K⁻ビームを用いたハイパートライトンの寿命直接測定の現状(2)
-$^{3}_{\Lambda}$H production result-

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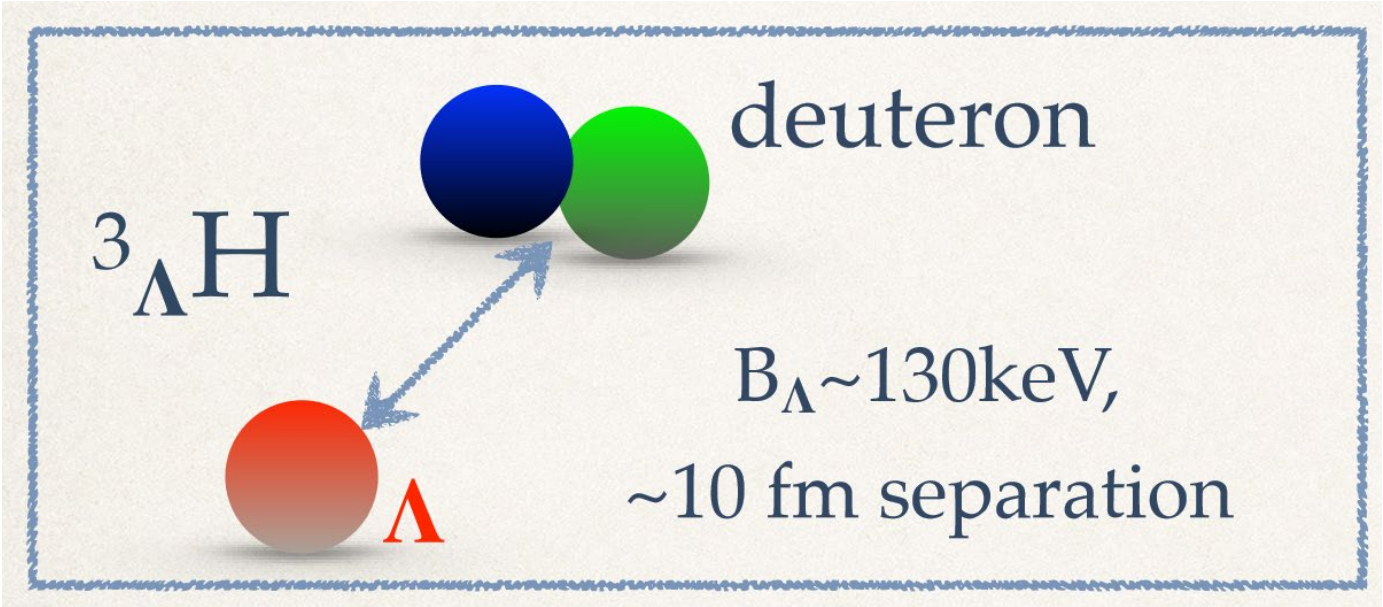
For the J-PARC E73 collaboration

Introduction

- Hypertriton ($^{3}_{\Lambda}$H): Lightest hypernucleus with p, n and Λ
  - ➢Benchmark for hypernuclear physics
  - ➢Small binding energy by emulsion data has been generally accepted.

