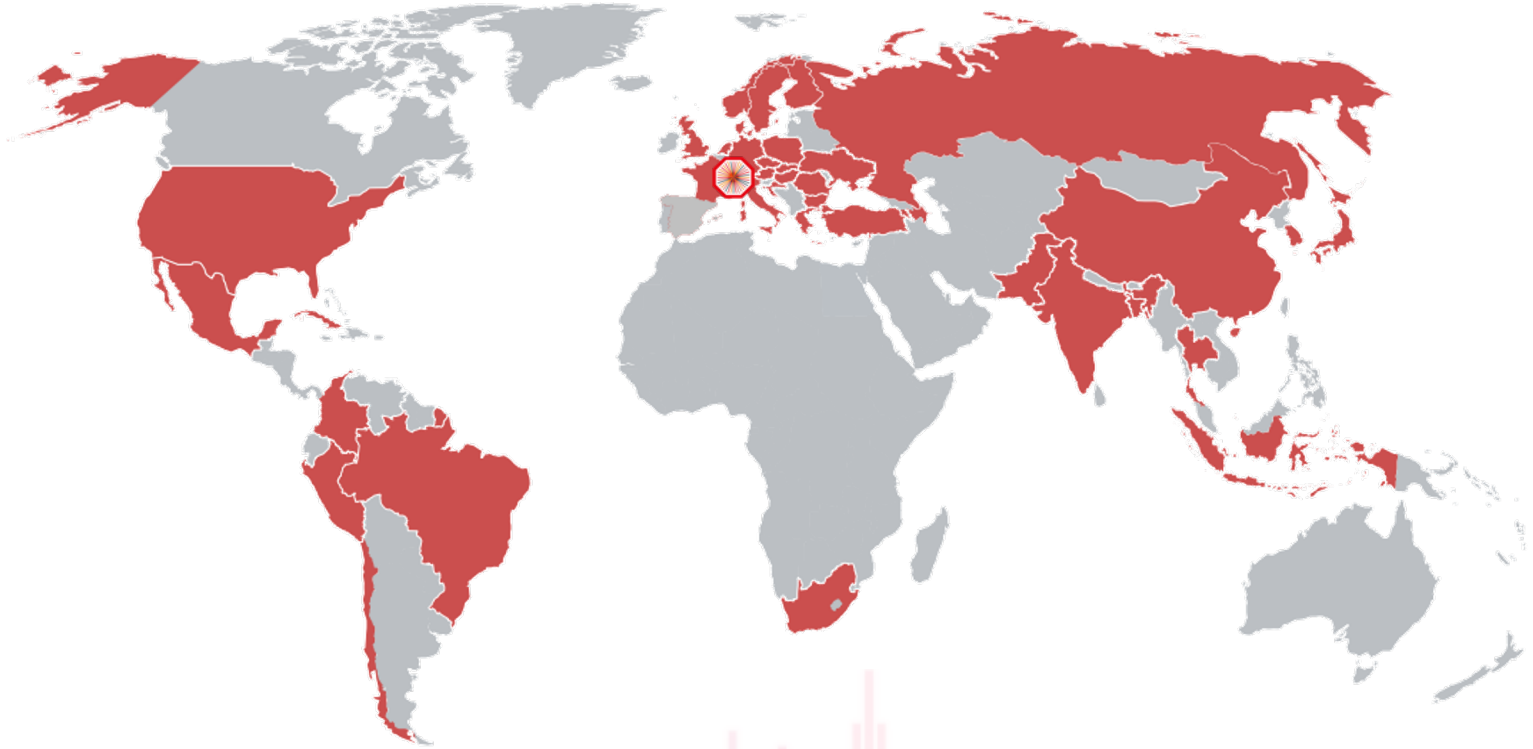
Highlights from **ALICE**

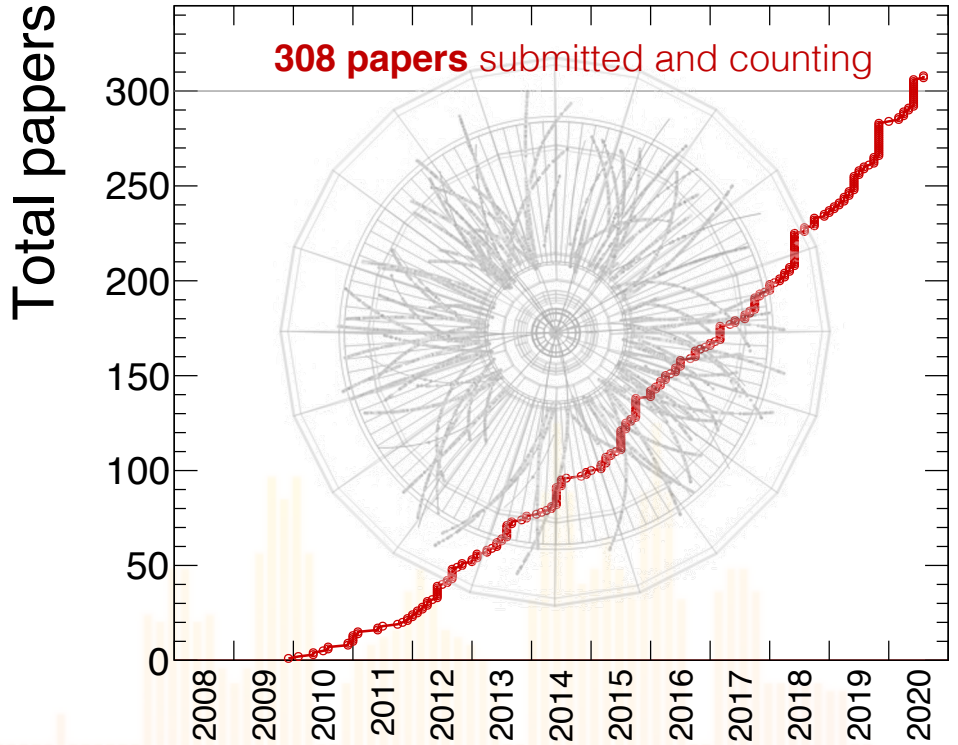
D.D. Chinellato for the ALICE Collaboration

40th International Conference on High Energy Physics – ICHEP 2020

The ALICE Collaboration



- **1025 Authors**
- **174 Institutes**
- **39 Countries**



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

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}	Run 1
Xe-Xe	2017	5.44	0.3 μb^{-1}	Run 1
p-Pb	2013 2016	5.02 5.02, 8.16	15 nb^{-1} 3 nb^{-1}, 25 nb^{-1}	Run 1 Run 2
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13	200 μb^{-1}, 100 nb^{-1} 1.5 pb^{-1}, 2.5 pb^{-1} 1.3 pb^{-1} 36 pb^{-1}	Run 1 Run 2 Run 2 Run 2

ALICE at ICHEP 2020: a busy week

29 physics talks

1. Beauty production and anisotropy with ALICE at the LHC / Xinye Peng
2. Measurement of electroweak-boson production in p-Pb and Pb-Pb collisions / Mingrui Zhao
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+1 diversity talk
+1 outreach talk
+3 posters

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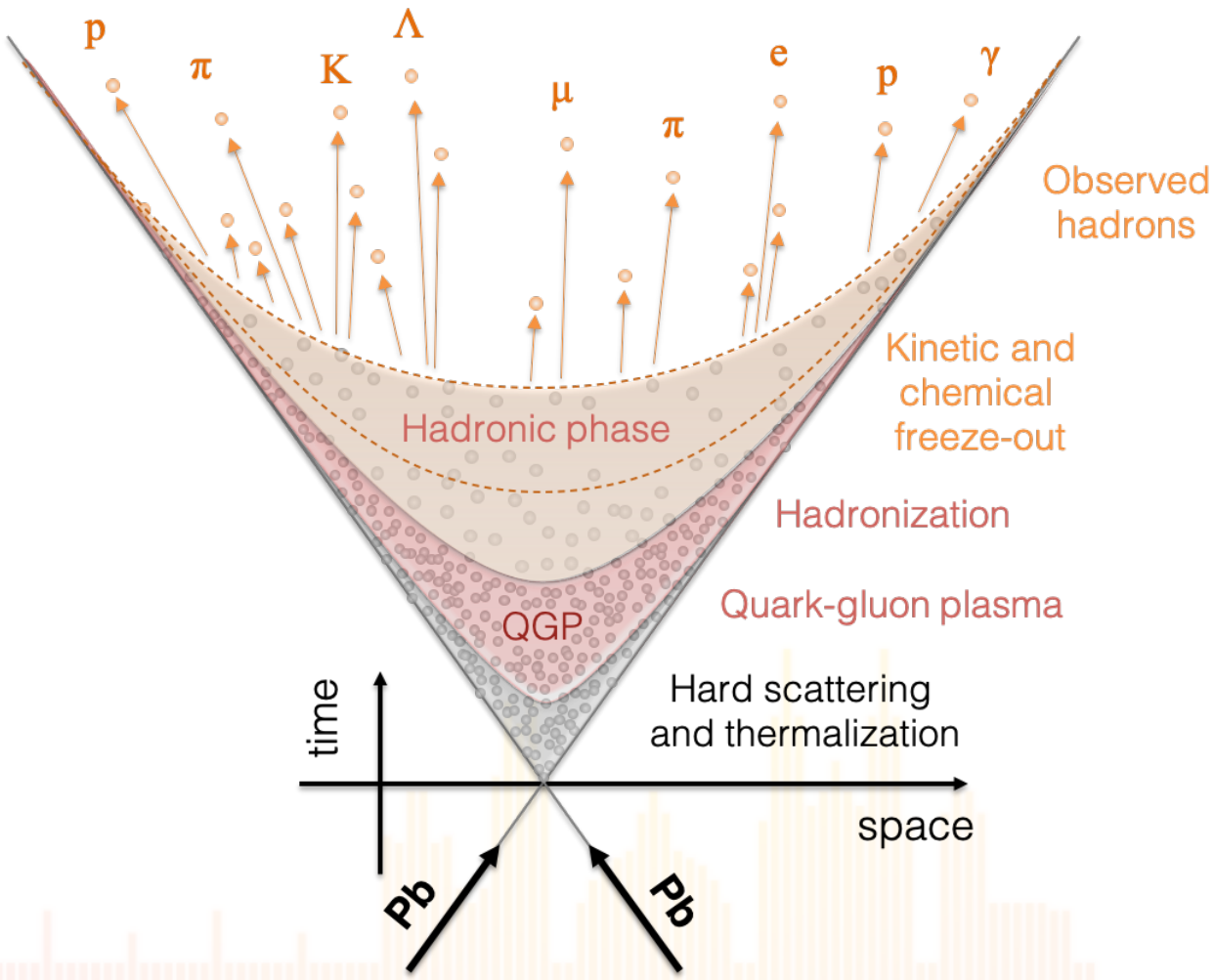
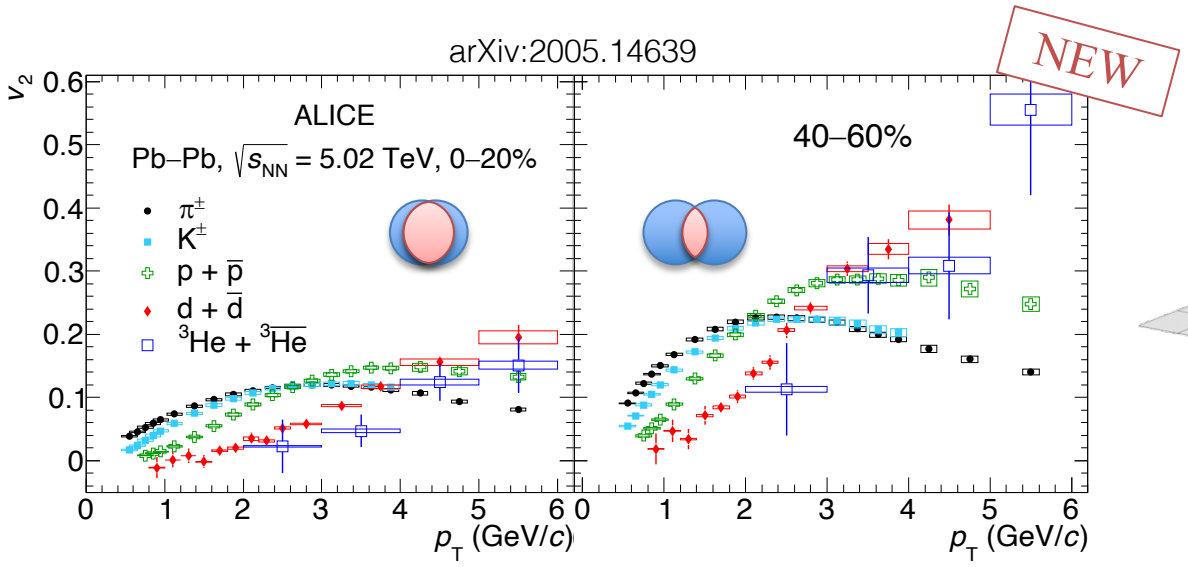
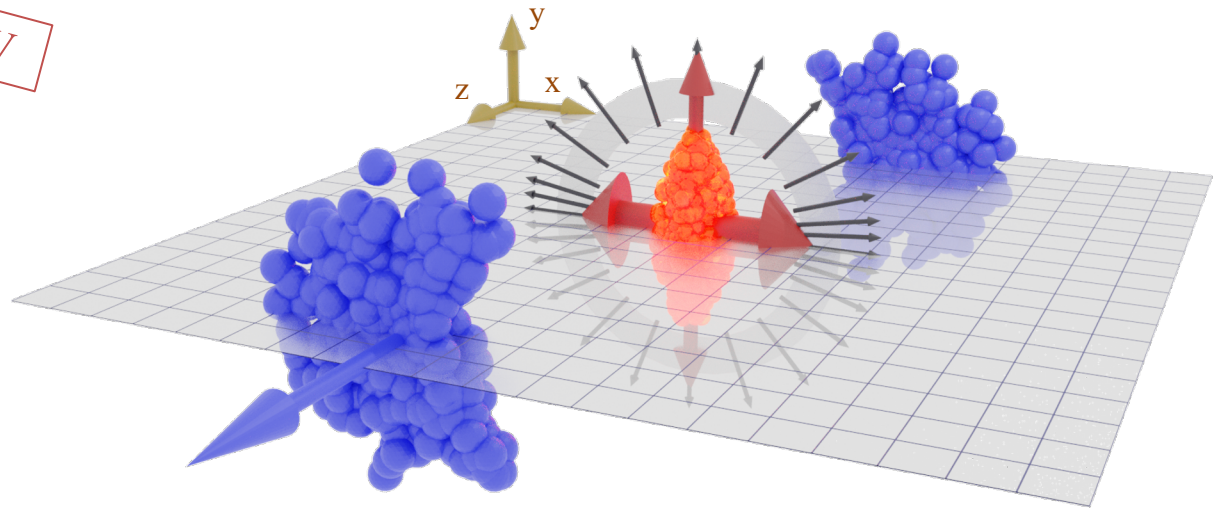
Properties of the Quark-Gluon Plasma

