Tuesday wrap-up

Alexander Kalweit, *CERN*

Emmi workshop

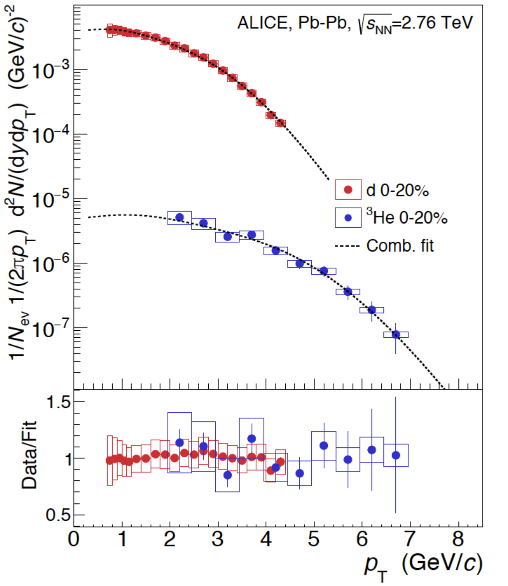
7th November 2017

Baseline model for soft light flavor particle production in heavy-ion collisions:

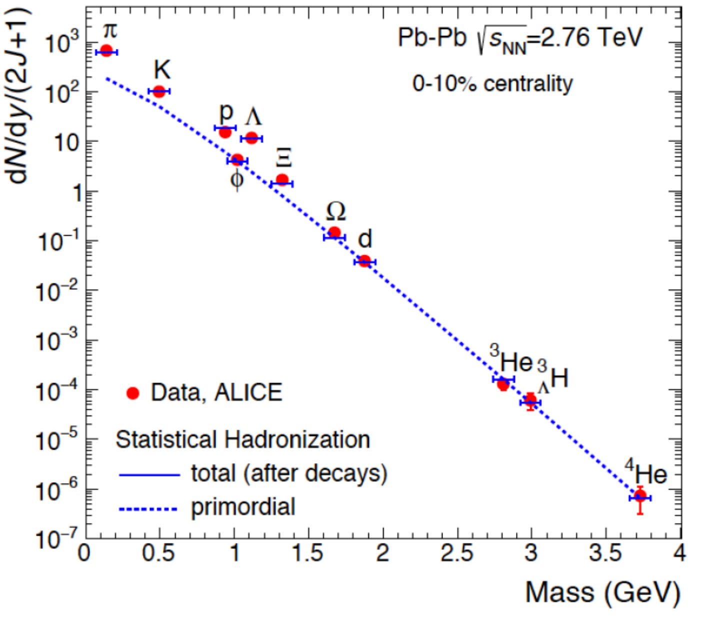
fireball in local thermodynamic equilibrium

- Success of hydrodynamics (spectral shape via radial flow, elliptic flow) → kinetic equilibrium.
- Success of thermal-statistical model for hadronisation → chemical equilibrium.

➔Works also for light (anti-)(hyper-) nuclei despite $T_{kin/chem} >> E_B$!



Scenario A: multi-quark bags produced at the phase boundary

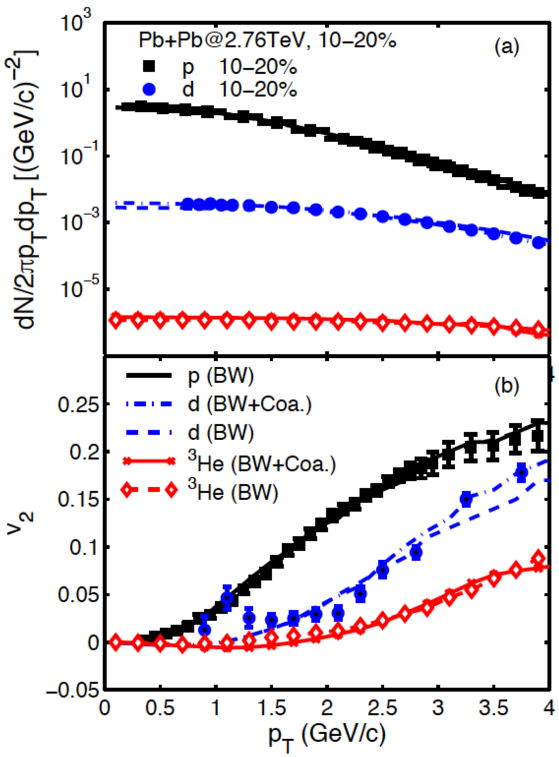


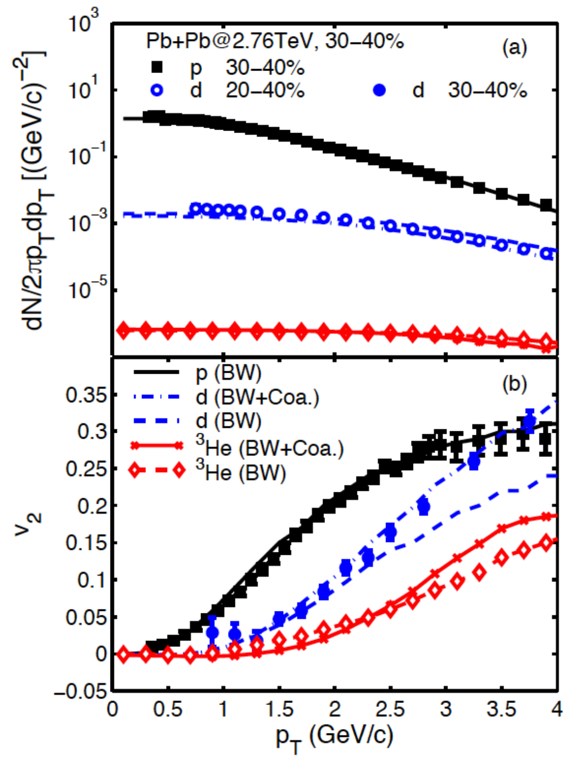
Scenario B: only coalescence

Transverse momentum spectra and elliptic flow at LHC

Zhu, Zheng, Ko & Sun, arXiv:1710.05139 [nucl-th]

