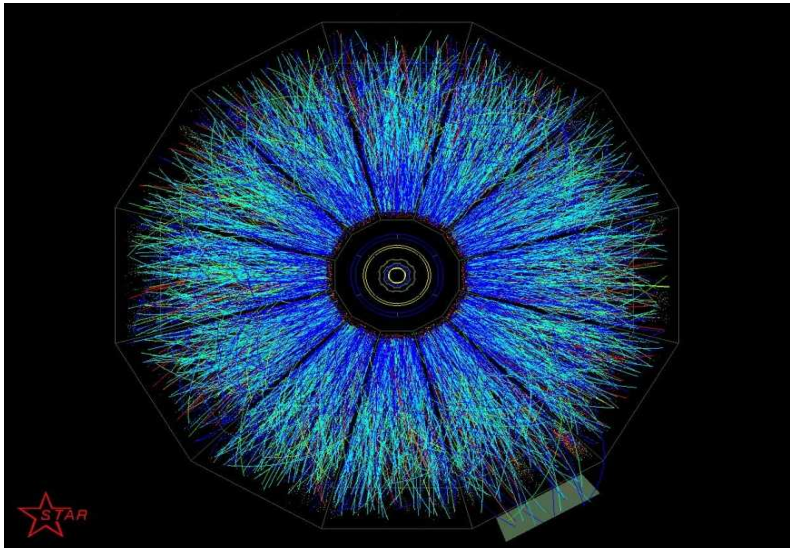
Hyper-nucleus study with BES at STAR

Neha Shah

Shanghai Institute of Applied Physics, CAS



Outline

- **Motivation**
- **Results and discussions**
    - **Lifetime**
    - **Ratios**
- **BES-II and FXT**
- **Summary**

Hypertriton study with BES at STAR

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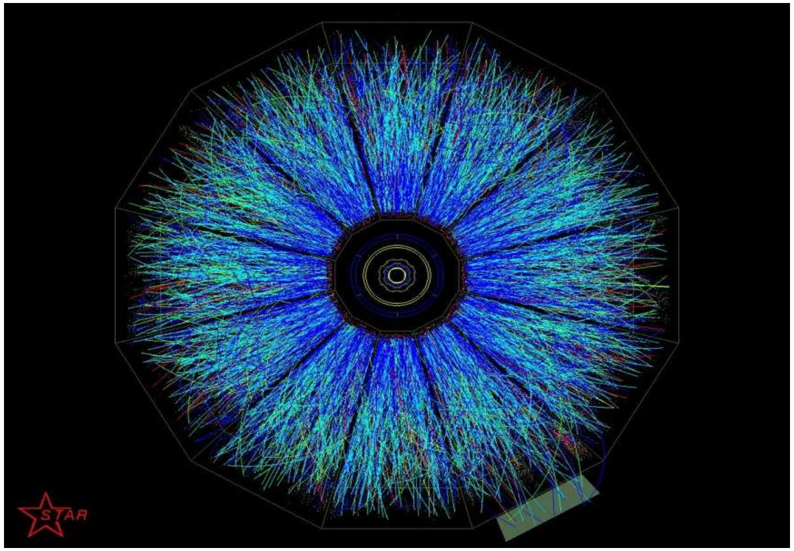

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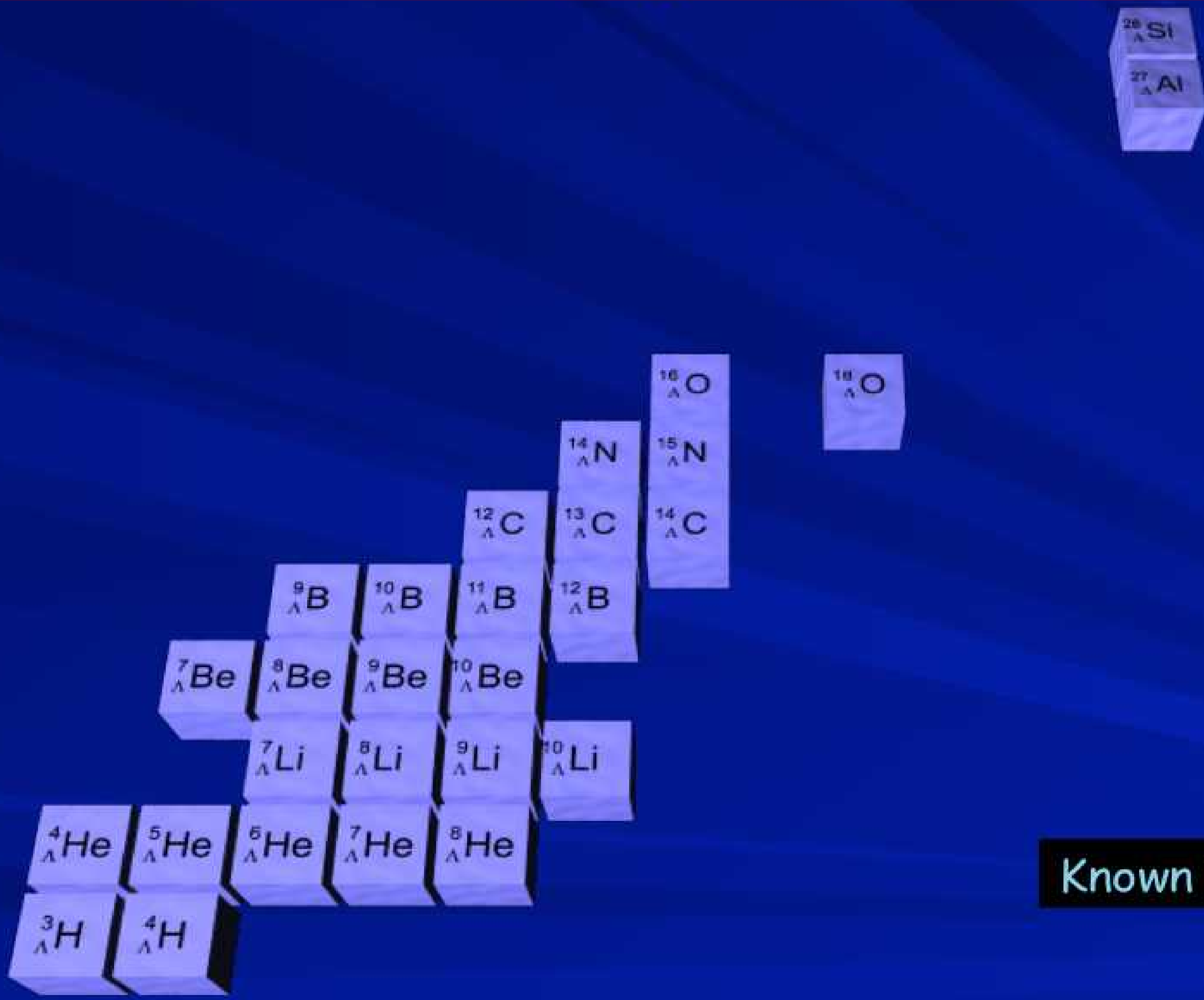
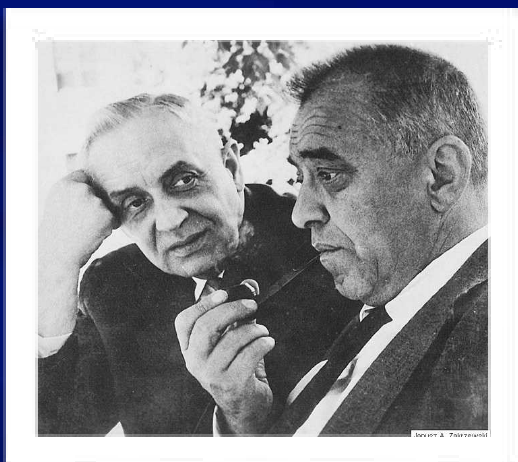
Present hypernuclear landscape

