Measurement of the Coulomb dissociation cross section of the neutron rich nitrogen isotopes $^{20,21}N$

Marko Röder

NAVI Meeting
February 2015, Darmstadt

Supported by
GSI F&E (DR-ZUBE),
NupNET NEDENSAA (05 P09 CRFN5),
Plattform für Detektortechnologie und -systeme

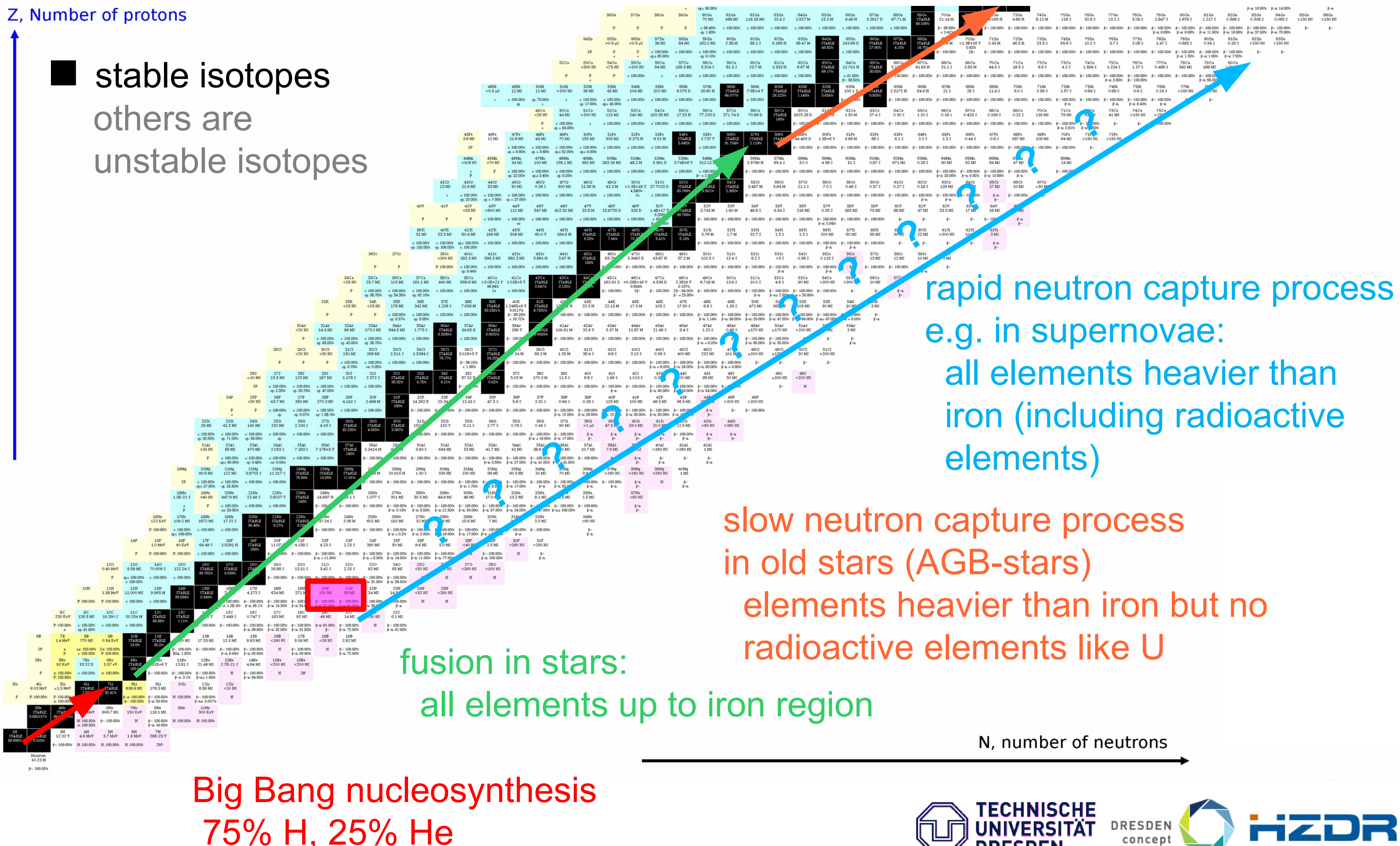
TECHNISCHE UNIVERSITÄT DRESDEN

Partner von DRESDEN concept exzellenz-dresden.de

HZDR

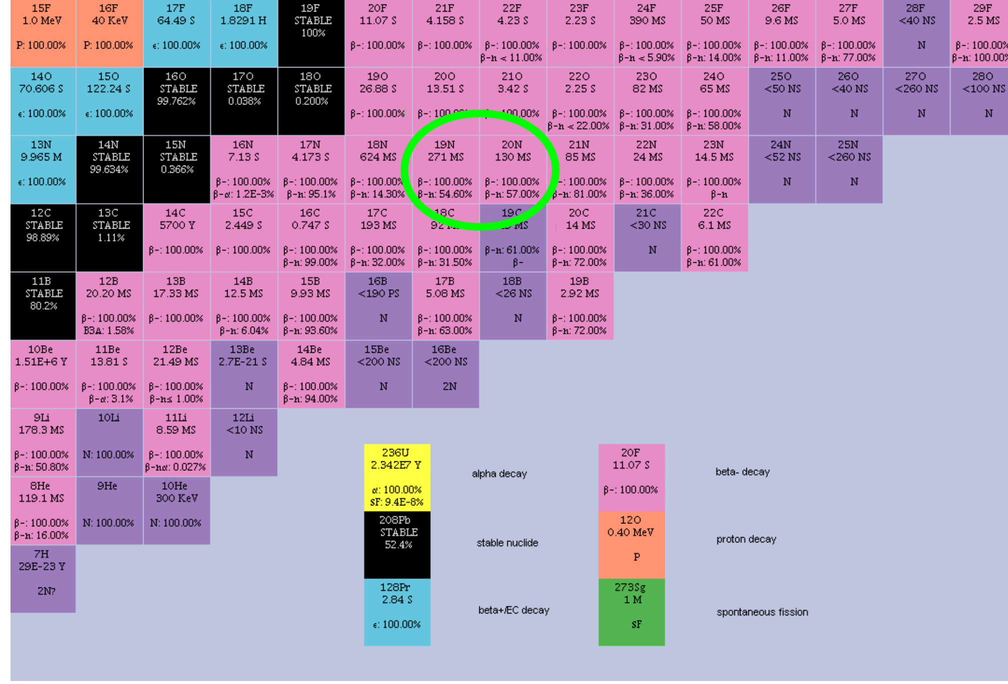
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Nucleosynthesis



TECHNISCHE UNIVERSITÄT DRESDEN
DRESDEN concept
HZDR

Astrophysical Motivation



How were the chemical elements created?

- elements up to iron by fusion in Big Bang and stars
- heavier elements by neutron capture processes
  - slow (s-process): discrepancies with observations
  - rapid (r-process): its path involves nuclei far away from the valley of stability (^{14}N, ^{15}N are stable)

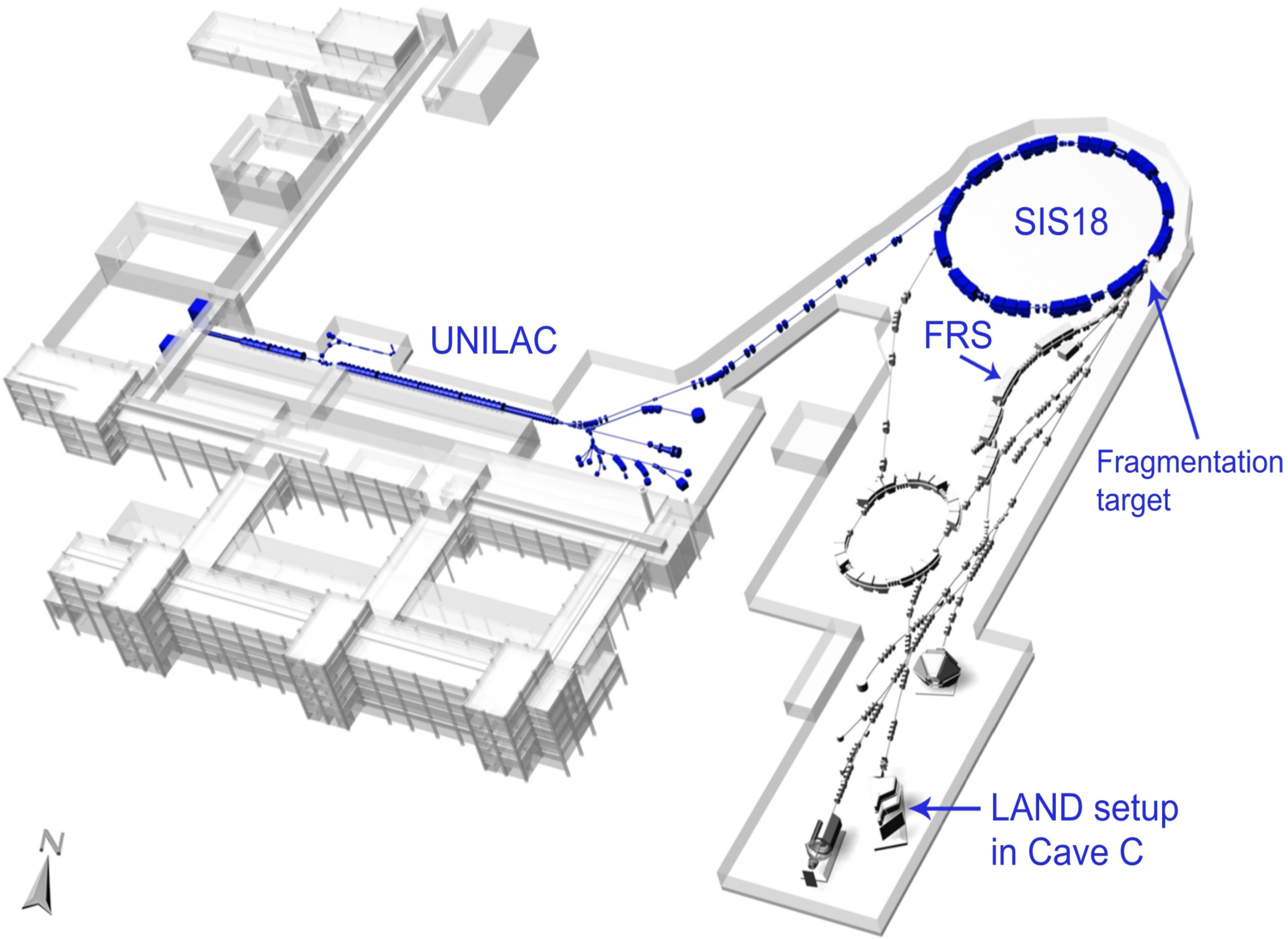
- ^{20}N(γ,n)^{19}N studied to extract cross sections of ^{19}N(n,γ)^{20}N via time inversion
- core-collapse supernova with neutrino driven wind scenario (Takahashi et al. 1994)
- Big Bang nucleosynthesis (Rauscher et al. 1994)

Impact of Light Neutron Rich Nuclei to r-process Abundance

M. Terasawa et al. (2001):

"[…] We find that a new nuclear reaction flow path opens in the very light, neutron-rich region. This new nuclear reaction flow can change the final heavy-element abundances by as much as an order of magnitude. [...]"

