Light Flavour: nuclei and corserved-charge fluctuations
YR chapter status

F. Bellini (CERN) for the Nuclei and Net-Particle working group

WG5-HI meeting, 01.06.2018

"Light flavor and nuclei" chapter

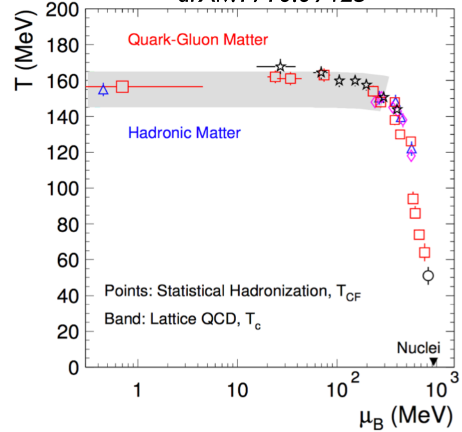
Focus of the chapter: light flavor, soft regime, PID

Interplay with other chapters: "system/multiplicity dependence" chapter (nuclei, ...)

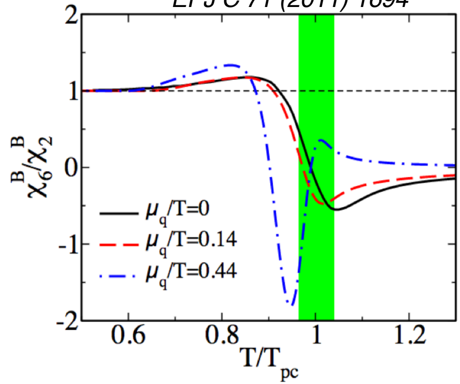
- **(Anti-)nuclei and (anti-)(hyper-)nuclei**
  - production yields are **sensitive to the chemical freeze-out temperature** and thermal properties of the medium.
  - address the puzzle of **survival of loosely bound states** in the hadronic phase

- **Fluctuations of conserved charges**
  - 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

arXiv:1710.09425



EPJ C 71 (2011) 1694



Organization and status

Main activity within ALICE*

- dedicated meeting on April 10th → *chapter content and outline*
- Nuclei: dedicated simulations for projections → *work in progress*
- Chapter writing: specific people contacted for theory part + EoI's received → *list of contributors to be finalized by HL-LHC workshop*

New mailing list open to WG5: hllhc-wg5-lf-nuclex-netparticleATcern.ch

**People involved so far (ALICE):* M. Arslandok, N. Behera, F. Bellini (chapter contact), R. Bellwied, B. Donigus, A. Kalweit, R. Lea, A. Mastroserio, T. Nayak, A. Ohlson, V. Okorokov, S. Pathak, S. Piano, M. Puccio, A. Rustamov, S. Trogolo, E. Umaka, M. Weber

Chapter outline

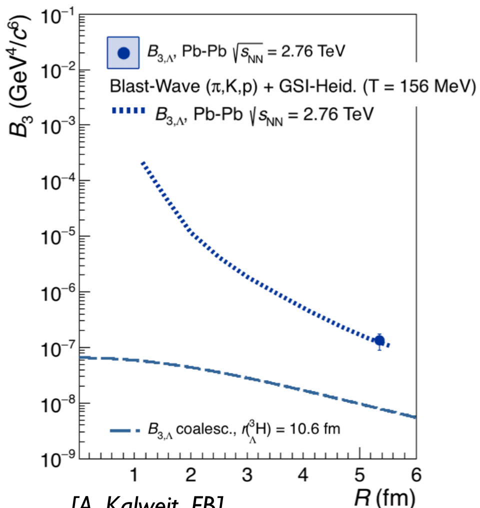
[see WG5 meeting, March 22nd: https://indico.cern.ch/event/698005/]

