

E73 status report

Ready for data taking

(80kW × 25days)

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on behalf of J-PARC E73 collaboration

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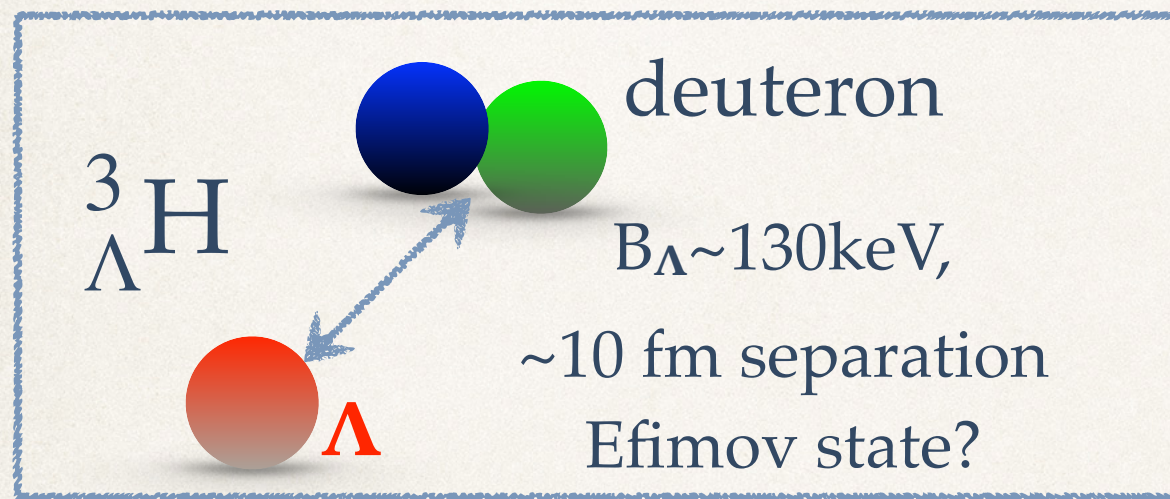
January 24th, 2024

Outline

- ❖ Introduction to J-PARC E73:
 - ❖ The first direct measurement for ${}^3\Lambda\text{H}$ lifetime
- ❖ J-PARC E73 review
 - ❖ Pilot run: ${}^4\Lambda\text{H}$ lifetime as feasibility study, June, 2020
 - ❖ Stage-1: ${}^3\Lambda\text{H}$ production cross section measurement, May, 2021
 - ❖ Stage-2: ${}^3\Lambda\text{H}$ lifetime measurement
 - ❖ Stage-2 approved by the 33rd PAC with $80\text{kW} \times 25\text{days}$ beam time;
 - ❖ Beam time allocation confirmed by the 34th, 35th and 36th PAC
- ❖ Summary

Introduction: hypertriton lifetime puzzle

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



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

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

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

a small term
(separation of $\sim 10 \text{ fm}$)

Introduction: hypertriton lifetime puzzle

E73 proposal submitted in 2018

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

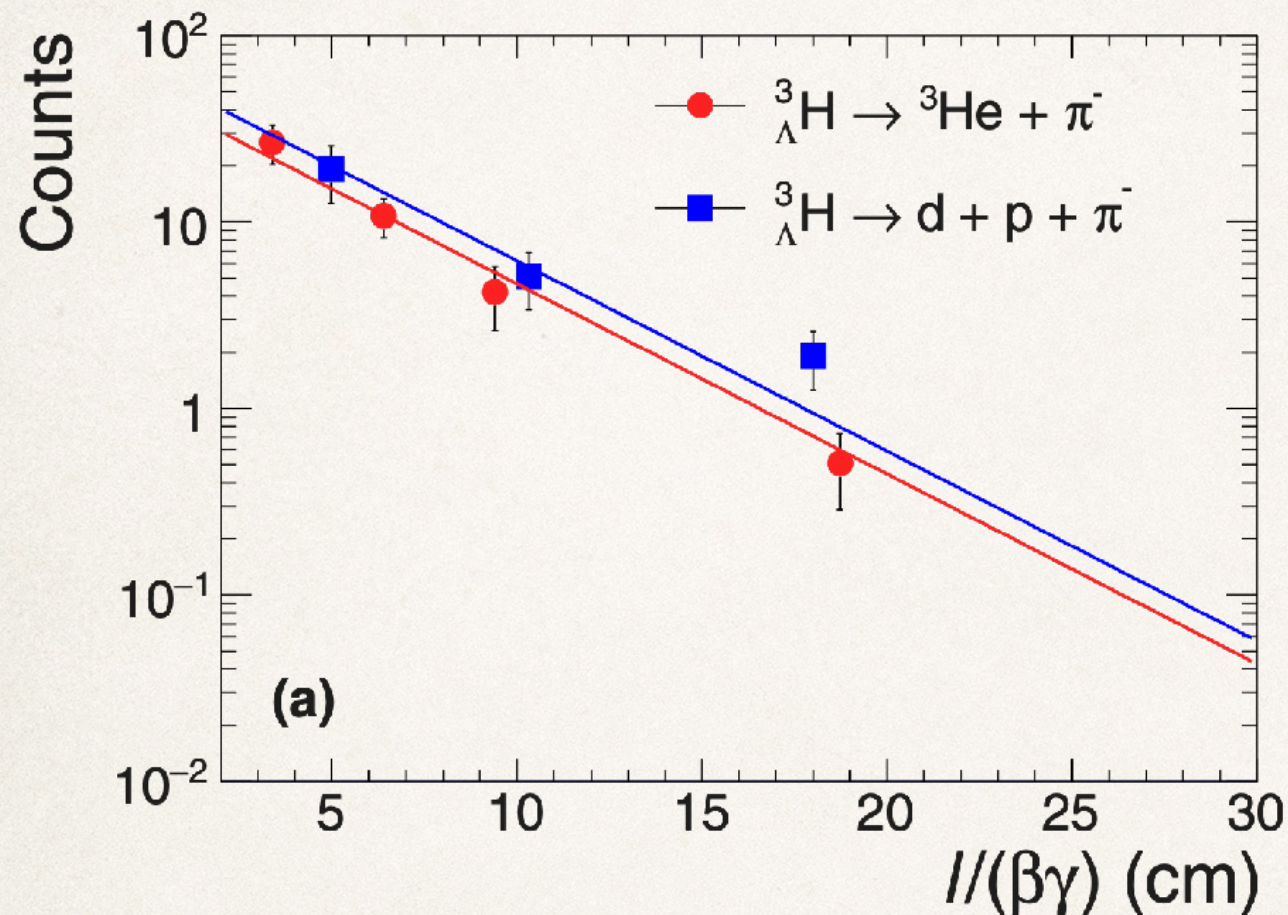
Table 1: Summary of recent measurements on ${}^3_{\Lambda}\text{H}$ lifetime.

