Study of Antimatter-Over-Matter Ratios for the Measurement of the Baryon Chemical Potential at the LHC with ALICE

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The Baryon Chemical Potential

- **Chemical potential:** internal energy variation ($\mathrm{d}U$) due to variation in the particle number ($\mathrm{d}N$)

$$\mu = \left(\frac{\mathrm{d}U}{\mathrm{d}N}\right)_{S,V}$$

- baryon number B → μ_B → **antimatter-matter balance in hadron systems at thermal and chemical equilibrium**
- In $\sqrt{s_{NN}}$ = 2.76 TeV Pb–Pb collisions at the LHC[1], μ_B = 0.7 ± 3.8 MeV

Antiparticle-to-particle Ratios

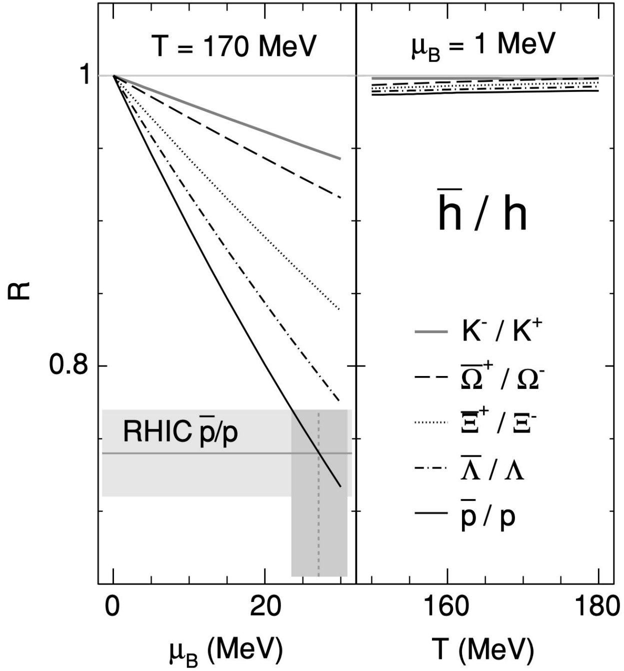
- From the Statistical Hadronisation Model[2,3]

strangeness

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

isospin chemical potential

- Large $B + S/3$ → high sensitivity to μ_B → (anti)p, ^{3}He, $^3_\Lambda$H (and $\pi^\pm$ for μ_{I3})
- Small dependence on temperature T → fixed from other studies
- Ratios → reduce systematic uncertainties → precise μ_B measurement



[1]A. Andronic et al., Nature 561, 321-330 (2018), [2]J. Cleymans *et al.*, Phys. Rev. C 74, 034903 (2006), [3]J. Cleymans and H. Satz., Z. Phys. C 57, 135–147 (1993)

Analysis of Antiparticle-to-particle Ratios: Pions and Protons

ALICE

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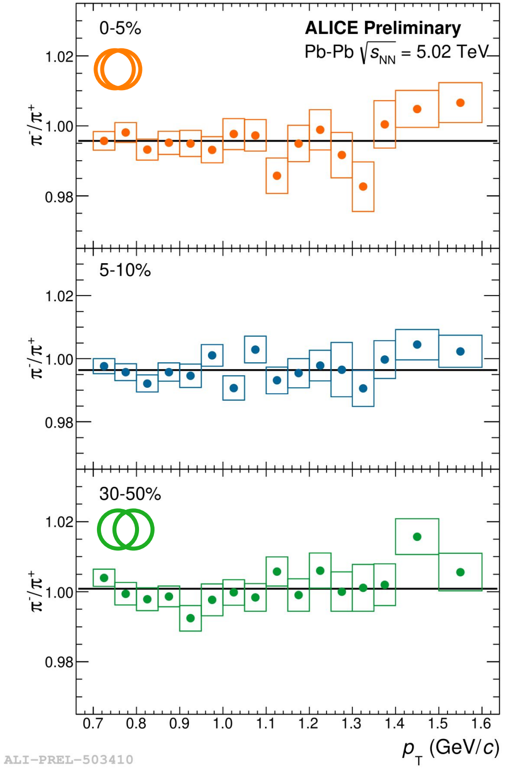

