J-PARC P73:

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

Submitted for pilot run with
$^{4}He\ (K^{-}, \pi^{0})\ ^{4}_{\Lambda}H$ reaction @ 1GeV/c, 50kW*1week

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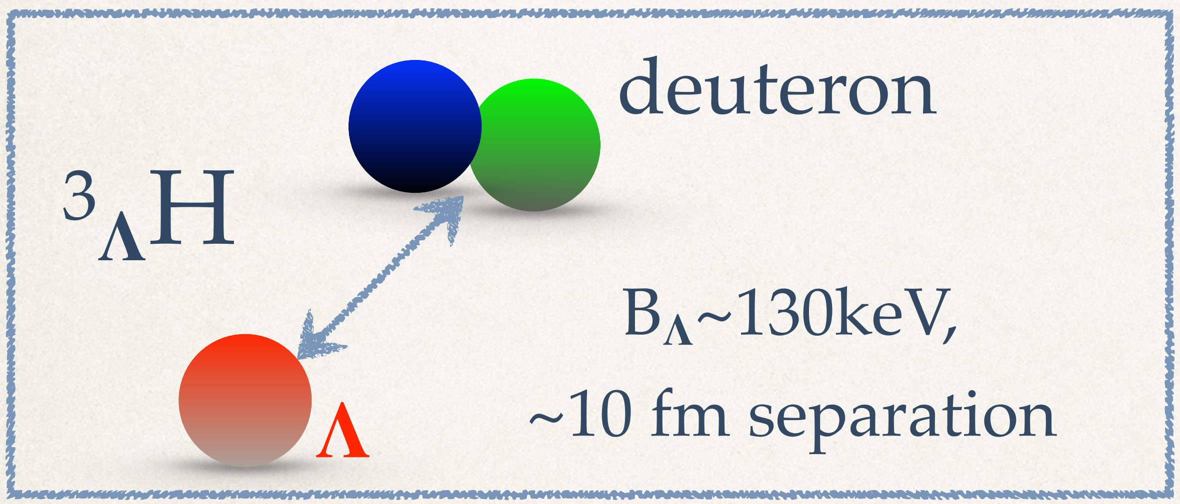
2020/01/16

Outline

- Introduction to J-PARC P73
- P73 proposal status
- Preparation for pilot run (J-PARC P77)
- 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).

decay probability:
kinematics$\times$|transition matrix|^2
~ phase space$\times$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.

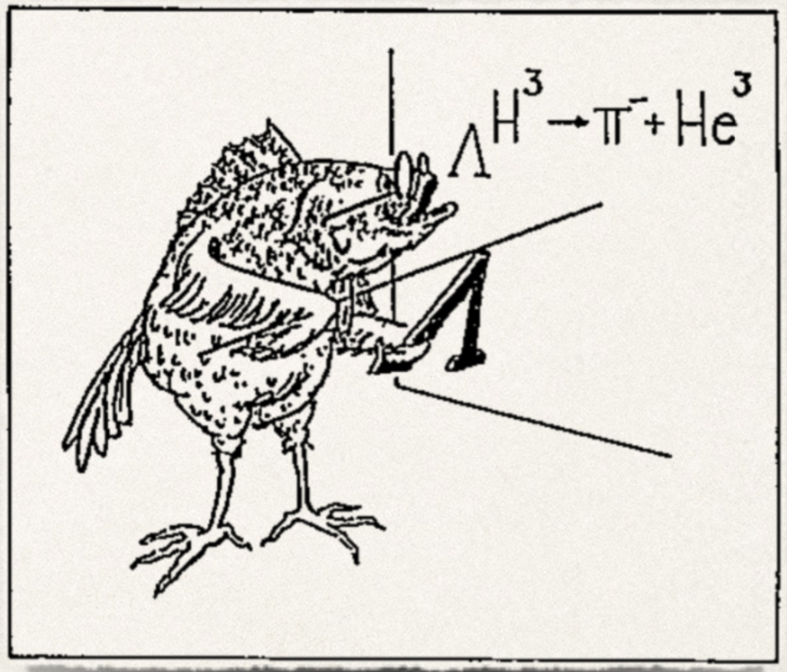
Introduction: motivation

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

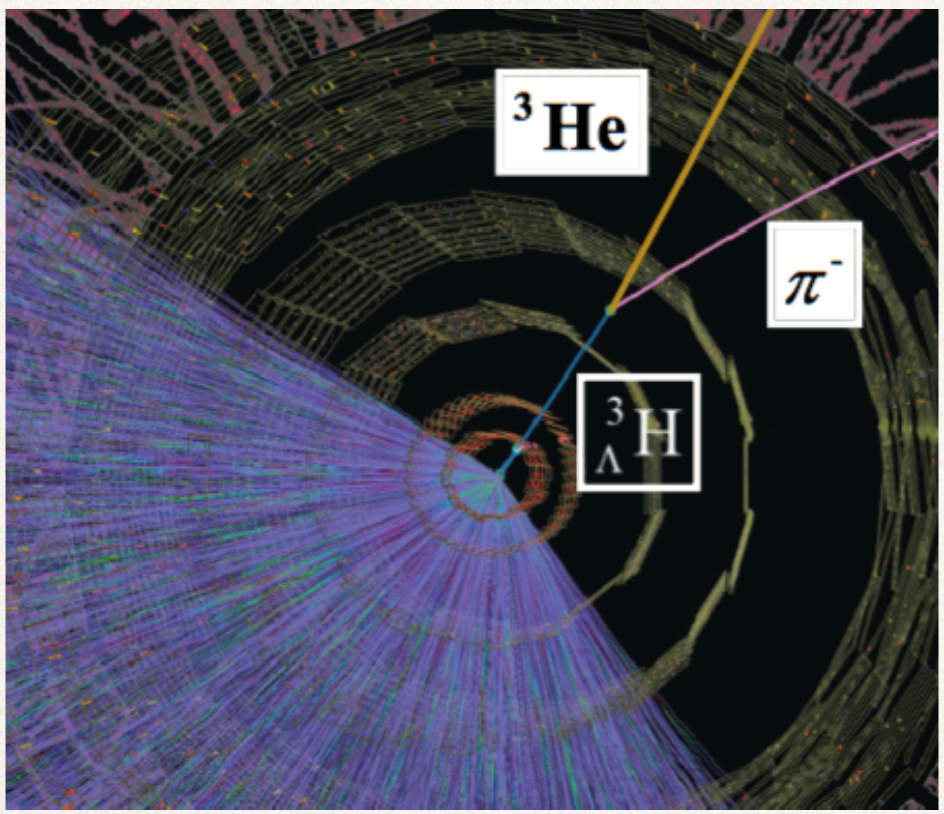


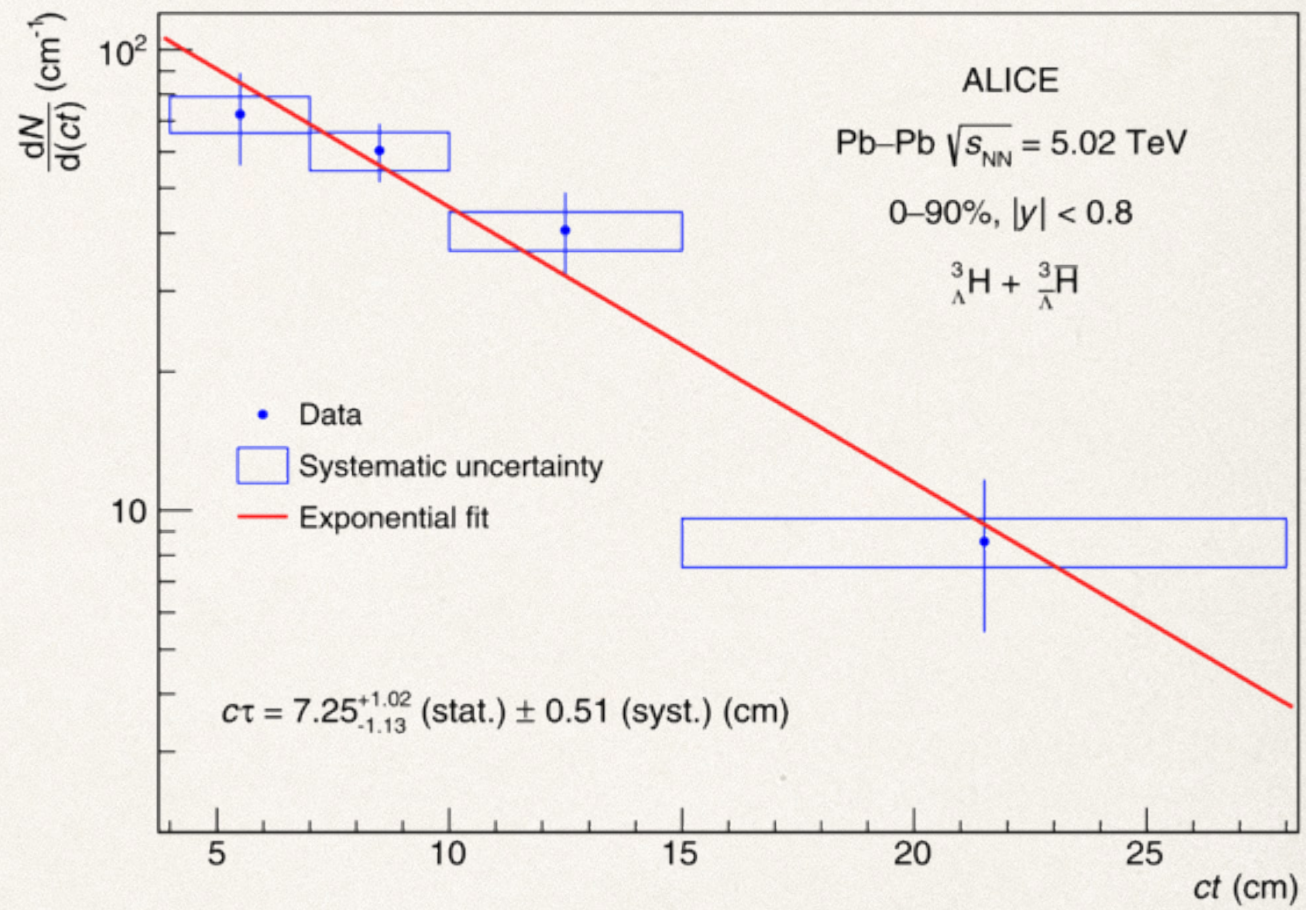
Neither fish nor fowl?

