Experimental status toward the direct lifetime measurement of Hypertriton using the (K^-, π^0) reaction at J-PARC

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For the J-PARC E73 collaboration

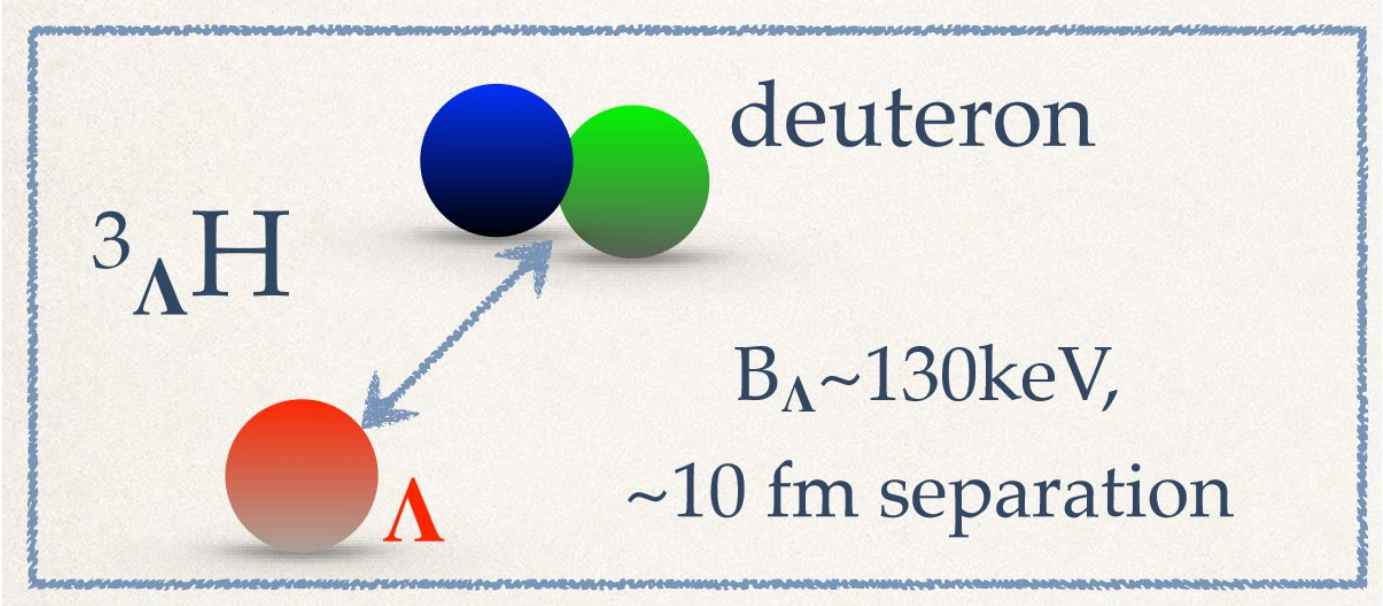
Outline

- Introduction
  - Hypertriton lifetime
  - Motivation of J-PARC E73 experiment
- J-PARC E73 experiment
  - Experimental principle
  - Result of ${}^{4}_{\Lambda}\mathrm{H}$ data
  - ${}^{3}_{\Lambda}\mathrm{H}$ production result with pilot run
- Summary

