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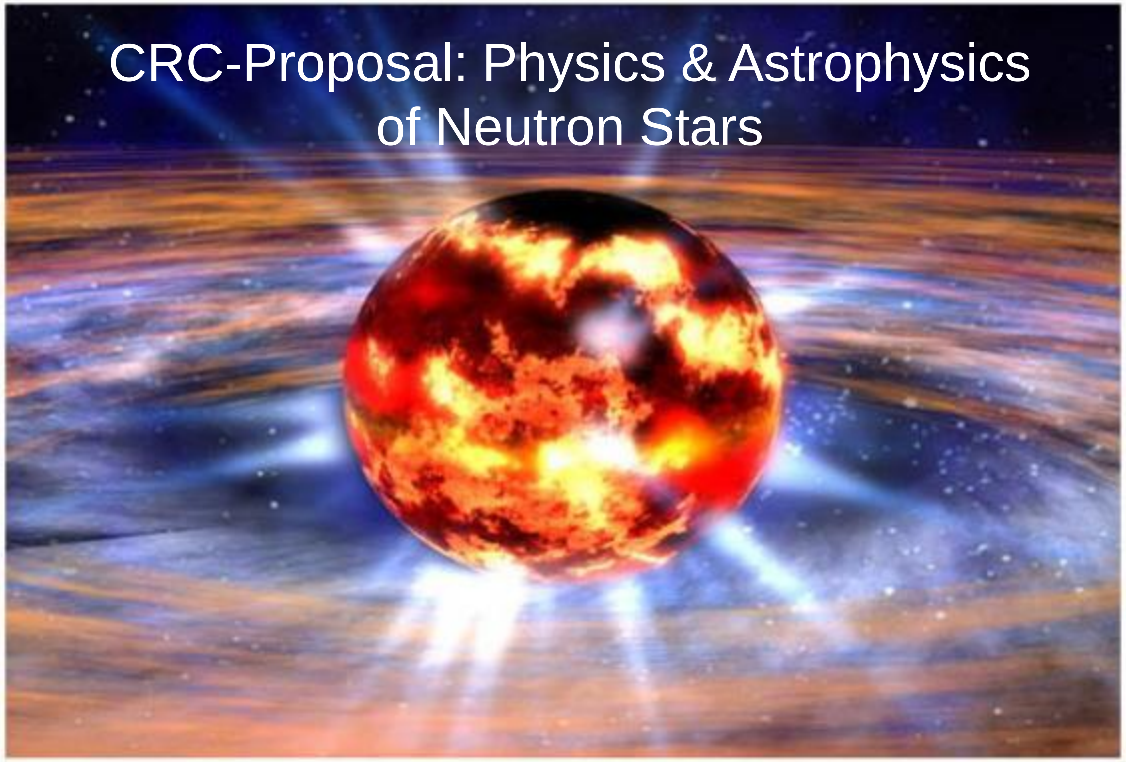
Hypernuclei and Hyperon-Hyperon Interactions

(Incomplete) Overview on Experimental Status

STAR, ALICE, KEK, …

Scope of the Workshop

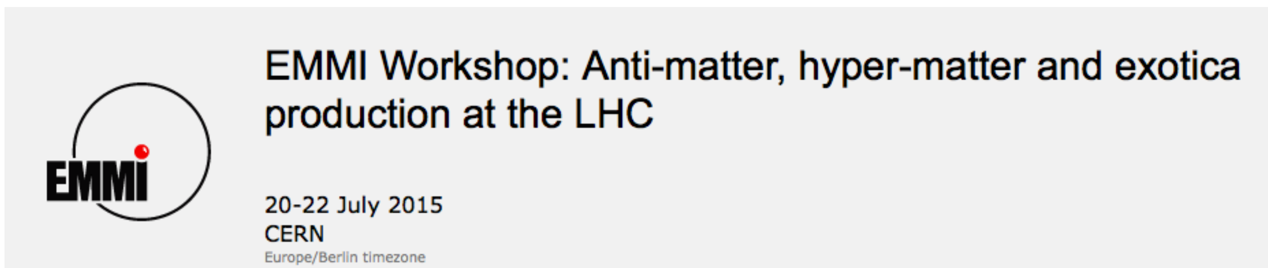


Subtopic:
The role of hyperons in the nuclear matter equation of state.

- shed light, both experimentally and theoretically, on hyperon-interactions, which is important to constrain the equation of state for nuclear matter including strange quark degree of freedom
- connection to neutron stars

Recent Hyperon/Strangeness Workshops

and sources of this overview….



Hyperon Interactions

- Hyperon interactions are notoriously difficult to measure because of the short decay length of $< 10\ cm/GeV/c$.

- Hyperon beams have been provided at CERN-SPS (1991-93) delivering $10^5\ \Sigma^-$ per beam pulse at $340\ GeV/c$ to the Omega spectrometer facility.
  - No potential (elastic) scattering at these energies, which would allow to measure phase shifts or scattering length.

- Low energy ΛN interactions (i.e., s-wave scattering) so far only from stopped K-beams in bubble chambers (<1970), some 100 events, and hypernuclei.

- Obviously no scattering on a hyperon target, i.e., no hyperon-hyperon scattering data.