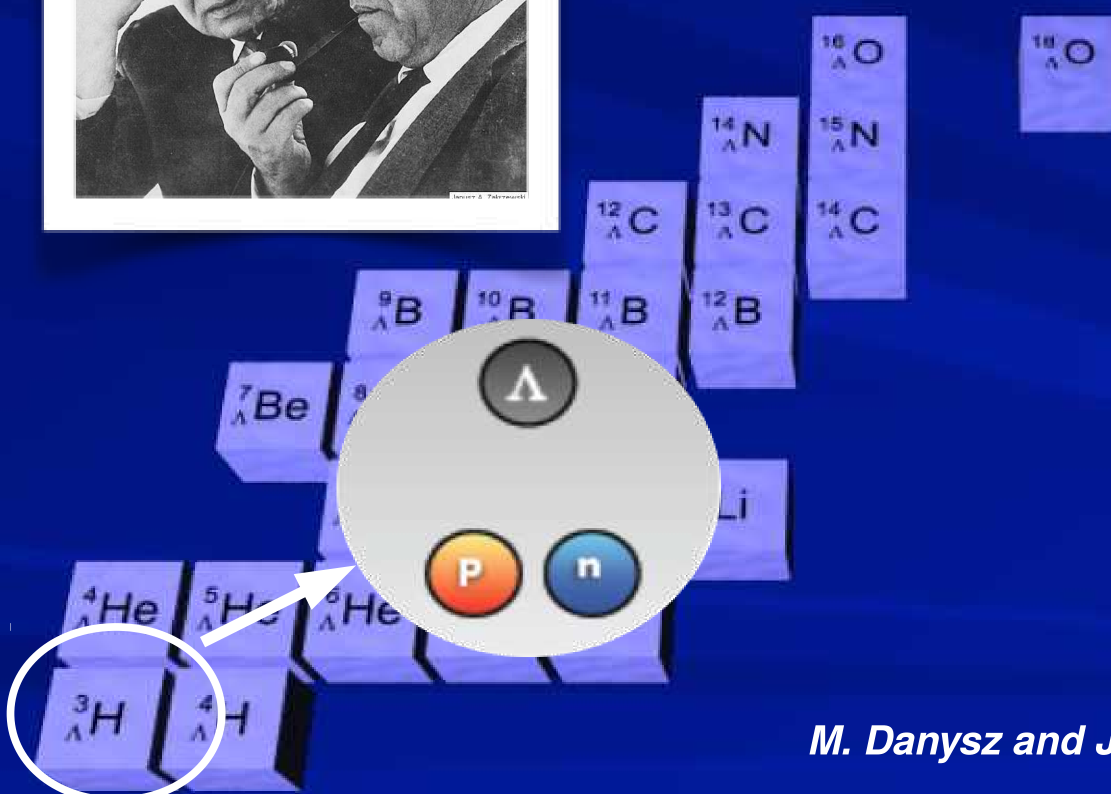


Known hypernuclei

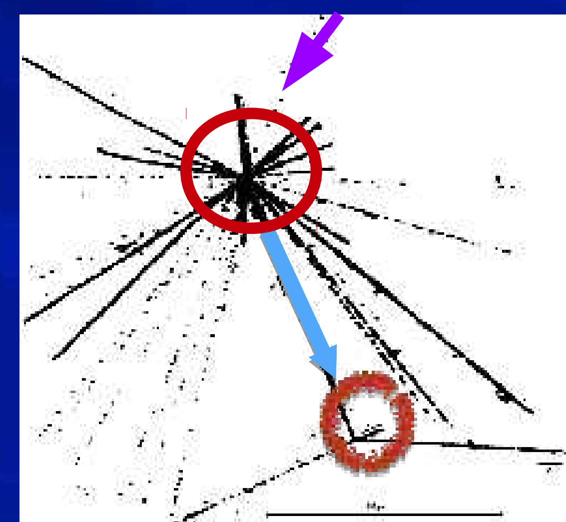
Present hypernuclear landscape

Hypertriton is the hyper nucleus with lowest A.





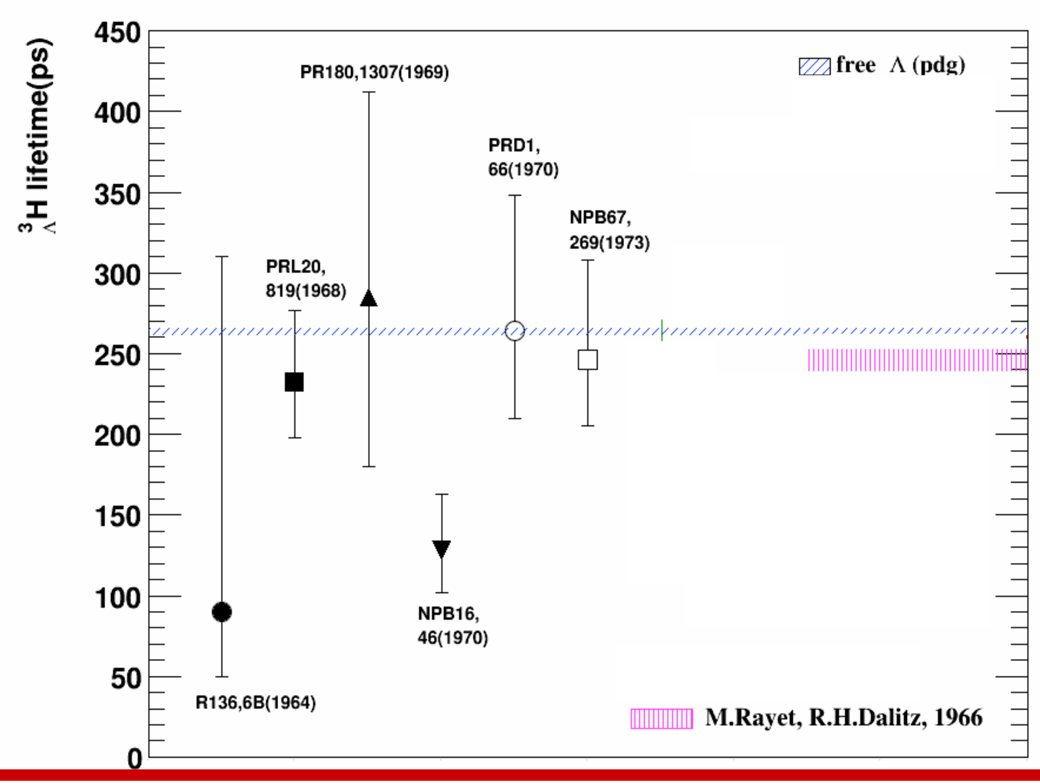
The first hyper nucleus was observed in 1953.



M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

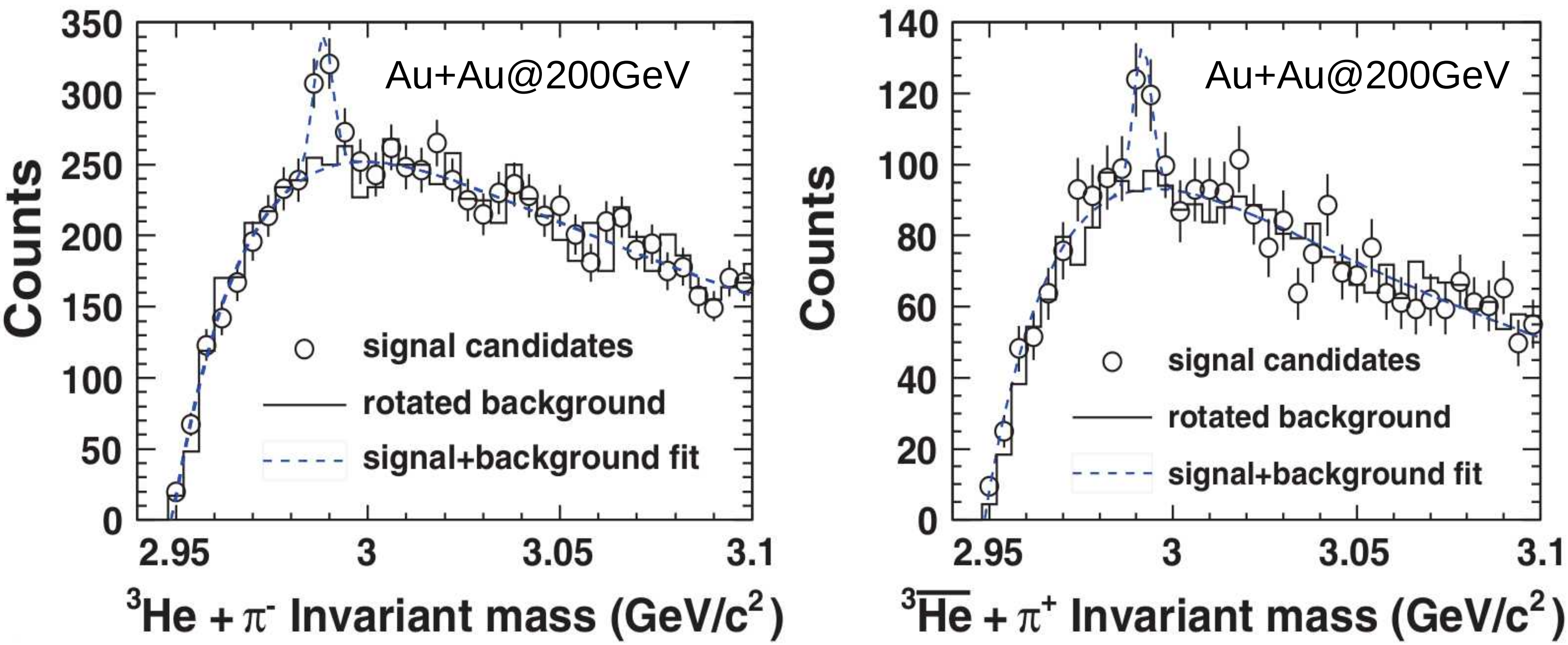
Hypertriton

- YN interaction will help to understand strong interactions and neutron stars.
- Binding energy and lifetime are sensitive to YN interaction.
- Binding energy = 130 keV



