

STRONG-2020



## Annual Meeting

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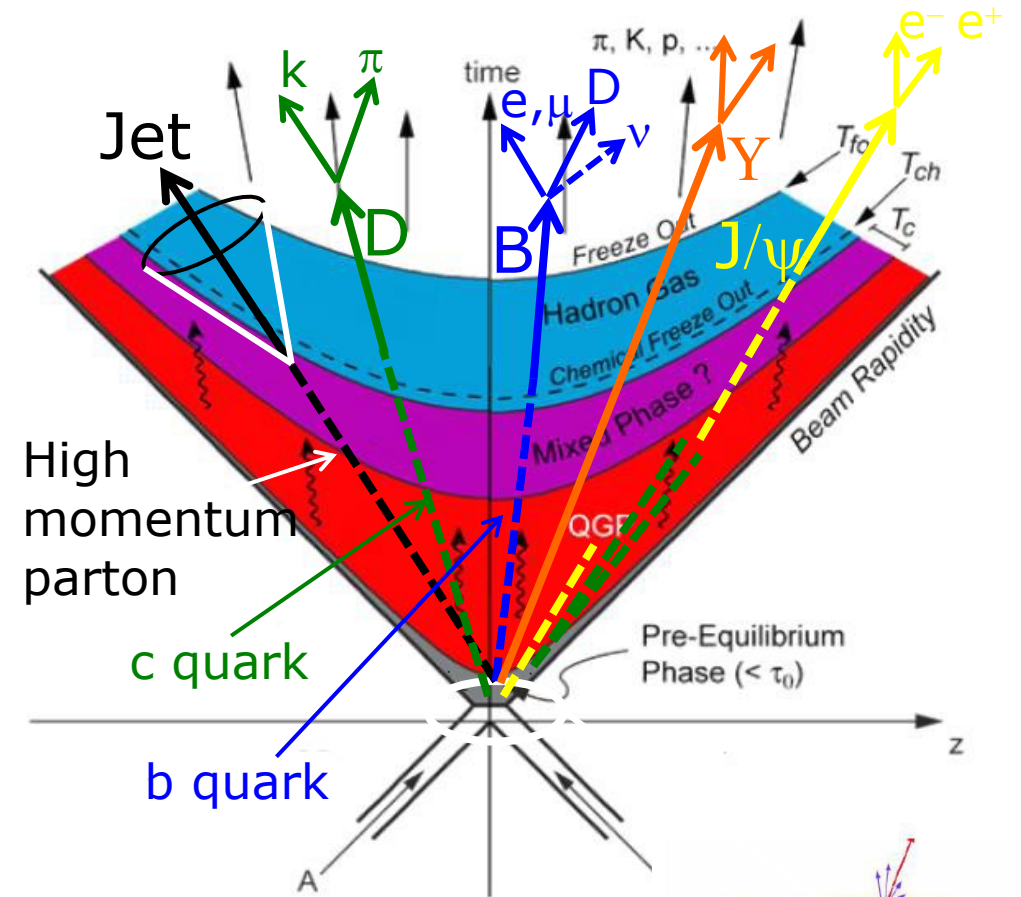
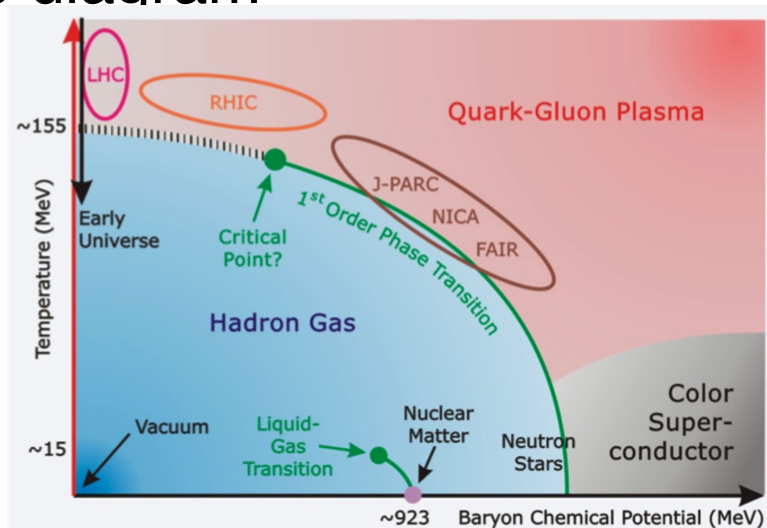
WP18 – NA7 "HF-QGP"

Giuseppe Bruno

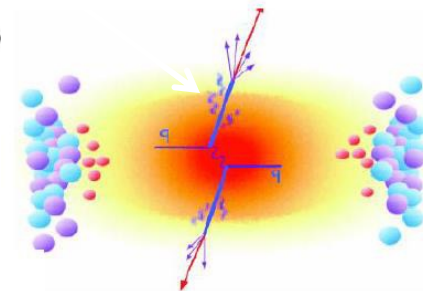
# Scope of the networking activity NA7

## Quark-Gluon Plasma characterisation with heavy flavour probes (Hf-QGP)

→ focus has been on the QGP properties at the LHC energy, but also aiming at using these unique probes in other regions of the QCD phase diagram



$$\tau_f = \frac{\hbar}{m_T}$$



# NA7, a *networking* activity

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- Limited budget w.r.t. other kinds of activities
- Shared between both theorists and experimentalists
- Three formal beneficiaries (tot. direct costs ~ 290 k€):
  - INFN ~ 75 k€
  - cnrs ~ 175 k€
  - gsi ~ 40k€

Spokespersons:

- Joerge Aichelin (cnrs) & G.B. (INFN)

# Plan of the presentation

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1. Main achievements in the whole project
2. Progress achieved by the WP during the last year
3. Remaining task until the end of the project (31 July 2024)

