E73 status report

toward Stage-2 approval

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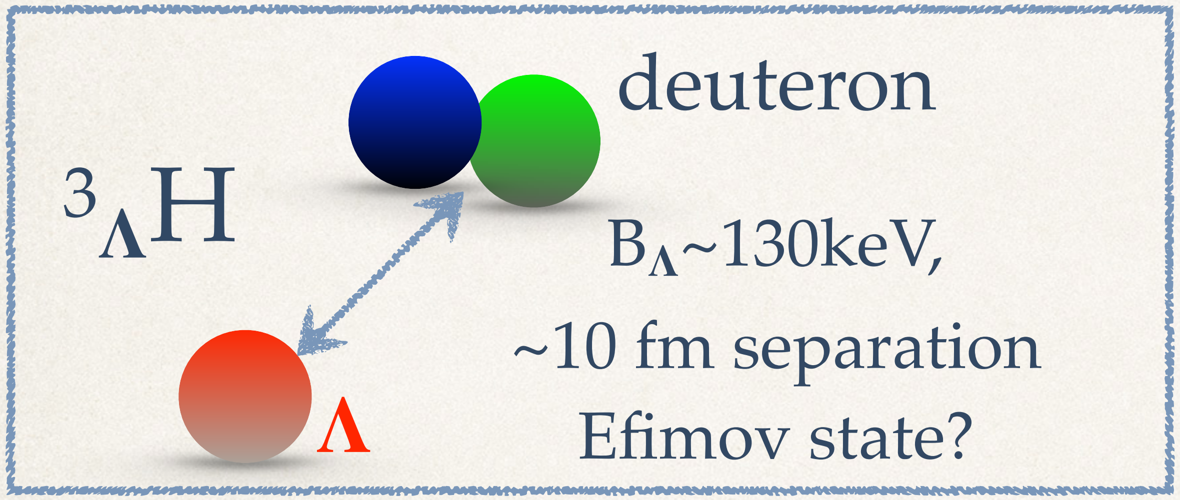
Outline

- Introduction to J-PARC E73:
  - The first direct measurement for $^{3}_{\Lambda}H$ lifetime
- J-PARC E73 staging & status
  - Phase-0: $^{4}_{\Lambda}H$ lifetime as feasibility study, June, 2020
  - Phase-1: $^{3}_{\Lambda}H$ production cross section measurement, May, 2021
- Summary

Introduction: hypertriton lifetime puzzle

As the lightest hypernucleus, $^3_\Lambda H$ serves as the corner stone 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).



$^3_\Lambda H \longrightarrow {}^3He + \pi^-$ 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: hypertriton lifetime puzzle

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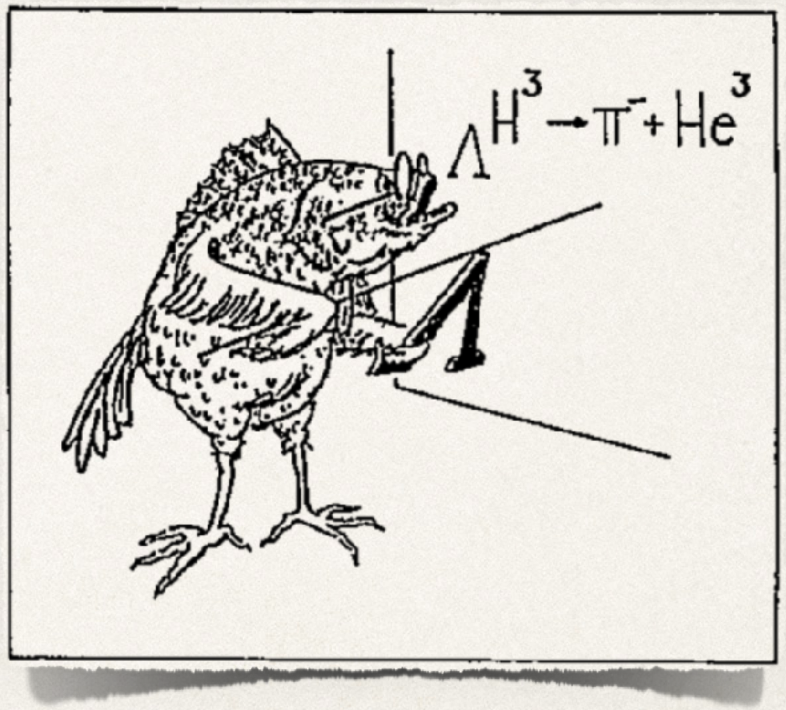
Up to a few years ago, we believe: $\tau \approx 263$ ps ($B_\Lambda = 130 \pm 50$ keV);

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

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

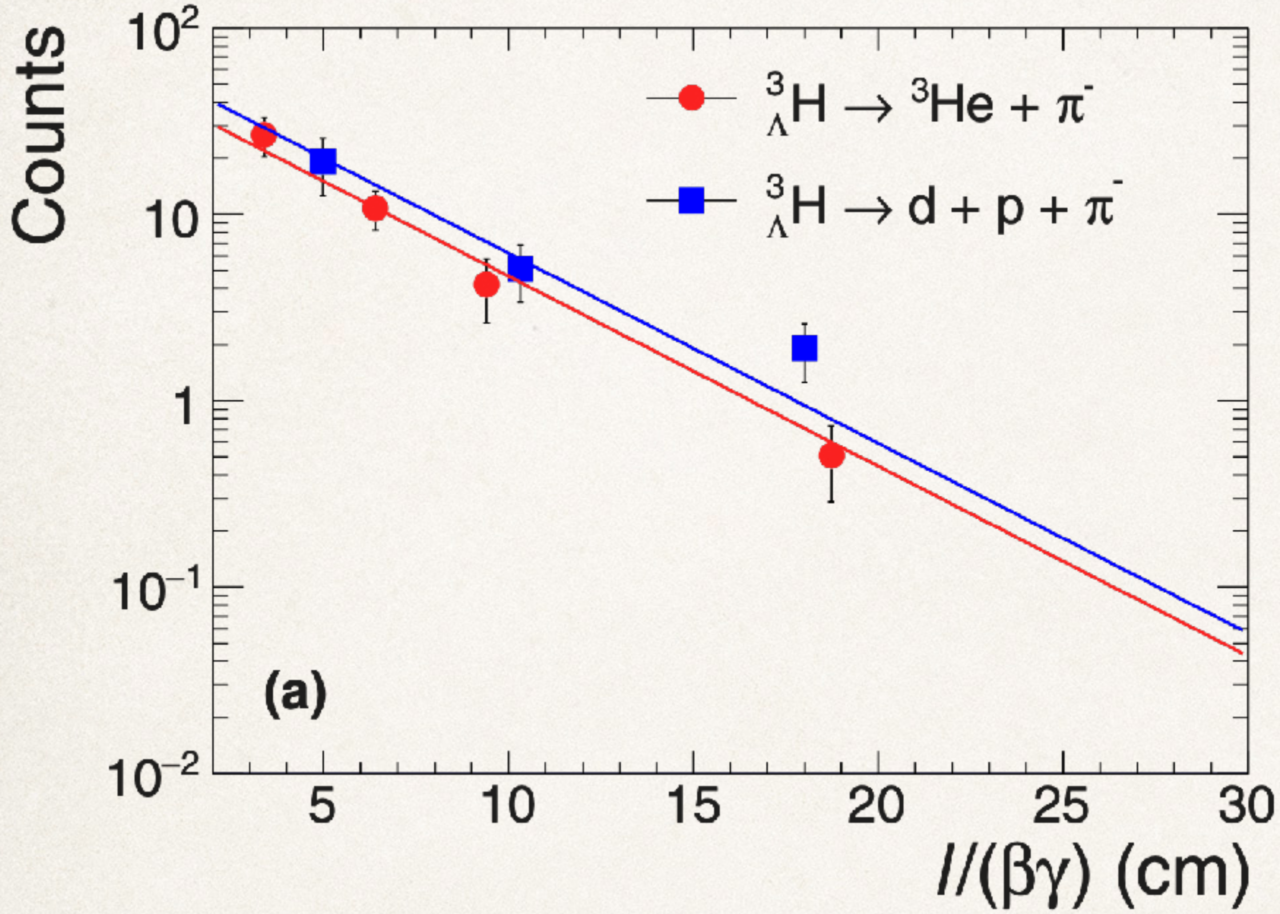
Collaboration	Experimental method	$^3_\Lambda H$ lifetime [ps]	Release date
ALICE	Pb collider	240^{+40}_{-31}(stat.)±18(syst.)	2019
STAR	Au collider	142^{+24}_{-21}(stat.)±29(syst.)	2018
HypHI	fixed target	183^{+42}_{-32}(stat.)±37(syst.)	2013

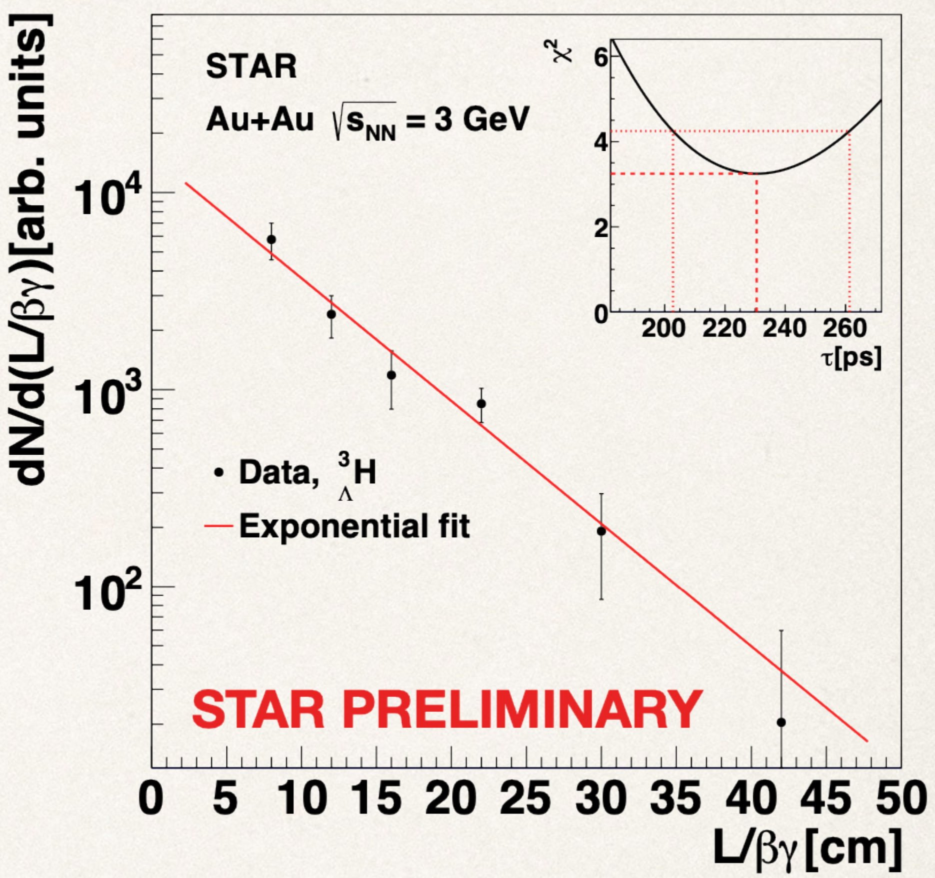


Neither fish nor fowl?

