Light Flavour:
Nuclei and conserved charge fluctuations

Focus on the preparation for the Yellow Report chapter

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WG5-HI meeting, 06.03.2018

Content of the chapter and organisation

Focus of the chapter: light flavor, soft regime, PID

- **(Anti-)nuclei and (anti-)(hyper-)nuclei** production yields are sensitive to the chemical freeze-out temperature and thermal properties of the medium. Address also the puzzle of survival of loosely bound states in the hadronic phase.

- **Fluctuations of conserved charges (net-baryon, net charge)** are sensitive to the critical fluctuations near the chiral crossover. Higher moments of net-particle have direct correspondence with the thermodynamic susceptibilities that can be extracted *ab initio* by lattice QCD and provide direct experimental access to the critical behavior at the phase transition.

Main activity within ALICE
– so far discussed in internal meetings and within working groups
→ *next: dedicated meetings focused on YR*
→ *task force for the chapter writing to be organized with contributors*
→ *mailing list will be set up*

Chapter outline

Tentative outline

1. **Introduction**
   - Short physics introduction, motivation to study light-flavors in Run 3+4
   - outline of the chapter
2. **(Anti-)(hyper-)nuclei production**
   1. Thermal production and nucleon coalescence models
   2. Accessible observables and state of the art
   3. Projections for LHC Run 3 and 4
   4. Nuclei in pp, pA and impact for astrophysics
3. **Fluctuations of conserved charges**
   1. Physics introduction and observables
   2. State of the art from experiments and present limitations
   3. Complementarity with other facilities (RHIC BESII, FAIR, …)
   4. Projections for LHC Run3 and 4
4. **Summary of experimental reach and sensitivity**
   - Includes summary of section 2 and 3, outlook beyond HL-LHC

Introduction

- What we have learnt from LF observables in Run I+2
  - Collectivity, hadrochemistry, strangeness production and enhancement
  - System in equilibrium in AA → precise determination of thermal properties
  - A smooth evolution of the system in equilibrium from small to large systems?
    → addressed in the "small system" chapter, following in YR

- Open points and list of observables to address them in Run 3+4:
  - Focus on observables directly linked to fundamental properties of system
  - Exploit available integrated luminosity for "rare" LF probes
  - HI as favorable environment to produce light (anti-)(hyper-)nuclei

- Outline of the chapter

(Anti-)(hyper-)nuclei production

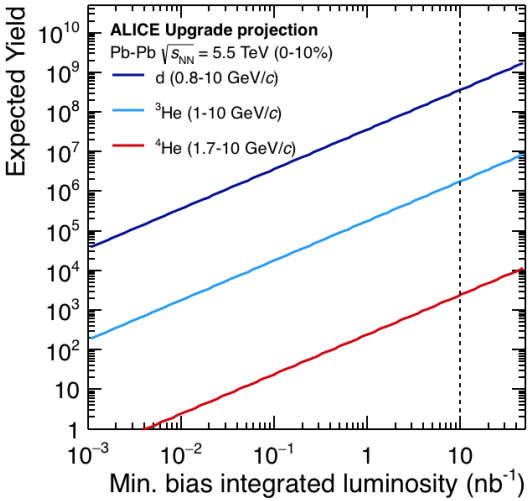
- Thermal production and nucleon-coalescence
  - Recap on models, where models succeed / fail
  - How they can be directly compared [ongoing study]
  - Are composite objects as (anti)(hyper)nuclei thermally produced?
  - How can loosely bound /large objects survive in the hadronic phase?

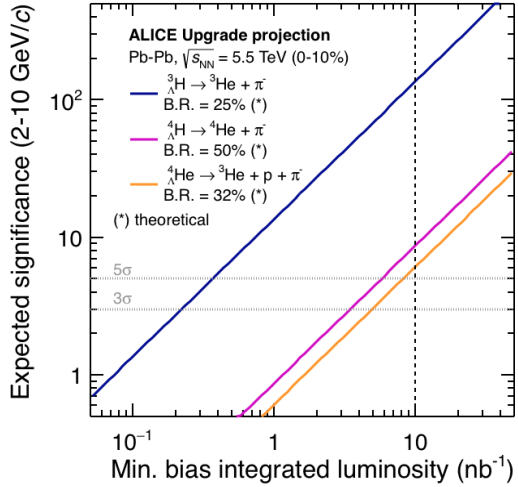
  [A. Andronic, P. Braun-Munzinger, J. Stachel, U. Heinz, …]

