^{16}O(n,α_0) cross section measurement at GELINA

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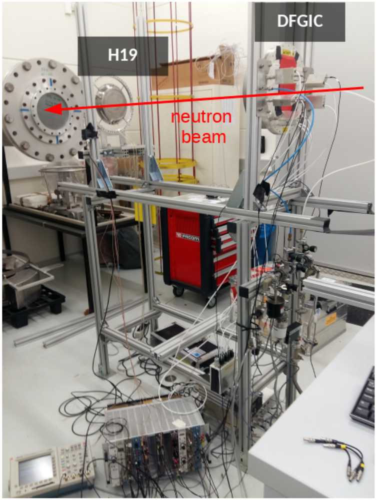
[1] HZDR [2] JRC [3] IJCLab

1. ^{16}O(n,α_0) reaction measurement at GELINA
2. renormalization of ^{16}O(n,α) and ^{13}C(α,n) cross section data

$^{16}O(n,\alpha)$ reaction measurement at GELINA



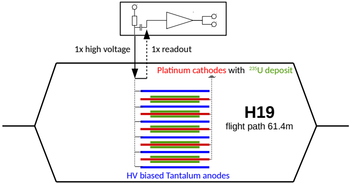
Flight Path (FP) station 16-60m:

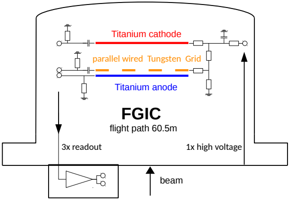
- neutron beam diameter: 63mm
- duration: 2 weeks (9.5 days)
- rep. rate: 400Hz

Detectors:

- H19 fission Ionization Chamber[1]
- Frisch Grid Ionization Chamber (FGIC)

Experimental Setup





H19 (61.4 m):

- 10x ^{235}U deposits
- 1x readout
- deposit diameter: 76 mm
- total deposit mass: 200 mg

FGIC (60.5 m):

- cathode, grid and anode
- active volume (target) between cathode and grid
- counting gas: 95%Kr + 5%CO_2
- pressure: 2 bar

Analysis of wave forms from digital data acquisition

H19:

- time-of-flight t_{ToF}
- pulse height

$\Rightarrow$ FF selection

FGIC:

- time-of-flight t_{ToF}
  $\rightarrow$ cathode
- drift time t_{drift}
  $\rightarrow$ anode - cathode
- rise time t_{rise}
  $\rightarrow$ grid
- pulse height E_{dep}
  $\rightarrow$ anode

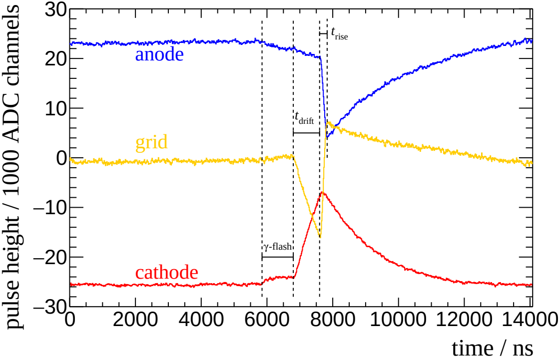
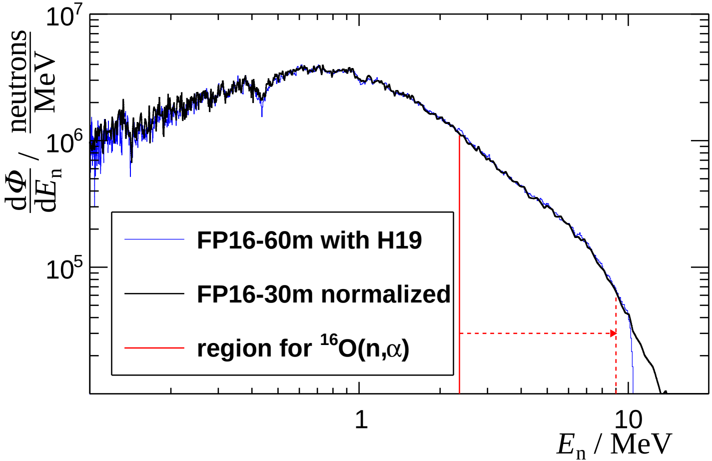


Figure: Wave form traces from FGIC.