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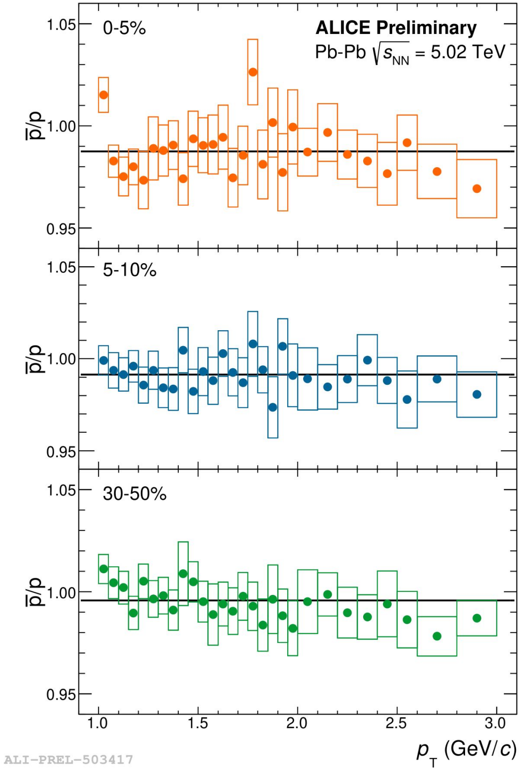

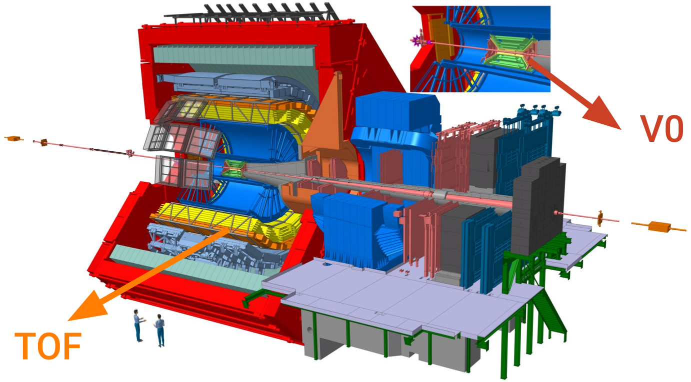

Protons and Pions

- Particle identification with **Time-Of-Flight (TOF)** detector
- Centrality from **V0** detector
- Ratios as a function of p_T in central and semicentral events

→ no dependence on p_T

→ weighted average of p_T-differential points

Analysis of Antiparticle-to-particle Ratios: Helium and Hypertriton

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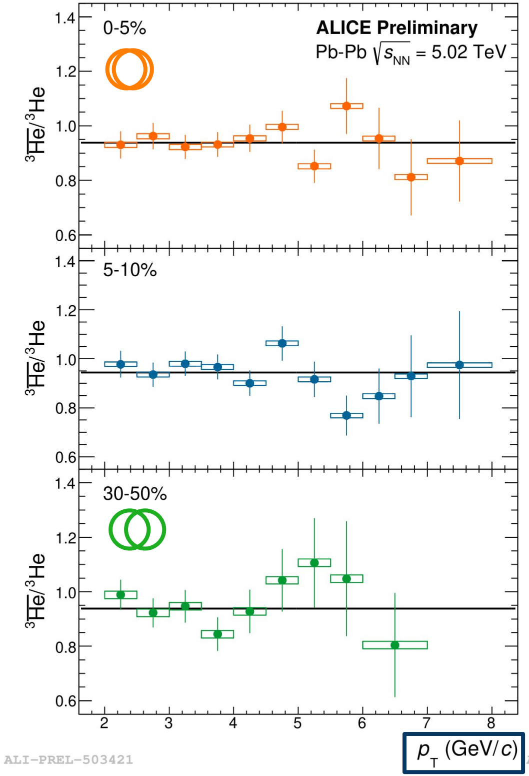

