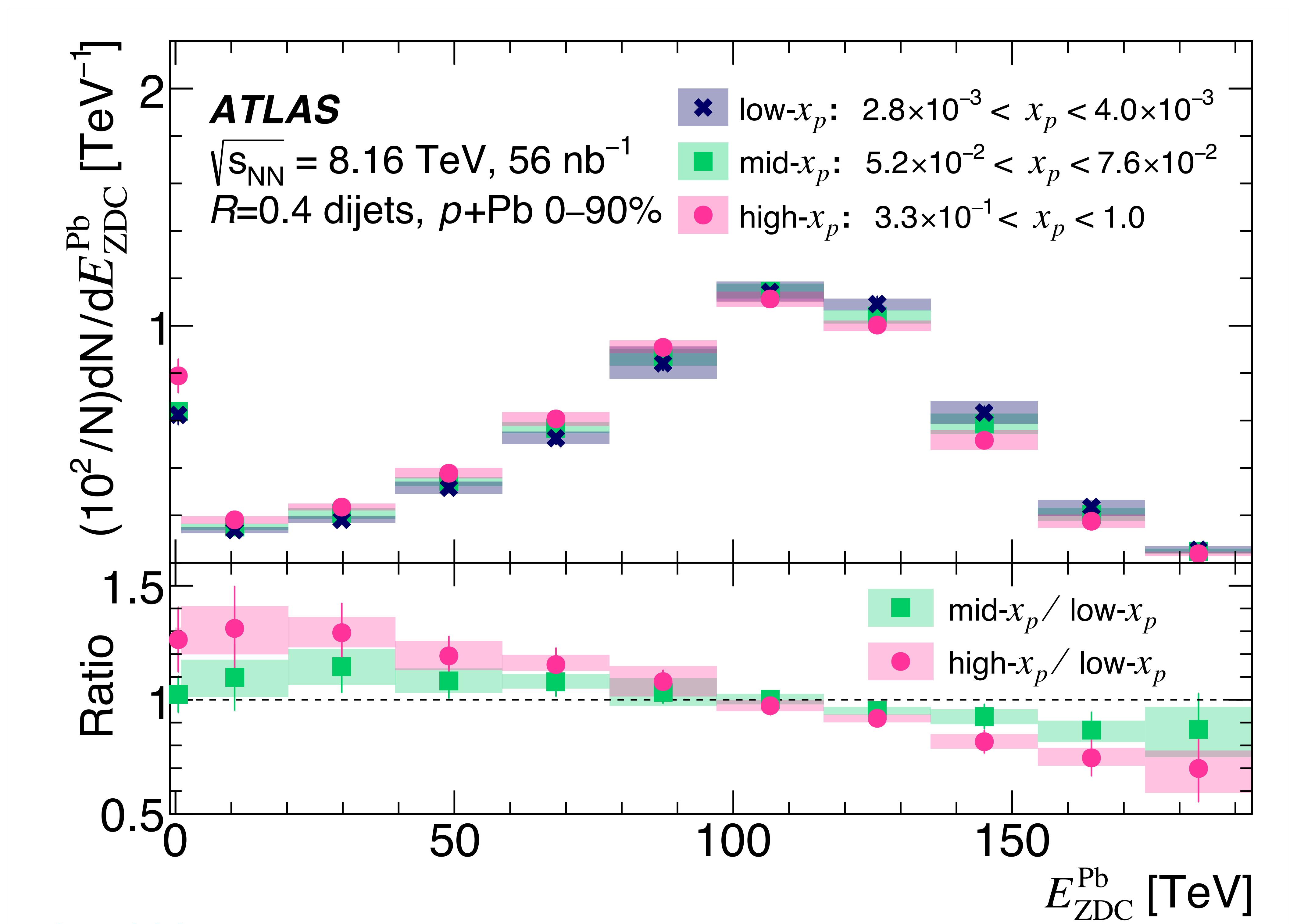


HION-2024-11

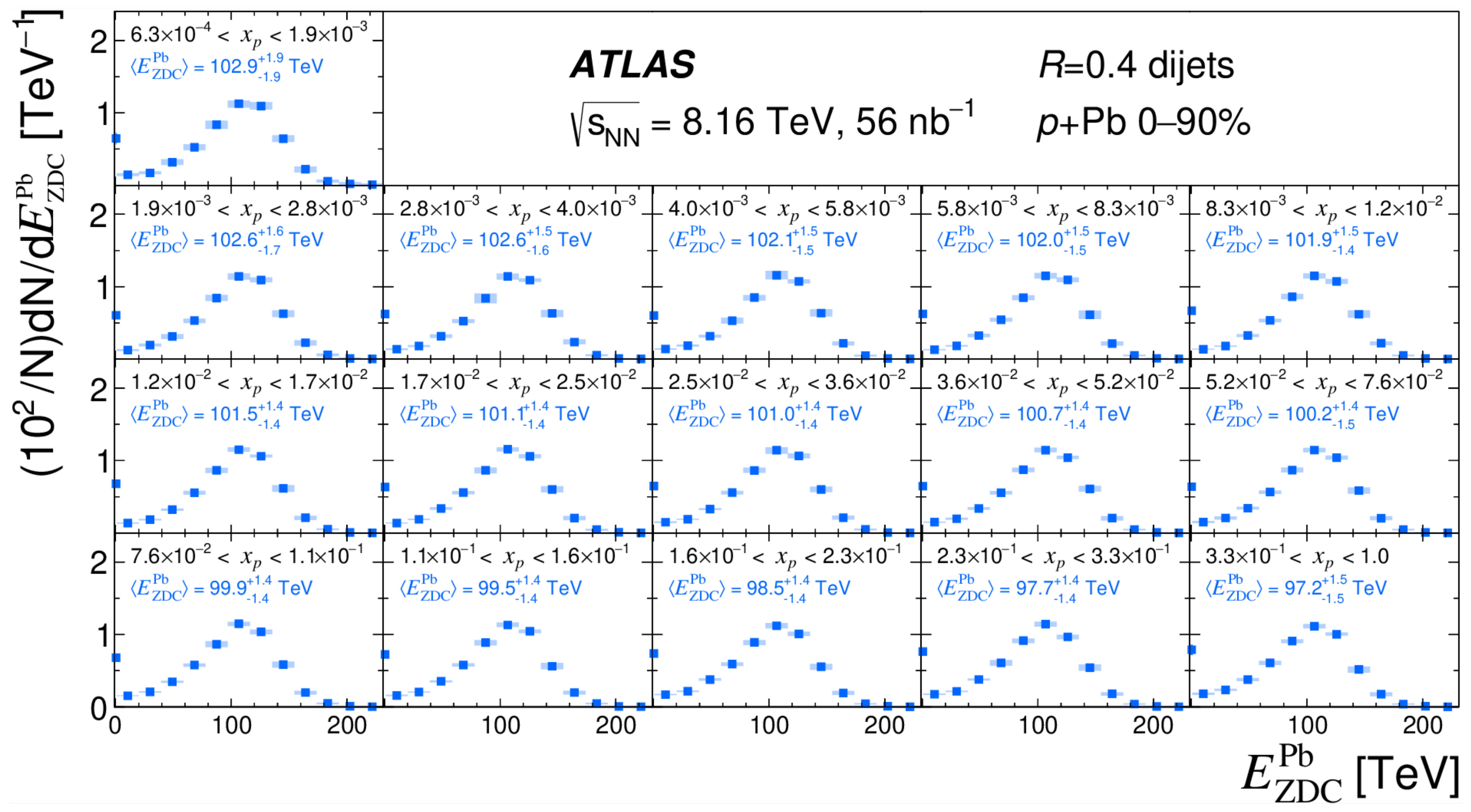
- Using again dijets to access the IS kinematics
- **Event activity ~5.5 times more sensitive** to the hard-scattering kinematics compared to **ZDC**
- Even though more robust, the **ZDC is also sensitive to x_p**



ATLAS input++ on small proton configurations

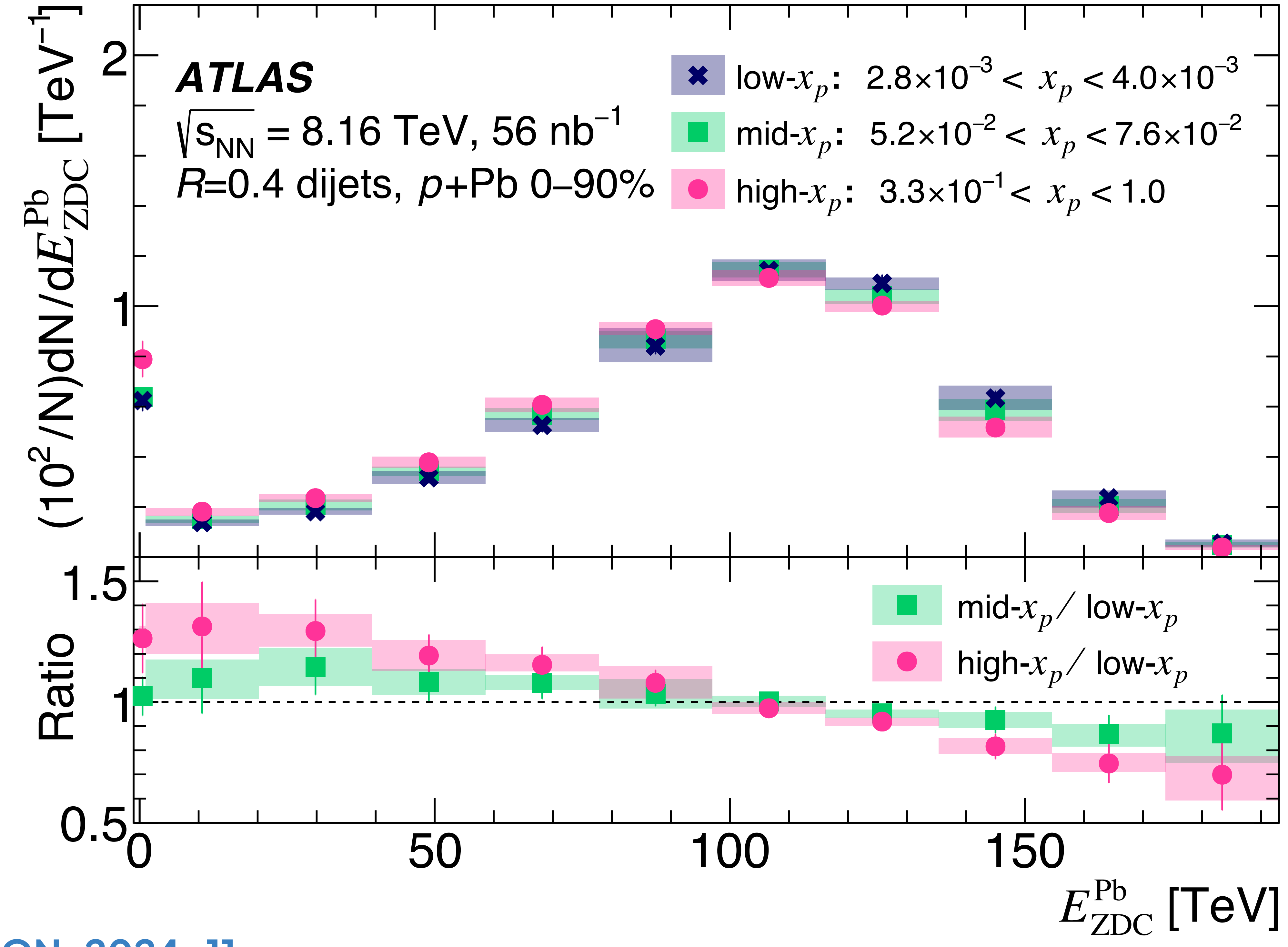


HION-2024-11



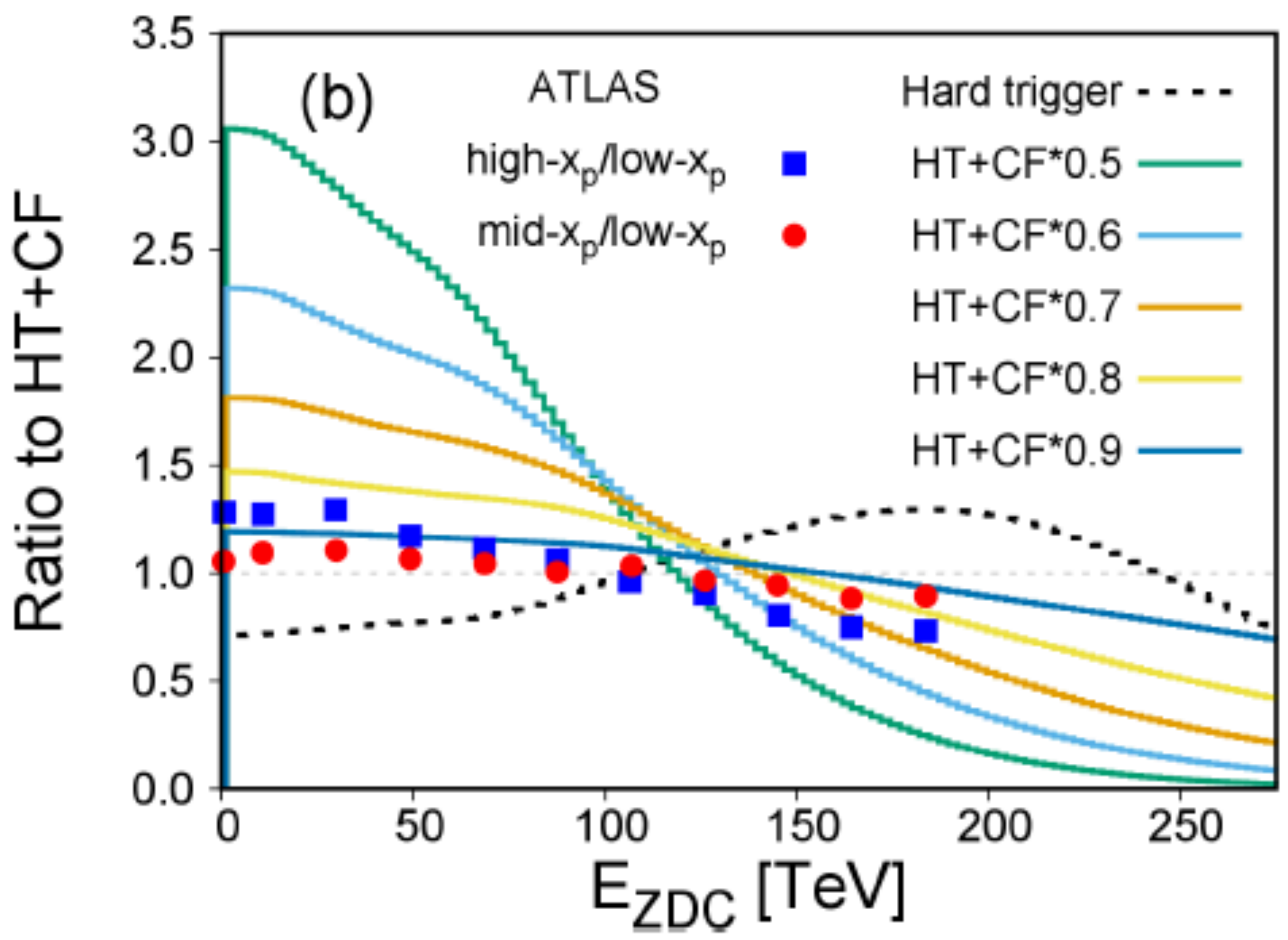
Analysis also provides the ratios and the ZDC distributions as a function of x_p, as input for the modeling of the nuclear breakup

ATLAS input++ on small proton configurations

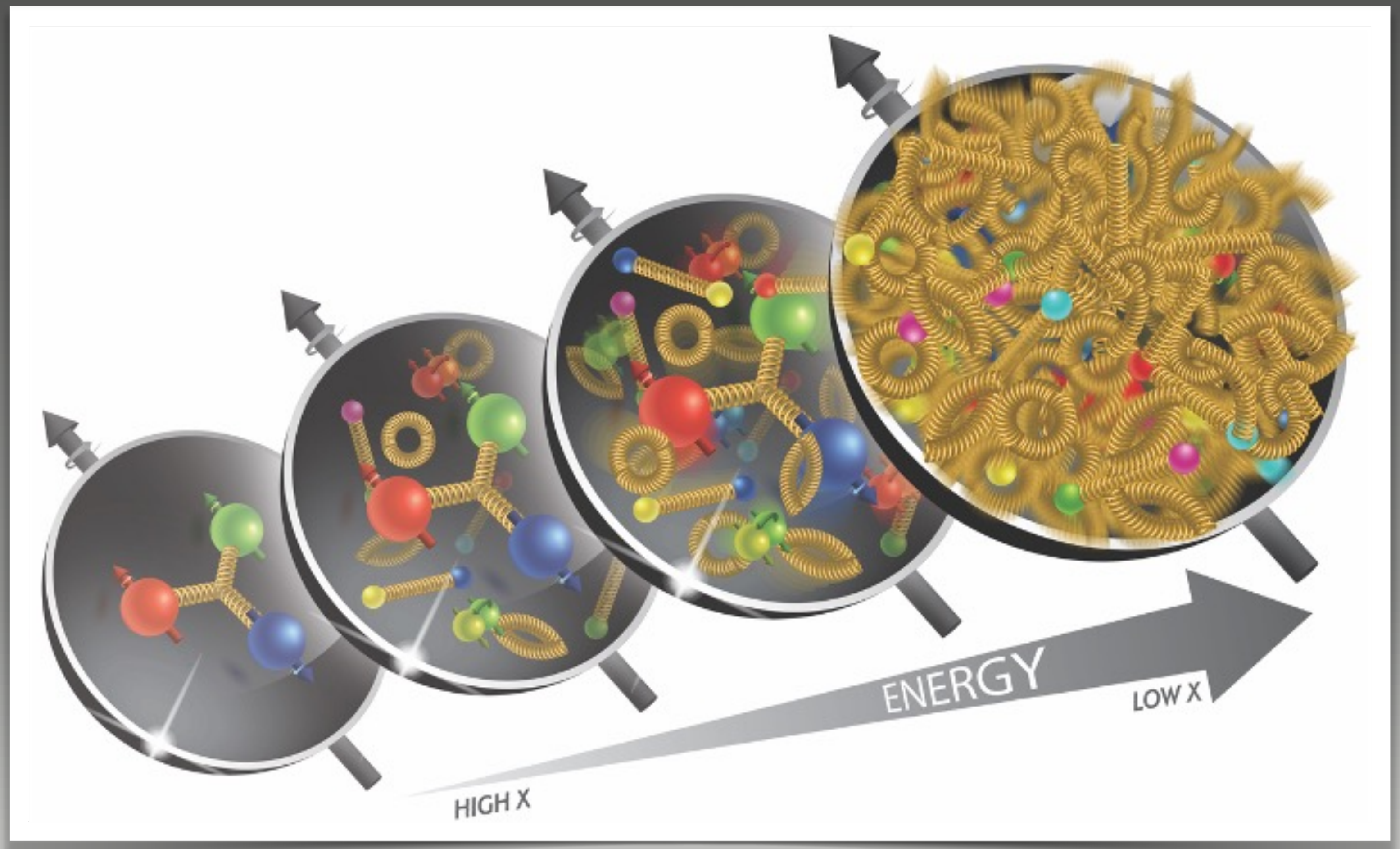


HION-2024-11

- Models already propagated to p+Pb by Alvioli, Guzey & Strikman (**arXiv:2504.07514** – kudos!)



- Qualitative description of the ratios – still need tuning for the neutron yields
- Next step experimentally would be to study the same effects on resolved UPCs
- A lot of input could still come from ATLAS before the EIC on this matter

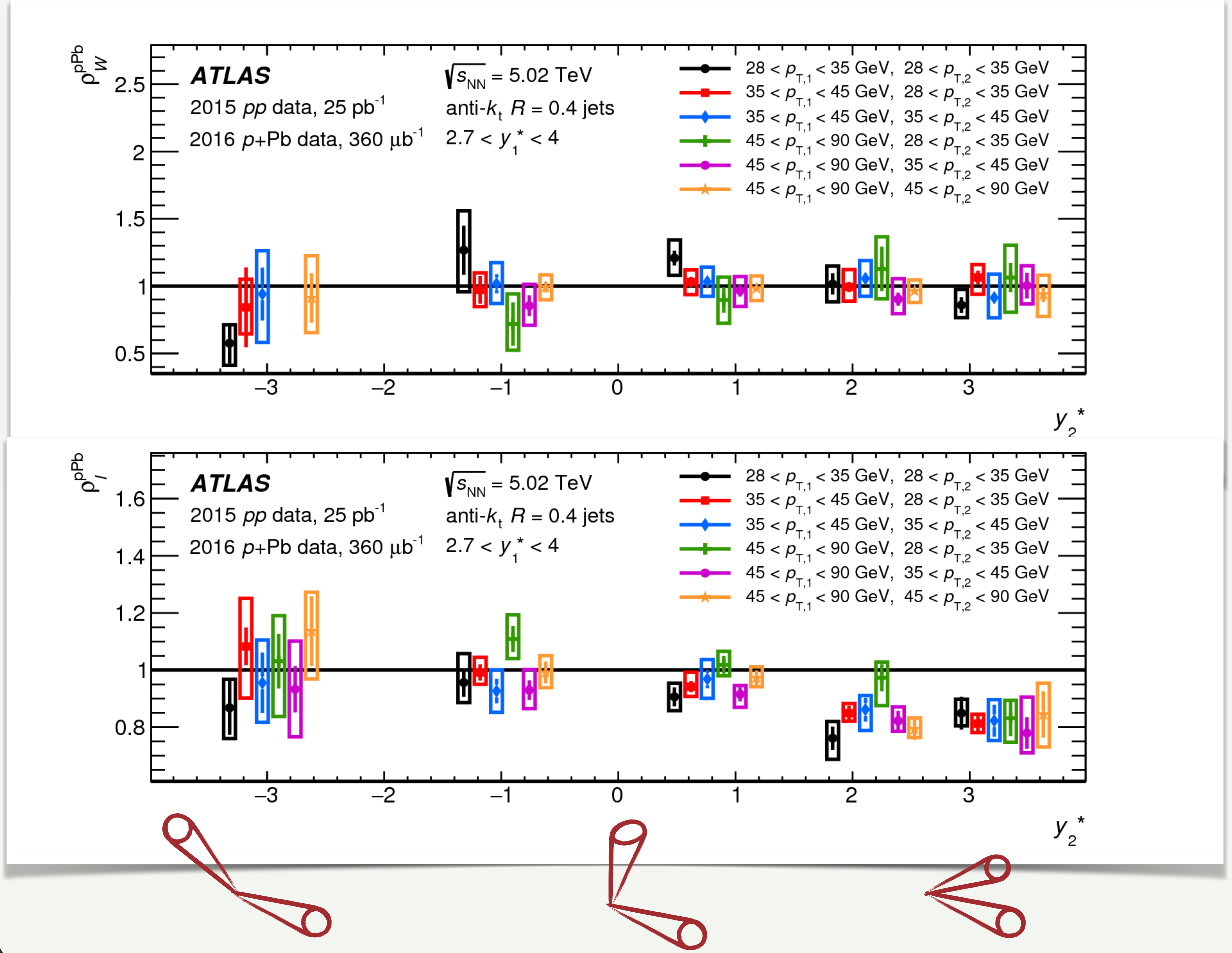


Search for gluon saturation onset

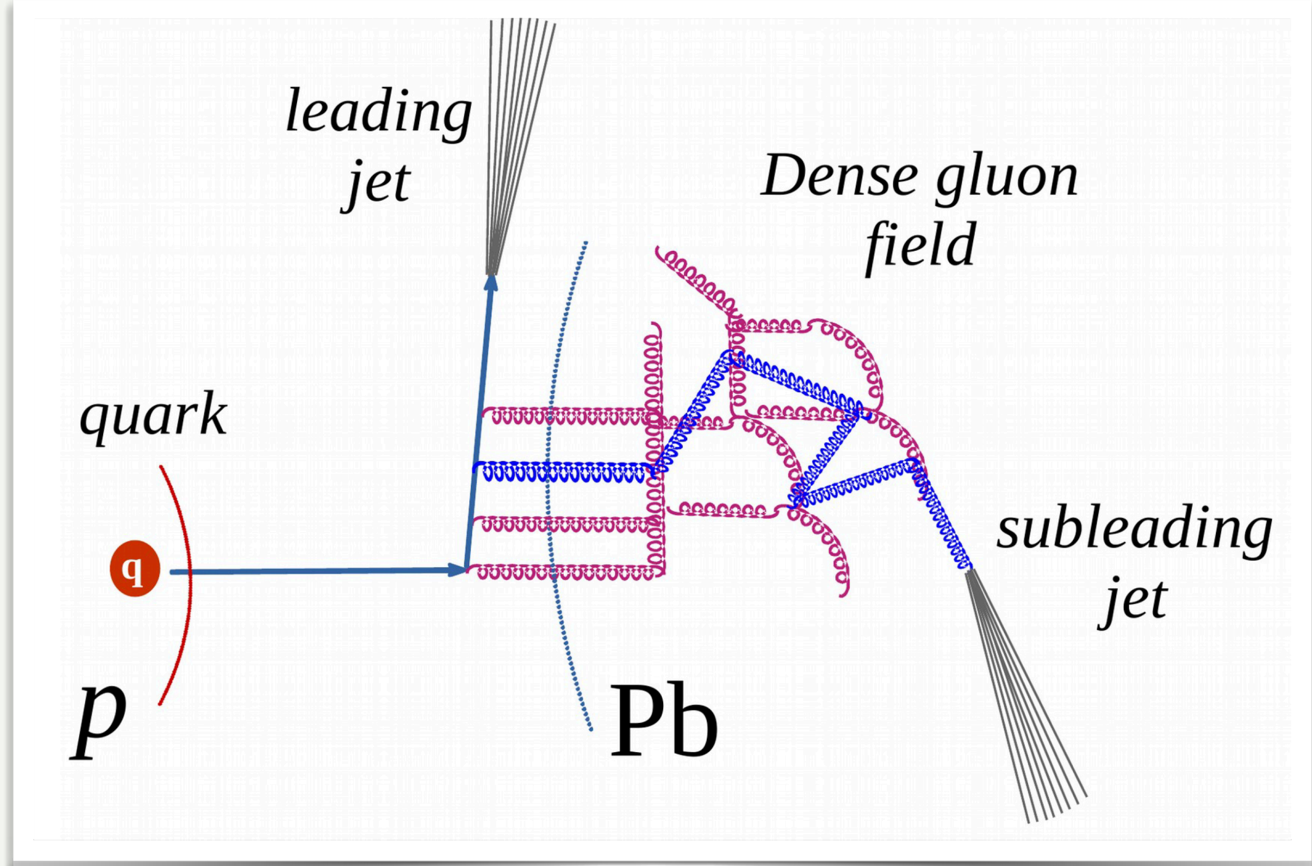
Dijet probes on non-linear gluon states

ATLAS EXPERIMENT

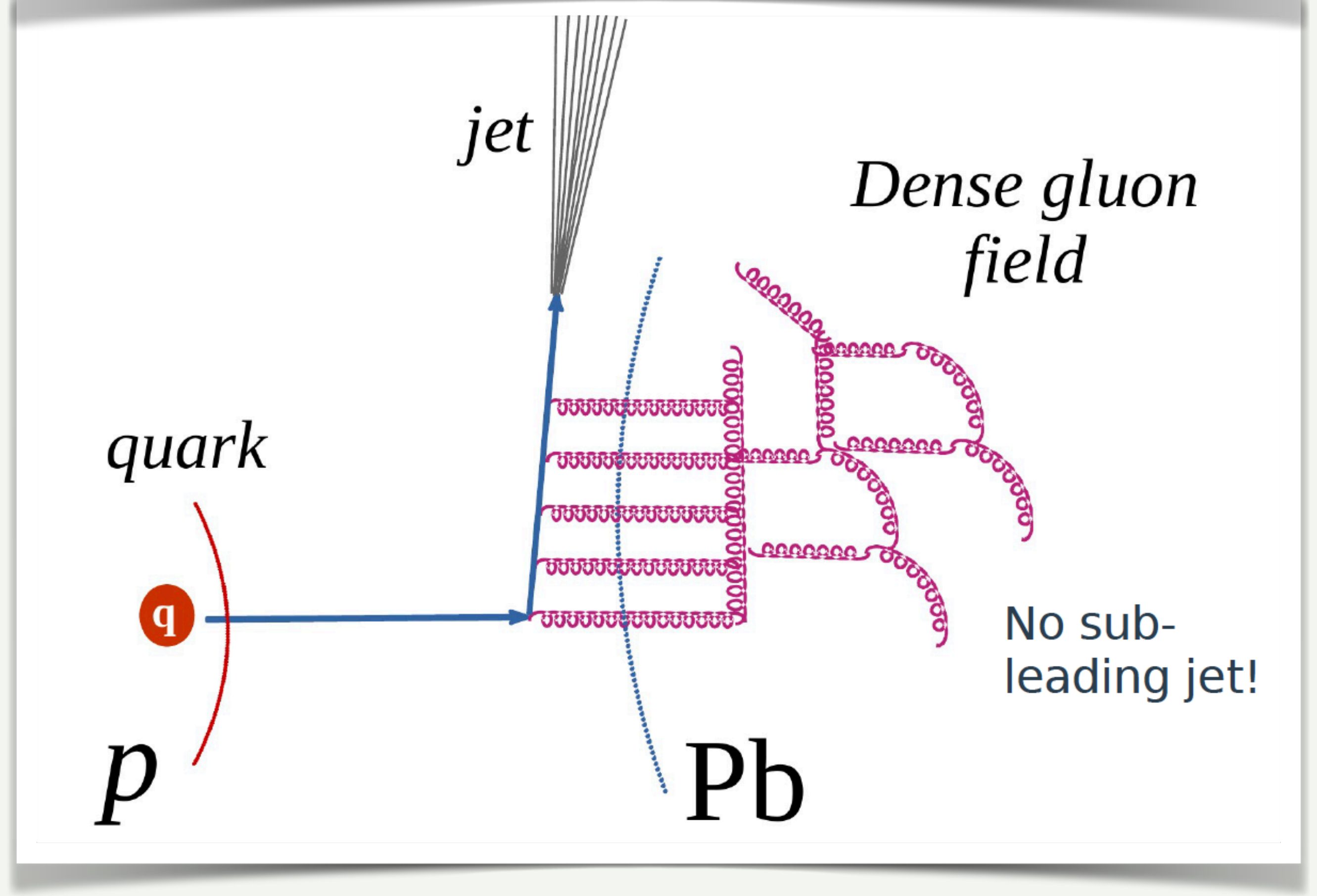
Search for azimuthal broadening or forward dijet conditional yield suppression as a manifestation of CGC (see **K.Kutak et al, Eur.Phys.J.C 83 (2023) 10, 947**)



