Unbound states of neutron-rich oxygen isotopes: Investigation into the N=16 shell gap

FLORIDA STATE UNIVERSITY · 1851 ·

NSCL

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Motivation to Study ^{25}O

Why is the oxygen drip line at ^{24}O?

- ^{26}O unbound to neutron decay
- ^{28}O should be tightly bound if the traditional magic numbers exist (Z = 8, N = 20), but found to be unbound

Shell evolution for neutron-rich nuclei

- Evidence for a new magic number at N = 16
- ^{24}O is now doubly magic (Z = 8 , N = 16)
- Must understand the location of the $\nu 0d_{3/2}$ single-particle orbit

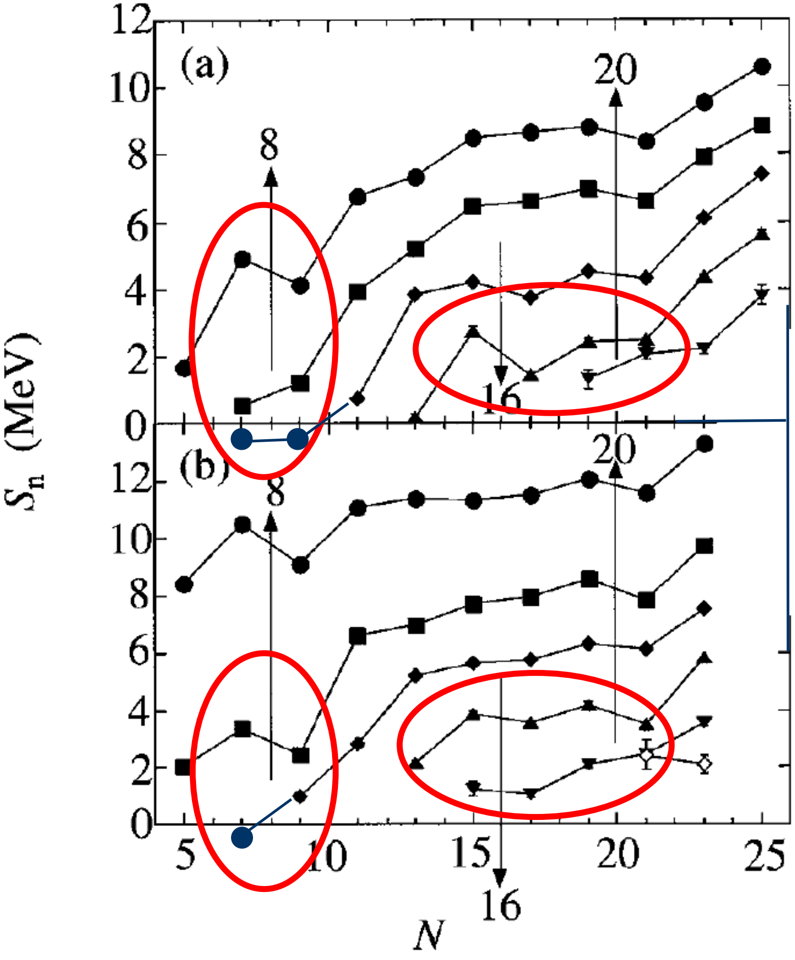
Shell Gap Evolution for Large T_z

- One Neutron Separation Energies

$$Sn = -M(A,Z) + M(A-1,Z) + n$$

- Low Isospin N = 8 and 20 Gaps

- High Isospin Evidence of a New Gap at N =16



T_z = 1/2

Even Z

Odd N

T_z = 7/2

T_z = 9/2

T_z = 0

Odd Z

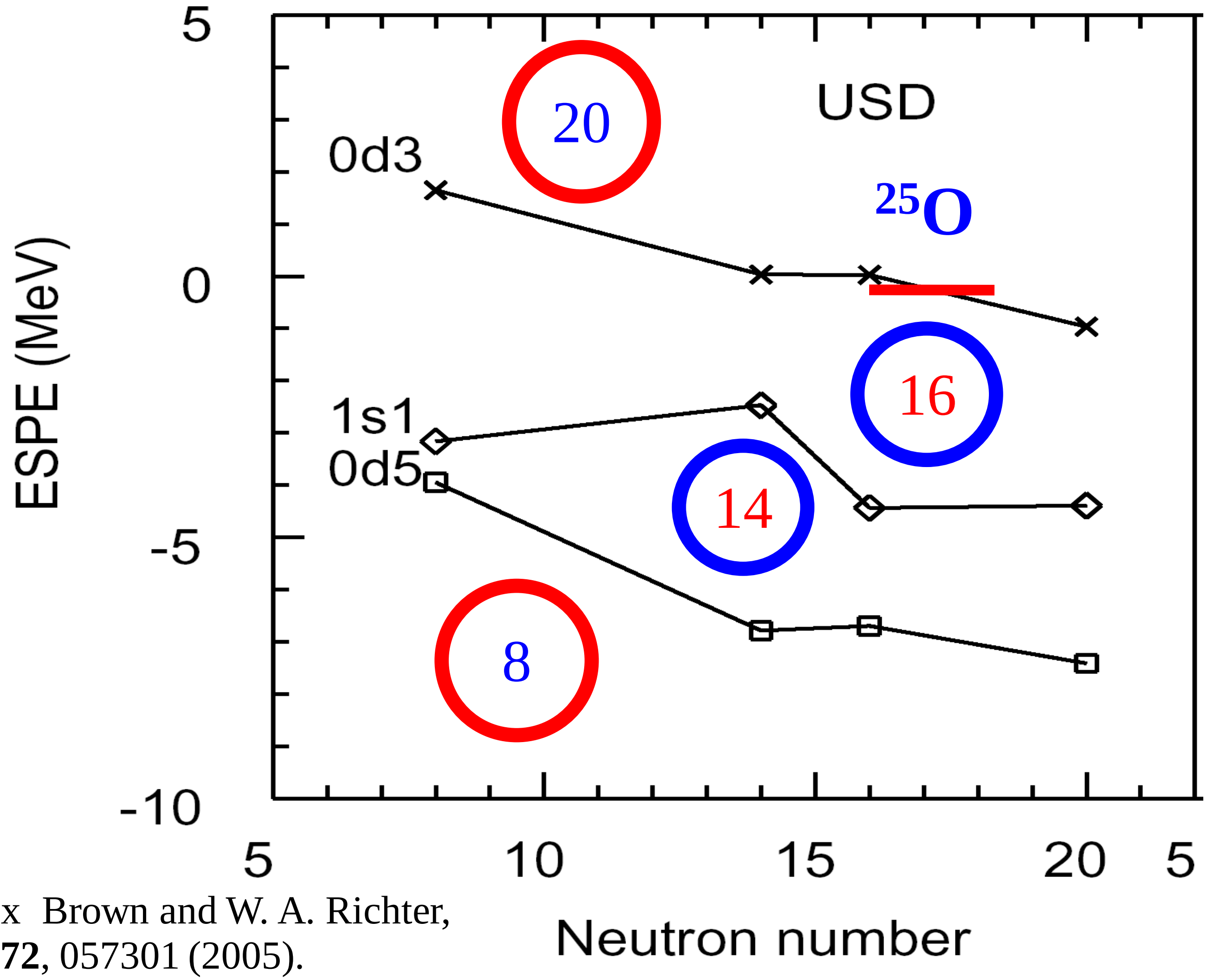
Odd N

T_z = 4

T_z = 5

