J-PARC P73:

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

Status report for T77 as a feasibility study for P73

${}^{4}He\ (K^{-}, \pi^{0})\ {}^{4}_{\Lambda}H$ reaction @ 1GeV/c, 3days × 50kW

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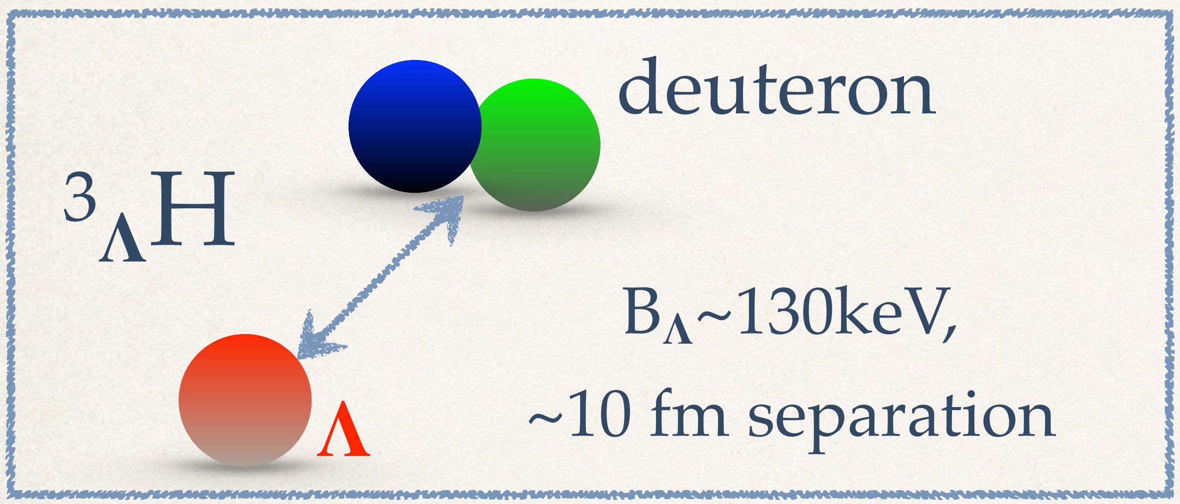
Outline

- Introduction to J-PARC P73:
  - The first direct measurement for ${}^{3}_{\Lambda}H$ lifetime
- Feasibility study for P73:
  - T77 experiment
- 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).

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.

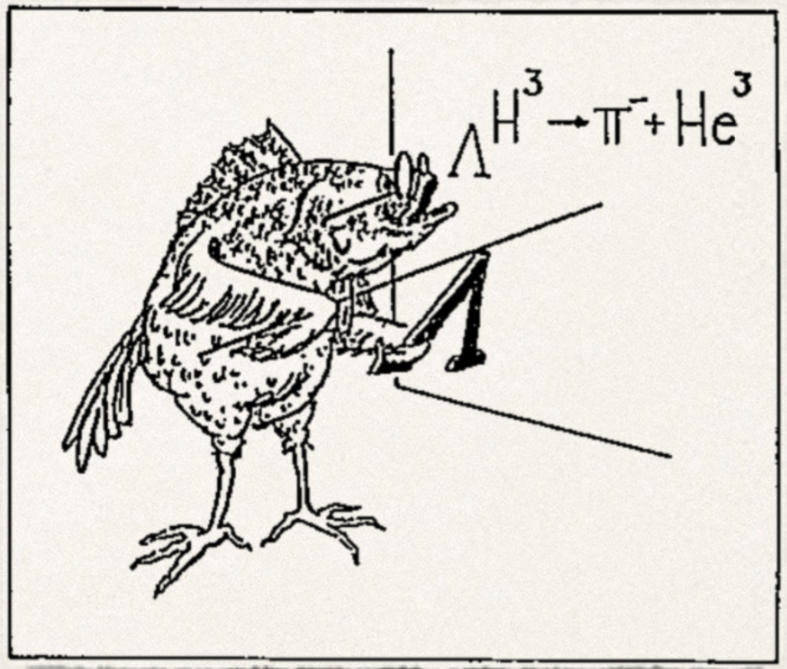
Introduction: motivation

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.

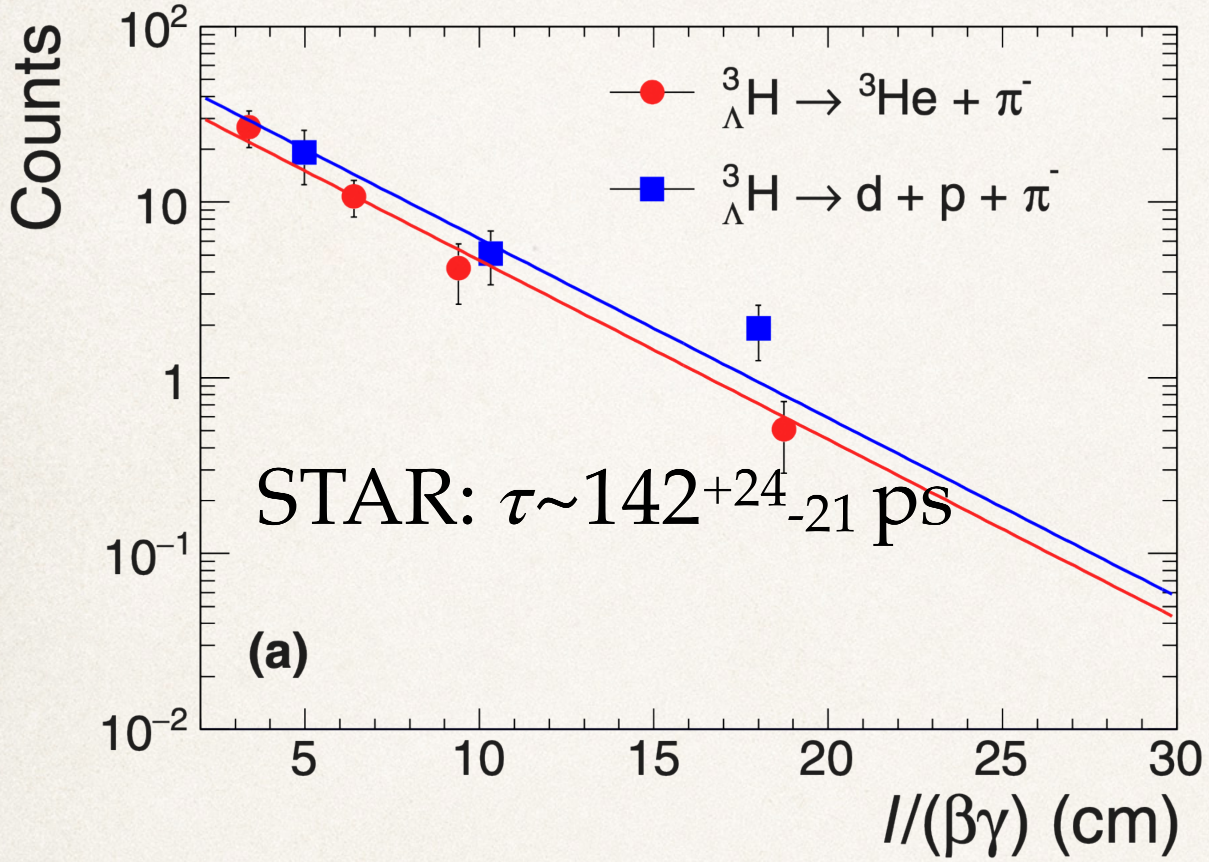
Collaboration	Experimental method	${}^{3}_{\Lambda}H$ lifetime [ps]	Release date
ALICE	Pb collider	240^{+40}_{-31}(stat.)±18(syst.)	2019
STAR	Au collider	142^{+24}_{-21}(stat.)±29(syst.)	2018
HypHI	fixed target	183^{+42}_{-32}(stat.)±37(syst.)	2013

