# Stage-1 beam time request for J-PARC E73:

# ${}^{3}_{\Lambda}$H mesonic weak decay lifetime measurement with ${}^{3}$He($K^-$, $\pi^0$)${}^{3}_{\Lambda}$H reaction

Yue Ma from RIKEN

y.ma@riken.jp

*2021/01/20*

# 30th PAC comment for E73

Based on this successful test, P73 now requests stage-1 status. In addition, they ask for a pilot run with the $^{3}$He target with 350kW×day before the long shut down in 2021. The aim of this pilot run is to determine the unknown production cross section of $^{3}_{\Lambda}$H with the $^{3}$He target. This will then allow them to make an informed estimate of the total beam time which is required for the final physics run.

The PAC congratulates the collaboration for this excellent interim result of T77, which proves that this new experimental method works. The PAC realizes the importance of the pilot run with $^{3}$He. Therefore, the PAC supports the continuation of T77 by an explorative run with the $^{3}$He target. If the opportunity arises, the $^{3}$He data should be taken already before the long shutdown. The PAC also suggests stage-1 status for P73.

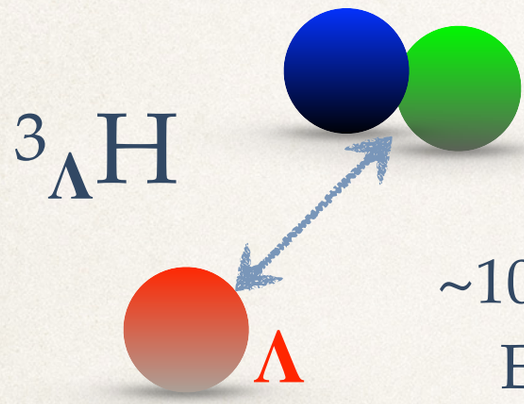
***This talk: E73 readiness for stage-1 beam time before the long shut down***

# Outline

- Introduction to J-PARC E73:
  - The first direct measurement for ${}^{3}_{\Lambda}\mathrm{H}$ lifetime
- Current status
  - Fully ready for data taking
- Summary & beam time request

# 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).

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

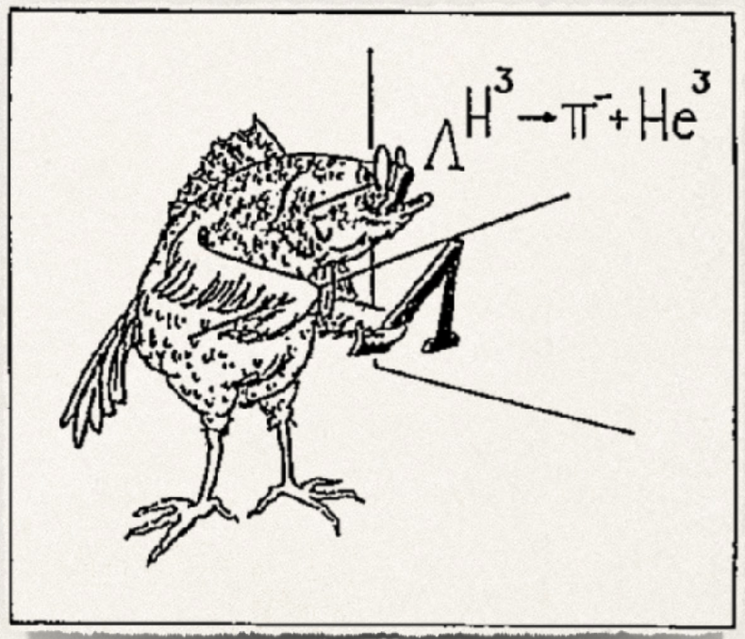
# Introduction: motivation

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);
However, heavy ion experiments suggest $\tau \approx 180$ ps…

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

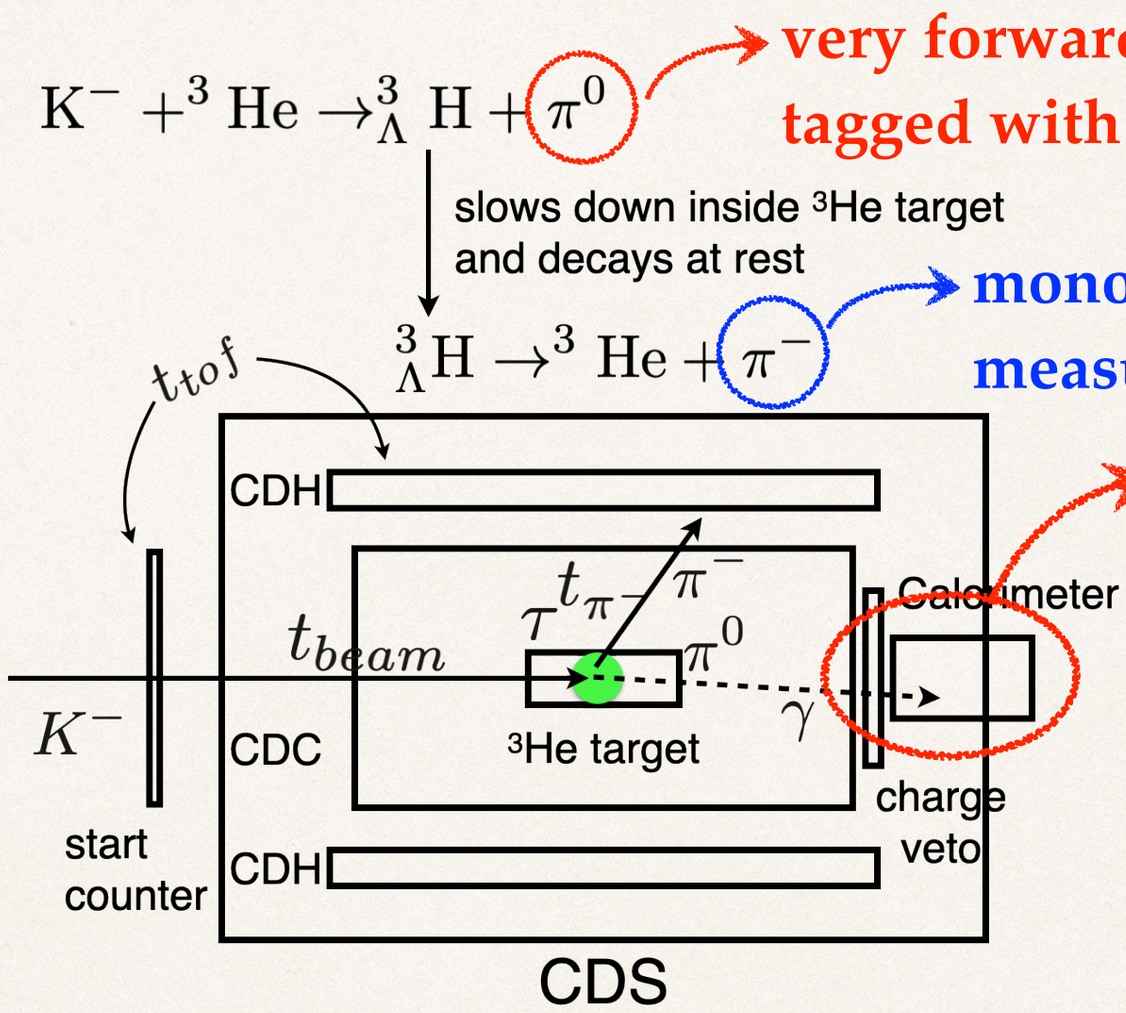
| Collaboration | Experimental method | ${}^{3}_{\Lambda}$H lifetime [ps] | Release date |
|---|---|---|---|
| ALICE | Pb collider | $240^{+40}_{-31}$(stat.)±18(syst.) | 2019 |
| STAR | Au collider | $142^{+24}_{-21}$(stat.)±29(syst.) | 2018 |
| HypHI | fixed target | $183^{+42}_{-32}$(stat.)±37(syst.) | 2013 |




Neither fish nor fowl?