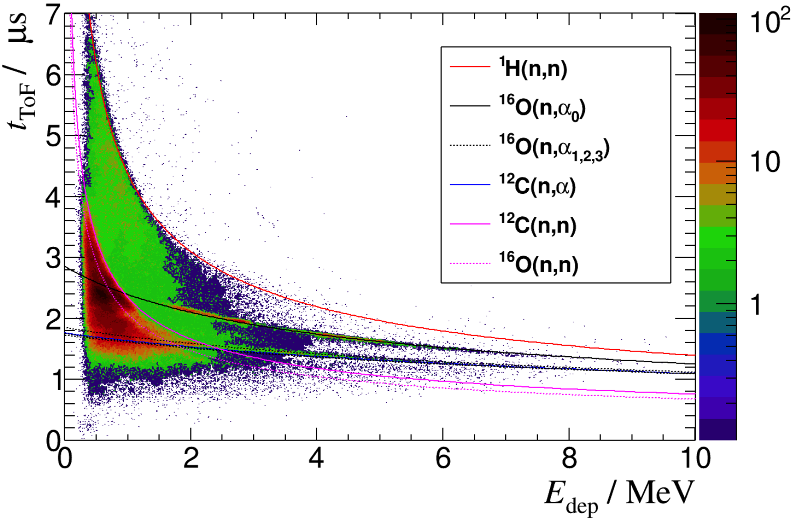
$\Rightarrow$ cuts for t_{ToF} , t_{drift}, t_{rise} and E_{dep} for (n,α) selection

The neutron spectrum (H19)

- FP16-60m spectrum absolute normalization measured with H19
- spectral shape has good agreement with FP16-30m spectrum[2]
- energy region for $^{16}O(n,\alpha)$: 2.35 MeV - 9 MeV

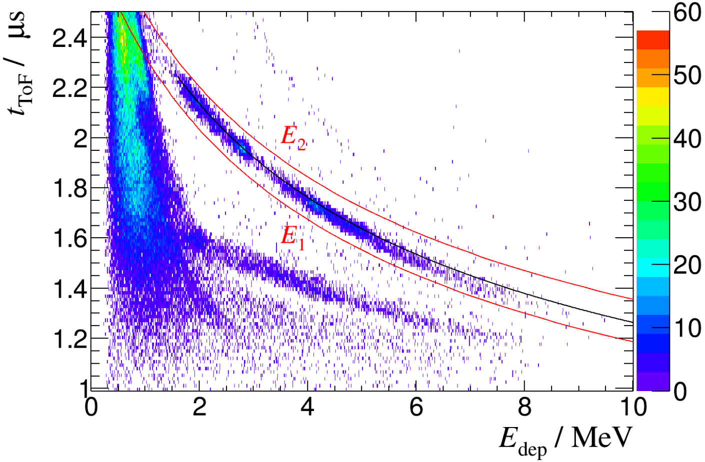


Selection of charged particle events



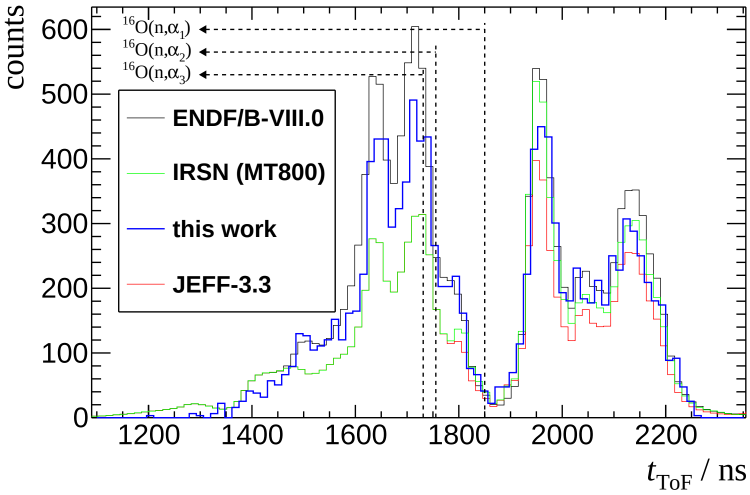
Selection of (n,α_0) events (Time-of-Flight)

- ^{16}O(n,α_1), ^{16}O(n,α_2), ^{16}O(n,α_3) and ^{12}C(n,α) events not separable
- ^{16}O(n,α_0) events separable above 1.5 μs ($E_n < 9$ MeV)



