Design of an experiment for hypernuclear lifetime measurement with photon beam

Contents

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2017/3/13

Emulsion Experiment
(1960's~70's)

Λ binding energy of $^3_\Lambda$H
(3-body decays)

$^4_\Lambda$He

RANGE: 1.59 cm

RANGE: 1.4 mm

$^4_\Lambda He \rightarrow \pi^- + {}^1H + {}^3He$

π⁻

p

³He

100 μm
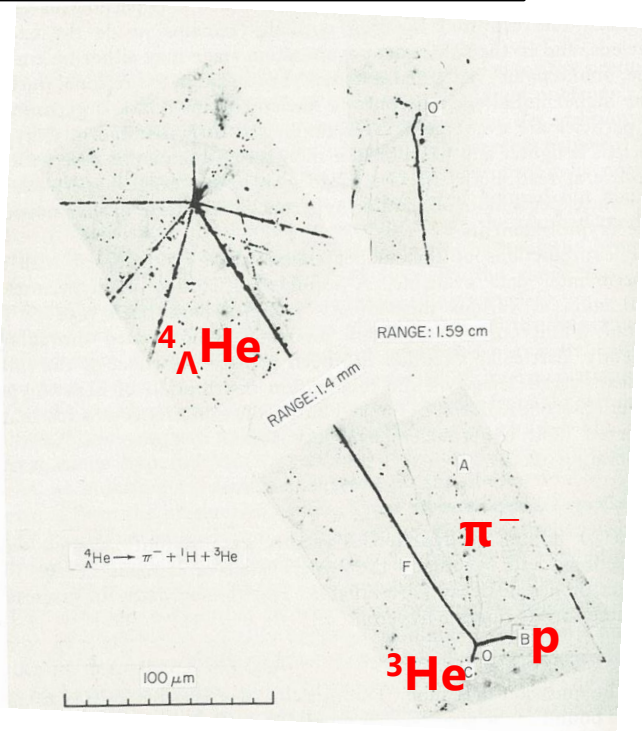
W.H. Barkas,
Nuclear Research Emulsions: Vol.2, (1973)
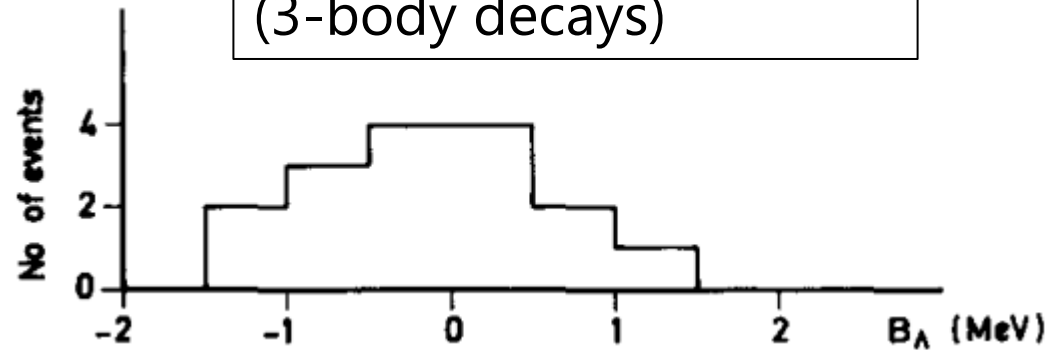
G.Bohm et al., NPB4 (1968) 511.

B_Λ = 0.13±0.05 MeV

M.Juric et al., NPB52 (1973) 1.
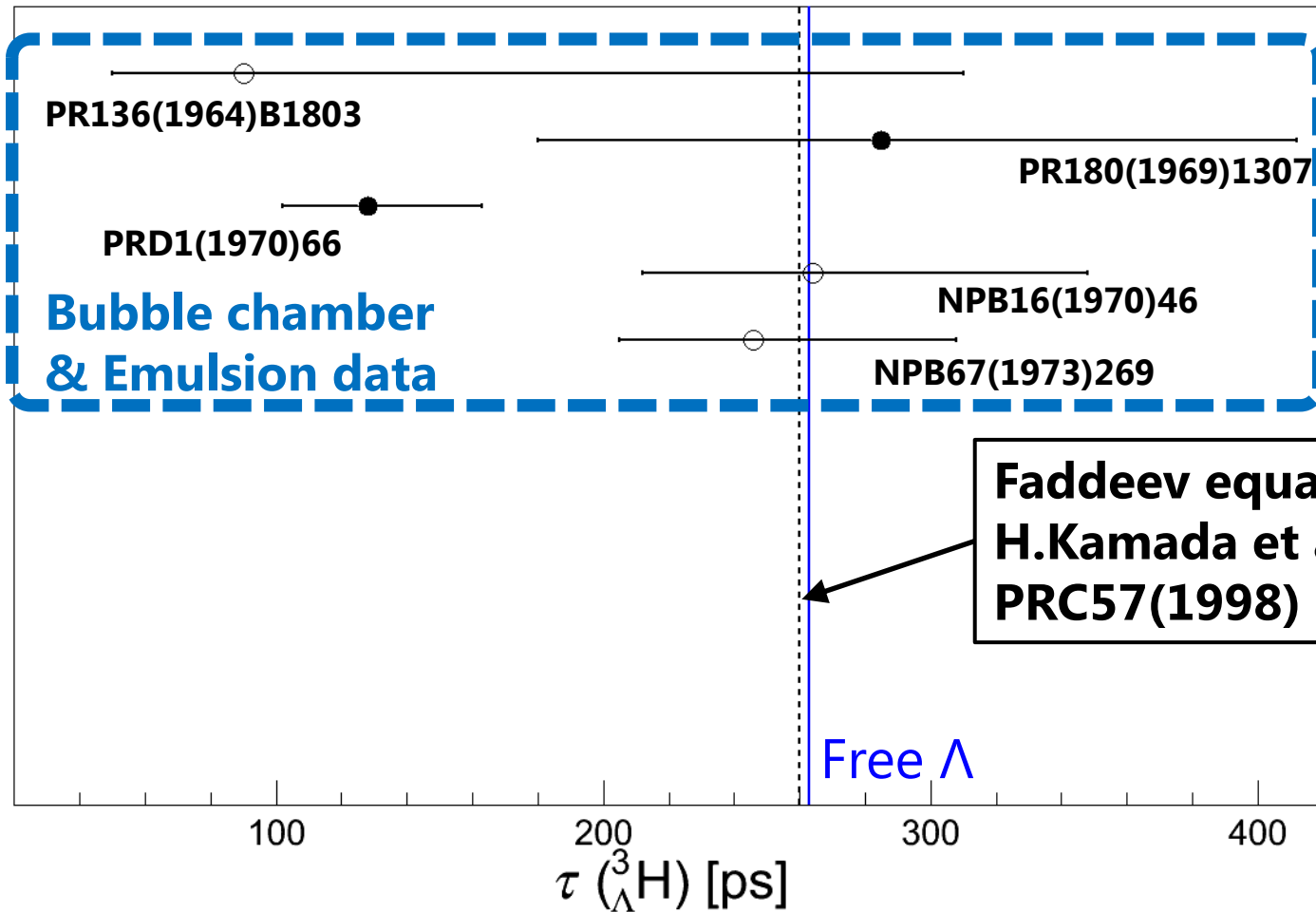
World data of hypertriton's lifetime

PR136(1964)B1803

PR180(1969)1307

PRD1(1970)66

**Bubble chamber
& Emulsion data**

NPB16(1970)46

NPB67(1973)269

**Faddeev equation
H.Kamada et al.
PRC57(1998) 1595.**

Free Λ

$\tau\,(^{3}_{\Lambda}\mathrm{H})$ [ps]

