Light-flavour measurements in Run 3 and 4 with ALICE

PHENOMenal Workshop

https://indico.cern.ch/event/1206467/

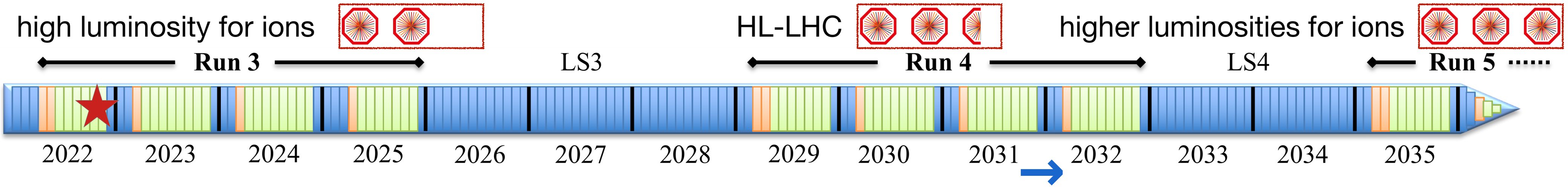
Building on the shoulder of giants

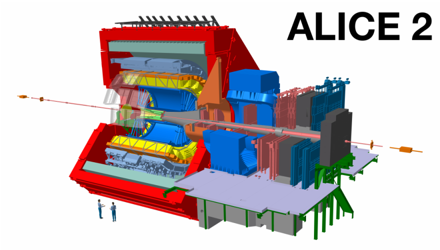
11/11/2022

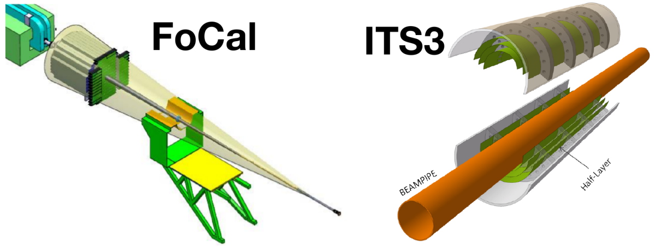
Nicolò Jacazio (Bologna University)

https://about.me/jacazio

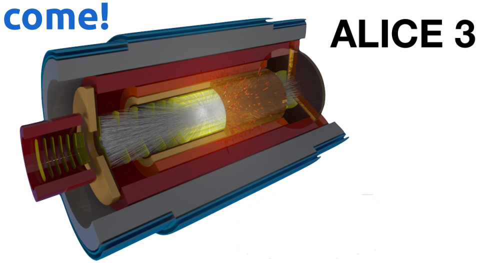
An evolving ALICE detector: Run 3 and 4 (and 5)







CERN-LHCC-2020-009 CERN-LHCC-2019-018



CERN-LHCC-2022-009

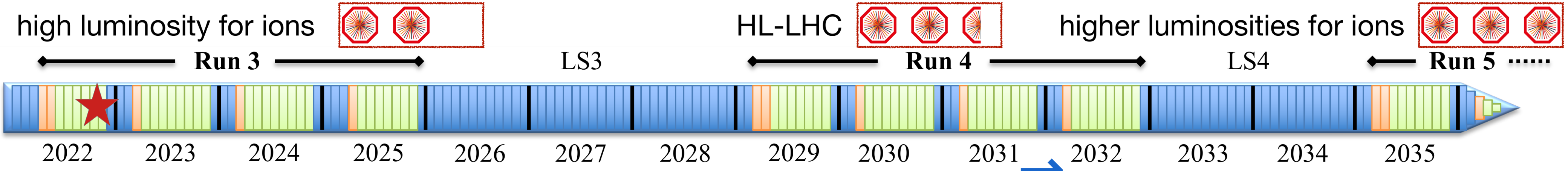
The heavy-ion experiment at the CERN LHC

- Unique PID capabilities among all LHC experiments
- Covers broad kinematic range
- Many different PID techniques
- Excellent performance in Run 1 and Run 2

Run 3+4 goals for data:

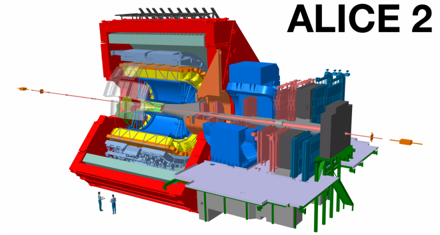
- Increase statistics
  - » 50 kHz in Pb-Pb → 13 nb^{-1} in Run 3+4
  - » 200 pb-1

An evolving ALICE detector: Run 3 and 4 (and 5)

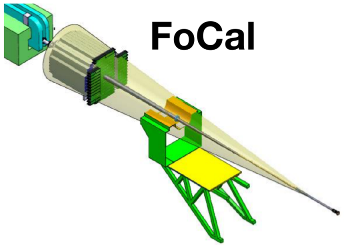


More to come!

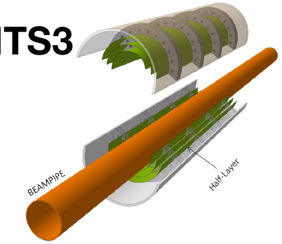
ALICE 2



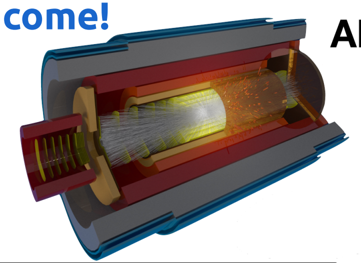
FoCal



ITS3



ALICE 3



The heavy-ic

- Unique P
- Covers b
- Many dif
- Excellent

nb^{-1} in Run 3+4

A new detector

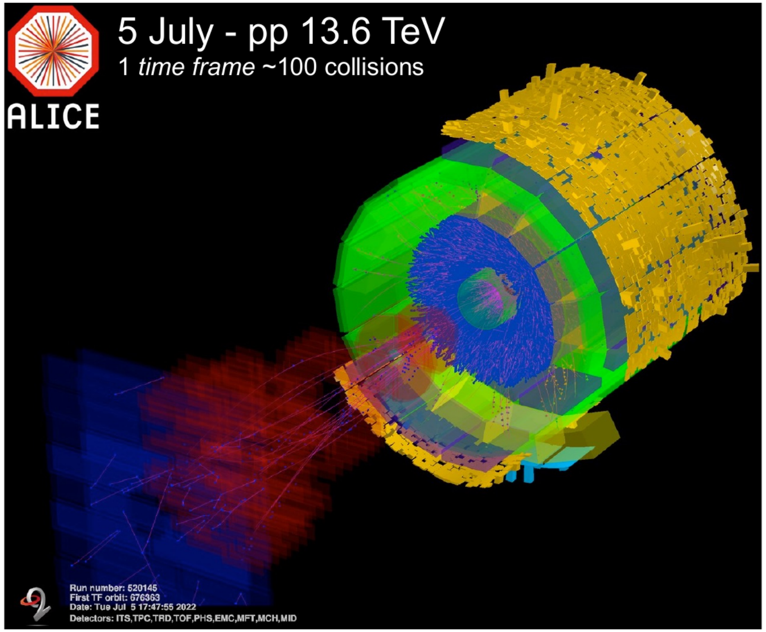
- Upgraded of Time Projection Chamber (TPC) with GEM amplification in continuous readout → **improved readout rate**
- New Inner Tracking system (ITS) → **Improved resolution**, lower material budget
- New Muon Forward Tracker (MFT) → Vertex tracker at forward rapidity
- New Fast Interaction Trigger (FIT) → Centrality, event plane, luminosity, interaction time
- New data acquisition and reconstruction framework – (Online – Offline , O2)
- **Record minimum bias Pb-Pb data at 50 kHz (x50 maximum Run 2 rate)**

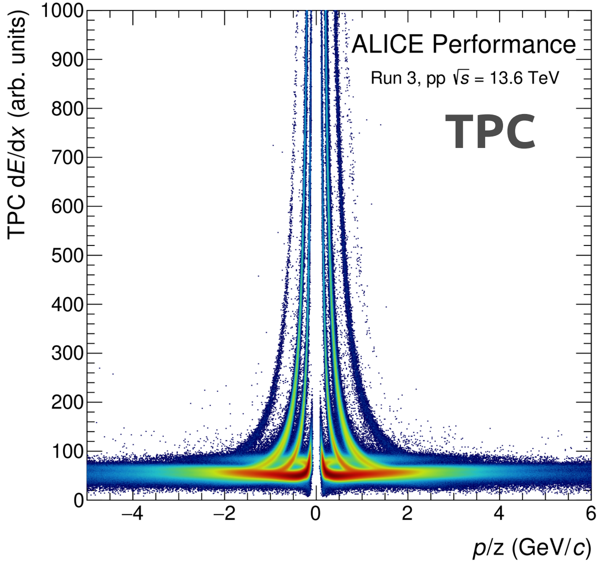
A near future

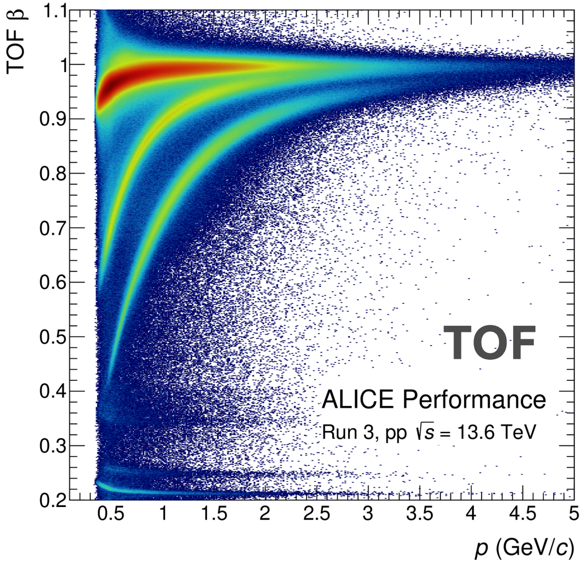
- Run 3 has started already since July
- Already recorded more pp collisions of Run 2!
- And performance is here!

