E73 status report

Ready for data taking in FY2023

$(80kW \times 25days)$

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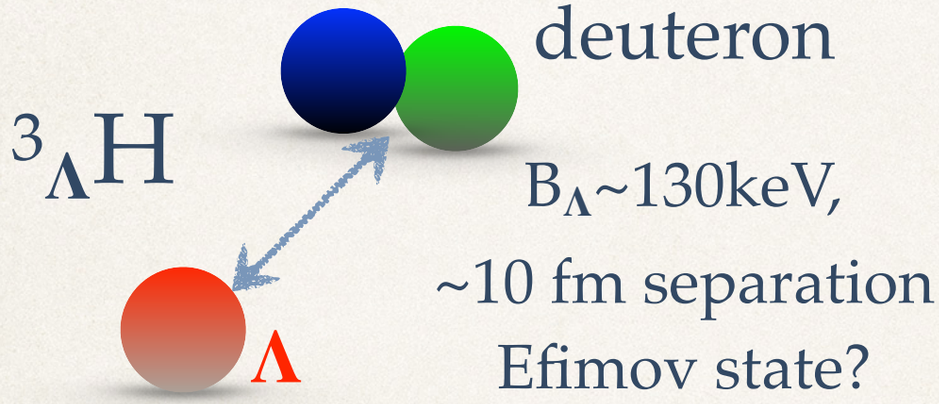
Outline

- Introduction to J-PARC E73:
  - The first direct measurement for ${}^{3}_{\Lambda}\mathrm{H}$ lifetime
- J-PARC E73 review
  - Pilot run: ${}^{4}_{\Lambda}\mathrm{H}$ lifetime as feasibility study, June, 2020
  - Stage-1: ${}^{3}_{\Lambda}\mathrm{H}$ production cross section measurement, May, 2021
  - Stage-2: ${}^{3}_{\Lambda}\mathrm{H}$ lifetime measurement
    - Stage-2 approved by the 33rd PAC with $80kW \times 25days$ beam time;
    - Beam time allocation confirmed by the 34th PAC
- Summary

Introduction: hypertriton lifetime puzzle

As the lightest hypernucleus, ${}^{3}_{\Lambda}\mathrm{H}$ serves as the cornerstone for hypernuclear physics just as deuteron for nuclear physics.



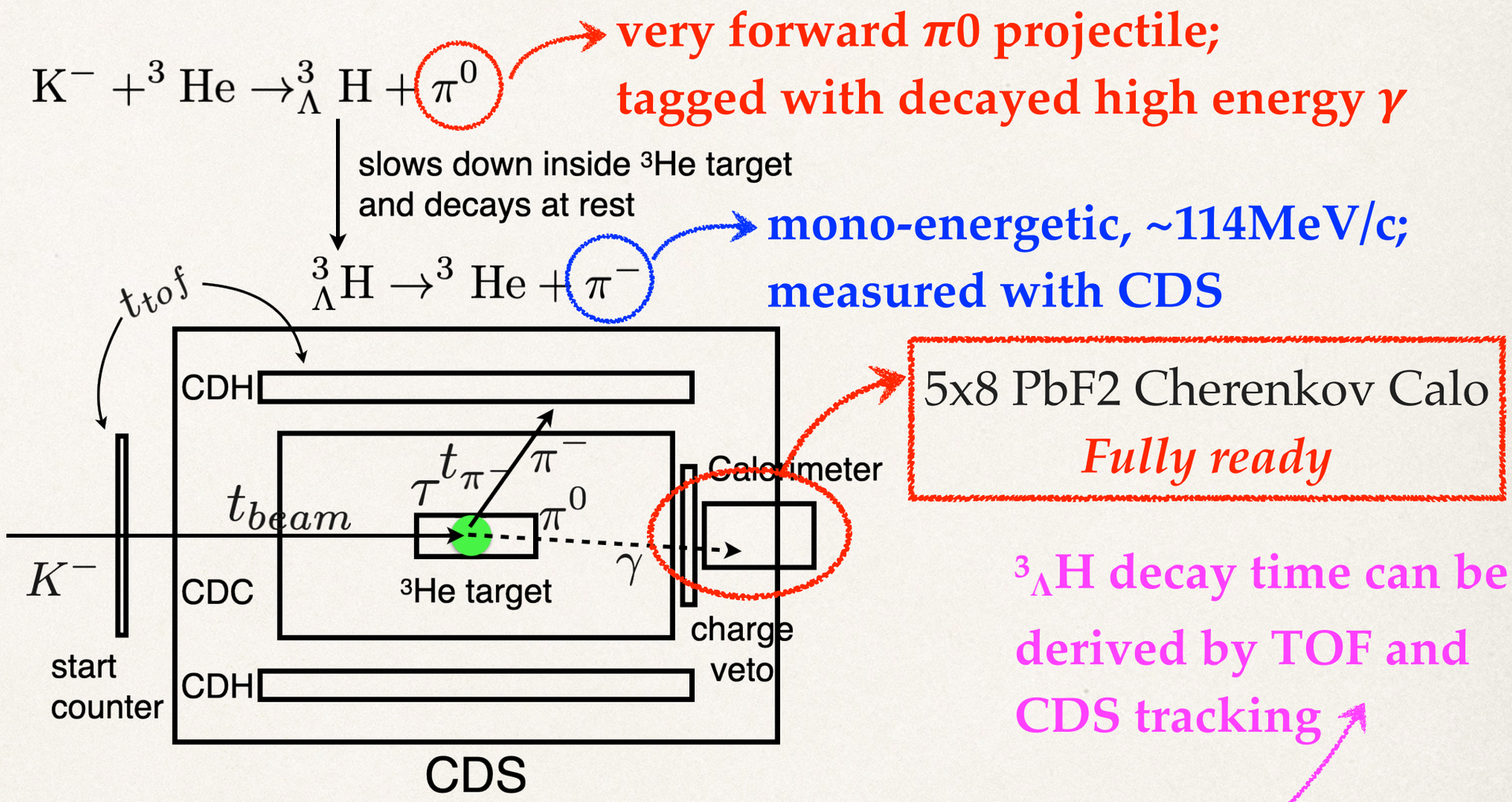
Up to a few years ago, we believe:
$\tau \approx 263$ ps ($B_\Lambda = 130 \pm 50$ keV);
However, heavy ion experiments suggest $\tau \approx 180$ ps…

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

a small term
(separation of ~10fm)

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

E73 experimental setup



The idea of ***direct measurement***: T_{CDH}-T_0=t_{beam}+t_{π^-}+τ;

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

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

J-PARC E73 staging & status

Staging:	Pilot (June, 2020)	Stage-1 (May, 2021)	Stage-2
Task:	Background study with $^{4}_{\Lambda}$H	First measurement for $^{3}_{\Lambda}$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	Successfully observed $^{3}_{\Lambda}$H from mesonic weak decay	Request for beam time allocation (80kWx25days)