World data of hypertriton's lifetime

PR136(1964)B1803

PR180(1969)1307

PRD1(1970)66

NPB16(1970)46

NPB67(1973)269

Bubble chamber & Emulsion data

STAR Science328(2010)58

HypHI NPA913(2013)170

ALICE PLB754(2016)360

Heavy-ion colli

$$\tau = 215^{+18}_{-16}\ \text{ps}$$

$\tau\ (^{3}_{\Lambda}\text{H})$ [ps]
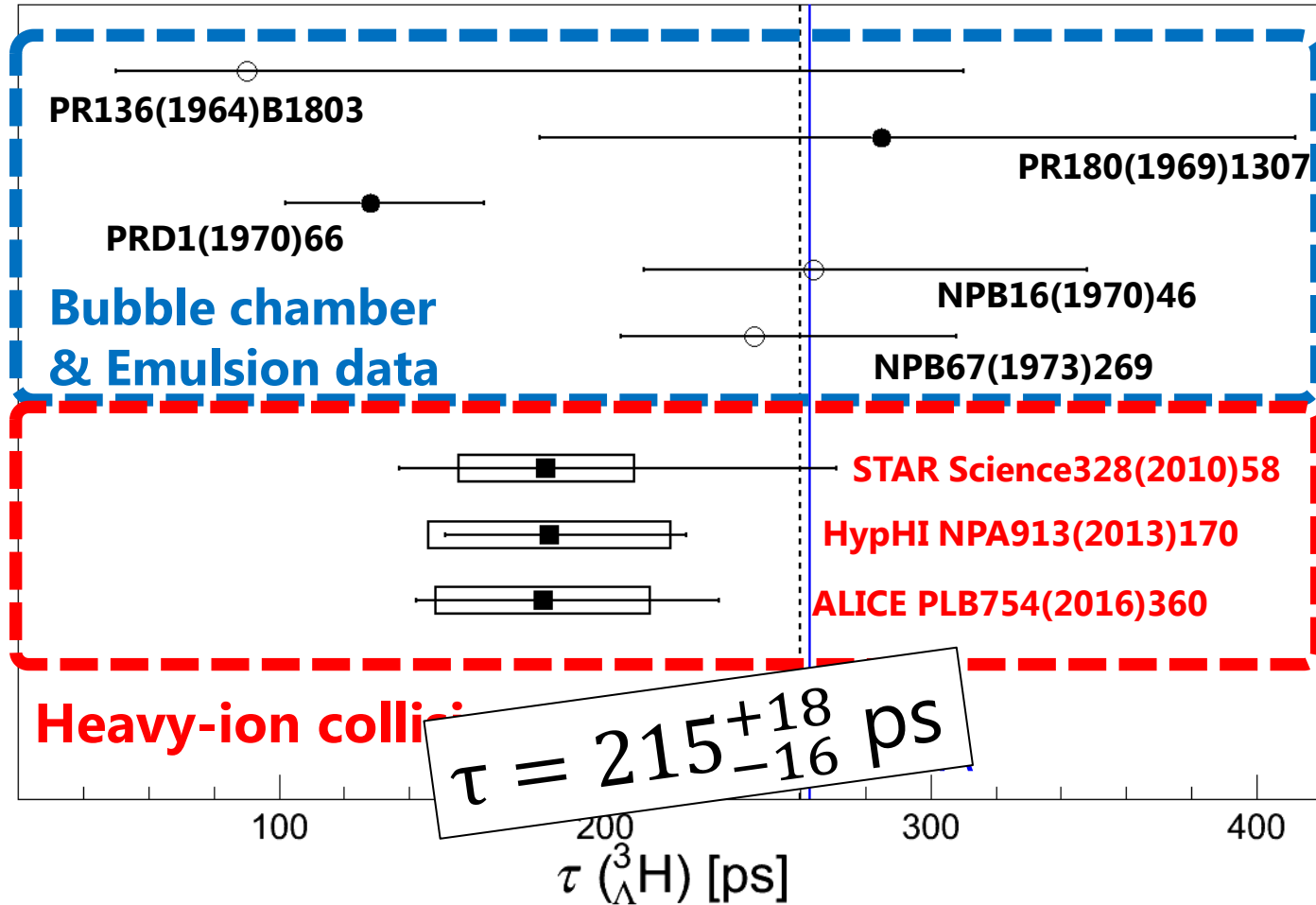
B_Λ = 0.13 MeV ⟷ **τ = 215 ps**

Decay pion spec. [MAMI-C]

New measurement [ELPH]

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

PRL114(2015)232501.
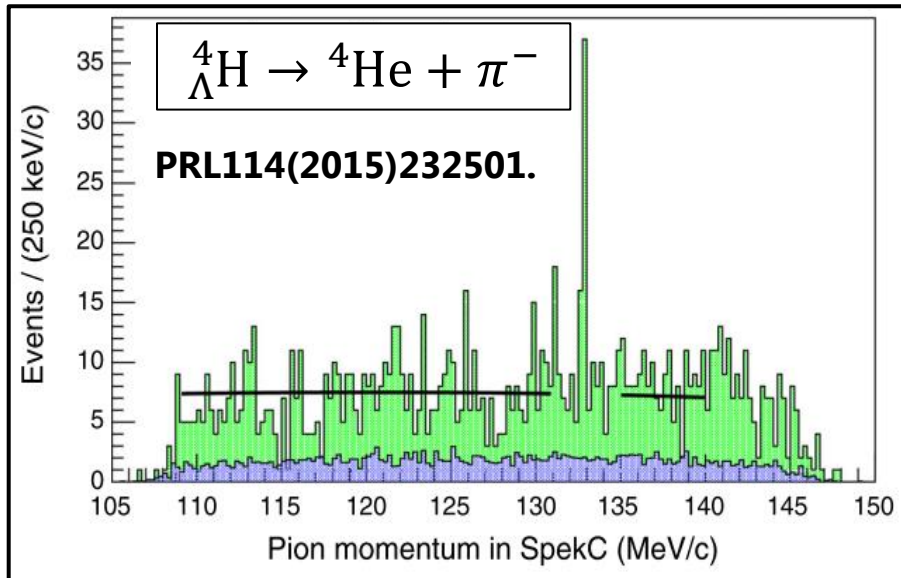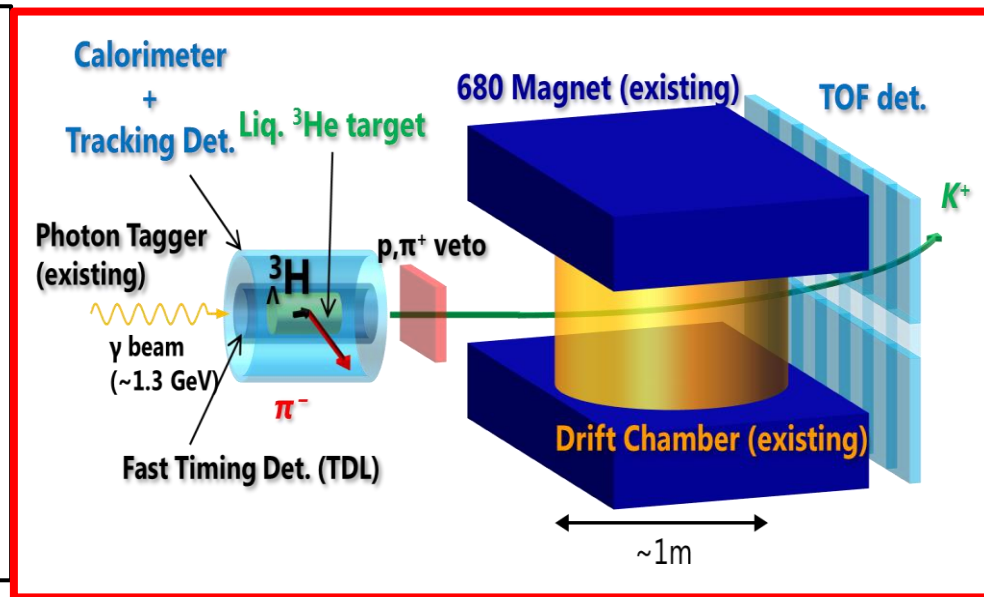
Hypernuclear experiment with photon beam

Hypernuclear lifetime measurement with photon beam

	Meson beam	Electron beam	Photon beam
Channel	$n \to \Lambda$ [$^3H(\pi^+,K^+)^3_\Lambda H$]	$p \to \Lambda$ [$^3He(\gamma,K^+)^3_\Lambda H$]	
Cross section	$\sim$10 µb / sr	$\sim$ 100 nb /sr	
Beam Int. (/sec)	10^7 π^+	$10^{13\sim14}$ e^- $\to 10^{9\sim10}$ γ^*	10^7 γ
Target Thick	a few g/cm^2	0.1 g/cm^2	
Resolution ($\Delta E/E$)	10^{-3}	10^{-4}	
Spec. Acceptance	$\sim$ 100 msr	$\sim$ 10 msr	
Background	○	✕	△

Hypernuclear lifetime measurement with photon beam

	Meson beam	Electron beam	Photon beam
Channel	$n \to \Lambda$ [${}^3H(\pi^+,K^+){}^3_\Lambda H$]	**$p \to \Lambda$** [${}^3He(\gamma,K^+){}^3_\Lambda H$]	
Cross section	∼10 µb / sr	∼ 100 nb /sr	
Beam Int. (/sec)	$10^7 \pi^+$	$10^{13\sim14}$ e^- $\to 10^{9\sim10}$ γ^*	$10^7 \gamma$
Target Thick	a few g/cm^2	0.1 g/cm^2	**> g/cm^2**
Resolution (ΔE/E)	10^{-3}	10^{-4}	**$10^{-3\sim-2}$**
Spec. Acceptance	∼ 100 msr	∼ 10 msr	**100 msr ~ 4π**
Background	○	✕	△

