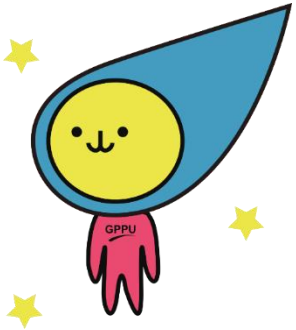
Study of 3-body system with S=-1

Nuclear physics lab.
Yuichi Toyama



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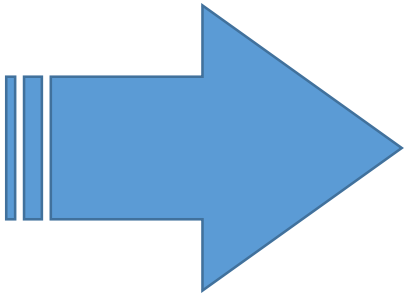
  - Goal of (hyper)nuclear physics
  - ${}^{3}_{\Lambda}\mathrm{H}$ puzzle
- My activities
  - Lifetime measurement of at ELPH
  - Binding energy measurement of at MAMI
  - nnΛ state search at JLab
- Summary & future plans

Goal of (hyper)nuclear physics

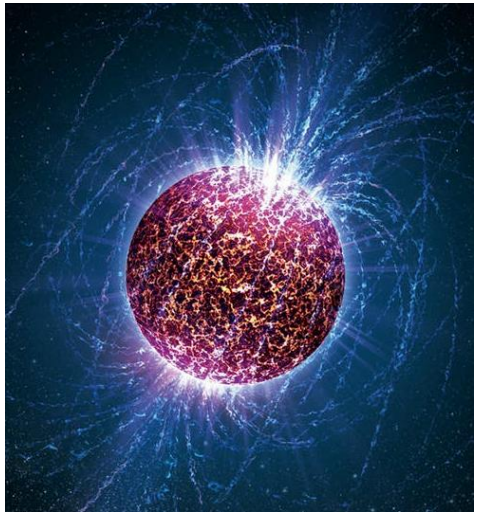
Understand deuteron(r~ a few fm) and neutron star(r~10 km)
in a same frame work

A = 2

r ~ fm



$A \sim 10^{57}$



r ~ 10 km

3-body system cannot be skipped!

Goal of (hyper)nuclear physics

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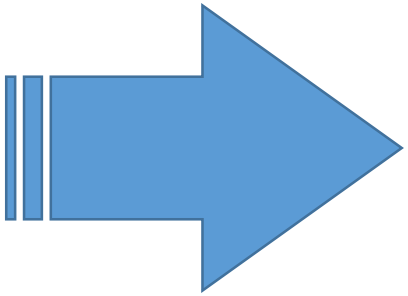
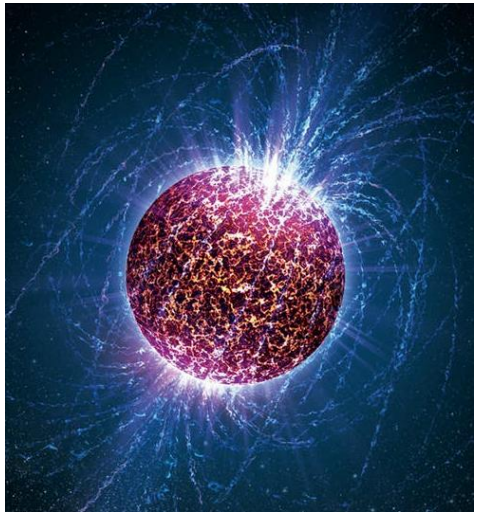


A ~ 10^{57}

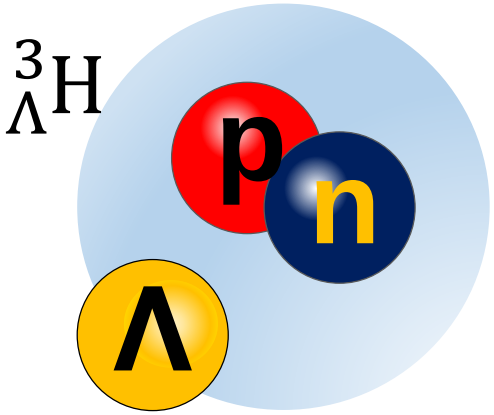


r ~ 10 km

3-body system cannot be skipped!

However, understanding of 3-body system with S = -1 is not enough!
($^{3}_{\Lambda}\mathrm{H}$ puzzle)

${}^{3}_{\Lambda}$H puzzle

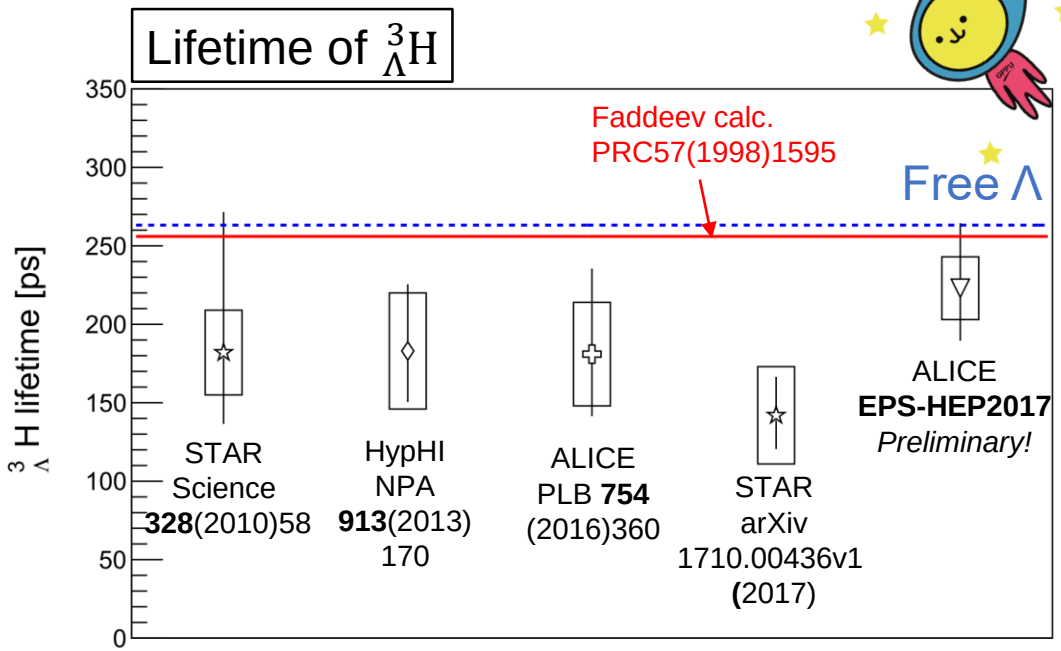


B_Λ~0.13 MeV[1]
(${}^{4}_{\Lambda}$H : B_Λ=2.12 MeV[2])

Shallow binding
~ Free Λ

τ ~200 ps
(Λ : τ =263 ps)

Short lifetime



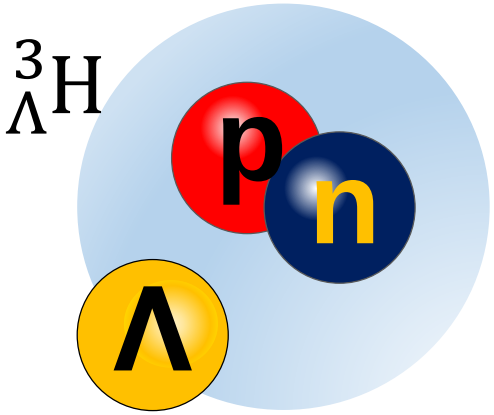
Shorter than free Λ?

Difficult to explain B_Λ and lifetime of ${}^{3}_{\Lambda}$H simultaneously

Precise measurement of ${}^{3}_{\Lambda}$H lifetime is required

[1] M.Juric *et al.*, Nucl. Phys. **B 52**(1973) 1-30.
[2] S.Nagao, Doctoral thesis 2015 Tohoku University. ;
A.Esser, S.Nagao, F.Schulz *et al.*, Phys. Rev. Lett. **114**(2015)222501.

${}^{3}_{\Lambda}$H puzzle



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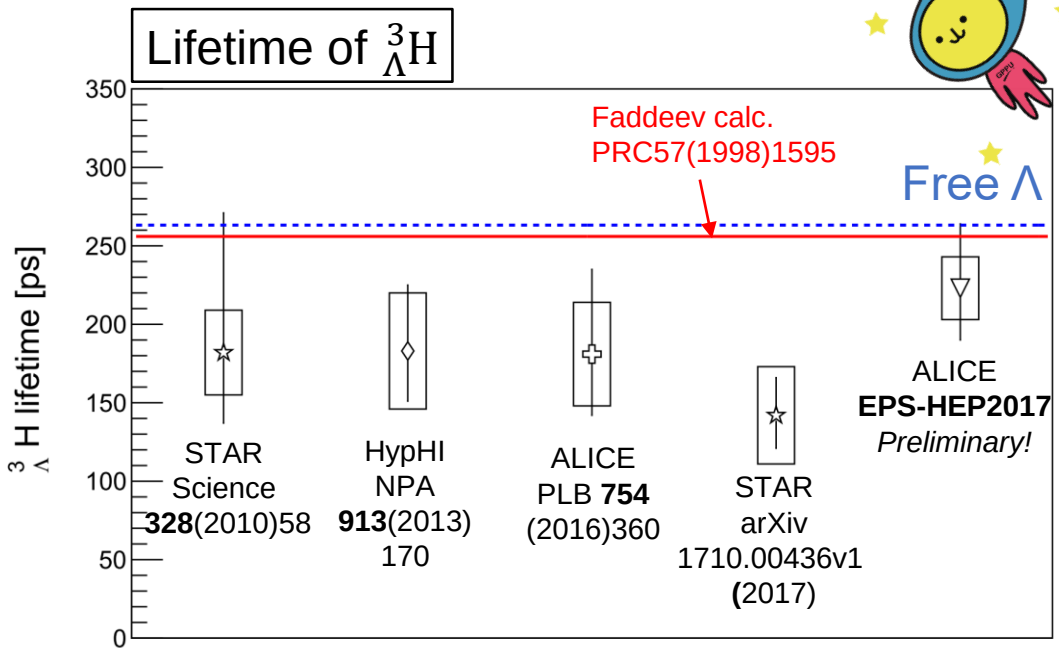


Shorter than free Λ?

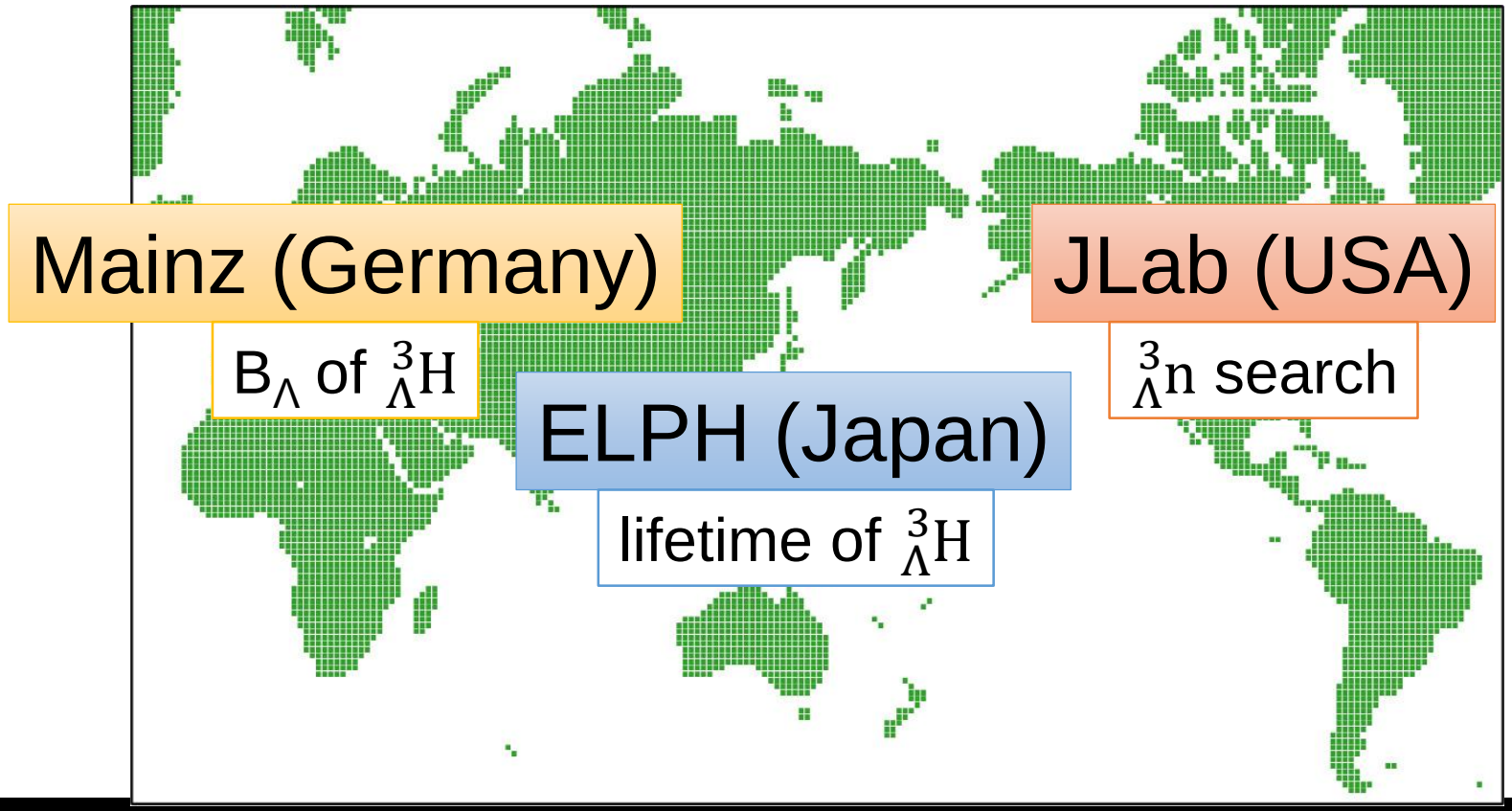
Difficult to explain B_Λ and lifetime of $^{3}_{\Lambda}$H simultaneously

