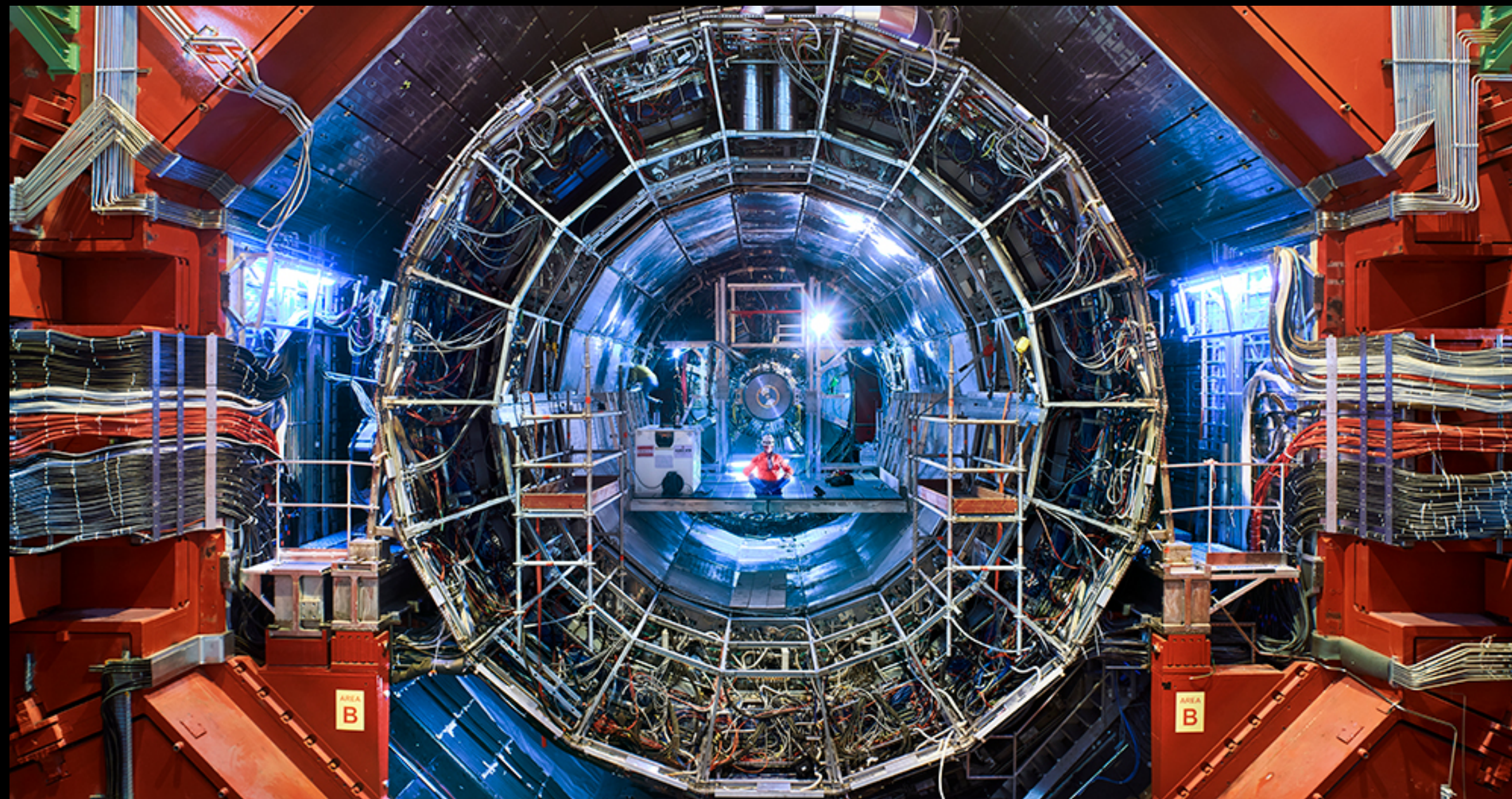


High-Energy Nuclear Physics (ALICE-DK)

Activities Report



You Zhou

Niels Bohr Institute



UNIVERSITY OF
COPENHAGEN

ALICE-Denmark Group

- ❖ In 2022, we had **6** senior staff, **1** postdoc, **2** PhD, **9** MSc
- ❖ In 2026, we have **2** senior staff, **2** Professor Emeritus, 4 postdocs, **4** PhD, **9** MSc



ALICE Thesis Award

- Christian H. Christensen (2008)
- Katarina K. Gajdosova (2019)

SQM Young Scientist Prize

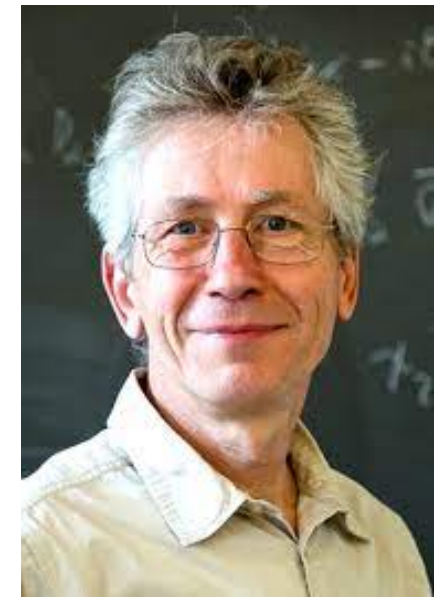
- Vojtěch Pacik (2017)
- Vojtěch Macháček (2026)



Official positions in ALICE



- ❖ Jens Jørgen Gaardhøje
 - Vice president, CERN council
 - ALICE Management Board
 - Project leader FMD



- ❖ Børge Svane Nielsen
 - ALICE Technical Board
 - Project Leader TPC Laser



- ❖ Ian Bearden
 - ALICE Editorial Board
 - Project Leader FoCal



- ❖ You Zhou
 - ALICE Physics Board
 - Convener of Physics Work Group (PWG-CF)
 - Coordinator of Physics Analysis Group (Flow)

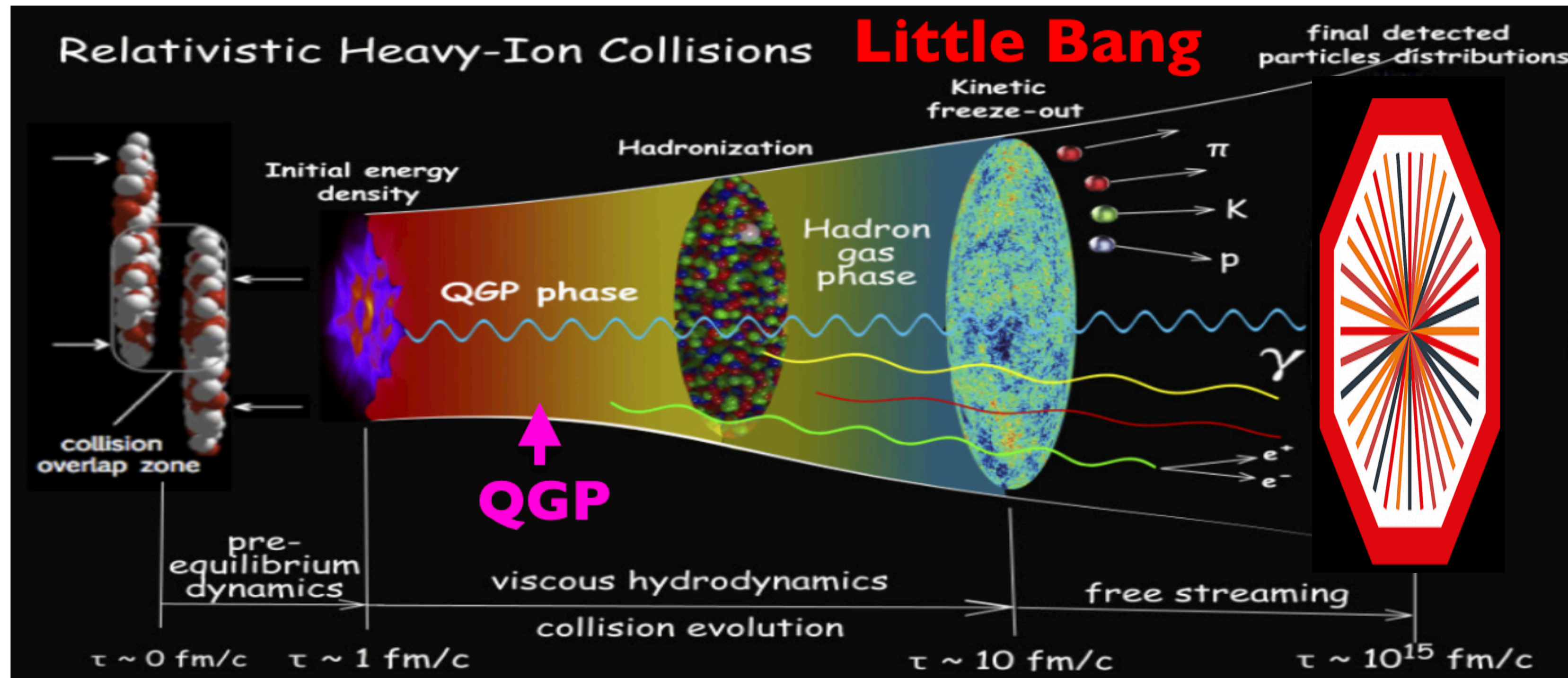


- ❖ Kristjan Gulbrandsen
 - ALICE Run Coordination
 - Coordinator of Physics Analysis Group (GEO)



- ❖ Zuzana Moravcová
 - ALICE Management Board
 - ALICE Juniors' Representative

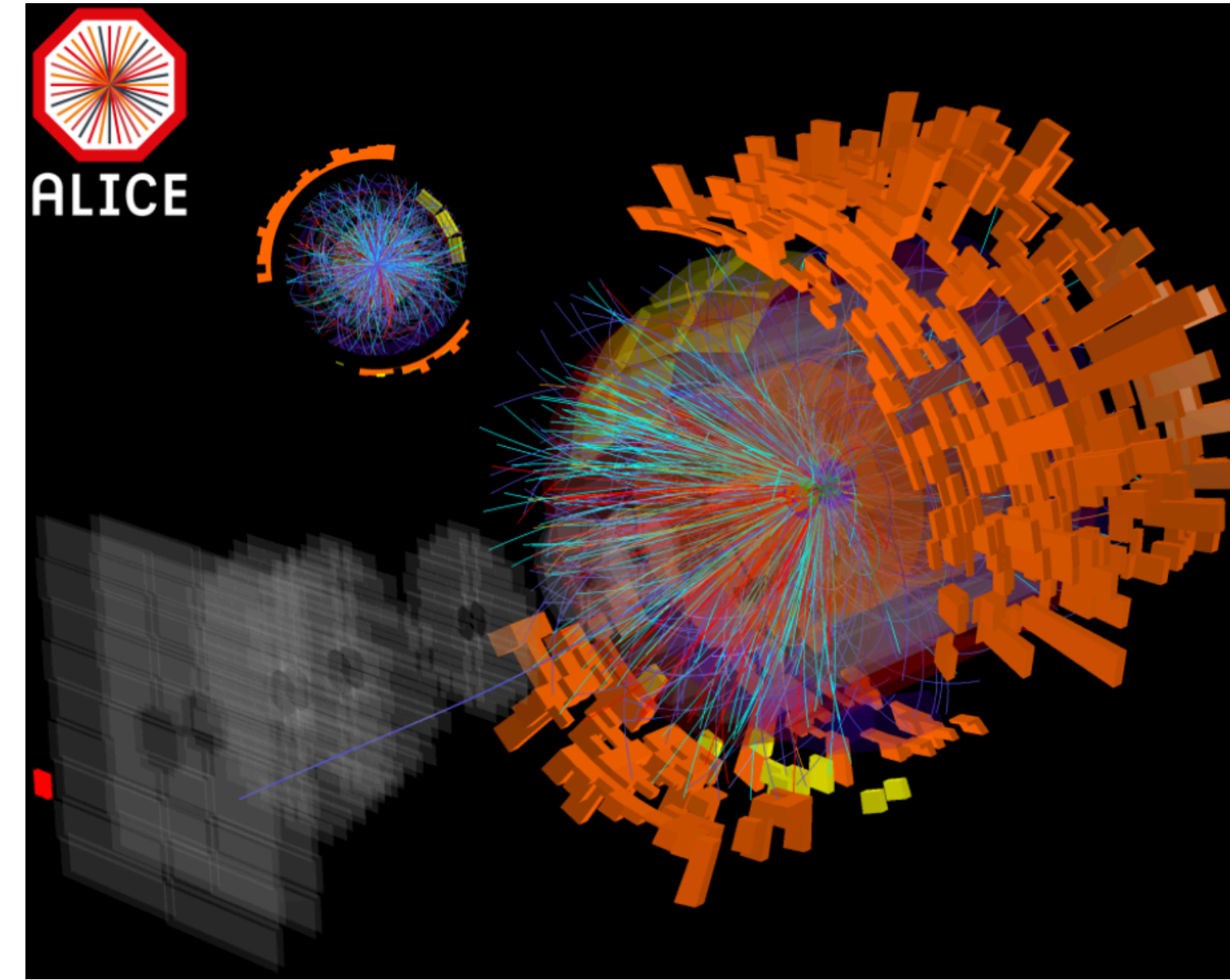
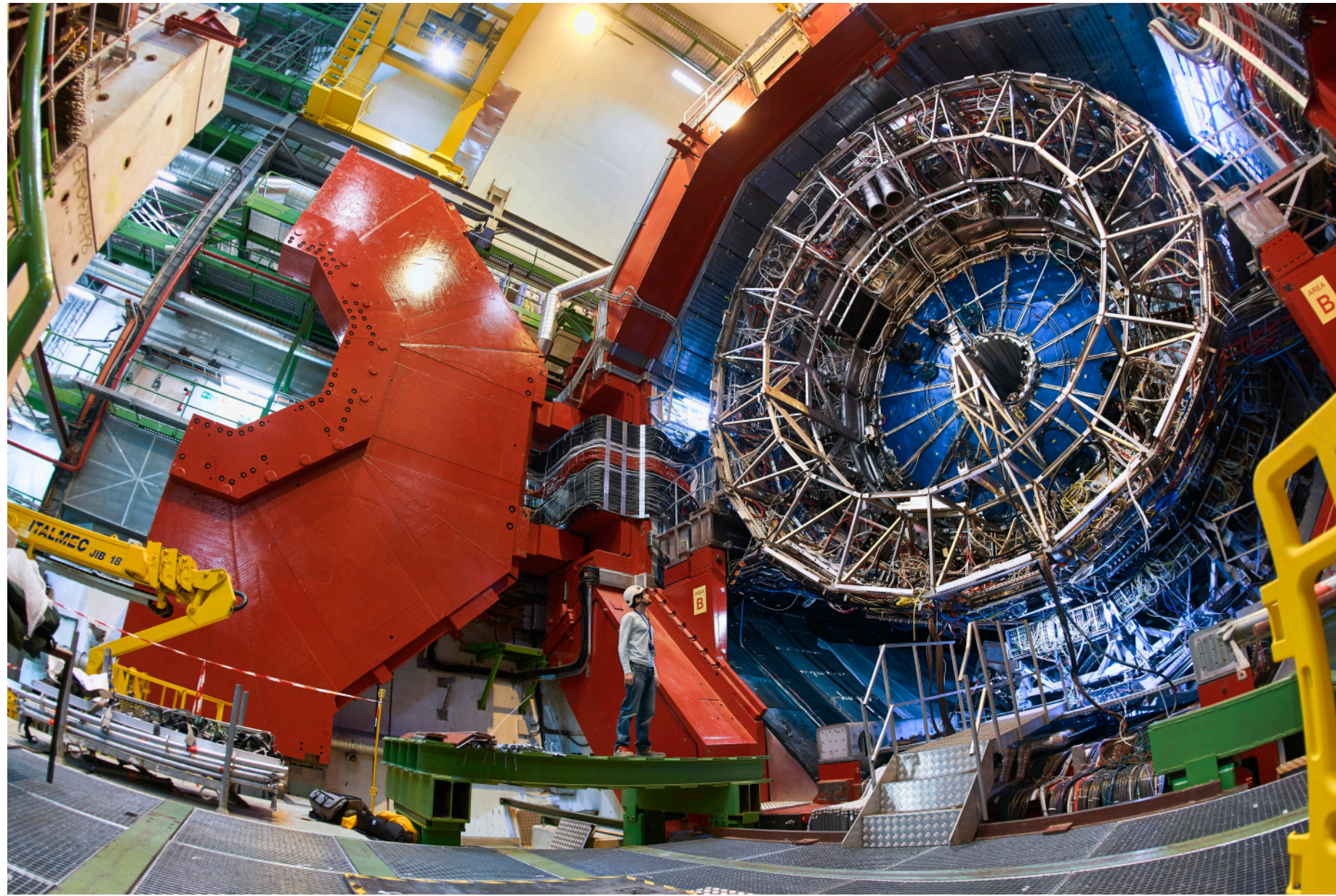
Recreating the QGP in the laboratory



Fundamental goals of ultra-relativistic heavy-ion program at the LHC

- recreate the Quark-Gluon Plasma (primordial matter) in the laboratory
- study its properties and understand its time evolution