+1 diversity talk
+1 outreach talk
+3 posters



Flow for all





- Nearly all particle species participate in collective flow: quantified via a Fourier decomposition [1]
- Light flavor: mass ordering (π, K, p, d, ^{3}He)

[1] Constraining the transport properties of QGP with latest flow measurements / V. Vislavicius

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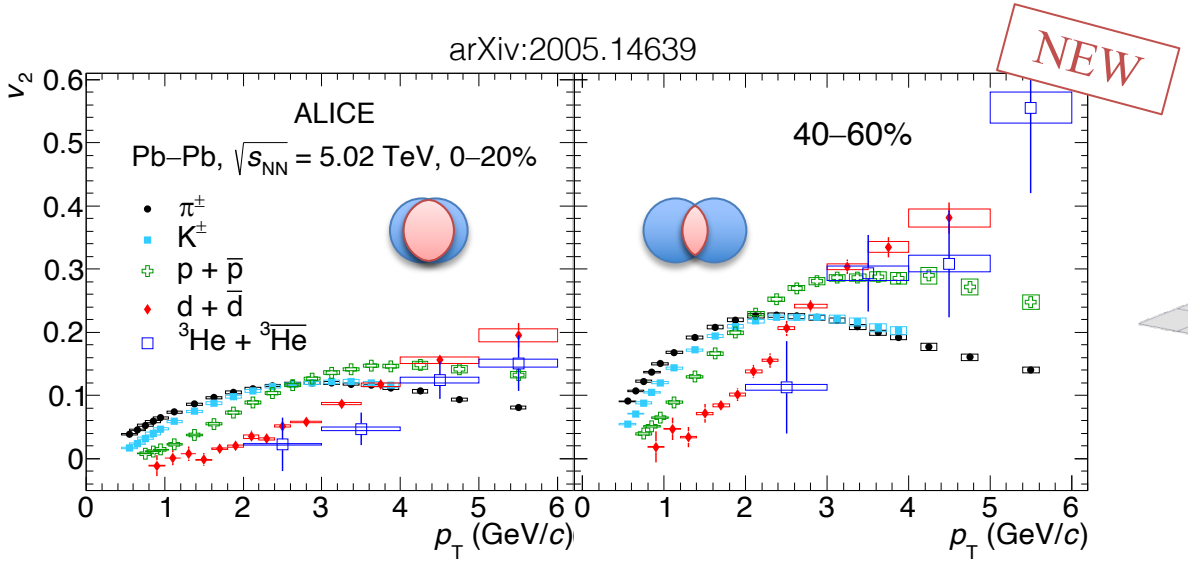

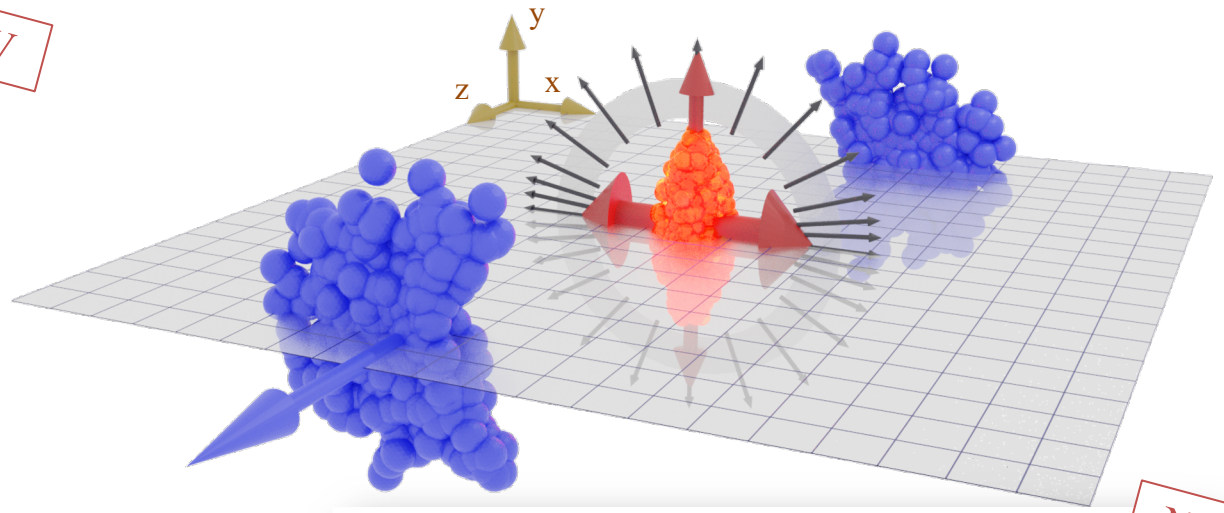

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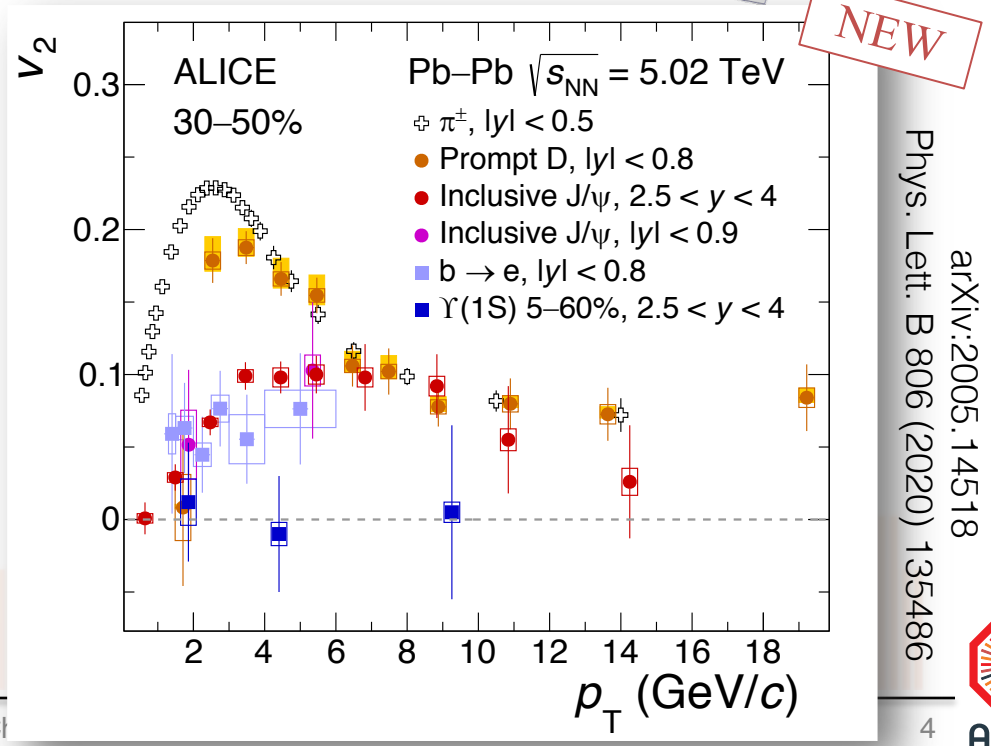
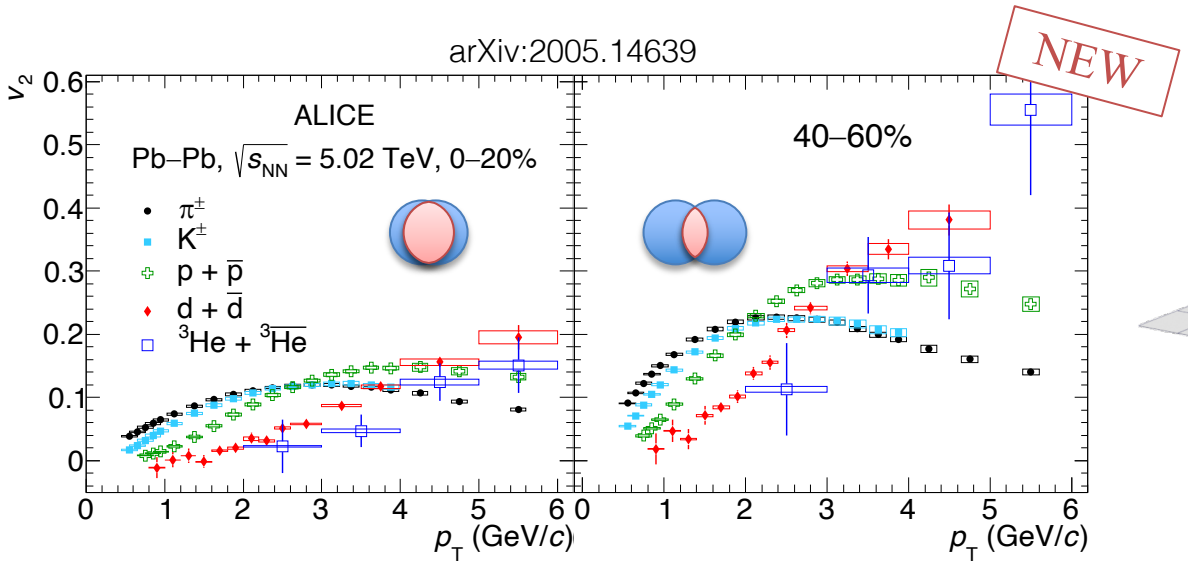
- Heavy flavor: progressively lower flow for D^0, J/ψ, b → e
  - No flow for ϒ(1S)

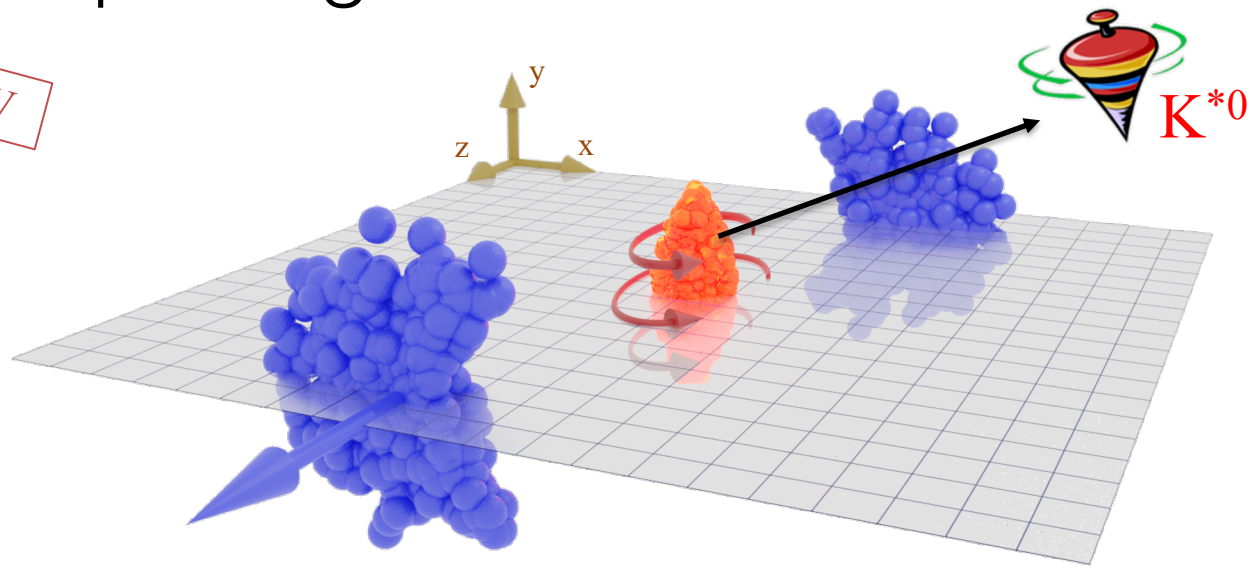


arXiv:2005.11130
arXiv:2005.14518
Phys. Lett. B 806 (2020) 135486

[1] Constraining the transport properties of QGP with latest flow measurements / V. Vislavicius

Flow for all and spin alignment for some





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- Light flavor: mass ordering (π, K, p, d, ^{3}He)
- Heavy flavor: progressively lower flow for D^0, J/ψ, b → e
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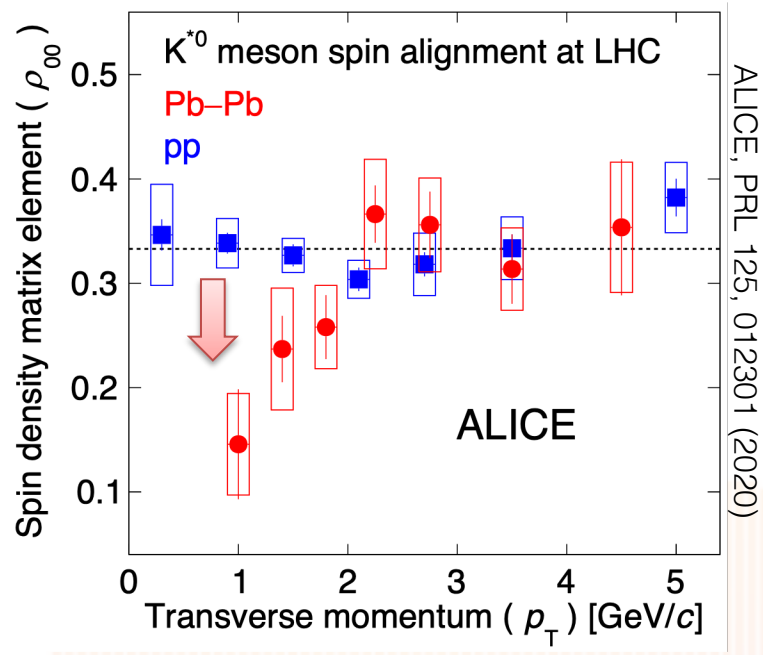
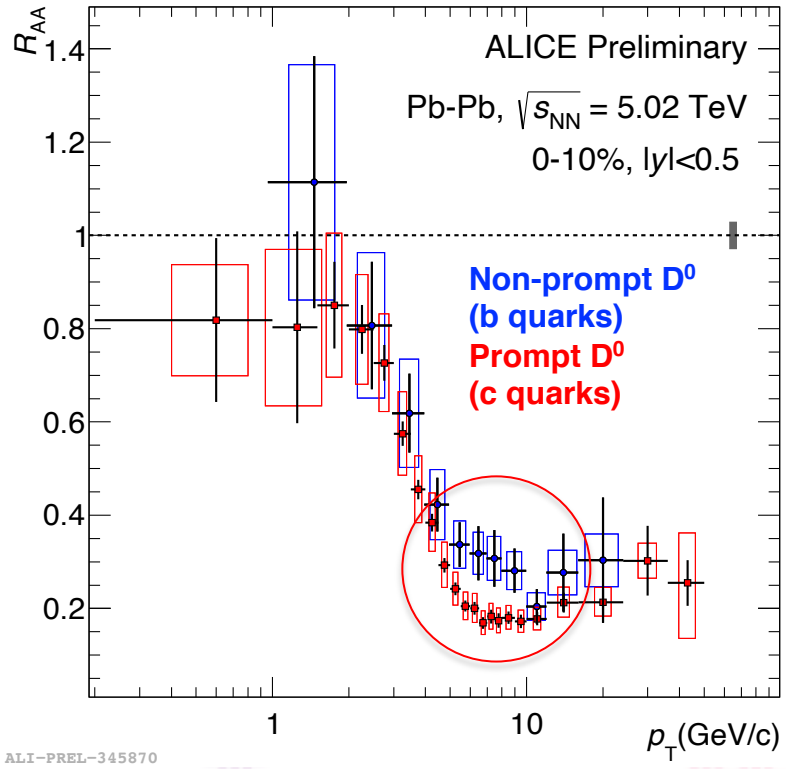
- Rotating QGP aligns vector-meson spin [2]

