$^{3}_{\Lambda}\mathrm{H}$ and $^{4}_{\Lambda}\mathrm{H}$ Lifetime Measurements in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 3$ GeV with the STAR detector

2020 Fall Meeting of the APS Division of Nuclear Physics

Session RB: The Chiral Magnetic Effect and Strangeness

Virtual meeting ~~Hyatt Regency Hotel in New Orleans, LA~~

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- Lawrence Berkeley National Laboratory

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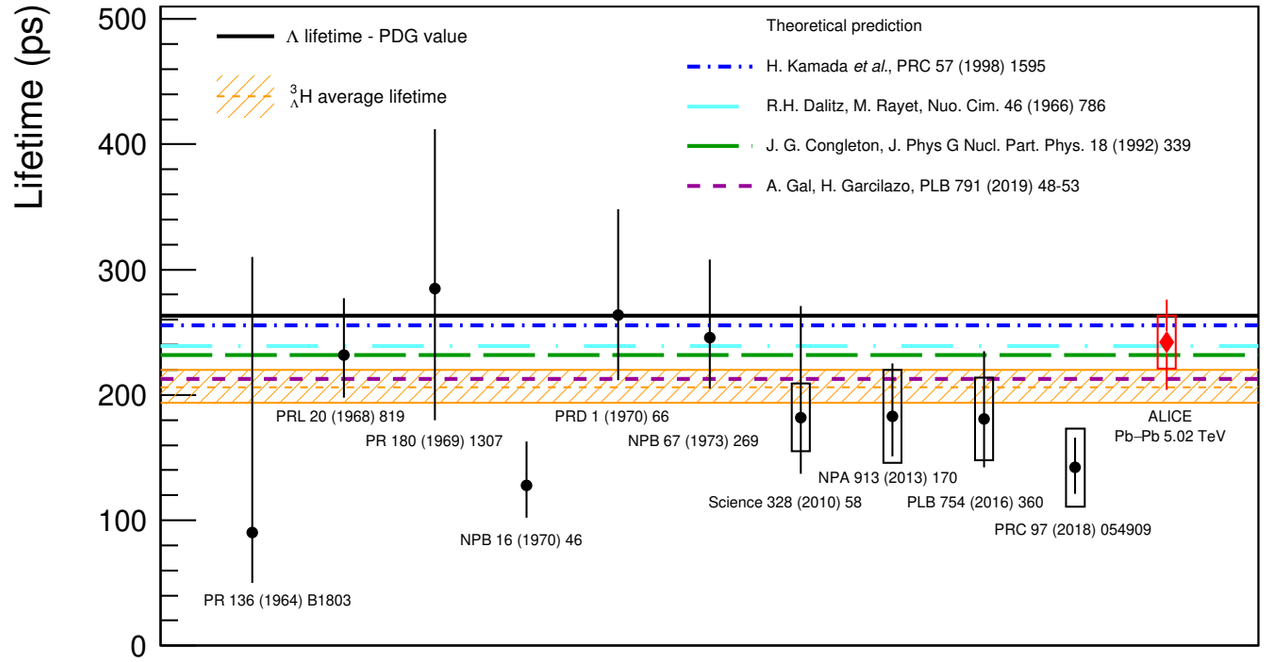
Introduction (Physics motivation)

- Hypernuclei can serve as an experimental probe to study the hyperon-nucleon (YN) interaction
    - Modelling the EOS of astrophysical objects like neutron stars
    - Precise measurements of hypernuclei lifetime, branching ratios, and binding energy provide key information to understand the YN potential