Phys. Rev. C 100 (2019) 034903



Struck gluon in the nucleus scatters over other gluons before forming a jet → **azimuthal broadening** signature



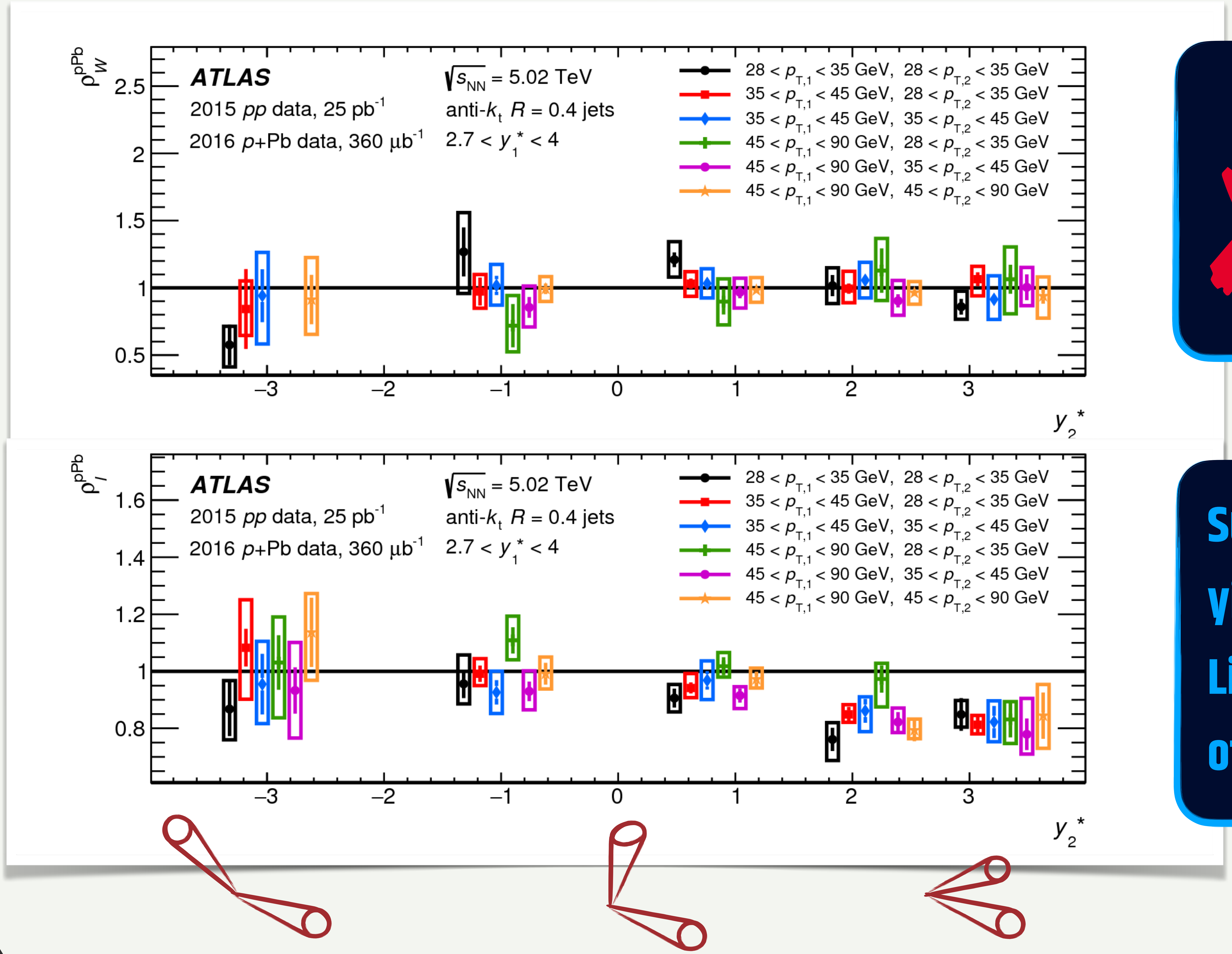
Incoming parton recoils off the lead nucleus coherently → **mono-jet** signature

See also Talk by A. van Hameren – Tue

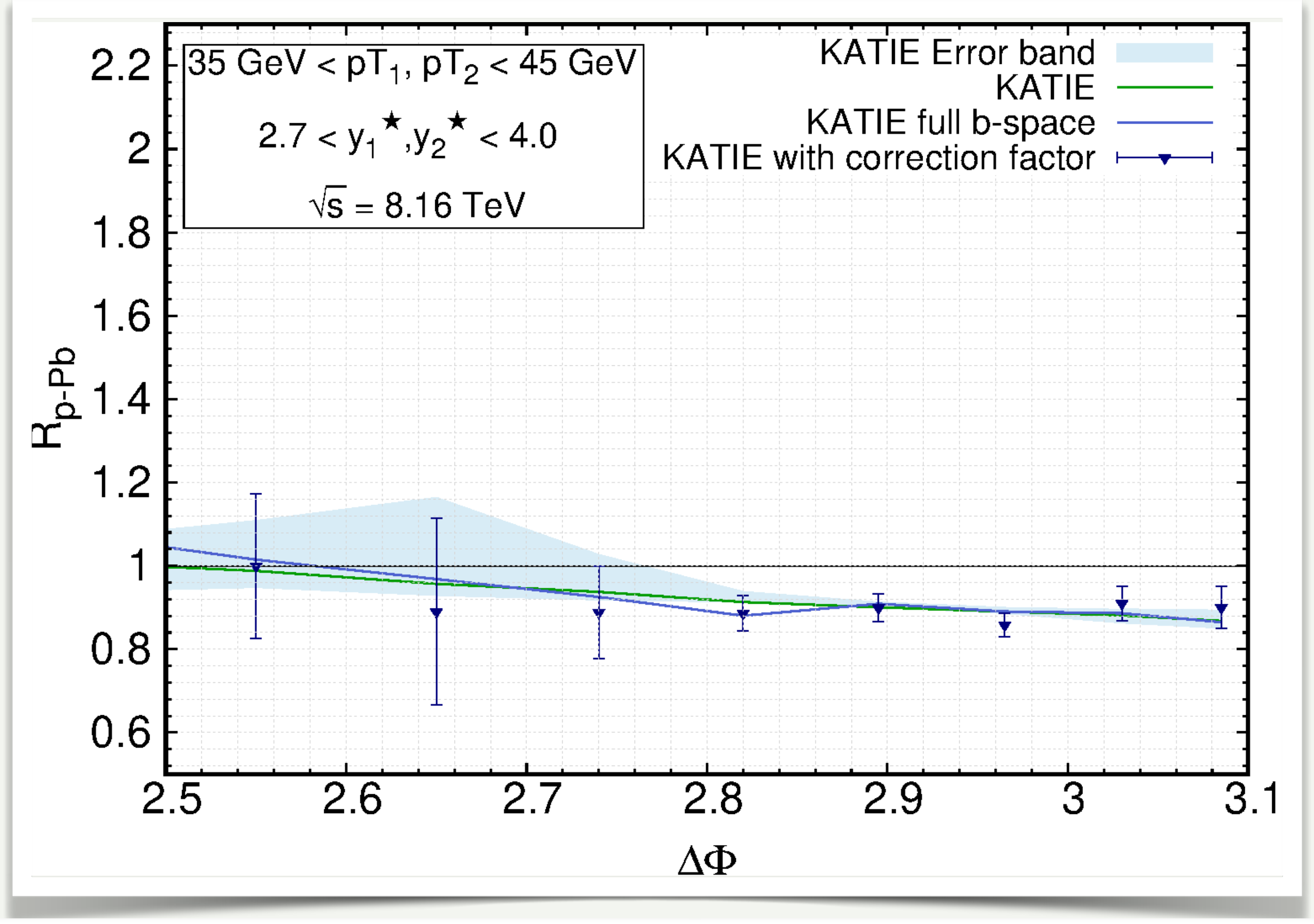
Dijet probes on non-linear gluon states

ATLAS EXPERIMENT

Search for azimuthal broadening or forward dijet conditional yield suppression as a manifestation of CGC (see **K.Kutak et al, Eur.Phys.J.C 83 (2023) 10, 947**)

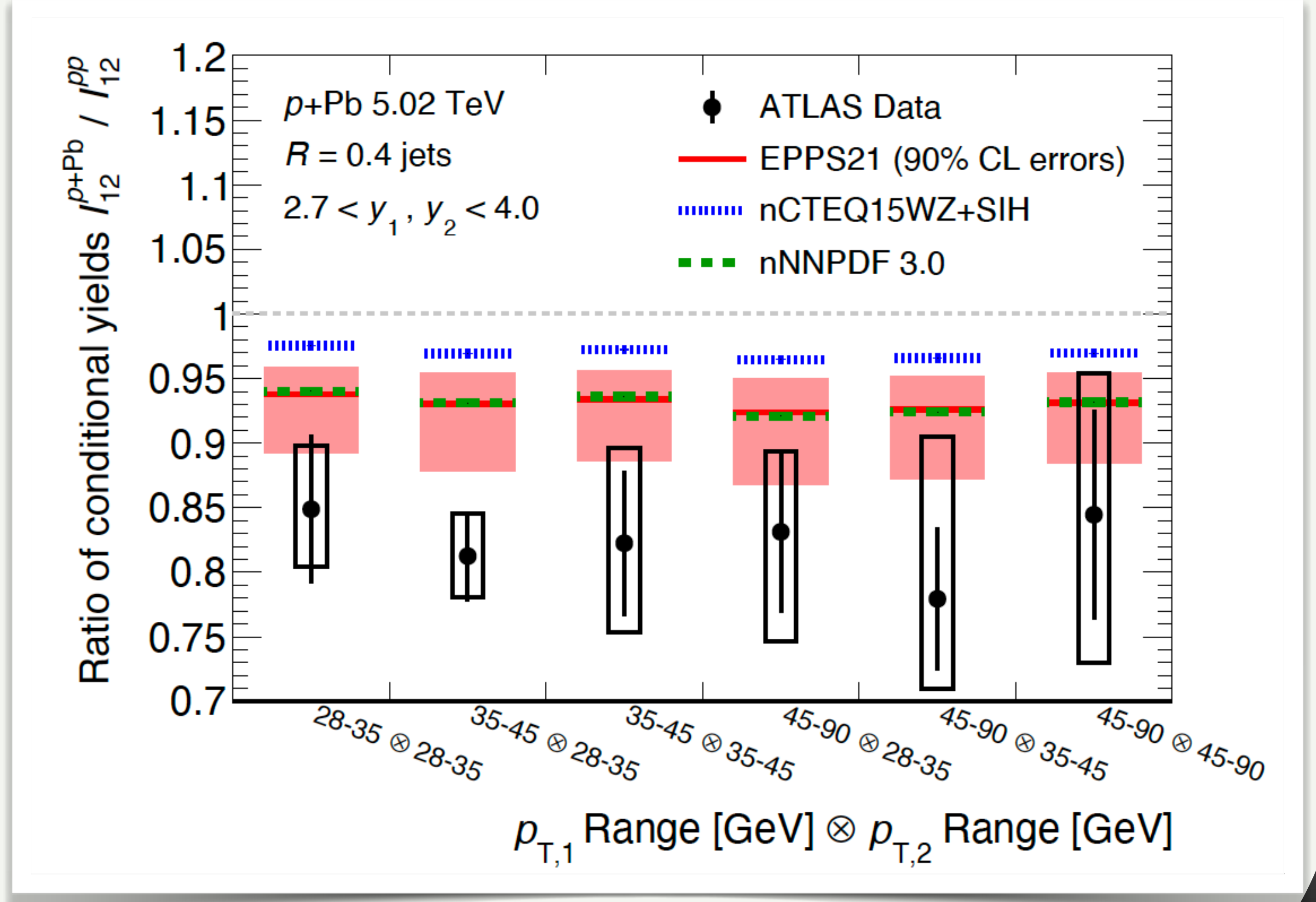


Phys. Rev. C 100 (2019) 034903



No effect observed within available experimental sensitivity

Suppression of conditional yields of forward dijets. Limited precision to rule out other effects (e.g. nPDFs?)



D.Perepelitsa, Phys.Rev.C 111 (2025) 5, 054901

Summary: HL-LHC vs EIC schedule

ATLAS EXPERIMENT

LHC Long term schedule

YOU ARE HERE

Very dynamic picture.
Don't mark your calendars (yet!)

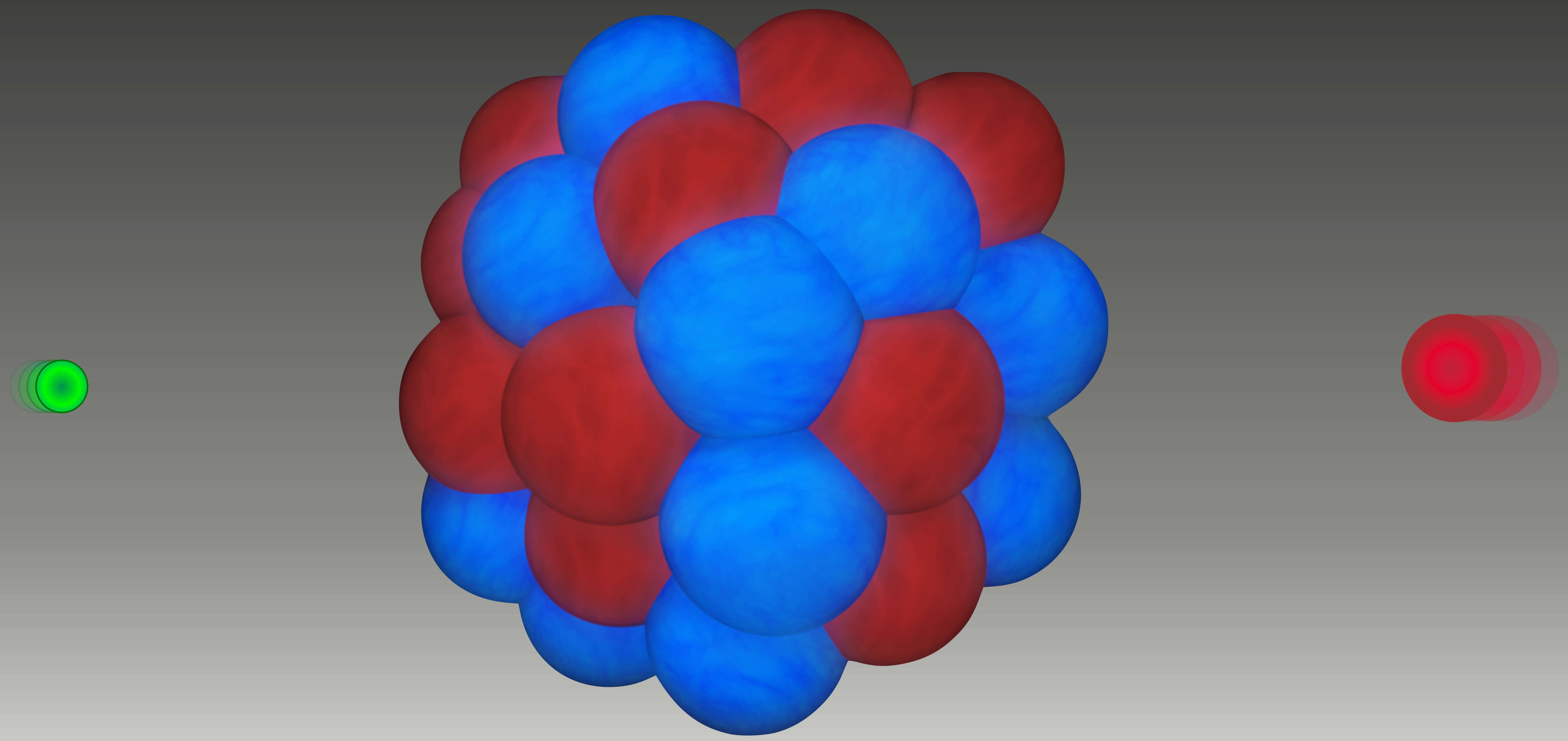
Facility/Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	++
LHC	LS2		Run 3				LS3 HL-LHC Upgrade				Run 4				LS4	
EIC (ePIC)	R&D and Design Phase R.Ent – Monday								Construction & Installation						Commissioning & start of Operations	

Currently, great complementarity in the EIC (ePIC) and HL-LHC programs scheduling

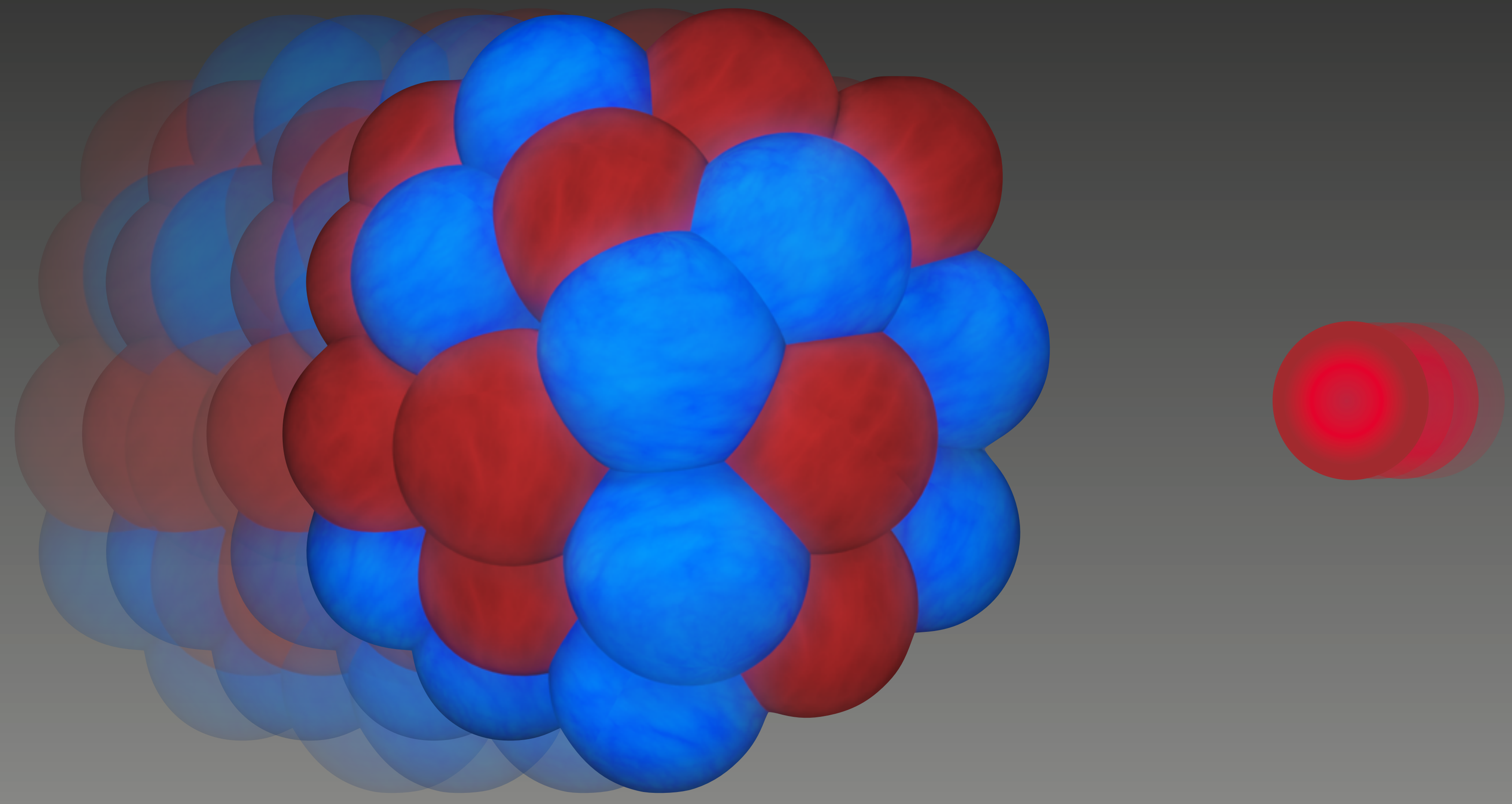
Allows for parallel deployment of scientific effort on both sides

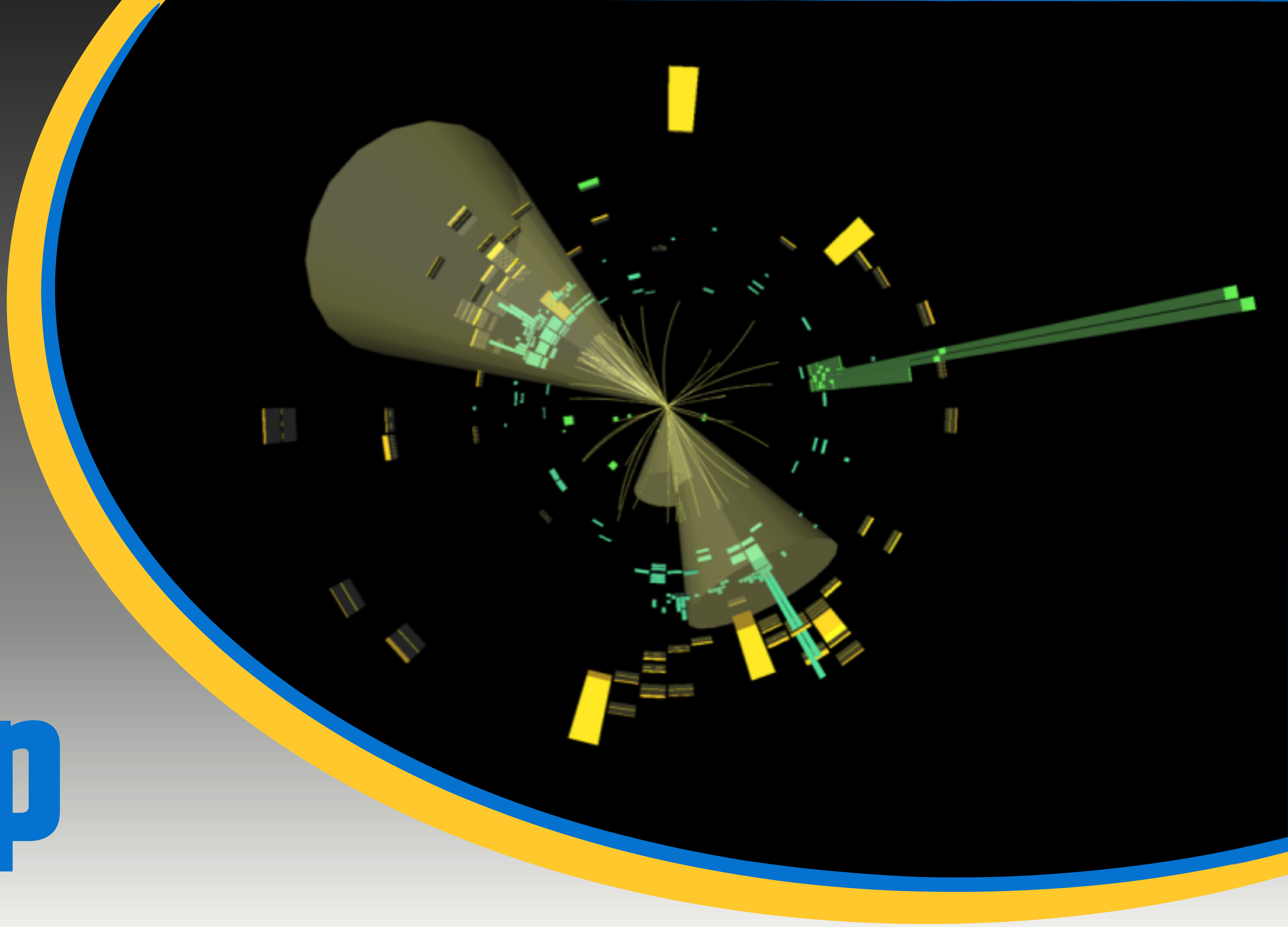
ATLAS results can spur theoretical developments in advance of the machine turn-on, e.g., helping to speed up the physics discoveries at the EIC.

➨Several points of contact between the ATLAS HI program and the EIC. New exciting opportunities ahead to advance our understanding of the strong force

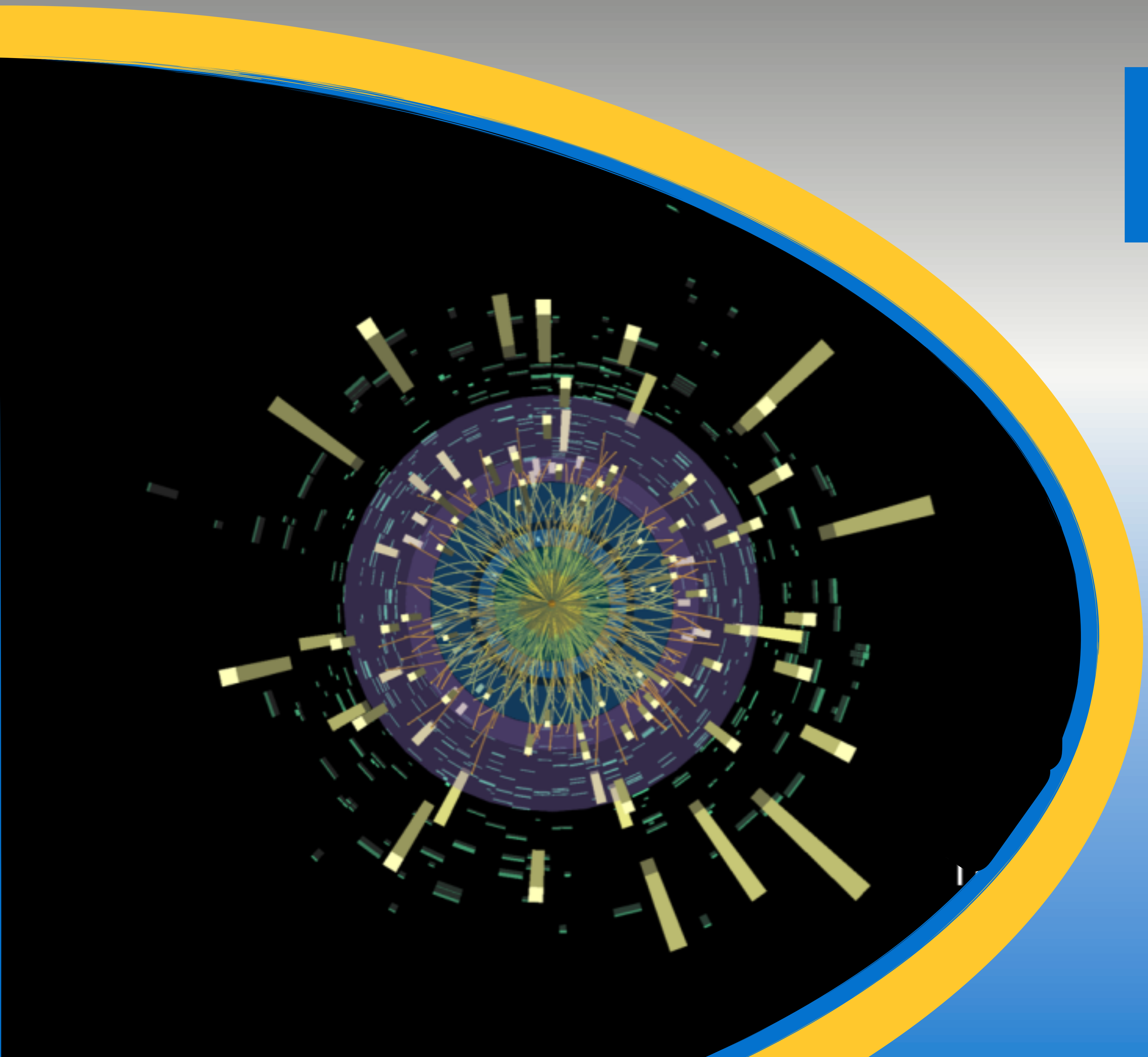


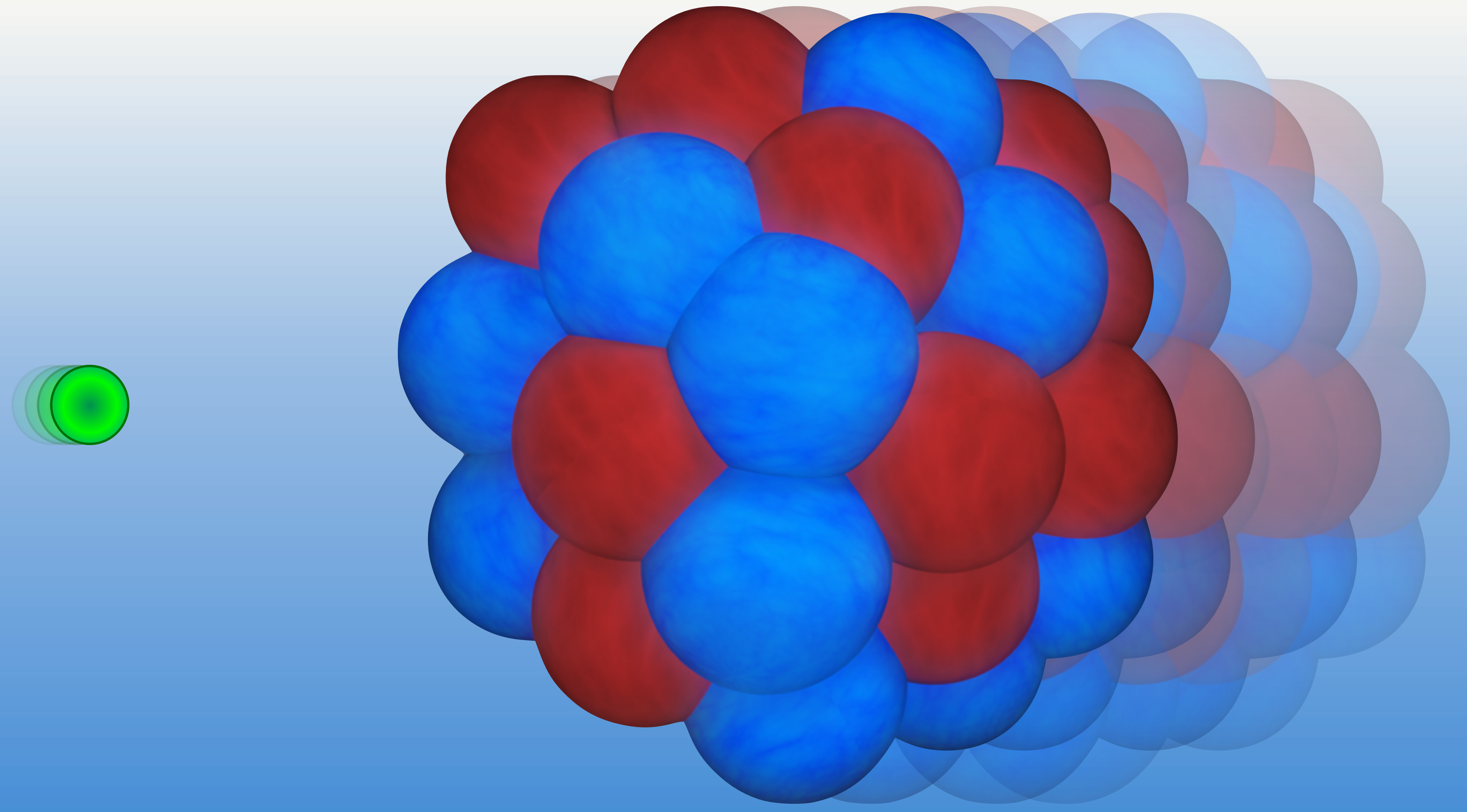
Thank you for your attention!