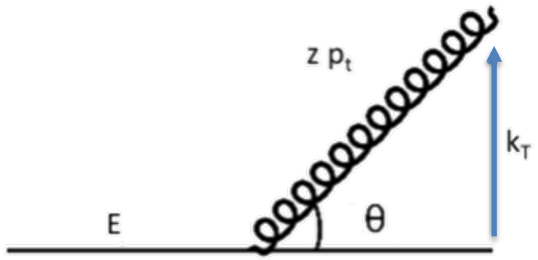


[1] Constraining the transport properties of QGP with latest flow measurements / V. Vislavicius
[2] Spin alignment measurements of vector mesons / B. Mohanty

The QGP quenches jets



- Partons produced in high Q^2 processes lose energy while traversing the medium
- Quantified via the nuclear modification factor
  - Indicates beauty loses less energy than charm [1]
- 'Dead cone' effect: suppression of collinear ($\theta < m_q/E_q$) gluons



$$R_{\mathrm{AA}} = \frac{dN^{AA}/dp_{\mathrm{T}}}{\langle N_{\mathrm{coll}} \rangle \, dN^{pp}/dp_{\mathrm{T}}}$$

[1] Beauty production and anisotropy with ALICE at the LHC / X. Peng

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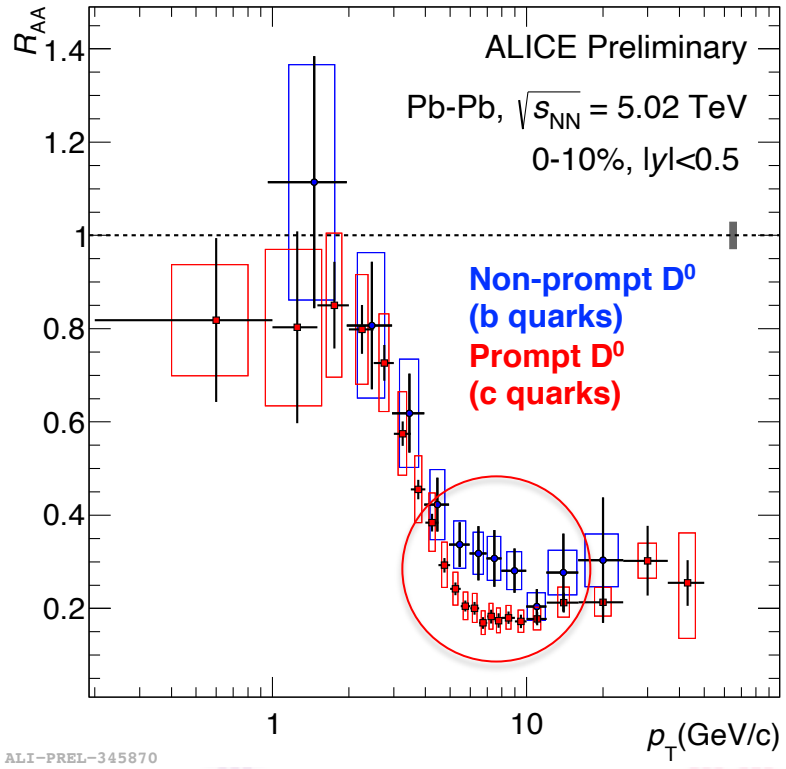

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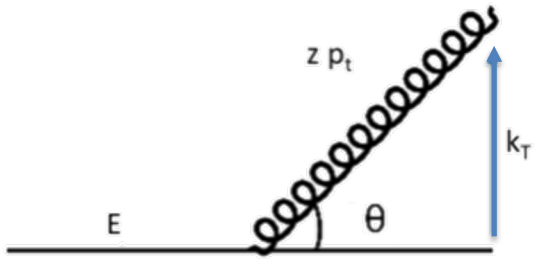
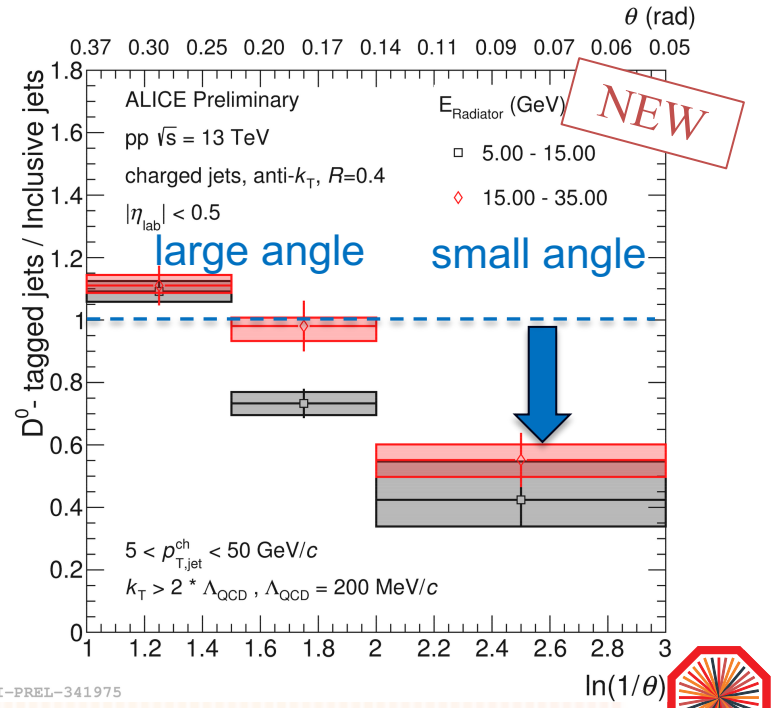


Dead cone effect was in fact observed directly for the first time for charm in pp [2] using iterative jet declustering and Lund plane analysis →



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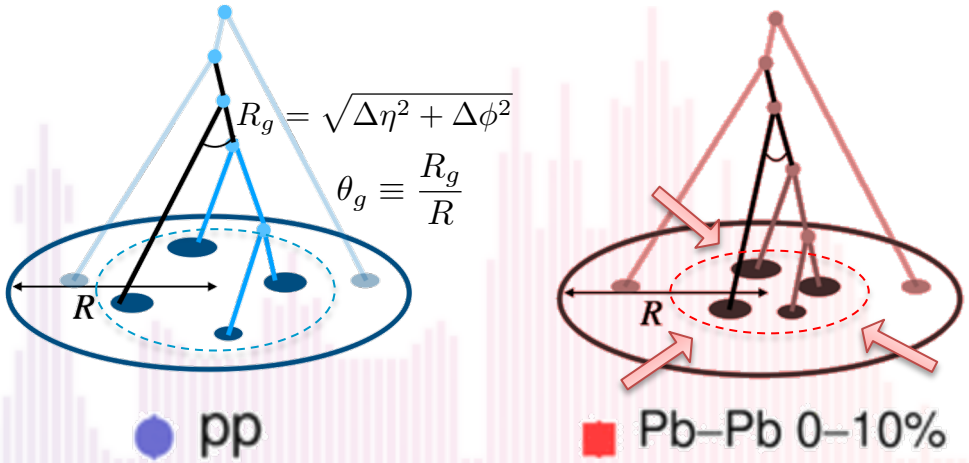
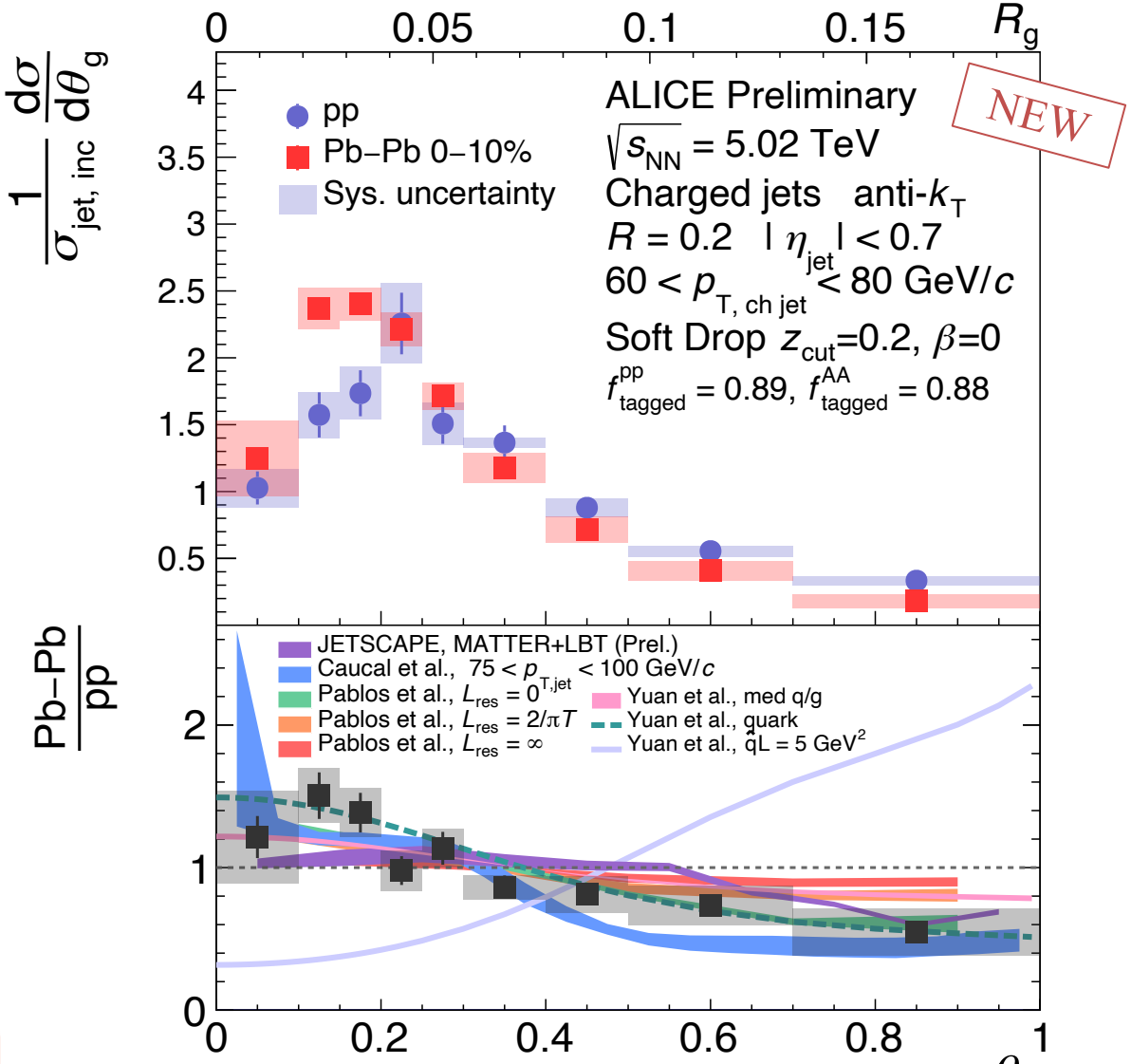
[2] First direct measurement of the dead-cone effect at colliders / L. Cunqueiro

The QGP alters jet substructure

- Medium modifies parton shower
- Studied via jet grooming: find first hard splitting [1]
- Jet core more collimated in Pb-Pb than pp
- Model comparisons indicate QGP resolves individual hard prongs that interact incoherently
  - More info here: ALICE-PUBLIC-2020-006 [2]





[1] Overview of the latest jet physics results from ALICE / J. Mulligan
[2] http://cds.cern.ch/record/2725572

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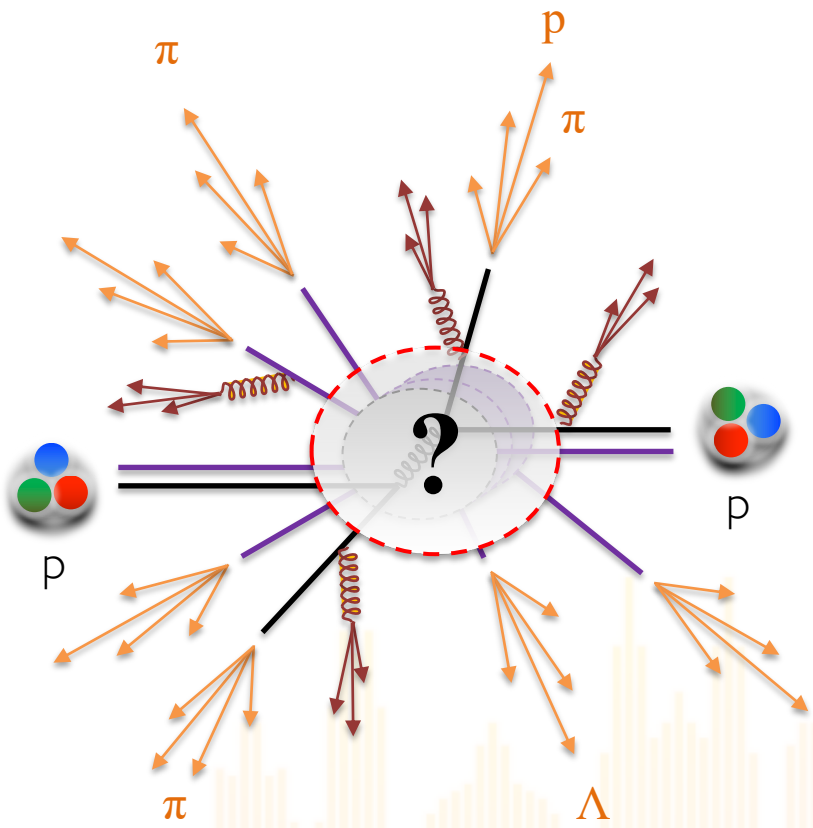
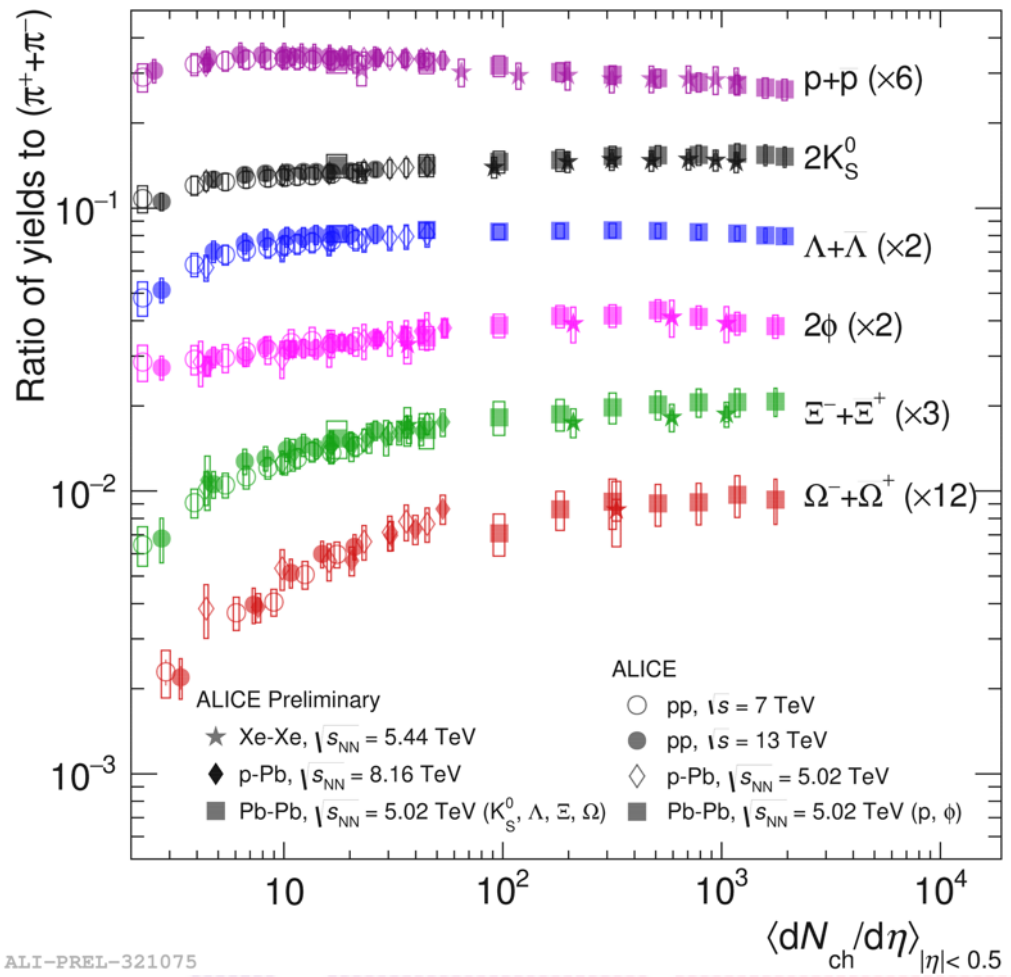
Emergence of QGP phenomena from QCD