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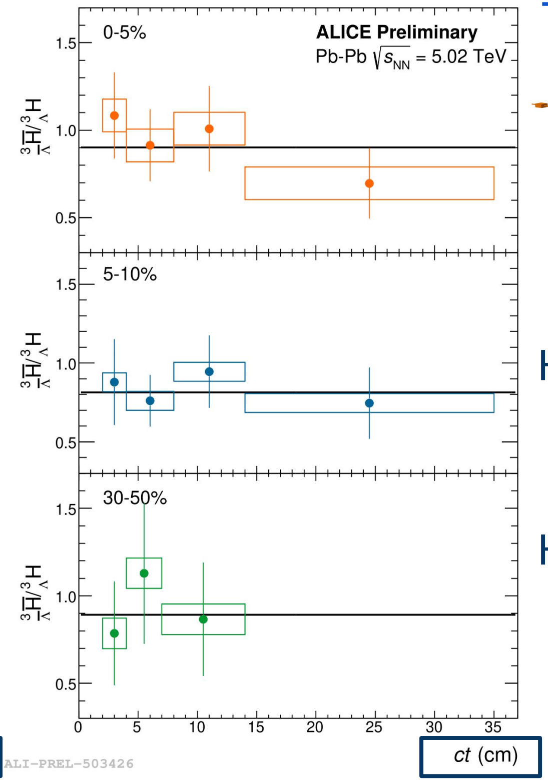
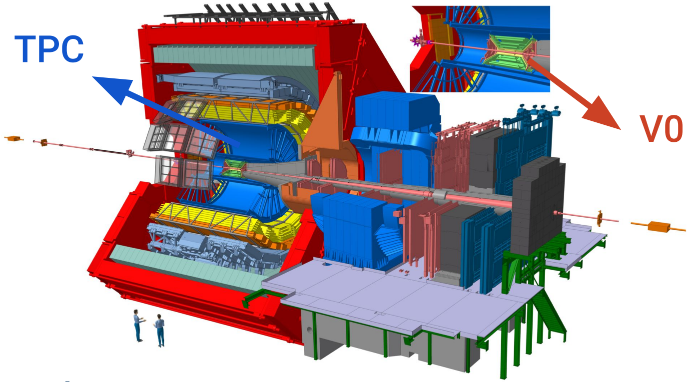


[1] T. Chen et al., (2016 arXiv:1603.02754 [cs.LG],
[2] ALICE Collaboration, (2021) arXiv:2107.10627 [nucl-ex]



Helium-3

- Particle identification with **Time Projection Chamber (TPC)** detector
- Ratios as a function of p_T

Hypertriton

- Reconstructed via 2-body mesonic decay

$$^3_\Lambda\mathrm{H} \rightarrow {}^3\mathrm{He} + \pi^- (+\ \mathrm{c.c.})$$

- pion yield → **~10^7x** helium yield → large combinatorial background
  → BDT candidate selection using *XGBoost*[1,2]
- Ratios as a function of proper decay length ***ct***

Measurement of μ_B: Statistical Hadronisation Model Fit

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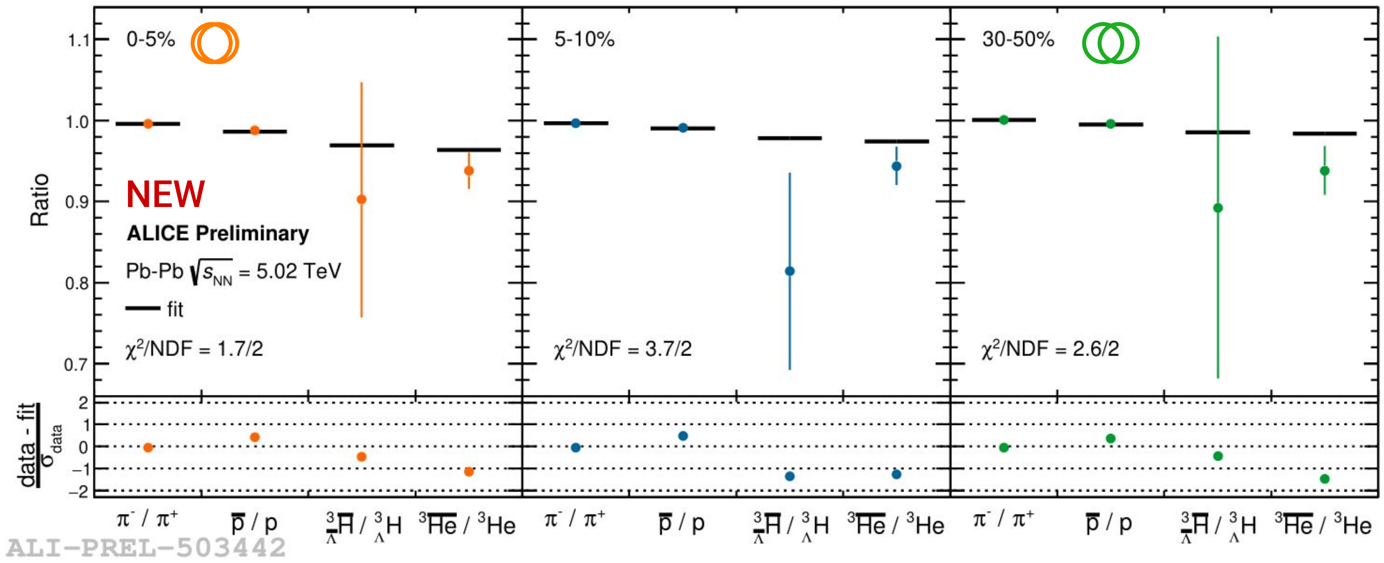