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# Gathering the community (despite the Covid)

Theory workshops:

<http://theory.gsi.de/~ebratkov/Conferences/STRONG2021/index.html>



4.10 – 8.10 2021

<http://theory.gsi.de/~ebratkov/Conferences/HFHF-STRONG-2023//index.html>



28.9 – 4.10 2023

# Gathering the community (despite the Covid)

Online workshop:

<https://indico.cern.ch/event/1022351/>

## HF-QGP: theory meets experiments for the usage of RIVET

Thursday 8 Apr 2021, 09:00 → 18:00 Europe/Zurich

Giuseppe Bruno (Universita e INFN, Bari (IT)) , Joerg Aichelin (Subatech/CNRS)

**Description** It is the purpose of this first meeting to start the communication between the Rivet development teams, the different experiments and the people doing actively numerical simulation for heavy ion collisions with a focus on heavy flavour.

On the one side it has the goal to get familiar with the perspectives of the further development of Rivet, on the other side to discuss the concerns and difficulties which the theorists have with Rivet and how one can overcome these concerns.

HF-QGP is a networking activity of the STRONG\_2020 project (see <http://www.strong-2020.eu/>) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093



# Gathering the community (despite the Covid)

Hybrid workshop:

<https://indico.cern.ch/event/866418/overview>

## Heavy-flavour hadronization in pp and heavy ion collisions at the LHC

2-3 Mar 2020  
CERN  
Europe/Zurich timezone

Enter your search term

Overview

Organizing committee

Timetable

Registration

Participant List

Videoconference

The LHC Collaborations reported measurements of the baryon-to-meson ratios for open charm and bottom hadrons in pp, p-Pb and, to some extent, Pb-Pb collisions at the LHC that challenge the present understanding of heavy-quark hadronization in hadronic collisions. The  $\Lambda_c/D$ ,  $X_c/D$  and  $\Lambda_b/B$  ratios at low momentum are larger than those measured in  $e^+e^-$  and ep collisions at LEP and HERA and predicted by event generators based on string fragmentation and tuned to describe the LEP and HERA data. The  $\Lambda_c/D$  ratio in pp and p-Pb collisions is remarkably similar to the  $\Lambda_b/K$  ratio and both are larger than the p/ $\pi$  ratio.

These findings show that the baryon-to-meson ratio depends on the collision system, highlighting the relevance of "long-distance" effects in heavy-quark hadronization. Various QCD mechanisms are recently being considered in the theory community to describe the observations, including colour reconnection, ropes, or statistical approaches. Such effects also have an impact on the measurement of the total heavy-quark production cross section and on the usage of D and B meson production measurements to constrain the PDFs in the proton and in the nucleus.

In nucleus-nucleus collisions, where a hot and dense quark-gluon plasma forms and collectively expands, the enhancement of baryon-to-meson ratios is predicted by theoretical models in which heavy quarks with low momentum hadronize by coalescence with light quarks from the plasma. The first measurements of  $\Lambda_c$  production in nucleus-nucleus at the LHC (and at RHIC) hint at a larger ratio to D mesons, with respect to the case of pp collisions.

The goals of the proposed workshop are:

1. review and compare the results from the LHC experiments in various collision systems
2. review the status of hadronisation in pp and p-Pb collisions as described in event generators
3. discuss possible new measurements and theory developments
4. discuss the possible commonalities of the physics mechanisms in small and large hadronic collision systems as well as in the light- and heavy-flavour sectors.


VIDYO connection will be available.

For information relative to housing, access to CERN for those not holding a CERN card and laptop registration, please check <http://lpc.web.cern.ch/about>

The workshop is co-sponsored by the [STRONG 2020 project](#) (EU Horizon 2020 grant 824093).



 **Starts** 2 Mar 2020, 09:00  
**Ends** 3 Mar 2020, 18:10  
Europe/Zurich

 **CERN**  
4/3-006 - TH Conference Room  
[Go to map](#)



# Gathering the community (despite the Covid)

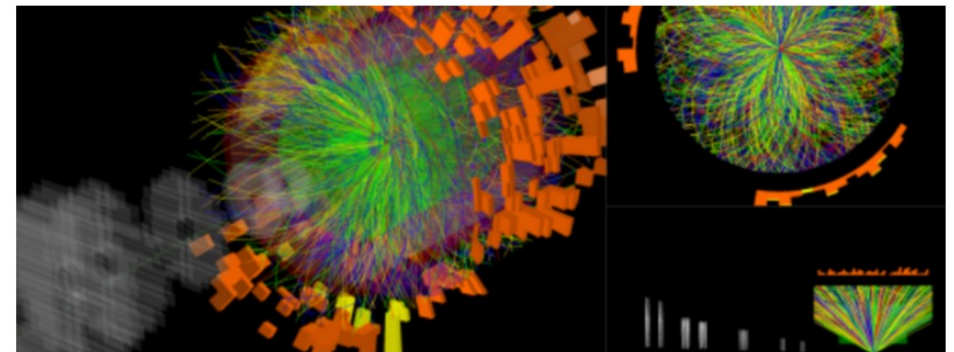
Hybrid workshop:

Main workshop at ECT\* in Nov. 2021:

<https://www.ectstar.eu/workshops/quark-gluon-plasma-characterisation-with-heavy-flavour-probes/>

- One of the first workshop with the possibility of *in person* participation after the long lockdown of the Covid19 Pandemic
- ORGANIZERS:
  - Giuseppe Bruno (Politecnico & INFN Bari, Italy)
  - Joerg Aichelin (SUBATECH, France)
  - Ralf Averbeck (GSI & EMMI, Germany)
  - Fabrizio Grosa (INFN Torino, Italy)
- NUMBER OF PARTICIPANTS:
  - 60 (about 20 in persons and 40 from remote). The workshop took place as a hybrid meeting.

