E73 status report

Ready for data taking

$(80kW \times 25days)$

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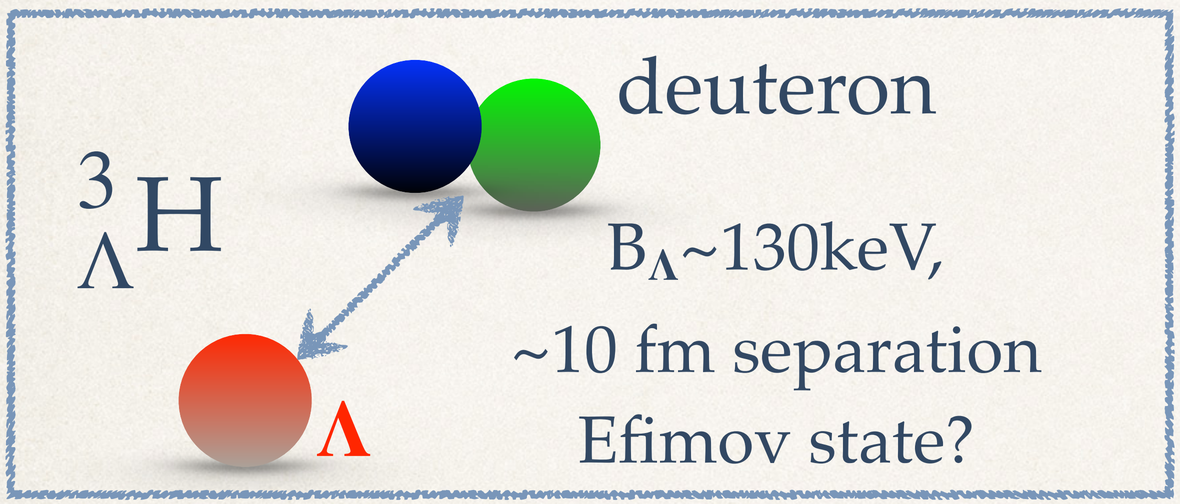
Outline

- Introduction to J-PARC E73:
  - The first direct measurement for ${}^{3}_{\Lambda}H$ lifetime
- J-PARC E73 review
  - Pilot run: ${}^{4}_{\Lambda}H$ lifetime as feasibility study, June, 2020
  - Stage-1: ${}^{3}_{\Lambda}H$ production cross section measurement, May, 2021
  - Stage-2: ${}^{3}_{\Lambda}H$ lifetime measurement
    - Stage-2 approved by the 33rd PAC with $80kW \times 25days$ beam time;
    - Beam time allocation confirmed by the 34th and 35th PAC
- Summary

Introduction: hypertriton lifetime puzzle

As the lightest hypernucleus, ${}^{3}_{\Lambda}H$ serves as the cornerstone for hypernuclear physics just as deuteron for nuclear physics.

Up to a few years ago, we believe:
$\tau \approx 263$ ps ($B_{\Lambda} = 130 \pm 50$ keV);
However, heavy ion experiments suggest $\tau \approx 180$ ps…



${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$ decay probability:
kinematics× | transition matrix |^{2}
~ phase space×wave function overlap

a small term
(separation of ~10fm)

Hypertriton lifetime puzzle challenges the very foundation of our knowledge for hypernucleus.

Introduction: hypertriton lifetime puzzle

E73 proposal submitted in 2018

Collaboration	Experimental method	${}^{3}_{\Lambda}$H lifetime [ps]	Release date
STAR	Au collider	142^{+24}_{-21}(stat.)±29(syst.)	2018
ALICE	Pb collider	181^{+54}_{-39}(stat.)±33(syst.)	2016
HypHI	fixed target	183^{+42}_{-32}(stat.)±37(syst.)	2013