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

Introduction: heavy ion results

ALICE as an example for the experimental approach.





$$\tau = 240^{+40}_{-31}(\text{stat.}) \pm 18(\text{syst.})$$

Depends on tracking results for decay length and momentum as $t = L/\beta\gamma c$

ALICE collaboration, PLB, 797 (2019) 134905

Experimental setup

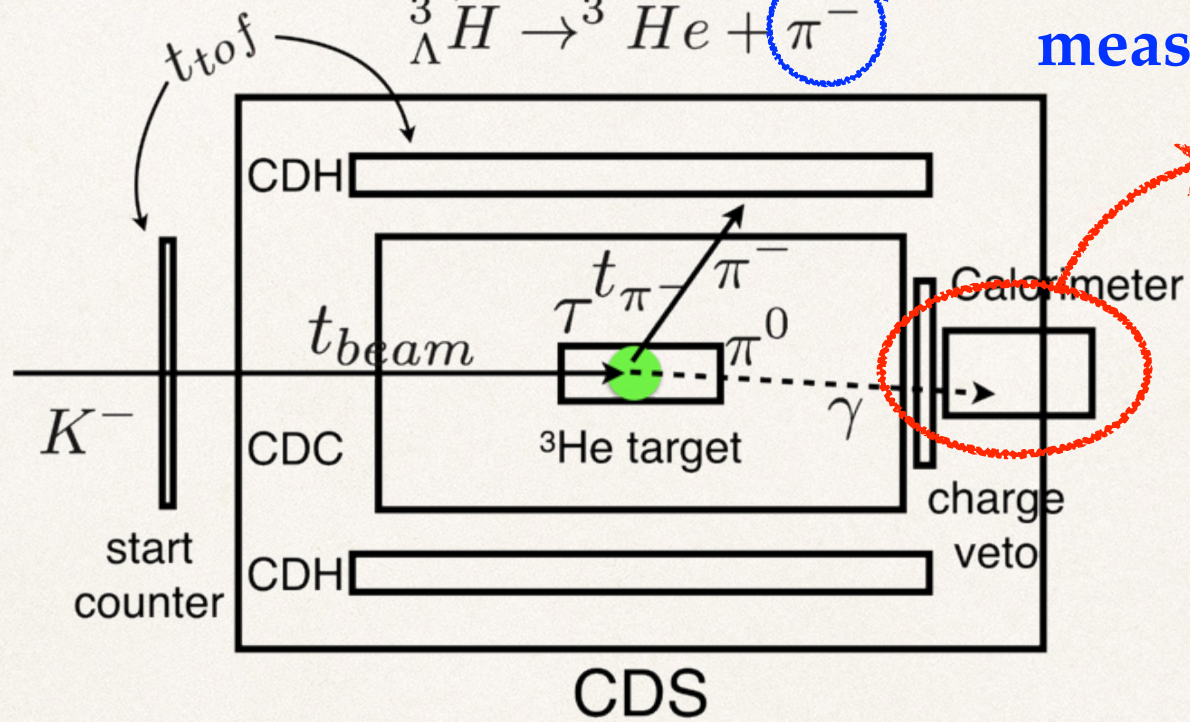
$K^- + {}^3He \rightarrow {}^3_\Lambda H + \pi^0$

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

slows dow inside ³He target
and decays at rest

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

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



5x8 PbF2 Cherenkov Calo
R&D has been completed

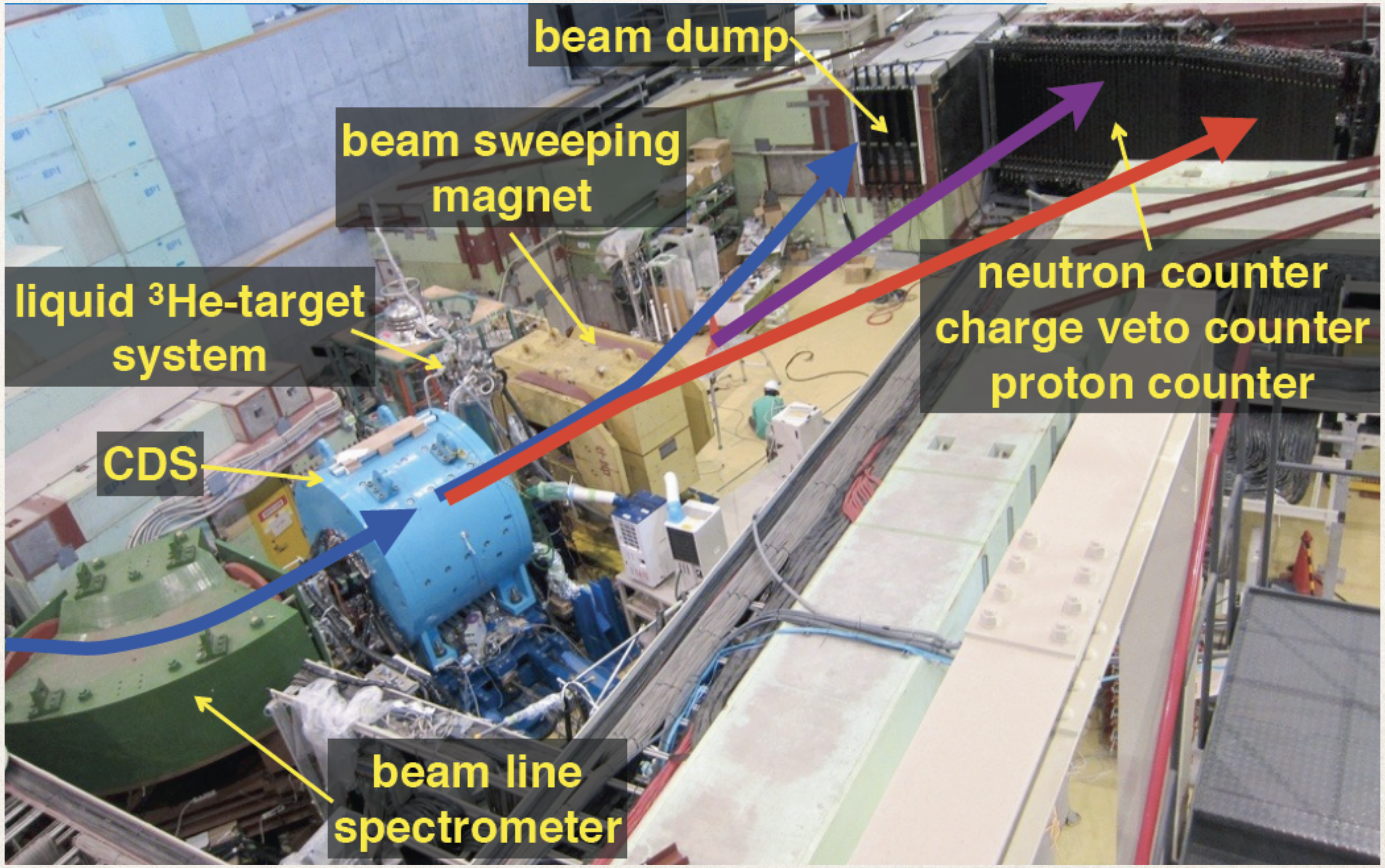
${}^3_\Lambda$H decay time can be derived by TOF and CDS tracking

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

Experimental setup

The main apparatus to measure decayed pi- momentum
is a solenoid spectrometer,
Cylindrical Spectrometer System (CDS).
Successfully employed for E15 and E31 at K18BR of Hadron Hall.



Performance estimation: yield estimation

Target: liquid 3He, 10cm	1.6×10^{23} / cm^2
K- power @ 1GeV/c	50kW (2×10^5/5.2s)
σ of ${}^3_\Lambda$H g.s.	0.0126 mb
Total yield	1.8×10^5/4 weeks
Beam acep. & DAQ eff.	50%
${}^3_\Lambda H \rightarrow {}^3He+\pi$- b.r.	25%
π- & π0 acceptance	6%
${}^3_\Lambda$H signal yield	***~1000 events/4 weeks***

${}^4_\Lambda$H signal yield (same target cell):

~3(cross section)×2(π^- branching ratio)×${}^3_\Lambda$H signal yield

==> ***~1000 events/1 week***

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 pilot run with He4 target

New proposal(P77) for P73 pilot run

Test beam proposal for the J-PARC P73:

Feasibility study for ${}^{3}_{\Lambda}$H mesonic weak decay lifetime measurement with ^{4}He(K^{-}, π^{0})${}^{4}_{\Lambda}$H reaction[1]

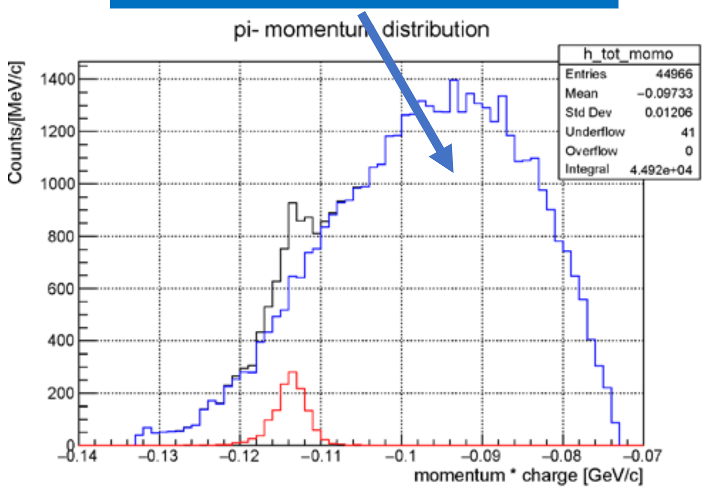
- This talk is part of the efforts for applying pilot run with He4 target:
  - J-PARC P77: ^{4}He (K^{-}, π^{0}) ${}^{4}_{\Lambda}$H reaction @ 1GeV/c, 50kW*1week
- Motivation for the pilot run and preparation status will be covered in the next slides

Mission for the ^{4}He (K$^-$, π^0) $^4_\Lambda$H pilot run

Expected S/BG Ration with Different Models

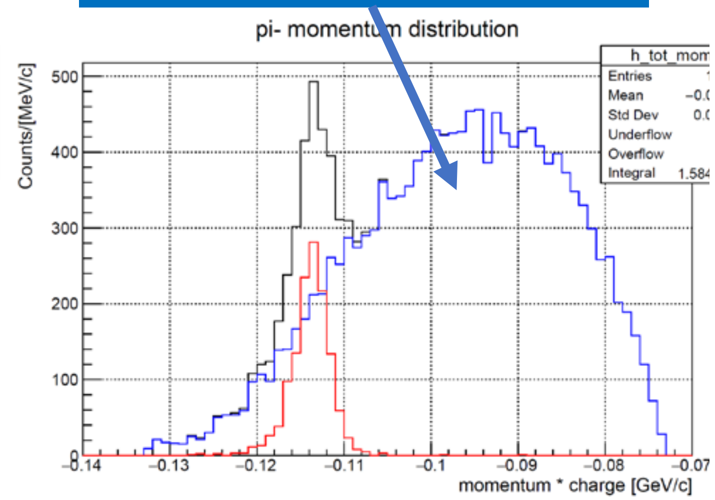
Signal yield is assumed to be ~ 1k in all cases (4w, 50kW)

