The ^{22}Ne(α,*n*) Reaction at DRAGON

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The **r-process** is expected to produce **~50%** of all elements in the galaxy

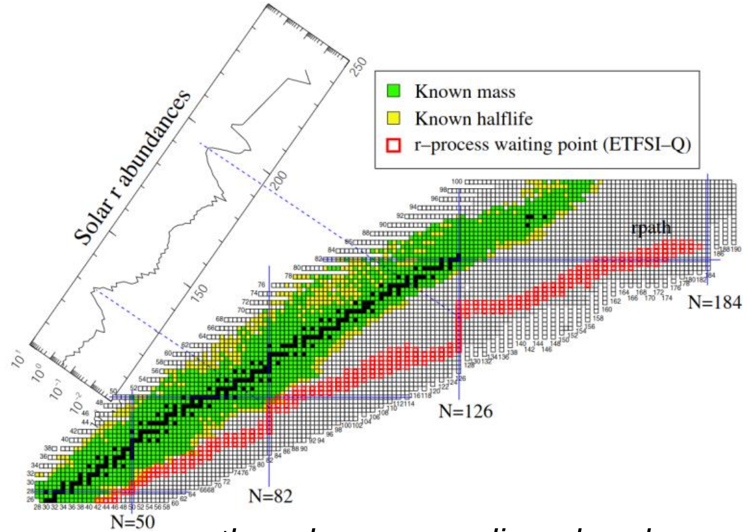
Rapid neutron capture produce heavy elements far from stability that **beta decay** to stability

Gives rise to the abundance peaks below magic number

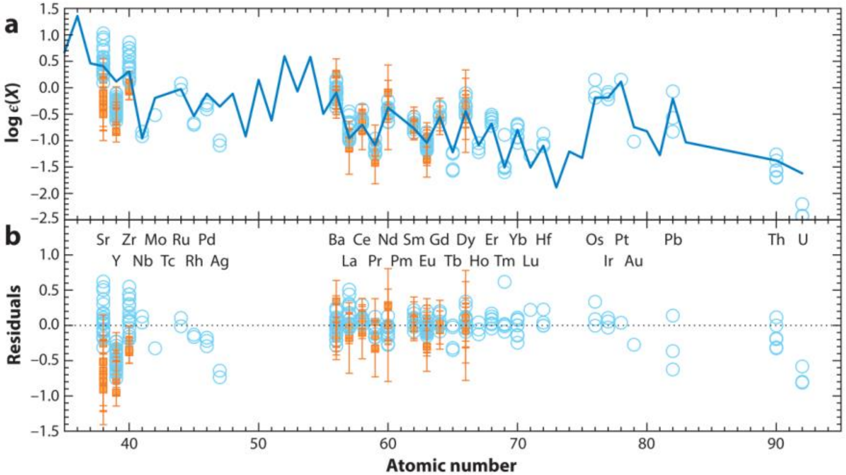
There is observational evidence that the r-process occurs in **neutron star mergers**

There is evidence that there must be **other sites** since:

1. Stars older than neutron stars contain r-process nuclei
2. Some star have an enhanced abundance of light heavy nuclei



r-process path and corresponding abundance peaks (Grawe, 2007)



Comparison between observation and predictions of abundance of r-process nuclei (Frebel, 2018)

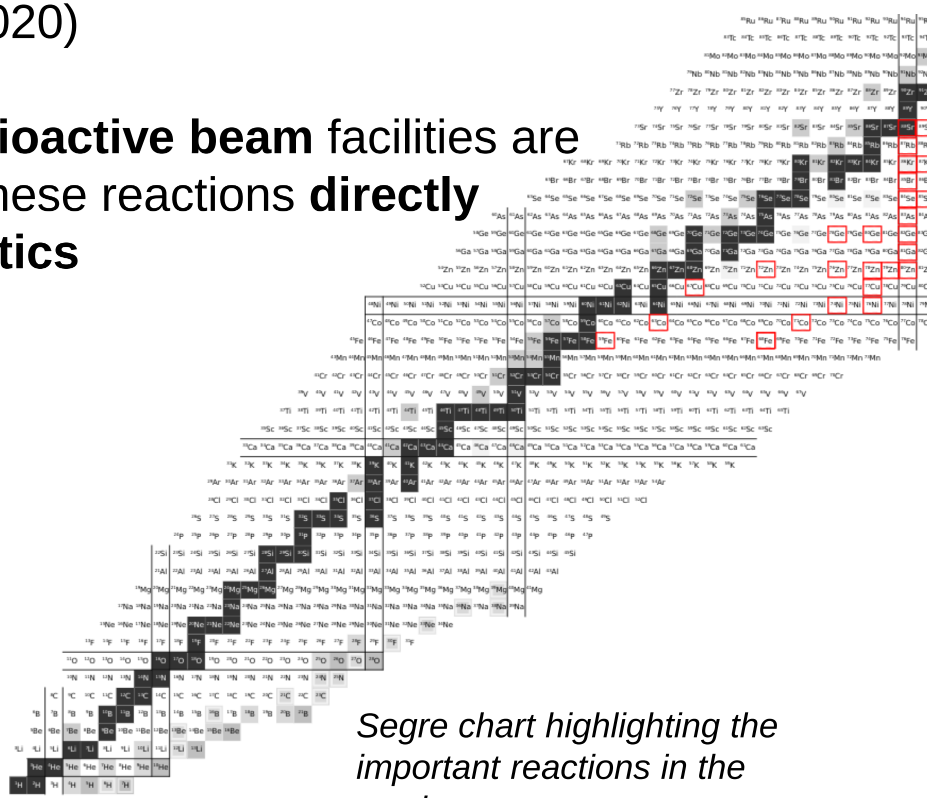
Core-Collapse Supernovae

Core-collapse supernovae are another potential site

Nucleosynthesis is driven by the alpha or **weak r-process** producing elements upto Ag via (a,*n*) reactions

A sensitivity study has identified 45 (α,*n*) reactions which are predicted to be important (Bliss, 2020)

In most cases, **radioactive beam** facilities are required to study these reactions **directly** in **inverse kinematics**



Segre chart highlighting the important reactions in the weak r-process

Artists impression of a core-collapse supernova

Detecting Neutrons

Since **neutrons** have **no charge**, detecting them proves a challenge

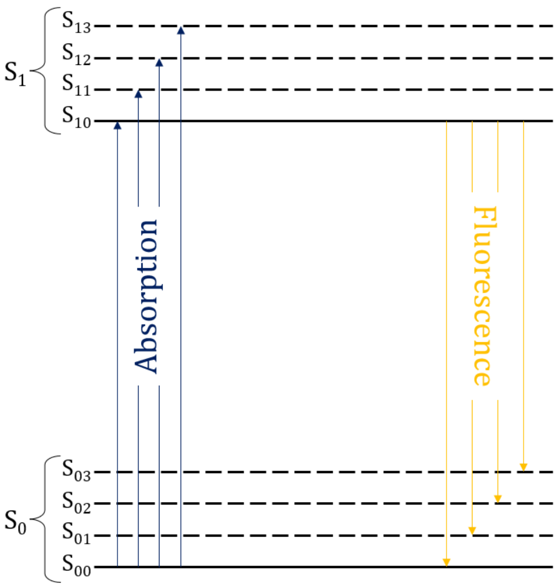
Organic scintillator detectors can be used **identify neutrons** from other events (e.g. γ rays) and provide a **prompt response**

Neutrons will interact with the scintillator material by **scattering of protons**

The **recoiling proton** will then **excite electrons** in the material. When electrons **de-excite**, they will **emit light**