+1 diversity talk
+1 outreach talk
+3 posters



High-multiplicity pp collision

Towards understanding strangeness enhancement



s = 0

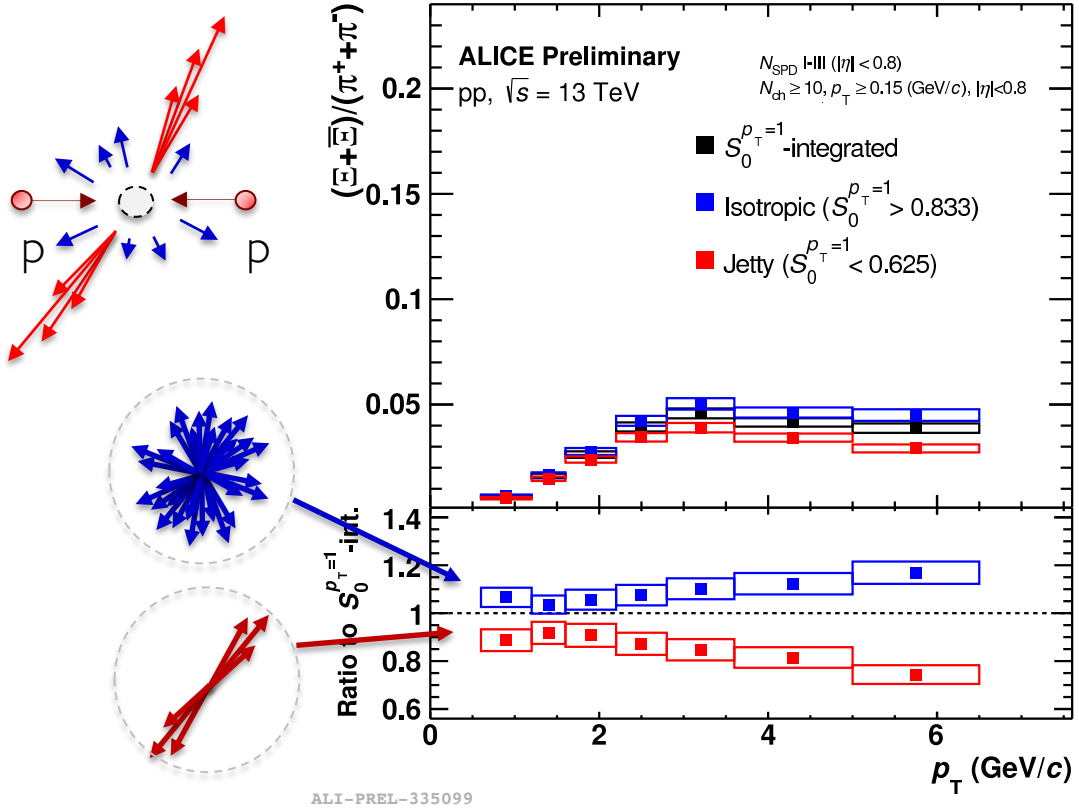
s = 1

s = 1

s = 0

s = 2

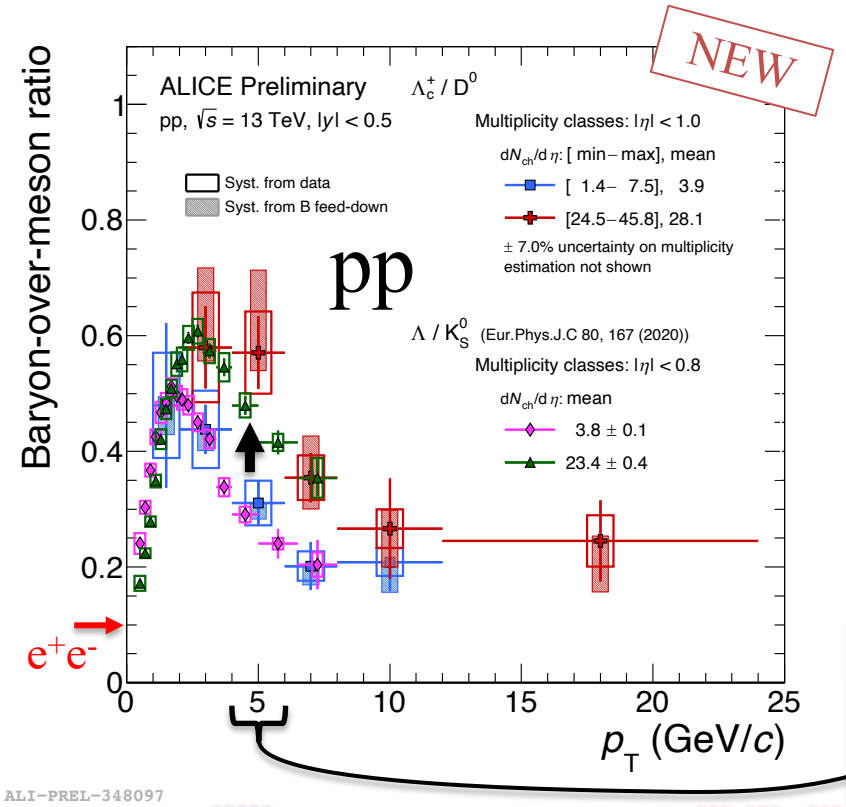
s = 3

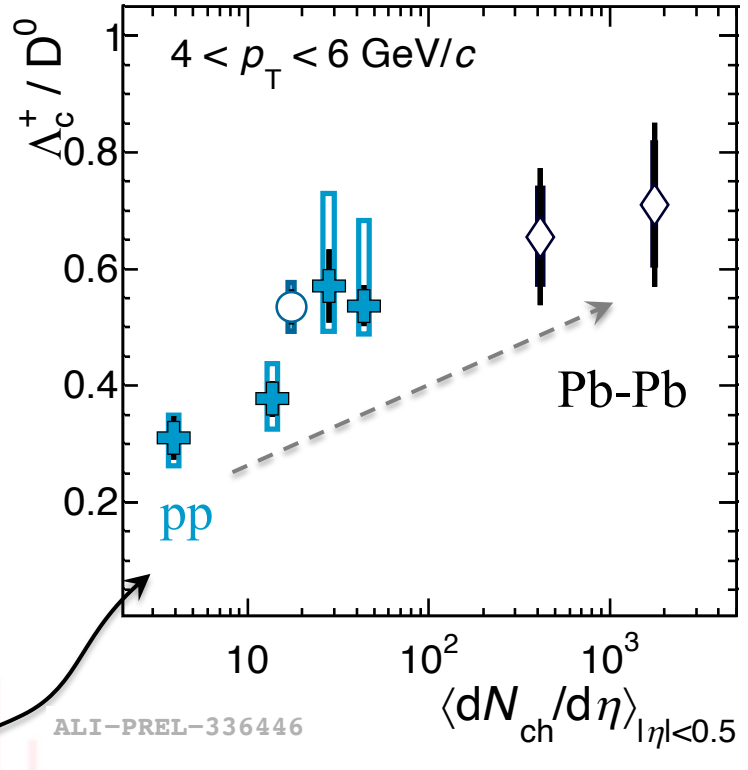


- Smooth evolution of particle ratios with multiplicity [1, 2]: strangeness enhanced already in high-multiplicity pp, p-Pb
- Spherocity selection: isotropic events → extra strangeness [3]

[1] Study of hadronization through the meas. of LF part. prod. / G. Volpe
[2] Hadronization studies at the LHC with ALICE / J. Zhu
[3] Topological studies of LF hadron prod. in high mult. pp collisions / S. Tripathy

Probing charmed baryon production





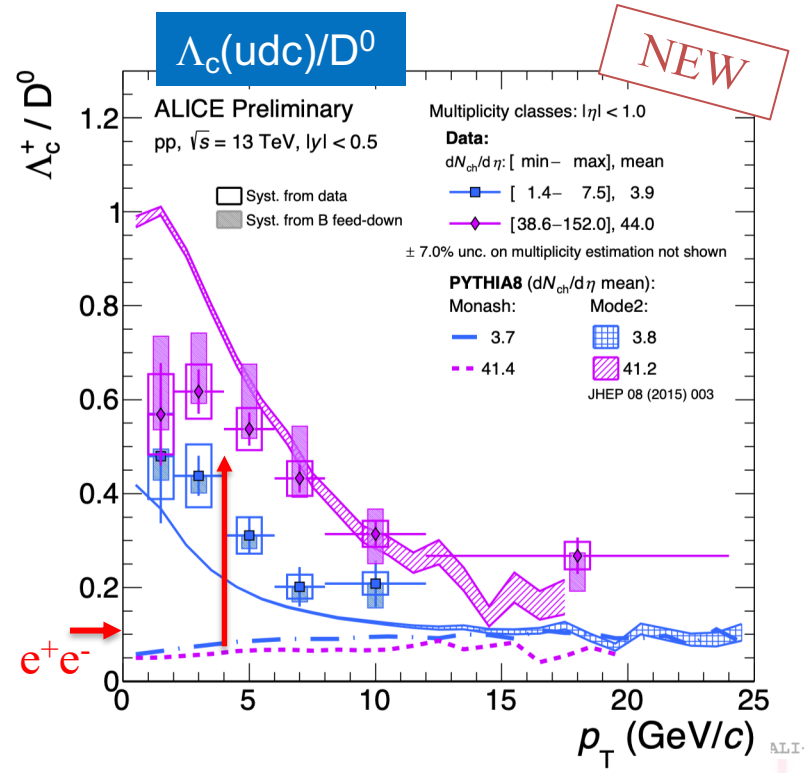
ALICE Preliminary

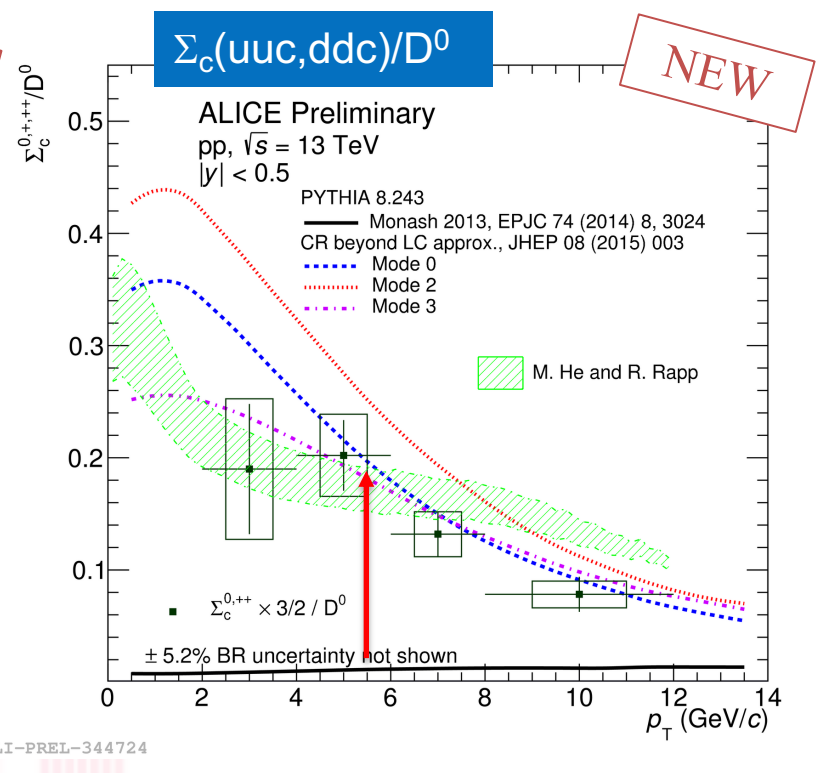
pp, $\sqrt{s}$ = 13 TeV
SPD multiplicity classes
p–Pb Minimum Bias, $\sqrt{s_{NN}}$ = 5.02 TeV
Pb–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
V0 multiplicity classes