from Geant4 CS



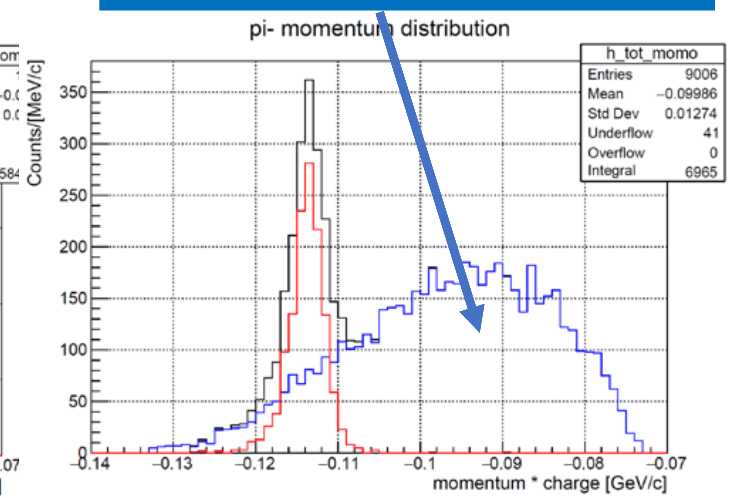
S/BG ~ 1/42

from BNL E905 CS



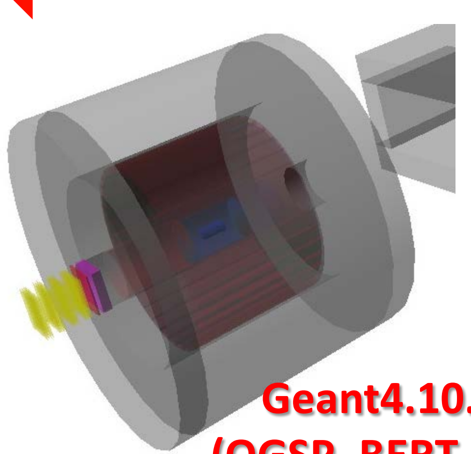
S/BG ~ 1/16

from theoretical CS



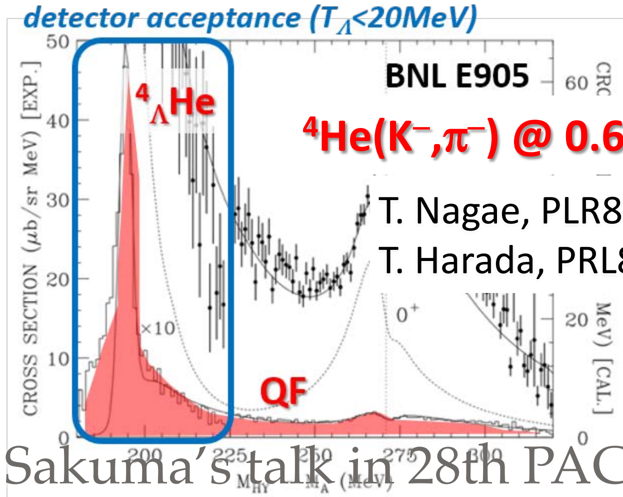
S/BG ~ 1/6

Worst case — *Need to confirm with the pilot-run data* — Best case



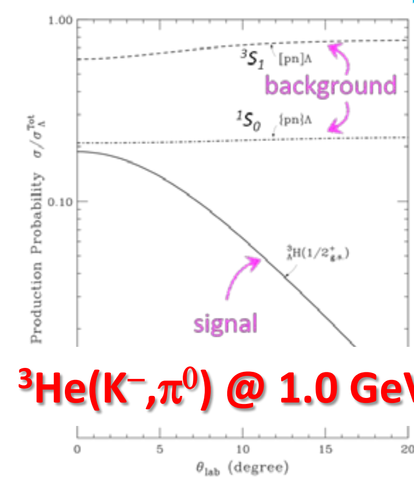
Geant4.10.0 (QGSP_BERT_HP)

detector acceptance (T_Λ<20MeV)



^{4}He(K$^-$,π^-) @ 0.6 GeV/c

T. Nagae, PLR80(98)1605
T. Harada, PRL81(98)5287



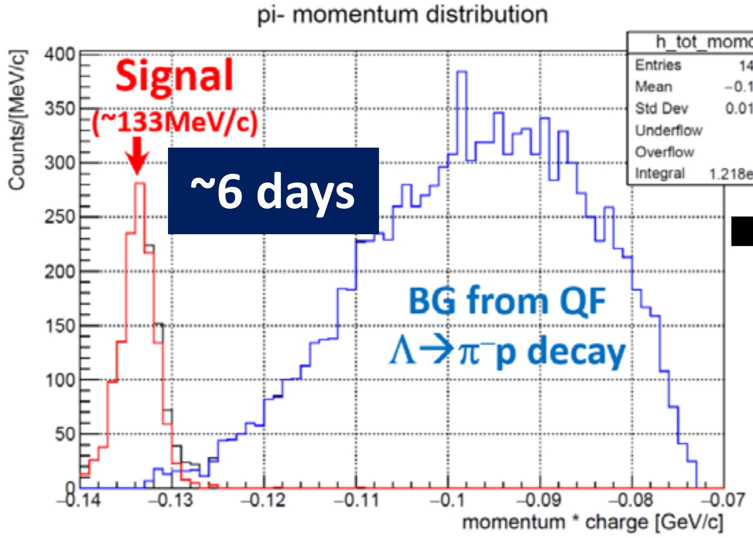
^{3}He(K$^-$,π^0) @ 1.0 GeV/c

F. Sakuma's talk in 28th PAC

Mission for the ^{4}He (K$^-$, π^0) $^4_\Lambda$H pilot run

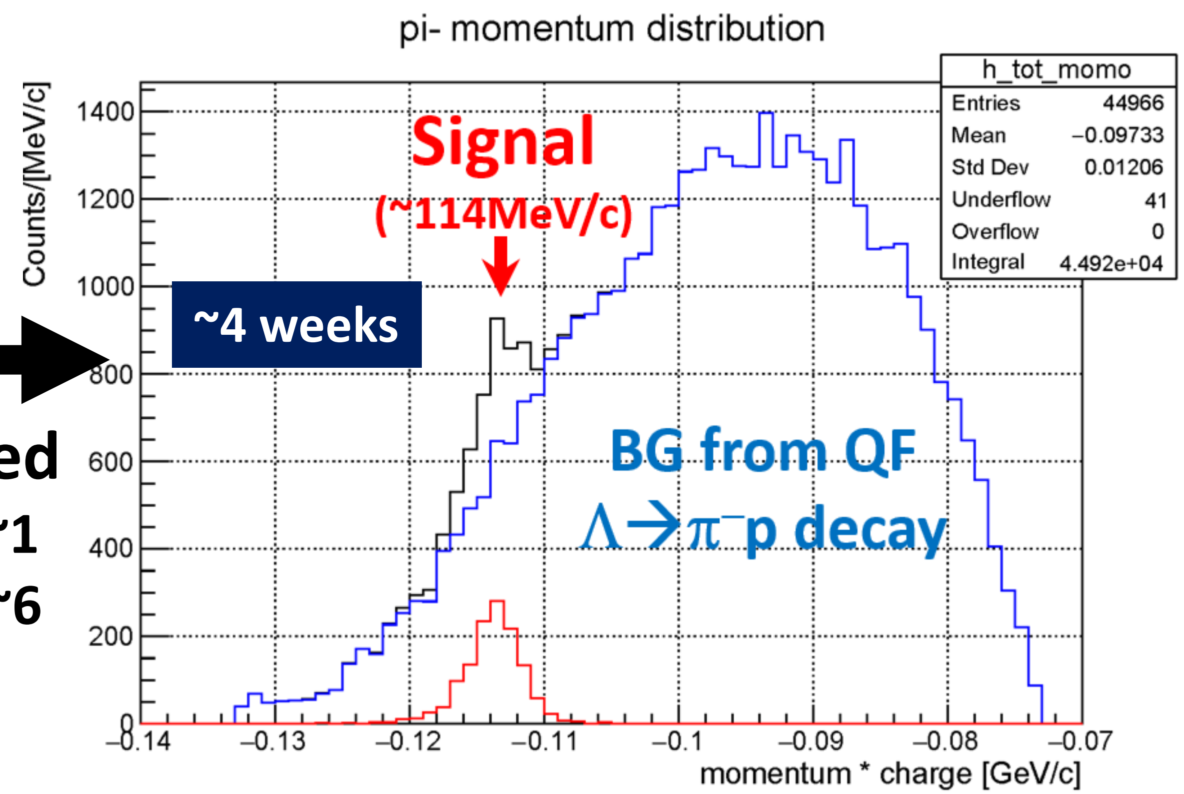
Realistic Estimation using ^{4}He Data

K$^-$ + ^{4}He



scaled
S x ~1
B x ~6

K$^-$ + ^{3}He



- **Using the signal and BG obtained from K$^-$ + ^{4}He data, we can do an realistic estimation of the $^3_\Lambda$H measurement**
  - BG is expected to be almost the same between ^{3}He and ^{4}He
  - Signal and BG can be scaled

