Probing stellar explosions with radioactive beams at ORNL

M. S. Smith

Probing Stellar Explosions with Radioactive Beams at ORNL

— ISOL
CYCLOTRON → ION SOURCE
MASS/ISOBAR
CHG EX
TANDEM

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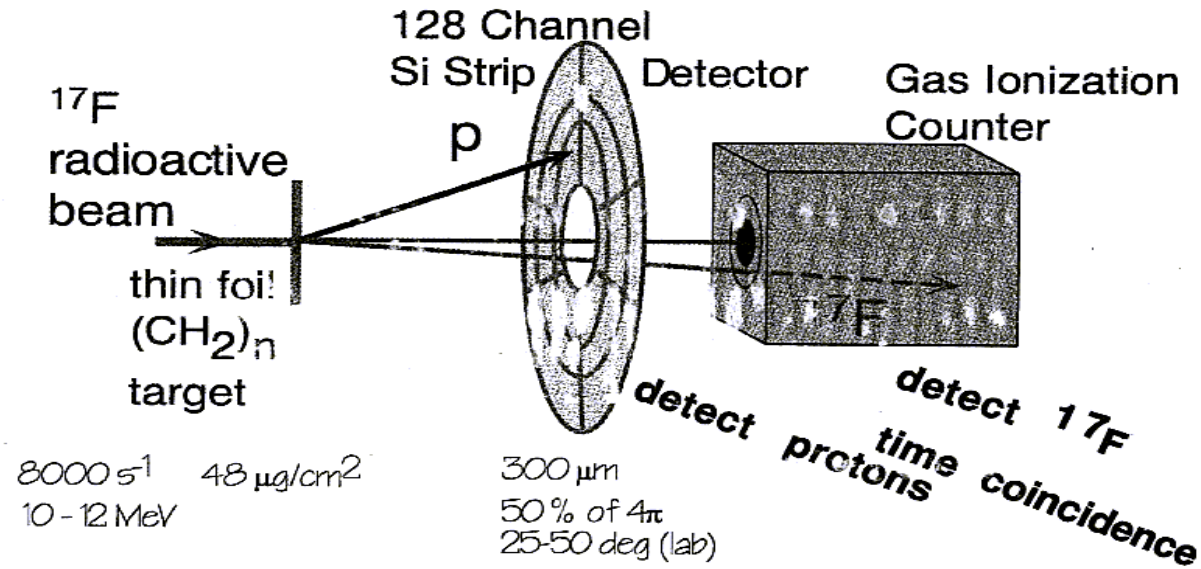
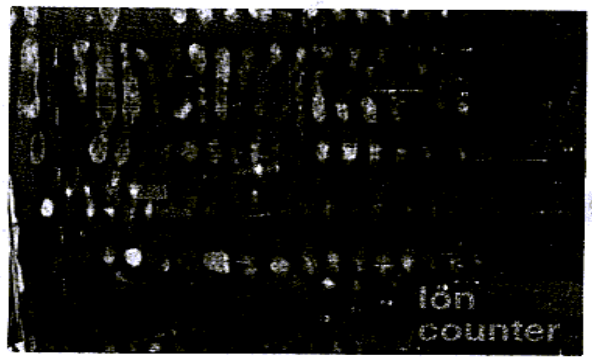
- Motivation – to better understand novae, x-ray bursts, & other explosions, we have measured a number of reactions with radioactive beams at ORNL's Holifield Radioactive Ion Beam Facility
- $^{17}F(p,p)$ Measurement
- $^{17}F(p,\alpha)$ Measurement
- $^{18}F(p,p)$ Measurement
- $^{18}F(p,\alpha)$ Measurement
- Future Measurements
- Collaborators

