The Baryon Chemical Potential

- **Chemical potential**: internal energy variation ($dU$) due to variation in the particle number ($dN$)
  \[ \mu = \left( \frac{dU}{dN} \right)_{S,V} \]
- **Baryon number**: $B \rightarrow \mu_B$ → antimatter-matter balance in hadron systems at thermal and chemical equilibrium
- In $\sqrt{s_{NN}} = 2.76 \text{ TeV Pb–Pb}$ collisions at the LHC\(^1\), $\mu_B = 0.7 \pm 3.8$ MeV

Antiparticle-to-particle Ratios

- **From the Statistical Hadronisation Model\(^2\)\(^3\)**
  
- **Strangeness**: $B + S/3 \rightarrow$ high sensitivity to $\mu_B \rightarrow (\text{anti})p, \ ^3\text{He}, \ ^3\text{H}$ (and $\pi^\pm$ for $\mu_{I_3}$)
- **Small dependence on temperature $T$ → fixed from other studies**
- **Ratios → reduce systematic uncertainties → precise $\mu_B$ measurement**

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

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

NEW

Helium-3
- Particle identification with Time Projection Chamber (TPC) detector
- Ratios as a function of $p_T$

Hypertriton
- Reconstructed via 2-body mesonic decay $\Lambda^3 H \rightarrow \Lambda^3 He + \pi^-(+ \text{ c.c.})$
- Pion yield $\rightarrow \sim 10^7 \times$ helium yield $\rightarrow$ large combinatorial background
- BDT candidate selection using XGBoost
- Ratios as a function of proper decay length $c_t$
Measurement of $\mu_B$: Statistical Hadronisation Model Fit

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

Fit to Ratios

<table>
<thead>
<tr>
<th>$\pi^+$</th>
<th>p</th>
<th>$^3$He</th>
<th>$^3$H</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>3</td>
<td>8/9</td>
</tr>
<tr>
<td>$I_3$</td>
<td>1/2</td>
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</tbody>
</table>

Mario Ciacco
Measurement of $\mu_B$: Results and Outlook

Results

○ precise evaluation of antiparticle-over-particle ratios
○ agreement with previous studies (in 2018: $\mu_B = 0.7 \pm 3.8$ MeV)
○ $\sim6x$ improvement in precision from previous studies $\rightarrow$ 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
  ○ $\Omega \rightarrow B + S/3 = I_3 = 0$
    $\rightarrow$ expected ratio = 1
  ○ $^3\text{H} \rightarrow B + S/3 = 3, I_3 = -1/2$
    $\rightarrow$ negative-isospin $^3\text{He}$ counterpart