Multineutron correlations in the breakup of Helium-8
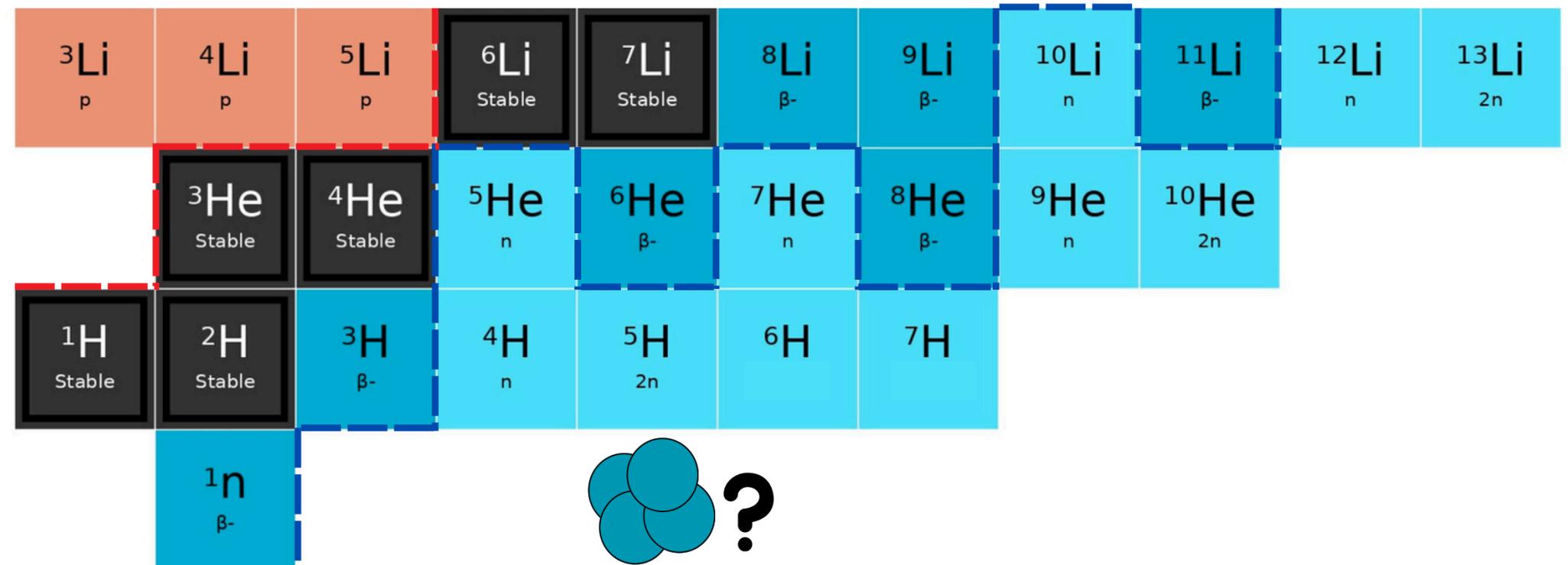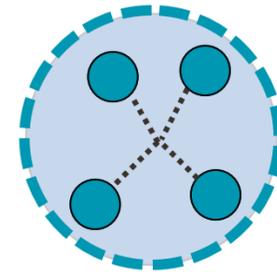
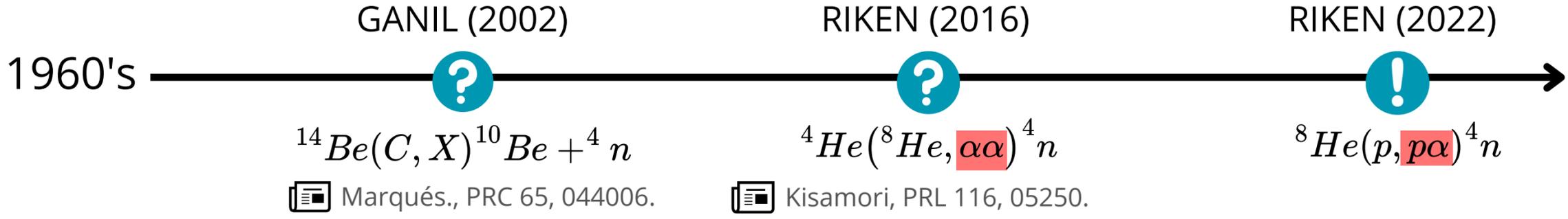## Audrey ANNE

LPC Caen

for the SAMURAI S34 collaboration

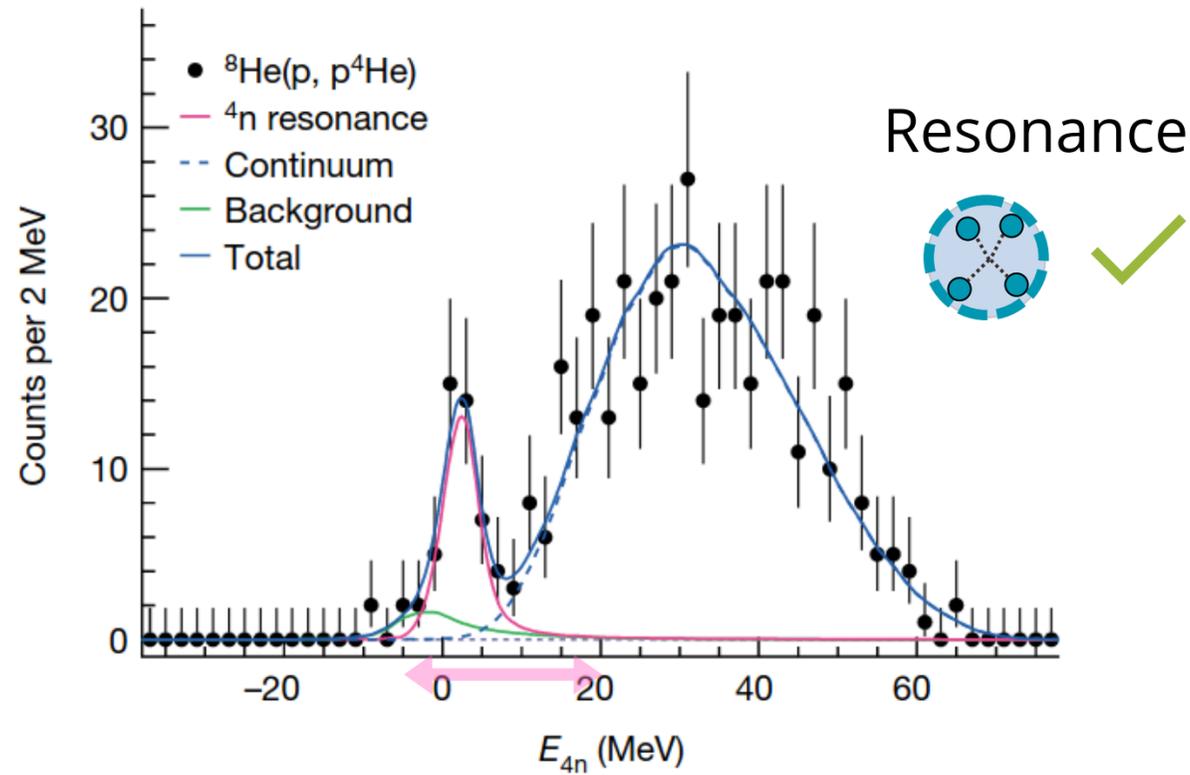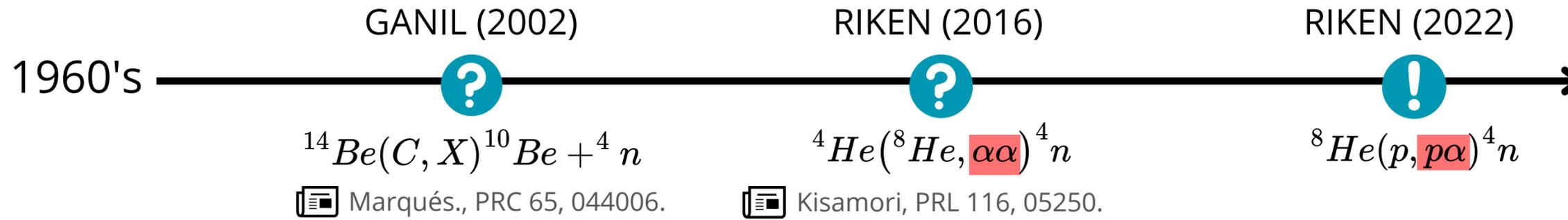# Scientific motivation: is there any multineutron system ?

- one constituent ⬤
- only strong interaction → no Coulomb
- ab initio & exact calculations

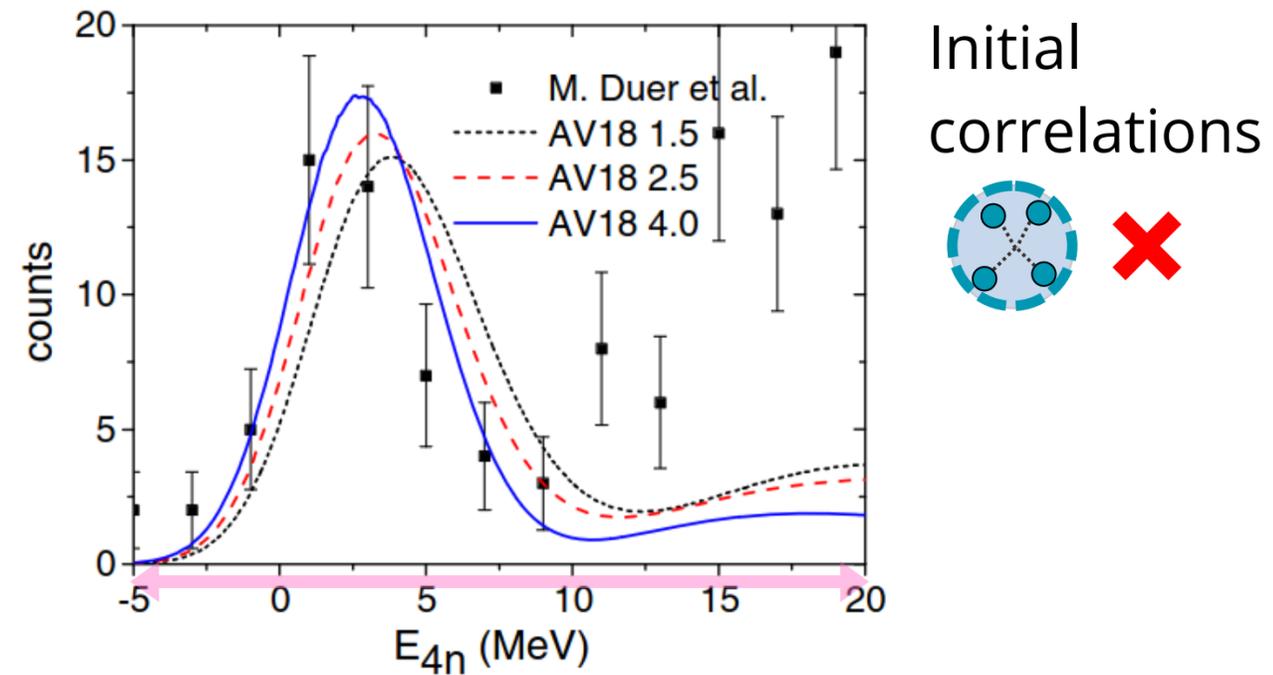# Tetraneutron positive signals

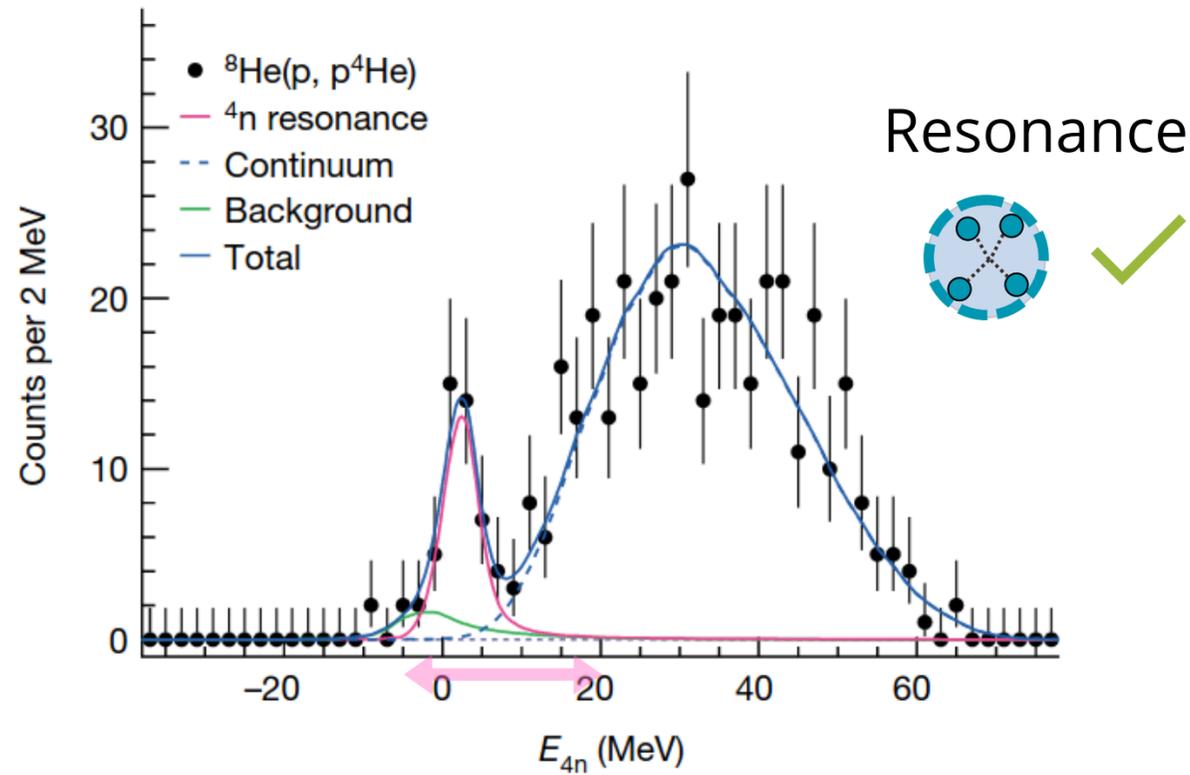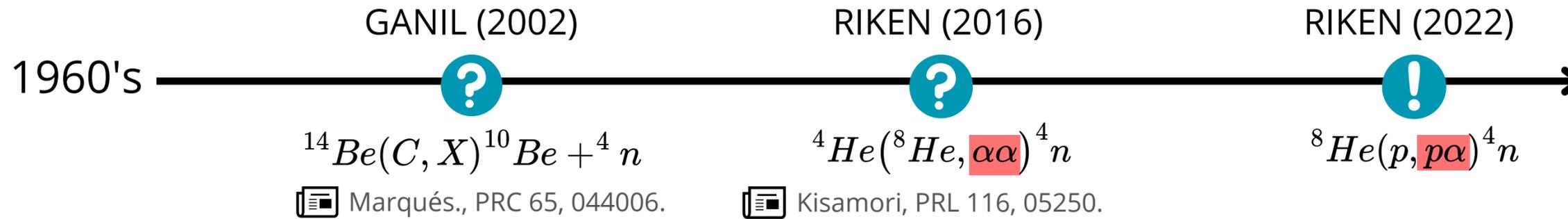GANIL (2002)   RIKEN (2016)   RIKEN (2022)

1960's

$^{14}Be(C,X)^{10}Be + {}^{4}n$

$^{4}He\left({}^{8}He, \alpha\alpha\right){}^{4}n$

$^{8}He(p, p\alpha){}^{4}n$

Marqués., PRC 65, 044006.

Kisamori, PRL 116, 05250.

Tetraneutron positive signals

1960's   GANIL (2002)   RIKEN (2016)   RIKEN (2022)

$$^{14}Be(C,X)^{10}Be + {}^4n$$

$$^4He({}^8He, \boxed{\alpha\alpha})^4 n$$

$$^8He(p, \boxed{p\alpha})^4 n$$

Marqués., PRC 65, 044006.

Kisamori, PRL 116, 05250.

Resonance ✓

Duer, Nature 606, 678-682.

Tetraneutron positive signals

1960's

GANIL (2002)
$^{14}Be(C,X)^{10}Be+^4n$

Marqués., PRC 65, 044006.

RIKEN (2016)
$^4He(^8He, \alpha\alpha)^4n$

Kisamori, PRL 116, 05250.

RIKEN (2022)
$^8He(p, p\alpha)^4n$

- $^8He(p, p^4He)$
- ^4n resonance
- Continuum
- Background
- Total

Resonance ✓

Initial correlations ✗

M. Duer et al.
AV18 1.5
AV18 2.5
AV18 4.0

Duer, Nature 606, 678-682.