    B_Λ = 130 ± 50 keV

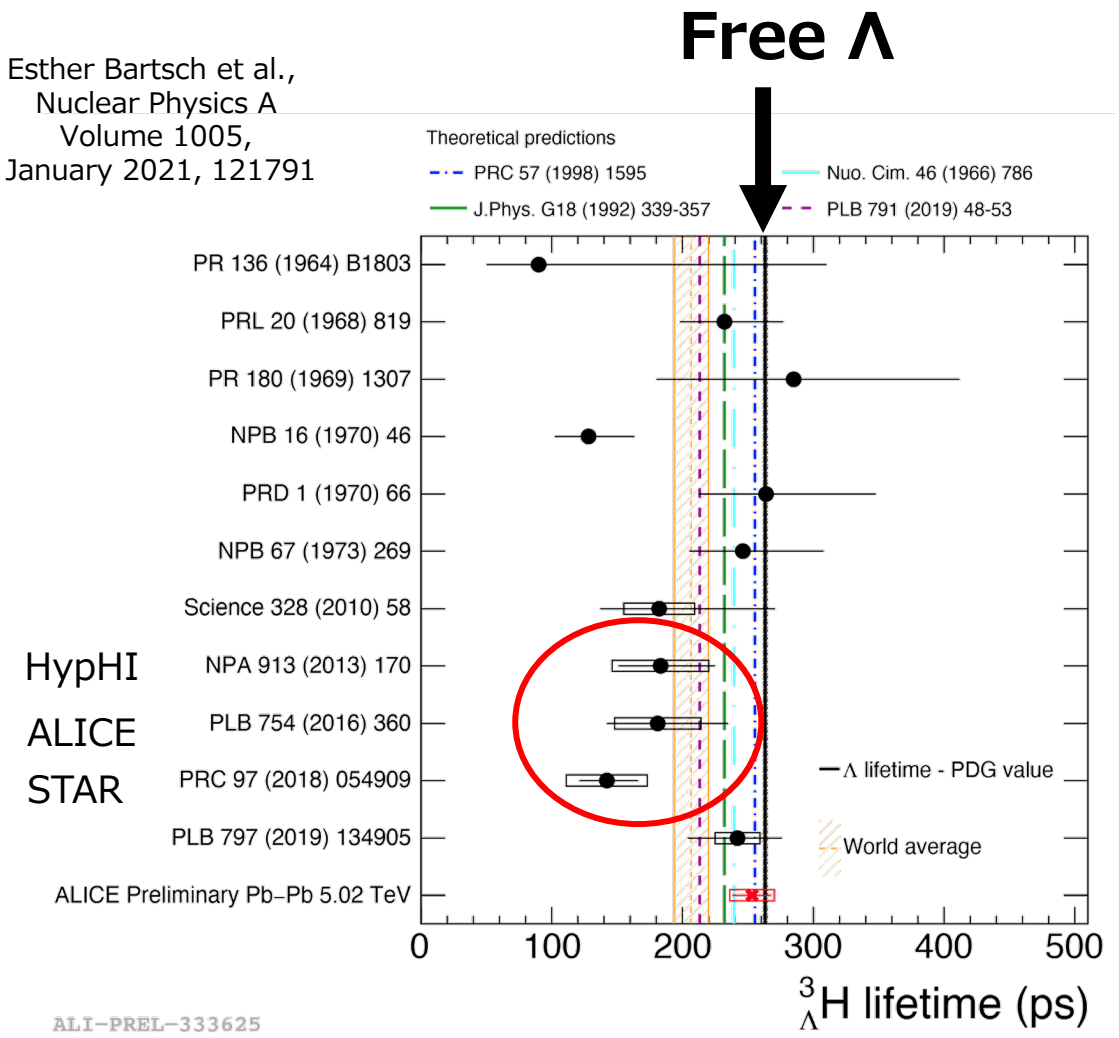


✓Small B_Λ → large separation between Λ & d

→ **lifetime τ ~ free Λ is naively expected**

Hypertriton lifetime puzzle

Esther Bartsch et al.,
Nuclear Physics A
Volume 1005,
January 2021, 121791



Exp.	Lifetime
HypHI(2013)	$183^{+42}_{-32} \pm 37$ ps
ALICE(2016)	$181^{+54}_{-39} \pm 33$ ps
STAR(2018)	$142^{+24}_{-21} \pm 29$ ps

Free Λ(263 ps)

- **Short lifetimes** from heavy ion experiments in 2010's

Hypertriton lifetime puzzle

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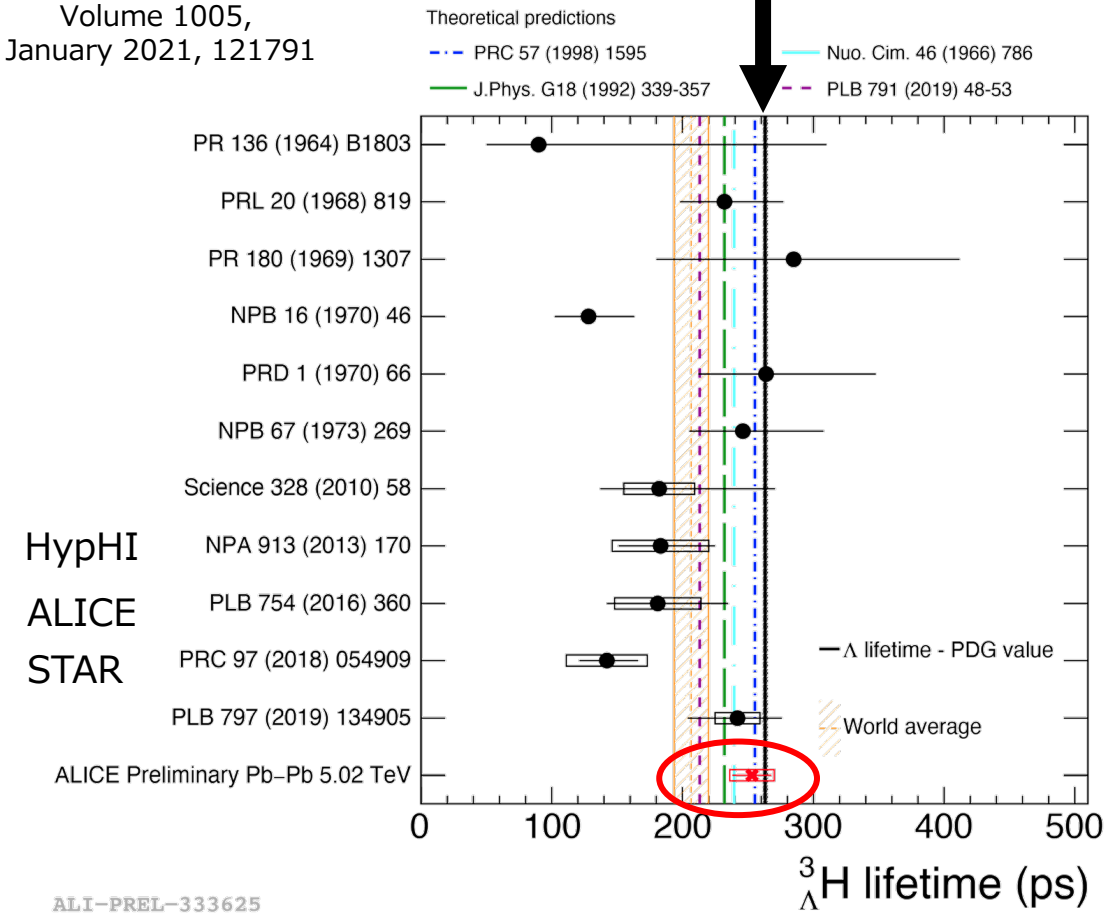