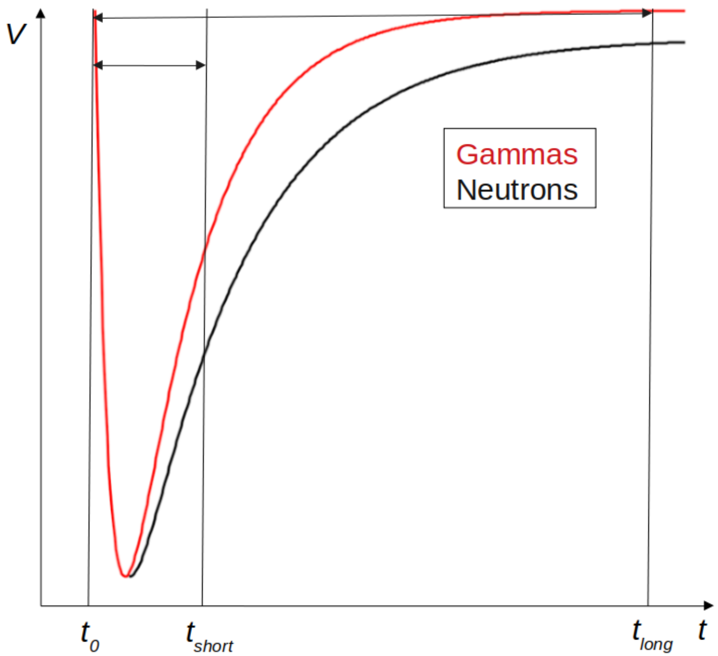
By **collecting the light** produced, using a **PMT** or **SiPM**, the neutron can be detected

*Plastic scintillators (*https://eljentechnology.com/)



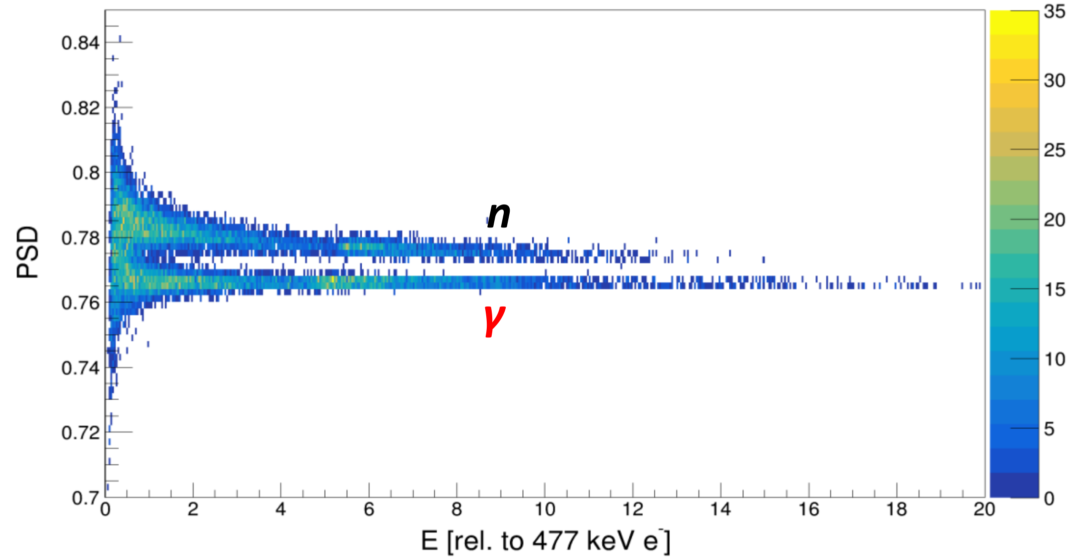
Fluorescence process in an organic scintillator

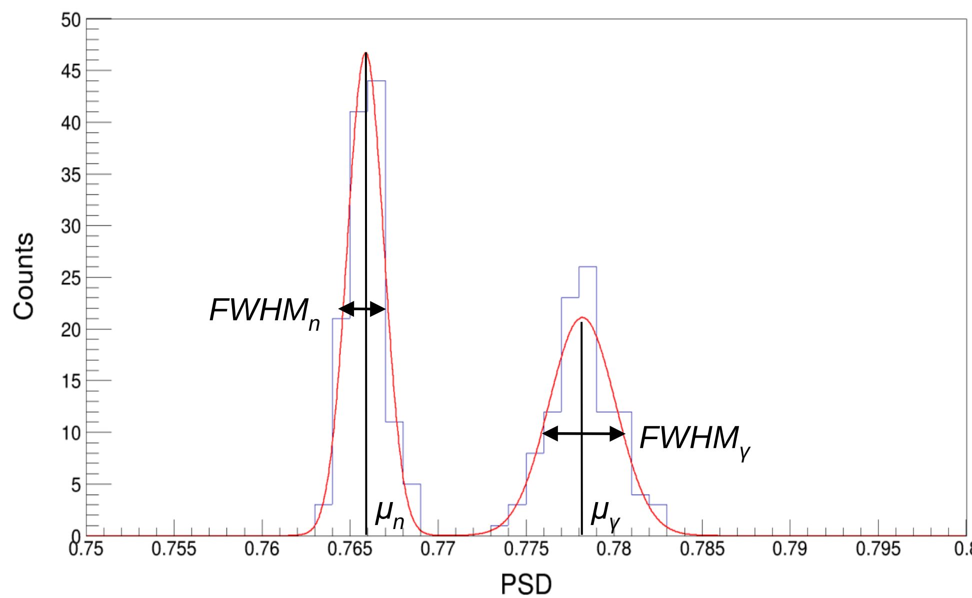
Pulse Shape Discrimination



$$PSD = 1 - \frac{Q_{short}}{Q_{long}}$$

$$FOM = \frac{\mu_n - \mu_\gamma}{FWHM_n + FWHM_\gamma}$$





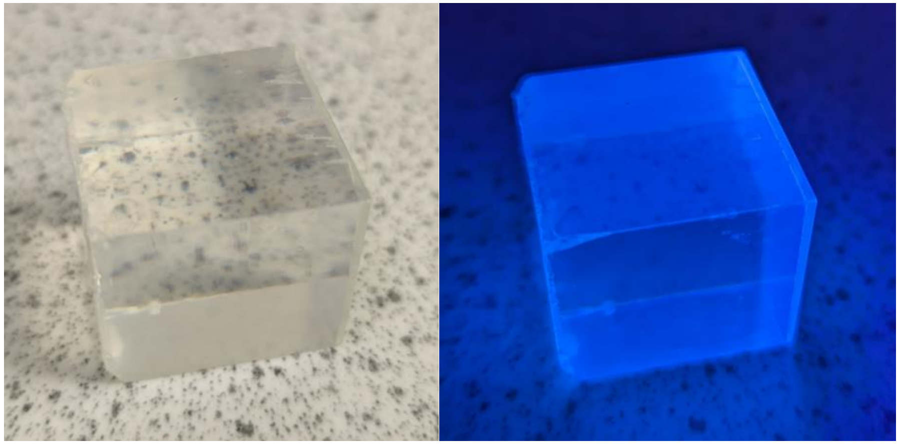
Organic Glass Scintillators (OGS)

Developing an array of **OGS detectors** called **DEMAND** (Direct Experimental Measurements of Astrophysical reactions using Neutron Detectors)