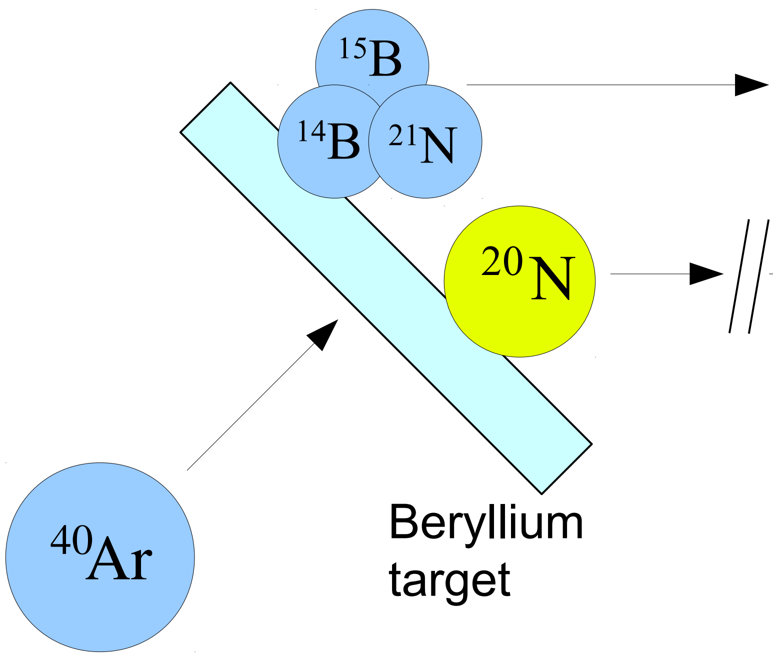
GSI Accelerator Facility



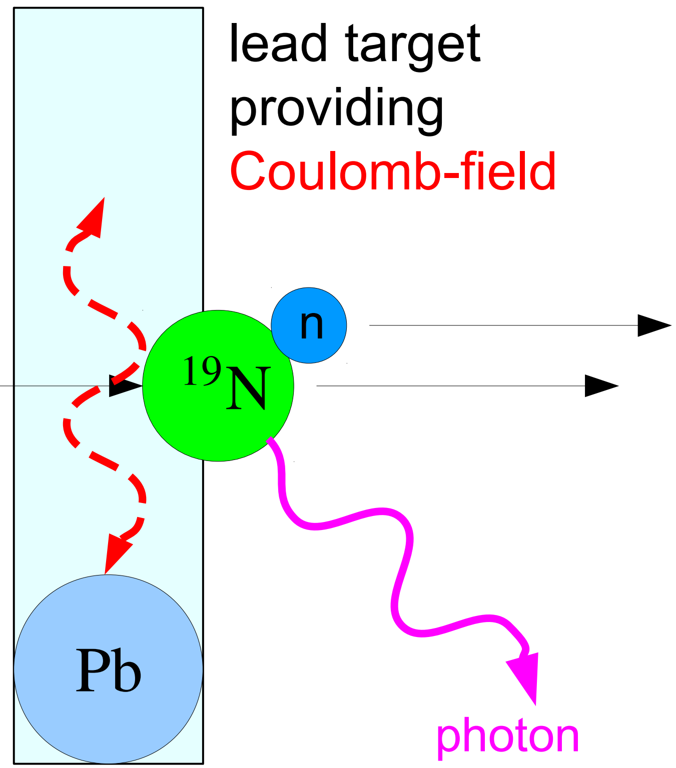
Coulomb Dissociation

$$\sigma_{CoulEx} = p_{Pb} \cdot \frac{M_{Pb}}{d_{Pb} \cdot N_A} - p_C \cdot \alpha \cdot \frac{M_C}{d_C \cdot N_A} - p_{empty} \cdot \left(\frac{M_{Pb}}{d_{Pb} \cdot N_A} - \alpha \cdot \frac{M_C}{d_C \cdot N_A} \right)$$