Francesco Mazzaschi
THEIA-STRONG 2020
ALICE Preliminary result

Exp.	Lifetime
ALICE(2020)	$254 \pm 15 \pm 17$ ps
STAR(2021)	$232 \pm 29.2 \pm 36.7$ ps

Yue-Hang Leung
REIMEI-THEIA web seminar
STAR Preliminary result

Comparable with Free Λ

the Hypertriton lifetime puzzle is still not solved

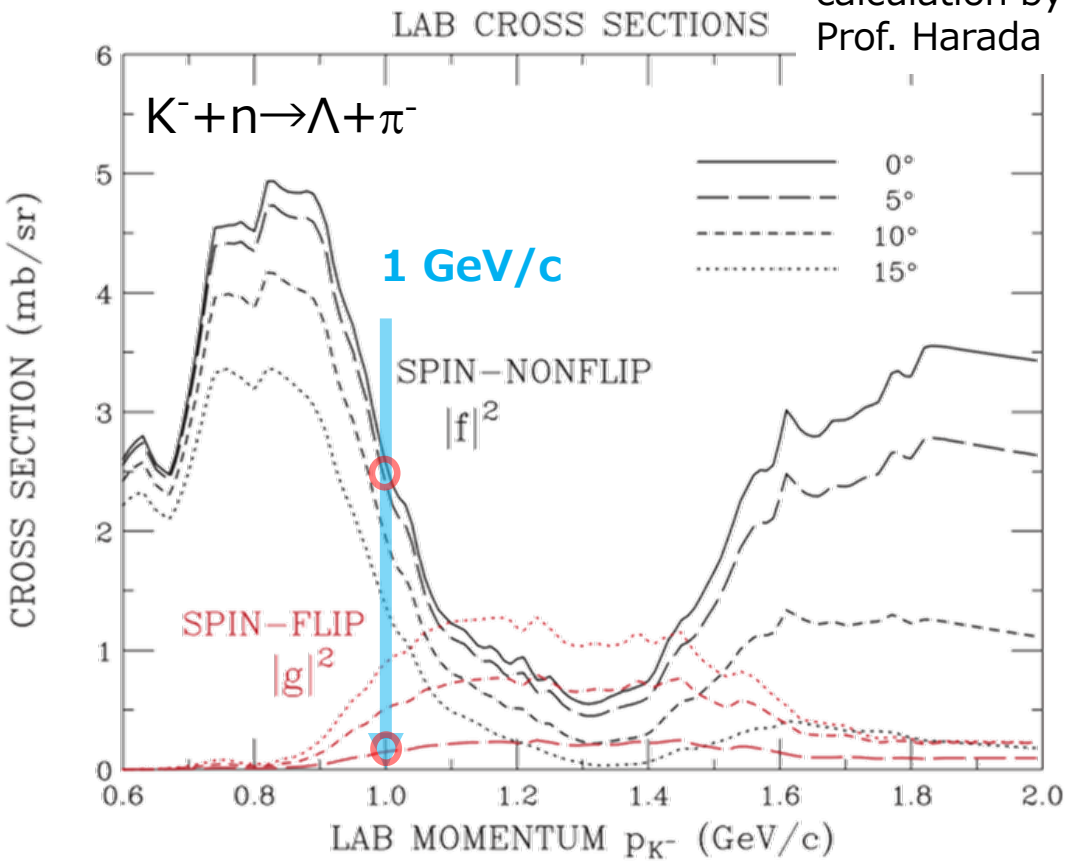
⇒ **spin mixture of 1/2 and 3/2 should be avoided**

Toward solving hypertriton lifetime puzzle

- the detail of the ${}^{3}_{\Lambda}$H should be clearly understood
  ⇒an independent and complementary approach

Experiment	ALICE, STAR	J-PARC E73
Production method	Heavy ion collision	^{3}He(K^-, π^0)${}^{3}_{\Lambda}$H
Microscopic process	Thermal model; Coalescence model	**Strangeness exchange**
Quantum number	1/2 and 3/2 mixture?	**spin=1/2 dominant**