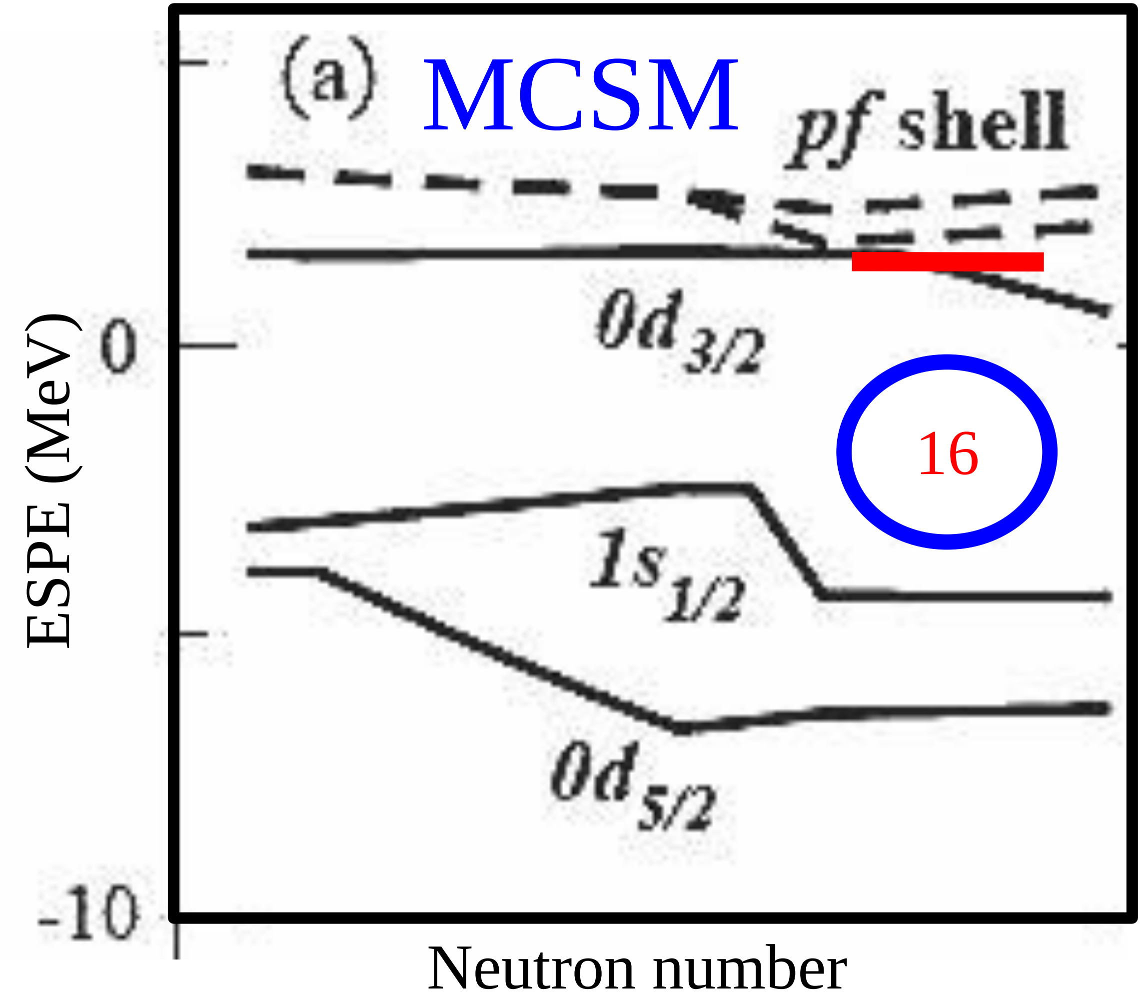
Taken from: A. Ozawa *et al.*, Phys. Rev. Lett. **84**, 5493 (2000).

Evolution of Effective Single Particle Energies



Taken from: B. Alex Brown and W. A. Richter, Phys. Rev. C **72**, 057301 (2005).

Evolution of Effective Single Particle Energies

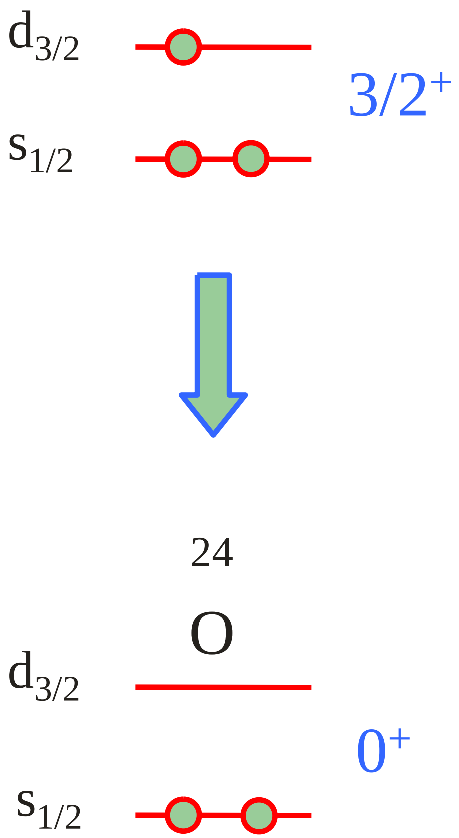


Taken from: Otsuka *et al*., Eur. Phys. J. A **15** 151-155 (2002)

25O Measurement

^{25}O good nucleus to study the size of the 2$s_{1/2}$ - 1$d_{3/2}$ shell gap

Decay of ^{25}O



- One neutron in the $d_{3/2}$ just beyond the N = 16 gap (N = 17)
- Neutron unbound so cannot study with standard mass-measurement techniques ($\tau \sim 10^{-21}$s)
- Must use neutron spectroscopy

^{25}O: Experimental Method

- One proton knockout from a radioactive ^{26}F beam
- ^{25}O immediately neutron decays
- ^{24}O fragment selected by sweeper magnet and measured in focal plane
- Neutron detected by MoNA
- Invariant mass method used to determine ^{25}O decay