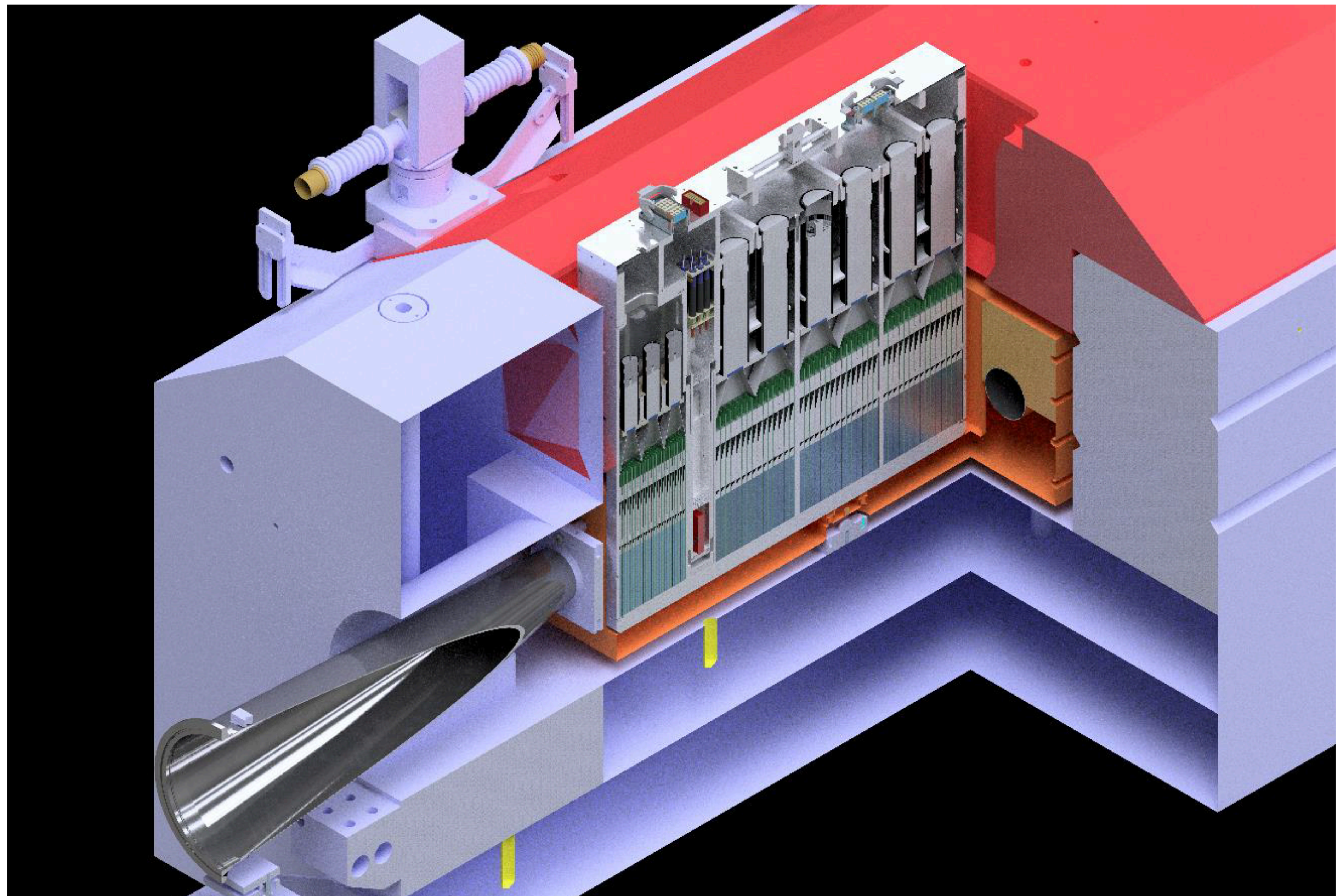


Backup





HL-ZDC: final checklist



The HL-ZDC – fully integrated in the TAXN slot

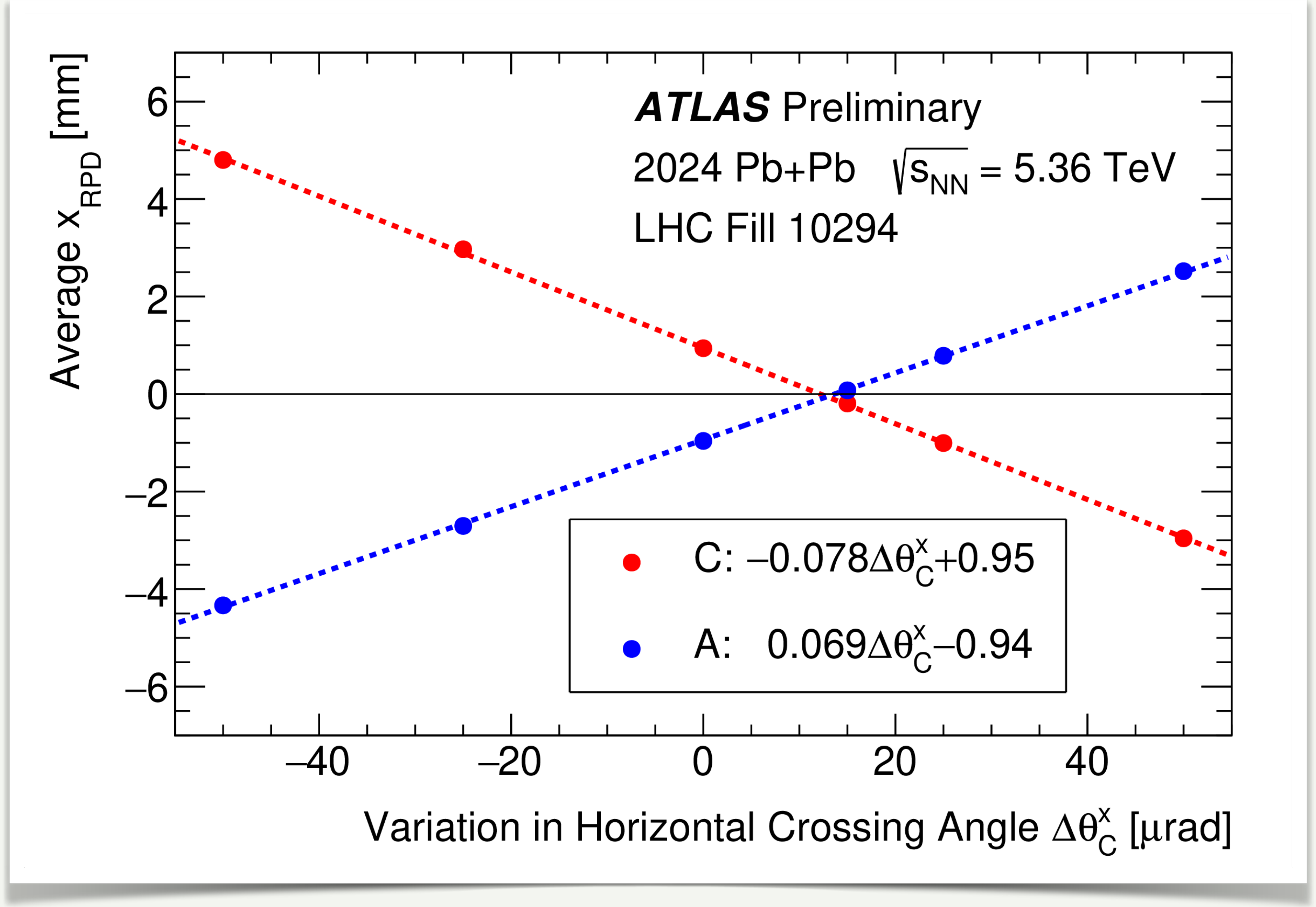
- Rad-hard detector: stable performance during the running period ✔
- Well-controlled energy scale (via good 1n, 2n and 3n resolution) ✔
- Good γ/n separation using segmented EM module ✔
- Reaction Plane Detector ✔
- Compatible with TAXN slot constraints and fully integrated with the machine ✔
- Simplified connection procedures to reduce radiation exposure ✔

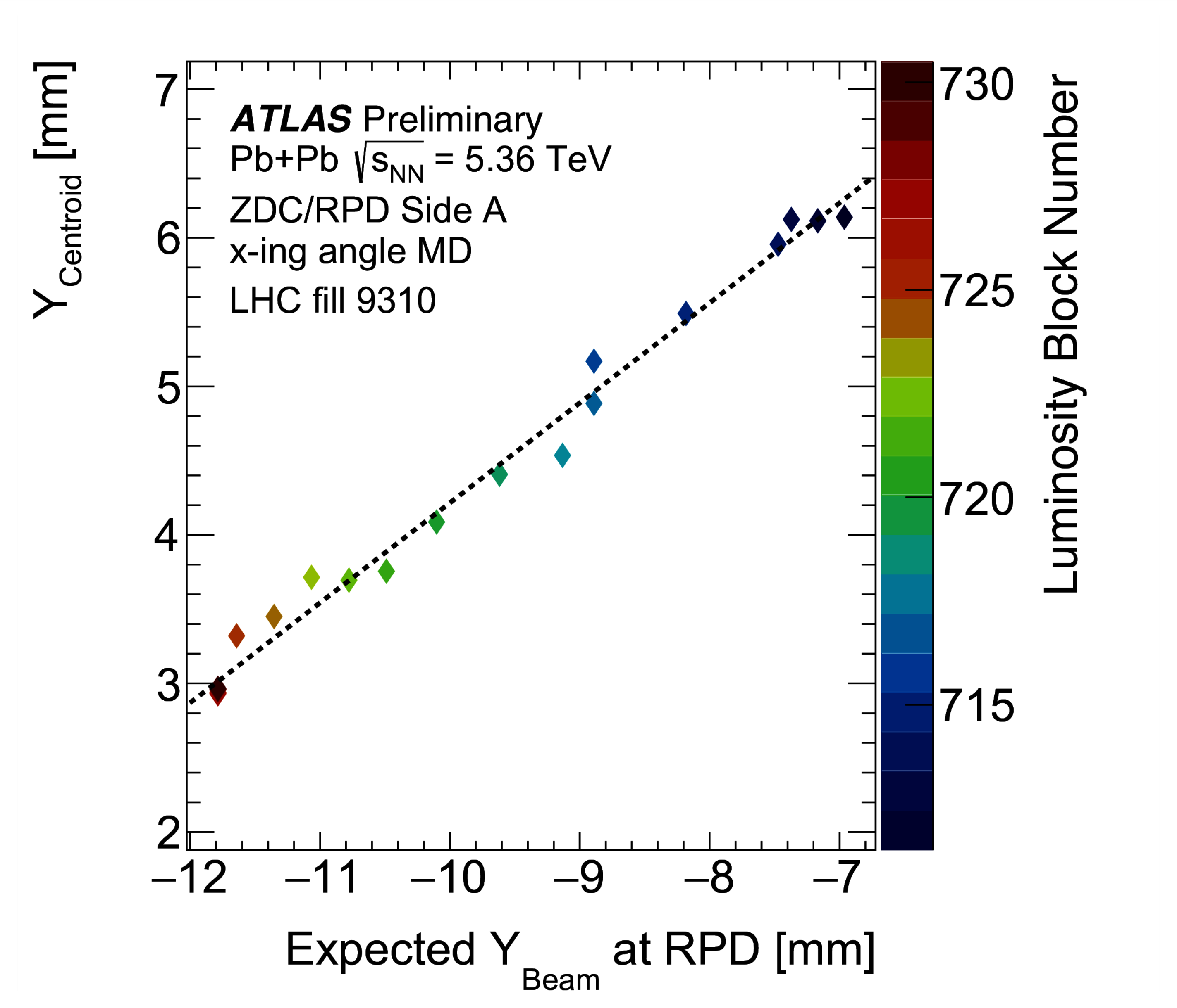
HL-ZDC

Project to start construction of the pre-production detector this fall – to test @ SPS next summer (before LS3 starts for the injectors)

HL-ZDC: expected RPD performance

- Pivotal experience from ATLAS Run 3 implementation & operations



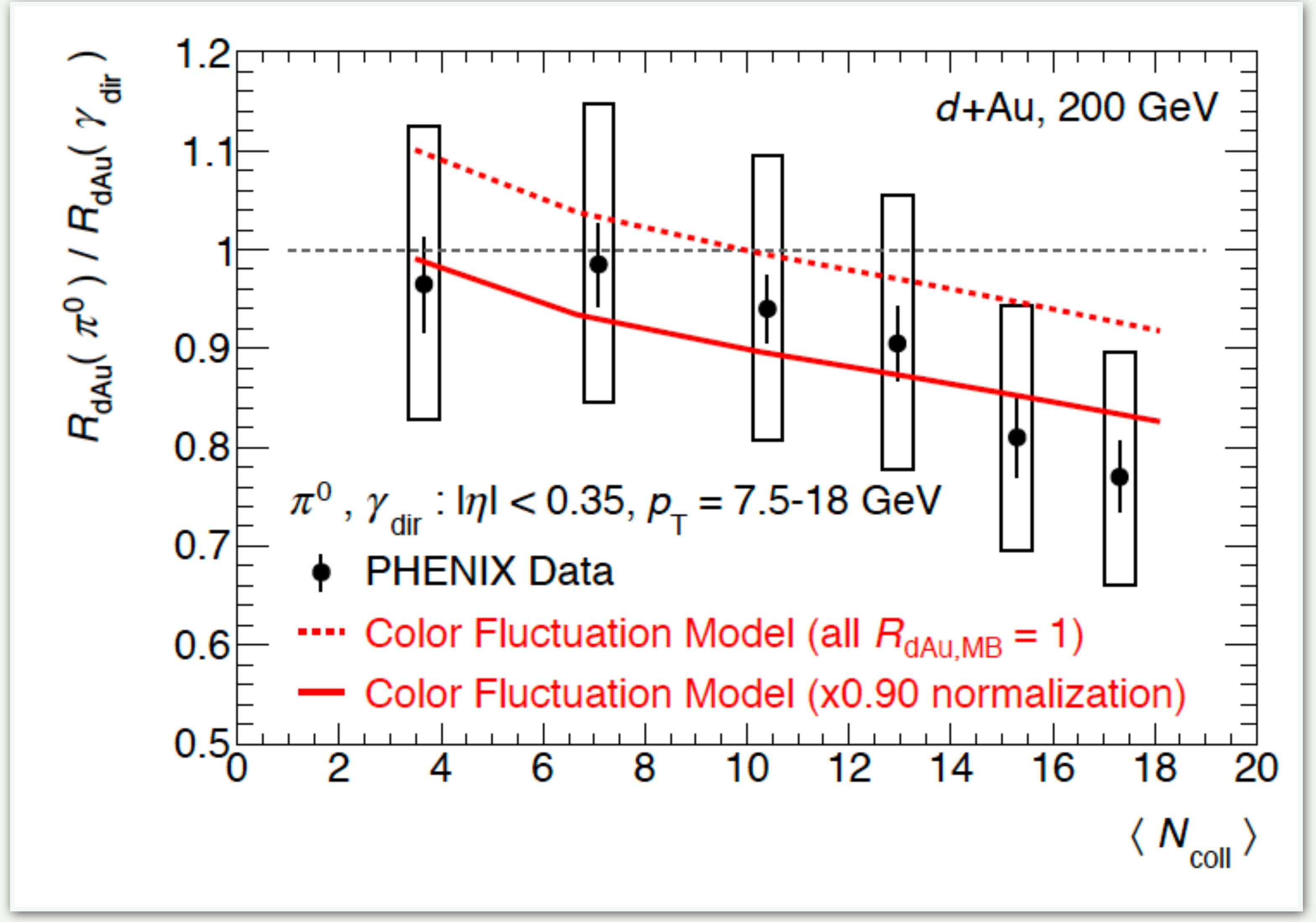


[ATLAS FWD performance webpage]

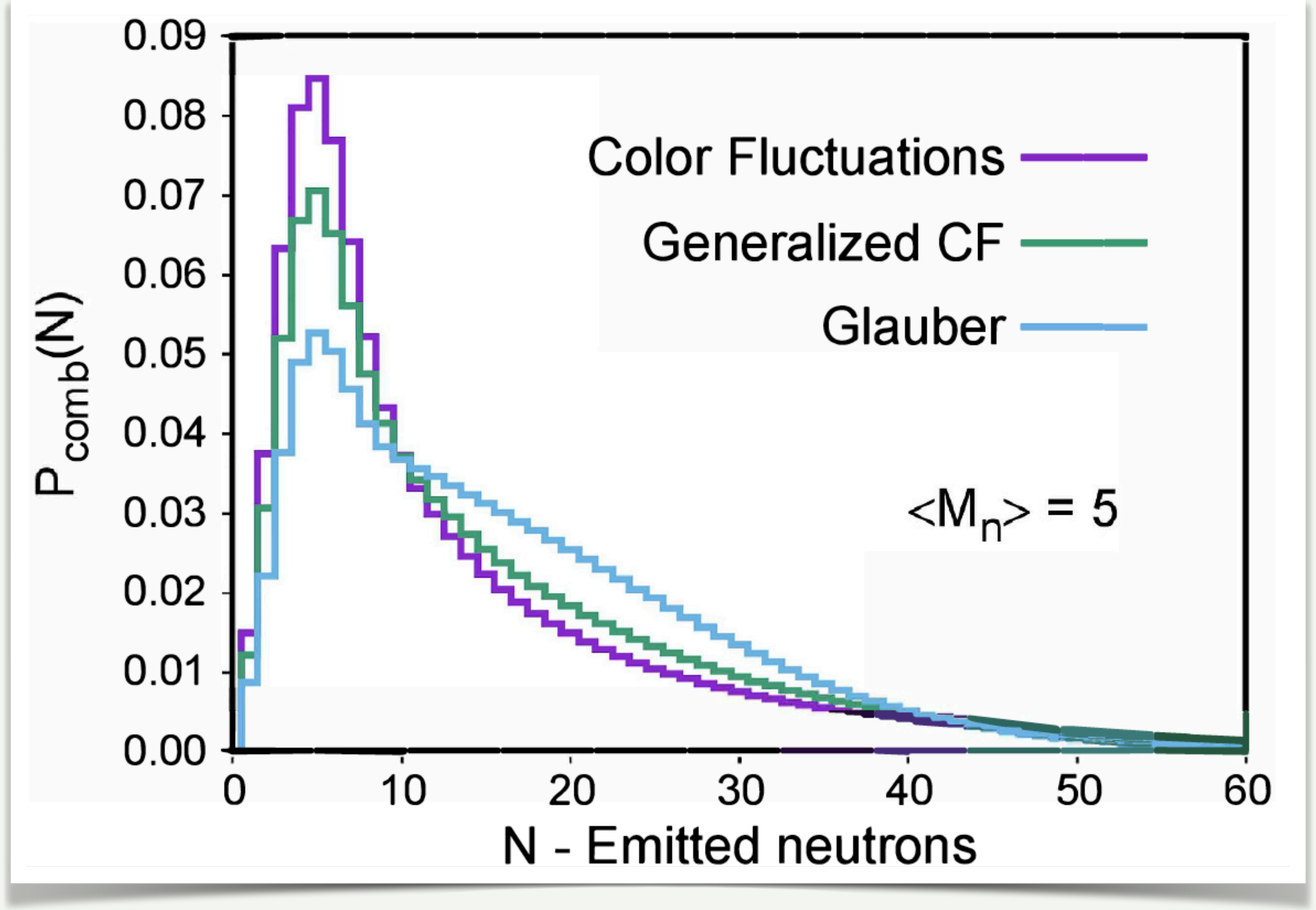
➨ATLAS RPD tracking both the beam *x* and *y* positions during different crossing angle scans in HI

- Intense work on detector calibration and run-by-run perfomance using standard reaction-plane reconstruction techniques
- Preliminary performance in line with MC expectations
- Aiming at testing ML-based reconstruction techniques next year

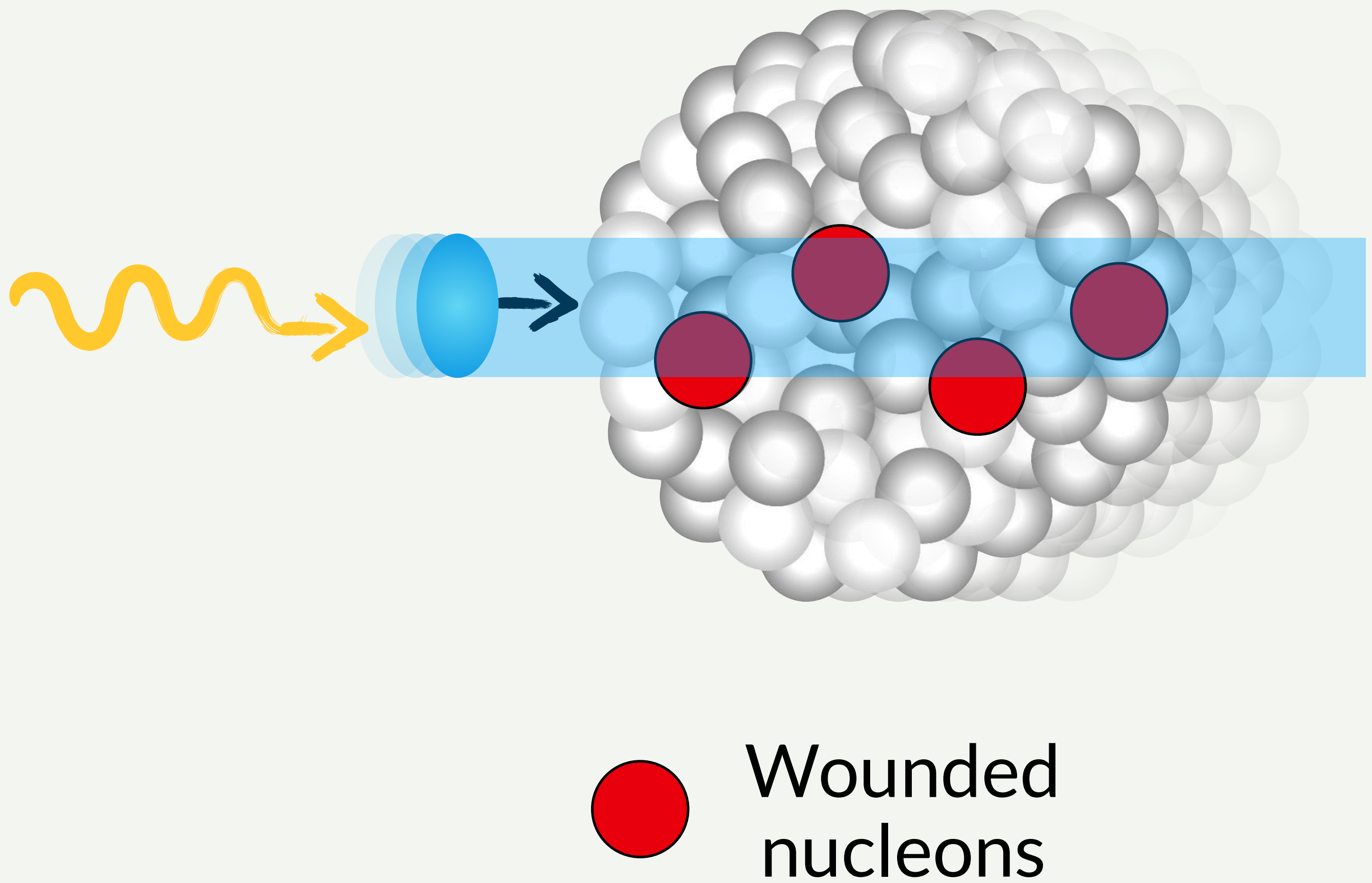
Increasing attention on CF effects



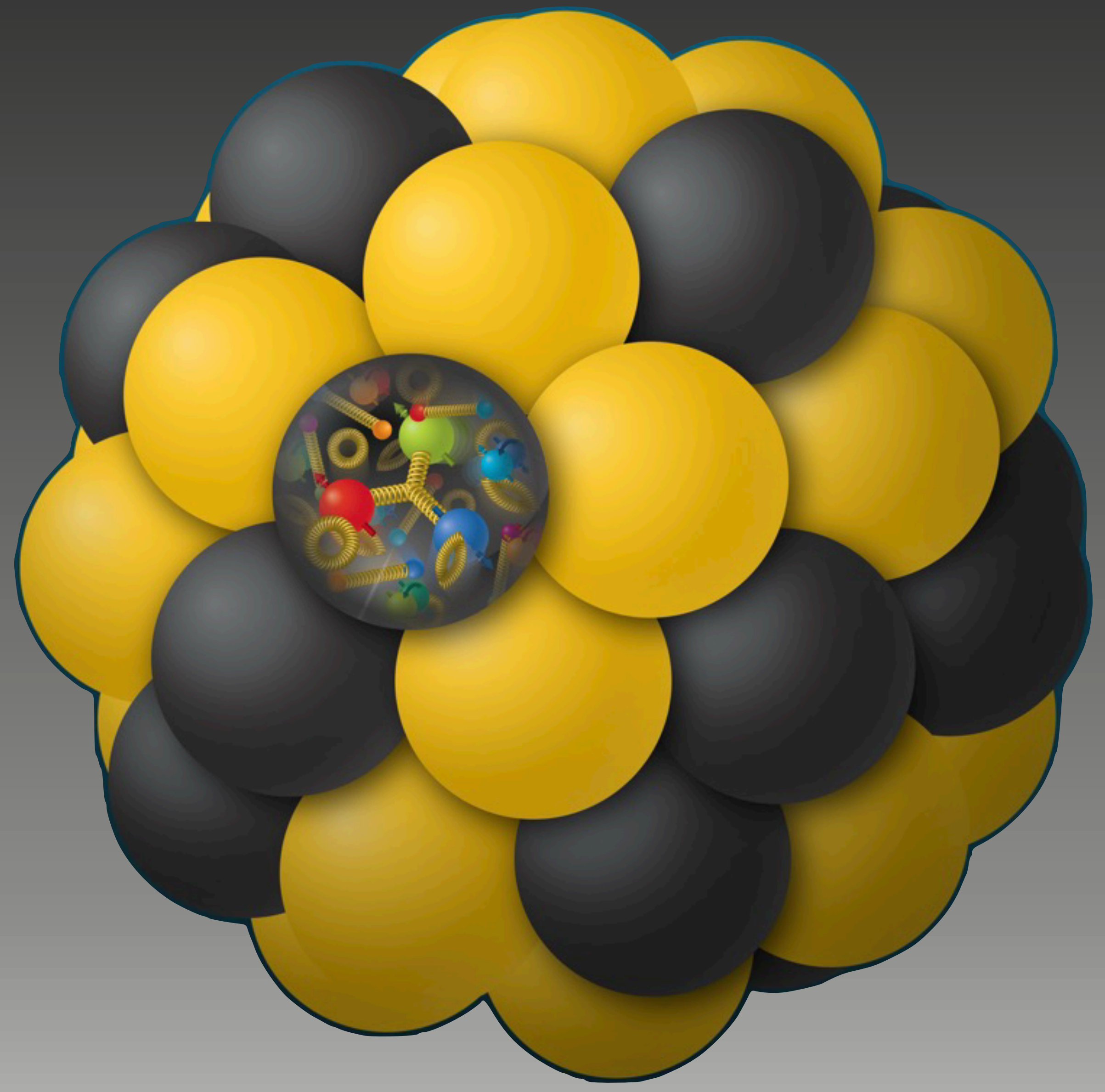
D.Perepelitsa, **Phys. Rev. C 110, L011901**
CF model can explain suppression observed by PHENIX in the relative yield of π^0 to γ^{dir} (**Phys. Rev. Lett. 134, 022302 (2025)**) and be compatible w/ other observations at LHC and RHIC