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

Recent updates from STAR (as an example)





STAR 2018: $\tau \sim 142^{+24}_{-21} \pm 29$ ps

STAR 2021: $\tau = 232.1 \pm 29.2 \pm 36.7$ ps

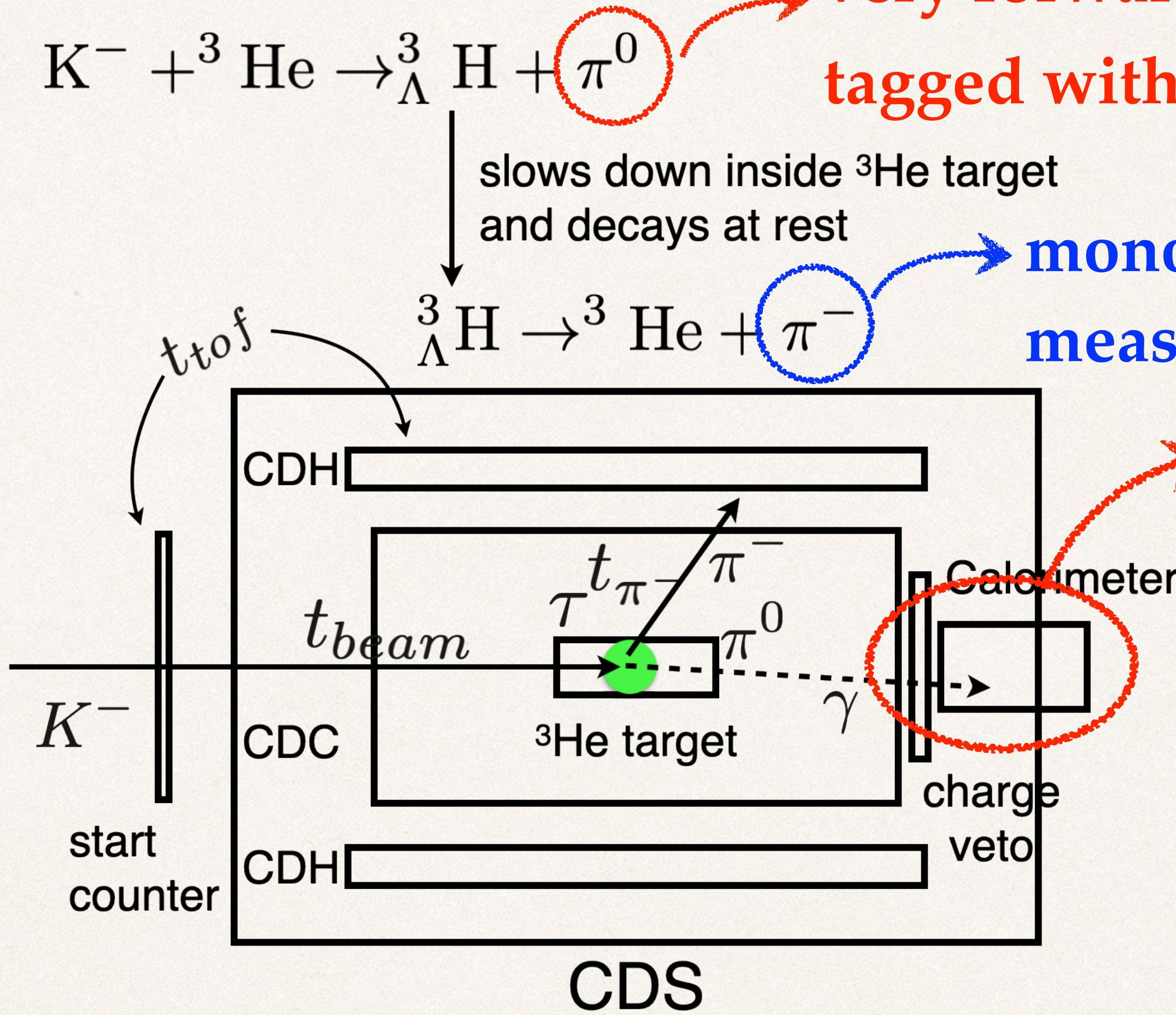
What happened? What shall we do?

L. Adamczyk et al., Phys. Rev. C, 97, 054909, (2018)

$^{3}\mathrm{He}(\mathrm{K}^{-},\pi^{0})^{3}_{\Lambda}\mathrm{H}$ 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; $^{4}{}_{\Lambda}$He mixture?
Quantum number	spin=1/2 dominant	1/2 and 3/2 mixture?
Lifetime derivation	Time of flight	Decay length

E73 experimental setup



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

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

J-PARC E73 staging & status

Staging:	Phase-0 (June, 2020)	Phase-1 (May, 2021)	Phase-2
Task:	Background study with $^4He(K^-,\pi^0)^4_\Lambda H$	First measurement for $^3He(K^-,\pi^0)^3_\Lambda H$ 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 Phase-1 results

To be covered in this talk

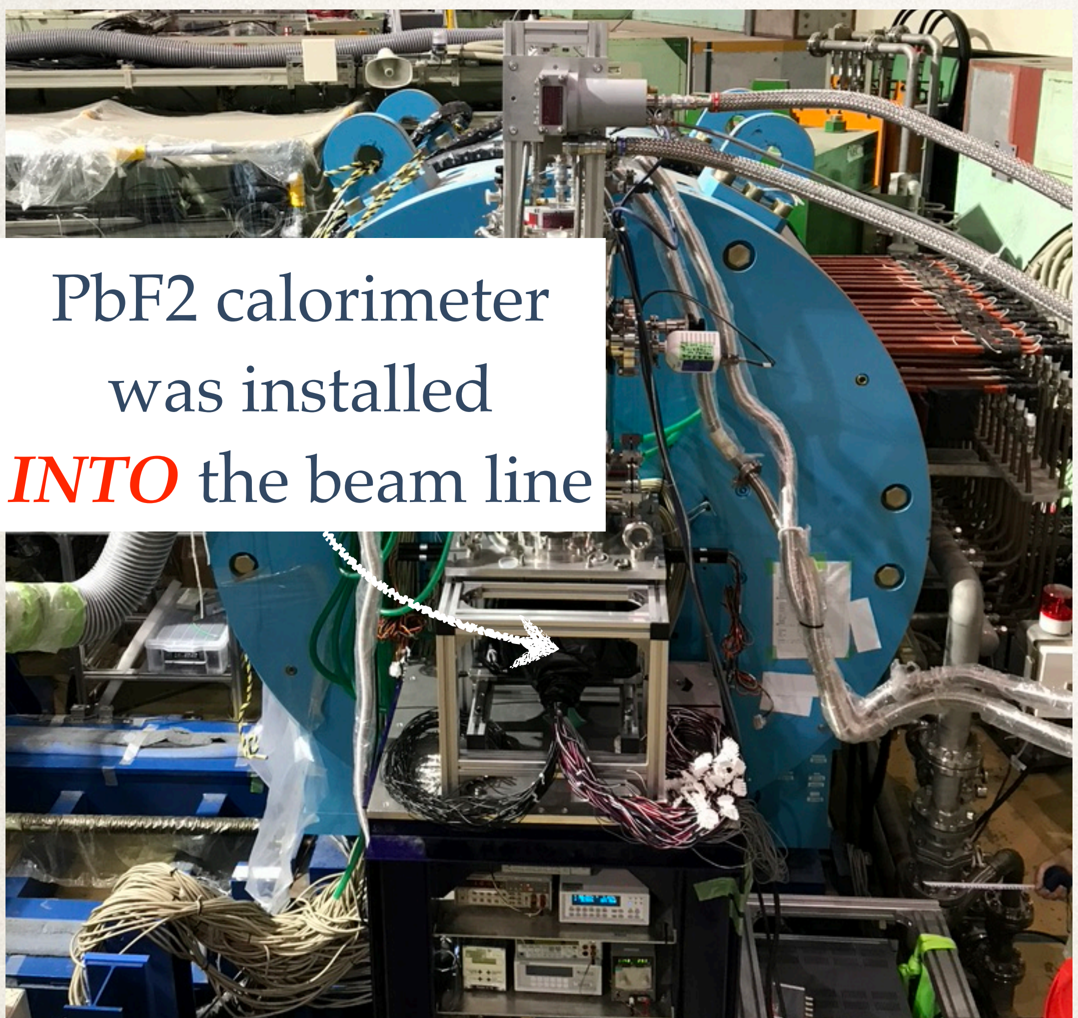
E73 Phase-0: feasibility study

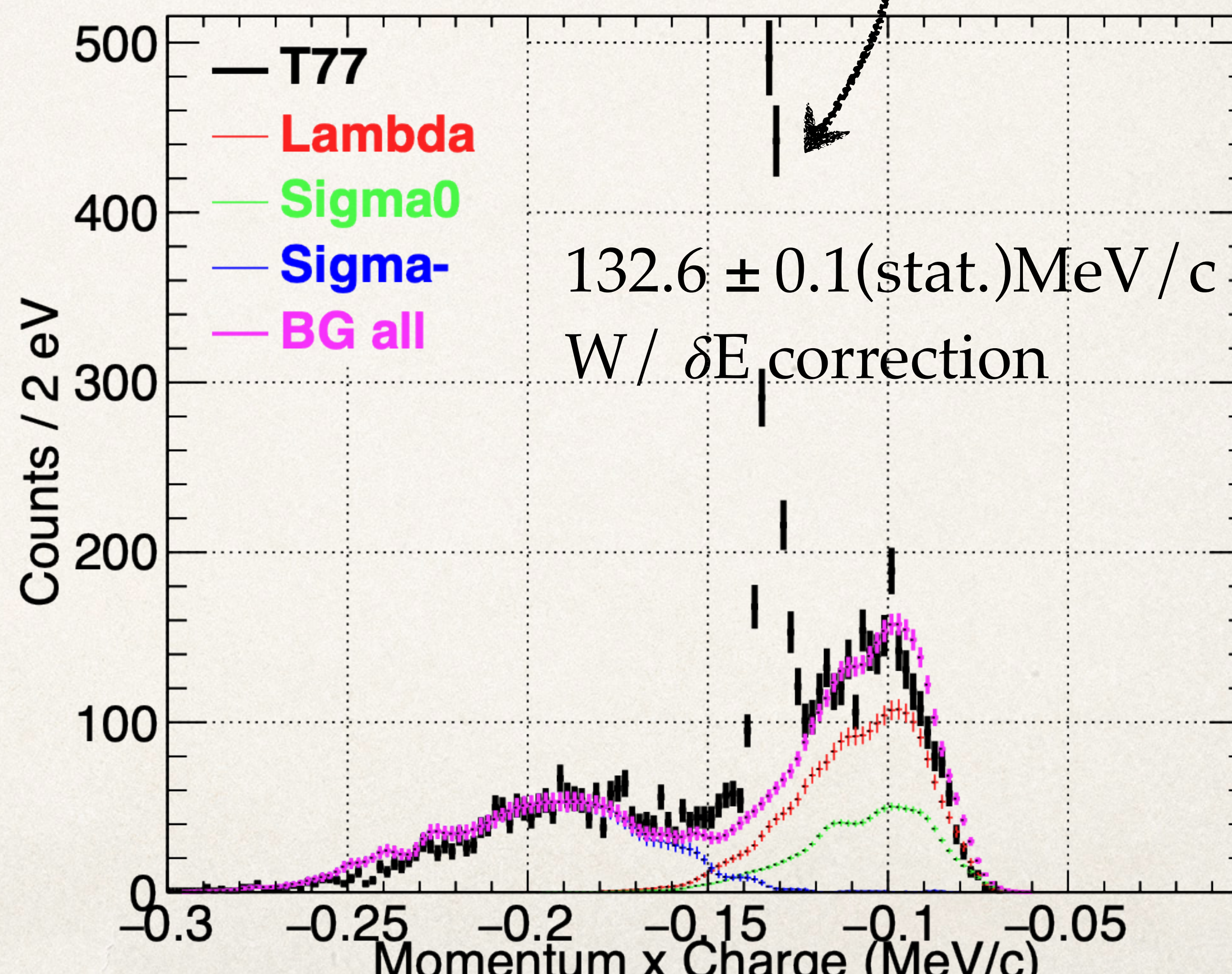
World record data for ${}^{4}_{\Lambda}H$ lifetime measurement