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

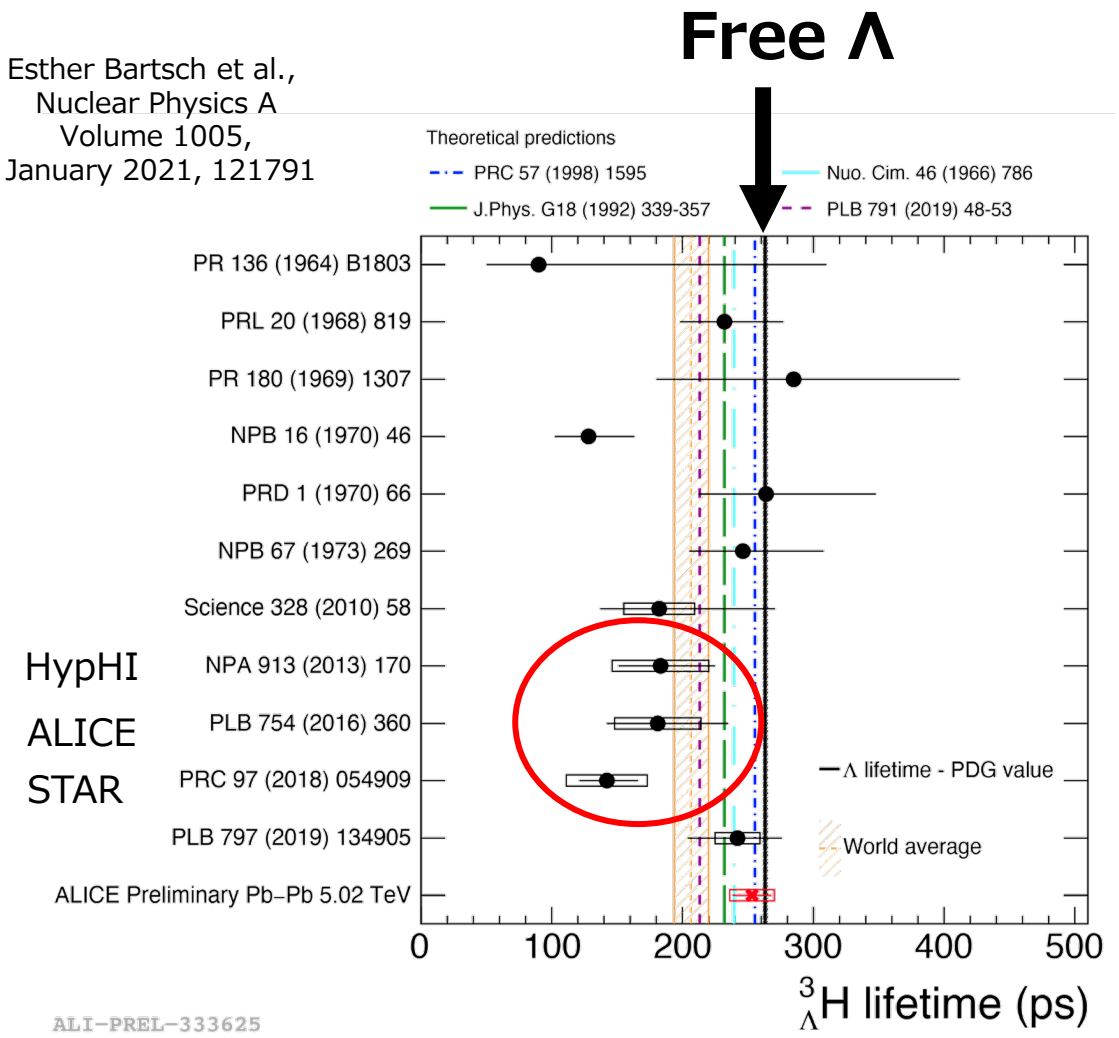


✓Small B_Λ → large separation between Λ & d

→ **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

Esther Bartsch et al.,
Nuclear Physics A
Volume 1005,
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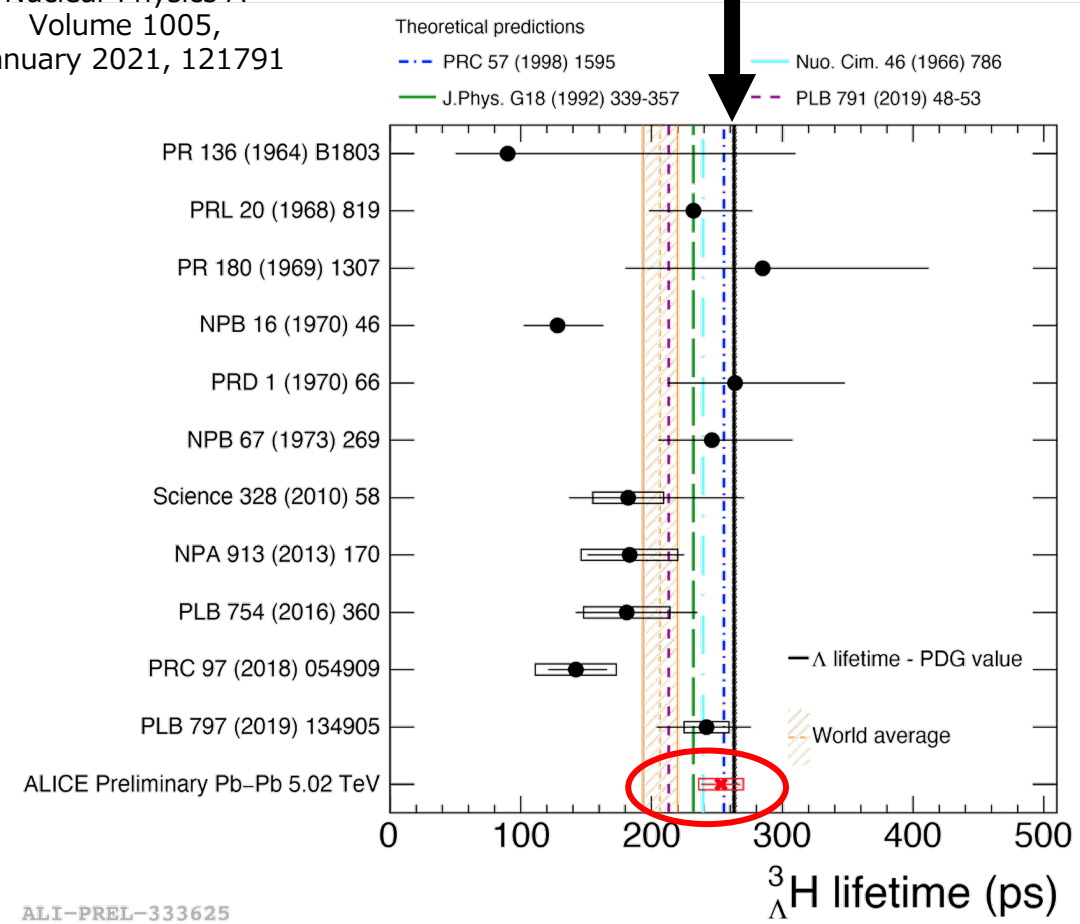
Free Λ



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

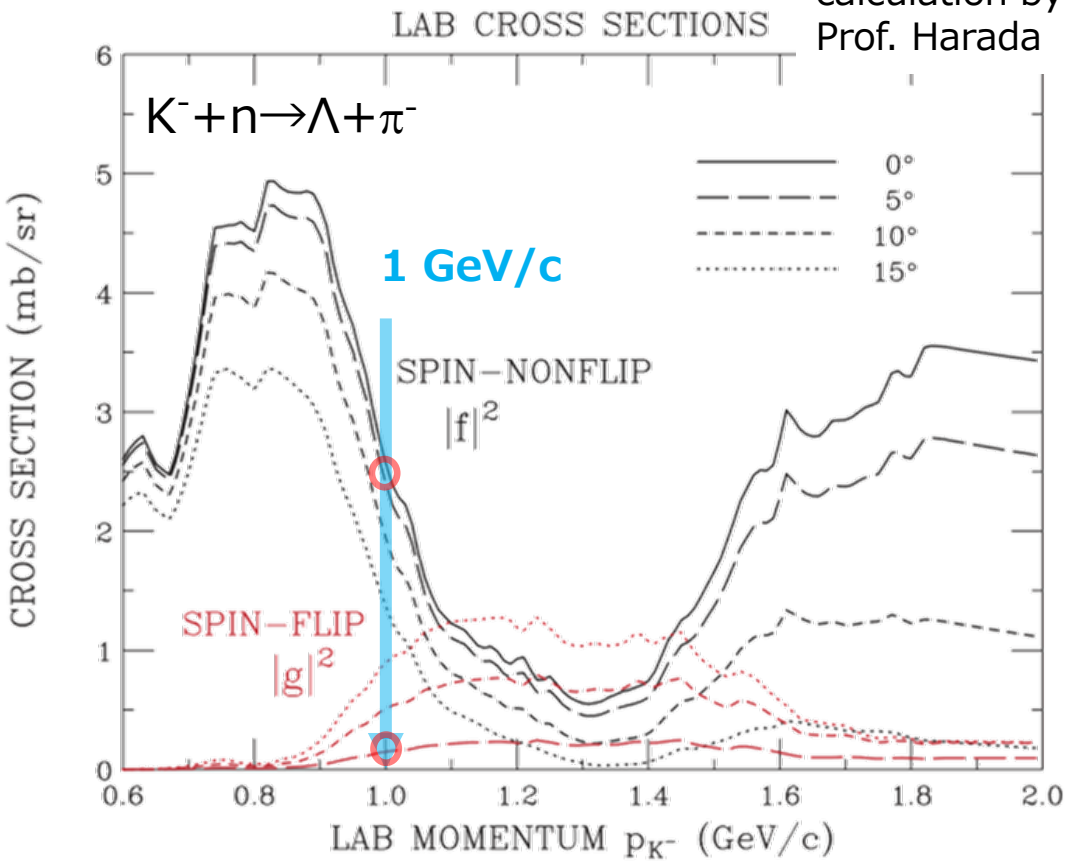
⇒ **spin mixture of 1/2 and 3/2 should be avoided**

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



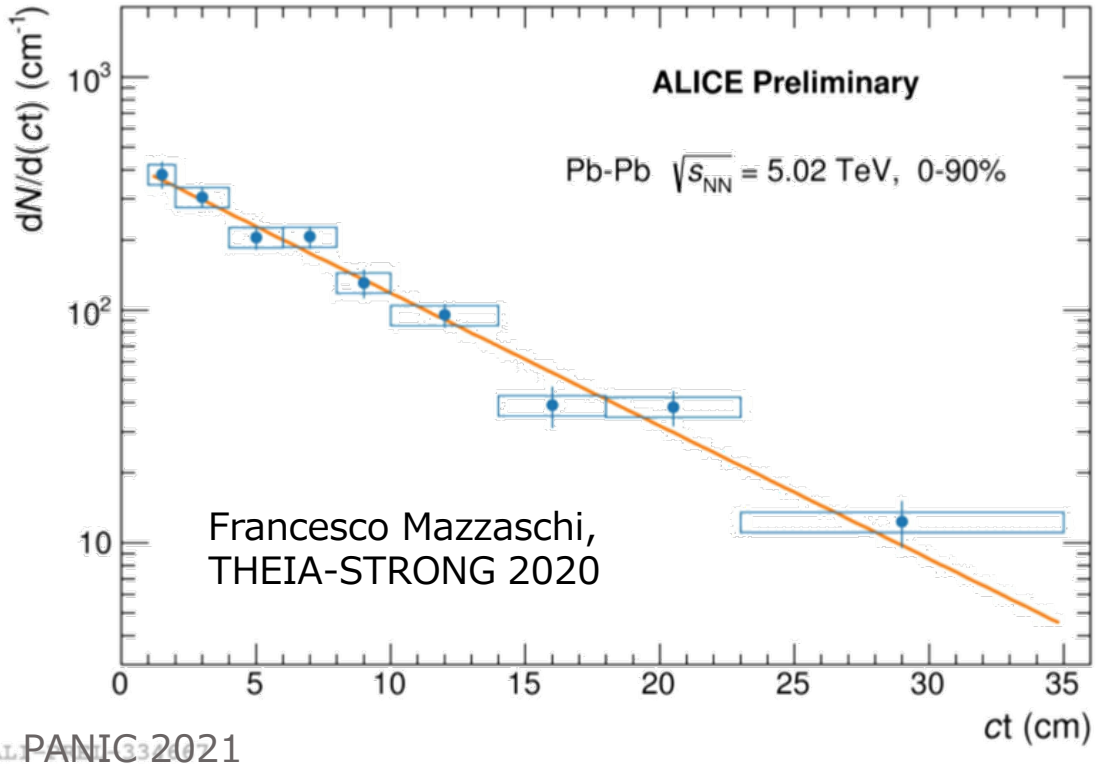
- produce the ground state of ${}^{3}_{\Lambda}$H($1/2^+$)
- **provide important data on the hypertriton lifetime puzzle**