Updated results since then

Collaboration	Experimental method	${}^3_{\Lambda}\text{H}$ lifetime [ps]	Release date
HypHI	fixed target	$183^{+42}_{-32}(\text{stat.})\pm 37(\text{syst.})$	2013 [4]
STAR	Au collider	$142^{+24}_{-21}(\text{stat.})\pm 29(\text{syst.})$	2018 [2]
		$221\pm 15(\text{stat.})\pm 19(\text{syst.})$	2021 [6]
ALICE	Pb collider	$181^{+54}_{-39}(\text{stat.})\pm 33(\text{syst.})$	2016 [3]
		$253\pm 11(\text{stat.})\pm 6(\text{syst.})$	2023 [5]

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

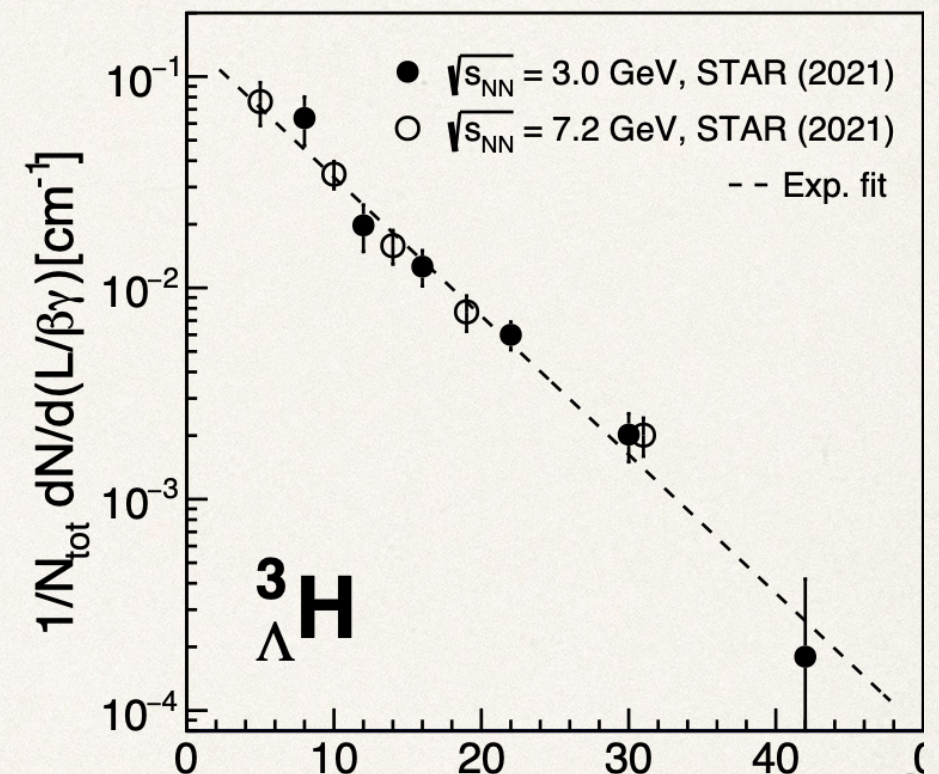
Introduction: hypertriton lifetime puzzle



STAR 2018:

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

(doi.org/10.1103/PhysRevC.97.054909)



(doi.org/10.1103/PhysRevLett.128.202301)

