Light hypernuclear studies at ELPH and MAMI

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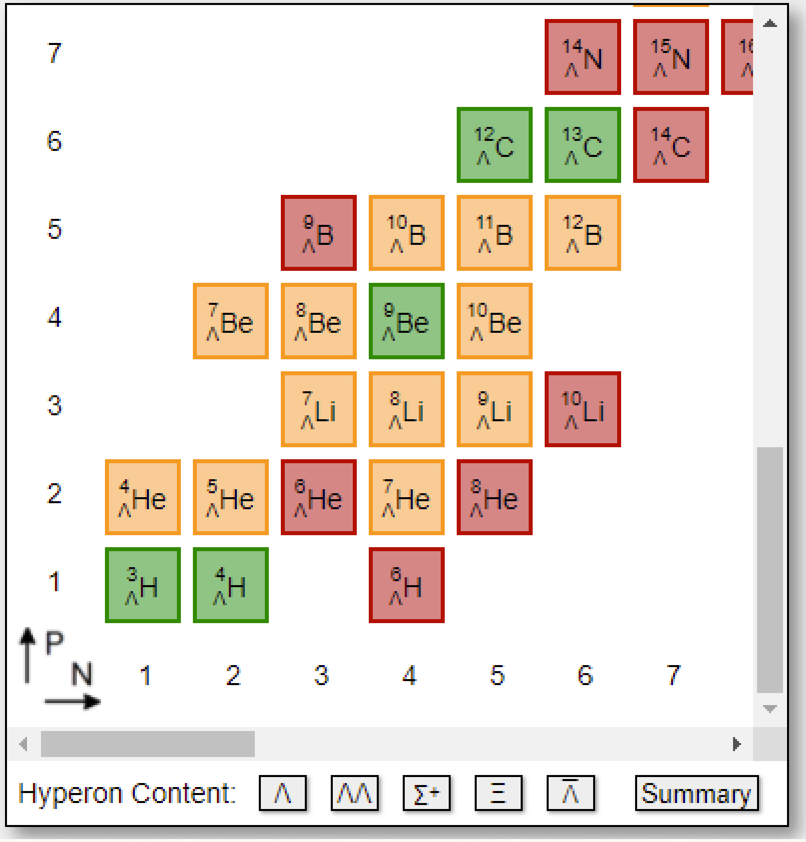
Contents

Hypertriton Binding Energy

CHART OF HYPERNUCLIDES – Hypernuclear Structure and Decay Data

JG|U STRONG 2020

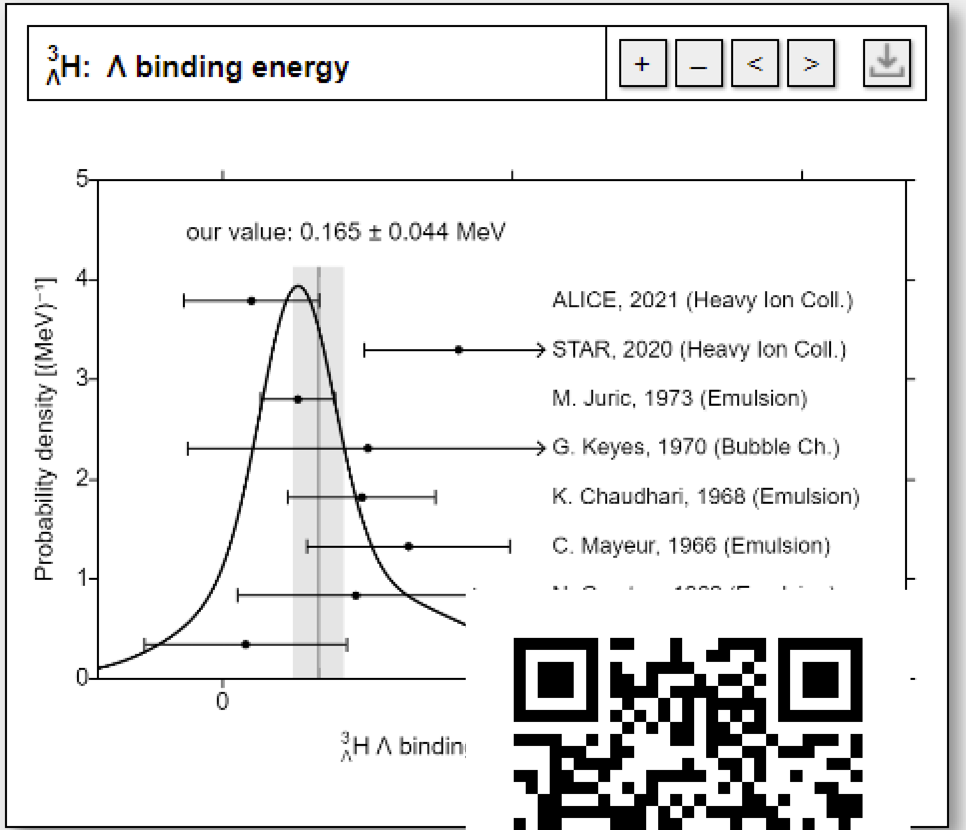


$^{3}_{\Lambda}$Hydrogen

- Non-strange core: ^{2}H
  - mass: m_{GS} = 1875.613 MeV/c^2
  - mean life time: stable
  - ground state spin/parity: 1^+
- Hyperon Content: Λ
  - mass: m_{GS} = 1115.683 MeV/c^2
  - mean life time: τ = 263.1 ps
  - spin: $\frac{1}{2}$