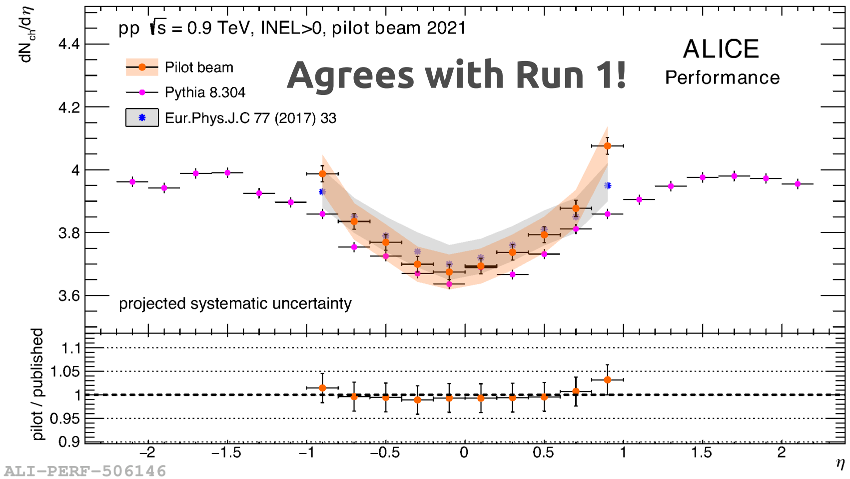
Goal → better tracking and unchanged PID capabilities

and we are getting there

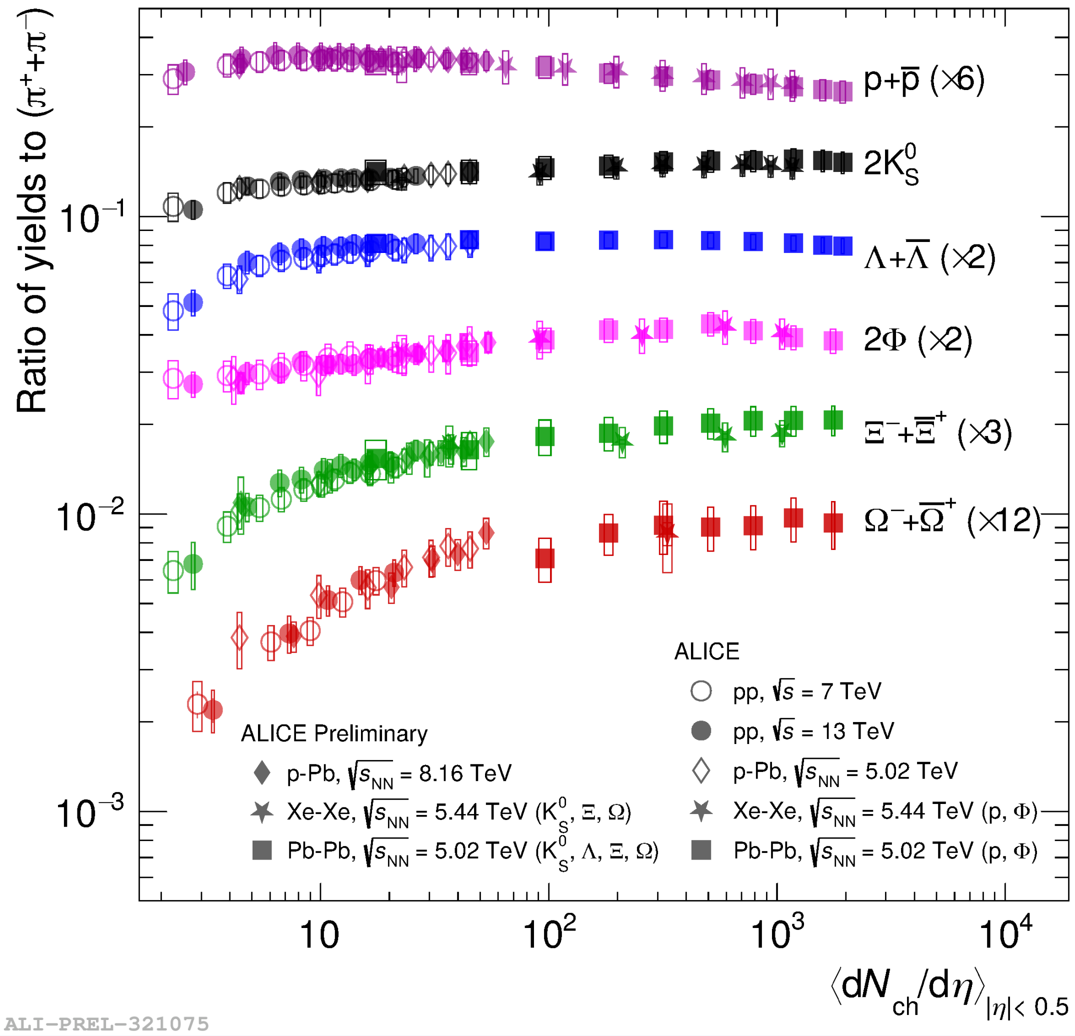








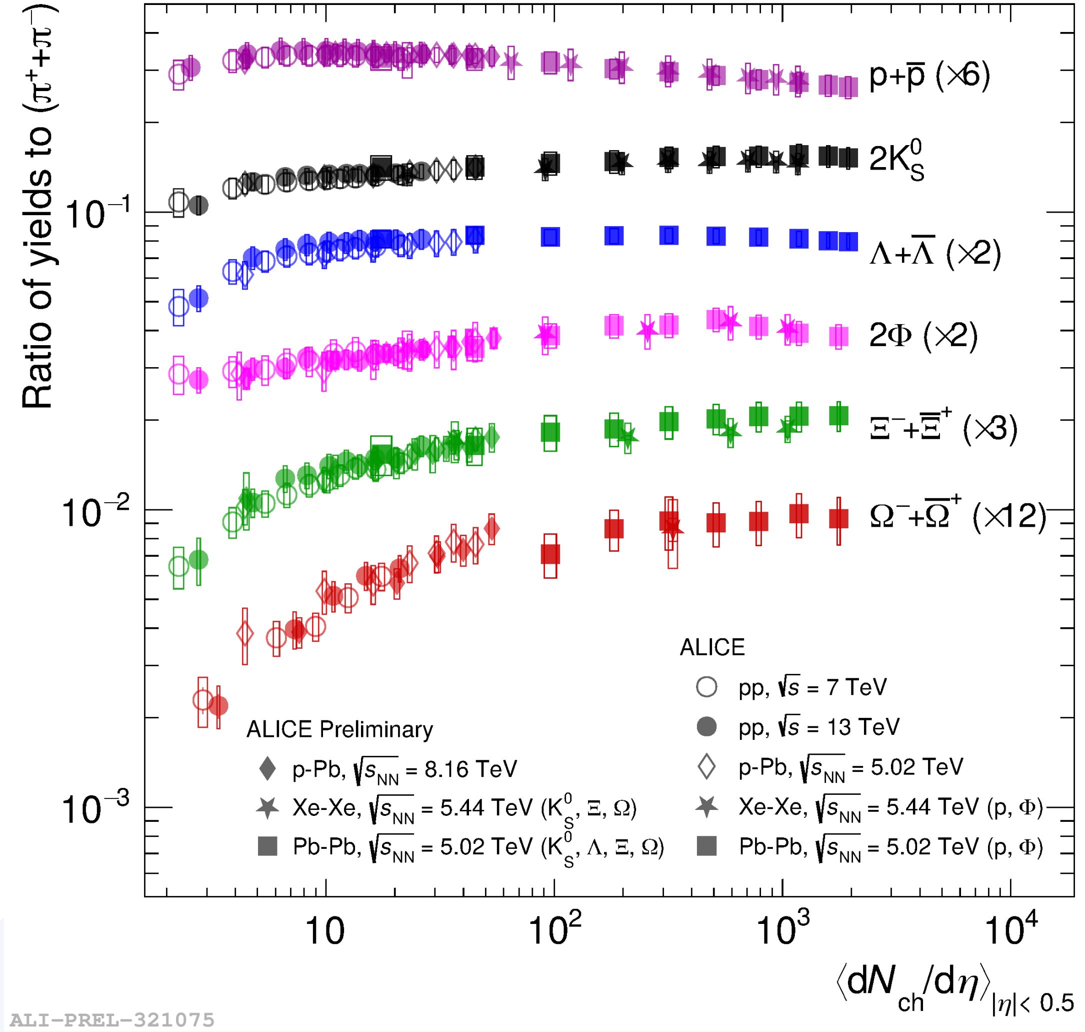
Filling the gap: from small to large systems



From Run 1+2:

- At LHC energies continuous evolution is observed also when considering small systems (pp and p-Pb)
- In pp, p-Pb, Xe-Xe and Pb-Pb the charged **particle multiplicity is a good scaling observable to describe particle production**
- Steeper increase in particles with more stangeness content indicating that the **strangeness enhancement starts at the charged-particle multiplicity reached in small systems**

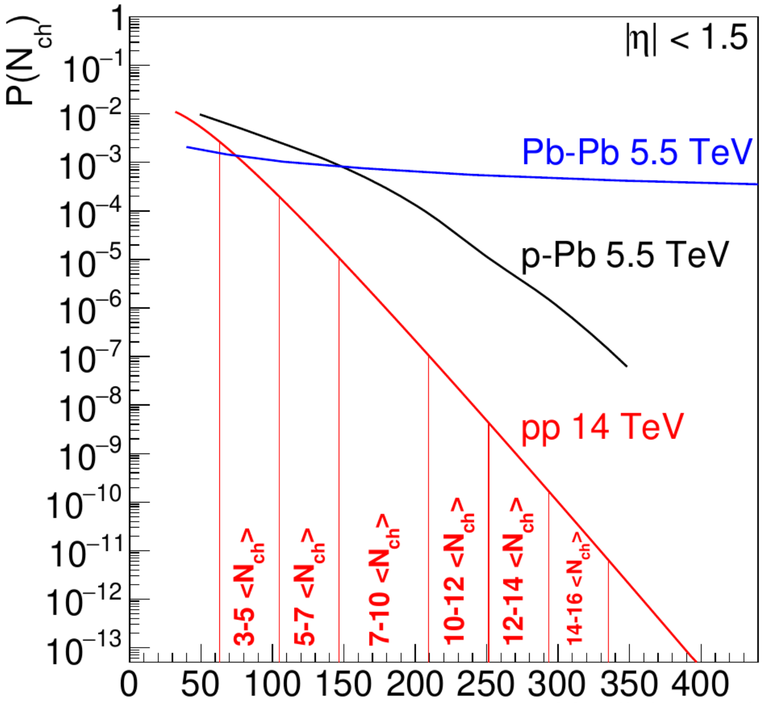
Filling the gap: from small to large systems



