Precision Spectroscopy of Hydrogen-5 as a benchmark for the Hyperhydrogen-6 nucleus

SAMURAI Workshop 2024

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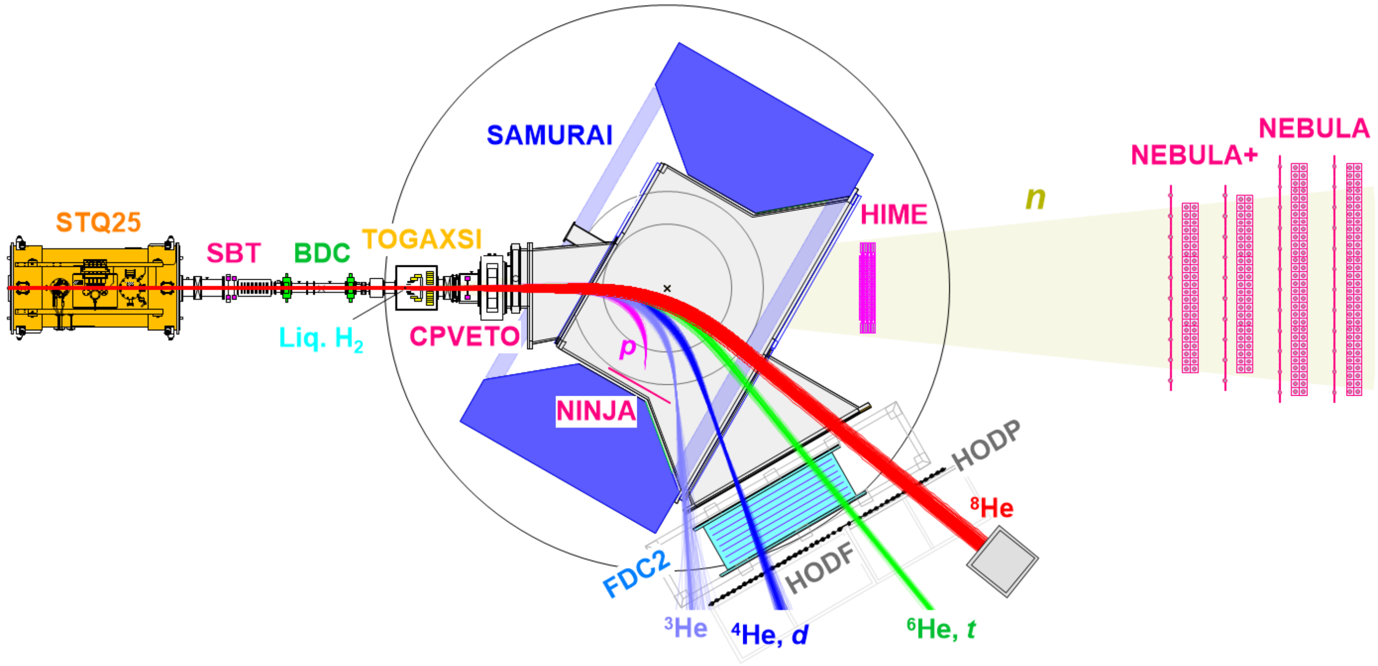
RIBF NP-PAC-23 Experiment



Miki / Duer, Accepted Proposal, RIBF NP-PAC-23

- ^{8}He/^{6}He beam at ~200 MeV/nucleon
- Maximum beam intensity of 10^6 pps
- Liquid hydrogen target 2 cm