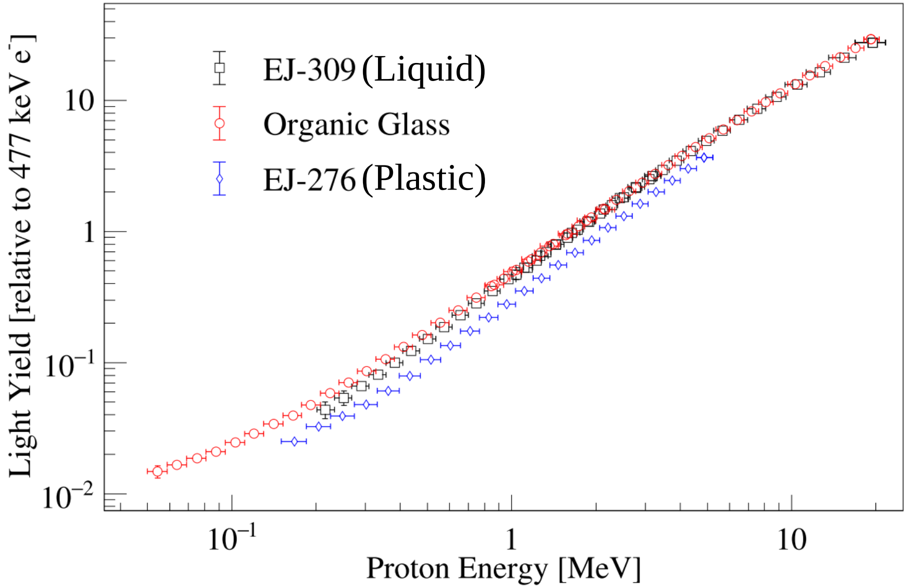
A collaboration between **TRIUMF**, **Saint Mary's University** and the **University of Surrey**, funded by **UK STFC**

OGS detectors made by **BlueShift Optics**

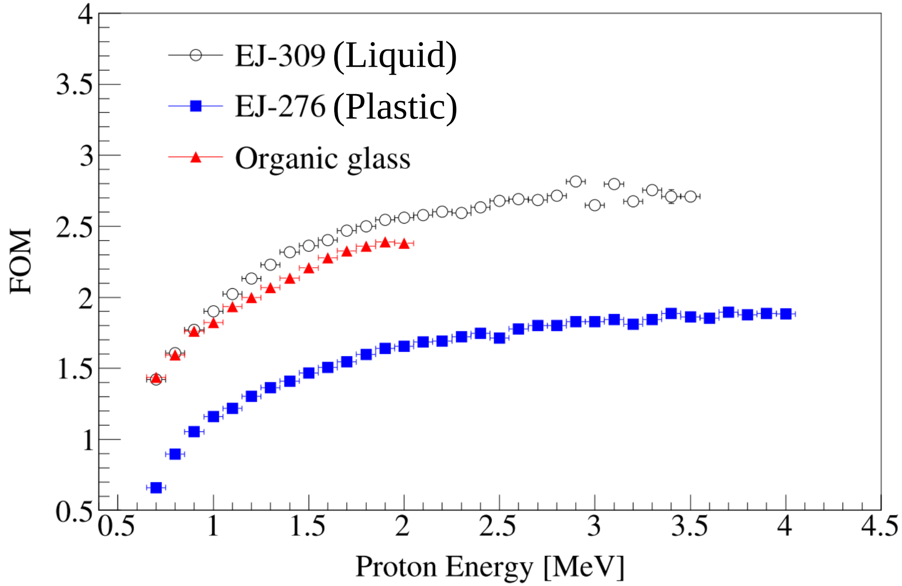
OGS detectors have excellent **PSD**, **light output** and **timing** properties



An OGS cube scintillating under UV radiation



Comparison between the light output of OGS with a plastic and liquid scintillator (Laplace, 2020)



Comparison between the pulse shape discrimination capabilities of OGS with a plastic and liquid scintillator (Laplace, 2020)

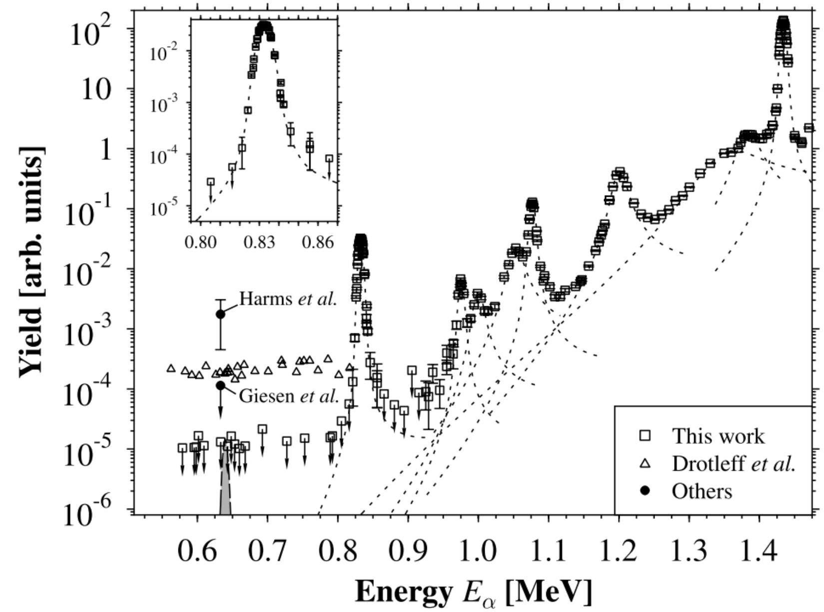
$^{22}Ne(\alpha,n)^{25}Mg$ Reaction

As a proof-of-concept experiment, aim to directly study the ^{22}**Ne(α,*n*)**^{25}**Mg** reaction

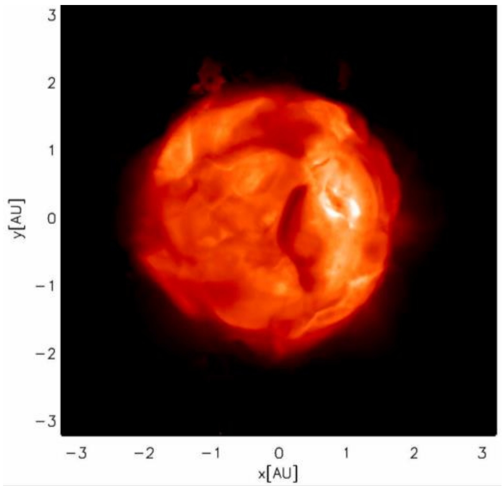
This reaction is the main **source of neutrons** for the **s-process** in AGB stars

Strong resonances have already been **identified** in a measurement performed in **normal kinematics** (Jaeger, 2001)

Resonance at $\boldsymbol{E_r}$ **= 1.43 MeV** has a measured **resonance strength** of **1.067 eV**, making it an ideal test case



Excitation function of the $^{22}Ne(\alpha,n)^{25}Mg$ reaction (Jaeger, 2001)



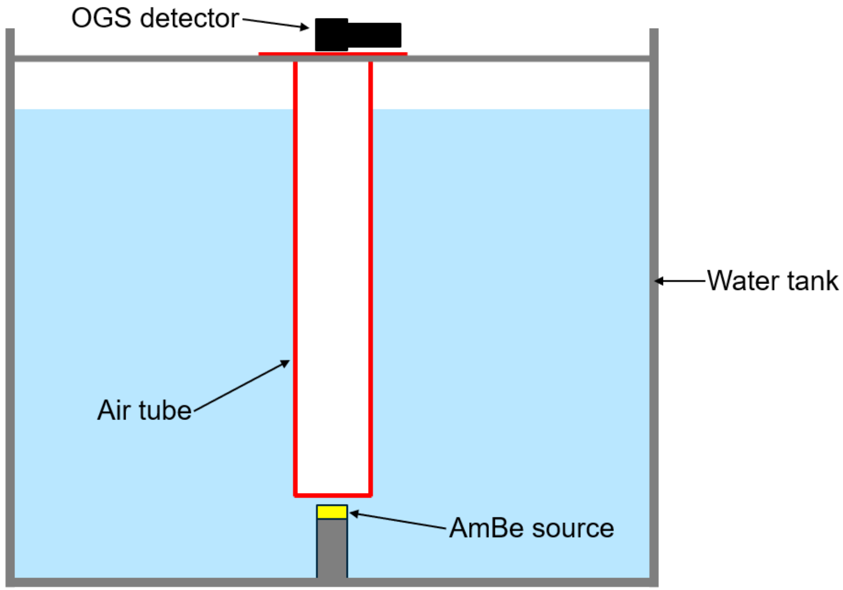
Simulation of an AGB star (credit: A. Chiavassa, B. Freytag, M. Schultheis)