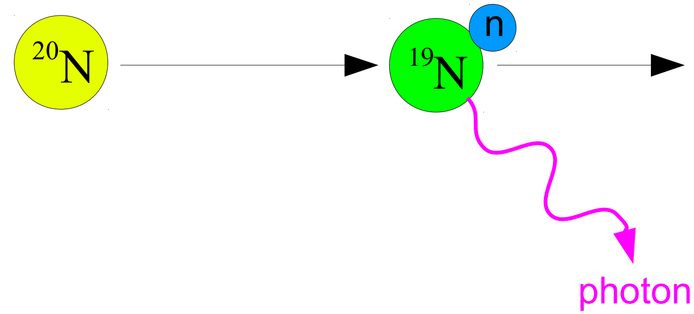
Radioactive Ion Beam Production



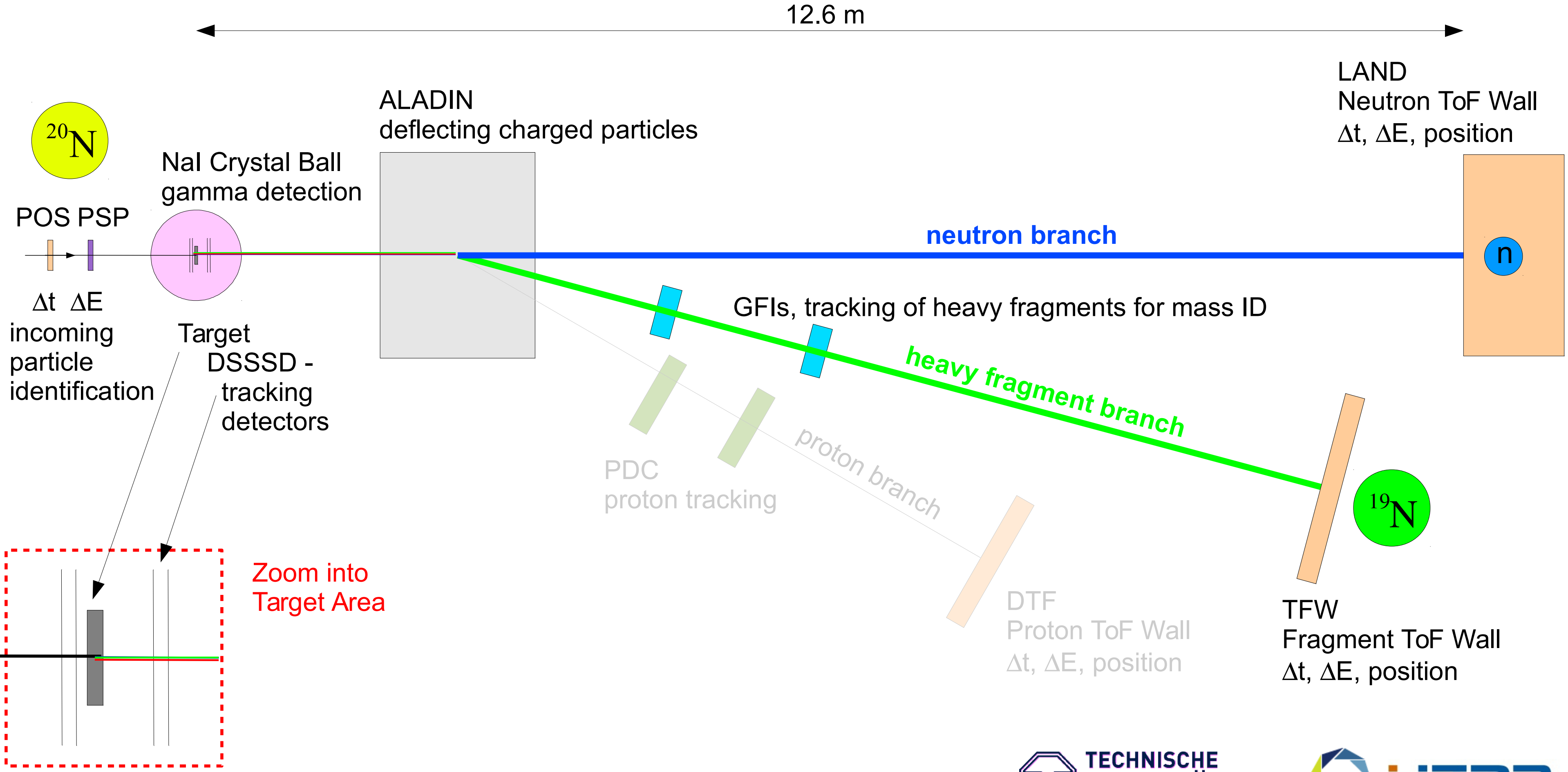
Reaction at R3B Setup



LAND/R3B Setup

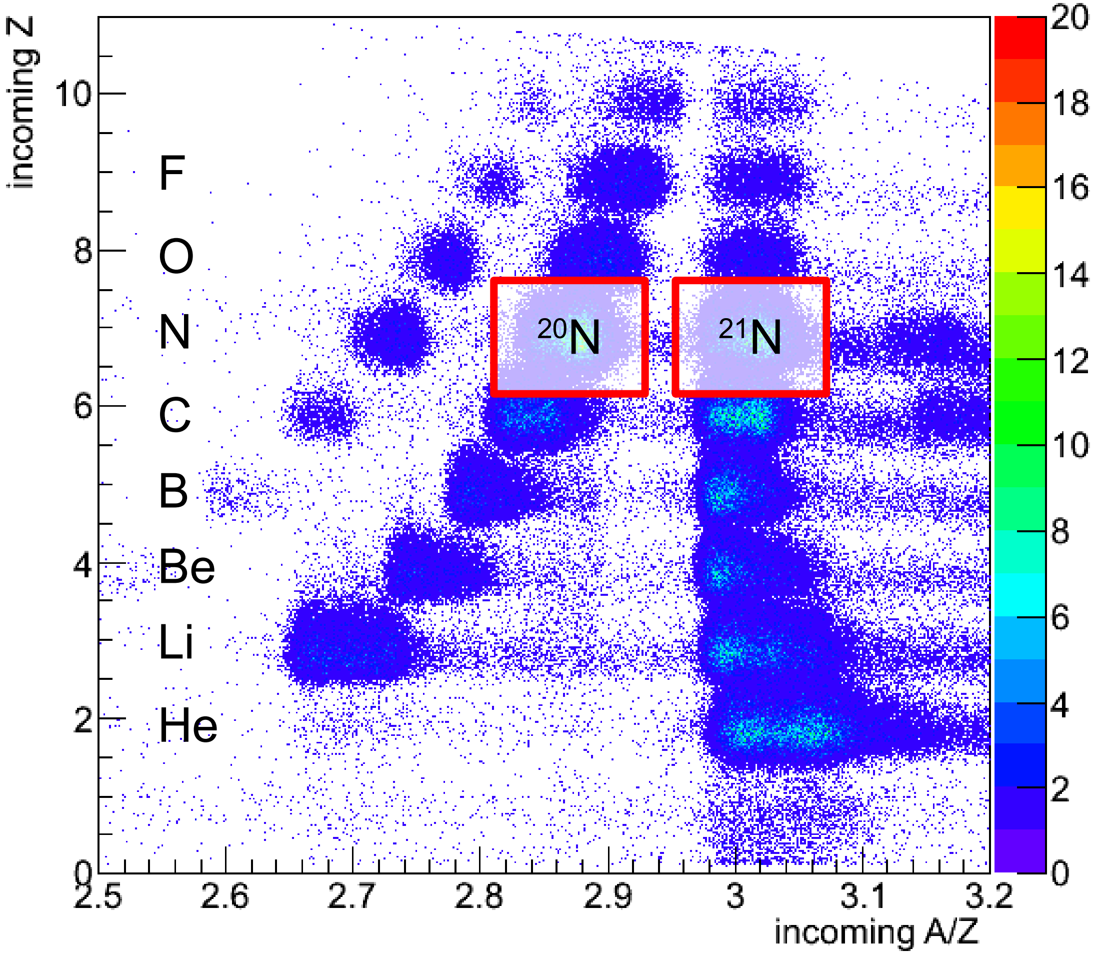


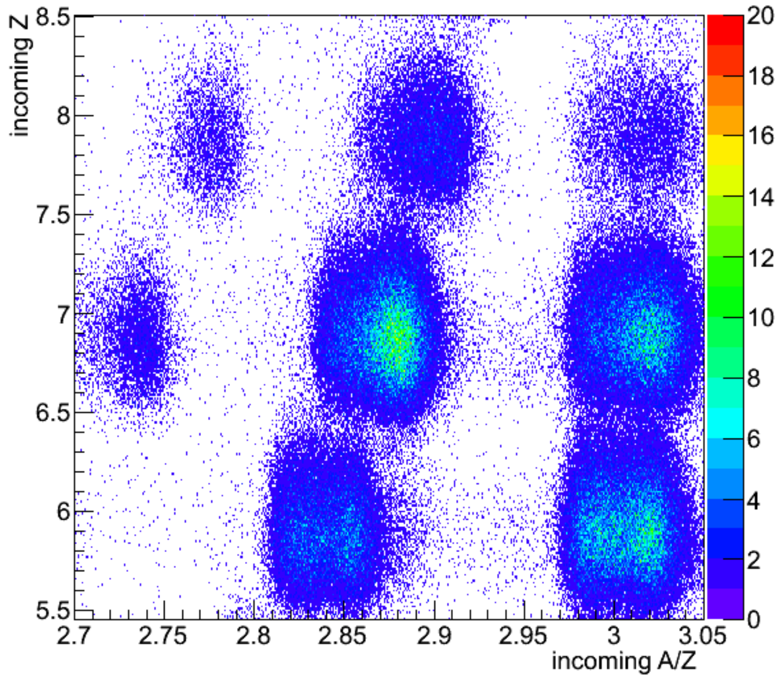
- kinematically complete measurement
- measure all outgoing particles



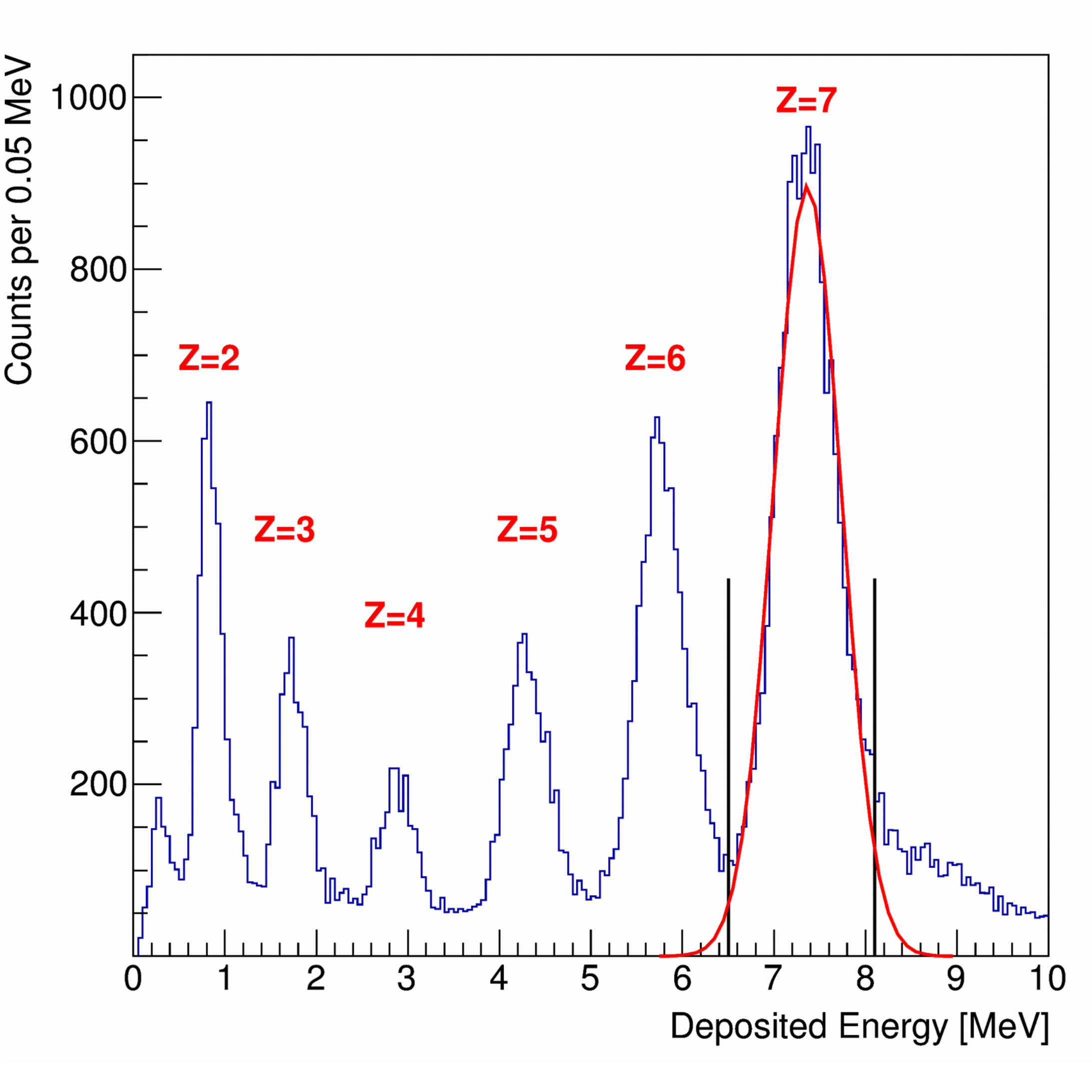
TECHNISCHE UNIVERSITÄT DRESDEN   DRESDEN concept   HZDR

