Measurement of the $^{12}C(p,\gamma)^{13}N$ S-factor in inverse kinematics

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Partner von DRESDEN concept exzellenz-dresden.de

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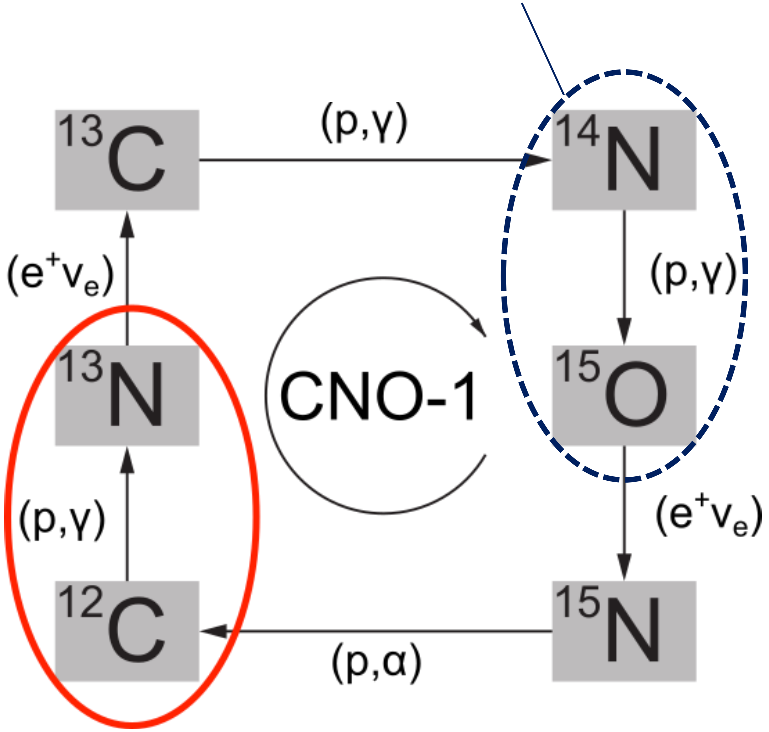
Motivation

- Part of an effort to restudy the CNO cycle
- $^{12}C(p,\gamma)^{13}N$ dominates CNO rate in early developement phase of stars and in outer parts of solar core
- Responsible for ^{13}C production in red giant stars
- Radial emission profile of solar neutrinos from β^+-decay depends on $^{12}C(p,\gamma)^{13}N$ rate

Wagner+, Phys. Rev. C 97, 015801 (2018)



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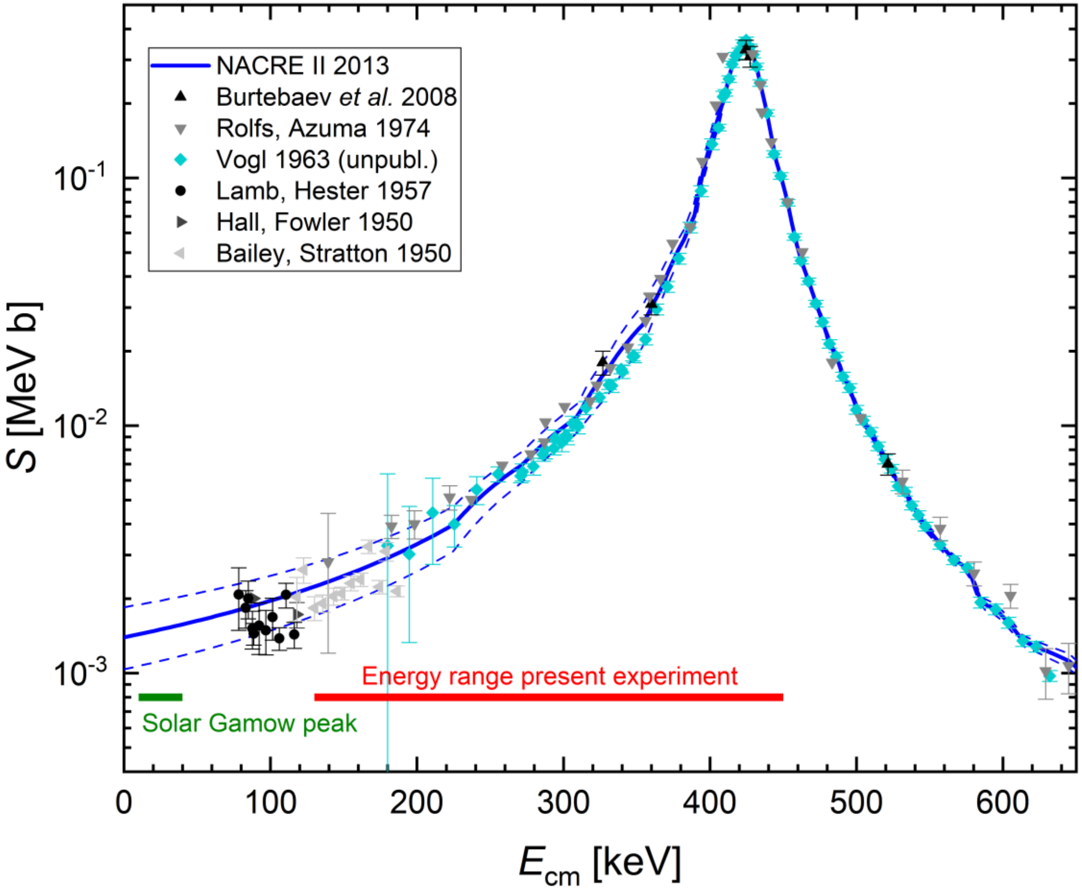
State of the art