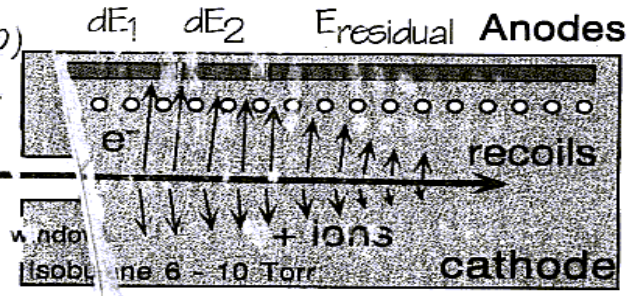
Experimental Setup



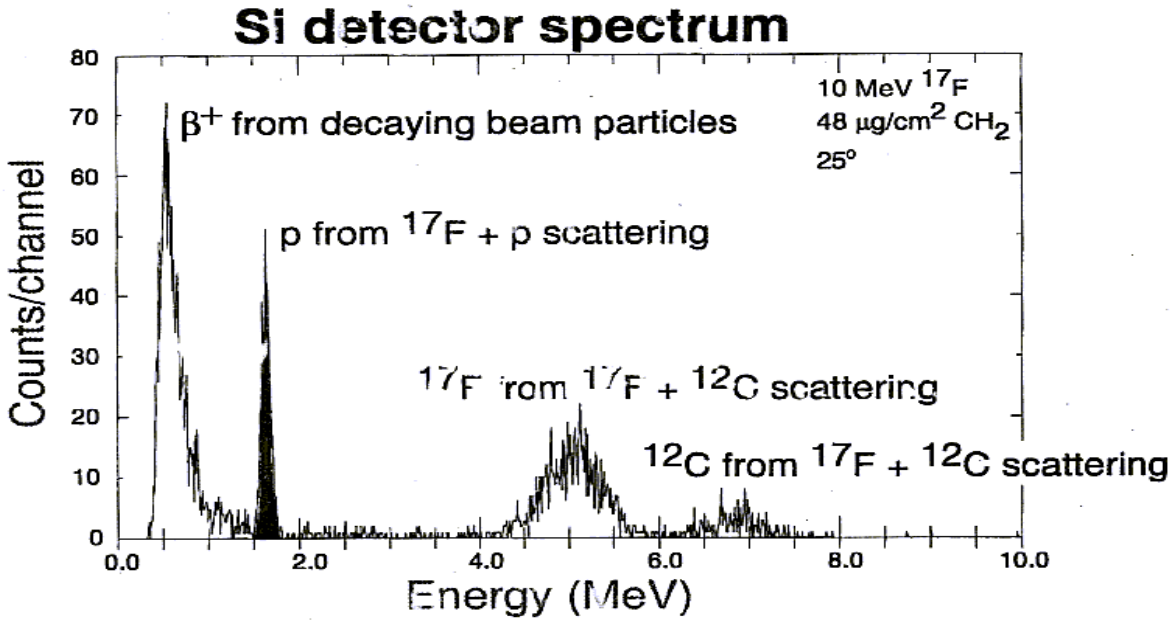


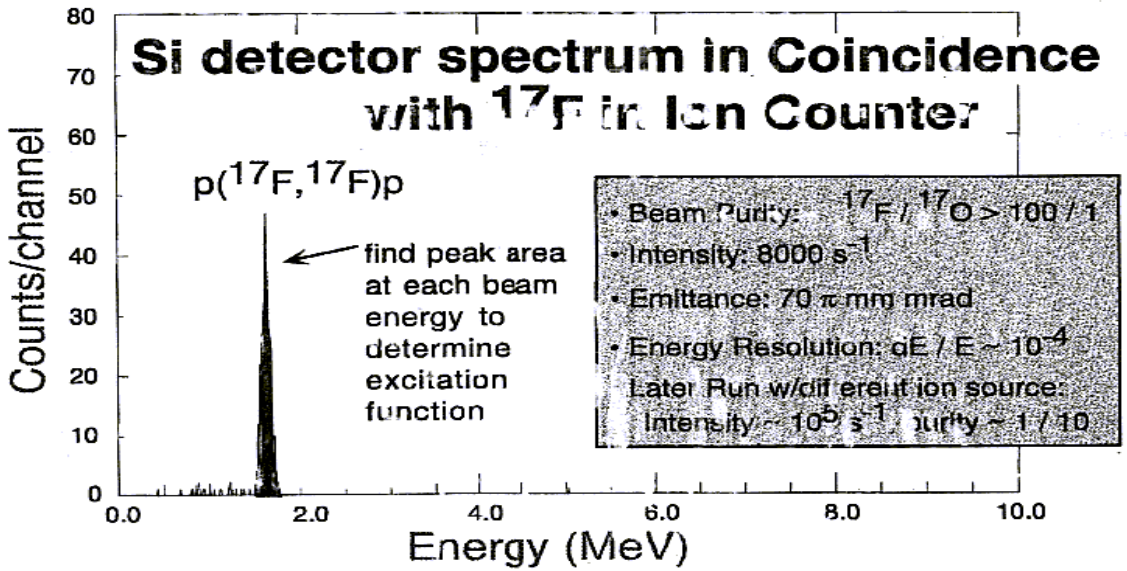
Determine Sensitivity with $^{17}O(p,p)$