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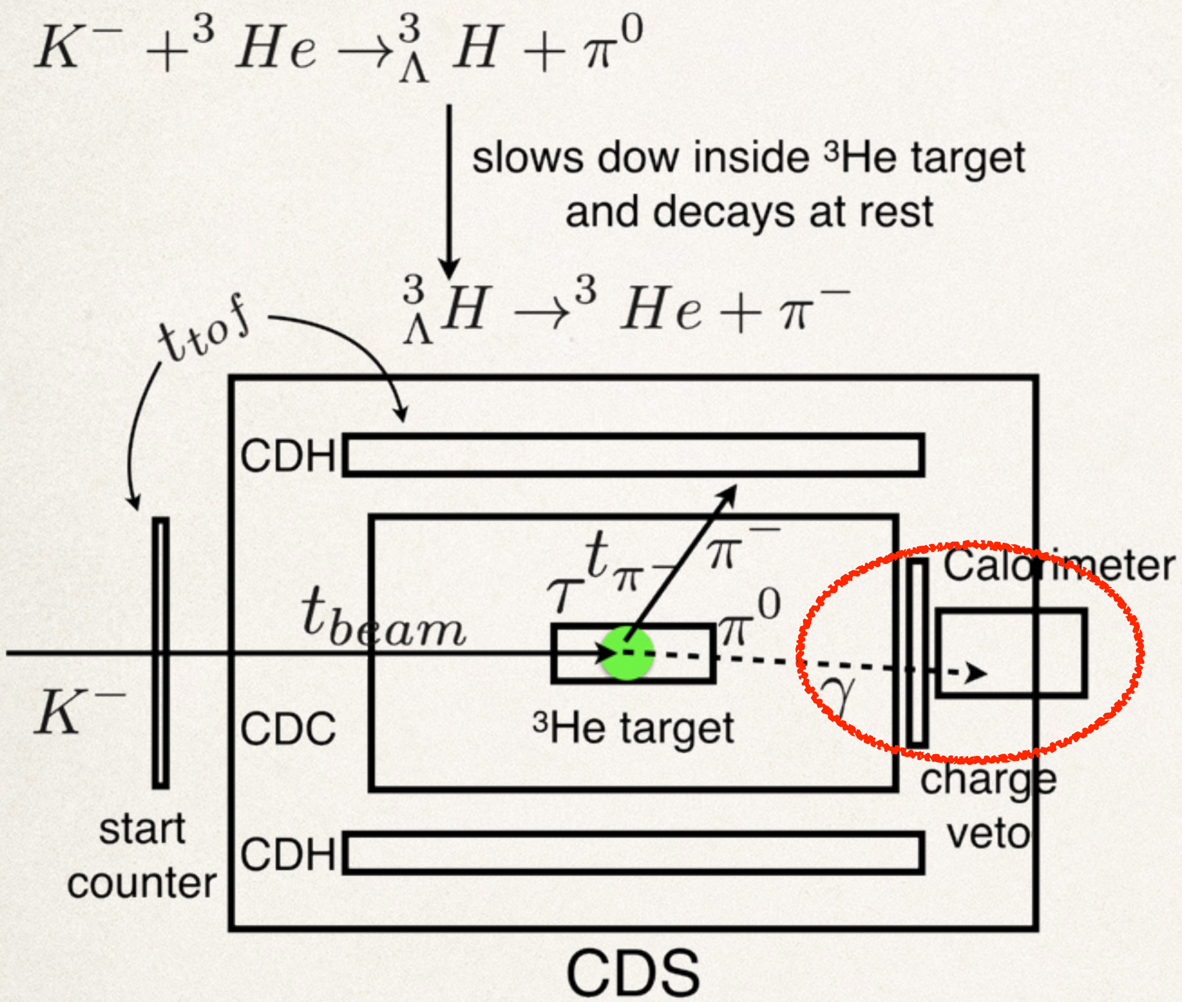
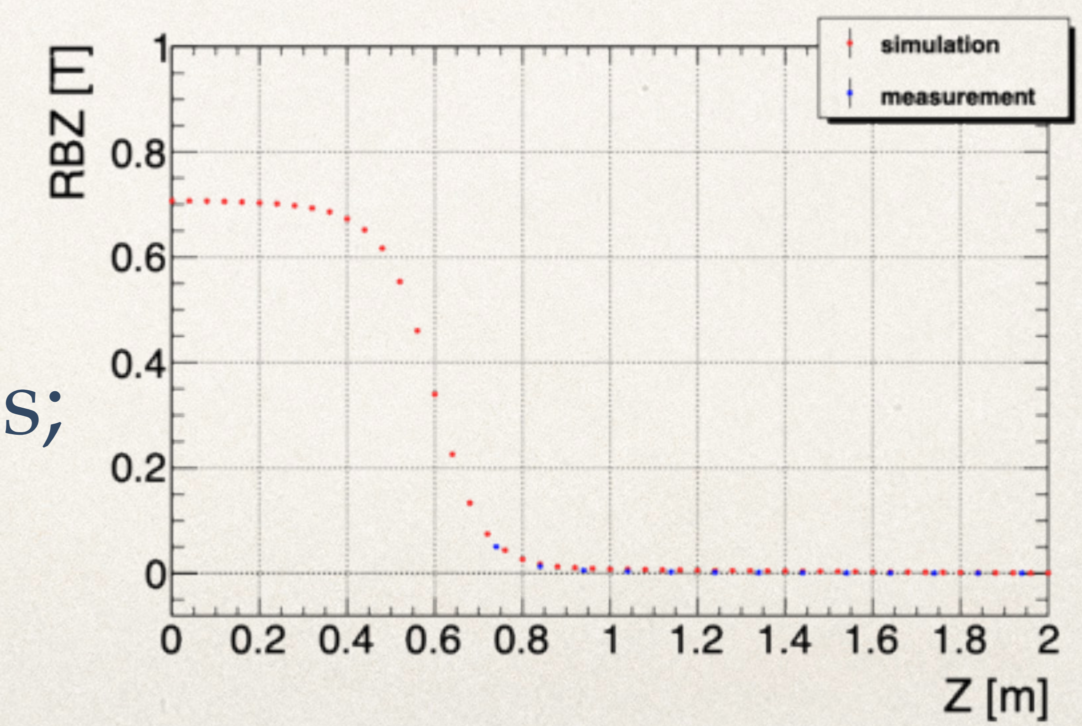
F. Sakuma's talk in 28th PAC

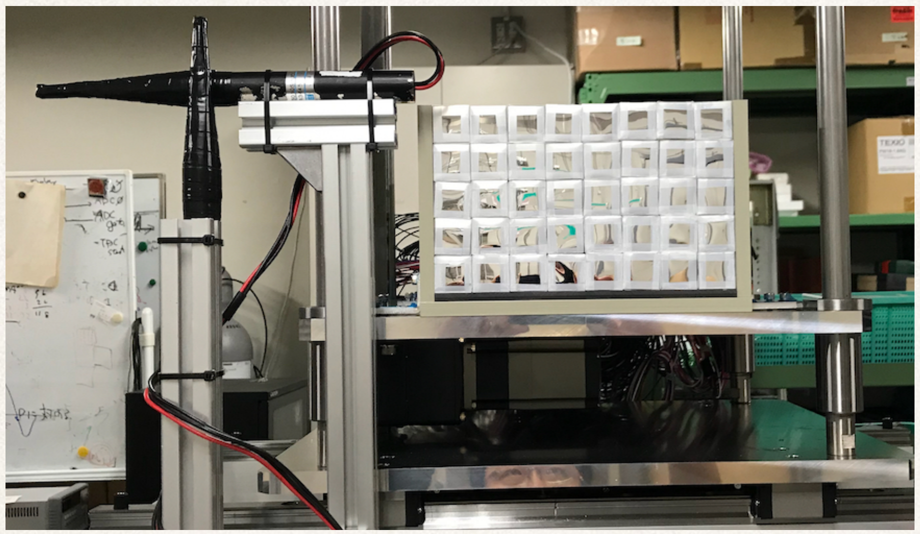
Preparation status: Calorimeter

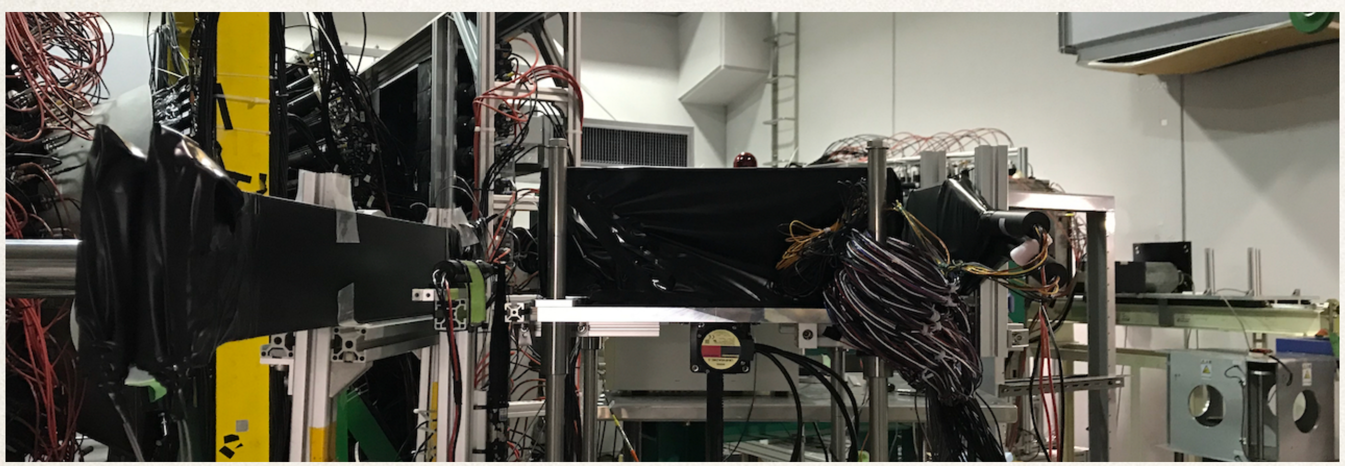


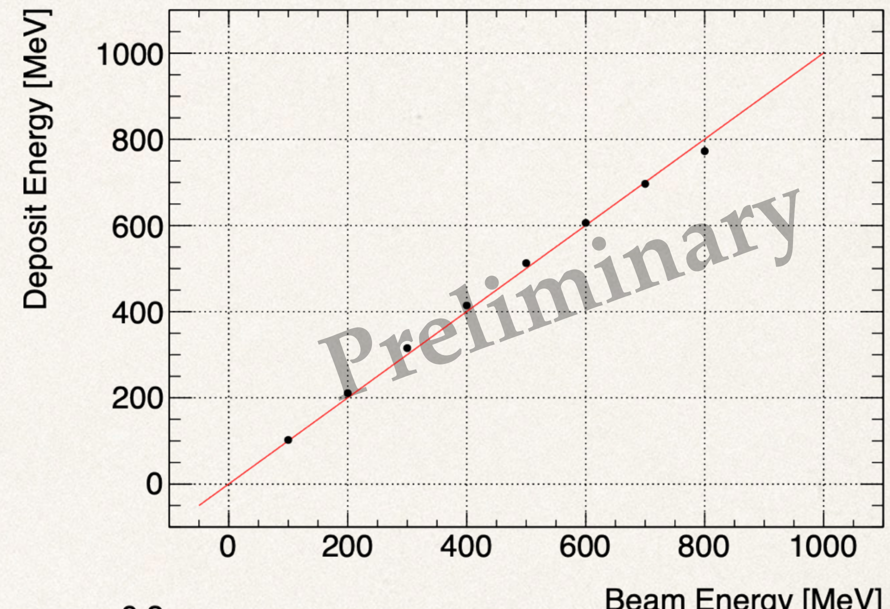


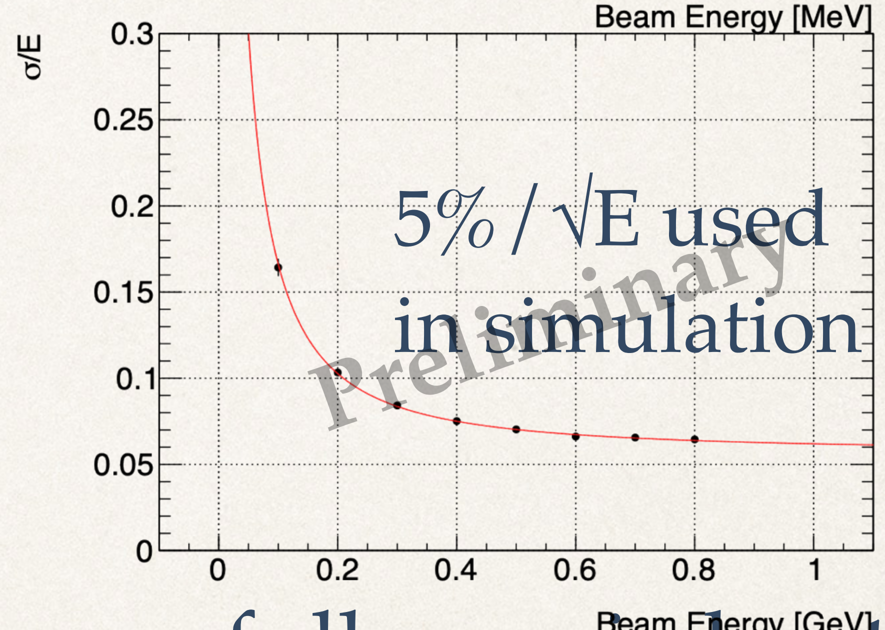
- Residual field from CDS is suppressed down to ~3 Gauss;
- No noticeable distortion for PMT signal is observed

Preparation status: Calorimeter









5% / √E used in simulation

- Energy calibration has been successfully carried out at ELPH, Tohoku Univ. in Dec. 2019;
- Performance is confirmed and ready for data taking