Study of hypernuclei with photon beam is unique.
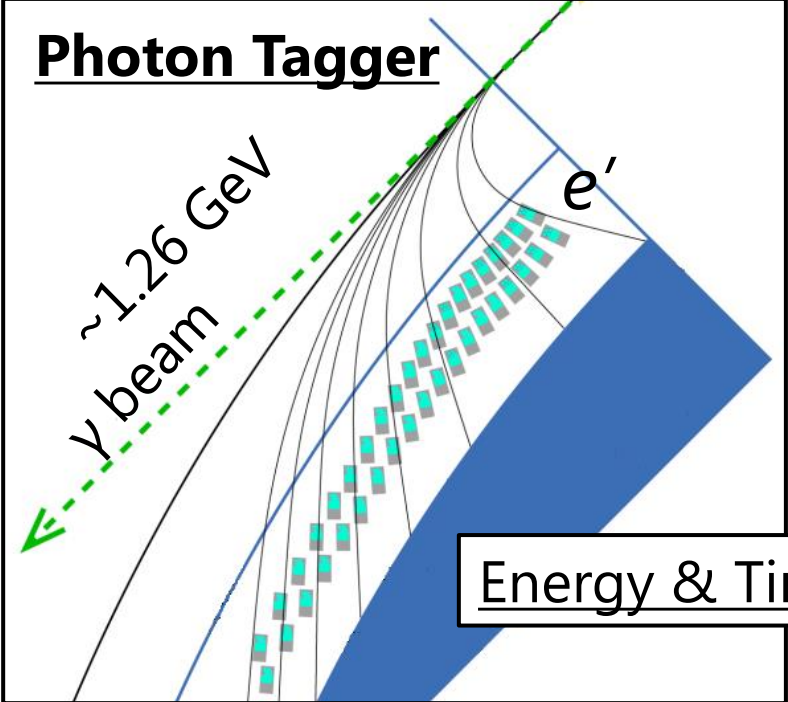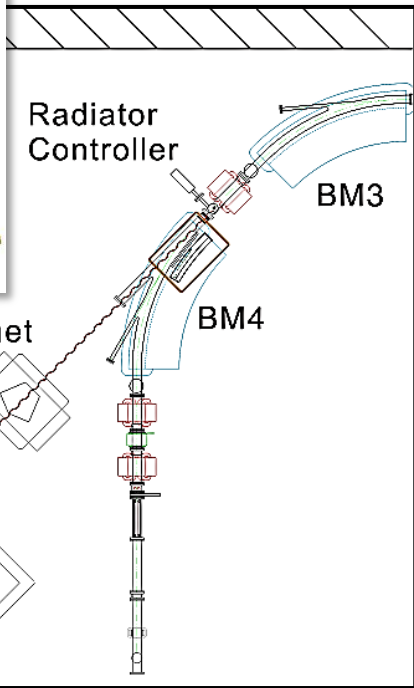
Hypernuclear Chart
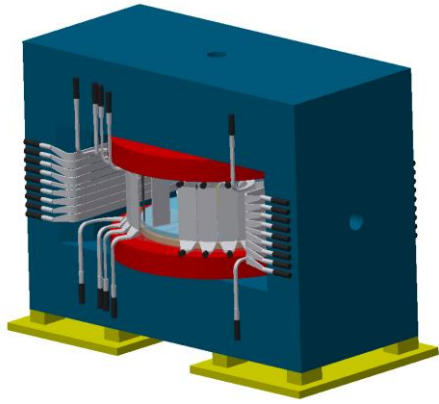

Isospin Mirror Hypernuclei
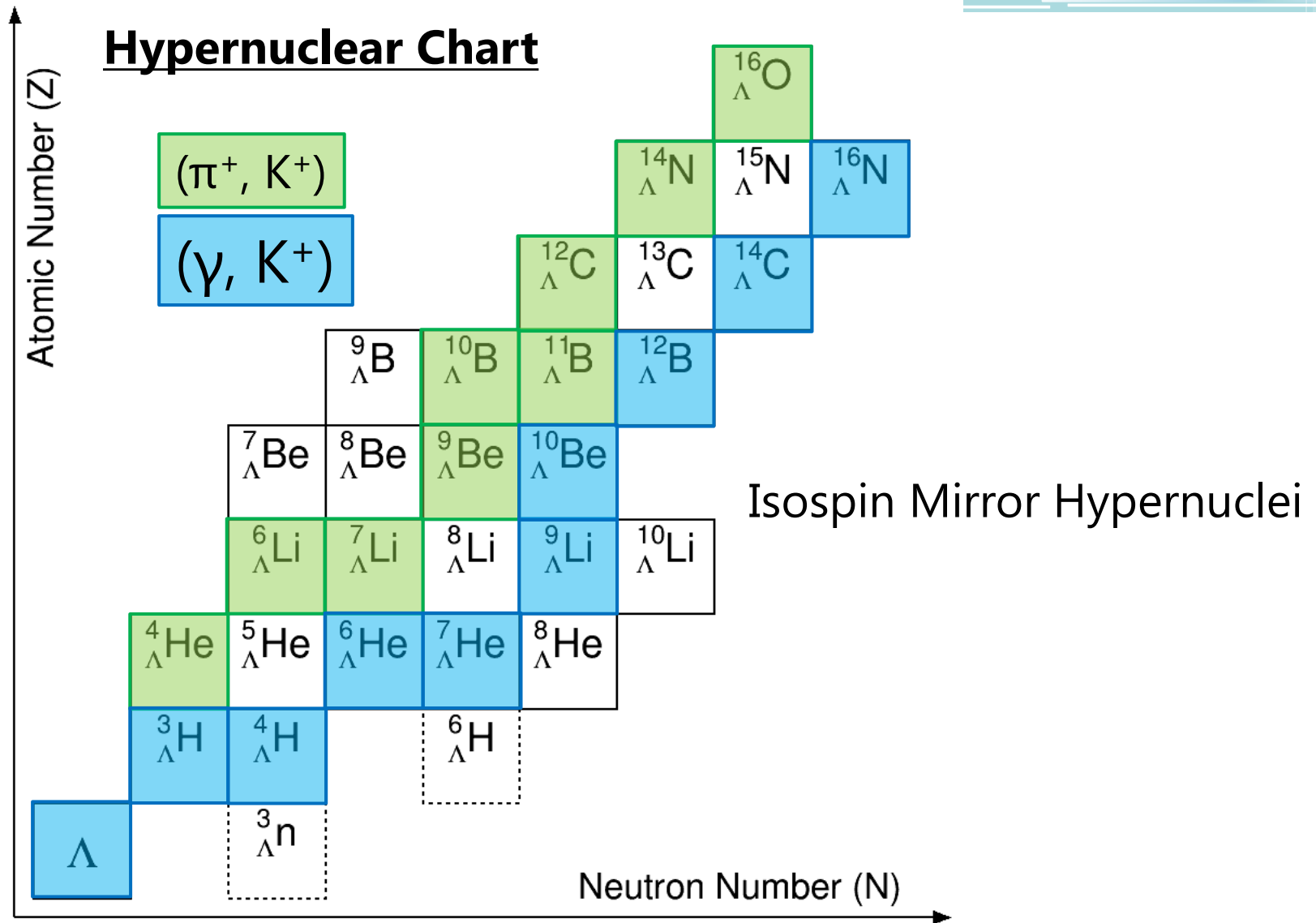
Photon beam facility
ELPH

Photon beam facility ELPH (Tohoku Univ.)

BST Ring

ttp://hayabusa1.lns.tohoku.ac.jp/

Photon Tagger

~1.26 GeV γ beam

e'

Radiator Controller

BM3

Pair Magnet

BM4

NKS2

Photon Beam

Energy & Timing

BST Ring

**Photograph
by Dr. Kanda & Ninomiya**

18.4 mm

#38

40 mm

Pair Magnet

NKS2

BM3

BM4

Photon Beam

~1.26 GeV

γ beam

e⁻

Energy & Timing
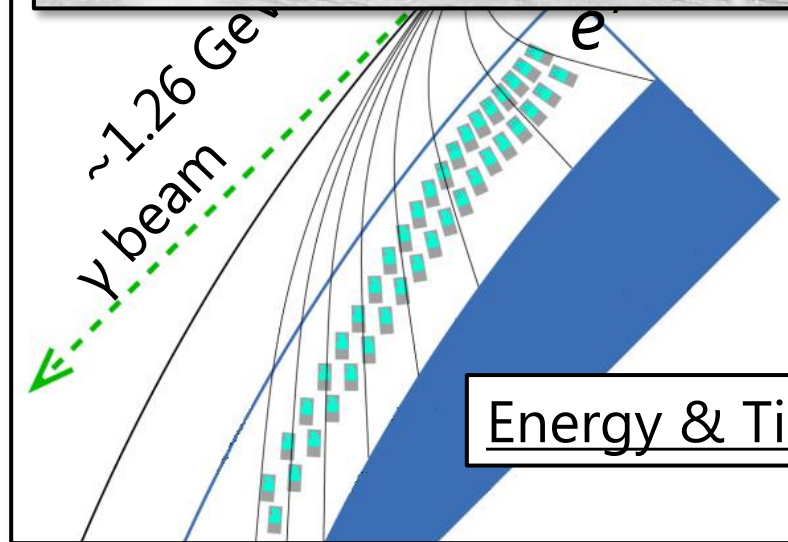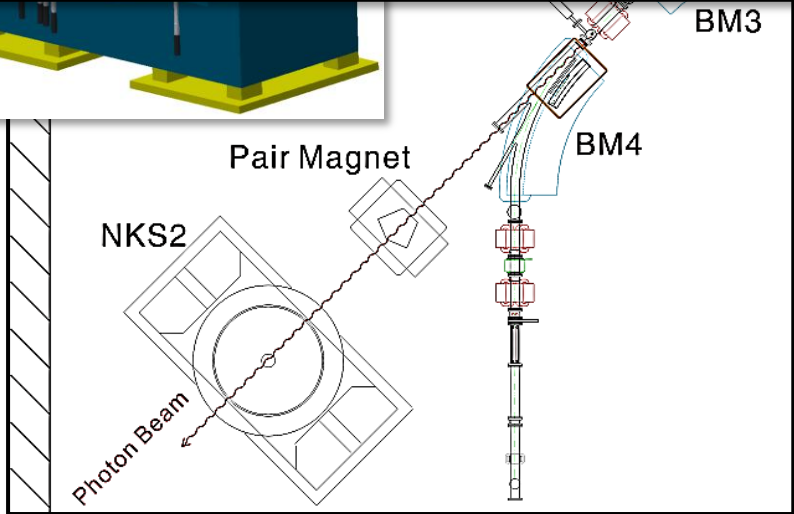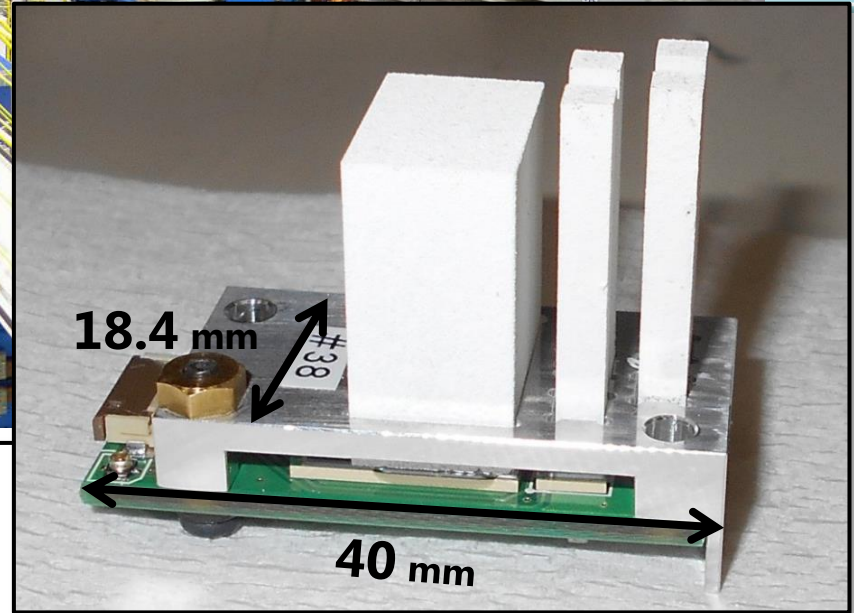
Ee = 1.2 GeV
Eγ = ∼1.08 GeV