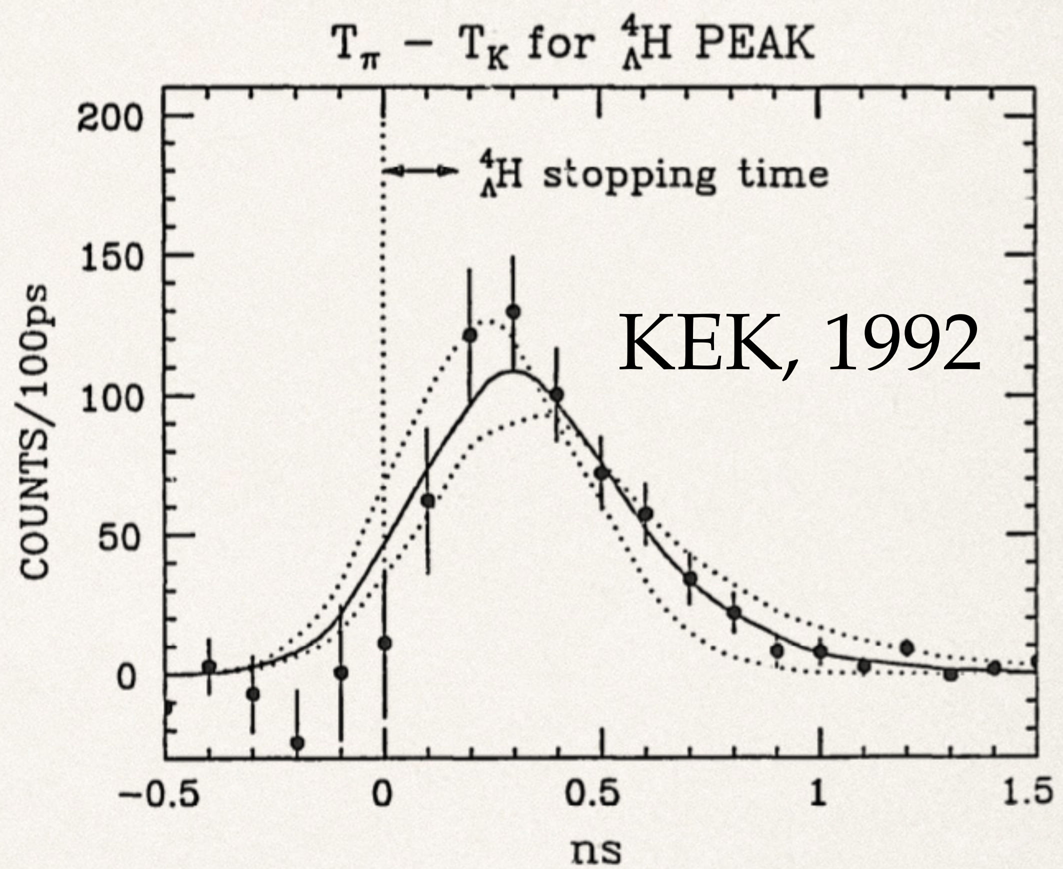


Neither fish nor fowl?

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

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:

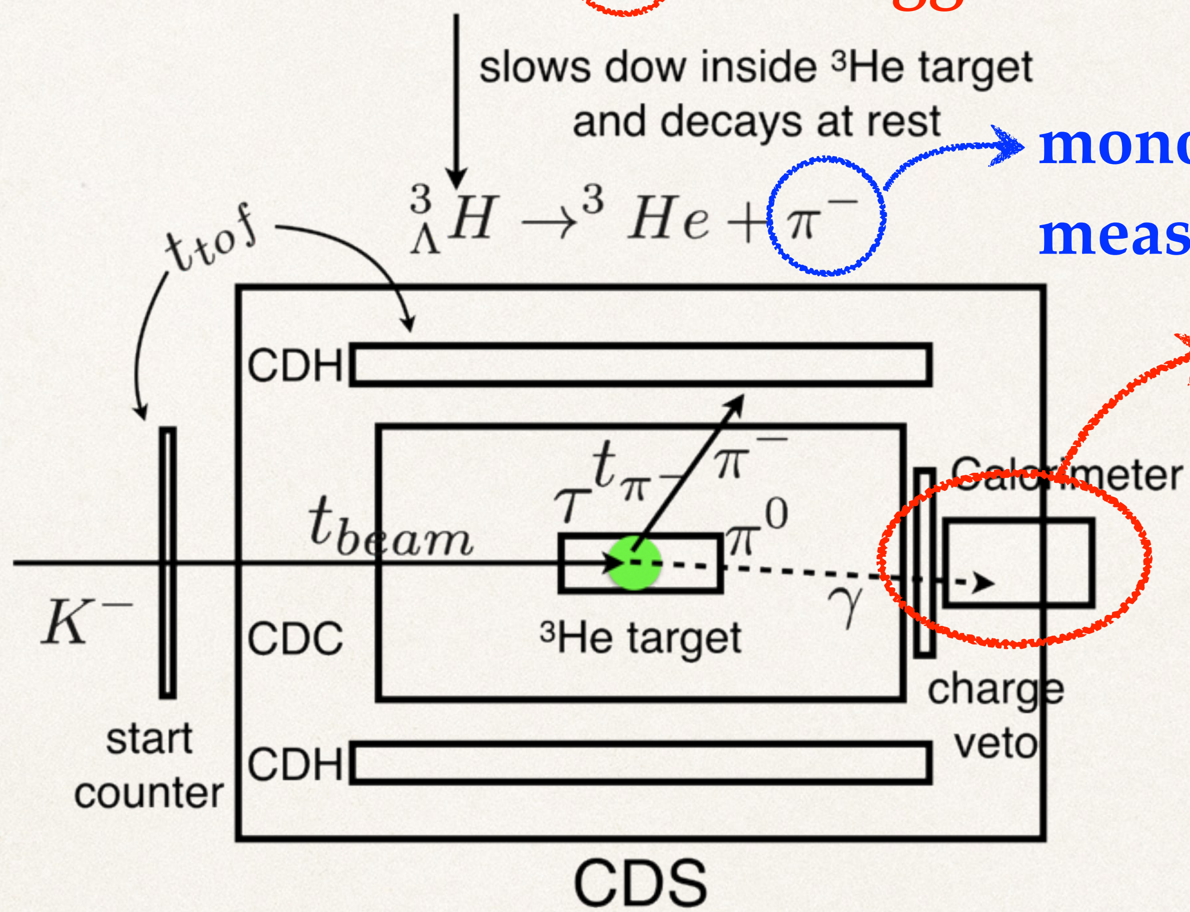
- Lifetime convoluted with time resolution;
- Relatively wide fitting range.

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

P73 Experimental setup

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

very forward $\pi0$ projectile; tagged with decayed high energy γ



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

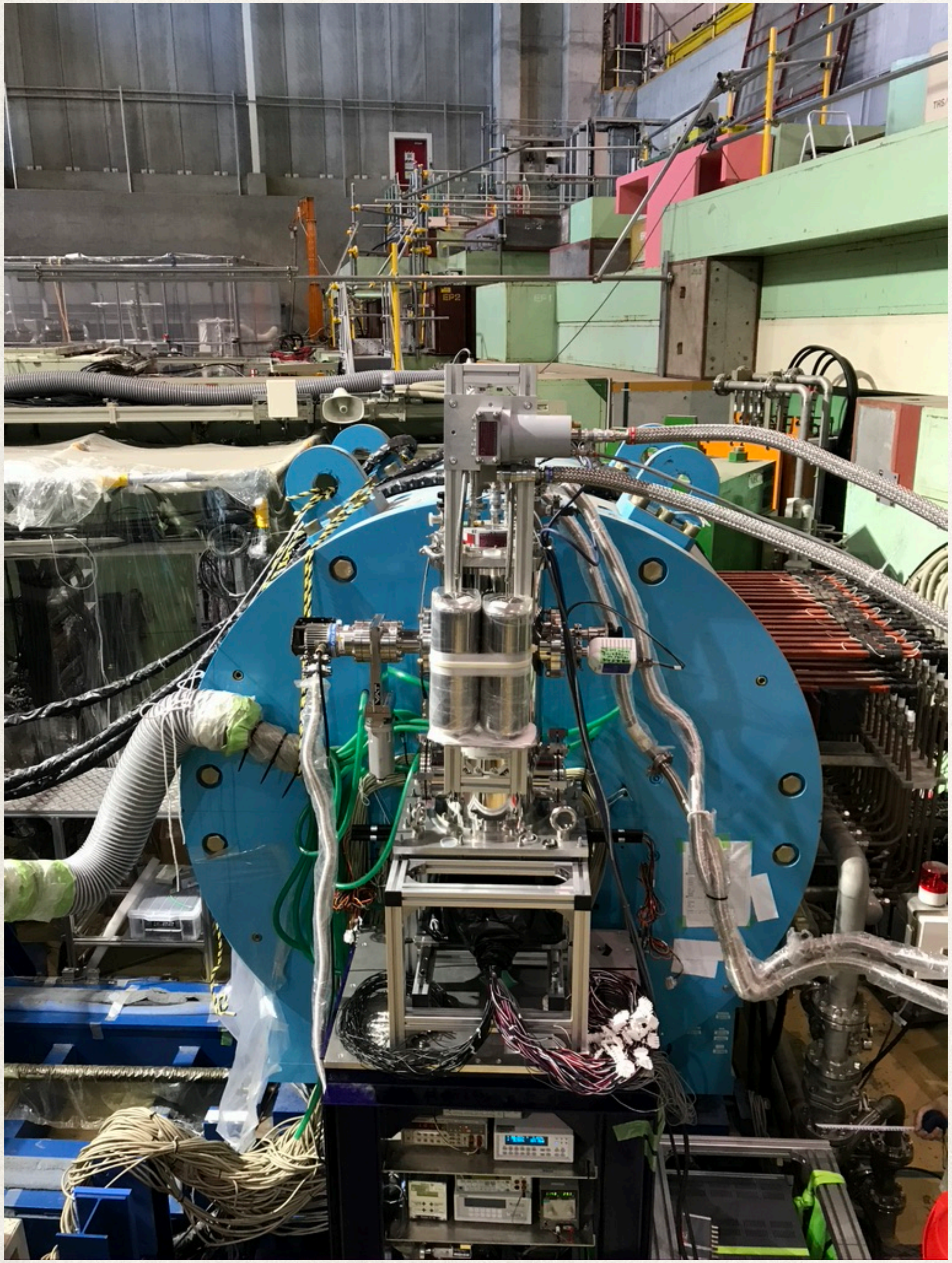
5x8 PbF2 Cherenkov Calo
R&D has been completed

