The ^{18}F (α,p)^{21}Ne reaction: neutron source for r-process in supernovae

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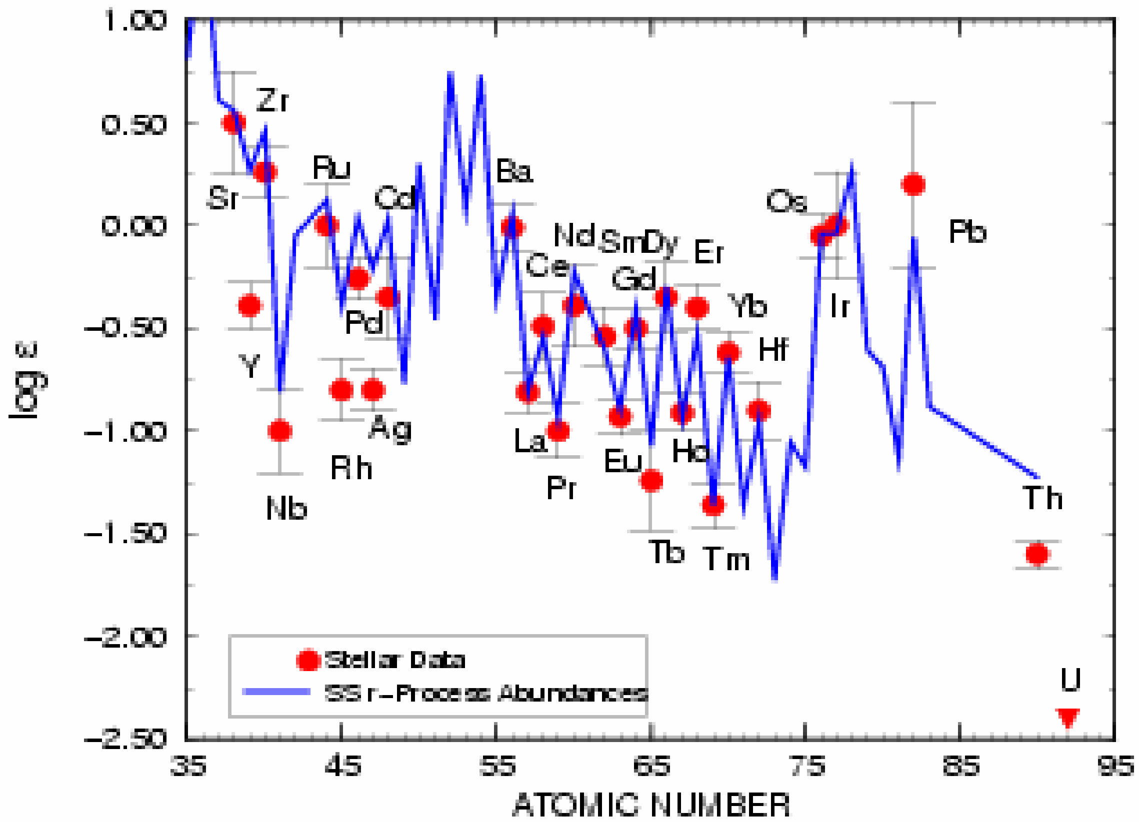
A possible alternative site to the r-process?



J.Cowan et al. The 10th workshop on Nuclear Astrophysics (2000) 64

- The main r-process: A ≥ 130~140
- The weak r-process: A ≤ 130~140

Why $^{18}F(\alpha,p)^{21}Ne$ in supernova shock front?

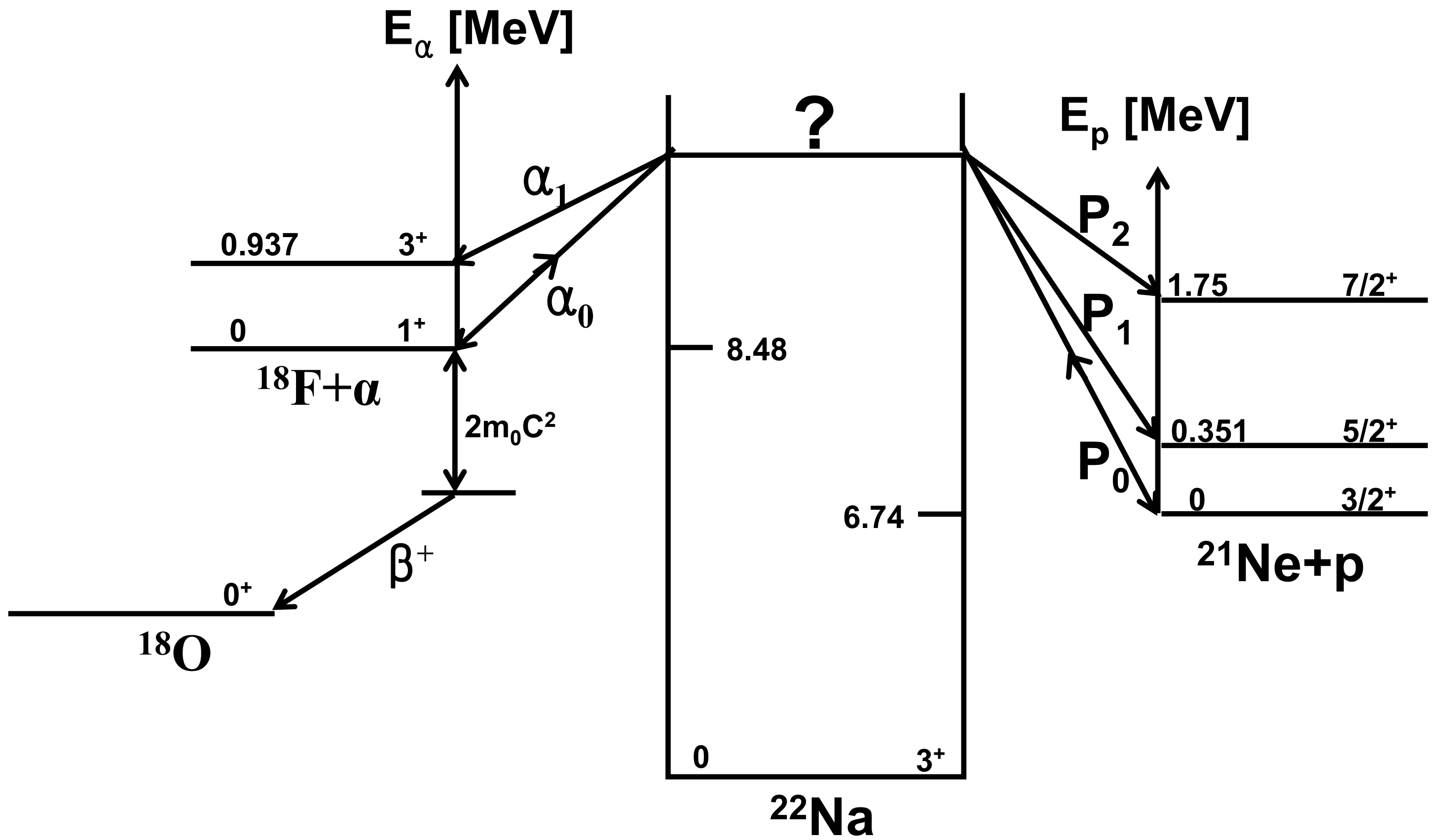
The possible neutron sources:

