Discussion on the hypertriton lifetime measurements

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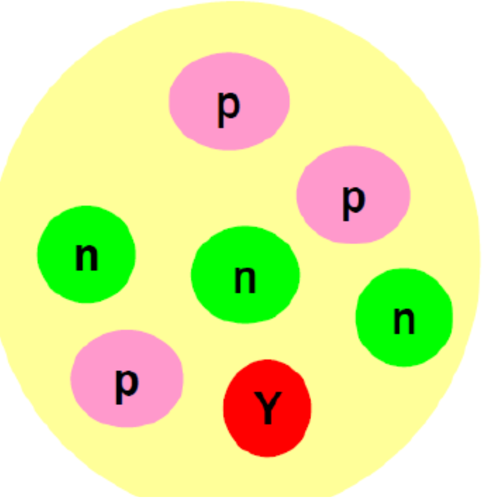
- Why we revisit the lifetime
- New measurement from STAR
  - Signal in separate bins
  - Updated results and world data
  - Discussions
- Conclusion and Outlook

Why hypernuclei?



★ QCD theory development

- Micro-lab. with proton, neutron and hyperons;
- YN & YY interaction (strangeness sector of hadronic EOS)

★ Astrophysics

- Hyperons are important for cosmology, physics of neutron stars…

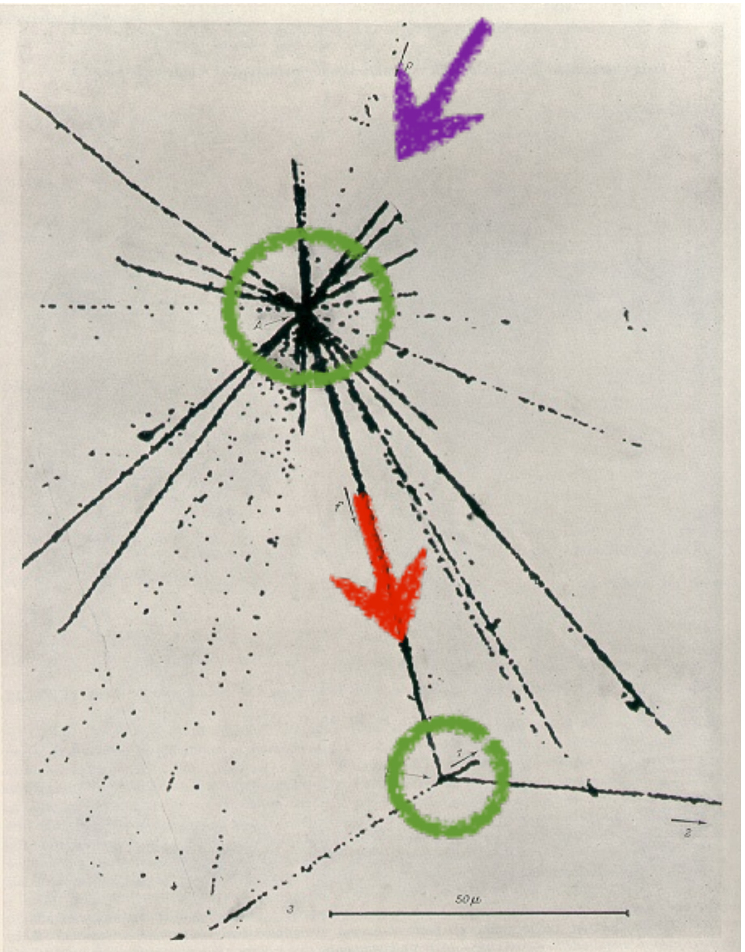
★ Nuclear Physics

- Phenomenology: extension of nuclear charts into strangeness, exotic nuclei…
- Structure theory: nuclear dof for investigating interaction of baryons in nuclei (hyperons – w/o Pauli blocking)
- Reaction theory: new probe for fragmentation of nuclei, phase transition and EOS in hypermatter and finite hypernuclei

The first hypernucleus?

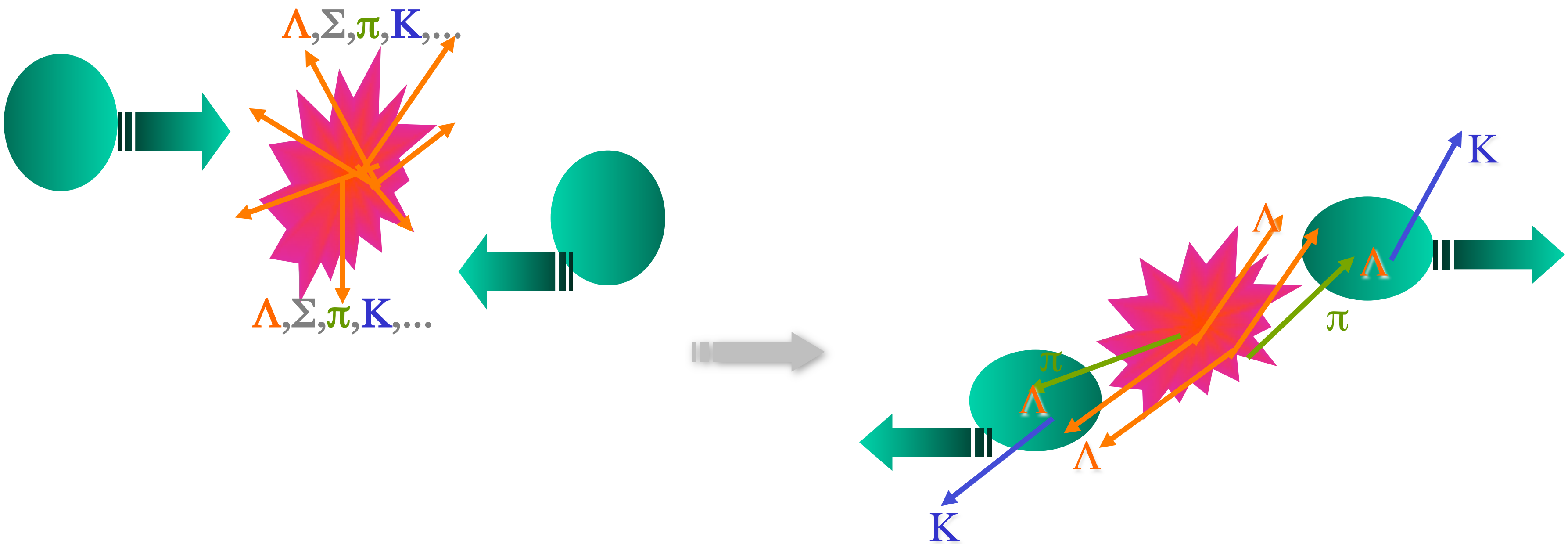
★ The 1st hypernucleus was observed in a stack of photographic emulsions exposed to cosmic rays at about 26 km above the ground.

