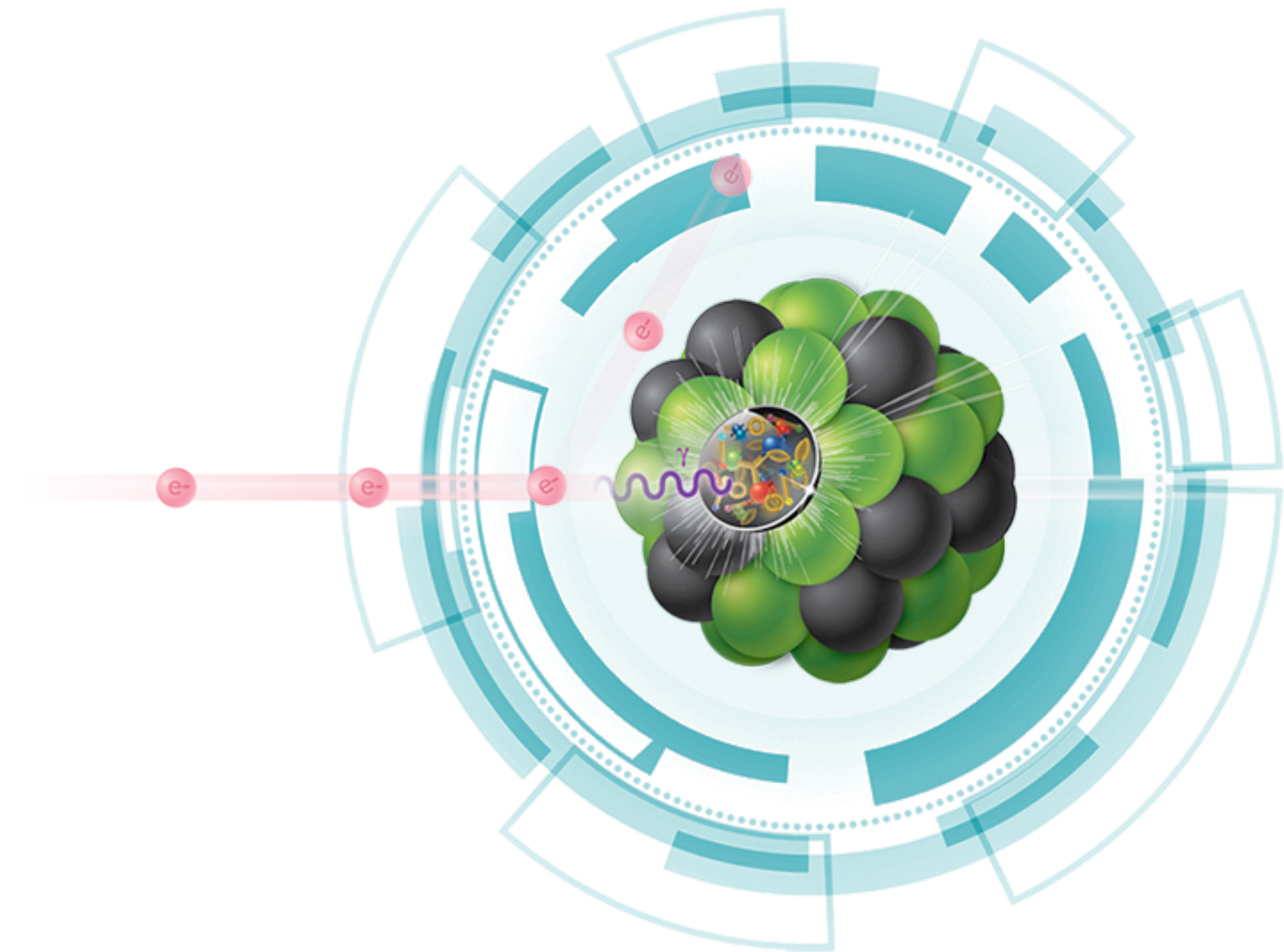
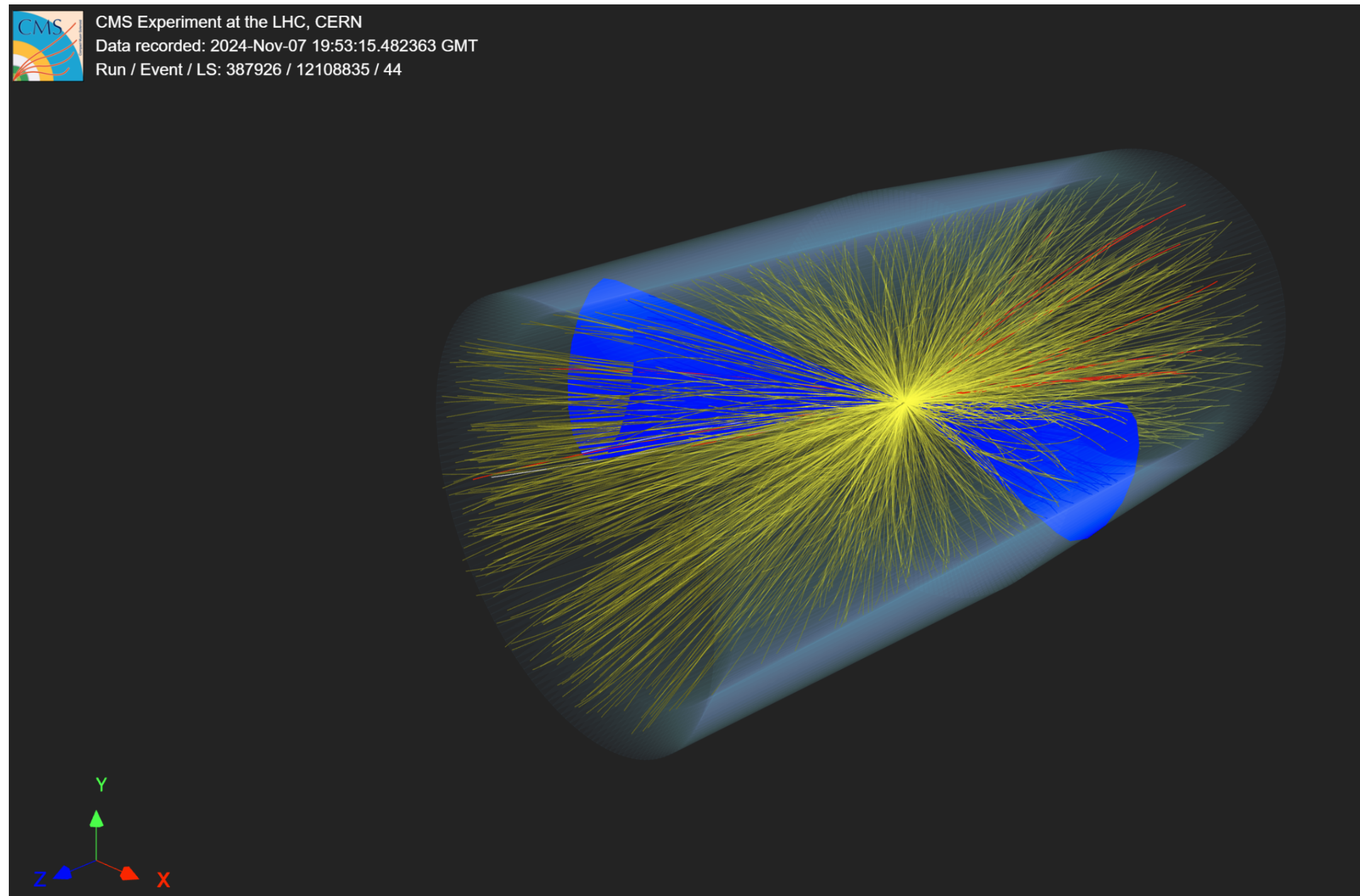


Heavy-ions with CMS @ the LHC

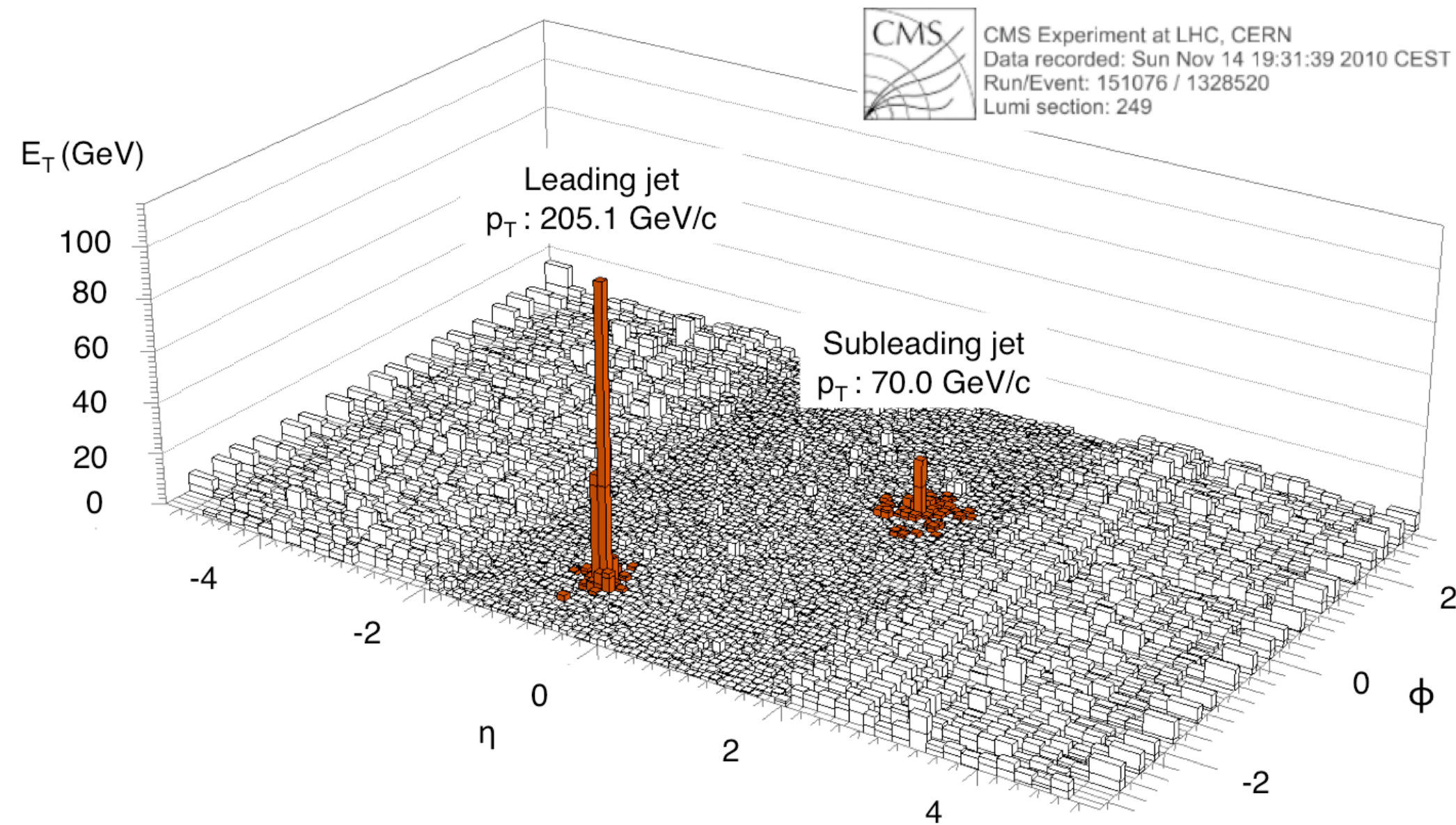
& the future electron-ion collider



Matthew Nguyen, LLR-Tourniquet, November 18th, 2024

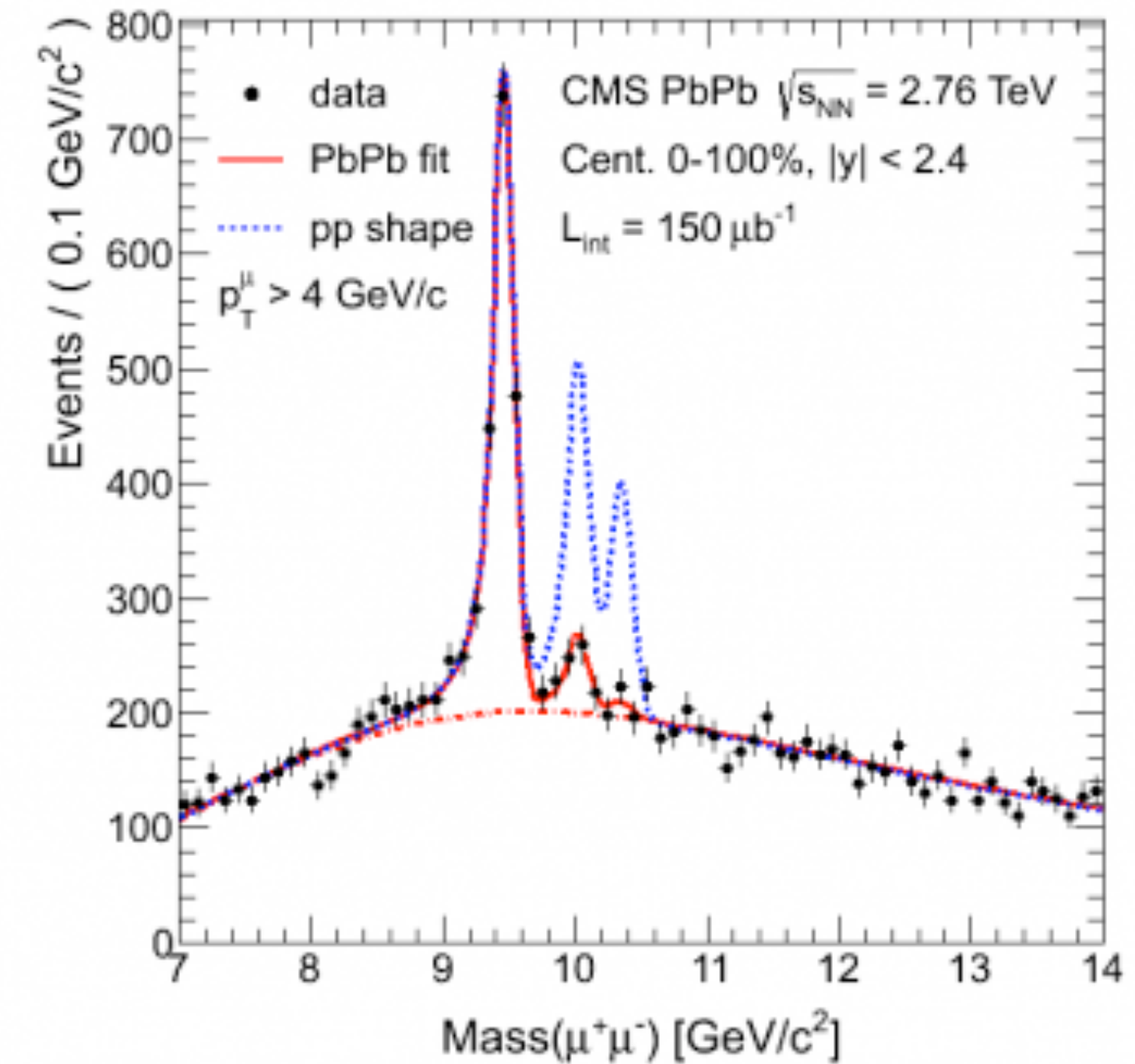
Heavy ions with CMS

Two pillars of the CMS heavy-ion program at LLR



Jet quenching

<https://cms.cern/news/jet-quenching-observed-cms-heavy-ion-collisions>



Quarkonium dissociation

<https://cms.cern/news/cms-observes-hints-melting-epsilon-particles-lead-nuclei-collisions>

Group composition & evolution

- As of today: 1 senior + 2 postdocs + 1 PhD student
- ▶ Arriving in 2025: Postdoc (lab), PhD (IN2P3), pending Marie Curie fellow

Last few years only:

Matthew Nguyen

Raphael Granier (< 2024)

Leticia Cunqueiro (2021-2022)

Cristian Baldenegro (2021-2023)

Florian Damas (2021-2024)

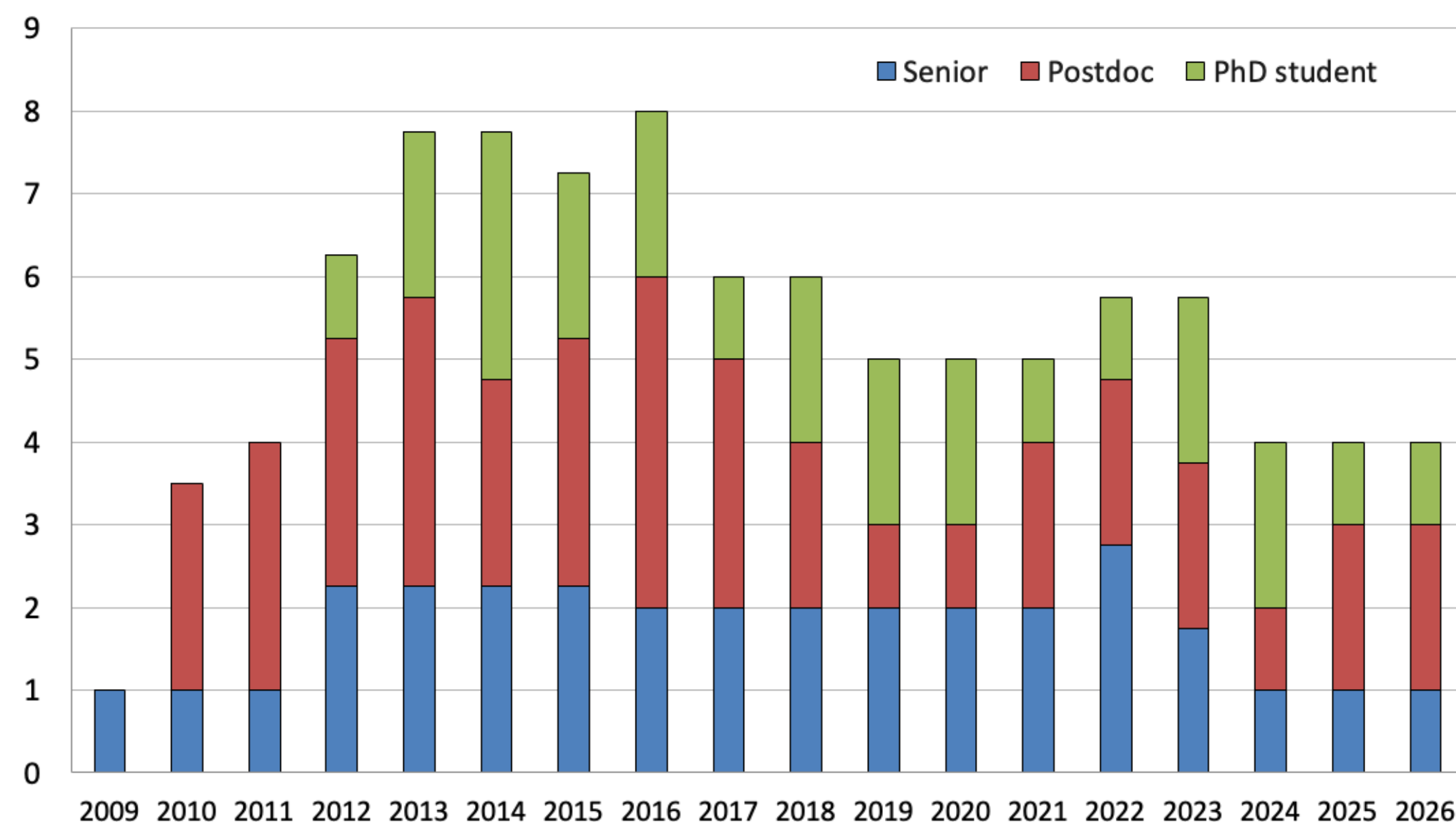
Postdoc (2024-2026)