Incoming Particle Identification





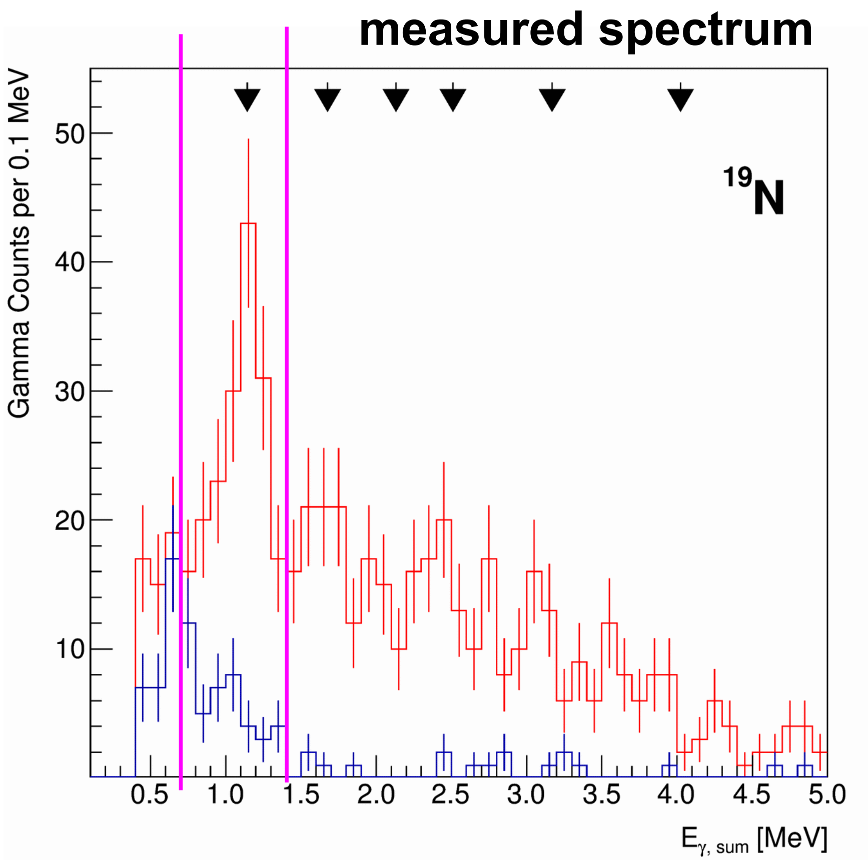
Identifying Charge of outgoing Fragment

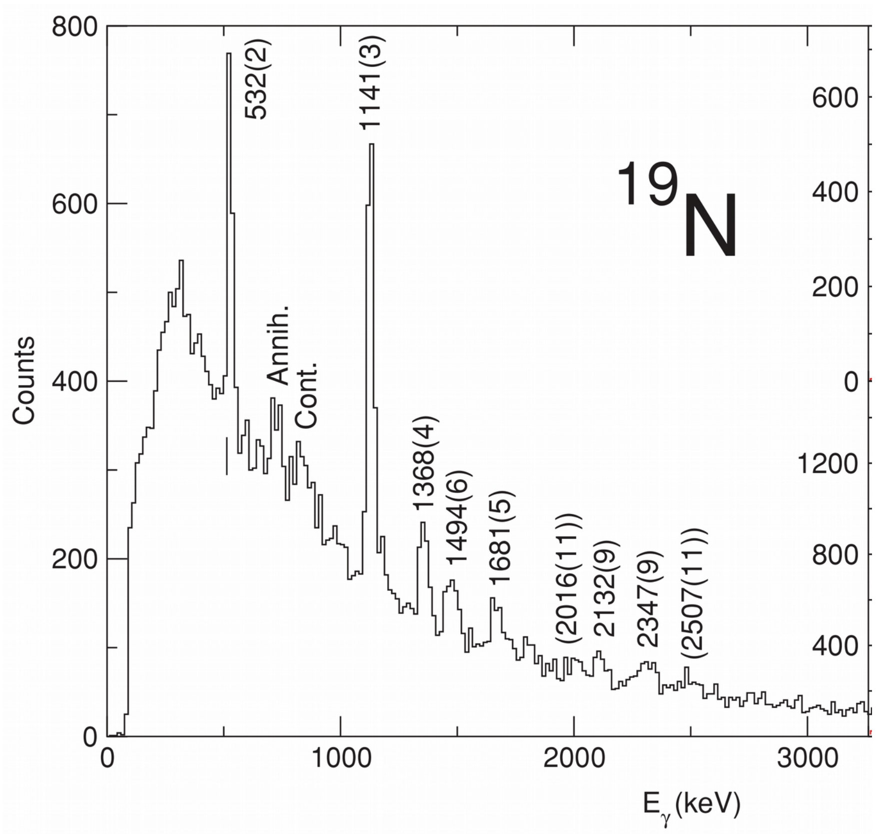


- Incoming ^{20}N
- Requiring one hit in LAND
- Accepting only one hit in Fragment ToF Wall (TFW)

Measured Gamma Spectrum

$^{20}N(\gamma`,n)^{19}N$





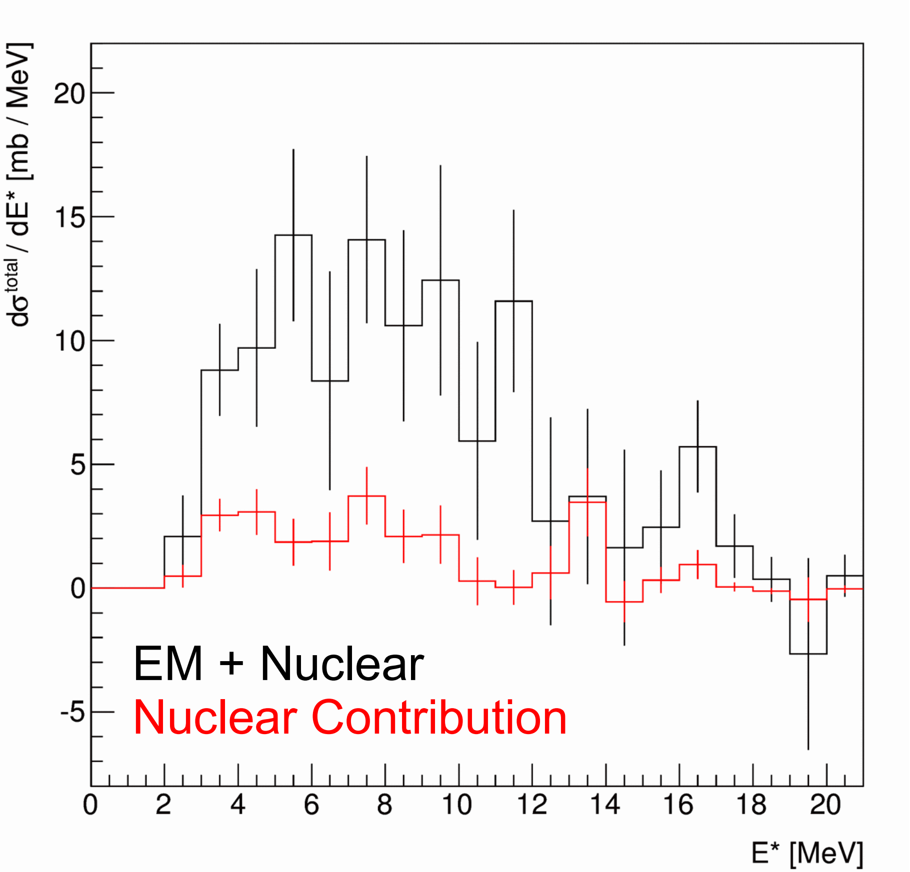
in ^{20}N, Pb-target, out ^{19}N, Hit in LAND
Summed energy of all detected γ

Threshold for Addback:	0.3 MeV
Threshold for cluster summing:	0.4 MeV

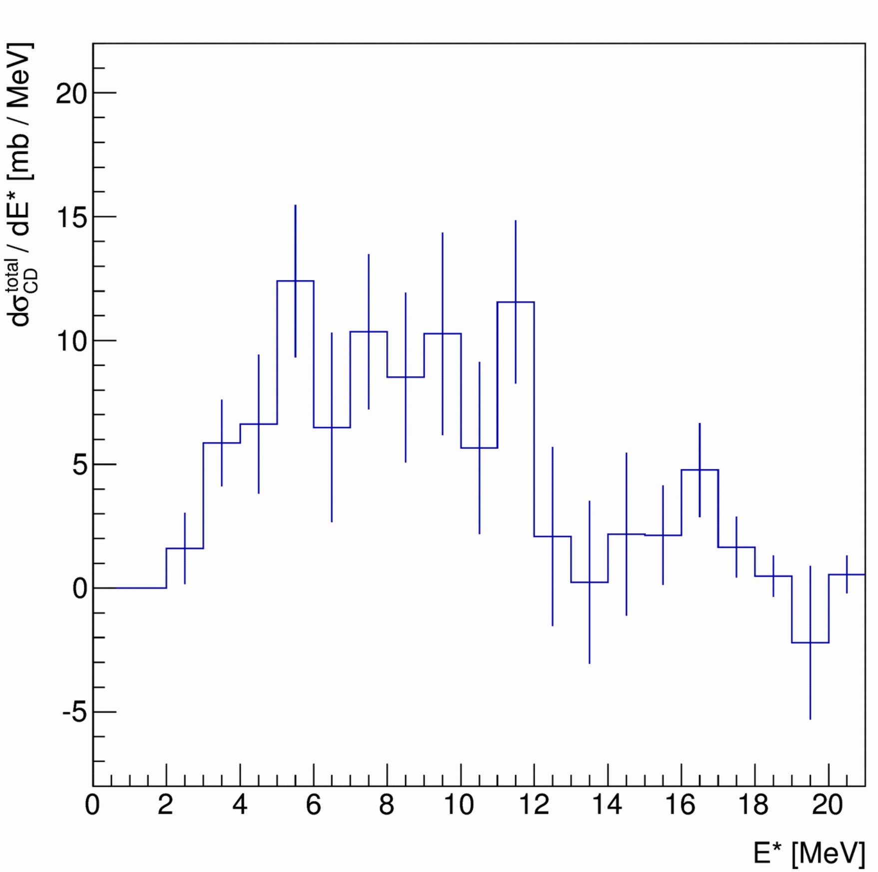
D. Sohler, et al., 2008, PRC 77, 044303 at GANIL, in-flight spectra with Doppler-correction, Addback, Ge-detector, E(^{36}S)=77.5MeVA

