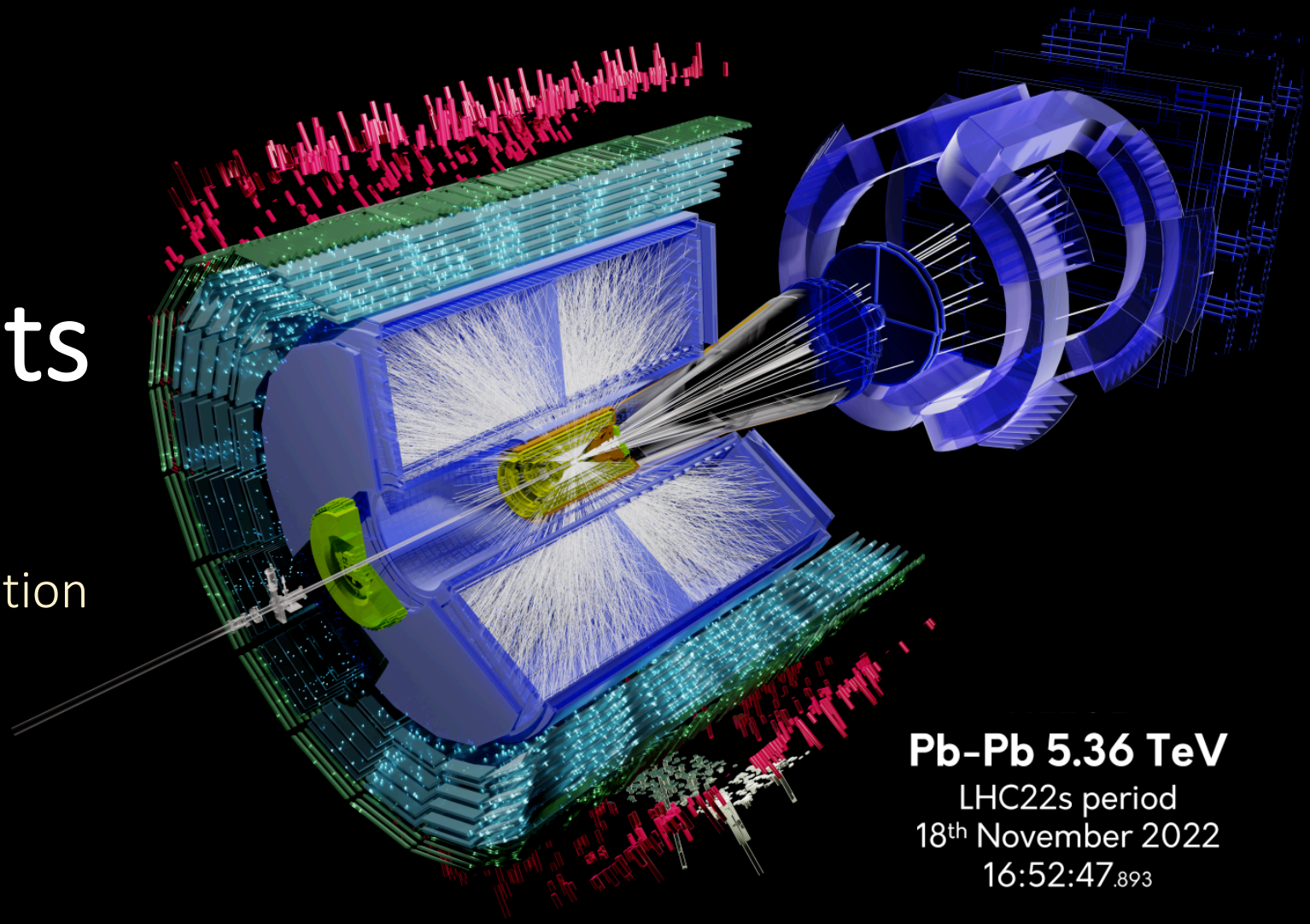
ALICE Highlights

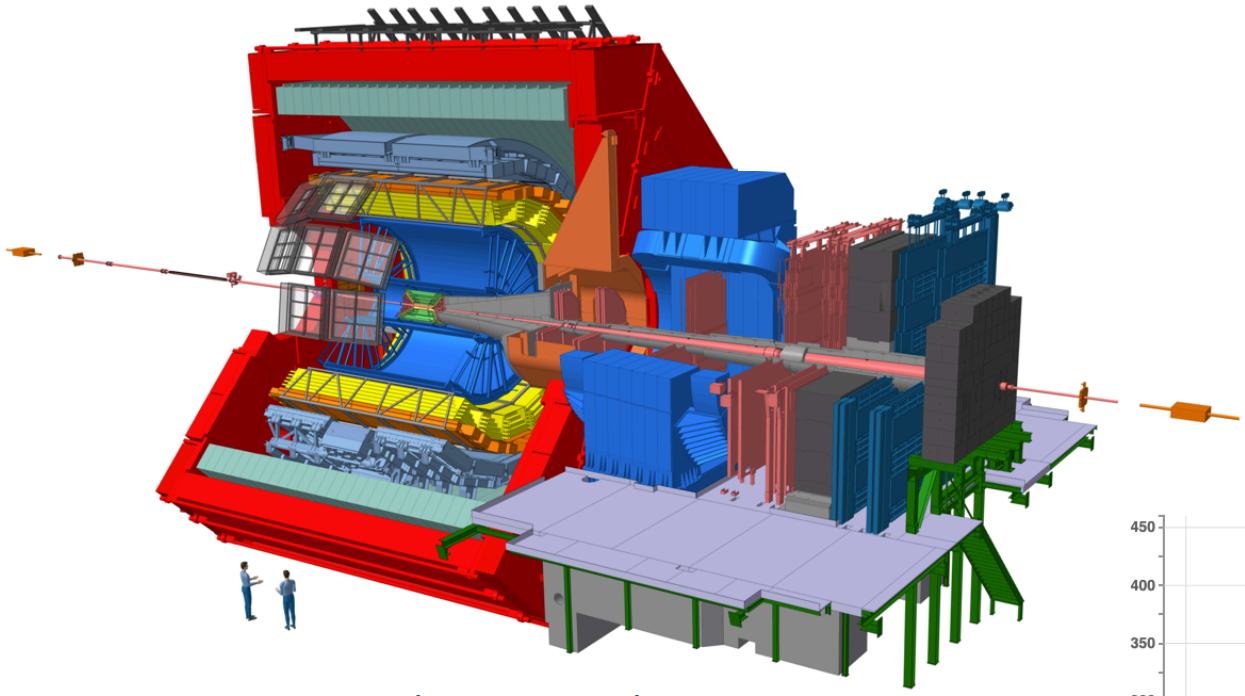
Igor Altsybeev (TUM)
on behalf of the ALICE Collaboration

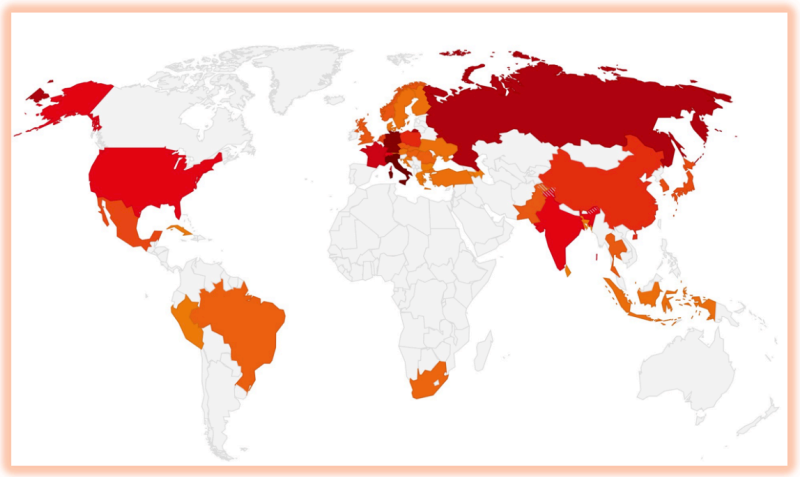
LHCP 2023
Belgrade, 22 May 2023



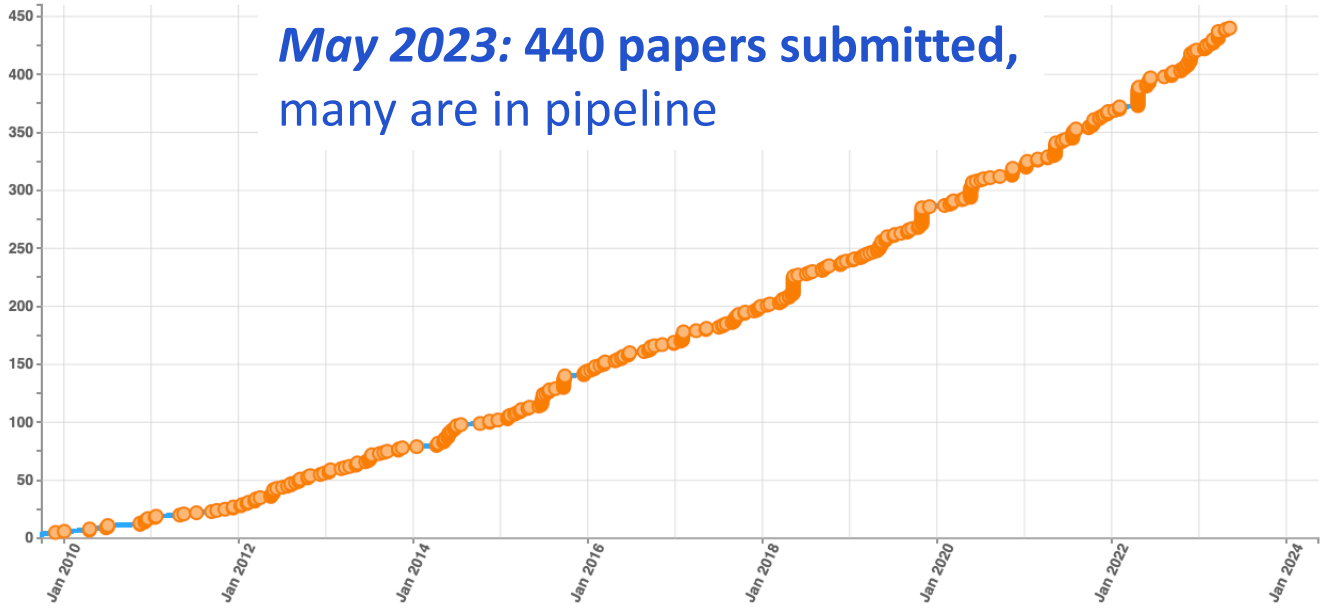
LHCPhysics
Belgrade, 22 - 26 May 2023

ALICE Collaboration





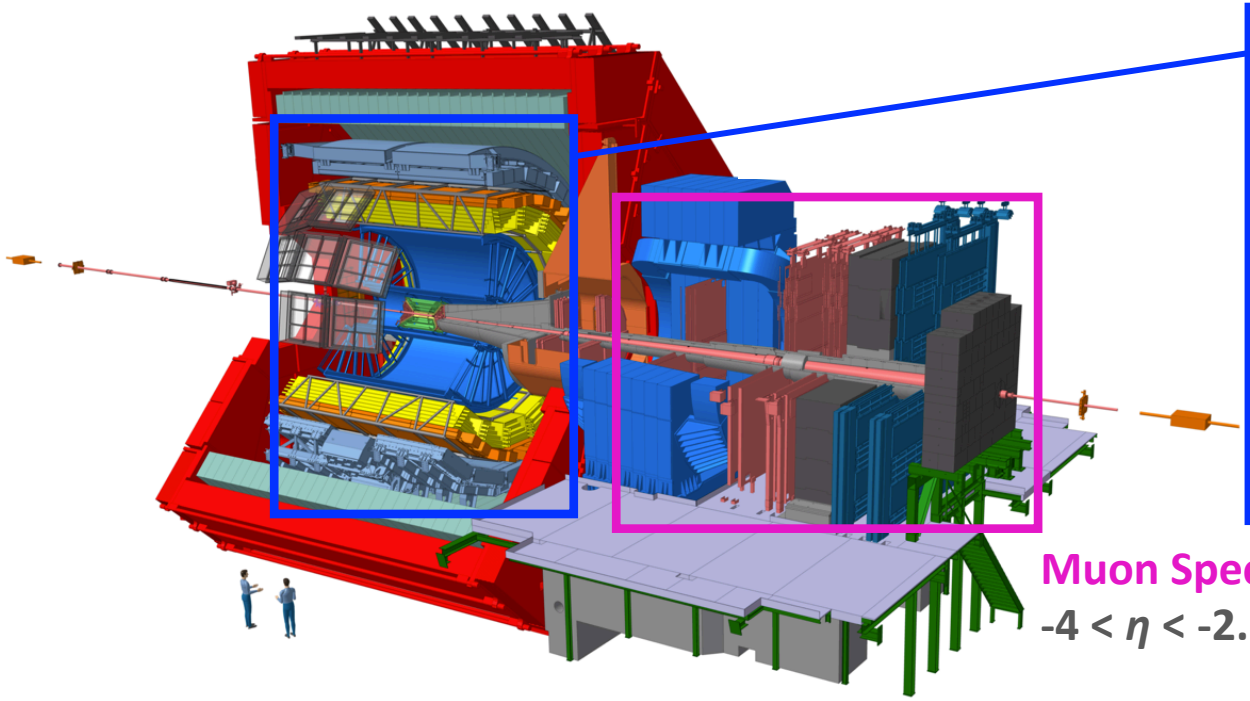
- **40 countries, 174 institutes**
- **~2000 Members, >1000 scientific authors**



Runs 1&2 (2009-2018):

System	Energy
pp	0.9, 2.76, 7, 8, 13 TeV
p–Pb	5.02, 8 TeV
Pb–Pb	2.76, 5.02 TeV
Xe–Xe	5.44 TeV

ALICE detector and datasets in **Run 1&2**

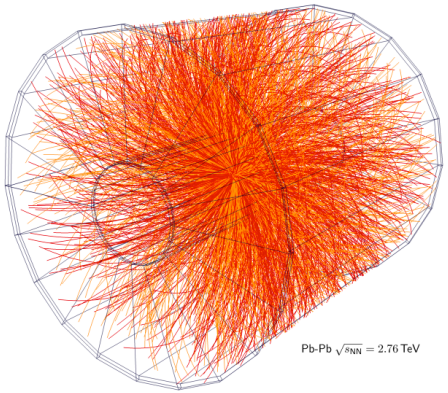


Barrel $|\eta|<0.8$:

Inner Tracking System (ITS)
tracking + triggering + PID

Time Projection Chamber (TPC)
tracking + PID

Time Of Flight (TOF)
PID



TRD, HMPID, EMCal, PHOS

Muon Spectrometer
$-4 < \eta < -2.5$

Forward detectors:
AD (diffraction selection)
V0 (trigger, centrality)
T0 (timing, lumi)
ZDC (centrality, ev. sel.)
FMD (N_{ch})
PMD ($N\gamma$, N_{ch})
+ ACORDE (cosmics)

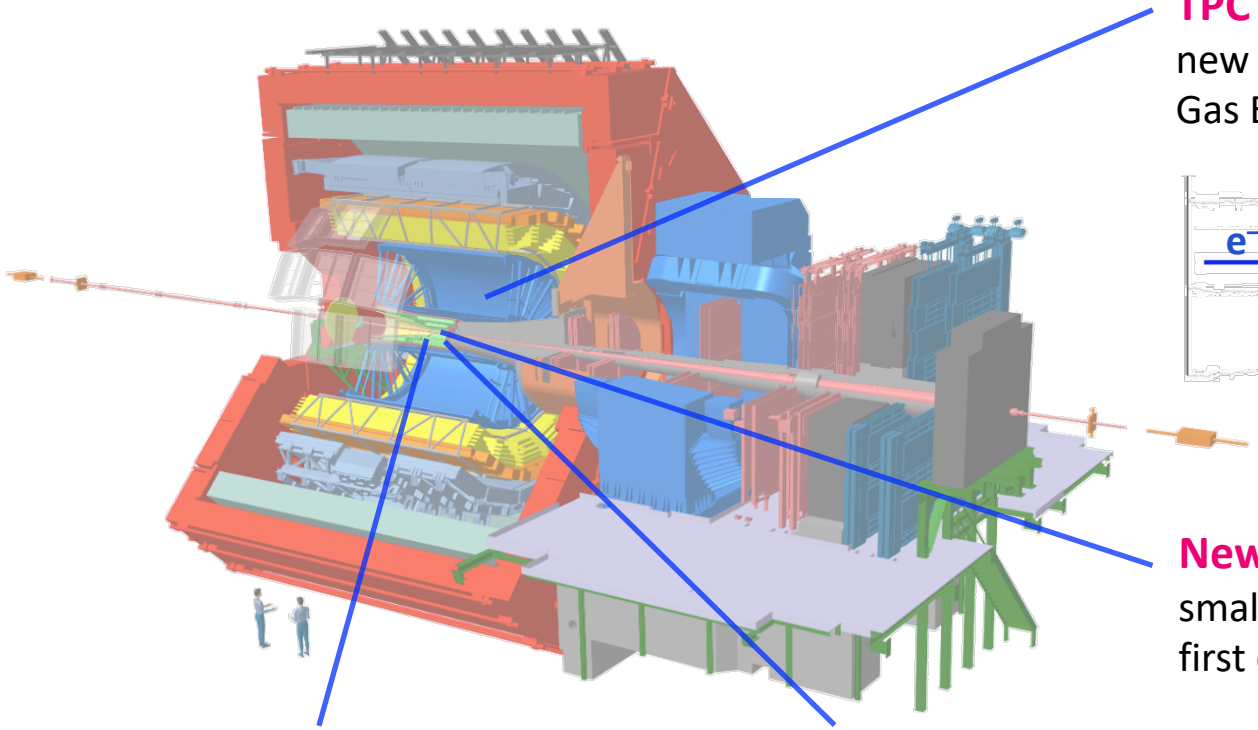
Runs 1&2 (2009-2018):

System	Energy
pp	0.9, 2.76, 7, 8, 13 TeV
p–Pb	5.02, 8 TeV
Pb–Pb	2.76, 5.02 TeV
Xe–Xe	5.44 TeV

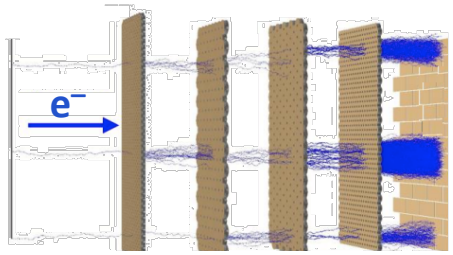
- minimum bias triggers
- rare triggers (muons, EMCal, PHOS, high mult. pp, etc.)