γA in $A + A$ collisions via
resolved photon



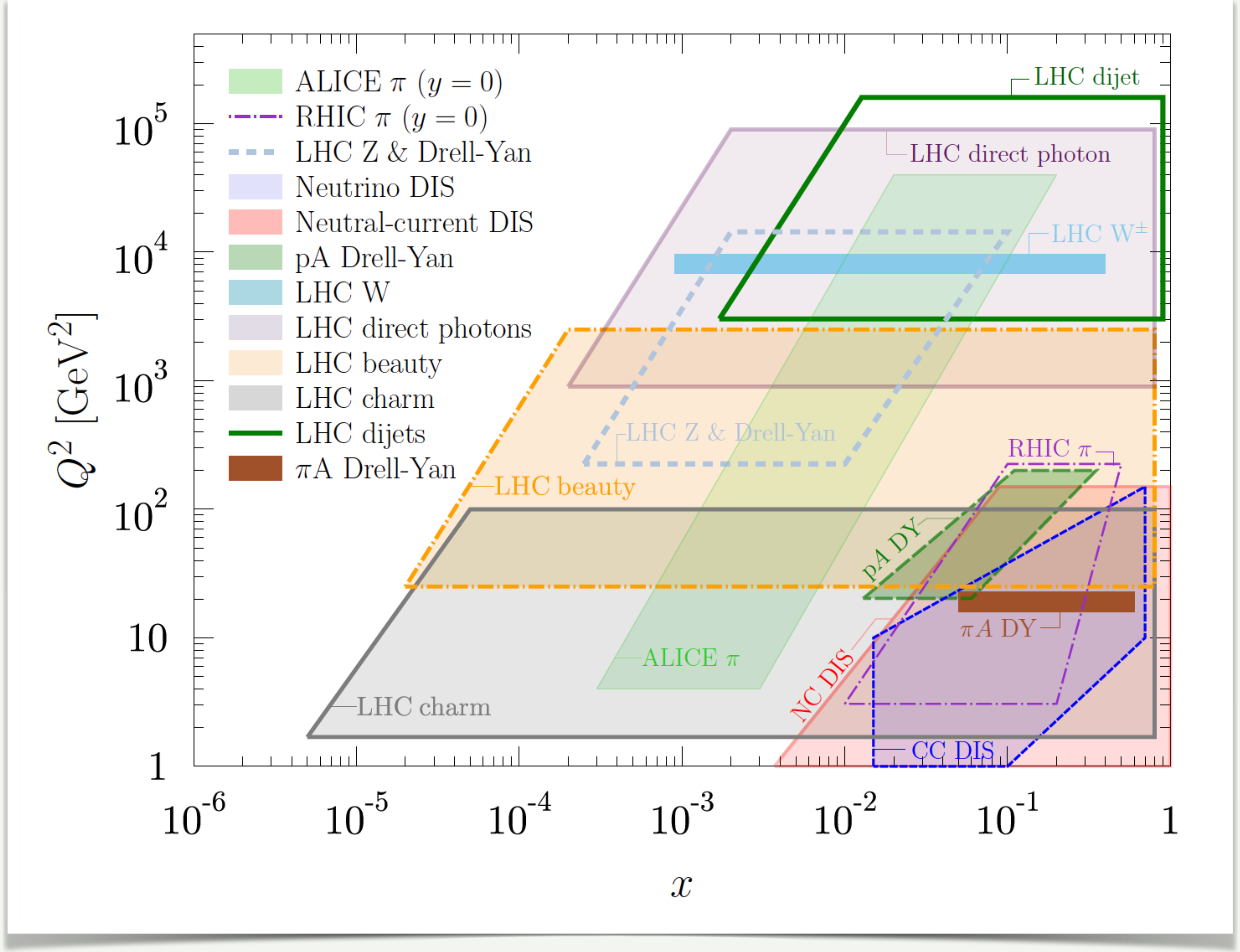
Alvioli, Guzey and Strikman in **PRC 110, 025205 (2024)** show the impact of CF on nuclear breakup in resolved UPC collisions in Pb+Pb



Nuclear modification of parton distributions

nPDFs: current landscape

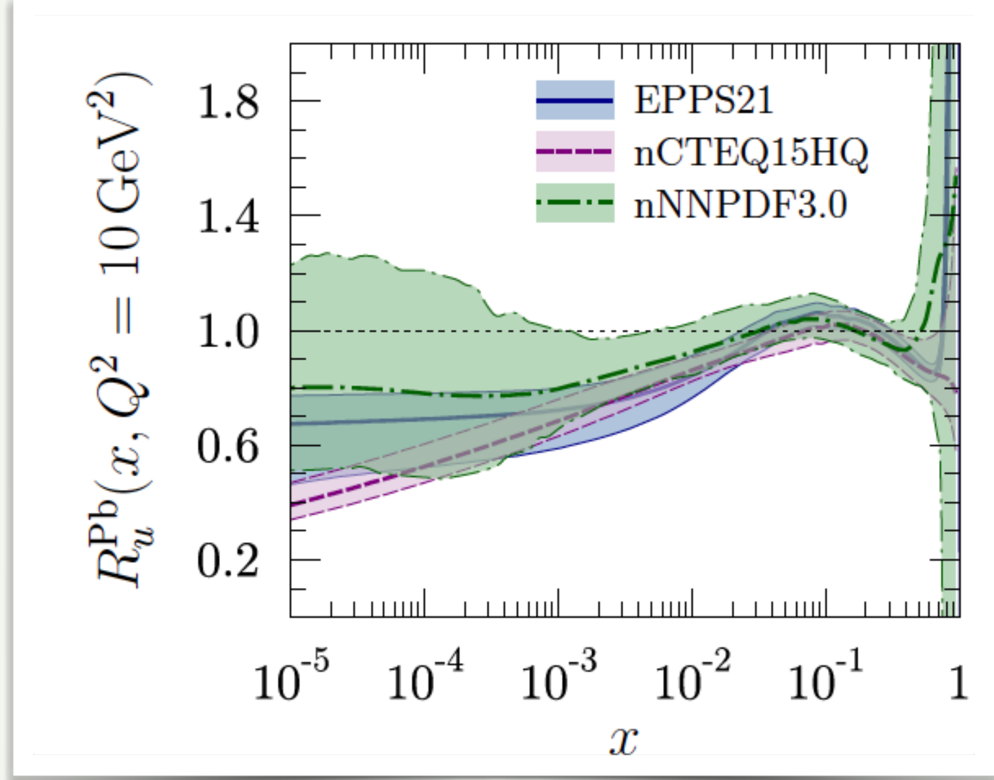
ATLAS EXPERIMENT

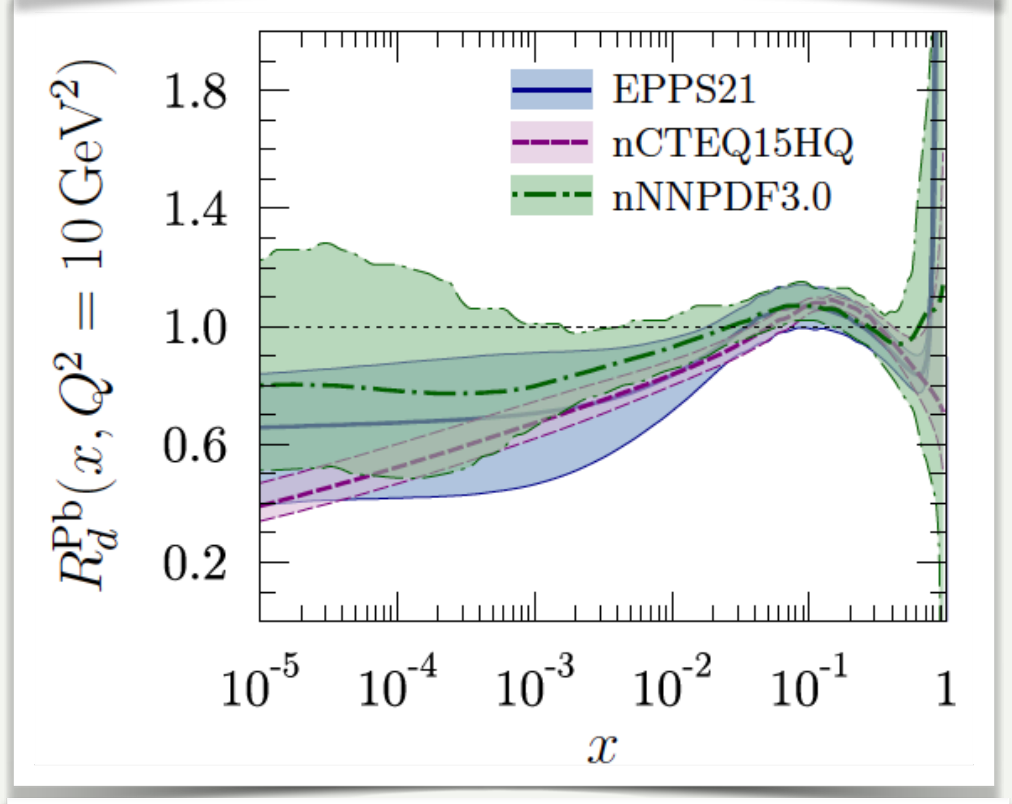


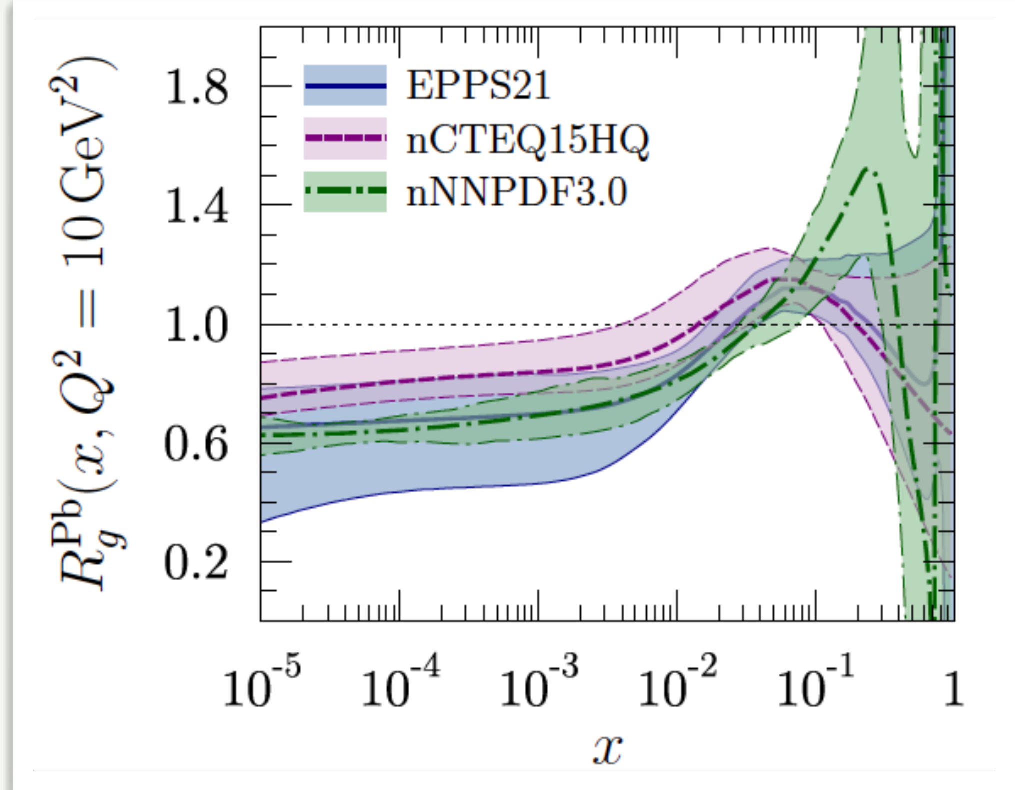
(x,Q²) Phase space coverage of data currently available on the market
Taken from Klasen & Paukkunen
Ann. Rev. Nucl. Part. Sci. 2024. 74:1–41

Large variety of data from different experiments, spanning over a wide (x,Q²) range, down to x ~ 10⁻⁵

Different combinations of these data included in different nPDF parametrizations:
EPPS21
TUJU21
nCTEQ15HQ
nNNPDF3.0
KSAG20

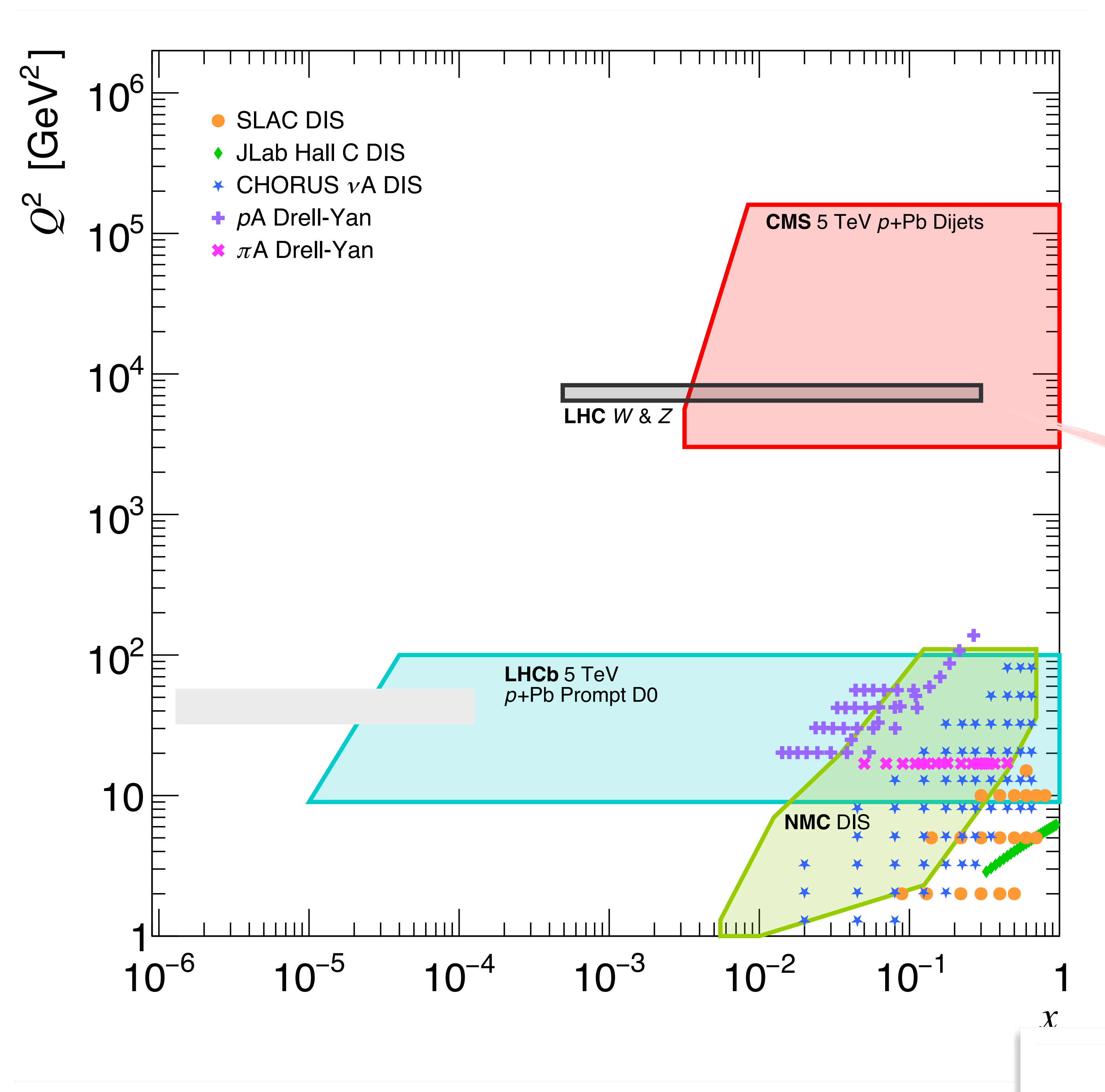






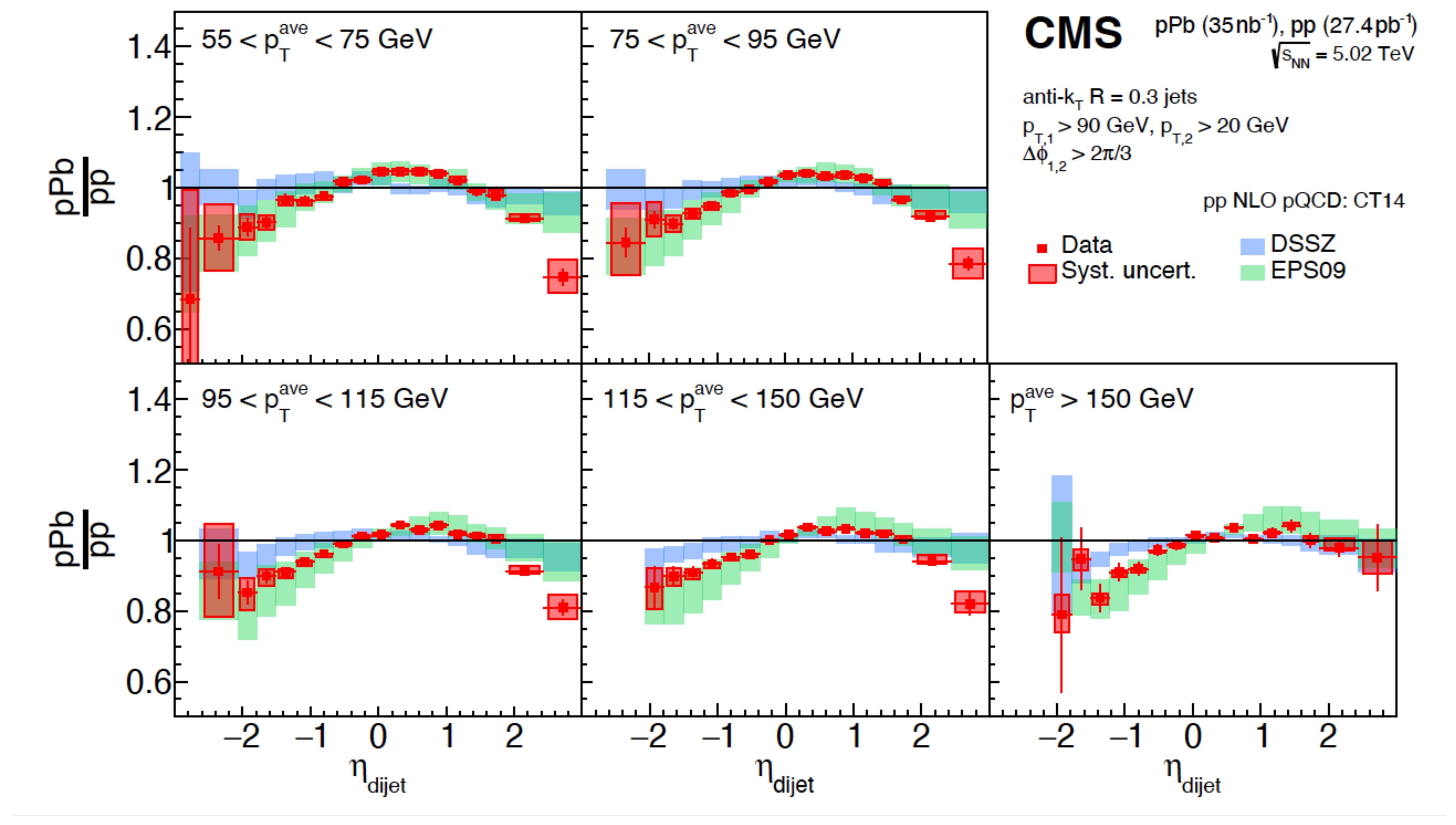
Dijet for nPDF constraints

Adapted from **Eur. Phys. J. C (2022) 82:413**



Wide (x, Q^2) phase space region could be explored using dijets in p+Pb @ LHC

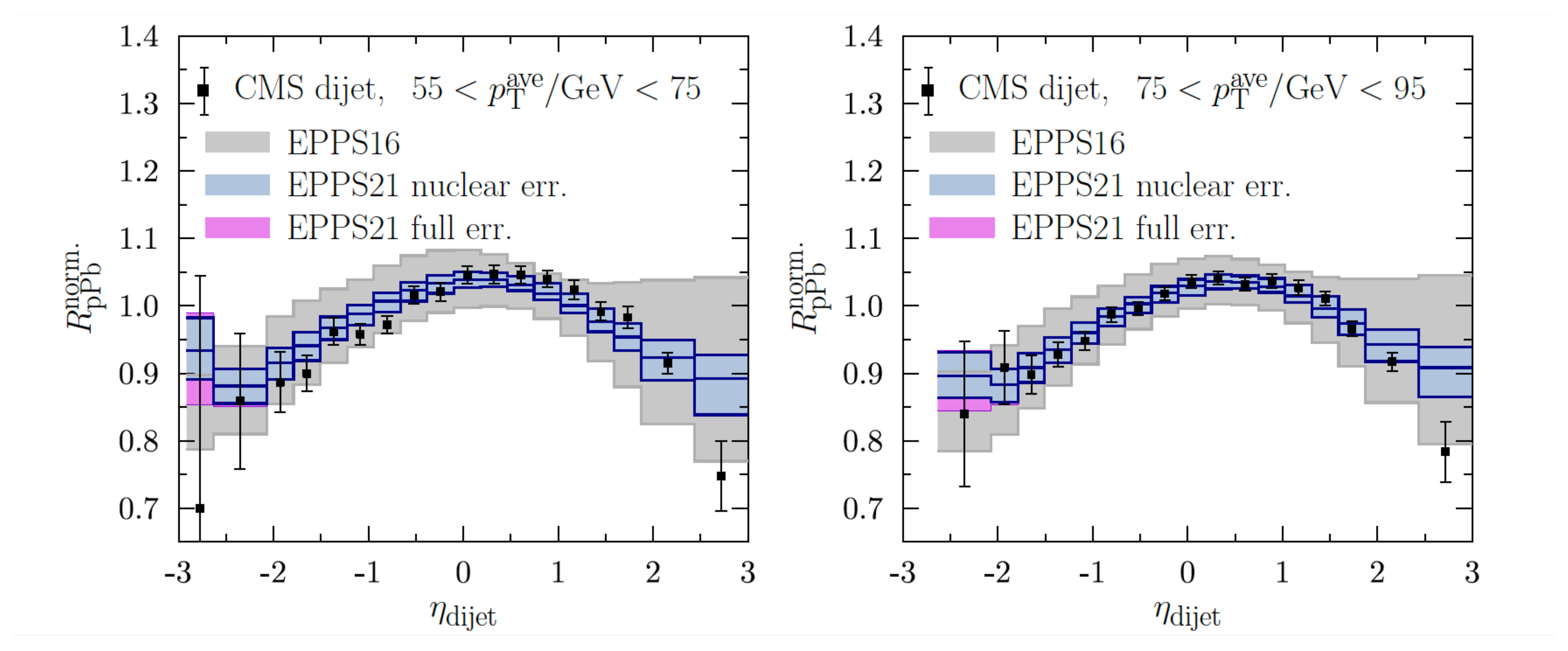
PRL 121, 062002 (2018)



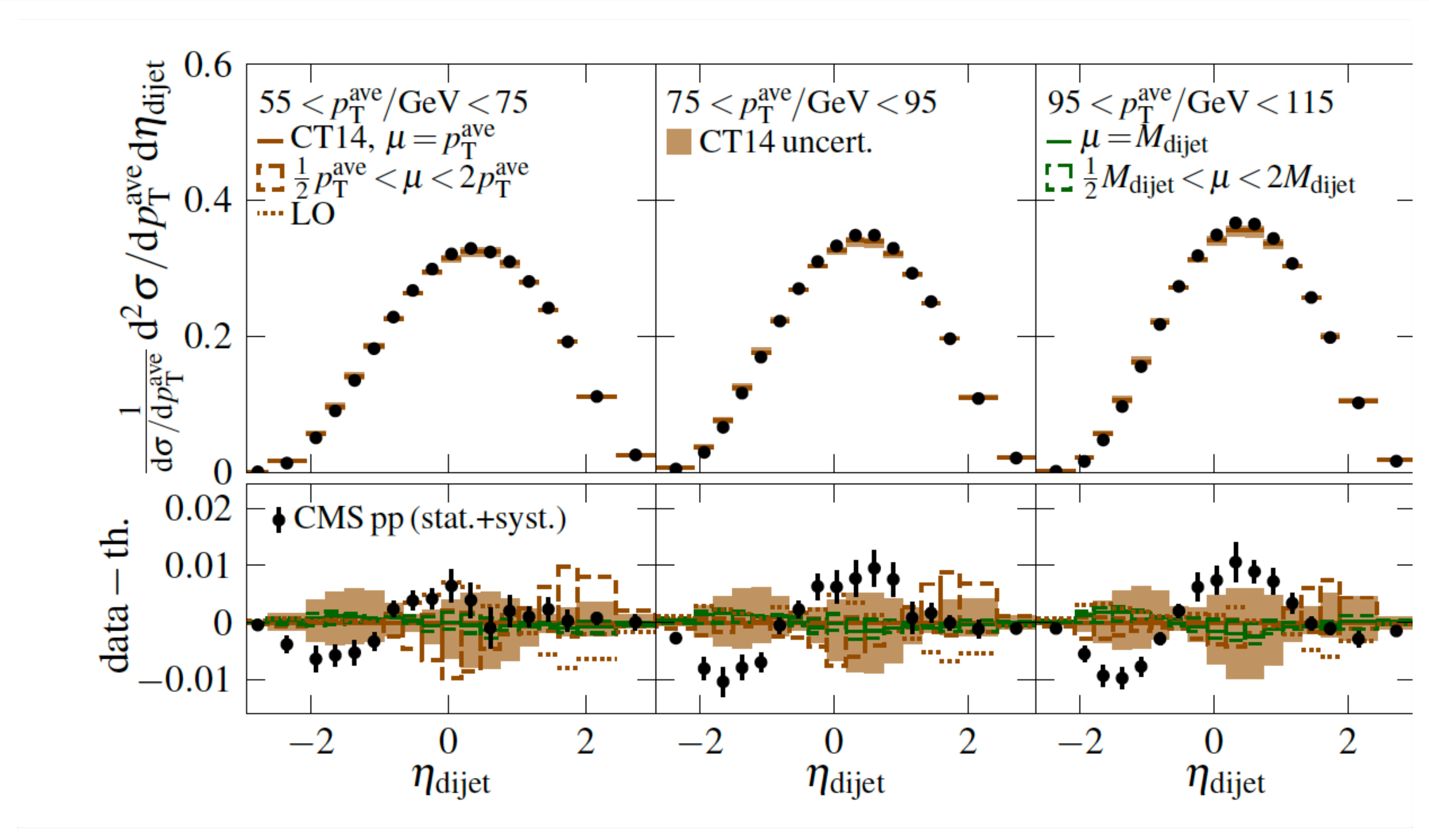
CMS dijet data @ 5.02 TeV only one published so far

Ratios are well described!