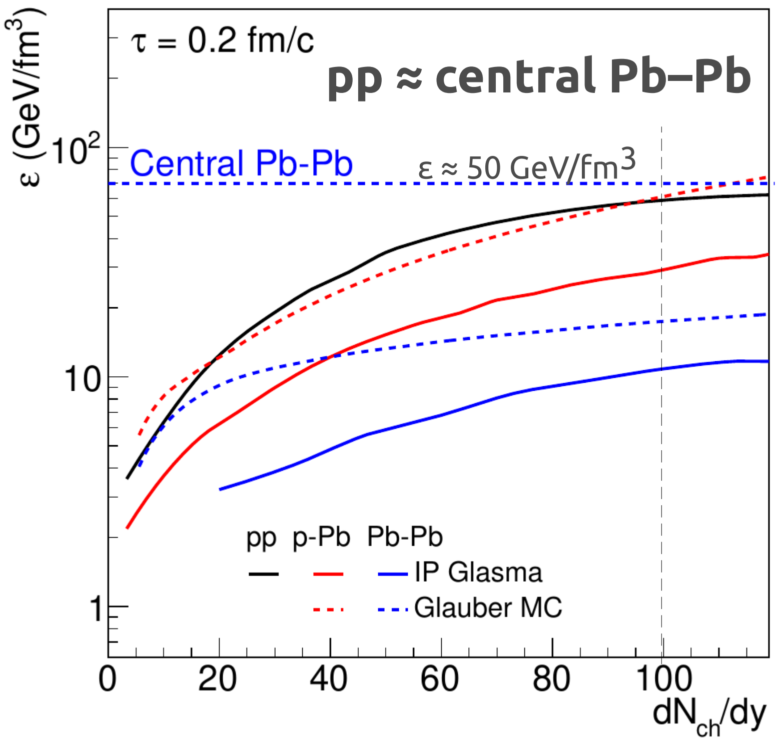
From Run 1+2:

- At LHC energies continuous evolution is observed also when considering small systems (pp and p-Pb)
- In pp, p-Pb, Xe-Xe and Pb-Pb the charged **particle multiplicity is a good scaling observable to describe particle production → does it hold true?**
- Steeper increase in particles with more stangeness content indicating that the **strangeness enhancement starts at the charged-particle multiplicity reached in small systems → is it valid for extreme pp events?**

With large statistics comes great multiplicity

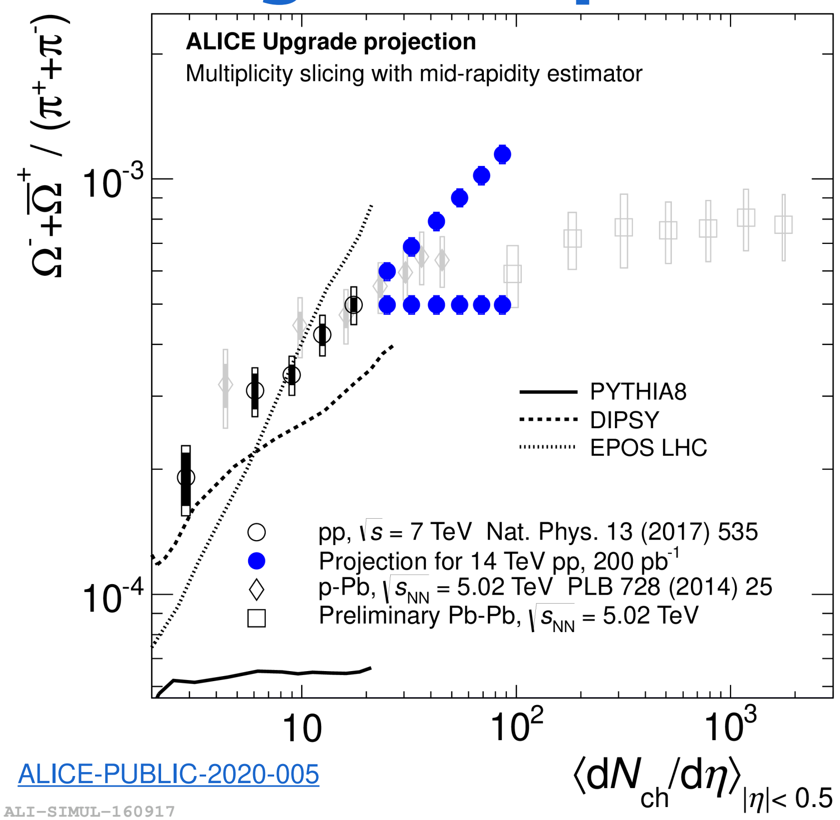


ALICE-PUBLIC-2020-005



- For pp $dN_{ch}/d\eta \approx 100$ (**similar energy density** as found in central Pb–Pb collisions)
- Assuming an integrated luminosity of about 200 pb^{-1} (interaction rate 0.5 MHz): $N_{ev}(dN_{ch}/d\eta|_{100}) = 2.8 \times 10^4$ → close to 65% most central Pb–Pb collisions
- Will be able to **fill the gap** between small and large systems and look for **rare events**

Strangeness production



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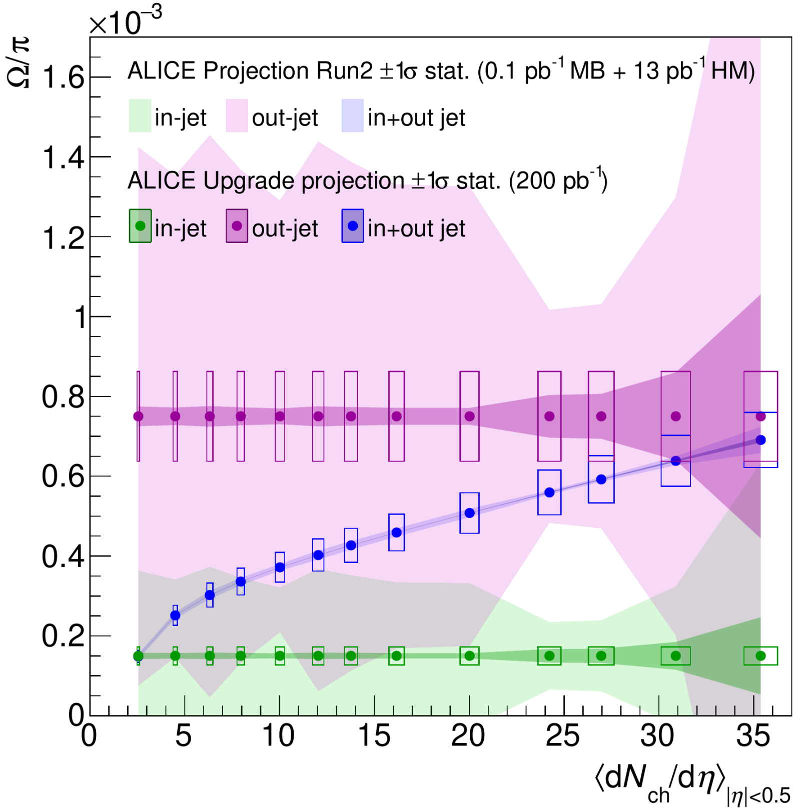
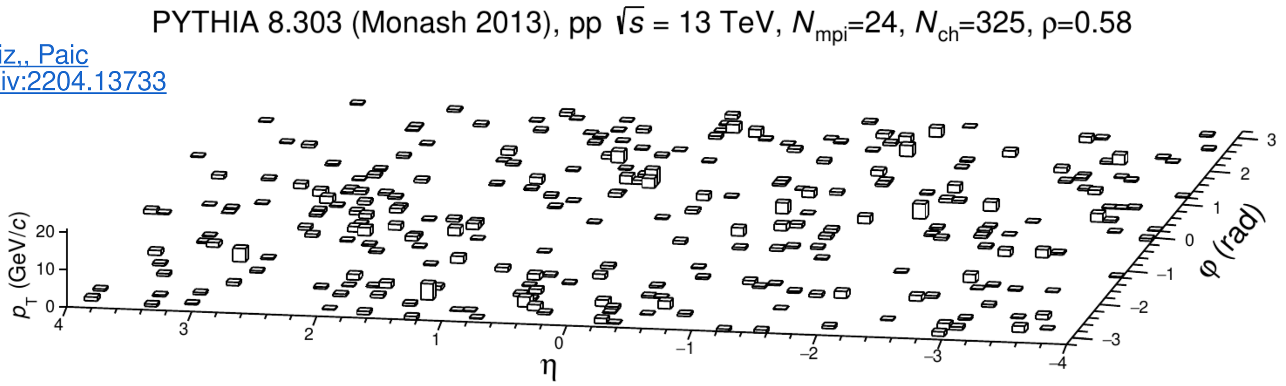


- Does strangeness production reach the thermal limit in high-multiplicity pp collisions?
- Measuring pp events with **$dN_{ch}/d\eta$ > 100 is a strong need!**
- Going more differential is the key to give model constrains → **high precision is a must!**

Looking at rare pp events: flatenicity

Ortiz,, Paic
arXiv:2204.13733



- More data means more differential measurements
- Going towards a very fine underlying event definition

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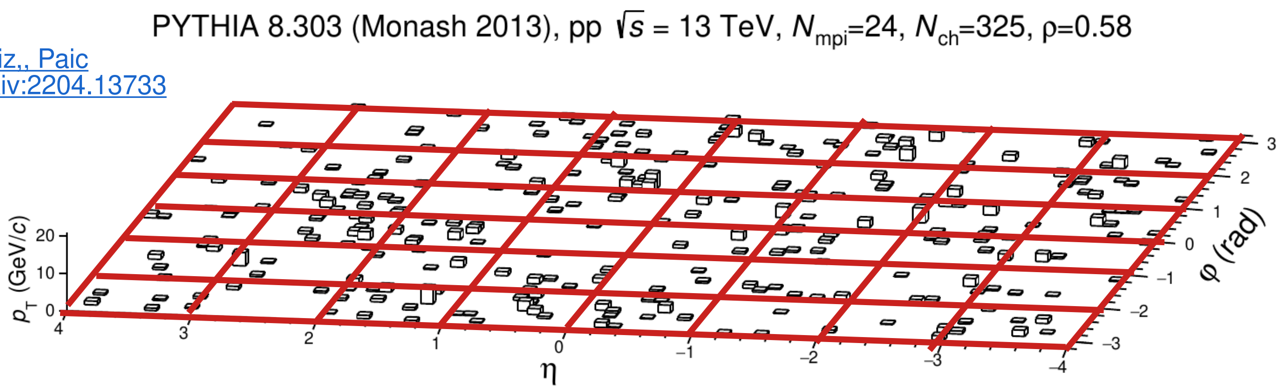
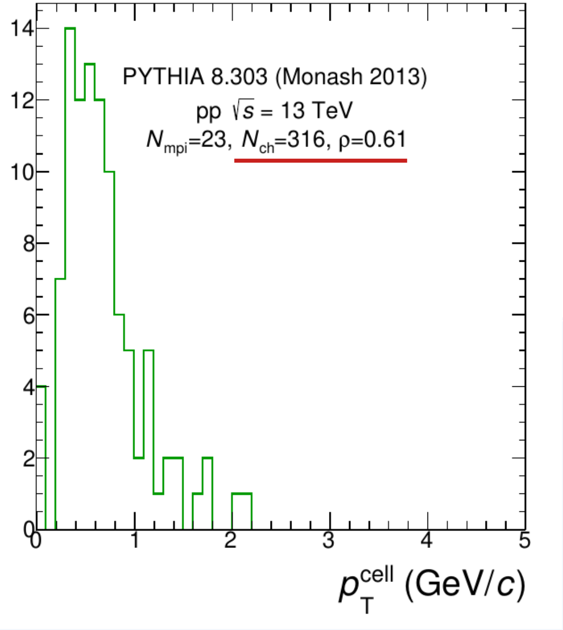


$$\rho = \frac{\sigma_{p_T^{cell}}}{\langle p_T^{cell} \rangle}$$

ρ: 0 (jetty) to 1 (isotropic)