Several by products:

$$^{6(8)}\mathrm{He}(p,2p)^{5(7)}\mathrm{H}$$

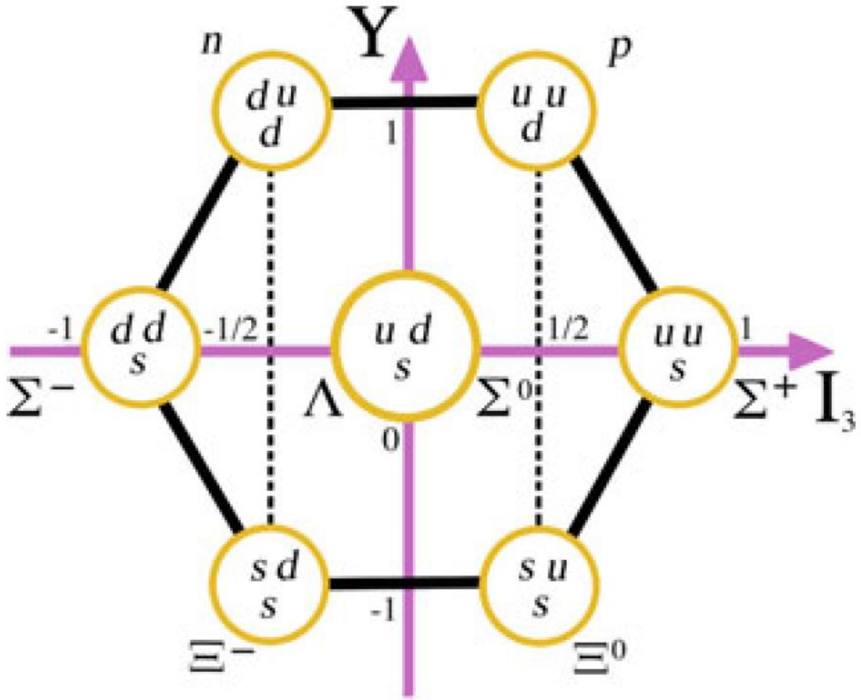
$$^{6(8)}\mathrm{He}(p,pn)^{5(7)}\mathrm{He}$$

$$^{6(8)}\mathrm{He}(p,p^3\mathrm{He})^{3(5)}n.$$

→ Interested in ^{5}H

Physics with Hypernuclei

- Hypernuclei are nuclei with at least one strange quark
- Possibilities of Hypernuclei stem from the shell structure
- Lightest hyperon is Λ-particle
- Decay time 263 ps due weak decay (no strangeness conservation)
- Observed glue-like effect, when adding hyperon to nucleon