Bharad Harikrishnan (2021-2024)

Lida Kalipoliti (2020-2025)

PhD Student (2025-2027)

- Historically supported by ext. grants
- ▶ No new permanent staff since 2011



ERC

ANR

ERC

NB: Also 5 Marie Curie fellows

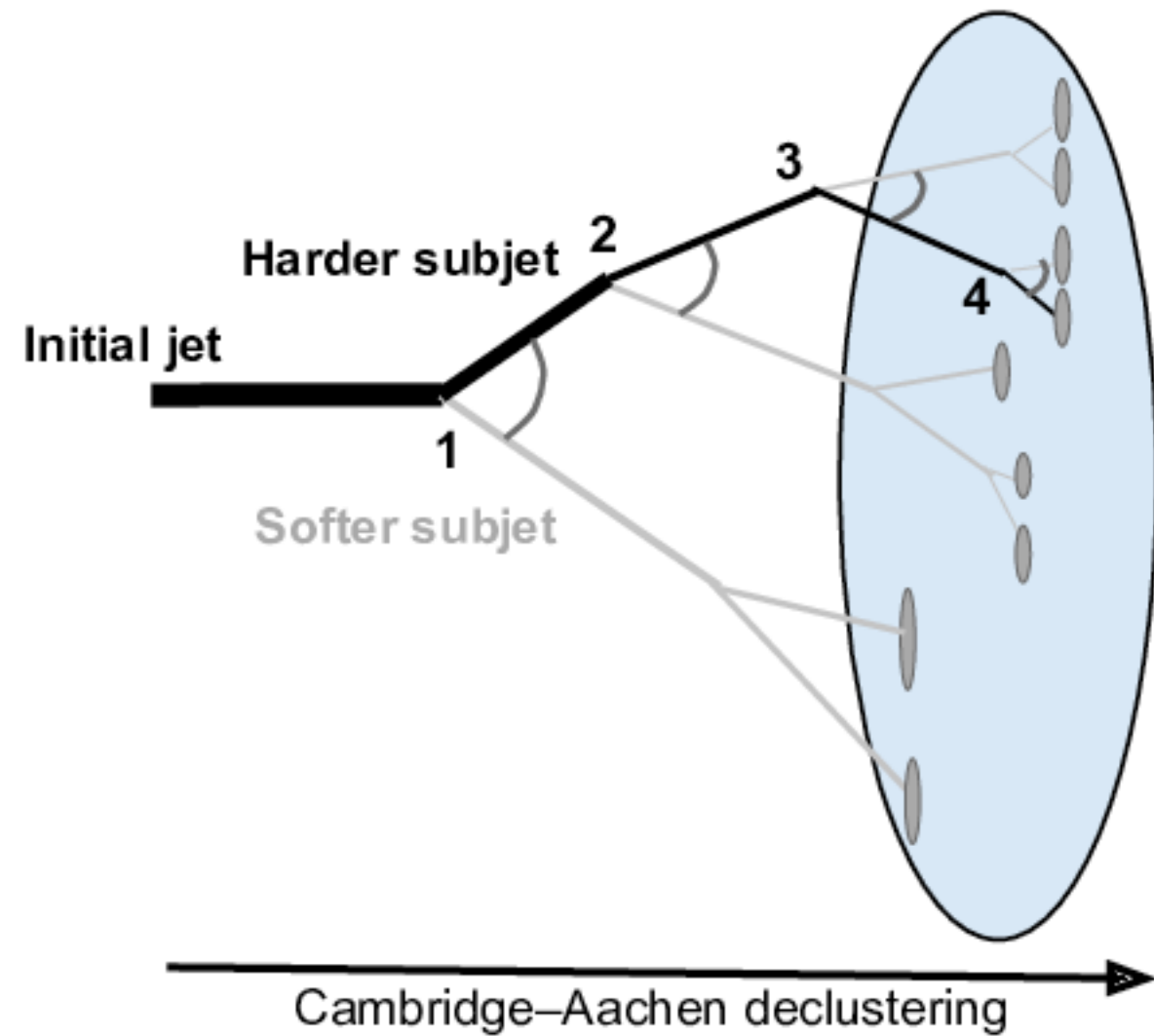
Responsibilities within CMS

- Matthew Nguyen:
 - Coordinator of CMS heavy-ion program on CMS executive board (since 2019)
 - Responsible for CMS computing in France (since 2013)
 - CMS Reconstruction “level-2” convener (L2, 2022-2024)
 - CMS Offline Software Release Manager (L2, 2024-2026)
- Raphael Granier: Heavy-ion Publication Committee Chair (2022-2024)
- Florian Damas: Convener of heavy-ion dilepton group (L3, 2023-2024)
- Cristian Baldenegro: Convener of heavy-ion forward group (L3, 2023-2024)

Previously many convener roles in Heavy-ion PAG,
particularly in dilepton and high p_T group

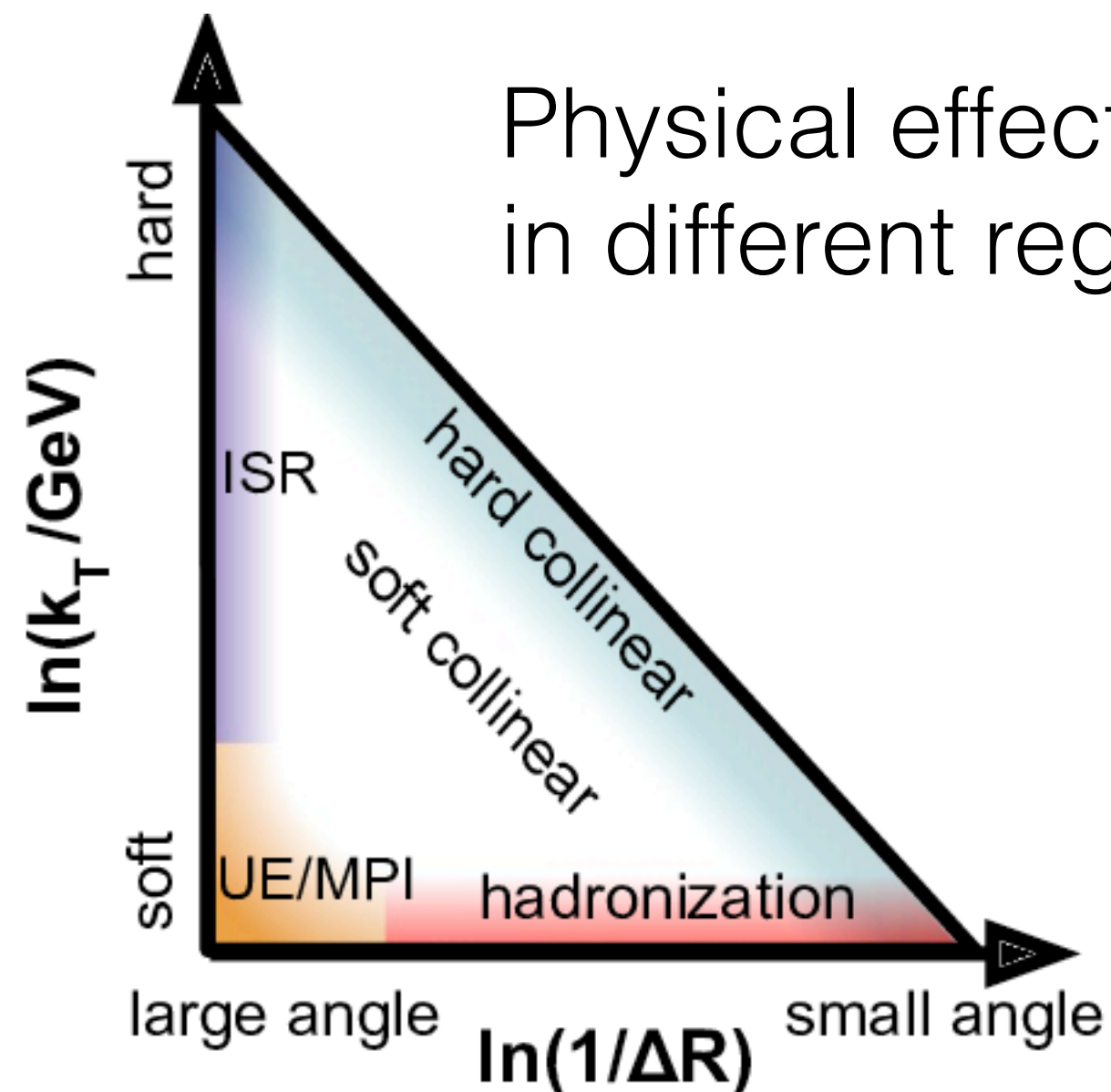
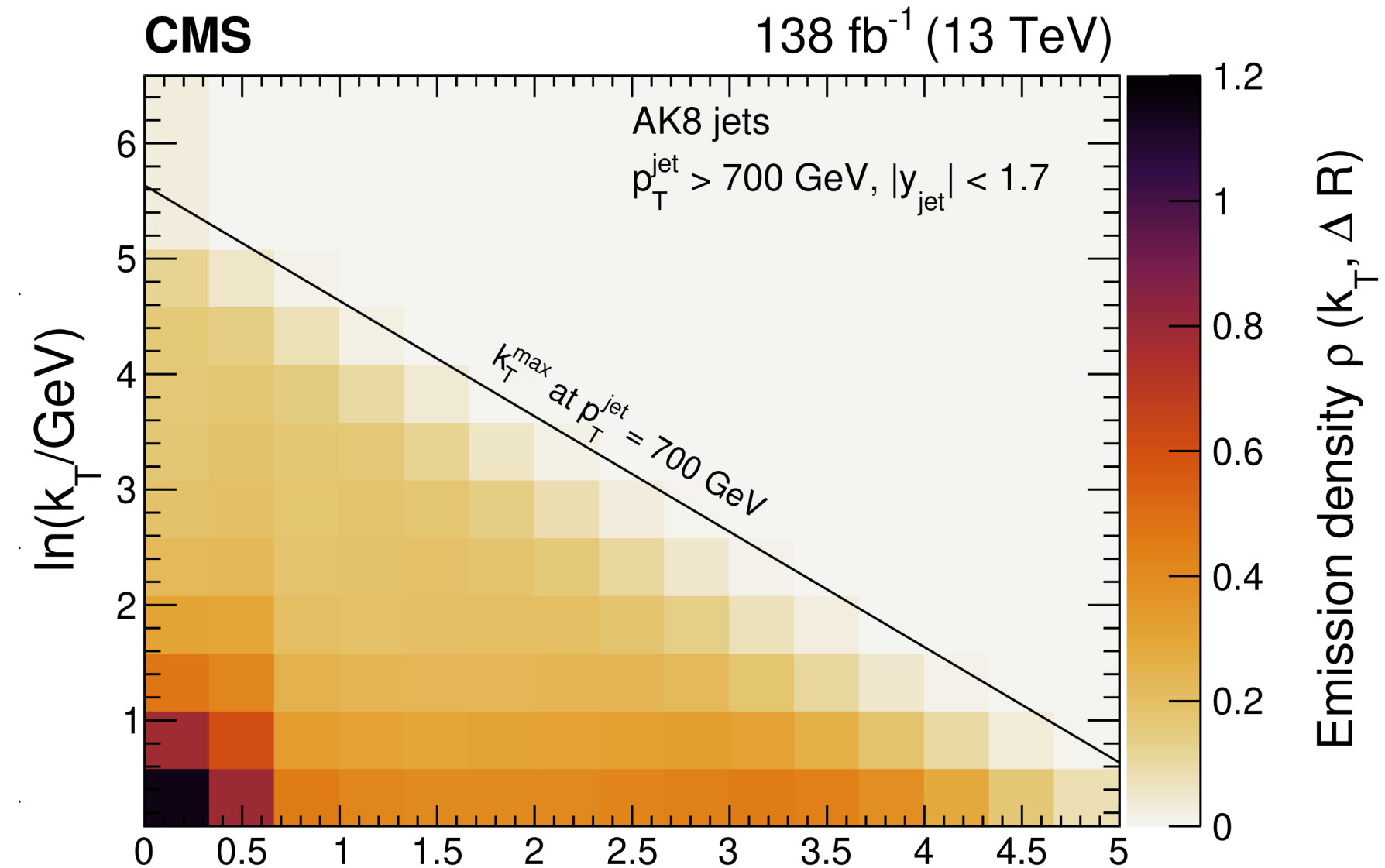
Selected results from the past few years

Primary Lund Jet Plane



Iterative decluttering of jet tree following the hardest prong

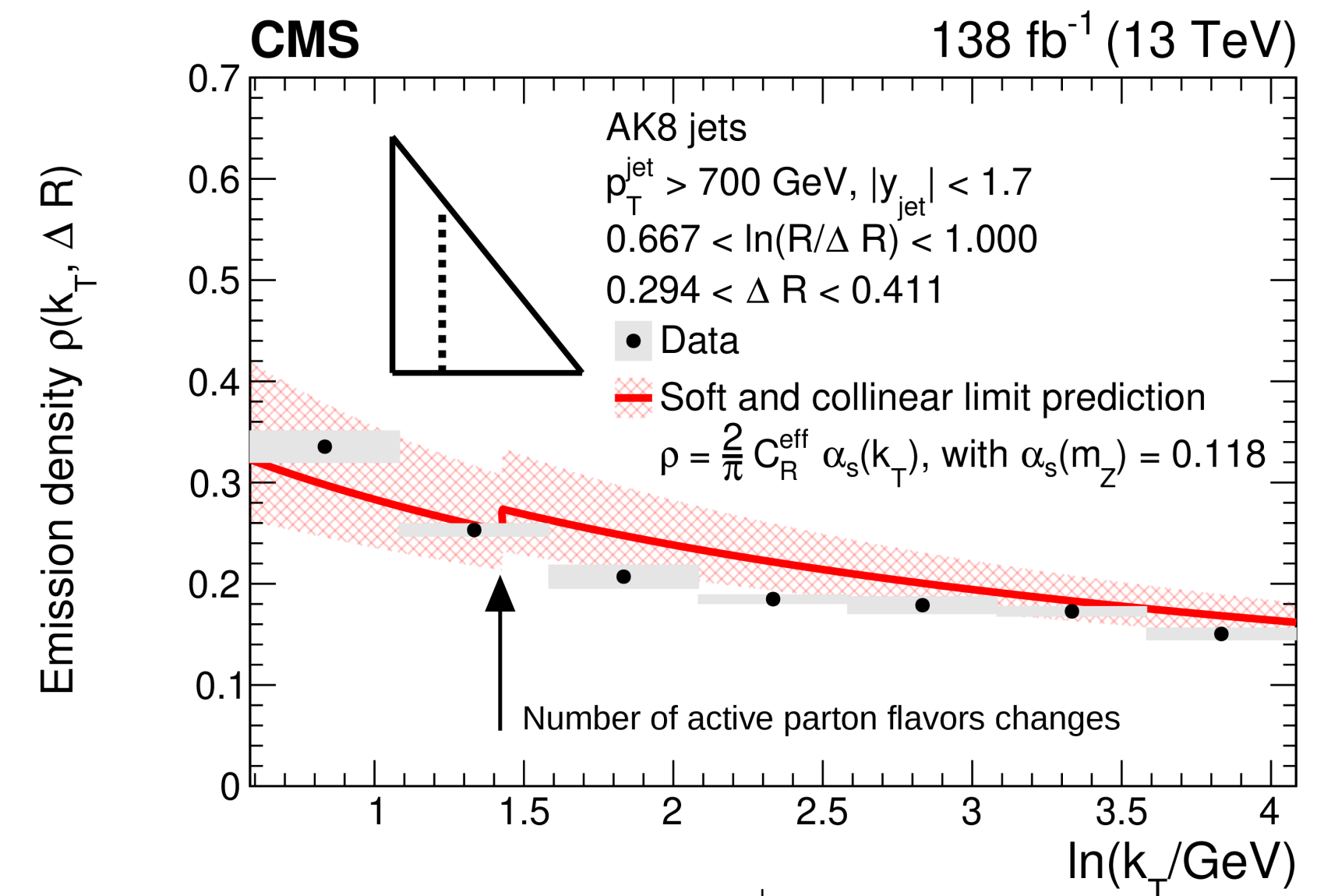
Emission density measured in *Lund jet plane*: k_T vs R



Slices of LJP compared to models, e.g., with different strong coupling

Analysis led by C. Baldenegro
[CMS, JHEP 05 \(2024\) 116](#)

