RECENT HYPERNUCLEI MEASUREMENTS FROM THE STAR EXPERIMENT

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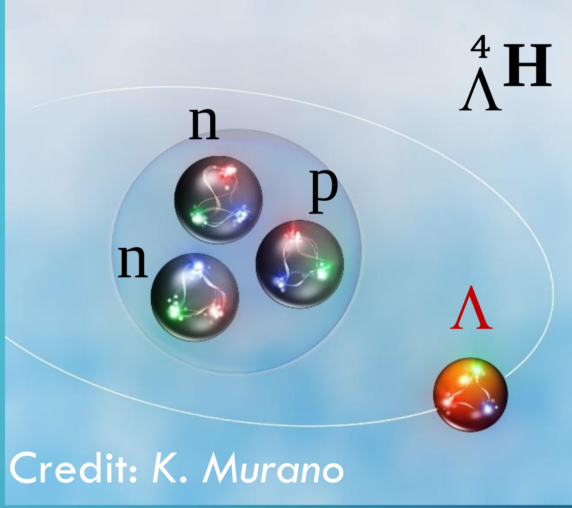
FOR THE STAR COLLABORATION

GSI FAIR

Outline

- Introduction
- Hypernuclei lifetimes
- Hypernuclei Yields
- Particle ratios and energy dependence
- Hypernuclei collectivity
- Hypernuclei in Express production (Run 2021)
- Summary

HYPERNUCLEI



- Precise measurements of hypernuclei lifetime (**YN** interaction)
- Strangeness in high density nuclear matter, EoS for NS, Hadronic phase of HI collisions
- Measurement of branching ratios of hypernuclei decays, Dalitz plots for 3-body decays
  - hypernuclei internal structure
- Measurements of B_Λ in the hypernuclei
  - direct access to the hyperon-nucleon **YN** interaction

BES - II DATA SETS:

Most precise data to map the QCD phase diagram

$3 < \sqrt{s_{NN}} < 200$ GeV; $750 < \mu_B < 25$ MeV

Au+Au Collisions at RHIC									
Collider Runs					Fixed-Target Runs				
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	Run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	Run
1	200	380 M	25 MeV	Run 10, 19	1	13.7 (100)	50 M	280 MeV	Run-21
2	62.4	46 M	75 MeV	Run-10	2	11.5 (70)	50 M	320 MeV	Run-21
3	54.4	120 M	85 MeV	Run-17	3	9.2 (44.5)	50 M	370 MeV	Run-21
4	39	86 M	112 MeV	Run-10	4	7.7 (31.2)	260 M	420 MeV	Run-18, 19, 20
5	27	585 M	156 MeV	Run-11, 18	5	7.2 (26.5)	470 M	440 MeV	Run-18, 20
6	19.6	595 M	206 MeV	Run-11, 19	6	6.2 (19.5)	120 M	490 MeV	Run-20
7	17.3	256 M	230 MeV	Run-21	7	5.2 (13.5)	100 M	540 MeV	Run-20
8	14.6	340 M	262 MeV	Run-14, 19	8	4.5 (9.8)	110 M	590 MeV	Run-20
9	**11.5**	57 M	316 MeV	Run-10, 20	9	3.9 (7.3)	120 M	633 MeV	Run-20
10	**9.2**	160 M	372 MeV	Run-10, 20	10	3.5 (5.75)	120 M	670 MeV	Run-20
11	**7.7**	104 M	420 MeV	Run-21	11	3.2 (4.59)	200 M	699 MeV	Run-19
					12	3.0 (3.85)	2300 M	750 MeV	Run-18, 21

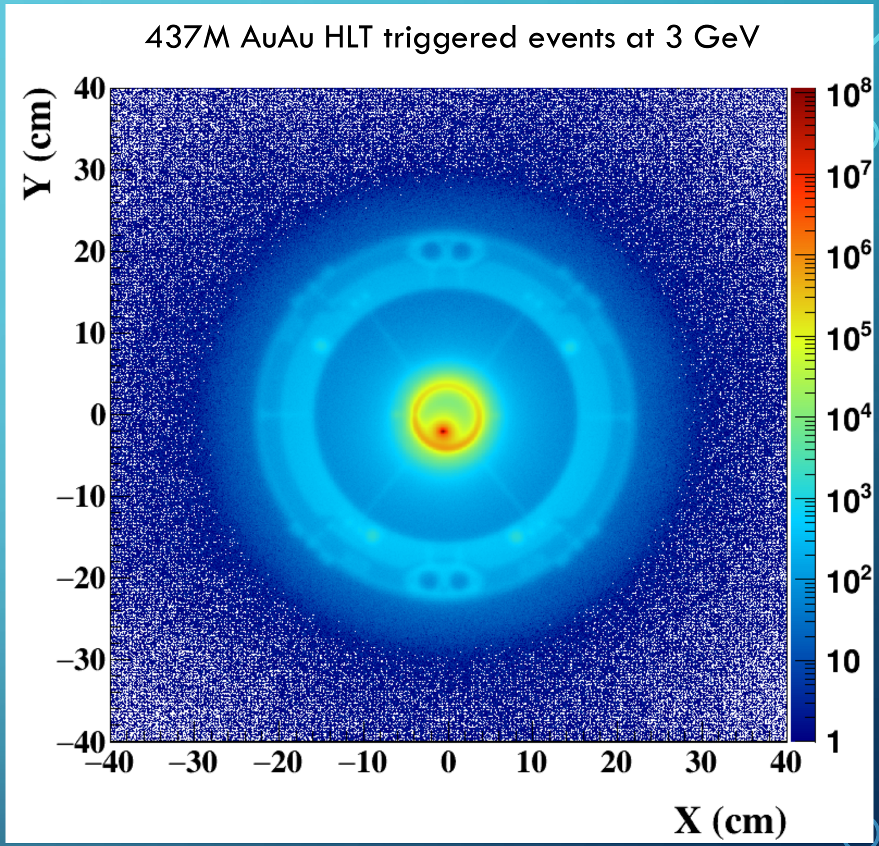
SOME MAJOR UPGRADES FOR BES-II

iTPC:

- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 to 60 MeV/c
- Ready in 2019

eTOF:

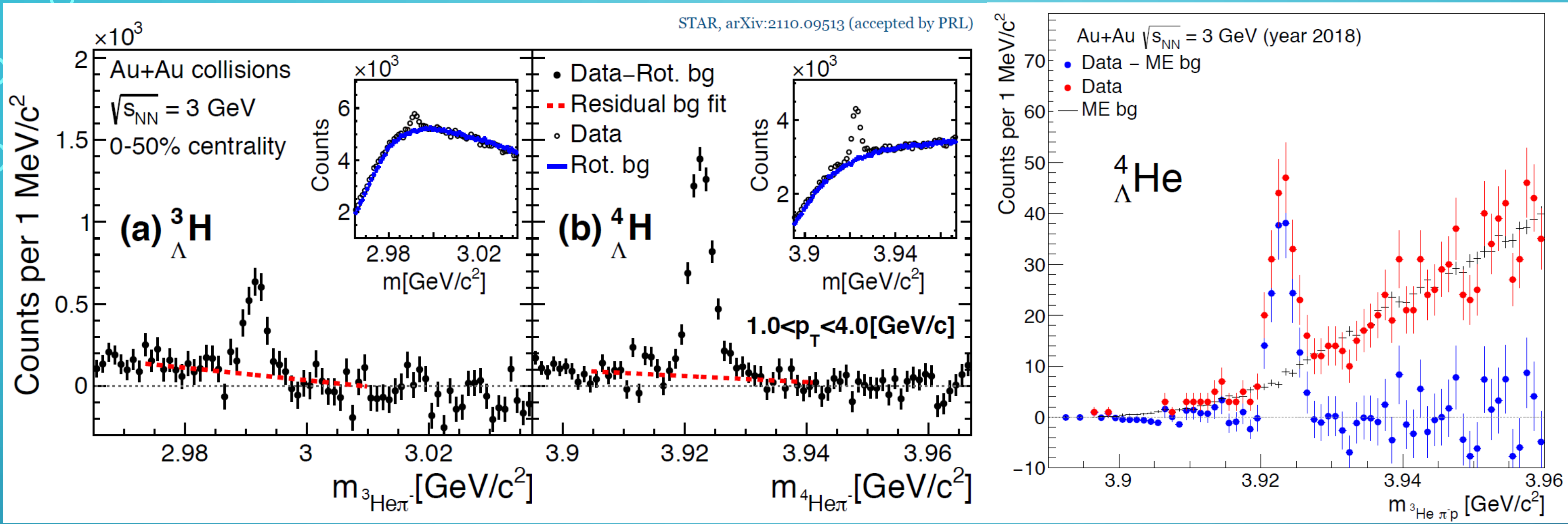
- Forward rapidity coverage
- PID at η = 0.9 to 1.5
- **Borrowed from CBM-FAIR**
- Ready in 2019