ALICE: 2010-2026

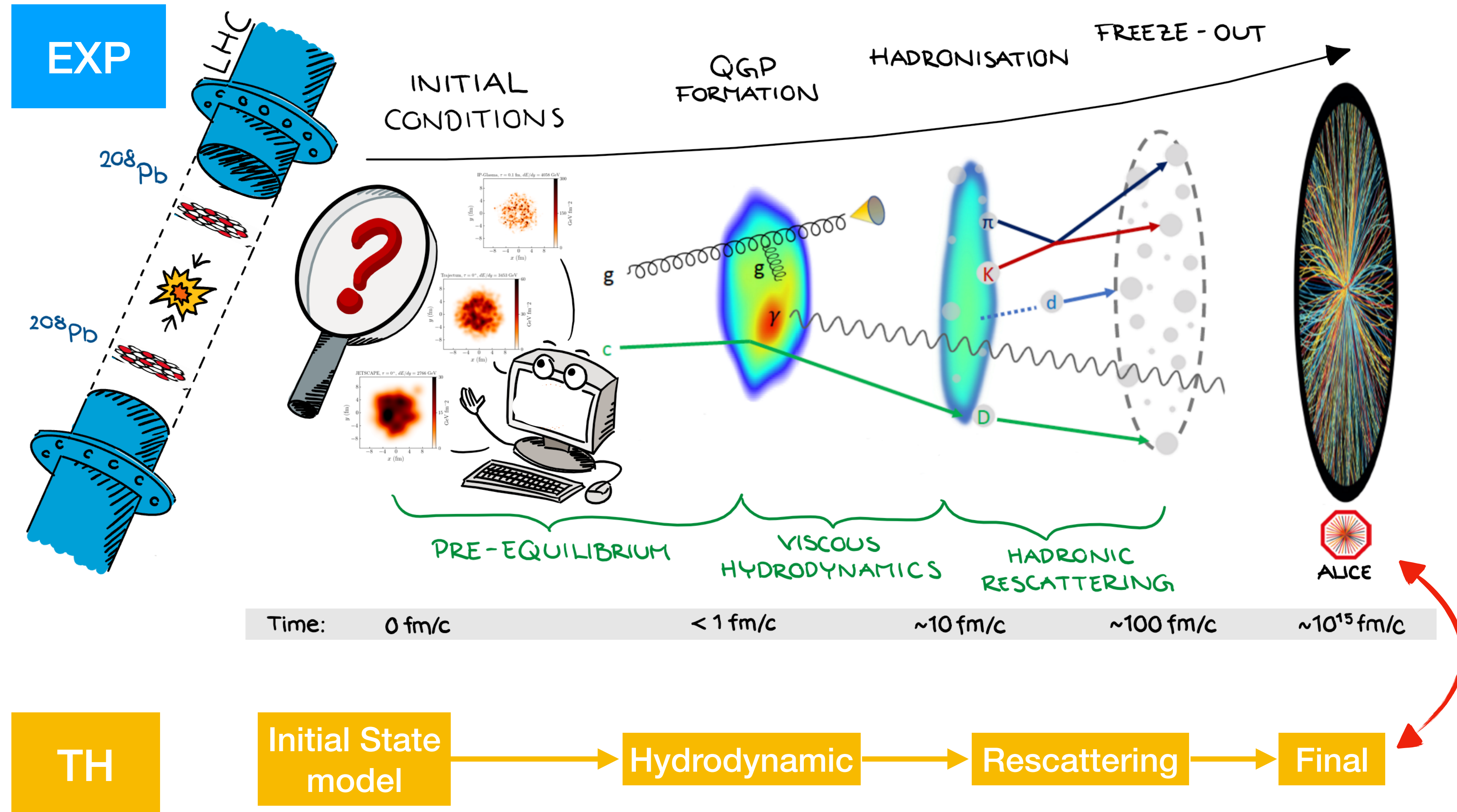


Key milestones of the ALICE Collaboration at Run 1-3

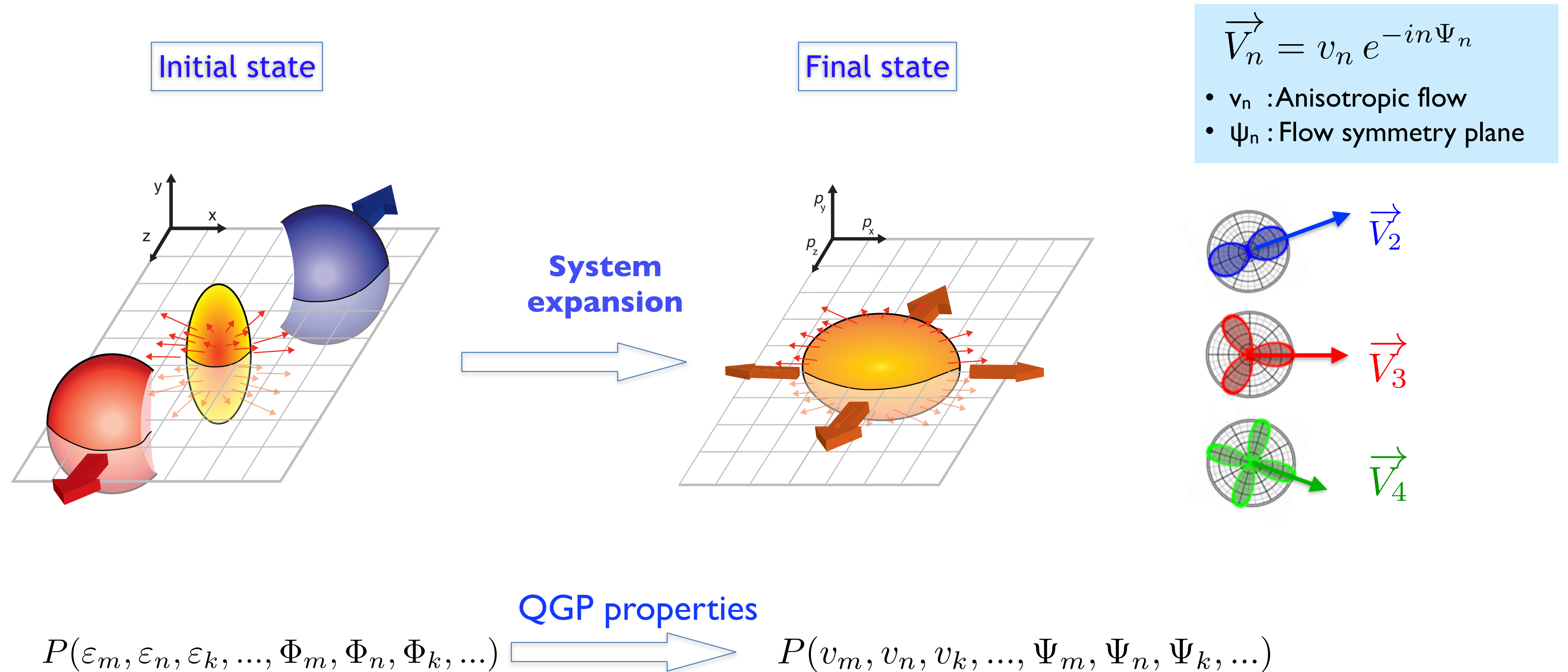
- ❖ Extract precise properties and time evolution of QGP in heavy-ion collisions [Expected]
- ❖ Discovery of collective flow in small collision systems [Unexpected]

ALICE-DK group played and is playing a leading role.

Heavy-ion collision: a complex system

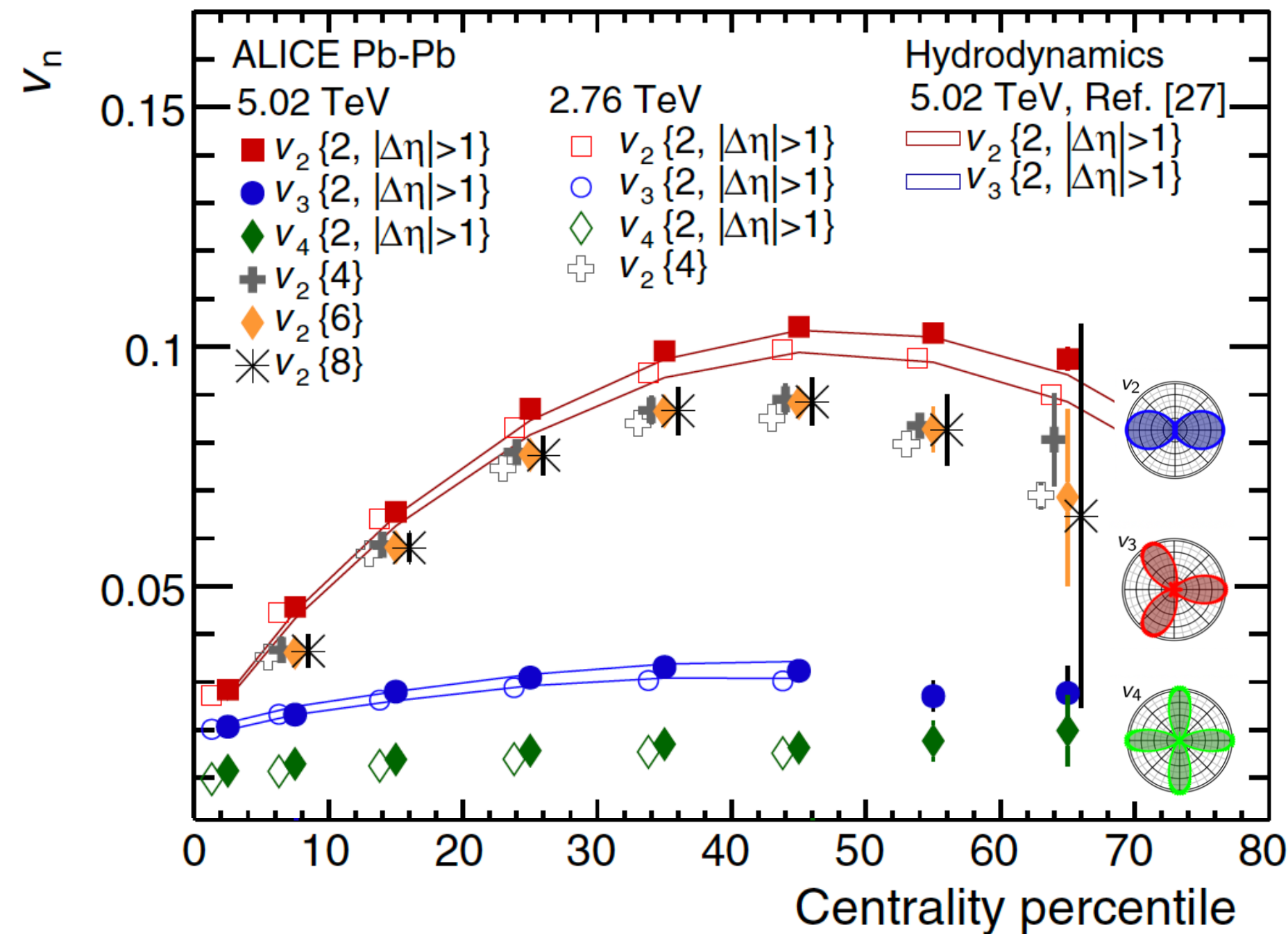


Probing QGP using Anisotropic Flow



A perfect fluid

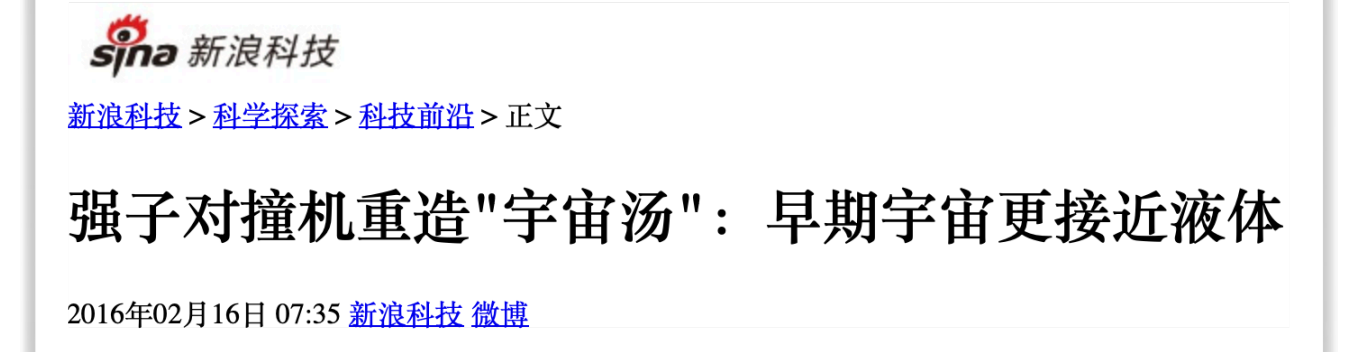
ALICE, Physical Review Letters 116 (2016), 132302



UK, 《Daily mail》



腾讯太空

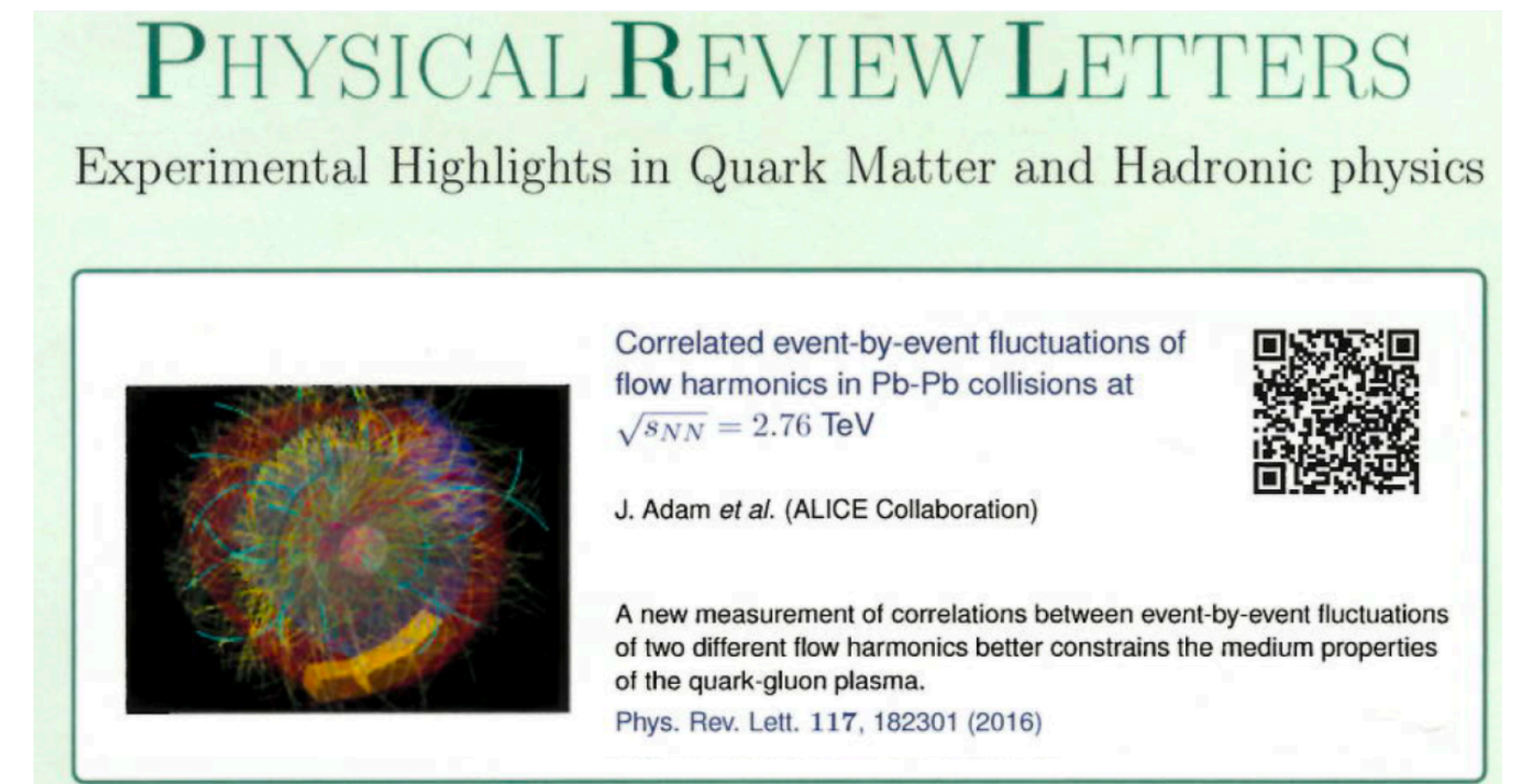
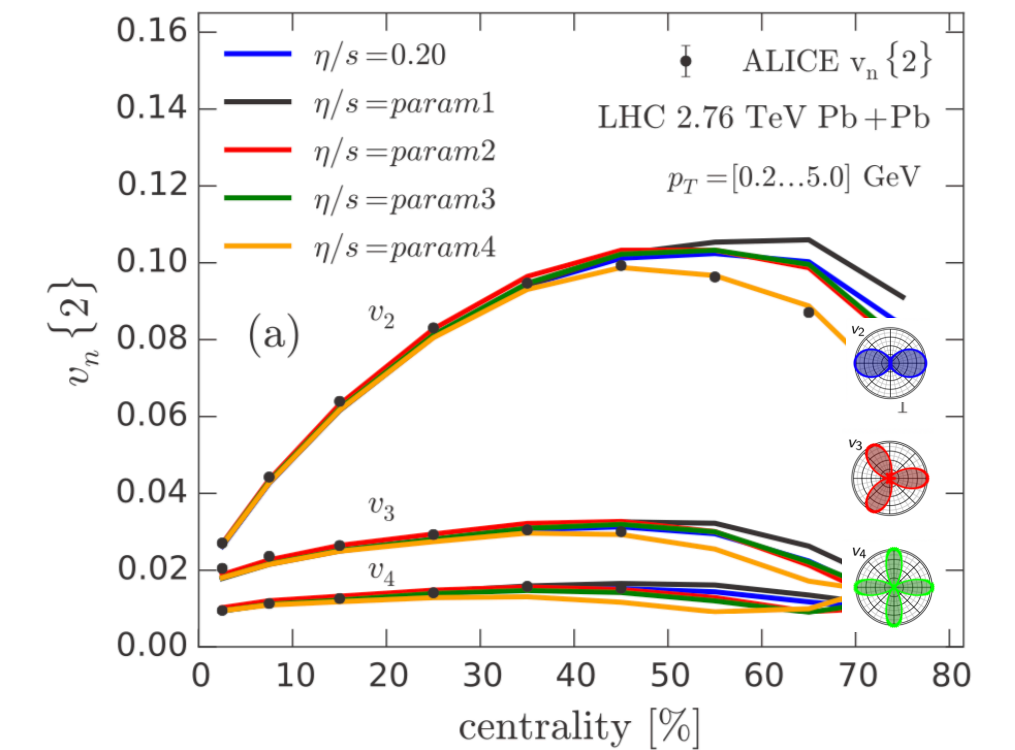
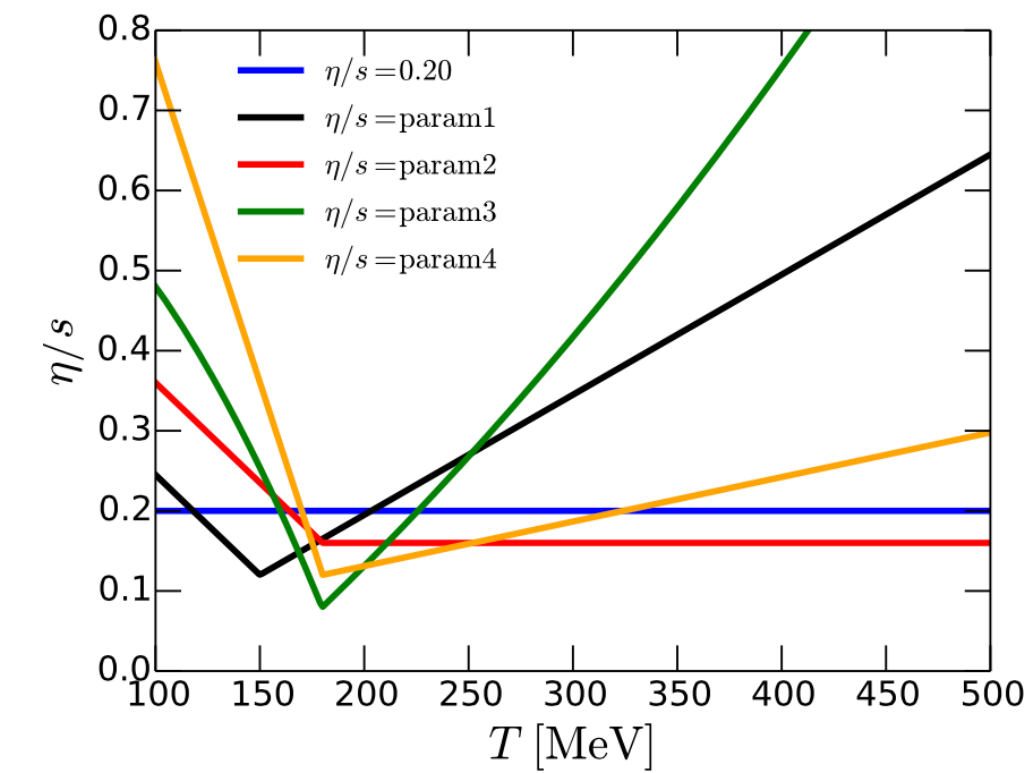
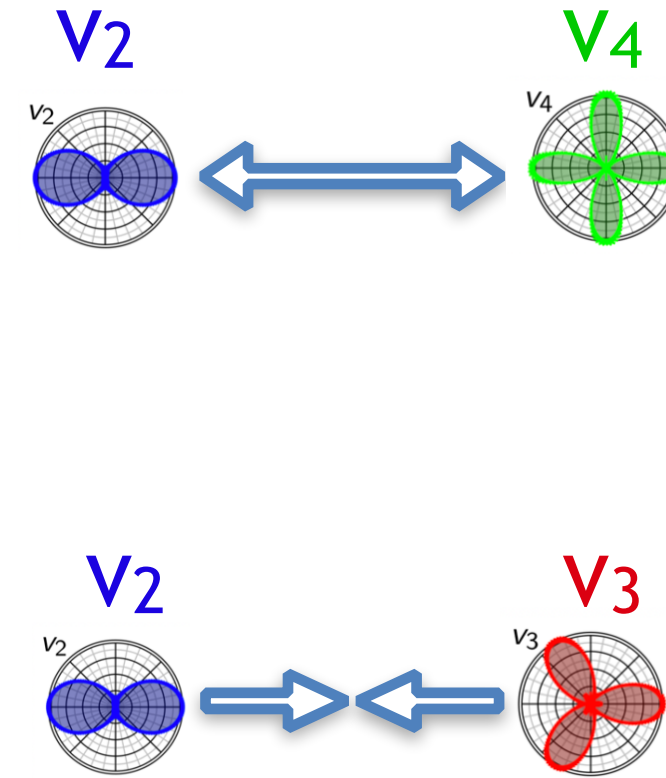
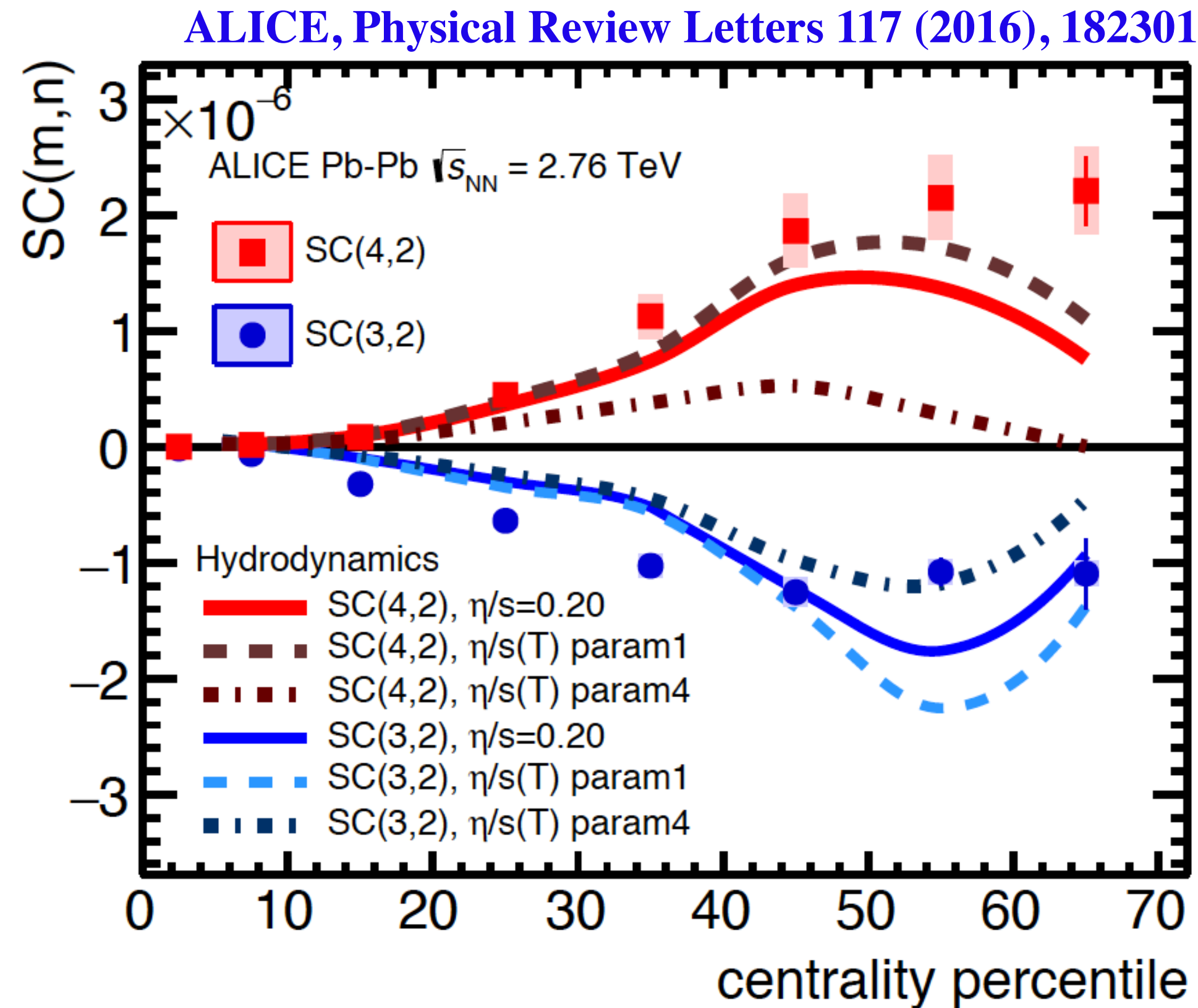