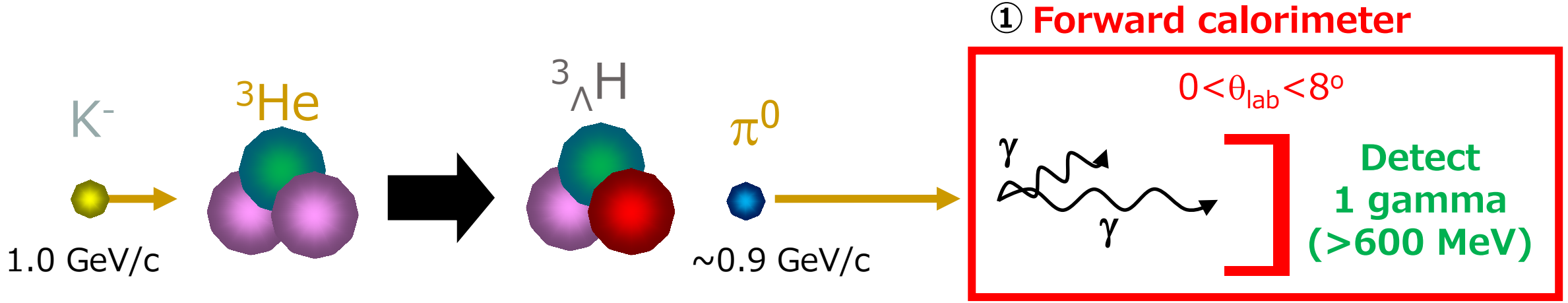
calculation by Prof. Harada



- produce the ground state of ${}^{3}_{\Lambda}$H($1/2^+$)
- **provide important data on the hypertriton lifetime puzzle**

J-PARC E73: Experimental principle

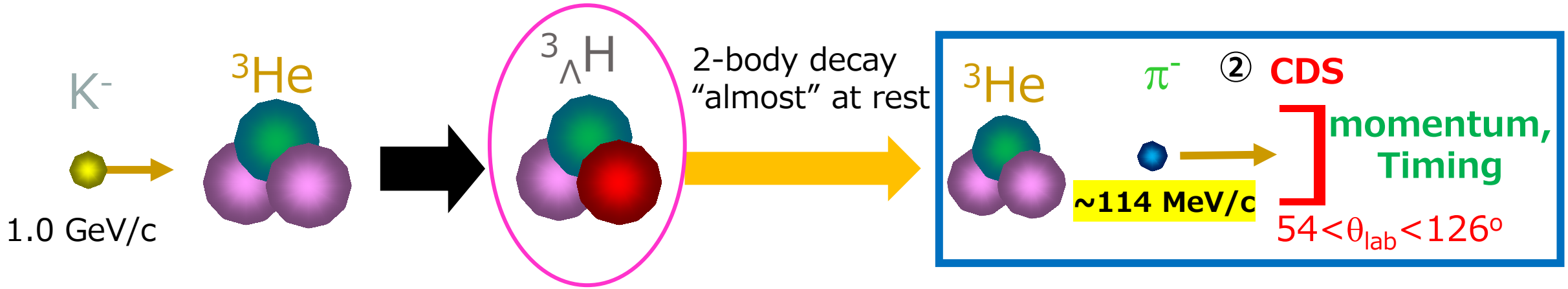
✓^{3}He(K^-, π^0)$^{3}_{\Lambda}$H reaction



①tag (K^-, π^0) reaction by detecting
forward single high-energy gamma with calorimeter
→almost 100% detection efficiency for forward going π^0 ($0< \theta_{lab}^{\pi^0} <10$)
⇒**tag Λ production with low recoil momentum**
Reduce BG from Y decays and multi pion production

J-PARC E73: Experimental principle

✓^{3}He(K^{-}, π^{0})$^{3}_{\Lambda}$H reaction



②Measure Momentum and Timing with Cylindrical Detector System (CDS)