⟹ **1.31 GeV, ∼ 1.26 GeV**

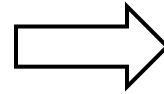## Differential Cross Section of p(γ,K⁺)Λ

PRC 81(2010)025201
PRC 73 (2006) 035214
PRC 73(2006)035202
EPJ A19(2004)251

0.85<cosθ<0.95

Λ production with higher yield
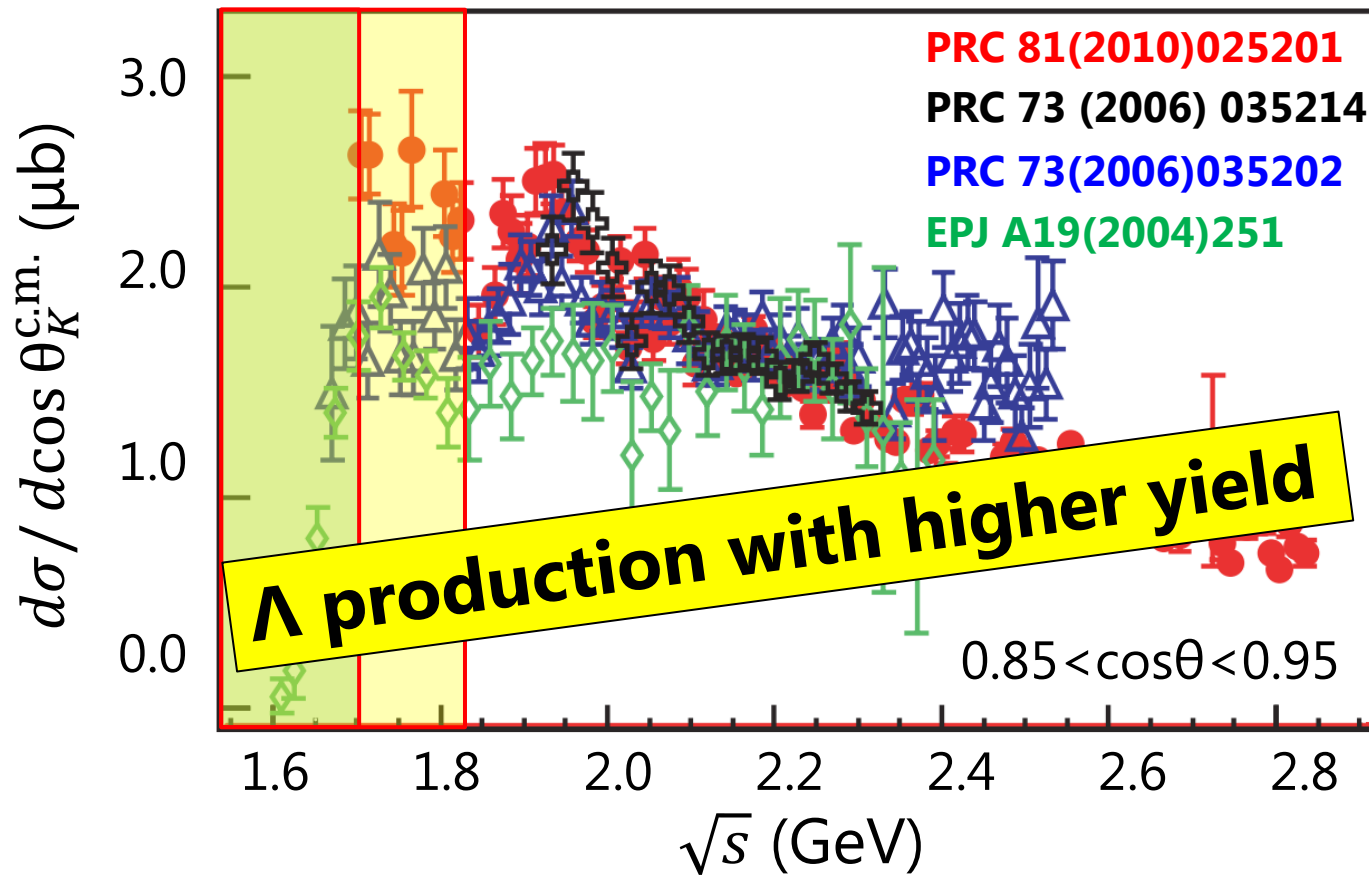
Hypernuclear lifetime measurement with photon beam

A direct lifetime measurement of hypertriton
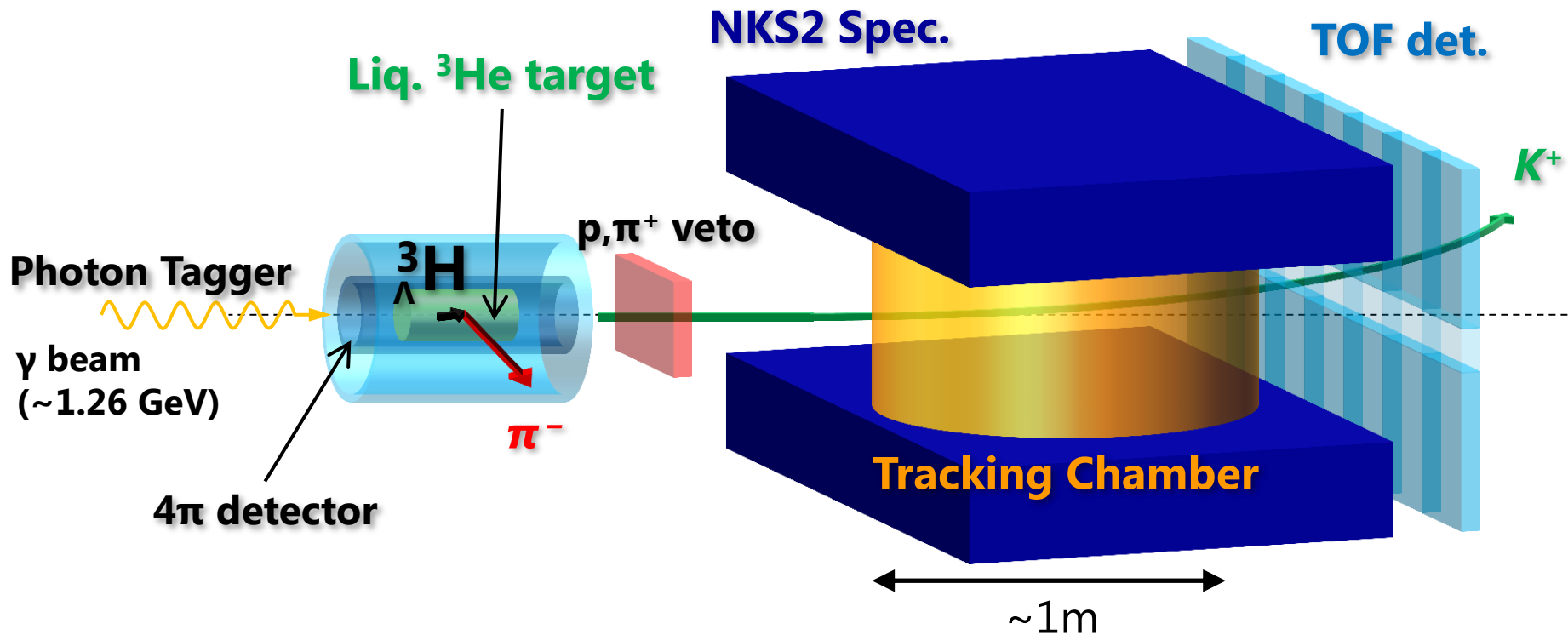
Lifetime measurement with decay pion in $^{3}_{\Lambda}\text{H} \rightarrow \pi^{-} + \text{X}$

$\sim$4 MHz photon beam & T=50 cm Liq. ^{3}He target

Lifetim ~4 arget

$^3_\Lambda$H ID on Missing Mass

q.f. Λ

$^3_\Lambda$H

Counts / MeV

B$_\Lambda$ (MeV)

TOF det.