ALICE detector **in Run 3**

ALICE upgrades during LS2
arXiv:2302.01238

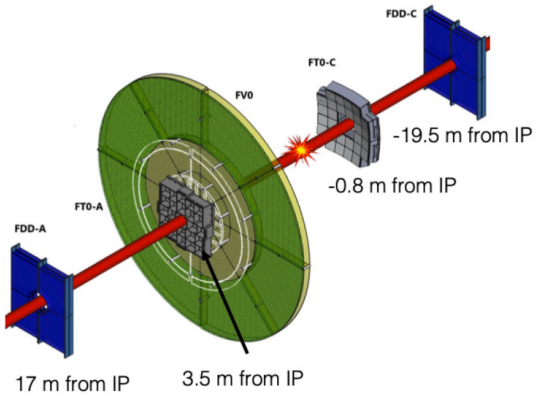


TPC
new readout chambers with
Gas Electron Multipliers (**GEM**s)

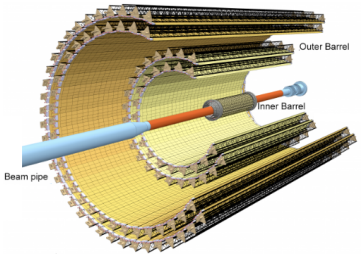


New beampipe
smaller diameter (36.4 mm),
first detection layer at 20 mm

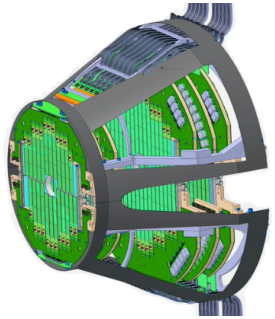
New Fast Integration Trigger (FIT)
interaction trigger, online luminometer,
forward multiplicity



New Inner Tracking System (ITS2)
7 layers, 10 m^2 silicon tracker
based on MAPS (12 G pixels)



New Muon Forward Tracker (MFT)
5 planes of MAPS
forward vertexing for muons



- operation at much **higher interaction rate**
- improved **vertexing** (central and forward) and tracking **resolution at low p_T**

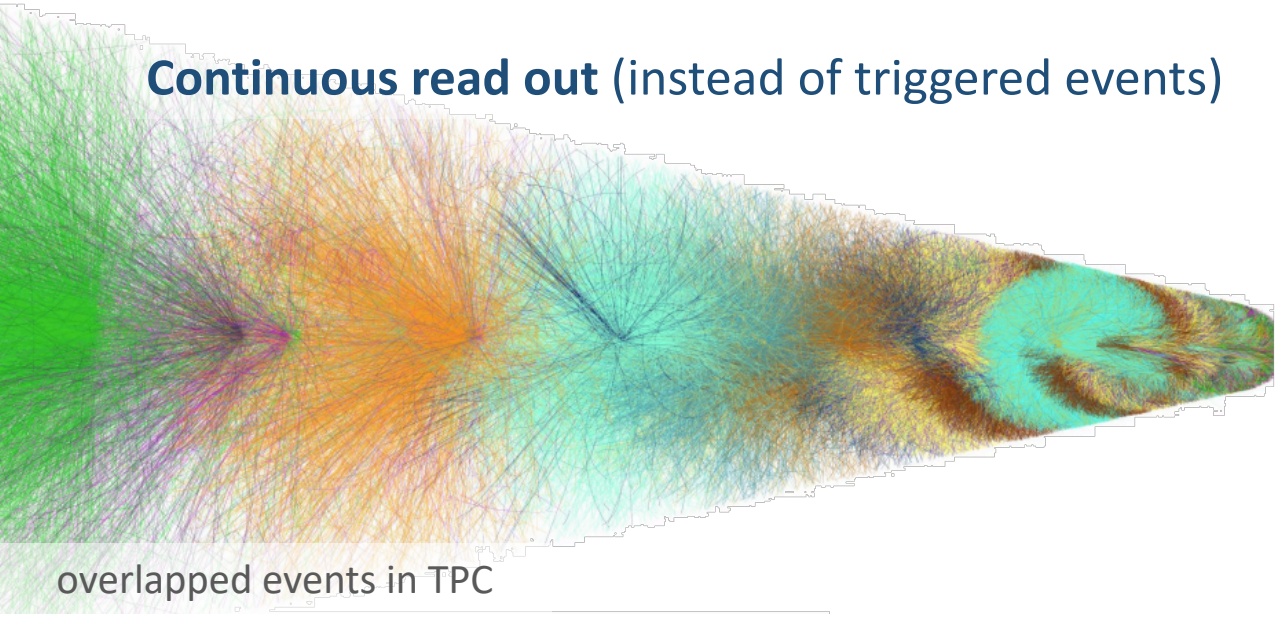
J. Liu, Tue, 11:30

M. Faggin, Thu, 12:24

Data processing in Run 3+4

ALICE upgrades during LS2
arXiv:2302.01238

Continuous read out (instead of triggered events)



overlapped events in TPC

***O*²** – new framework for **online/offline** data **reconstruction** and **analysis**

- **~500 kHz** interactions **at pp** data taking

Selection of high-multiplicity and rare events using **software triggers** with a selection factor of **~10^{-4}**

- will operate at **50 kHz** during the **Pb-Pb** run
- **x50** increase in statistics for observables

J. Liu, Tue, 11:30

M. Fontana, Tue, 12:44

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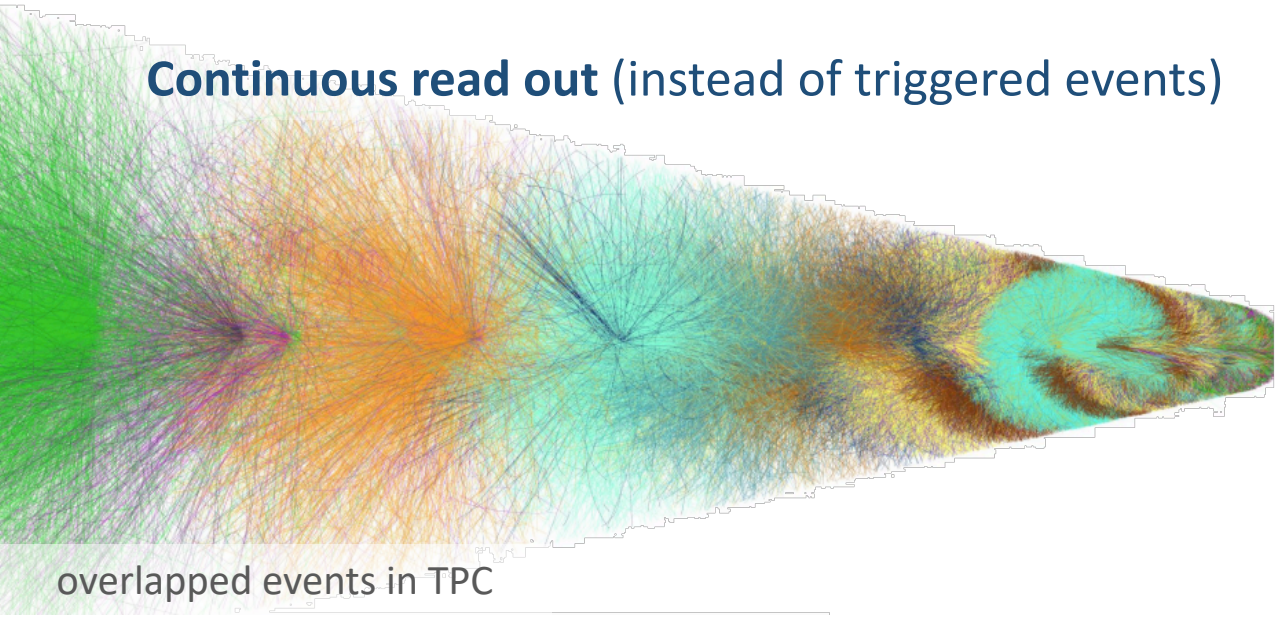

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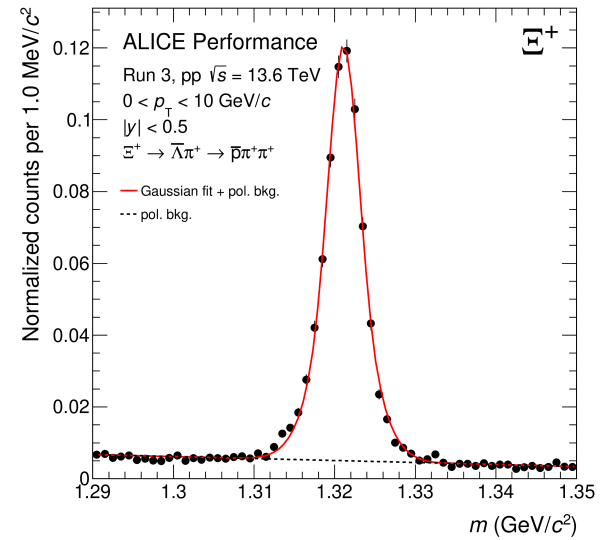
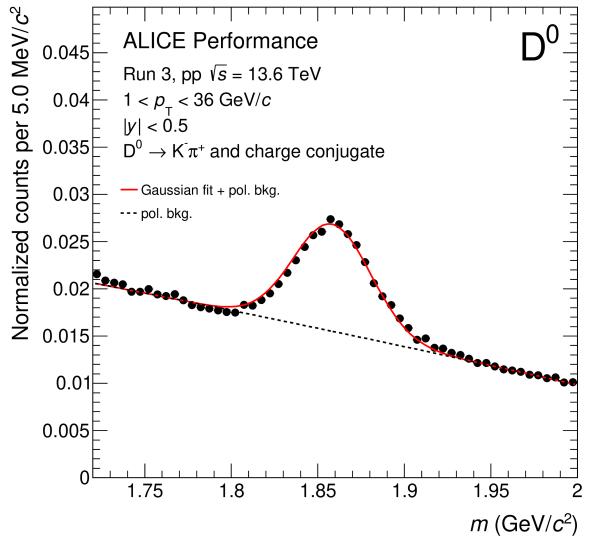
***O*²** – new framework for **online/offline** data **reconstruction** and **analysis**

Good reconstruction performance with the latest calibrations



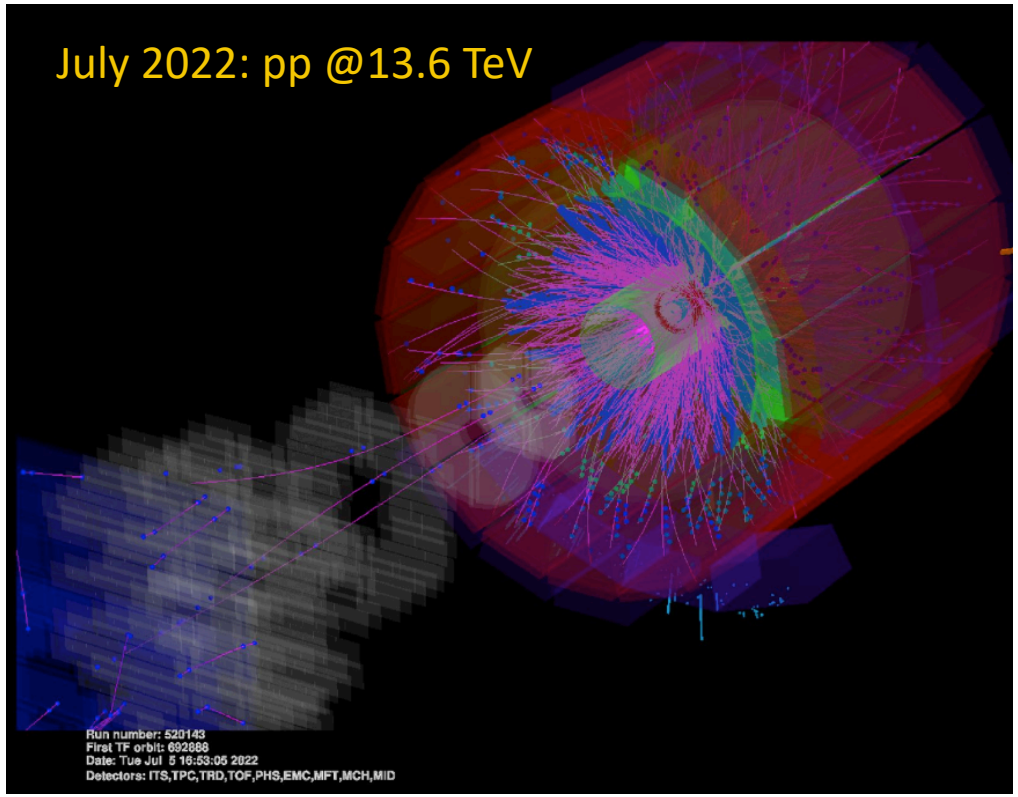


J. Liu, Tue, 11:30

M. Fontana, Tue, 12:44

Data taking in Run 3 – 2022

- **July 2022** – first pp collisions at 10 kHz **@13.6 TeV**
- pp physics data taking at **~500 kHz**
- pp **1-4 MHz** tests (pp@4.5 MHz is equivalent to Pb–Pb@50 kHz)



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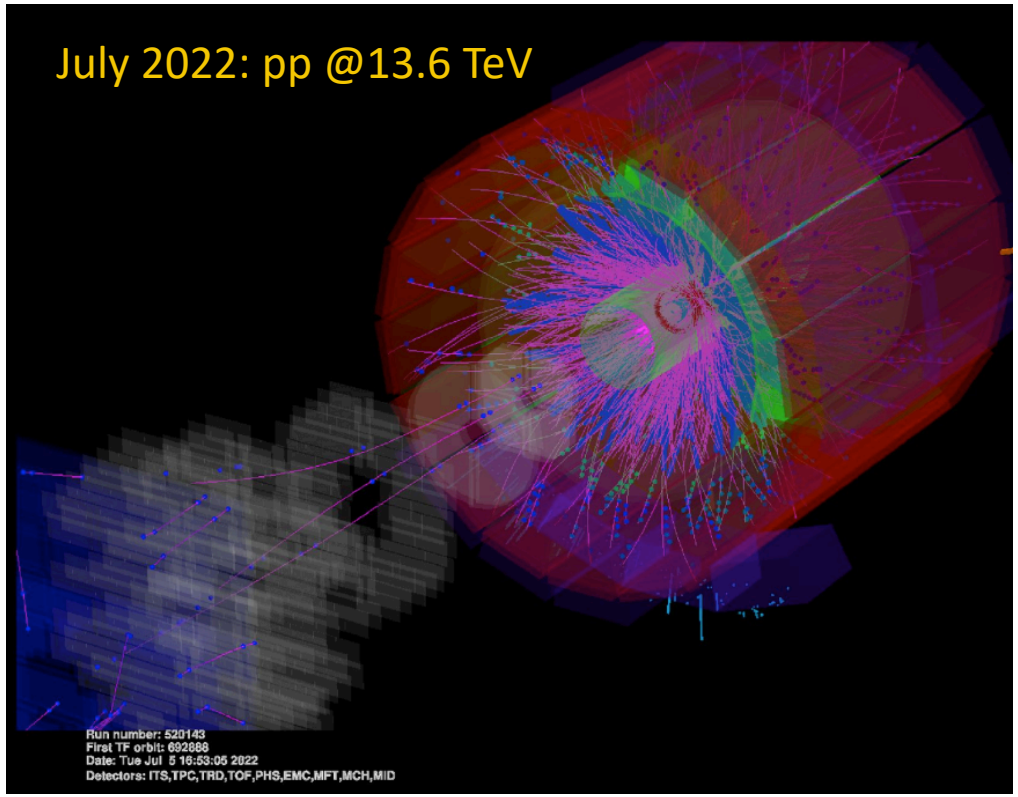
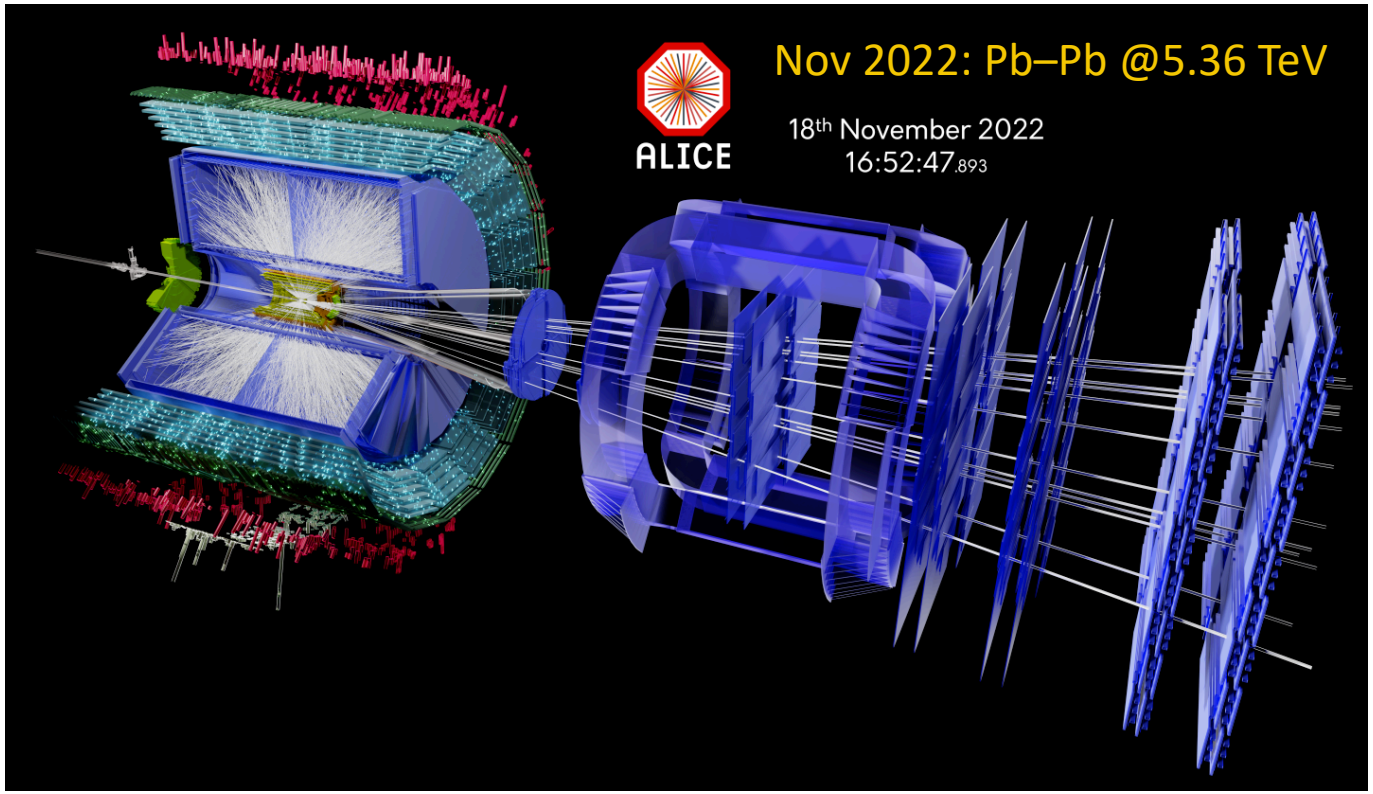
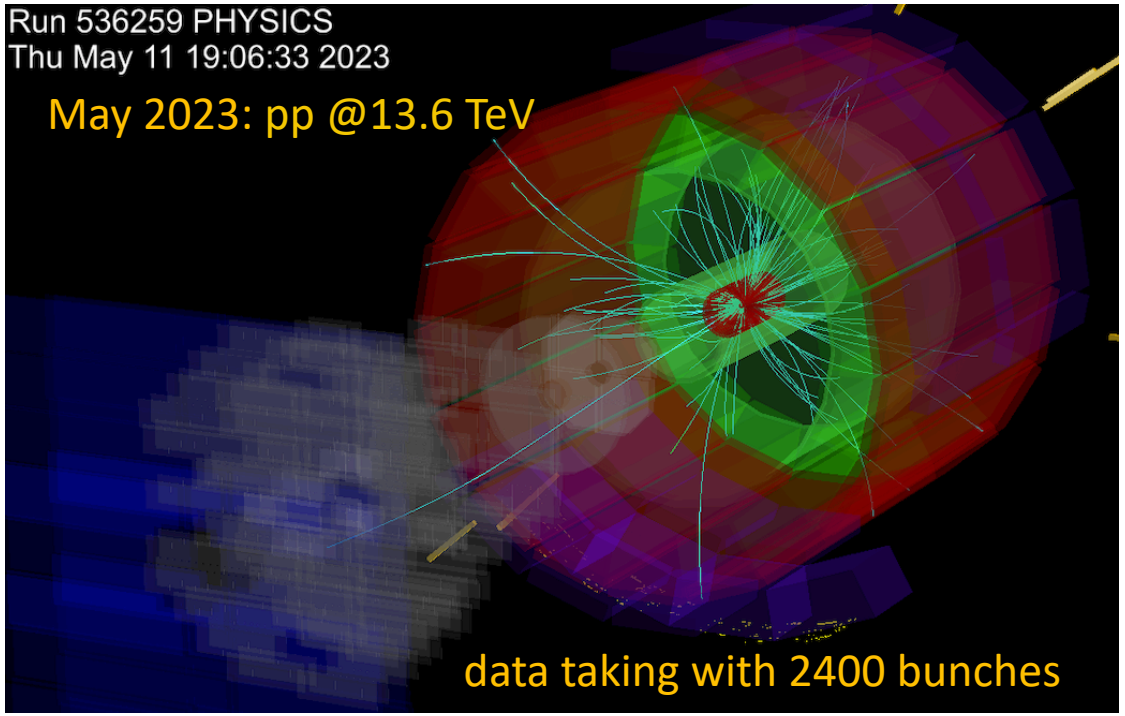
- pp physics data taking at **~500 kHz**
- pp **1-4 MHz** tests (pp@4.5 MHz is equivalent to Pb–Pb@50 kHz)
- **Pilot beam Pb–Pb @5.36 TeV** on 17-18 November 2022