select the mono-momentum of π- after 2-body decay

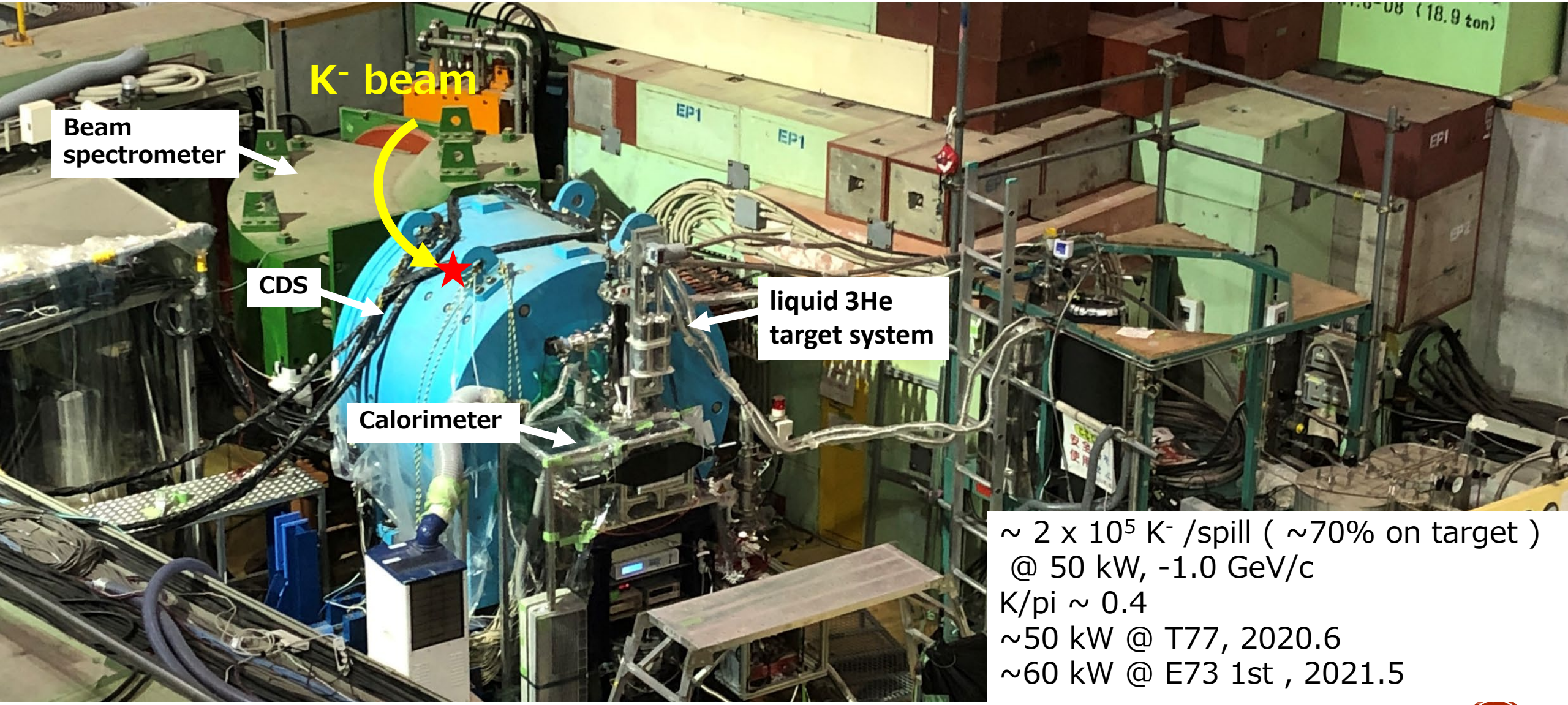
low recoil momentum (~100 MeV/c)

→Hypertriton stops immediately inside the target

⇒2-body decay "almost" at rest

Identify $^{3}_{\Lambda}$H and derive lifetime from decay time

J-PARC K1.8BR Beamline



~ 2 x 10^5 K^- /spill (~70% on target)
@ 50 kW, -1.0 GeV/c
K/pi ~ 0.4
~50 kW @ T77, 2020.6
~60 kW @ E73 1st , 2021.5

