First results of $({}^{3}_{\Lambda}\mathrm{H}, {}^{4}_{\Lambda}\mathrm{H})$ $(dN/dy, c\tau, v_1)$ from 3 GeV Au+Au collisions with the STAR detector

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CPOD2021 - International Conference on Critical Point and Onset of Deconfinement

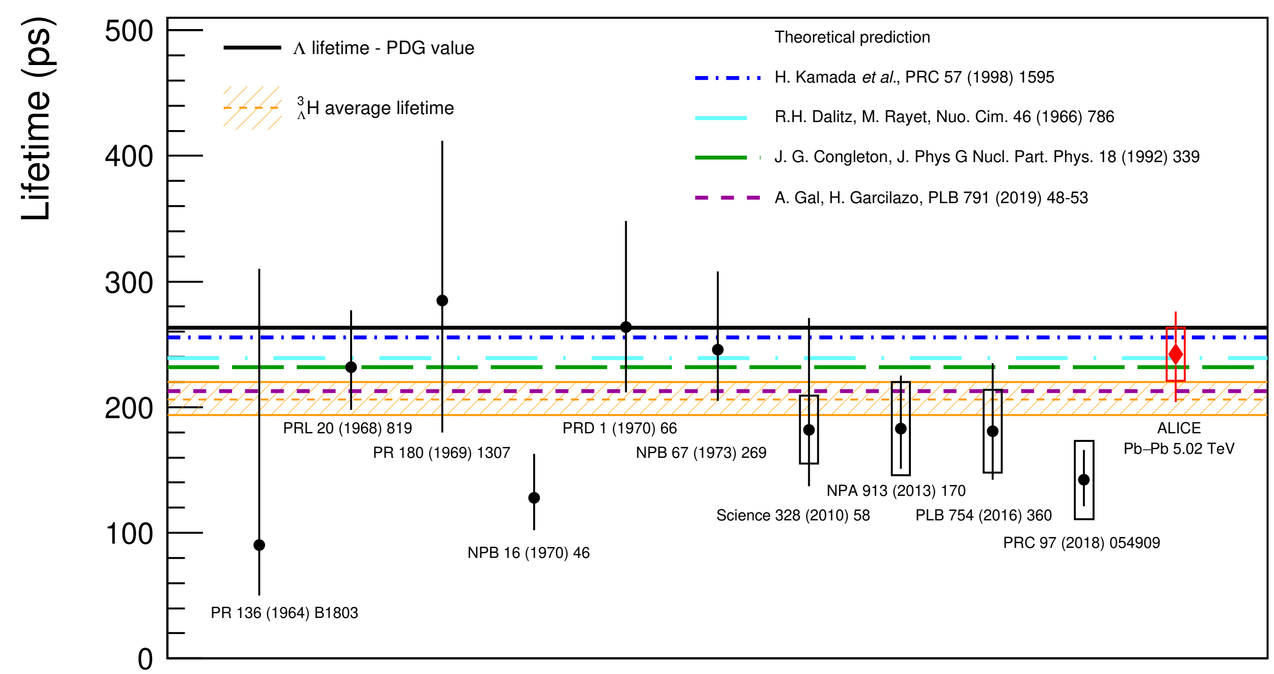
Supported in part by:

U.S. DEPARTMENT OF ENERGY | Office of Science

Introduction

- **Hypernuclei -> experimental probe to study the hyperon-nucleon (YN) interaction**
    - Modeling the EOS of astrophysical objects
    - Lifetime, branching ratios, and binding energy measurements provide key information to understand the YN potential

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



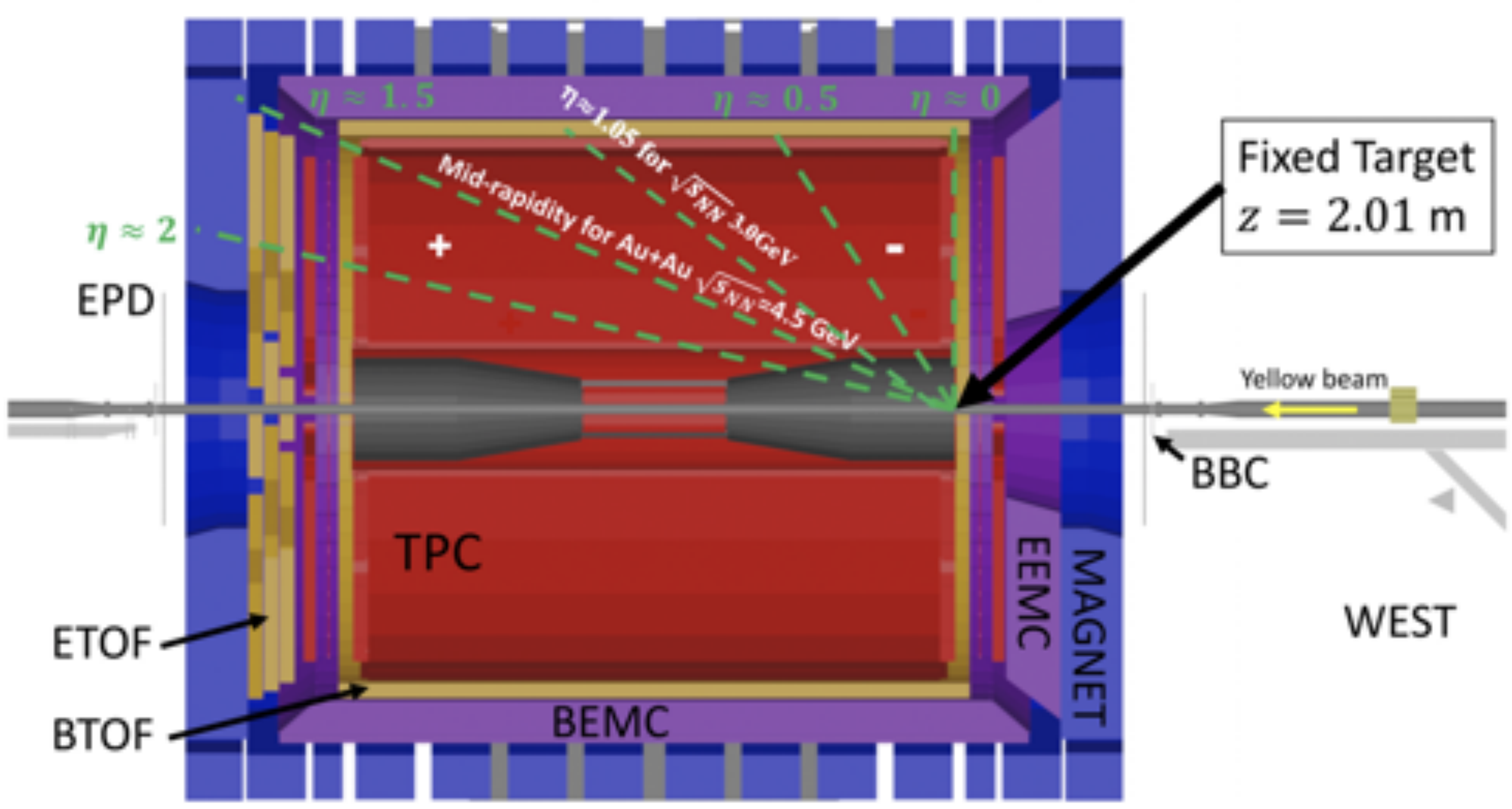
PLB797 (2019) 134905 (ALICE)

