Towards solving the hypertriton lifetime puzzle with *direct lifetime measurement*: current status of J-PARC E73 experiment

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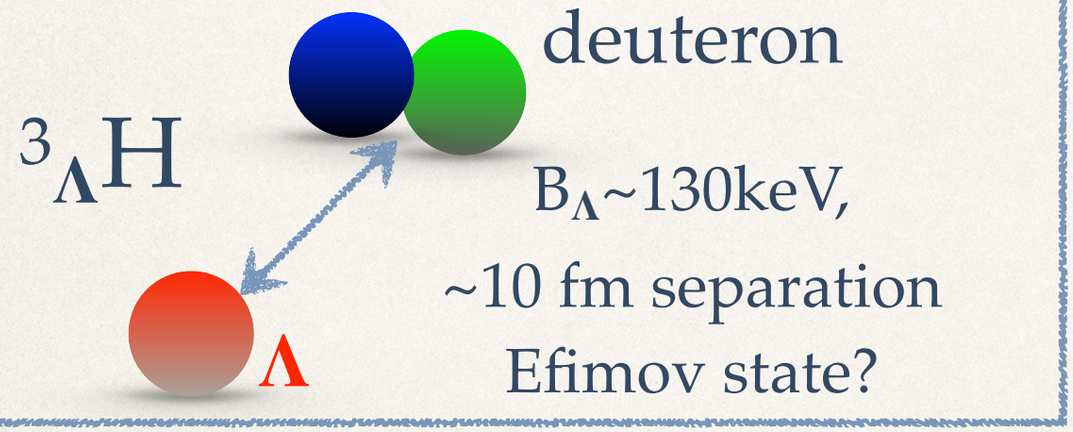
Outline

- Introduction & motivation
- J-PARC E73:
  - Experimental method
  - Current status
- Summary

Introduction: motivation

As the lightest hypernucleus, ${}^{3}_{\Lambda}$H should tell us some important fact of YN interactions just as deuteron for nuclear physics.



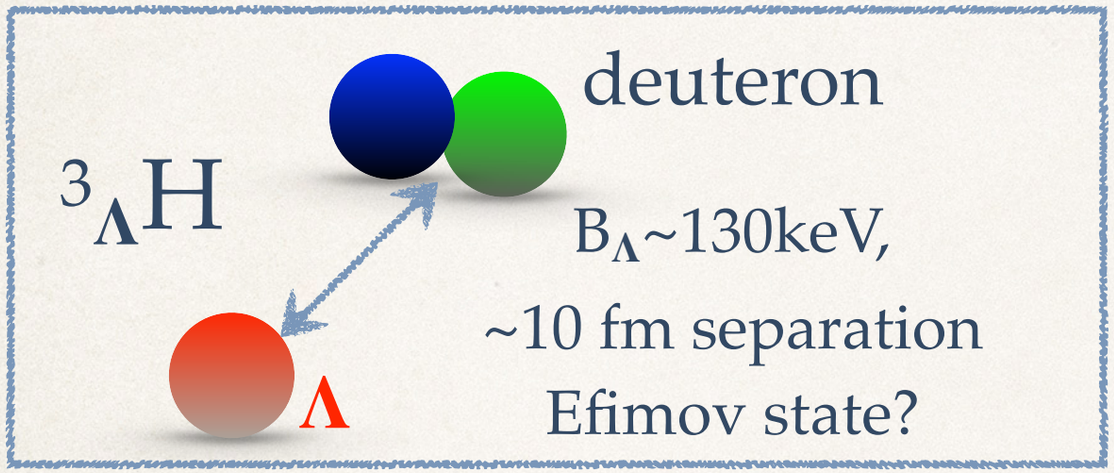
Up to a few years ago, we believe:
$\tau \approx 263$ ps ($B_\Lambda = 130 \pm 50$ keV).

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

a small term
(separation of ~10fm)

A well separated wave function between **Λ** and deuteron implies small modification of ${}^{3}_{\Lambda}$H lifetime from deuteron and, thus, its lifetime should be presumably determined by free **Λ** decay.

Motivation of E73 experiment

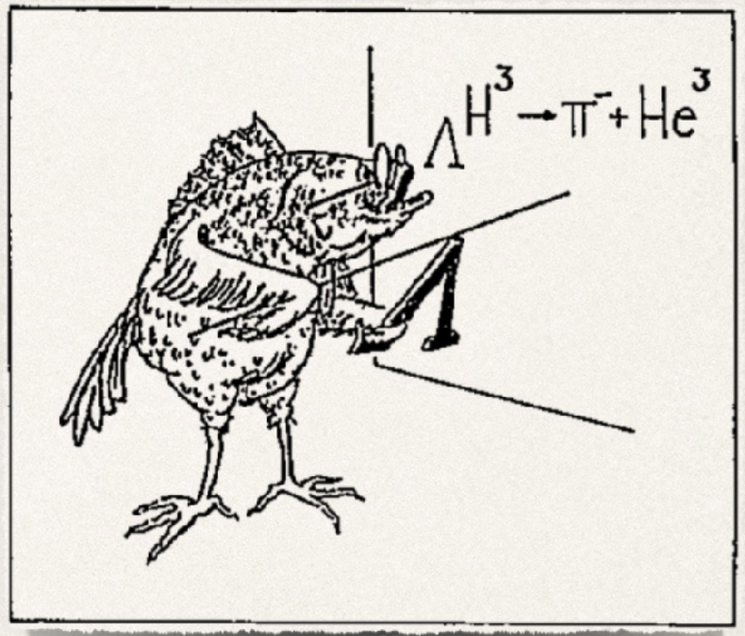


Up to a few years ago, we believe:
$\tau \approx 263$ ps ($B_\Lambda = 130 \pm 50$ keV);
However, heavy ion experiments suggest $\tau \approx 180$ ps…

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

ALICE 2019:
$\tau = 240\ ^{+40}_{-31} \pm 18$ ps
STAR 2021:
$\tau = 232.1 \pm 29.2 \pm 36.7$ ps

Is the Hypertriton lifetime puzzle solved?



Neither fish nor fowl?