K^+

p, π^+ veto

Photon Tagger

$^3_\Lambda$H
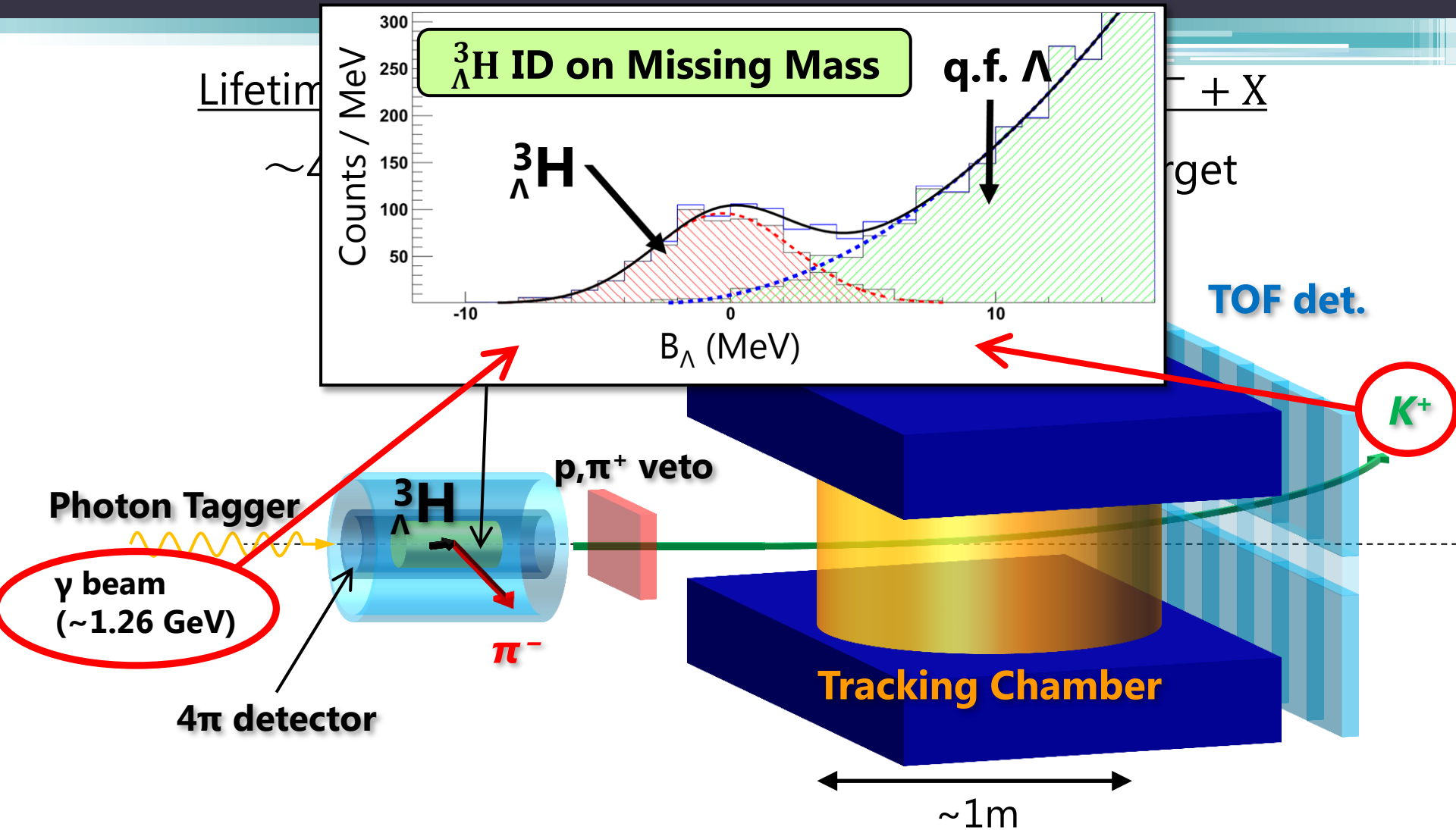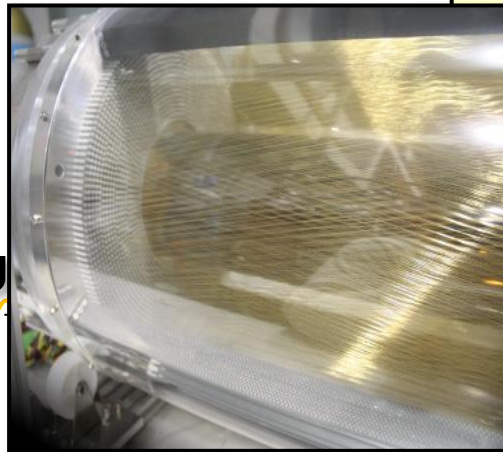
γ beam
(~1.26 GeV)

π^-

4π detector

Tracking Chamber

~1m

A direct lifetime measurement of hypertriton

Lifetime measurement with decay pion in ${}_\Lambda^3 H \rightarrow \pi^- + X$

~4 MHz photon b

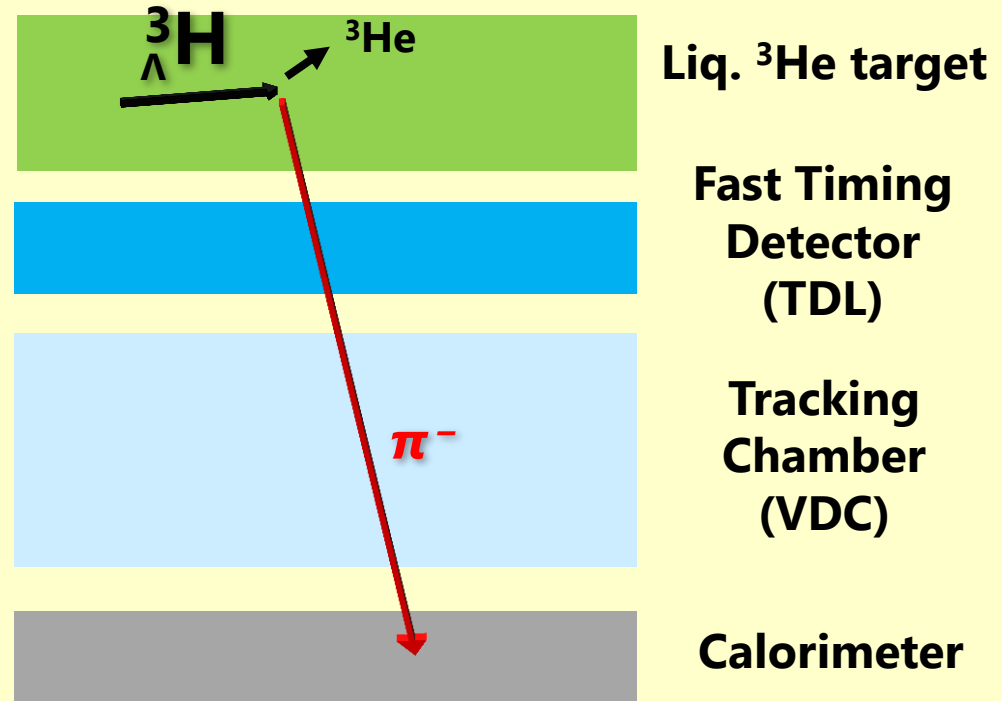**Photon Tagg**

γ beam
(~1.26 GeV)

4π detector

π^- ID, Vertex
Decay time measurement

4π detector for decay pion

${}_\Lambda^3$H → ³He

Liq. ³He target

Fast Timing
Detector
(TDL)

Tracking
Chamber
(VDC)