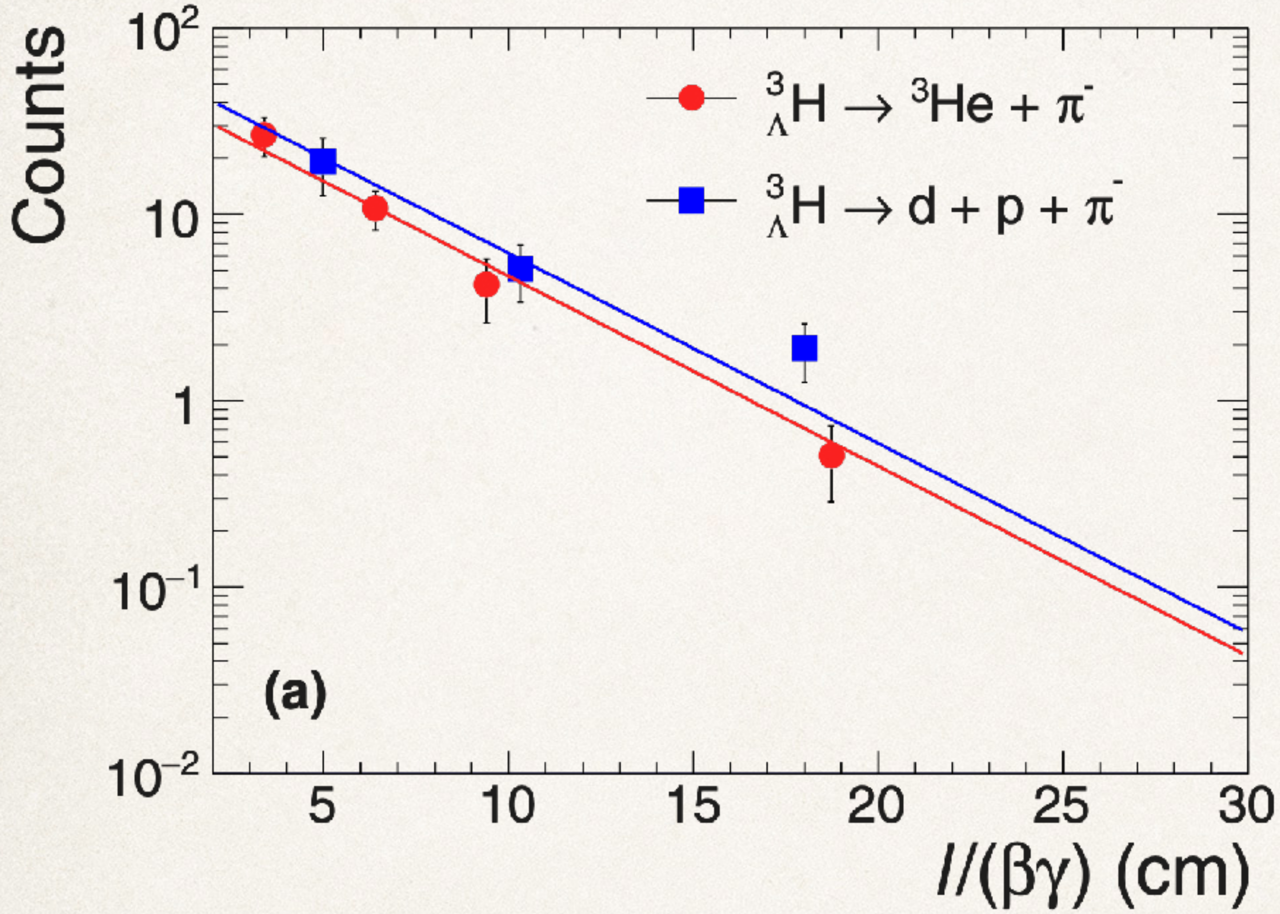
Table 1: Summary of recent measurements on ${}^{3}_{\Lambda}$H lifetime.

