Hadrons in heavy-ion collisions at ALICE

Małgorzata Janik
for the ALICE Collaboration

20th International Conference on Hadron Spectroscopy and Structure
HADRON 2023

The ALICE Collaboration

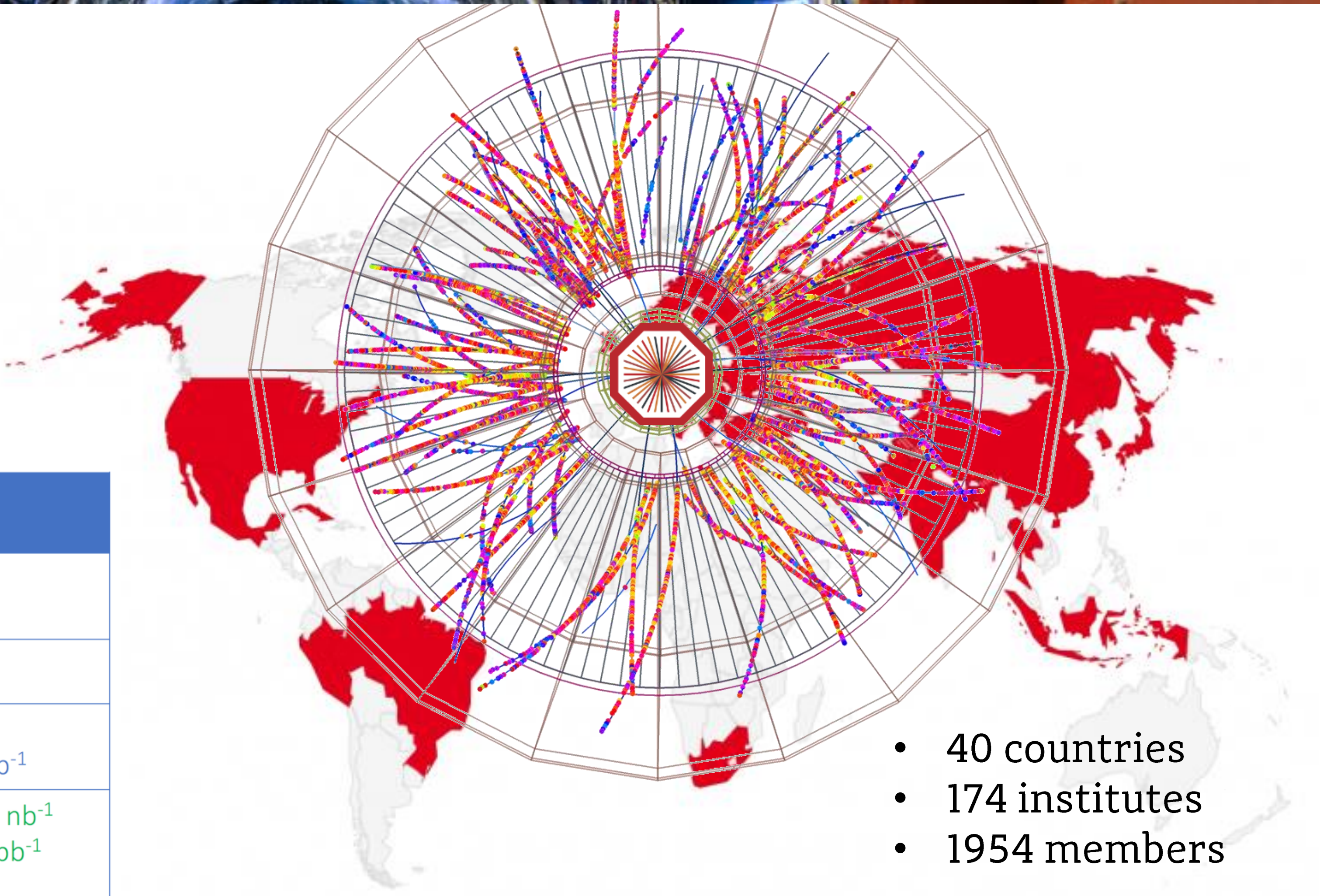
- Run 1 + Run 2 data:

436 ALICE papers on arXiv

https://alice-publications.web.cern.ch/submitted

Run 1 | Run 2

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010, 2011 2015, 2018	2.76 5.02	~75 μb^{-1} ~800 μb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	~15 nb^{-1} ~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13	~200 mb^{-1}, ~100 nb^{-1} ~1.5 pb^{-1}, ~2.5 pb^{-1} ~1.3 pb^{-1} ~36 pb^{-1}



- 40 countries
- 174 institutes
- 1954 members

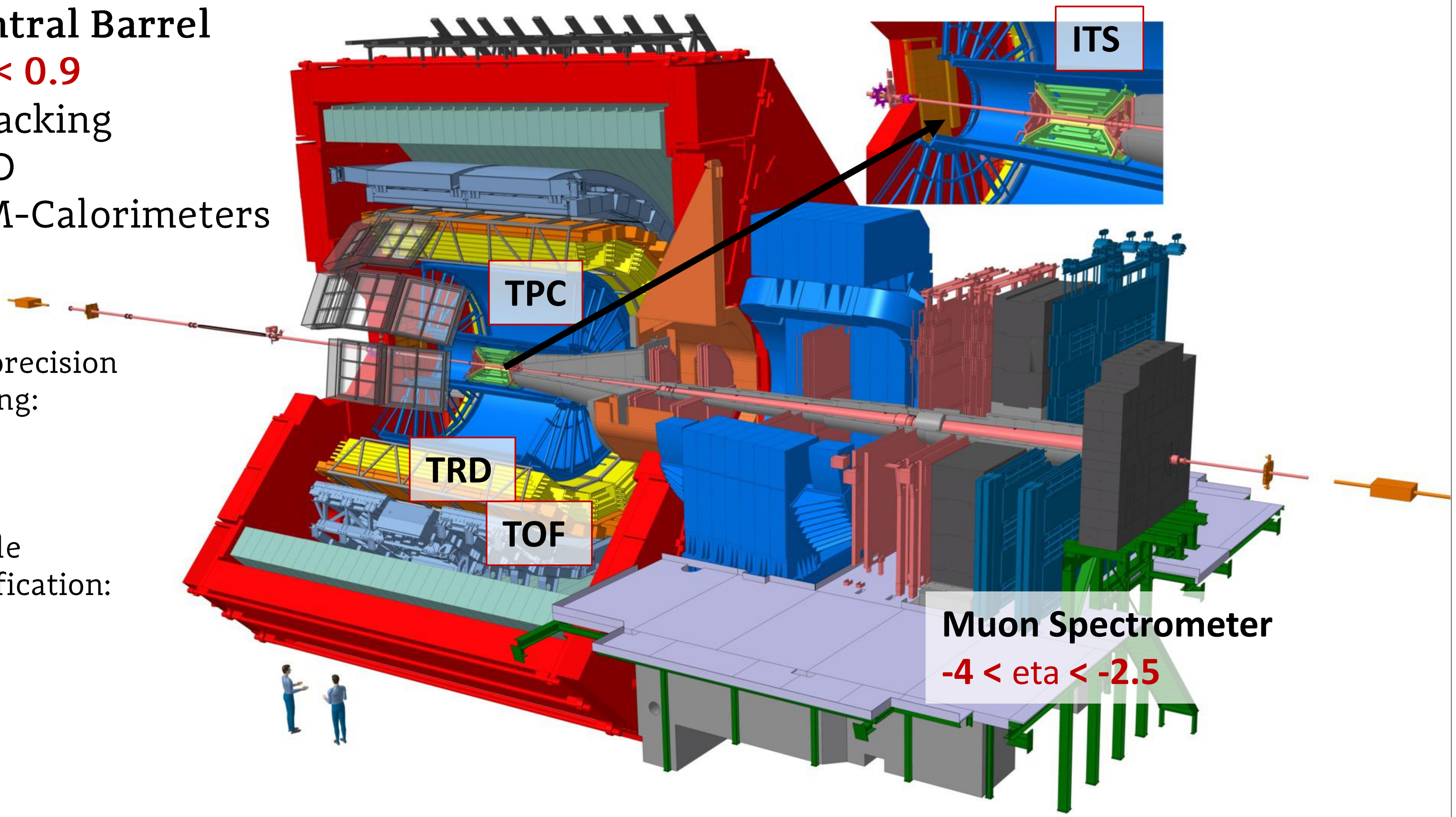
ALICE detector

Run 1 + Run 2 version:

Central Barrel
|η| < 0.9
- Tracking
- PID
- EM-Calorimeters

High precision tracking:
- TPC
- ITS

Particle Identification:
- TPC
- TOF
- TRD
- EMC

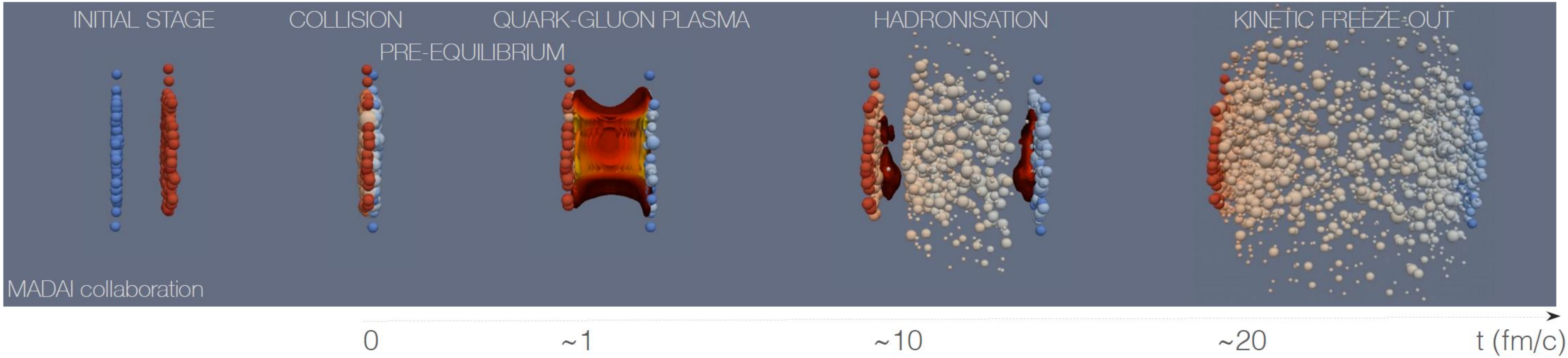


Forward detectors:
- AD (diffraction selection)
- V0 (trigger, centrality)
- T0 (timing, luminosity)
- ZDC (centrality, ev. sel.)
- FMD (N_{ch})
- PMD (N_{γ}, N_{ch})

ACORDE (cosmics)

ALICE physics

Explore the deconfined phase of QCD matter : quark-gluon plasma (QGP)



Study the properties and evolution of QGP:
→ Color deconfinement
→ Parton interactions
→ Expansion dynamics and hadronization

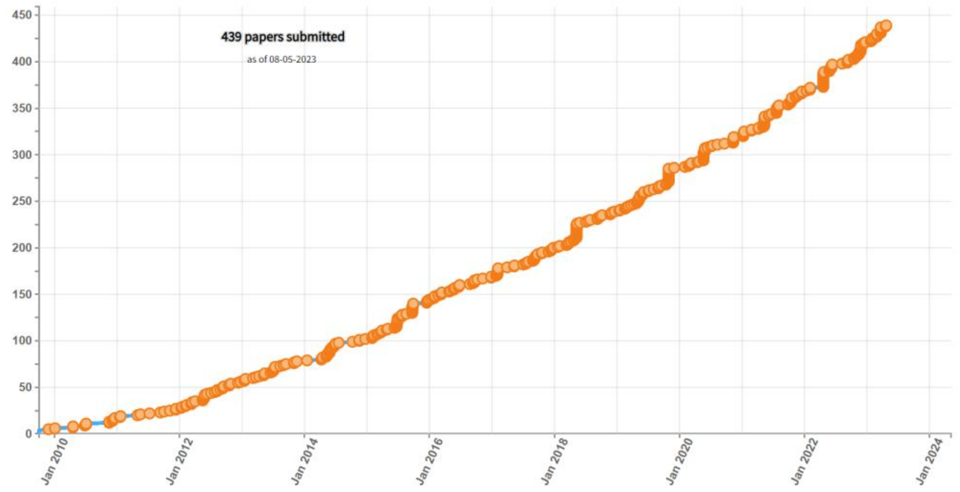
...and more!

→ Study QCD with small systems

→ Study hadron-hadron interactions

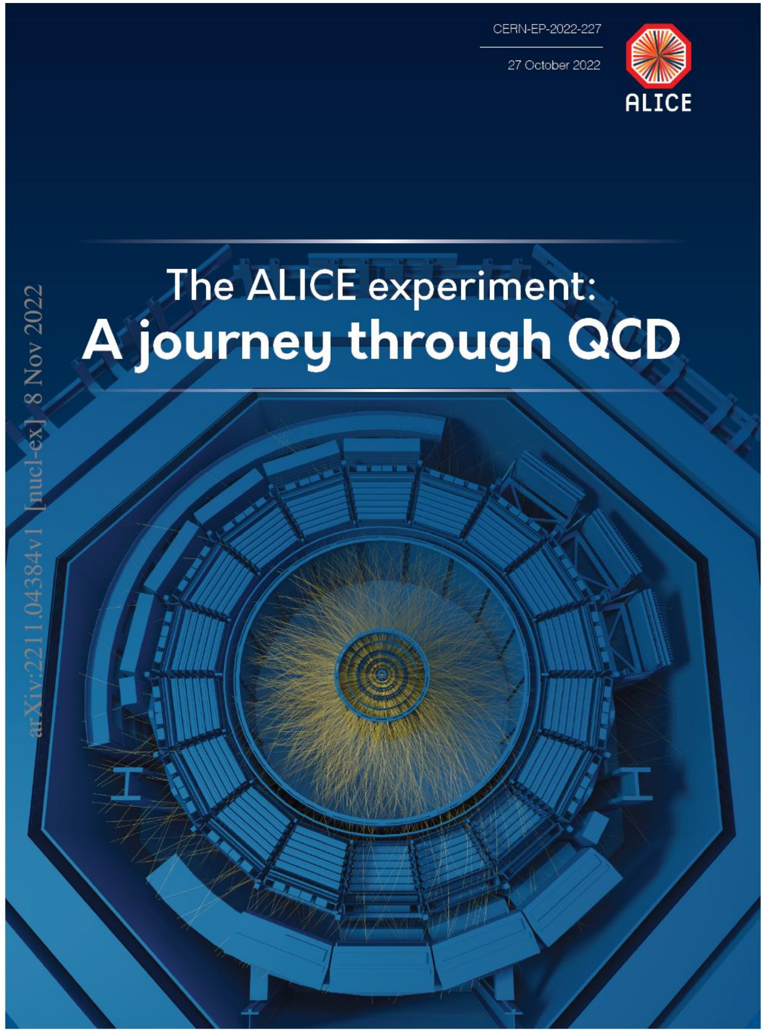
Just a small selection...

Publications
alice-publications.web.cern.ch

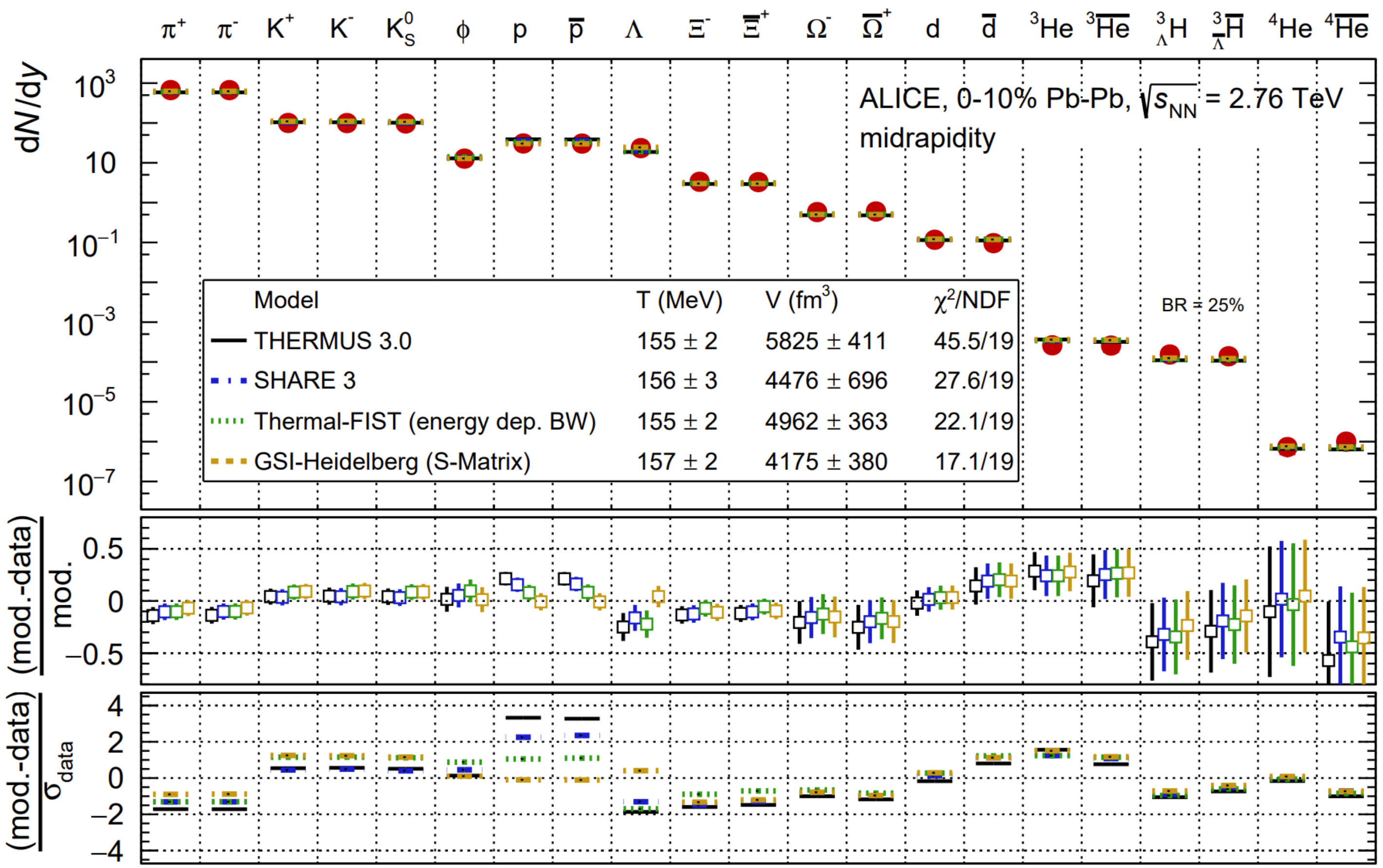


Preliminary results
alice-figure.web.cern.ch

ALICE review paper
- arXiv: 2211.04384
- selected physics highlights from Run 1 and Run 2



Light-flavor production



arXiv: 2211.04384

→ **Hadron yields described by statistical hadronisation models over many orders of magnitude**

→ **Chemical freeze-out**

happens near the hadronization of the QGP itself

→ **Chemical equilibrium** close to QGP transition temperature:

- $T_{chem} \approx T_c \approx 156$ MeV

Light-flavor hadron production with ALICE at LHC

A. Caliva

Mon 5 Jun 2023, 14:00

Probing hadron formation at the LHC through the study of strange particles in different collision systems and energies with ALICE at the LHC

M. Barlou

Mon 5 Jun 2023, 15:00

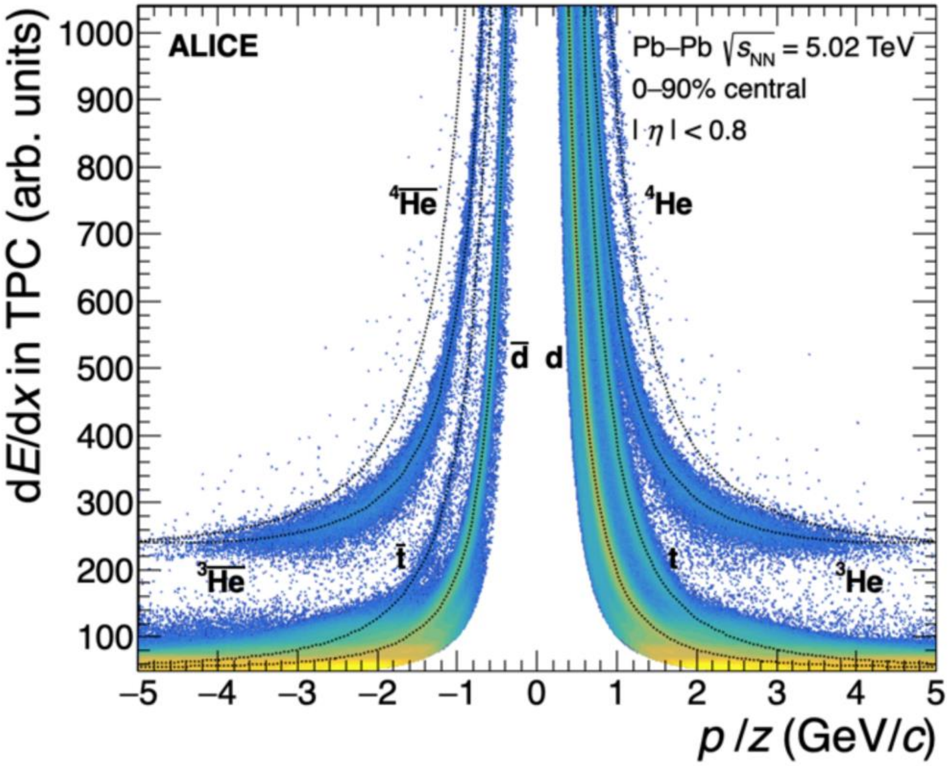
Light (anti)nuclei production

LHC – (anti)nuclei factory

Nuclei accessible in Run 2:

d, t, ${}^{3}_{\Lambda}H$, ${}^{3}He$, ${}^{4}He$

arXiv: 2211.14015



Production of (anti)nuclei:

- sensitive to hadronization;
- formation mechanisms - statistical hadronization of quark and gluons versus coalescence of nucleons

Overview and new directions about light (anti)nuclei measurements with ALICE
M. Rasa
Wed 7 Jun 2023, 17:00

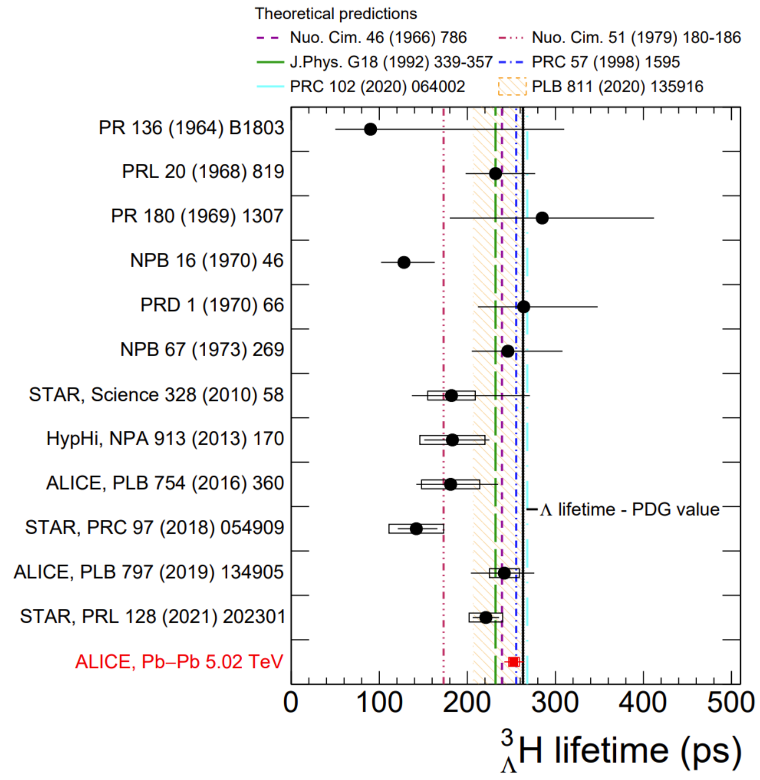
Constraining the formation mechanisms of light (anti)nuclei at the LHC and applications for cosmic ray physics
G. Malfattore
Wed 7 Jun 2023, 17:50

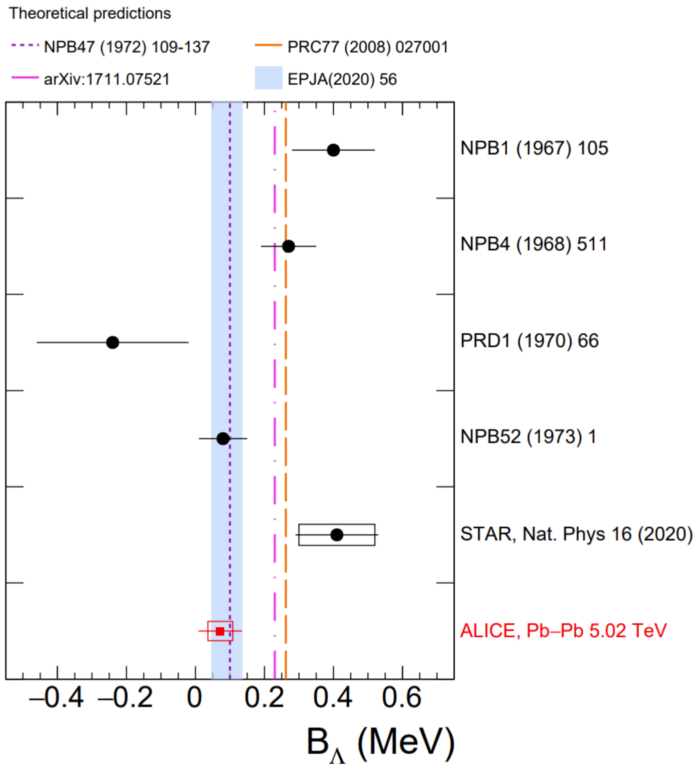
A study of K−d and K+d interactions via femtoscopy technique
W. Rzesa
Wed 7 Jun 2023, 14:25

Hypertriton lifetime

Measurements of the hypertriton production and properties with ALICE
S. Bufalino
Thu 8 Jun 2023, 14:00

60 years after discovery, its properties were not yet well measured...
Unprecedented precision with Pb-Pb Run 2 data:



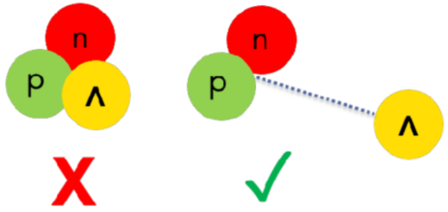


arXiv: 2209.07360

- Lifetime: no deviation from the free Λ lifetime

- abundantly produced in QGP
– even if size comparable to medium!

- Binding energy B_{Λ} : this is a loosely bound deuteron-Λ molecule

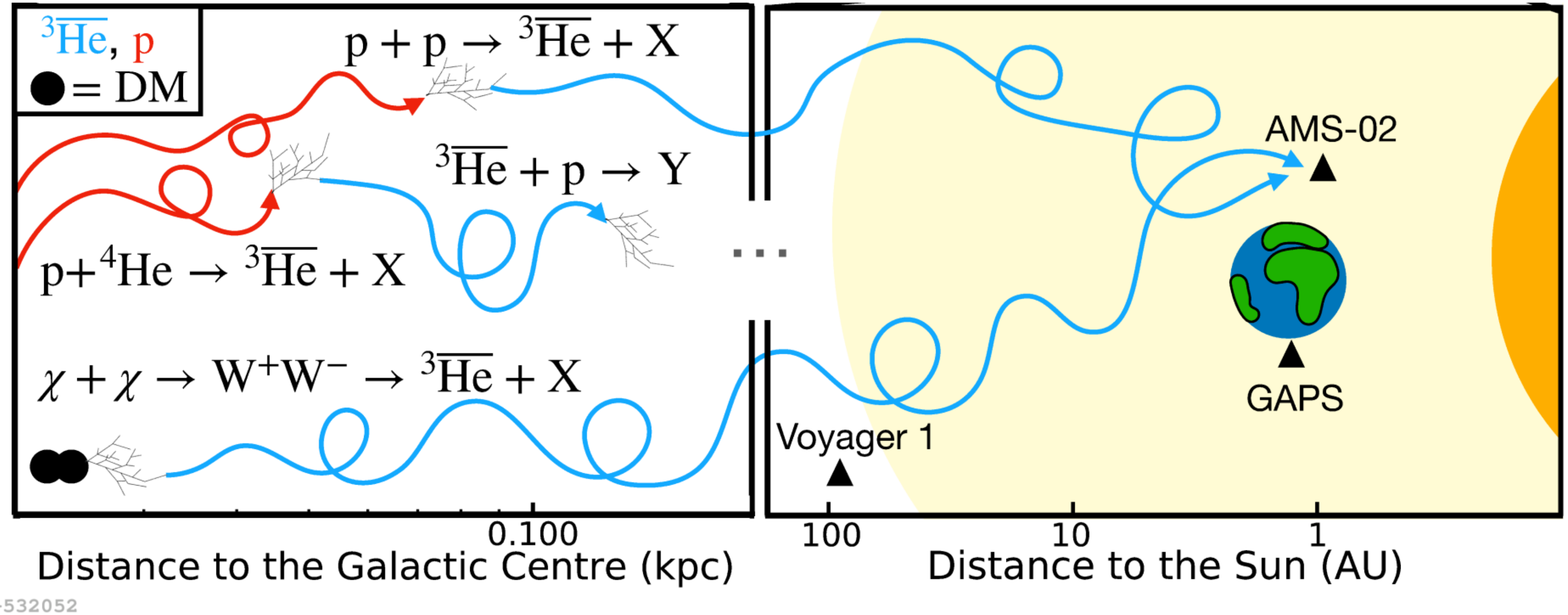


Light antinuclei absorption in ALICE and Galaxy

Information about antinuclei has **strong impact on dark matter searches** in space,
e.g. $\chi_0\chi_0 \rightarrow$ anti-d, anti-^{3}He+X (AMS-02, GAPS, BESS)

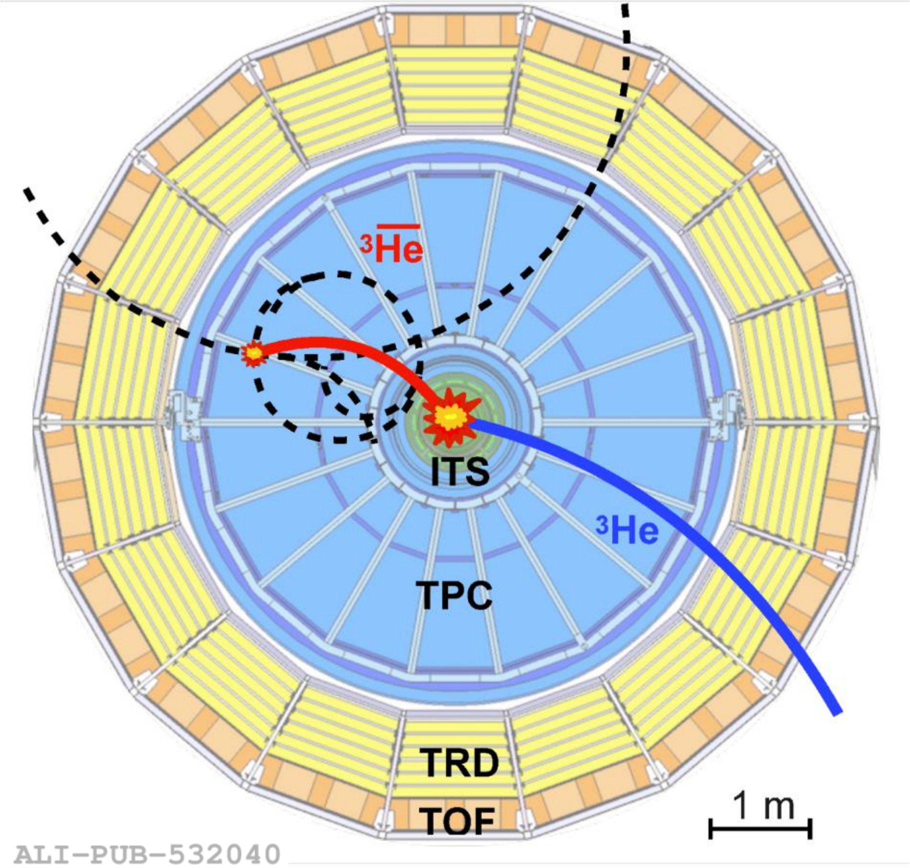
- Antinuclei cosmic rays could provide a smoking gun signal for dark matter (virtually background free).
- **Antinuclei absorption** in space poorly known.

Nature Phys. 19 (2023) 1, 61-71



Light antinuclei absorption in ALICE and Galaxy

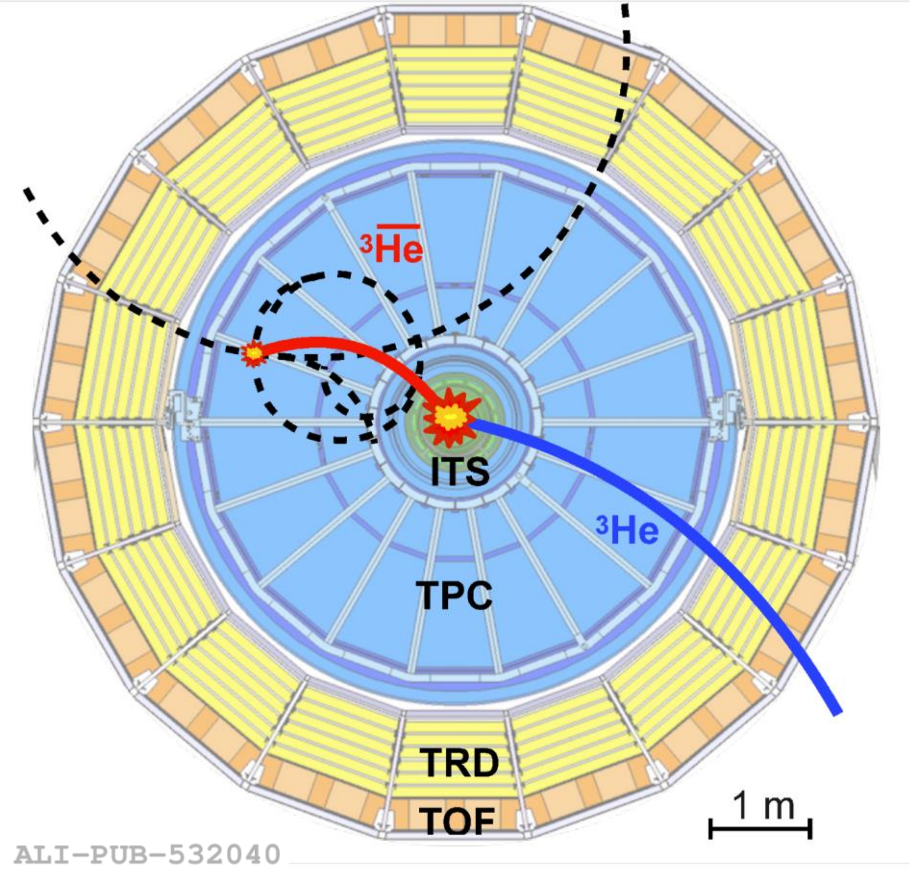
Nature Phys. 19 (2023) 1, 61-71



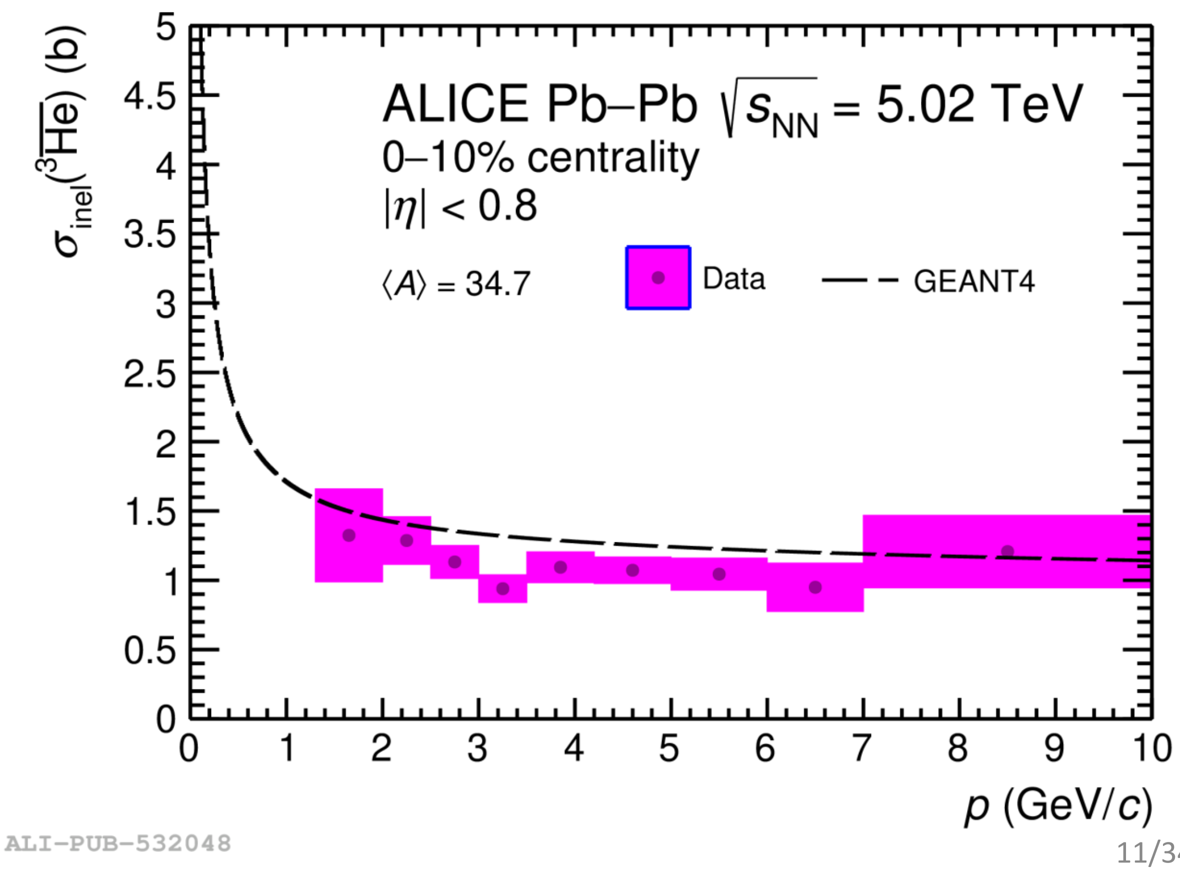
- Novel technique to use detector as an antiparticle absorber
- First experimental measurement of $\sigma_{inel}(^{3}\overline{He})$

Light antinuclei absorption in ALICE and Galaxy

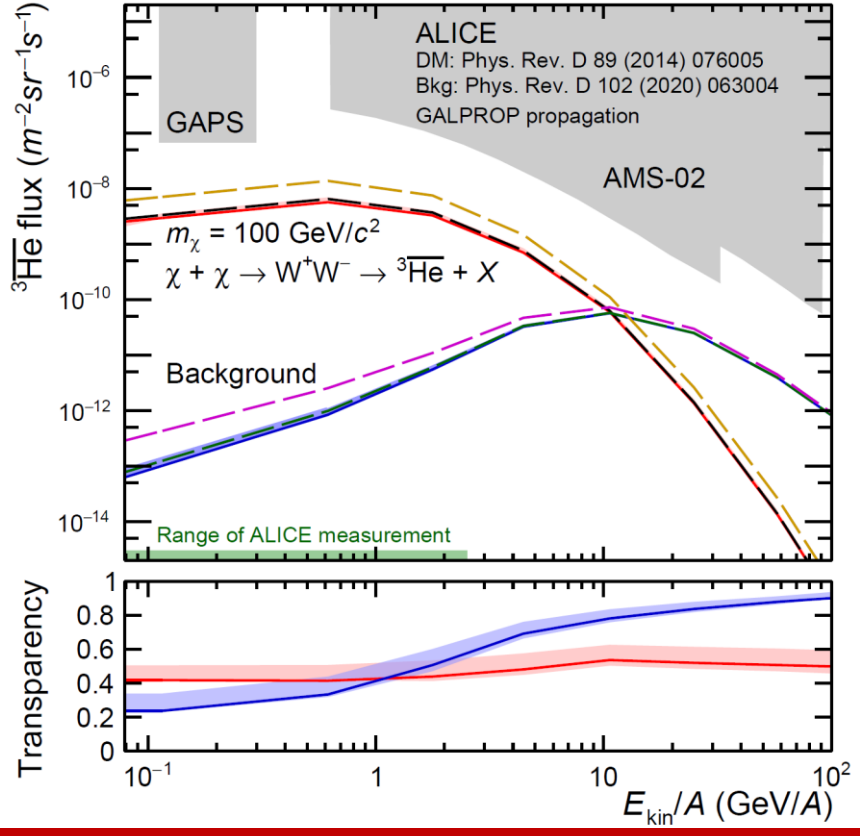
Nature Phys. 19 (2023) 1, 61-71



- Novel technique to use detector as an antiparticle absorber
- First experimental measurement of $\sigma_{\mathrm{inel}}(^{3}\overline{\mathrm{He}})$

