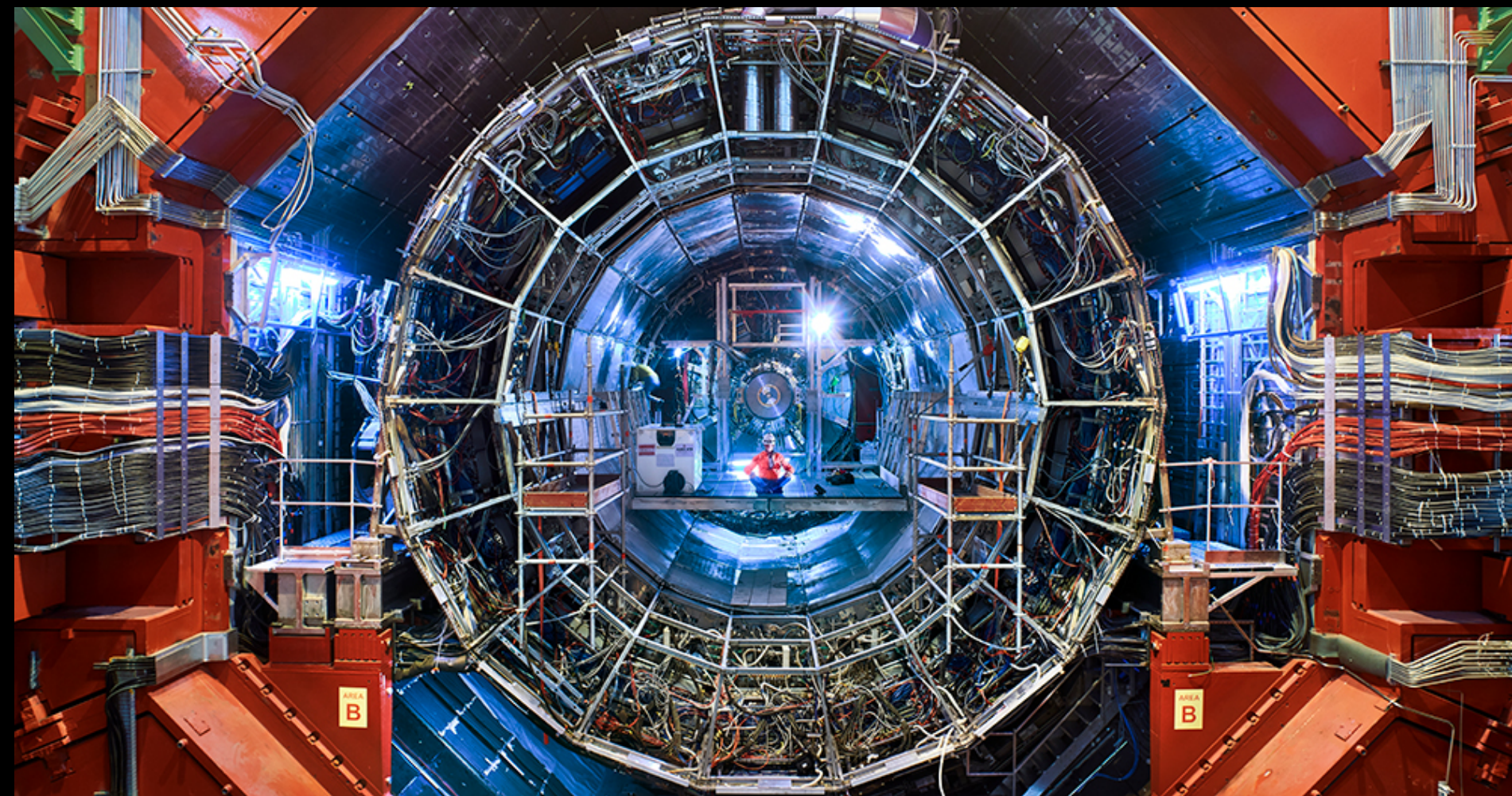


ALICE-Denmark Activities Report

(rECFA meeting)



You Zhou

Niels Bohr Institute



ALICE



UNIVERSITY OF
COPENHAGEN

I am You

2015.1 Moved to Denmark as a Postdoc



2019.1 Assistant Professor

2019.8 Associate Professor
(5-years temporary position)

20?? ??



2017 Carlsberg postdoc fellowship
(1.2M DKK for 2 years)
CARLSBERG FOUNDATION



2018 DFF-Sapere Aude Research Group Leader
(6.4M DKK for 4 years), declined
 DANMARKS FRIE
FORSKNINGSFOND



2019 Villum Young Investigator
(10M DKK for 5 years)
THE VELUX FOUNDATIONS
VILLUM FONDEN ✕ VELUX FONDEN



2022 Preparing for ERC-StG final interview
(11.1M DKK for 5 years)



ALICE-Denmark Group

- ❖ In 2022, we have **6** senior staff (**3** permanent, 3 non-permanent), **1** postdoc, **2** PhD, **9** MSc
 - By the end of 2024, only **1** senior staff left if no new hiring
- ❖ In the past 5 years, 7 Postdocs, 9 PhD students, and 14 MSc (with excellent diversity)



ALICE Thesis Award 2019
Katarina Gajdosova (NBI)



Official positions in ALICE (last five years)



- ❖ 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-H



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

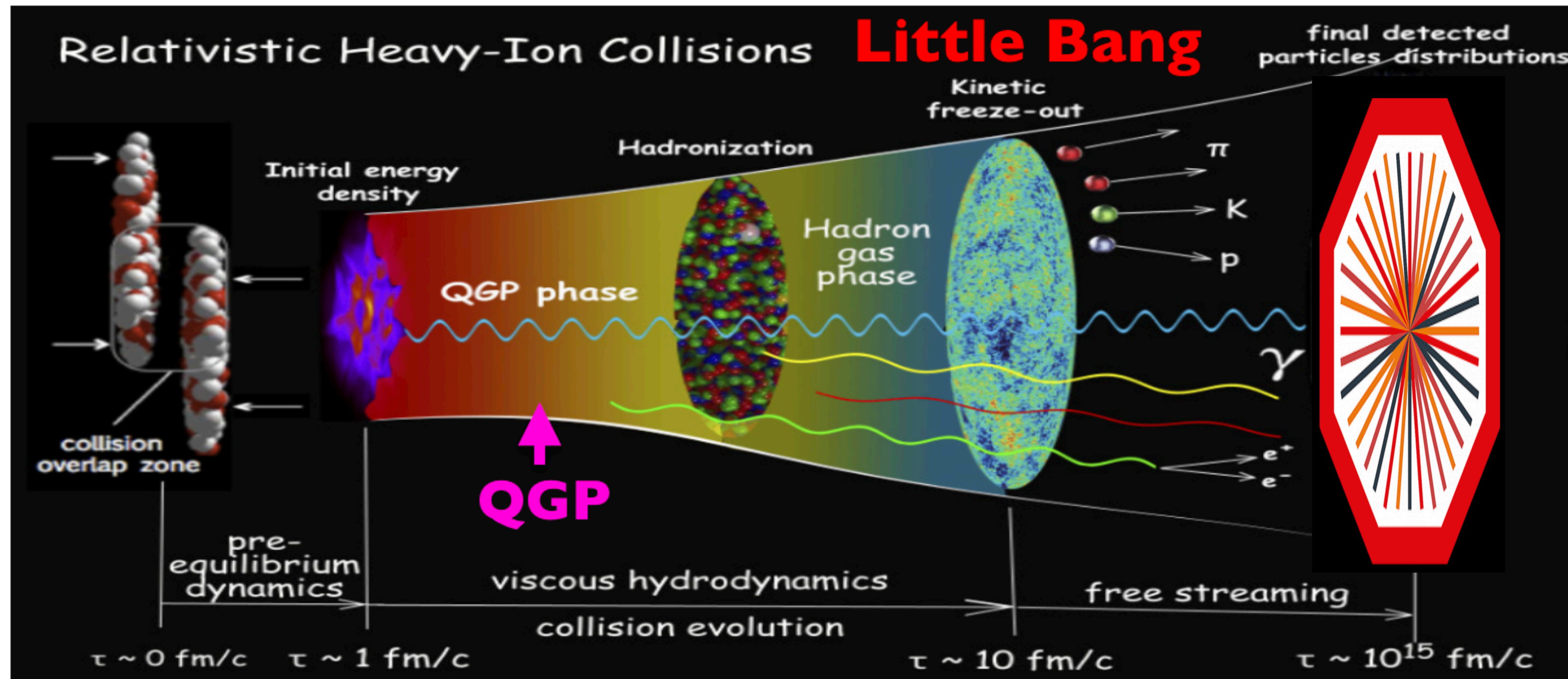


- ❖ You Zhou
 - ALICE Physics Board
 - Convener of Physics Work Group (PWG-CF)
 - Coordinator of Physics Analysis Group (Flow)



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

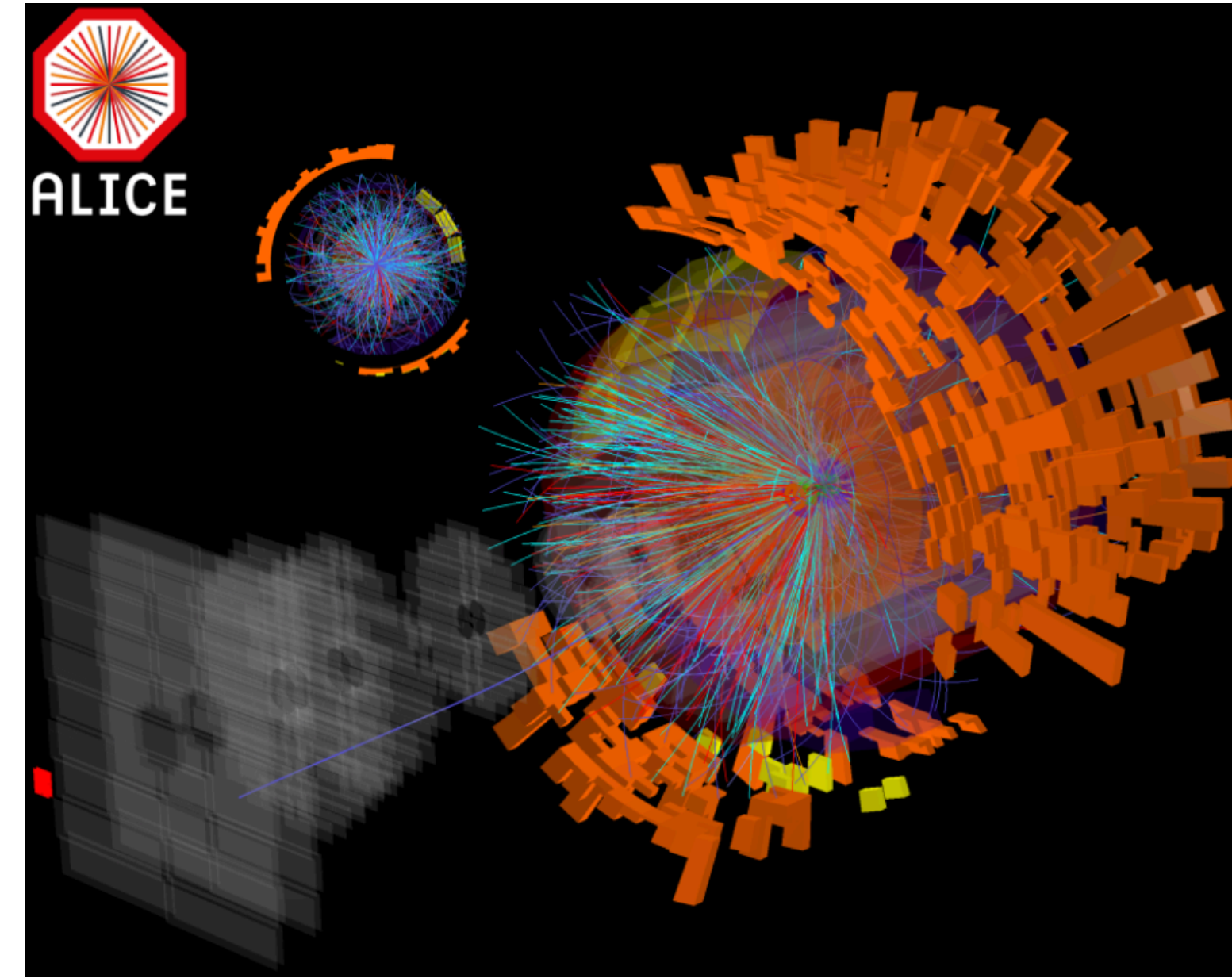
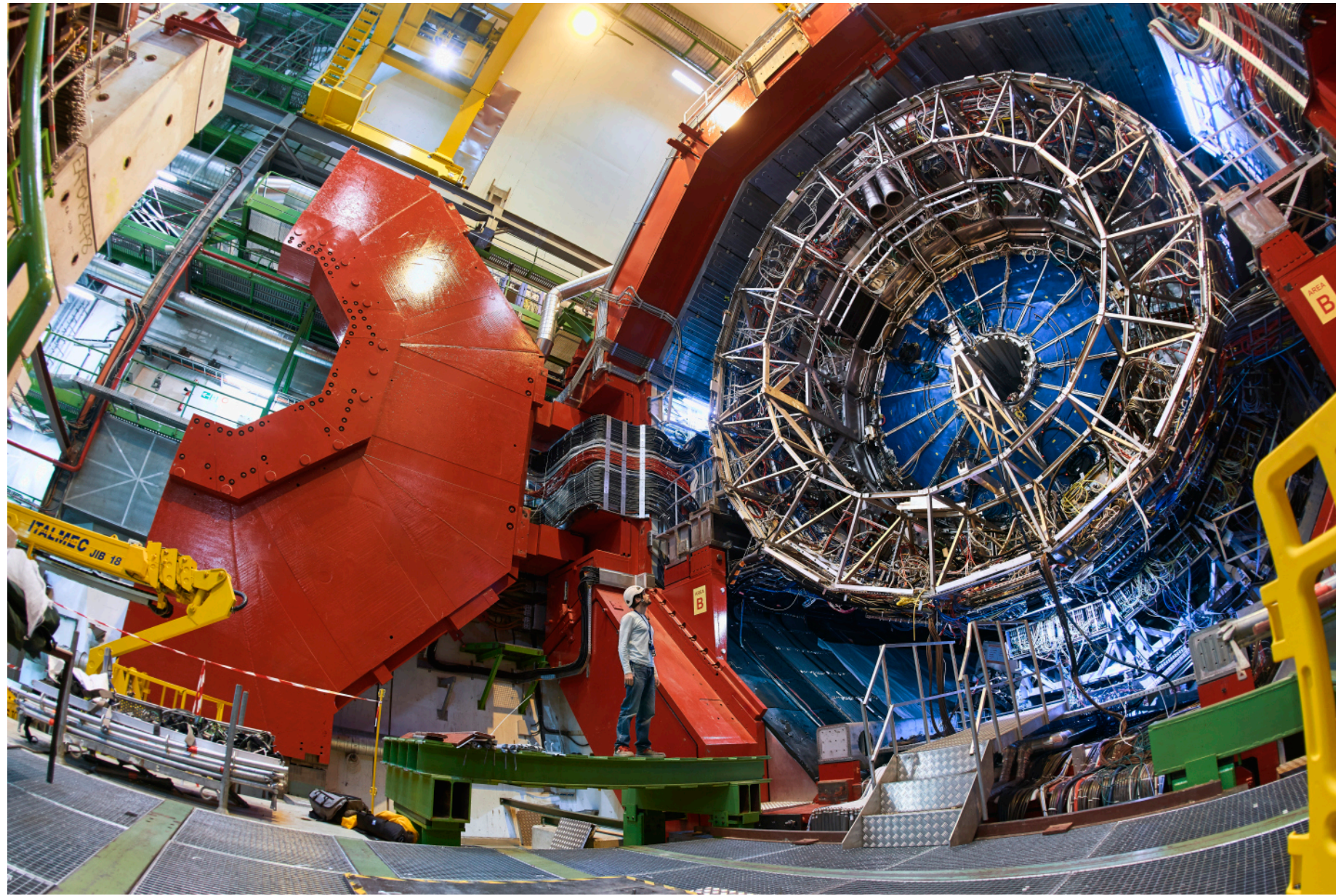
Recreating the QGP in the laboratory