- Information on hyperon-hyperon interactions from correlations:
  - $\Lambda\Lambda$ correlations (HBT, femtoscopy)
  - $(\Lambda\Lambda)_\mathrm{b}$ H-dibaryon search
  - double hypernuclei, e.g. ${}^{6}_{\Lambda\Lambda}He$

Hyperons ($\Lambda\Lambda$) Correlations at KEK

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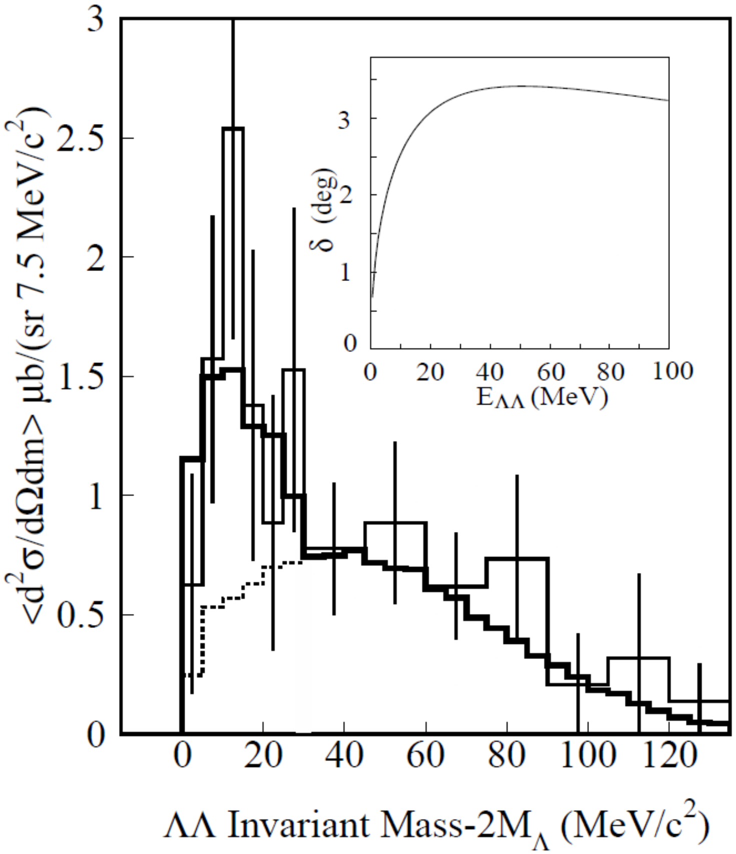
reaction: $(K^-, K^+\Lambda\Lambda)$
K. Yoon et al., Int J Mod Phy E19 (2010)2448
K. Yoon et al, Phys. Rev. C 75, 022201(R) (2007)



$\Lambda\Lambda$ invariant mass spectrum reproduced with FSI

scattering length $a_{\Lambda\Lambda} = -0.10^{+0.45}_{-2.35} \pm 0.04\ fm$
effective range $r_{\Lambda\Lambda} = 13.90^{>+16.10}_{<-13.30} \pm 9.48\ fm$

related to phase shift δ via

$$k\cot\delta = -\frac{1}{a_{\Lambda\Lambda}} + \frac{1}{2} r_{\Lambda\Lambda} k^2$$

<u>conjecture</u>:
enhancement above combinatorial background due H-dibaryon resonance and/or attaractive FSI

Hyperons ($\Lambda\Lambda$) Correlations at the SPS

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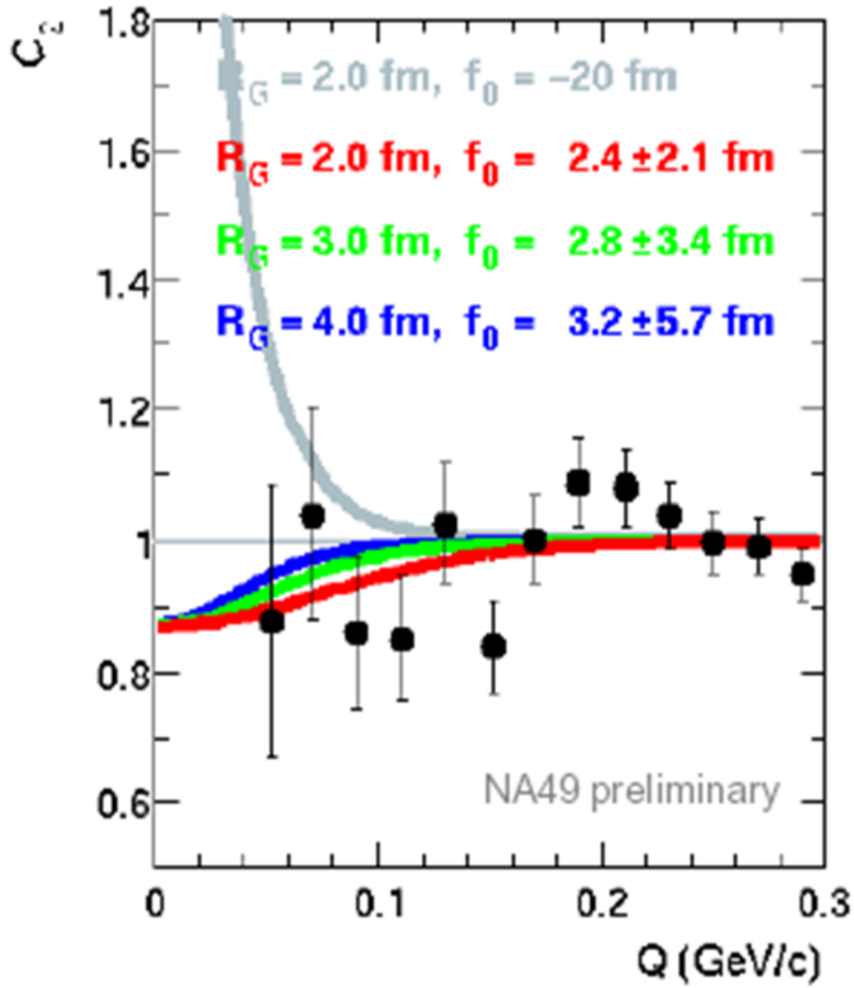
$Pb + Pb$ 158 $AGeV$
Nucl. Phys. A715 (2003) 55



