Hypernuclei Production in Ni+Ni Collisions at 1.91 A GeV

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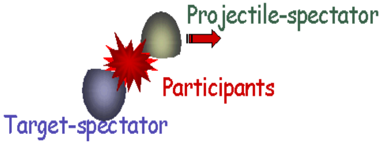
Outline

Hypernuclei Production in HICs at a few GeV/u

HICs at SIS18/SIS100/HIAF/NICA energies:



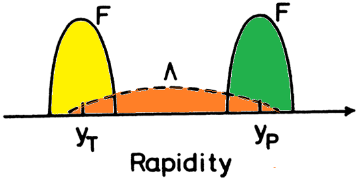
Unique environment to study:

- Exotic clusters
- In-medium properties of hadrons

Hypernucleus: nucleus contains at least one hyperon $(\Lambda, \Sigma, \cdots)$

- Coalescence process

$$\Lambda + {}^{A}Z \rightarrow {}^{A+1}_{\Lambda}Z$$

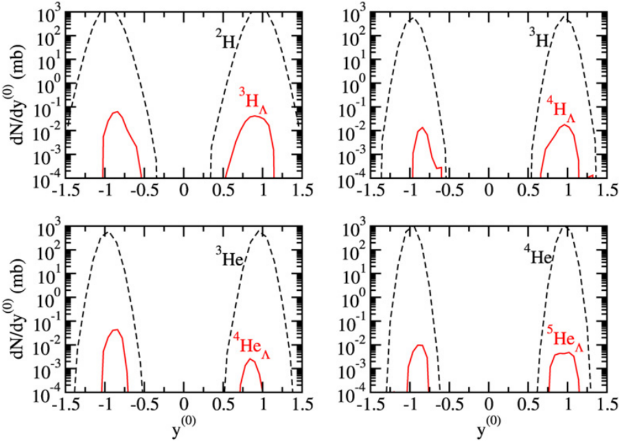


- $\pi^{\pm}$-induced reaction
  - $\pi^- + p \rightarrow \Lambda + K^0$
  - $\pi^+ + n \rightarrow \Lambda + K^+$
- K^--induced reaction
  - $K^- + p \rightarrow \Lambda + \pi^0$
  - $K^- + n \rightarrow \Lambda + \pi^-$
- Thermal production
- Other

M.Wakai et al. PRC.38.748(1988); T. Gaitanos et al. PLB.675.297(2009)

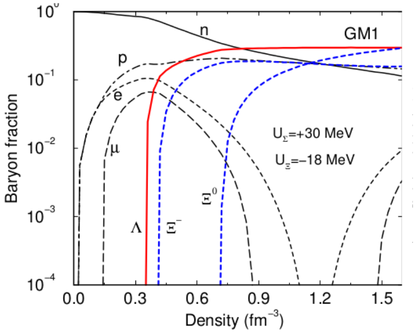
GiBUU transport model calcualtion

C+Li@2 A GeV

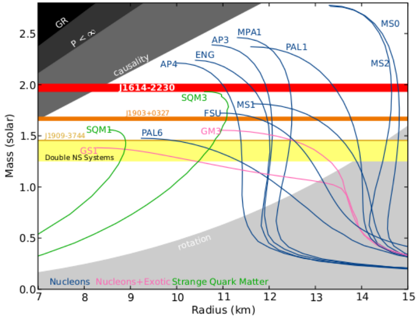


T. Gaitanos et al. PLB.675.297(2009)

YN interaction and neutron star



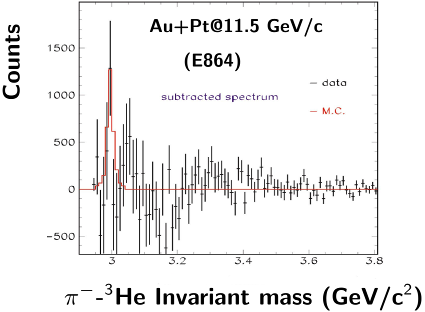
J. Schaffner-Bielich (2010).NPA 835 279

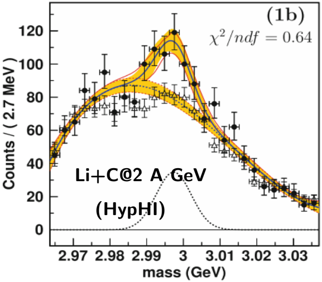


Nature 467 1081 (2010)