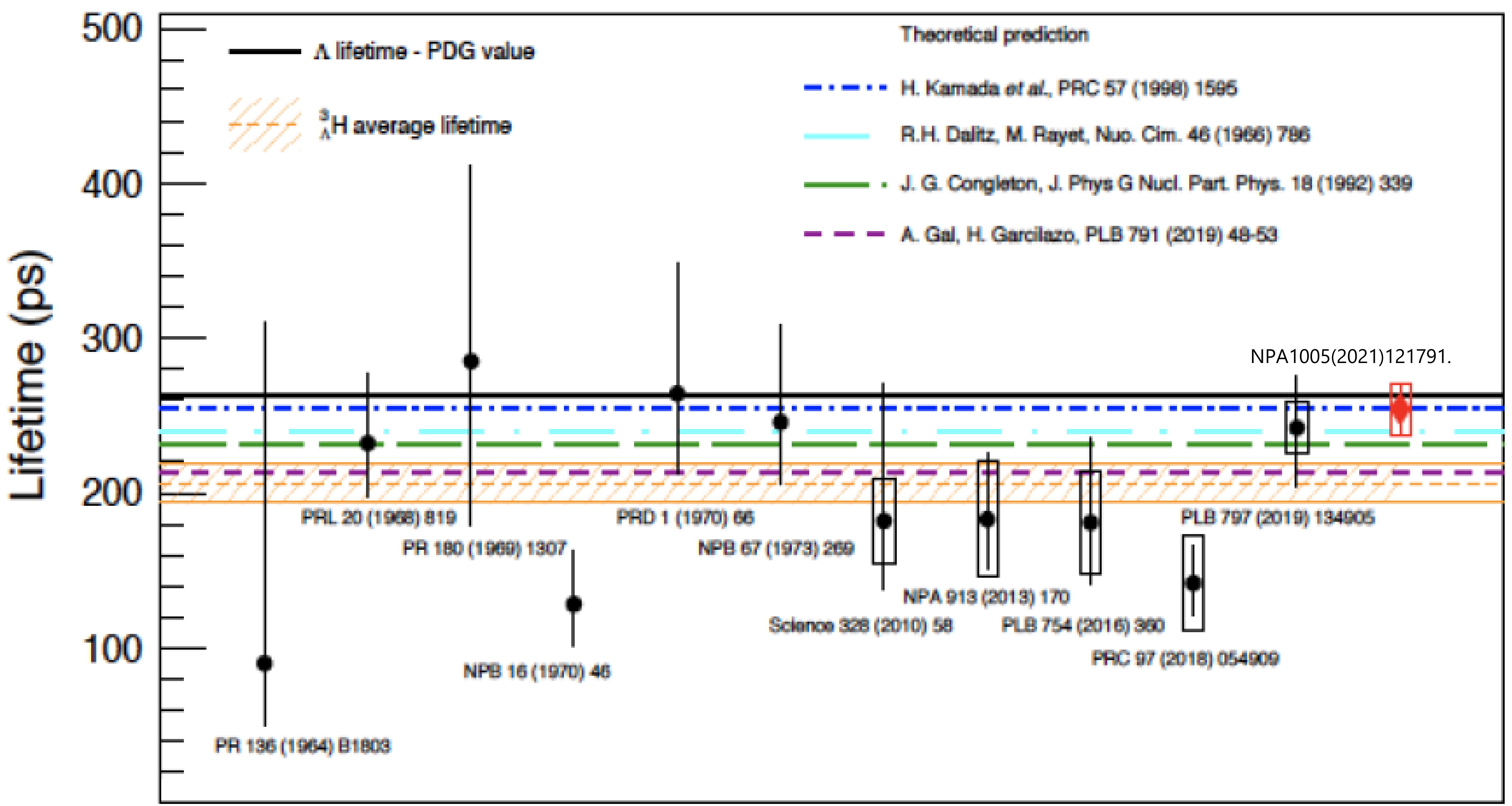
Chart Legend - available data

- less than 6 values
- less than 20 values
- at least 20 values



https://hypernuclei.kph.uni-mainz.de/

Hypertriton Lifetime

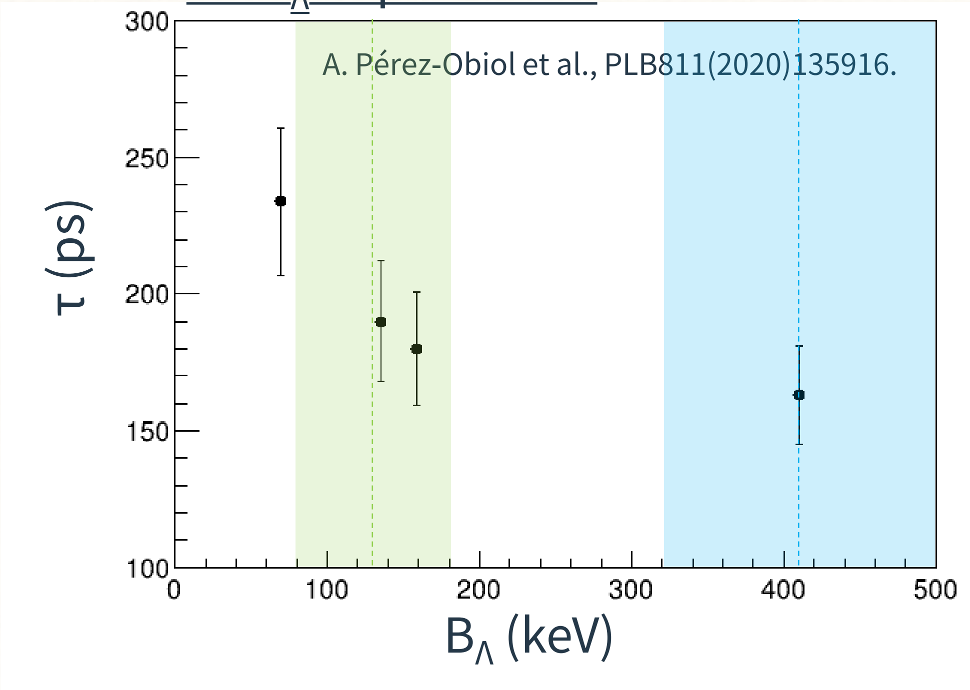


Theoretical Predictions

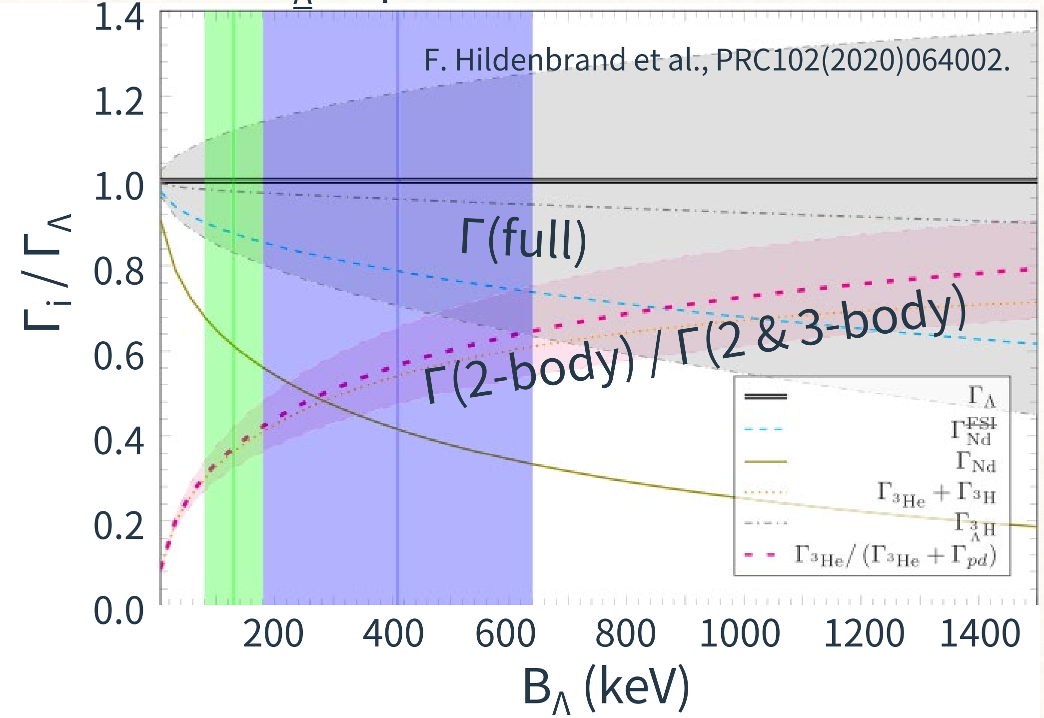
Three-body Faddeev approach: 256 ps H.Kamada et al., PRC57(1998)1595.

Faddeev + attractive pion FSI : 213 ps A.Gal et al., PLB791(2019)48.

τ—B_Λ dependence



Γ—B_Λ dependence



Strong correlation with lifetime−B_Λ and width−B_Λ.

Measurement of B_Λ, lifetime, and decay branch is important.

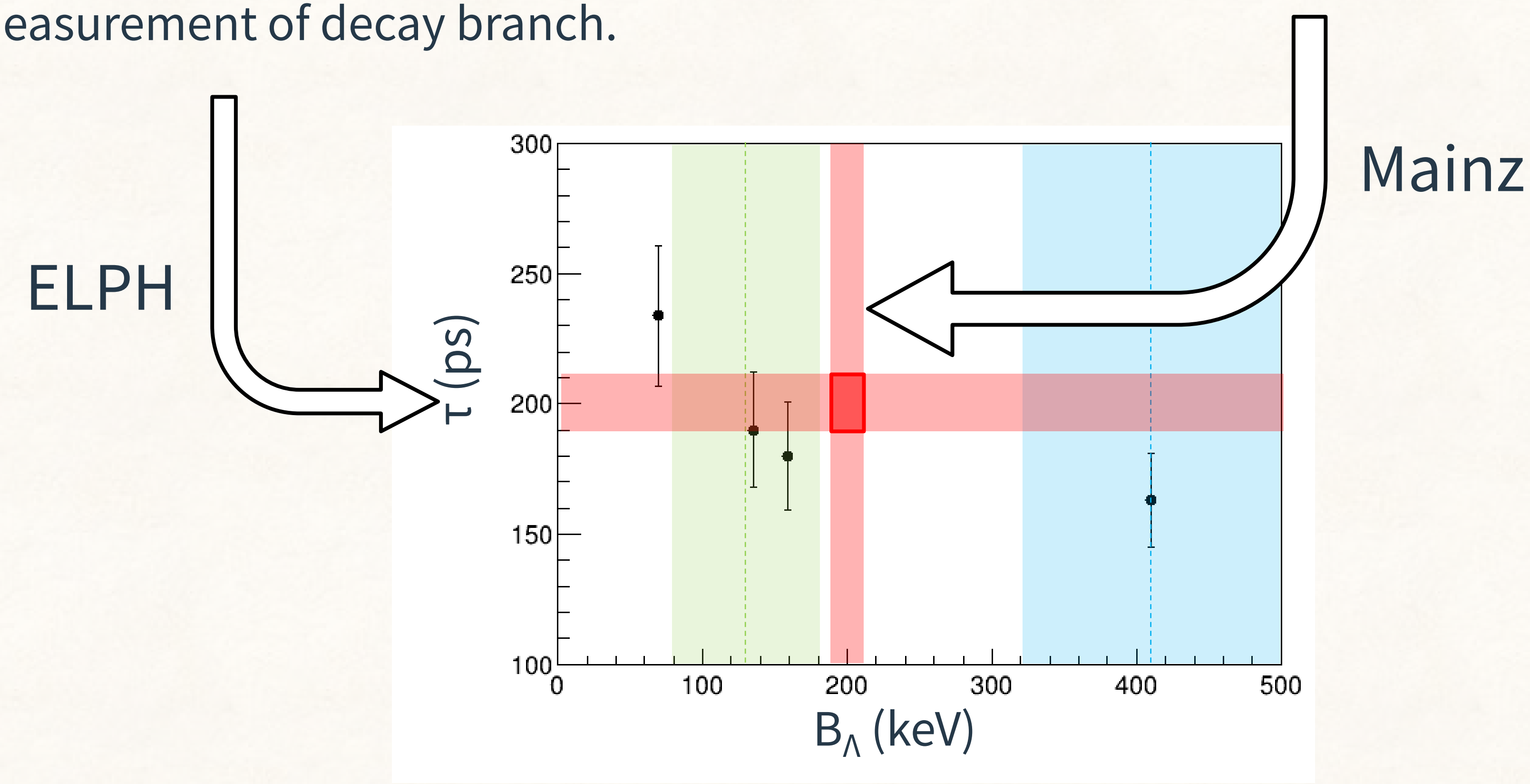
Towards resolving the hypertriton puzzle

Lifetime

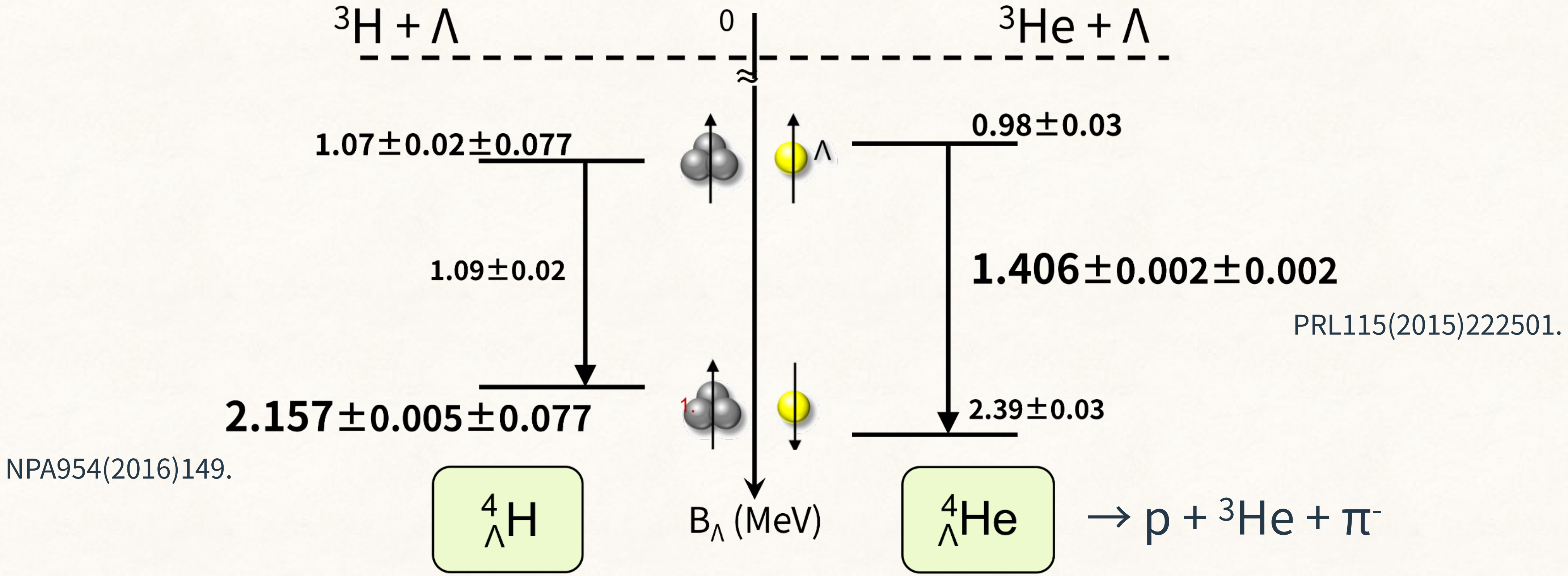
- Data with a different approach.
- $^{3}He(\gamma, K^{+})^{3}_{\Lambda}H$ reaction at ELPH.
- $\delta\tau$ ~ 10 ps.
- Measurement of decay branch.

Λ Binding Energy

- More precise and accurate measurement.
- Decay pion spectroscopy at MAMI.
- δB_{Λ} ~ 10 keV (including syst.).