NA49

- 3500 $\Lambda\Lambda$ pairs with $Q < 0.3 \frac{GeV}{c}$
- fit done with fixed R_G and λ, scattering length f_0 varied
- tendency for small, positive f_0 ($a_{\Lambda\Lambda} := -f_0 < 0$), but inconclusive due to low statistics

Hyperons (ΛΛ) Correlations at RHIC/STAR

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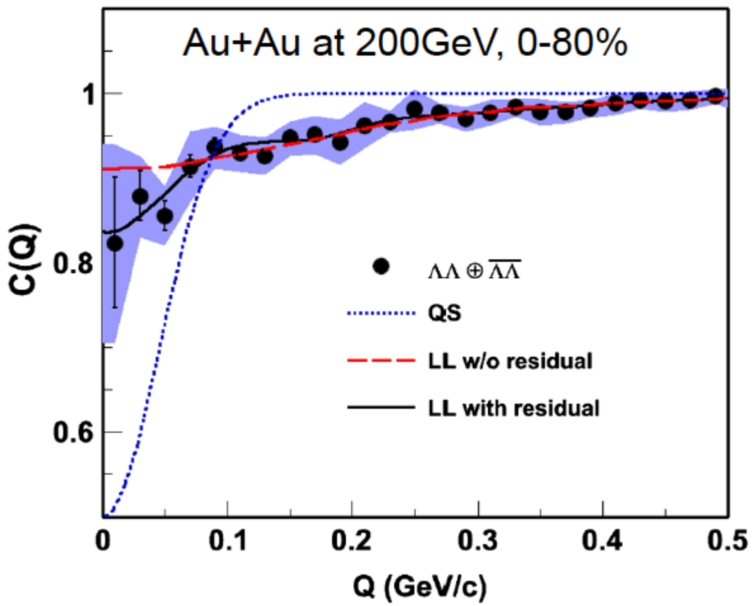
STAR Col. Phys. Rev. Lett. 114, 022301(2015)



- $\sim 8 \times 10^8$ events analyzed
- fit to data with Lednicky-Lyuboshitz model w and w/o residual ΛΛ interaction:
- $CF(Q = 0) > \mathrm{CF}_{\mathrm{QS}}(\mathrm{Q} = 0) \Rightarrow$ attractive interaction
  - no correction from feed down, i.e. residual correlation (only 45% of $\Lambda's$ are primary)
- scattering length $a_{\Lambda\Lambda} = -1.0 \pm 0.38^{+0.96}_{-0.02}\ fm$
- effective range $r_{\Lambda\Lambda} = 8.52 \pm 2.56^{+2.09}_{-0.74} fm$
- conclusion on attractive or repulsive potential is model dependent and limited by statistics

feed down: $\Lambda's$ from $\Sigma^0\Lambda$, $\Sigma^0\Sigma^0$, and $\Xi^-\Xi^-$.

Jinhui Chen @ SQM 2015

$H = (\Lambda\Lambda)_b$ search

mass : (1.9-2.8) GeV/c[2]

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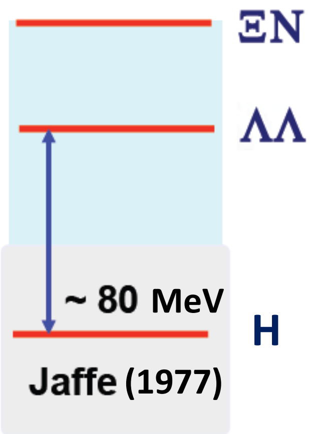
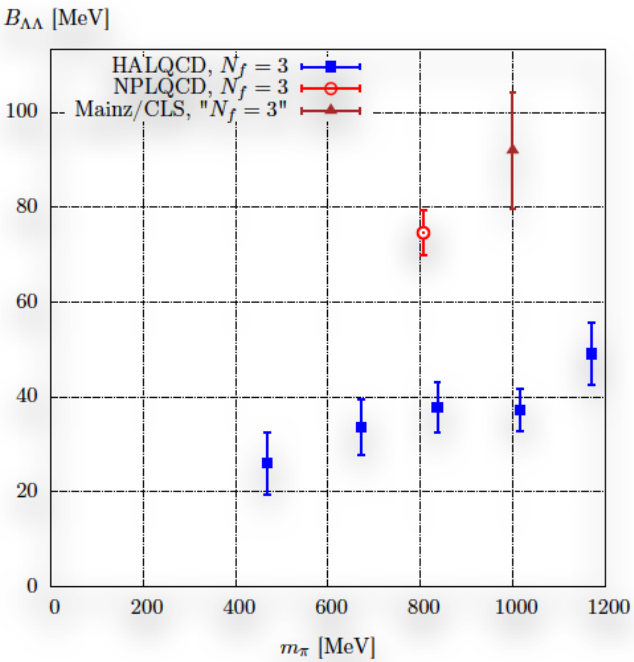