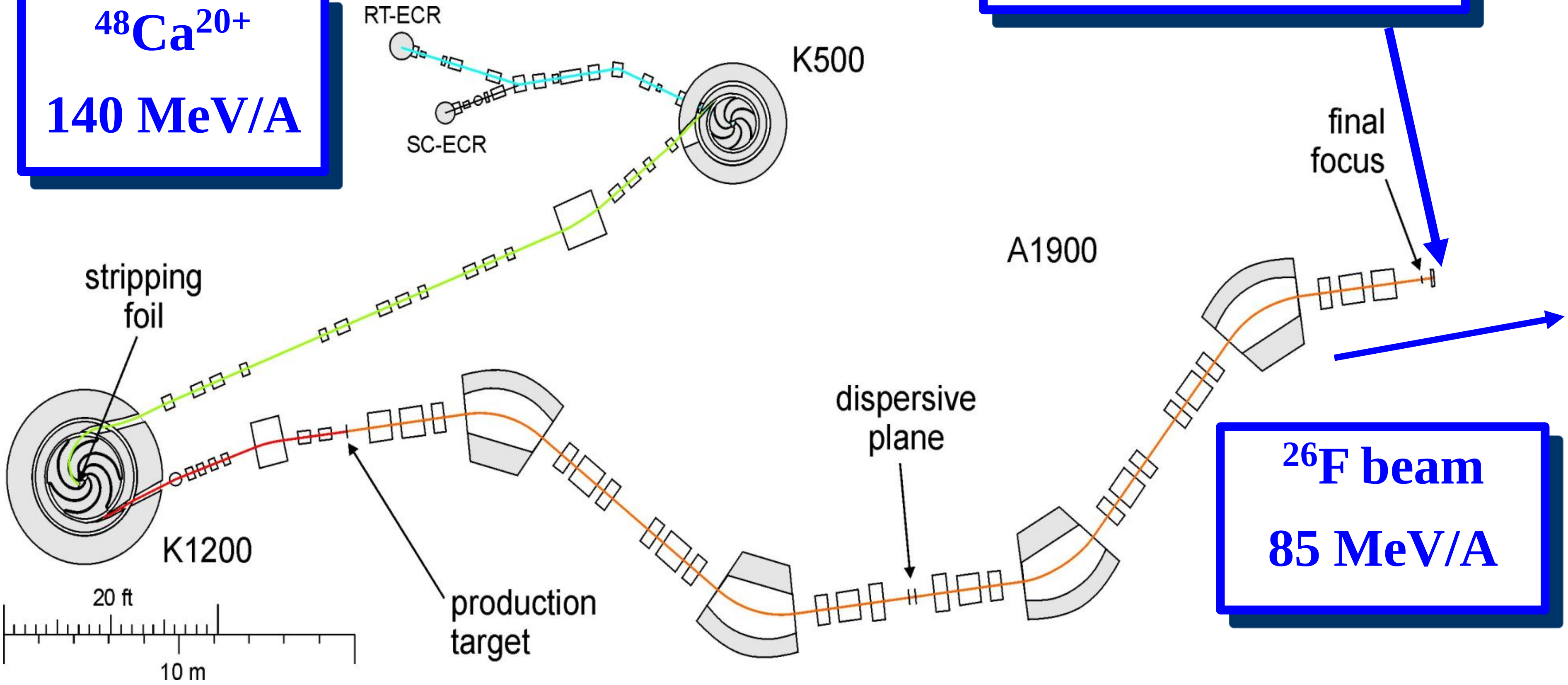
[illegible]