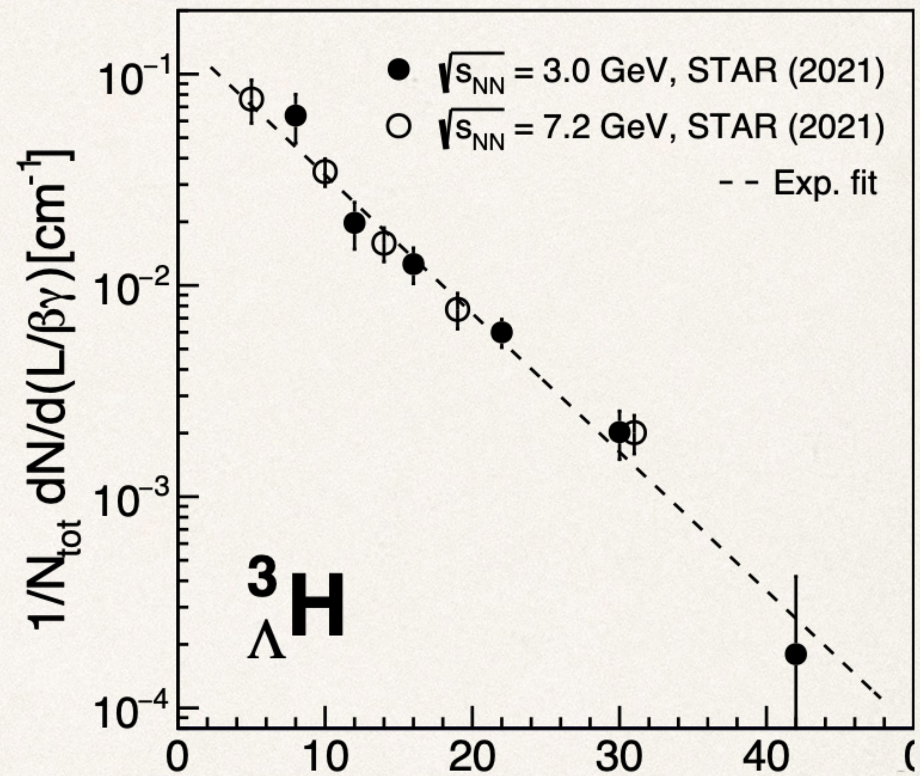
Updated results since then

Collaboration	Experimental method	${}^{3}_{\Lambda}$H lifetime [ps]	Release date
HypHI	fixed target	183^{+42}_{-32}(stat.)±37(syst.)	2013 [4]
STAR	Au collider	142^{+24}_{-21}(stat.)±29(syst.) 221±15(stat.)±19(syst.)	2018 [2] 2021 [6]
ALICE	Pb collider	181^{+54}_{-39}(stat.)±33(syst.) 242^{+34}_{-38}(stat.)±17(syst.)	2016 [3] 2019 [5]

TABLE I. Summary of recent measurements on ${}^{3}_{\Lambda}$H lifetime.

Introduction: hypertriton lifetime puzzle





(doi.org/10.1103/PhysRevLett.128.202301)

STAR 2018:

$\tau \sim 142^{+24}_{-21} \pm 29$ ps

(doi.org/10.1103/PhysRevC.97.054909)