Total Excitation Energy Spectrum
$^{20}N(\gamma`,n)^{19}N$

Partial Contributions

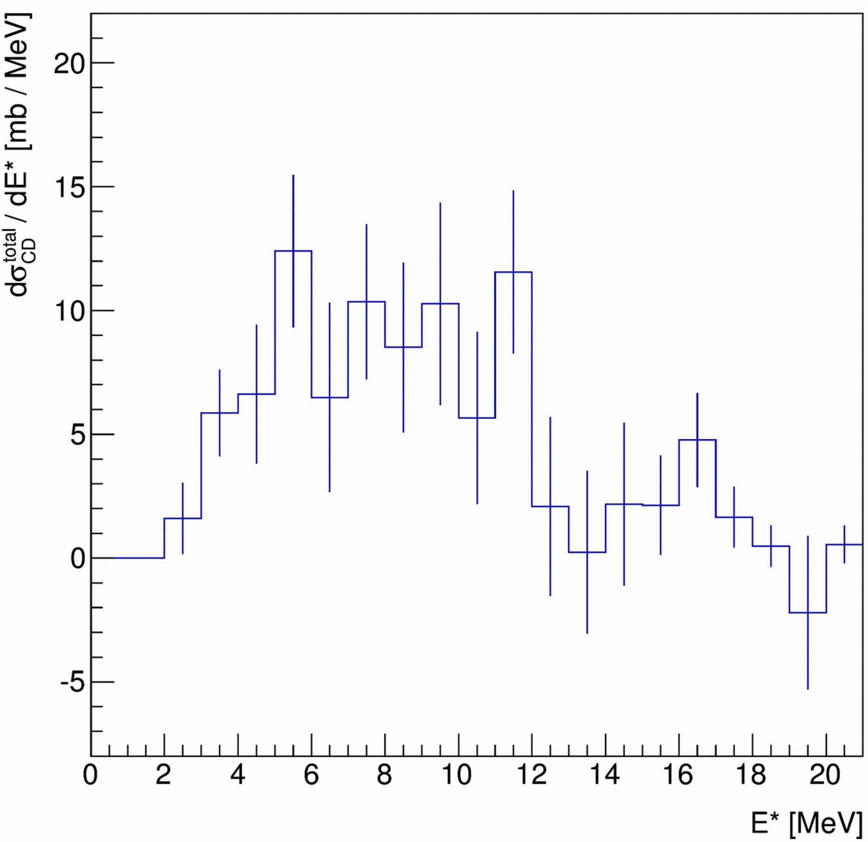


Coulomb Dissociation Cross Section

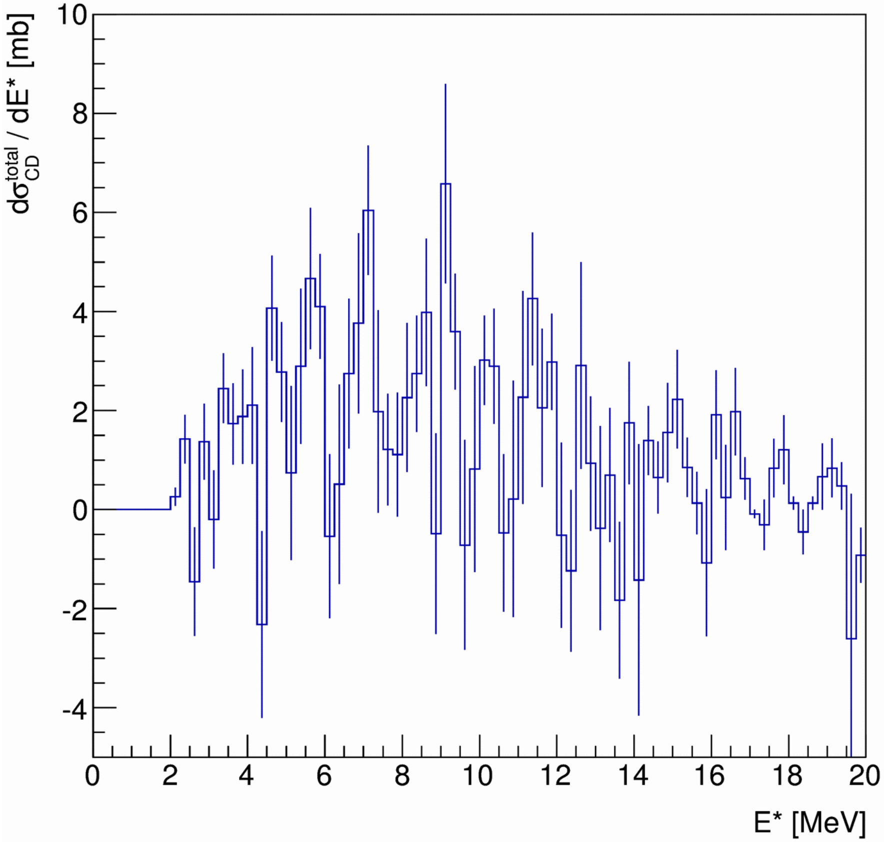


Total Excitation Energy Spectrum $^{20}N(\gamma`,n)^{19}N$

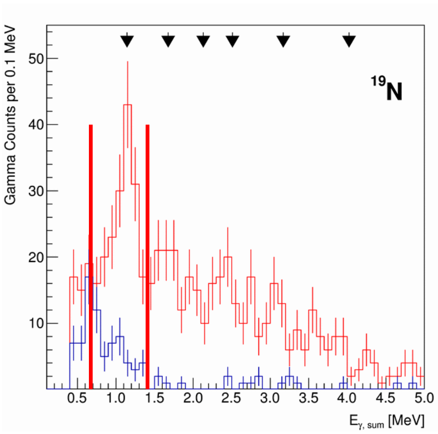
Coulomb Dissociation Cross Section



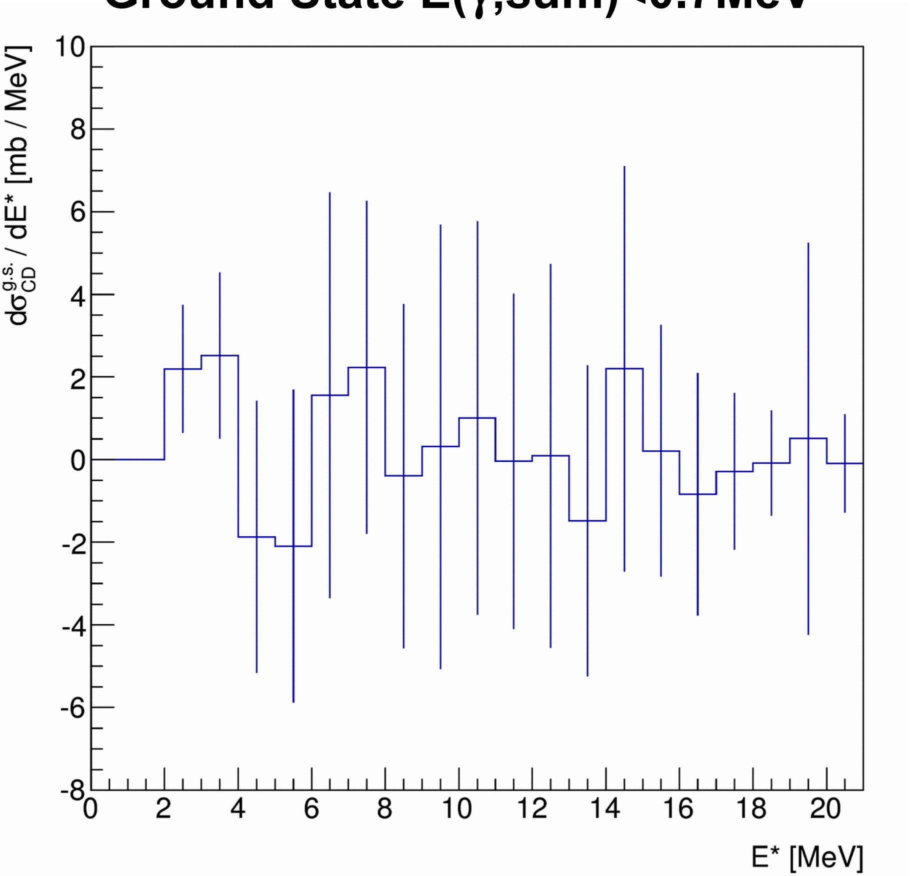
Finer Binning



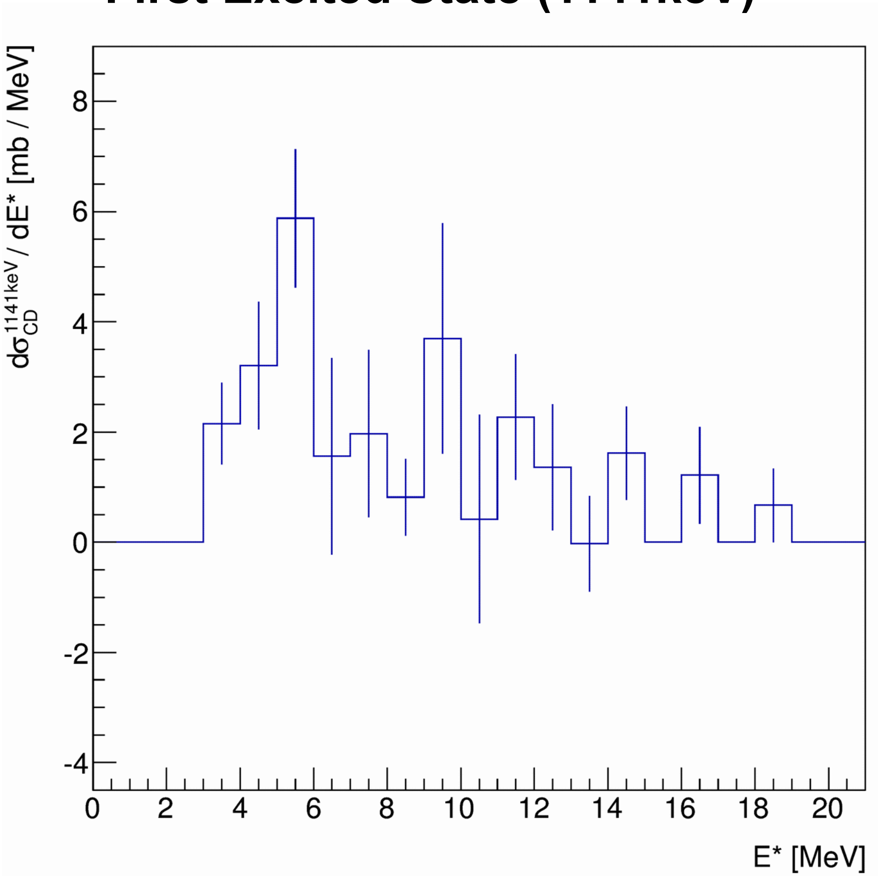
Excitation Energy Spectrum $^{20}N(\gamma`,n)^{19}N$