Lazauskas, PRL 130 (2023) 102501

Tetraneutron positive signals

1960's   GANIL (2002)   RIKEN (2016)   RIKEN (2022)

$^{14}Be(C,X)^{10}Be + ^4n$ $^4He(^8He, \alpha\alpha)^4n$ $^8He(p, p\alpha)^4n$

Marqués., PRC 65, 044006.   Kisamori, PRL 116, 05250.
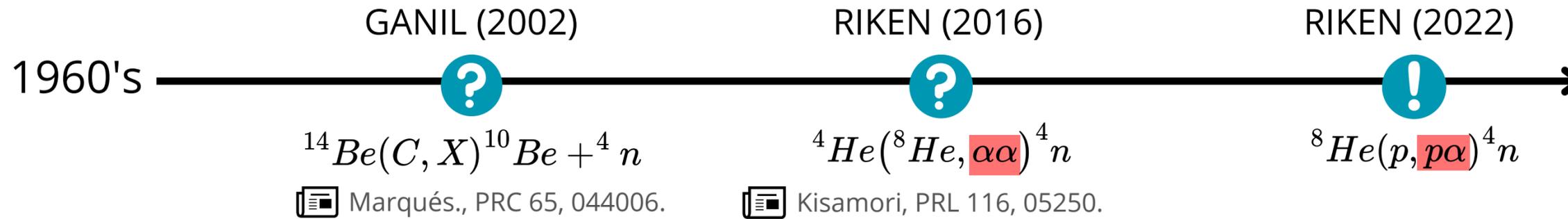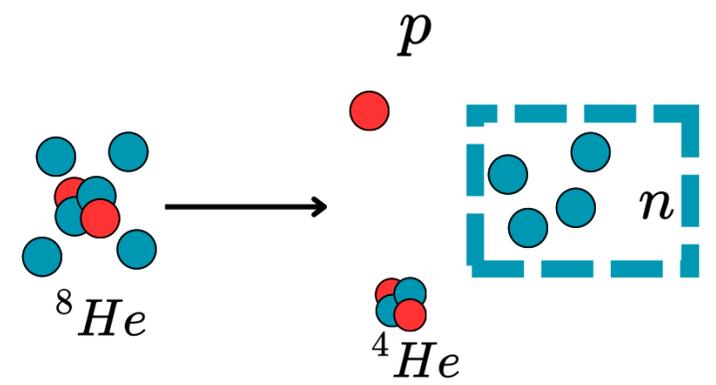
New experiment

Direct measurement
of neutrons

Resonance
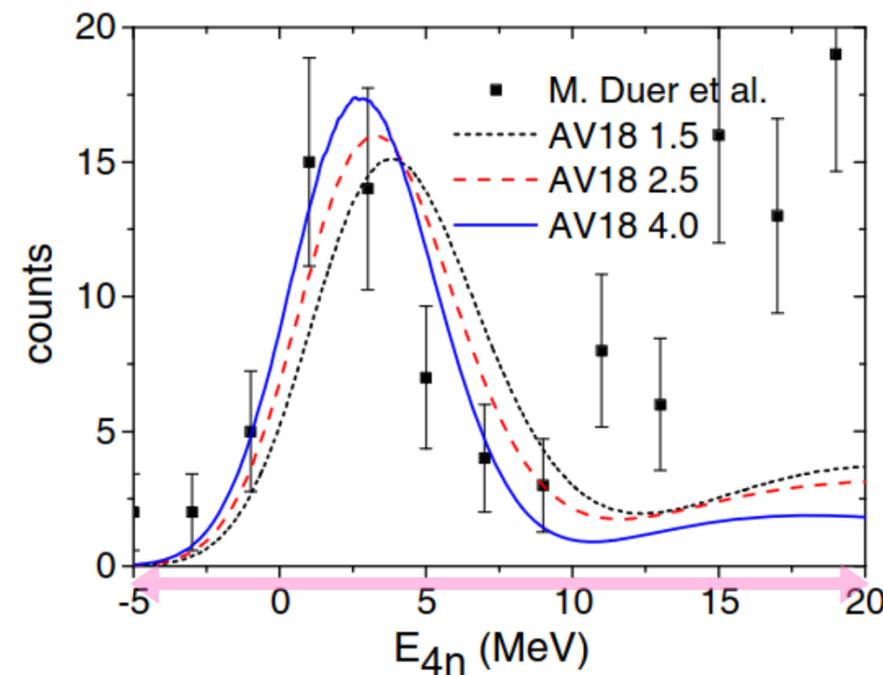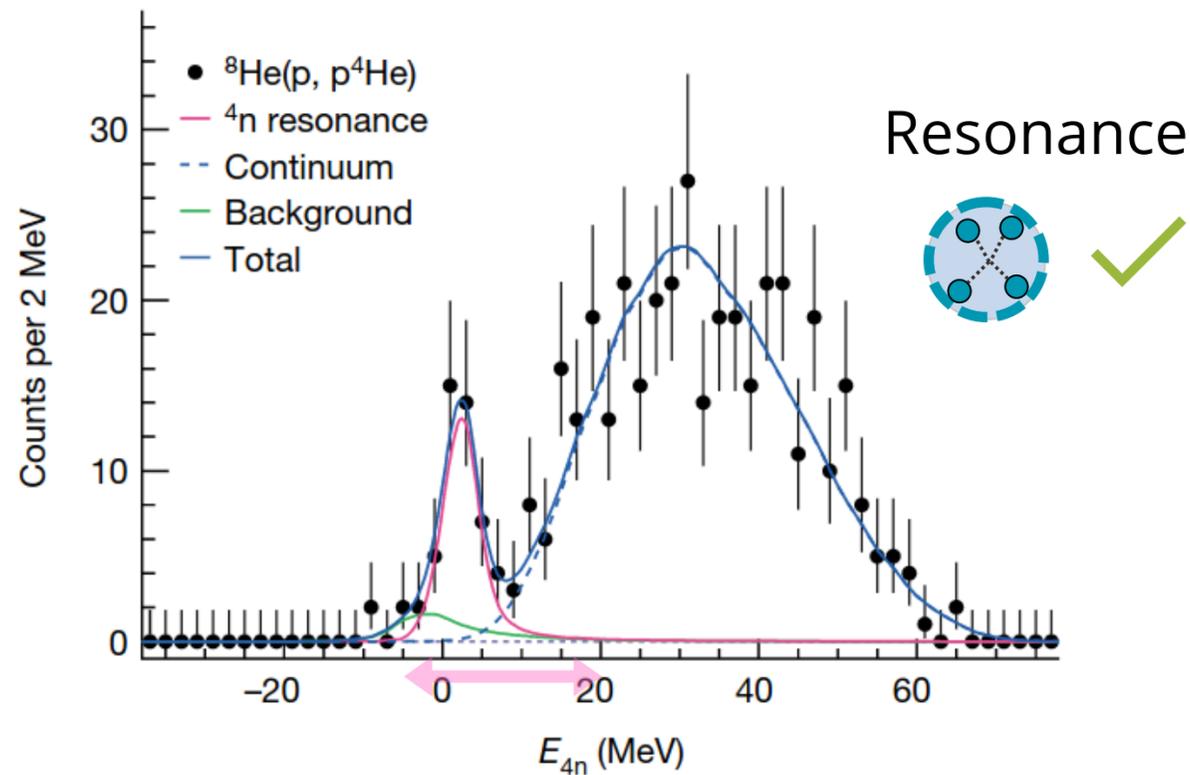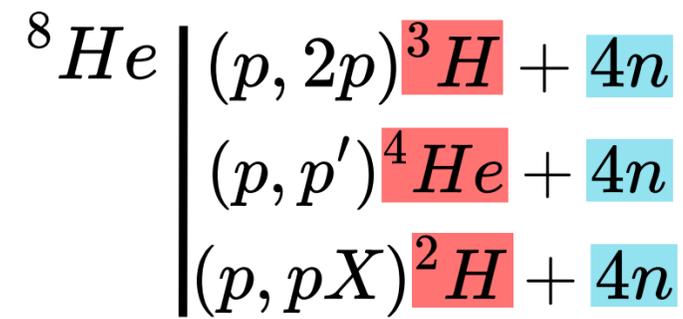
Initial
correlations
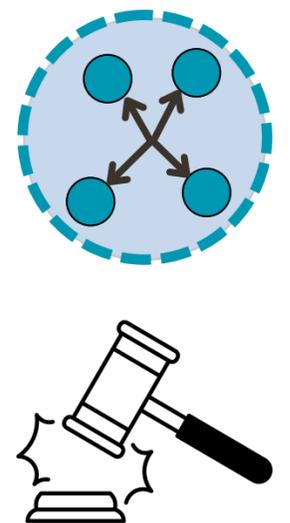
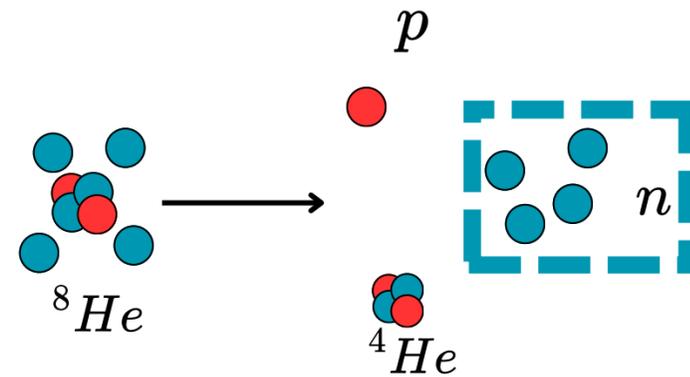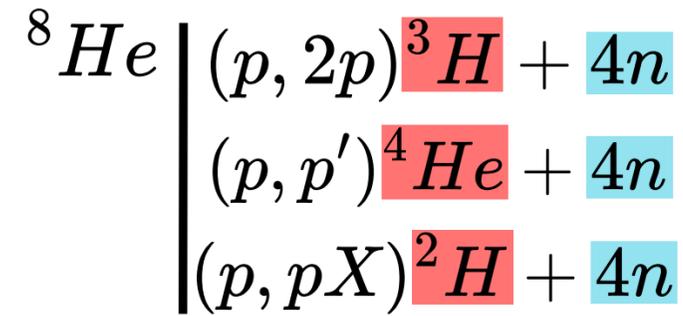Duer, Nature 606, 678-682.   Lazauskas, PRL 130 (2023) 102501

SAMURAI34 RIKEN

$$^8He \begin{cases} (p,2p)^3H + 4n \\ (p,p')^4He + 4n \\ (p,pX)^2H + 4n \end{cases}$$

NEBULA

NeuLAND

SAMURAI dipole

p target

^8He beam

Hodoscope

Drift chamber

SAMURAI34 RIKEN

$$^8He \left| \begin{array}{l} (p,2p)^3H + 4n \\ (p,p')^4He + 4n \\ (p,pX)^2H + 4n \end{array} \right.$$
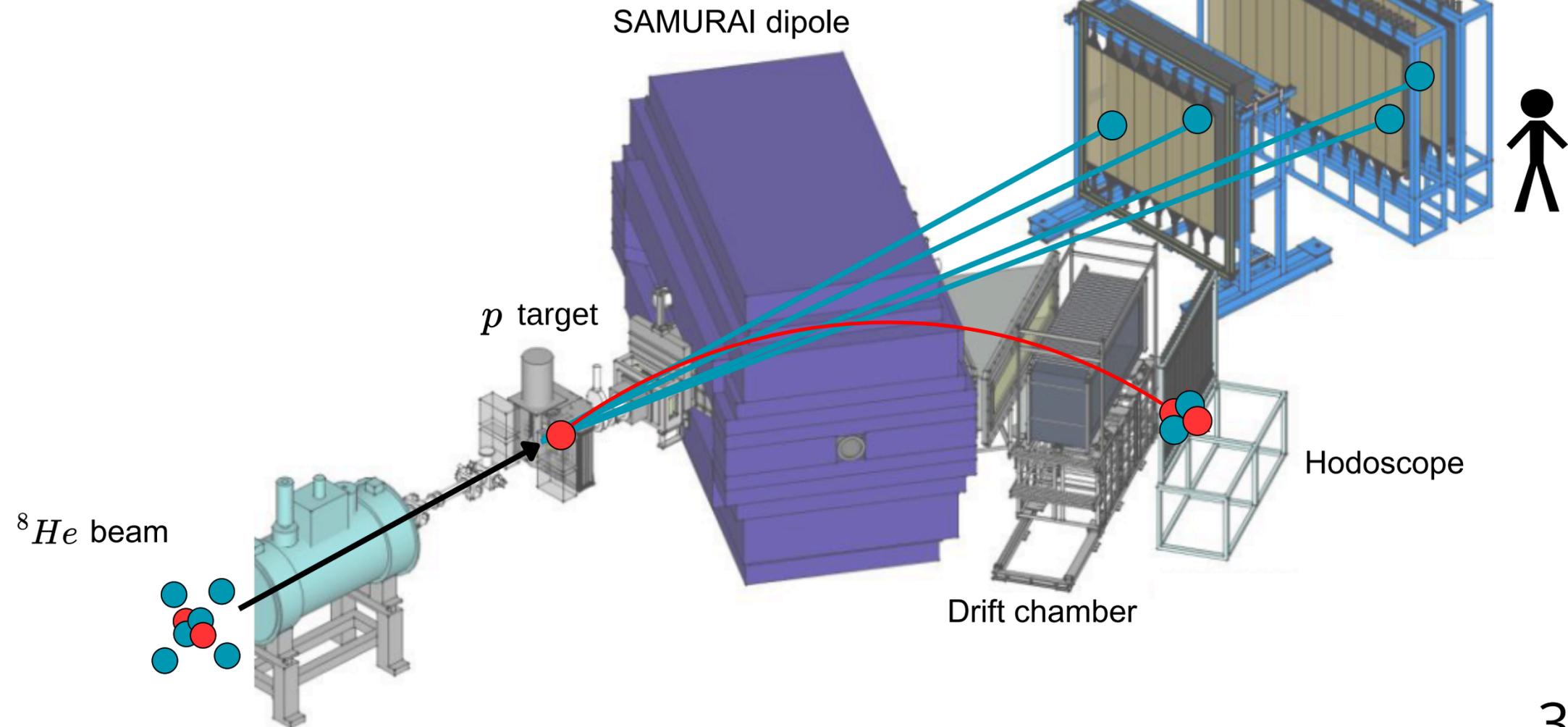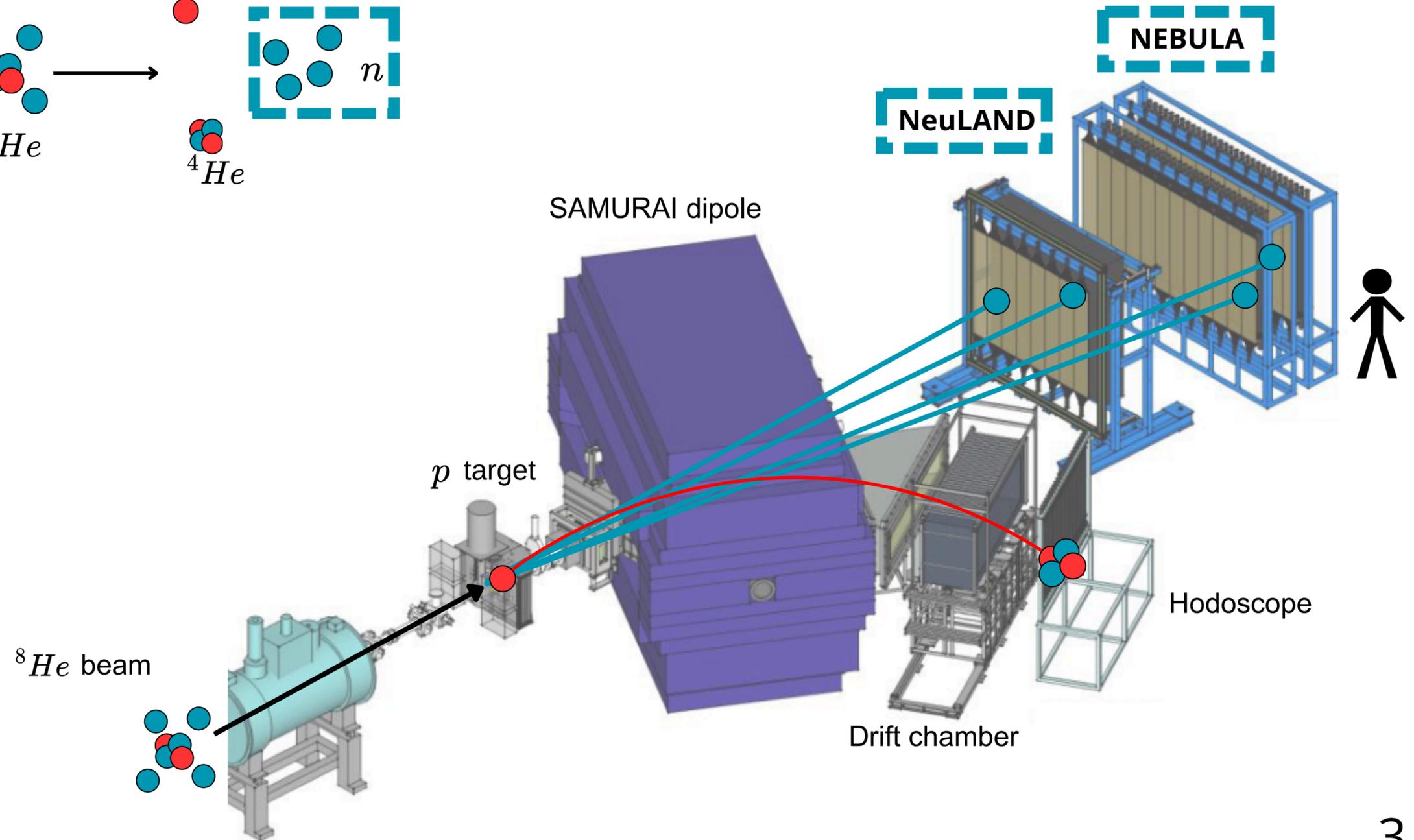
NeuLAND & NEBULA

