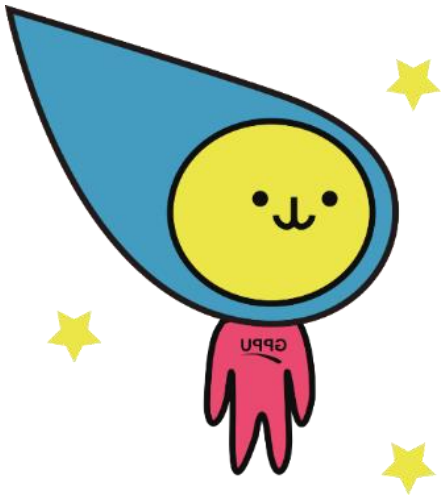
Detector performance for a lifetime measurement of light hypernuclei

Nuclear physics lab.
Yuichi Toyama



TOHOKU UNIVERSITY

GP.PU
GRADUATE PROGRAM ON PHYSICS FOR THE UNIVERSE
宇宙創成物理学
国際共同大学院

Contents

- Detector test experiment at ELPH
  - Overview
  - TDL & VDC performance
- nnΛ search experiment at JLab
  - Overview
  - My contribution
- Summary & future plans

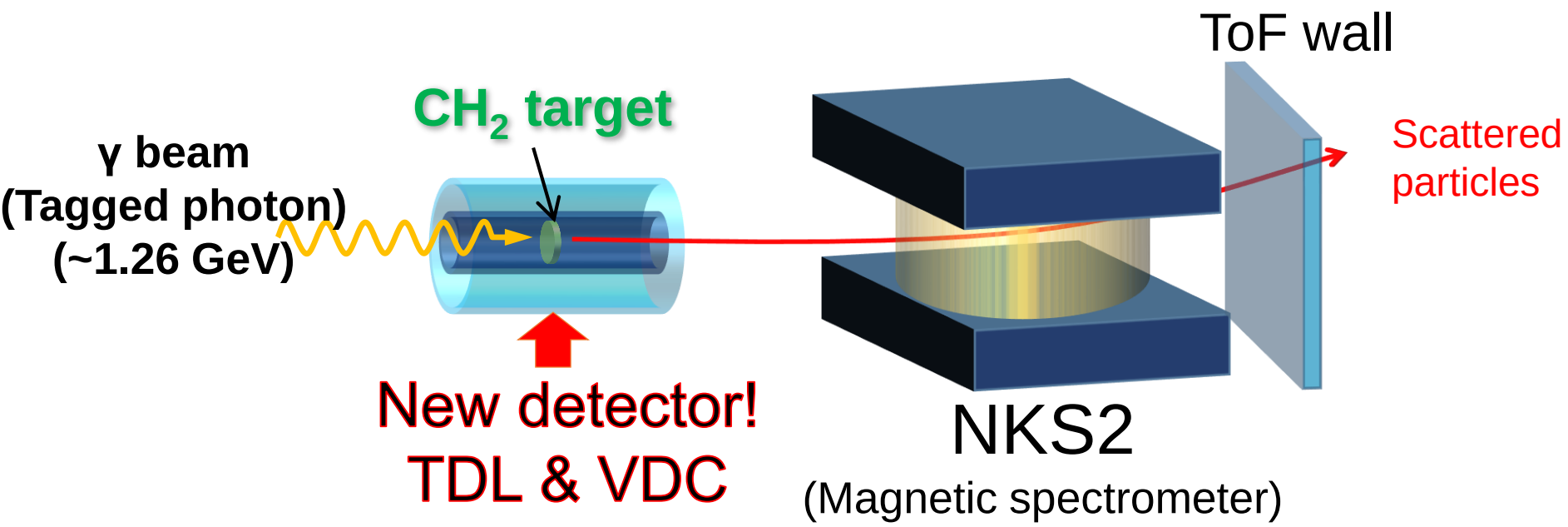
Detector test experiment

Our goal : Lifetime measurement of $^{3}_{\Lambda}H$

Dec. 2018 & Jan. 2019

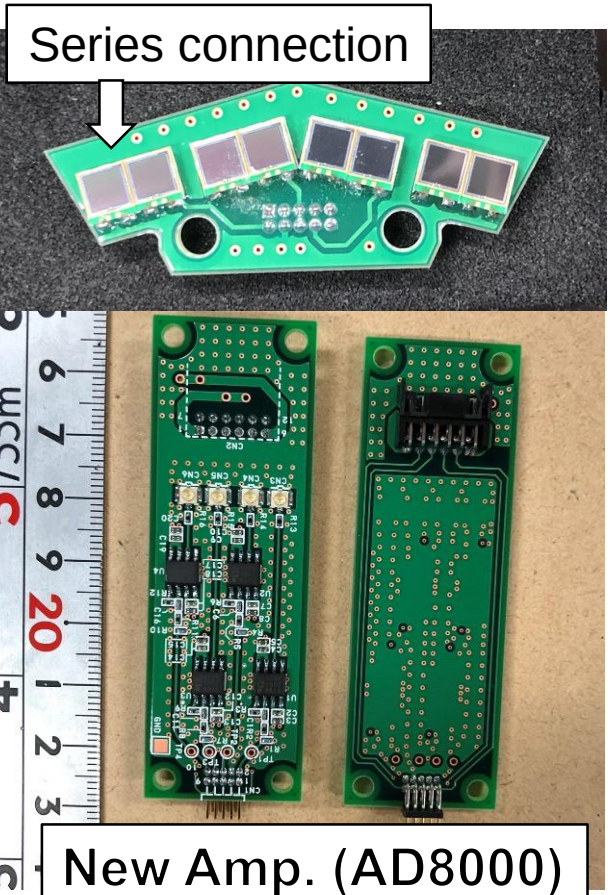
Study items of commissioning run

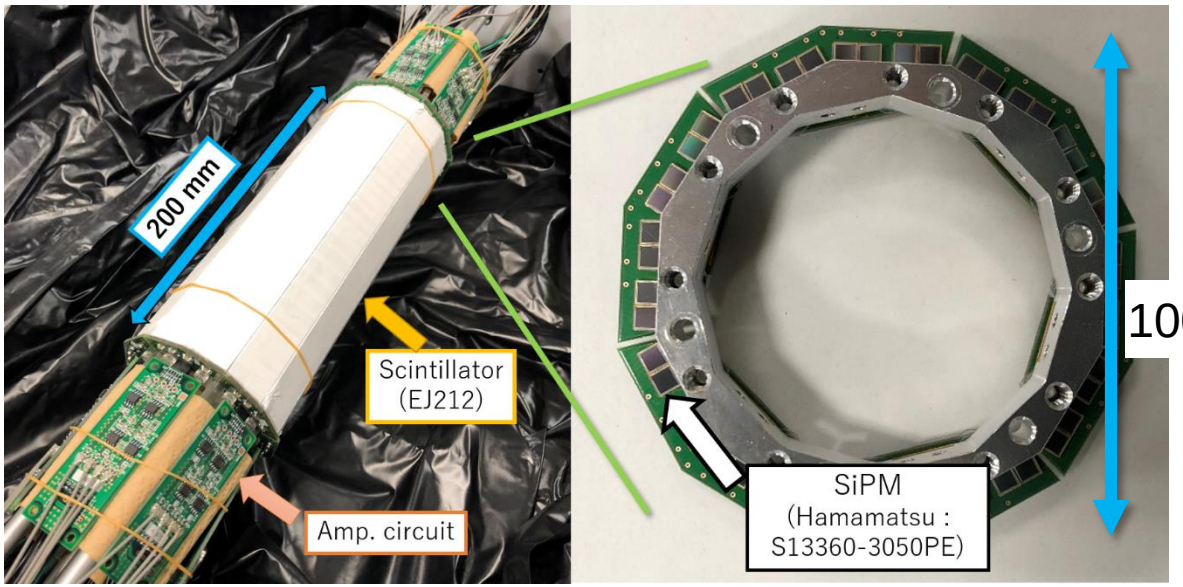
- New trigger (for DAQ)
- Vertex resolution
- Response function of decay time



new TDL

Timing counter for **D**irect **L**ifetime measurement of hypernuclei





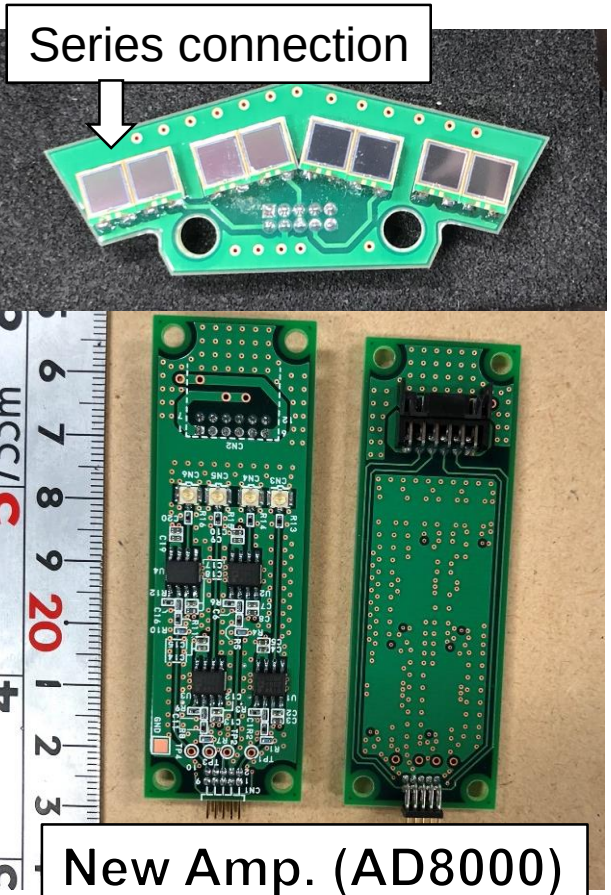
Requirements

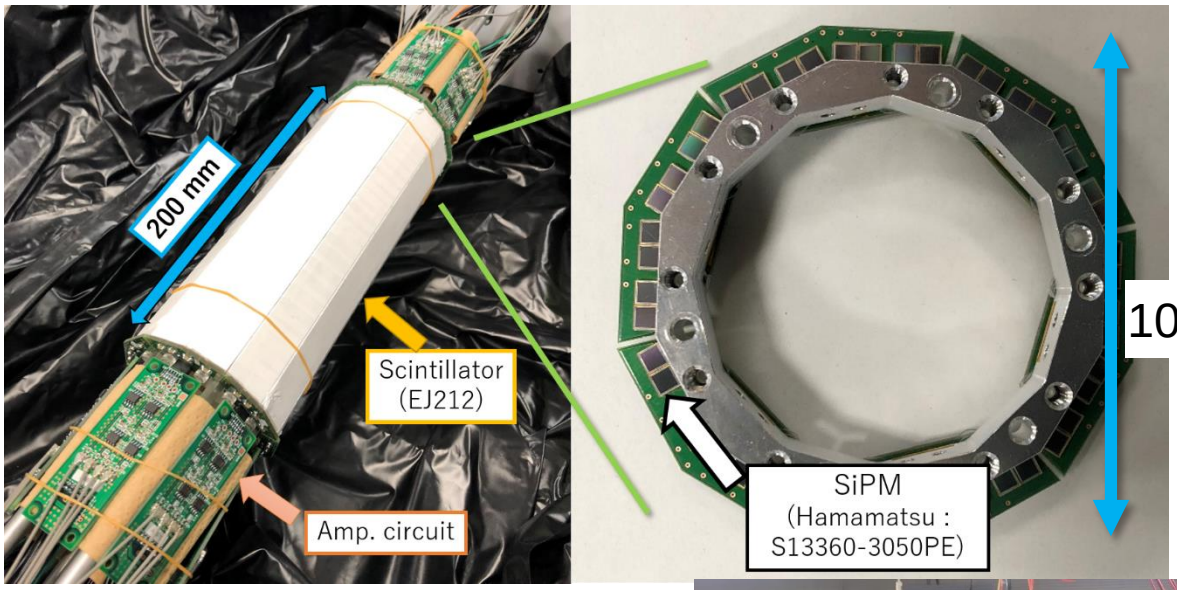
- Good time resolution
- Compact size
- Large acceptance
- Stable performance

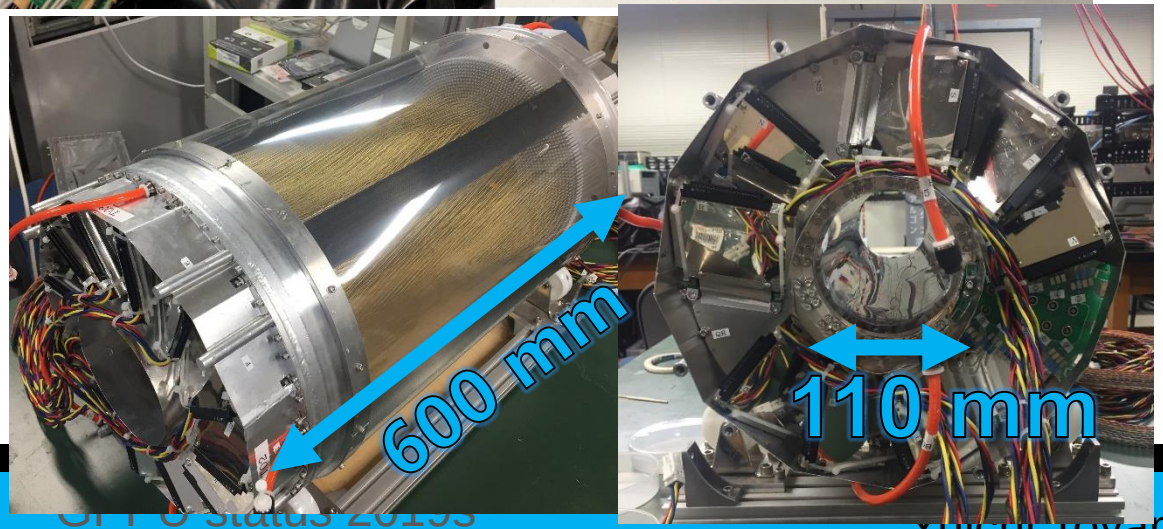
- 2MPPC series connection
- Dodecagon shape
- 48 scintillator bars
- Large solid angle (>3π sr)
- Installed inside of VDC

