

E73 status report

Apply for Stage-2 approval

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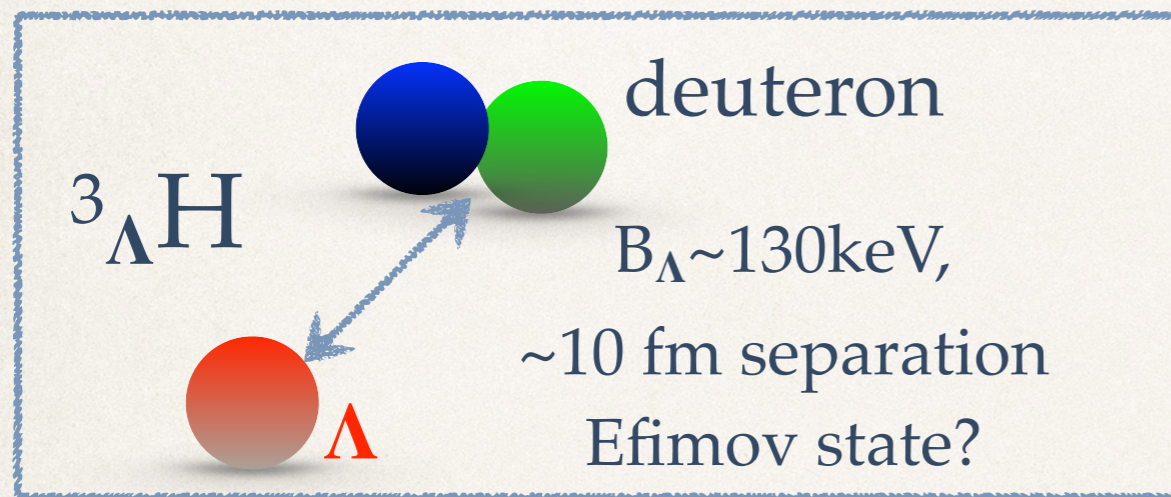
Jan. 20th, 2022

Outline

- ❖ Introduction to J-PARC E73:
 - ❖ The first direct measurement for ${}^3_{\Lambda}\text{H}$ lifetime
- ❖ J-PARC E73 staging & status
 - ❖ Phase-0: ${}^4_{\Lambda}\text{H}$ lifetime as feasibility study, June, 2020
 - ❖ Phase-1: ${}^3_{\Lambda}\text{H}$ production cross section measurement, May, 2021
 - ❖ Phase-2: ${}^3_{\Lambda}\text{H}$ lifetime measurement in early 2023
 - ❖ Request for Stage-2 approval in this talk
- ❖ 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 $\tau \approx 180 \text{ ps}$...

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

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

J-PARC E73 staging & status

Staging:	Phase-0 (June, 2020)	Phase-1 (May, 2021)	Phase-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 ${}^3_{\Lambda}\text{H}$ @ 1 GeV / c	Pin down Hypertriton lifetime puzzle
Status:	${}^4_{\Lambda}\text{H}$ lifetime publication under preparation	Fully ready for beam time from now on	Request for Stage-2 approval

Request from the 32nd PAC meeting

The PAC understands the importance of the measurement as well as the readiness of the experiment. The earliest beam time will be in the fourth quarter of 2022. Before granting the stage-2 status to E73, the PAC suggests to the experiment: (1) complete the analysis of ${}^4\text{He}(\text{K}^-, \pi^0){}^4_{\Lambda}\text{He}$ reaction and determine the systematic uncertainties and (2) Prepare a detailed document on the analysis procedure for the lifetime measurement and submit the material before the next PAC meeting.

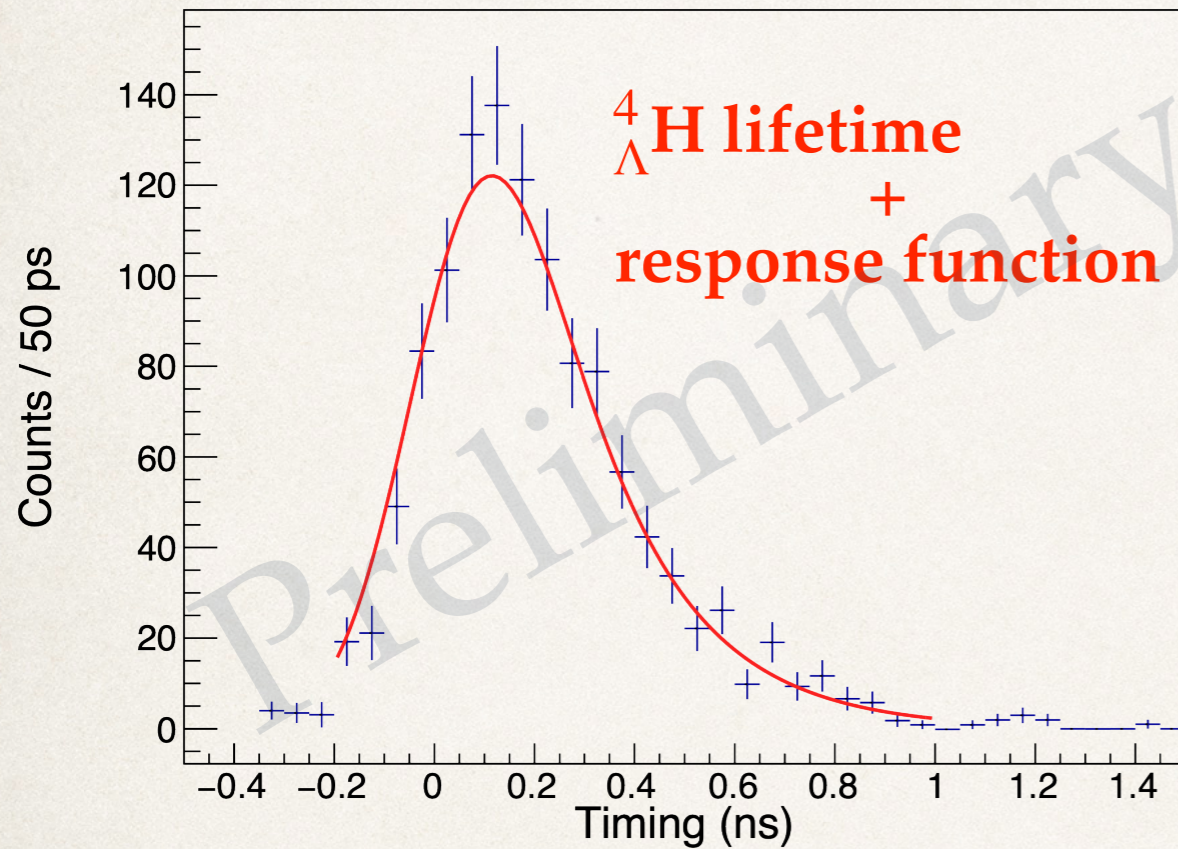
Homework assigned by the last PAC:

1, accomplished, will be covered by this talk

2, a detailed analysis report has been submitted

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

$190 \pm 8(\text{stat.}) \pm 17(\text{sys.}) \text{ ps}$



$194^{+24}_{-26} \text{ ps}$ @ 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

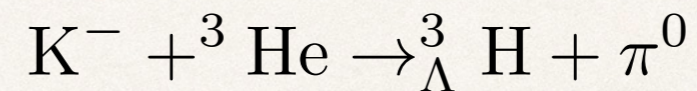
Preparing for publication...

Contribution	Value
Uncertainty of time calibration	$\pm 10 \text{ ps}$
Intrinsic bias of T77(E73) approach	$-5 \pm 5 \text{ ps}$
Uncertainty induced by background subtraction	$\pm 8 \text{ ps}$
Uncertainty induced by fitting range	$\pm 10 \text{ ps}$