Aim of this work

- Measurement in wide energy range between 130 and 450 keV
- Improve data in low energy region
- Use of inverse kinematics (no previous data with this method)
  - Different systematics
  - Lower beam induced background
- Low natural background due to thick lead shielding and active muon veto

Astrophysical *S* factor: $\sigma(E) = S(E)\frac{1}{E}e^{-2\pi\eta}$

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Setup

Accelerator and ion beam

- Rossendorf 3 MV Tandetron accelerator
- $^{12}C^{2+}$ beam on target: 5 – 20 µA

Targets

- TiH_2 targets with Ta backing
  - 3 hydrated, 200 nm TiH_2
  - 2 hydrated, 100 nm TiH_2
  - 1 H-implanted, 100 nm TiH_2
- Mounted with 55° angle towards beam axis

Detector and shielding

- HPGe detector with 90% relative efficiency at 55°
- 12 cm thick lead castle
- 5 cm thick scintillators for active muon veto

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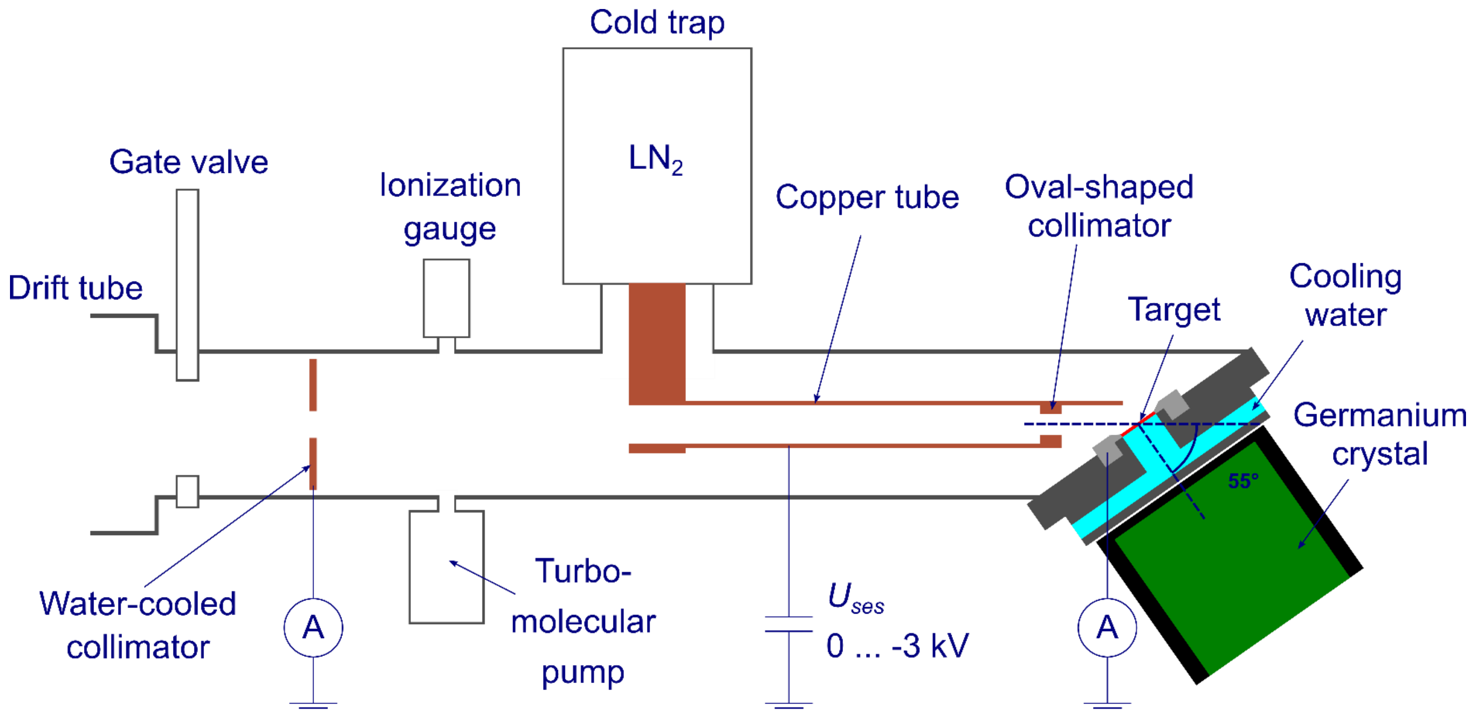
Setup (continued)