π^-

Calorimeter

Expected yield

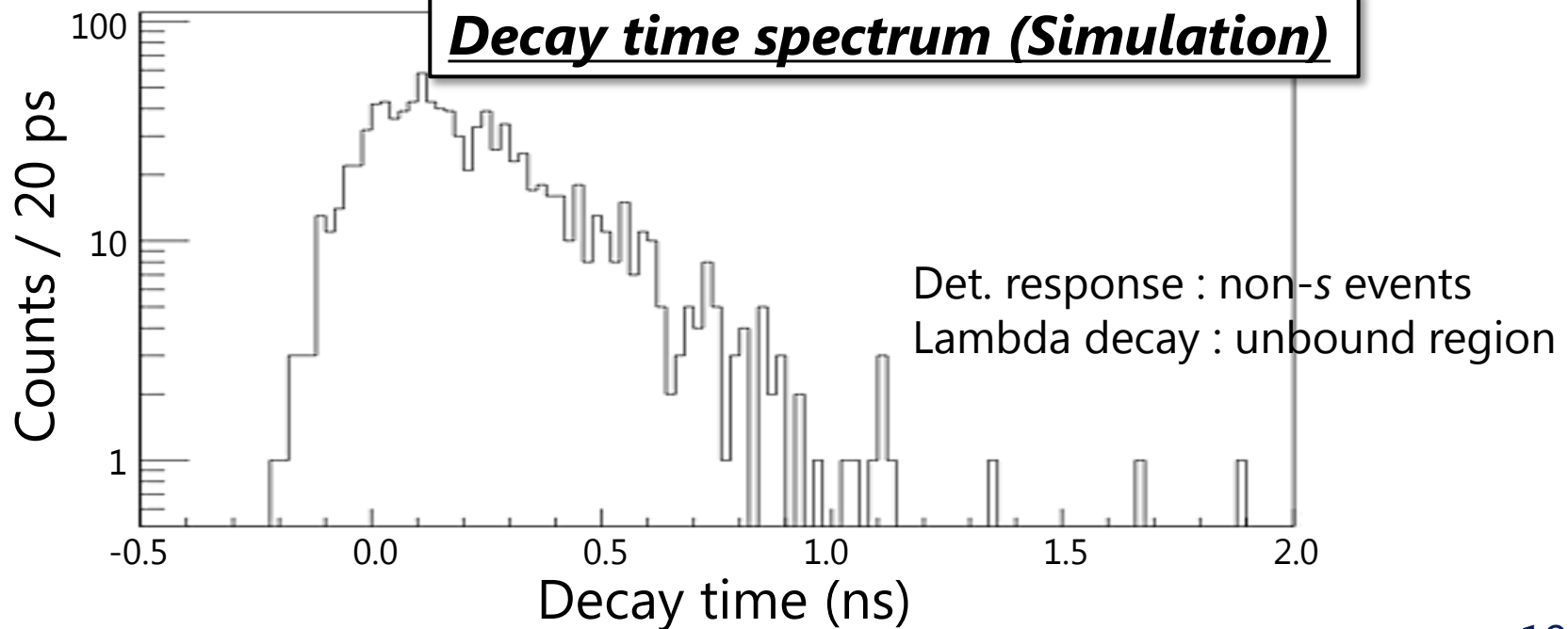|	
Beam intensity	4 MHz
Duty Factor	0.7
Cross section	20 nb
Target thickness	3.2 g/cm^2
$^3_\Lambda$H rate	0.034 Hz
$^3_\Lambda$H $\to X + \pi^-$ ratio	60%
π^- detector acceptance	>90%
K^+ detector acceptance	2.4%
K^+ survival ratio	56%
Photon tagging efficiency	70%
Detector efficiency	99%
Tracking efficiency	95%
DAQ efficiency	60%
detected $^3_\Lambda$H rate	1.5×10^{-4} Hz

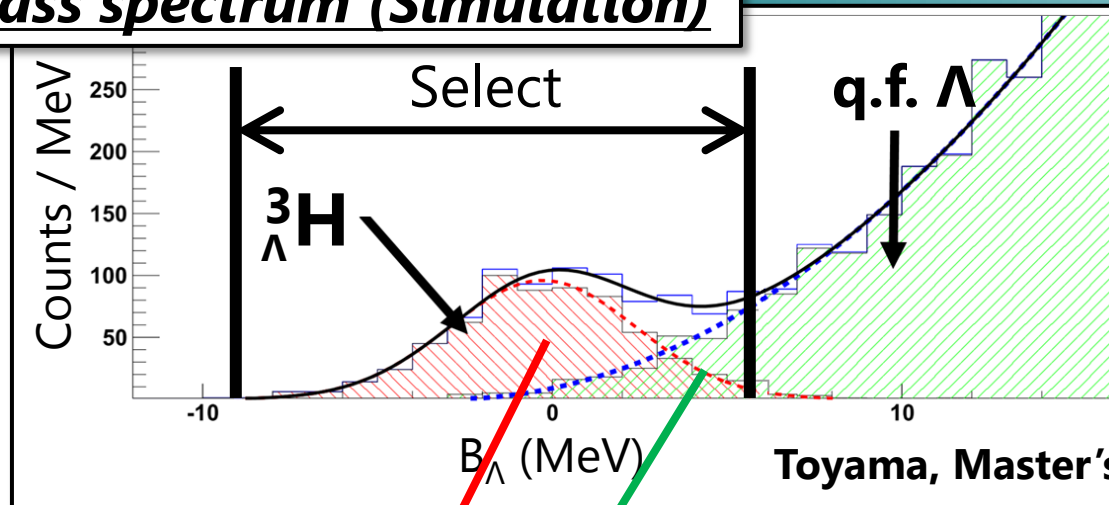## 650 events in 50 days
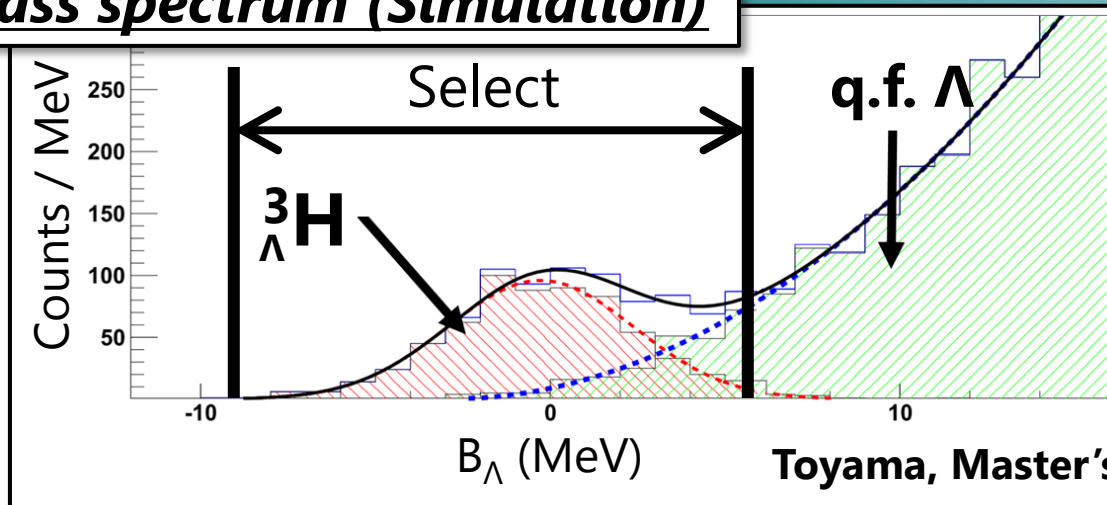
Missing Mass spectrum (Simulation)

Select

q.f. Λ

$^3_\Lambda$H

Counts / MeV

250
200
150
100
50

-10   0   10

B_Λ (MeV)

Toyama, Master's thesis (2017)

Decay time spectrum (Simulation)

Counts / 20 ps

100

10

1

-0.5   0.0   0.5   1.0   1.5   2.0

Decay time (ns)

Det. response : non-*s* events
Lambda decay : unbound region

Missing Mass spectrum (Simulation)

$^3_\Lambda H$

Select

q.f. Λ

Counts / MeV

B_Λ (MeV)

Toyama, Master's thesis (2017)

Decay time spectrum (Simulation)