1. **Introduction**
   – Short physics introduction, motivation to study light-flavors in Run 3+4
   – outline of the chapter
   – No figures foreseen
2. **(Anti-)(hyper-)nuclei production**
   1. Thermal production and nucleon coalescence models
   2. Observables and projections for LHC Run 3 and 4
   3. 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. Projections for LHC Run3 and 4
   4. Complementarity with other facilities (RHIC BESII, FAIR, …)
4. **Summary of experimental reach and sensitivity**
   – Includes summary of section 2 and 3, outlook beyond HL-LHC
   – No figures foreseen

(Anti-)(hyper-)nuclei production

2.1 Thermal production and nucleon-coalescence

- Recap on models, where models succeed / fail
- How they can be directly compared → **B_A as a tool to compare production models**
- Open questions to be answered
  - Are composite objects as (anti)(hyper)nuclei thermally produced?
  - How can loosely bound/large objects survive in the hadronic phase?



[A. Kalweit, FB]

Figure placeholder:
coalescence parameter for hypertriton from coalescence model calculation (U. Heinz) compared to thermal model (GSI-Heidelberg) + Blast-Wave

- A=4 to be added
- Pseudo-data with Run3+4 projections to be added

→ By HL-LHC workshop

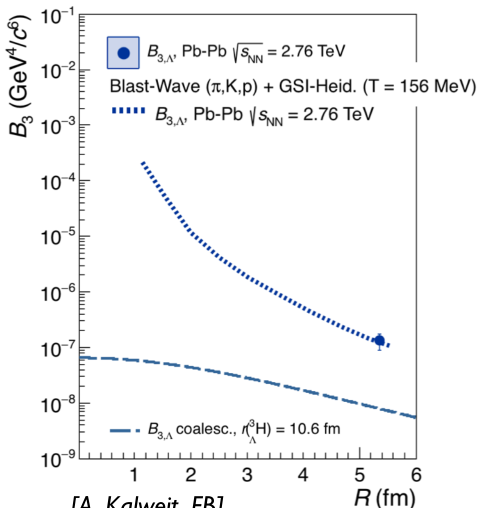
(Anti-)(hyper-)nuclei production

Building the physics case for Run3 & 4

→ What is the centrality dependence of the hypertriton in Pb-Pb?

→ Can we produce at all the hypertriton in pp collisions?

→ Go more differential for A = 3, measure B_4 for ^{4}He, $^4_\Lambda$H, $^4_\Lambda$He



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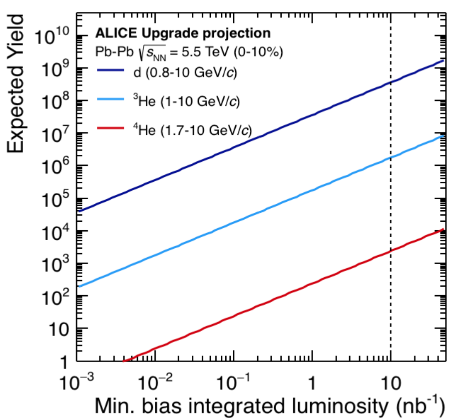
(Anti-)(hyper-)nuclei production

2.2 Run 3+4 as "precision era" for (anti-)(hyper-)nuclei observables

- **A = 2, A = 3, hyper-triton production**: yields, coalescence parameters, system size dependence
- Newly accessible observables
  - **A = 4**, A = 5 with potential for discovery for anti-nuclei
  - coalescence parameters for objects of different size in all collision systems (largely different emission volume)
- Hypertriton lifetime "puzzle" (LHC/RHIC)



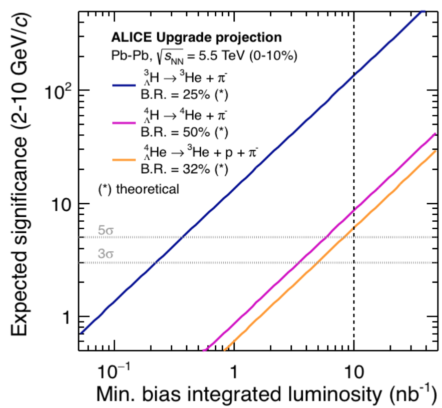


Figure placeholder: projections for nuclei and hyper-nuclei p_T-integrated yields as a function of integrated luminosity