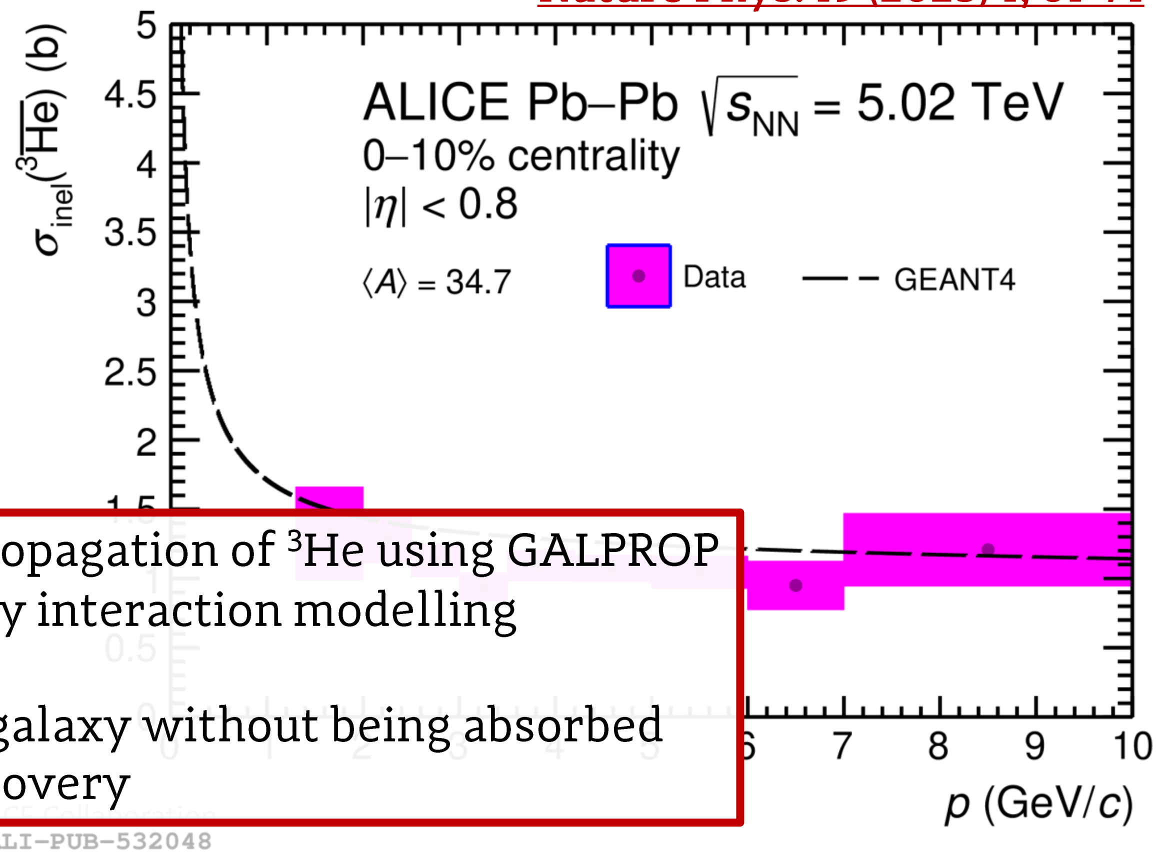


Light antinuclei absorption in ALICE and Galaxy



- Novel technique to use detector as an antiparticle absorber
- First experimental measurement of $\sigma_{inel}({}^3\overline{He})$

Nature Phys. 19 (2023) 1, 61-71



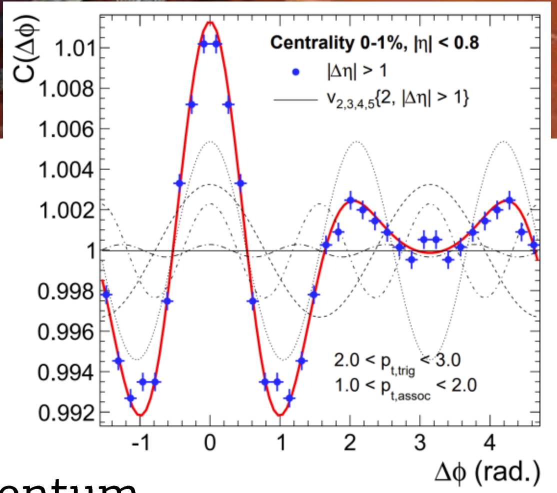
→ measured $\sigma_{inel}({}^3\overline{He})$ was employed to carry out the propagation of $^3\overline{He}$ using GALPROP

- can be used by for any dark-matter or cosmic-ray interaction modelling

→ $^3\overline{He}$ nuclei can travel distances of several kpc in our galaxy without being absorbed

- excellent probe for new physics that awaits discovery

Elliptic flow in Pb-Pb



v_2 – tool to study the flow of produced particles

- non-central collisions : elliptical geometry

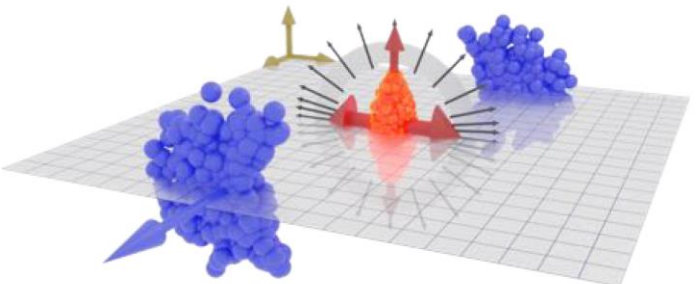


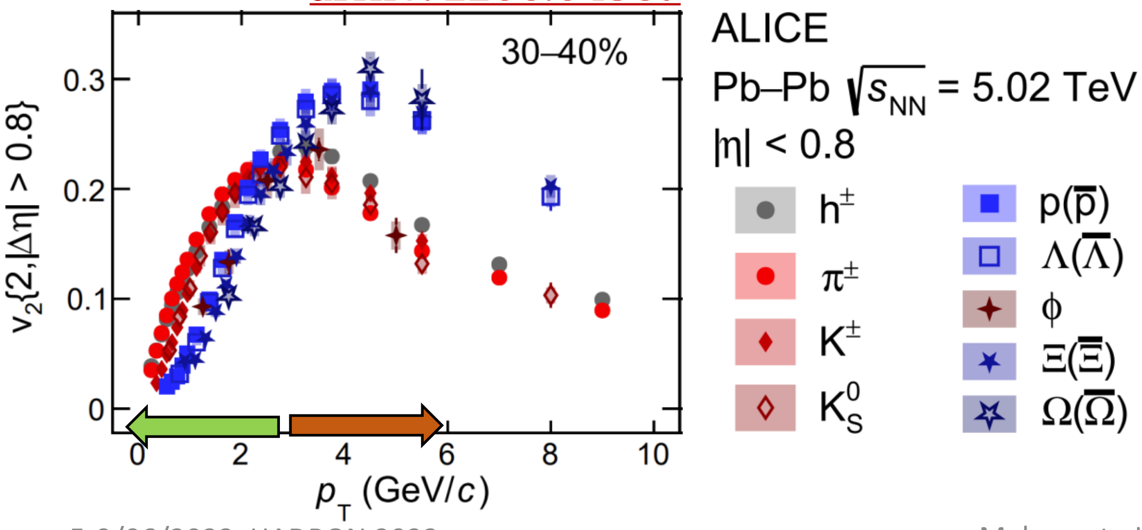
Fig. D. Chinnelato

expansion (flow) → azimuthal modulation in momentum
decomposed into Fourier expansion

$$\frac{dN}{Nd\phi} = 1 + 2v_2 \cos\left(2(\phi - \Psi_{RP})\right) + \textit{higher harmonics } (v_3, v_4, \ldots)$$

$v_n \neq 0$ → indicates presence of collective behavior

arXiv: 2206.04587

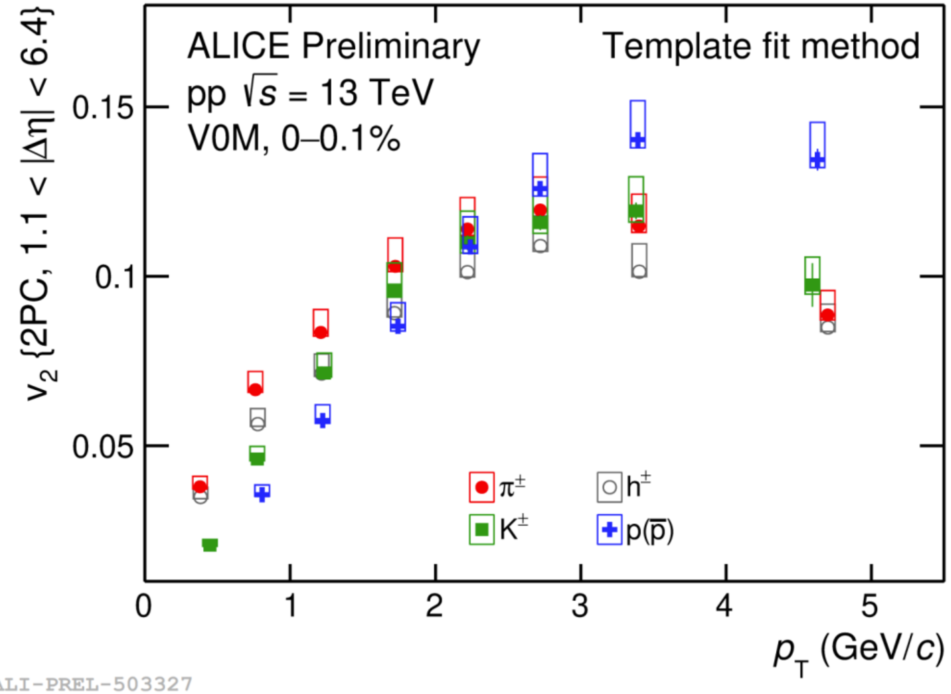


Mass ordering at low p_T:
described by hydrodynamics

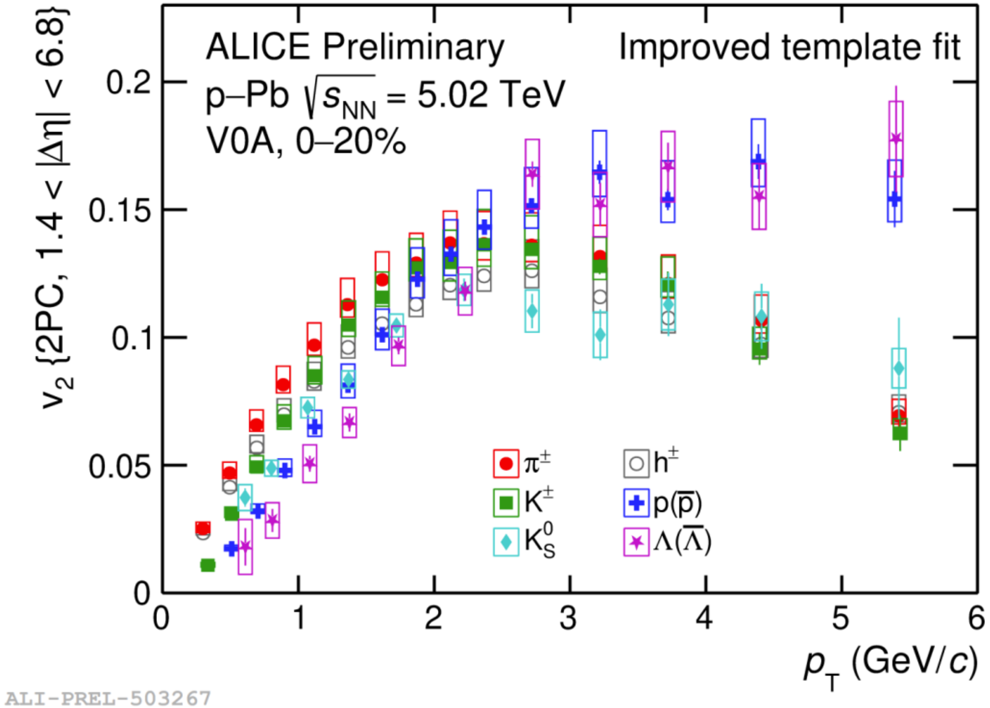
Baryon vs meson splitting at high p_T:
quark-level flow + recombination

Elliptic flow in small systems

- Mass ordering at low p_T: described by hydrodynamics
- Baryon vs meson splitting at high p_T: quark-level flow + recombination



ALI-PREL-503327

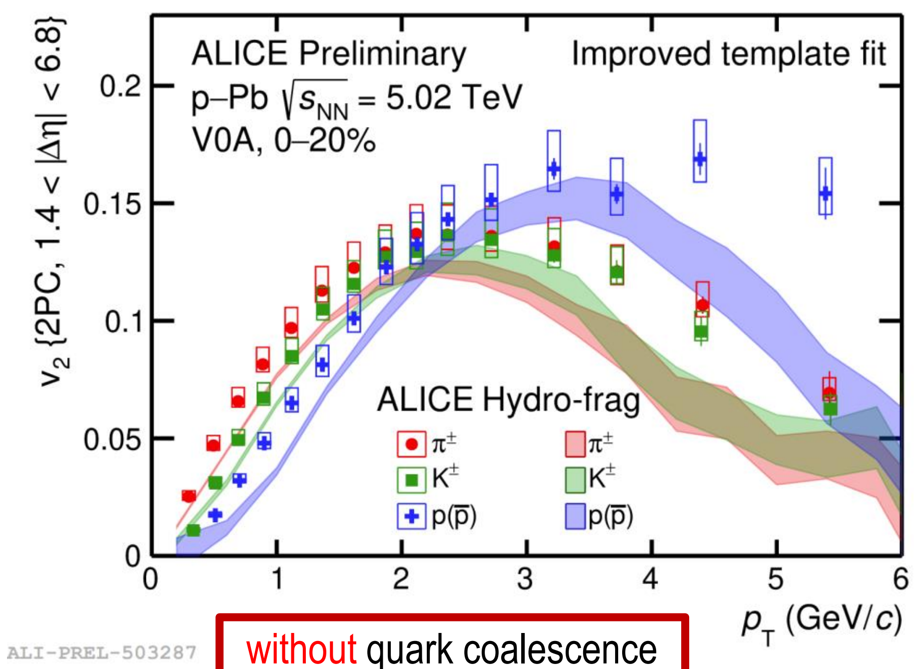


ALI-PREL-503267

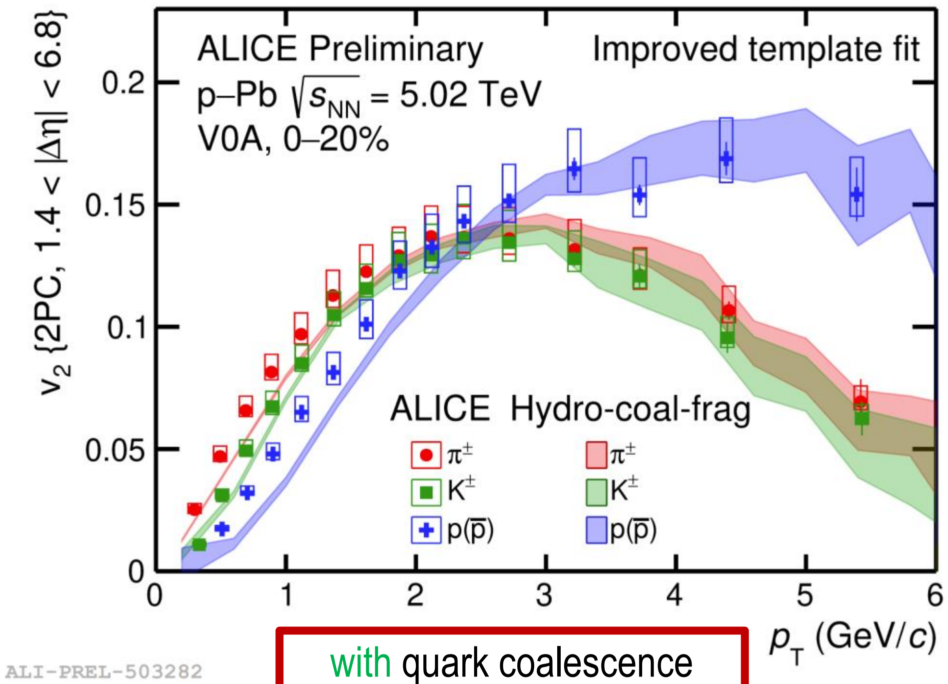
- Characteristic flow behaviors of Pb-Pb have been observed in pp and p-Pb collisions!

Flow of partons in small systems

- Mass ordering at low p_T: described by hydrodynamics
- Baryon vs meson splitting at high p_T: quark-level flow + recombination



without quark coalescence



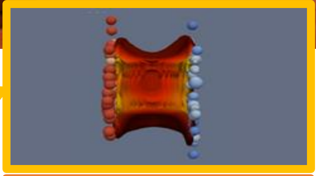
with quark coalescence

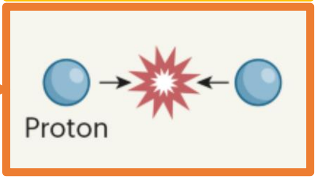
- Model without quark coalescence cannot qualitatively describe trends seen in data
- Indication of partonic flow in small systems

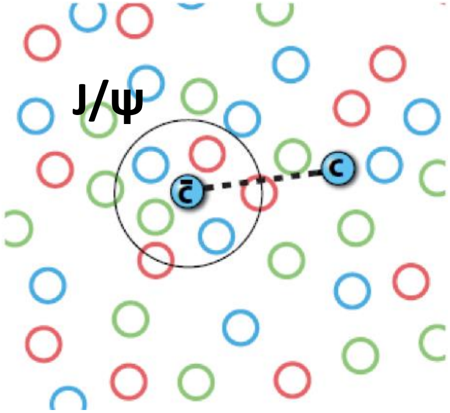
Quarkonia

- **J/ψ suppression** due to color screening in QGP

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dp_T|_{PbPb}}{dN/dp_T|_{pp}}$$



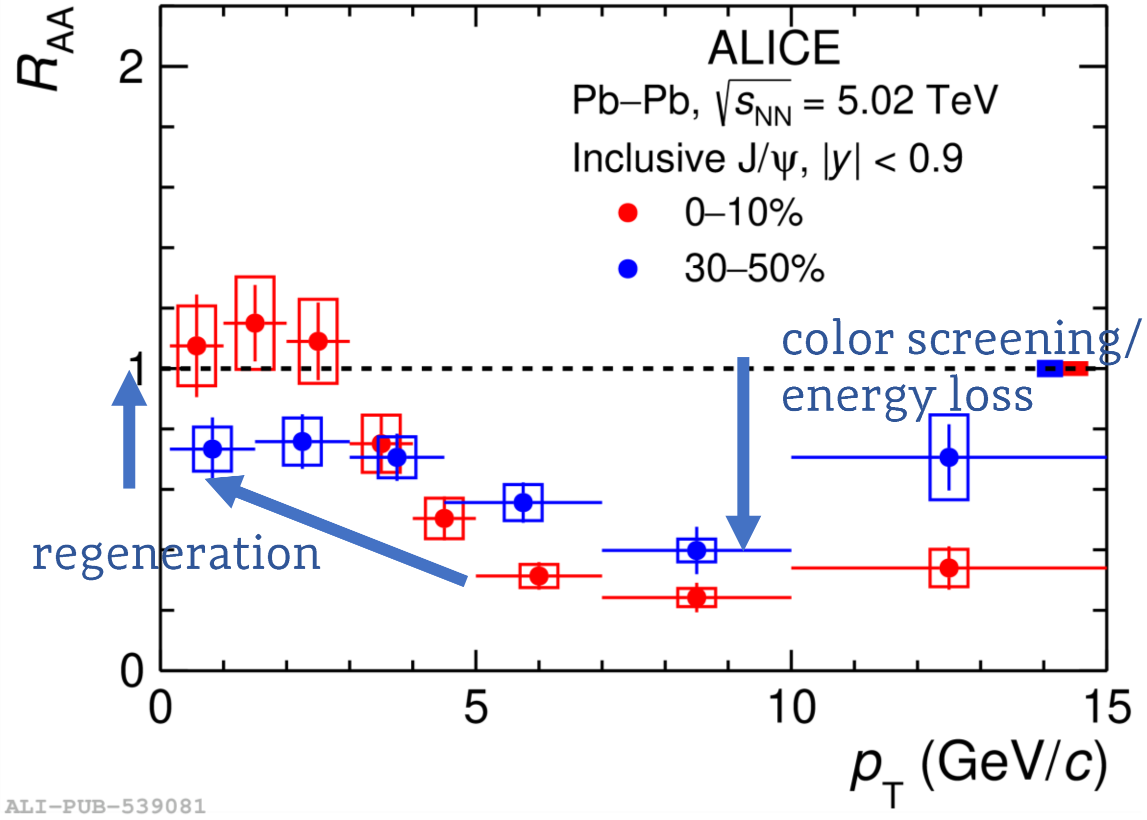




J/ψ dissociation and (re)combination at the LHC

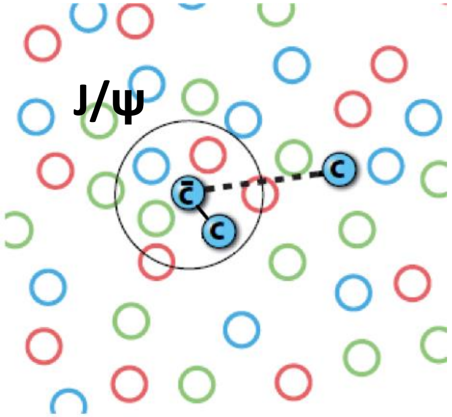
~100 $c\bar{c}$ pairs in central Pb-Pb at LHC

arXiv: 2303.13361



Quarkonia

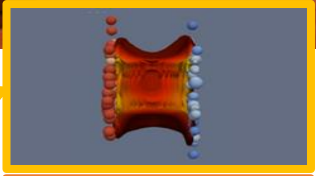
- **J/ψ suppression** due to color screening in QGP
  + interplay with $c\bar{c}$ recombination
  (in low p_T and large centrality)