$\Delta\tau = 10$ ps $(\tau=200ps)$

Det. response : non-*s* events
Lambda decay : unbound region

Counts / 20 ps

Decay time (ns)
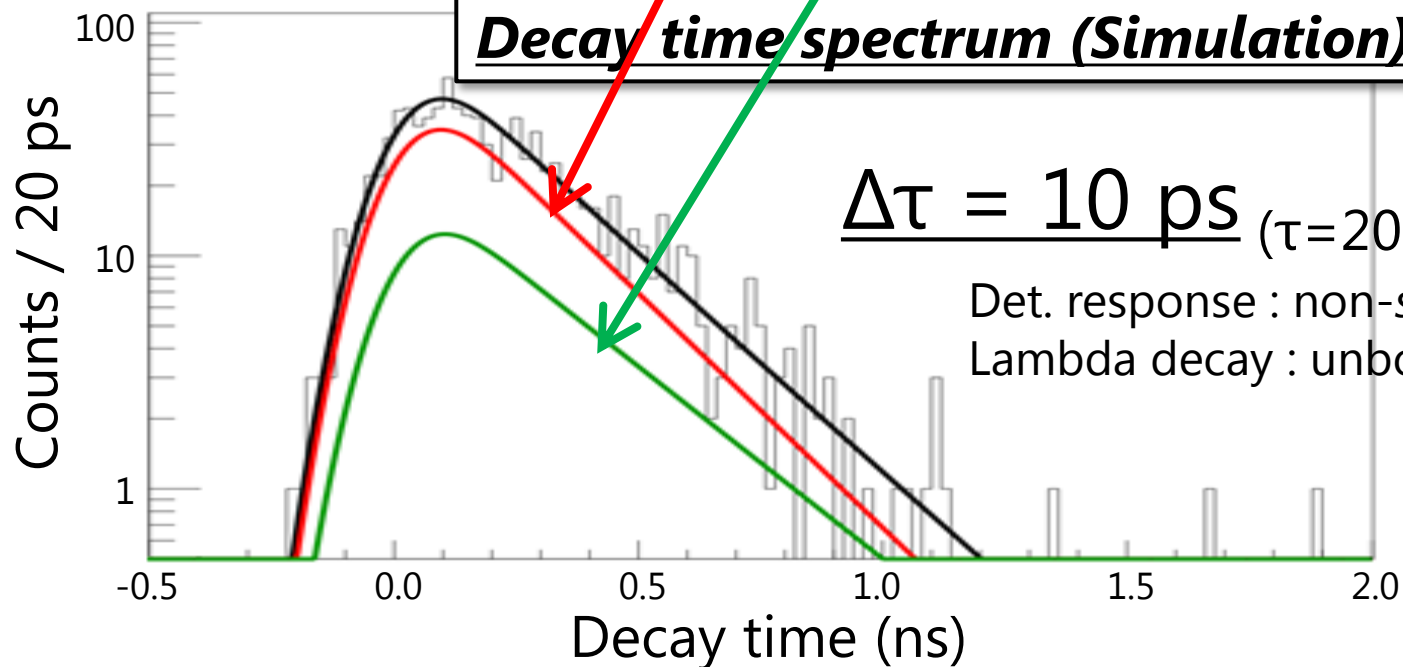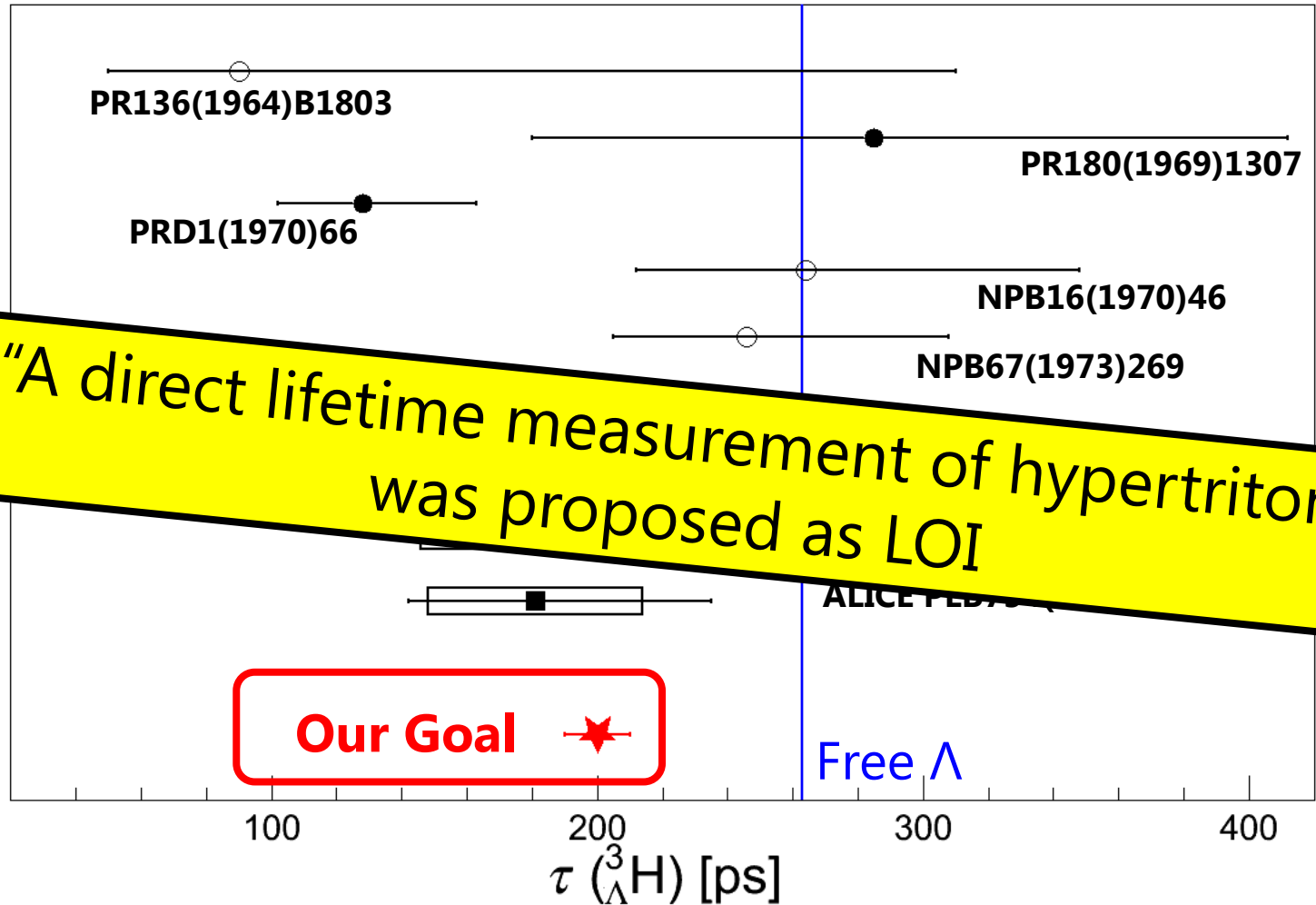
$^3_\Lambda$H lifetime would be measured much preciously.

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

Λ lifetime

- Establish lifetime measurement method of τ ~ 200 ps

$^4_\Lambda$**H lifetime**

- Establish hypernuclear production with photon beam
- Establish lifetime measurement method with hypernuclear decay pion

$^3_\Lambda$**H lifetime**

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

| Λ lifetime | April 2017 |

⬇

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

⬇

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

Checking feasibility as reasonable as possible.
Whether τ = 200 ps can be deduced or not ??
τ (Λ) = 263.2 ± 2.0 ps

Checking feasibility as reasonable as possible.
Whether τ = 200 ps can be deduced or not ??
τ (Λ) = 263.2 ± 2.0 ps

Liq. H$_2$ target

~~**Liq. ^{3}He target**~~

NKS2 Spec.

TOF det.

$p(\gamma,K^+)\Lambda$ reaction

K^+

p,π$^+$ veto

Photon Tagger

γ beam (~1.26 GeV)