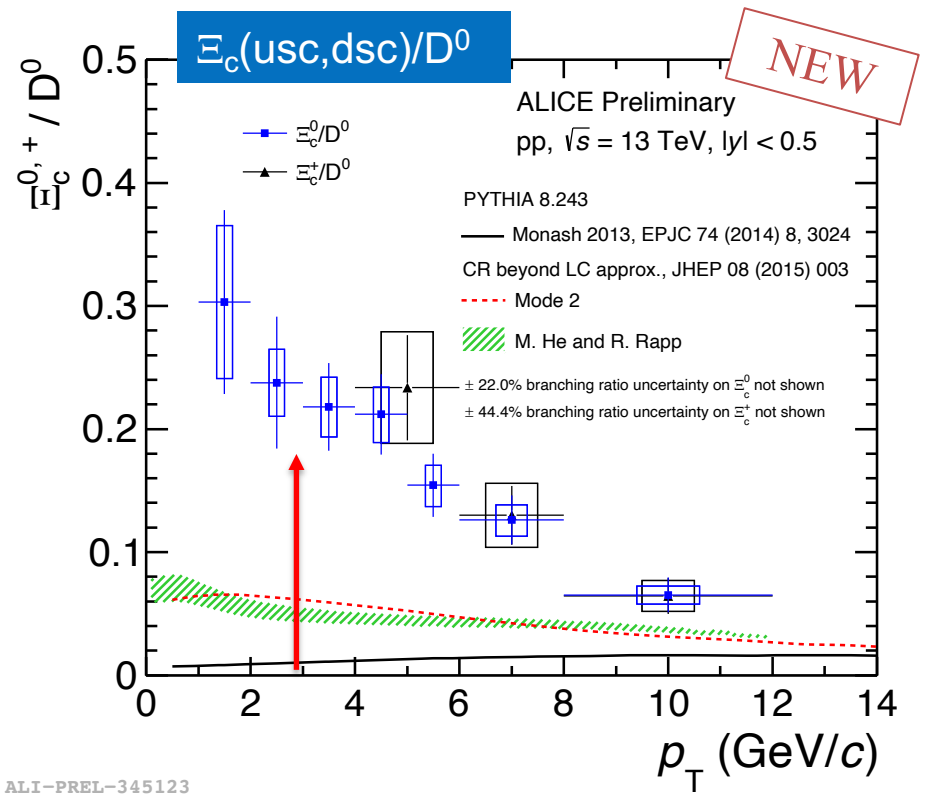
- Baryon anomaly: heavy flavor Λ_c/D^0 [1] modified similarly to the strange baryon/meson ratio Λ/K^0 for high-multiplicity pp, hints of similarity in p-Pb, ~10x bigger than in e^+e^- collisions

[1] Open heavy-flavour production from small to large collision systems with ALICE at the LHC / L. Vermunt

Meet the charmed baryon family







- Baryon anomaly: heavy flavor Λ_c/D^0 [1] modified similarly to the strange baryon/meson ratio Λ/K^0 for high-multiplicity pp, hints of similarity in p-Pb, ~10x bigger than in e$^+$e$^-$ collisions
- Also measured: Σ_c/D^0, Ξ_c/D^0: 20-30x higher than e$^+$e$^-$
- PYTHIA with junctions: reasonable reproduction for Λ_c/D^0 , Σ_c/D^0 but not Ξ_c/D^0

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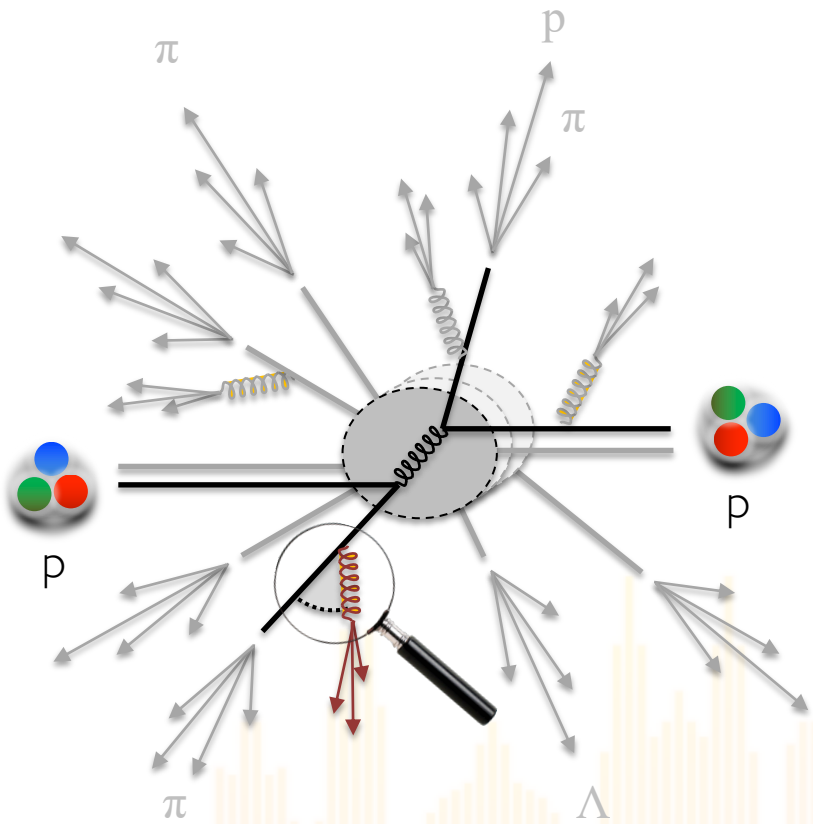
Beyond heavy ions:
The LHC as a general-purpose QCD lab



+1 diversity talk
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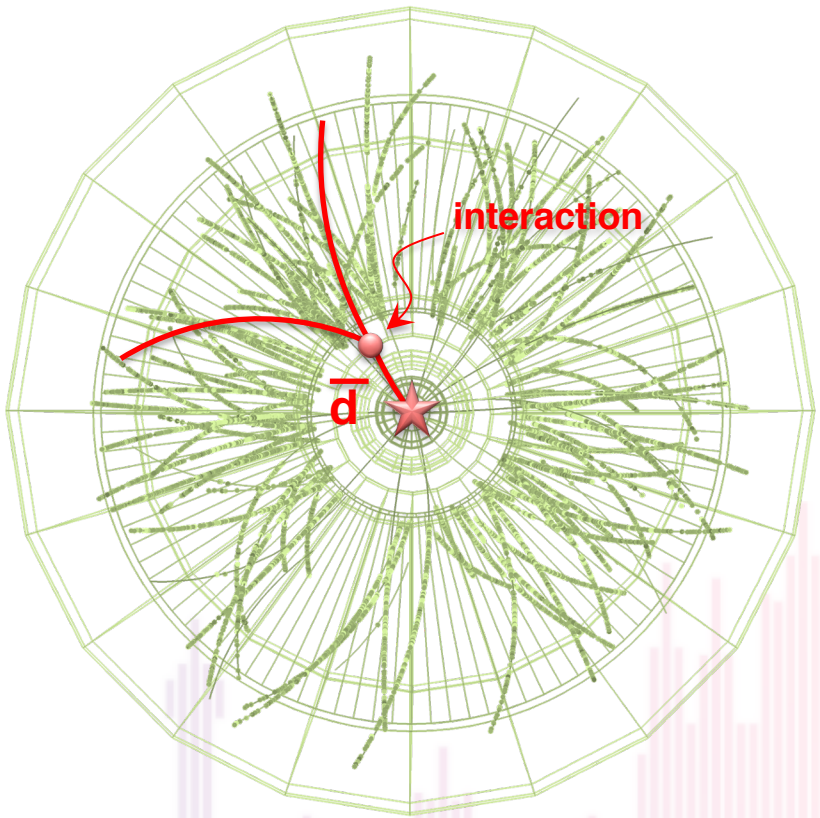
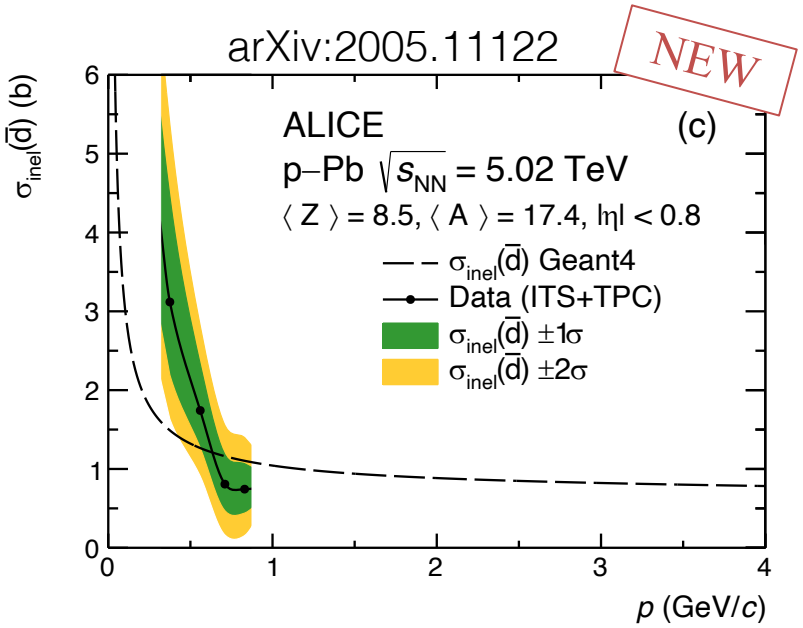
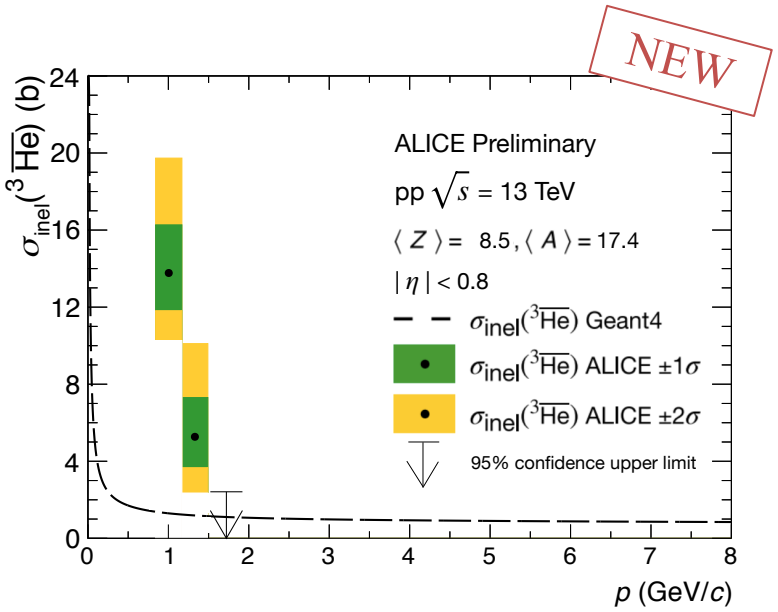
Antinuclei measurements with impact for astrophysics



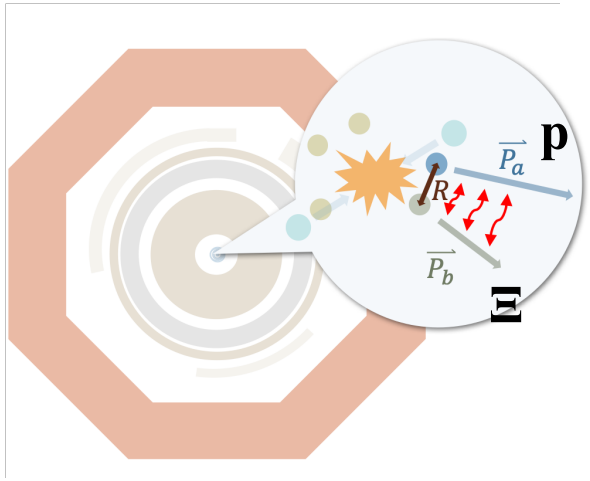




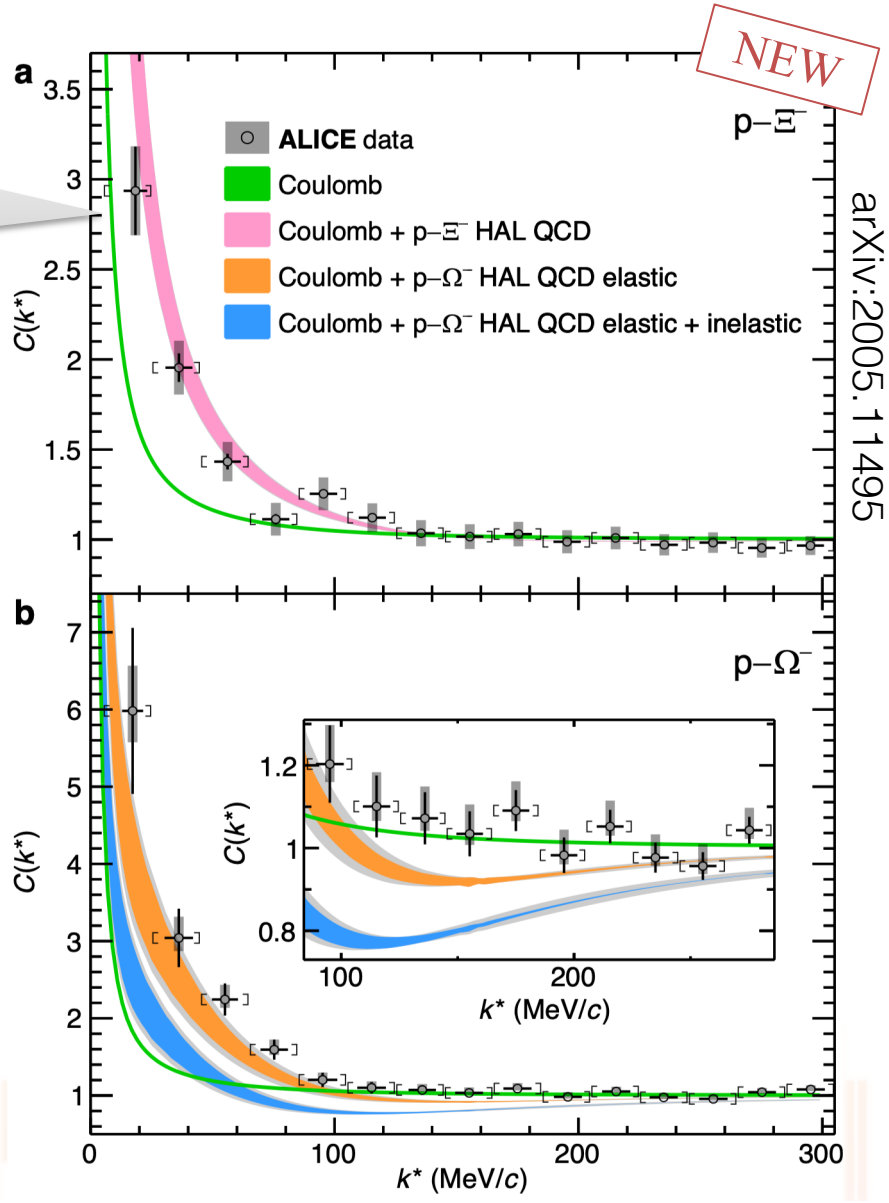
- Antideuteron and antihelium absorption cross sections measured as a function of momentum when interacting with the ALICE detector [1]
- Important input for antinuclei propagation in interstellar medium:
  - cosmic rays, antinuclei searches in space

[1] Measurement of the antinuclei nuclear inelastic cross sections / S. A. Konigstorfer