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- **Flatenicity** → track distribution divided into 2D cells
- Straightforward implementation into the detector acceptance

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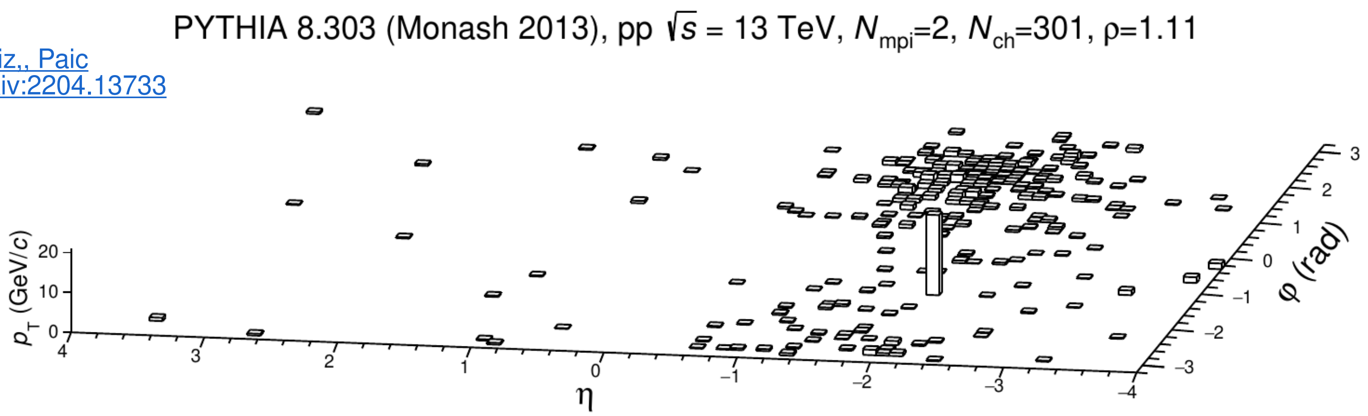

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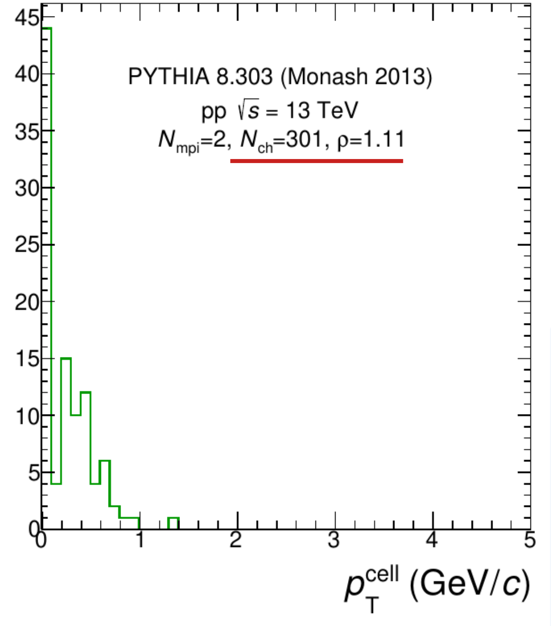

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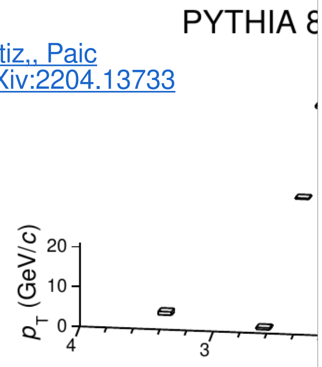
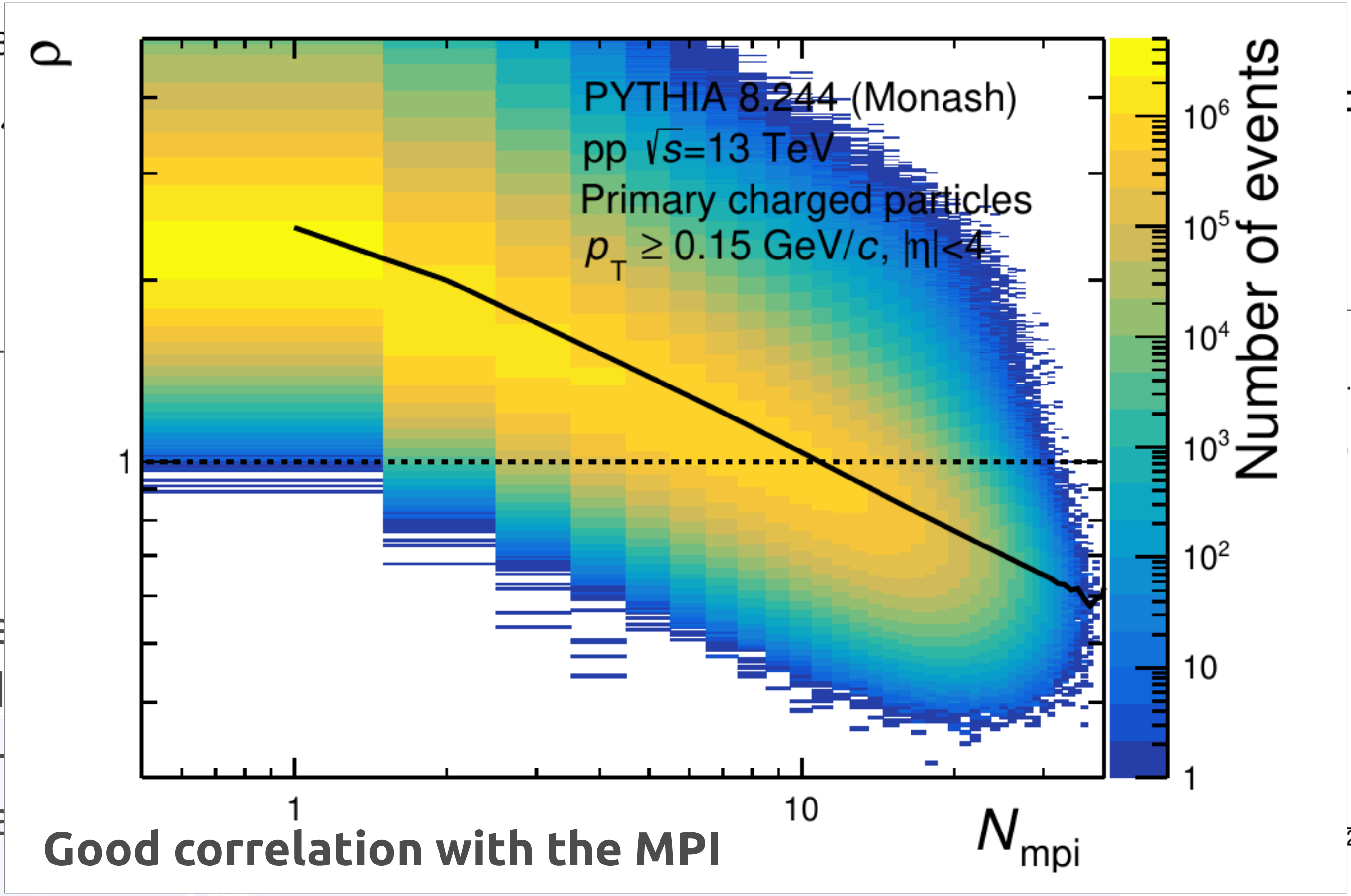
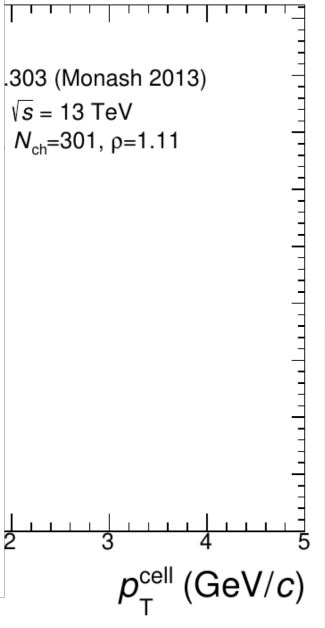