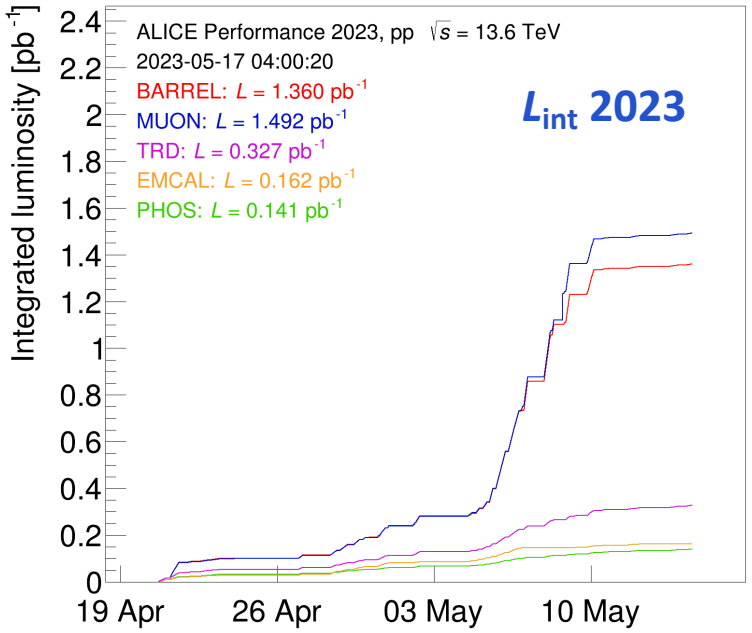




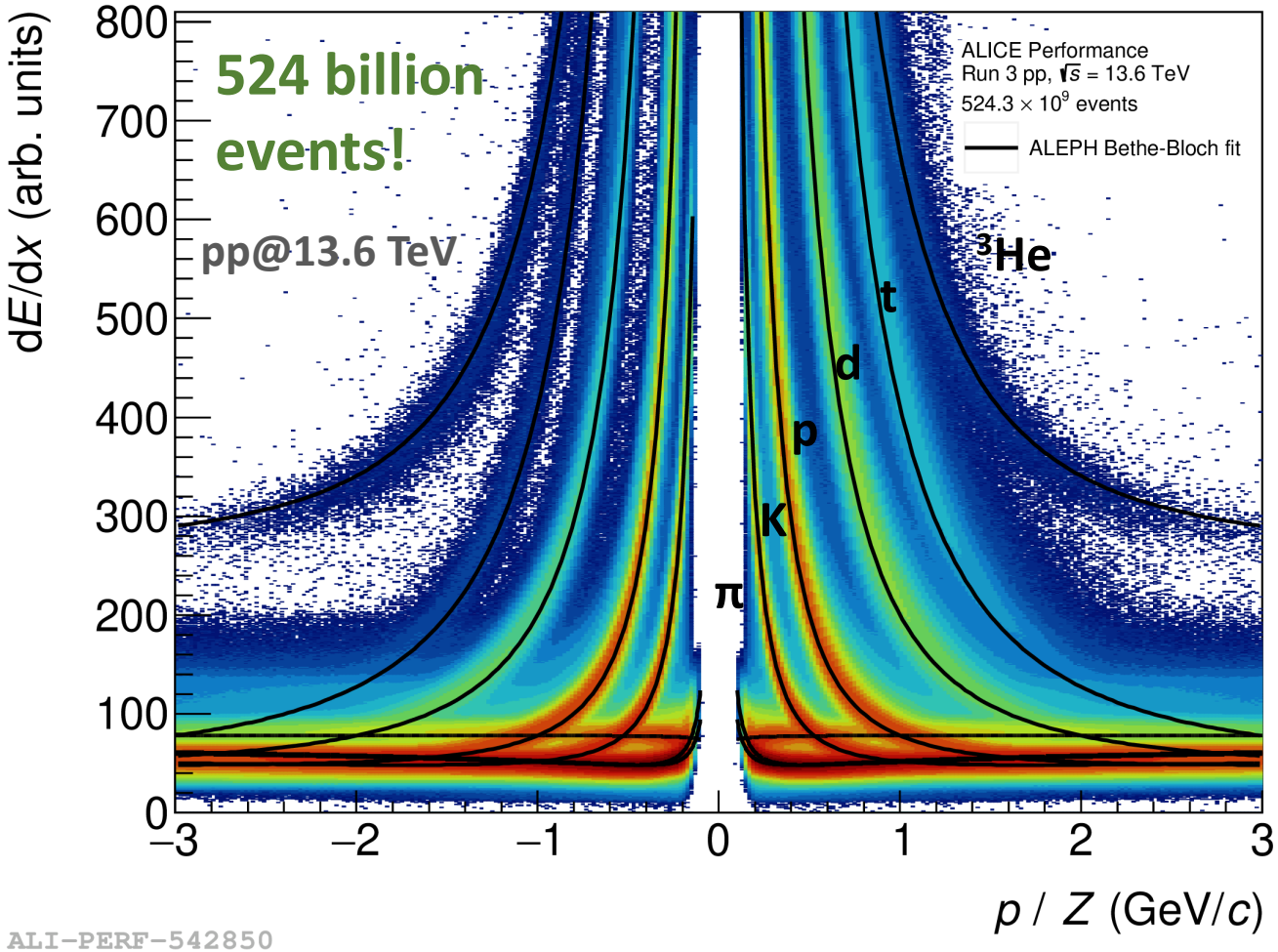
Data taking in Run 3 – 2023

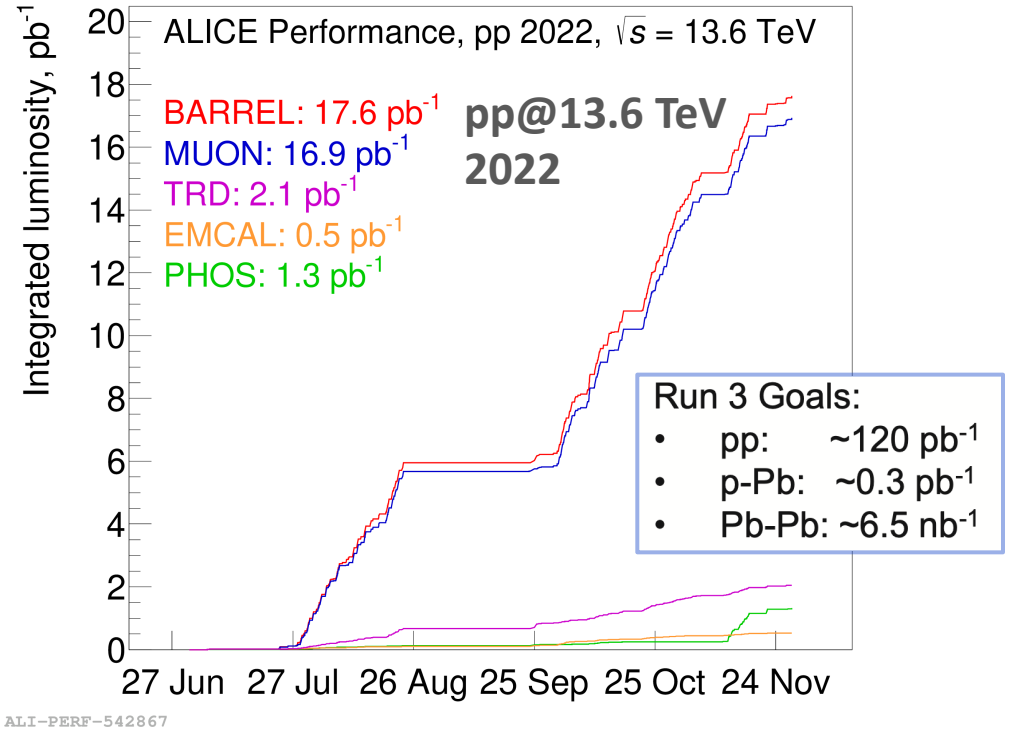
- **April 6** – first stable beam, pp **@0.9 TeV**
- **April 21** – first pp**@13.6 TeV**
- physics data taking at **~500 kHz**
- **anticipating Pb-Pb run**
  - 5+2 days pp reference, 27+4 days Pb-Pb





Particle identification with TPC: full 2022 pp statistics





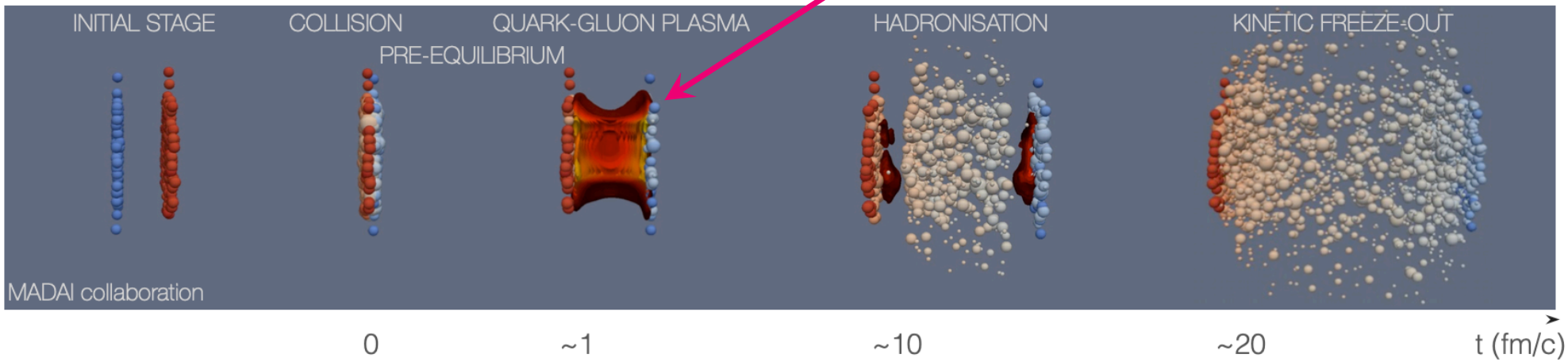
→ **High-precision measurements with nuclei**

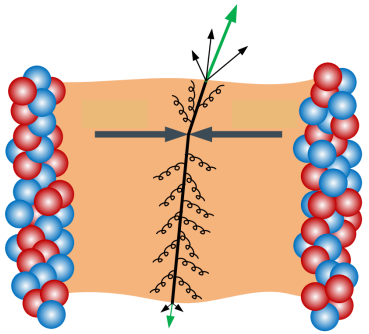
C. Sonnabend, Thu, 12:42

Physics with ALICE

Quark-gluon plasma (QGP) = deconfined strongly-interacting QCD matter with color degrees of freedom

stages of heavy-ion collision:





Studies with observables which characterize:

- **bulk properties** of the produced medium
- medium **evolution** and **interaction with hard probes, hadronisation**
- collective effects in **high-multiplicity pp and pA collisions**

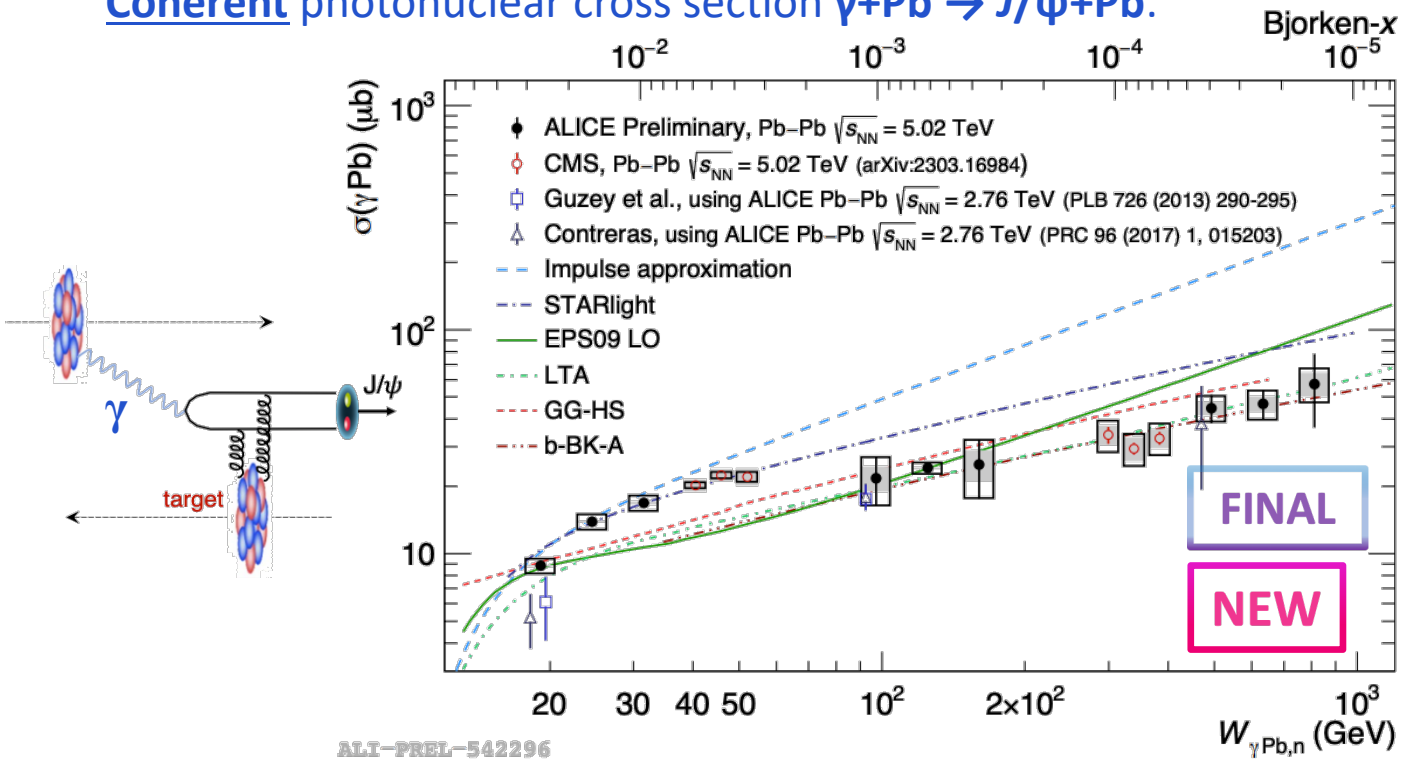
Measurements at high multiplicities down to low p_T with precise PID are required (ALICE)

QGP-dedicated plenary talks:

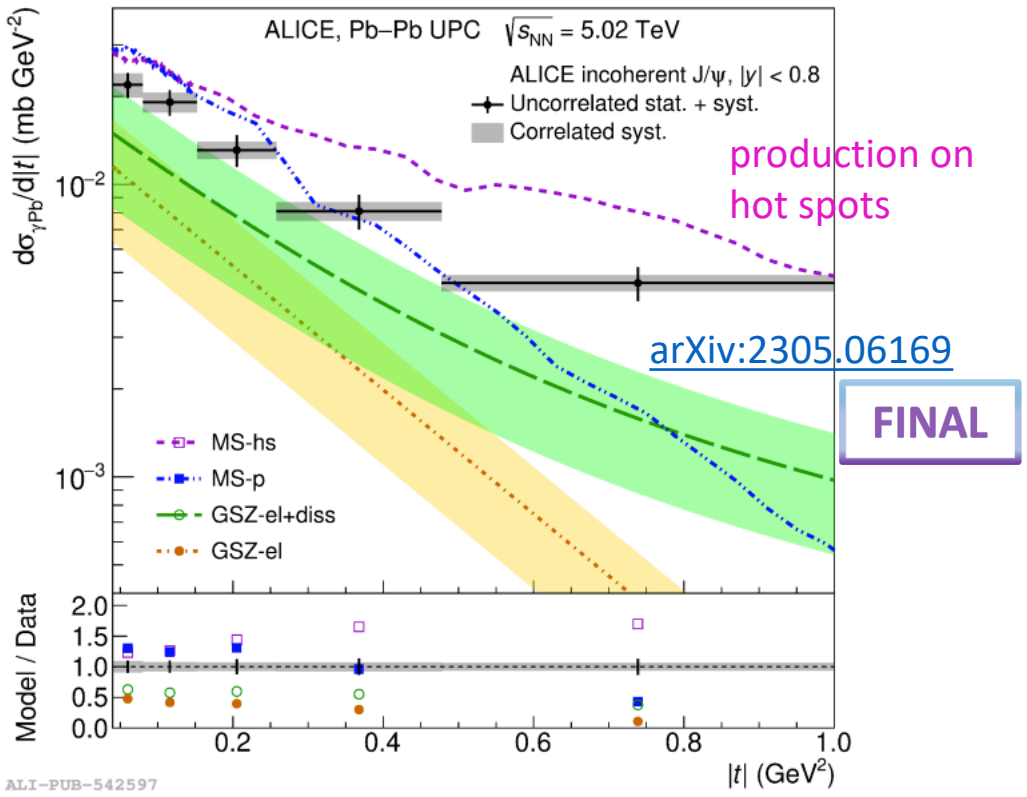
Quark-gluon plasma properties from LHC data — A. Timmins, Mon, 18:15
The limits of QGP-like effects towards smaller systems — N. Jacazio, Tue, 10:36
QGP with high-p_T probes — L. Cunqueiro Mendez, Wed, 09:00

Initial stage: probing **gluons in nuclei** with **ultra-peripheral collisions**

Coherent photonuclear cross section **γ+Pb → *J*/ψ+Pb**:



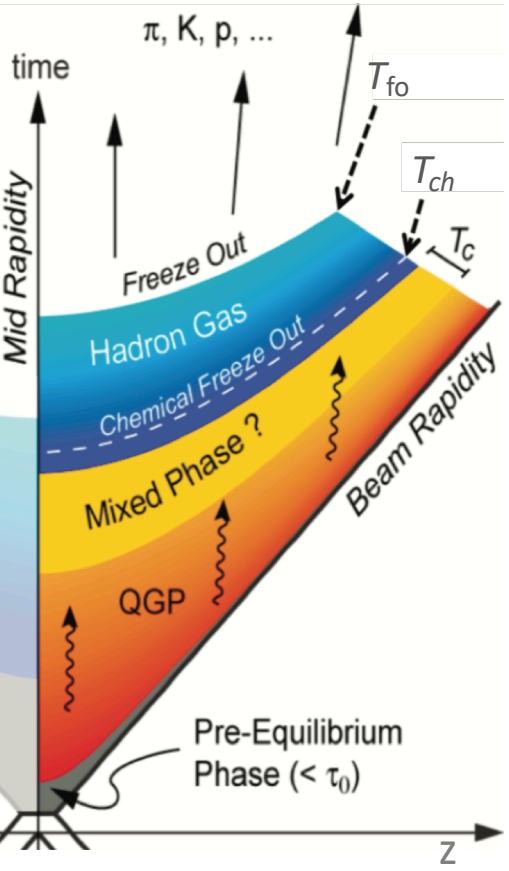
Incoherent ***J*/ψ production** ***vs*** **Mandelstam *t*:**



- Cross section rises with γ-nucleon CM energy W
- **Constrain gluon densities down to *x* ~ 10^{-5}**

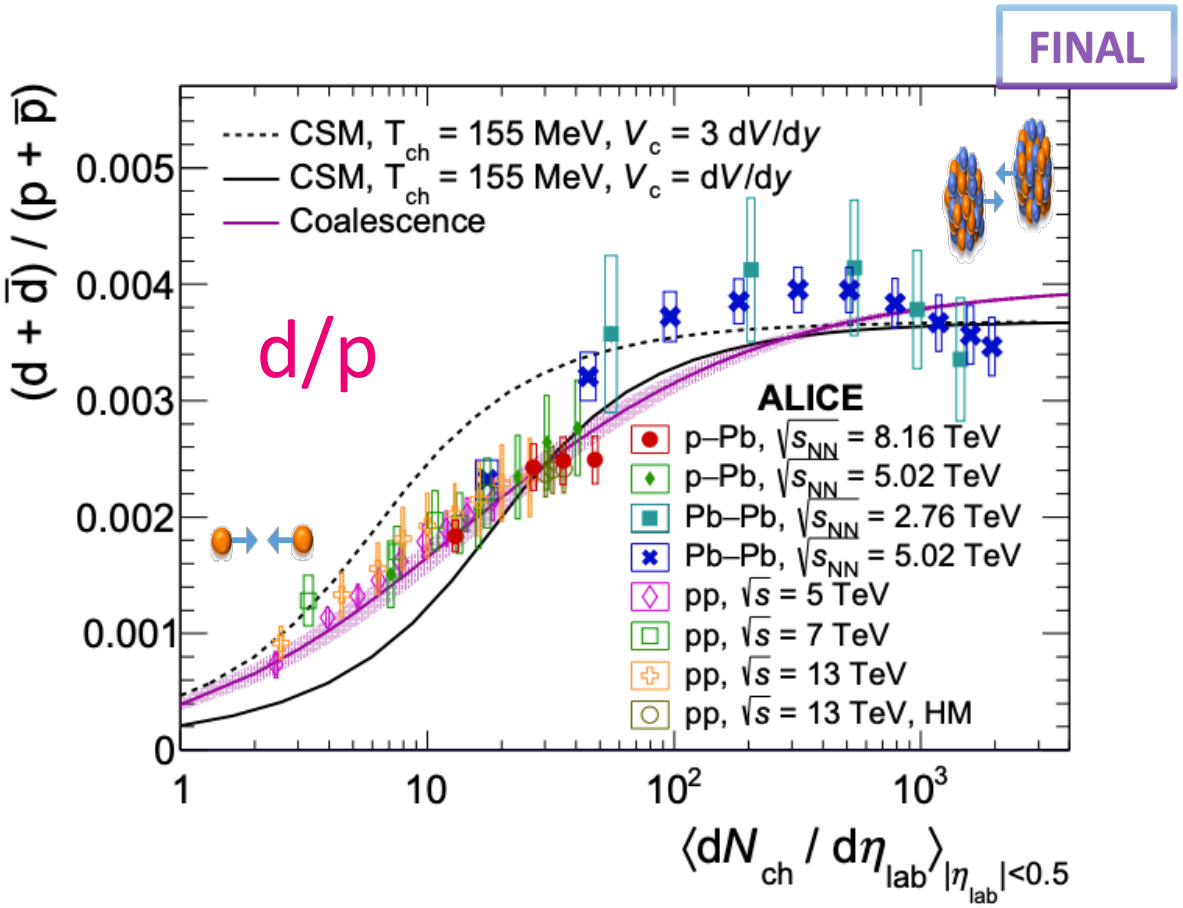
- **Larger |*t*| → smaller structures resolved**
- Models with **sub-nucleon hot spots** agree with the slope of data better

