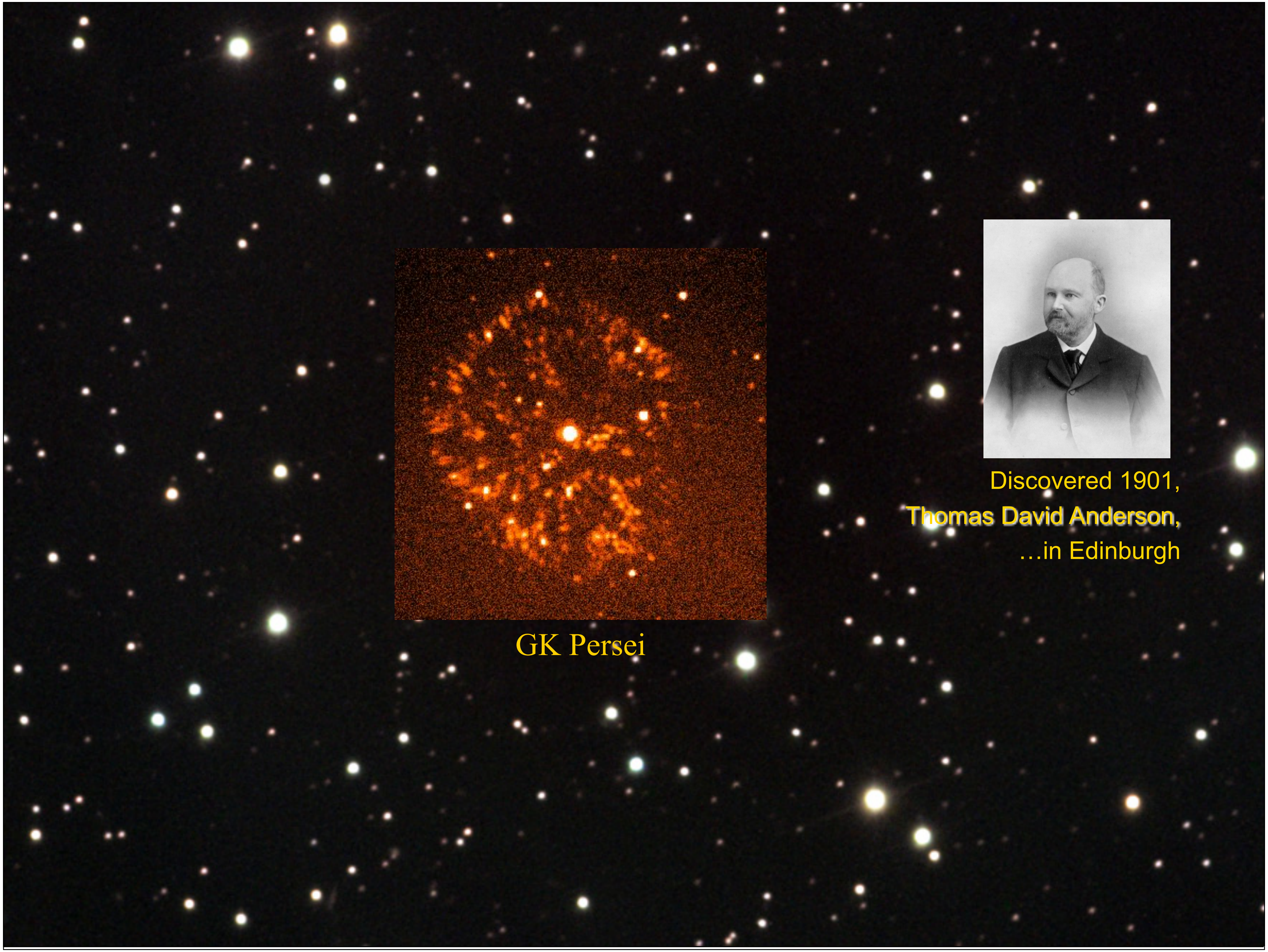
Radioactive beam experiments relevant to gamma-ray emitters in novae and supernovae

Alex Murphy
School of Physics & Astronomy

Motivation


GK Persei
Discovered 1901,
Thomas David Anderson,
…in Edinburgh

Astronomy & Astrophysics manuscript no. arxiv
January 10, 2010

New estimates of the gamma-ray line emission of the Cygnus region from INTEGRAL/SPI observations

Pierrick Martin[1,2], Jürgen Knödlseder[1,2], Roland Diehl[3], and Georges Meynet[4]

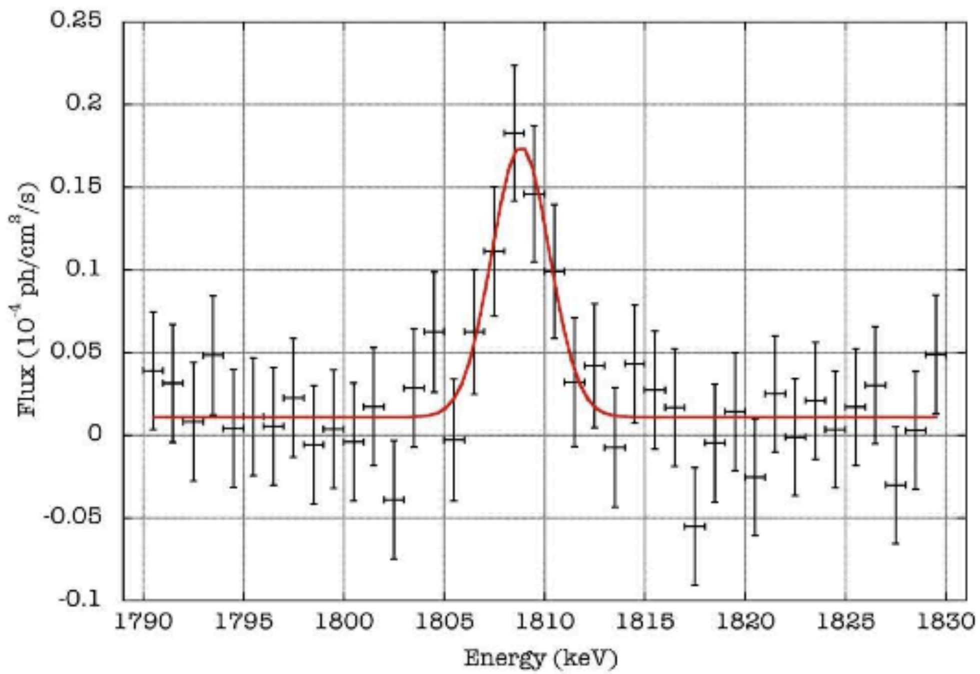
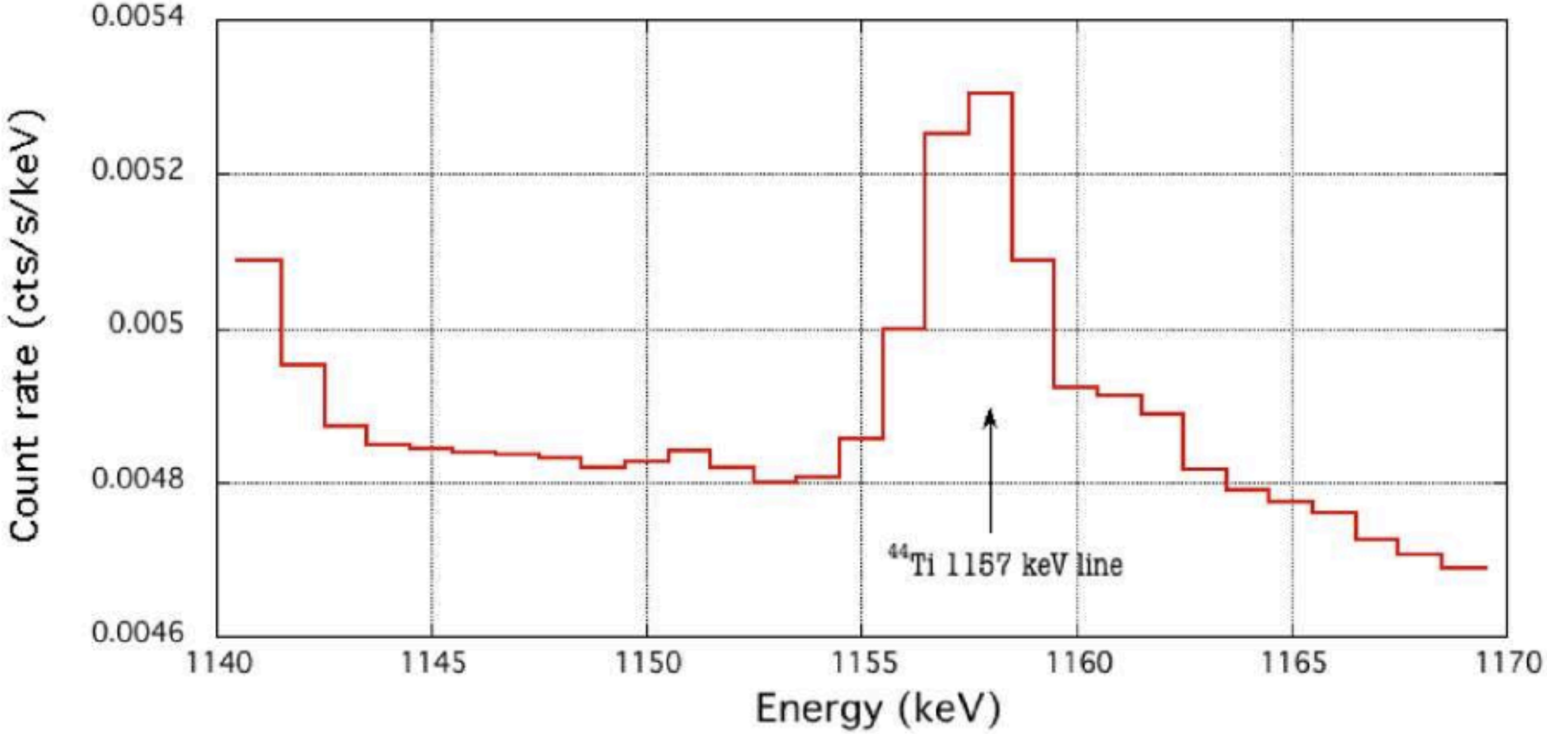