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

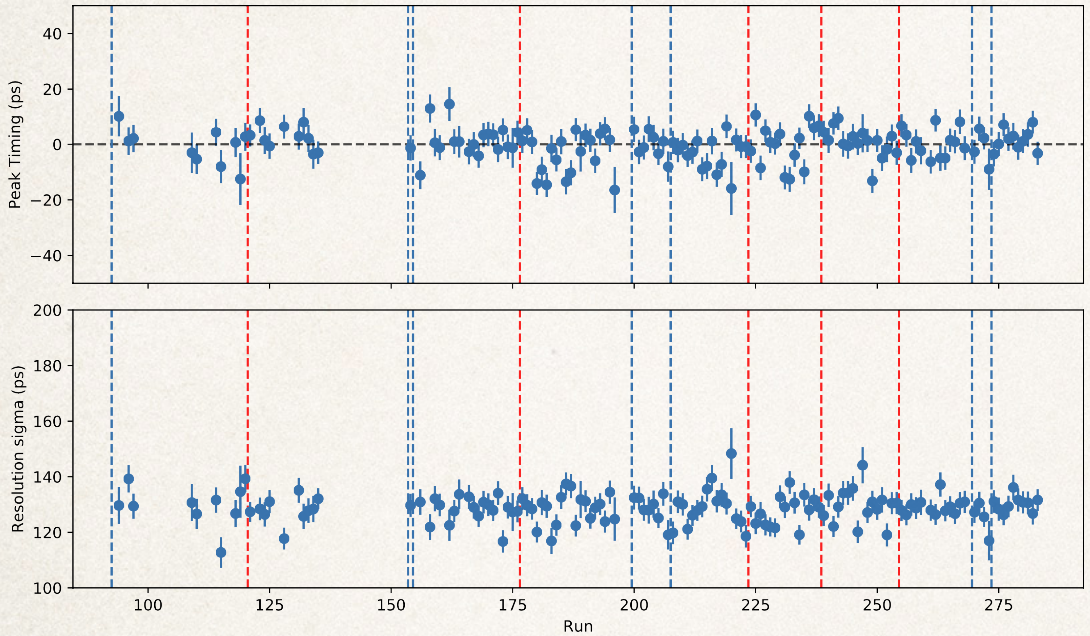
slows down inside ${}^4He$ target and decays at rest

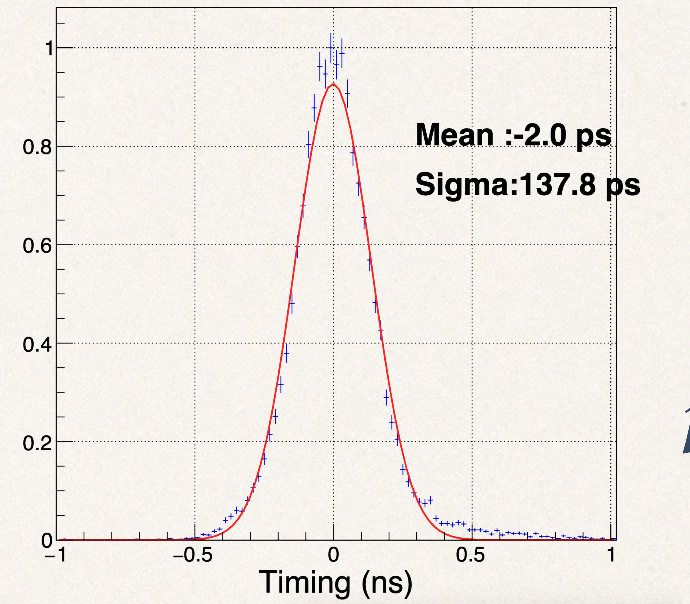
$${}^4_{\Lambda}H \rightarrow {}^4He + \pi^- \quad 132.9\ \mathrm{MeV/c}$$





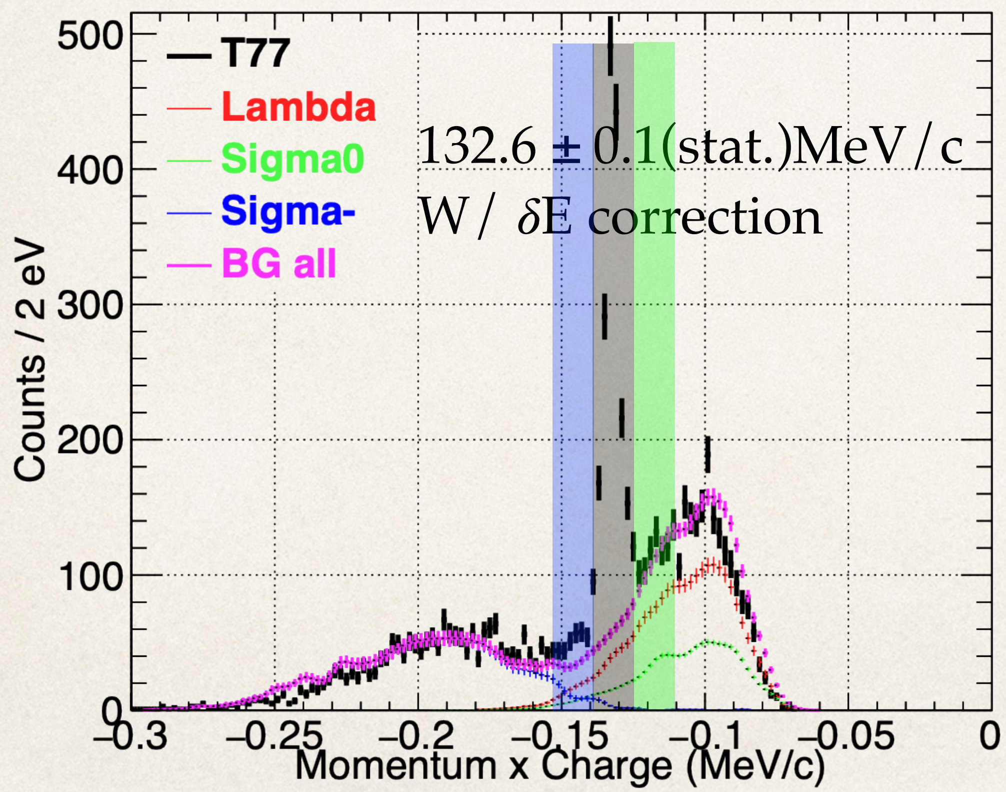
E73 Phase-0: ${}^{4}_{\Lambda}$H lifetime results



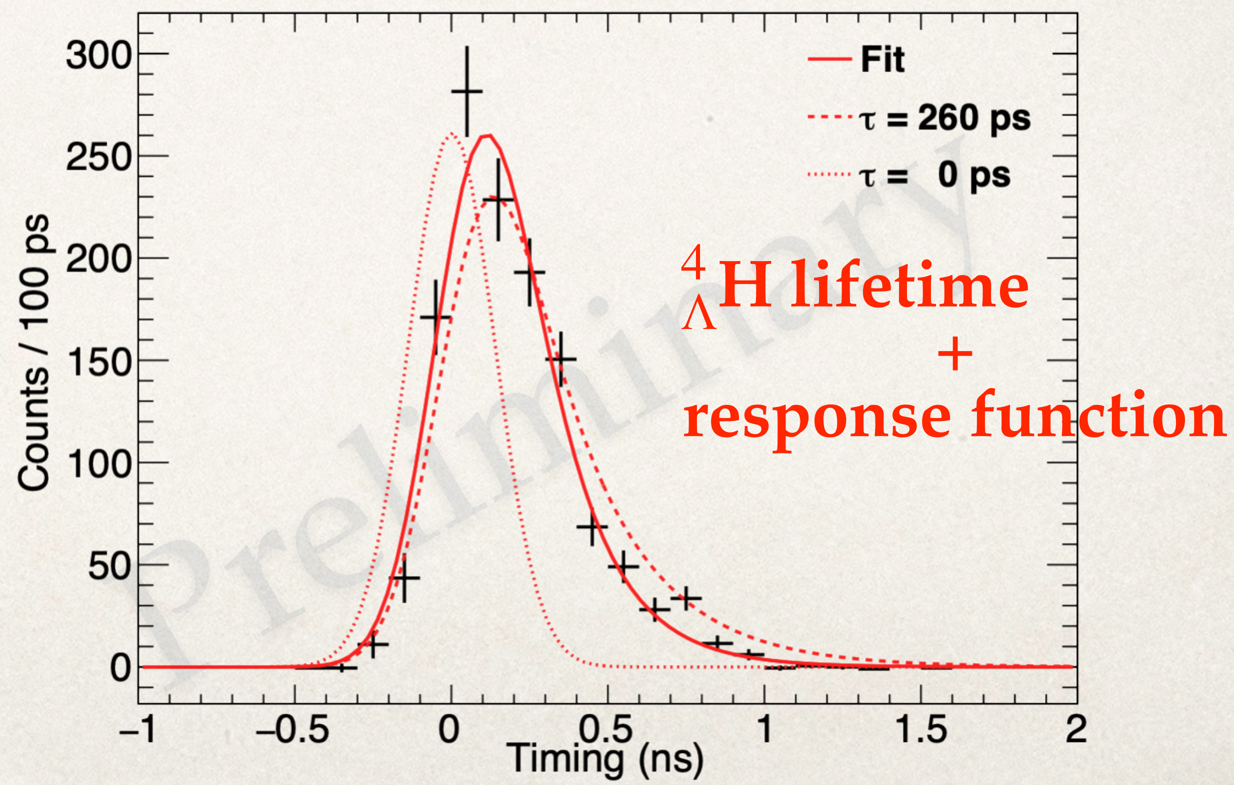


Stability and time response function from prompt hadronic events

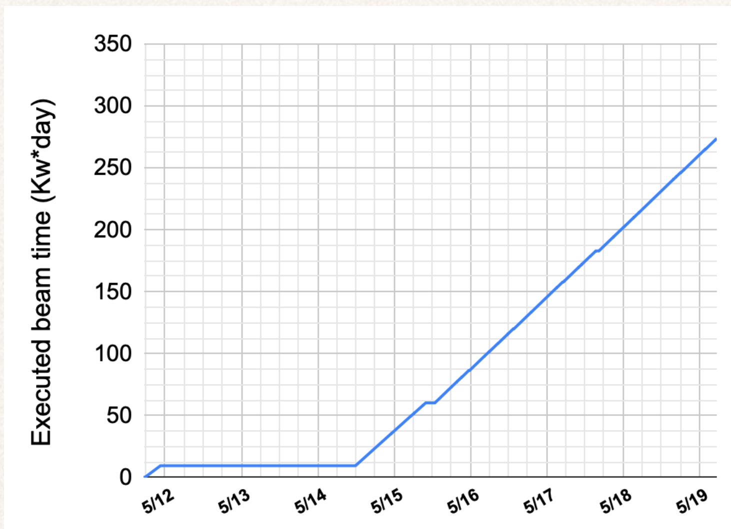
Background subtraction



$\tau = 180 \pm 7$ ps (stat. only)



E73 Phase-1: ${}^{3}_{\Lambda}\mathrm{H}$ production cross section



Completed in May, 2021
Stable beam condition: 97.5% up time
Thanks for the J-PARC staffs!