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



- Incoming high energy proton from cosmic ray, colliding with a nucleus of the emulsion, breaks it in several fragments forming a star.
- All nuclear fragments stop in the emulsion after a short path
- From the 1st star, 21 tracks → 9α + 11H + 1 $_{\Lambda}$X
- The fragment $_{\Lambda}$X disintegrates later, makes the bottom star. Time takes~10^{-12} sec (typical for weak decay)
- This particular nuclear fragment, and the others obtained afterwards in similar conditions, were called hyperfragments or hypernuclei

Hypernuclei production in HI Collisions



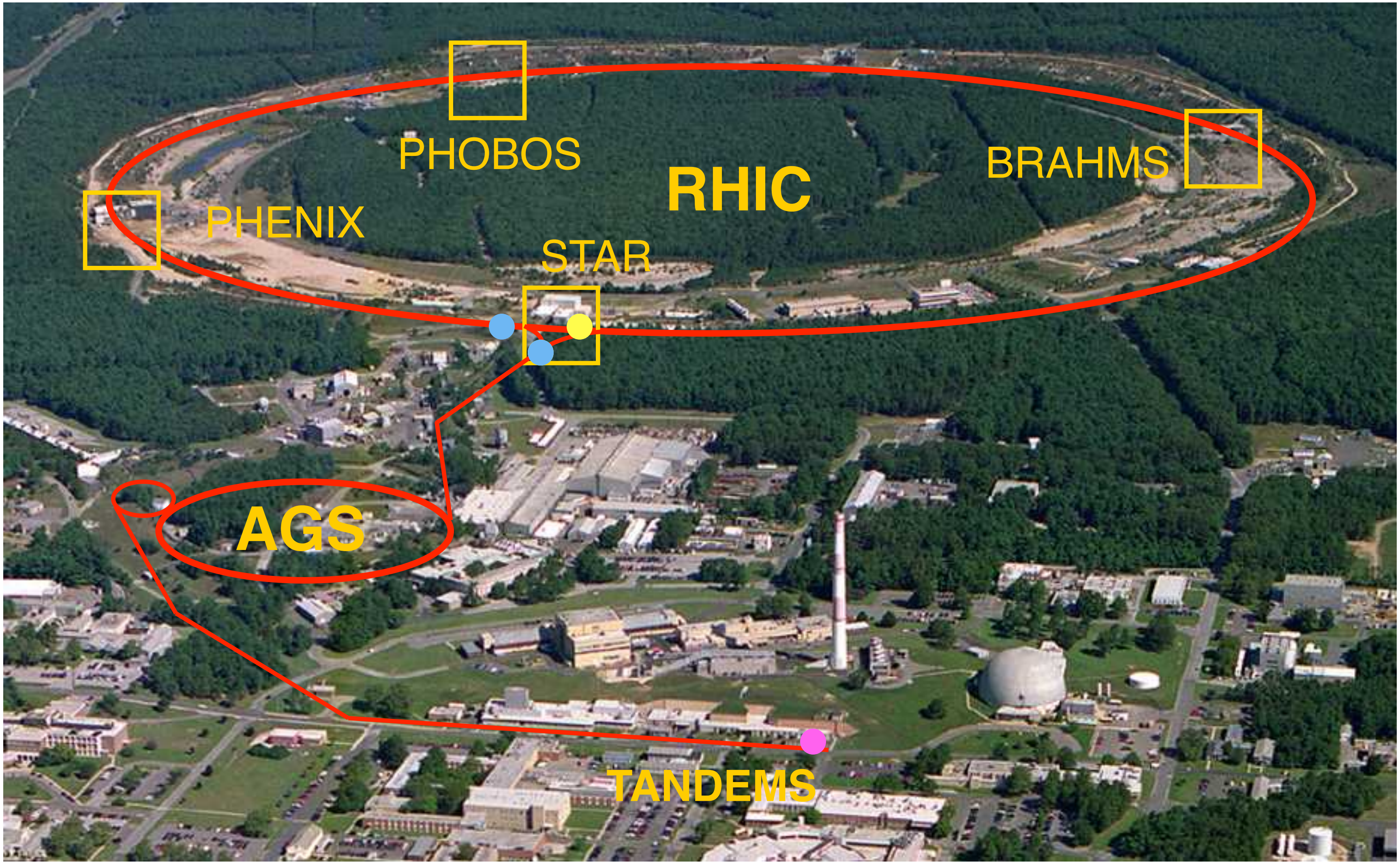
★ Production of hypermatter in relativistic HI and hadron collisions

- Production of strange particles and hyperons by "participants",
- Rescattering and absorption of hyperons by excited "spectators"
- Will focus on the hypertriton in this talk

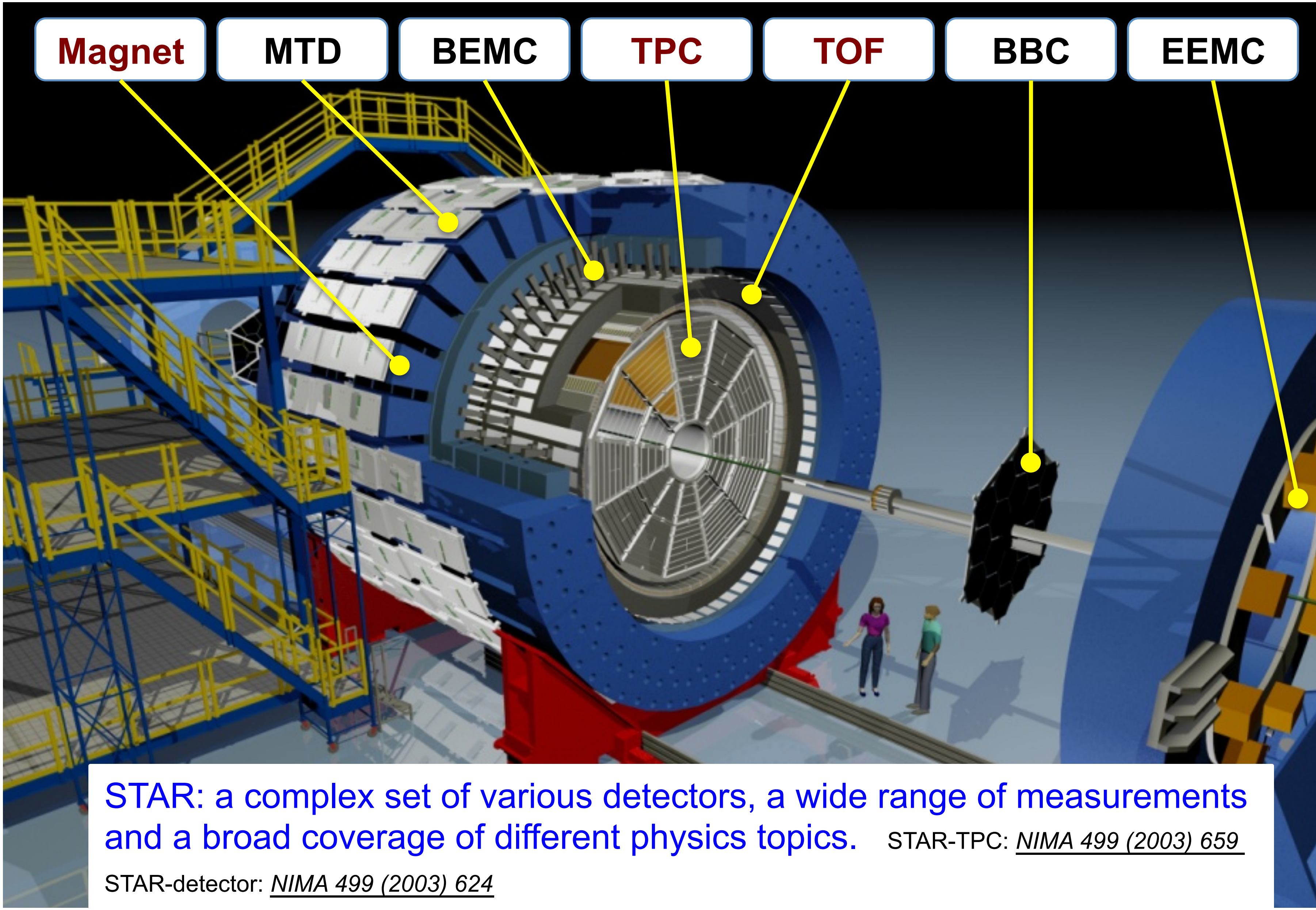
$$ {}^{3}_{\Lambda}H(n+p+\Lambda) $$

$$ {}^{3}_{\bar{\Lambda}}\overline{H}(\bar{n}+\bar{p}+\bar{\Lambda}) $$

Relativistic Heavy Ion Collider (RHIC)