Strategy of J-PARC E73

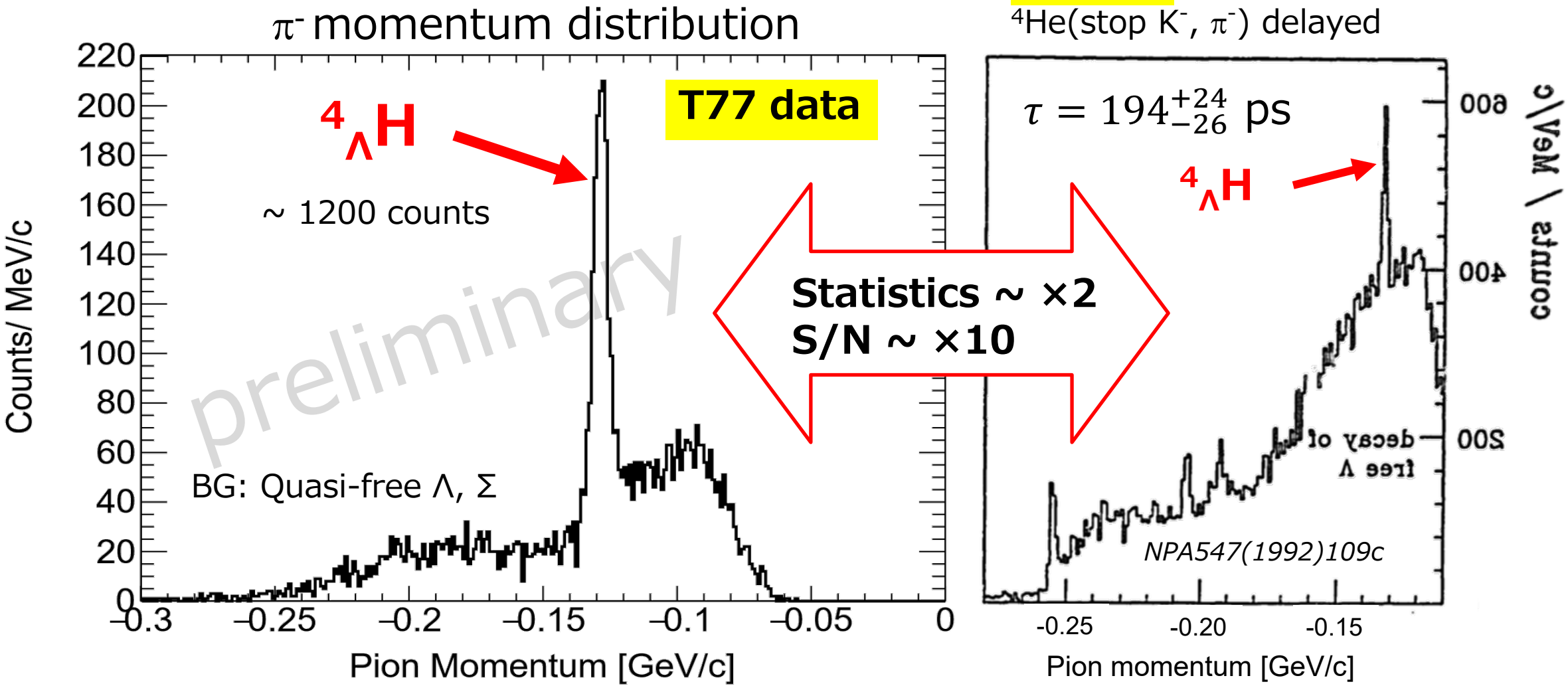
- Phase-0
  - Feasibility study of new method with the (K-, π^0) reaction using ^{4}He target
    ⇒expected to be relatively easy to generate and identify $^4_\Lambda$H
  - Data taking in June 2020 (3 d)
- Phase-1 **New**
  - Production cross section study for $^3_\Lambda$H
  - Data taking in May 2021(4 d)
- Phase-2
  - Direct lifetime measurement for $^3_\Lambda$H
  - planned in JFY2022 (1 month)

Hypernucleus	$^4_\Lambda$H	$^3_\Lambda$H
Branching ratio to 2-body decay	50 %	25 %
Relative cross section	1	0.3—0.4
Relative yield	1	0.15—0.2

calculation of cross section by Prof. Harada

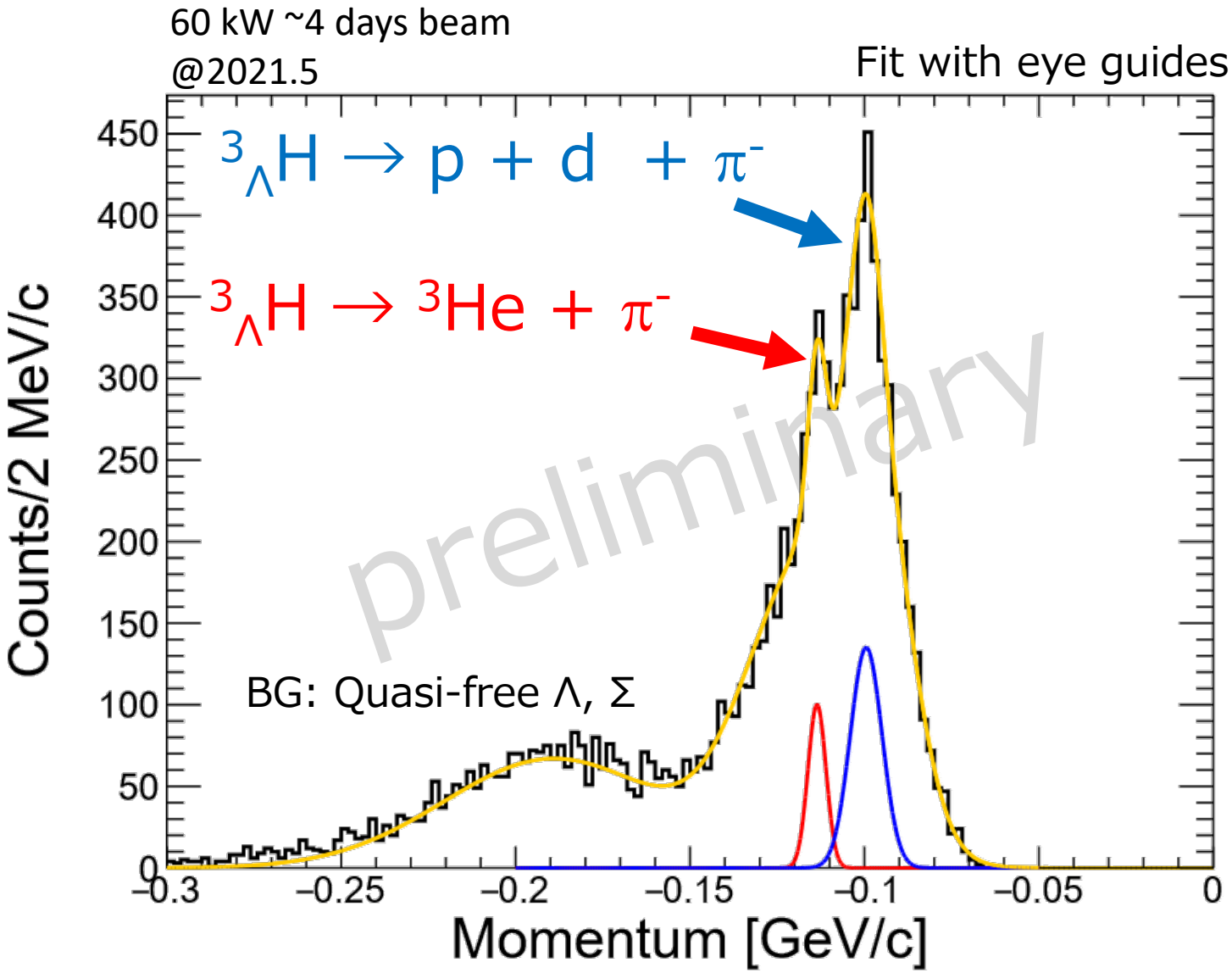
T. Harada and Y. Hirabayashi, https://arxiv.org/abs/2106.04256v2