Solution of the puzzle from lifetime measurement

- Short lifetime ⇒ Deep bound system more than expected (nnΛ can be bound?)
- Long lifetime ⇒ Systematic error of previous experiment

Experimental approach to ${}^{3}_{\Lambda}\mathrm{H}$ puzzle

- ${}^{3}_{\Lambda}\mathrm{H}$: lifetime & B_Λ
- ${}^{3}_{\Lambda}\mathrm{n}$: exist or not



My activities in last semester

- Lifetime measurement of ${}^{3}_{\Lambda}\mathrm{H}$ at ELPH (Japan)
  - Analysis of phase0 experiment
- Binding energy measurement of ${}^{3}_{\Lambda}\mathrm{H}$ at MAMI (Germany)
  - Test experiment for systematic error suppression
- nnΛ state search at JLab (the U.S.)
  - Detector test using cosmic rays

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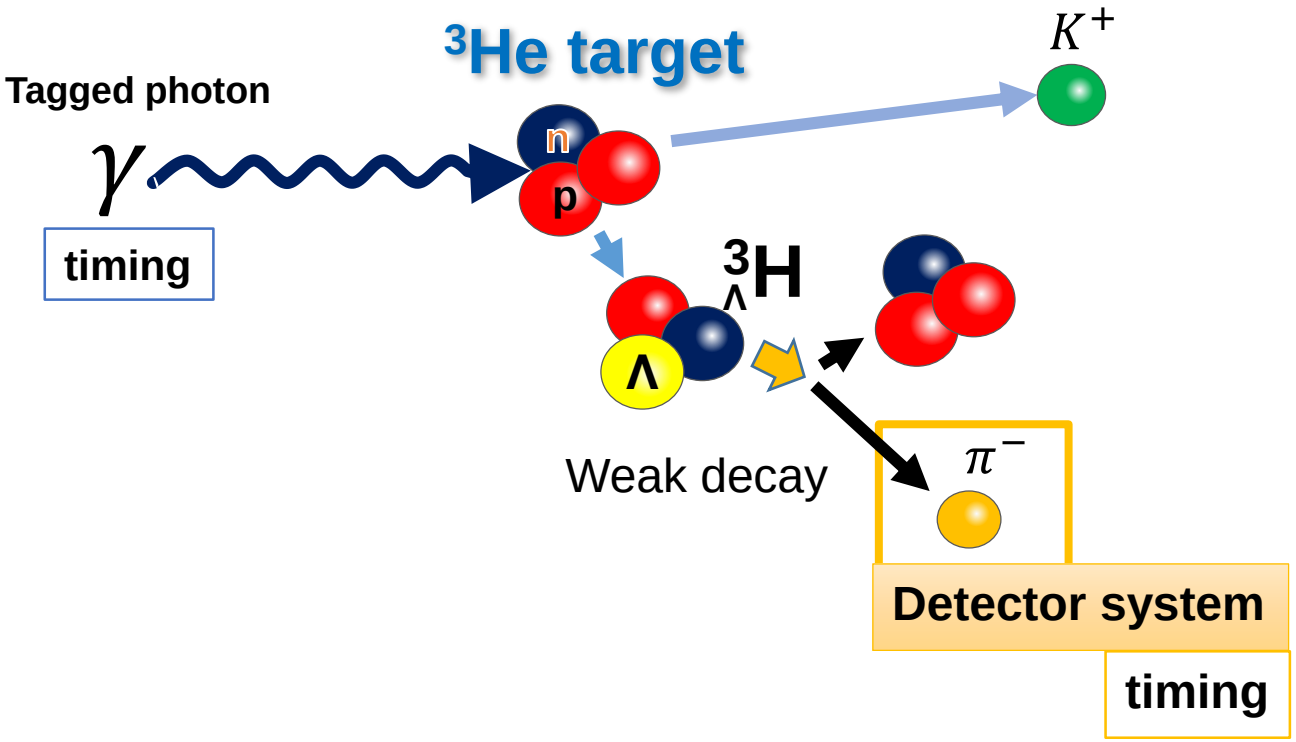
Lifetime measurement at ELPH



- Different experimental method from heavy ion collision exp.
  - Different systematic error

⇨ Need to establish experimental method

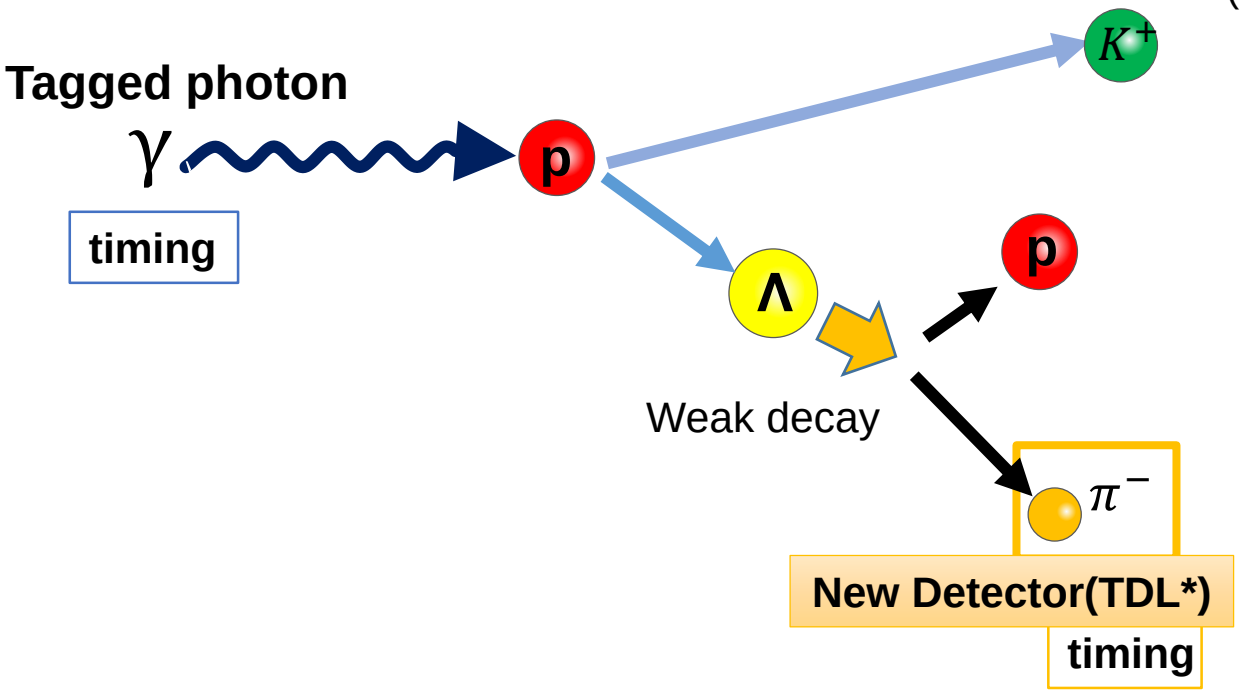
Phase0 experiment at ELPH

Apr. 2017

Is it possible to measure lifetime of hypernuclei(τ~200 ps) at ELPH?

⇒ Show feasibility of lifetime measurement of hypernuclei using Λ

(τ_Λ=263.2±2.0 ps)



* Timing counter for Direct Lifetime measurement

Phase0 experiment at ELPH

Apr. 2017

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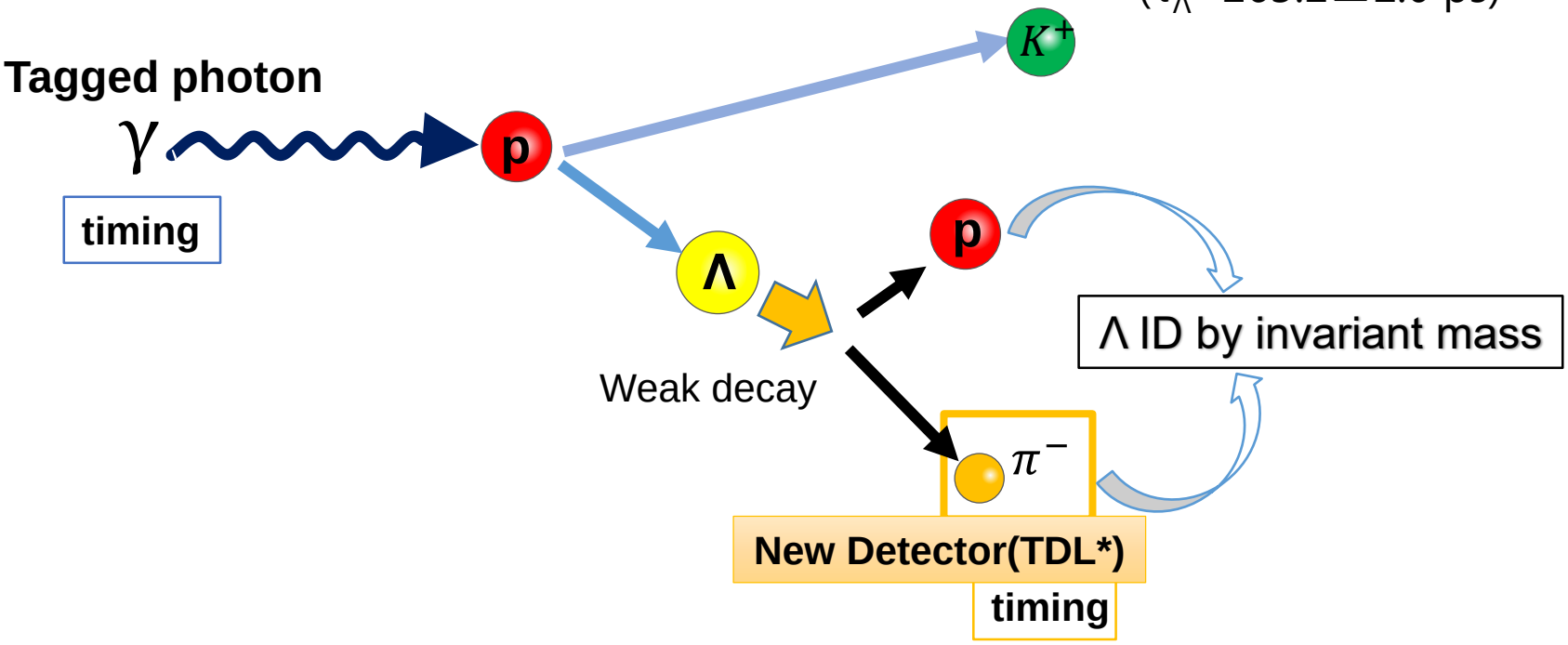