Pilot run results: ${}^{4}_{\Lambda}\mathrm{H}$ lifetime

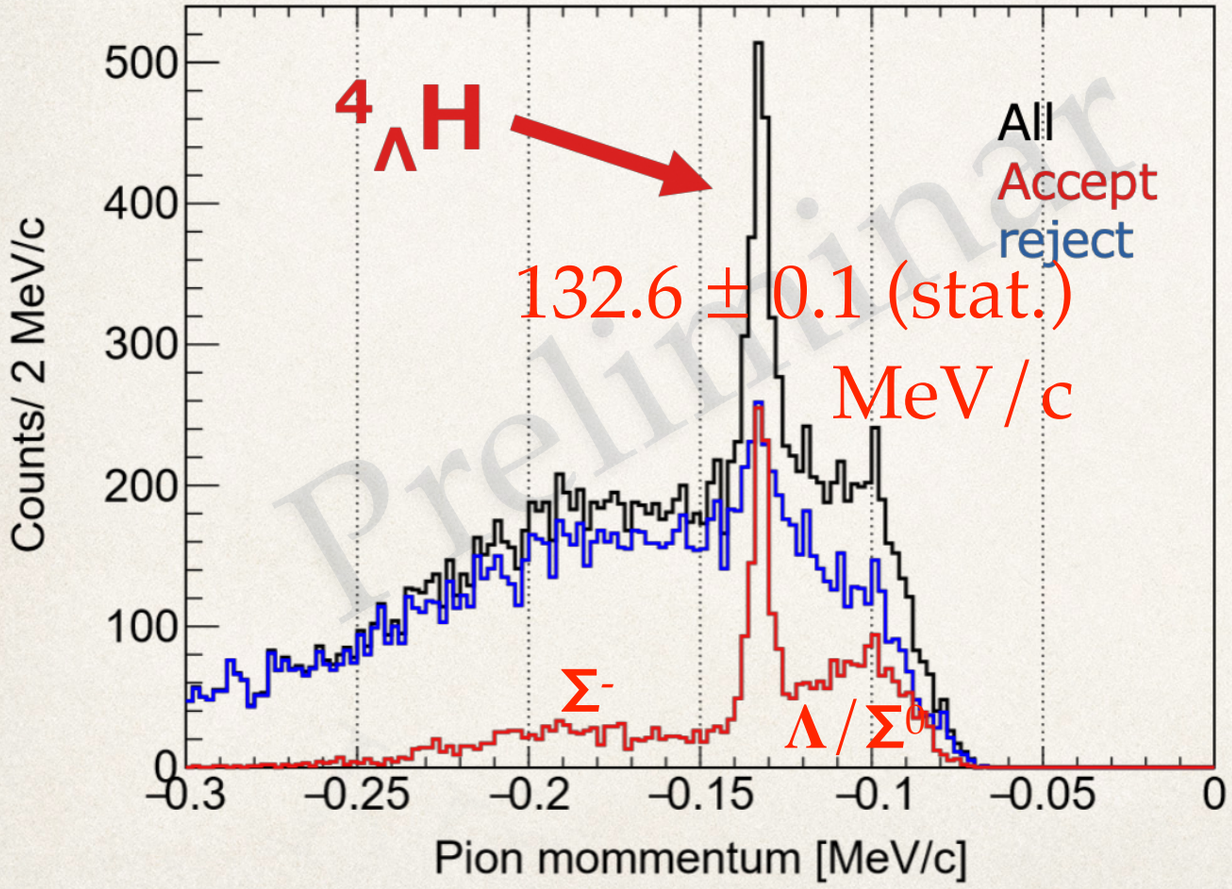
$$K^- + {}^4He \rightarrow {}^4_\Lambda H + \pi^0$$

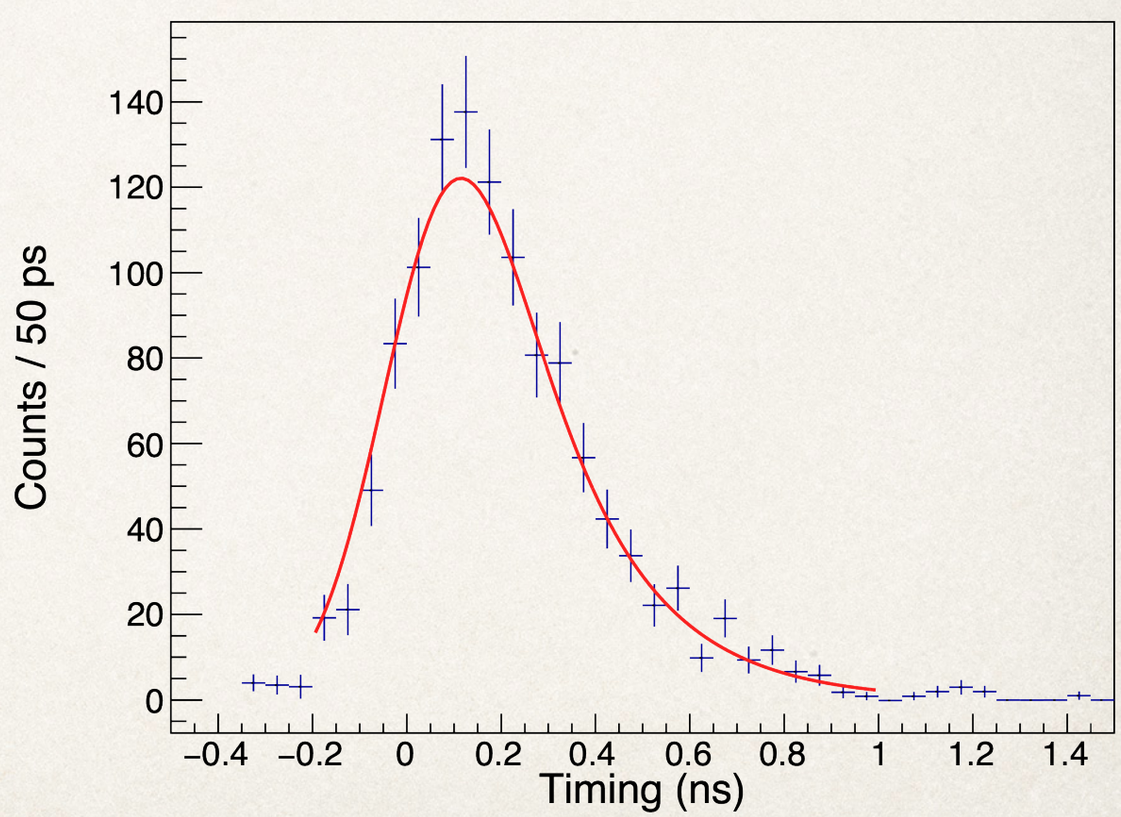
slows down inside ⁴He target and decays at rest

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

218 ± 6(stat.) ± 13(sys.) ps
@ STAR, Au-Au collision
arXiv:2110.09513

200 ± 8(stat.) ± 17(sys.) ps





Stage-1 results: ${}^{3}_{\Lambda}\mathrm{H}$ cross section

- First measurement for ^{3}He(K-, pi0)$^3_\Lambda$H reaction cross section; direct determination of $^3_\Lambda$H ground state spin;
- Ready for E73 Stage-2 beam time with 25days @ 80kW beam time for ~1k 2-body decay events scaled with Phase-1 data
- Expected precision for ${}^{3}_{\Lambda}\mathrm{H}$ lifetime:
  - statistical error ~20 ps;
  - systematic error ~30 ps based on the ${}^{4}_{\Lambda}\mathrm{H}$ result