Production of ^{26}F Beam at NSCL

$^{48}Ca^{20+}$

140 MeV/A

Timing scintillator



^{26}F beam

85 MeV/A

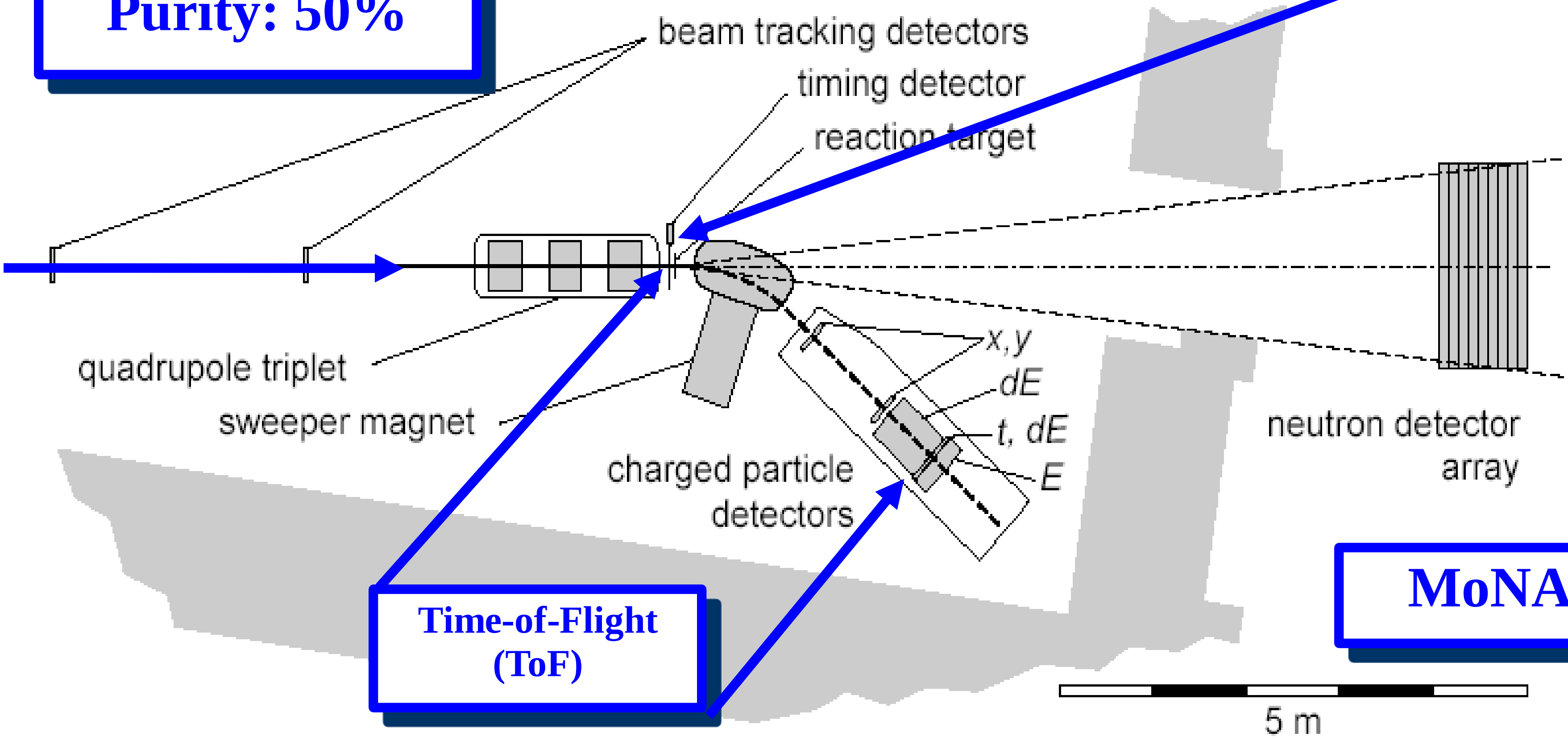
893 mg/cm^2 Be

Experimental Setup

^{26}F^{9+} 85 MeV/A

Purity: 50%

470 mg/cm^{2} Be

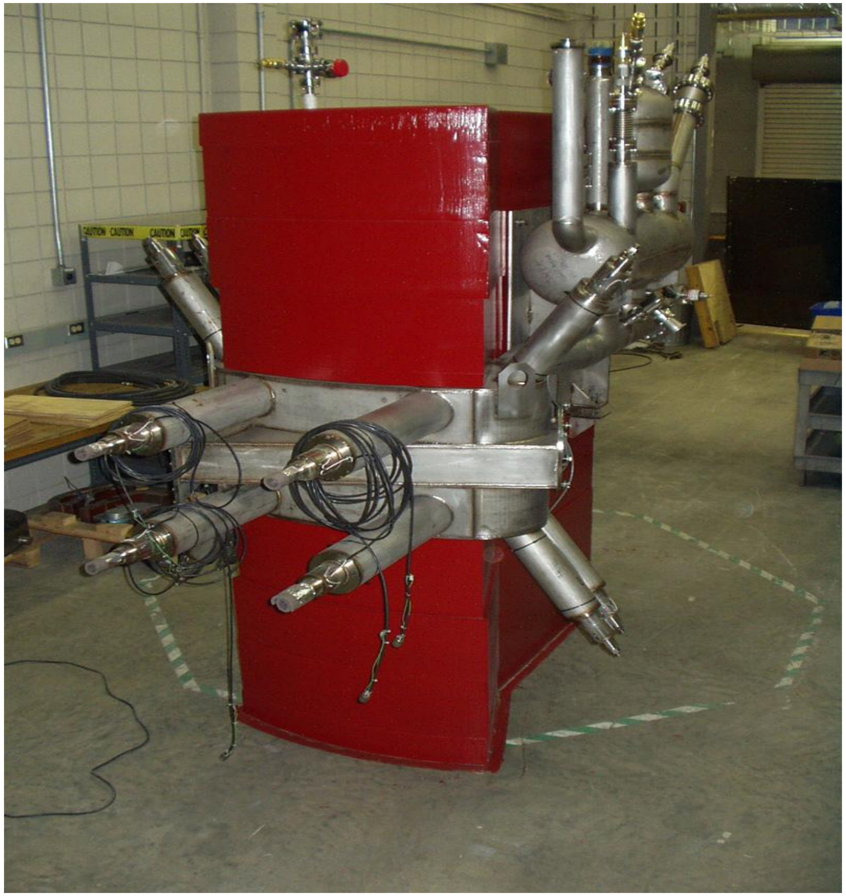


Time-of-Flight (ToF)

MoNA

MSU/FSU Sweeper Magnet

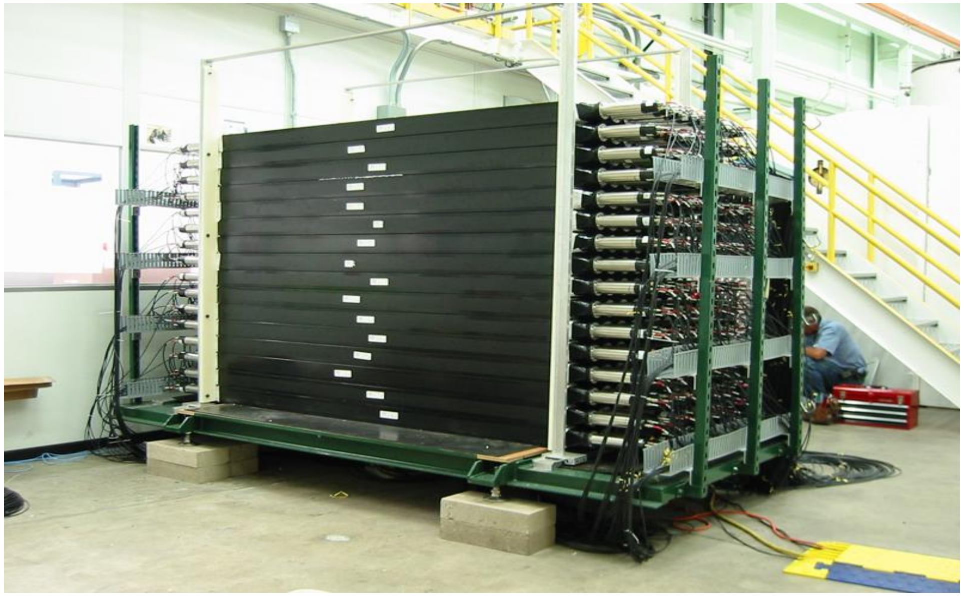
- Large gap dipole magnet
  - 14 cm vertical
- 4 Tm maximum central track rigidity
- ~ 16% total momentum acceptance
- Bend angle of 43^0



Constructed at the National High Magnetic Field Laboratory (NHMFL) at Florida State University.

The Modular Neutron Array (MoNA)

- ToF Neutron Detector
- 10 X 10 X 200 cm Bar of Plastic Scintillator
- 9 Layers of 16 Stacked Bars
- Time Resolution < 1 ns
- Position Resolution ~ 10 cm
- Detection Efficiency ~ 70 % for 85 MeV/A Neutrons



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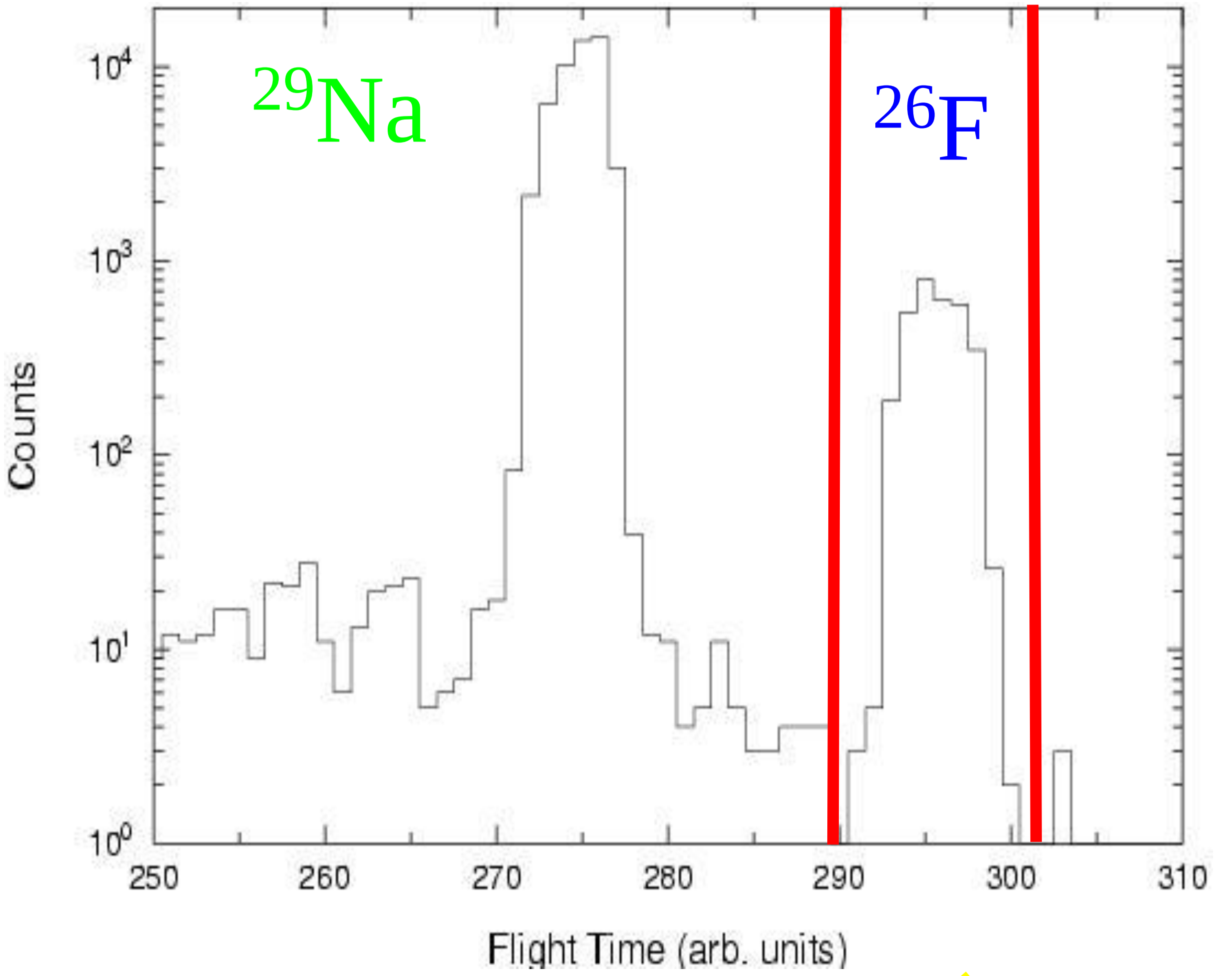
Distinguishing ^{26}F Secondary Beam