new TDL

Timing counter for **D**irect **L**ifetime measurement of hypernuclei



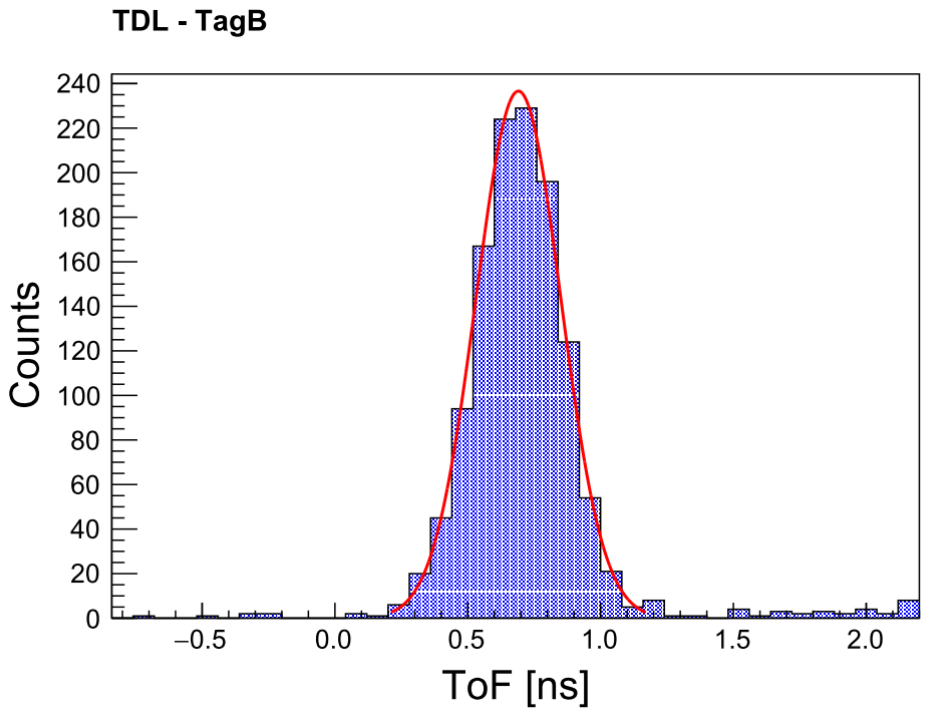




Decay time spectrum

- Evaluation method

ToF of TDL-Tagger, TDL-RF and Tagger-RF→Intrinsic time resolution



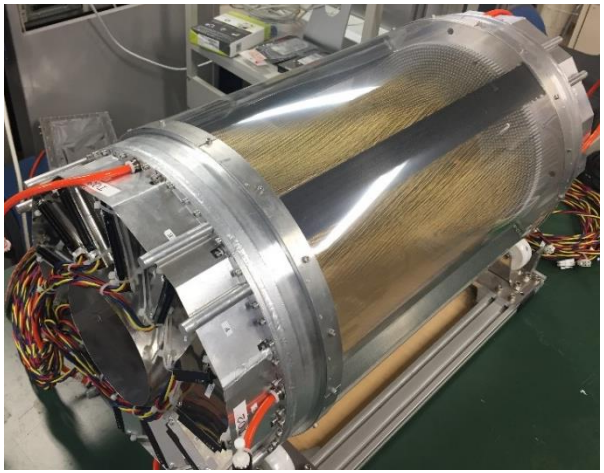
TDL-Tagger : 160 ± 4 ps(σ)
TDL-RF : 172 ± 1 ps(σ)
Tagger-RF : 114.9 ± 0.4 ps (σ)

TDL : 145 ± 2 ps(σ)
RF : 92 ± 3 ps(σ)
Tagger : 68 ± 4 ps (σ)

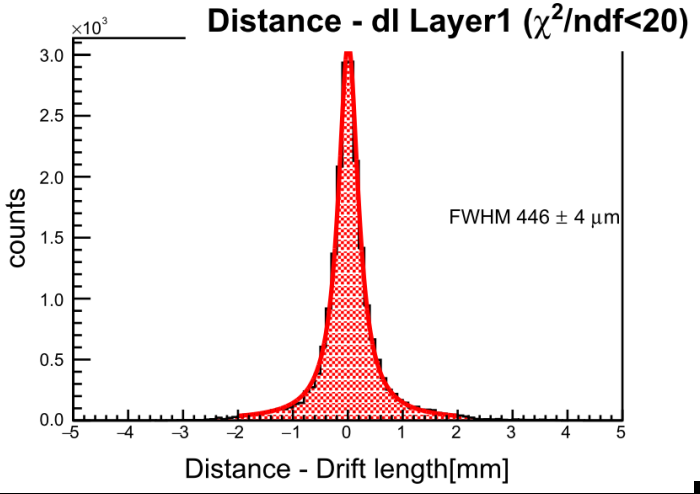
- RF resolution ~100 ps

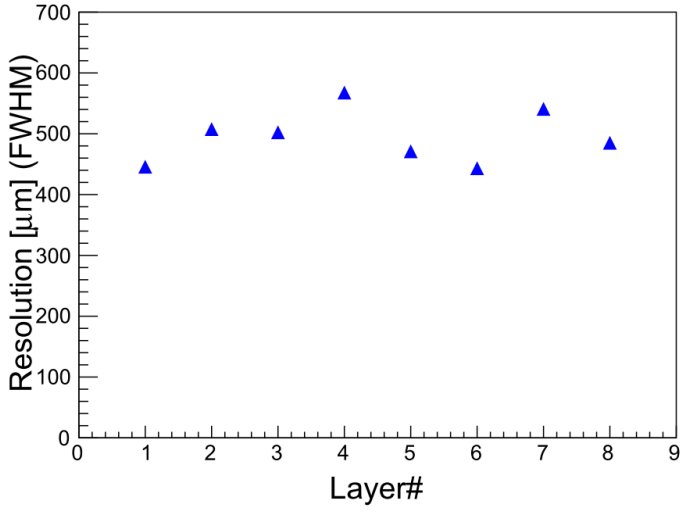
⇒ Consistent with other group's result

Performance of VDC



- I made new tracking code for this setup
- Position resolution ~500 μm(FWHM)
  - Same with previous exp.



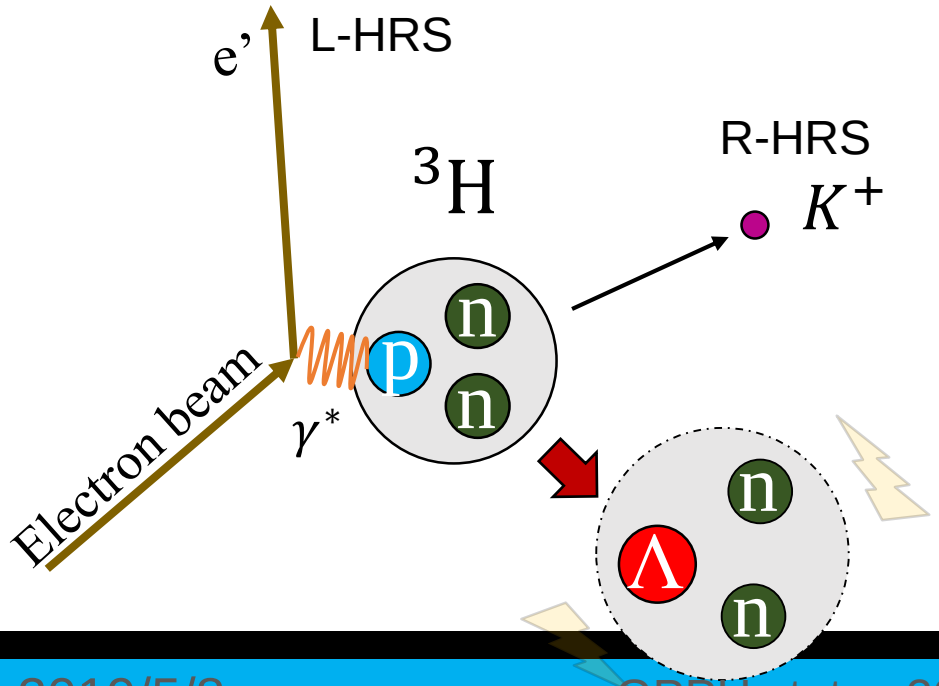


nnΛ search exp. at JLab

Overview of E12-17-003 (nnΛ search)

Beam time Oct. – Nov. 2018.

- Purpose : Search for nnΛ state with missing mass spectroscopy
- Spectrometer : HRS × 2
- Target : ^{3}H



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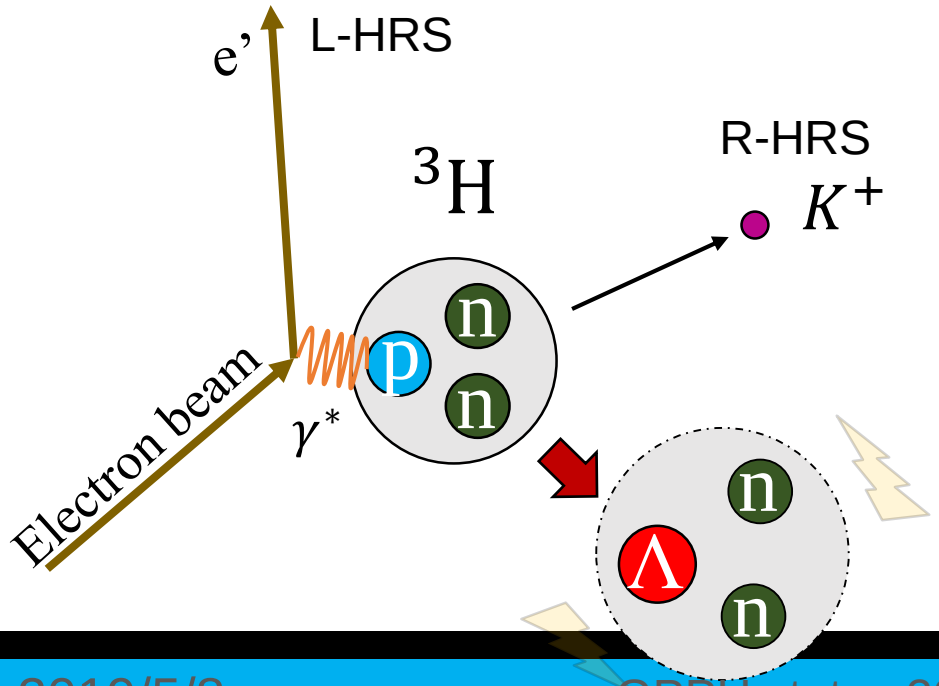
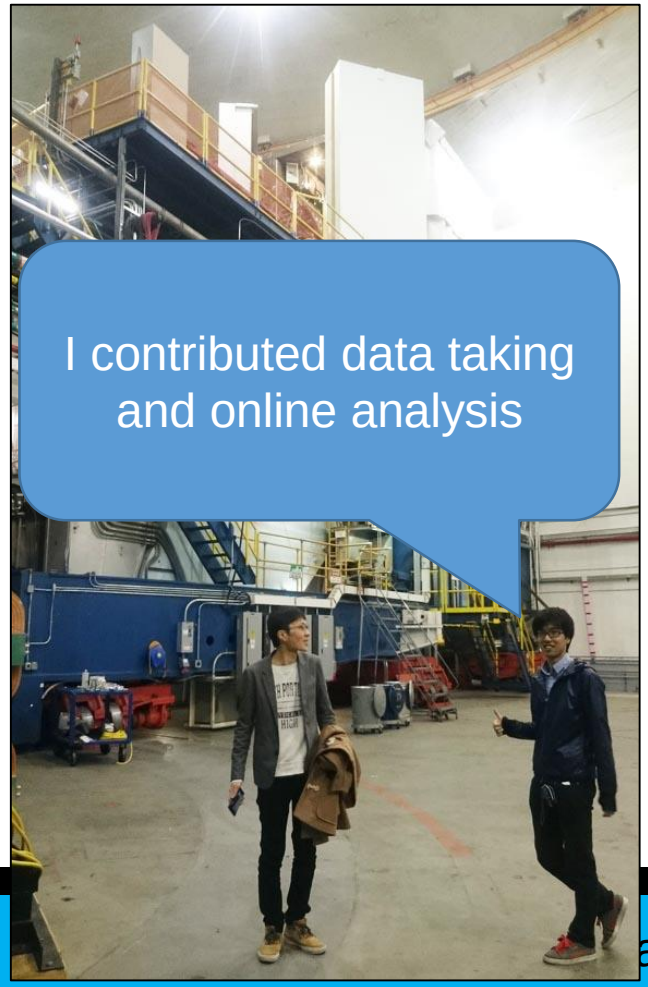




JLab stay

- My stay : Oct. 14th – Nov. 11th
- We took many shifts! ☺

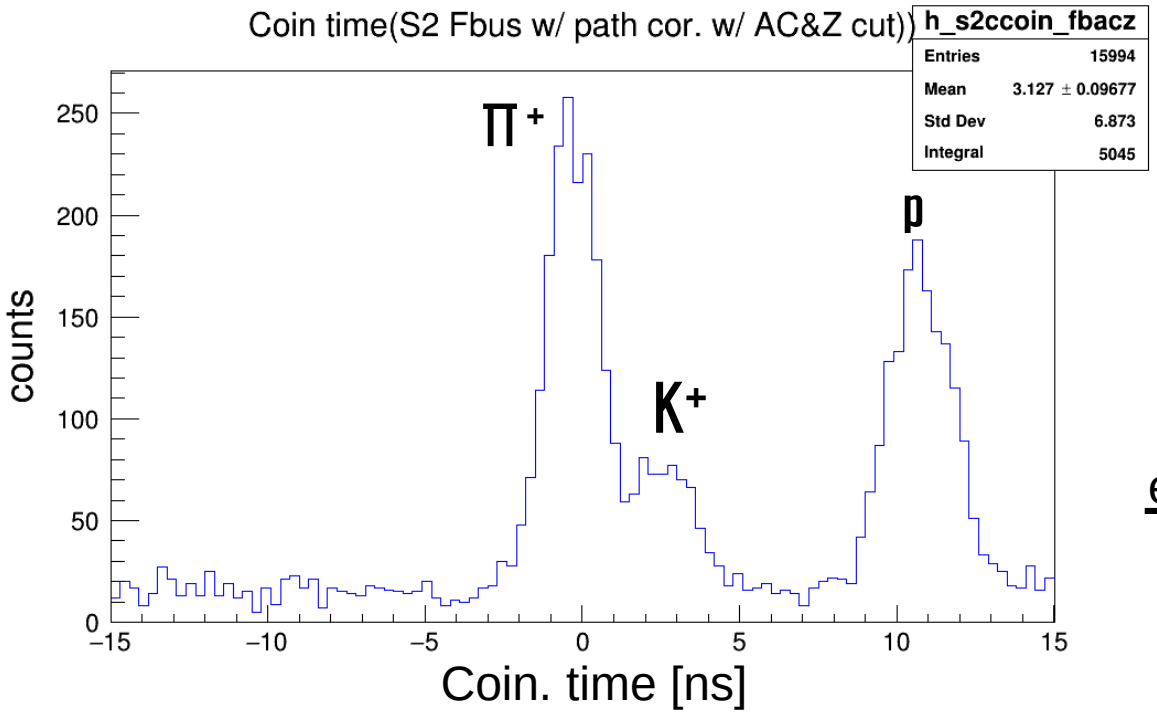
(8 h/shift)