Hypertriton

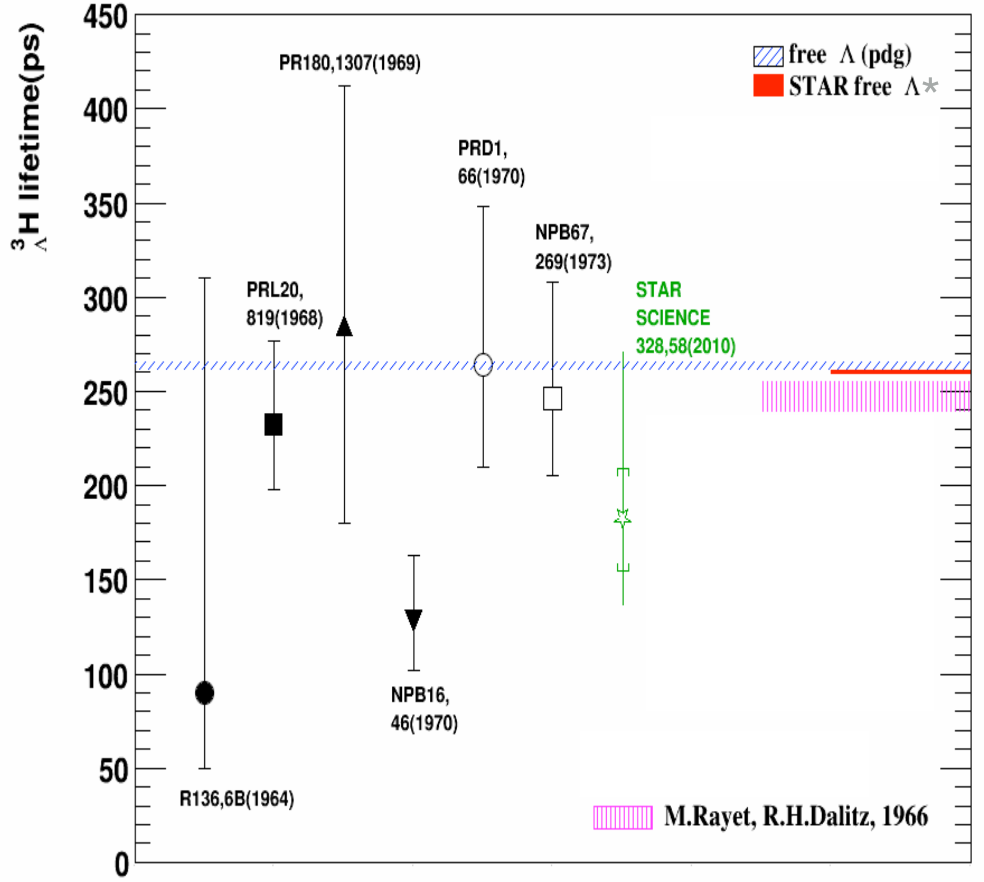
- Hypertriton could be abundantly produced in Heavy Ion Collisions.



STAR Collaboration, SCIENCE 328, 58 (2010)

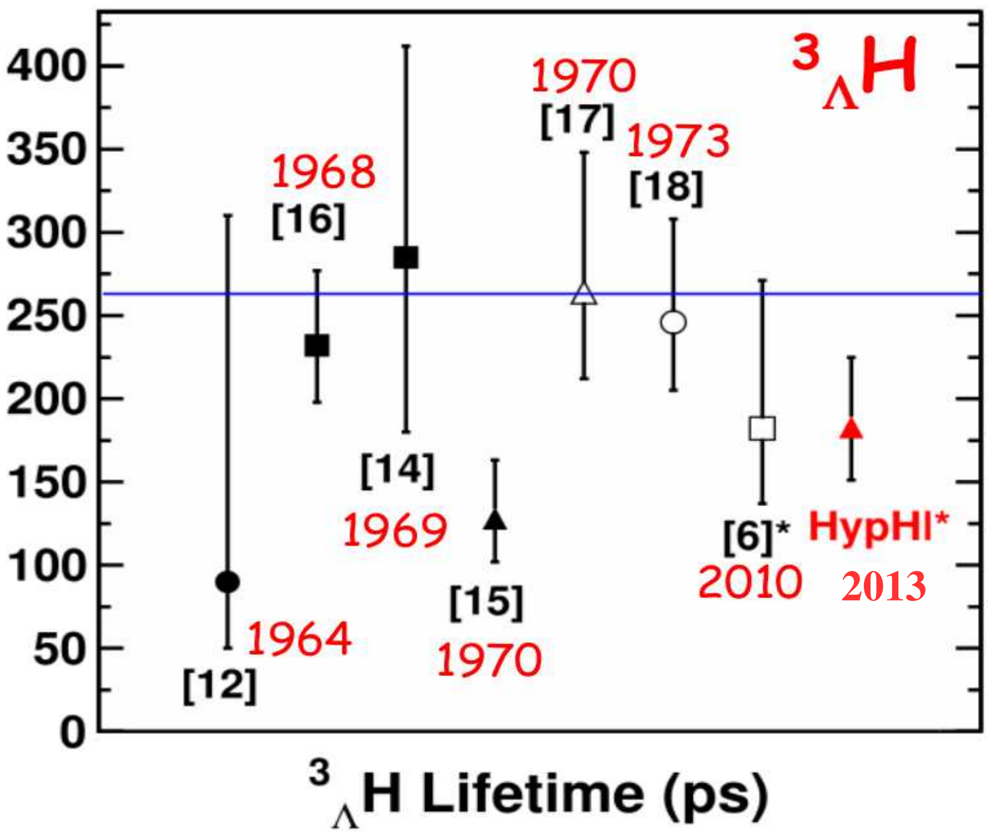
Hypertriton lifetime

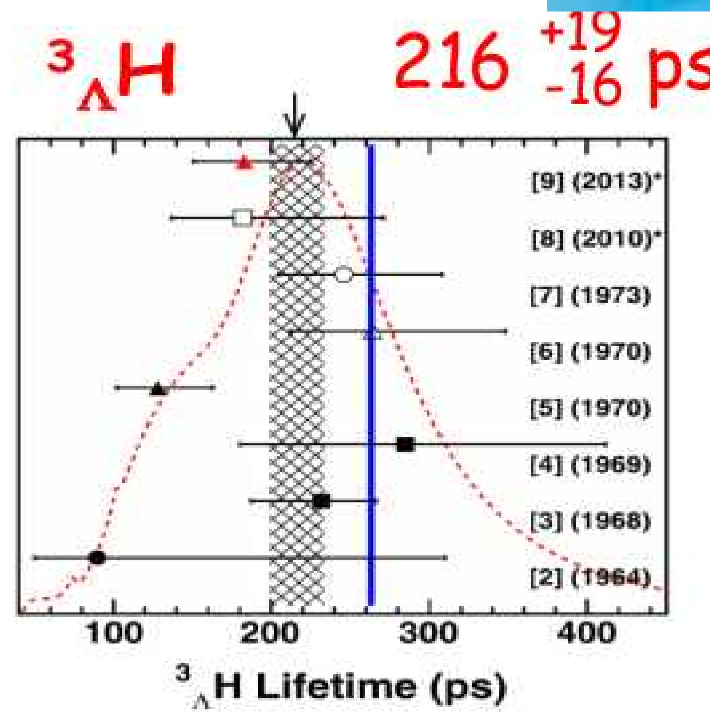
Status after STAR measurement



** The same method is applied for calculation of STAR free Λ lifetime.*

Hypertriton lifetime





Bayesian analyses:

- Upper limit with 95 % confidence level
  $^3_\Lambda$H : 250 ps [redacted]

C. Rappold et al. / Physics Letters B 728 (2014) 543–548

Sensitivity to QCD Phase Transition

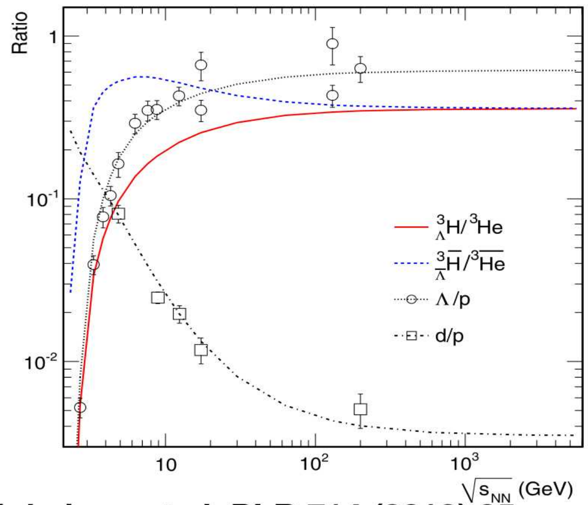
Hypertriton is a local baryon-strangeness correlation system

Strangeness Population Factor

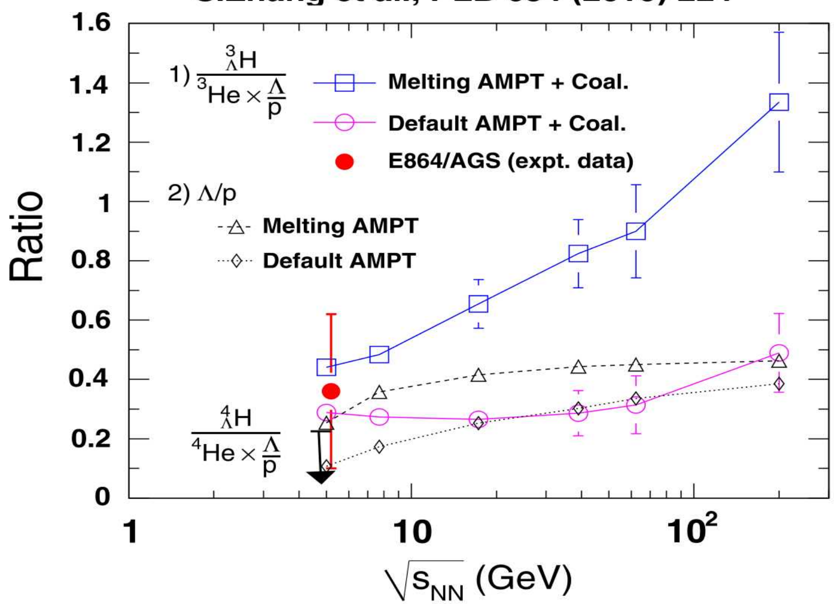
$$S_3 = {}^3_\Lambda H / ({}^3He \times \Lambda / p)$$