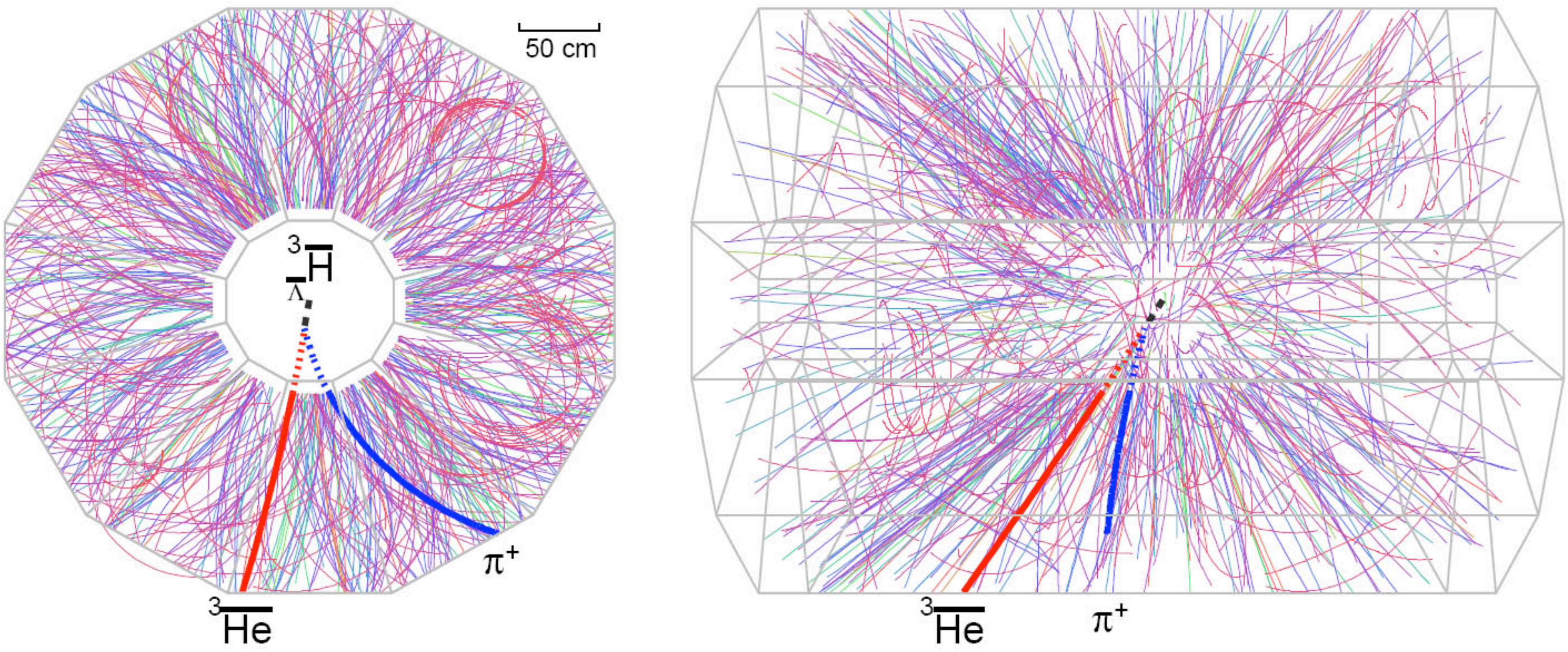
The STAR detector



STAR: a complex set of various detectors, a wide range of measurements and a broad coverage of different physics topics. STAR-TPC: *NIMA 499 (2003) 659*

STAR-detector: *NIMA 499 (2003) 624*

Event display



★ A beautiful event in the STAR TPC that includes the production and decay of a antihypertriton candidate. (Data taken from Run4 Au+Au 200GeV MB collision)

The mesonic decay of hypertriton

Kamada et al., PRC 57, 1595(1998)

TABLE I. Partial and total mesonic and nonmesonic decay rates and corresponding lifetimes.

Channel	Γ [sec^{-1}]	Γ/Γ_Λ	$\tau=\Gamma^{-1}$ [sec]
^{3}He $+\pi^-$ and ^{3}H $+\pi^0$	0.146×10^{10}	0.384	0.684×10^{-9}
$d+p+\pi^-$ and $d+n+\pi^0$	0.235×10^{10}	0.619	0.425×10^{-9}
$p+p+n+\pi^-$ and $p+n+n+\pi^0$	0.368×10^{8}	0.0097	0.271×10^{-7}
All mesonic channels	0.385×10^{10}	1.01	0.260×10^{-9}
$d+n$	0.67×10^{7}	0.0018	0.15×10^{-6}
$p+n+n$	0.57×10^{8}	0.015	0.18×10^{-7}
All nonmesonic channels	0.64×10^{8}	0.017	0.16×10^{-7}
All channels	0.391×10^{10}	1.03	2.56×10^{-10}
Expt. [6]			$2.64\ +0.92\ -0.54\times10^{-10}$
Expt. (averaged) [11]			$2.44\ +0.26\ -0.22\times10^{-10}$

$$\frac{1}{\tau}=\sum_i\frac{1}{\tau_i}$$

- Though the mesonic decays are Pauli blocked in heavier hypernuclei, they are the dominant channels in hypertriton.
- In experiment, the 2-body helium3 channel and the 3-body deuteron channel are more easy to access.

Focus on the hypertriton lifetime (1)

☆ The lifetime measurements are interest especially in view of the short values from early experiments :

The 1st measurements is $(0.95^{+0.19}_{-0.15})*10^{-10}$s from helium bubble chamber, by Block et al., presented in the proceeding of Conference on Hyperfragments at St, Cergue, 1963, p.62

Results from AGS nuclear-emulsion experiments: $(0.9^{+2.2}_{-0.4})*10^{-10}$s,
Phys. Rev.136 (1964) B1803,
from Bevatron and AGS: Phys. Rev.139 (1965) B401
2-body (3 in flight, 4 at rest) $(0.8^{+1.9}_{-0.3})*10^{-10}$s
2-body combined with 3-body (5 in flight, 18 at rest) $(3.4^{+8.2}_{-1.4})*10^{-10}$s

☆ Nuclear-emulsion with maximum likelihood procedure, Nucl. Phys. B 16 (1970) 46, $(1.28^{+0.35}_{-0.26})*10^{-10}$s,

Focus on the hypertriton lifetime (2)

- But NEW measurements gave different values:

  Helium bubble chamber from Argonne ZGS:

  $(2.32^{+0.45}_{-0.34})*10^{-10}$s, PRL 20(1968)819
  $(2.64^{+0.84}_{-0.52})*10^{-10}$s, PRD 1(1970)66
  $(2.46^{+0.62}_{-0.41})*10^{-10}$s, NPB 67(1973)269

  Nuclear-emulsion from Bevatron:

  2-body is $(2.00^{+1.10}_{-0.64})*10^{-10}$s and 3-body $(3.84^{+2.40}_{-1.32})*10^{-10}$s, and a combined of $(2.74^{+1.10}_{-0.72})*10^{-10}$s
  PRL20(1968)1383

- How about the theoretical understanding of these experimental results?

Focus on the hypertriton lifetime (3)

- The hypertriton being a loosely-bound nuclear system, its mean lifetime should not be significantly different from that of the free Lambda

  Theoretical calculations from Dalitz et al., initially gave a short value and updated later on a larger value close to the free Lambda's
  Phys. Lett. 1 (1962) 58 and Nuovo Cimento A 46,786 (1986)

  The calculations based on modern 3-body interaction force, the total lifetime is predicted to be $2.56*10^{-10}$s, Phys. Rev. C 57 (1998) 1595

- The hypertriton lifetime data are not sufficiently accurate to distinguish between model, more precise measurements are needed.