Unprecedented precision in proton-hyperon interactions



Correlation peak at small momentum differences: signature of interaction



- Proton-hyperon strong interaction poorly known
- Measured in ALICE: momentum correlation of proton-hyperon pairs from a source of known size [1]
- Latest result [2]: precise measurement of attractive strong interaction for p-Ξ, p-Ω
  - Direct comparison to lattice QCD
  - p-Ξ important for neutron star EoS
- More to come in Run 3: d-Λ, p-Σ, Ω-Ω

[1] Characterizing the particle-emitting source using femtoscopy in pp collisions / A. Mathis
[2] ALICE measurements of Ξ- and Ω-nucleon int. and constraints on lattice QCD potentials / O. V. Doce

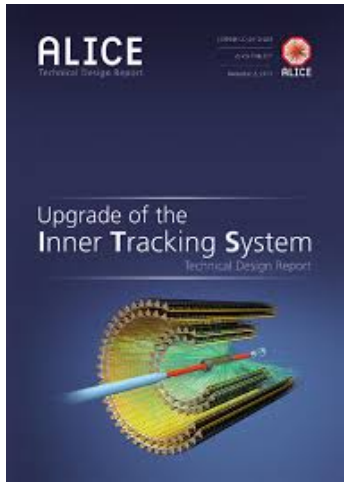
ALICE at ICHEP 2020: a busy week

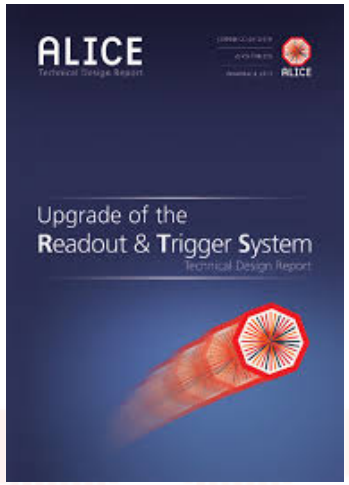
29 physics talks

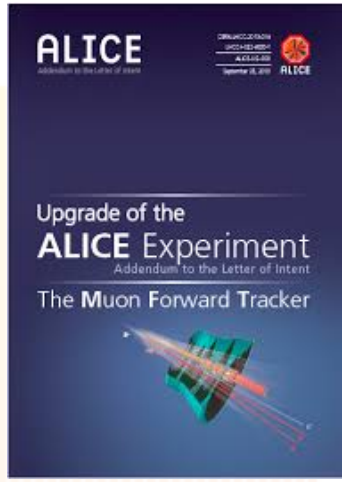
1. Beauty production and anisotropy with ALICE at the LHC / Xinye Peng
2. Measurement of electroweak-boson production in p-Pb and Pb-Pb collisions / Mingrui Zhao
3. Vector meson photoproduction in ultra-peripheral Pb-Pb collisions / Valeri Pozdniakov
4. Measurement of charmonium production in Pb-Pb and p-Pb collisions / Alexandra Neagu
5. Bottomium measurements in nucleus-nucleus and proton-nucleus collisions / Robin Caron
6. Constraining the transport properties of QGP with latest flow measurements / Vytautas Vislavicius
7. Overview of the latest jet physics results from ALICE / James Mulligan
8. Spin alignment measurements of vector mesons / Bedangadas Mohanty
9. Study of hadronization through the measurement of LF particle production / Giacomo Volpe
10. Hadronic resonance production / Paraskevi Ganoti
11. Latest results on light (anti-)nuclei production in Pb-Pb collisions / Chiara Pinto
12. Open heavy-flavour production from small to large collision systems with ALICE at the LHC / Lucas Vermunt
13. Heavy-flavour jet production and fragmentation and heavy-flavour correlations / Marianna Mazzilli
14. Hadronization studies at the LHC with ALICE / Jianhui Zhu
15. ω and η' production in proton-proton collisions at the LHC / Florian Jonas
16. Topological studies of LF hadron production in high multiplicity pp collisions / Sushanta Tripathy
17. Dilepton measurements with ALICE at the LHC / Jerome Jung
18. Understanding the background in DM searches by studying antinucleosynthesis / Sebastian Hornung
19. Measurement of the antinuclei nuclear inelastic cross sections / Stephan Alexander Konigstorfer
20. Investigating the hyperon-nucleon strong interaction with the prec. meas. of hypertriton lifetime / Francesco Mazzaschi
21. ALICE measurements of Ξ- and Ω-nucleon int. and constraints on lattice QCD potentials / Oton Vazquez Doce
22. Characterizing the particle-emitting source using femtoscopy in pp collisions / Andreas Mathis
23. First direct measurement of the dead-cone effect at colliders / Leticia Cunqueiro Mendez
24. ALICE upgrades for Run 3 / Stefano Panebianco
25. Status of the Fast Interaction Trigger for ALICE Upgrade / Maciej Slupecki
26. GPU-based online-offline reconstruction in ALICE for LHC Run 3 / Matteo Concas
27. ALICE data processing for Run 3 and Run 4 at the LHC / Chiara Zampolli
28. Fast Entropy Coding for ALICE Run 3 / Michael Lettrich
29. ALICE upgrades for LHC Run 4 and beyond / Andrea Rossi

A bright future ahead!

+1 diversity talk
+1 outreach talk
+3 posters







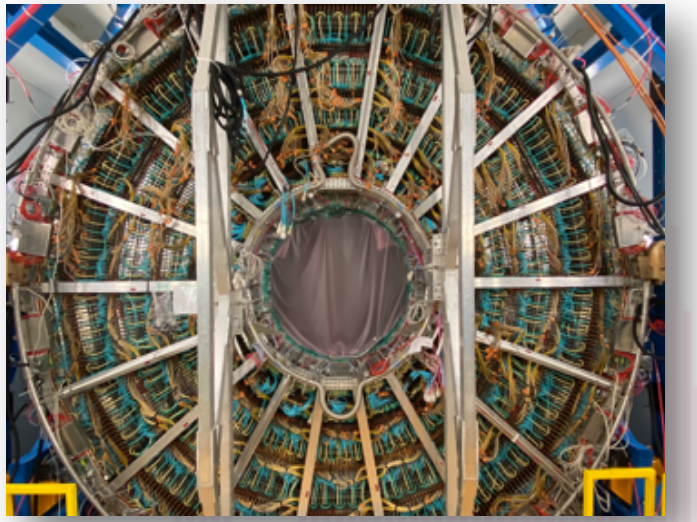
Upgrades: **50x** faster and **3x** more precise data

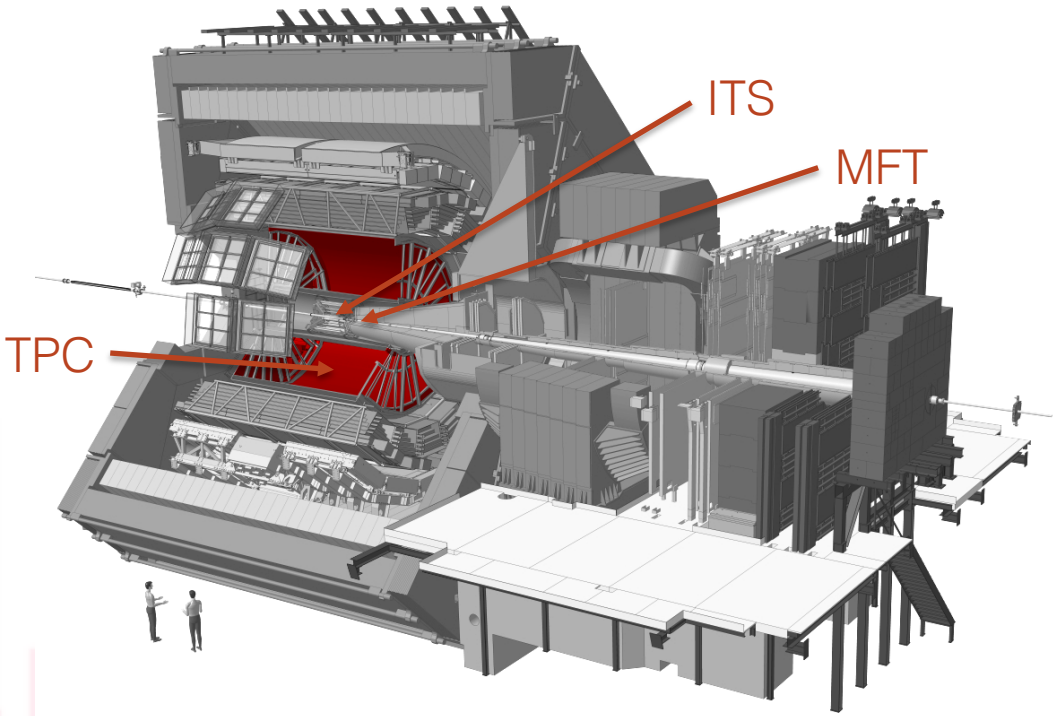
Run 1&2 TPC: MWPC-based
~1 kHz readout

Run 3 TPC: GEM-based
50 kHz readout

50x higher data rate

GEM-based TPC readout



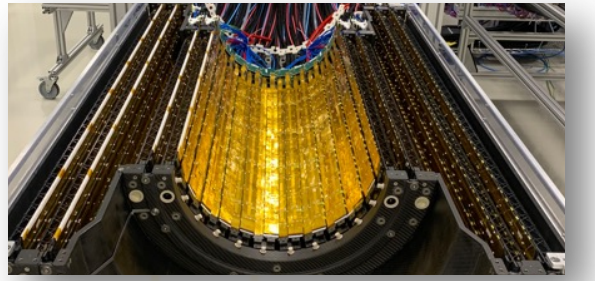


Run 1&2 ITS:
~10^7 channels

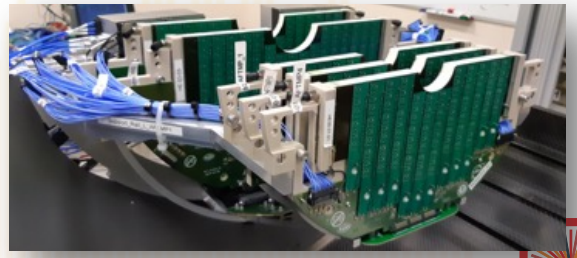
Run 3 ITS2 + MFT:
13x10^9 pixels

+**3x** in tracking precision

Monolithic-pixel Inner Tracking System: ITS2

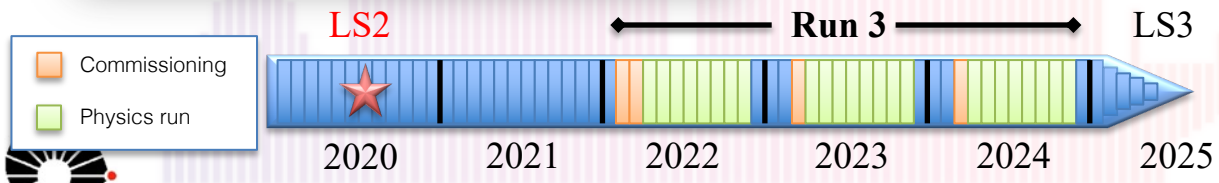


Pixel Muon Forward Tracker (MFT)



MILESTONE

TPC will be lowered into the pit tomorrow (4th August)



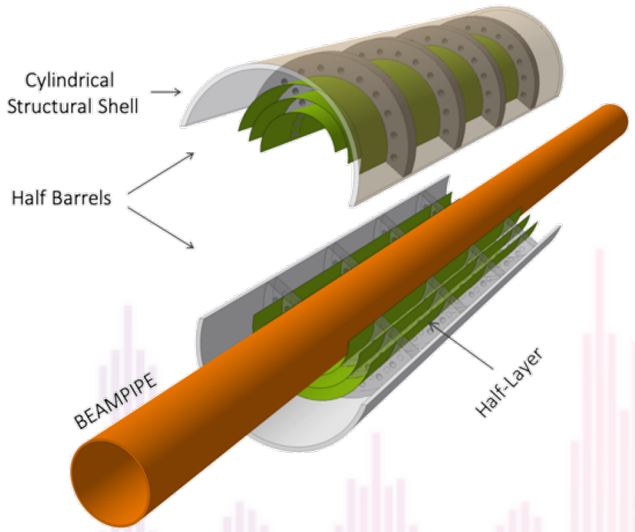
In store for LS3 / Run 4: ITS3 and FoCal

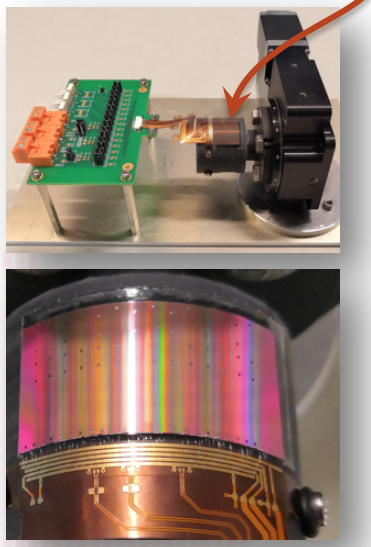
ITS3: new inner barrel: ≥3 truly cylindrical MAPS layers around smaller beam pipe → **ultimate vertexing** [1]

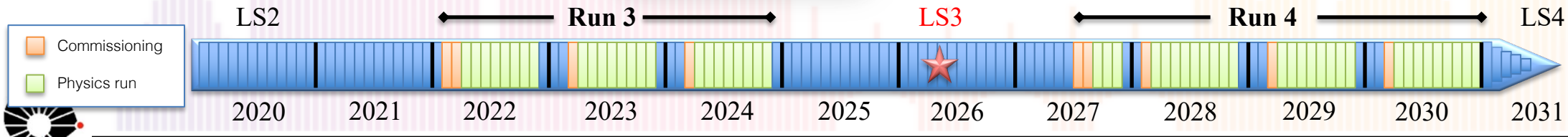
- **3x** less material budget
- **2x** tracking precision and efficiency at low p_T

LoI approved (CERN-LHCC-2019-018)

Fully functional ALPIDE (ITS2) sensor curved to R = 1.8 cm







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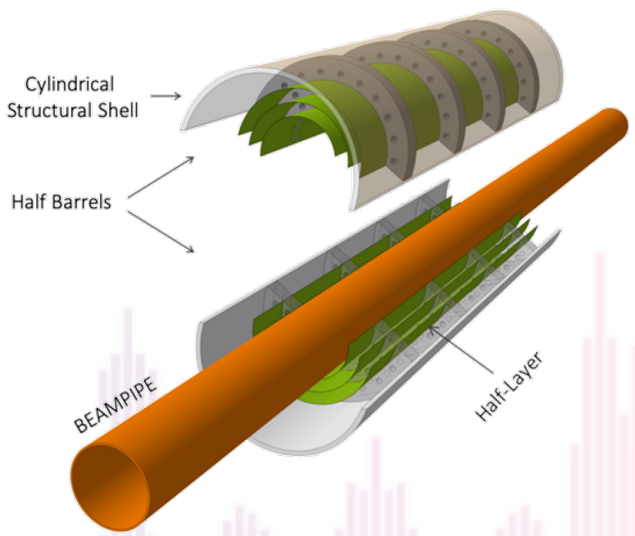
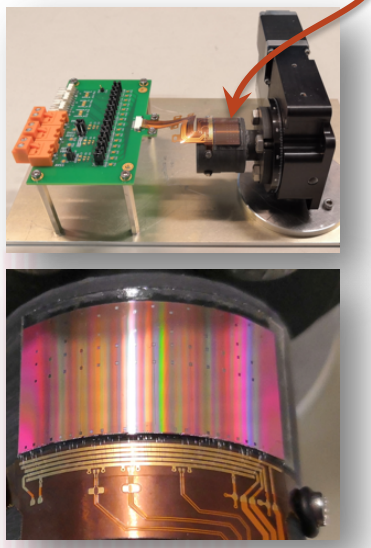
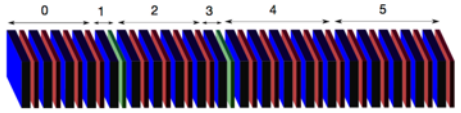