Picture taken from MM. Block et al. Proc. Int. Conf. Hyperfragments, 1963

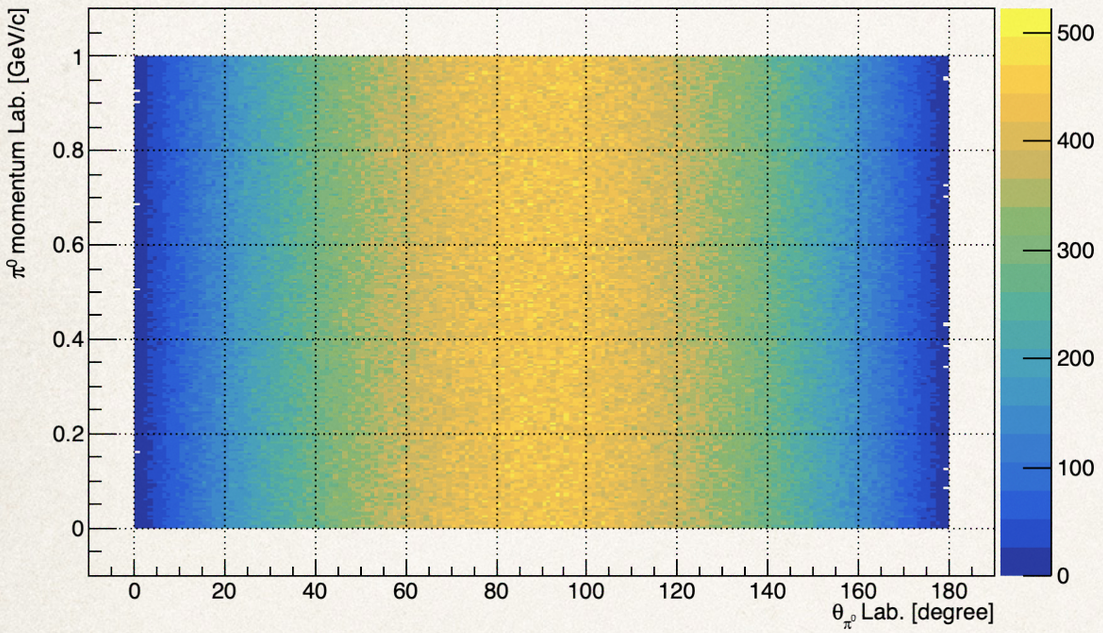
${}^{3}\mathrm{He}(\mathrm{K}^{-}, \pi^{0})^{3}_{\Lambda}\mathrm{H}$ vs heavy ion production

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

How does E73 work by tagging single γ-ray?