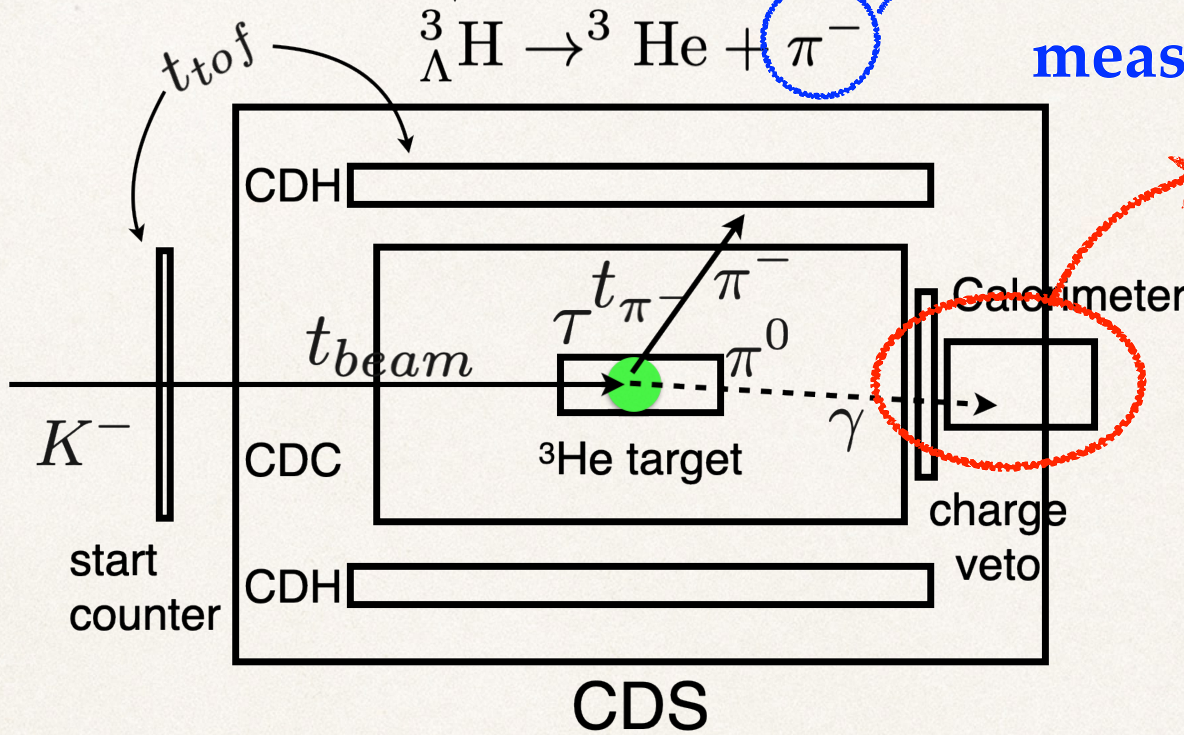
STAR 2022:

$\tau = 221 \pm 15 \pm 19$ ps

(doi.org/10.1051/epjconf/202227108002)

What happened? What shall we do?

E73 experimental setup



$K^- + {}^3\mathrm{He} \rightarrow {}^3_\Lambda\mathrm{H} + \pi^0$

very forward π0 projectile;
tagged with decayed high energy γ

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

mono-energetic, ~114MeV/c;
measured with CDS

5x8 PbF2 Cherenkov Calo
Fully ready

${}^3{}_\Lambda$H decay time can be derived by TOF and CDS tracking

The idea of ***direct measurement***: T_{CDH}-T_0=t_{beam}+$t_{\pi-}$+τ;

1. A complementary measurement for Heavy Ion results
2. Achievable precision: $\sigma/\sqrt{N} < 20$ps
3. ***Direct lifetime measurement with fixed J=1/2 state***

$^{3}He(K^{-}, \pi^{0})^{3}_{\Lambda}H$ vs heavy ion production

Experiment	J-PARC E73	BNL STAR
Production method	$^{3}He(K-, pi0)^{3}_{\Lambda}H$	Au+Au
Microscopic process	Strangeness exchange	Thermal model; Coalescence model
PID	pi- momentum	Invariant mass;
Quantum number	spin=1/2 dominant	1/2 and 3/2 mixture?
Lifetime derivation	Time of flight	Decay length