HI exp. vs direct measurement

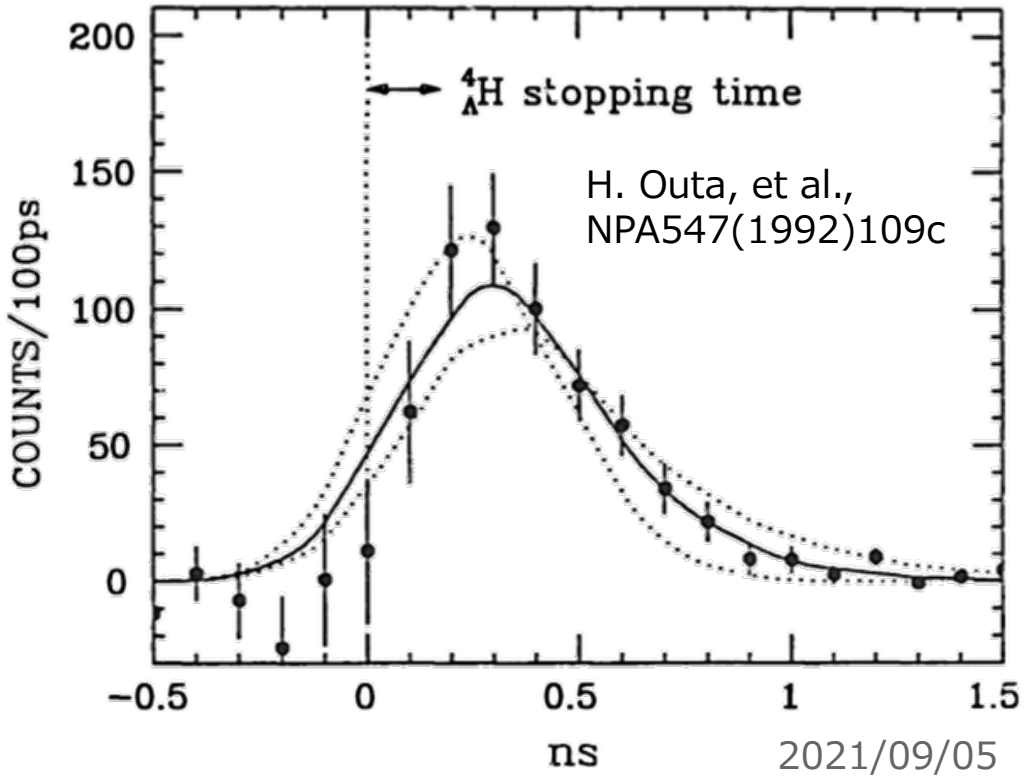
- Heavy ion experiments
  - reconstructed by invariant mass
  - Indirect measurement using decay length
- Counter experiment
  - Direct timing measurement using Decay pion

complementary

$^{3}_{\Lambda}$H lifetime@ALICE



^{4}He(stop K^{-}, π^{-})$^{4}_{\Lambda}$H @KEK



HI exp. vs direct measurement

- Heavy ion experiments
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complementary

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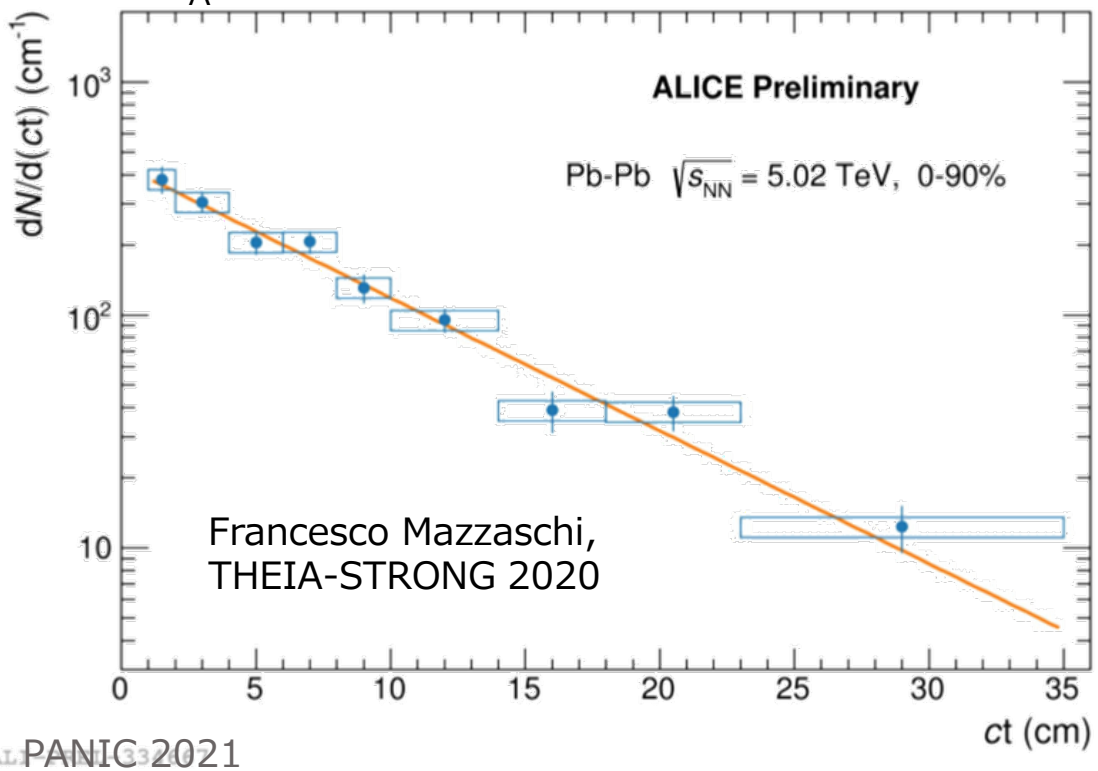
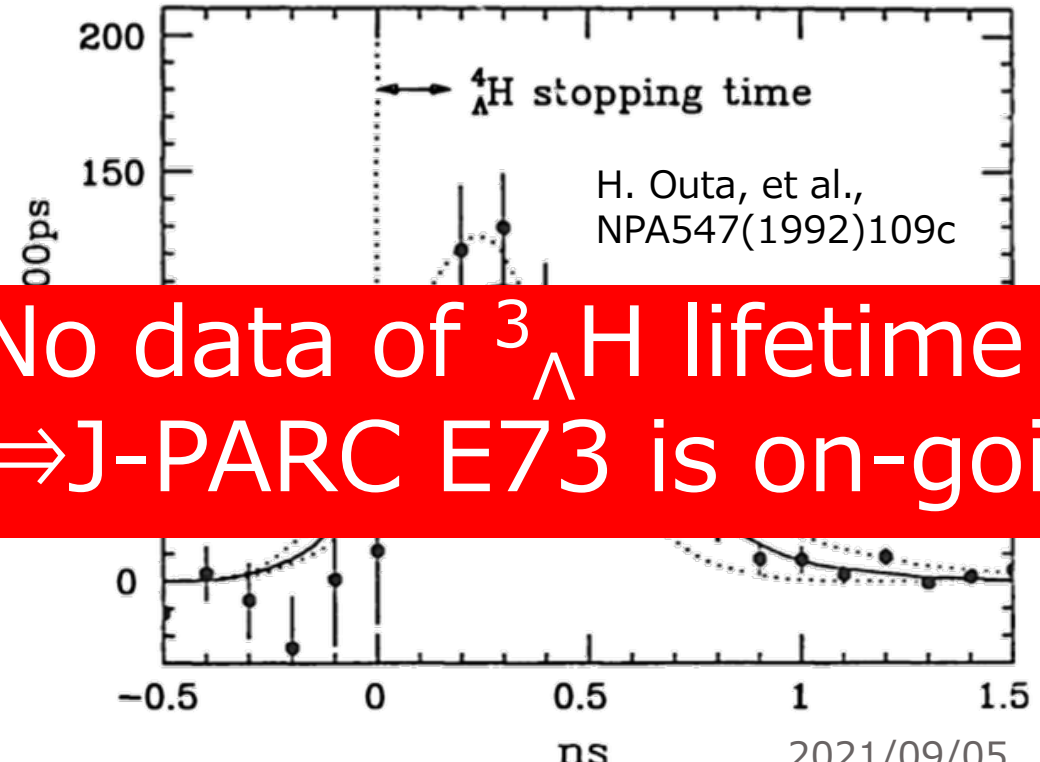
$^{3}_{\Lambda}$H lifetime@ALICE