Spin 1/2 Octet

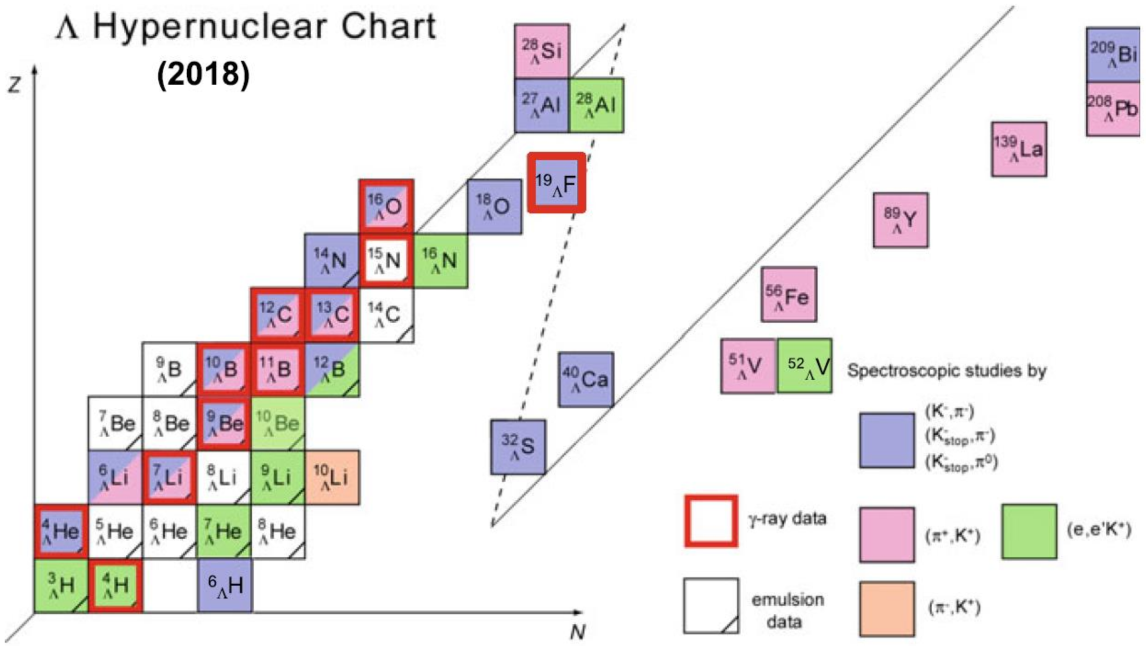
Interest for Hydrogen-5

- For Z > 1 neutron rich hypernuclei have been found: ${}_{\Lambda}^{6}He$, ${}_{\Lambda}^{7}Be$, ${}_{\Lambda}^{10}B$
- No hypernucleus for Z = 1 unbound nuclei so far
- Hydrogen-5 is most promising canditate
- Measurement of ${}_{\Lambda}^{6}H$ in FINUDA experiment:

  B_{Λ} = (4.0 +/- 1.1) MeV

  M. Agnello *et al*., PRL 108, 042501 (2012)

→ Yet, experimental(J-Parc) and theoretical confirmation necessary



Courtesy H. Tamura, Tohoku University

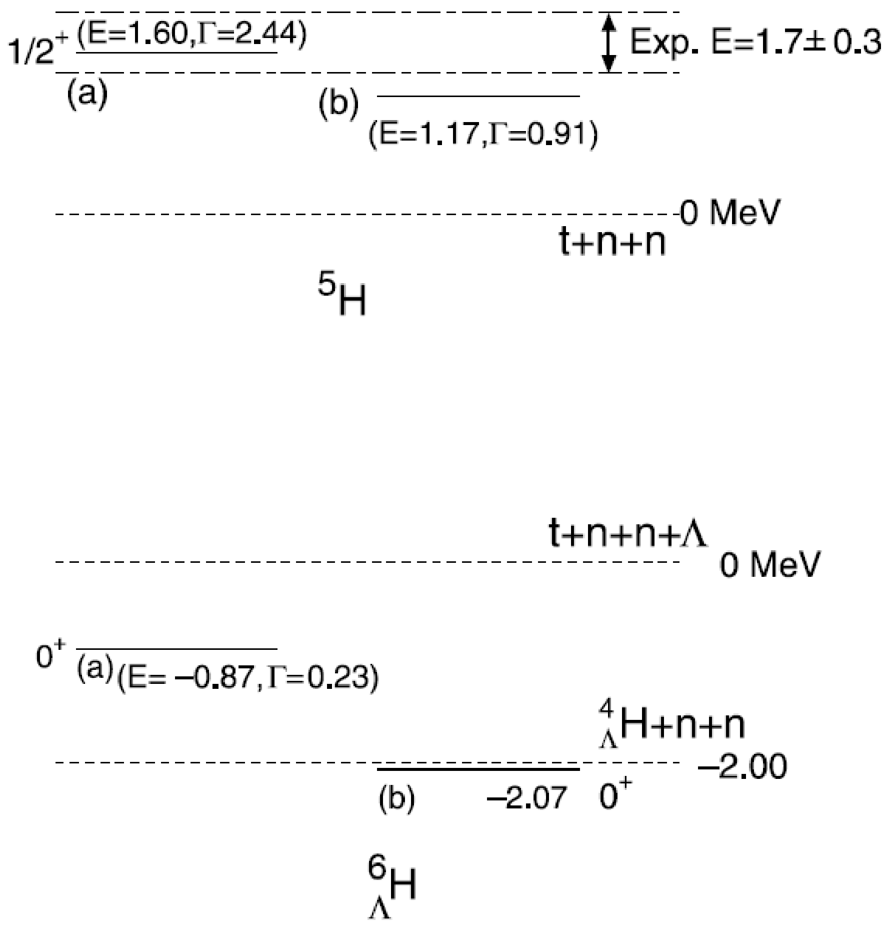
Theoretical calculations

- Theoretical calculation using *tnnΛ* four body system
- Based on structure of Hydrogen-5:
  E_r = 1.7 +/- 0.3 MeV, Γ = 1.9 +/- 0.4 MeV
  A. A. Korsheninnikov *et al*., Phys. Rev. Lett. 87, (2001), 092501