- Flight Time from A1900 to Target
- Clean Separation of ^{26}F from ^{29}Na
- ^{26}F Rate: ~ 0.8 pps/pnA



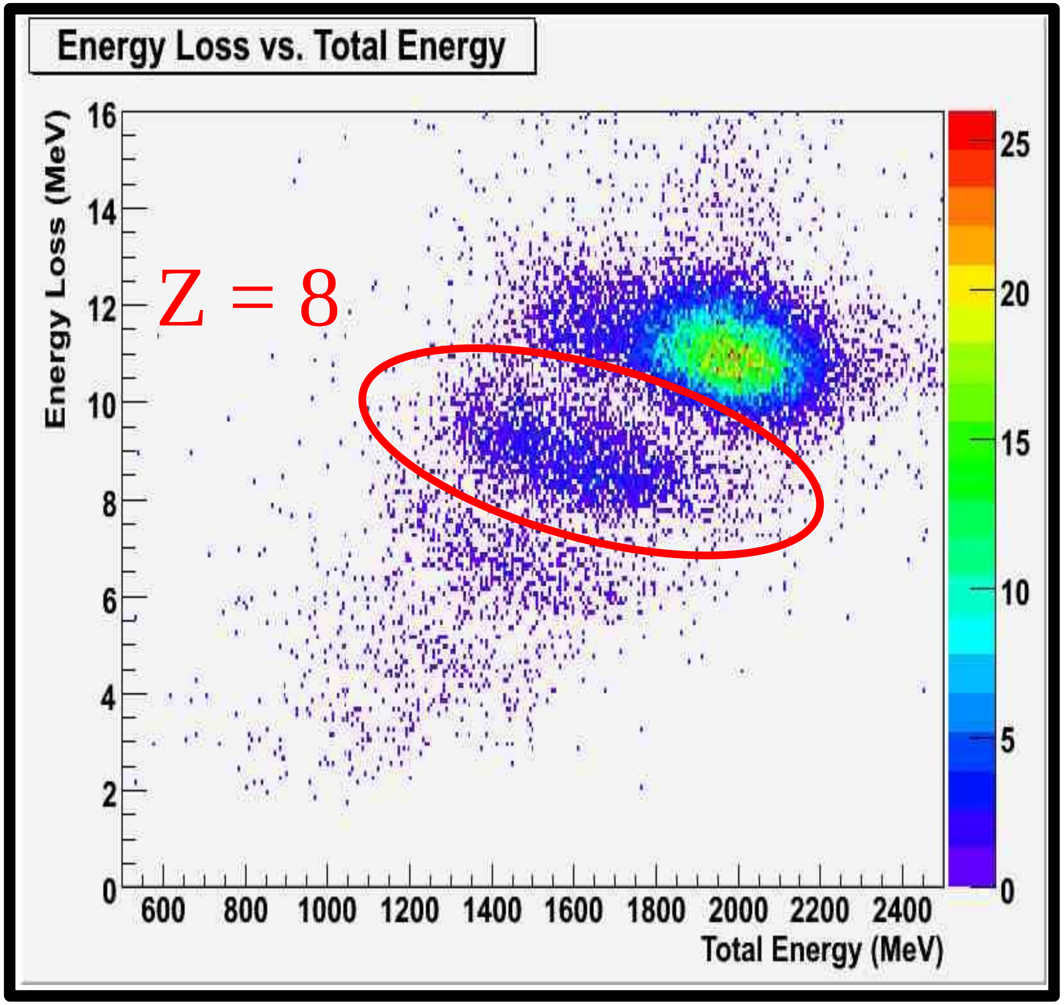
Element Identification

- Energy loss of a charged particle through a material:

$$dE/dX \sim mZ^2 / E$$

- Use energy measurements:
  - Ion Chamber
  - Thin Plastic Scintillator
  - Thick Plastic Scintillator