Ground State E(γ,sum)<0.7MeV



First Excited State (1141keV)



Cross Section $^{20}N(\gamma`,n)^{19}N$

Uncertainties

- statistical uncertainty
- LAND efficiency 6%
- Crystal Ball eff. 5%
- incoming particle identification

$\sigma_{CD}(\text{total}) = (96 \pm 12^{stat} \pm 4^{InPID} \pm 6^{LAND})$ mb

$\sigma_{CD}(\text{all excited}) = (80 \pm 10^{stat} \pm 2^{InPID} \pm 5^{LAND} \pm 5^{CB})$ mb

$\sigma_{CD}(\text{ground state}) = (16 \pm 15^{stat} \pm 1^{InPID} \pm 1^{LAND} \pm 1^{CB})$ mb

$\sigma_{CD}(\text{1st excited state}) = (28 \pm 5^{stat} \pm 2^{InPID} \pm 2^{LAND} \pm 2^{CB})$ mb

Photo Absorption Cross Section

$$\sigma_{\gamma,\mathrm{n}} \equiv \sigma_{\mathrm{E1}}^{\mathrm{photo}} = \frac{d\sigma_{CD}}{dE^*} \frac{1}{n_{\mathrm{E1}}(E^*)} E^*$$

$$E_\gamma = E^*$$

σ[^{20}N(γ,n)^{19}N$^{g.s.}$] < 9.2 mb for E* = (0 MeV, 15 MeV); 90% confidence level

Invariance under time reversal via principle of detailed balance

Neutron Capture Cross Section

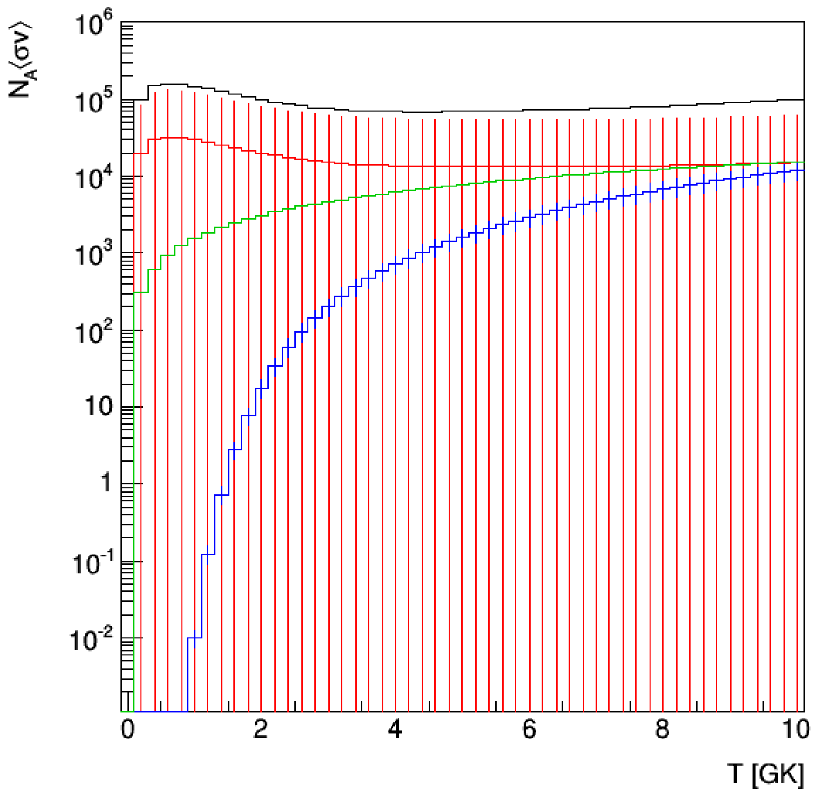
$$\sigma_{n,\gamma} = \frac{2(2J_A+1)}{(2J_{A-1}+1)(2J_n+1)} \frac{k_\gamma^2}{k_{c.m.}^2} \sigma_{\gamma,n}$$

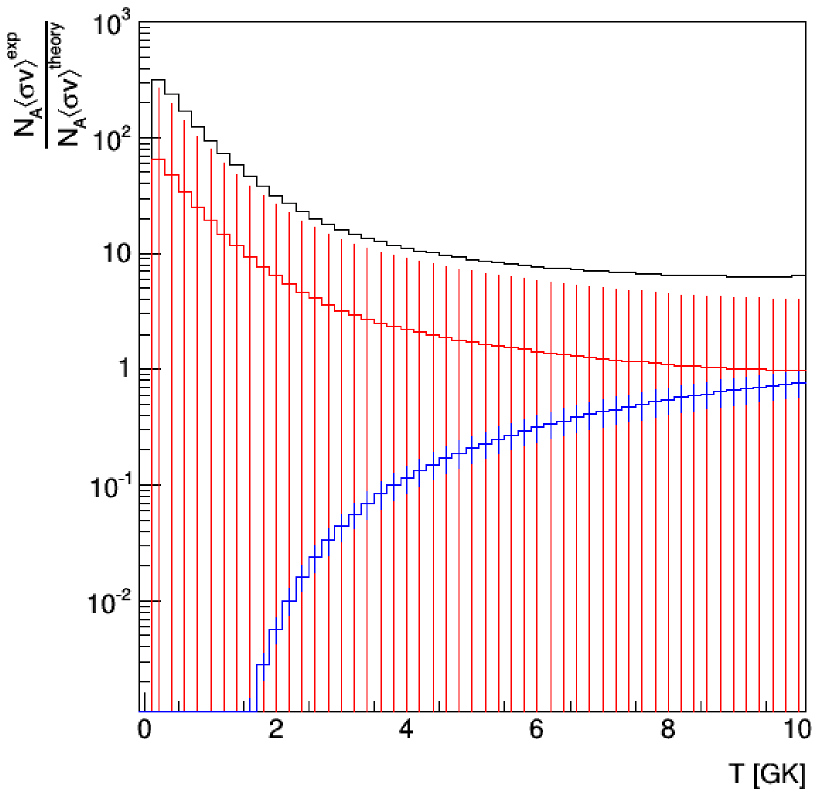
$$k_\gamma = E^*/(\hbar c)$$
$$k_{c.m.}^2 = 2\mu(E^* - S_{1n})/\hbar^2$$
$$\mu = (M_{^{19}\mathrm{N}} \cdot M_{\mathrm{n}})/(M_{^{19}\mathrm{N}} + M_{\mathrm{n}})$$

σ[^{19}N$^{g.s.}$(n,γ)^{20}N] < 0.24 mb for E* = (0 MeV, 15 MeV); 90% confidence level

Maxwellian Average Reaction Rates

Scaled to theoretic data





^{19}N[g.s.] (n,γ)^{20}N

^{19}N[1st excited state] (n,γ)^{20}N including population probability

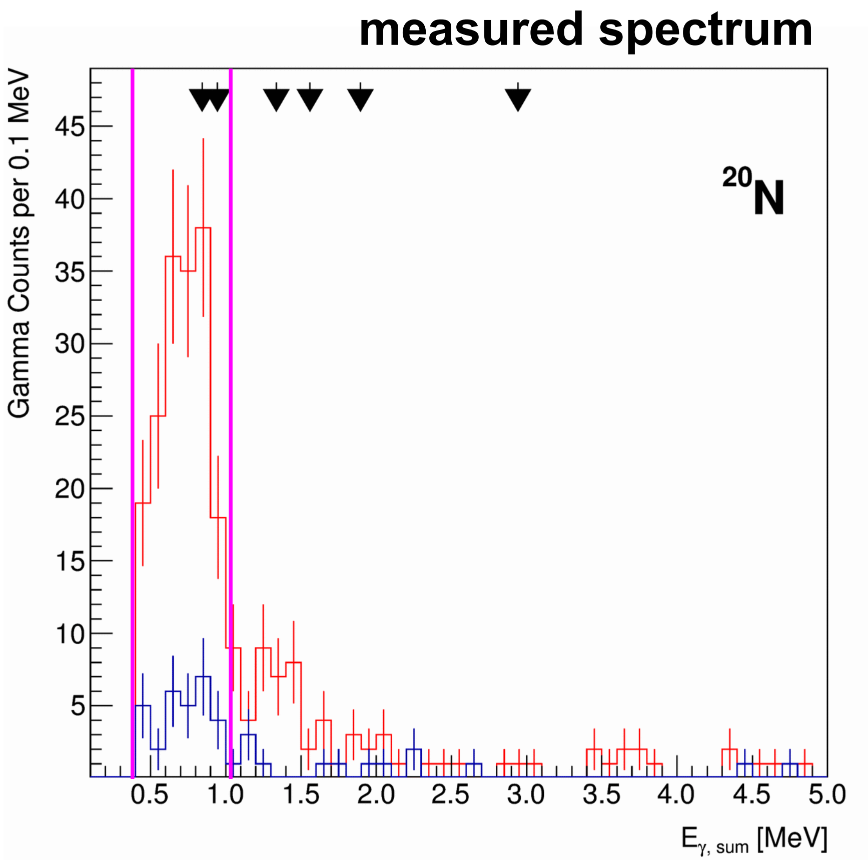
^{19}N(n,γ)^{20}N upper limit of g.s. and 1st excited state transitions

