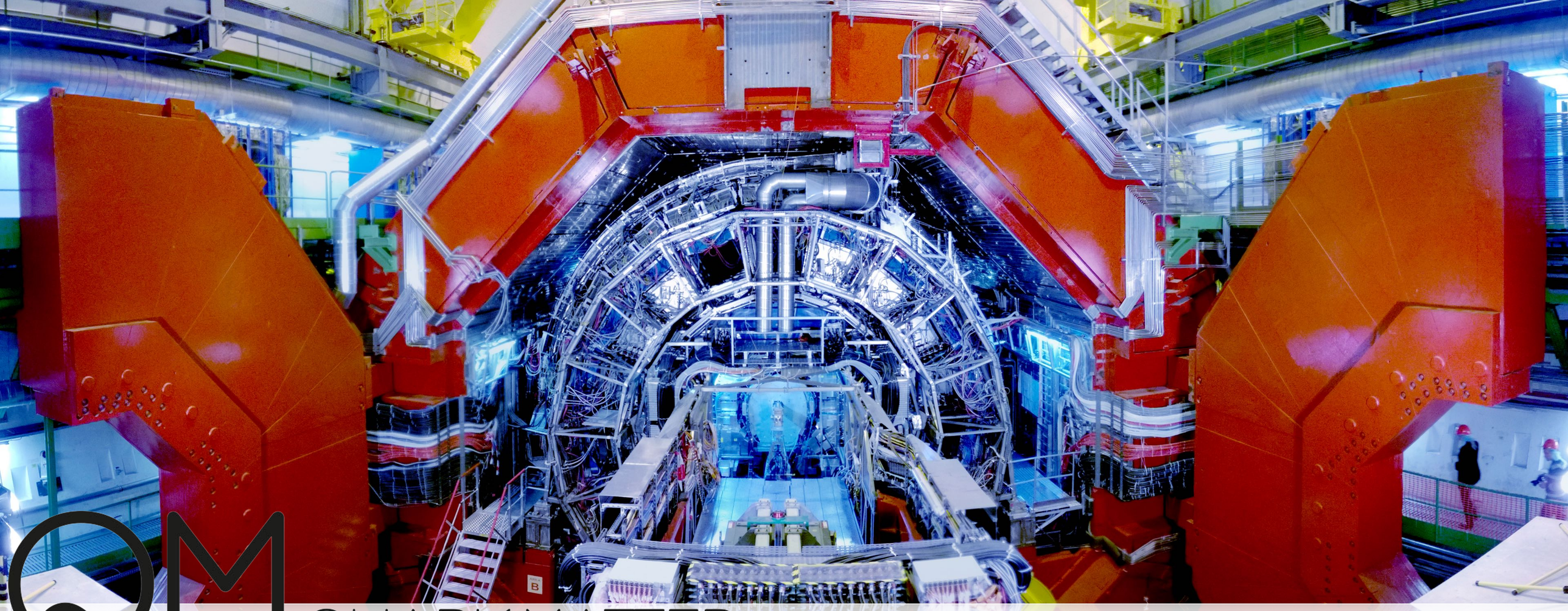


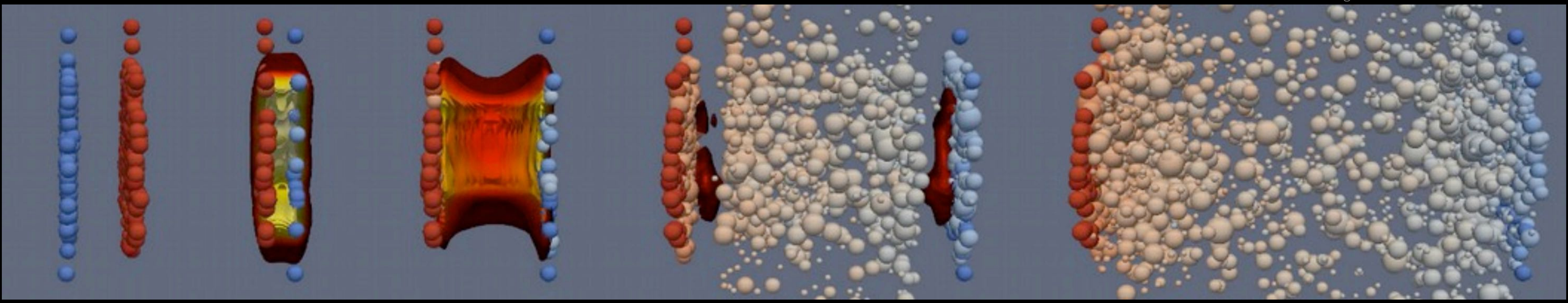
QUARK MATTER
KRAKÓW
2022

5th April 2022

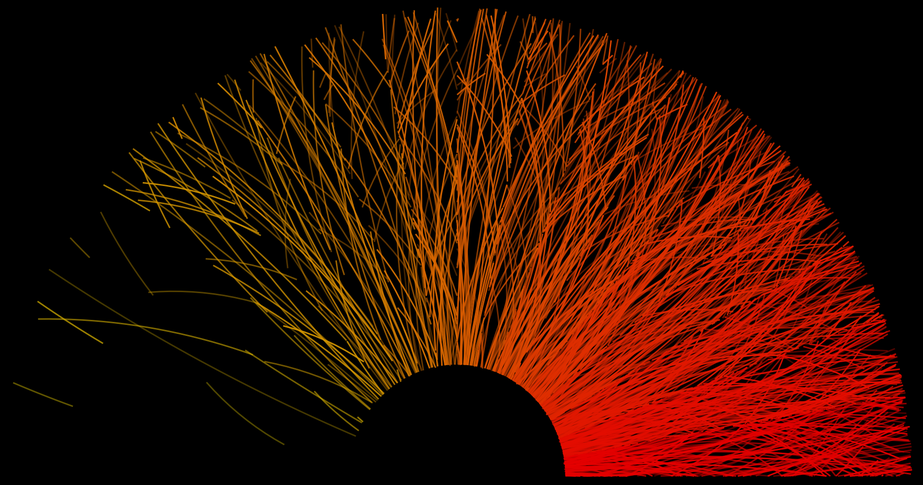
Highlights from ALICE

Maximiliano Puccio (CERN) for the collaboration

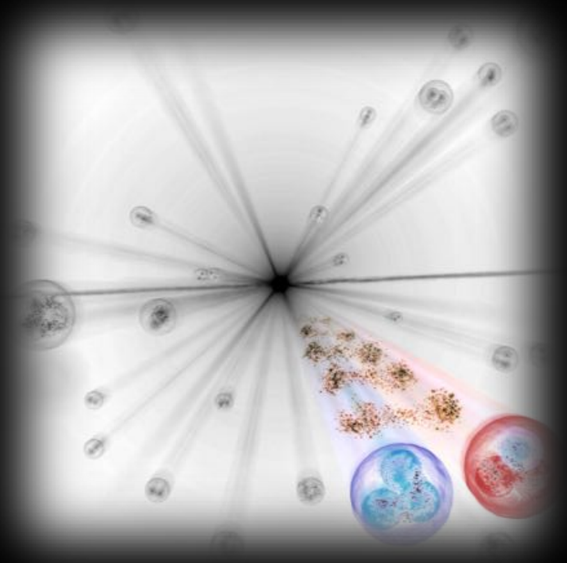
Figure credit: MADAI collaboration



Properties and evolution of a heavy ion collision

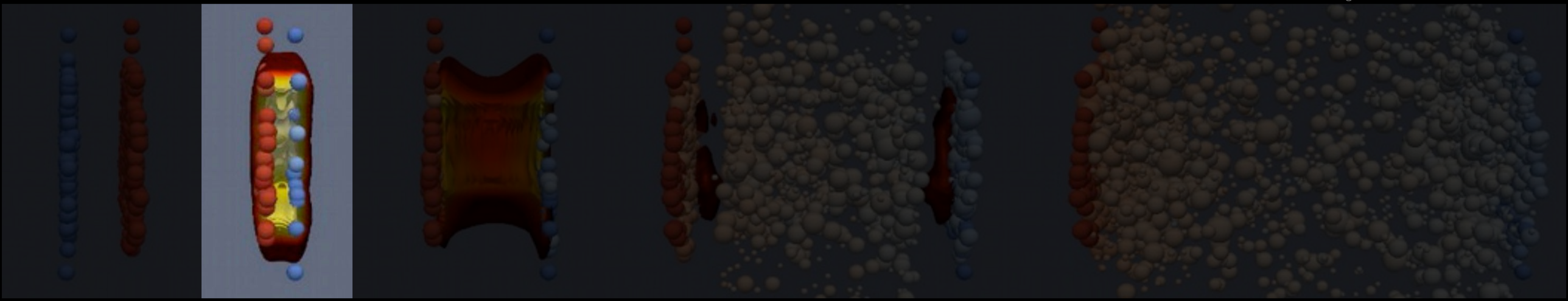


Small systems and hadronisation



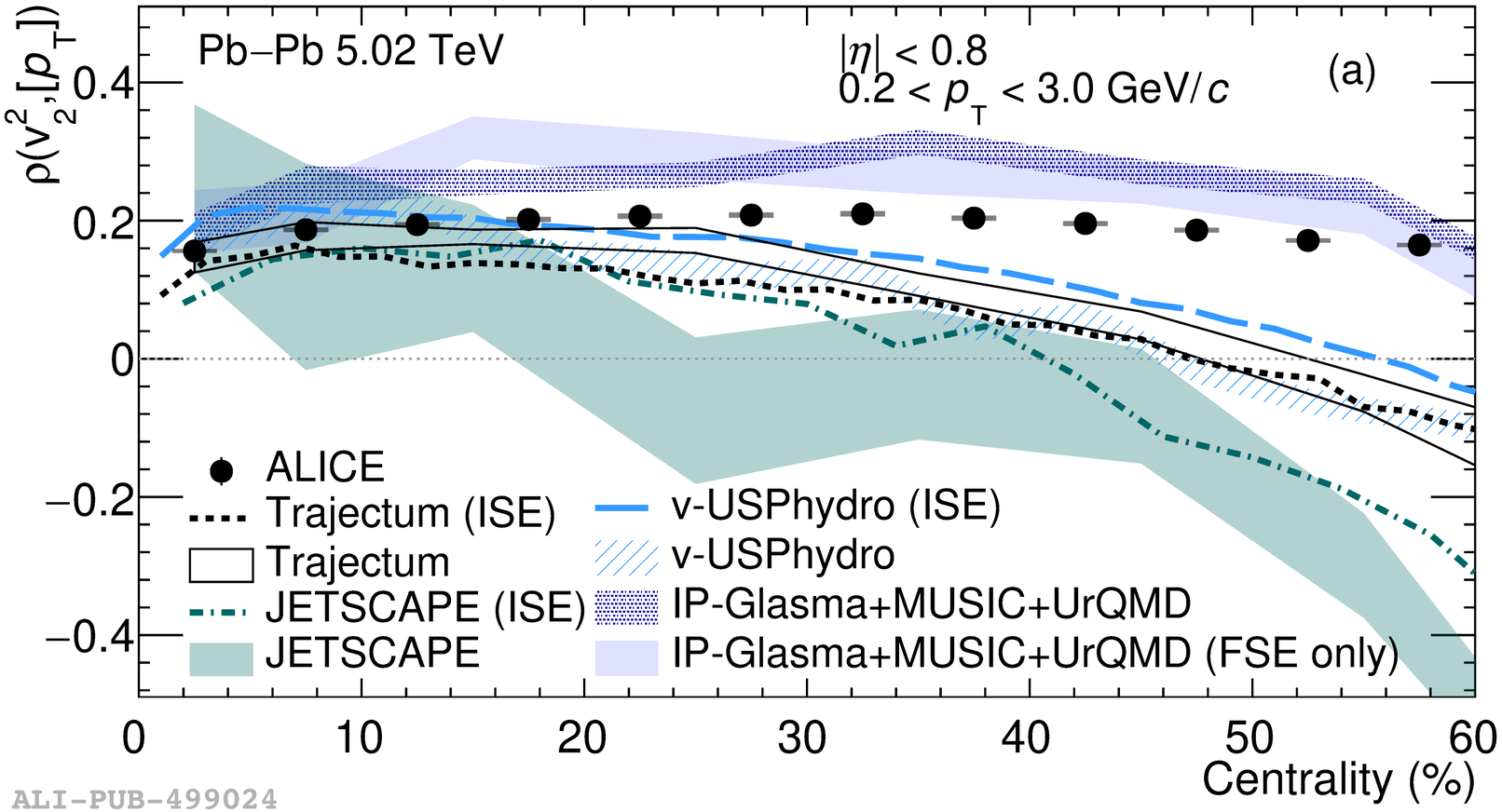
Hadron-hadron interactions

Figure credit: MADAI collaboration



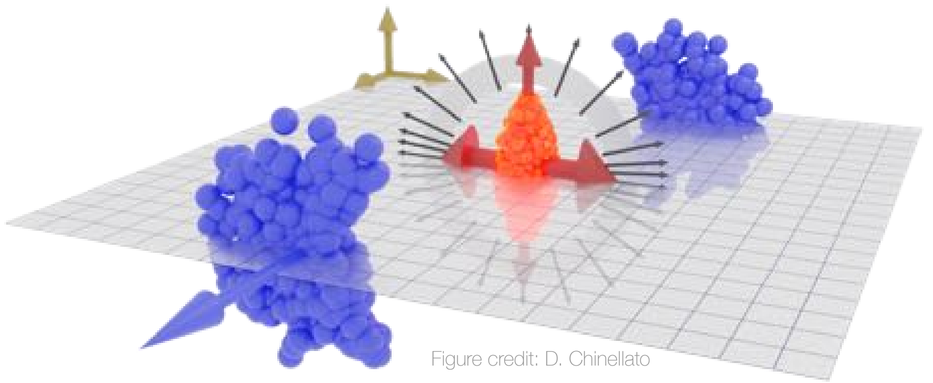
Initial conditions

Investigating the initial stages with correlations



ALI-PUB-499024

ALICE, arxiv:2111.06106



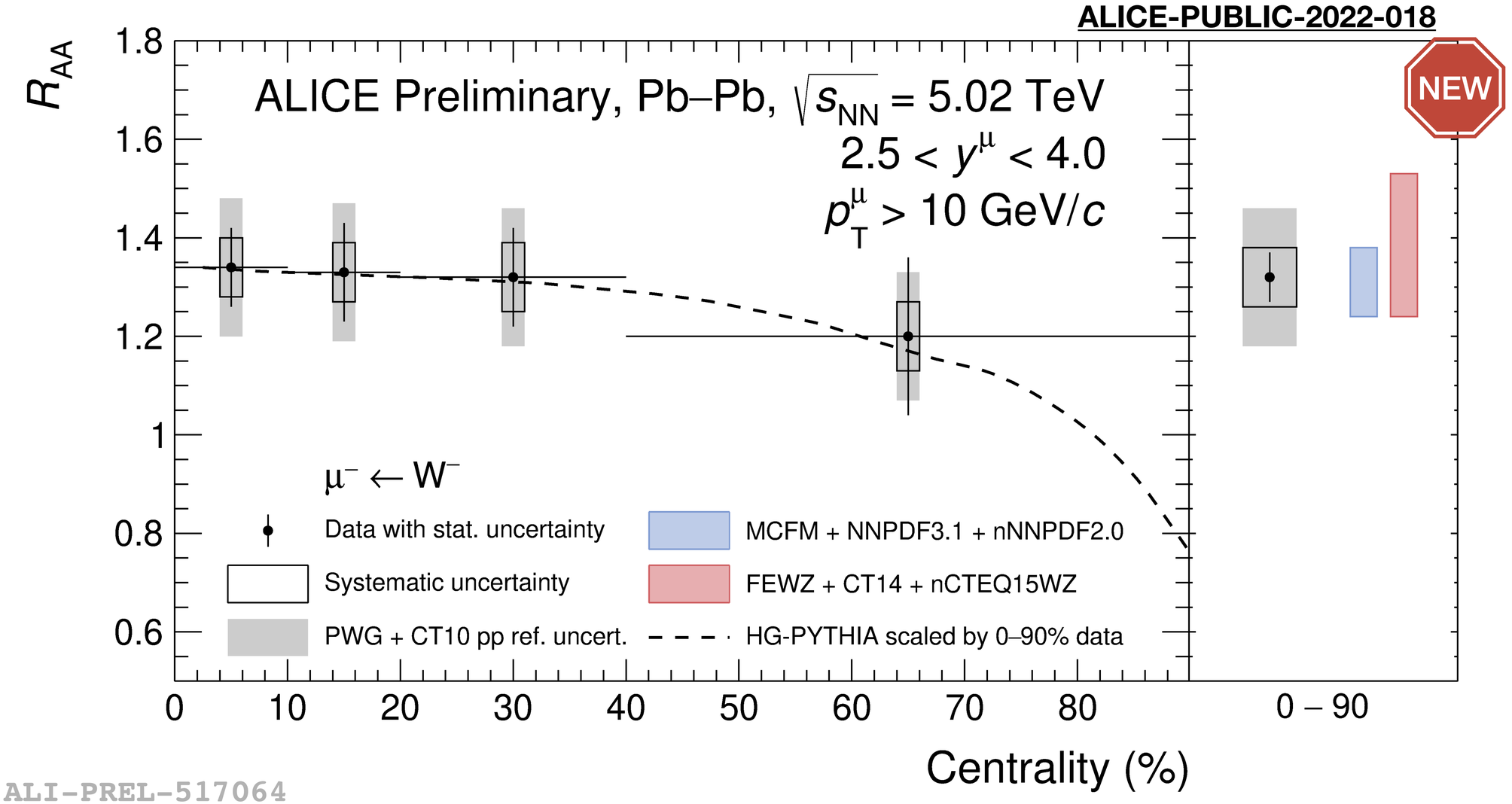
$$\rho_n(v_n^2, [p_T]) = \frac{\mathrm{cov}(v_n^2, [p_T])}{\sqrt{\mathrm{var}(v_n^2)}\sqrt{\mathrm{var}([p_T])}}$$

Study of the correlation between the shape of the fireball (v_2) and its size ($[p_T]$)

- Access to the initial conditions through bulk observables
- No quantitative description of the data
  - Slightly better agreement with models using IP-Glasma initial conditions

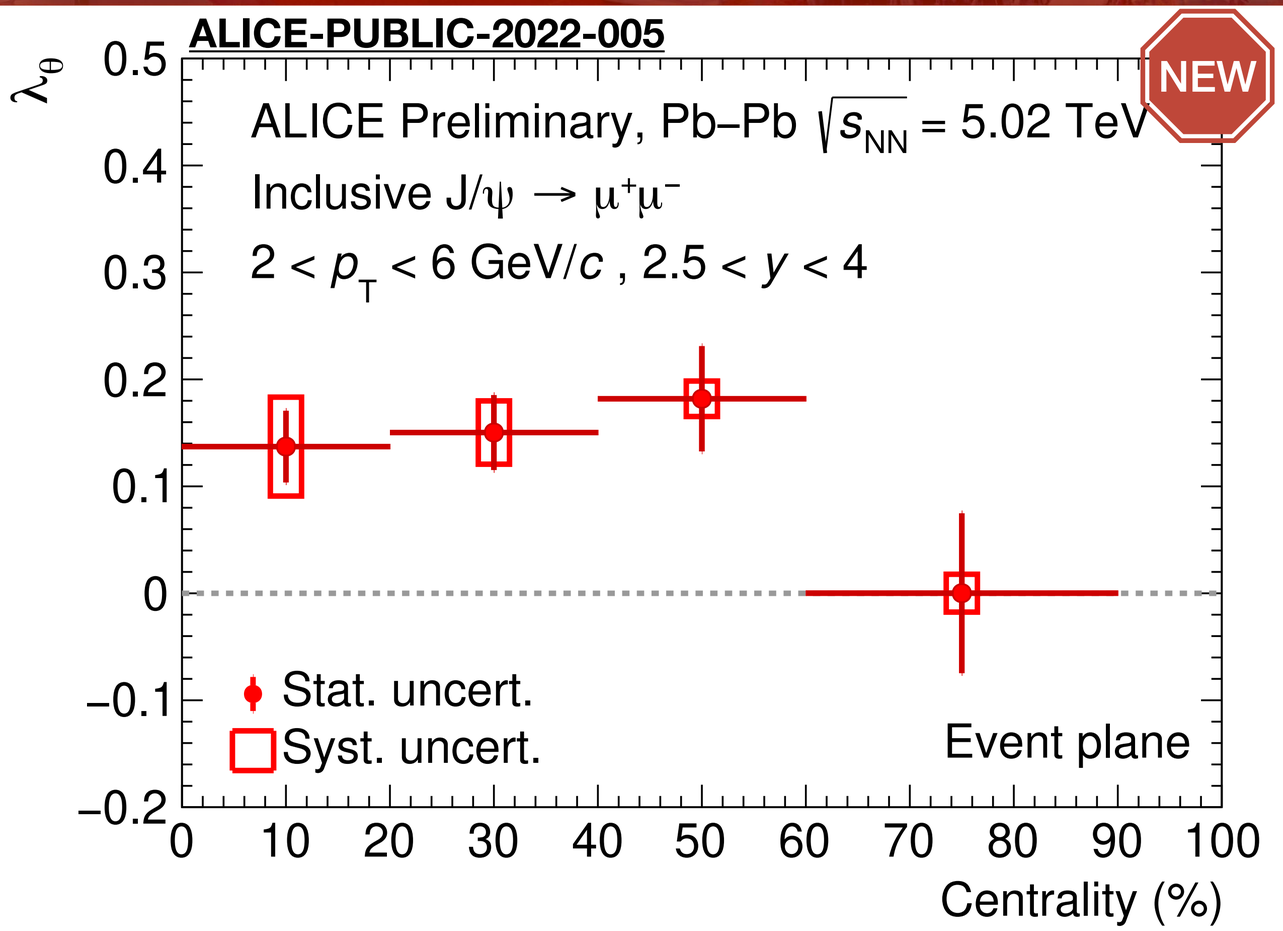
V. Vislavicius - 07/04/2022, 12:50

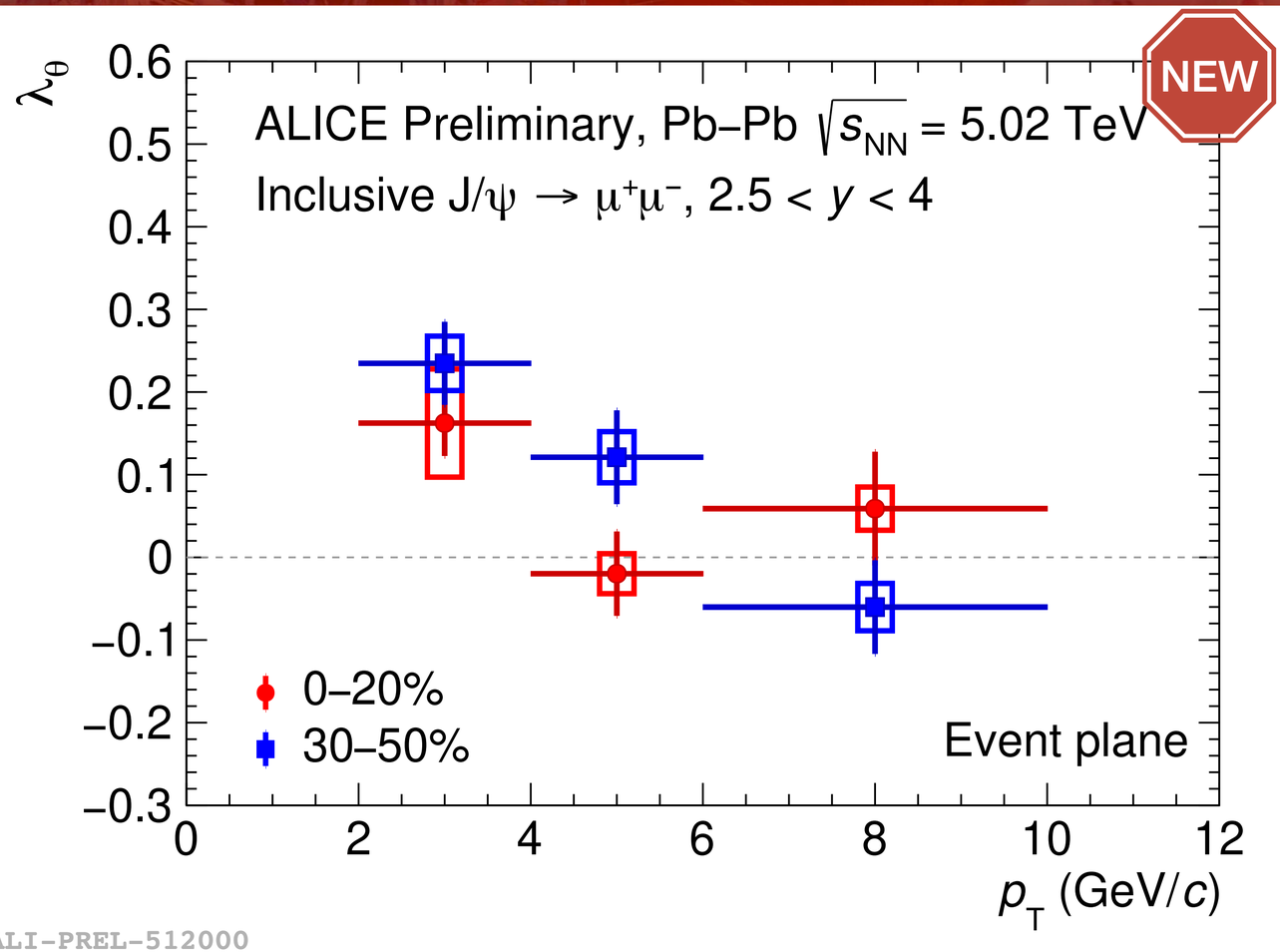
Production of W boson in Pb-Pb collisions



➡First ALICE measurement in Pb-Pb at 5 TeV: consistent with N_{coll} scaling in all centralities

Polarisation of quarkonia in Pb-Pb collisions

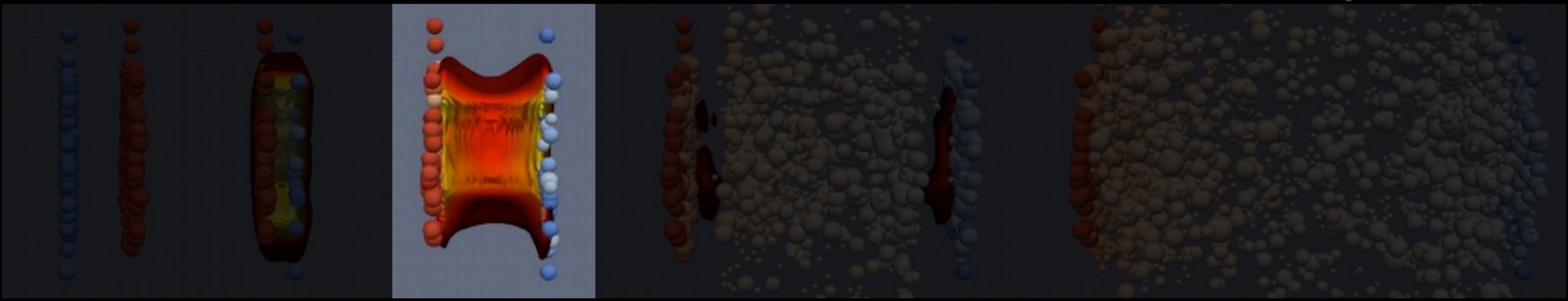




Evidence of inclusive J/ψ polarisation with respect to the event plane at low p_T