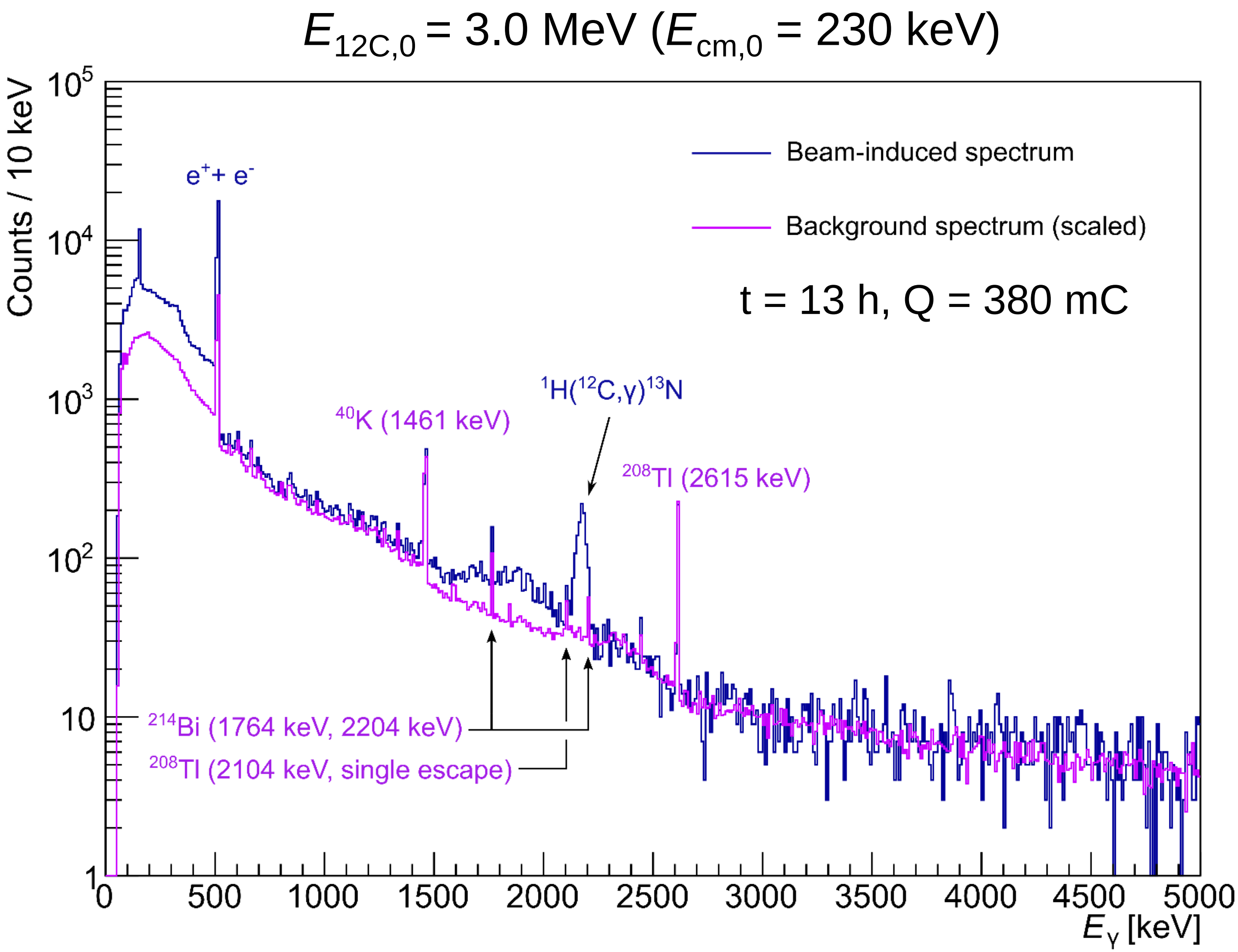
Target chamber and detector



Data aquisition

- Analog chain
  - ORTEC 671, ORTEC 919E (MAESTRO, histogramming)
- Digital chain
  - CAEN N1728b 100 Ms/s digitizer (TNT2, list mode data)

Gamma-ray spectra



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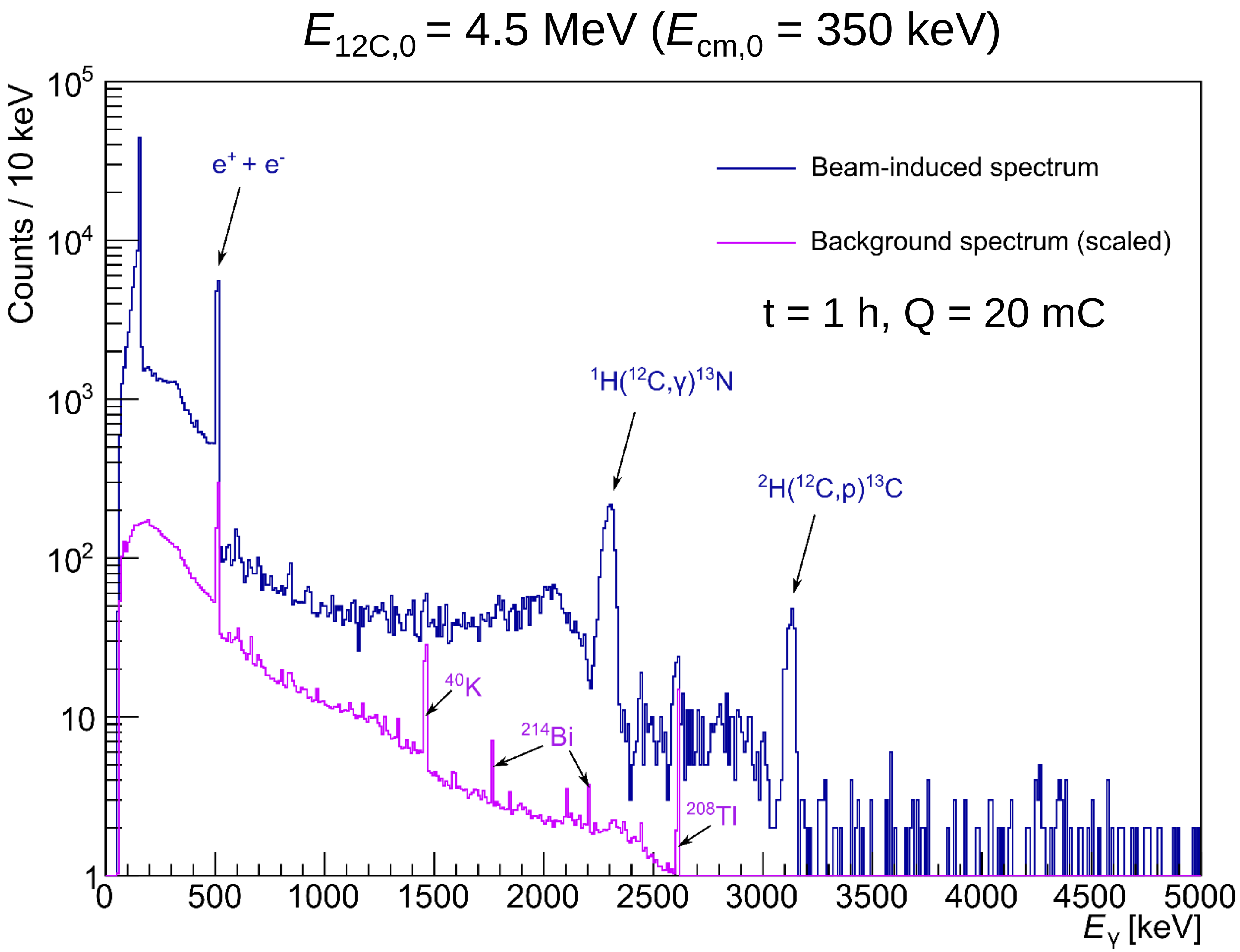