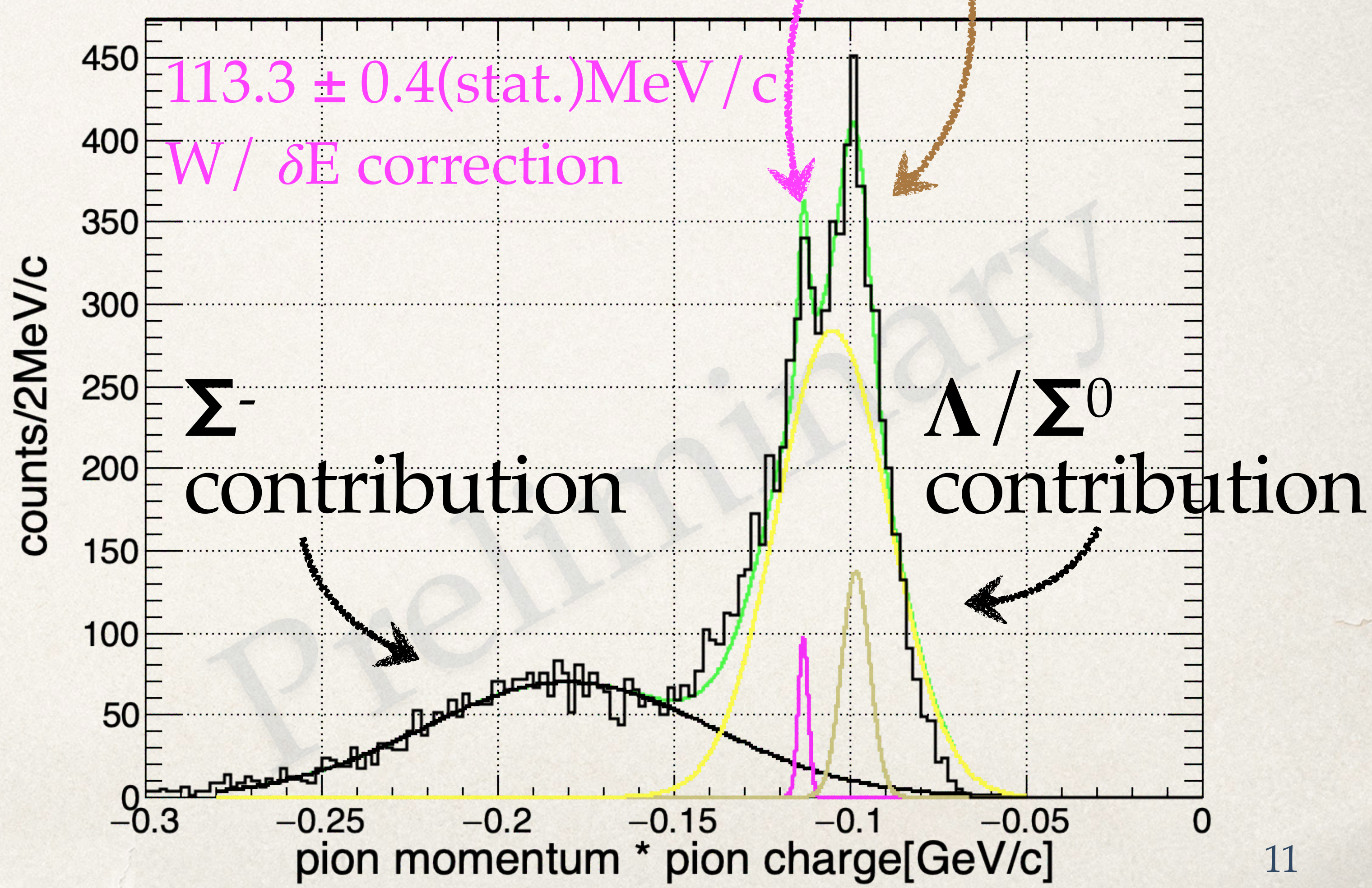
- ${}^{3}_{\Lambda}\mathrm{H}$ production cross section;
- Both 2-body & 3-body decay from ${}^{3}_{\Lambda}\mathrm{H}$ has been observed;

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

slows down inside ^{3}He target and decays at rest

$${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-} \quad 114\ \mathrm{MeV/c}$$

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



E73 Phase-1: ${}^{3}_{\Lambda}H$ discussion

- First ***direct*** determination for ${}^{3}_{\Lambda}H$ ground state spin (I=1/2)
  - Yield of ${}^{3}_{\Lambda}H$ is comparable with Prof. Harada's calculation (arXiv:2106.04256v1)
  - No ambiguities from 3/2 excited state and mis-identification as in heavy-ion experiments
- Main source of background is from quasi-free hyperon in-flight decay; systematic error can be estimated by comparing simulation with controlled sample as demonstrated by ${}^{4}_{\Lambda}H$ --> in progress

Summary

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

Thank you for your attention!

P73/T77 collaborator list

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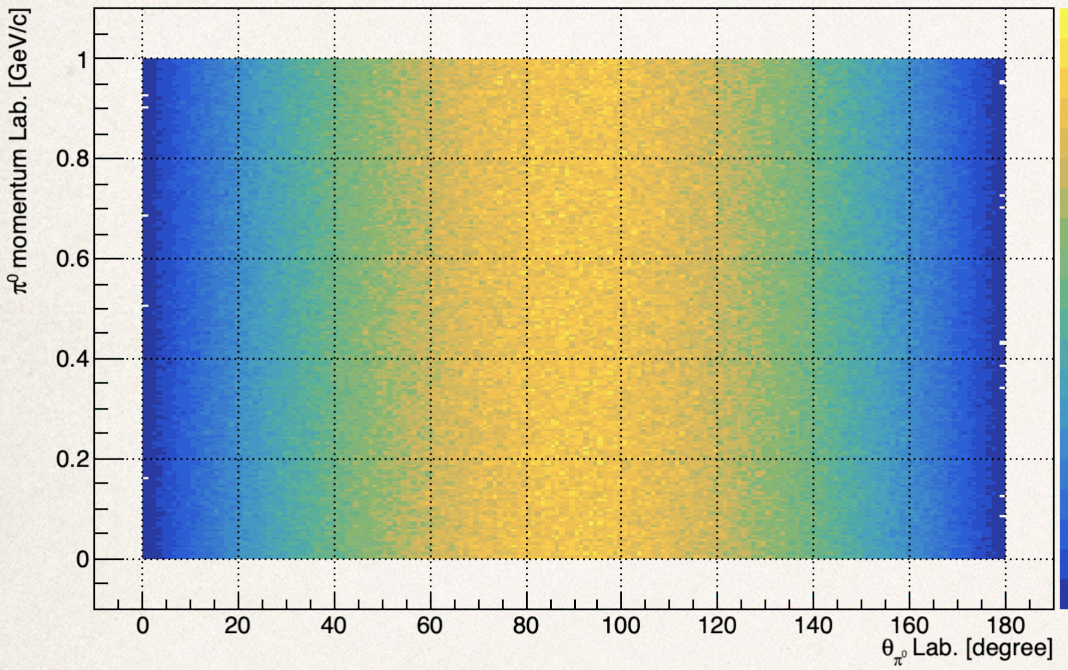
backup

How does E73 work by tagging single γ-ray?