- E_x determined to 0.3 keV
- Γ determined to 0.5 keV
- systematic uncertainties determined
- largest $^{17}F(p,p)$ background measured



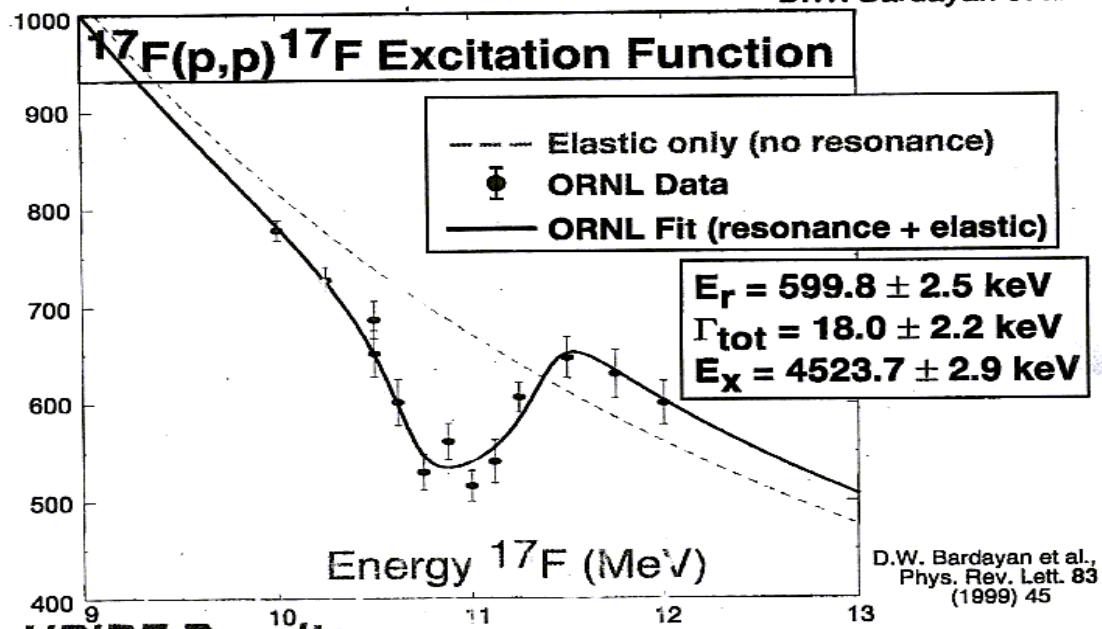
$^{17}F(p,p)$ Silicon Detector Array Data





$^{17}F(p,p)^{17}F$ Measurement at HRIBF

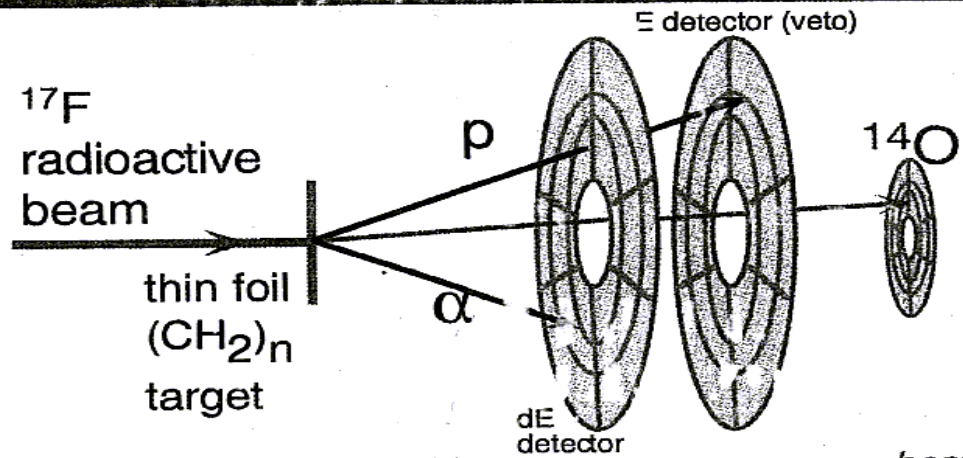
D.W. Bardayan et al.