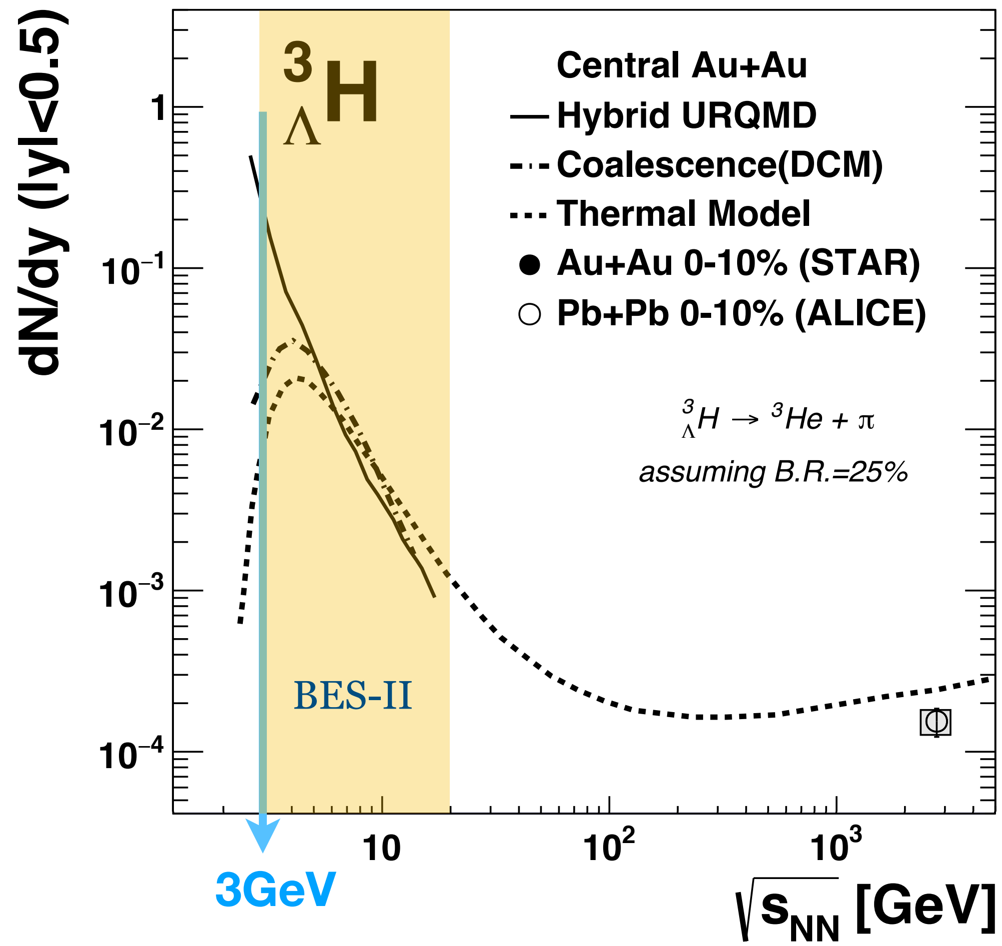
- Few measurements of ${}^{3}_{\Lambda}\mathrm{H}$, ${}^{4}_{\Lambda}\mathrm{H}$ in heavy-ion collisions
    - Yield and flow -> insight on the production mechanisms and hyperon contribution to the EoS

STAR BES-II

- Higher baryon density at lower beam energies
  - STAR BES-II -> great opportunity to study hypernuclei production

STAR Fixed-target Experiment Setup





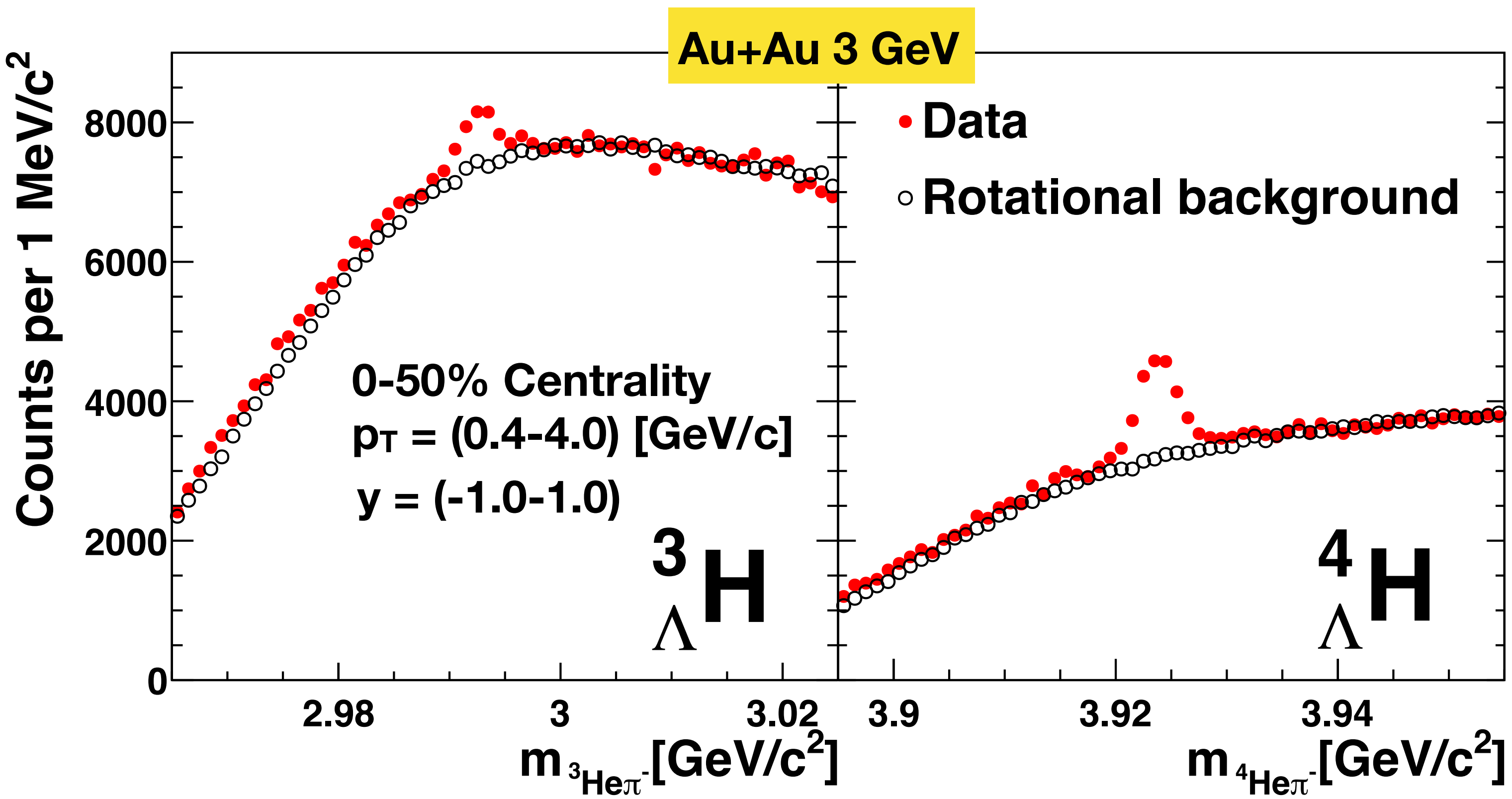
PLB714(2012),85 (Hybrid URQMD, Coalescence(DCM))