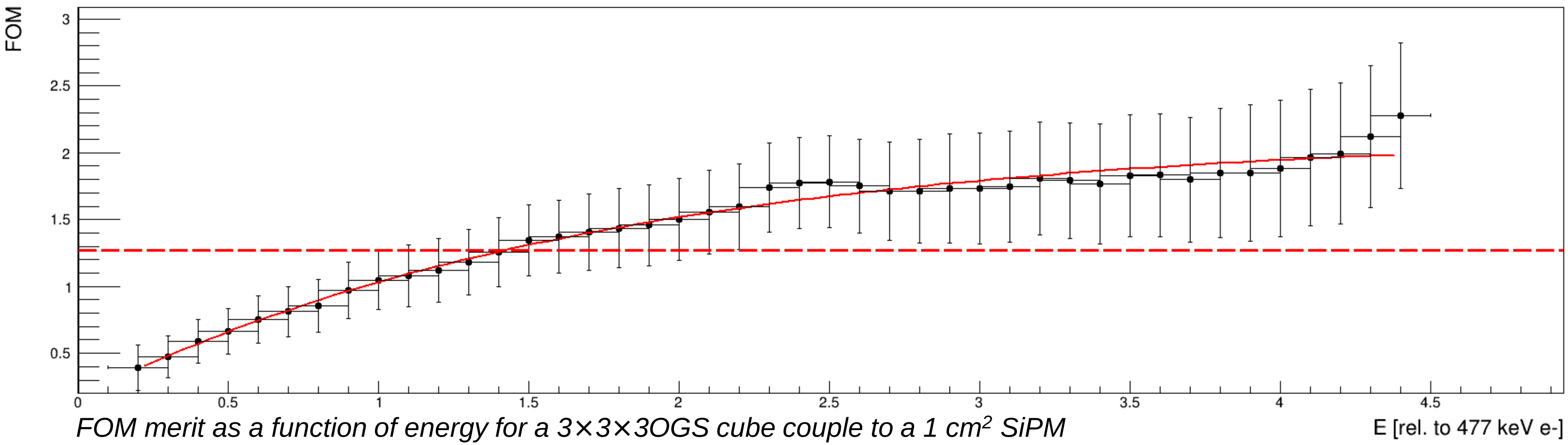
Detector Tests

Tests of detector capabilities carried out at the University of Surrey using an **AmBe source**

Tested two methods of light collection – PMT and SiPM

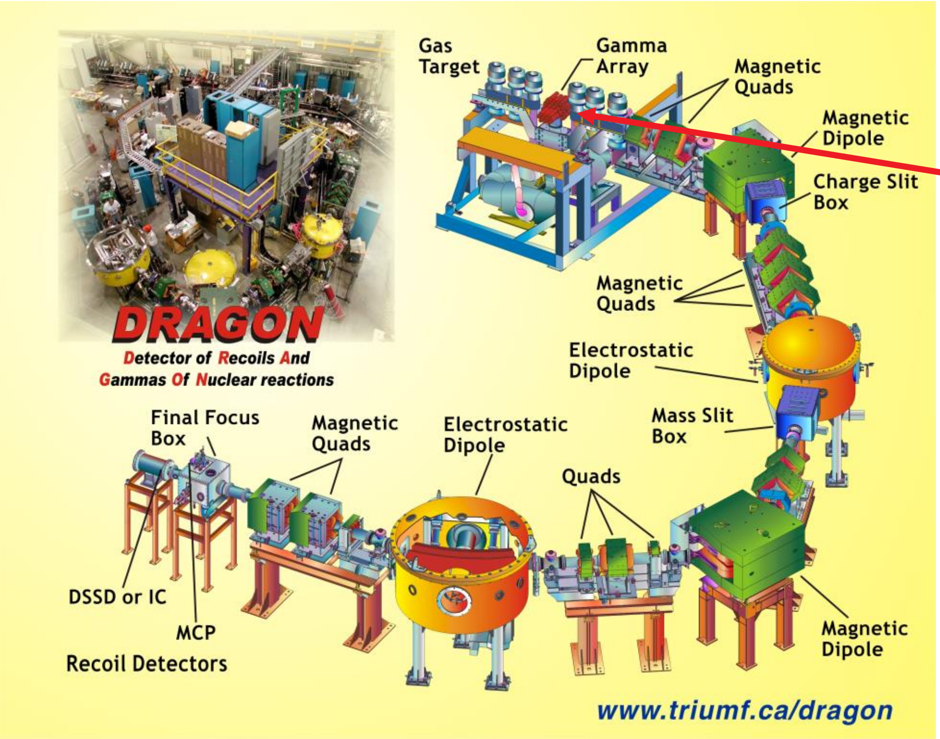
Predicted **detector efficiency** is **13%**

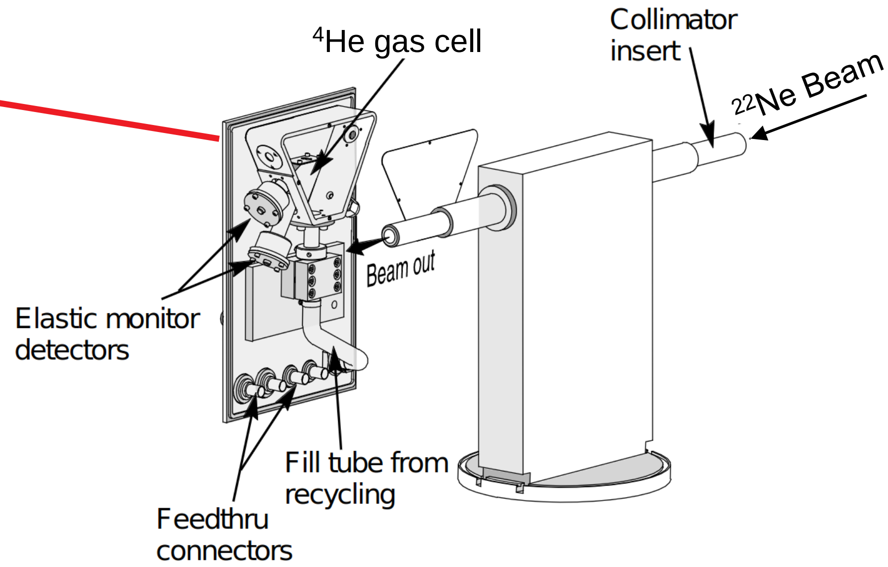




FOM merit as a function of energy for a 3×3×3OGS cube couple to a 1 cm² SiPM

Experiment Setup @ TRIUMF



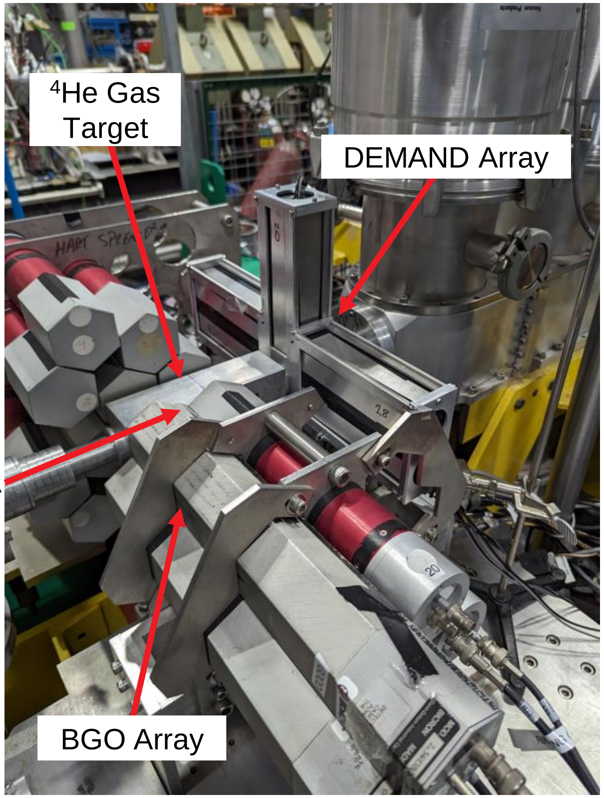


Beam of **8.14-MeV ^{22}Ne** impinged onto **^{4}He windowless gas target**

Neutrons detected in an array of **8 OGS detectors**

The **DRAGON spectrometer** was tuned for **^{25}Mg recoils**, which were be detected using a **DSSD** and pair of **MCPs**