Results from RHIC-STAR Col.

- Previous measurement (before 1973)
  Use nuclear emulsion or bubble chamber
  Accepted events: less than 80

- STAR 2010 measurement

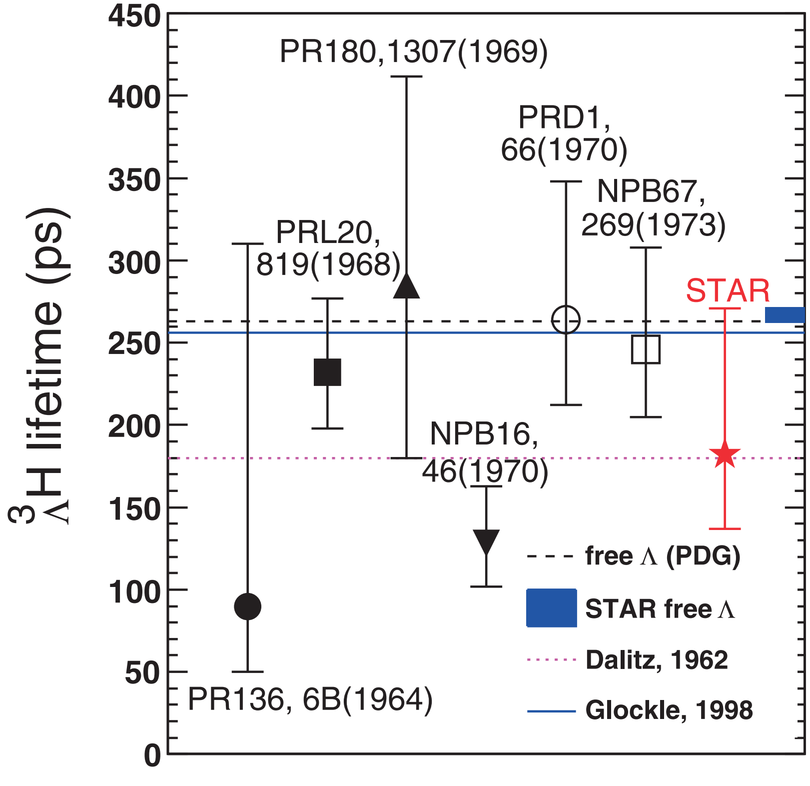
Run4 200GeV	MB	22M
Run4 200GeV	Central	23M
Run7 200GeV	MB	68M

- STAR 2012 measurement

Run10 200GeV	MB	~223M
Run10 200GeV	Central	~199M
Run10&11 low energies	MB	~213M

Previous measurement

STAR Collaboration, Science 328 (2010)58



World data

- It is promising to obtain an improved lifetime measurement using the new data

Datasets and track selection

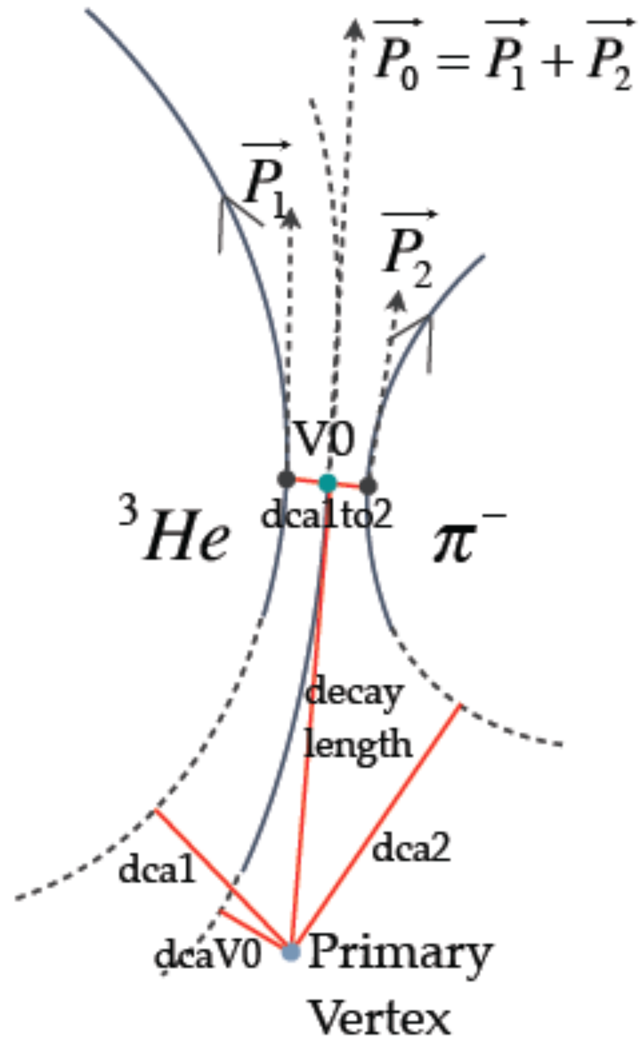
★ Datasets and event statistics

Run10 7.7GeV	MB	~4M
Run10 11.5GeV	MB	~11M
Run11 19.6GeV	MB	~31M
Run11 27GeV	MB	~49M
Run10 39GeV	MB	~118M
Run10 200GeV	MB	~223M
Run10 200GeV	Central	~199M
Run7 200GeV	MB	~56M

★ Analysis method: secondary vertex finding technique

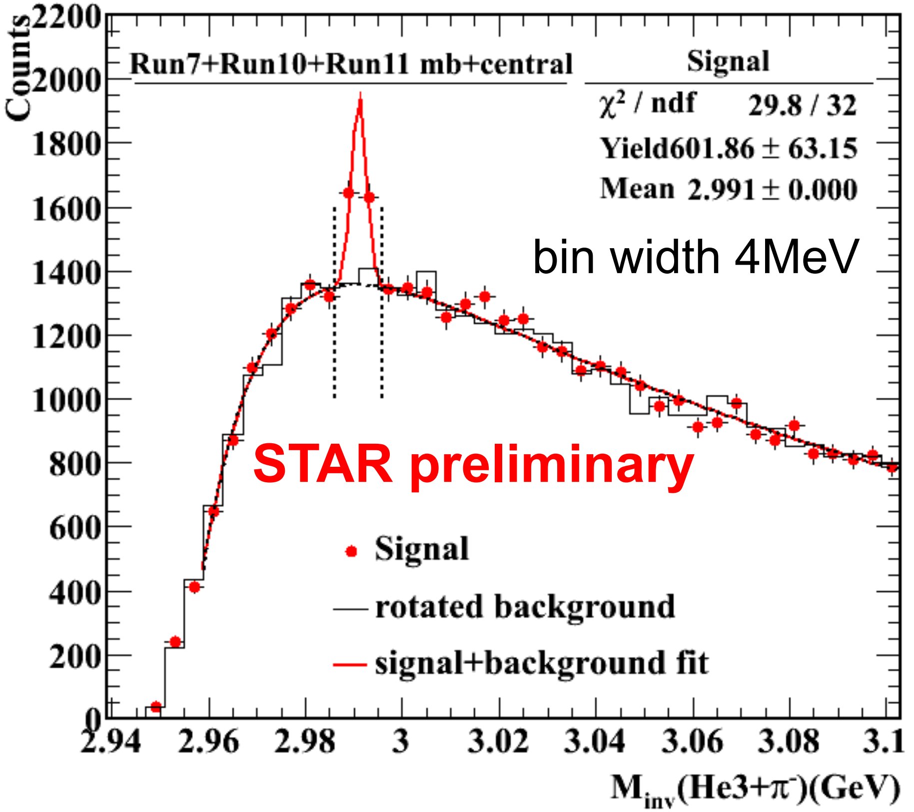
- Identify ^{3}He and π candidate
- Find the V0 position from daughters pairing
- Plot the invariant mass dis. of daughters
- Combinatorial background analysis