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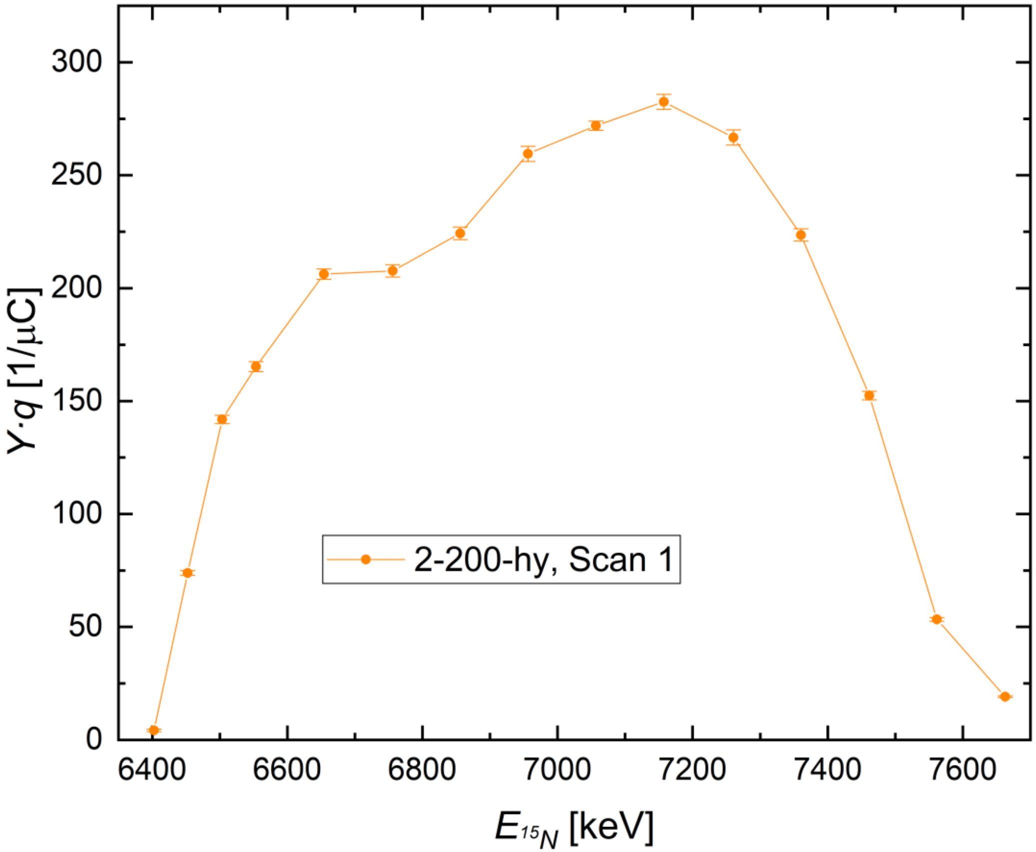
Nuclear Resonant Reaction Analysis (NRRA)



Target #2, 200 nm, hydrated

Target scans

- Use of $^{1}H(^{15}N,\alpha\gamma)^{12}C$ reaction
  - Yield of E_γ = 4439 keV
  - E_{15N} = 6.4 MeV narrow resonance

Reinhardt+, Nucl. Inst. Meth. B 381, 58-66 (2016)

- Measured each day and after switching the target
- Changed target after significant decrease of hydrogen content
  - After 2-3 days for 200 nm targets
  - After 1 day for 100 nm targets

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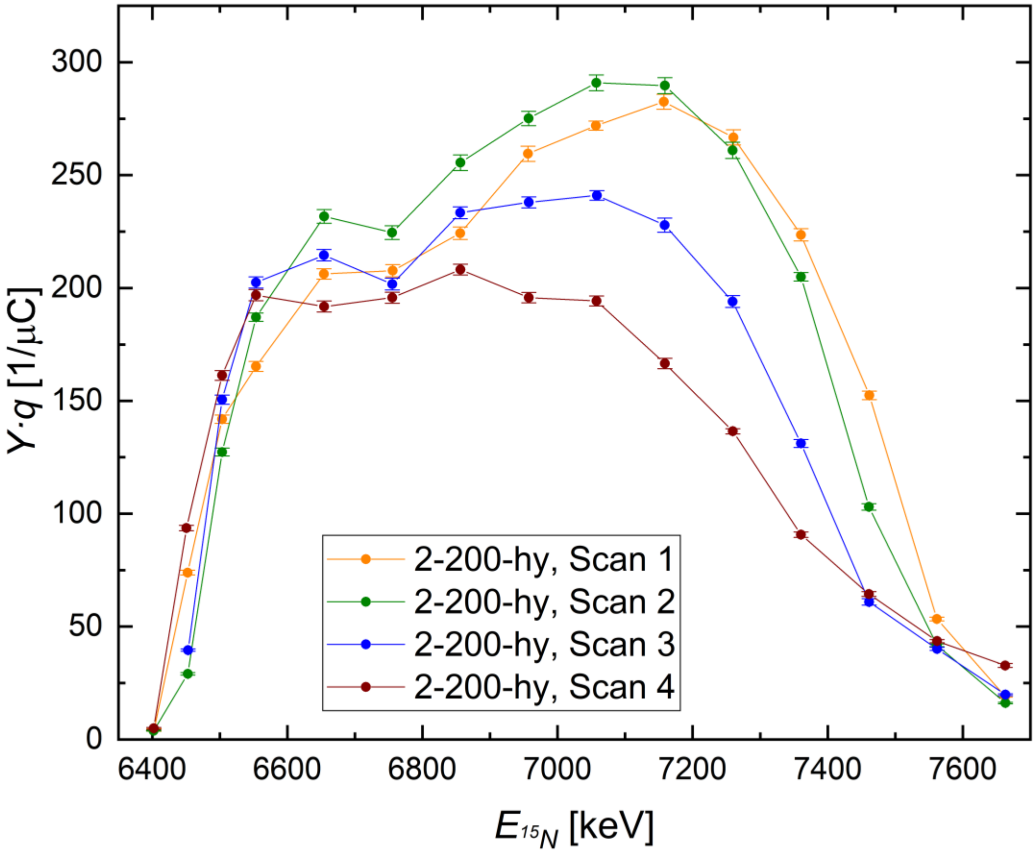