Experiment Setup @ TRIUMF



Eight enclosed OGS Detectors

Beam of **8.14-MeV ^{22}Ne** impinged onto **^{4}He windowless gas target**

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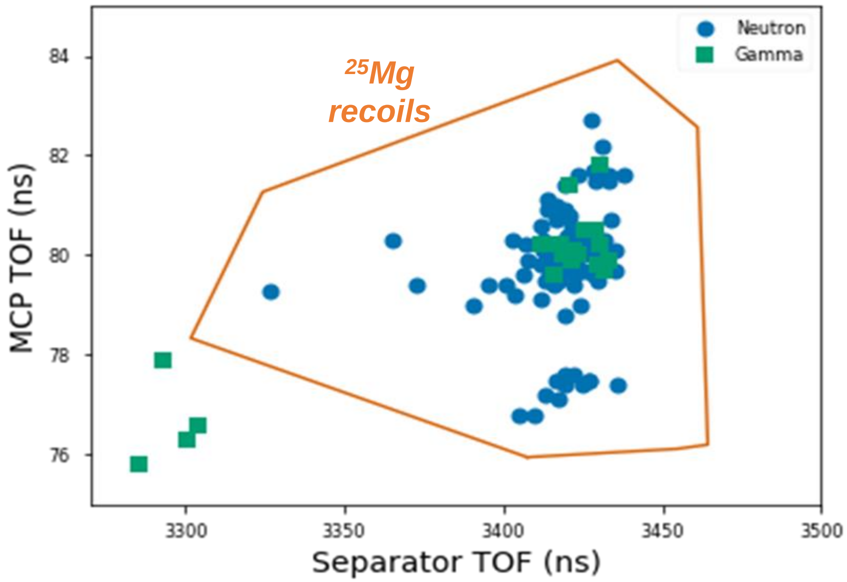
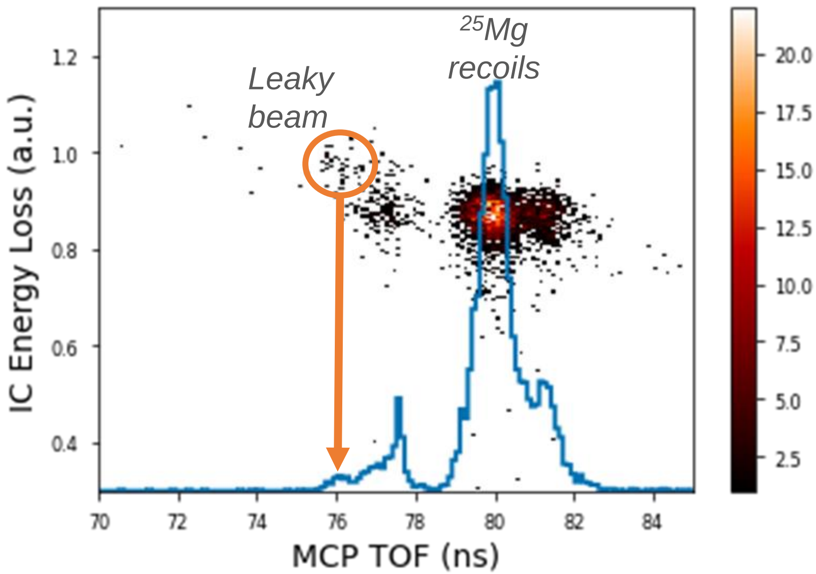
Preliminary Results: Recoil ID

Coincidences – MCP TOF vs. Separator TOF



Singles – Ion Chamber ΔE vs MCP TOF

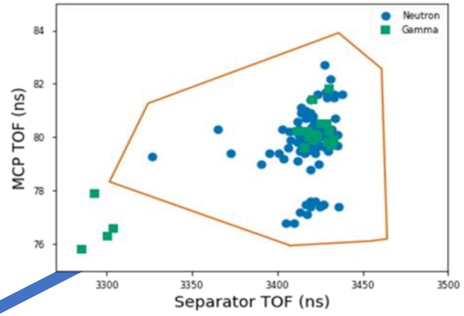


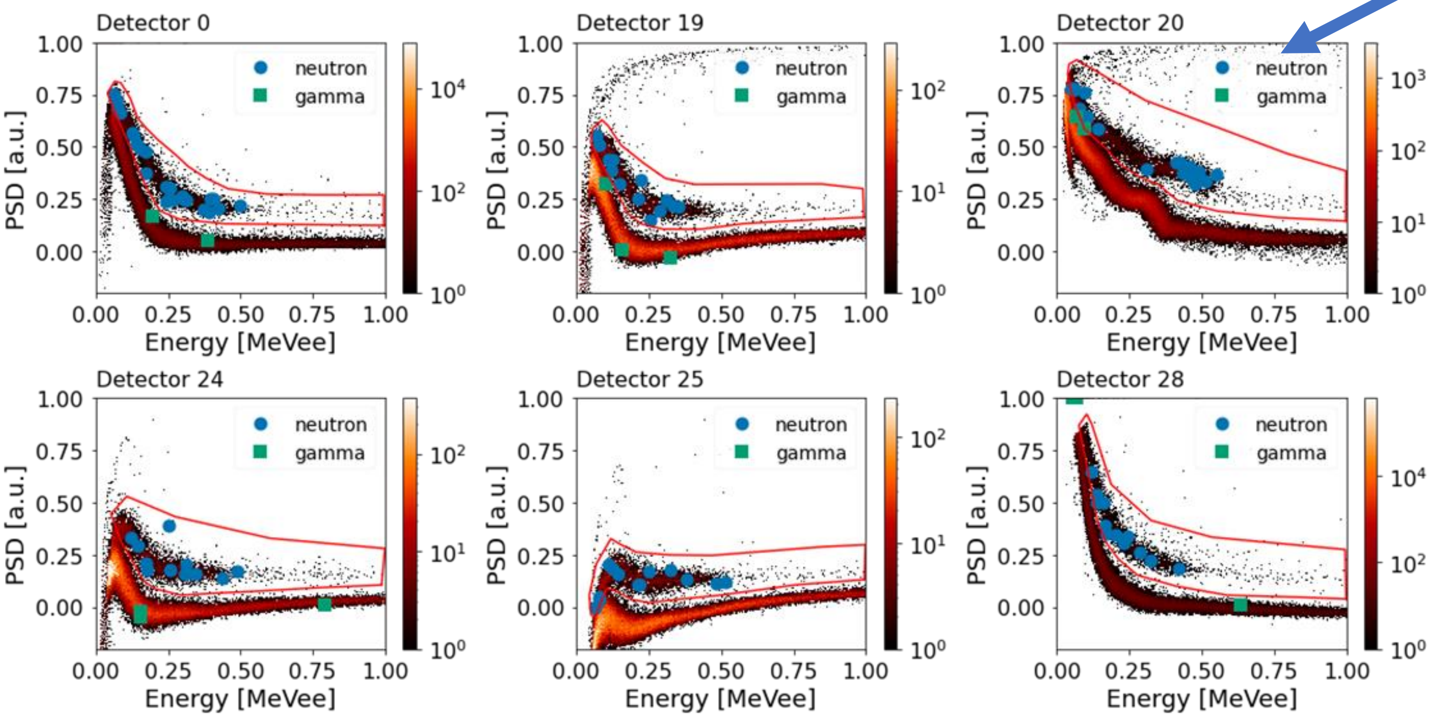
Figures courtesy of G. Christian

Preliminary Results: n/γ PSD

TRIUMF
Saint Mary's University

Most coincidences show up in neutron band in PSD plot





Good prospects for neutron singles measurement as well.