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

# E73 Experimental setup




**very forward $\pi$0 projectile; tagged with decayed high energy $\gamma$**

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

5x8 PbF2 Cherenkov Calo

***Fully ready***

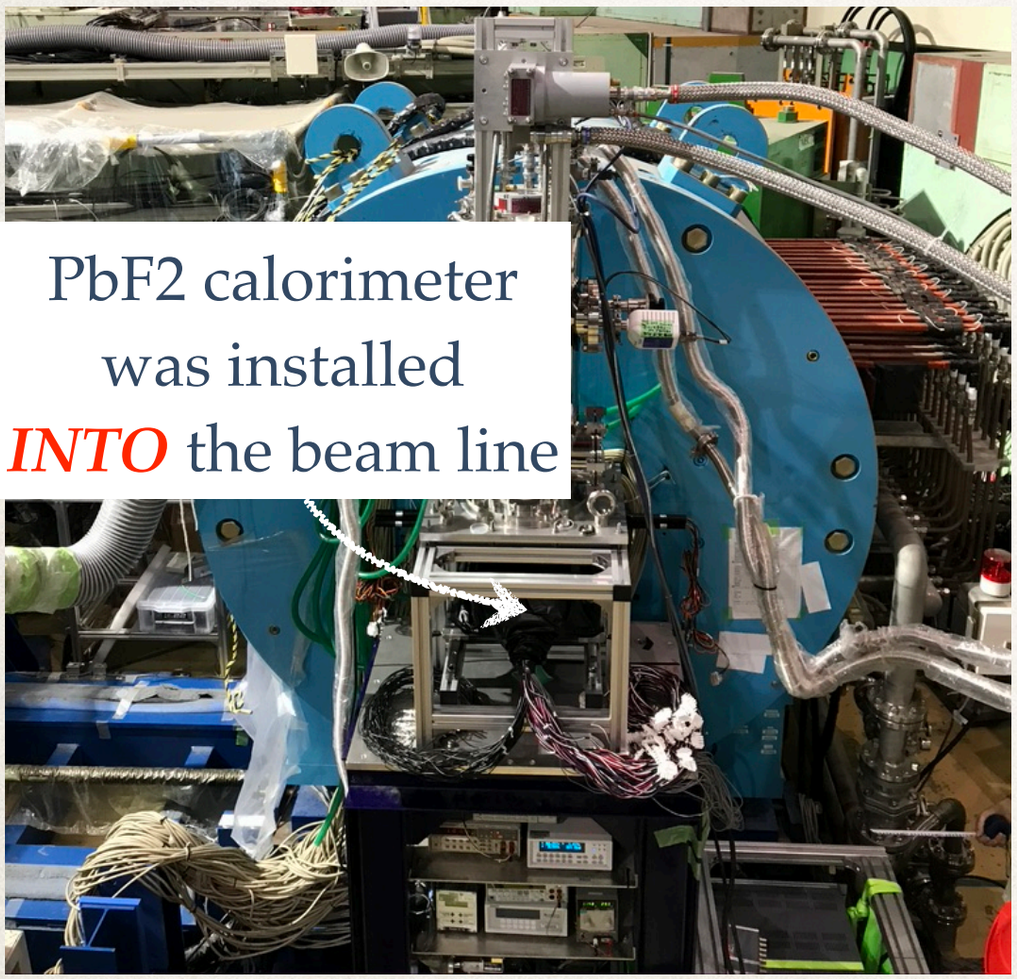
**${}^3_\Lambda$H decay time can be derived by TOF and CDS tracking**