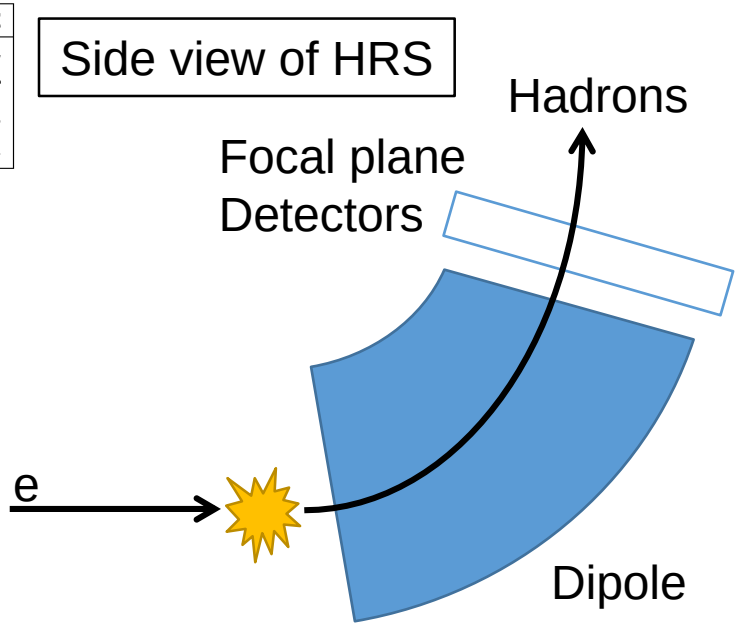
shifts one has signed up for between the period of Sep 12 to Nov 20, 2018

Rank	Institution	Number of shifts	Weighted num. of shifts
1	Tohoku University, Sendai, Japan	88	126.5
2	Hampton University , Hampton, VA	51	82.5
3	University of New Hampshire, Durham, NH	37	63

Name	Institution	Num of shifts	Weighted
Toshiyuki Gogami	Tohoku University, Sendai, Japan	32	44.5
Nathaniel Lashley-Colthirst	Hampton University , Hampton, VA	21	33.5
Yuichi Toyama	Tohoku University, Sendai, Japan	18	27
Kosuke Itabashi	Tohoku University, Sendai, Japan	15	22.5
Bishnu Pandey	Hampton University , Hampton, VA	14	21

Kaon ID

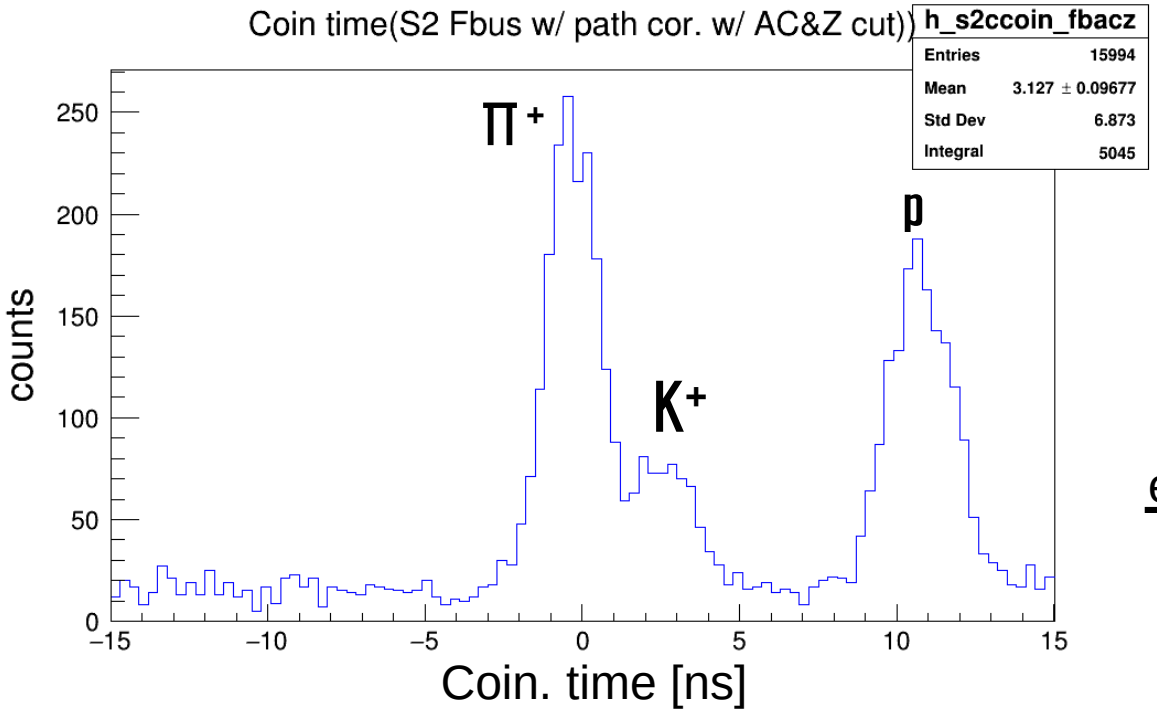


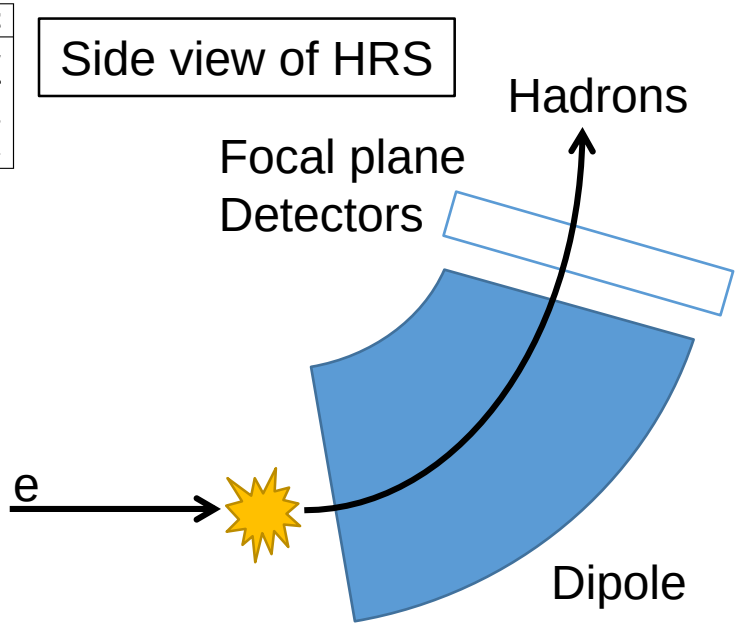


Coin time = $(t_{e'} - ToF_e) - (t_K - ToF_K)$
t : time at focal plane detector (scintillator)
ToF : time of flight calculated from path length and momentum

Kaon ID

First observation of K^+ in this experiment.





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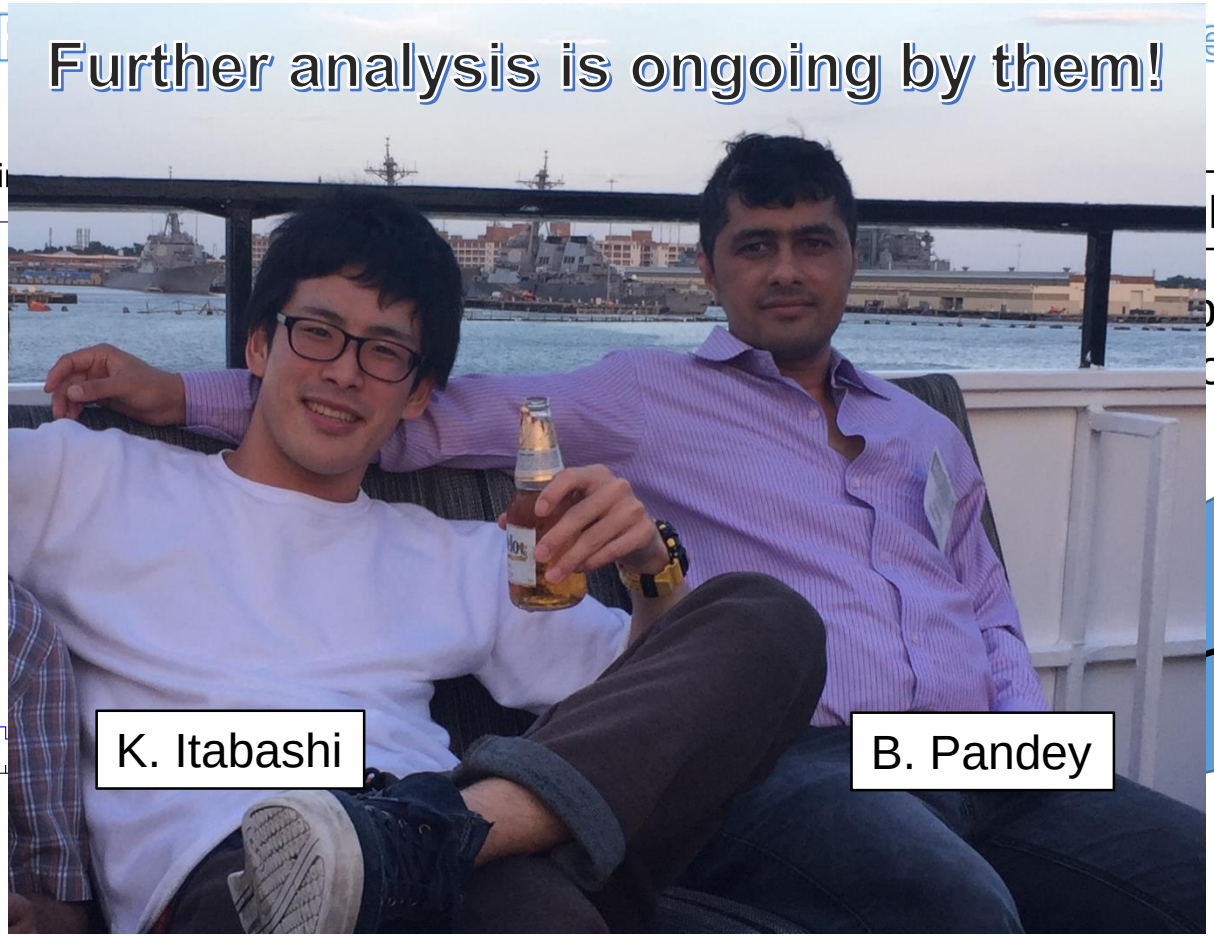

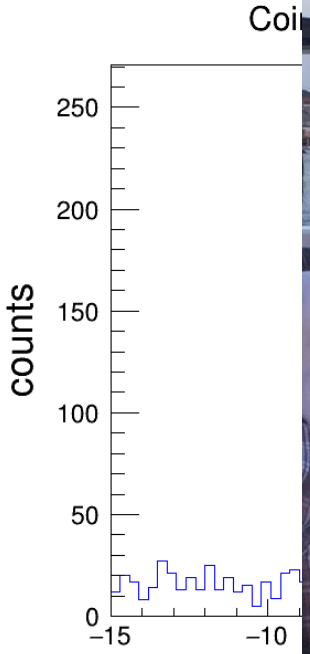

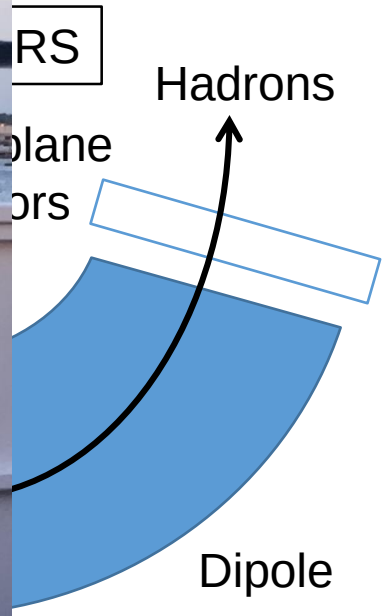

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Summary

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

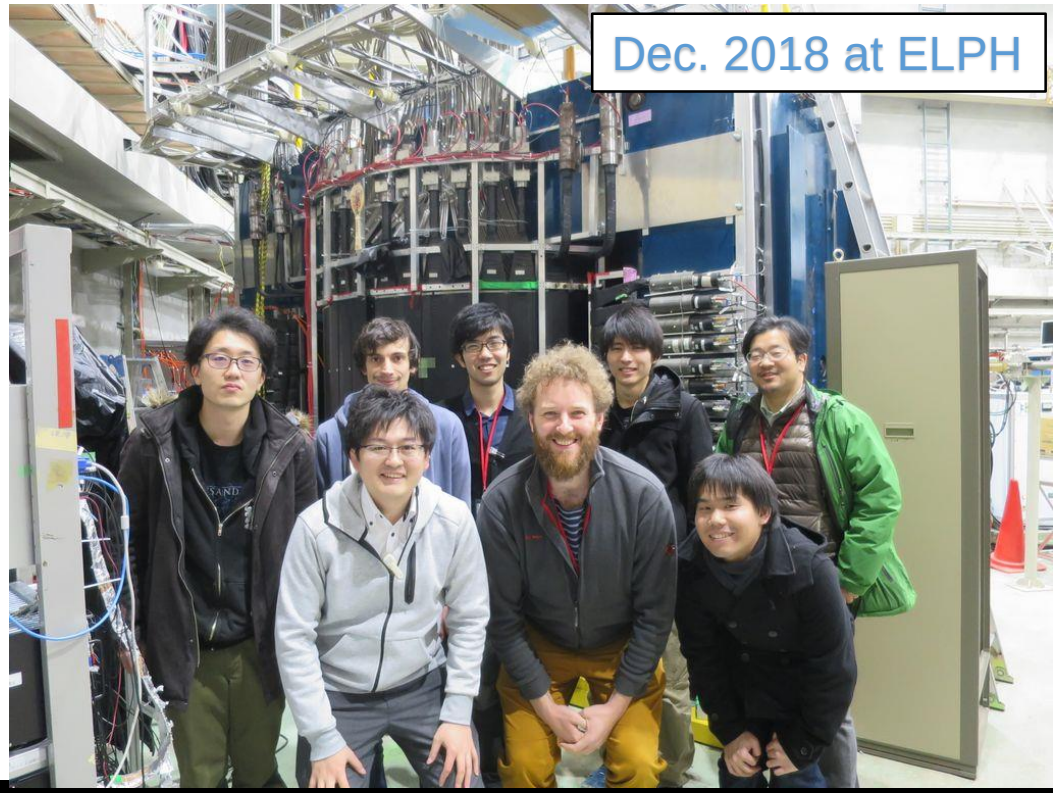
- Test experiment of TDL&VDC at ELPH

nnΛ search experiment at JLab in Oct. & Nov. 2018

- Data taking was done!