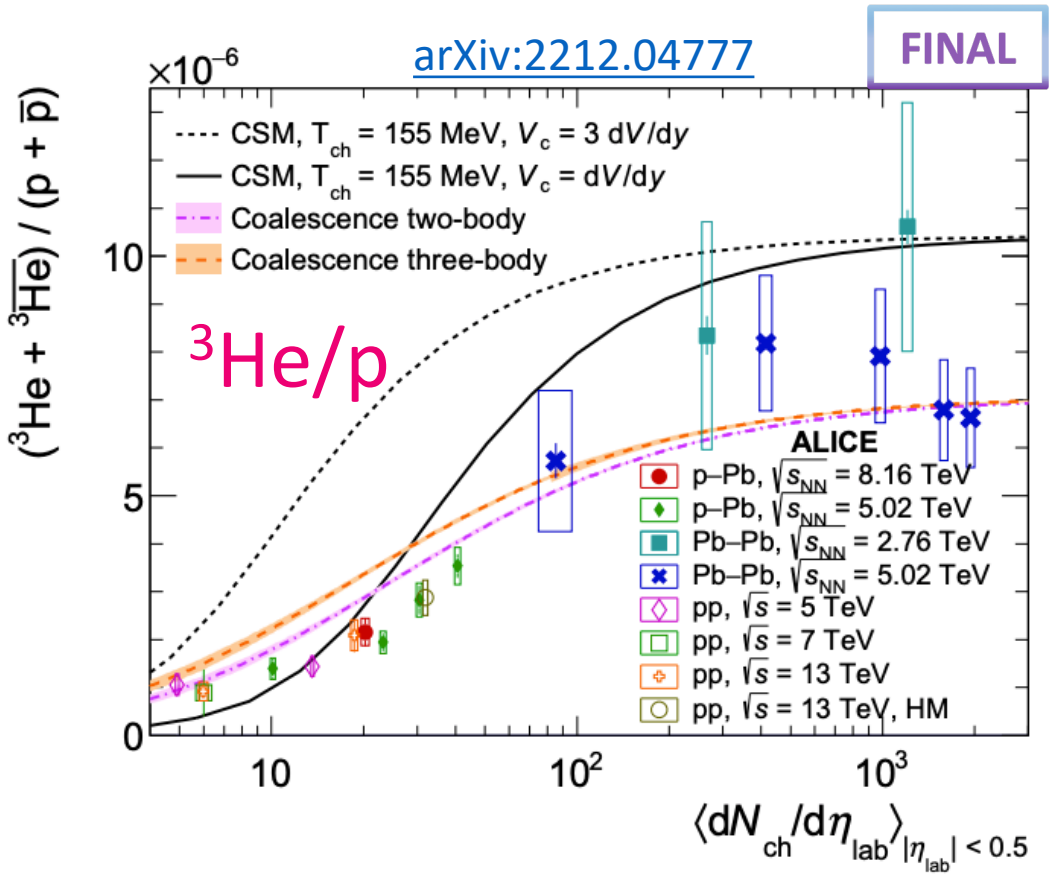
J. G. Contreras Nuno, Thu, 16:12



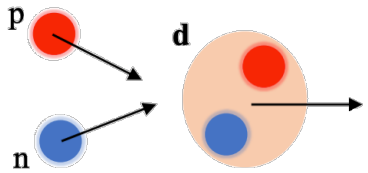
Particle production from QGP

Light (anti)nuclei production





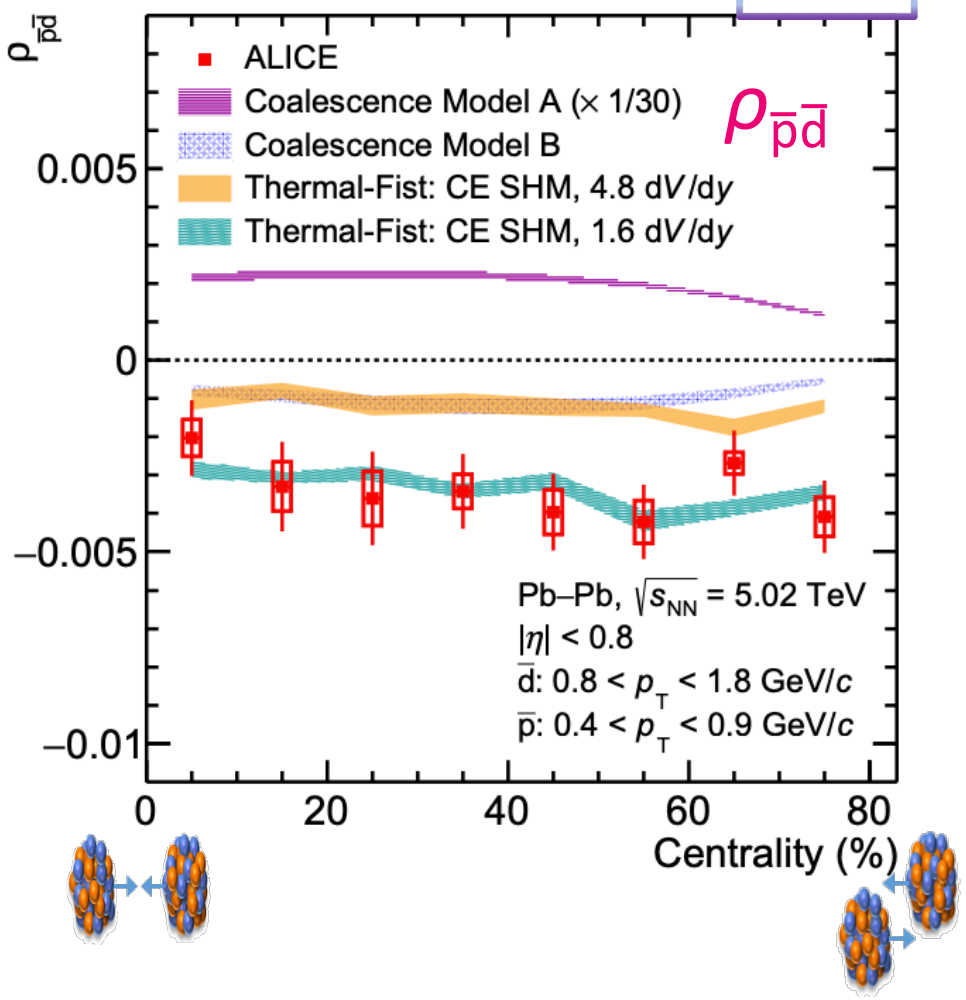
- d/p and ^{3}He/p ratios evolve smoothly with multiplicity → dependence on the **system size**
- **Thermal (statistical) production** or **coalescence**? → **small systems seem to favor coalescence**



R. Rath, Thu, 15:20

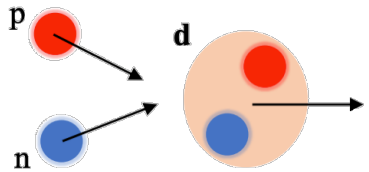
Deuteron-proton correlations in Pb-Pb

arXiv.2204.10166 **FINAL**



Pearson correlation coefficient:

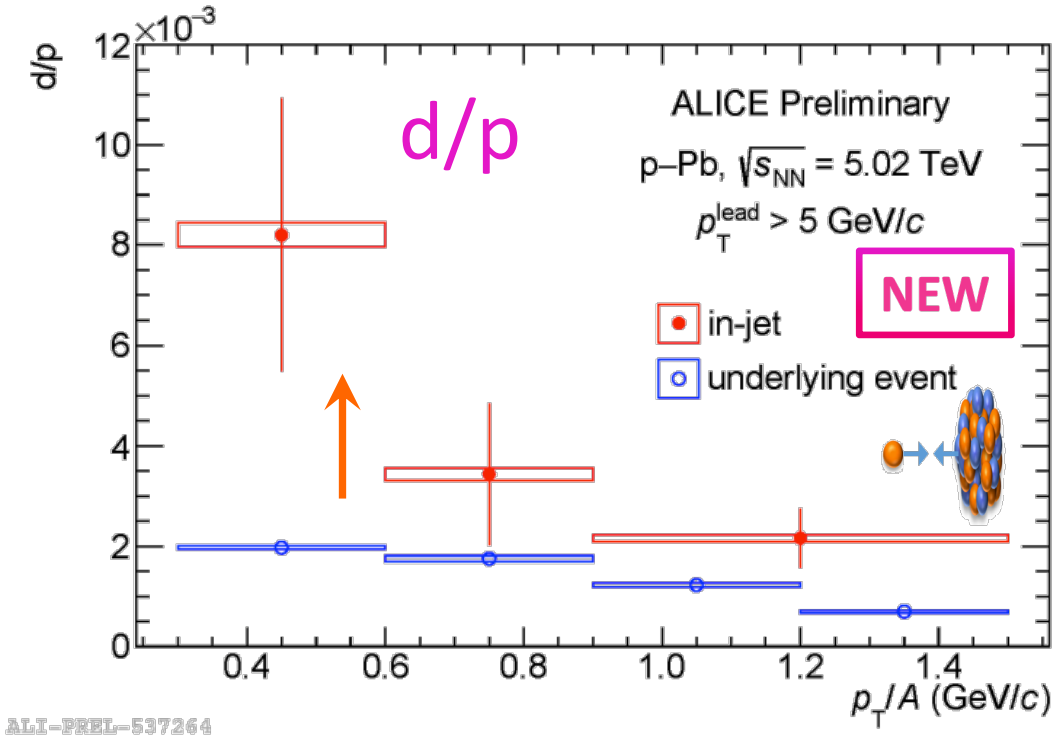
$$\rho_{\bar{p}\bar{d}} = \frac{\langle (n_{\bar{d}} - \langle n_{\bar{d}} \rangle)(n_{\bar{p}} - \langle n_{\bar{p}} \rangle) \rangle}{\sqrt{\kappa_{2\bar{d}} \kappa_{2\bar{p}}}}$$



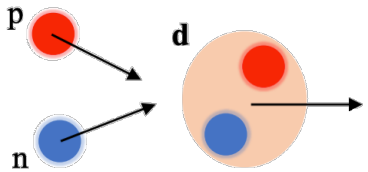
- **Negative correlation observed**
- qualitatively described by **coalescence** with independent nucleons
- better explained by Statistical Hadronisation (in **Canonical Ensemble**)

T. Nayak, Mon, 14:30

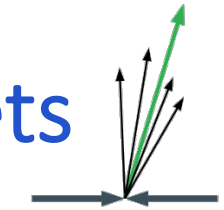
Deuteron production in and out of jets



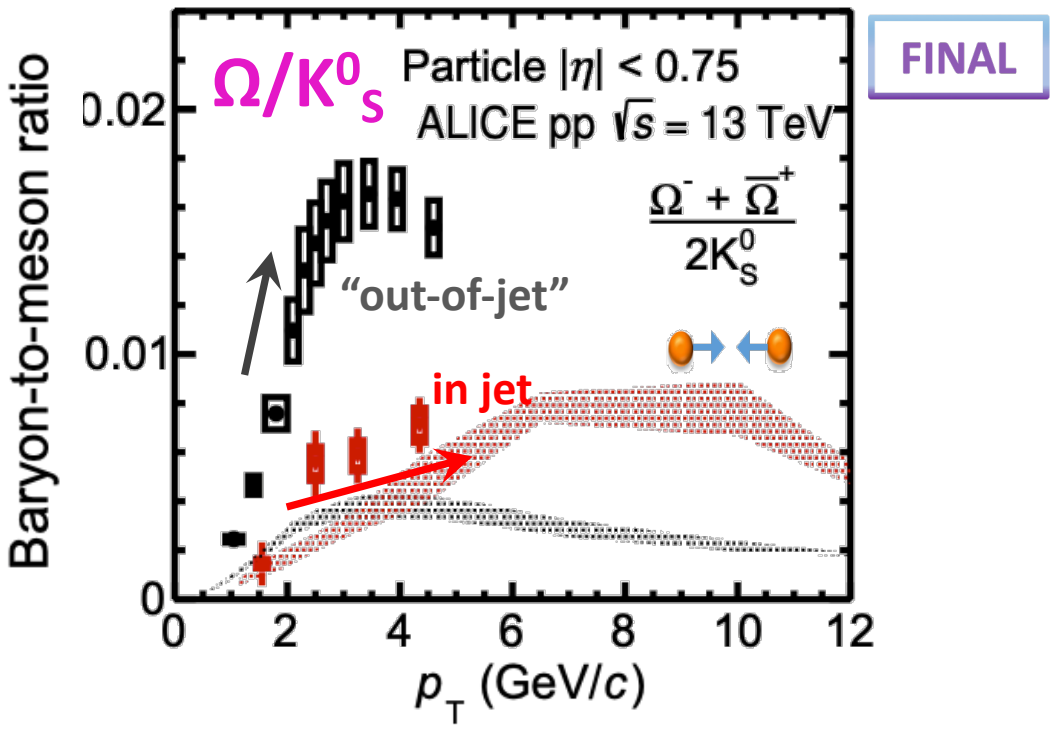
- Hint to **higher d/p in jets** than in "bulk" medium
- **More nucleons close in phase-space within jet?**



R. Rath, Thu, 15:20



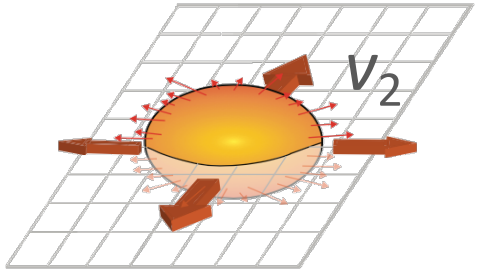
arXiv.2211.08936



- Out-of-jet underlying event processes give **dominant contribution to strange particle production**

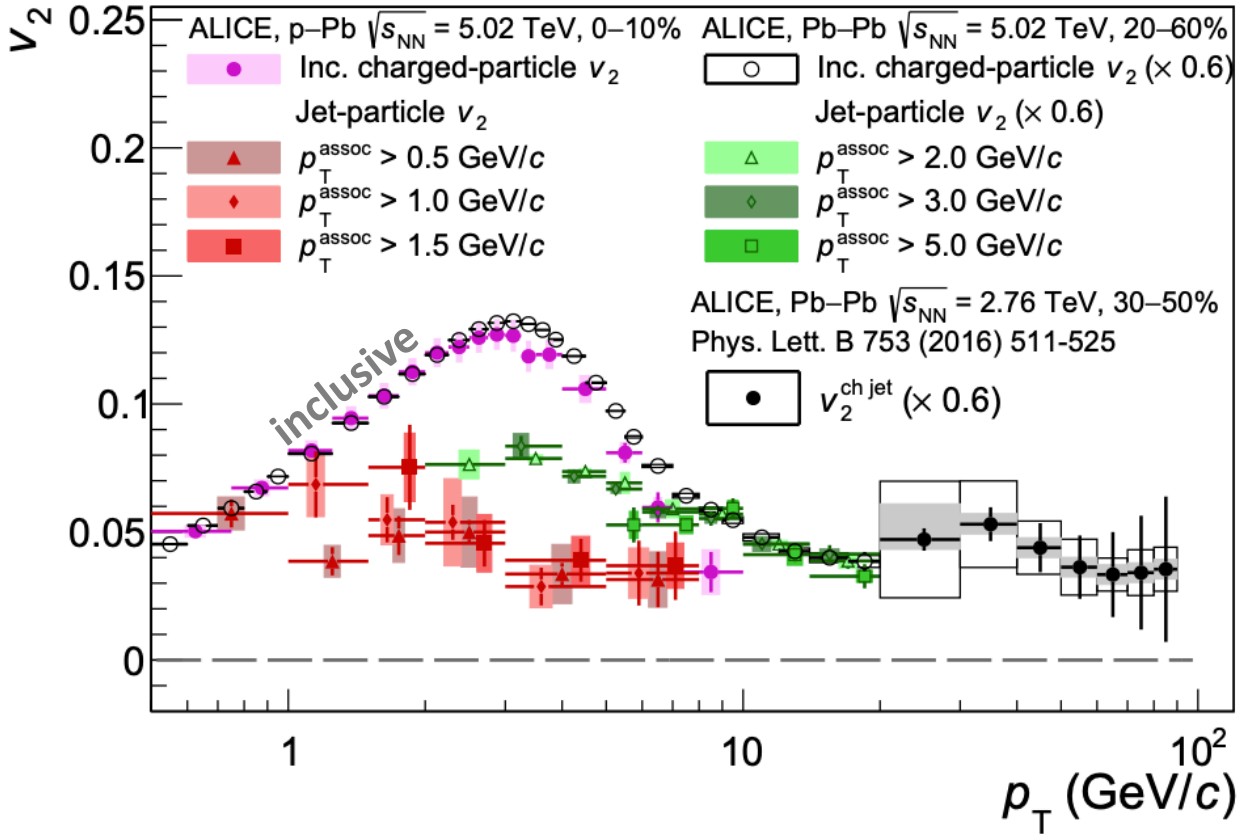
C. De Martin, Thu, 15:38

Flow of particles in **jets**

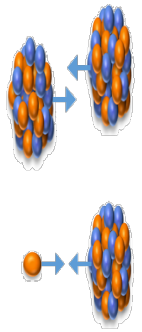


$$\vec{V}_n = v_n e^{in\Psi_n}$$

arXiv:2212.12609



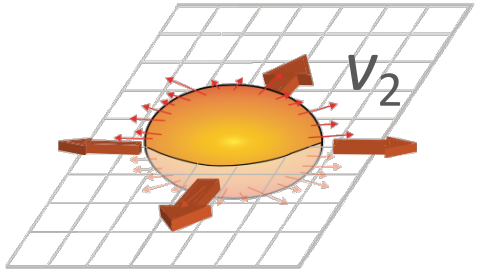
FINAL



L. A. Tarasovicova, Mon, 14:47

A. Rádl, Tue, 15:38

Flow of particles in **jets**



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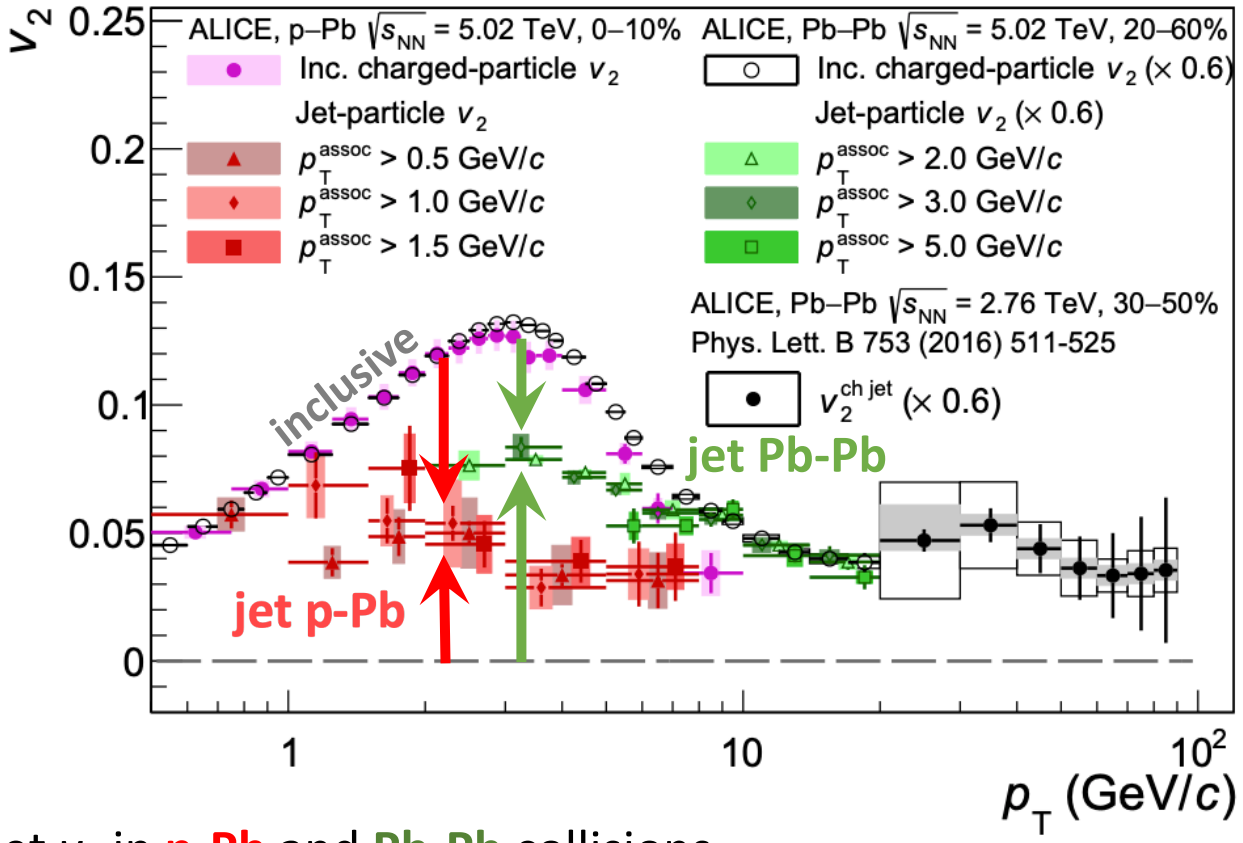
arXiv:2212.12609



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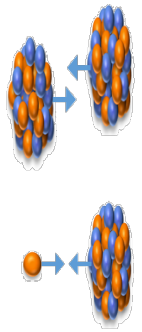
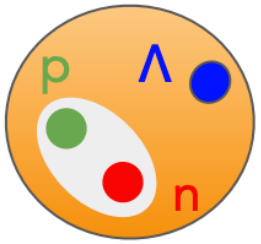


- Non-zero jet v_2 in **p-Pb** and **Pb-Pb** collisions
- … but smaller magnitude than **inclusive (medium)** v_2
- v_2 of jets in p-Pb driven by **anisotropic parton escape mechanism**?