Fig. 1. Spectrum of the 1809 keV emission from the Cygnus region, from about 4 years of INTEGRAL/SPI observations. The red line represents the best Gaussian fit to the data points.

Astronomy & Astrophysics manuscript no. arxiv
January 6, 2010

Constraints on the kinematics of the ^{44}Ti ejecta of Cassiopeia A from INTEGRAL/SPI

Pierrick Martin[1,2], Jürgen Knödlseder[1,2], Jacco Vink[3], Anne Decourchelle[4], and Matthieu Renaud[5]

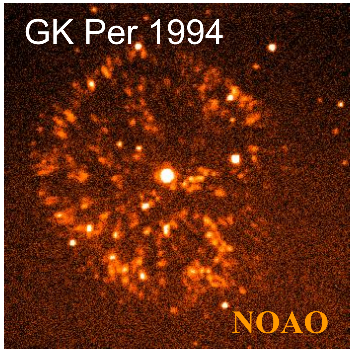


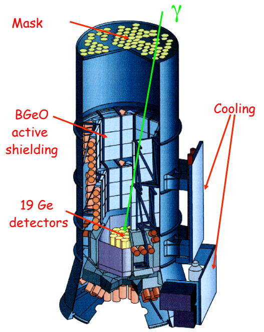
Gamma Ray Emitters

Nucleus	lifetime	Emission	Source
^{13}B	862 s	511 keV	CO Novae ONe Novae
^{18}F	158 m	511 keV	CO Novae ONe Novae
^{7}Be	77 d	478 keV	CO Novae
^{22}Na	3.75 yr	1275 keV	ONe Novae
^{26}Al	1.0 Myr	1809 keV	WR, CC SNe?
^{44}Ti	87 yr	1157 keV	CC SNe
^{60}Fe	2.2 Myr	1173,1333 keV	CC SNe

$^{18}F(p,\alpha)^{15}O$ in novae

- ^{18}F is the leading candidate for satellite gamma-ray observation from Novae
- $^{18}F(p,\alpha)^{15}O$ is the main nuclear physics uncertainty in ^{18}F production
- Issues concerning ℓ=0 resonances, missing, broad and sub-threshold resonances
- Recent data from TRIUMF and GANIL





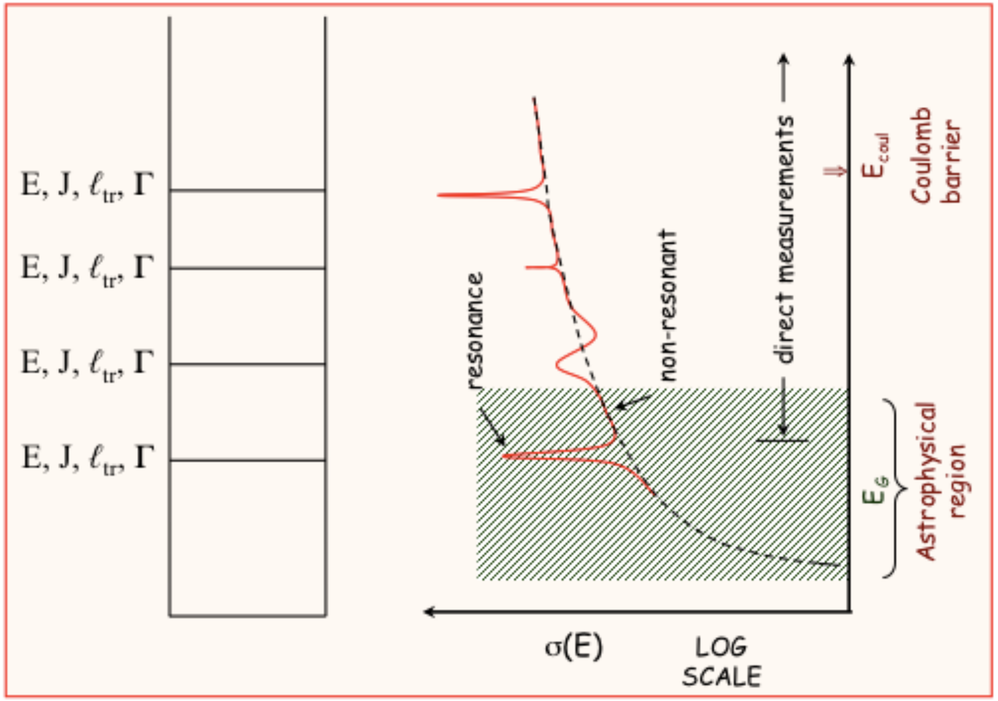
Nuclear Physics: Options

Direct

– Explicitly perform the reaction, 1 event at a time
– Event rate very low at relevant temperatures