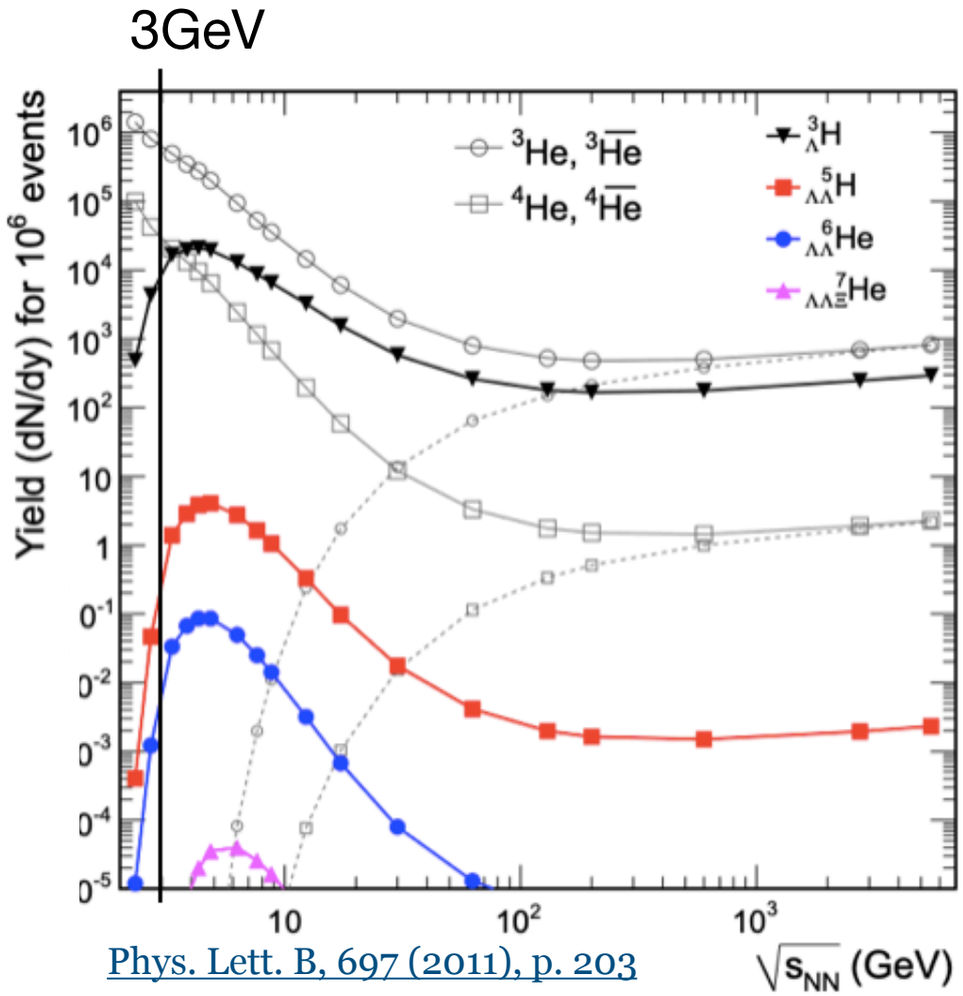
- ${}^{3}_{\Lambda}\mathrm{H}$ (Λpn) is the lightest hypernuclei
    - Binding energy~0.4MeV
    - Theory predicts lifetime close to the free lambda lifetime



Phys.Lett. B797 (2019) 134905

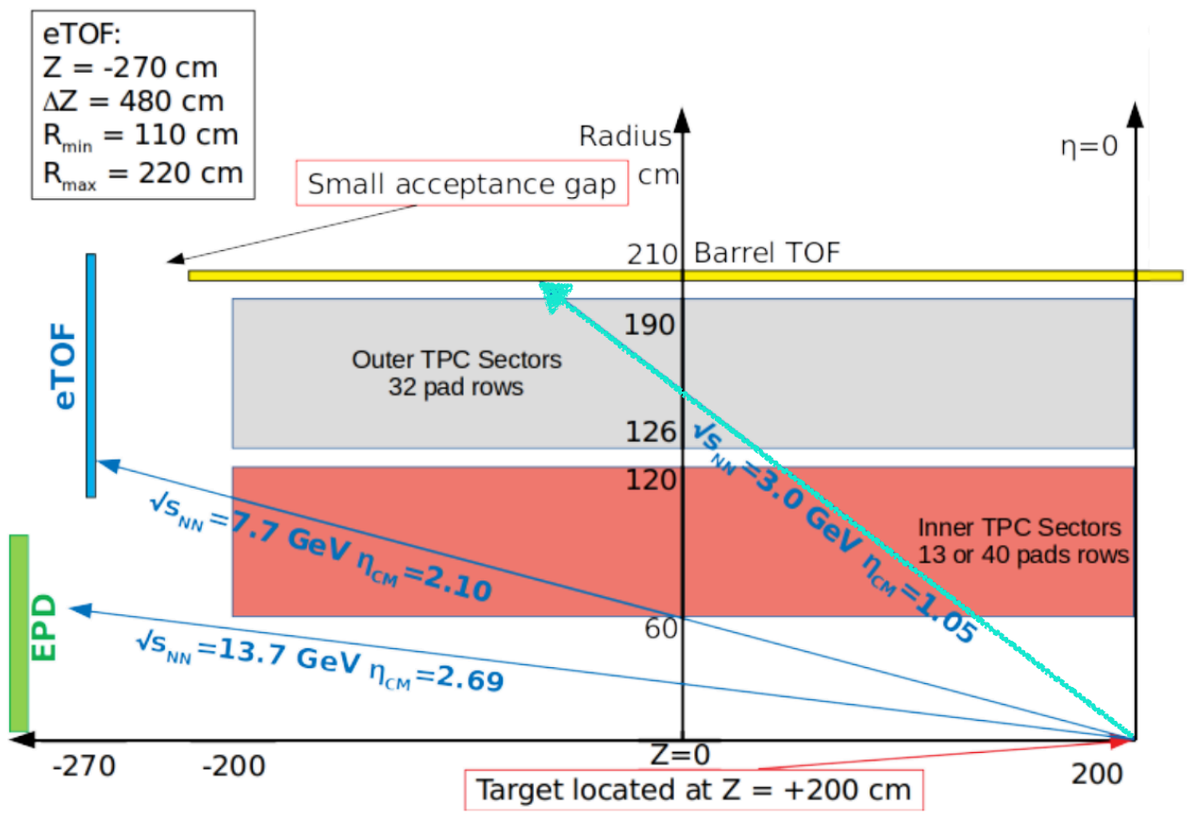
Introduction (STAR BES-II)

- Hypernuclei abundantly produced at low beam energies.
    - Baryon density increases as beam energy decreases