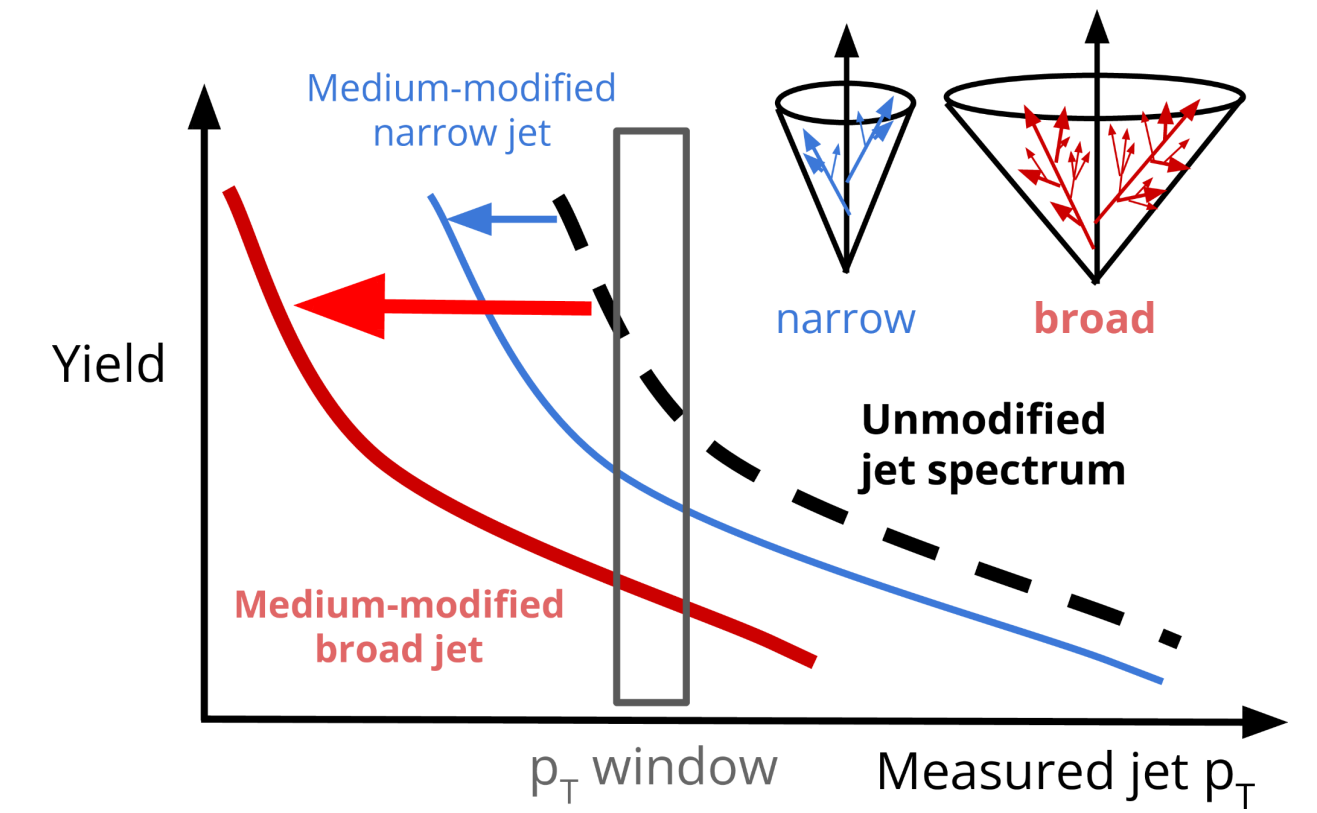
[Lund Jet Plane Institute @ CERN, July 2023](#)



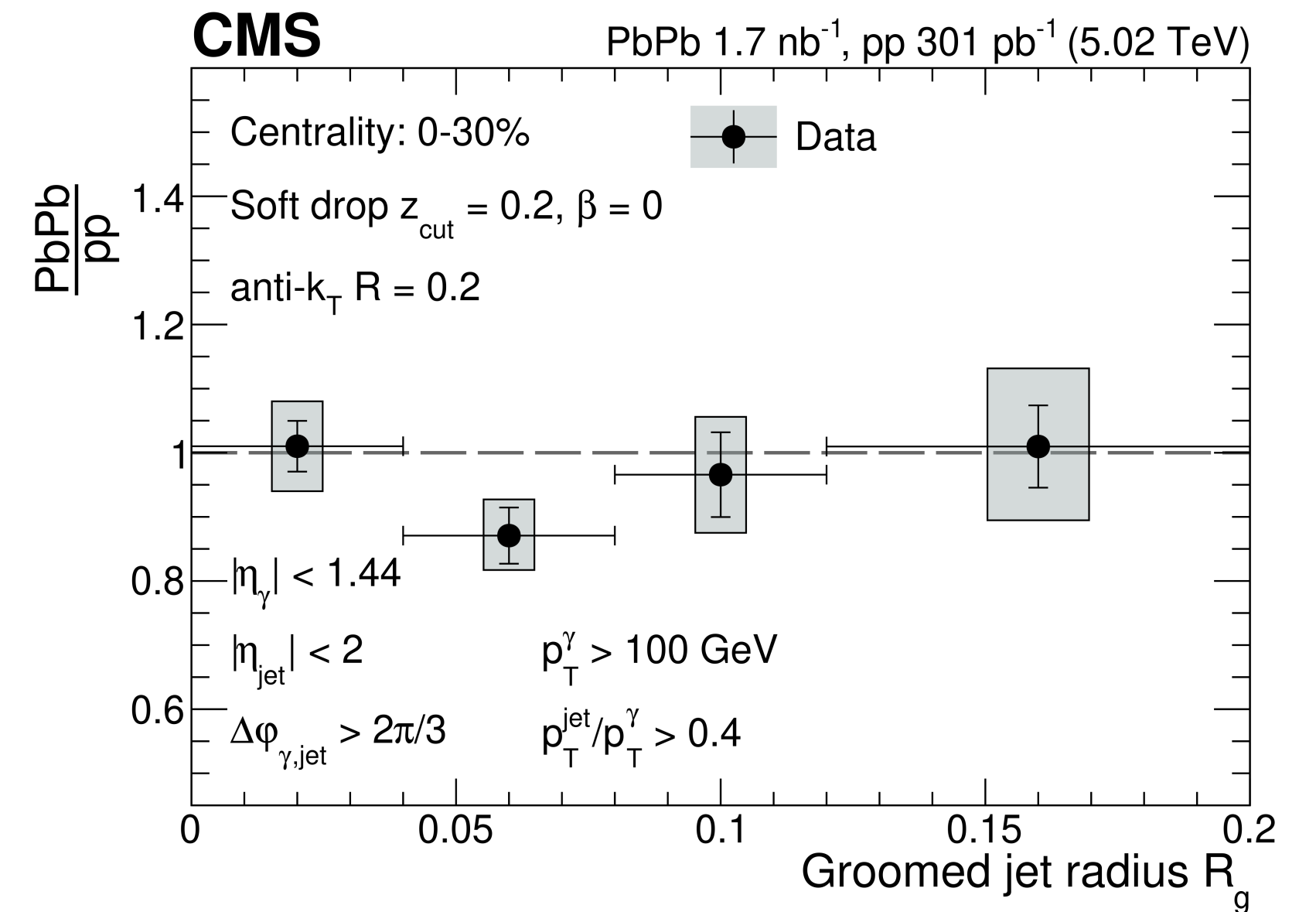
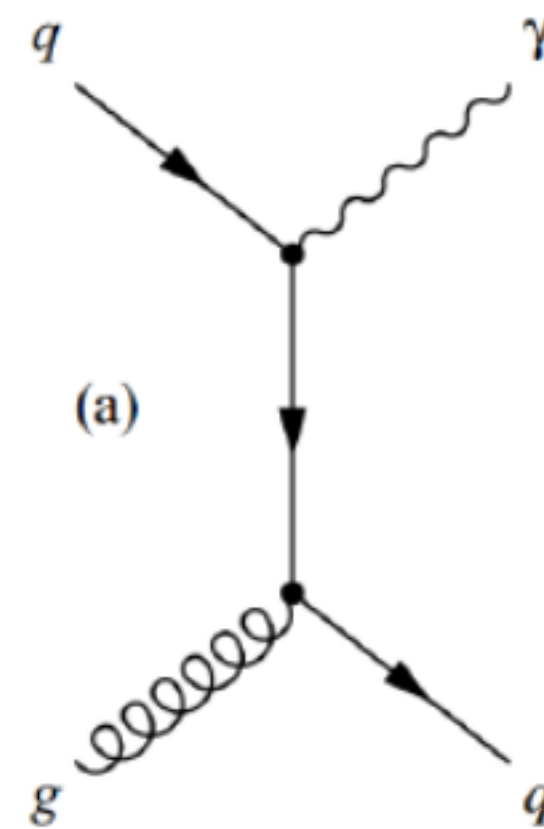
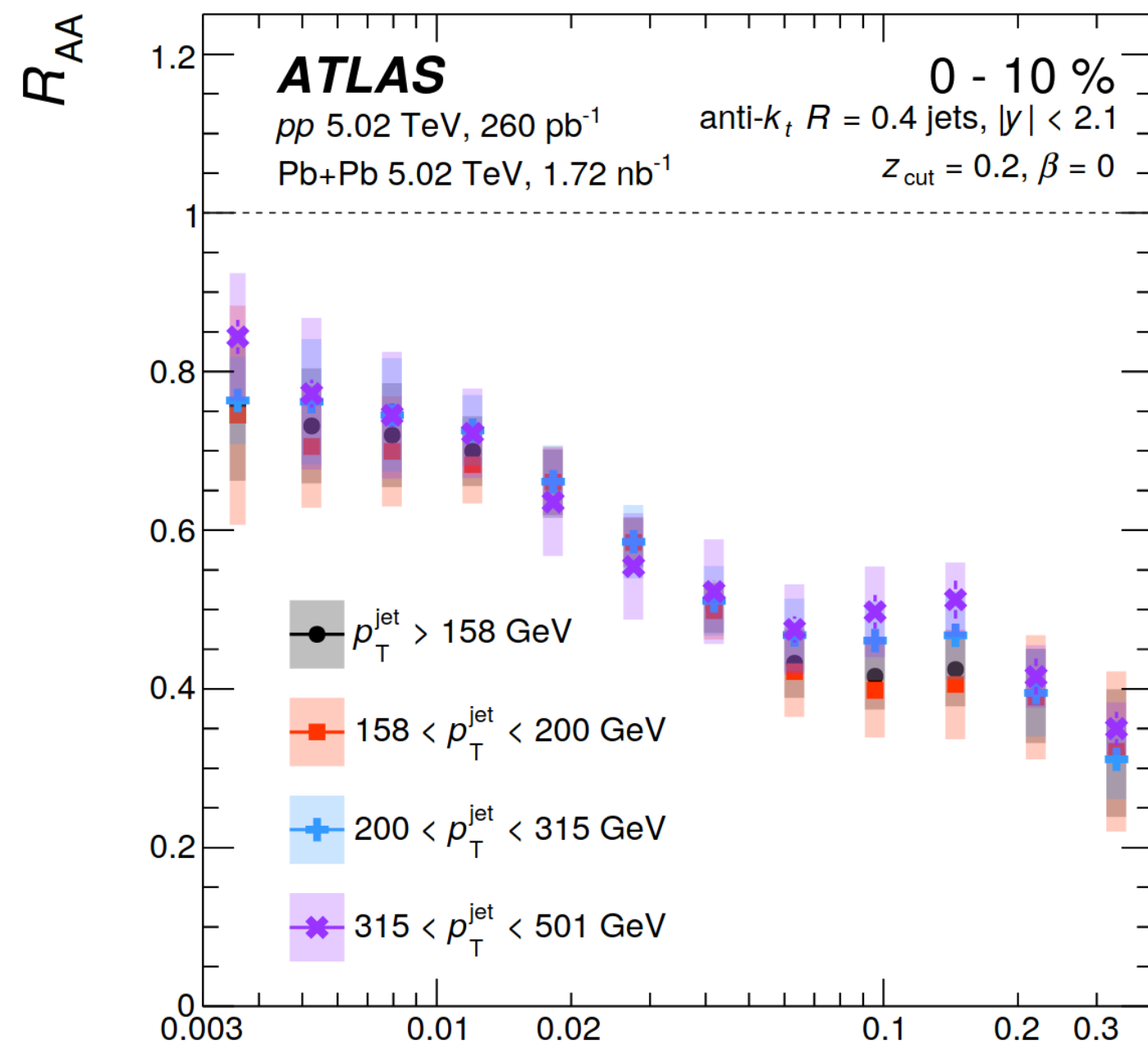
Substructure in photon+jet events

Observed narrowing of jets could be indication of color coherence effects

OTOH one has to be wary of selection biases



γ +jet provides unbiased sample of recoiling jets

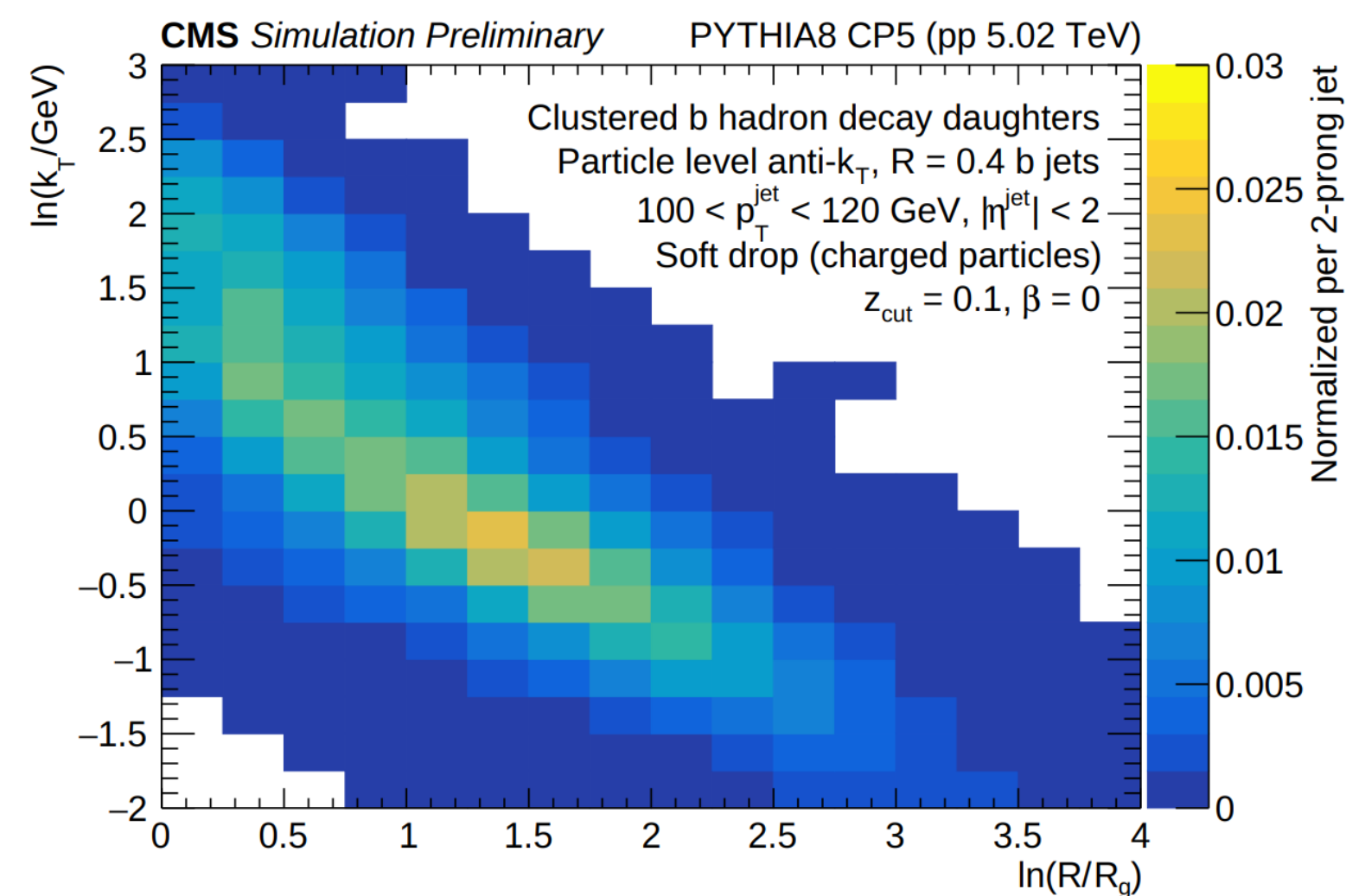
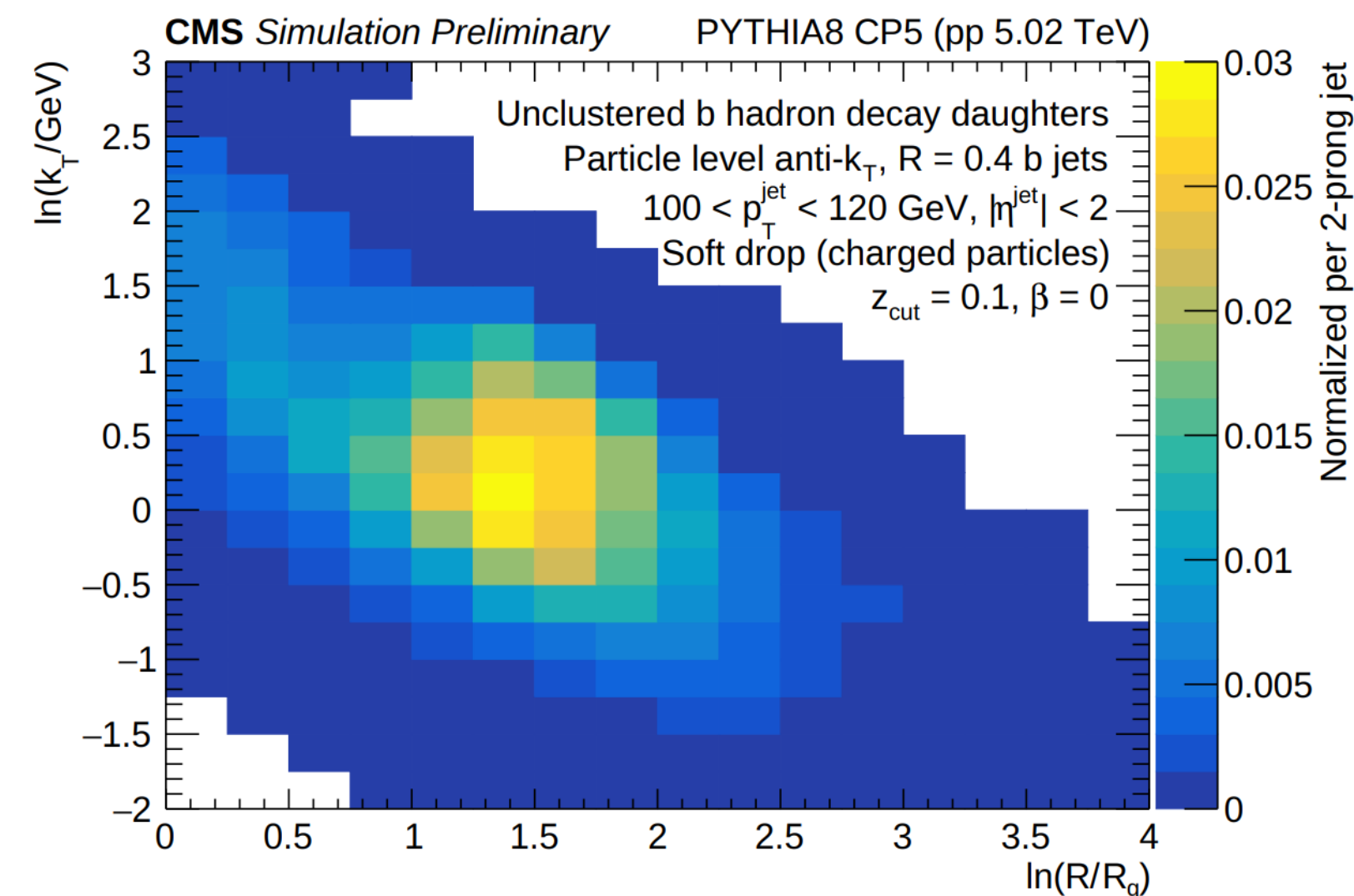
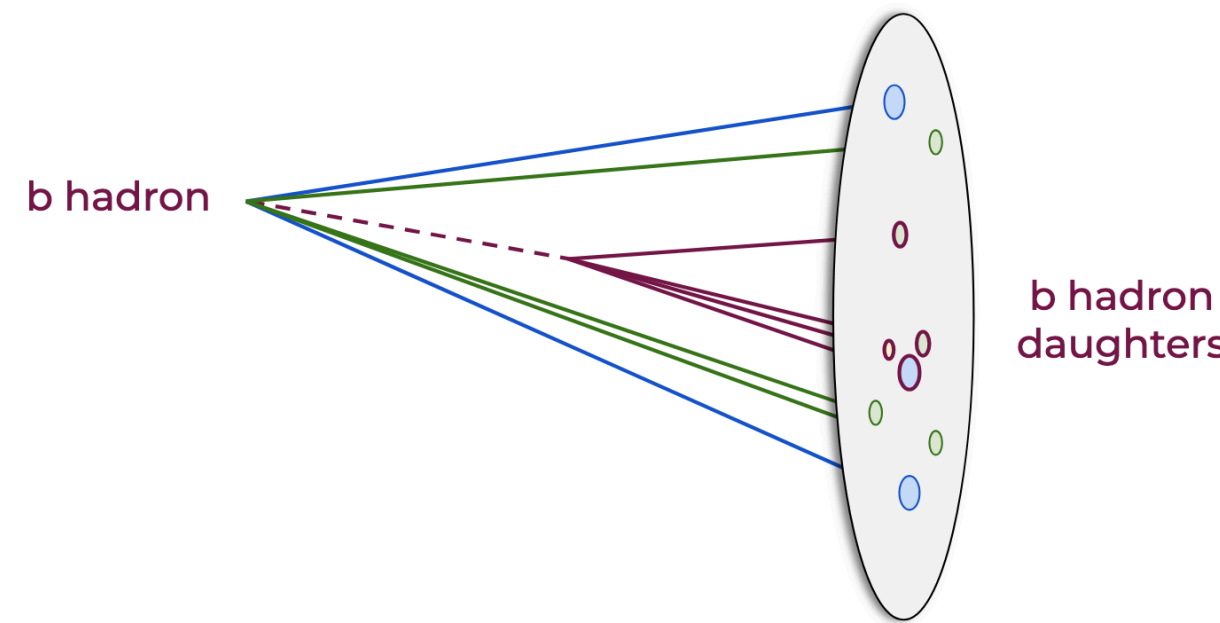