Λ / p

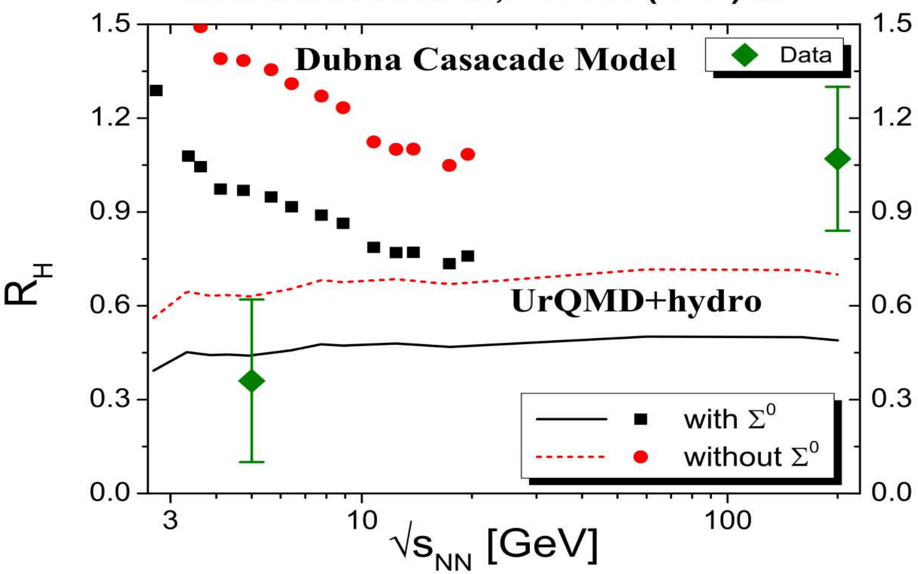
A.Andronic et al., PLB 697 (2011) 203



S.Zhang et al., PLB 684 (2010) 224



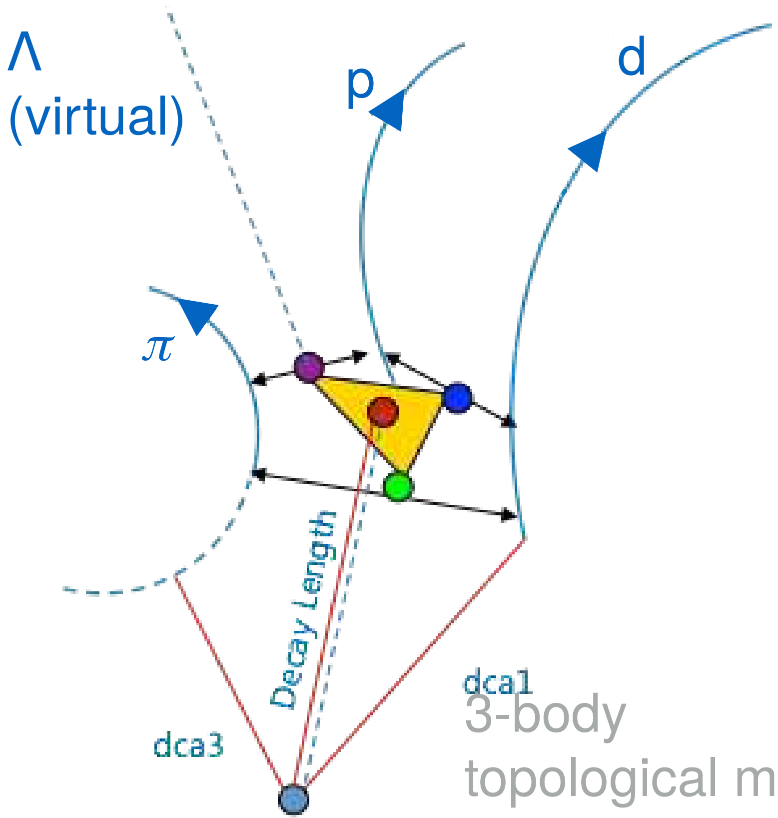
J. Steinheimer et al.,PLB 714 (2012) 85



Dataset

Channel	Theoretical B.R.
$^{3}He+\pi^{-}$	24.88%
$d+p+\pi^{-}$	40.15%

*Physical Review C.57.1595(1998)



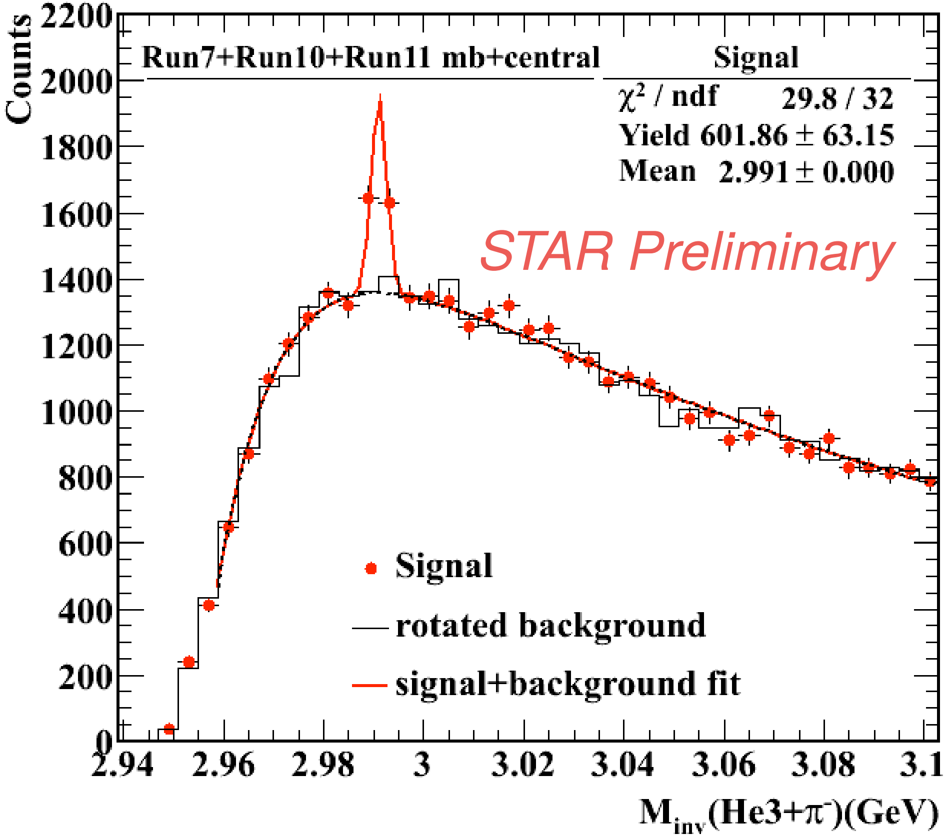
3-body topological map

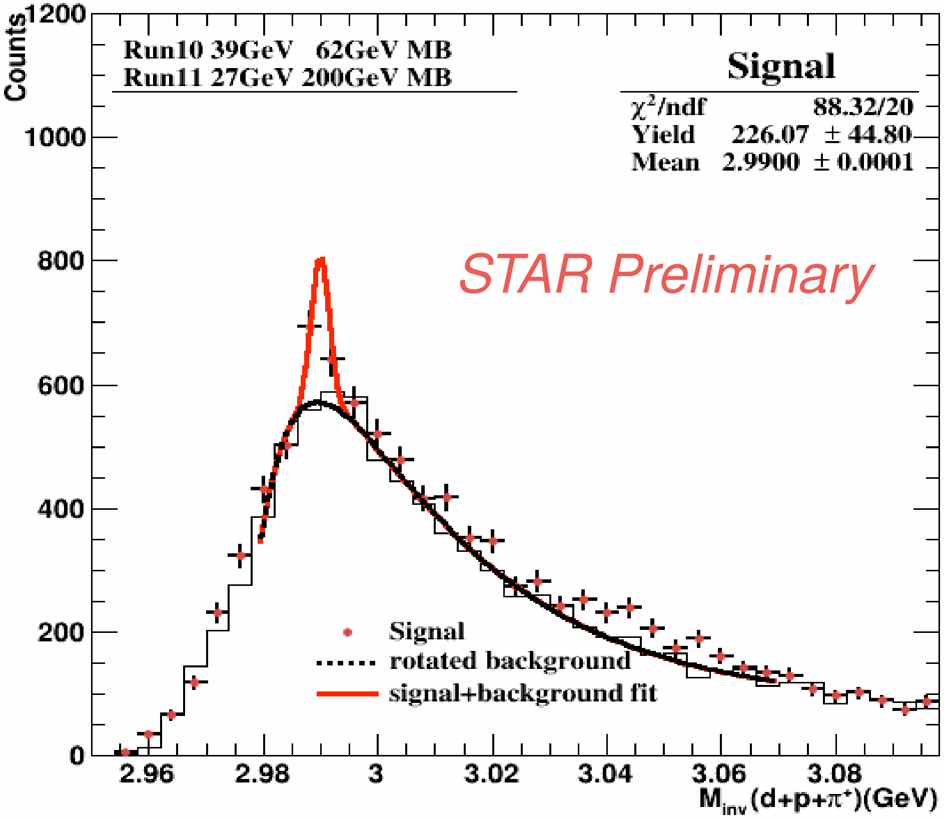
2-body	Event #
Run10 7.7	3.98 M
Run10 11.5	10.98 M
Run11 19.6	31.15 M
Run11 27	48.65 M
Run10 39	118.02 M
Run10 200	222.73 M
Total	**435.51 M**