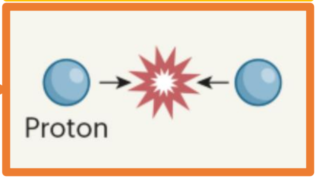


J/ψ dissociation and (re)combination at the LHC

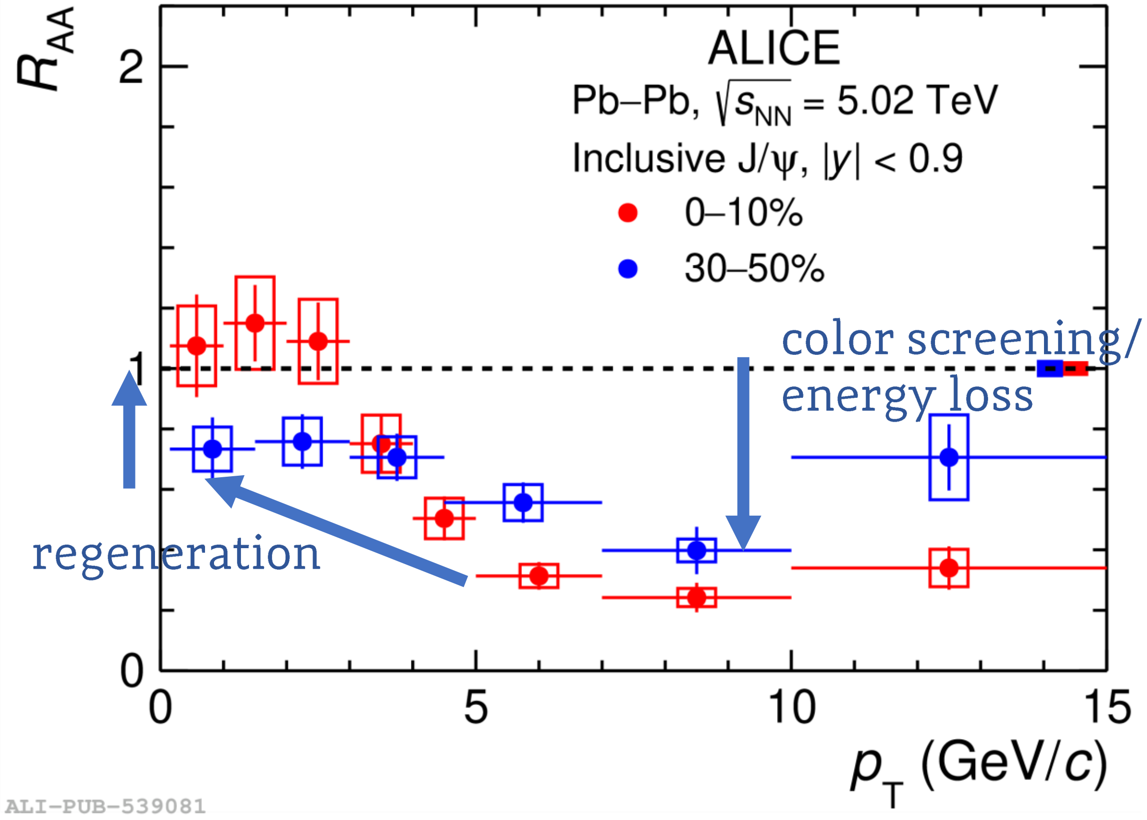
~100 $c\bar{c}$ pairs in central Pb-Pb at LHC

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dp_T|_{PbPb}}{dN/dp_T|_{pp}}$$



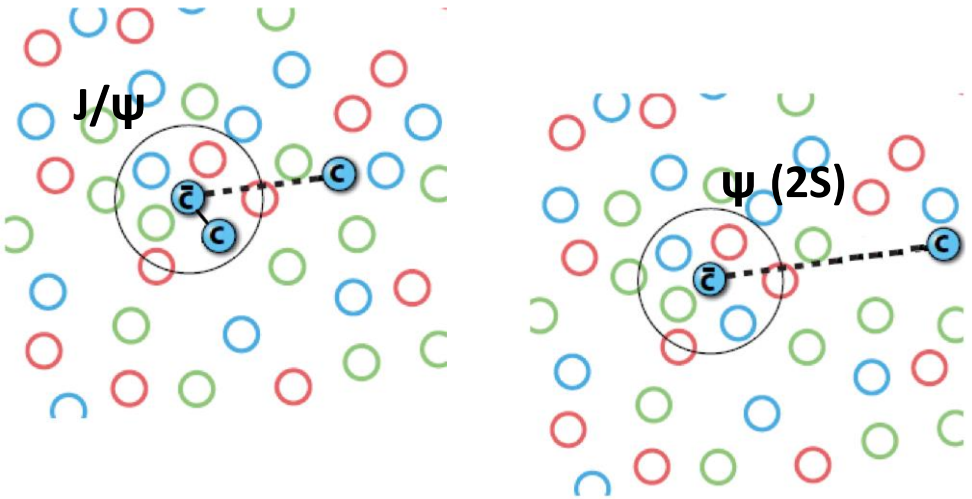


arXiv: 2303.13361



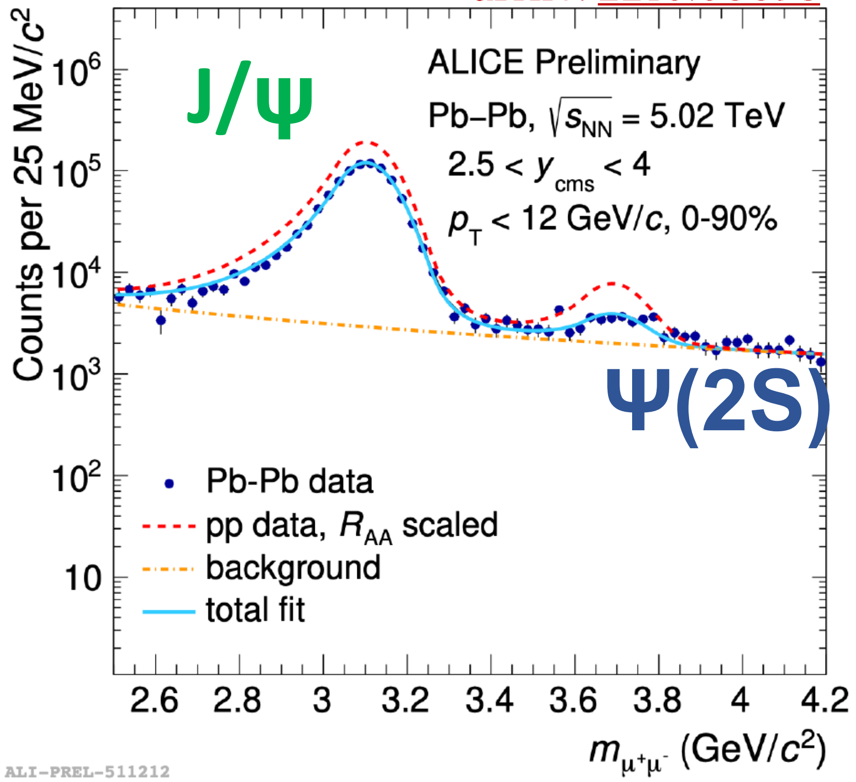
Quarkonia

- J/ψ suppression due to color screening in QGP
  + interplay with $c\bar{c}$ recombination
  (in low p_T and large centrality)



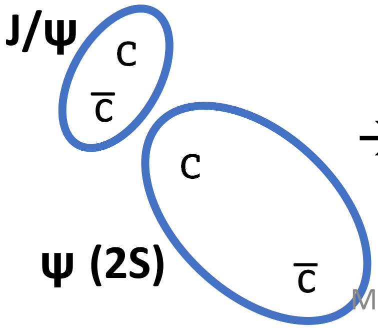
New ψ(2S) measurement

arXiv: 2210.08893



New result:
measured ψ(2S) – 10x lower binding energy!

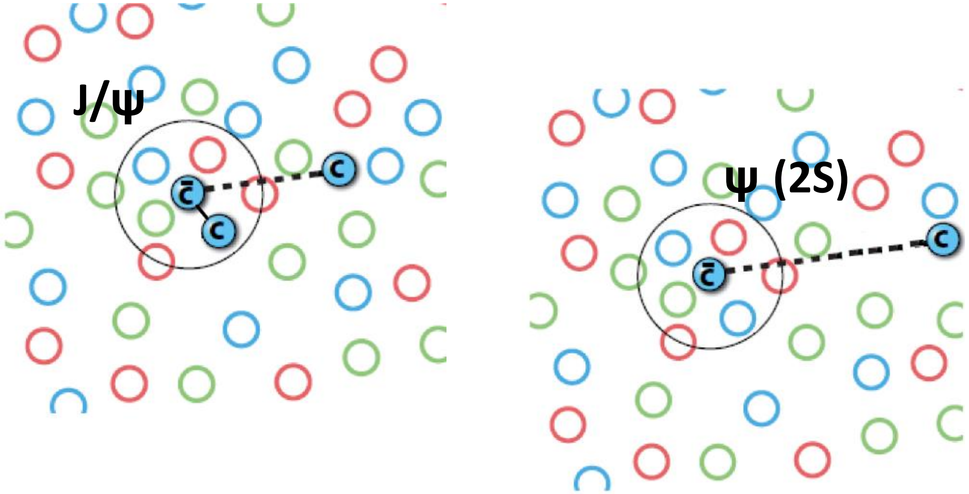
State	J/ψ,	ψ(2S)
Mass (GeV/c²)	3.07	3.68
Binding (GeV)	0.64	0.05



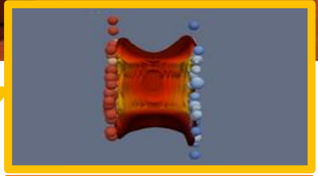
→ expected higher suppression for the ψ(2S) compared to the J/ψ

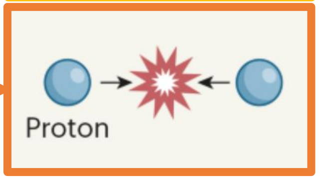
Quarkonia

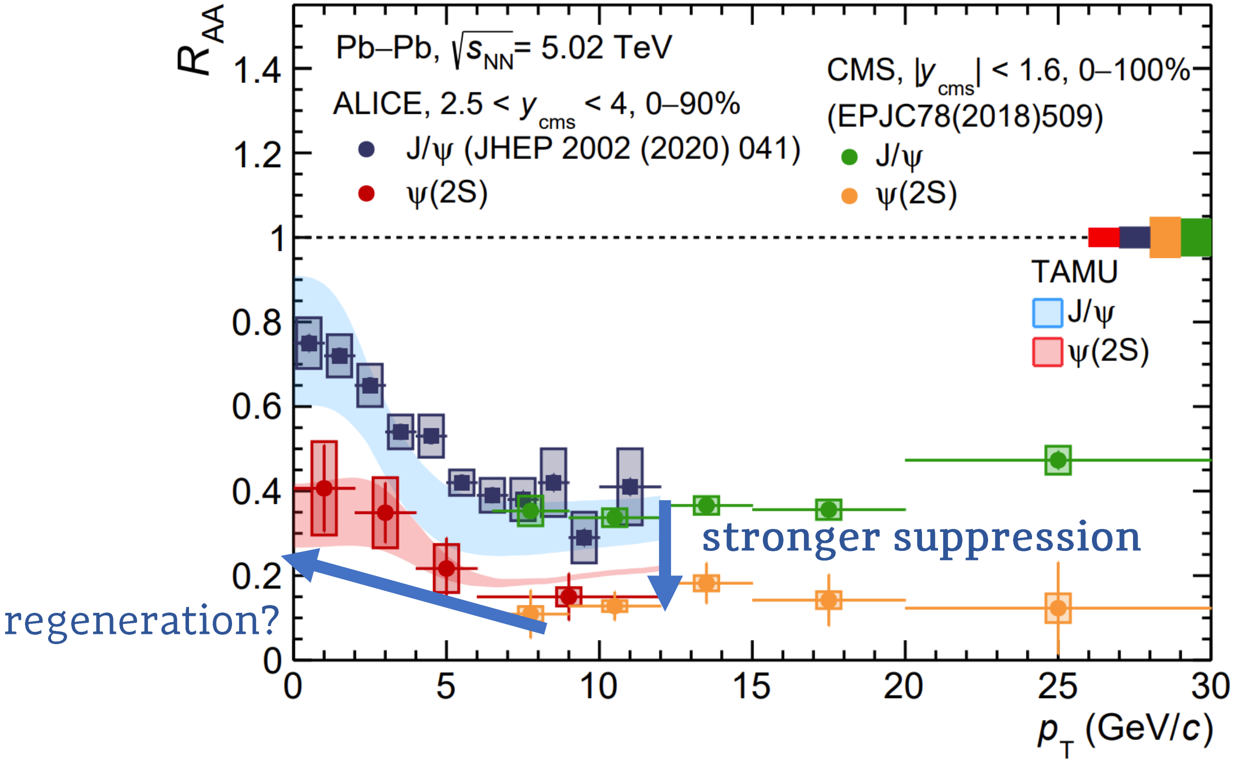
- J/ψ suppression due to color screening in QGP
  + interplay with $c\bar{c}$ recombination
  (in low p_T and large centrality)



$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dp_T|_{PbPb}}{dN/dp_T|_{pp}}$$







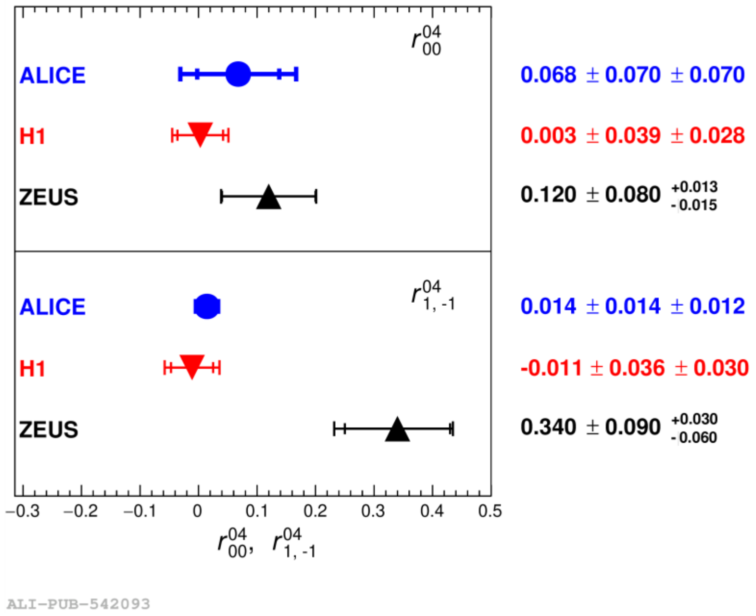
Extension of the ψ(2S) measurement down to 0 p_T

New result:
measured ψ(2S) – 10x lower binding energy!

→ 2 x stronger suppression of ψ(2S) than J/ψ
→ hints of regeneration of ψ(2S)

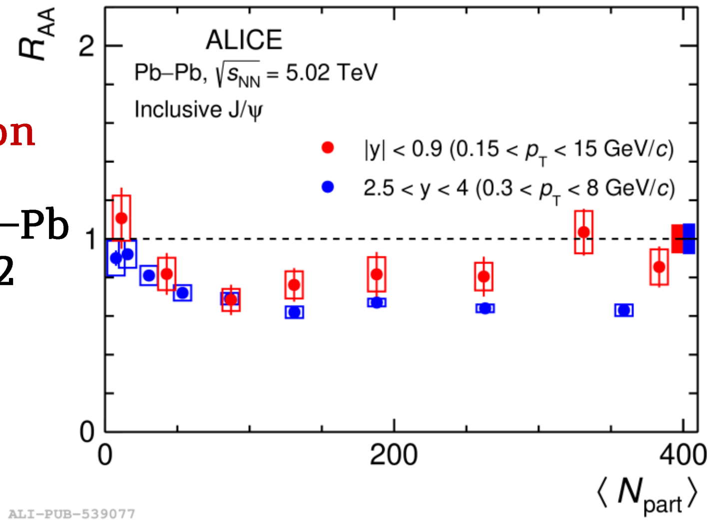
More about quarkonia…

- First polarisation measurement of coherently photoproduced J/ψ in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, arXiv: 2304.10928

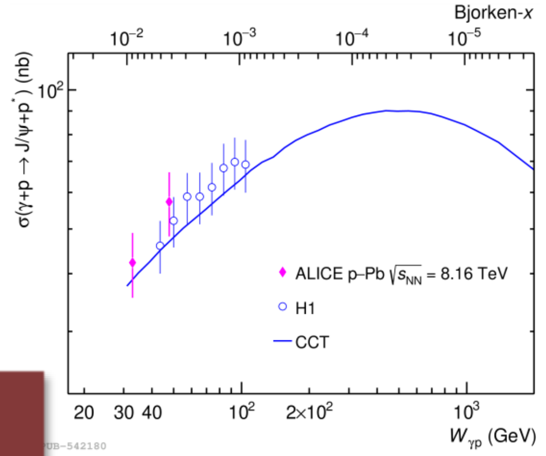


- Measurement of inclusive J/ψ pair production cross section in pp collisions at $\sqrt{s}$ = 13 TeV, arXiv: 2303.13431

- Measurements of inclusive J/ψ production at midrapidity and forward rapidity in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, arXiv: 2303.13361



- Exclusive and dissociative J/ψ photoproduction, and exclusive dimuon production, in p–Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV, arXiv: 2304.12403



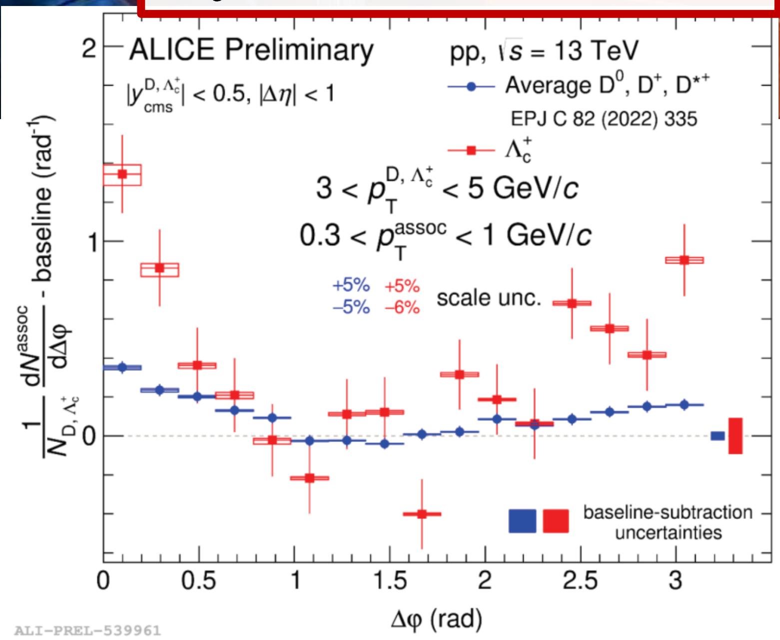
Quarkonium production in small collision systems in ALICE
M. Pennisi
Mon 5 Jun 2023, 14:25

...and open heavy-flavor

Λ^+_c, D^0-hadron correlations

Most recent heavy-flavor ALICE publications:

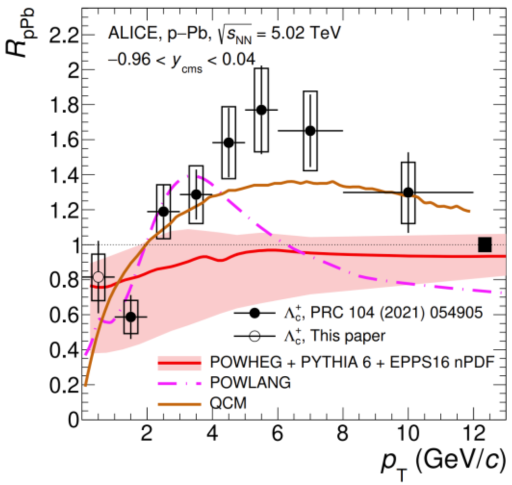
- Inclusive and multiplicity dependent production of electrons from heavy-flavour hadron decays in pp and p–Pb collisions arXiv: 2303.13349,
- Measurement of the non-prompt D-meson fraction as a function of multiplicity in proton–proton collisions at √s=13 TeV, e-Print: arXiv: 2302.07783,
- Exploring the non-universality of charm hadronisation through the measurement of the fraction of jet longitudinal momentum carried by Λ^+_c baryons in pp collisions, arXiv: 2301.13798 ,
- First measurement of prompt and non-prompt D^{*+} vector meson spin alignment in pp collisions at √s=13 TeV, arXiv: 2212.06588,
- First measurement of Λ^+_c production down to p_T=0 in pp and p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, arXiv: 2211.14032 ,
- Measurement of electrons from beauty-hadron decays in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, arXiv: 2211.13985.