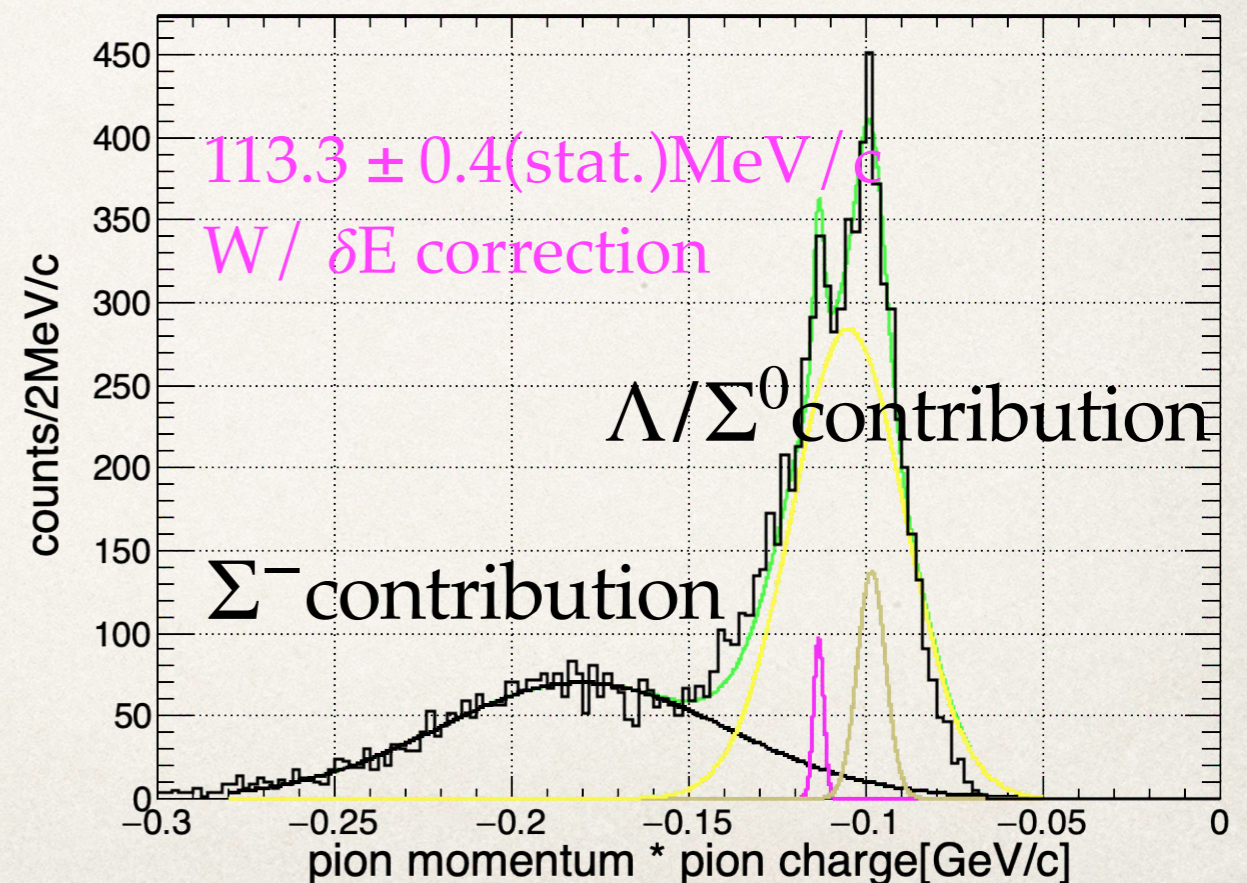
Request for Stage-2 approval

- ❖ Request for E73 Stage-2 approval with 25 days @ 80kW beam time for ~1k 2-body decay events scaled with Phase-1 data
- ❖ Expected precision for ${}^3_{\Lambda}\text{H}$ lifetime:
 - ❖ statistical error ~20 ps;
 - ❖ systematic error <30 ps based on the ${}^4_{\Lambda}\text{H}$ result

273kW*Day executed in May, 2021



↓ slows down and decays at rest



Summary

- ❖ Based on previous results, E73 is ready for the Stage-2 approval
 - ❖ Phase-0 (June, 2020): ${}^4_{\Lambda}\text{H}$ lifetime has been obtained to demonstrate the feasibility of our approach
 - ❖ Phase-1 (May, 2021): ${}^3_{\Lambda}\text{H}$ production cross section has been measured as a reference for Stage-2 beam time request
- ❖ Request for E73 Stage-2 approval with 25days @ 80kW beam time for ~1k 2-body decay events (scaled with Phase-1 data)

Q/A 1

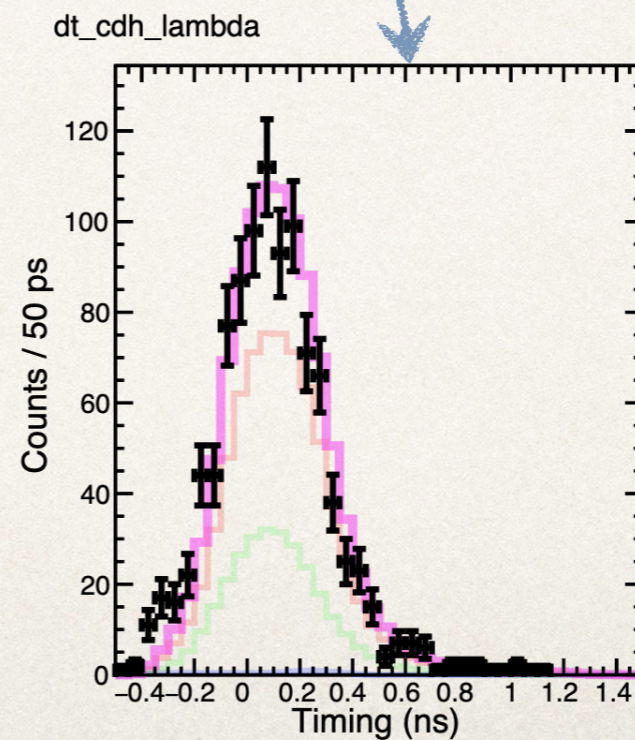
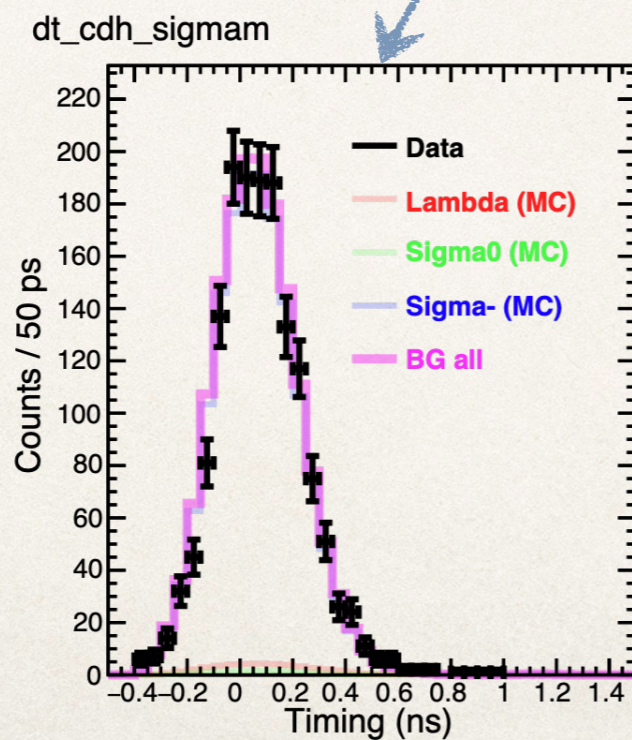
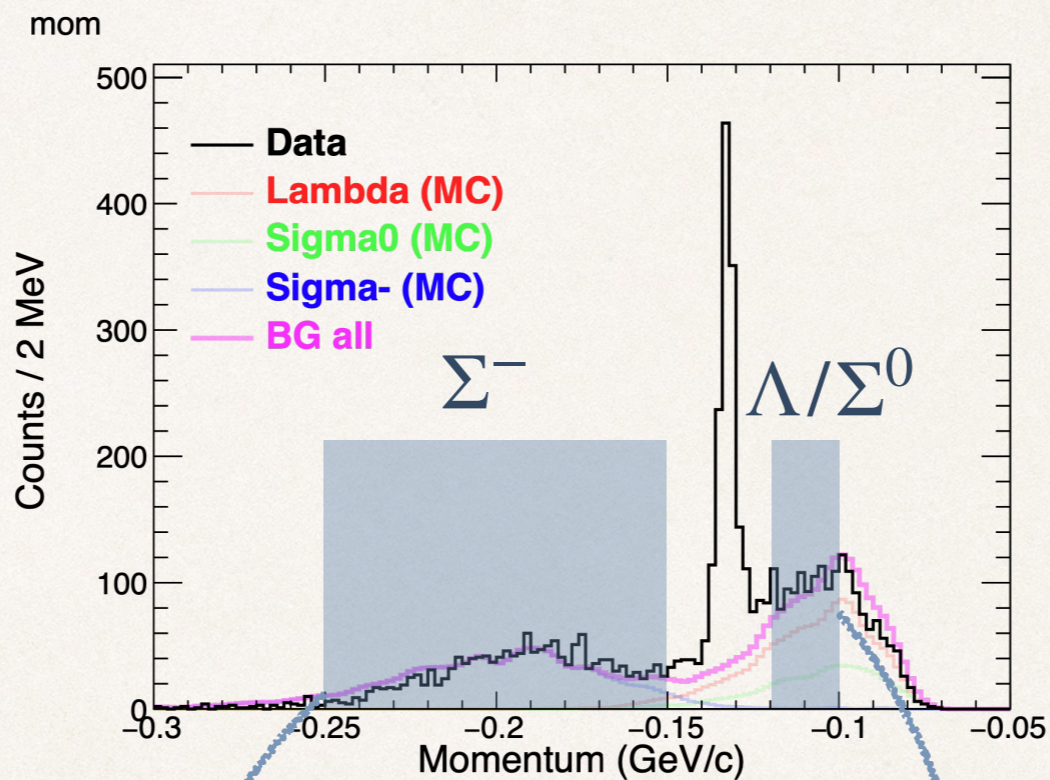
- Can you determine the "lifetime" of the background events by selecting events near $p = 0.1 \text{ GeV}/c$ or near $p = 0.2 \text{ GeV}/c$ from the measured momentum spectrum. According to the MC shown on p.10 that should correspond to mostly quasi-free Lambda and Σ^- , respectively. How do these "lifetimes" compare to the Lambda and Σ^- lifetimes?

A:

Yes, the π^- events around $0.1 \text{ GeV}/c$ and $0.2 \text{ GeV}/c$ are from quasi-free Lambda and Σ^- , respectively. To effectively select the H4-Lambda physics events, we request the π^- track comes close to the K- beam ($DCA < 5 \text{ mm}$), which applies a bias for the quasi-free hyperon events: only the events decay fast enough can pass this selection. Therefore, the hyperon "lifetime" in p.10 is shorter than the physics value. This effect has been well investigated with simulation and validated by comparing the corresponding lifetime spectrum with the T77 data.