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

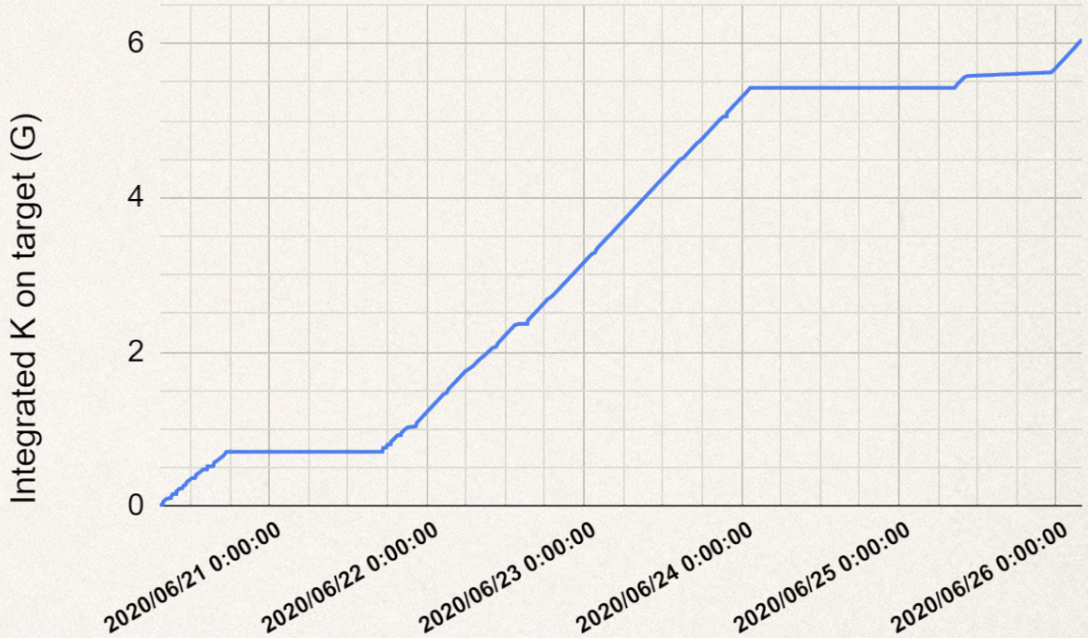
The idea of ***direct measurement***: $T_{CDH}-T_0=t_{beam}+t_{\pi^-}+\tau$;

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

T77 experiment: background study for P73



6G Kaon- shoot on He4 target, ~3days, in June 2020



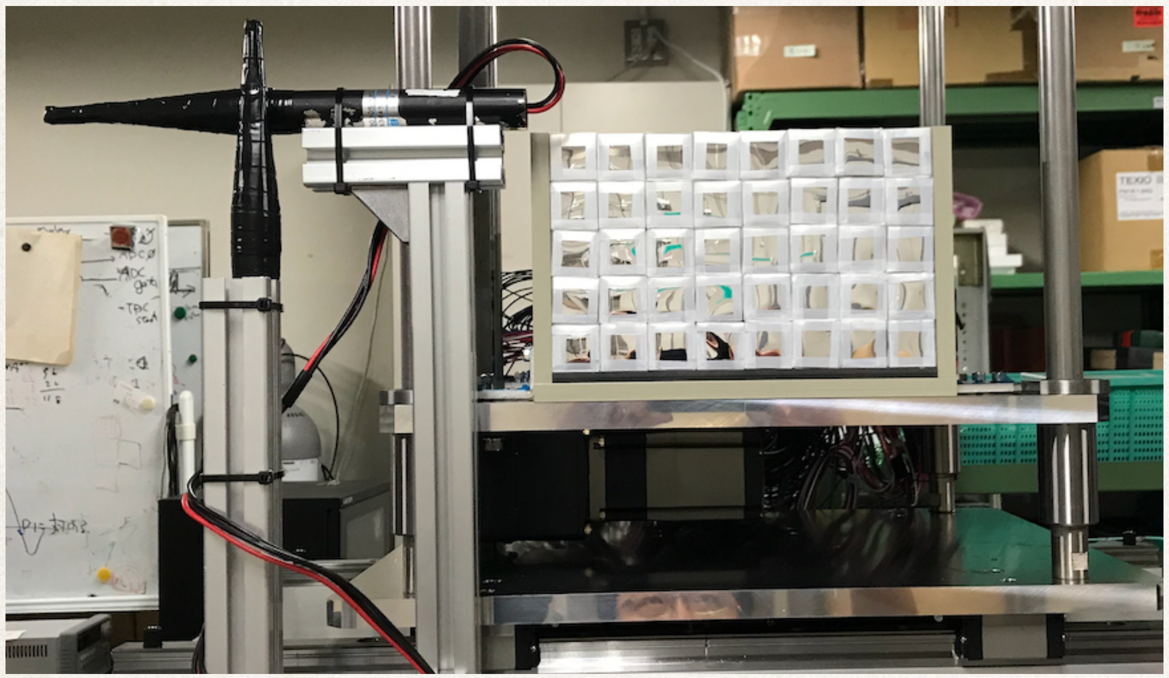
Identical with P73 experimental setup except the target material:

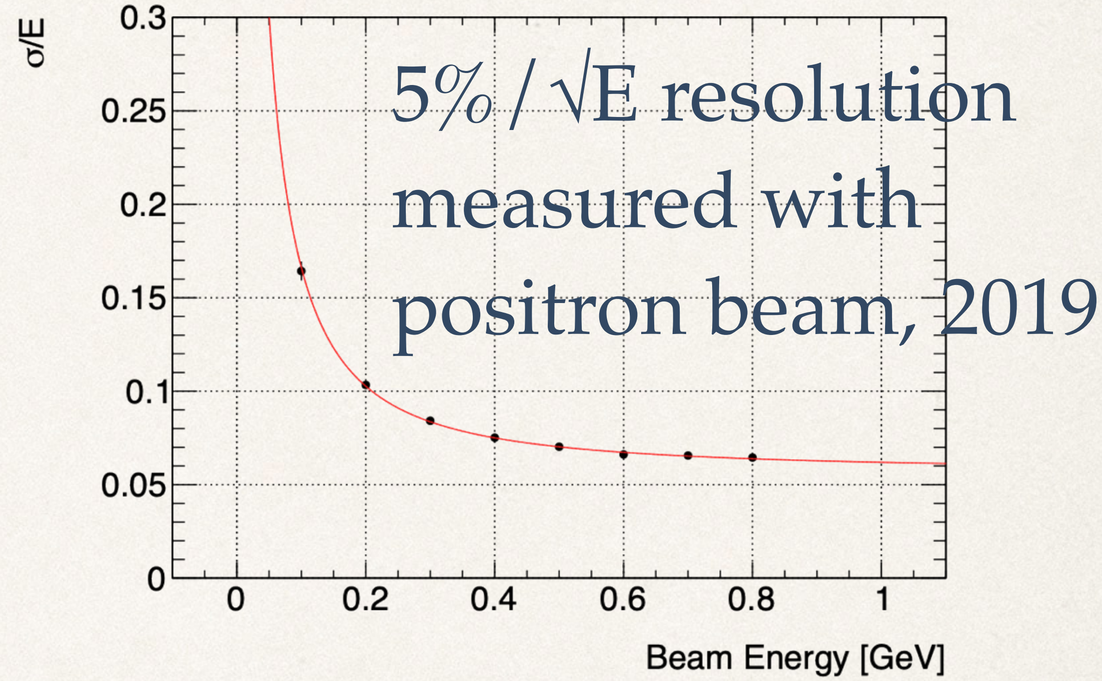
P73: ^{3}He, T77: ^{4}He

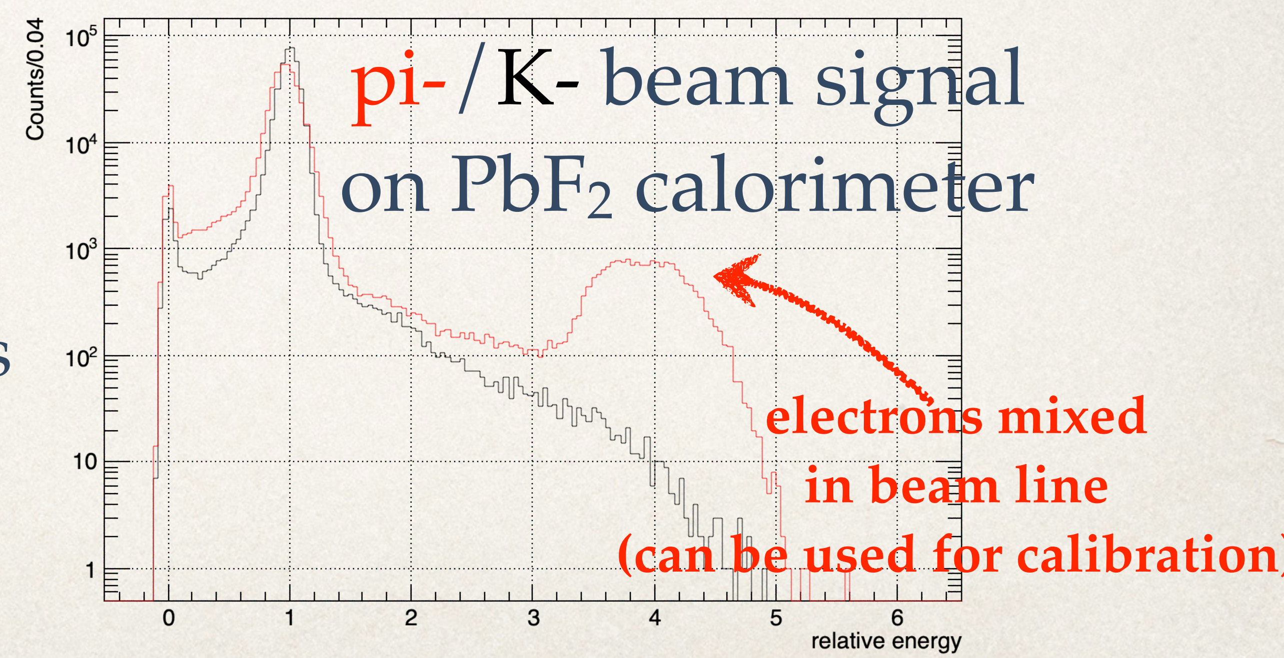
$^{4}{}_{\Lambda}H$ has ~6 times higher S/N than $^{3}{}_{\Lambda}H$

($^{4}{}_{\Lambda}H/^{3}{}_{\Lambda}H$ ~ 3 × B.R. 2)

PbF2 calorimeter performance

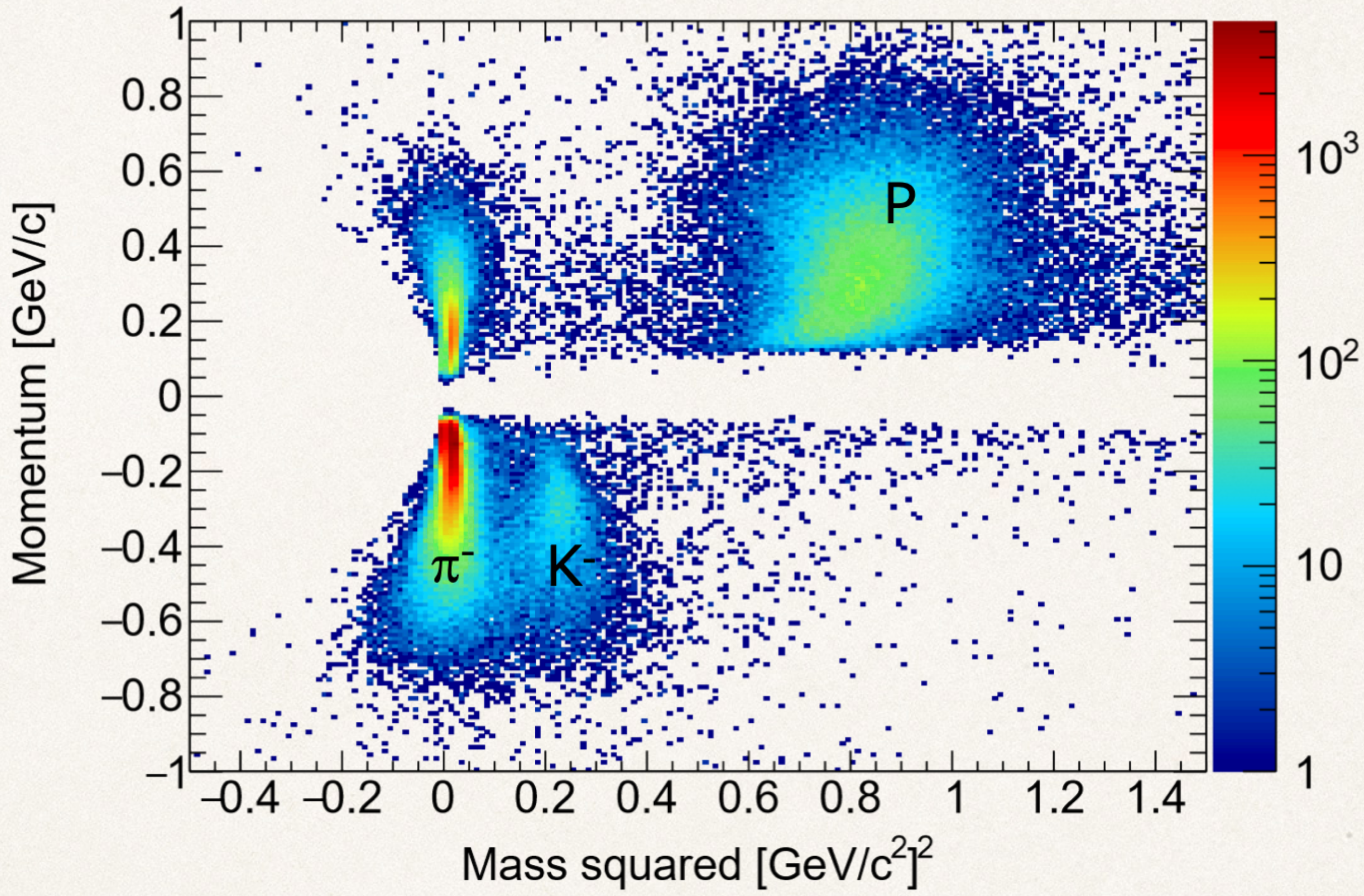






- PbF2 calorimeter is installed ***INTO*** the meson beam line to tag fast pi0;
- All segments of PbF2 calorimeter works well with reasonable resolution even in high rate conditions.