GP-PU credit

- ✓Overseas training (>3 month)
- ✓Experimental course (15GEP)
- Seminar (18/20 pt)



Backup

まとめ

- 東北大学電子光理学研究センターにおいて寿命測定実験を計画中
- Λ粒子の弱崩壊による遅延成分の観測に成功

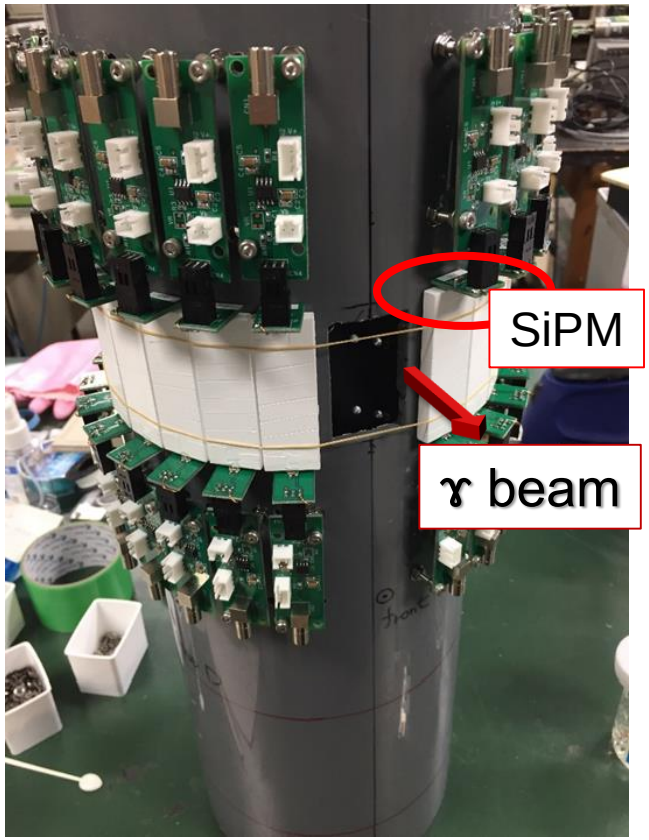
- 全96ch 読み出しの崩壊粒子検出器・TDLを製作
  - 固有時間分解能 $\sigma_t = 145$ ps

- 崩壊時間分解能 $\sigma_{decay} = 160$ ps を達成

今後
- トラッキング情報を用いたσ_{decay}の再評価
- 欠損質量、崩壊点位置分解能の評価

- ${}^{4}_{\Lambda}\mathrm{H}$の寿命測定実験を実地予定 (2019年度)

検出器のアップグレード

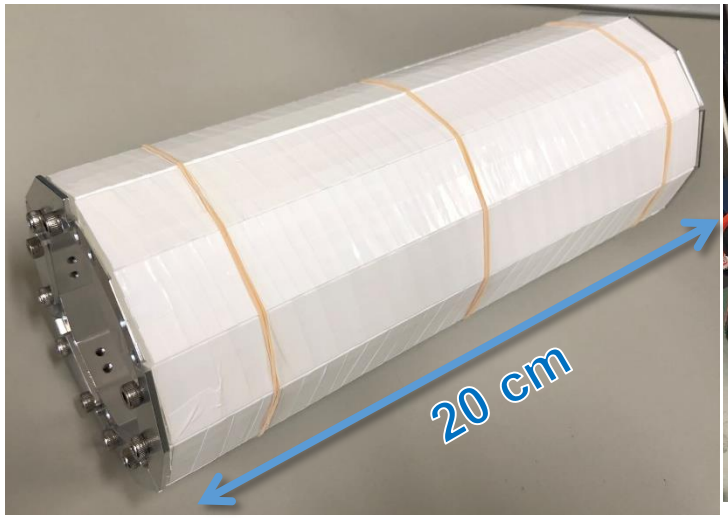


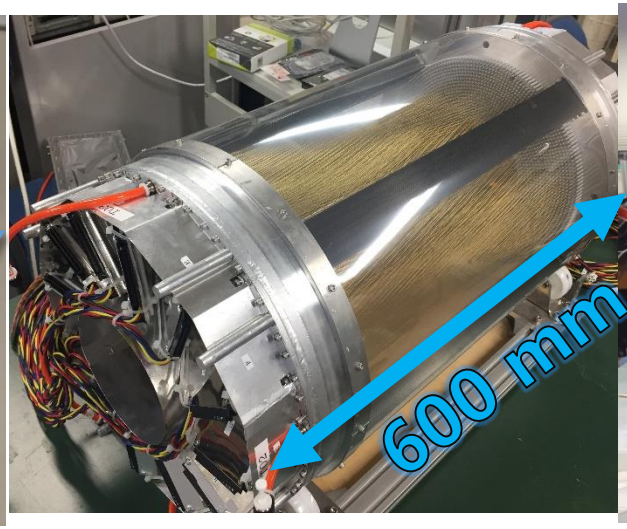
γ beam

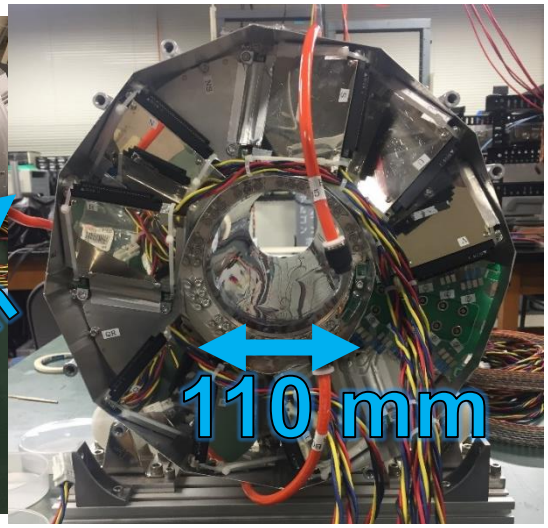
^{3}He Target (20 cm、設計中)

TDL

Timing counter for **D**irect **L**ifetime measurement of hypernuclei







- Dodecagon frame
- 48 scintillators
- Will be installed inside of VDC

TDL has been developed since 2016.

New circuit boards and jig in Sep. 2018

Motivation & Strategy

Motivation : Precise measurement of ${}^{3}_{\Lambda}\mathrm{H}$ lifetime

time

Λ lifetime (1) — Phase 0 in Apr. 2017 ⇨ Λ ID : invariant mass & prototype TDL

Decay π^- detector construction & commissioning — We are here now

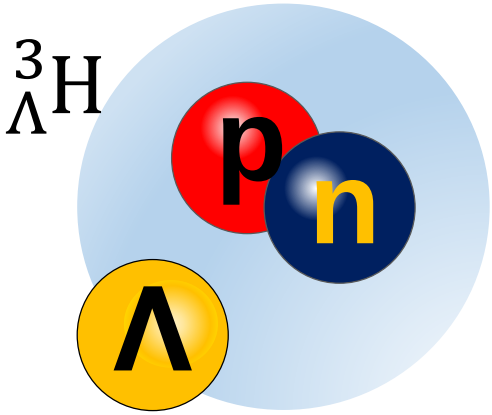
Λ production (2) — Phase 1 in 2019 ⇨ Λ ID : missing mass & actual detectors

New AC & ToF wall install

${}^{4}_{\Lambda}\mathrm{H}$ lifetime — Phase 2 in 2019 ⇨ Liq. ^{4}He target

${}^{3}_{\Lambda}\mathrm{H}$ lifetime — Phase 3 in 2020 ⇨ Liq. ^{3}He target

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

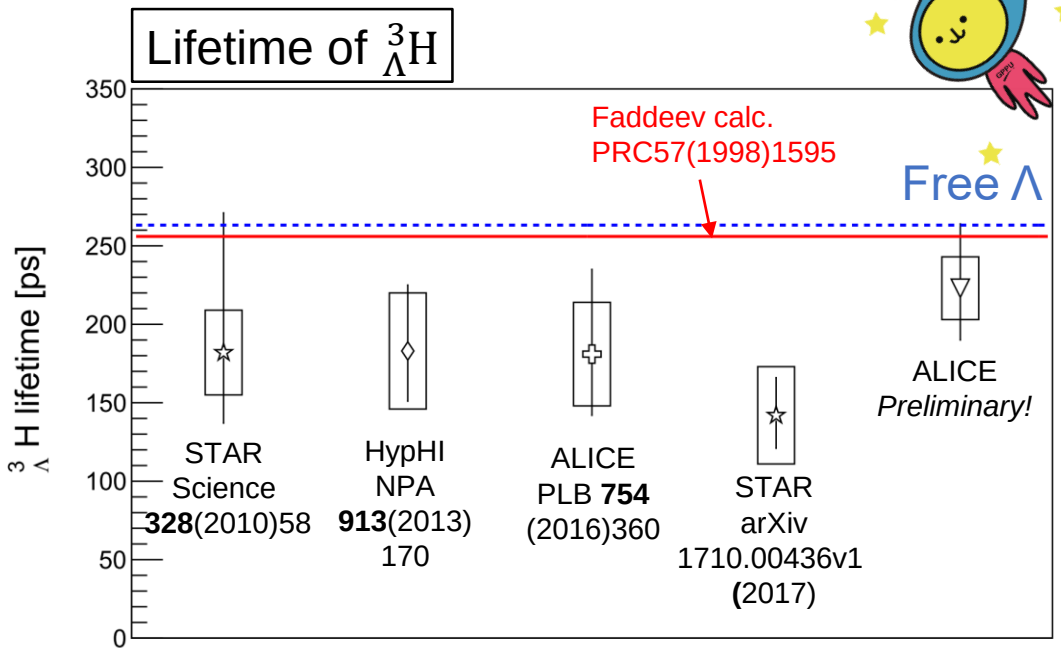


B_Λ~0.13 MeV[1]
(${}^{4}_{\Lambda}$H : B_Λ=2.12 MeV[2])

Shallow binding
~ Free Λ

τ ~200 ps
(Λ : τ =263 ps)

Short lifetime



Shorter than free Λ?

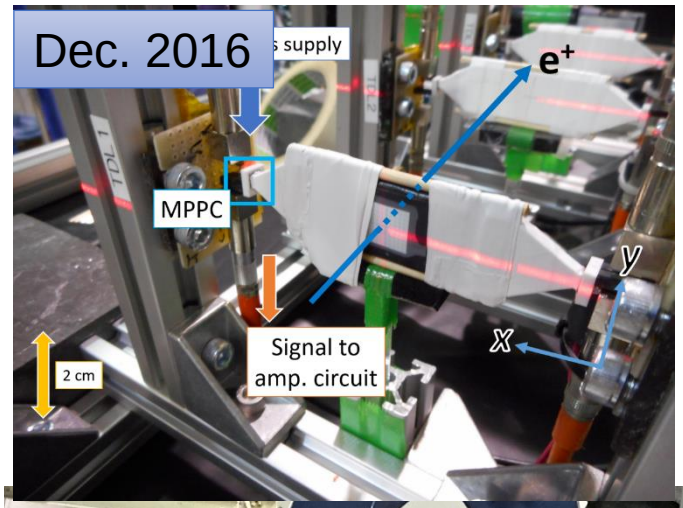
Difficult to explain B_Λ and lifetime of ${}^{3}_{\Lambda}$H simultaneously

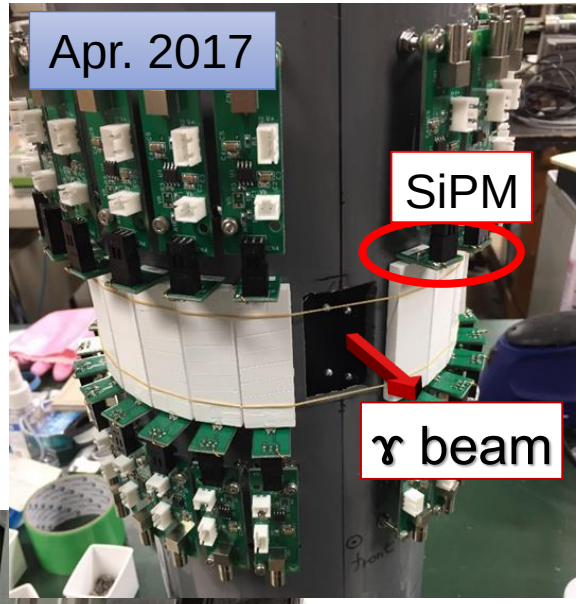
Precise measurement of ${}^{3}_{\Lambda}$H lifetime is required

[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.

TDL

Timing counter for **D**irect **L**ifetime measurement of hypernuclei





Requirements

- Good time resolution
- Compact size
- Large acceptance
- Stable performance

⇒ Plastic scintillator & SiPM

TDL has been developed since 2016.

TDL

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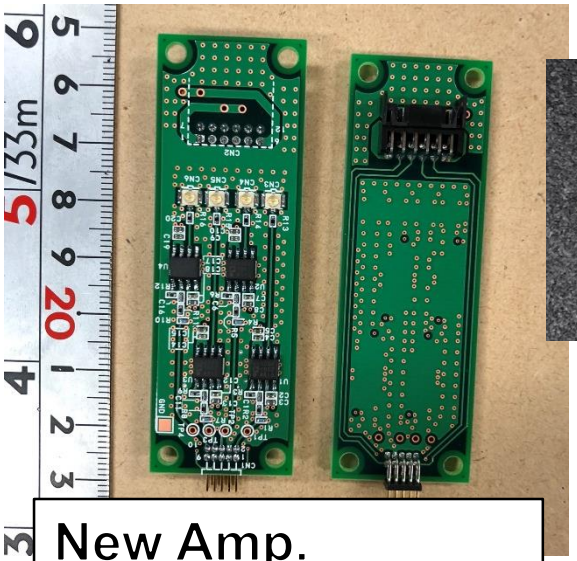
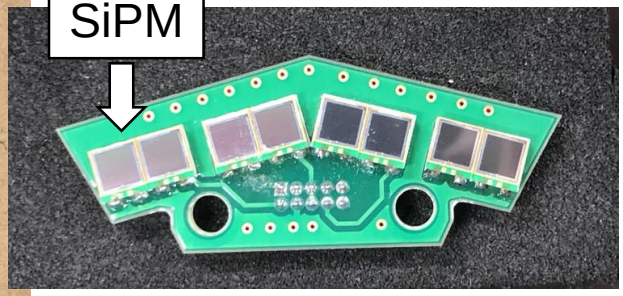