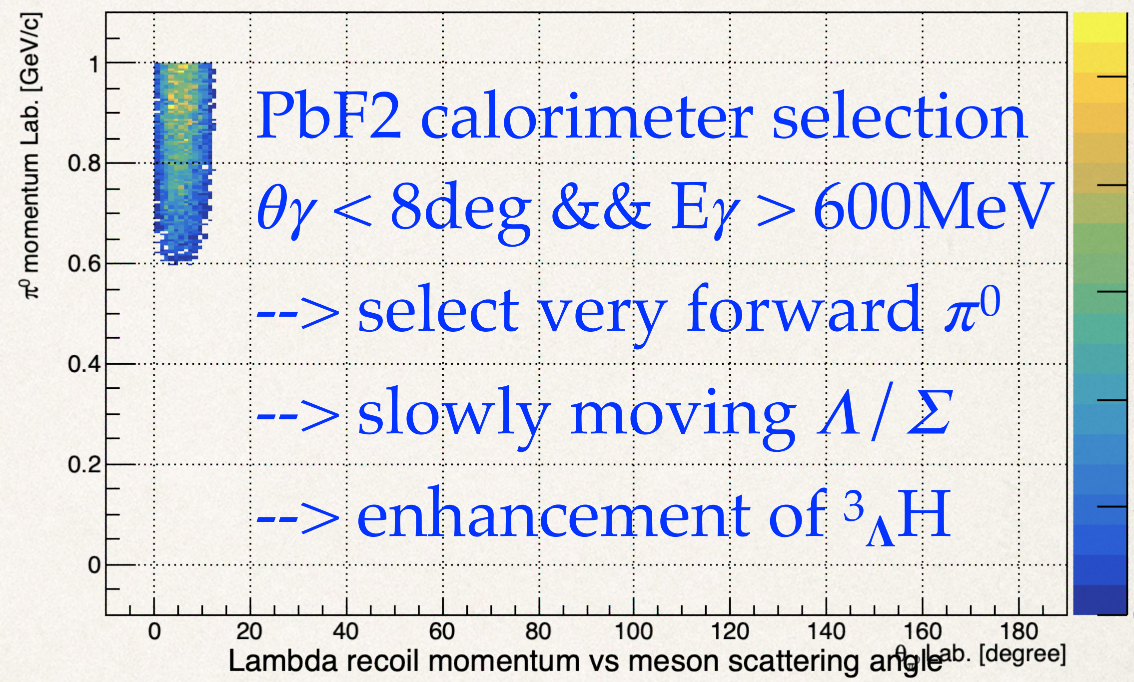
Input

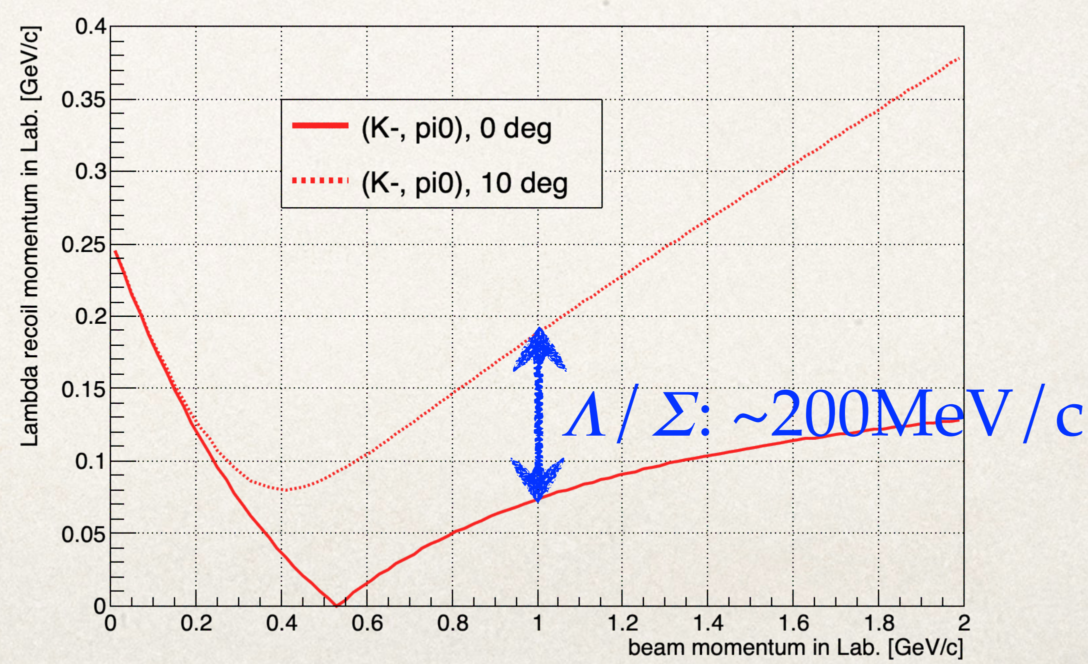
π^0: 0~1GeV/c; 0~180deg



W/ PbF2 calorimeter cut

π^0: 0.8~1GeV/c; 0~10deg



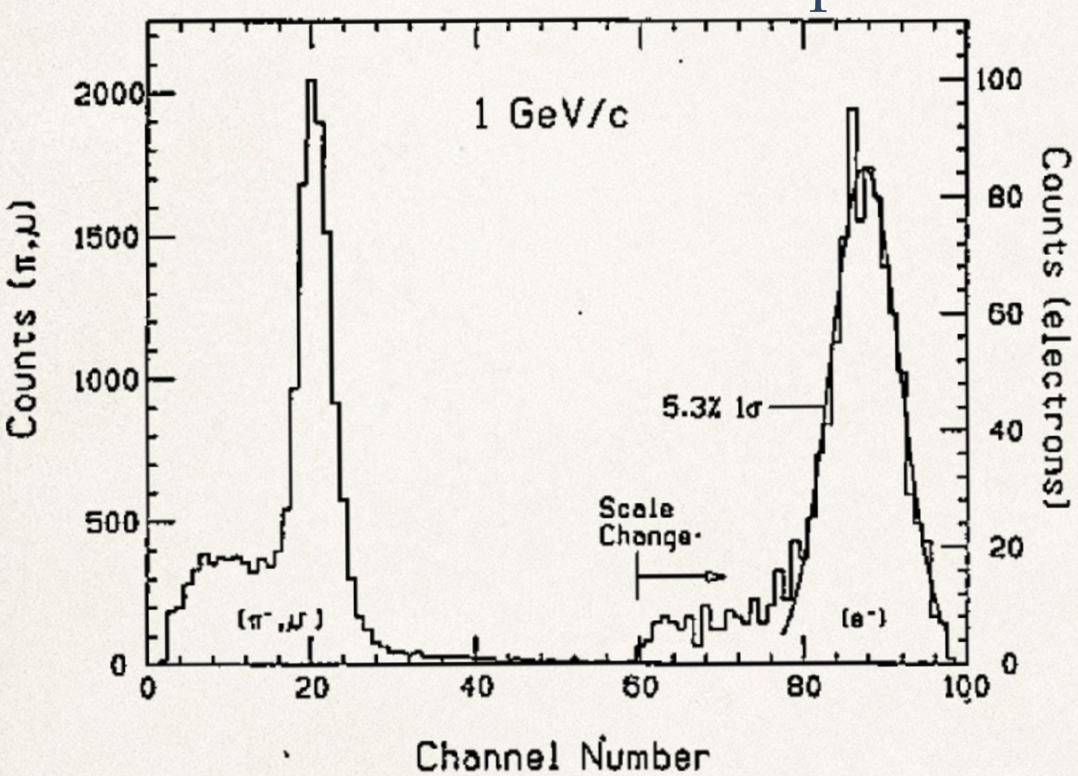


^{3}He(K-, pi0)$^3{}_\Lambda$H strangeness exchange reaction is known for its spin non-flip feature --> helps to pin down the $^3{}_\Lambda$H Q.N.

Experimental setup: π^0 tagger (PbF_2)

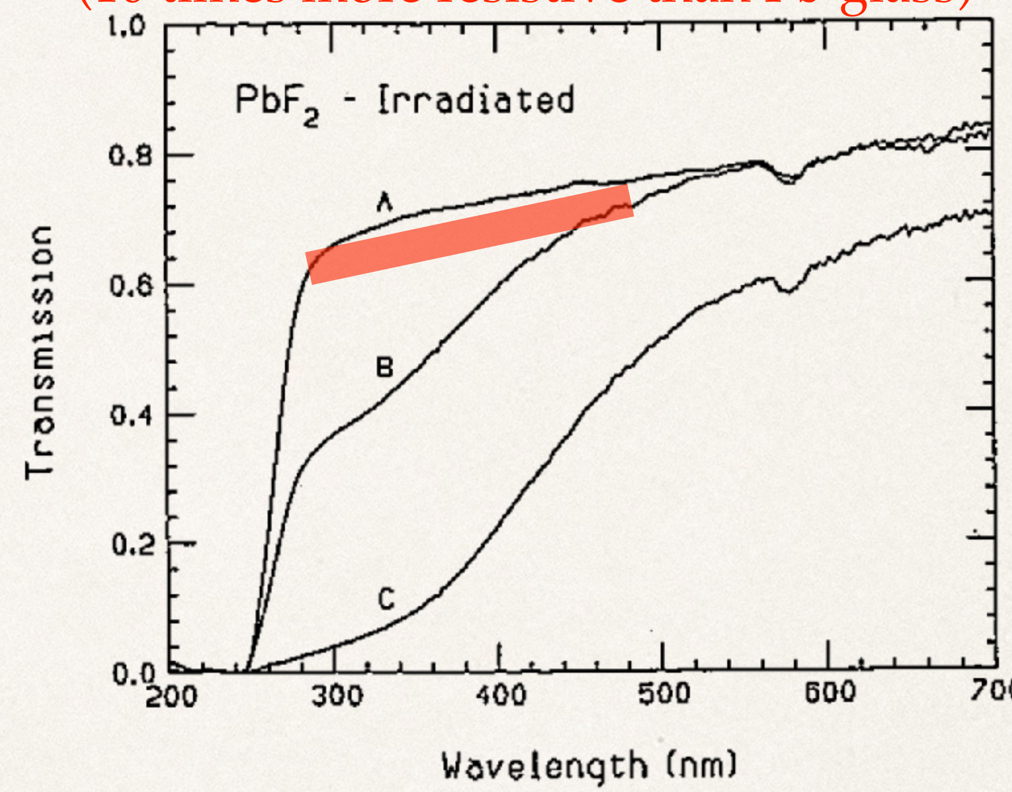
π^- peak

electron peak



expected performance after one month beam time

(10 times more resistive than Pb glass)

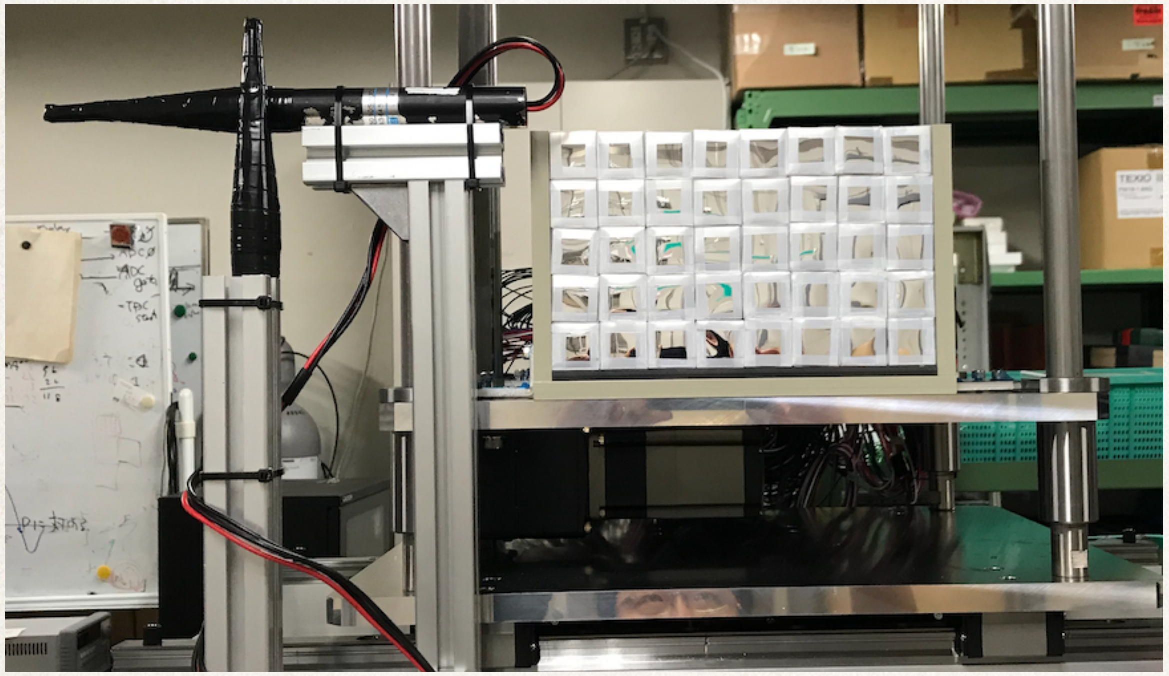


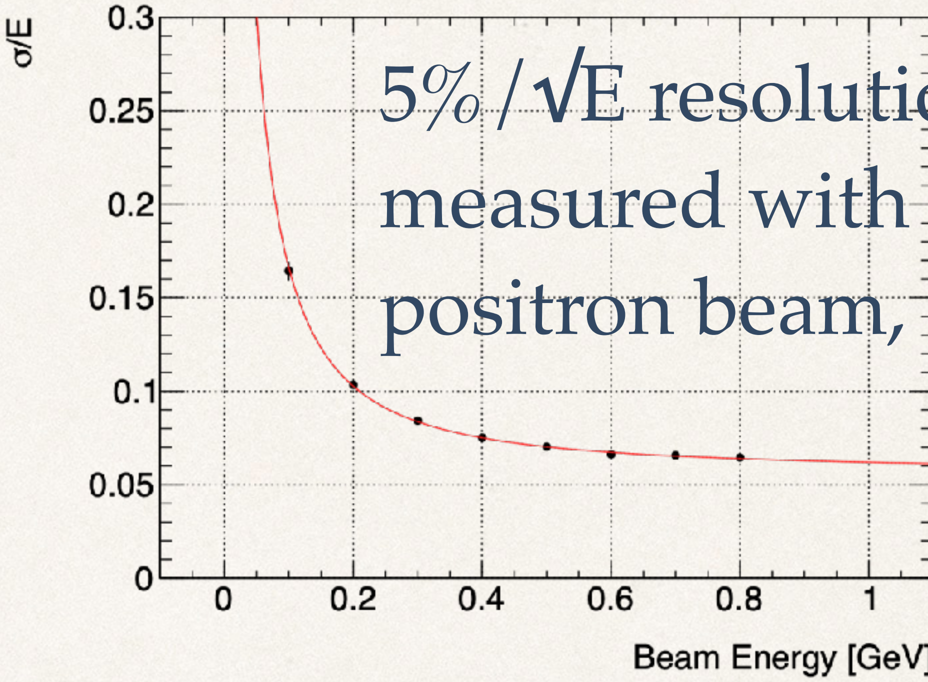
Crystal	Radiation length	Moliere radius	Density	Cost	Resolution	Signal length
PbF_2	0.93 cm	2.22 cm	7.77 g/cm^3	12 USD/cc	5%	2ns