Preparation status: Cryogenic target

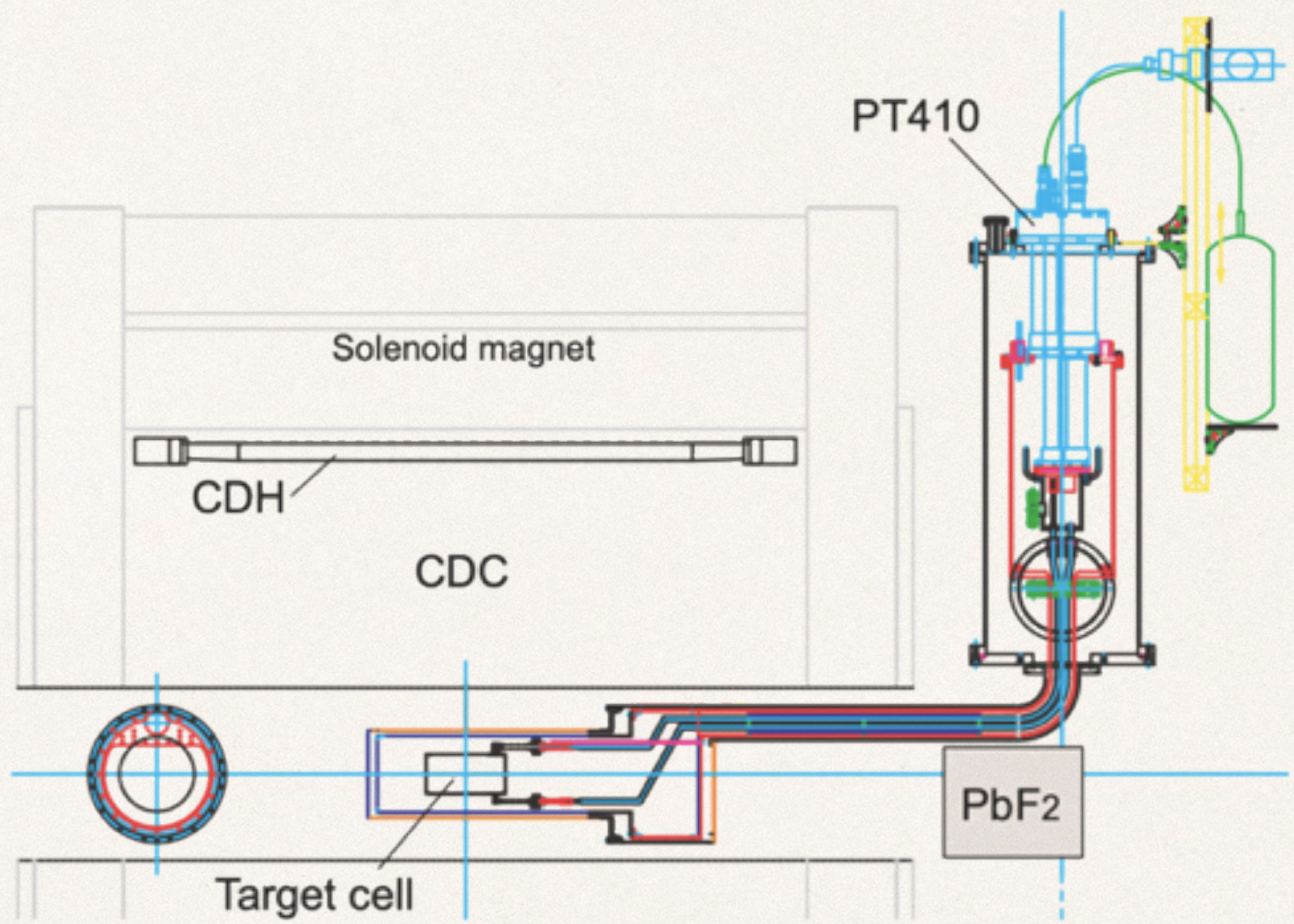


Figure 7: Design of the target system for P73.

- Target geometry is modified to tolerate the calorimeter;
- All components are in hands and will be assembled soon

Summary

- Proposal for P73 pilot run is submitted to PAC
- 1week beam time @50kW with He4 target can help us to pin down the uncertainty in the background yield estimation and also confirm statistical/systematic errors
  - *We submitted J-PARC P77 as pilot run of P73 for this purpose*
- The whole system will be ready for data taking by the end of this fiscal year (March 2020)

Acknowledgement

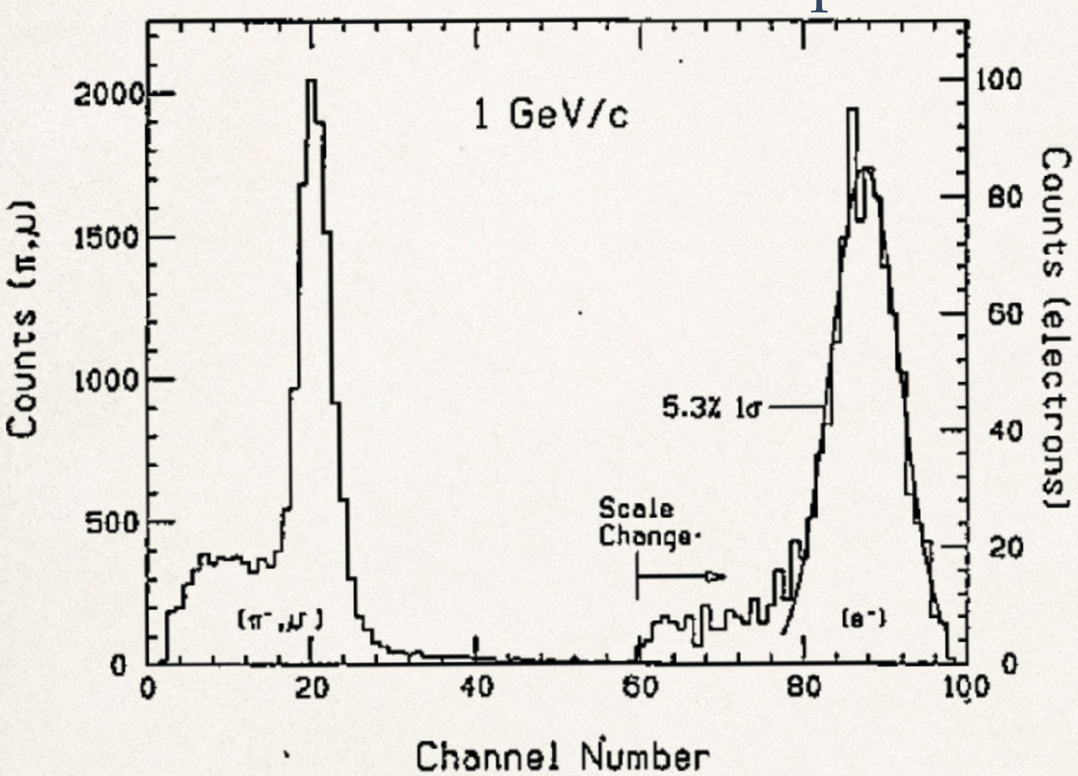
- Financial support from Prof. M. Iwasaki
- Support from ELPH staff Prof. T. Ishikawa
- Support from KEK staff S. Ishimoto, S. Suzuki
- Our brilliant collaborators:
  - T. Akaishi, T. Yamaga, T. Hashimoto, F. Sakuma

- Backup

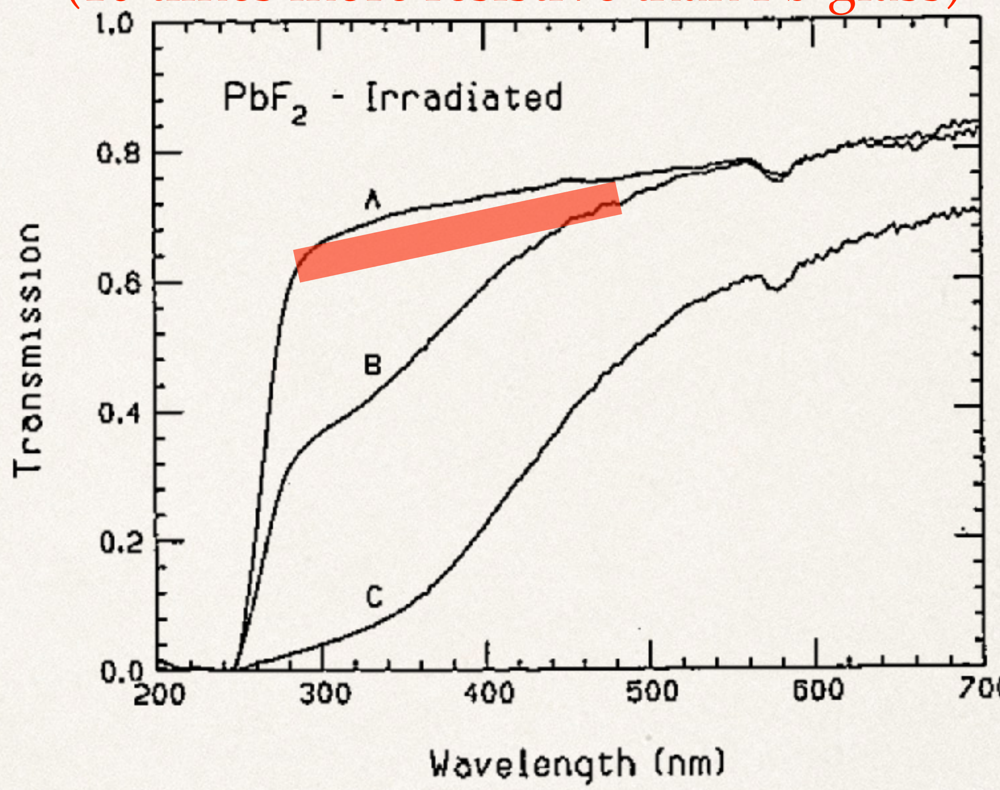
Experimental setup: π^0 tagger (PbF_2)

π^- peak

electron peak



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

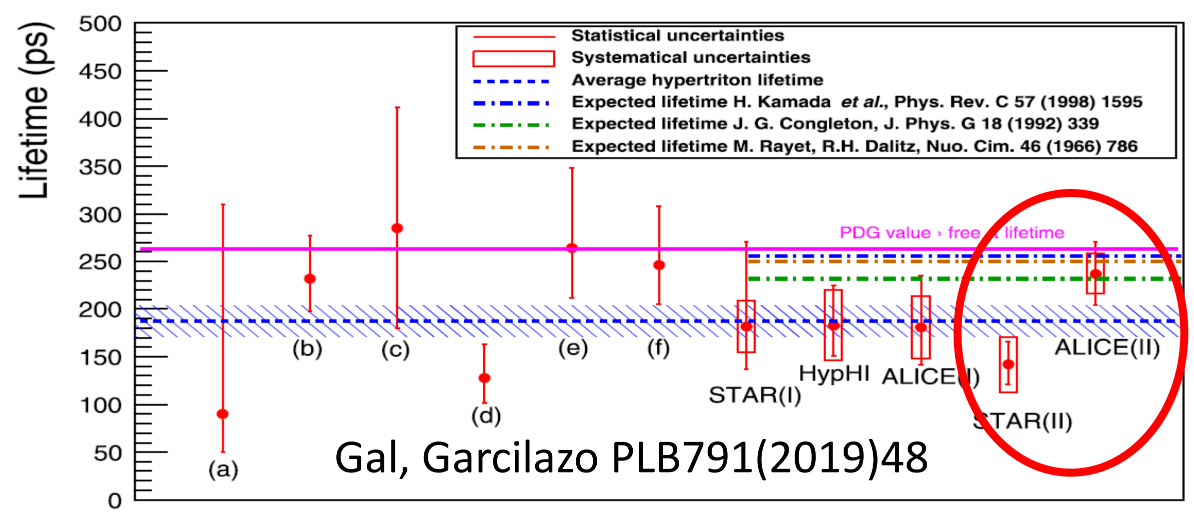
D.F. Anderson, ***et al.***, Nucl. Inst. Meth. A290 (1990) 385
P. Achenbach, ***et al.***, Nucl. Inst. Meth. A416 (1998) 357