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: 2010-2022

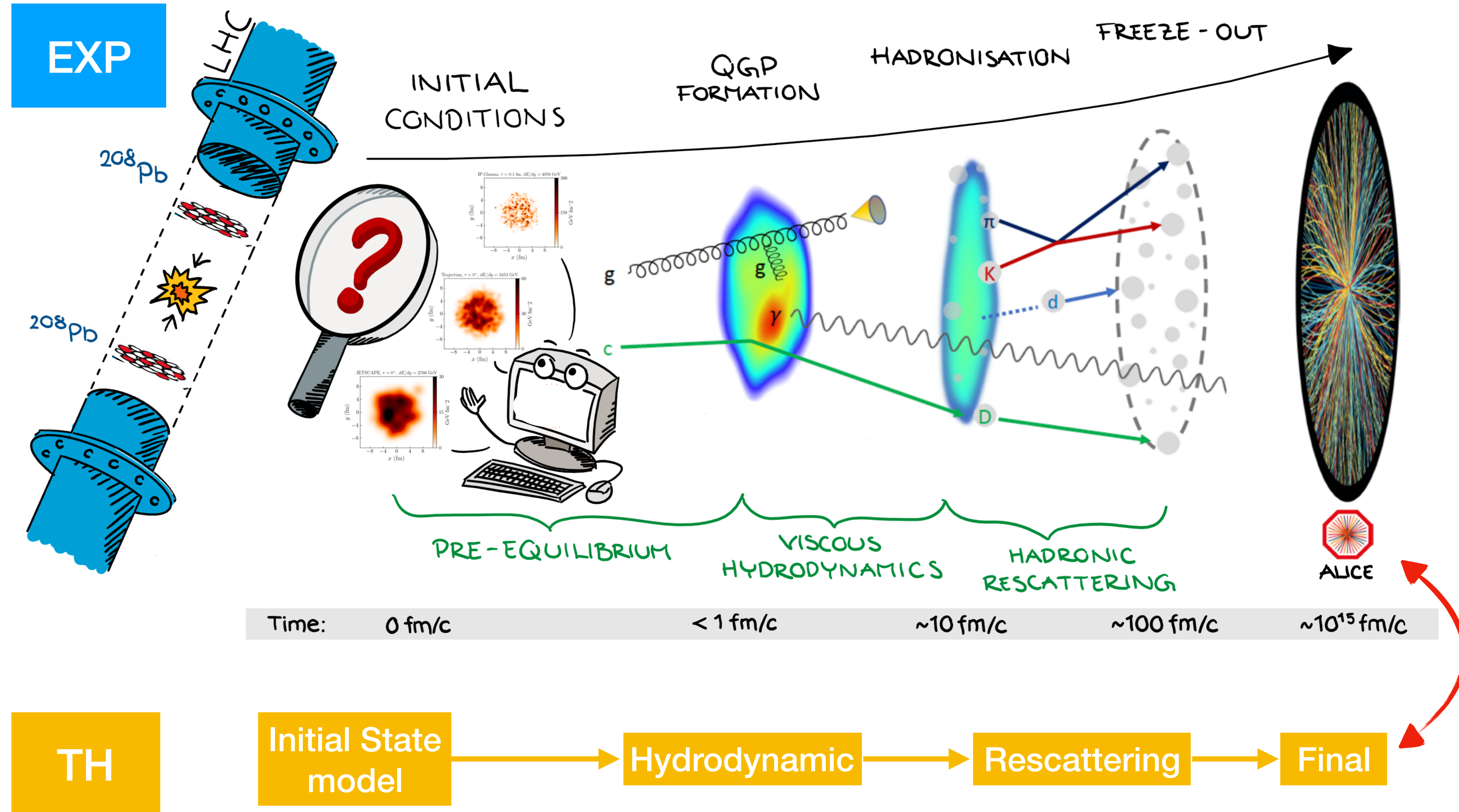


Key milestones of the ALICE Collaboration at Run I&2

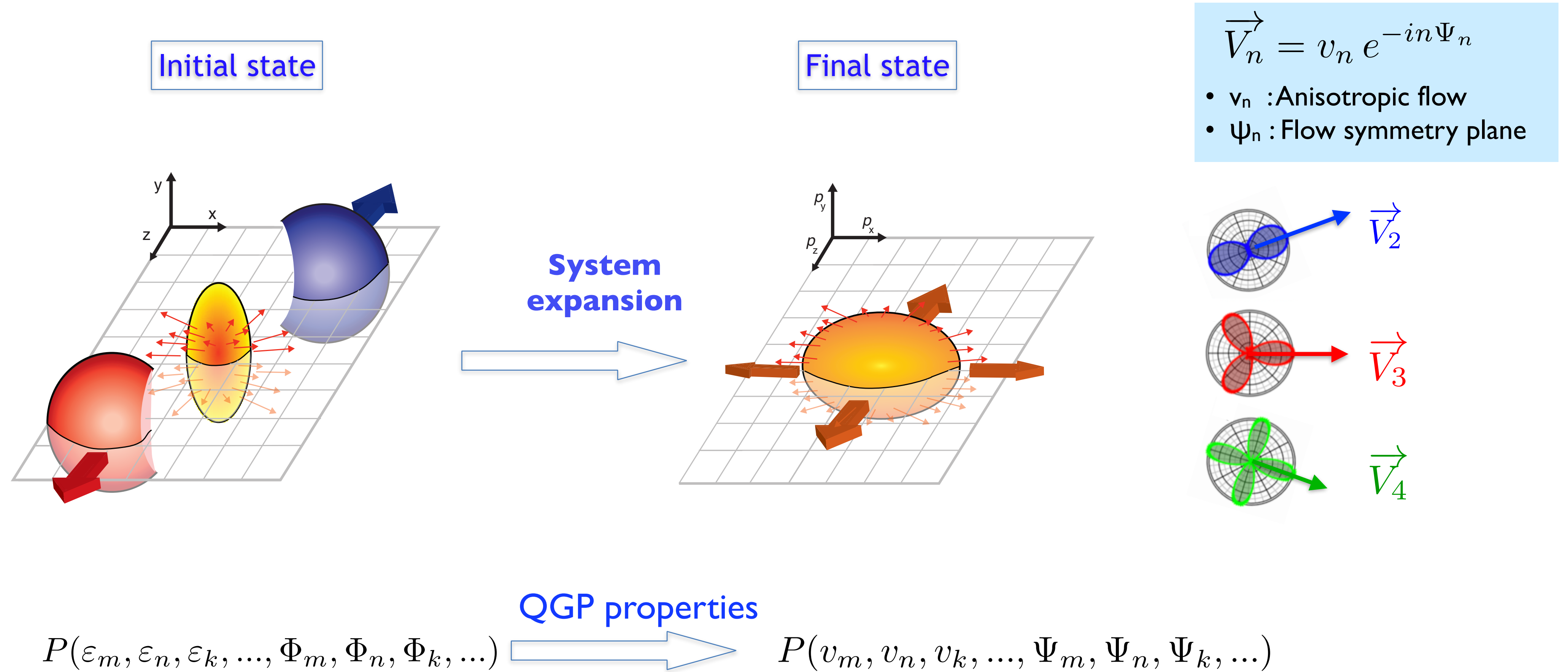
- ❖ Extract precise properties and time evolution of QGP in heavy-ion collisions [Expected]
- ❖ Discovery of collective flow in small collision systems [Unexpected]

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

Heavy-ion collision: a complex system

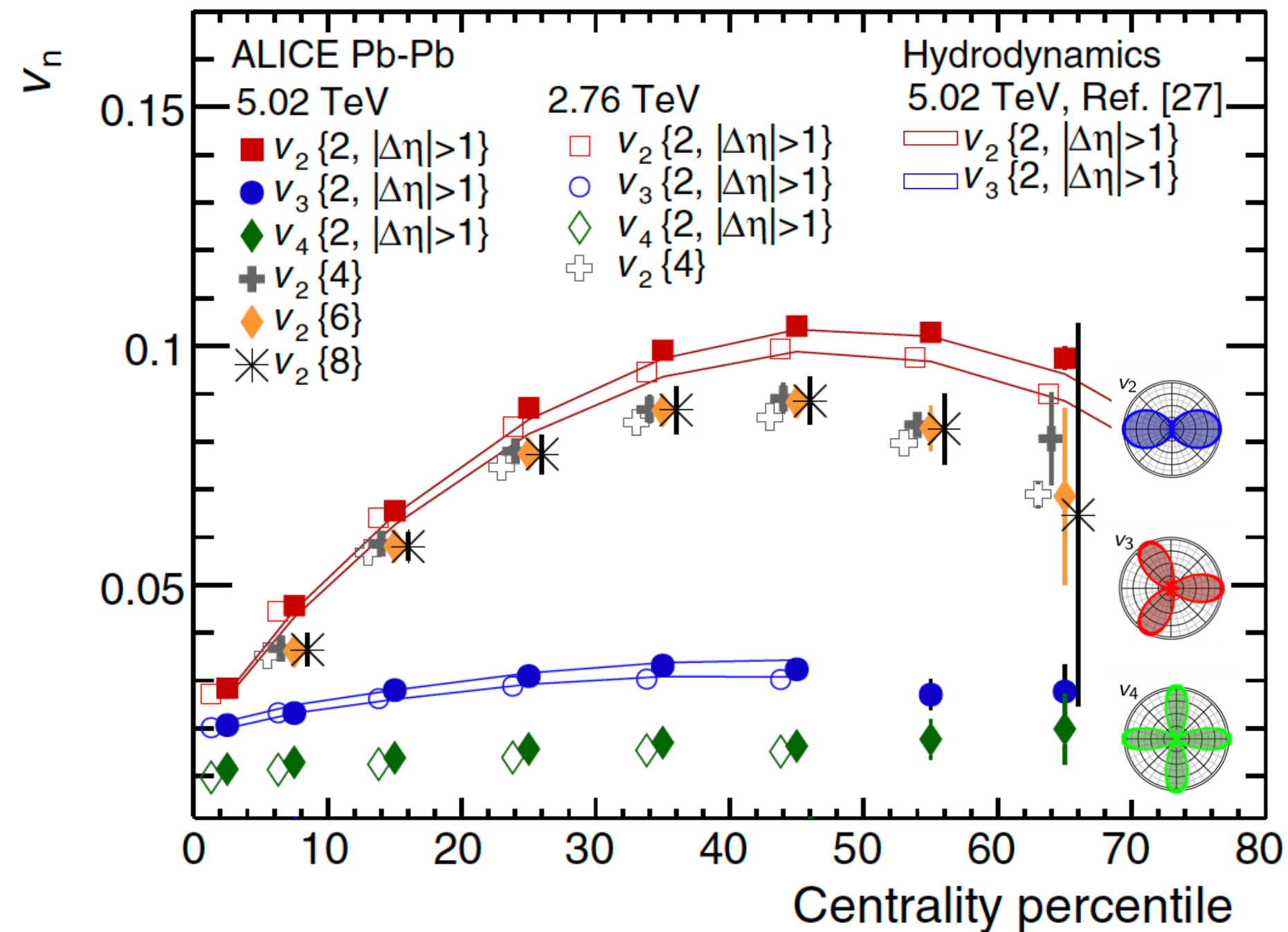


Probing QGP using Anisotropic Flow



A perfect fluid

ALICE, Physical Review Letters 116 (2016), 132302



CERN COURIER

Reporting on international high-energy physics

Physics Technology Community In focus Magazine

STRONG INTERACTIONS | NEWS

Anisotropic flow in Run 2

18 March 2016

Exploiting the data collected during November 2015 with Pb-Pb collisions at the record-breaking energy of $\sqrt{s_{NN}} = 5.02$ TeV, ALICE measured for the first time the anisotropic flow of charged particles at this energy.