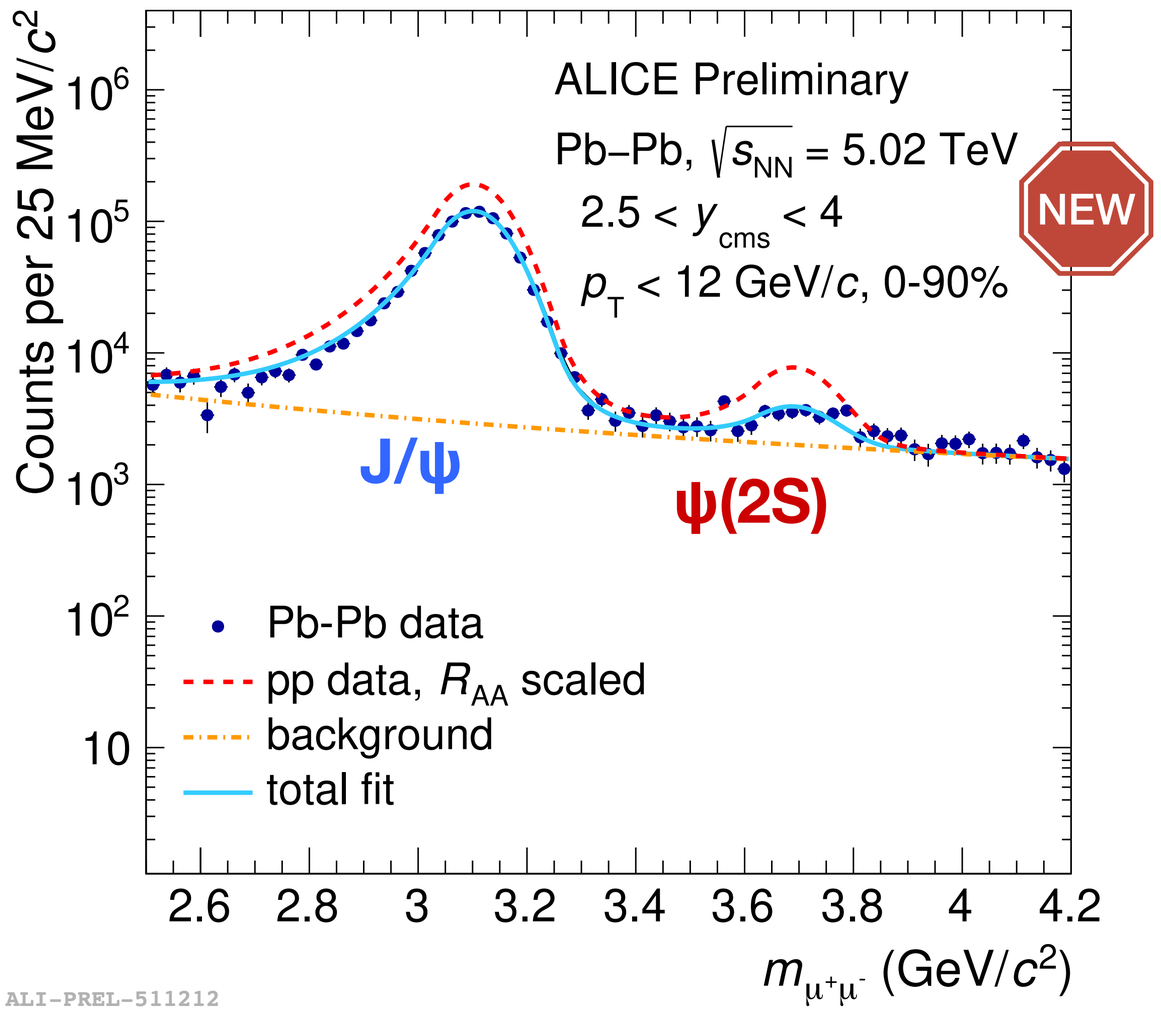
- Significant effect up to semicentral
- Vanishing polarisation at larger momenta: sensitive to vorticity and magnetic field?

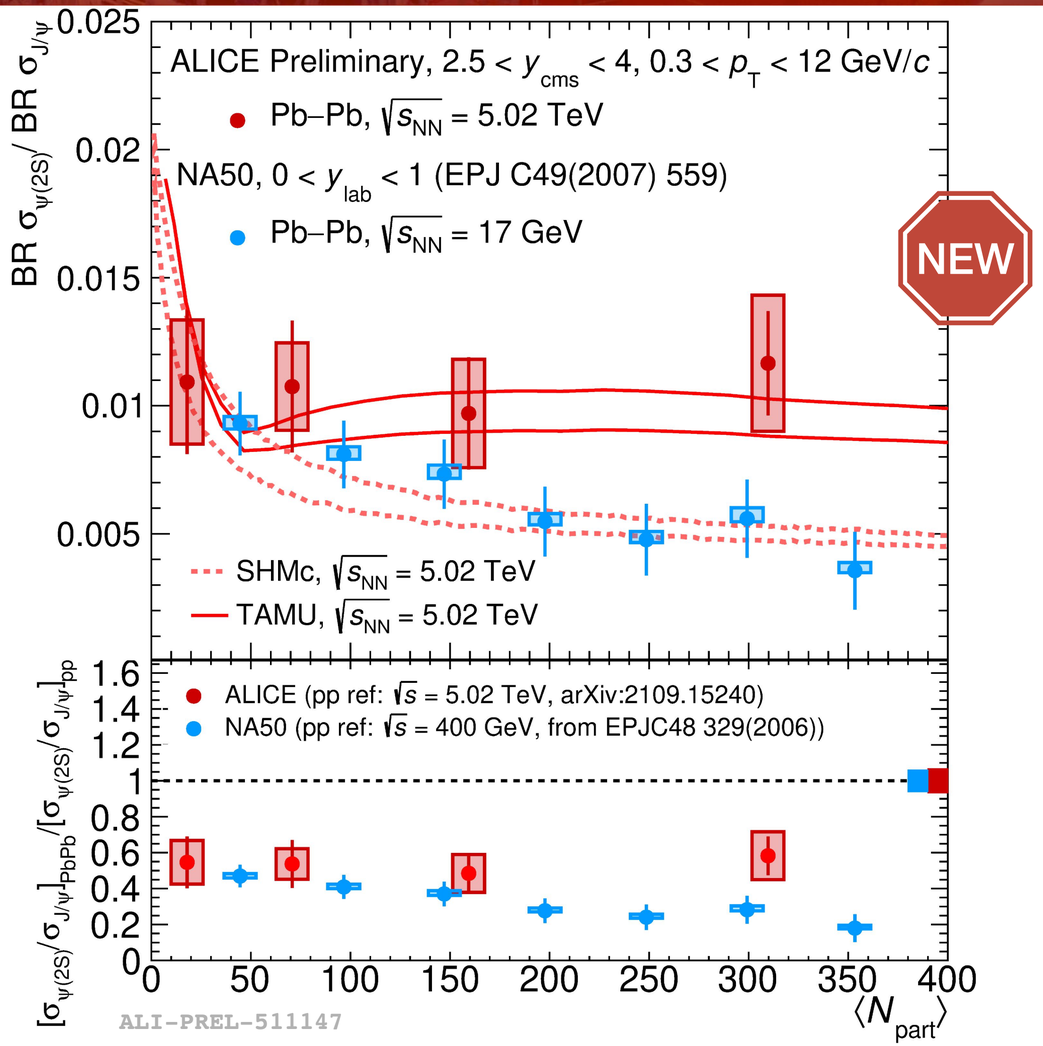
Figure credit: MADAI collaboration



Medium properties

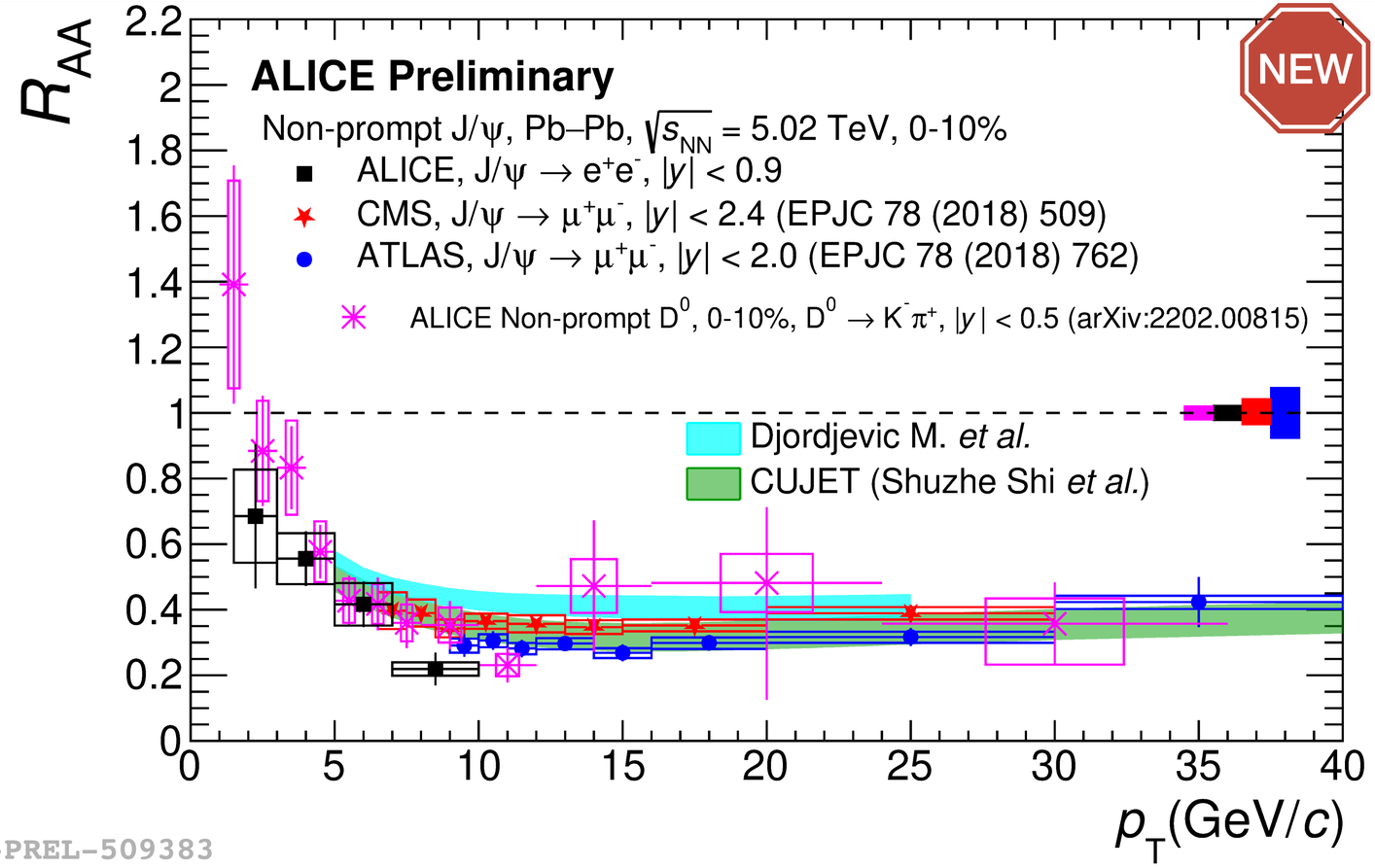
ψ(2S) production in Pb-Pb collisions





- Extension of the ψ(2S) measurement down to 0 transverse momentum
- Clear hierarchy of suppression between J/ψ and ψ(2S) over all the p_T and for all centralities.

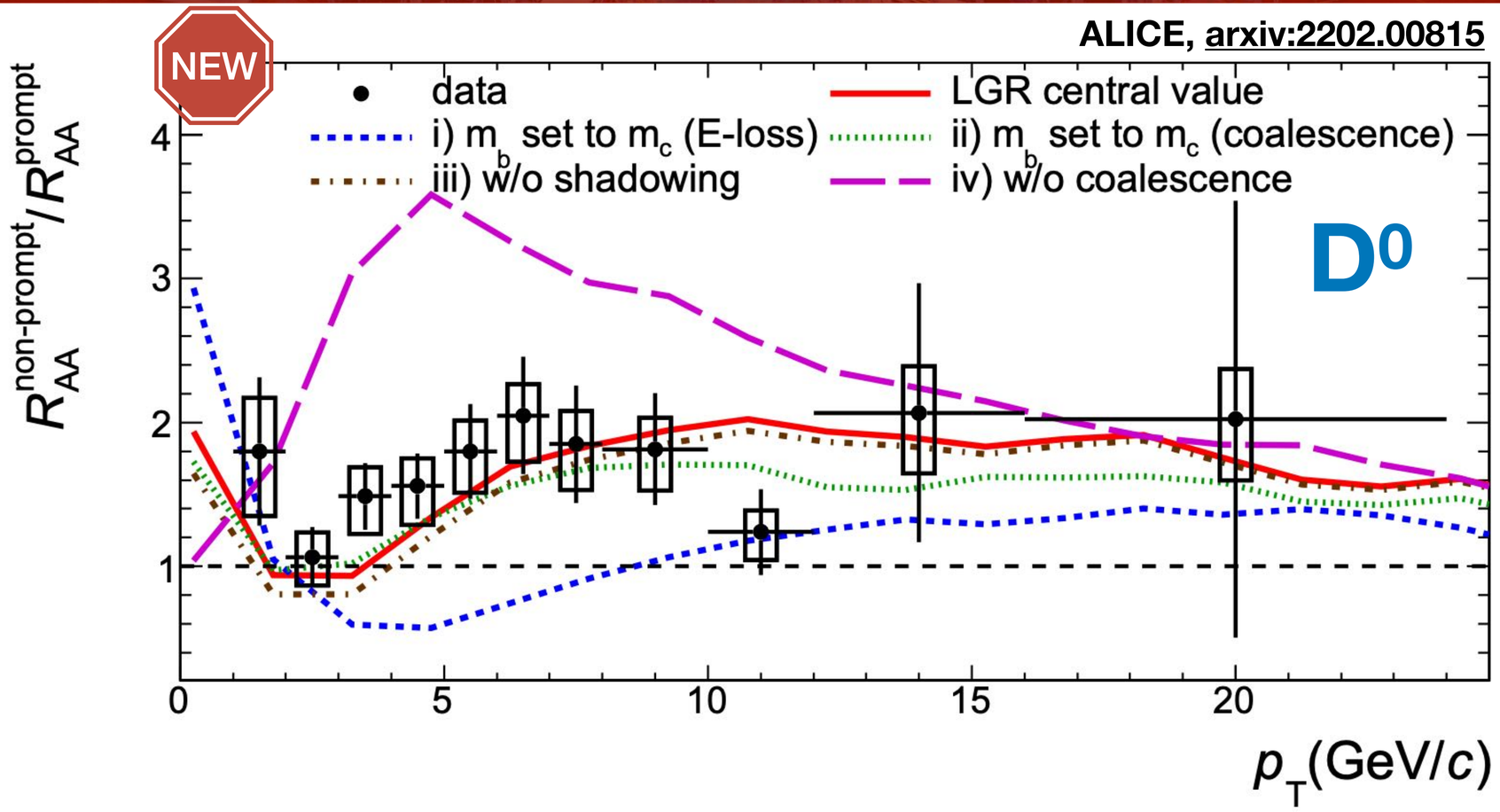
R_{AA} of J/ψ and D meson from beauty



- Unprecedented access to the low p_T region for beauty hadron R_{AA} through the measurement of non-prompt J/ψ and D meson

R_{AA} of J/ψ and D meson from beauty

ALICE, arxiv:2202.00815



- Unprecedented access to the low p_T region for beauty hadron R_{AA} through the measurement of non-prompt J/ψ and D meson
- R_{AA}(non-prompt)/R_{AA}(prompt) larger than unity for p_T > 5 GeV/c
  - Model description requires mass-dependent energy loss and coalescence

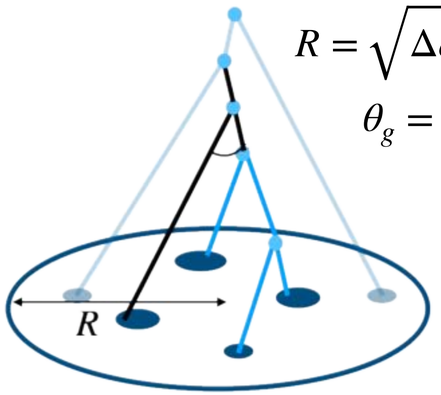
X. Peng - 06/04/2022, 12:10

Medium induced jet modifications

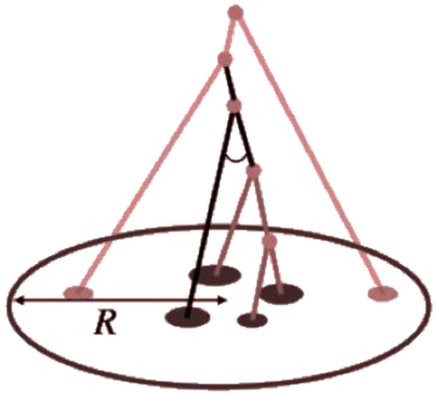
- Studied via jet grooming: find first hard splitting
- Model comparisons indicate QGP resolves individual hard prongs that interact incoherently
- Jet core more collimated in Pb-Pb than pp

$$R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

$$\theta_g = R_g / R$$

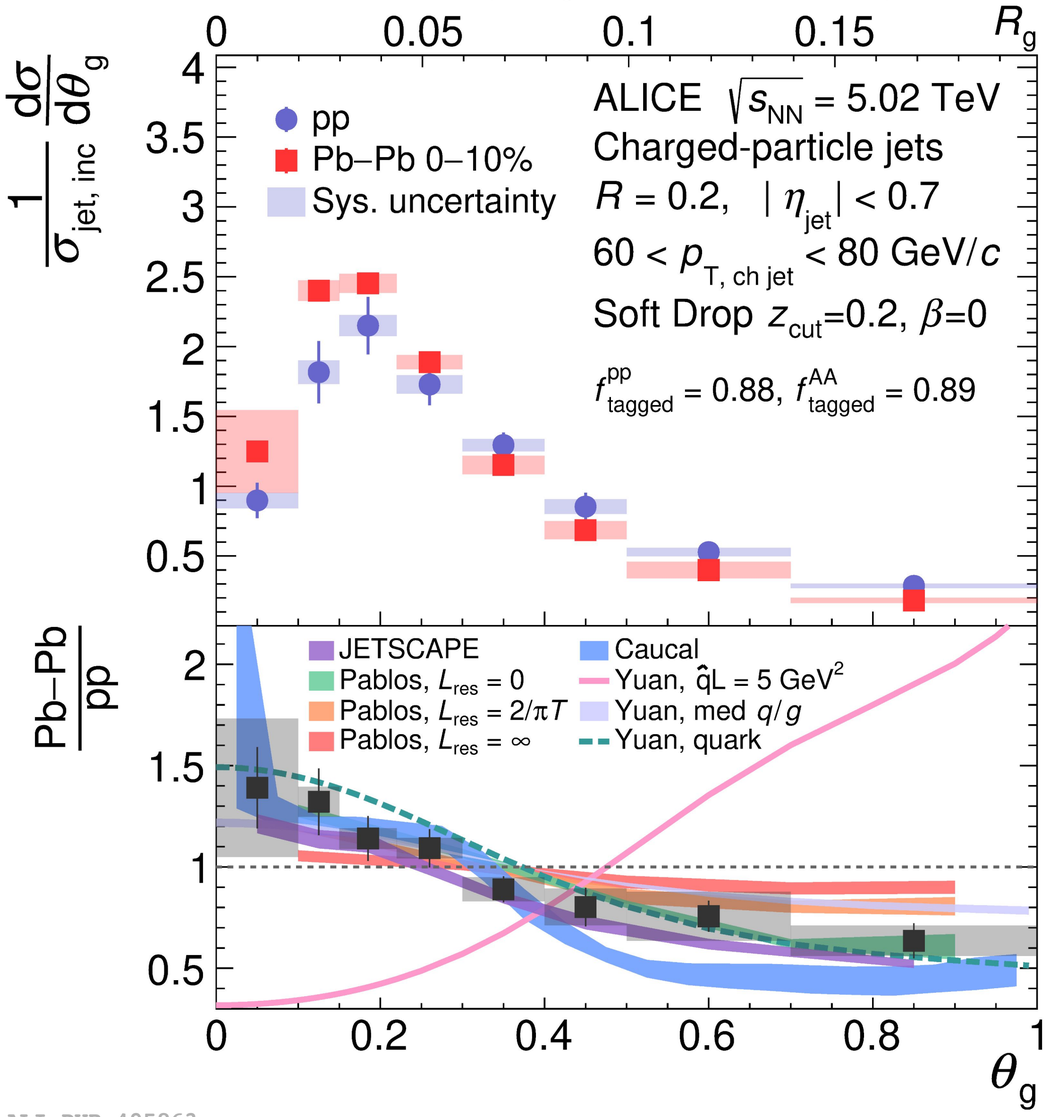


pp



Pb-Pb

ALICE, Phys. Rev. Lett. 128, 102001



ALI-PUB-495863

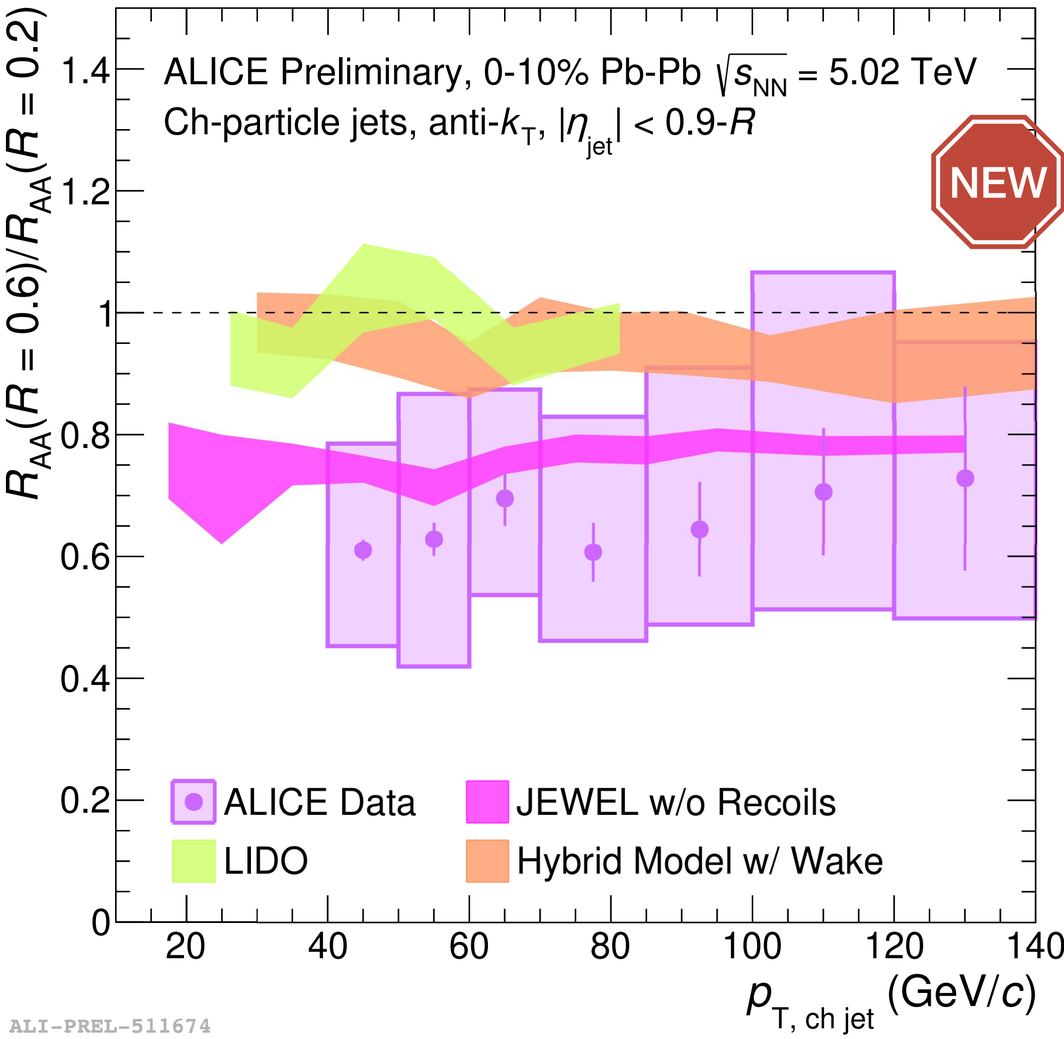
R. Cruz Torres - 07/04/2022, 18:30 / J. Mulligan - 06/04/2022, 10:00

Jet modifications in Pb-Pb collisions

- Studied via jet grooming: find first hard splitting
- Model comparisons indicate QGP resolves individual hard prongs that interact incoherently
- Jet core more collimated in Pb-Pb than pp

R=0.6 jets are more suppressed than R=0.2 in Pb-Pb

- Hint of R dependent suppression; not seen up to R=0.4
- Consistent with narrower jet population