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

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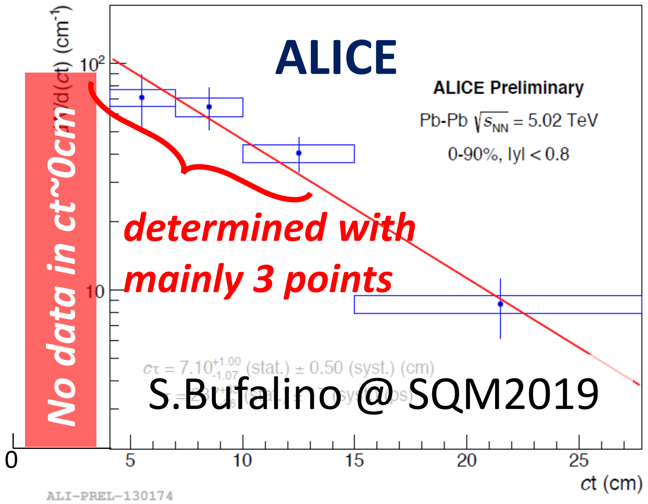
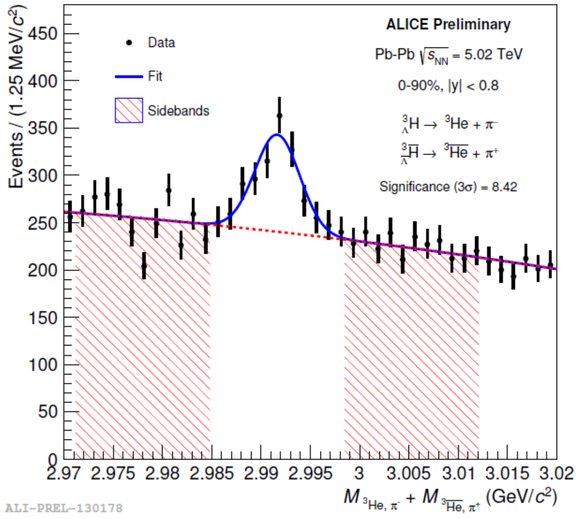
Heavy-Ion Experiment

Heavy-ion experiment **STAR, ALICE, HypHI**

- **Invariant mass reconstruction**
  - Difficult to use $^{3}{}_{\Lambda}H$ information in ct~0cm region
  - Huge combinatorial BG





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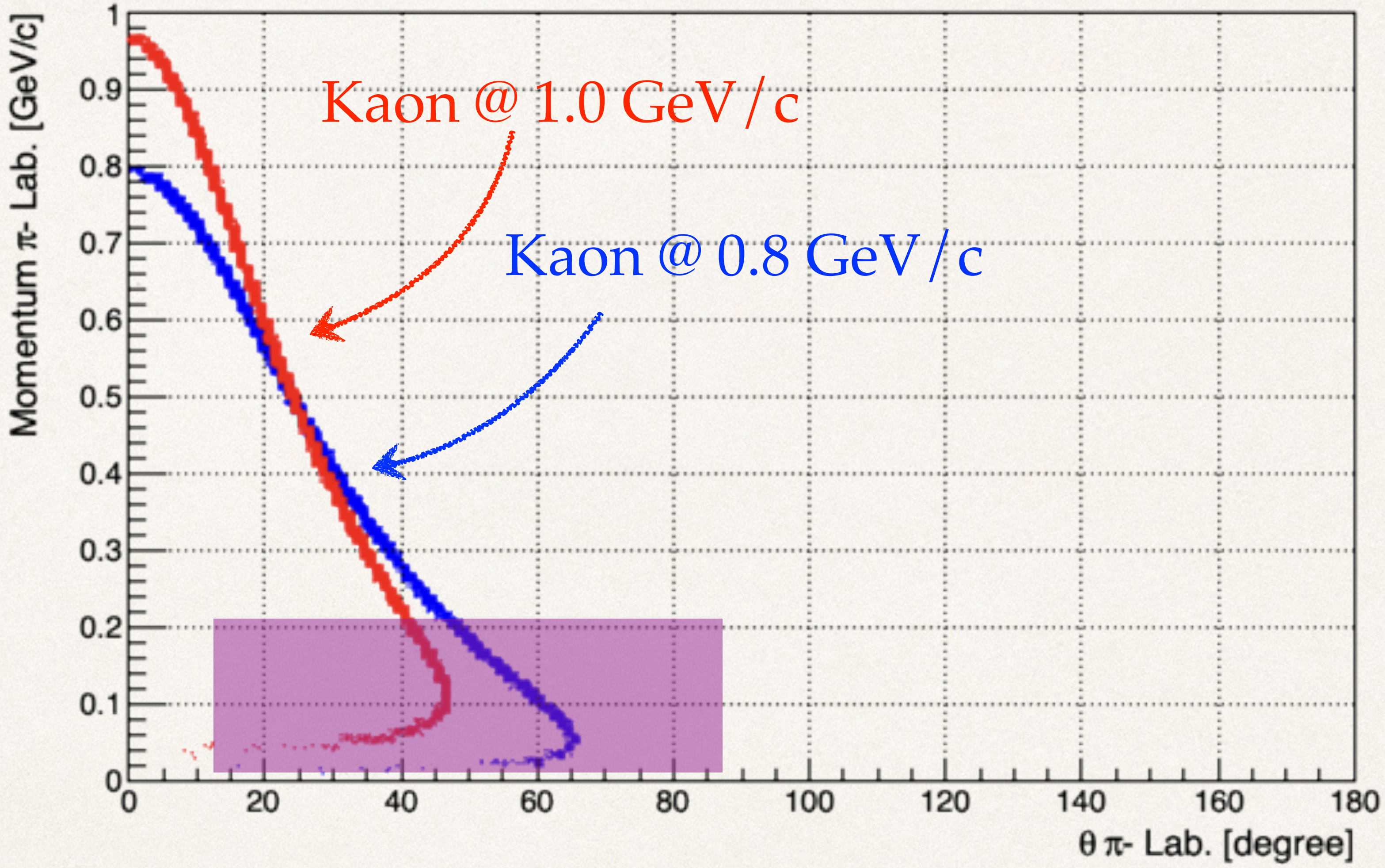
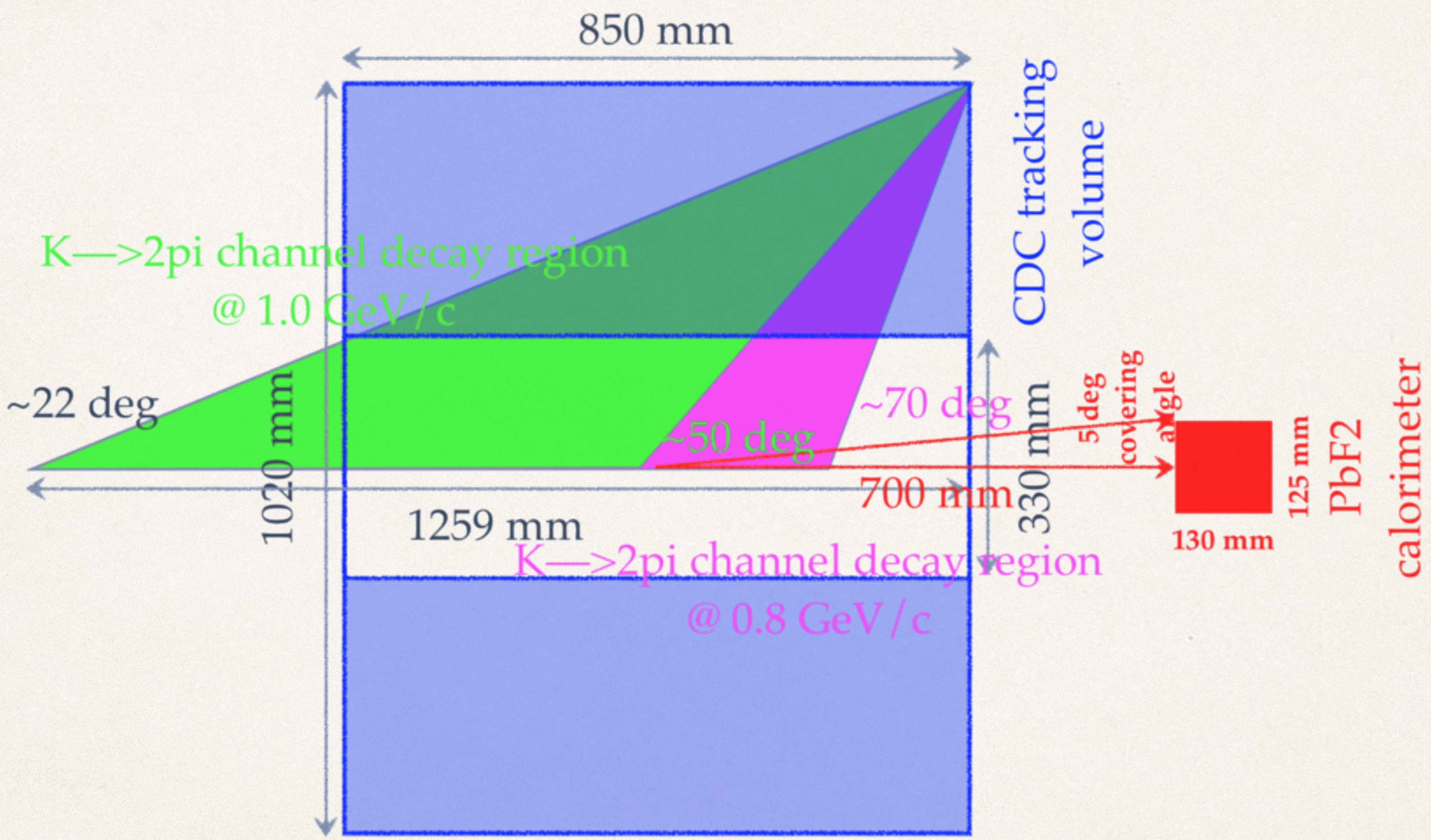
Background events from Kaon in-flight decay



For setup like SKS dipole magnet spectrometer, there are severe BG from K- inflight decay.
But in our case, a conjunction measurement of both pi- and pi0, the kaon decay backgrounds can be suppressed by using the pi- decay angle and decay vertex.