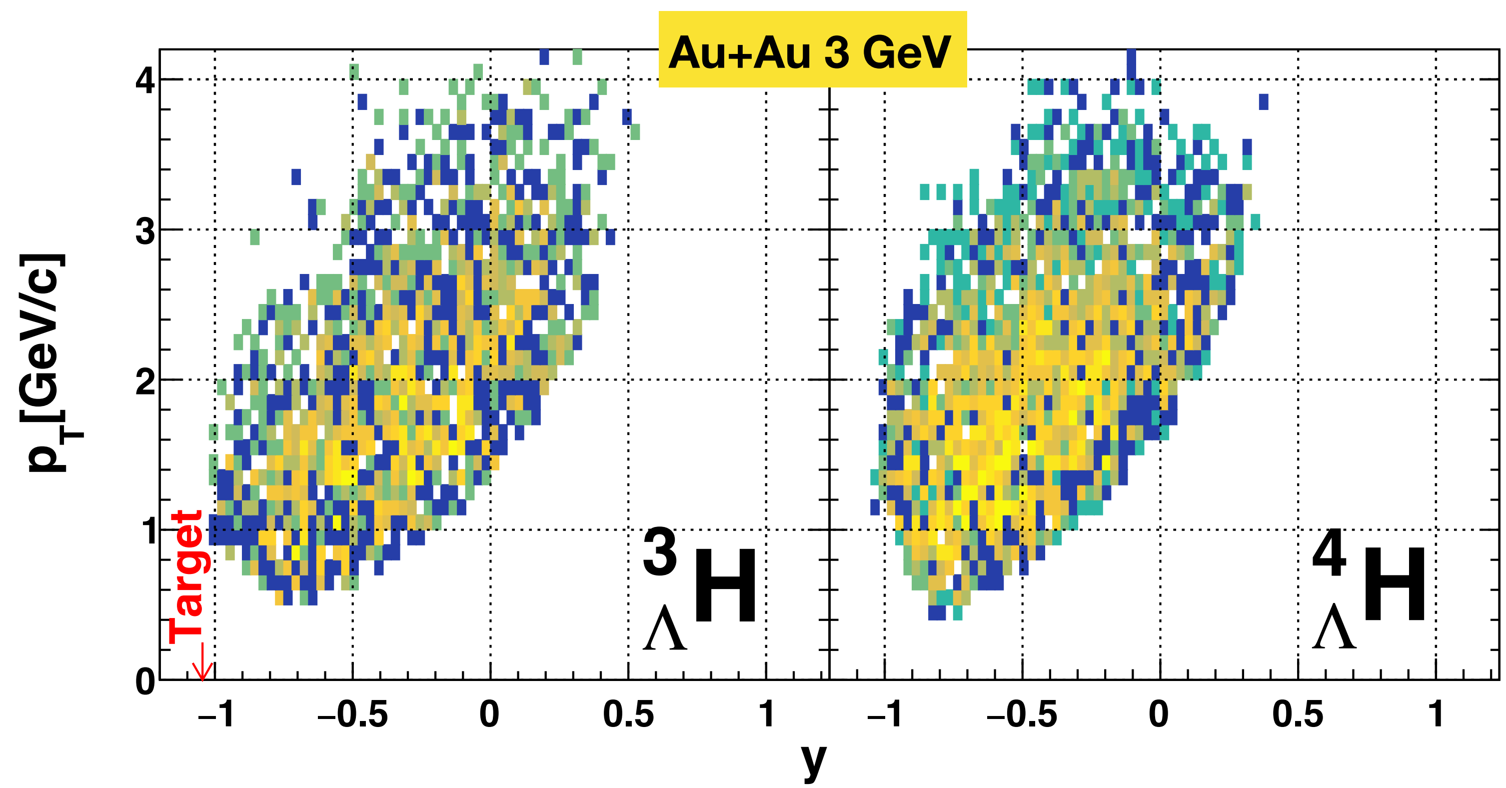
PLB 697 (2011)203 (Thermal Model)

PLB 754 (2016)360 (ALICE)

- 250M events at $\sqrt{s_{NN}} = 3$ GeV with STAR fixed target mode

Hypernuclei reconstruction and acceptance





- Decay channels

$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi \quad (B.R. \approx 25\%)$

~2900 candidates PRC57(1998)1595

$^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi \quad (B.R. \approx 50\%)$

~6300 candidates NPA585(1995) 365c NPA639(1998) 251c

$^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{p} + \pi \quad (B.R. \approx 40\%)$

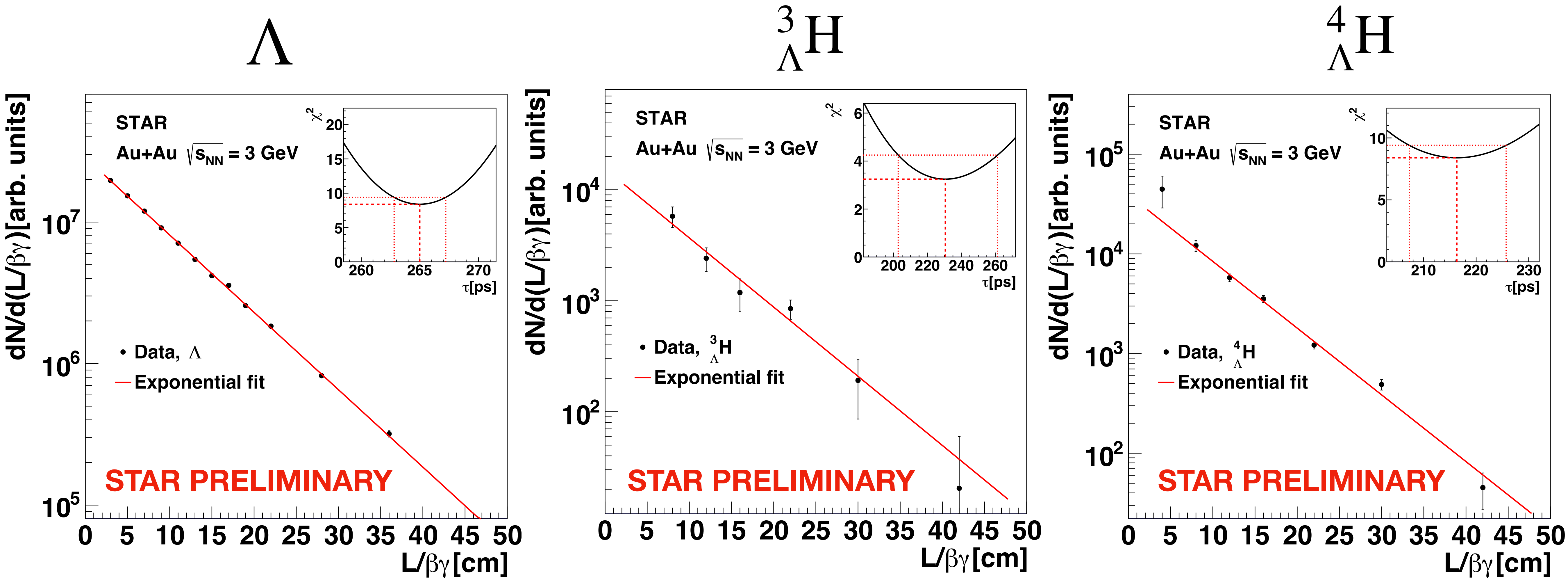
~7000 candidates PRC57(1998)1595

- Good mid-rapidity coverage at 3 GeV

**KFParticle package used for reconstruction*

*M. Zyzak, "Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR", thesis, urn:nbn:de:hebis:30:3-414288