Phys. Lett. B, 697 (2011), p. 203

- ~250M events taken at $\sqrt{s_{NN}} = 3.0\text{GeV}$ with STAR fixed target mode



courtesy of Benjamin Kimelman

Analysis outline

- 1. Measure the signal counts as a function of $L/\beta\gamma$

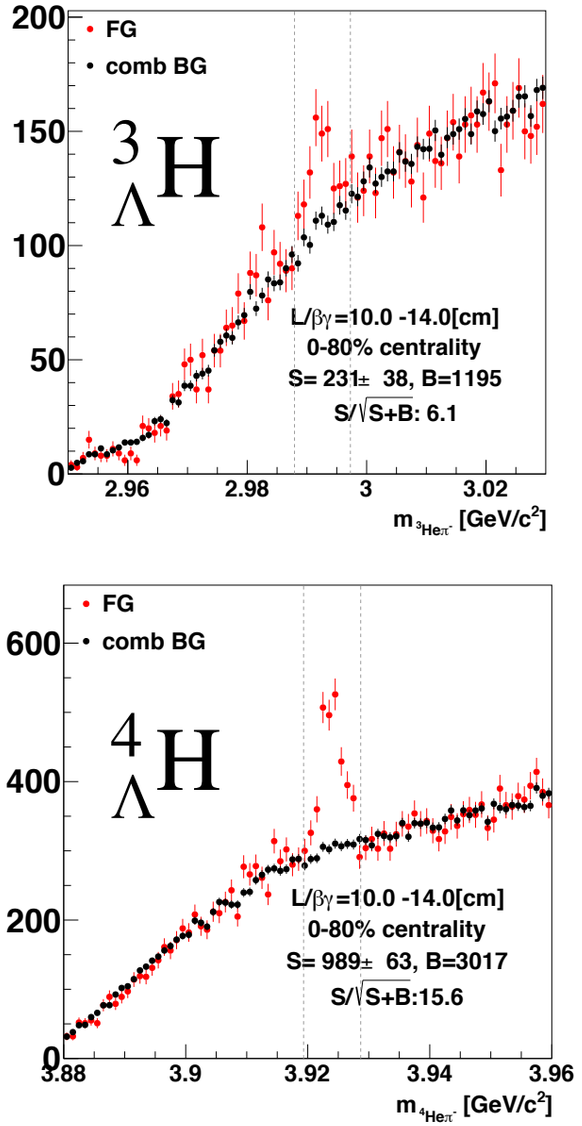
$$L/\beta\gamma = ct$$

L : decay length

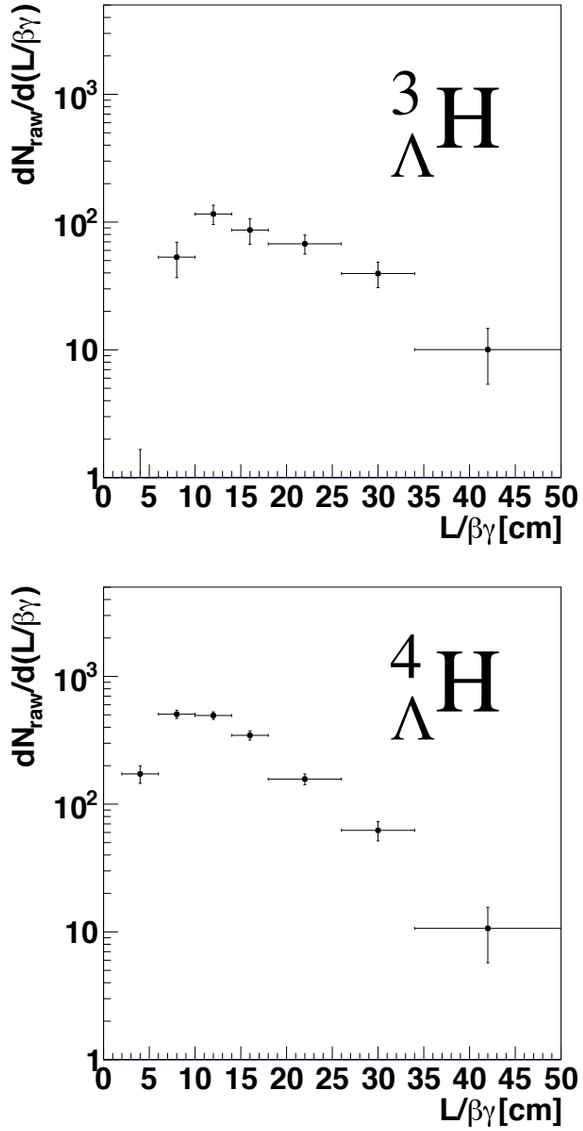
t : proper time

  - 2-body decay channel

$$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$$
$$^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$$