- High neutron efficiency

Thick target + vertex tracker:
- High luminosity
- High statistic
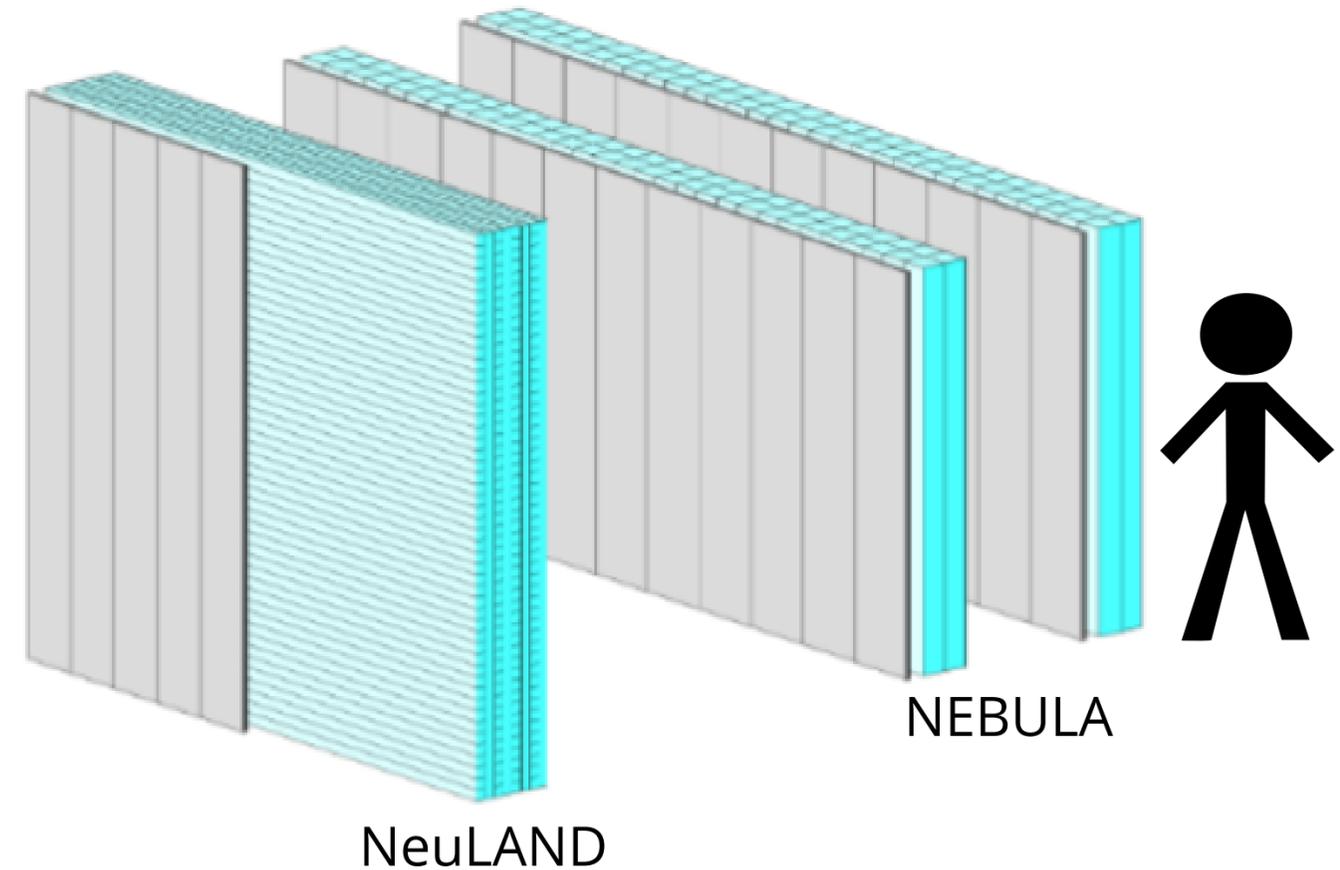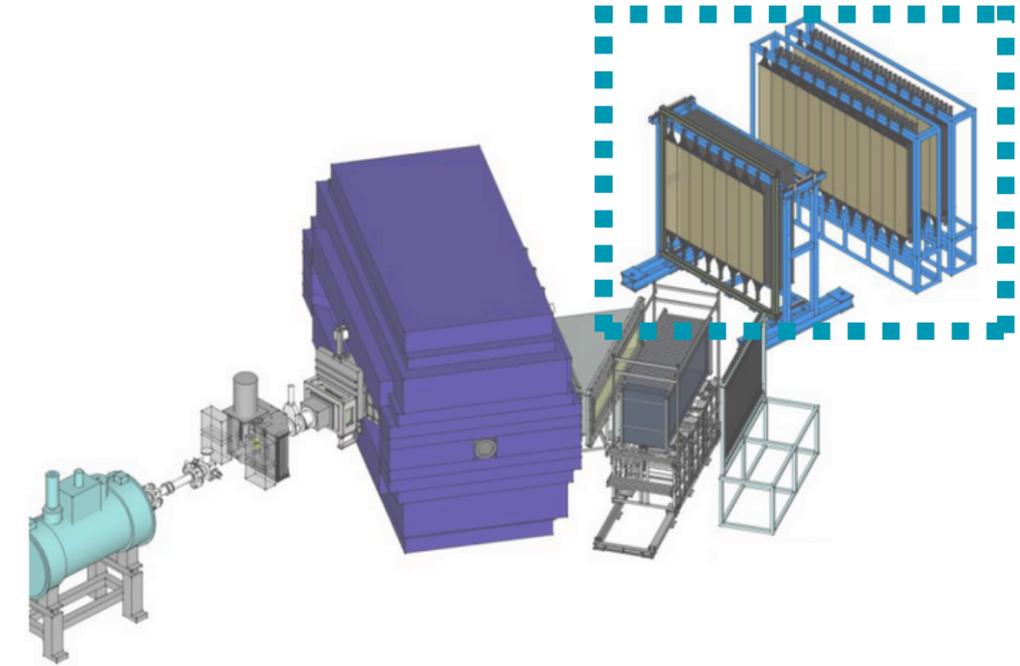+ Good resolution

3

Multineutron multidetectors

520 plastic scintillators

NeuLAND

$400 \times [250 \times 5 \times 5\text{cm}]$ @ 11 m

NEBULA

$120 \times [180 \times 12 \times 12\text{cm}]$ @ 14 m

NeuLAND

NEBULA

Multineutron multidetectors

520 plastic scintillators

NeuLAND

400 $\times$ [250$\times$5$\times$5cm] @ 11 m

NEBULA

120 $\times$ [180$\times$12$\times$12cm] @ 14 m

Bar size + number:

✓ acceptance

✓ granularity

✓ efficiency $\quad \varepsilon_{4n} \lesssim (\varepsilon_{1n})^4$
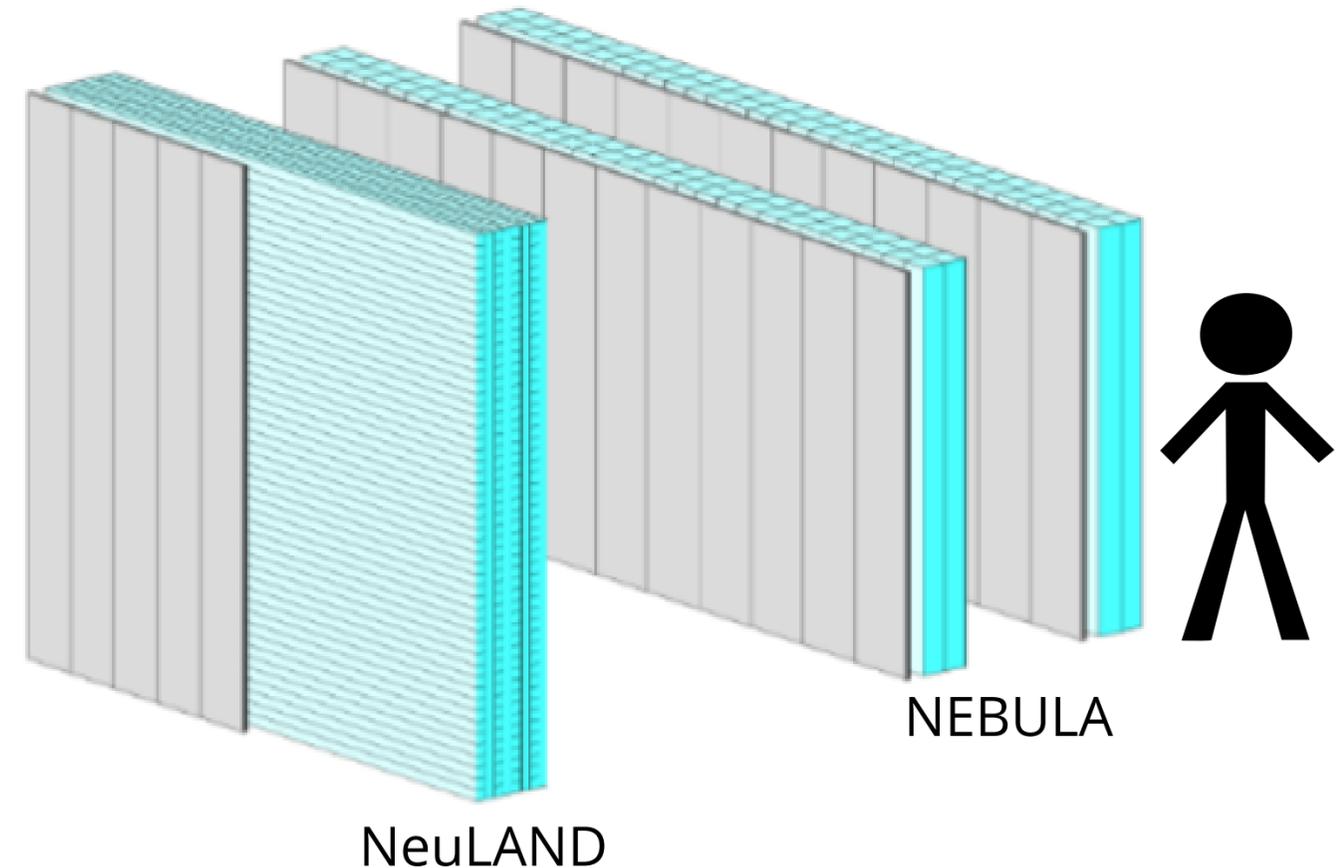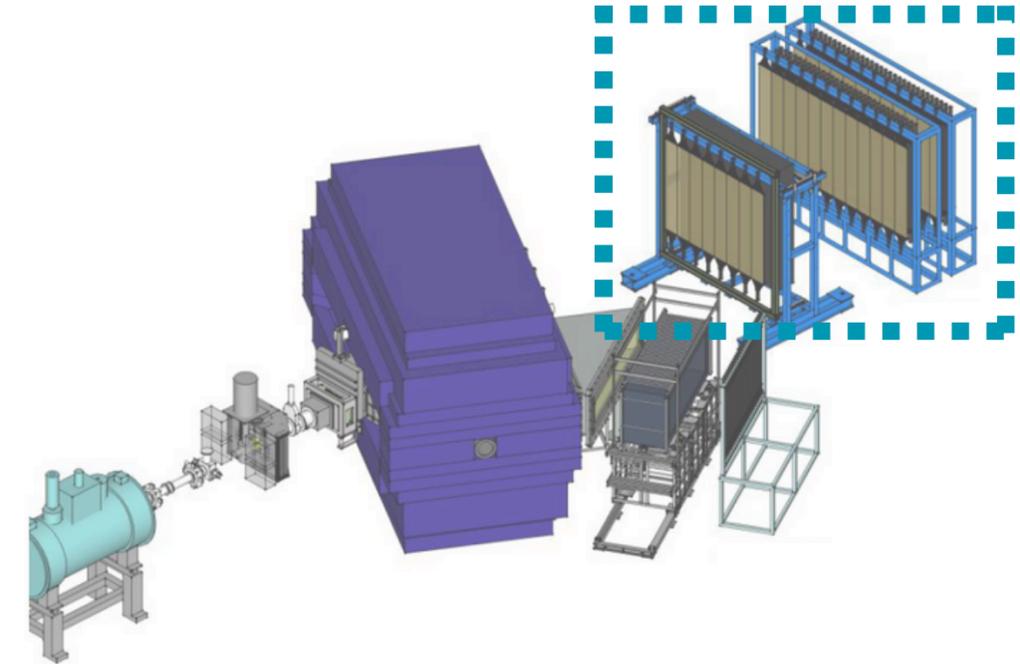
NeuLAND

NEBULA

Multineutron multidetectors

520 plastic scintillators

NeuLAND

$400 \times [250 \times 5 \times 5 \text{cm}]$ @ 11 m

NEBULA

$120 \times [180 \times 12 \times 12 \text{cm}]$ @ 14 m
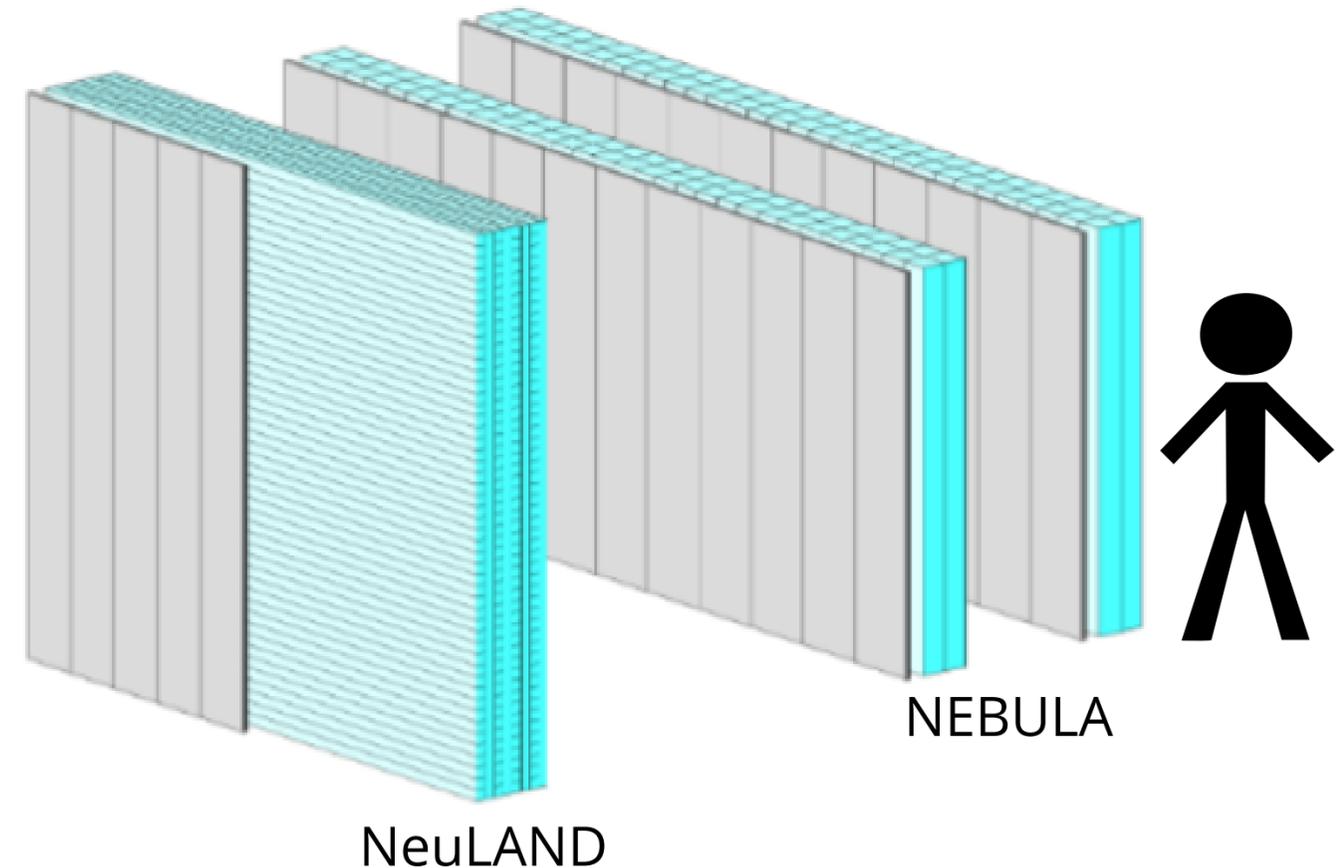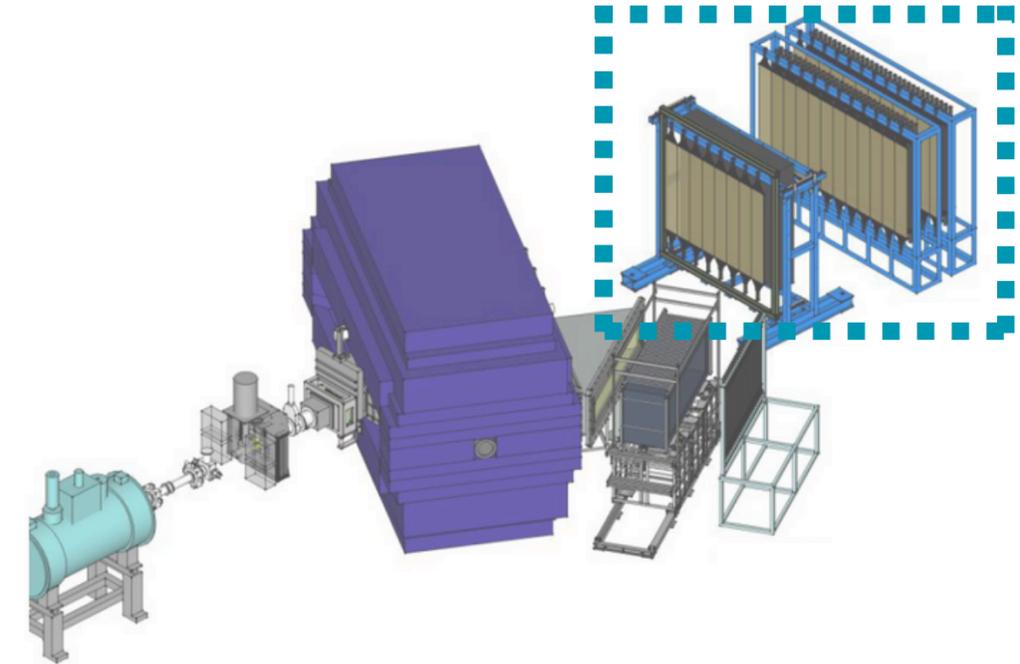
Bar size + number:

✓ acceptance

✓ granularity

✓ efficiency $\quad \varepsilon_{4n} \lesssim (\varepsilon_{1n})^4$

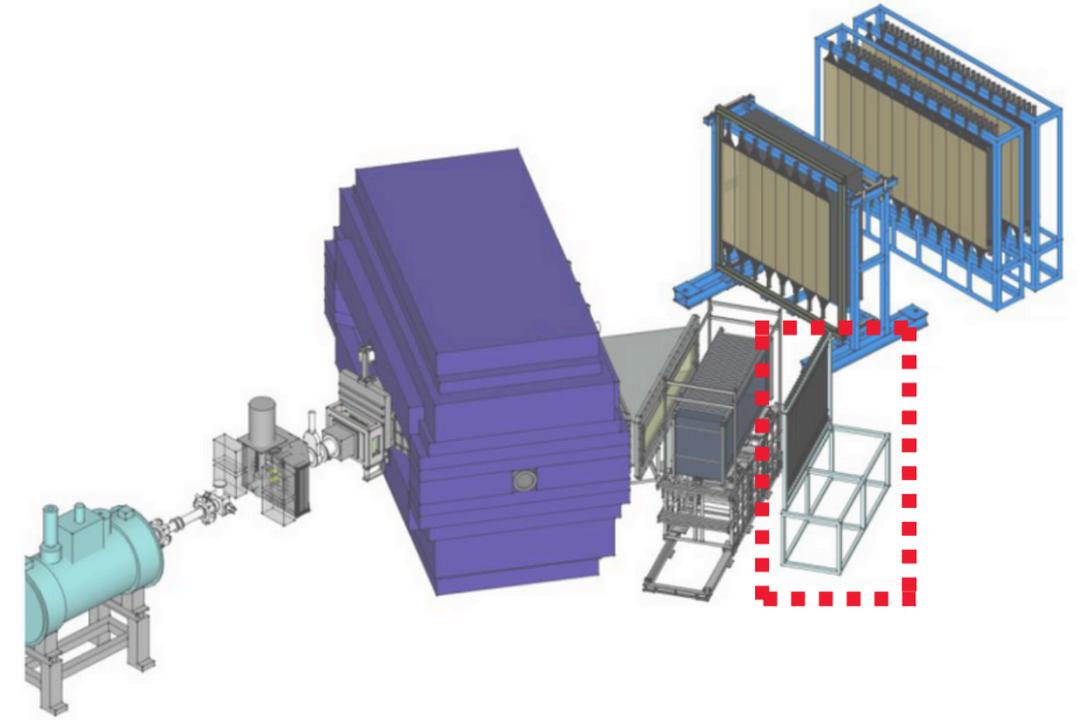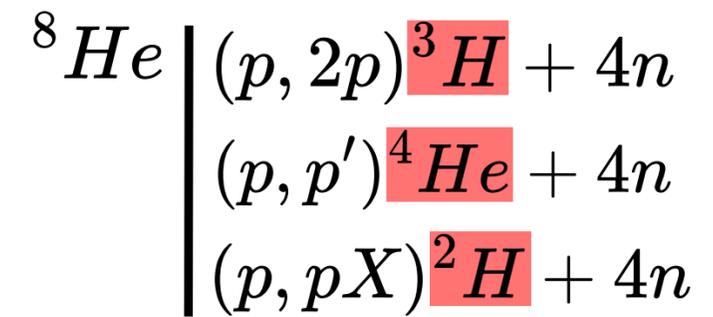Crosstalk effect: well-known algorithm

Kondo, Nature 620, 965–970 (2023).