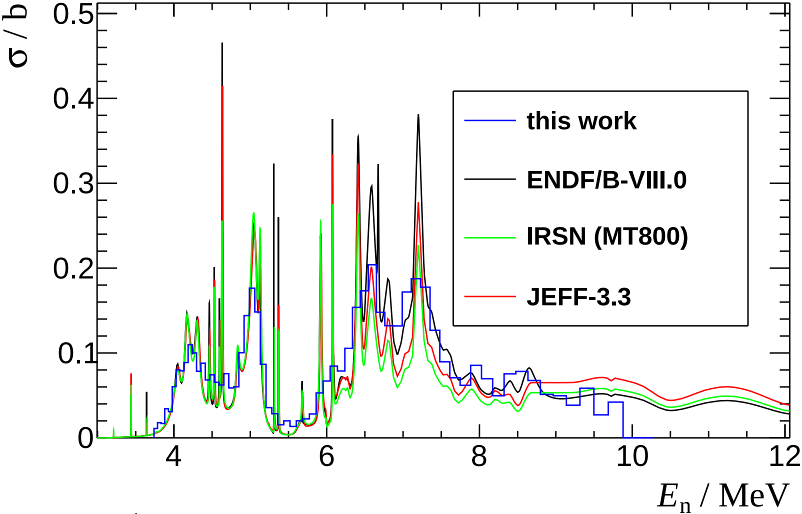
Time-of-flight spectra comparison with evaluated data

- normalization region between 1900 - 2200 ns (4.0 - 5.3 MeV)
- above 1800 ns (below 5.6 MeV): ^{16}O(n,α) = ^{16}O(n,α_0)
- Experimental Time-of-flight resolution (27 ns FWHM)



Cross section renormalization of evaluated data

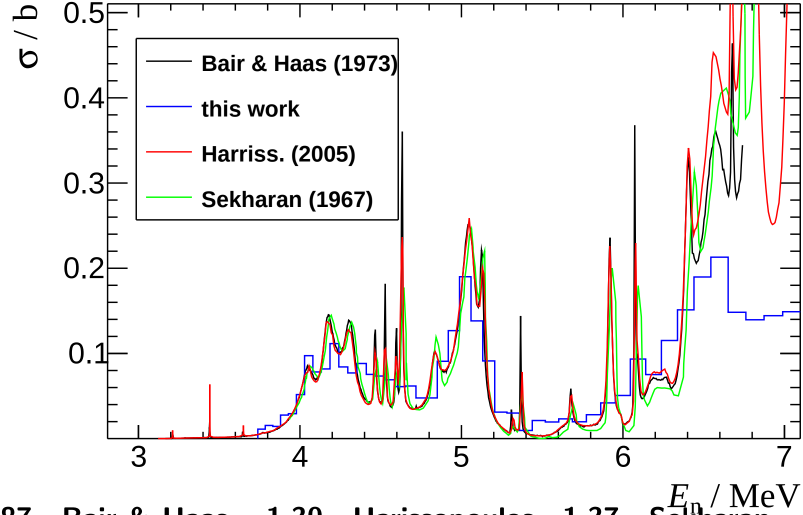
- normalization region between 4.0 - 5.3 MeV



0.92 · ENDF/B-VIII.0 , 1.26 · JEFF 3.3 , 1.02 · IRSN

Cross section renormalization of ^{13}C(α,n) data

- using detailed balance to transform ^{13}C(α,n) to ^{16}O(n,α) data
- normalization region between 4.0-5.3MeV