bound $(uuddss)$- object below ΛΛ threshhold
$m_H = 1.9 - 2.8\ GeV/c^2$

strong decay of H-dibaryon: visible ΛΛ as "bump" in correlation function

weak decay of H-dibaryon: visible in invariant mass spectrum $H \rightarrow \Lambda + p + \pi$



lattice QCD:

- bound state only at unphysical pion mass
- extrapolation to physical pion masses yield unbound H

STAR: Di-baryon Search

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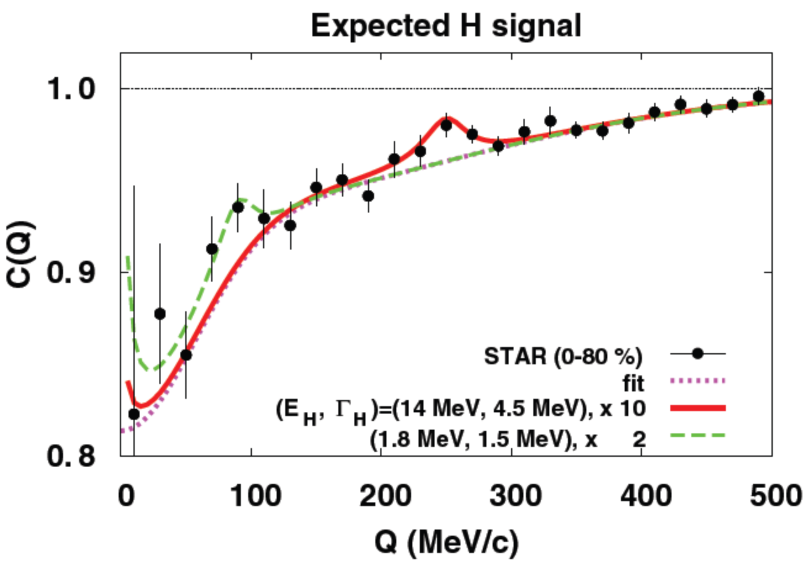

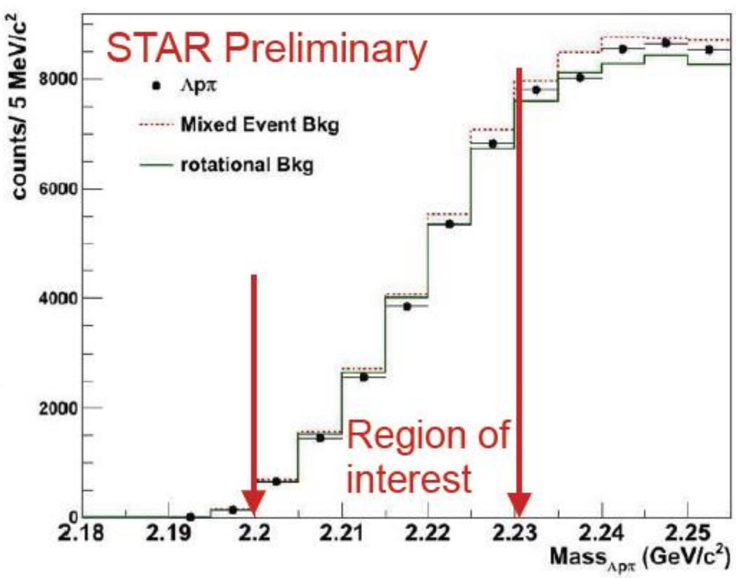

<u>correlations:</u>
no significant enhancement seen in data

K. Morita et al, Phys. Rev. C 91, 024916 (2015)

original idea:
C. Greiner and B. Müller, Phys. Lett. B, 219 (1989) 199

<u>invariant mass:</u>
no visible signal with respect to mixed event or rotational background