Kondo, NIM 463, 173-178 (2020).

NeuLAND

NEBULA

4

Hodoscope
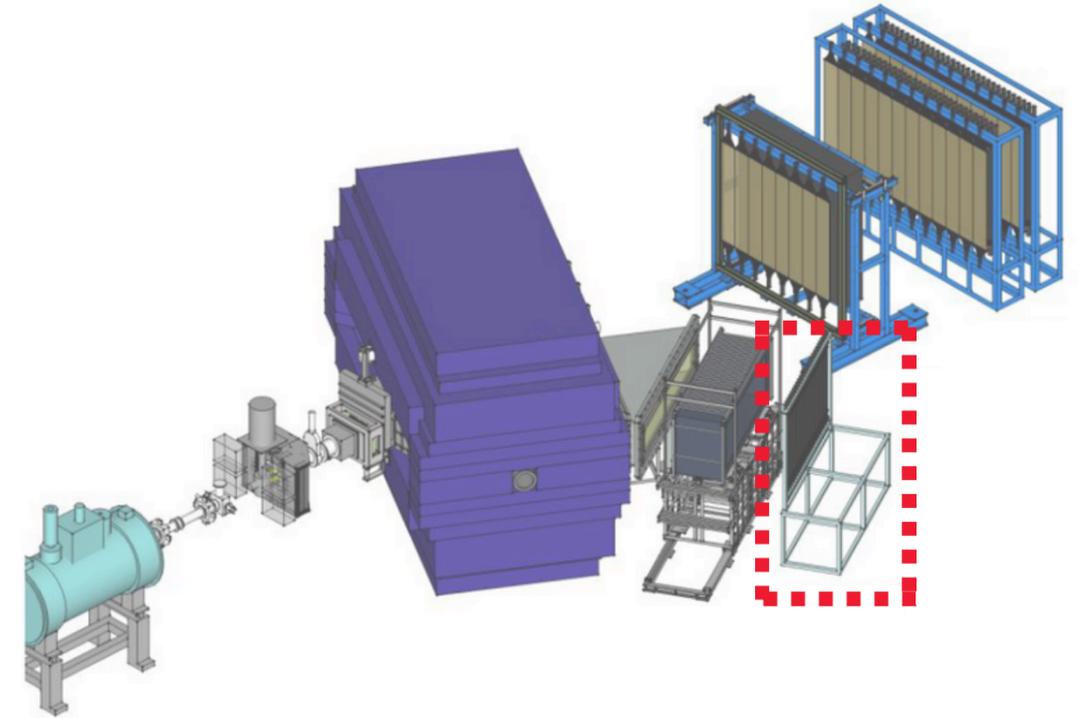
Plastic scintillators

$40 \times [120{\times}10{\times}1\mathrm{cm}]$

$$^{8}He \left| \begin{array}{l} (p,2p)^{3}H + 4n \\ (p,p')^{4}He + 4n \\ (p,pX)^{2}H + 4n \end{array} \right.$$

Hodoscope

Plastic scintillators

$40 \times [120 \times 10 \times 1\,\text{cm}]$

$${}^{8}He \left| \begin{array}{l} (p, 2p)\,{}^{3}H + 4n \\ (p, p')\,{}^{4}He + 4n \\ (p, pX)\,{}^{2}H + 4n \end{array} \right.$$

$\propto \dfrac{A}{Z}$

ΔE

Hodoscope

SAMURAI
magnet

Target

Hodoscope

Plastic scintillators

$40 \times [120 \times 10 \times 1 cm]$

$$^{8}He \begin{cases} (p, 2p)^{3}H + 4n \\ (p, p')^{4}He + 4n \\ (p, pX)^{2}H + 4n \end{cases}$$

$\propto \dfrac{A}{Z}$

ΔE

Hodoscope

SAMURAI magnet

Target
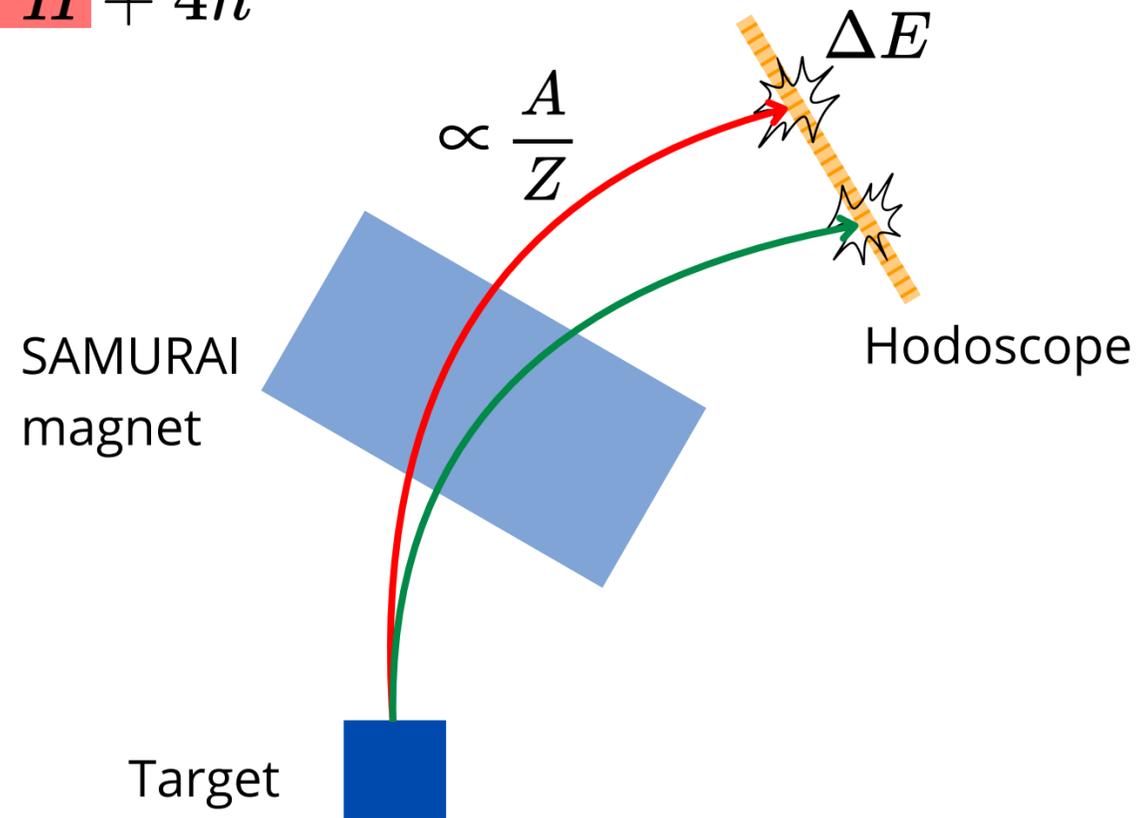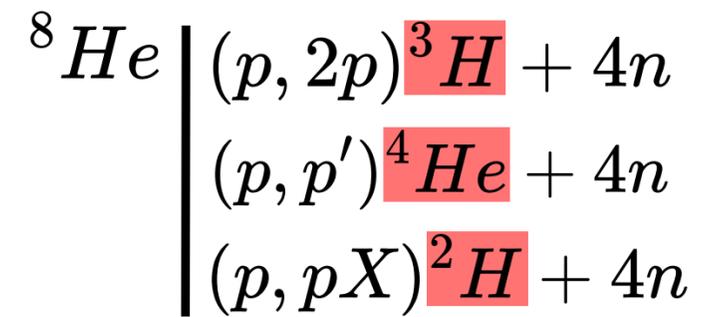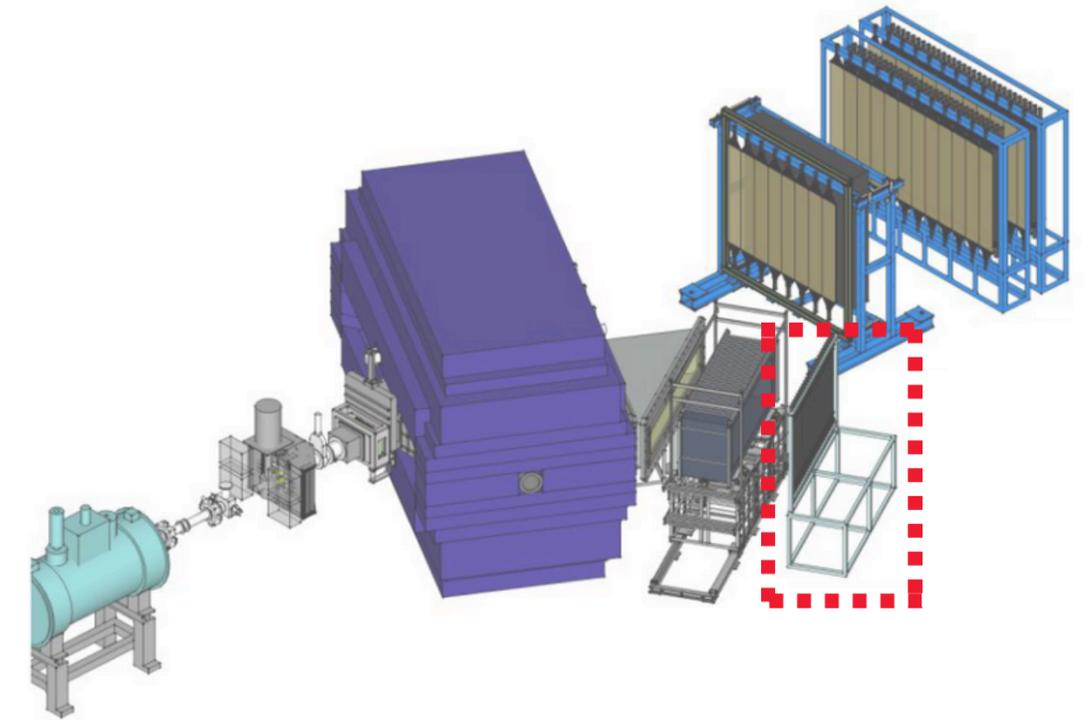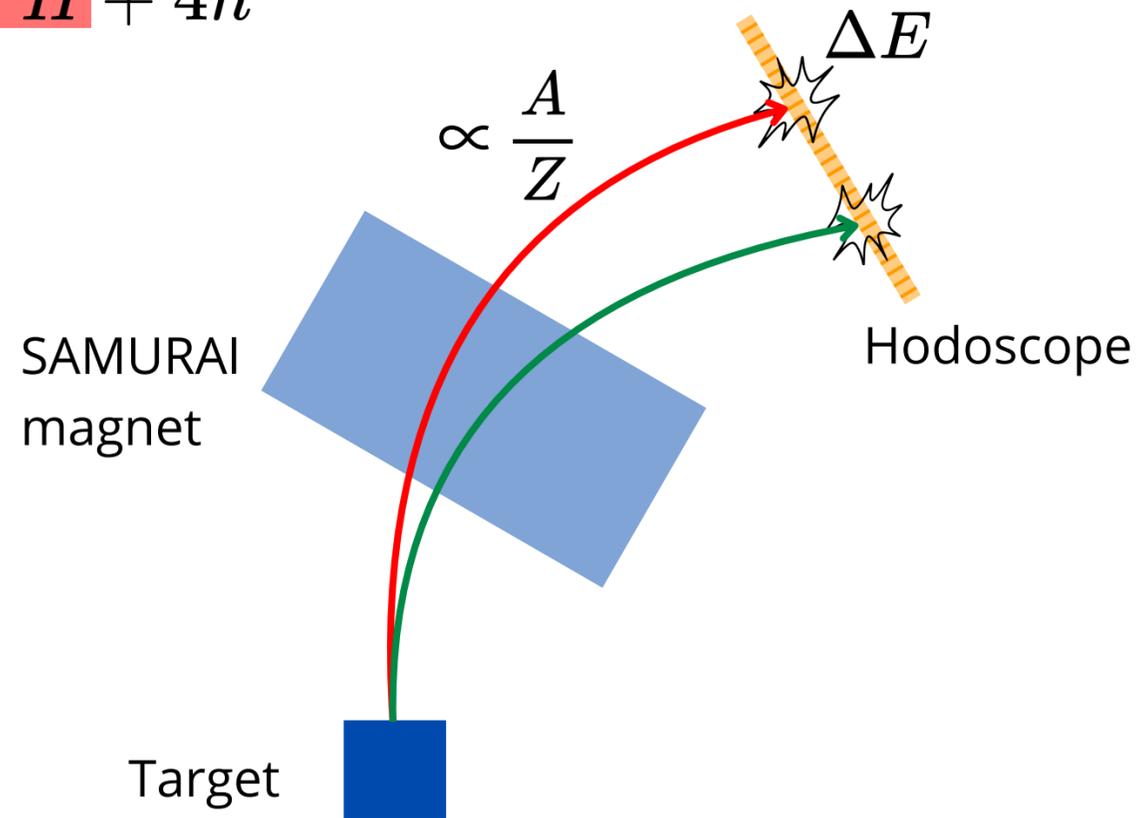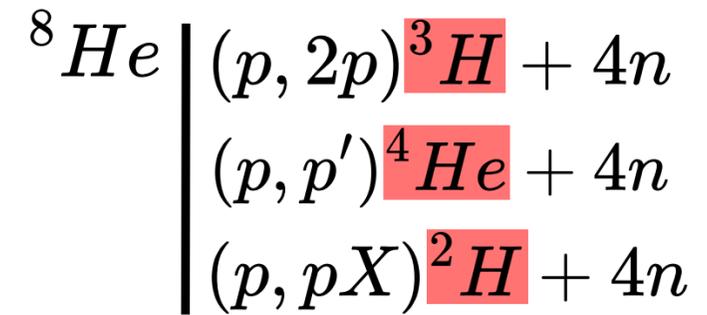
Fragment identification: ΔE & $\dfrac{A}{Z}$

4n reaction channels

Hodoscope

Plastic scintillators

$40 \times [120 \times 10 \times 1cm]$

$$^{8}He \left| \begin{array}{l} (p,2p)^{3}H + 4n \\ (p,p')^{4}He + 4n \\ (p,pX)^{2}H + 4n \end{array} \right.$$