3-body	Event #
Run11 27	53.31 M
Run10 39	134.41 M
Run11 200	516.87 M
Total	**704.59 M**

Hypertriton signal

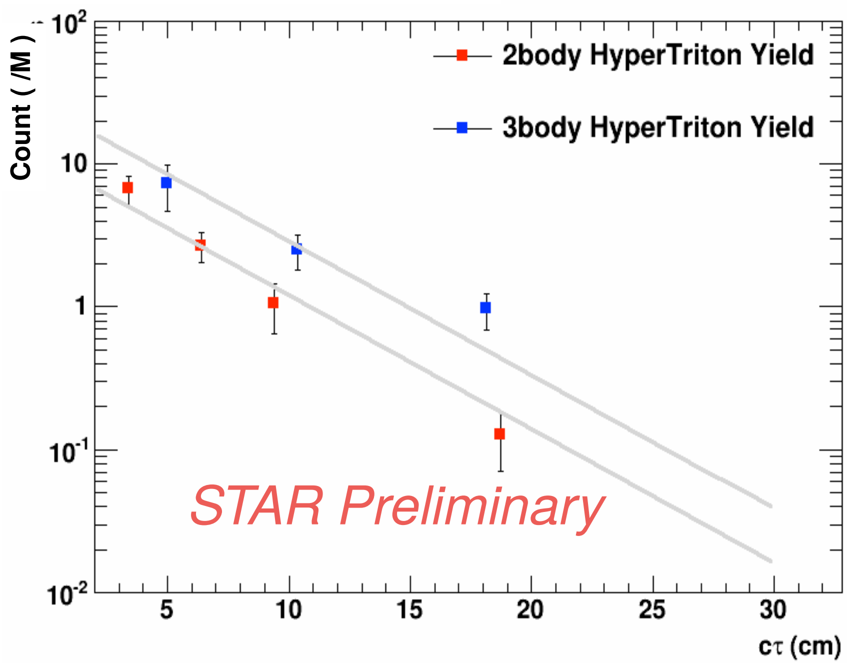
Reconstructed Invariant mass for 2-body and 3-body:

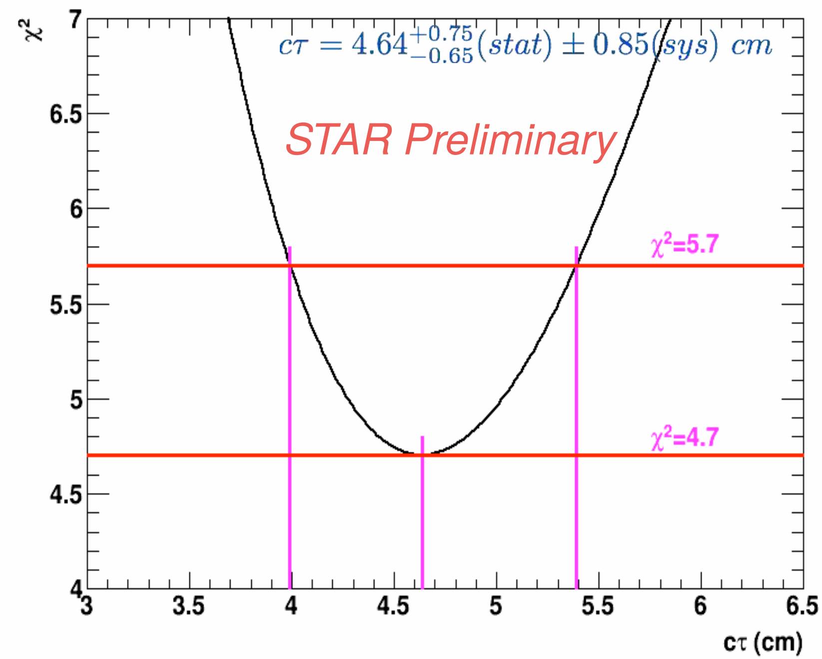




Measured Lifetime

With 2-body and 3-body data, we can calculate χ^2 distribution with $c\tau$.





Hypertriton lifetime from combined channels :

$$\tau = 155^{+25}_{-22}(stat) \pm 29(sys)\ ps$$

We take into account two kinds of contributions to systematic errors:

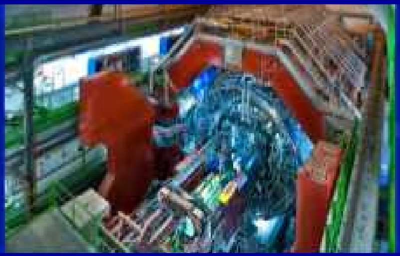
- binning effect
- different (V0) cuts.

Recent status of lifetime values of $^{3}_{\Lambda}H$

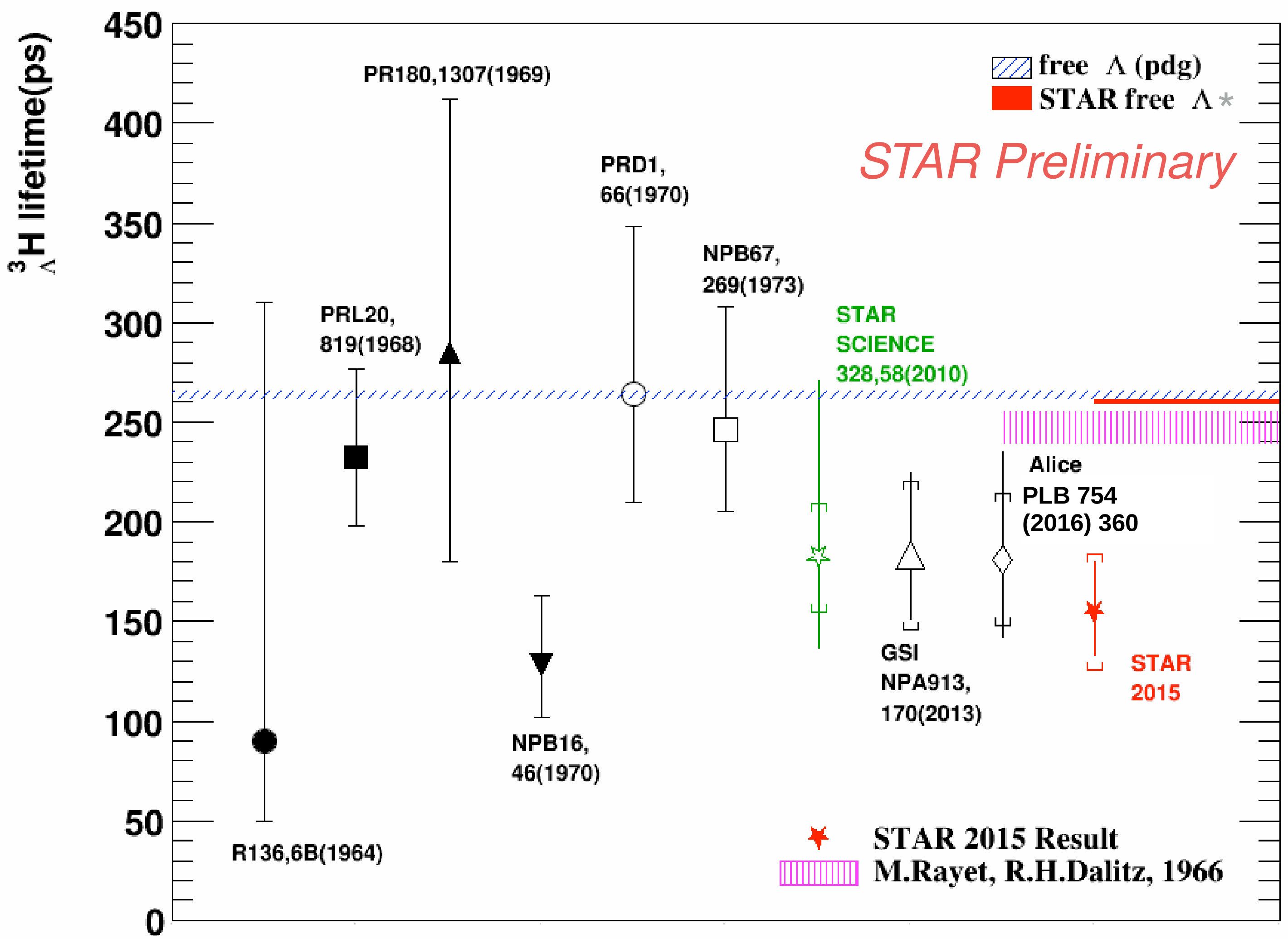
HYP2015

- HypHI
  - $^{6}Li+^{12}C$ and $^{20}Ne+^{12}C$ at 2 A GeV at GSI
  - Phase 0 ($^{6}Li+^{12}C$), 183^{+42}_{-32} ps (Λ: 263 ps)
  - Phase 0 ($^{20}Ne+^{12}C$), 170^{+46}_{-30} ps (Λ: 263 ps)
- STAR at BNL RHIC
  - $^{197}Au+^{197}Au$
  - Observation of short lifetime of $^{3}_{\Lambda}H$
  - Two/three-body decays combined: 155^{+25}_{-22} ps