Charge Symmetry Breaking in A=4 system



- Updated $B_\Lambda(0^+)$ of ${}^4_\Lambda$H and $B_\Lambda(1^+)$ of ${}^4_\Lambda$He at MAMI and J-PARC, respectively.
- Large difference for ground state and less for excited state.
- More accurate and data for other states is very important.
- Decay width is also sensitive to this symmetry.

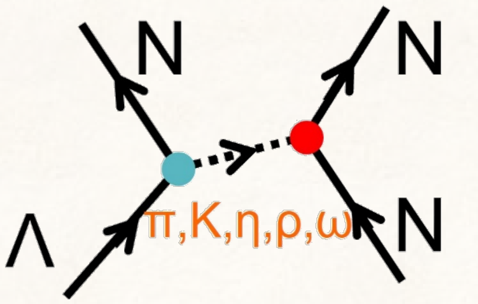
Non-mesonic weak decay width of A=4 hypernuclei

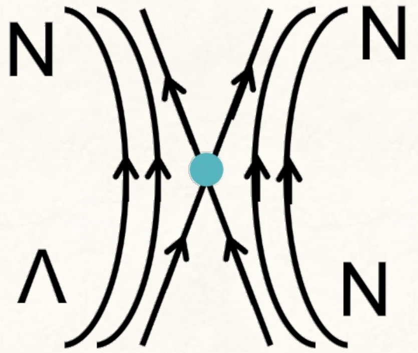
Weak decay is the dominance of ΔI=1/2 channel.

This "rule" can be applied in the short-range interaction or not?

Emitted nucleon has larger momentum in the non-mesonic decay process.

Heavy mesons and baryons in the short distance is important.





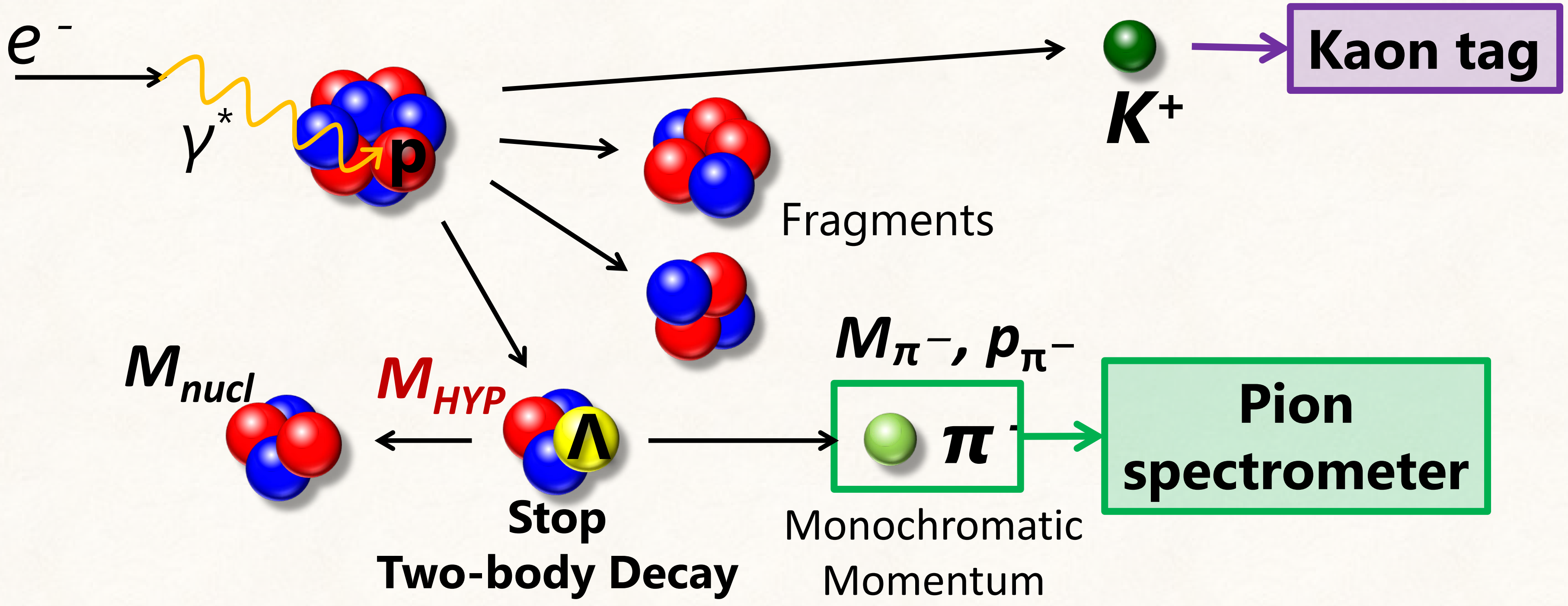
$$\frac{\Gamma_p({}^4_\Lambda\mathrm{H})}{\Gamma_n({}^4_\Lambda\mathrm{He})} = \frac{1}{2}$$ ΔI=1/2 dominant

$$\frac{\Gamma_p({}^4_\Lambda\mathrm{H})}{\Gamma_n({}^4_\Lambda\mathrm{He})} = 2$$ ΔI=3/2 dominant

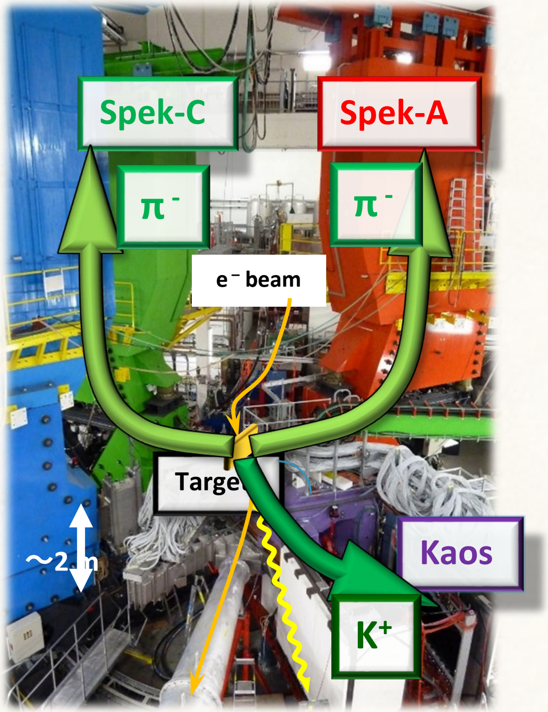
	τ	$\Gamma p\ /\Gamma_\Lambda$	$\Gamma n\ /\Gamma_\Lambda$
${}^4_\Lambda\mathrm{He}$	255^{+27}_{-27}	0.16±0.02	$0.01^{+0.04}_{-0.01}$
${}^4_\Lambda\mathrm{H}$	194^{+24}_{-26}	×	×

MAMI

Decay pion spectroscopy



$$M_{HYP} = \sqrt{M_{nucl}^2 + p_{\pi^-}^2} + \sqrt{M_{\pi^-}^2 + p_{\pi^-}^2}$$



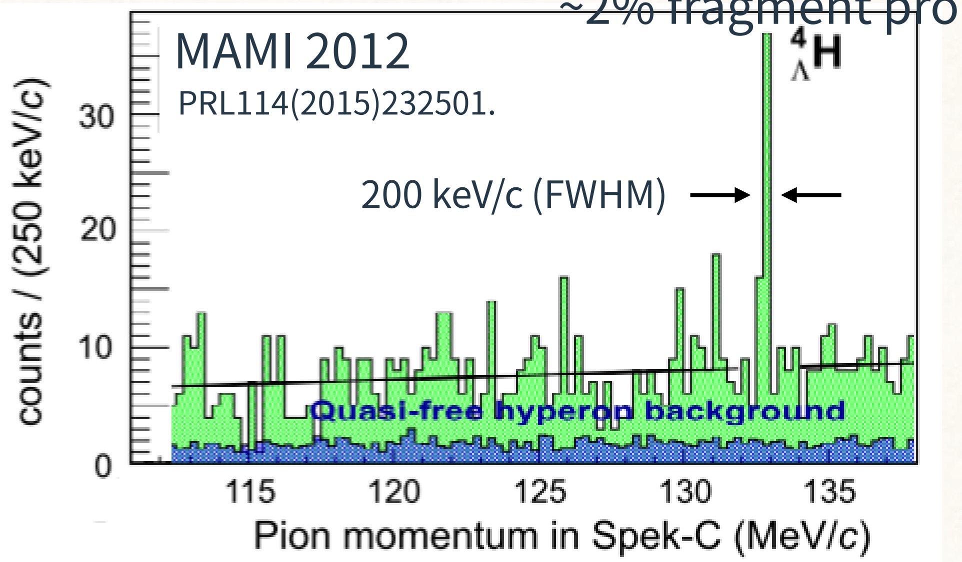
High resolution spectroscopy of low momentum charged pion.

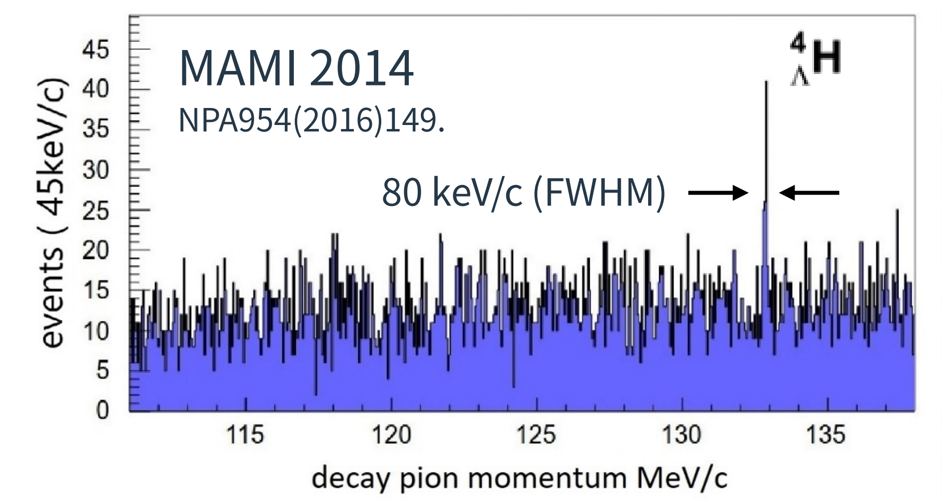
Excellent resolution and precision thanks to high quality beam and less material.