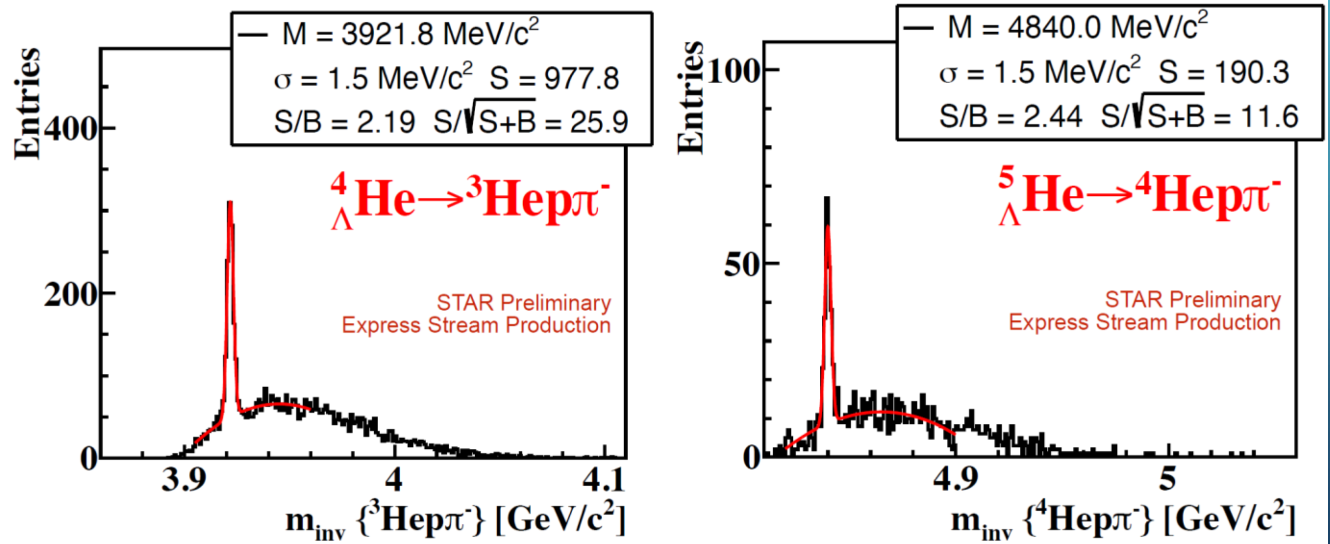
STAR Express Analysis:

- pileup control
- PV and STAR tomography
- Heavy Fragment trigger
- Hypernuclei Express reconstruction
- Ready in 2018

HYPERNUCLEI RECONSTRUCTION



2018-2020, 2021x FXT and 2021x collider at 7.7 GeV



Good mid rapidity coverage at 3 GeV

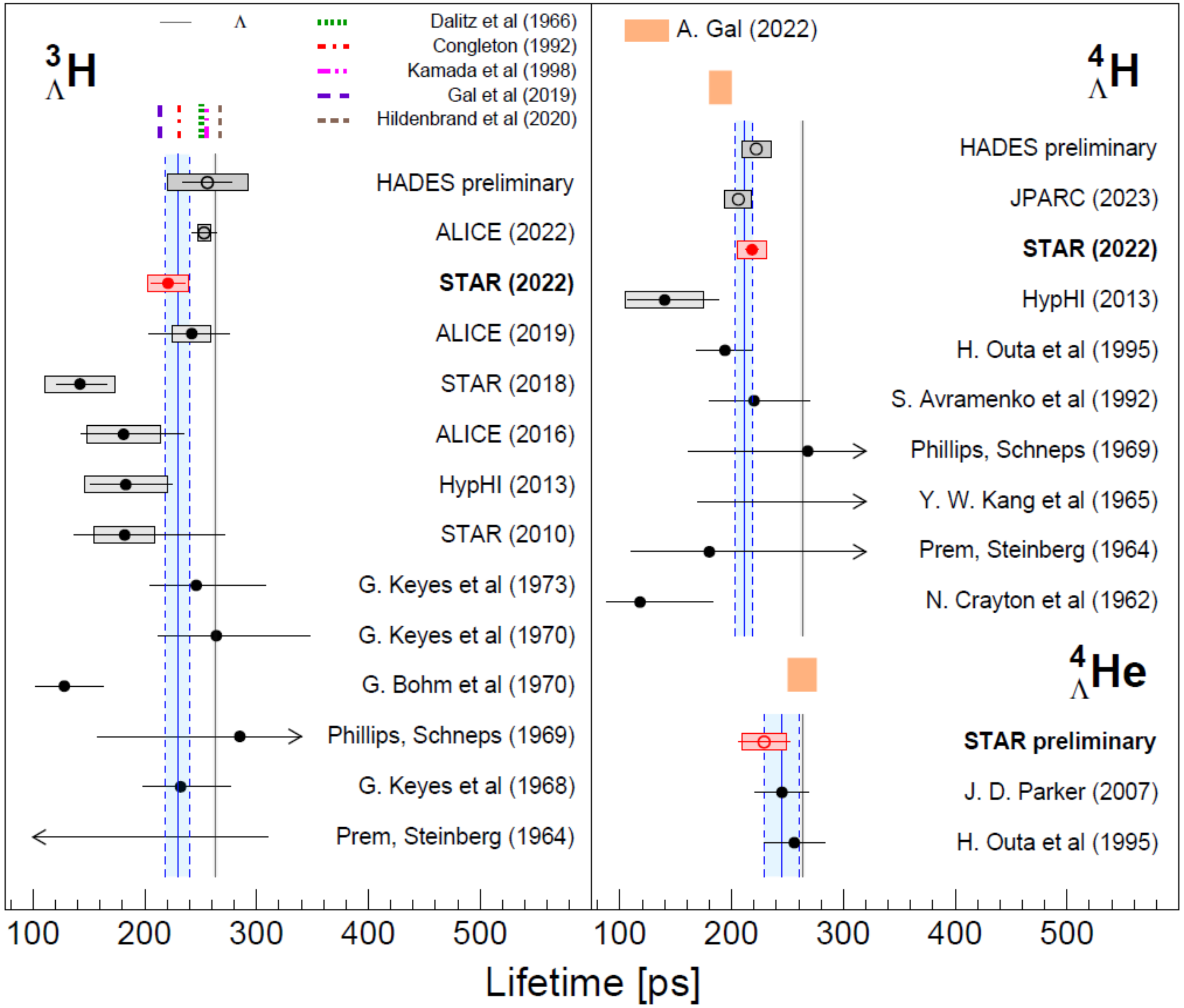
Hypernuclei are reconstructed with KFParticle Finder in following decay channels:

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

$^{3}_{\Lambda}H \rightarrow d + p + \pi^-$ $\quad$ $^{4}_{\Lambda}He \rightarrow {}^{3}He + p + \pi^-$

$^{5}_{\Lambda}He \rightarrow {}^{4}He + p + \pi^-$

HYPERNUCLEI LIFETIMES



${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$ lifetimes shorter than τ_{Λ} (with 1.8σ, 3.0σ respectively)

Consistent with theoretical calculations including pion FSI

A. Gal et al, PLB791(2019)48

$\frac{\tau_{avg}\,{}^{4}_{\Lambda}H}{\tau_{avg}\,{}^{4}_{\Lambda}He} = 0.85 \pm 0.07$, consistent with theoretical estimation: 0.74 ± 0.04

A. Gal (2021), arXiv:2108.10179

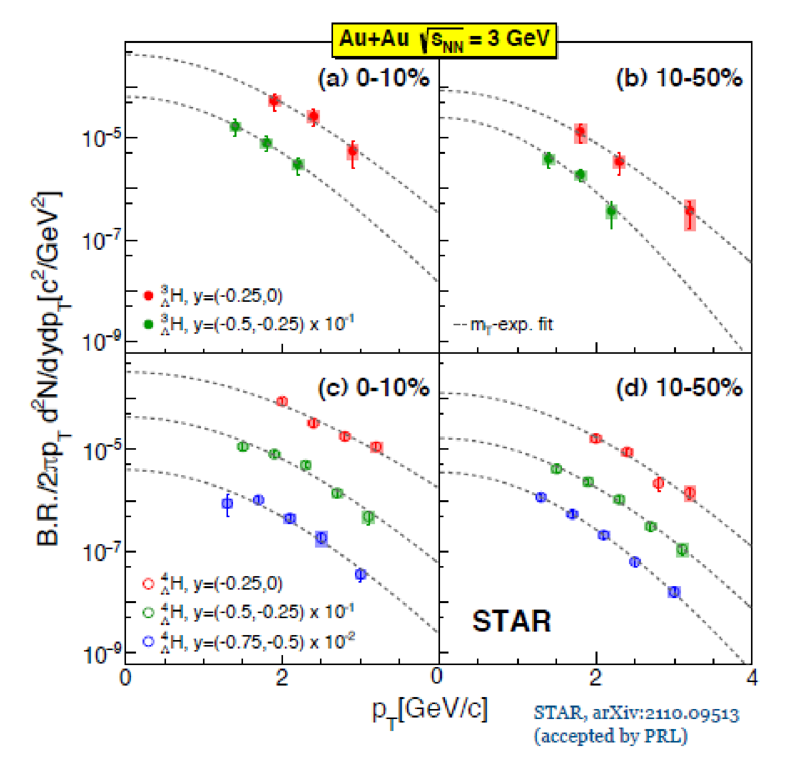
ALICE H3L lifetime (2022) arXiv:2209.07360