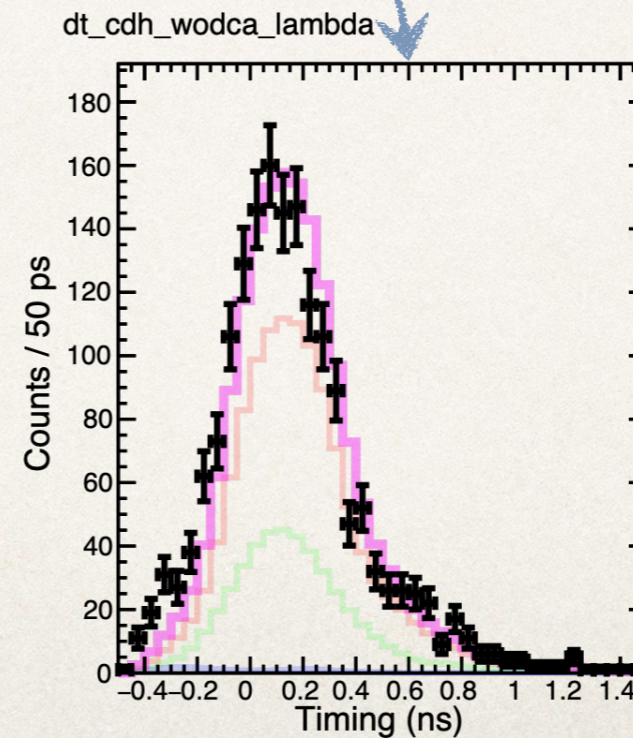
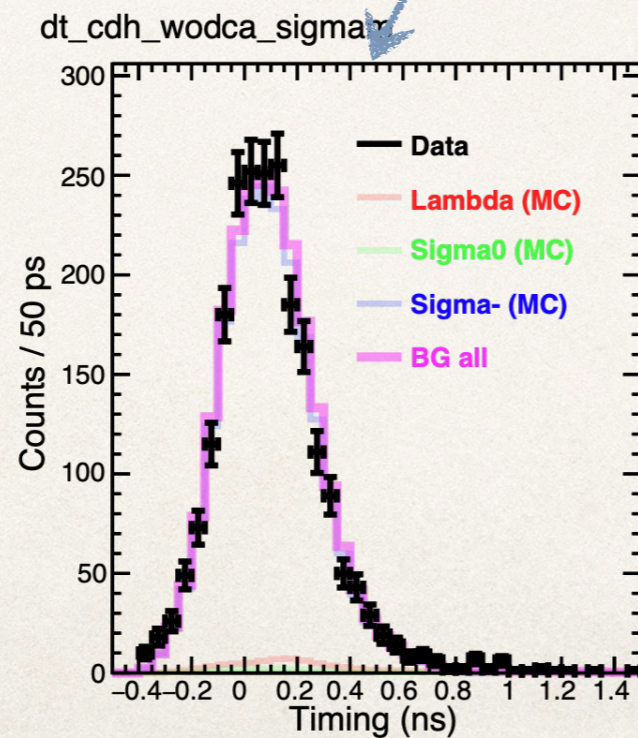
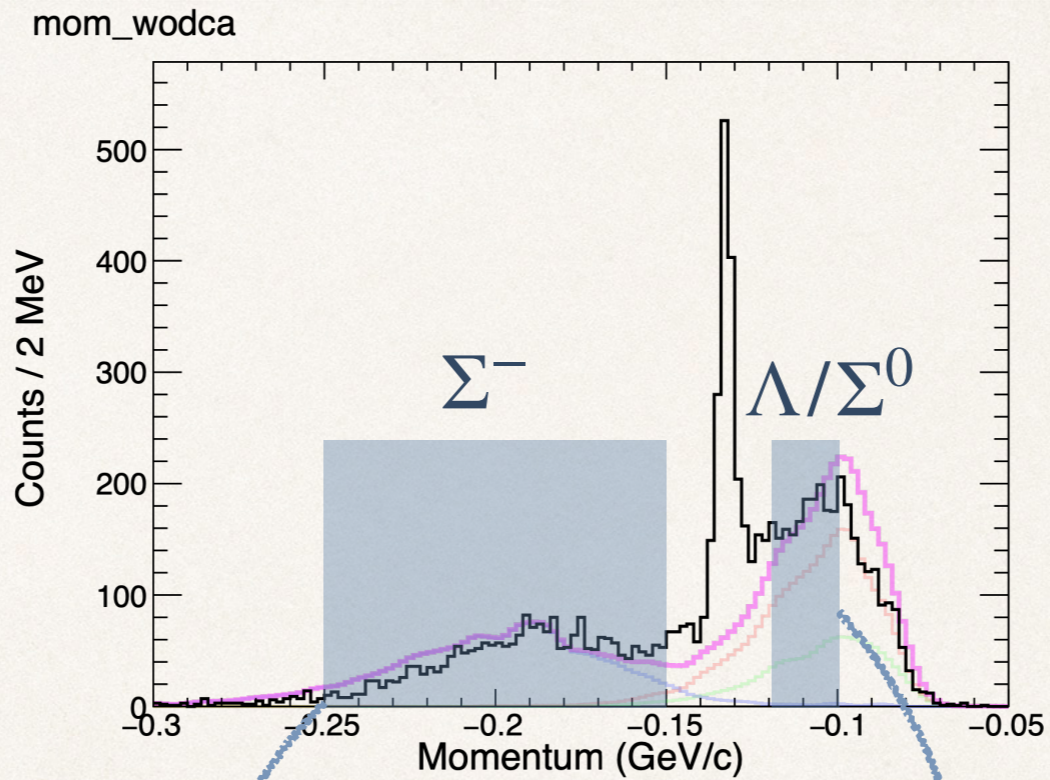
Q/A 1: quasi-free hyperon decay time spectrum

W/ DCA < 5mm cut



Q/A 1: quasi-free hyperon decay time spectrum

W/O DCA cut



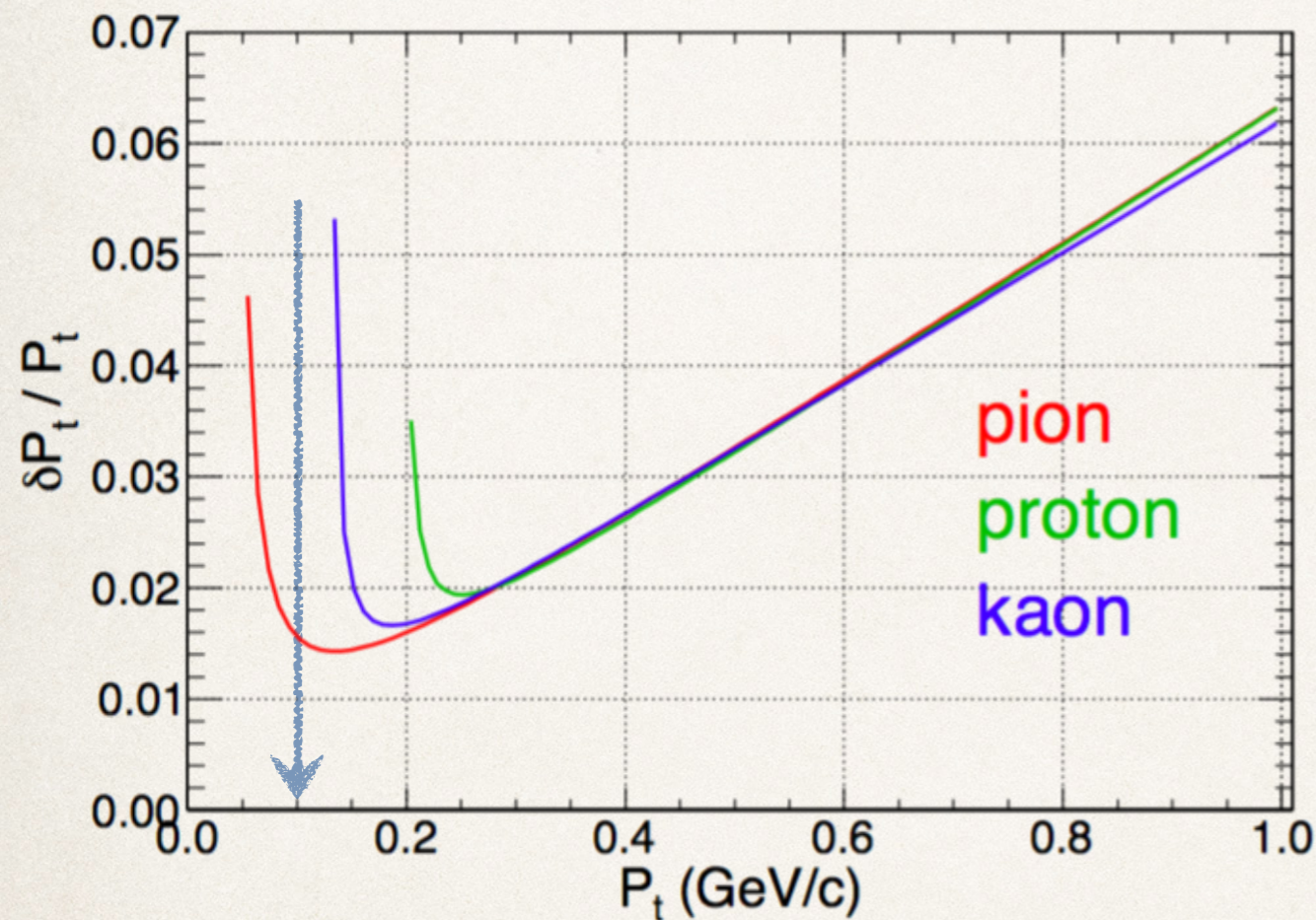
Q/A 2

- Is this "lifetime" of the background events below the H4-Lambda peak covered by the systematic uncertainty of ± 8 ps discussed on p.11?