Hadronisation of heavy quarks in small systems with ALICE at the LHC

T. Cheng

Fri 9 Jun 2023, 9:00



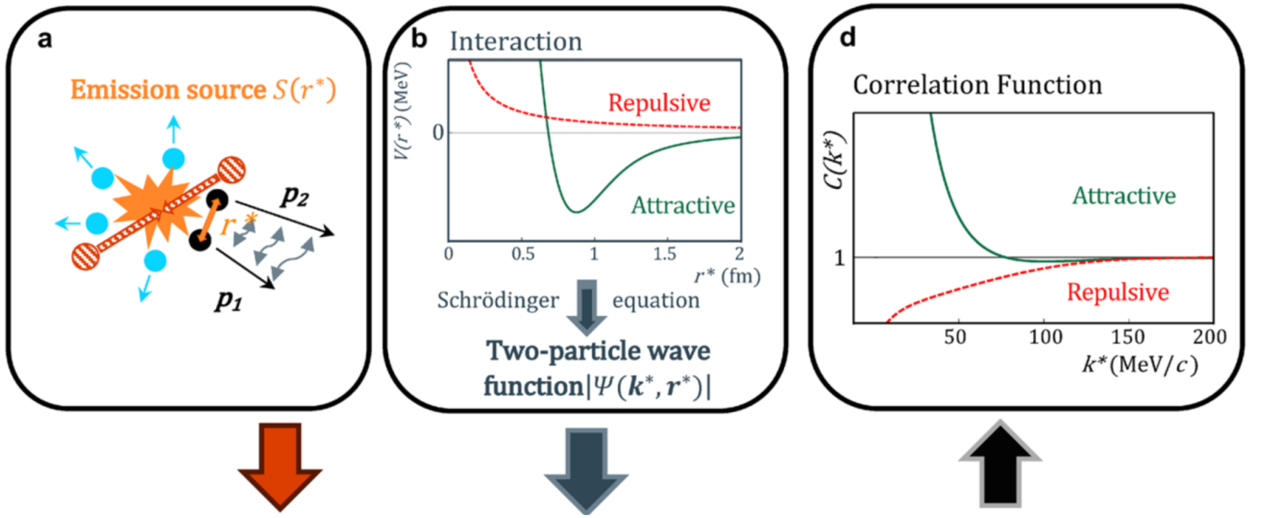
Measurement of Λ^+c production in pp, p-Pb, and Pb-Pb collisions with the ALICE experiment at the LHC

C. Bartels

Mon 5 Jun 2023, 15:40

Source size – femtoscopy measurement

Femtoscopic correlation function carry information about the particle source $S(r^*)$ from which pairs emerge, as well as the interaction potential via the two-particle wave function ***ψ(k*,r*)***.

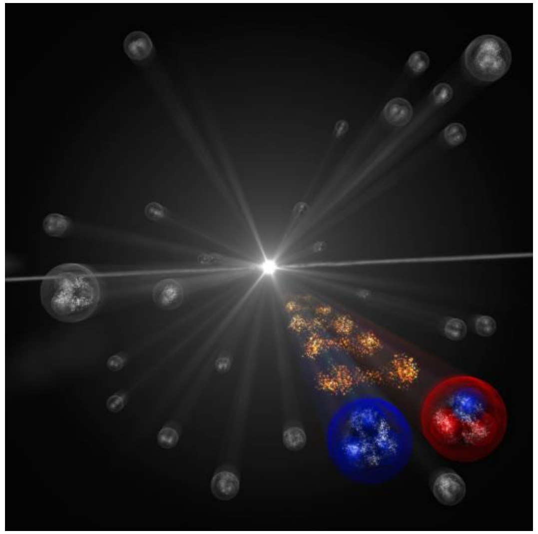


c

unknown

measured $$C(k^*) = \int S(r^*)\, |\Psi(k^*,r^*)|^2\, d^3r^* = \xi(k^*) \cdot \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

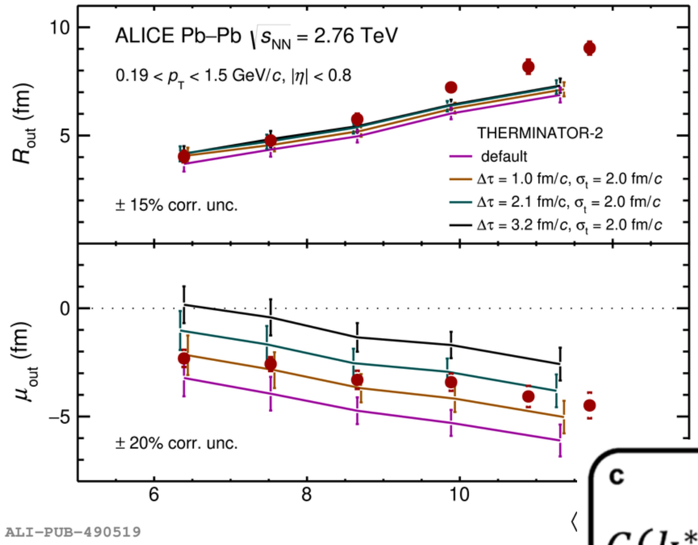
known



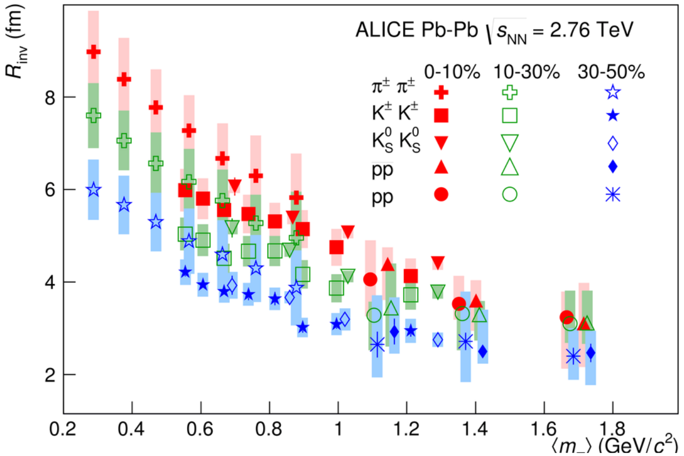
If the interaction is well known we can study the source $S(r^*)$ by measuring correlation function C(k*)

Source size – femtoscopy measurement

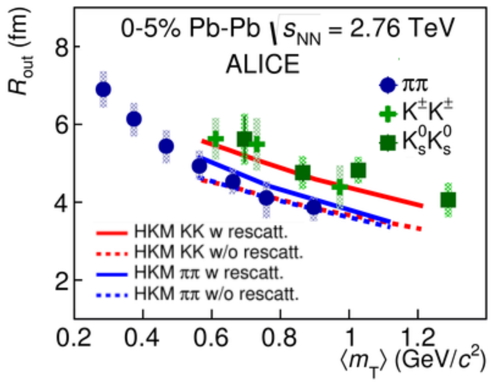
PLB 813 (2021) 136030

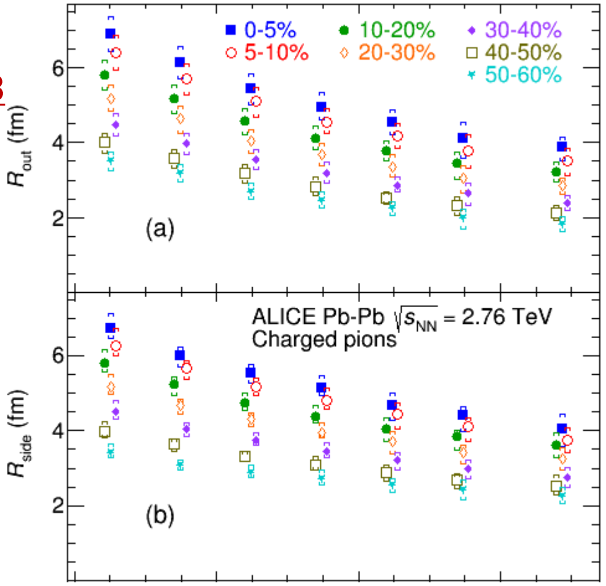


Phys. Rev. C 92 (2015) 054908



Phys. Rev. C96 (2017) 064613



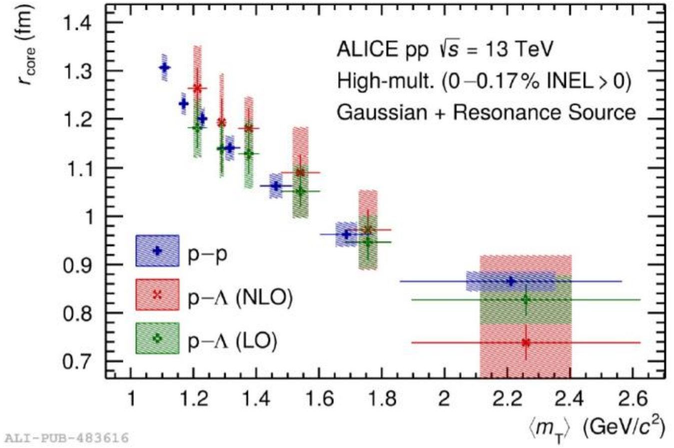


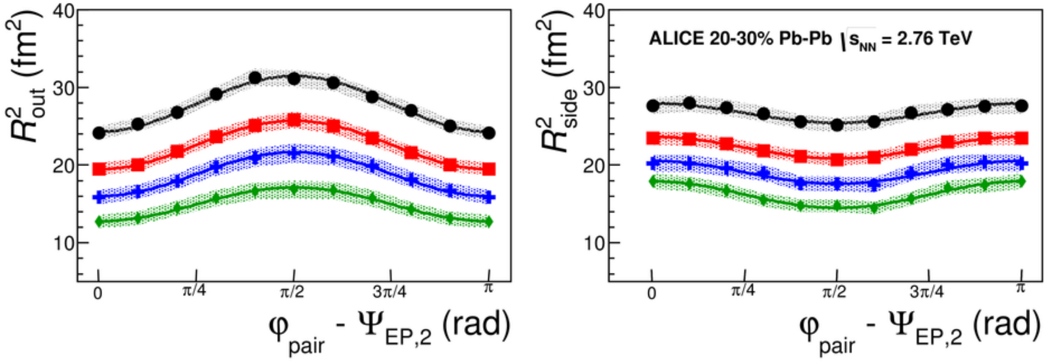
Phys. Rev. C93 (2016) 024905

c

$$C(k^*) = \int S(r^*) \; |\Psi(\mathbf{k}^*, \mathbf{r}^*)|^2 \, d^3r^* = \xi(k^*) \cdot \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

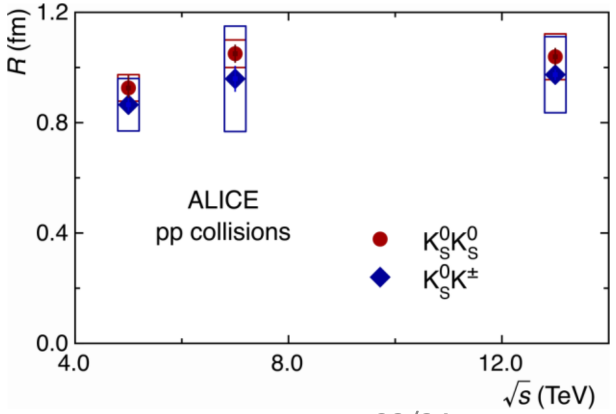
Phys. Lett. B 811 (2020) 135849





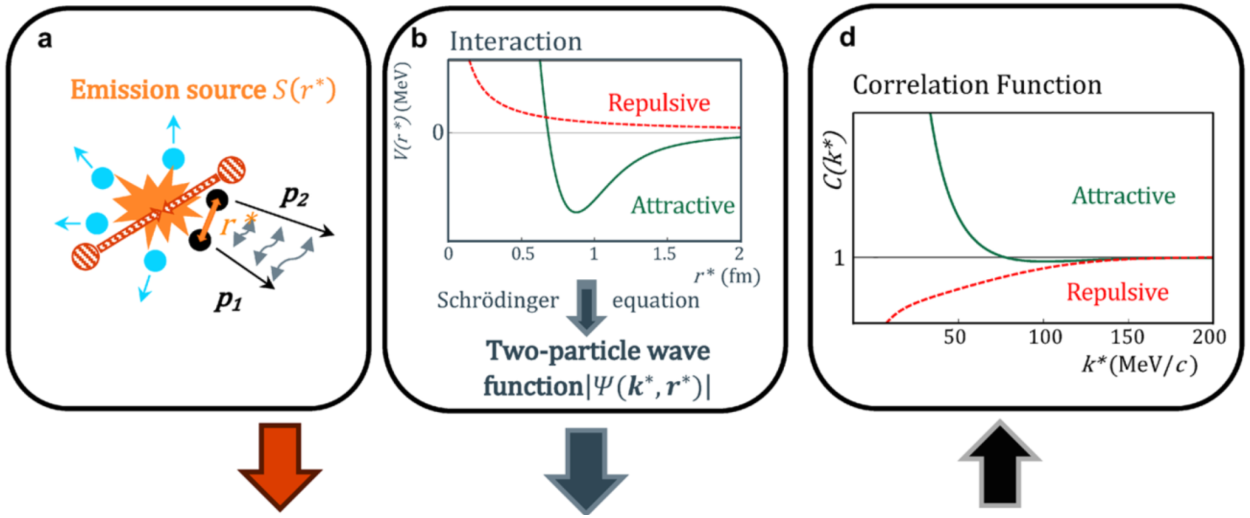
Phys. Rev. Lett. 118 (2017) 222301

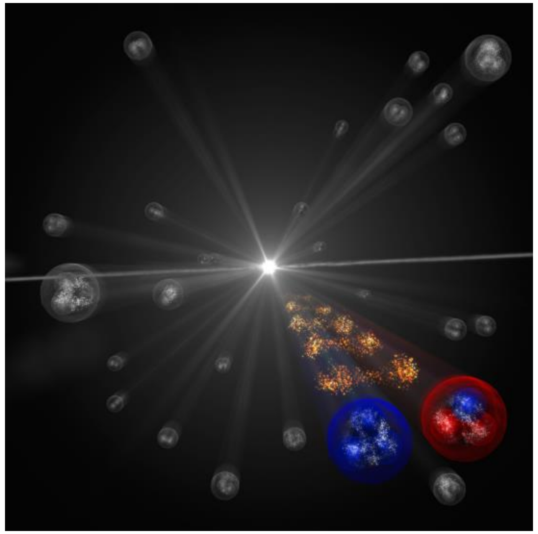
arXiv:2111.06611



Hadron-hadron interaction

Femtoscopic correlation function carry information about the particle source $S(r^*)$ from which pairs emerge, as well as the interaction potential via the two-particle wave function $\boldsymbol{\psi(k^*,r^*)}$.





c

unknown

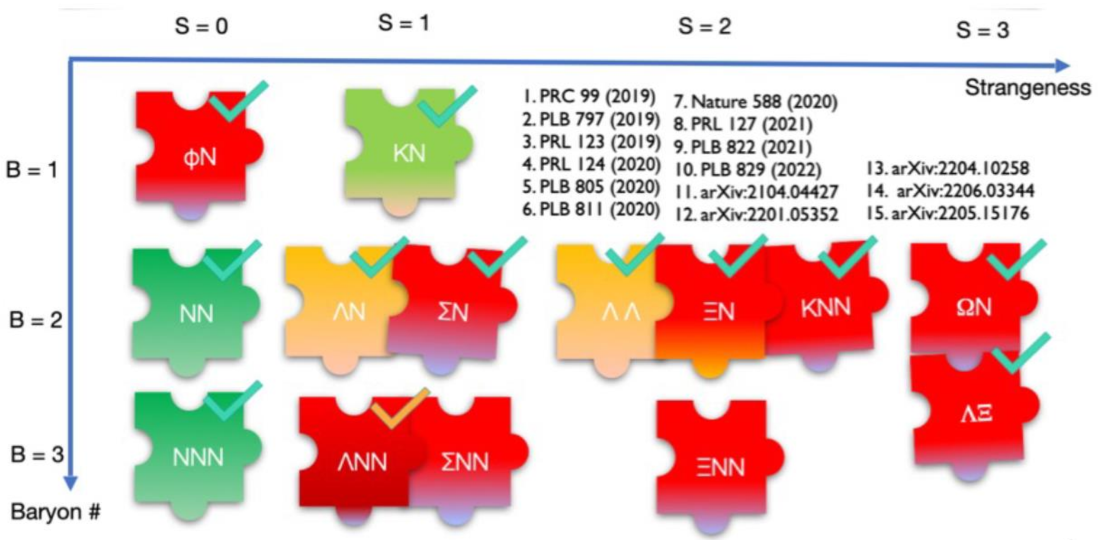
measured $C(k^*) = \int S(r^*) \, |\Psi(k^*,r^*)|^2 \, d^3r^* = \xi(k^*) \cdot \frac{N_{same}(k^*)}{N_{mixed}(k^*)}$

known

- We constrain the source $S(r^*)$ from pairs where interaction is known
- We can use femtoscopy to measure the interactions $\boldsymbol{\psi}$ between other particle species

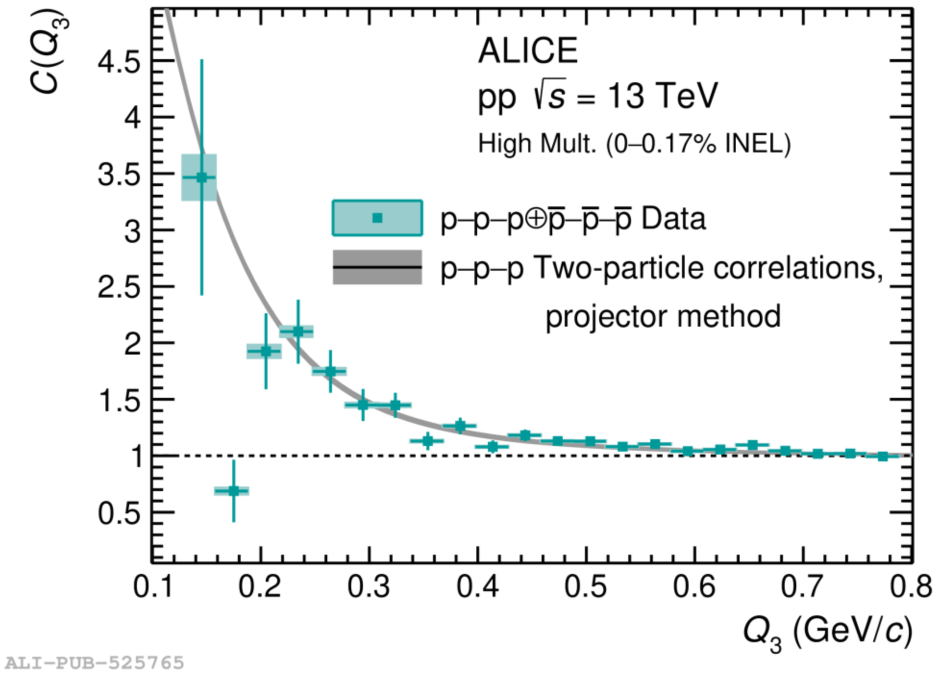
Hadron-hadron interaction:

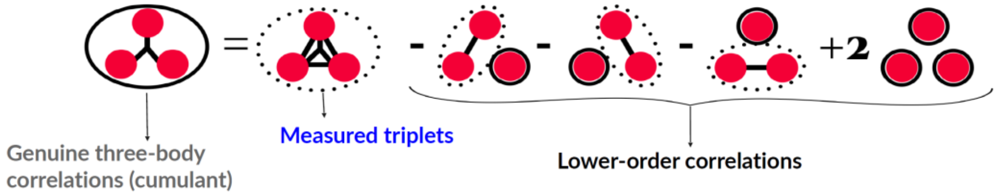
- Poorly known for strange baryons
  → Relevant for neutron star modeling
- Unknown for charm hadrons and 3-body



p-p-p

arXiv: 2206.03344

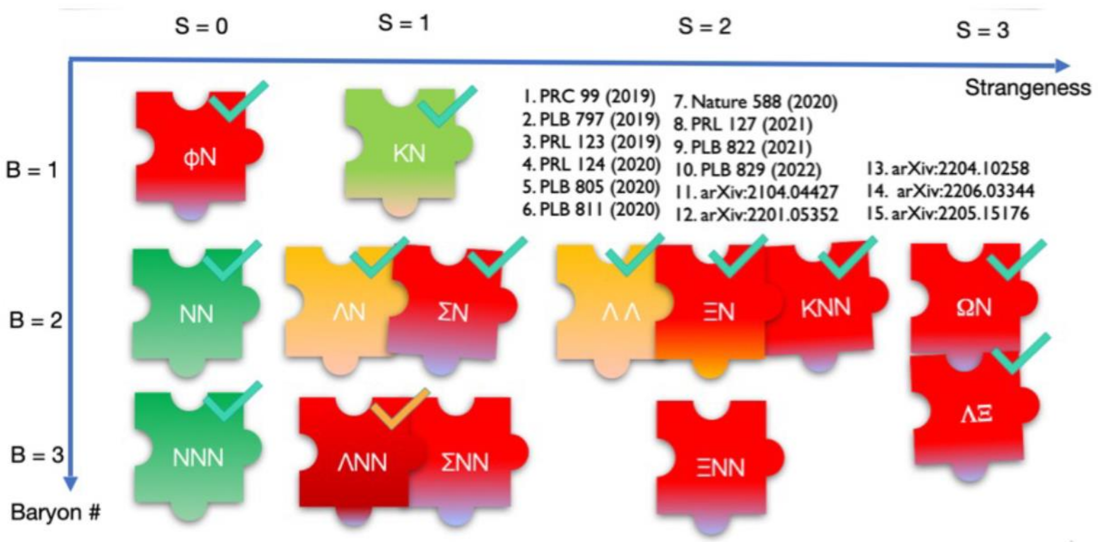




Hadron-hadron interaction

Hadron-hadron interaction:

- Poorly known for strange baryons
  → Relevant for neutron star modeling
- Unknown for charm hadrons and 3-body



<u>Novel technique to access the three-body interactions with ALICE at the LHC</u>
L. Serksnyte
Wed 7 Jun 2023, 15:15

<u>A study of K−d and K+d interactions via femtoscopy technique</u>
W. Rzesa
Wed 7 Jun 2023, 14:25

<u>Constraining coupled channels dynamics using femtoscopic correlations with ALICE at LHC</u>
R. Lea
Thu 8 Jun 2023, 15:42

<u>Constraining the equation of state of neutron stars with femtoscopy measurements by ALICE</u>
M. Lesch
Thu 8 Jun 2023, 15:15

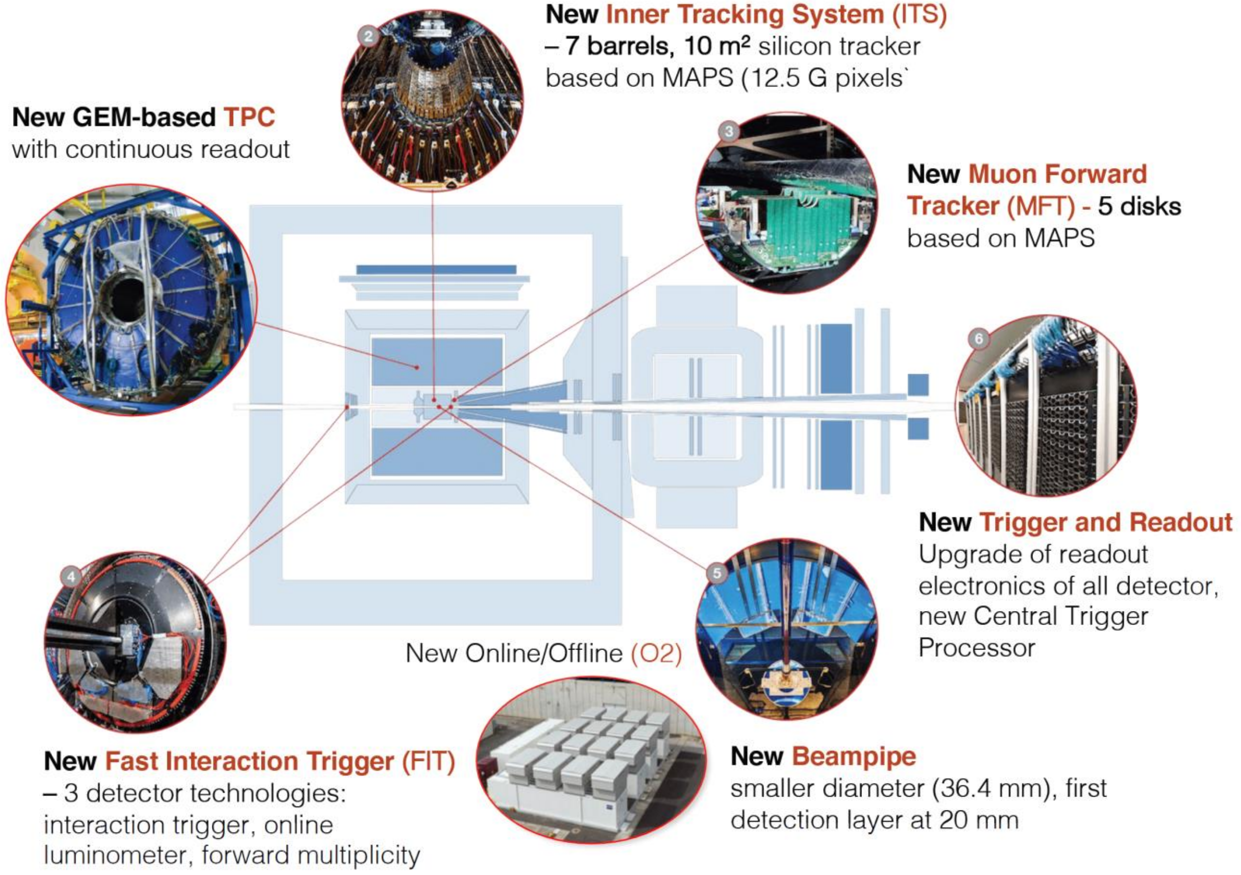
<u>A laboratory for QCD: how to employ LHC to study hadron-hadron interactions</u>
V. Mantovani
Mon 5 Jun 2023, 14:30

ALICE upgrade for Run 3

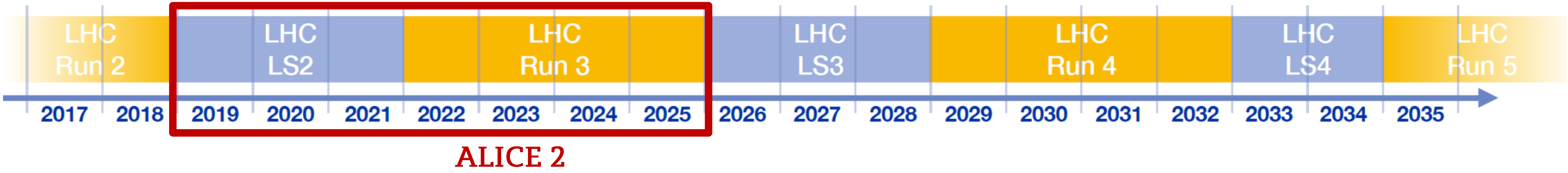
ALICE 2

- Tracking resolution **x3**
  (especially low p_T!)
- Pb-Pb rate **x50**
  (continuous readout,
  50 times more statistics for most observables!)
- New analysis software
  (O2 framework)

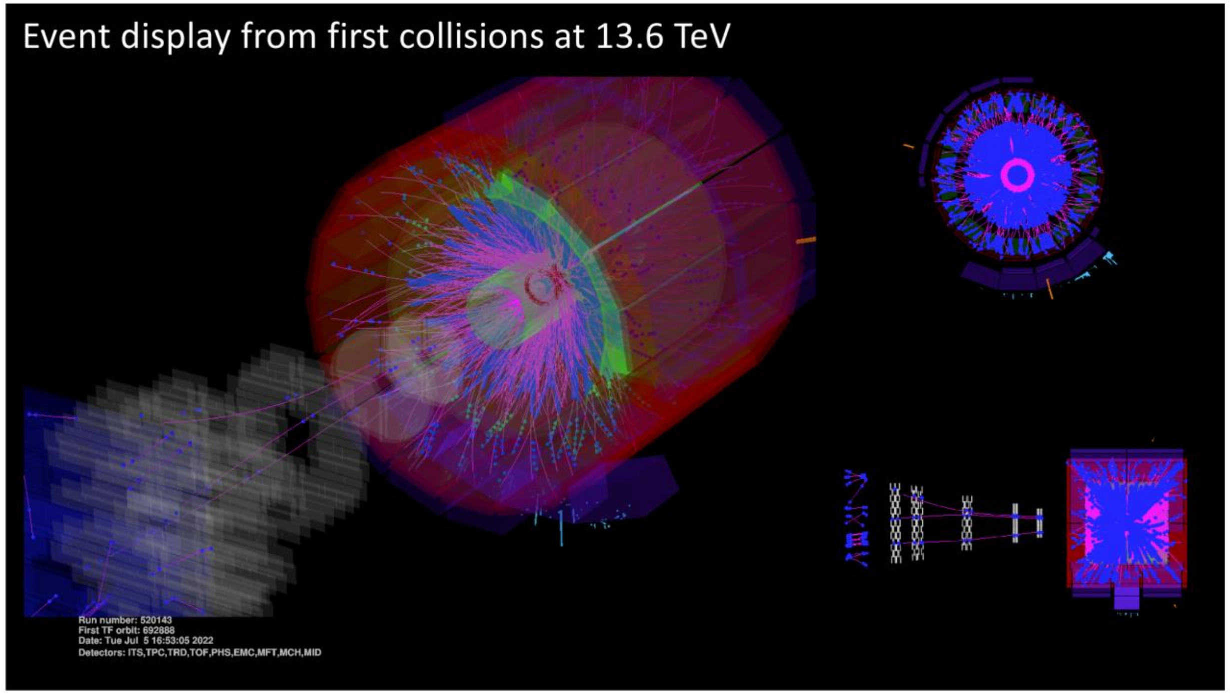
ALICE upgrades during the LHC Long Shutdown 2 arXiv:2302.01238

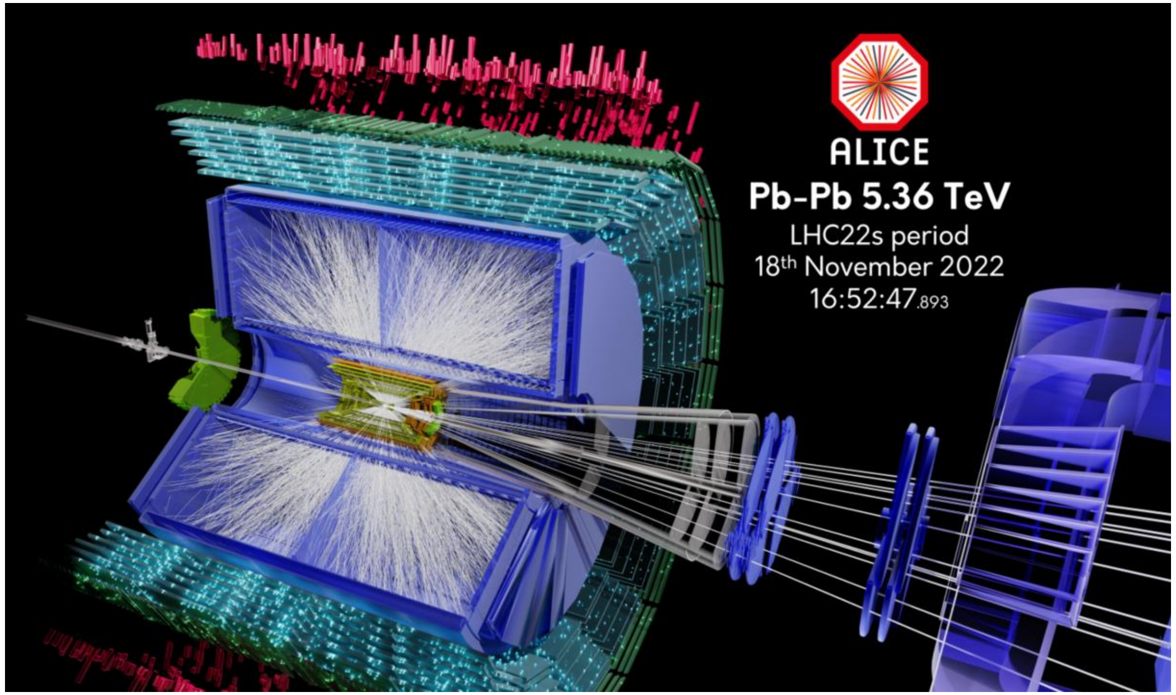


First results from Run 3



- Collisions from Run 3: data-taking on the way!



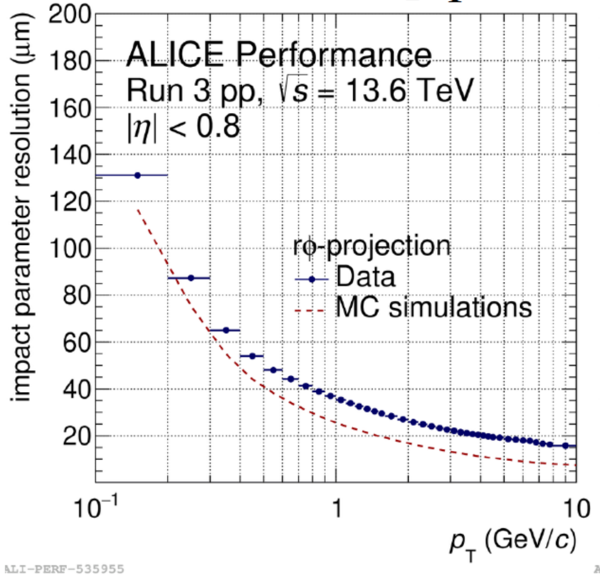


First results from Run 3

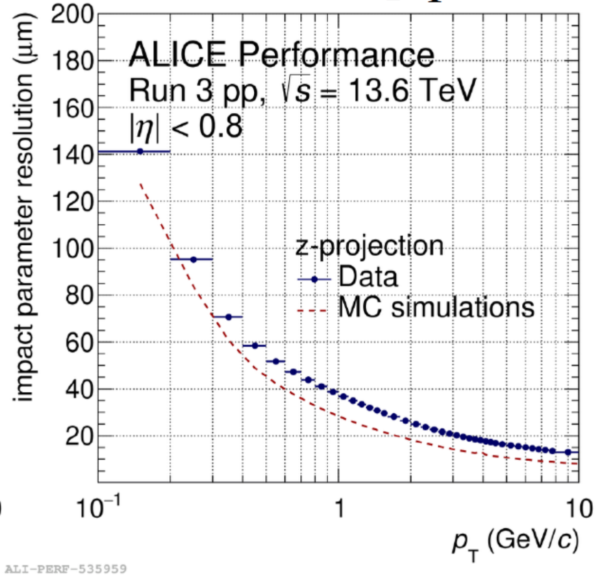
- Successful commissioning and data-taking in pp collisions and Pb-Pb test run

Impact parameter resolution

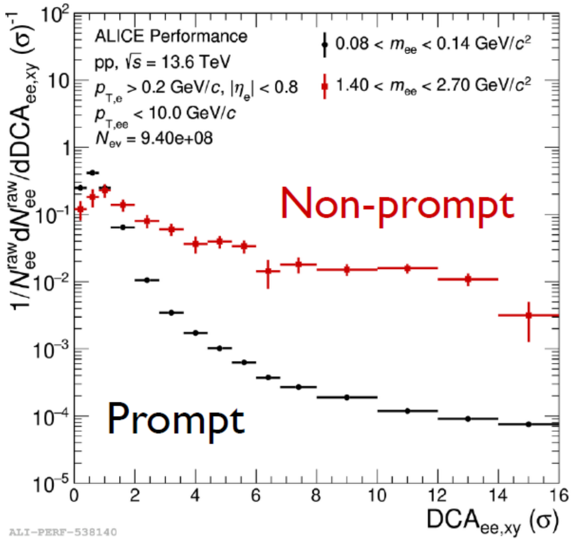
$r - \phi$ vs. p_T



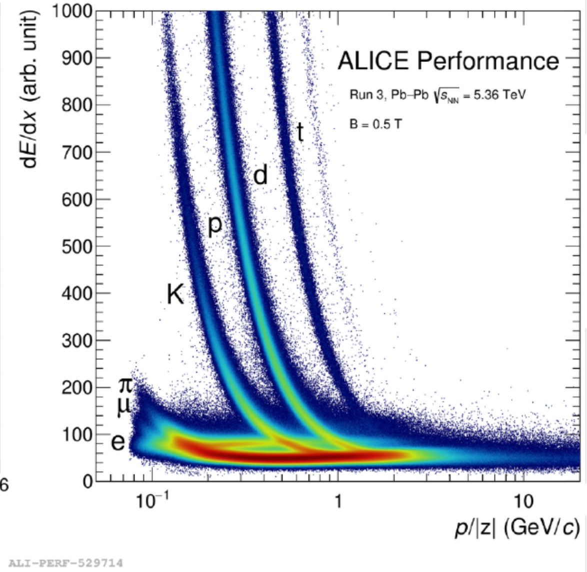
z vs. p_T



Di-electron separation



TPC dE/dx

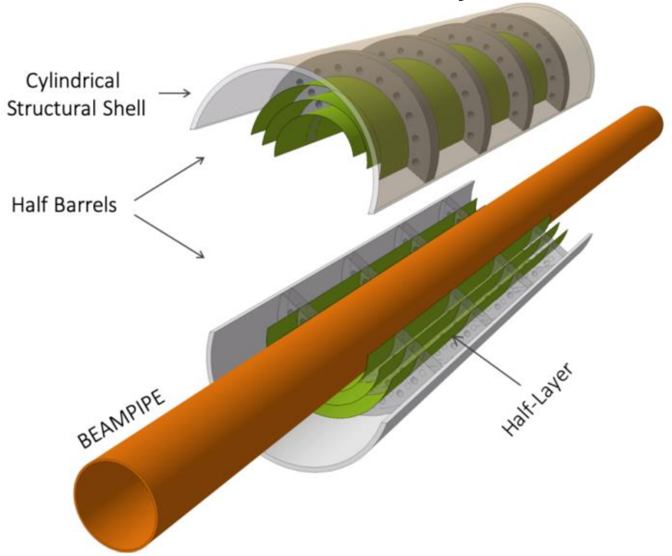


LS3 and Run 4

ALICE 2.1

Upgrades in Long Shutdown 3:

- **ITS-3**
  - More precise tracking with less material budget.
  - Good for heavy flavor measurements

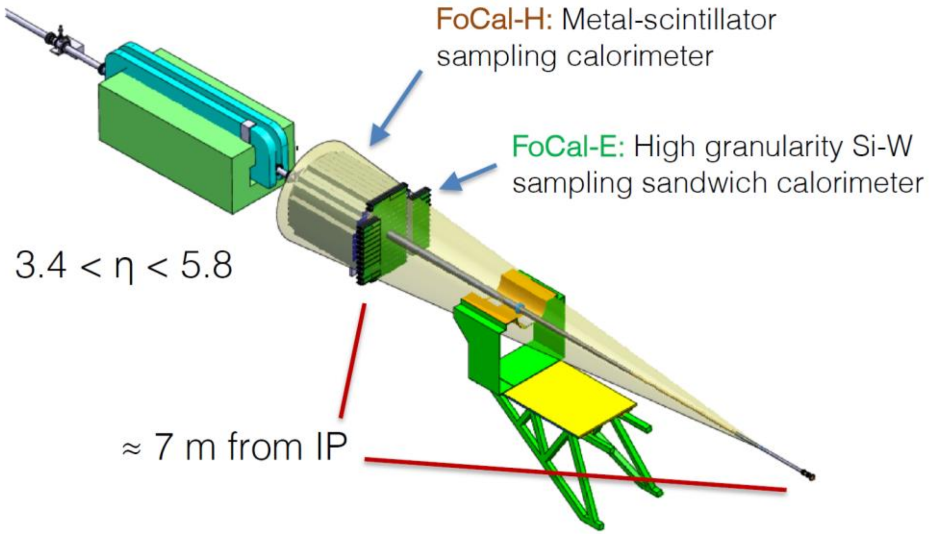


ITS-3 Letter of Intent

FoCal Letter of Intent

Forward Calorimeter (FoCal)

Forward physics at LHC provides an opportunity to study the low-x region:
gluon saturation at low-x with forward direct photons

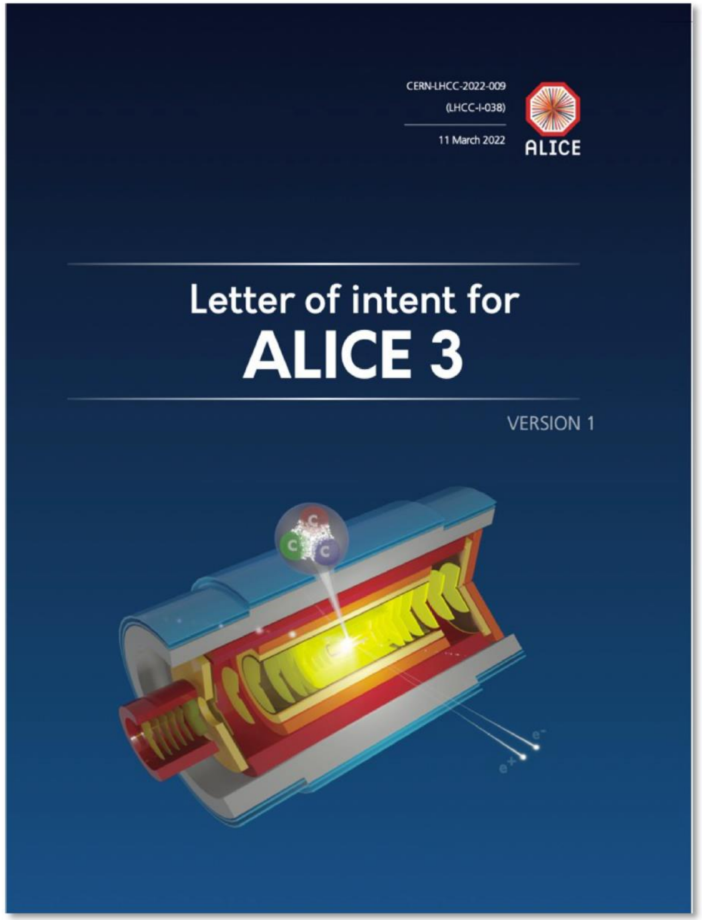


ALICE 3

ALICE 3: a new experiment for Run 5 and beyond

- Compact and ultra-light all-silicon tracker with large acceptance and high-resolution vertex detector
- Superconducting magnet system
- Particle identification down to vanishing p_T over 8 units of pseudorapidity

ALICE 3 Letter of Intent



- How do **partons transition to hadrons** as the QGP cools?
- Is the **hadronization** at the QGP-hadron phase boundary **different from pp** collisions?
- What is the nature of **parton interactions** in the QGP?
- What are the mechanisms for **chiral symmetry restoration** in the QGP?
- What mechanisms drive the QGP toward equilibrium?