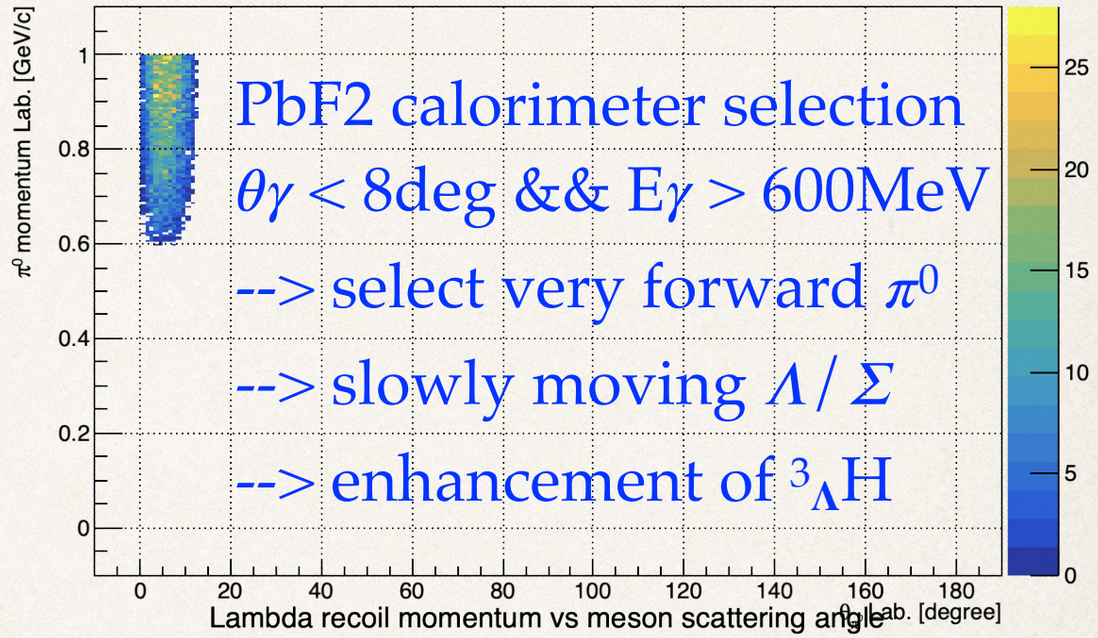
Input

π^0: 0~1GeV/c; 0~180deg

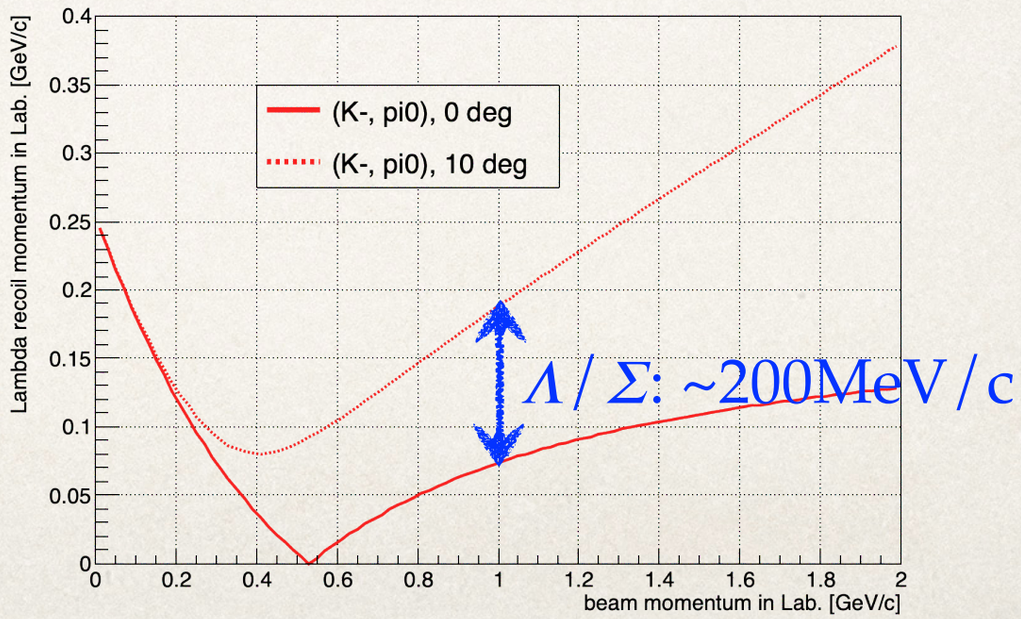


W/ PbF2 calorimeter cut

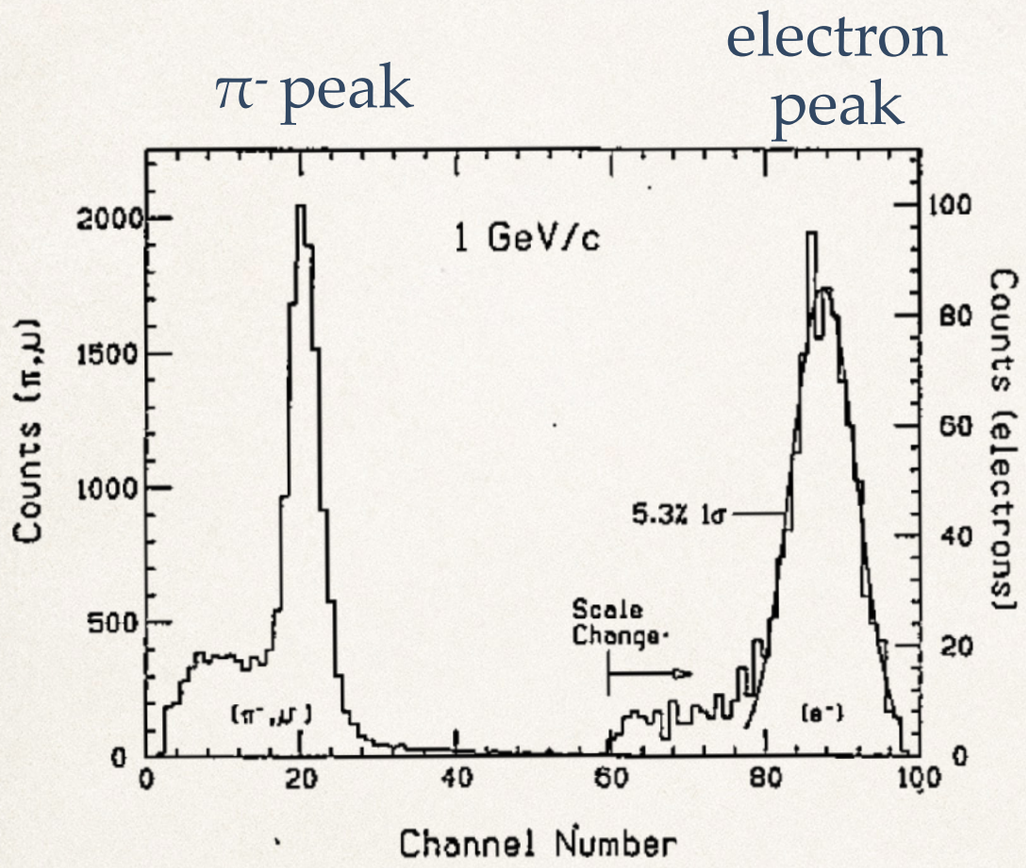
π^0: 0.8~1GeV/c; 0~10deg



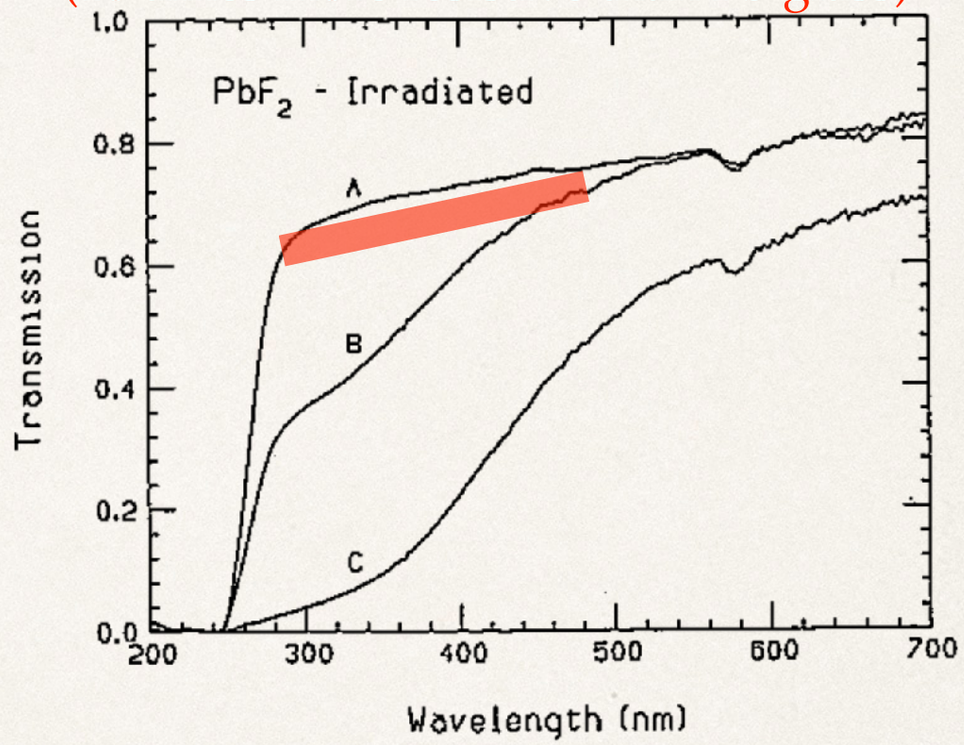
^{3}He(K-, pi0)$^3_\Lambda$H strangeness exchange reaction is known for its spin non-flip feature --> helps to pin down the $^3_\Lambda$H Q.N.



Experimental setup: π^0 tagger (PbF_2)