N.Shah, STAR coll., Nucl. Phys. A914 (2013) 410

Jinhui Chen @ SQM 2015

STAR: Hyper-Tritons

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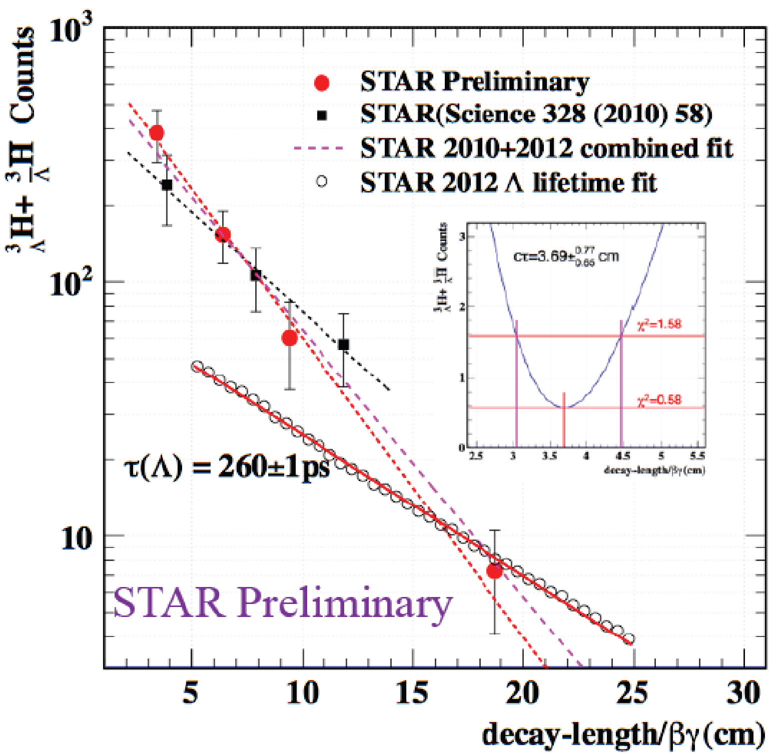
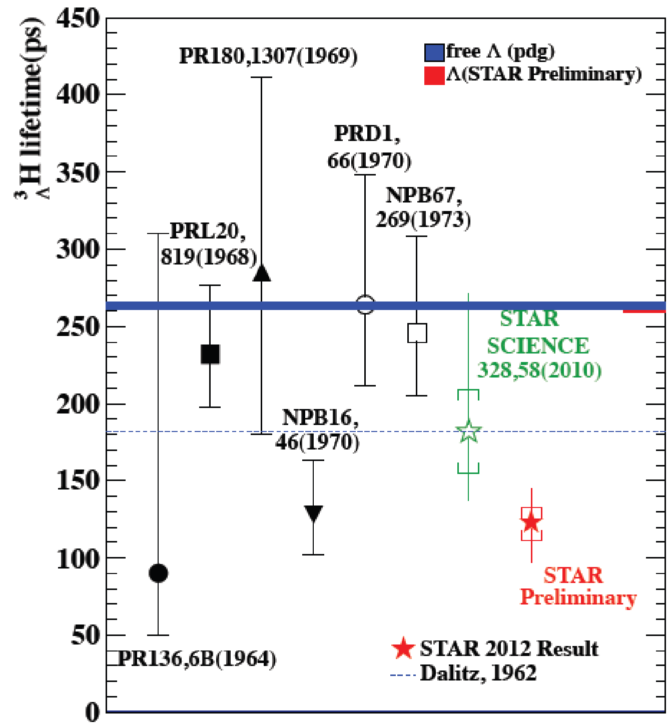
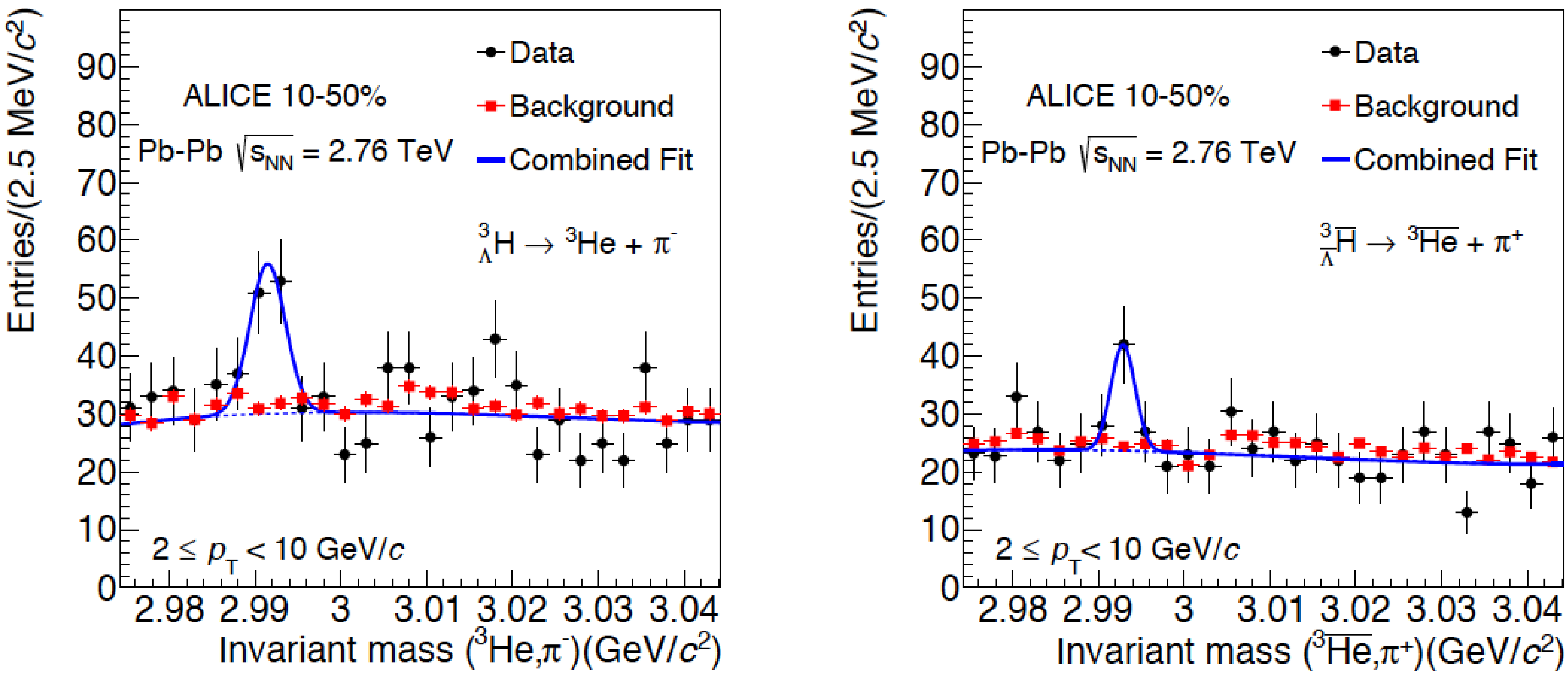