$$t_{decay} = (t_{TDL} - ToF_\pi) - (t_{Tag} + ToF_\gamma)$$

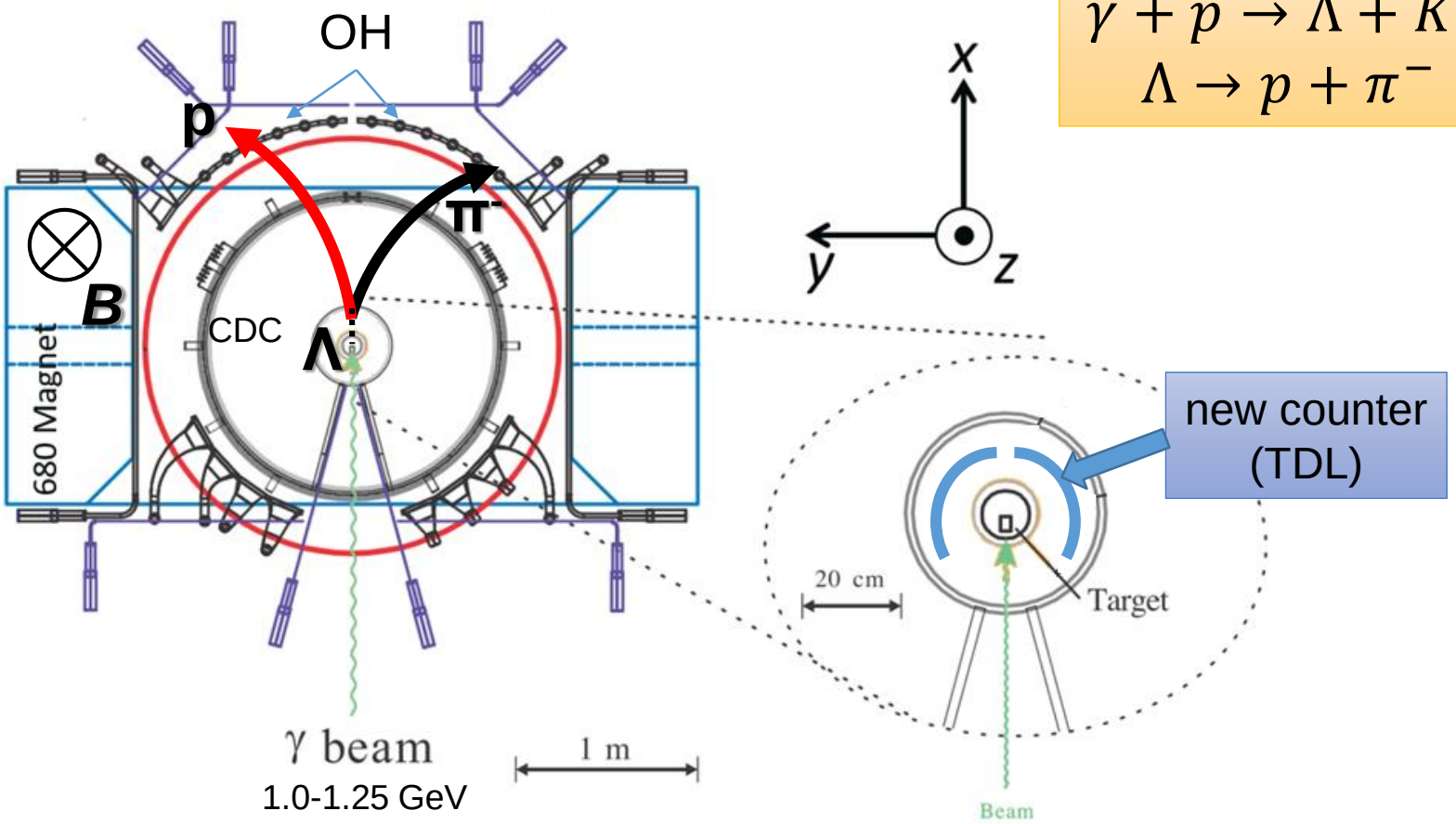
* Timing counter for Direct Lifetime measurement

Setup of phase0 exp. at ELPH

Top view of NKS2

Apr. 2017

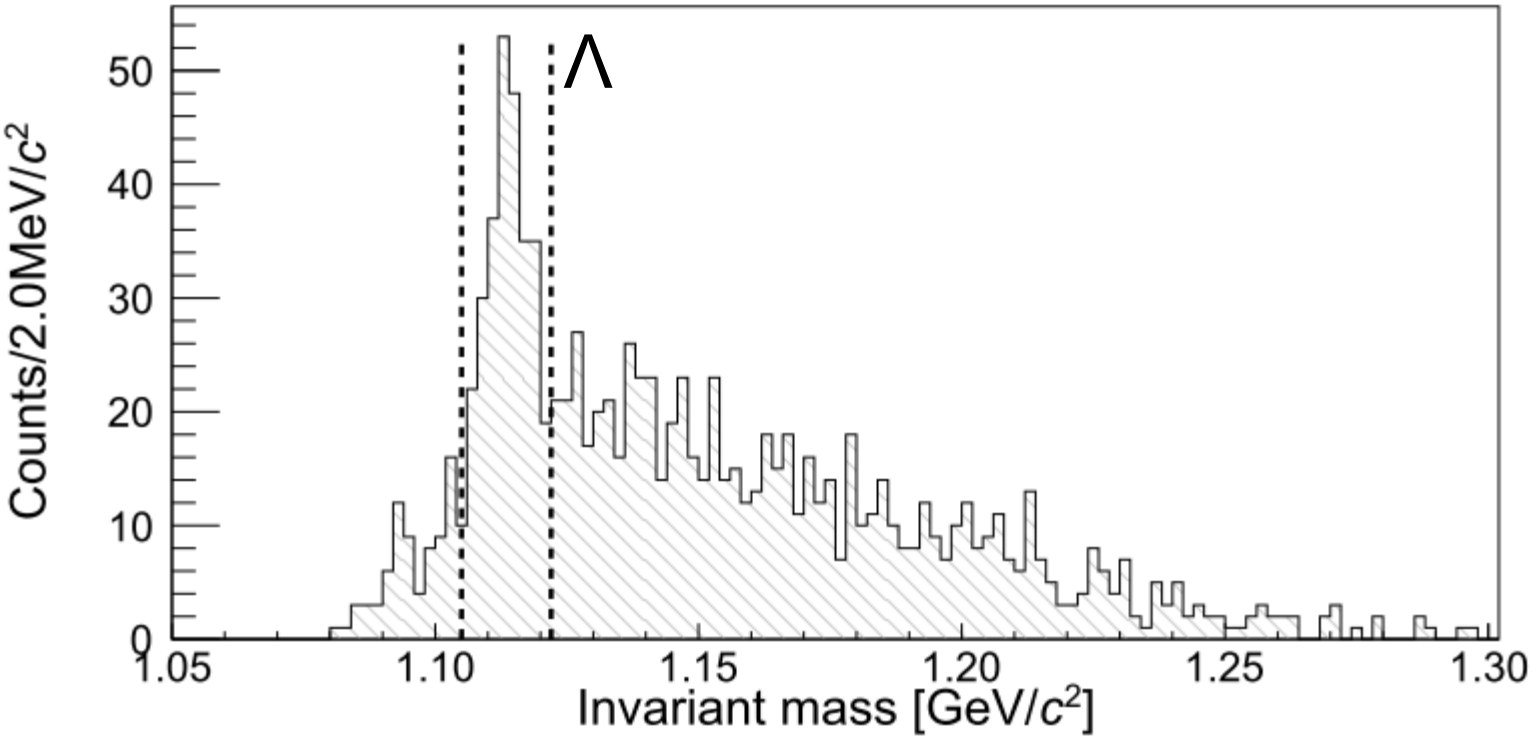
$$\gamma + p \rightarrow \Lambda + K^+$$
$$\Lambda \rightarrow p + \pi^-$$



$$t_{decay} = (t_{TDL} - ToF_{\pi}) - (t_{Tag} + ToF_{\gamma})$$

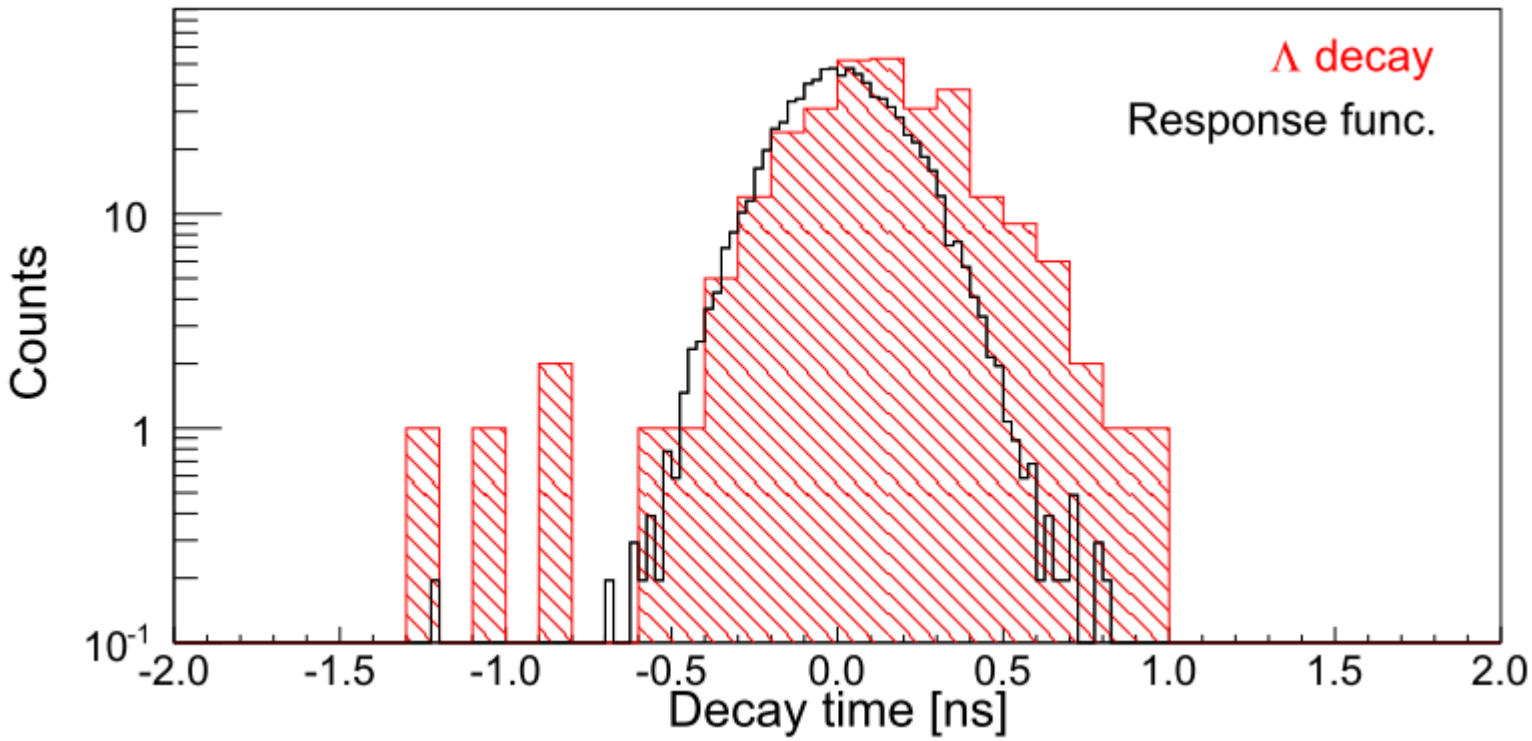
Invariant mass of p & π^-

$$M_{inv} = \sqrt{\left(E_p + E_\pi\right)^2 - \left(\boldsymbol{p_p} + \boldsymbol{p_\pi}\right)^2} \quad (c=1)$$