a. $^{14}N(\alpha,\gamma)^{18}F(\beta^+,\nu)^{18}O(\alpha,\gamma)^{22}Ne(\alpha,n)^{25}Mg$
b. $^{14}N(\alpha,\gamma)^{18}F(\beta^+,\nu)^{18}O(\alpha,n)^{21}Ne(\alpha,n)^{24}Mg$
c. $^{18}F(\alpha,p)^{21}Ne(\alpha,n)^{24}Mg$

★ At the low temperature (up to T_9=0.4): $^{18}F(\beta^+,\nu)^{18}O$ is dominant.
★ At the high temperature : $^{18}F(\alpha,p)^{21}Ne$ reaction is more favored.

As the stage of r-process, the explosive helium burning is valid during the supernova explosion(T_9~1). But the reaction rate is not yet determined experimentally.

Nuclear physics aspect



Cross section

1+2⟶3+4

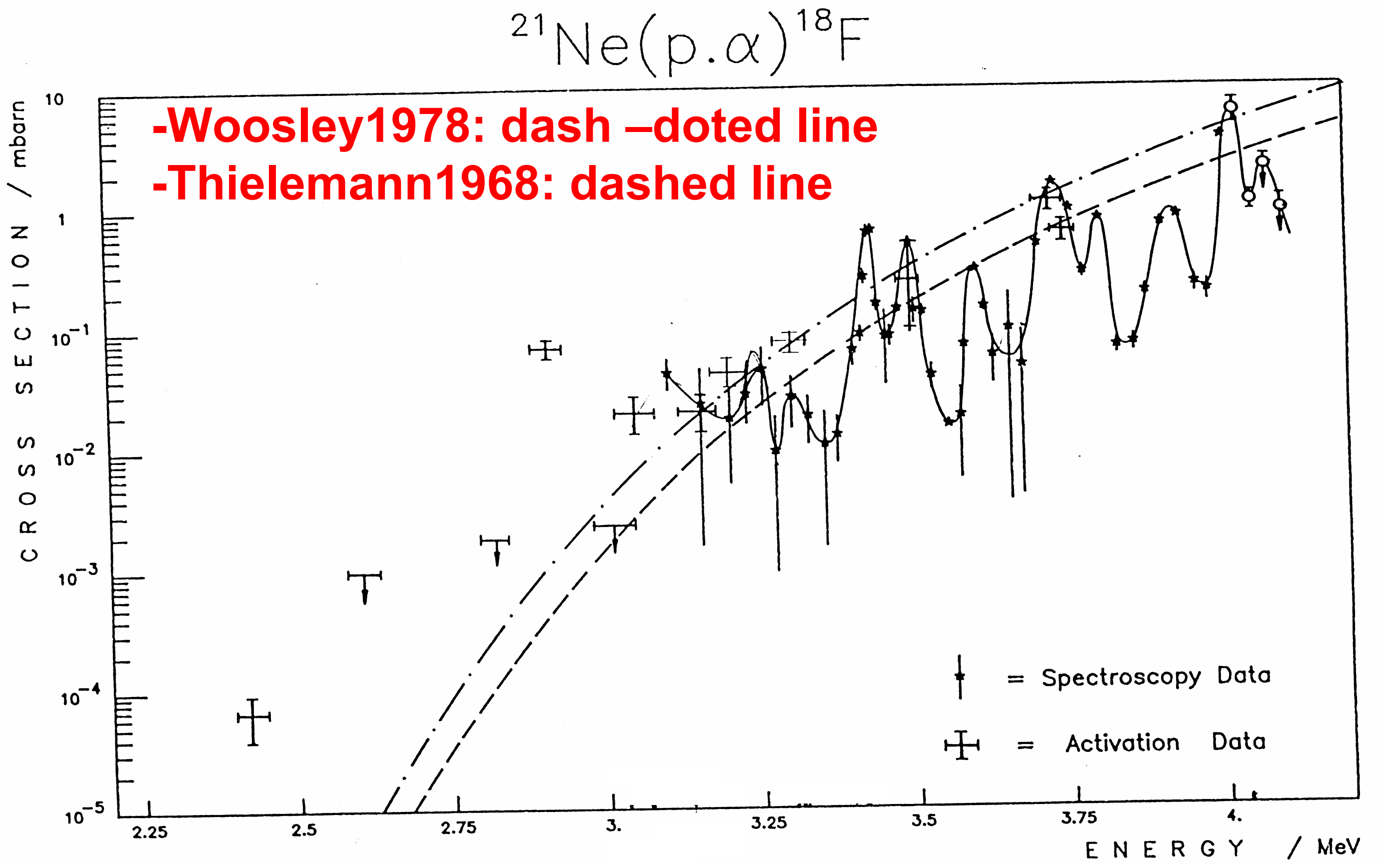
$$\frac{\sigma_{12}}{\sigma_{34}} = \frac{(2j_3+1)(2j_4+1)\,m_3 m_4 E_{34}}{(2j_1+1)(2j_2+1)\,m_1 m_2 E_{12}}$$