Lifetime measurements



- **Yields of** Λ, $^{3}_{\Lambda}\mathrm{H}$, $^{4}_{\Lambda}\mathrm{H}$ **as a function of** $L/\beta\gamma$
    - **Well described by exponential functions** $N(t) = N_0 e^{-L/\beta\gamma c\tau}$

- **Lifetime extracted with** χ^2 **fit**

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

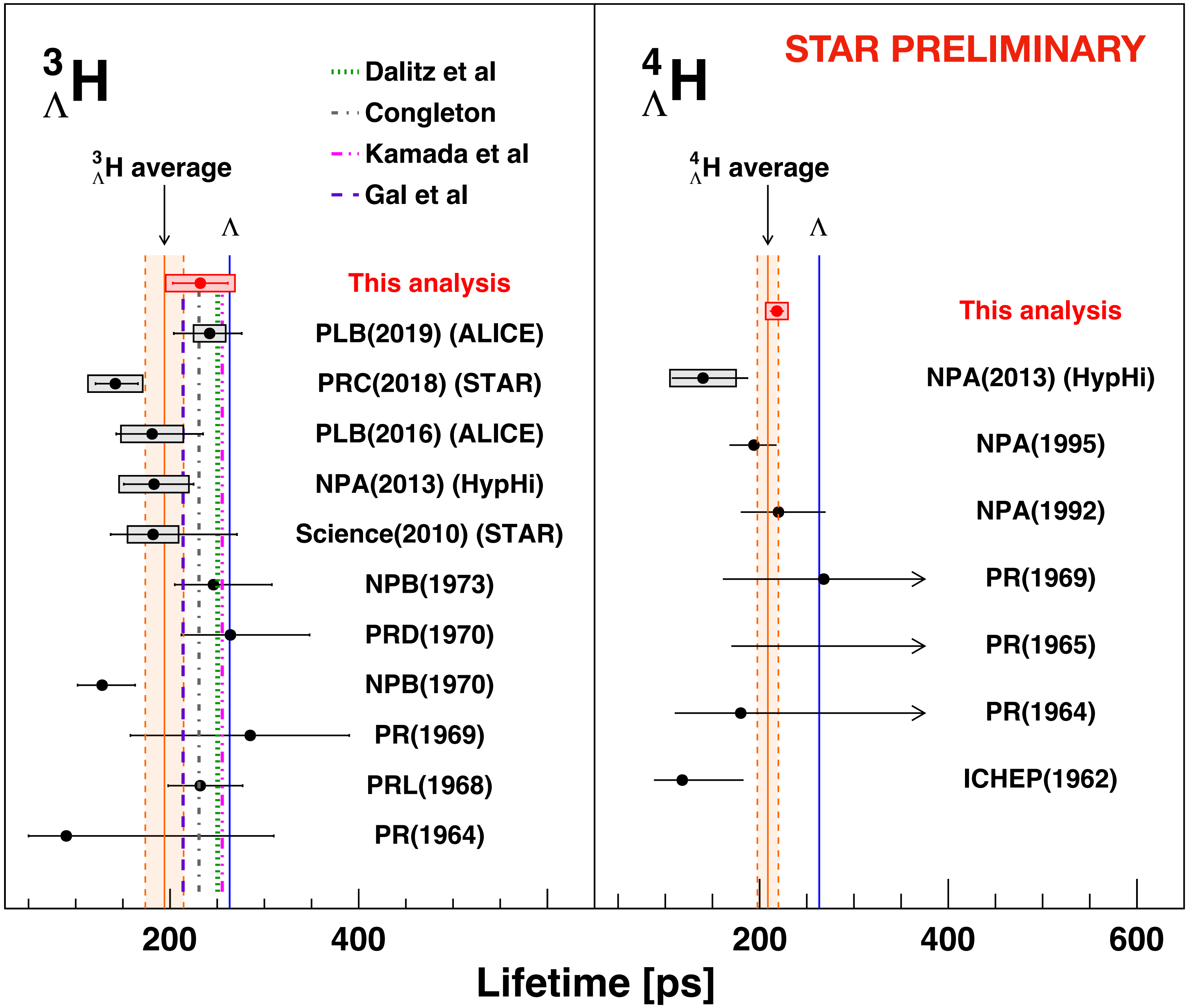
Systematic uncertainties on the lifetime

- (1) Analysis cuts
  - Imperfect description of topological variables between simulations and real data
- (2) Input MC p_T/rapidity/lifetime
  - 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

syst. uncertainty	${}^{3}_{\Lambda}\mathrm{H}$	${}^{4}_{\Lambda}\mathrm{H}$
Analysis cuts	9.7%	5.0%
Input MC	9.1%	1.3%
Tracking efficiency	7.7%	1.1%
Signal extraction	3.8%	0.9%
Total	15.8%	5.4%

Table: Syst. uncertainty for ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$ lifetime