No narrowing in γ +jet

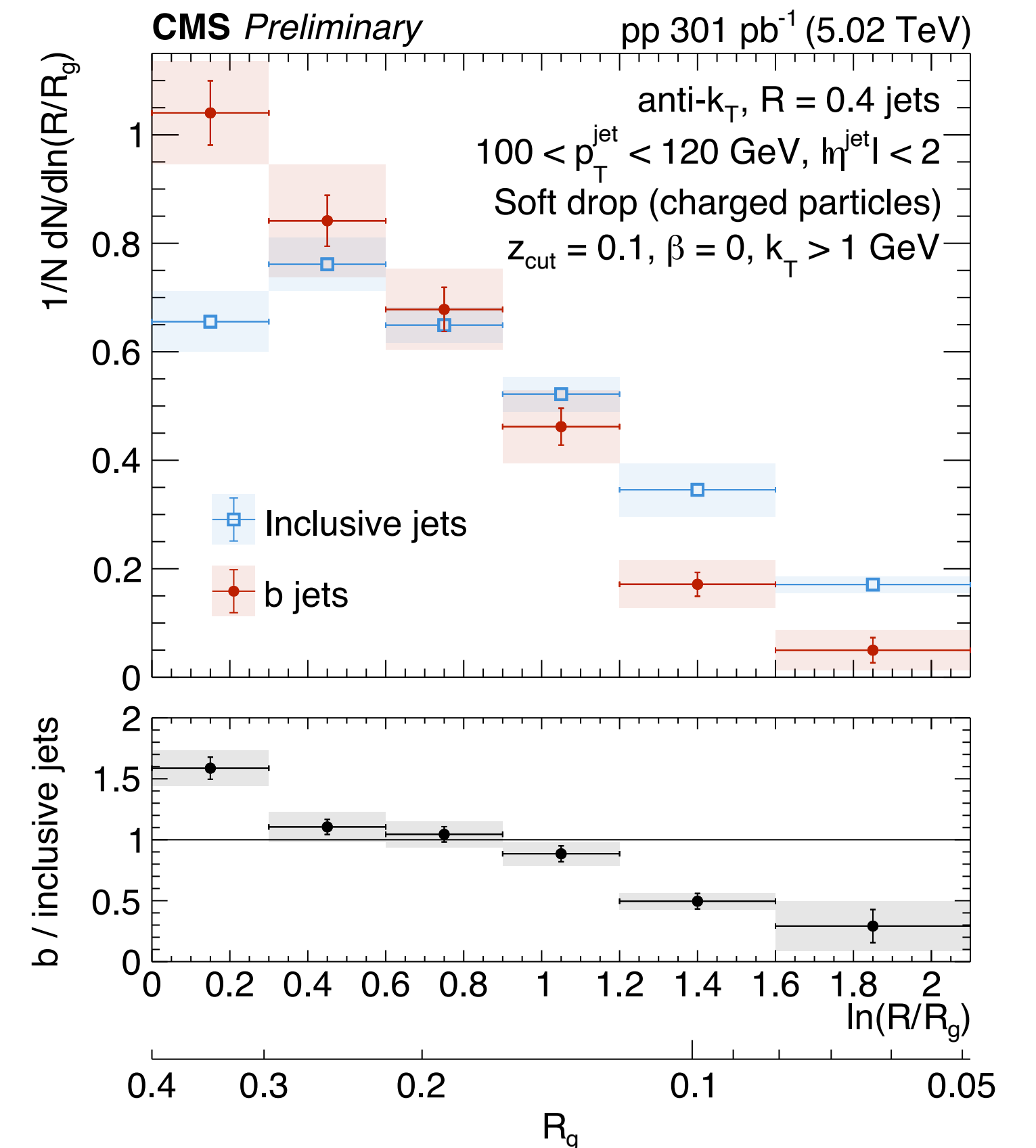
PhD thesis of B. Harikrishnan
[Accepted for publication by PLB](#)

Substructure of heavy quark jets

- Mass & flavor dependence of jet quenching is of fundamental interest
- b-hadron decay kinematics observe parton-level branchings by filling the radiative “dead cone”



PhD thesis of L. Kalipoliti
Preliminary, for submission to JHEP

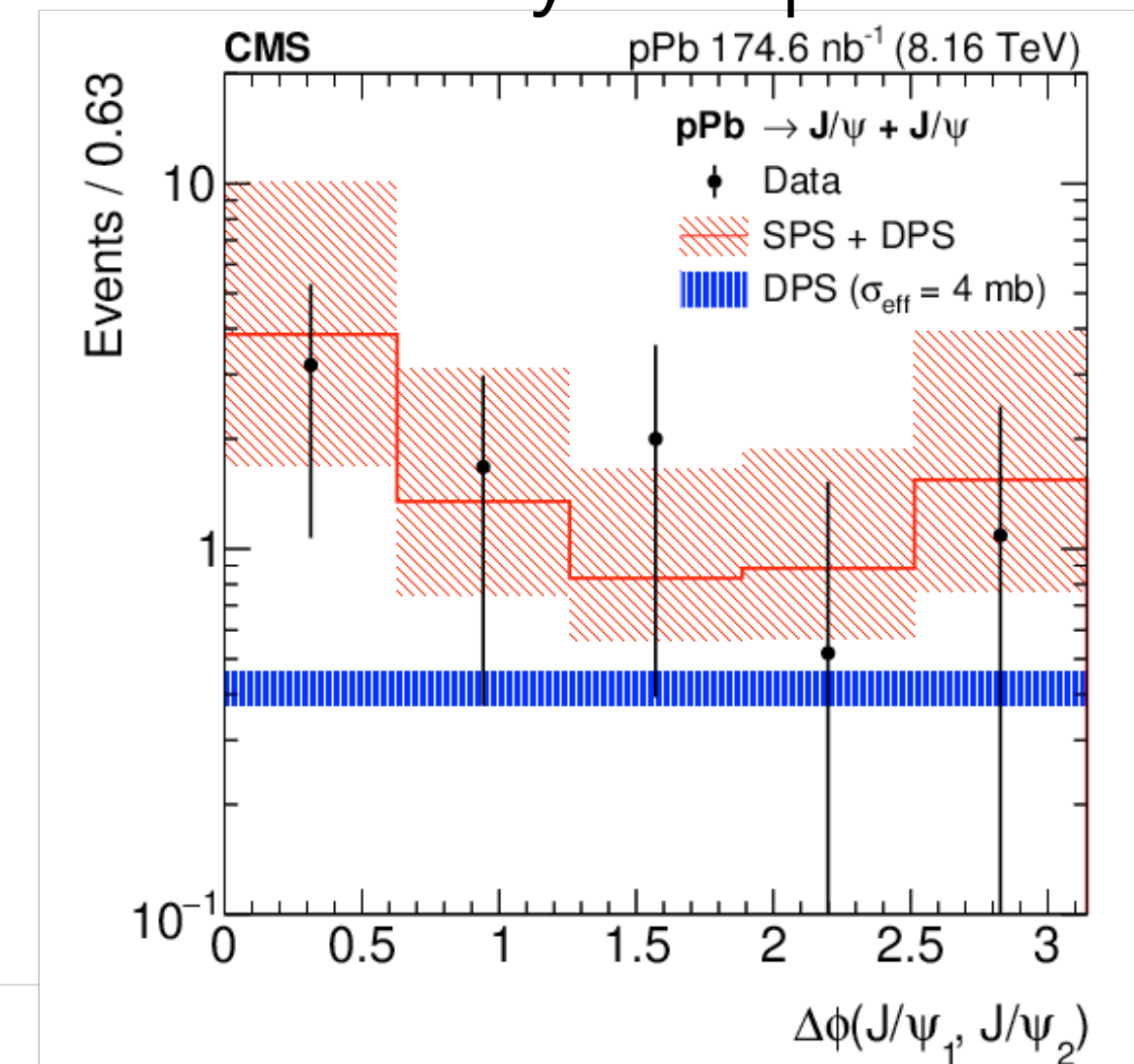
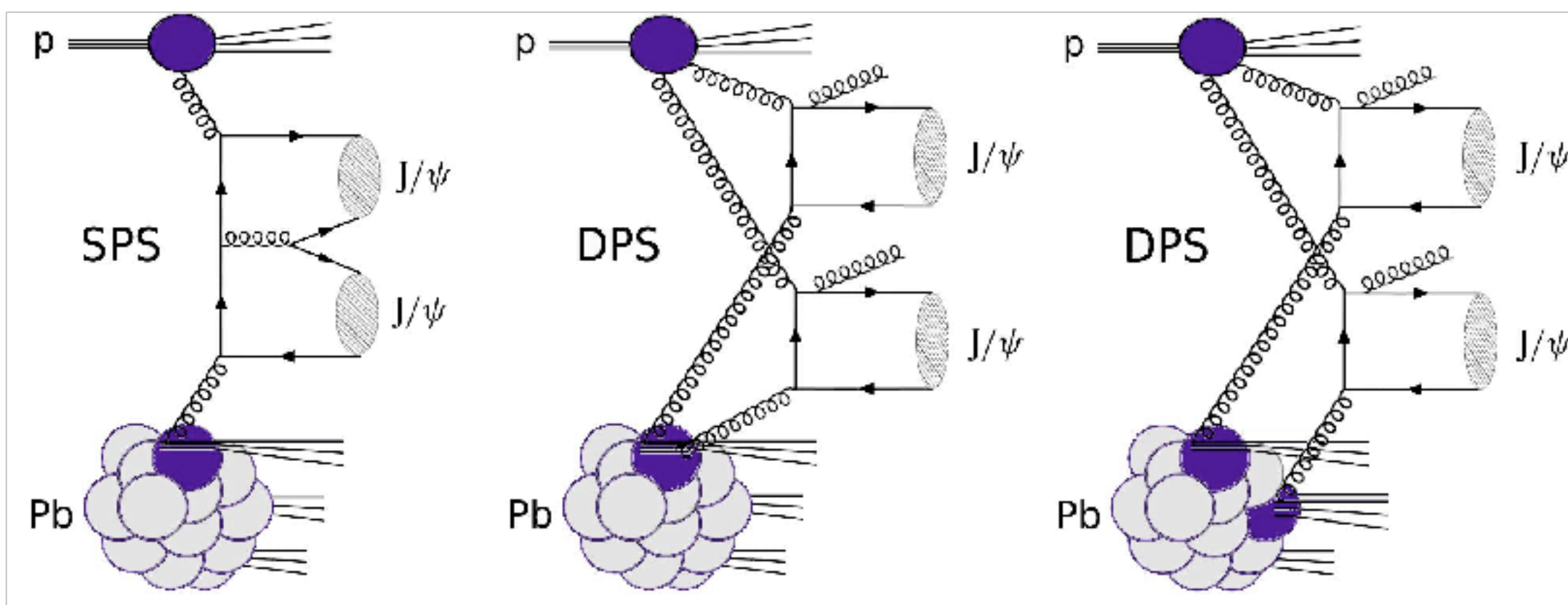


- Dead cone suppression observed
- PbPb measurement in preparation

Double parton scattering in proton-lead collisions

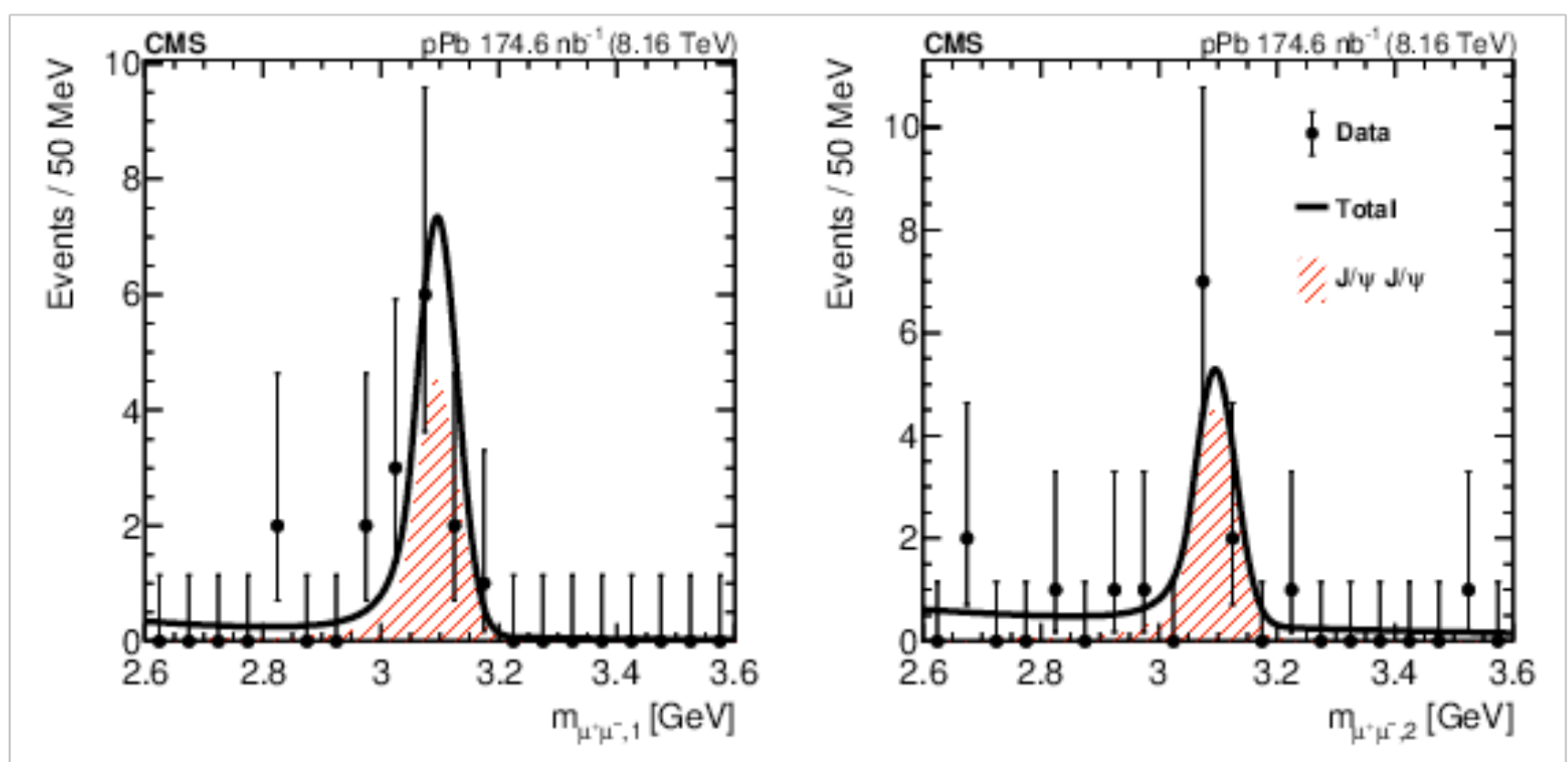
DPS possible from one or two different nucleons in pPb