$^3_\Lambda$H production in HICs

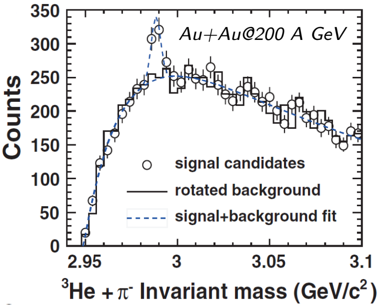
Particle	"core"	B_Λ (MeV)	τ (ps)	spin
$^3_\Lambda$H	^{2}H	0.13±0.05	100-300	1/2
$^4_\Lambda$H	^{3}H	2.08±0.08	194^{+24}_{-26}	0



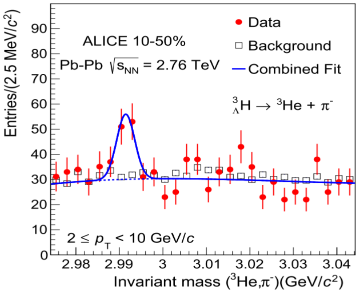


T. A. Armstrong, et al. , Phys. Rev. C 70, 024902 (2004) *C. Rappold et al., Nucl. Phys. A 913, 170 (2013)*

(Anti-) $^{3}_{\Lambda}$H production in relativistic HICs

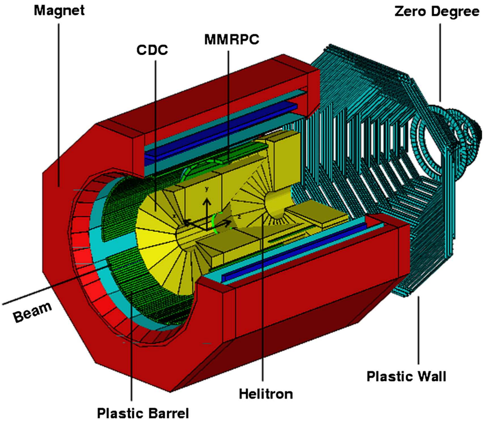


The STAR Coll., Science, 328, 58



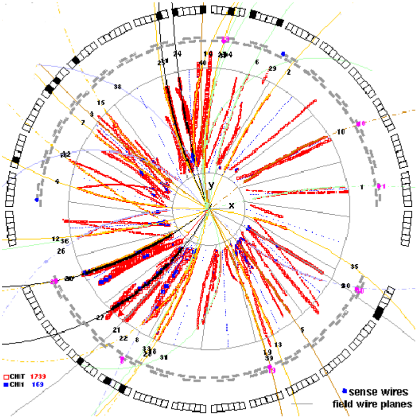
ALICE Coll. Physics Letters B 754 (2016)

FOPI detector



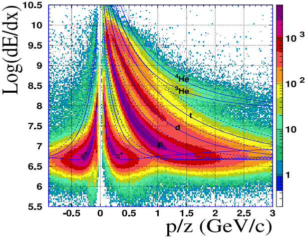
- Target position: -40 cm
- Magnetic field: 0.6 T
- CDC: $30^o < \theta < 110^o$
- MMRPC: $30^o < \theta < 51^o$
- Plastic Berral (PLB): $54^o < \theta < 110^o$
- Helitron: $8^o < \theta < 20^o$
- Plastic Wall (PLW): $7^o < \theta < 25^o$

Particle identification (PID)

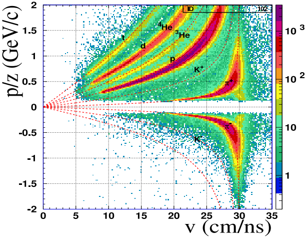


Ni+Ni at 1.91A GeV, most-central collisions (60% of σ_{geo}), $\sim 5.6 \times 10^6$ events.

- dE/dx vs. $p/|z|$

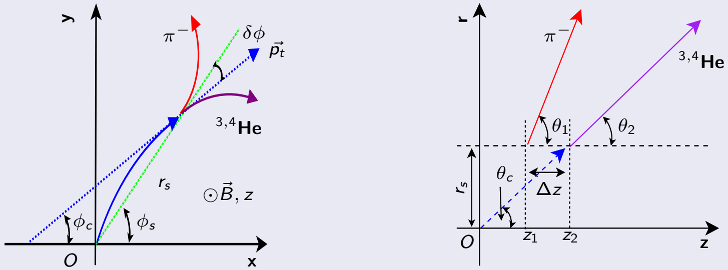


- v vs. $p/|z|$



Reconstruction method

Topological criteria

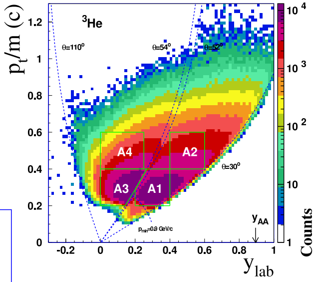


- Invariant mass

$$m_{inv}c^2 = \sqrt{E_{tot}^2 - (\overrightarrow{p}_{tot}c)^2} = \sqrt{(E_1 + E_2)^2 - (\overrightarrow{p}_1 c + \overrightarrow{p}_2 c)^2}$$