$He-\pi^-$ invariant mass distribution in one $L/\beta\gamma$ bin

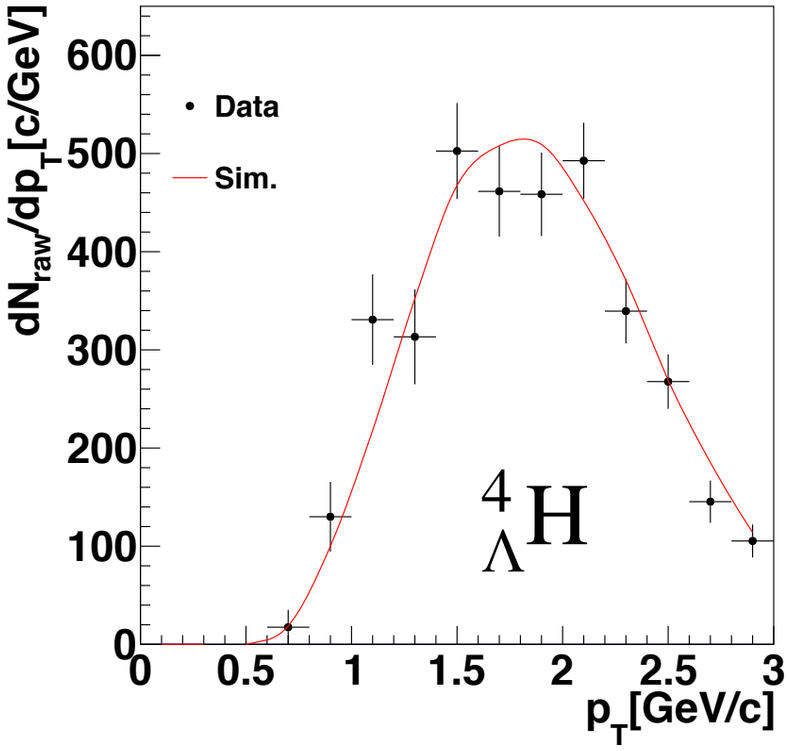


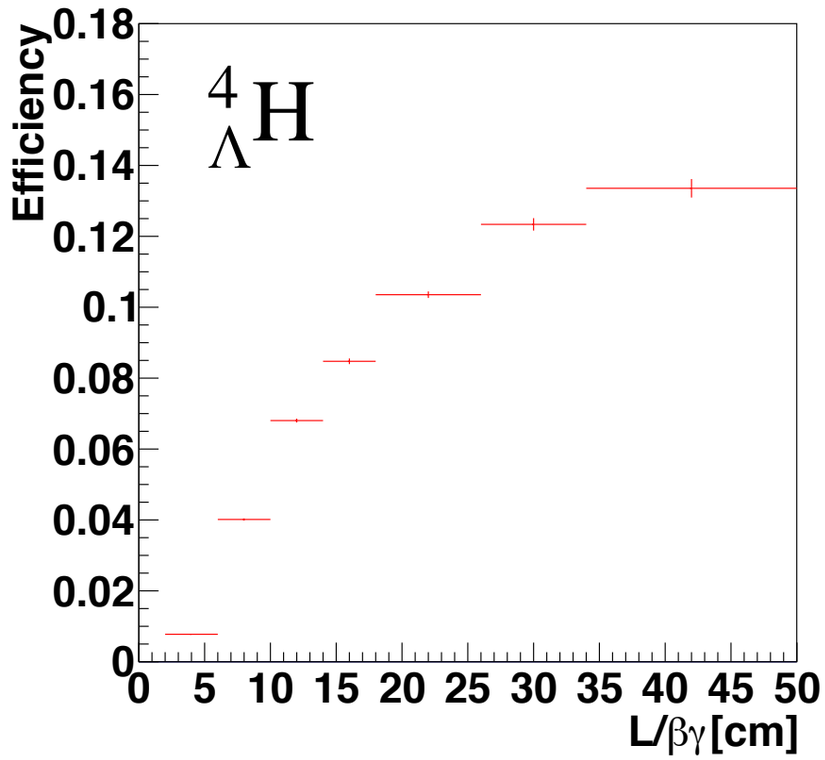
Raw signal counts as a function of $L/\beta\gamma$

	Signal counts (S)	Significance (S/S+B)
$^{3}_{\Lambda}\mathrm{H}$	982	11.0
$^{4}_{\Lambda}\mathrm{H}$	3962	27.2

Analysis outline (cont.)

- 2. Correct for efficiency as a function of $L/\beta\gamma$
  - From GEANT4 simulations
  - Apply weighting to simulations to describe p_T and rapidity distributions in real data