  → (a) Cannot predict a bound state
- (b) Artificial B_Λ = 3.24 MeV with respect to ^{5}H + Λ

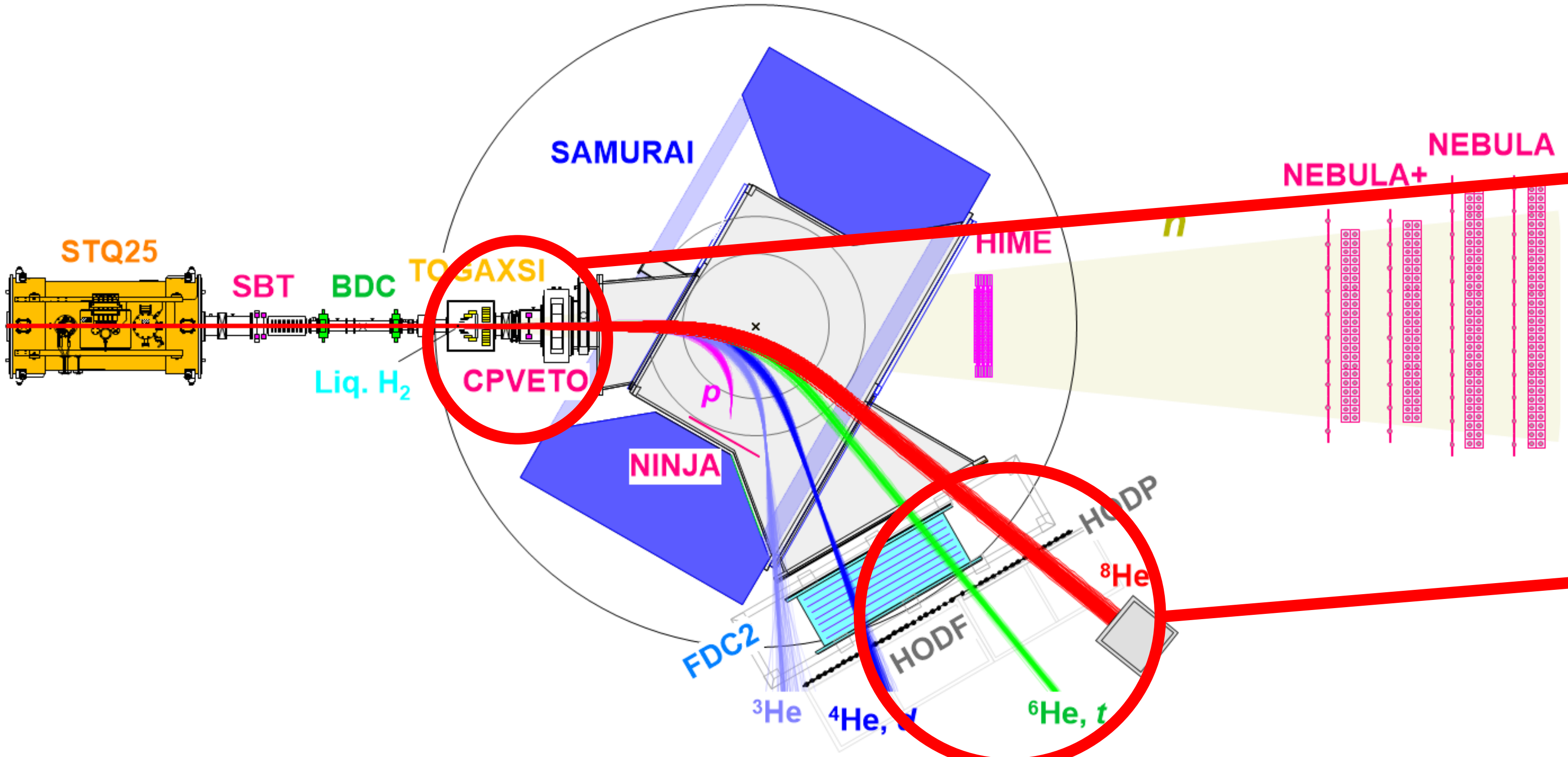
- No *ΛN – ΣN* coupling included (three-body force of hypernuclei)
- Excitation energy for Λ to Σ is 76 MeV (273 MeV for Δ)
- Three body force is necessary to predict oxygen dripline
- Effect is discussed among theorists: 0 – 0.6 MeV