J-PARC E73 staging & status

Staging:	Pilot (June, 2020)	Stage-1 (May, 2021)	Stage-2
Task:	Background study with $^4He(K^-,\pi^0)^4_\Lambda H$	First measurement for $^3He(K^-,\pi^0)^3_\Lambda H$ reaction	Direct lifetime measurement for $^3_\Lambda H$
Output:	Established a new method as: (K-,pi0) + decay spectrum	Production cross section study for $^3_\Lambda H$ @ 1GeV/c	Pin down Hypertriton lifetime puzzle
Status:	$^4_\Lambda H$ lifetime paper submitted to PLB	Successfully observed $^3_\Lambda H$ from mesonic weak decay	Request for beam time allocation (80kWx25days)

Pilot run results: ${}^{4}_{\Lambda}$H lifetime

$$K^{-} + {}^{4}\mathrm{He} \rightarrow {}^{4}_{\Lambda}\mathrm{H} + \pi^{0}$$

slows down inside ^{4}He target and decays at rest

$${}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-} \quad 132.9\ \mathrm{MeV}/c$$

132.6 ± 0.1 (stat.) MeV / c

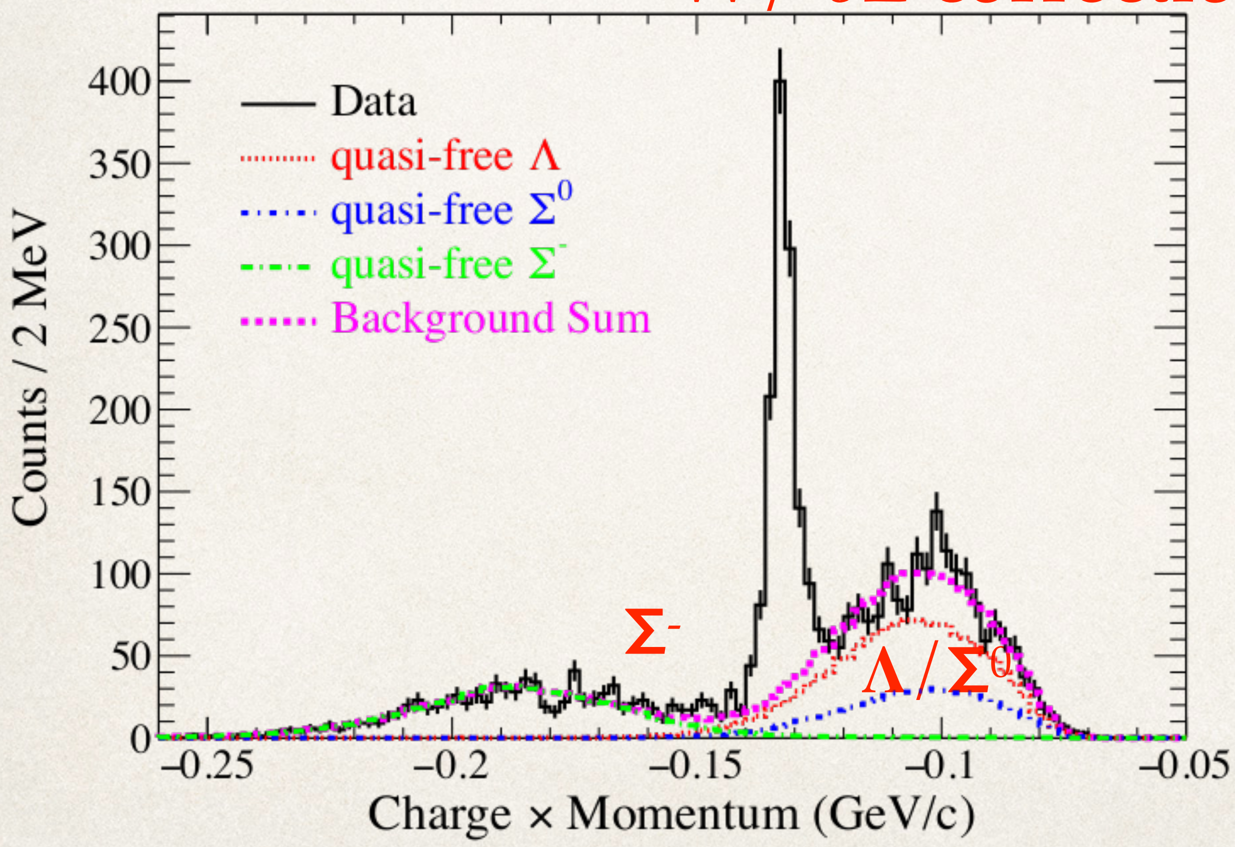
W/ δE correction

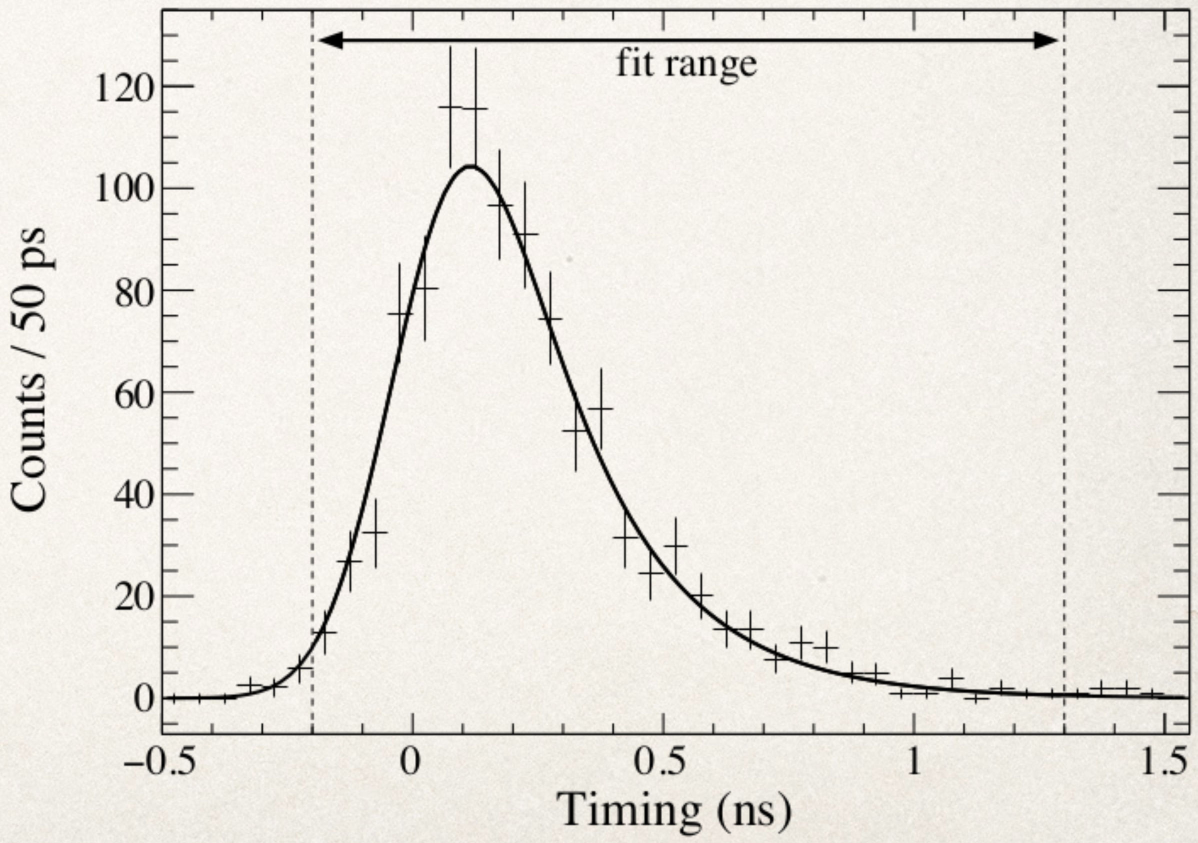
218 ± 6(stat.) $\pm$ 13(sys.) ps

@ STAR, Au-Au collision

(doi.org/10.1103/PhysRevLett.128.202301)