0.87 · Bair & Haas , 1.30 · Harissopoulos, 1.37 · Sekharan

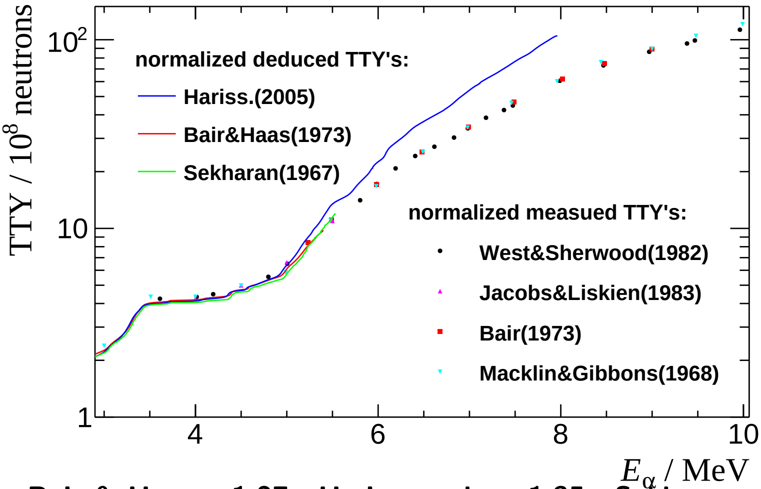
Uncertainties

$$\frac{C}{E} = \frac{\varepsilon_{\text{FGIC}}}{\varepsilon_{\text{H19}}} \frac{N_T^{16\text{O}}}{N_\text{T}^{235\text{U}}} \frac{N_{\text{FF}}}{N_{\alpha_0}} \frac{\langle \sigma_{\text{n},\alpha}^{16\text{O}} \rangle}{\langle \sigma_{\text{n,f}}^{235\text{U}} \rangle} \;, \; \Delta \frac{C}{E} = \mathbf{5.8\%}$$

quantity	value	unc. (%)
^{235}U(n,f) events N_{FF}	37000	0.5
$N_\text{T}^{235\text{U}}$ (atoms/b)	1.138 10^{-5}	0.3
inhomogeneity ^{235}U	4%	0.2
detection efficiency ε_{H19}	91.7%	1.8
$\langle \sigma_{\text{n,f}}^{235\text{U}} \rangle$	1.1 b	1.3
^{16}O(n,α_0) events N_{α_0}	2670	1.9
$N_T^{16\text{O}}$ (atoms/b):	9.79 10^{-6}	4.8
remaining proton background	15%	1

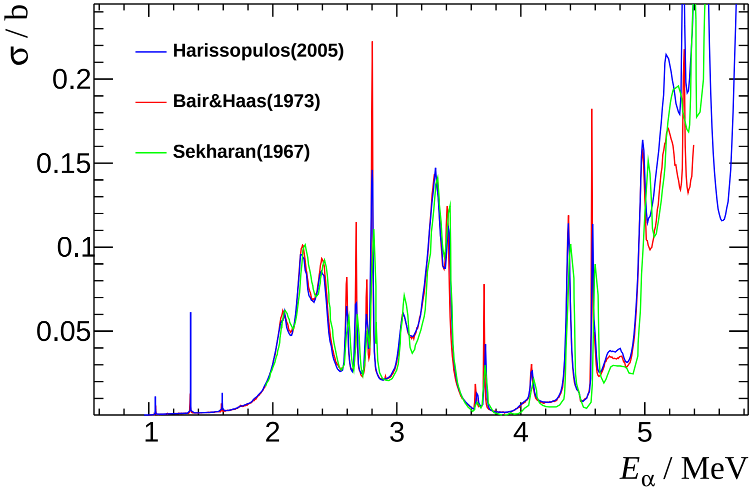
$^{13}C(\alpha,n)$ cross section normalization to thick target yield

- normalization between 3.5-5MeV to West & Sherwood's TTY
- below 5MeV: $^{13}C(\alpha,n)={}^{13}C(\alpha,n_0)$



0.85 · Bair & Haas , 1.27 · Harissopoulos, 1.35 · Sekharan

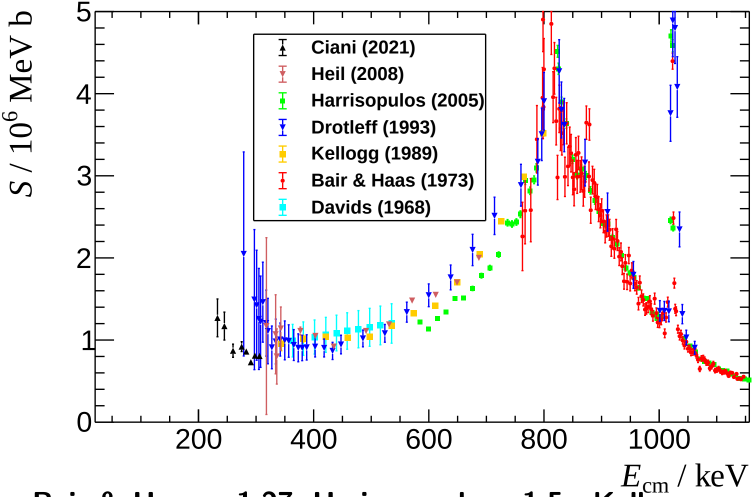
$^{13}C(\alpha,n)$ cross section normalization to thick target yield