Indirect

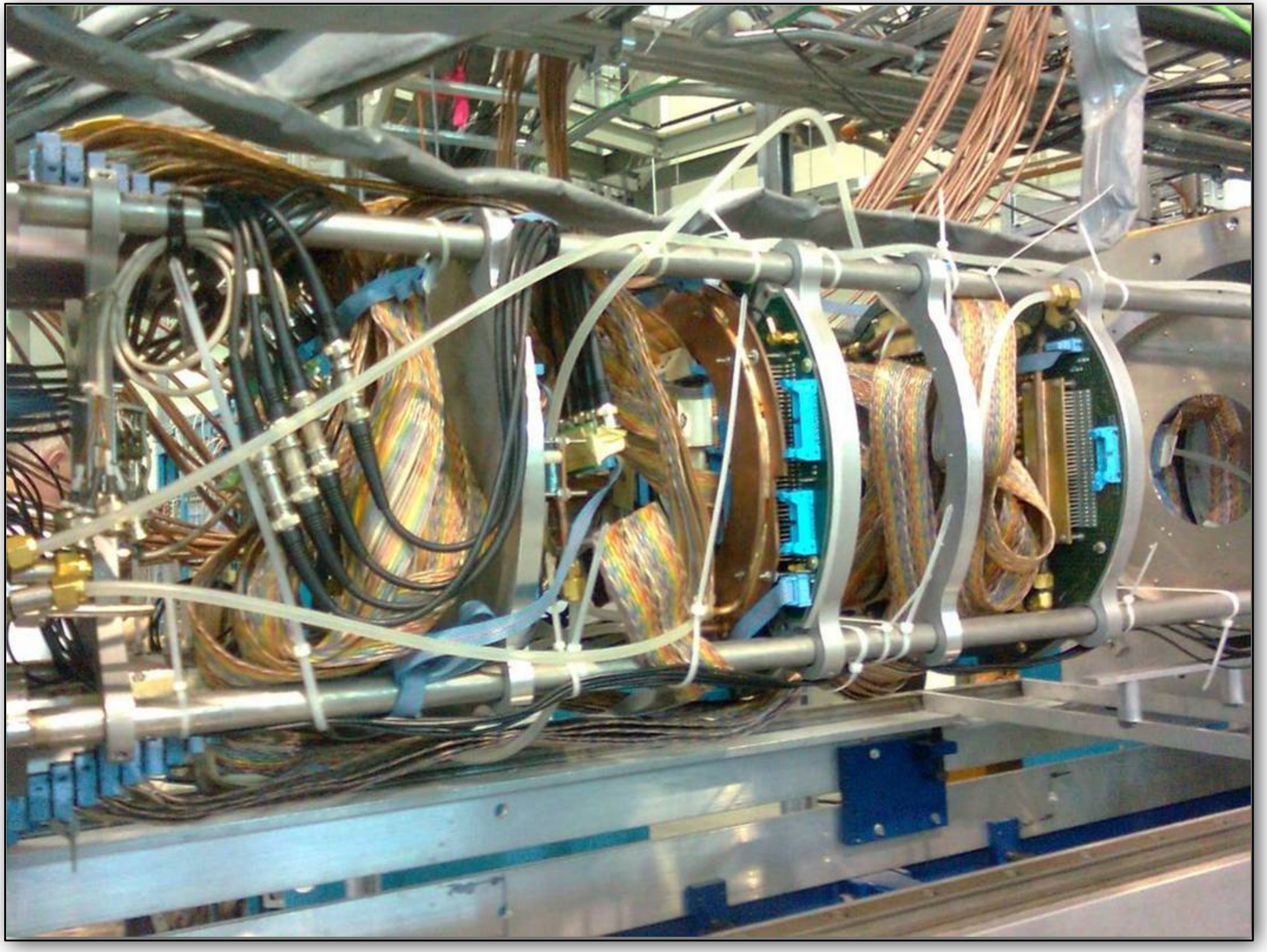
– 'Use' nuclear physics to access experimentally challenging region
– But... issues: extrapolation, interference, structure differences...