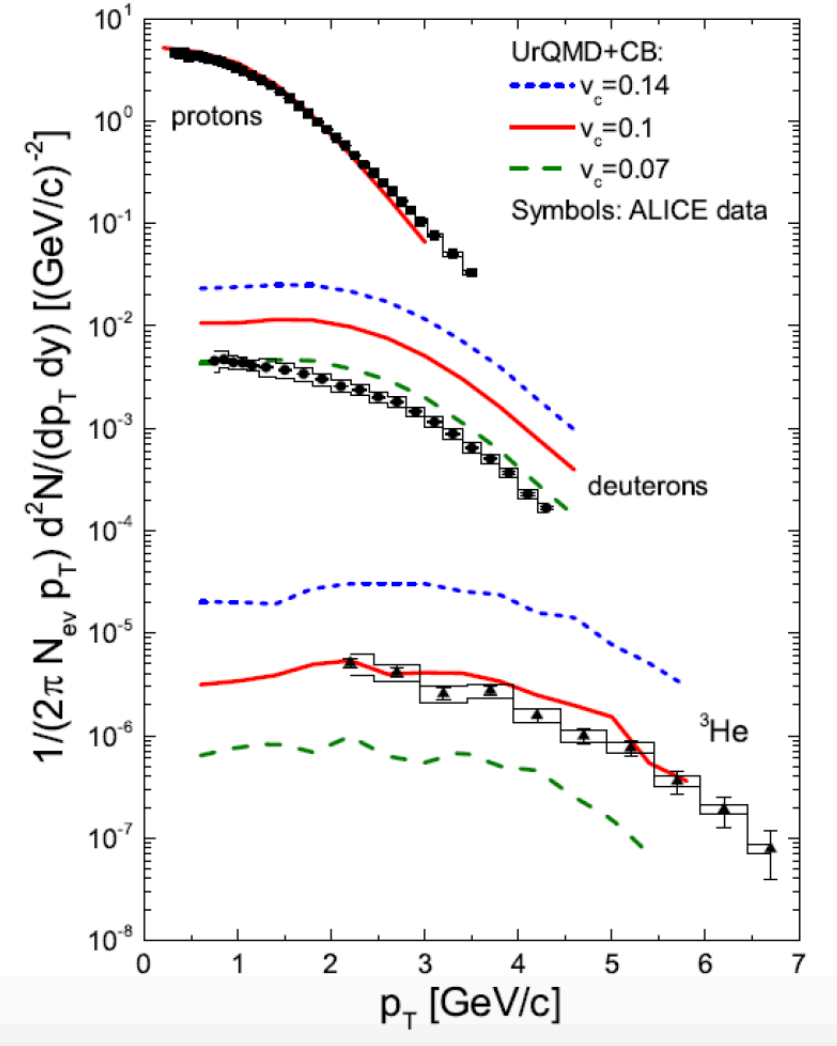
Che-Ming Ko





Centr. (%)	ξ	τ_0 (fm/c)	T_K (MeV)	β_0	R_0 (fm)	c_1	c_2 (GeV/c)	s_2	a (GeV/c)$^{-1}$
10-20	5.5	13.5	120	0.84	17.0	0.09	4.6	-0.07	0.05
30-40	5.0	10.5	120	0.825	13.0	0.15	3.3	-0.12	0.02

Scenario B: only coalescence



A. Botvina

Different coalescence parameters needed for different nuclei.

→ To be directly deduced from wave function. There should be no "fit" to the data.

→ Probing (anti-)nuclei with very different wave functions should provide the crucial test.

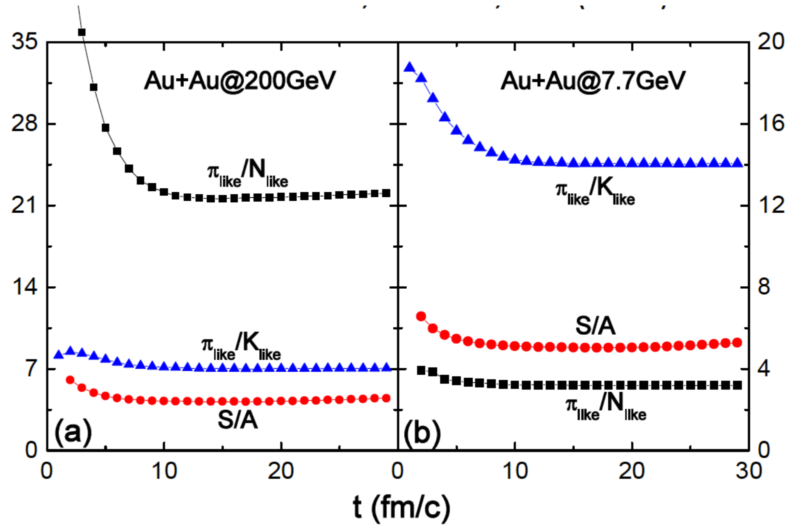
Scenario C: coalescence with memory

Quantum coalescence:

$$E\frac{d^3N_A}{d^3P} = \frac{2J_A+1}{(2\pi)^3}e^{\mu_A/T}\int_{\Sigma_f} P\cdot d^3\sigma(R)\, e^{-P\cdot u(R)/T}\,(H(R))^A\,\mathcal{C}_A(R,P)$$
$$\approx \frac{2J_A+1}{(2\pi)^3}e^{\mu_A/T}\langle\mathcal{C}_A\rangle(P)\int_{\Sigma_f} P\cdot d^3\sigma(R)\, e^{-P\cdot u(R)/T}\,(H(R))^A$$

For freeze-out at constant energy density, temperature and chemical potential: $H(R) = \mathrm{const.} = 1 = (H(R))^A \implies$ **thermal emission and classical coalescence give identical results** while quantum coalescence gives slightly (15-20%) smaller yields.

Che-Ming Ko



Borromean Nuclei

In Borromean nuclei, three separate parts of the nucleus are bound together in such a way that if any one is removed, the remaining two become unbound. The expression originates from the Borromean Rings which consists of interlocking rings. Carbon-12, in its excited state, is one example of a Borromean nucleus. It consists of three sub-units of helium-4. If one is removed, the result is beryllium-8 which is not bound. Other examples are helium-6, lithium-11, beryllium-14, and carbon-22.