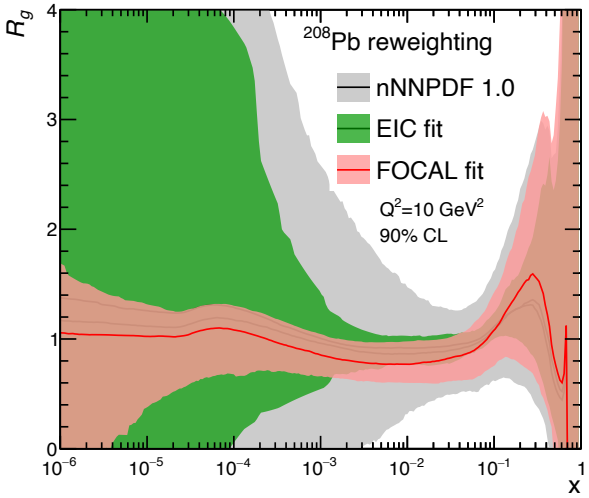
FoCal: forward EM calo with Si readout for isolated γ measurement in $3.4 < \eta < 5.8$ in p-Pb [1]

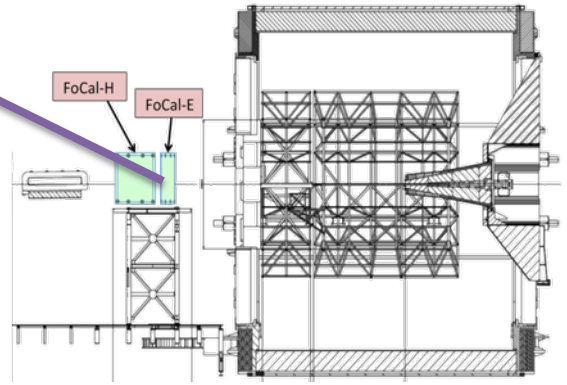
- Better precision than EIC for gluon nPDF for $x < 10^{-3}$
- Constrains nPDF to $x < 10^{-5}$

LoI approved (ALICE-PUBLIC-2019-005)

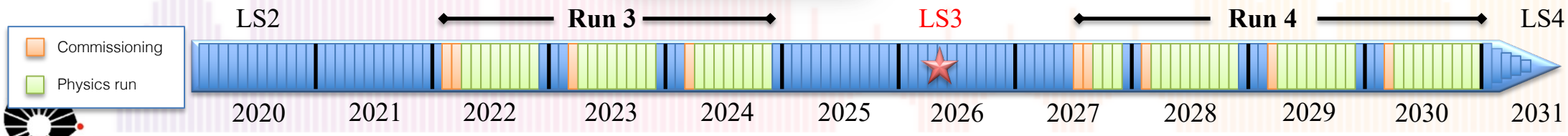


Si pad / pixel readout

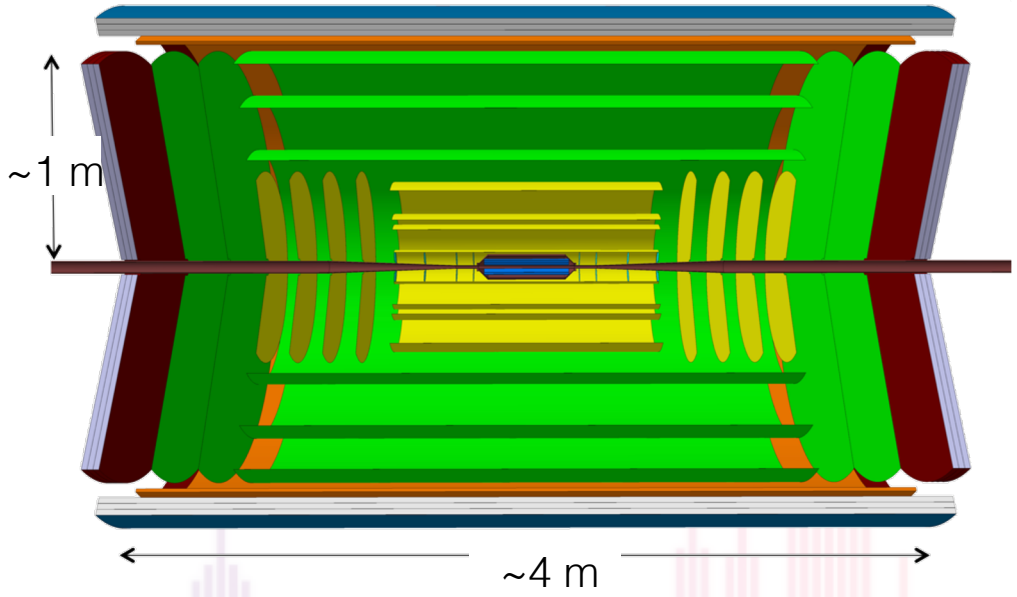




Impact on gluon nPDFs:
Present nNNPDF
with FoCal pseudodata
with EIC pseudodata



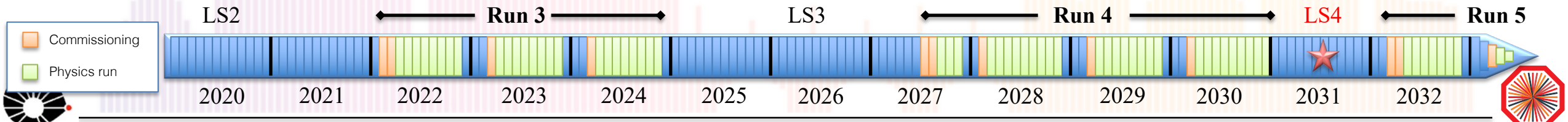
ALICE 3: a next generation HI experiment for Runs 5 and 6



Fast, ultra-thin detector with precise tracking and timing [1]

- Another factor of **50x** in luminosity
- Exploit higher LHC lumi with nuclei lighter than Pb
- Si-based Time Of Flight determination: ~20 ps time resolution
- Ultimate performance for (multi-)HF, thermal radiation and soft hadrons (p_T < 50 MeV/c)
- Beyond HI: new physics in soft sector, e.g. dark photons
- **Initiative supported in ESPPU**

[1] arXiv:1902.01211
[2] ALICE upgrades for LHC Run 4 and beyond / A. Rossi



Conclusions

A wealth of Run 1 + 2 results offer:

- Detailed insights into **QGP characteristics**
- Fundamental advances in **QCD at high density**
- Contributions to astrophysics, hadron structure, …

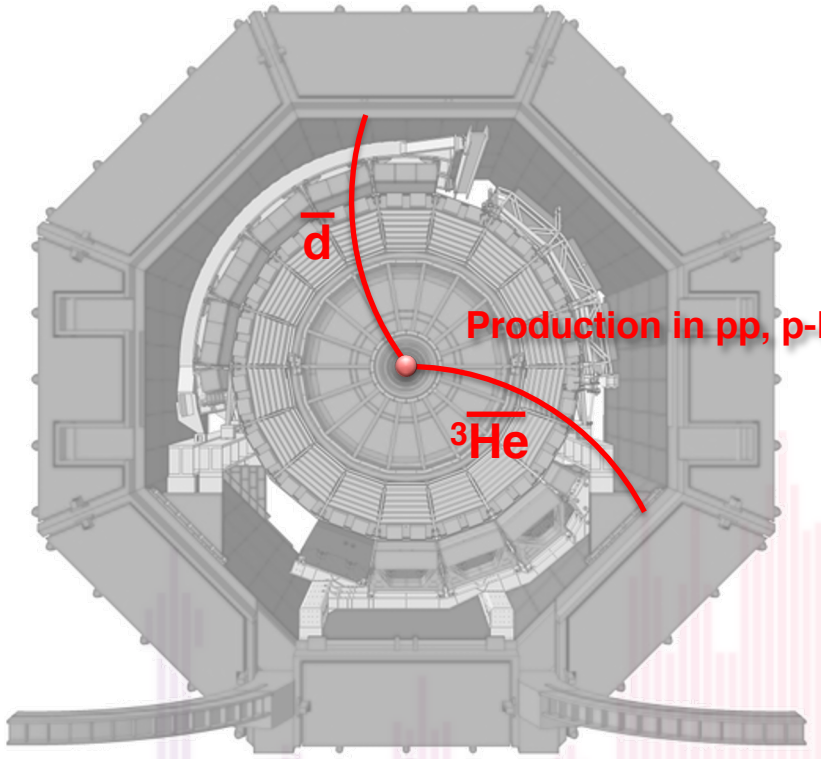
Underway and coming up:

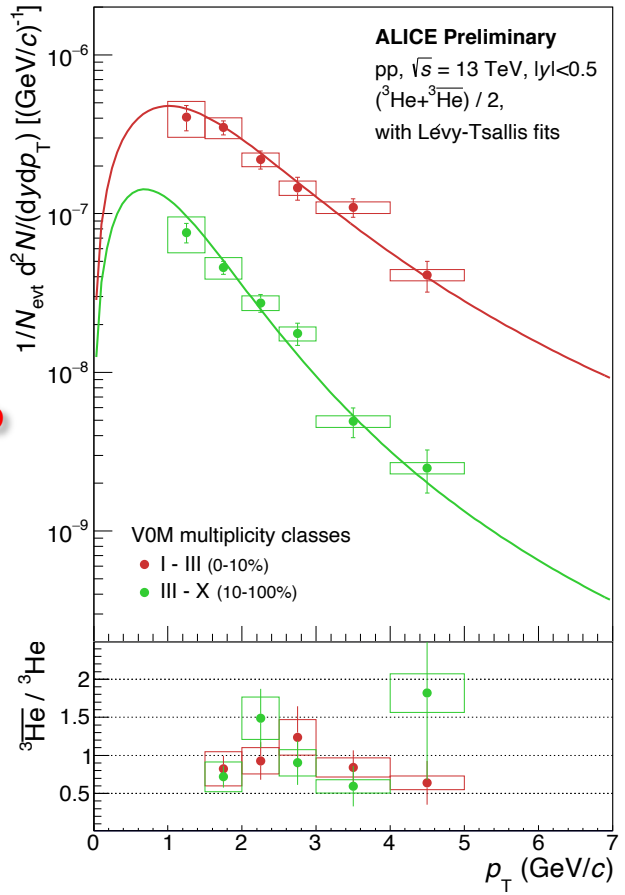
- Major LS2 upgrade on track for pp in September 2021
- In preparation: ITS3, FoCal in LS3
- Ambitious plans for Run 5+: the next generation

Thank you!

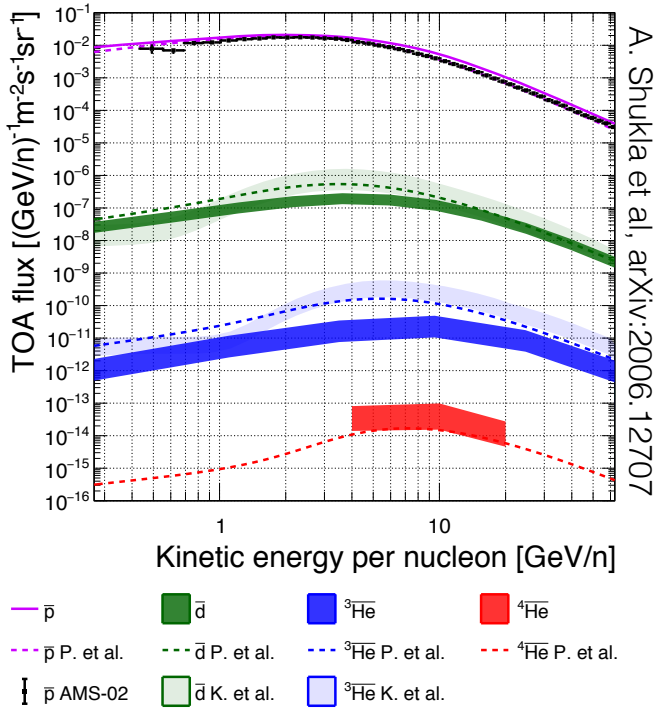
Backup

Cosmic rays and dark matter: Antimatter production & propagation





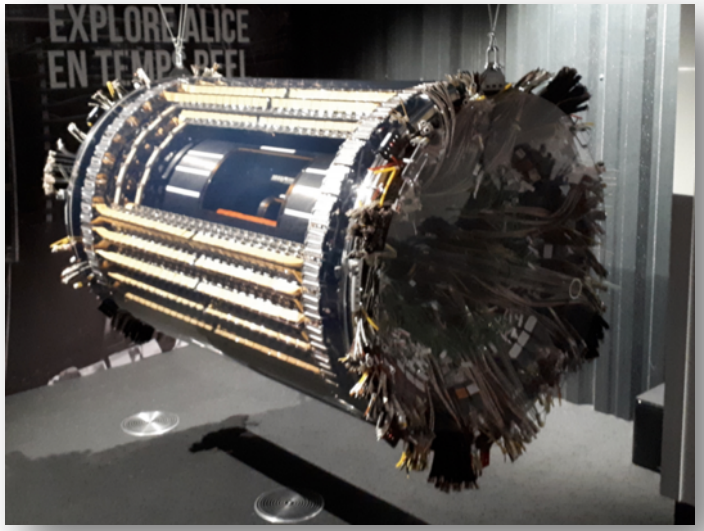
ALI-PREL-329515

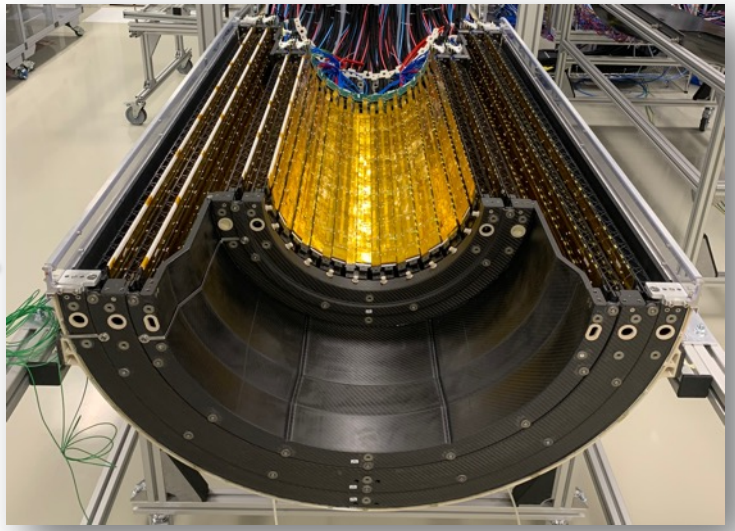


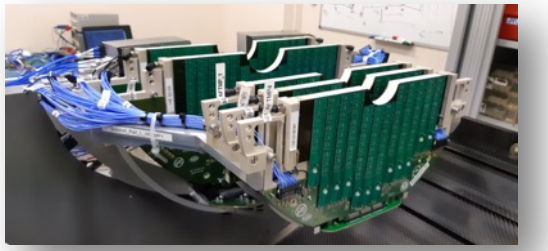
- Antimatter production from cosmic rays at the top of the atmosphere (TOA) constrained by ALICE measurements [1]
- DM searches: precise anti-A background and propagation info needed