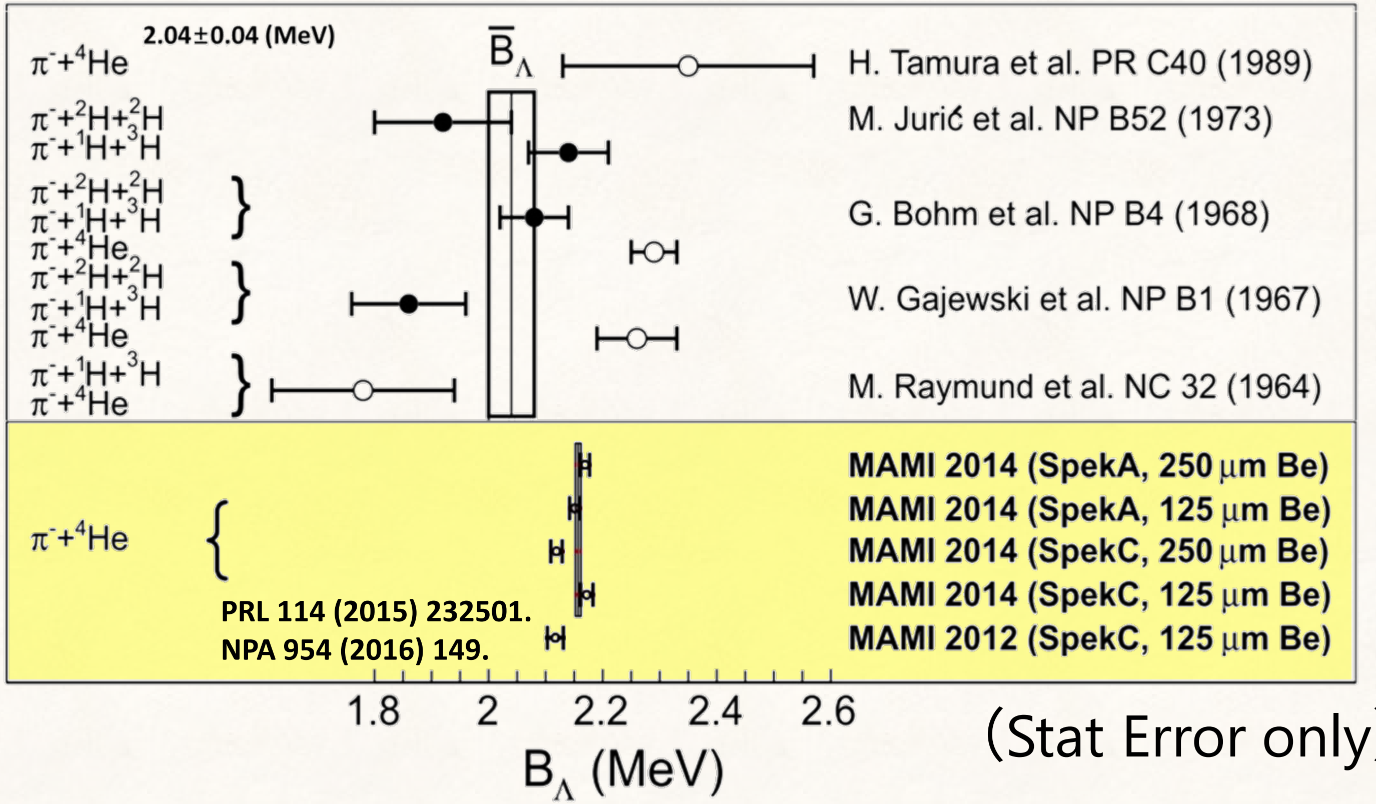
Small systematic uncertainty thanks to well studied spectrometer.

New Determination of $^{4}_{\Lambda}H$ binding energy

~2% fragment prob.







(Stat Error only)

B_Λ (MAMI 2012) = 2.12 ± 0.01(stat.) ± 0.09(syst.) MeV

B_Λ (MAMI 2014) = 2.157 ± 0.005(stat.) ± 0.077(syst.) MeV

Higher accuracy

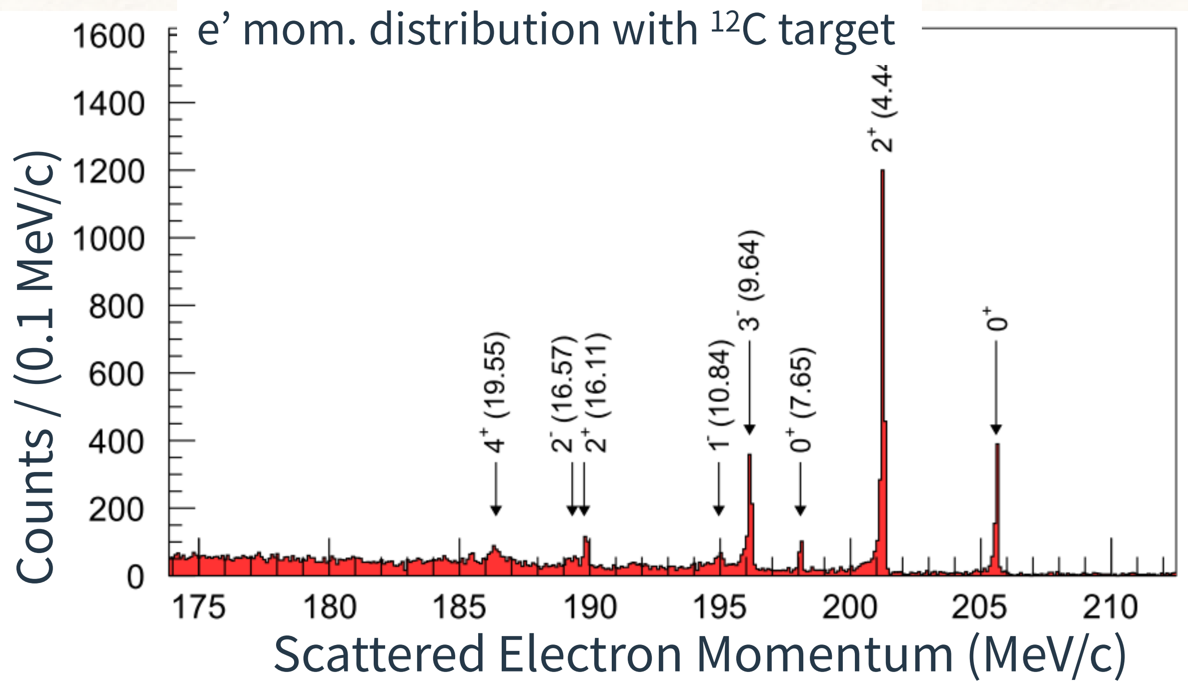
High yield & background suppression

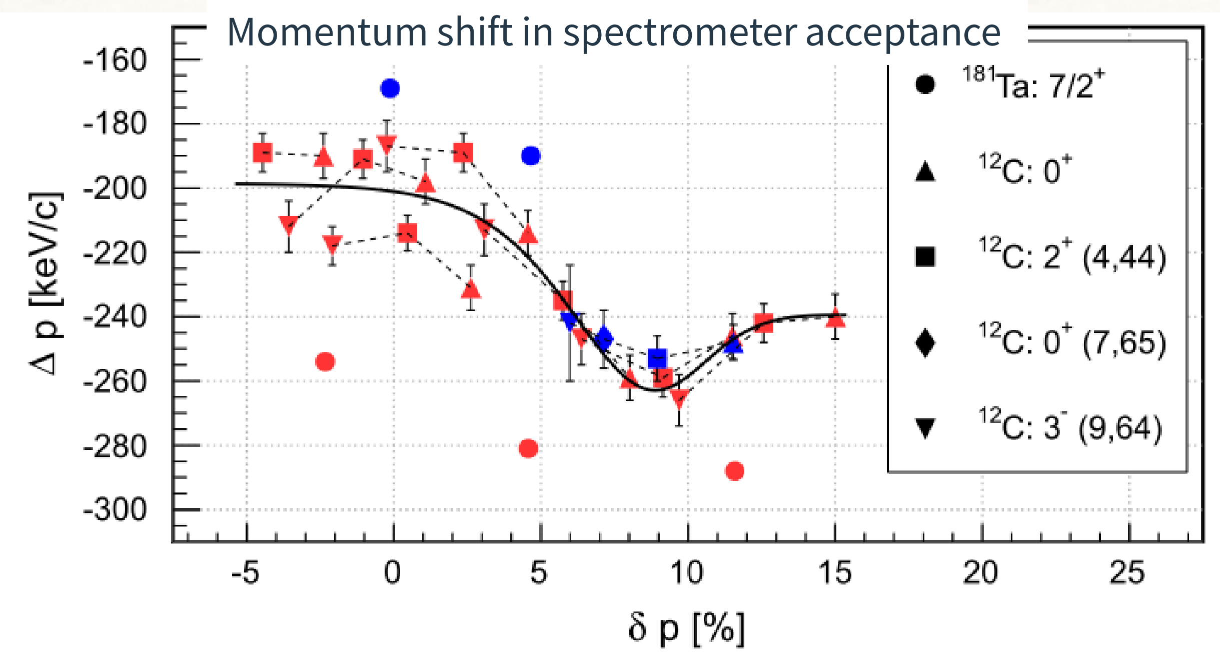
$$E_{e'} = \frac{E_e}{1 + E_e / M_{tar} (1 - \cos(\theta_e))}$$

210.10 MeV (E_e)

^{12}C, ^{181}Ta (M_{tar})

93.50° (θ_e)





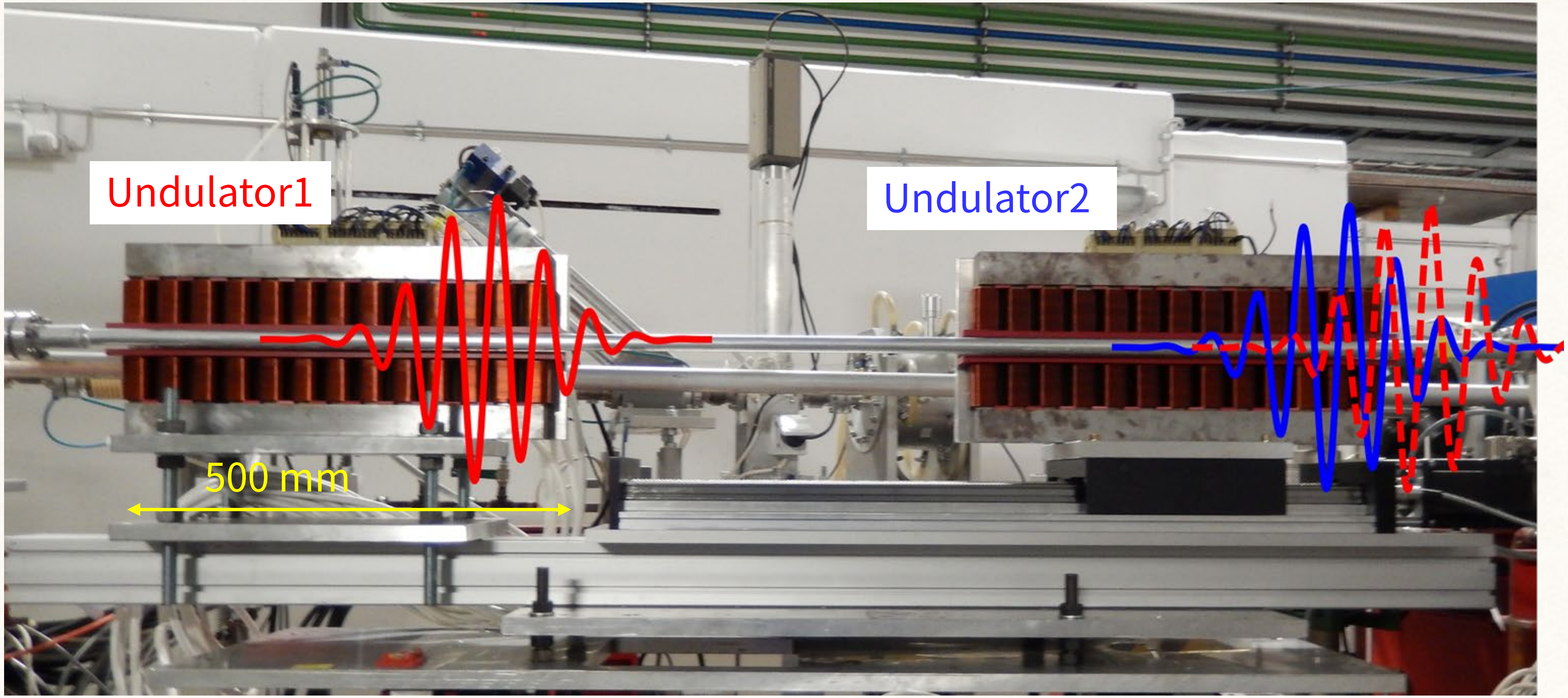
Careful momentum calibration was performed by changing beam energy and central momentum