D.W. Bardayan et al., Phys. Rev. Lett. 83 (1999) 45

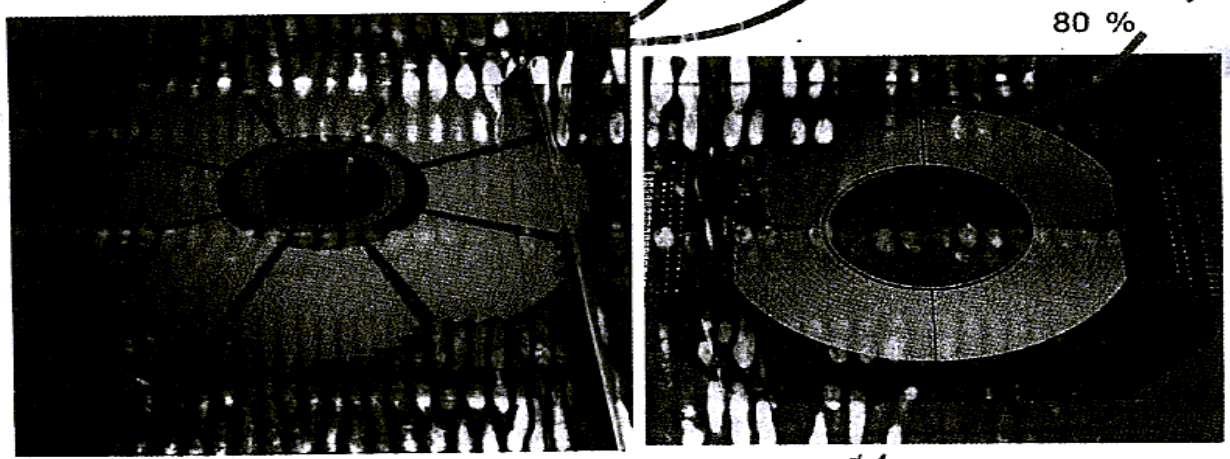
- ***New HRIBF Results***
  - ***first unambiguous evidence for resonance***
  - *precise determination of E_{res} & Γ_{tot}*
  - *strong evidence (width, angular distribution) for $J^{\pi} = 3^{+}$*
  - *3^{+} level (4523.7 ± 2.9 keV) lies right on top of the known 1- state (4519 ± 8 keV)*
  - *all previous resonance parameters inconsistent with current excitation function*
  - *very few total ^{17}F beam particles used ($2 \cdot 10^{9}$ ions – equivalent to 1pnA for 0.3 sec) ⇒ highly efficient technique*
  - *new resonance parameters change predictions of synthesis of certain isotopes by over 10^{3}*

Experimental Setup: $p(^{17}F, ^{14}O)\alpha$



light ion Si detectors — *heavy ion Si detector*

$2 \cdot 10^6\ s^{-1}$	$50\ \mu g/cm^2$	100 μm	300 μm	300 μm
66 MeV		128 strips	128 strips	64 strips
		50 % of 4π	(8 used)	Coincidence efficiency 80 %