206 ± 8(stat.) $\pm$ 12(syst.) ps





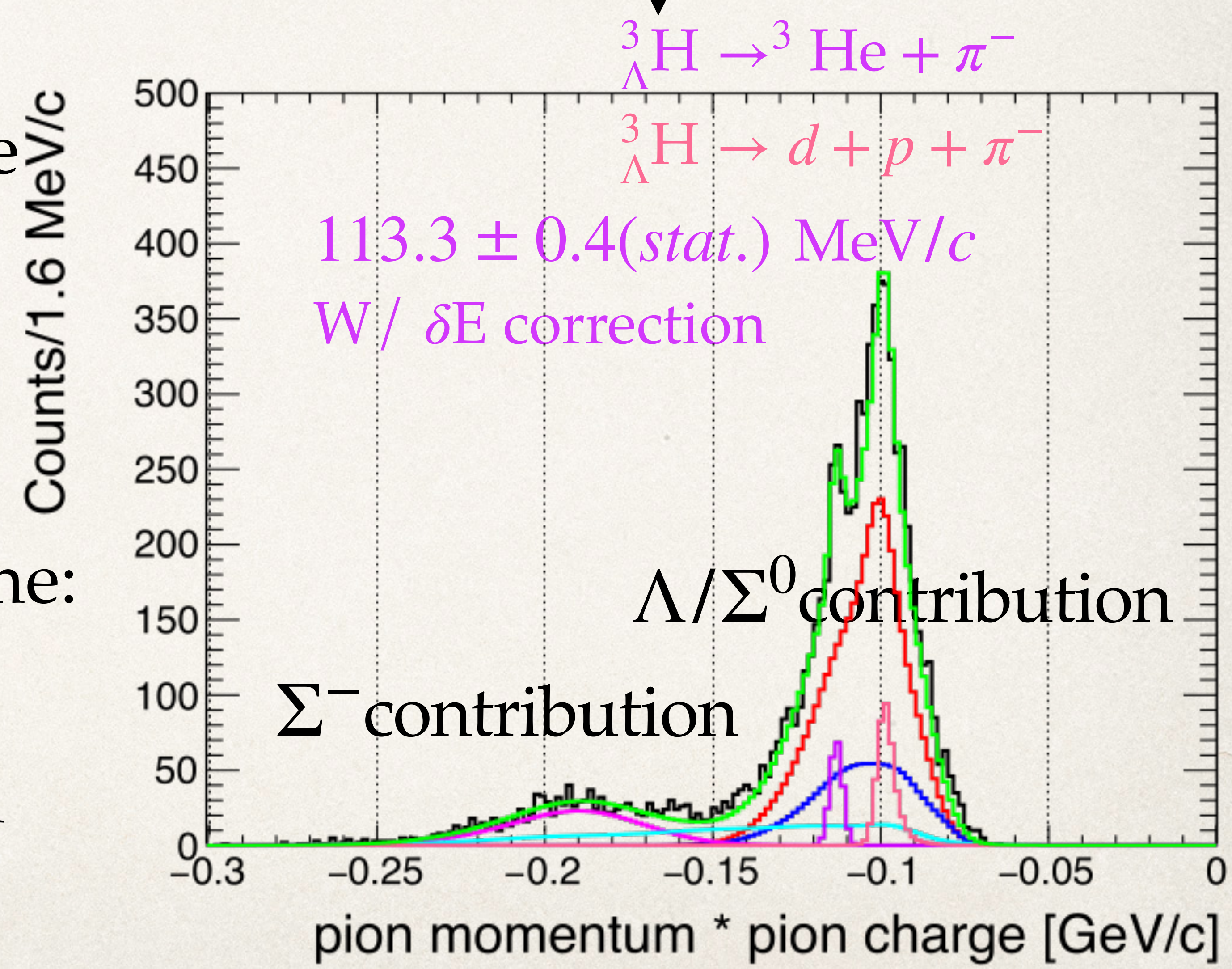
Stage-1 results: ${}^{3}_{\Lambda}$H cross section