DPS separated from SPS by template fit

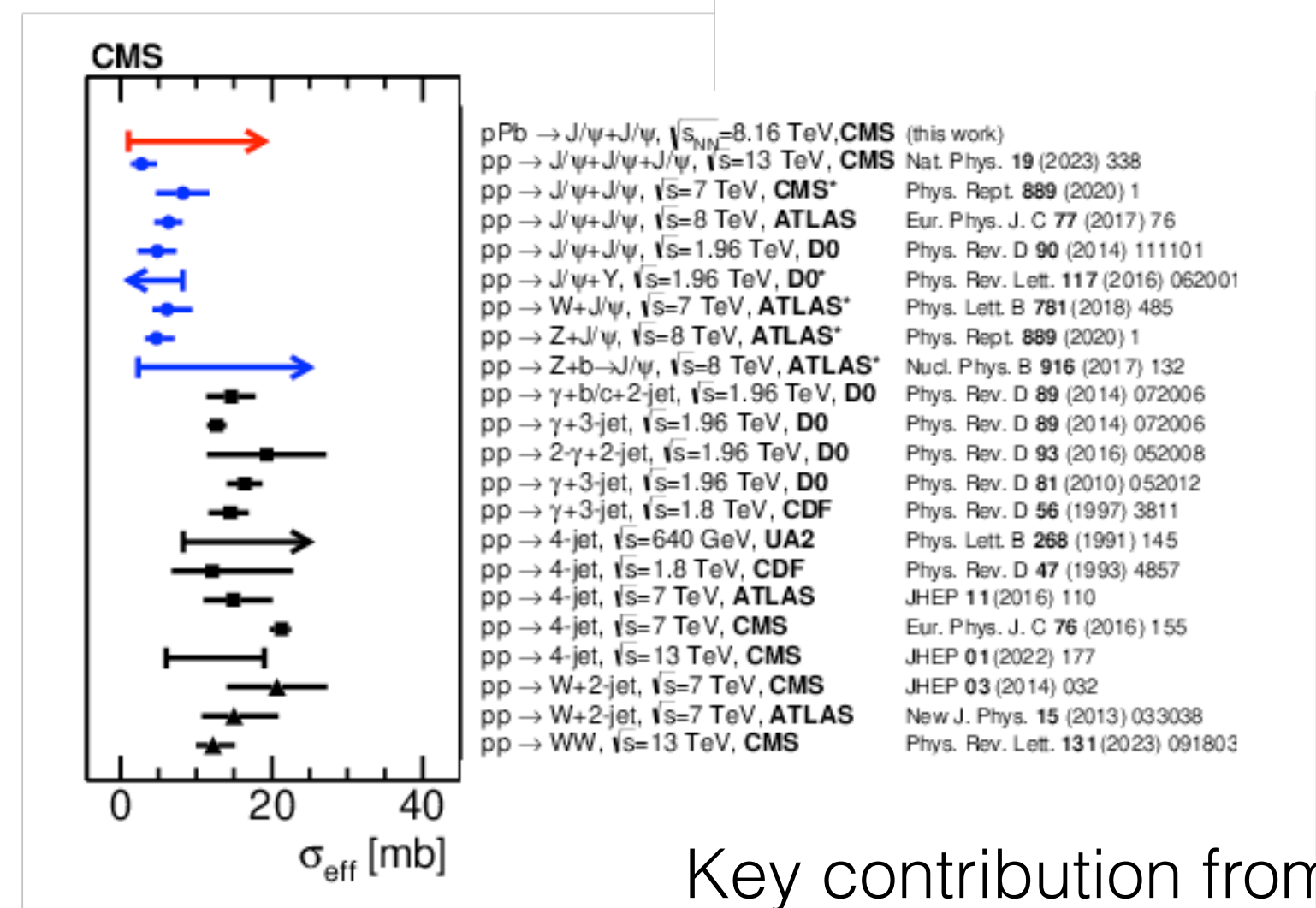


Upper limit placed on DPS x-section

Is DPS modified in pPb collisions compared to pp?



Observation of 5σ of J/Psi pair production

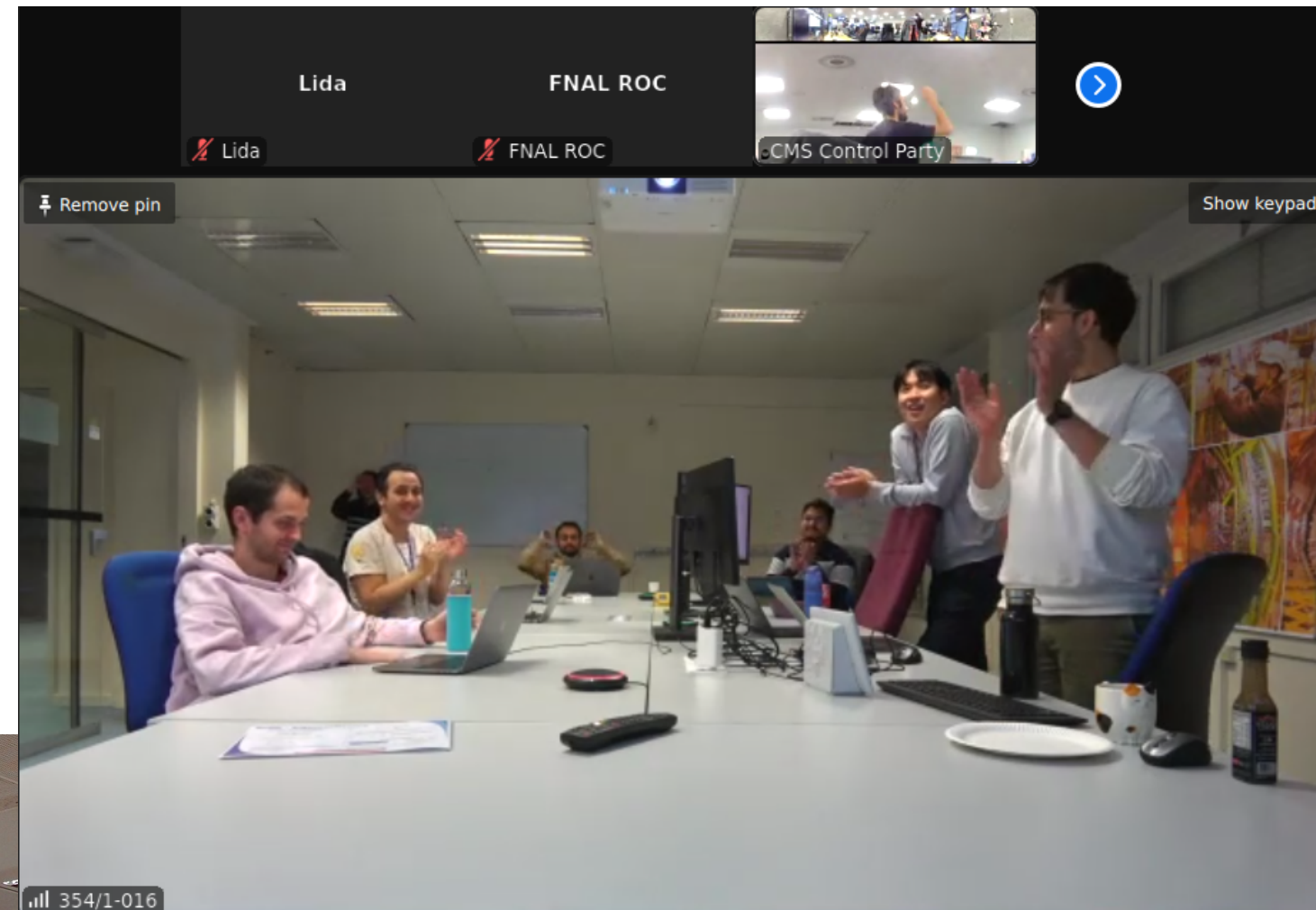


Key contribution from F. Damas
[CMS PRD 110 \(2024\) 092002](https://arxiv.org/abs/2409.2002)

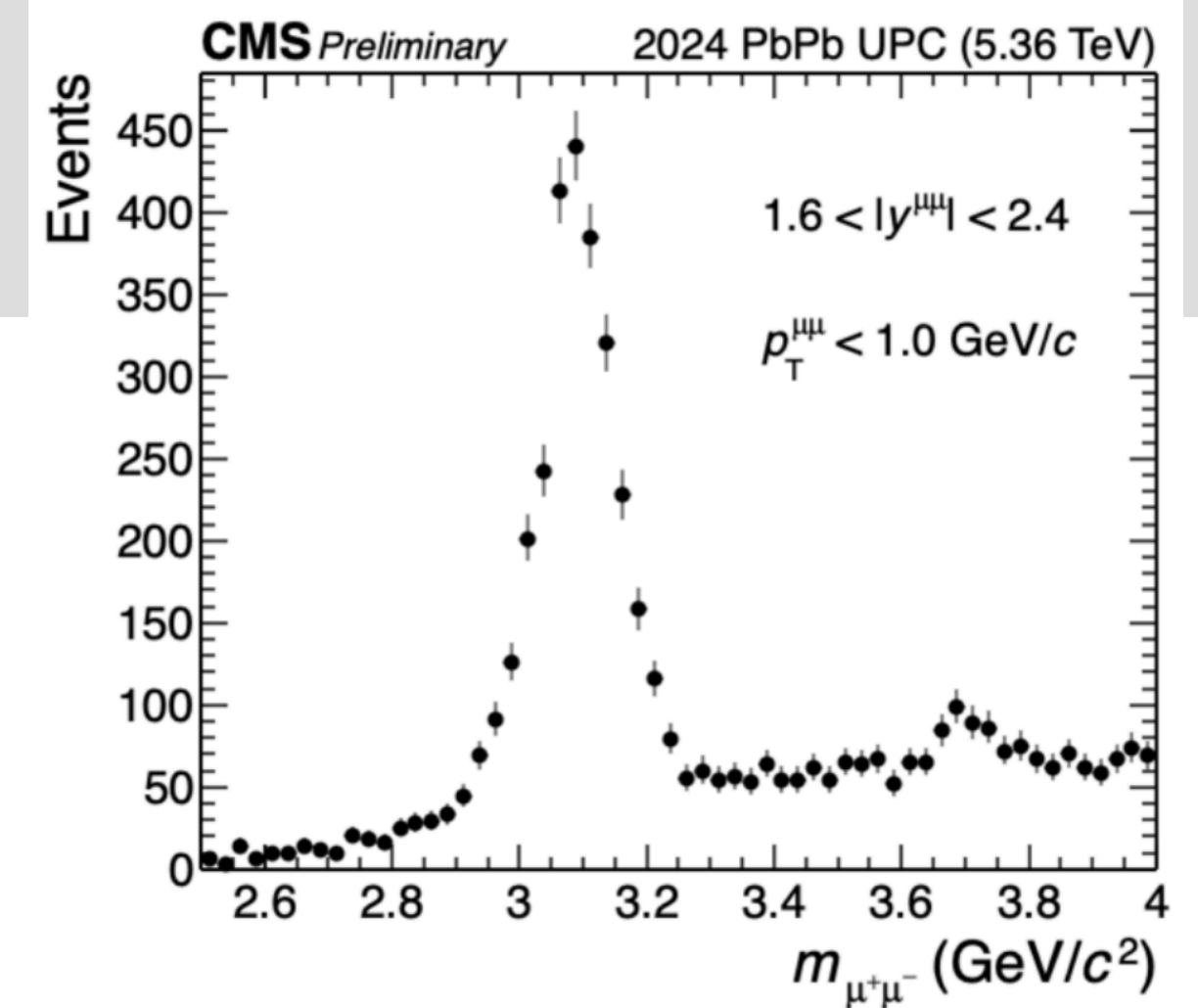
Heavy ions in LHC Run 3

LLR team has important responsibilities during data taking
Run coordination, trigger optimization, shift leader, etc.

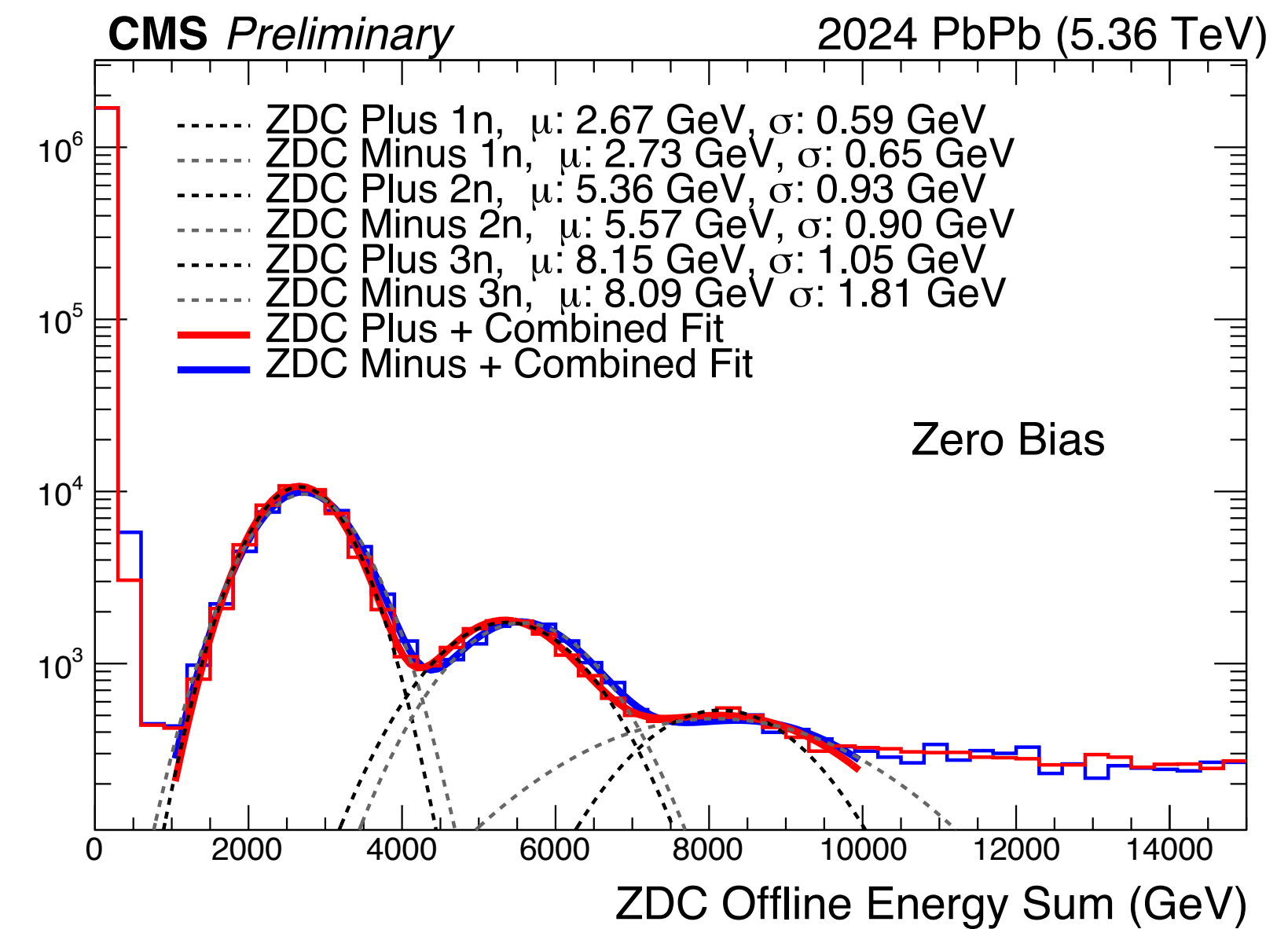
First PbPb collisions in 2024



CMS heavy ion team
in the CMS center



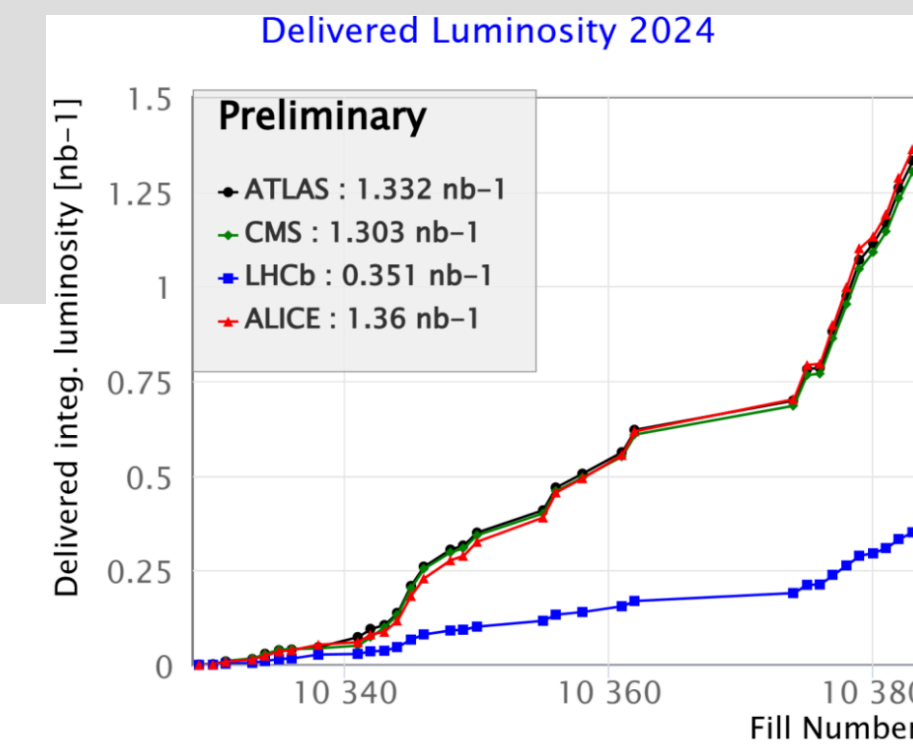
Zero Degree calorimeters are an essential
component of the CMS heavy-ion program