All of this and more will be explored by ALICE 3!

Summary

The ALICE results from Run 1 and 2 offer

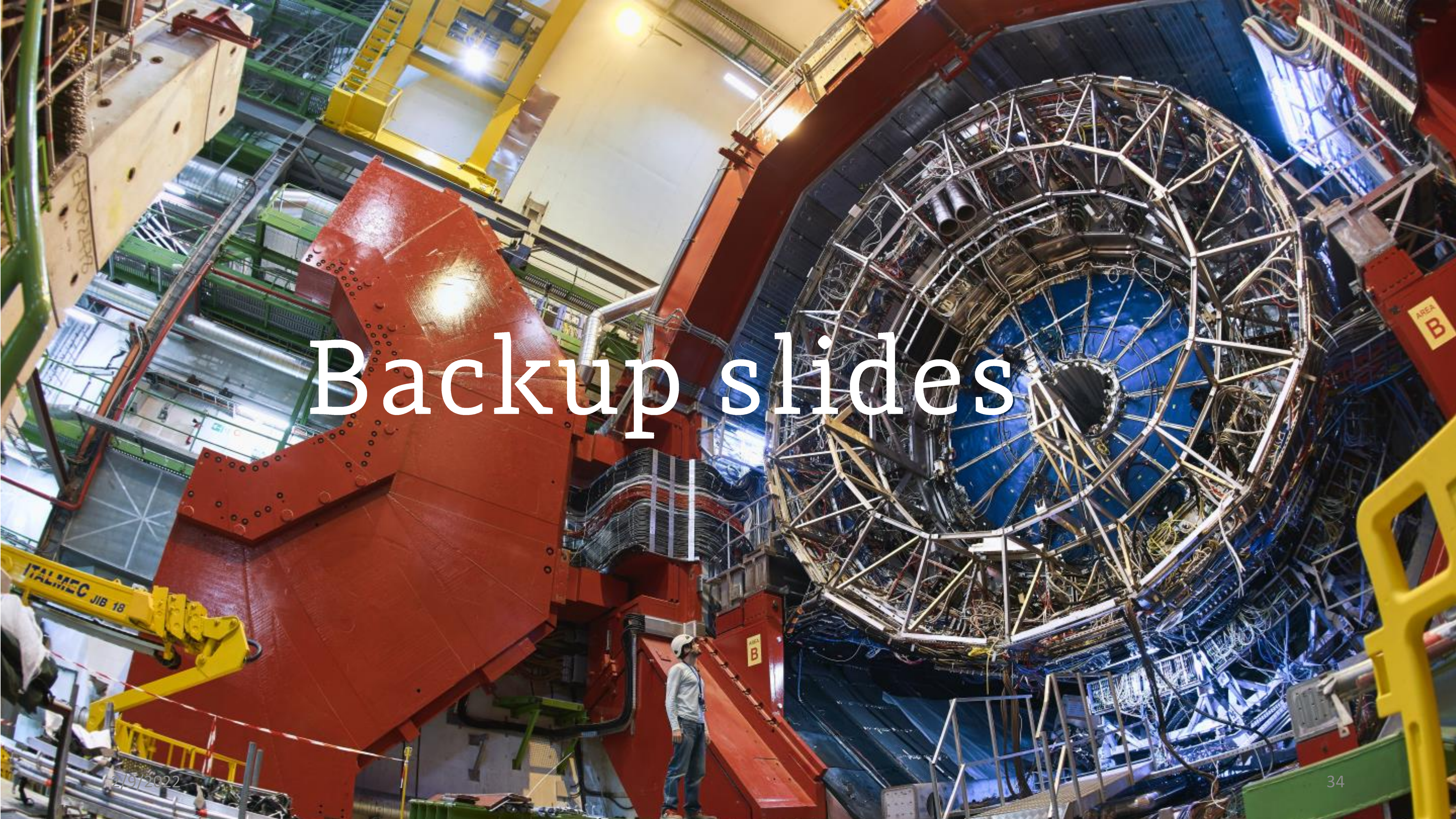
- detailed description of the **QGP properties**
  - including particle production, fluid-dynamic properties, heavy quark interactions
  - as well as an **insights into QCD**: formation and annihilation of nuclei, hadron-hadron interactions, ...

ALICE **completed the upgrade** and is now **taking data in Run 3** with significantly enhanced capabilities, and **first results already on the way.**

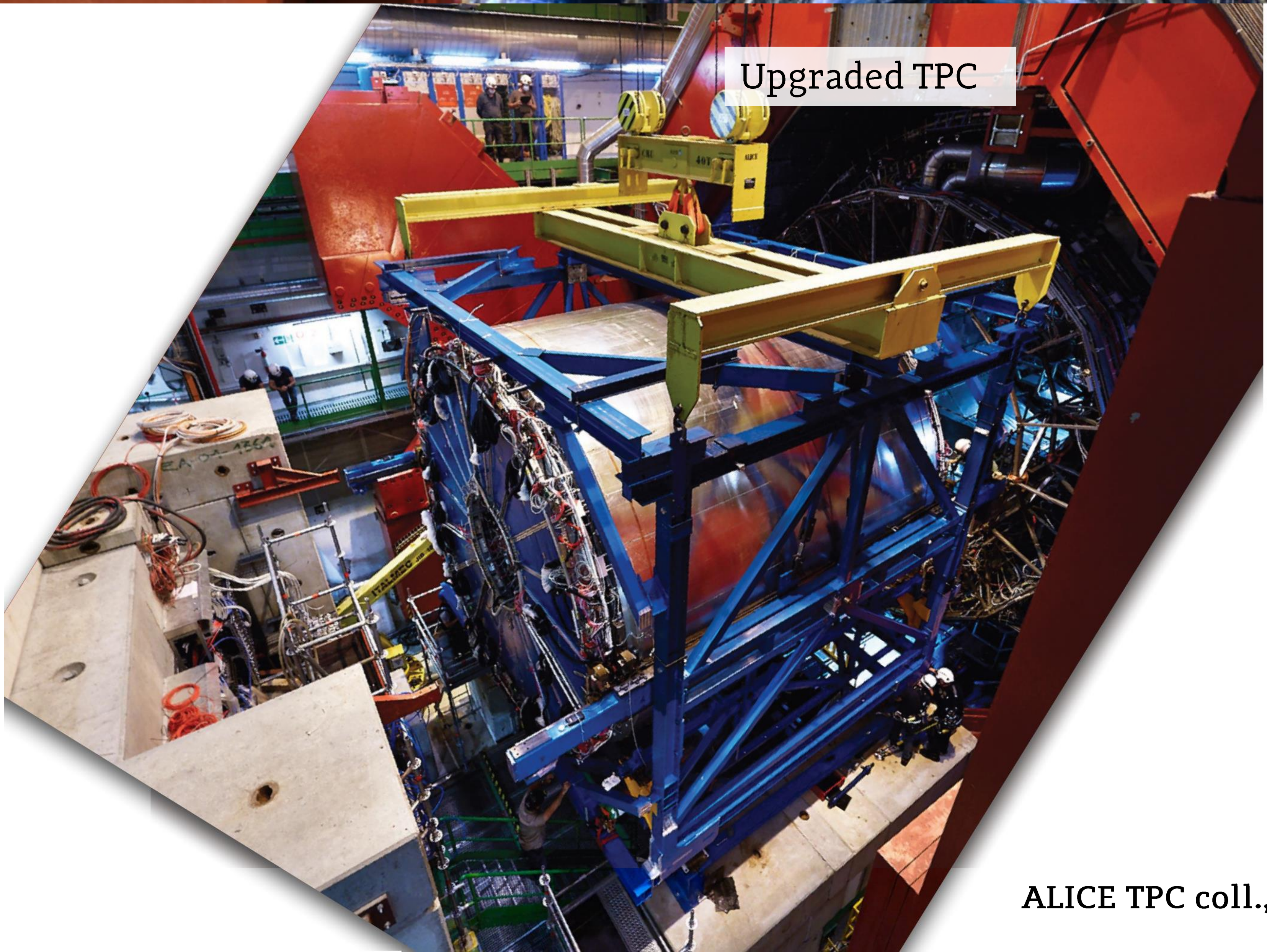
ALICE HADRON talks

Antinuclei:	Speaker	Time
• Constraining the formation mechanisms of light (anti)nuclei at the LHC and applications for cosmic ray physics	Giovanni Malfattore	Wed 7 Jun 2023, 17:50
• Overview and new directions about light (anti)nuclei measurements with ALICE	Marika Rasa	Wed 7 Jun 2023, 17:00
• Measurements of the hypertriton production and properties with ALICE	Stefania Bufalino	Thu 8 Jun 2023, 14:00
Production and hadronization:		
• Light-flavor hadron production with ALICE at LHC	Alberto Caliva	Mon 5 Jun 2023, 14:00
• Measurement of Λ^+_c production in pp, p-Pb, and Pb-Pb collisions with the ALICE experiment at the LHC	Clara Bartels	Mon 5 Jun 2023, 15:40
• Light flavour resonance production with the ALICE at the LHC	Neelima Agrawal	Mon 5 Jun 2023, 16:30
• Quarkonium production in small collision systems in ALICE	Michele Pennisi	Mon 5 Jun 2023, 14:25
• Hadronisation of heavy quarks in small systems with ALICE at the LHC	Tiantian Cheng	Fri 9 Jun 2023, 9:00
• Probing hadron formation at the LHC through the study of strange particles in different collision systems and energies with ALICE at the LHC	Maria Barlou	Mon 5 Jun 2023, 15:00
• Two-particle angular correlations of identified particles in pp collisions at $\sqrt{s}$ = 13 TeV	Daniela Ruggiano	Wed 7 Jun 2023, 15:35
Femtoscopy:		
• A study of K−dand K+d interactions via femtoscopy technique	Wioleta Rzesa	Wed 7 Jun 2023, 14:25
• Constraining coupled channels dynamics using femtoscopic correlations with ALICE at LHC	Ramona Lea	Thu 8 Jun 2023, 15:42
• Novel technique to access the three-body interactions with ALICE at the LHC	Laura Serksnyte	Wed 7 Jun 2023, 15:15
• Constraining the equation of state of neutron stars with femtoscopy measurements by ALICE	Marcel Lesch	Thu 8 Jun 2023, 15:15
New techniques:		
• Advanced Tools for physics analysis in ALICE	Tuba Gundem	Mon 5 Jun 2023, 17:00

Backup slides

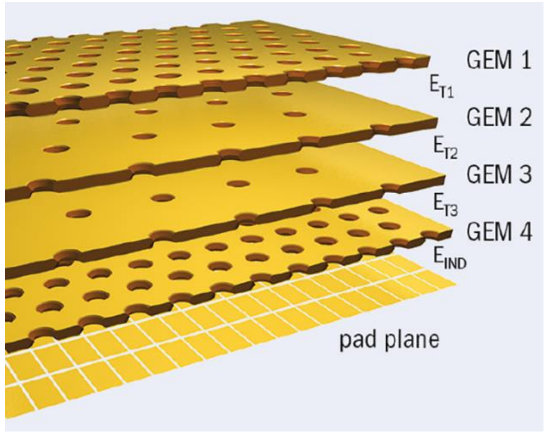


ALICE upgrade for Run 3: TPC



New TPC:

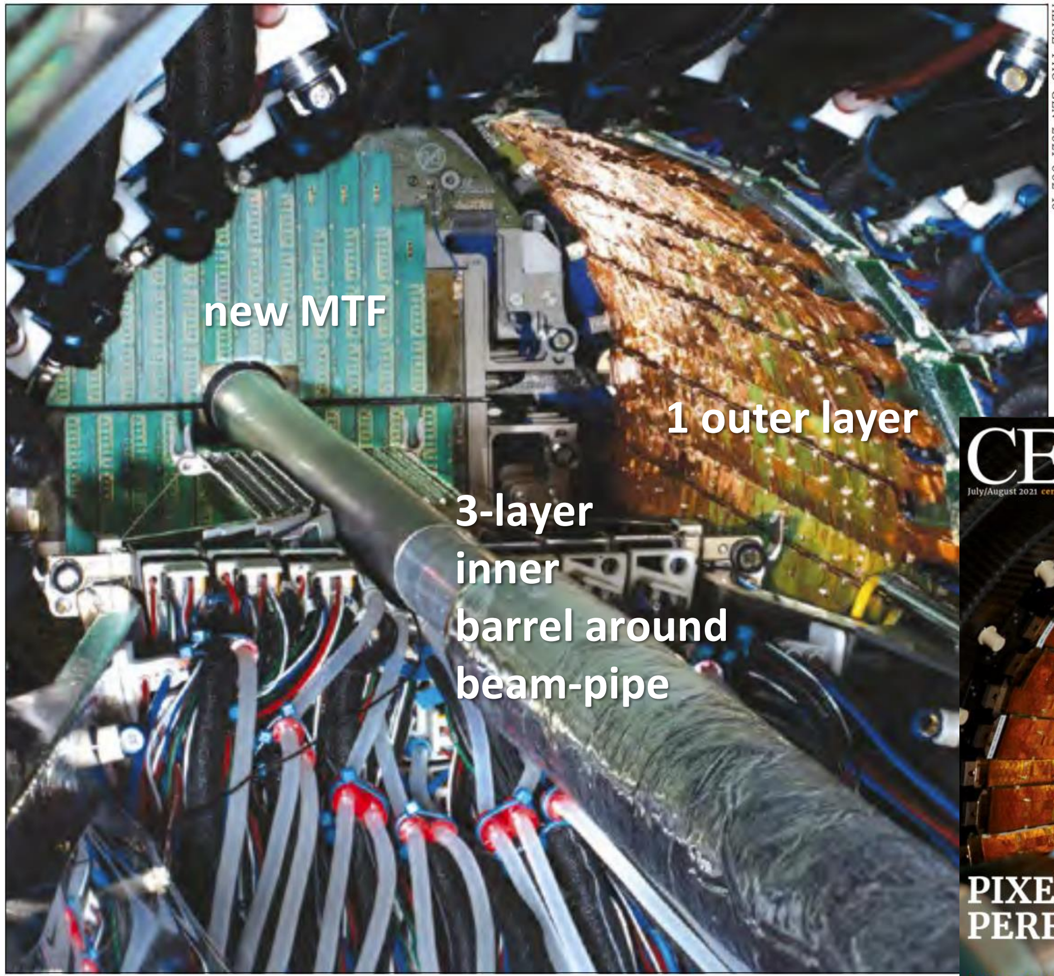
- MWPCs replaced with GEMs
- Enabling continuous readout @50 kHz Pb-Pb interaction rate
- Fully installed in August 2020



ALICE TPC coll., JINST 16 (2021) 03, P03022

ALICE upgrade for Run 3: ITS

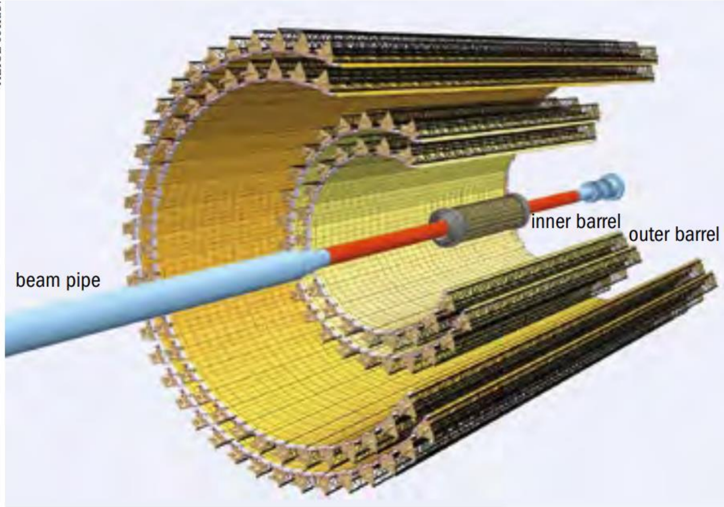
ALICE inner tracking system is the largest pixel detector ever built



New ITS:

- Inner tracking with 7 barrels (3 inner and 4 outer)
- Improved pointing resolution (× 3)
- Smaller beam pipe, 1st layer closer (22 mm)

ALICE collab.



μ_B : Antimatter / matter imbalance

Baryochemical potential

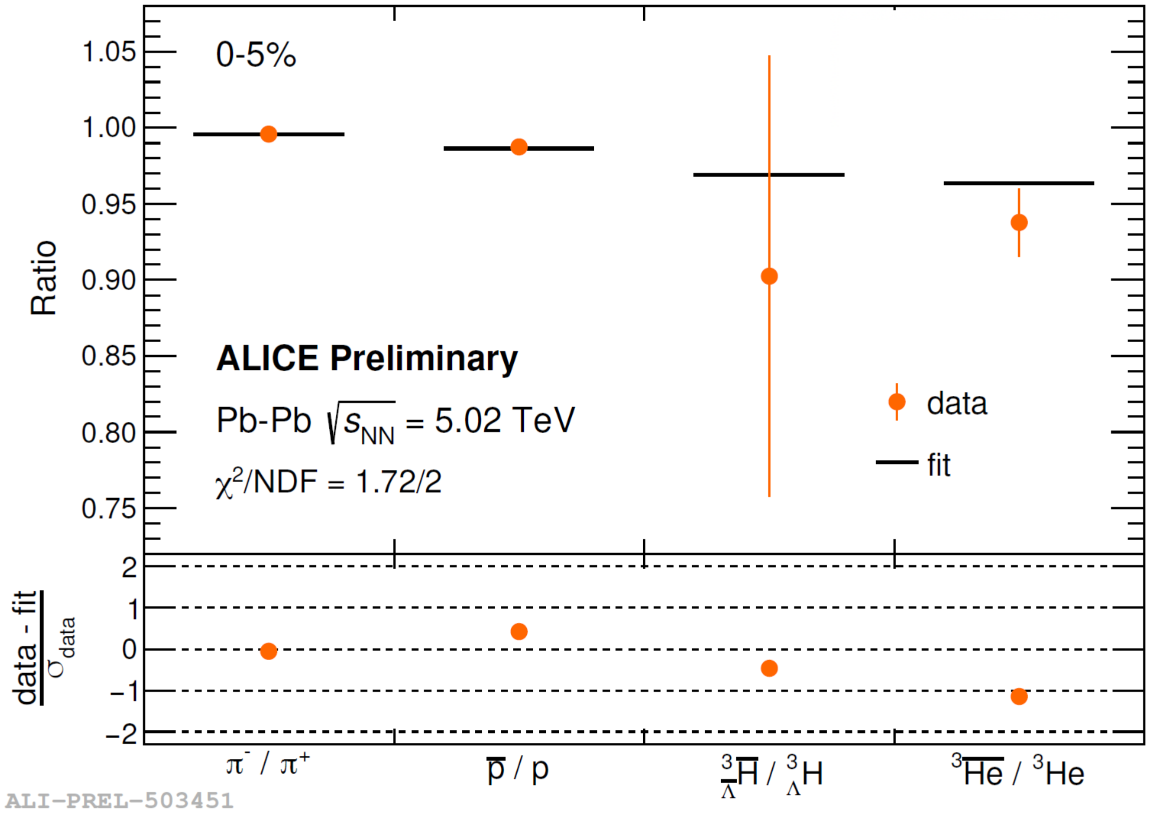
- μ_B → antimatter-matter balance in hadron systems at thermal and chemical equilibrium

Baryochemical potential μ_B can be obtained from the Statistical Hadronisation Model by fitting antihadron/hadron yield ratios :

$$\frac{\bar{h}}{h} \propto exp\left[-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T} - 2I_3\frac{\mu_{I_3}}{T}\right]$$

where: with T = 156.2 +/- 2 MeV

	π^+	p	^{3}He	$^3_\Lambda$H
$B+S/3$	0	1	3	8/9
I_3	1	1/2	1/2	0



Thanks to using ratios → cancellation of uncertainties

μ_B : Antimatter / matter imbalance

Baryochemical potential

- $\mu_B \rightarrow$ antimatter-matter balance in hadron systems at thermal and chemical equilibrium