## QUARK-GLUON PLASMA CHARACTERISATION WITH HEAVY FLAVOUR PROBES



15 November 2021 — 19 November 2021 Hybrid/Mixed

Heavy flavor (HF) quarks are excellent probes for the properties of the QGP created in ultra-relativistic heavy-ion collisions. Open HF hadron production allows one to determine the transport coefficients of the QGP. At high transverse momentum, they serve to study parton energy-loss mechanisms in the QGP. Present models, however, differ in many details. In the quarkonia sector, open questions include: up to which temperature can the different quarkonium states survive in a QGP and how do these objects interact with the QGP? How can the recombination of HF quarks/antiquarks from independent hard parton-parton interactions be described in an expanding medium? How constraining is the knowledge of the total HF production crosssection? How do quarkonia interact with the expanding gas of hadrons? Experimentalists and theorists will gather to contribute to answering these questions.

The workshop will take place as a hybrid meeting, with limited on-site participation, provided that the pandemic situation permits this

# Supporting the participations of students at major conference

## 11th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

<https://indico.uni-muenster.de/event/1409/page/48-supported-by>

## Supported by

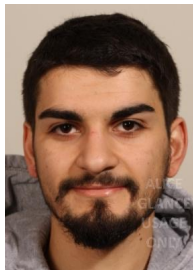
The HP2023 conference is supported by donations from the

- Brookhaven National Laboratory
- Central China Normal University, Wuhan, China
- CERN
- CRC-TR 211: *Strong-interaction matter under extreme conditions*, Darmstadt, Frankfurt
- ExtreMe Matter Institute (EMMI), GSI
- HFHF - *The Helmholtz Research Academy Hesse for Future Accelerators*
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- NRW-FAIR Network
- NuPECC
- RTG 2149: *Strong and Weak Interactions - from Hadrons to Quarks*
- Strong-2020 - an EU Horizon 2020 Project



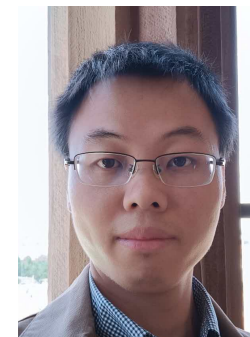
# Routeing outstanding young researchers

- 1. Fabrizio Grosa (Ph.D. in 2020) – post-doc co-funded by NA7 at INFN-To in 2020**  
→ Present activity / position - ALICDE PWG-HF convener; CERN fellow, then (presently) CERN LD position
- 2. Luca Micheletti (Ph.D. in 2021) – post-doc cofounded by NA7 at INFN-To in 2021**  
→ Present activity / position - ALICDE PWG-DQ convener; INFN staff researcher (permanent)
- 3. Fabio Colamaria (Ph.D. in 2014) – a few months of his contract (INFN permanent researcher) covered by NA7**  
→ Present activity / position - ALICE PWG-HF convener; INFN staff senior researcher (permanent) at INFN-Ba  
→ We could get back from INFN a fraction of these costs and co-fund still another post-doc
- 3.a Antonio Palasciano (Ph.D in 2024) – currently post-doc at INFN-Ba – next ALICE PAG-HFJC convener**



# Routeing outstanding young researchers

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4. Jiaxing Zhao (Ph.D. in 2020 ) – post-doc in Nantes till May 2024 – outstanding activity in the networking (see later) – now post-doc in Frankfurt University
  5. **Himanshu Sharma** (Ph.D. in 2023 “Prompt and non-prompt J/ $\psi$  production in Pb–Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV with ALICE experiment”)– post-doc at INFN-Pd in 2023 – still ongoing
  6. **Ravindra Singh** (Ph.D. in 2023 “Heavy flavour azimuthal correlations from small to large systems” at Indian Inst. Tech.) - post-doc at GSI – still ongoing



# Publications

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- Sound record of theory papers since the very start of the projects
  - **Just in the last year:** 14 publications supported by STRONG-2020
- Recognition of works done within experimental collaborations required a lengthy process

In ALICE: finally agreed with the management in Feb 2023 →

→ presently 83 articles with acknowledgment to grant n. 824093

including several older papers, starting from 1.1.2022, which were kept in “stand-by” while discussing affiliation of Russian colleagues

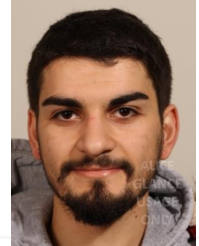
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# $\Delta\varphi$ distributions between charm-hadron and charged particles