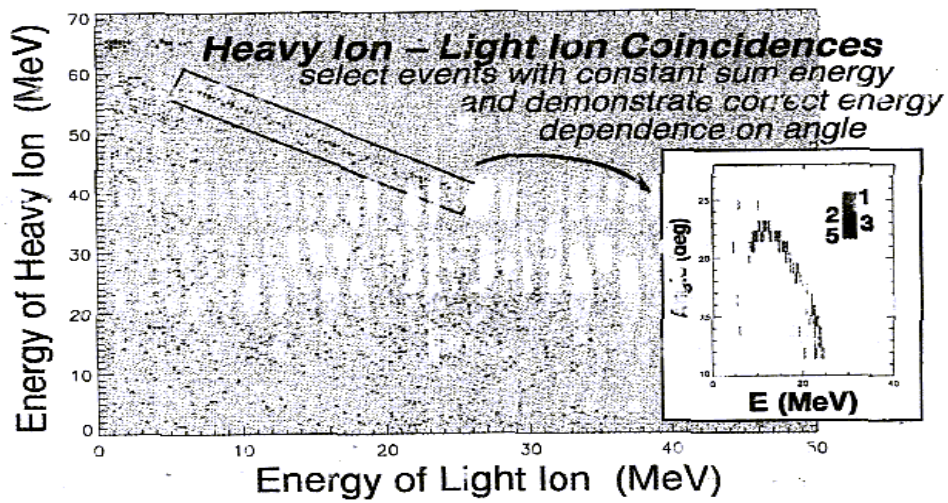


α – time coincidence – ^{14}O position correlation

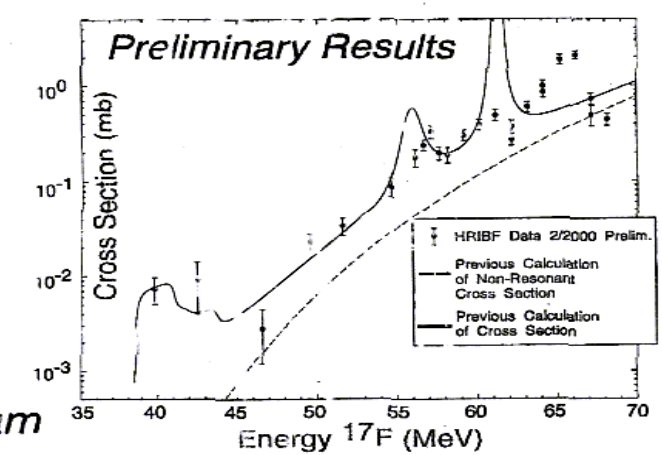
$^{17}F + p \rightarrow {}^{14}O + \alpha$ Measurement at HRIBF

J.C. Blackmon et al.

- HRIBF measurement at 21 energies completed 2/00



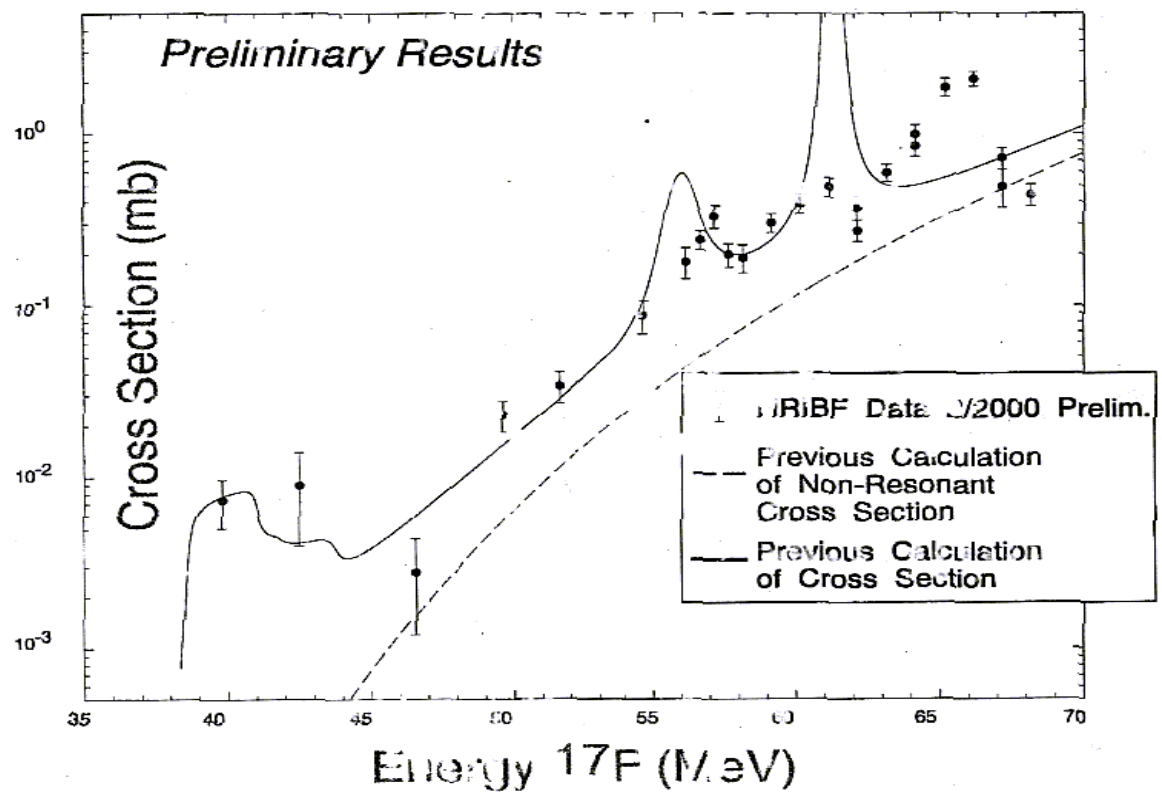
- New HRIBF Results –
  - first statistically significant measurement over entire energy range important for stellar explosions
  - results differ from predictions
  - cross section varies by factor of ~ 1000 over measured energies energy range
  - possible only with a radioactive beam