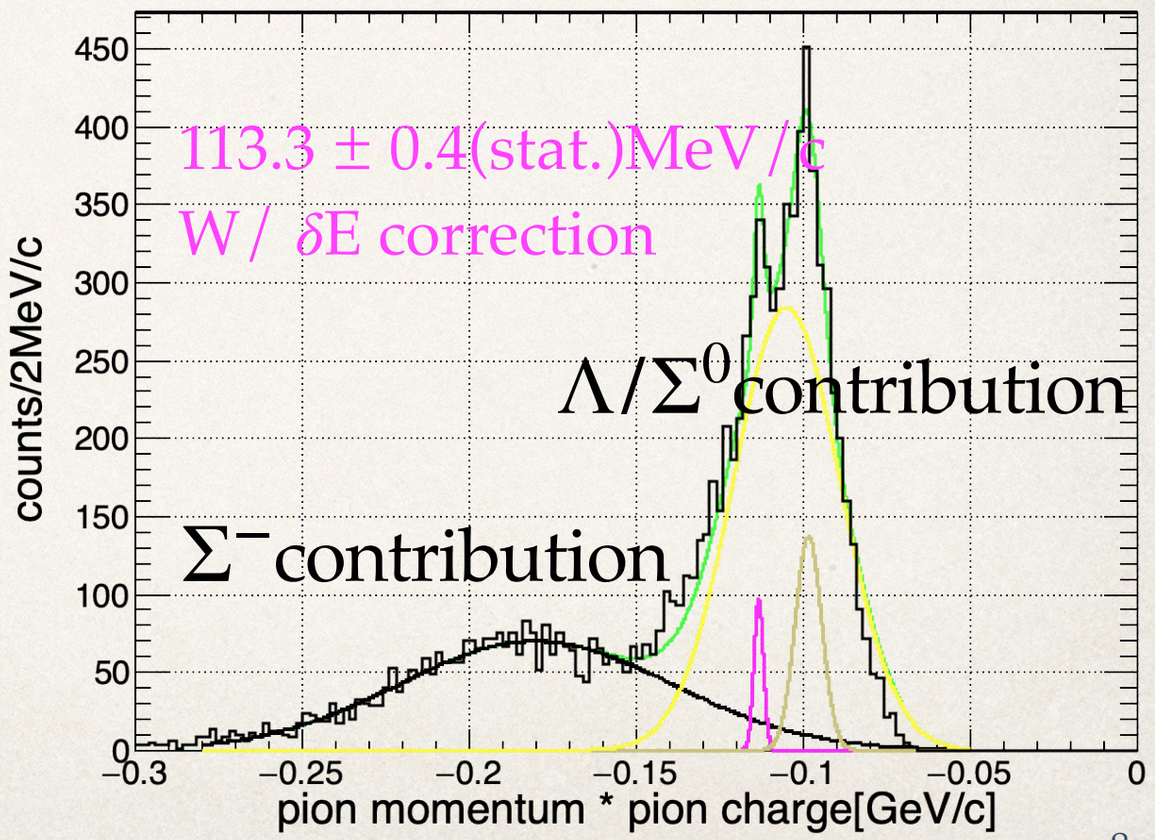
273kW*Day executed in May, 2021

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

slows down and decays at rest

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

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



Comments from the 34rd PAC meeting

E73

PAC33 has recommended stage-2 approval for E73 with 80kW beam and 25-day for data taking. At this PAC meeting, the experiment requested an additional day for calibration reaction $p(K^-,\pi^0)$. The requested beam is the same as for the physics production run, 80kW.

This PAC recommends allocating the 25-day 80kW beam for the experiment, in early 2023 if the schedule and the budget permits. The newly requested additional day of $p(K^-,\pi^0)$ run should be included in the original requested beam time. Note that the exact length of the run will be determined according to the FY23 budget, schedule, and the availability of the intense beam requested by E73.

- We will be ready for data taking in the beginning of FY2023
- Physics paper for ${}^{3}_{\Lambda}\mathrm{H}$ lifetime is finalized and under review

Summary

- 34th PAC recommends $80kW \times 25days$ beam time
- E73 full setup will be ready in the beginning of FY2023
- Physics paper for ${}^{3}_{\Lambda}\mathrm{H}$ lifetime measurement as an output for our pilot run (T77) will appear very soon

E73/T77 collaborator list

T. Akaishi[1], H. Asano[2], X. Chen[5], A. Clozza[7], C. Curceanu[7], R. Del Grande[7], C. Guaraldo[7], C. Han[5], T. Hashimoto[4], M. Iliescu[7], K. Inoue[1], S. Ishimoto[3], K. Itahashi[2], M. Iwasaki[2], Y. Ma[2], M. Miliucci[7], R. Murayama[2], H. Noumi[1], H. Ohnishi[10] S. Okada[2], H. Outa[2], K. Piscicchia[7,9], A. Sakaguchi[1], F. Sakuma[2], M. Sato[3], A. Scordo[7], K. Shirotori[1], D. Sirghi[7,8], F. Sirghi[7,8], S. Suzuki[3] K. Tanida[4], T. Toda[1], M. Tokuda[1], T. Yamaga[2], X. Yuan[5], P. Zhang[5], Y. Zhang[5], H. Zhang[6]

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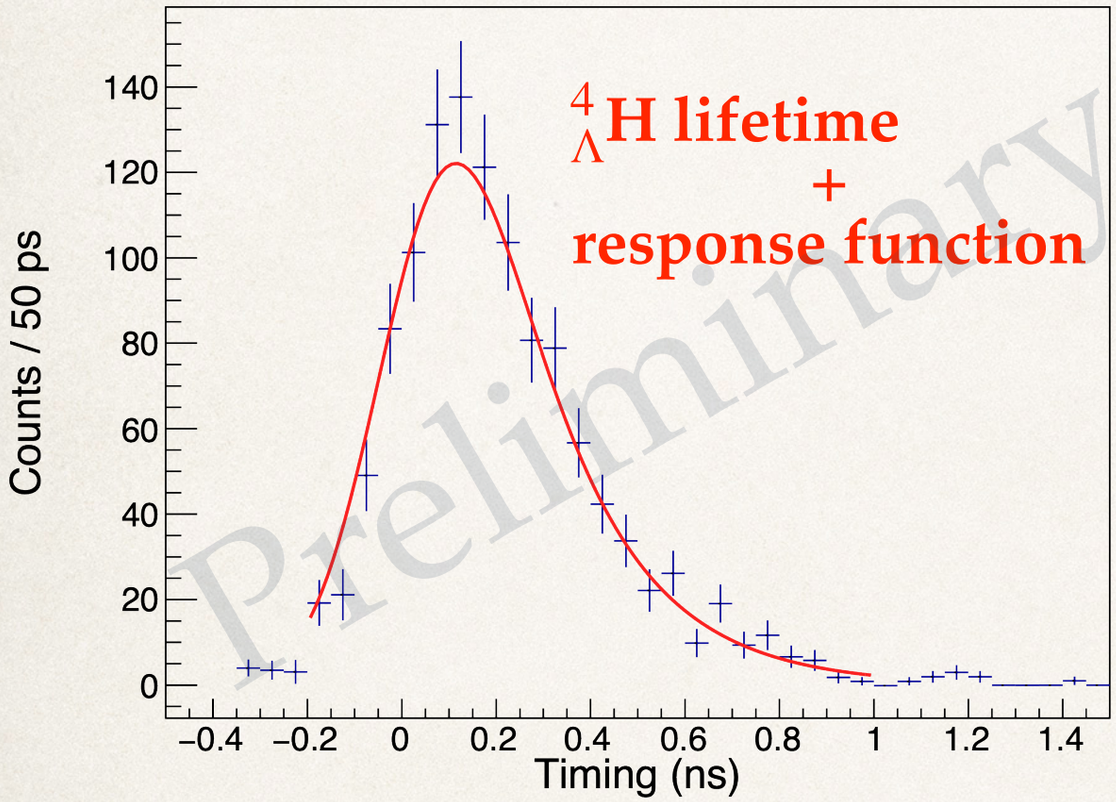
backup