→ Goal is to reduce experimental error < 100 keV



E. Hiyama *et al*., Nucl. Phys. A 908, 2013, 29 - 39

Realisation of Measurement



No FDC0/FDC1 due to high beam intensity
→Use of Fiber detector

Resolution sufficient?

^{6}He beam overlaps with triton
→ No use of FDC2 for triton measurement possible ?

(for p3p FDC2 is not needed)

Miki / Duer, Accepted Proposal, RIBF NP-PAC-23

Particle tracking after the target

- Expected vertex resolution from TOGAXSI silicon detector ~0.2 mm

- Resolution achieved at SAMURAI with FDC1 and only NEBULA:

$$\Delta E_{\mathrm{rel}} \approx 0.4\sqrt{E_{\mathrm{rel}}}$$

E_{rel} = 2.31(3) keV with 8 mm C target

J.W. Hwang *et al.*, Phys. Lett. B 768, (2017), 503 – 508

- For E_{rel} = 1.7 MeV → ΔE_{rel} = 0.52 MeV

- Resolution of FDC1 ~ 0.2 mm

  Resolution of fiber tracker ~ 0.5 mm

- From no-relativistiv formula increased to ~0.52 keV when FDC1/Fiber Detector is placed ~1 m from target

$$\Delta E_{\mathrm{rel}} \propto \sqrt{\left(\frac{\Delta v_1}{\bar{v}}\right)^2 + \left(\frac{\Delta v_2}{\bar{v}}\right)^2 + \Delta\theta_{12}^2}$$

Use of FDC2 possible?

1. Use at lower voltage

- Use FDC2 and lower voltage
- Trigger could be gated by hodoscope on Z = 1

→ Problem: Is efficiency of FDC2 at low voltage high enough?

2. Place a dump to block ^{6}He and let the triton pass

- ~ 38.8 cm Water for ~200 MeV/nucleon
- ~ 7.1 cm lead for ~200 MeV/nucleon
- Beam profile of ^{6}He is expect to be narrow

→ Problem: Creation of reaction particles

Reaction yield

Yield estimation for ^{5}H:

N(events/day) = N x DAQ x σ x d x ε_{2n} x $\varepsilon_{p\text{-}p}$ = 2650060 events/day

→ Sufficient

N: 10^6 x 24 x 3600 particles/day

DAQ: 0.5

σ: 6 mb (from comparable (p,2p) reactions)

d: 0.142 g/cm^2

ε_{2n}: 0.18 (18%) (NEBULA + NEBULA+, no HIME included)

$\varepsilon_{p\text{-}p}$: 0.40 (40%) (STRASSE and TOGAXSI expectation)

Thank you for your attention!