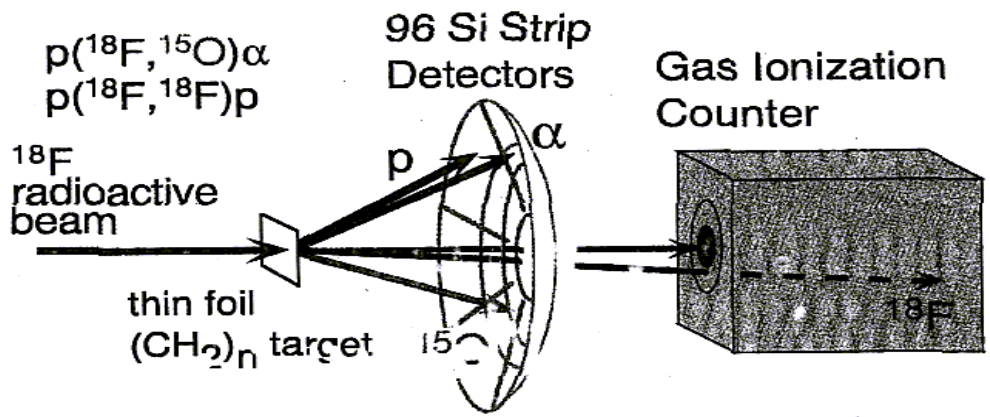
$^{17}F + p \rightarrow {}^{14}O + \alpha$ Measurement at HRIBF

J.C. Blackmon et al.

- **Cross Section measured at 21 Energies in Jan - Feb 2000**
- **Data Analysis in Progress**

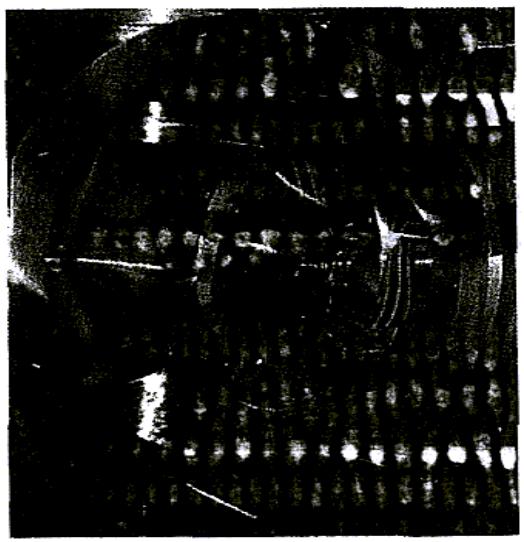


Experimental Setup: $^{18}F + p$



$p(^{18}F,^{15}O)\alpha$: $\alpha - {}^{15}O$ *time coincidence & position correlation*