❖ Flow measurements at the top LHC energy agree with hydrodynamic predictions

- **The Quark-Gluon Plasma (Early Universe) behaves like a perfect fluid**
- “fluid”: matter described by hydrodynamics
- “perfect”: very small shear and bulk viscosities



Temperature (time) evolution of QGP fluid



- ❖ Symmetric cumulant, developed by us, is sensitive to the temperature dependence of viscosity of QGP
 - For the first time probing the evolution of QGP in experiments

QGP evolution, state-of-the-art

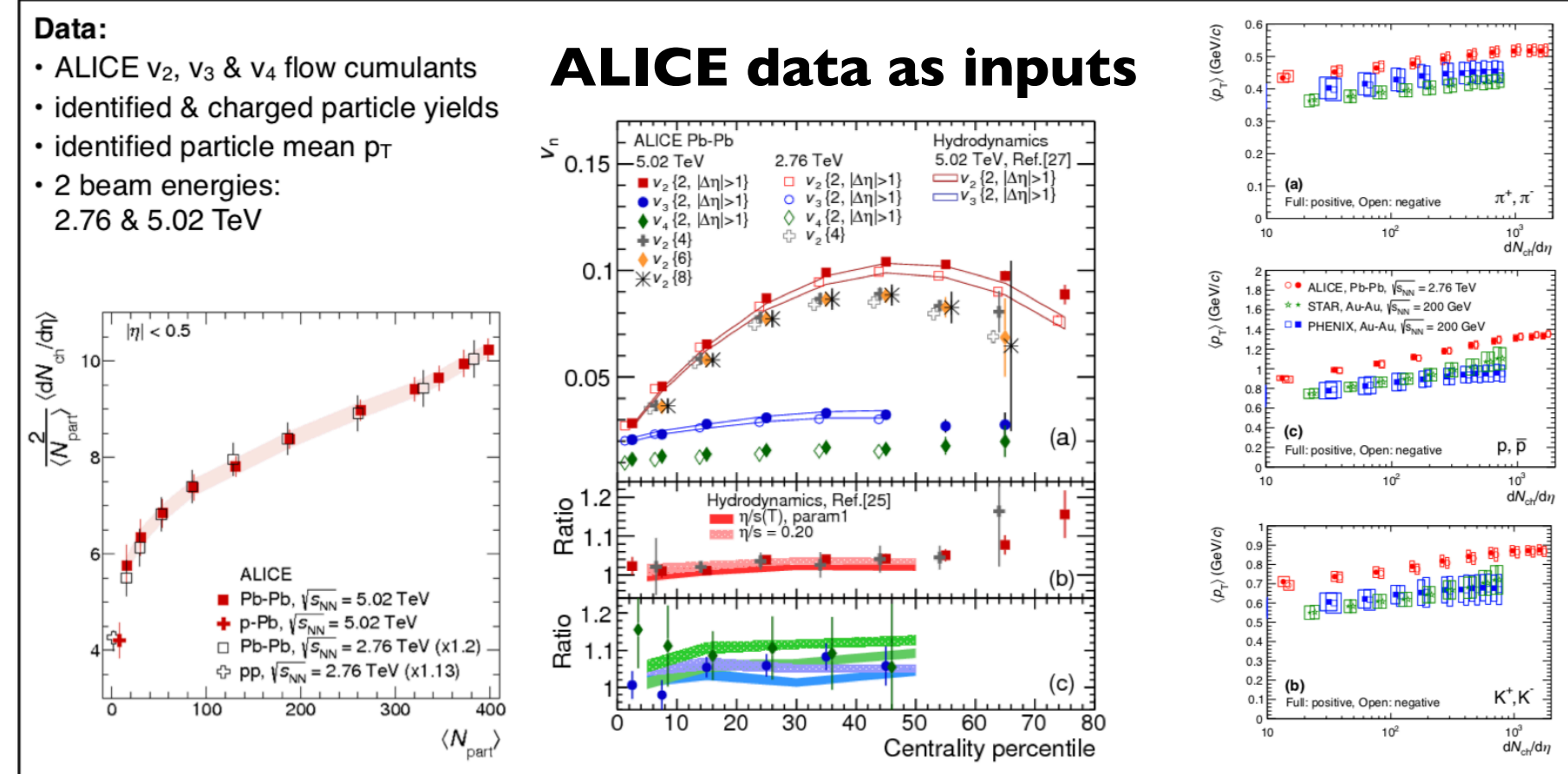
nature
physics

LETTERS

<https://doi.org/10.1038/s41567-019-0611-8>

Bayesian estimation of the specific shear and bulk viscosity of quark-gluon plasma

Jonah E. Bernhard¹*, J. Scott Moreland¹ and Steffen A. Bass¹



Bayesian analysis framework

Model Parameters - System Properties

- initial state
- temperature-dependent viscosities
- hydro to micro switching temperature

estimate or calculate parameters

Bayesian analysis

Physics Model:

- Trento
- iEBE-VISHNU

Experimental Data

- ALICE flow & spectra

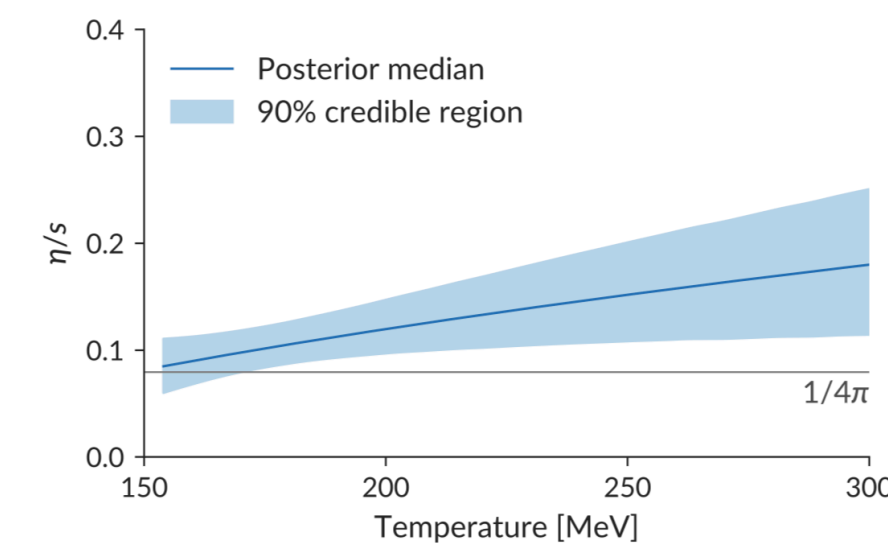
calculate observables & compare to data

- Bayesian analysis allows us to simultaneously calibrate all model parameters via a model-to-data comparison
- determine parameter values such that the model best describes experimental observables
- extract the probability distributions of all parameters

- First extraction of temperature dependent viscosity of QGP**
- Reveal the time evolution of the Early Universe with the first microsecond

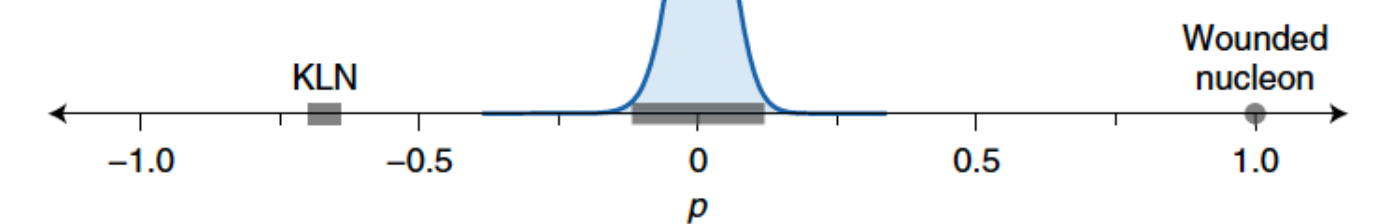
Close collaboration with CCNU (华中师大)

Temperature-dependent viscosities



Initial conditions

Calibrated to:
 Pb-Pb 2.76 and 5.02 TeV



UNIVERSITY OF
 COPENHAGEN

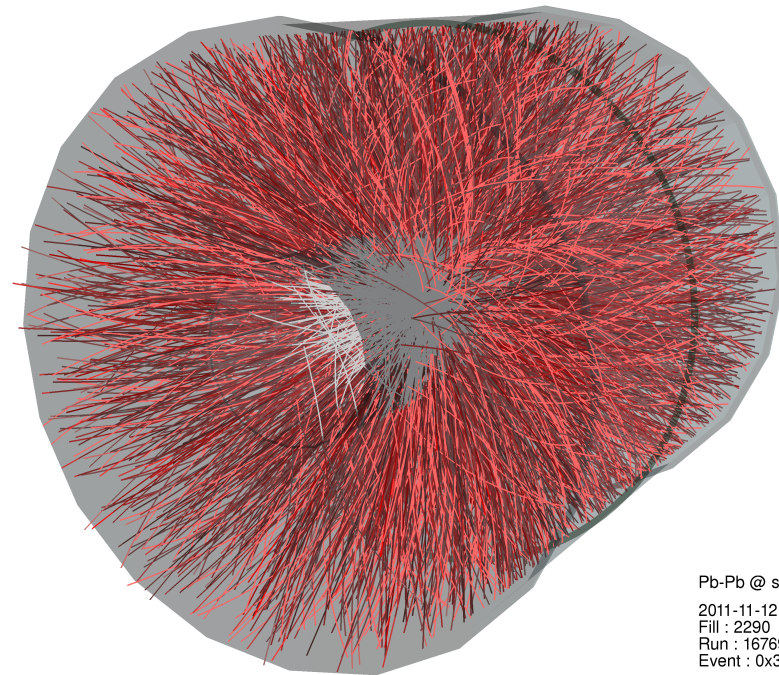
You Zhou (NBI) @ Visit of Chinese Nuclear Physics Society

June 25th, 2026

10

Small droplets of QGP?

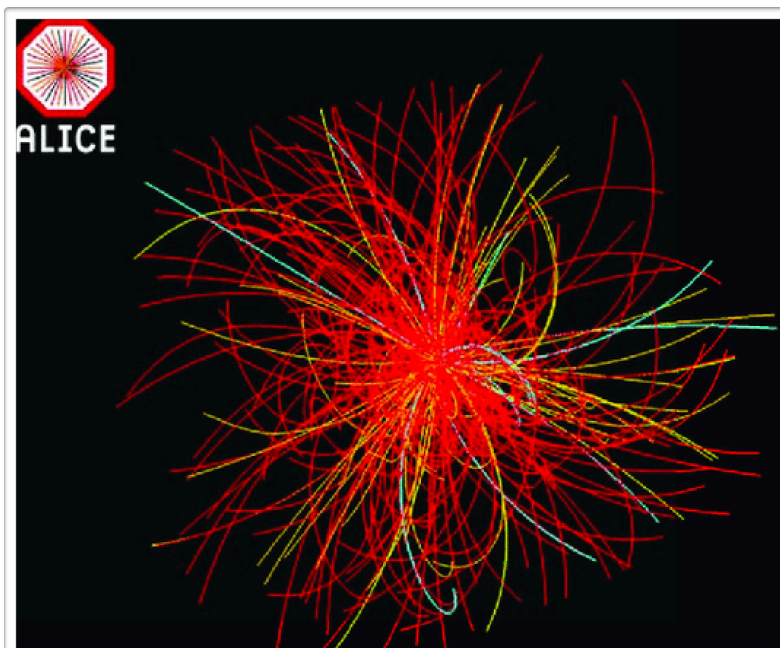
Pb-Pb collisions



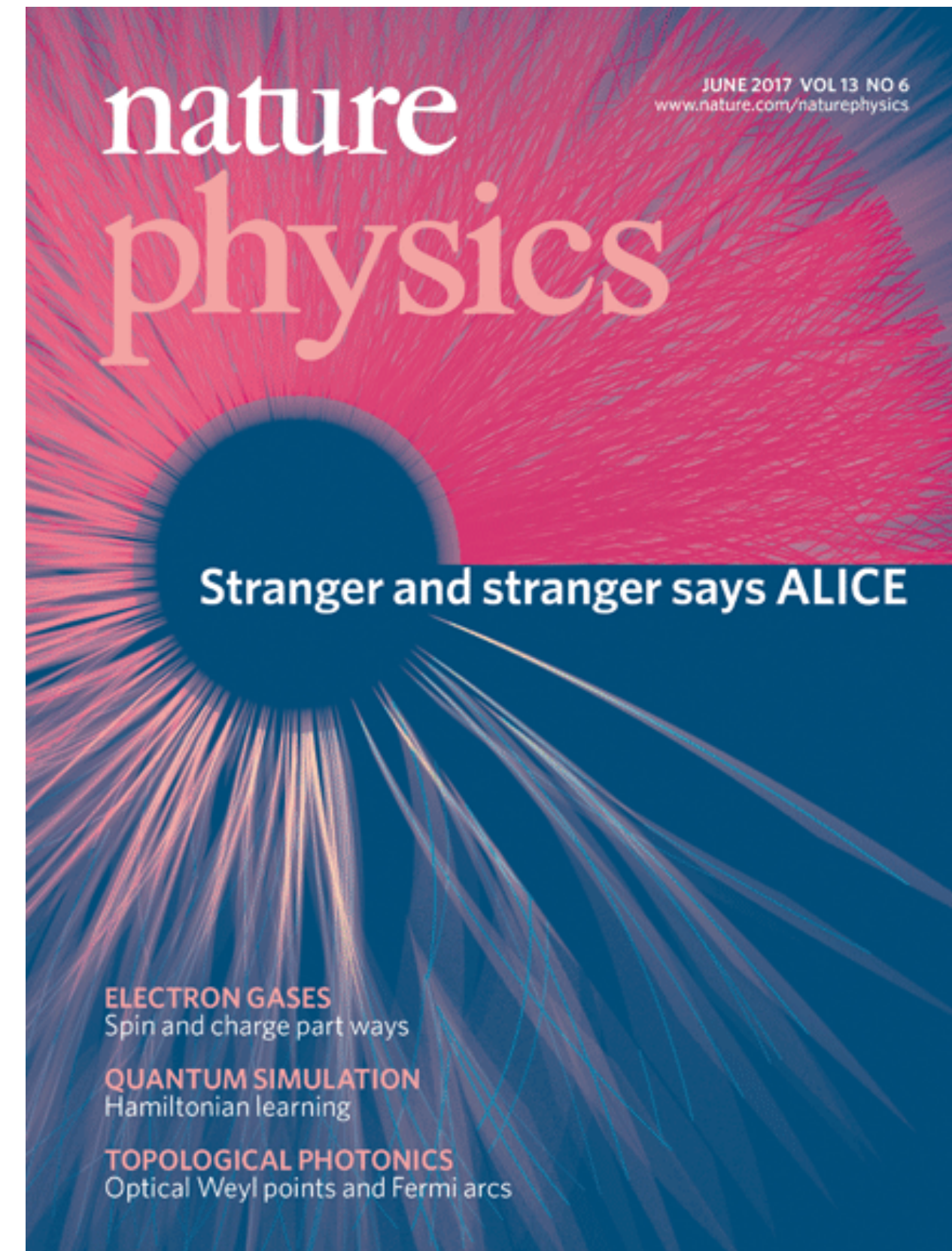
Pb-Pb @ $\sqrt{s} = 2.76$ ATeV
2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a

(peripheral Pb-Pb)
~hundreds of charged particles
produced

pp



(high multiplicity pp)
~100 charged particles
produced

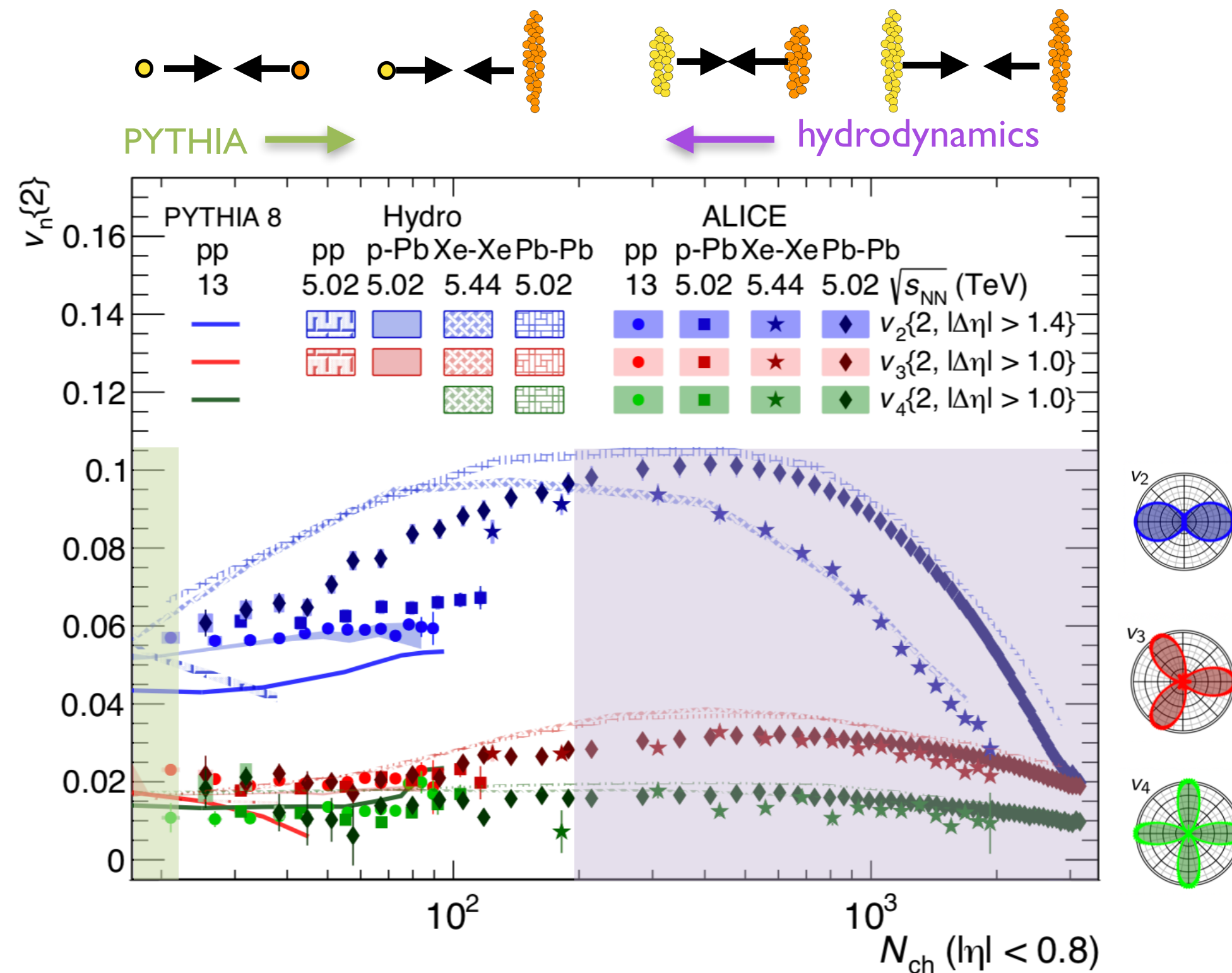


For many years, the **proton-proton** collision was used as “reference data” where no QGP is expected ...