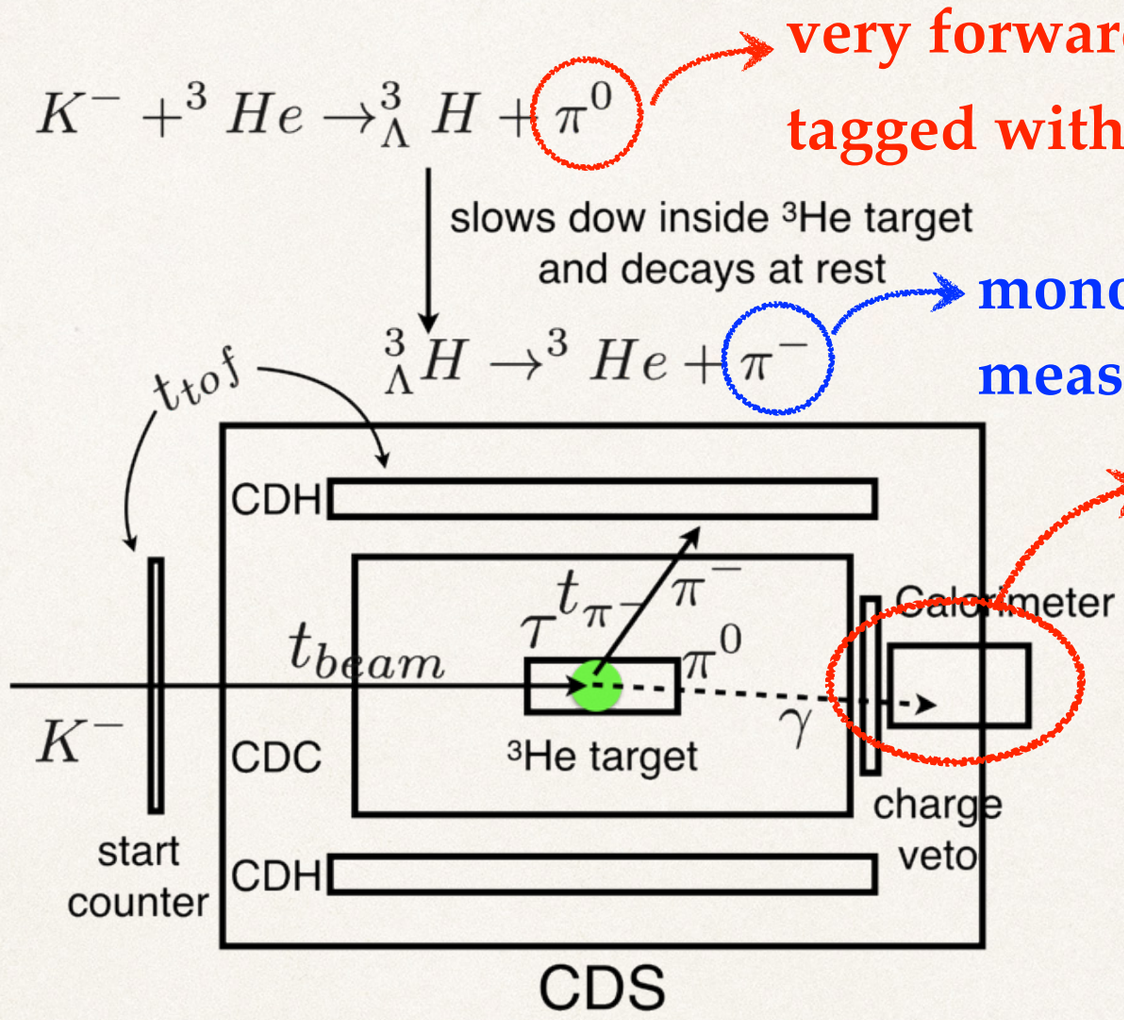
expected performance after one month beam time
(10 times more resistive than Pb glass)



Crystal	Radiation length	Moliere radius	Density	Cost	Resolution	Signal length
PbF_2	0.93 cm	2.22 cm	7.77 g/cm^3	12 USD/cc	5%	2ns

D.F. Anderson, ***et al.***, Nucl. Inst. Meth. A290 (1990) 385
P. Achenbach, ***et al.***, Nucl. Inst. Meth. A416 (1998) 357

E73 Experimental setup



very forward π0 projectile;

tagged with decayed high energy γ

mono-energetic, ~114MeV/c;