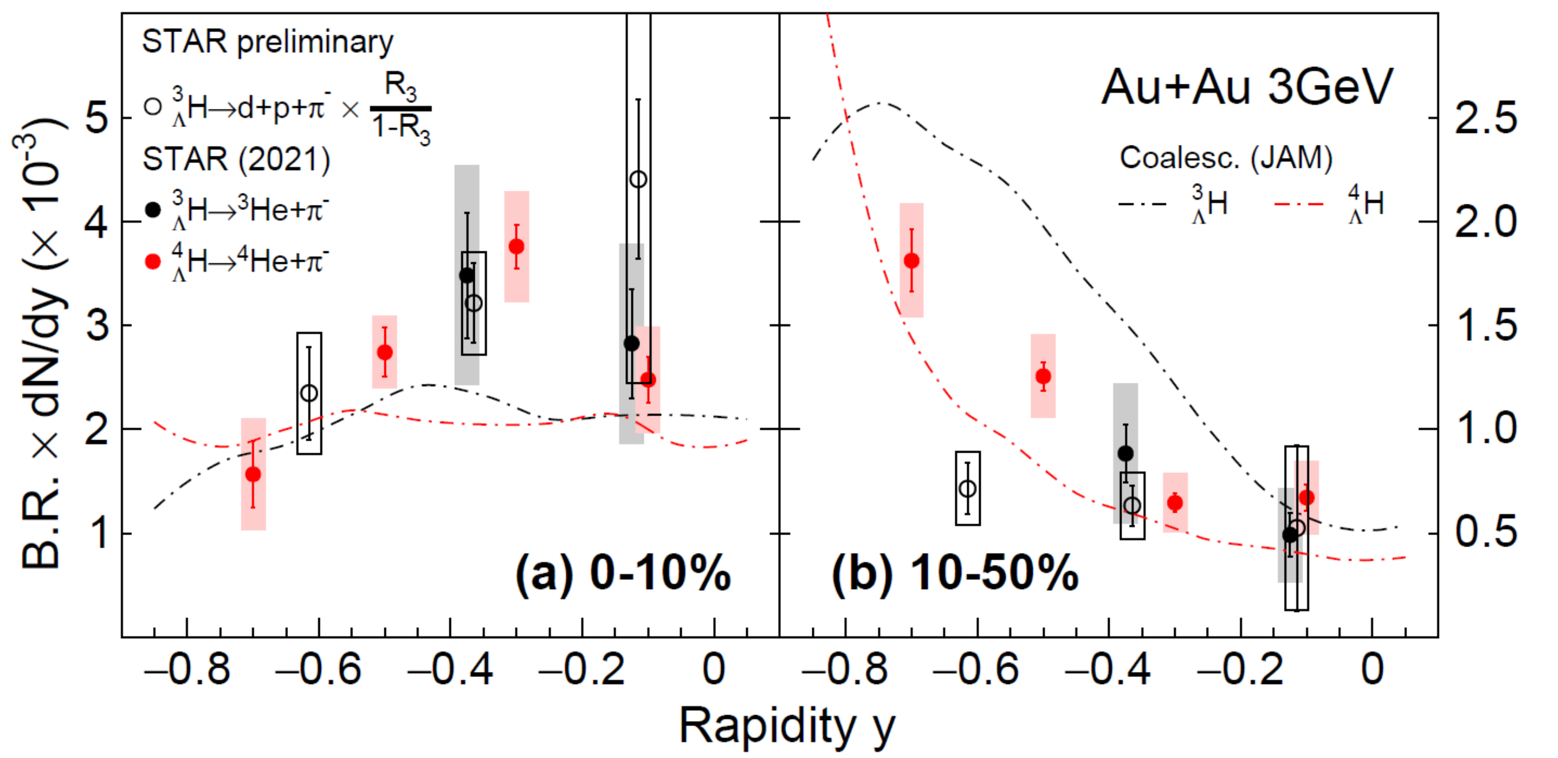
HADES H3L, H4L lifetime (preliminary) S. Spies (HADES), QM2022

JPARC H4L lifetime (2022) arXiv:2302.07443

$$\tau({}^{3}_{\Lambda}H) = 221 \pm 15(stat) \pm 19(syst)\ [ps]$$
$$\tau({}^{4}_{\Lambda}H) = 218 \pm 6(stat) \pm 13(syst)\ [ps]$$
$$\tau({}^{4}_{\Lambda}He) = 229 \quad 23(stat) \pm 20(syst)\ [ps]$$

${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H PRODUCTION AT 3 GEV



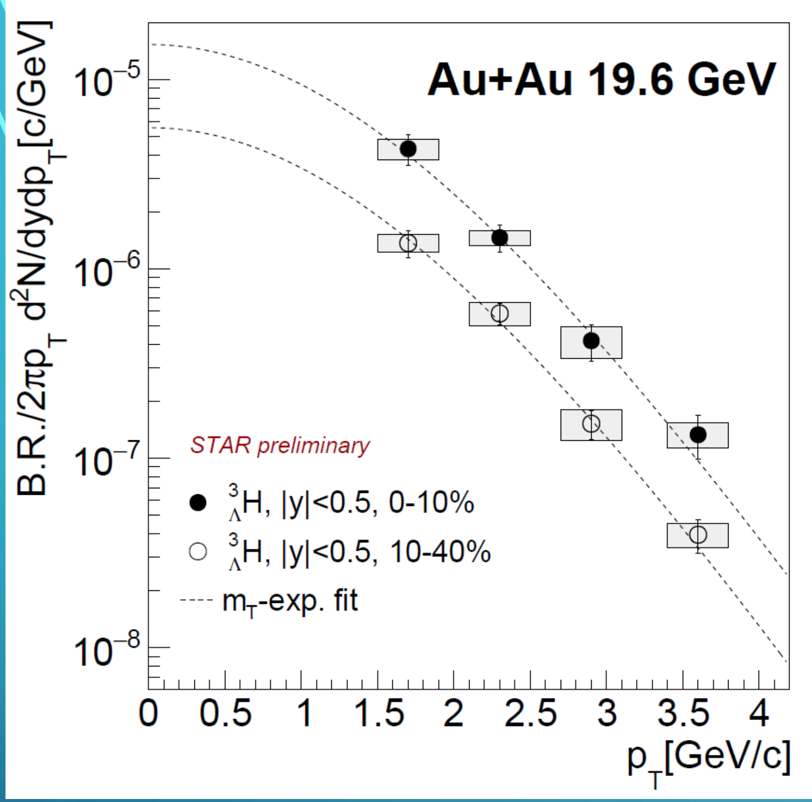


${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H yields obtained as a function of p_T, rapidity and centrality

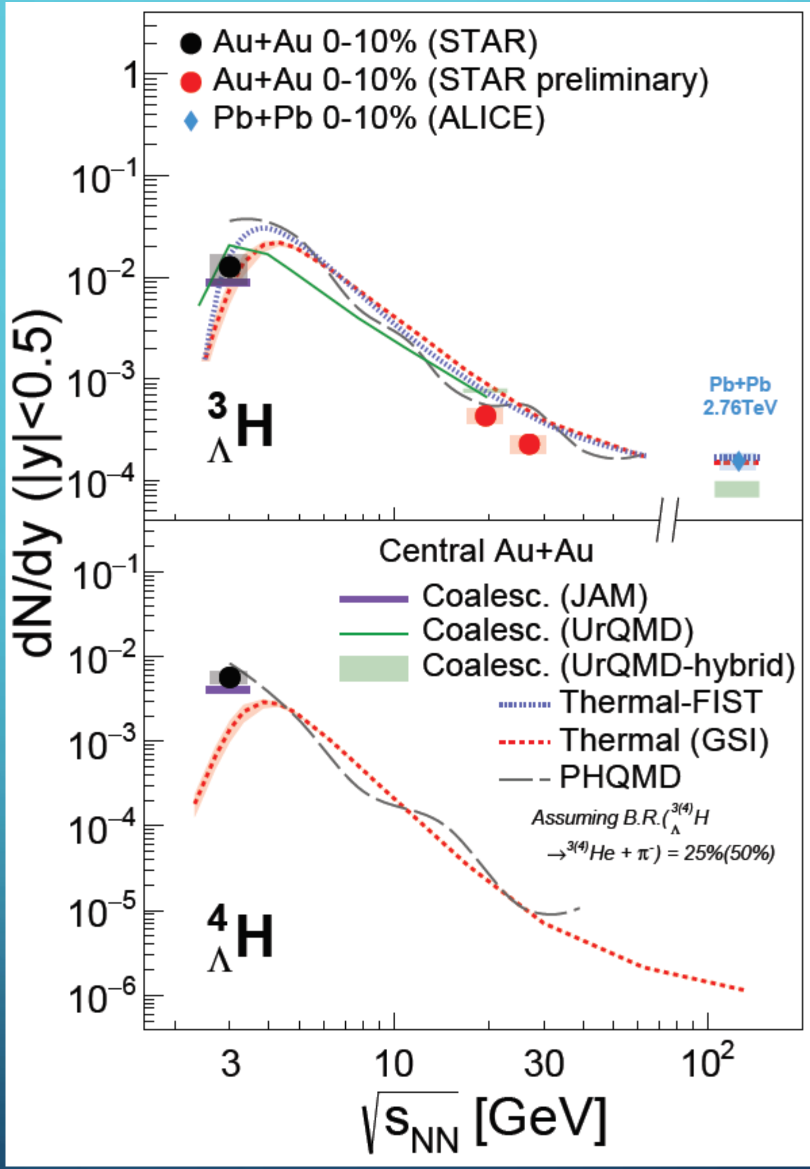
- **First measurement of dN/dy of hypernuclei in HI collisions**
- New challenges for the models

STAR, Phys. Rev. Lett. 128(2022)20, 202301
Y. Nara et al, (1999) PRC 61(1999)024901 (JAM)

$^{3}_{\Lambda}\mathrm{H}$, $^{4}_{\Lambda}\mathrm{H}$ PRODUCTION AT 3 GEV



$^{3}_{\Lambda}\mathrm{H}$ mid-rapidity yields obtained as a function of p_T and centrality at 19.6 and 27 GeV