^{4}He(stop K^{-}, π^{-})$^{4}_{\Lambda}$H @KEK



No data of $^{3}_{\Lambda}$H lifetime
⇒J-PARC E73 is on-going

Experiments on Hypertriton

- Heavy ion-based experiments
  - STAR
  - ALICE
  - GSI (WASA-FRS experiment)

- Counter experiments for lifetime
  - ELPH, Tohoku-U, Japan: (γ, K^+)
  - J-PARC P74: (π^-, K^0)
  - J-PARC E73: (K^-, π^0) ← Our project

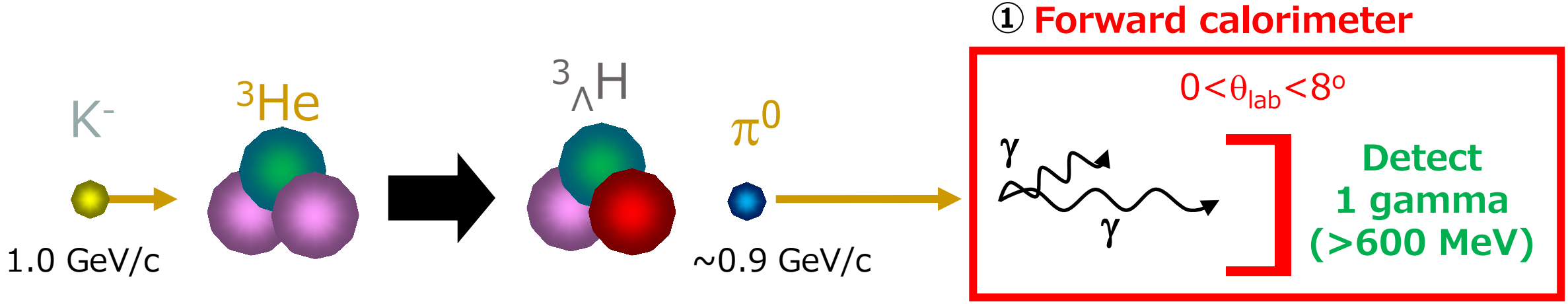
  - Binding energy measurement
    - MAMI (e, e'K) decay pion spectroscopy
    - JLab (e, e'K)
    - J-PARC E07: Emulsion full scan

Hypertriton still motivates activates studies

J-PARC E73 experiment

J-PARC E73: Experimental principle

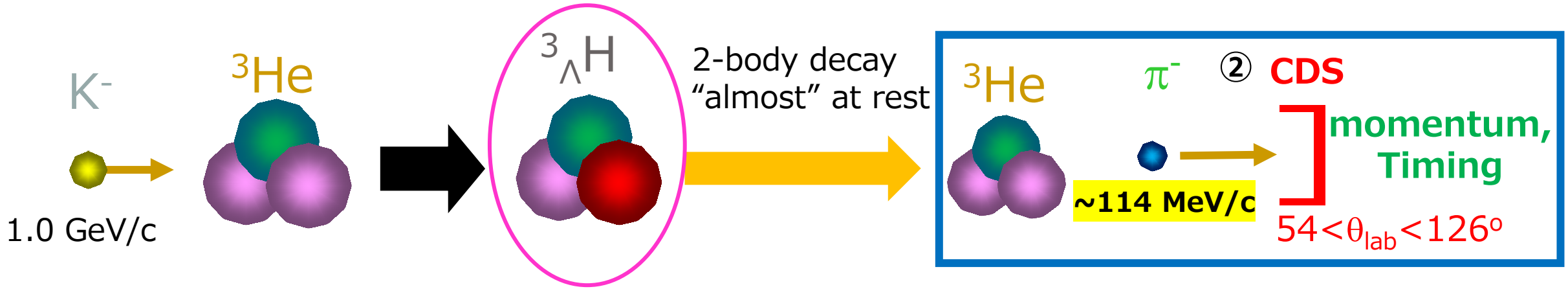
✓^{3}He(K^-, π^0)$^{3}_{\Lambda}$H reaction



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 experiment

✓^{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

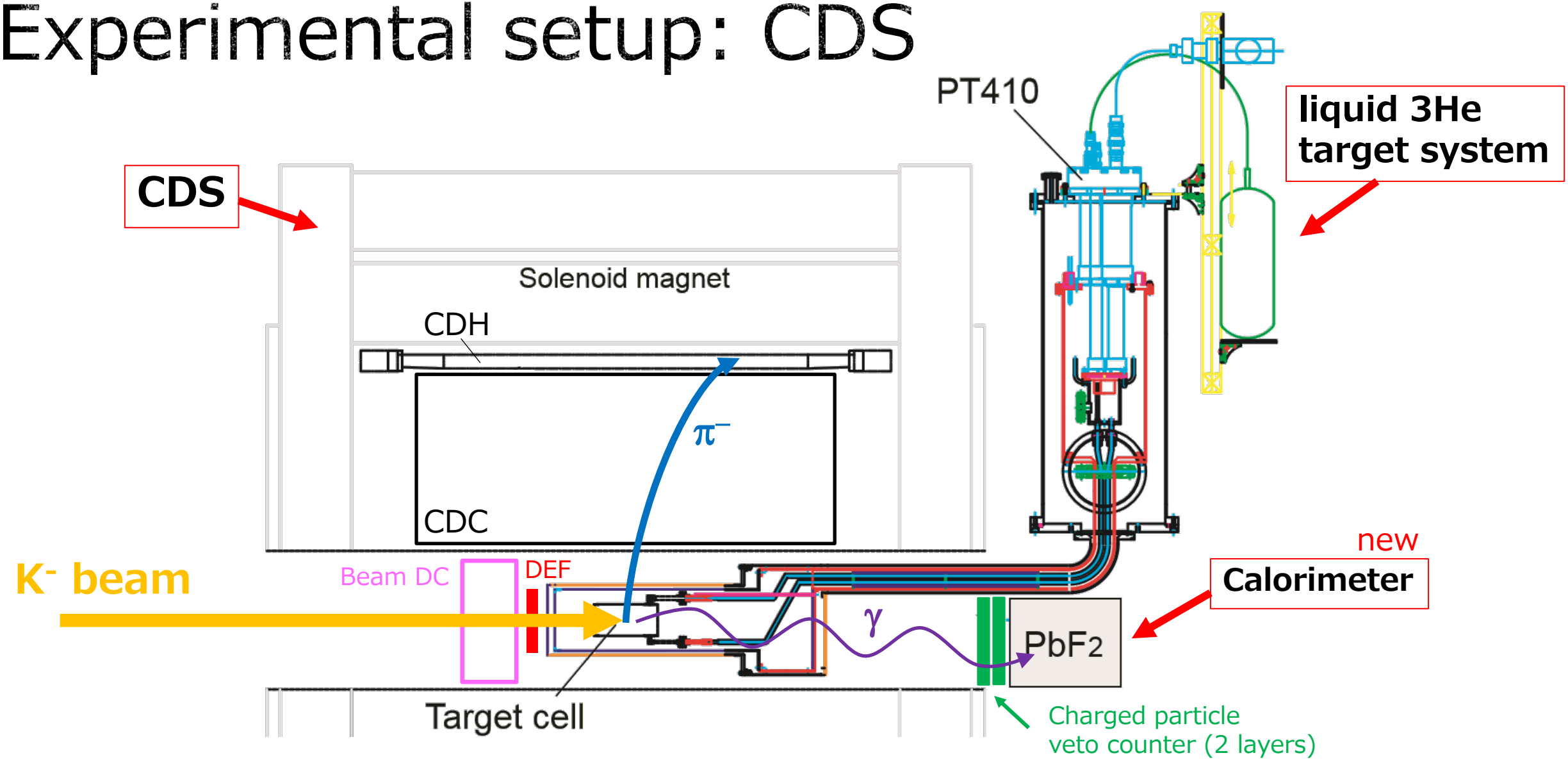
low recoil momentum (~100 MeV/c)