CDC acceptance vs Kaon decay background

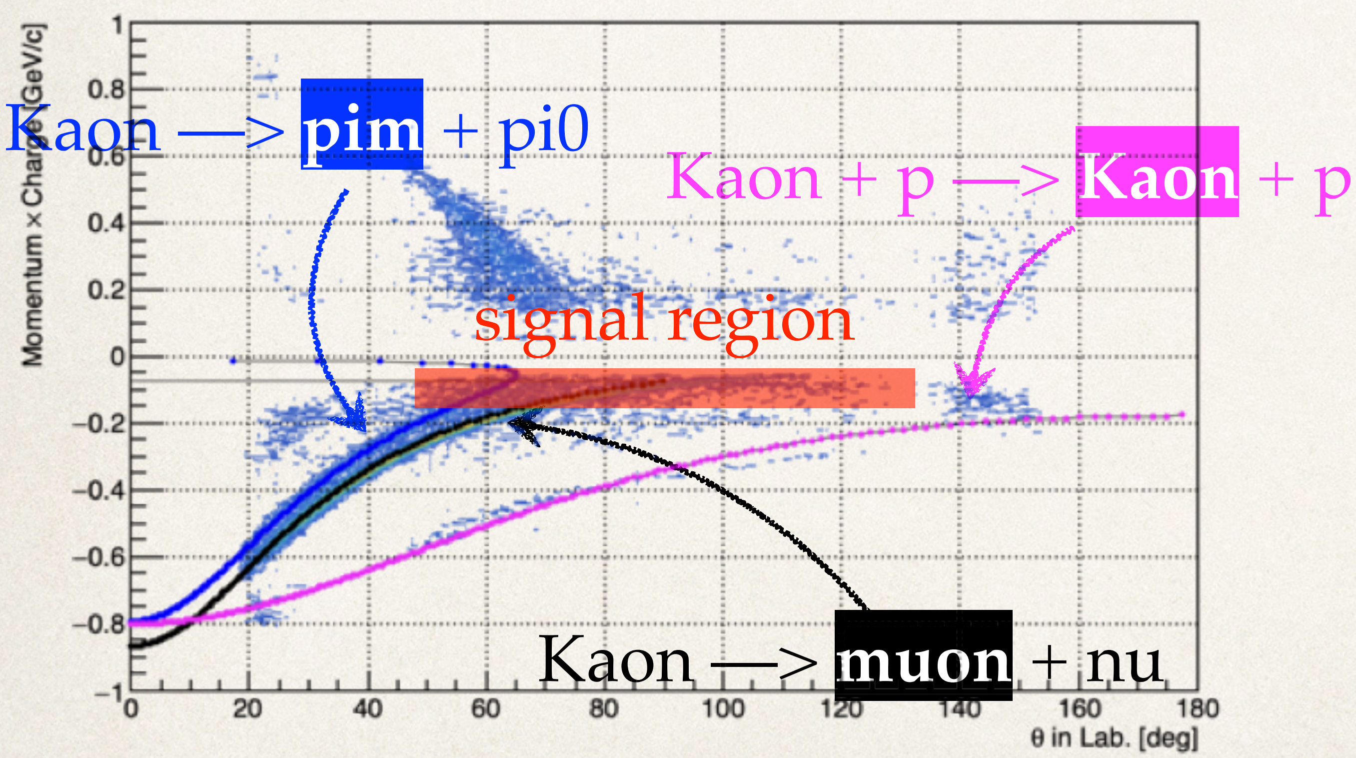


Most of the 1.0 GeV/c K- beam in-flight decay background is out of the acceptance of CDS spectrometer.

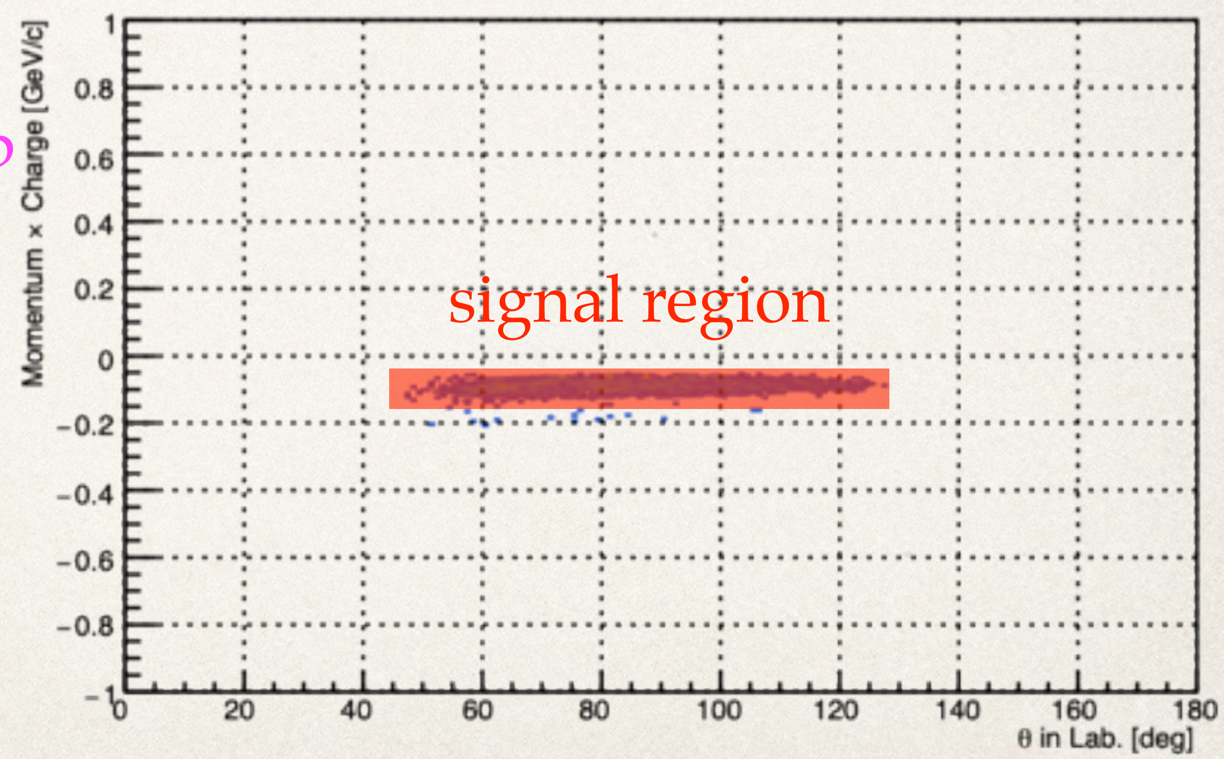
Event selection conditions

- dE veto counter <= 0.2 MeV && PbF2 calorimeter >= 600 MeV
- IH == 1 && CDS charged track == 1
- CDS tracking mass >= 0 && <= 0.3 GeV / c^2
- DCA <= 5mm && fiducial cut

From Monte Carlo information, only hyperon and hypernucleus events survived the event selection --> effective trigger and analysis method