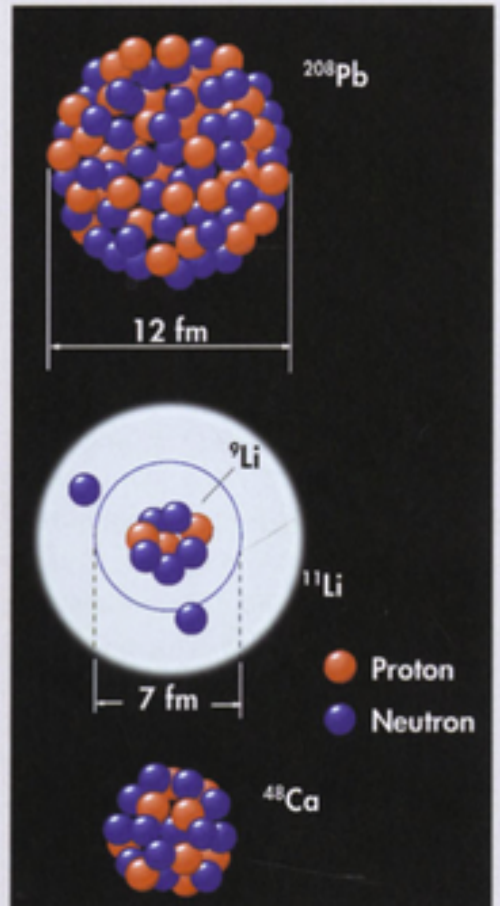
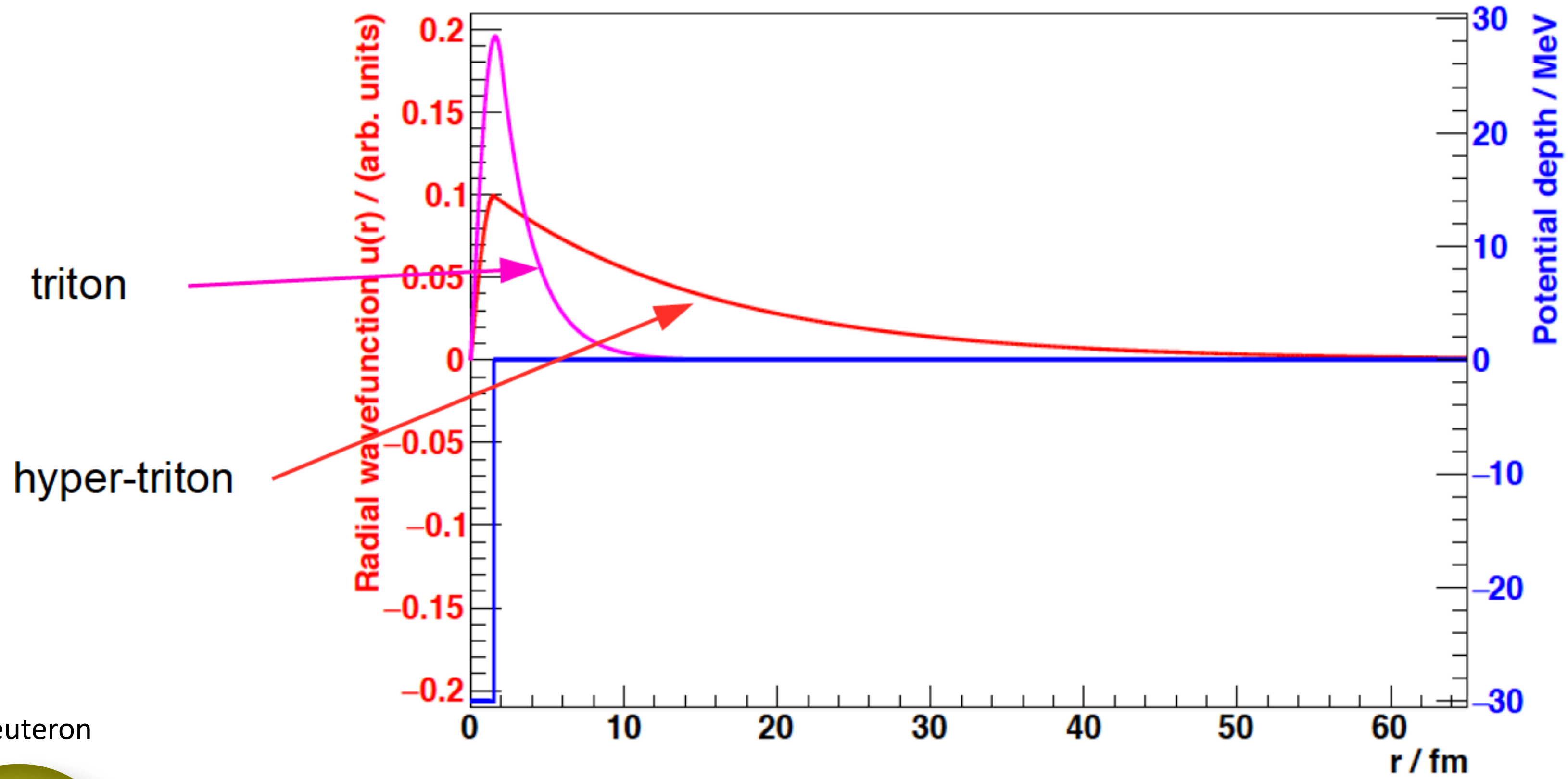
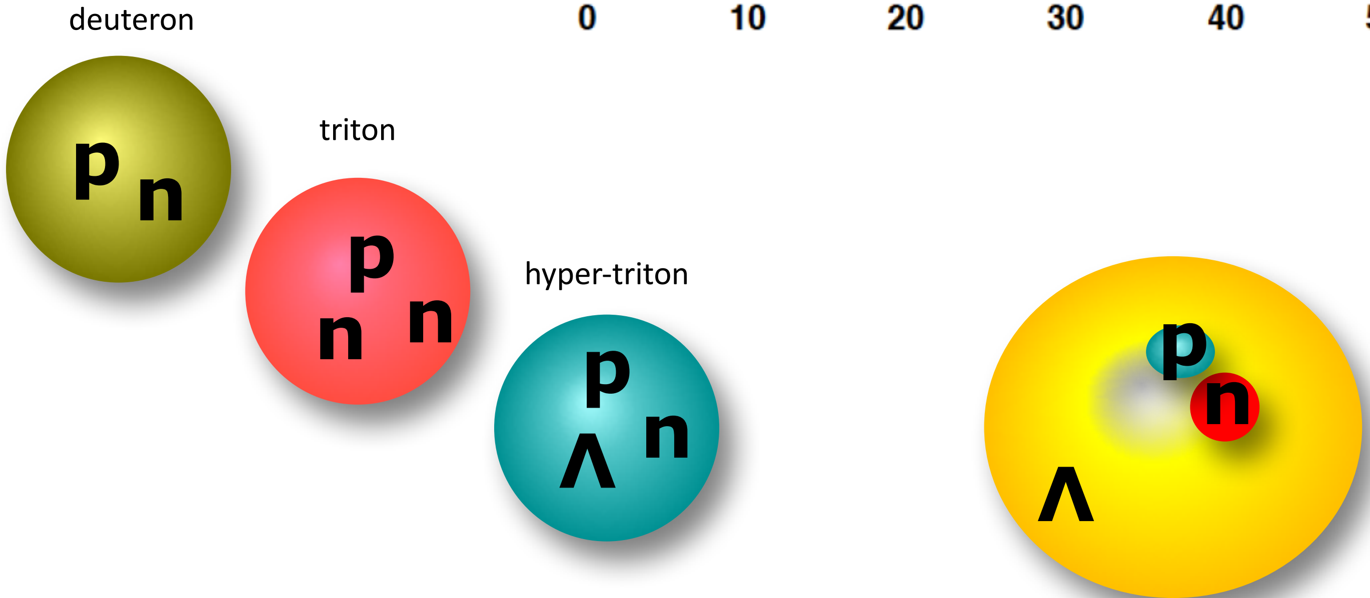