$\propto \dfrac{A}{Z}$

ΔE

SAMURAI magnet

Hodoscope

Target
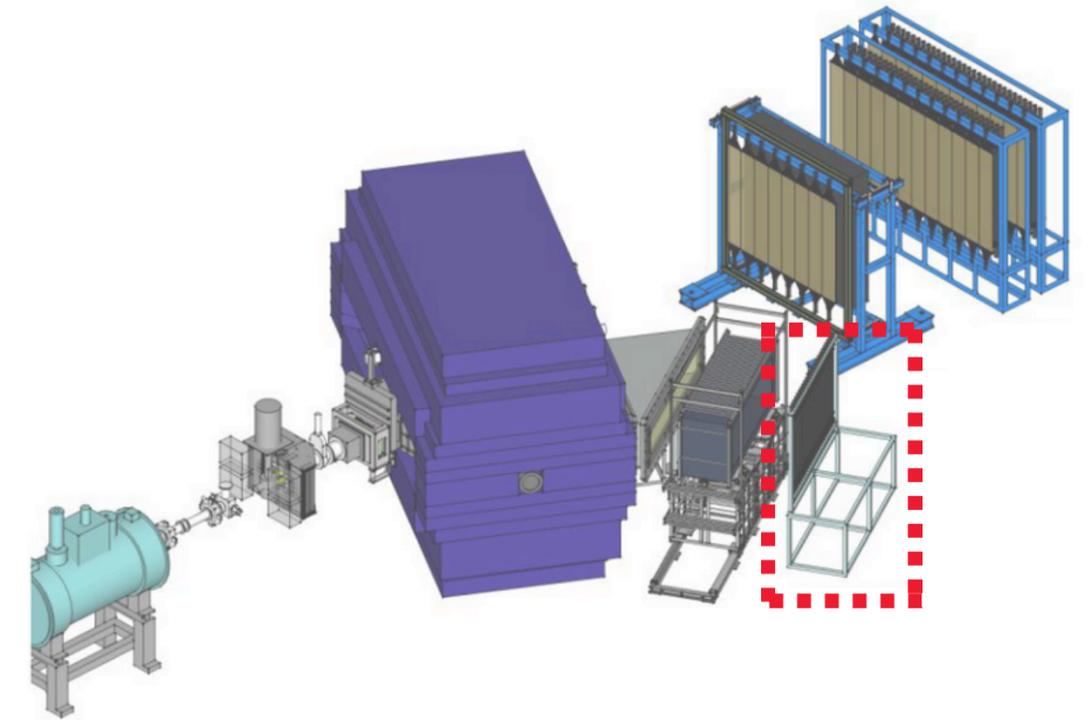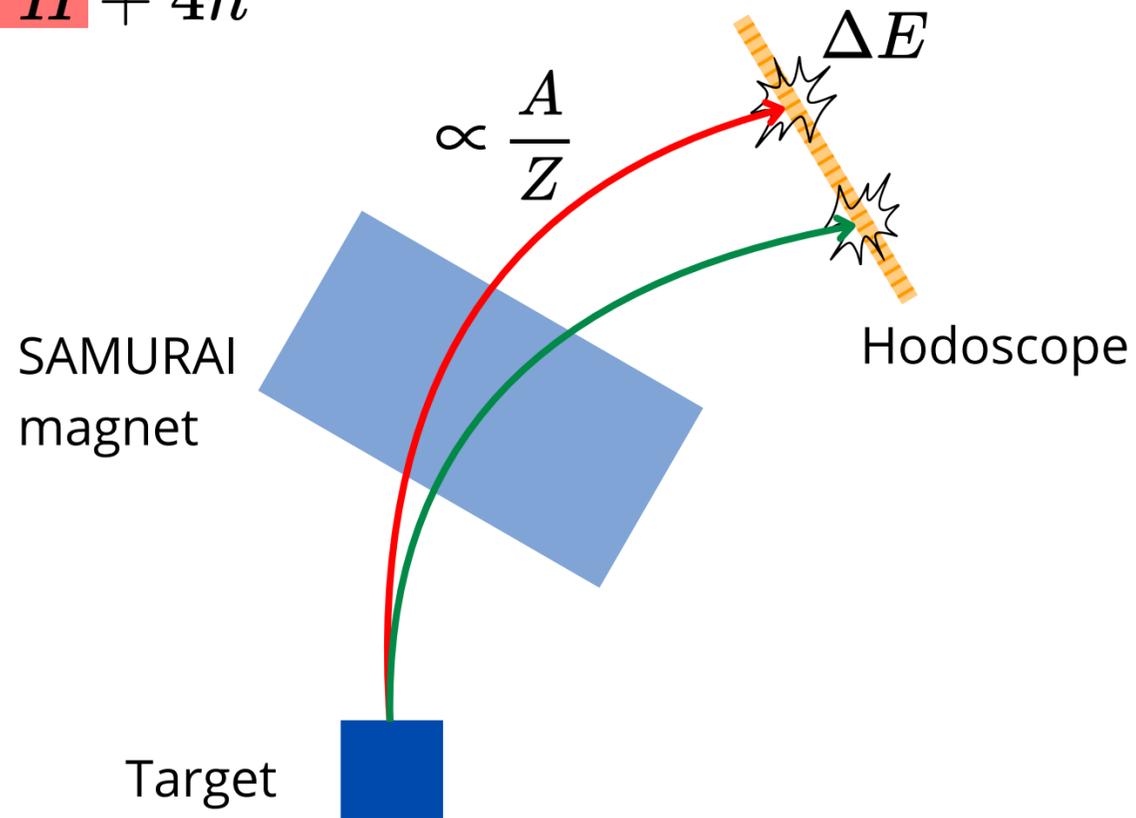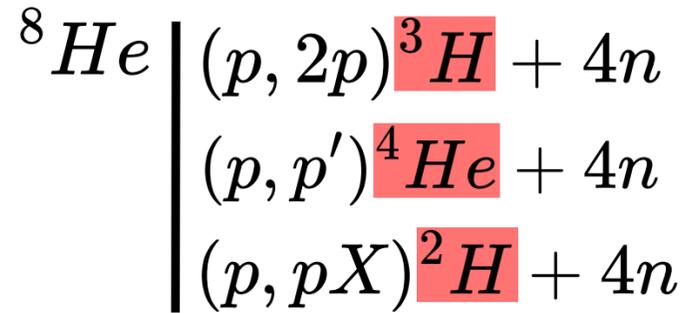
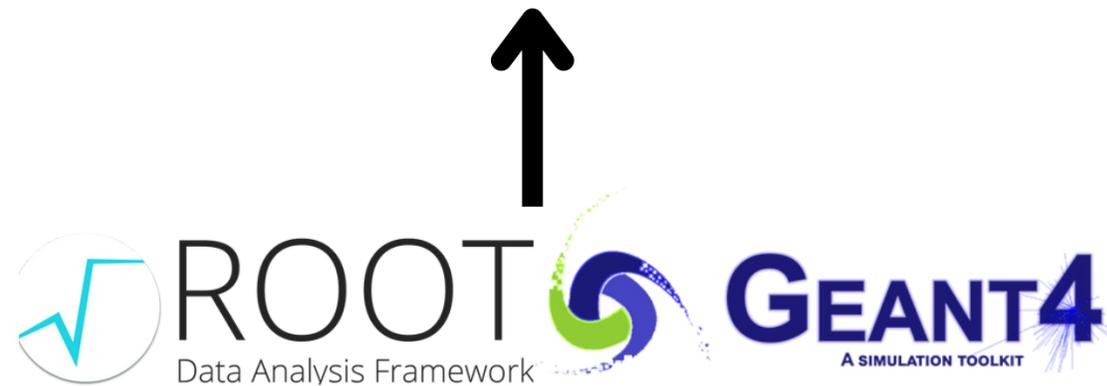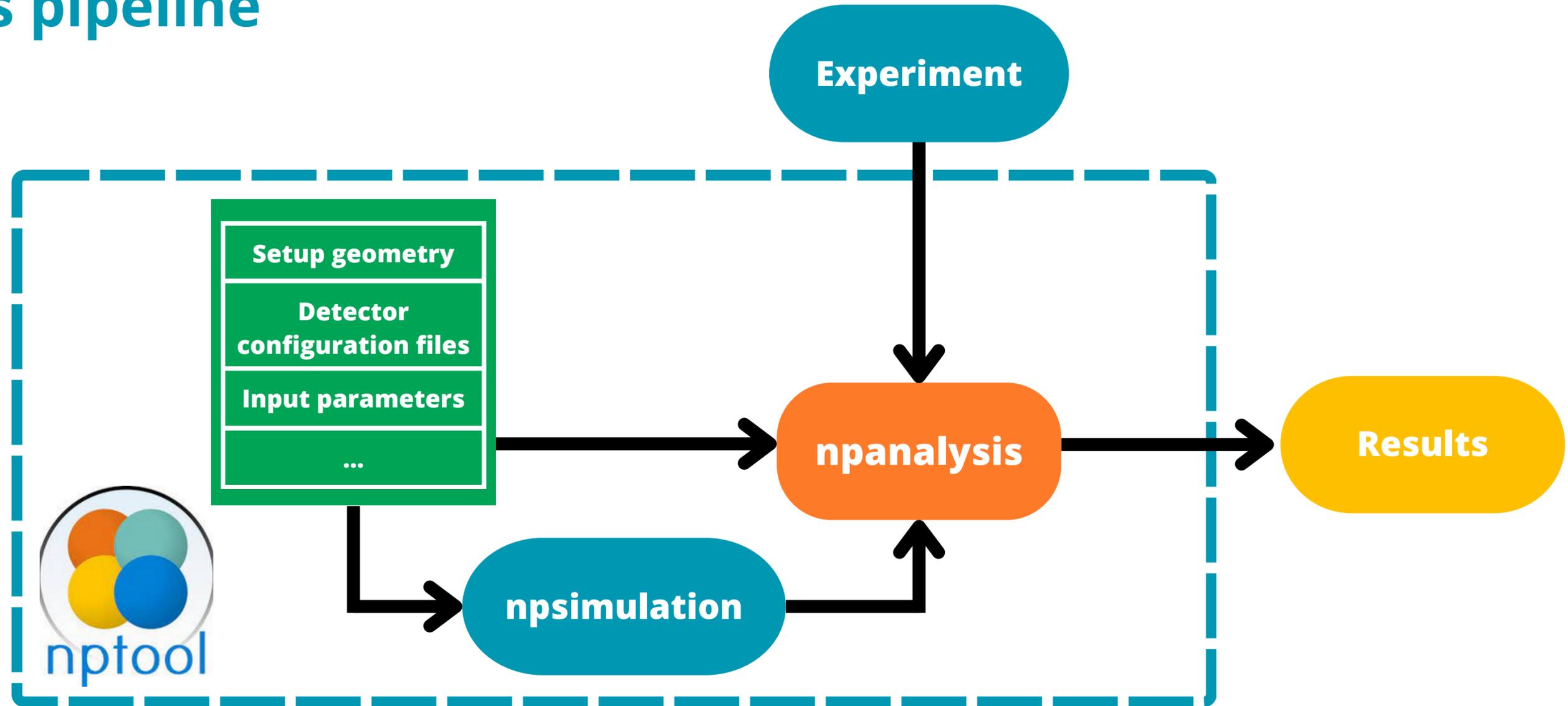Fragment identification: ΔE & $\dfrac{A}{Z}$

4n reaction channels

Complex detection system

$\rightarrow$ complete & realistic simulation:

- 4n efficiency ~1%

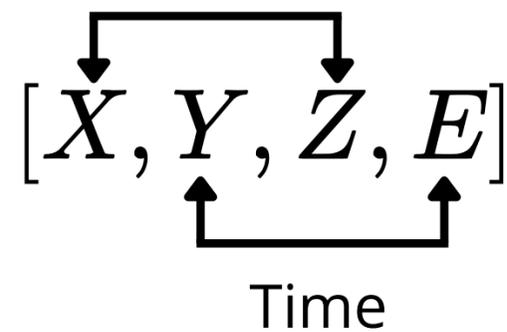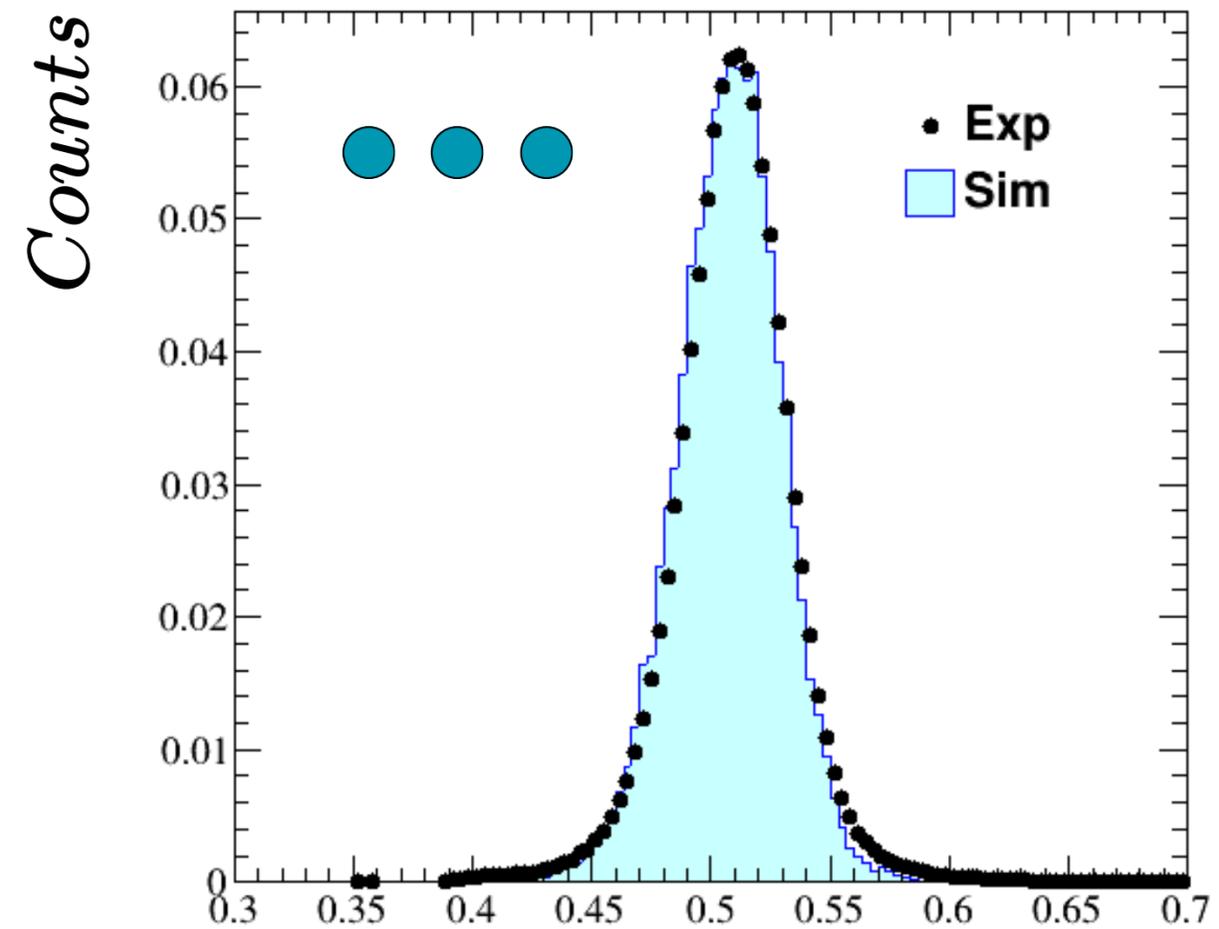- E(4n) resolution ~200 keV

5

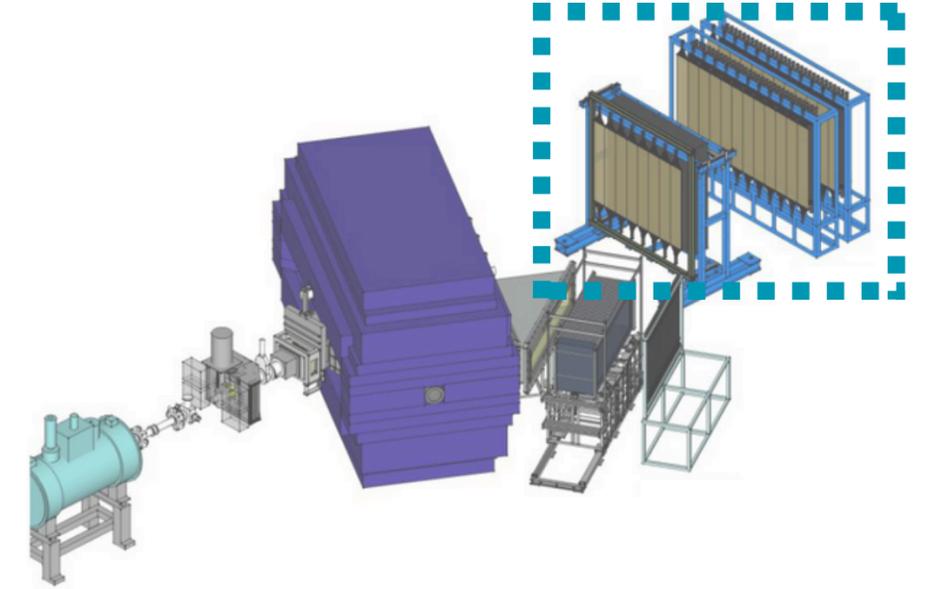# Analysis pipeline

Neutron properties

NeuLAND & NEBULA

- Include geometry

- Calibration

- Time resolution

Configuration

$$[X, Y, Z, E]$$

Time

$$^8He(p,pn)^7He^* \rightarrow^4 He + 3n$$
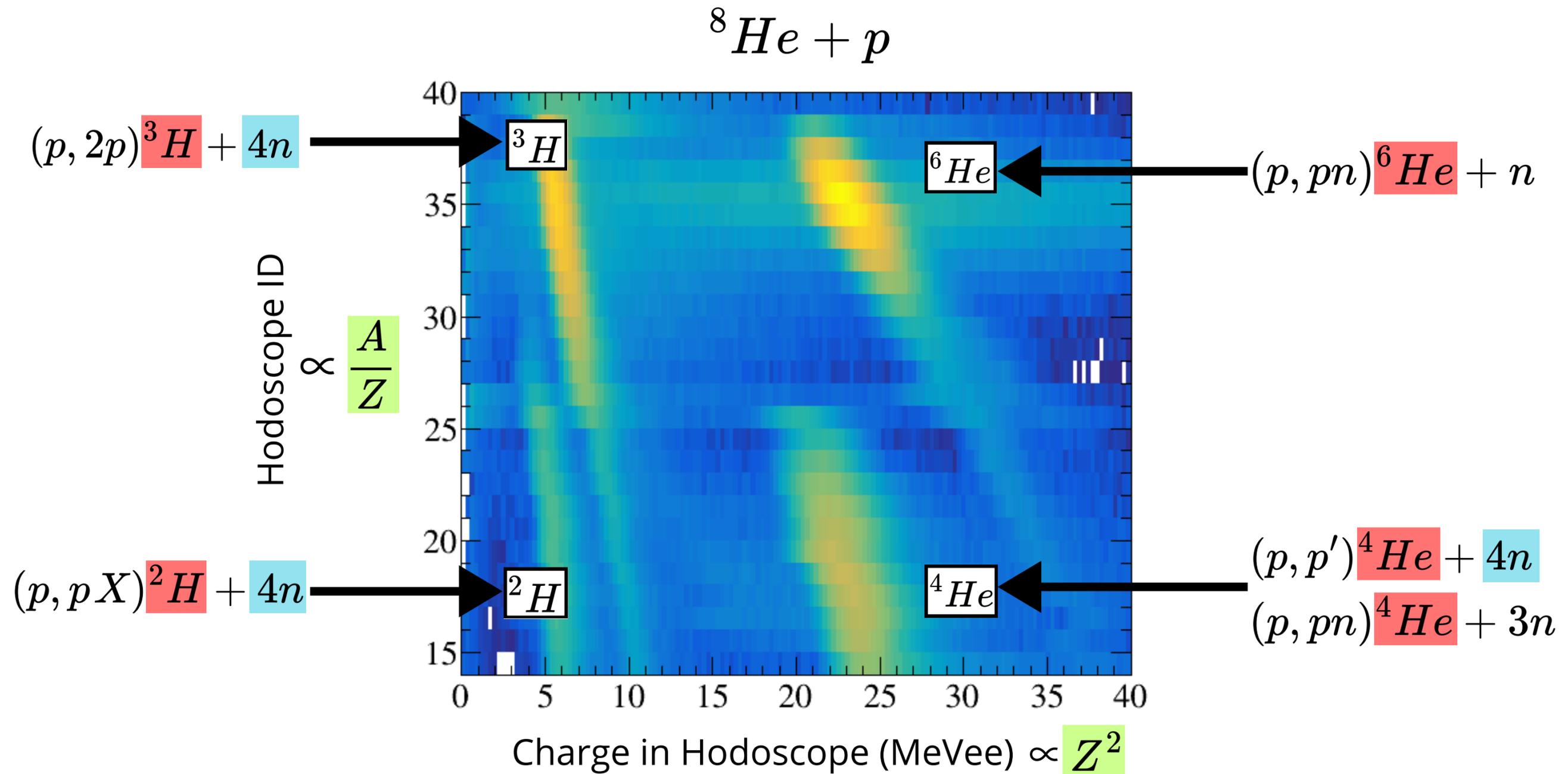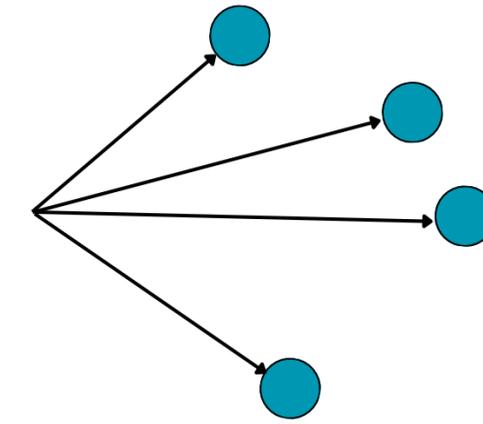
$$\beta_n \approx 0.51$$