But !



Flow in Pb-Pb, Xe-Xe, p-Pb and even pp



ALICE,
Physical Review Letters
123, 142301

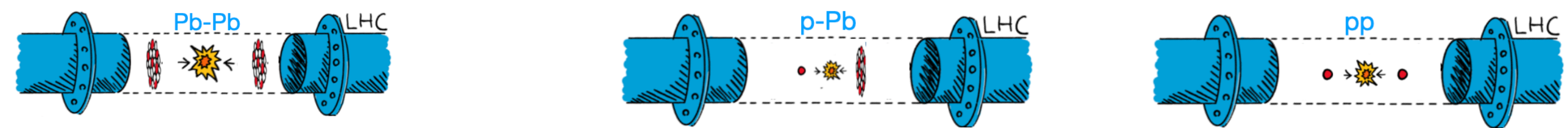
Major contributions:
Mingrui Zhao (CIAE/NBI)

- ❖ **Discovery of flow in small collision systems (proton-lead, proton-proton collisions)**
- ❖ **Challenges two paradigms at once!**
 - How far down in system size does the “Standard model of heavy ions” (**hydrodynamics**) remain?
 - Can the standard tool for minimum bias pp (**PYTHIA**) remain standard?

Smallest droplet of Quark-Gluon Plasma

❖ Flow of identified particles in p-Pb and pp collisions

- Confirm that the flow was established at the quark level
- Model without quark coalescence cannot qualitatively describe trends seen in data
- **Discovery** of partonic (quark & gluon) flow in small systems -> a small droplet of QGP



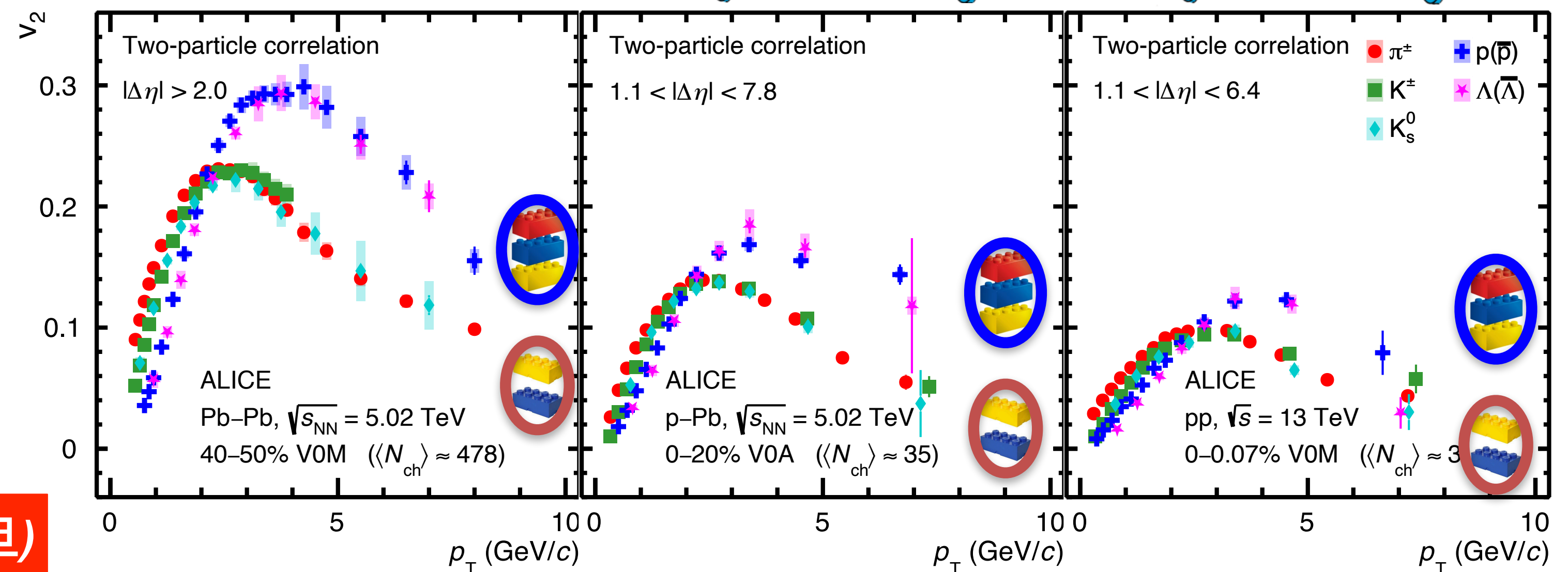
nature communications



Article

<https://doi.org/10.1038/s41467-025-67795-1>

Observation of partonic flow in proton–proton and proton–nucleus collisions



Close collaboration with Fudan U. (复旦)



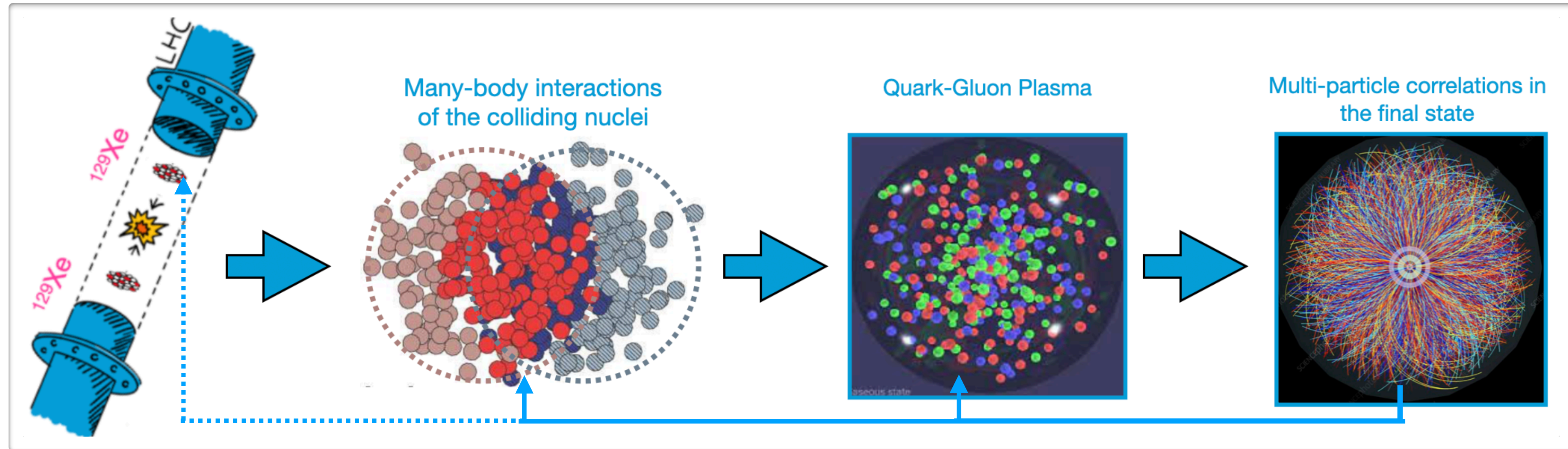
UNIVERSITY OF
COPENHAGEN

You Zhou (NBI) @ Visit of Chinese Nuclear Physics Society

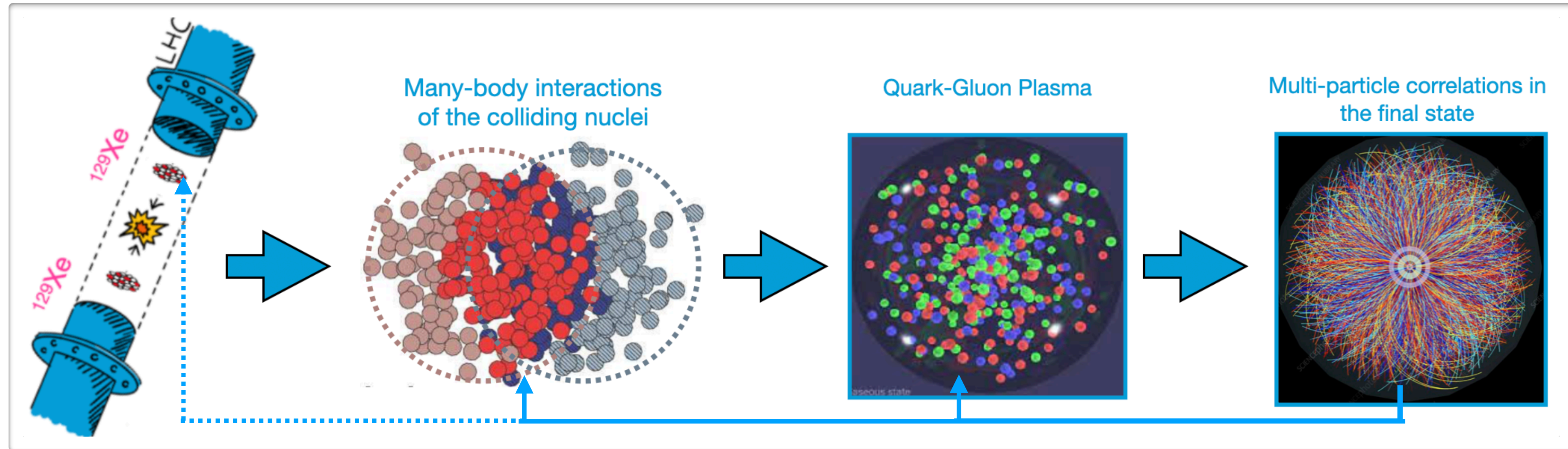
June 25th, 2026

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Paradigm Shift Research: Nuclear Structure at the LHC



Paradigm Shift Research: Nuclear Structure at the LHC



The Nobel Prize in Physics 1975



Photo from the Nobel Foundation archive.
Aage Niels Bohr

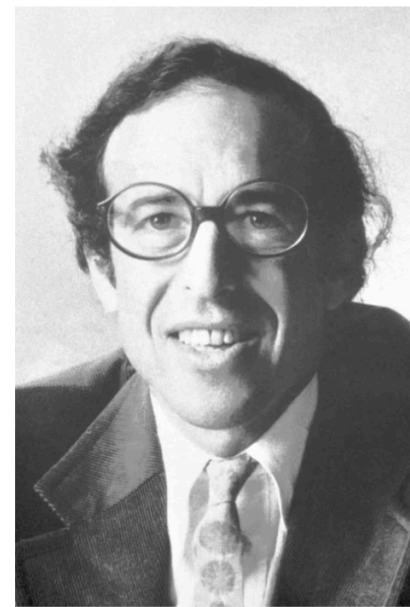


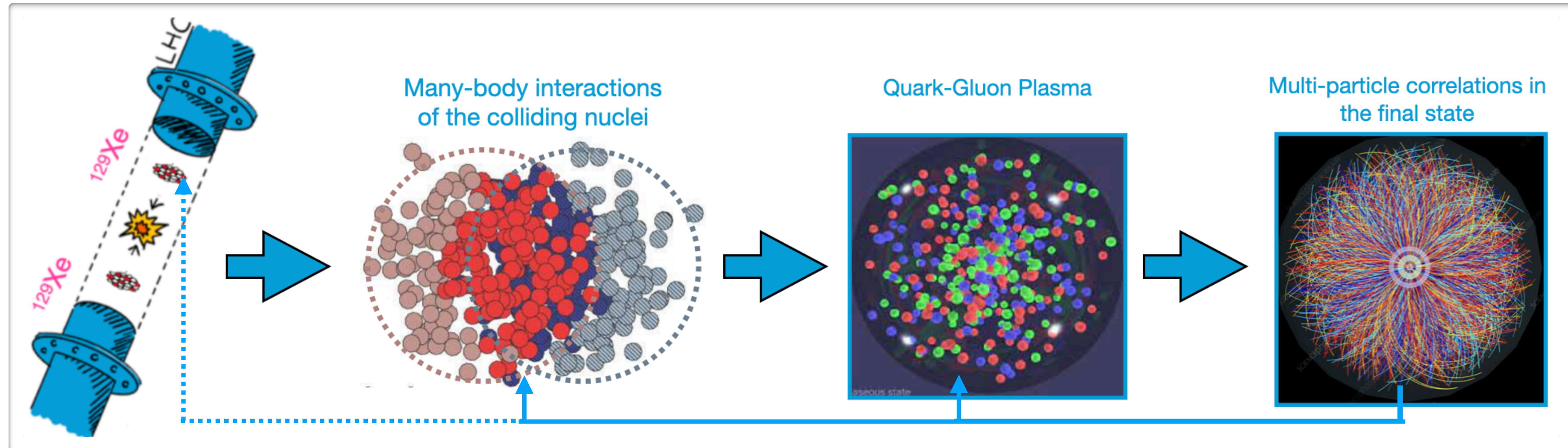
Photo from the Nobel Foundation archive.
Ben Roy Mottelson



Photo from the Nobel Foundation archive.
Leo James Rainwater

“for the discovery of the connection between **collective motion** and **structure of the atomic nucleus...**”

Paradigm Shift Research: Nuclear Structure at the LHC



The Nobel Prize in Physics 1975



Photo from the Nobel Foundation archive.
Aage Niels Bohr

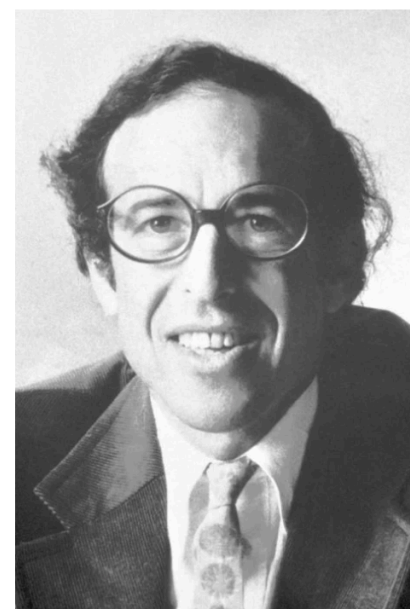
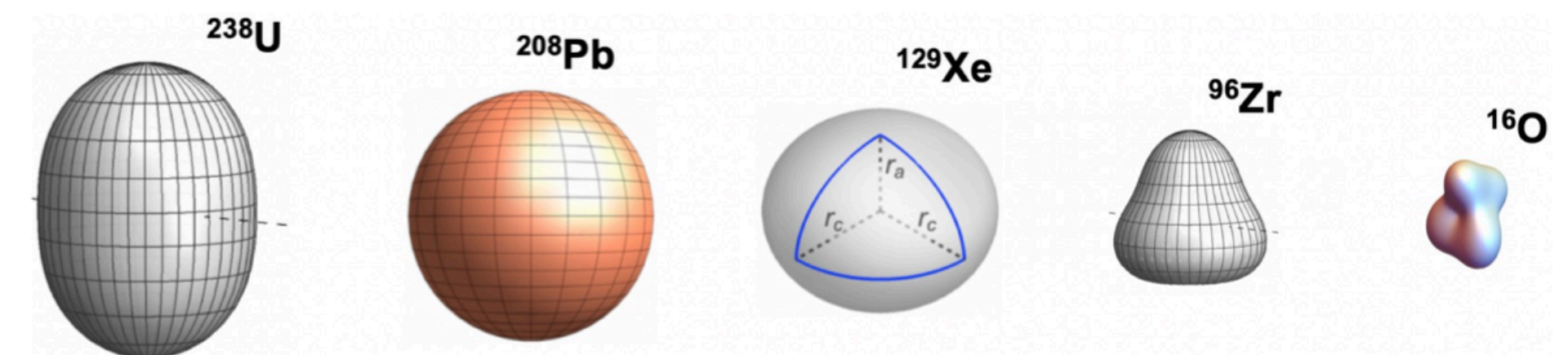


Photo from the Nobel Foundation archive.
Ben Roy Mottelson



Photo from the Nobel Foundation archive.
Leo James Rainwater

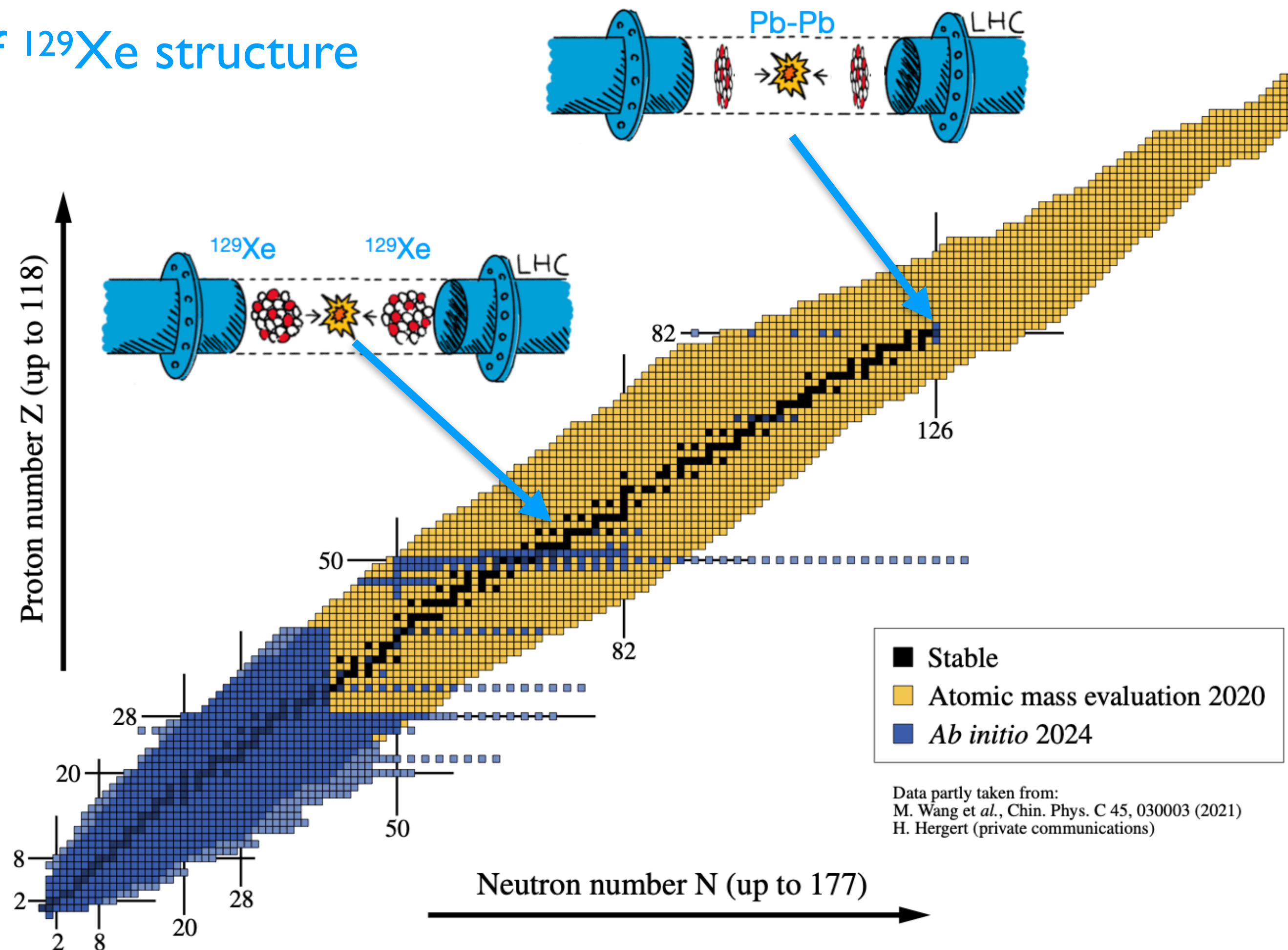
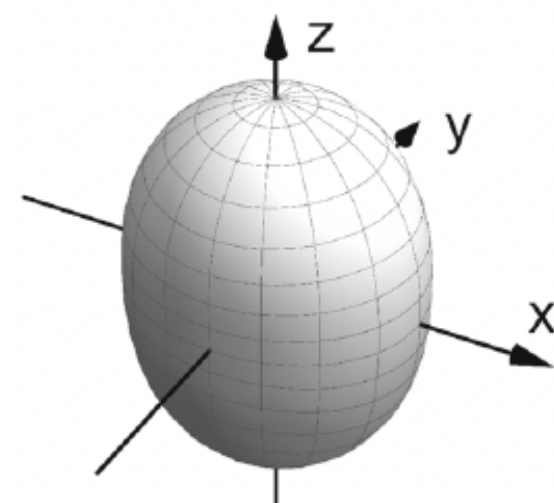
“for the discovery of the connection between **collective motion** and **structure of the atomic nucleus...**”