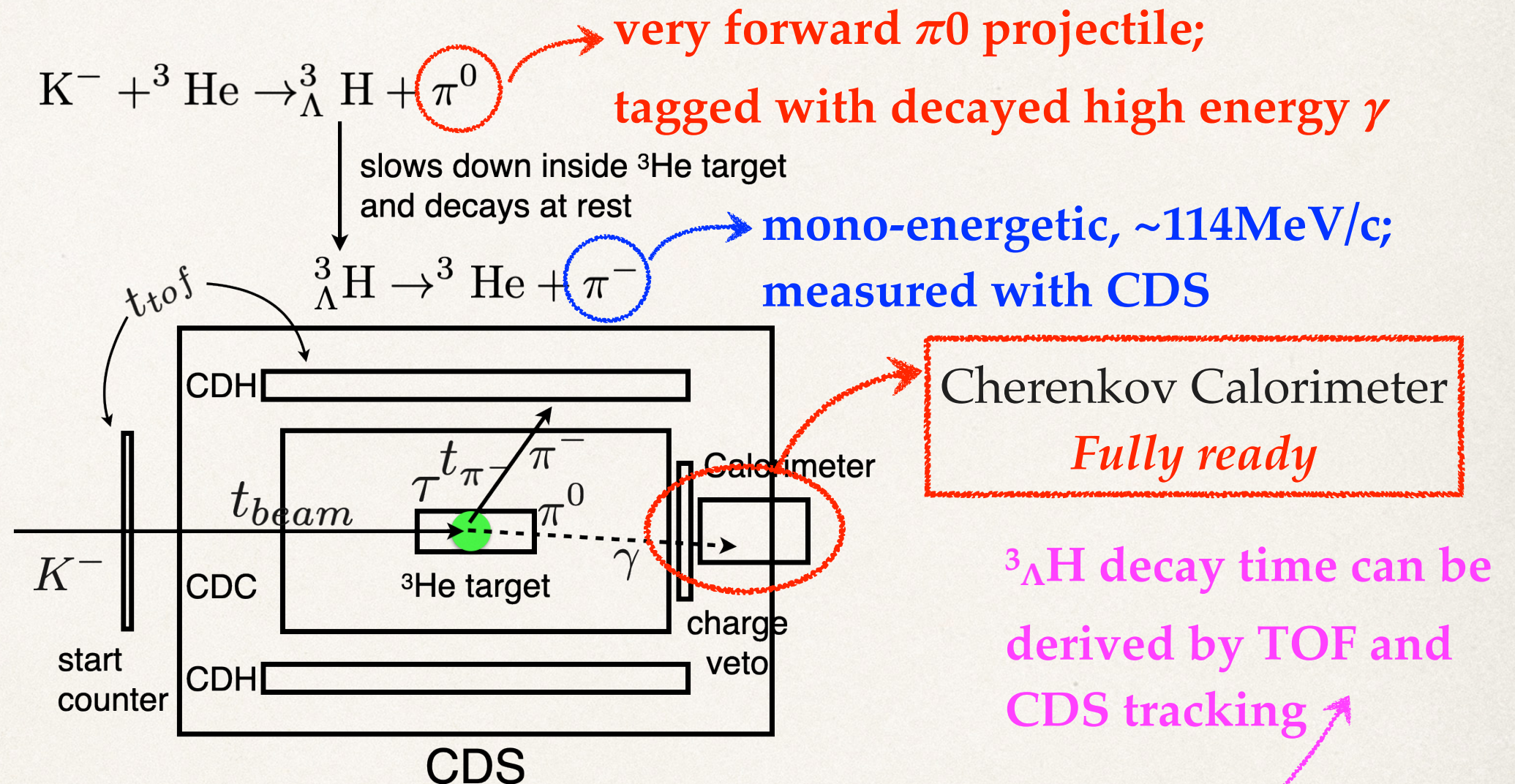
STAR 2022:

$$\tau = 221 \pm 15 \pm 19 \text{ ps}$$

(doi.org/10.1051/epjconf/202227108002)

What happened? What shall we do?

E73 experimental setup



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

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

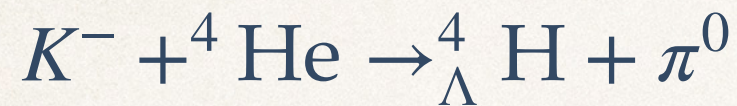
${}^3\text{He}(\text{K}^-, \pi^0){}_\Lambda^3\text{H}$ vs heavy ion production

Experiment	J-PARC E73	BNL STAR
Production method	${}^3\text{He}(\text{K}^-, \pi^0){}_\Lambda^3\text{H}$	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