Previous measurement of $^{21}Ne(p,\alpha)^{18}F$

In 1987, U.Giesen(Münster Univ.) measured the cross section with gas target by

[1] the α−spectroscopy using ΔE−E detector (SSB) at Ep=3.2~4.05MeV

[2] the activation method using NaI detector

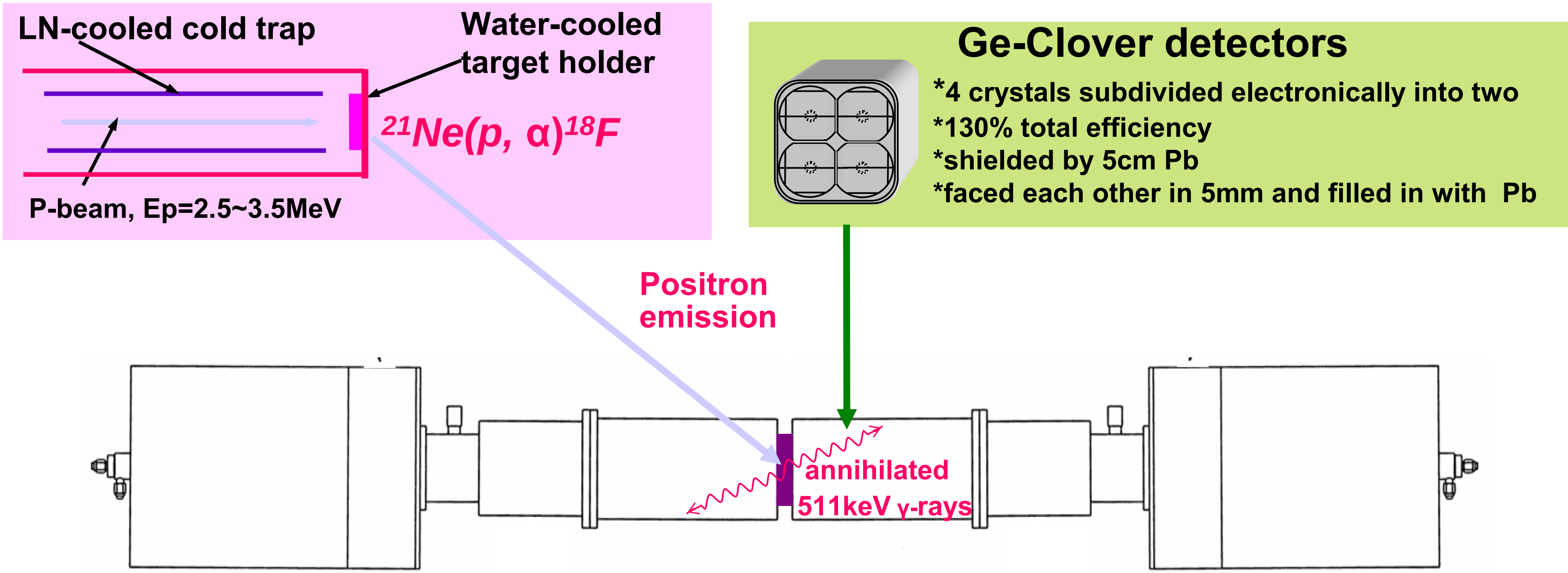


$^{21}Ne(p,\alpha)^{18}F$ by Activation Method at ND

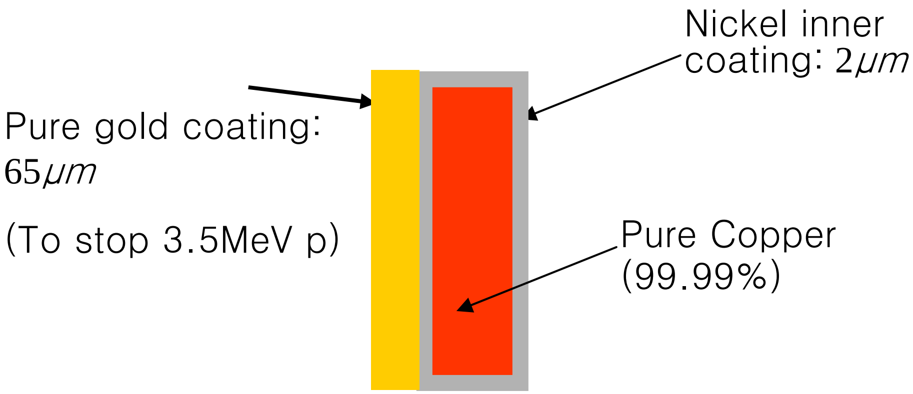
☸ Advantages of activation method:

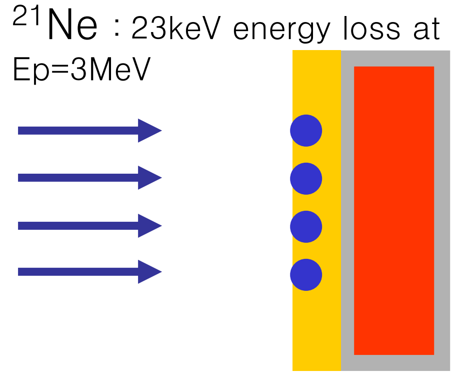
- increase the sensitivity
- determine total cross section independent of angular distributions
- at these low proton energies, no other open reaction channel, but $^{18}O(p,n)\ ^{18}F$
- higher beam current
- better peak-to-background ratio

☸ Set-up:

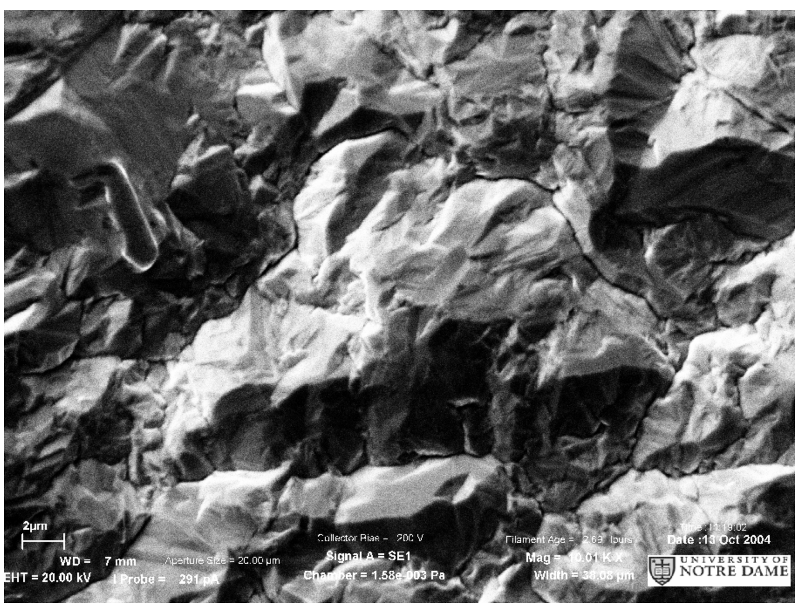


Scanning Electron Microscope(SEM) for target

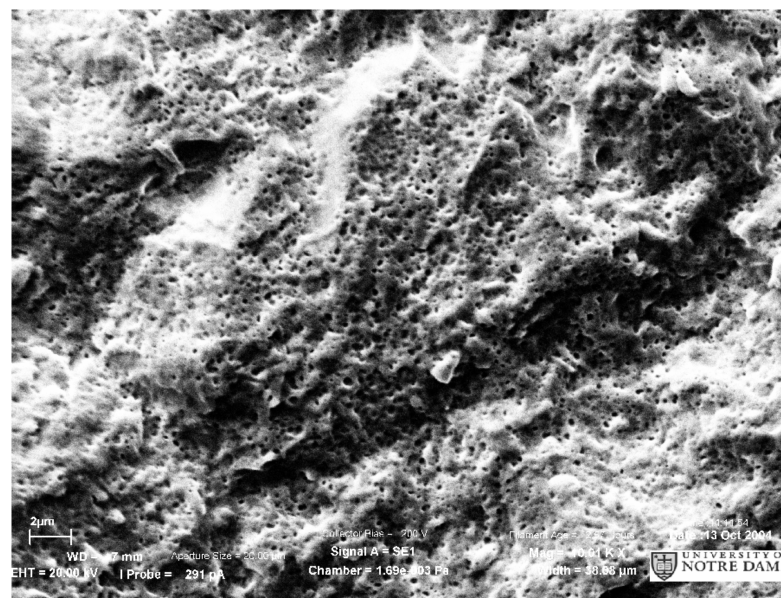




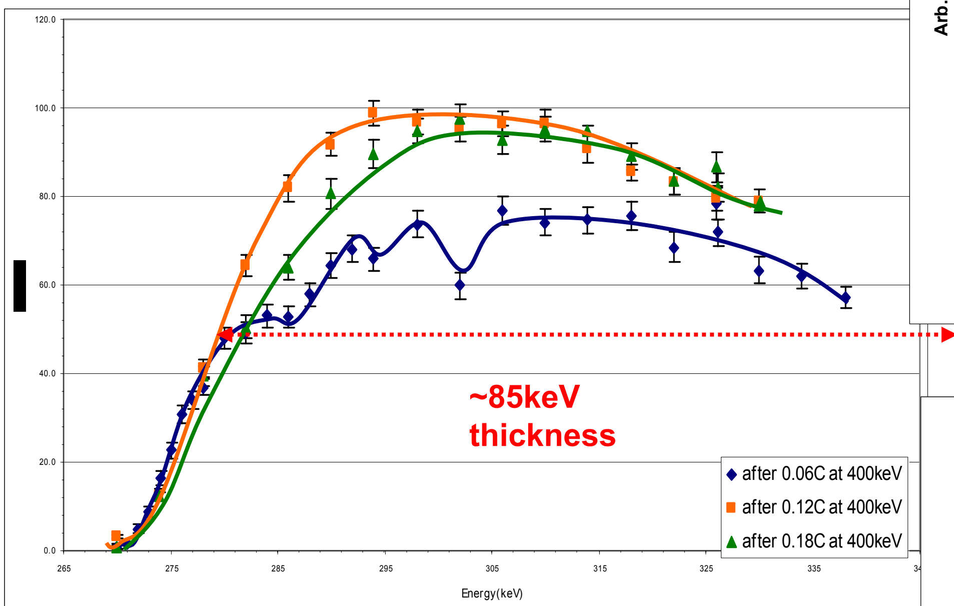
Before implantation: Au/Cu backing

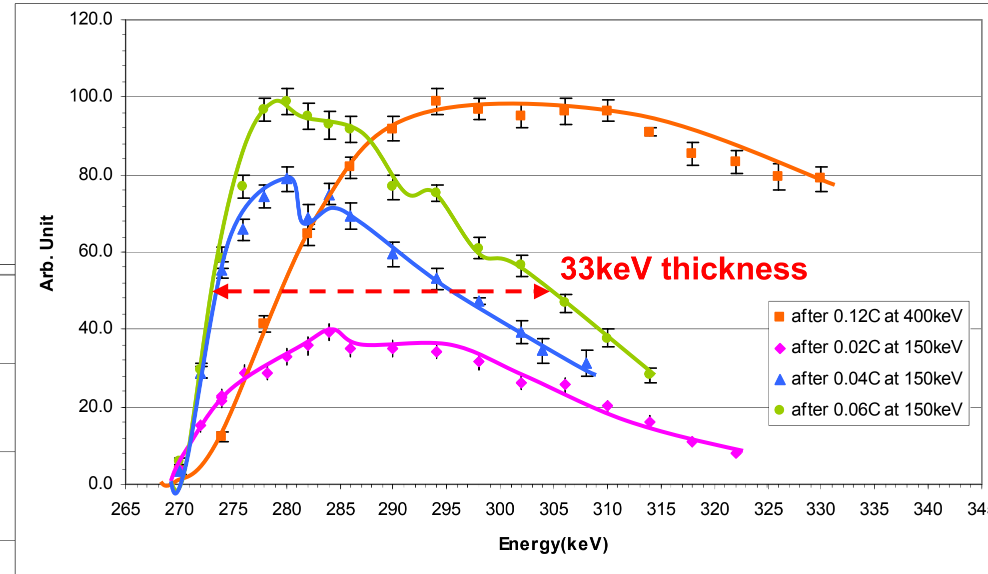


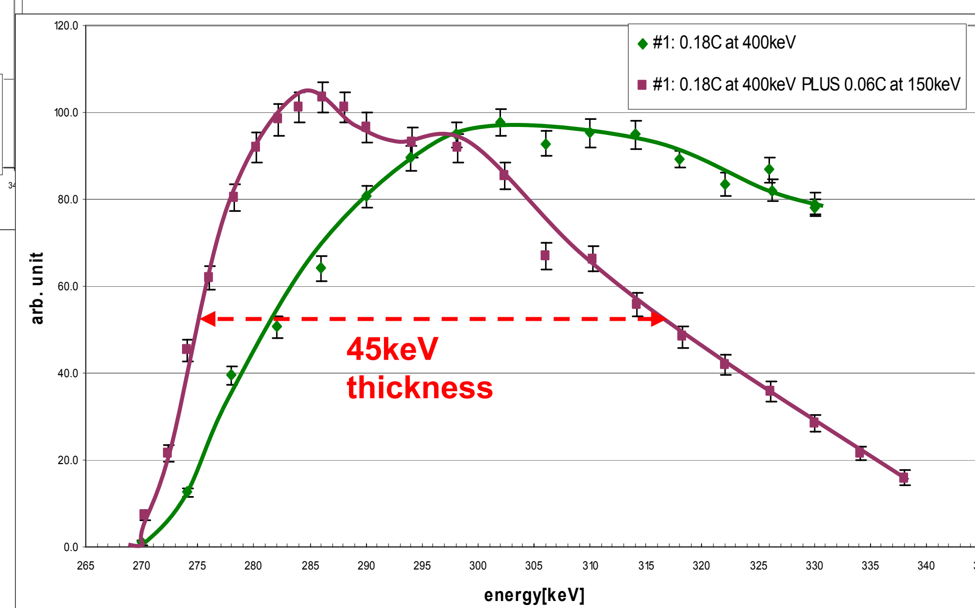
^{21}Ne (@400+150keV), Q=0.24C implanted: Au/Cu backing



target test $^{21}Ne(p,\gamma)$ at E_p=272keV







Surface cleaning to remove oxygen

A. Test different chemicals with activation method with KN

:bombarding proton(Ep=3MeV) for 4hours, then counting ^{18}F. due to $^{18}O(p,n)$

[1] Blank Au/Cu

[2] Implanted target by ^{20}Ne