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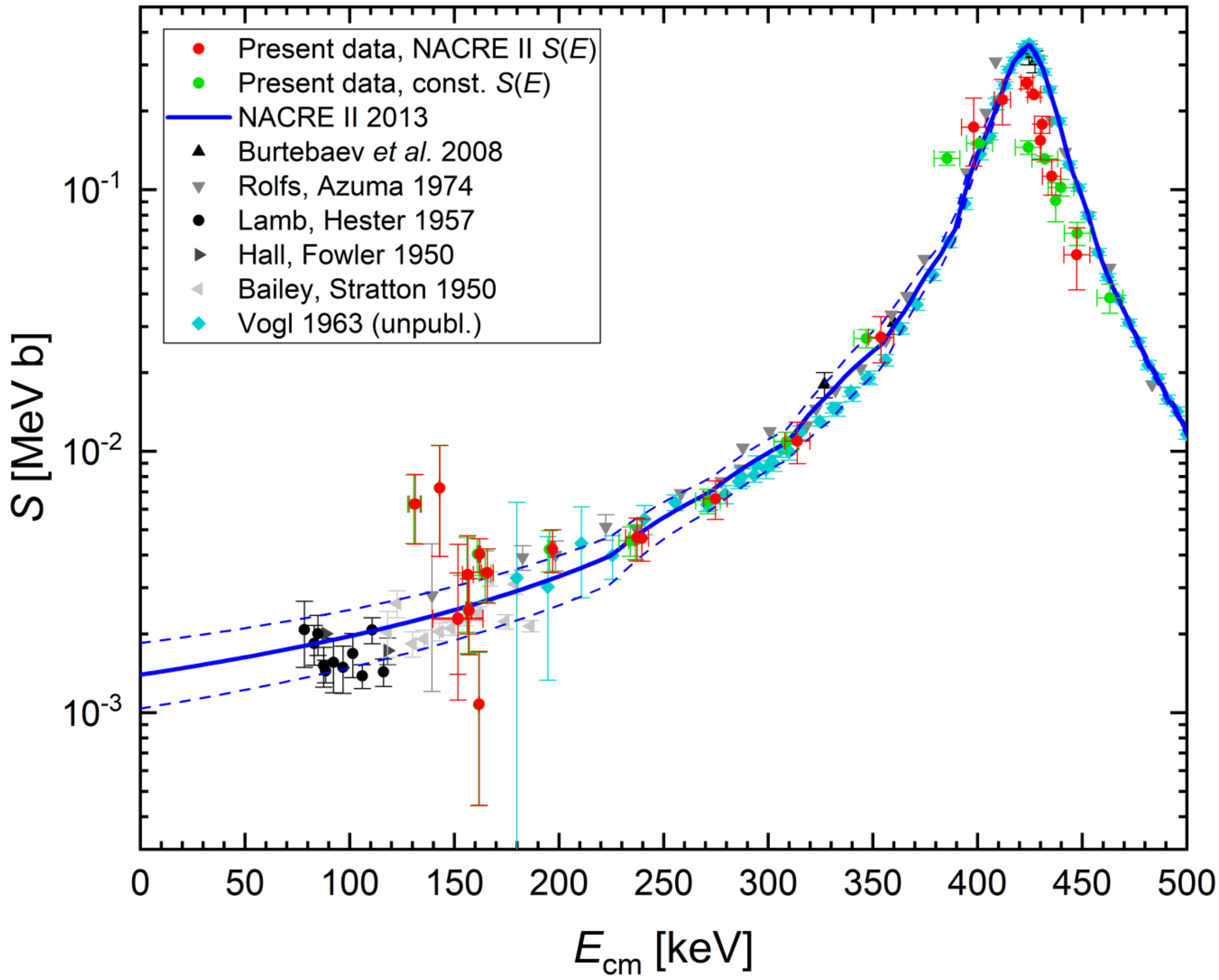
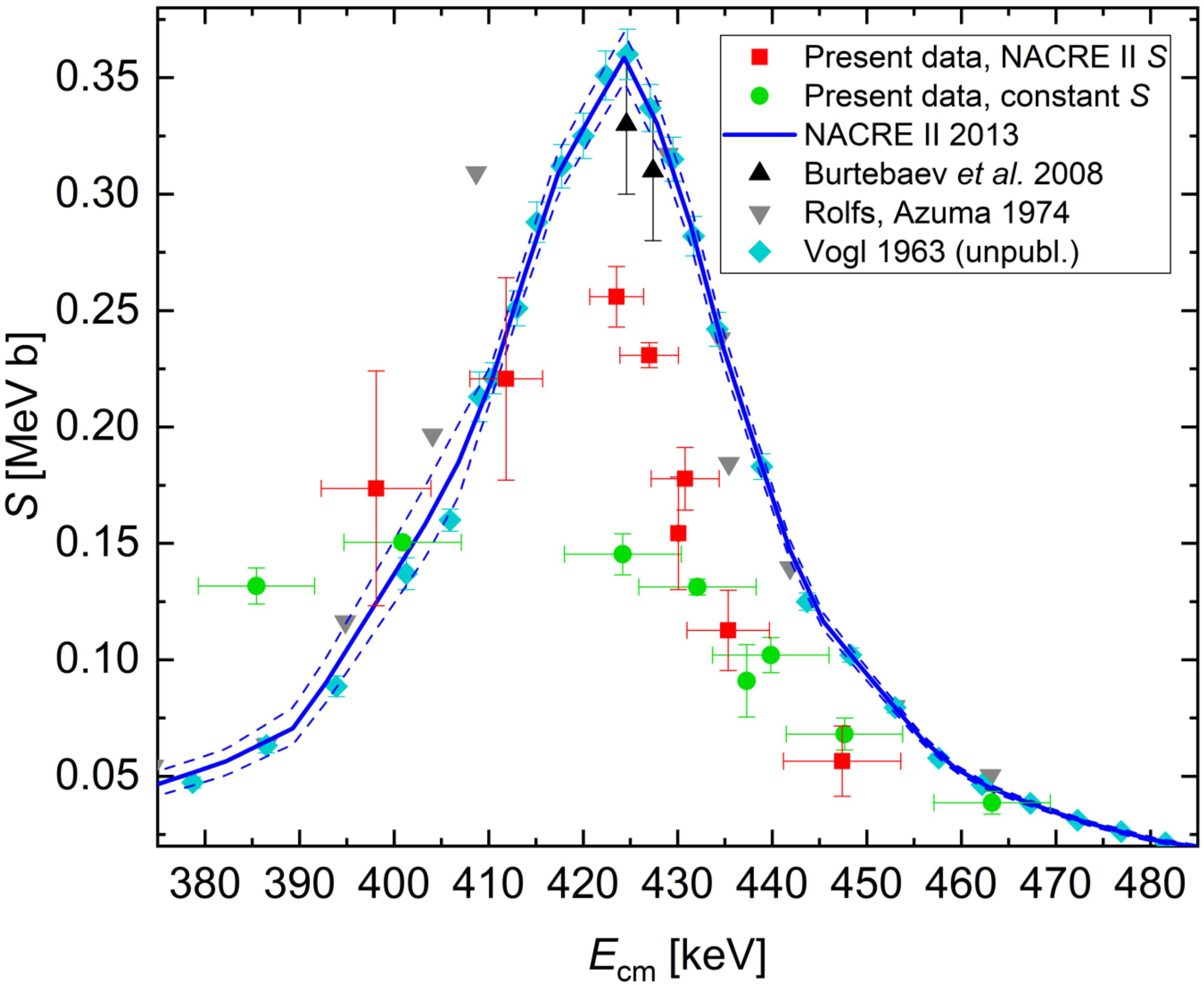
Assumed energy dependence of S