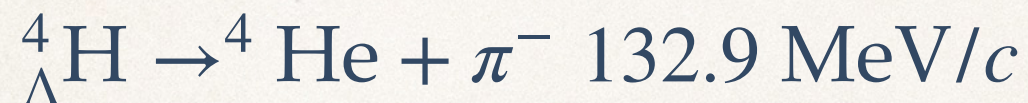
J-PARC E73 staging & status

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

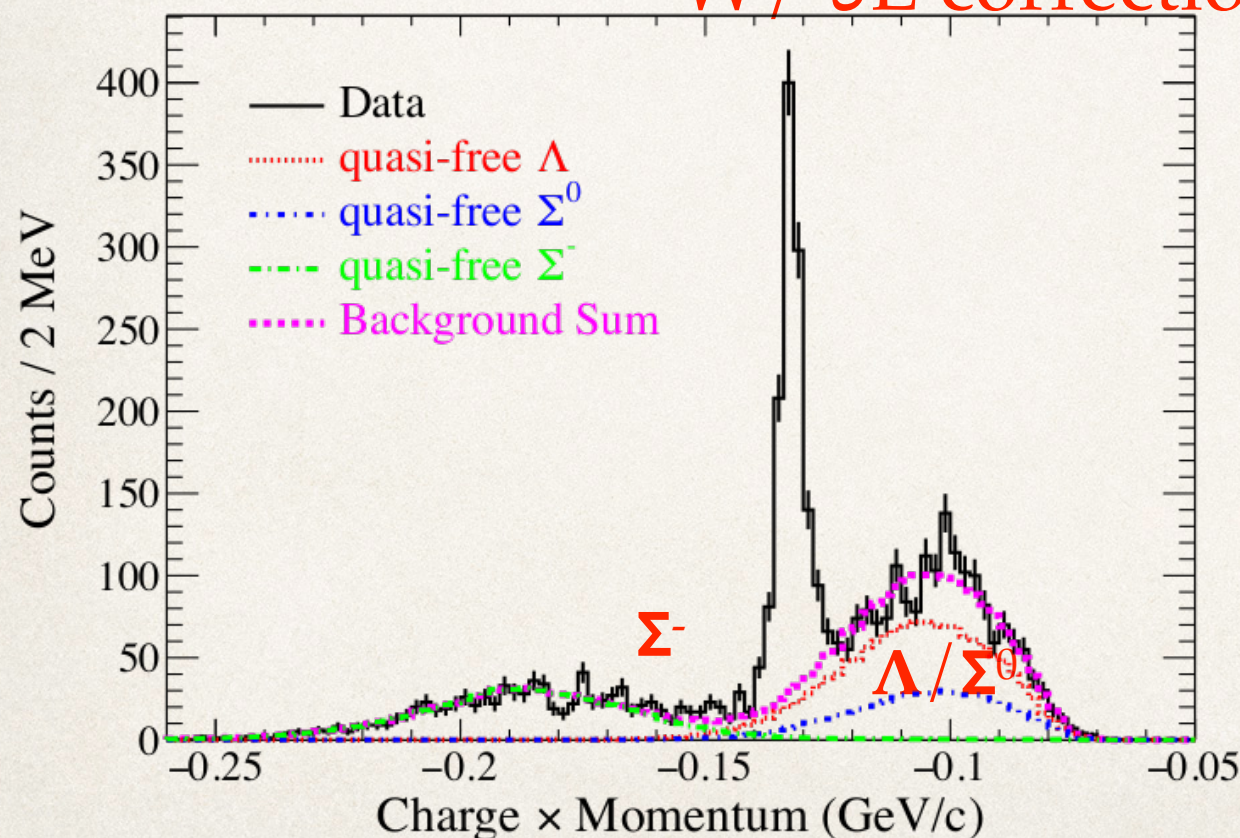
Pilot run results: ${}^4_{\Lambda}\text{H}$ lifetime



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



$132.6 \pm 0.1 \text{ (stat.) MeV}/c$
 $W / \delta E$ correction

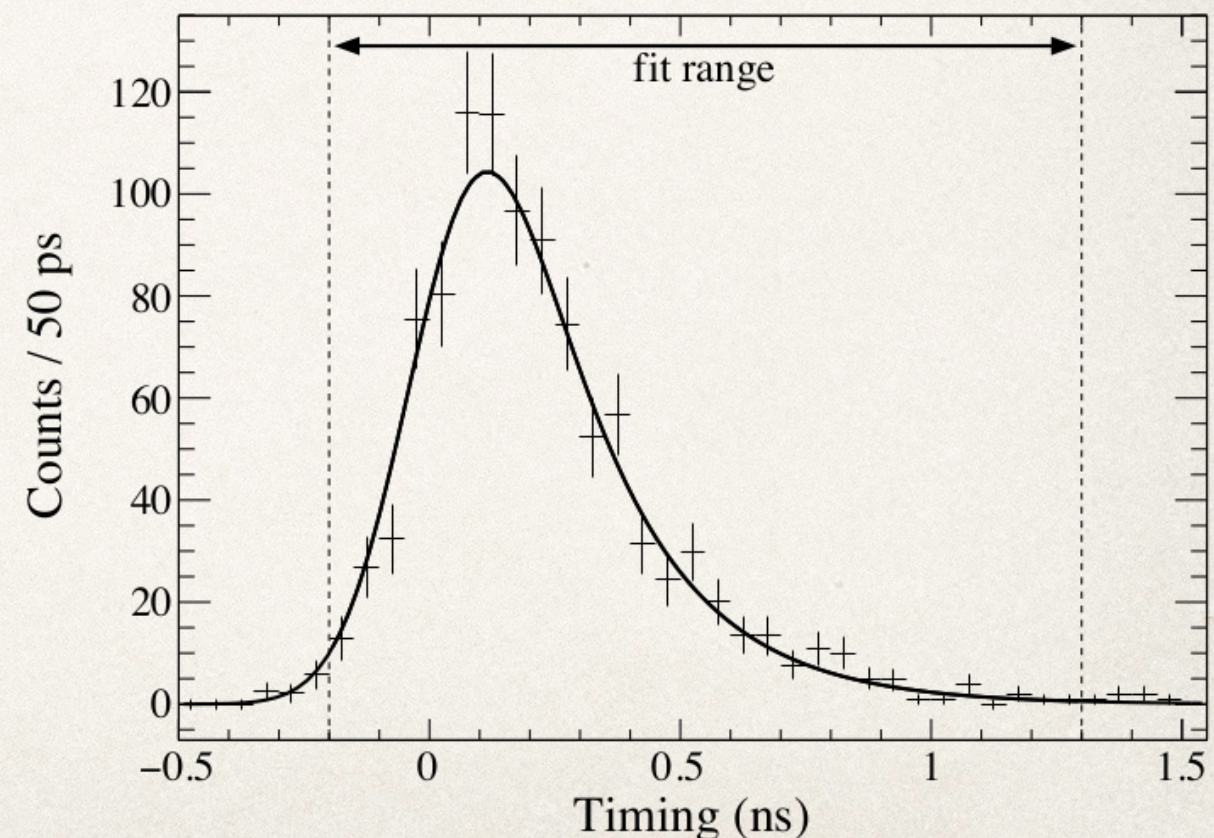


$218 \pm 6 \text{ (stat.)} \pm 13 \text{ (sys.) ps}$

@ STAR, Au-Au collision

(doi.org/10.1103/PhysRevLett.128.202301)