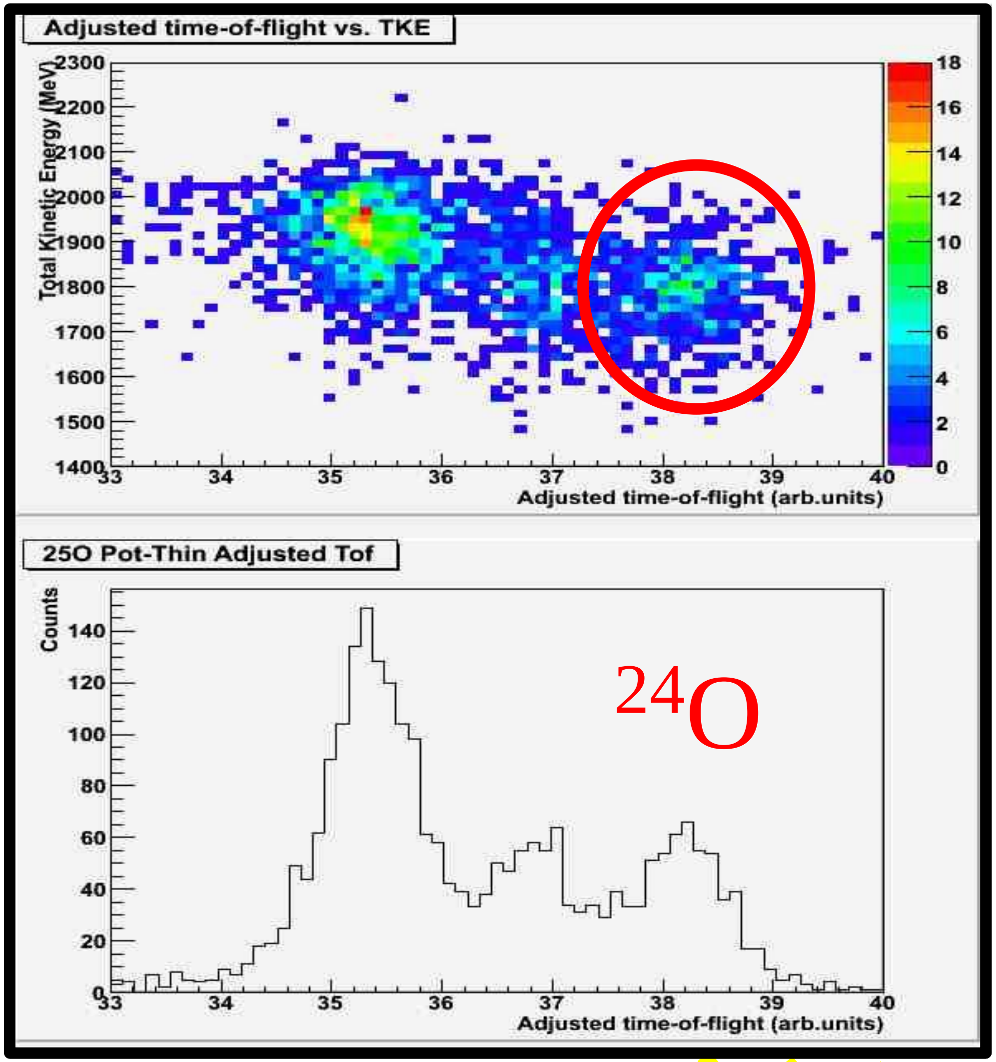
Ion Chamber Energy Loss (MeV)



Total Energy (MeV)

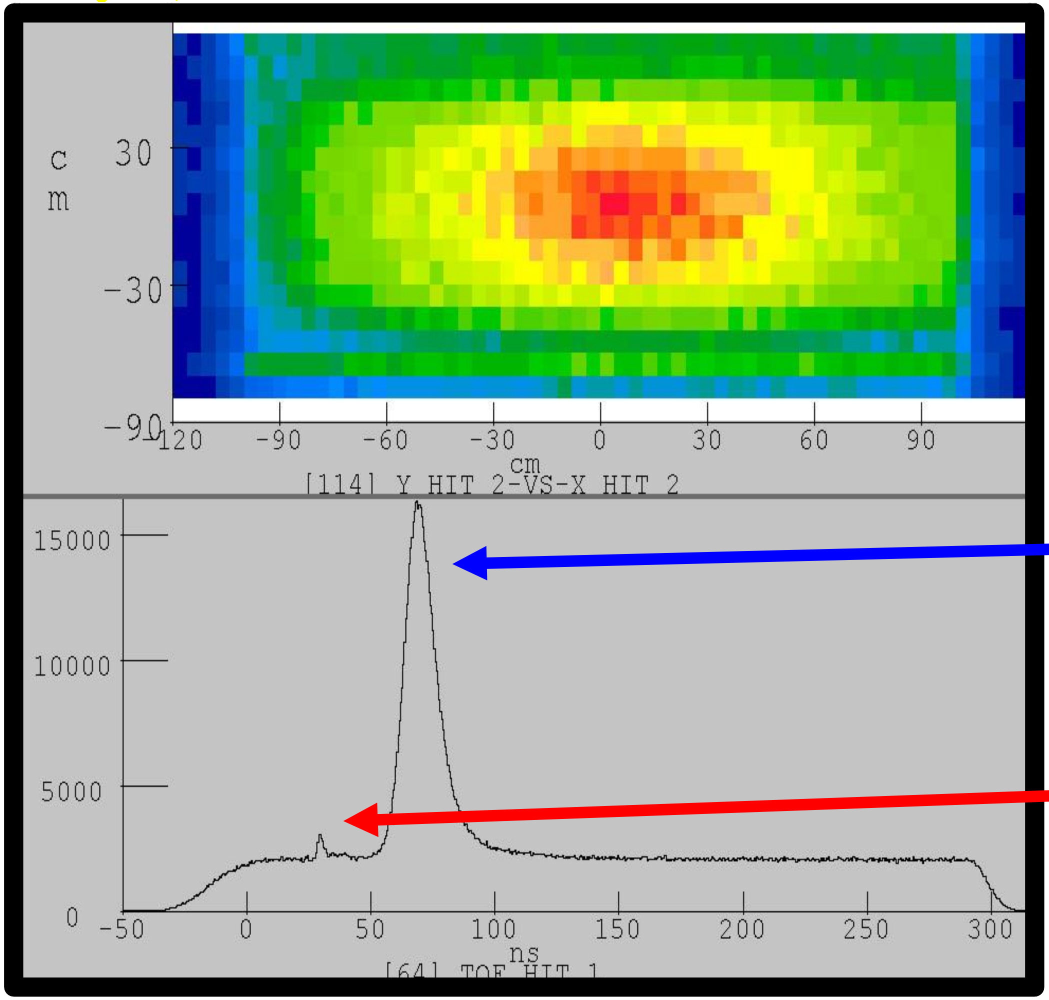
Isotopic Separation (Z = 8)

- Constant Bρ ~ ν∗(A/Z)
  - TKE ~ 1/A
- Adjusted tof ~ A
  - Time-of-flight between target and plastic scint.
  - Adjusted for flight path
    - FP dispersive angle, position
    - Target positions