More issues when trying to describe separately p+p and p+Pb data



Eskola et al., Eur.Phys.J.C 82 (2022) 5, 413

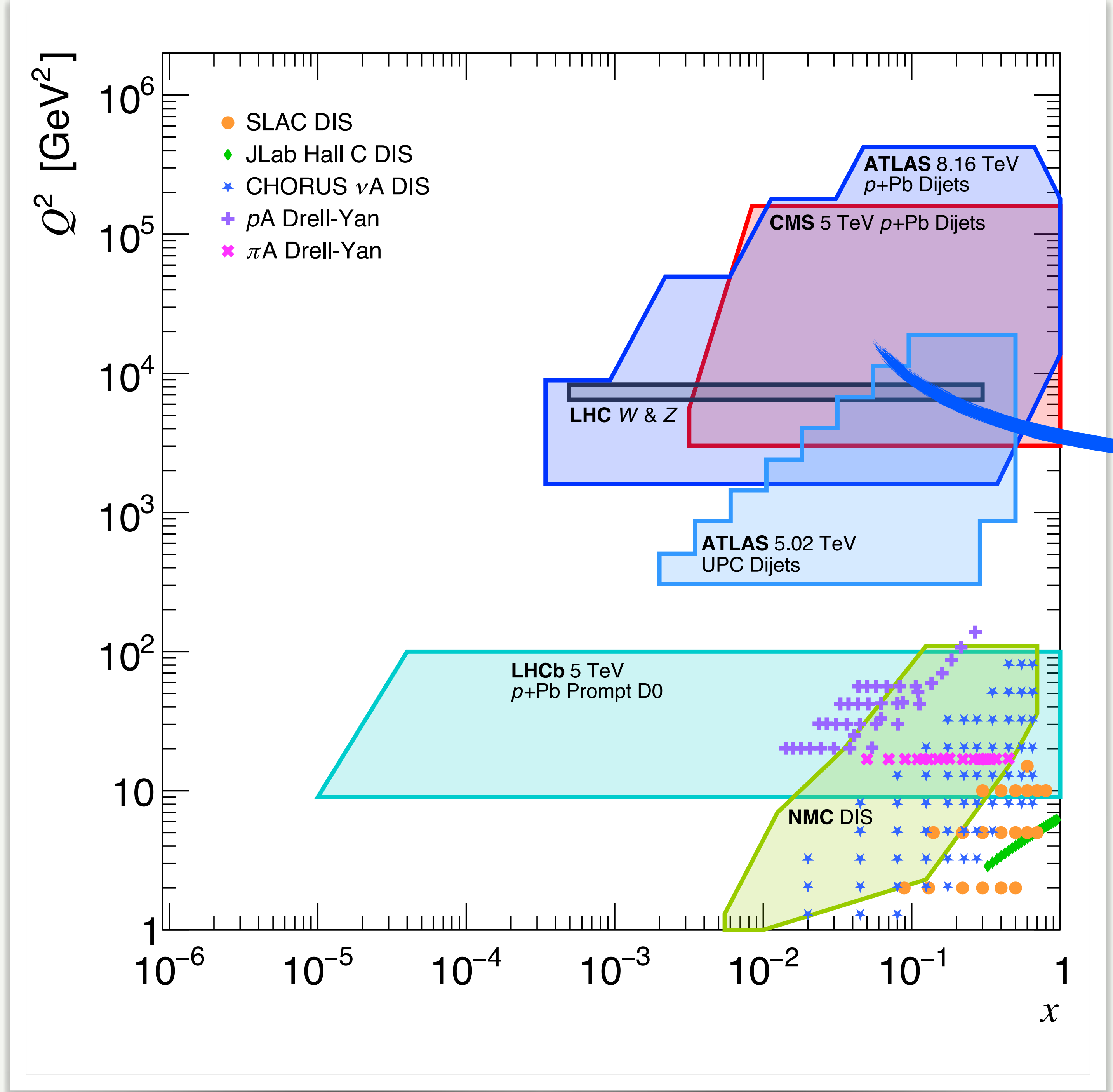


Eskola et al., Eur.Phys.J. C79 (2019) no.6, 511

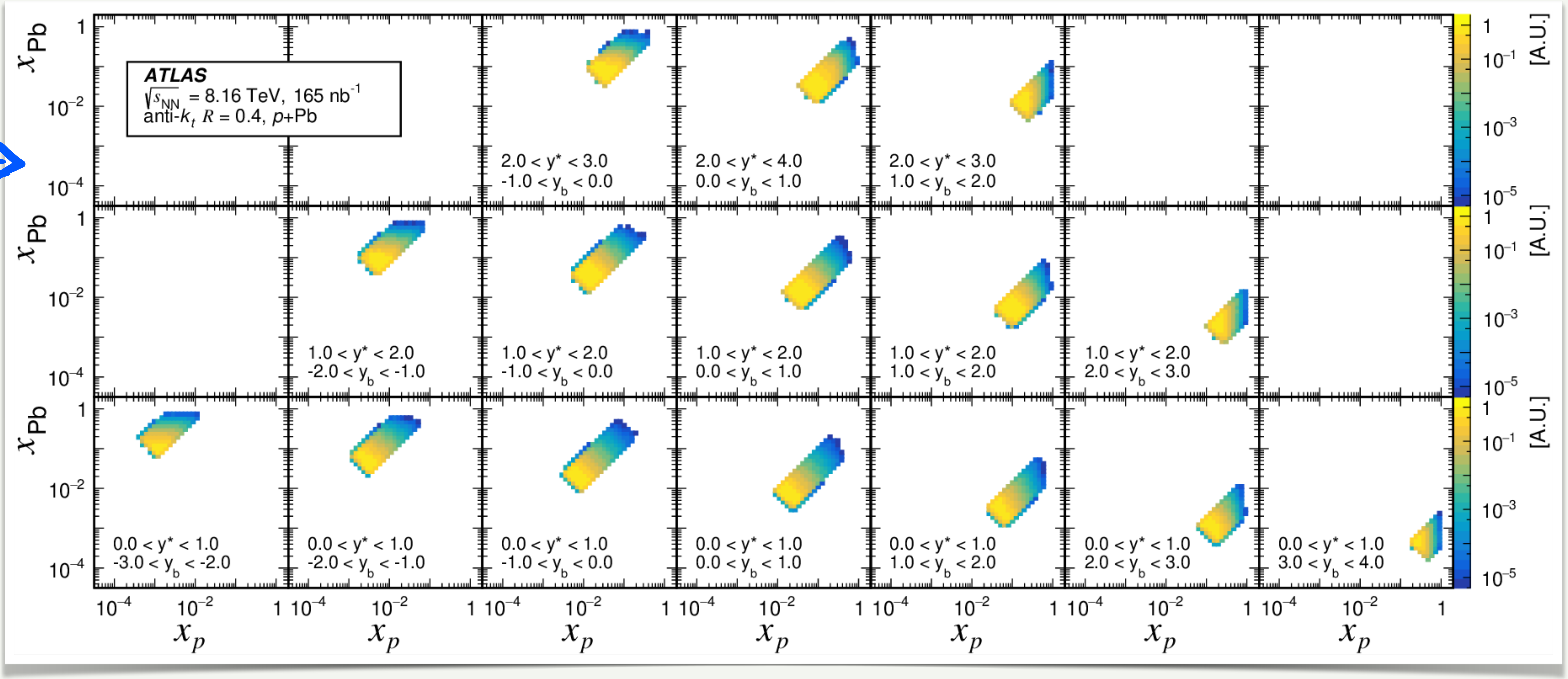
Dijet for nPDF constraints: ATLAS input

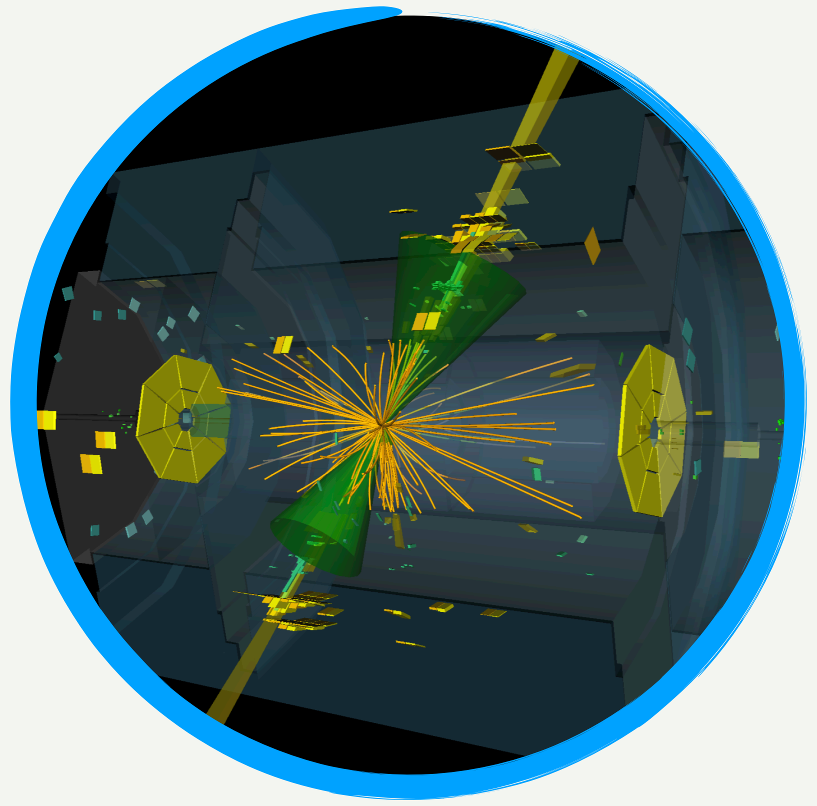
ATLAS EXPERIMENT

Adapted from **Eur. Phys. J. C (2022) 82:413**



Dijet in p+Pb @ 8.16 TeV measured by ATLAS using the full acceptance of the calorimeter explore a wide kinematic range



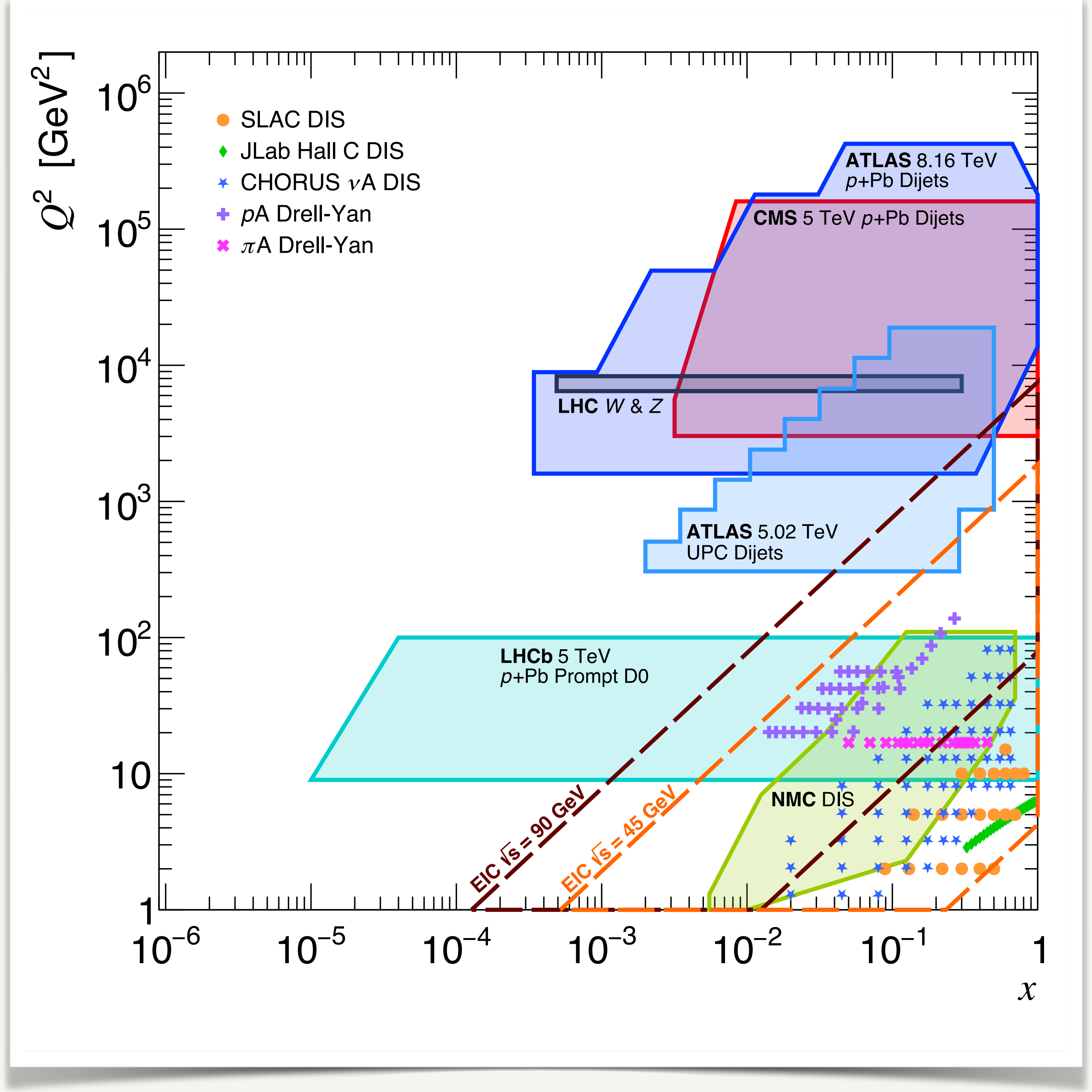


Ongoing Measurement of dijet production over ~4 orders of magnitude in x_p, x_{Pb} !

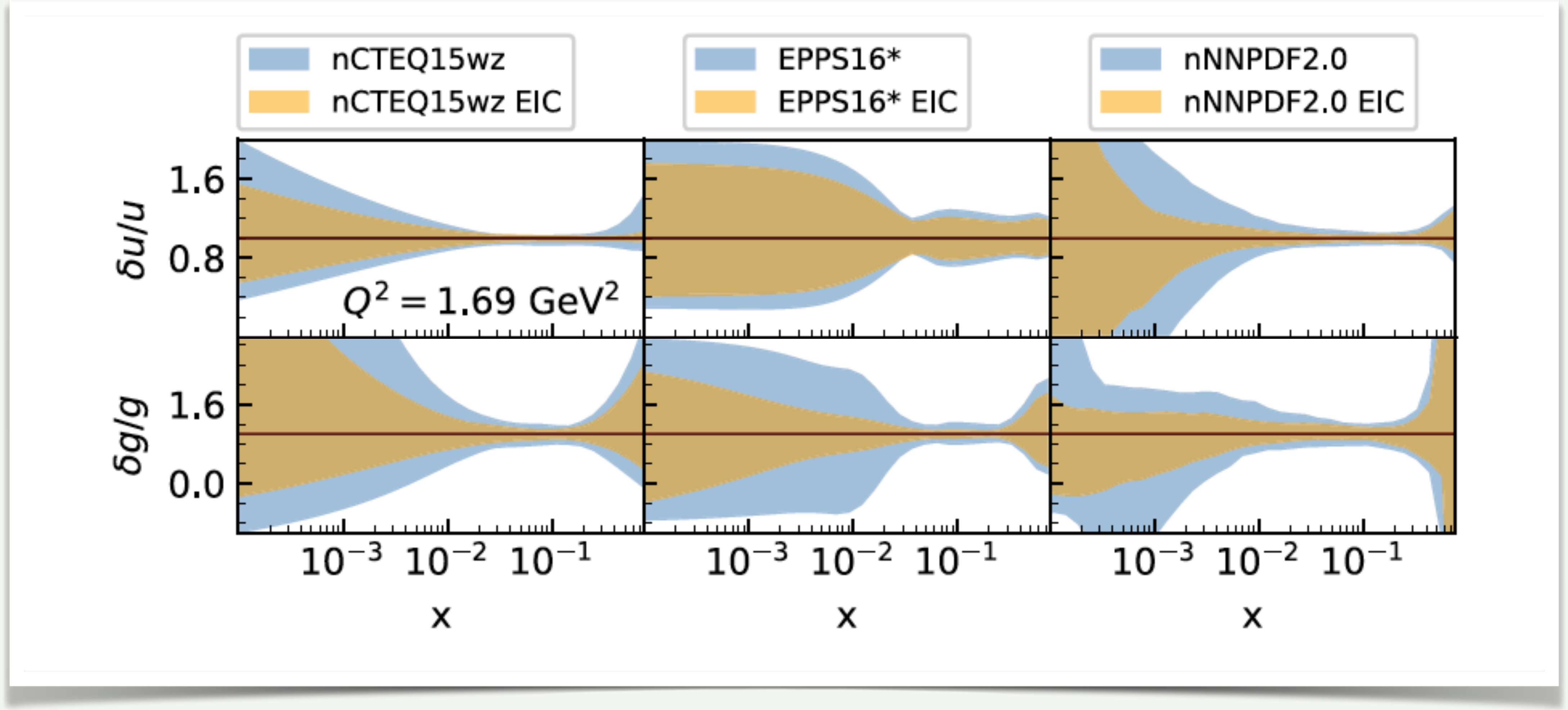
The EIC contribution

ATLAS EXPERIMENT

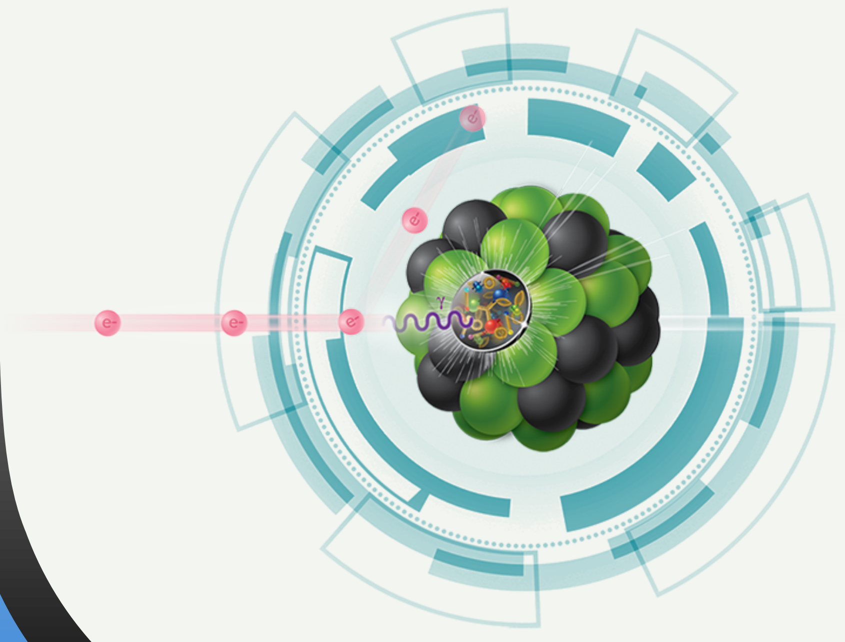
Adapted from **Eur. Phys. J. C (2022) 82:413**



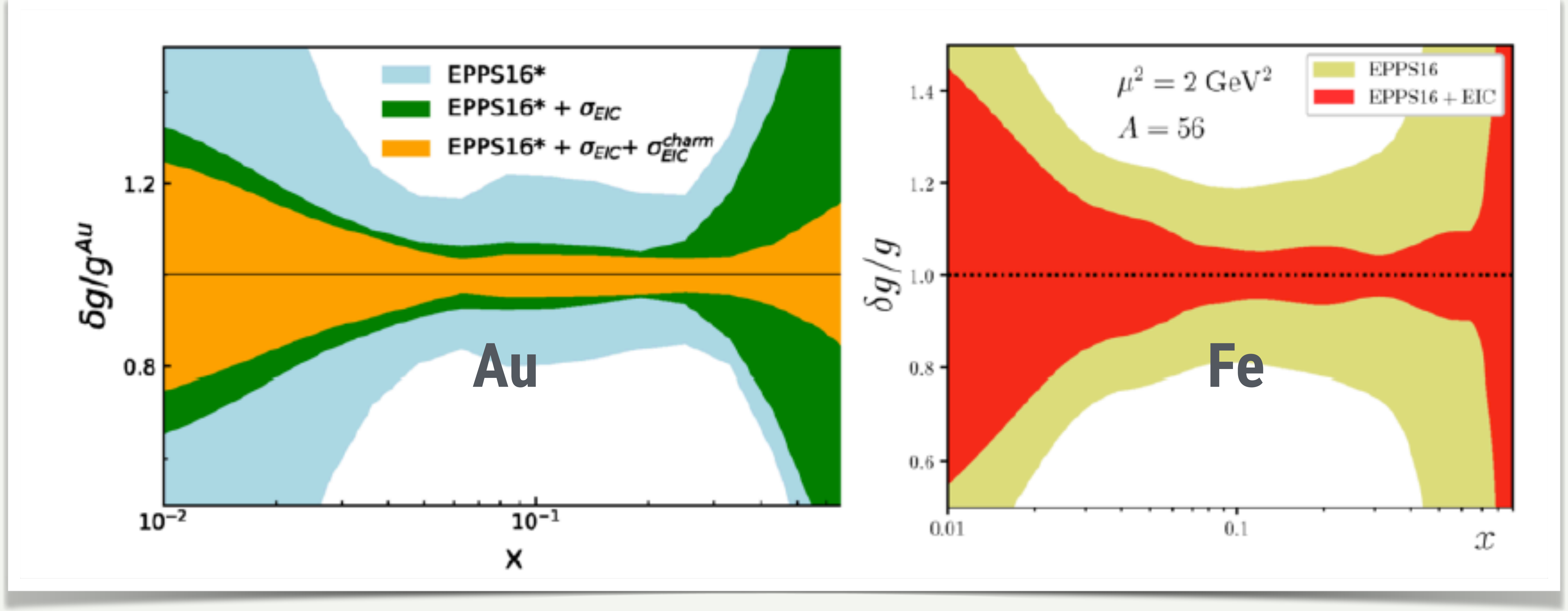
Nucl.Phys.A 1026 (2022) 122447



Precision measurements to constraint nPDF at low-x



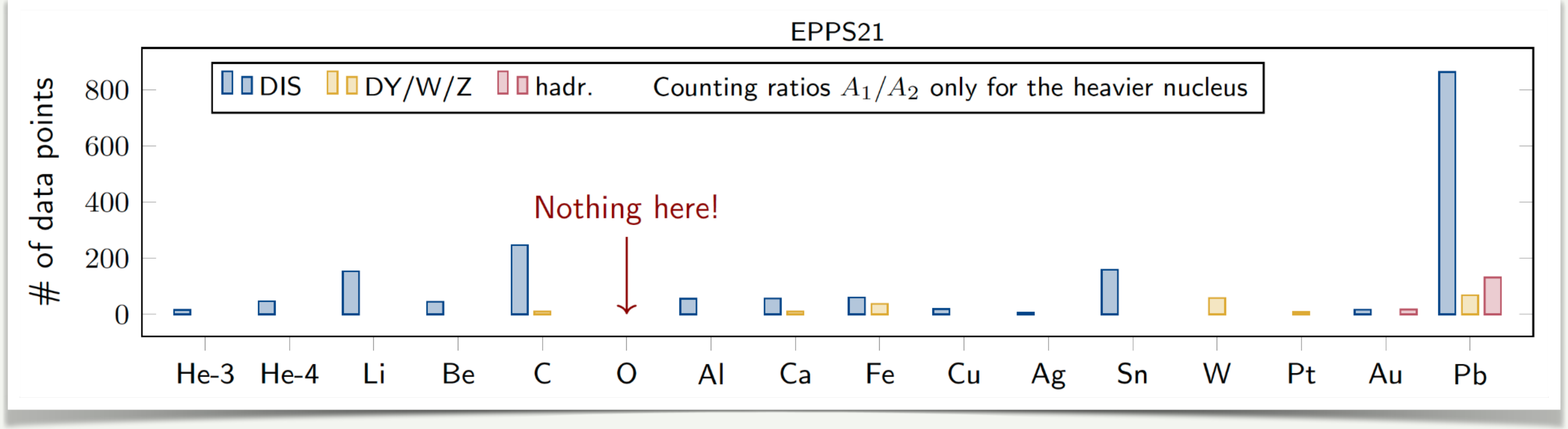
e⁻+A: much cleaner compared to p+A;
easier to disentangle cold nuclear matter effects from other higher twist effects



A-dependence of nPDFs

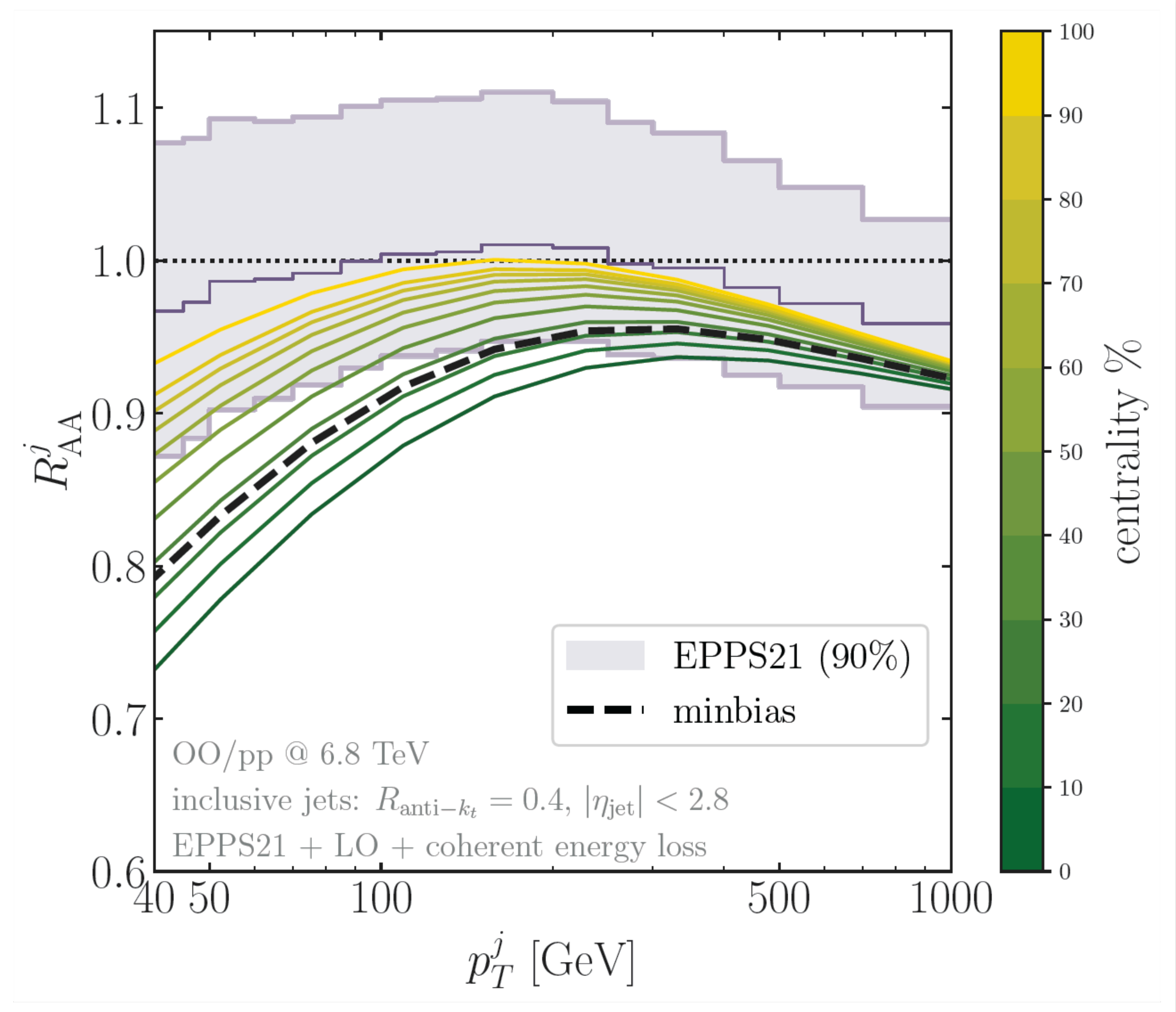
nPDF @ ATLAS: near future

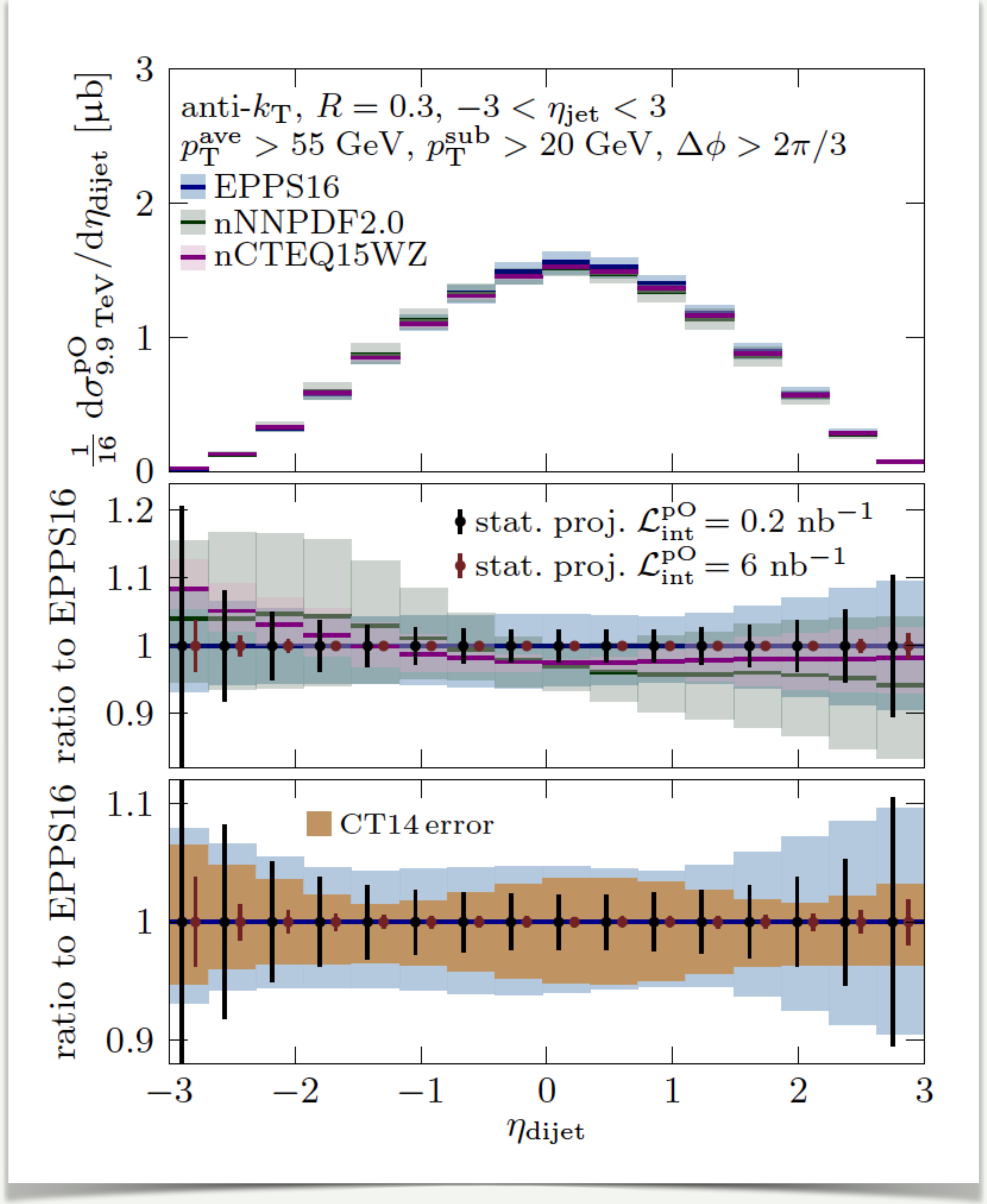
ATLAS EXPERIMENT



P.Paakkinen
PRD 105, L031504 (2022)

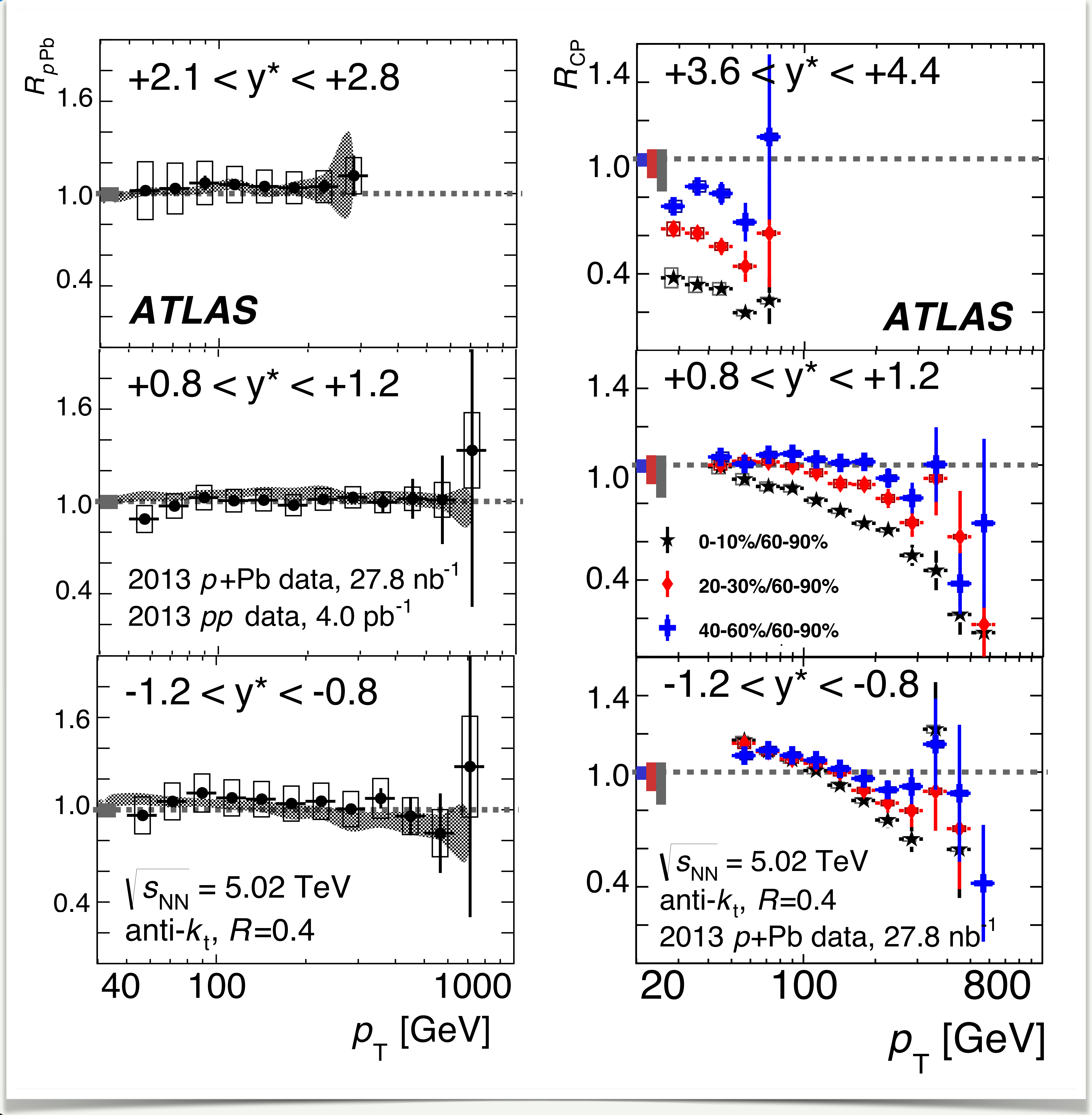
- 7 nb^{-1} of p+O data taking (first ever @ LHC!) recorded by ATLAS in July
  - Limited luminosity – officially an 'LHC pilot run' + running w/ LHCf
  - Still – great physics potential – first opportunity to explore O nuclear structure
    - Also tied to understanding O+O collisions @ LHC (Run 3 novelty)!