→Hypertriton stops immediately inside the target

⇒2-body decay "almost" at rest

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

Experimental setup: CDS

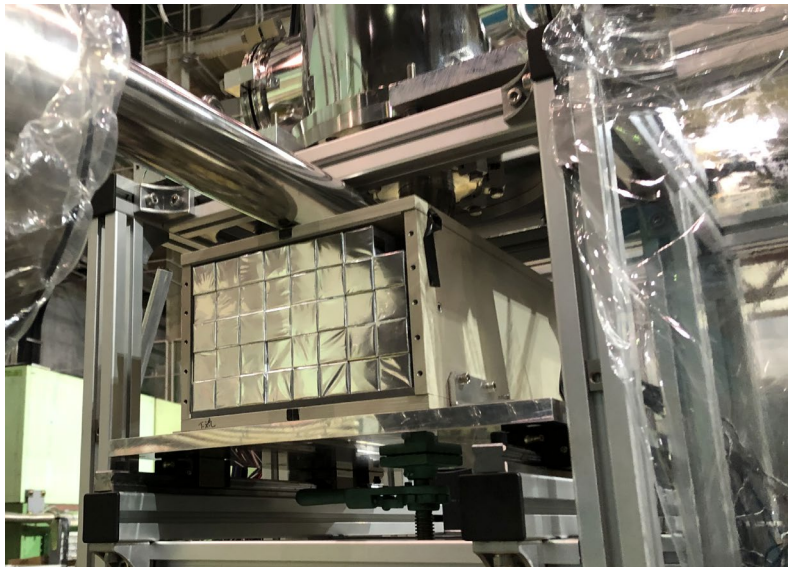


CDS has worked well in K1.8BR Beamline

Using E15(K^-pp)/E31(Λ1405)/E57(K^-d atom)

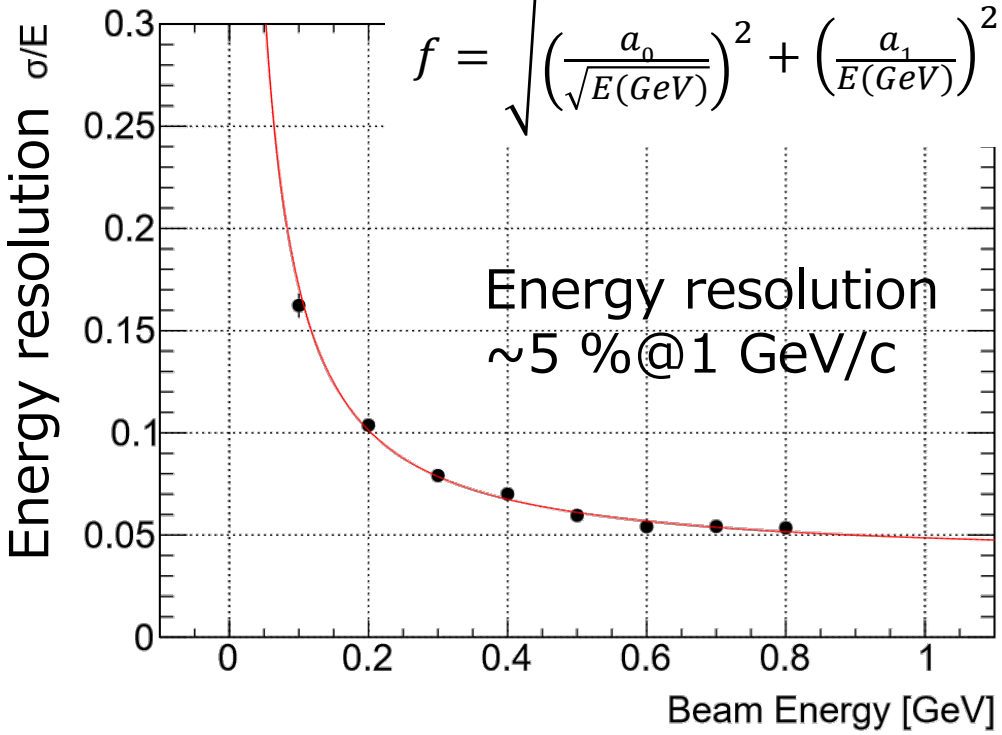
PbF_2 calorimeter performance

- PbF2 calorimeter is installed into the meson beam line to tag fast π^0
- 40 segments used

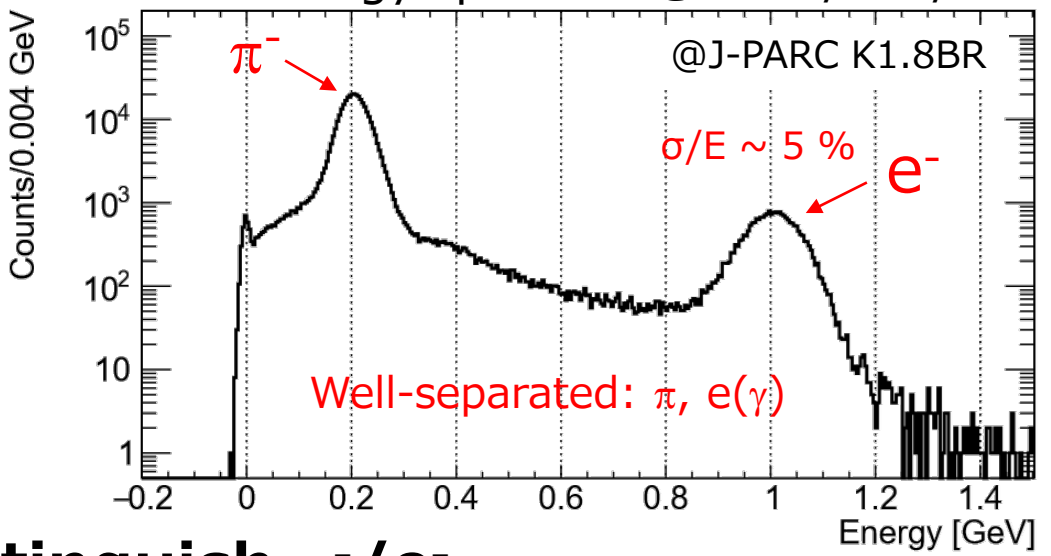


2019.12: Test experiment @ ELPH e^+ beam

$$f = \sqrt{\left(\frac{a_0}{\sqrt{E(GeV)}}\right)^2 + \left(\frac{a_1}{E(GeV)}\right)^2 + b^2}$$