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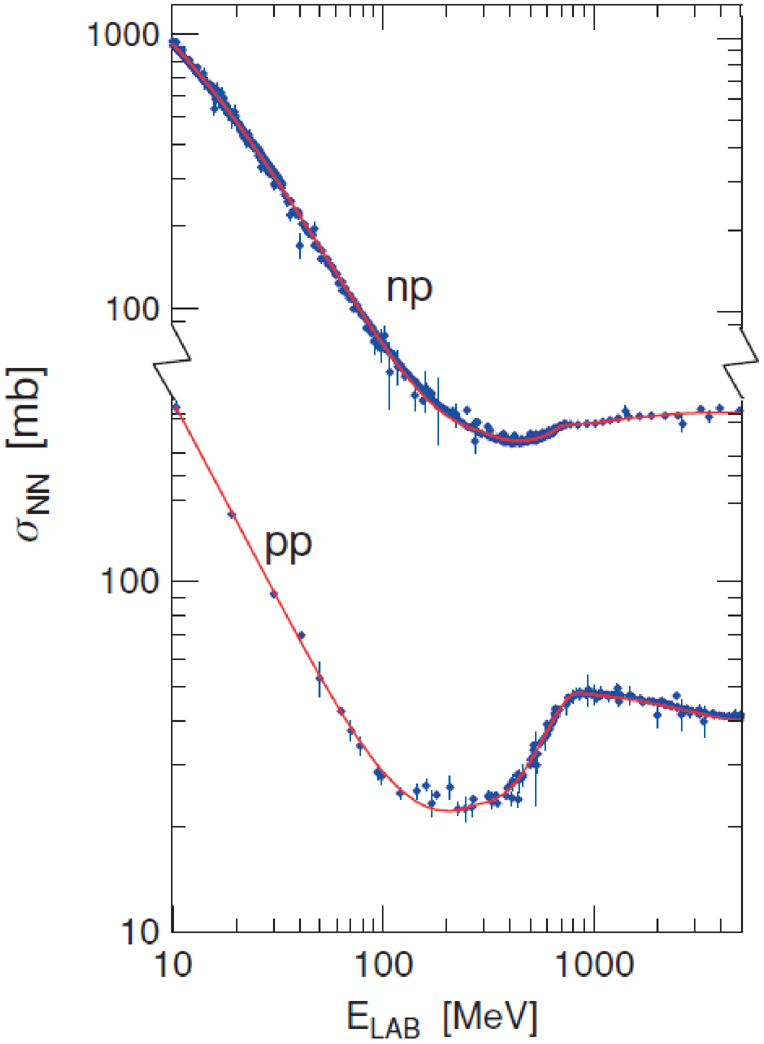
Additonal slides