[3] Blank, after rinsing with 99.7% acetone

[4] Blank, after baking with heat gun for 20min.

B. Test with Deuteron-Induced ɣ-ray Emission(DIGE) with FN

:measuring 871keV, which is transition from 1st excited to ground state of $^{16}O(d,p\gamma)\,^{17}O$ at Ed=2MeV

[1] Blank Ta

[2] Blank Au/Cu

[3] Blank, after dipping in 2% HF* for 1min and rinsing with DI water

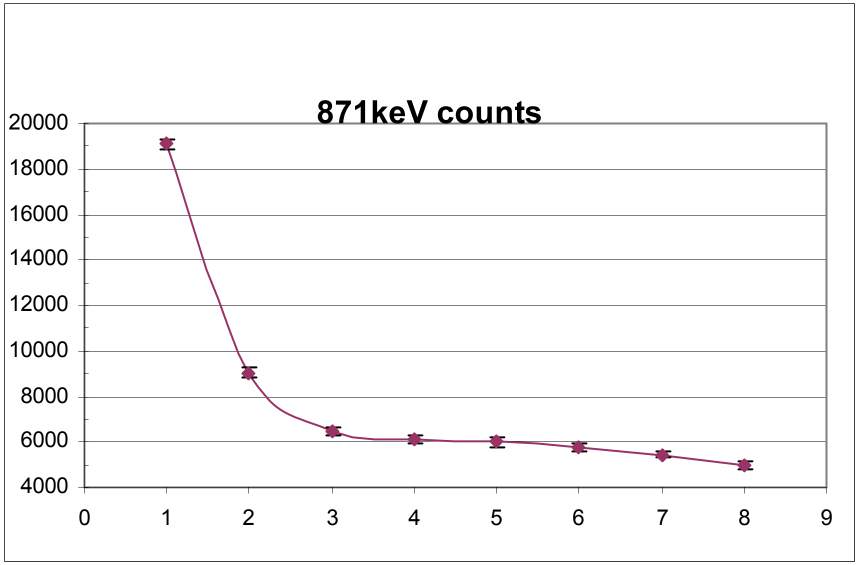
[4] Blank, after [3] and baking for 10min above 100°C

[5] Blank, after [4] and baking for 20min above 100°C

[6] Blank, after dipping in 2% HF for 2min, rinsing with DI water, Acetone, Alcohol under Ar gas flushing