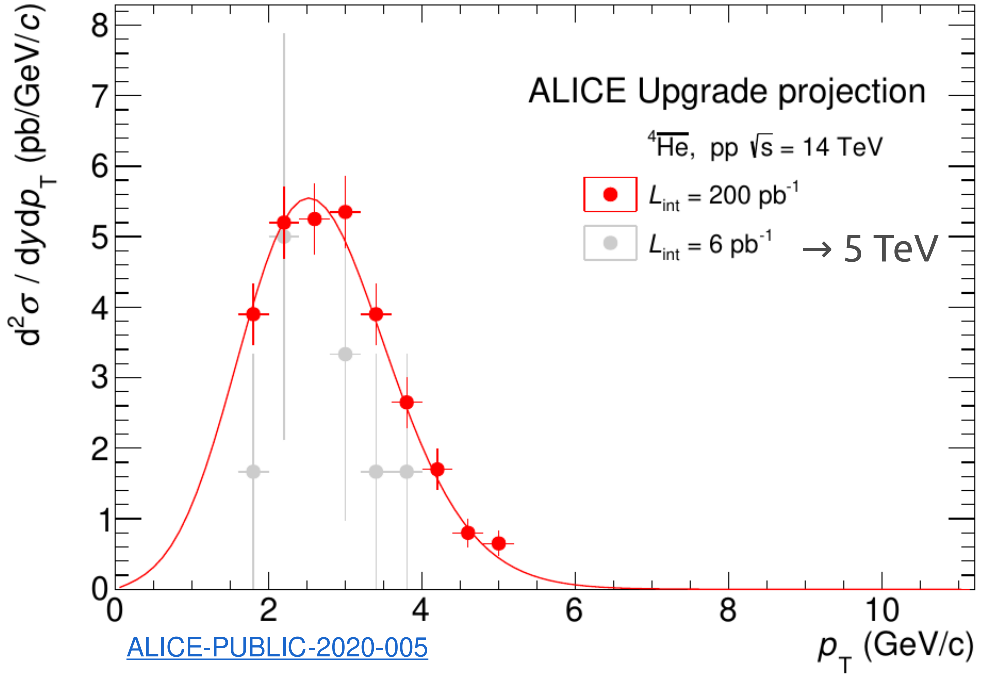
Good correlation with the MPI

$$\rho = \frac{\sigma_{p_T^{cell}}}{\langle p_T^{cell} \rangle}$$



- More data me
- Going toward
- **Flattenicity** -
- Straightforwa

Light nuclei in pp collisions



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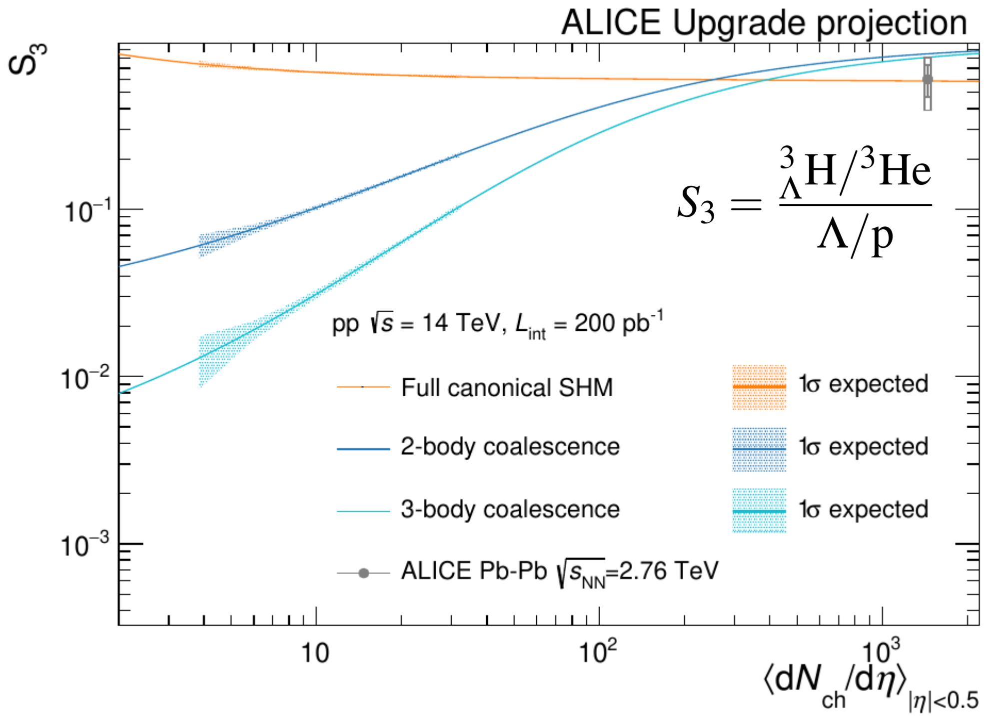
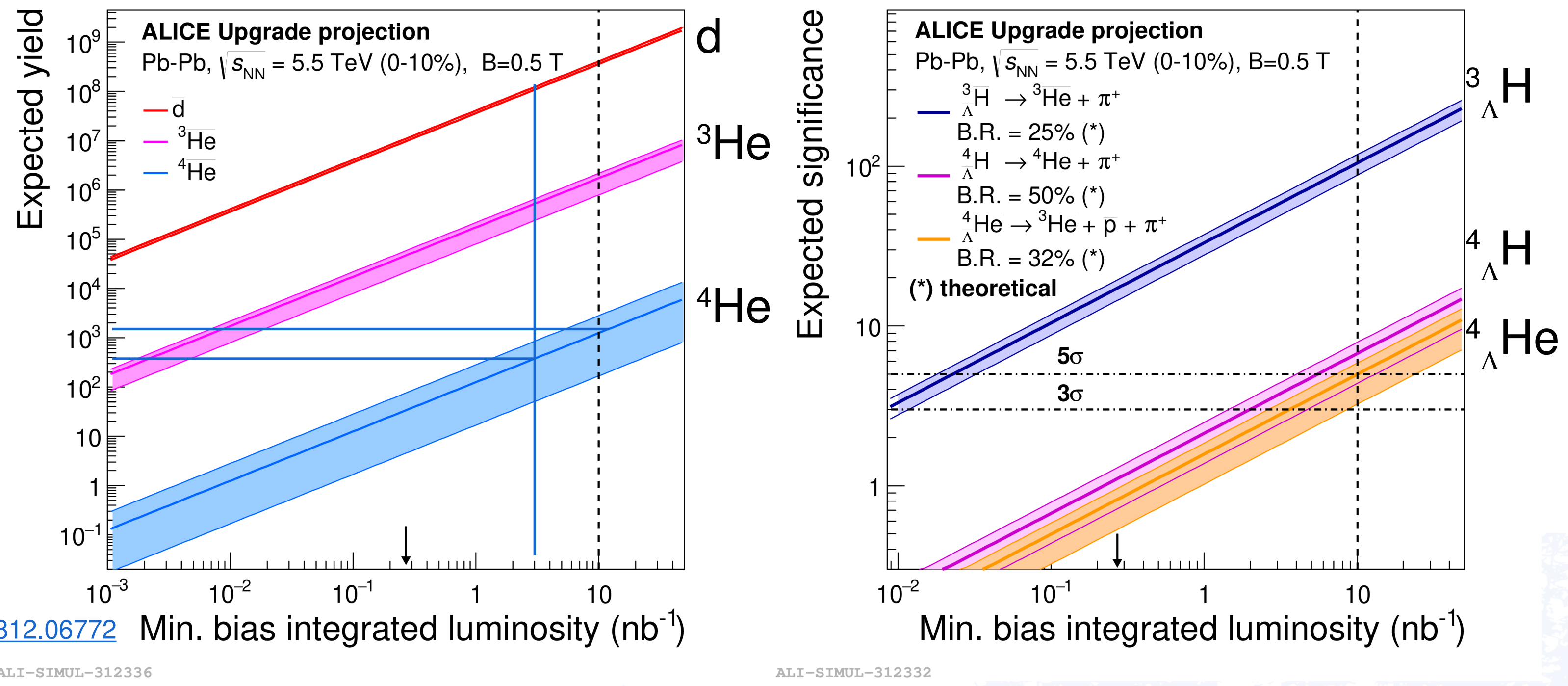


- First measurement of (anti)^{4}He and (anti-)$^{3}_{\Lambda}$He in pp
- More insight into the particle production mechanisms

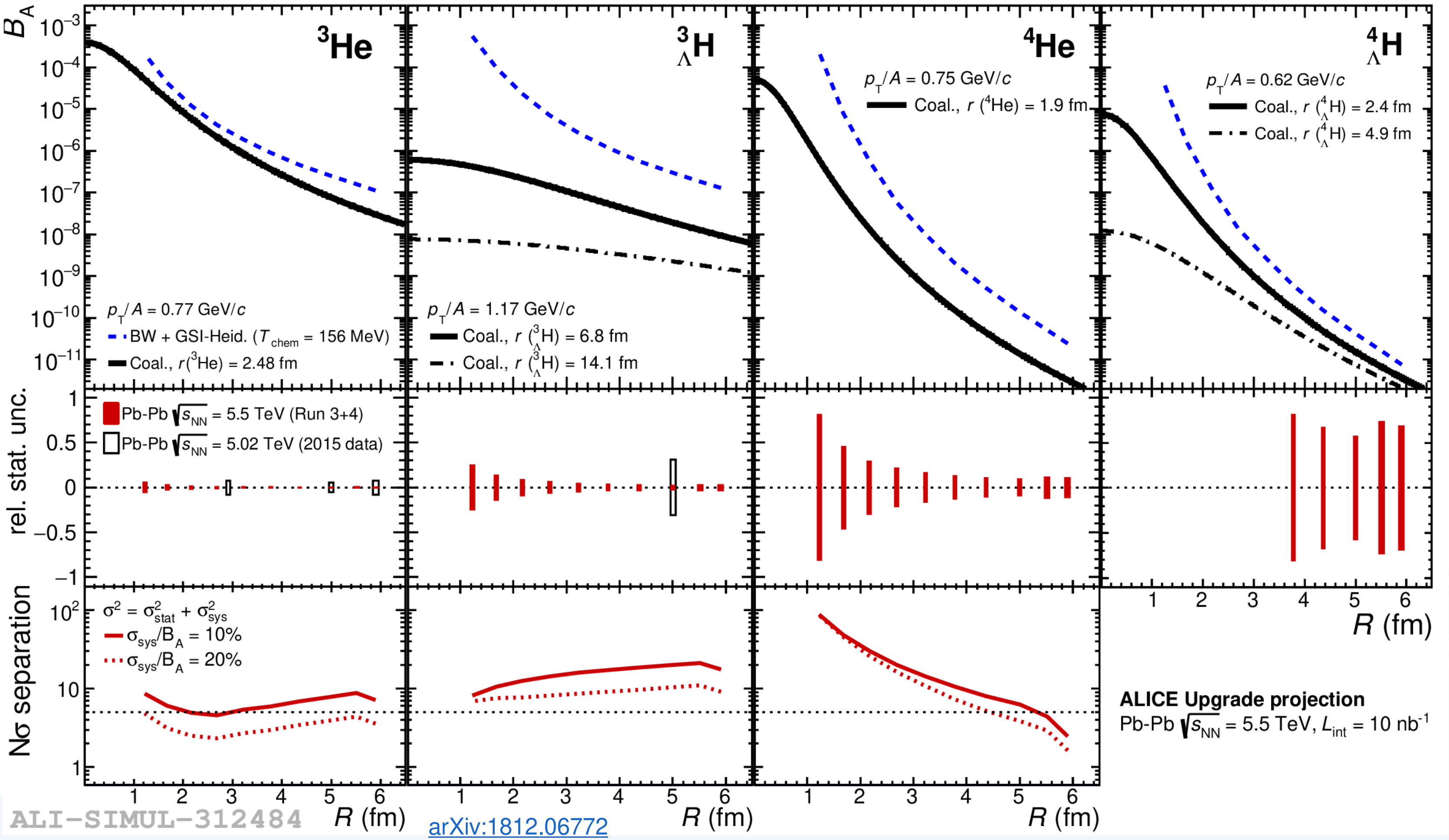
Going to AA → nuclei production projections



arXiv:1812.06772

- Nuclei production yield in Run 3 increased by a factor 100 due to the increased statistics
- Compensating for the penalty factor of ~300 in Pb-Pb → **A=3 tomorrow will be A=2 today**
- Possible **first observation** of (anti-)$^4_\Lambda$H and (anti-)$^4_\Lambda$He