New results on ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ lifetime

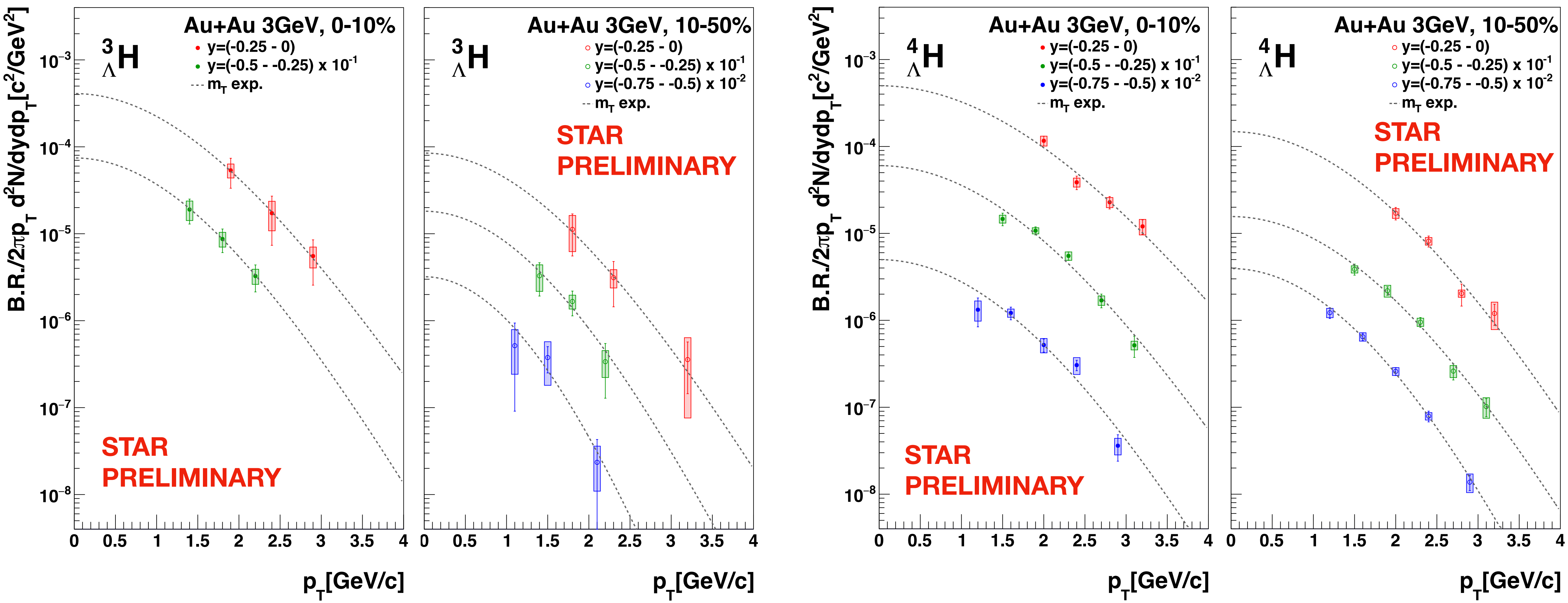


$${}^{3}_{\Lambda}H: \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$$
$${}^{4}_{\Lambda}H: \tau = 218.3 \pm 7.5(stat) \pm 11.8(syst)[ps]$$

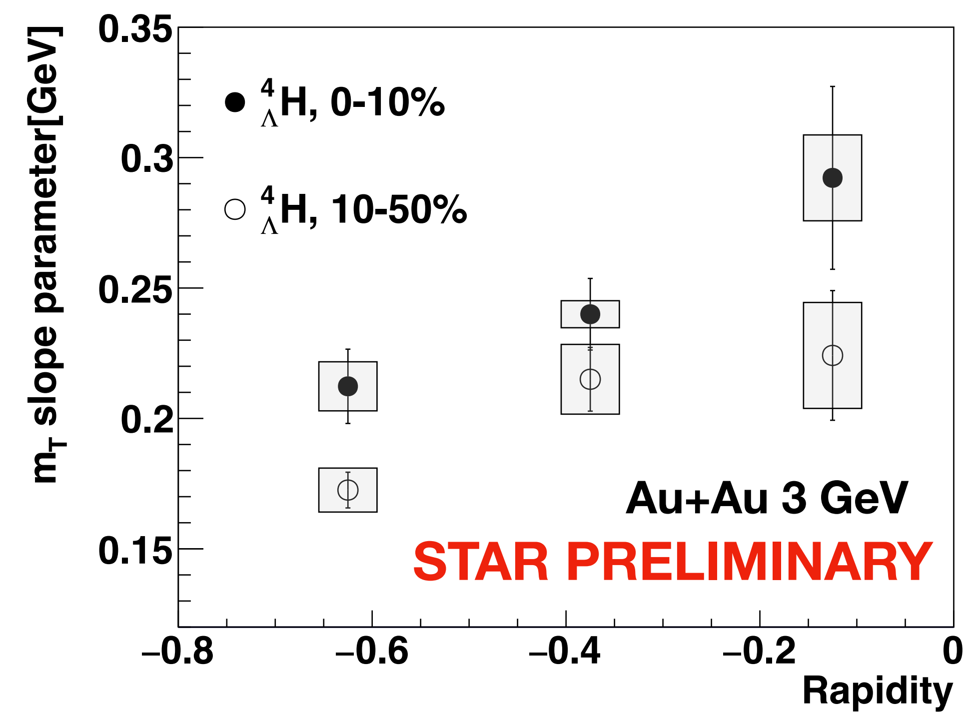
- ${}^{4}_{\Lambda}H$:
  - **Most precise measurement to date.**
  - **Consistent with previous measurements.**
- ${}^{3}_{\Lambda}H$:
  - **Consistent with theoretical calculations including pion FSI.**

NC46(1966)786 (Dalitz et al)
JPG NPP 18(1992)339 (Congleton)
PRC57(1998)1595 (Kamada et al)
PLB791(2019)48 (Gal et al)

${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ p_T spectra



- **Extract ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ spectra in 0-10% and 10-50% centralities.**
  - **${}^{4}_{\Lambda}H$ spectra becomes softer at more backward rapidities.**



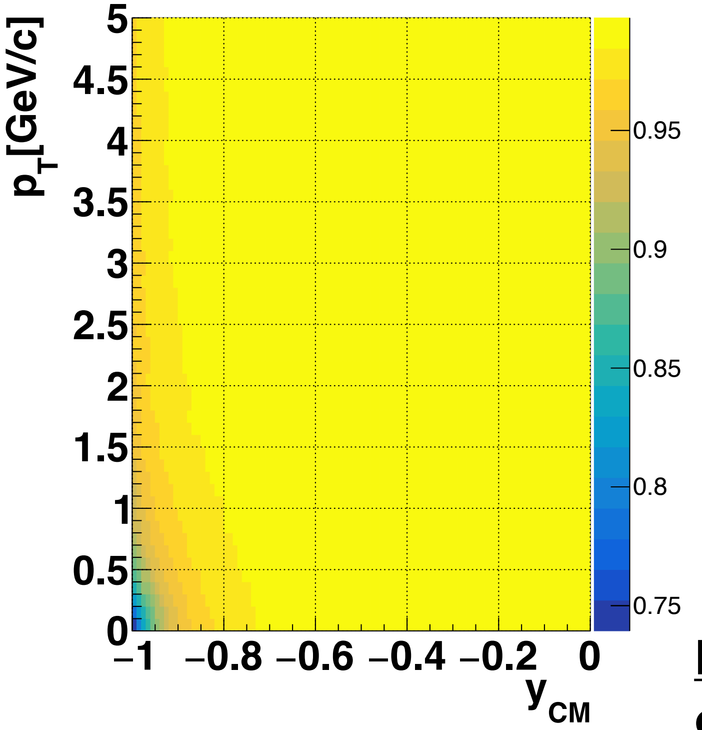
- **Extrapolate to p_T = 0 GeV/c to obtain dN/dy**

Systematic uncertainties on the spectra

- Additional sources of systematic uncertainties considered:
- <u>Extrapolation</u>
  - Different functions for extrapolation to estimate uncertainty
    - m_T exponential, blast wave, Boltzmann, etc.
- <u>Target material</u>
  - Took into account possible Coulomb dissociation when traversing target material
    Physics of Atomic Nuclei, 2007, Vol. 70, No. 9, pp. 1617–1622
  - Survival probability >95% in kinematic regions analyzed

syst. uncertainty	${}^{3}_{\Lambda}$H	${}^{4}_{\Lambda}$H
Analysis cuts	19.3%	4.1%
Input MC	10.0%	4.0%
Tracking efficiency	3.7%	2.9%
Signal extraction	6.0%	4.0%
Extrapolation	11.8%	12.8%
Detector material	4.0%	< 1%
Total	26.0%	14.9%
Branching ratio	40.0%	20.0%