Antonio Palasciano @ INFN-Ba



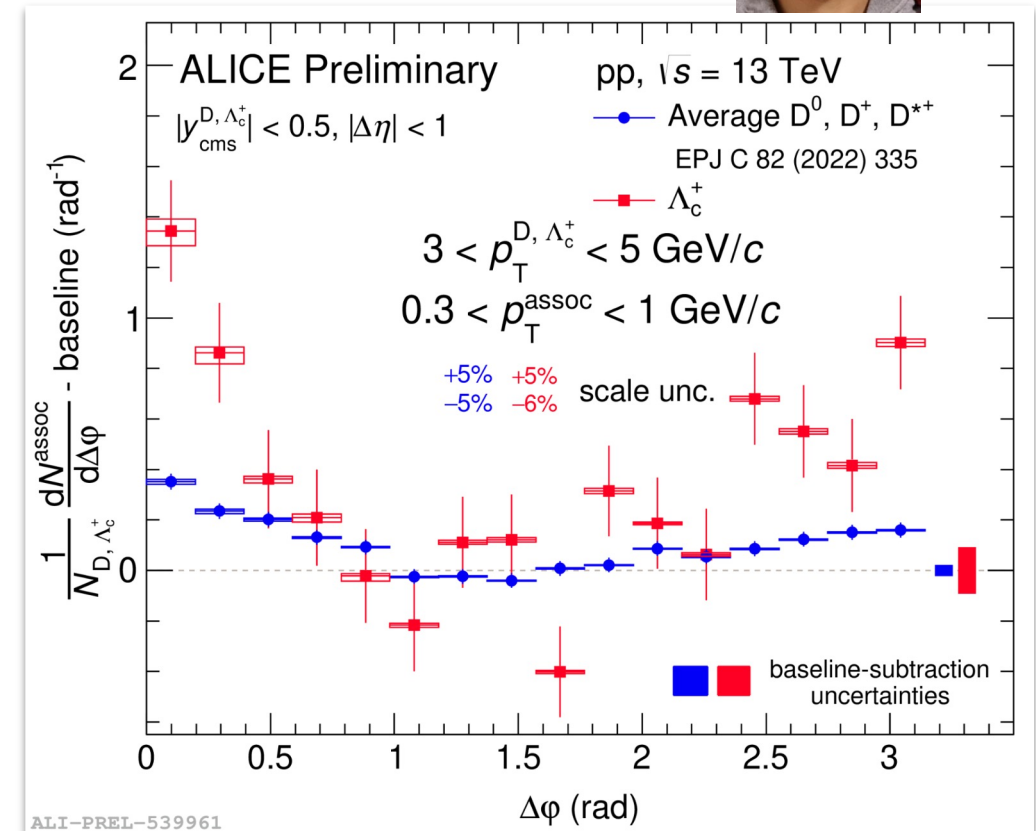
## Physics motivations

- Description of charm fragmentation
  - access to the jet shape and its composition
- Sensitivity to charm-quark production mechanisms
- Possible influence of hadronisation mechanisms
  - interest in **charm-to-meson** vs **charm-to-baryon**

! Paper in preparation:  $\Lambda_c^+ - h$  in pp collisions at  $\sqrt{s} = 13$  TeV

Preparation of **Run 3** analysis framework aiming to:

- extended trigger  $p_T$  reach, higher granularity, ...
- more charm hadron states to study ( $D_s, \Sigma_c^+, \dots$ )



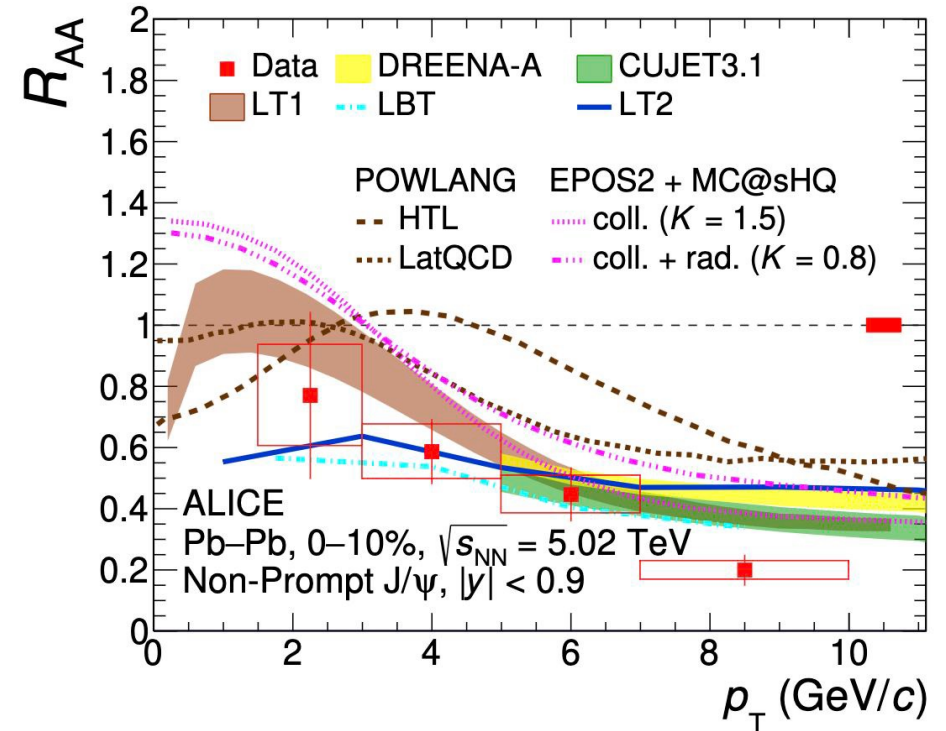
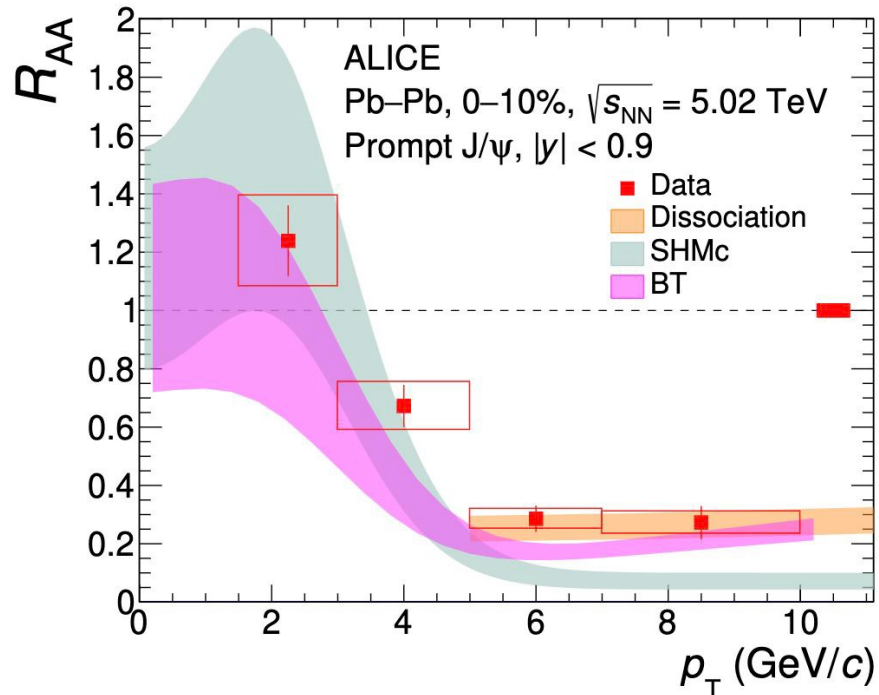
# Prompt and non-prompt $J/\psi$ measurements in Pb-Pb collisions