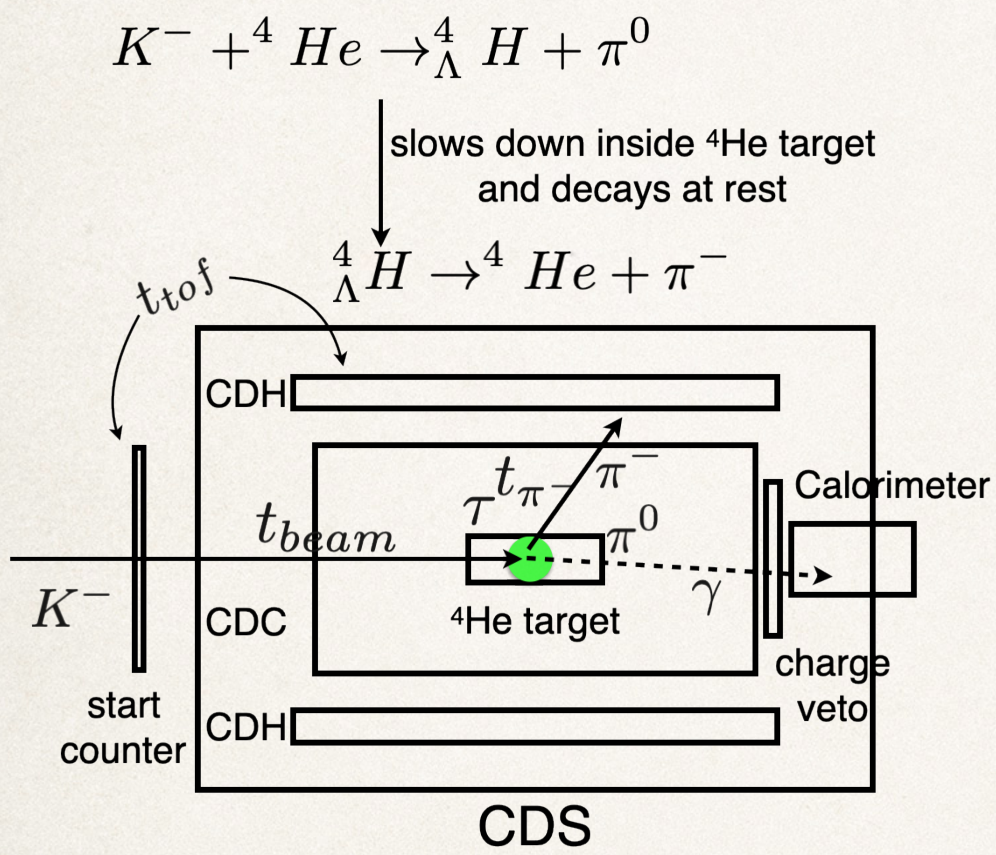
CDS tracking performance



- CDS tracking system works well;
- ~2% momentum resolution for ~100MeV/c pi- signals;
- Further improvement can be expected by employing energy loss correction (in progress)

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

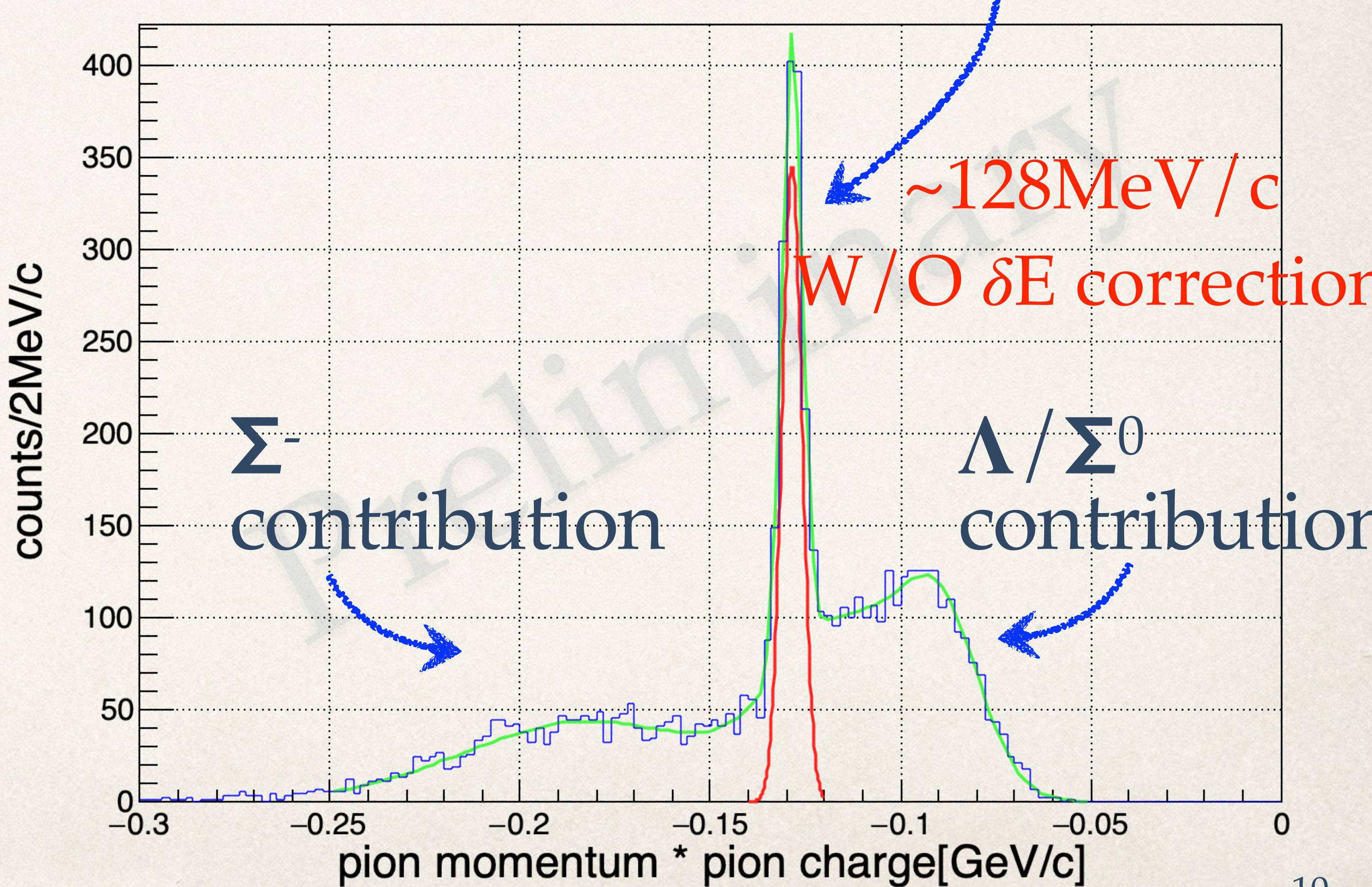
$$K^- + {}^4He \rightarrow {}^4_\Lambda H + \pi^0$$



slows down inside 4He target
and decays at rest

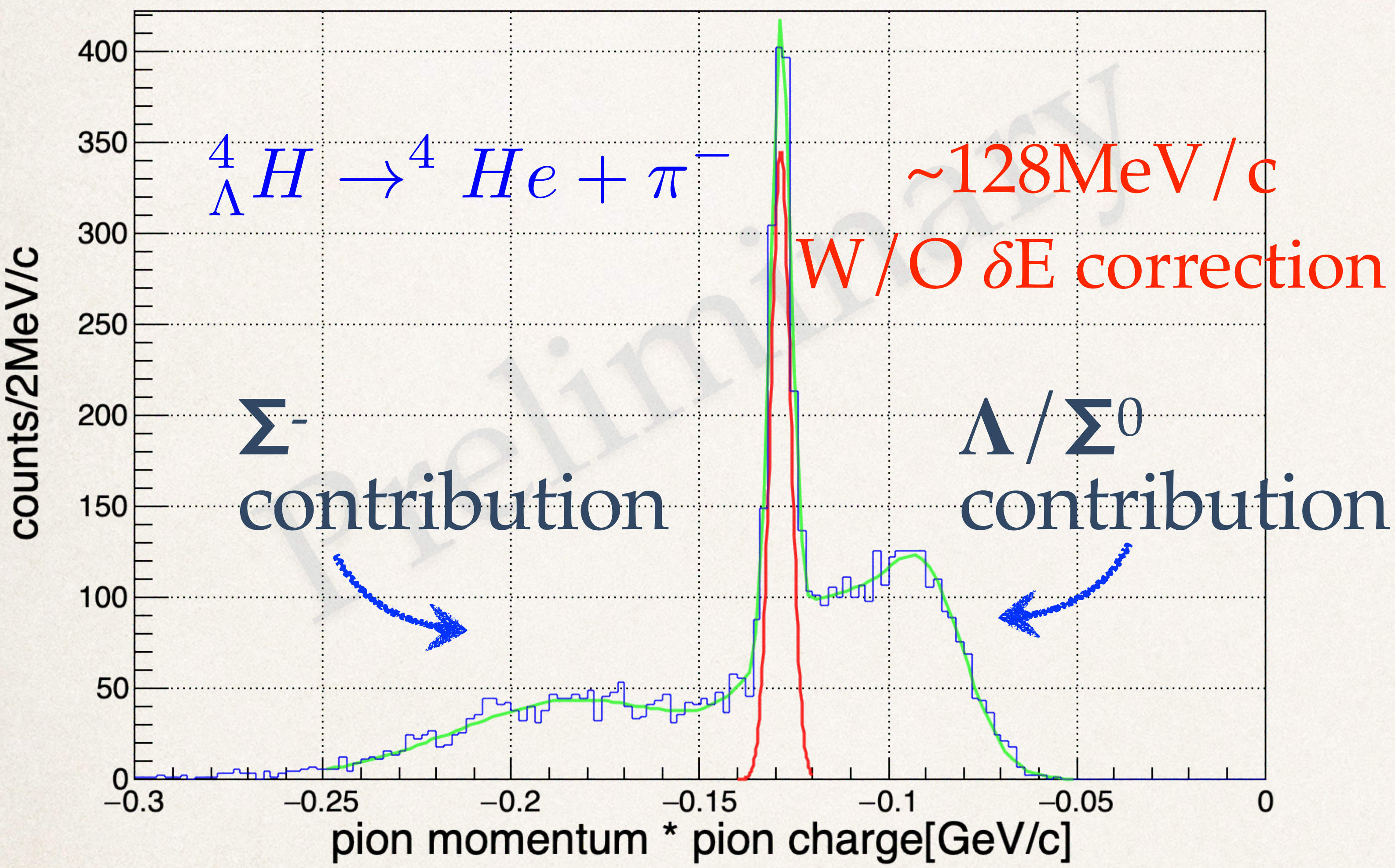
${}^4_\Lambda H \rightarrow {}^4He + \pi^-$ ~133MeV/c