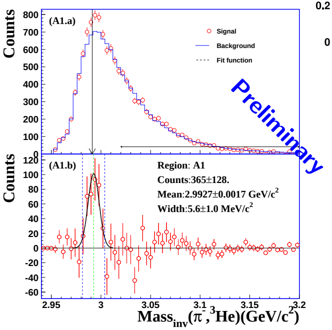
- Mixed-event method to rebuild the combinatorial background
  - Rotated into reaction plane
  - Centrality class
  - Verified by the reconstruction of invariant mass of Λ hyperon

$\pi^- - {}^3$He invariant mass

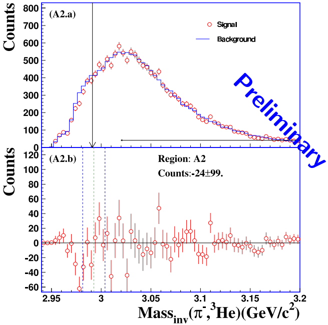


$$y_{lab} = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right) = \tanh^{-1}\beta_z$$

Region A1



Region A2

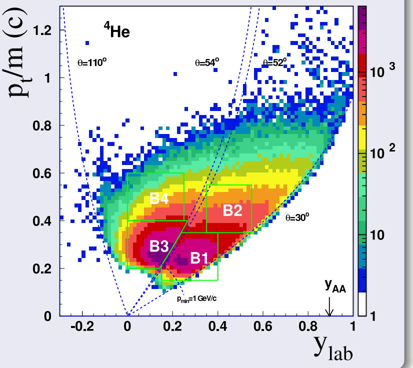


$$Snf_{A1} = \frac{S}{\sqrt{S+B}} = 5.6$$

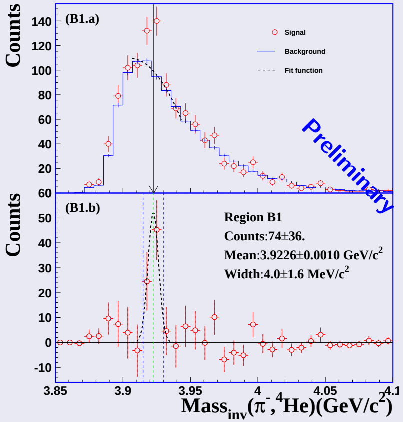
$$SOB_{A1} \sim 1/10$$

π^-—^{4}He invariant mass

^{4}He phase space distribution



π^-—^{4}He inv. mass in region B1



The mean of the excess is consistent with the nominal mass of $^4_\Lambda$H

Monte Carlo simulation

Geant Simulation

- Geant 3.21 (in Fortran)
- Detector response
- Performance of electronics

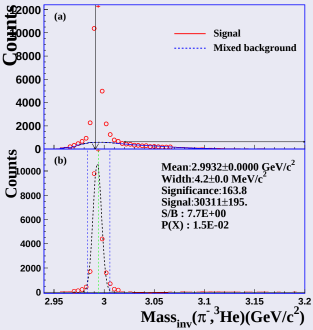
Background Event:

1. IQMD calculation of Ni+Ni at 1.93A GeV.
2. Thermal Λ hyperon source
3. Additional ^{3}He and ^{4}He

Signal Event:

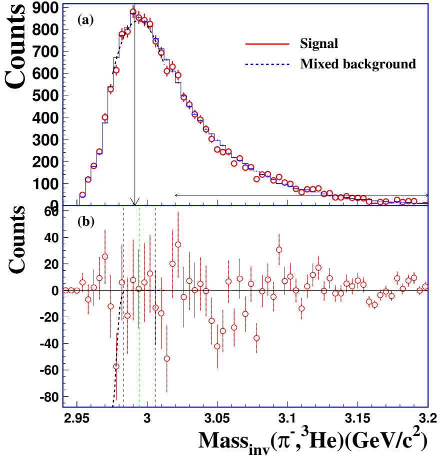
$^3_\Lambda$H and $^4_\Lambda$H sampled from a flat $p_t - y_{lab}$ distribution

$\pi^- - {}^3$He inv. mass in MC



$^3_\Lambda$H background events simulation

With applying the very same cuts used for $^3_\Lambda$H reconstruction in experimental data.