^{24}O

Neutron Energies and Positions



- Position sensitivity
- Neutron time-of-flight

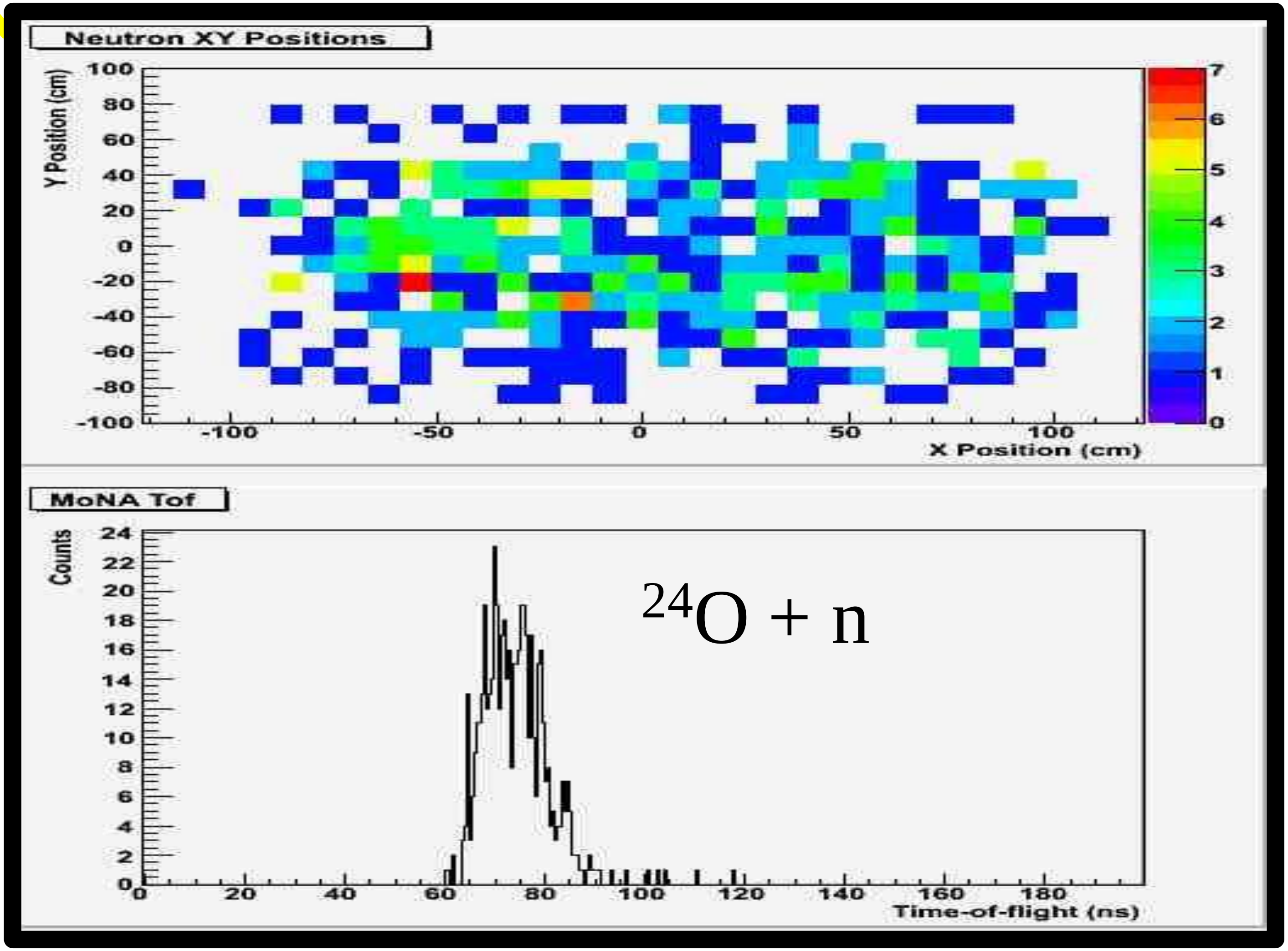
$V = D / ToF$

$KE = M_n(\gamma - 1)$

Neutron ToF Peak

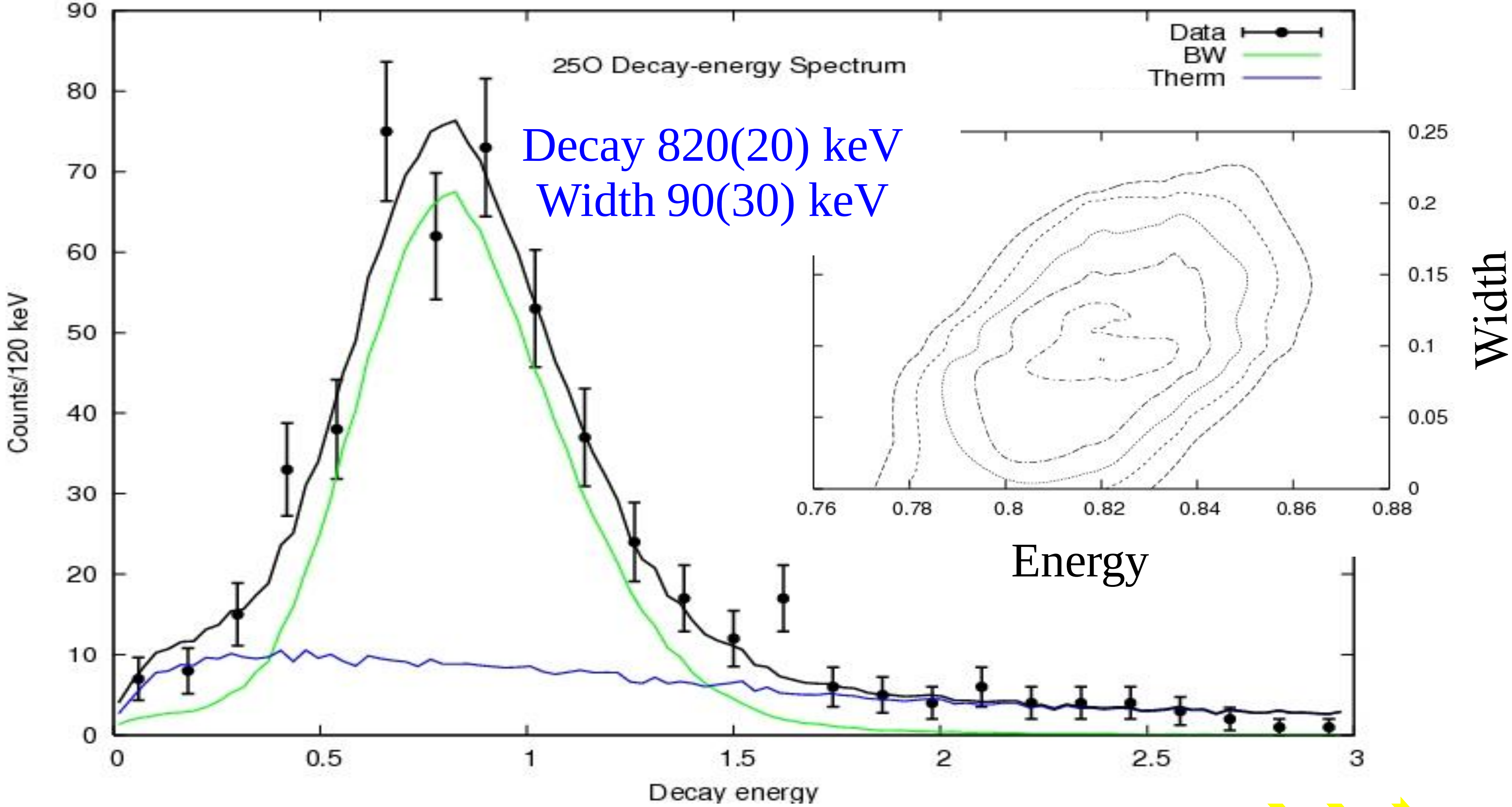
γ-ray flash used for neutron ToF calibration