Energy spectrum@1GeV/c π-/e-



Good performance to distinguish $\pi^-/e^-,\gamma$

Strategy of J-PARC E73

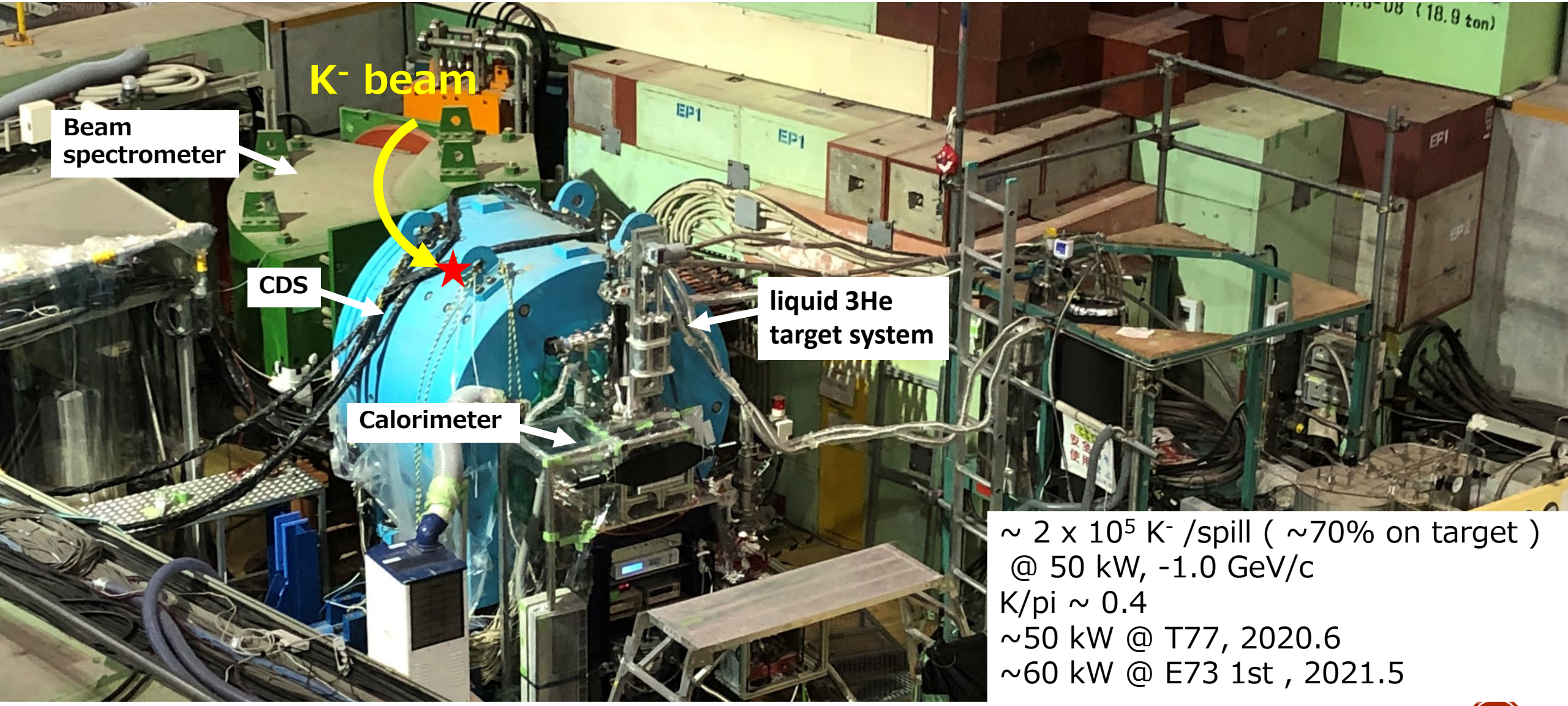
- Phase-0
  - Feasibility study of new method with the (K-, π^0) reaction using ^{4}He target
    ⇒expected to be relatively easy to generate and identify $^4_\Lambda$H
  - Data taking in June 2020 (3 d)
- Phase-1
  - Production cross section study for $^3_\Lambda$H
  - Data taking in May 2021(4 d)
- Phase-2
  - Direct lifetime measurement for $^3_\Lambda$H
  - planned in FY2022 (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