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

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

# T77 experiment: feasibility study for E73

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

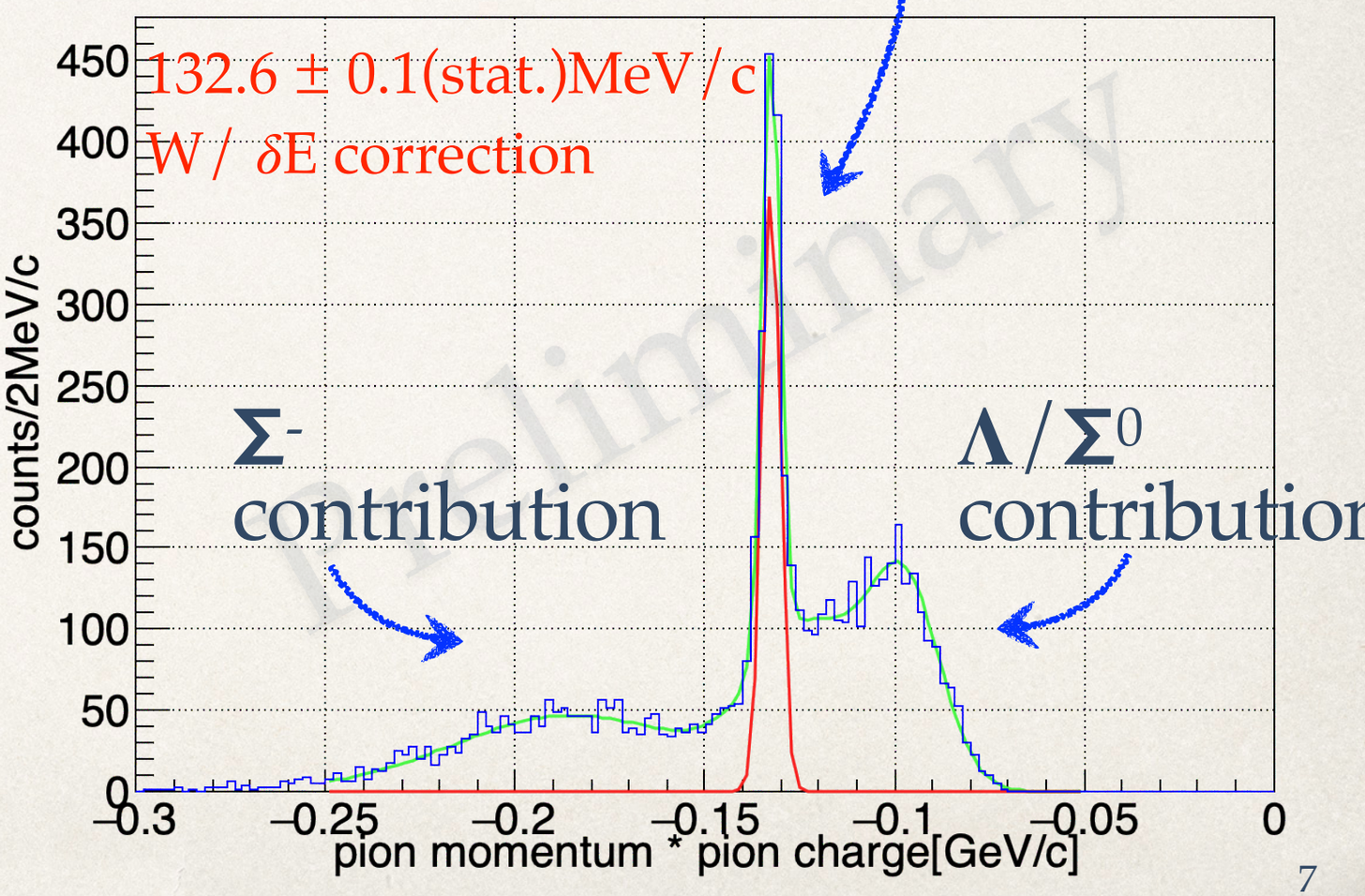


PbF2 calorimeter was installed ***INTO*** the beam line

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

slows down inside ⁴He target and decays at rest

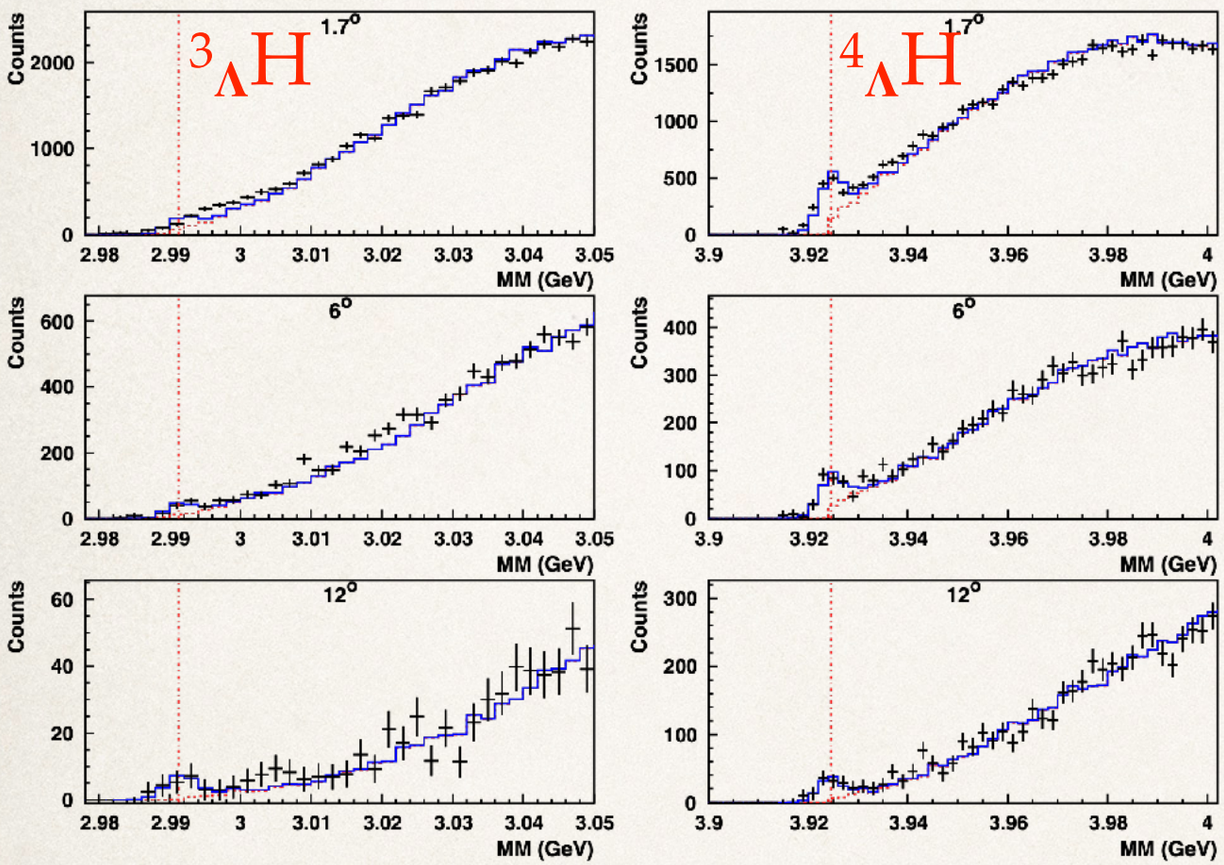
$${}^4_\Lambda\mathrm{H} \rightarrow {}^4\mathrm{He} + \pi^- \quad 132.9\ \mathrm{MeV/c}$$



# Stage-1 beam time request for E73

| Staging: | Stage-0 | Stage-1 | Stage-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 Stage-1 results |

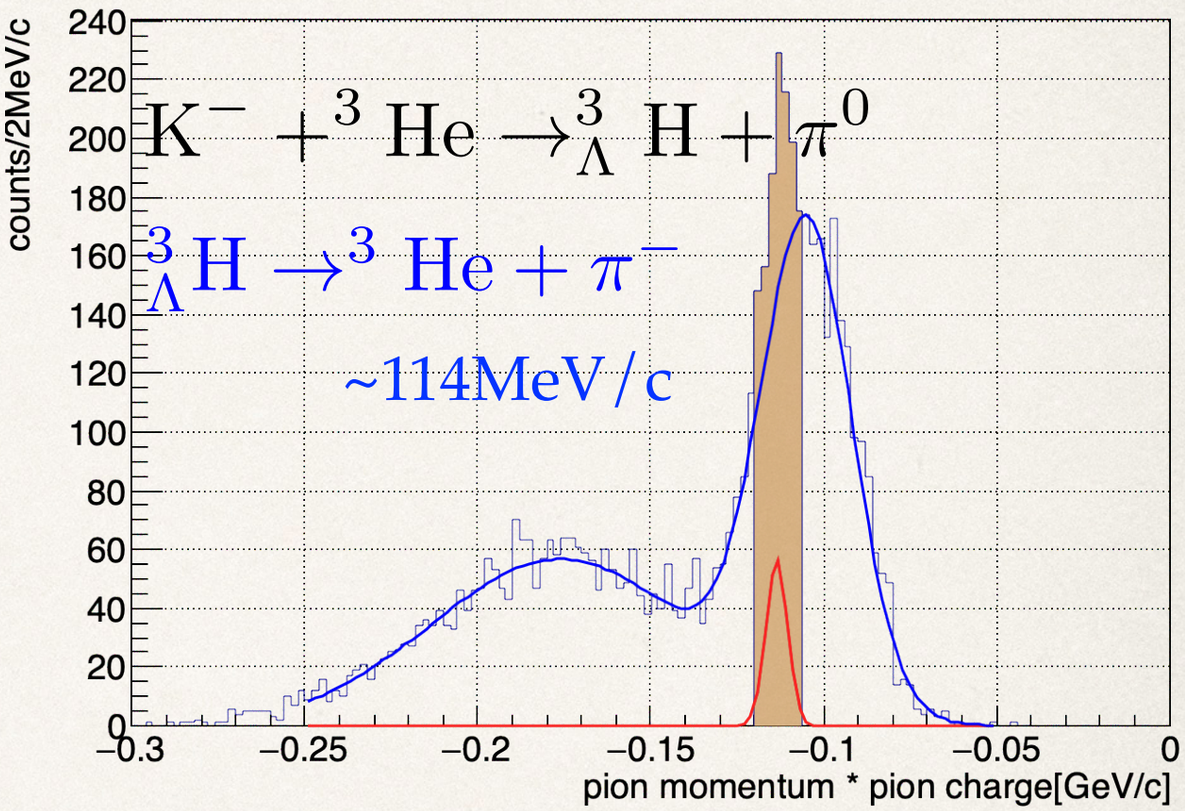
# ${}^{3}_{\Lambda}$H yield estimation W/ T77 and JLab data




$^{3,4}$He(e, e'K+)$^{3,4}_{\Lambda}$H reaction at JLab

$^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H ~ 0.26 ± 0.10 --> large uncertainty