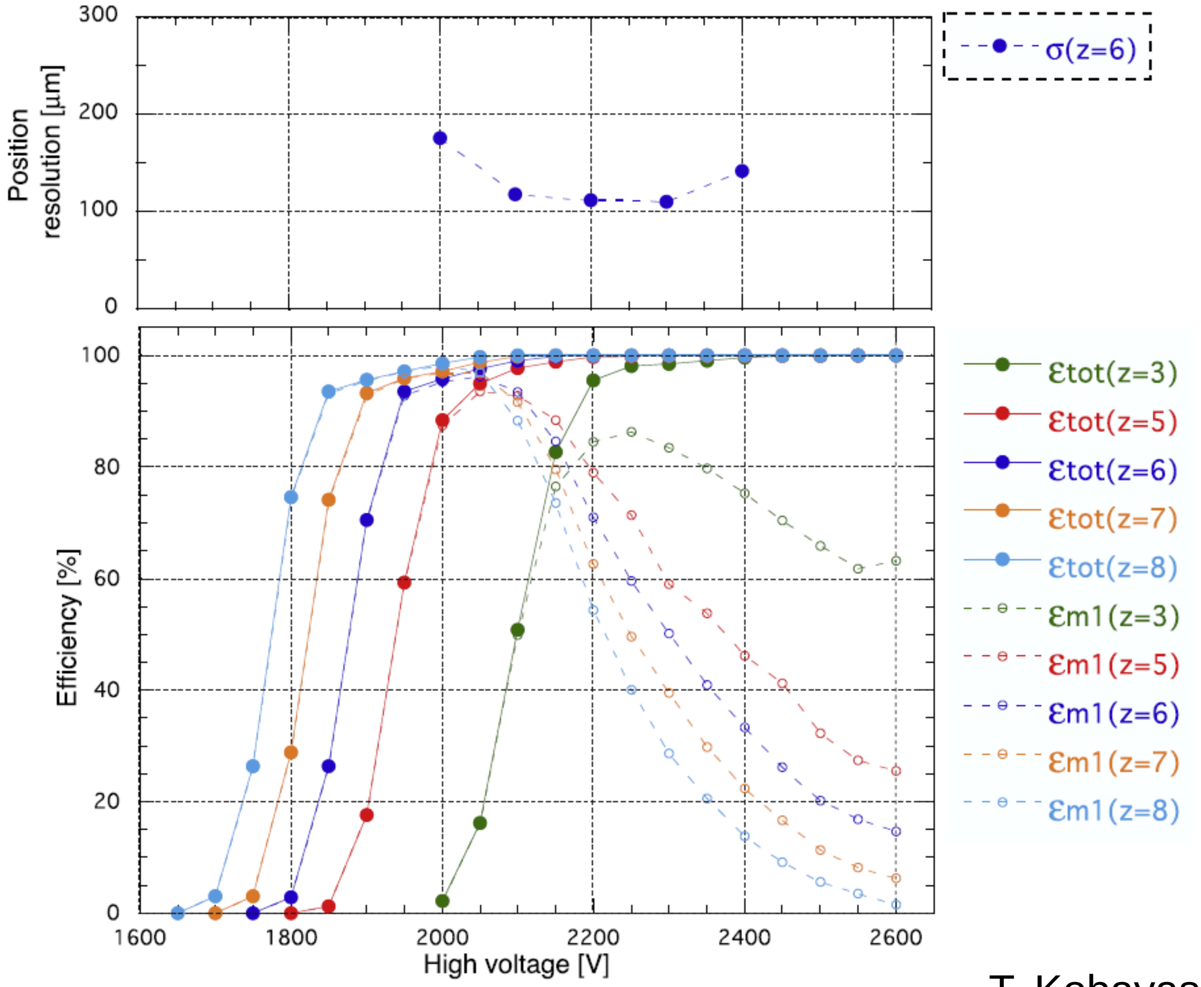


- Nucleon-Nucleon interaction
- Approximately not much difference between 200 and 400 MeV/nucleon

C. Bertulani *et al*., Phys. Rev. C 81, 064603, (2010)

Additonal slides

FDC2 efficiency plot



T. Kobayashi *et al*., NIM B 317, (2013), 294-304

Additonal slides

Reaction	$S_n(^{A-1}N)$ [MeV]	$S_p(^{A-1}N)$ [MeV]	E_{beam} [MeV/u]	σ_{exp} [mb]	σ_{theory} [mb]	R
$^{13}O(p,2p)^{12}N$	15.0	0.60	401	5.78(0.91)[0.37]	18.96	...
$^{14}O(p,2p)^{13}N$	20.1	1.94	351	10.23(0.80)[0.65]	15.09	0.68(7)
$^{15}O(p,2p)^{14}N$	10.6	7.55	310	18.92(1.82)[1.20]	12.19	...
$^{16}O(p,2p)^{15}N$	10.9	10.2	451	26.84(0.90)[1.70]	38.34	0.70(5)
$^{17}O(p,2p)^{16}N$	2.49	11.5	406	7.90(0.26)[0.50]	12.23	0.65(5)
$^{18}O(p,2p)^{17}N$	5.89	13.1	368	17.80(1.04)[1.13]	9.95	...
$^{21}O(p,2p)^{20}N$	2.16	17.9	449	5.31(0.23)[0.34]	9.16	0.58(4)
$^{22}O(p,2p)^{21}N$	4.59	19.6	415	5.93(0.39)[0.40]	8.54	...
$^{23}O(p,2p)^{22}N$	1.28	21.2	448	5.01(0.97)[0.33]	8.06	0.62(13)

Atar *et al.*, PRL 120, 052501 (2018)

^{22}O has roughly same proton separation energy as ^{6}He: ~ 22 MeV