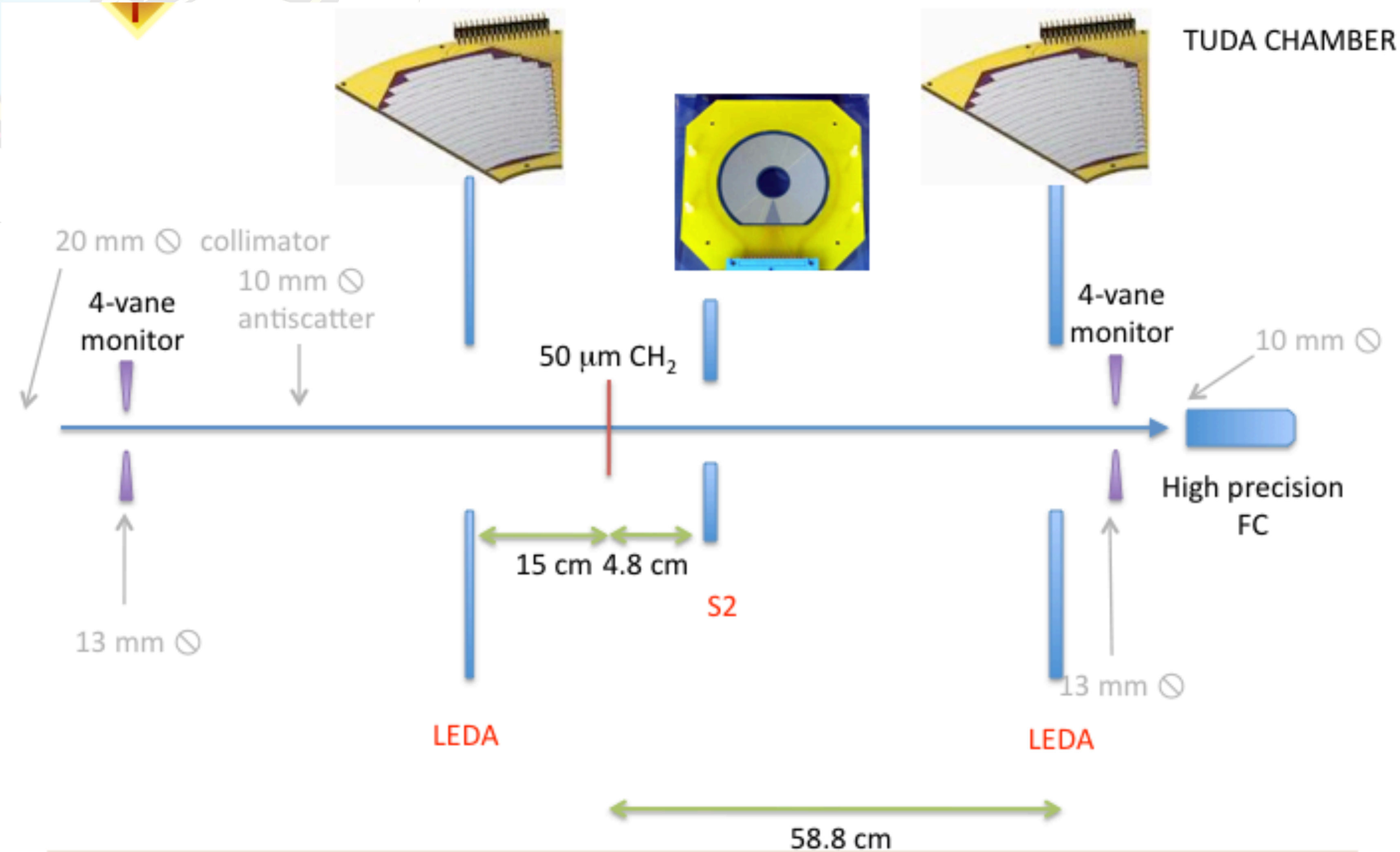
Indirect: TRIUMF

TRIUMF

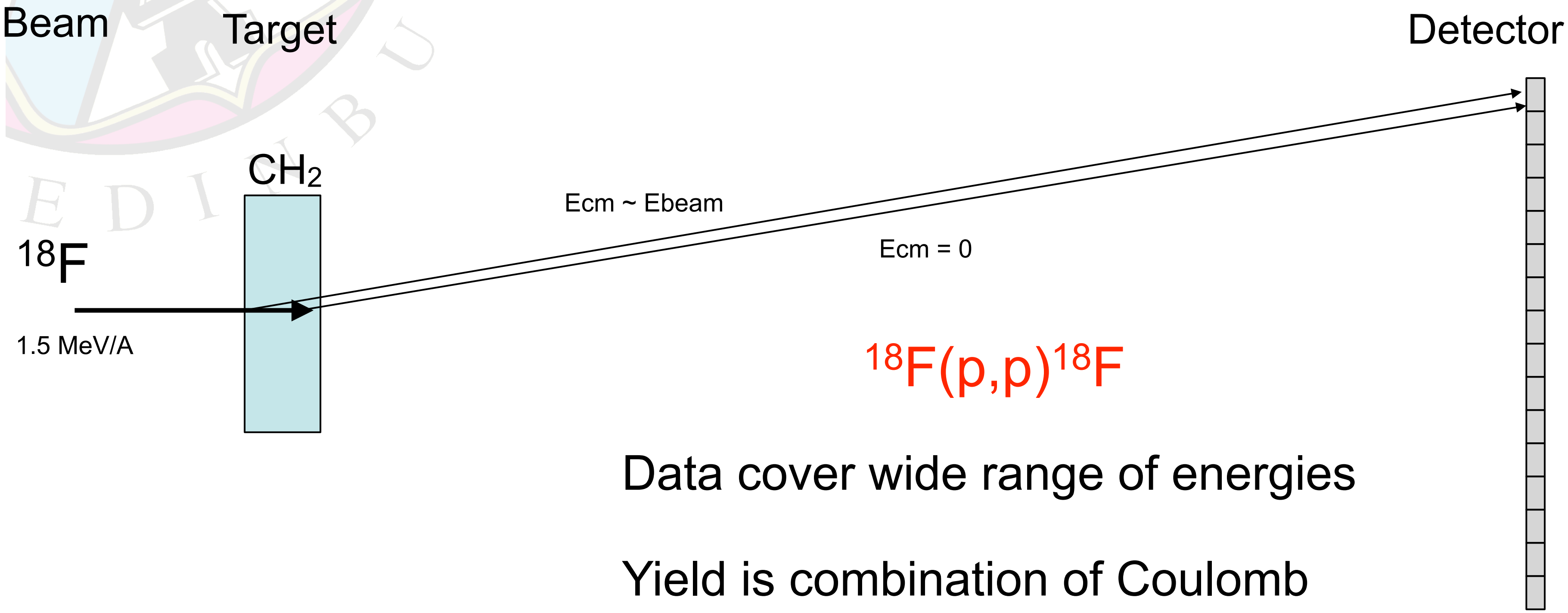
(Typical) TRIUMF set-up



(Typical) TRIUMF set-up



Thick Target Technique



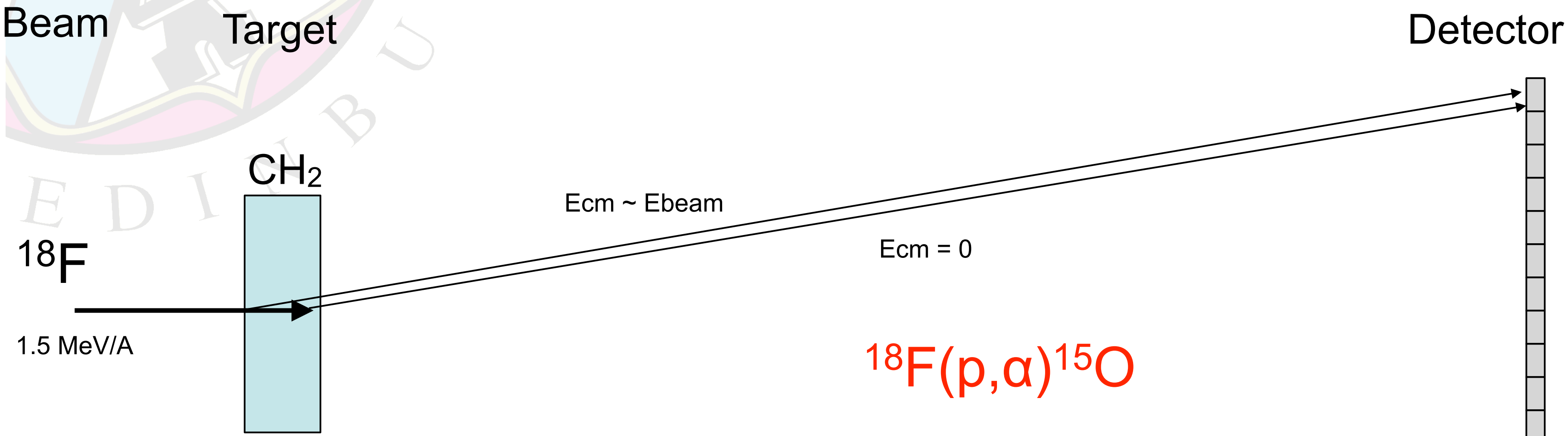
$^{18}F(p,p)^{18}F$

Data cover wide range of energies

Yield is combination of Coulomb scattering and resonant contribution

Detailed shape of excitation function contains required nuclear information

Thick Target Technique



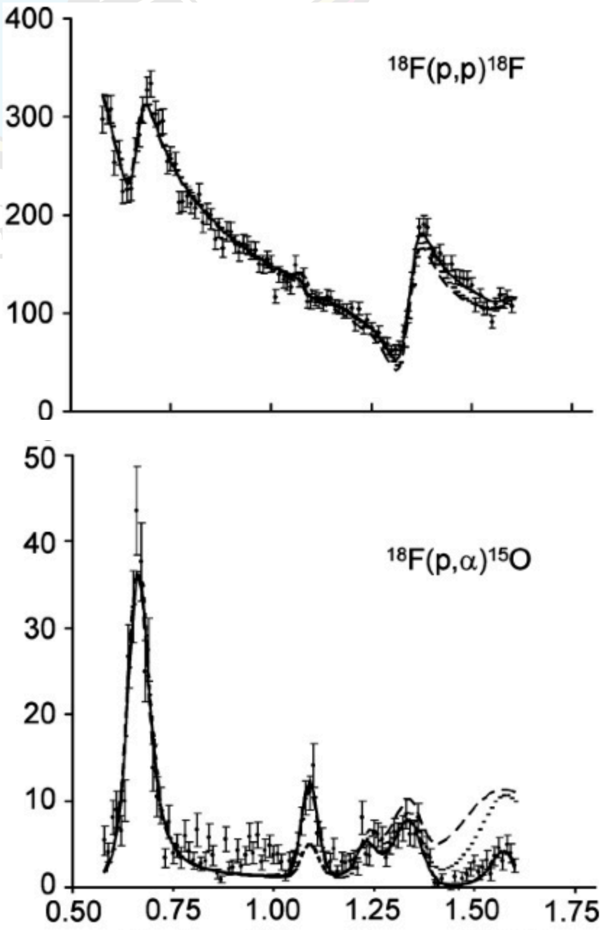
$^{18}F(p,\alpha)^{15}O$

Data cover wide range of energies

Yield is from resonant contribution only

Shape is simpler

Data



ASM et al. PRC 79 (2009)

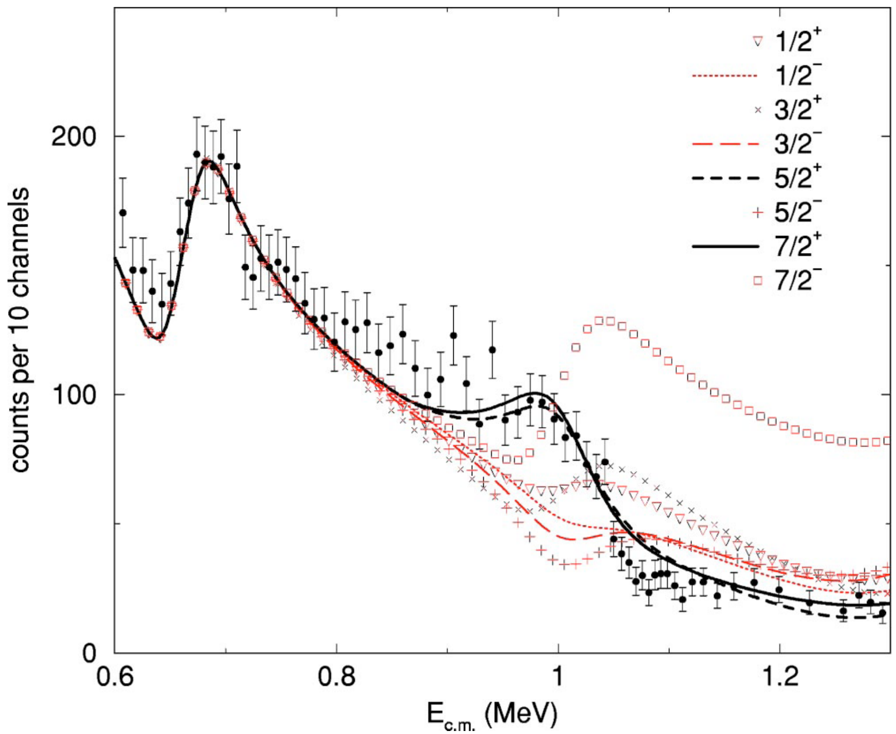
- R-matrix analysis
- Analysis based on (p,p) only would have been VERY different to that based on simultaneous (p,p) and (p,α)
- Deduce $E, \Gamma_p, \Gamma_\alpha, \ell,$ interference

State at 1009 keV?