A:

Yes, the ± 8 ps systematic uncertainty contains the background "lifetime" effect. We verified the reliability of our simulation by comparing the MC π^- time distribution in the side-band region with T77 data. Given the fact that the signal region is close enough to the side bands, the MC time distribution under the H4-Lambda signals should be precise enough for our purpose. The main contribution is then from the uncertainty of background yield, which corresponds to the under subtraction or over subtraction. This uncertainty is estimated by applying $\pm 5\sigma$ deviation from the best fit for background yield, which generates the value of ± 8 ps quoted in our results. In addition, we have also compared with conventional side-band subtraction by only using T77 data, whose result is consistent within ± 8 ps.

Q/A 3



- What are the widths of the H4-Lambda and H3-Lambda peaks? Are you expecting them to be identical considering the different decay-pion momenta, momentum straggling, instrumental resolution, etc.?
(Referee: Patrick Achenbach)

A:

The width of H4-Lambda and H3-Lambda peaks are both in the order of ~ 2.5 MeV/c, which are consistent with our simulation. Precisely speaking, the H3-Lambda signal suffers more from the multiple scattering because of its smaller magnitude and has a slightly worse momentum resolution of $\sim 20\%$ than H4-Lambda.

E73/T77 collaborator list

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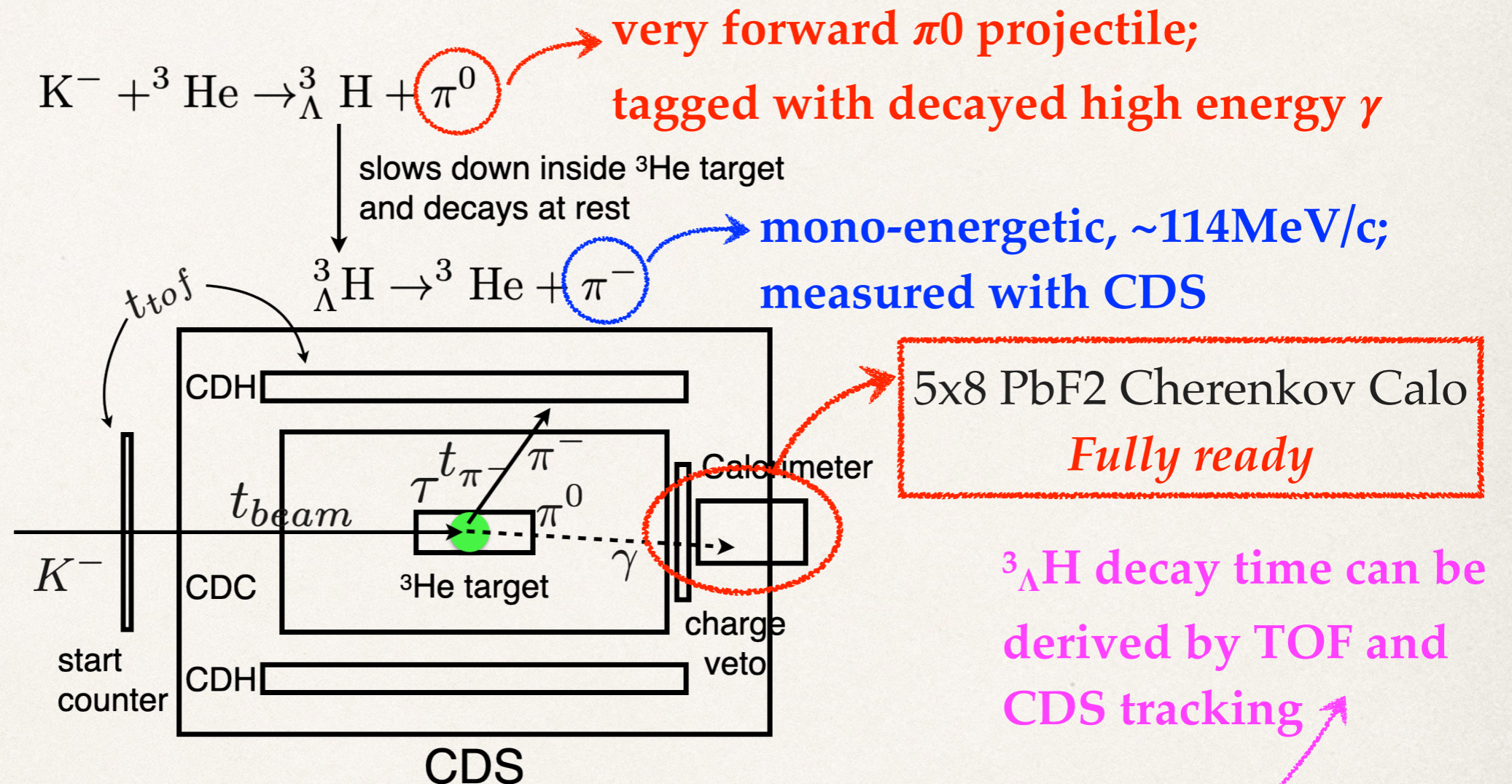
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backup

E73 experimental setup



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

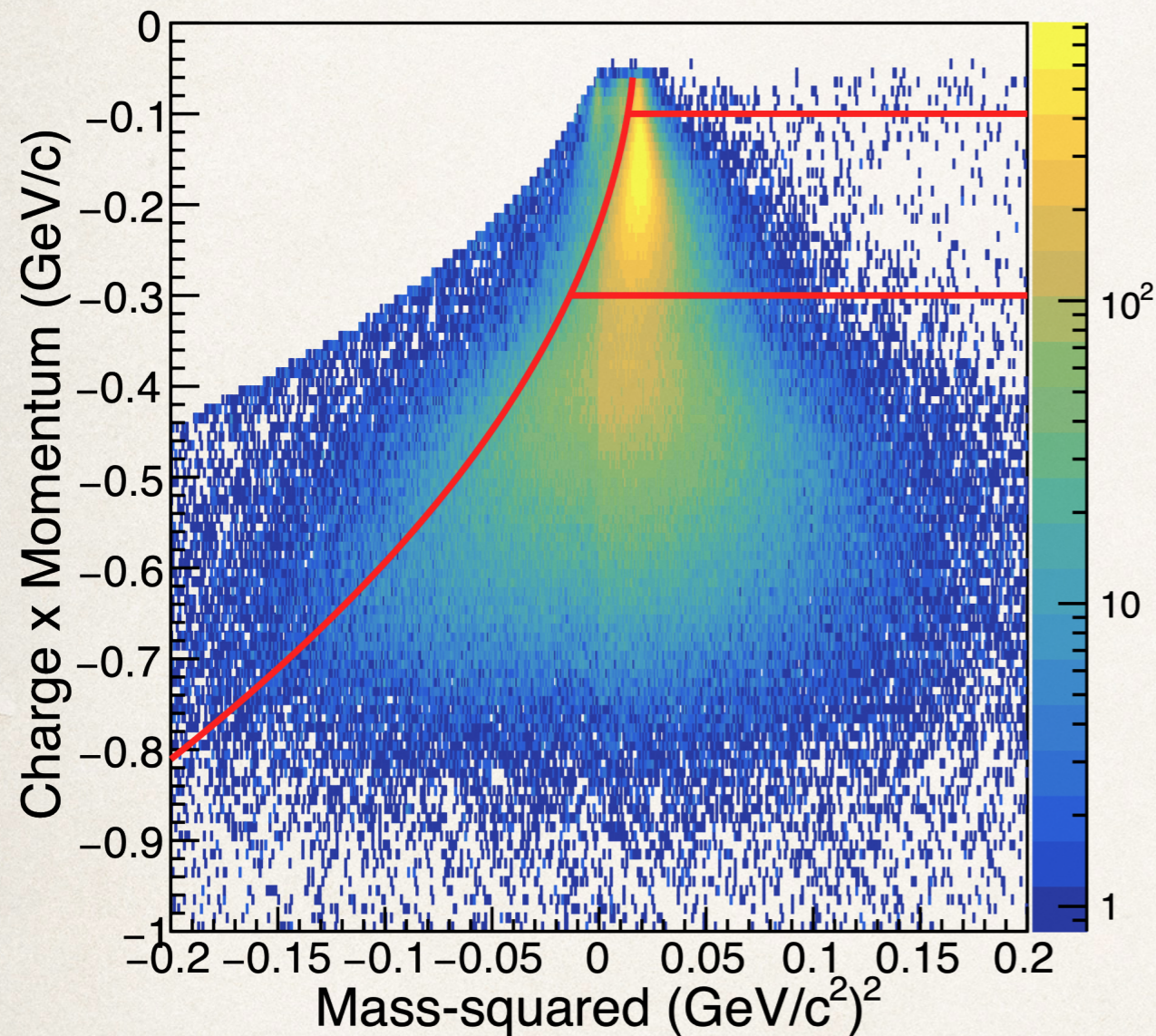
1. A complementary measurement for Heavy Ion results
2. Achievable precision: $\sigma/\sqrt{N} < 30\text{ps}$
3. *Direct lifetime measurement with fixed $J=1/2$ state*