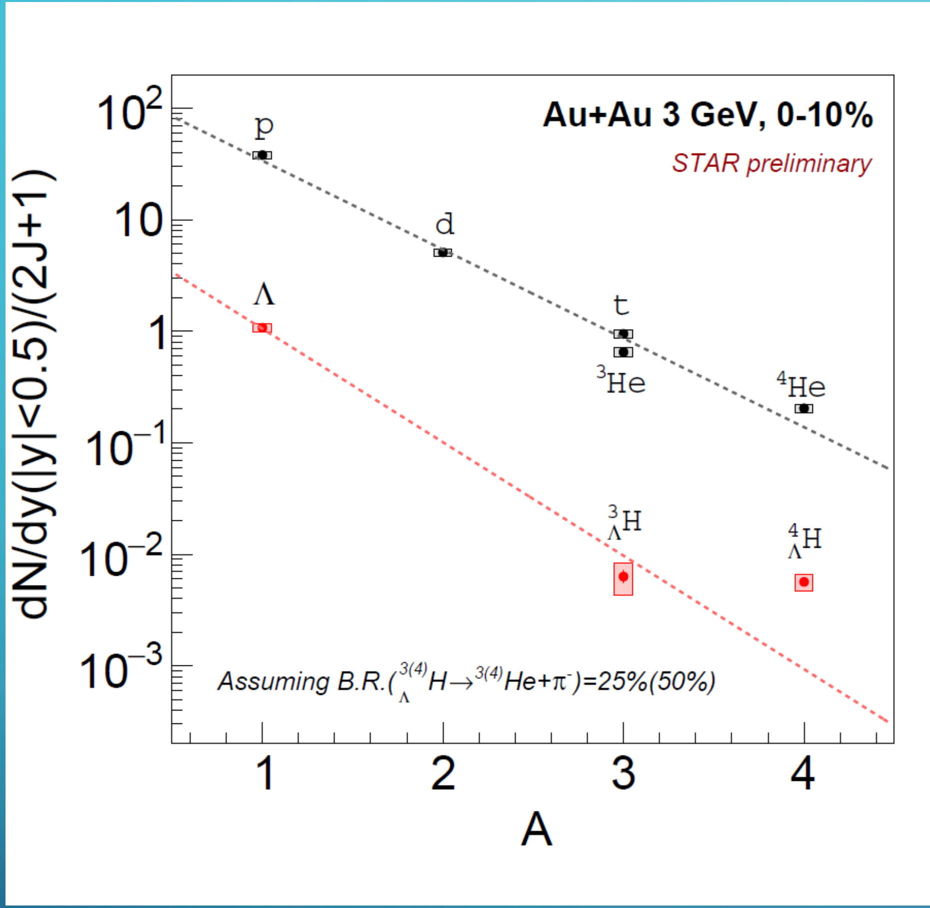
$^{3}_{\Lambda}\mathrm{H}$ yield at mid-rapidity increases about factor of 10^2 from 2.76 TeV to 3 GeV

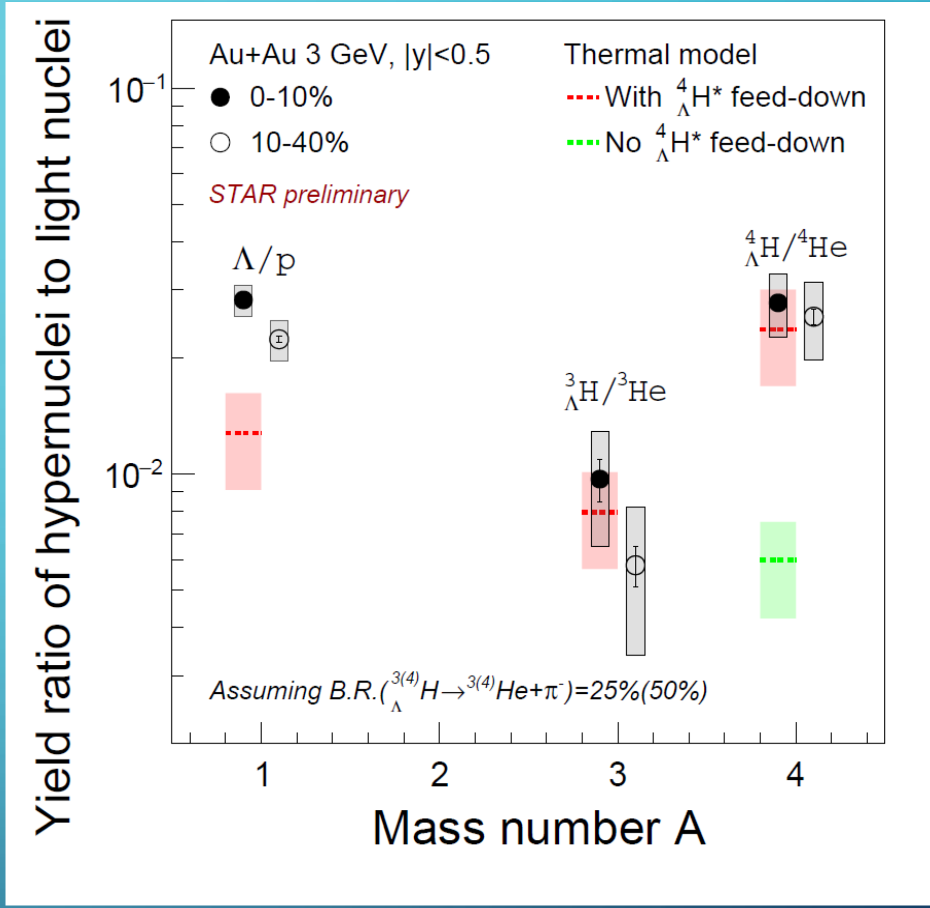
Thermal model (GSI-Heidelberg) reproduces the trend, but does not quantitatively describe the yields of $^{3}_{\Lambda}\mathrm{H}$ and $^{4}_{\Lambda}\mathrm{H}$

PHQMD reproduce $^{4}_{\Lambda}\mathrm{H}$ yield, but overestimate $^{3}_{\Lambda}\mathrm{H}$

New data provide first constraints for hypernuclei production models in the high-baryon-density region

HYPERNUCLEI VS LIGHT NUCLEI AT 3 GEV





Thermal/coalescence models predict approximately exponential dependence of yields/(2J+1) vs A

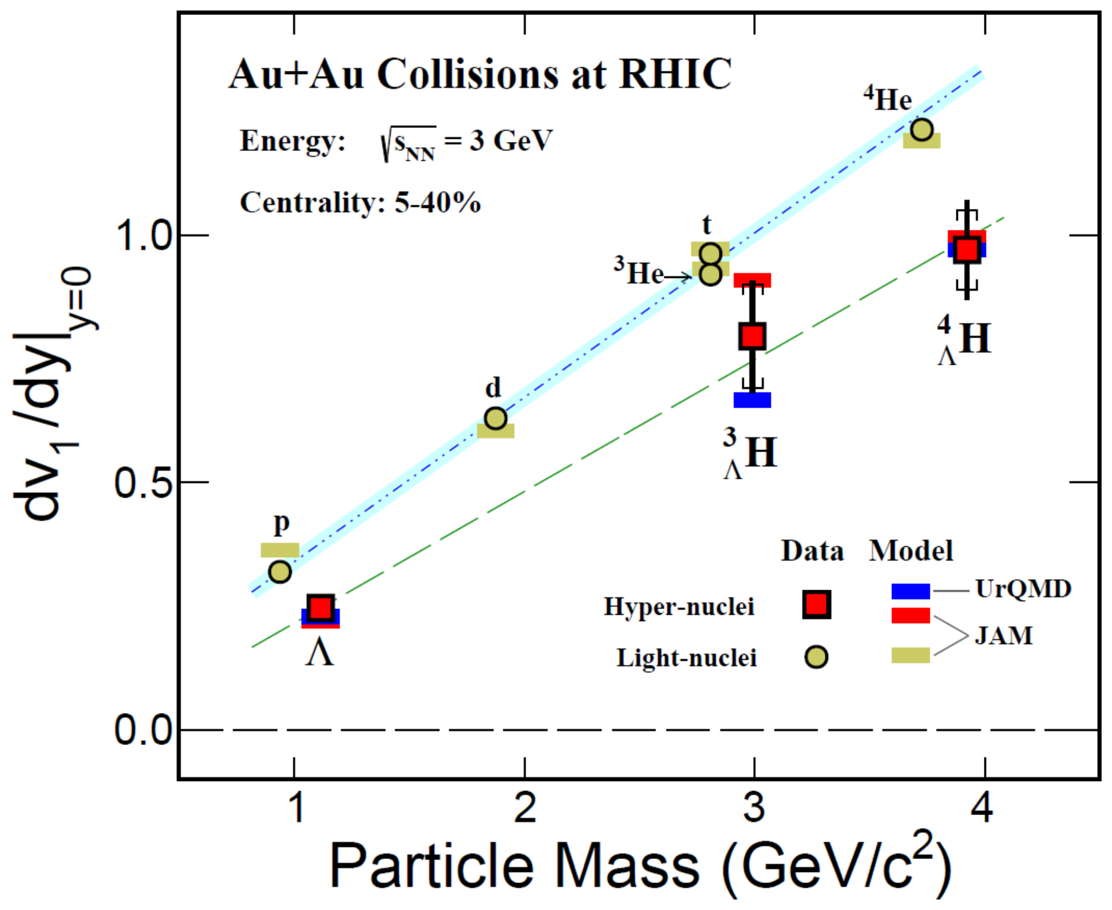
factor 6 above fit for $^{4}_{\Lambda}\mathrm{H}$