PHYSICAL REVIEW C **70**, 015804 (2004)

Search for astrophysically important ^{19}Ne levels with a thick-target ^{18}F$(p,p)^{18}$F measurement

D. W. Bardayan,[1] J. C. Blackmon,[1] J. Gómez del Campo,[1] R. L. Kozub,[2] J. F. Liang,[1] Z. Ma,[3] L. Sahin,[4,5] D. Shapira,[1] and M. S. Smith[1]

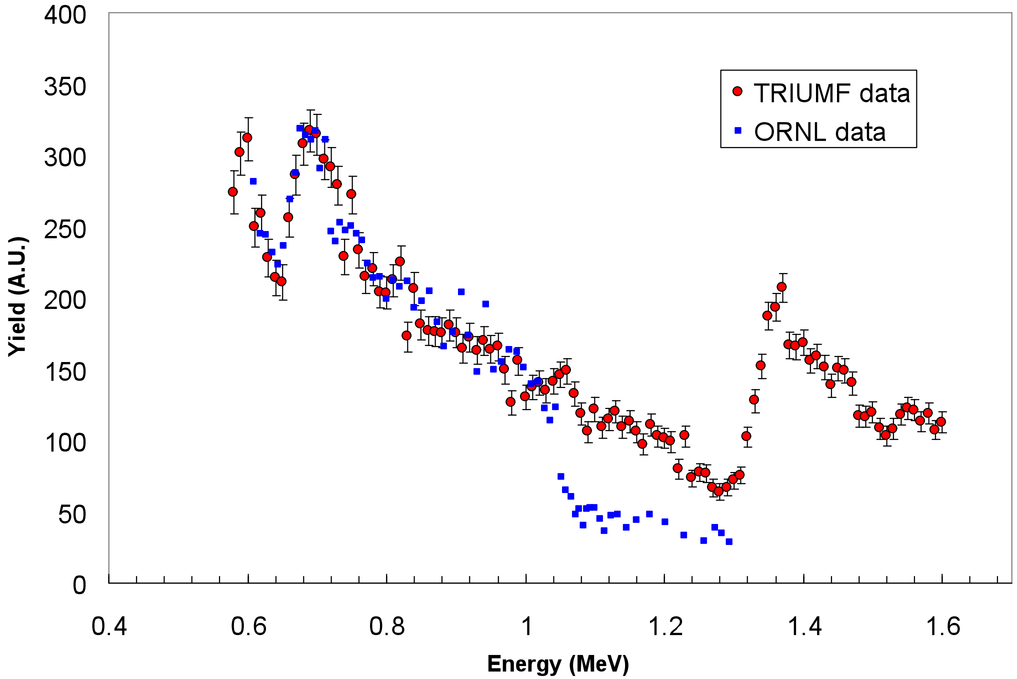


...No state at 1009 keV!

PHYSICAL REVIEW C **79**, 058801 (2009)

Simultaneous measurement of the ^{18}F$(p,p)^{18}$F and ^{18}F$(p,\alpha)^{15}$O reactions: Implications for the level structure of ^{19}Ne, and for ^{18}F production in novae

A. St. J. Murphy,[1,*] A. M. Laird,[2] C. Angulo,[3] L. Buchmann,[4] T. Davinson,[1] P. Descouvemont,[5] S. P. Fox,[2] J. José,[6] R. Lewis,[2] C. Ruiz,[4] K. Vaughan,[2] and P. Walden[4]



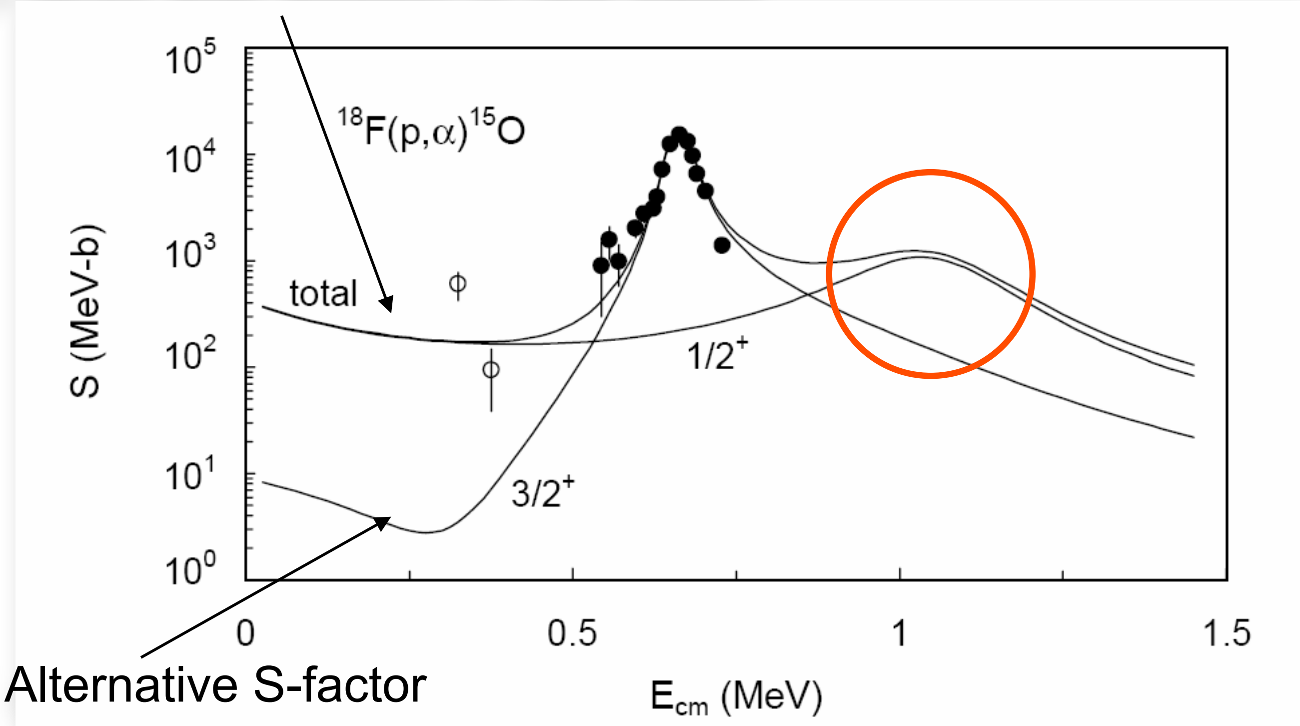
Broad $\ell = 0$ state at ~1.5 MeV?

NUCLEAR PHYSICS A

The ^{18}F(p, α) ^{15}O low-energy *S*-factor:
A microscopic approach

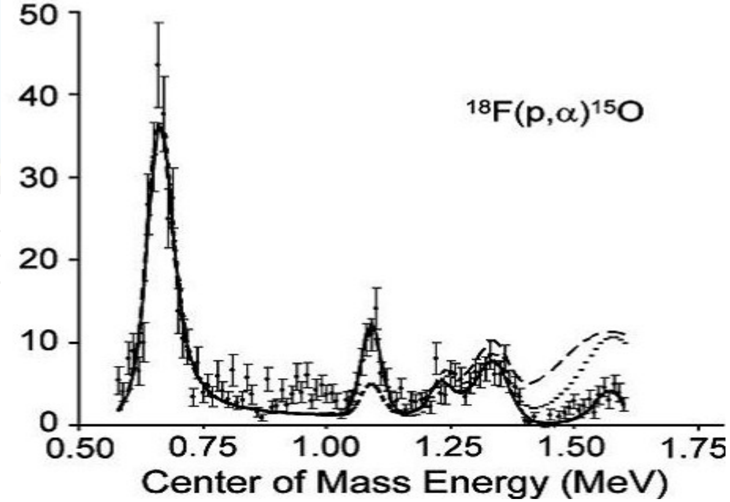
M. Dufour[a], P. Descouvemont[b,*,1]

S-factor after addition of new states



Alternative S-factor

Broad $\ell = 0$ state at ~1.5 MeV?