- Run 3+4 as "precision era" for (anti-)(hyper-)nuclei observables
  - A = 2, A = 3: yields, spectra, v_2, coalescence parameters, system size dependence
  - Hyper-triton yields and spectra, coalescence parameter, lifetime "puzzle" (LHC/RHIC)

- Newly accessible observables
  - A = 4, A = 5 with potential for discovery for anti-nuclei
  - Measurements of coalescence parameters for objects of different size in all collisions systems (largely different emission volume)

(Anti-)(hyper-)nuclei production





- Projections to be included [work in progress]:
  - **TABLE/FIGURE** with projections for 3 nb^{-1}, 10 nb^{-1} for list of (anti-)nuclei
    → addressed with dedicated ALICE simulation + projections based on Run 1+2
    → desirable to include projection of systematics from exp. and uncertainty from models
  - **FIGURE** for significance for hyper-nuclei
  - Ongoing discussions to add more exotic states (di-baryon, higher mass hyper nuclei, other exotica…)

Light (anti-)nuclei in small systems

Short subsection:

- Motivation for studies of light (anti-) nuclei in small systems
  - Coalescence as sensitive to the size of the emission volume (and size of the object relative to it) → Systematic study of object with different size in pp, pA, AA

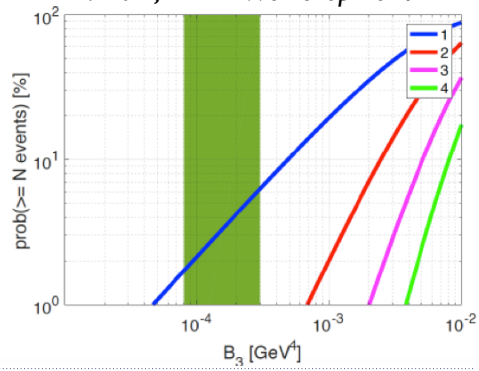
- Application to other fields (dark matter, astrophysics)
  - Example: measurement of coalescence parameters for anti-deuteron and anti-^{3}He can be used to estimate amount of astrophysical background (secondary anti-nuclei produced in cosmic ray interactions) for dark matter searches.

  → Need input from theory to identify useful observables

- Sensitivity and projections with Run 3+4 luminosity
  - Interplay with "small systems" chapter

  → Discuss impact and unicity of the LHC data

K. Blum, EMMI Workshop 2017



Poisson prob. for detecting N≥1, 2, 3, 4 ^{3}He-bar events in a 5-yr analysis of AMS02 → **AFTER ALICE**

Fluctuations of conserved charges

Recent effort, discussions ongoing to provide list of sensitive observables.

- Theory introduction
  - Search for the critical fluctuations and accessibility to critical behavior at LHC
  - Higher moments of distributions of conserved quantities are sensitive to criticality
  - Direct comparison to lQCD predictions

  [P. Braun-Munzinger, J. Stachel, A. Rustamov, Houston, T. Nayak …]
- Definition of observables (net-charge, net-proton, net-strangeness, high order cumulants, cross-cumulants, …)
- Open points or parallel development needed from theory side in parallel to Run 2 data based analyses
  - Example: can net-strangeness be approximated by net-kaon or net-lambda as much as net-baryon can be approximated by net-proton?
- Contextualisation and complementarity wrt. lower energy experiments (RHIC BES II, FAIR)
- Projection for LHC with Run3+4 statistics
  - Investigate extension of the identity method to higher moments
  - Study dependence on pseudo-rapidity window

  → Goal to provide quantitative estimates and projections on needed statistics

Summary

- Chapter covering physics case for measurements in the light-flavor sector
  - Precision measurements for (anti)(hyper)nuclei → thermal properties of medium
  - Statistics hungry observables in conserved-charge fluctuation sector → traces of critical behavior

- Most ingredients available for nuclei part, MC simulation in preparation
- Need external input on nuclei in small systems
- Need to work towards quantitative estimates for conserved charge fluctuations part and input from theory

- Working plan:
  - Finalise list of observables to be included
  - Get projections for the observables under study [ongoing]
  - Look to get in touch with theorists
  - Next milestone: HL-LHC workshop in June

Additional ideas? Please get in touch!

People involved so far (ALICE): F. Bellini (contact), B. Donigus, A. Kalweit, R. Lea, A. Mastroserio, T. Nayak, S. Piano, M. Puccio, A. Rustamov, S. Trogolo, M. Weber