Decay mode: ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ and ${}^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+}$ Y. Zhu for STAR Col. Nucl. Phys. A 904 (2013) 551

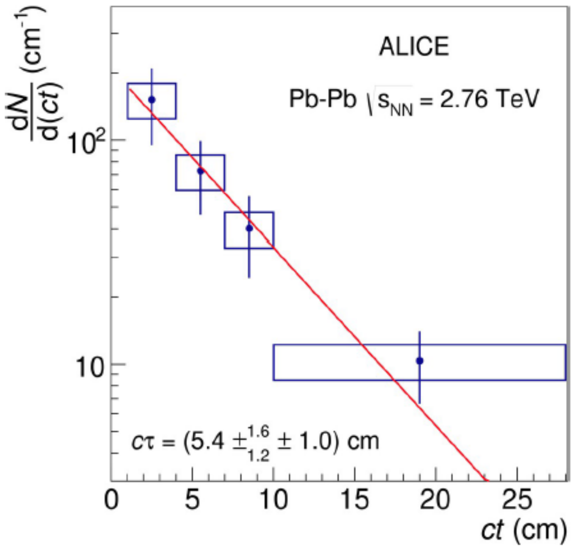
- lifetime measurement provides information on the ΛN - interaction strength
- STAR: short lifetime ($\tau = 123^{+26}_{-22} \pm 10\ ps$) compared with world average and free τ

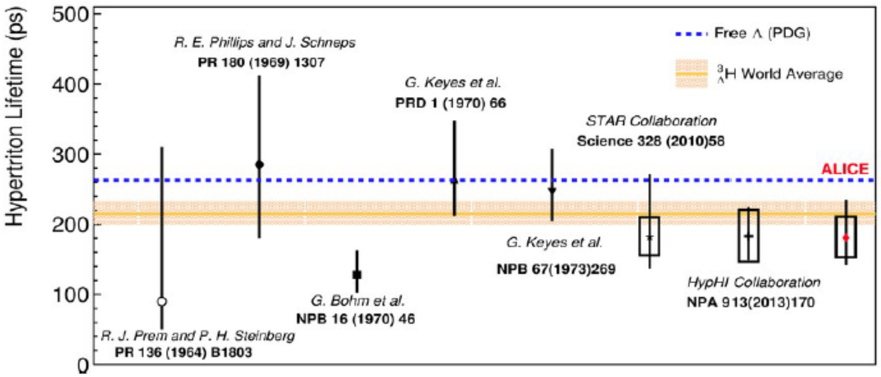
ALICE: Hyper-Tritons



Yields reproduced by thermal models….

ALICE: Hyper-Triton Lifetime





- Measurement of lifetime: anti-hyp. + hyper. sample in 4 intervals
- Exponential fit is performed: $c\tau = \left(5.4^{+1.6}_{-1.2}(\mathrm{stat.}) \pm 1.0(\mathrm{syst.})\right)$ cm
- From ALICE data: $\tau = \left(181^{+54}_{-39}(\mathrm{stat.}) \pm 33(\mathrm{syst.})\right)$ ps
- World average: $\tau = \left(215^{+18}_{-16}\ \mathrm{ps}\right)$
- ALICE result compatible with the computed average