E_x=1573+6411=7984 keV

$\Gamma_p = 8^{+8}_{-4}$ keV

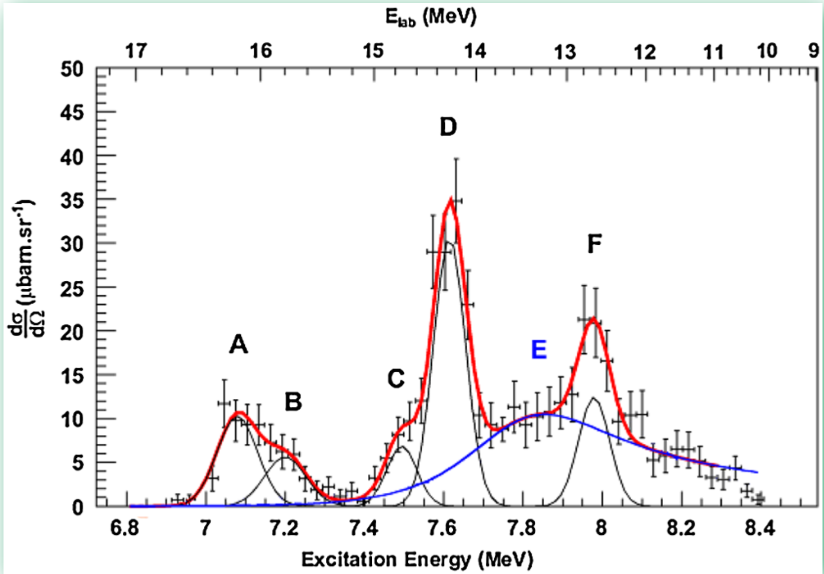
Γ_α = 34± 13 keV

Dalouzy *et al.* PRL 102 (2009) 162503

Use inelastic scattering
$^{1}H(^{19}Ne,p)^{19}Ne^{*}(p)^{18}F$

E_x=7863±39 keV

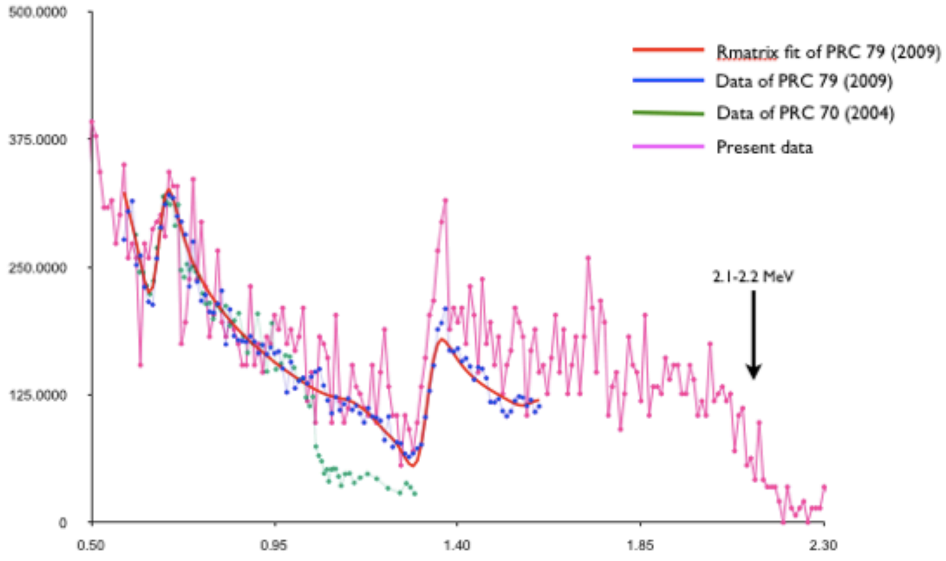
Γ_{tot} =292± 107 keV



Indirect: GANIL

GANIL: Preliminary results

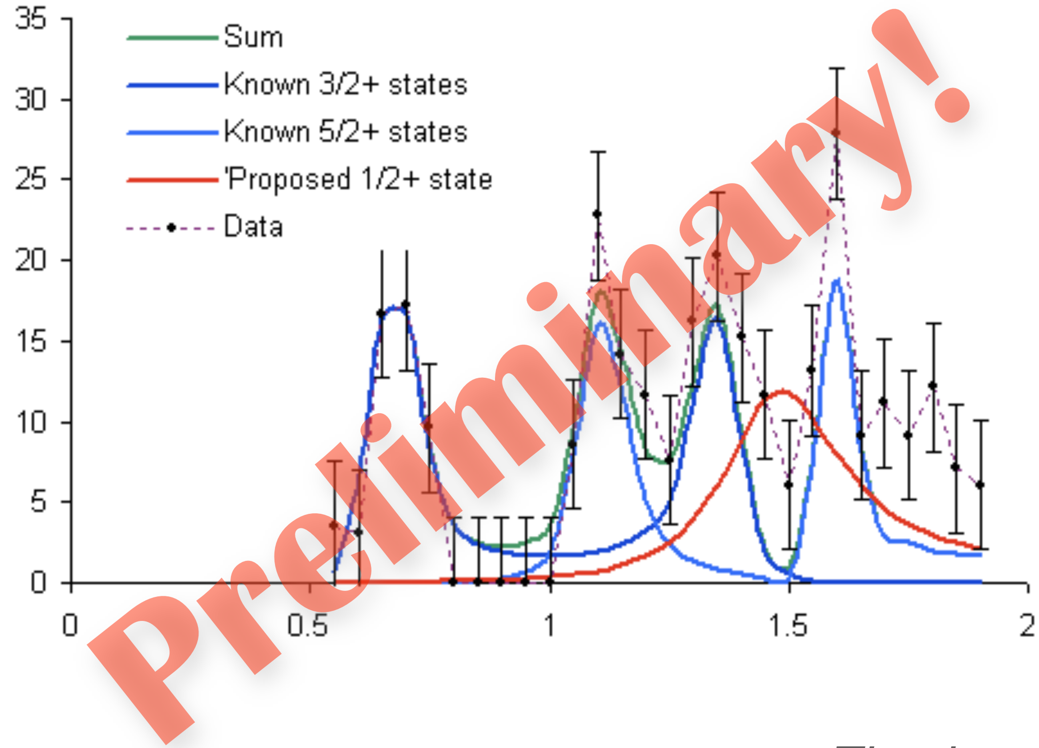
$^{18}F(p,p)$



- More work needed
- Broadly consistent with TRIUMF data
- Confirms 1009 keV resonance result
- Unclear regards 1.49 MeV state

GANIL: Preliminary results

$^{18}F(p,\alpha)$



- More work needed!
- Backgrounds clearly need to be better understood
- However... one might argue that there is ‘no room’ for the 1.49 MeV state...

Thesis work of David Mountford (Edinburgh)

Direct: TRIUMF

Thesis work of Clare Beer (York)

$^{18}F(p,\alpha)$ in the Gamow Window

Key issue to be resolved:

What is the cross section in the Gamow window?

Solution:

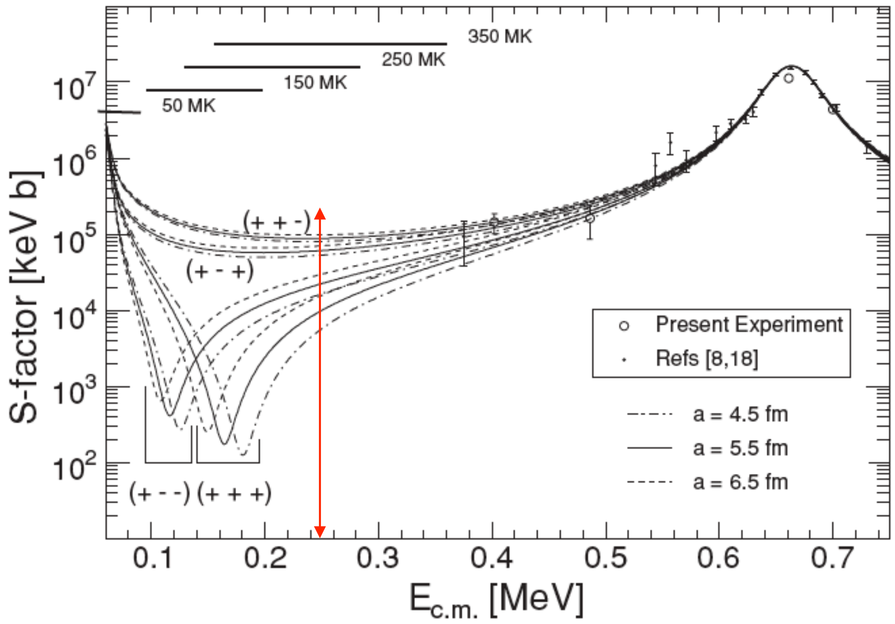
Make a measurement at low energy

250 keV

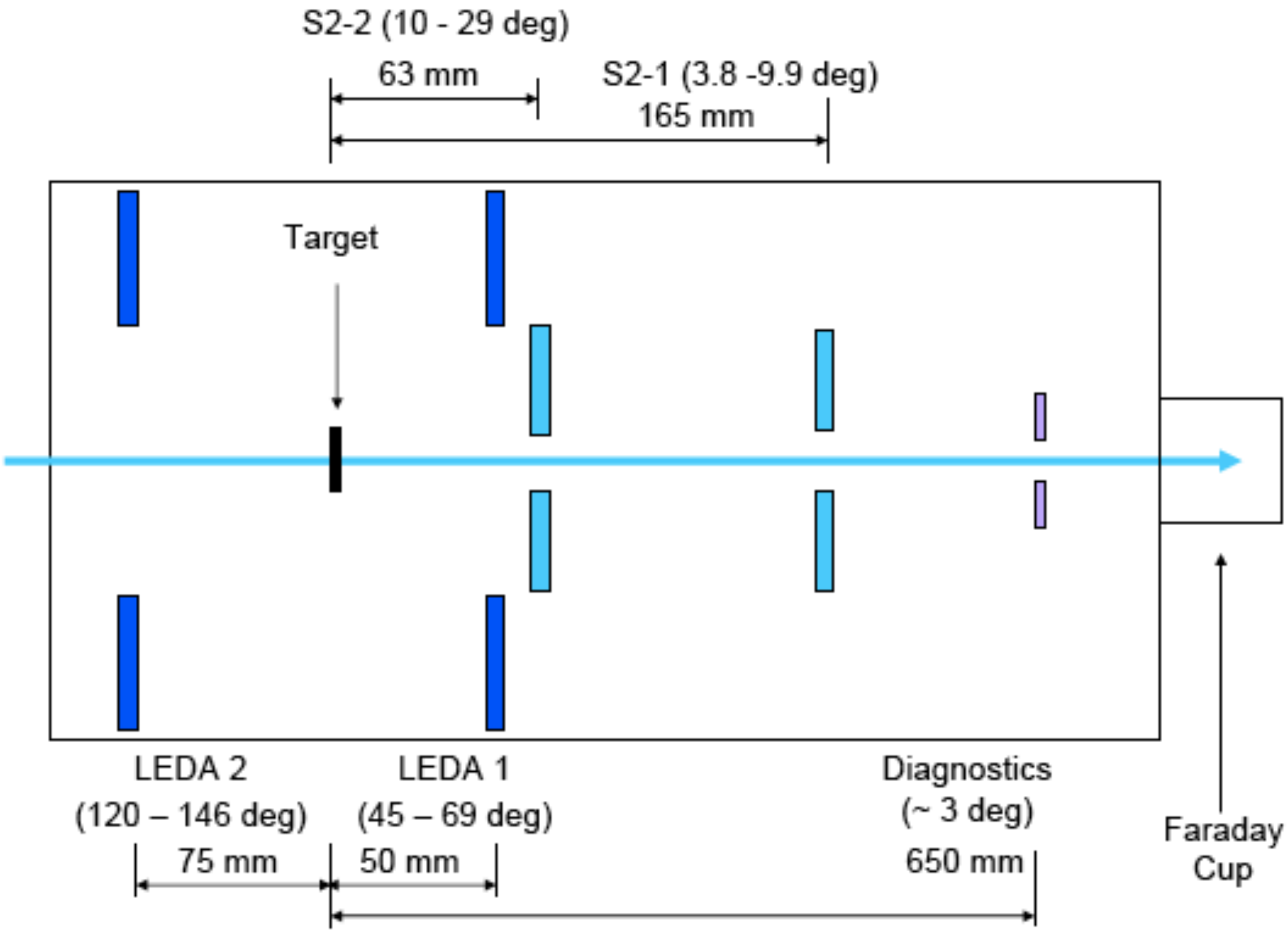
PHYSICAL REVIEW C 79, 015801 (2009)

Low-energy $^{18}F(p,\alpha)^{15}O$ cross section measurements relevant to nova γ-ray emission

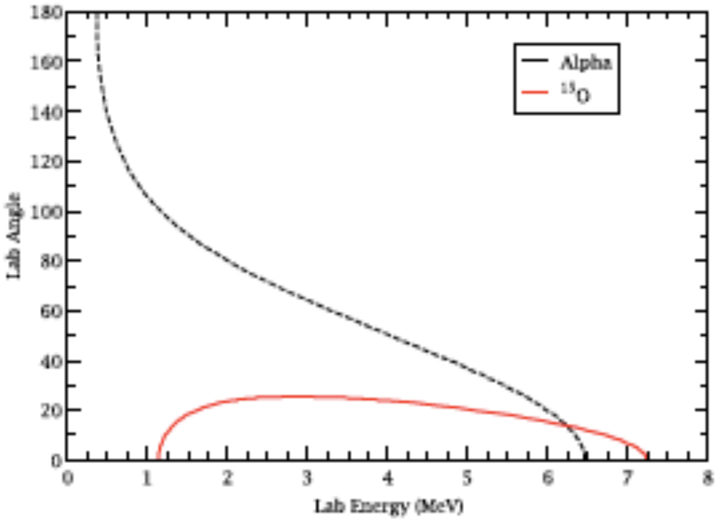
N. de Séréville,[1,2,*] C. Angulo,[1,†] A. Coc,[3] N. L. Achouri,[4] E. Casarejos,[5] T. Davinson,[6] P. Descouvemont,[7] P. Figuera,[8] S. Fox,[9] F. Hammache,[2] J. Kiener,[3] A. Laird,[9] A. Lefebvre-Schuhl,[3] P. Leleux,[1] P. Mumby-Croft,[9] N. A. Orr,[4] I. Stefan,[2,10] K. Vaughan,[9] and V. Tatischeff[3]



Thin target


S2-2 (10 - 29 deg)
63 mm
S2-1 (3.8 -9.9 deg)
165 mm
Target
LEDA 2
(120 – 146 deg)
75 mm
LEDA 1
(45 – 69 deg)
50 mm
Diagnostics
(~ 3 deg)
650 mm
Faraday
Cup

Kinematics work!



(b) Kinematic plot showing θ_{lab} vs. E_{lab}

Figure 4.10: Kinematic θ_{lab} vs. θ_{cm} and θ_{lab} vs. E_{lab} plots, calculated using Kin2b for the $^{18}F(p,\alpha)^{15}O$ reaction at E_{cm} = 250 keV.