Before event selection

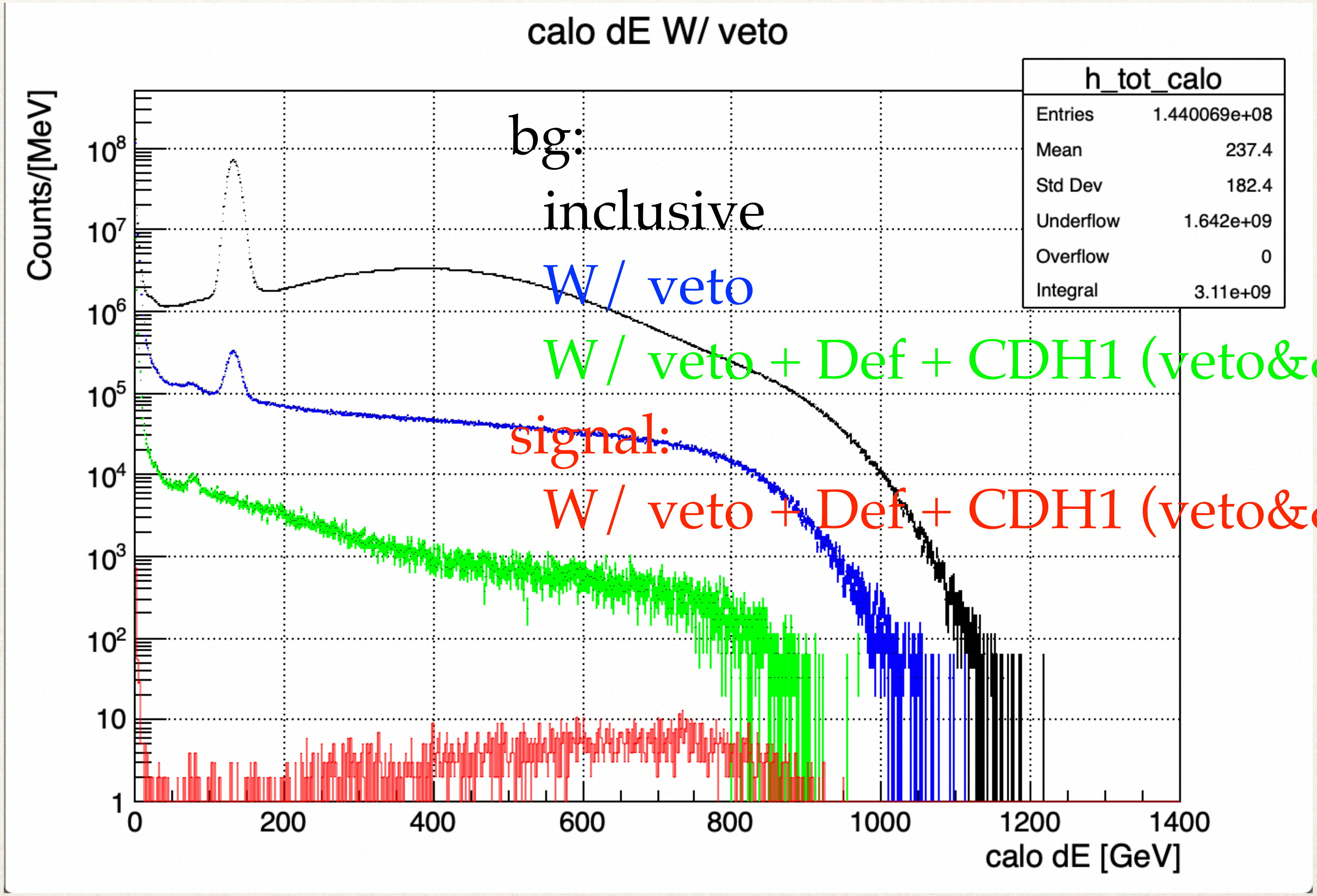


After event selection

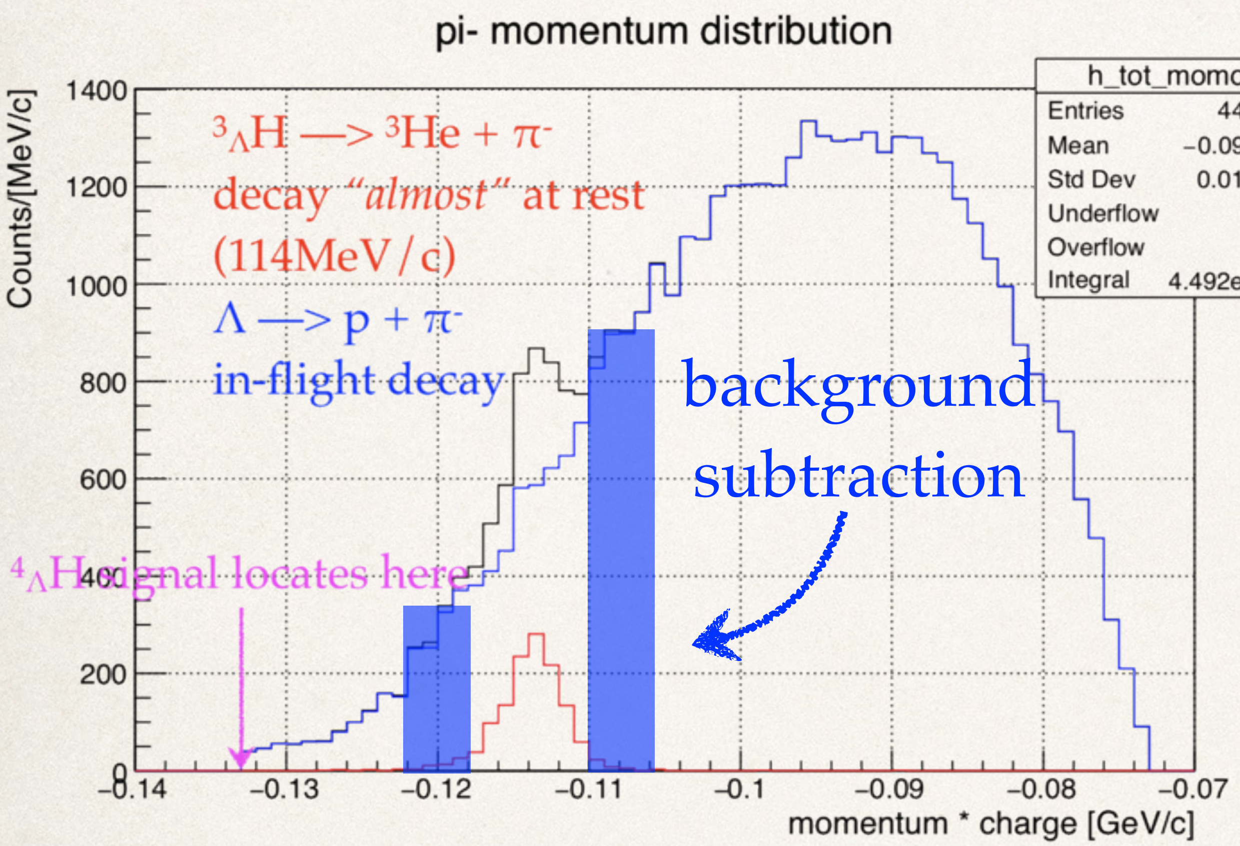
blue: inclusive calo dE W/ veto: K- in-flight decay + …
red: signal calo dE W/ veto

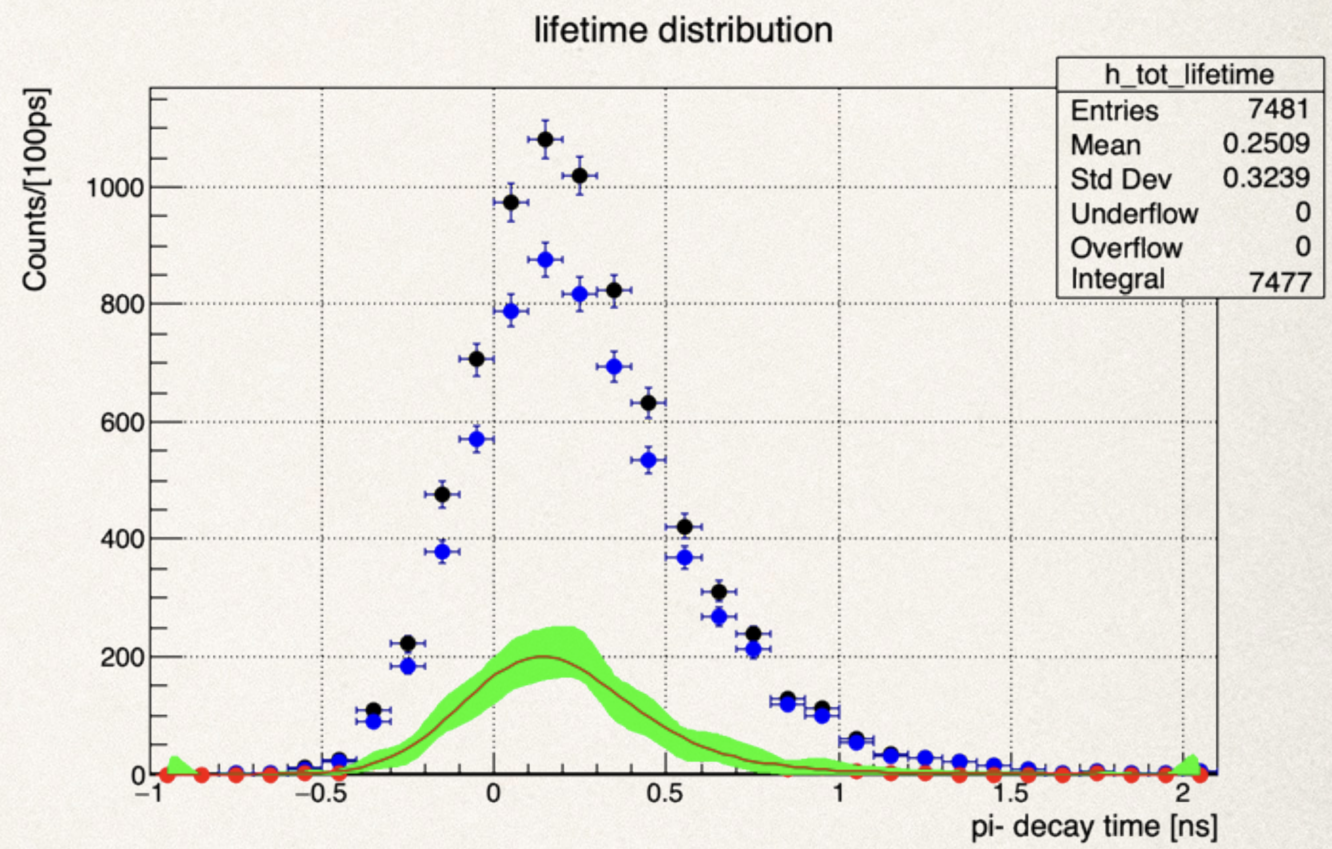
most of events from Kaon in-flight decay

veto_vtx ~ to def&&veto



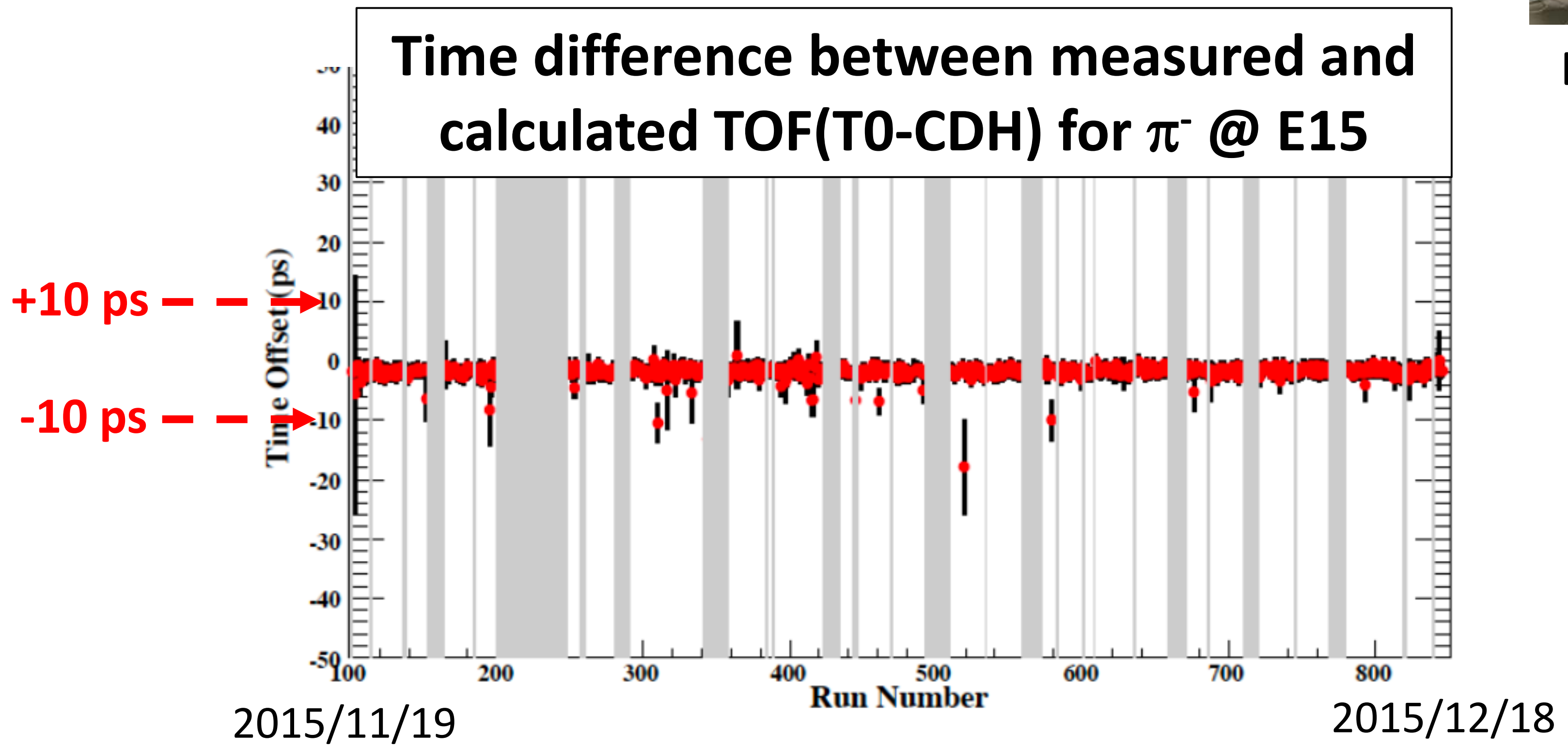
Estimate $^{3}_{\Lambda}H$ lifetime resolution

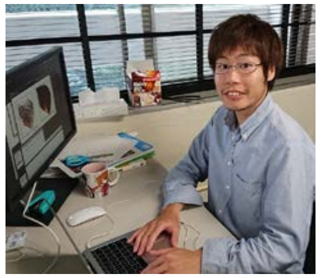




- A stand alone lifetime generator based on simulated background shape: --> statistical error ±25ps
- Systematic error is evaluated by assuming the time zero alignment has ~20ps accuracy --> systematic error ±20ps

Time Zero Alignment Estimation with the E15 Data





Dr. Yamaga, RIKEN

- 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