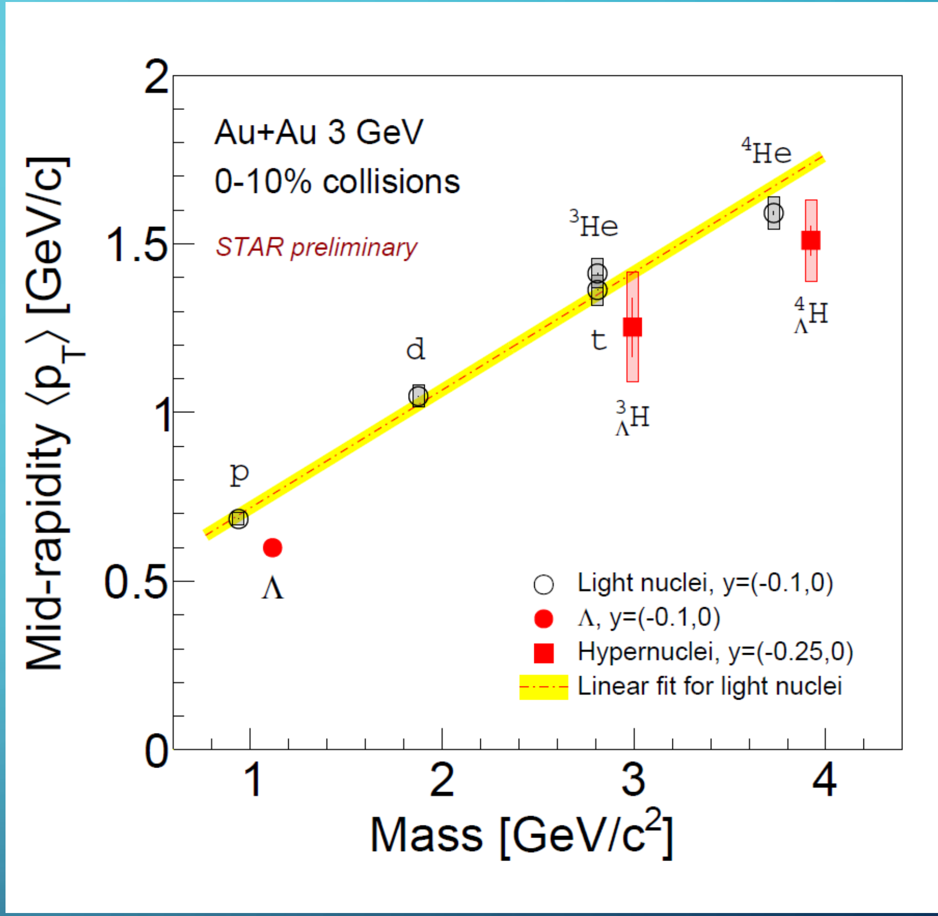
Non-monotonic behavior in light-to hyper-nuclei ratio vs A observed

Data support creation of excited A=4 hypernuclei from heavy-ion collisions

$^{4}_{\Lambda}\mathrm{H}^{*}(J^{+}=1) \rightarrow {}^{4}_{\Lambda}\mathrm{H}(J^{+}=0) + \gamma$

HYPERNUCLEI COLLECTIVITY AT 3 GEV



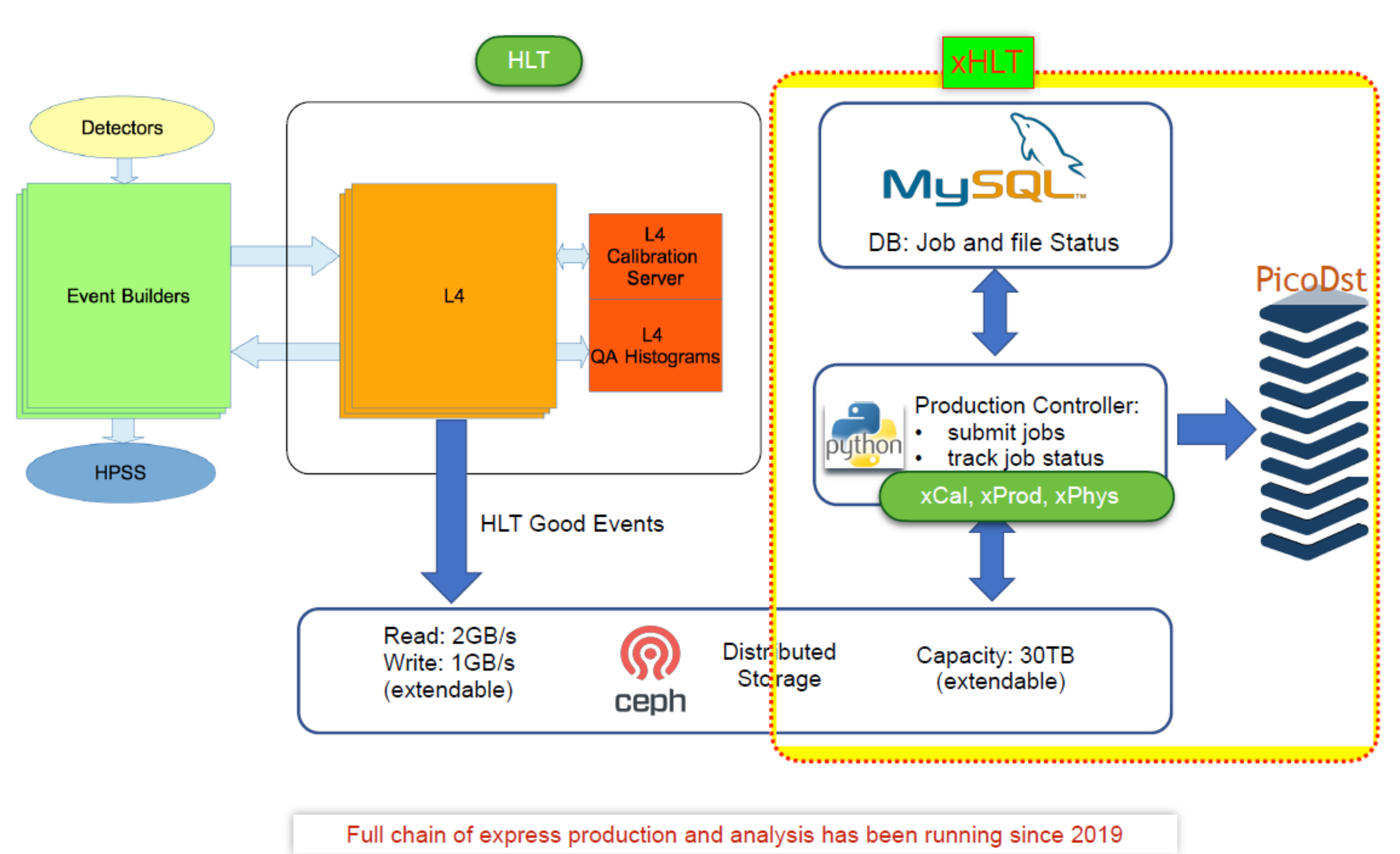


- **First observation of hypernuclei collectivity v_1 in HI collisions**
- v_1 slope follows **mass number scaling** in 5-40% 3 GeV Au+Au collisions, similar to light nuclei

Phys. Rev. Lett. **130**, 212301 (2023)

Dominance of collective radial motion

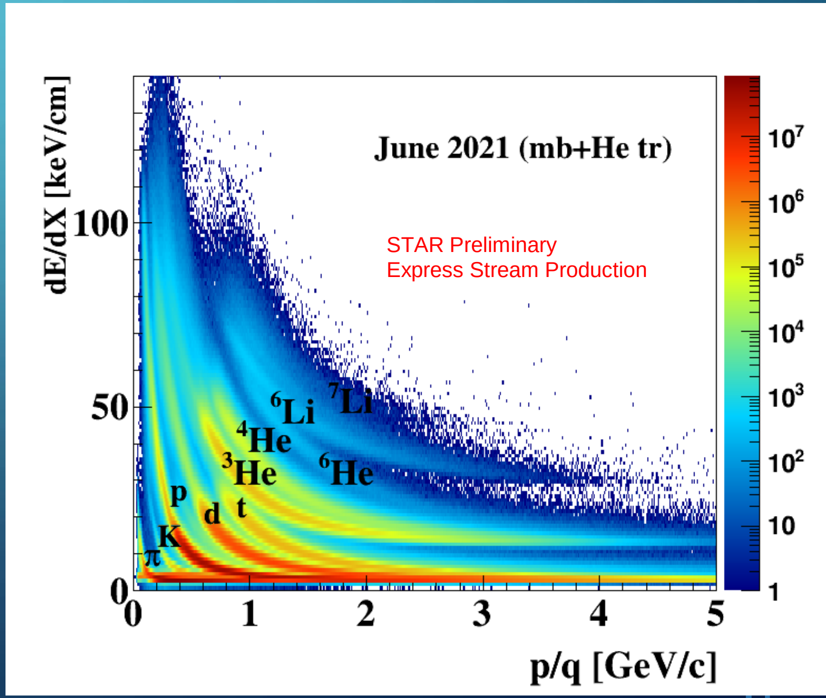
HYPERNUCLEI IN STAR WITH EXPRESS ANALYSIS



Express Production (selection) jobs on HLT farm (300-500 job slots)

