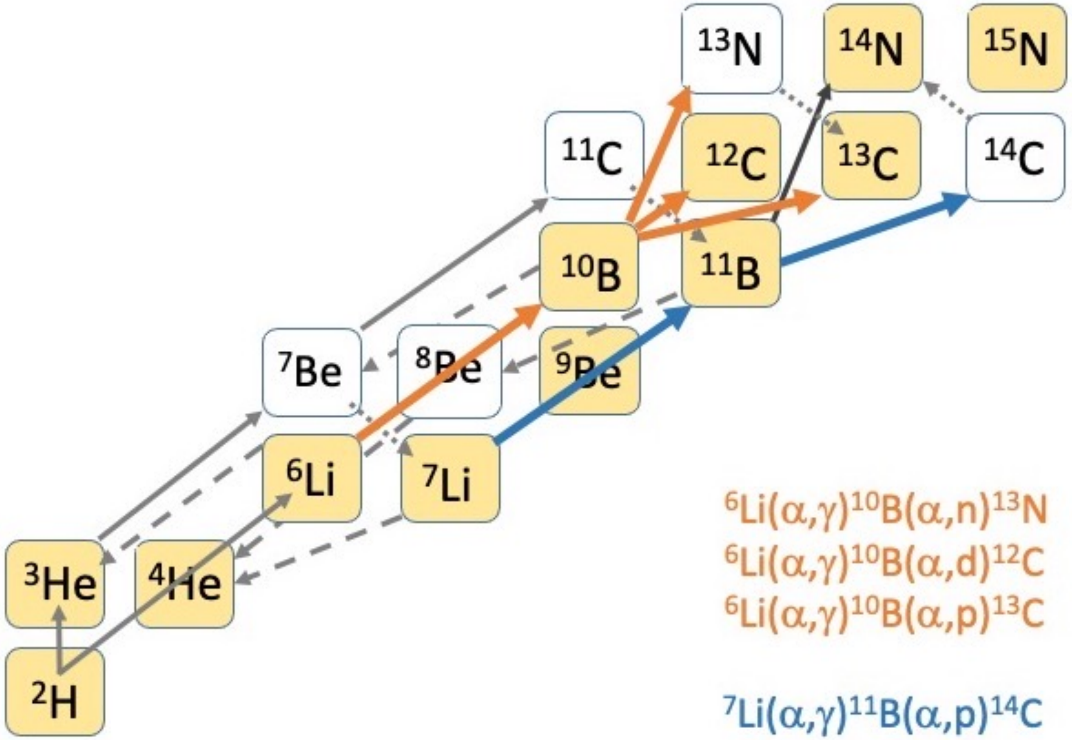
$^{10}B(\alpha,n)^{13}N$ Measurement plan

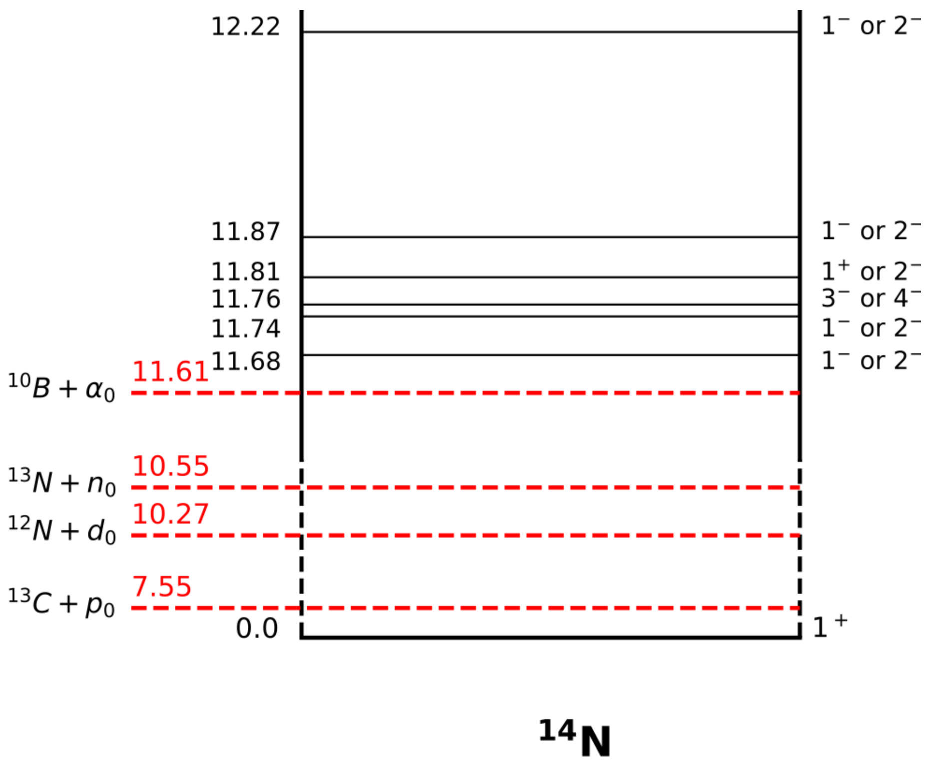
Astrophysical interest

- The 3α process is believed to be the primary link between p-p chain and the CNO cycle
- Alternative reactions such as $^{10}B(\alpha,n)^{13}N$ and $^{10}B(\alpha,d)^{12}C$ may bridge p-p chain to CNO cycle without the 3α process
- Further experimental measurements are needed on these reactions to understand potential paths