The invariant mass peak of $^3_\Lambda$H and $^4_\Lambda$H are not induced by biased cuts.

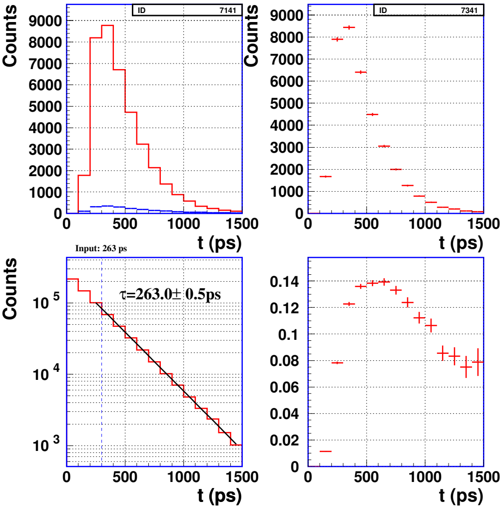
Decay time efficiency of Λ hyperon

- Decay time

$$t = r_s/(\beta\gamma c)_T = r_s/(p_t/m)_T$$

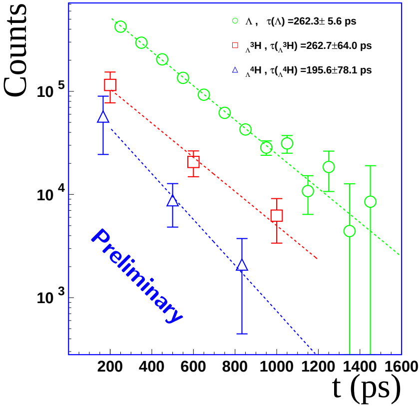
- Fitting function

$$N = N_0 e^{-t/\tau}$$



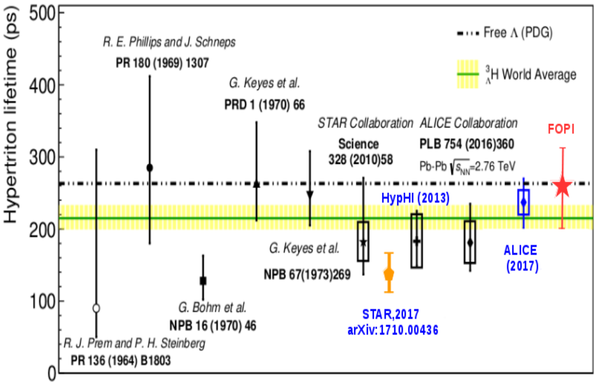
Mean lifetime of Λ, ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H

Efficiency-corrected decay time spectrum of Λ, ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H



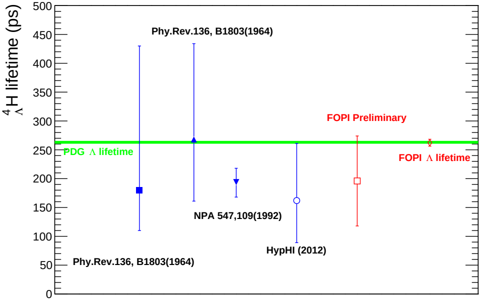
- Decay time
$$t = r_s/(\beta\gamma c)_T = r_s/(p_t/m)_T$$
- Fitting function
$$N = N_0 e^{-t/\tau}$$

$^{3}_{\Lambda}$H lifetime measurement status



S. Trogolo (ALICE), PoS:EPS-HEP2017 (2017) 200

$^4_\Lambda$H lifetime measurement status



- Lifetime of the Λ hyperon is consistent with PDG value.
- Lifetime of $^3_\Lambda$H is consistent with Λ hyperon lifetime.
- Lifetime of $^4_\Lambda$H is consistent with other measurements.

Coalescence production

Production channel:

- $\Lambda + d \rightarrow {}^{3}_{\Lambda}H$
- $\Lambda + t \rightarrow {}^{4}_{\Lambda}H$

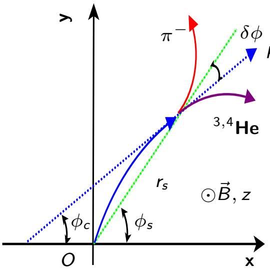
Assuming the particles in the same phase space cell have the same probability to “stick” together during the emission.