To be updated after dedicated ALICE simulation and projections based on Run 1+2
→ in progress, no updates by HL-LHC
→ include projection of systematics from exp. and uncertainty from models for YR

(Anti-)(hyper-)nuclei production

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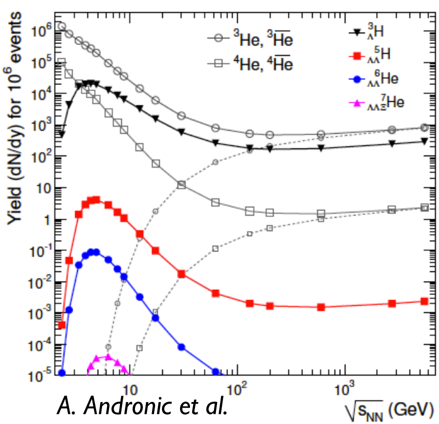
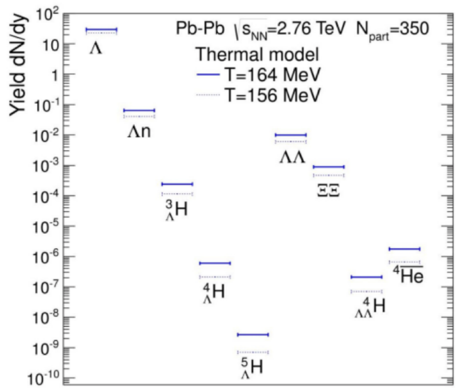


A. Andronic et al.



arXiv:1602.04120

Figure/Table placeholder: expected yield for A<7 (hyper-)nuclei and exotica from thermal model (no detector efficiency)

Ongoing discussions to addALICE projections for higher-A states + exotic states (di-baryon, other exotica…)
→ unknown efficiency x acceptance, being addressed with dedicated simulation → by end of summer

(Anti-)(hyper-)nuclei production

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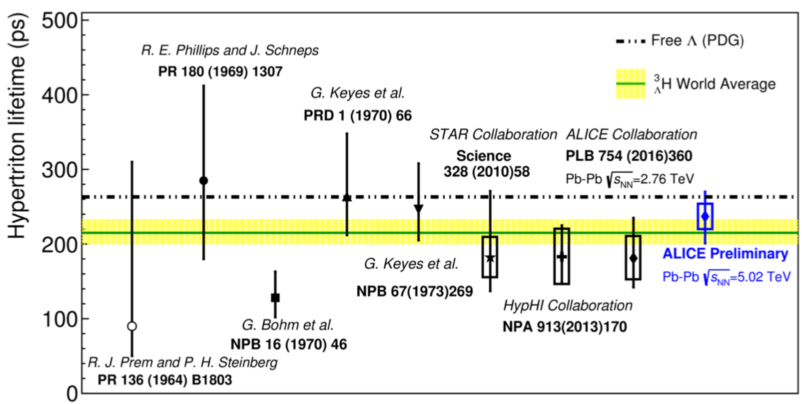


ALI-PREL-130195

NEW Figure/Table placeholder: Estimate of the statistical uncertainty on hyper-triton lifetime with Run 3 and 4 data (and also 2018 Pb-Pb)

→ By the HL-LHC workshop

(Anti-)(hyper-)nuclei production

2.3 Anti-nuclei in small systems

- Coalescence as sensitive to the relative size of the object wrt size of the emission volume
  → **systematic study as a function of system size**
- Application to other fields (**dark matter, astrophysics**)
  - measurement of B_A for anti-deuteron and anti-^{3}He can be used to estimate amount of astrophysical background for dark matter searches in space-based experiments
- These data might reveal useful for **future experiments** (or new lines of research) and LHC will be the only HE facility operating in 2020-2030. Has to be a systematic study, should **not be limited by our present knowledge**.