Himanshu Sharma @ INFN-Pd



Nuclear modification factors of prompt and non-prompt  $J/\psi$  in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV in LHC Run 2  
□ Presented the results in EPS-HEP 2023, Hamburg

○ [Link to presentation](#)



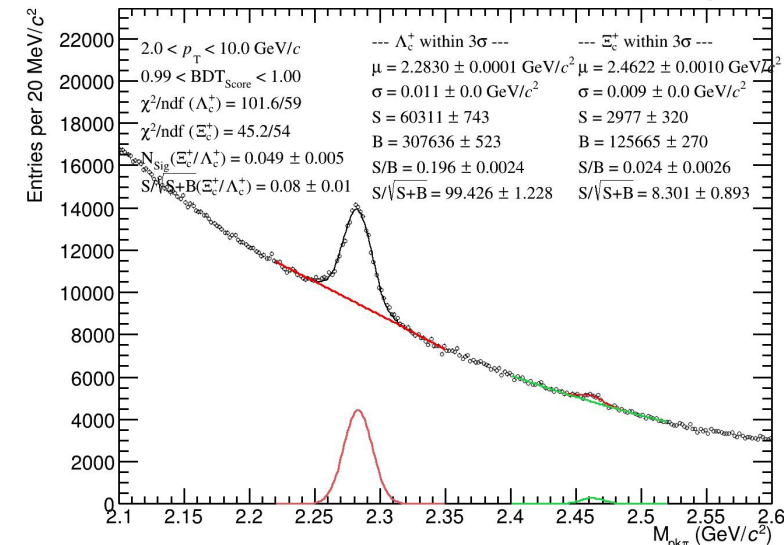
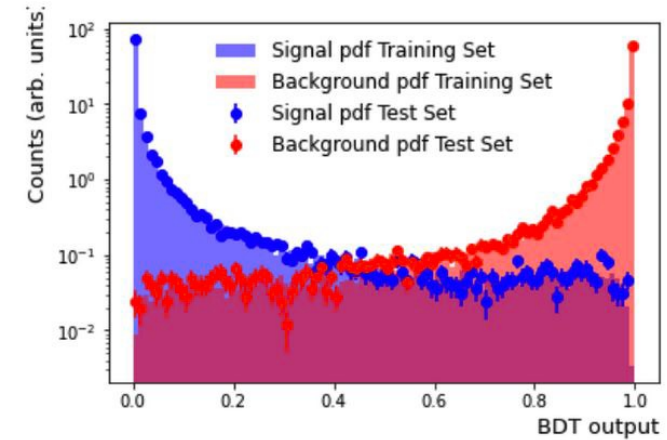


# $\Xi_c^+$ baryon measurement in heavy ion collisions with LHC Run3 data



Himanshu Sharma @ INFN-Pd

- Important to understand charm quark hadronization in pp and Pb-Pb collisions
  - Branching fraction is not precisely determined for  $\Xi_c^+ \rightarrow pk^-\pi^+$  decay channel  $\sim (0.45 \pm 0.21)\%$  [1]
  - In LHC Run 3, large data taking rates in ALICE, should improve the statistical precision
  - $\Xi_c^+ \rightarrow pk^-\pi^+$  is more constrained compared to previously measured  $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^-$
- **Work ongoing:**
  - Using Boosted decision tree (BDT) for signal-background discrimination in pp collisions
  - Same procedure can be applied in Pb-Pb collisions in future