$Y({}^{3}_{\Lambda}H) \propto Y(\Lambda) \cdot Y(d)$ $\quad$ $Y({}^{4}_{\Lambda}H) \propto Y(\Lambda) \cdot Y(t)$

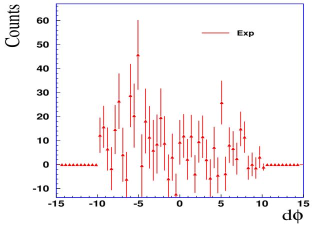
Region	Y(Λ)	Y(d)	Region	Y(Λ)	Y(t)
A1	1.3×10^{-3}	3.3×10^{-1}	B1	1.2×10^{-3}	6.6×10^{-2}
A2	2.2×10^{-3}	3.0×10^{-1}	B2	2.3×10^{-3}	6.7×10^{-2}

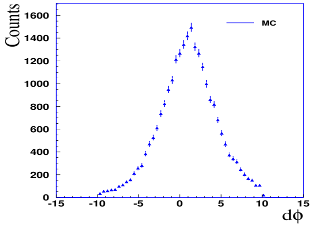
- These naive expectations are not compatible with the experimental observations.
- Other production modes (e.g $\pi^{\pm}$, K^{-}-induced reactions) can only be studied via model comparison.

Data and MC comparison : $d\phi$

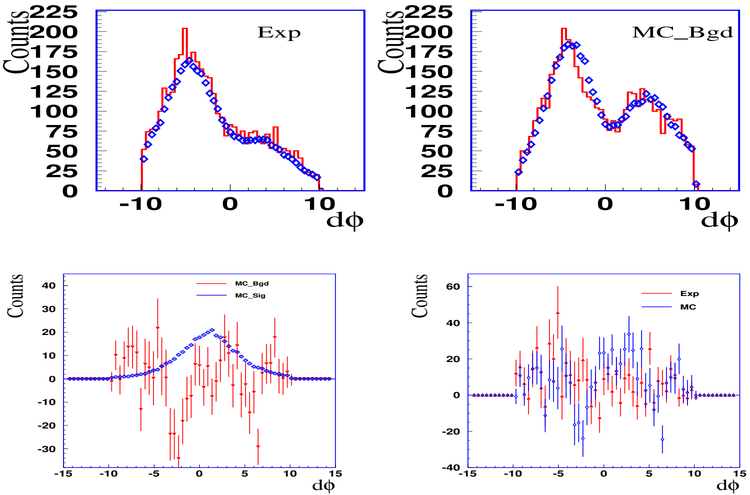


$$d\phi = \phi_s - \phi_c - \delta\phi$$





Data and MC comparison : background $d\phi$



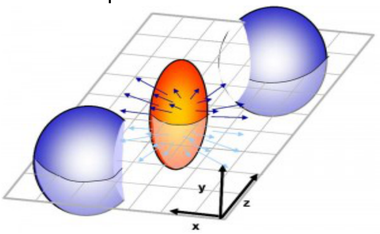
Summary

1. $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H are identified from their two-body π^{-}-decay channel in Ni+Ni collisions at 1.91A GeV for the first time.
2. The mean lifetime of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H is found to be 263±64(sta.)±44(sys.) ps and 196±75(sta)±43(sys.)
3. The yield of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H for the analyzed event sample is 7.7×10^{-4} and 1.3×10^{-4} per event, systematic error are close to finalization
4. The $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H production via coalescence process is naively discussed and it is shown that the observed results are not compatible with the expectations.

Thanks for your attention!

Back-up: Collective flow

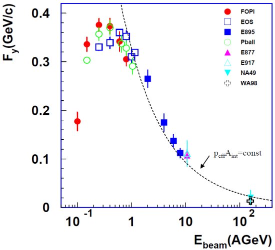
Reaction plane

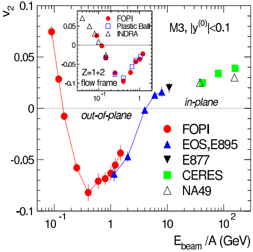


Fourier series:

$$\frac{dN}{d\phi} \propto (1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + \cdots)$$

$$v_n = \langle cos(n\phi) \rangle$$





Nucl-ex/9711003; Physics Letters B 612, 173

Annual Review of Nuclear and Particle Science 49, 581;