Phase-0: pi- momentum dis. of $^{4}_{\Lambda}$H



- **Successfully established new method of (K$^-$, π^0) reaction**

Phase-1: pi- momentum dis. of $^{3}_{\Lambda}$H



- Hypertriton events can be seen
  - ~ 200 events(2 body)
- 3-body decay events can also be seen around ~100 MeV/c

✓**cross section(B.R.×σ)**

✓**2-body/3-body ratio will be derived**

not enough to derive lifetime
⇒ need more statistics

Phase-1: cross section ratio ${}^{3}_{\Lambda}\mathrm{H}/{}^{4}_{\Lambda}\mathrm{H}$

- Rough estimation

Hypernucleus	${}^{3}_{\Lambda}\mathrm{H}$	${}^{4}_{\Lambda}\mathrm{H}$	
Luminosity	11.32 G Kaon × 0.070 g/cm^3	6.05 G Kaon × 0.145 g/cm^3	→ **Almost same**
# of signal	~200	~1200	→ **1/6**
Branching ratio to 2 body decay	25 %	50 %	→ **1/2**

$$\Rightarrow \sigma({}^{3}_{\Lambda}\mathrm{H})/\sigma({}^{4}_{\Lambda}\mathrm{H}) \sim 1/3$$

Consistent with calculation of cross section by Prof. Harada

T. Harada and Y. Hirabayashi,
https://arxiv.org/abs/2106.04256v2

Summary

- J-PARC E73: Direct measurement of $^{3}_{\Lambda}$H lifetime
  - Different experimental method from heavy ion-based experiment
  - Selectively produce ground state of $^{3}_{\Lambda}$H($1/2^{+}$)

- Current status of the experiment
  - Phase-0: established a method by (K^{-}, π^{0}) reaction
    $\Rightarrow$ $^{4}_{\Lambda}$H lifetime
  - Phase-1: confirmed $^{3}_{\Lambda}$H production
    $\Rightarrow$cross section of $^{3}_{\Lambda}$H
  - Phase-2: $^{3}_{\Lambda}$H lifetime measurement
    ~ 1 month beam time, $^{3}_{\Lambda}$H ~1000 events, ~10 % error
    $\rightarrow$ in JFY2022