There is an uncertainty of ~ 100 keV on the beam energy itself.

Accurate beam energy measurement

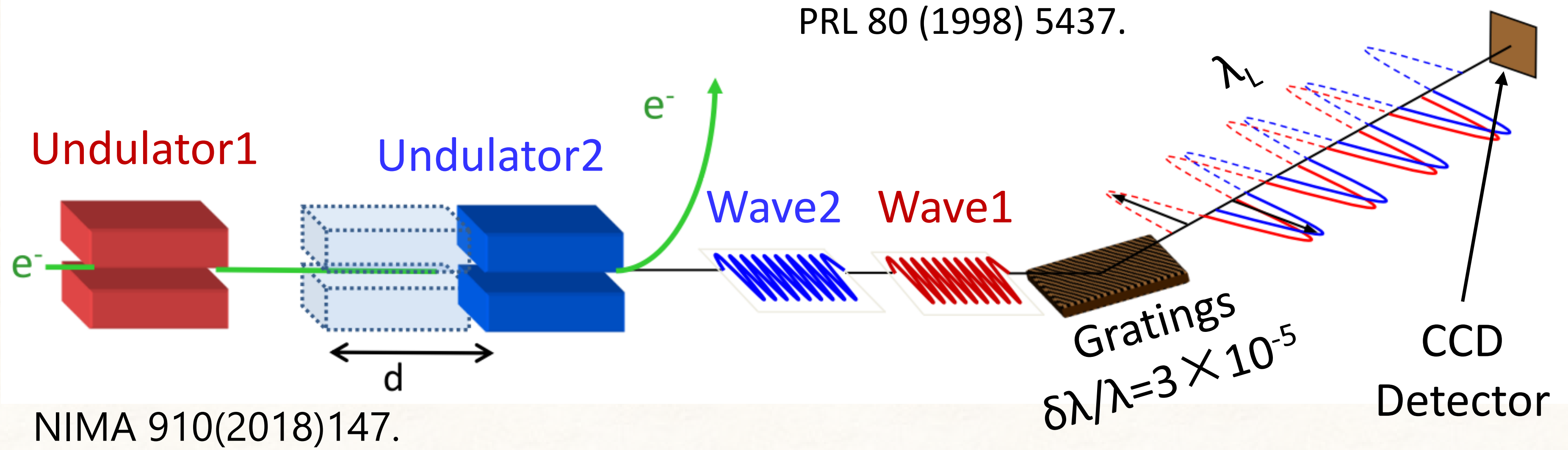
Novel optical interferometry of synchrotron radiation for absolute electron beam energy measurements

NIMA 910(2018)147.



Beam Energy Determination with Undulator lights

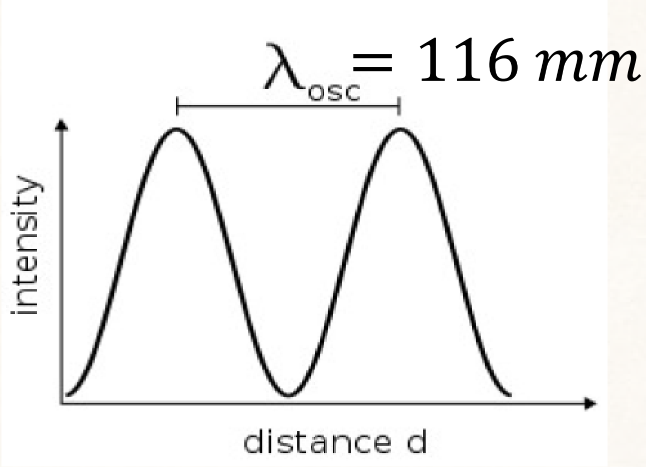
Based on "Novel Interferometer in the Soft X-Ray Region"
PRL 80 (1998) 5437.

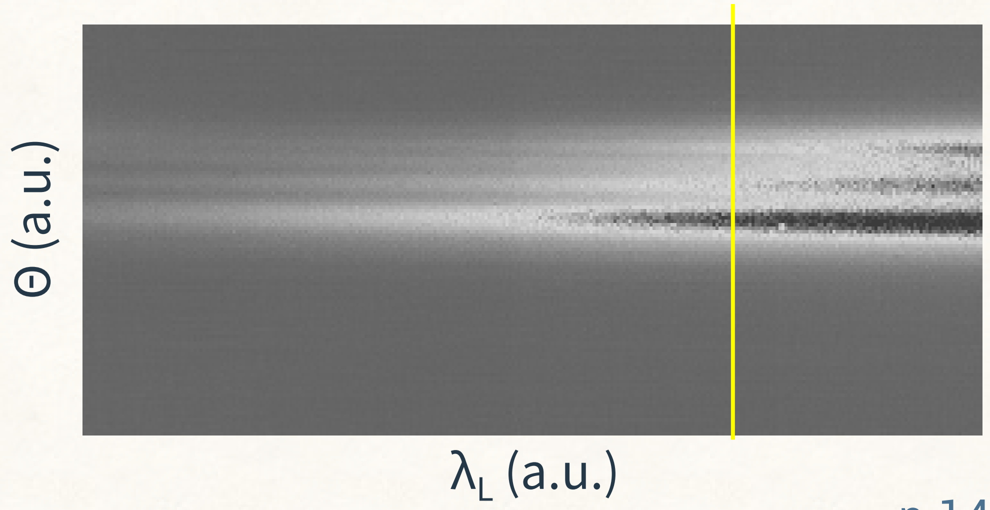


NIMA 910(2018)147.

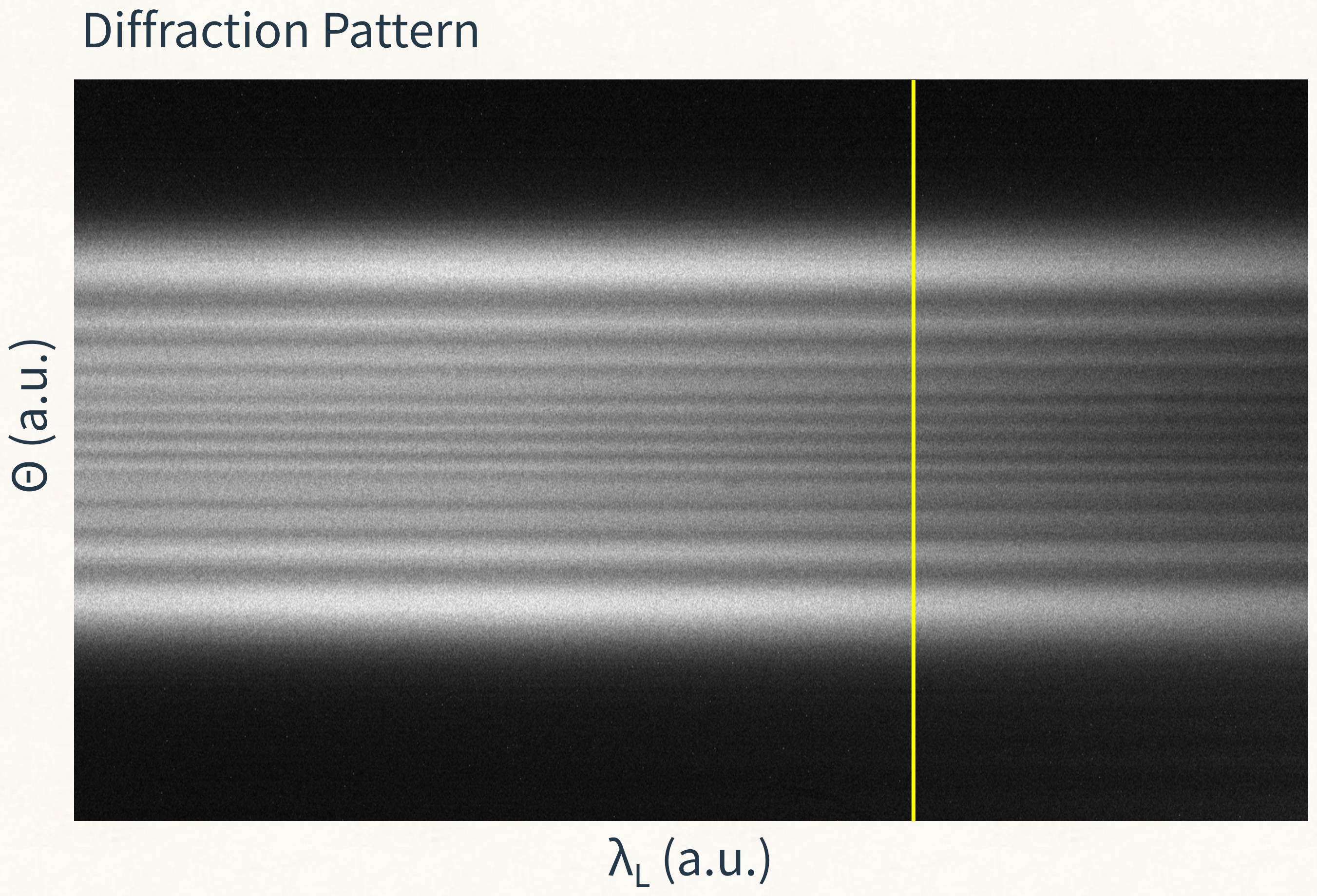
$$\gamma = \sqrt{\lambda_{osc}(\Theta)/2\lambda_L}$$