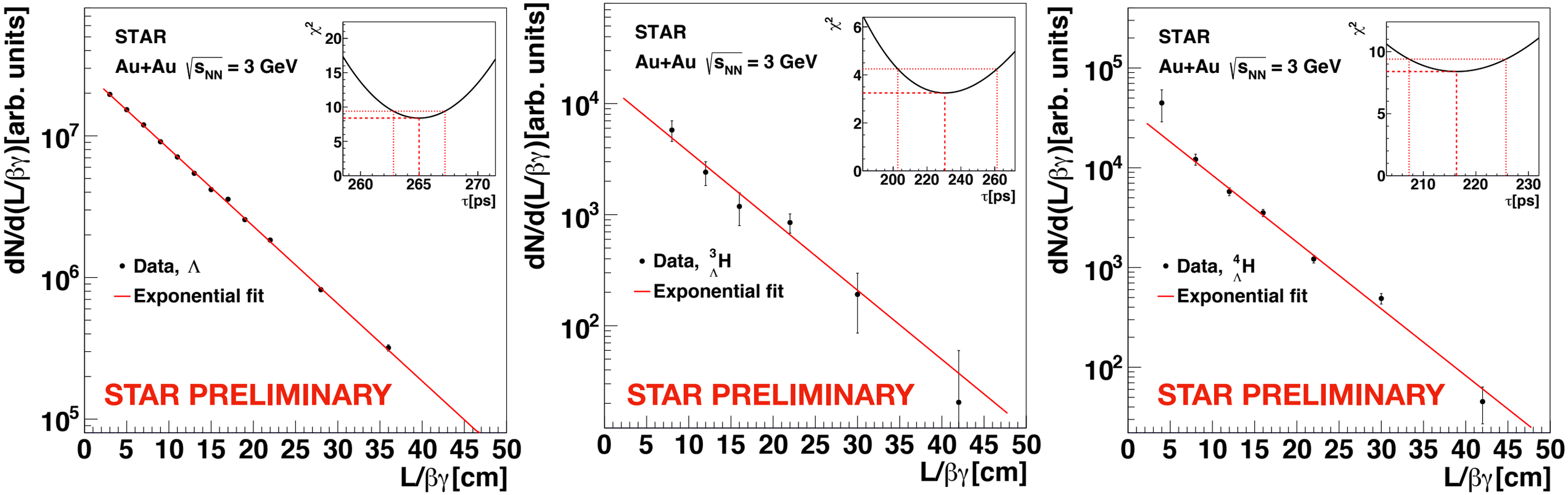


- 3. Fit with an exponential to extract the lifetime

$$N(t) = N_0 e^{-t/\tau} = N_0 e^{-L/\beta\gamma c\tau}$$

Fit results

Λ $^{3}_{\Lambda}\mathrm{H}$ $^{4}_{\Lambda}\mathrm{H}$



- **Yields of Λ, $^{3}_{\Lambda}\mathrm{H}$, $^{4}_{\Lambda}\mathrm{H}$ as a function of $L/\beta\gamma$.**
  - **Distributions well described by exponential functions.**

- **Lifetime extracted with χ^2 fit.**
  - **Statistical uncertainty assigned to be the difference between the lifetime value corresponding to minimum χ^2 (red dashed) and the lifetime values corresponding to minimum $\chi^2 + 1$ (red dotted)**

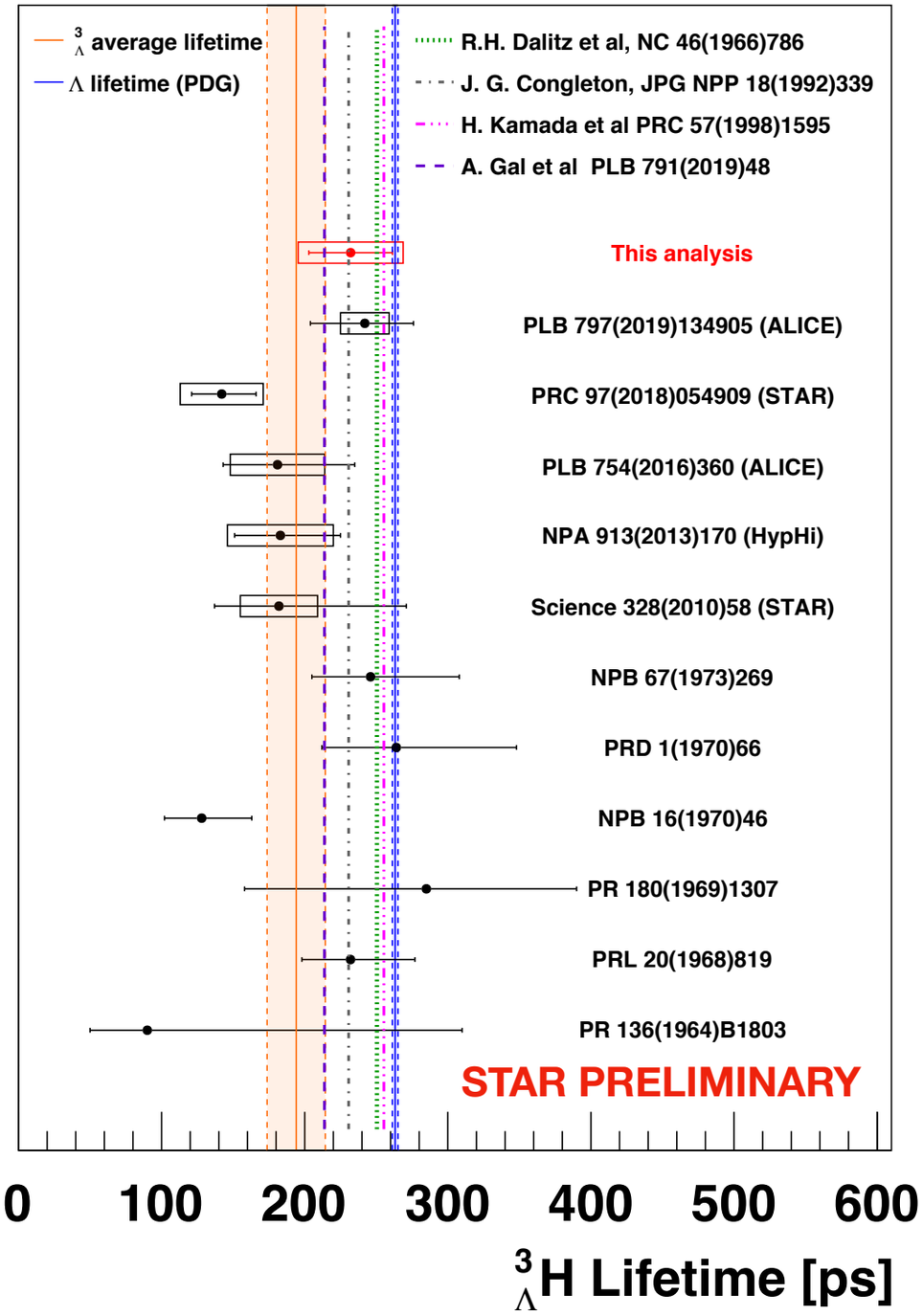
- **Extracted Λ lifetime $(265.0 \pm 2.2)[\mathrm{ps}]$ consistent with PDG value $(263.1 \pm 2.0)[\mathrm{ps}]$**