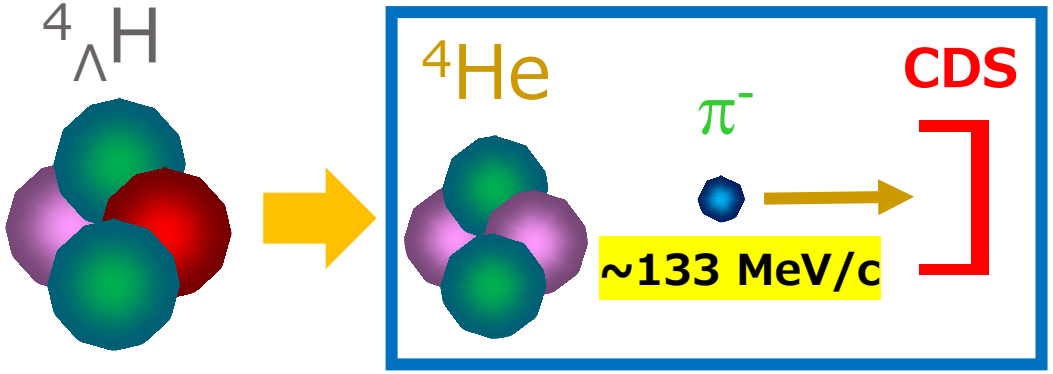
J-PARC K1.8BR Beamline

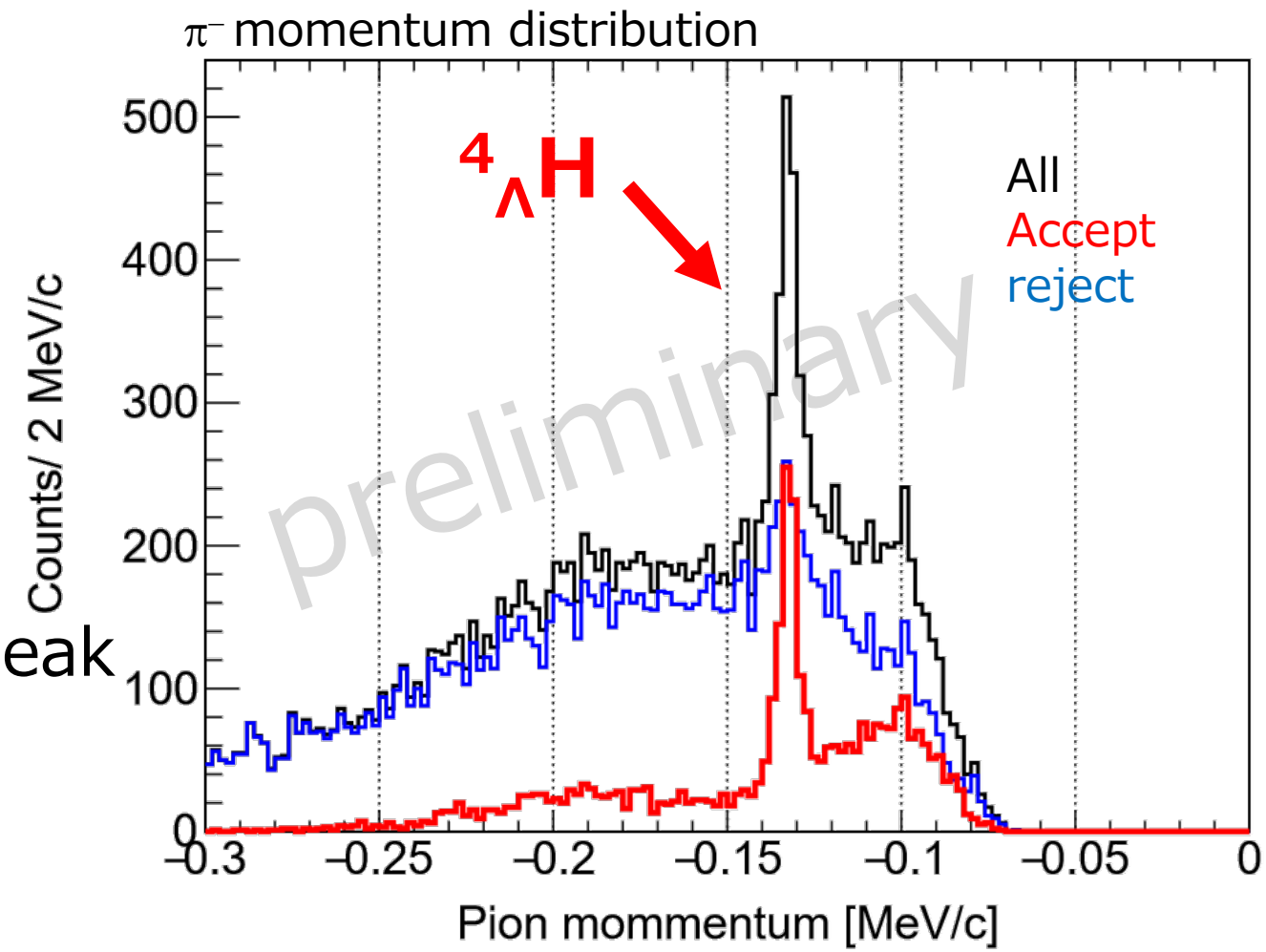


~ 2 x 10^5 K^- /spill (~70% on target)
@ 50 kW, -1.0 GeV/c
K/pi ~ 0.4
~50 kW @ T77, 2020.6
~60 kW @ E73 1st , 2021.5

Phasae-0: Feasibility study

- ^{4}He(K^-, π^0)$^4_\Lambda$H reaction

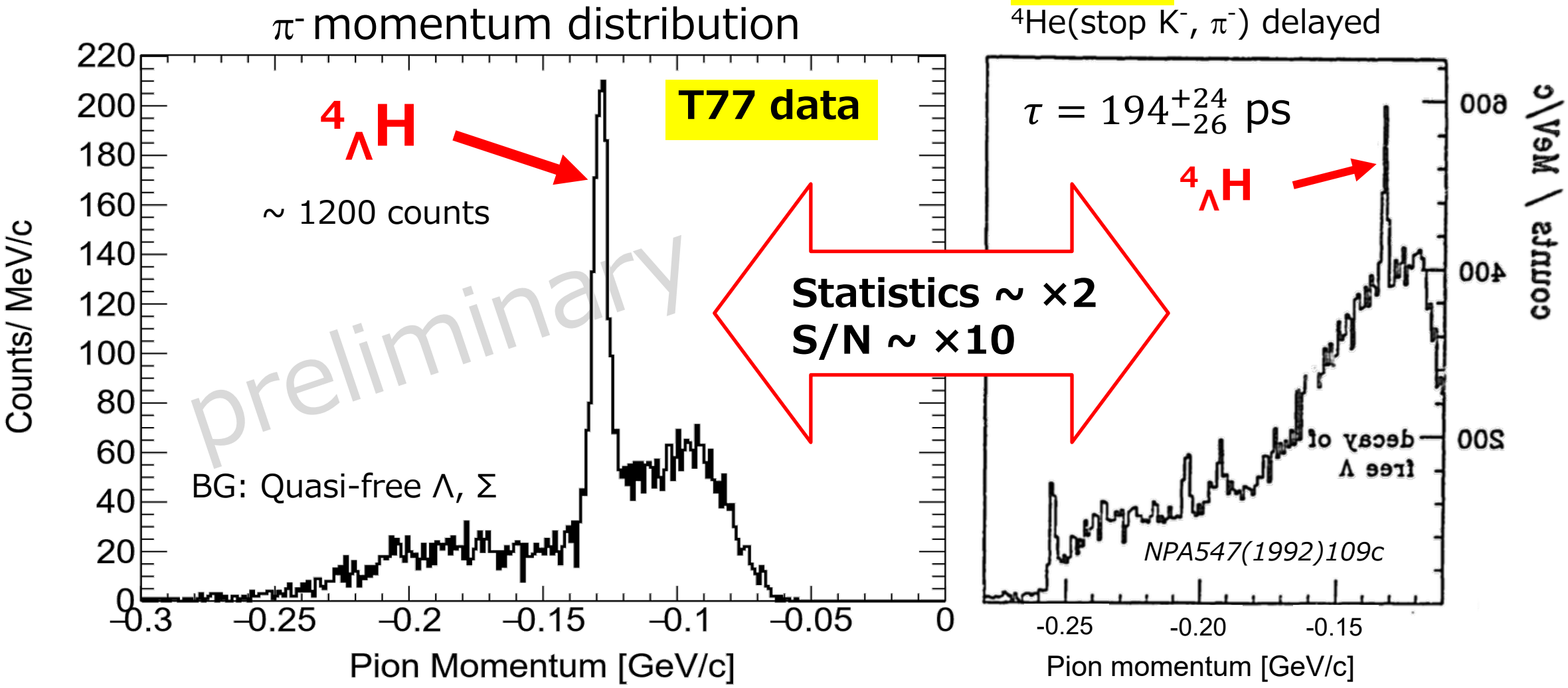




- select 1 gamma ray ⇒ the $^4_\Lambda$H peak can be seen like the black line
- Background reduction by PbF2
  - Selection of high energy γ-rays for $^4_\Lambda$H production

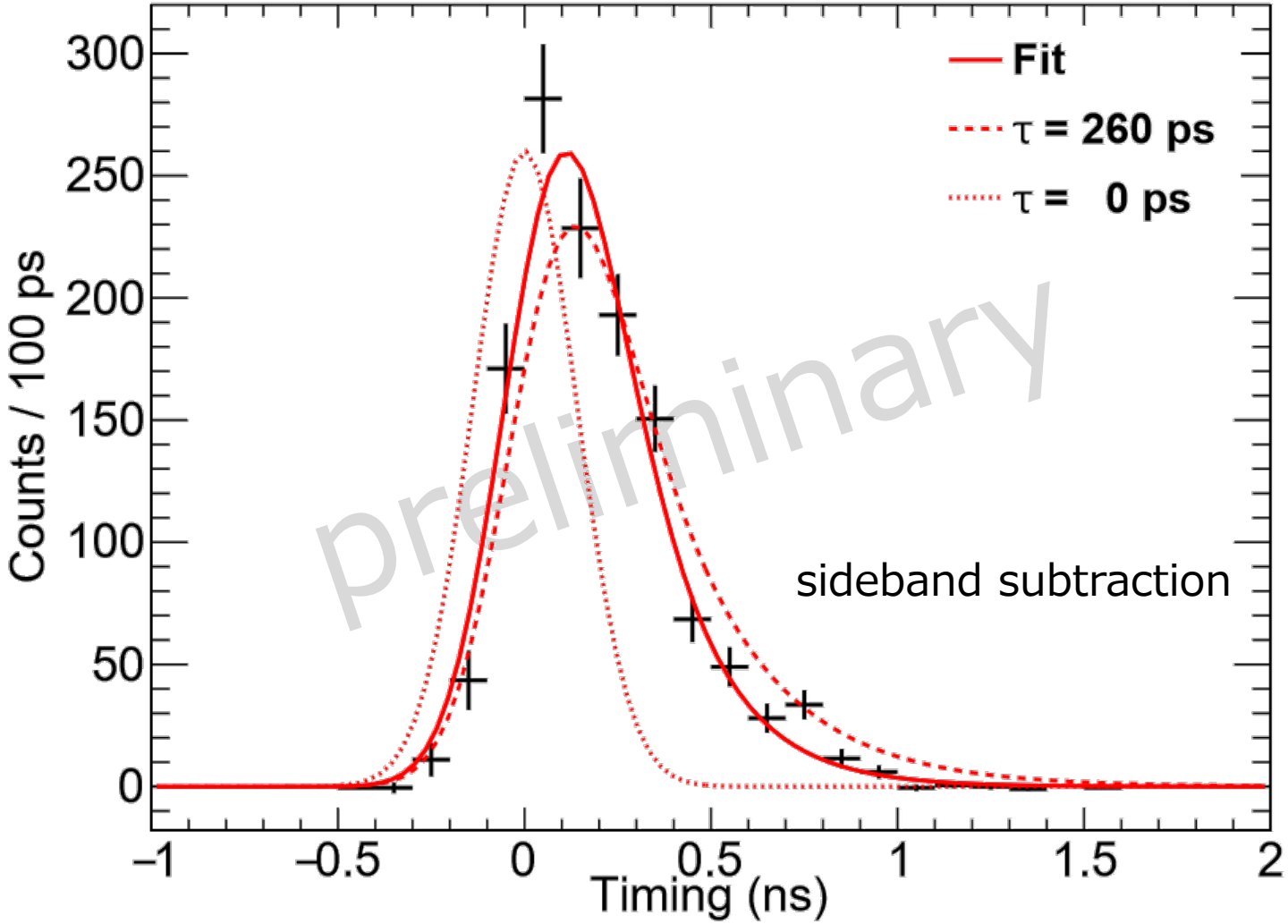
    ⇒Improved S/N ratio(3/2 → **4/1**) Red line