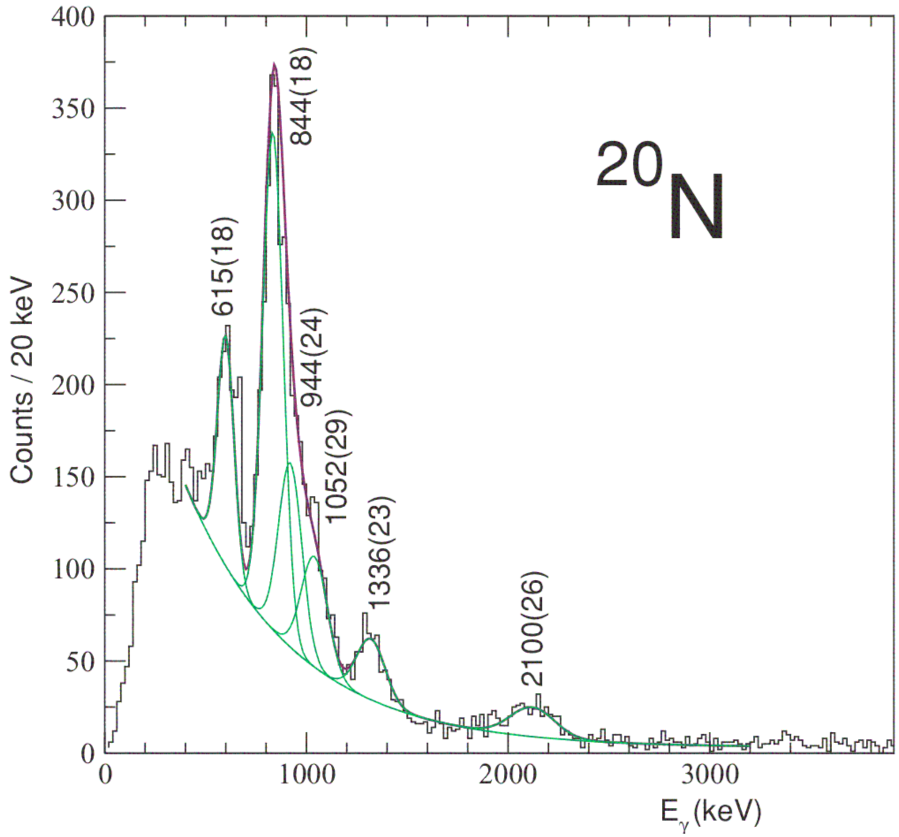
^{19}N(n,γ)^{20}N Rauscher et al. 1994 (theoretic)

$^{21}N(\gamma`,n)^{20}N$

Measured Gamma Spectrum

$^{21}N(\gamma`,n)^{20}N$



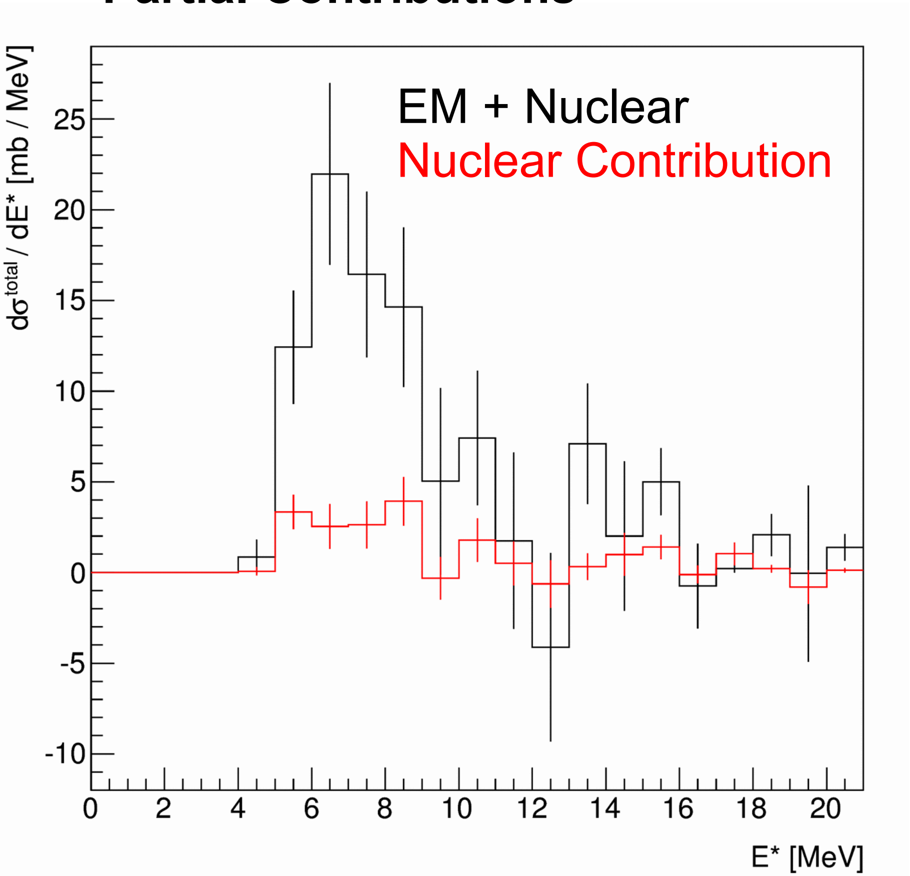


in ^{21}N, Pb-target, out ^{20}N, Hit in LAND
Summed energy of all detected γ
Threshold for Addback: 0.3 MeV
Threshold for cluster summing: 0.4 MeV

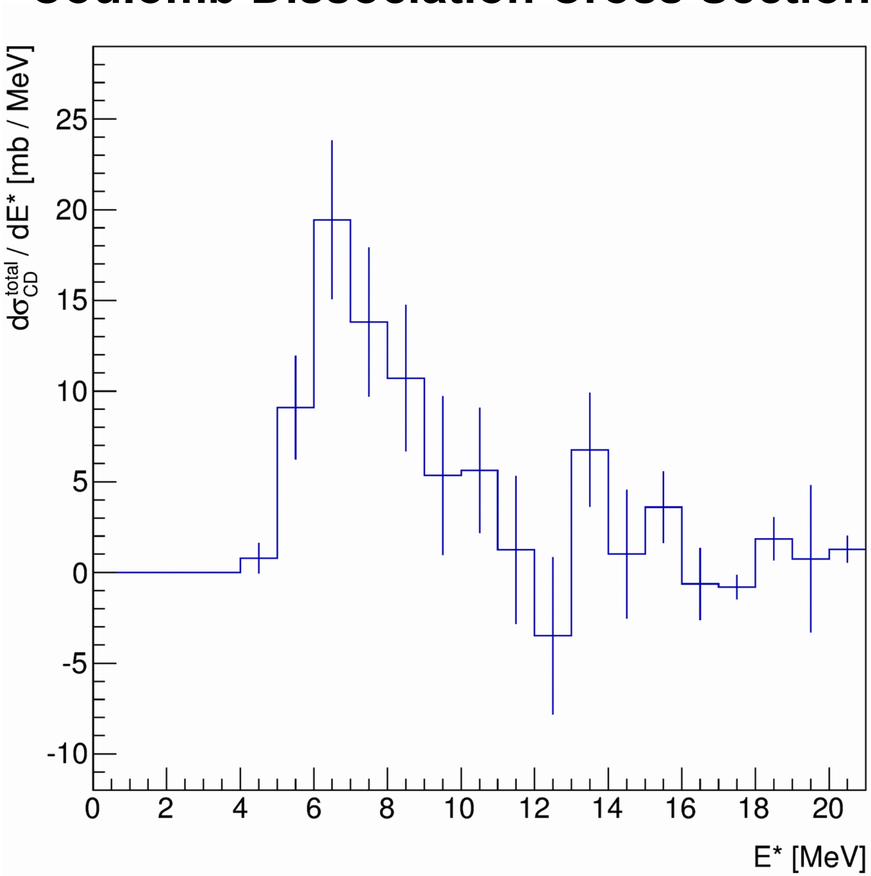
D. Sohler, et al., 2008, PRC 77, 044303
at GANIL, in-flight spectra with Doppler-correction, Addback, BaF_2,
$E(^{36}S)$=77.5MeVA