$^{10}B(\alpha,n)^{13}N$

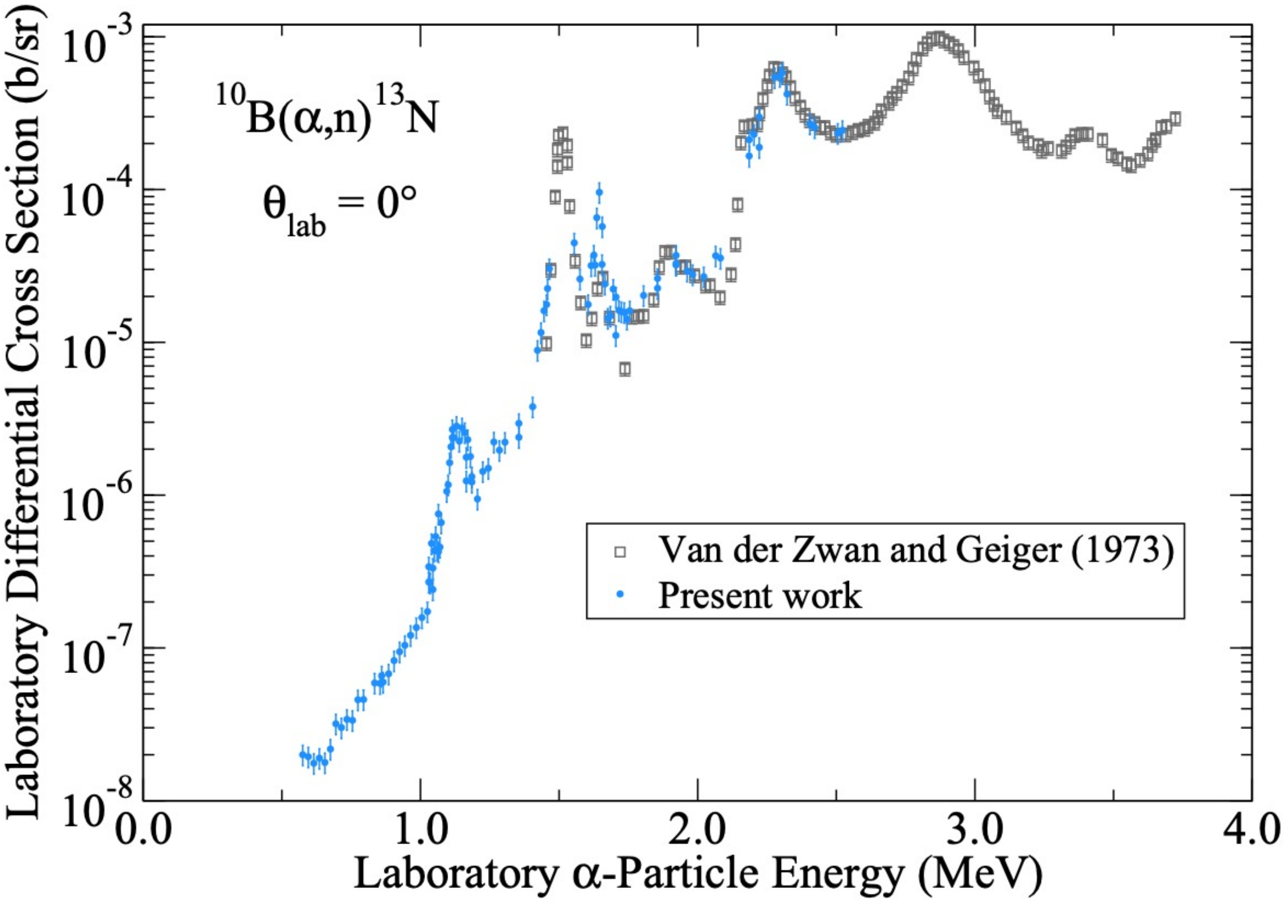
- Q-Value = 1058.7 keV
- $^{13}N \rightarrow {}^{13}C + \beta^+ + ...$
- $\beta^+ + e^- \rightarrow \gamma_{(511\ keV)} + \gamma_{(511\ keV)}$



Liu, Q.(2020). Low-energy cross-section measurement of the 10B(α,n)13N reaction and its impact on neutron production in first-generation stars. *Physical Review C, 101*(2), 025808. https://doi.org/10.1103/PhysRevC.101.025808