D.F. Anderson, ***et al.***, Nucl. Inst. Meth. A290 (1990) 385

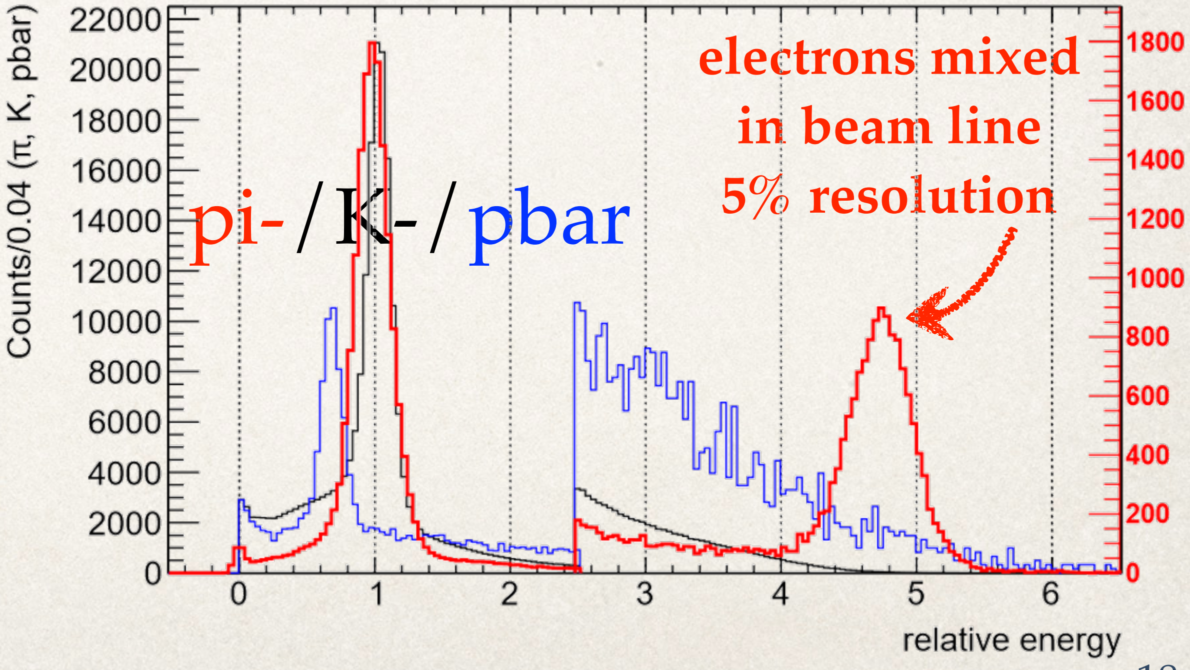
P. Achenbach, ***et al.***, Nucl. Inst. Meth. A416 (1998) 357

PbF2 calorimeter performance

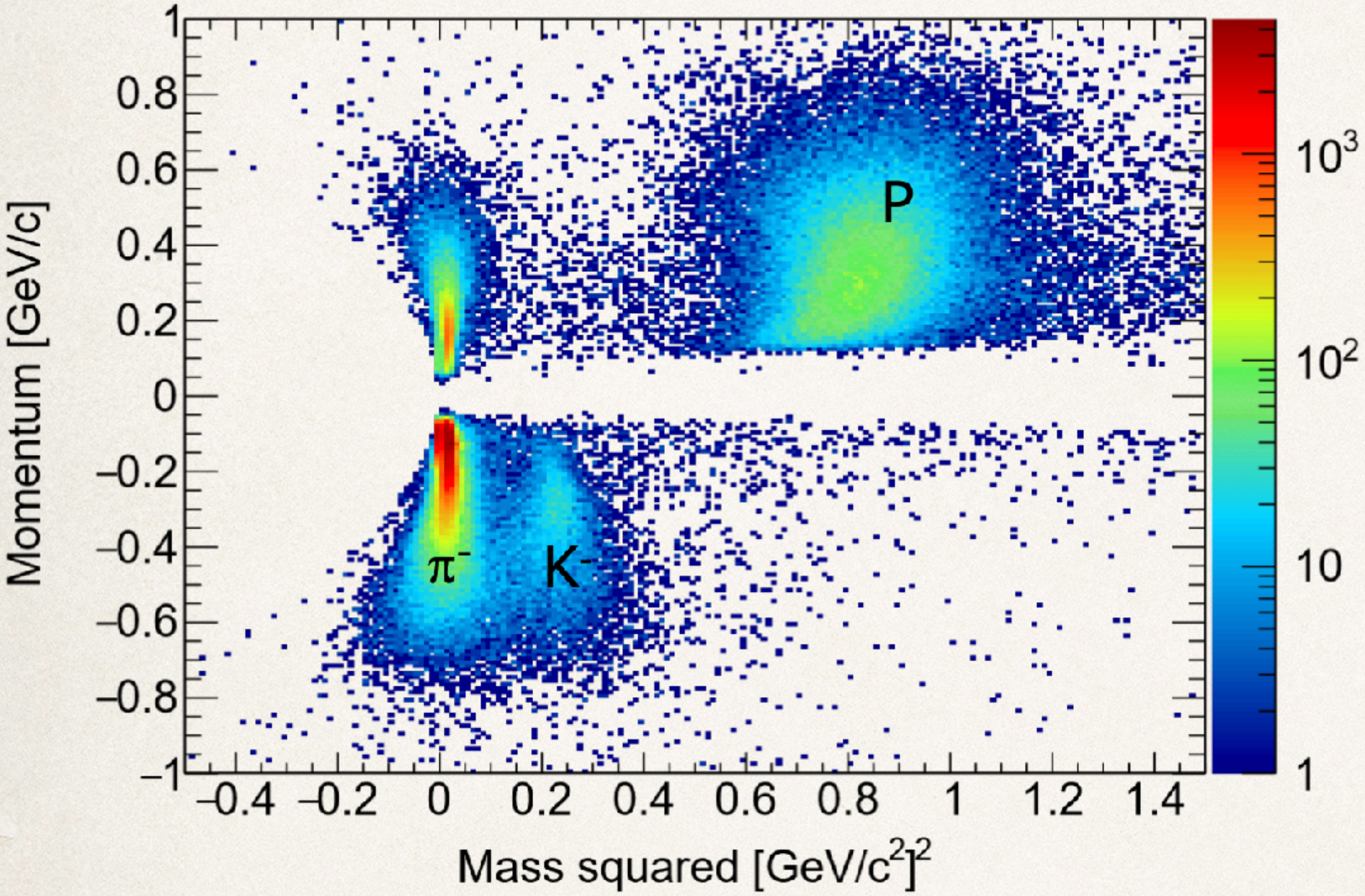


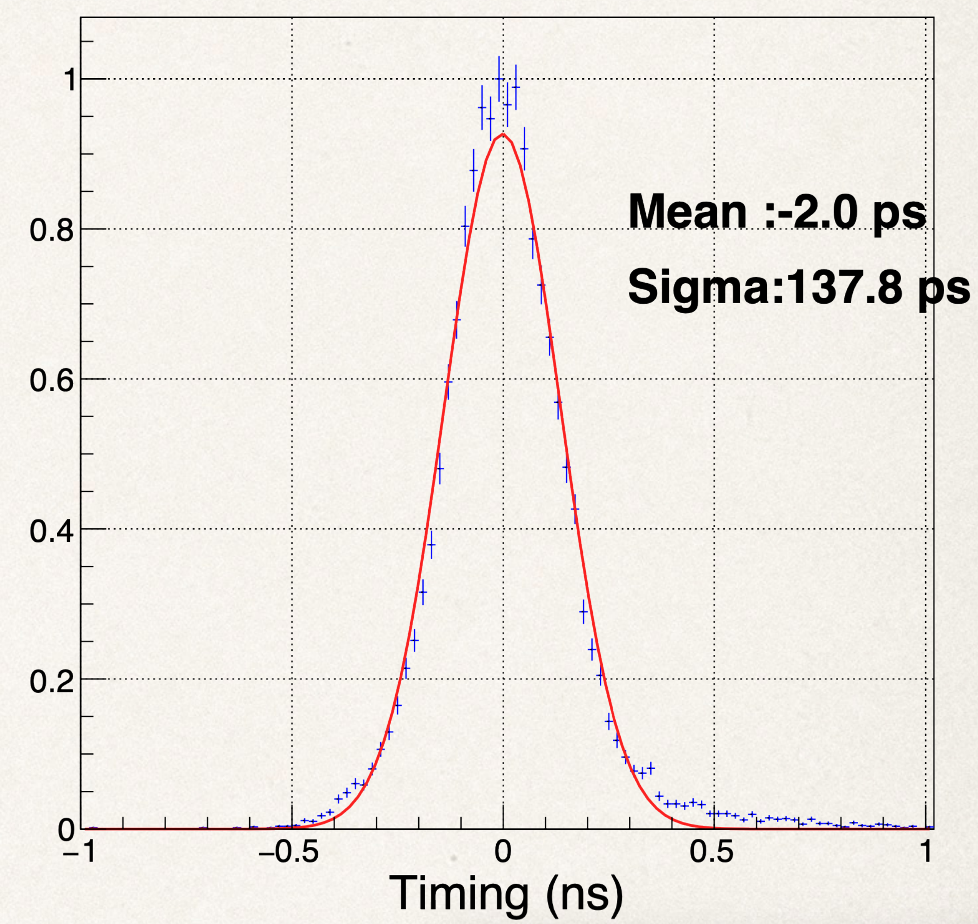


- PbF2 calorimeter is installed ***INTO*** the meson beam line to tag fast pi0;
- All segments of PbF2 calorimeter works well with reasonable resolution even in high rate conditions.