Figure 2.6 (*left*)
The neutron halo in ^{11}Li extends to fill the volume equivalent to ^{208}Pb, with very dilute, pure neutron matter. Courtesy Wilton Catford, from the SIRIUS Science Booklet

Figure 2.7 (*above*)
The Borromean rings provide an analogy for the structure of halo nuclei in which the removal of any one of the three major components breaks the whole system. Courtesy Wilton Catford, from the SIRIUS Science Booklet

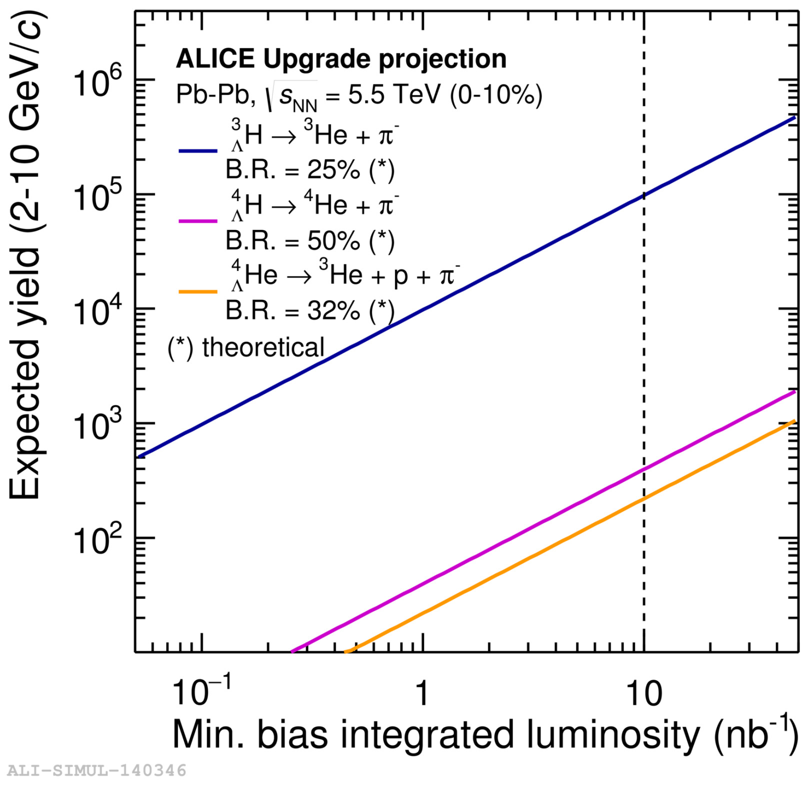
In an ideal world, we would compare anti-^{6}Li to anti-^{6}He. But this would need a dedicated detector at the FCC and we would still only see a handful.


triton
hyper-triton
Radial wavefunction u(r) / (arb. units)
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
Potential depth / MeV
30
20
10
0
−10
−20
−30
0
10
20
30
40
50
60
r / fm


deuteron
p n
triton
p n n
hyper-triton
p Λ n
p n Λ

The way forward (1)

- The best *quantitative* description is currently only available from scenario A.
- We need *quantitative* predictions/calculations from coalescence for *all* relevant (anti-)(hyper-)nuclei
  → Crucial test: wide wave-function of the hyper-triton
- In the foreseeable future, we will have 3He/hyper-triton measurements at the 10% level.



The way forward (2)