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

200 ± 8(stat.) ± 17(sys.) ps



194^{+24}_{-26} ps @ KEK stop K-

H. Outa, et al., Nucl. Phys. A 547, (1992), 109c-114c

218 ± 6(stat.) ± 13(sys.) ps

@ STAR, Au-Au collision

arXiv:2110.09513

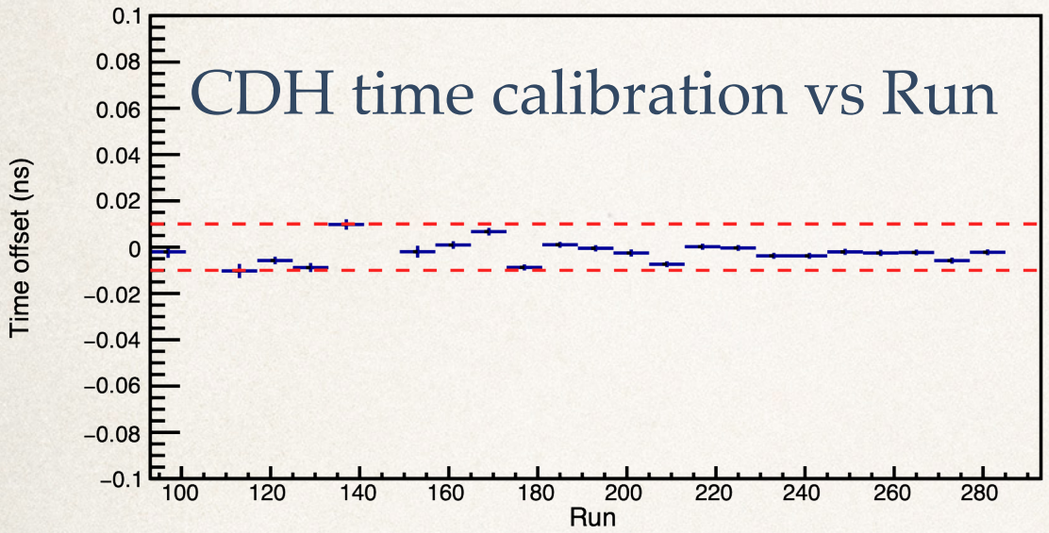
Contribution	Value
Uncertainty of time calibration	±10 ps
Intrinsic bias of T77(E73) approach	-5 ±5 ps
Uncertainty induced by background subtraction	±8 ps
Uncertainty induced by fitting range	±10 ps

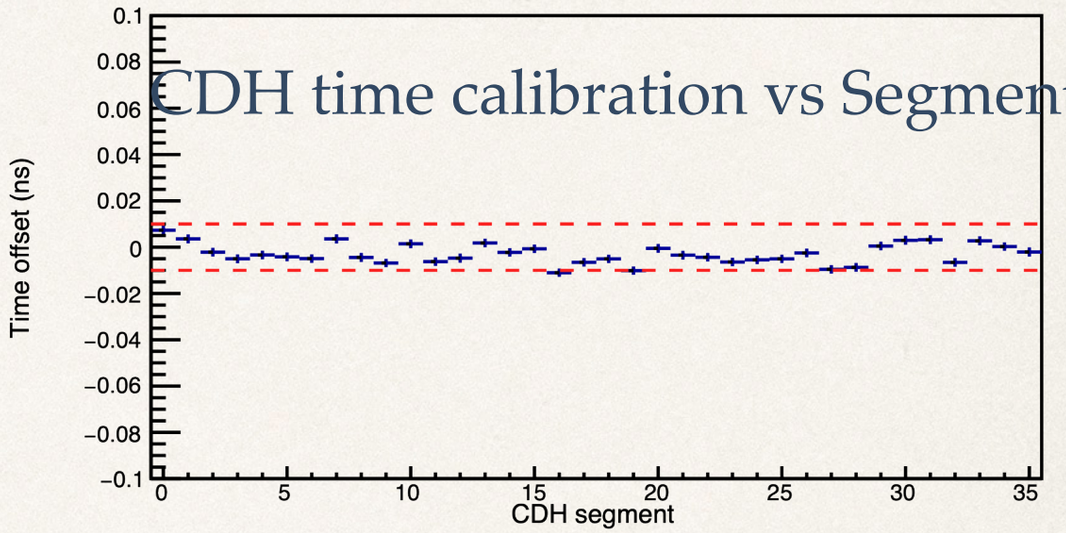
We will go through these numbers in this talk.