Preliminary $\omega\gamma$ ~ 790 meV
Good agreement w/ literature

Figures courtesy of G. Christian

Conclusions

The **DEMAND array** has been developed to **directly study (α,*n*) reactions** in inverse kinematics

A **proof-of-principle experiment** was carried out to measure the strength of the **1.43-MeV resonance** in the **^{22}Ne(α,*n*)^{25}Mg** reaction

Results show the **excellent PSD** capabilities of the OGS detectors

Preliminary calculations of the **resonance strength** gives a values that is **close to the literature value**

Improved simulations are required to determine the **detection and transport efficiency**

Future Work

Finalise calculations of resonance strength of 1.43 MeV resonance in the ^{22}Ne(α,*n*)^{25}Mg reaction

Perform calculation using **singles data** to verify if array can be used in singles only

Potential future reactions to study:

- The xxx resonance in the **^{22}Ne(α,*n*)^{25}Mg** reaction as this is predicted to be the dominant resonance

- **^{88}Sr(α,*n*)^{91}Zr** – one of the 45 reactions predicted to be **important for the week r-process** and **^{88}Sr is stable**

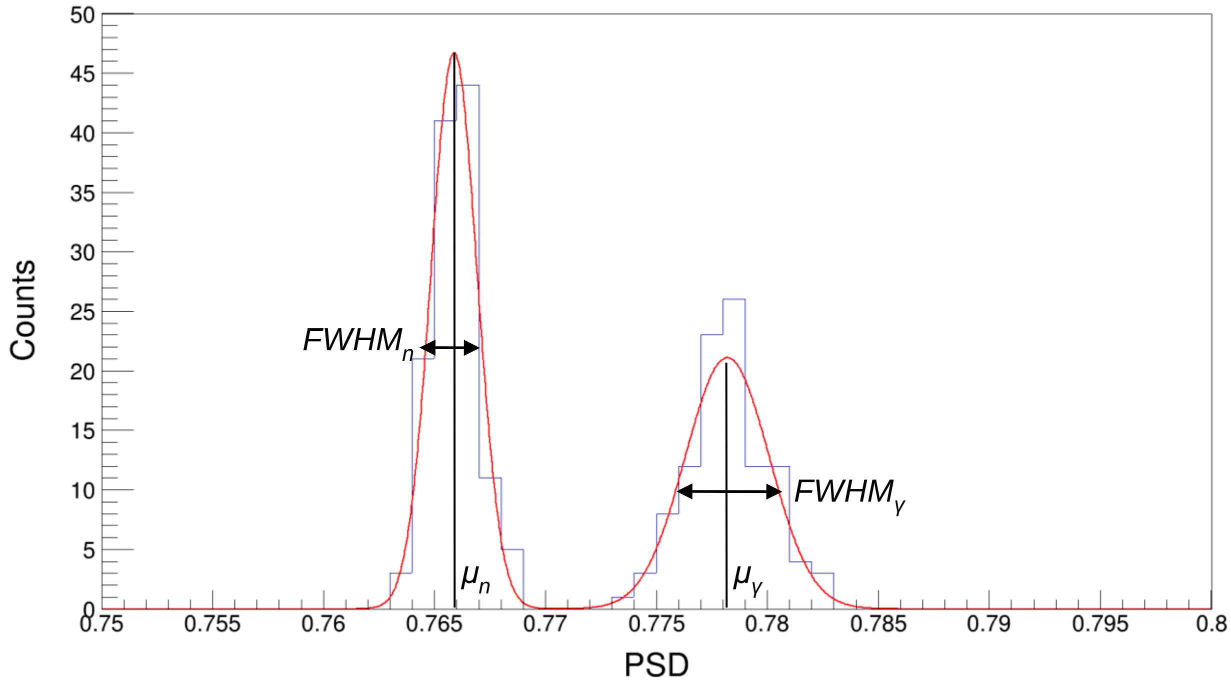
- **^{59}Fe(α,*n*)^{62}Ni** – the **lightest reaction** that is **important for the week r-process**

Acknowledgements

G. Lotay[1], G. Christian[2], C. Ruiz[3,4], A. Lennarz[3], G. Bartram[1], S. Collins[5], D.T. Doherty[1], J. Henderson[1], D. A. Hutcheon[3], A. Katrusiak[3], M. Loria[3,4], C. O'Shea[1], C. Paxman[1], P. Regan[1,5], L. Wagner[3], M. Williams[1]

[1] University of Surrey, UK
[2] Saint Mary's University, Canada
[3] TRIUMF, Canada
[4] University of Victoria, Canada
[5] National Physics Laboratory, UK