DOI: 10.1103/PhysRevLett.93.242501



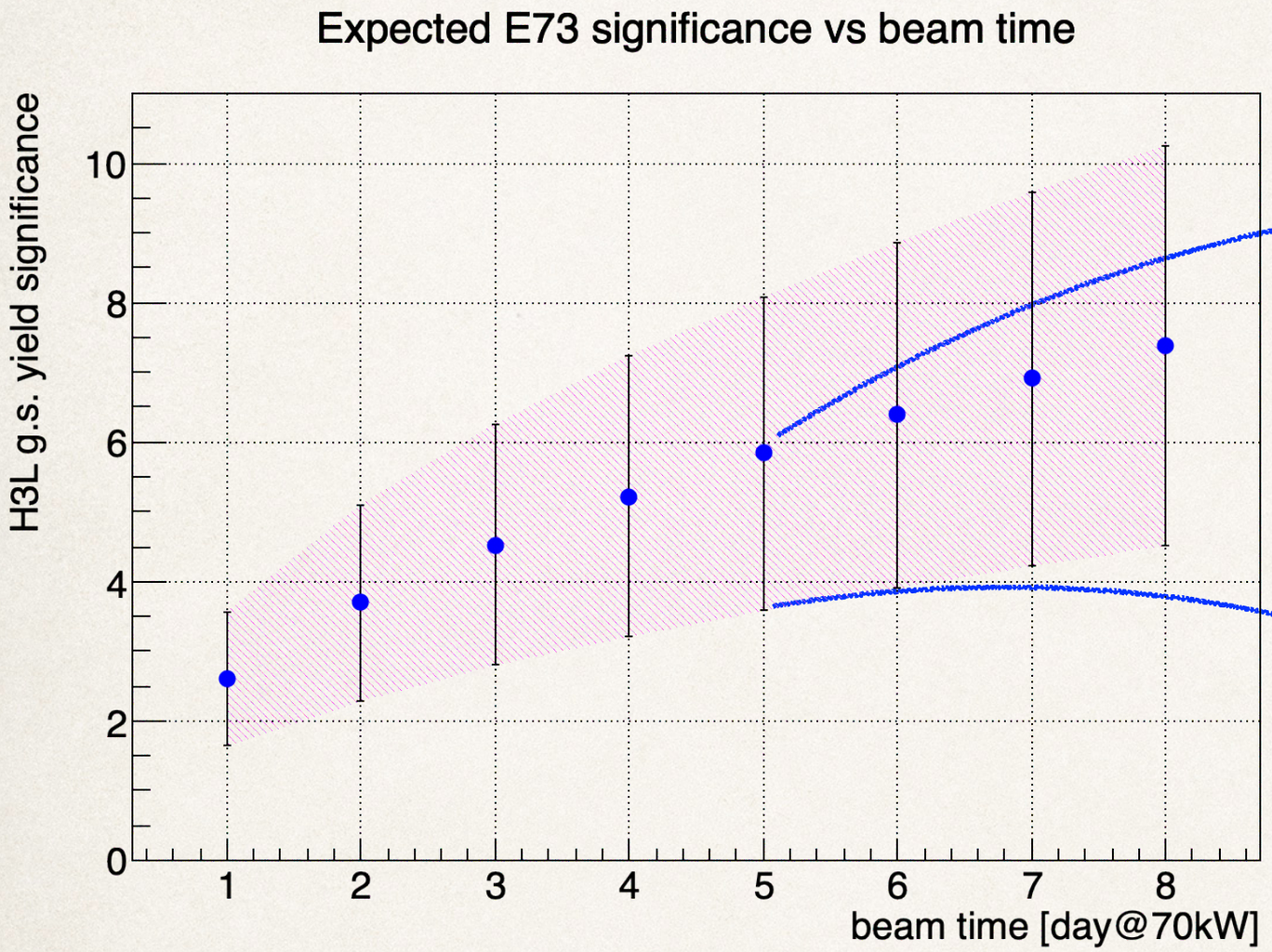

Expected pi- spectrum with $^{3}$He target

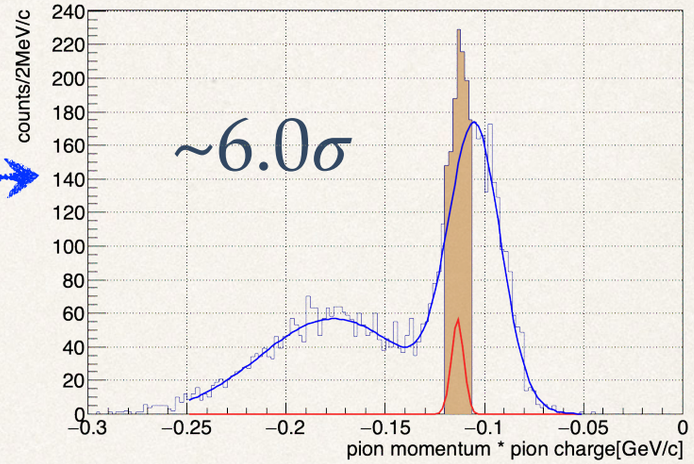
~6.0$\sigma$ significance W/ 350kW*day

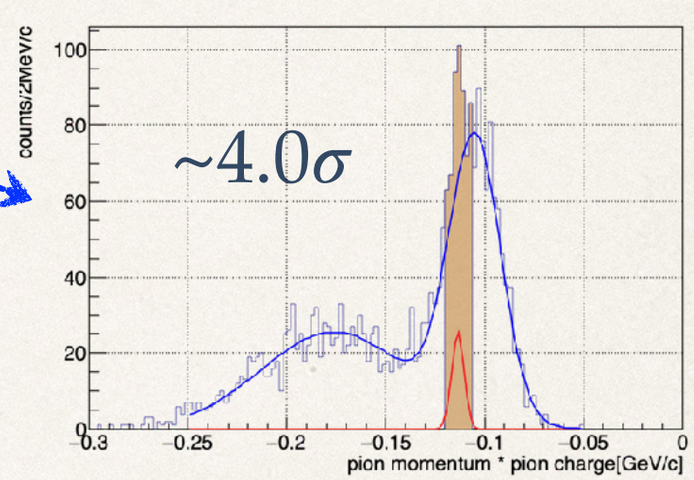
($^{3}_{\Lambda}$H/$^{4}_{\Lambda}$H ~ 0.26 ⊗ two-body B.R. ~ 0.5)

- To achieve statistical meaningful results for $^{3}$He(K-,pi0)$^{3}_{\Lambda}$H, 5days × 70kW beam time is necessary

# Statistical significance vs beam time




$^{3}_{\Lambda}H/^{4}_{\Lambda}H$ two-body B.R. ~ 0.5 assumed

- The significance of $^{3}_{\Lambda}H$ yield ($S/\sqrt{(S+N)}$) vs beam time
- JLab data uncertainty is dominant $^{3}_{\Lambda}H/^{4}_{\Lambda}H \sim 0.26 \pm 0.10$
- To achieve statistical meaningful results for $^{3}He(K^-,pi0)^{3}_{\Lambda}H$, 5days × 70kW beam time is necessary

# Summary and beam time request

- E73 experiment has been approved as Stage-1 and ready for data taking from now on

- 5days × 70kW (350kW*day) beam time with liquid $^{3}$He target before long shut down

- for a good estimation for the Stage-2 Physics run in 2022 with our well established CDS spectrometer before its upgrade

- maximize the output of J-PARC facility: $^{3}_{\Lambda}$H production cross section measurement