- ALICE at LHC CERN
  - $^{208}Pb+^{208}Pb$
  - 181^{+54}_{-39} ps

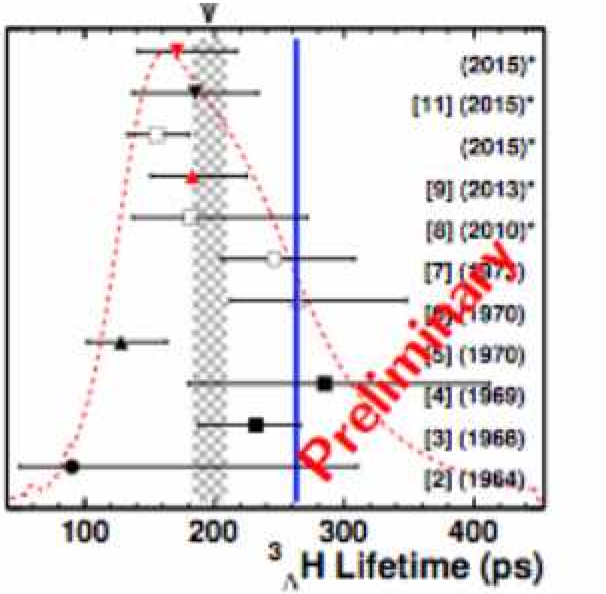


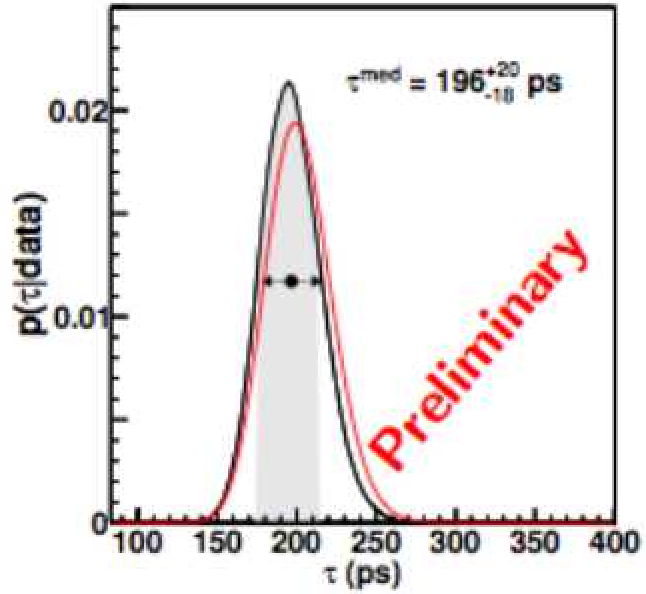
World Data



The same method is applied for calculation of STAR free Λ lifetime.

Recent status of lifetime





T. Saito, HYP2015

- PDG says need to rescale errors if $\chi^2 > 1$
  - initial χ^2=1.18, $197.5^{+12.4}_{-11.2}$ ps
  - scaled χ^2=0.98, $195.9^{+13.8}_{-12.5}$ ps
- Upper Limit at 95% : 223.9 ps & at 99% : 234.0 ps
- Bayesian :
  - $195.9^{+19.7}_{-18}$ ps & Upper Limit 95% : 229 ps

All recent lifetime measurements are smaller than free Lambda lifetime.

No theory is available to explain shorter lifetime.

HYP2015

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  - $^{6}Li+^{12}C$ and $^{20}Ne+^{12}C$ at 2 A GeV at GSI
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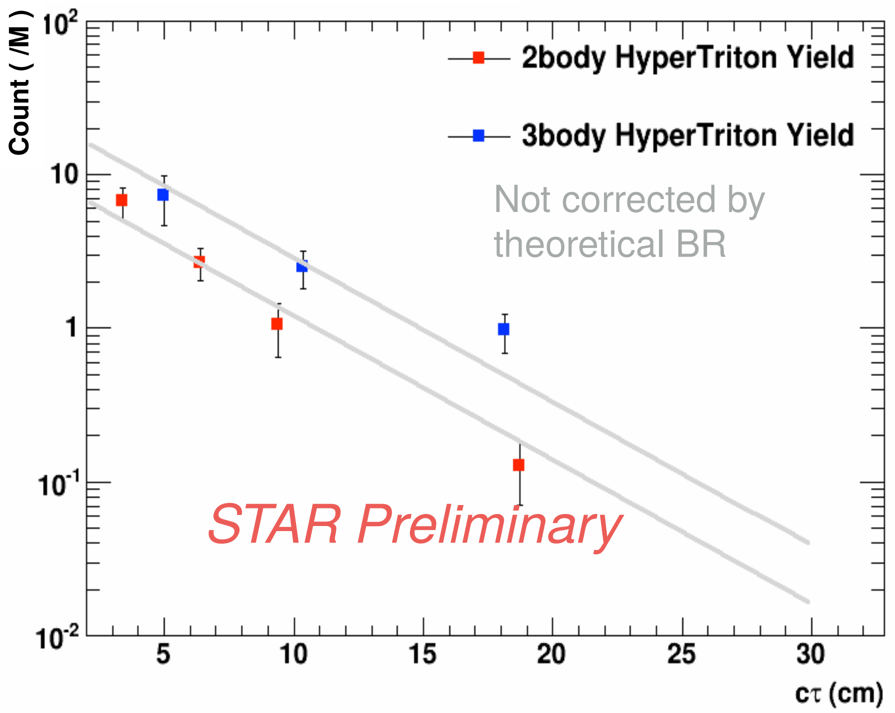
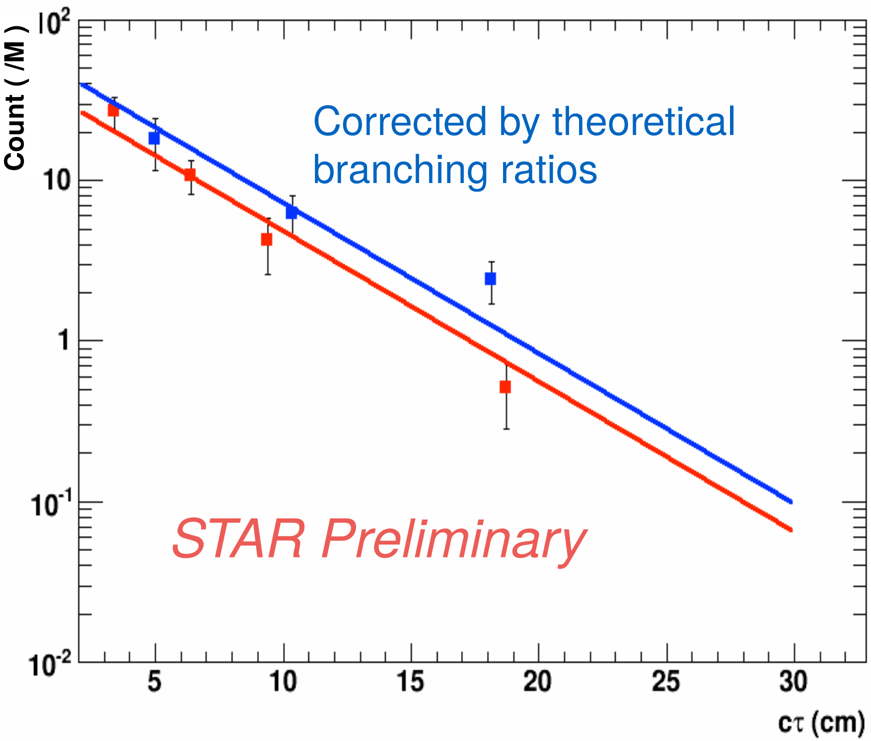
Measured Ratio of B.R.

Branching ratio (B.R.) can be calculated by decay law :

$$f(t) = N_0 Bre^{-\frac{t}{\tau}}$$





$$\frac{B.R.(d+p+\pi^-)}{B.R.(^3He+\pi^-)} = 2.41^{+0.39}_{-0.34}$$

Theoretical : $\left(\frac{40.15}{24.88} = 1.61\right)$

*Physical Review C.57.1595(1998)

Measured Ratio of B.R.

Table 4. Measurements of the decay branching ratio R.

R	Reference
0.39 ± 0.07	Block *et al* [32]
$0.36^{+0.08}_{-0.06}$	Keyes *et al* [27, 28]
0.30 ± 0.07	Keyes *et al* [20]
0.35 ± 0.04	Mean value

Table 5. Theoretical calculations of the decay branching ratio R.