Trigger on He has been introduced to enhance **hypernuclei.**

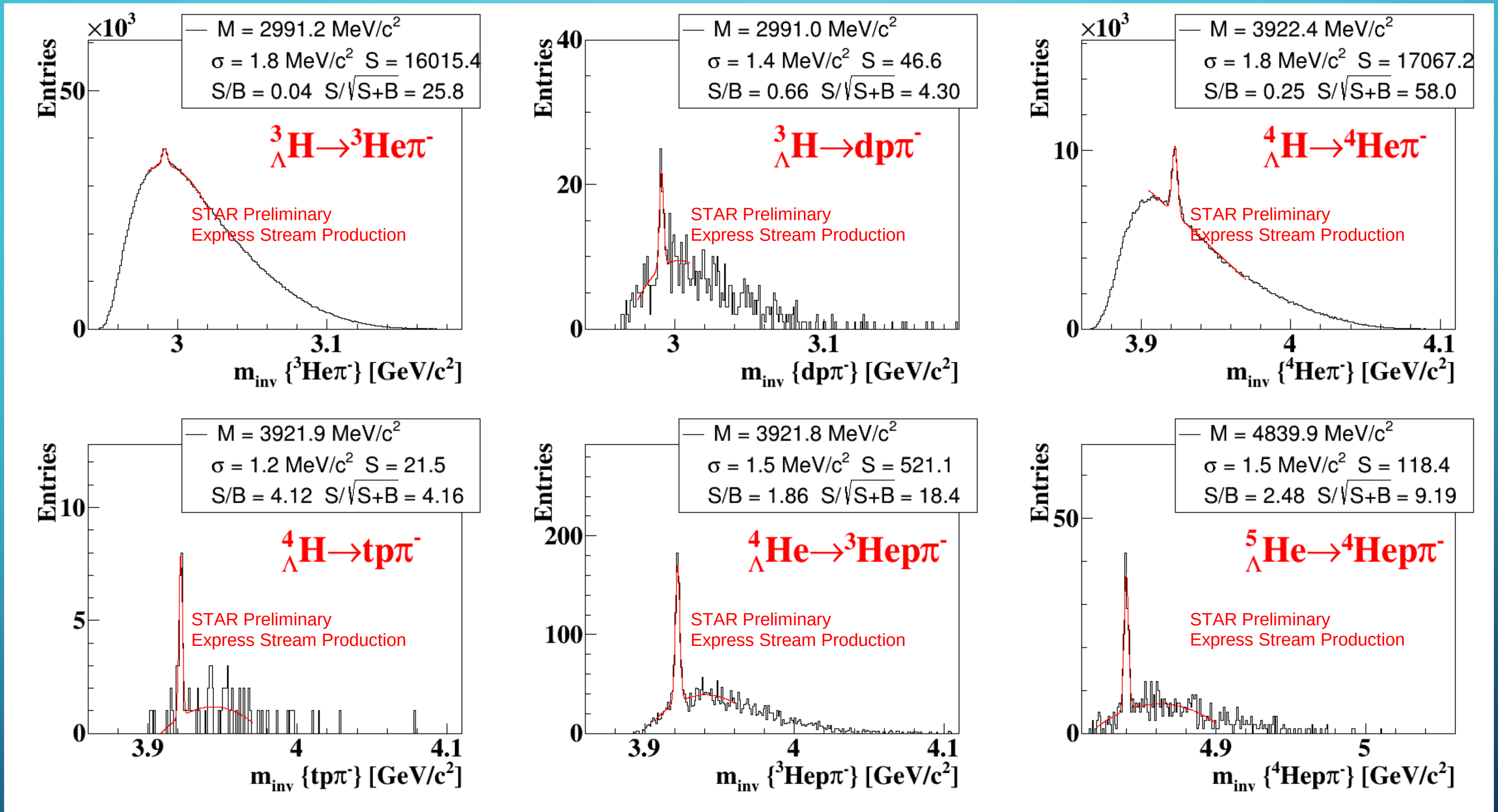
437M AuAu HLT triggered events at 3 GeV



Save HLT good events to a local disk directly

PicoDst files produced in hours (collisions) or days (FXT) after data taking

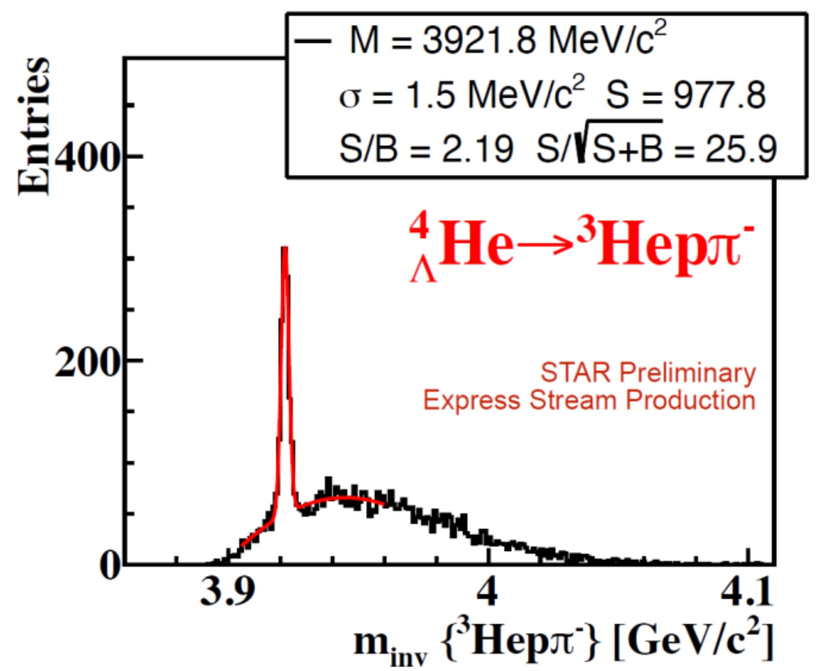
437M HLT TRIGGERED EVENTS AT 3 GEV

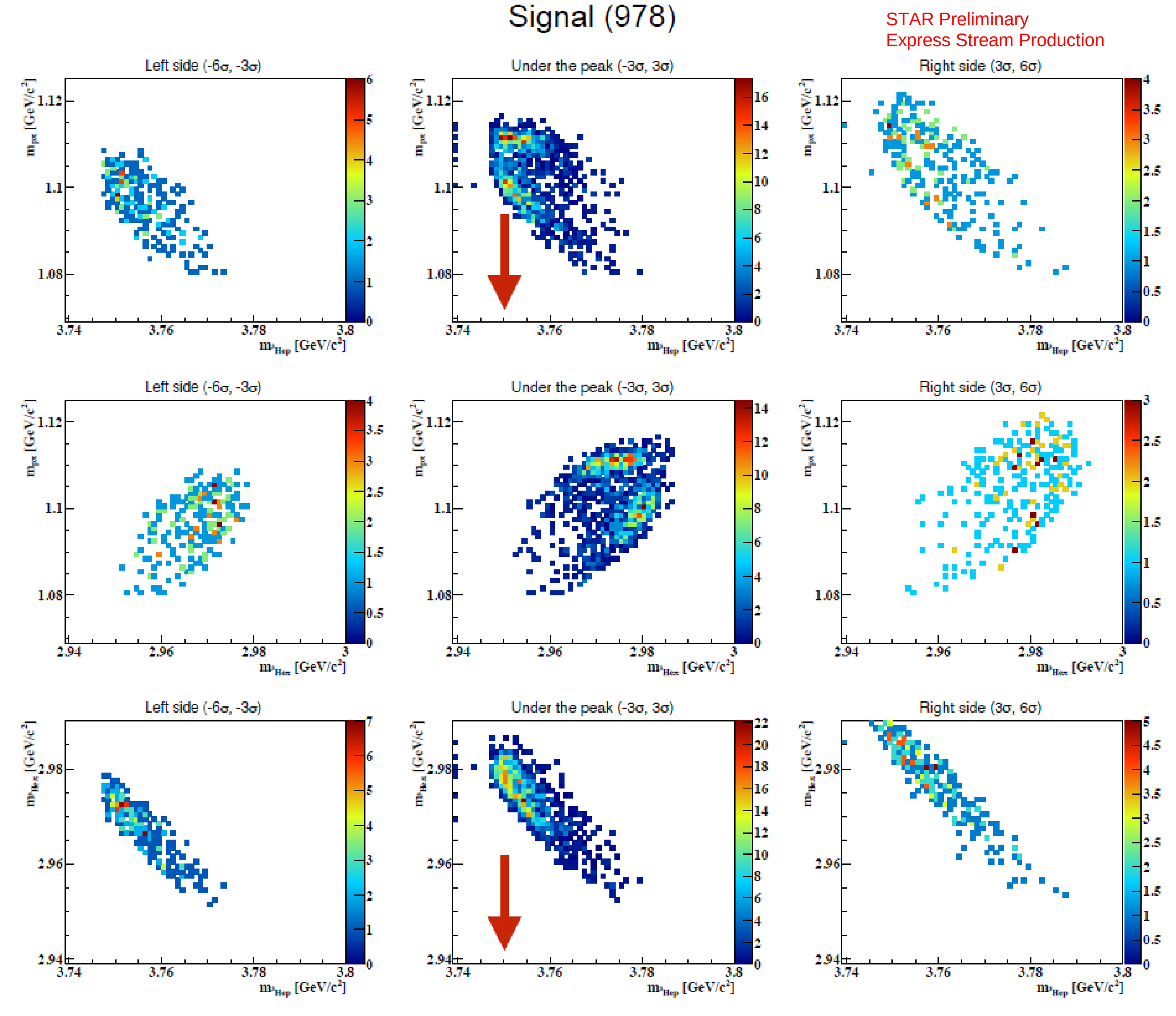


- With increased beam collision intensity in the Fixed Target mode HLT farm had not enough capacities to process all collected data online.
- Therefore a trigger on He has been introduced to enhance hypernuclei.

The collected statistics is enough to measure yields, lifetimes and spectra of these hypernuclei