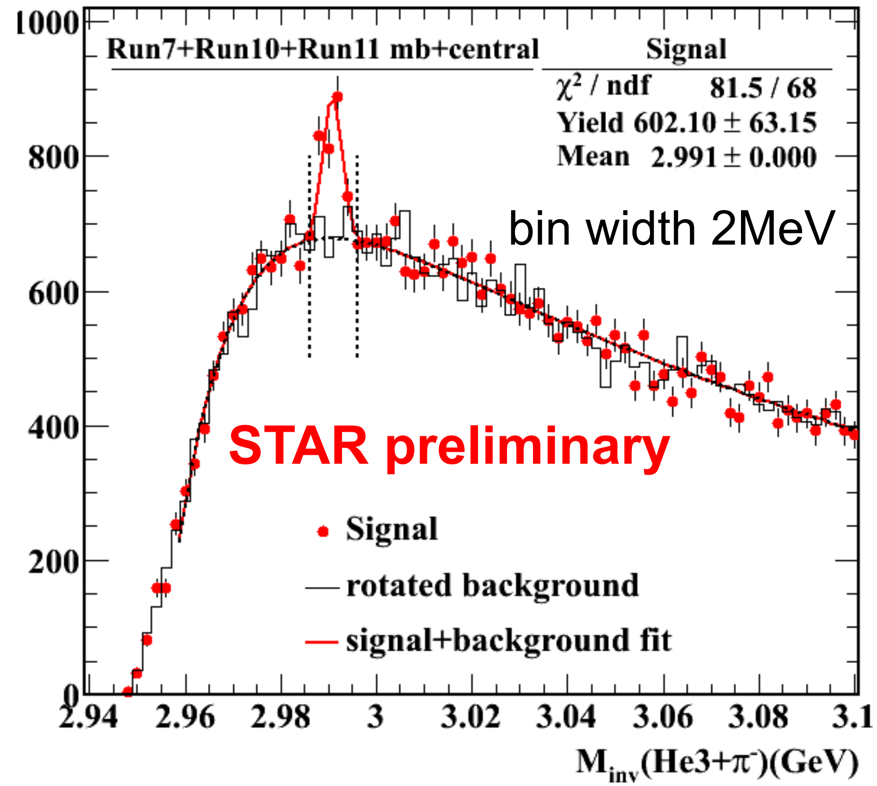
$$^3_\Lambda H \rightarrow {}^3He + \pi^-$$



The largest hypertriton sample

- Statistics: Run7+Run10+Run11 MB+Central, ~610M events

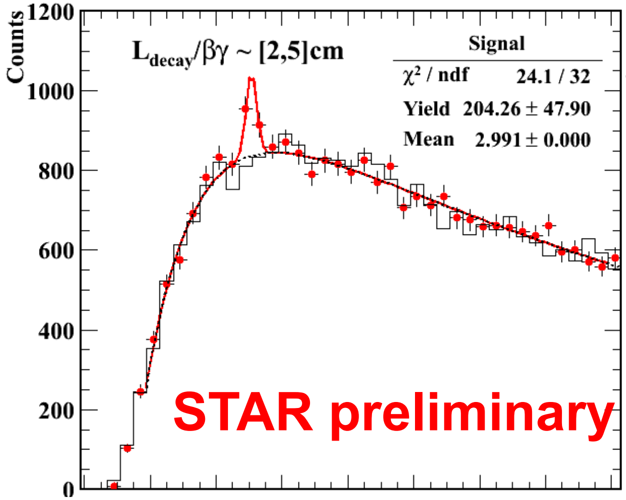


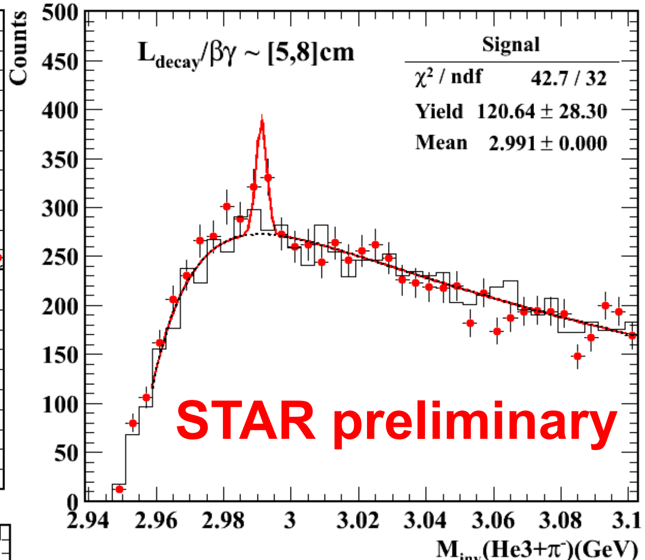


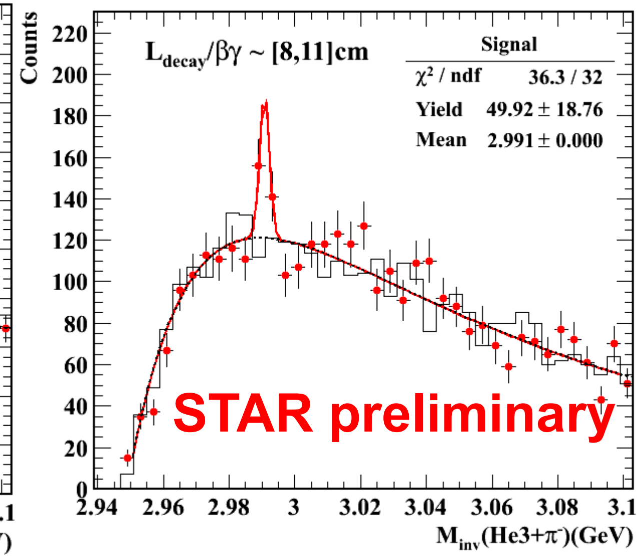
- Signal observed from the data (bin-by-bin counting [2.986,2.996]GeV): **602±63**, the largest hypertriton sample ever created
- Background estimation: rotated background