R	Reference
0.17–0.26	Dalitz [17]
0.10–0.24	Leon [18]
0.26	V1 Kolesnikov and Kopylov [10]
0.55	V2
0.52	V3
0.50	V4
0.32	V5

Needs multiplication by 2 due to error in calculation

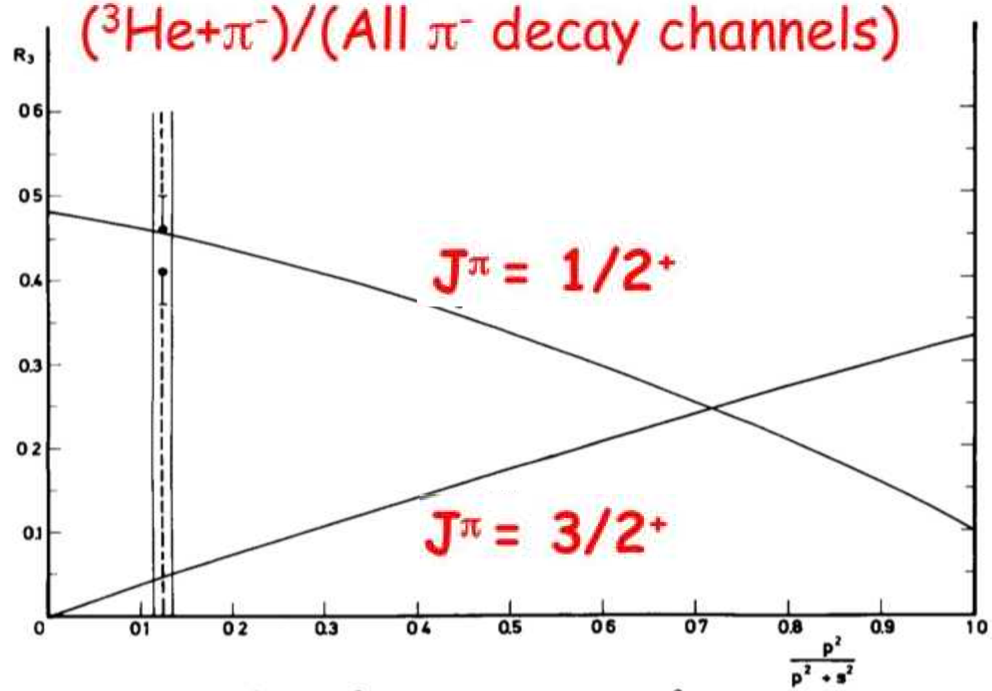


Fig. 4. The ratio $R_3 = ({}^3_\Lambda H \to \pi^- + {}^3He)/(\text{all } \pi^- \text{ mesonic decays of } {}^3_\Lambda H)$ as a function of $p^2/(p^2+s^2)$. The curves illustrate the results of the calculations made by Dalitz and Liu [4] for $J({}^3_\Lambda H) = \frac{1}{2}$ and $\frac{3}{2}$.

T. Bertrand et al., NPB 16(1970)77

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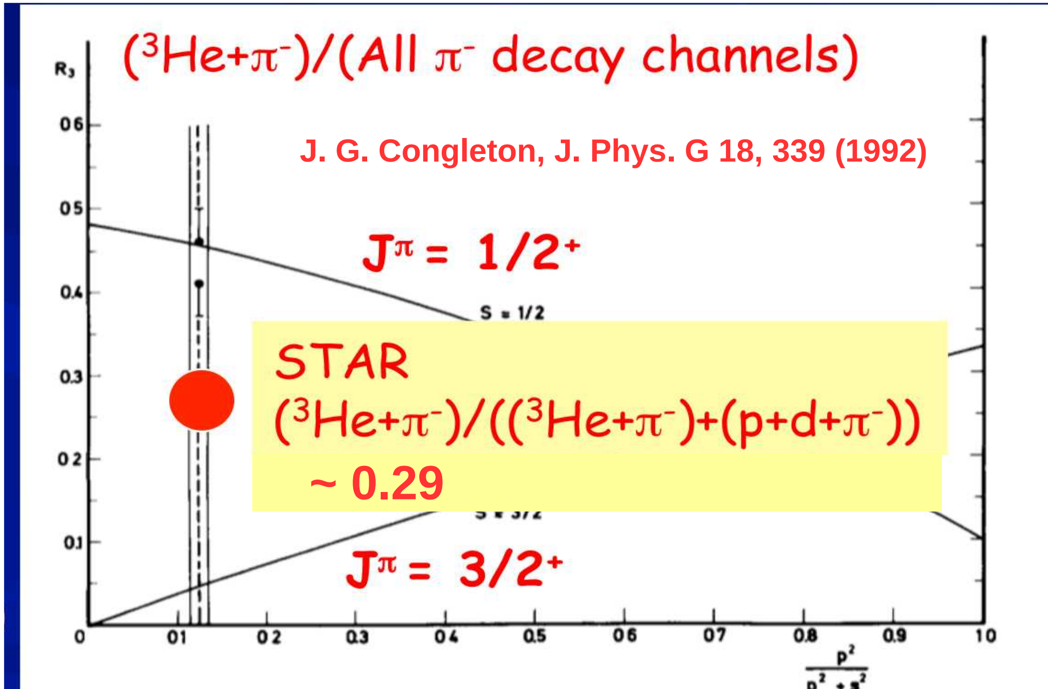
0.32	V5

Needs multiplication by 2 due to error in calculation

- **The ratio is consistent with previous measurements.**
- **However with small BE = 130 keV, it is difficult to explain shorter lifetime**



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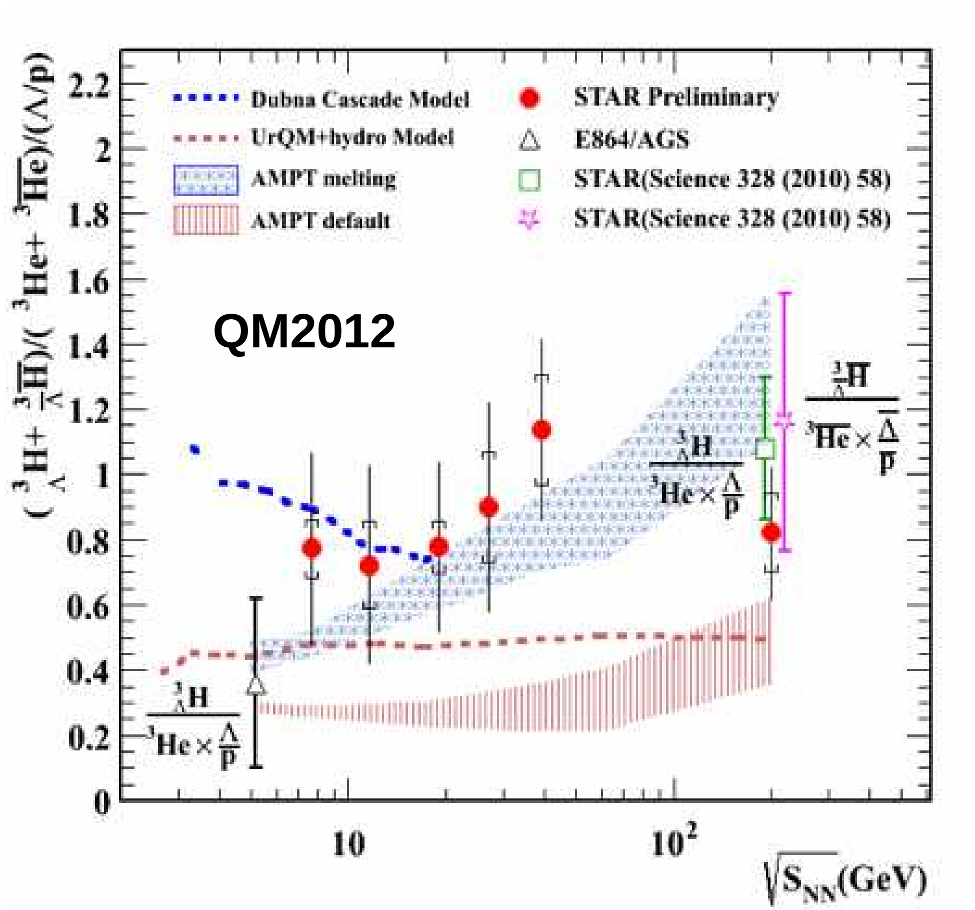
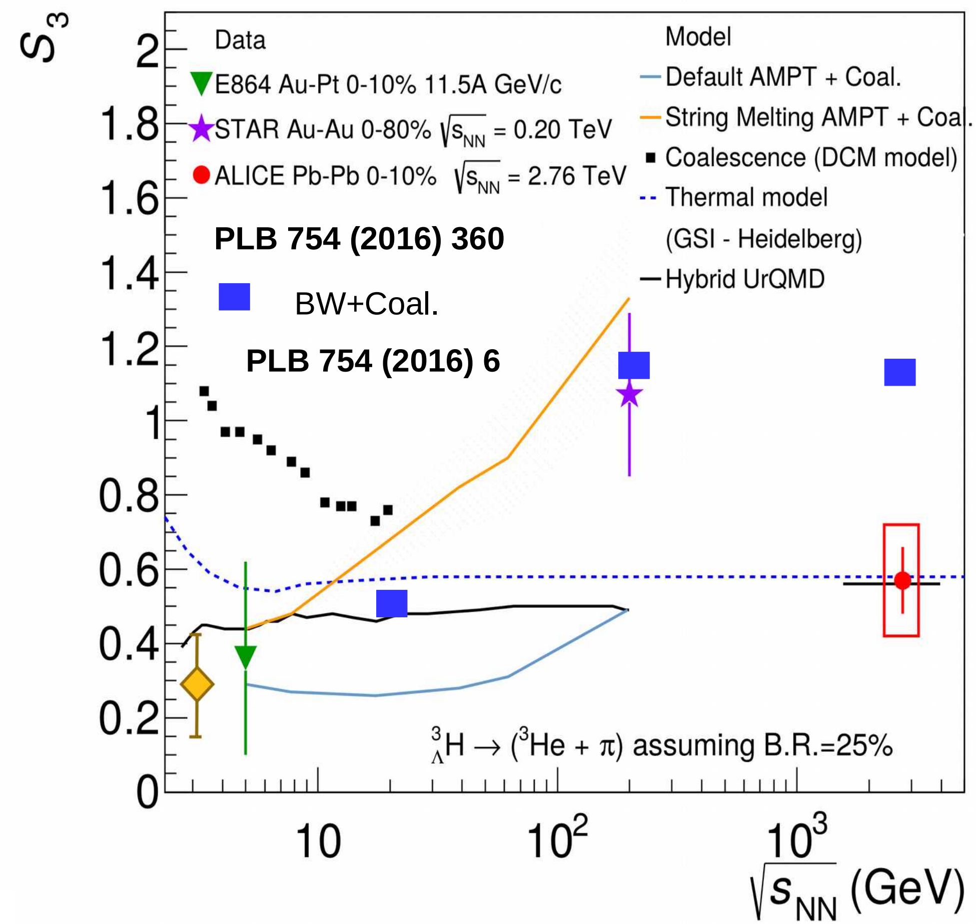
T. Bertrand et al., NPB 16(1970)77