CERN COURIER

Reporting on international high-energy physics

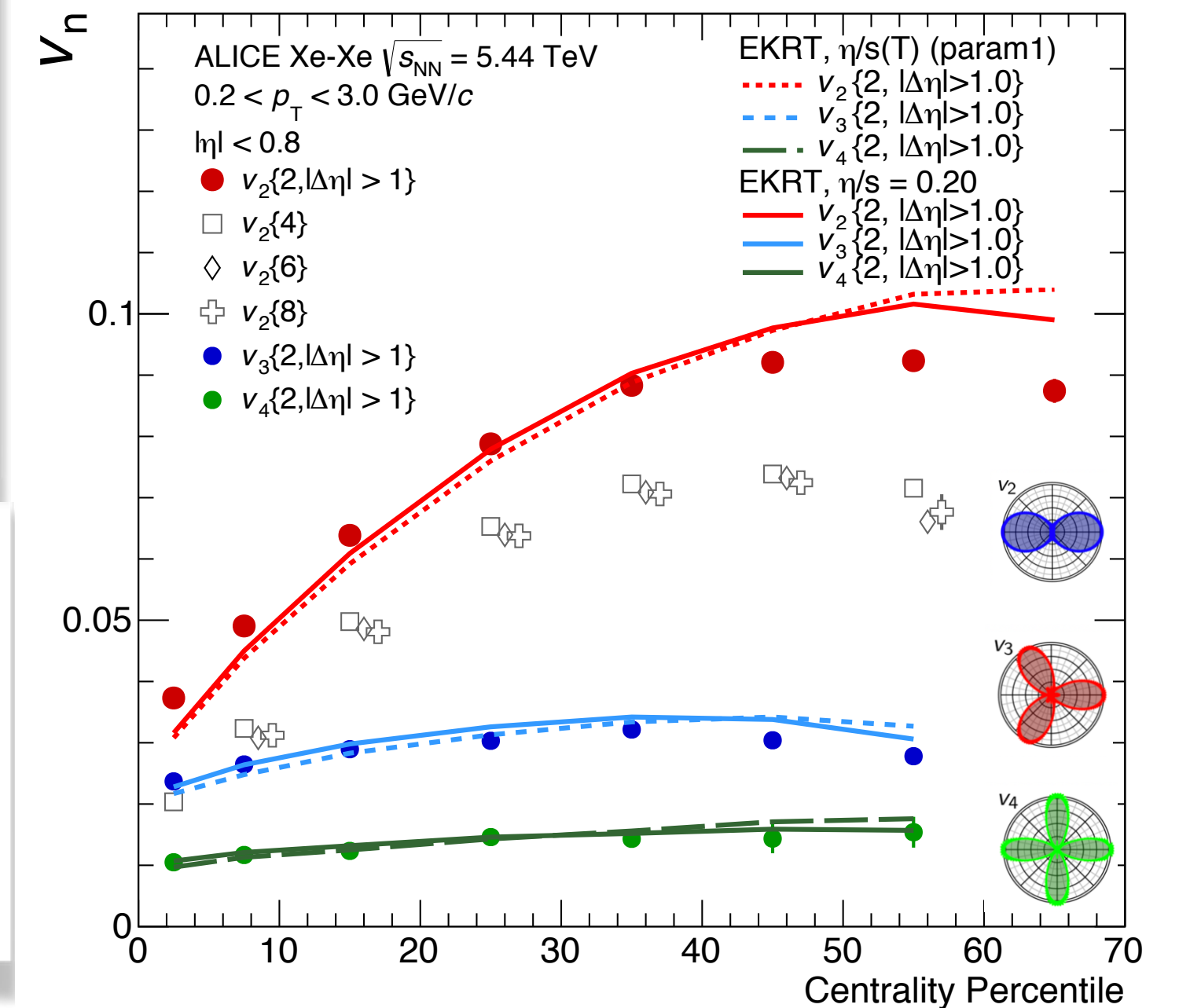
Physics Technology Community In focus Magazine

STRONG INTERACTIONS | NEWS

Anisotropic flow in Xe-Xe collisions

9 July 2018

ALICE, Physics Letters B784 (2018) 82

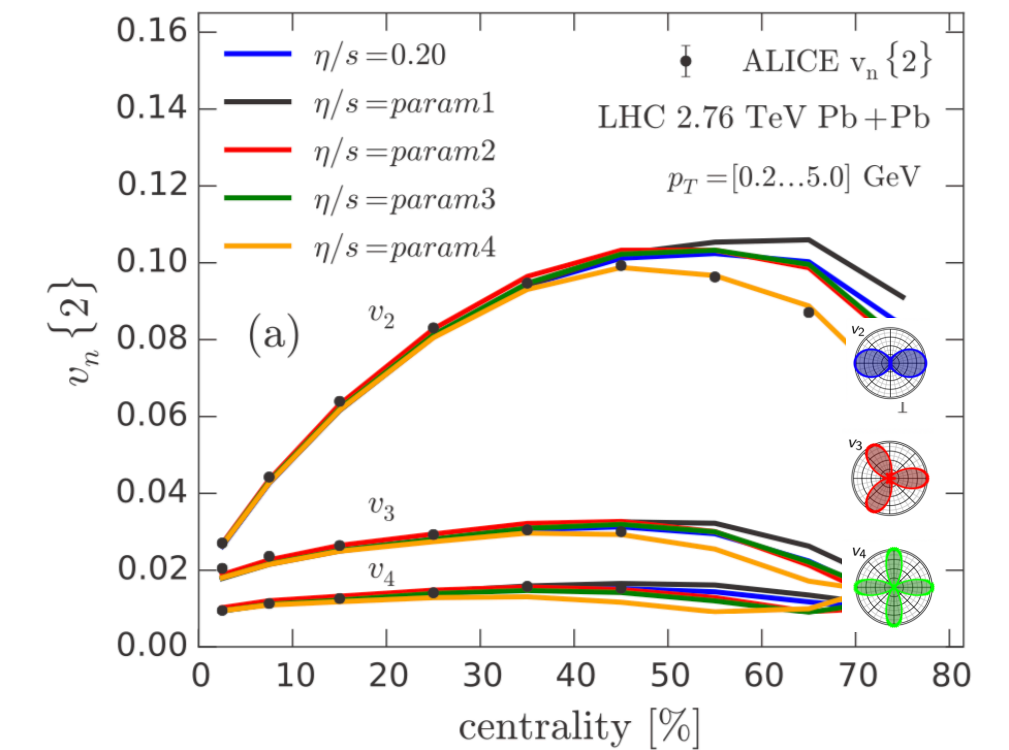
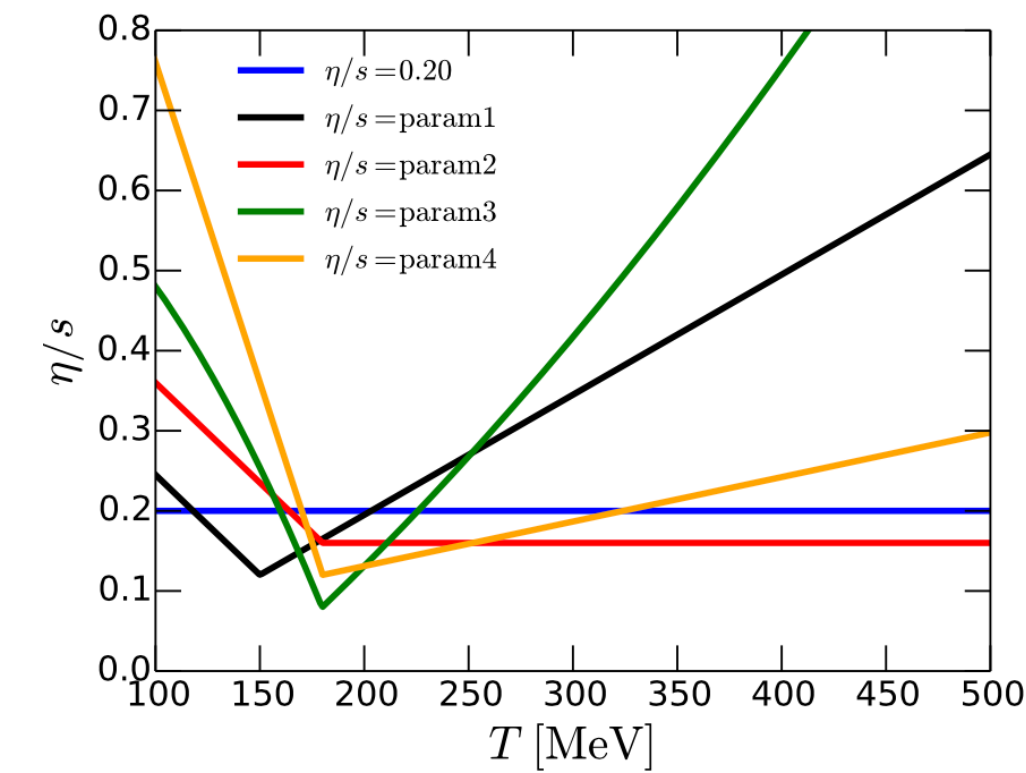
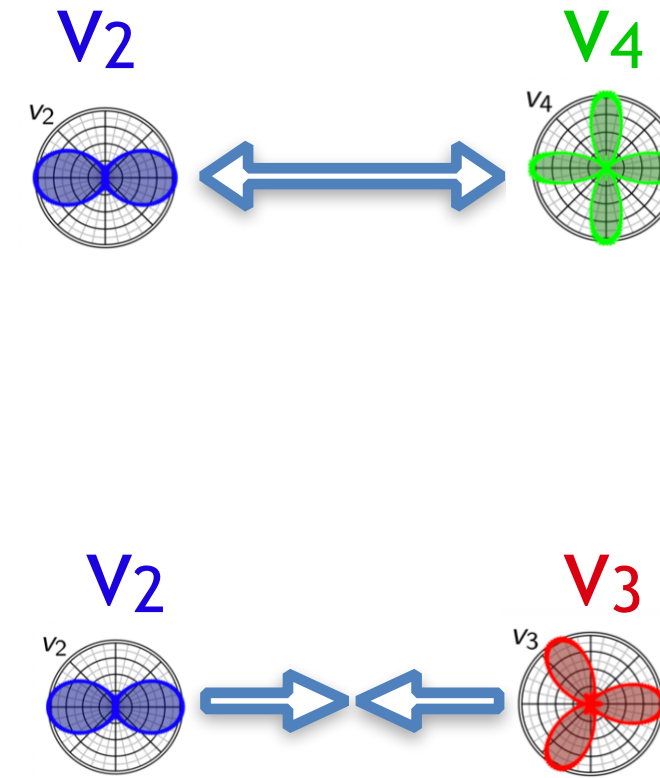
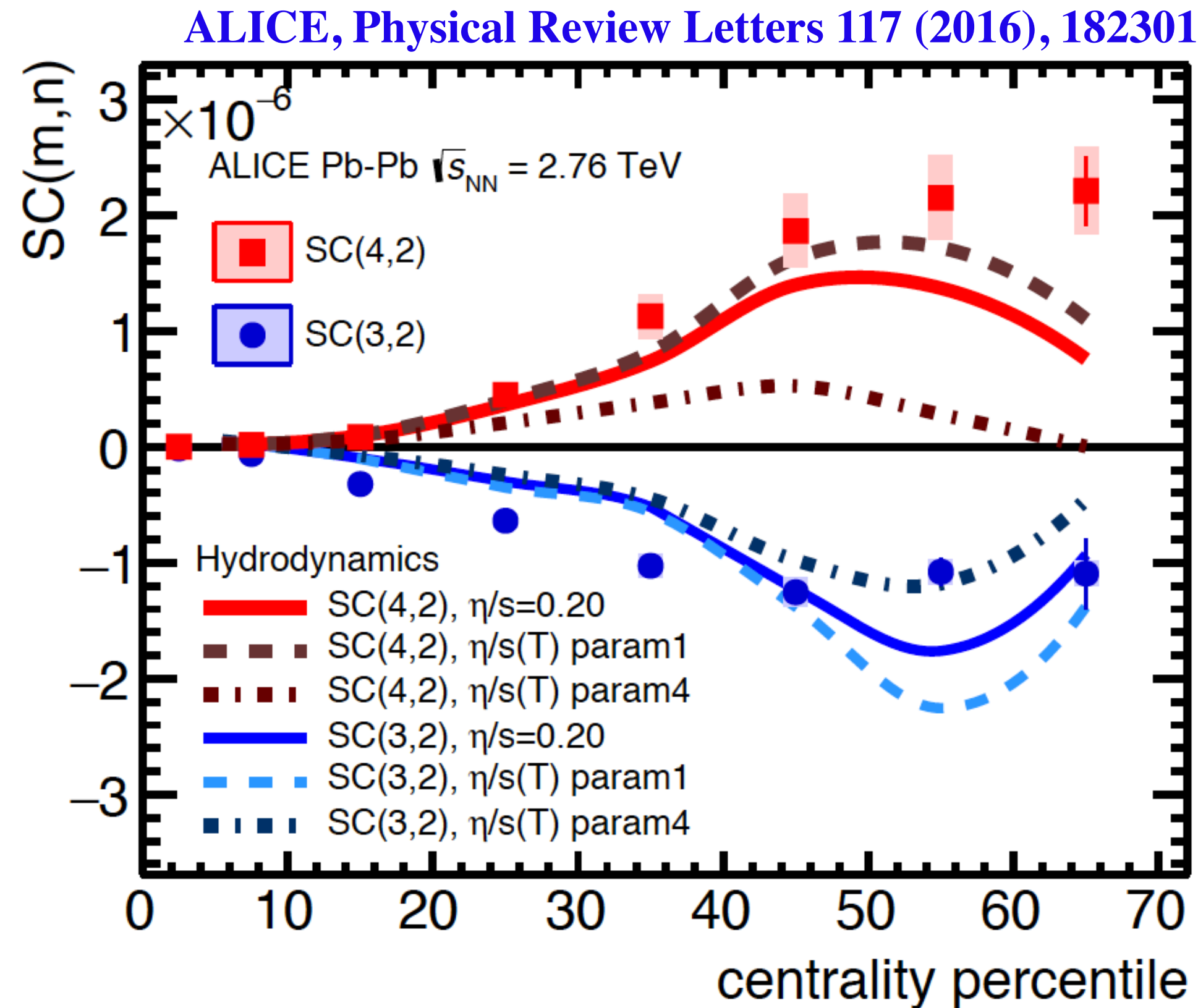