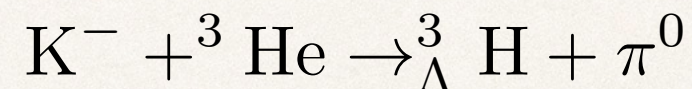
$206 \pm 8 \text{ (stat.)} \pm 12 \text{ (syst.) ps}$



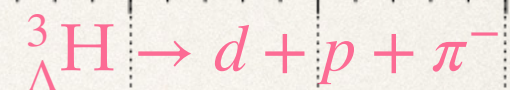
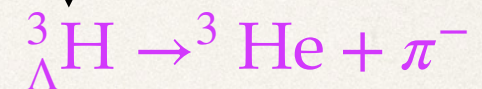
Stage-1 results: ${}^3_{\Lambda}\text{H}$ cross section

- ❖ First measurement for ${}^3\text{He}(\text{K}^-, \pi^0){}^3_{\Lambda}\text{H}$ reaction cross section; direct determination of ${}^3_{\Lambda}\text{H}$ ground state spin;
- ❖ Ready for E73 Stage-2 beam time with 25days @ 80kW beam time for $\sim 1\text{k}$ 2-body decay events scaled with Phase-1 data
- ❖ Expected precision for ${}^3_{\Lambda}\text{H}$ lifetime:
 - ❖ statistical error ~ 20 ps;
 - ❖ systematic error ~ 20 ps based on the ${}^4_{\Lambda}\text{H}$ result