Production of large nuclear states



arXiv:1812.06772

Potential to discriminate between different production mechanisms

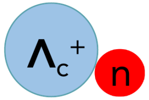
More exotic states

	Model	$f_0(980)$	N(1875)	$N\Xi$	$N\Omega$	$N\Lambda_c$
Structure		$q q \bar{q} \bar{q}$ or $K\bar{K}$	hadron molecule	dibaryon	dibaryon	dibaryon
$\left(\frac{dN}{dy}\right)_{th}$	q-coal.	5.4×10^{-2}	-	-	1.8×10^{-3}	1.5×10^{-3}
	h-coal.	$3.2^{\dagger}$	-	-	1.6×10^{-3}	5×10^{-3}
	thermal	10	3×10^{-1}	8.7×10^{-3}	5.7×10^{-3}	4×10^{-3}
Decay channel		$\pi\pi$ / $K\bar{K}$	$\Sigma^*(\rightarrow \Lambda\pi)K$	$\Xi \rightarrow \Lambda\pi$	$\Omega \rightarrow \Lambda K$	$\Lambda_c \rightarrow \pi K p + \Lambda_c \rightarrow K^0_S p$
B.R. (%)		dominant / seen†	unknown (87)	99.9	67.8	6.2 + 1.58
Mass (MeV/c^2)		990	1850 – 1920	-	-	-
Width (MeV/c^2)		10 – 100	120 – 250	-	-	-
S_{raw}	q-coal.	1.8×10^{8}	-	-	6.2×10^{4}	1.5×10^{4}
	h-coal.	$6.4 \times 10^{6\,\dagger}$	-	-	5.5×10^{4}	5.1×10^{4}
	thermal	3.6×10^{10}	5.5×10^{7}	6.7×10^{5}	1.9×10^{5}	4.1×10^{4}
$\frac{S}{\sqrt{S+B}}$	q-coal.	130-3.5	-	-	-	-
	h-coal.	-	-	-	-	-
	thermal	2600-70	520-360	-	-	-

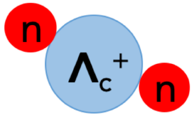
arXiv:1812.06772 Yields of exotic states in 0–10% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV

- Hadron identification, including topological reconstruction of weak decays, are particularly suited for these studies → ALICE's special
- Potential for discovery of new bounds states
- Bound state properties and potentials depend on basic QCD properties

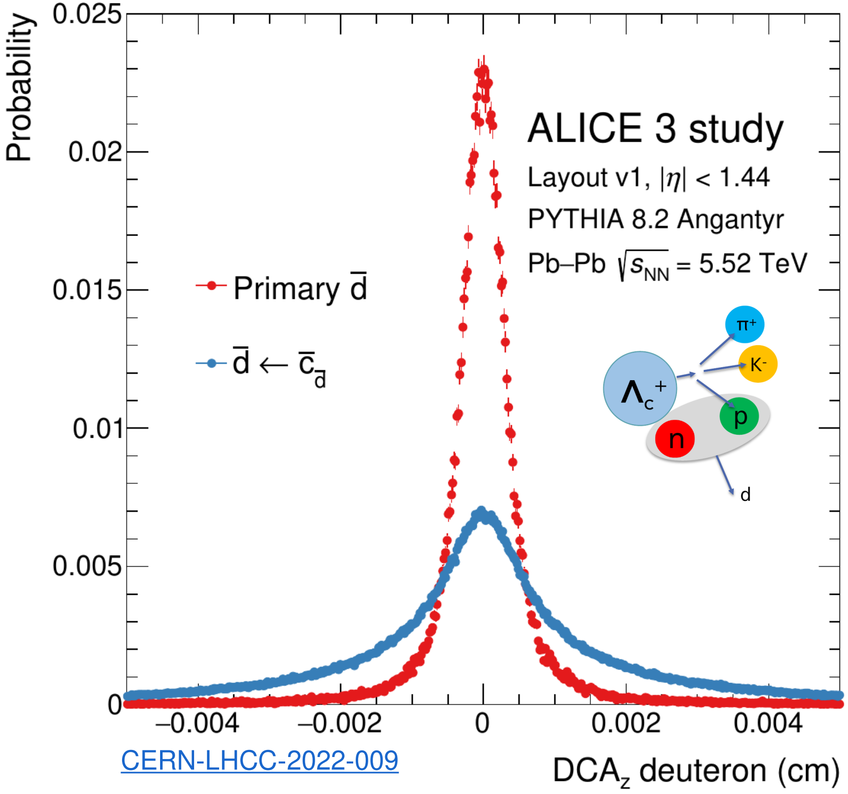
Discovery potential for charmed nuclei



c-deuteron



c-triton



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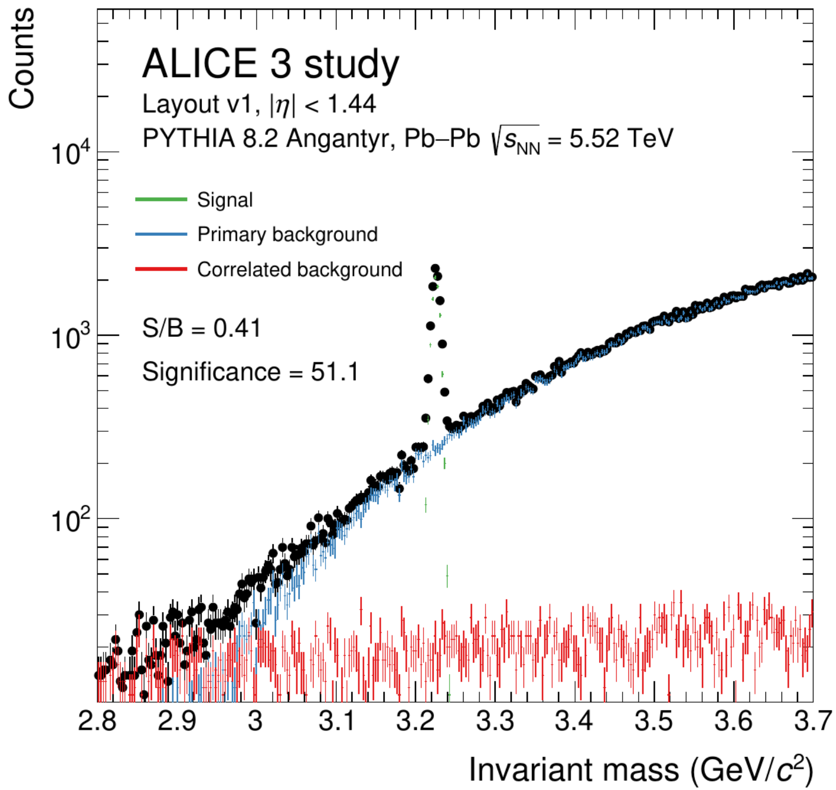
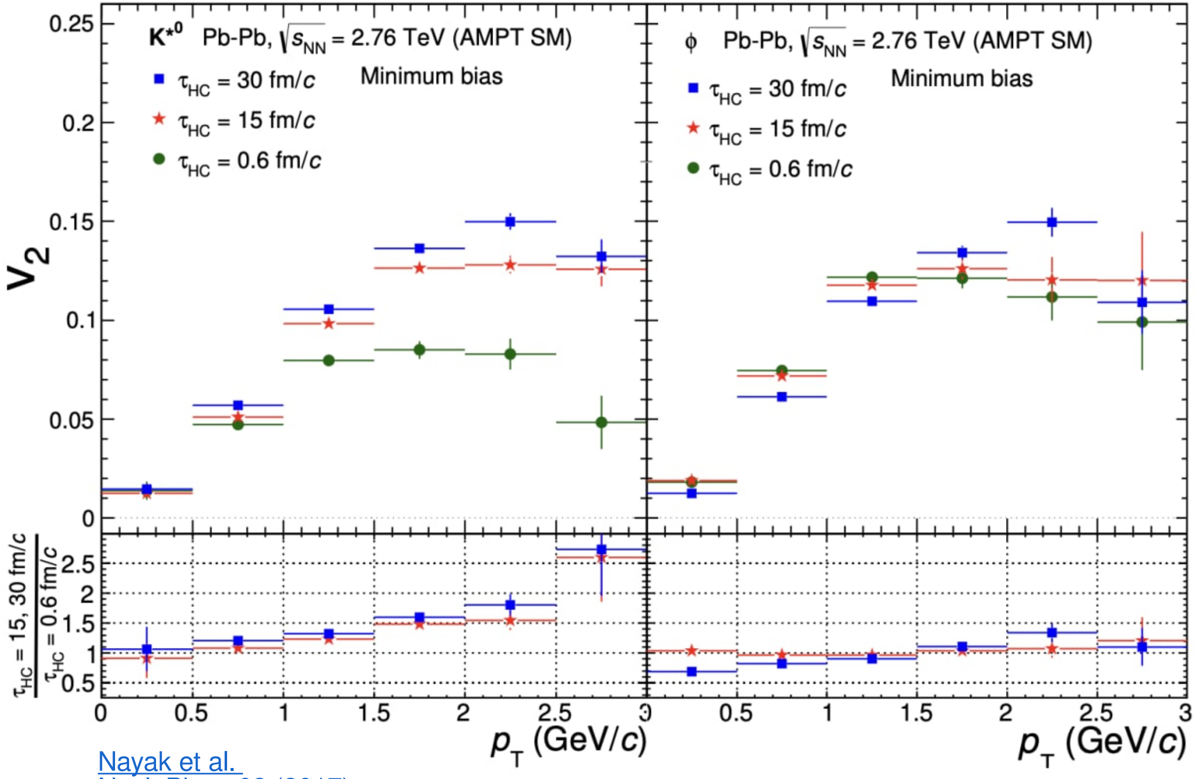


- c-nuclei are on the frontier between light and heavy flavours → extension of hyper-nuclei
- ALICE in Run 4 will start to become sensitive to c-deuteron production (if it exists)
- Run 5 with ALICE 3 will give the definitive answer