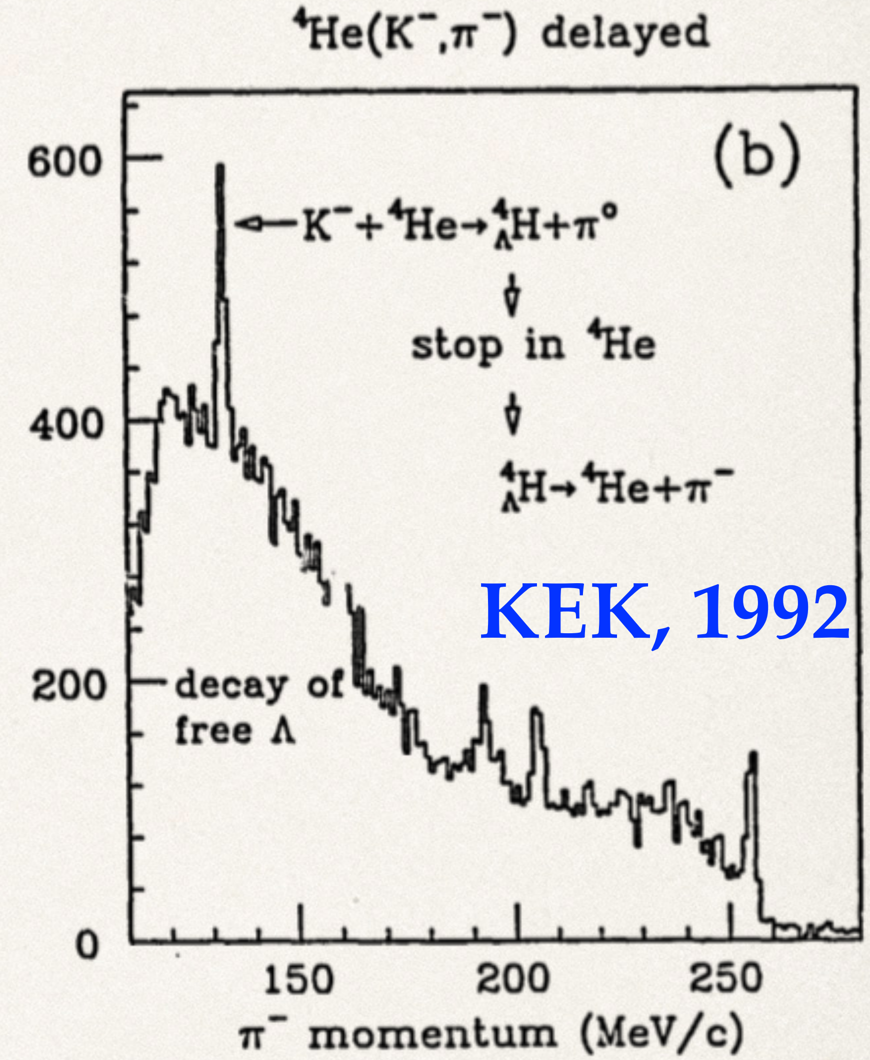
With ***only 3days*** beam time,
we successfully observed ***~1.2k***
$^{4}{}_{\Lambda}H$-->^{4}He+pi- events.



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

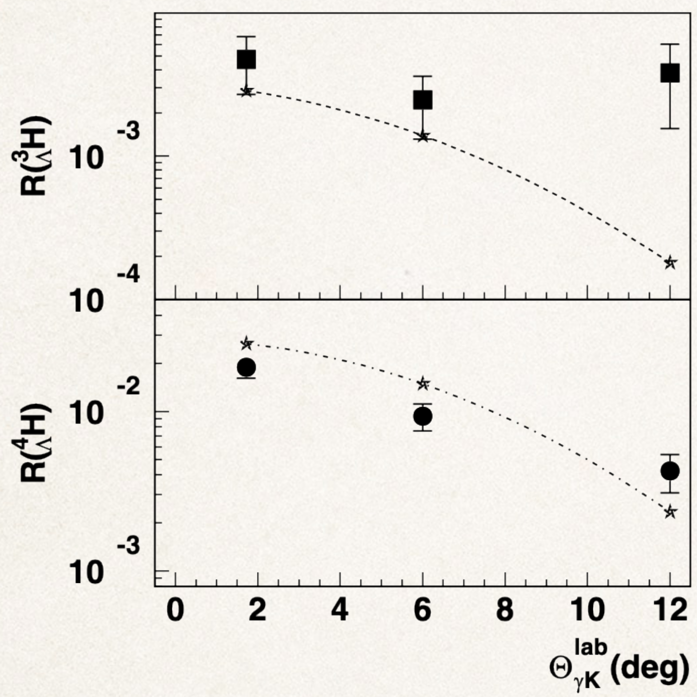
$$K^- +^4 He \rightarrow^4_\Lambda H + \pi^0$$



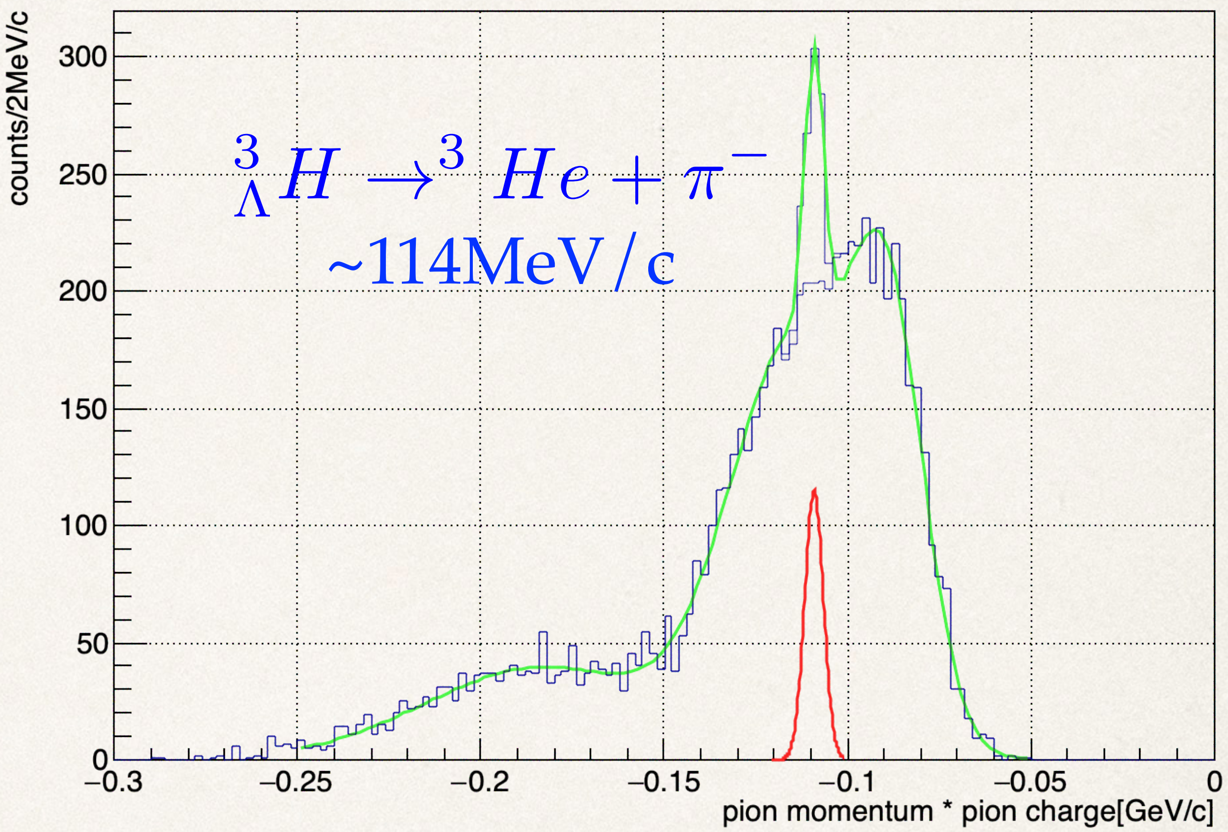


- T77 refreshes world record for ${}^{4}_{\Lambda}H$ statistics by twice;
- New method improves S/N by ~ 10 times;
- ***All these happen within 3days of beam time!***