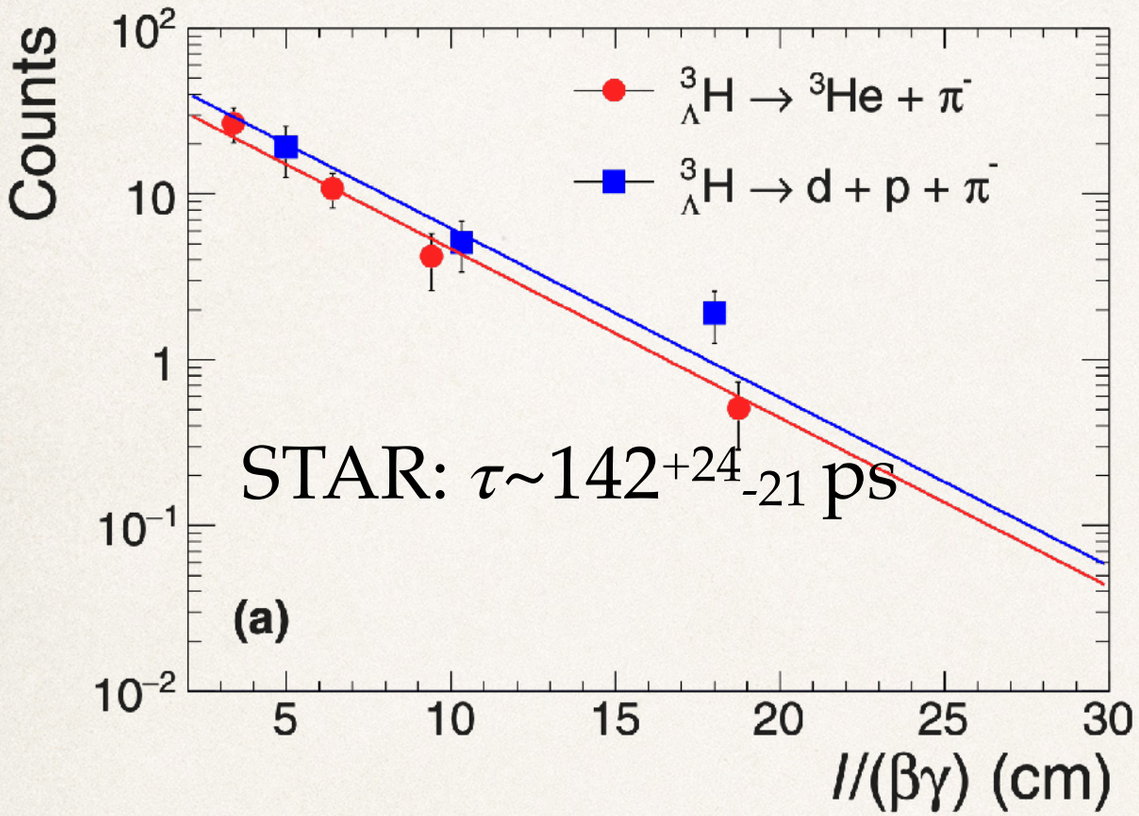
# Backup

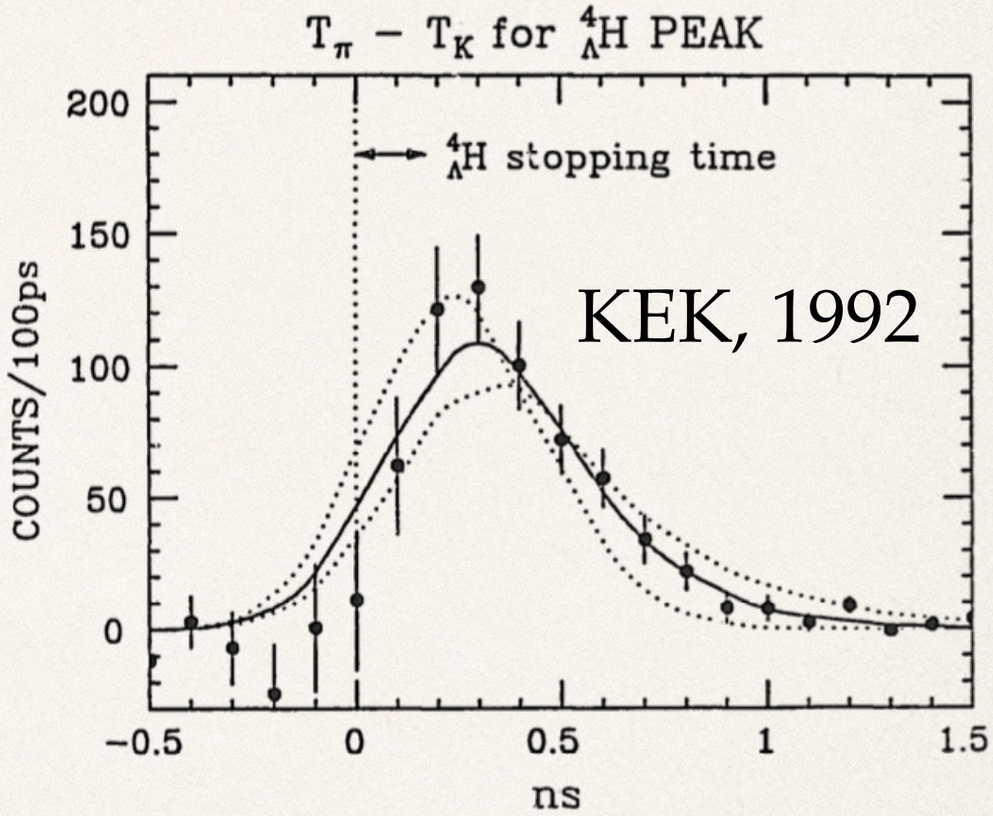
# P73/T77 collaborator list

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]

[1]Osaka University, Osaka, 560-0043, Japan
[2]High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan
[3]Japan Atomic Energy Agency, Ibaraki 319-1195, Japan
[4]Institute of Modern Physics, Gansu 730000, China
[5]School of Nuclear Science and Technology, Lanzhou University, Gansu 730000, China
[6]Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy
[7]Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Magurele, Romania
[8]CENTRO FERMI - Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi", 00184 Rome, Italy
[9]Tohoku University, Miyagi, 982-0826, Japan
[10]RIKEN, Wako, 351-0198, Japan

# Heavy ion results vs direct lifetime measurement




**Heavy ion results:**

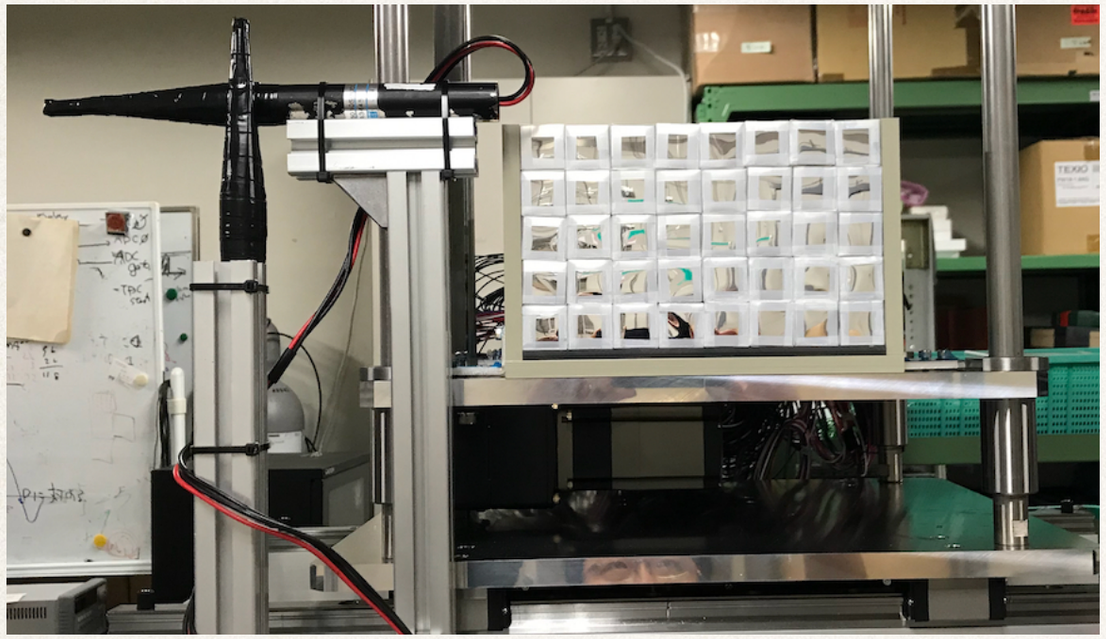
- Convert decay length to lifetime ($t = L/\beta\gamma c$);
- Statistics concentrate in the first few bins.