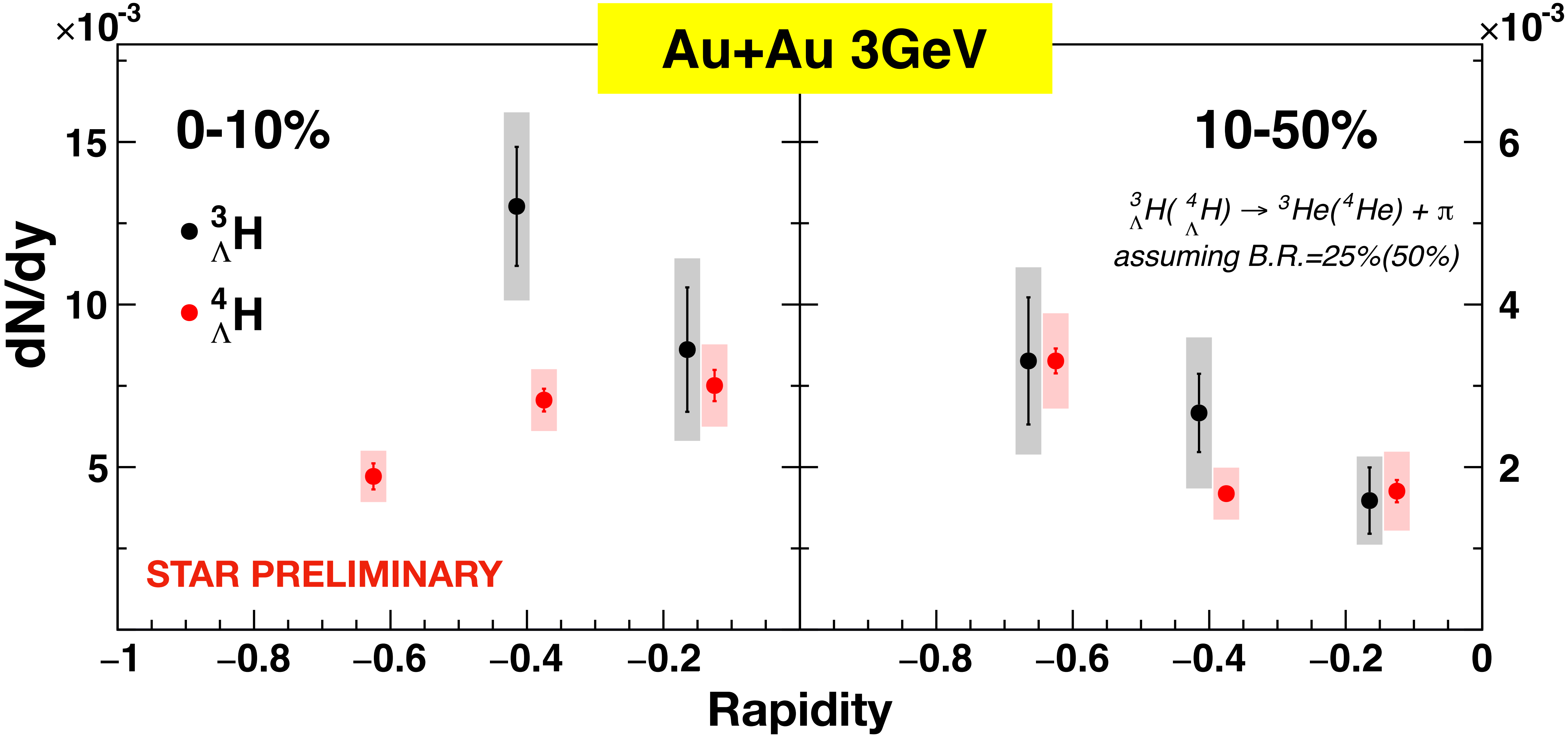
<u>Table: Syst. uncertainty for ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H dN/dy at |y|<0.5 in Au+Au 0-10%.</u>



<u>Fig: Survival prob. for ${}^{3}_{\Lambda}$H estimated from MC study</u>

**Target thickness = 0.25mm*

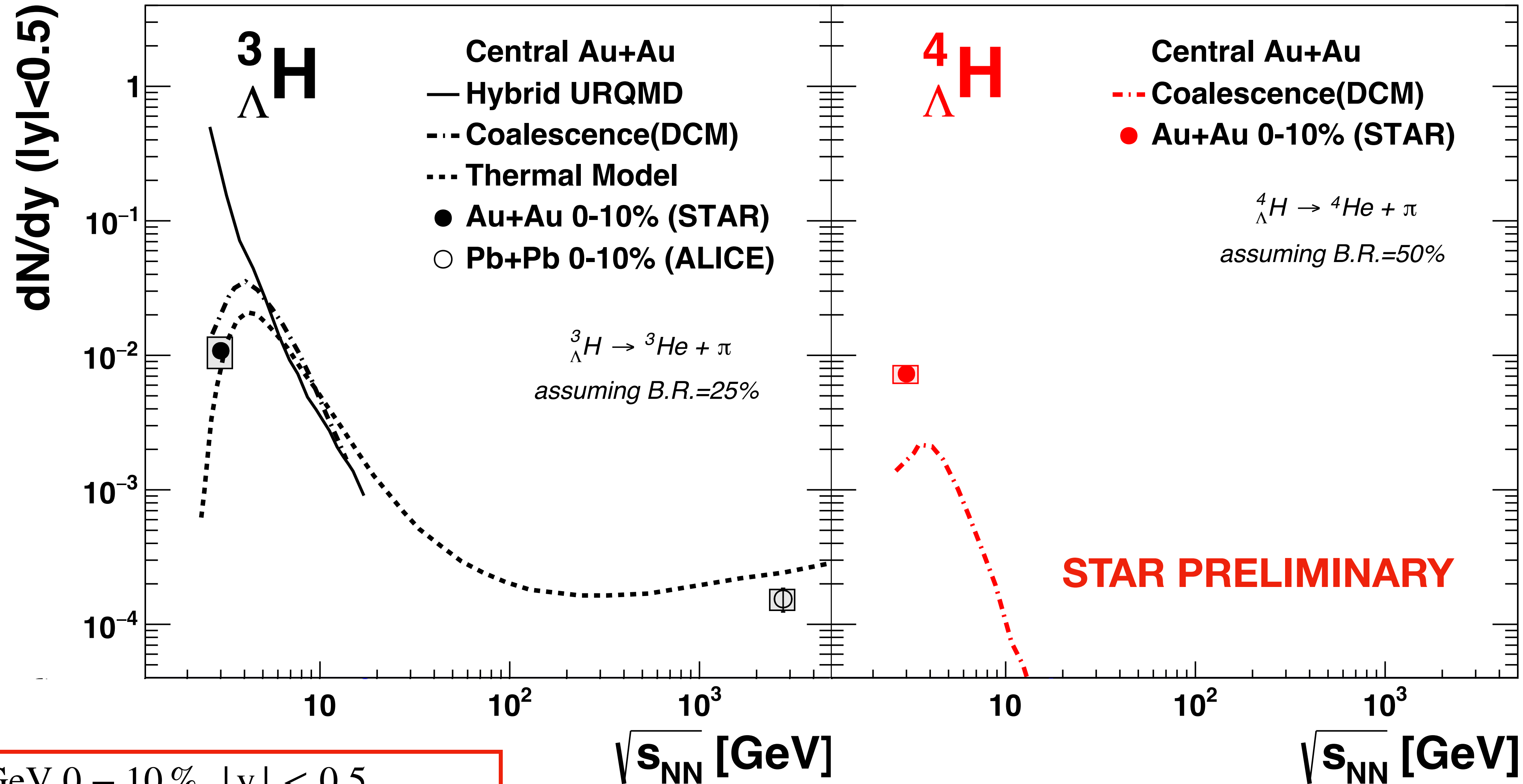
${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$ dN/dy at $\sqrt{s_{NN}} = 3$ GeV