Systematic uncertainties

- **(1) Analysis cuts**
  - **Imperfect description of topological variables between simulations and real data**
- **(2) Input MC p_T/rapidity**
  - **Imperfect knowledge in the real kinematic distributions of the hypernuclei**
- **(3) Single track efficiency**
  - **Mismatch of single track efficiency between simulations and data**
- **(4) Signal extraction**
  - **Uncertainties related to the background subtraction technique**

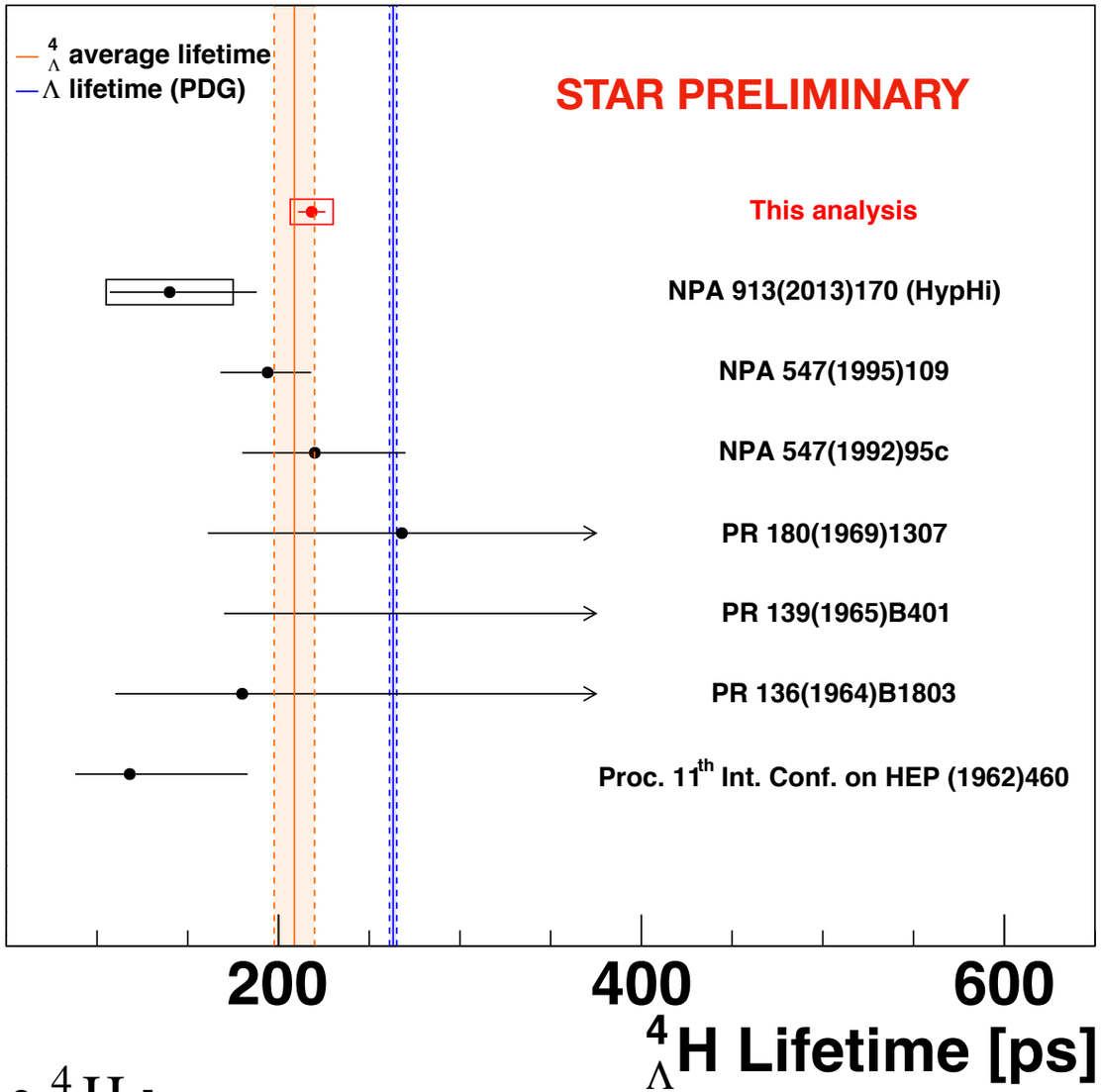
	$^{3}_{\Lambda}\mathrm{H}$	$^{4}_{\Lambda}\mathrm{H}$
(1) Analysis cuts	9.7%	5.0%
(2) Input MC p_T/rapidity	9.1%	1.3%
(3) Single track efficiency	7.7%	1.1%
(4) Signal extraction	3.8%	0.9%
Total	**15.8%**	**5.4%**