New Amp.
4ch readout/board



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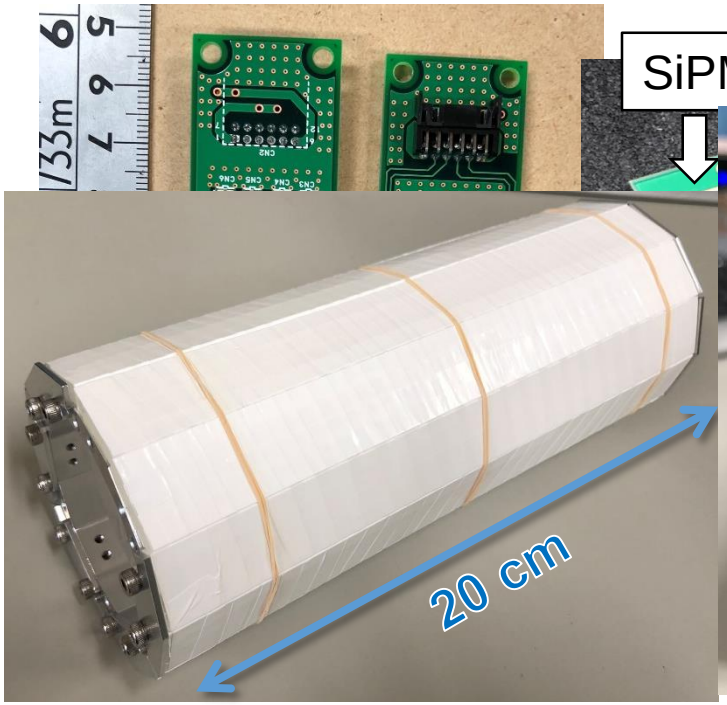

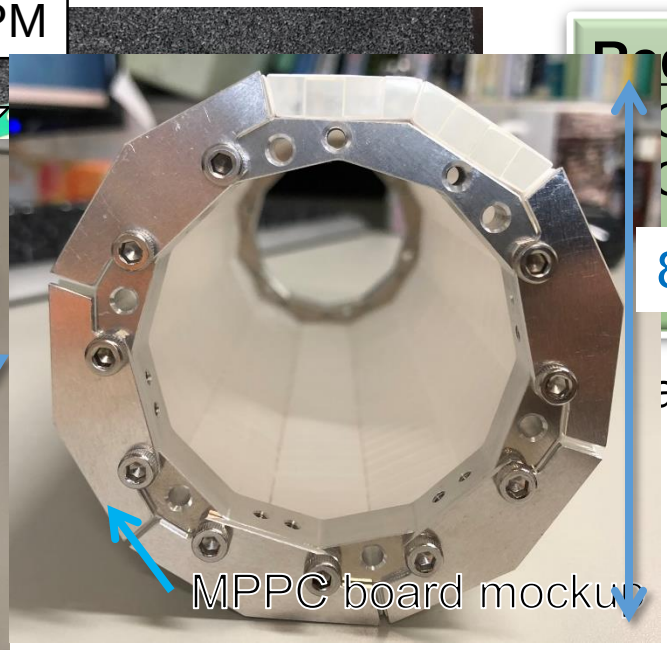

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- Good time resolution
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- performance

astic scintillator & SiPM

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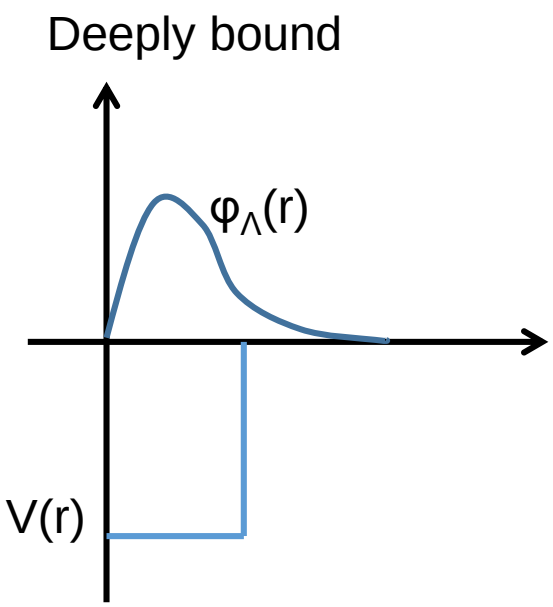
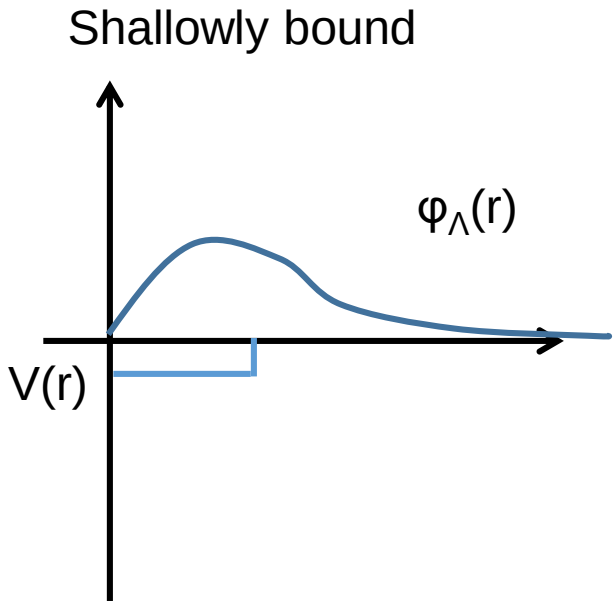
Naive explanation of short lifetime



Γ(ΛN→NN) > 0



Γ(ΛN→NN) ~ 0
⇒ ~ free Λ

TDL

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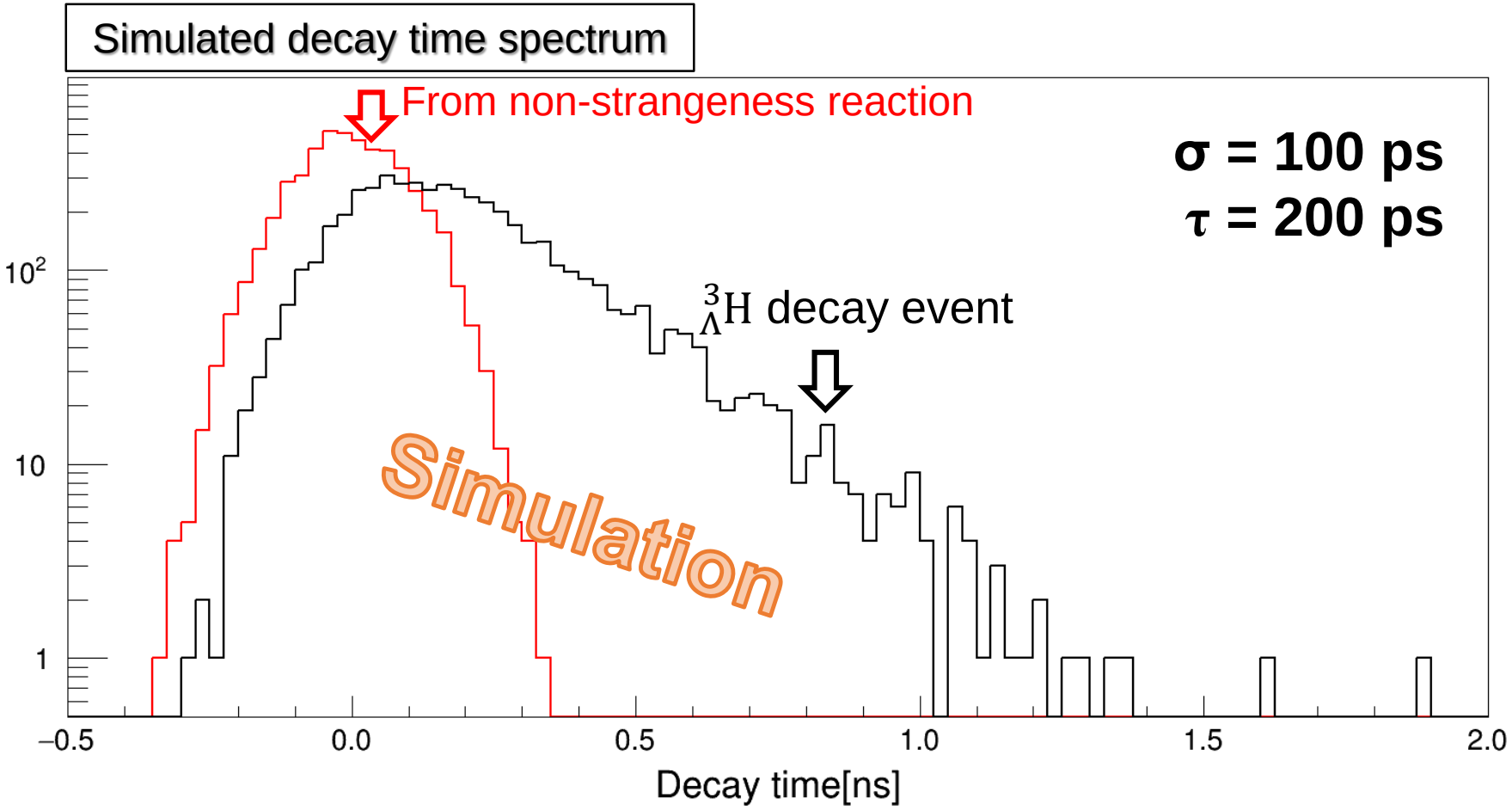

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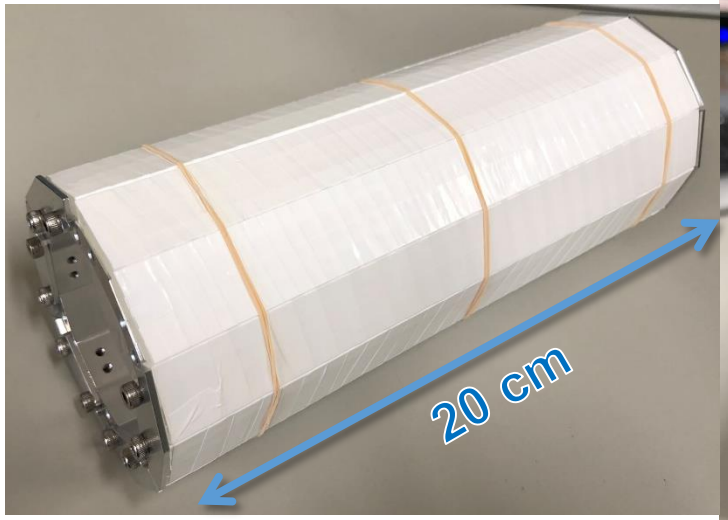

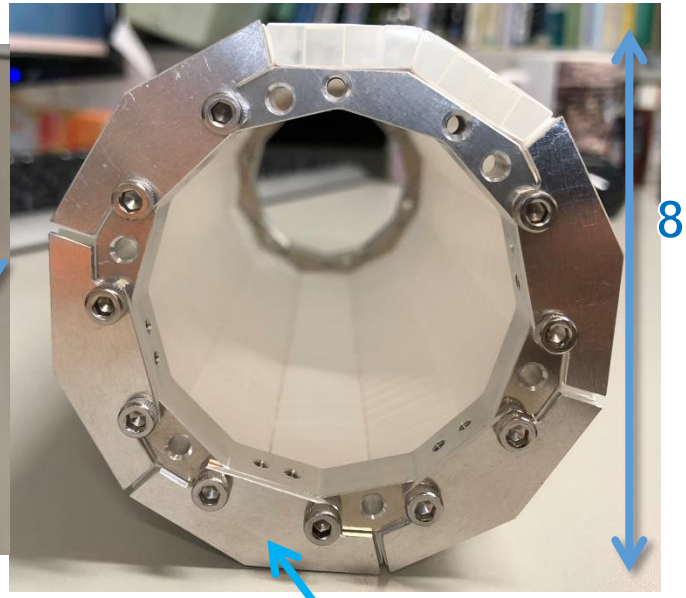

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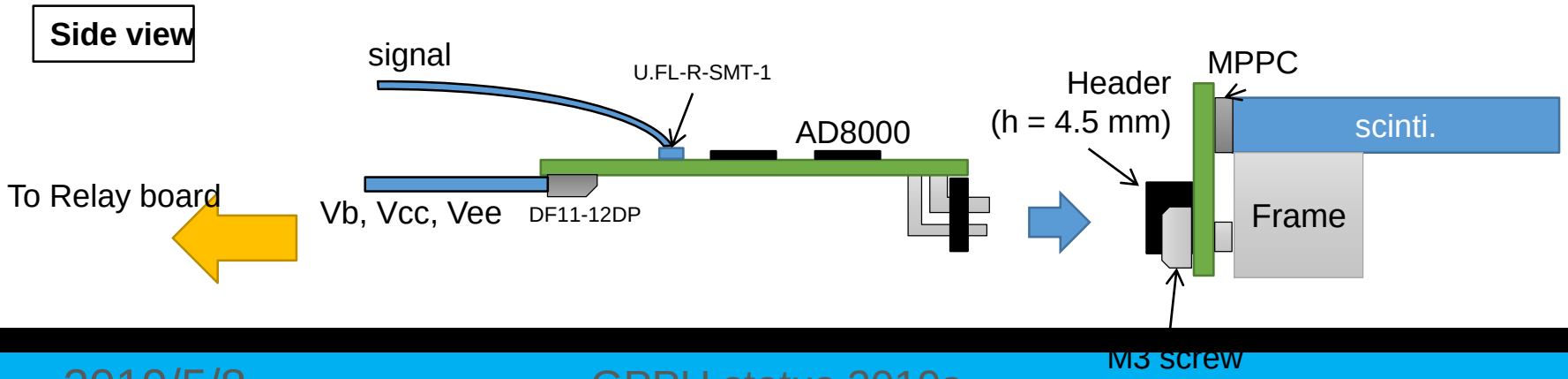
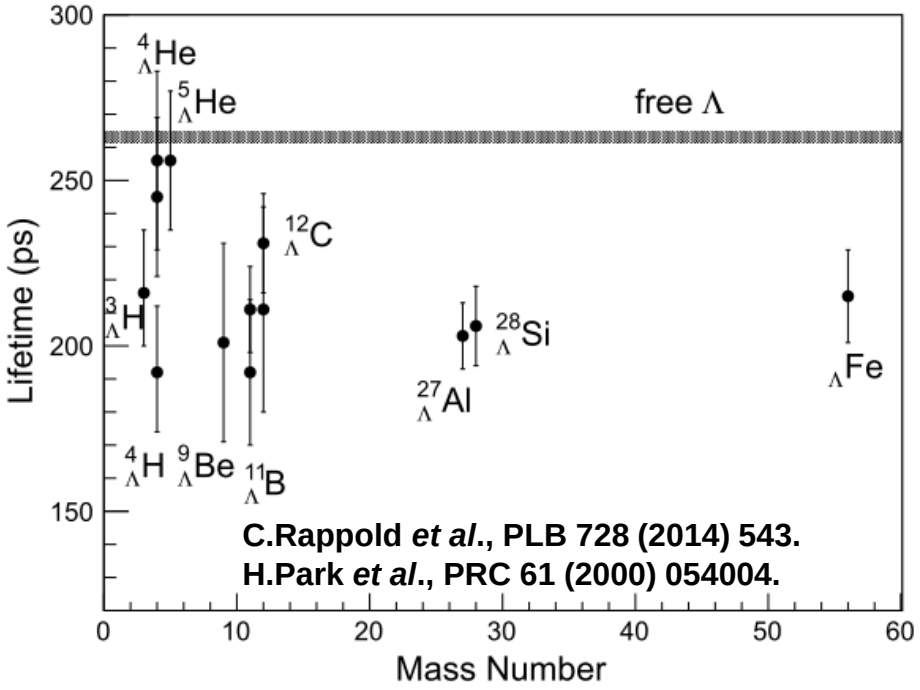