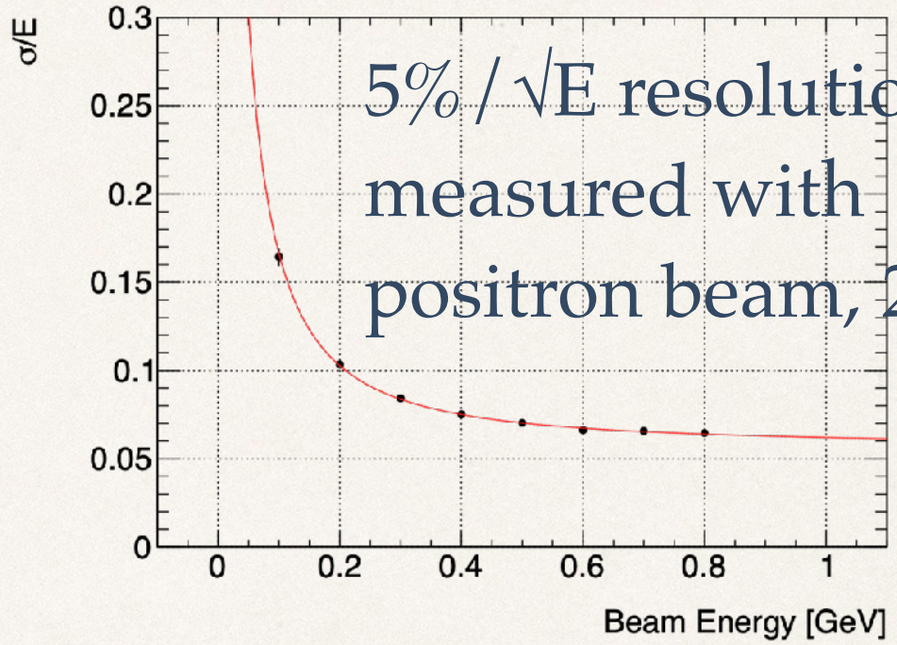
**Direct lifetime measurement:**

- Lifetime convoluted with time resolution;
- Relatively wide fitting range.


L. Adamczyk et al., Phys. Rev. C, 97, 054909, (2018)
H. Outa, *et al.*, Nucl. Phys. A 547, (1992), 109c-114c

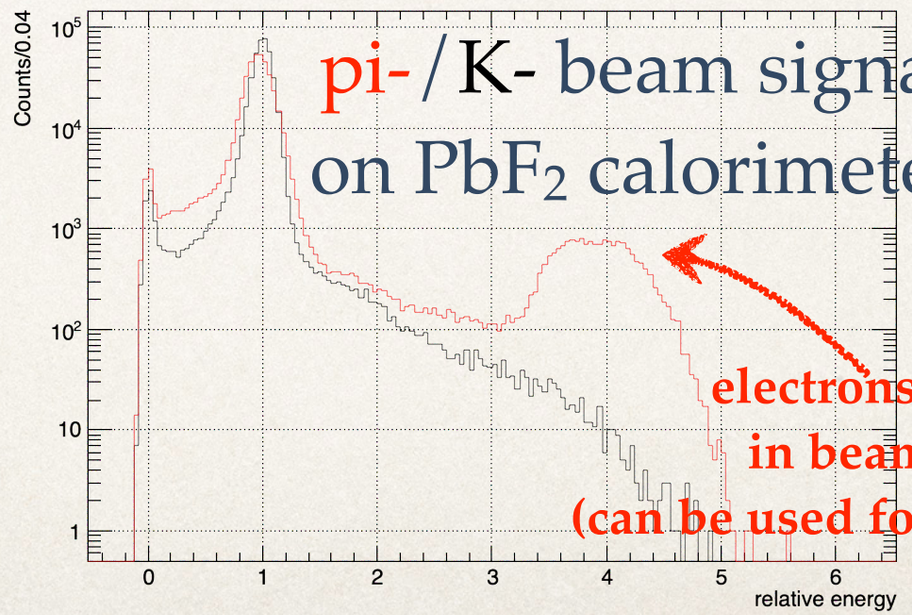
# PbF2 calorimeter performance






5%/√E resolution measured with positron beam, 2019

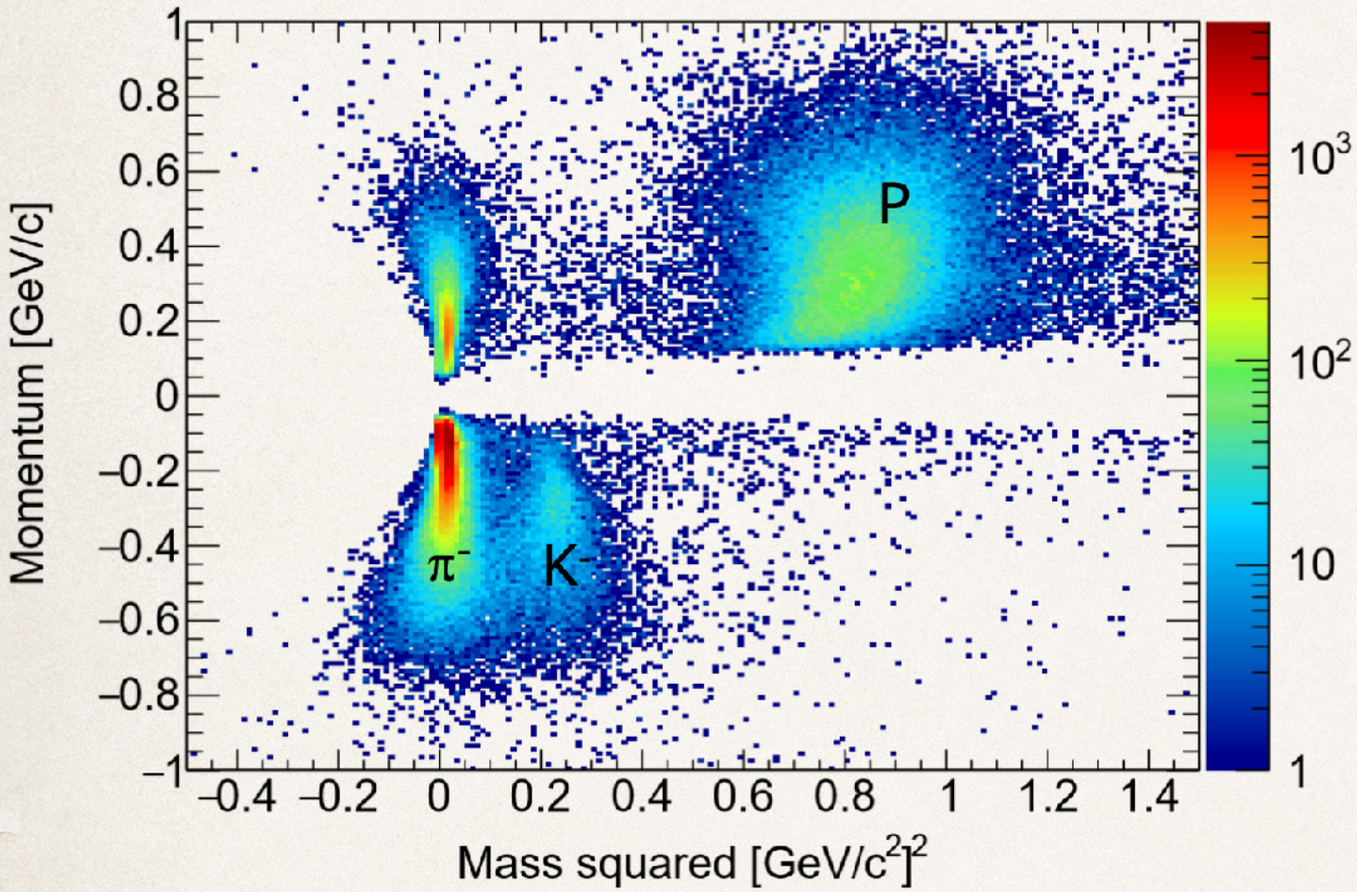
- PbF2 calorimeter is installed ***INTO*** the meson beam line to tag fast pi0;
- All segments of PbF2 calorimeter works well with reasonable resolution even in high rate conditions.