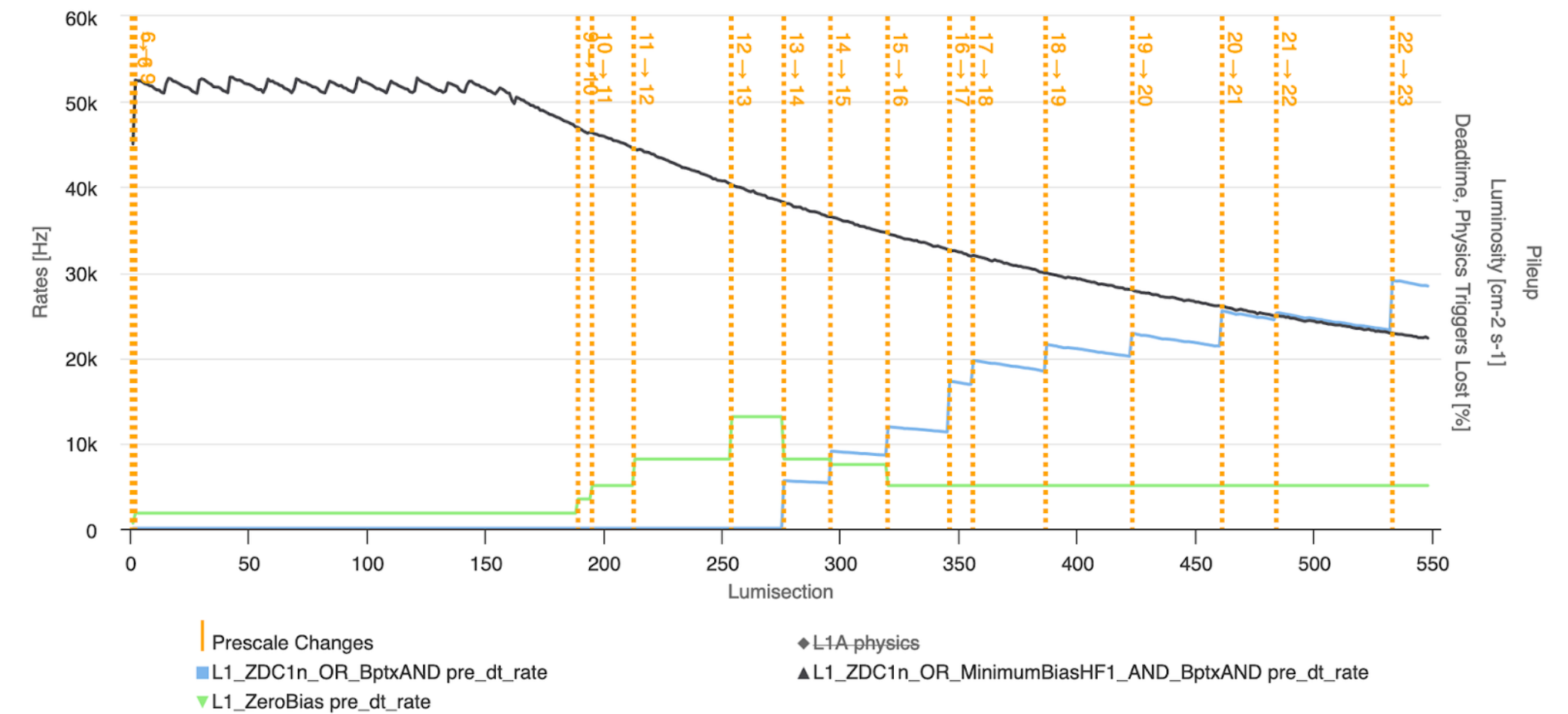
S. Obratsov played a key role in ZDC commissioning

Run 3 data taking strategy

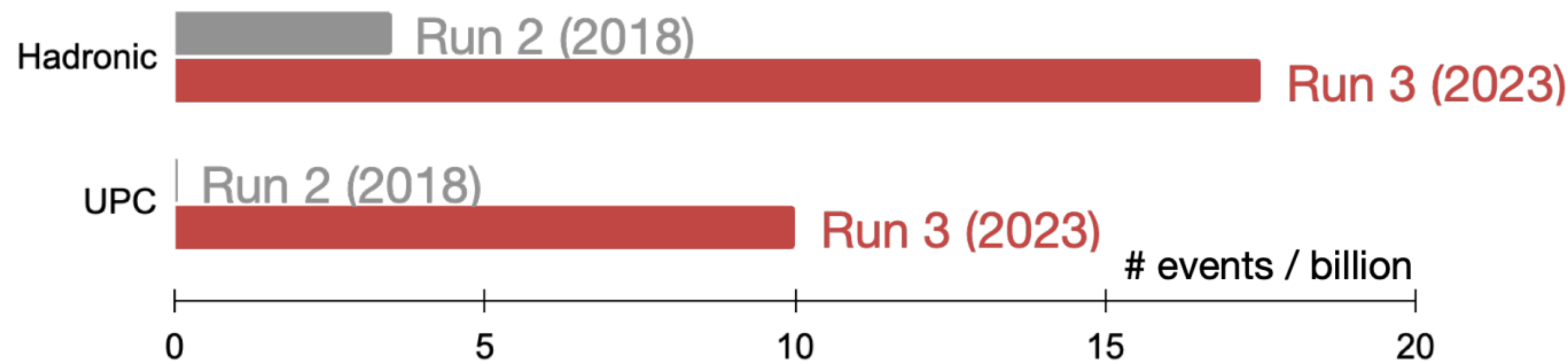
- Up to Run 2 we focused on “hard probes” of the QGP using rare object triggers
- During LS2 we have dramatically increased our data taking capabilities
 - now recording 30 GB/sec, record for CMS



L1 trigger rates in a typical fill in 2024

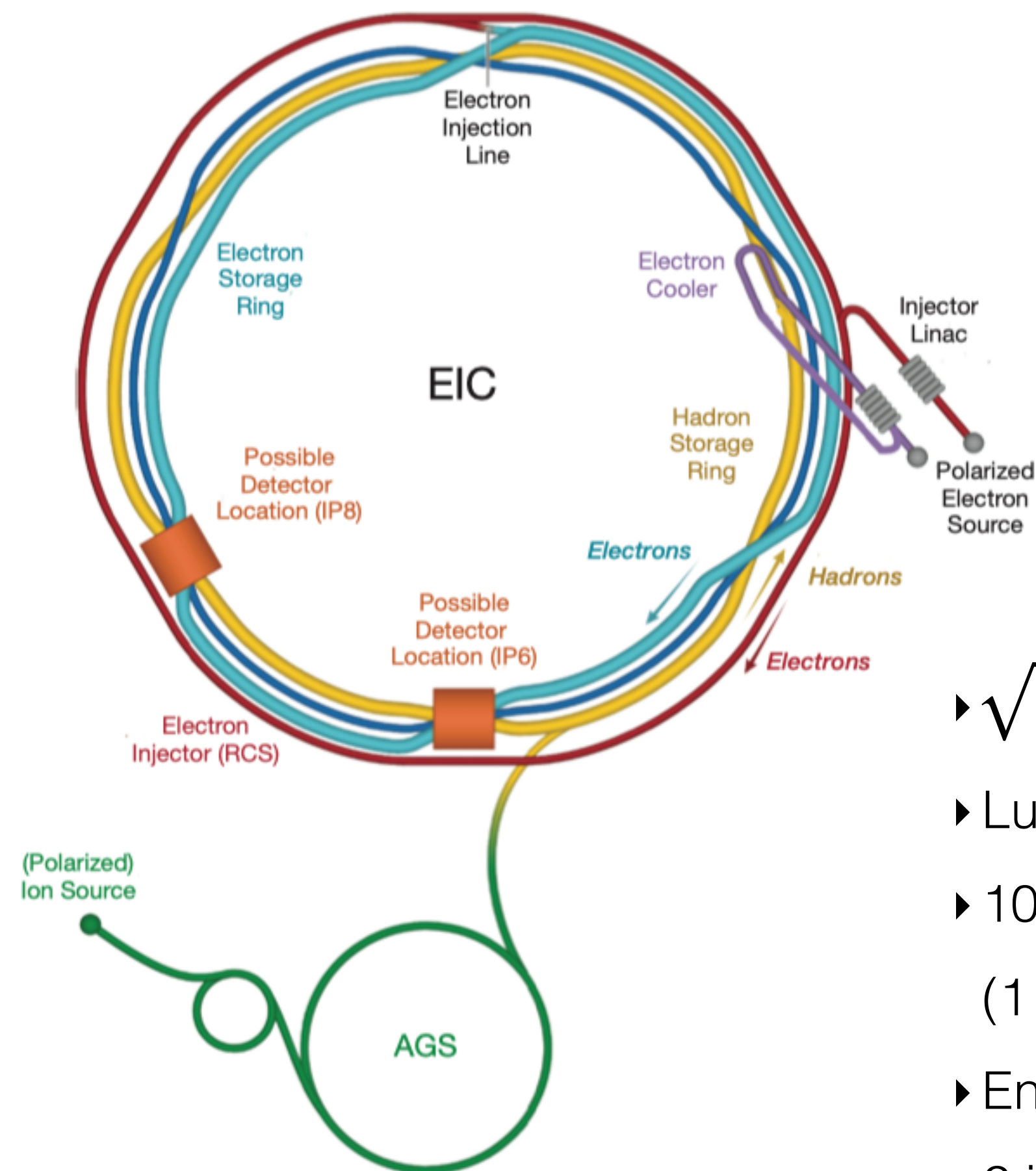


Data samples recorded in 2023



- In Run 3 we are now recording ALL hadronic interactions with minimum bias triggers
- In addition, we are recording large samples of EM interactions (most photon-nucleus)
 - Opens up new possibilities for heavy flavor (MB) or ultra-peripheral collisions

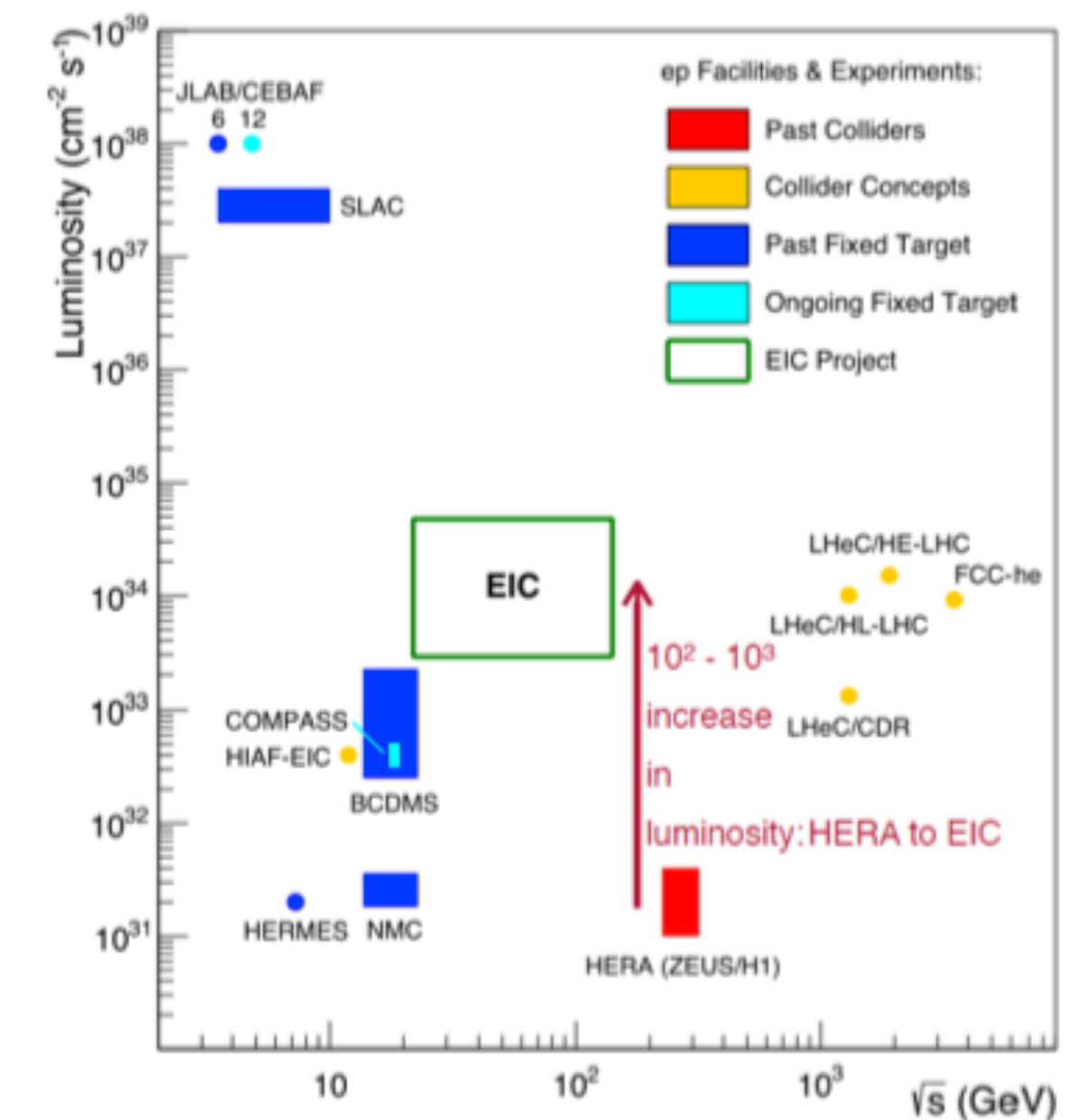
What is the electron-ion collider?



A new collider based on existing proton (500 GeV) and ion (e.g., Au @ 200 GeV) rings at BNL

- ➔ Features polarized (>70%) DIS with e-p
- ➔ Large variety of colliding nuclei up to uranium

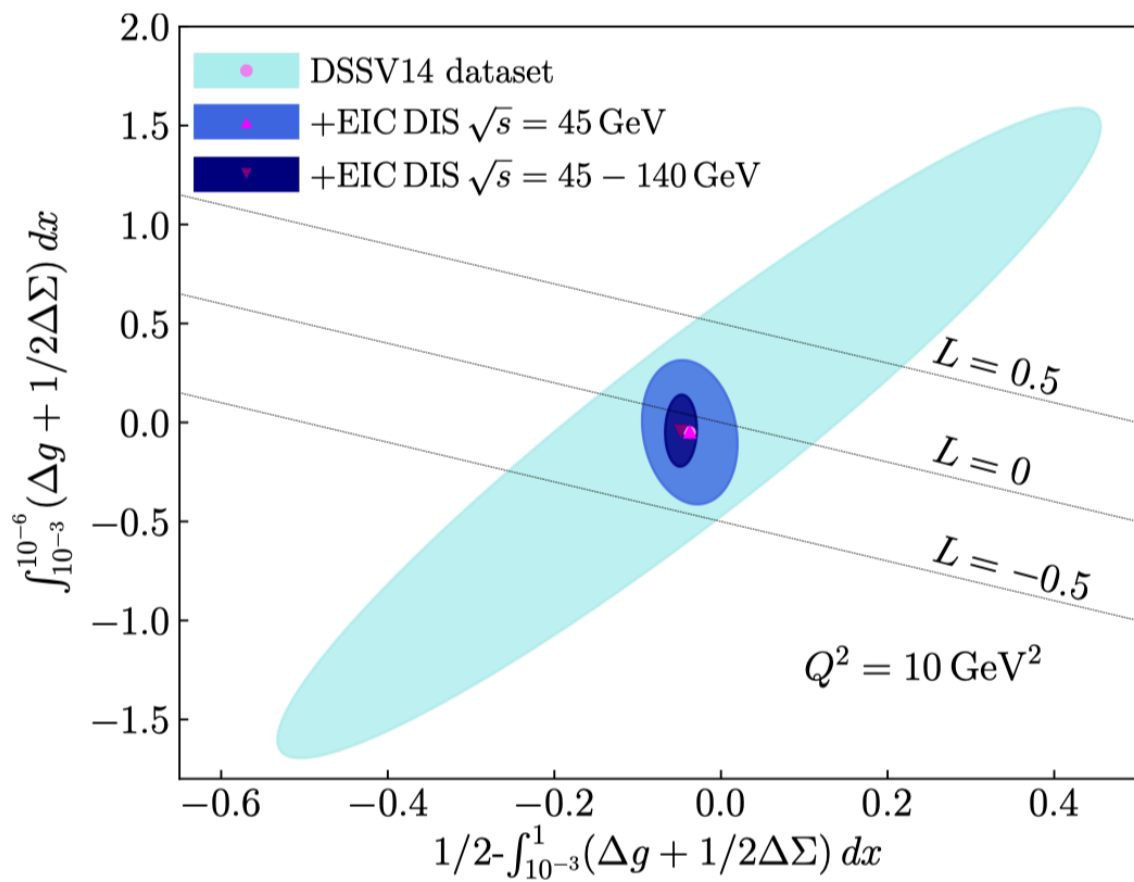
- ▶ $\sqrt{s_{NN}} = 29 - 140 \text{ GeV}$
- ▶ Luminosity = $10^{33-34} / \text{cm}^2/\text{s}$, 10-100 /fb/year
- ▶ 10 ns bunch spacing w/ 500 kHz integration rate (1 collision per 200 BX)
- ▶ Energy recovery linac w/ hadron beam cooling
- ▶ 2 interaction points with detector caverns



Slide from CS of LLR

Why does the world need an EIC?