Clear peak of Λ

Decay time spectrum

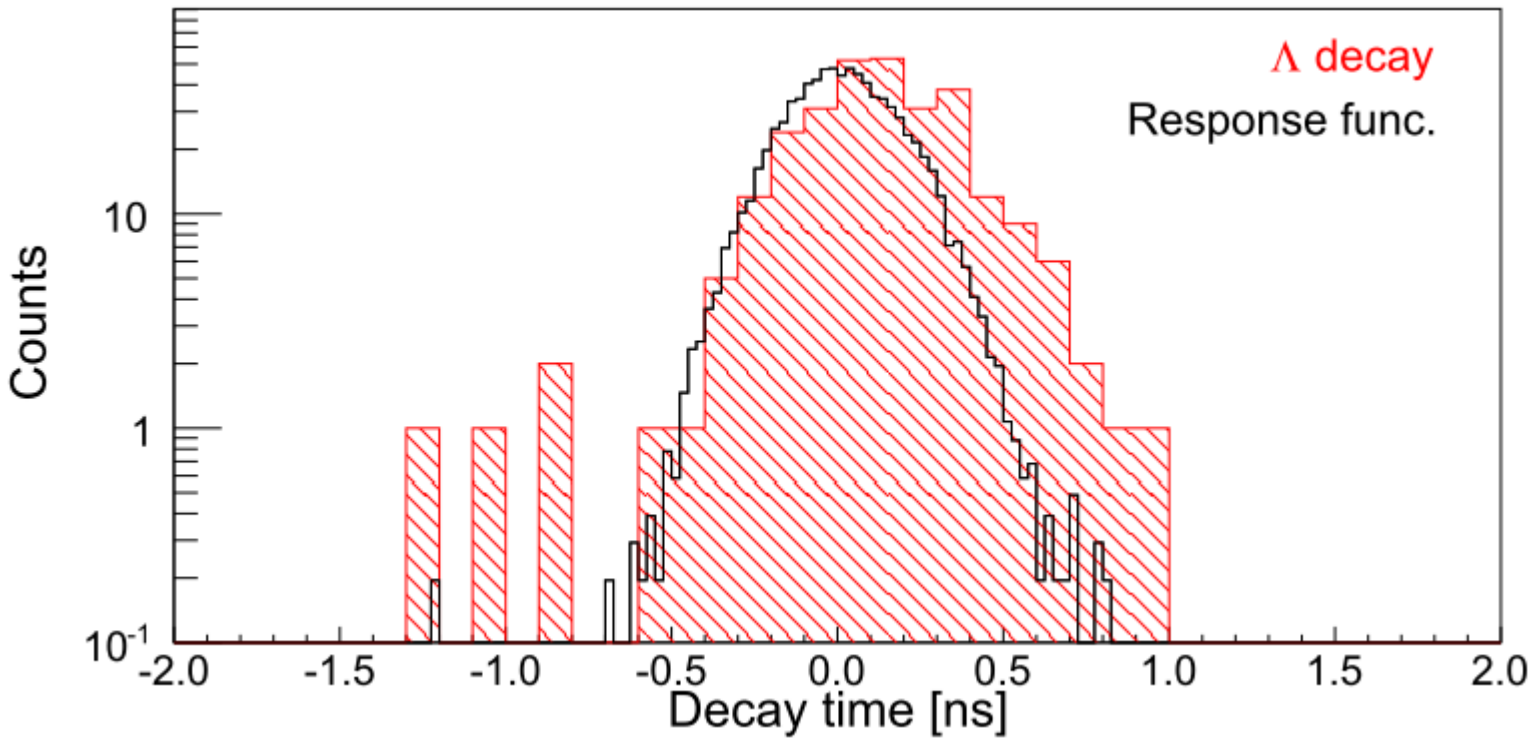


$$t_{decay} = (t_{TDL} - ToF_{\pi}) - (t_{Tag} + ToF_{\gamma})$$

Response function : $\gamma + p \rightarrow p + \pi^{-} + \pi^{+}$

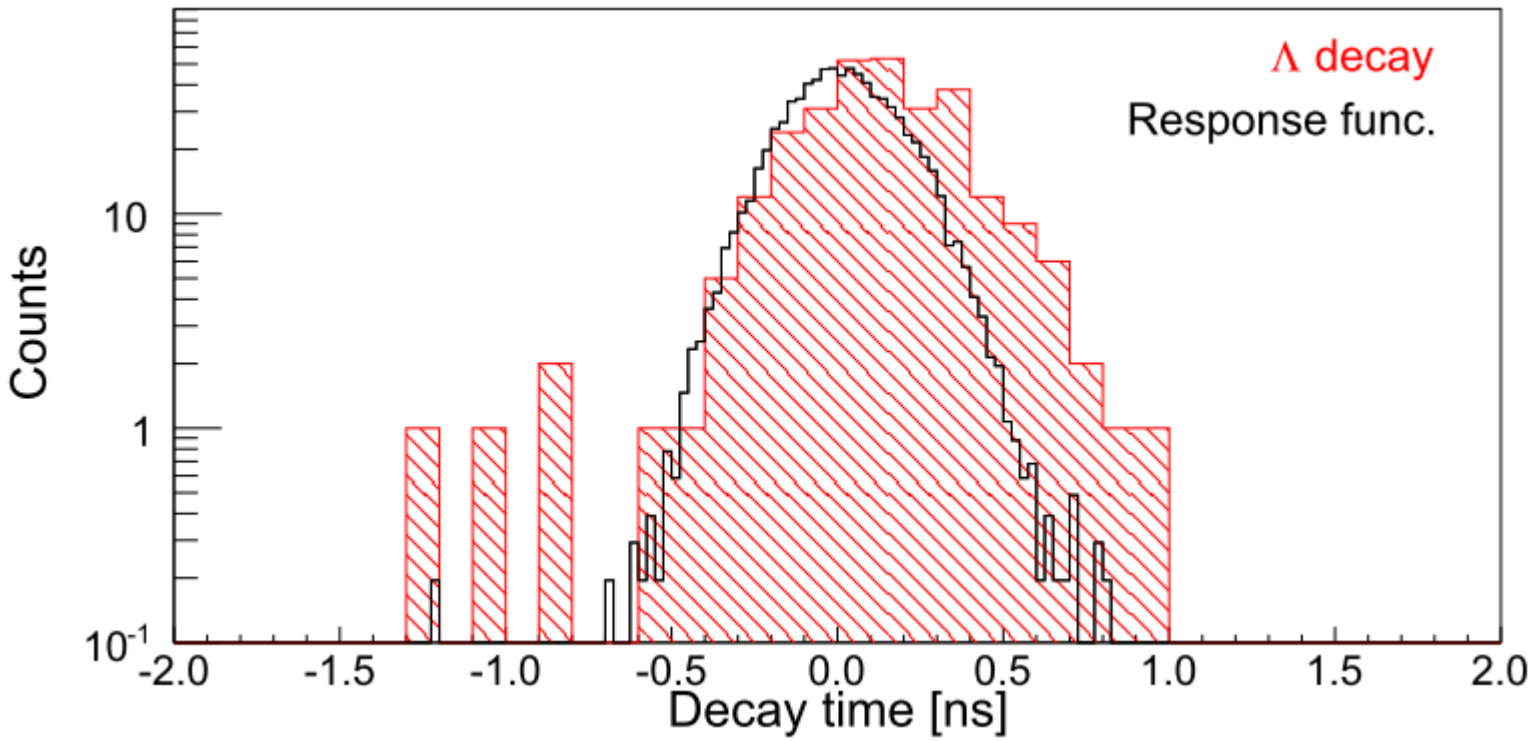
Delayed component can be seen.

Decay time spectrum



That's one small step for [a] man, one giant leap for mankind.
Neil Alden Armstrong

Decay time spectrum



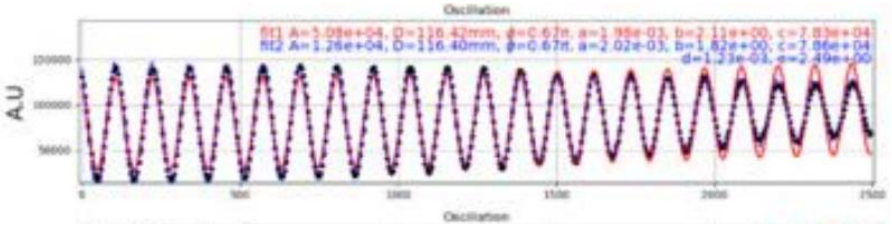
That's one small step for [a] man, one giant leap for mankind.
Neil Alden Armstrong

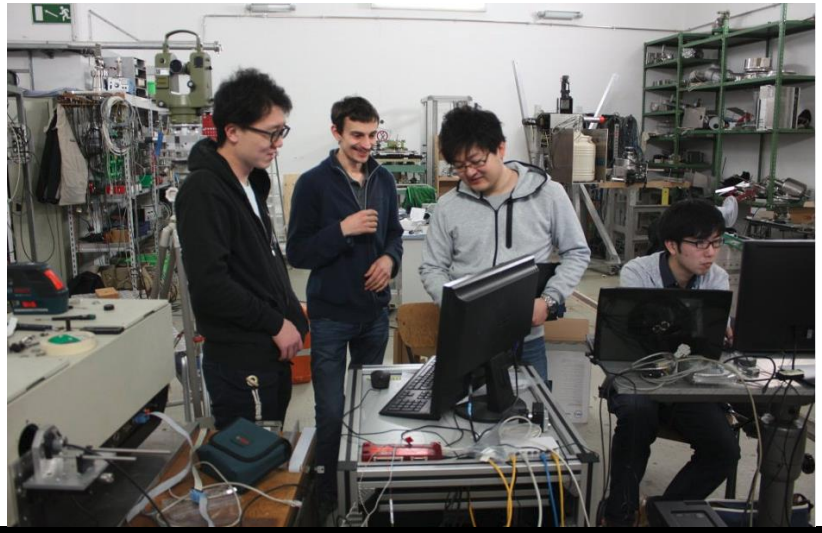
That's one small step for mankind, one giant leap for me.
Yuichi TOYAMA

Activities at Mainz and JLab

Mainz (Feb. 2018)

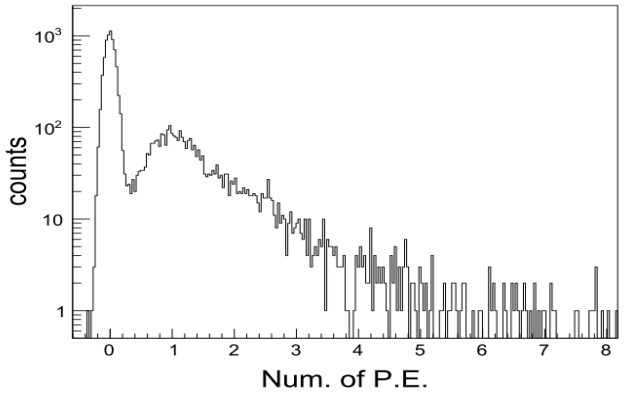
Beam energy calibration exp.

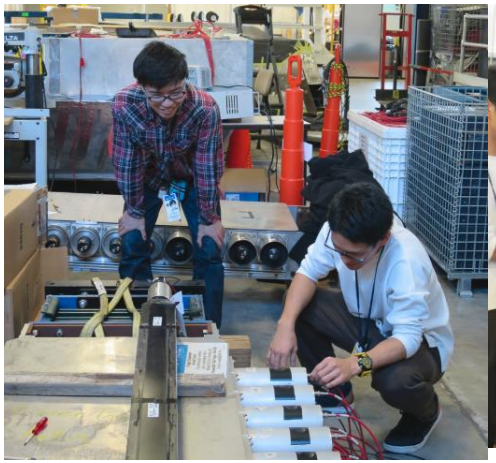


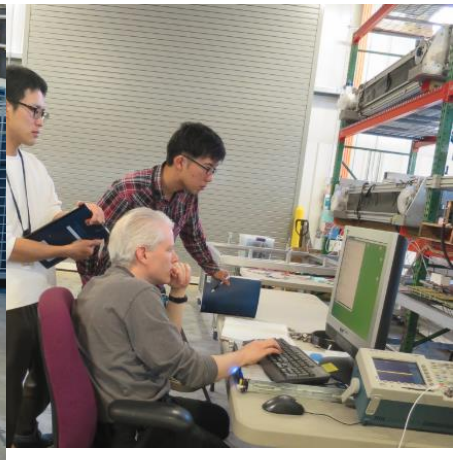


JLab (Nov. 2017)

Aerogel Cherenkov detector test







Summary and future plans

Lifetime measurement of ${}^{3}_{\Lambda}\mathrm{H}$ at ELPH

- Phase0 exp. analysis
  - First observation of delayed component from hyperon decay

- Activities at Mainz and JLab
  - Beam energy calibration exp. using undulators at Mainz
  - Detector test at JLab

Summary and future plans

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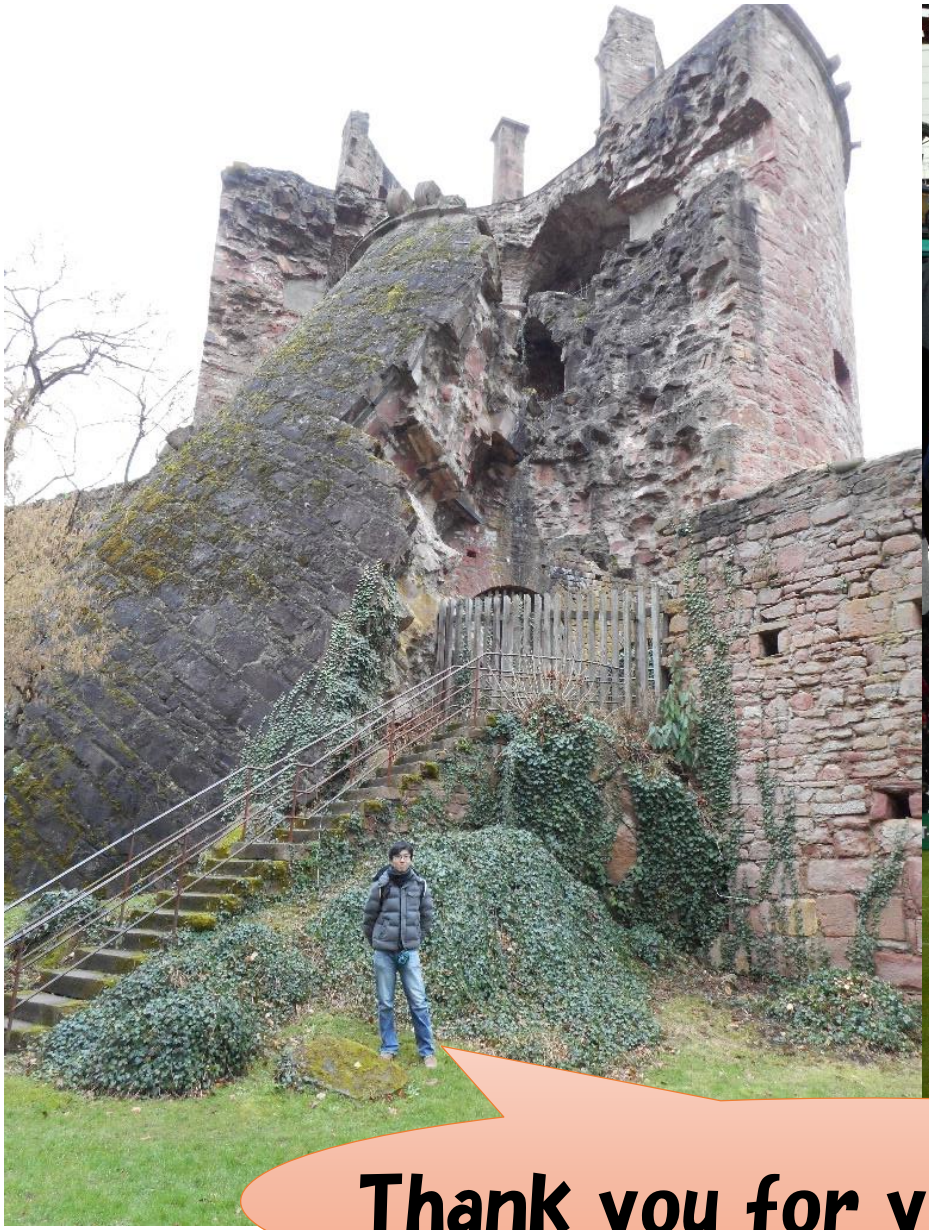
◆ Future plan of lifetime project
- π detector system test exp. Oct. 2018
- Hypernuclear spectroscopy at ELPH Jan. 2019
- ${}^{3}_{\Lambda}\mathrm{H}$ lifetime measurement 2020