H. Bossi - 07/04/2022, 18:10

Jet modifications in Pb-Pb collisions

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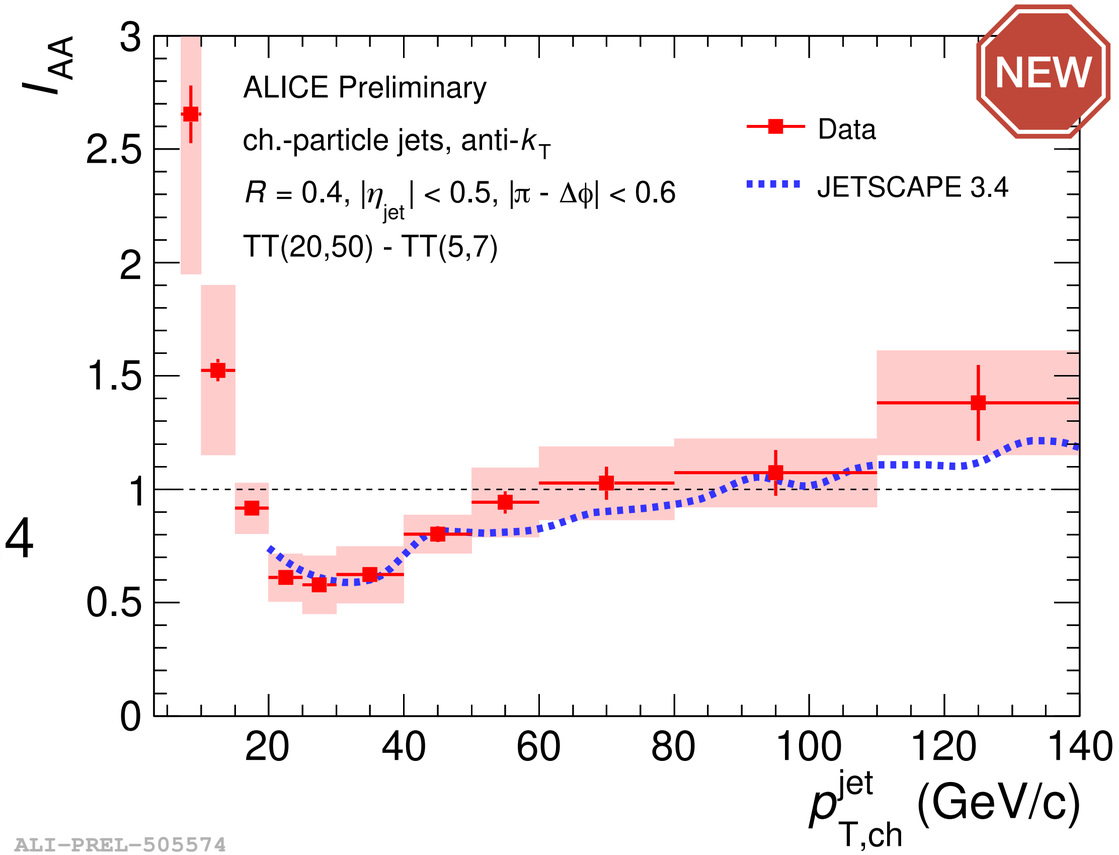
R=0.6 jets are more suppressed than R=0.2 in Pb-Pb

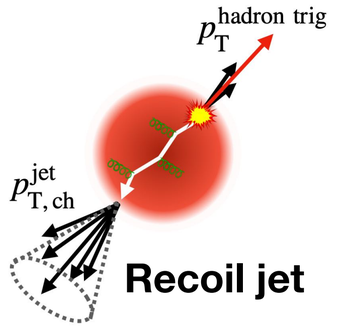
- Hint of R dependent suppression; not seen up to R=0.4
- Consistent with narrower jet population

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

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



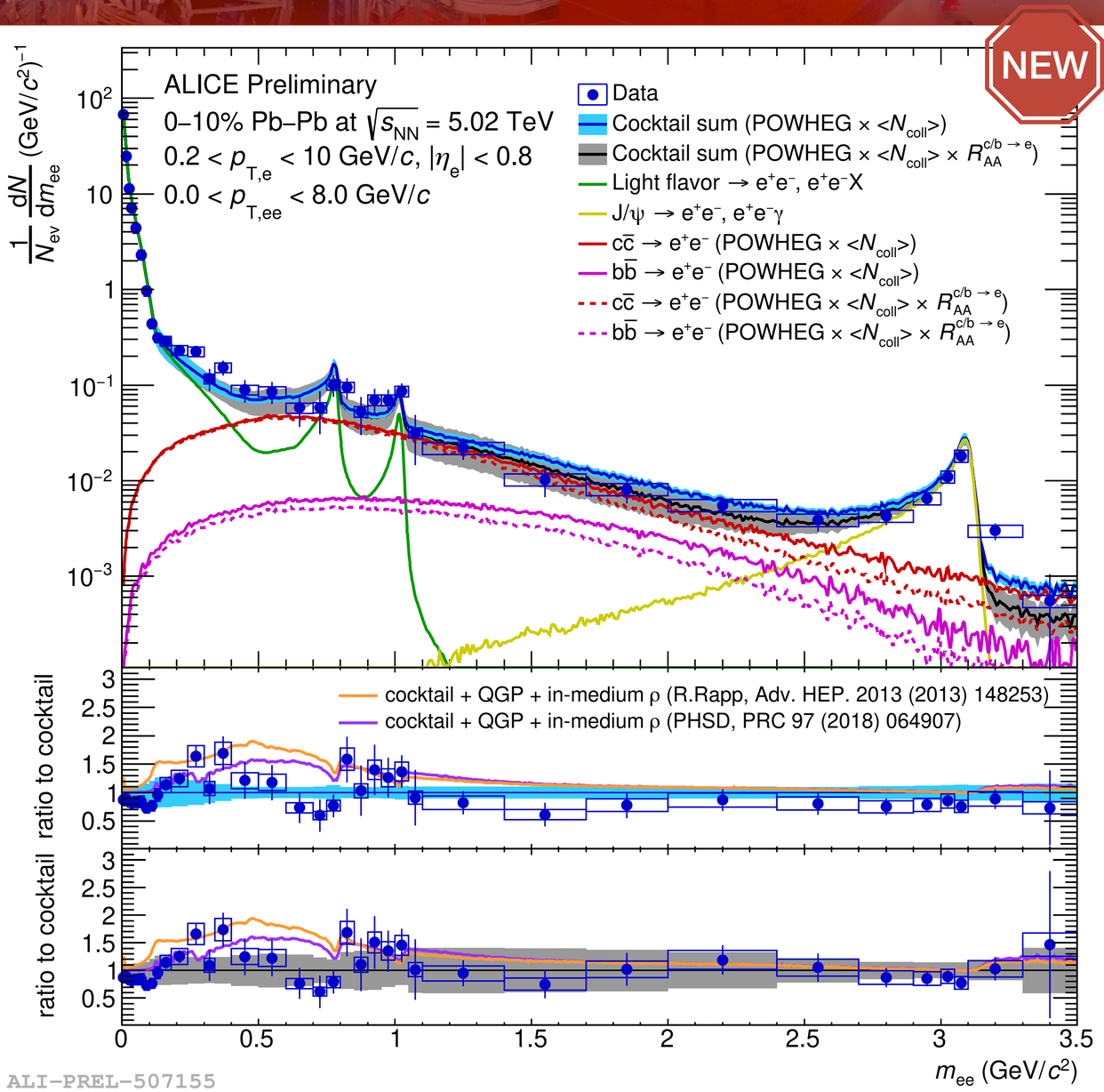
$$I_{AA} = \frac{\Delta_{recoil}(Pb - Pb)}{\Delta_{recoil}(pp)}$$



R. Cruz Torres - 07/04/2022, 18:30

Real and virtual direct photons with ALICE

- Hint for an excess at low m_{ee}
  - Consistent with additional thermal radiation from the medium
- Need to control heavy-flavour background
  - first DCA_{ee} studies in Pb-Pb
- Extract fraction of direct photons by fitting the m_{ee} spectra ($m_{ee} < 0.4$ GeV/c^2)



J. Jung - 07/04/2022, 15:20

Real and virtual direct photons with ALICE

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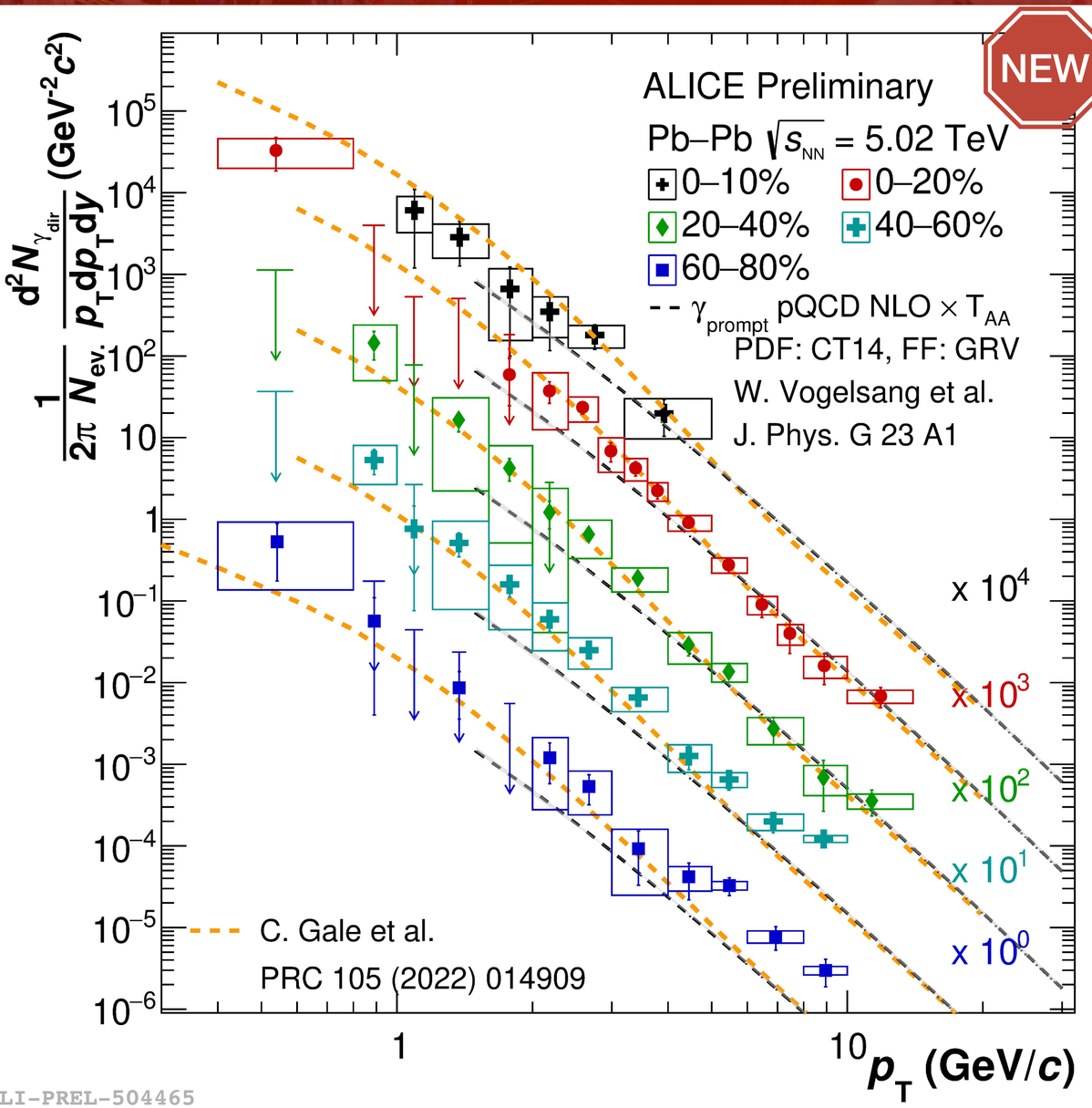
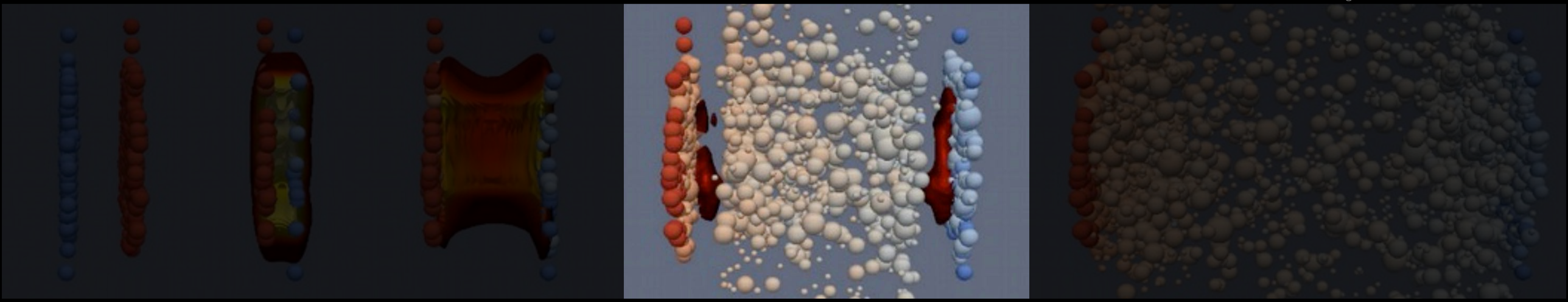
- Need to control heavy-flavour background
  - first DCA_{ee} studies in Pb-Pb
- Extract fraction of direct photons by fitting the m_{ee} spectra ($m_{ee} < 0.4$ GeV/c^2)

- First measurement of direct γ in Pb-Pb at 5.02 TeV
  - Virtual photon method 0–10%
  - Real photons with conversion reconstruction (other centralities)
- High p_T: prompt photons consistent with pQCD expectation
- Low p_T: data consistent with model containing in addition pre-equilibrium and thermal photons



ALI-PREL-504465

Figure credit: MADAI collaboration



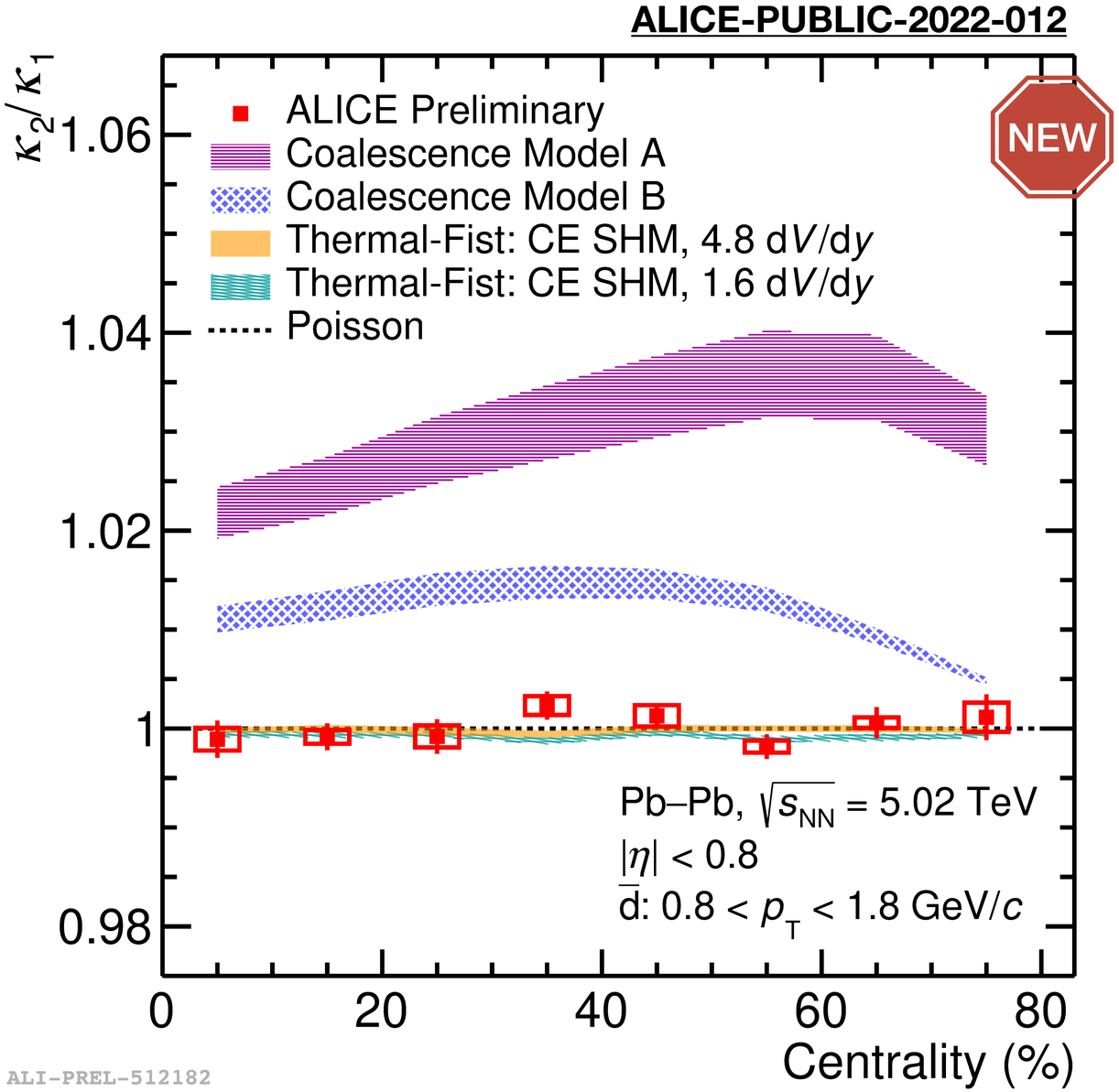
Freeze-out and rescattering

Beyond the average: antinuclei number fluctuations

New observables based on event-by-event fluctuations to distinguish Statistical hadronisation and hadron coalescence

$$\frac{\kappa_2}{\kappa_1} = \frac{\langle (n - \langle n \rangle)^2 \rangle}{\langle n \rangle}$$

- Cumulant ratio clearly favours the SHM



S. Kundu - 07/04/2022, 18:50

Beyond the average: antinuclei number fluctuations

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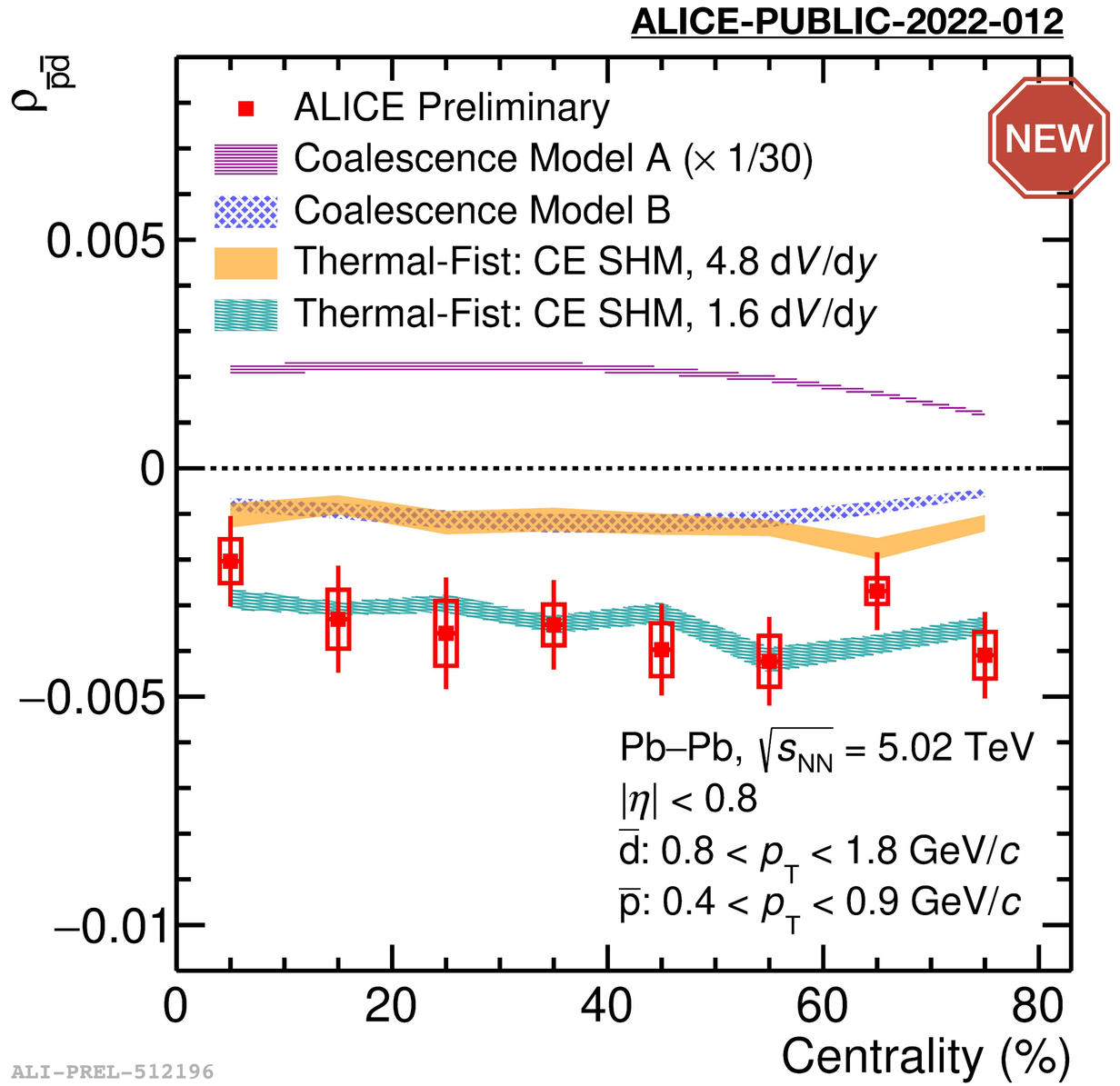
$$\frac{\kappa_2}{\kappa_1} = \frac{\langle (n - \langle n \rangle)^2 \rangle}{\langle n \rangle}$$

- Cumulant ratio clearly favours the SHM

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

- Pearson correlation constrains the correlation volume for baryon number
  - Agrees with results from (anti)nuclei yields
  - Different wrt results from (anti)proton yields and fluctuations



S. Kundu - 07/04/2022, 18:50

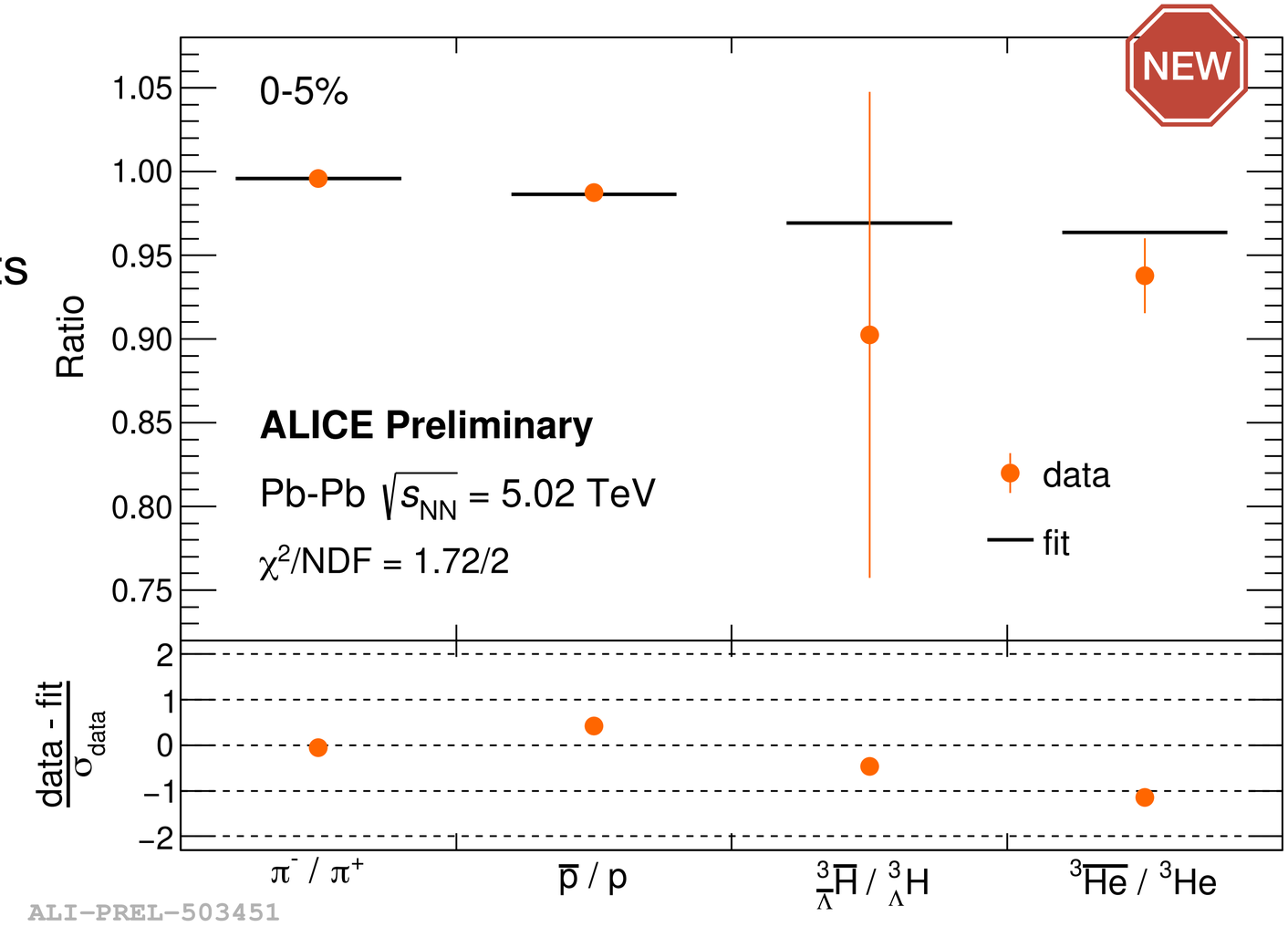
Antimatter/matter imbalance at the LHC

New measurement of the antimatter/matter imbalance at the LHC

- Hierarchy with baryon number
- Expected SHM trend fits the measurements

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

with $T = 156.2 \pm 2$ MeV



S. Kundu - 07/04/2022, 18:50

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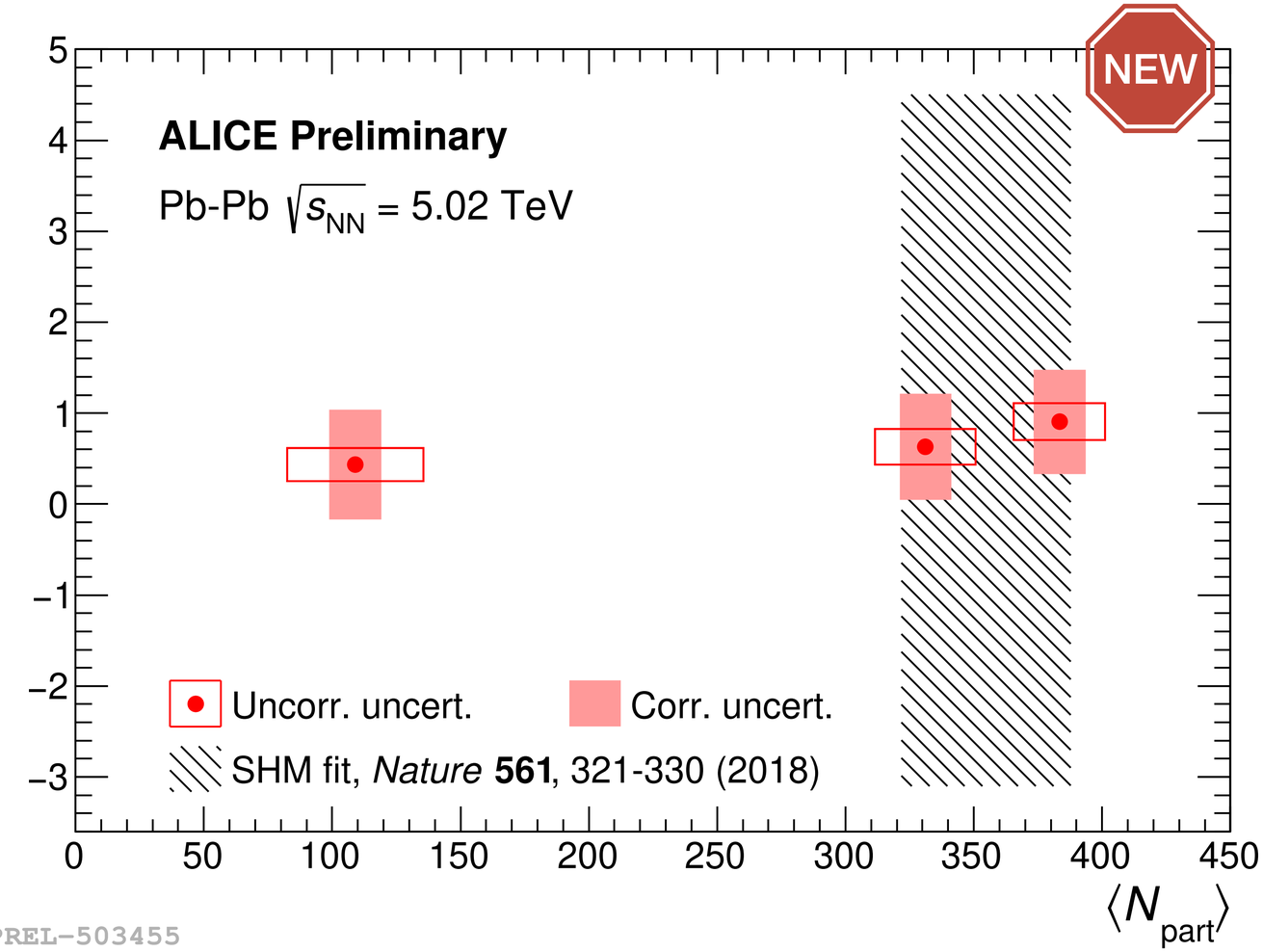
with $T = 156.2 \pm 2$ MeV