Estimation for $^{3}_{\Lambda}H$ yield based on T77



$^{3}_{\Lambda}H / ^{4}_{\Lambda}H \sim 1/4$
with (e, e′K+) reaction at JLab



Expected pi- spectrum from ^{3}He target
($^{3}_{\Lambda}H / ^{4}_{\Lambda}H \sim 1/3$ assumption)

- JLab data shows $^{3}_{\Lambda}H / ^{4}_{\Lambda}H \sim 1/4$ for (e, e'K+) channel; we estimate $^{3}_{\Lambda}H / ^{4}_{\Lambda}H \sim 1/3$ for (K-, pi0) channel (thanks for Prof. Harada);
- ***With a well known background from T77***, we need ***5days × 70kW*** beam time to measure the $^{3}_{\Lambda}H$ production cross section

DOI: 10.1103/PhysRevLett.93.242501

Estimation for ${}^{3}_{\Lambda}H$ yield based on T77

Target	^{4}He	^{3}He	
Density	2.17E+23 / cm^2	1.42E+23 / cm^2	
Beam time	3days × 50kW	5days × 70kW	
two-body pi- decay B. R.	50%	25%	
Relative cross section	1 A. U.	1/3 A. U. (educated guess)	1/4 A. U. (JLab data)
pi- signal yield	~1.2k	~300	~200

${}^{3}_{\Lambda}H$ yield needs to be measured in Stage-1 experiment, helping to determine the beam time for lifetime measurement.

Staging strategy for P73

Staging:	Stage-0	Stage-1	Stage-2
Task:	Background study for $^{3}_{\Lambda}H$	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:	Cleared by T77 experiment	Applied for Stage-1 approval in this talk	Depends on Stage-1 results

Summary

- We have successfully performed J-PARC T77 to study the feasibility of P73
    - With only 3days beam time, we refreshed the world record of ${}^{4}_{\Lambda}H$ statistics for its lifetime measurement
    - a new and effective way to study hypernucleus is established
- ***A direct measurement for hypertriton lifetime proposed in P73 has been proved to be feasible and promising by T77***

Acknowledgement

- Support from ELPH staff Prof. T. Ishikawa
- Financial support from Prof. M. Iwasaki and great help from many other collaborators
- In particular, our brilliant main collaborators:
  - ***T. Akaishi (PhD student), T. Yamaga (Postdoc)***
  - ***T. Hashimoto, F. Sakuma (co-spokesperson)***

P73/T77 collaborator list

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Requests for J-PARC Hadron Facility

- After successfully carried out Stage-0 study as T77, we formally apply for stage-1 approval
  - P73 --> E73
- Beam time request:
  - 5days × 70kW (350kW*day) beam time with liquid He3 target to study the Hypertriton production cross section
- Beam time allocation:
  - P73 will be fully ready to run by December, 2020
  - We request beam time BEFORE long shut down of 2021

- Backup

P73 proposal status

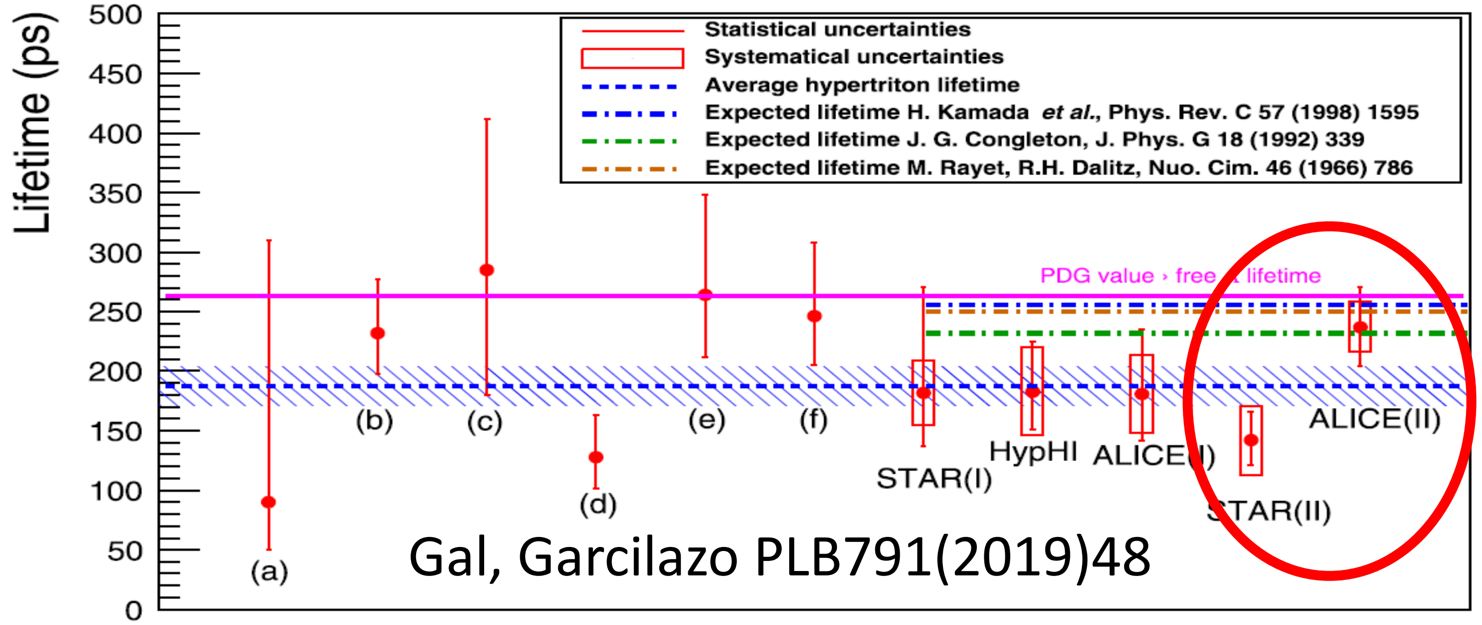
- First version submitted to 26th PAC --> more details should be provided based on simulation
- Revised proposal submitted to 27th PAC --> need to clarify systematic error
- Systematic error explained in 28th PAC by F. Sakuma --> PAC suggests us to carry out feasibility study with He4 target
- Feasibility study with He4 is proposed as P77 --> ***29th PAC approved our T77 proposal --> our presentation today & apply for Stage-1 approval***

Physics Motivation

- Recent heavy-ion experiments reported different lifetime of **hyper-triton, $^{3}_{\Lambda}$H**:

STAR (2018)	ALICE (2018)	free Λ
$142^{+24}_{-21} \pm 29$ ps	$237^{+33}_{-36} \pm 17$ ps	263 ± 2 ps

- $\tau(^{3}_{\Lambda}\mathrm{H}) \sim \tau(\text{free } \Lambda)$ is naively expected, because $^{3}_{\Lambda}$H is known to be very loosely bound system (~0.13MeV)