Luminosity requirements for multiplicity dependence of (anti-)^{3}He

pp: ~ 10 pb^{-1} ***p-Pb: ~ 100 nb^{-1}***

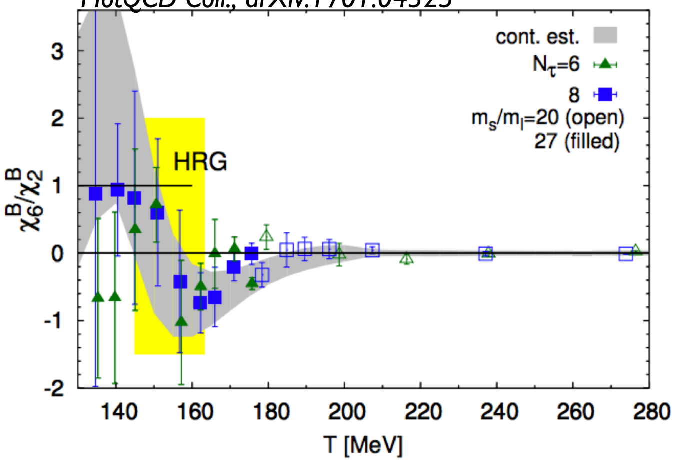
- For same statistical uncertainty as present measurements for (anti-)deuterons
- penalty factor for ^{3}He production in pp/p-A collisions is ~600-1000

Fluctuations of conserved charges

3.1 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 l-QCD predictions

HotQCD Coll., arXiv:1701.04325



Placeholder figure:
Ratio of sixth and second order cumulants of net-baryon number fluctuations

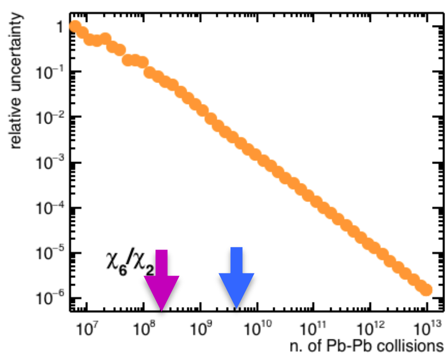
To be included:
- comparison of available calculations from l-QCD Collaborations, e.g. Wuppertal-Budapest Coll., arXiv:1805.04445

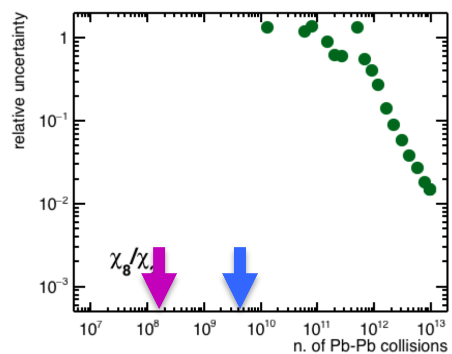
Fluctuations of conserved charges

3.2 State of the art of observables and present limitations

- Recent developments presented at QM 2018:
  - M. D'Elia, QM 2018 plenary (slides) and references therein -- summary of recent lattice developments
  - A. Rustamov, QM 2018 (slides) on fluctuations in the Grand Canonical Ensemble and comparison to data
  - A. Ohlson, QM 2018 (slides) on net-Lambda fluctuations at LHC (exp)
  - N. Behera, QM 2018 (slides) on higher order moments (exp)
- Net-charge, net-proton, net-strangeness, high order cumulants, cross-cumulants
- Discussion of experimental challenges: PID, particle detection efficiencies, pile-up treatment, baseline definition.

3.3 Projections for LHC Run3 and 4





Placeholder figure: relative statistical uncertainty of ratios of higher-order cumulants vs statistics in Run3+4 from toy MC. To be updated.

Need more discussion / iterations.

2018 central sample, **Run 3+4** central sample

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

- Nuclei
  - main content established, need to update estimates
  - MC simulation in preparation but not on time for HL-LHC in June

- Fluctuations of conserved charges:
  - Need more discussion to define more precisely the content of the chapter
  - Several recent developments in theory/exp. → dedicated update at the HL-LHC workshop?