Assumed energy dependence of S (continued)



Resonance energy?

ENSDF

E_x = (2364.9 ± 0.6) keV

Width: 31.7 keV

	E_R [keV]
Fowler+ (1949)	420.7 ± 1.8
Hunt+ (1953)	421.4 ± 0.5
Vogl (1963)	424.9
Rolfs+ (1974)	421.6 ± 0.9
Blatt+ (1974)	421.5
Hinds+ (1992)	423.2

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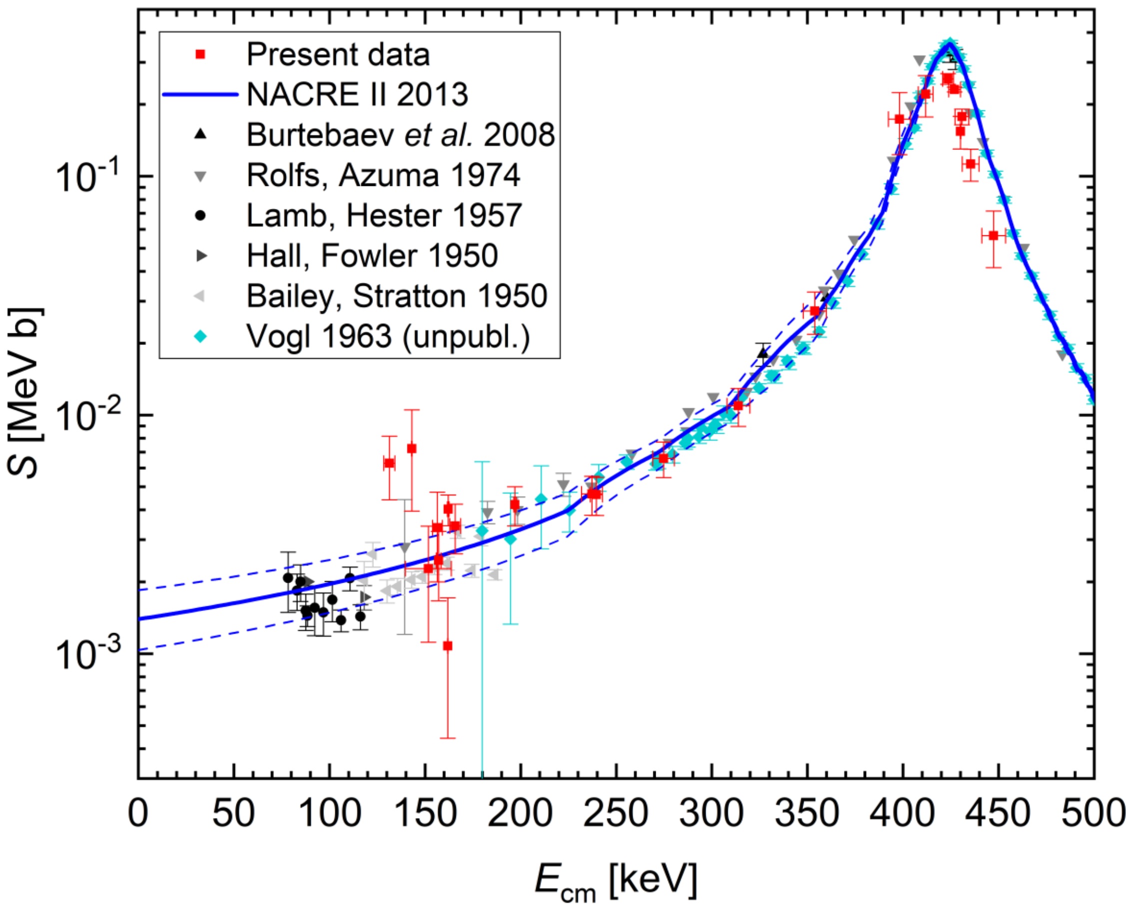
Conclusion