measured with CDS

5x8 PbF2 Cherenkov Calo

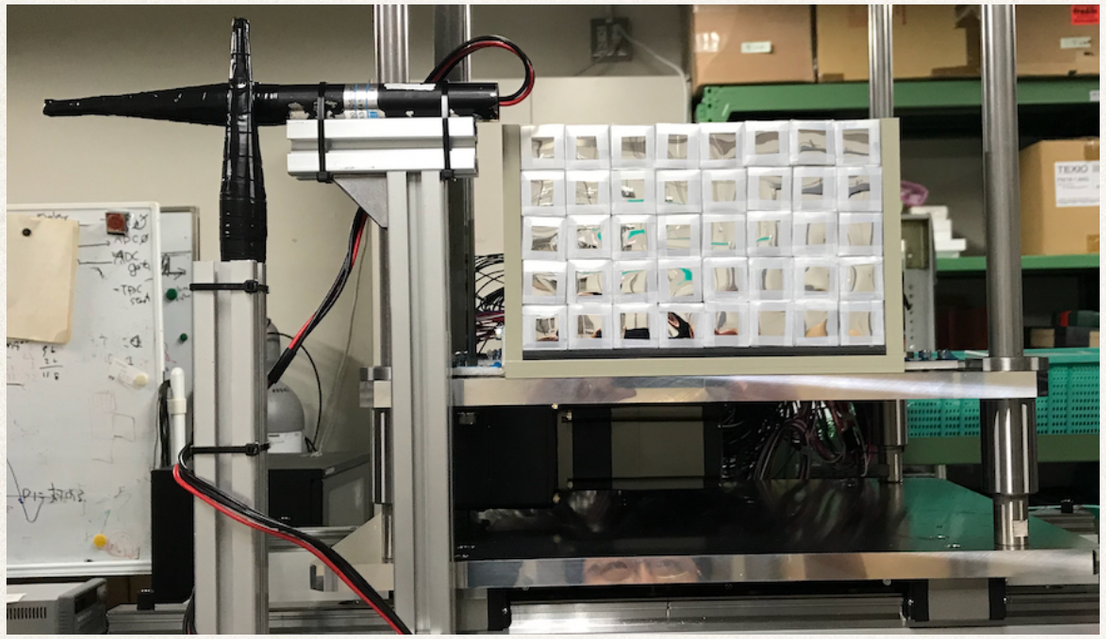
R&D has been completed

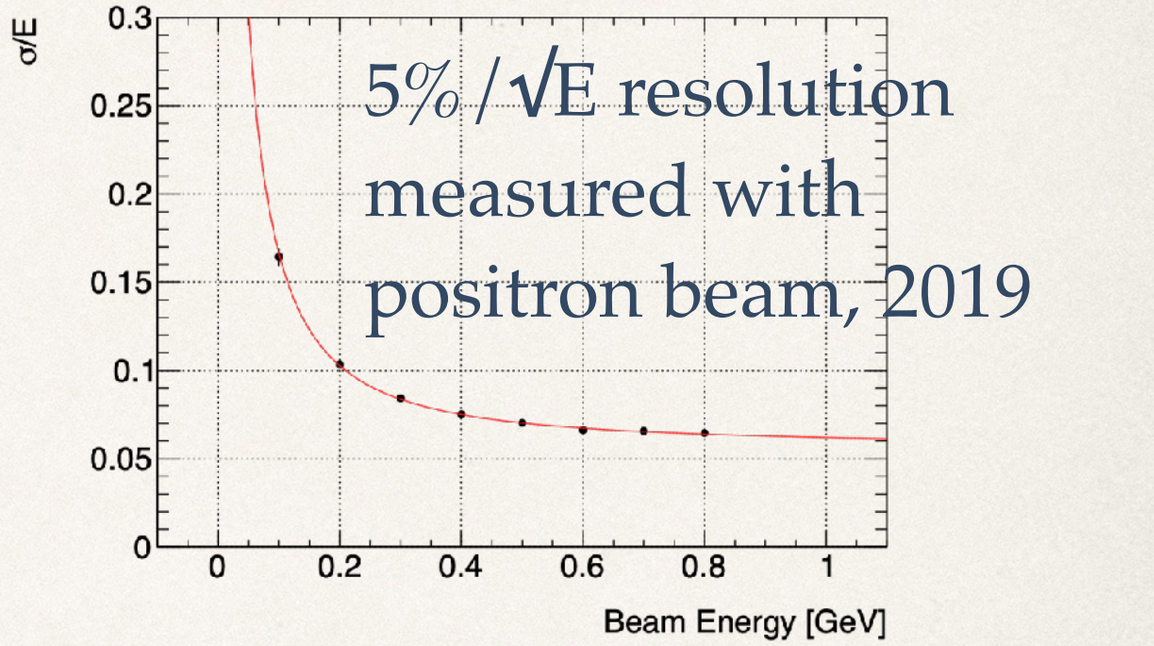
${}^3_\Lambda$H decay time can be derived by TOF and CDS tracking

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

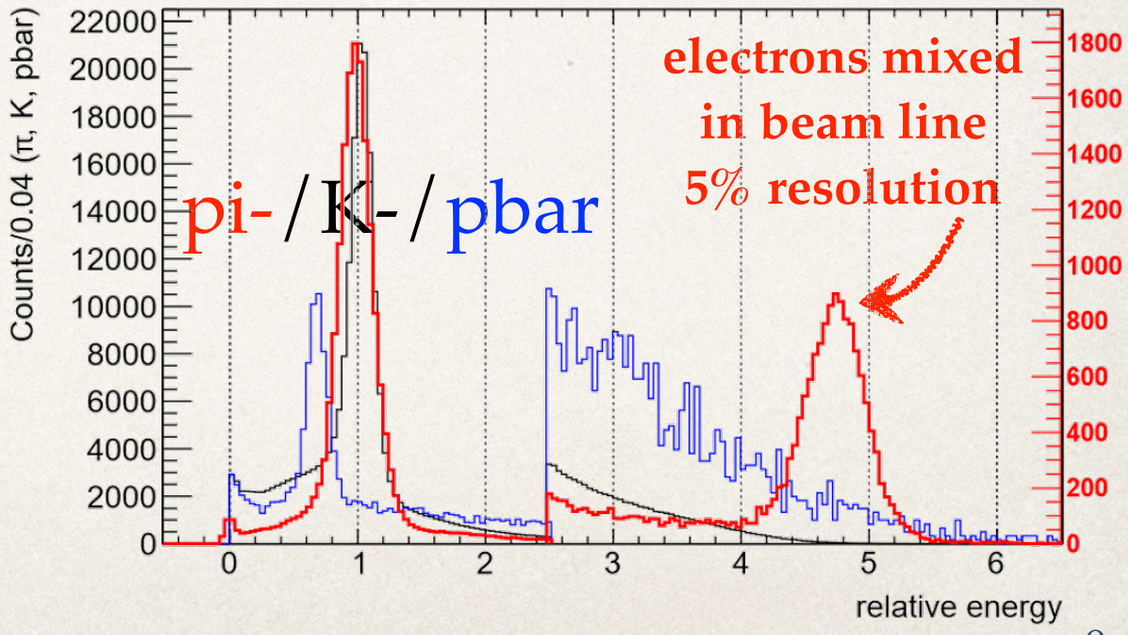
1. A complementary measurement for Heavy Ion results
2. Achievable precision: $\sigma/\sqrt{N}$ ~ 30ps

PbF2 calorimeter performance





- PbF2 calorimeter is installed ***INTO*** the meson beam line to tag fast pi0;
- All segments of PbF2 calorimeter works well with reasonable resolution even in high rate conditions.