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

Detector performance: tracking and PID

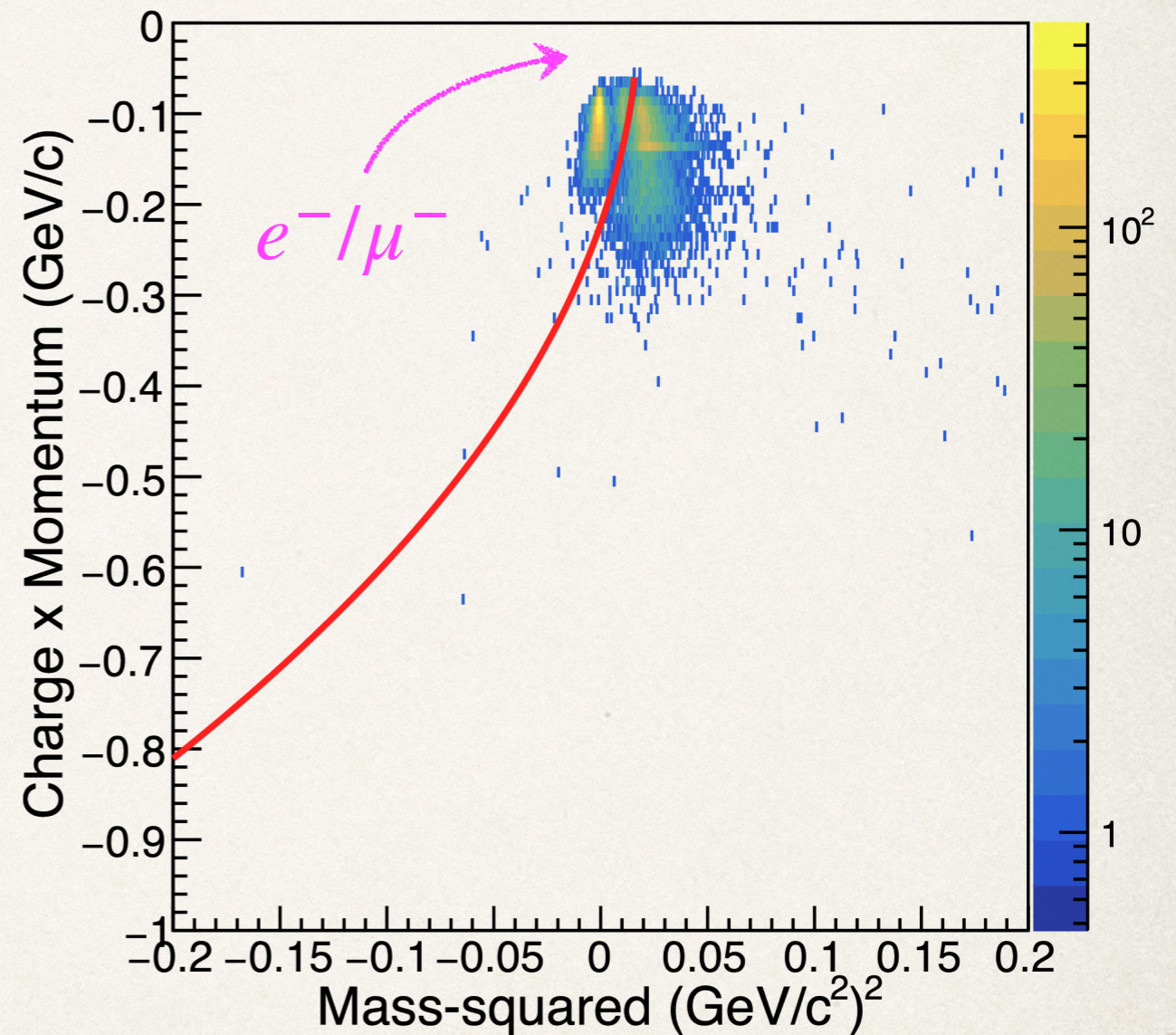
Calibration and slewing correction events



(K^-, π^-)

W/O requesting calorimeter dE

Interested physics events



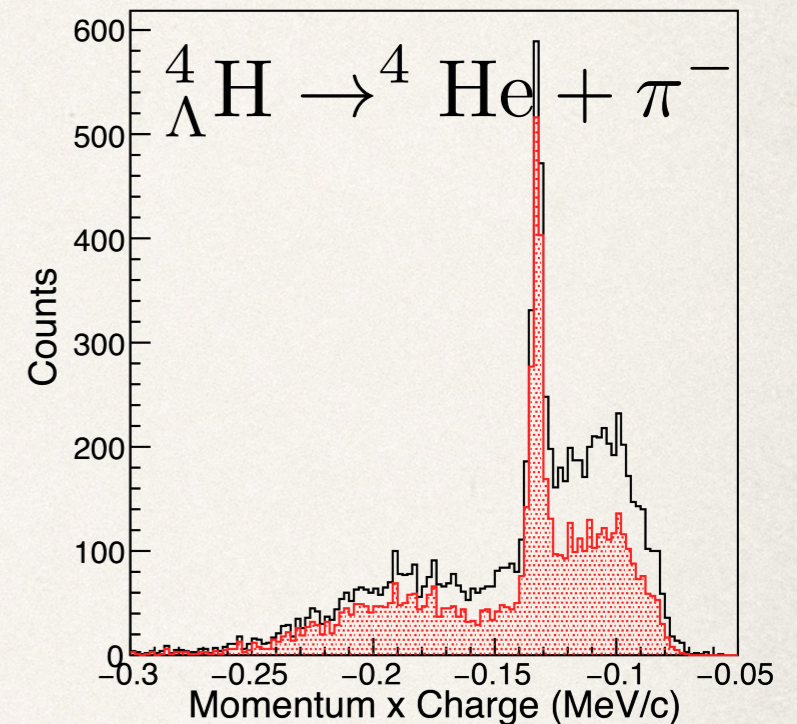
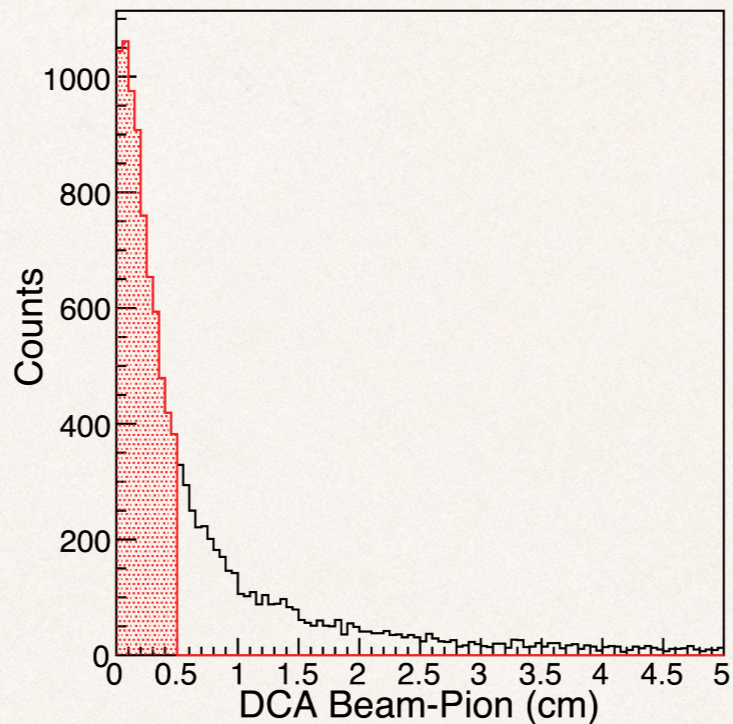
(K^-, π^-)

W / requesting calorimeter

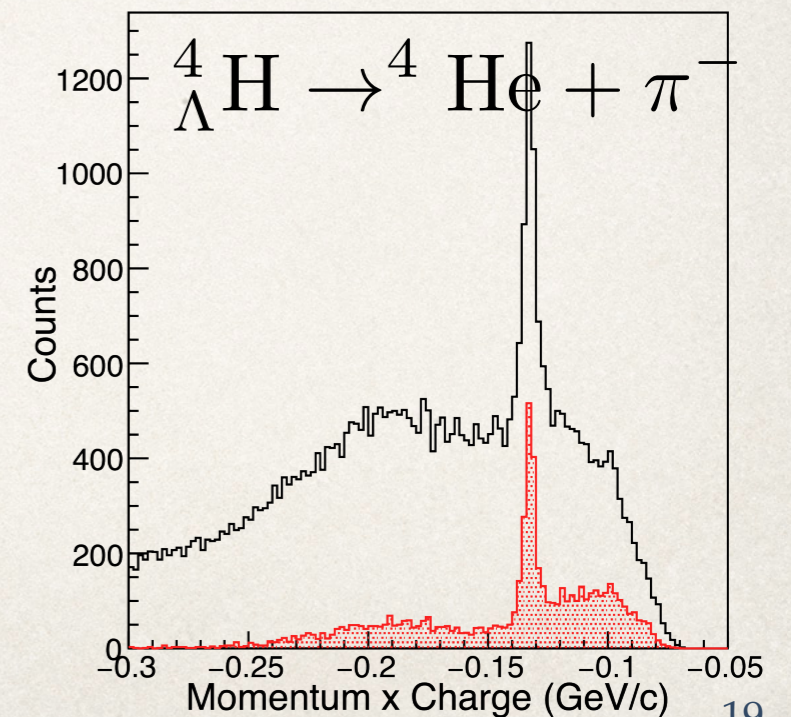
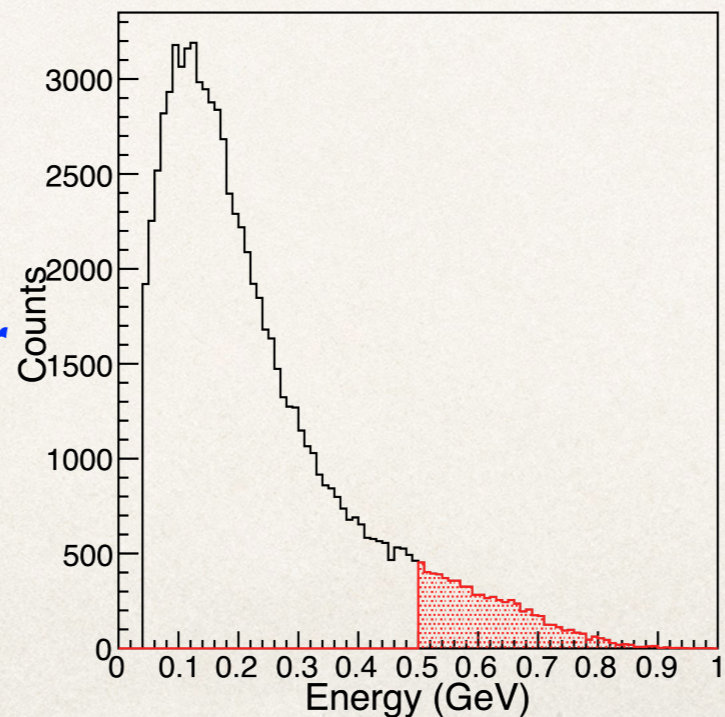
dE > 500 MeV