L. A. Tarasovicova, Mon, 14:47

A. Rádl, Tue, 15:38

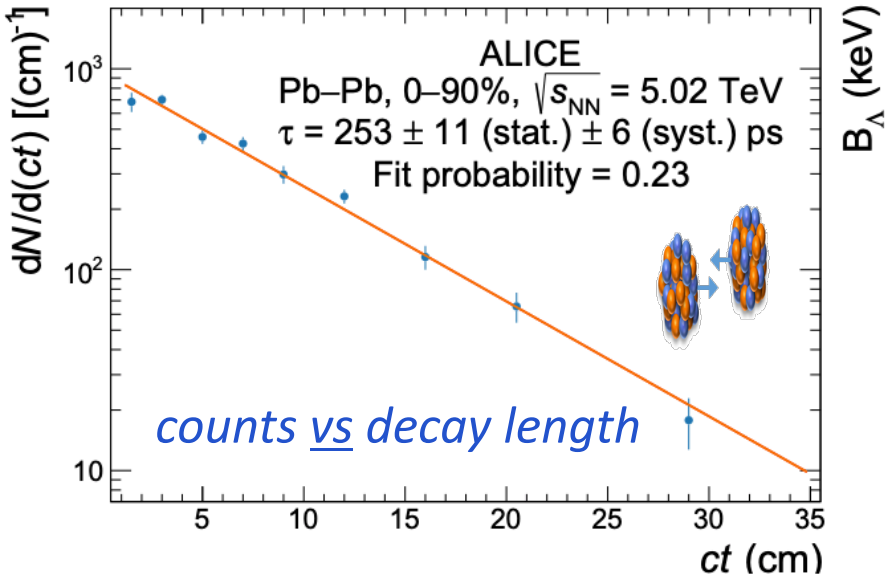
Hypertriton lifetime



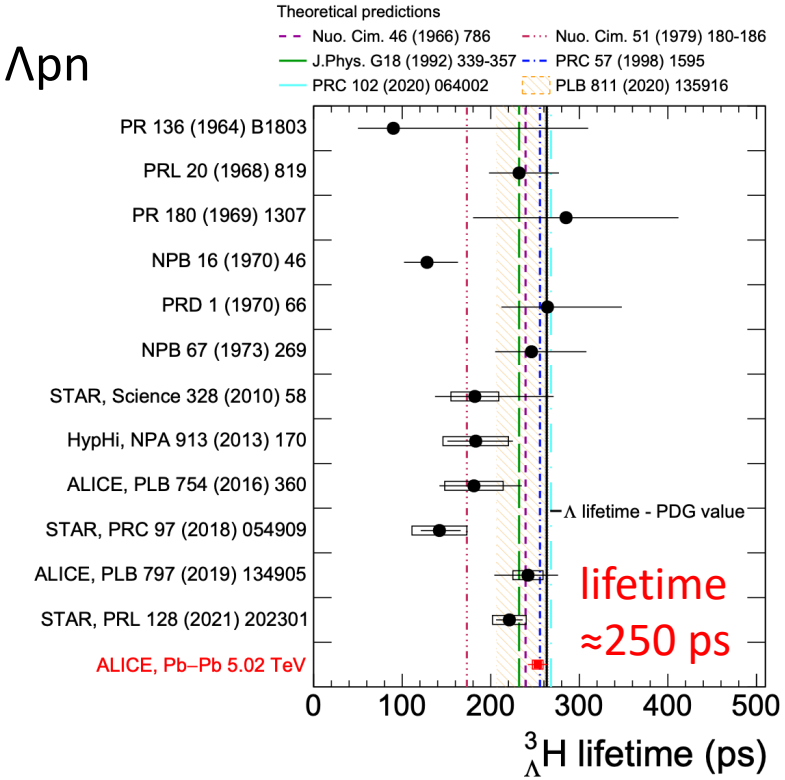
$^{3}_{\Lambda}\mathrm{H}$ – weakly bound state of Λpn

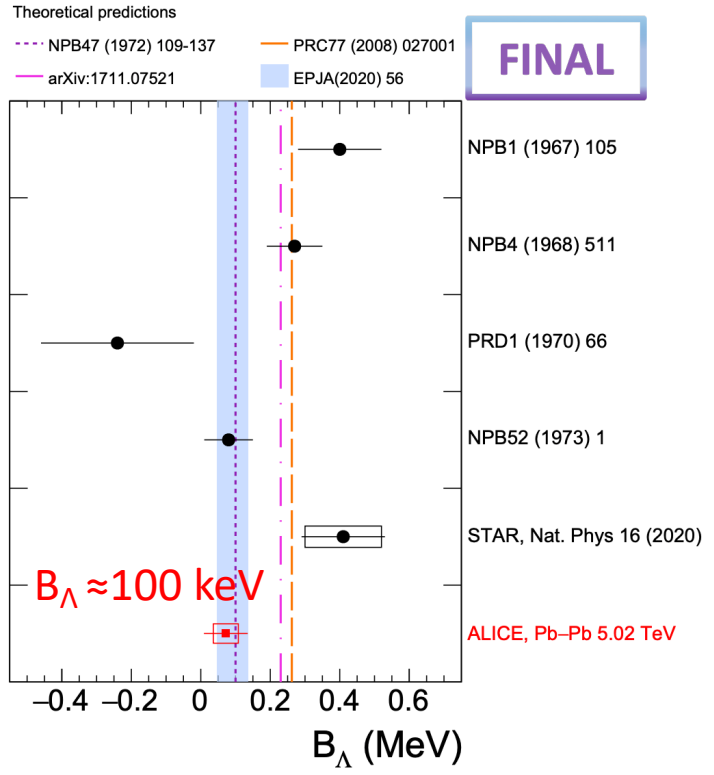
decay channel:

$$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$$



arXiv:2209.07360





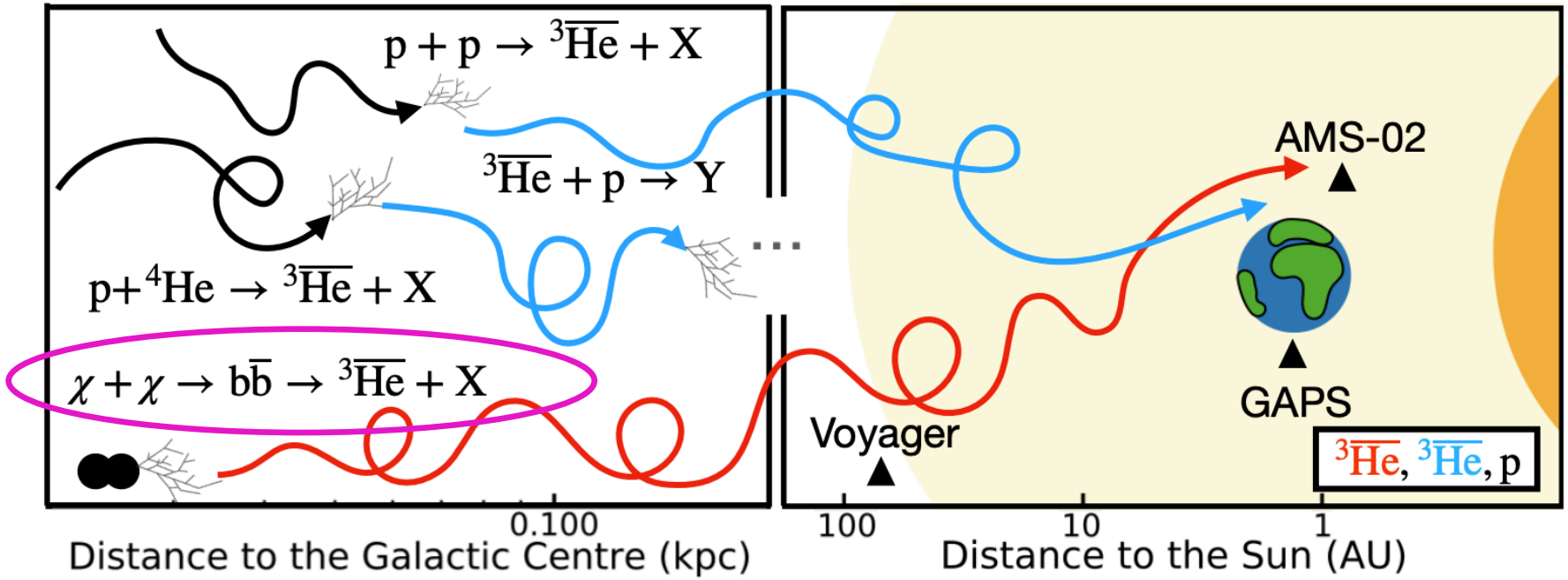
- life time **consistent with free Λ**
- **confirmed loosely bound nature of $^{3}_{\Lambda}$H** → large radius ~5 fm
- production via coalescence?

PRL 128 (2022) 252003

R. Del Grande, Wed, 12:04

Propagation of $^{3}\overline{\mathrm{He}}$ nuclei in the Galaxy

- **DM annihilation** – possible production source of **antihelium-3**
- **Disappearance probability** of antinuclei (quantified by σ_{inel}) is crucial for studying the **galaxy transparency**



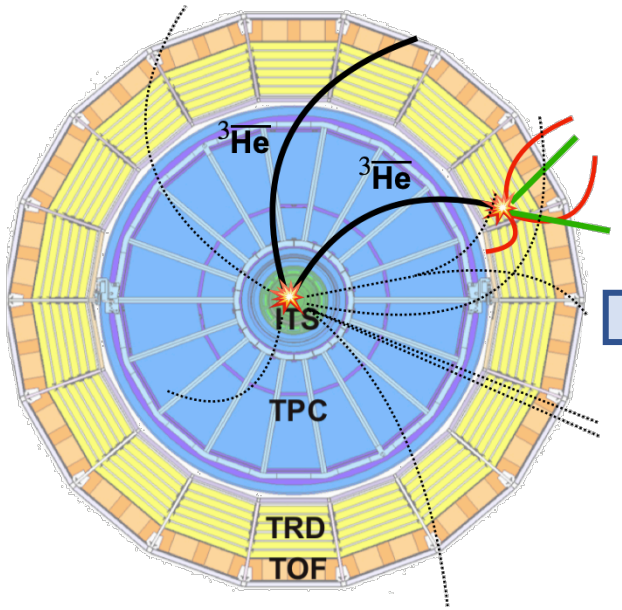
P. Larionov, Mon, 16:12

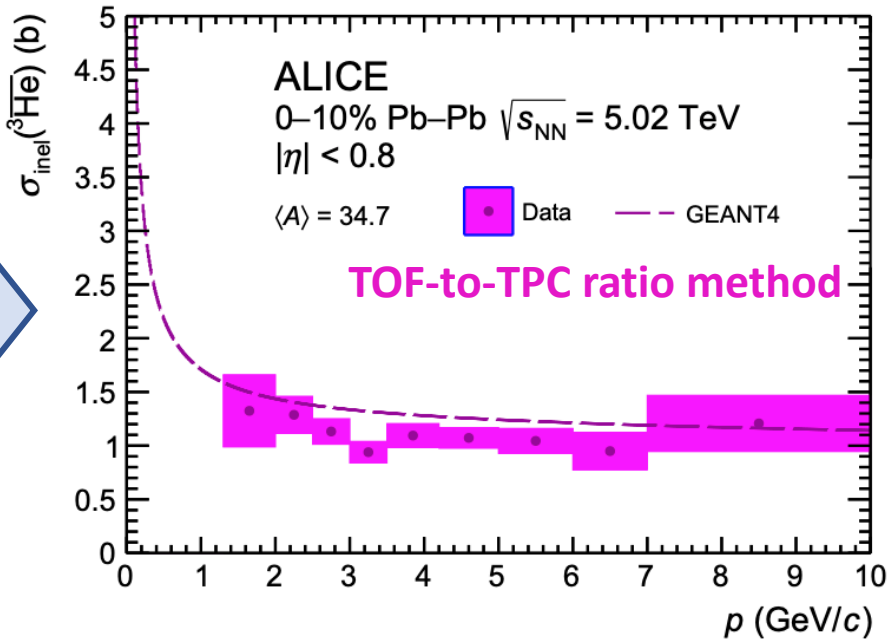
Propagation of $^{3}\overline{\mathrm{He}}$ nuclei in the Galaxy

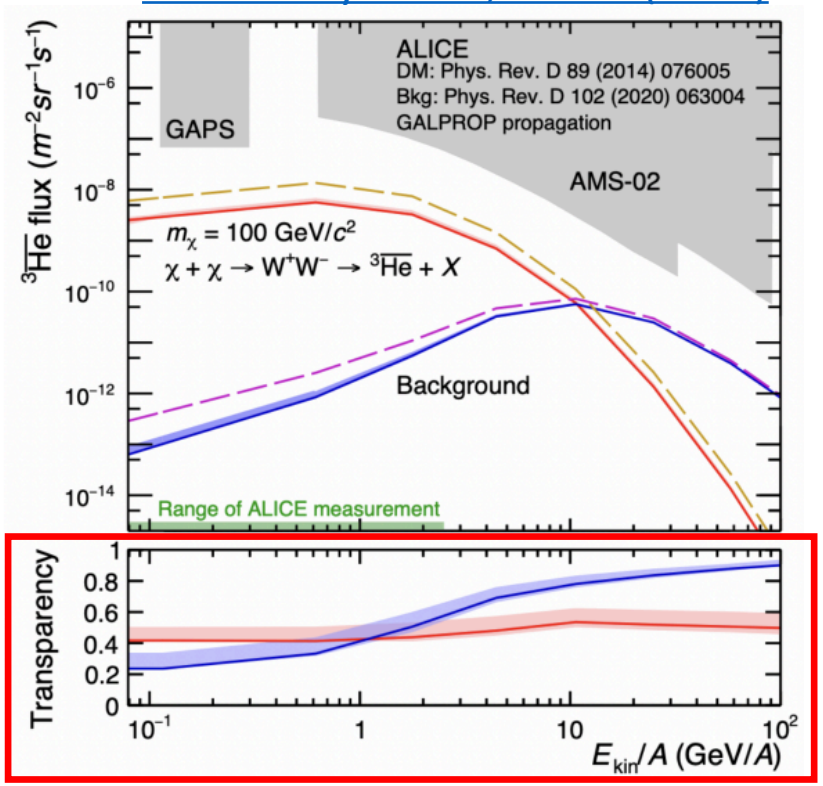
ALICE as antinuclei factory + interaction in detector material → measurement of σ_{inel} for $^{3}\overline{\mathrm{He}}$

FINAL

Nature Physics 19, 61–71 (2023)







- First ever measurement of antihelium-3 inelastic cross sections
- **High transparency of 50% for typical DM scenario and 25-90% for background**

P. Larionov, Mon, 16:12

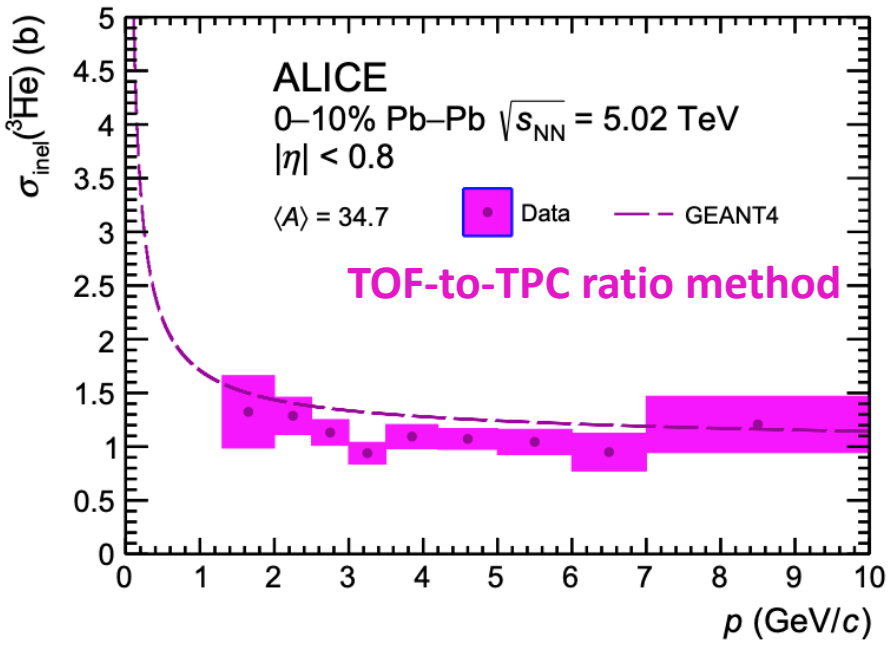
Propagation of $^3\overline{\text{He}}$ nuclei in the Galaxy

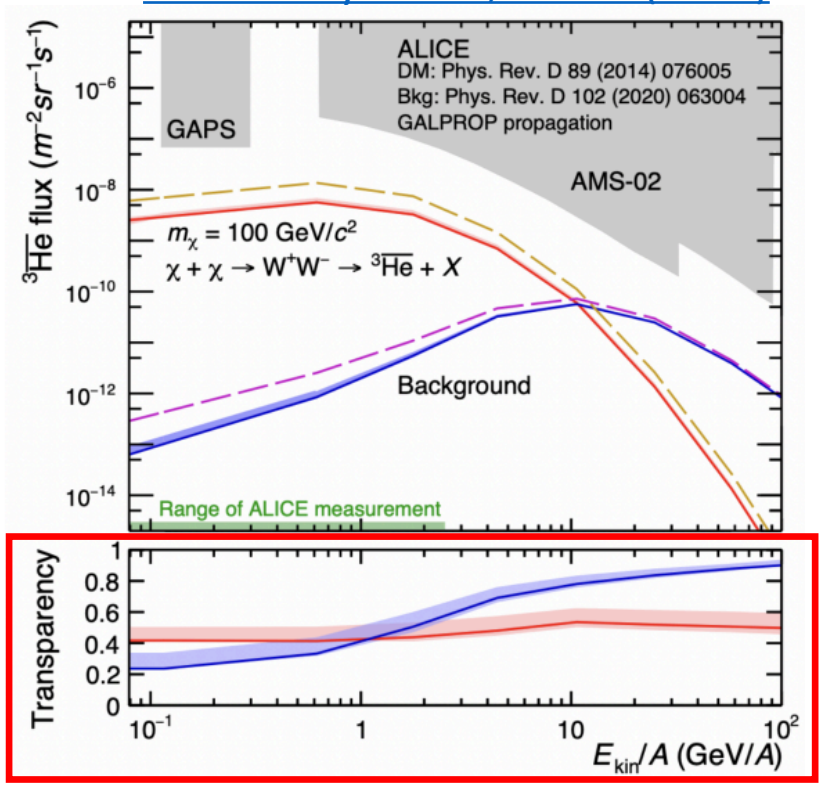
ALICE as antinuclei factory + interaction in detector material → measurement of σ_{inel} for $^3\overline{\text{He}}$

FINAL

Nature Physics 19, 61–71 (2023)

CERN Courier Mar-Apr 2023

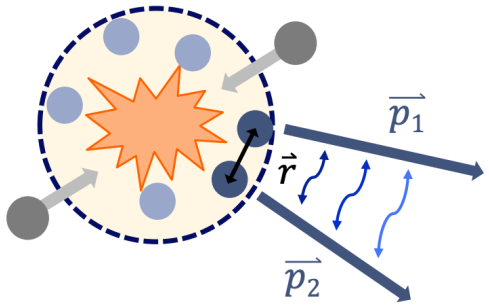




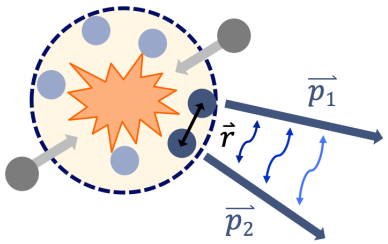
- First ever measurement of antihelium-3 inelastic cross sections
- **High transparency of 50% for typical DM scenario and 25-90% for background**

P. Larionov, Mon, 16:12

Strong final-state interaction between hadrons

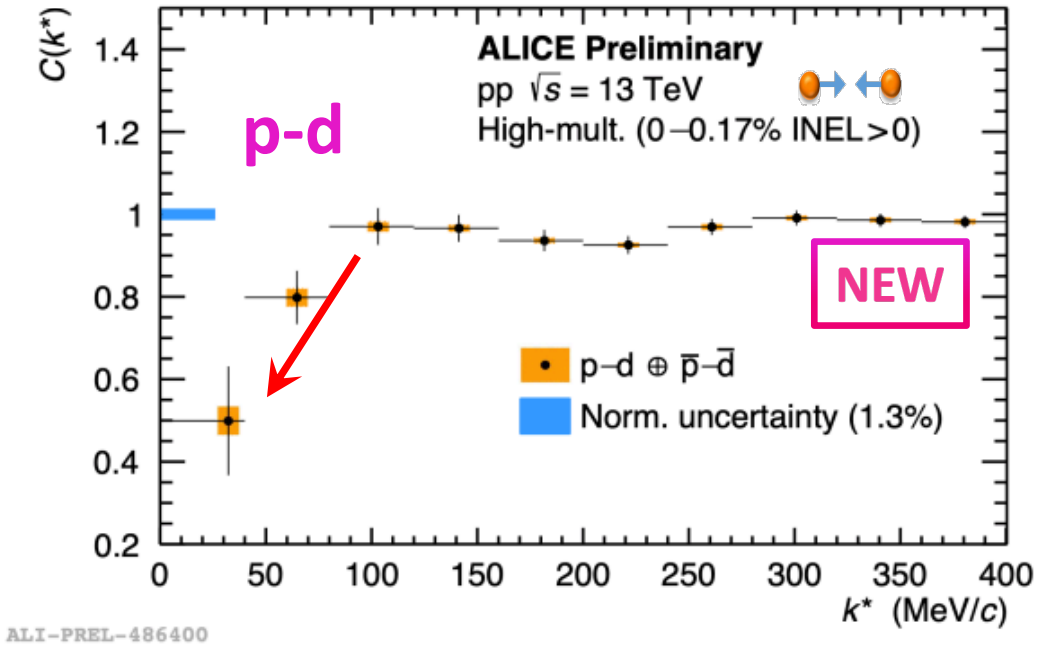


Strong interaction between hadrons (1)