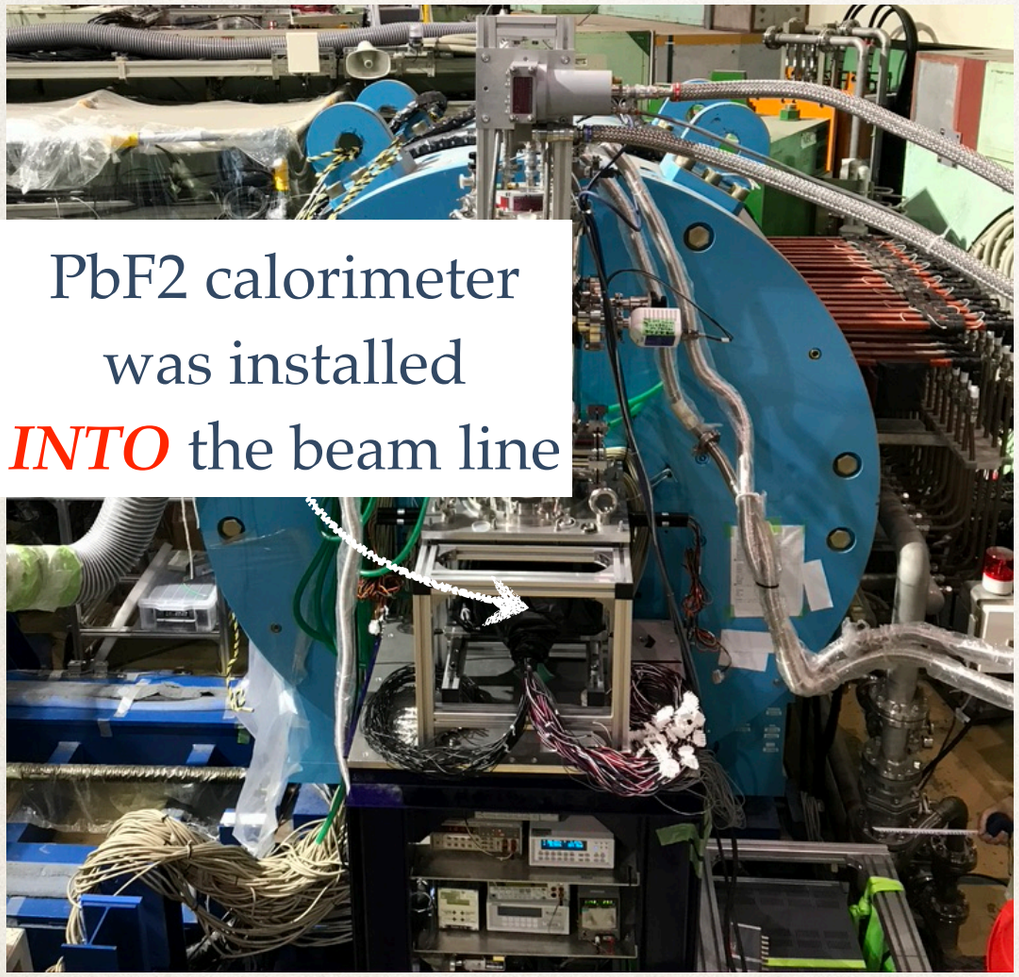
J-PARC E73 staging & status

Staging:	Phase-0 (June, 2020)	Phase-1 (May, 2021)	Phase-2
Task:	Background study with ^{4}He(K-,pi0)$^{4}_{\Lambda}$H	First measurement for ^{3}He(K-, pi0)$^{3}_{\Lambda}$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 publication under preparation	Fully ready for beam time from now on	Depends on Phase-1 results

Covered in this talk

E73 Phase-0: feasibility study

World record data for ${}^{4}_{\Lambda}$H lifetime measurement

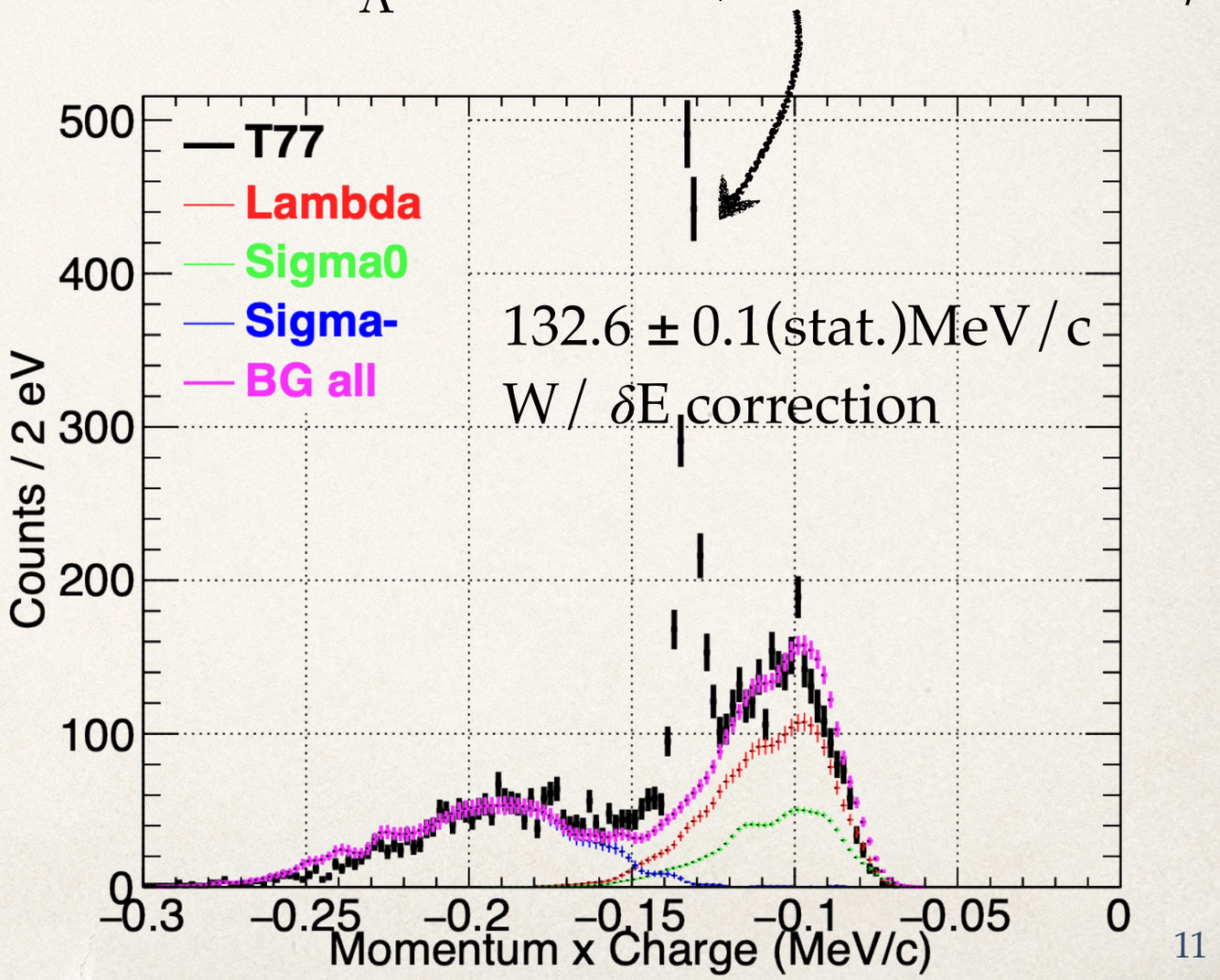


PbF2 calorimeter was installed ***INTO*** the beam line

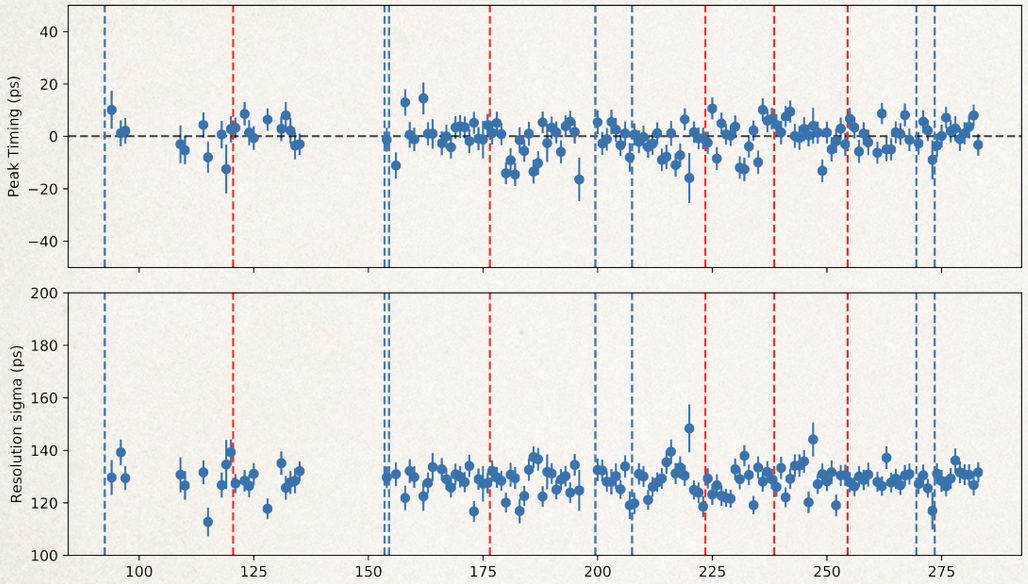
$$K^- + {}^4\mathrm{He} \rightarrow {}^4_\Lambda\mathrm{H} + \pi^0$$