Results



$$^{3}_{\Lambda}\mathrm{H} : \tau = 232.1 \pm 29.2(\mathrm{stat}) \pm 36.7(\mathrm{sys})[\mathrm{ps}]$$

$$^{4}_{\Lambda}\mathrm{H} : \tau = 218.3 \pm 7.5(\mathrm{stat}) \pm 11.8(\mathrm{sys})[\mathrm{ps}]$$



- $^{4}_{\Lambda}\mathrm{H}$:
  - **Most precise measurement to date.**
  - **Consistent with previous measurements.**
- $^{3}_{\Lambda}\mathrm{H}$:
  - **Consistent with theoretical calculations including pion FSI.**

Summary

- Presented the results from analyses of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$ lifetime measurements at $\sqrt{s_{\mathrm{NN}}} = 3$ GeV

$${}^{3}_{\Lambda}\mathrm{H} : \tau = 232.1 \pm 29.2(\mathrm{stat}) \pm 36.7(\mathrm{sys})[\mathrm{ps}] \qquad {}^{4}_{\Lambda}\mathrm{H} : \tau = 218.3 \pm 7.5(\mathrm{stat}) \pm 11.8(\mathrm{sys})[\mathrm{ps}]$$

  - Consistent with previous measurements
  - Most precise ${}^{4}_{\Lambda}\mathrm{H}$ lifetime measurement, providing more stringent constraints to theory