0.85 · Bair & Haas , 1.27 · Harissopoulos, 1.35 · Sekharan

Implication for s-process stellar nucleosynthesis

- agreement between 800 and 1000keV: Drotleff, Bair & Haas and Har.
- agreement between 300 and 800kev: Drotleff, Heil, Davids



0.85 · Bair & Haas , 1.27· Harissopoulos, 1.5 · Kellogg

Results and comparison

	^{16}O(n,α_0) data (this work)	West and Sherwood TTY [3]	Pigni and Croft [4]	Ciani et al. [5]
main uncertainty	5% $N_T^{16\mathrm{O}}$ (^{16}O target)	8% ^{13}C abundance	8% ^{13}C abundance	8% detection efficiency
Bair and Haas [6]	0.87	0.85	0.8	
Harissopulos [7]	1.30	1.27	1.15	1.37
Sekharan [8]	1.37	1.35		
IRSN [9]	1.02	1.00		
ENDF/B-VIII.0	0.92	0.89		
JEFF-3.3	1.26	1.25		

Conclusion: Normalization of $^{16}O(n,\alpha_0)$

- ENDF/B-VIII.0 $^{16}O(n,\alpha_0)$ is 8% too high
- JEFF 3.3 $^{16}O(n,\alpha_0)$ is 26% lower than our data
- IRSN agrees with our data (below 5.5 MeV)
- normalizations based on: this $^{16}O(n,\alpha_0)$ measurement and on $^{13}C(\alpha,n)$ TTY data from West&Sherwood - are consistent
- renormalized data of Bair & Haas and Harissopulos are consistent with low energy data (Drotleff, Heil, Davids, Ciani)

- uncertainties of TTY normalization is about 9%:
  8% ^{13}C abundance, about 3% stopping range, 2% from TTY meas.
- uncertainty of $^{16}O(n,\alpha_0)$ measurement is 6%:
  2% from H19, 2% from stat. and 5% from syst. unc. for FGIC
- new measurement to improve time resolution and counting statistics

Thank you for your attention!

Acknowledgement

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[5] G.F. Ciani et al. Phys. Rev. Lett. 127, 152701 (2021).
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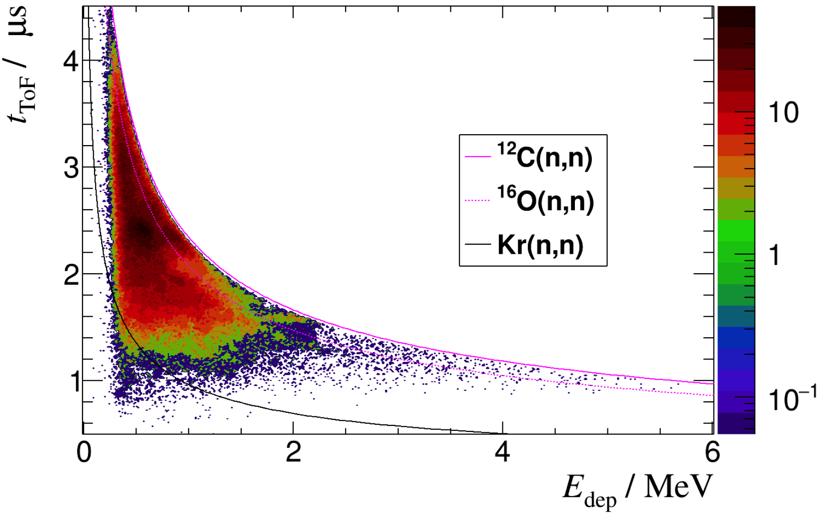
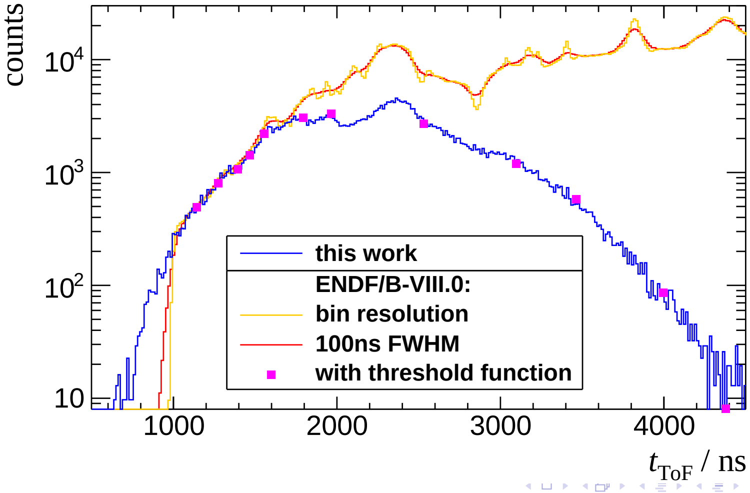
Selection of elastic scattering events