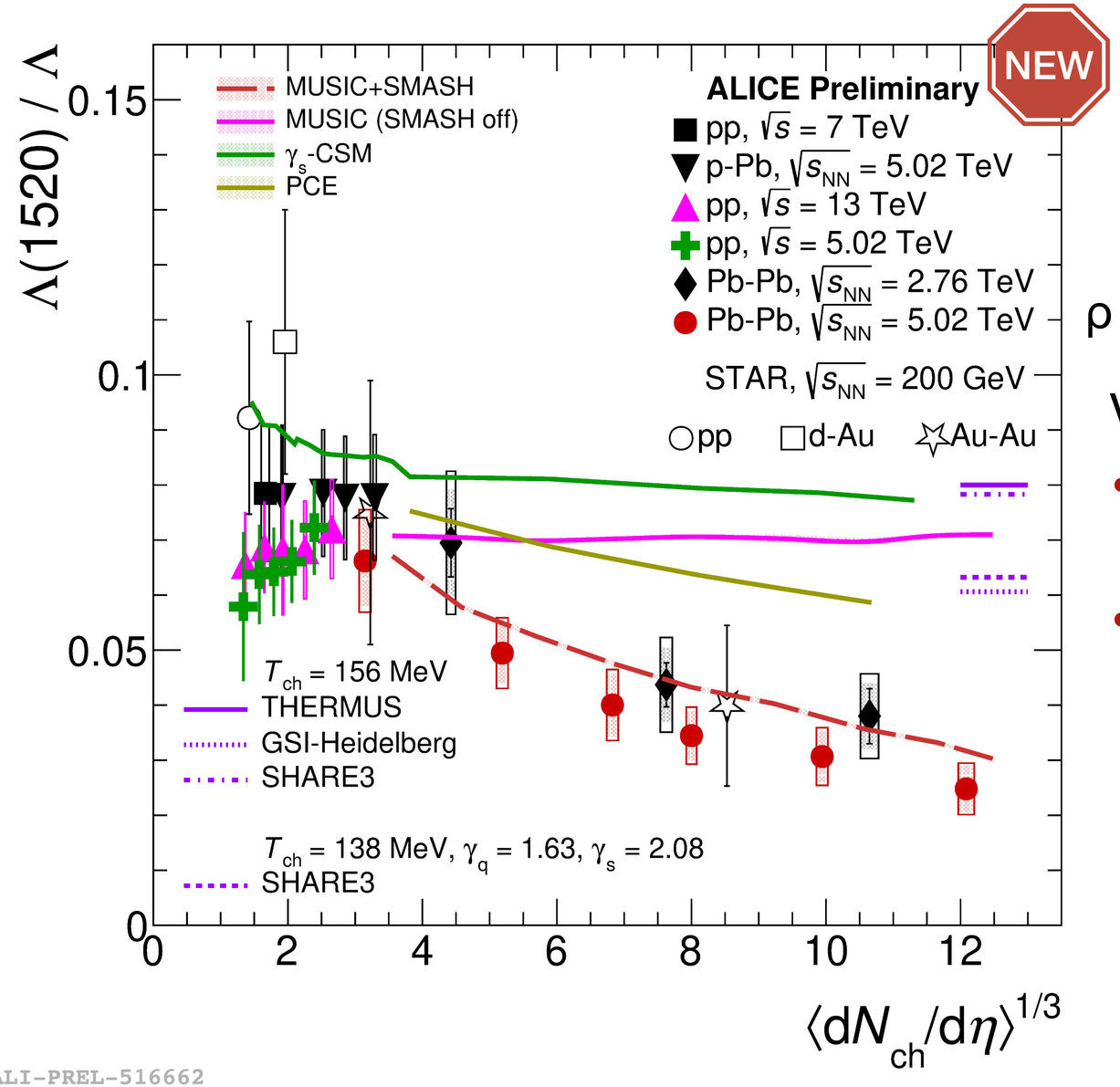
From the fits new determination of the baryochemical potential at hadronisation

- Far smaller uncertainties thanks to the direct cancellation of uncertainties in the ratios



ALI-PREL-503455

Gauging the rescattering: Λ(1520) in Pb-Pb



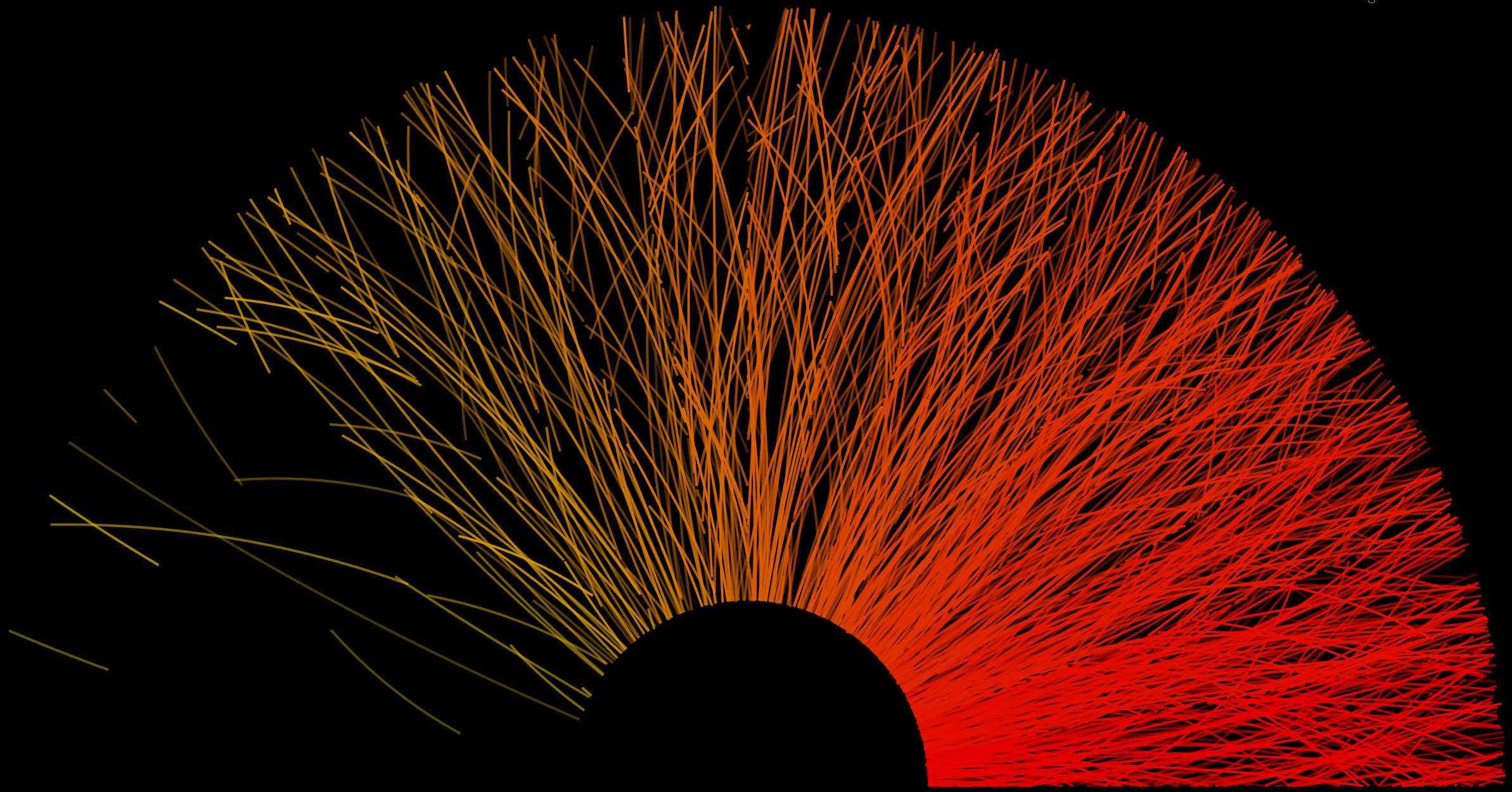
Resonance lifetime (fm/c)

ρ (1.3) < K* (4.2) < Σ* (5.5) < Λ* (12.6) < Ξ* (21.7) < Φ (46.2)

Very precise measurement of the yield of Λ(1520)

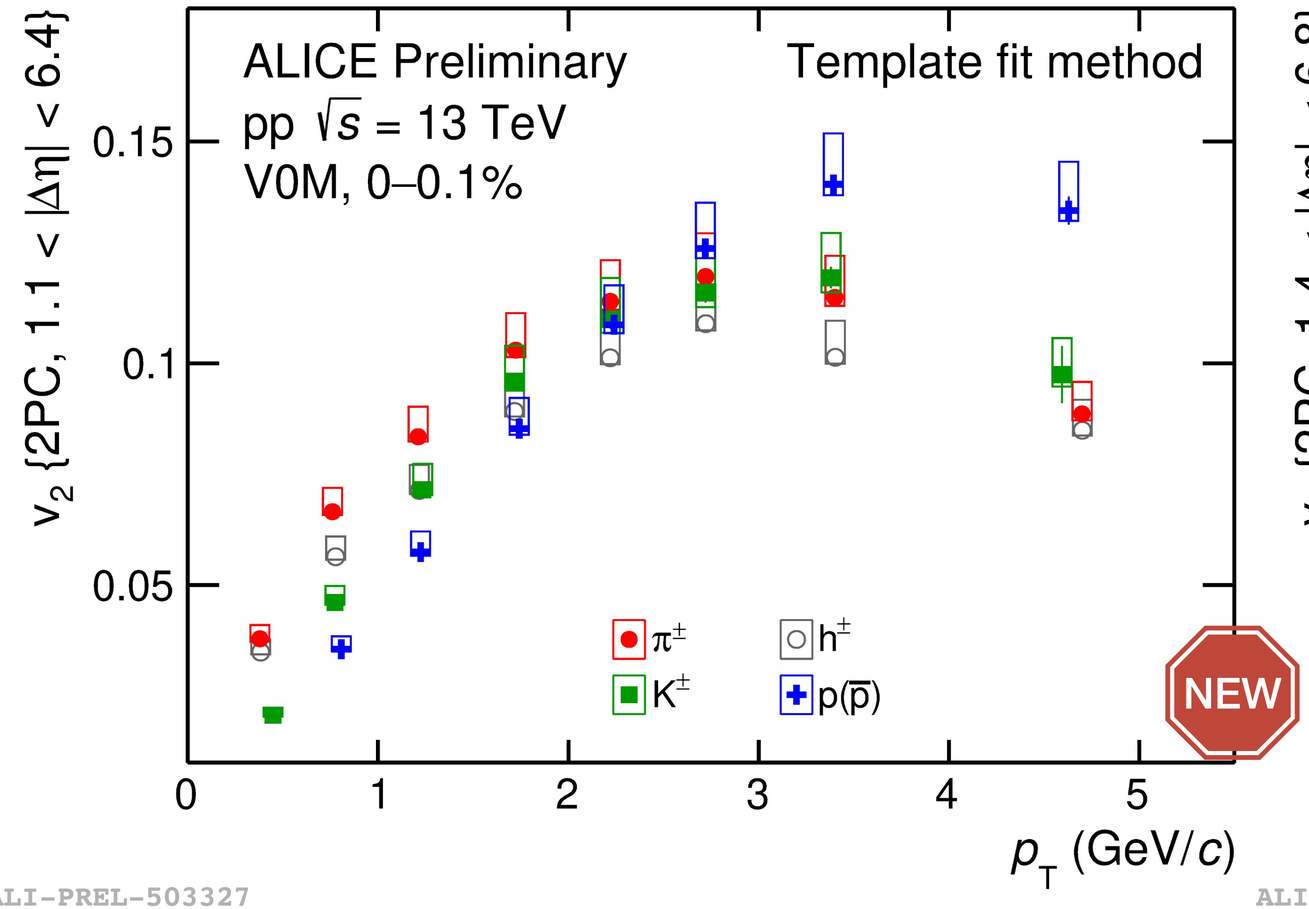
- Suppression in central Pb-Pb collisions wrt peripheral established with ~7σ significance
- Trend with centrality reproduced by hydro with the SMASH hadronic phase afterburner

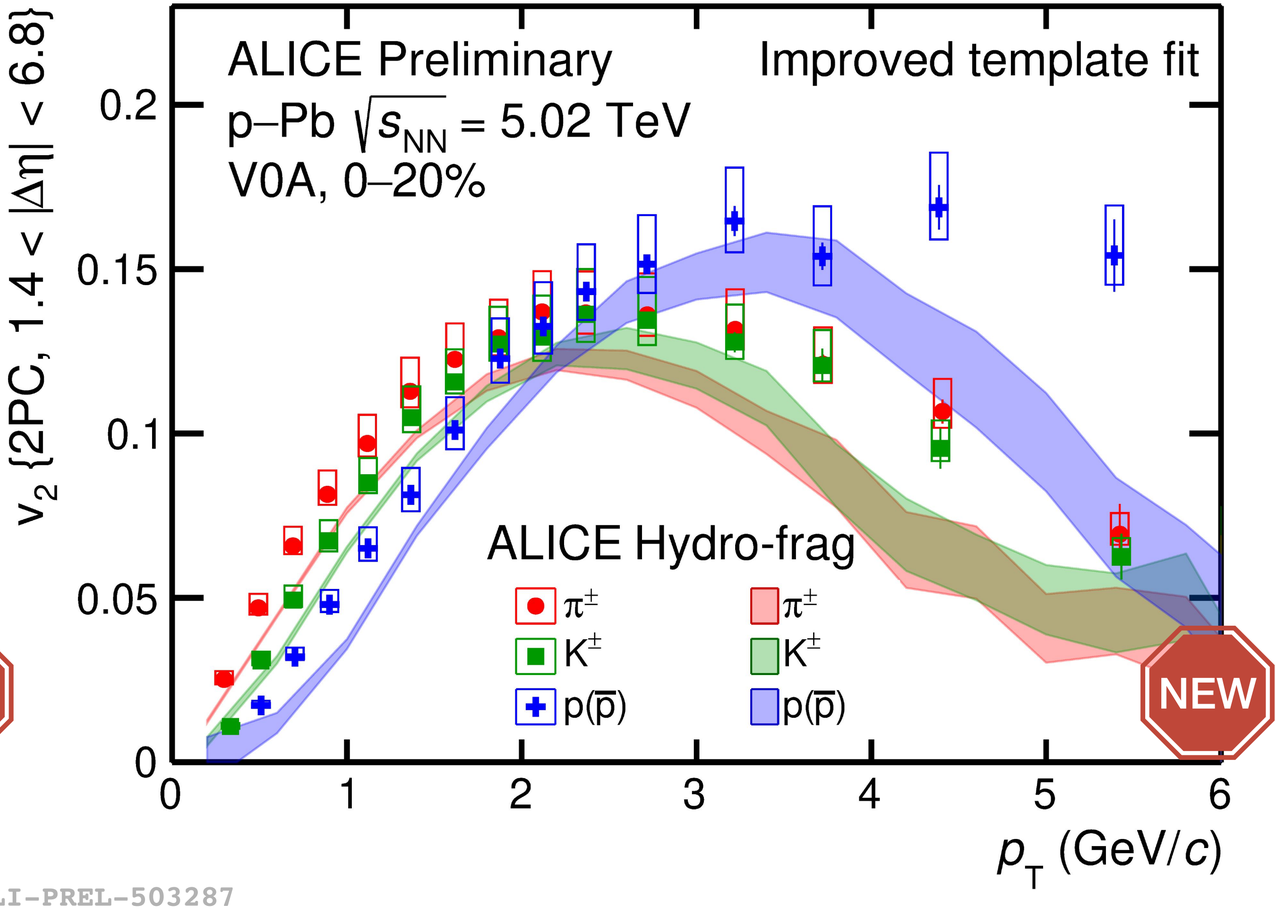
Figure credit: D. Chinellato



Small systems and hadronisation

Identified particles flow in small systems

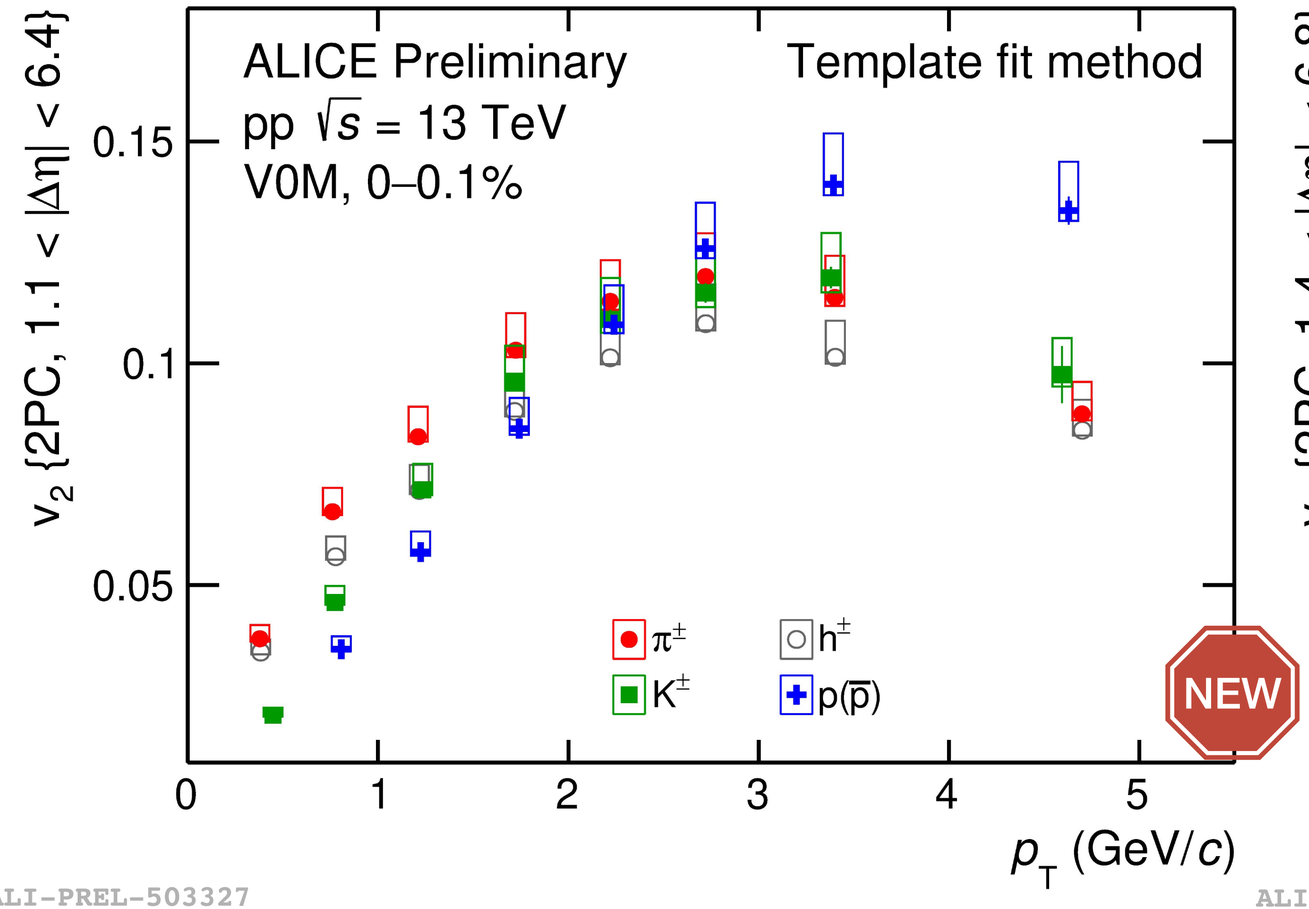


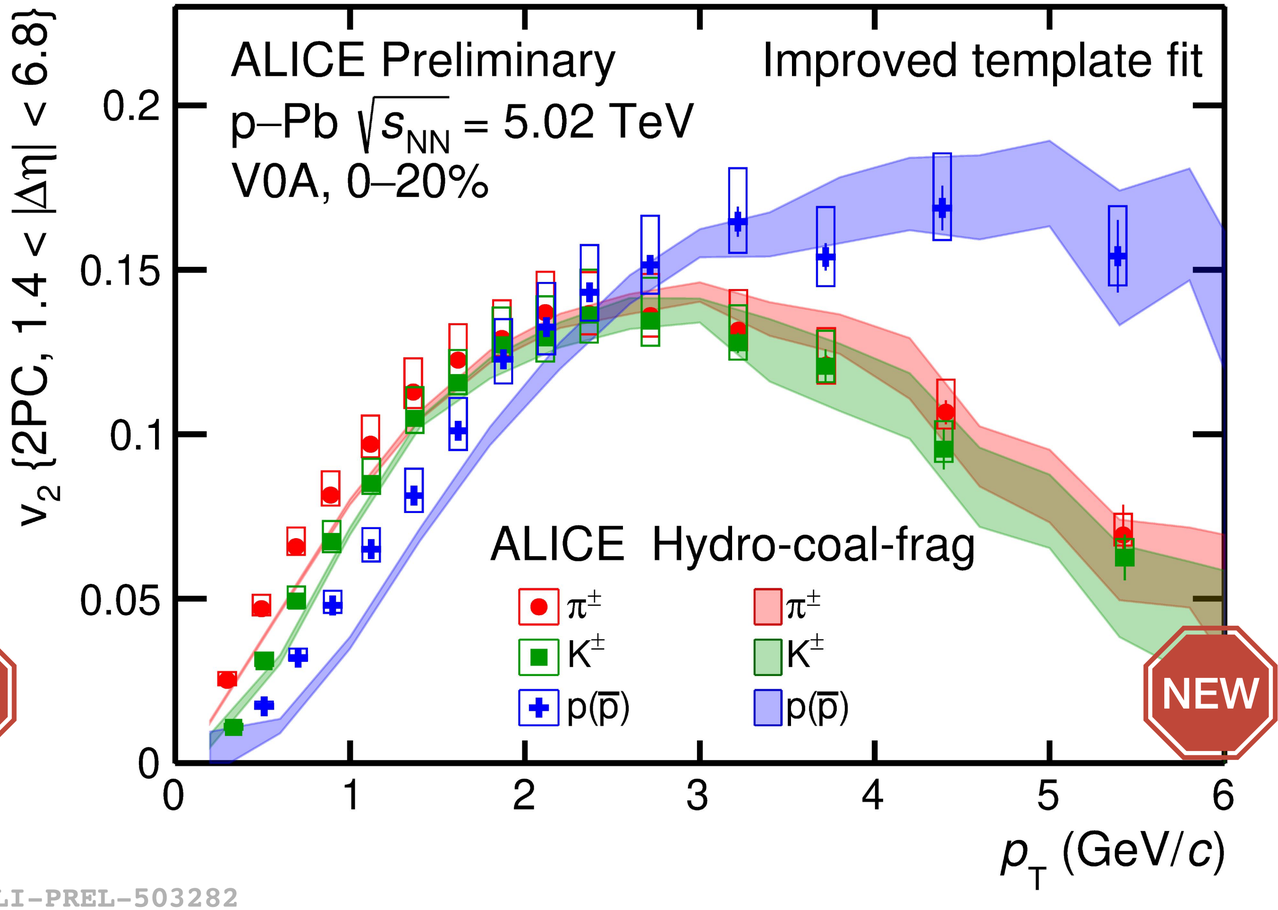


- Baryon - meson splitting in both pp and p-Pb
- p-Pb model comparison indicates partonic flow + coalescence
- No J/ψ flow within uncertainties in high-multiplicity pp collisions