❖ Flow measurements at the top LHC energy agree with hydrodynamic predictions

- **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

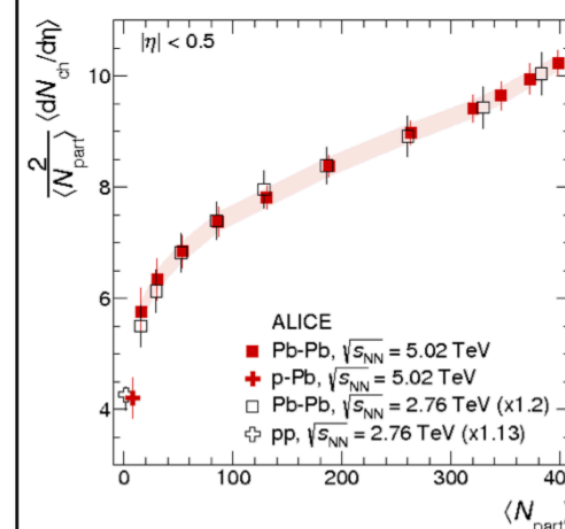
<https://doi.org/10.1038/s41567-019-0611-8>

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

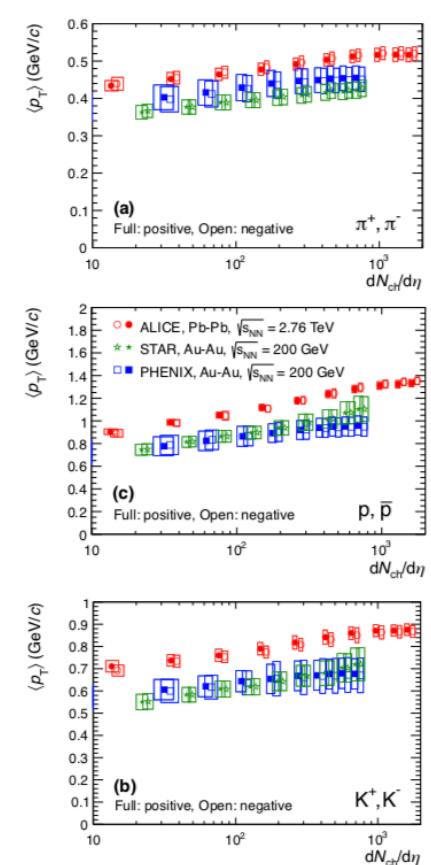
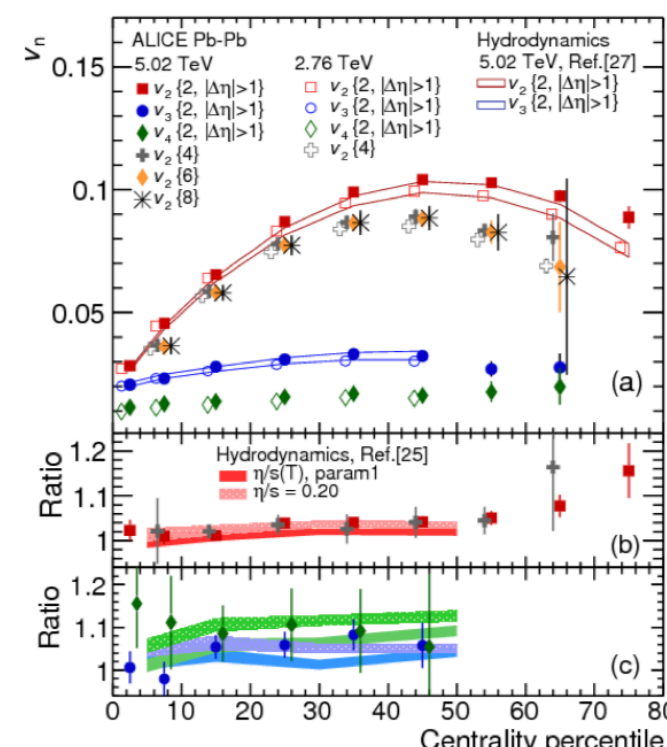
Jonah E. Bernhard¹*, J. Scott Moreland¹ and Steffen A. Bass¹

Data:

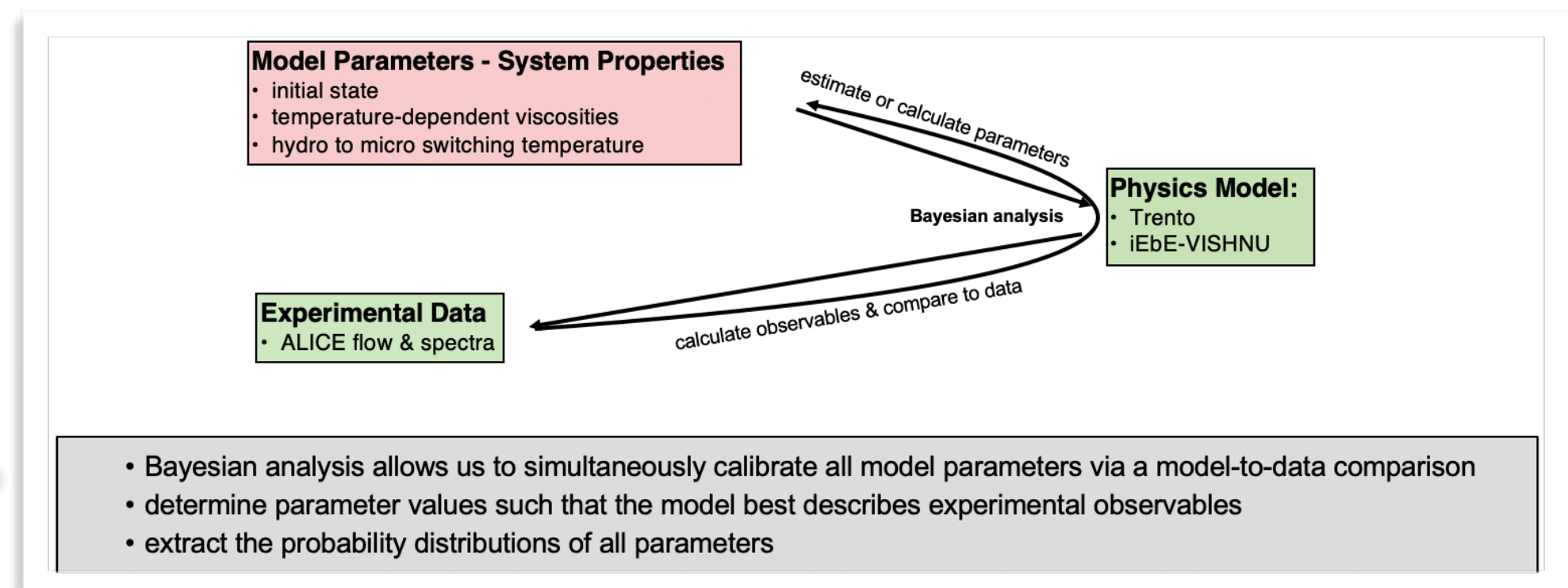
- ALICE v_2 , v_3 & v_4 flow cumulants
- identified & charged particle yields
- identified particle mean p_T
- 2 beam energies: 2.76 & 5.02 TeV



ALICE data as inputs

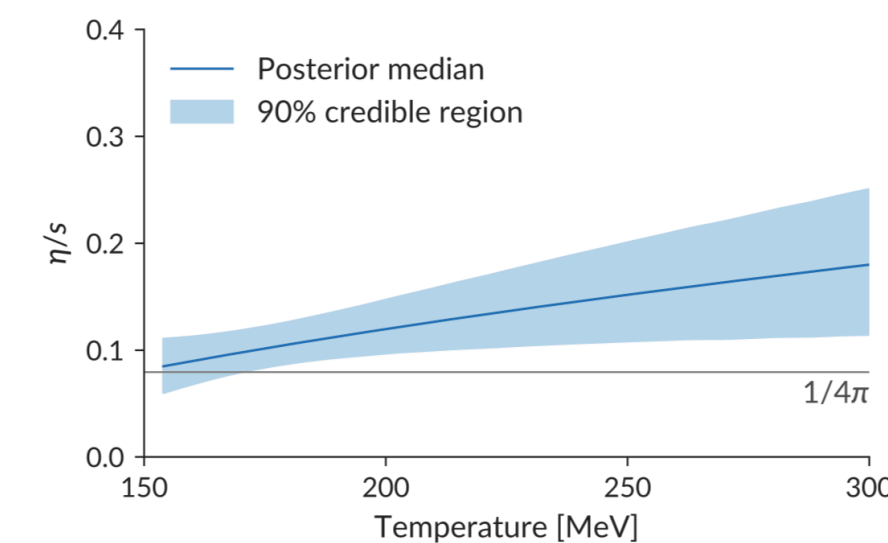


Bayesian analysis framework

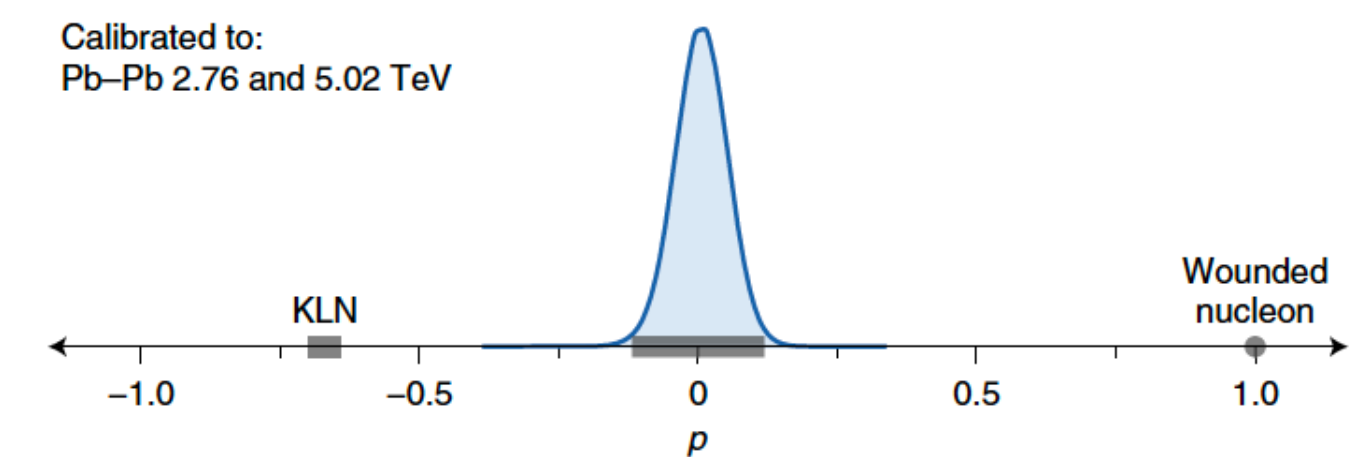


- **First extraction of temperature dependent viscosity of QGP**
- Reveal the time evolution of the Early Universe with the first microsecond