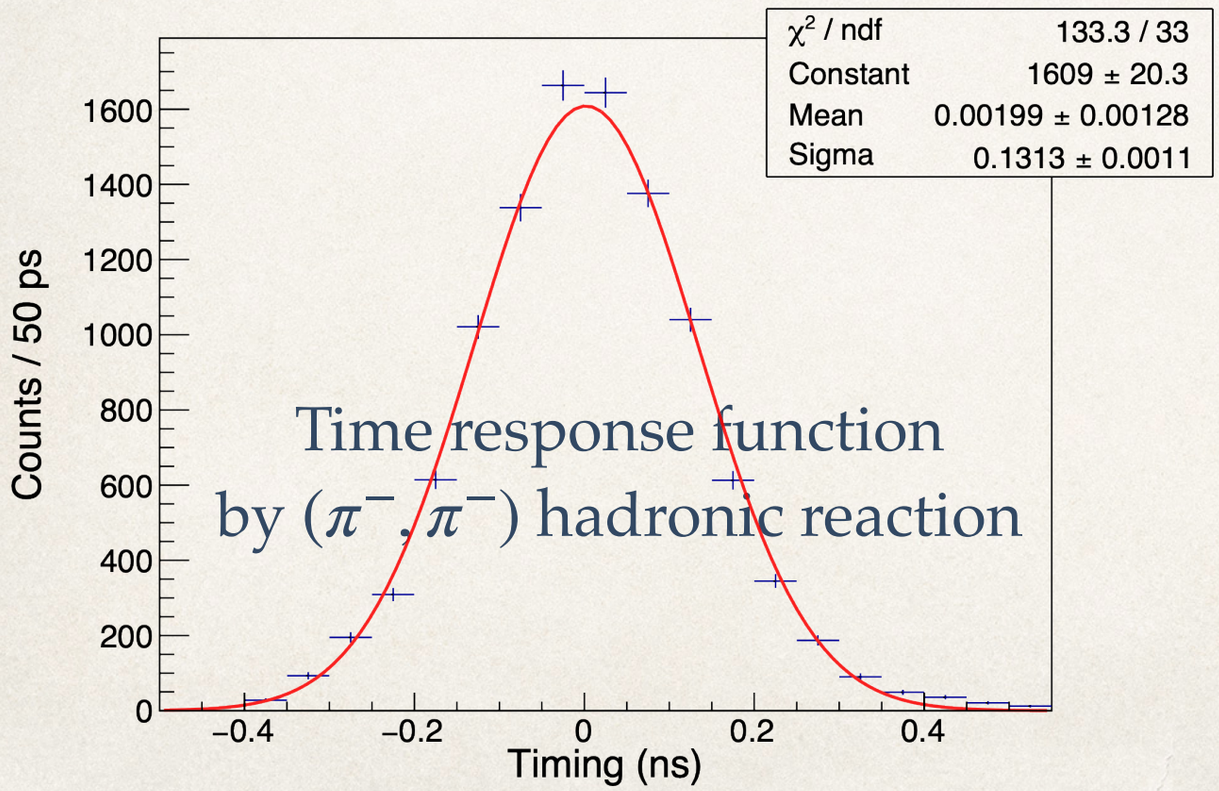
verified by tuning fitting range

Uncertainty of time calibration: ±10 ps

±10 ps systematic uncertainty



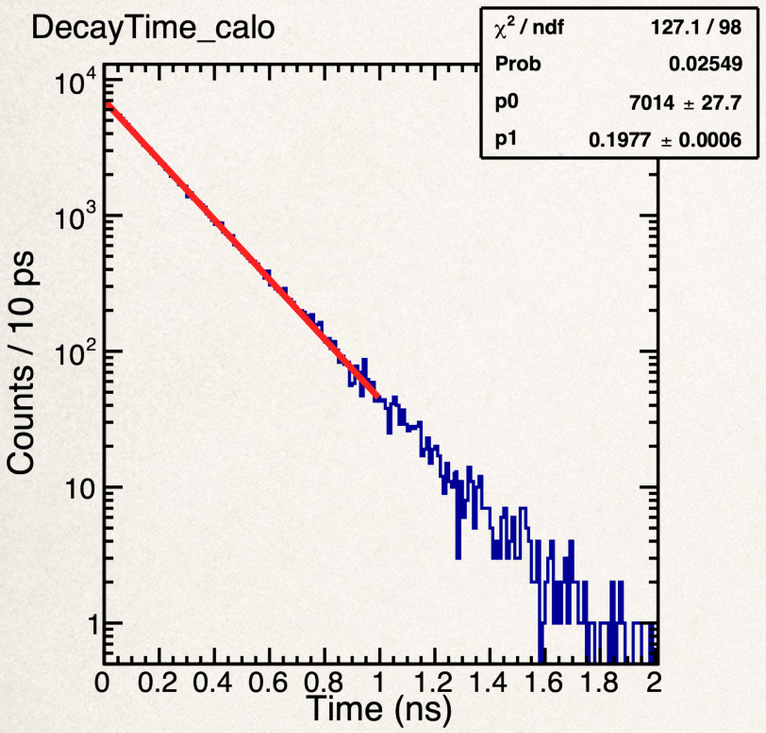




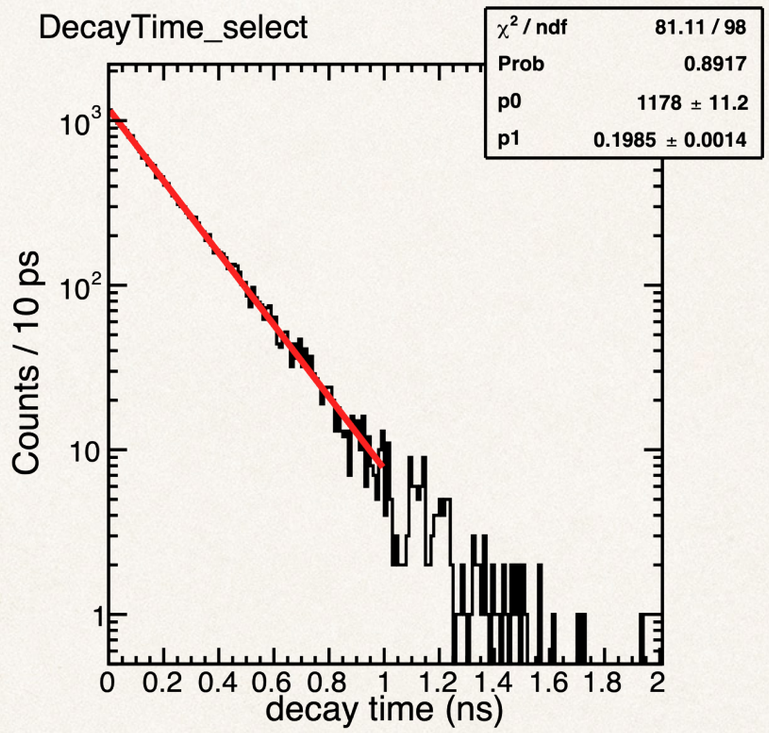
- CDH time calibration performed run-by-run & segment-by-segment;
- Calibration precision < 10ps;
- (π^-, π^-) hadronic events used to obtain time response function;
- Time resolution: σ_t ~ 130 ps