[7] Blank, after [6] and baking for 10mn above 100°C

[8] Blank, after [7] and baking for 20min above 100°C

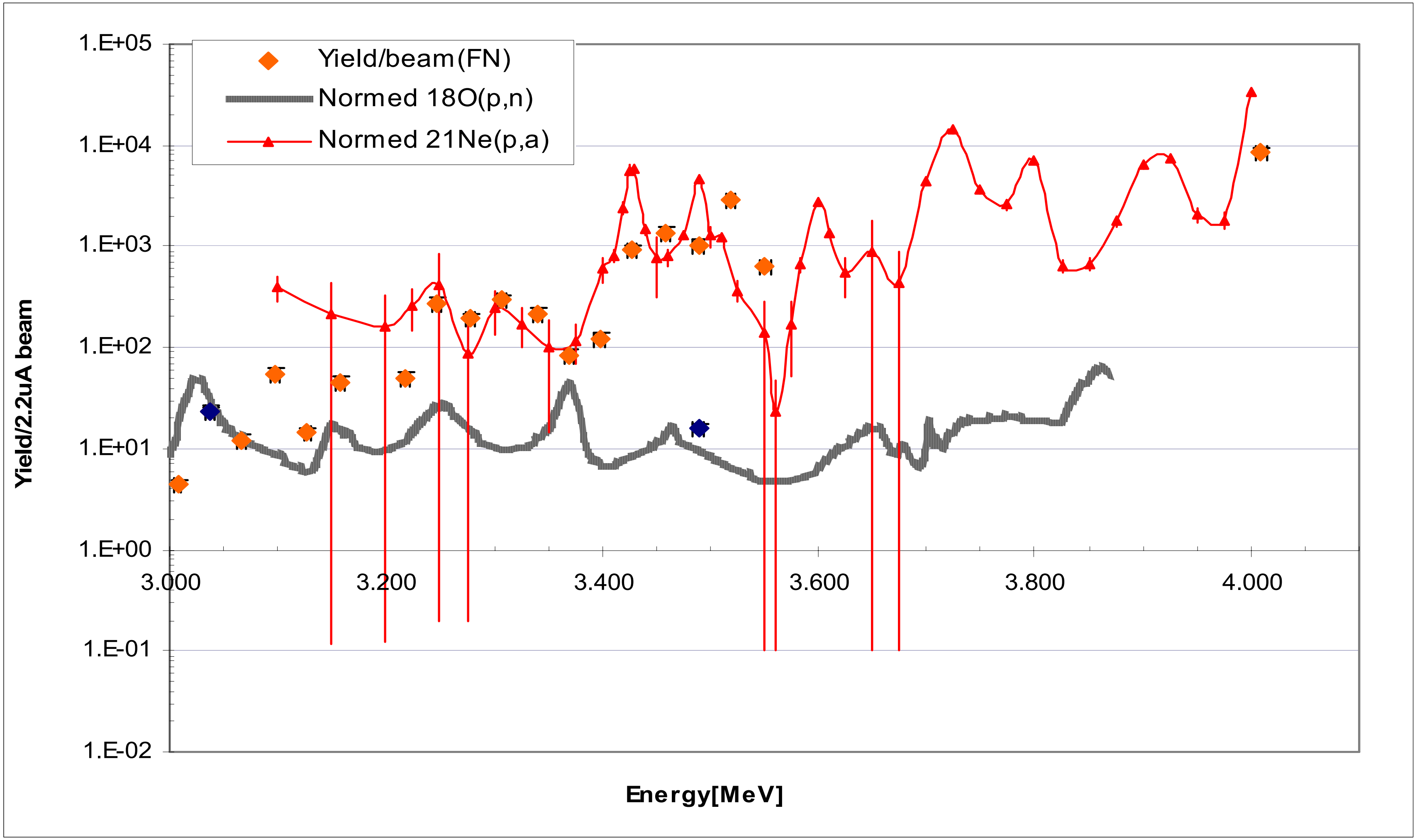


*:Reference to RCA cleaning procedure for wafers

Activation with FN

*Energy range : 3MeV ~ 4MeV

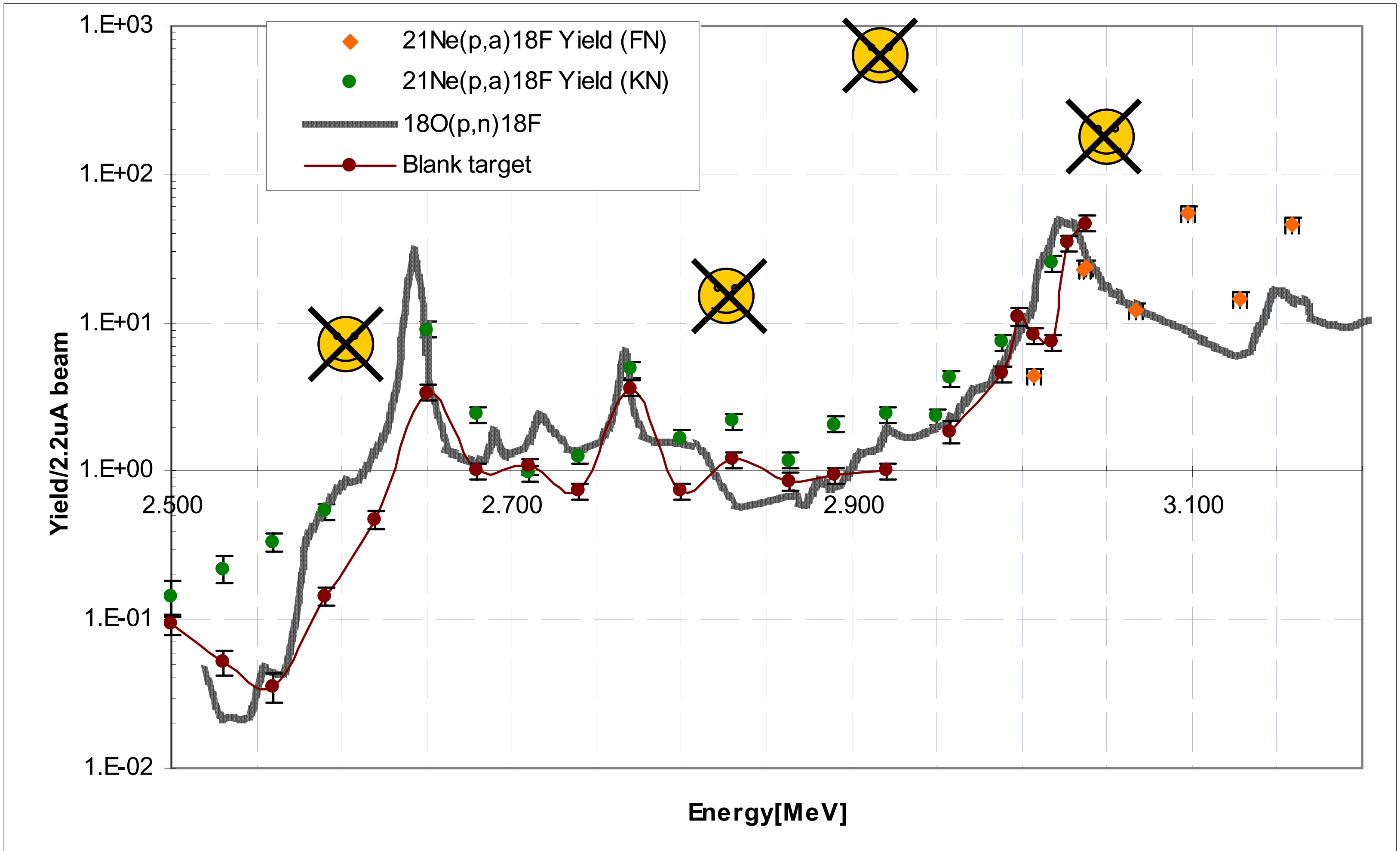
*Beam current : 1.7 μA ~ 4.2 μA



Activation with KN

*Energy range : 2.5MeV ~ 3MeV

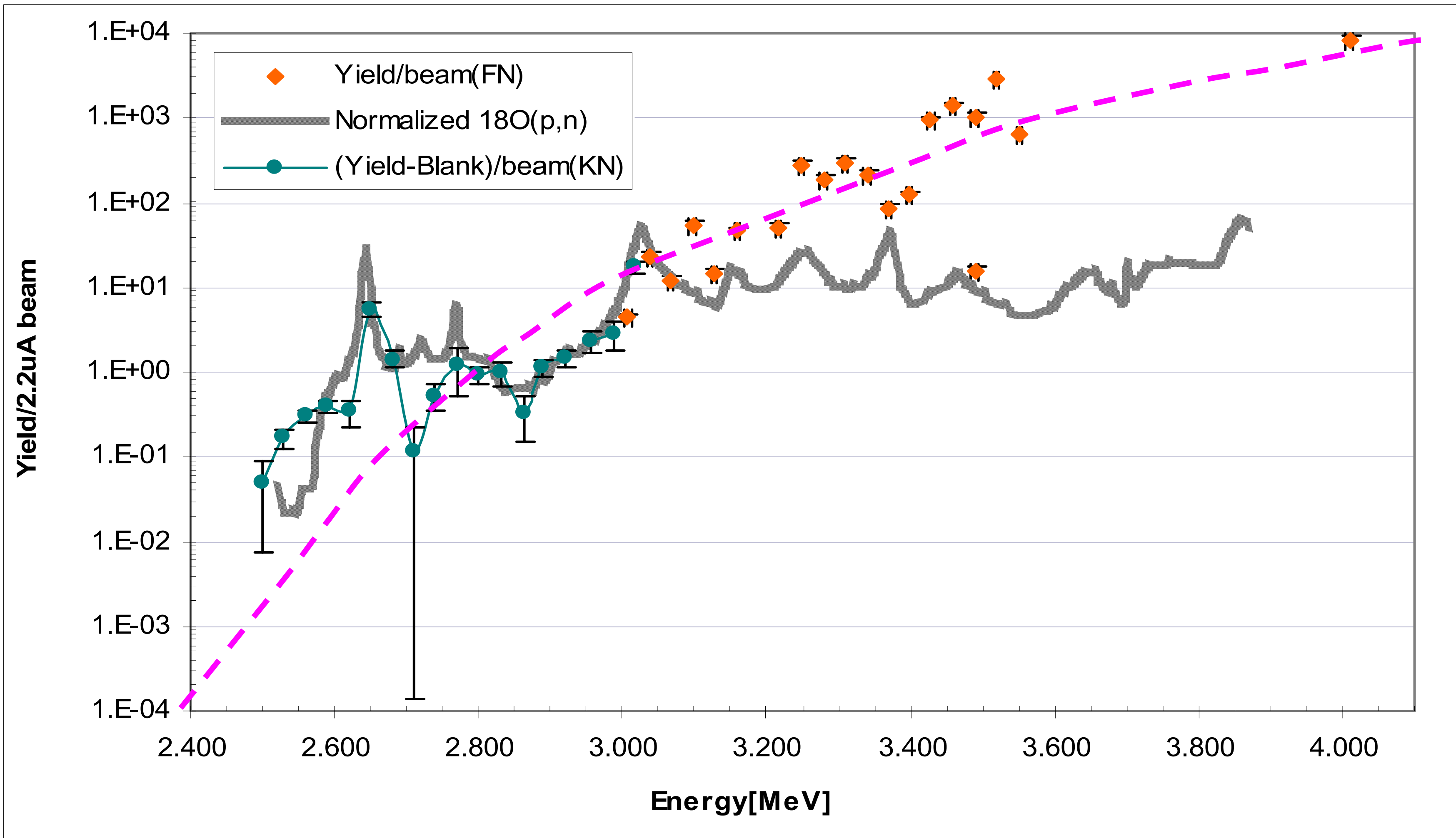
*Beam current : 16 μA ~ 26 μA



Preliminary data

*Gamow Energy range : 1.24±0.38 MeV at T9~1K for $^{18}F(\alpha,p)^{21}Ne$