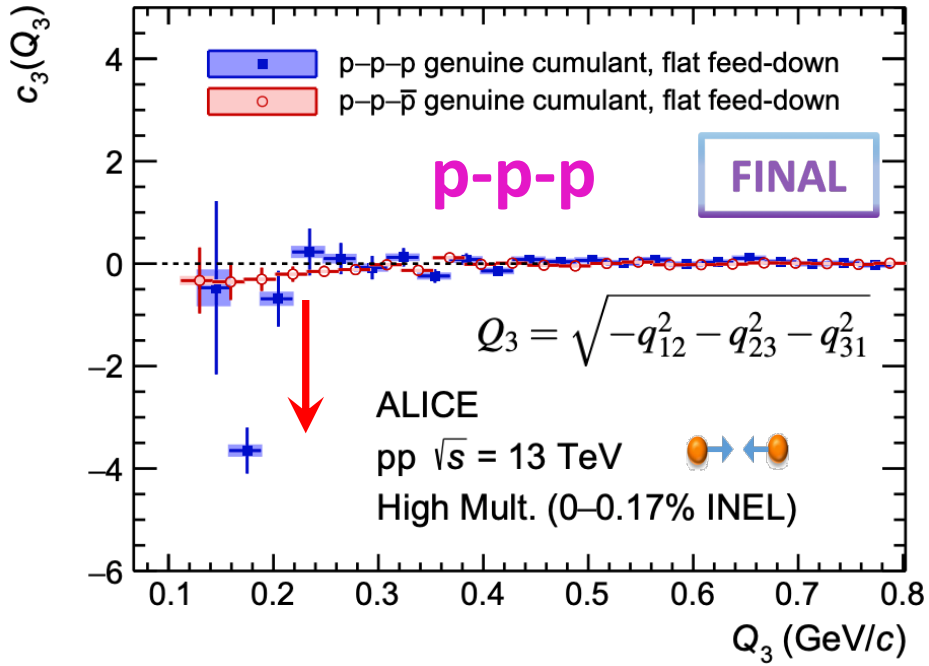


Relative momentum $\vec{k}^* = \frac{1}{2} | \vec{p}_1^* - \vec{p}_2^* |$

2-particle correlation:



3-body correlation: arXiv:2206.03344

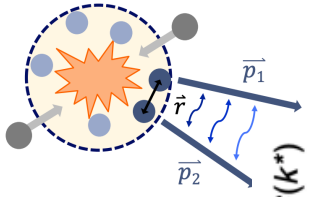


- models with **point-like deuteron** fail
- models with **deuteron as a composite object** work better

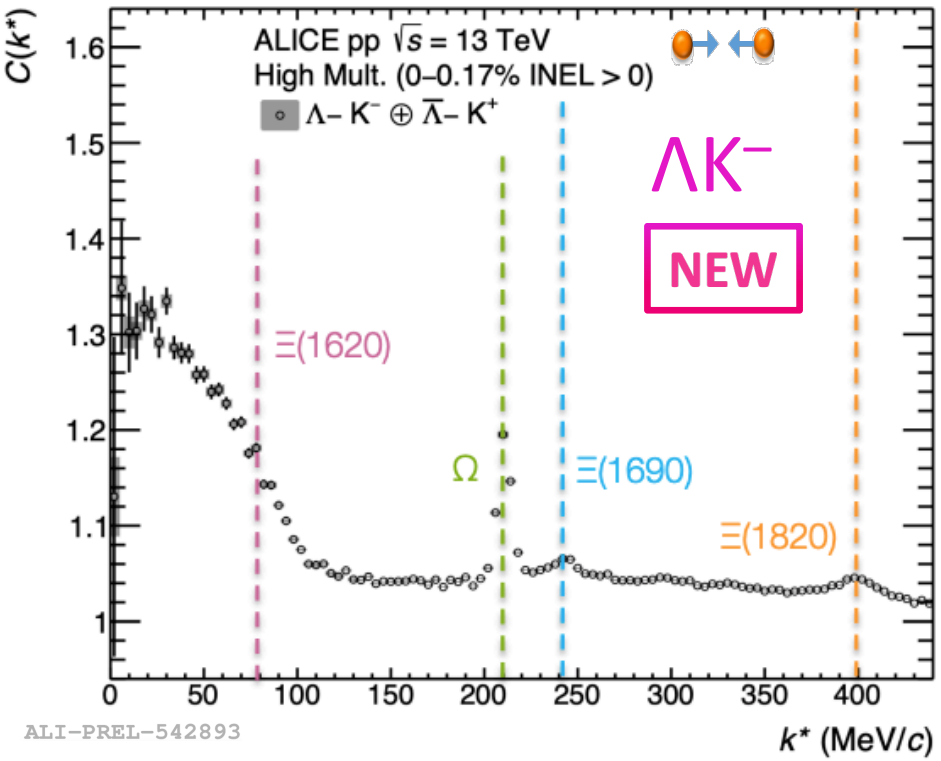
- **Negative p-p-p correlation**
  - 3-body **strong interaction**
  - **Pauli blocking** at the 3-particle level?

R. Del Grande, Wed, 12:04 M. Csanad, Mon, 15:21

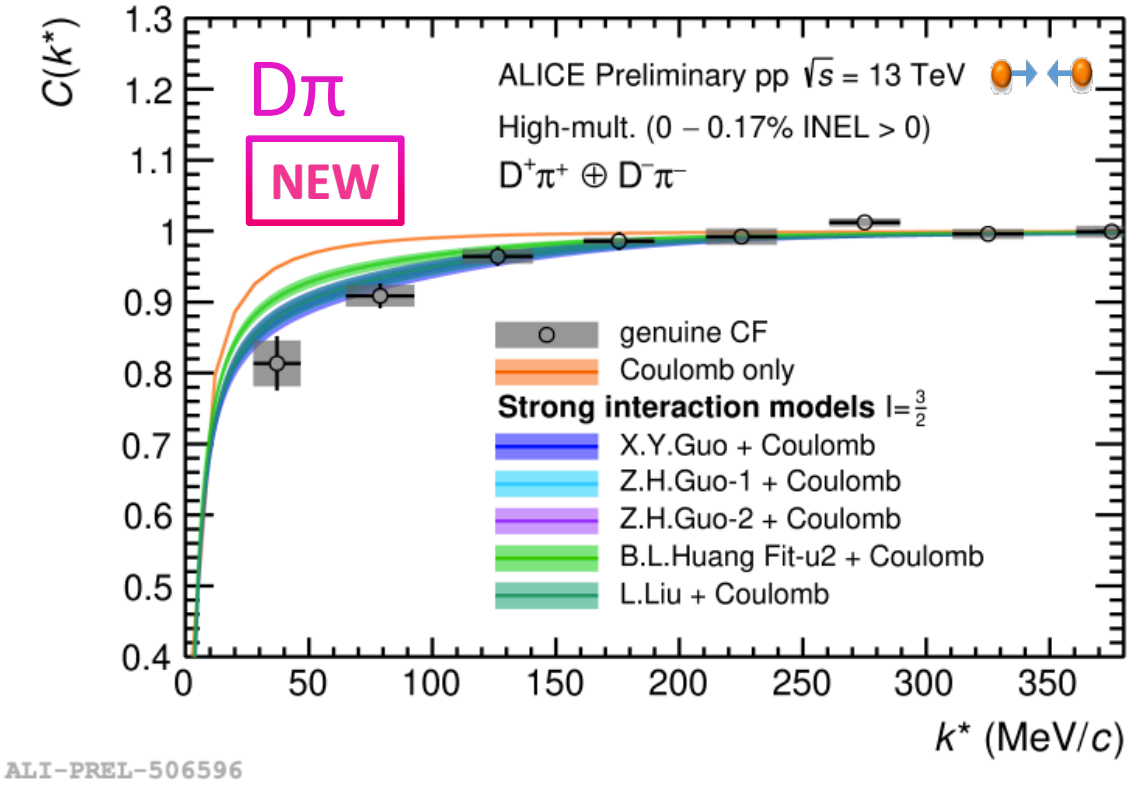
Strong interaction between hadrons (2)



strange-strange



with charm



First experimental evidence of **Ξ(1620)** decay into ΛK⁻
→ shed **light on its nature**

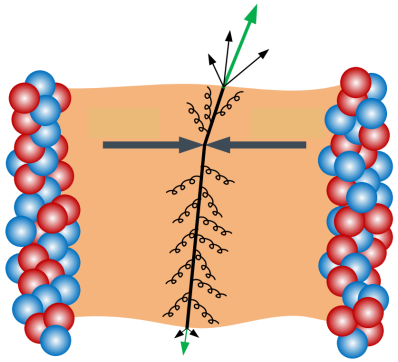
V. Mantovani Sarti, Tue, 09:24

Testing theories with I=3/2 and 1/2

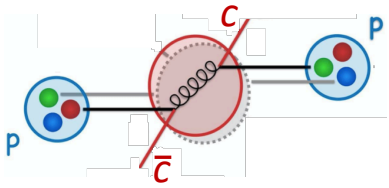
D. Battistini, Fri, 12:24

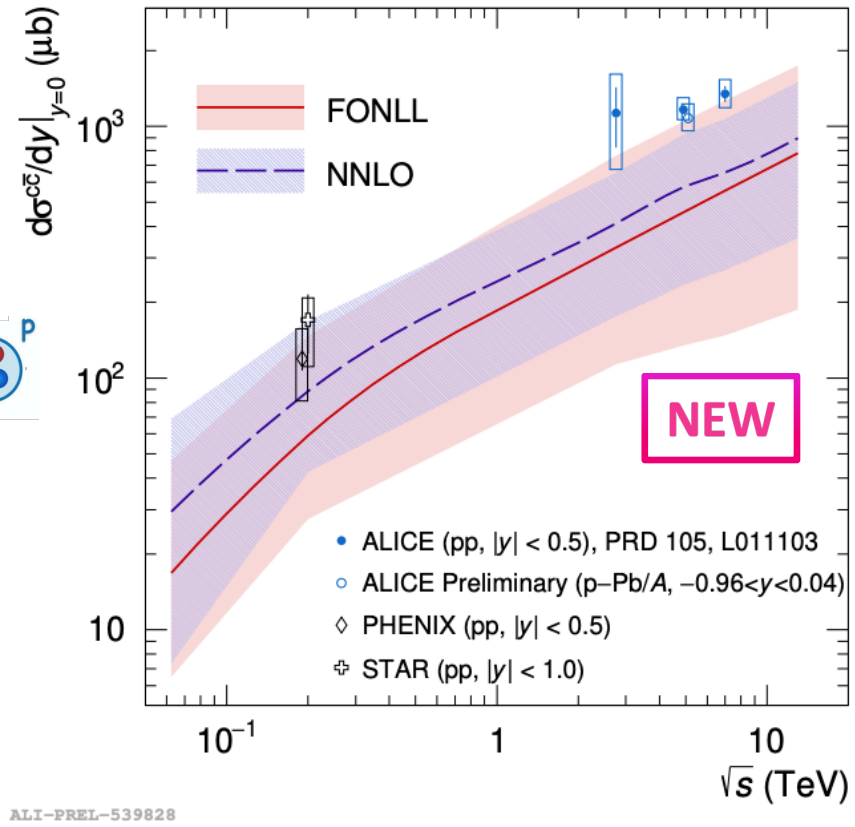
Hard Probes

(heavy flavours, jets)



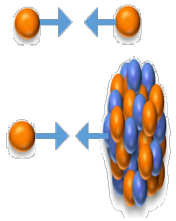
Charm **cross-section** and **fragmentation**

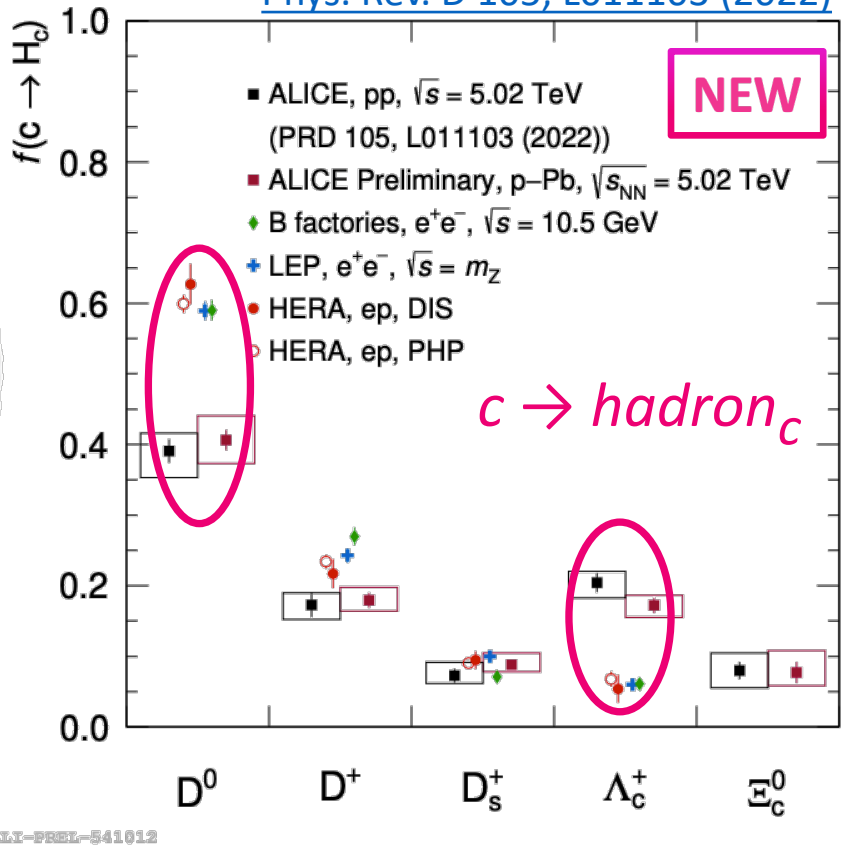




- Heavy-flavour production at midrapidity described by **FONLL** and **NNLO** calculations

Phys. Rev. D 105, L011103 (2022)



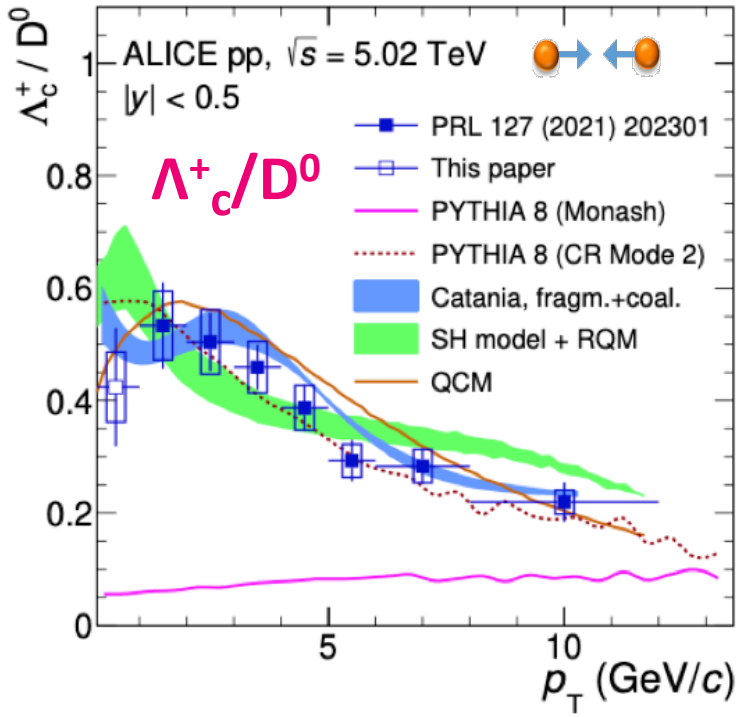


- results in **pp** and **p–Pb** collisions are in good agreement
- **differences in FF with e^+e^-** measurements – **still a puzzle**

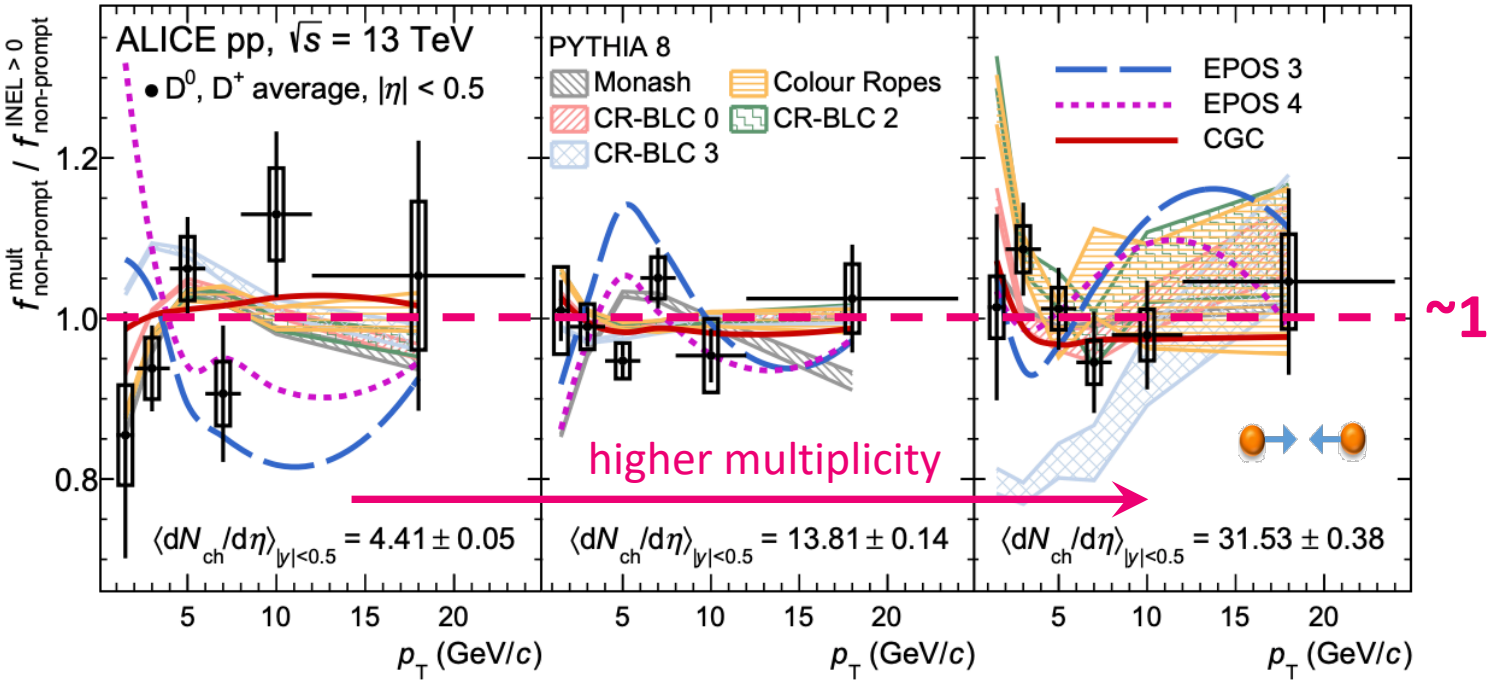
F. Catalano, Wed, 11:30

Heavy flavor **hadronization** in pp

arXiv:2211.14032 **FINAL**



D non-prompt / prompt ratio *vs* multiplicity: arXiv:2302.07783 **FINAL**



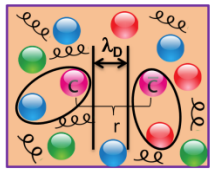
- Models based on fragmentation functions from e^+e^- underestimate the data
- Models with coalescence, modified color reconnection and SHM work better

Only mild multiplicity dependence
→ **similar production mechanism for *c* and *b* vs N_{ch}**