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

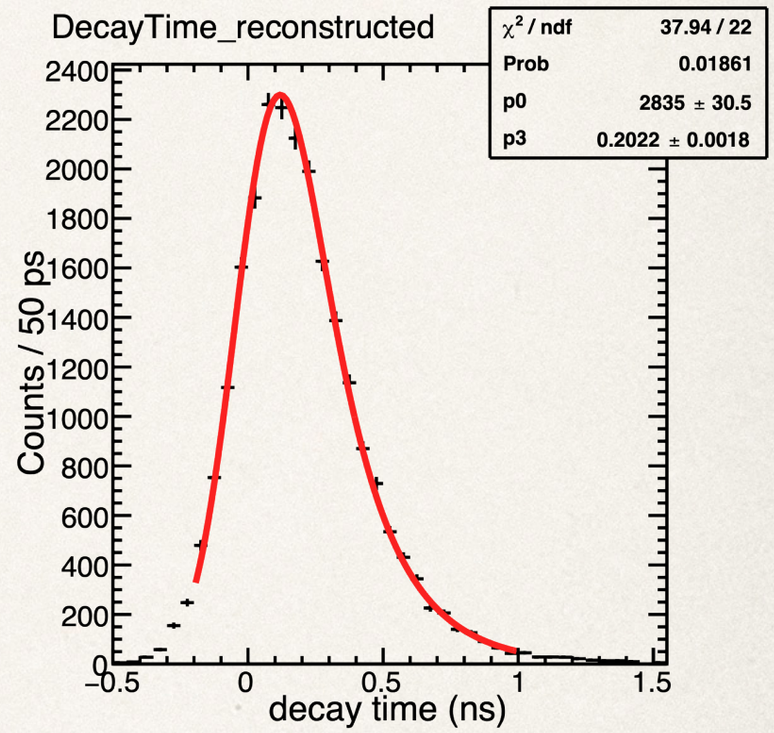
MC input:
$\tau = 197.7$ ps



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



Analyzer output:
$\tau = 202.2$ ps

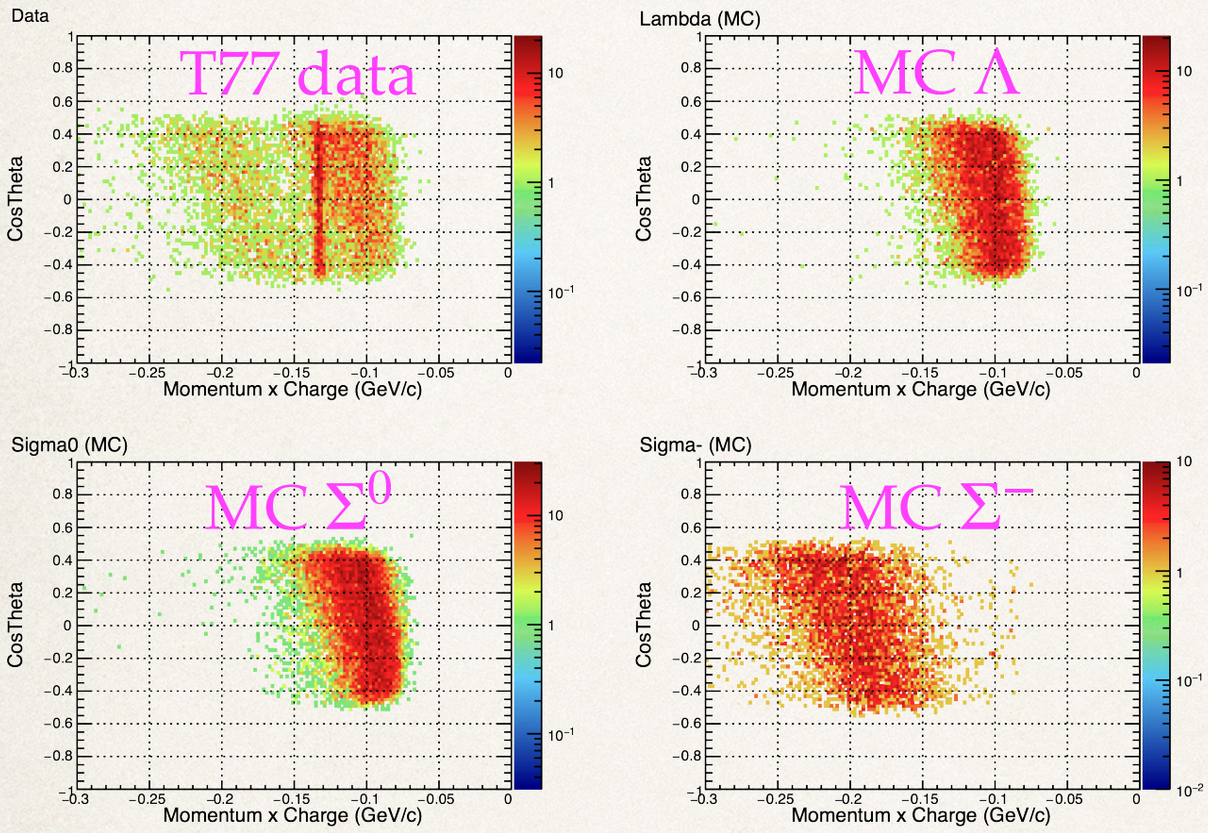


- ${}^{4}_{\Lambda}\mathrm{H}$ differential cross section from Prof. T. Harada;
- Assuming reaction vertex is the same as the decay vertex;
  - Vertex determined by connecting K^- and π^- track;
  - A systematic bias studied with MC data

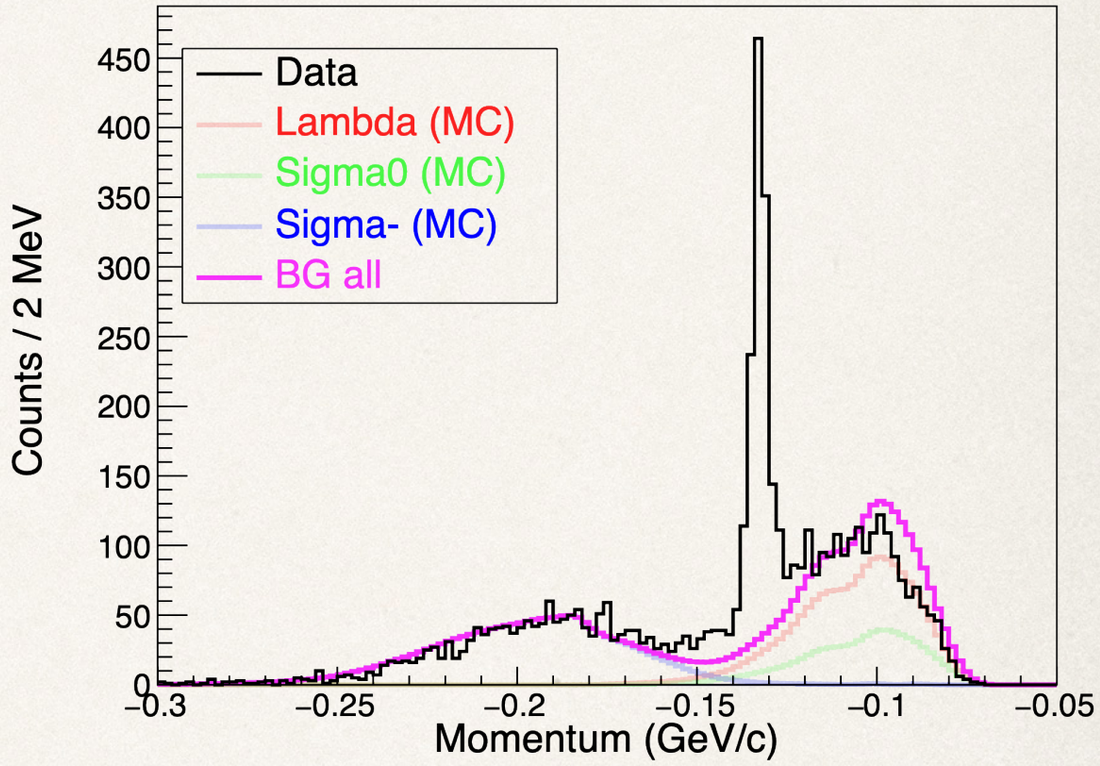
T. Harada, Y. Hirabayashi, Nucl. Phys. A, 1015, 122301 (2021)

Simulation validation

decay π^- momentum vs angle



MC yield tuned to match data



GEANT4 based simulation for quasi-free Λ/Σ in-flight decay;