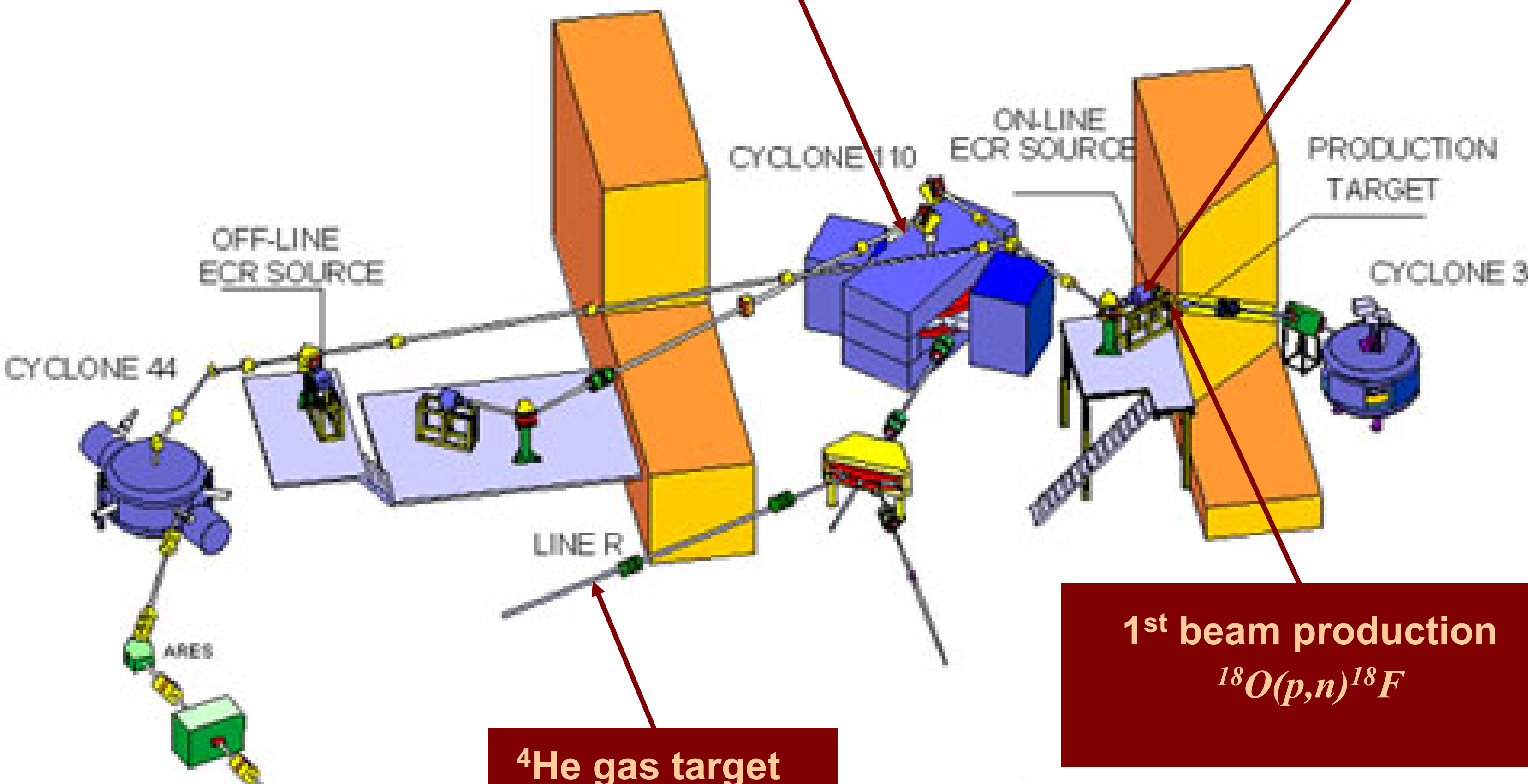
*Lab Energy: 3.12±0.40 MeV



Radioactive beam of ^{18}F at CRC in Belgium

$^{18}F^{2+}$ Acceleration

^{18}F ionized to $^{18}F^{2+}$



1st beam production

$^{18}O(p,n)^{18}F$

^{4}He gas target

Experimental Setup of $^{18}F(\alpha,p)^{21}Ne$ at CRC

Gas cell:
8am in length
6cm in diameter
He,250*mbar*

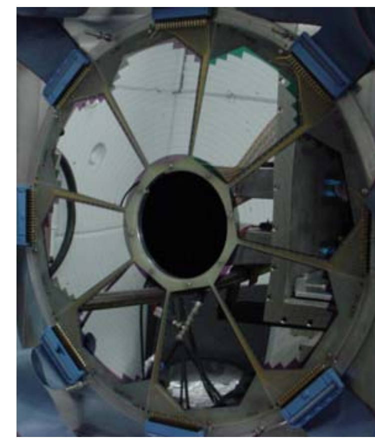
$^{18}F^{2+}$ beam

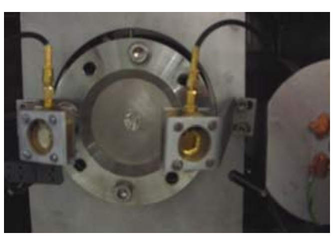
E_{lab}=23MeV
I=5X10^6 pps