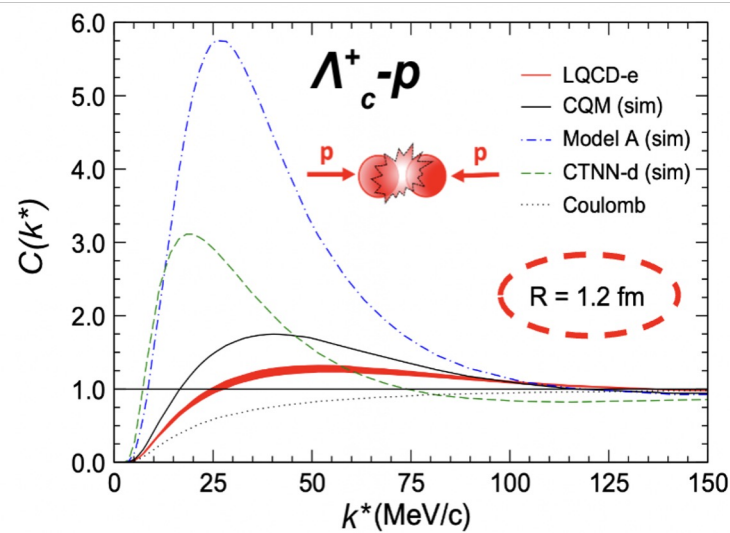
# Study towards charm nuclei formation



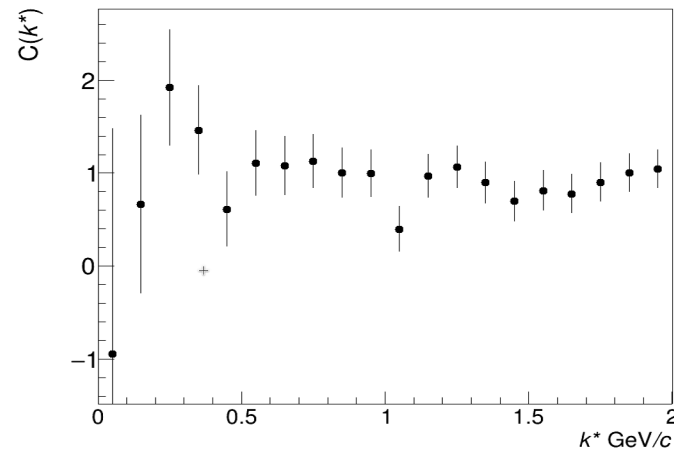
Ravindra Singh @ GSI

## ➤ Possibility to **constrain the $\Lambda_c$ -N interaction potential**

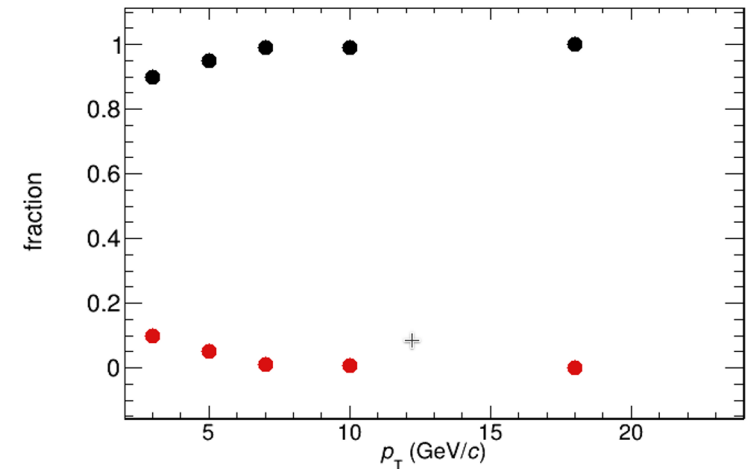
- Distinct source size dependence of the correlation function in presence of bound states



## ➤ First look of $\Lambda_c$ (candidate)-proton correlation function



## ➤ Fraction of prompt and non-prompt $\Lambda_c \rightarrow pK\pi$ with machine learning (BDT) $\approx 90\%$



## Outlook:

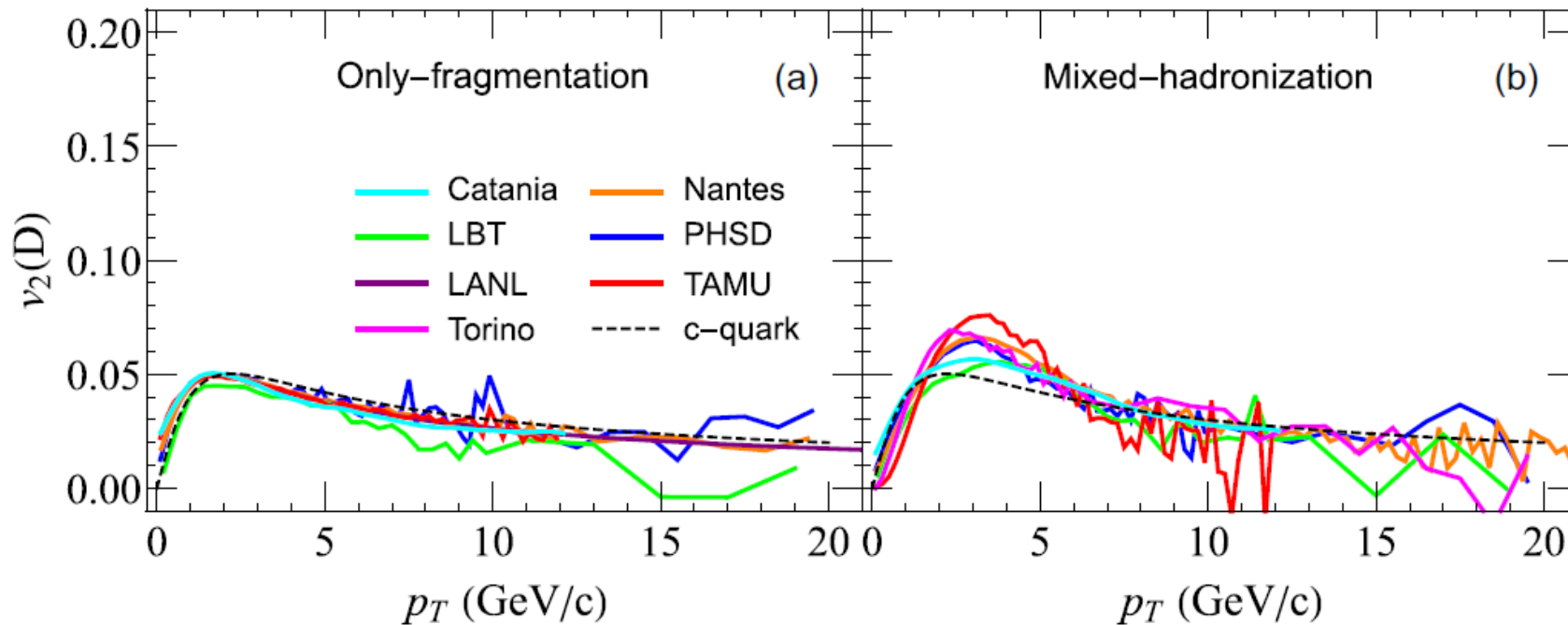
- Optimisation ML model with latest data
- Background subtraction from the correlation function

# Hadronization of heavy quarks

Work coordinated by Jiaying Zhao @ Nantes



The last paper of the systematic comparison of transport approaches for heavy quarks/hadrons published



“Hadronization of heavy quarks,”  
J. Zhao, J. Aichelin, P. B. Gossiaux,  
A. Beraudo, S. Cao, W. Fan, M. He,  
V. Minissale, T. Song and I. Vitev,  
et al.