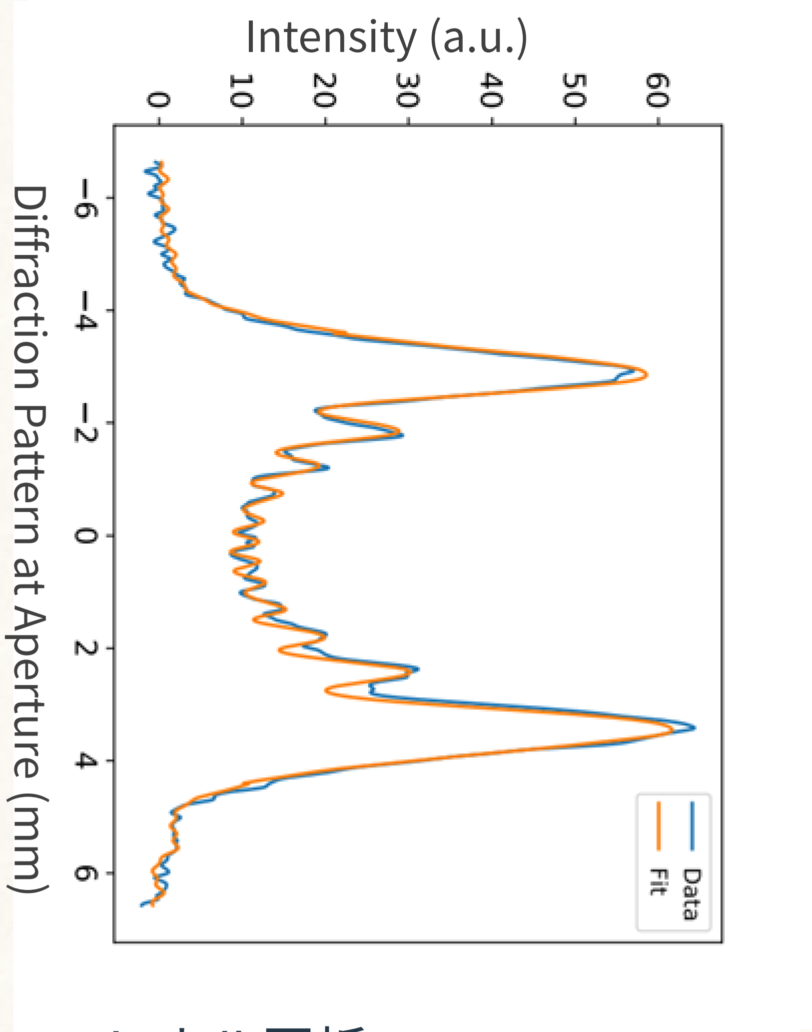
$$\lambda_L = 400\,nm$$
$$E = 195\,\mathrm{MeV}$$
$$\gamma = 381$$





An example

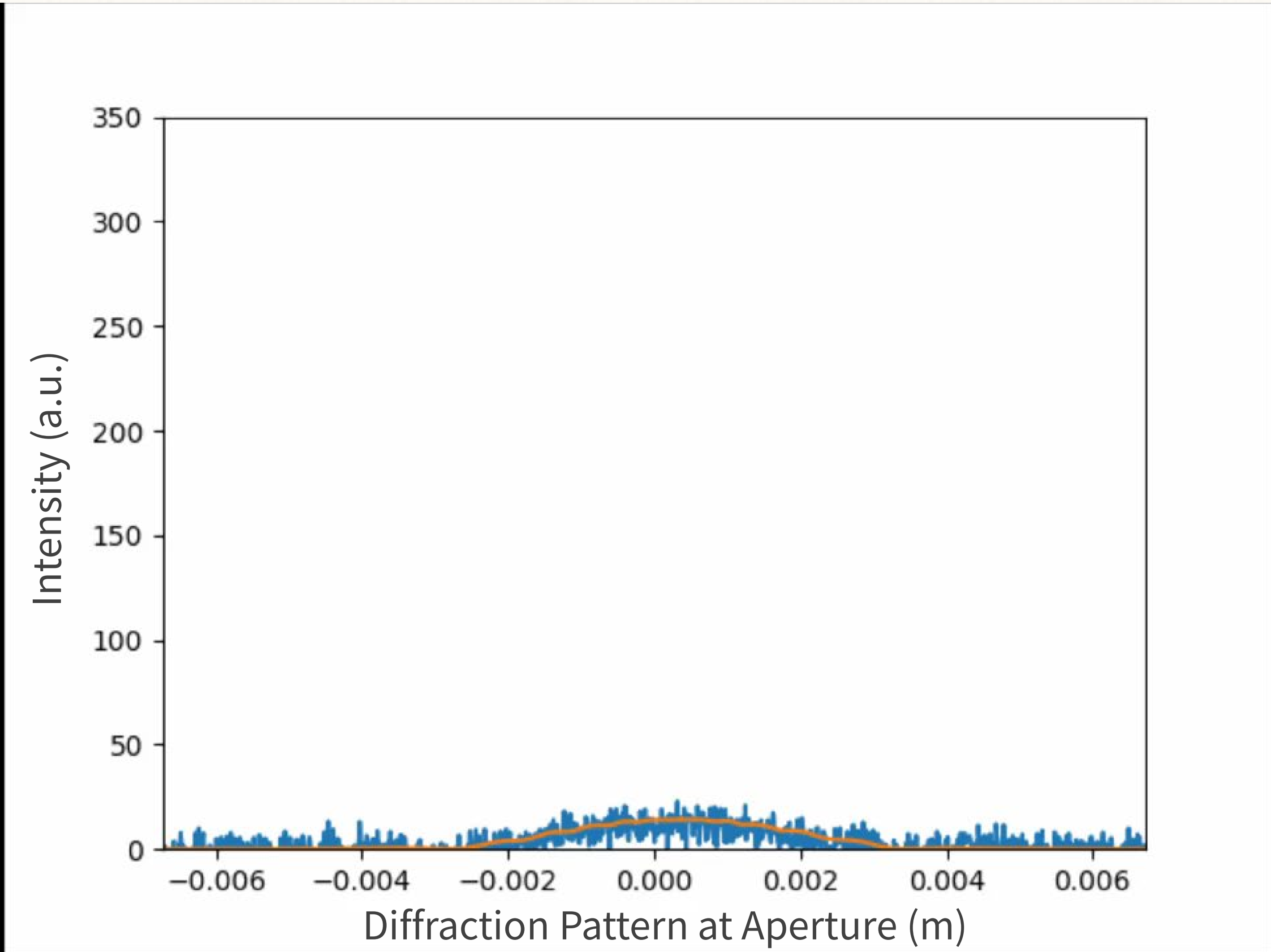




回折パターン = 非分散方向の高次項 + フレネル回折

回折パターンを完全にフィット → $\delta\gamma = 3\times10^{-5}$

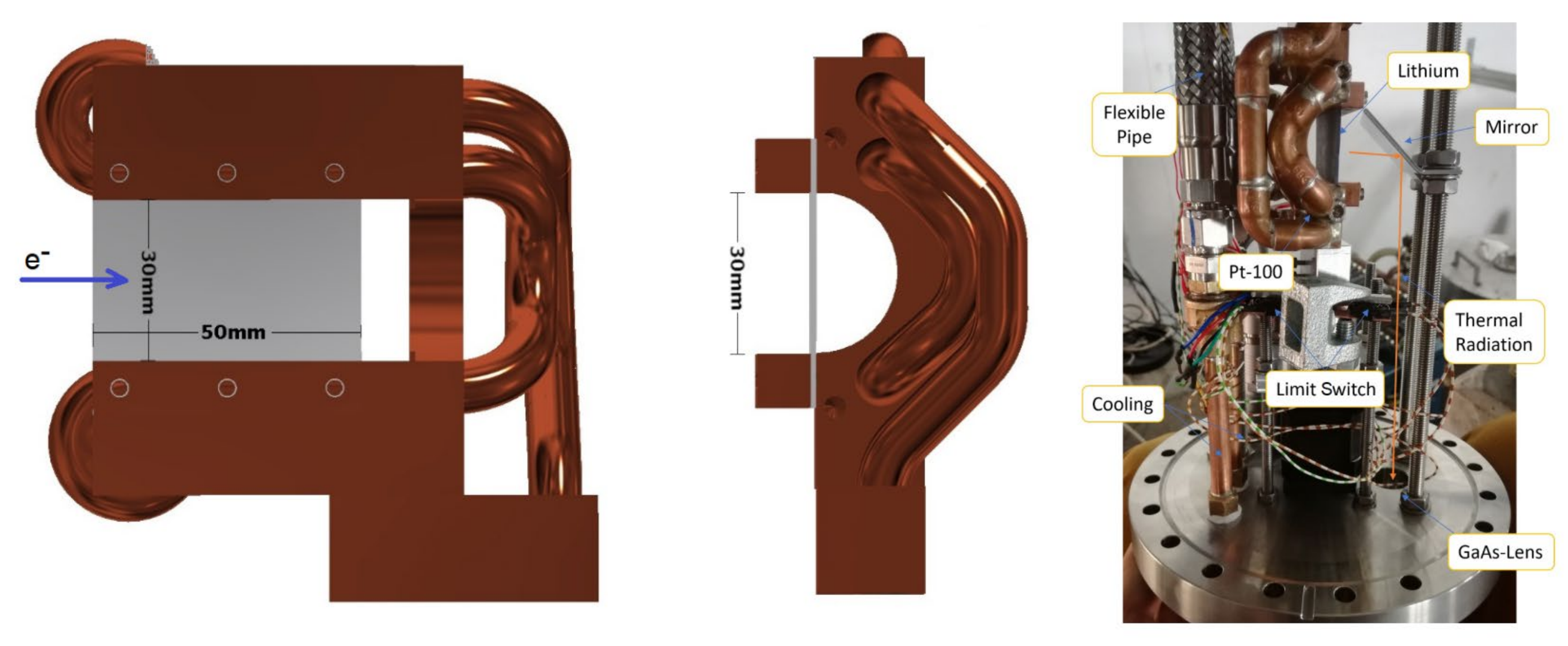
Fitting Results



Provided by P.Klag

New Target for the next experiment

Background suppression and higher yield is very important.
→ Thicker Li target & Lower beam current.