Ch. Gu, Thu, 15:04

A. Martínez, Tue, 09:48

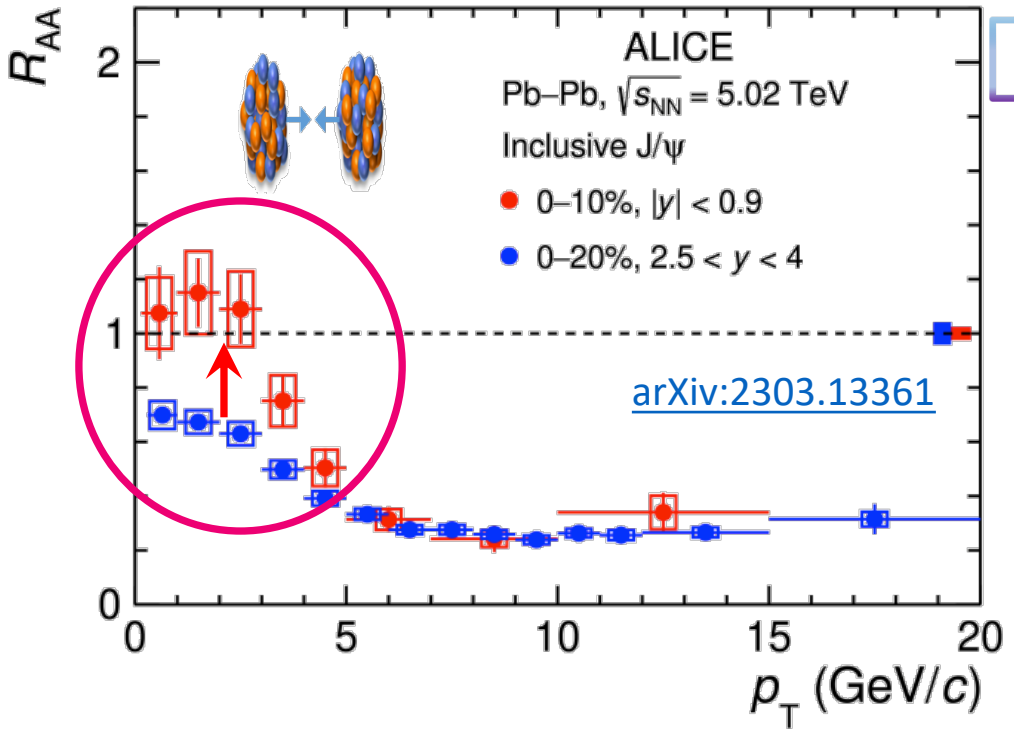
Charmonium **suppression** in Pb–Pb



"melting" *vs* **recombination**

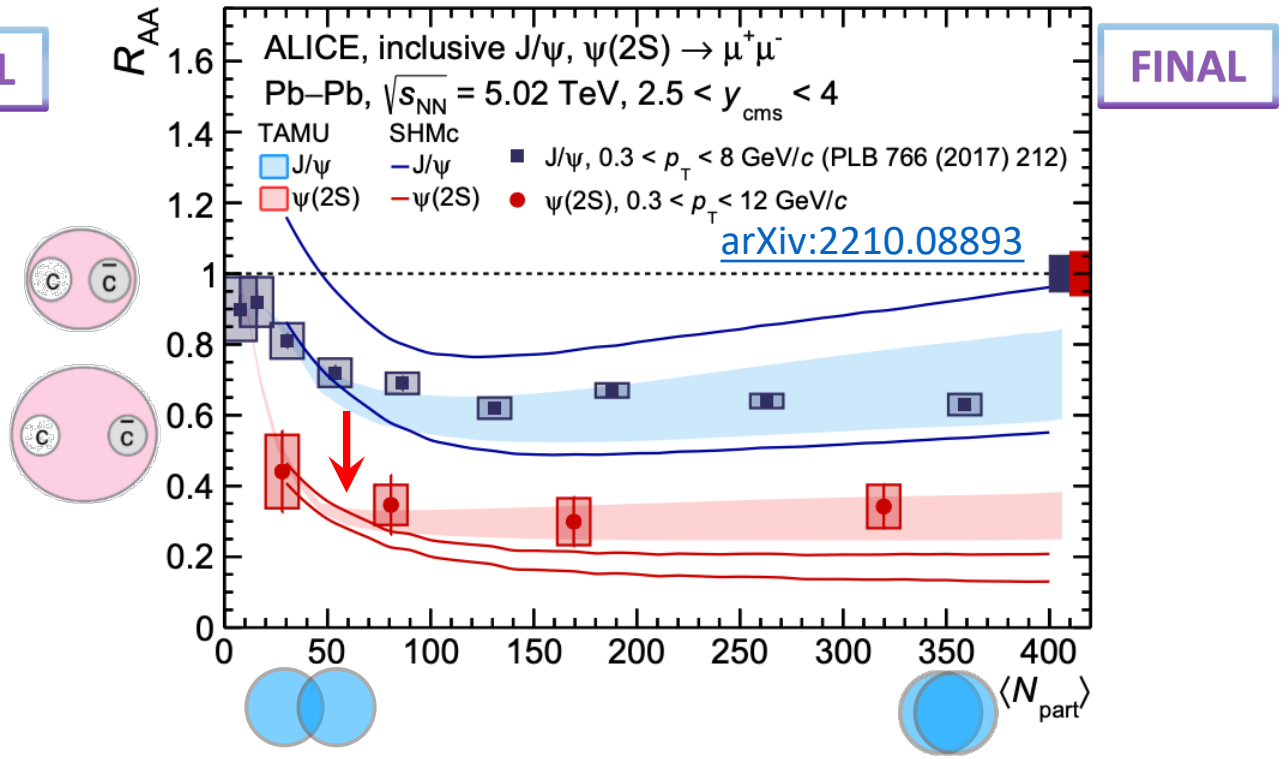
$$R_{AA} = \frac{AA}{\langle T_{AA} \rangle pp}$$

J/ψ rapidity dependence:



FINAL

ψ(2S) vs J/ψ :



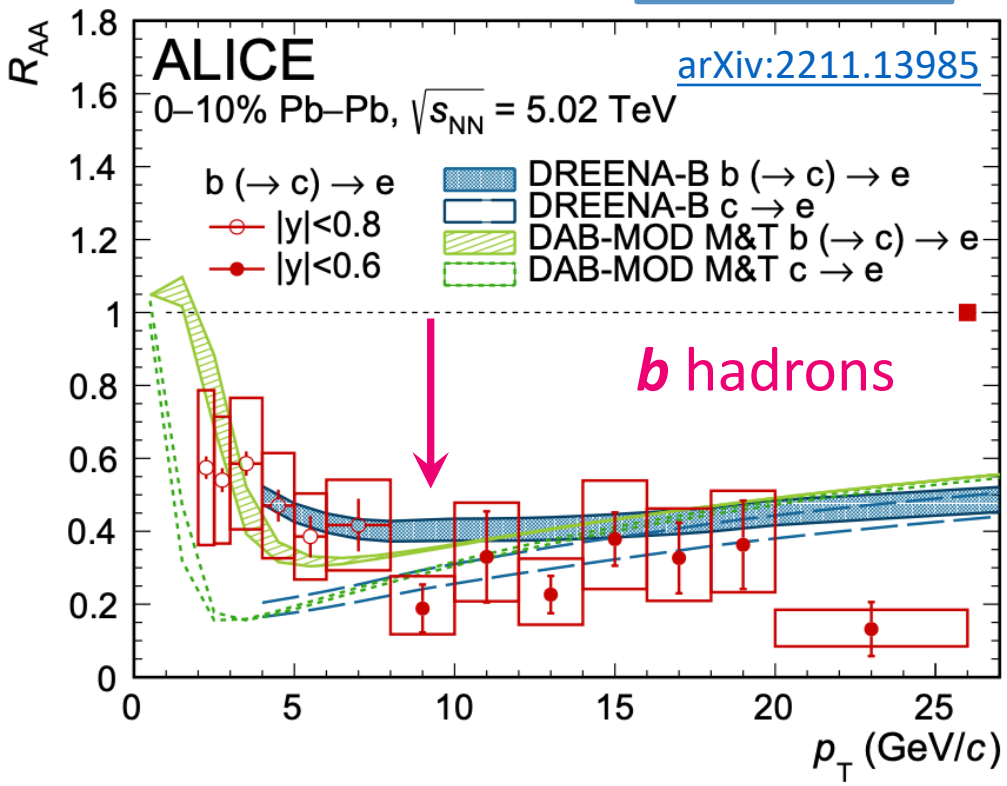
FINAL

- J/ψ **less suppressed** at **low p_T** and at **mid-rapidity** (recombination)
- **ψ(2S) suppressed more than the J/ψ by a factor 2** (lower binding energy for ψ(2S), ~50 MeV *vs* J/ψ ~640 MeV)

C. Hadjidakis, Tue, 12:06 Y. Wei, Thu, 14:47

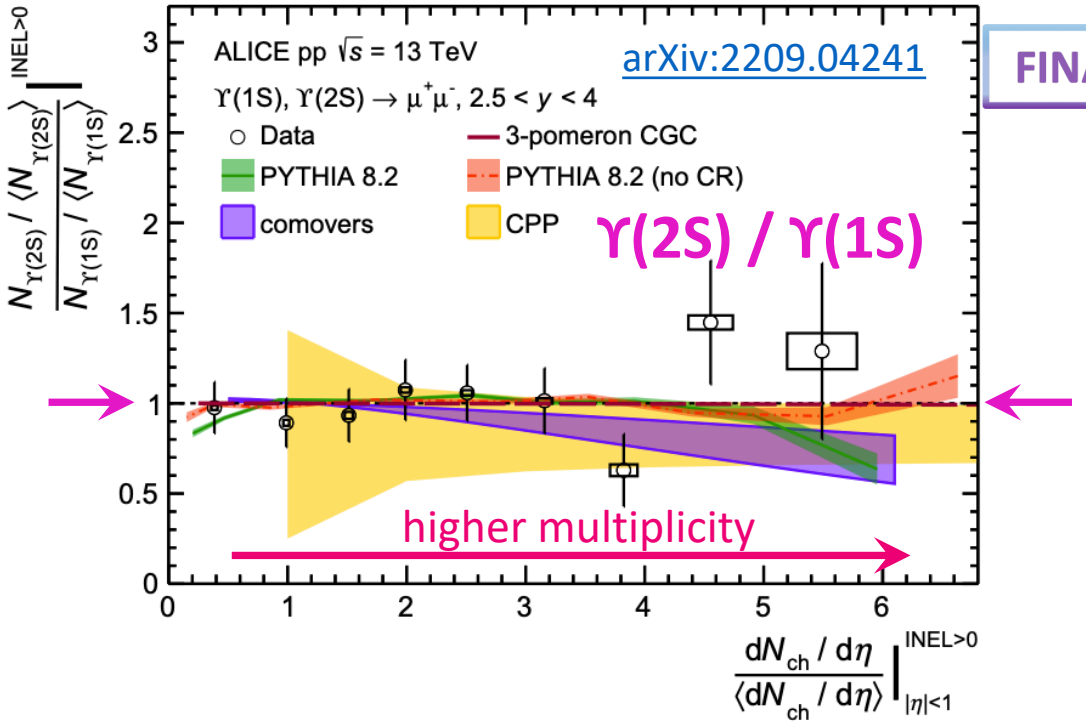
b-quarks in medium

Suppression factor: $R_{AA} = \frac{AA}{\langle T_{AA} \rangle pp}$



- electrons from b-hadron decays
- **consistent with models of b-quark energy loss**
  - *c, b → e* in pp, p-Pb: arXiv:2303.13349

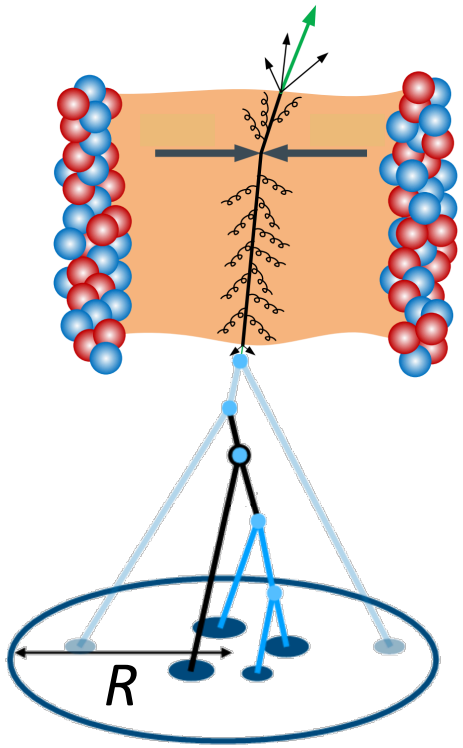
ϒ(nS) / ϒ(1S) at high pp multiplicity



- self-normalized yields: **no dependence on multiplicity**
- any suppression (melting) at **pp high multiplicity?**
  → **analysis with Run 3 data needed!**

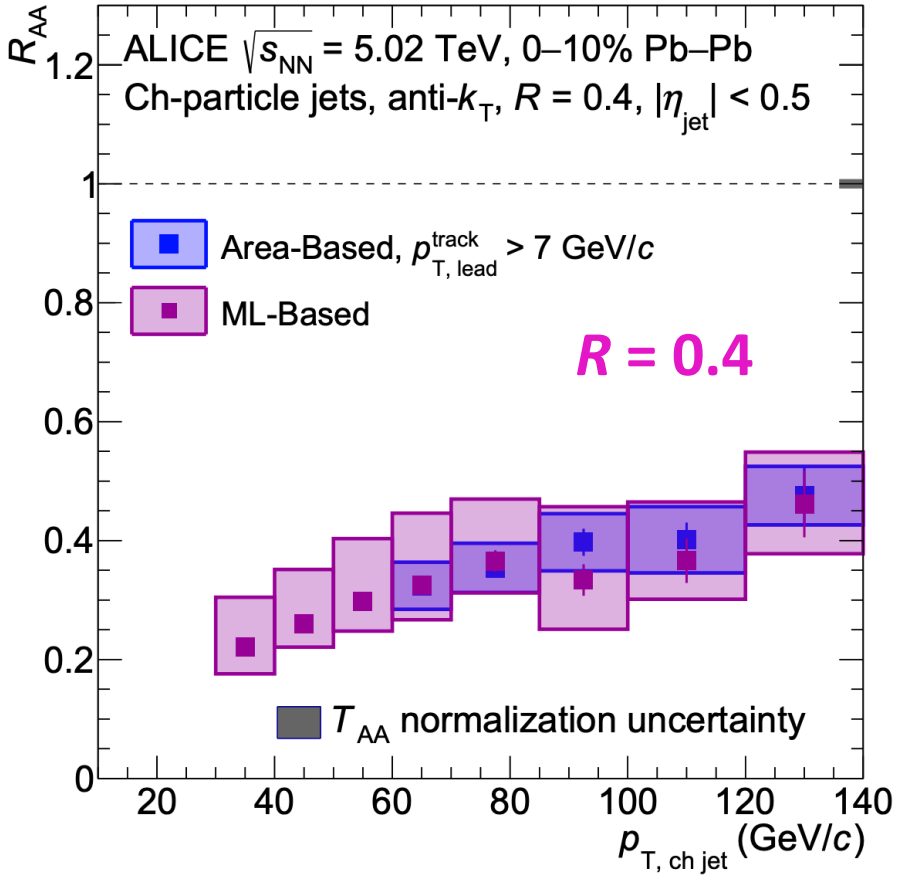
A. Rakotozafindrabe, Wed, 11:47

Jet **modification** in Pb–Pb

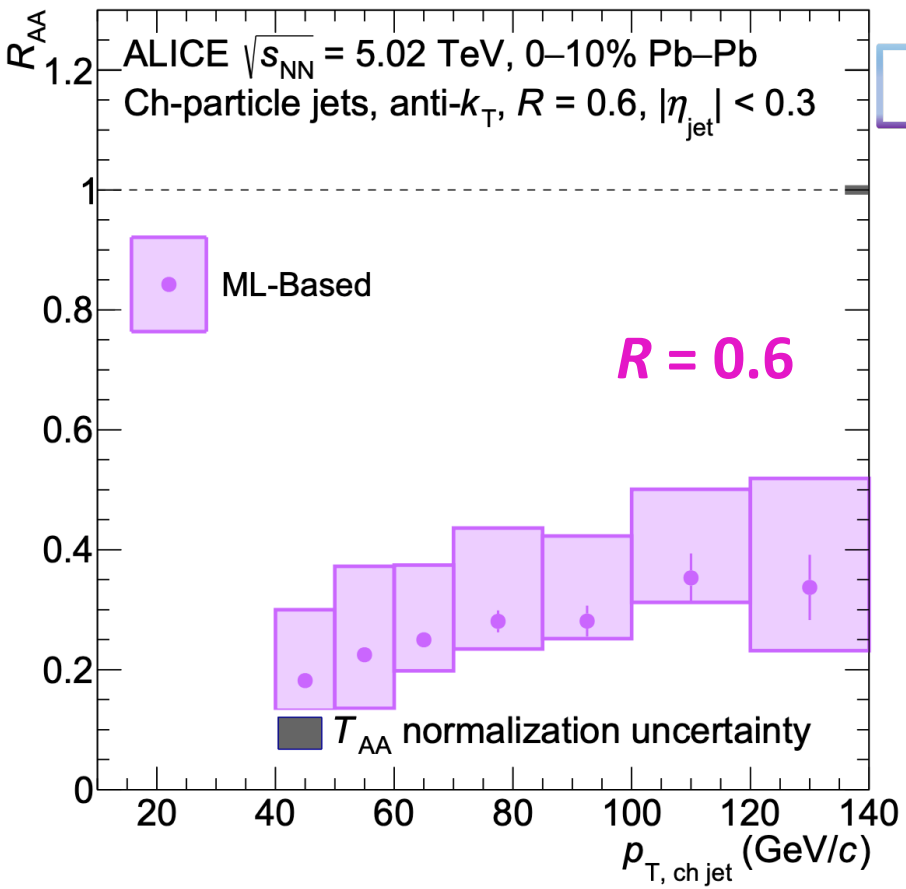


suppression factor:

$$R_{AA} = \frac{AA}{\langle T_{AA} \rangle \, pp}$$



arXiv:2303.00592

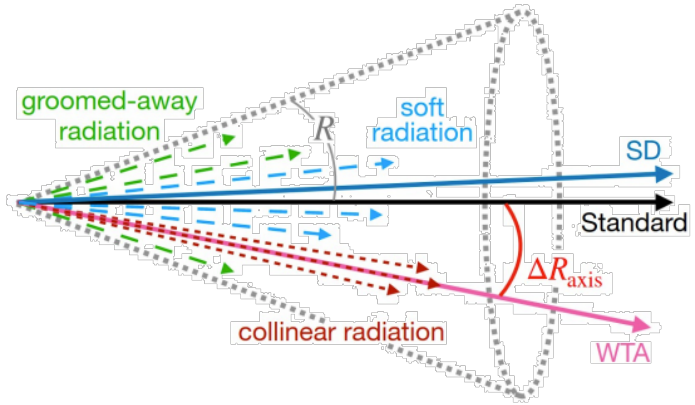


FINAL

- **Machine learning** allows for the **extension to lower p_T** and **large R=0.6**

L. Cunqueiro Mendez, Wed, 09:00 M. Spousta, Tue, 16.12

Jet **substructure** – Pb-Pb *vs* pp



arXiv:2211.08928

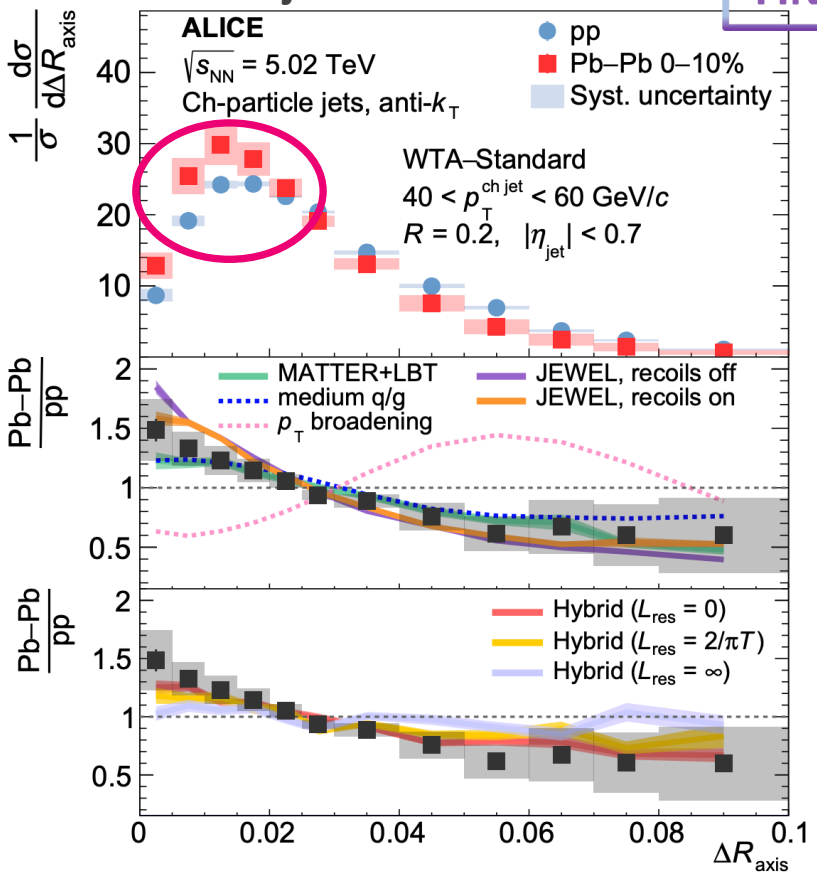
arXiv:2303.13347

R. Vertesi, Tue, 15:55

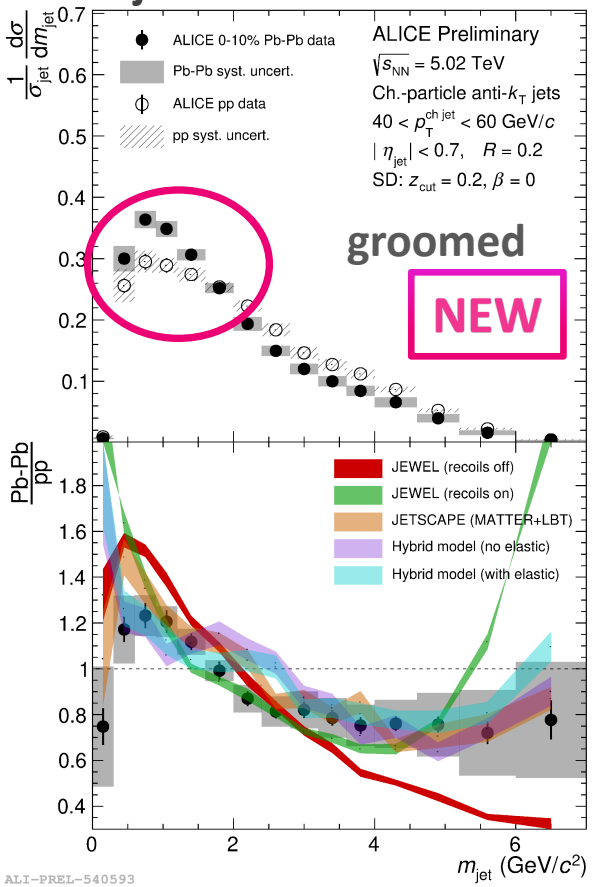
A. Schmier, Mon, 15:04

jet axis differences

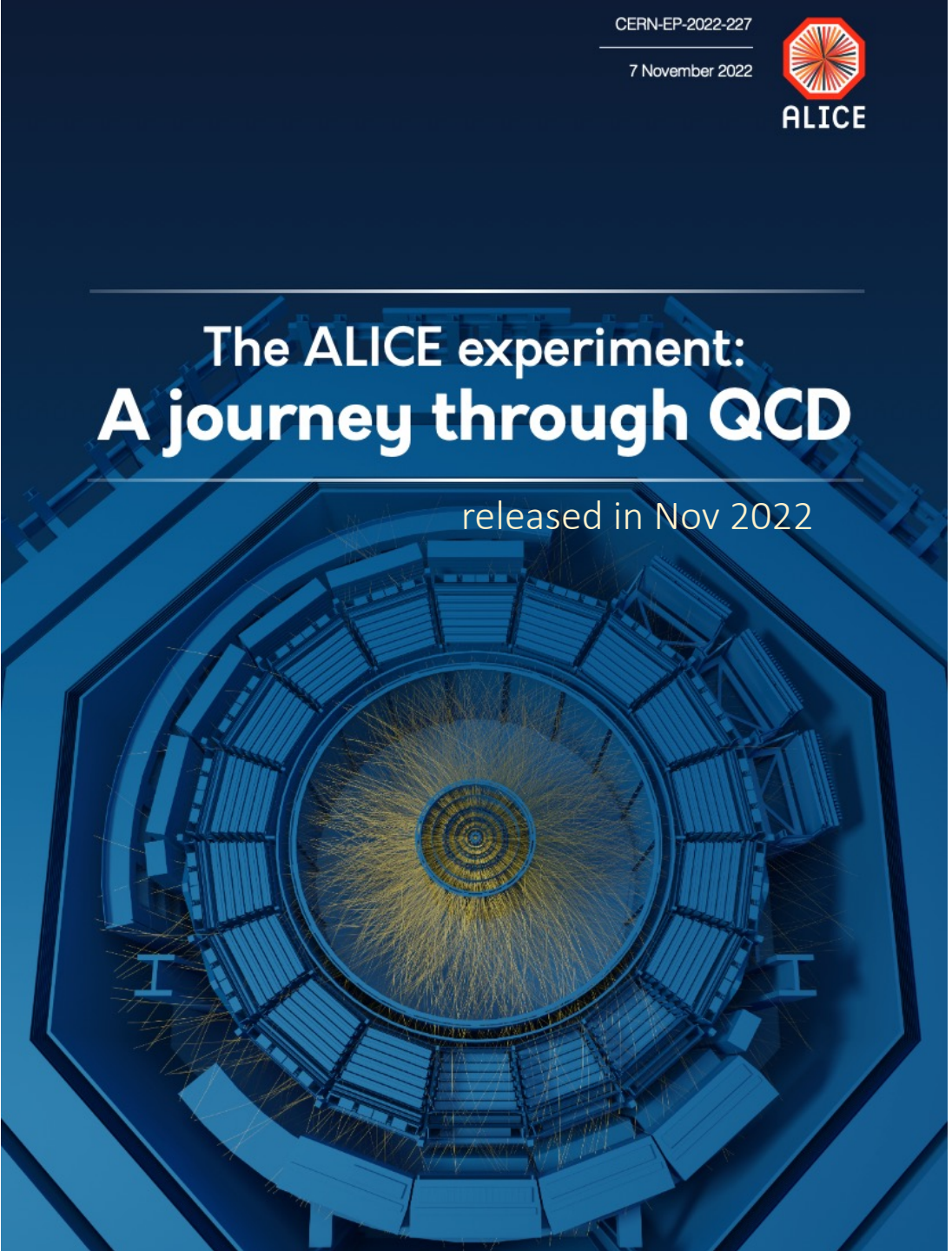
FINAL



jet mass differences



- **modification of jet fragmentation** in **Pb-Pb** compared to the vacuum (pp)
- sensitive to shower parton **coherence of the energy loss in QGP**