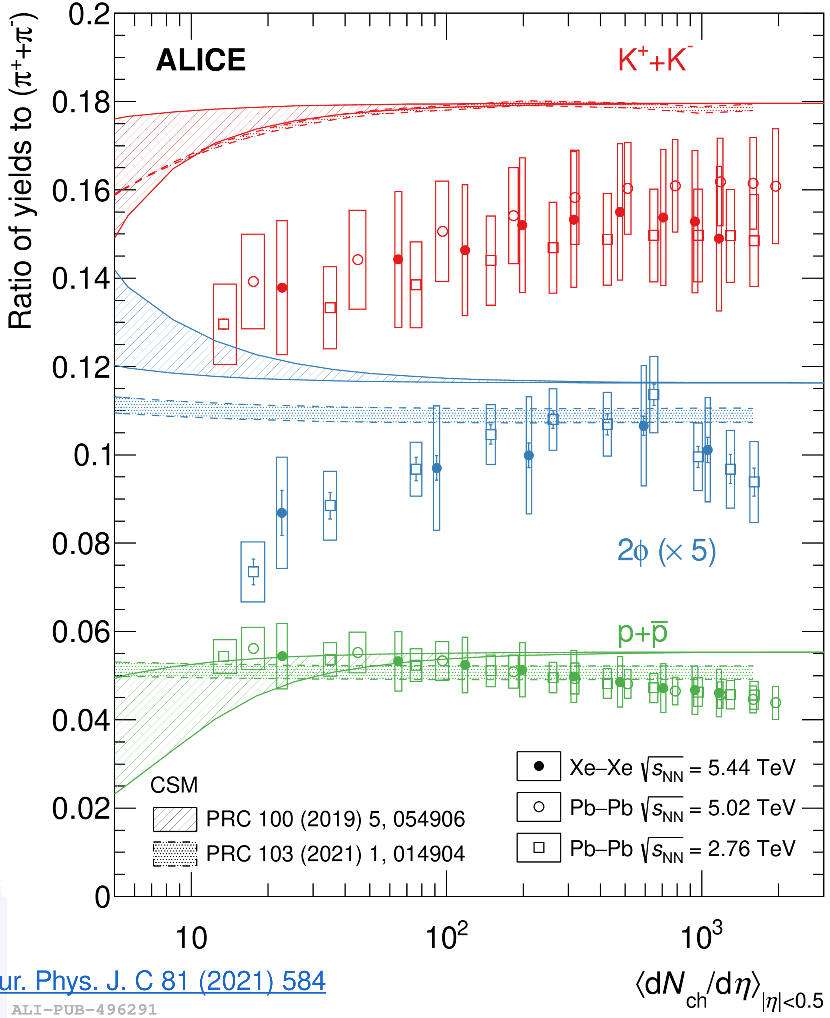
Resonances constraining the hadronic phase



[Nayak et al. Nucl. Phys. 62 (2017)]

- Precision measurements of resonances flow will be the way to constrain the duration of the hadronic phase

Looking at hadrochemistry in detail



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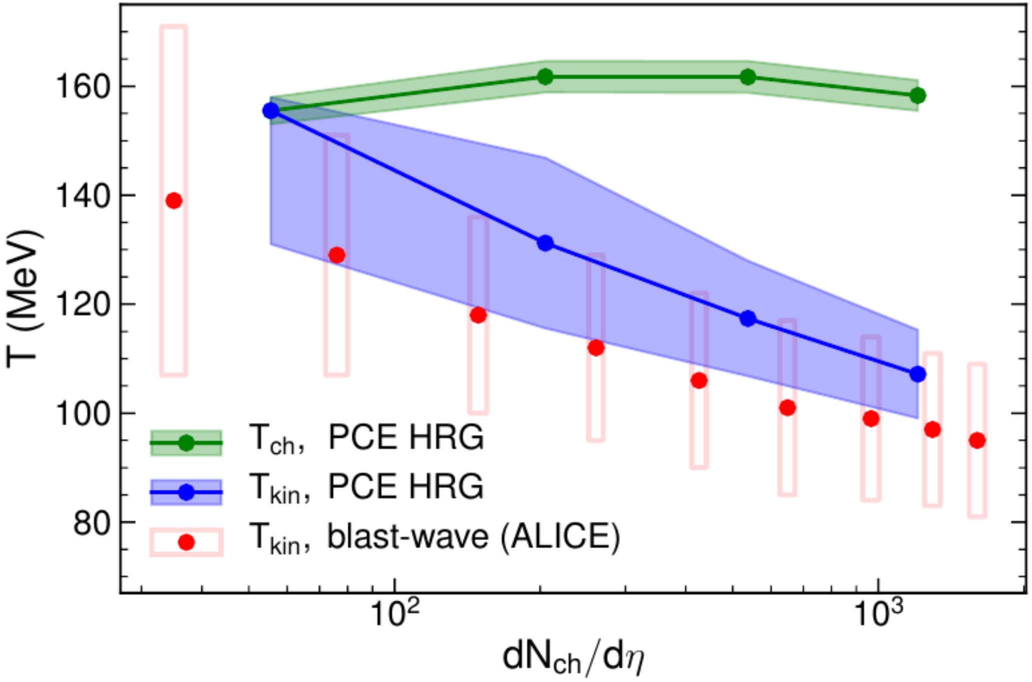
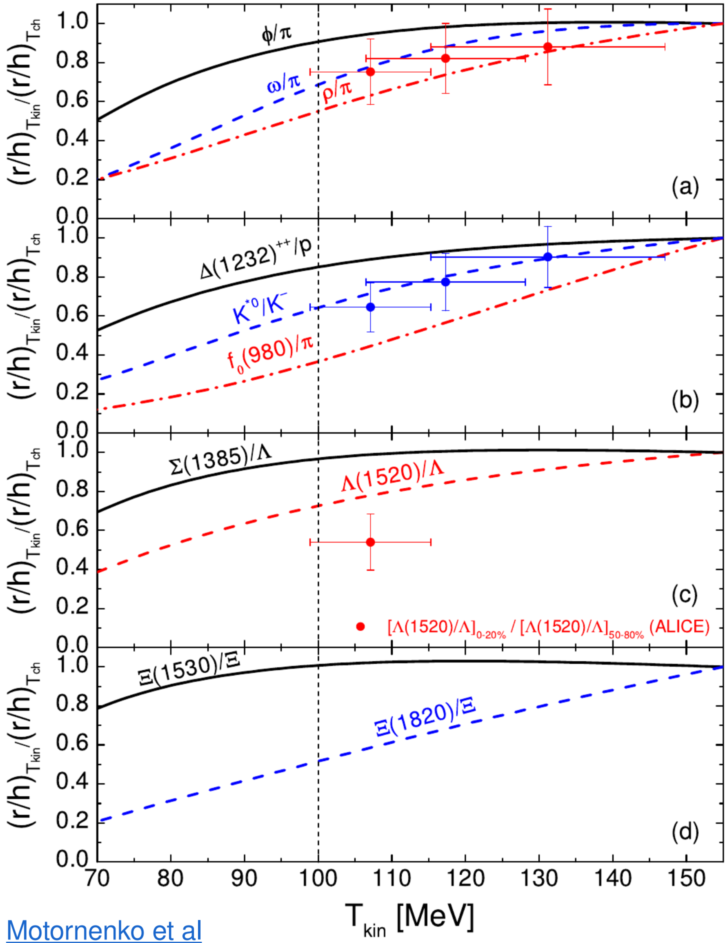
- What happens for the most central collisions?
  - » Decreasing trend ?
- More statistics → more bins, more precise, more particle species
  - » Will resolve these behaviors
- Multiple light nuclei probes → learn from Xe-Xe in Run 2

Nuclear chemistry: exotic states

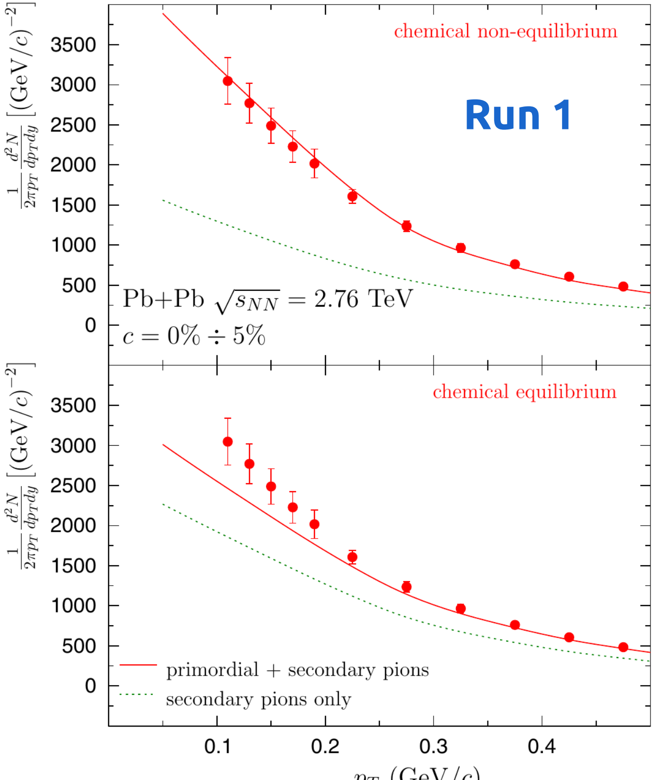




Motornenko et al
arXiv:1908.11730

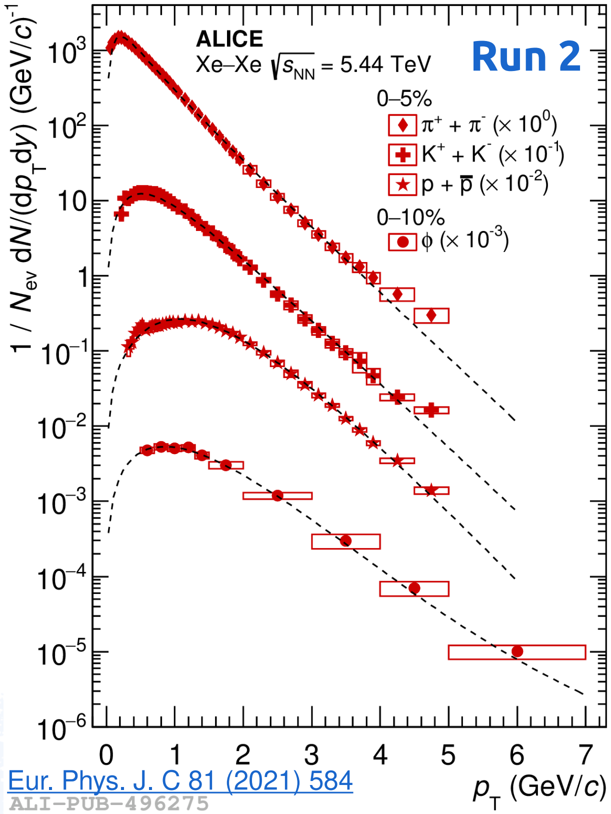
- Use the sensitivity of short-lived resonance yields to extract the kinetic freeze-out temperature
- Give stronger constrains with high precision measurements