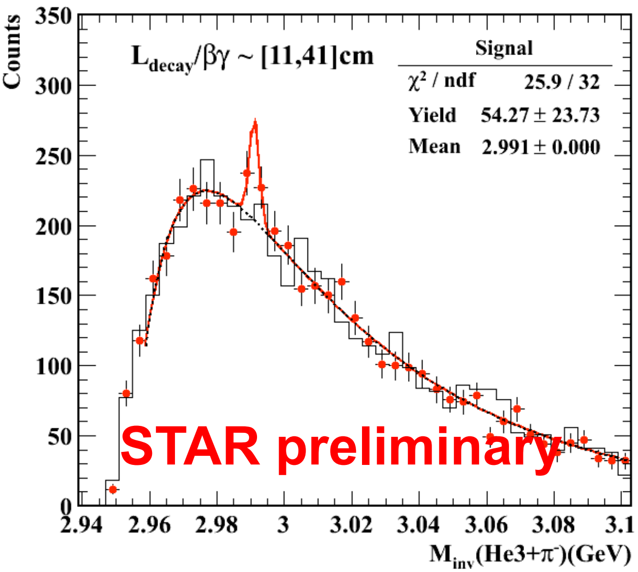
Signal in separate bins

★ $$N(t) = N(0) \times e^{-t/\tau} = N(0) \times e^{-L/\beta\gamma c\tau}$$









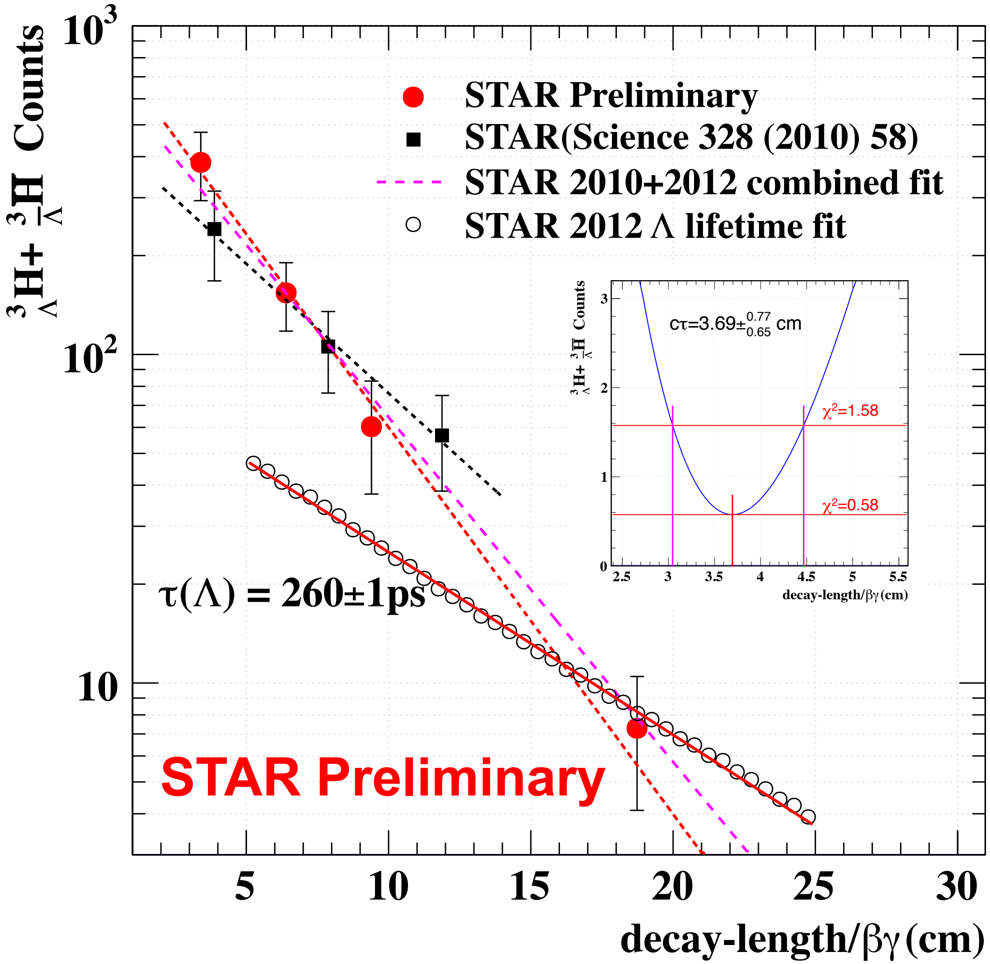
★ Measure the hypertriton signal in different L/βγ bins: 2-5-8-11-41cm

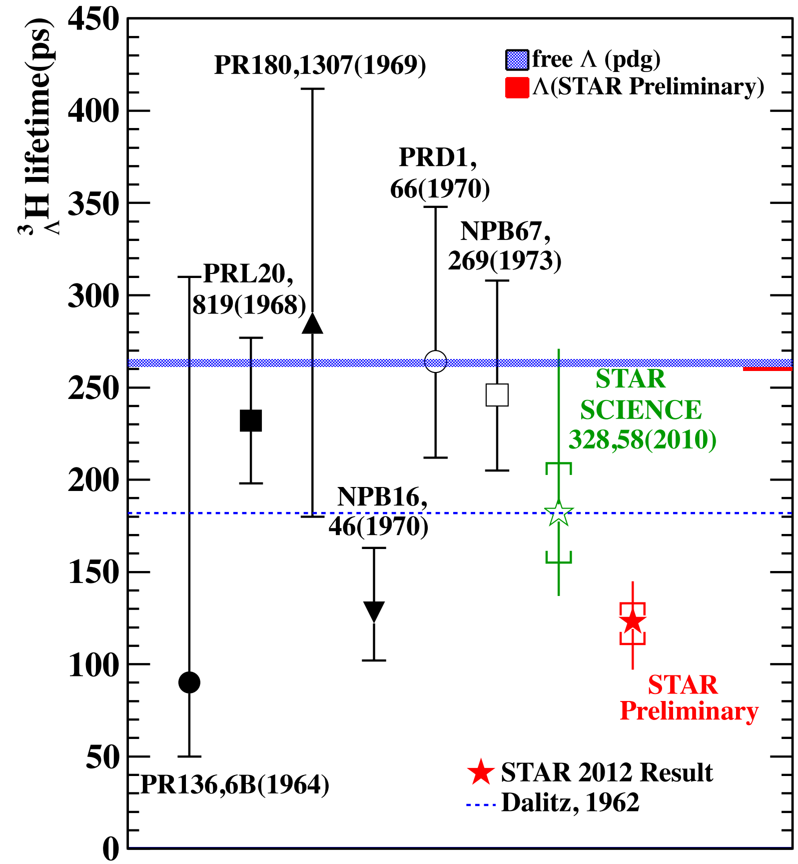
★ Combined datasets: run10 7.7,11.5,39,200GeV MB,