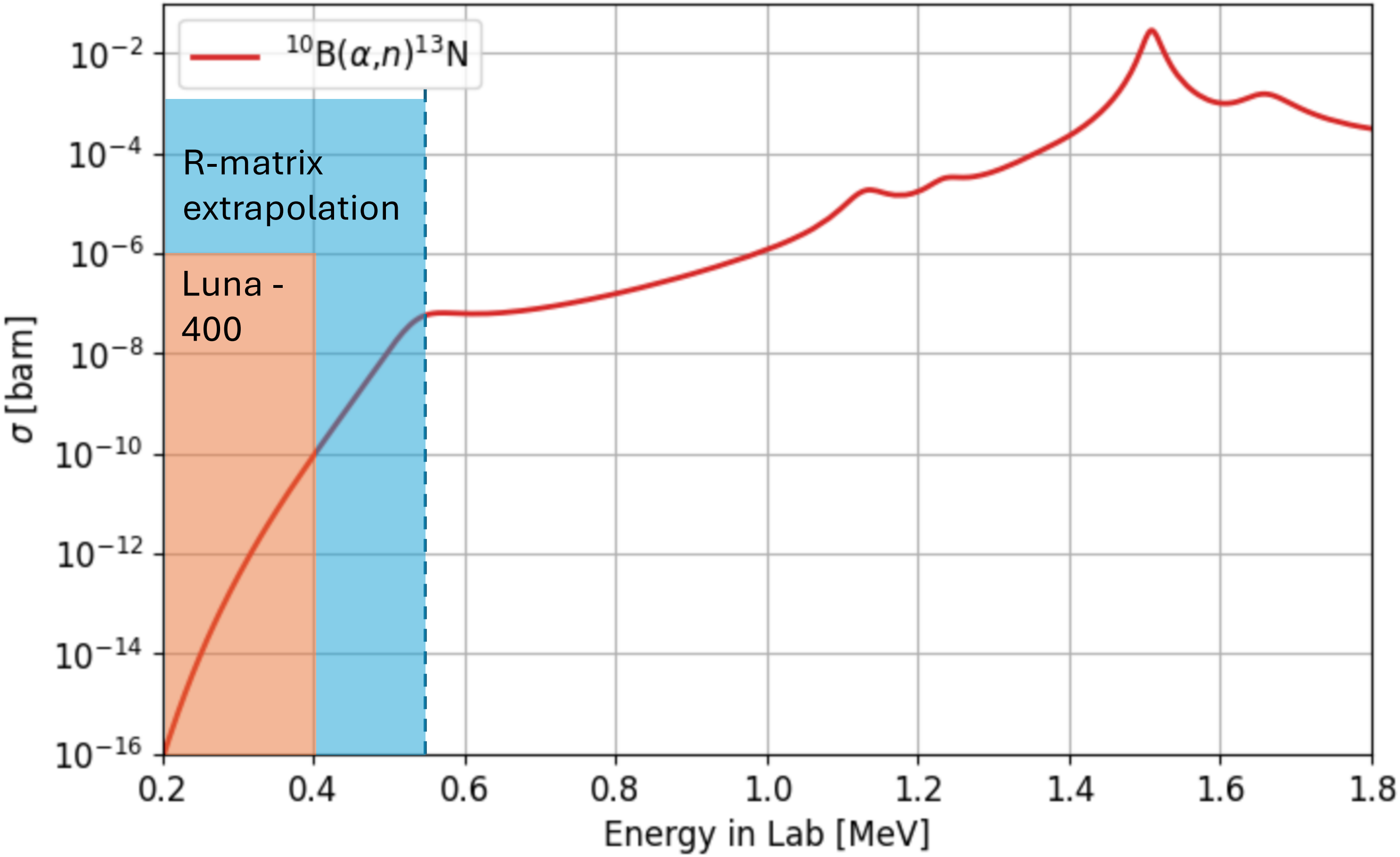
Previous Studies

- Measurements performed at Notre Dame
- Published 2020
- E_{α} = 575 – 2500 keV
- Neutron detection with EJ301D deuterated liquid scintillator at $E_{lab} = 0°$
- First observation of high energy tail of low energy resonance

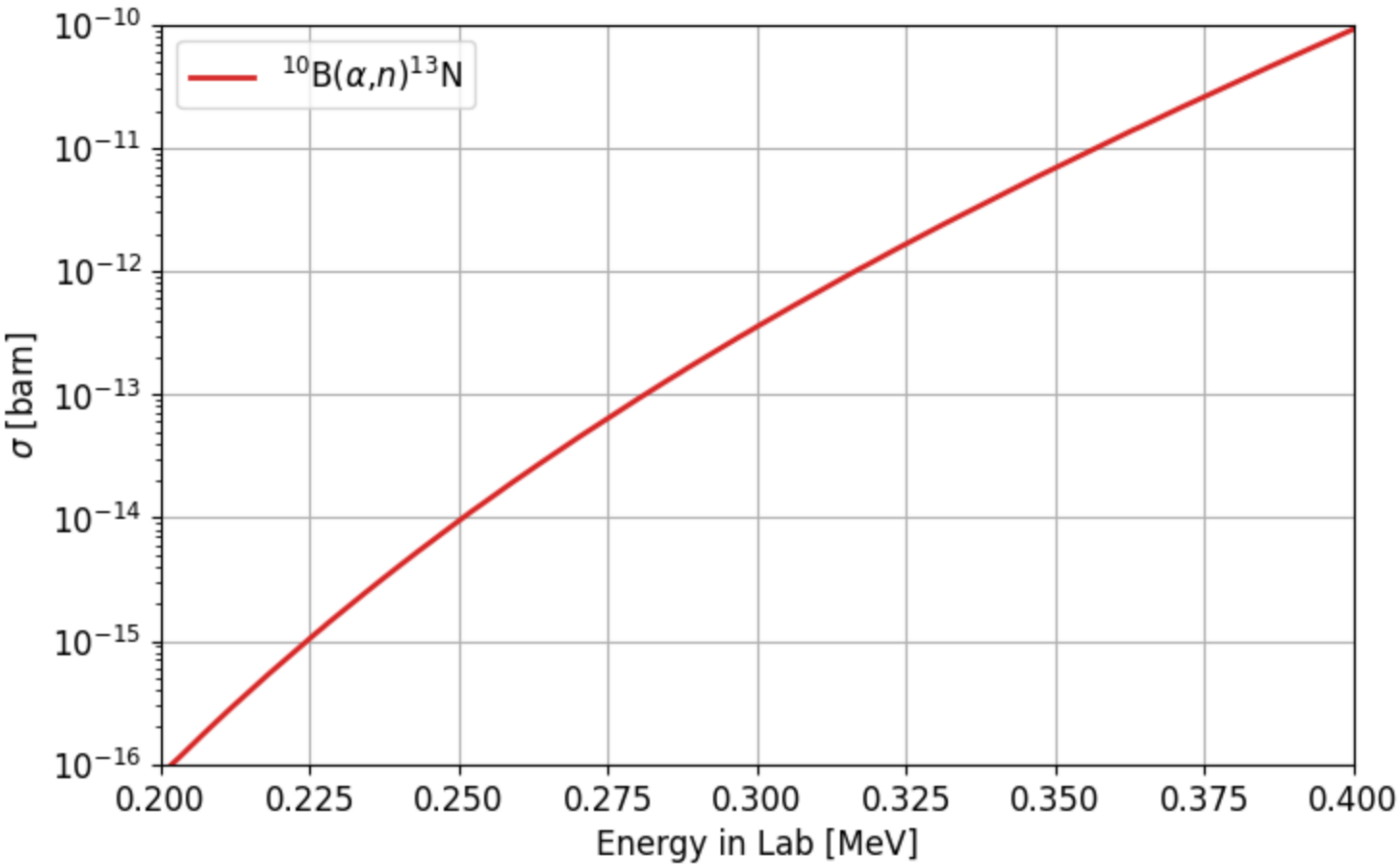


Liu, Q.(2020). Low-energy cross-section measurement of the 10B(α,n)13N reaction and its impact on neutron production in first-generation stars. *Physical Review C, 101*(2), 025808. https://doi.org/10.1103/PhysRevC.101.025808