H-dibaryon search at ALICE

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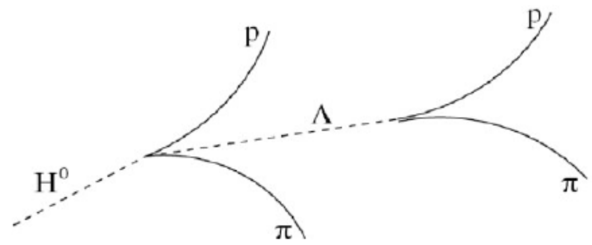
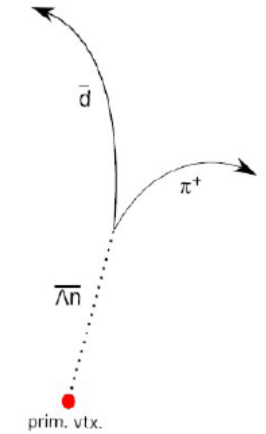
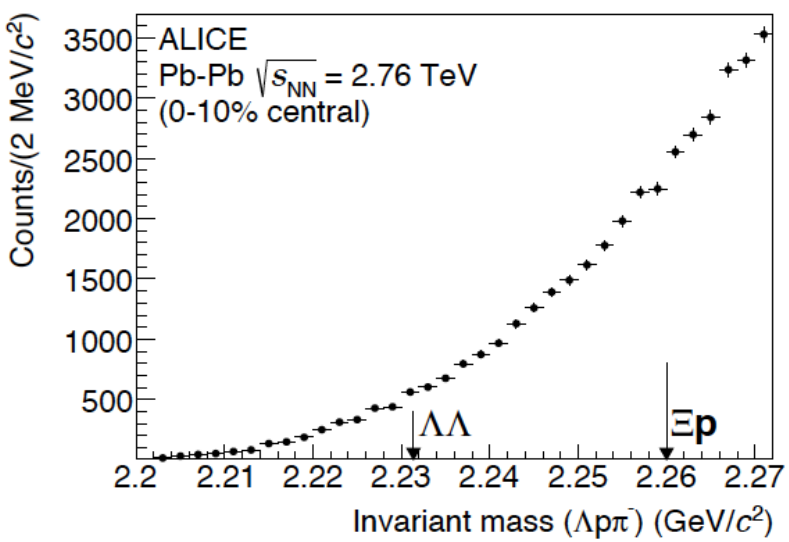


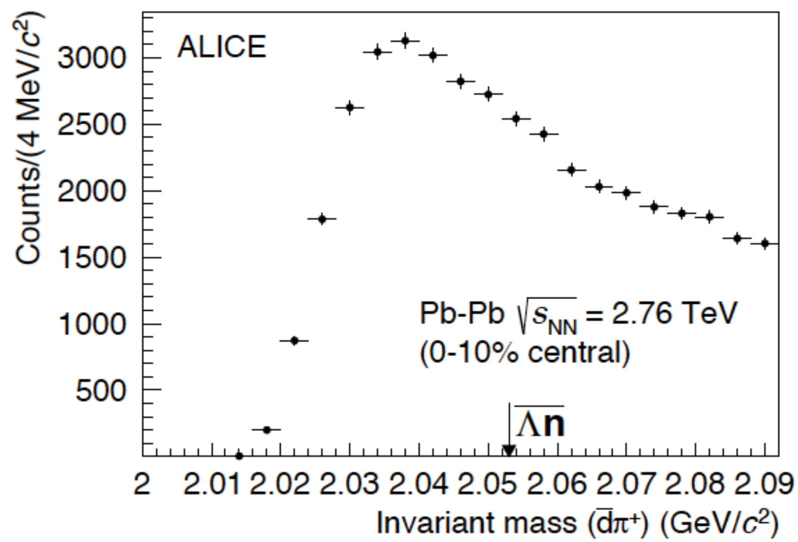
$$\text{H-dibaryon} \rightarrow \Lambda p \pi^-$$

$$2.200\,\mathrm{GeV}/c^2 < m_\mathrm{H} < 2.231\,\mathrm{GeV}/c^2$$

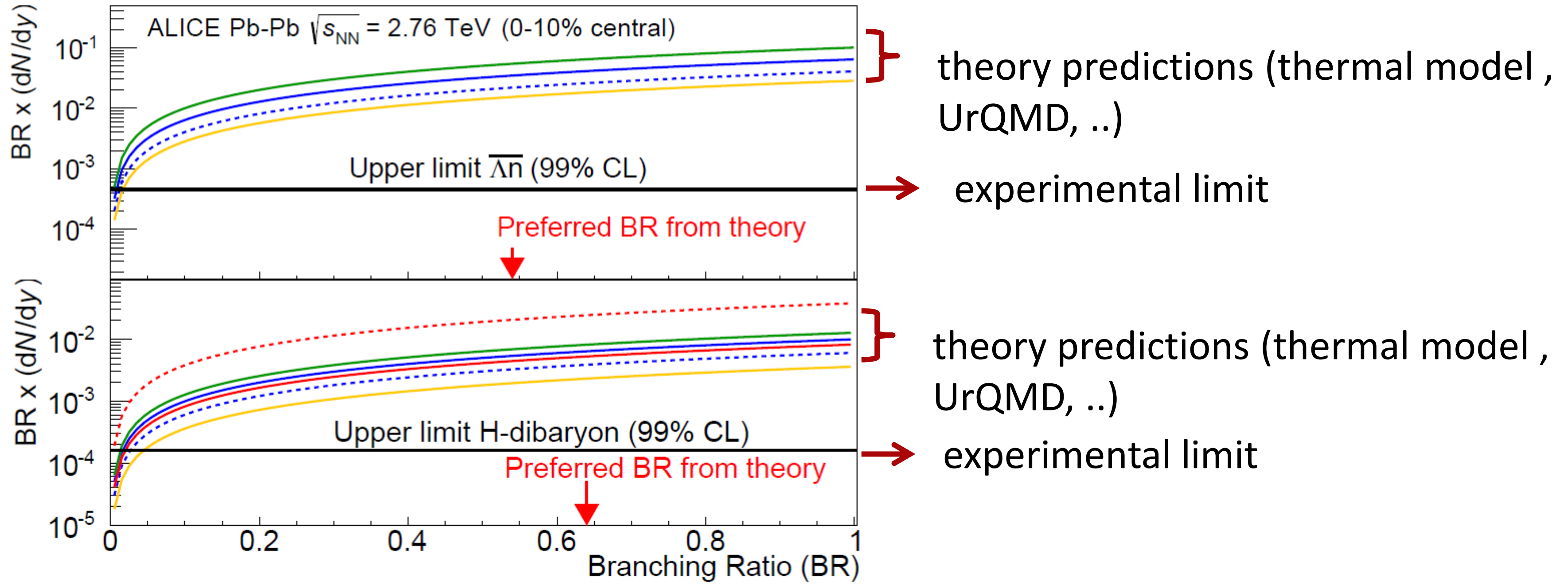
$$\overline{\Lambda \mathrm{n}} \rightarrow \bar{\mathrm{d}} \pi^+$$