J-PARC E73 collaboration

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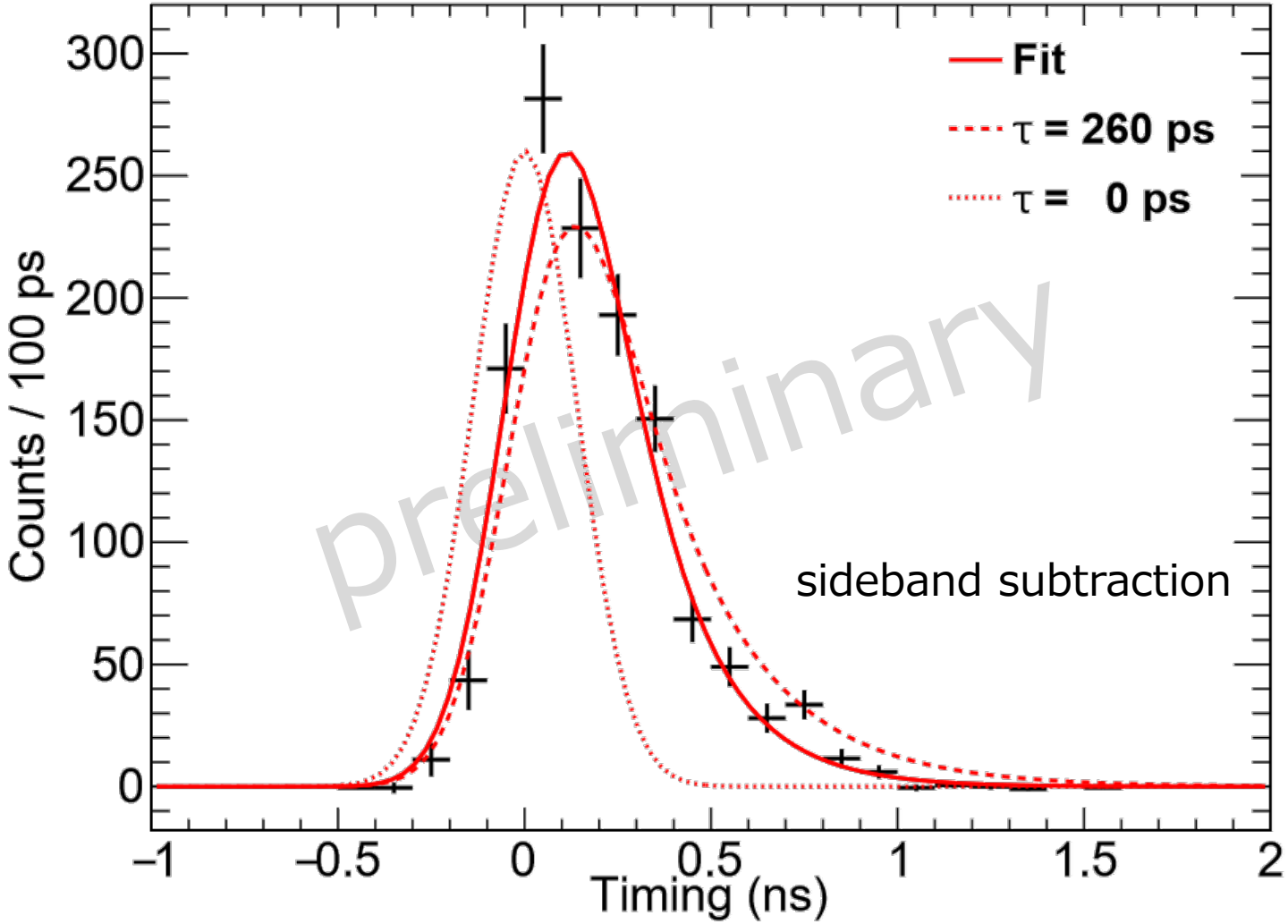
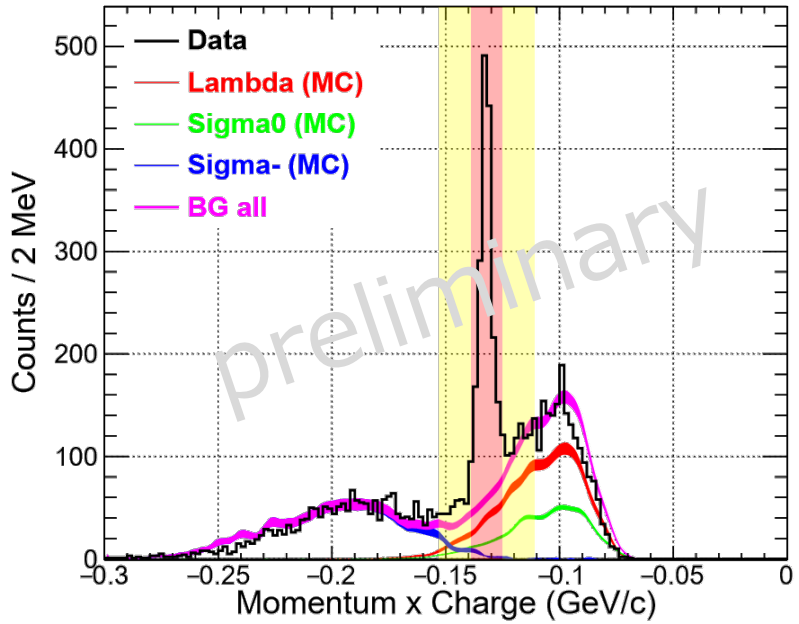
Backup

Phase-0: timing spectrum of ${}^{4}_{\Lambda}$H data





- Timing response evaluated by $\pi^{-}N \rightarrow \pi^{-}N$ scattering
- statistical error < 10 ps

will be finalized soon

Phase-1: ${}^{3}_{\Lambda}$H 3-body decay

- Why be seen peak structure of 3-body decay
  - Qualitative
    - ✓${}^{3}_{\Lambda}$H 3-body decay
    - ✓large separation between Λ & d → fermi motion of Λ is small
    - ✓Small effect to pion momentum
  - Theorical
    - ✓H. Kamada, et al.,
      Phys. Rev. C57, 1595 (1998)

need to be careful
when estimating the # of events