Temperature-dependent viscosities



Initial conditions



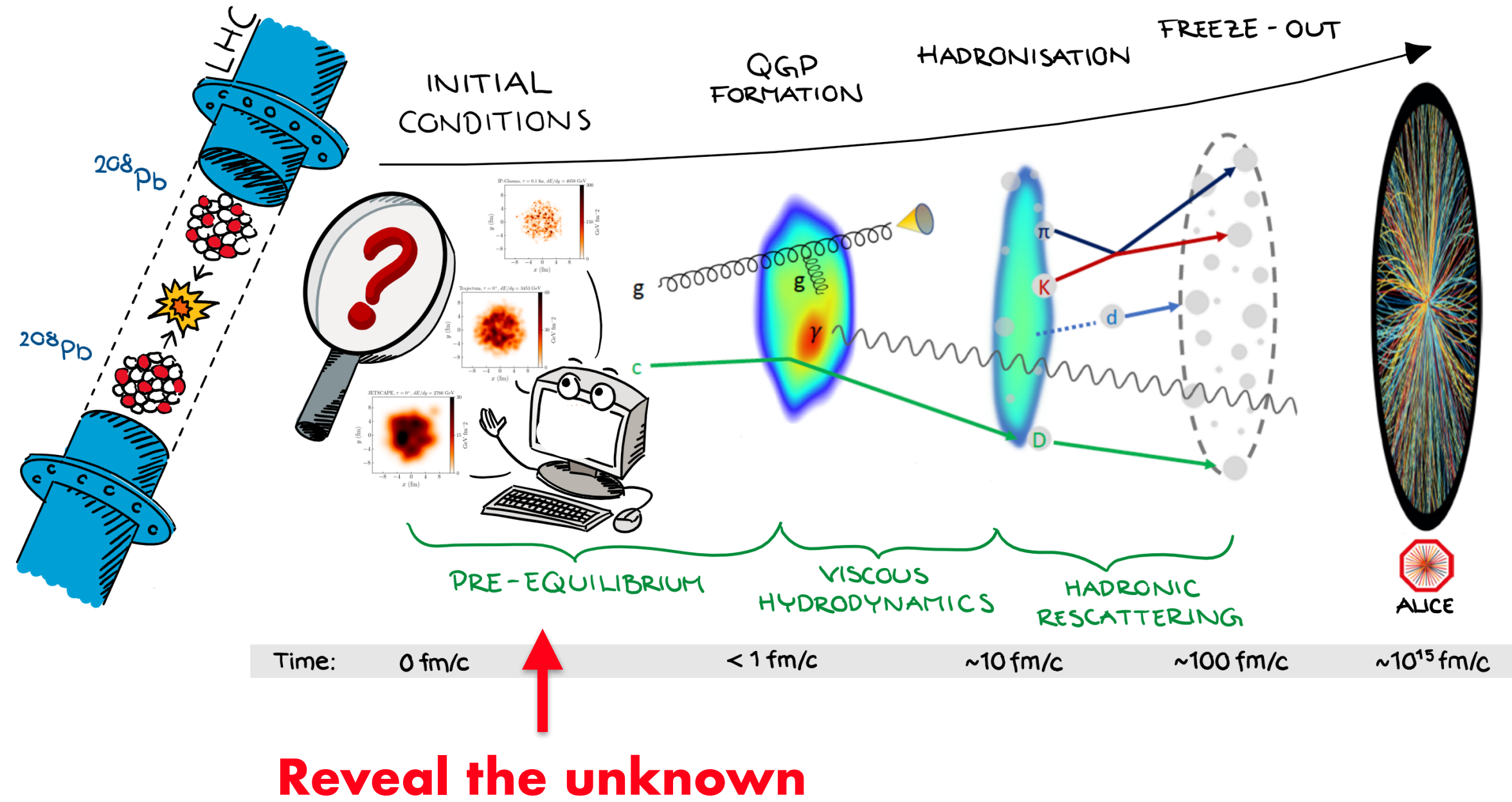
UNIVERSITY OF
COPENHAGEN

You Zhou (NBI) @ rECFA meeting (Denmark)

May 12th, 2022

11

Direct access to unknown initial conditions

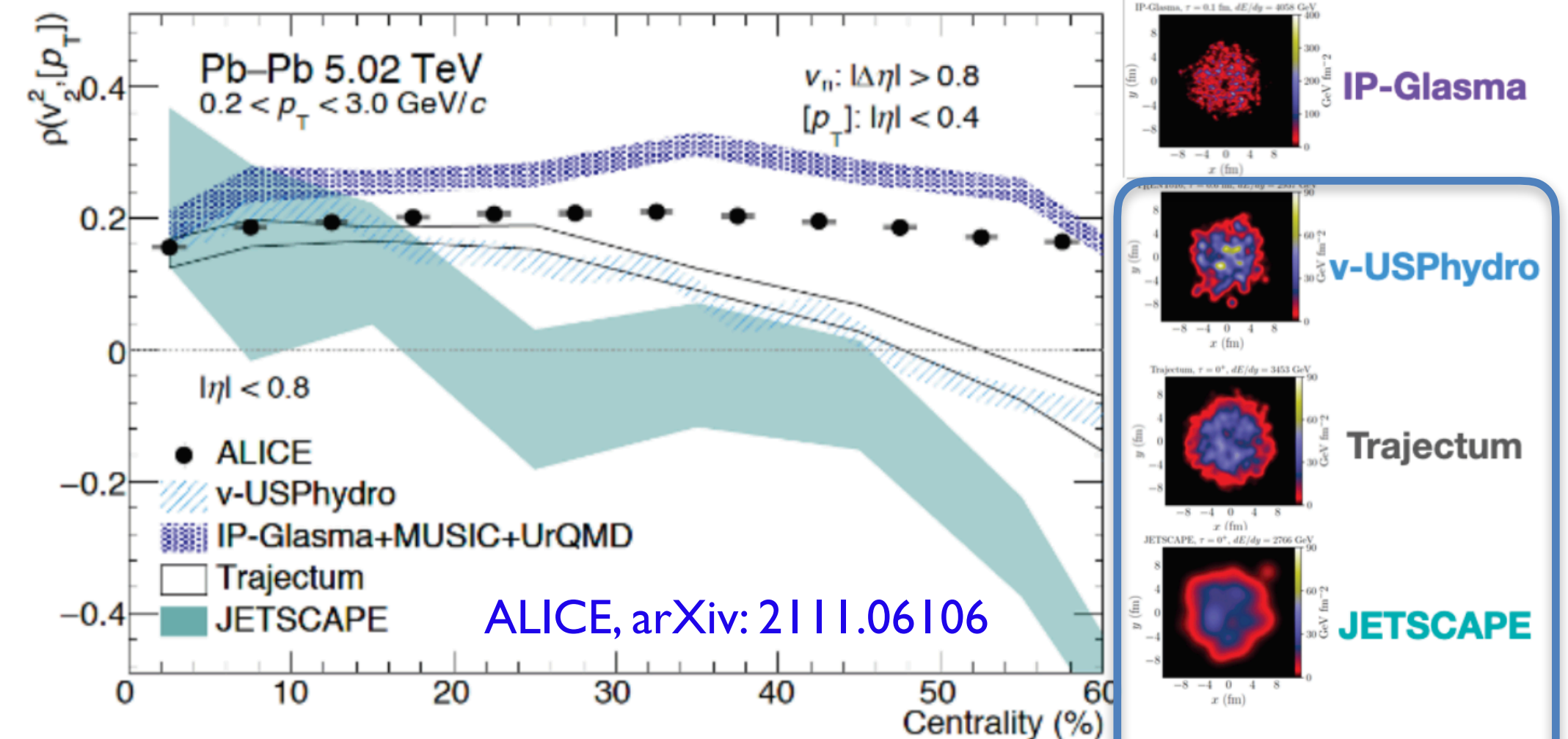


CERN COURIER

VOLUME 62 NUMBER 3 MAY/JUNE 2022

ALICE

Accessing the precursor stage of QGP formation

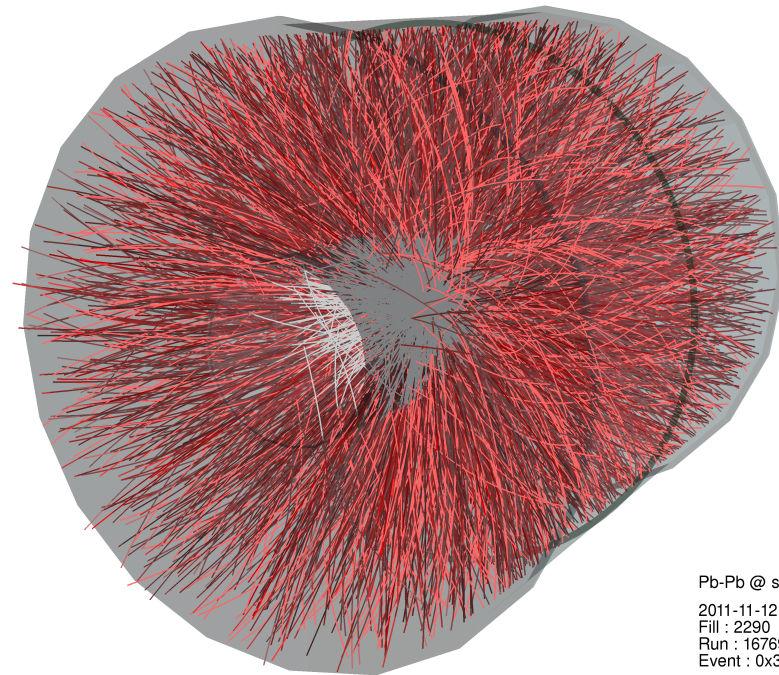


Bayesian IC

- A new observable $\rho(v_n^2, [p_T])$, quantifying the correlations between v_n and $[p_T]$, giving us direct access to the initial conditions (independent of QGP properties).
- The **best understanding** of initial conditions from the state-of-the-art Bayesian analyses **failed completely** to describe the new ALICE measurements.
- Significant improvements in the understanding of the initial conditions!

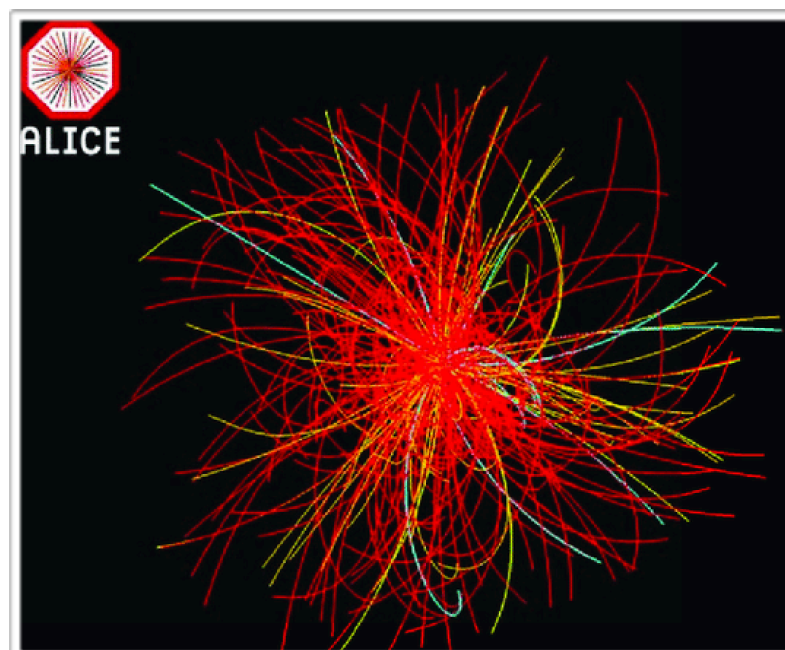
Small droplets of QGP?