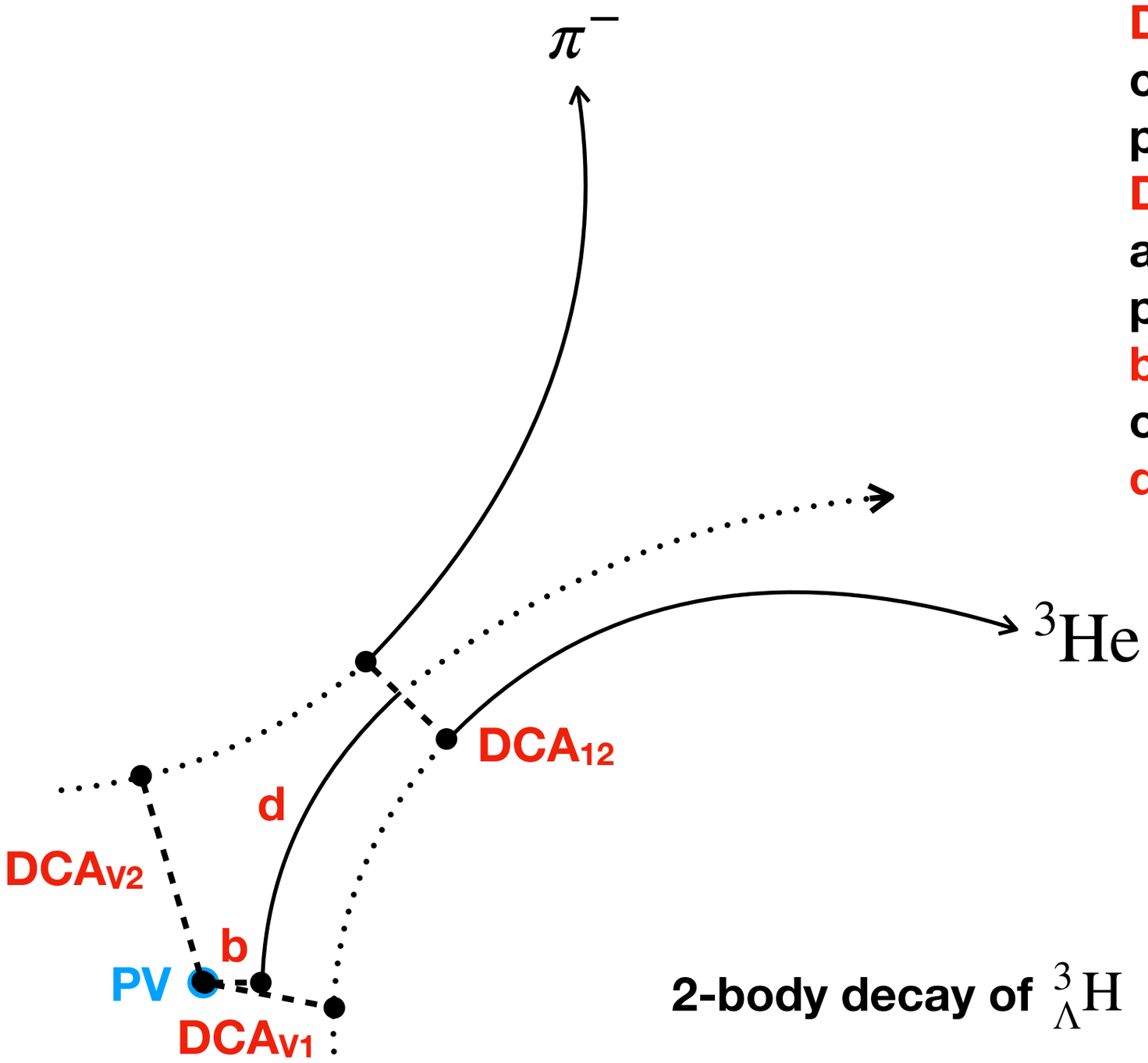
Further work

- Additional studies to reduce systematic uncertainties
- Other data sets to improve statistical precision

Outlook

- Precise measurements of hypernuclei binding energy, spectra expected with STAR BES-II
- Improve our understanding on properties of high baryon density matter

Backup slides follow



PV : primary vertex
DCA_{V1} , DCA_{V2} : distance of closest approach of daughter particle to PV
DCA_{12} : distance of closest approach between daughter particles
b: distance of closest approach of parent particle to PV
d: decay length of parent particle

2-body decay of $^3_\Lambda$H

Analysis outline (cont.)

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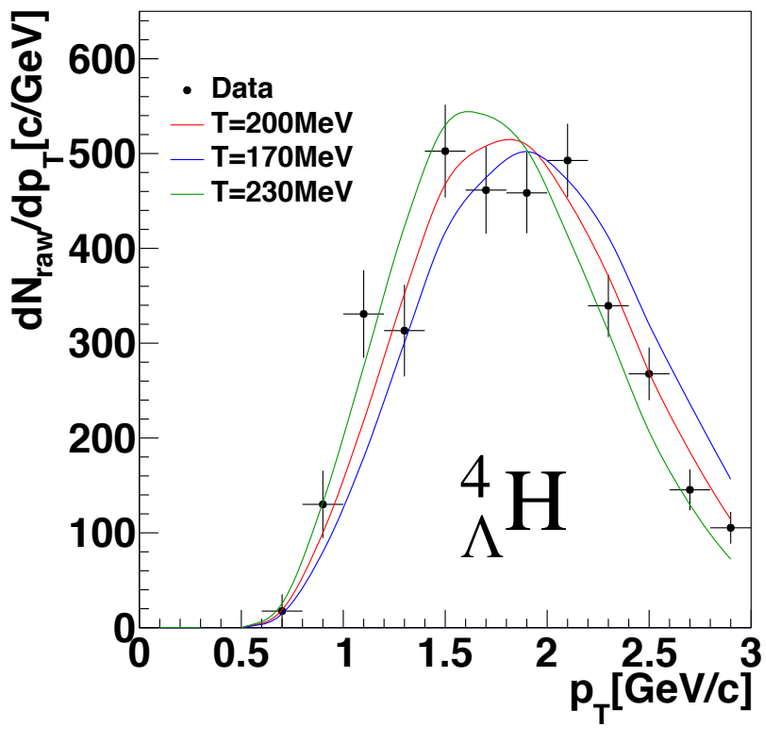

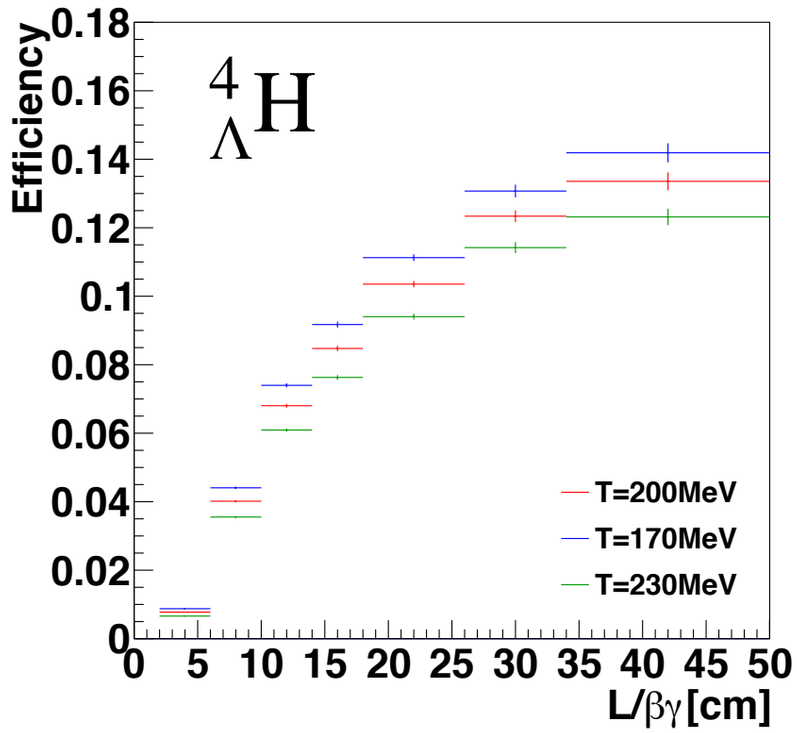

Invariant mass spectra