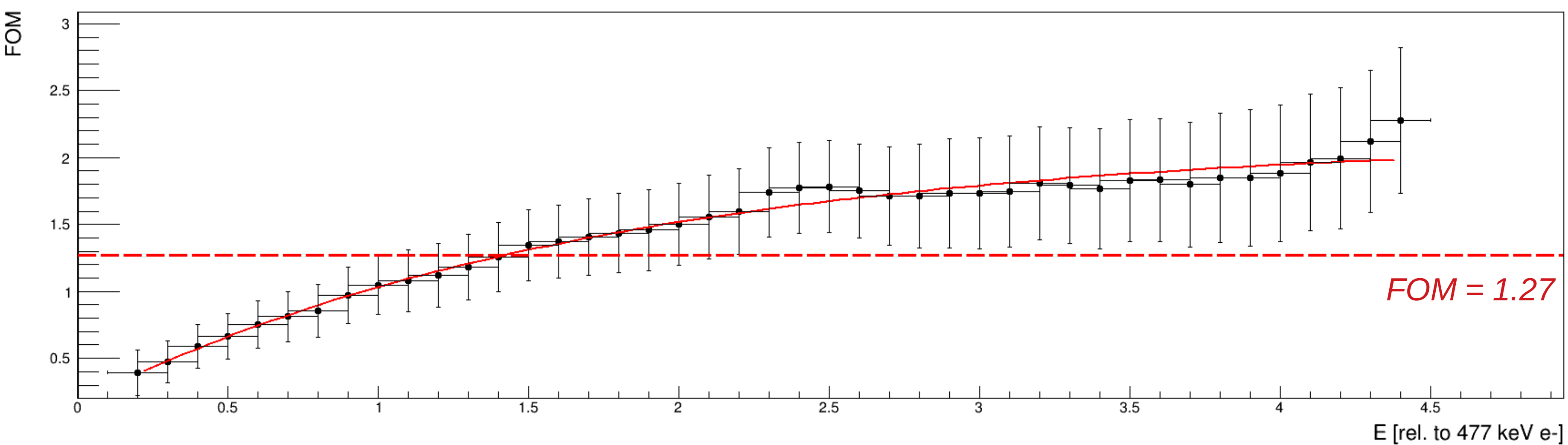
Pulse Shape Discrimination

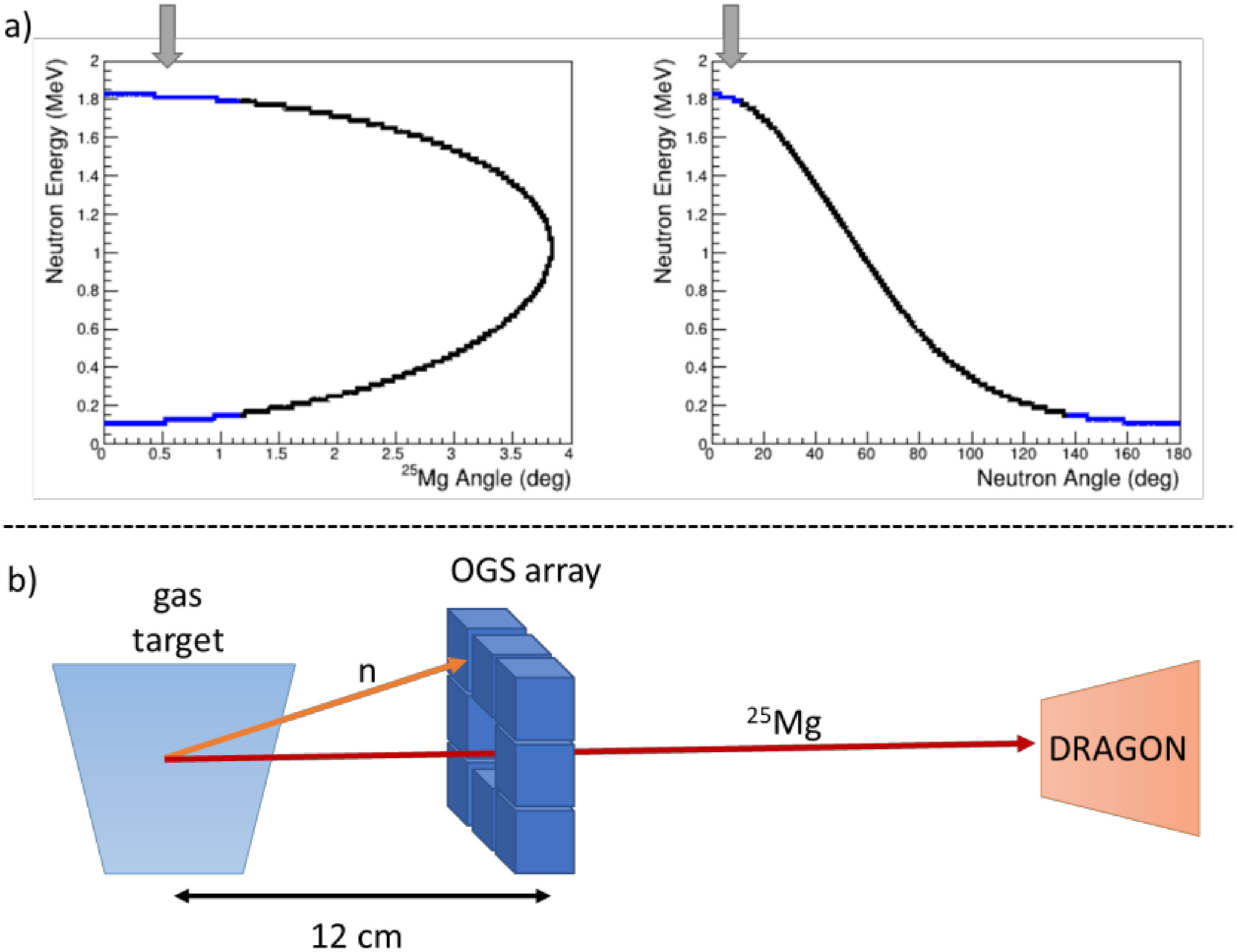


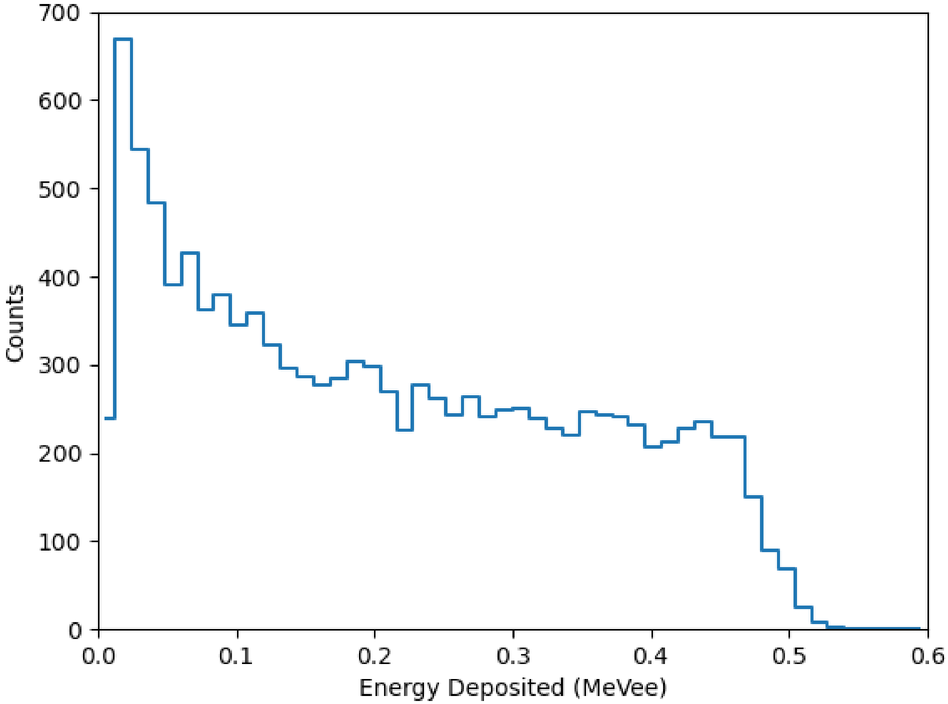
$$FOM = \frac{\mu_n - \mu_\gamma}{FWHM_n + FWHM_\gamma}$$

Average **minimum distinguishable energy** is **617 keVee**

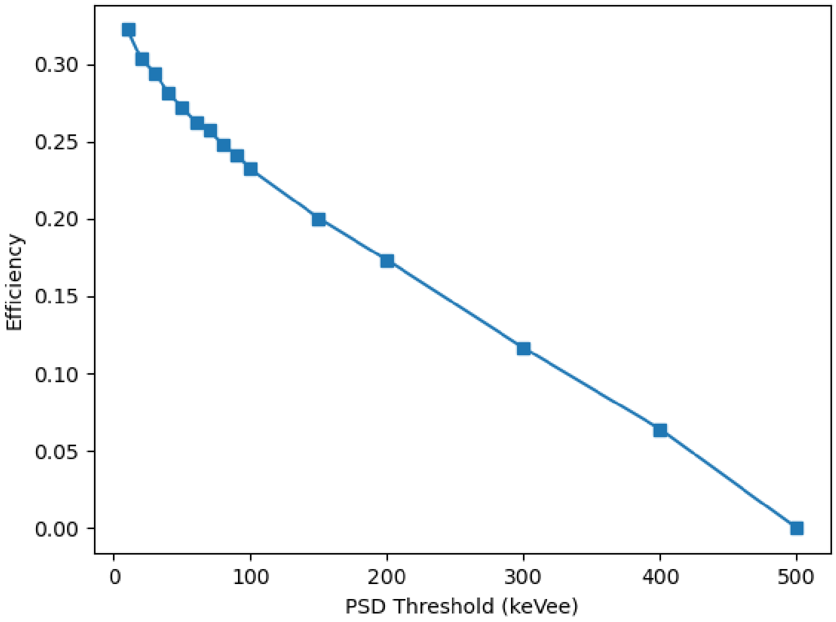
With better light collection this should be reduced to ~100 keVee