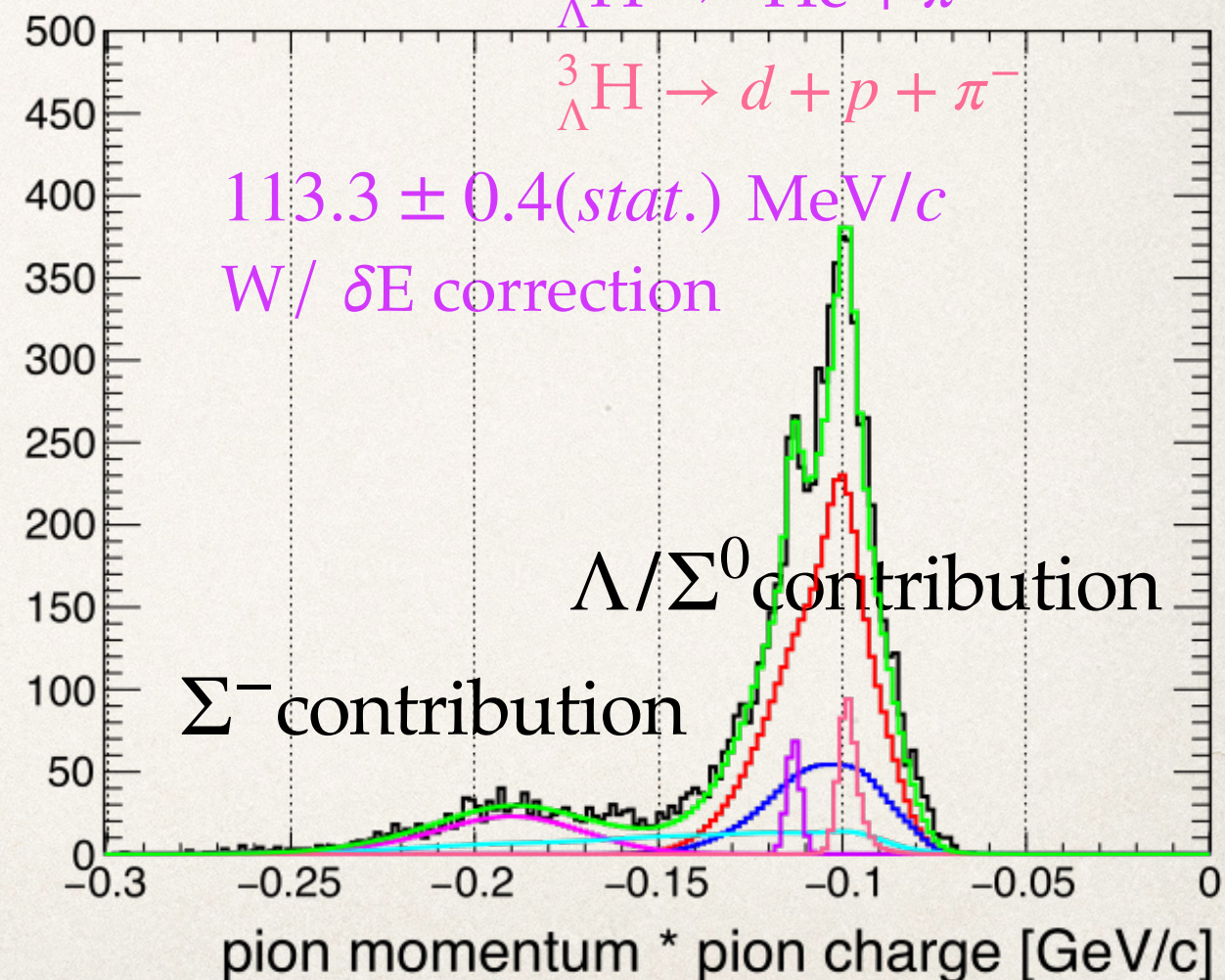
273kW*Day executed in May, 2021



↓ slows down and decays at rest



$113.3 \pm 0.4(\text{stat.}) \text{ MeV}/c$
W/ δE correction



Comments from the 35th PAC meeting

E73

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

Comments from the 36th PAC meeting

E73 (hypertriton lifetime)

The PAC congratulates the collaboration for their successful demonstration of the identification of ${}^4_{\Lambda}\text{H}$ and ${}^3_{\Lambda}\text{H}$ hypernuclei, for their measurement of γ -decay from π^0 , and the successful measurement of the ${}^4_{\Lambda}\text{H}$ lifetime through directly tagging the π^- decay product. The PAC congratulates the collaboration for the imminent publication of the latter result. From the observed data of the ${}^4_{\Lambda}\text{H}$ decay, the collaboration has estimated the precision of the ${}^3_{\Lambda}\text{H}$ lifetime measurement as 20 ps (stat) and 20 ps (syst). The PAC recognizes the idea that the ratio of the production cross sections of ${}^3_{\Lambda}\text{H}$ and ${}^4_{\Lambda}\text{H}$ provides the binding energy, giving a better understanding of the structure of ${}^3_{\Lambda}\text{H}$.

The PAC already recommended allocating a 25-days 80 kW beam time for E73 in JFY2023 even though the limited beam operation has not allowed execution. PAC recommends allocating 1 cycle of data taking to E73 before July 2024 at high priority.

E73 output (before physics run!)

- ❖ ${}^4_{\Lambda}\text{H}$ lifetime paper published by Physics Letters B:
<https://doi.org/10.1016/j.physletb.2023.138128>
- ❖ Mr. T. Akaishi submitted his PhD thesis to Osaka University

Summary

- ❖ 36th PAC reconfirms $80kW \times 25days$ beam time for E73 experiment with high priority (including controlled run)
 - ❖ Expected precision for ${}^3_{\Lambda}H$ lifetime: ~ 20 ps (stat.) ~ 20 ps (syst.)
- ❖ We are *ready* for data taking and aim to complete before Summer, 2024
- ❖ Outputs:
 - ❖ ${}^4_{\Lambda}H$ lifetime paper published by Physics Letter B
 - ❖ Mr. Akaishi's PhD thesis submitted to Osaka University

E73/T77 collaborator list

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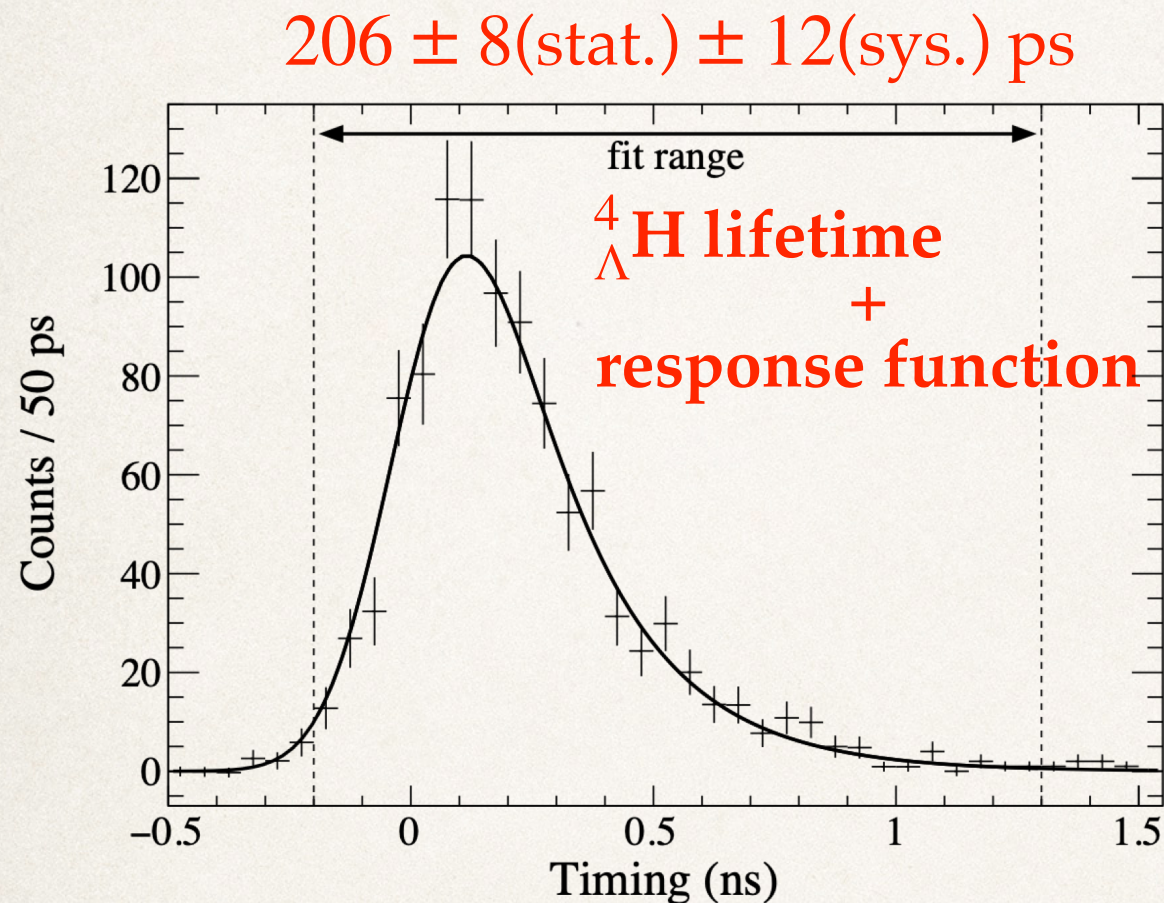
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backup