[1] Understanding the background in DM searches by studying antinucleosynthesis / S. Hornung

TPC and ITS upgrades

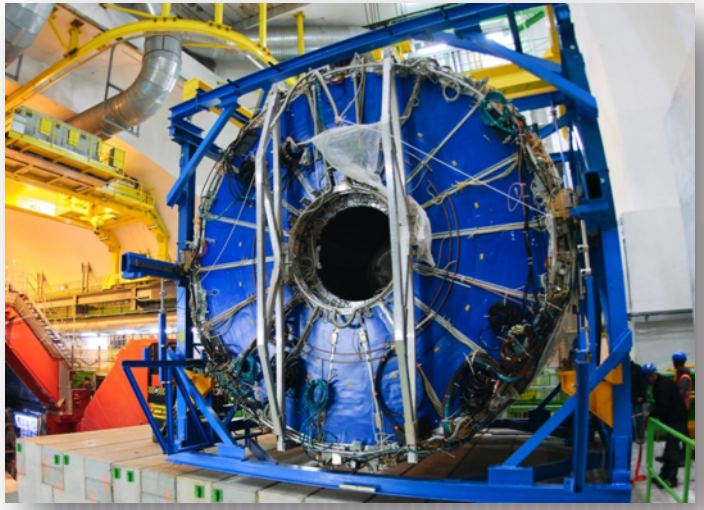


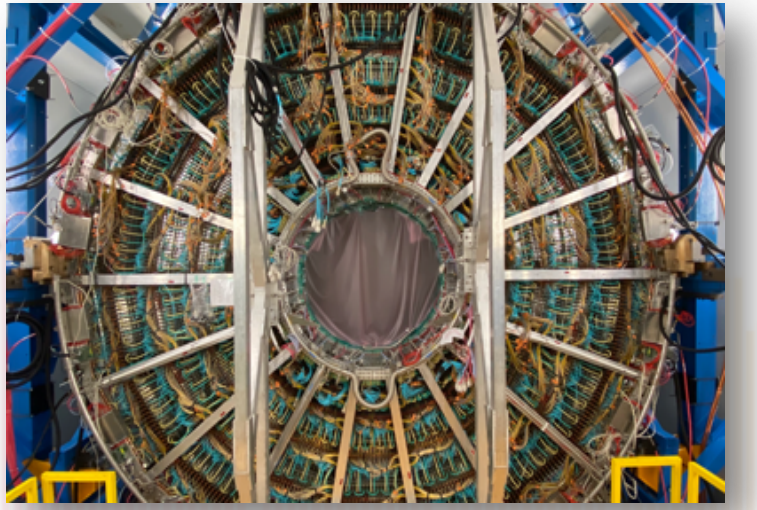




Run 1&2 ITS:
~10^7 channels

Run 3 ITS2 + MFT:
13x10^9 pixels





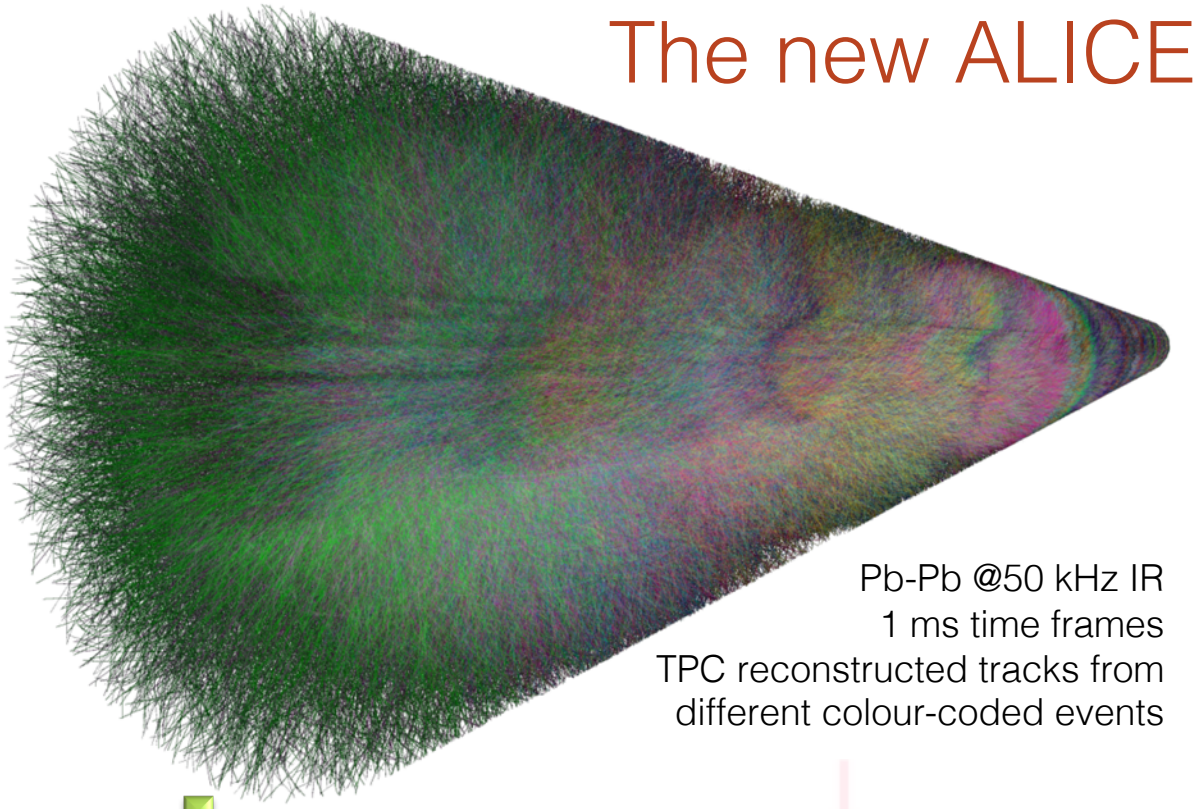
Run 1&2 TPC: MWPC-based
~1kHz readout

Run 3 TPC: GEM-based
50kHz readout

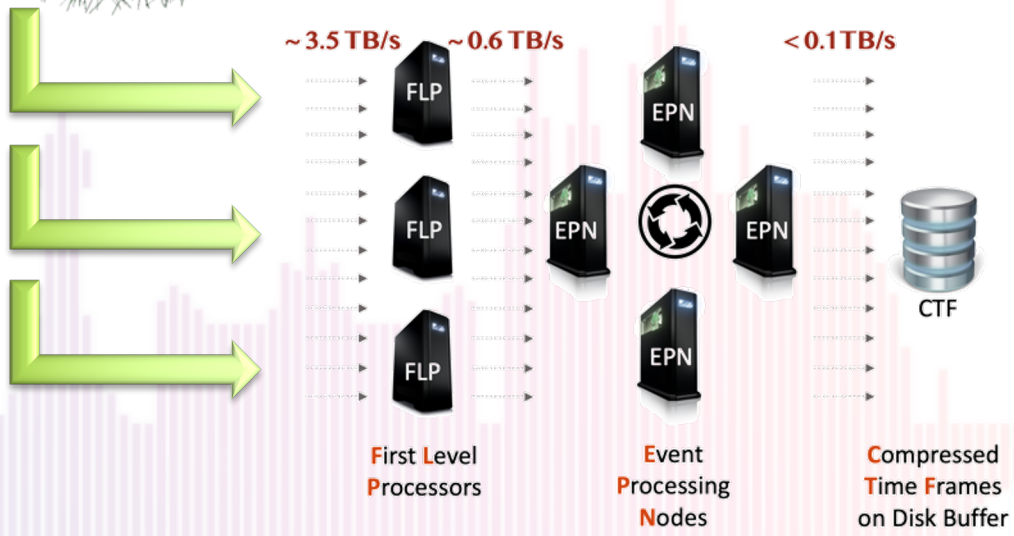
BREAKING NEWS

TPC will be lowered into the pit tomorrow (4th August)

The new ALICE processing chain



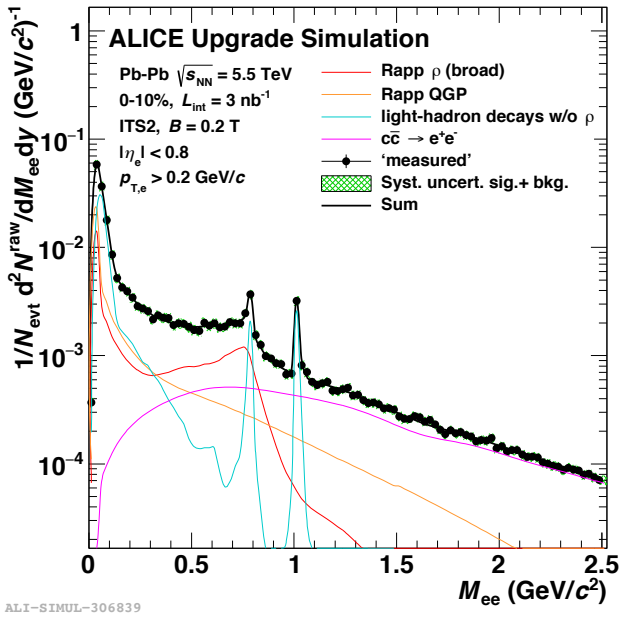
Pb-Pb @50 kHz IR
1 ms time frames
TPC reconstructed tracks from
different colour-coded events

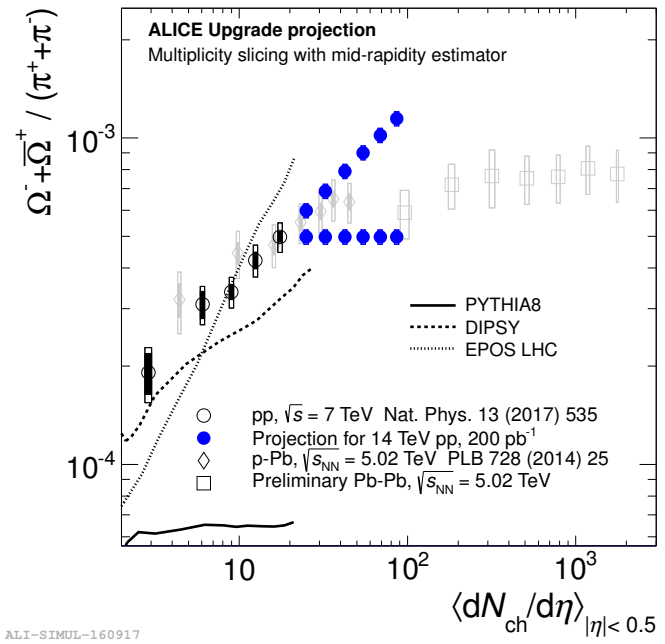


- Enormous challenge to cope with data
- Met with complete overhaul of data processing system [1]
- Online (synchronous) data reduction: 35x
- Comprehensive use of GPU technology [2]
  - 40x more performant, 4x more expensive
  - ~1500 GPUs used
- State-of-the-art coding algorithms [3]

[1] ALICE data processing for Run 3 and Run 4 at the LHC / C. Zampolli
[2] GPU-based online-offline reconstruction in ALICE for LHC Run 3 / M. Concas
[3] Fast Entropy Coding for ALICE Run 3 / M. Lettrich

50x more data: ALICE in Run 3



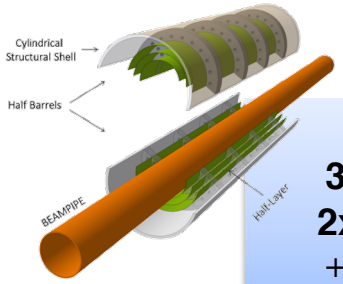


- Low-p_T heavy-flavour mesons and baryons
  - study QCD with heavy quarks created in initial hard scattering
- Low-p_T charmonia
  - c-cbar melting and re-generation in deconfined system
- Low-mass di-electrons
  - QGP thermal radiation via virtual photons
- High readout rate
  - crucial for high-multiplicity studies in pp, p-Pb

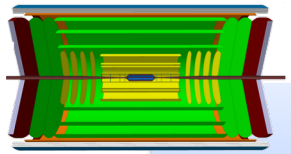
More info: Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC, https://cds.cern.ch/record/2703572?ln=en

ALICE in wonderland: the future

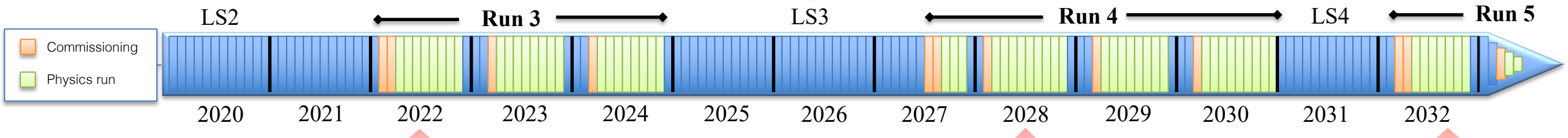
GEM-based TPC, ITS2, MFT
50x readout capability
3x tracking precision



ITS3, FoCal
3x tracking precision
2x efficiency at low p_T
+ forward γ detection



ALICE 3
Ultra-thin, entirely Si-based
50x readout capability



- EM radiation from the QGP: low-mass di-electrons
- Low-p_T heavy-flavour mesons, baryons
- Precise J/ψ and ψ(2S)
- High multiplicity pp, p-Pb: hadrochemistry, collectivity
- Hadronic interactions up to **Ω-Ω**
- (Anti)(hyper)nuclei production up to A = 4

- Higher precision: c, b baryons, beauty mesons, EM radiation
- Gluon nPDF down to x <10^{-5}
- Jet quenching at forward rapidity
- Long-range collectivity with FoCal
- Search for charmed nuclei

- Multiply-charmed baryons
- EM radiation: ultra-soft photons
- Hadronization at very low p_T
- Coherent pion production
- Diffusion of conserved charges
- Search for dark photons