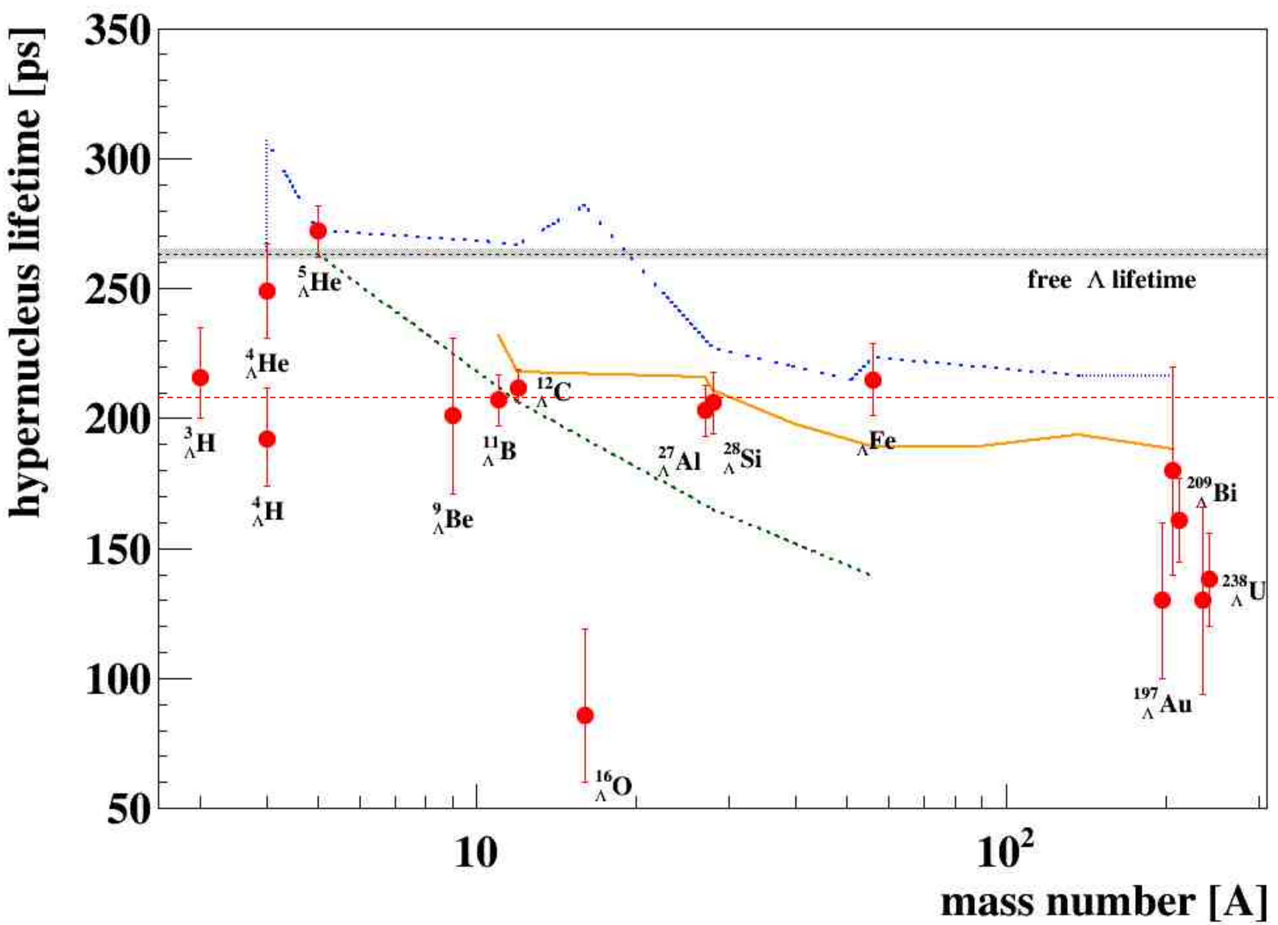
→ If we want to make a point with the hyper-triton, we have to understand the hyper-triton. Luckily, hyper-nuclei are not only interesting for heavy-ion physicists

Outline

- Hypernuclear Physics at the border between Particle and Nuclear Physics

Tullio Bressani

lifetime of Hypernuclei



τ = 208.8 ps

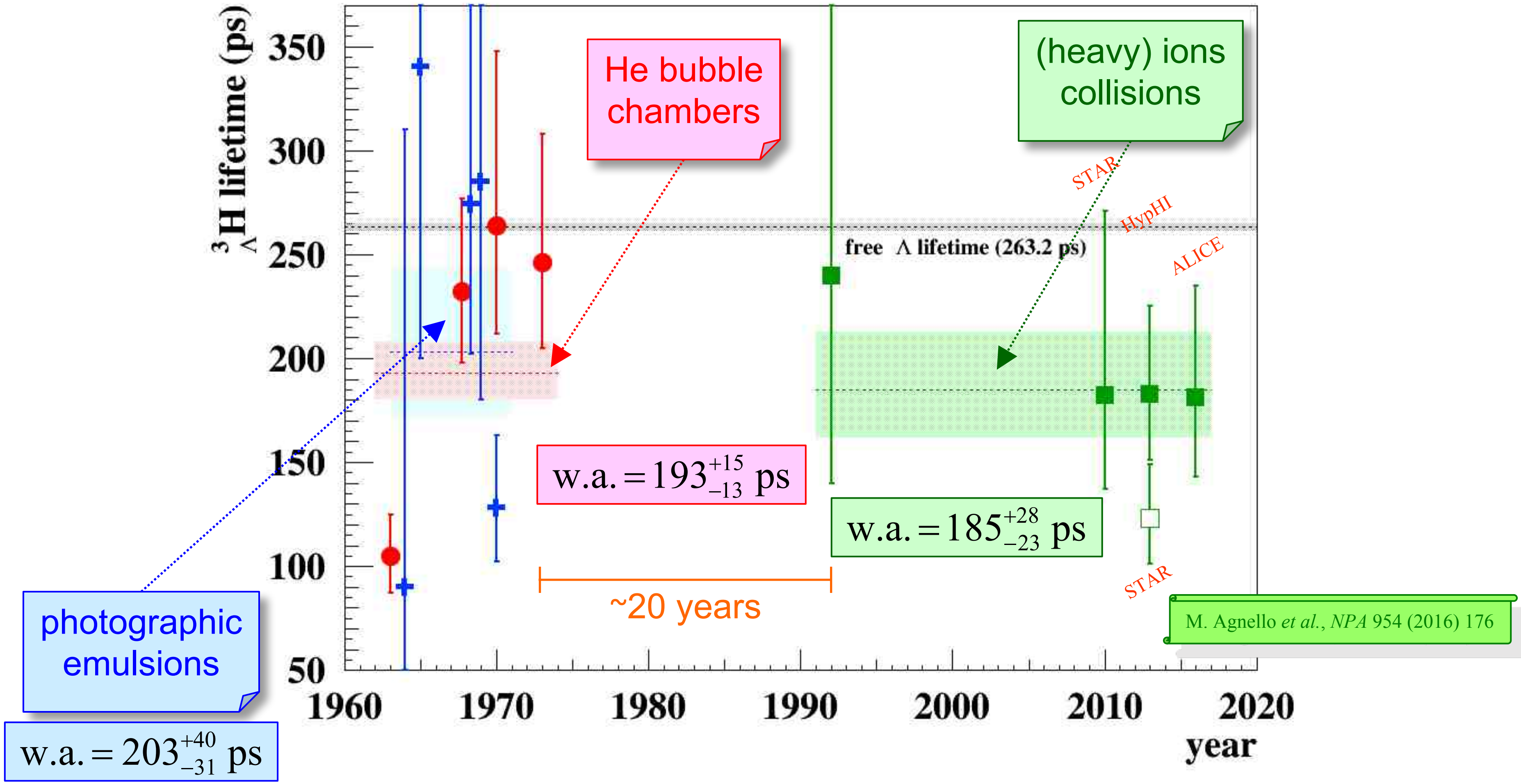
Tullio Bressani

for heavy systems τ was obtained indirectly from delayed fission induced by the energy release in NMWD of Hypernuclei produced with p (CERN) or p (COSY) beam.