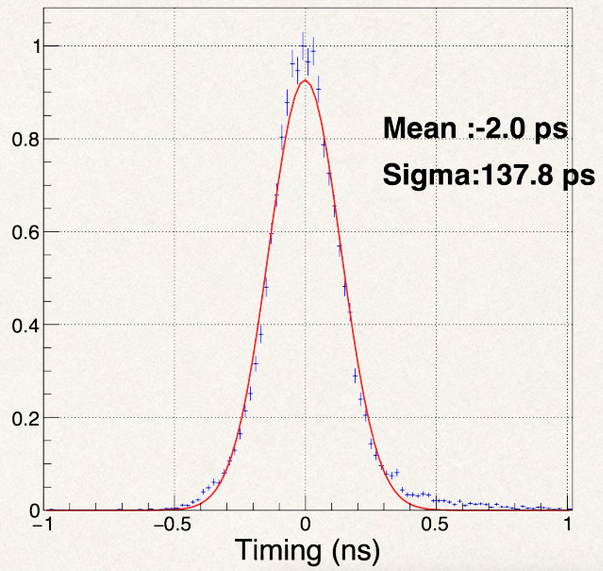
slows down inside ⁴He target and decays at rest

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



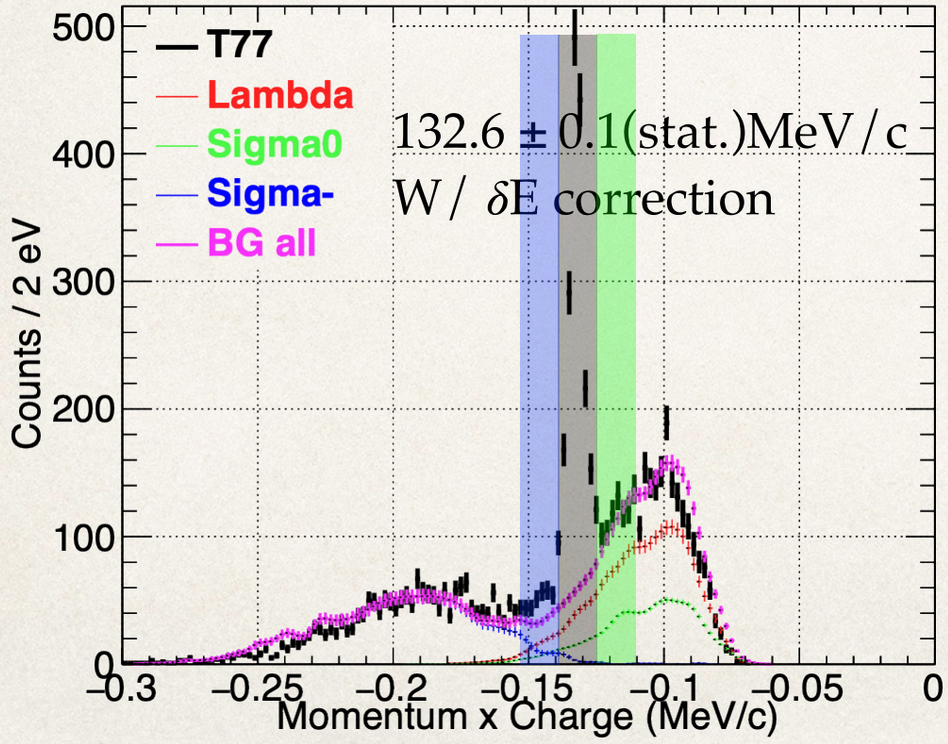
E73 Phase-0: ${}^{4}_{\Lambda}\mathrm{H}$ lifetime results