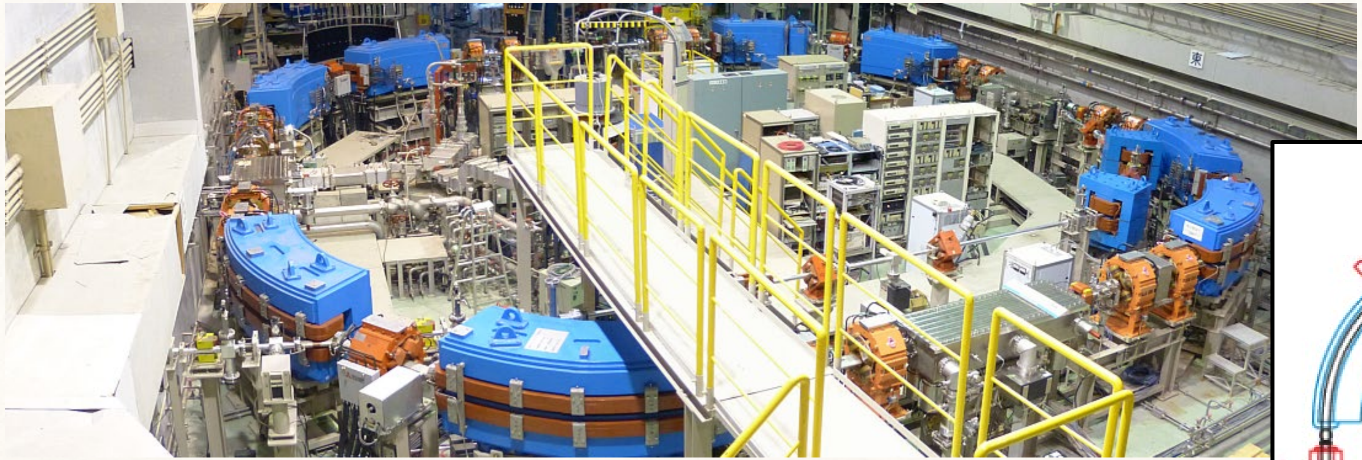
Last : ^{9}Be 47mg/cm^2 40~60 μA
Next : Li 2700 mg/cm^2 2~10 μA

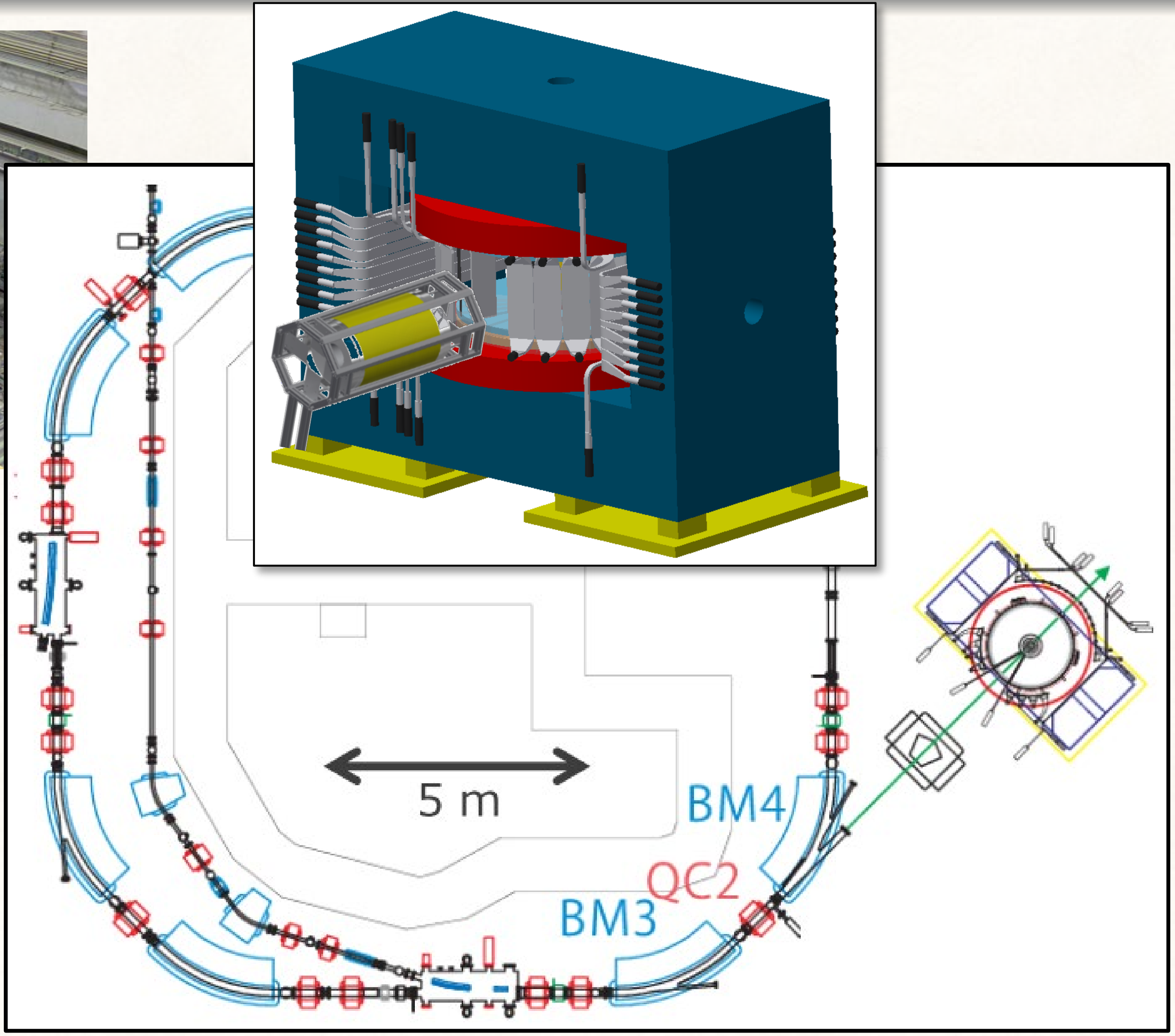
NKS2

Hyper experiment with the photon beams

	Meson	Electron	Photon
channel	p → Λ [^{3}He(π,K)$^3_\Lambda$H]	**p → Λ** [^{3}He(γ, K$^+$)$^3_\Lambda$H]	
beam intensity (/sec)	10^7 π$^+$	$10^{13\sim14}$ e$^-$ → $10^{9\sim10}$ γ*	10^7 γ
Target	a few g/cm^2	0.1 g/cm^2	**a few g/cm^2**
Resolution (ΔE/E)	10^{-3}	10^{-4}	**10^{-2}**
Acceptance	～ 100 msr	～ 10 msr	**200 msr**
Background	low	high	mid.