results strongly dependent on theoretical calculations!

lifetime of Hydrogen Hyperisotopes

Tullio Bressani



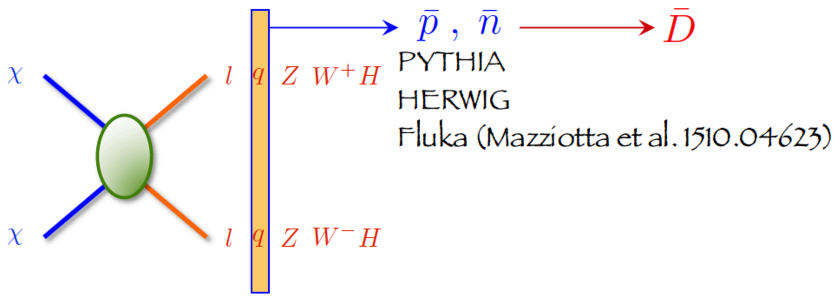
Interest raised in the last few years
thanks to results from STAR, HypHI and ALICE

hot topic in this Workshop!

It is not only relevant for our community..

… we have to understand the production of (anti-)(hyper-)matter in accelerator based experiments before we can search for anti-nuclei from new physics in the universe

Antideuteron from Dark Matter particles

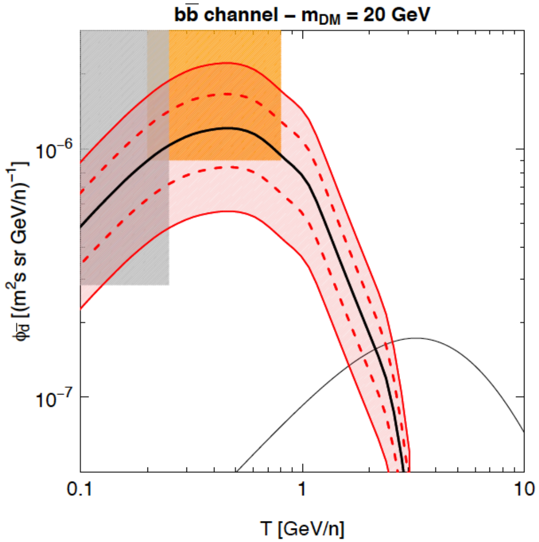


$$\frac{dN_{\bar{d}}}{dT_{\bar{d}}} = (4\pi E_{\bar{d}}\, k_{\bar{d}})\, F_{\bar{d}}(\sqrt{s}, \vec{k}_{\bar{d}})$$

$$F_{\bar{d}}(\sqrt{s}, \vec{k}_{\bar{d}}) = \int F_{(\bar{p}\bar{n})}(\sqrt{s}, \vec{k}_{\bar{p}}, \vec{k}_{\bar{n}})\, \mathcal{C}(\sqrt{s}, \vec{k}_{\bar{p}}, \vec{k}_{\bar{n}} | \vec{k}_{\bar{d}})\, d^3\vec{k}_{\bar{n}}\; d^3\vec{k}_{\bar{n}}$$