Simulated event

$$^8He(p,p')^4He + 4n$$
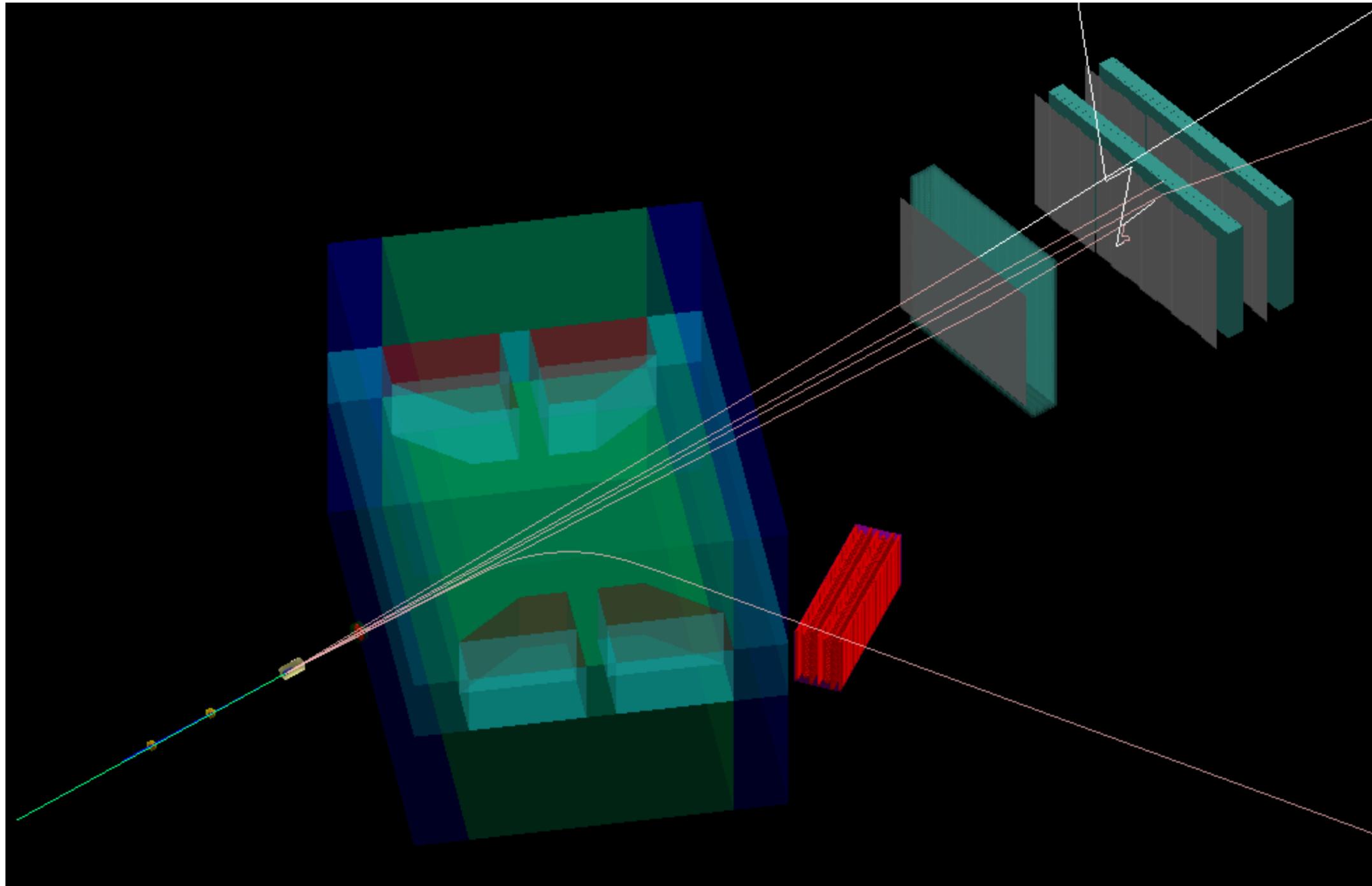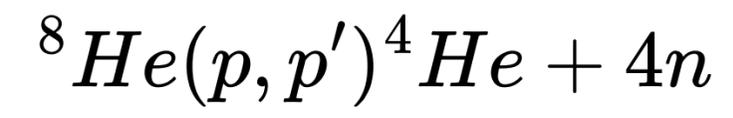
Fragment selection in Hodoscope

$$^8He + p$$

$(p, 2p)$$^3H$ + $4n$

$(p, pX)$$^2H$ + $4n$

$(p, pn)$$^6He$ + n

$(p, p')$$^4He$ + $4n$

$(p, pn)$$^4He$ + $3n$

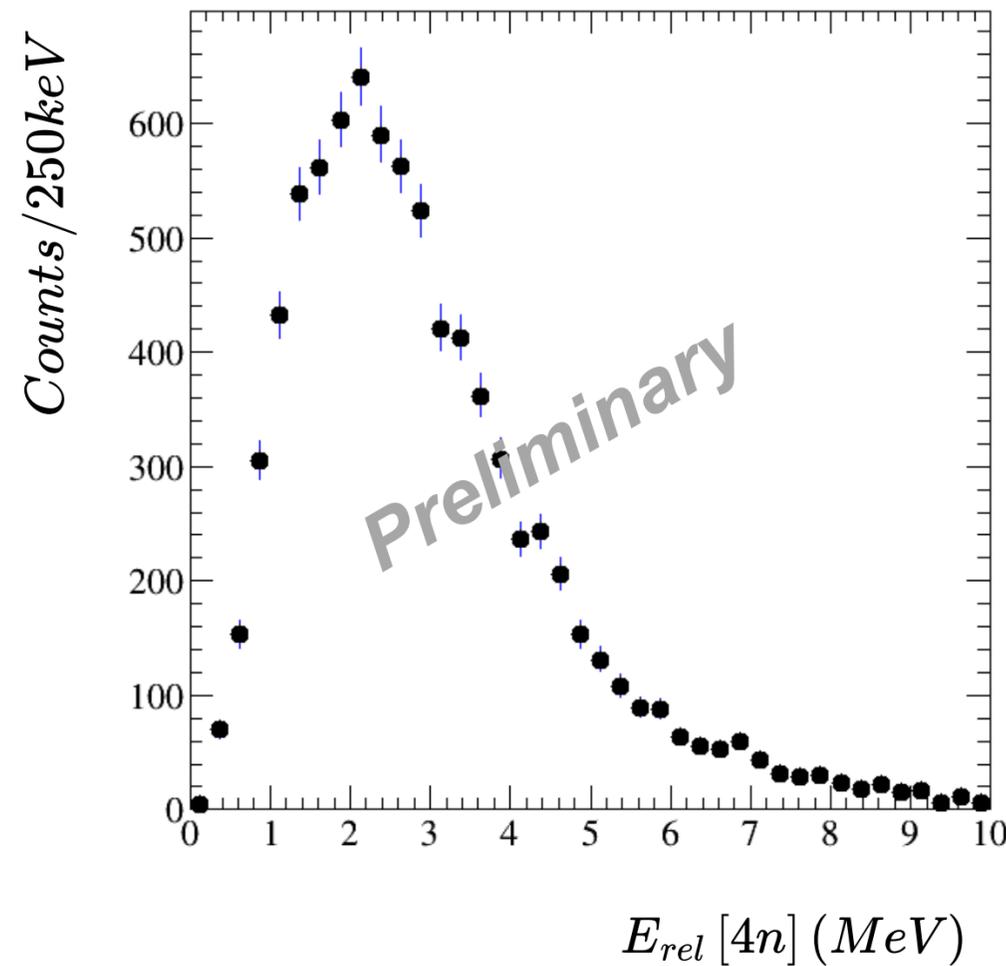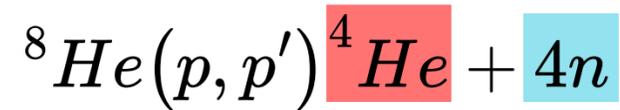Hodoscope ID $\propto \dfrac{A}{Z}$

Charge in Hodoscope (MeVee) $\propto Z^2$

Good fragment separation $\longrightarrow$ reaction channel + ● ● ● ●

9

Preliminary results: 4n invariant mass

$$^8He(p, 2p)\,{}^3H + 4n$$

$$^8He(p, p')\,{}^4He + 4n$$

$$(p, pX)\,{}^2H + 4n$$

$\approx 30\,000$ events
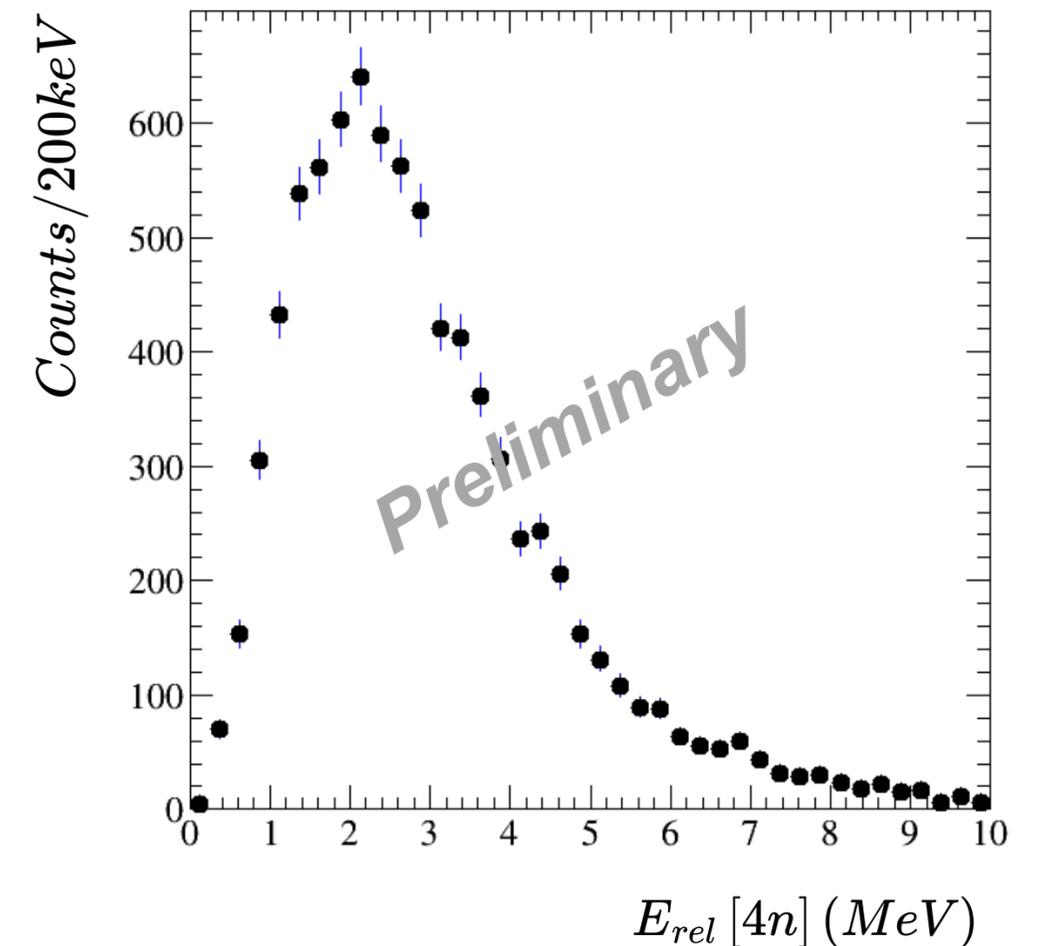
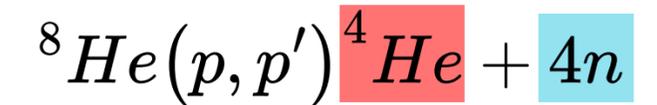$\approx 8\,000$ events

≈ 400 events

Summary

- Nature of the 4n signal ?