Beam Energy Dependence of S3

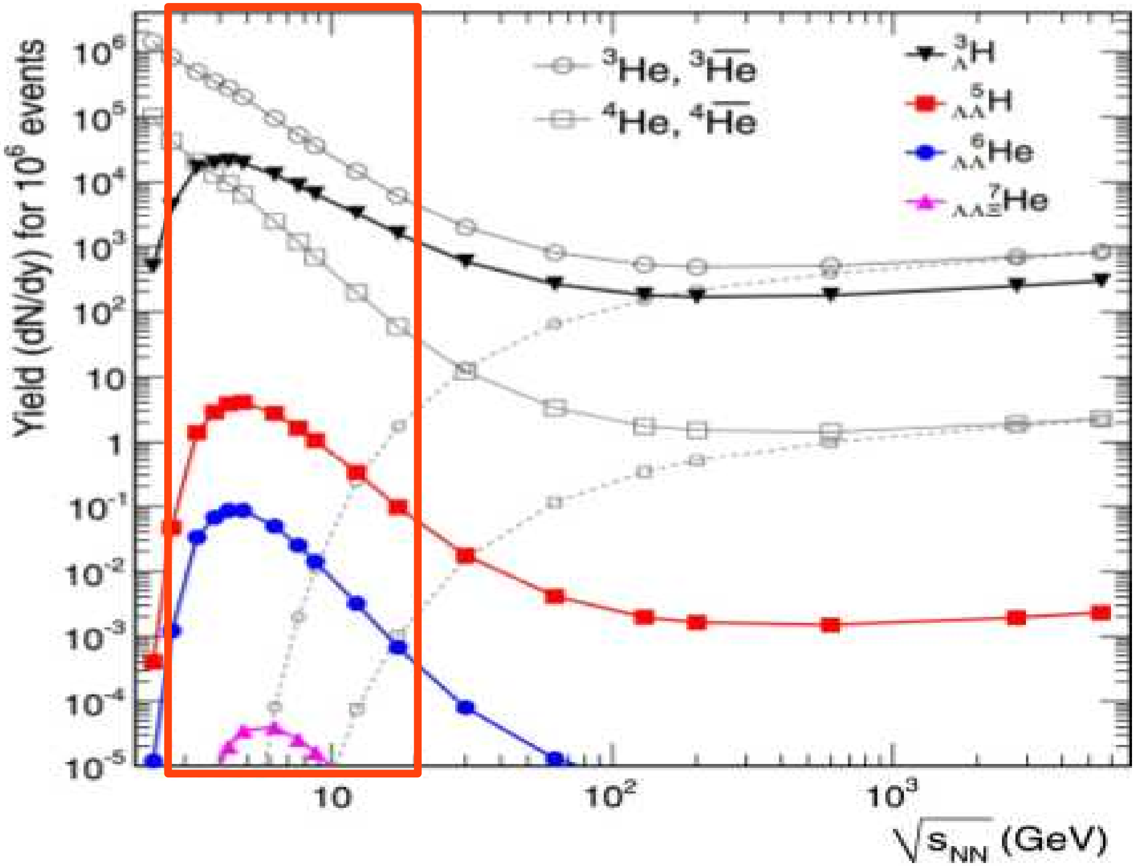
Strangeness population factor:





BES-II and FXT

- The BES-II + FXT energies are optimal for the hyper nuclei production.
- Precise measurement of lifetime and Strangeness Population factor S_3 over range of energies.



A. Andronic et al., Phys. Lett. B 697, 203 (2011)

BES-II and FXT

Expected yield of Hypertriton:

Efficiency (eff) ~ 5% and branching ratio (BR) = 25% for 2-body channel

Energy (GeV)	Total Yield (Y) (1M events)	Y*eff*BR (100M events)
14	332	416
11.5*	510	638
7.7	1064	1330
6.2	1520	1900
4.5	2595	3245
3.0	1195	1493
2.5	174	217

* N. Shah, Y. Ma, J. Chen, S. Zhang, PLB 754 (2016) 6

Summary

- **Measurement of hypertriton lifetime has been an interesting project in the field.**

- **New measurement from HI experiments gives a shorter lifetime than the expected free Lambda lifetime.**

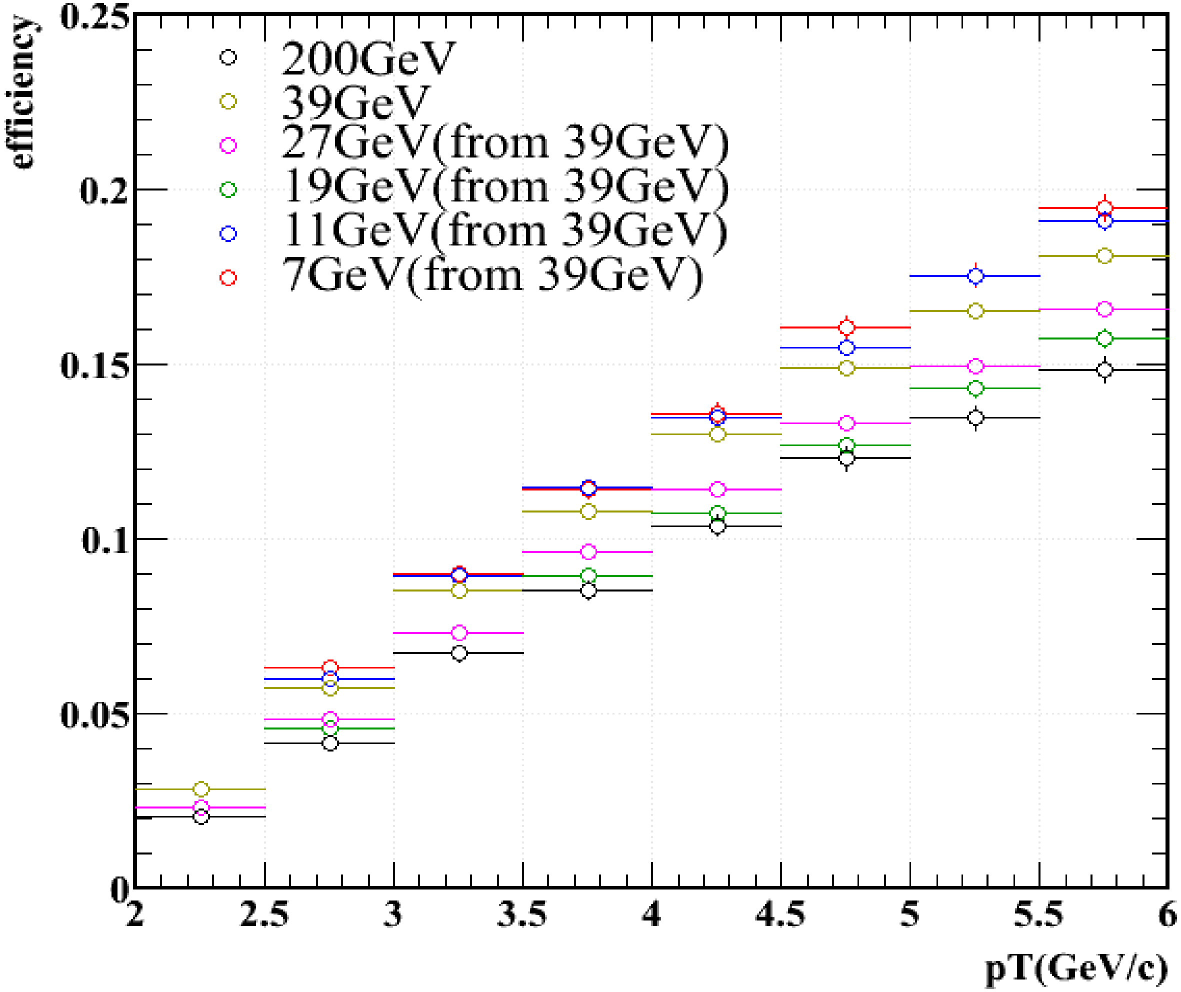
STAR: $\tau = 155^{+25}_{-22}(stat) \pm 29(sys)\ ps$

HypHI: $\tau = 183 \pm^{42}_{32} \pm 37\, ps$

ALICE: $\tau = 181 \pm^{54}_{39} \pm 33\, ps$

- **Precise measurement of hypertriton lifetime from BES-II and FXT will encourage more theorists to work on this puzzle and shed some light on structure of lightest hypernuclei.**

backup


efficiency
0.25
0.2
0.15
0.1
0.05
0
200GeV
39GeV
27GeV(from 39GeV)
19GeV(from 39GeV)
11GeV(from 39GeV)
7GeV(from 39GeV)
2
2.5
3
3.5
4
4.5
5
5.5
6
pT(GeV/c)