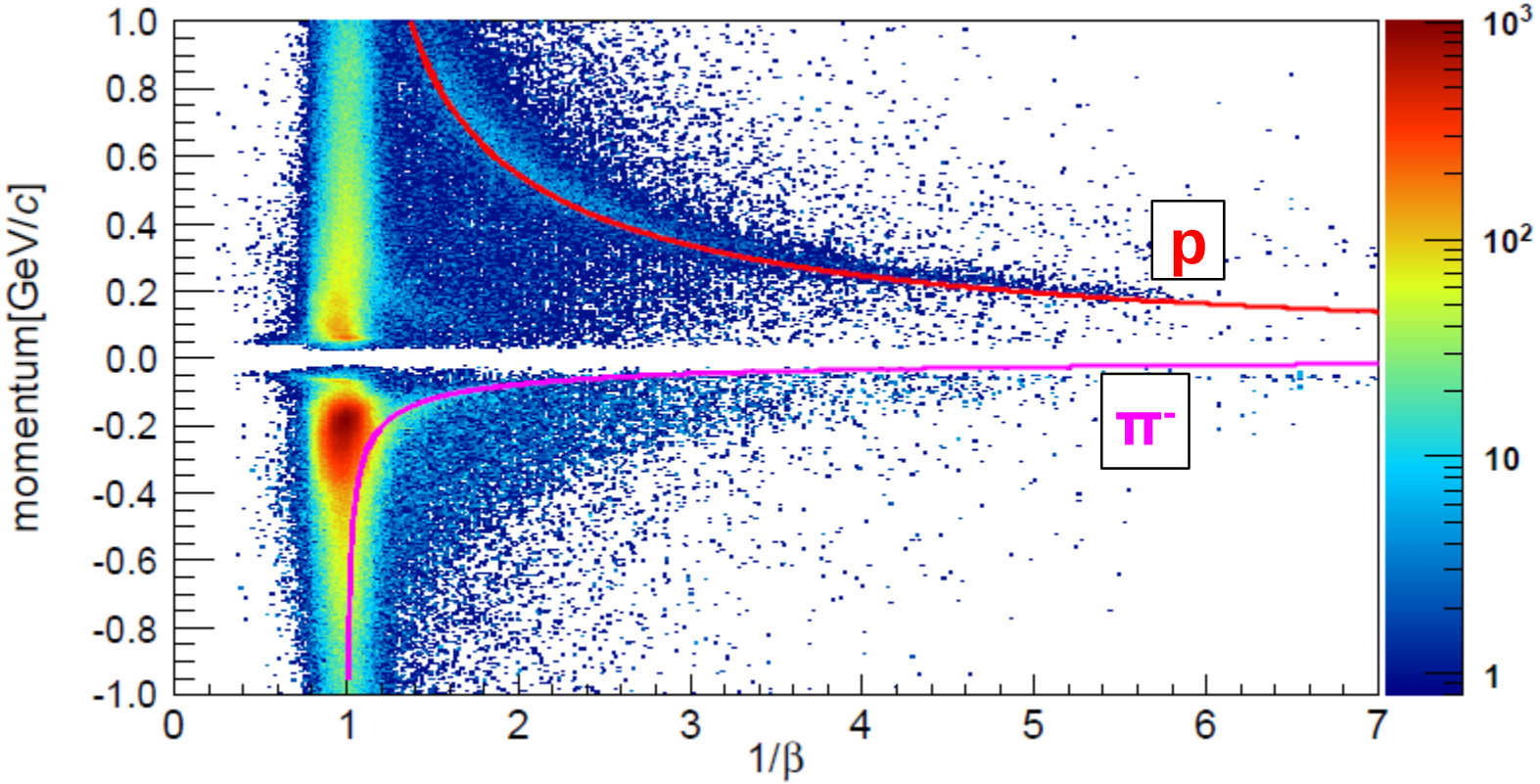
◆ **Overseas training**
- JLab Jun. 22nd – Jul. 15th



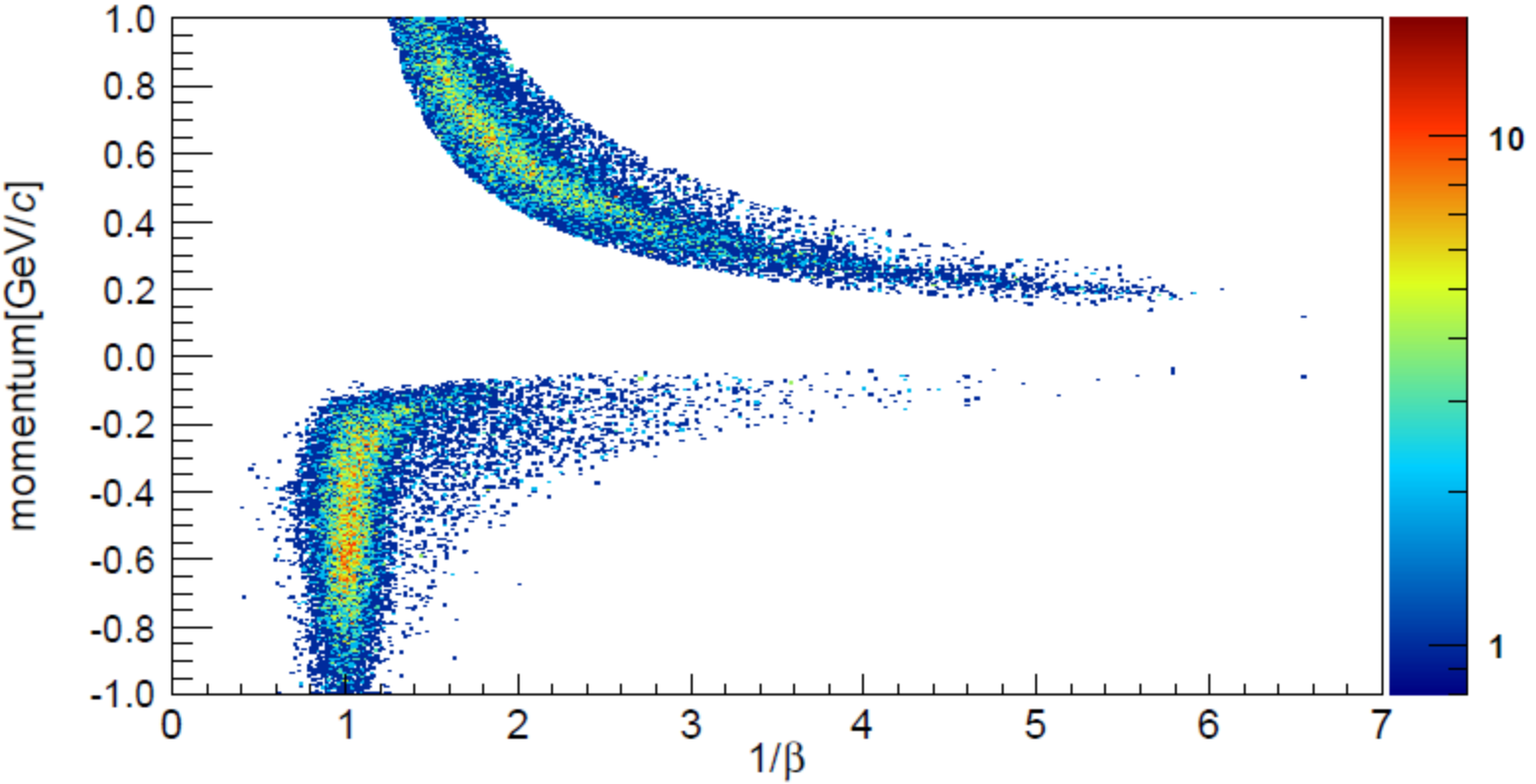
Thank you for your attention.

Backup

Particle ID

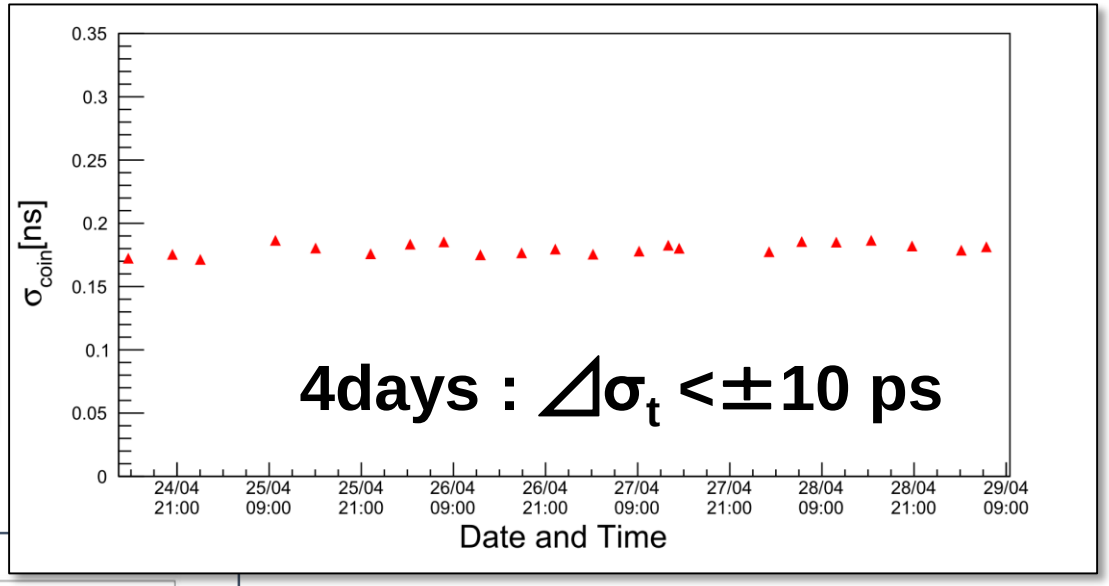

momentum[GeV/c]
1/β
p
π-
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
1
2
3
4
5
6
7
10³
10²
10
1

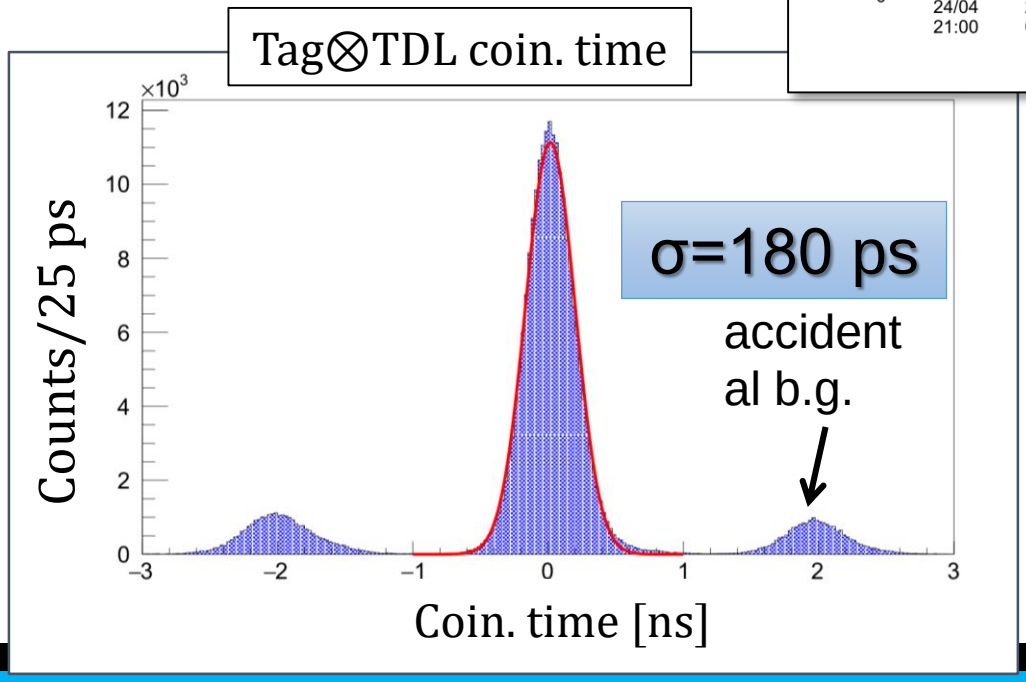
PID (p&π)



Detector performance

Requirements for a detector
- Good time resolution <100 ps
- ✓ Compact design
- ✓ Work in magnetic field
- ✓ Stable performance (~month)





Component	σ [ps]
TDL (π detector)	**140**
Production point	100
Photon tagger	50
Total	180

Strategy of hypertriton lifetime measurement

^{3}He target is very expensive ⇒ Feasibility exp. is quite important.

10 days exp.
Performed!

Λ lifetime

April 2017

Analysis.

Detector development.

Detector test exp.