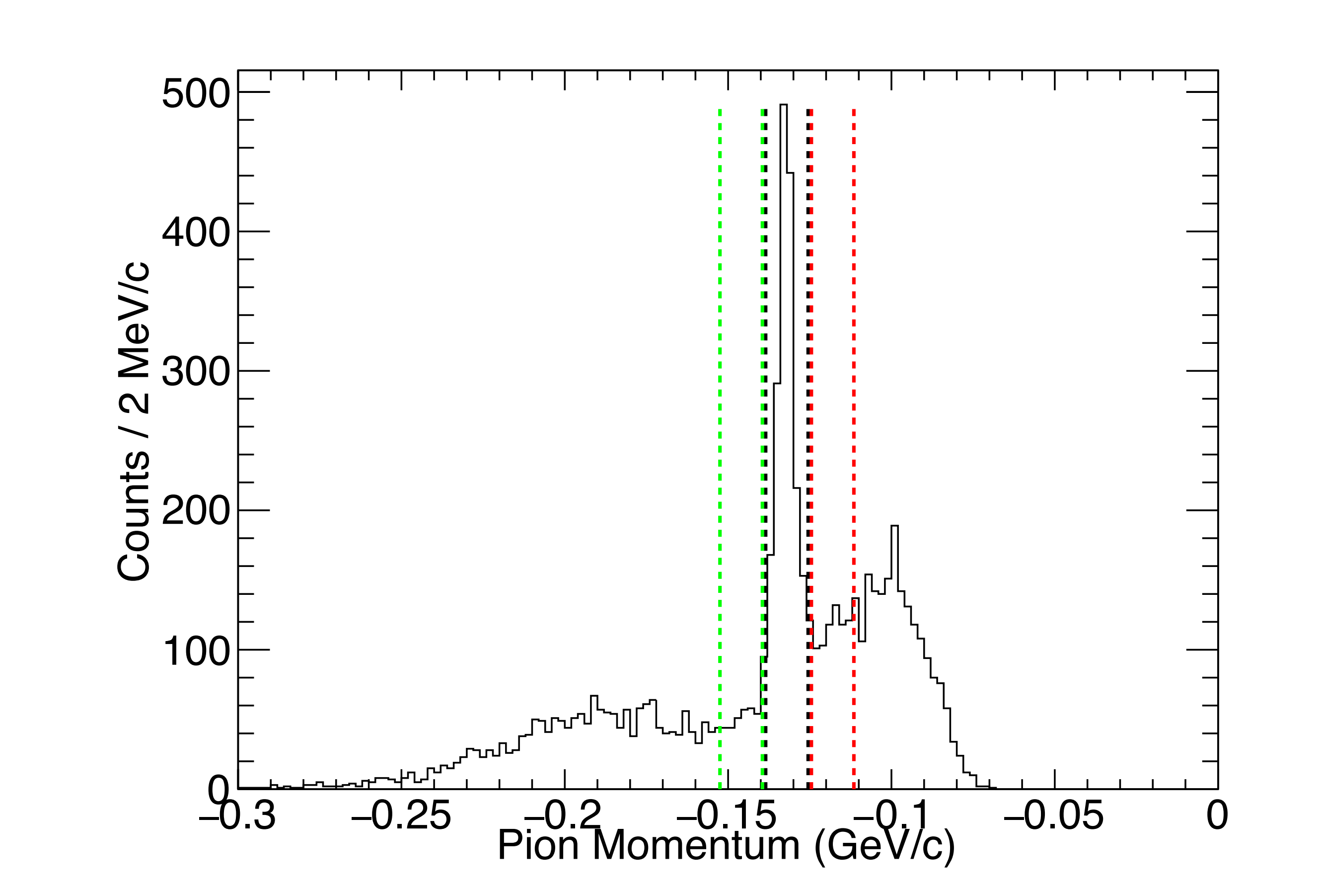
CDS tracking performance

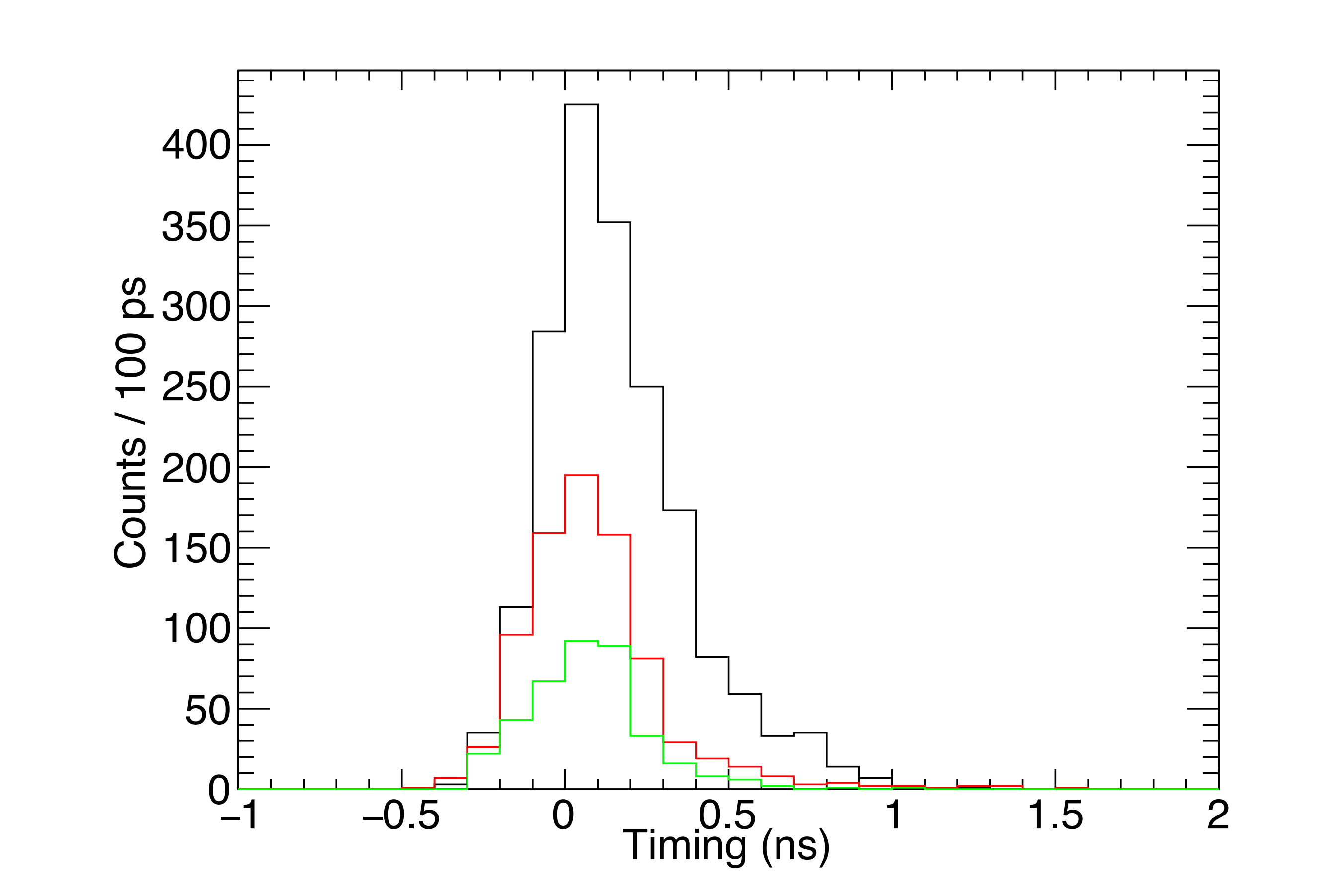




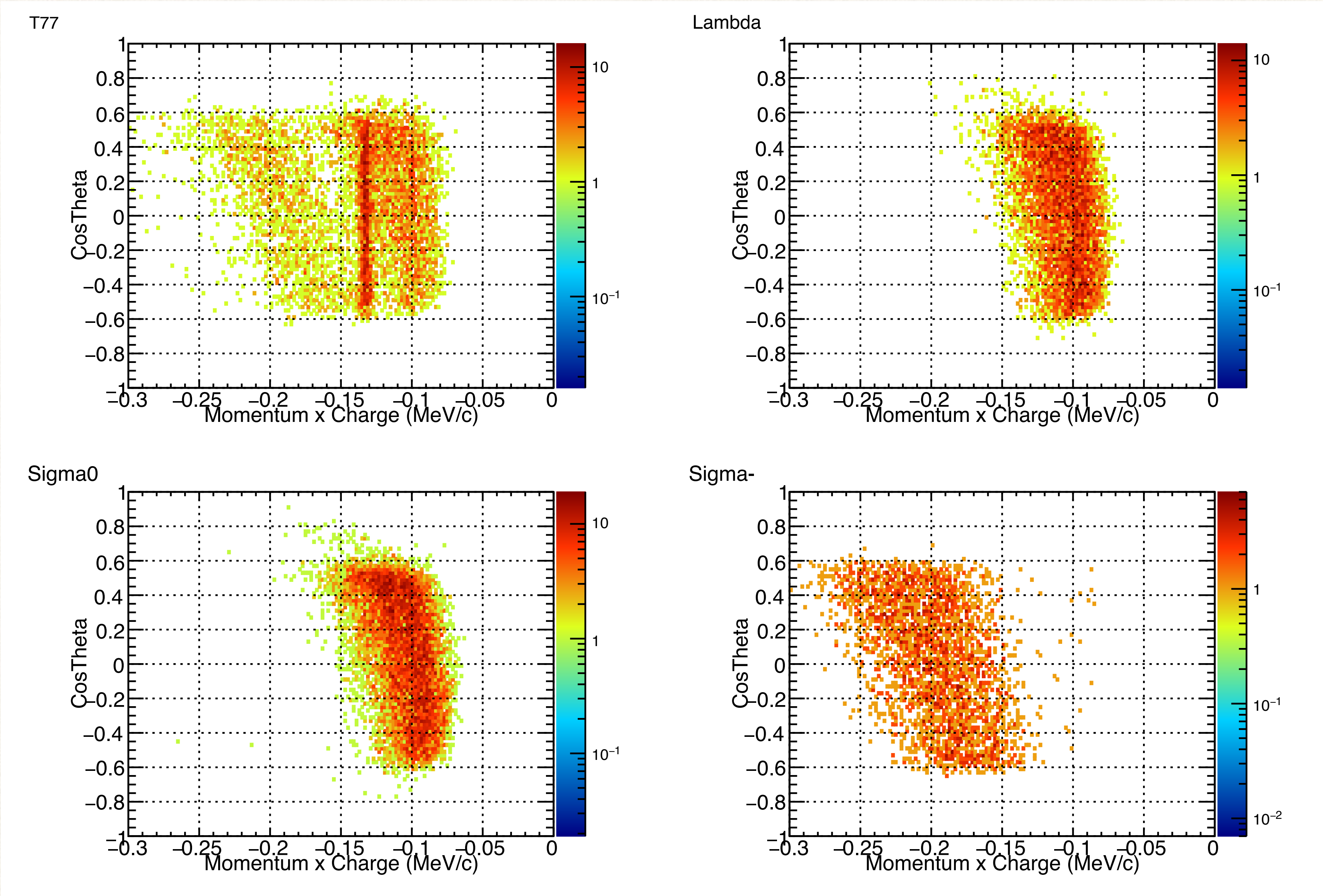
- CDS tracking system works well;
- ~2% momentum resolution for ~100MeV/c pi- signals;
- TOF resolution ~137ps from prompt pi- scattered event