2018-2020, 2021X FXT AND 2021X COLLIDER AT 7.7 GEV



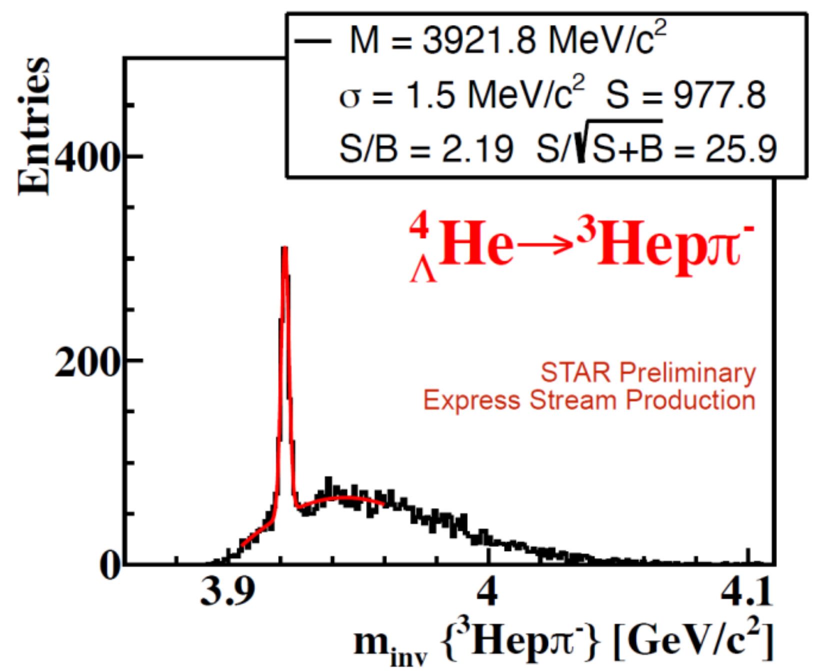


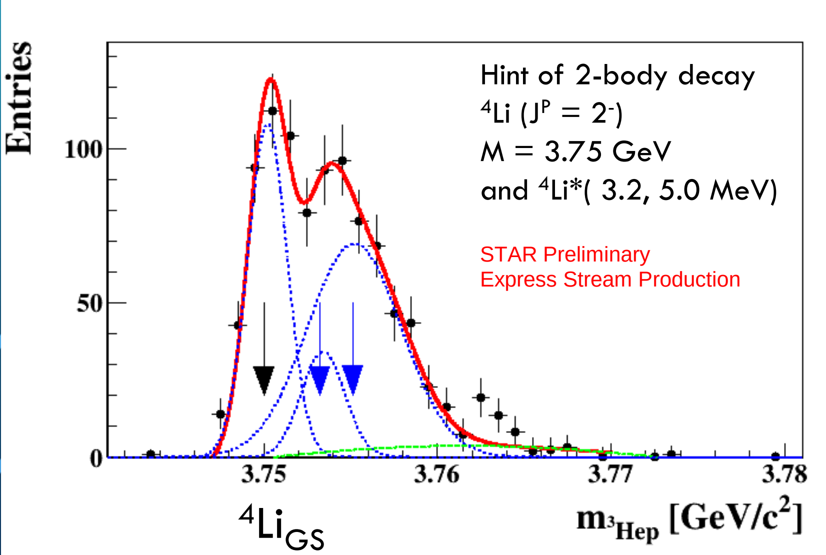
The background was estimated with the side band method and subtracted under the peak.

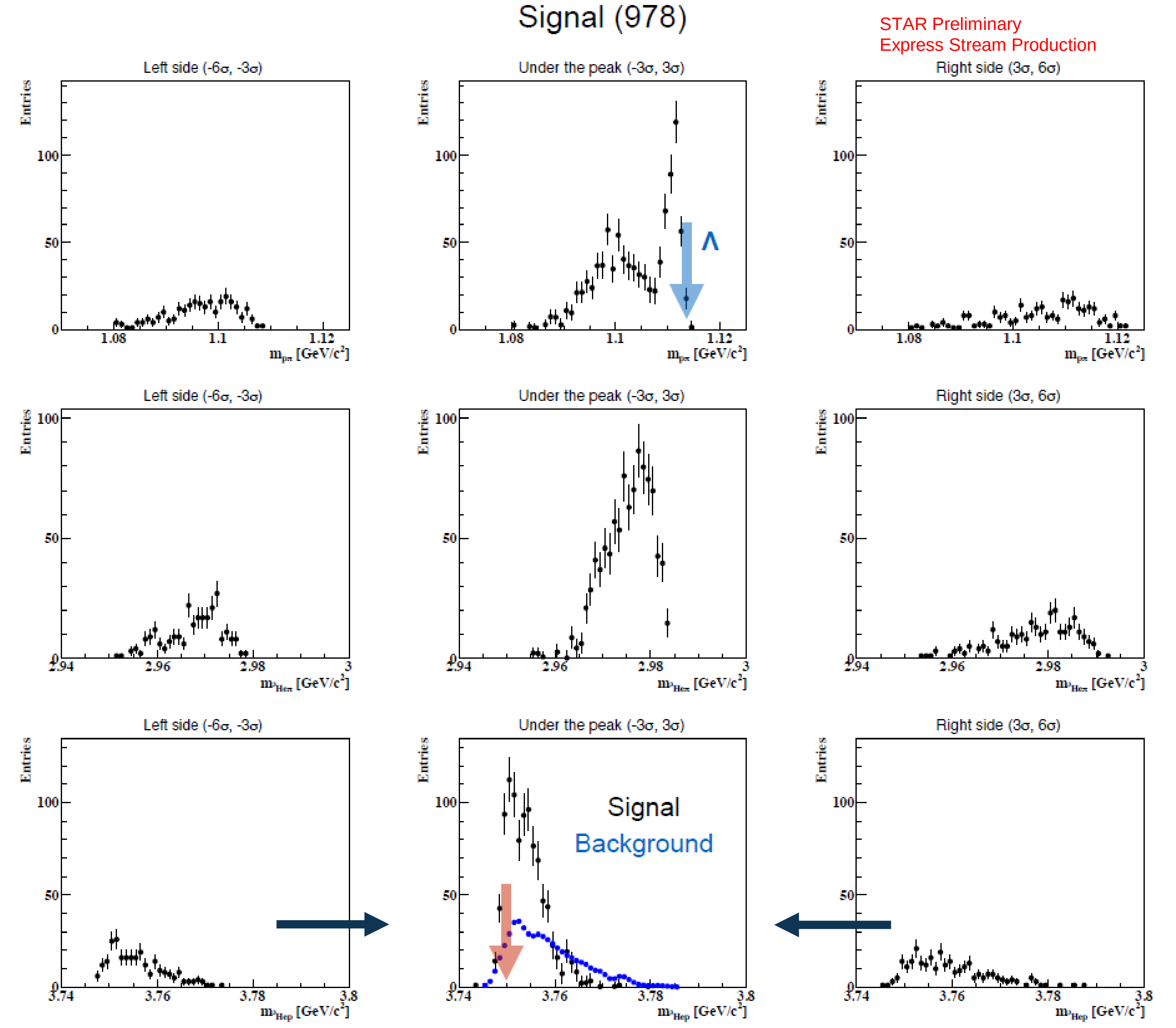
- The background is smooth and no structures is observed.
- A complex structure in the signal can be explained as a possible spin effect.

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

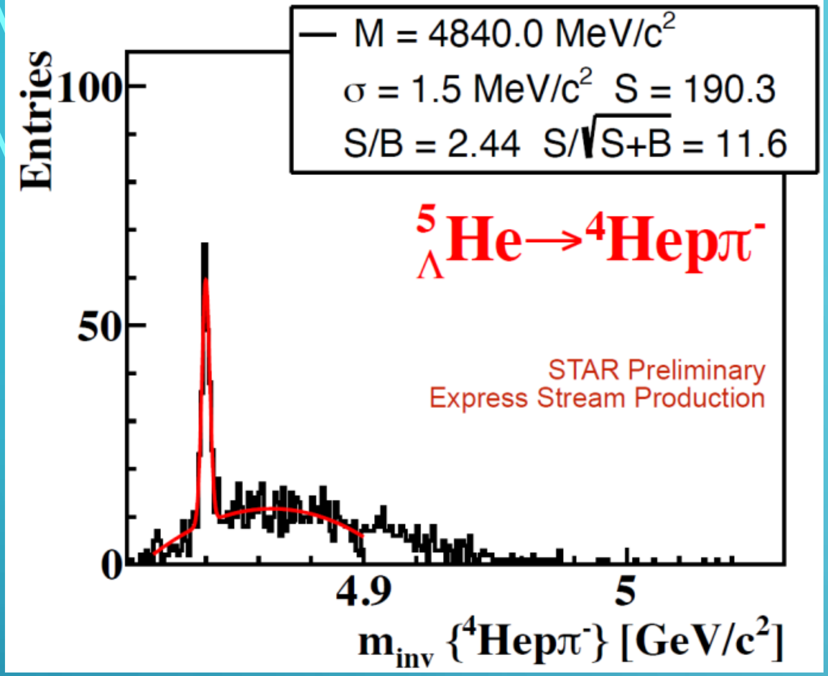
2018-2020, 2021X FXT AND 2021X COLLIDER AT 7.7 GEV