Total Excitation Energy Spectrum $^{21}N(\gamma`,n)^{20}N$

Partial Contributions

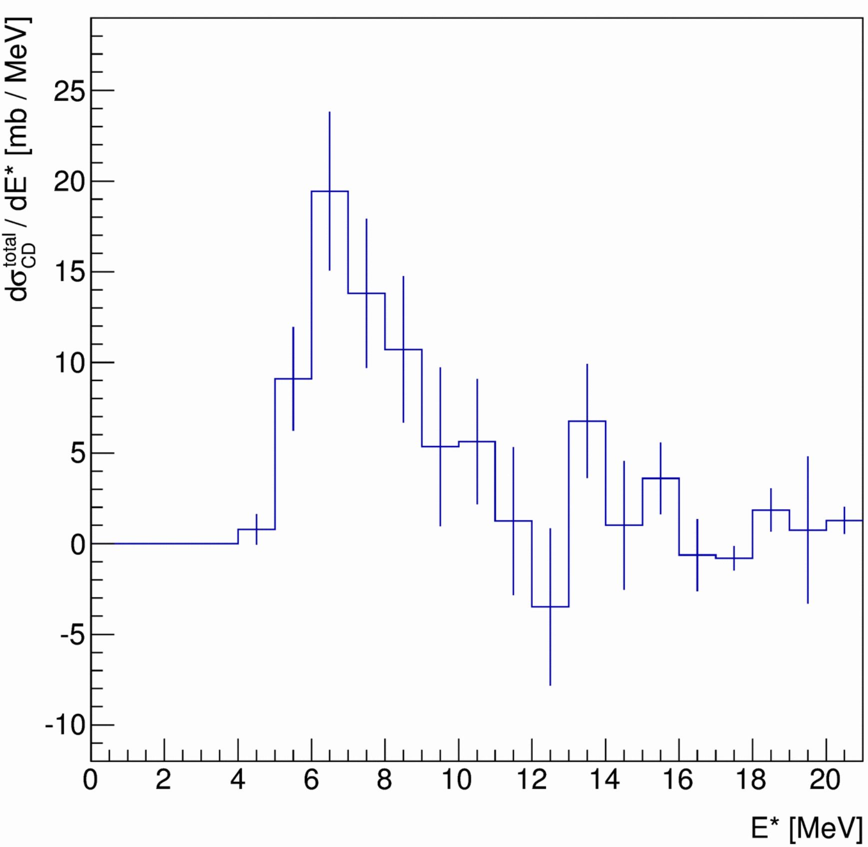


Coulomb Dissociation Cross Section

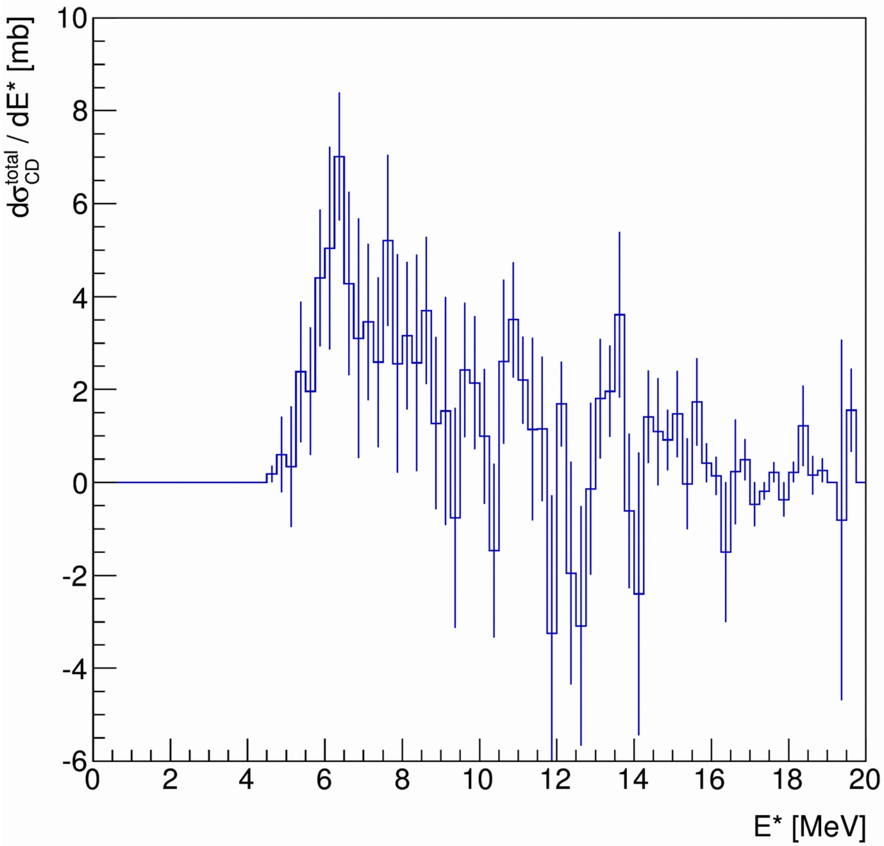


Total Excitation Energy Spectrum $^{21}N(\gamma`,n)^{20}N$

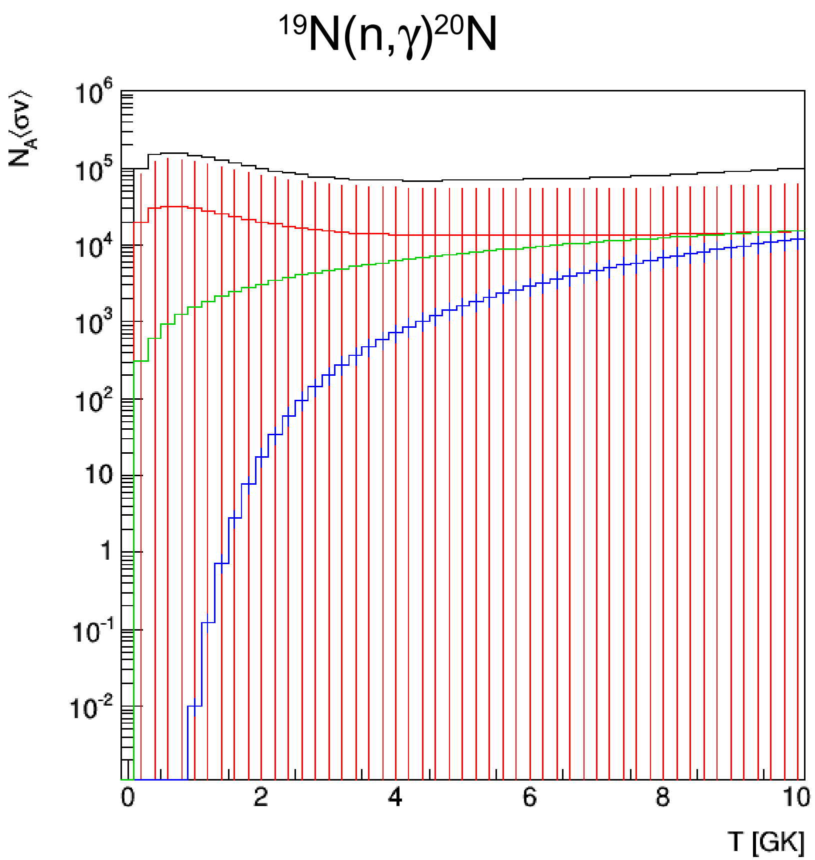
Coulomb Dissociation Cross Section

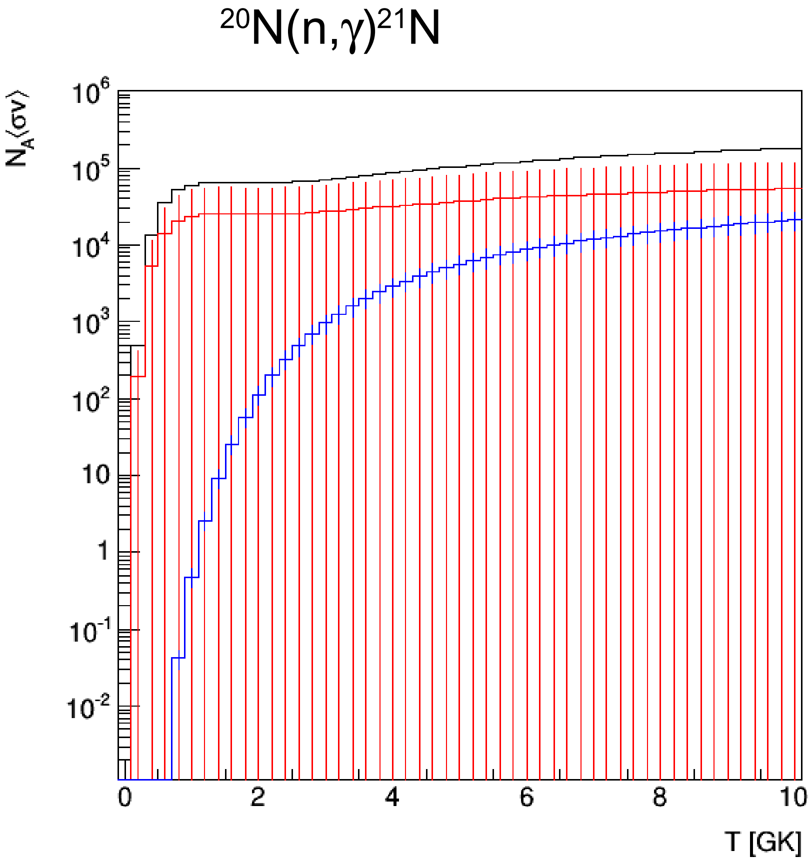


Finer Binning



Maxwellian Average Reaction Rates





^{A}N[g.s.] $(n,\gamma)^{A+1}N$

^{A}N[1st excited state] $(n,\gamma)^{A+1}N$ including population probability

$^{A}N(n,\gamma)^{A+1}N$ upper limit of g.s. and 1st excited state transitions

$^{A}N(n,\gamma)^{A+1}N$ Rauscher et al. 1994 (theoretic)

Cross Section $^{21}N(\gamma`,n)^{20}N$

σ_{CD}(total)	= (84 ± 12^{stat}	± 5^{inPID}	± 5^{LAND}		) mb
σ_{CD}(all excited)	= (53 ± 9^{stat}	± 0^{inPID}	± 3^{LAND}	± 3^{CB}	) mb
σ_{CD}(ground state)	= (31 ± 15^{stat}	± 5^{inPID}	± 2^{LAND}	± 2^{CB}	) mb

Photo Absorption Cross Section

$\sigma[^{21}N(\gamma,n)^{20}N^{g.s.}] < 10.8$ mb for E* = (0 MeV, 15 MeV); 90% confidence level

Neutron Capture Cross Section

$\sigma[^{20}N^{g.s.}(n,\gamma)^{21}N] < 0.13$ mb for E* = (0 MeV, 15 MeV); 90% confidence level

Summary

- Measured astrophysically relevant reaction via time inversion by principle of detailed balance
- Coulomb Excitation Cross Section for $^{20}N(\gamma,n)^{19}N$
  - σ_{CD}(total) = 96 mb, u_{stat} = ± 12 mb, $u_{sys,inPID}$ = ± 4 mb, $u_{sys,LAND}$ = ± 6 mb
- Neutron Capture Cross Section: $\sigma[^{20}N(\gamma,n)^{19}N^{g.s.}] < 9.2$ mb

- Coulomb Excitation Cross Section for $^{21}N(\gamma,n)^{20}N$
  - σ_{CD}(total) = 84 mb, u_{stat} = ± 12 mb, $u_{sys,inPID}$ = ± 5 mb, $u_{sys,LAND}$ = ± 5 mb
- Neutron Capture Cross Section: $\sigma[^{20}N^{g.s.}(n,\gamma)^{21}N] < 0.13$ mb

- Discussion & Outlook
  - include in Reaction Network Code for impact on r-process abundance
  - repeat with higher statistics (FAIR)