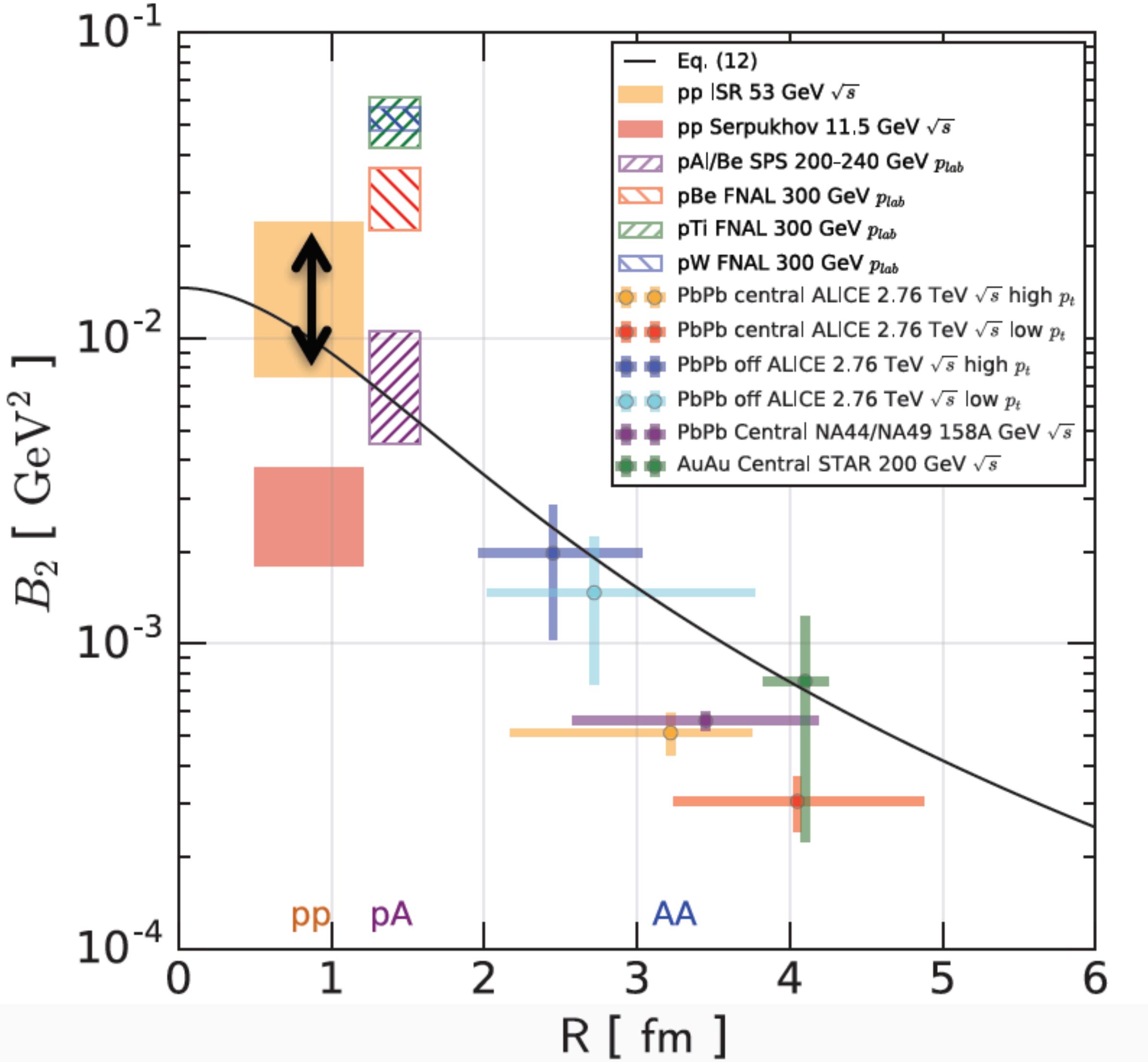
Coalescence function

Due to coalescence (p⁻-n⁻ fusion)



$$p_0 = (195 \pm 22)\ \mathrm{MeV}$$

F. Donato



Eq. (12)
pp ISR 53 GeV √s
pp Serpukhov 11.5 GeV √s
pAl/Be SPS 200-240 GeV p_lab
pBe FNAL 300 GeV p_lab
pTi FNAL 300 GeV p_lab
pW FNAL 300 GeV p_lab
PbPb central ALICE 2.76 TeV √s high p_t
PbPb central ALICE 2.76 TeV √s low p_t
PbPb off ALICE 2.76 TeV √s high p_t
PbPb off ALICE 2.76 TeV √s low p_t
PbPb Central NA44/NA49 158A GeV √s
AuAu Central STAR 200 GeV √s
pp
pA
AA
B_2 [GeV^2]
R [fm]

K. Blum

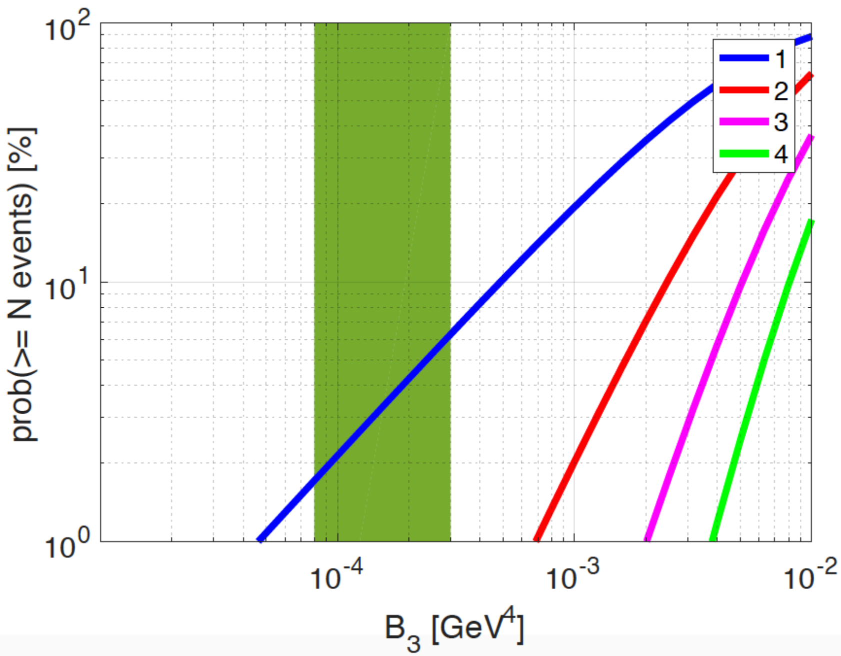
Understanding forward rapidities (1)

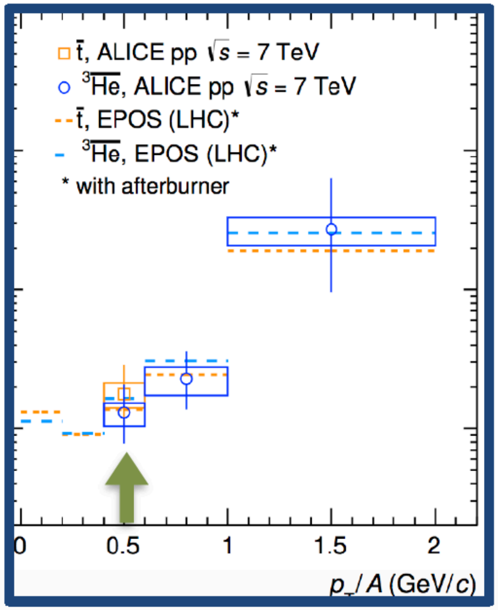
He3bar:
1 event/5yr plausible; 1 event/yr seems unlikely with current pp analysis.

Are we missing a large contribution in high-rapidity region (y >~ 1)?

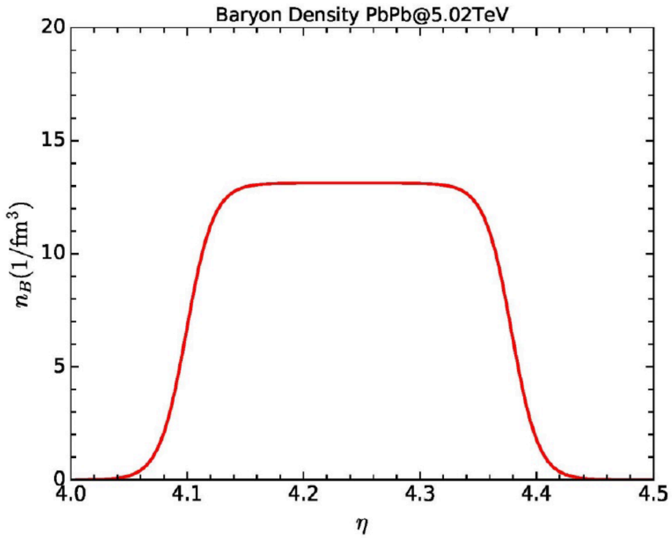
…is AMS02 seeing background?