Observing the low energy cross section



200 – 400 keV (R-Matrix)



Goals @ LUNA

- Measure cross sections at E_α < 400 keV
- Down to as low as feasible

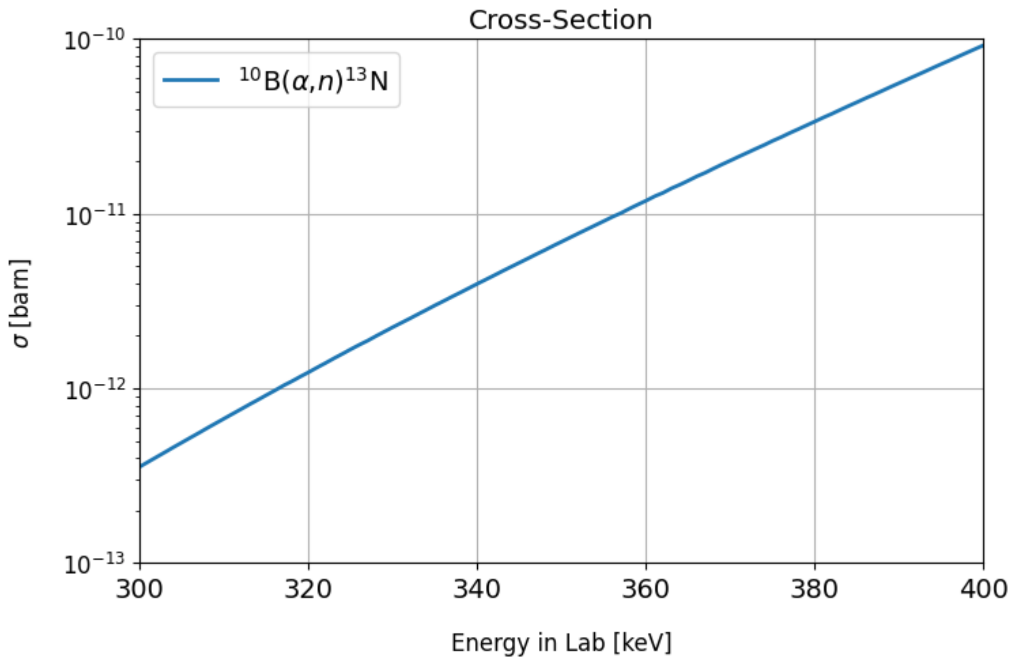
Collaboration LUNA – Notre Dame

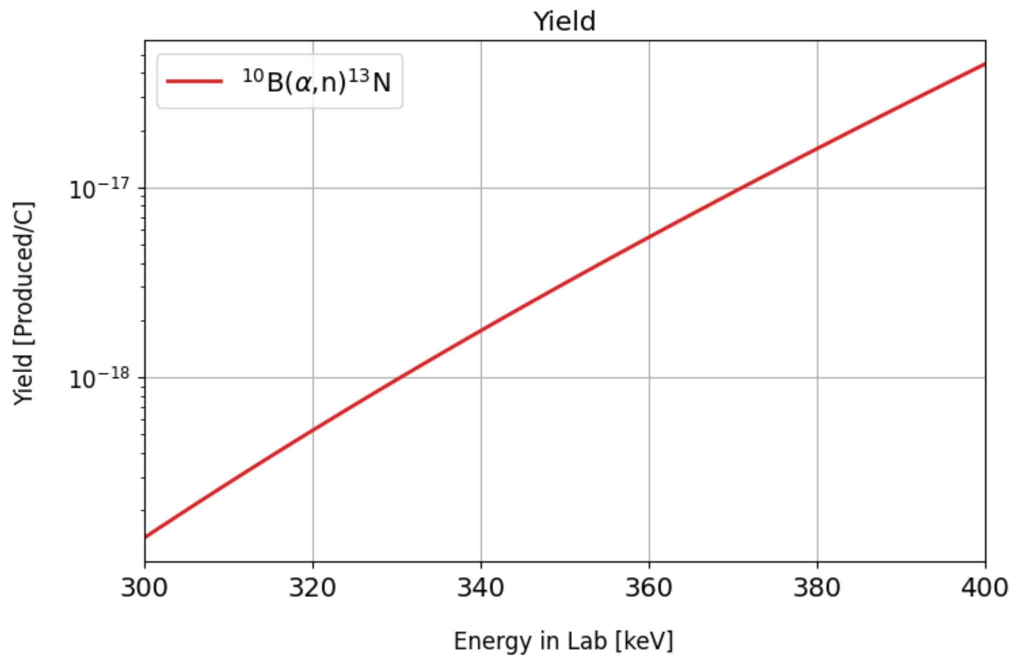
Reactions of interest for measurement

- The reaction of $^{10}B(\alpha,n)^{13}N$ is measured by direct neutron detection.
- ^{13}N decays via beta-plus decay (β^+) with $t_{1/2} \approx 10$ min, leading to annihilation with an electron and producing two 511 keV gamma rays in opposite directions.
- Thus, two measurement methods are used: direct neutron detection and coincidence detection of the 511 keV gamma rays.