Precise Nuclear Structure Tomography

❖ Precise Nuclear Structure Tomography of ^{129}Xe structure

- Report on Progress in Physics, in preparation
- Physical Review Letters 133 (2024) 192301
- Eur. Phys. J. C (2025) 85, 1016
- Eur. Phys. J. A (2025) 61, 237
- Phys. Lett. B 850 (2024) 138477
- Eur. Phys. J. A (2024) 60, 38
- Eur. Phys. J. A (2023) 59, 279
- Phys. Lett. B 834 (2022) 137393



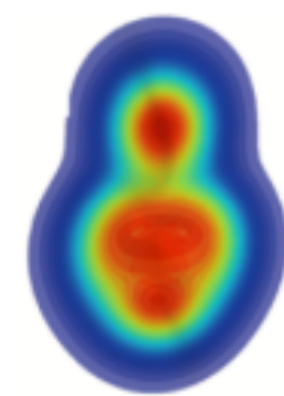
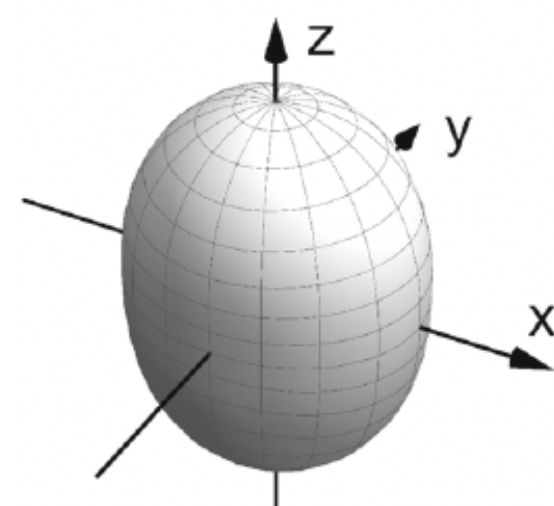
Close collaboration with CIAE (原子能院)



Precise Nuclear Structure Tomography

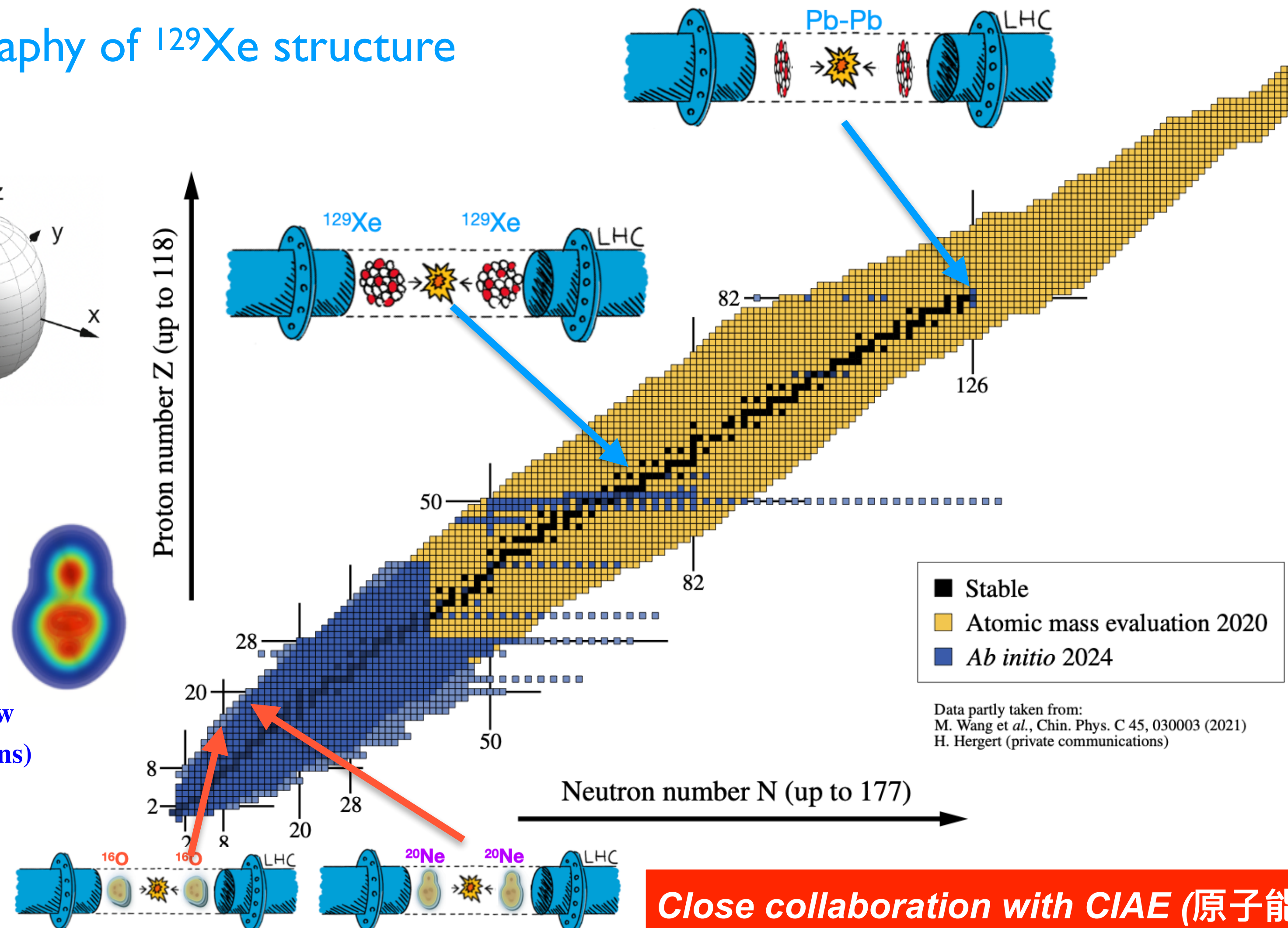
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- Eur. Phys. J. A (2023) 59, 279
- Phys. Lett. B 834 (2022) 137393



❖ Probe α -clustering structure of ^{20}Ne and ^{16}O

- Progress in Particle and Nuclear Physics, invited review
- arXiv: 2509.06428, Phys. Rev. Lett. (Editors' suggestions)
- Nature Physics, in Preparation
- Phys. Rev. Lett., in Preparation
- Phys. Lett. B 874 (2026) 140254
- Phys. Lett. B 868 (2025) 139698



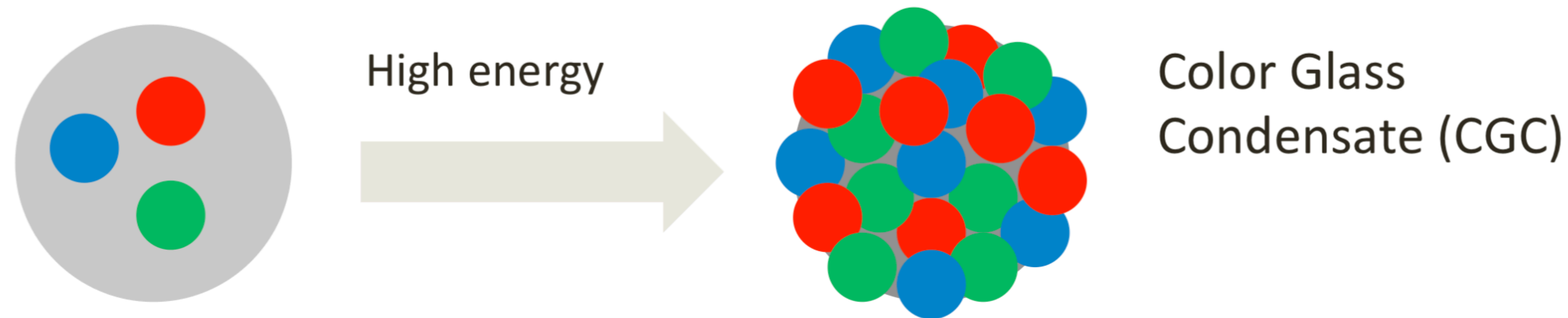
Long-term prospective: study of CGC



Color ... gluons have “colors”

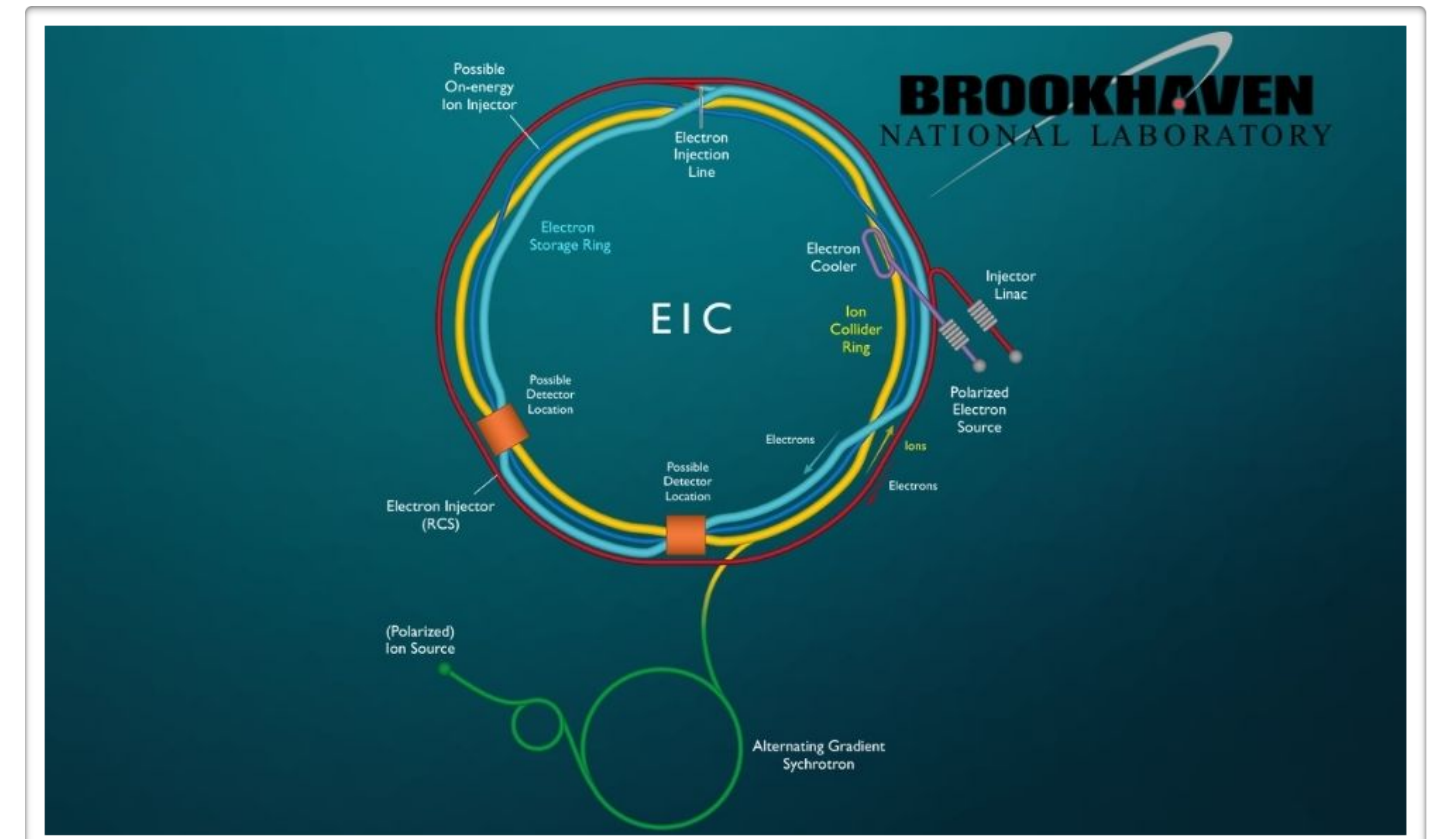
Glass ... gluons with small longitudinal mom. fractions ($x \ll 1$) are created by long-lived partons that are distributed randomly on the transverse disk

Condensate ... gluon density is very high, and saturated



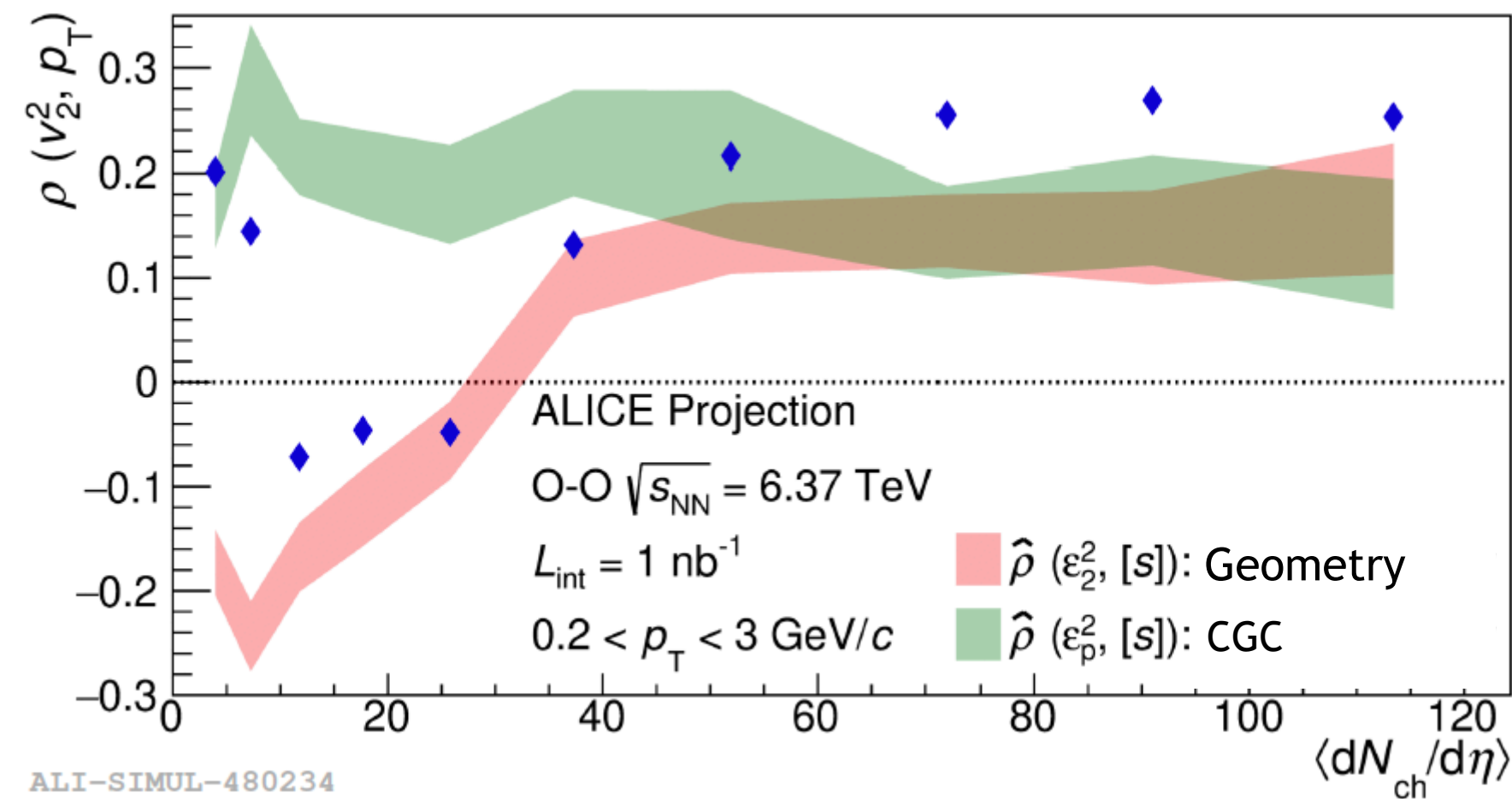
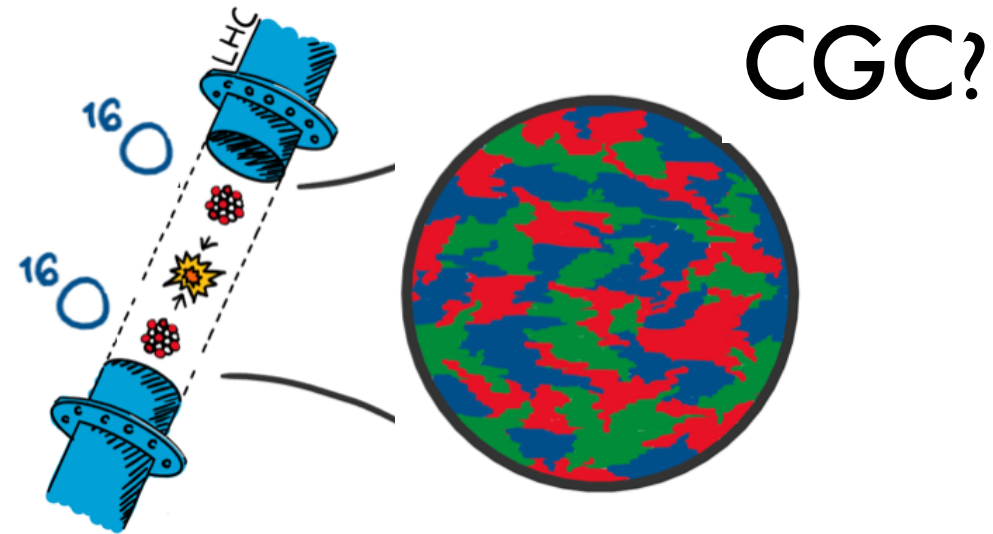
- **Most advanced** (and still developing) **theoretical picture of high energy scattering in QCD**

- CGC has the potential to explain unsolved puzzles:
 - how particles are produced in high-energy collisions,
 - the distribution of matter itself inside of these particles (initial conditions)
- Pay \$2 billion dollar to build Electron-Ion Collider in 2035, or something *cheaper* and *earlier*.



Discovery of CGC?