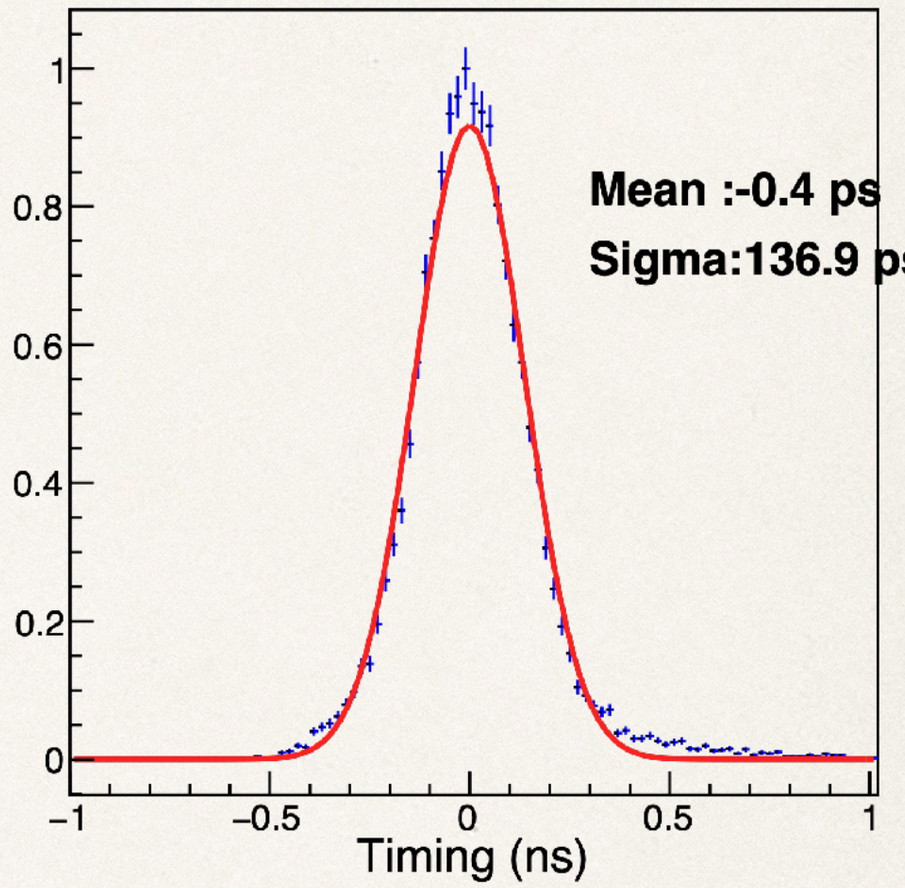



pi-/K- beam signal on $PbF_2$ calorimeter

**electrons mixed in beam line (can be used for calibration)**

# CDS tracking performance

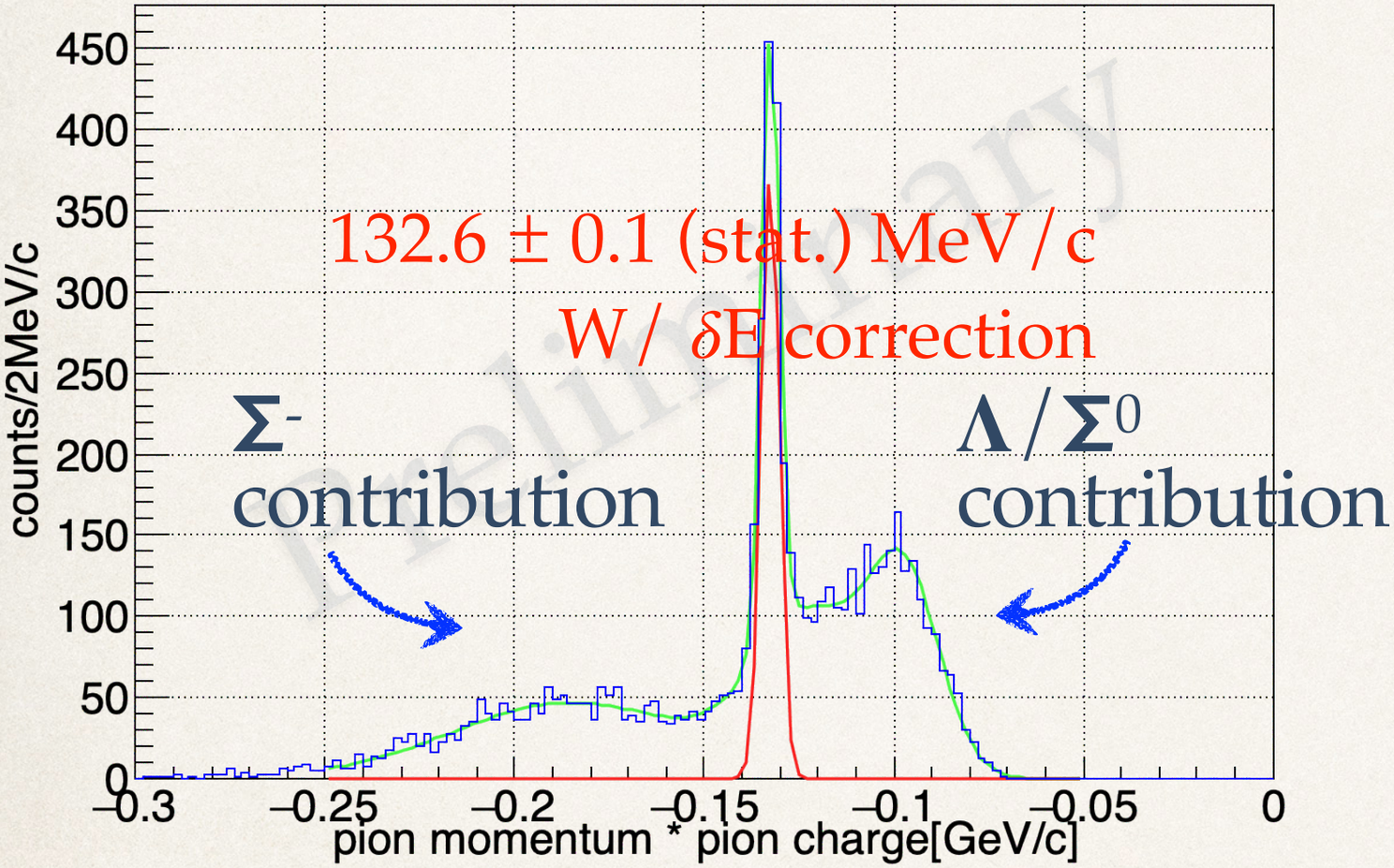


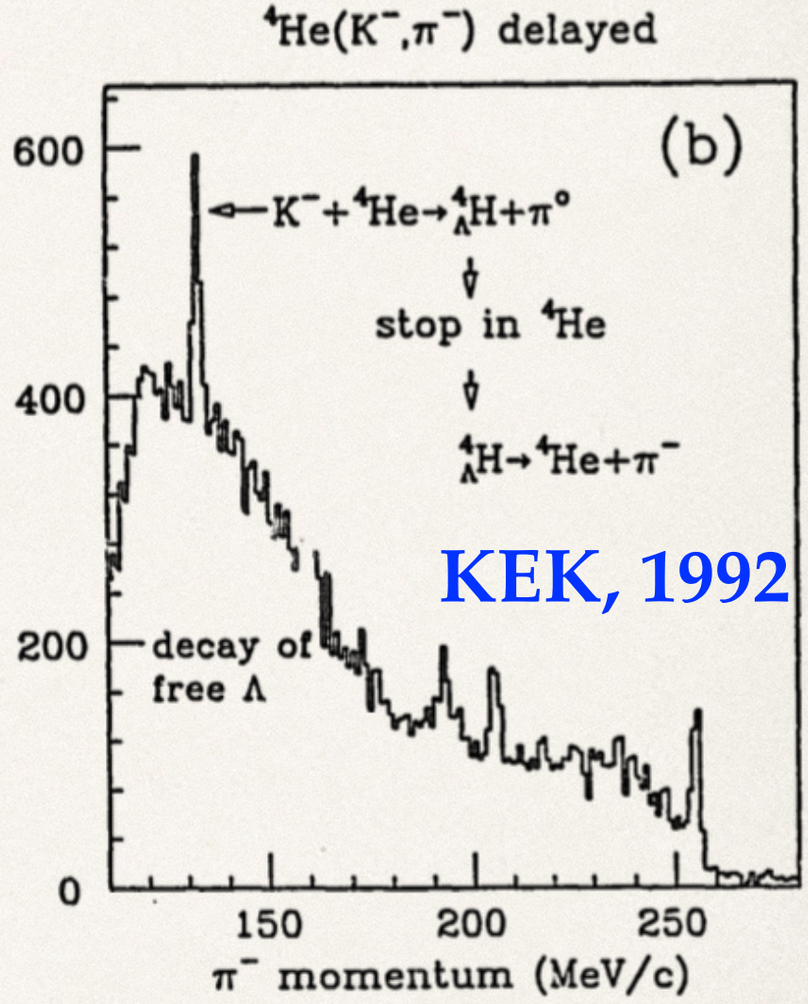




- CDS tracking system works well;
- ~2% momentum resolution for ~100MeV/c pi- signals;
- TOF resolution ~137ps from prompt pi- scattered event

# T77 results: pi- spectrum from ${}^{4}_{\Lambda}H$

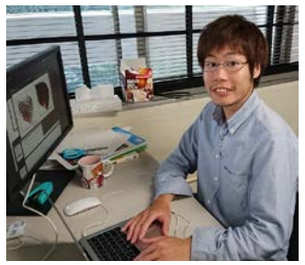
$$K^- + {}^4He \rightarrow {}^4_\Lambda H + \pi^0$$