$p(^{18}F,^{18}F)p$: $p - {}^{18}F$ *time coincidence*

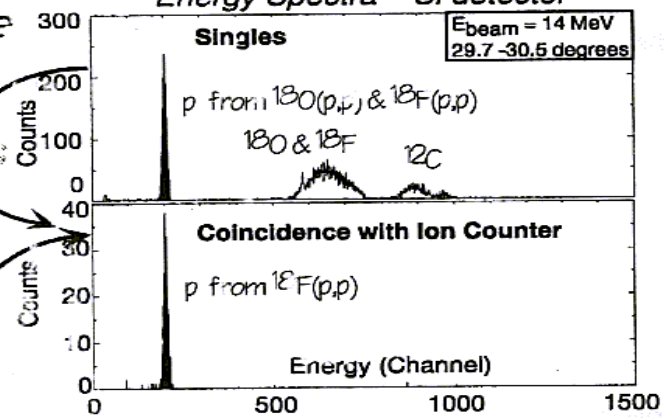


$^{18}F(p,p)^{18}F$ Measurement at HRIBF

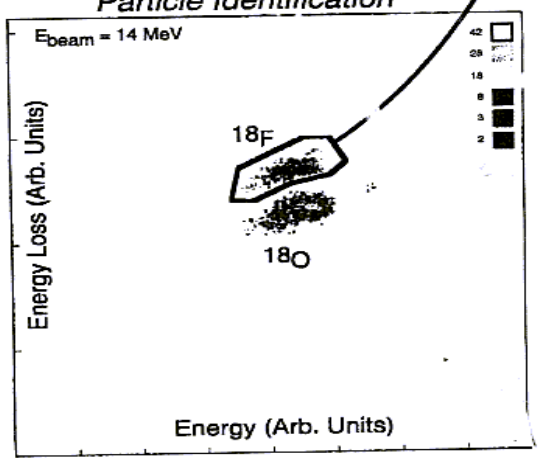
D.W. Bardayan et al.

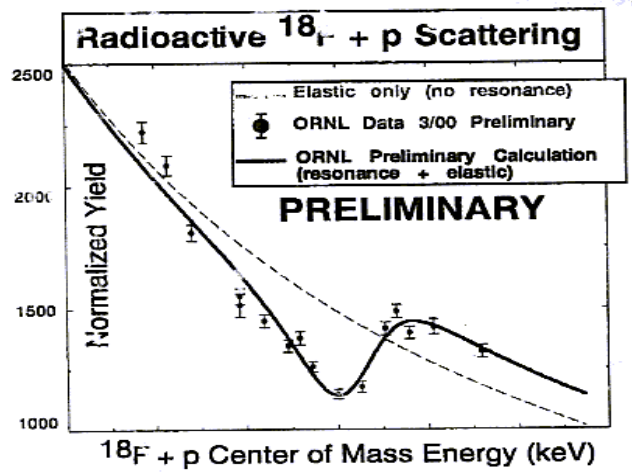
- Average intensity $2 \cdot 10^5$ ^{18}F/sec on target, ^{18}O / ^{18}F purity ~ 10 / 1 (March 2000)
- 15 energies measured near 660 keV ^{18}F + p resonance -- thought to dominate the stellar rate at high temps
- 93 % p - ^{18}F Coincidence Efficiency
- Additional Measurements planned on lower energy resonances

Energy Spectra – Si detector



Gas Ionization Counter – Particle Identification



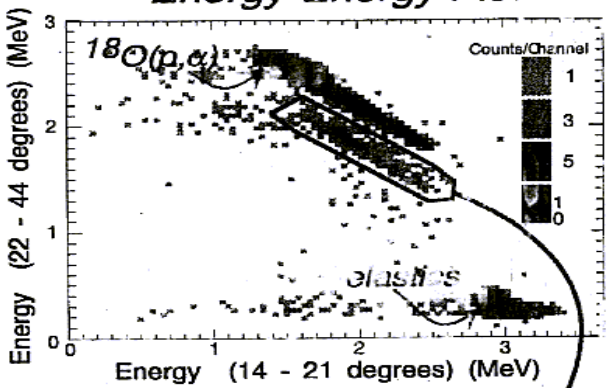


$^{18}F(p,\alpha)^{15}O$ Measurement at HRIBF

D.W. Bardayan et al.