Event selection: DCA & calorimeter cut

DCA < 5mm
used for event selection

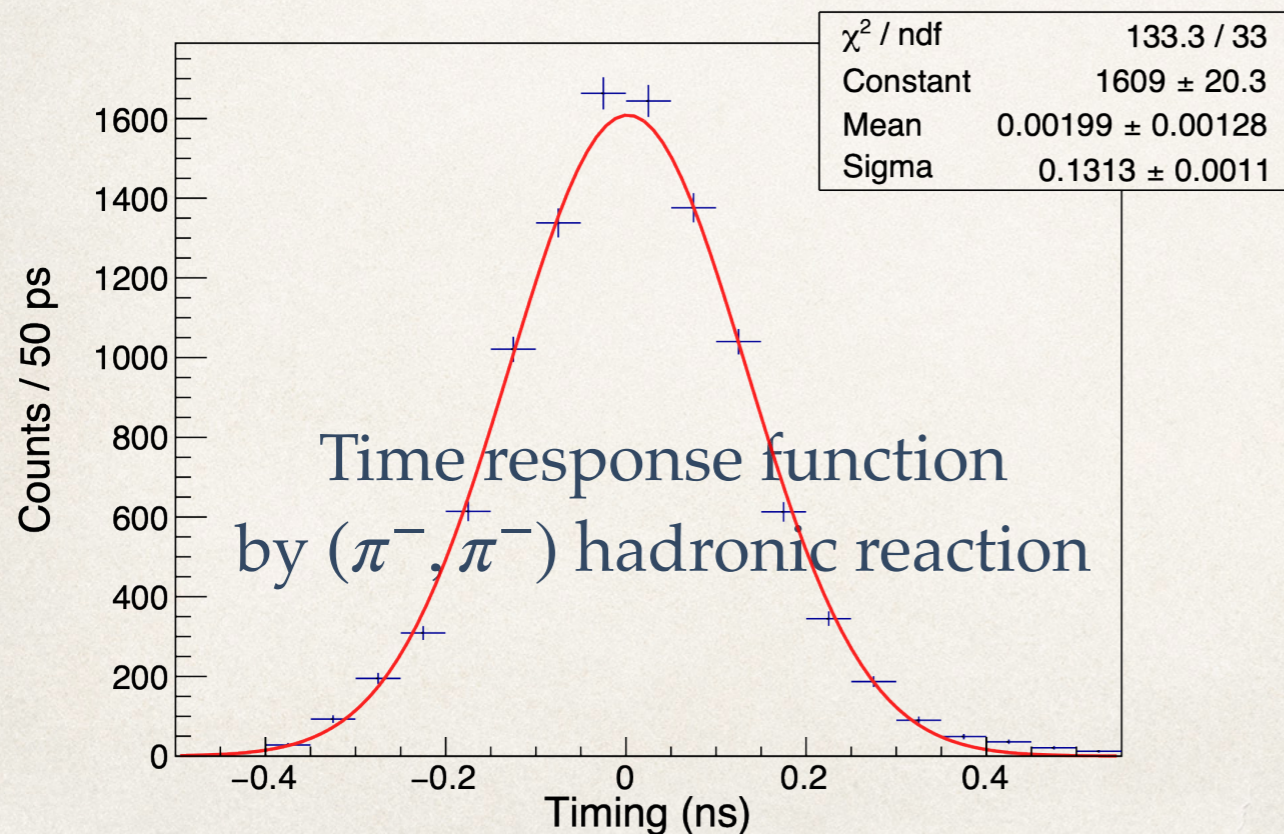
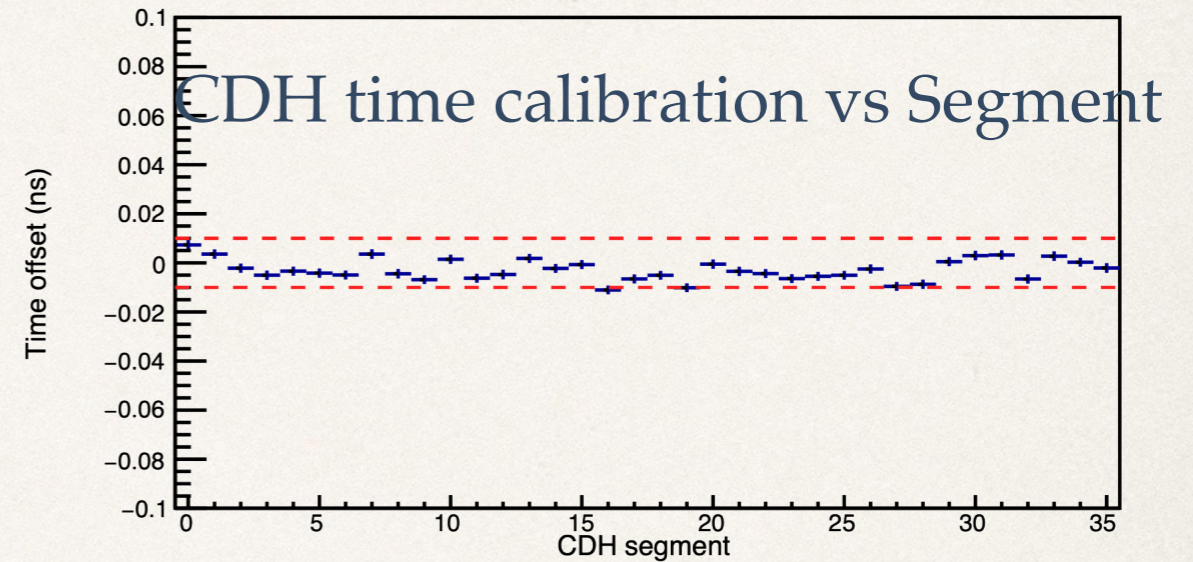
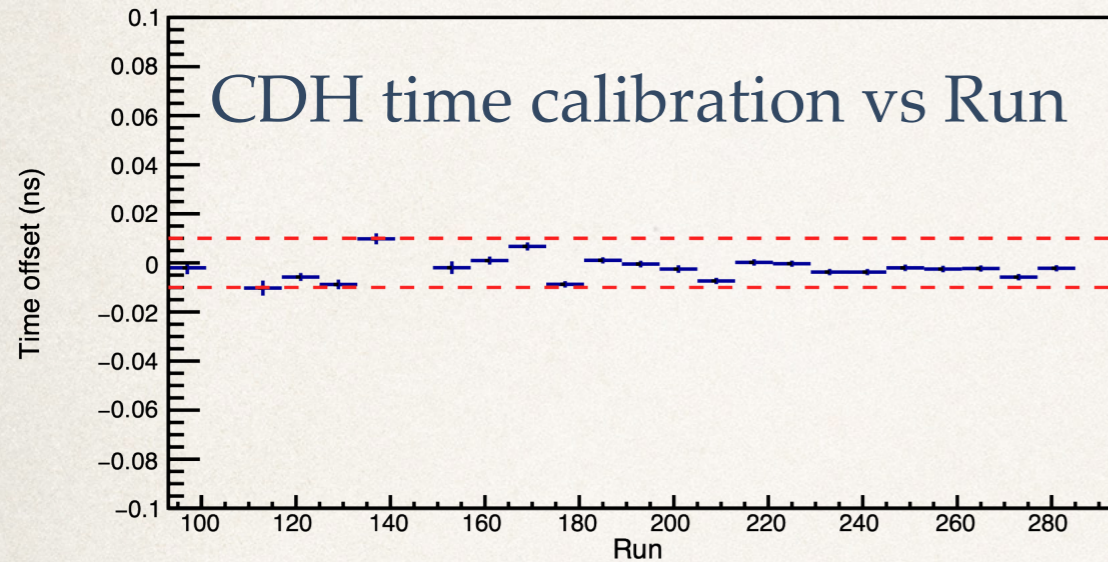


Selecting ${}^4_{\Lambda}\text{H}$ events by using
calorimeter $dE > 500\text{MeV}$
*--> our innovative method for
selecting hypernucleus by
tagging high energy gamma*