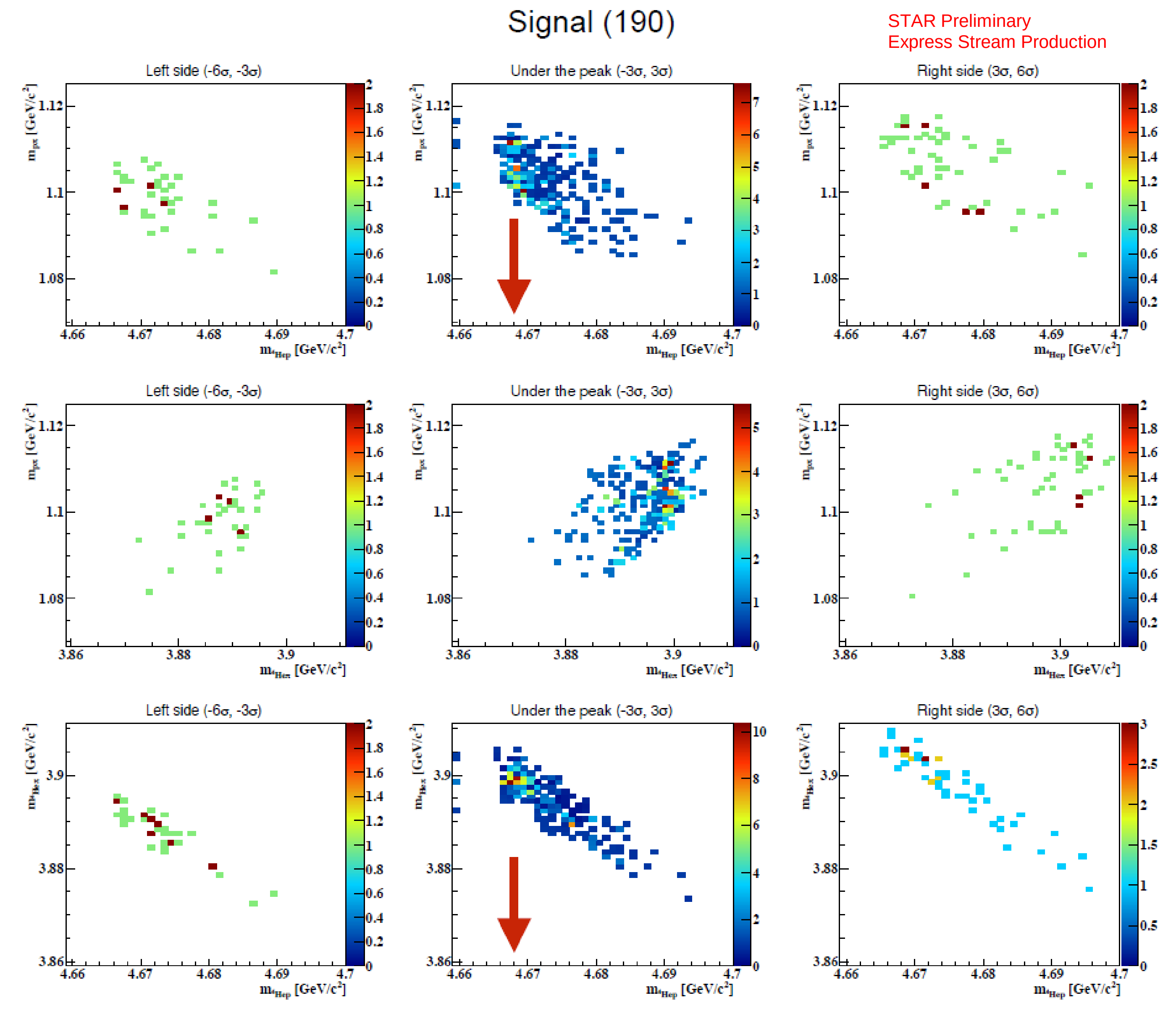






2018-2020, 2021X FXT AND 2021X COLLIDER AT 7.7 GEV

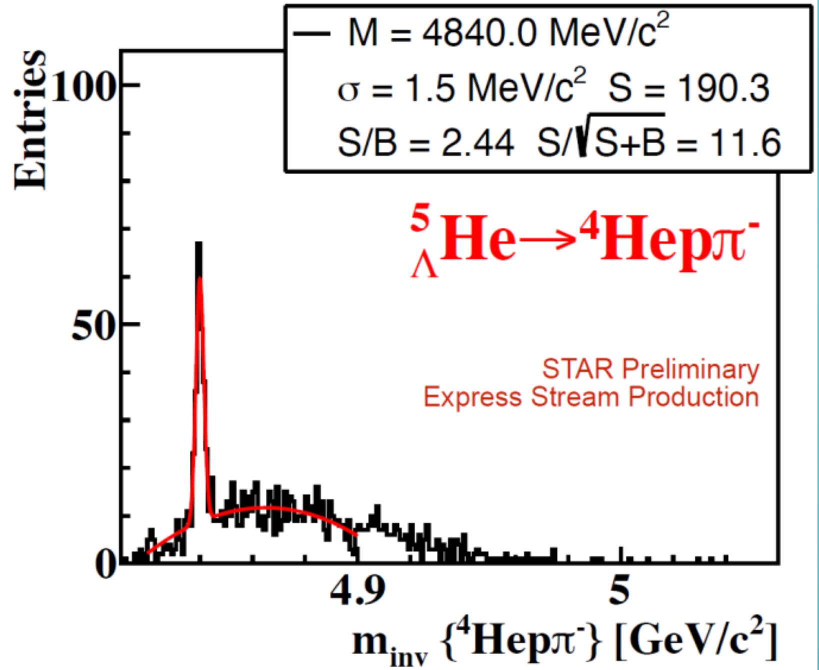


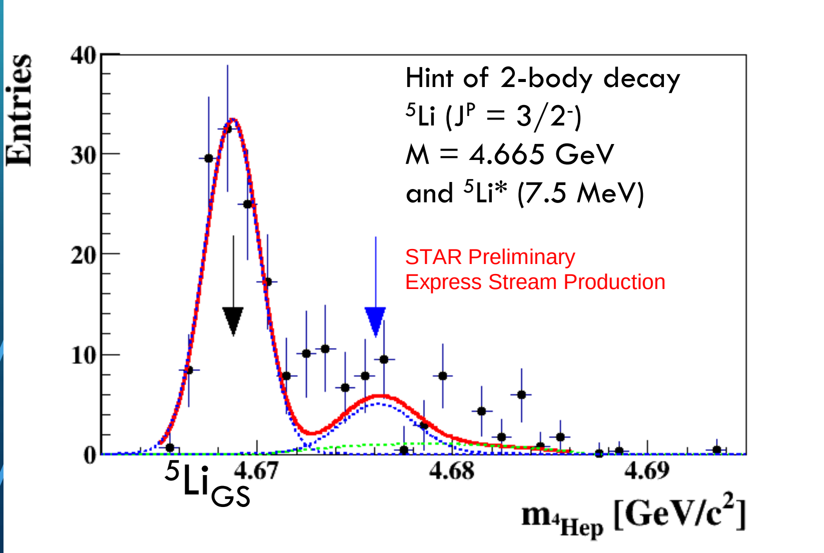


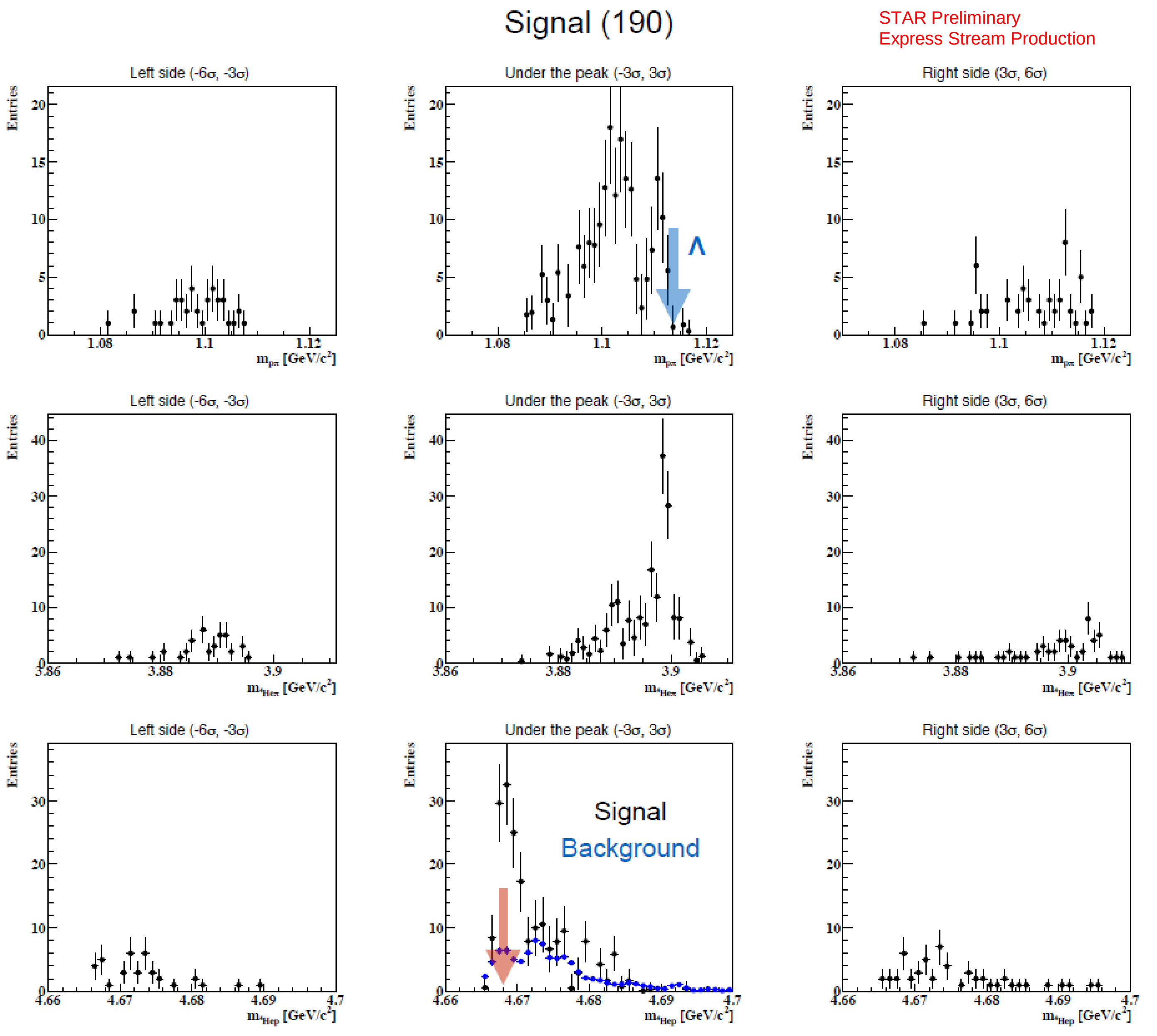
With ${}^{5}_{\Lambda}$He we observe similar structures to ${}^{4}_{\Lambda}$He case

The background is smooth and no structures are observed.

2018-2020, 2021X FXT AND 2021X COLLIDER AT 7.7 GEV







SUMMARY

- Updated set of hypernuclei measurements in the high-baryon-density region with high statistical precision
- ${}^{3}_{\Lambda}\mathrm{H}$, ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$ lifetimes measured with improved precision
- New measurements of ${}^{3}_{\Lambda}\mathrm{H}$, ${}^{4}_{\Lambda}\mathrm{H}$ differential yields at 3.0, 19.6 and 27 GeV
- First observation of hypernuclei collectivity v_1
- We observe ${}^{5}_{\Lambda}\mathrm{He}$ with significance of 11.6 σ
- Hints that a significant part of 3-body decays happen via nuclei resonances