O-O collisions @ Run3



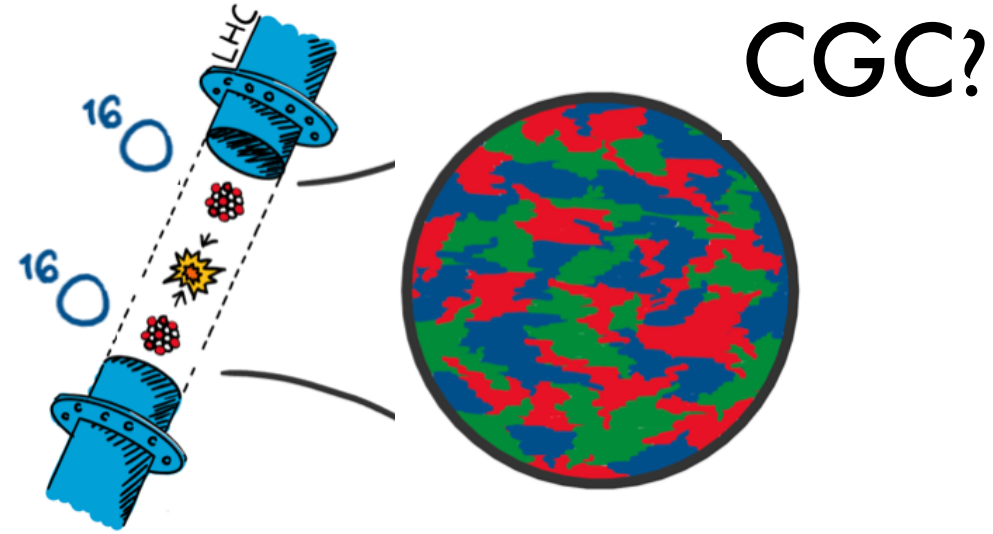
First probe of CGC with $\rho(v_n^2, [p_T])$ in O-O collisions at Run 3

- twice of sign changes -> signature of CGC

Major contributions:
Shihai Jia (CIAE/NBI)

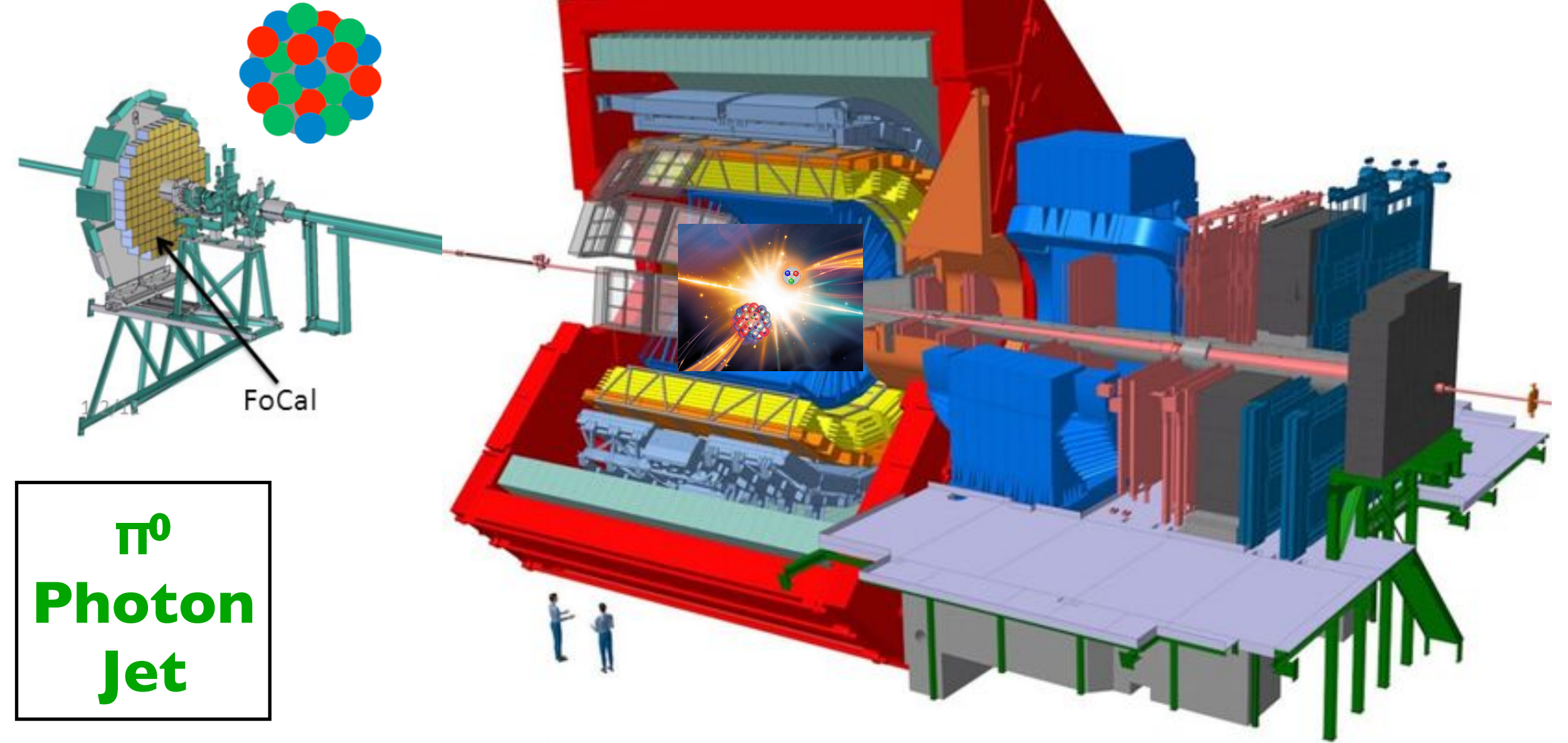
Discovery of CGC?

O-O collisions @ Run3

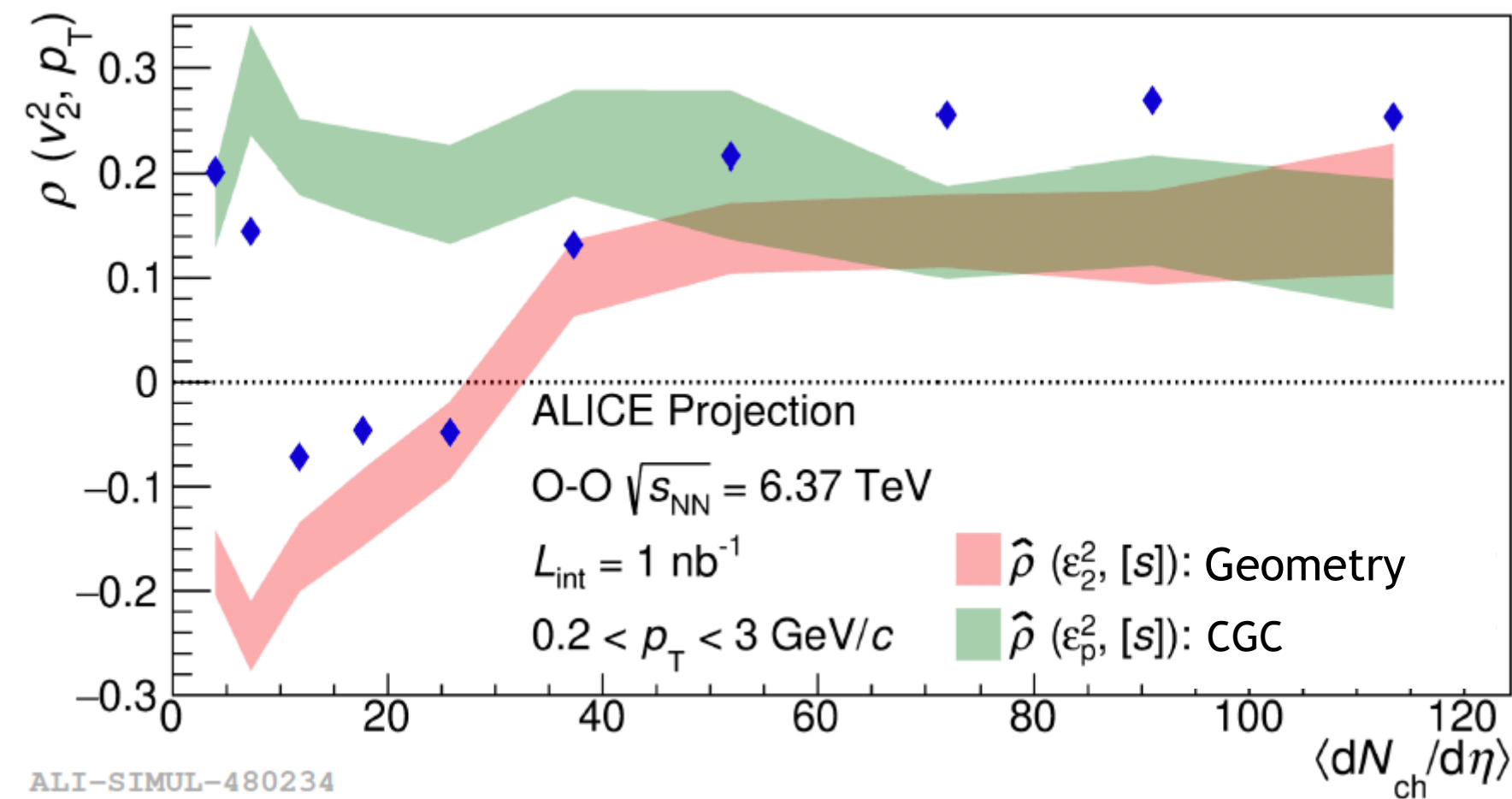


CGC?

FoCal @ Run 4



π^0
Photon
Jet



First probe of CGC with $\rho(v_n^2, [p_T])$ in O-O collisions at Run 3

- twice of sign changes -> signature of CGC

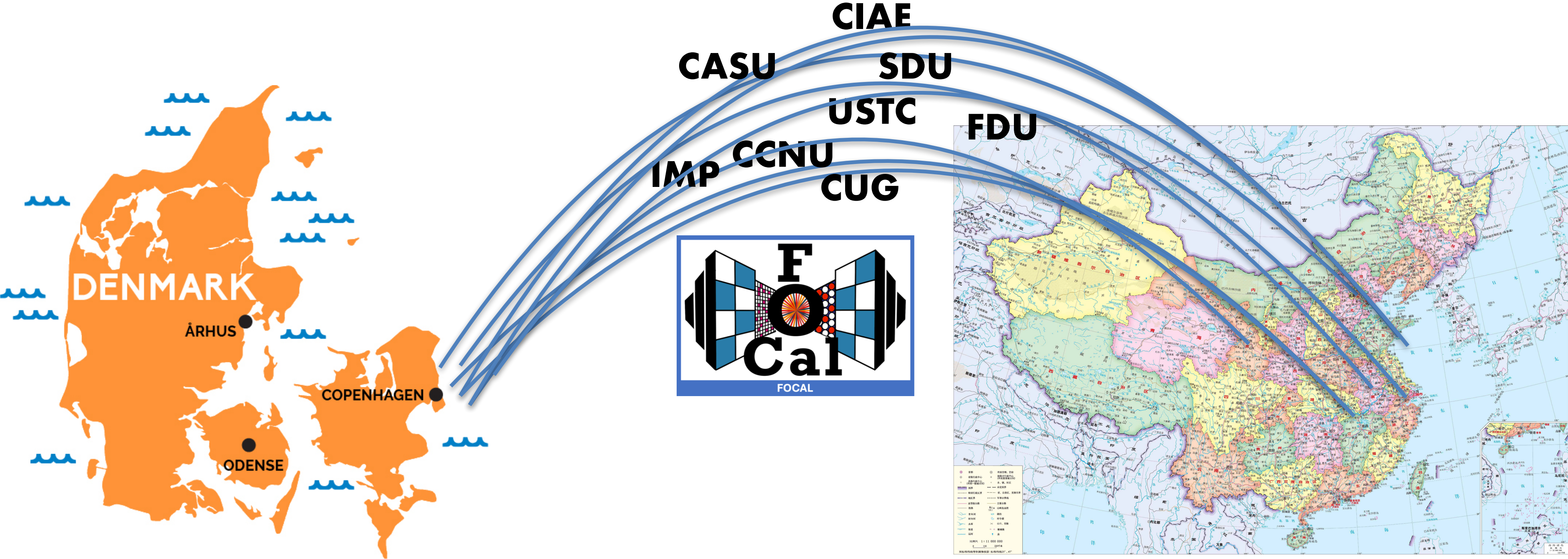
Future measurements with π^0 and photons with FoCal

- Proposal of FoCal has been approved by ALICE and LHCC, costs ~ 11M CHF
- Discover or disprove of CGC, challenging the advanced theory in the entire field

Major contributions:
Shihai Jia (CIAE/NBI)



Collaboration: developing next generation detector



中方单位：原子能院，国科大，近物所，复旦大学，山东大学，华中师范大学，中国地质大学
CIAE CASU IMP FDU SDU CCNU CUG



Challenge: International collaboration with long-term visit

Need urgent supports to continue the exchange program



时间: 2024 年 12 月 23 日

2024 年度“菁英启航”青年人才国际研修录取通知



Challenge: International collaboration with long-term visit

Need urgent supports to continue the exchange program

❖ New supports of Students Exchange Program need urgently!

- CSC(留学基金委) is no longer possible in many EU countries due to the political decisions



时间: 2024 年 12 月 23 日

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Challenge: International collaboration with long-term visit

Need urgent supports to continue the exchange program

❖ New supports of Students Exchange Program need urgently!

- CSC(留学基金委) is no longer possible in many EU countries due to the political decisions

❖ New financial supports for long-term visits are possible

- Mainly through individual research grants
- Regular exchange programs
 - with a very limited number per year
 - Available in very few universities and institutes



时间: 2024 年 12 月 23 日

2024 年度“菁英启航”青年人才国际研修录取通知



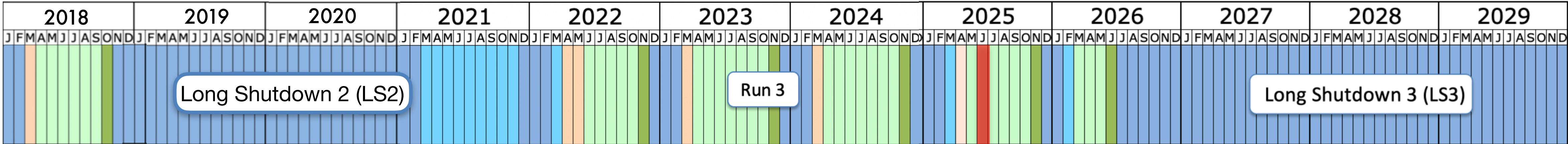
“Nyhavn” for the scientific collaboration between China and EU



Niels Bohr Institute

- ❖ Long-term collaborations with the Chinese colleagues
 - Established tight collaboration with **CCNU**, **CIAE**, **Fudan**, **PKU**
 - Joint PhD students, exchange/visiting programs
- ❖ Recognized expertise in collective flow studies
 - Group size: ~ 6 people (**0.3% ALICE members**)
 - Leading contributions in **10-20% ALICE publications**
 - Grants from ERC(欧盟研究委员会) and DFF(丹麦“基金委”)
- ❖ Leading the design and construction of ALICE-FoCal
- ❖ Host the visits of **100+** Chinese Nuclear Physicists in the past 10 years.

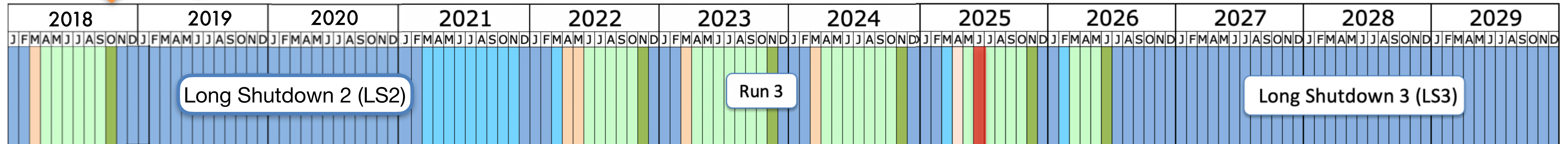
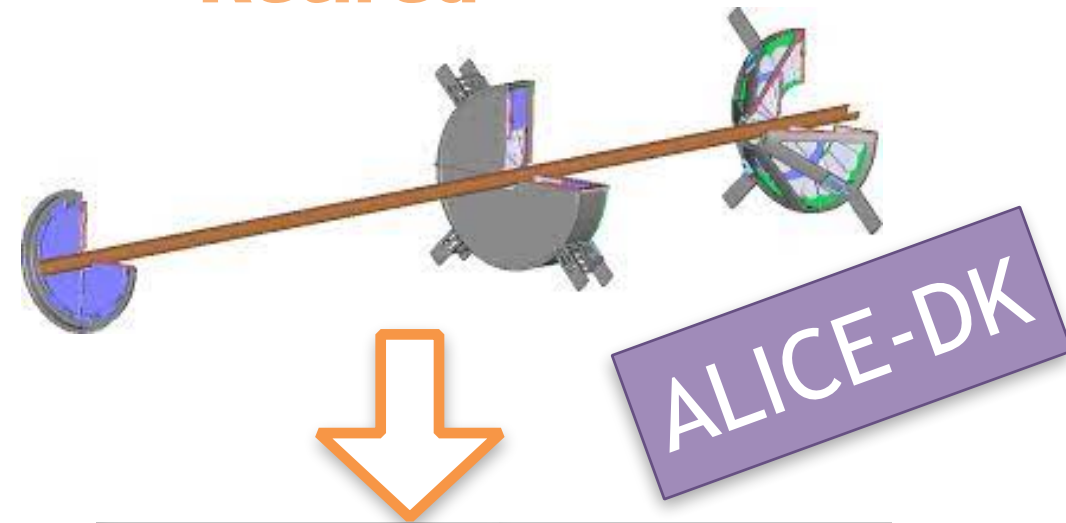
Timeline and milestones



Timeline and milestones

Forward Multiplicity Detector (FMD)

→ Retired



Run 2: exploration of QGP evolution

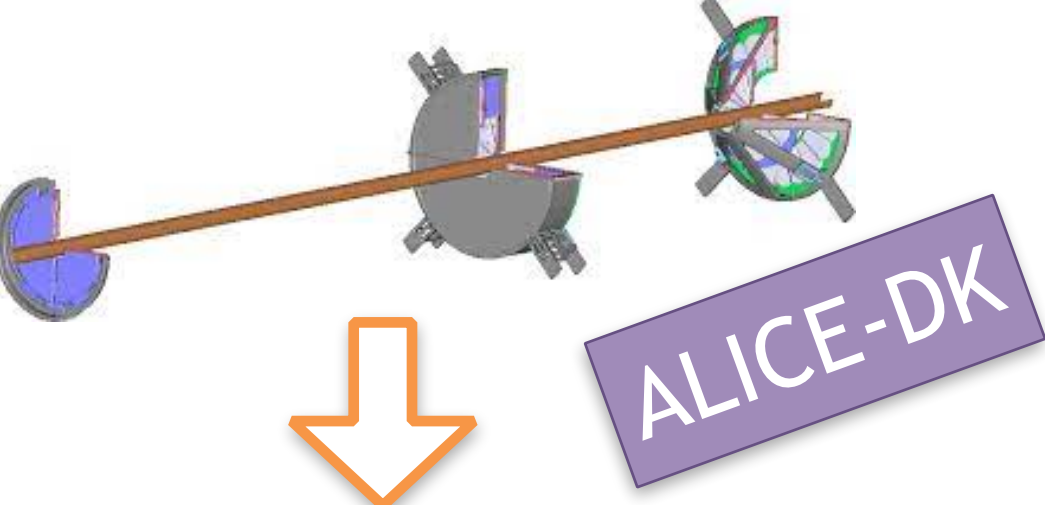
DNRF Discovery Center
100M DKK (10 years)

DFF-Project 2

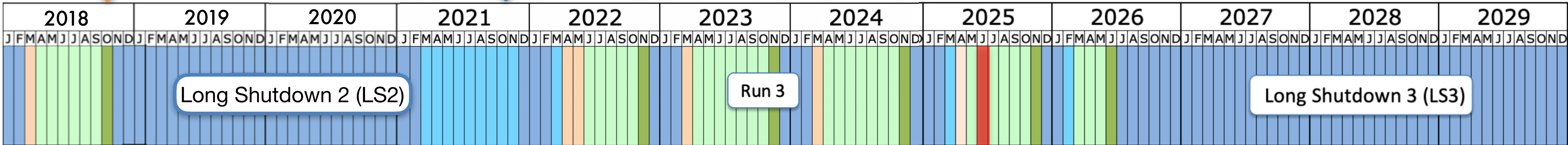
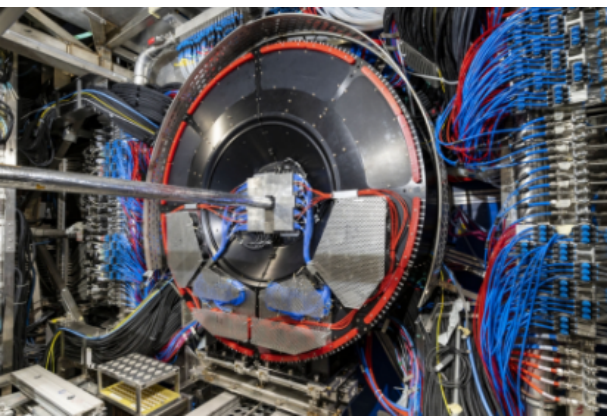
6.6 M DKK (5 years)

Timeline and milestones

Forward Multiplicity
Detector (FMD)
—> Retired



Fast Interaction Trigger (FIT)



Run 2: exploration
of QGP evolution

DNRF Discovery Center
100M DKK (10 years)
DFF-Project 2
6.6 M DKK (5 years)