run10 200GeV central,

run11 19.6, 27GeV MB

New hypertriton lifetime result

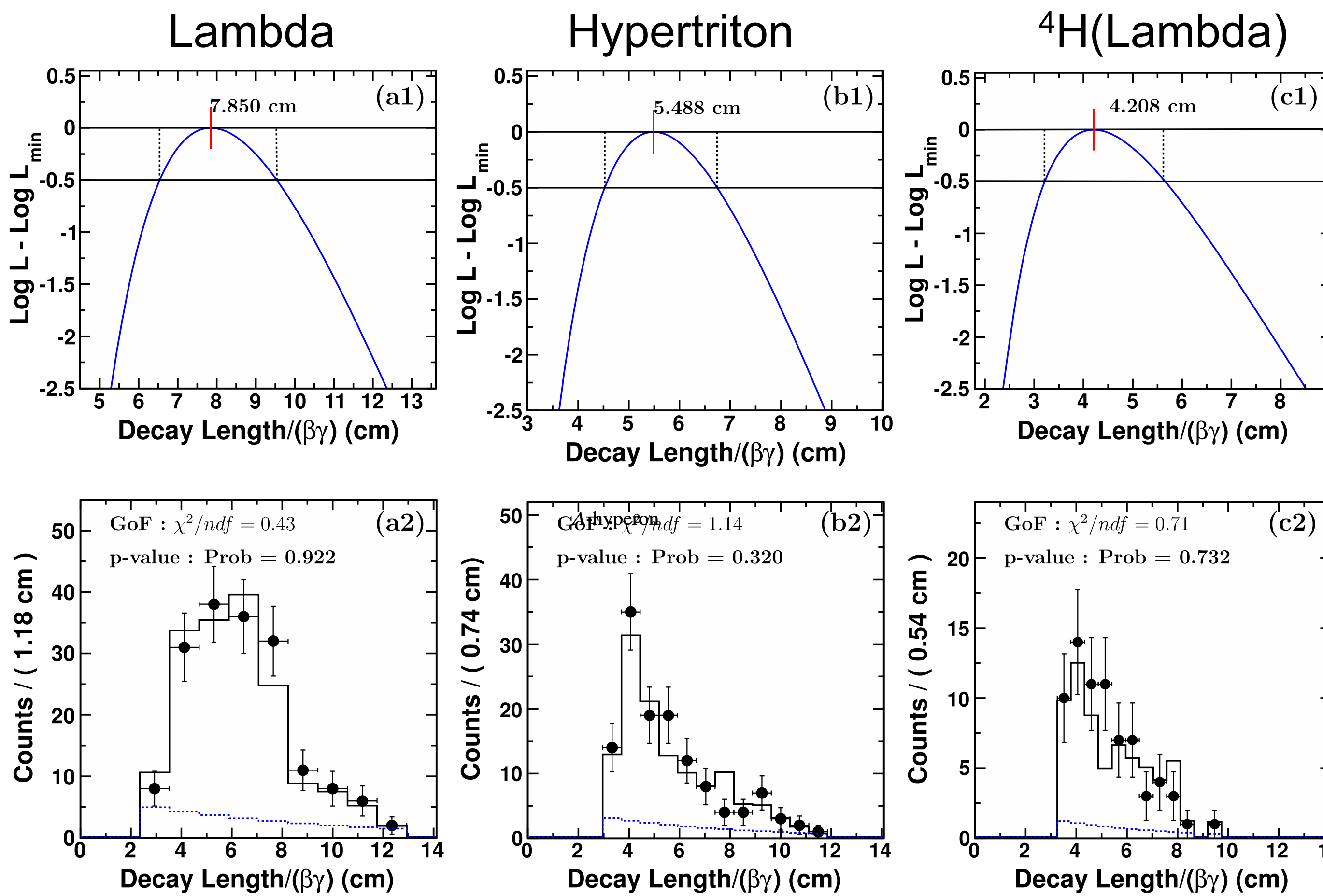




Y.H. Zhu for STAR Col., QM2012, USA
J.H. Chen for STAR Col., HYP2012, Spain

- STAR 2012 preliminary result: $\tau = 123 \pm^{26}_{22} \pm 10\, ps$
- STAR 2010+2012 combined fit: $\tau = 138 \pm^{23}_{20}\, ps$

Measurement from HpyHI project

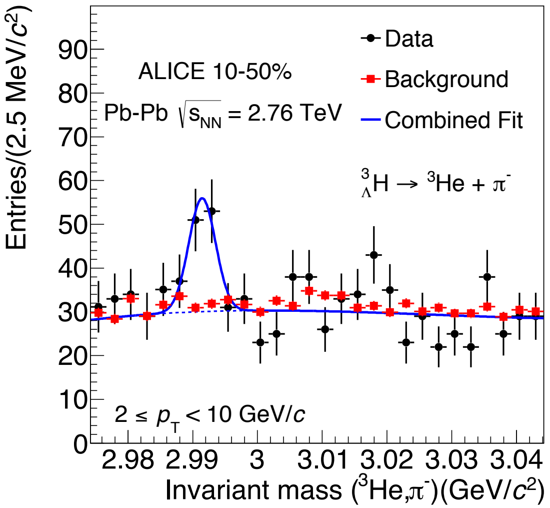


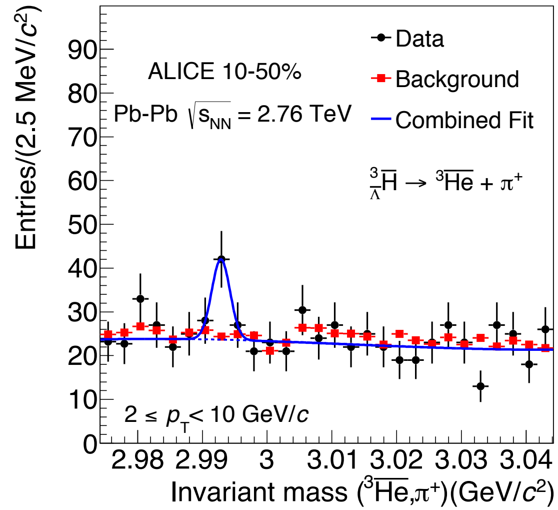
★ Hypernuclear spectroscopy at GSI: ^{6}Li projectiles on ^{12}C target at 2 A GeV presents the hypertriton lifetime measurement from 2-body channel:

Nucl. Phys. A 913(2013)170

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

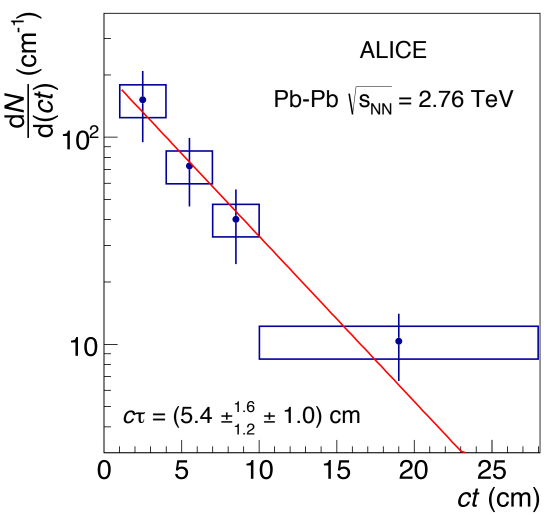
Measurement from LHC-ALICE

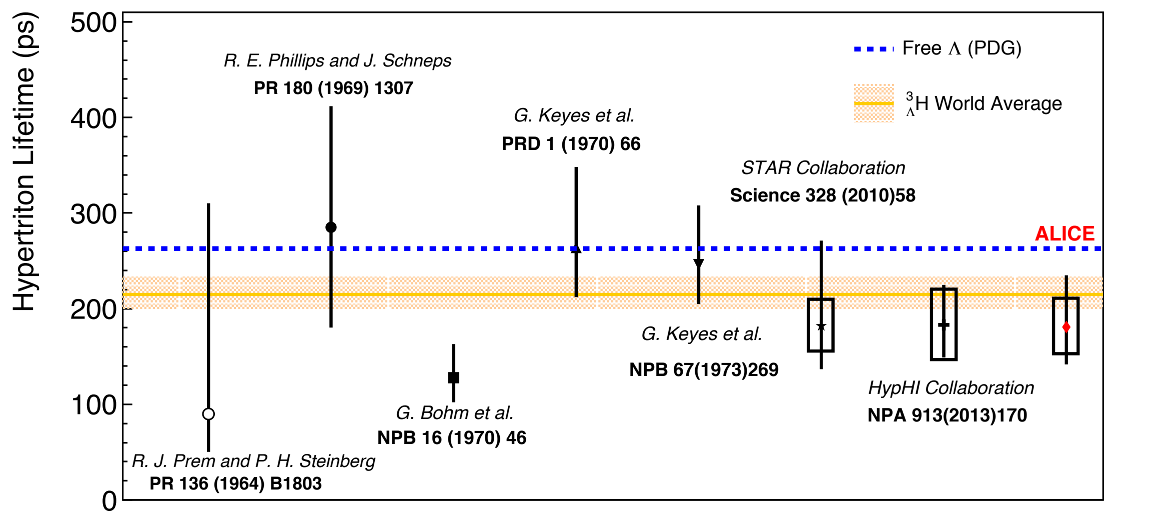




ALICE Collaboration
arXiv:1506.08453

$$\tau = 181^{+54}_{-39}(\text{stat.}) \pm 33(\text{syst.})$$





The physics for a short lifetime?