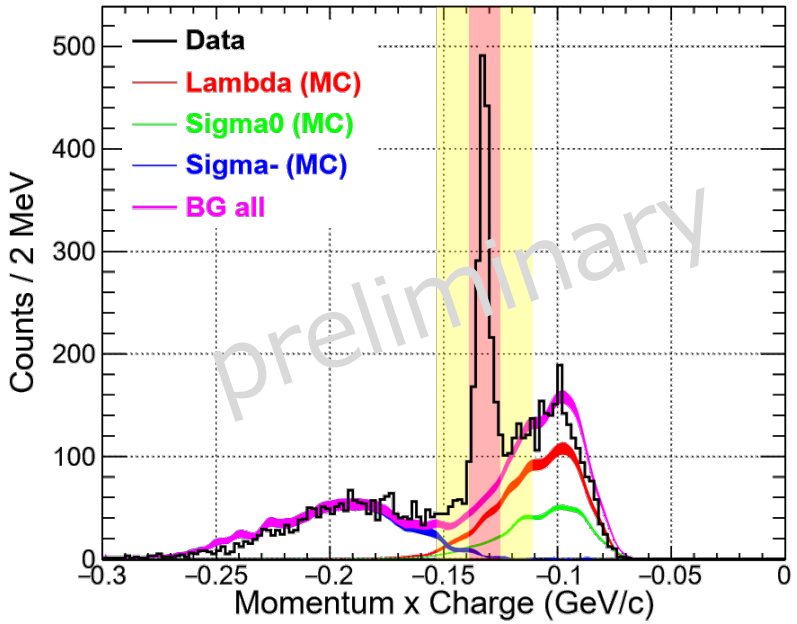
Phasae-0: pi- momentum dis. of $^{4}_{\Lambda}$H



- **Successfully established new method of (K-, pi0) reaction**

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

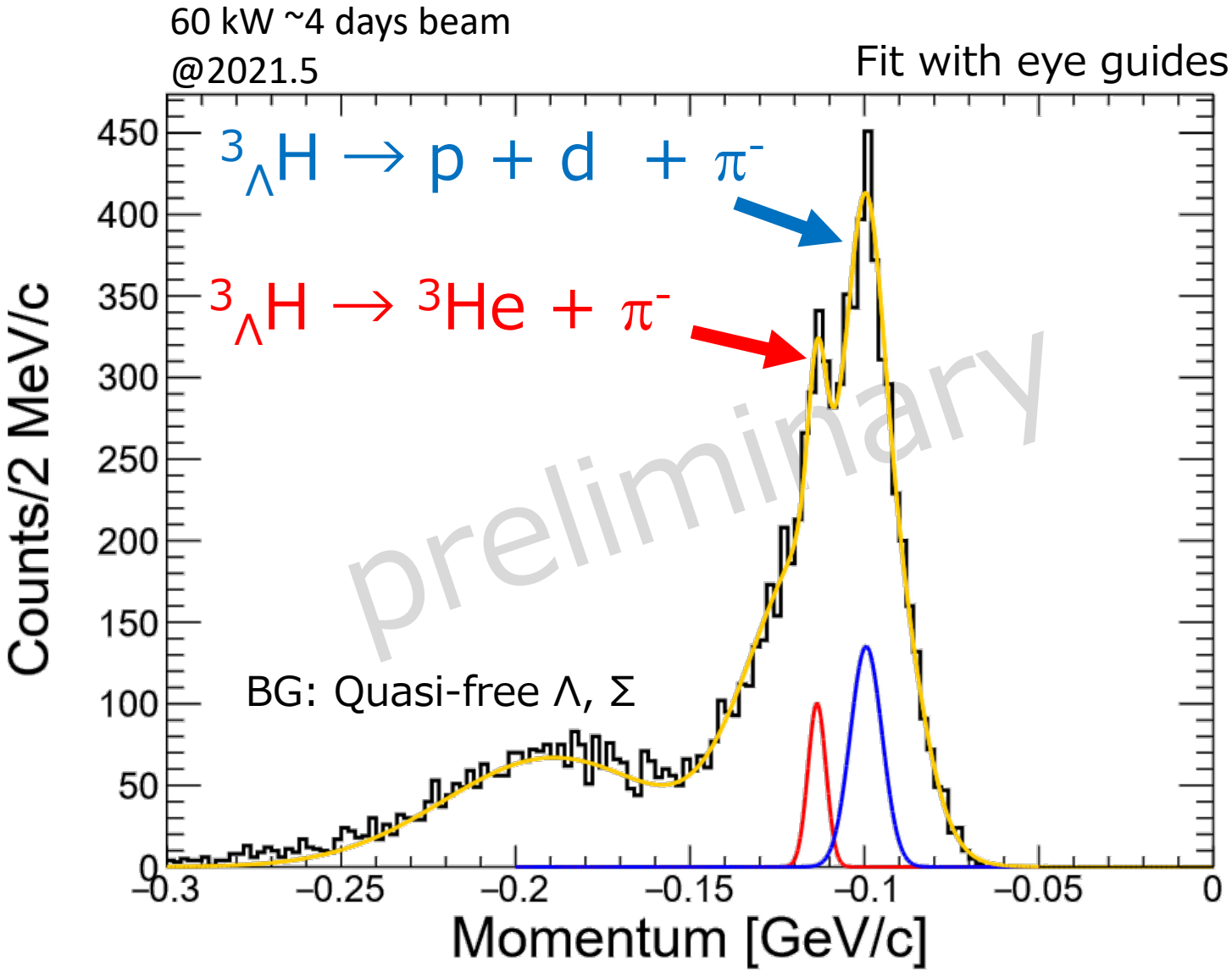




- Timing response evaluated by $\pi^{-}N \rightarrow \pi^{-}N$ scattering
- statistical error < 10 ps

will be finalized soon

Phase-1: 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

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 FY2022

J-PARC E73 collaboration

T. Akaishi[1], H. Asano[10], X. Chen[4], A. Clozza[6], C. Curceanu[6], R. Del Grande[6], C. Guaraldo[6], C. Han[4,10], T. Hashimoto[3], M. Iliescu[6], K. Inoue[1], S. Ishimoto[2], K. Itahashi[10], M. Iwasaki[10], Y. Ma[10], M. Miliucci[6], H. Noumi[1], H. Ohnishi[9], S. Okada[10], H. Outa[10], K. Piscicchia[6,8], F. Sakuma[10], M. Sato[2], A. Scordo[6], D. Sirghi[6,7], F. Sirghi[6,7], K. Shirotori[1], S. Suzuki[2], K. Tanida[3], T. Yamaga[10], X. Yuan[4], P. Zhang[4], Y. Zhang[4], H. Zhang[5]

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