- First measurement of dN/dy of hypernuclei in HI collisions
    - Different trends in the ${}^{4}_{\Lambda}H$ rapidity distribution in central (0-10%) and mid-central (10-50%) collisions

PRC57(1998)1595
NPA585(1995) 365c
NPA639(1998) 251c

$^{3}_{\Lambda}H$ and $^{4}_{\Lambda}H$ |y|<0.5 yield vs beam energy



Au + Au @ 3GeV, 0 – 10 %, |y| < 0.5

$^{3}_{\Lambda}H$: $dN/dy = 1.1 \pm 0.1(stat) \pm 0.3(syst) \times 10^{-2}$

$^{4}_{\Lambda}H$: $dN/dy = 7.3 \pm 0.3(stat) \pm 1.1(syst) \times 10^{-3}$

- **Thermal model (GSI-Heidelberg) which adopts the canonical ensemble, describes $^{3}_{\Lambda}H$ yield at 3 GeV**
- **Yield of $^{4}_{\Lambda}H$ not described by coalescence (DCM) model**

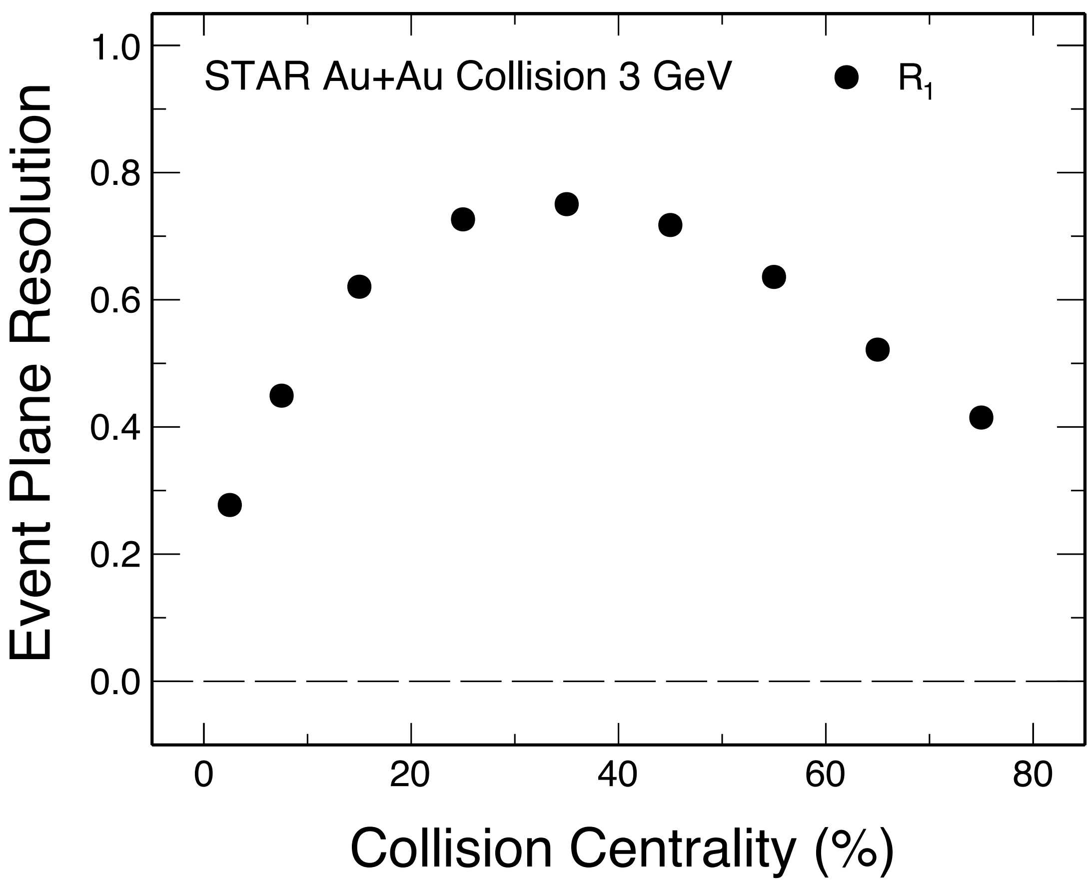
PLB714(2012),85 (Hybrid URQMD, Coalescence(DCM))

PLB 697 (2011)203 (Thermal Model)

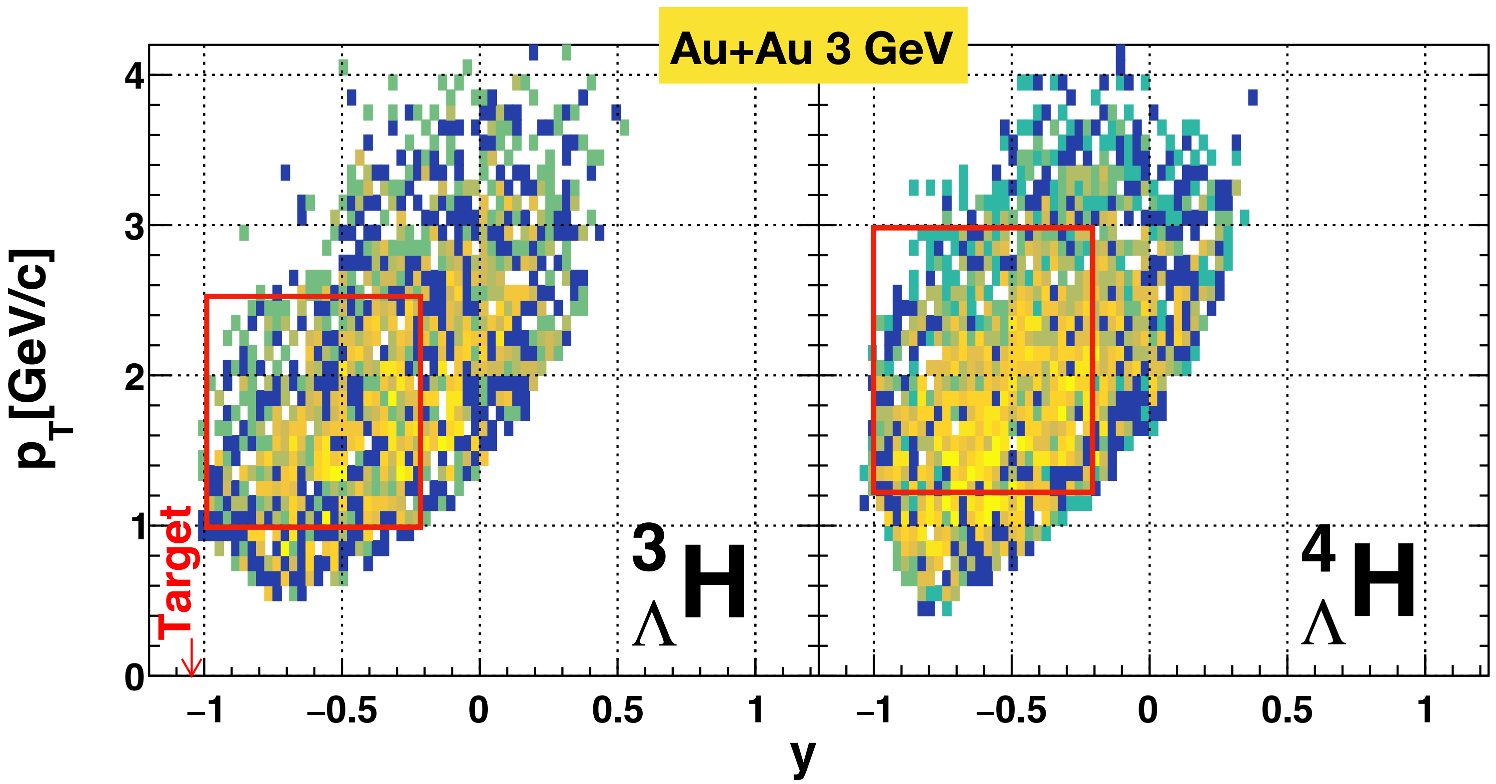
PLB 754 (2016)360 (ALICE)