- First measurement for ^{3}He(K-, pi0)$^{3}_{\Lambda}$H reaction cross section; direct determination of $^{3}_{\Lambda}$H ground state spin;
- Ready for E73 Stage-2 beam time with 25days @ 80kW beam time for ~1k 2-body decay events scaled with Phase-1 data
- Expected precision for ${}^{3}_{\Lambda}$H lifetime:
  - statistical error ~20 ps;
  - systematic error ~20 ps based on the ${}^{4}_{\Lambda}$H result

273kW*Day executed in May, 2021

$$\mathrm{K}^- + {}^3\mathrm{He} \rightarrow {}^3_\Lambda\mathrm{H} + \pi^0$$

slows down and decays at rest



Comments from the 35th PAC meeting

E73

PAC recommended allocating a 25-day 80 kW beam for E73 in FY2023 if the schedule and the budget permits in the 34th meeting. PAC congratulates that the team has obtained A, result of the measurement of the lifetime of $_{\Lambda}^{4}$H in the pilot experiment to demonstrate the feasibility of the experimental setup and is preparing its publication. PAC recognizes that B, ratio of the production cross sections of $_{\Lambda}^{3}$H and $_{\Lambda}^{4}$H provides the binding energy, giving a better understanding of the structure of $_{\Lambda}^{3}$H. We note that the length of the run will need be determined accordin C, the JFY2023 budget, schedule, and the availability of the intense beam requested by E73.

Update A: ${}^{4}_{\Lambda}H$ lifetime paper

- Submitted to Physics Letters B
- Received positive feed back from referee
- Revising our draft and the paper will appear soon

Update B: binding energy vs ${}^{3}_{\Lambda}H/{}^{4}_{\Lambda}H$ ratio

- With the help of Prof. Harada, remarkable progress has been made by our brilliant PhD student T. Akaishi from Osaka University.

- T. Akaishi is finalizing his results and writing his PhD thesis.

Update C: K1.8BR beam time schedule

- E73 is ready for data taking
- ***Because of the successive experiments assigned to K1.8BR beam line (c.f. backup slide P18), we propose to complete E73 data taking before the 2024 summer shut down***
  - ***If required, we can separate E73 data taking into two parts without degrading the precision of Hypertriton lifetime***

Summary

- 35th PAC recommends $80kW \times 25days$ beam time for E73 experiment
  - Expected precision for ${}^{3}_{\Lambda}H$ lifetime: ~20 ps (stat.) ~20 ps (syst.)
- We are ***ready*** for data taking and aim to complete before 2024 summer
- Outputs:
  - Physics paper for ${}^{4}_{\Lambda}H$ lifetime under review by Physics Letter B with positive feedback
  - PhD thesis on constraining ${}^{3}_{\Lambda}H$ binding energy with ${}^{3}_{\Lambda}H / {}^{4}_{\Lambda}H$ production cross section ratio by T. Akaishi

E73/T77 collaborator list

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backup

K1.8BR beam line schedule

Experimental Programs @ K1.8BR

- **Present CDS**
  - ✓E73 ($^{3}_{\Lambda}H$ lifetime) 25d@80kW

need 3-6 months for change-over

- **Hyp-TPC**
  - ✓E72 (Λ^*) 14d@80kW

need 1 year or more for change-over

- **New CDS with K1.8BR modification**
  - ✓E80 ($K^-ppn \rightarrow \Lambda d/\Lambda pn$) 35d@90kW
  - ✓P89 ($J^P(K^-pp)$) 56d@90kW