Z. Moravcova - 06/04/2022, 11:50

Identified particles flow in small systems





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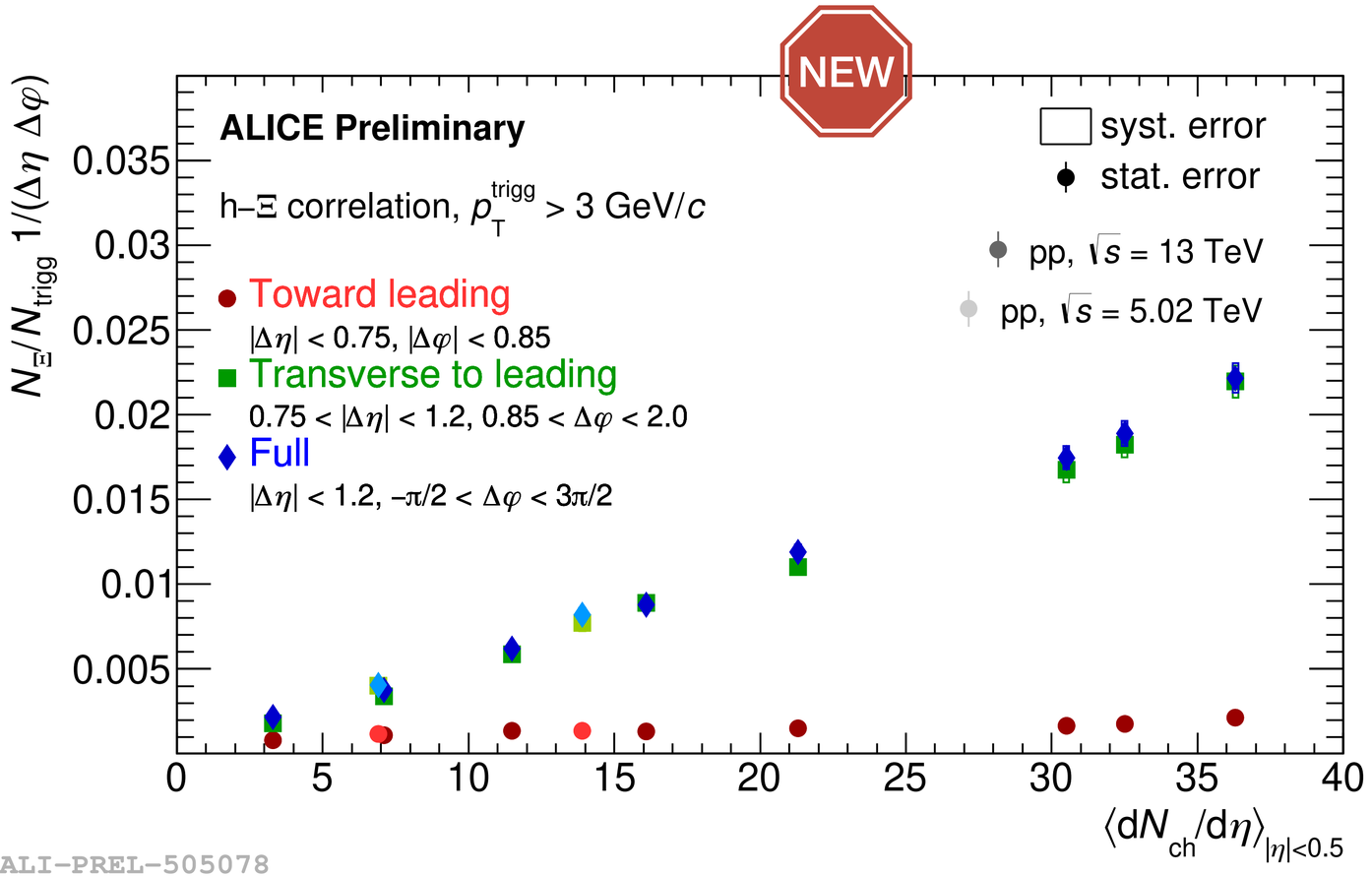
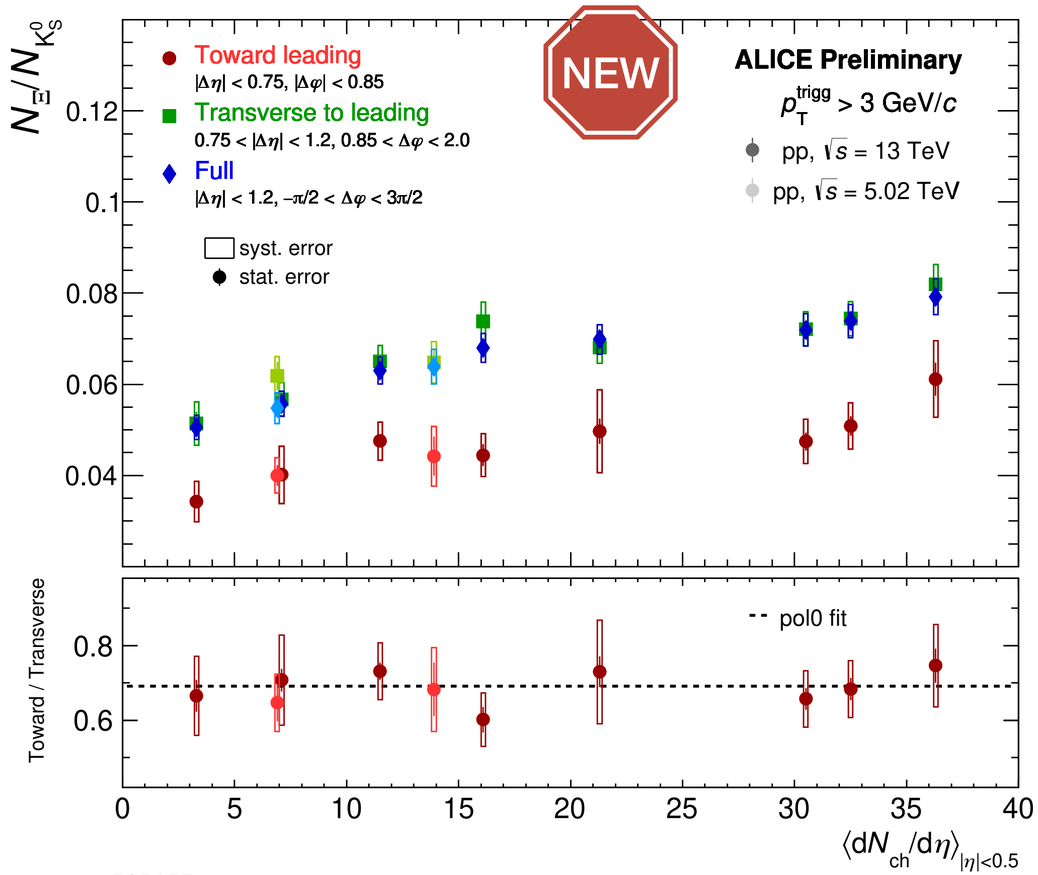
Investigating the strangeness enhancement



ALI-PREL-505078

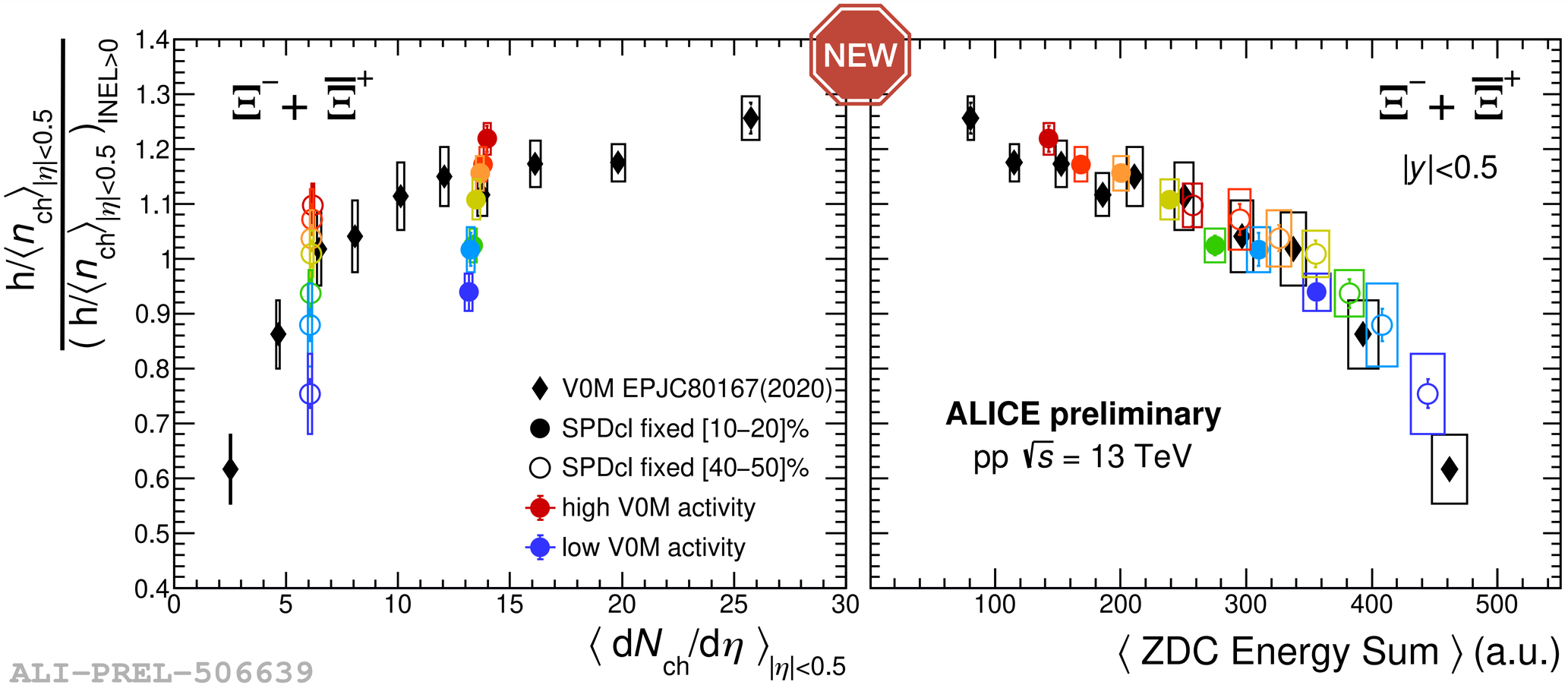


ALI-PREL-505157

Production of multi-strange hadrons occurs mostly transverse to high p_T particles

➡But the towards /transverse fraction is constant with multiplicity

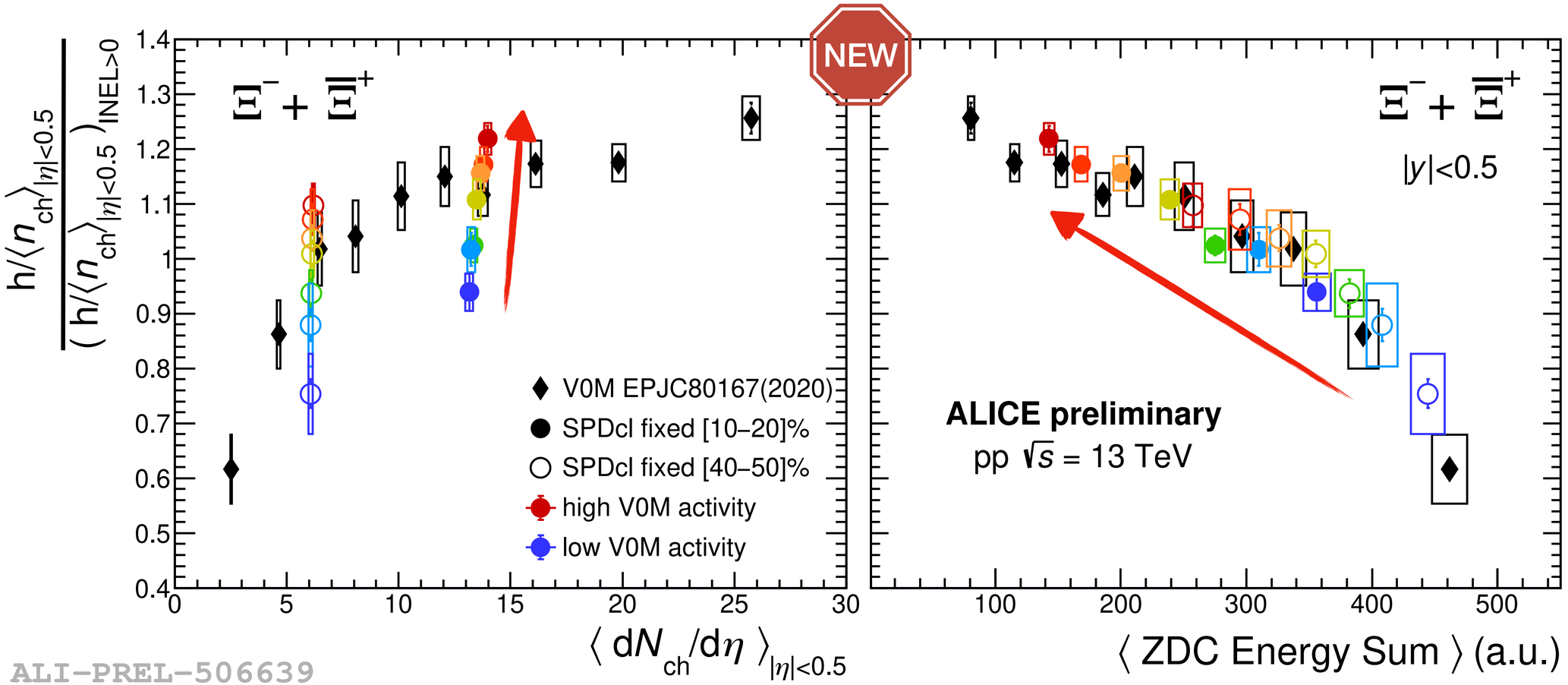
Investigating the strangeness enhancement



New study vs forward energy emission demonstrates that strangeness enhancement is anticorrelated with forward energy emission, even at fixed midrapidity multiplicity

- Early stages (large rapidity gap) matter in strangeness enhancement

Investigating the strangeness enhancement



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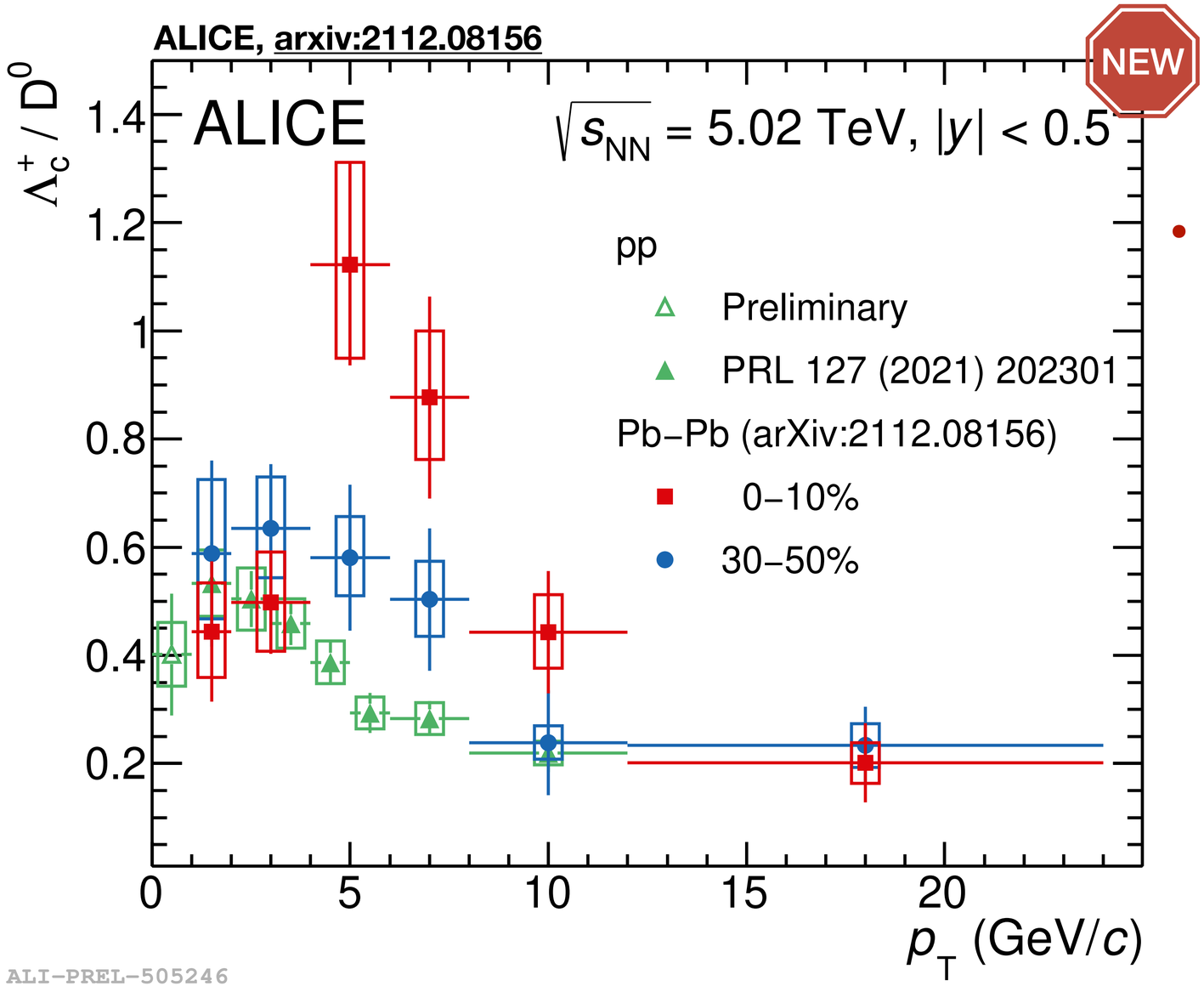
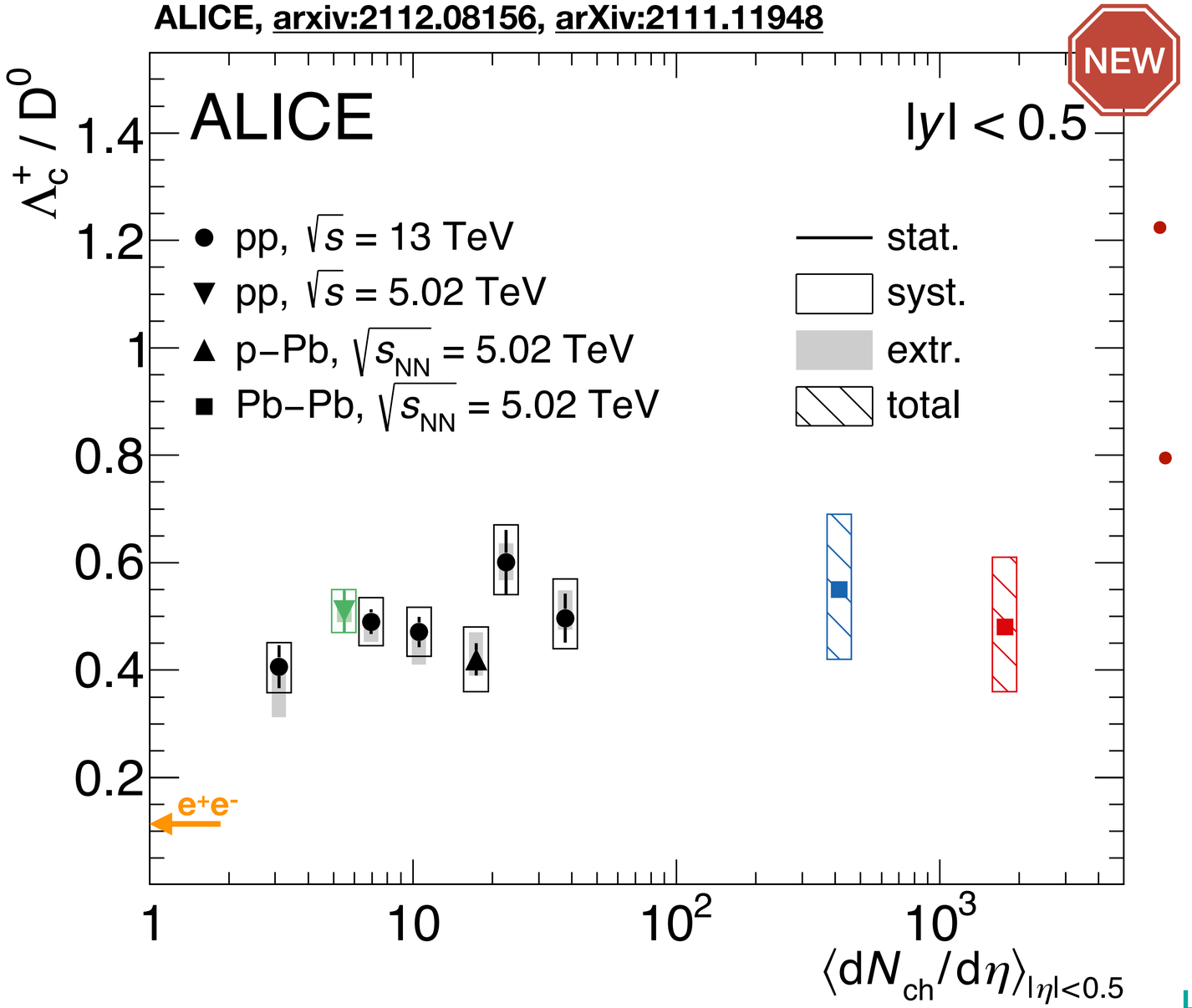
The “baryon anomaly” in the charm sector



- Enhancement of Λ_c/D^0 at intermediate momentum increasing going from pp to larger systems

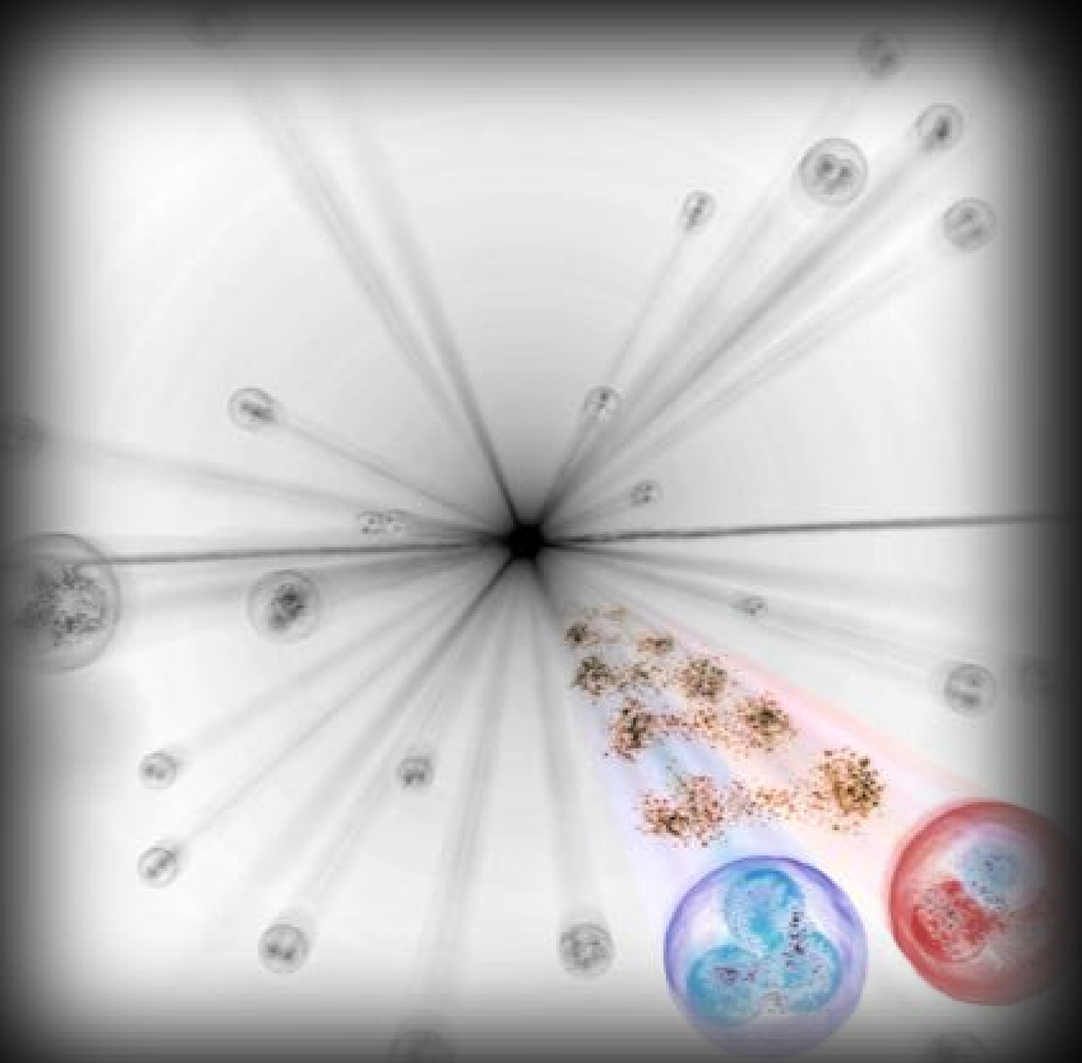
The “baryon anomaly” in the charm sector

ALICE, arxiv:2112.08156, arXiv:2111.11948



- Enhancement of Λ_c/D^0 at intermediate momentum increasing going from pp to larger systems
- However the p_T-integrated Λ_c/D^0 does not show a significant multiplicity dependence
  - Similar to what observed in the light flavour sector (Λ/K^0_S): significant change in the dynamics but similar chemistry across systems
    - Charm recombination + radial flow?