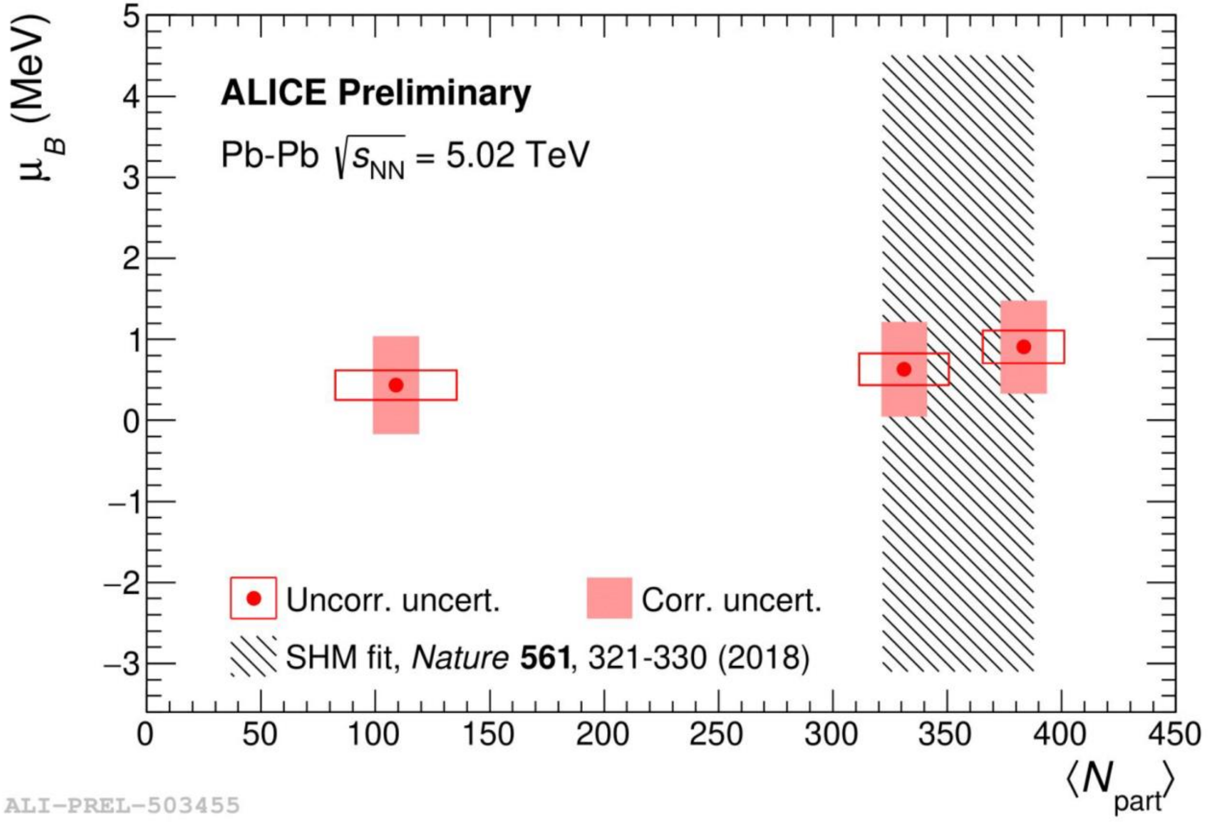
Baryochemical potential μ_B can be obtained from the Statistical Hadronisation Model by fitting antihadron/hadron yield ratios :

$$\frac{\bar{h}}{h} \propto exp\left[-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T} - 2I_3\frac{\mu_{I_3}}{T}\right]$$

→Thanks to using ratios : cancellation of uncertainties

→ Consistent with previous measurement but **with x6 better precision**

→ **Most precise μ_B measurement at TeV scale!**



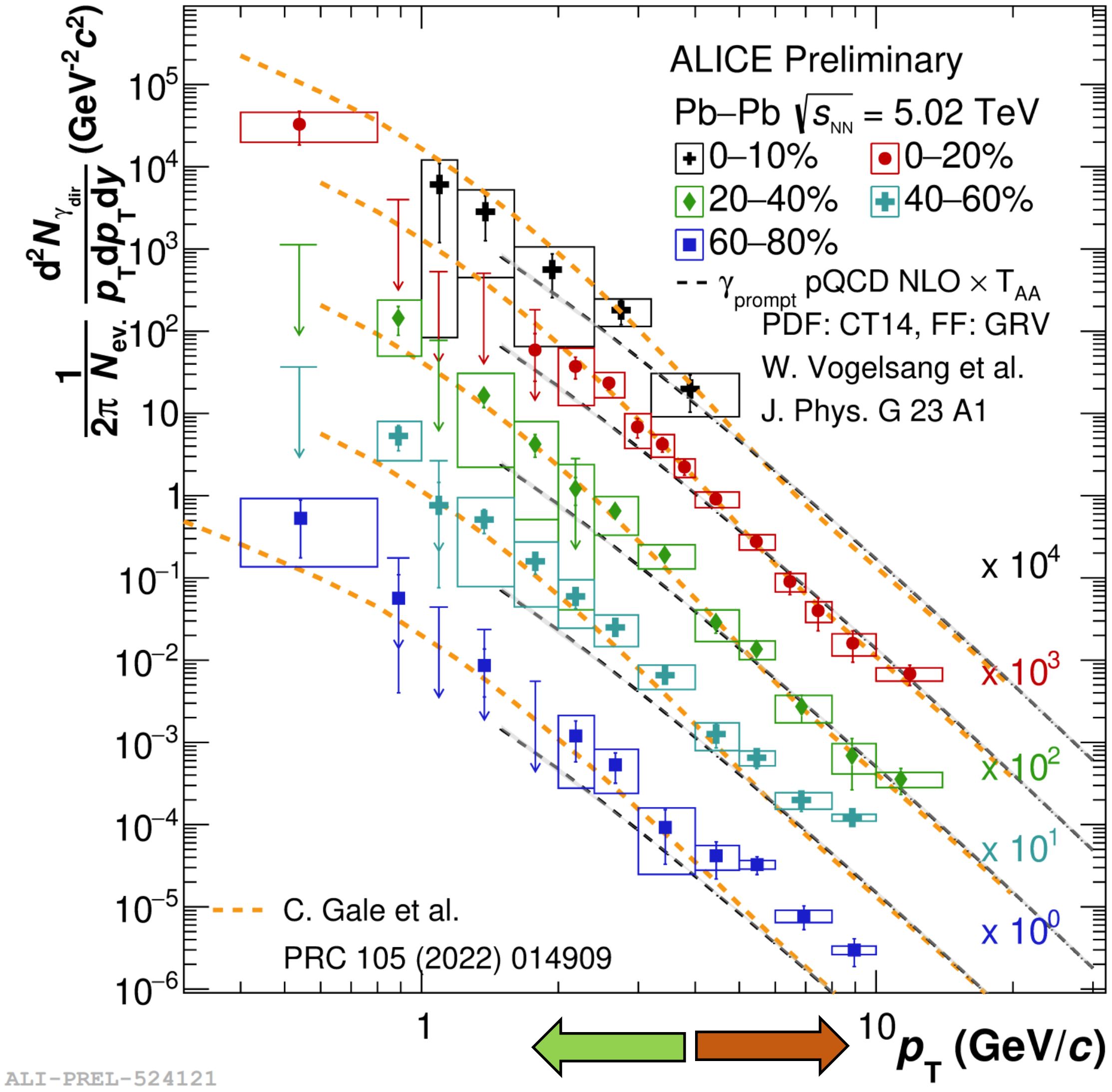
Direct (real and virtual) photons

Direct photons carry information about the properties and dynamics of QGP

New measurement of direct γ in Pb-Pb at 5.02 TeV
- Virtual γ (M_{ee} method), 0-10% centrality ■
- Real γ (conversion method), other centralities ■ ■ ■ ■

High p_T ($p_T \gtrsim 5$ GeV/c) – prompt photons
- consistent with pQCD expectations

Low p_T ($p_T \lesssim 4$ GeV/c) – “thermal” photons
- described by model with prompt + pre-equilibrium + thermal photons

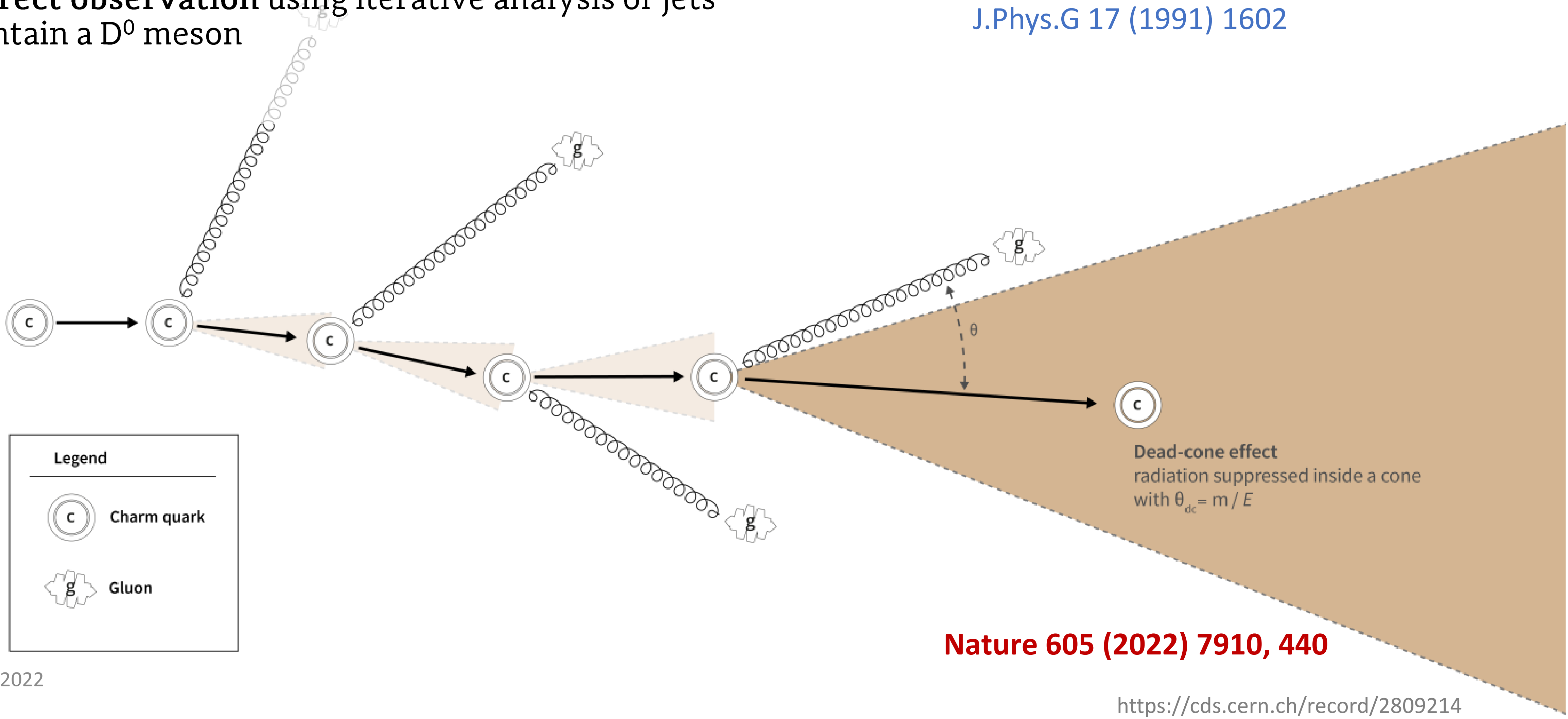


Dead-cone effect

“Dead cone” effect reduces small-angle gluon radiation for high-mass quarks.

- **First direct observation** using iterative analysis of jets that contain a D^0 meson

Dokshitzer, Khoze, Troian, J.Phys.G 17 (1991) 1602



Nature 605 (2022) 7910, 440

https://cds.cern.ch/record/2809214

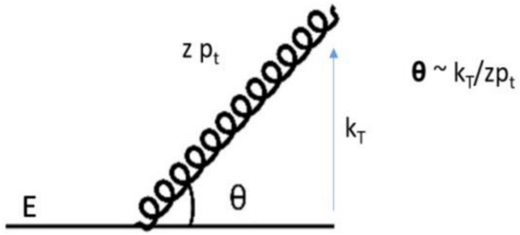
Dead-cone effect

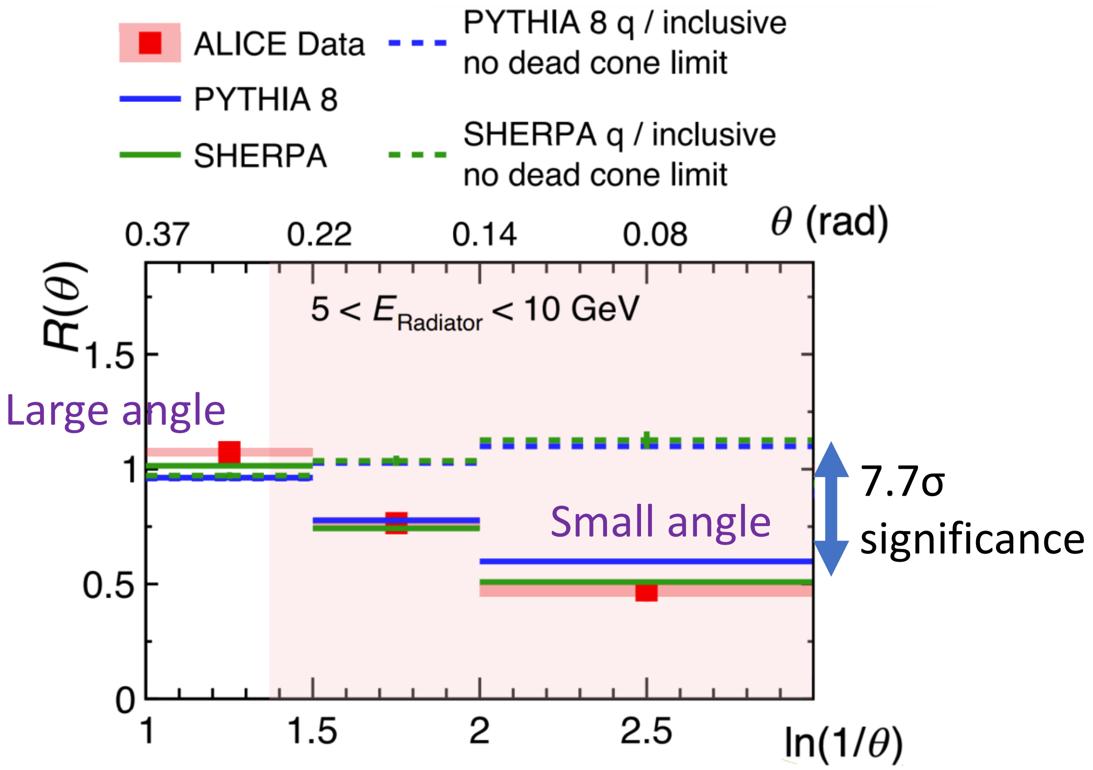
"Dead cone" effect reduces small-angle gluon radiation for high-mass quarks.

- **First direct observation** using iterative analysis of jets that contain a D^0 meson

The dead cone is uncovered through a direct measurement of the emission angle

Small angle emissions suppressed for charm quarks compared to light quarks and gluons





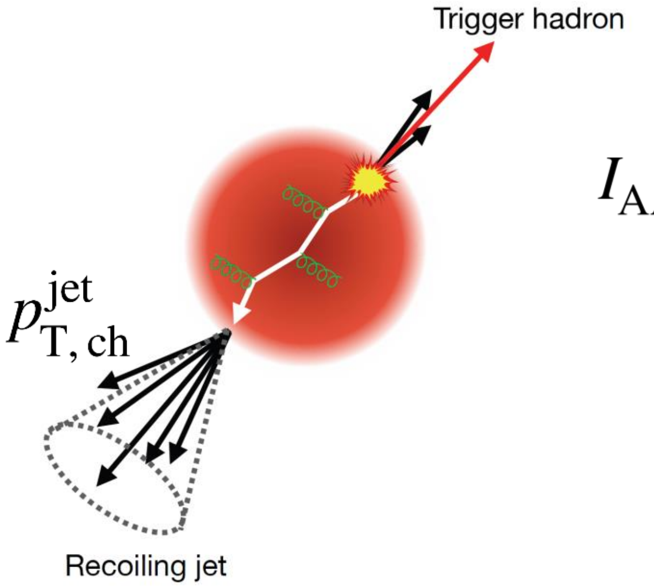
R(θ) – comparison of the angular distribution of charm-quark emissions to those of light quarks and gluons

$$R(\theta) = \frac{1}{N^{D^0 \text{ jets}}} \frac{dn^{D^0 \text{ jets}}}{d\ln(1/\theta)} \Big/ \frac{1}{N^{\text{inclusive jets}}} \frac{dn^{\text{inclusive jets}}}{d\ln(1/\theta)} \Bigg|_{k_T, E_{\text{Radiator}}}$$

Nature 605 (2022) 7910, 440

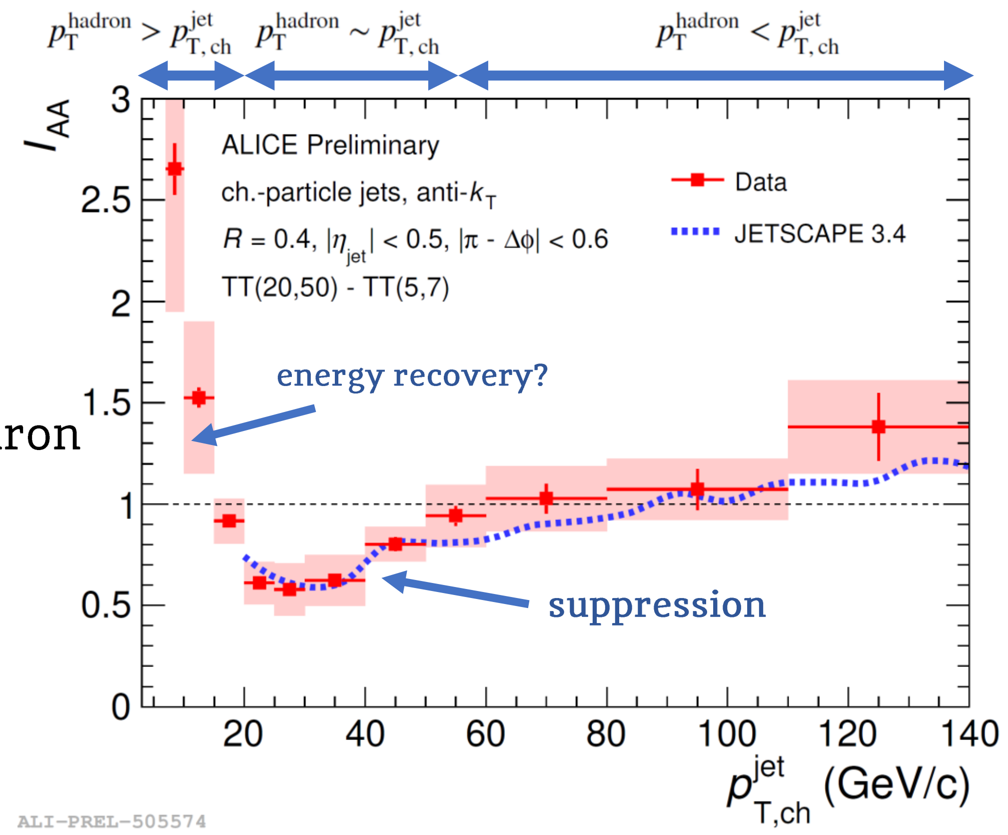
Jets: energy redistribution

- I_{AA} measurement shows how the jet energy is redistributed in heavy-ion collisions



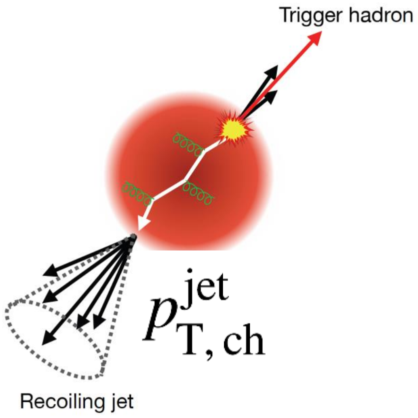
$$I_{AA} \equiv \frac{\Delta_{recoil}(Pb-Pb)}{\Delta_{recoil}(pp)}$$

ratio of the yields of jets recoiling from high-p_T hadron



- Hint of energy recovery at low momenta
  - In association with azimuthal broadening
- JETSCAPE predictions in agreement with data

Jets : energy redistribution



- I_{AA} measurement shows how the jet energy is redistributed in heavy-ion collisions

$$I_{AA} \equiv \frac{\Delta_{recoil}(Pb-Pb)}{\Delta_{recoil}(pp)}$$

Yield of jets recoiling from high-p_T hadron:

$$n \equiv \frac{1}{N_{trig}^{AA}} \frac{d^2 N_{jet}^{AA}}{dp_{T,ch}^{jet} d\eta_{jet}}$$

+ data-driven subtraction of uncorrelated background: yields measured in two exclusive trigger track classes :

$$\Delta_{recoil} = n(TT_{Sig}) - c_{Ref} \cdot n(TT_{Ref})$$

$c_{Ref} \equiv$ “alignment” constant extracted from data