June 2018
Accepted 10 shifts

$^4_\Lambda$H lifetime

Jan. 2019

$^3_\Lambda$H lifetime

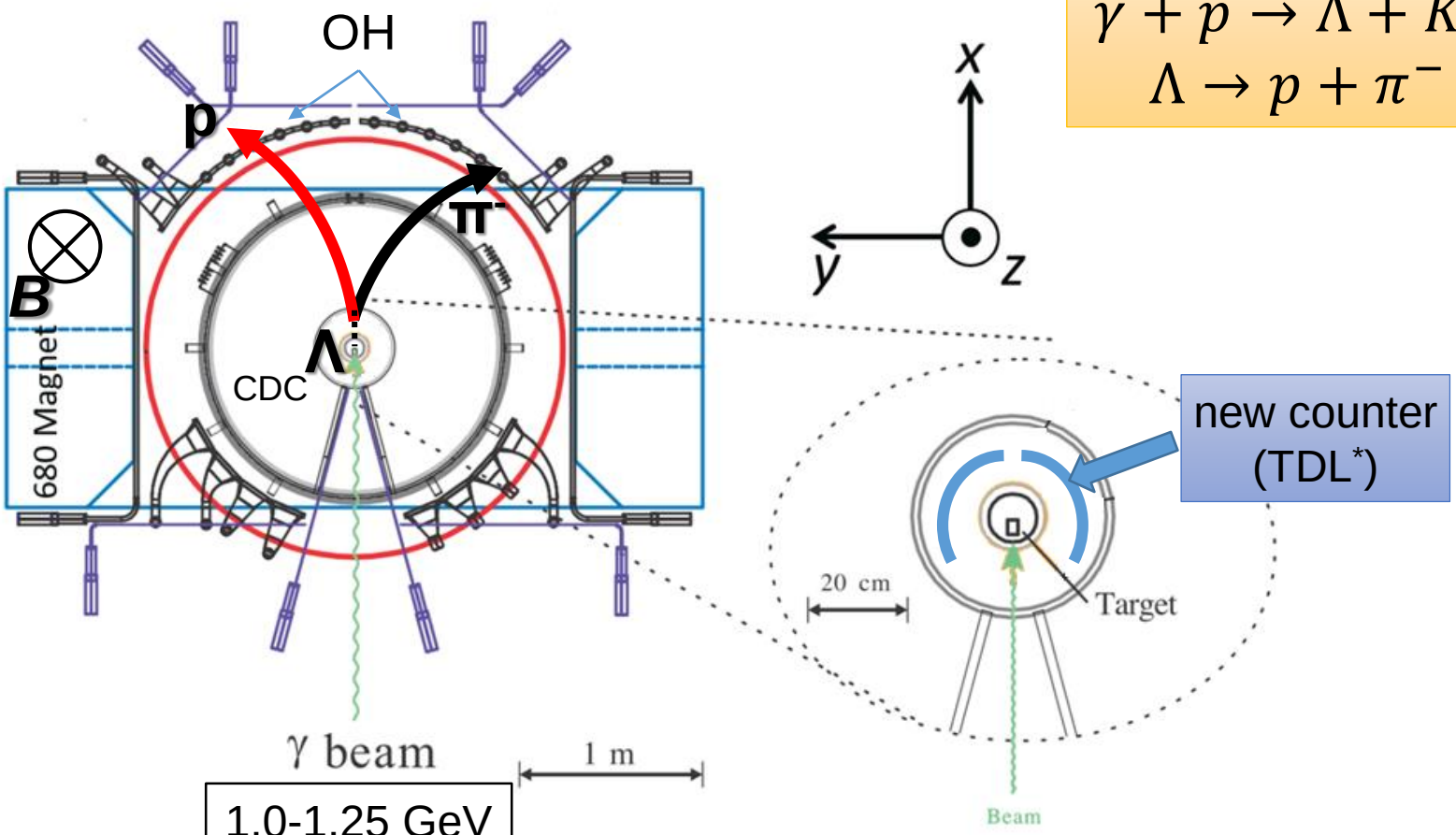
2020(?)

Setup of phase0 exp. at ELPH

Top view of NKS2

Apr. 2017 (10 days)

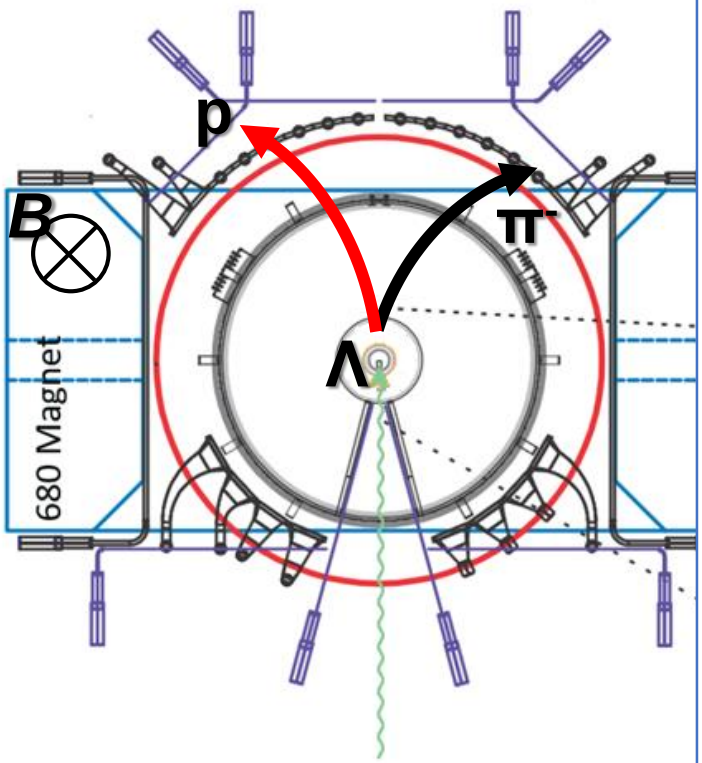
$$\gamma + p \rightarrow \Lambda + K^+$$
$$\Lambda \rightarrow p + \pi^-$$



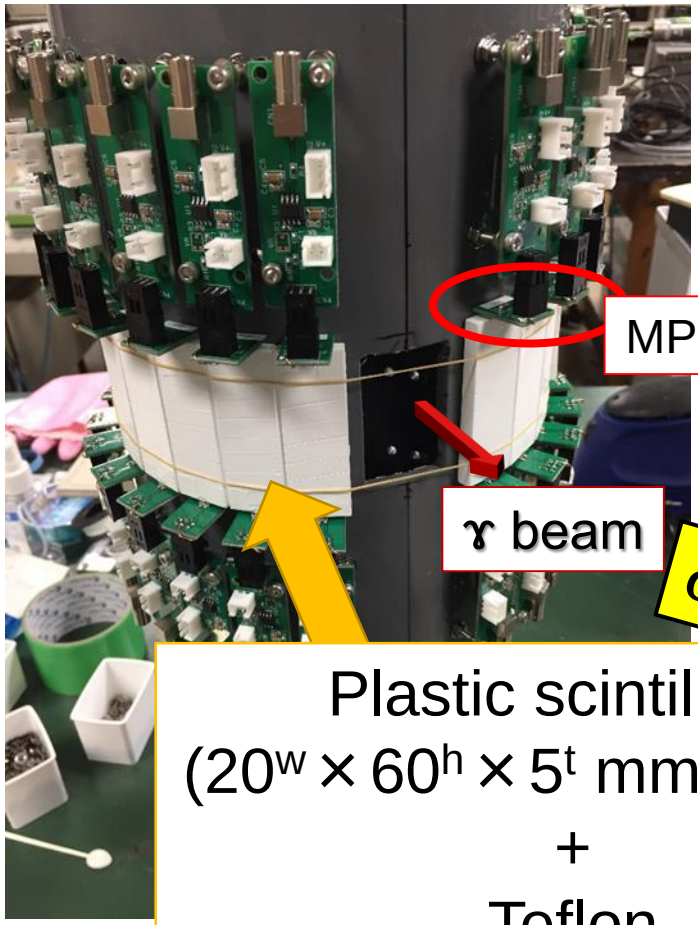
* Timing counter for Direct Lifetime measurement

Setup for Λ lifetime m

Top view of NKS2



1.0-1.25 GeV



$\sigma_t = 140$ ps

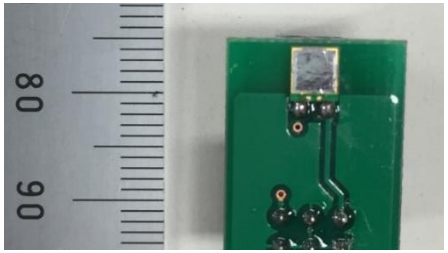
Plastic scintillator
($20^w \times 60^h \times 5^t$ mm^3, EJ212)
+
Teflon
(as reflective material)

* Timing counter for Direct Lifetime measuremen

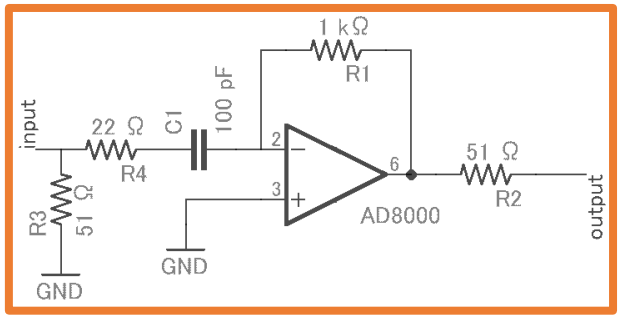
New detector for decay π

Timing counter for Direct Lifetime measurement (TDL)

Requirements for a detector
- Good time resolution <100 ps
- Compact design
- Work in magnetic field
- Stable performance (~month)



SiPM(MPPC S13360-3050PE)

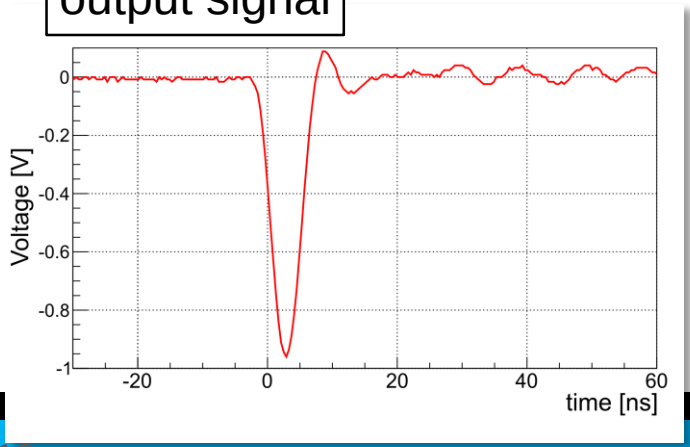


SiPM : MPPC (Hamamatsu)
3x3 mm^2 effective area
50 μm pixel pitch

Amp. circuit
Op. amp : AD8000 (Analog Device)
inversed differential circuit

Readout
QTC module + CAEN V1290(TDC)