Pb-Pb collisions

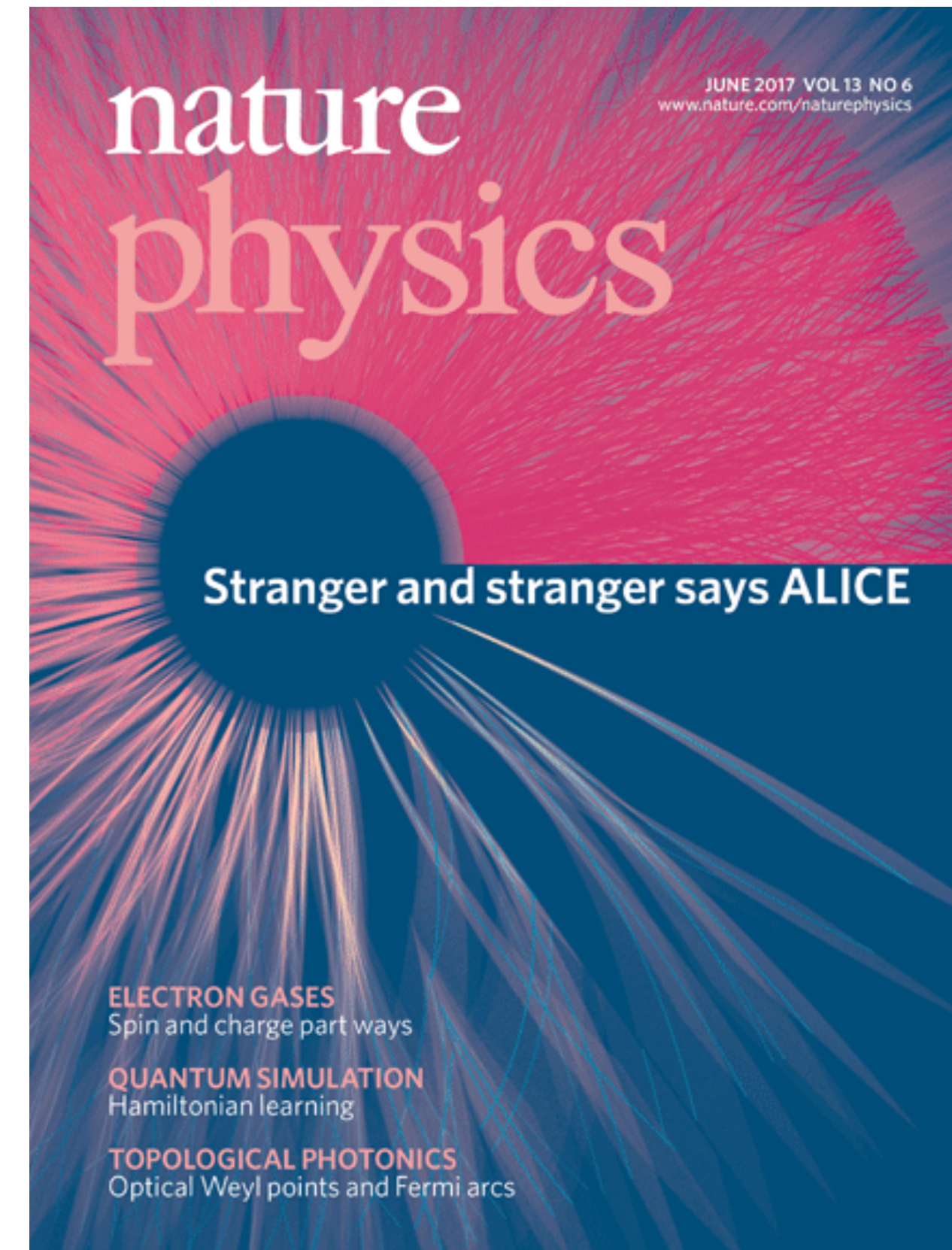


(peripheral Pb-Pb)
~hundreds of charged particles
produced

pp



(high multiplicity pp)
~100 charged particles
produced

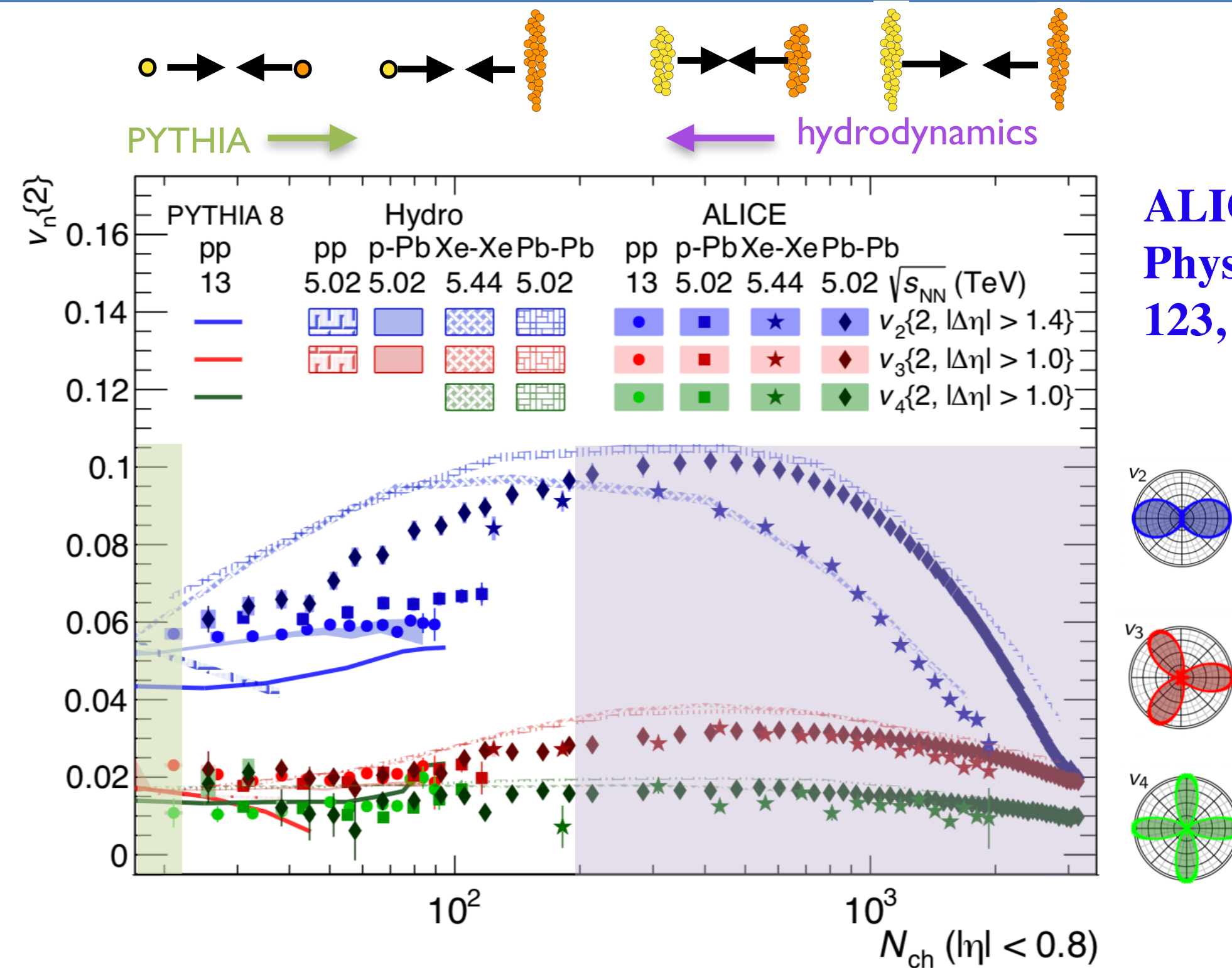


For many years, the **proton-proton** collision was used
as “reference data” where no QGP is expected ...

But !



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

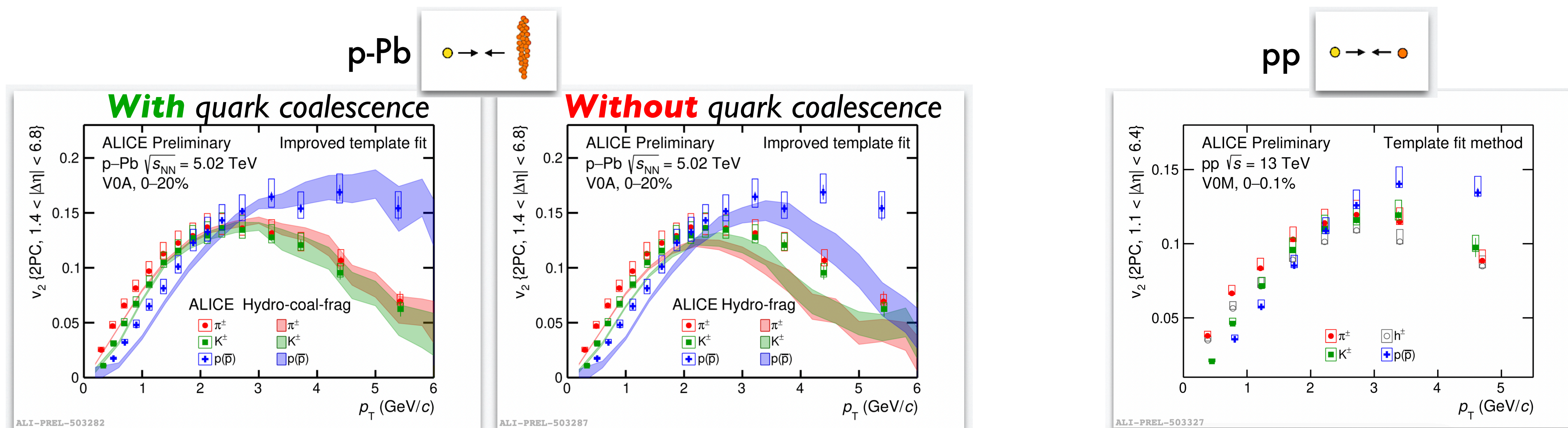


ALICE,
Physical Review Letters
123, 142301 (2019)

- ❖ Discovery of flow in small collisions 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
 - Mass ordering in low p_T region (described by hydrodynamics)
 - Baryon-meson v_2 splitting at intermediate p_T region by $> 3\sigma$
 - 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



Publications and Conferences

❖ Publications

- ALICE-NBI group (~10 members) led **24** of total **344** publications in ALICE (1900+ members)
➔ **~0.5%** ALICE member in Denmark contributed to **7%** total ALICE publications
- In addition, **10+** theoretical publications on the top journals in the last 5 years

❖ Conference talks

- At least **1** ICHEP, **2-3** EPS-HEP, **2** Quark Matter talks per conference



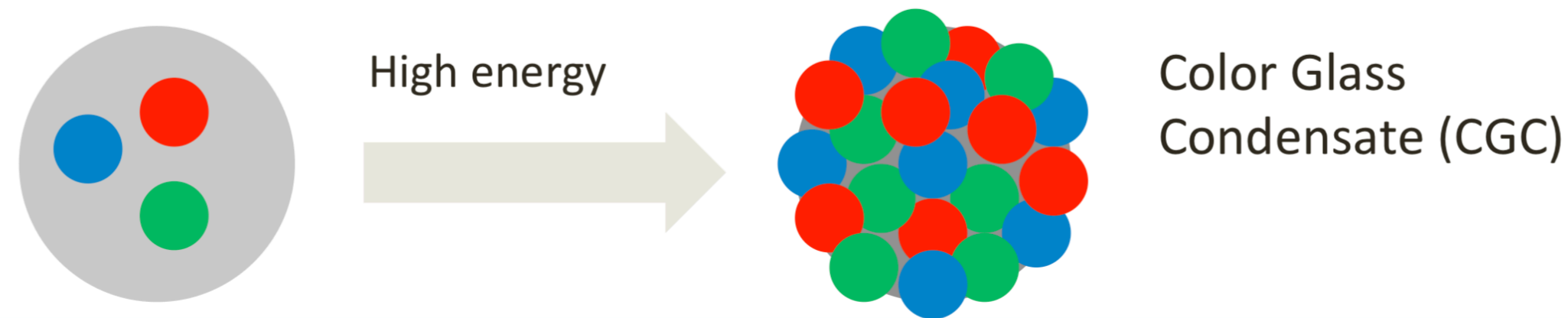
Long-term prospective: study of CGC



Color ... gluons have “colors”

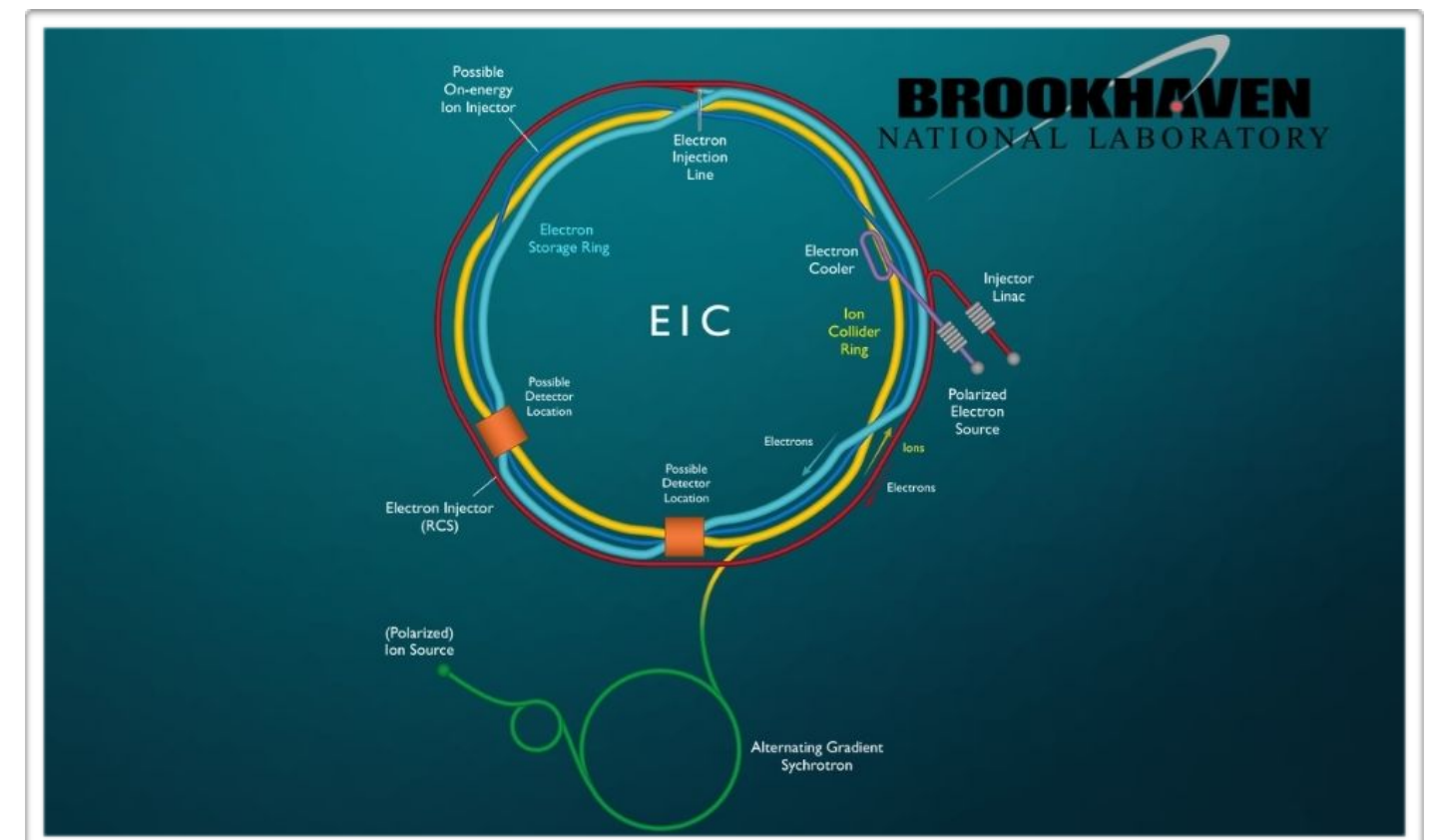
Glass ... gluons with small longitudinal mom. fractions ($x \ll 1$) are created by long-lived partons that are distributed randomly on the transverse disk

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



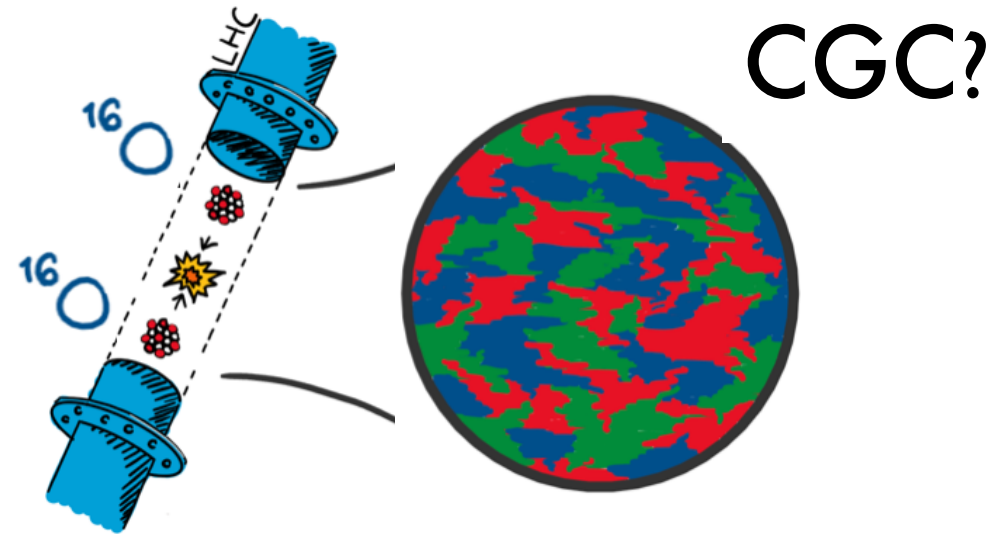
- **Most advanced** (and still developing) **theoretical picture of high energy scattering in QCD**

- 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*.