L. Vermunt - 07/04/2022, 09:00 / L. Dello Stritto - 07/04/2022, 16:00

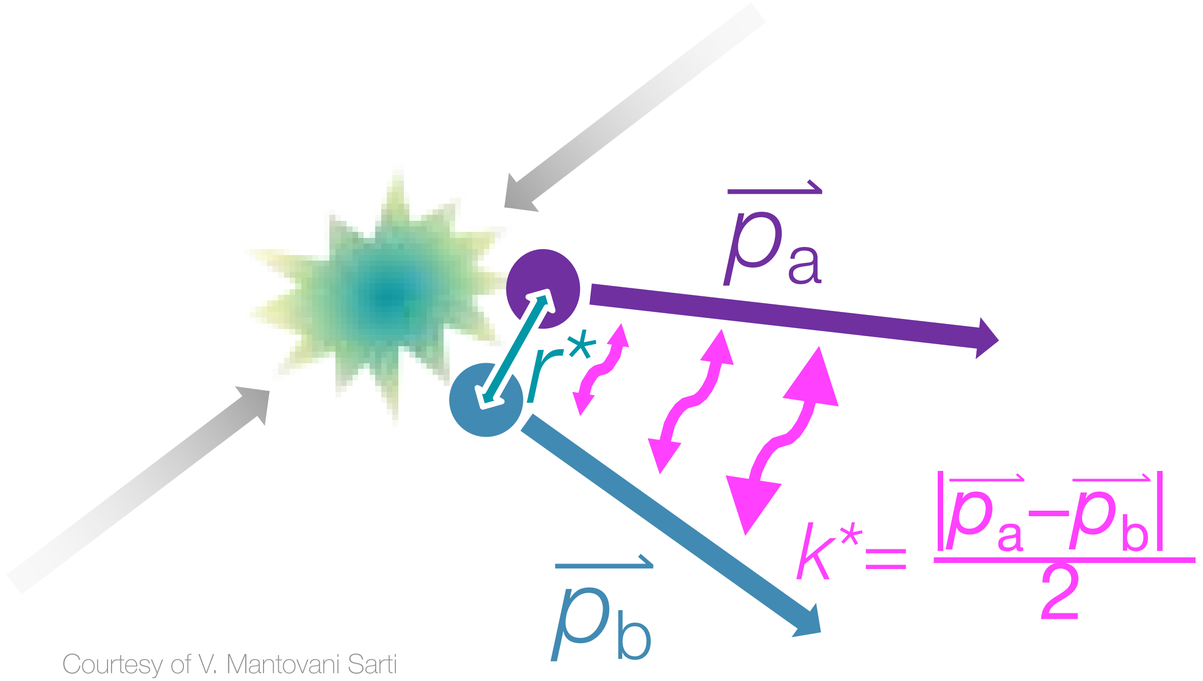


Study of hadron-hadron(-hadron) interaction

Charm hadron interaction with hadrons

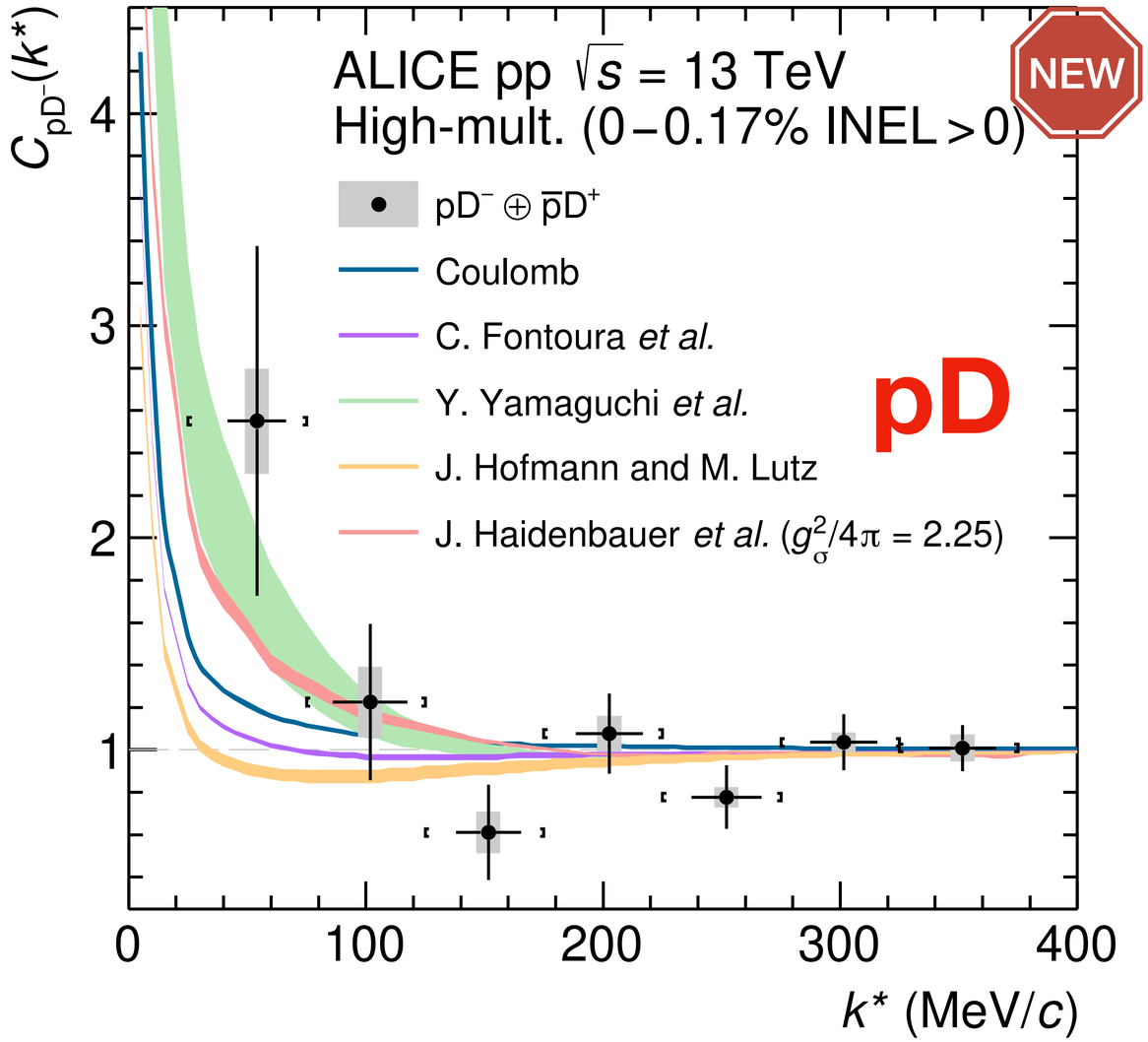
First studies of residual strong interaction between charm and light hadrons

- Data compatible with Coulomb interaction and with shallow attractive strong interaction



Courtesy of V. Mantovani Sarti

ALICE, arxiv:2201.05352



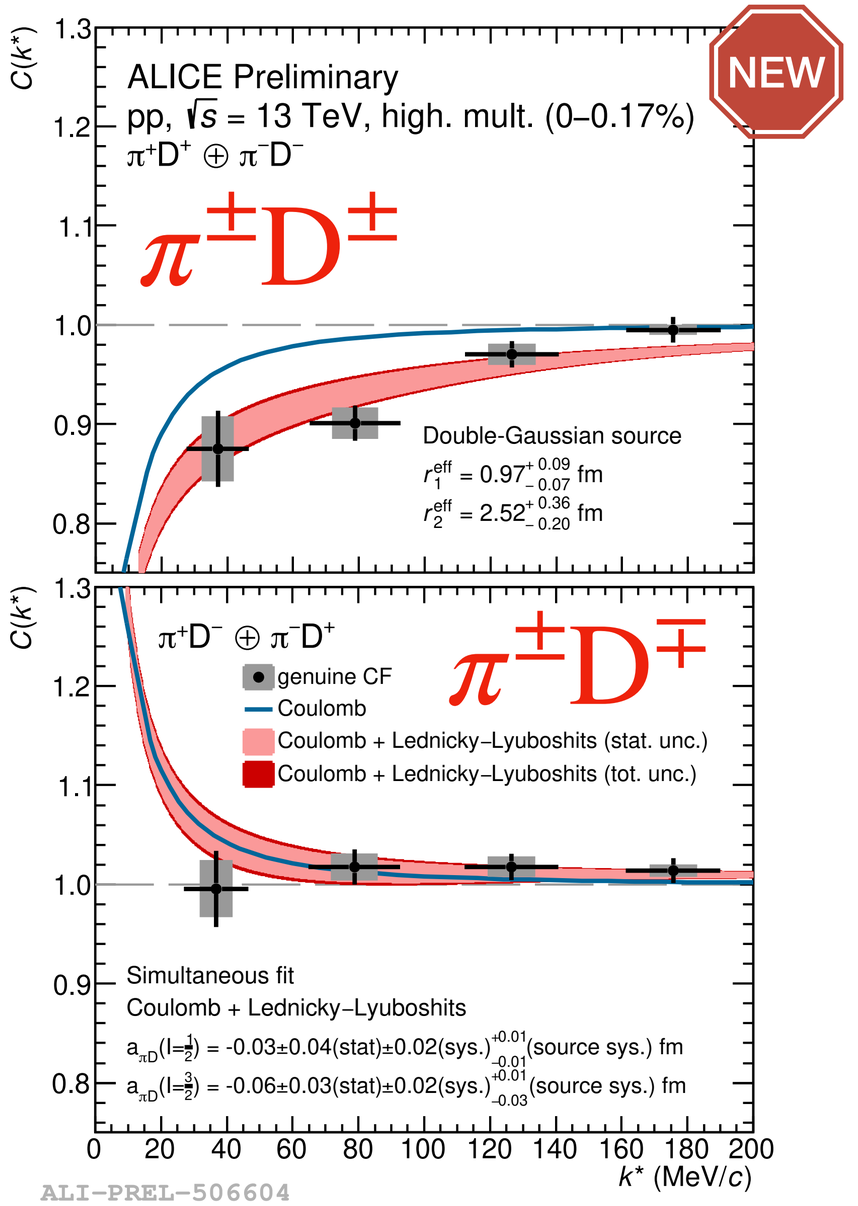
ALI-PUB-502166

Charm hadron interaction with hadrons

First studies of residual strong interaction between charm and light hadrons

- Data compatible with Coulomb interaction and with shallow attractive strong interaction

- Dπ correlation function suggest a deviation from the Coulomb baseline
  - Simultaneous fit to same sign and opposite sign correlations to study the isospin dependence



F. Grosa - 06/04/2022, 15:40

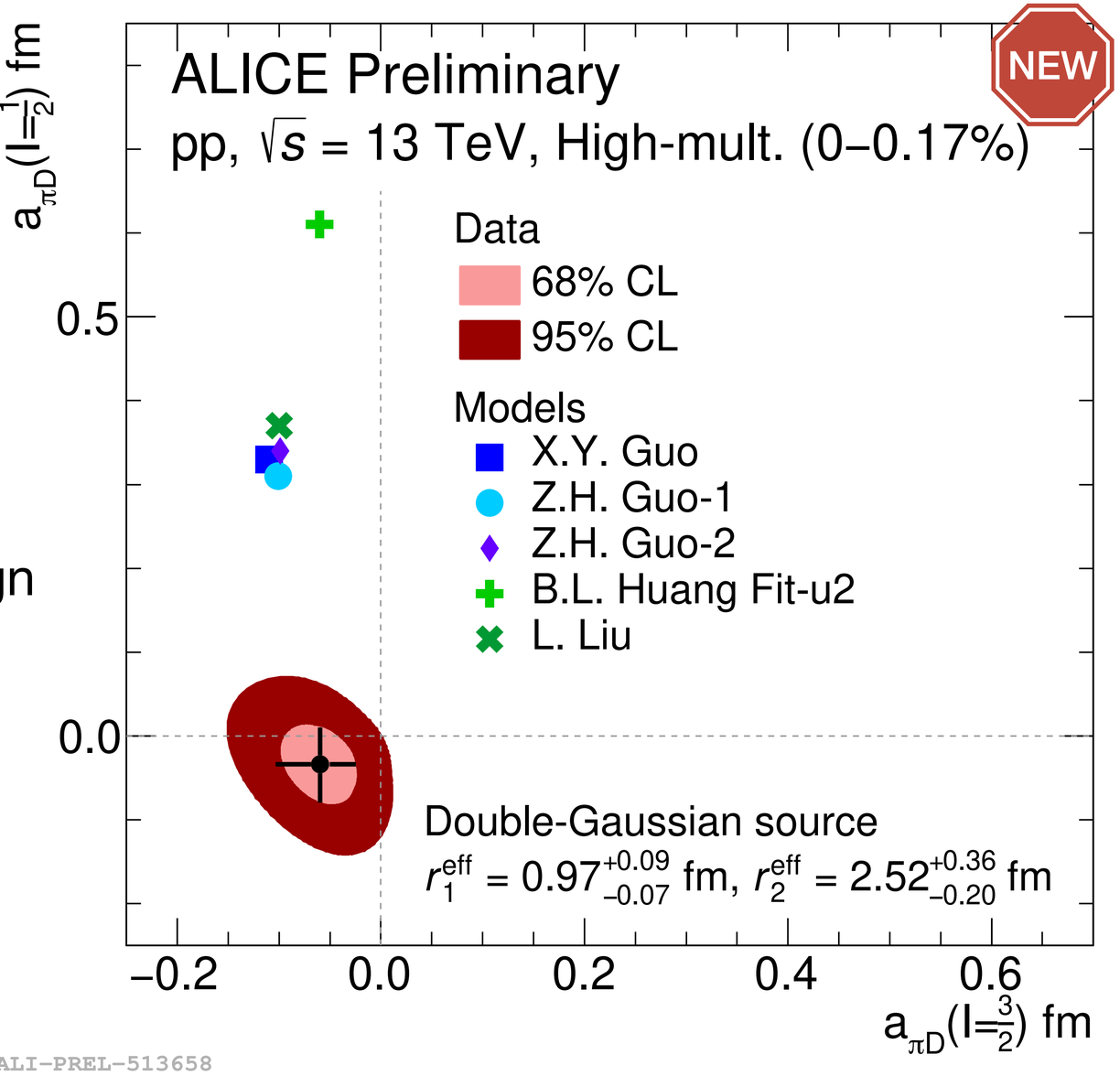
Charm hadron interaction with hadrons

First studies of residual strong interaction between charm and light hadrons

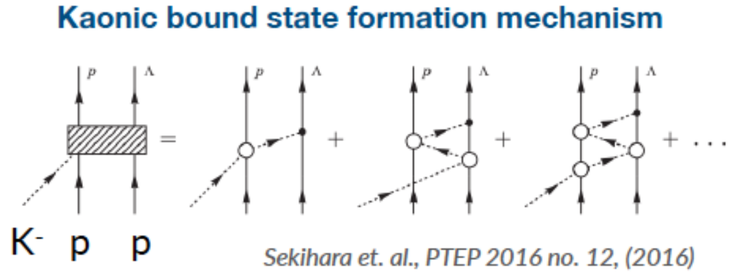
- Data compatible with Coulomb interaction and with shallow attractive strong interaction

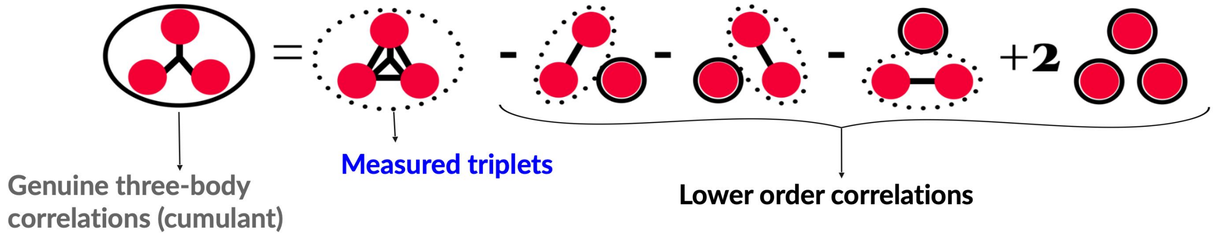
- Dπ correlation function suggest a deviation from the Coulomb baseline
  - Simultaneous fit to same sign and opposite sign correlations to study the isospin dependence

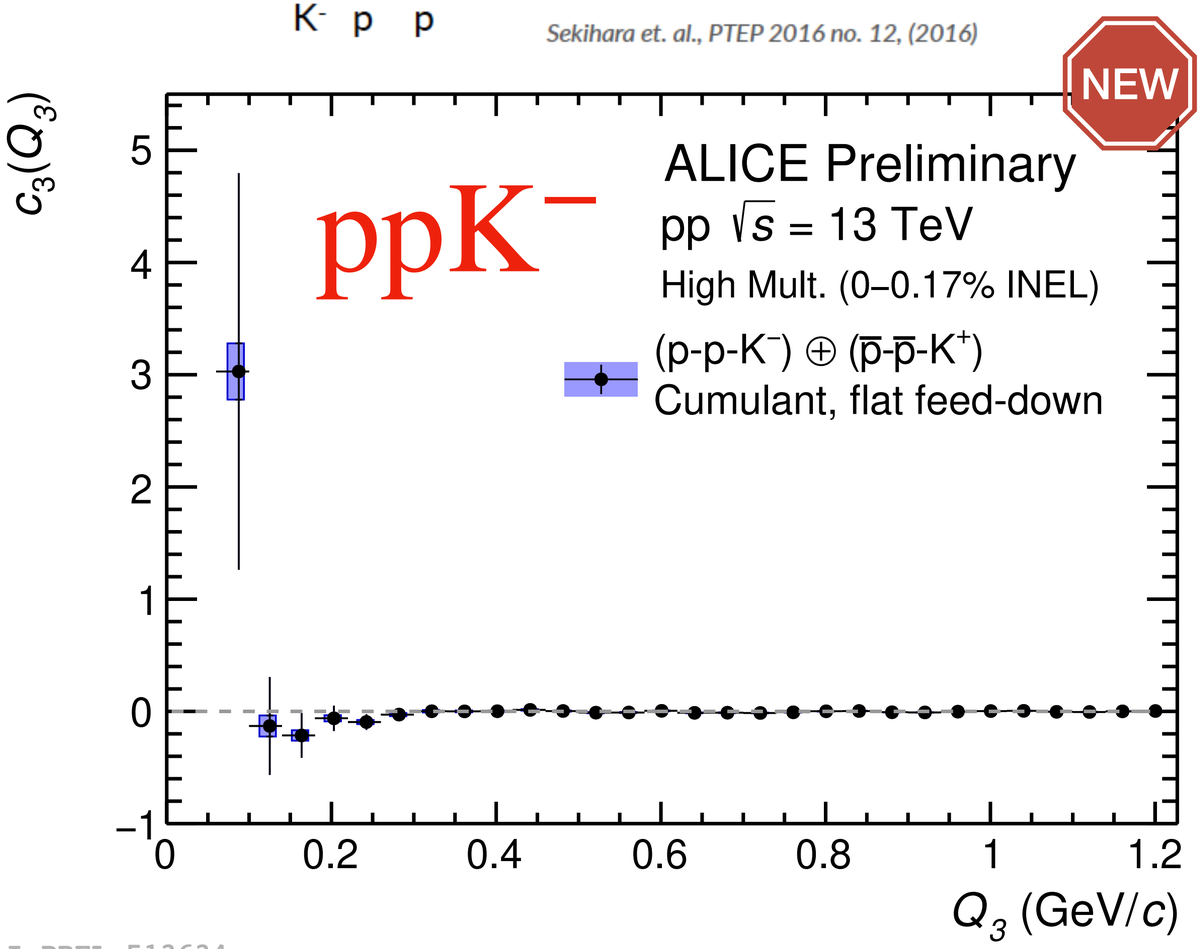
- Scattering parameters extracted are lower than LQCD expectations
  - Suggest limited relevance of D hadronic rescattering in HI



Three-body interactions: from kaonic bound states to nuclei



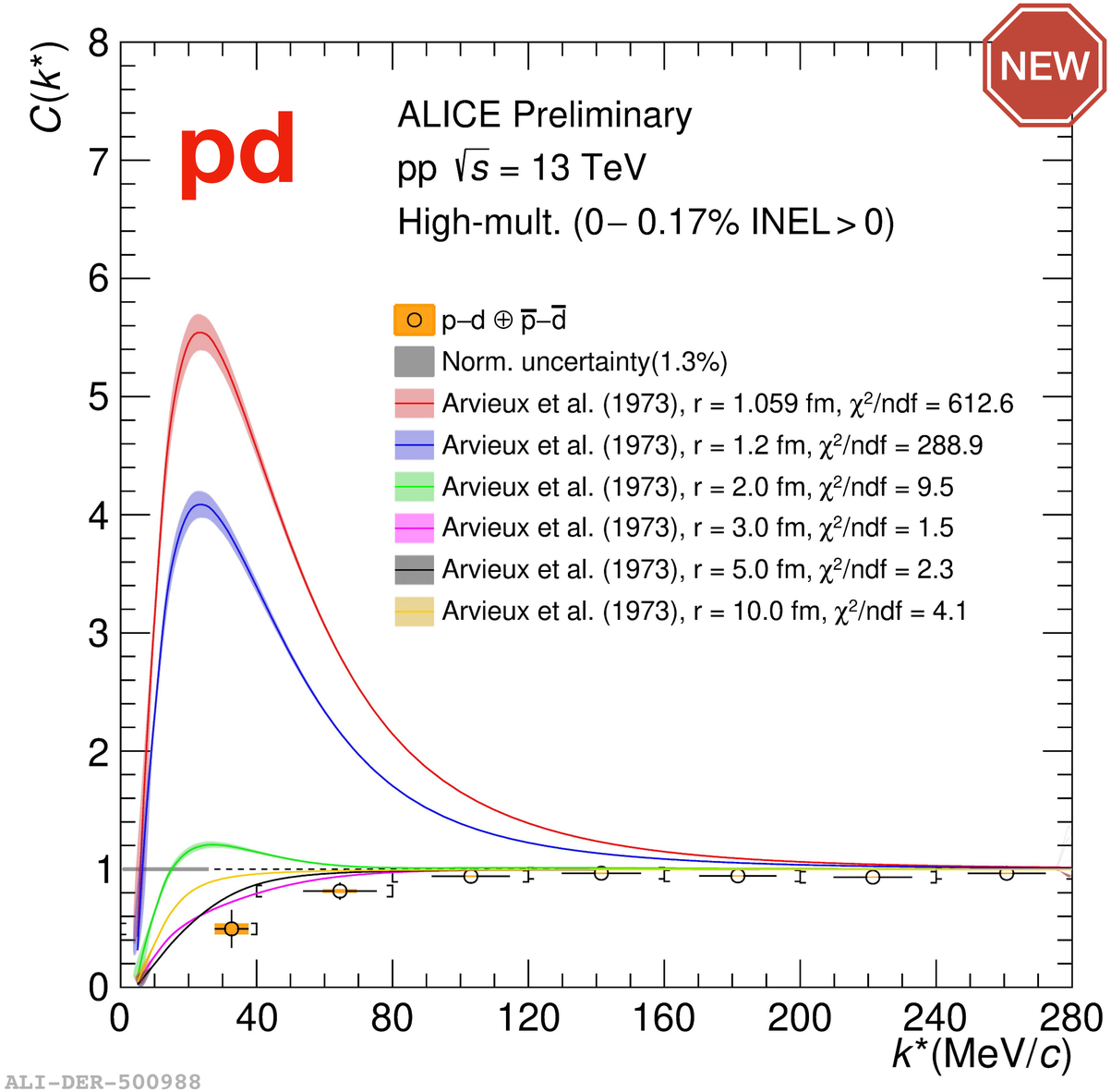




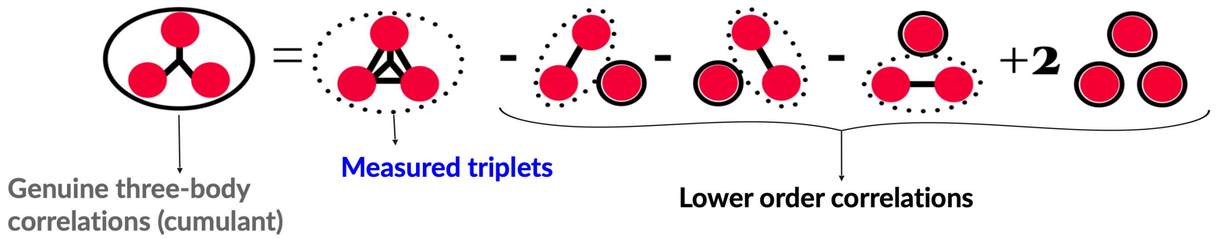
ALICE is pioneering new methods to explore the three body interactions

- First measurement of the genuine three-body $\mathrm{NN\overline{K}}$ interactions via cumulants
  - three-body effects are found to be not significant in $\mathrm{ppK^-}$ systems

Three-body interactions: from kaonic bound states to nuclei



ALI-DER-500988



ALICE is pioneering new methods to explore the three body interactions

- First measurement of the genuine three-body $\mathrm{NN\overline{K}}$ interactions via cumulants
  - three-body effects are found to be not significant in $\mathrm{ppK^-}$ systems

- First measurement of proton-deuteron interaction via correlations at the LHC
  - Model fits the data only for large source radii
    - Insights into the production time of nuclei?

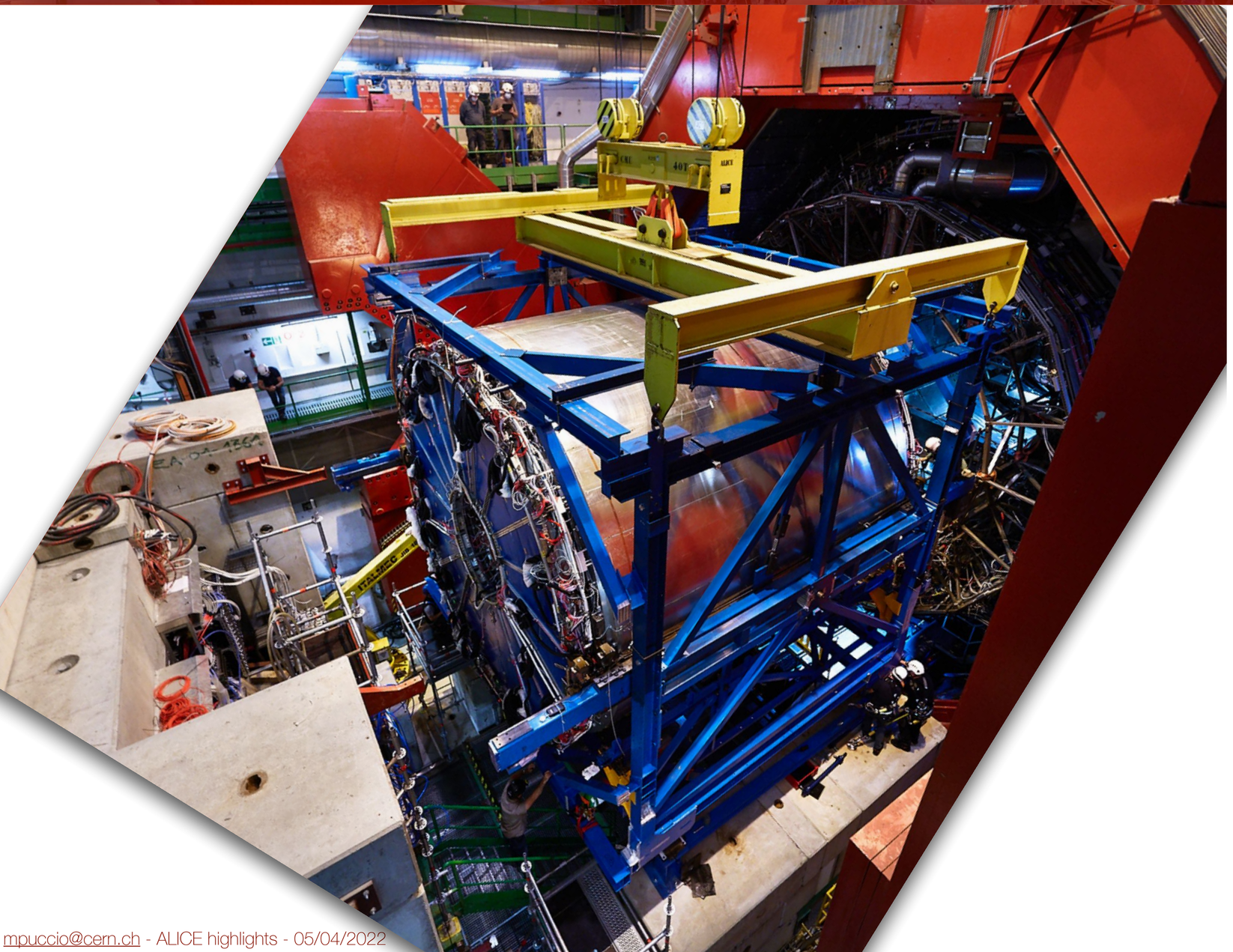
SIGH!