Run 3: discover QGP in small systems

10 M DKK (5 years) THE VELUX FOUNDATIONS

Run 3: Precise extraction of QGP properties

6.5 M DKK (4 years)



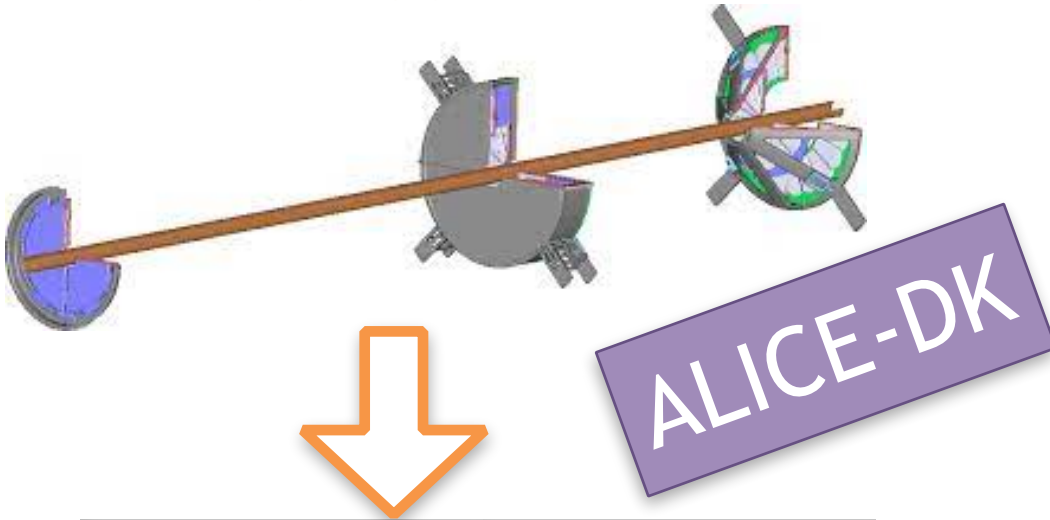
Run 3: Nuclear Structure at the energy frontier

11 M DKK (5 years)

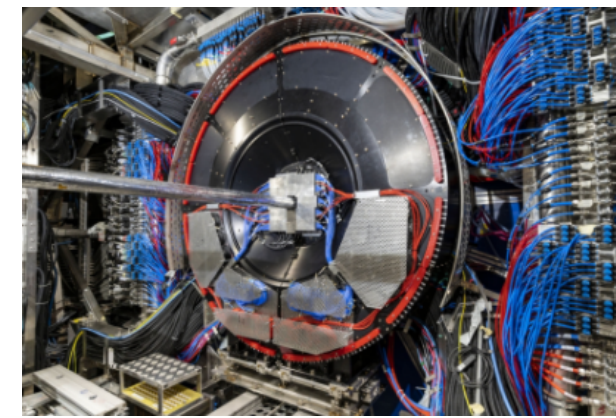


Timeline and milestones

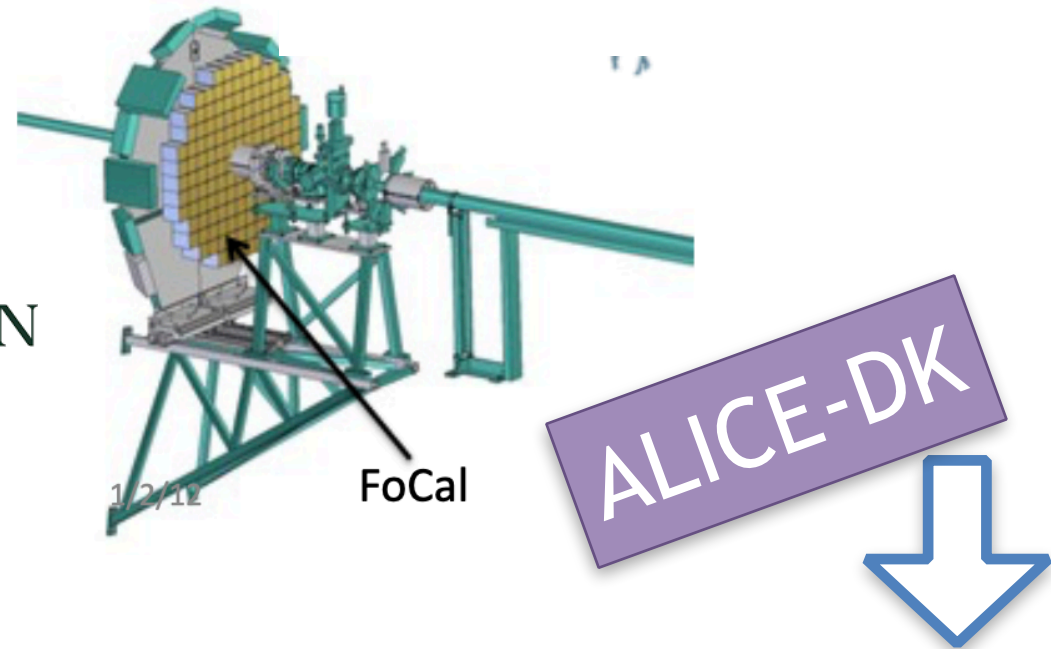
Forward Multiplicity Detector (FMD)
—> Retired



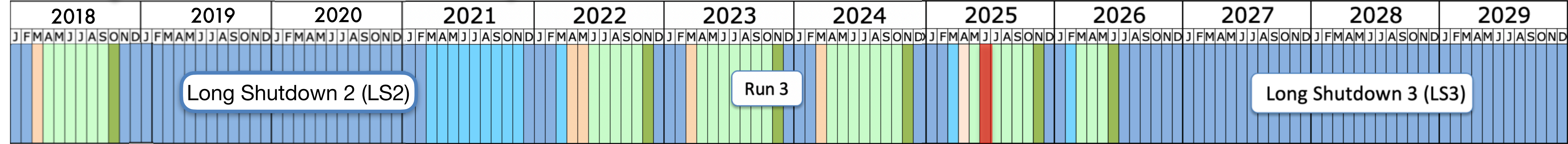
Fast Interaction Trigger (FIT)



Forward Calorimeter (FoCal)



CARLSBERG FOUNDATION
8.5 M DKK (5 years)



Run 2: exploration of QGP evolution

DNRF Discovery Center
100M DKK (10 years)
DFF-Project 2
6.6 M DKK (5 years)

Run 3: discover QGP in small systems

10 M DKK (5 years) THE VELUX FOUNDATIONS

Run 3: Precise extraction of QGP properties

6.5 M DKK (4 years)



Run 3: Nuclear Structure at the energy frontier

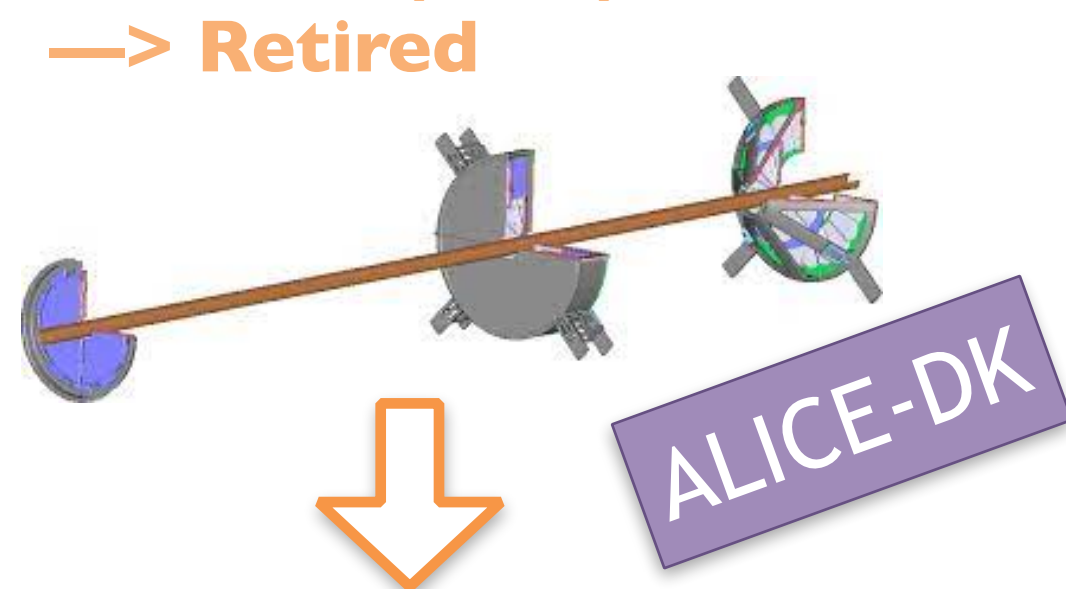
11 M DKK (5 years)

Run 4: discovery of CGC

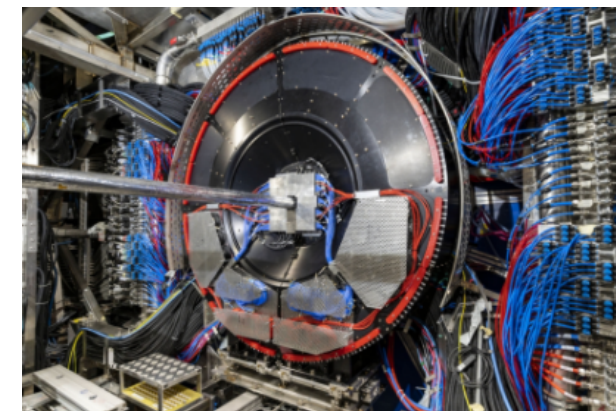


Timeline and milestones

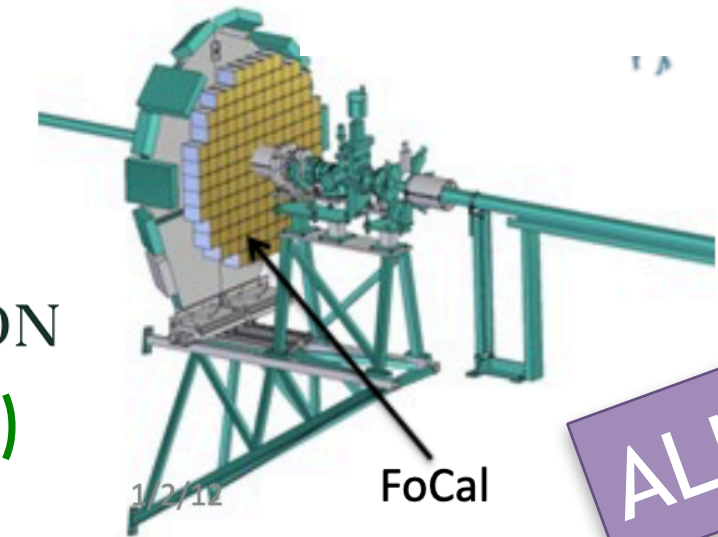
Forward Multiplicity Detector (FMD)
—> Retired



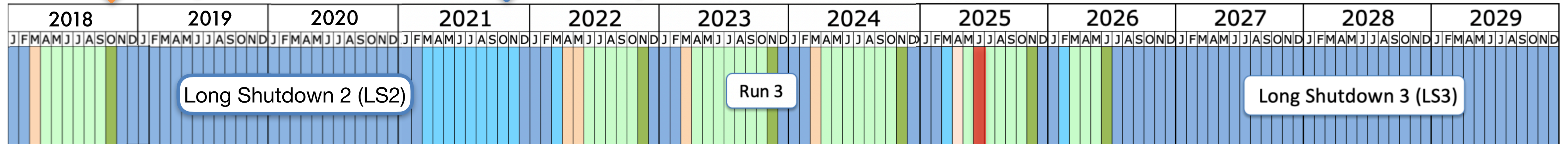
Fast Interaction Trigger (FIT)



Forward Calorimeter (FoCal)



CARLSBERG FOUNDATION
8.5 M DKK (5 years)



Run 2: exploration of QGP evolution

DNRF Discovery Center
100M DKK (10 years)

DFF-Project 2
6.6 M DKK (5 years)

Run 3: discover QGP in small systems

10 M DKK (5 years)

THE VELUX FOUNDATIONS

Run 3: Precise extraction of QGP properties

6.5 M DKK (4 years)



Run 3: Nuclear Structure at the energy frontier

11 M DKK (5 years)

Run 4: discovery of CGC



❖ LHC Run3 and Run4 programs

- New discoveries with major upgrades!



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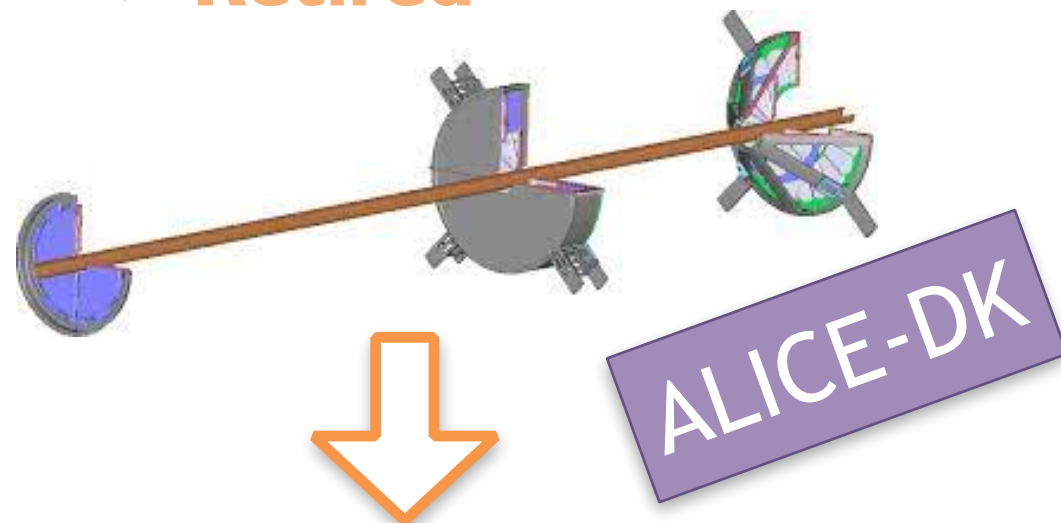
You Zhou (NBI) @ Visit of Chinese Nuclear Physics Society

June 25th, 2026

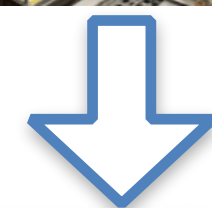
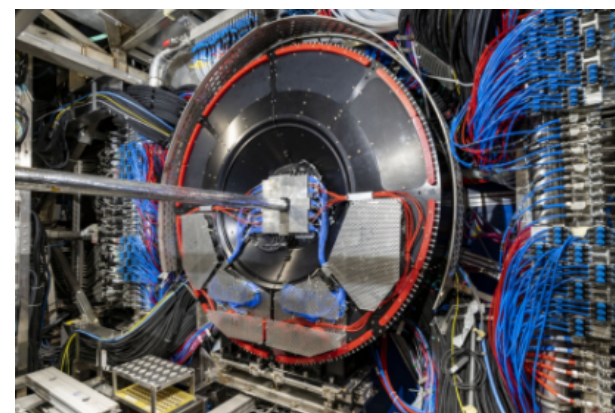
Timeline and milestones

Forward Multiplicity Detector (FMD)

—> Retired

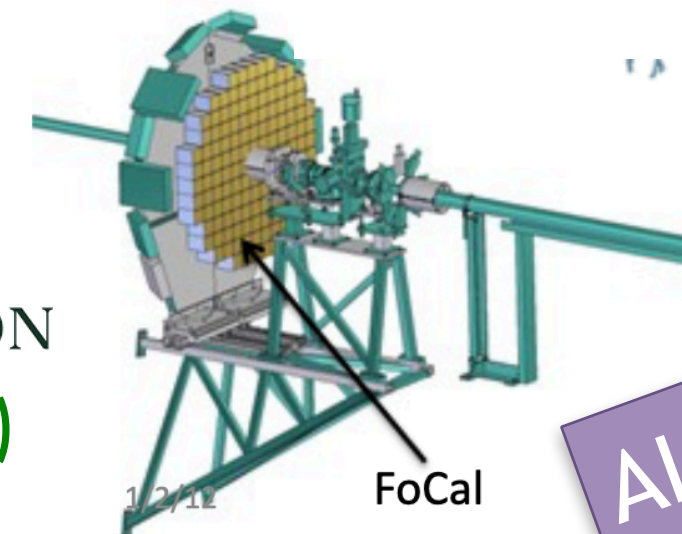


Fast Interaction Trigger (FIT)



ALICE-DK

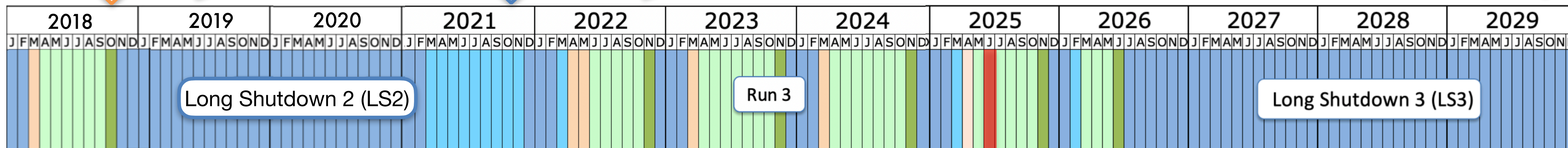
Forward Calorimeter (FoCal)