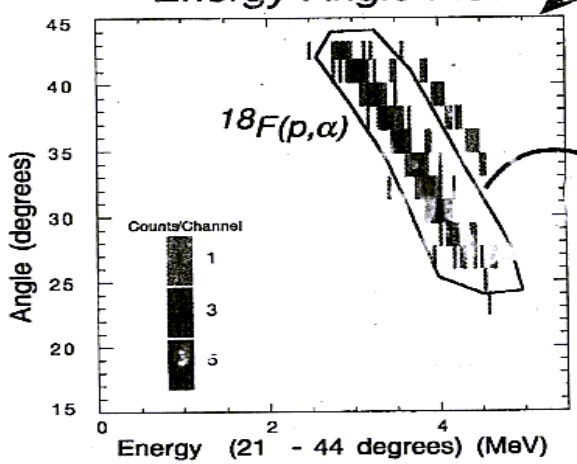
- Data Taken March 2000
- Average Intensity $2 \cdot 10^5$ ^{18}F/sec on target, ^{18}O / ^{18}F purity ~ 10 / 1
- Will enable precise determination of energy, width, Γ_p / Γ_α, & (p,α) strength of the resonance dominating the stellar rate at high temps

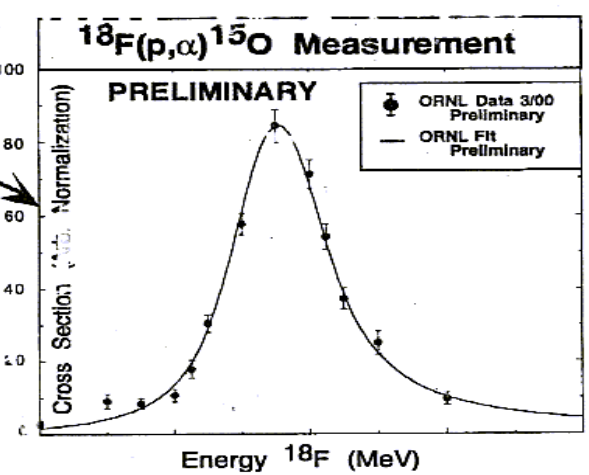
Energy-Energy Plot



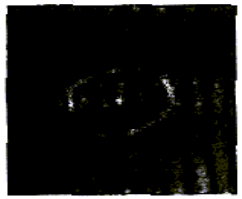
- Anticipated Precision:
  - E_{res} to 1 keV
  - Γ_{tot} to 3 keV
  - Γ_p / Γ_α to 5 %
- Additional Measurements planned on lower energy resonances

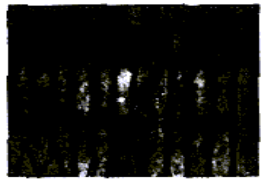
Energy-Angle Plot





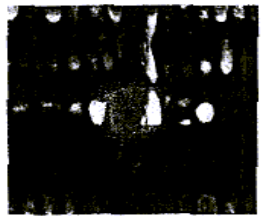
Future Measurements


Nova Cygni 1992


Nova T Pyxidis

Cataclysmic Binaries

Supernova 1987A


Nova QUVUL

Nova QVVUL

Stellar Explosions

- Fusion of Protons with ^{17}F, ^{18}F, $^{26,27}Si$, $^{33,34}Cl$, ^{25}Al

Solar Neutrino Problem

Solar Neutrino Problem

- Fusion of Protons with ^{7}Be

RIBENS Collaboration – Radioactive Ion Beams for Explosive Nucleosynthesis Studies

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Uwe Greife	Colorado School of Mines
Kevin Hahn	Ehwa Univ.
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Peter Parker	Yale Univ.
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Bob Runkle	UNC / TUNL
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Frank Streider	Ruhr-Univ. Bochum
Ken Swartz	Yale Univ.
Dale Visser	Yale Univ.
Phil Woods	Univ. of Edinburgh