Uncertainty of time calibration: ± 10 ps

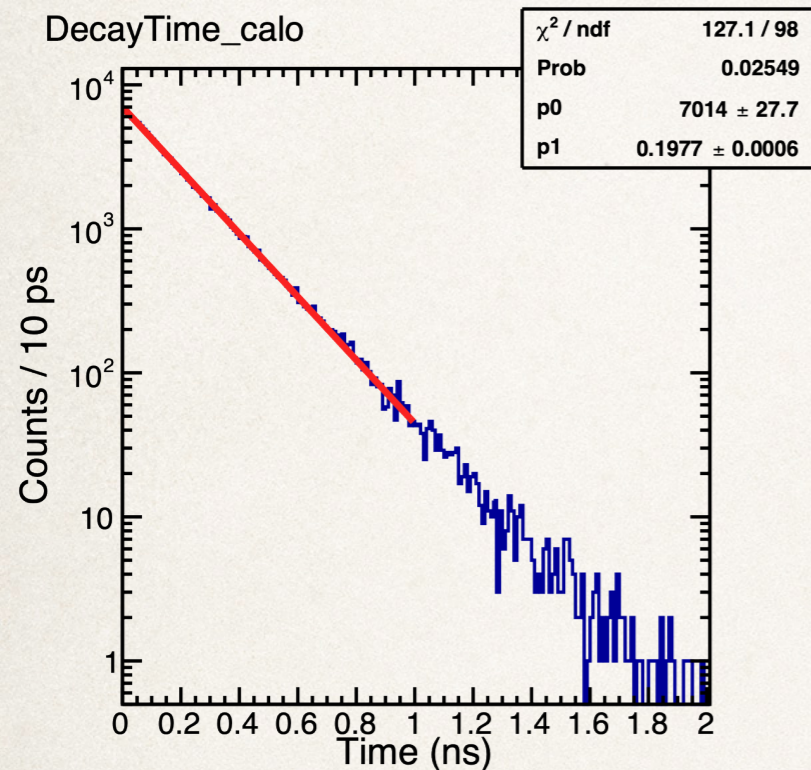
± 10 ps systematic uncertainty



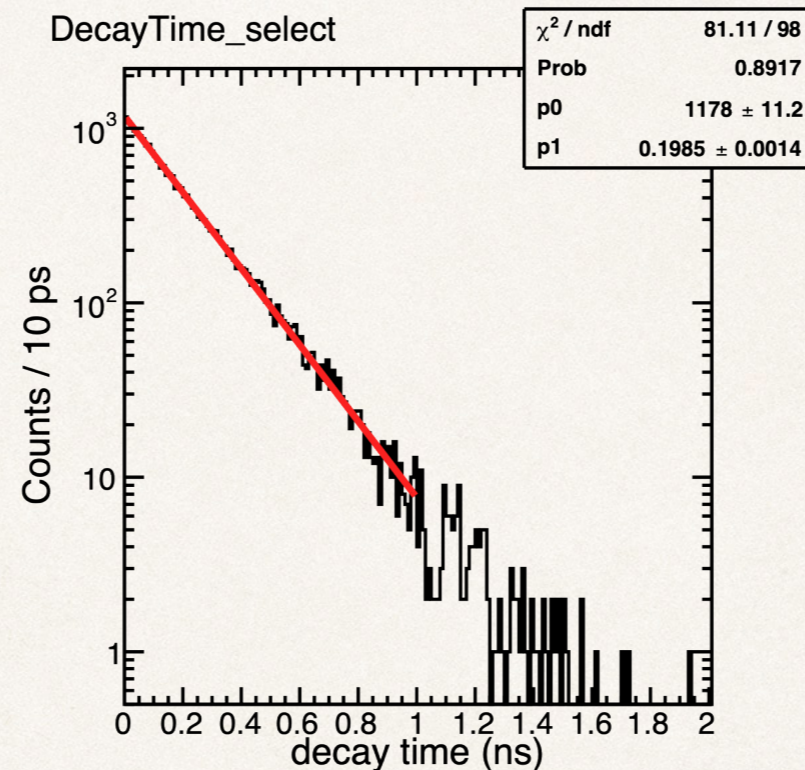
- ✦ CDH time calibration performed run-by-run & segment-by-segment;
- ✦ Calibration precision < 10 ps;
- ✦ (π^-, π^-) hadronic events used to obtain time response function;
- ✦ Time resolution: $\sigma_t \sim 130$ ps

Intrinsic bias of T77(E73) approach: -5 ± 5 ps

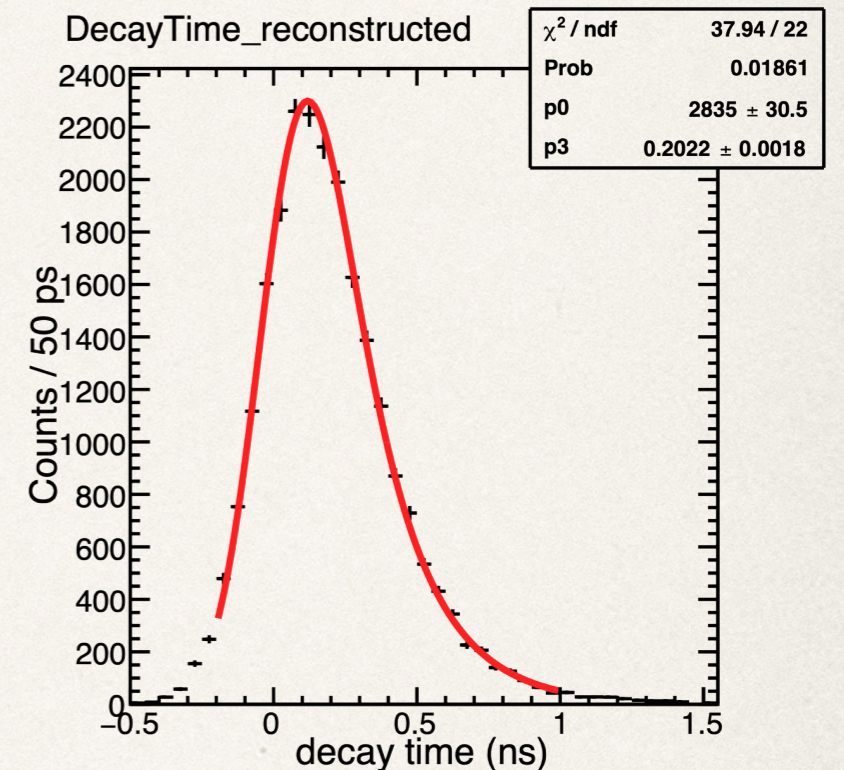
MC input:
 $\tau = 197.7$ ps



MC true W/ cuts:
 $\tau = 198.5$ ps



Analyzer output:
 $\tau = 202.2$ ps

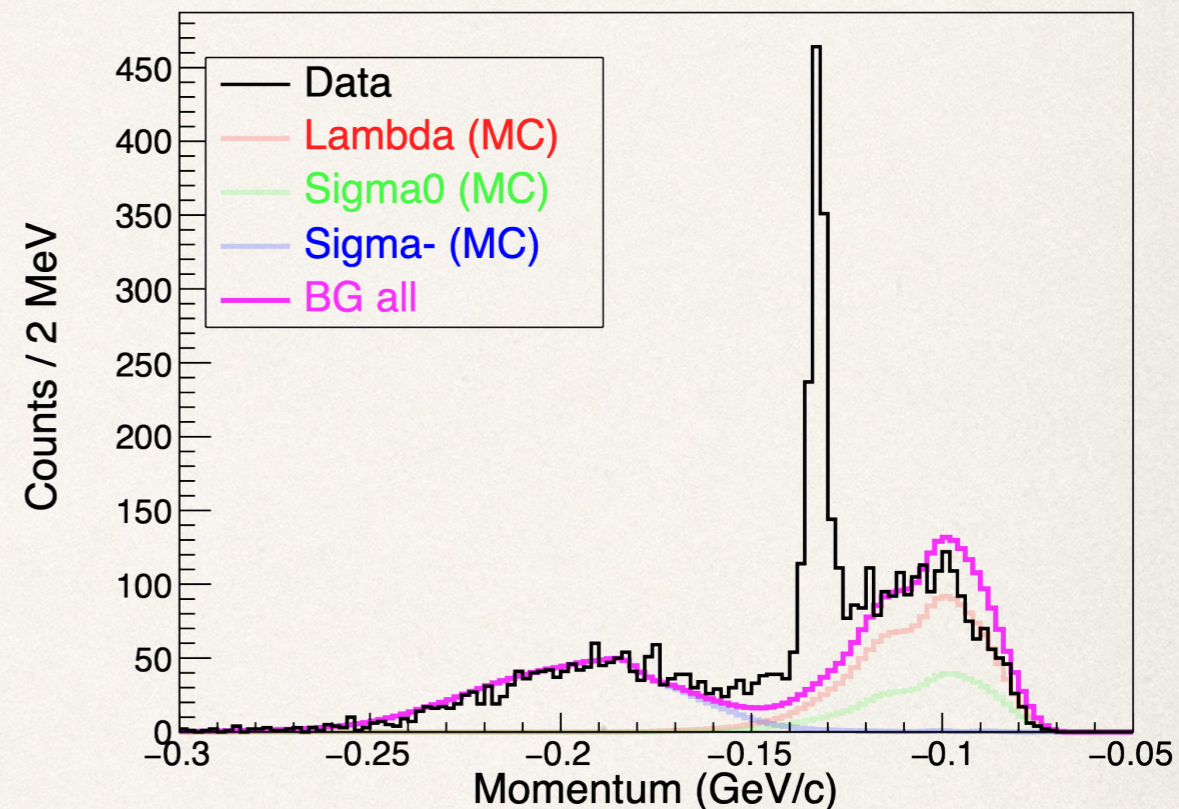
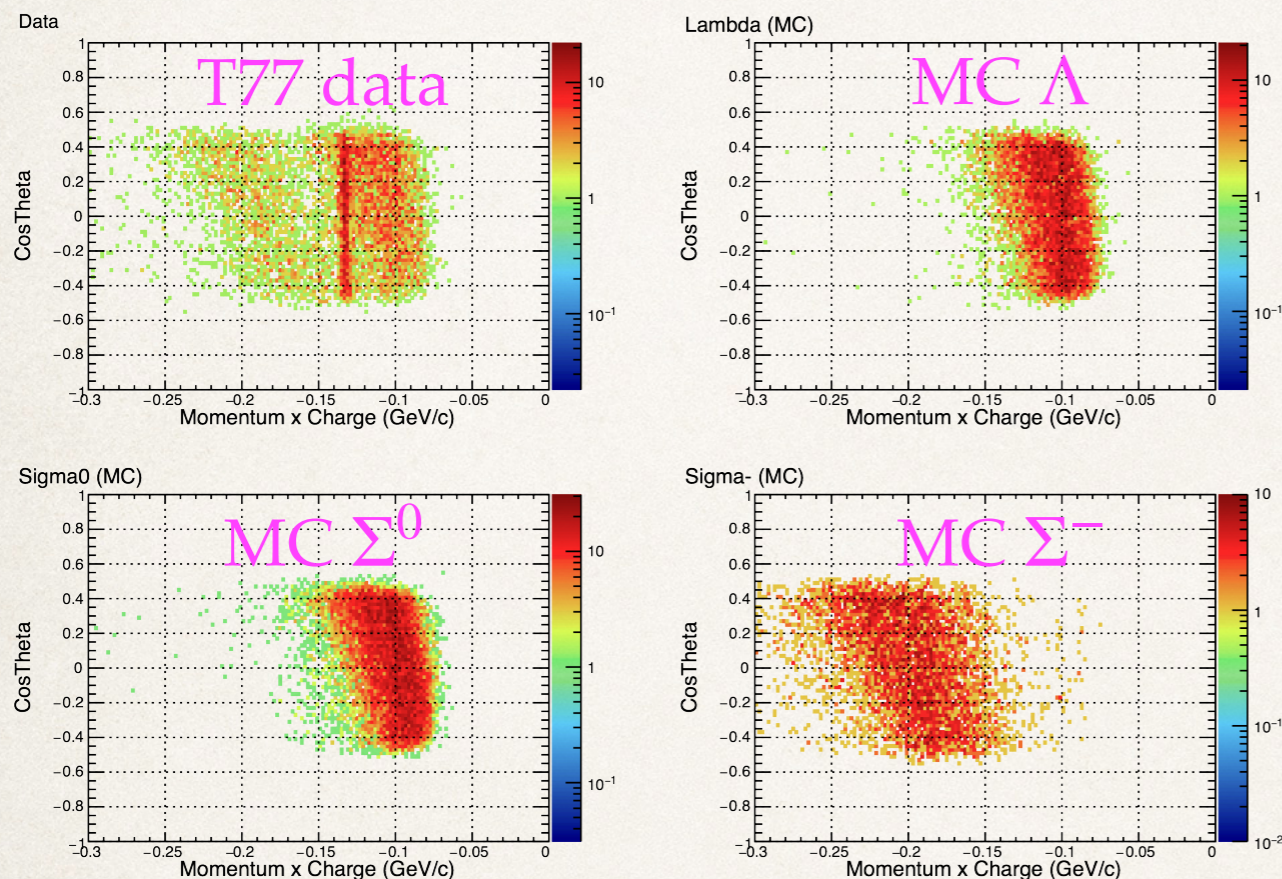