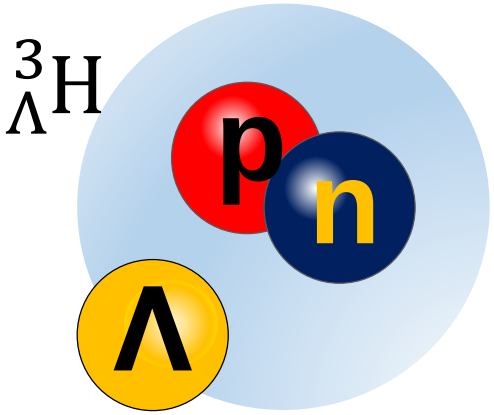
Naive explanation of short lifetime

- ΛN interaction is short range

→ Lifetime saturate



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



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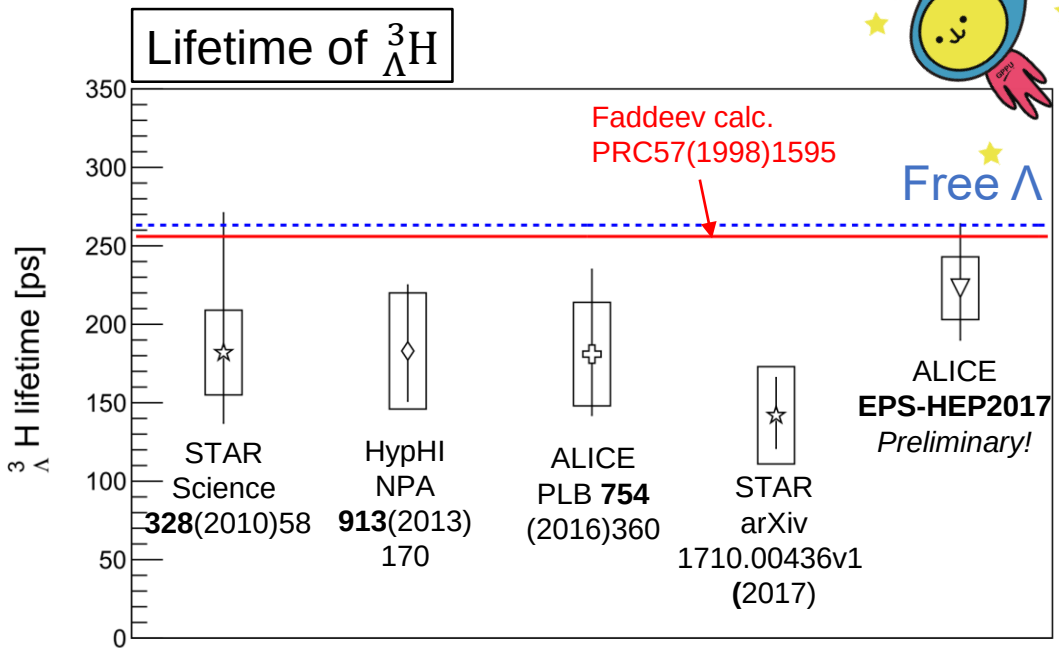


Shorter than free Λ?

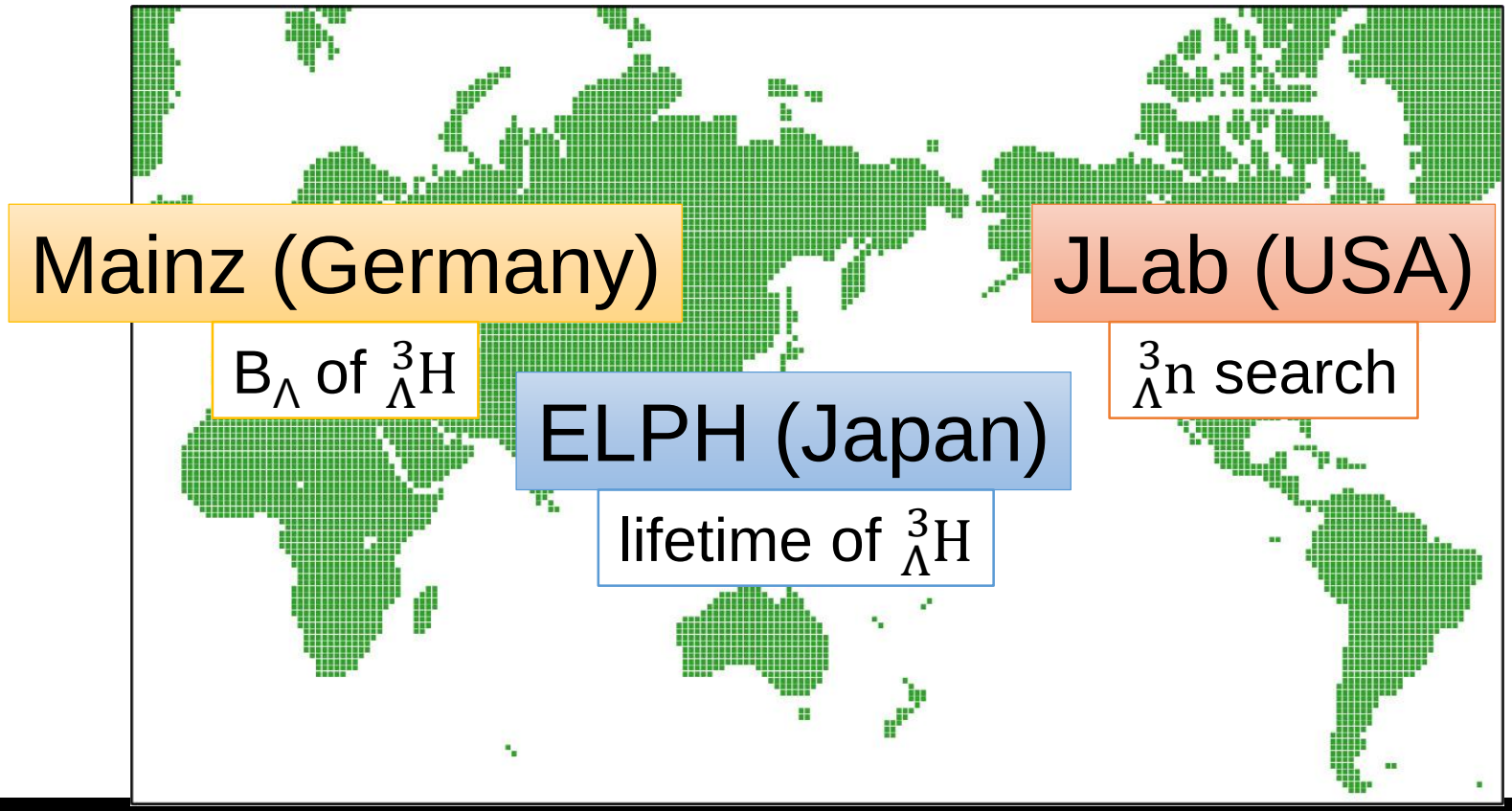
Difficult to explain B_Λ and lifetime of ${}^{3}_{\Lambda}$H simultaneously

Solution of the puzzle from lifetime measurement

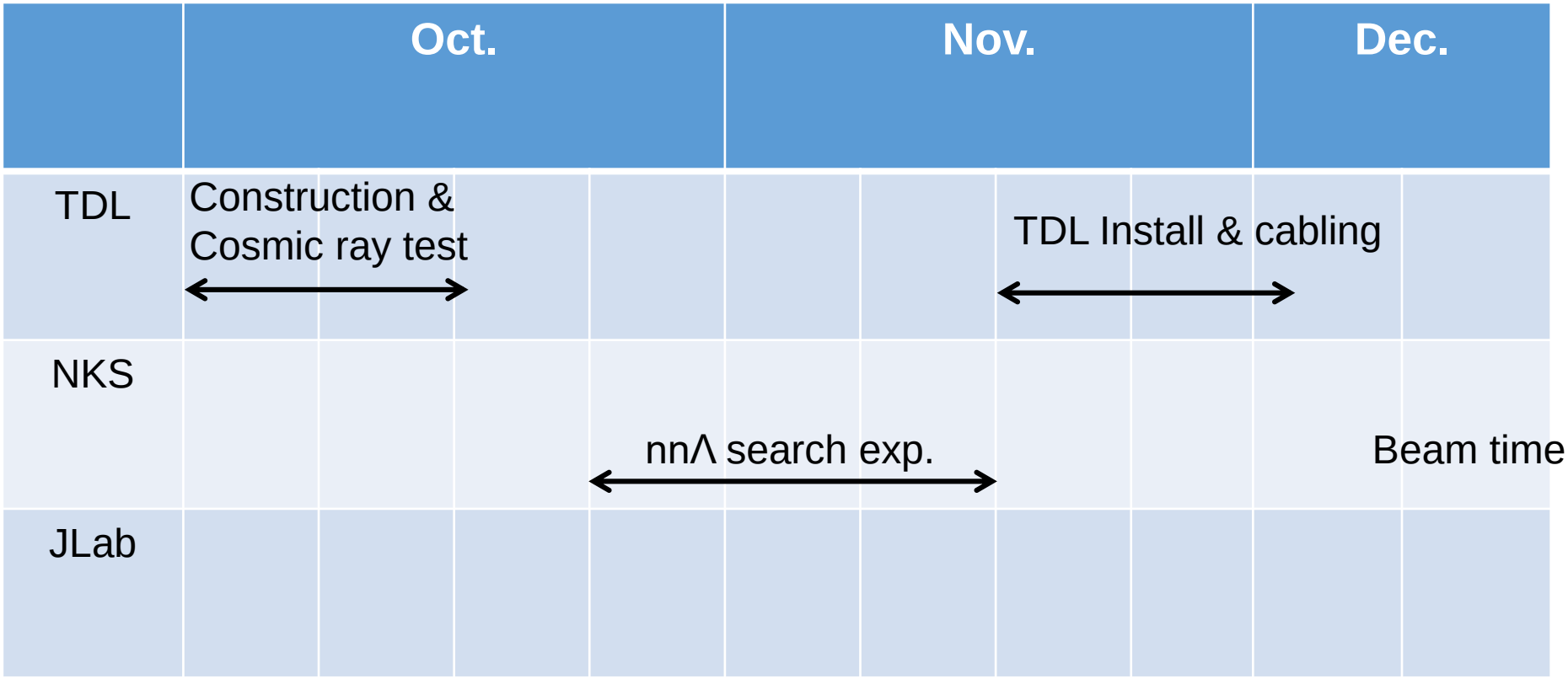
- Short lifetime ⇒ Deep bound system more than expected (nnΛ can be bound?)
- Long lifetime ⇒ Systematic error of previous experiment

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

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

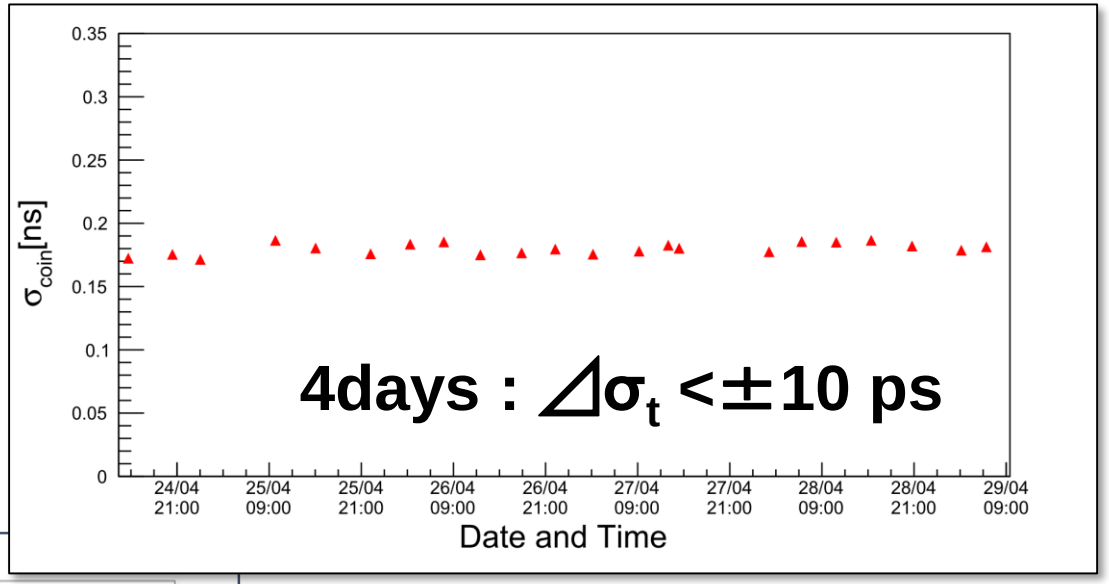


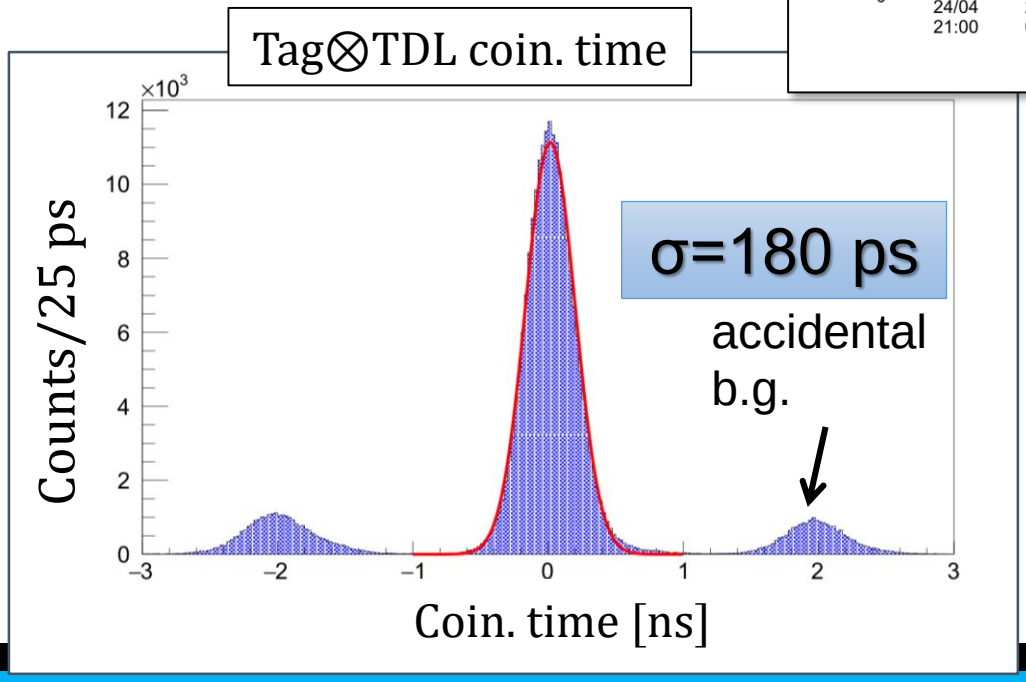
Schedule


Oct.
Nov.
Dec.
TDL
Construction &
Cosmic ray test
TDL Install & cabling
NKS
nnΛ search exp.
Beam time
JLab