Fit to Ratios

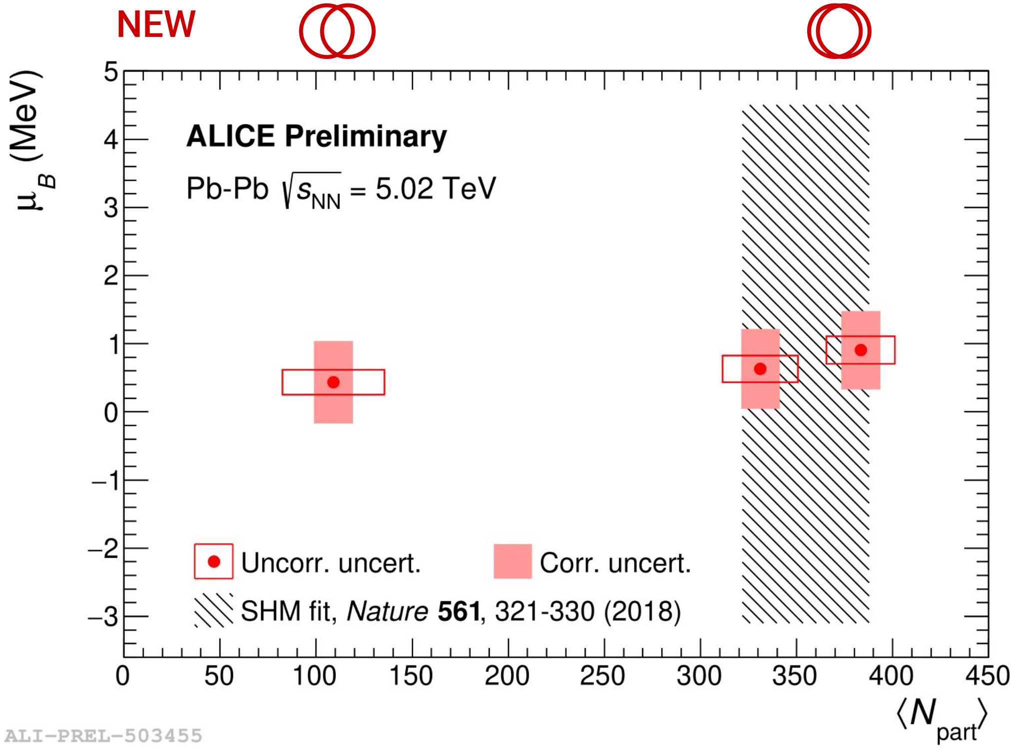
- Statistical Hadronisation Model → $\overline{h}/h \propto \exp\left[-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T} - 2I_3\frac{\mu_{I_3}}{T}\right]$
  → μ_B and μ_{I3} as fit parameters
- Fit results mostly driven by protons and pions
- Strangeness neutrality → $\mu_S \approx \mu_B/3$ → scaling of ratios with $B + S/3$ → verified

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

Measurement of μ_B: Results and Outlook

Results

- precise evaluation of antiparticle-over-particle ratios
- agreement with previous studies (in 2018: μ_B = 0.7 ± 3.8 MeV)
- ~6x improvement in precision from previous studies → most precise measurement in Pb–Pb at TeV scale
- no significant dependence on centrality from central to semicentral collisions



Outlook

- Further test the statistical model description with additional species
  - $\Omega \rightarrow B + S/3 = I_3 = 0$ → expected ratio = 1
  - ^{3}H → $B + S/3 = 3$, $I_3 = -1/2$ → negative-isospin ^{3}He counterpart