Exploring the bose condensate in AA



Phys. Rev. C 90, 014906

In Run 2:
→
extended momentum reach to 50 MeV/*c*



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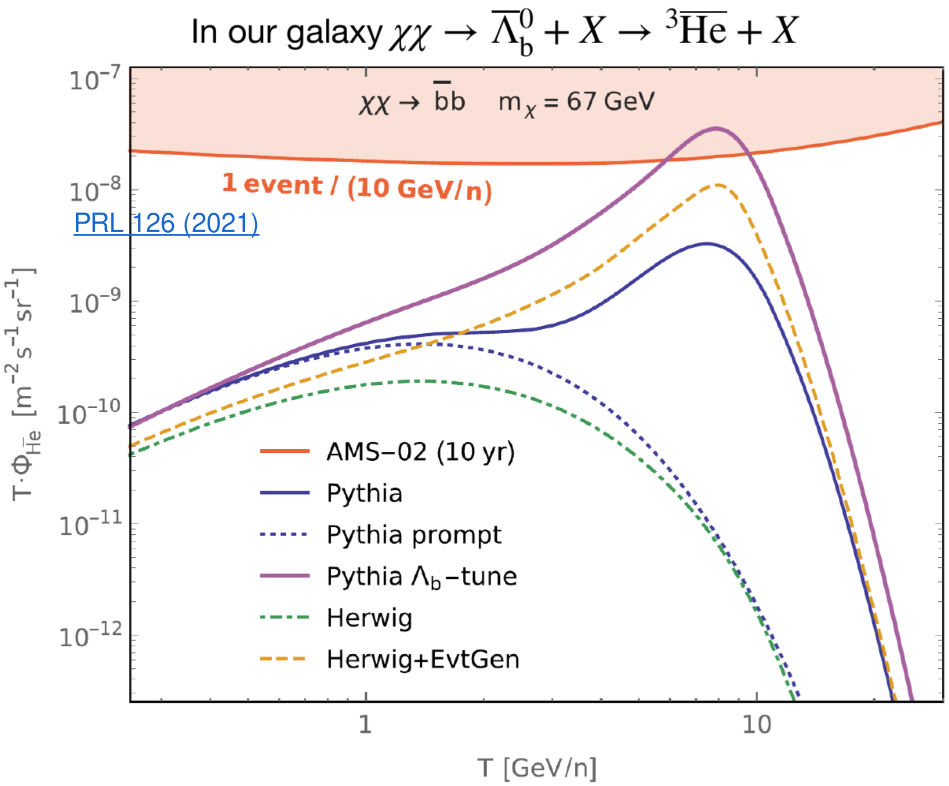
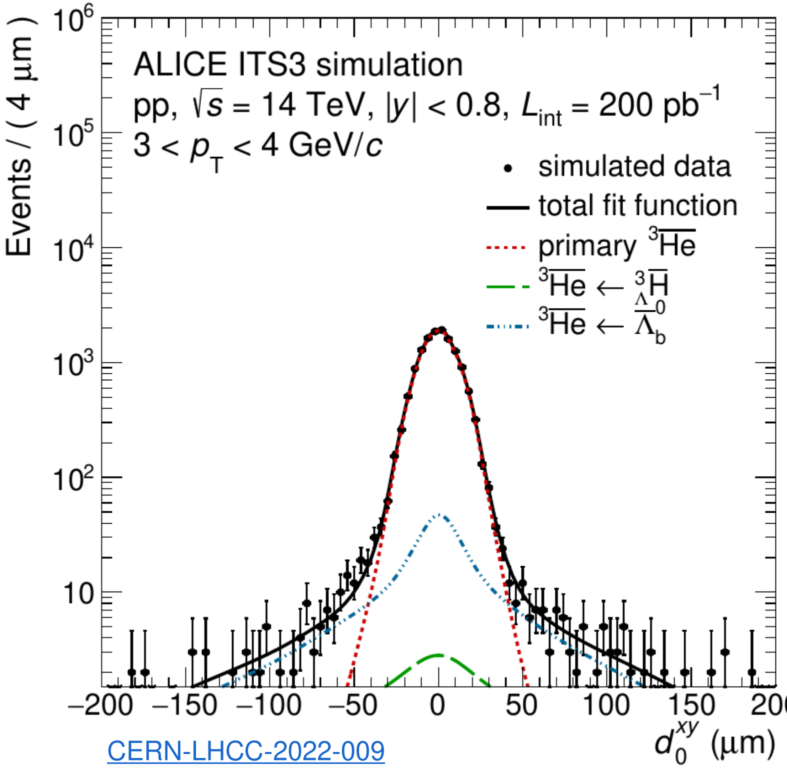
- Low B-field data taking are foreseen → discovery potential for the condensate in AA
- Lower material budget, closer to the interaction point → further extend momentum reach
- Lighter ions to explore initial state effect

Antinuclei production in b-quark decays



PRL 126 (2021)



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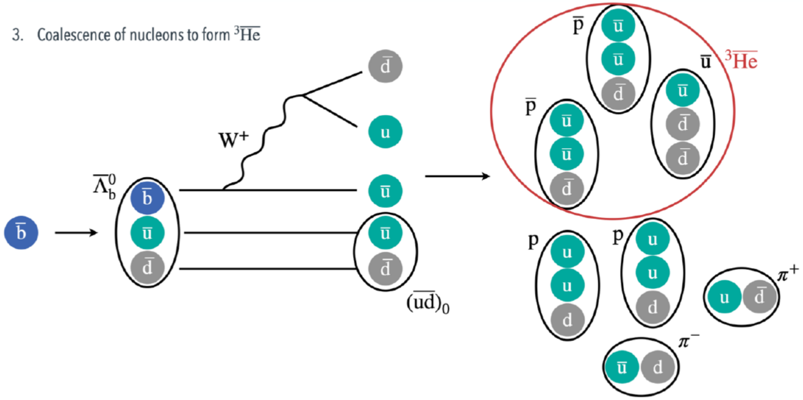
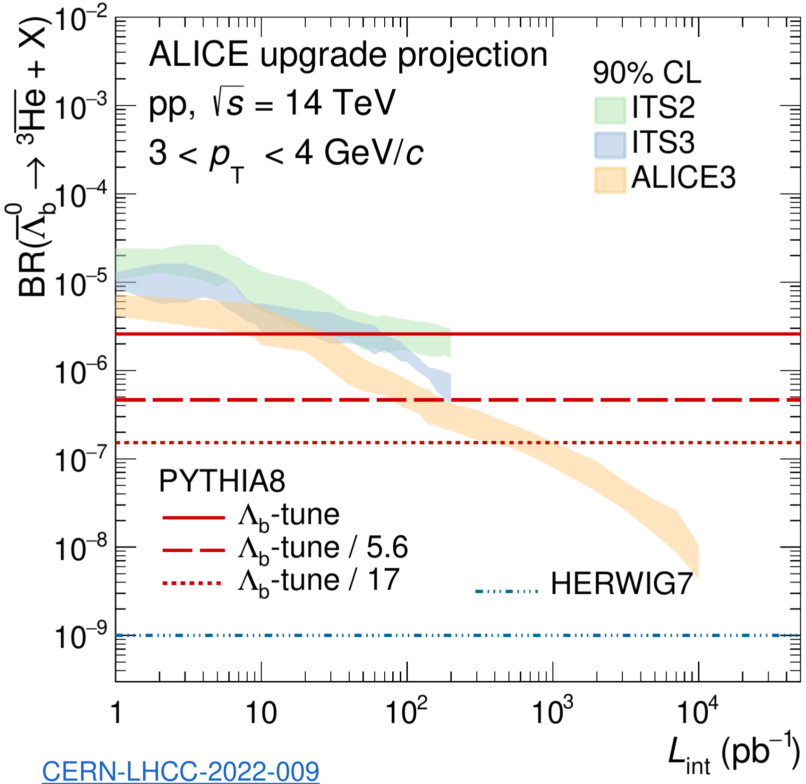
- Anti-³He originating from Λ_b decays from dark matter annihilation might lead to an enhanced flux of anti-³He near earth
- Accelerator based experiments like ALICE are in the best position to determine the branching ratios of these rare decays

Antinuclei production in b-quark decays

$$\chi\chi \rightarrow b\bar{b} \rightarrow \overline{\Lambda}_b^0 + X \rightarrow {}^3\overline{\mathrm{He}} + X$$





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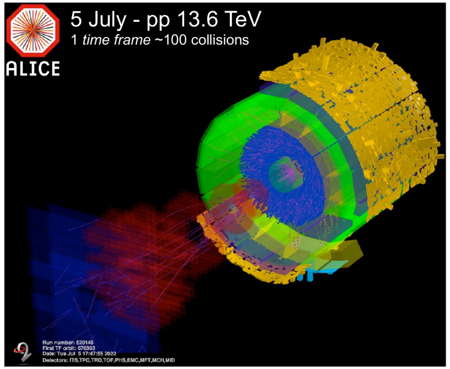
- After LHC Run 3 & 4, we will have understood the formation mechanisms of A < 5 anti- and hyper-nuclei from collisions, but will only start to probe their production in b-quark decays
- Run 5 & 6 will provide the definitive answer

Summary



First act → opening narration **arXiv:2211.04384**

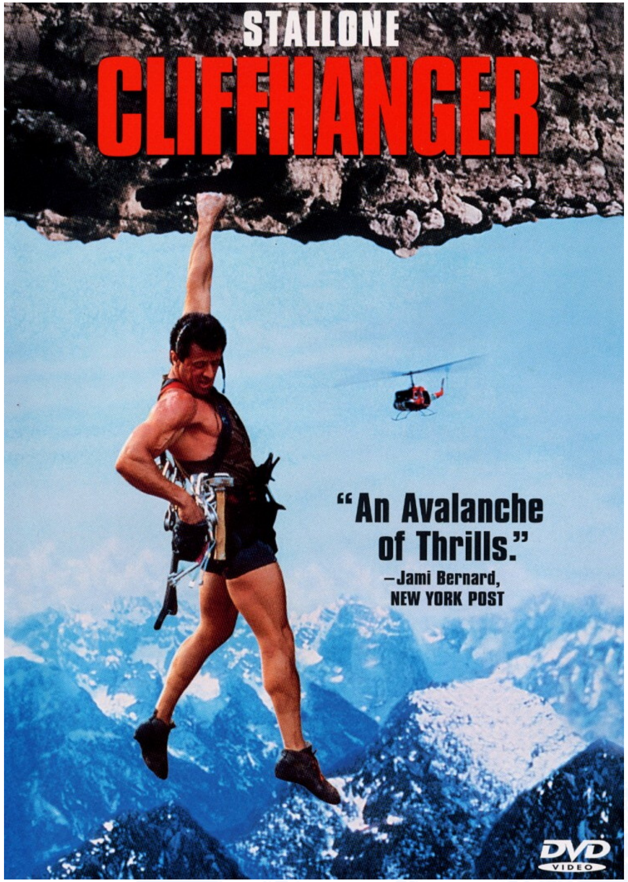
- Understanding the main characters

Second act → rising action **arXiv:1812.06772** and **ALICE-PUBLIC-2020-005**

- Run 3+4 has started → precision will be its driving force

Third act → resolution **CERN-LHCC-2022-009**

- ALICE 3 will bring the definitive answers



Thank you!

And for the discussion: F. Bellini, A. Caliva', A. Kalweit, R. Lea, A. Ortiz, S. Tripathy