130 – 200 keV:

- Present data on average about 20 % higher than NACRE II (consistent within error bars)
- Lower limit given by cosmic ray induced BG

230 – 415 keV:

- Present data consistent with NACRE II fit

420 – 450 keV:

- Present data significantly lower

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Summary

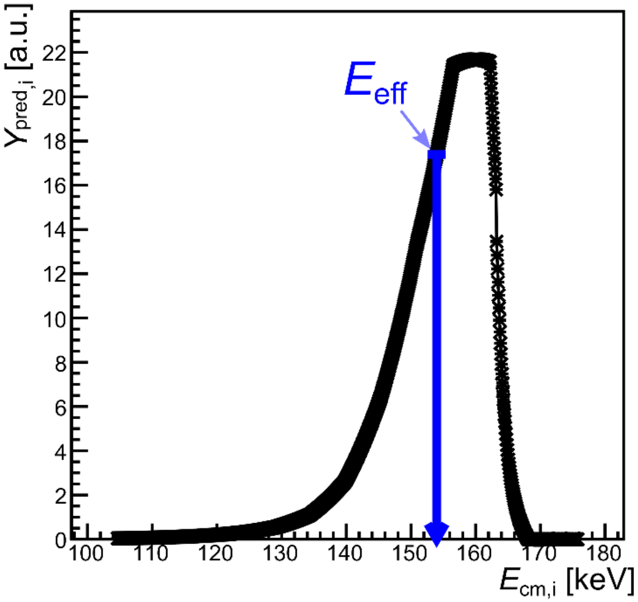
- Measurement of $^{12}C(p,\gamma)^{13}N$ S-Factor in inverse kinematics at E_{cm} = 130 – 450 keV
- New data in low energy region about 20% higher than NACRE II
- New data between 420 – 450 keV significantly below fit
  - Possible problem with resonance energy

Outlook

- Use of new data for extrapolation towards astrophysical energies
- Check resonance energy
- Extension towards lower energies
  - Use of underground accelerator to reduce laboratory background
    - LUNA Gran Sasso → direct kinematics
    - Felsenkeller Dresden → inverse kinematics

Backup

Determination of S factor



Predicted yield Y_{pred}

- Measured target profile divided into 1000 thin slices
- Calculation of energy $E_{cm,i}$ in each slice using stopping power from SRIM
- Assumed energy dependence $S_{pred}(E)$ from NACRE II curve

Effective Energy E_{eff}

- Mean value of the energy of each slice weighted with its yield contribution

$$S_{exp}(E_{eff}) = \frac{Y_{exp}}{Y_{pred}} S_{pred}(E_{eff})$$

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Determination of *S* factor (continued)