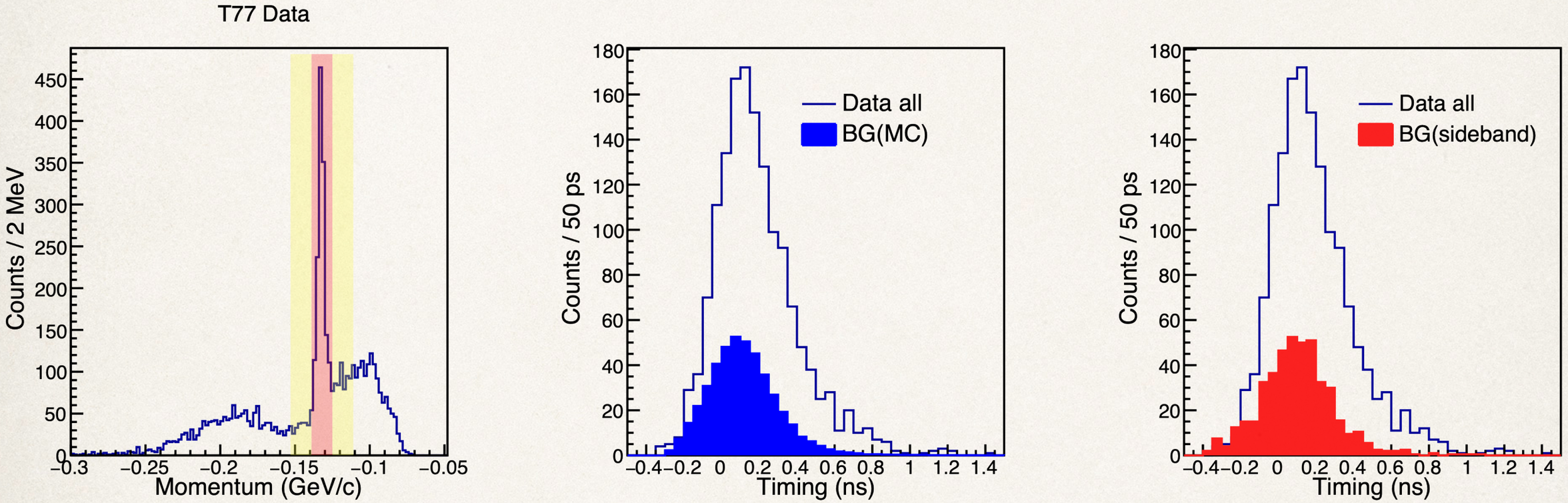
$N(K^-, \pi^0)$Y elementary reaction with published data +

convoluted with Argonne AV18+UX Fermi motion

R.B. Wiringa et al, Phys. Rev. C **89**, 024305

Uncertainty due to background subtraction: ±8 ps

MC yield was tuned up to $\pm 5\sigma$ from the best fit:
$^{4}_{\Lambda}$H lifetime converges within ±8 ps



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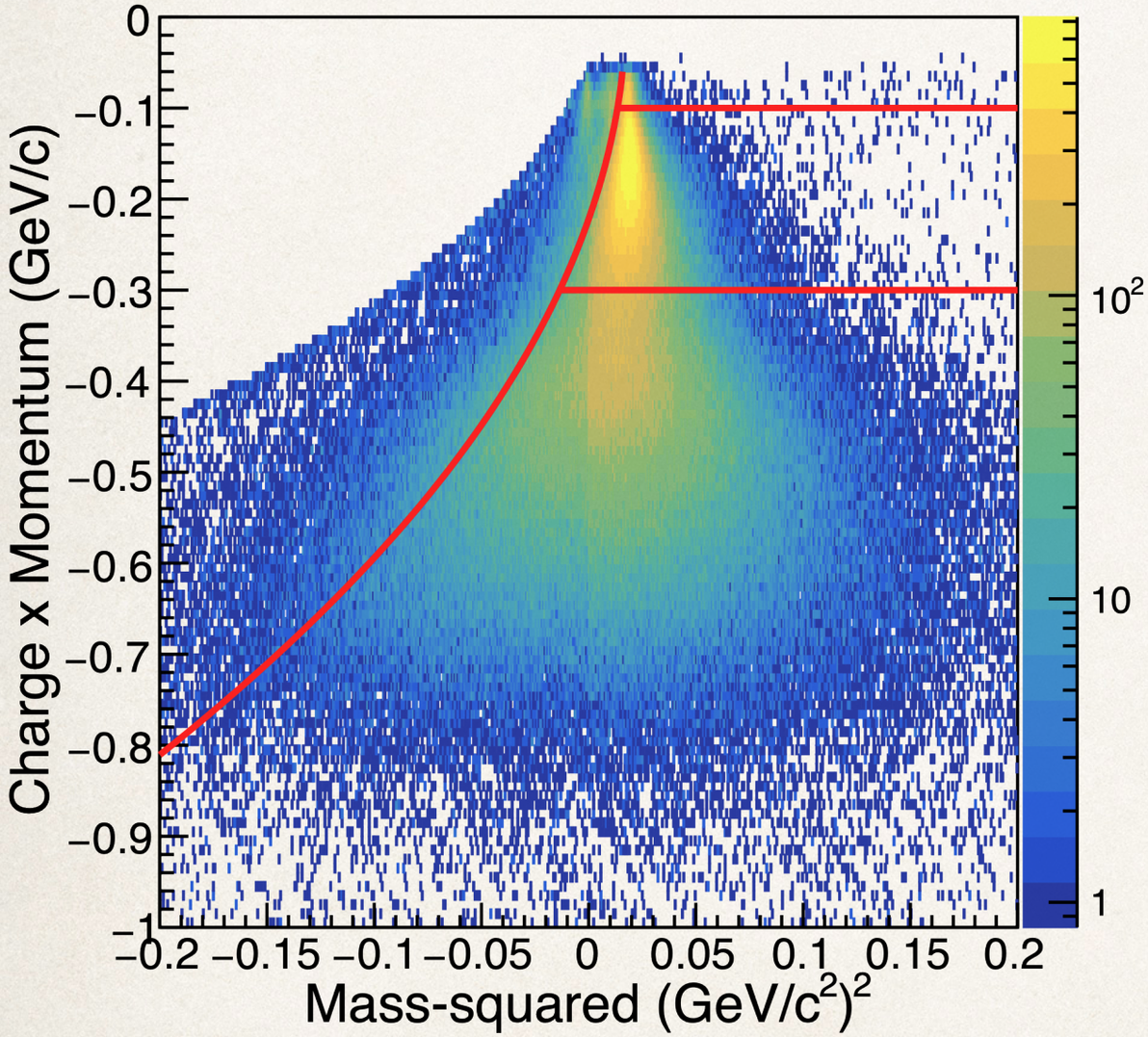
R.B. Wiringa et al, Phys. Rev. C **89**, 024305