- Direct detection of 4 neutrons

- Neutron & fragment multidetectors

- High statistics + resolution + several channels

Outlook

- Explore reaction kinematics

- Study of new neutron correlation observables

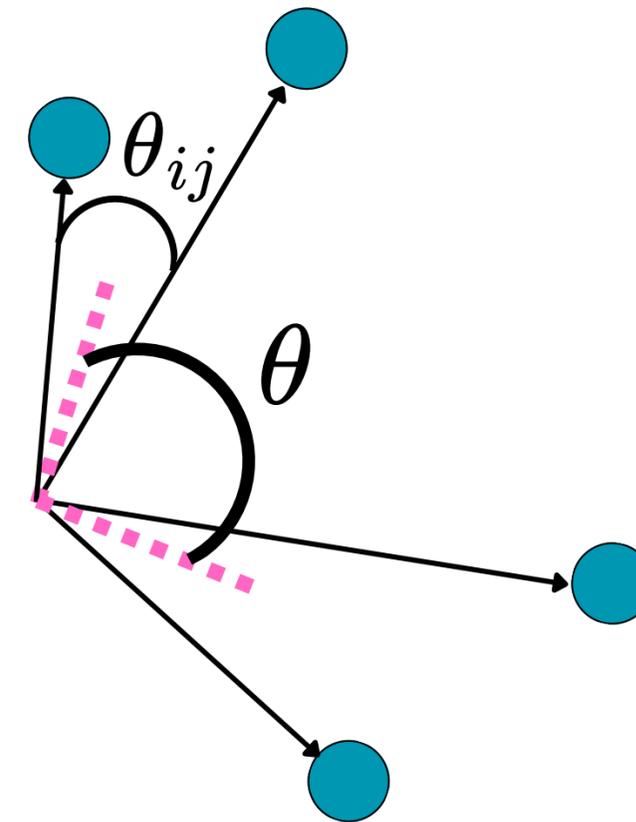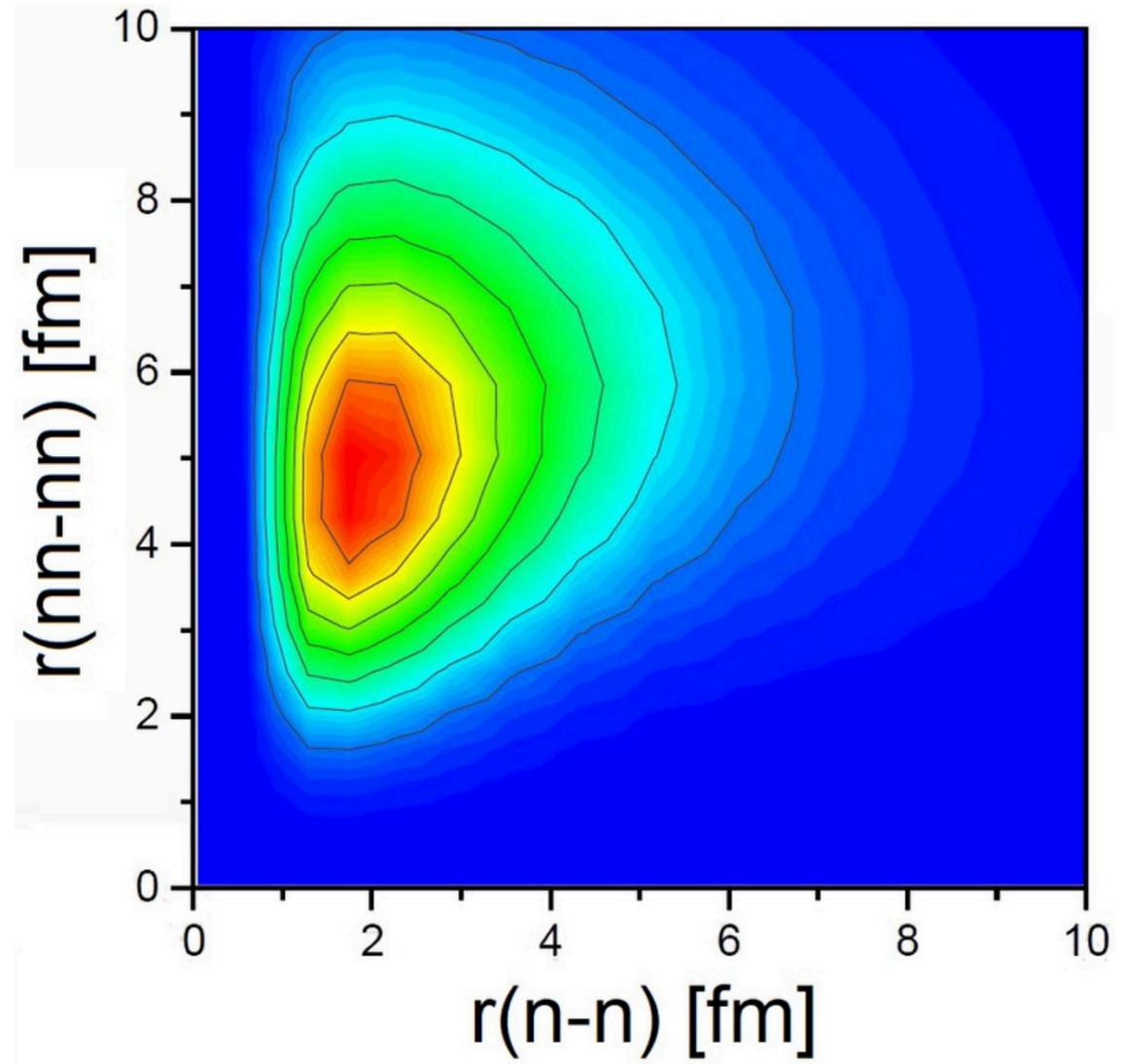- Comparison with simulations (and theory)
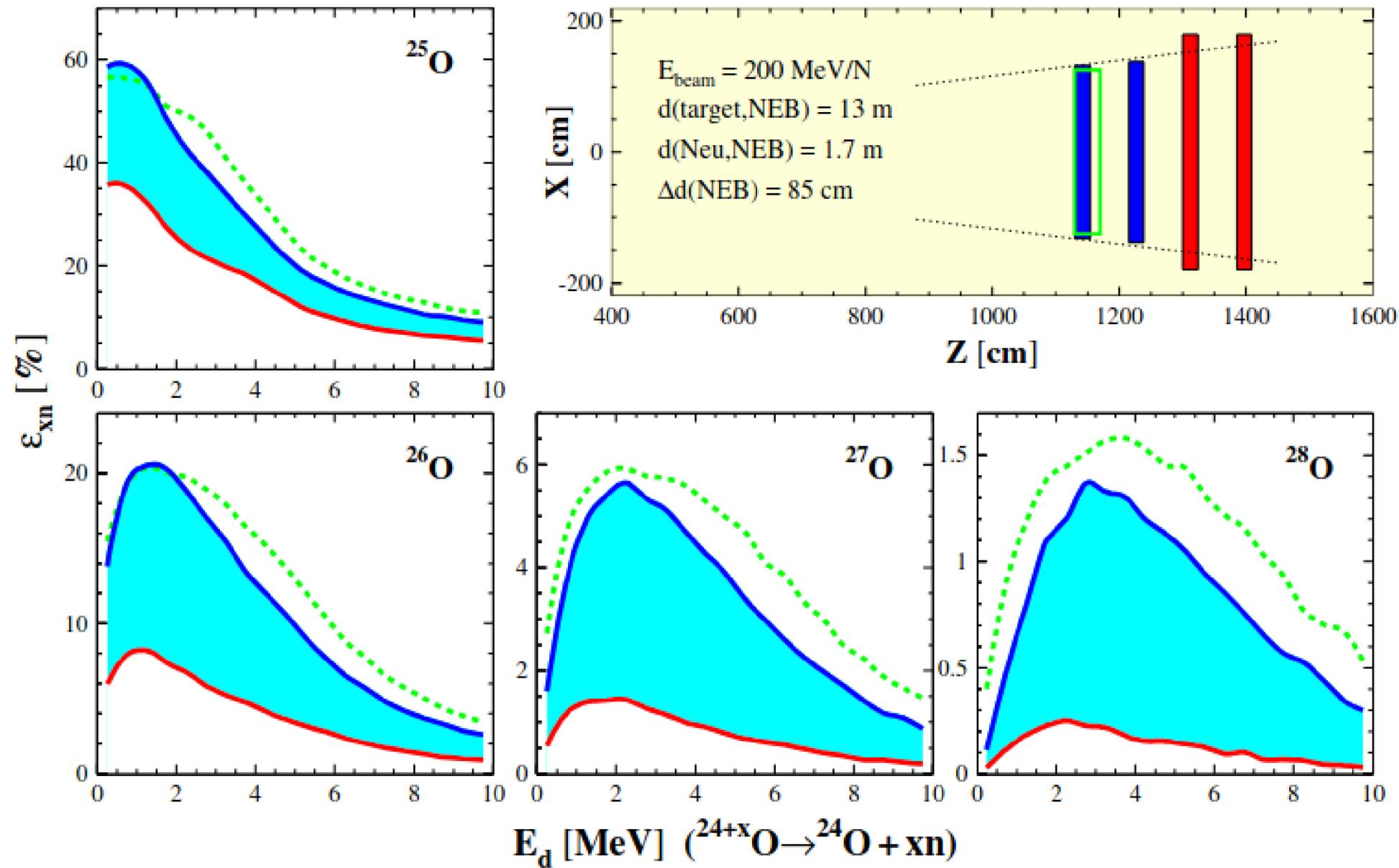
$${}^8He\left(p,p'\right){}^4He + 4n$$

Aknowledgement to the S34 collaboration

Backups
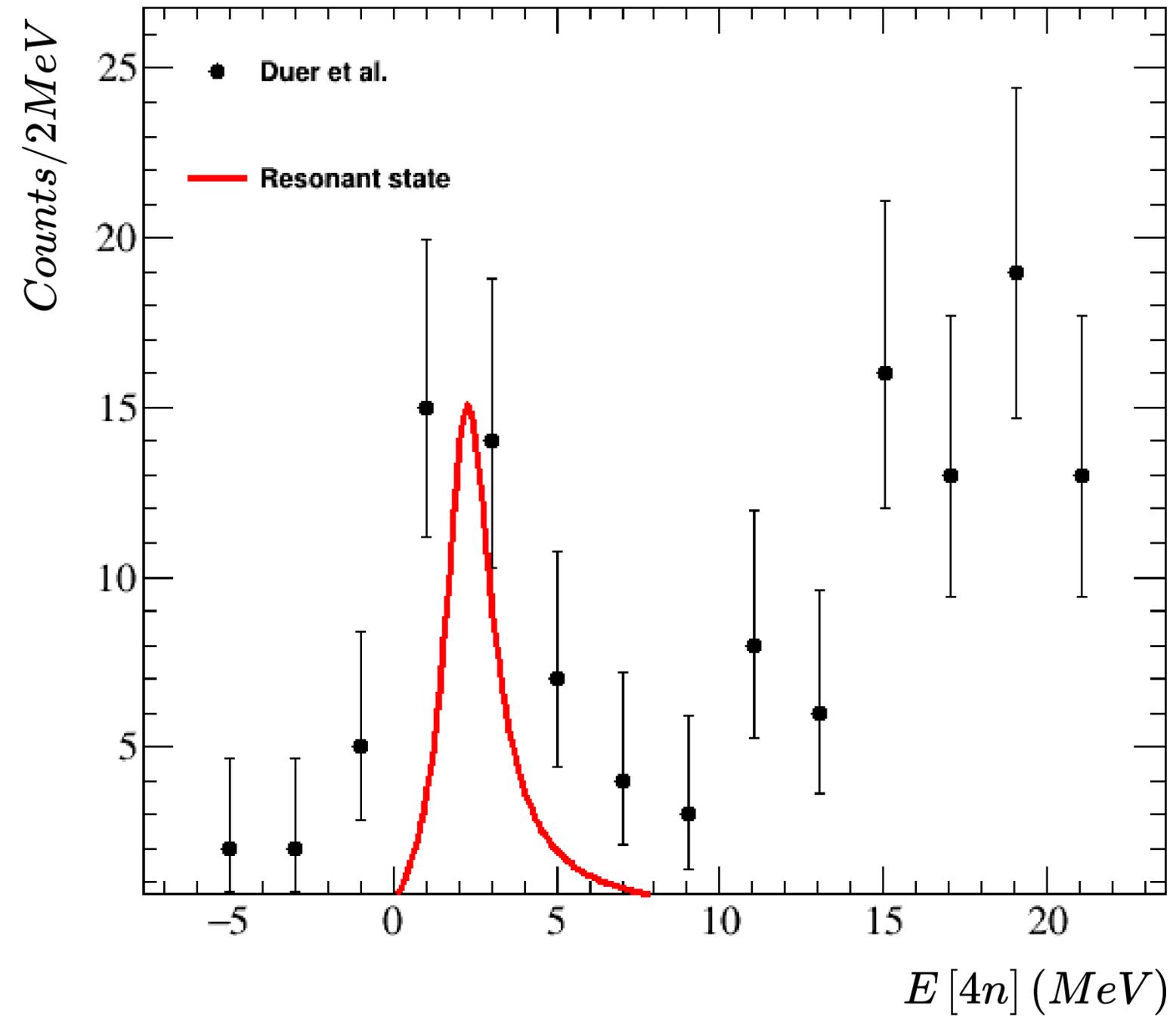
Neutron correlations

R. Lazauskas, private communication

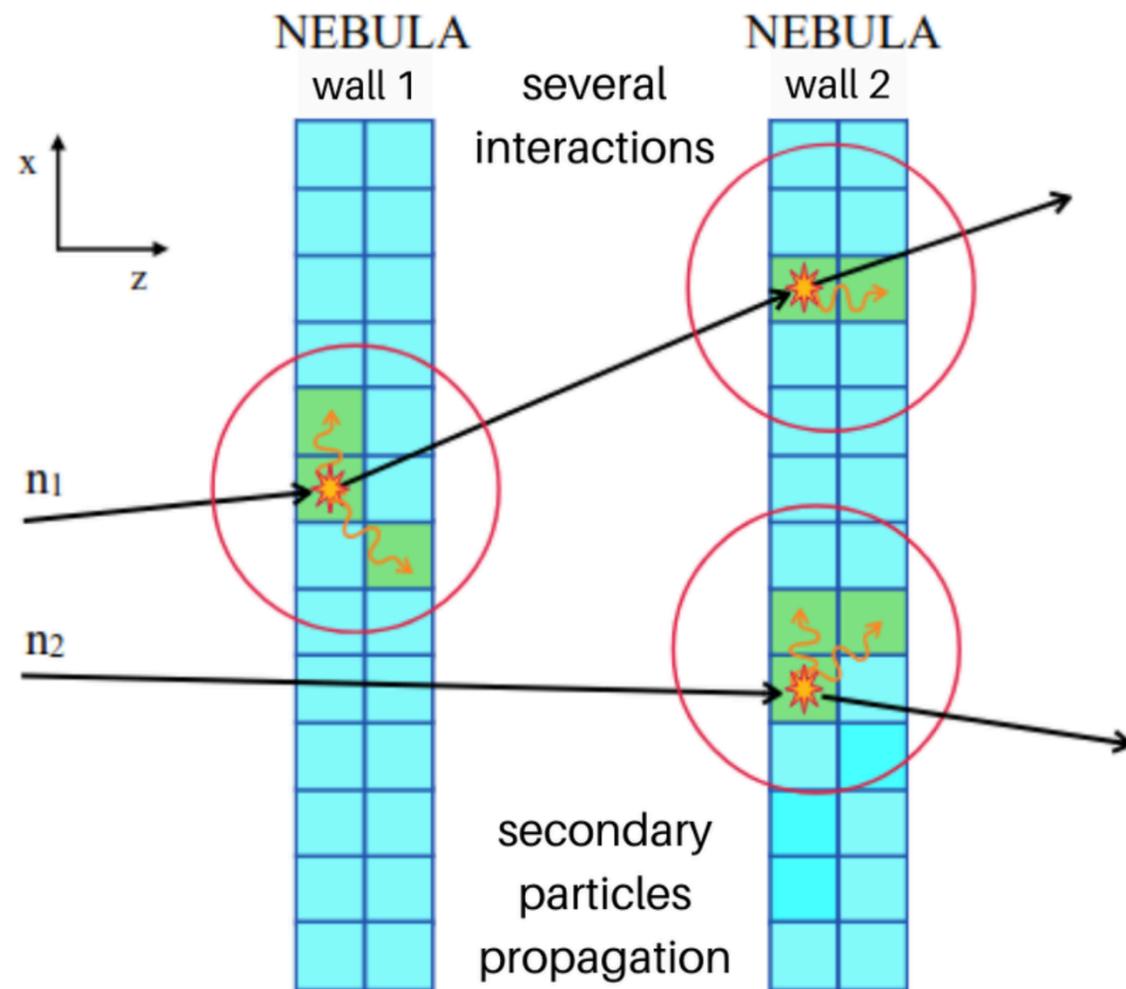# Neutron detection efficiency

Duer's resonance

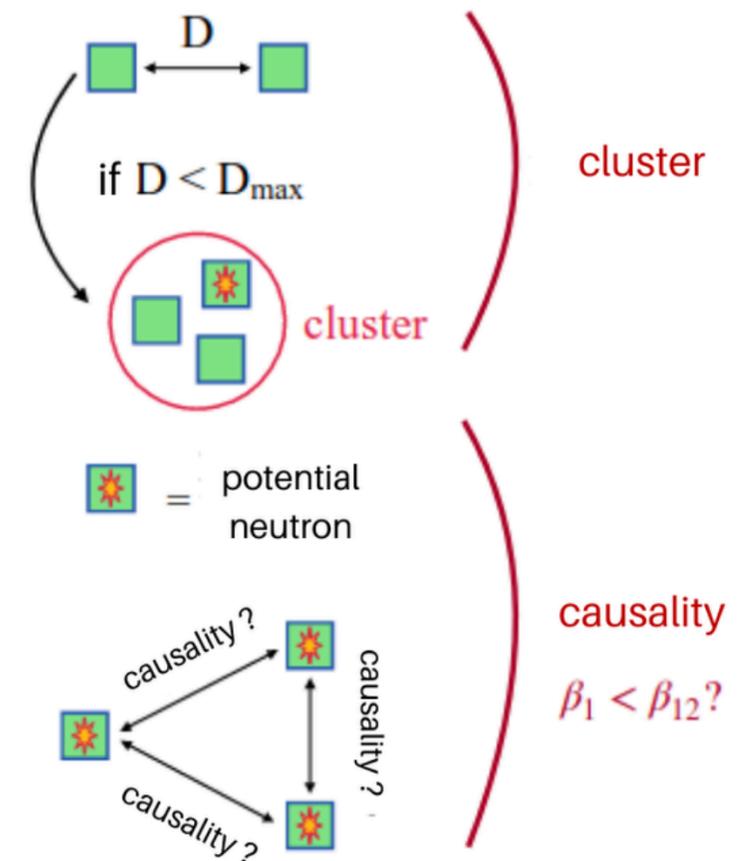$E_r = 2.37 MeV$

$\Gamma = 1.75 MeV$

Crosstalk

Interactions leading to scattered neutron signals:
- Single neutron with multiple detectors
- Recoil particle in several detector bars

Crosstalk filter
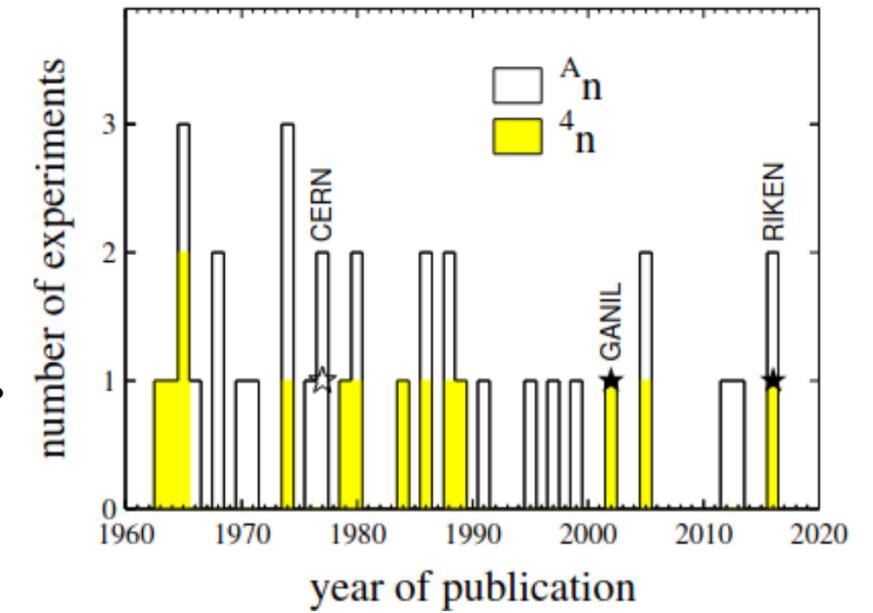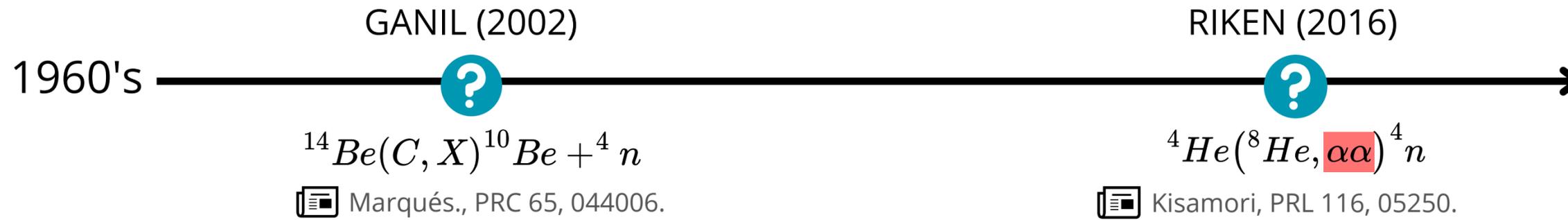- remove false neutron signals
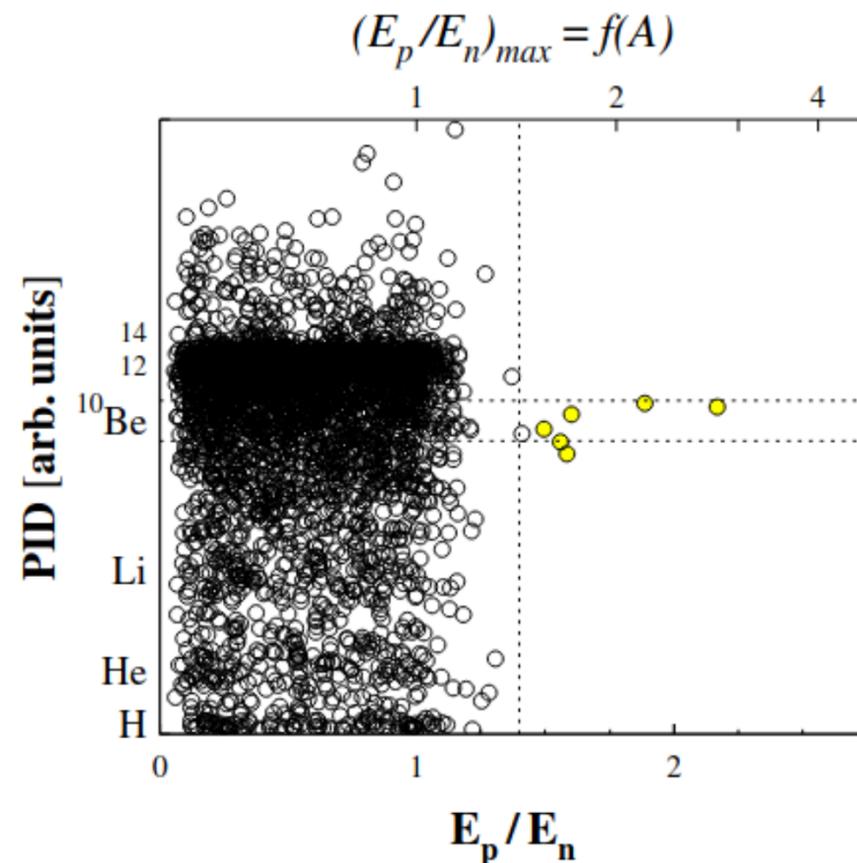- can also remove true events
  → must be optimised

C. Lenain, Ph.D. Thesis, 2021

Neutron detected with a velocity β_1
β_{12} velocity needed to travel the distance between this signal and another one

Tetraneutron positive signals

1960's

GANIL (2002)

$^{14}Be(C,X)^{10}Be + {}^4n$

Marqués., PRC 65, 044006.