**Phys. Rev. C 109, 054912 (2024)**

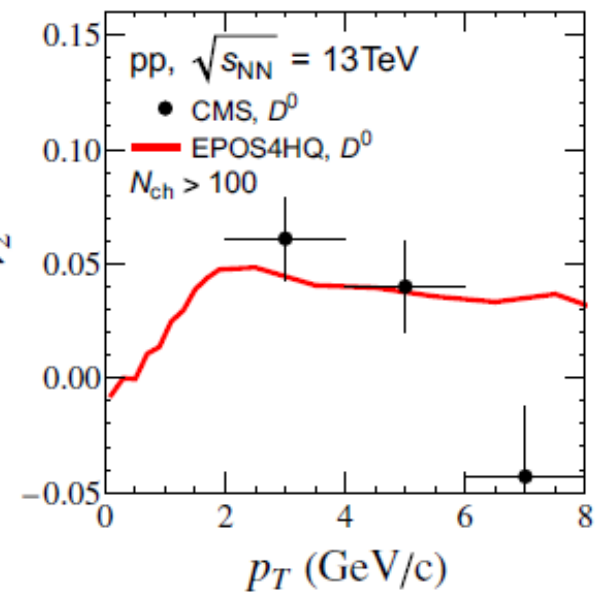
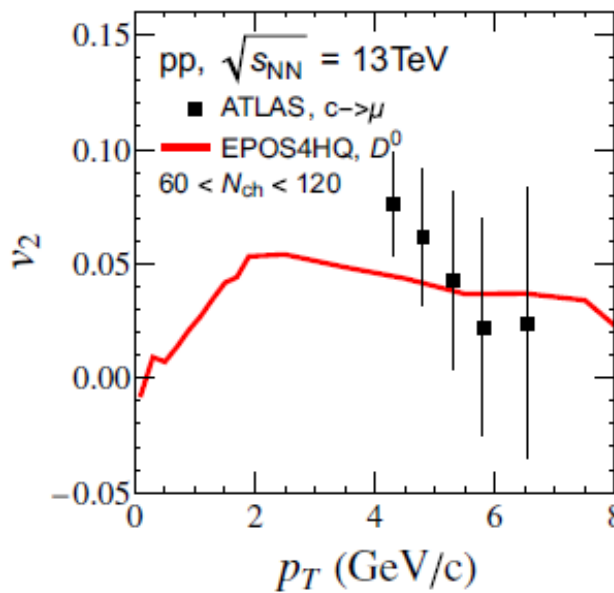
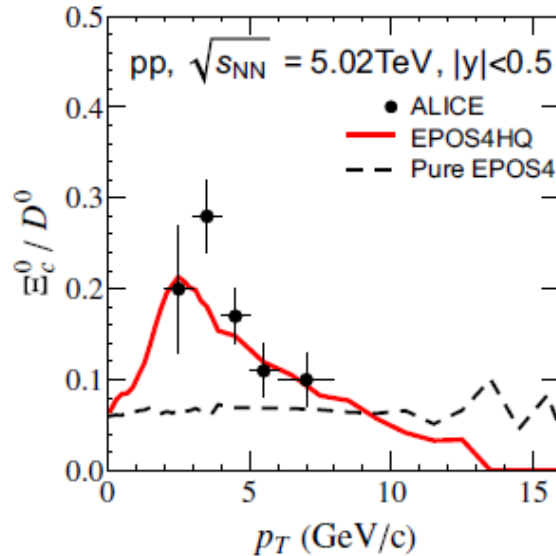
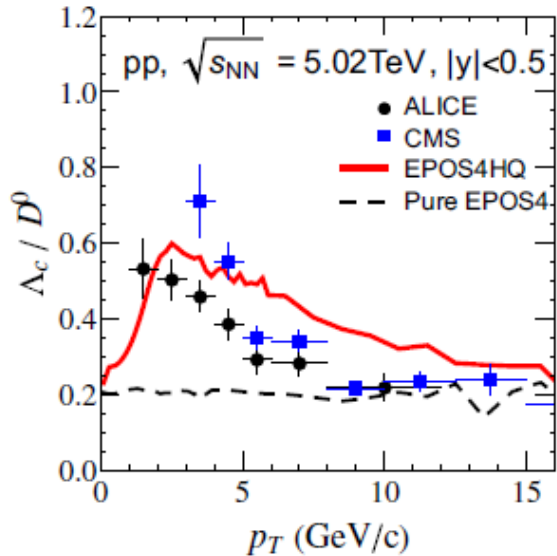
the differences in the hadronization processes due to the assumptions each approach studied in details , which paved the way to unify the hadronization procedures in the different codes

# Study in small colliding systems with EPOS4HQ

Jiaxing Zhao et al. @ Nantes



Phys.Rev.D 109 (2024) 5, 054011 (& arXiv:2401.17096)



The surprising enhancement of HF baryons over mesons and the appearance of an elliptic flow in proton-proton collisions can be understood assuming also in proton proton collisions a quark gluon plasma which is formed if critical energy density of  $0.57 \text{ GeV}/\text{fm}^3$  is obtained