Side band subtraction from $^{4}{}_{\Lambda}H$



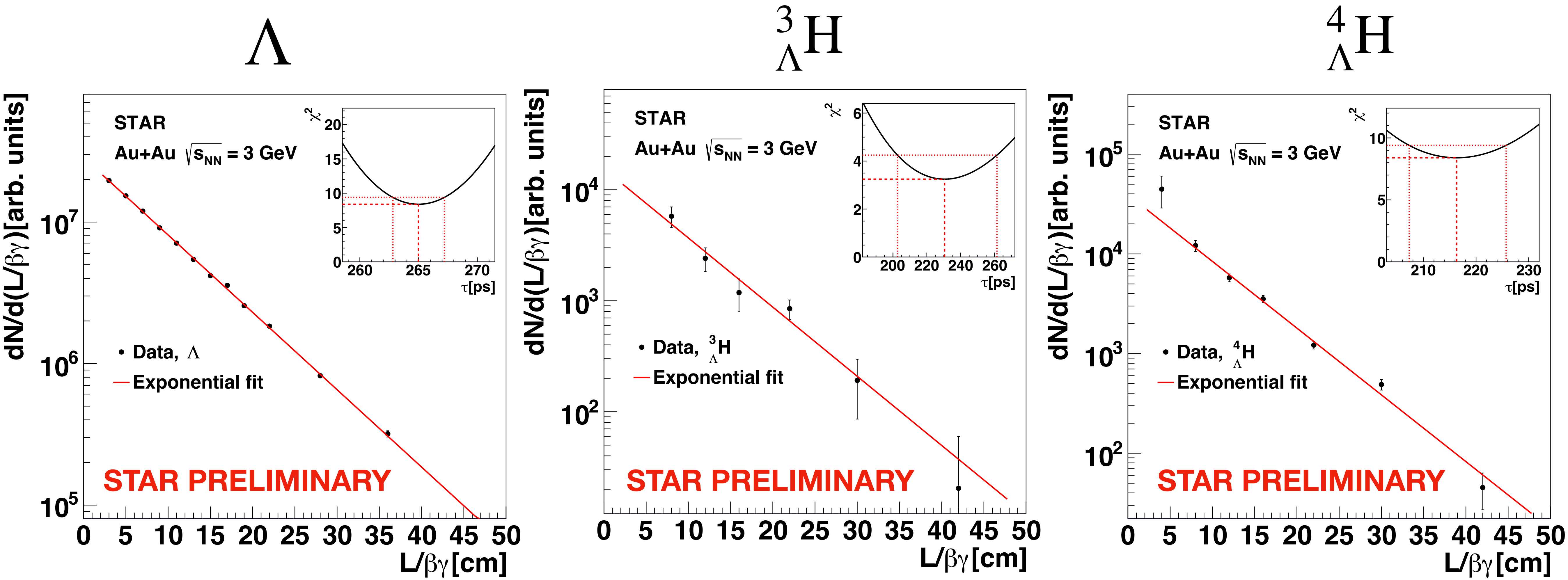


Background study



- Full simulation for quasi-free processes
- Angular distribution from the database,
- Tentative Fermi motion parameter from Ma-san

Lifetime analysis (cont.)



- **Yields of** Λ, $^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ **as a function of** $L/\beta\gamma$
  - **Well described by exponential functions** $N(t) = N_0 e^{-L/\beta\gamma c\tau}$
- **Lifetime extracted with** χ^2 **fit**
- **Extracted** Λ **lifetime** (265.0 ± 2.2)[ps] **consistent with PDG value** (263.1 ± 2.0)[ps]

Calculated 3-body decay spectrum

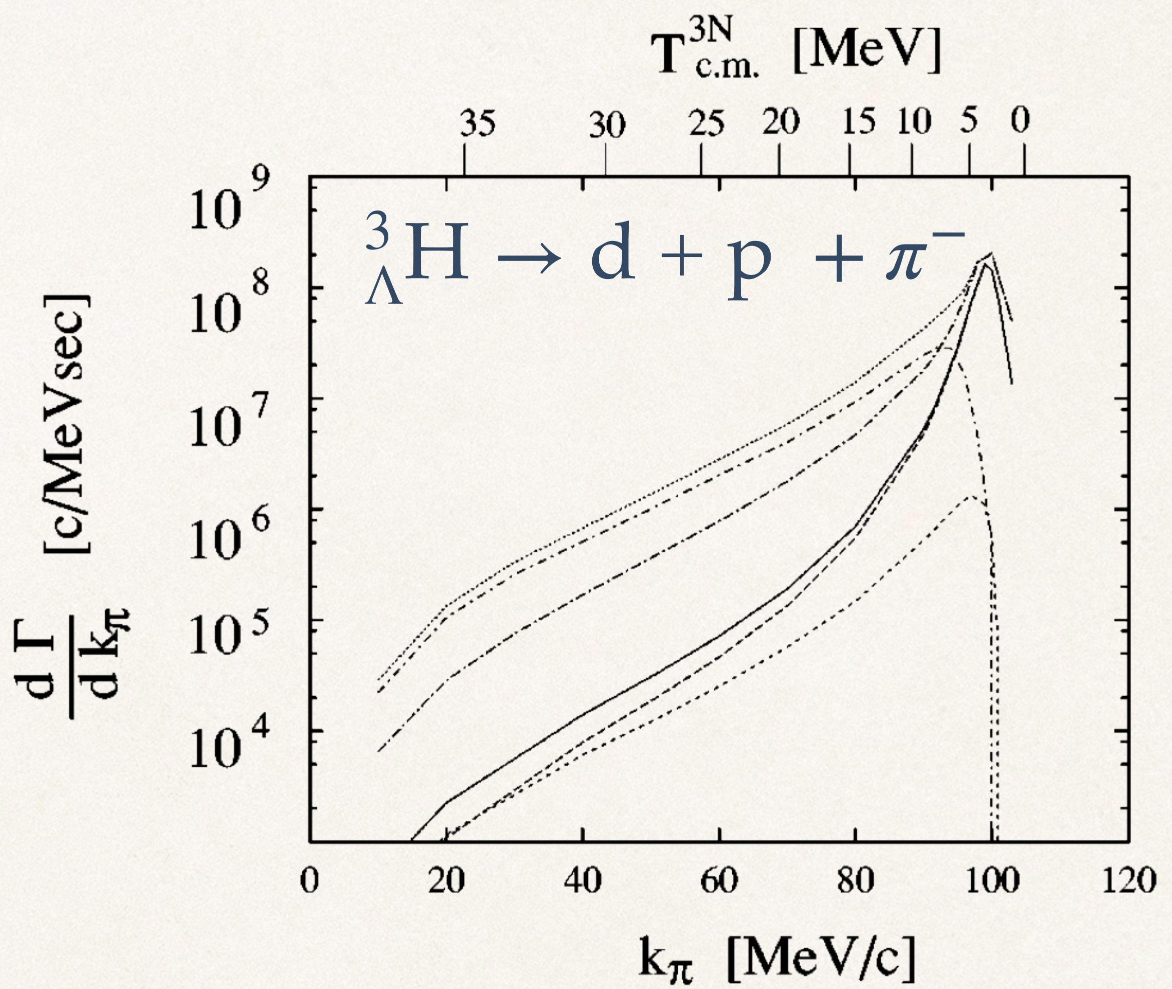
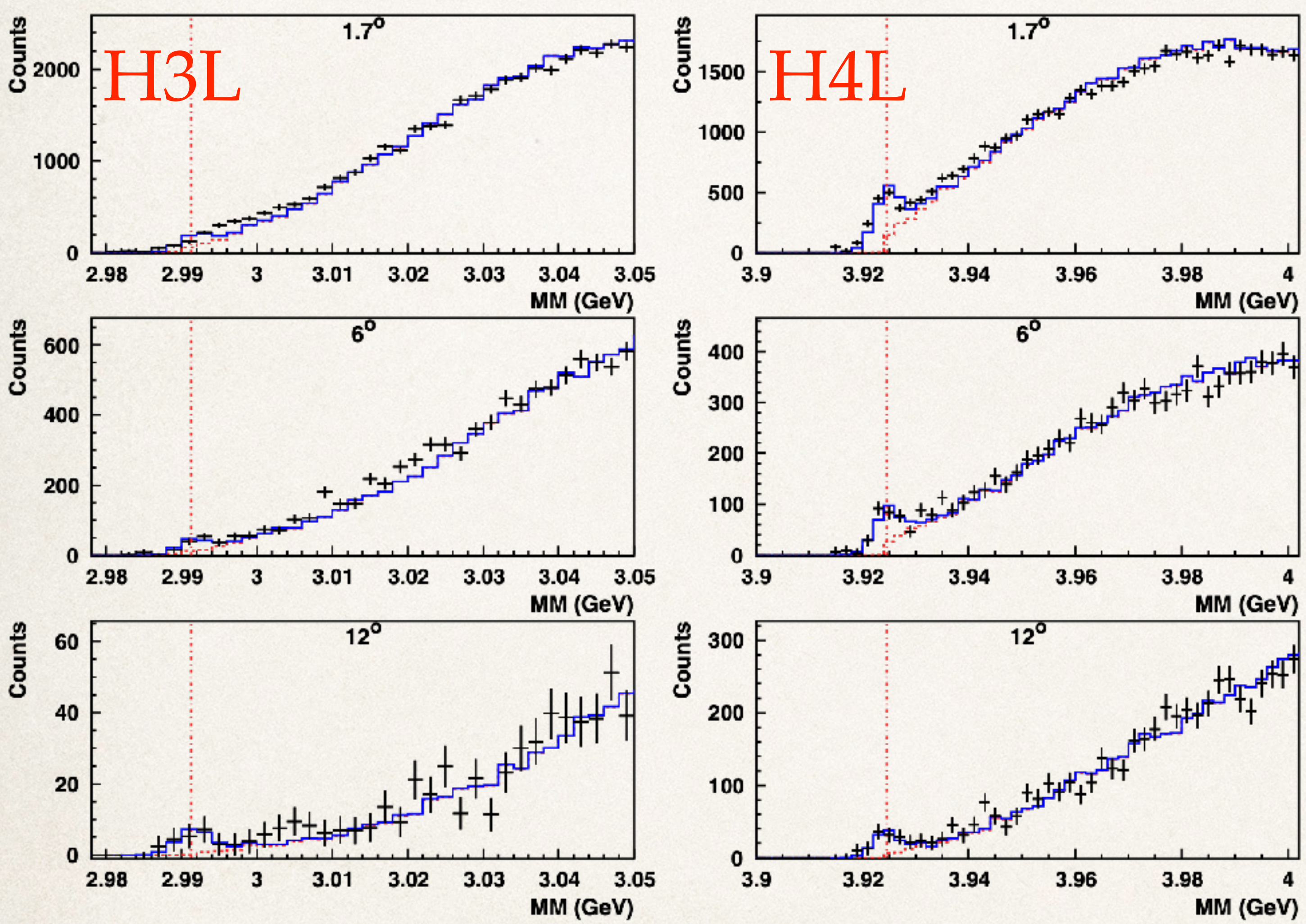


FIG. 4. Differential decay rates $d\Gamma^{p+d}/dk_\pi$ (long dashed curve), $d\Gamma^{p+p+n}/dk_\pi$ (short dashed curve), and their sum (solid curve) including FSI. Neglecting FSI the rates are drastically shifted: $d\Gamma^{p+d}/dk_\pi$ (long dashed dotted), $d\Gamma^{p+p+n}/dk_\pi$ (short dashed dotted), and their sum (dotted).

DOI:https://doi.org/10.1103/PhysRevC.57.1595

cross section & spin of Hypertriton

(e, e′K+) reaction @ J-Lab



- $^{4}_{\Lambda}$H contains both 0+ and 1+ states (spin-flip favored) in J-Lab results;
- $^{3}_{\Lambda}$H is pure 1/2+ or has a virtual 3/2+ state near threshold?
- Can not be distinguished with ~4MeV resolution

DOI: 10.1103/PhysRevLett.93.242501