Origin of nucleon spin



EIC YELLOW REPORT
Volume I: Executive Summary

~900 pages

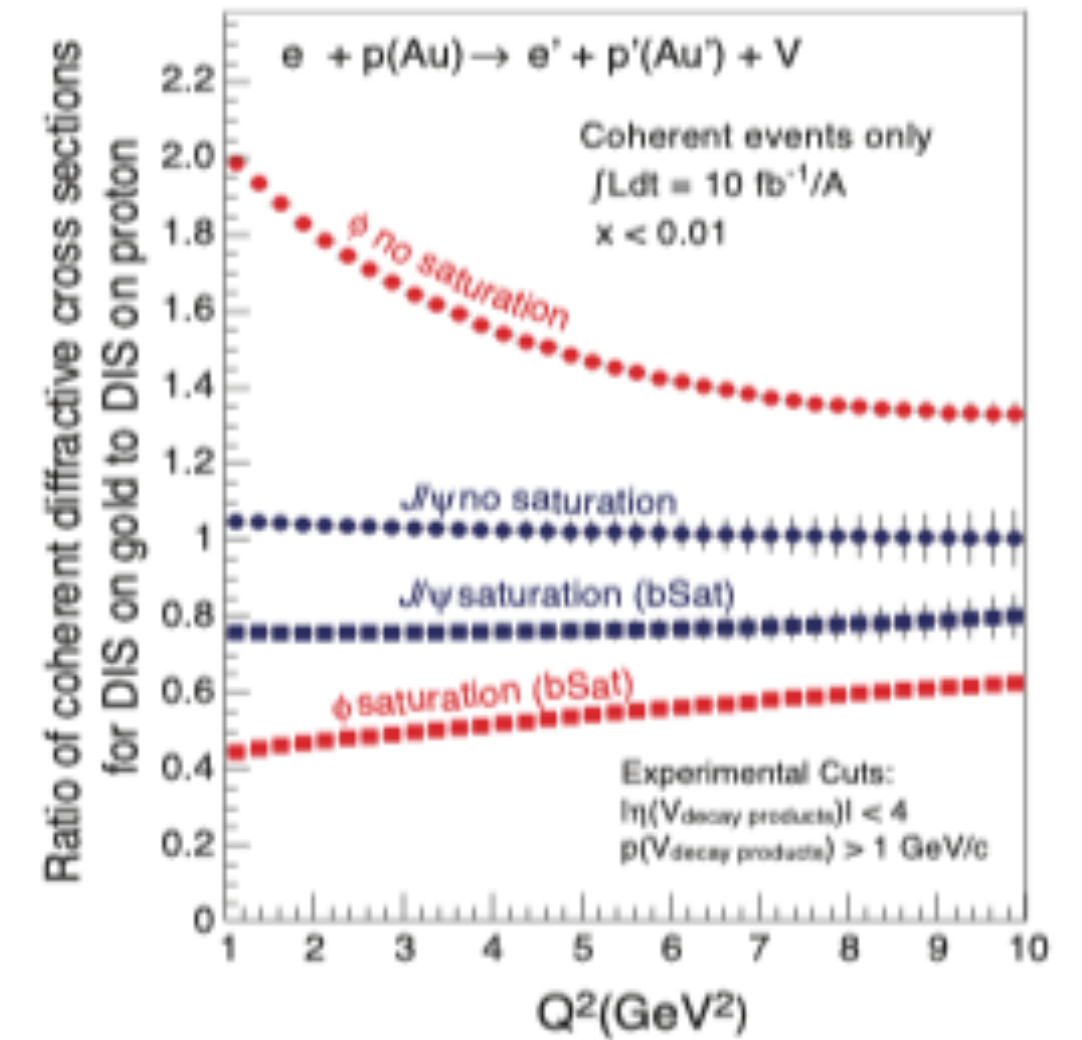
EIC YELLOW REPORT
Volume II: Physics

~400 authors including

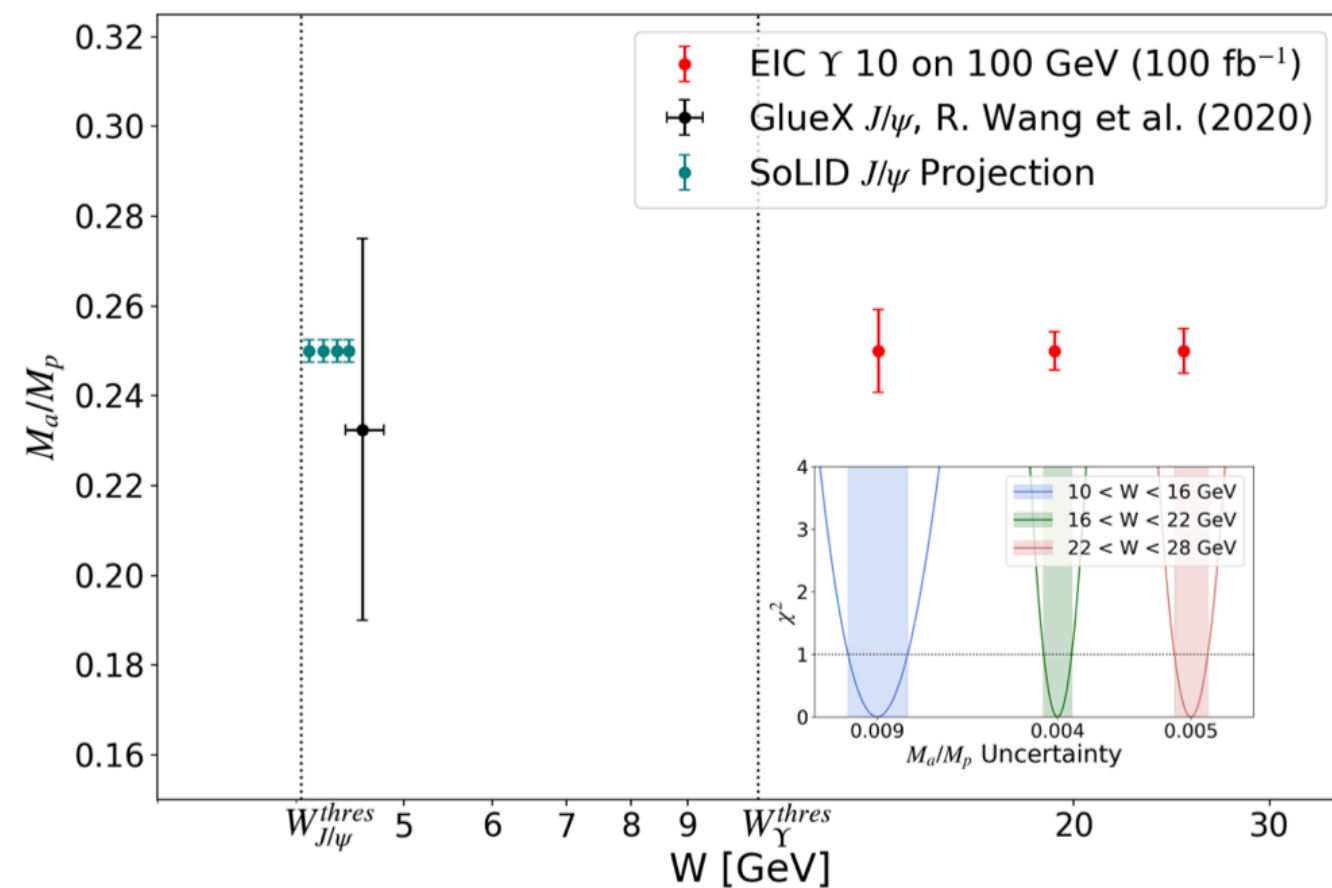
EIC YELLOW REPORT
Volume III: Detector

CEA, IJCLab, CPHT

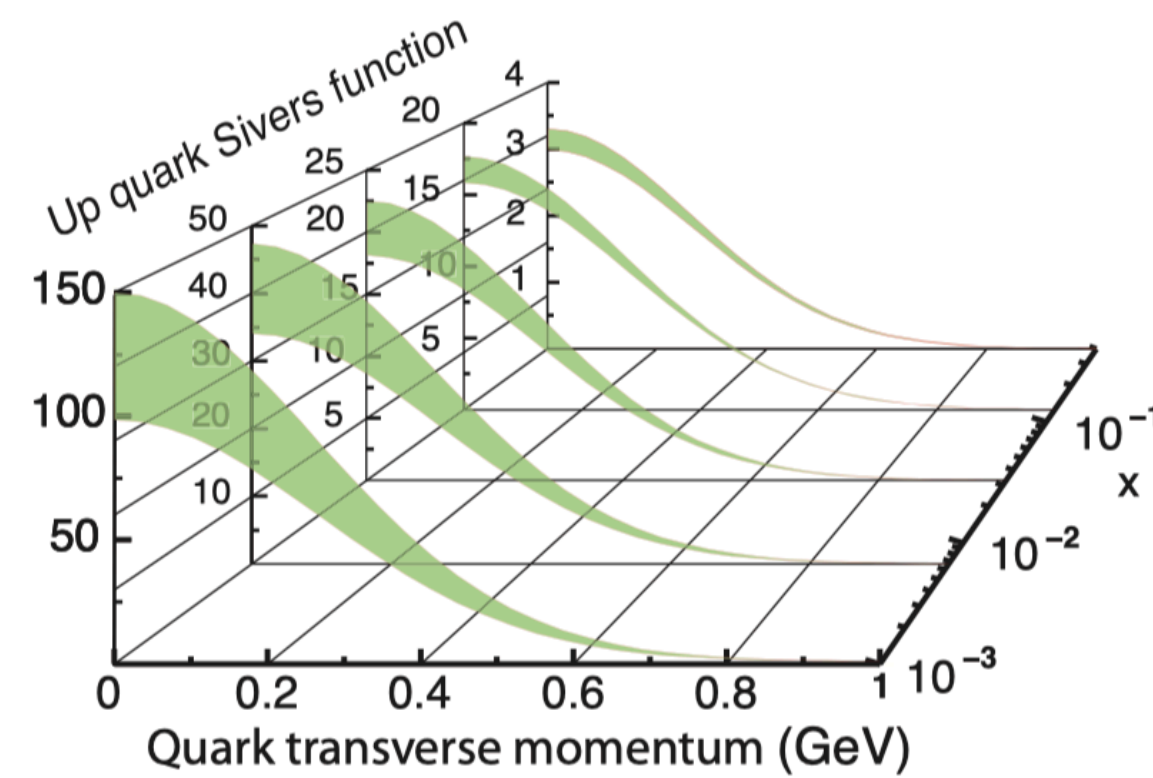
Gluon saturation



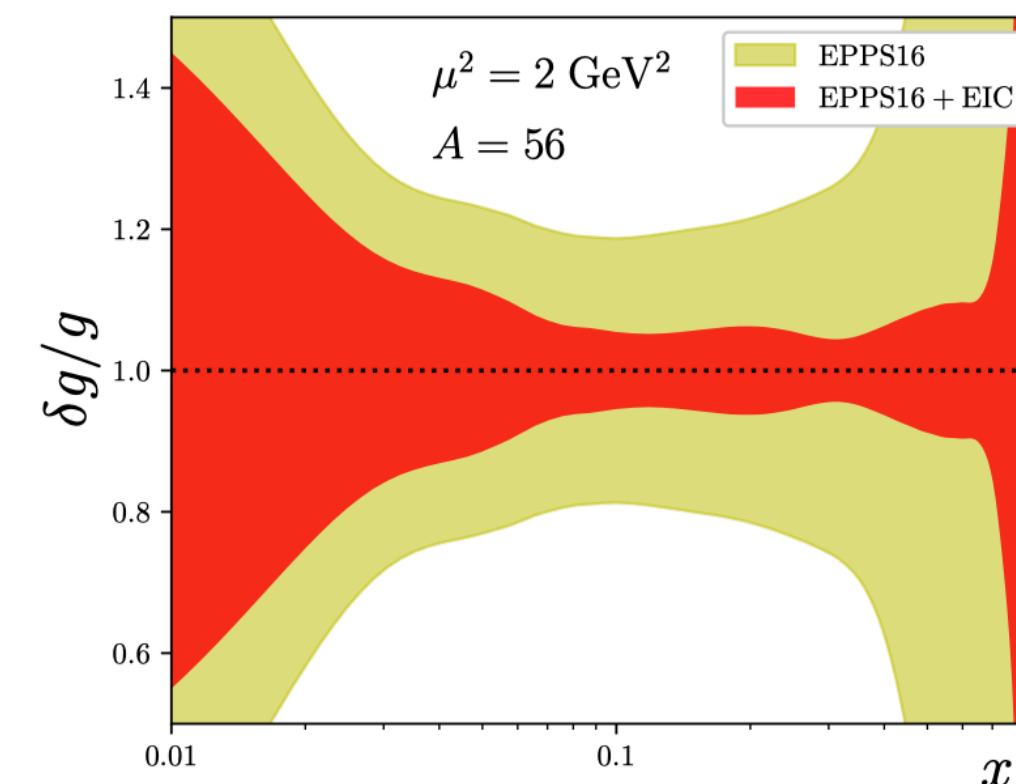
Origin of nucleon mass



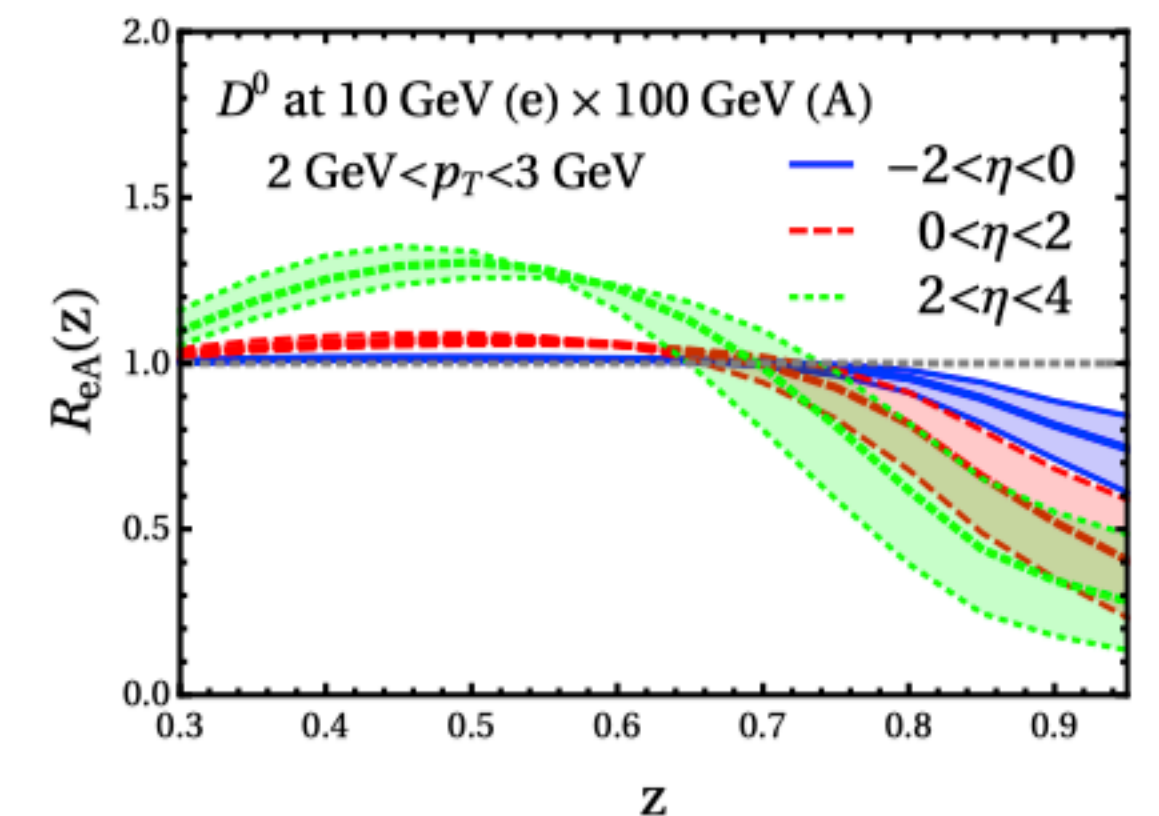
3D imaging of nucleon



Nuclear PDFs



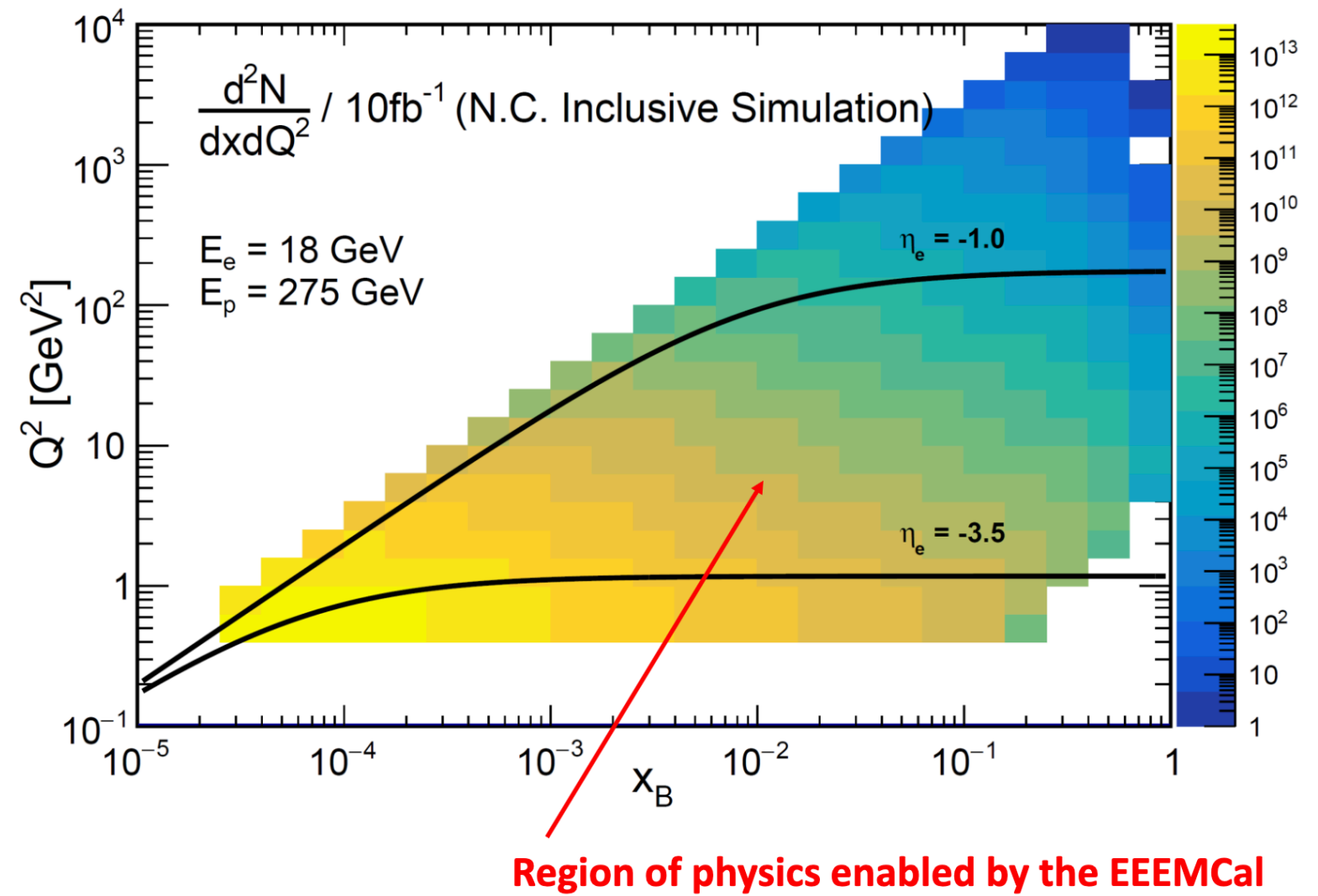
Cold nuclear matter





Electron-endcap EMCAL

Scattered electrons have to be detected in the Lepton Endcap ($-3.5 < \eta < -1.0$)