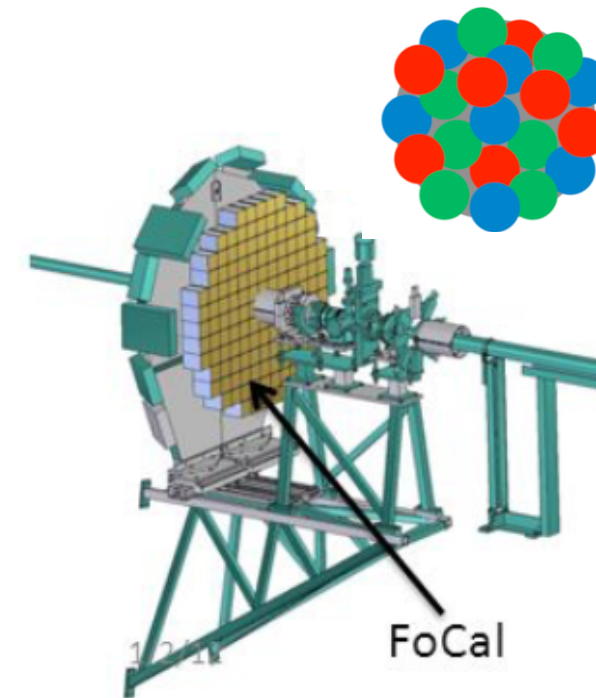
Discovery of CGC?

O-O collisions @ Run3

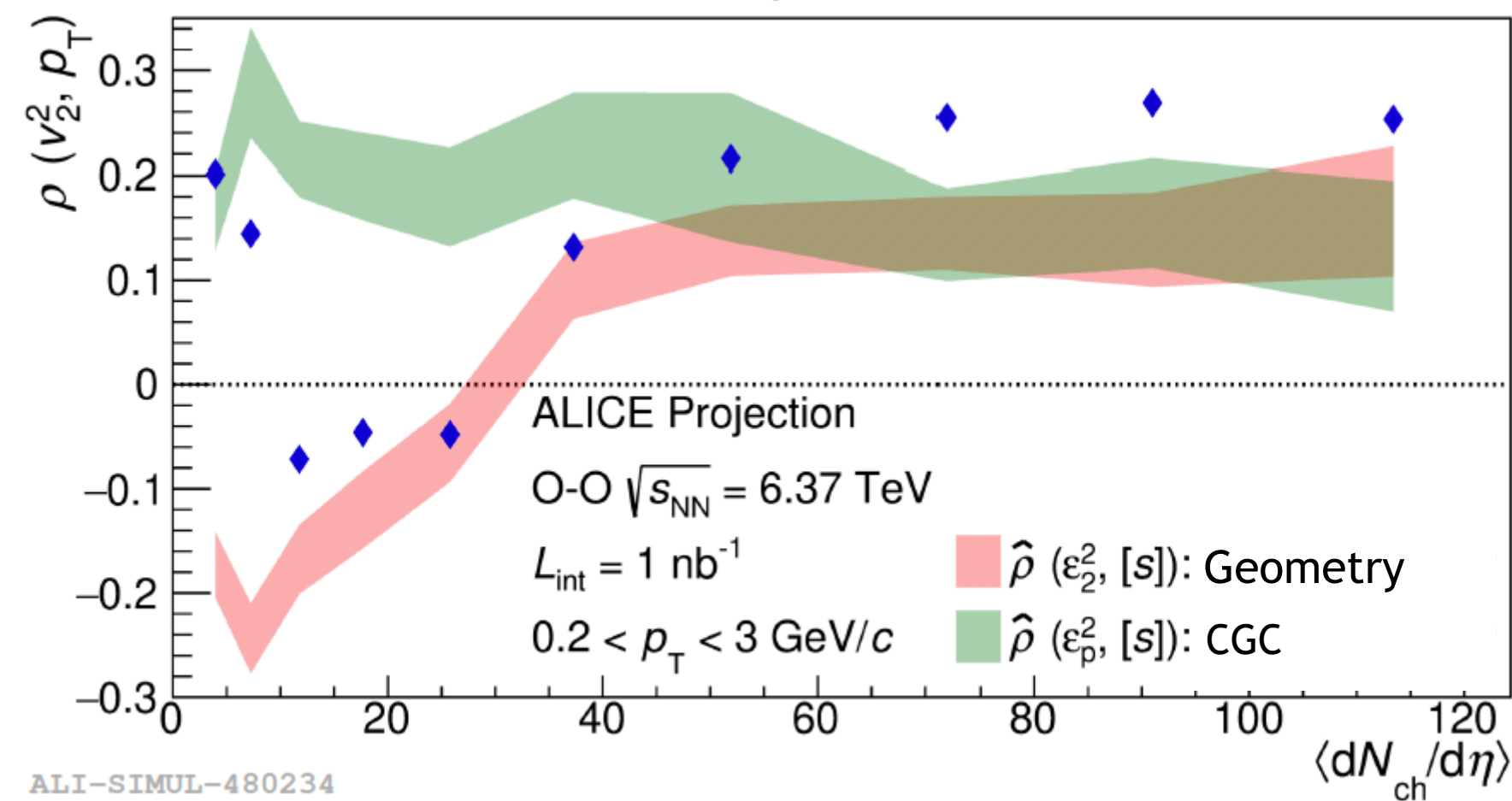
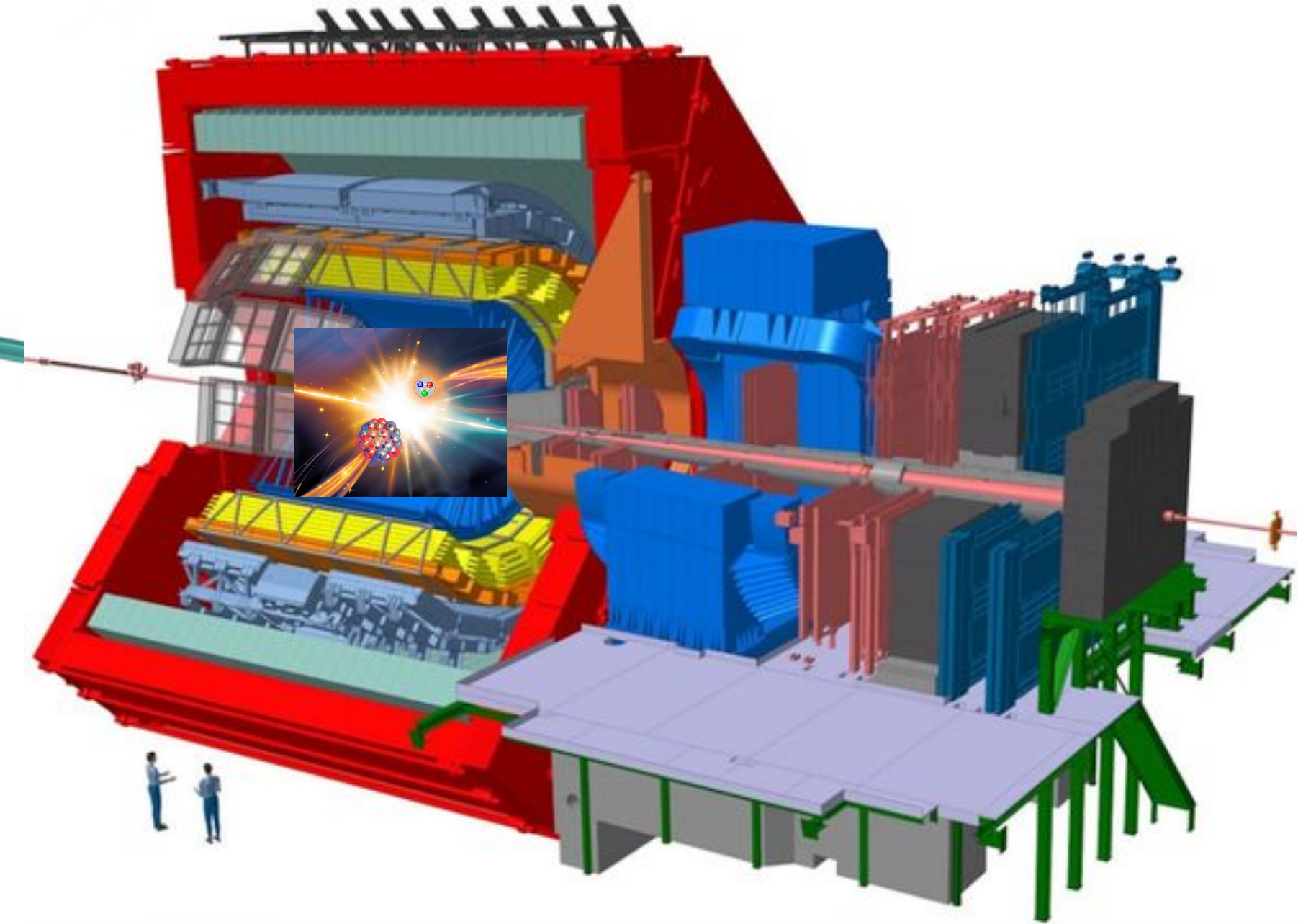


CGC?

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

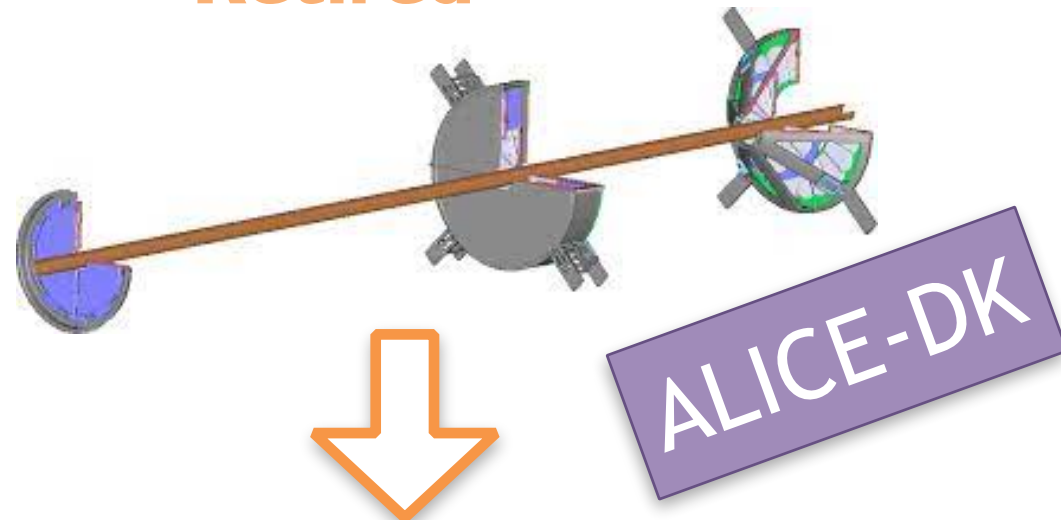
Future measurements with π^0 and photons with FoCal

- 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

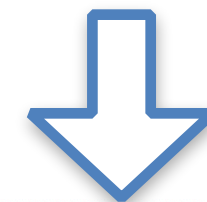
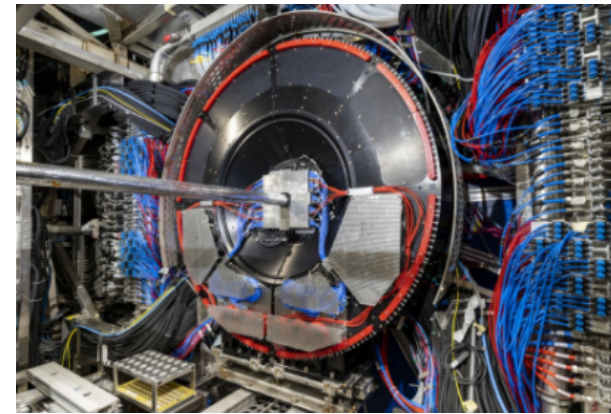
Timeline and milestones

Forward Multiplicity Detector (FMD)