4π detector

Tracking Chamber

~1m
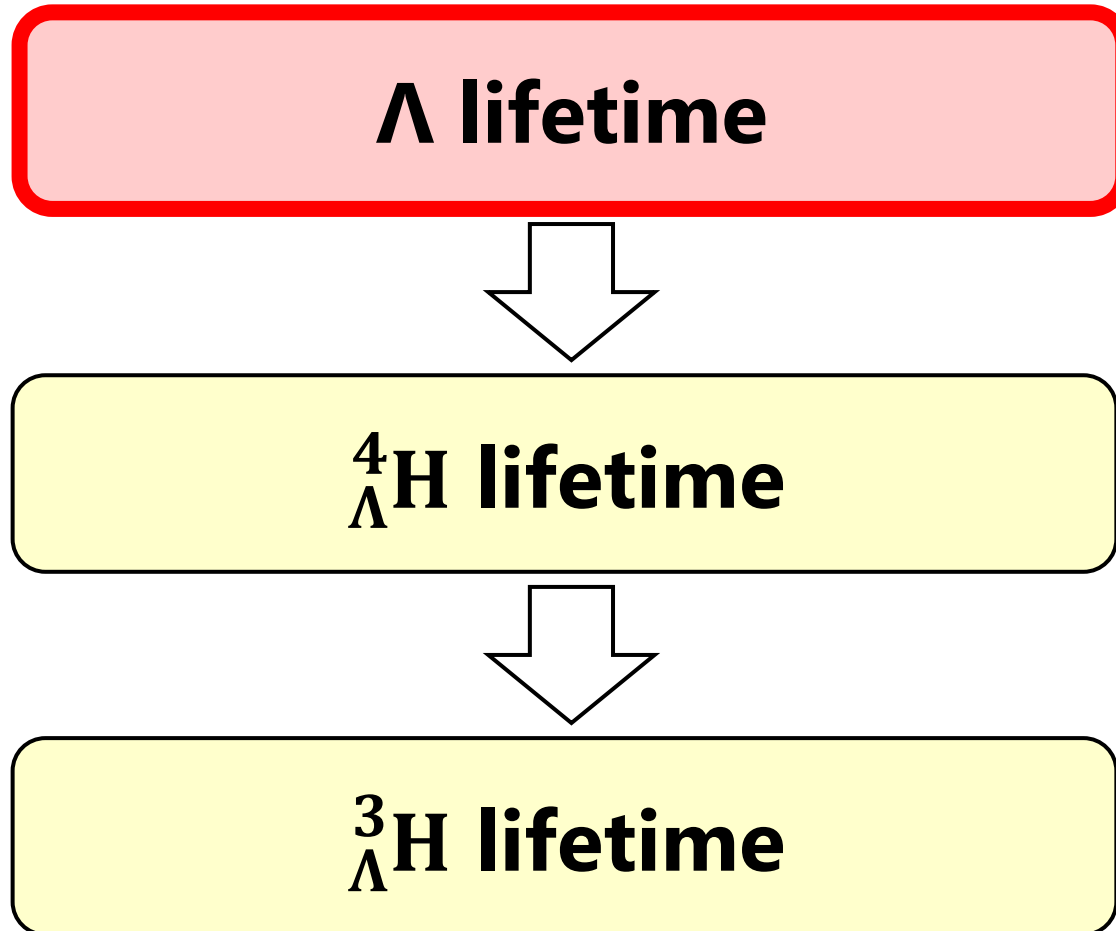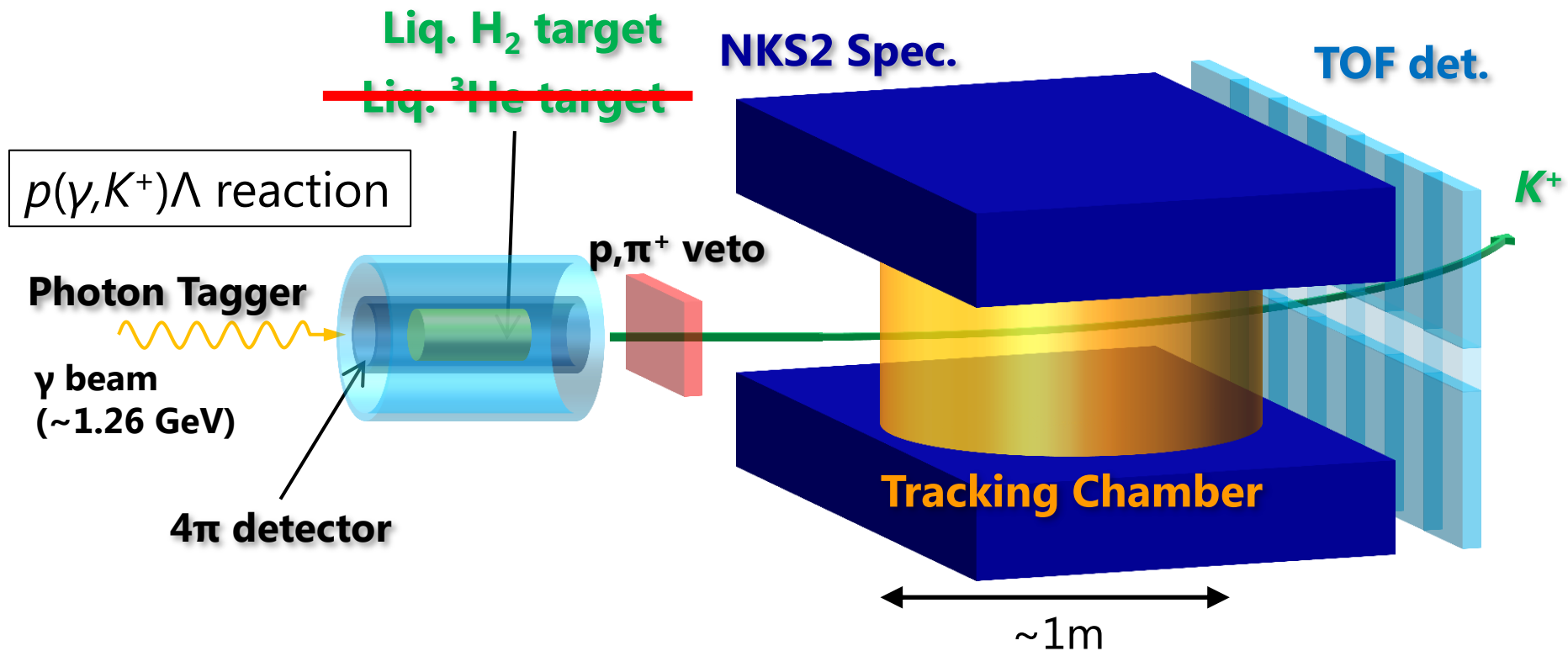
Requirement
- Good timing resolution (σ < 100 ps)
- Operating in Mag. Field
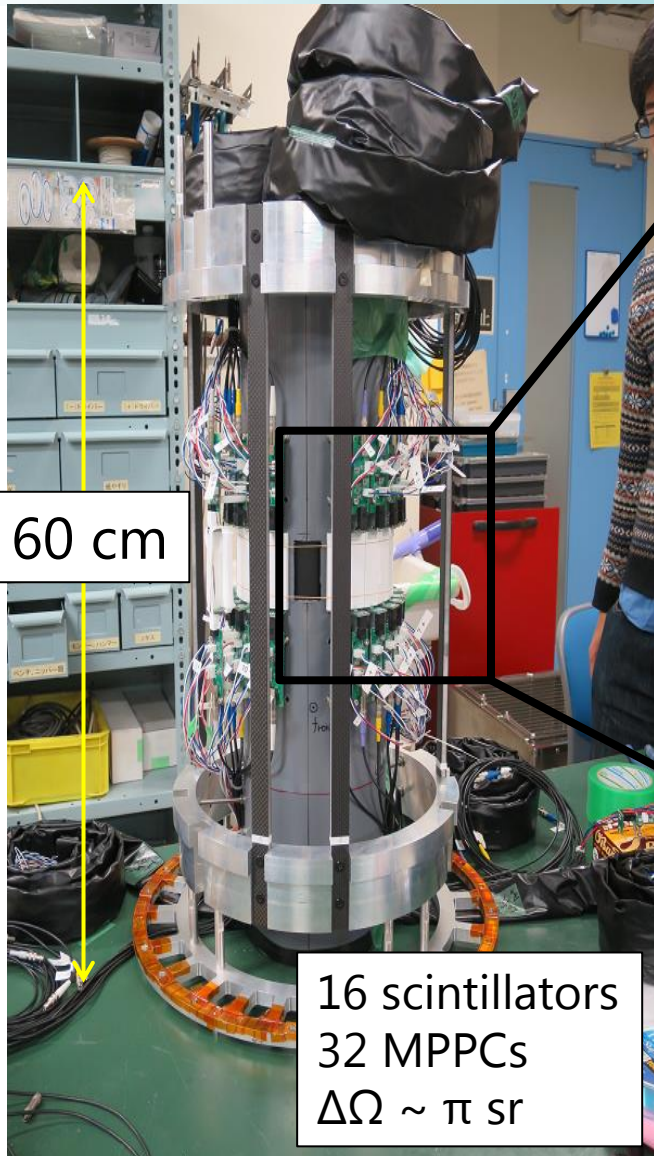 ⇒ Plastic scintillator + SiPM

EJ-212($20^W \times 60^L \times 5^T$ mm^3)
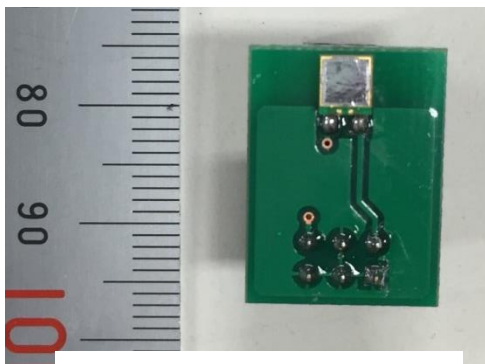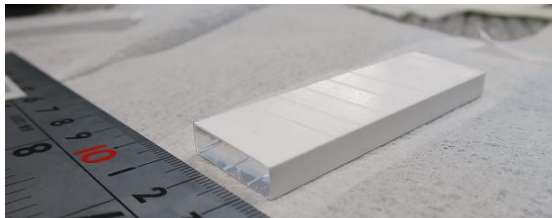
MPPC
S13360-3050PE

Inv. Diff. Amp. (AD8000)

Frame (PVC)

60 cm

16 scintillators
32 MPPCs
$\Delta\Omega \sim \pi$ sr
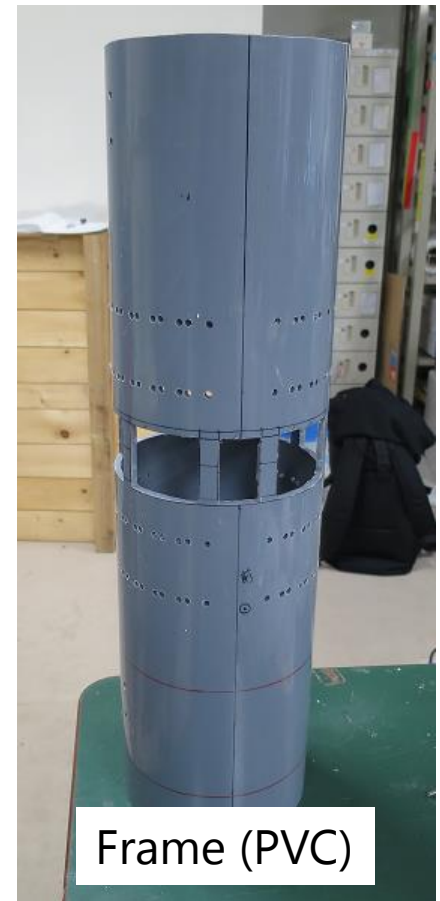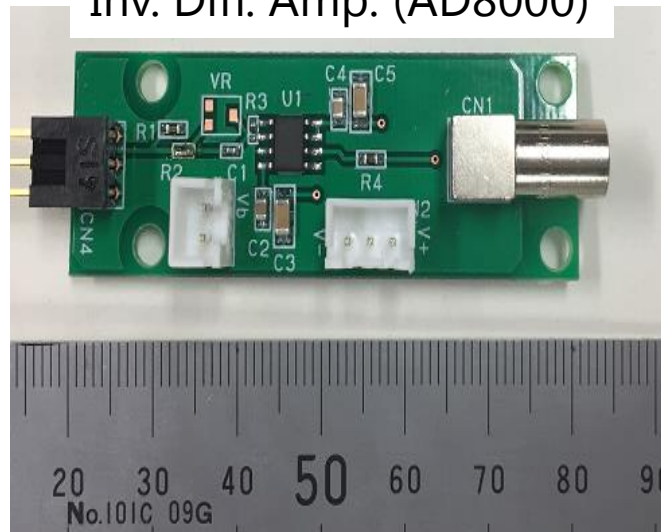
Timing & Charge : QTC → V1290 (CAEN)
$\sigma \sim$ 80 ps was achieved.
($\sigma \sim$ 50 ps would be achieved in future)

- **<u>Hypertriton puzzle</u>**
  - ➢ Exciting results from heavy-ion collision
  - ➢ Understanding small binding energy & short lifetime is very important.

- **<u>Lifetime measurement with photon beam at ELPH</u>**
  - ➢ Neutron-rich hypernuclei can be produced.
  - ➢ $^3_\Lambda$H can be produced from ^{3}He target
  - ➢ Lifetime would be deduced by measuring decay timing
  - ➢ 650 $^3_\Lambda$H events would be detected in 50 days
    $\Rightarrow$ $^3_\Lambda$H lifetime with a precision of 10 ps
  - ➢ Λ lifetime measurement, $^4_\Lambda$H lifetime measurement will be performed as a feasibility check.
  - ➢ Detectors for Λ lifetime measurement is ready