Dijet measurements to inform O nPDF parameterizations

Jet production & event-activity bias in p+Pb



PLB 748 (2015) 392–413:

- R_{pPb} results: no evidence for large modification of the total yield of jets relative to the geometric expectation observed
- R_{CP} results: suppression of central events compared to peripheral found to be function of the jet energy, suggesting direct link to initial state kinematics

Color Fluctuation effects in dijet events

ATLAS EXPERIMENT

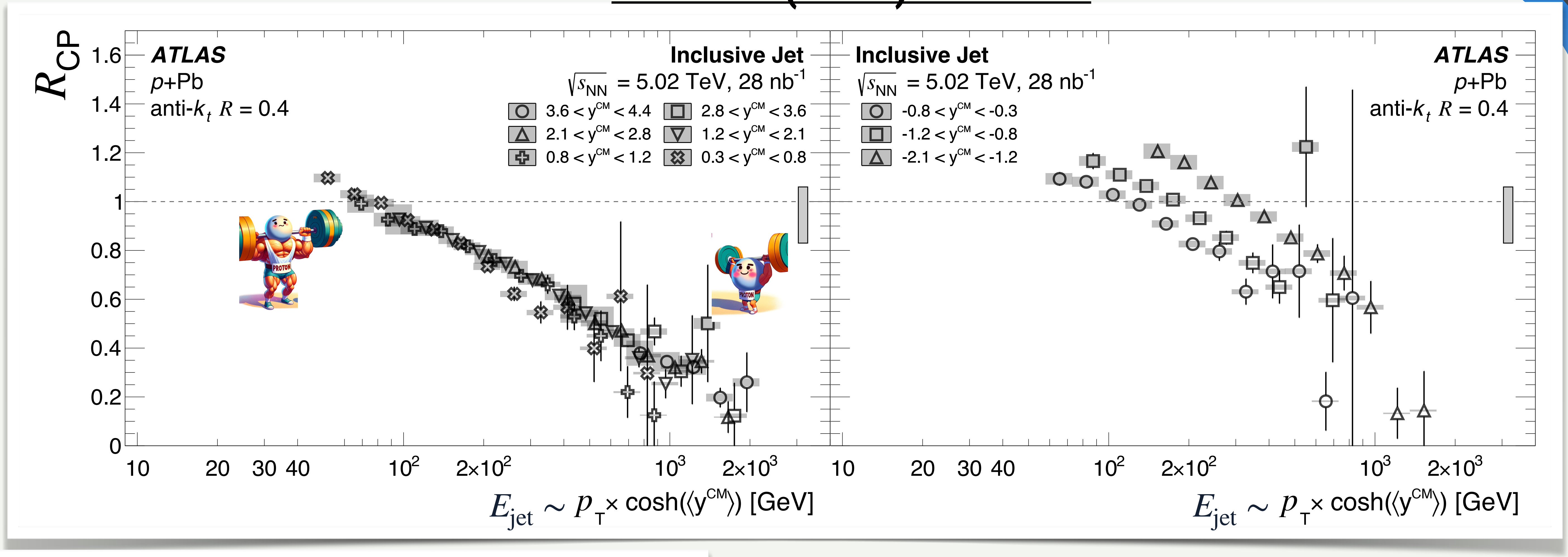
$$p_{\mathrm{T,Avg}} = \frac{p_{\mathrm{T},1} + p_{\mathrm{T},2}}{2}, \quad y_b = \frac{y_1^{\mathrm{CM}} + y_2^{\mathrm{CM}}}{2} \quad y^* = \frac{|y_1^{\mathrm{CM}} - y_2^{\mathrm{CM}}|}{2}$$

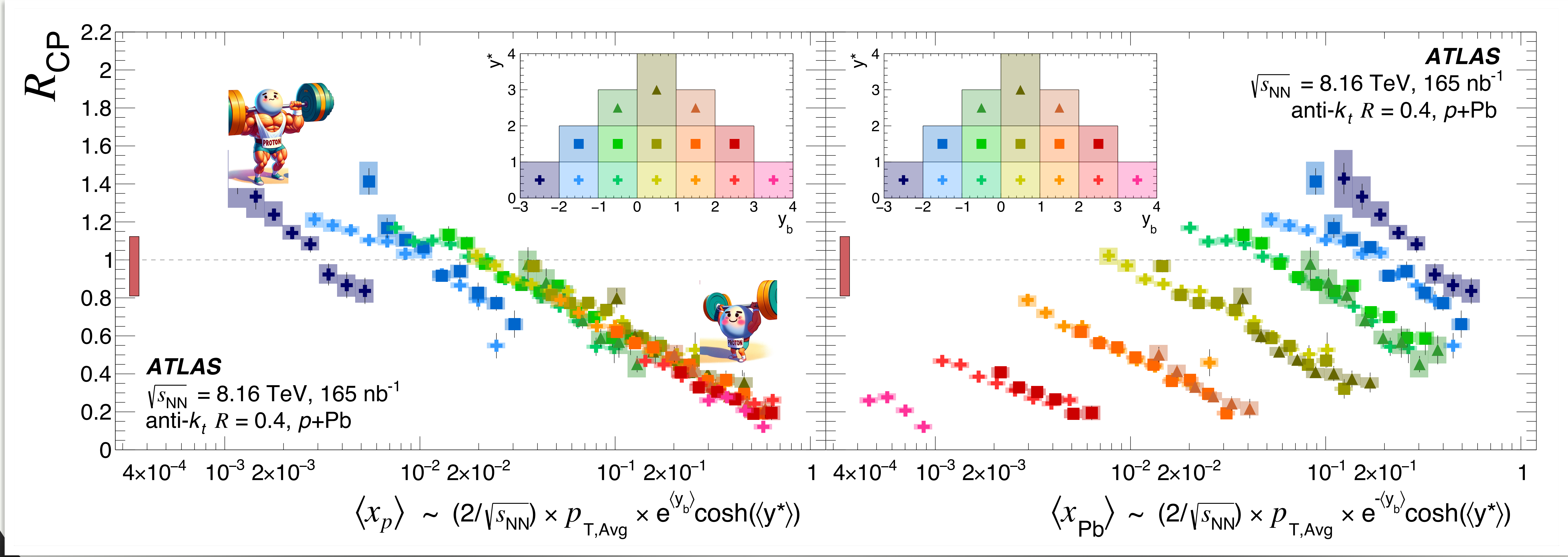
$$x_p \simeq \frac{2p_{\mathrm{T,Avg}}}{\sqrt{s_{\mathrm{NN}}}} e^{y_b} \cosh(y^*)$$

$$x_{\mathrm{Pb}} \simeq \frac{2p_{\mathrm{T,Avg}}}{\sqrt{s_{\mathrm{NN}}}} e^{-y_b} \cosh(y^*)$$

Dijets provide direct access to the kinematics of the hard-scattering

PLB 748 (2015) 392–413





Phys. Rev. Lett. 132 (2024) 102301

Striking scaling of the R_{CP} as a function of x_p!

Color Fluctuation effects in dijet events

ATLAS EXPERIMENT

Comparison between the two measurements achieved via x_F

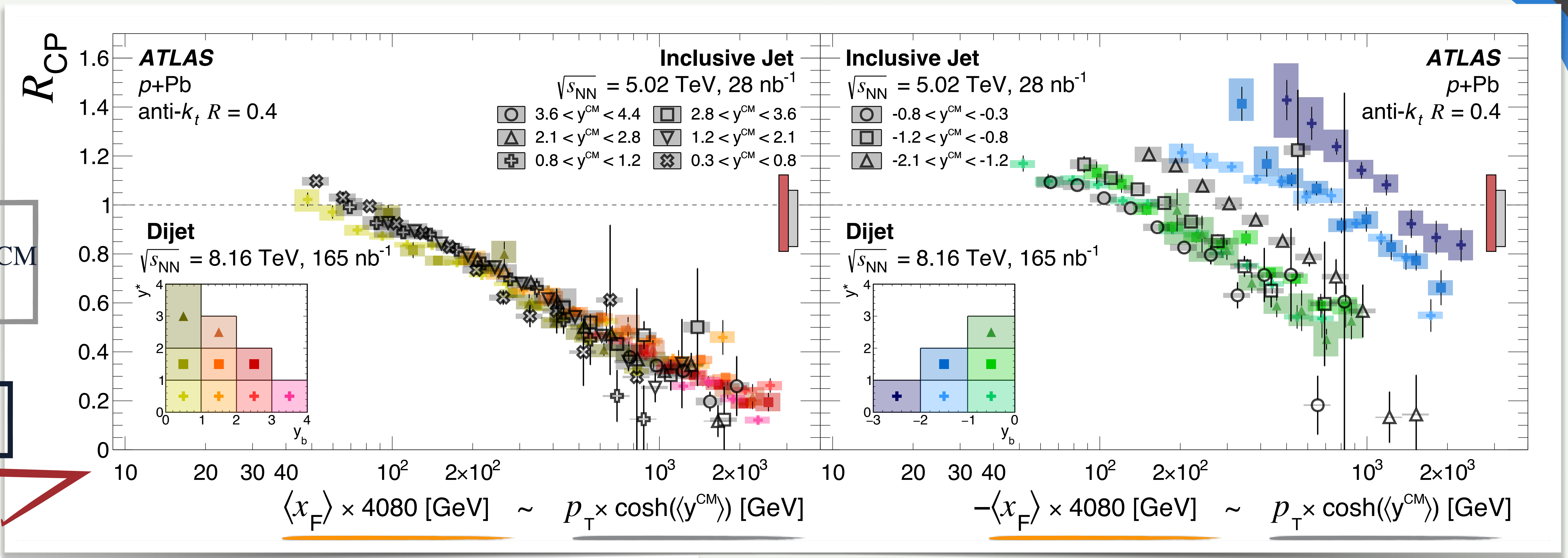
$$x_p - x_{Pb} = x_F = \frac{2p_z}{\sqrt{s_{NN}}} \sim \pm 2\frac{p_T \times \cosh y^{CM}}{\sqrt{s_{NN}}} \rightarrow \pm \frac{\sqrt{s_{NN}}}{2} \times x_F \sim p_T \times \cosh y^{CM}$$

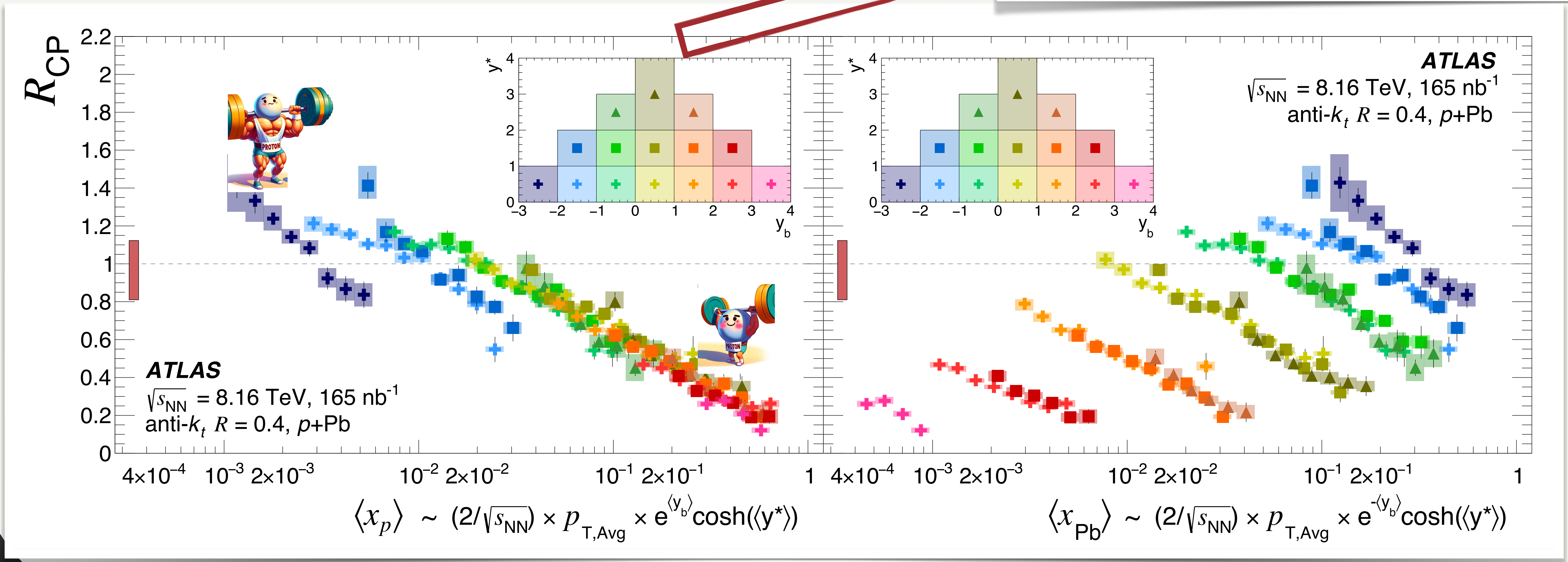
Initial state definition

Final state definition

Assuming

$$m_T = \sqrt{m^2 + p_T^2} \sim p_T \qquad \sinh y^{CM} \sim \pm \cosh y^{CM} \text{ if } |y^{CM}| \gg 0$$





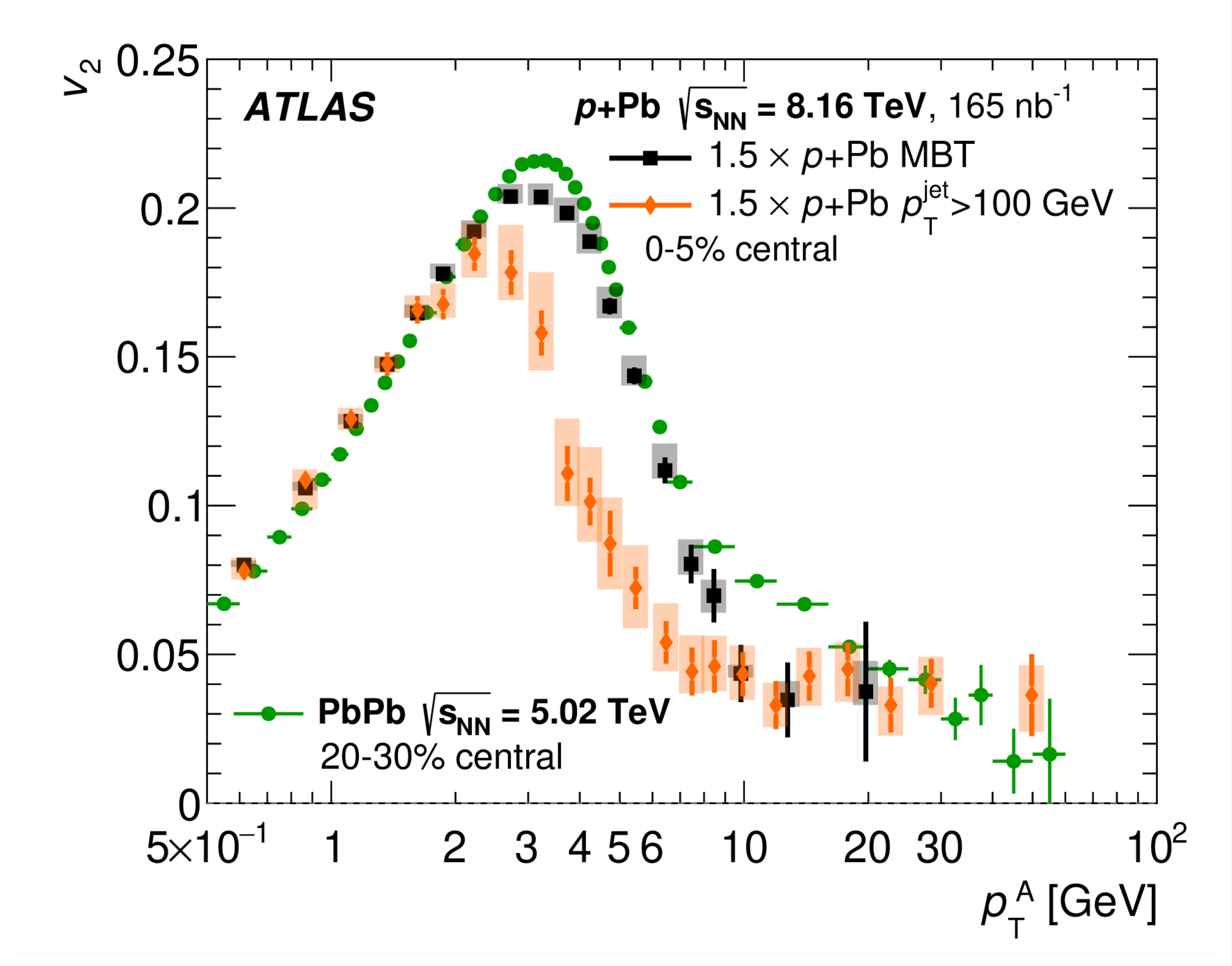
Same physics effect, driven by the initial state proton kinematics!

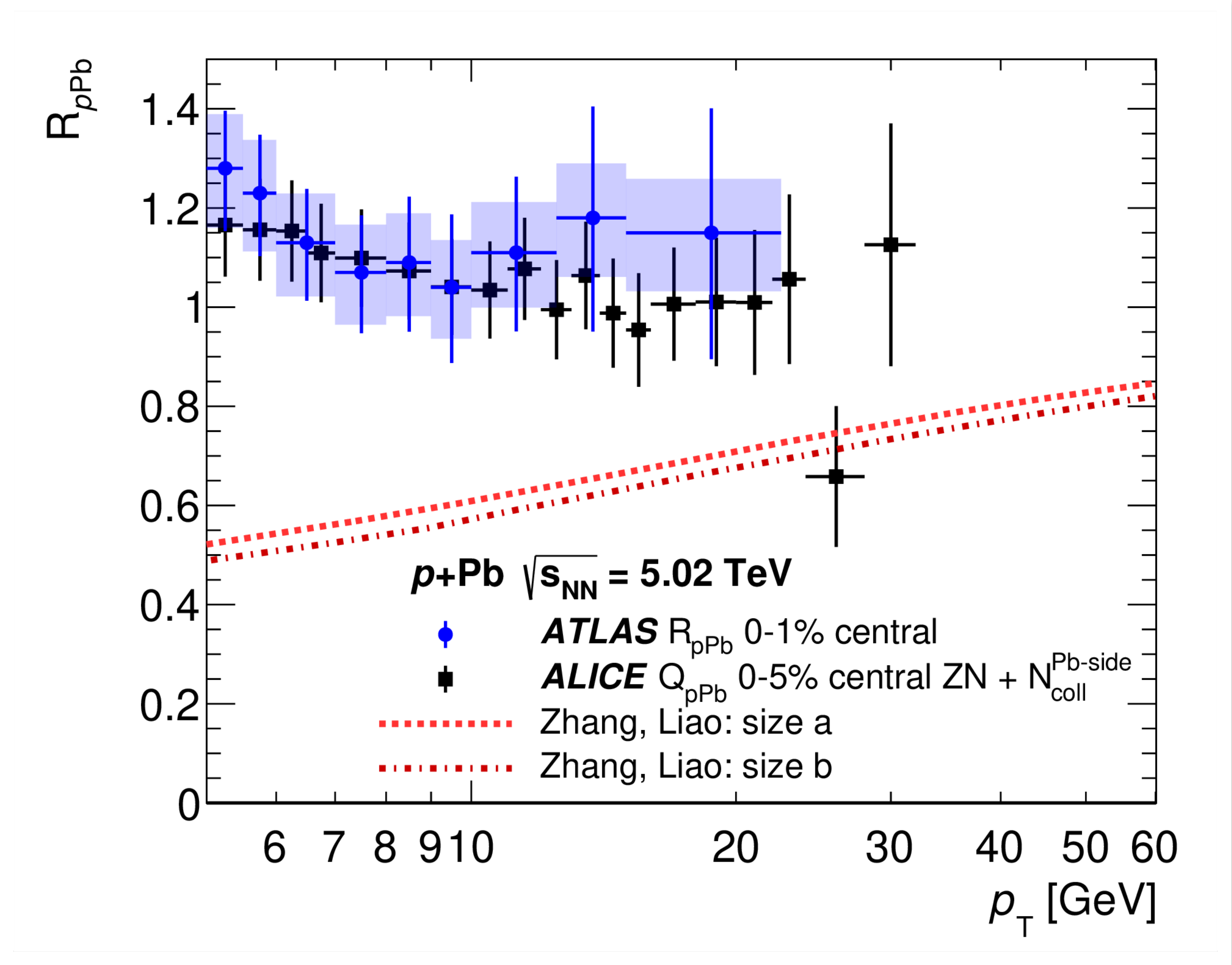
Phys. Rev. Lett. 132 (2024) 102301

High p_T puzzle: no energy loss but collectivity

ATLAS EXPERIMENT

Eur. Phys. J. C 80 (2020) 73



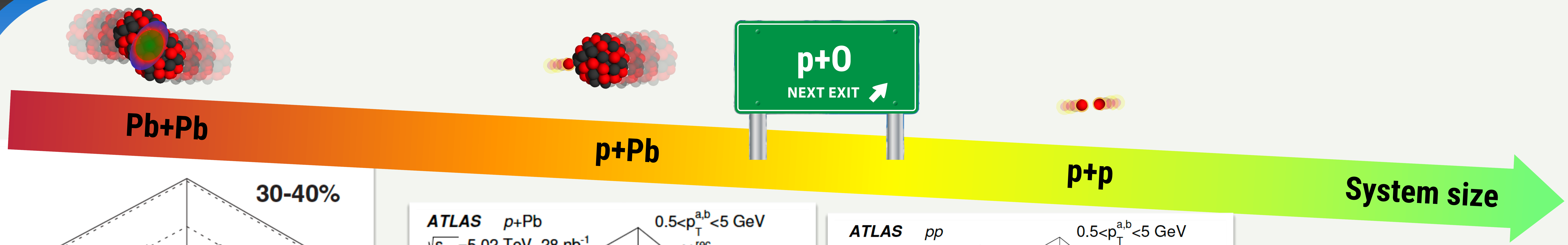


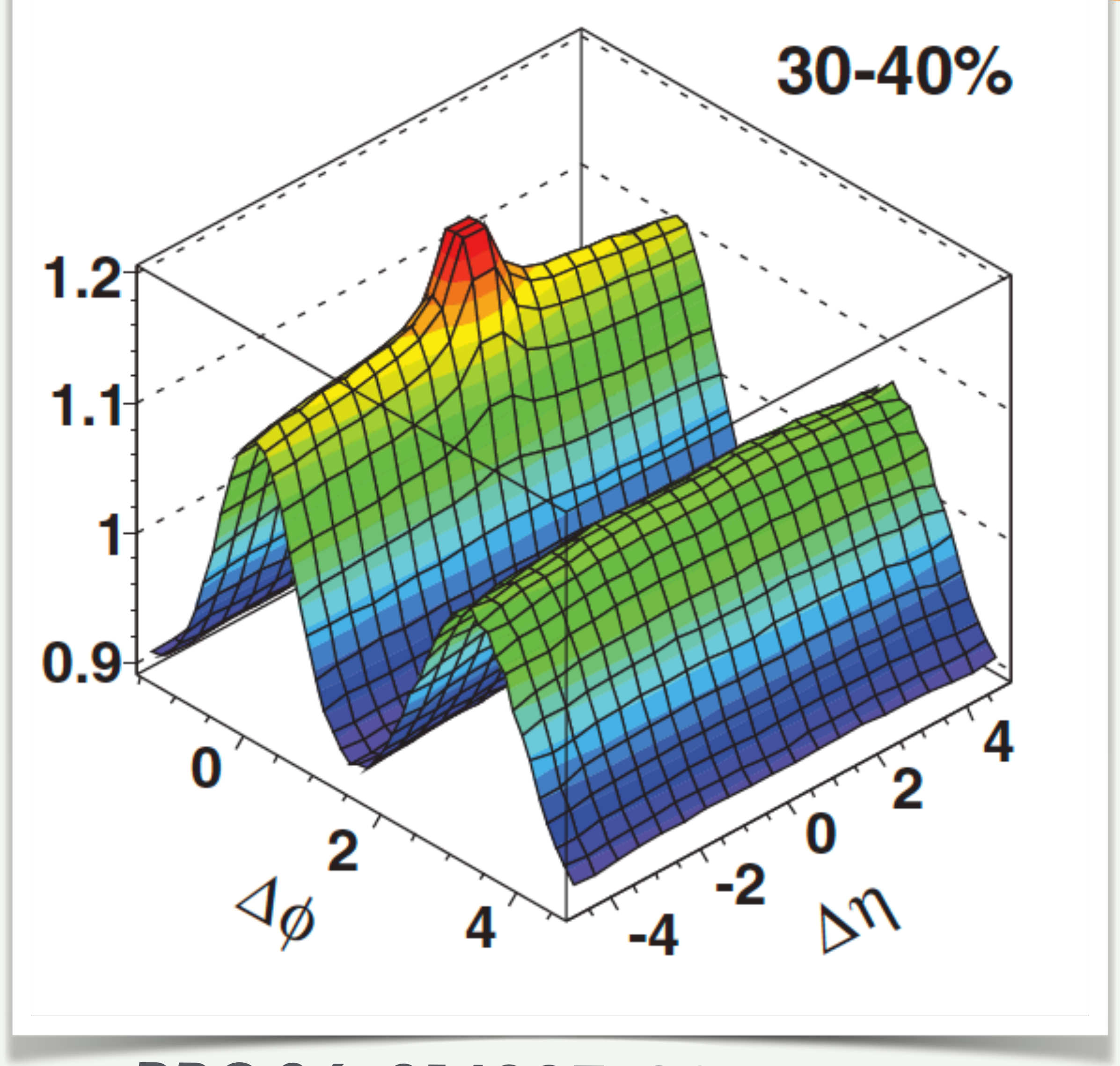
High p_T puzzle in small-systems

- No jet quenching
- Clear v_2 signal - similar to mid-central Pb-Pb
- Models that predict collective behavior largely overestimate R_{pPb} suppression

Turning off the collectivity?