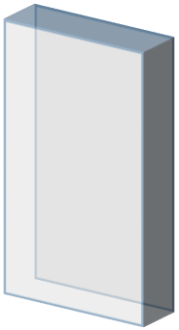
output signal

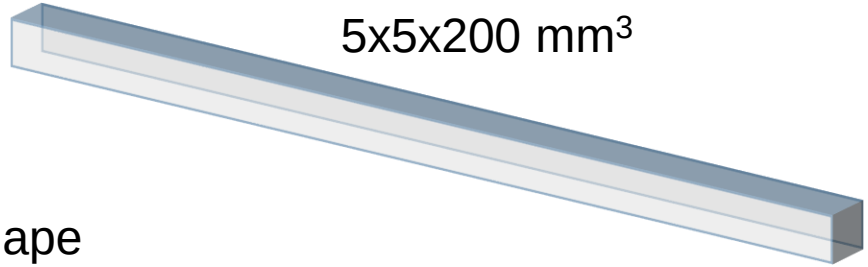


Detector update plan

- TDL resolution(140 ps) was main component of response function

20^{w} x 60^{h} x 5^{t} mm^3

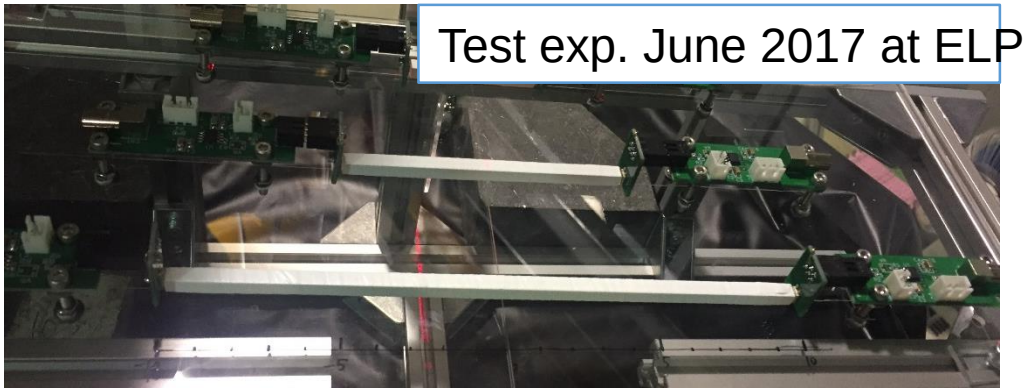




5x5x200 mm^3

If scintillator shape was changed…

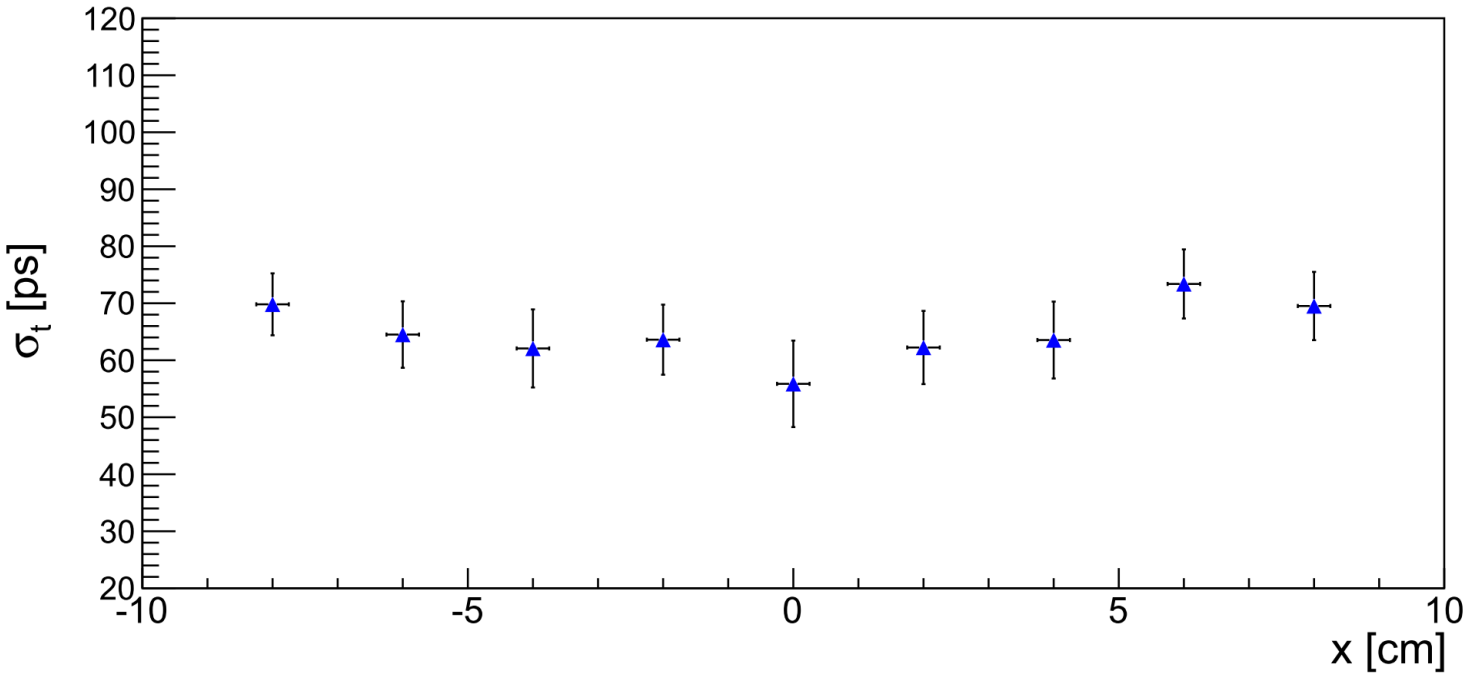
σ_t = 140 ps



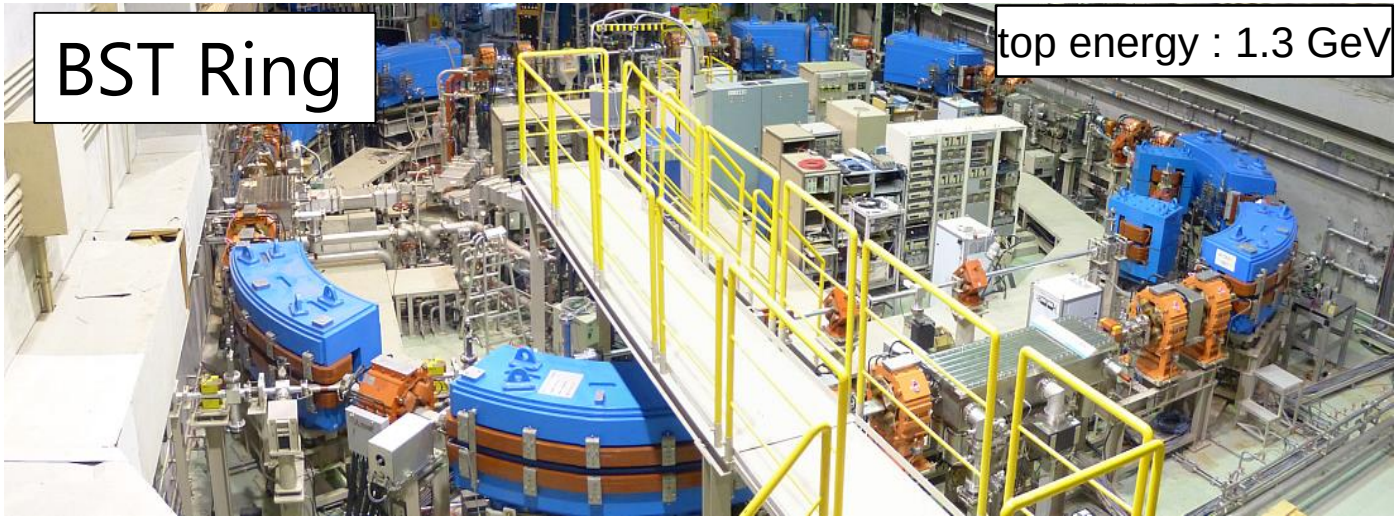
Test exp. June 2017 at ELPH

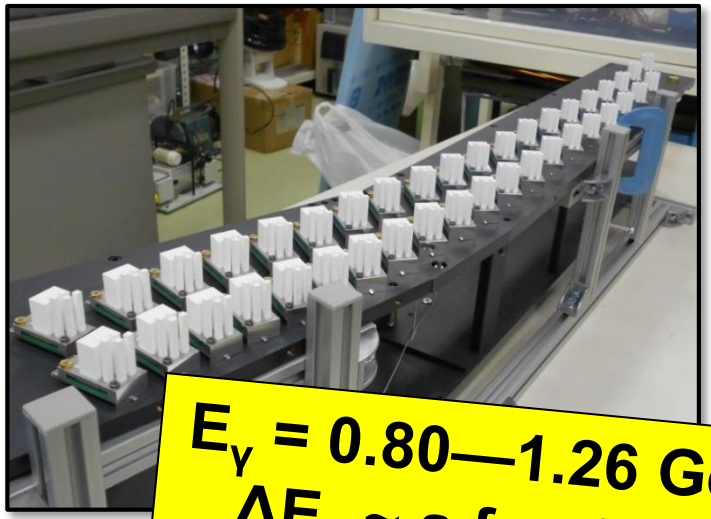
σ_t = 60 ps

Detector update plan

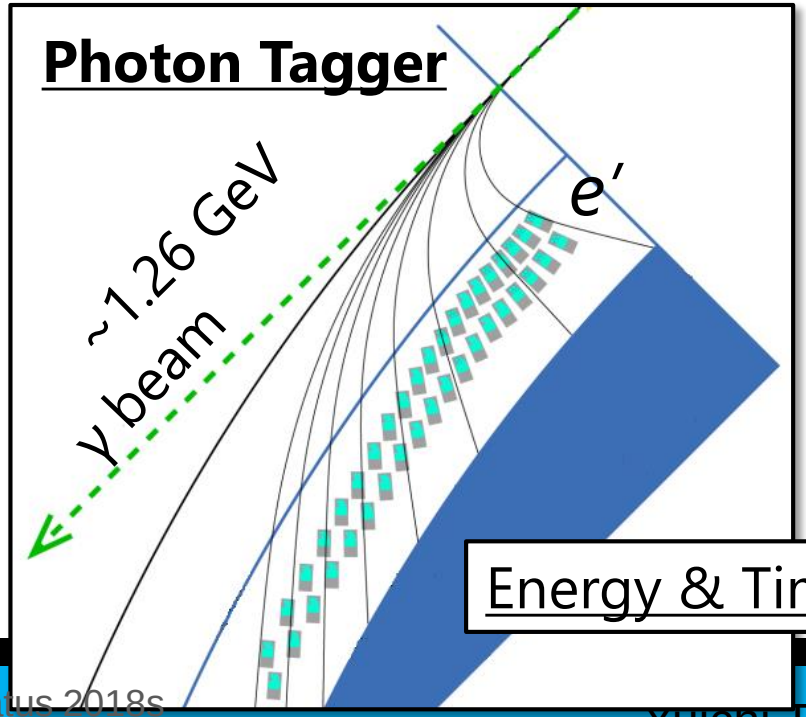


Photon beam at ELPH

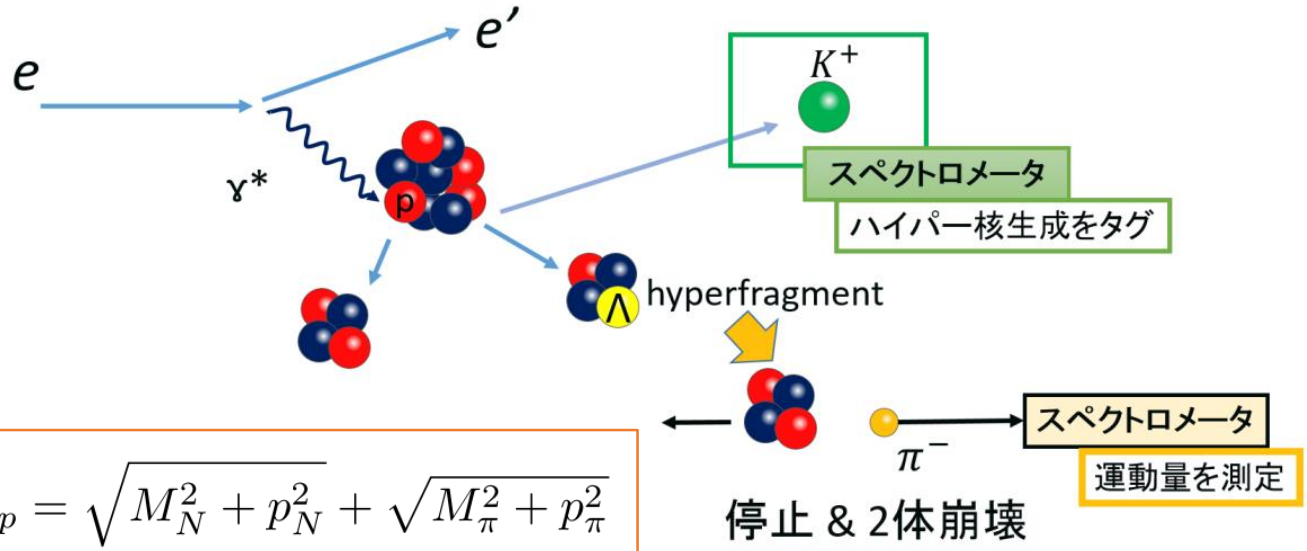




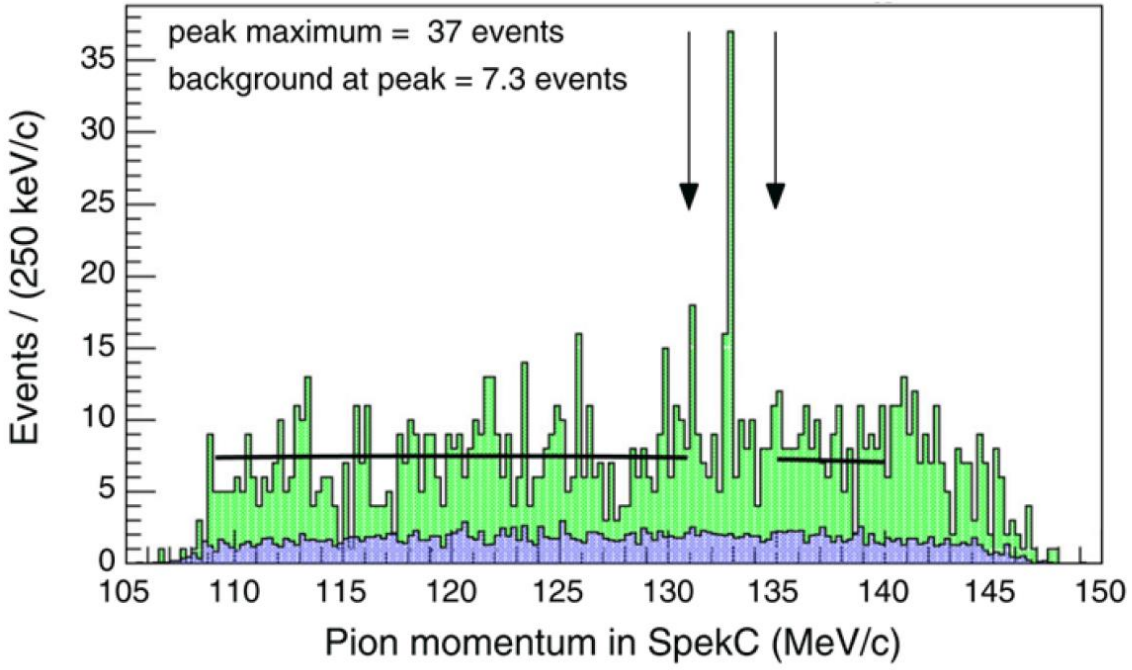
E_γ = 0.80—1.26 GeV
ΔE_γ ~ a few MeV
σ_t = 50 ps