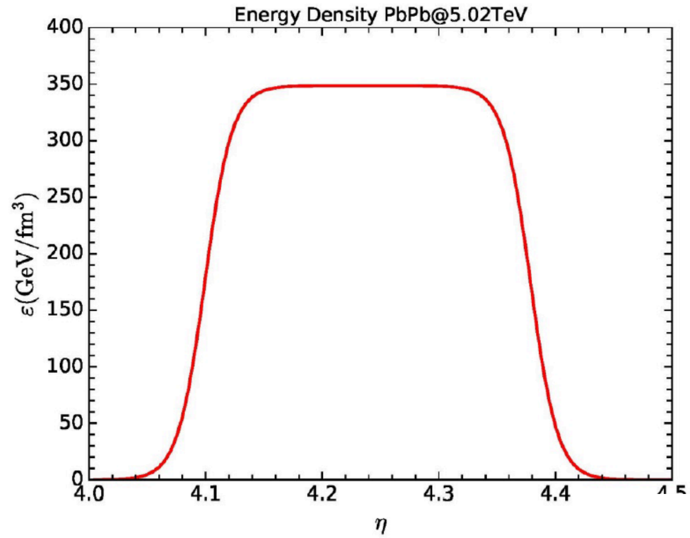
K. Blum

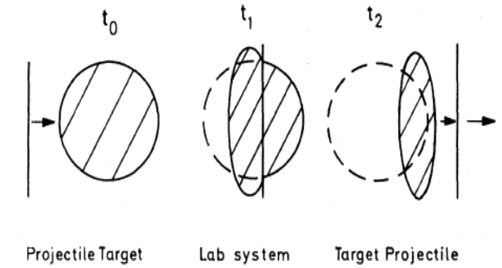




Understanding forward rapidities (2)





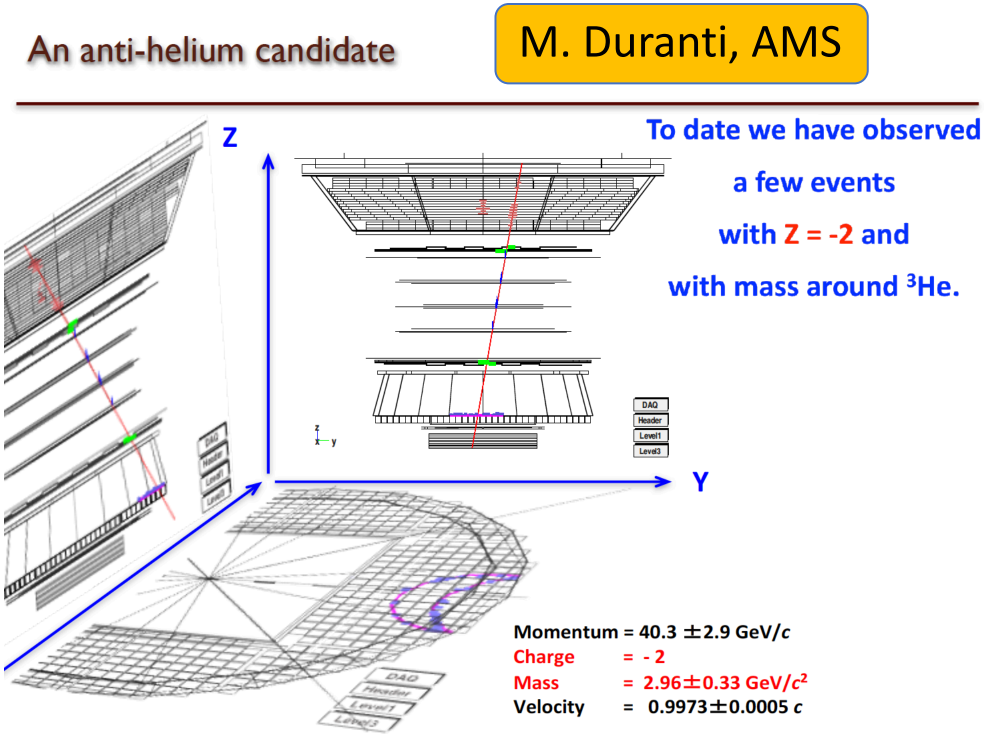


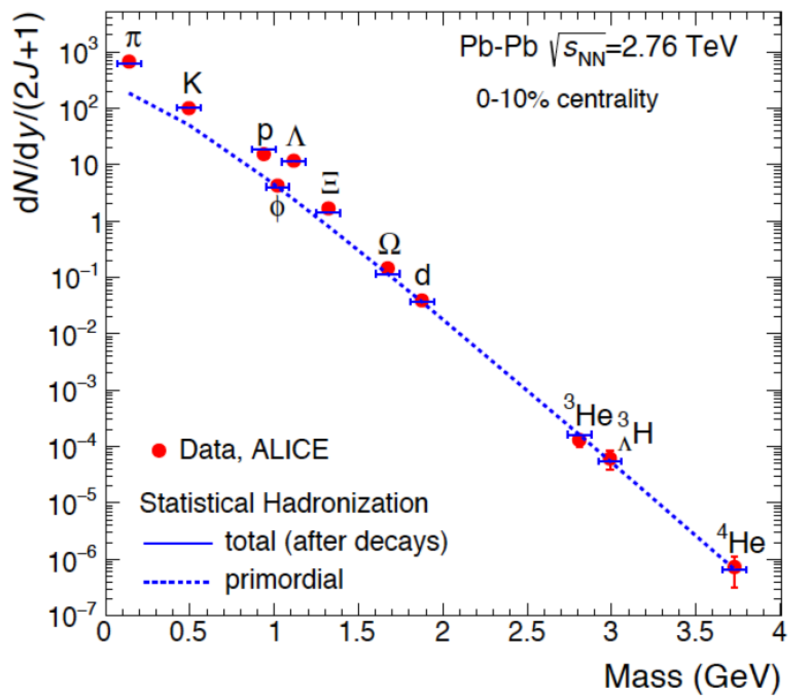
Central core of b=0 collisions Pb-Pb

$$\eta = \frac{1}{2}\ln\left(\frac{t+z}{t-z}\right)$$

J. Kapusta

Exciting times!





Stachel, Redlich, Andronic, Braun-Munzinger

Is this more than coalescence?
Dark matter in the universe / multi-quark bags formed at the QGP<->hadron phase transition