Not enough time to show all

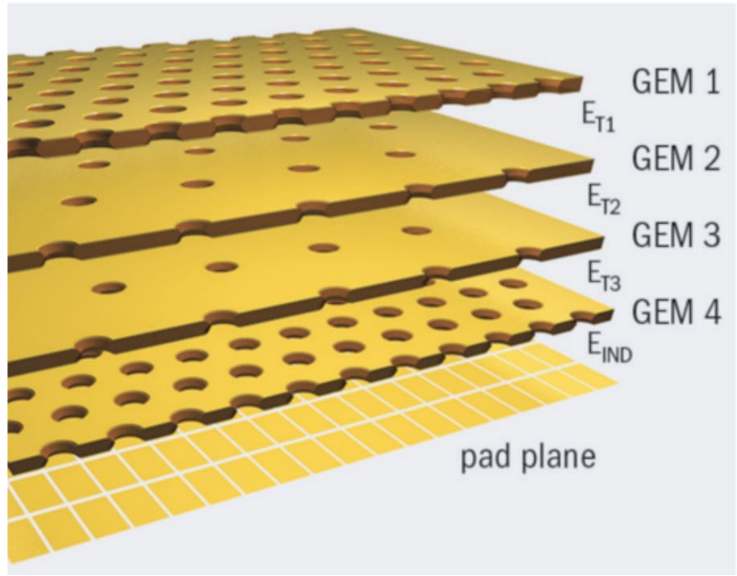
the ALICE results...

Last QM: farewell ALICE 1!

The Upgraded TPC back in ALICE

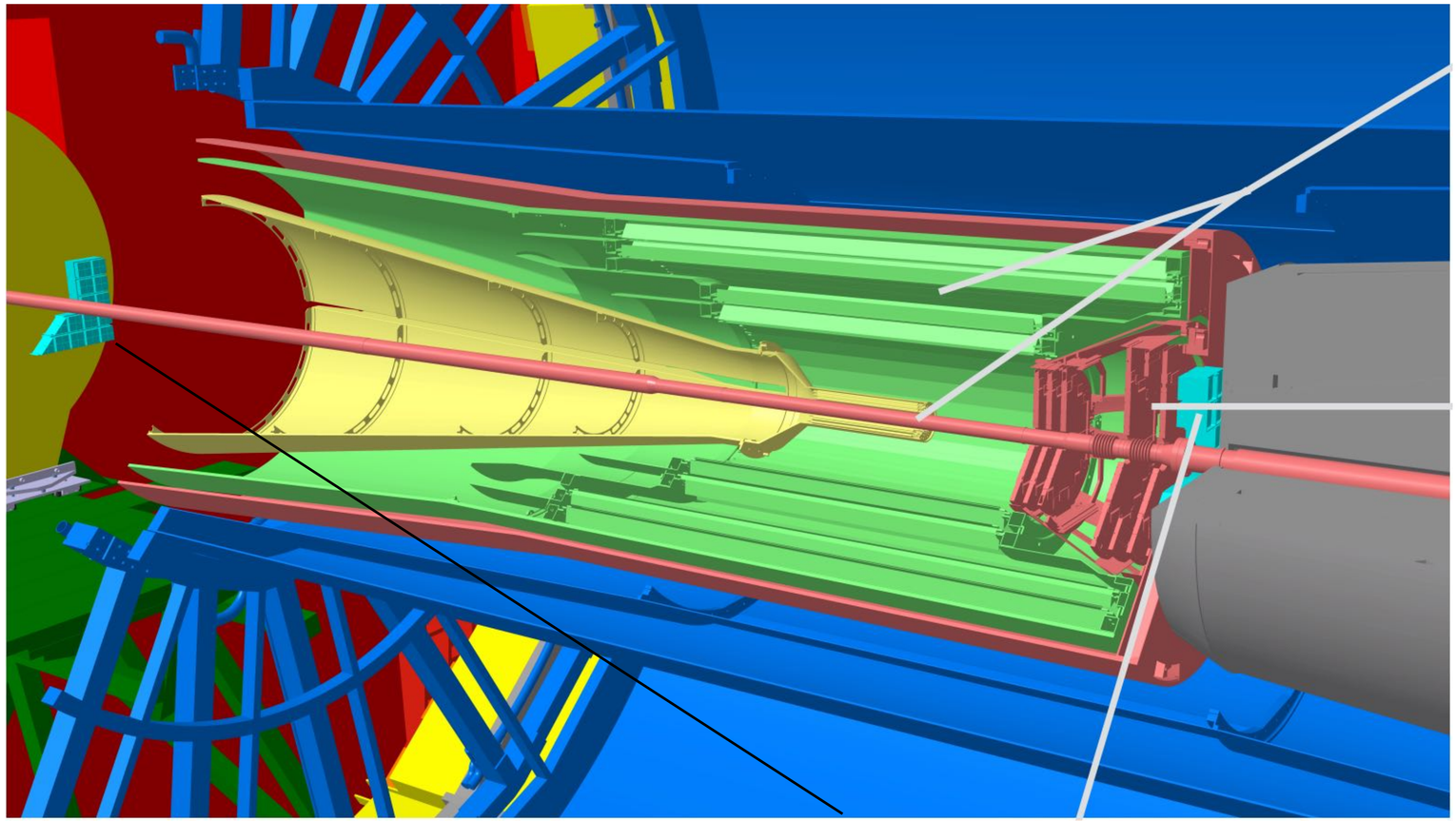


- MWPCs replaced with GEMs
  - Enabling continuous readout @50 kHz Pb-Pb interaction rate
- Fully installed in August 2020



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

The innermost detectors



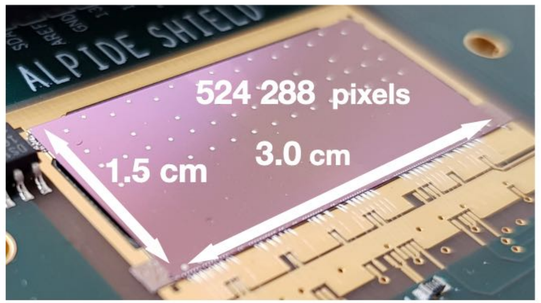
New fast interaction trigger (FIT)

ITS2: new inner tracking system

- Improved pointing resolution (× 3)
- Inner barrel: 0.35% X_0 per layer
- Smaller beam pipe, 1st layer closer (22 mm)

MFT: muon forward tracker

- New tracker based on ALPIDE
- Now tracking before the absorber: improved muon pointing



ALPIDE chip

MFT

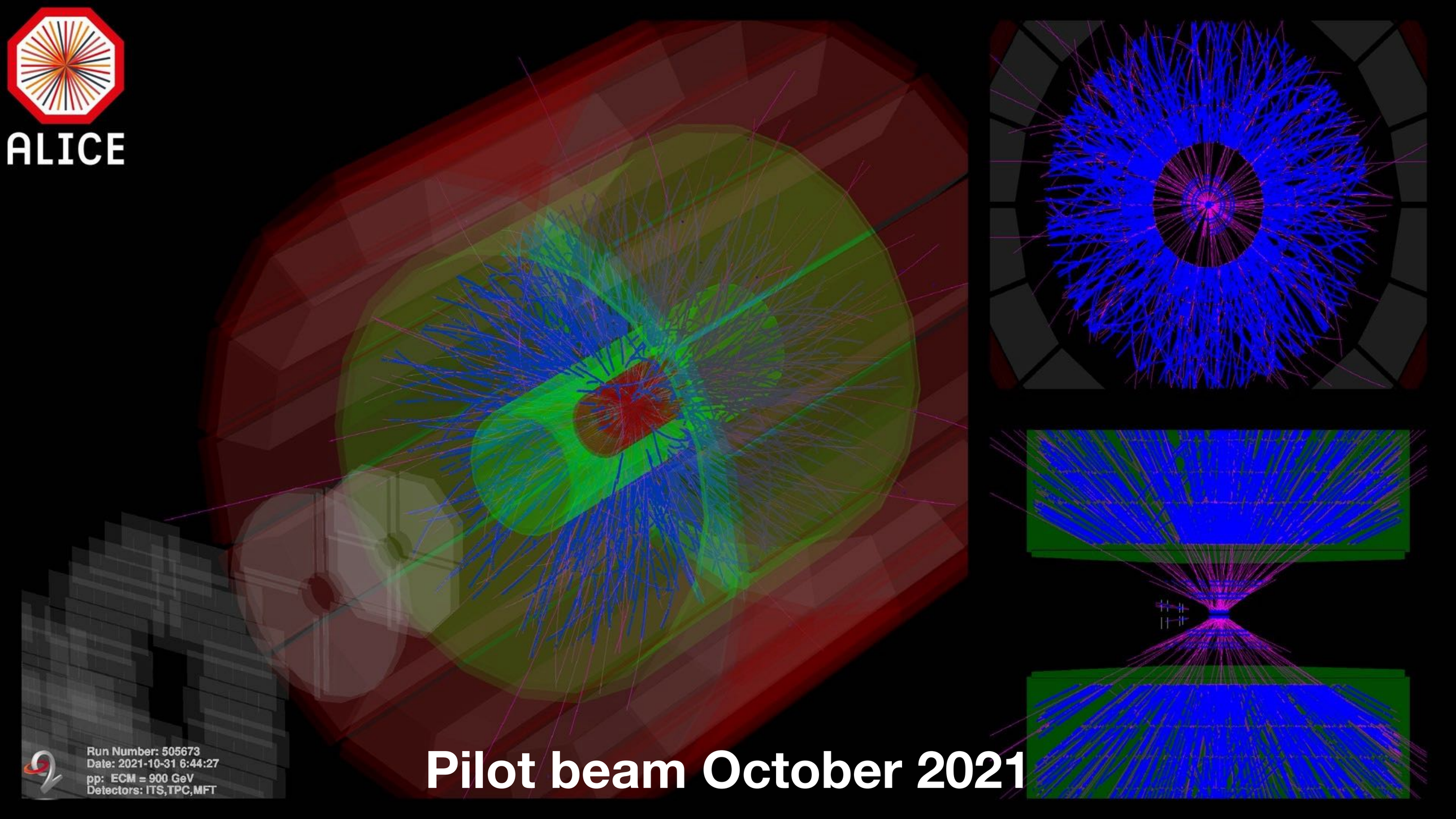
inner barrel
(bottom half)

outer barrel

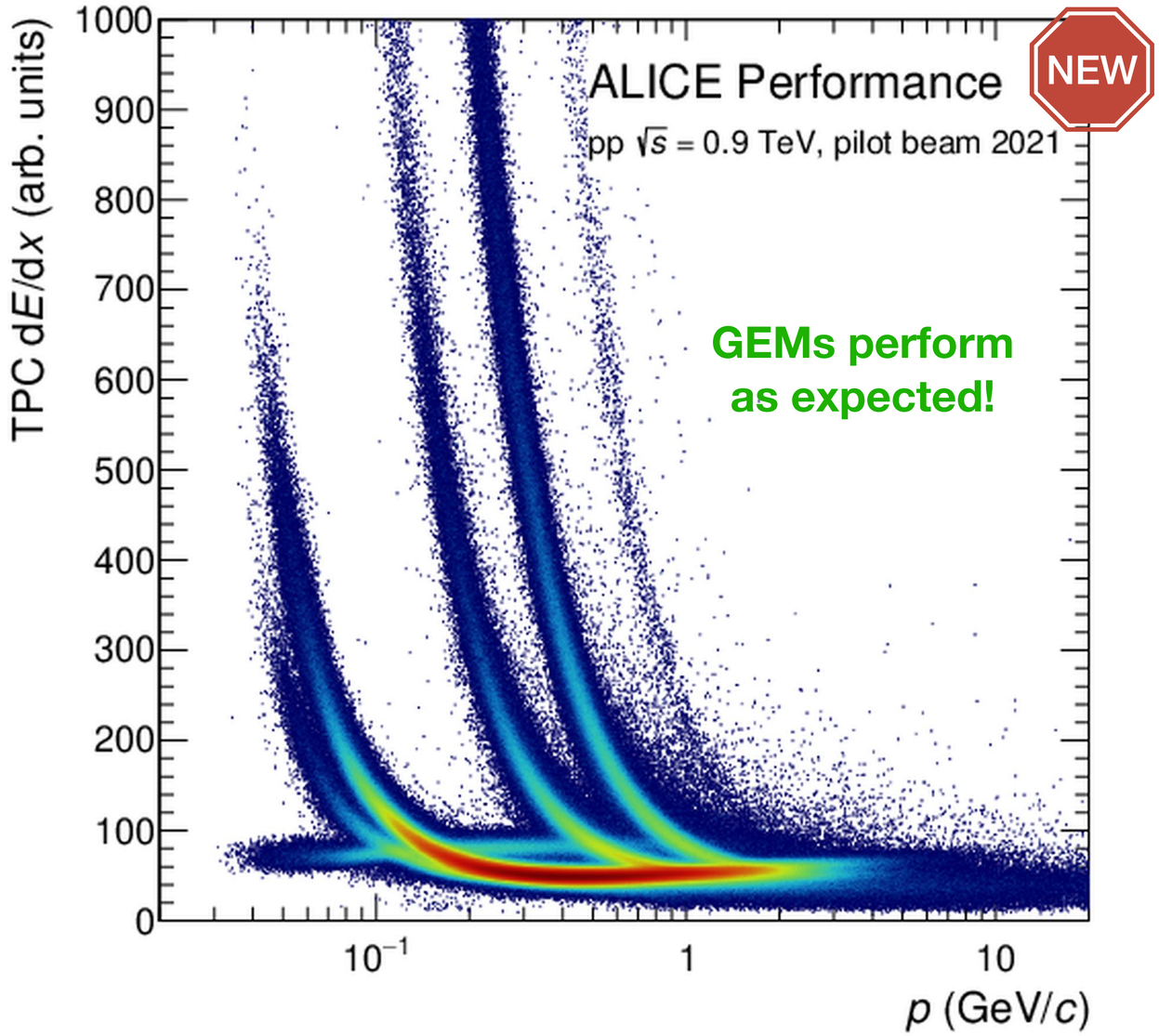
beampipe

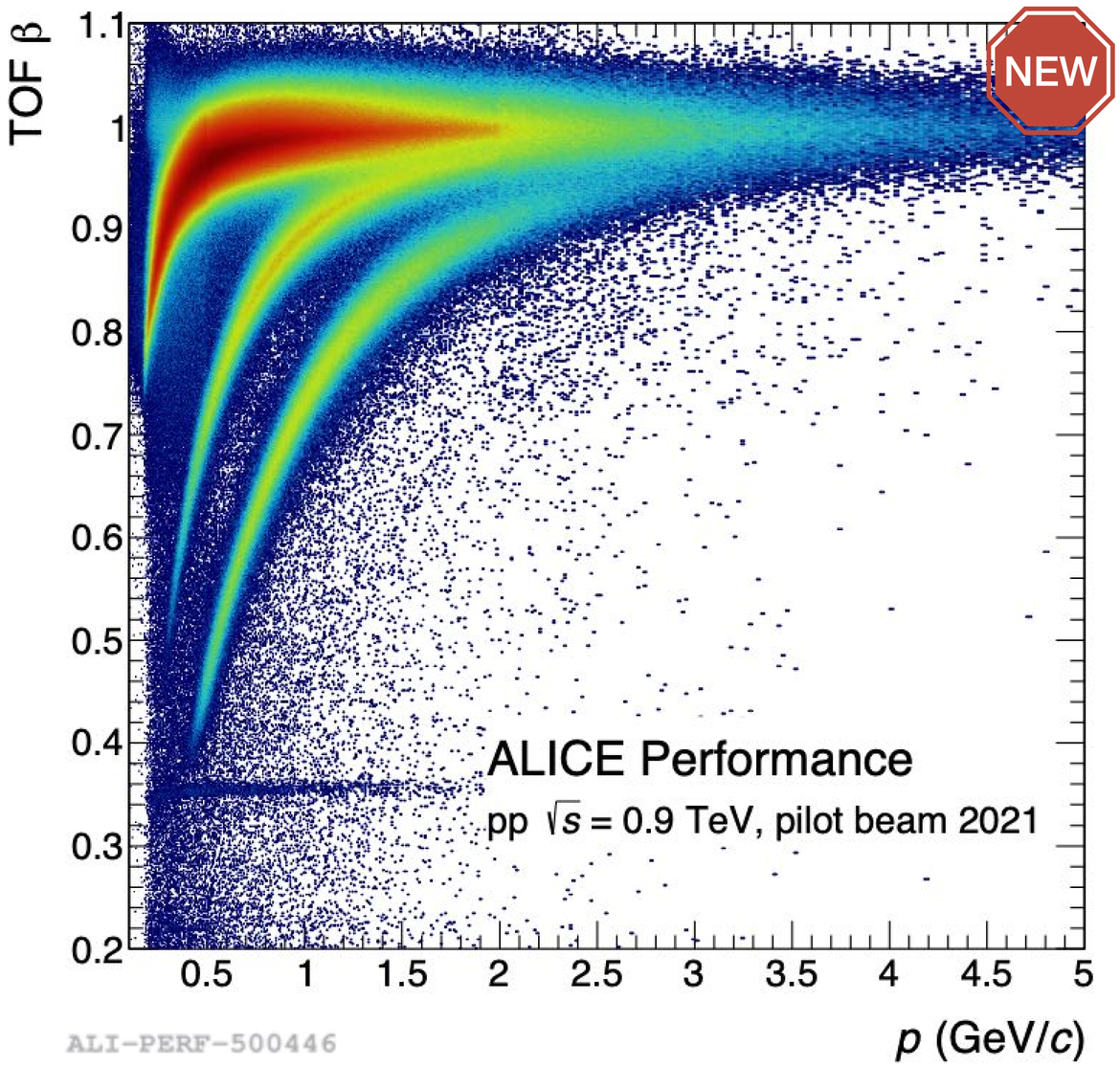
ITS2: 10 m^2, 12.5x10^9 monolithic CMOS pixels,
fully installed in May 2021


Summer 2021: welcome ALICE 2!


ALICE
Run Number: 505673
Date: 2021-10-31 6:44:27
pp: ECM = 900 GeV
Detectors: ITS,TPC,MFT
Pilot beam October 2021

ALICE 2 first collisions: pilot beam 2021

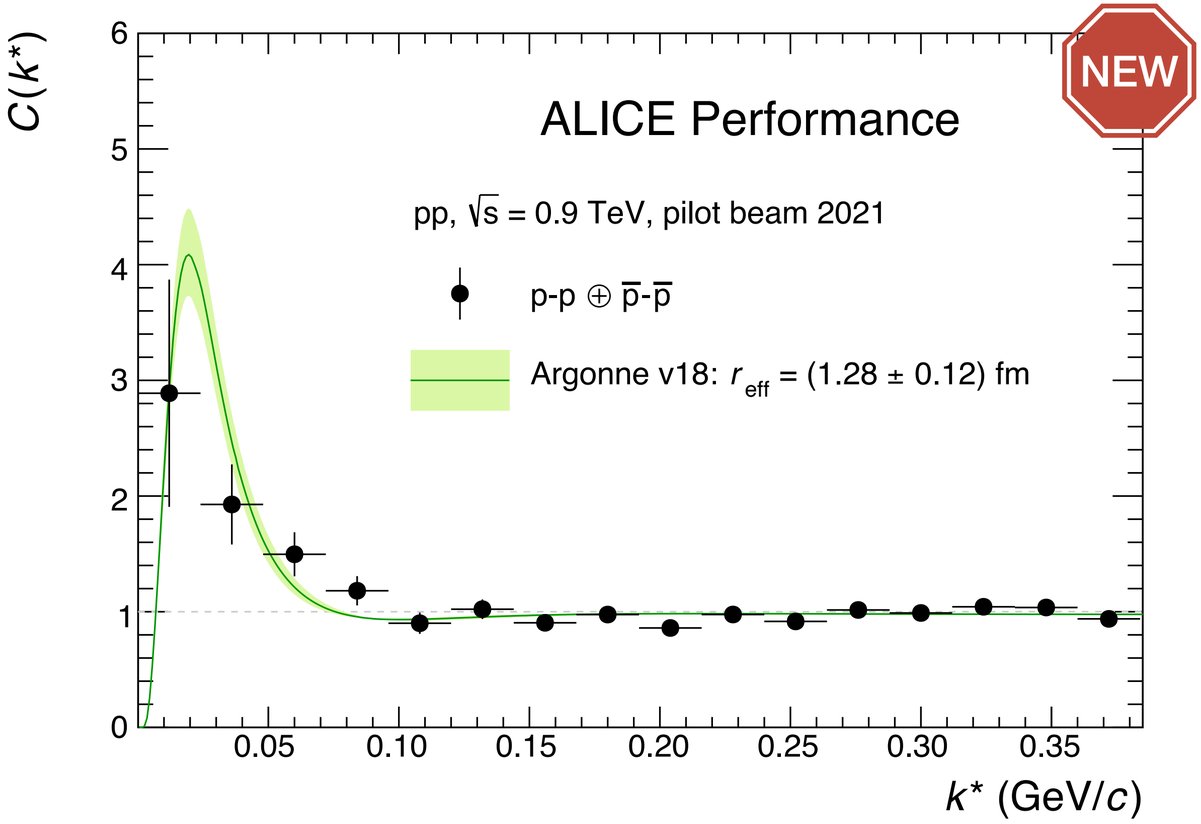


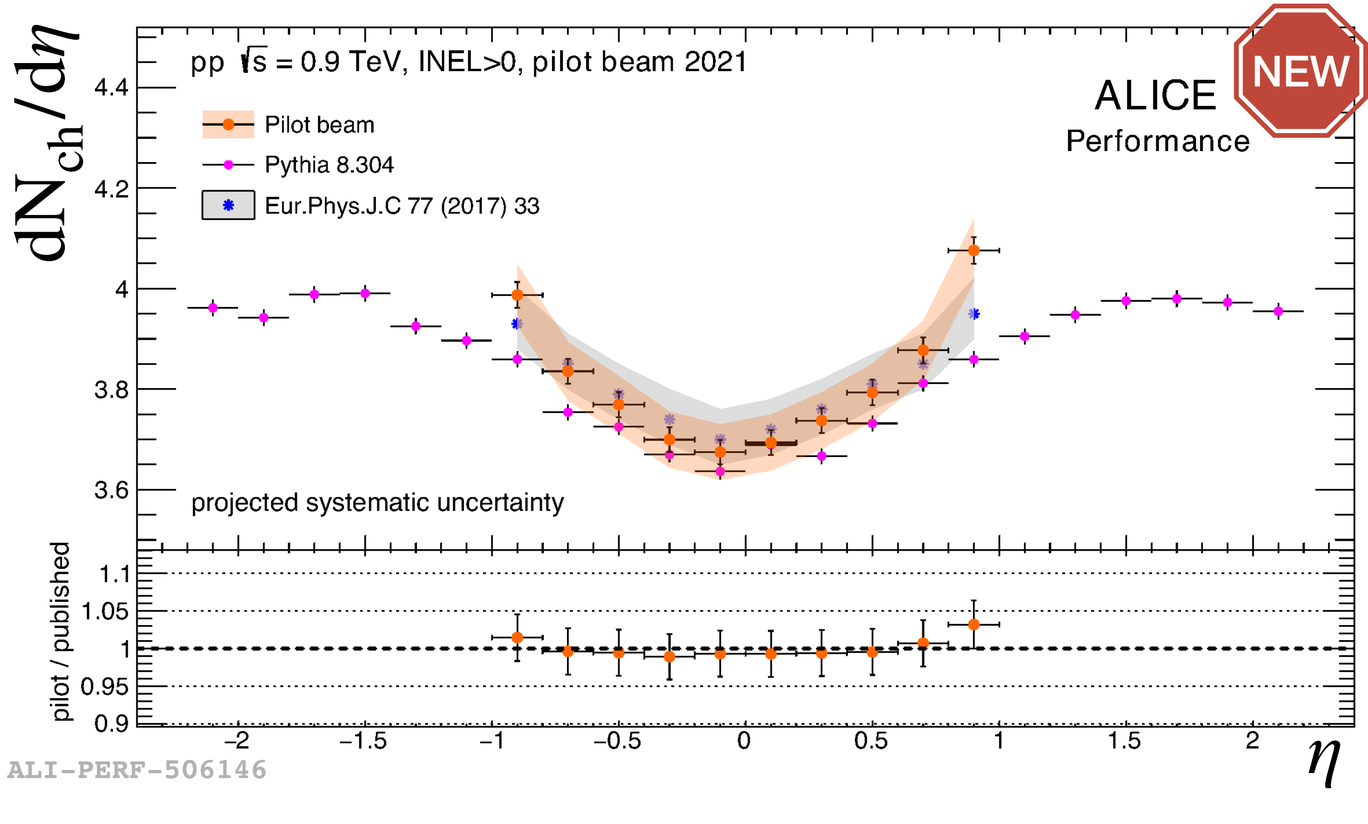


Full PID capabilities already available!

A. Alkin - 07/04/2022, 15:40

ALICE 2 first collisions: pilot beam 2021



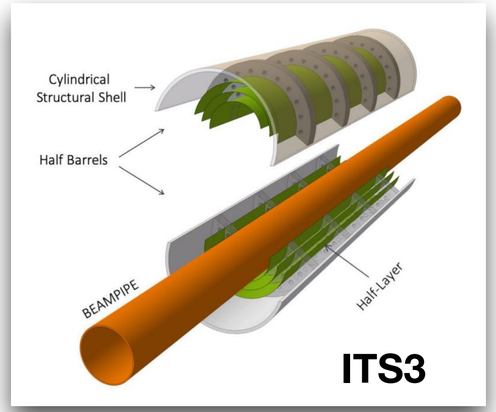


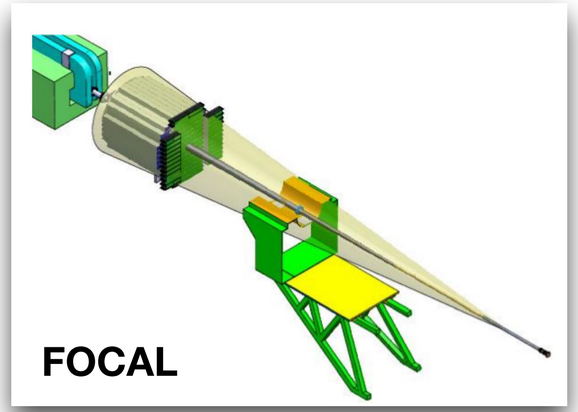
- First look at the pp correlation function in pp collisions at 900 GeV
- Measured $dN_{ch}/d\eta$ compatible with previous results!

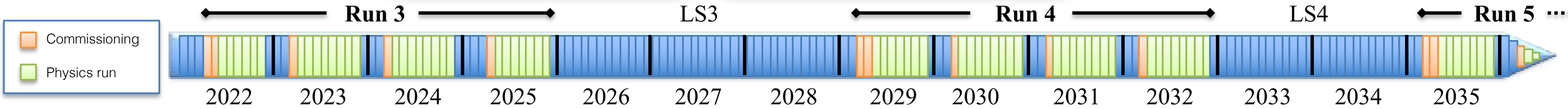
✓ Detector, simulation, reconstruction and analysis software ready for physics!