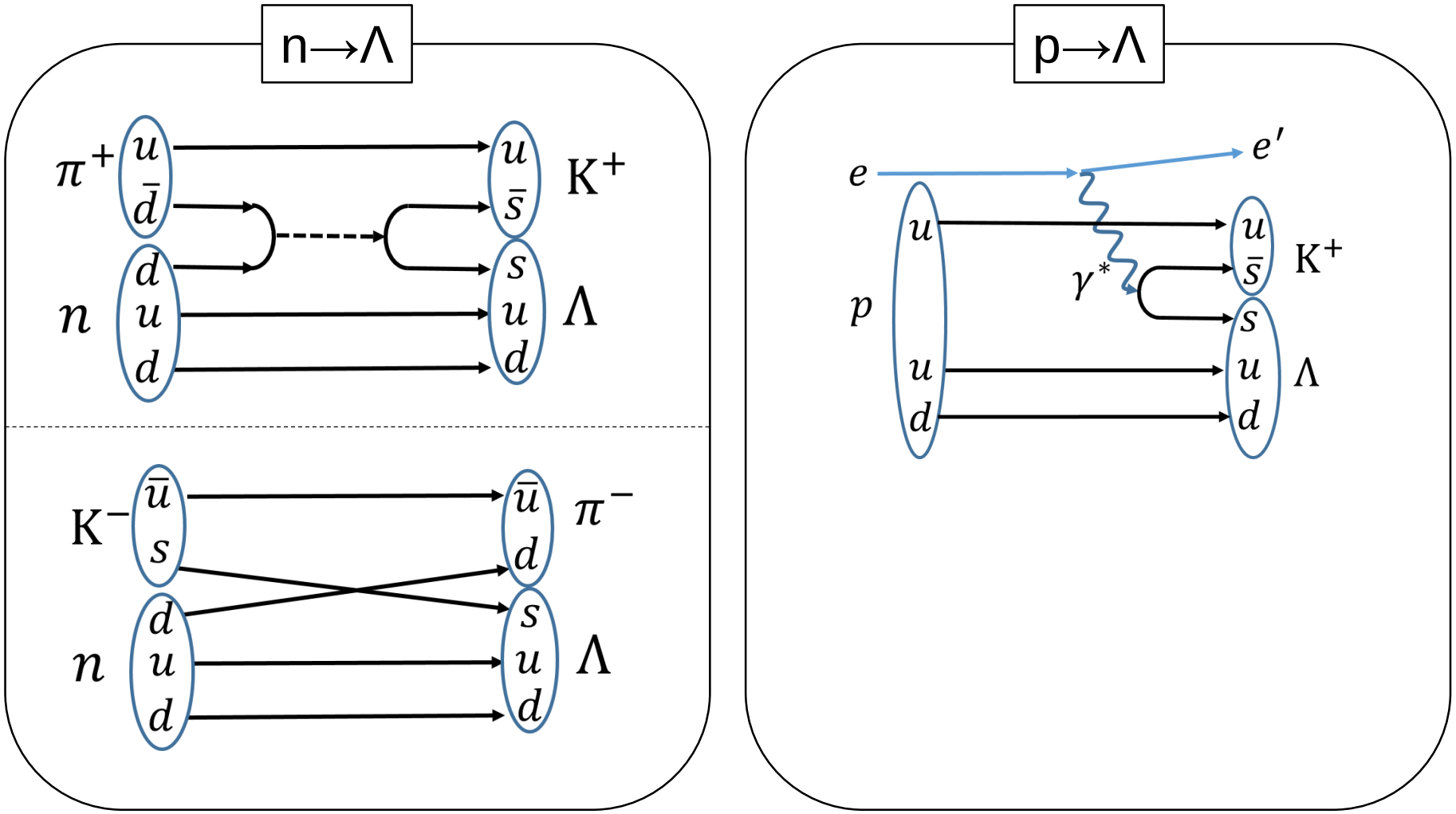
B_Λ



$$M_{hyp} = \sqrt{M_N^2 + p_N^2} + \sqrt{M_\pi^2 + p_\pi^2}$$

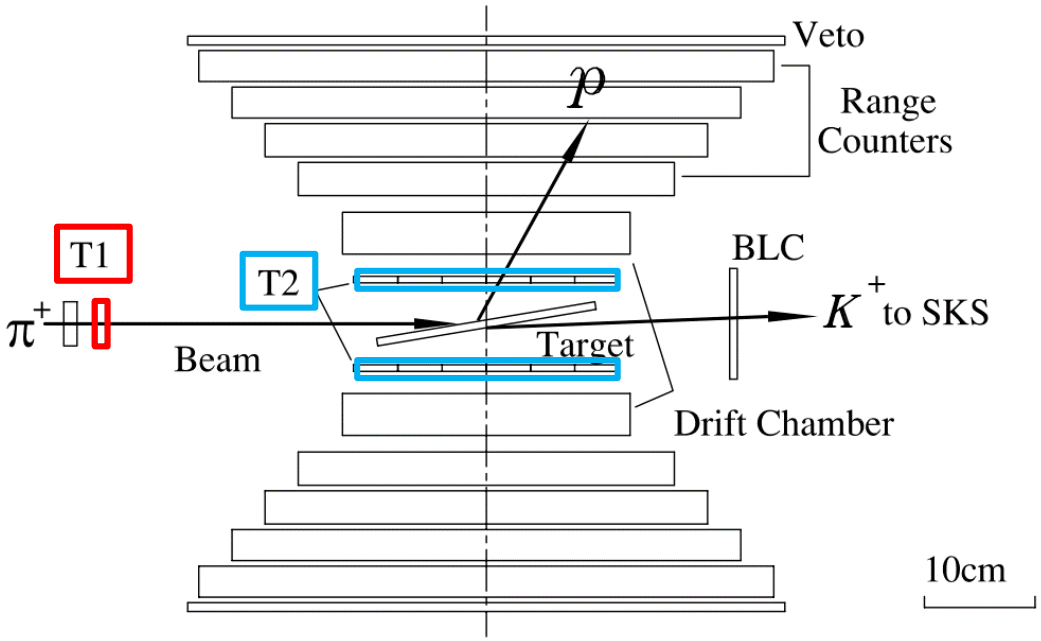


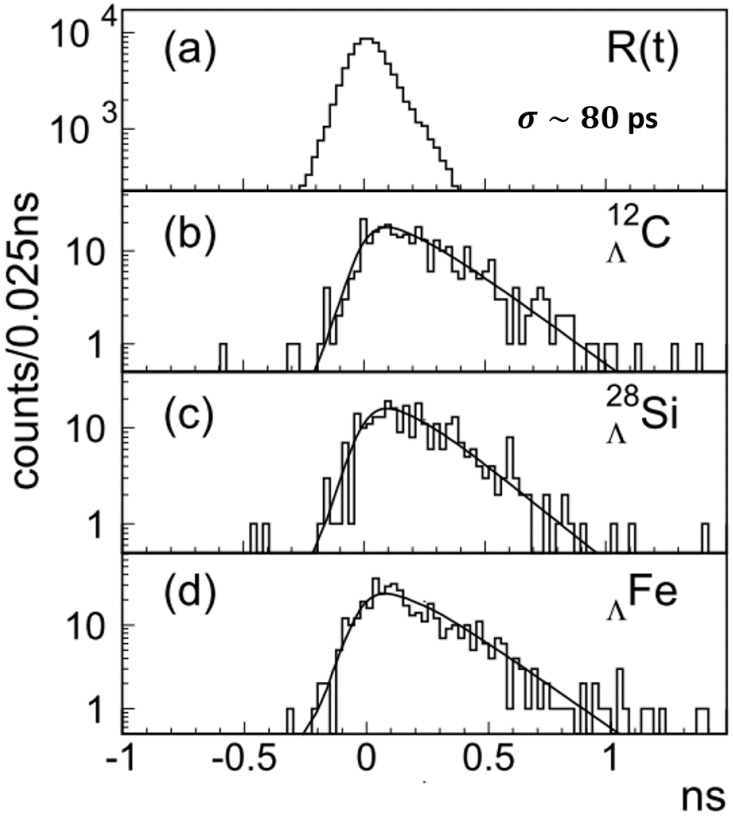
Λ hypernucleus production



Previous experiment @KEK

- (π^+, K^+) reaction





$$t_d = (\mathrm{T2} - TOF_2) - (\mathrm{T1} + TOF_1)$$

Target to T2

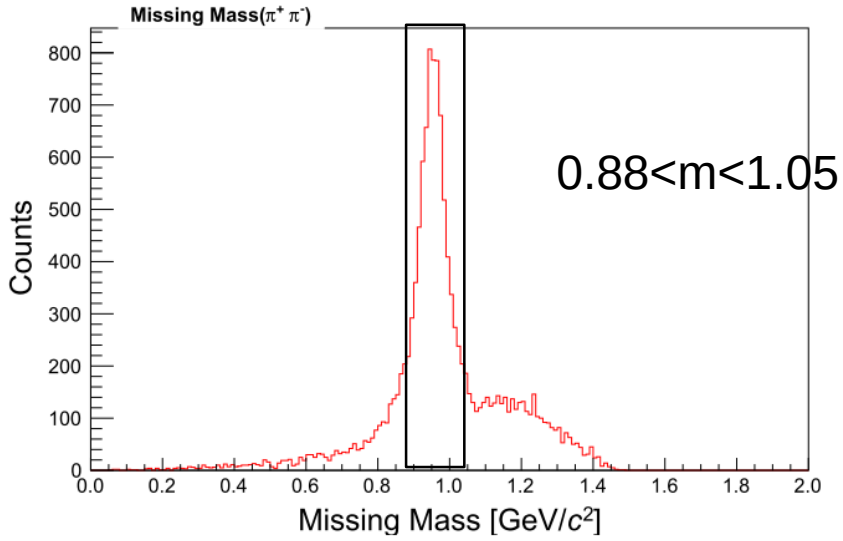
T1 to Target

$$D(t) = \int_0^\infty R(t-t')\mathrm{e}^{-t'/\tau}dt'$$

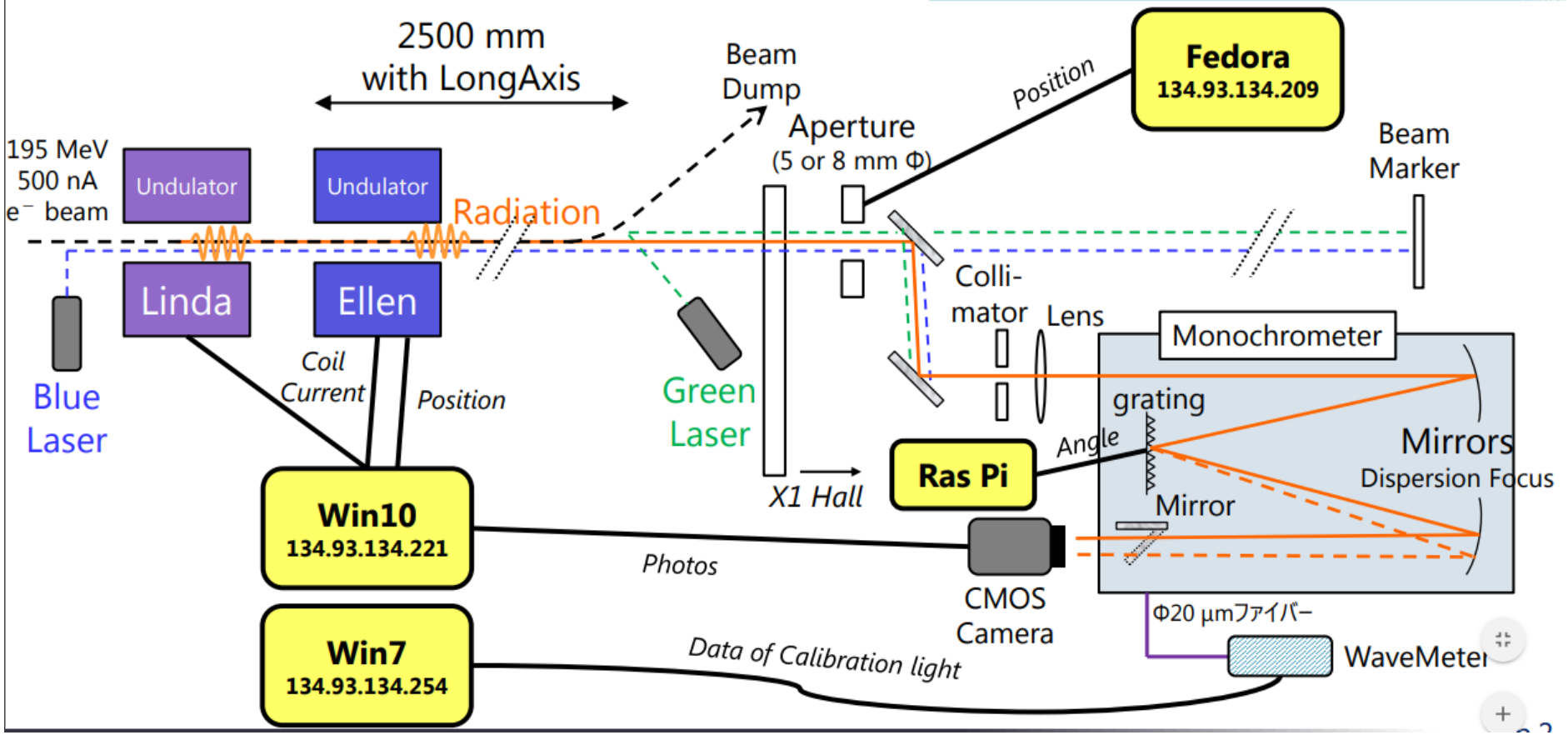
Hypernuclei	Number of events	Lifetime τ [ps]
$^{12}_{\Lambda}$C	323	231±15
$^{28}_{\Lambda}$Sr	206	206±12
$_{\Lambda}$Fe	309	215±14

$\gamma + p \rightarrow p + \pi^- + \pi^+$

- Select π^+ & π^- vertex event(PID & opening angle cut)
- Select MM = M_p event



Undulator Setup



Data taking system