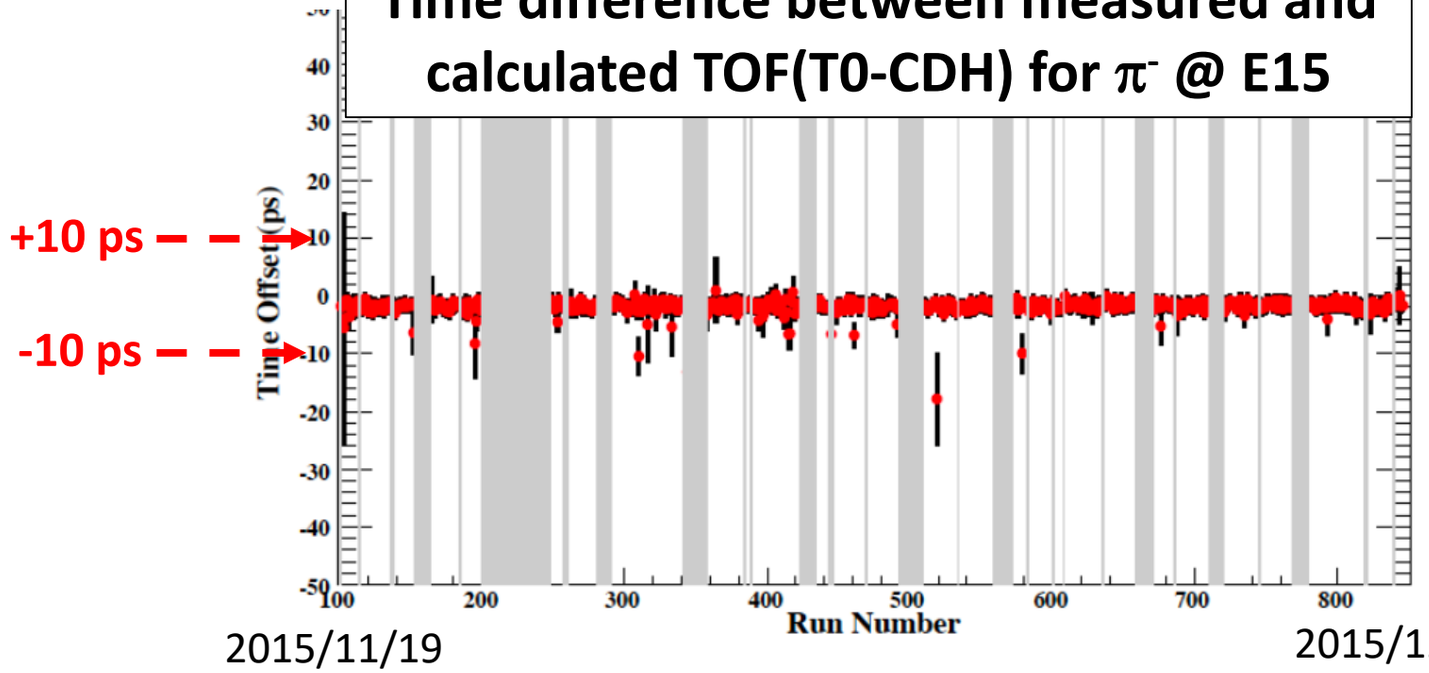

- T77 refreshes world record for ${}^{4}_{\Lambda}H$ statistics by twice;
- New method improves S/N by ~ 10 times;
- ***All these happen within 3days of beam time!***

# Time Zero Alignment Estimation with the E15 Data



Dr. Yamaga, RIKEN

**Time difference between measured and calculated TOF(T0-CDH) for $\pi^-$ @ E15**




- E15-2nd data (Run65, $^3$He($K^-$,$\pi^-$)X)
  - Time zero can be determined **within 5 ps**
- Error propagated from the time zero alignment is estimated to be **<5 ps** with MC simulation