${}^4_\Lambda\text{H}$ lifetime analysis published by PLB



$194^{+24}_{-26} \text{ ps}$ @ KEK stop K-
H. Ota, et al., Nucl. Phys. A 547,
(1992), 109c-114c

$218 \pm 6(\text{stat.}) \pm 13(\text{sys.}) \text{ ps}$
@ STAR, Au-Au collision
arXiv:2110.09513

Table 1

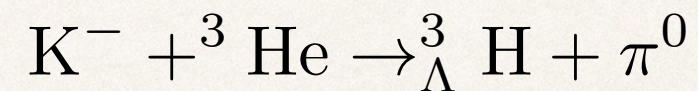
Systematic uncertainties for ${}^4_\Lambda\text{H}$ lifetime measurement.

Contribution	Value
Intrinsic bias of J-PARC T77 approach	$\pm 2 \text{ ps}$
Uncertainty from γ selection	$\pm 4 \text{ ps}$
Uncertainty of time calibration	$\pm 7 \text{ ps}$
Uncertainty of background subtraction	$\pm 5 \text{ ps}$
Uncertainty in fitting process	$\pm 7 \text{ ps}$
Total (quadratic sum)	$\pm 12 \text{ ps}$

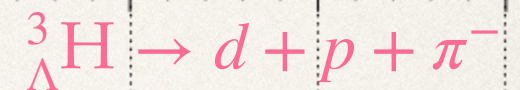
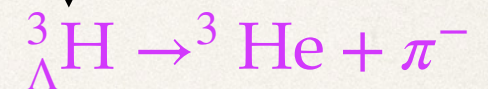
Luminosity: 80kW*25days

- ❖ Request for E73 Stage-2 approval with 25days @ 80kW beam time for ~1k 2-body decay events scaled with Phase-1 data
- ❖ Expected precision for ${}^3_{\Lambda}\text{H}$ lifetime:
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273kW*Day executed in May, 2021