PWO crystals read w/ SiPMs

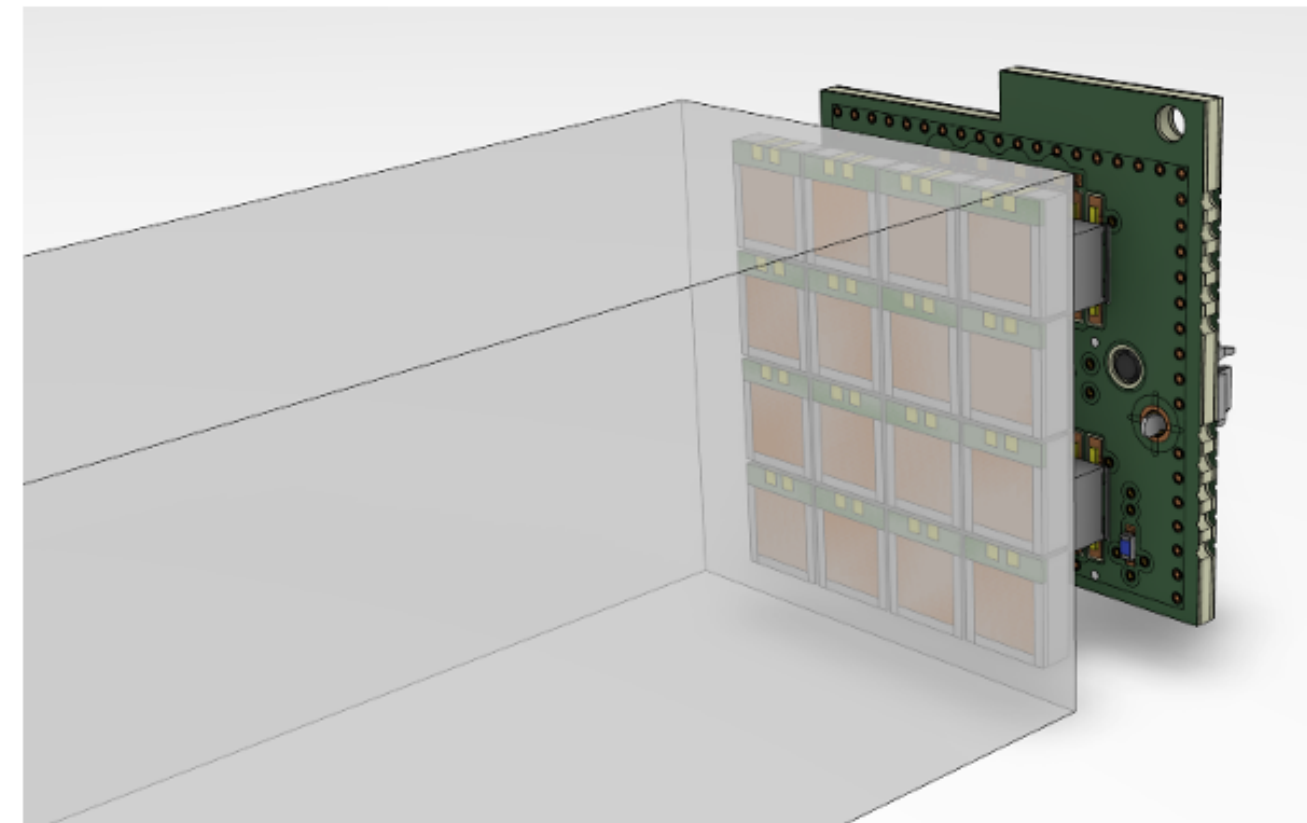
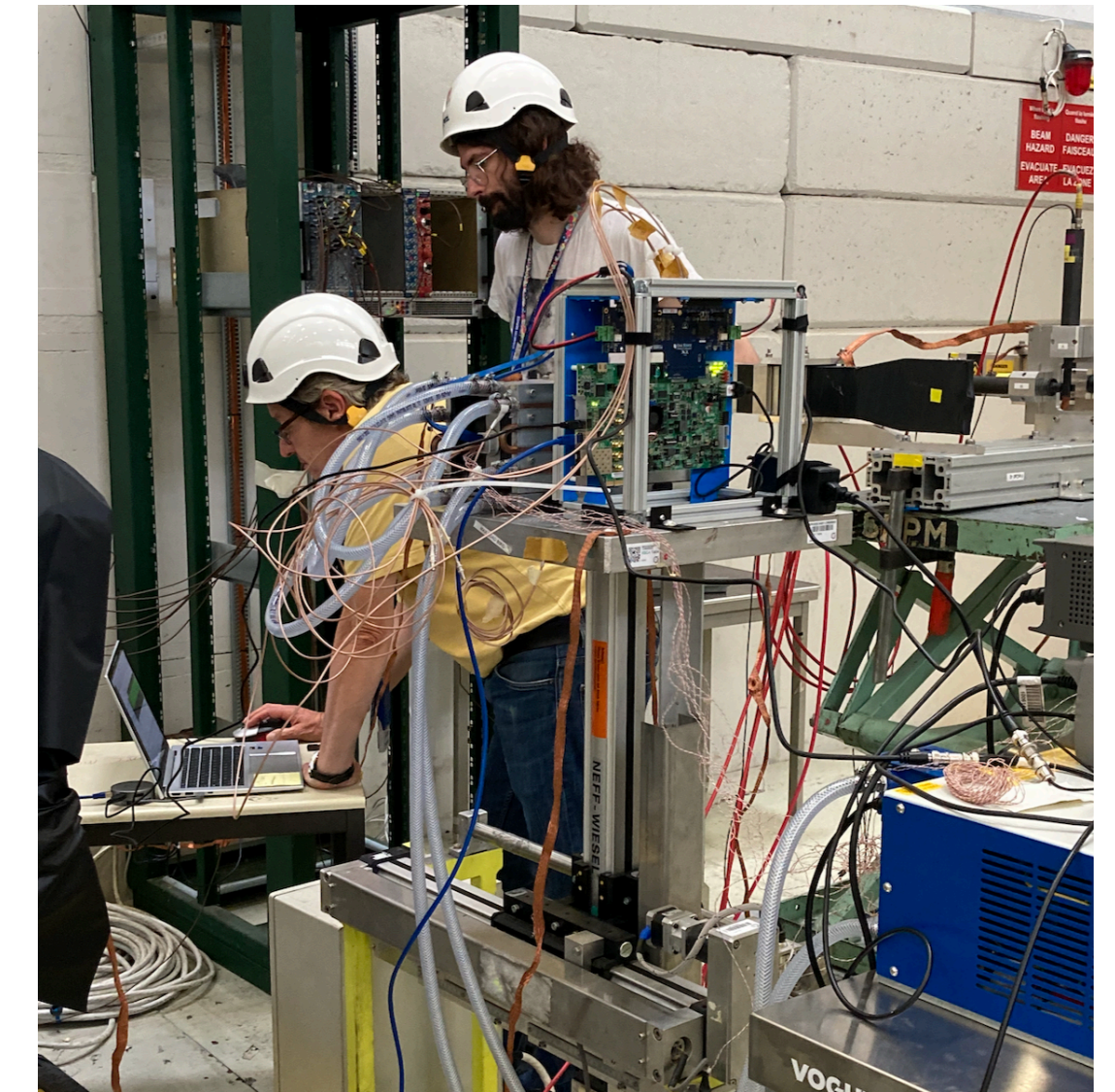


Figure 10: PWO crystal readout by an array of 16 Hamamatsu S14160-1315 SiPMs.

EEEMCal beamtest @ PS in August



Crucial role! Measure:

- ▶ Scattered e^- from DIS
- ▶ Direct γ from DVCS

Needs to:

- ▶ distinguish e^- from $\pi^{+/-}$
- ▶ collect bremsstrahlung γ 's
- ▶ reject photons from π^0

Near-term goals:

- Demonstrate readout w/ ASIC designed at OMEGA
- Design front-end electronics based on this ASIC
- TDR expected ~ end of 2025

Project presented to CS of IN2P3 in Oct.
IR* being negotiated w/ ministry

LLR Workforce:

- MN 50% over LS3
- S. Obratsov (PD) 50%
- New PD: 50%
- New PhD: 30-50%
- O. Le Dortz (IR): 30%
- New IR CDD: 90%

NB: L. Kalipoliti & S. Obratsov
deeply involved in ASIC testing for CMS

Summary & outlook

- We have been exploiting the Run 2 CMS heavy-ion data for QCD studies
 - Mainly focus: applying substructure tools to study jet quenching
 - Secondary focus: nuclear effects on quarkonium production
- Currently collecting data from ongoing LHC Run 3
- More jet quenching studies planned, but may pursue measurements of heavy flavor and/or ultra-peripheral collisions, depending on personnel
- Initiated participation in the electron-ion collider set to start around 2032
- Starting point is design of the front-end readout for electron-going ECAL, an essential detector for any of the physics being pursued there

Backup

Beamtest setup

1st test of complete chain conducted in September @ CERN, jointly with forward HCAL

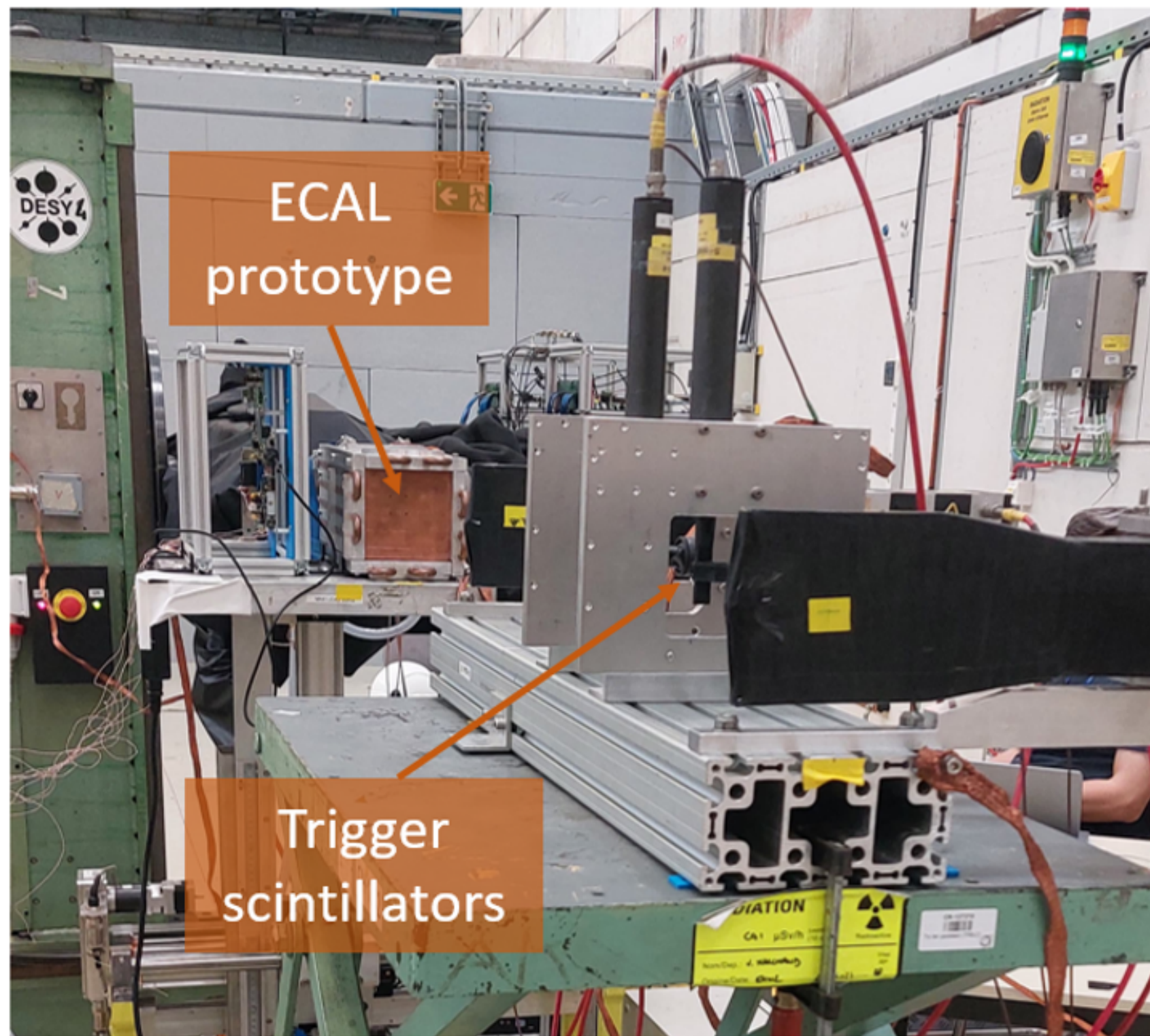


Figure 17: Beam test setup at CERN SP (September 2024).

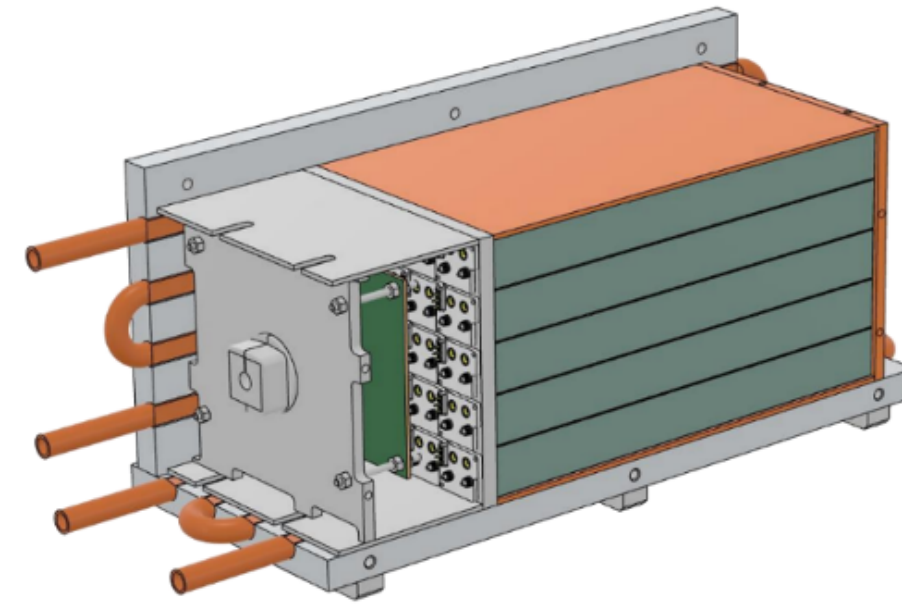
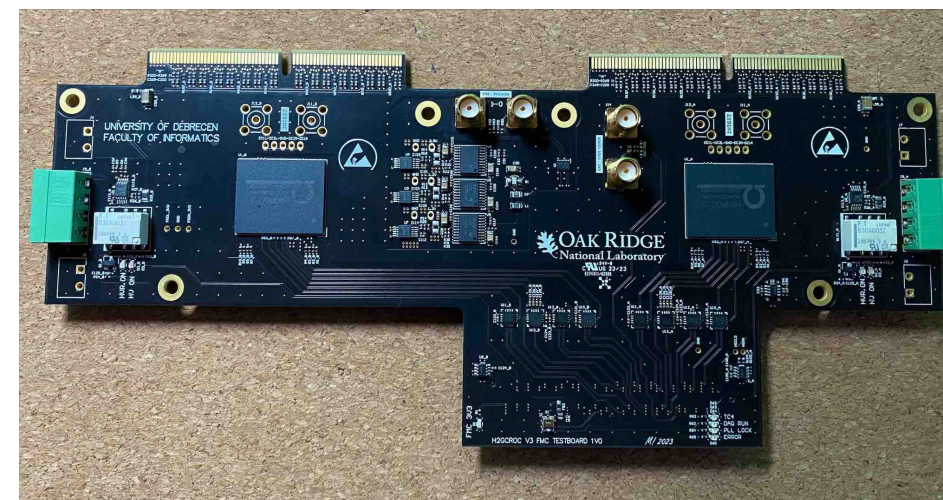


Figure 15: 5x5 PWO crystal prototype designed and built at IJCLab.

5x5 crystal prototype designed at IJCLab
Only 4 crystals equipped for 1st test



Readout identical to forward HCAL
HGCROC protoboard + KCU (FPGA)

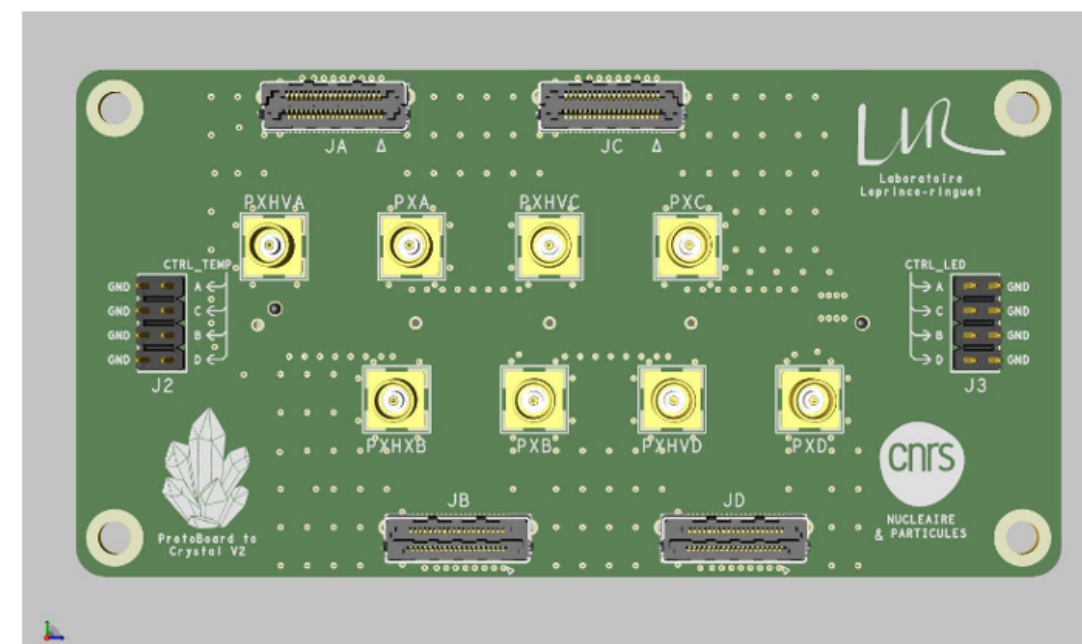


Figure 16: CAD drawing of the interface between the SiPMs and the ASICs.

Interface card between SiPM &
ASIC designed by LLR