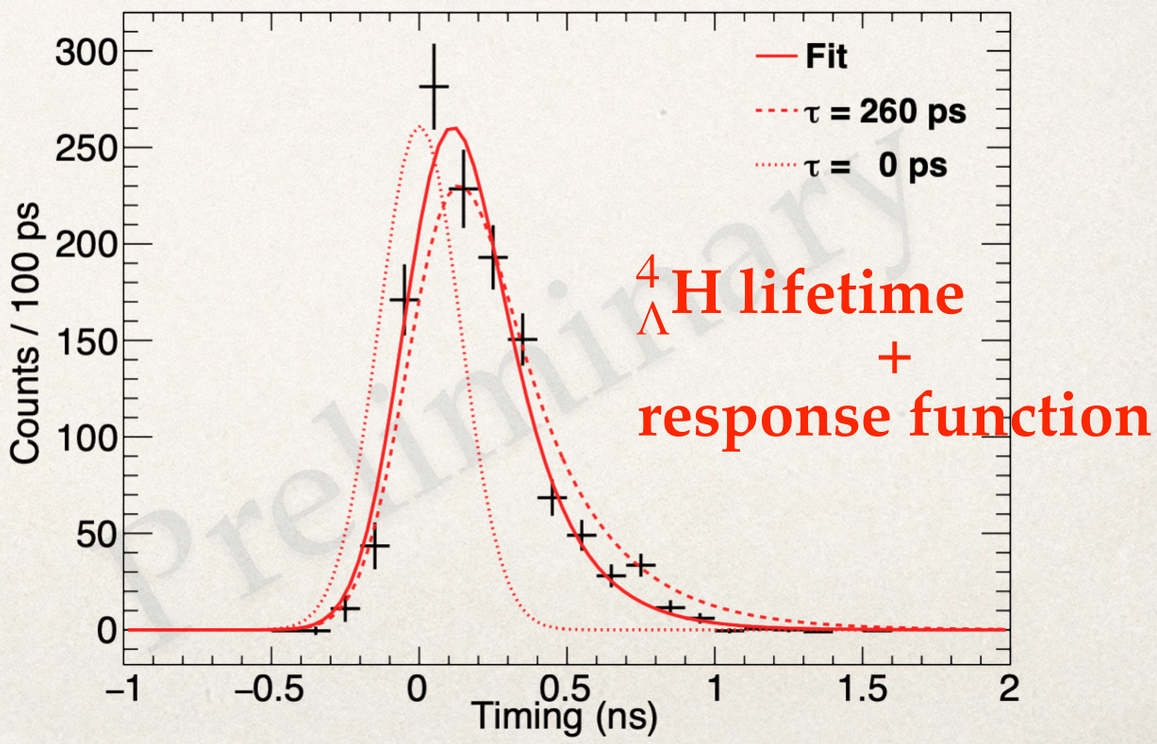


Stability and time response function from prompt hadronic events

Background subtraction

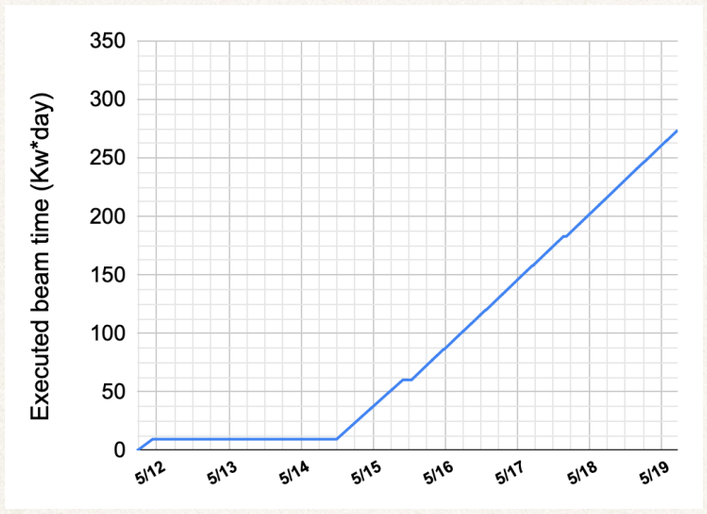


Analysis will be released soon



${}^{4}_{\Lambda}\mathrm{H}$ lifetime + response function

E73 Phase-1: ${}^{3}_{\Lambda}\mathrm{H}$ production cross section



Completed in May, 2021

Stable beam condition: 97.5% up time

(350kW*Day request, 273kW*Day executed)

Thanks for the J-PARC staffs!

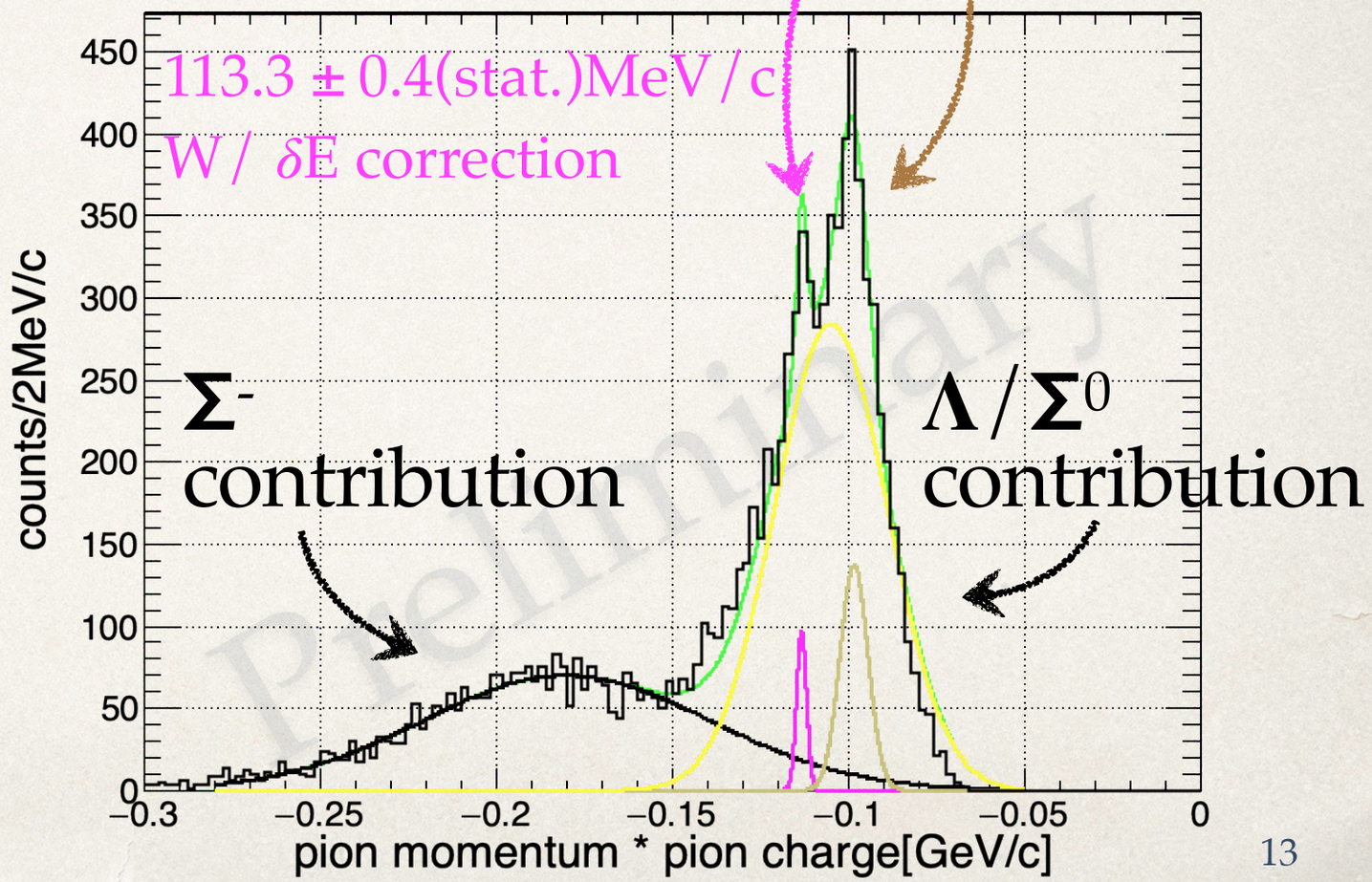
- ${}^{3}_{\Lambda}\mathrm{H}$ production cross section;
- Both 2-body & 3-body decay from ${}^{3}_{\Lambda}\mathrm{H}$ has been observed;

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

slows down inside ^{3}He target and decays at rest

$${}^3_\Lambda\mathrm{H} \rightarrow {}^3\mathrm{He} + \pi^- \quad 114\,\mathrm{MeV/c}$$

$${}^3_\Lambda\mathrm{H} \rightarrow {}^2\mathrm{H} + \mathrm{p} + \pi^-$$



Summary

- We have established a new method to investigate the isospin mirror Hypernuclei by gamma-ray tagging

- First counter experiment to determine the Hypertriton ground state spin & cross section

- ${}^{3}_{\Lambda}\mathrm{H}$ Lifetime measurement is planned around ~2023

Backup