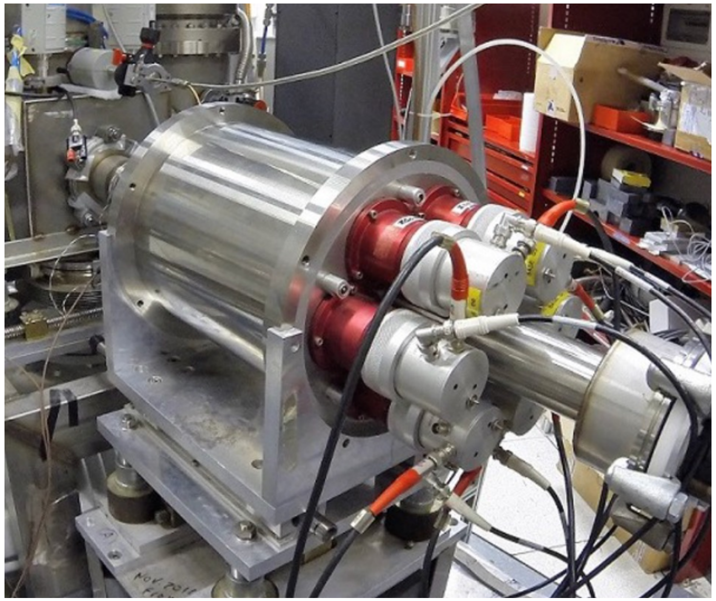
Neutron and annihilation yield

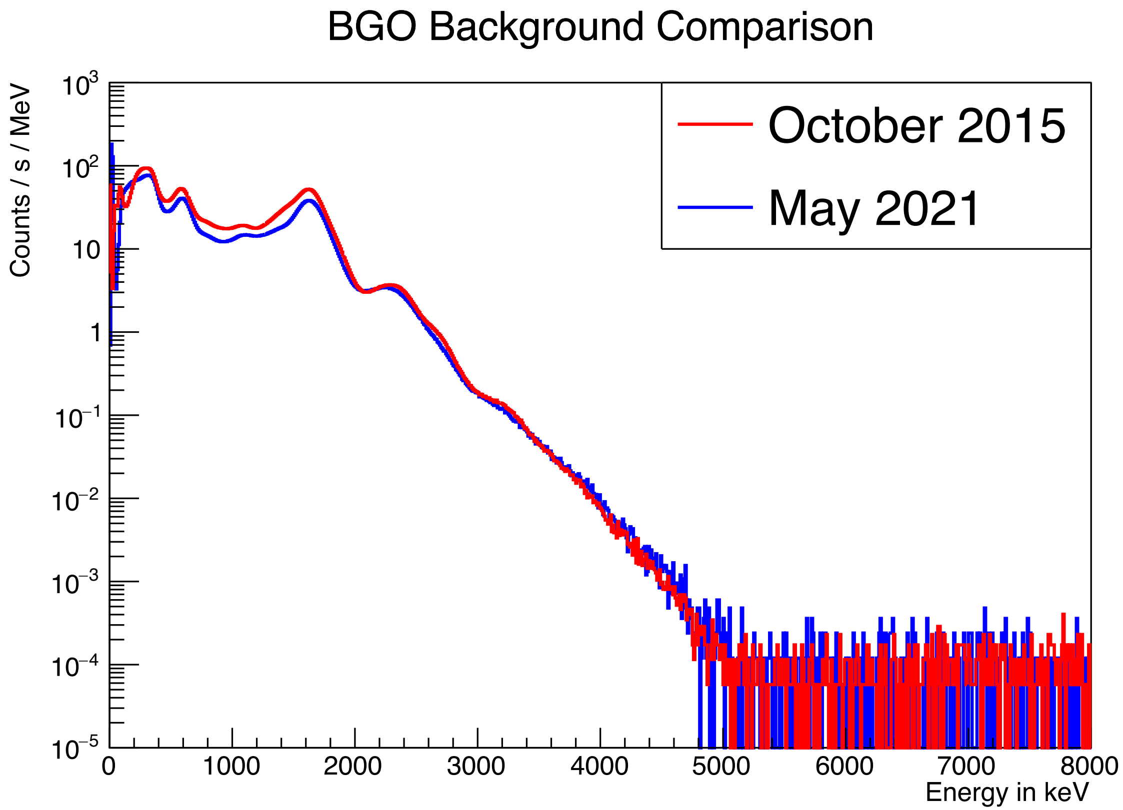
- Low cross-section of the $^{10}B(\alpha,n)^{13}N$ reaction
- Low yield from $^{10}B(\alpha,n)^{13}N$
- Low yield from $^{13}N \Rightarrow {}^{13}C + \beta^{+}$