Detector performance

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





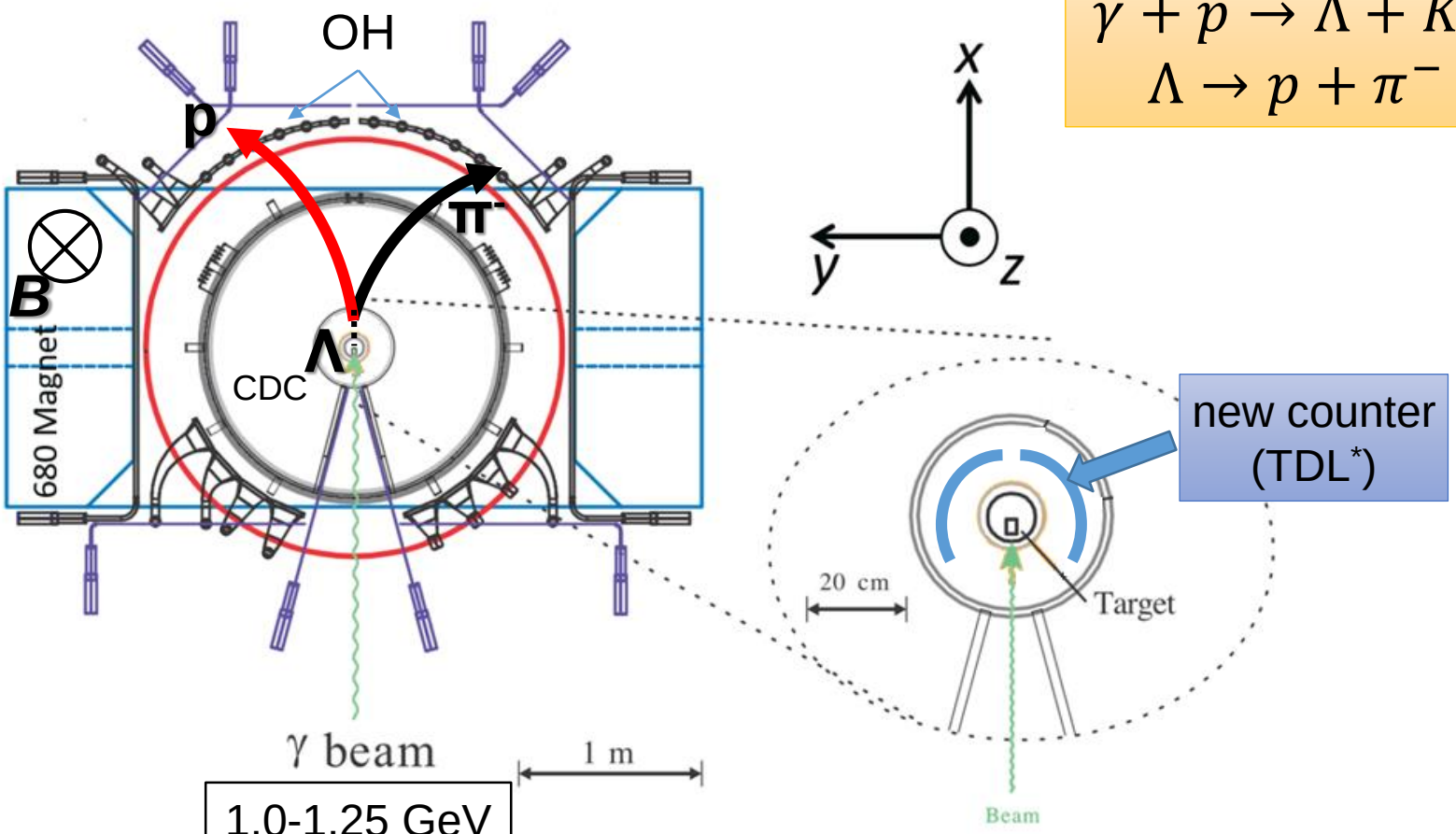
Component	σ [ps]
TDL (π detector)	**140**
Production point	100
Photon tagger	50
Total	180

Setup of phase0 exp. at ELPH

Top view of NKS2

Apr. 2017 (10 days)

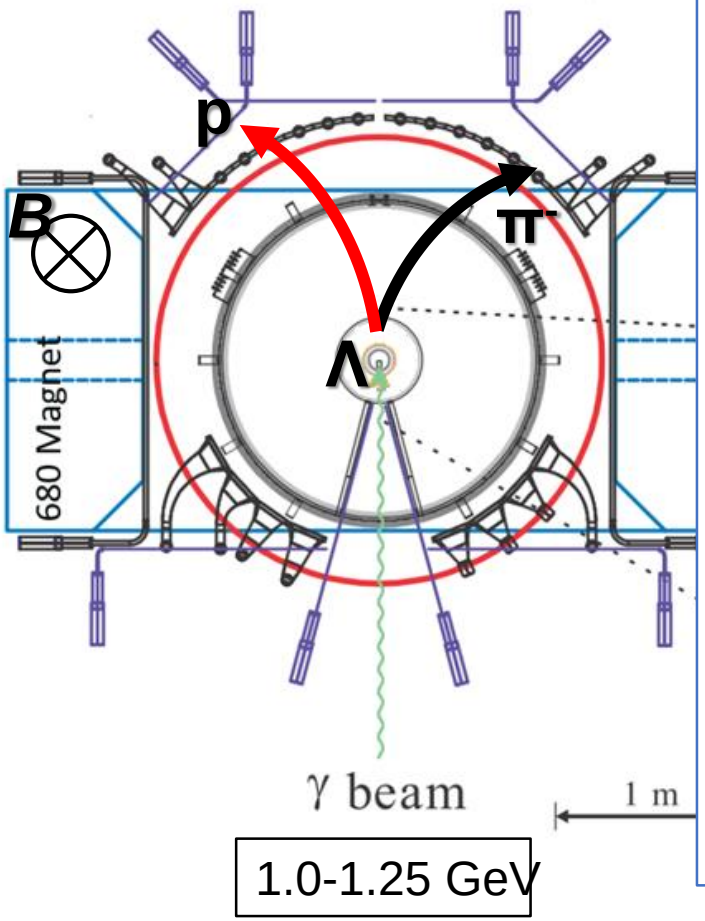
$$\gamma + p \rightarrow \Lambda + K^+$$
$$\Lambda \rightarrow p + \pi^-$$



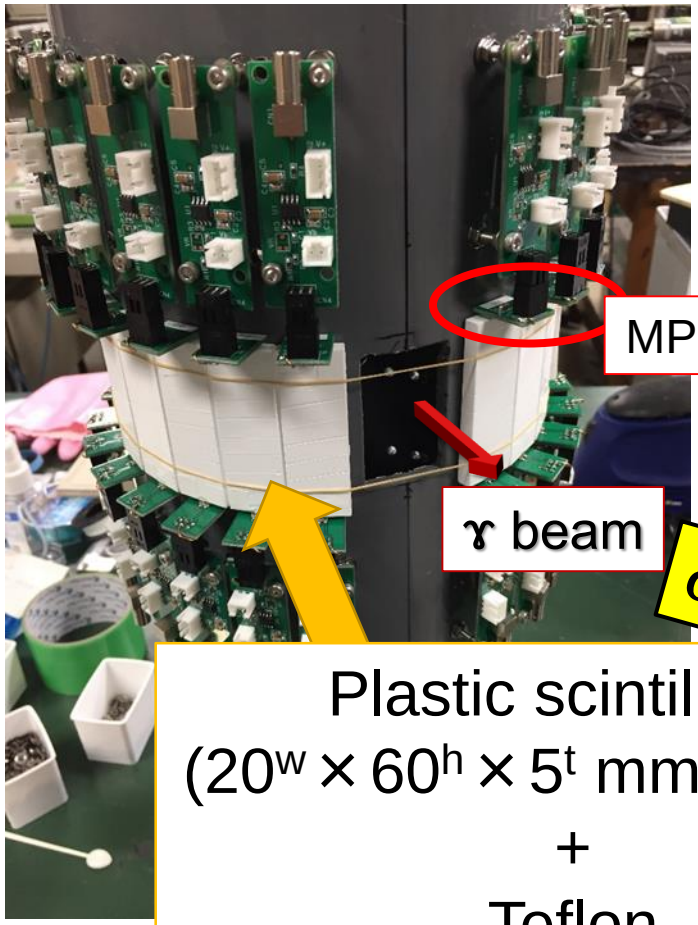
* Timing counter for Direct Lifetime measurement

Setup for Λ lifetime m

Top view of NKS2



1.0-1.25 GeV



$\sigma_t = 140$ ps

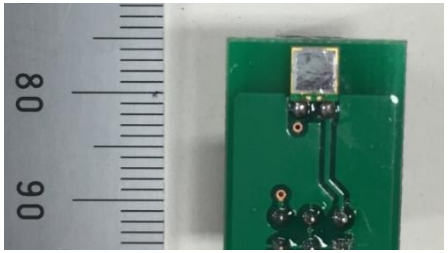
Plastic scintillator
($20^w \times 60^h \times 5^t$ mm^3, EJ212)
+
Teflon
(as reflective material)

* Timing counter for Direct Lifetime measuremen

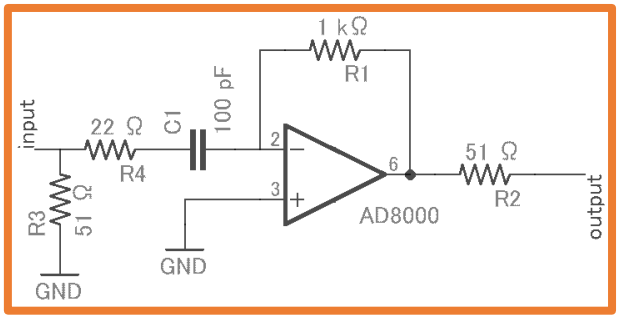
New detector for decay π

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)

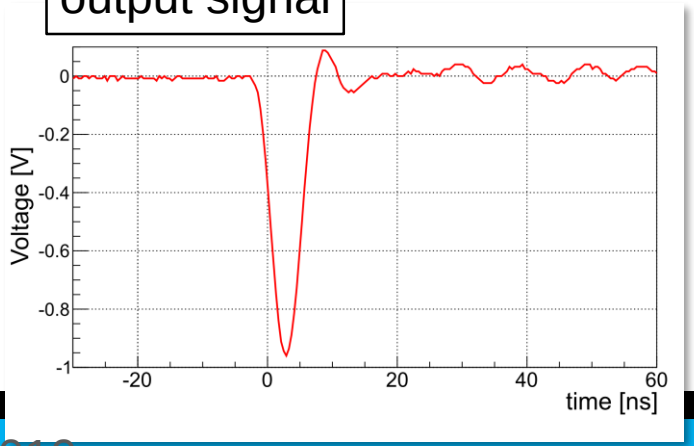


SiPM : MPPC (Hamamatsu)
3x3 mm² effective area
50 μm pixel pitch

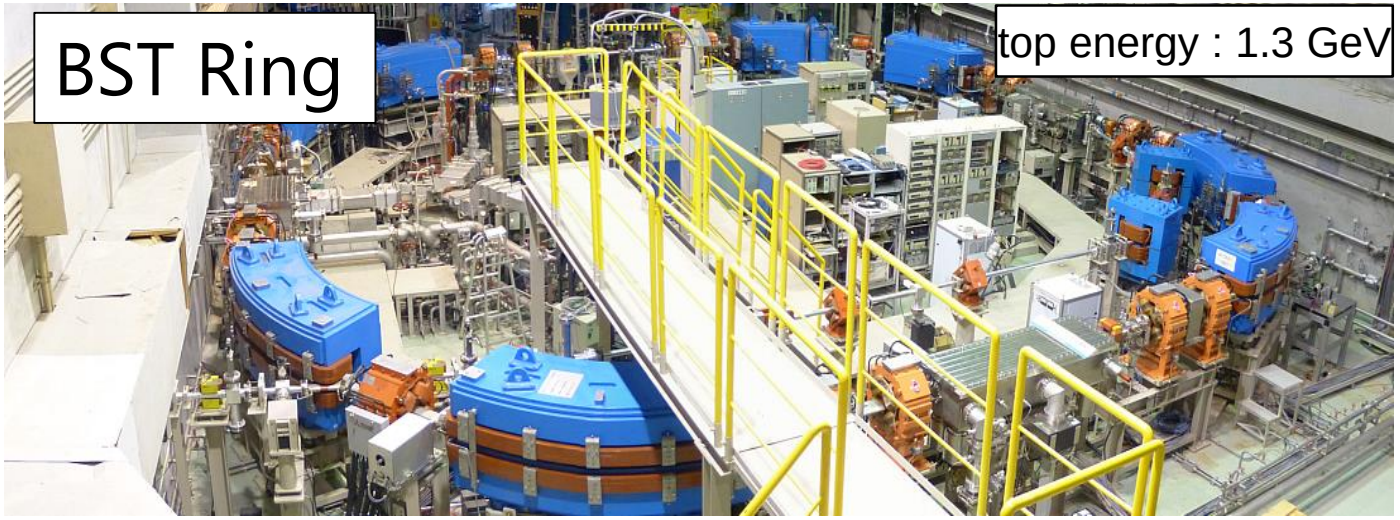
Amp. circuit
Op. amp : AD8000 (Analog Device)
inversed differential circuit