Neutron Energies and Positions



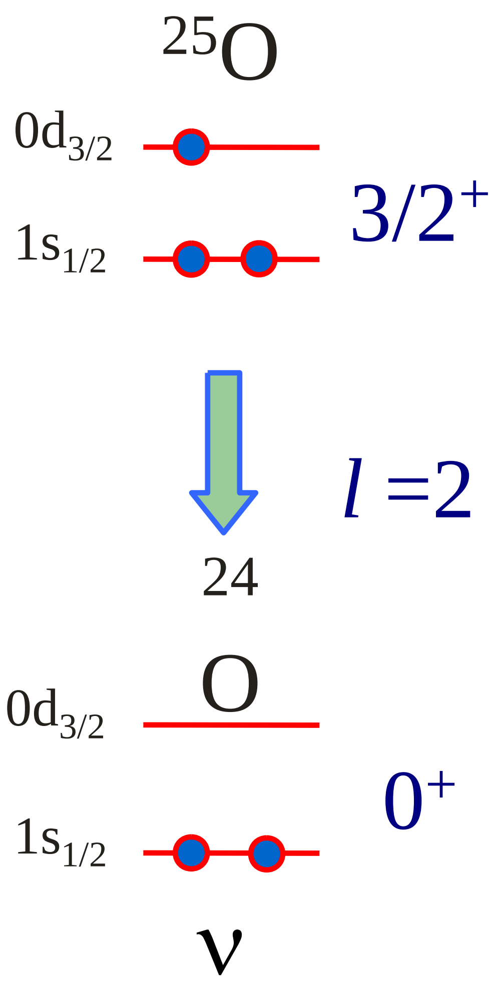
$^{24}O + n$

^{25}O Decay Spectrum



Decay 820(20) keV
Width 90(30) keV

Results



^{25}O

$0d_{3/2}$

$1s_{1/2}$

$3/2^+$

$l = 2$

^{24}O

$0d_{3/2}$

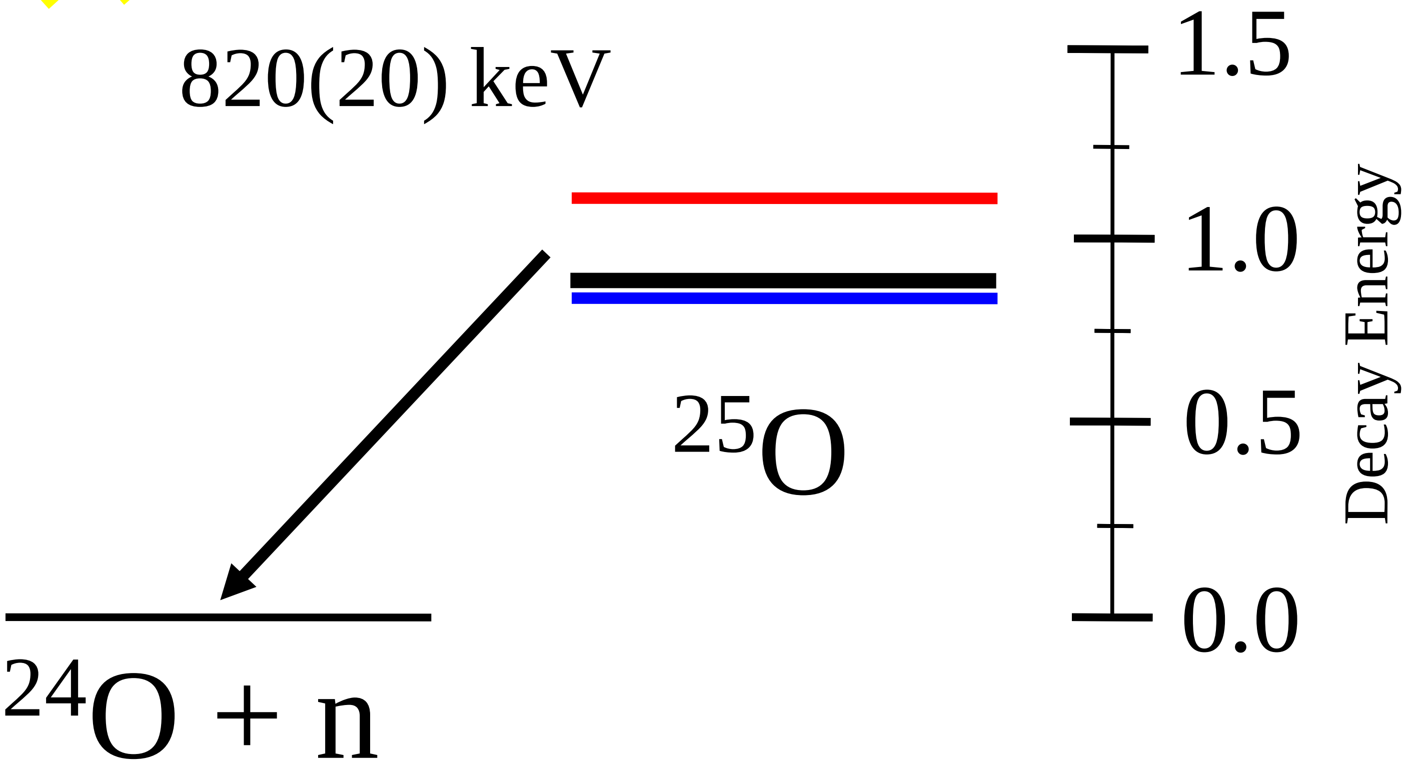
$1s_{1/2}$

0^+

ν

- **820(20) keV for removal of $0d_{3/2}$ neutron**
  - $S_n = -820(20)$ keV
  - ESPE for $0d_{3/2}$
- **$\Gamma = 90(30)$ keV consistent with $\Gamma_{s.p.} \sim 90$ keV for *l* = 2 neutron w/ spectroscopic factor of 0.92**
  - $\tau \sim 7\times10^{-21}$ sec

Theory comparison



- Exp. Result
- USD[a]
- USD05a,b[a]

[a] B. Alex Brown website: http://www.nscl.msu.edu/~brown

Discussion / Future Work

- USD-USD05 differ by an ~ 0.5 MeV increase in the $0d_{3/2}$ ESPE (N = 16 gap)

Although USD05 predicts unbound ^{26}O, it over predicts the size of the N = 16 gap for ^{25}O !!

MCSM Predictions?

- Reduction of the N = 20 gap, lowered fp shells
- Reduction of N,Z = 8 gap for O,F neutron-rich isotopes

Summary

- Knock-out reactions useful for studying unbound neutron-rich nuclei
- Produced ^{25}O via 1p removal from ^{26}F beam
- Using MoNA-Sweeper setup at NSCL/MSU reconstructed decay
- Resonance measured at 820(20) keV
- Agreement is better with old USD

Acknowledgments

Florida State: S. L. Tabor, G. V. Rogachev and A. Volya

MoNA Collaboration: M. Thoennessen[a], D. Bazin[a], T. Baumann[a], P. Deyoung[b], N. Frank[c], J. Hinnefeld[d], W. A. Peters[a], A. Schiller[a], and H. Scheit[a]

[a] NSCL / Michigan State University

[b] Hope College

[c] Concordia College

[d] Indiana University at South Bend