★ Revisit the previous theoretical calculation:

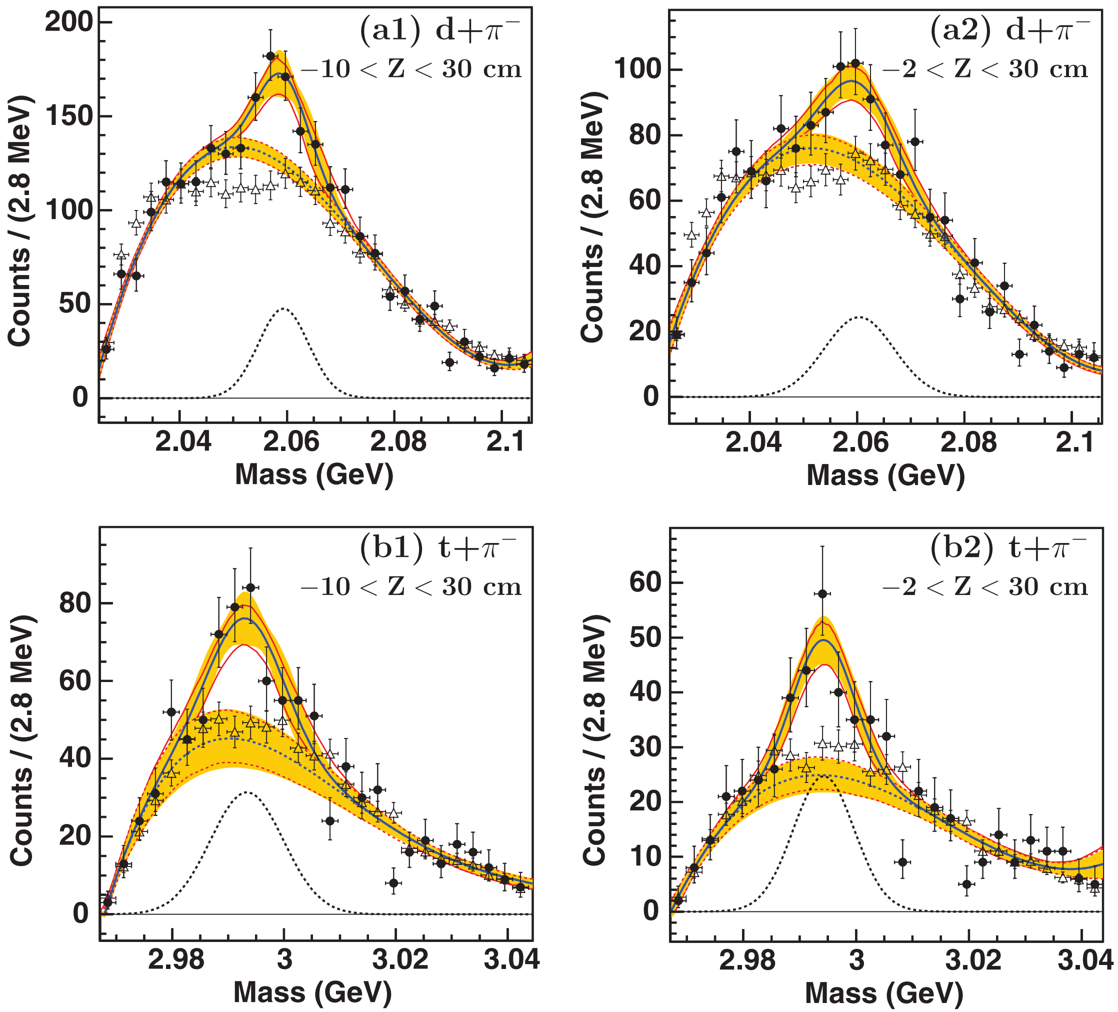
A statistical combination analysis of the experimental lifetime data give average of 216^{+19}_{-18} ps for hypertriton, indicated that the lifetime of light hypernuclei can be shorter than the free Lambda's

Rappold, Saito et al., PLB 728 (2013) 543

★ Revisit binding energy (130 ± 50 kev), STAR exp. 3-body analysis have significant progress.

★ Physics implication:

(nnΛ) signal in HI reaction?



HypHI exp. observed a signal in the invariant mass distribution of d+pi and t+pi channel.

PRC 88,041001R(2013)

Data from HIRES Col. Excluded the (Lp) candidates

PLB 687, 31(2010)
PRD 84, 032002(2011)

A possible interpretation might be the two- and three-body decays of an unknown bound state of 2 neutrons associated with a Lambda:

via ${}^{3}_{\Lambda}n \to t + \pi^{-}$ and ${}^{3}_{\Lambda}n \to t^{*} + \pi^{-} \to d + n + \pi^{-}$,

Concluding remarks

- Measurements of hypertriton lifetime have be interesting project in the field. Independent exp. present different results.

- Several theoretical interpretations have achieved in the field and tent to conclude a value close to the free Lambda's

- New and precise measurements (>600 signals) from STAR Col. in the Relativistic Heavy-Ion Collider give a short value:

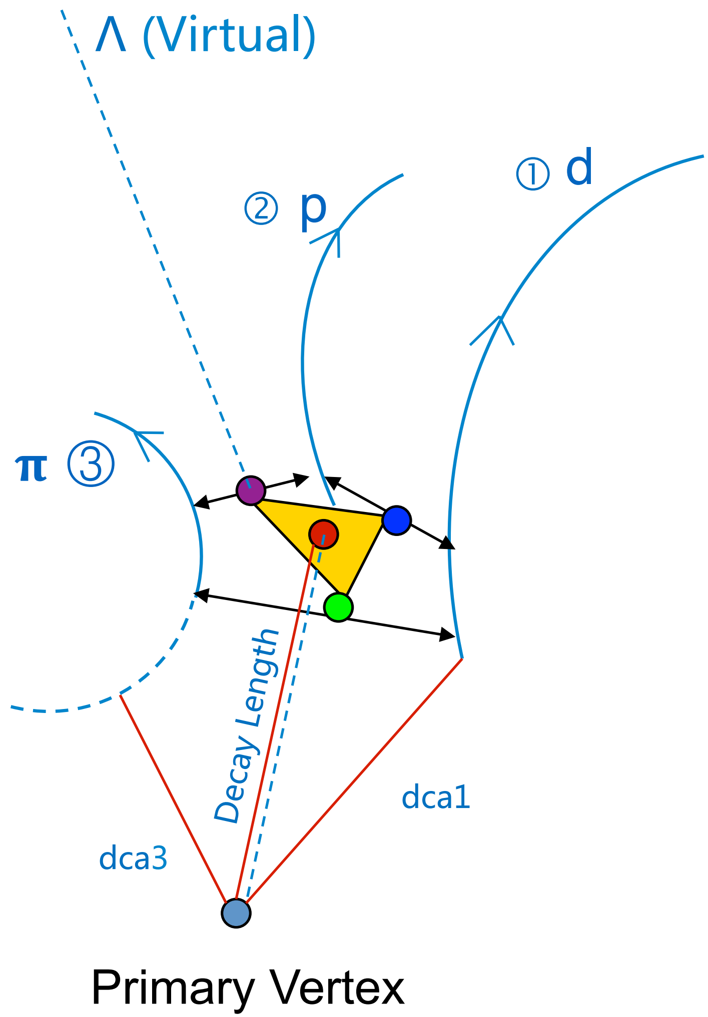
$$\tau = 123 \pm^{26}_{22} \pm 10\, ps$$

- Data from HypHI from GSI fixed target exp. and from LHC-ALICE exp. show the short lifetime value:

$$\tau = 183 \pm^{42}_{32} \pm 37\, ps \qquad \tau = 181 \pm^{54}_{39} \pm 33\, ps$$

- The discrepancy among different exp. is still there, the hypertriton lifetime is still a puzzle. New measurements from STAR Col. should shed new light on the puzzle.

Outlook



$$ {}^{3}_{\Lambda}H \rightarrow d + p + \pi^{-} $$

- v012 : Mid-point of DCA 1 to 2
- v012 : Mid-point of DCA 1 to 3
- v012 : Mid-point of DCA 2 to 3
- v0123 : Centre of gravity of the triangle

I. Yifei Xu (SINAP/BNL) : ongoing effort of reconstructing hypertriton via 3-body decay, lifetime, branching ratio etc.

II. Topical sessions on "Hypertriton lifetime" will be held during the 12th HYP (Sep. 7th -12th, 2015, Tohoku Uni. Japan)