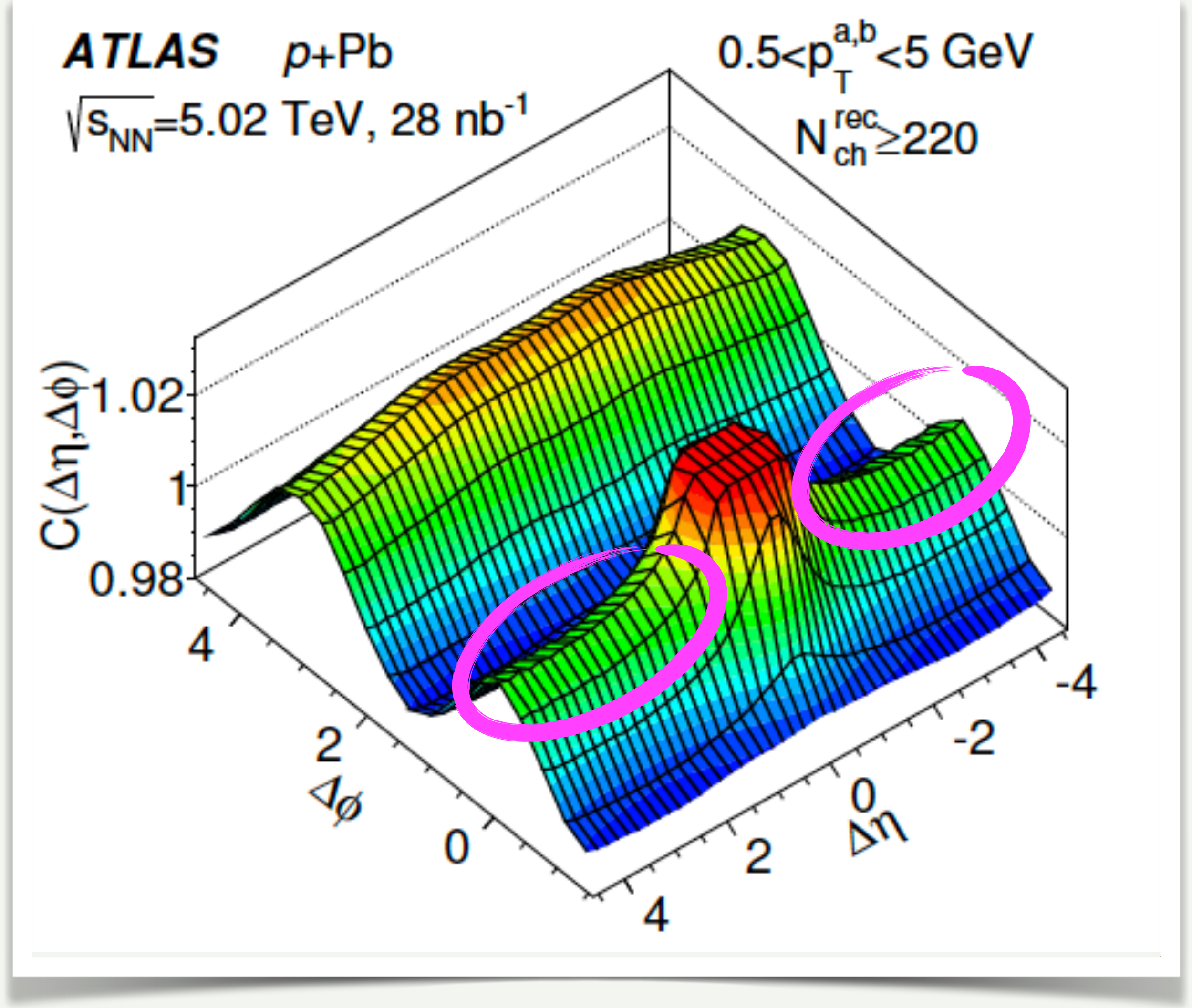
ATLAS EXPERIMENT



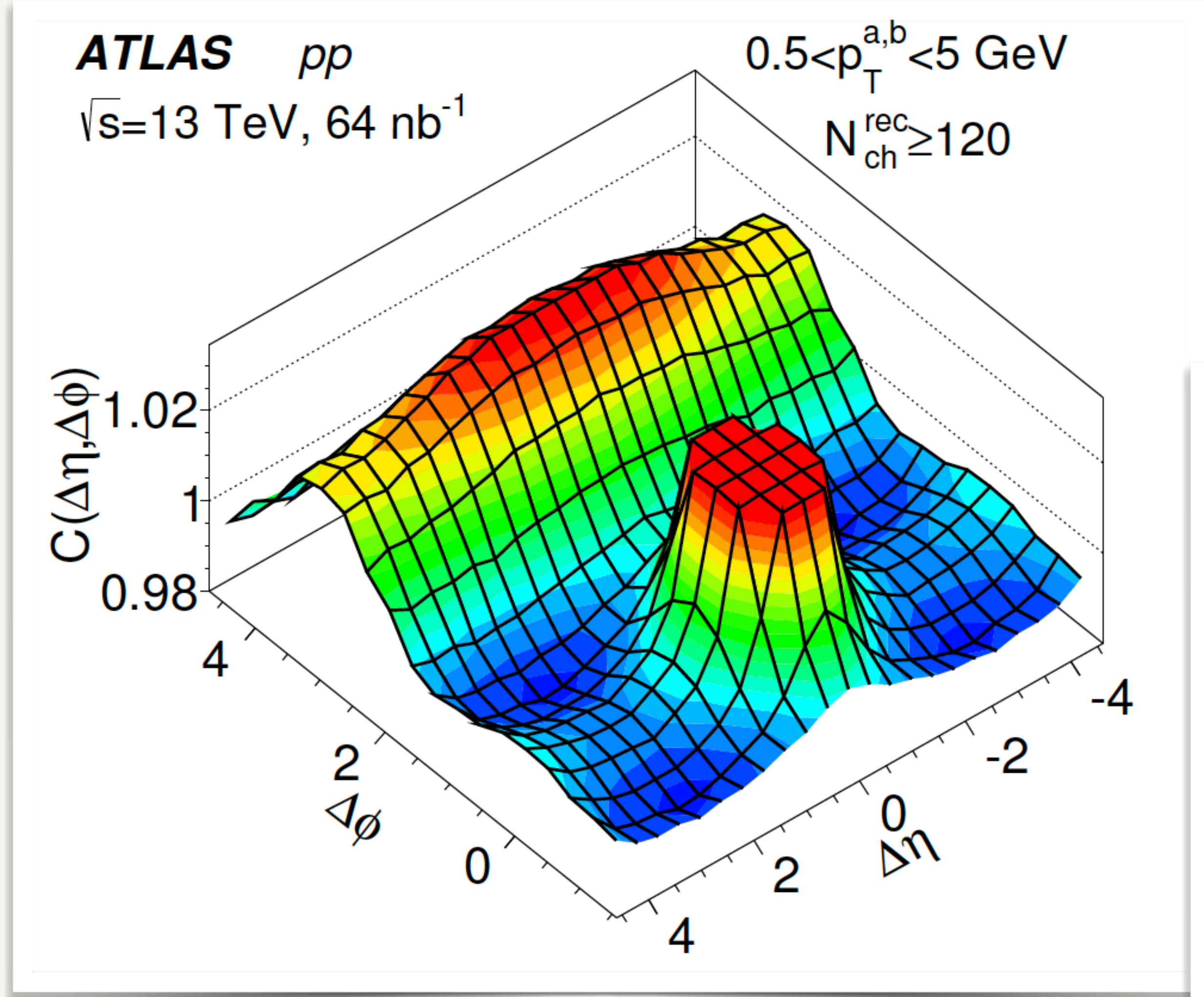


PRC 86, 014907 (2012)

Pb+Pb: collective, strongly-coupled long-distance behavior

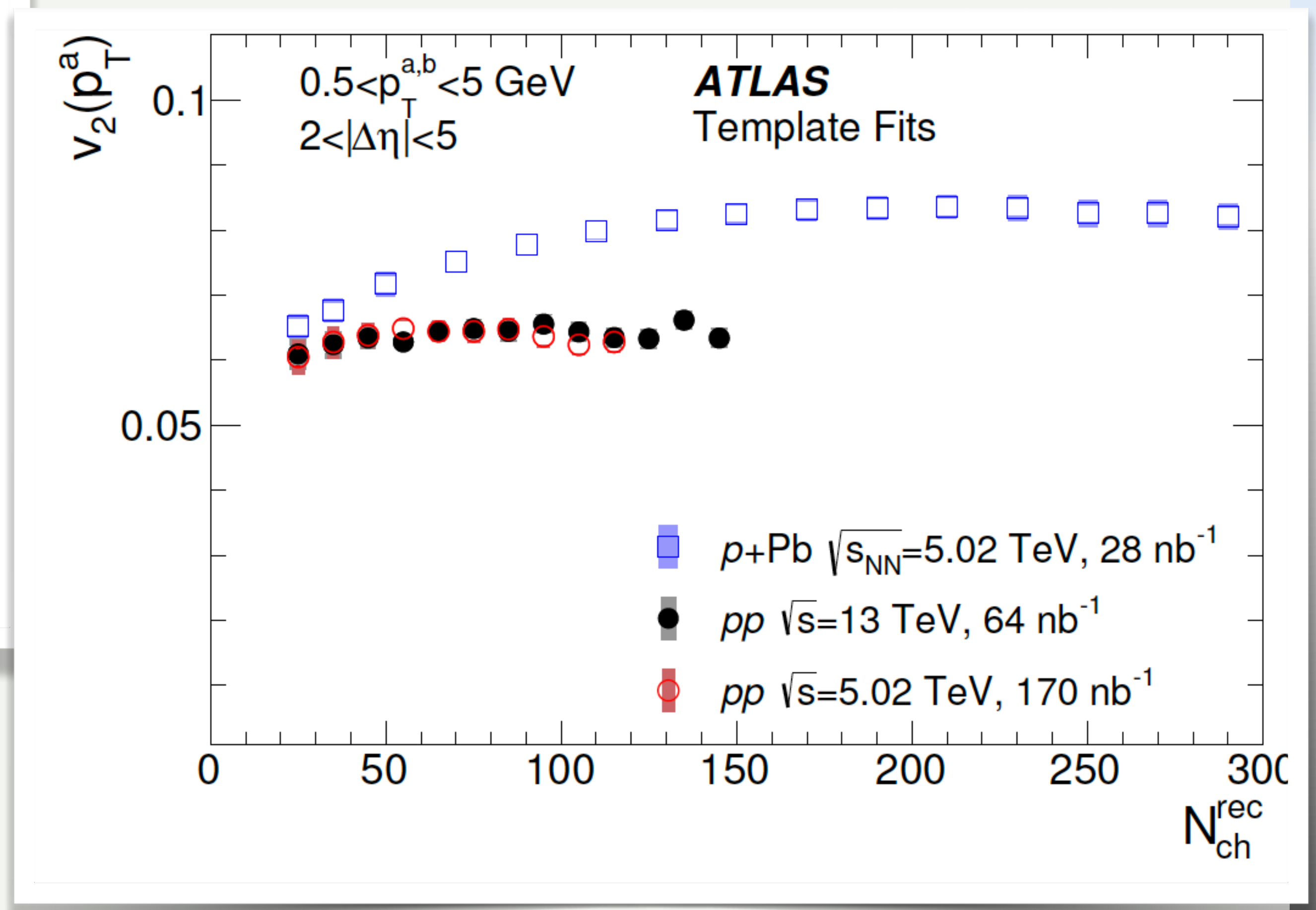


p+Pb: unexpected near-side ridge. QGP still on?



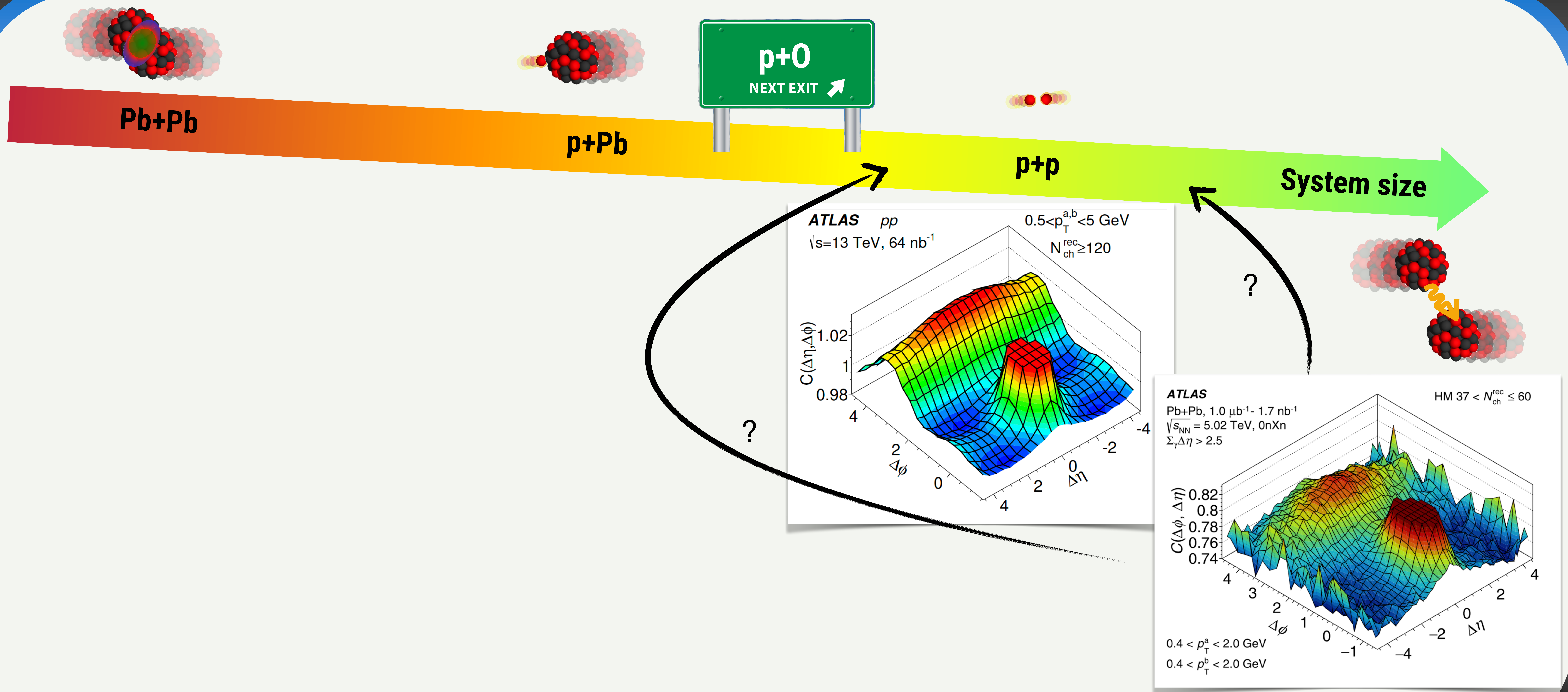
p+p: near-side ridge still present. Effect independent from collision energy

Phys. Rev. C 96 (2017) 024908



What about $\gamma + \mathrm{Pb}$?

ATLAS EXPERIMENT

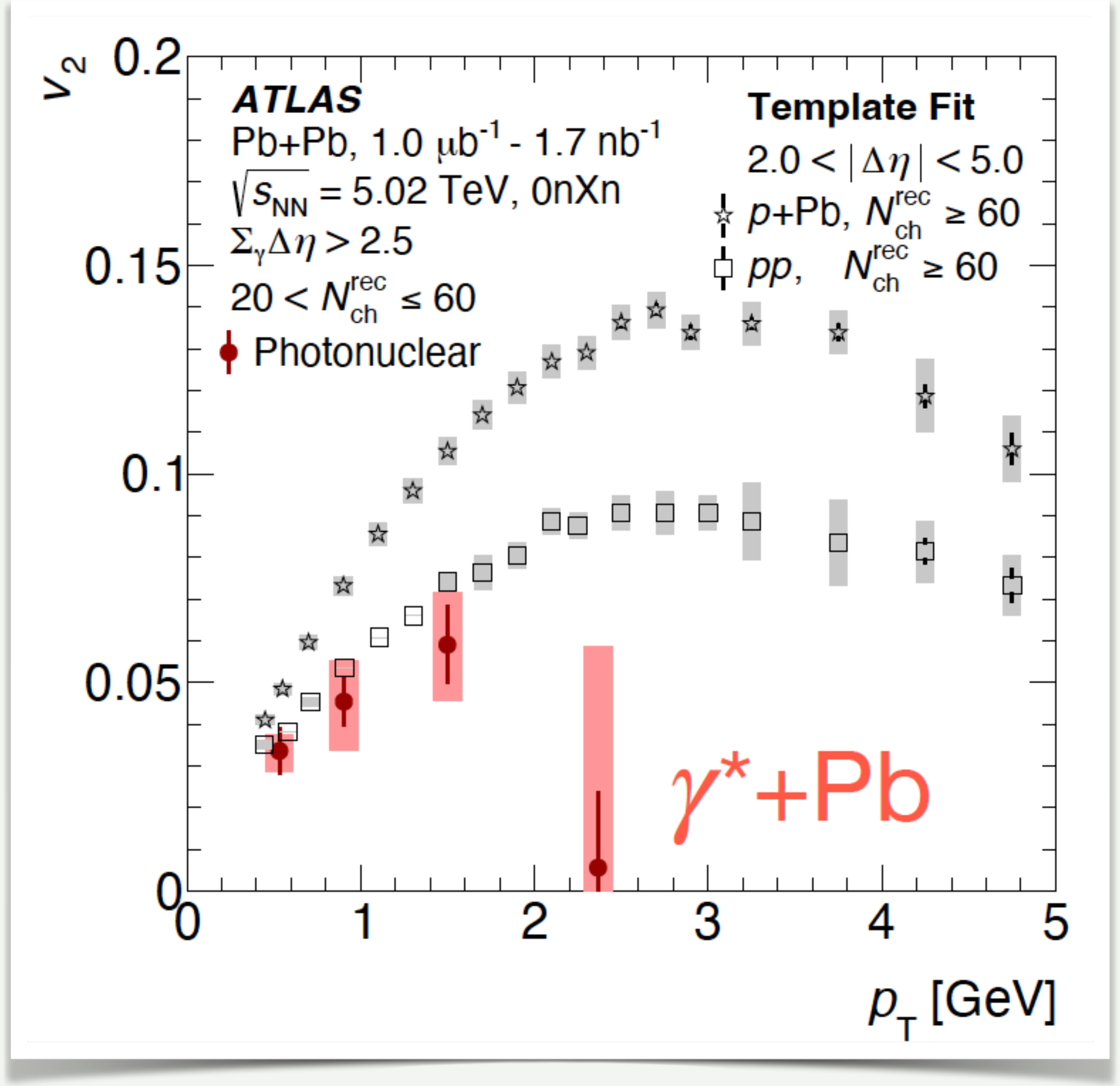


PRC 104, 014903 (2021)

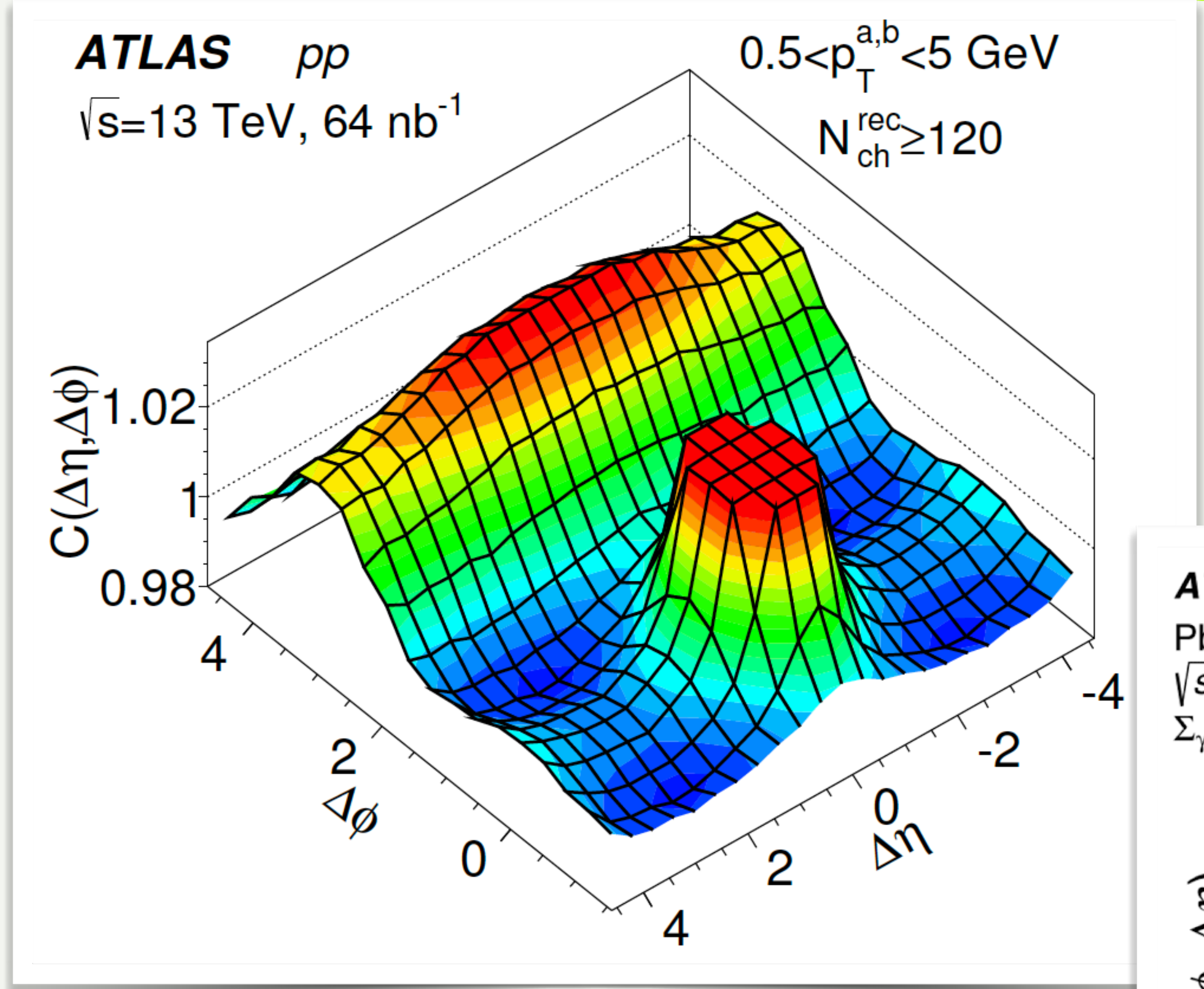
What about $\gamma + \mathrm{Pb}$?

QGP-like signature found by ATLAS in UPCs via (resolved?) photons

Hierarchy?



?



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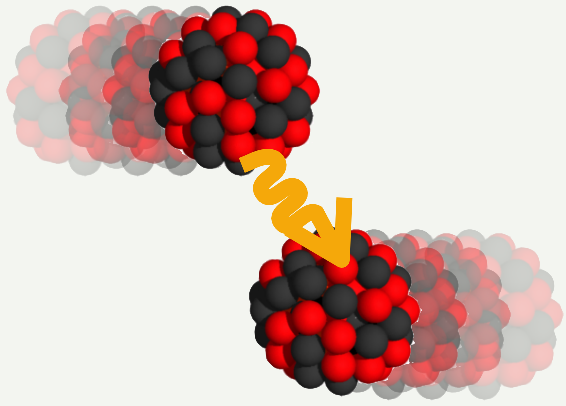
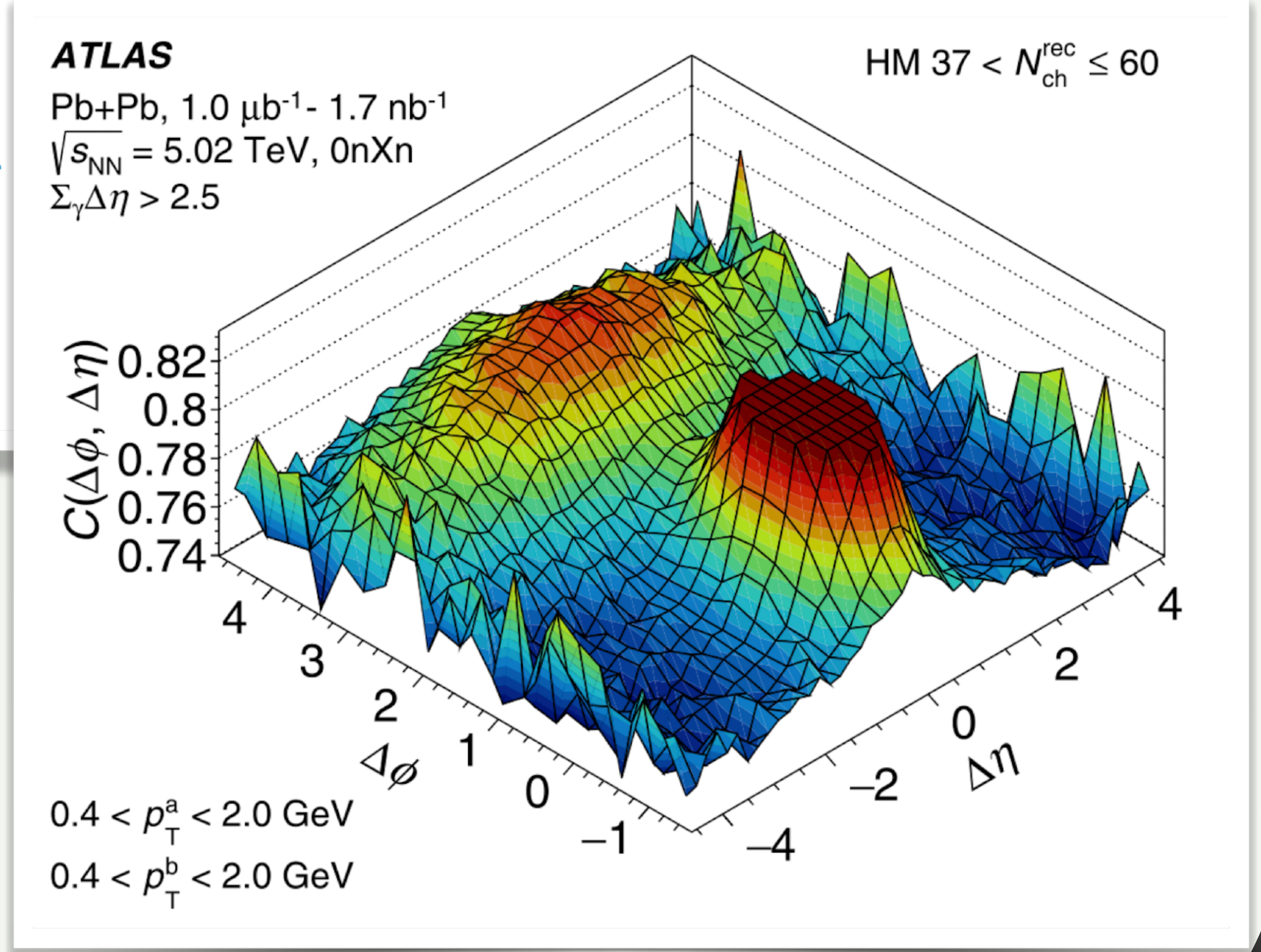


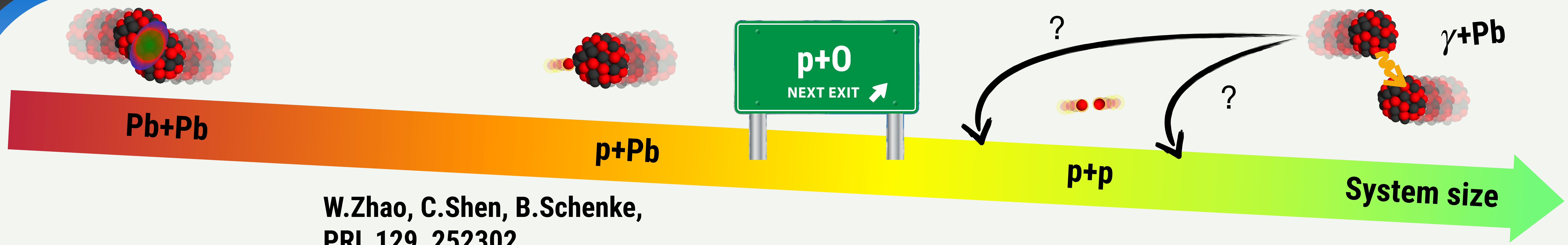


Two-dimensional correlation functions in $\gamma + \mathrm{Pb}$ have features similar to those observed in pp collision

PRC 104, 014903 (2021)

How $\gamma + \mathrm{Pb}$ and $p + \mathrm{Pb}$ compare?

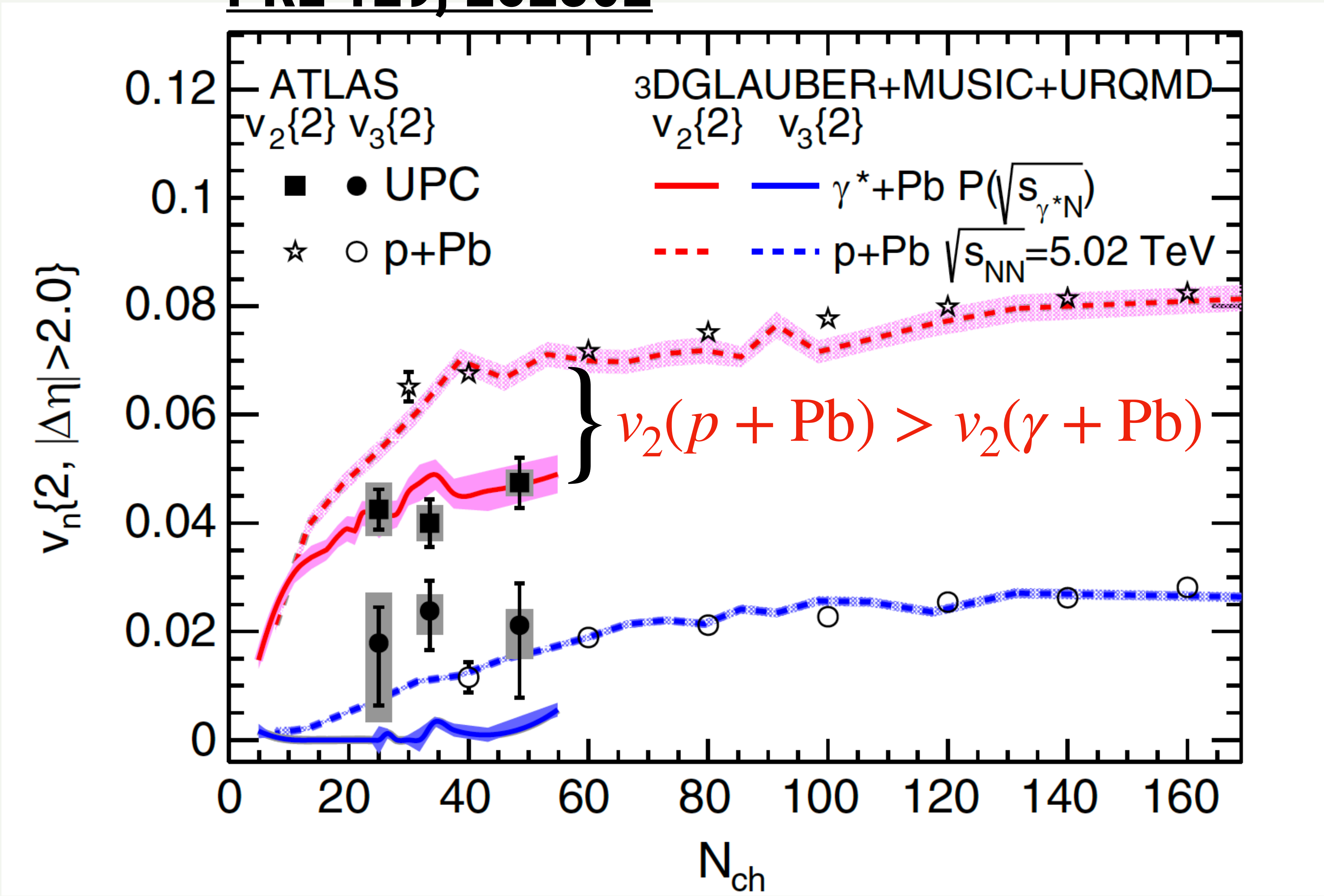
ATLAS EXPERIMENT



QGP-like signature found by ATLAS in UPCs via (resolved?) photons

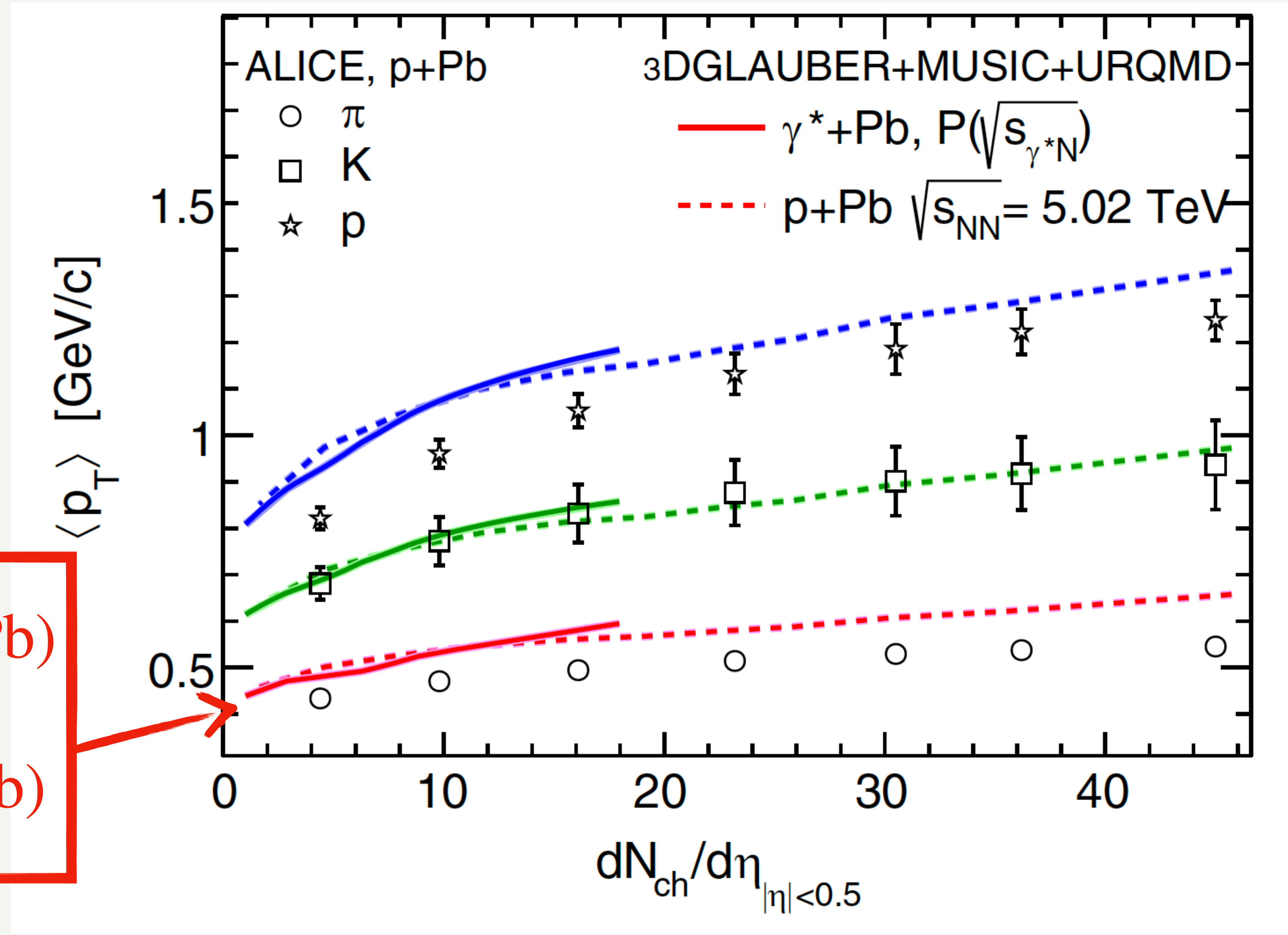
Hierarchy?