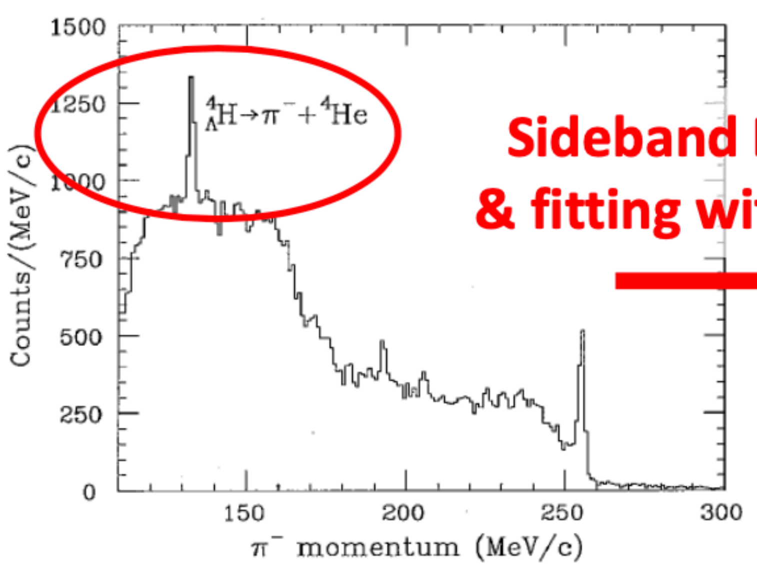


→ need to clarify the situation using different experimental technique

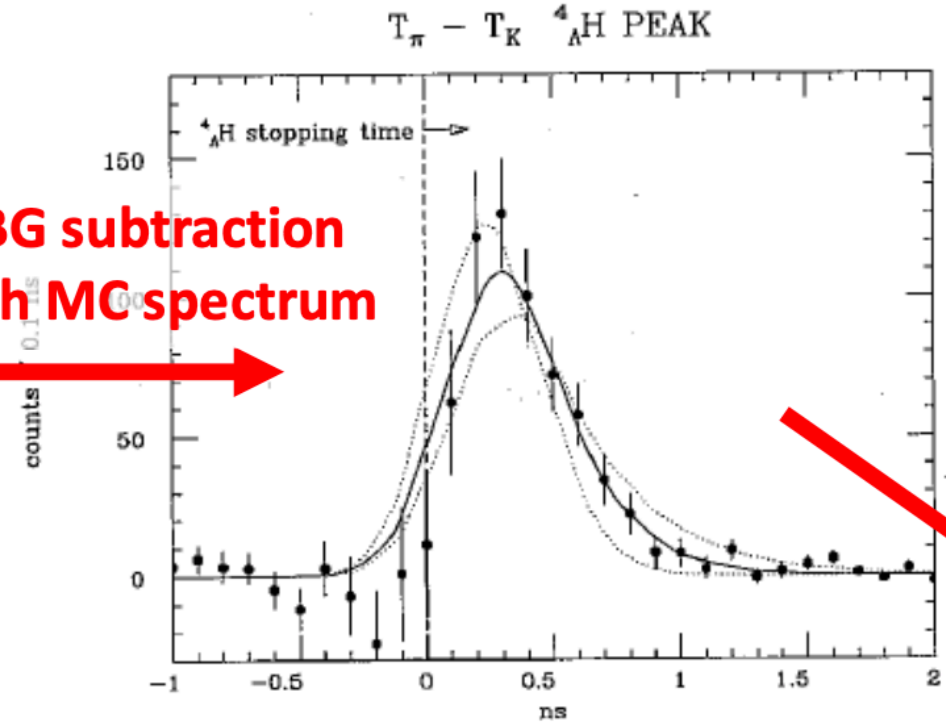
3

$^{4}{}_{\Lambda}H$ Lifetime @ KEK

- $^{4}He(\text{stopped } K^{-}, \pi^{-})^{4}{}_{\Lambda}H$ reaction
- The lifetime was obtained from a fitting with a simulated spectrum

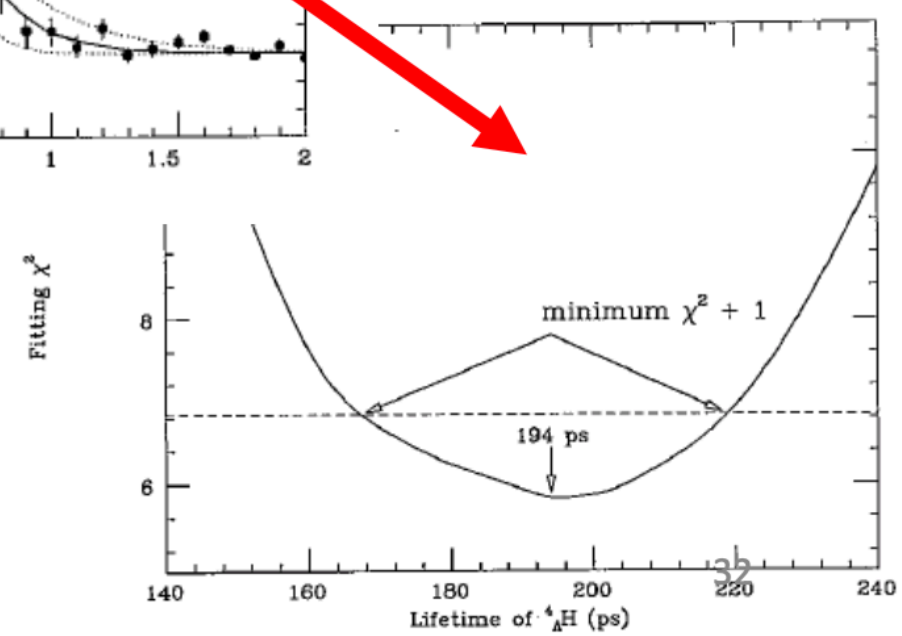


Sideband BG subtraction & fitting with MC spectrum



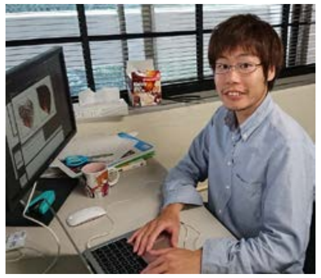
H. Outa, D-thesis

$^{4}{}_{\Lambda}H$ lifetime

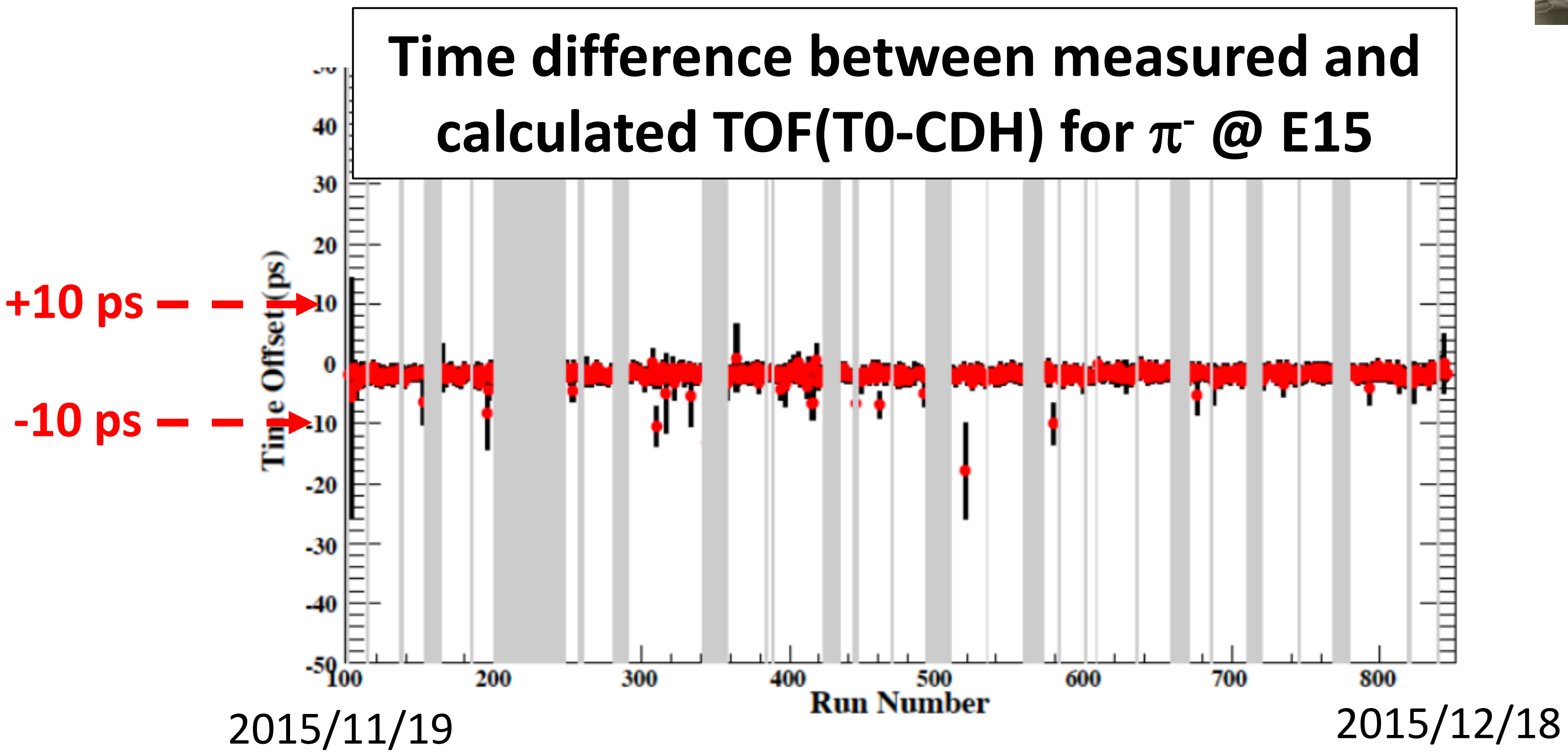


For cross-check, we will apply the same procedure to the $^{3}{}_{\Lambda}H$ analysis.

Time Zero Alignment Estimation with the E15 Data



Dr. Yamaga, RIKEN



- E15-2nd data (Run65, ^{3}He(K$^-$,π^-)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