RIKEN (2016)

$^4He\left({}^8He, \boxed{\alpha\alpha}\right)^4n$

Kisamori, PRL 116, 05250.

FMM/Carbonell, EPJA 57 (2021) 105

$(E_p/E_n)_{max} = f(A)$

Low-energy tetraneutron
resonance (E < 2 MeV)

Consistent with a tetraneutron resonance
E(4n) = 0.8 ± 1.3 MeV
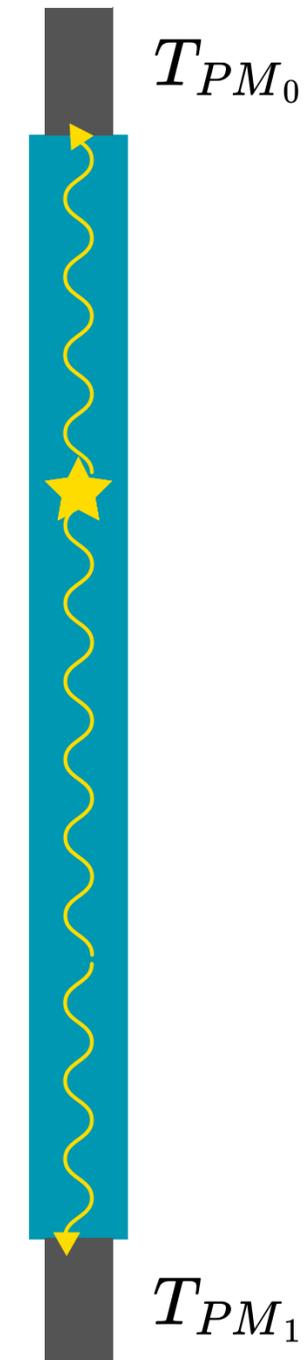Γ < 2.6 MeV

Neutron time and position reconstruction

Time:

$$T = \frac{T_{PM_0} + T_{PM_1}}{2}$$

Position:

Example for NEBULA

- X and Z given by detector geometry

- $Y = (T_{PM_0} - T_{PM_1}) \times v_{scint_{eff}}$

T_{PM_0}

T_{PM_1}

Fragment trajectory in SAMURAI magnet

$$B\rho = \frac{vm}{q} \quad \propto \frac{A}{Z}$$
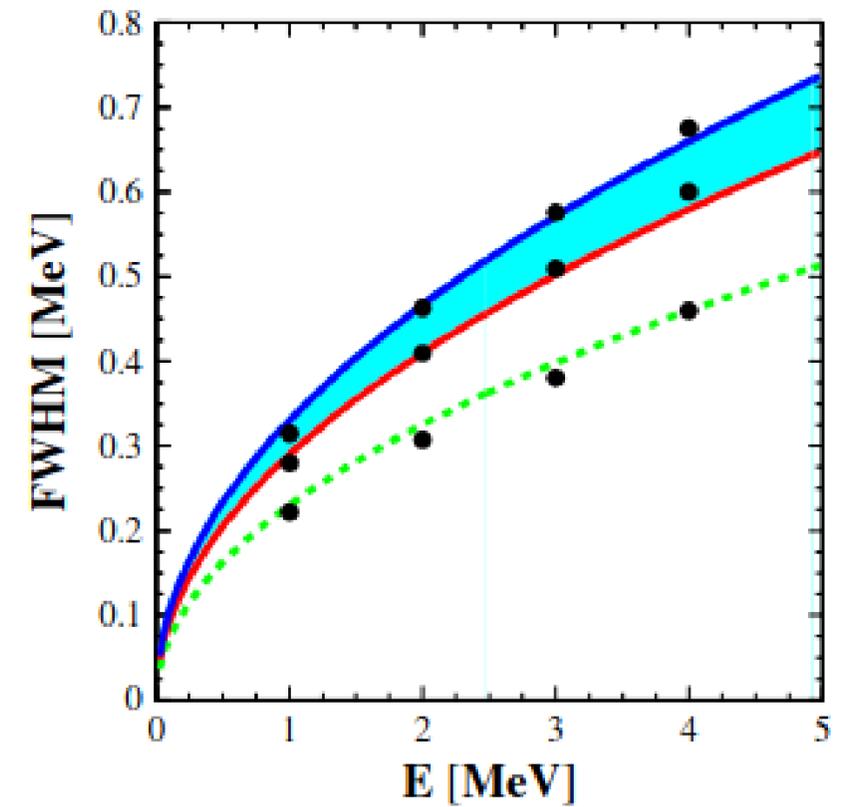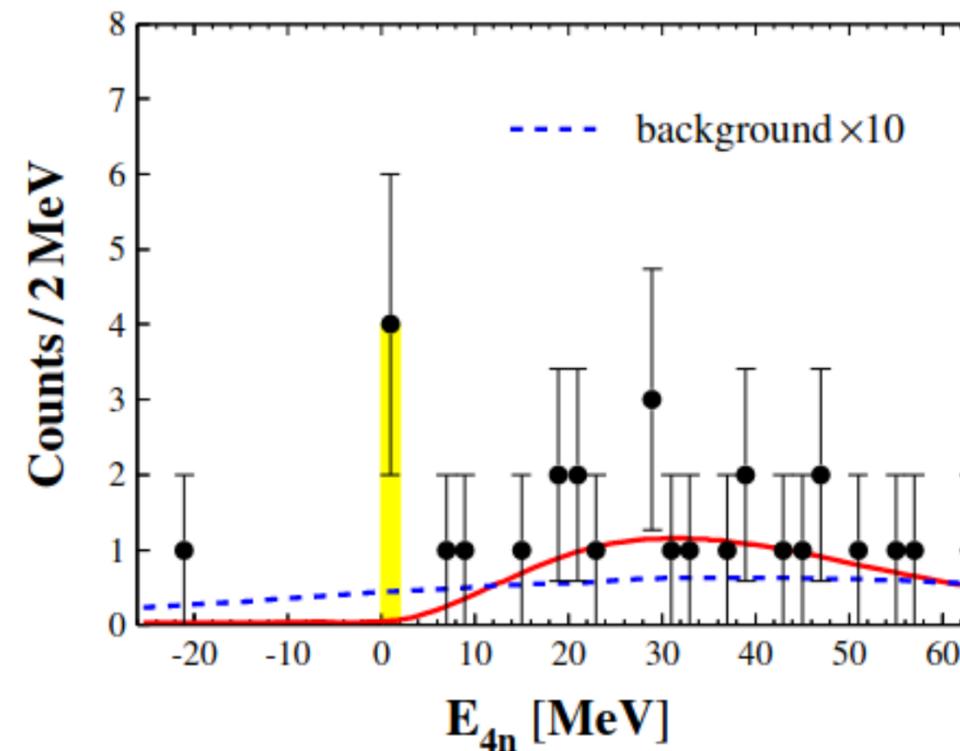
Fourth order Runge-Kutta technique
for trajectory reconstruction
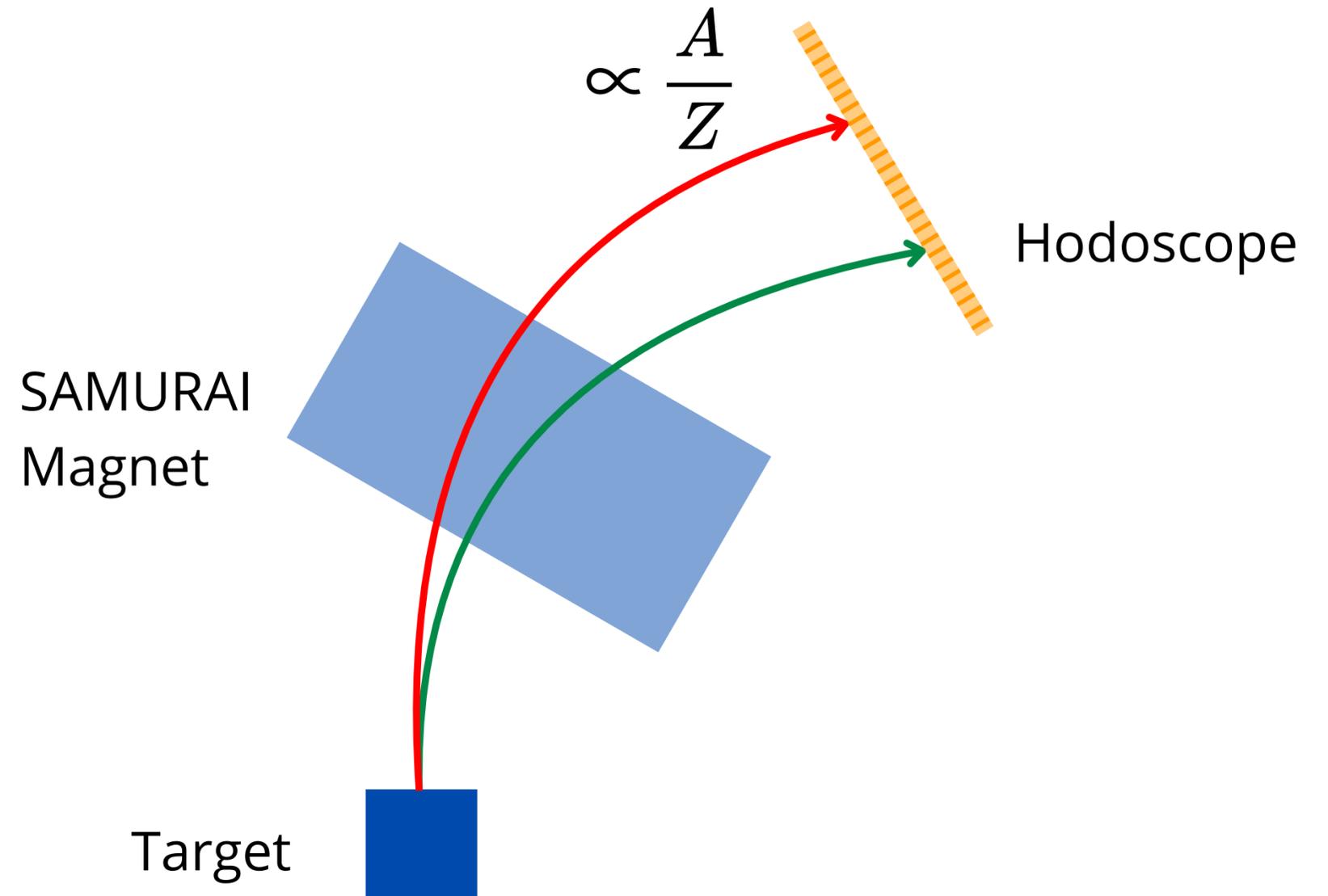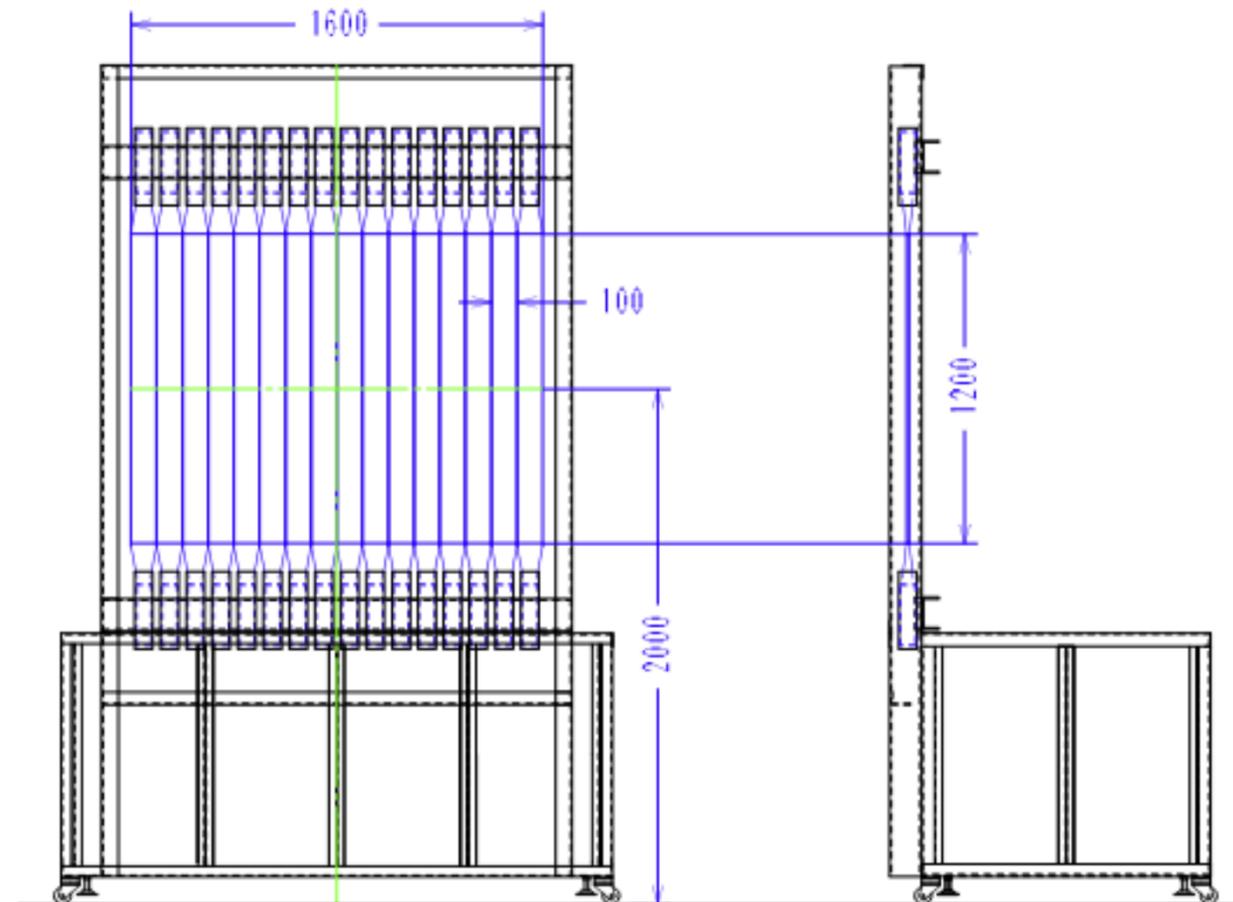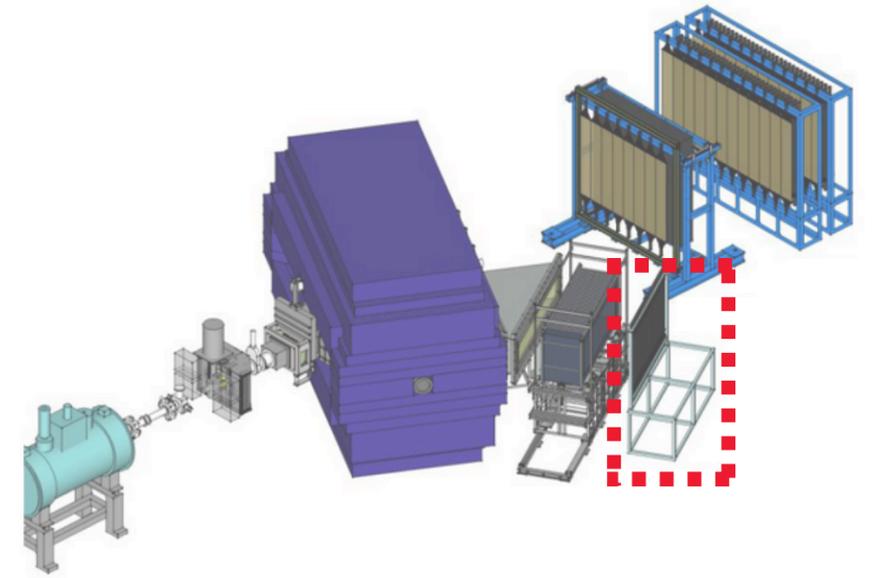
Hodoscopes

Plastic scintillators (BC408)

HODF

$24 \times [120{\times}10{\times}1\,\text{cm}]$

HODP

$14 \times [120{\times}10{\times}1\,\text{cm}]$

+ 2 bars to fill the gap between the 2 hodoscopes

Kobayashi, NIM-b, 317, 294-304

Beam

Secondary beam 8He:

- 156 MeV/nucleon

- 95k particules/second

- purity ≃ 98%

Charge F13 (ua) vs Time of flight F7-F13 (ns)