Detector performance: tracking and PID

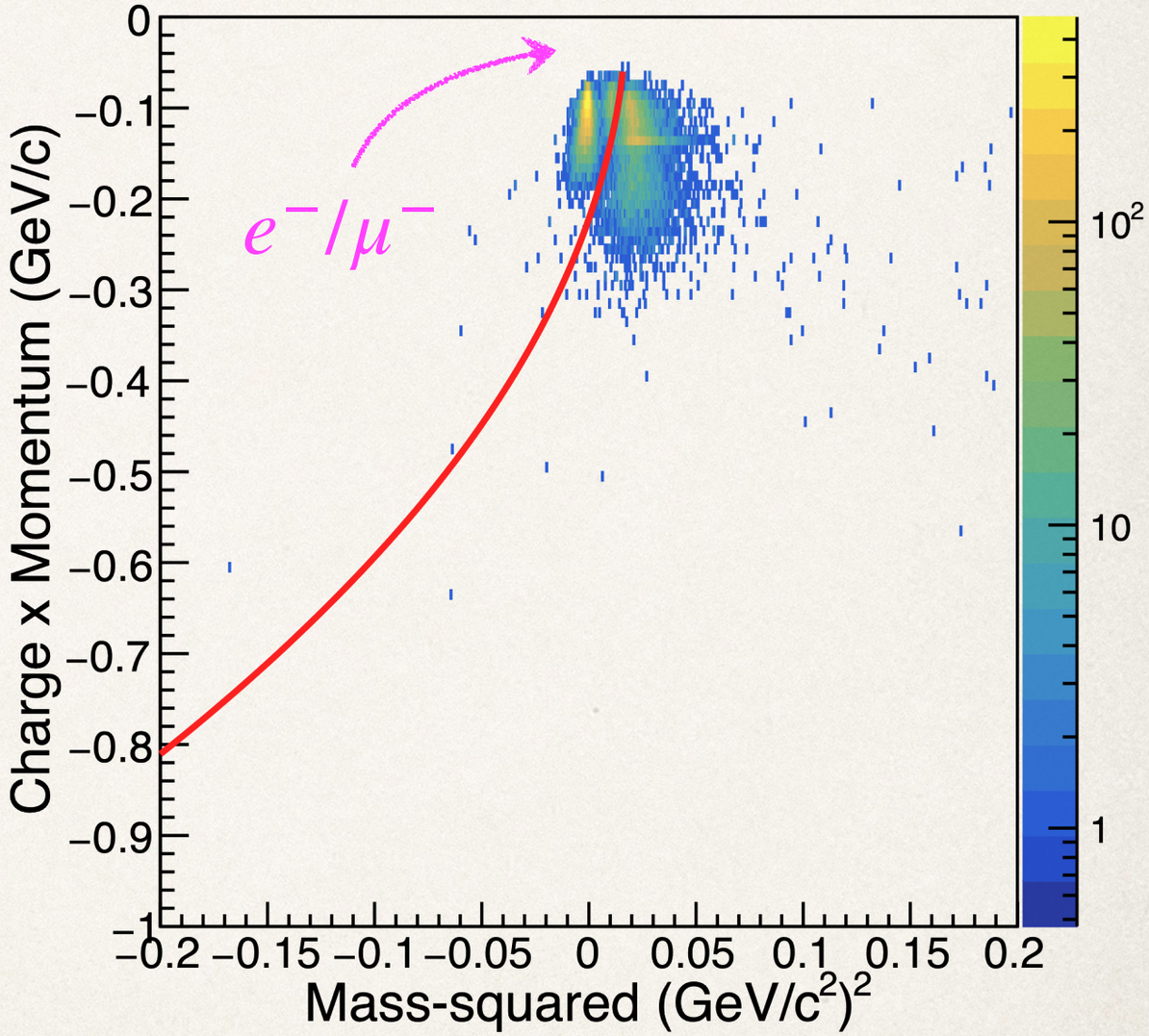
Calibration and slewing correction events



(K^-, π^-)

W/O requesting calorimeter dE

Interested physics events



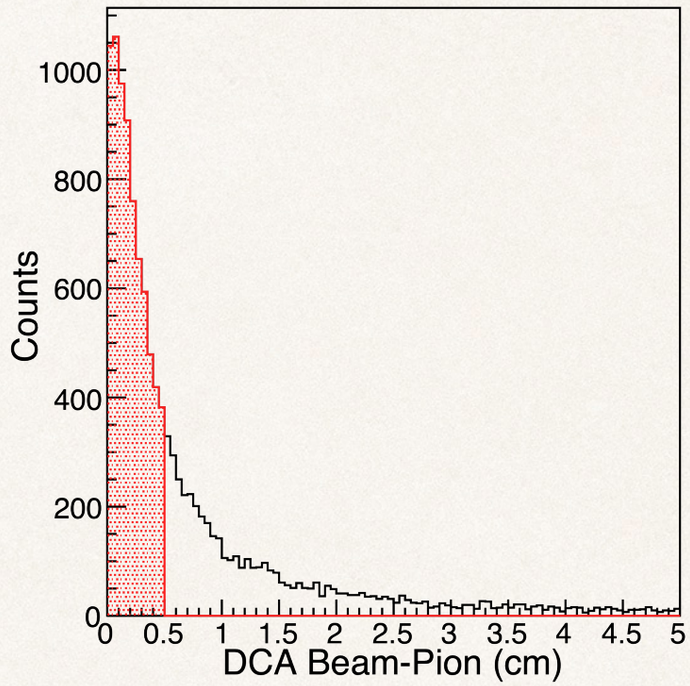
(K^-, π^-)

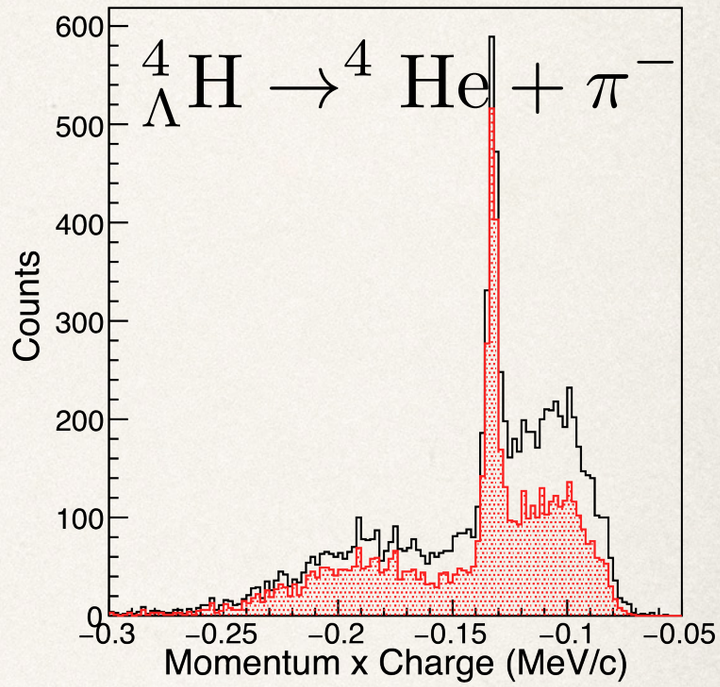
W/requesting calorimeter

dE > 500 MeV

Event selection: DCA & calorimeter cut

DCA < 5mm
used for event selection





Selecting $^{4}_{\Lambda}\mathrm{H}$ events by using calorimeter dE > 500MeV

--> our innovative method for selecting hypernucleus by tagging high energy gamma