H-dibaryon search at ALICE: Limits



- Limits obtained on the dN/dy are more than one order of magnitude below the expectations of particle production models
- Yields for a very loosely bound hypertriton (E_B < 150 keV) agree well with the prediction of the thermal model
  → Λn (if it exists) is predicted by this model and with a dN/dy ~ factor 300 higher that the measured hypertriton yield.
- Similar considerations for the H-dibaryon

Double-strange Hypernuclei

VOLUME 87, NUMBER 21 PHYSICAL REVIEW LETTERS 19 NOVEMBER 2001

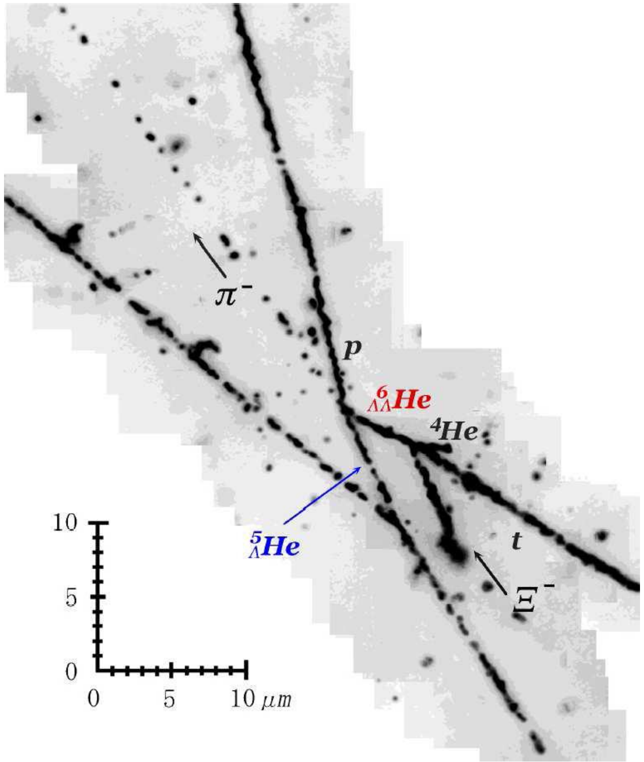
Observation of a $^{6}_{\Lambda\Lambda}$He Double Hypernucleus

H. Takahashi,[1,*] J. K. Ahn,[1,†] H. Akikawa,[1] S. Aoki,[2] K. Arai,[3] S. Y. Bahk,[4] K. M. Baik,[5] B. Bassalleck,[6] J. H. Chung,[7]

Observed ΛΛ hypernuclei:

1963: $_{\Lambda\Lambda}{}^{10}$Be (Danysz et al.)
1966: $_{\Lambda\Lambda}{}^{6}$He (Prowse et al.)
1991: $_{\Lambda\Lambda}{}^{10}$Be or $_{\Lambda\Lambda}{}^{10}$Be (KEK-E176)
2001: $_{\Lambda\Lambda}{}^{4}$H (BNL-E906)
2001: $_{\Lambda\Lambda}{}^{6}$He (KEK-E373)
2001: $_{\Lambda\Lambda}{}^{10}$Be (KEK-E373)

$$^{6}_{\Lambda\Lambda}He \rightarrow \Lambda\Lambda + ^4He, Q = 6.91\ MeV\ (?)$$



Status & Outlook

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Status:

- $\Lambda\Lambda$-correlations measured in STAR
  - firm conclusion on interaction potential still limited by statistics
- ALICE measures single light hypernuclei ($^3_\Lambda H$, $^3_\Lambda \overline{H}$)
- no evidence von H-dibaryon (ALICE, STAR)

Outlook:

- EOS from near-threshold hyperon production (→ Peter’s talk)
- for CBM (→Iouri’s talk):
  - correlation studies can be extend to $\Lambda\Xi$, $\Lambda\Omega$ $(?)$, $\Xi\Xi$ $(?)$
  - double hypernuclei “easy”