target

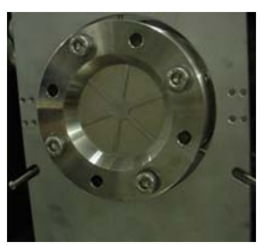
ΔE

E

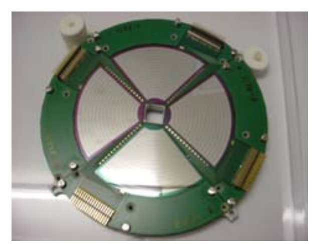




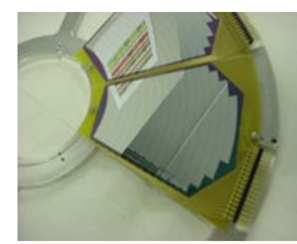
entrance foil:
Ni, 2μ*m*



exit foil:
Ni, 6μ*m*



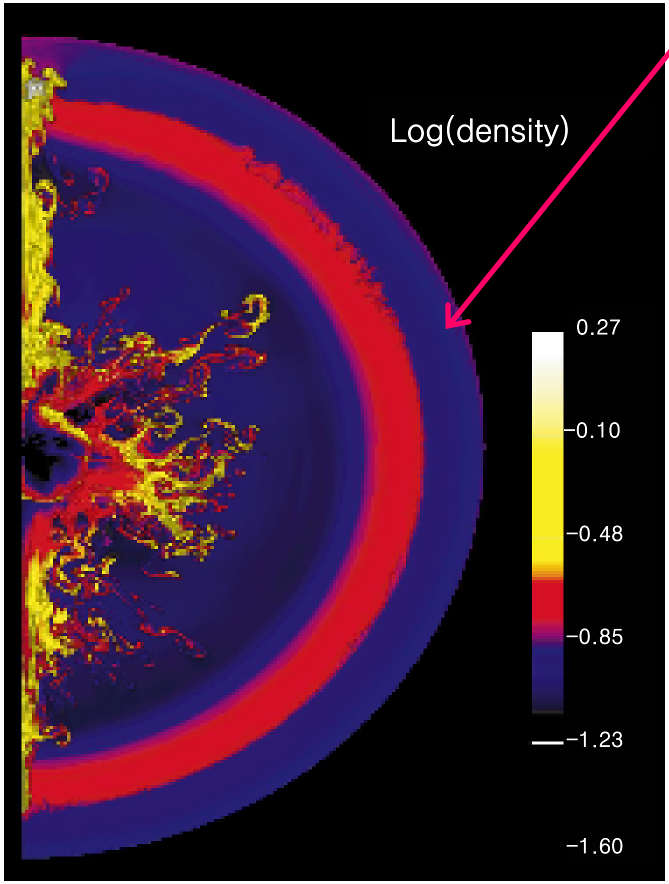
Segmented SSD:
16 annular strips
X 4 quadrants
Si, 45μ*m*



Louvain-Edinburgh
Detector Array:
16 annular strips
X 8 sectors
Si, 300μ*m*

The helium-driven r-process in supernovae(II)

Shock wave inside the hydrogen envelope



K. Kifonidis et al., ApJ 531 (2000) L123-126