⇒ Elastic scattering detected on C and O (not Kr)

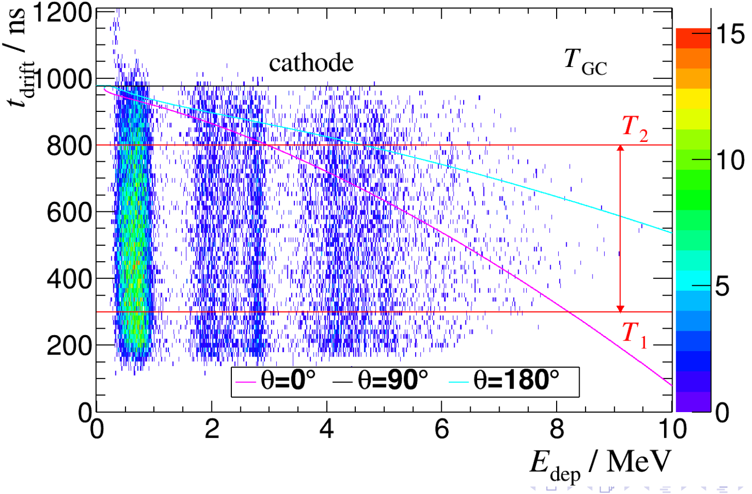
Alternative normalization by CO_2(n,n)

- measured neutrons (H19) and ENDF/B-VIII.0 CO_2(n,n) with experimental threshold function agree with data
- strong confirmation of normalization with H19



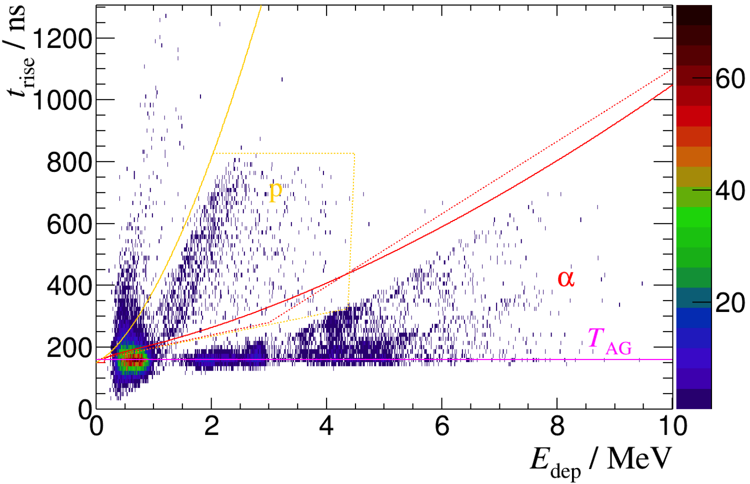
Selection of (n,α_0) events (drift time)

- active volume: drift times between 300ns and 800ns
- Edep<3MeV(En<5.2MeV): full energy deposition & angle integration
- Edep<7MeV(En<9.2MeV): inefficiency negligible



Selection of (n,α_0) events (rise time)

- ^{1}H(n,p) background separation from (n,α_0) events is needed
- maximum rise times calculated from α- and proton stopping ranges



Systematic uncertainties of FGIC

quantity	value	unc. (%)
$N_T^{16}\mathrm{O}$ (atoms/b):	9.79 10^{-6}	4.8
cathode-grid drift time (ns)	970	4.1
cathode-grid distance L_{CG} (mm)	39	1.3
CO_2 concentration	0.05	2
equation of state (ideal gas)		0.3
pressure (bar)	2.0	<0.1%
temperature (K)	296.67	<0.1%