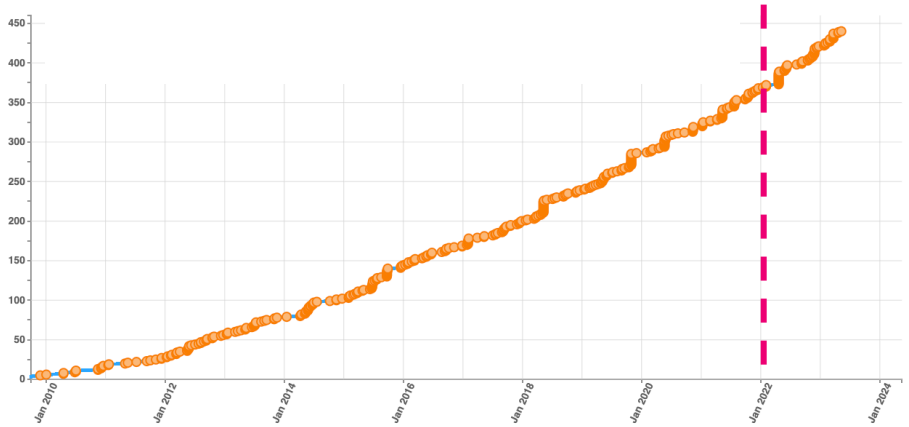


ALICE review paper:

physics results of Run 1+2

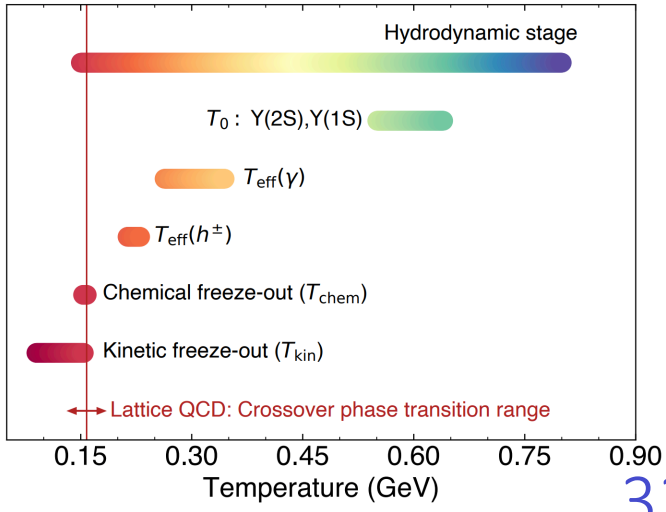
CDS, arXiv.2211.04384

https://twiki.cern.ch/twiki/bin/view/ALICEpublic/ALICEPublicResults



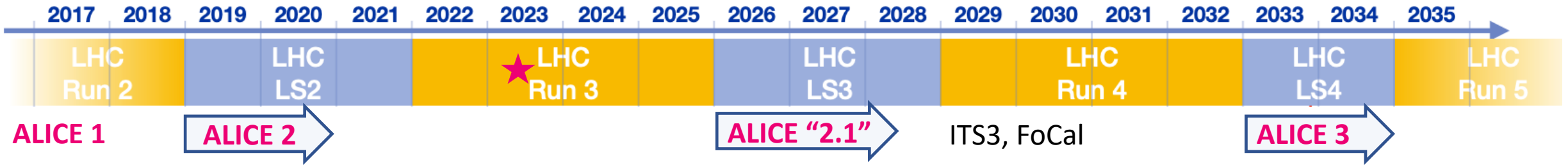
Quark-gluon plasma properties from LHC data

A. Timmins, Mon, 18:15



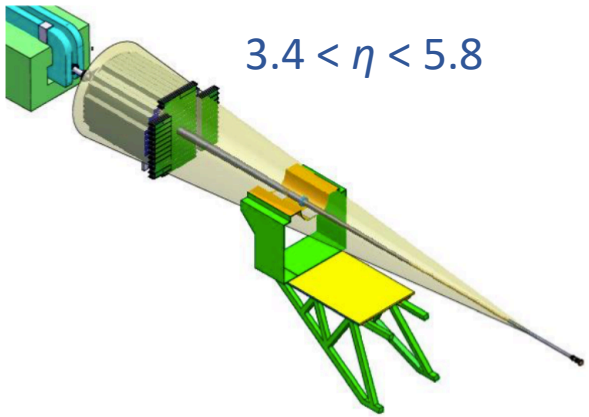
ALICE upgrades

R. Munzer, Thu, 17:24

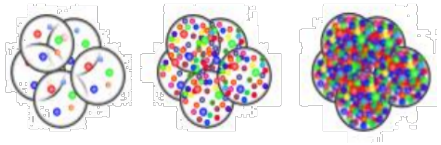


Letter of Intent: CERN-LHCC-2020-009

FoCal = ECal+HCal

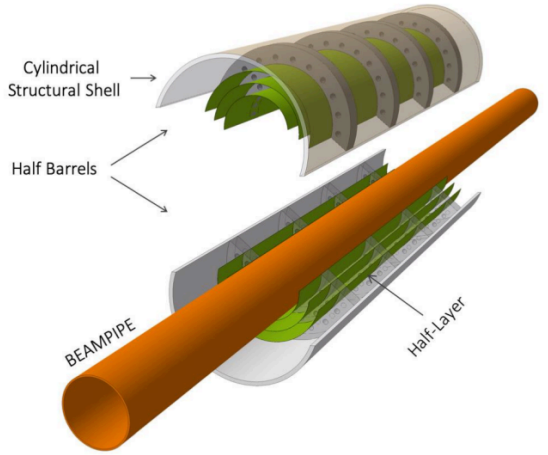


- direct photon detection to probe **gluon density at small *x***, forward π^0
- prototyping, beam tests



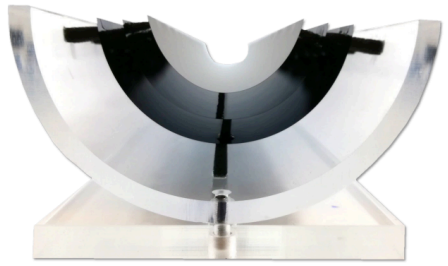
Letter of Intent: CERN-LHCC-2019-018

ITS3



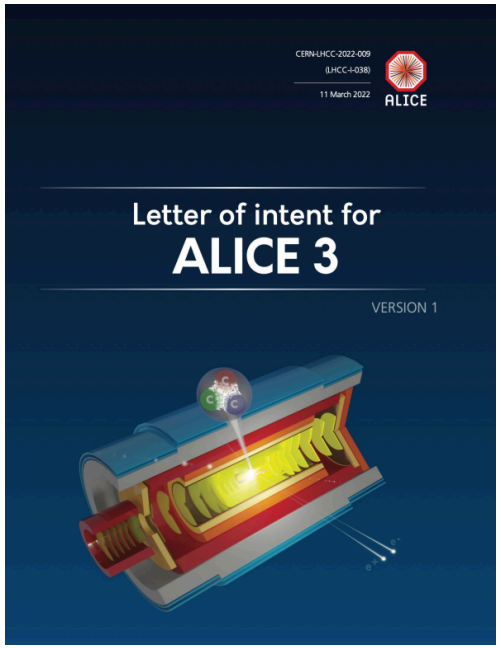
- truly cylindrical inner layers
- closer to the interaction point, reduced material budget

→ **Improved vertexing for heavy flavour probes, thermal dielectrons**

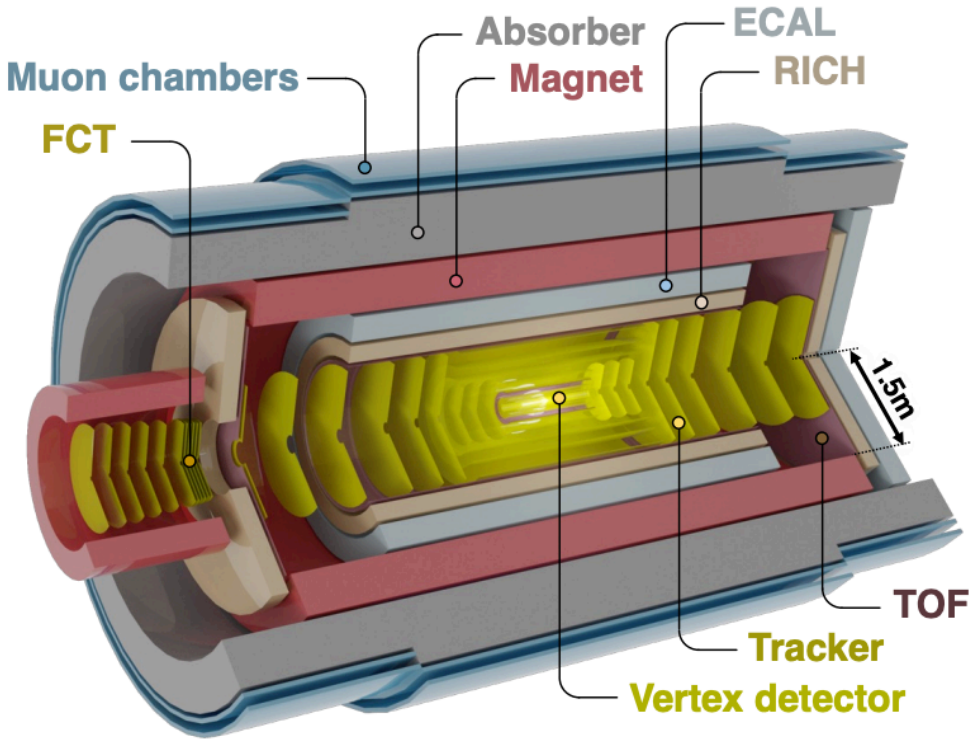


F. Carnesecchi, Wed, 12:06

Beyond 2033: ALICE 3

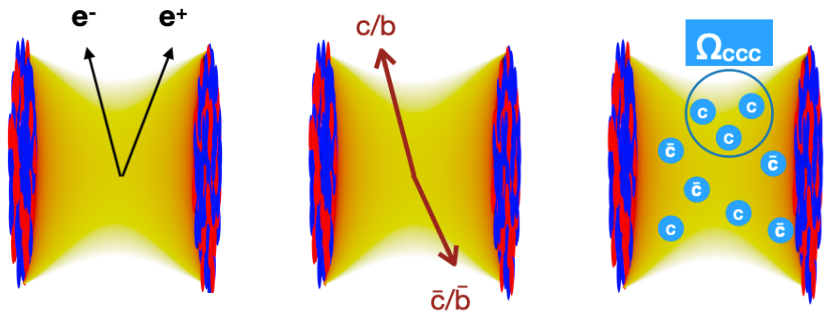


Nov 2022 - arxiv.2211.02491



Key objectives:

- precision measurements of **dileptons**
- systematic measurements of **(multi-) heavy flavour hadrons**
- hadron long-range correlations



R&D ongoing on many fronts

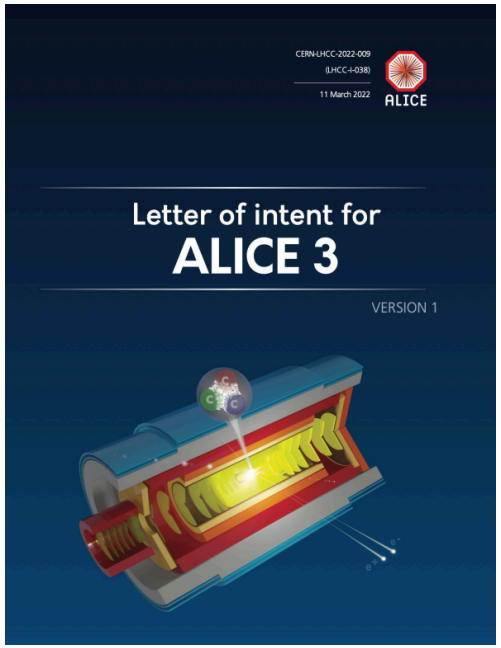
Detector concept:

- compact **low-mass** all-silicon tracker
- excellent **vertex** reconstruction
- wide acceptance $|\eta| < 4$
- PID in $0.3 < p_T < 7$ GeV/c

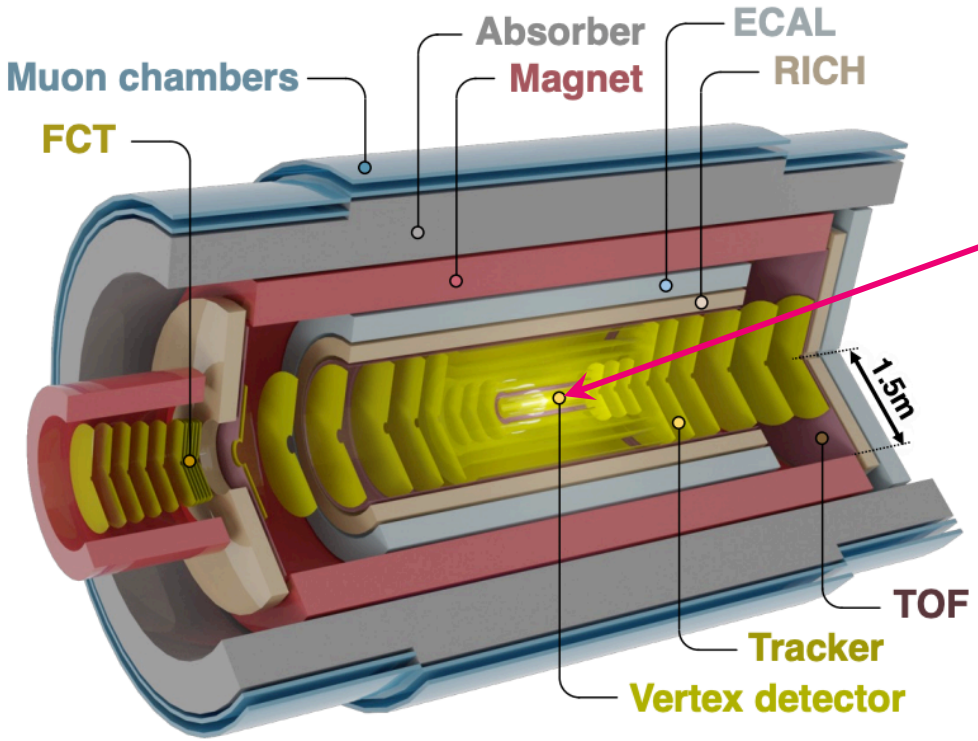
R. Munzer, Thu, 17:24

D. Zuolo, Thu, 11:30

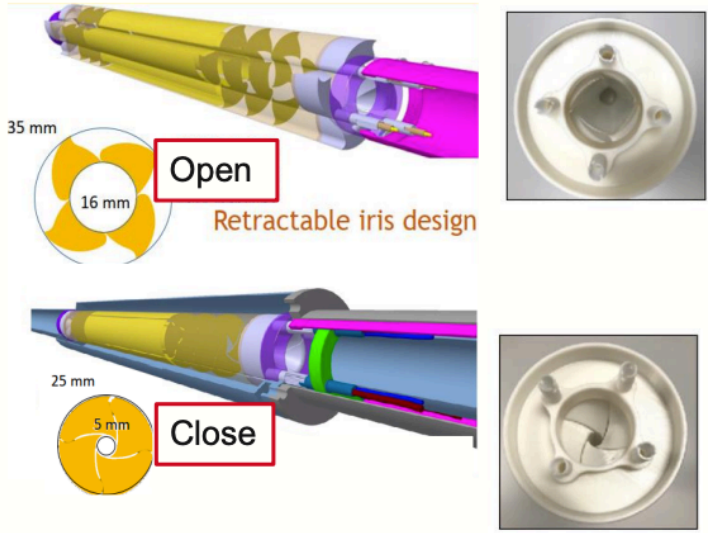
Beyond 2033: ALICE 3



Nov 2022 - arxiv.2211.02491



Vertex detector (IRIS) inside beam pipe:



first layer at midrapidity: 5 mm from beam!

Detector concept:

- compact **low-mass** all-silicon tracker
- excellent **vertex** reconstruction
- wide acceptance $|\eta| < 4$
- PID in $0.3 < p_T < 7$ GeV/c

R&D ongoing on many fronts

R. Munzer, Thu, 17:24

D. Zuolo, Thu, 11:30

Summary

- ALICE is efficiently taking Run 3 data with the upgraded detector
- A wealth of new results from Runs 1+2, many Run 3 results coming soon
- Harvest of physics results from Run 1+2 is summarized in the ALICE review paper
- Preparations for the future ALICE upgrades are ongoing
  - ITS3 and FoCal for Run 4
  - ALICE 3 LoI, installation in LS4
  - ambitious physics program ahead!

Thank you for your attention!

Talks with ALICE presenters

Plenary	Quark-gluon plasma properties from LHC data	Anthony Robert Timmins
Plenary	The limits of QGP-like effects towards smaller systems	Nicolo Jacazio
Plenary	Hadron spectroscopy and hadron-hadron interactions	Valentina Mantovani Sarti
Plenary Upgrades	ALICE Upgrades	Robert Helmut Munzer
HI	Light nuclei production in small systems	Rutuparna Rath
HI	Strangeness production in jets and out of jets in small systems	Chiara De Martin
HI	Probing gluons in nuclei using UPC	Guillermo Contreras Nuno
HI	Event-by-event fluctuations	Tapan Nayak
HI	Flow and correlation measurements in small and large systems	Lucia Anna Tarasovicova
HI	(Anti)nuclei production at colliders relevant for astroparticle physics	Pavel Larionov
HF	Measurement of scattering parameters governing the residual strong interaction	Daniel Battistini
QCD	Jet measurements in pp collisions from ALICE	Austin Schmier
QCD+HF	Investigating the strong interaction between hadrons and light nuclei	Raffaele Del Grande
QCD+HF	Charm and beauty production cross sections and fractions	Fabio Catalano
QCD+HF	Quarkonium production cross section and polarisation	Andry Rakotozafindrabe
QCD+HI	Jet substructure measurements in heavy-ion collisions	Robert Vertes
HF/HI	Charmonium modification in the quark gluon plasma	Cynthia Hadjidakis
PERF	Run 3 performance of new hardware in ALICE	Jian Liu
PERF	Tracking and vertexing	Mattia Faggin
PERF	Particle identification	Christian Sonnabend
Upgrade	Future Monolithic Pixel Detectors in ALICE and Beyond	Francesca Carnesecchi
Outreach	Mental health and wellbeing in the four large LHC collaborations	Petra Loncar