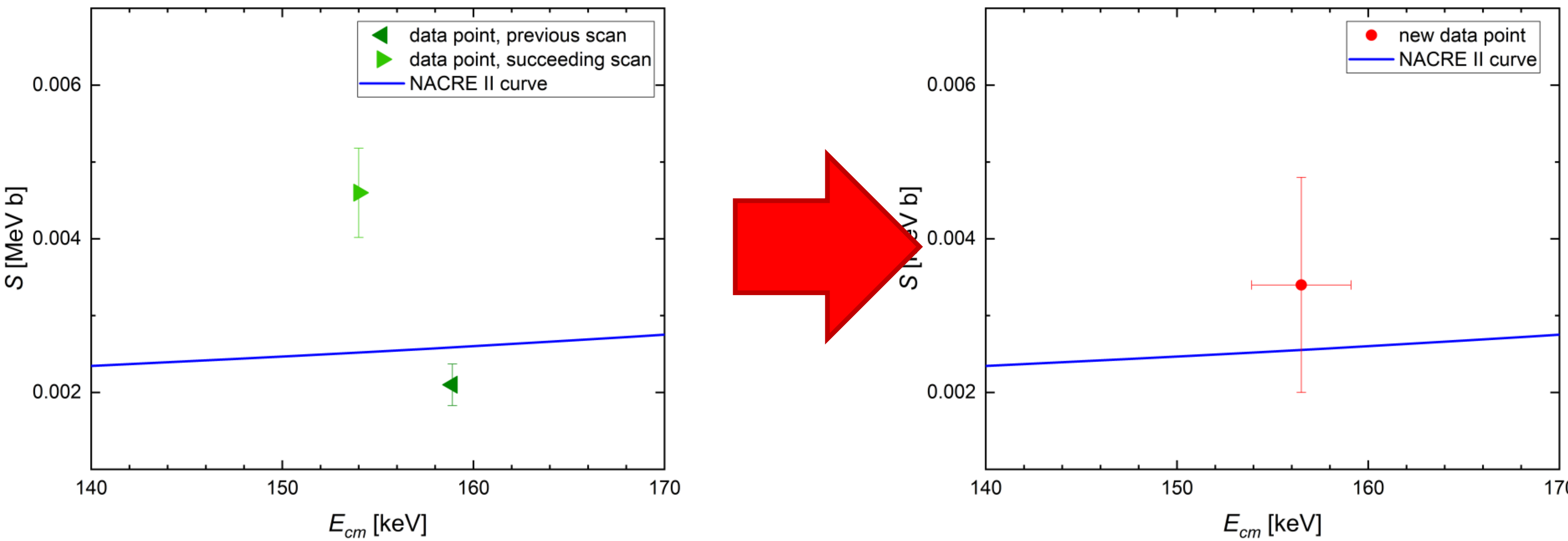
^{15}N beam scan

↓

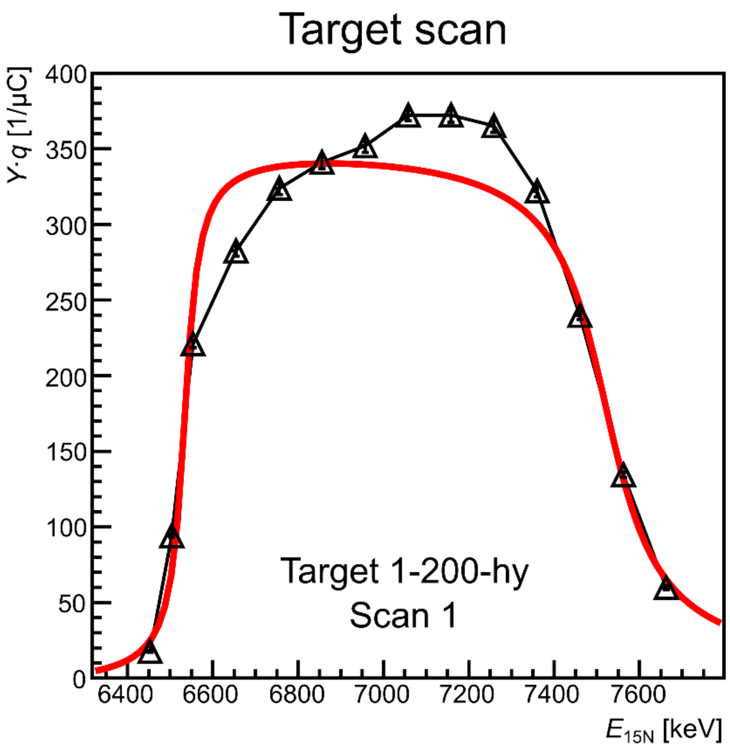
^{12}C beam run

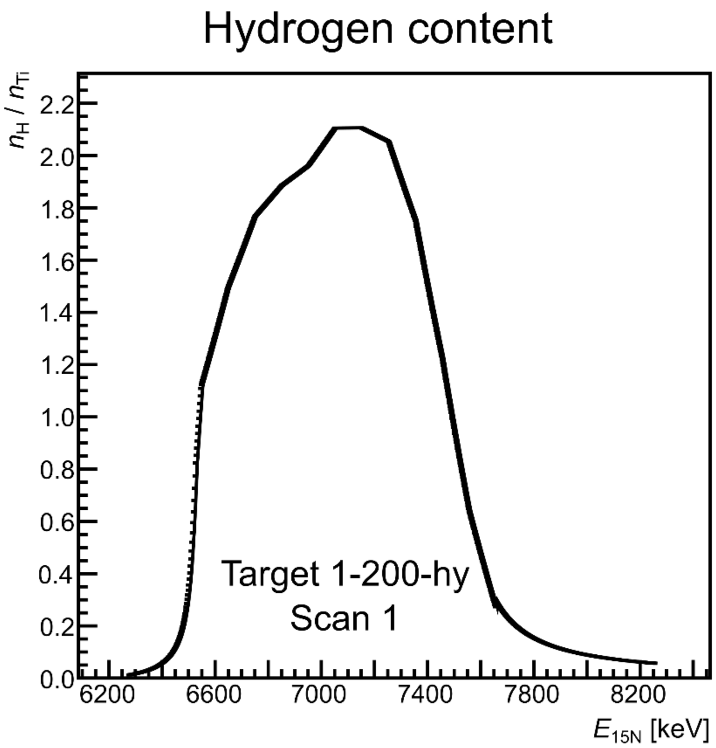
↓

^{15}N beam scan



Hydrogen content





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Uncertainties

S-Factor:

Quantity	Stat. uncert.	Sys. uncert.
Counts	1.0 – 54 %	
Change of H content	0.7 – 39 %	
Stopping (SRIM)		3 – 8 %
Fit of target scan		0.1 – 3 %
Efficiency		1.6 %
Charge		1 %
total	2.3 – 59 %	3.5 – 8.7 %

Effective energy:

Quantity	Stat. uncert.	Sys. uncert.
Change of H content	0.0 – 6.2 keV	
Accelerator voltage	0.1 keV	
Stopping (SRIM)		0.9 – 2.9 keV
Fit of target scan		0.1 – 1.3 keV
Energy calibration		0.2 keV
total	0.1 – 6.2 keV	0.9 – 3.2 keV