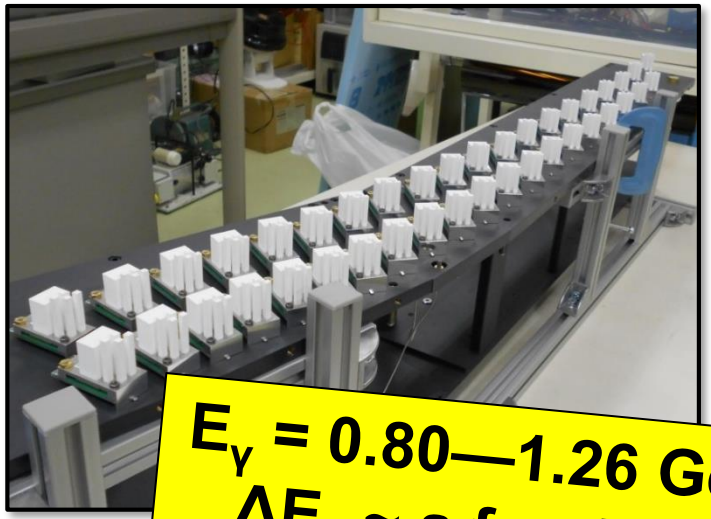
Readout
QTC module + CAEN V1290(TDC)

output signal

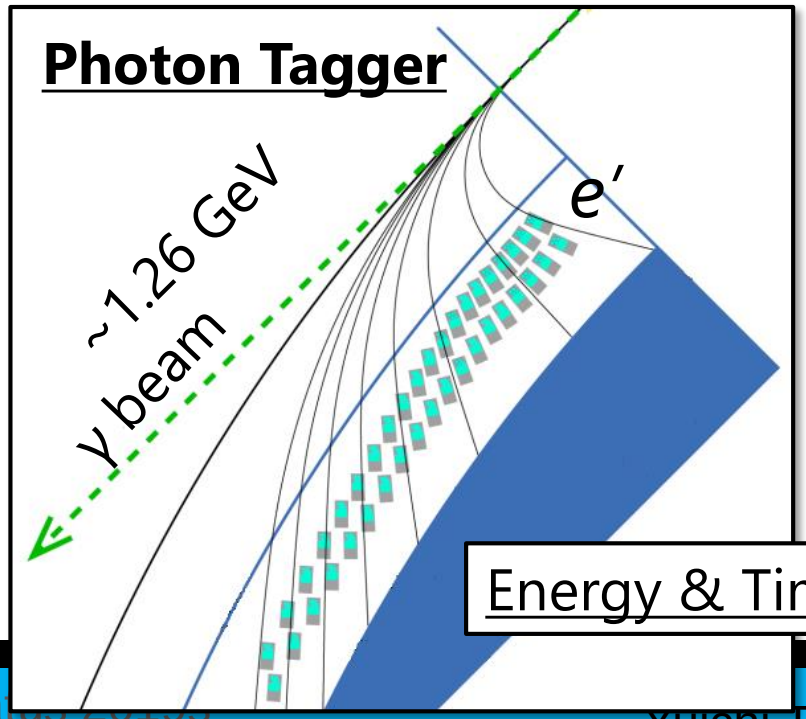


Photon beam at ELPH

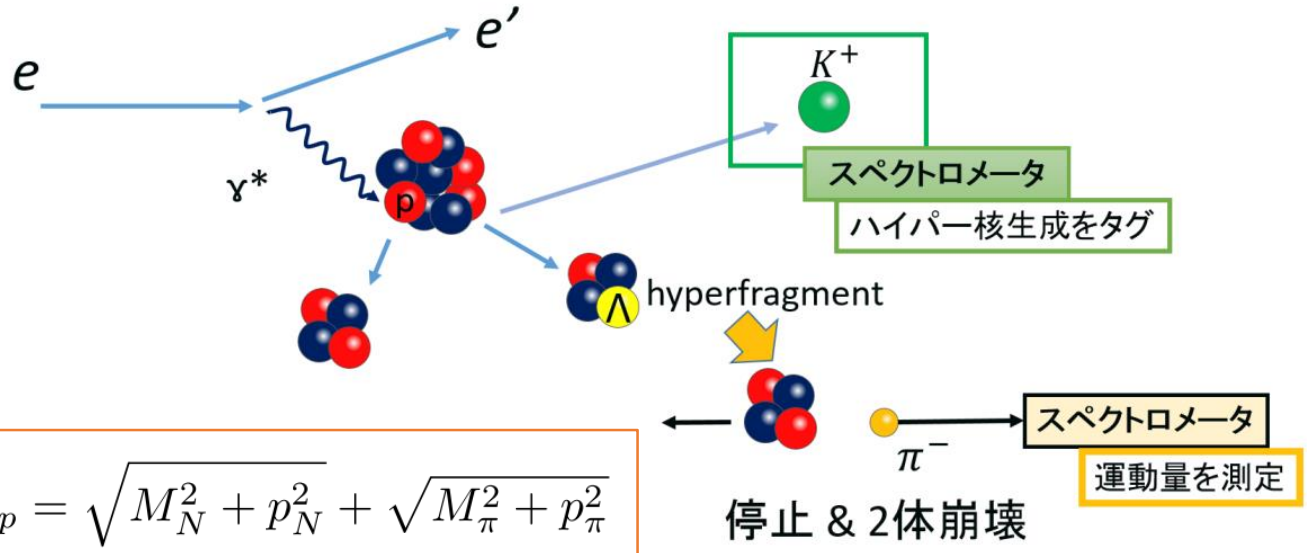




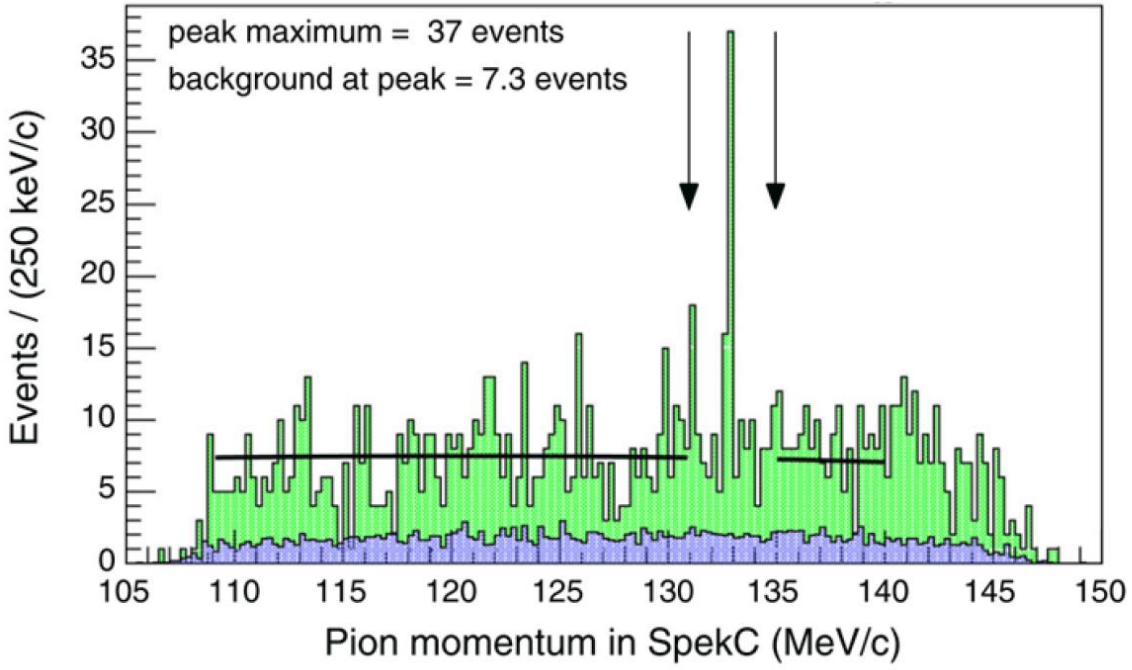
E_γ = 0.80—1.26 GeV
ΔE_γ ~ a few MeV
σ_t = 50 ps



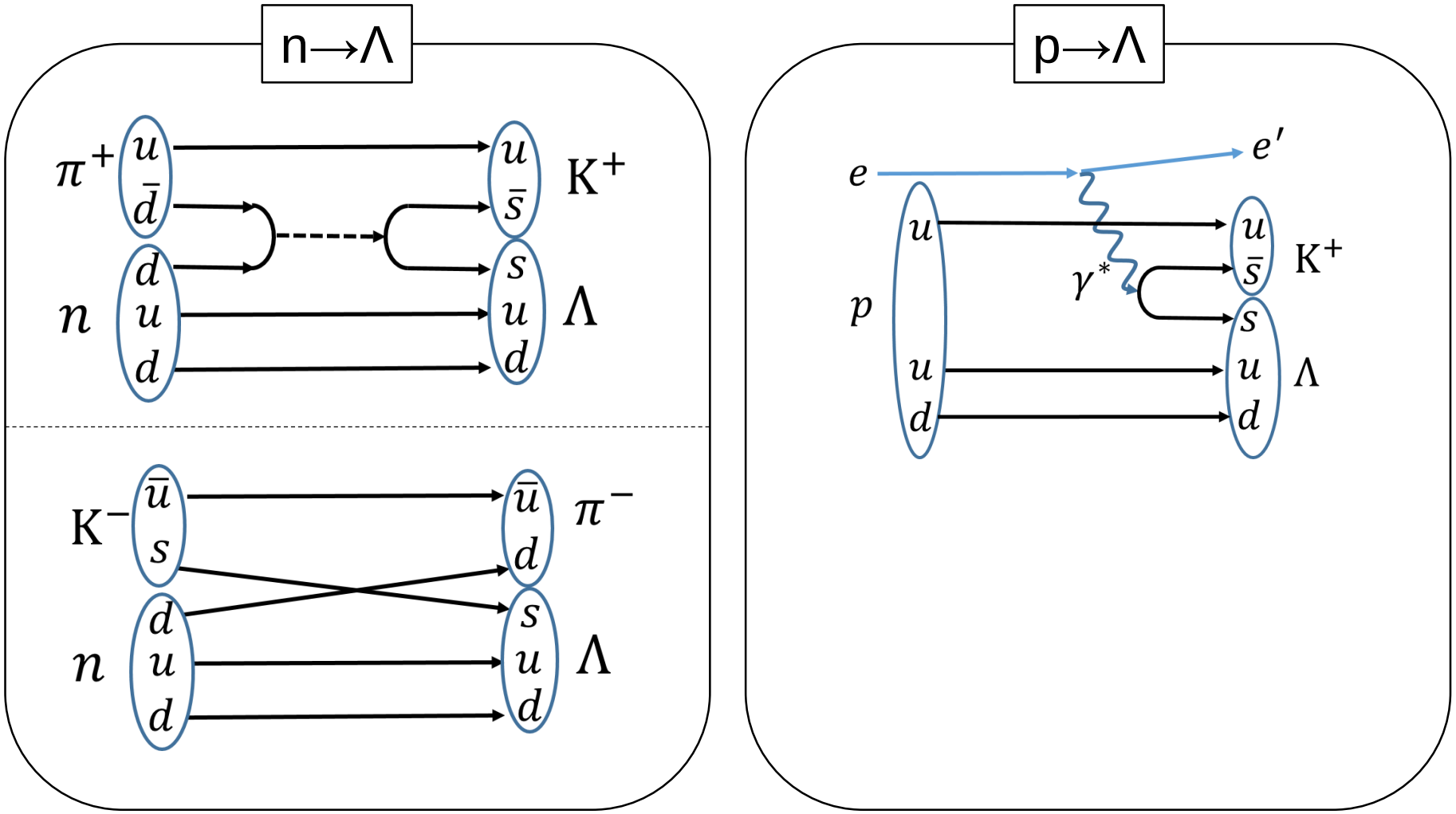
B_Λ



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

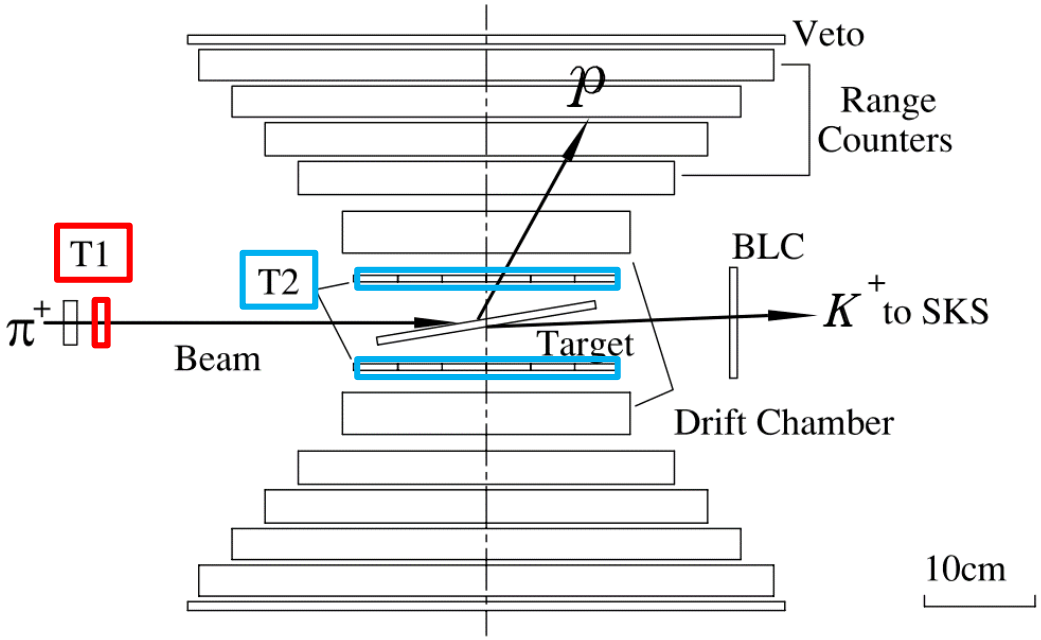


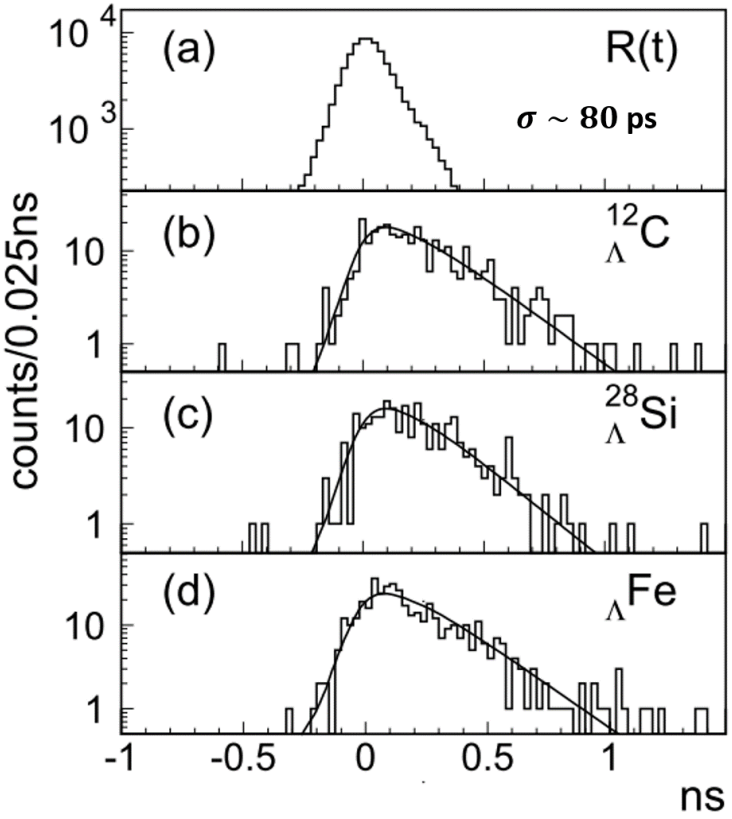
Λ hypernucleus production



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