—> Retired

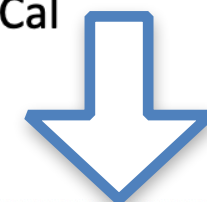
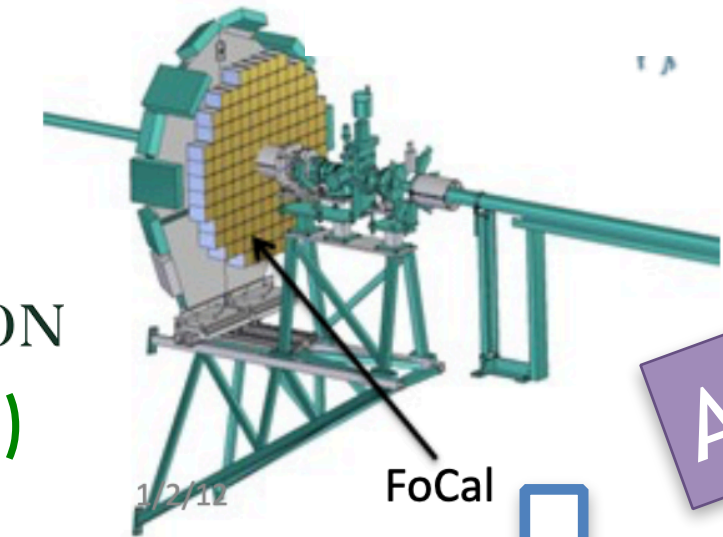


Fast Interaction Trigger (FIT)



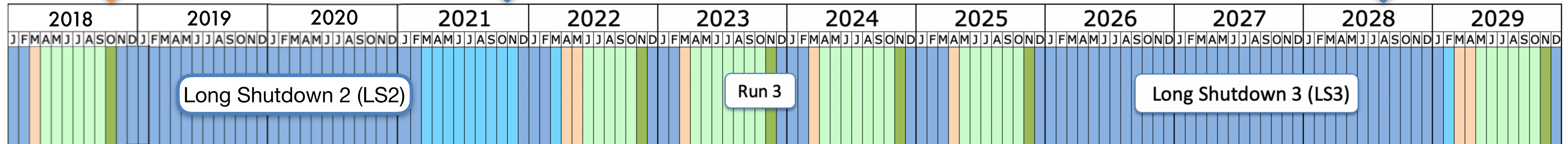
ALICE-DK

Forward Calorimeter (FoCal)



ALICE-DK

CARLSBERG FOUNDATION
8.5 M DKK (5 years)



Run 2: precise extraction of QGP properties

Run 3: discover QGP in small systems

10 M DKK (5 years) THE VELUX FOUNDATIONS
VILLUM FONDEN × VELUX FONDEN

Run 4: discover/disprove of CGC

❖ LHC Run3 and Run4 programs

- New discoveries with major upgrades!
- Retirements and contracts end of almost all senior staff by **2024** (challenging 🦴).



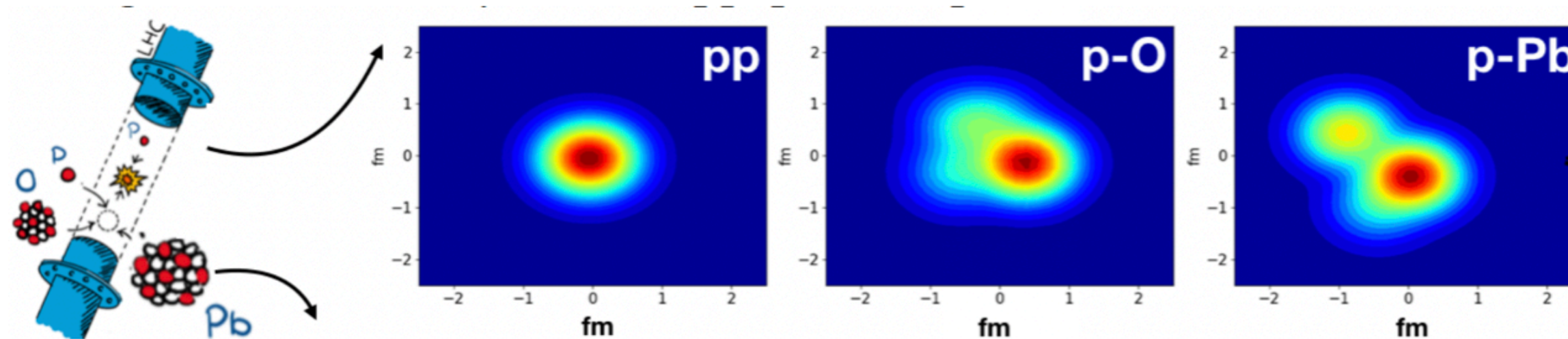
Backup



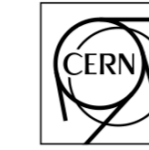
Highlight: small systems @ LHC

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

Harald Appelshäuser (Frankfurt),
Ionut Arsene (Oslo),
Livio Bianchi (Torino),
Leticia Cunqueiro (ORNL),
Fabrizio Grosa (Torino),
Jan Fiete Grosse-Oetringhaus (CERN),
Peter Jacobs (LBNL),
Alexander Kalweit (CERN),
Filip Krizek (Czech Academy of Sciences),
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

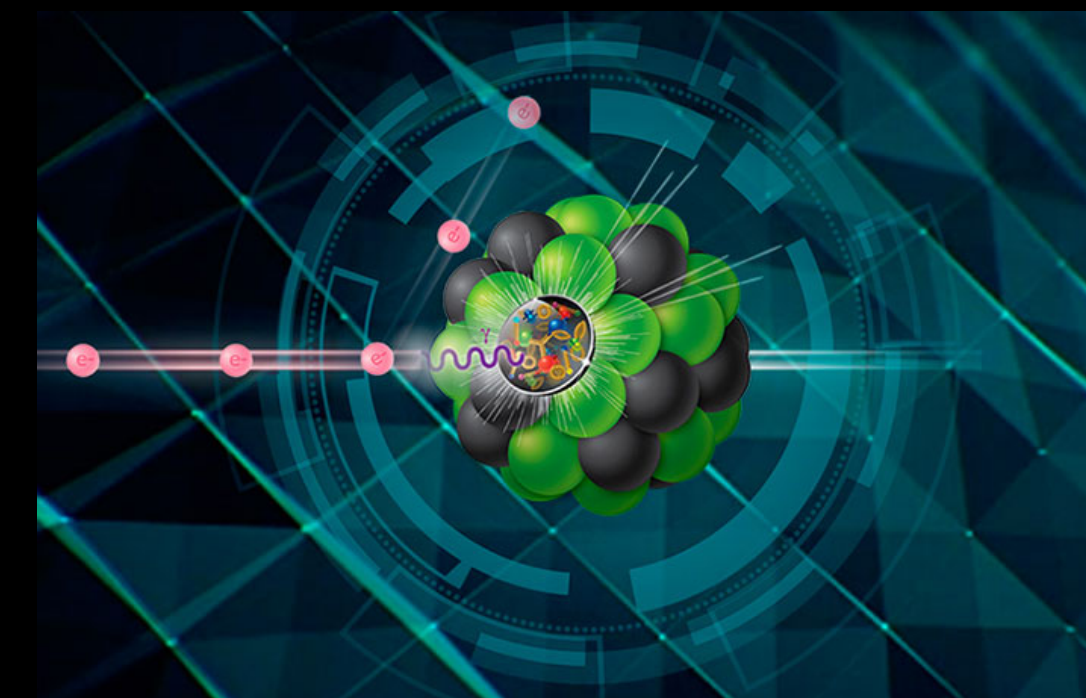
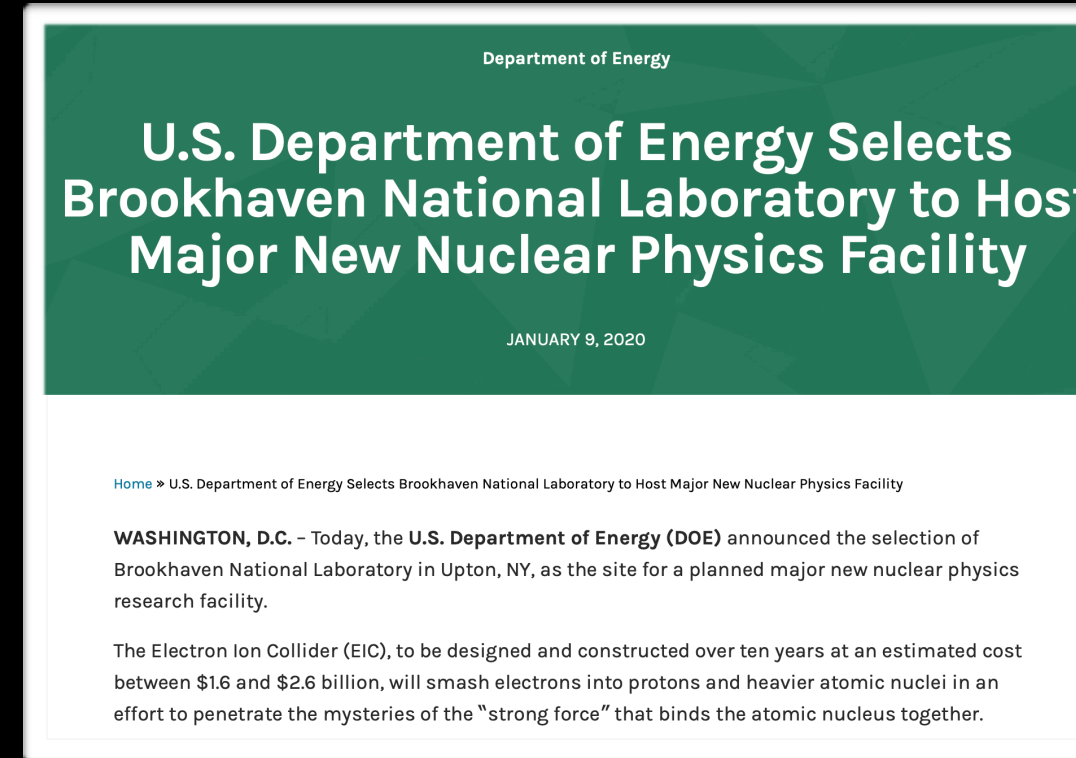
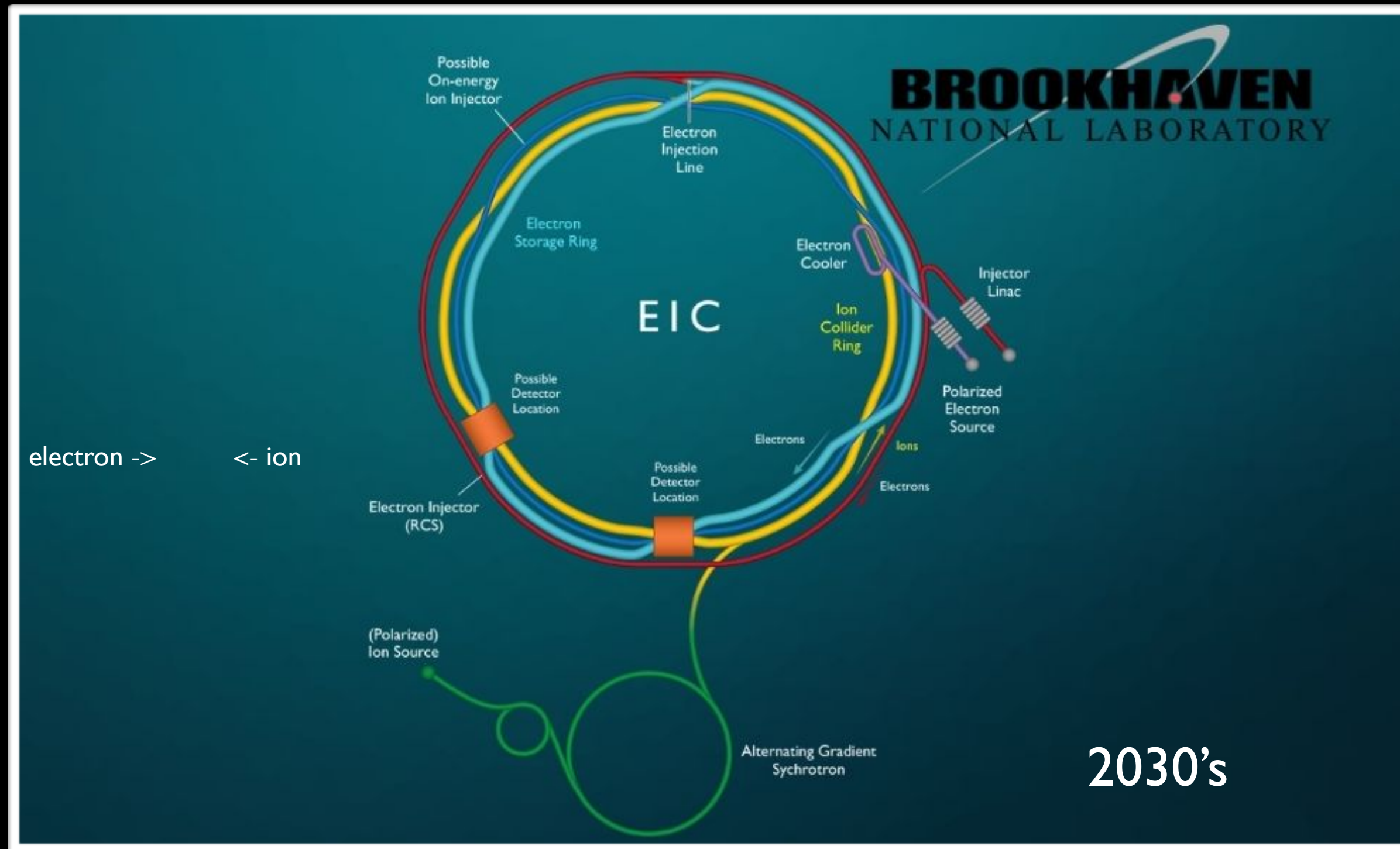
The discovery of QGP-like phenomena in small collision systems like pp and p-Pb collisions has surprised the community at large, and gave rise to a tremendous experimental and theoretical activity in recent years. The theoretical explanation and description attempts span today the entire field between 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