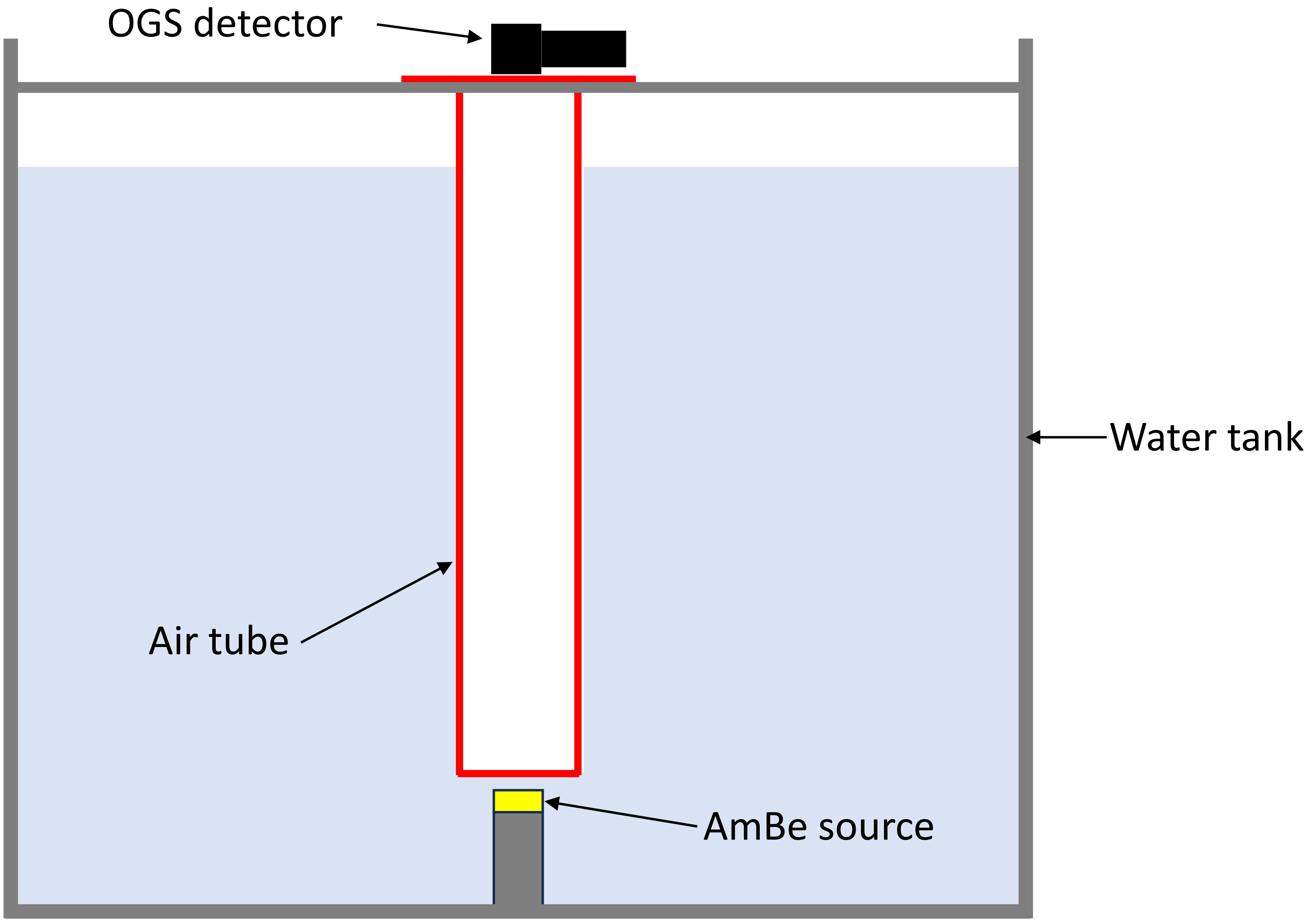

a)
Neutron Energy (MeV)
25Mg Angle (deg)
Neutron Energy (MeV)
Neutron Angle (deg)
b)
gas target
OGS array
n
25Mg
DRAGON
12 cm

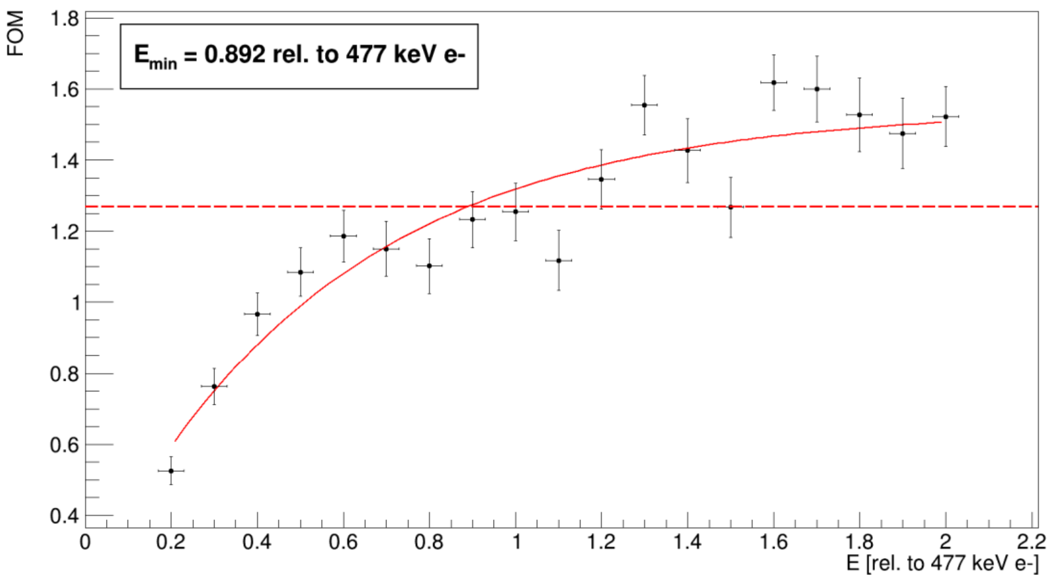


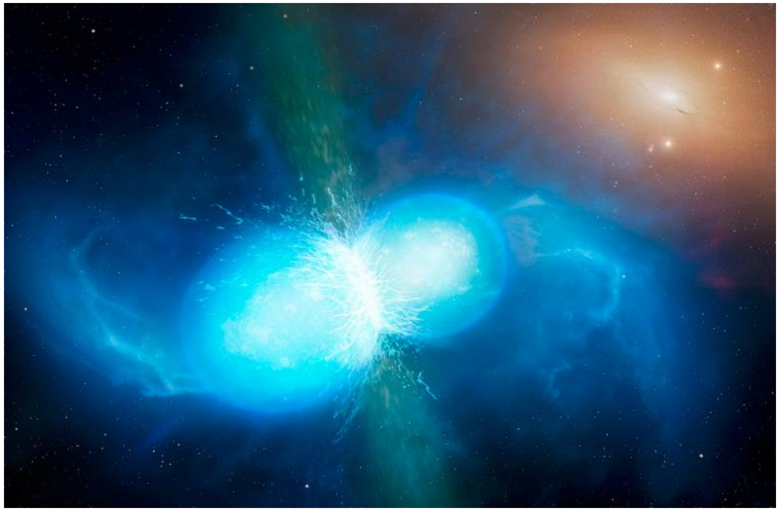
700
600
500
400
300
200
100
0
Counts
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Energy Deposited (MeVee)



0.30
0.25
0.20
0.15
0.10
0.05
0.00
Efficiency
0
100
200
300
400
500
PSD Threshold (keVee)


OGS detector
Water tank
Air tube
AmBe source





Artists impression of a neutron star merger (Credit: University of Warwick/ Mark Garlick)