- ❖ ${}^4_{\Lambda}\text{H}$ differential cross section from Prof. T. Harada;
- ❖ Assuming reaction vertex is the same as the decay vertex;
 - ❖ Vertex determined by connecting K^- and π^- track;
 - ❖ A systematic bias studied with MC data

Simulation validation

decay π^- momentum vs angle

MC yield tuned to match data



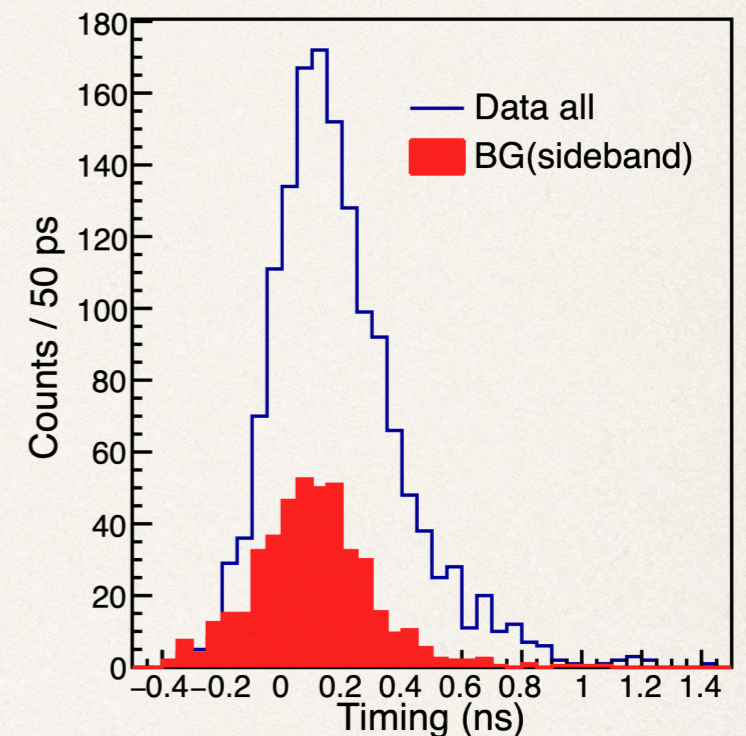
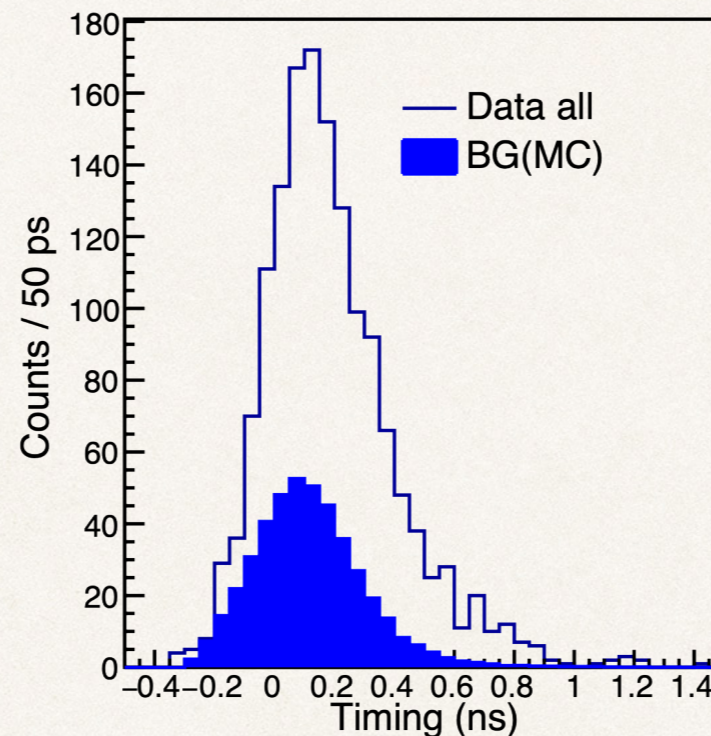
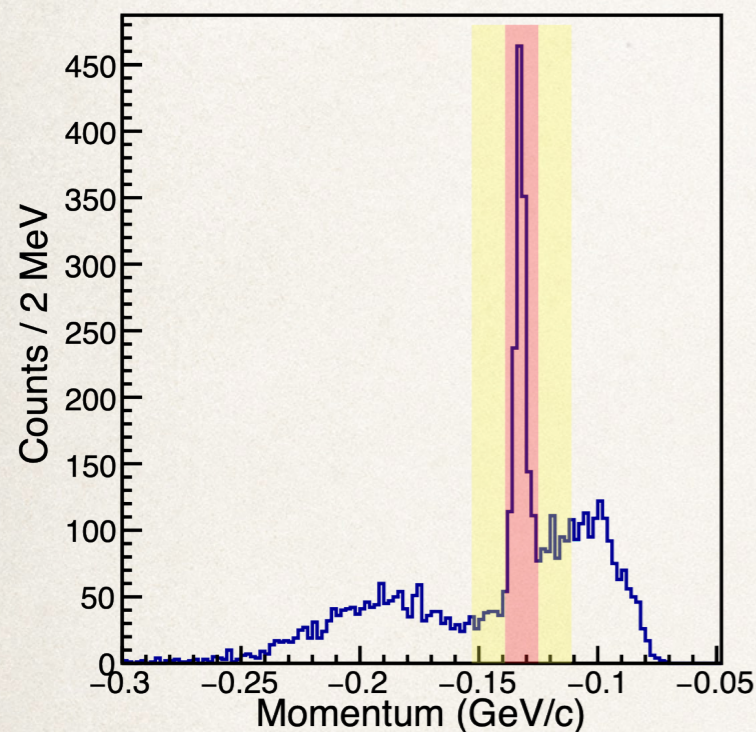
GEANT4 based simulation for quasi-free Λ/Σ in-flight decay;
 $N(K^-, \pi^0)\Upsilon$ elementary reaction with published data +
convoluted with Argonne AV18+UX Fermi motion

Uncertainty due to background subtraction: ± 8 ps

MC yield was tuned up to $\pm 5\sigma$ from the best fit:

${}^4\Lambda\text{H}$ lifetime converges within ± 8 ps

T77 Data



GEANT4 based simulation for quasi-free Λ/Σ in-flight decay;
 $N(K^-, \pi^0)\gamma$ elementary reaction with published data +
convoluted with Argonne AV18+UX Fermi motion