CARLSBERG FOUNDATION

8.5 M DKK (5 years)

ALICE-DK



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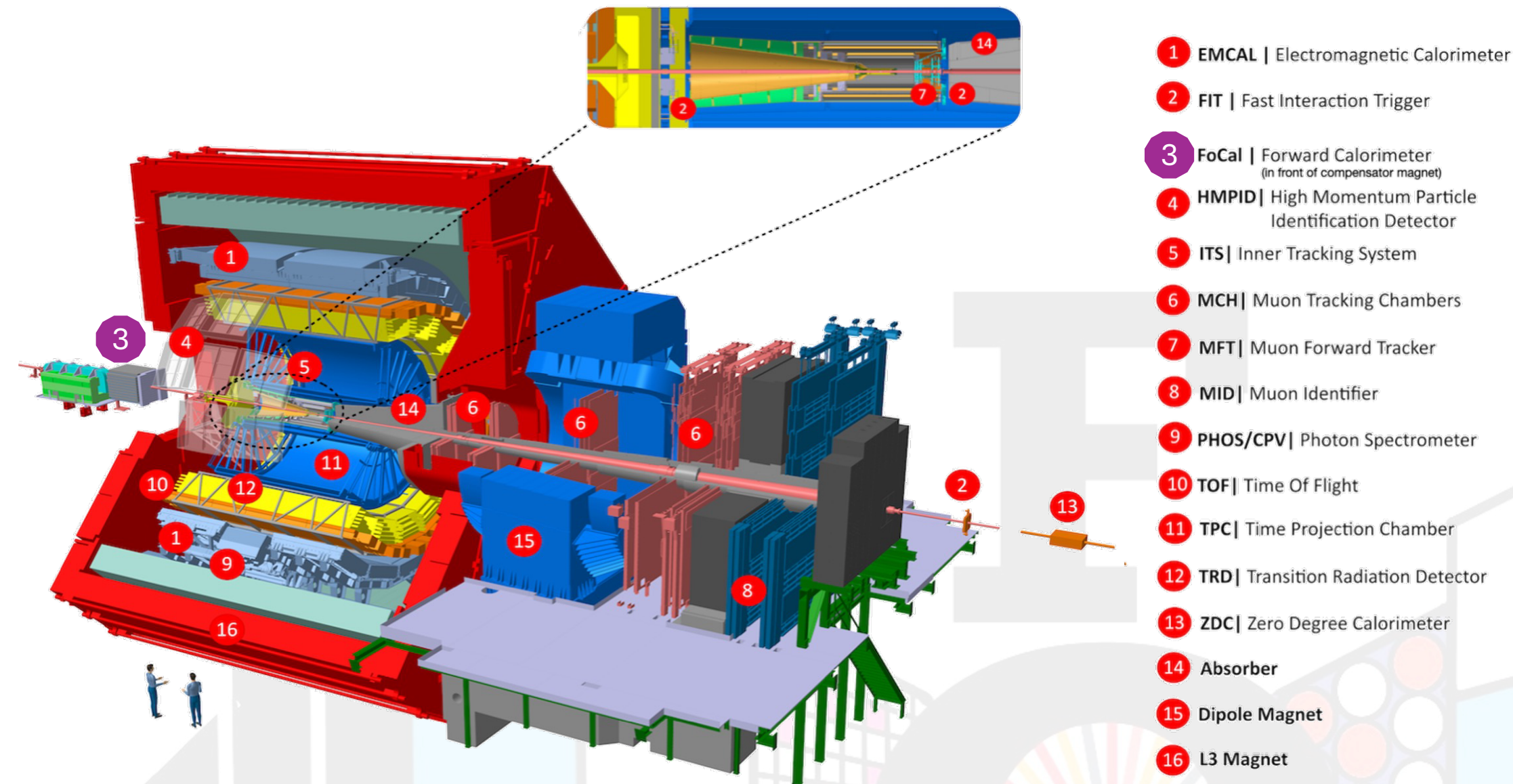
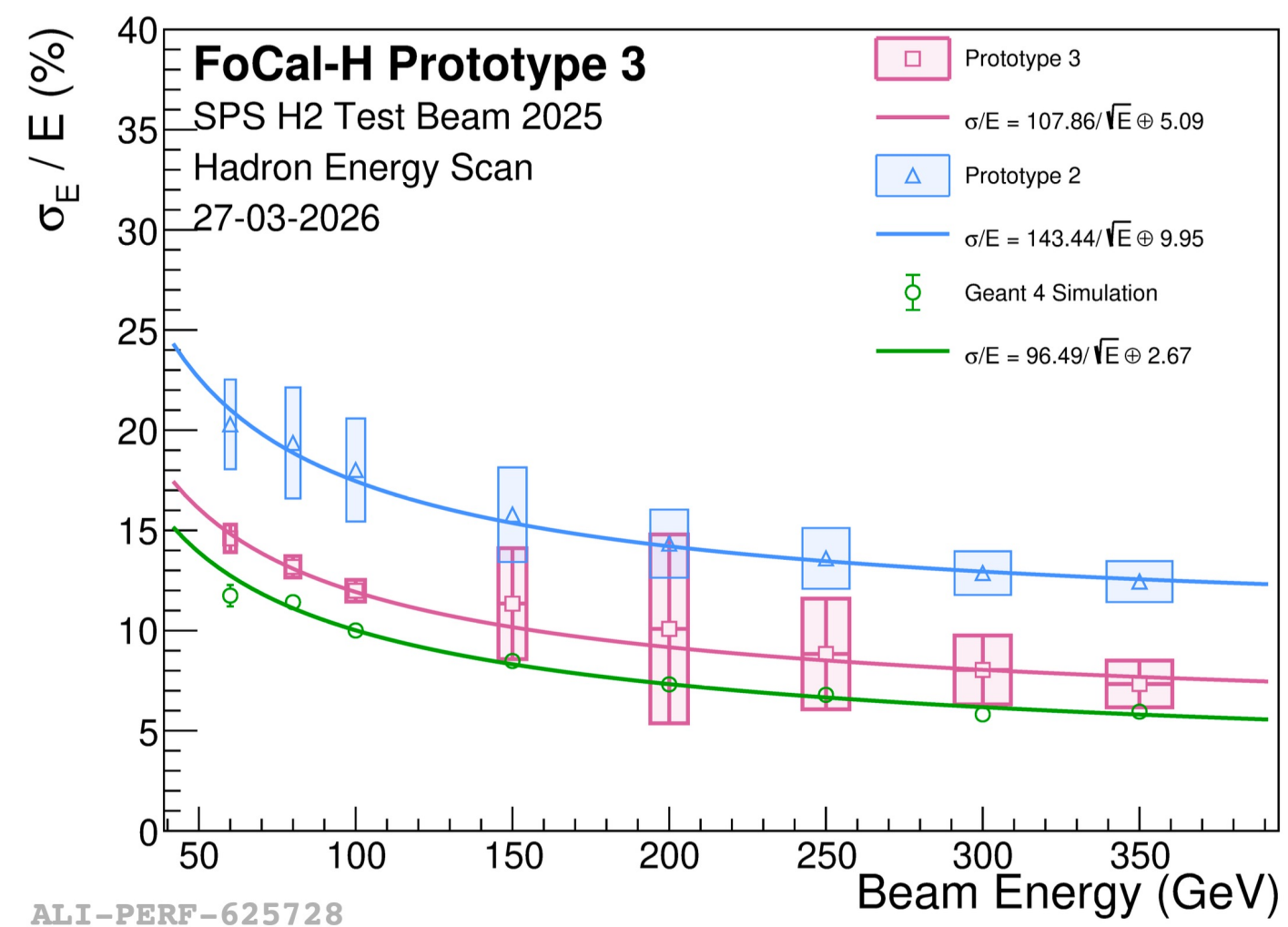
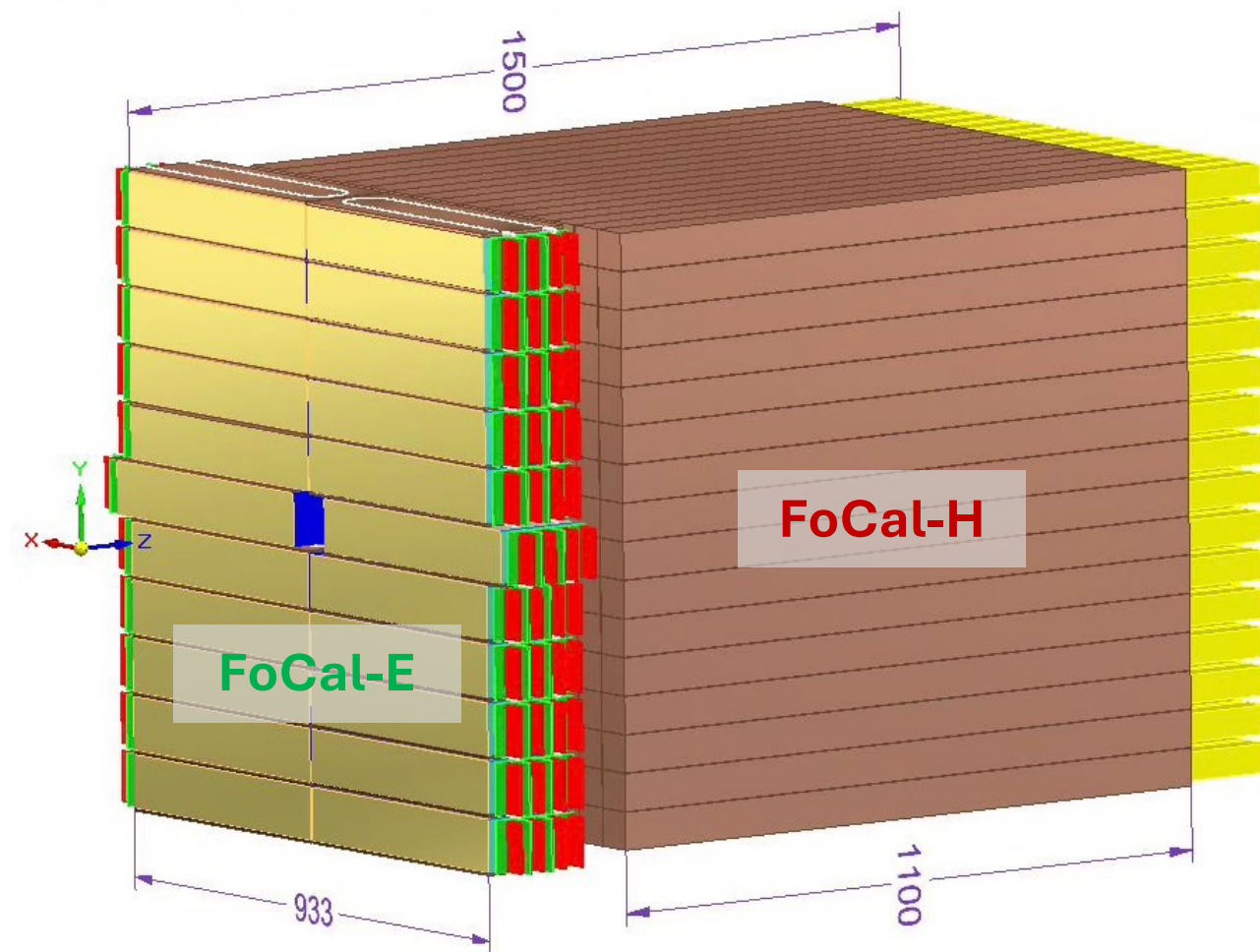
You Zhou (NBI) @ Visit of Chinese Nuclear Physics Society

June 25th, 2026

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Backup



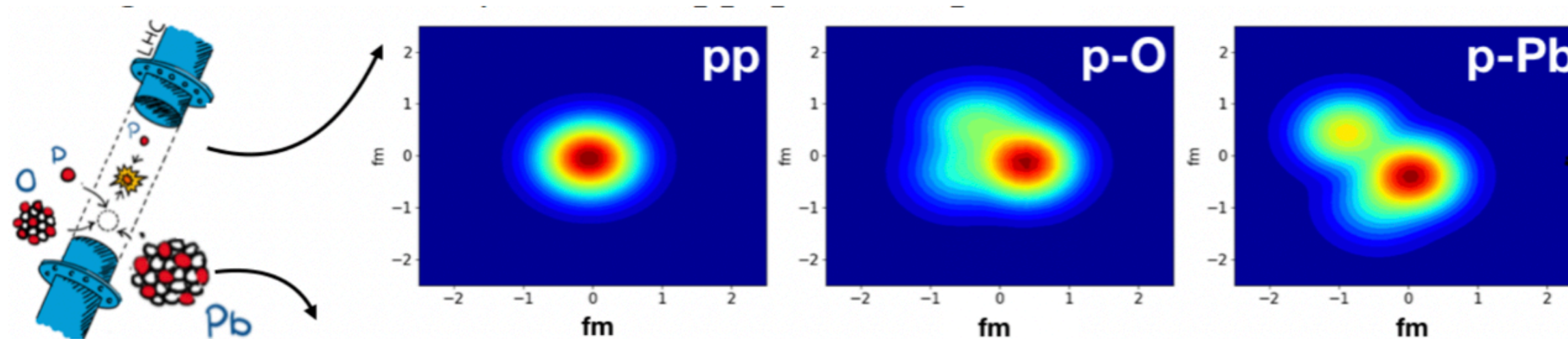


- FoCal is an upgrade of the ALICE experiment at the LHC, to be installed during **Long Shutdown 3** for data-taking in **Run 4**.
- It extends ALICE's reach to **forward rapidity** $3.2 < \eta < 5.8$, enabling precision direct photon measurements at small-x.
- NBI plays a leading role in FoCal-H, the hadronic part of FoCal.
- Recent SPS beam tests of the FoCal-H prototype achieved an energy resolution of about $108\%/\sqrt{E} \oplus 5\%$, meeting the LOI requirement.

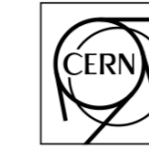
Highlight: small systems @ LHC

LHC Running Program

Year	Systems, time, L_{int}
2021	Pb-Pb, 3 weeks, 2.3/nb (0.5T) pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS
2022 (extended from 4 to 6 weeks)	p-O + O-O 7 TeV, 1 week, few 100/ μb (after EYETS?) Pb-Pb, 5 weeks, 3.9/nb (1.9@0.5T + 2@0.2T)
2023	pp 8.8 TeV, few days p-Pb 8.8 TeV, 3.x weeks



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



ALICE-PUBLIC-2020-005
CERN-LHCC-2020-018; LHCC-G-179

Future high-energy pp programme with ALICE

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Evgeny Kryshen (Petersburg Nuclear Physics Institute, Gatchina),
Andreas Mathis (TUM),
Maximiliano Puccio (CERN),
Marco van Leeuwen (NIKHEF),
Oton Vazquez Doce (TUM),
Michael Winn (CEA),
You Zhou (Copenhagen)

Abstract

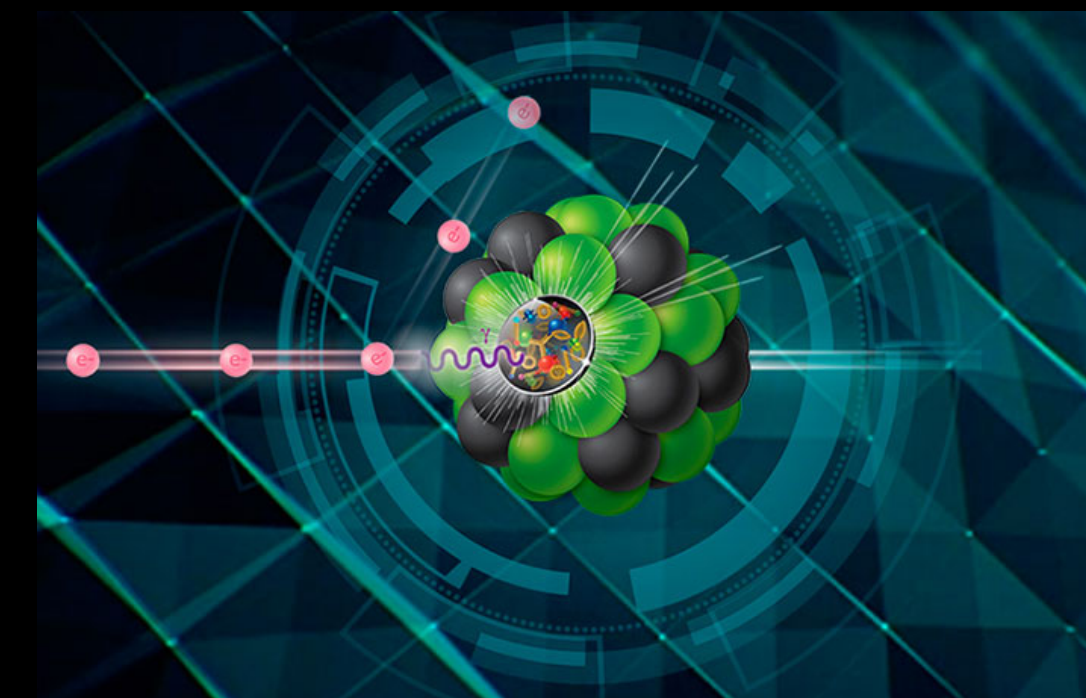
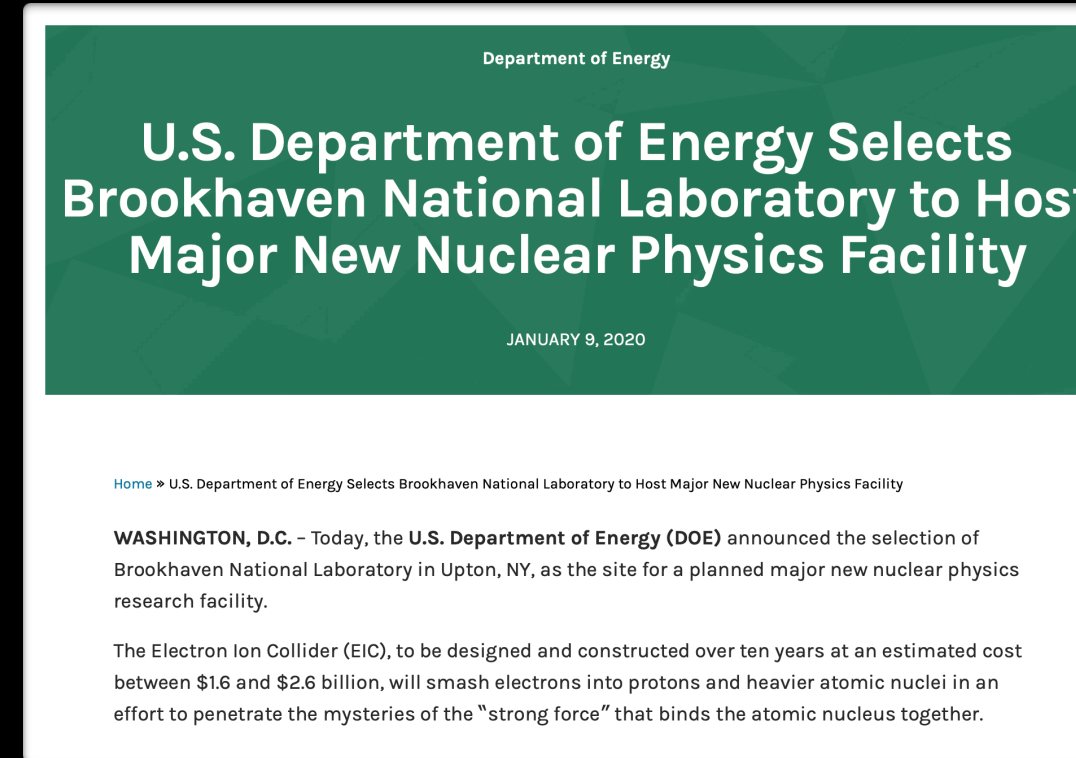
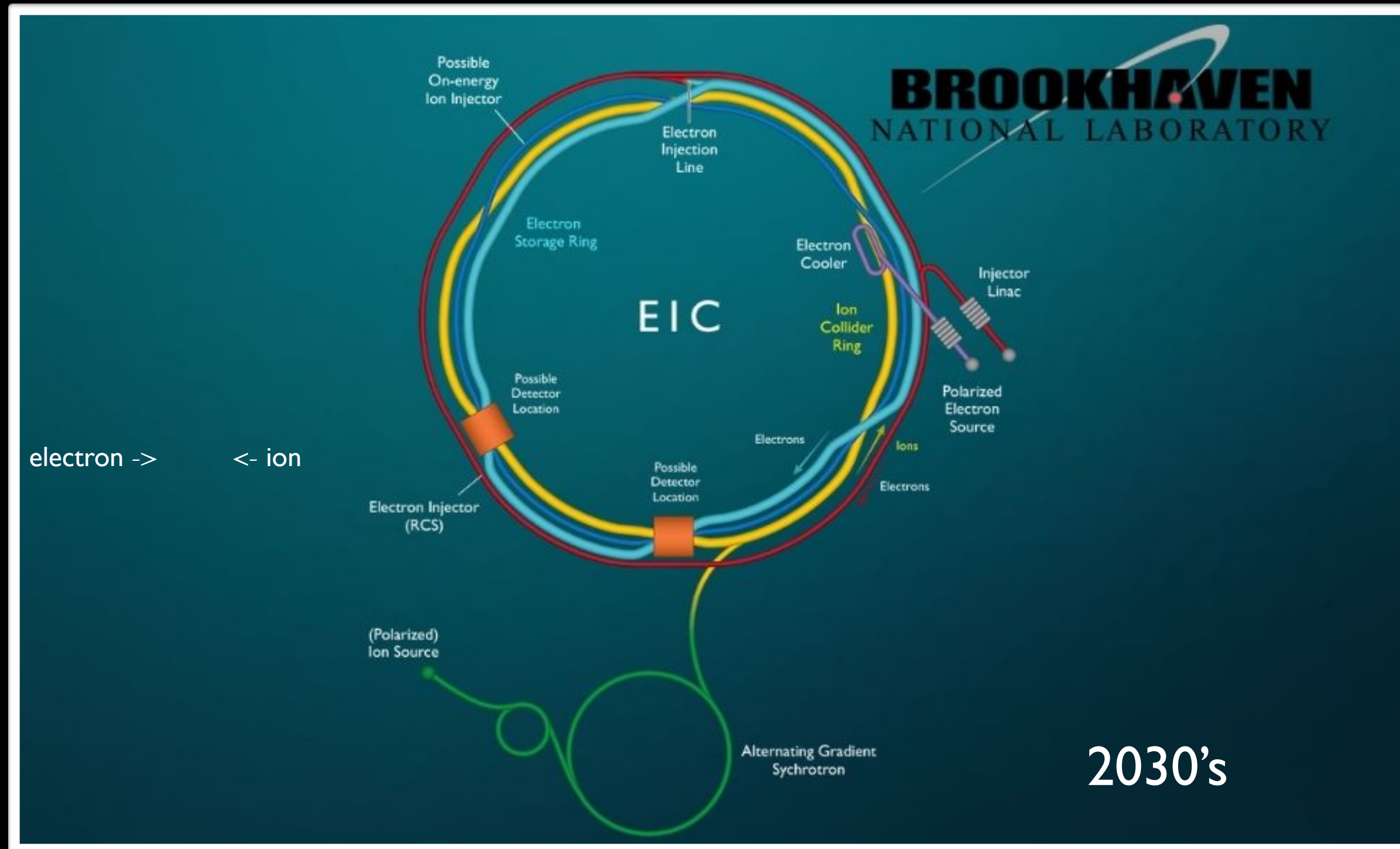
The discovery of QGP-like phenomena in small collision systems like pp and p-Pb collisions has surprised the community at large, and gave rise to a tremendous experimental and theoretical activity in recent years. The theoretical explanation and description attempts span today the entire field between fluid dynamics (many scatterings) and the free-streaming limit (no scatterings), and further experimental and theoretical work is needed for a full understanding of the underlying dynamics. In addition, high-statistics pp data can give insight into a number of interesting and important topics ranging from femtoscopy of strange baryons, over heavy-flavour objects to central-exclusive production of low-mass diffractive states. The present document discusses a number of contributions to this area that ALICE can give with dedicated pp data-taking in Run 3, together with possible data-taking strategy.

❖ Dedicated LHC running programs at Run3 and Run4

- Very high statistics collisions of pp, p-Pb, p-O, O-O (system size scan)
- Similar programs at RHIC@BNL with p-Al, p-Au, d-Au, ^3He -Au collisions
- ALICE-DK group led the O-O and p-O proposals



A new accelerator approved in US



- Critical importance of CGC, recognized by DOE of US, approved the design and construction of Electron-Ion Collider at a cost of \$1.6 - 2.6 Billion
- Can we do something similar but earlier and cheaper in Europe?
 - Also use the obtained knowledge as the input for EIC