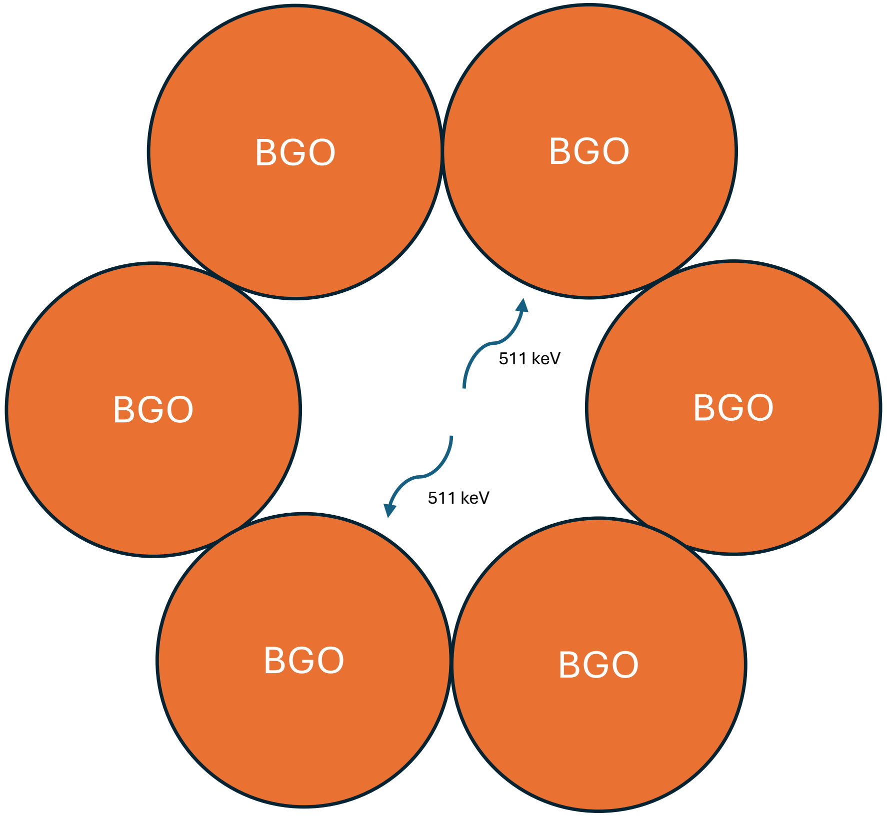
γ–γ Coincidence with the BGO



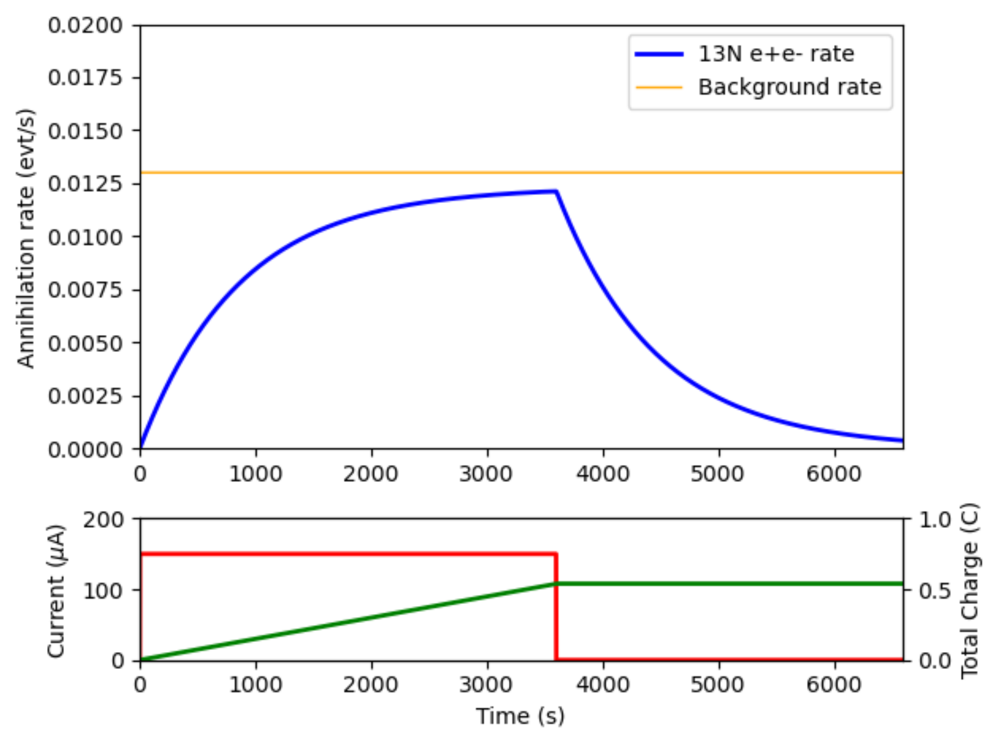


BGO

- $\approx 4\pi$ coverage
- 6 segmented crystals
- Coincidence efficiency $\approx$ 30%



Activation Measurement – Rate Estimates (BGO)



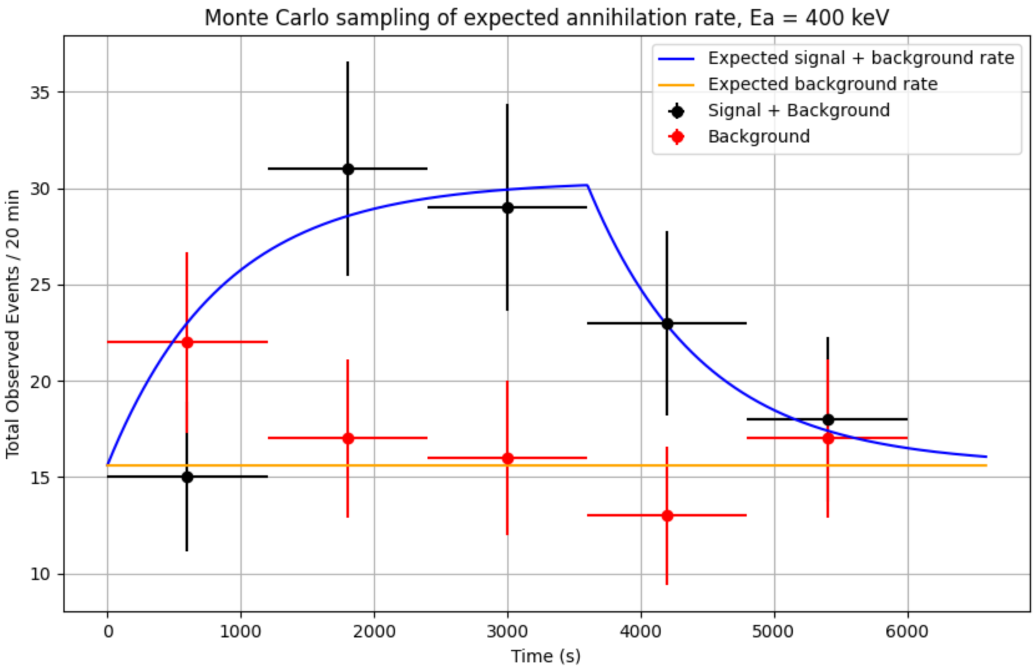
Beam Energy (keV)	Cycles	Coinc. / cycle	Targets	Days	Measurement uncertainty (%)
400	9	44.3	5	1.5	11
380	18	15.8	10	3	21
360	30	5.4	16	5	47

assumptions:

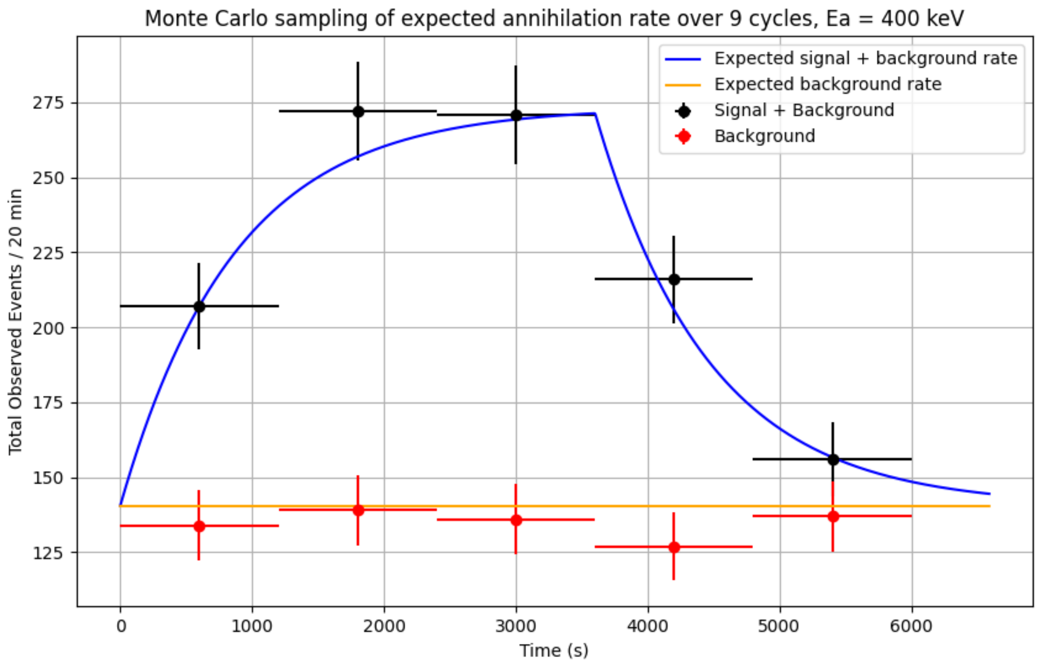
- Charge accumulated per target: 1 C
- Irradiation cycles per day: 6 (3 day + 3 night)
- Integrated charge per cycle: 0.5 C
- Total number of targets: 31

BGO Detector:
Expected Rates for 511keV Coincidence @ E_α = 400 keV

after 1 cycle (1h beam on, 1h beam off)



after 9 cycles (1h beam on, 1h beam off)



Neutron Channel with Neutron Detectors

EJ301D:

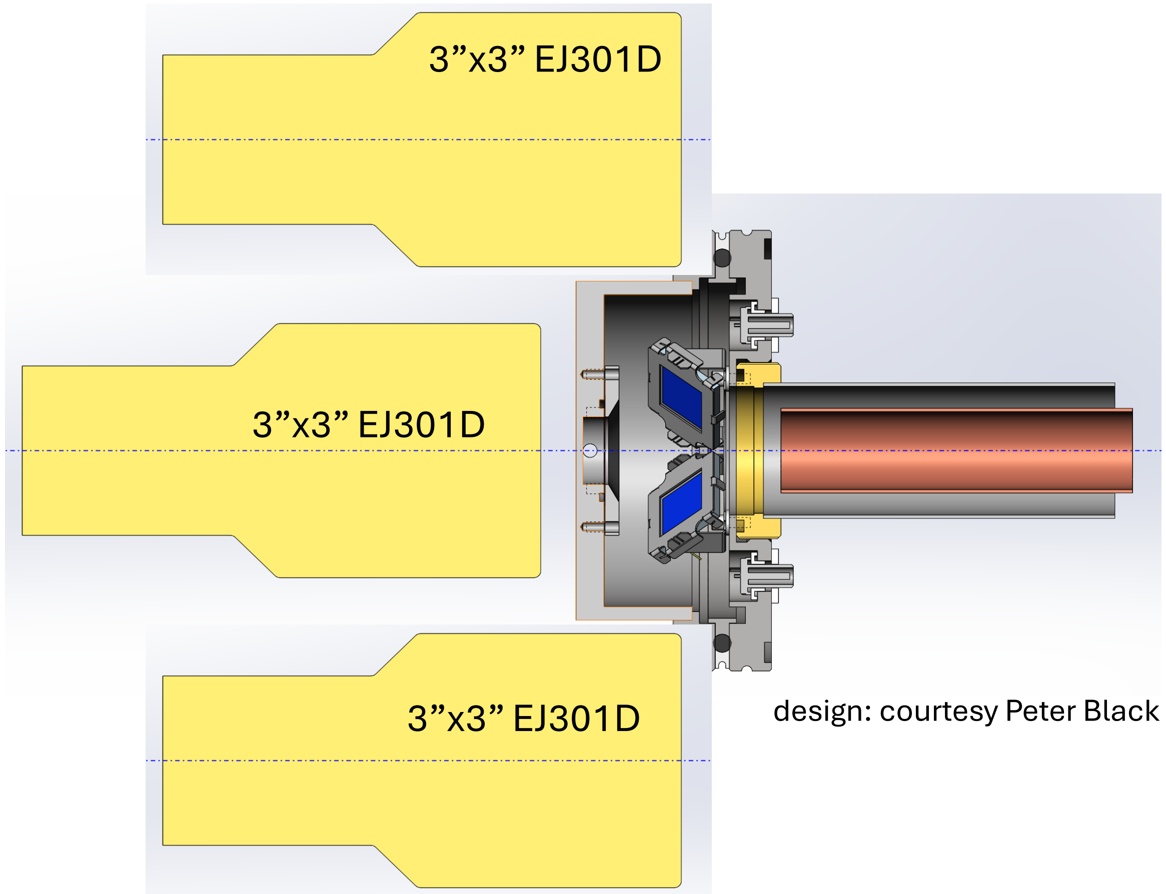
deuterated liquid scintillators

for neutron detection with energy

discrimination capabilities

BUT: authorization required

new chamber & detectors to be
installed at the end of the second beamline
with BGO detector fully retracted



design: courtesy Peter Black

Expected Beam Time Required for neutron detection

E_α (keV)	Beam on (h)	Total Counts	Days	Error
400	18	101	3	10%
380	24	48	4	14%
360	42	29	7	19%
340	42	9	7	33%
320	84	6	14	42%
300	168	3	28	58%

```
Current: 150.00 uA
Target thickness: 20.00 ug/cm^2
Targtes needed: 105
Targtes needed for 340-400 energies: 63
```

Down to 340 keV: 21 days
Down to 320 keV: 28 days

Challenges

- Due to the low cross section, the background dominates
- This is especially clear for the BGO measurement
- Background not known for the Direct measurement
- BGO can still be performed.
- Neutron background level needs to be determined in neutron energy region of interest.

Closing Remarks

- It is possible to gain results for α energies starting from 400 keV down to 360 keV using the BGO and down to 340-320 keV using direct measurement.
- BGO measurement requires multiple runs to reduce the statistical uncertainty due to the background rate.
- Direct detection requires multiple runs to gain enough stats
- Direct detection is assuming no neutron background at $E_n \approx 1400 \sim 1300$ keV

Charged-particle + Gamma-ray Detection Setup

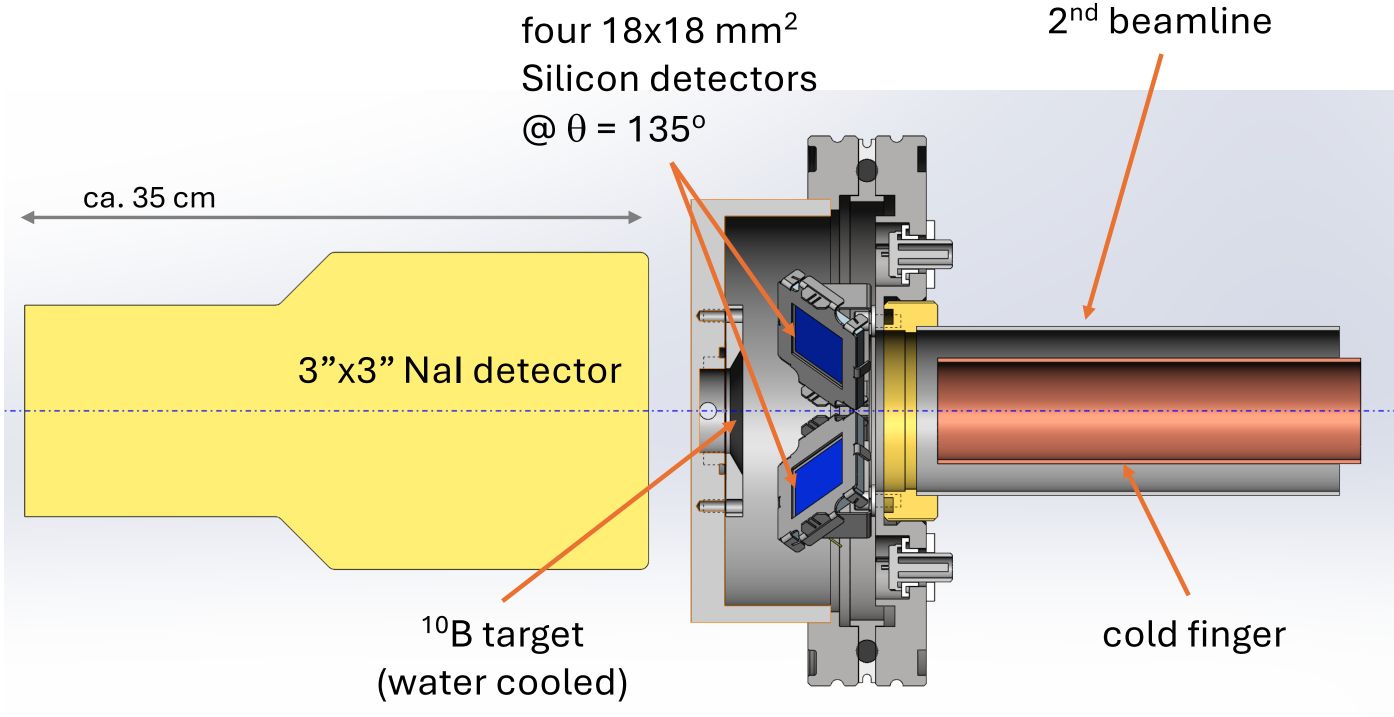
new chamber to be

installed at the end

of the second beamline

with BGO detector

fully retracted



design: courtesy Peter Black