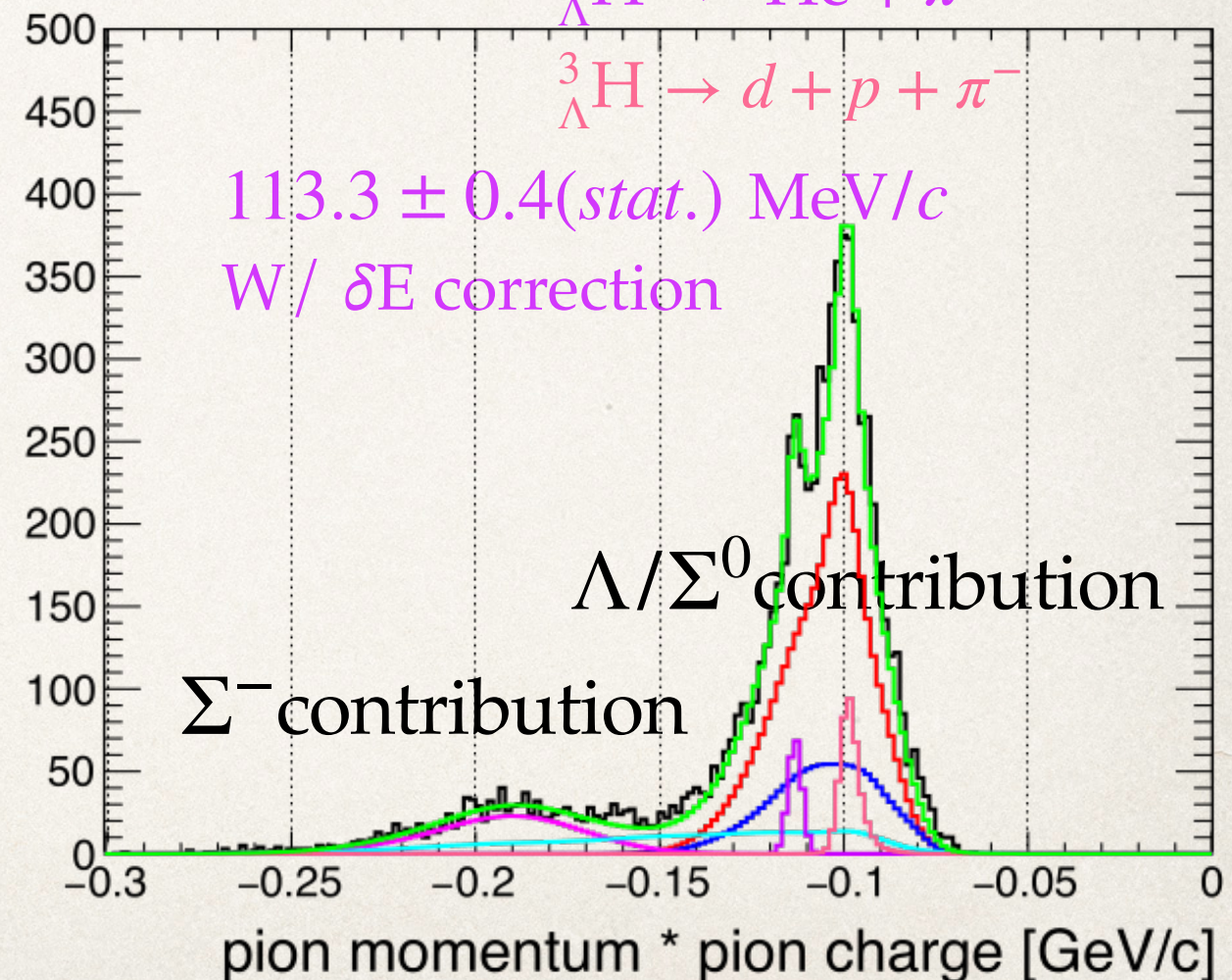


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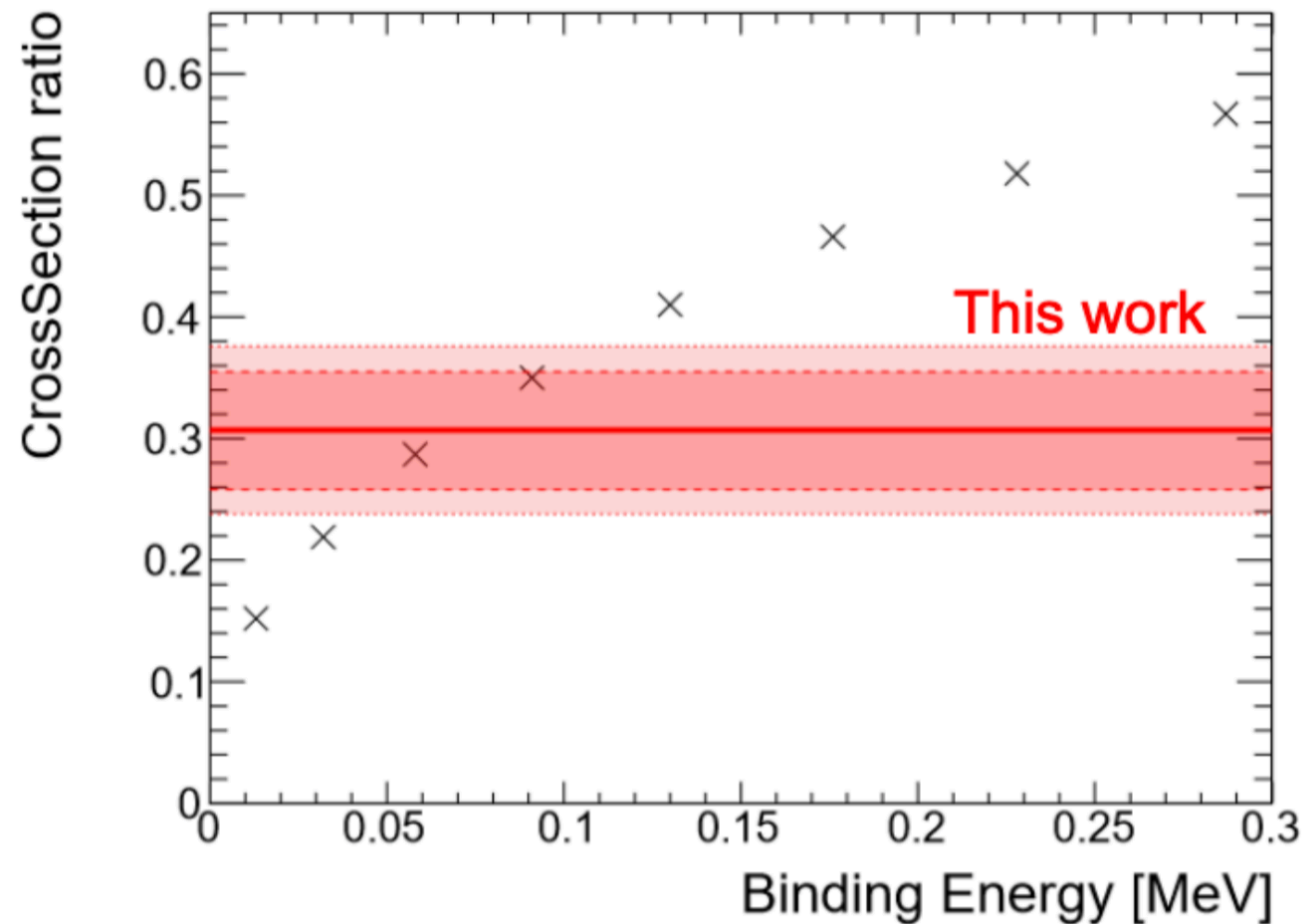


$113.3 \pm 0.4(\text{stat.}) \text{ MeV}/c$
W/ δE correction

Counts/1.6 MeV/c



T. Akaishi's PhD thesis results



Emulsion1973

STAR2020

ALICE2023

World Ave.

This work