Directed flow of hypernuclei ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$

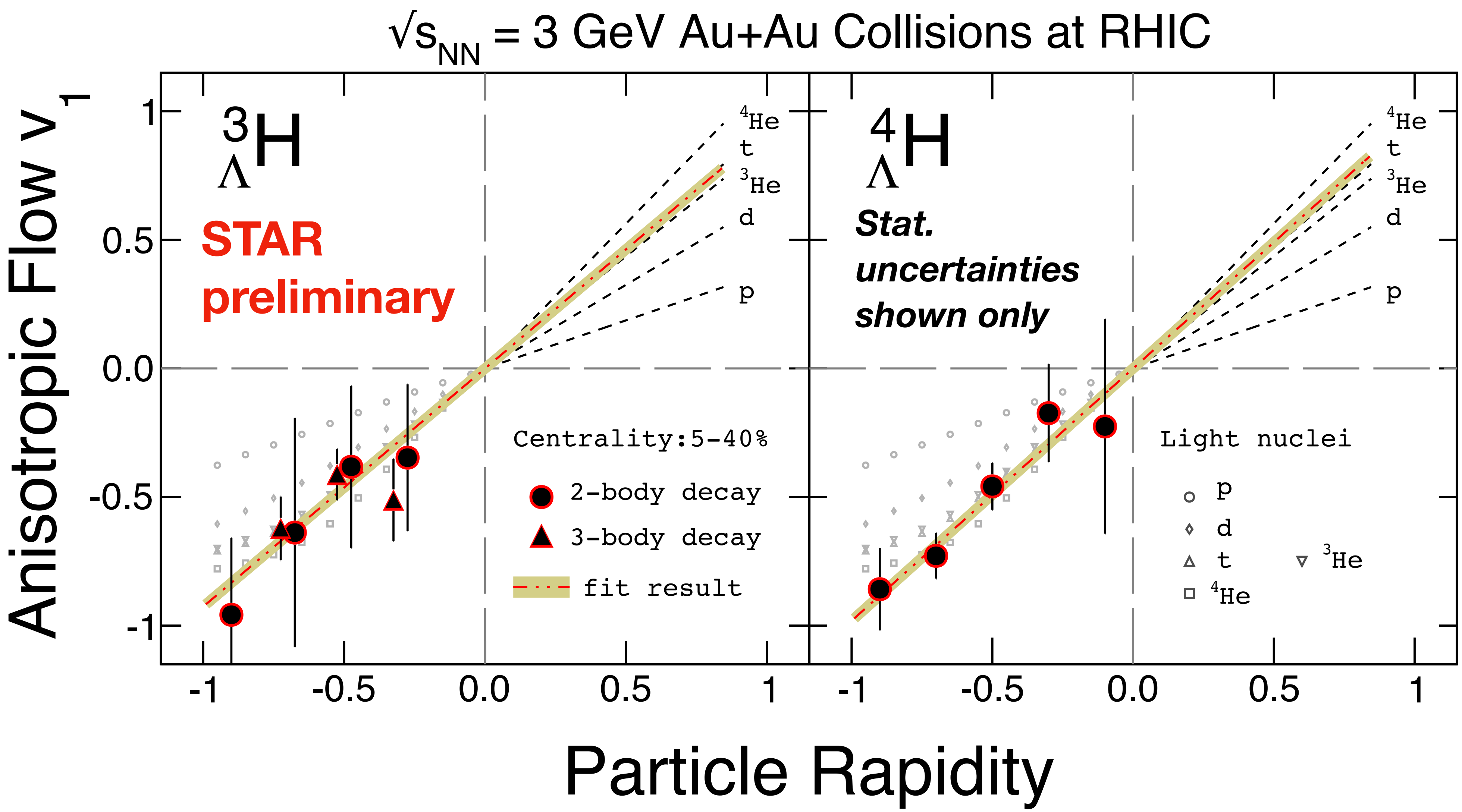
- **We use the <u>event plane method</u> to extract the v_1 of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$**
  - **1st order event plane angle measured by Event Plane Detector (EPD)** $(-5.3 < \eta < -2.6)$
  - **Event plane resolution R_1 from 3-sub-event method**



- **Kinematic range for extraction of v_1 slope:**



Directed flow of hypernuclei ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$



- First observation of hypernuclei collectivity v_1 in HI collisions.
- v_1 slope follow <u>baryon number scaling</u> in 5-40% 3 GeV Au+Au collisions
    - Results consistent with hypernuclei production from coalescence of hyperons and nucleons

Summary and Outlook

- Established new directions in the study of HI collisions
  - First measurement of hypernuclei dN/dy in HI collisions
    - Different trends in the ${}^{4}_{\Lambda}\mathrm{H}$ rapidity distribution in central (0-10%) and mid-central (10-50%) 3 GeV Au+Au collisions
    - Thermal model describes ${}^{3}_{\Lambda}\mathrm{H}$ yield, while coalescence (DCM) model does not describe ${}^{4}_{\Lambda}\mathrm{H}$ yield.
  - First observation of hypernuclei collectivity v_1 in HI collisions
    - v_1 slope of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$ follow baryon number scaling in 5-40% collisions.
  - Improved precision on ${}^{3}_{\Lambda}\mathrm{H}, {}^{4}_{\Lambda}\mathrm{H}$ lifetimes
- BES-II + FXT : $\sqrt{s_{\mathrm{NN}}} = 3 - 20$ GeV
  - Energy dependence, heavier hypernuclei, S=2 hypernuclei, etc.

Moving towards a quantitative understanding of QCD matter in the high baryon density region

Thank you for listening!