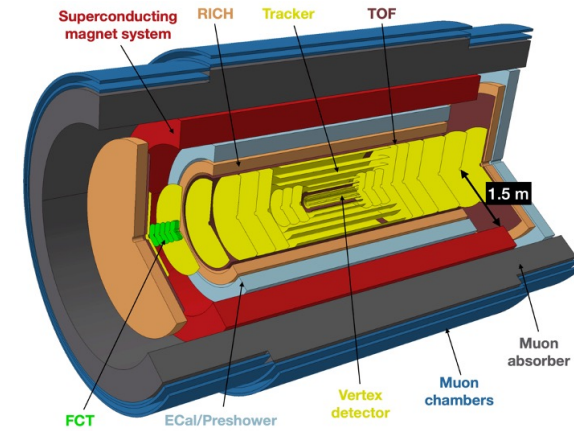
# Plan of the presentation

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# Report with recommendations for ion periods after LHC Long Shutdown 4 (LS4)

> 2035



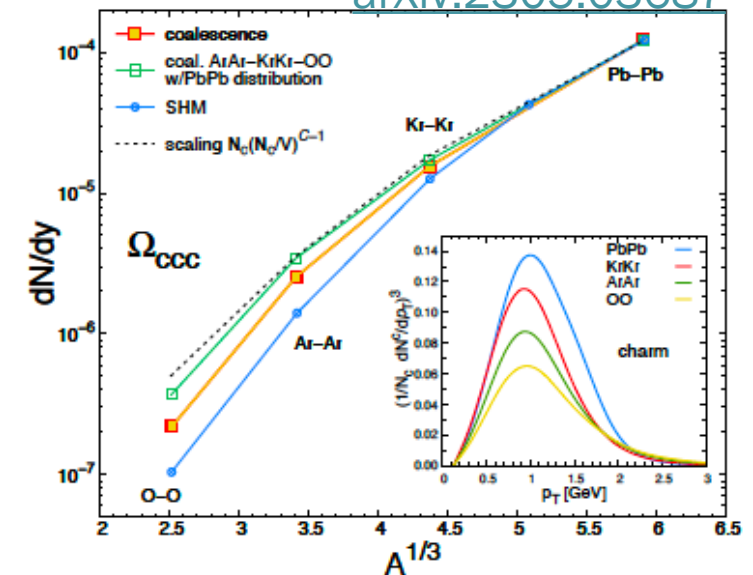
- The proposed new experiment ALICE 3 will have a main focus on rare HF observables, and it would be the major player for ion-ion runs at the LHC after LS4
- not granted that Pb-Pb would be the best system to be studied  
 → eventually central collisions in lighter systems (e.g. O-O, In-In, Ar-Ar) more indicated

arXiv:2305.03687

## Two observables selected as benchmarks:

- multi-charmed baryons:  $\Xi_{ccc}$  or  $\Omega_{ccc}$  (the latter out of reach in Pb-Pb)
- DDbars angular correlations

the experimental reach to be compared with theoretical predictions

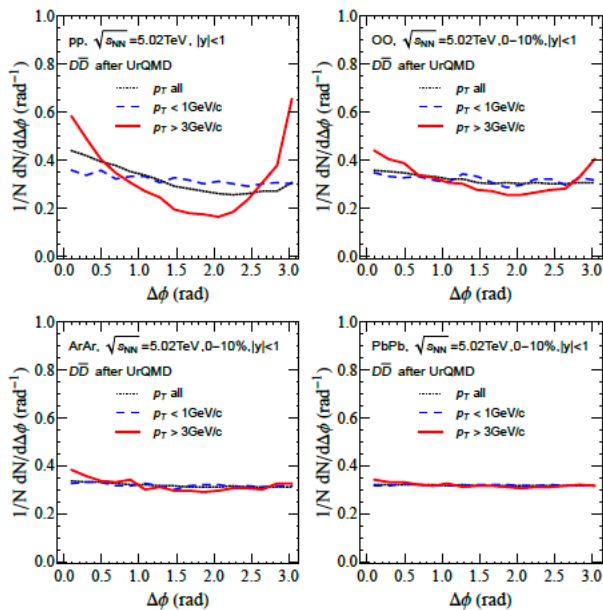
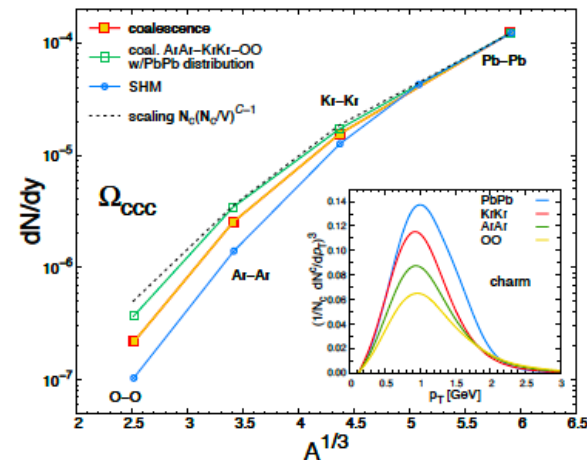


# Report with recommendations for ion periods after LHC Long Shutdown 4 (LS4)

[arXiv:2305.03687](https://arxiv.org/abs/2305.03687)

Several work performed to reach this goal over the last year(s):

- Theoretical efforts to obtain predictions in other colliding systems for
  - multi-strange baryons ([arXiv:2305.03687](https://arxiv.org/abs/2305.03687))
  - D-Dbar angular correlations (Jiaxing Zhao, paper draft ready)



- Experimental efforts to obtain performance with ALICE 3 in other colliding systems for
  - multi-strange baryons (A. Palasciano, D. Chinnellato)
  - D-Dbar angular correlations (Marianna Mazzilli)

Draft of the report based on these studeis has been prepared

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



An ALICE 3 collision system study

ALICE Collaboration

Abstract

This document summarizes basic predictions for different collision systems using two models: PYTHIA Angantyr 8.303 and Glauber Monte Carlo 3.2. Please note that, at least for the time being, the values in this document are to be used as rough guide-lines only and are subject to change.