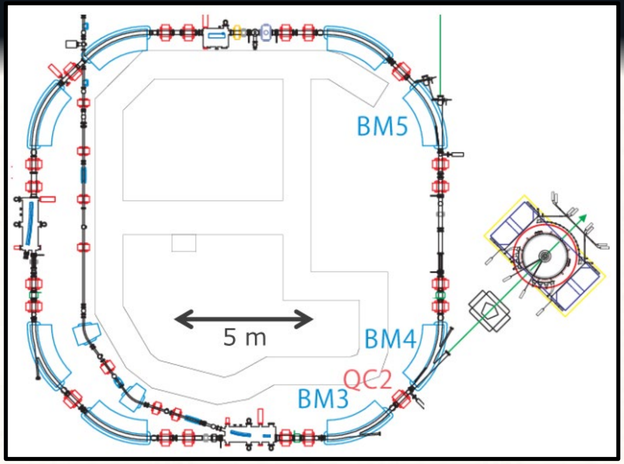
Photon beam facility

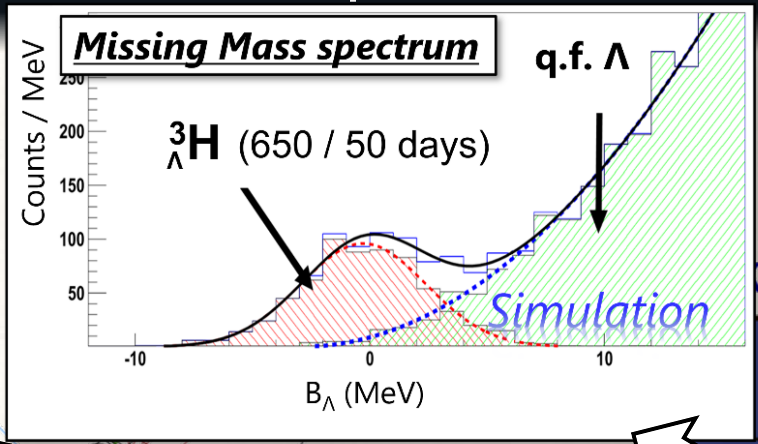


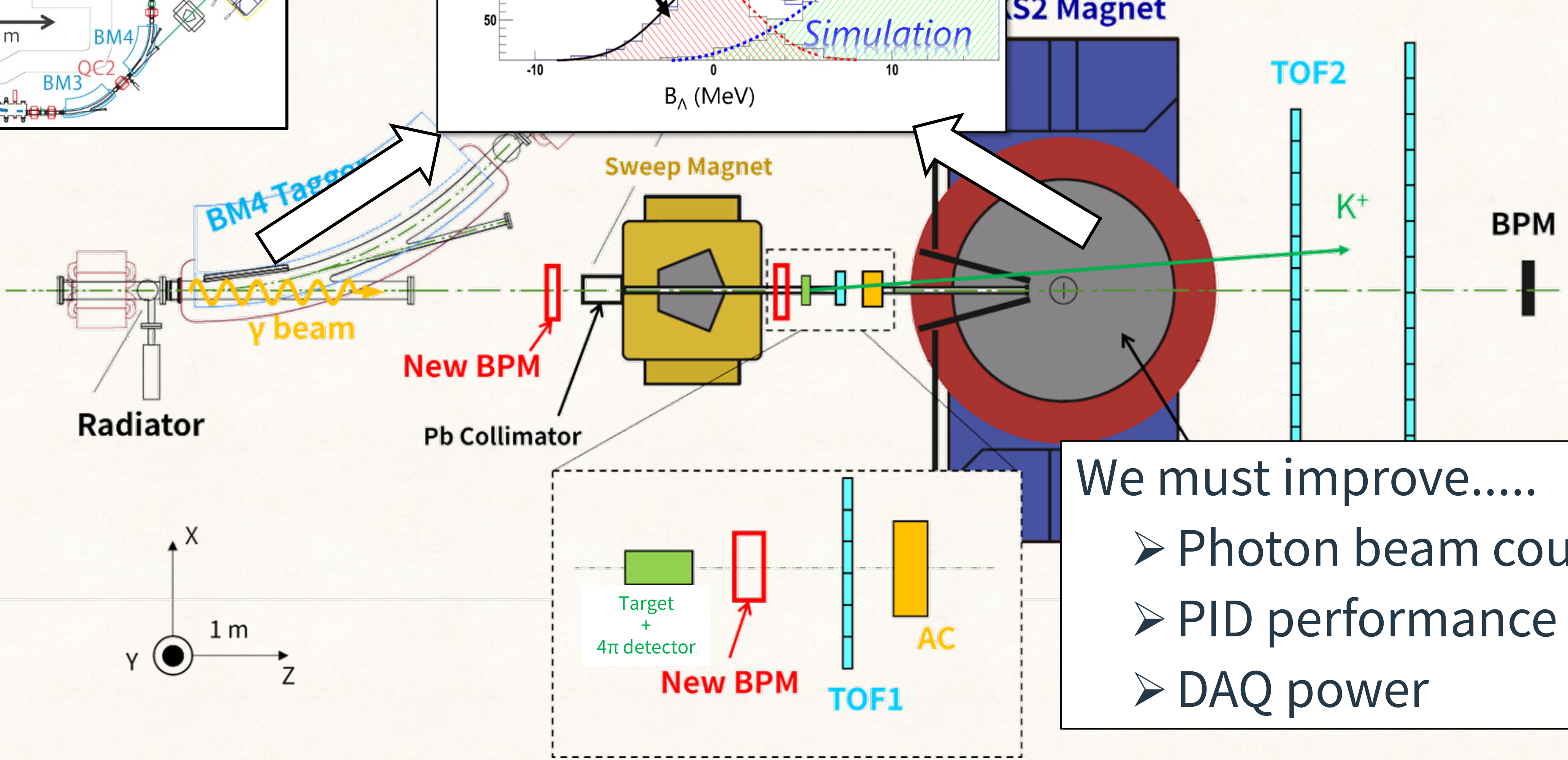


ELPH (Tohoku) has an electron synchrotron ring (BST).
Max. Beam energy: 1310 MeV
Max. Beam current: 30 mA.
Two tagged photon beam course: BM4 and BM5
Photon beam characteristics:
Intensity: 1 MHz (at BST current =2 mA)
Energy Range: 800~1250 MeV with 5 MeV bins
(W = 1550 ~ 1800)
Time resolution: ~100 ps (rms)

NKS2 spectrometer







We must improve.....

- ➢ Photon beam course
- ➢ PID performance
- ➢ DAQ power

Yield estimation

$$N_\Lambda = N_t\, N_\gamma\, \varepsilon\, \frac{\partial\sigma}{\partial\Omega_K}\, \Delta\Omega$$

200 msr

5M γs / sec

DAQ Effi.	0.90
Acc. Duty	0.60
Photo Tag. Eff.	0.70
Track Eff.	0.95
K^+ ID Eff.	0.90
K^+ Survival Ratio	0.56

${}^{3}_{\Lambda}$H: 10 nb/sr

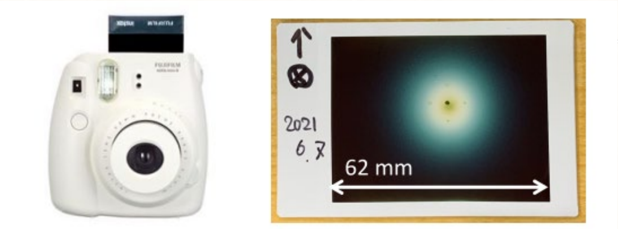
${}^{4}_{\Lambda}$H: 20 nb/sr

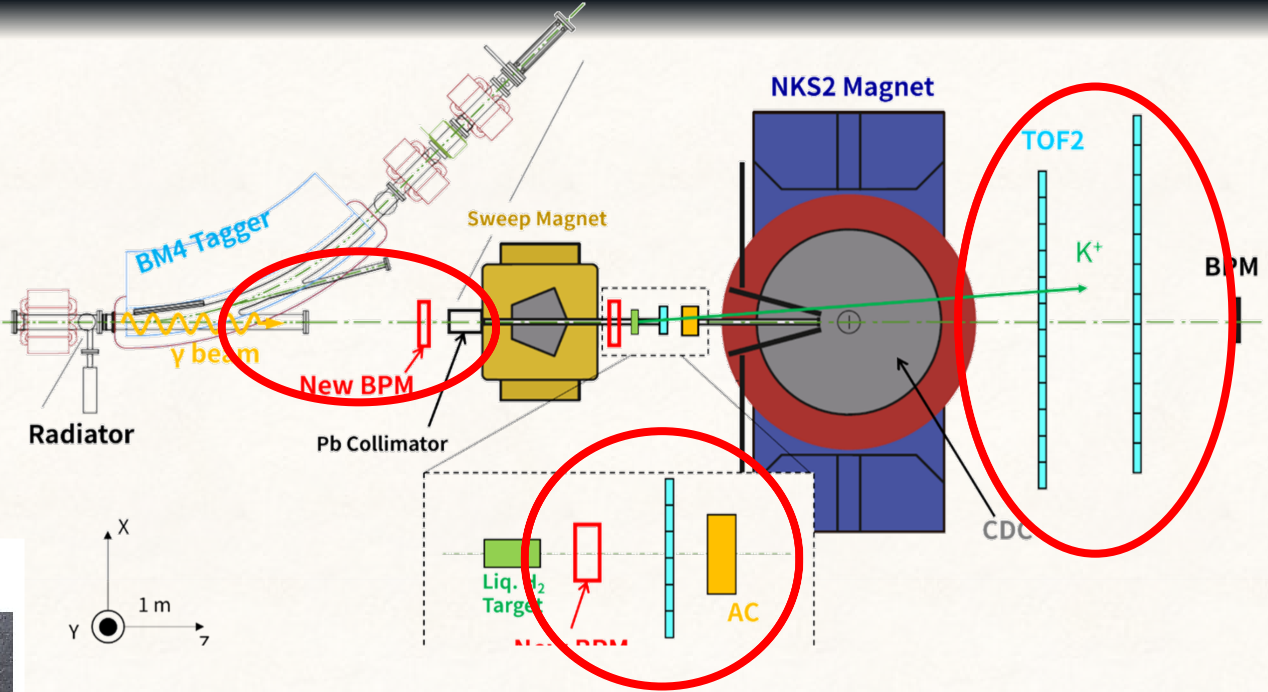
${}^{12}_{\Lambda}$C: 100 nb/sr

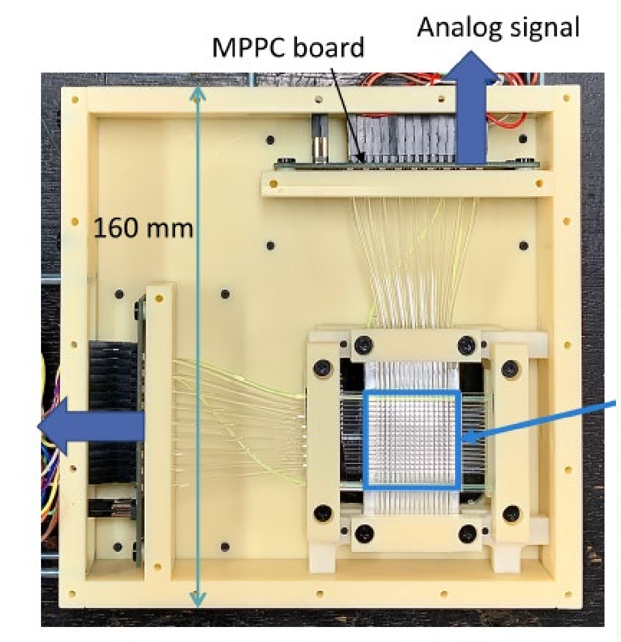
$$N_\Lambda = 2000$$
$$N_{H3L} = 40$$
$$N_{H4L} = 80$$
$$N_{C12L} = 400$$

counts / day

Detector Development

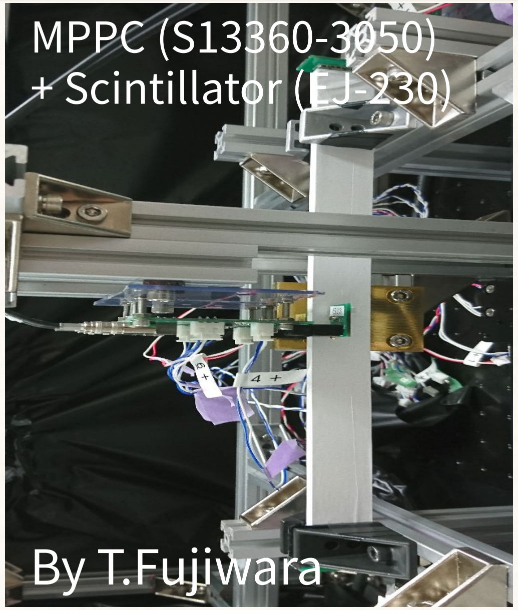






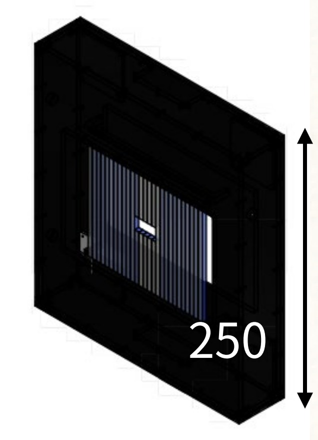
Beam Position Monitor

By R.Kino

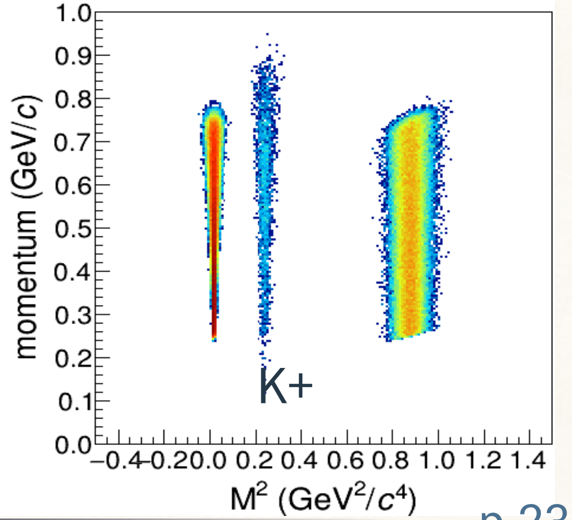


σ_{TOF} < 150 ps

2.5in Fine-Mesh PMT
+ n=1.05 Aerogel



ε_{π} > 90%



Summary

Precise measurement of light hypernuclei is important resolving the effective ΛN interaction.

- Hypertriton binding energy and lifetime inconsistency
- Measurement of hypernuclear binding energy and decay width is important

Experimental approach

More accurate B_Λ measurement with decay pion spectroscopy at Mainz (Mid. 2022~)

High intensity electron beam and new Li target will be used.

δB_Λ ~ 10 keV will be expected.

More precise lifetime measurement with (γ,K^+) reaction at ELPH (Early 2022~)

Real photon beam and He target will be used.

$\delta\tau$ ~ 10 ps will be expected.