W.Zhao, C.Shen, B.Schenke, PRL 129, 252302



3+1D hydrodynamics suggests v_2 hierarchy between p+Pb and γ+Pb driven by flow decorrelations

$\langle p_T \rangle(p + \mathrm{Pb}) \sim \langle p_T \rangle(\gamma + \mathrm{Pb})$

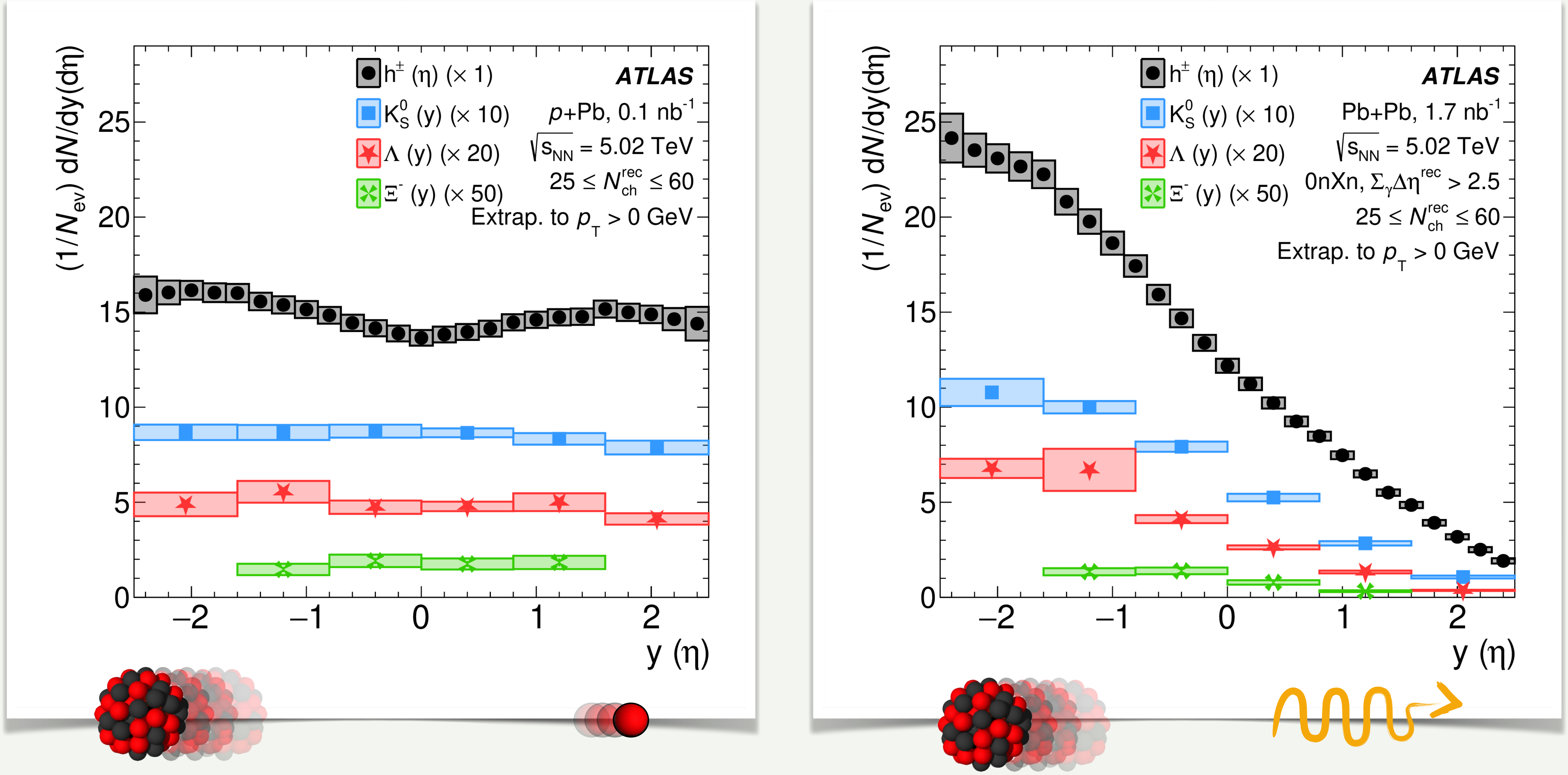


Same model predicts ~same radial flow for both systems → same $\langle p_T \rangle$

How γ + Pb and p + Pb compare?

ATLAS EXPERIMENT

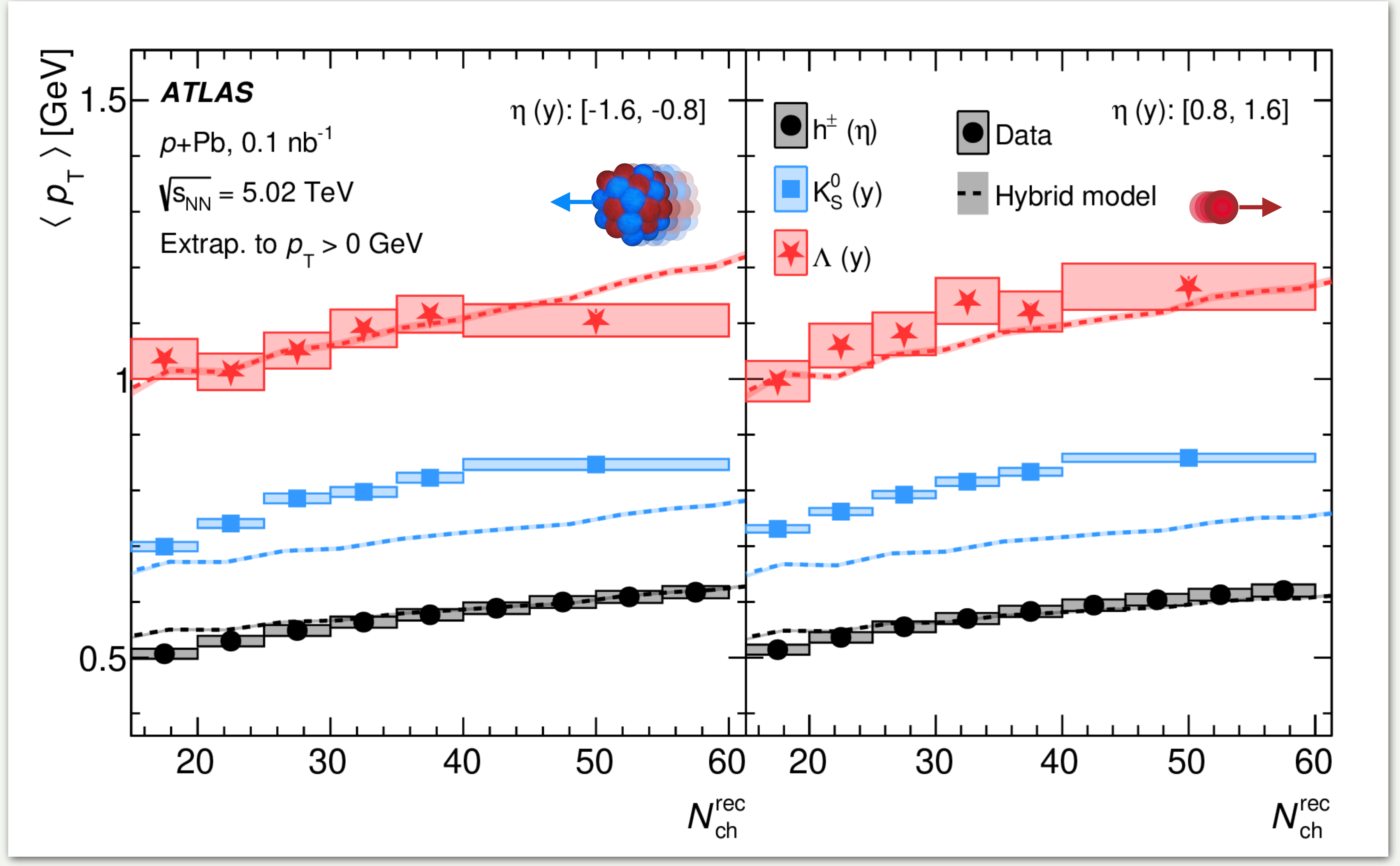
- Analysis in the same multiplicity region for both γ+Pb and p+Pb
- γ+Pb distribution highly asymmetric (E_γ << energy per nucleon in the Pb)
- p+Pb distribution nearly simmetric

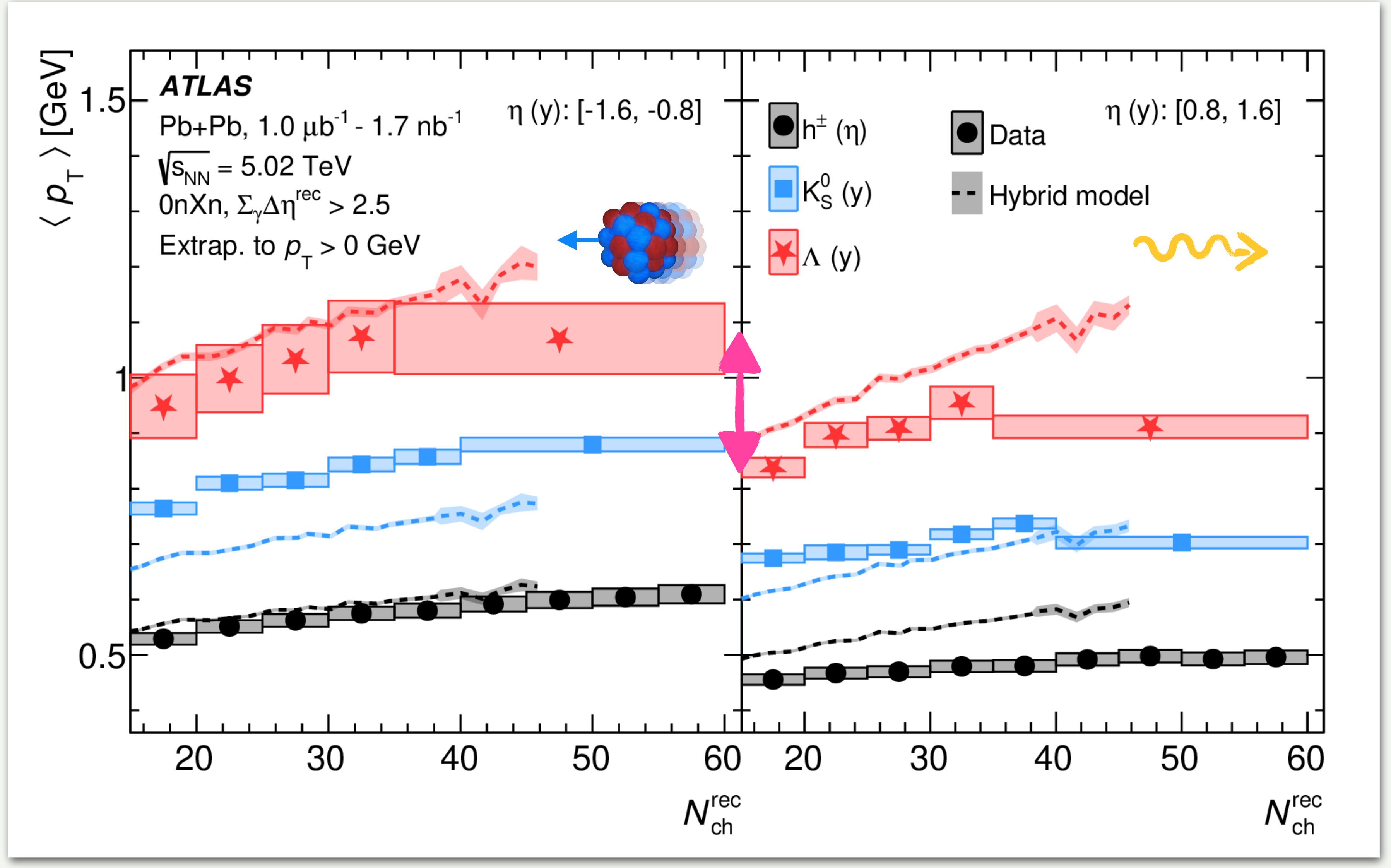


Phys. Rev. C 111 (2025) 064908

How $\gamma + \mathrm{Pb}$ and $p + \mathrm{Pb}$ compare?

- Larger radial flow, Λ/K_S^0 ratio and strangeness enhancement in Pb-going direction for γ+Pb events
- Similar magnitude of QGP-like signals in Pb-going direction in p+Pb and γ+Pb → γ+Pb are dominated by resolved photon collisions (hadronic)





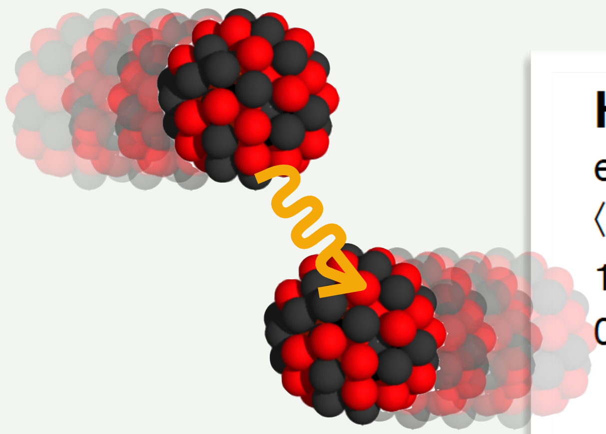
Phys. Rev. C 111 (2025) 064908

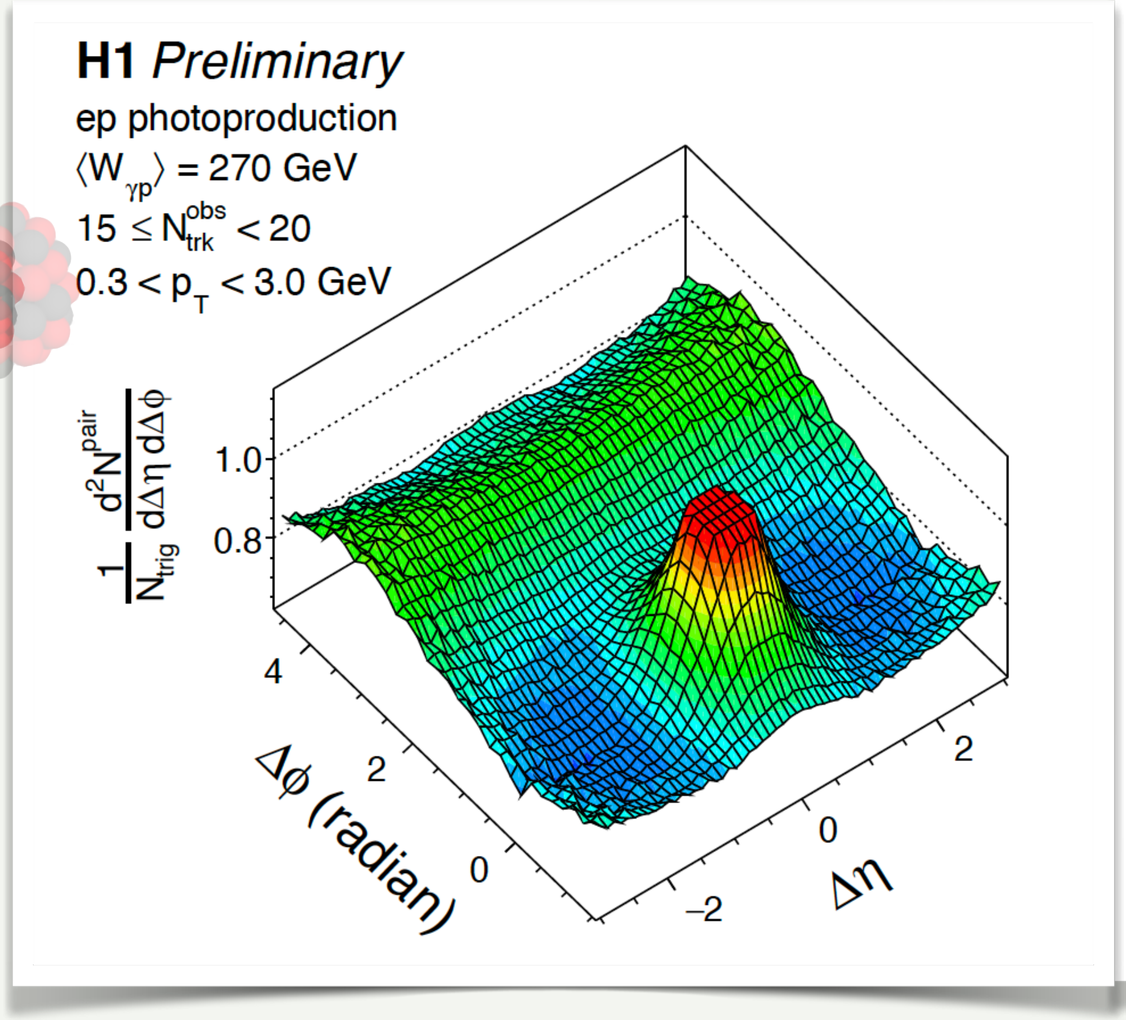
Collectivity onset - the EIC contribution

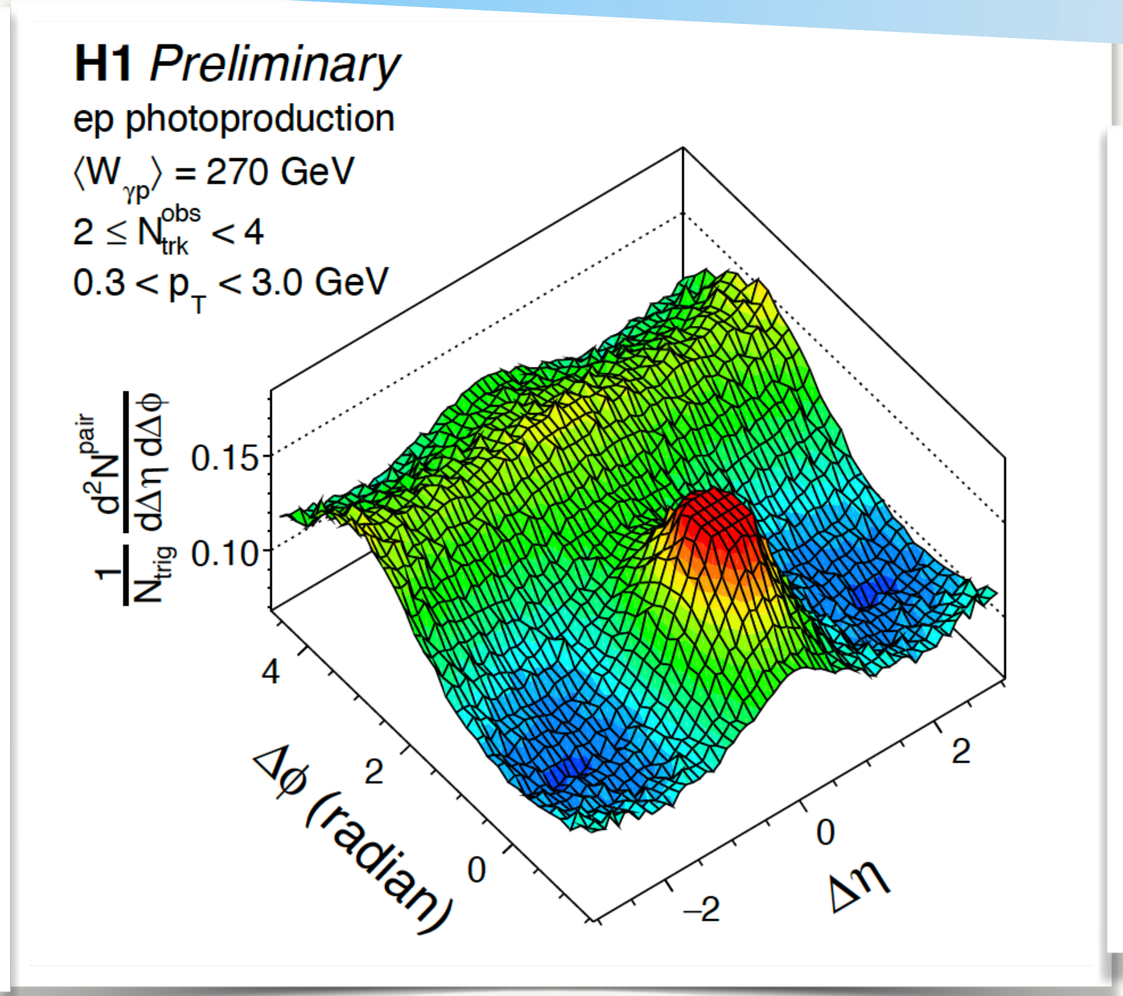
ATLAS EXPERIMENT

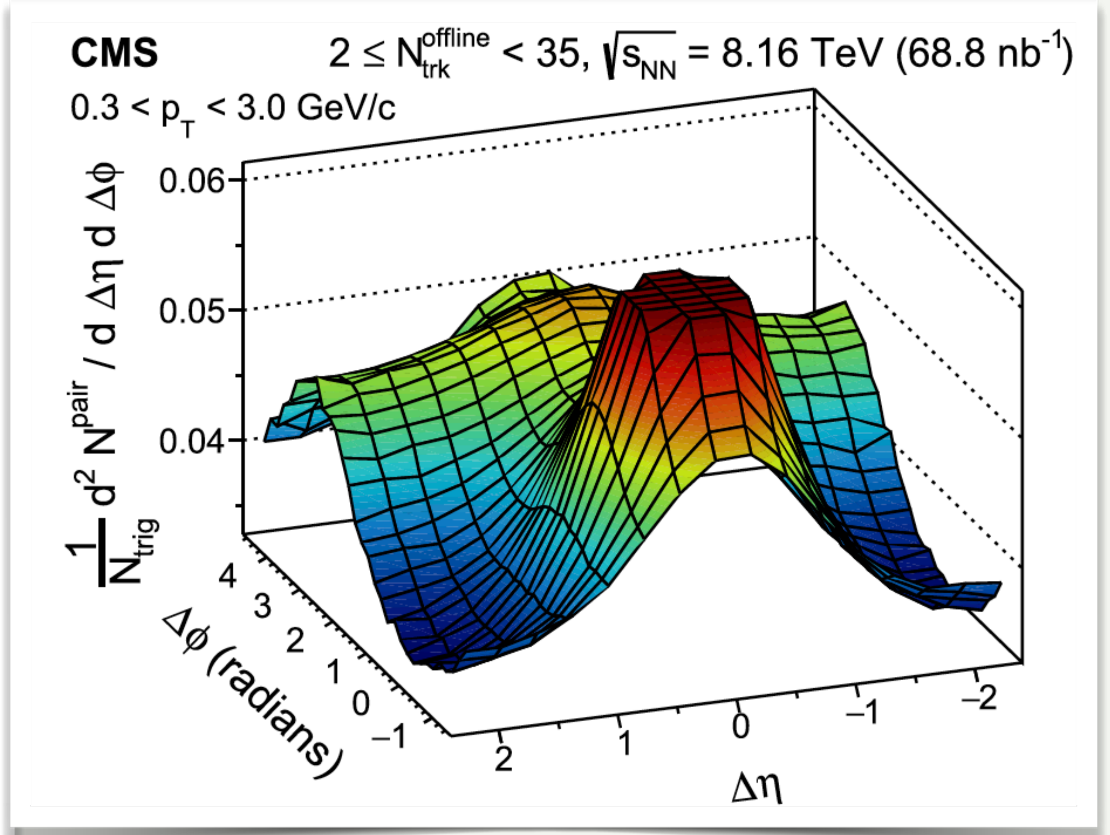
Lately, several searches in smaller systems were carried out

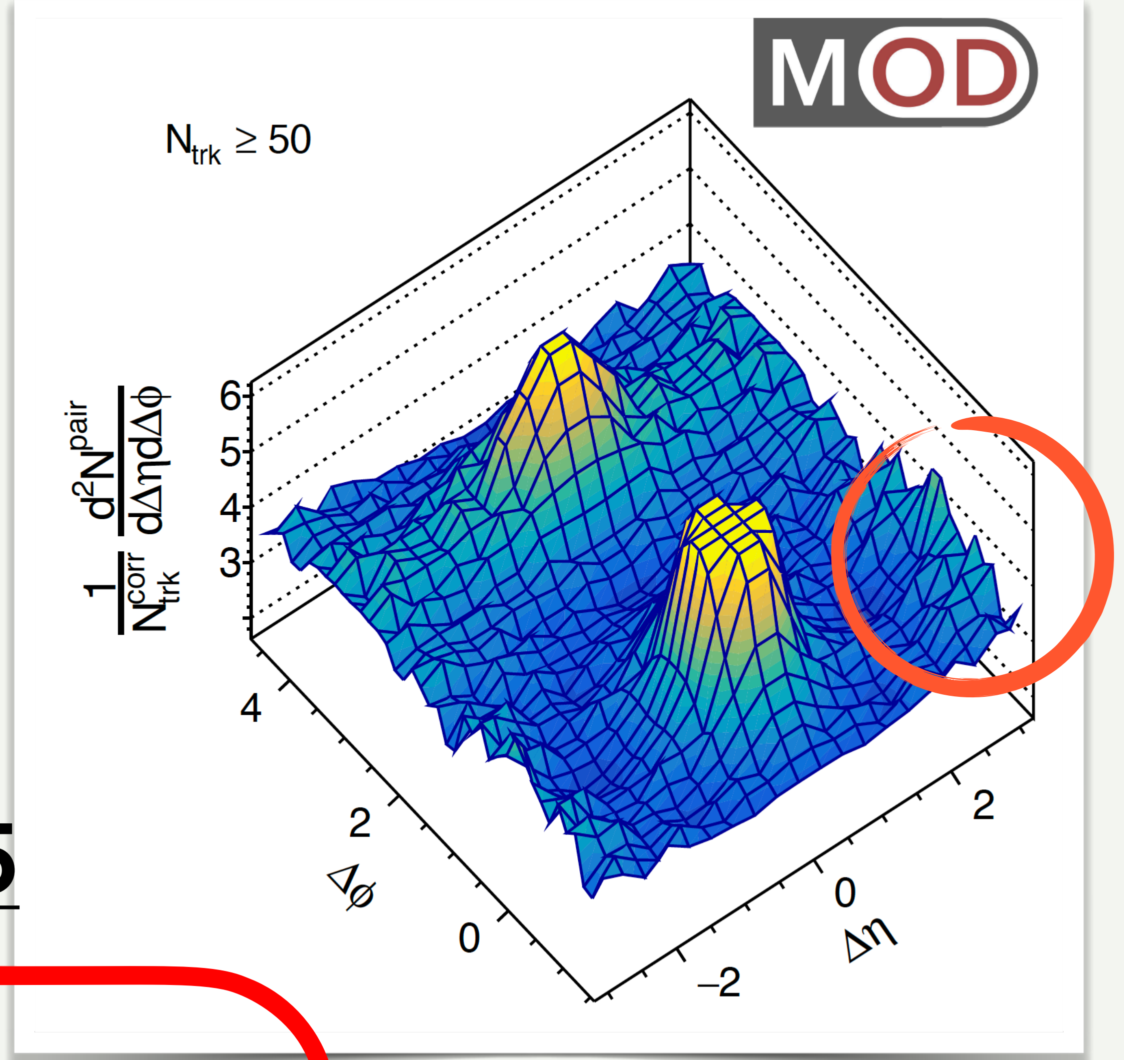
... p+p, γ+Pb — $e^{-}(\gamma^{*})$+p — γ+p — e^{-}+e^{+}







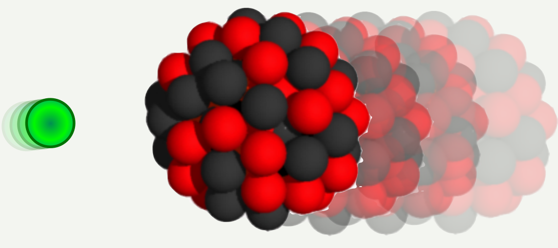




H1 Preliminary

CMS, PLB 844 (2023) 137905

arXiv:2312.05084



WHAT WE WILL FIND IN $e^{-}+p/A$ AT EPIC ?
ANOTHER PIECE TO COMPLETE THE PUZZLE
(OR EXPAND IT...)

ePIC