The future of ALICE

H.S. Scheid - 07/04/2022, 16:00

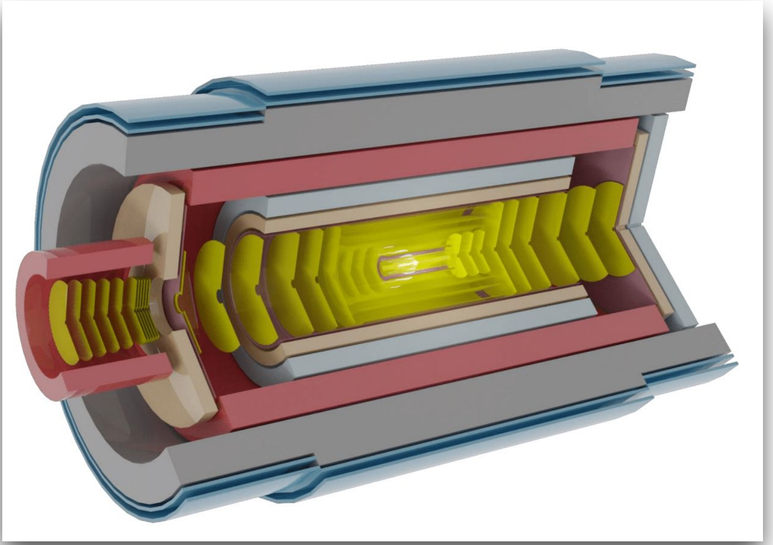






ALICE 3

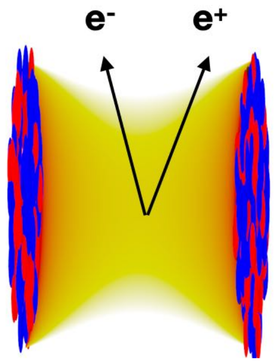
Heavy ion programme for LHC Run 5 and 6

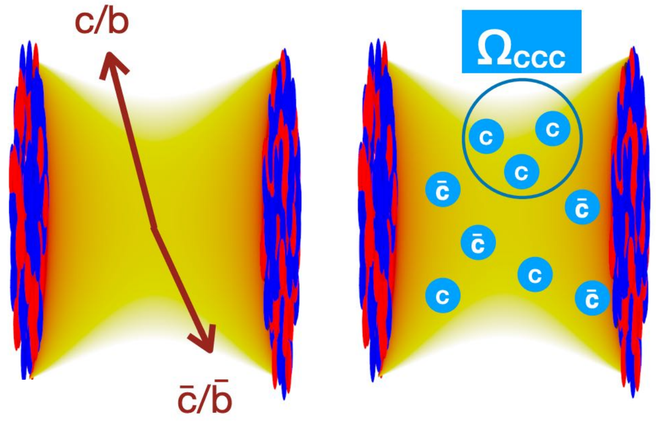


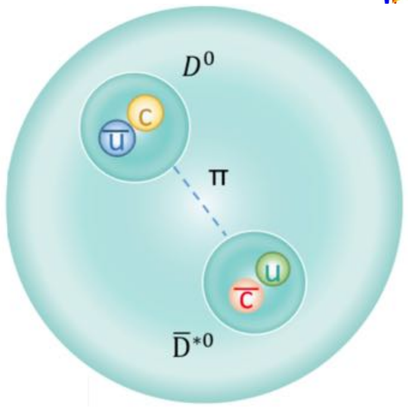
Physics beyond LHC Run 4

Progress beyond Run 3 and 4 relies on

- precision measurements of dileptons
  - evolution of the quark-gluon plasma
  - mechanisms of chiral symmetry restoration in the quark-gluon plasma
- systematic measurements of (multi-)heavy-flavoured hadrons
  - transport properties in the quark-gluon plasma
  - mechanisms of hadronisation from the quark-gluon plasma
- hadron correlations
  - interaction potentials
  - susceptibility to conserved charges
- …







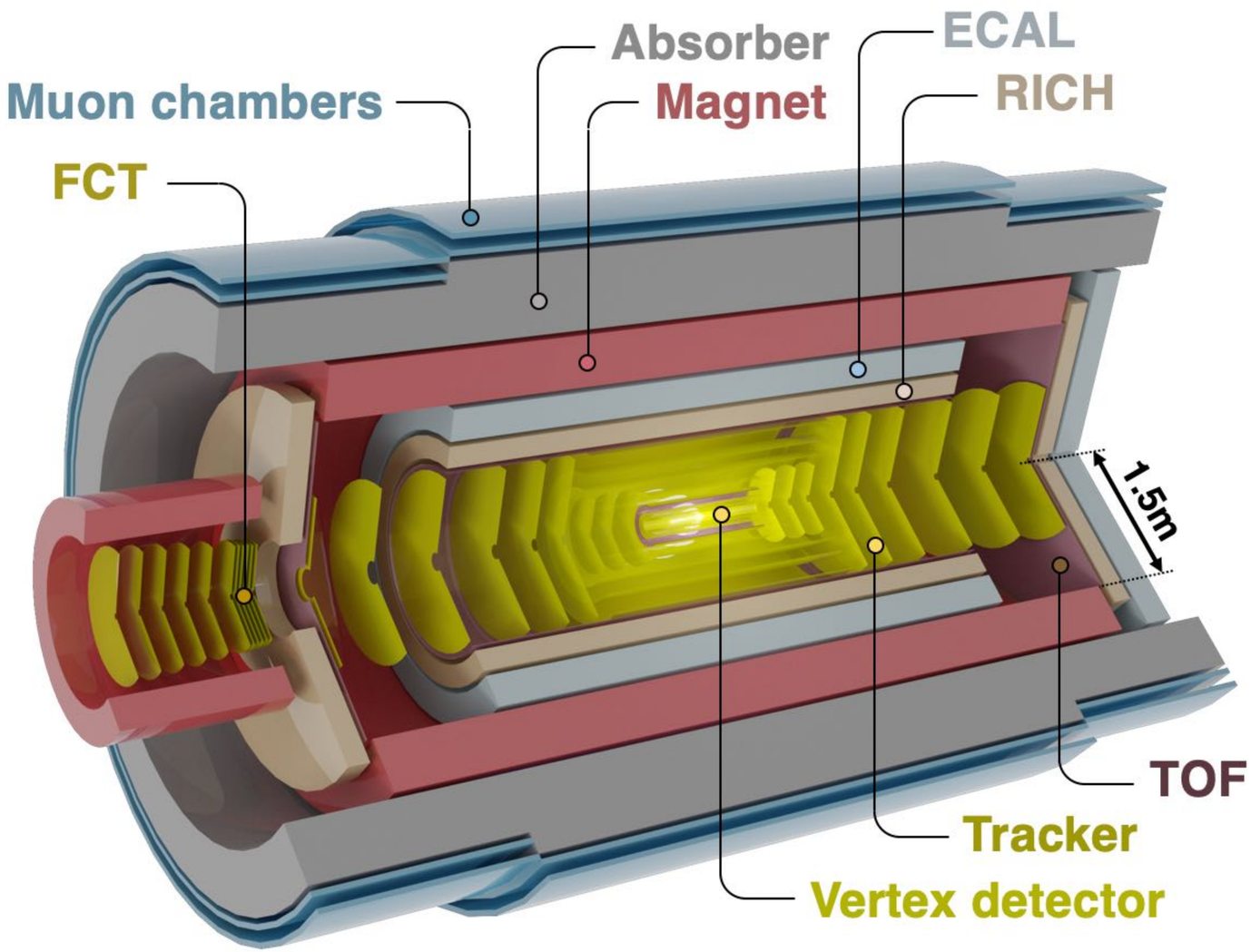
$D^0\overline{D}^{*0}$ molecule
as large as 5 fm

ALICE 3

- All silicon tracker with $\sigma_p/p \sim 1\,\%$ over large acceptance
  - ~10% X_0 overall material budget
- Excellent hadron and lepton PID
  - Silicon-based TOF and RICH
  - Muon chambers with absorber
- Impact parameter resolution: 10 μm at p_T = 200 MeV/c
  - First tracking layer at 5 mm from primary vertex
  - 1‰ X_0 for the innermost layers

Letter of Intent reviewed by the LHCC (LHCC-2022-009)

✓**Recommendation to proceed with the R&D programme**



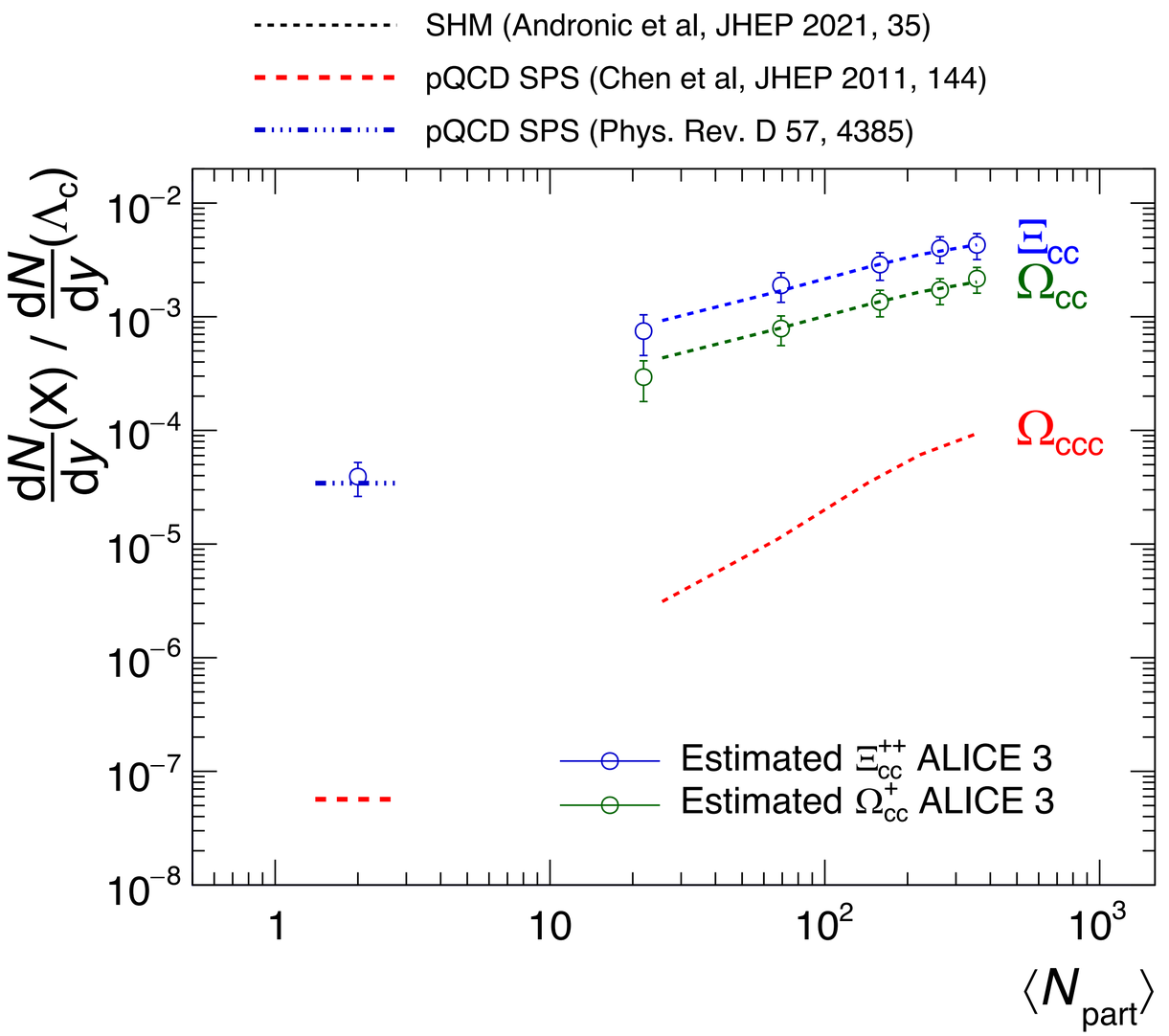
High rate capabilities: fully exploit LHC potential

➡ x5 more AA luminosity than Run 3&4

(Some) ALICE 3 physics highlights

- Multi-charm baryon measurements: key insight into charm production and hadronization
  - Expected level of precision similar to strangeness in Run 1 and Run 2
  - Pointing resolution, large integrated luminosity and acceptance are instrumental

ALICE 3 LOI - LHCC-2022-009



H.S. Scheid - 07/04/2022, 16:00

(Some) ALICE 3 physics highlights

- Multi-charm baryon measurements: key insight into charm production and hadronization
  - Expected level of precision similar to strangeness in Run 1 and Run 2
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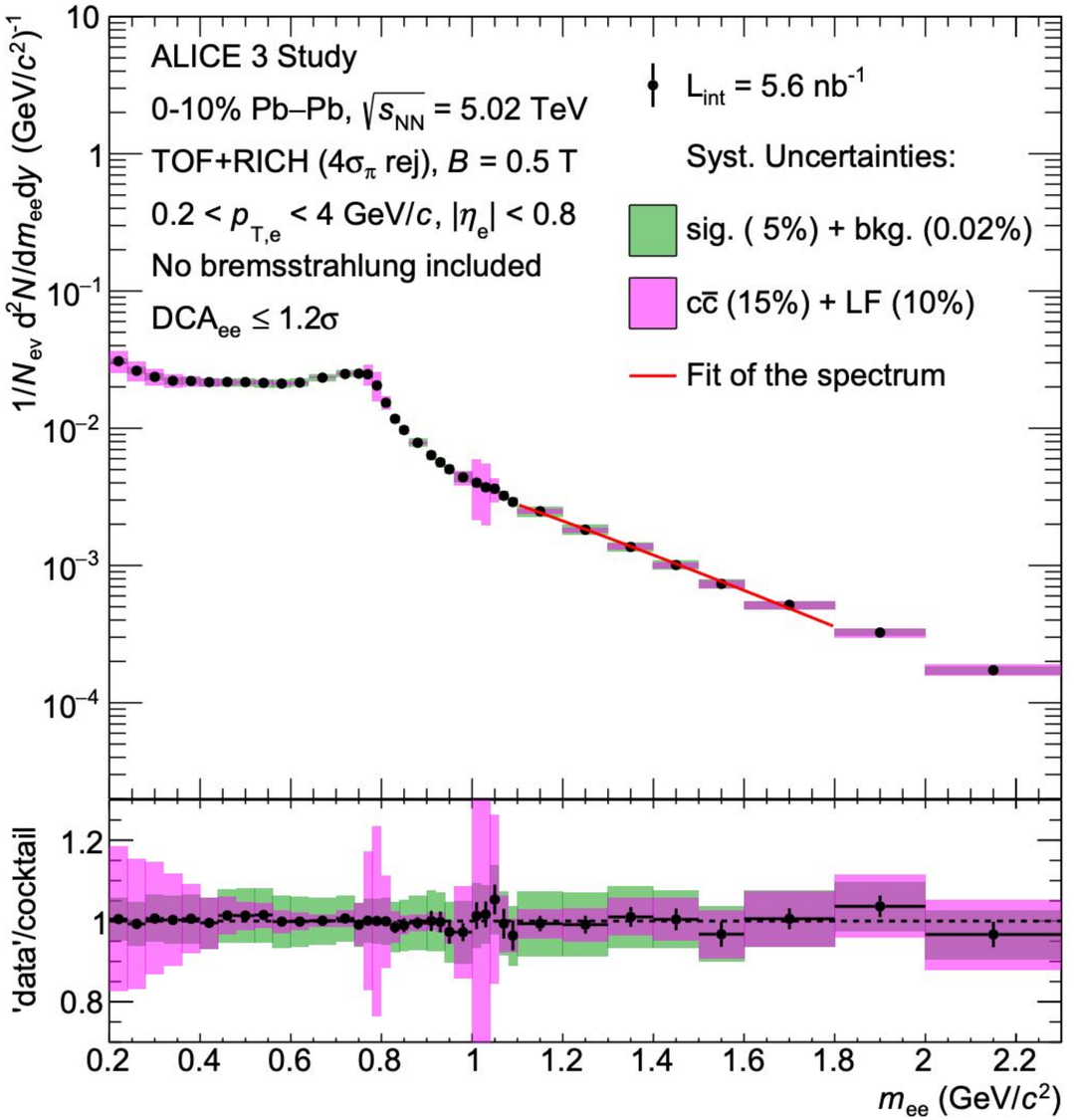
Excellent electron PID and rejection of hadronic electrons and photon conversion

- Temperature determination with dileptons as a function of momentum will be possible
  - Probe different times in the fireball evolution
- Dilepton v_2 and correlations
- Study of $\rho - a_1$ mixing

ALICE 3 LOI - LHCC-2022-009



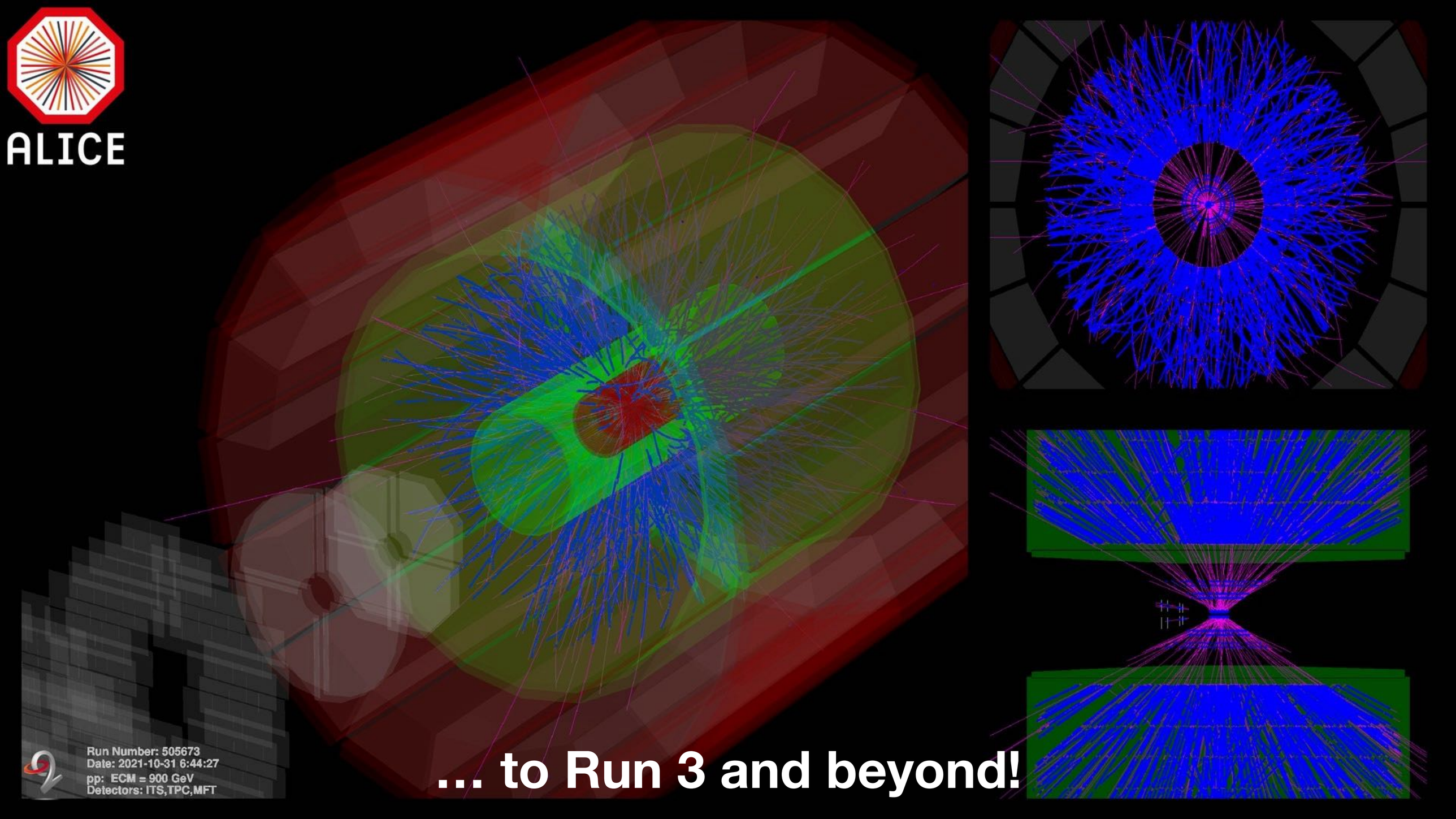
H.S. Scheid - 07/04/2022, 16:00

Come to see all ALICE contributions

- **Isolated-photon production and photon-jet correlations in pp and Pb-Pb collisions at 5.02 TeV in ALICE**
  Alwina Liu (UC Berkeley) - 05/04/2022, 16:30
- **Probing the initial state with isolated-photon production and dijet invariant mass distributions in small collision systems with ALICE**
  Sinjini Chandra (Department of Atomic Energy (IN)) - 05/04/2022, 16:30
- **Quarkonium polarization in Pb-Pb and pp collisions with ALICE**
  Luca Micheletti (Universita e INFN Torino (IT)) - 05/04/2022, 16:50
- **Anisotropic flow fluctuations relative to participant and spectator planes in heavy-ion collisions with ALICE**
  Lukas Kreis (GSI - Helmholtzzentrum für Schwerionenforschung GmbH (DE)) - 06/04/2022, 08:40
- **Study of path-length dependent energy loss of jets in p-Pb and Pb-Pb collisions with ALICE**
  Caitlin Beattie (Yale University (US)) - 06/04/2022, 08:40
- **Jet angularity and fragmentation measurements in heavy-ion collisions with ALICE**
  James Mulligan (University of California, Berkeley (US)) - 06/04/2022, 10:00
- **Precision studies of the strong interaction in Λ-hadron systems up to S=–3 with ALICE**
  Valentina Mantovani Sarti (Technische Universitaet Muenchen (DE)) - 06/04/2022, 10:00
- **Observation of partonic flow in small collision systems with ALICE at the LHC**
  Zuzana Moravcova (University of Copenhagen (DK)) - 06/04/2022, 11:50
- **Beauty production in heavy-ion collisions with ALICE at the LHC**
  Xinye Peng (China University of Geosciences) - 06/04/2022, 12:10
- **Search for jet quenching in high-multiplicity pp collisions using inclusive and semi-inclusive jet production in ALICE**
  Filip Krizek (Czech Academy of Sciences (CZ)) - 06/04/2022, 12:50
- **Heavy-flavour jet properties and correlations from small to large systems measured with ALICE**
  Marianna Mazzilli (CERN) - 06/04/2022, 14:40
- **New experimental frontiers in the study of many-body nuclear interactions with ALICE**
  Raffaele Del Grande (Technische Universitaet Muenchen (DE)) - 06/04/2022, 15:00
- **ALICE determines the scattering parameters of D mesons with light-flavor hadrons**
  Fabrizio Grosa (CERN) - 06/04/2022, 15:40
- **Particle production as a function of underlying-event activity in pp, p–Pb, and Pb–Pb collisions and search for jet-like modifications with ALICE**
  Antonio Ortiz Velasquez (Universidad Nacional Autonoma (MX)) - 06/04/2022, 15:40
- **Open and hidden heavy-flavor production in small systems with ALICE**
  Sebastien Perrin (Université Paris-Saclay (FR)) - 06/04/2022, 16:00
- **Understanding the nature of f0(980) via K+K– correlation and production yield with ALICE**
  Neelima Agrawal (Universita e INFN, Bologna (IT)) - 06/04/2022, 16:40
- **Charm production: constraint to transport models and charm diffusion coefficient with ALICE**
  Lucas Anne Vermunt (Utrecht University (NL)) - 07/04/2022, 09:00

… and here all the posters

- **J/ψ photoproduction and the production of dileptons via photon-photon interactions in hadronic Pb–Pb collisions measured with ALICE**
  Alexandra Neagu (University of Oslo (NO)) - 07/04/2022, 09:20
- **Constraining hadronization processes with charm baryons in pp and p-Pb collisions with ALICE**
  Mattia Faggin (Universita e INFN, Padova (IT)) - 07/04/2022, 11:10
- **J/ψ photoproduction results from ALICE**
  Tomas Herman (Czech Technical University in Prague (CZ)) - 07/04/2022, 11:30
- **Accessing the initial conditions of heavy-ion collisions with correlations and fluctuations of anisotropic flow in ALICE**
  Vytautas Vislavicius (University of Copenhagen (DK)) - 07/04/2022, 12:50
- **Charmonium production in Pb–Pb collisions with ALICE**
  Jon-Are Saetre (University of Bergen (NO)) - 07/04/2022, 14:40
- **Direct photon production and HBT correlations in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with the ALICE experiment**
  Meike Charlotte Danisch (Ruprecht Karls Universitaet Heidelberg (DE)) - 07/04/2022, 14:40
- **Thermal radiation and direct photon production in Pb-Pb and pp collisions with dielectrons in ALICE**
  Jerome Jung (Goethe University Frankfurt (DE)) - 07/04/2022, 15:20
- **ALICE upgrades and preparations for physics in Run 3**
  Anton Alkin (CERN) - 07/04/2022, 15:40
- **Future ALICE upgrades for Run 4 and beyond**
  Horst Sebastian Scheid (Goethe University Frankfurt (DE)) - 07/04/2022, 16:00
- **Heavy-flavour production as a function of the event activity with ALICE**
  Luigi Dello Stritto (Universita e INFN, Salerno (IT)) - 07/04/2022, 16:00
- **Electroweak-boson production from small to large collision systems with ALICE at the LHC**
  Shingo Sakai (University of Tsukuba (JP)) - 07/04/2022, 17:10
- **The dark side of ALICE: from antinuclei interactions to dark matter searches in space**
  Stephan Alexander Konigstorfer (Technische Universitaet Muenchen (DE)) - 07/04/2022, 17:30
- **ALICE search for the collective origin of strangeness enhancement**
  Chiara De Martin (Universita e INFN Trieste (IT)) - 07/04/2022, 17:50
- **Measurement of the hypertriton properties and production with ALICE**
  Francesco Mazzaschi (Universita e INFN Torino (IT)) - 07/04/2022, 18:10
- **Measurements of the R-dependence of inclusive jet suppression and groomed jet splittings in heavy-ion collisions with ALICE**
  Hannah Bossi (Yale University (US)) - 07/04/2022, 18:10
- **Jet acoplanarity and energy flow within jets in Pb-Pb and pp collisions with ALICE**
  Reynier Cruz Torres (Lawrence Berkeley National Lab. (US)) - 07/04/2022, 18:30
- **Latest results on resonance production from small to large systems with ALICE**
  Bong-Hwi Lim (Pusan National University (KR)) - 07/04/2022, 18:30
- **New experimental observables to probe (anti)nucleosynthesis at the LHC with ALICE**
  Sourav Kundu (CERN) - 07/04/2022, 18:50


ALICE
Run Number: 505673
Date: 2021-10-31 6:44:27
pp: ECM = 900 GeV
Detectors: ITS,TPC,MFT
… to Run 3 and beyond!