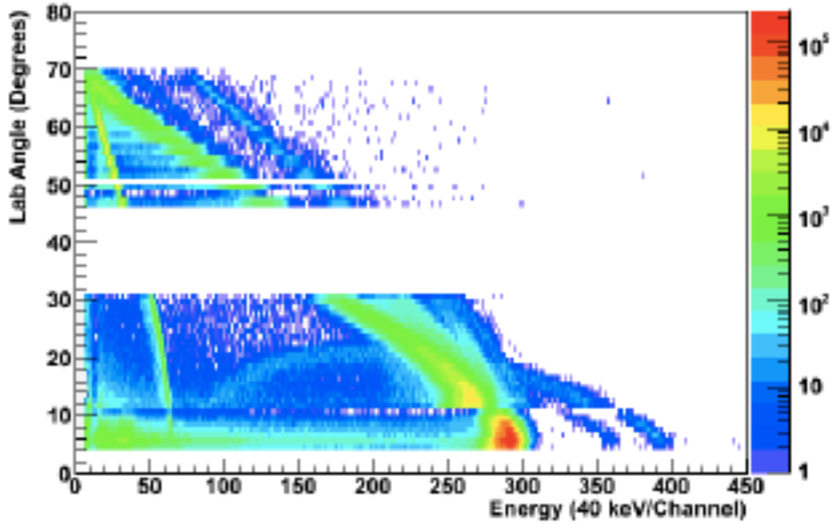
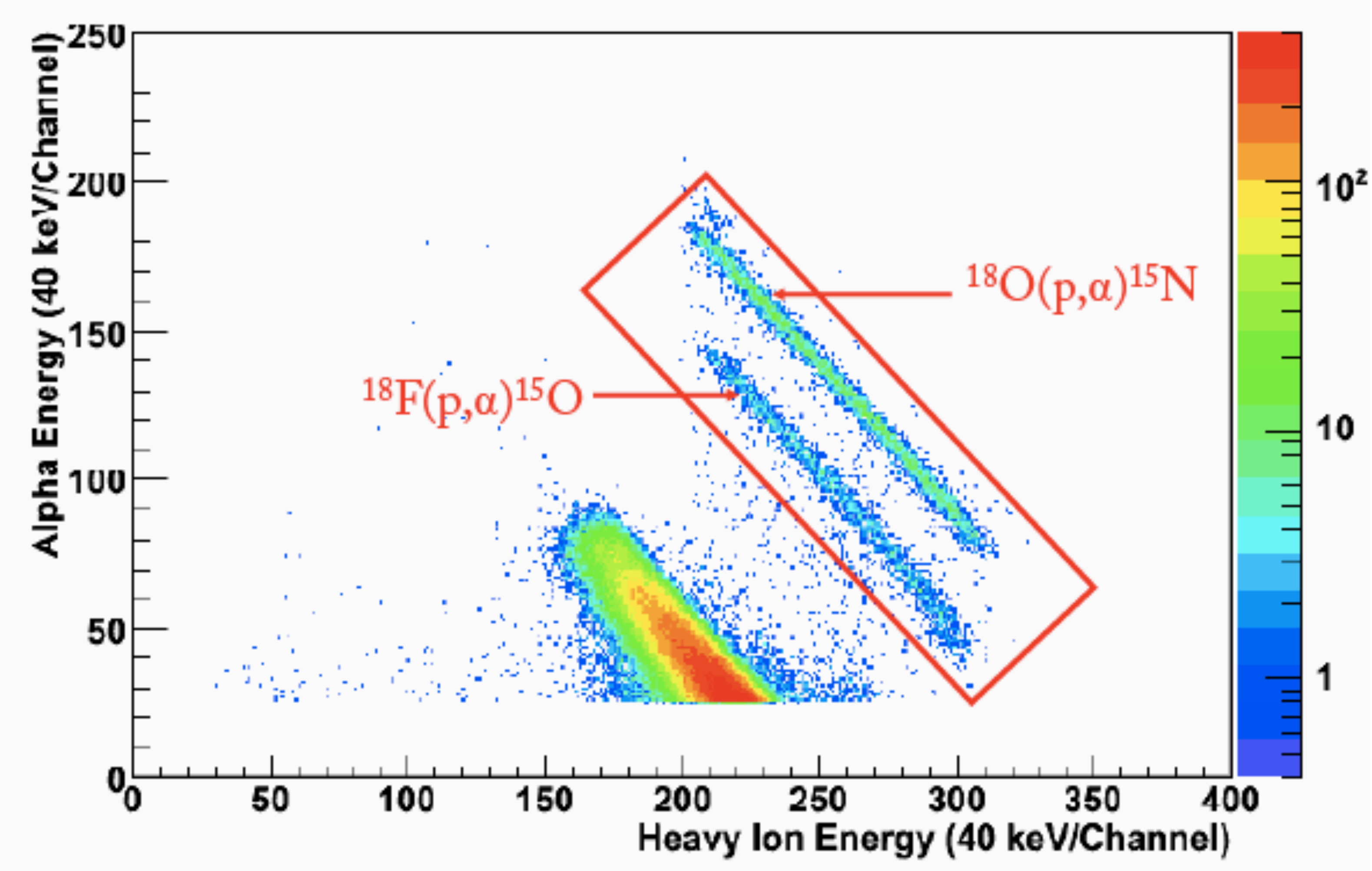


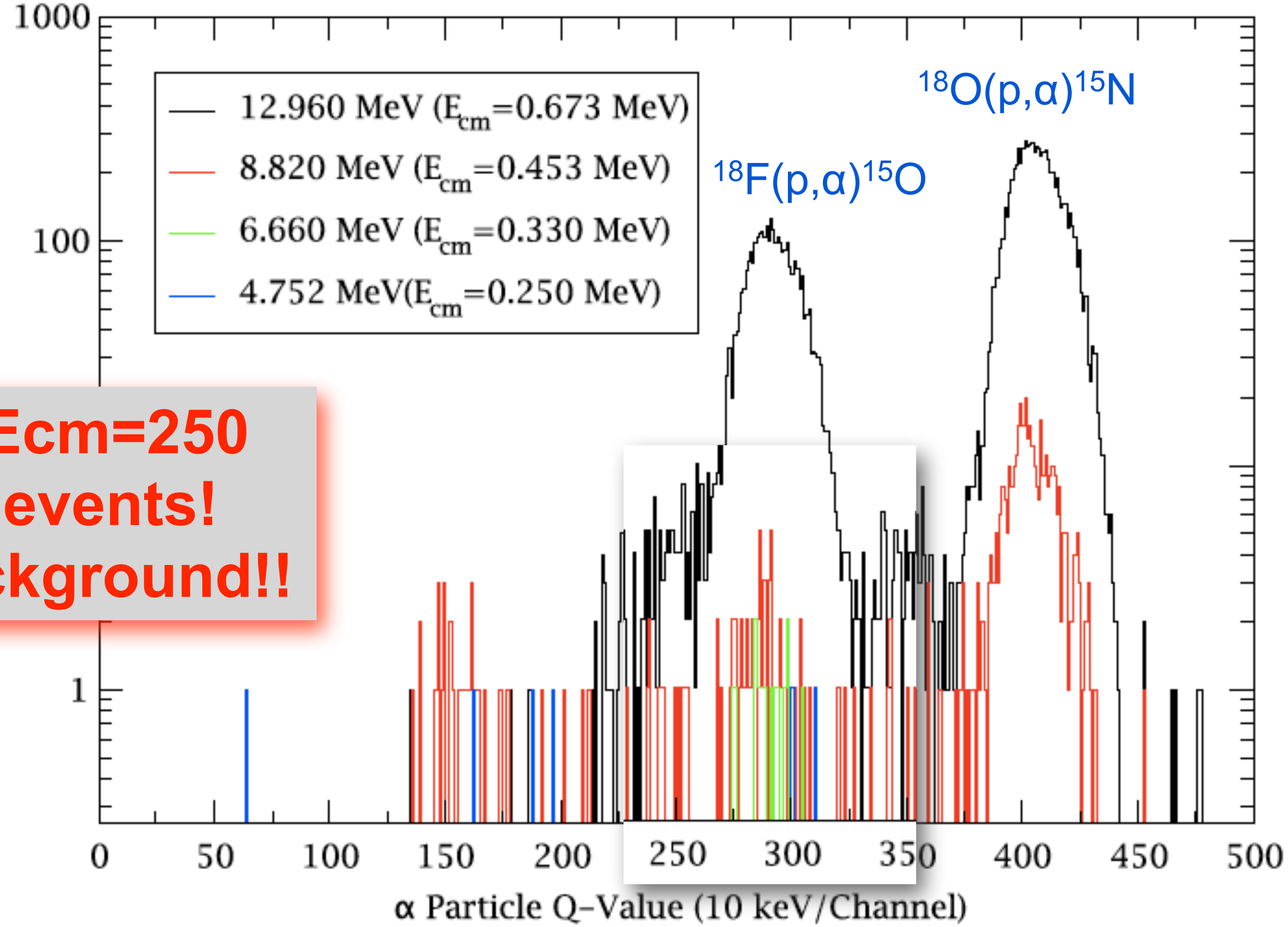
Figure 6.1: Raw data recorded for a single ^{18}F E_{beam} = 12.96 MeV run.

Thesis work of Clare Beer (York)

Rare event searches!

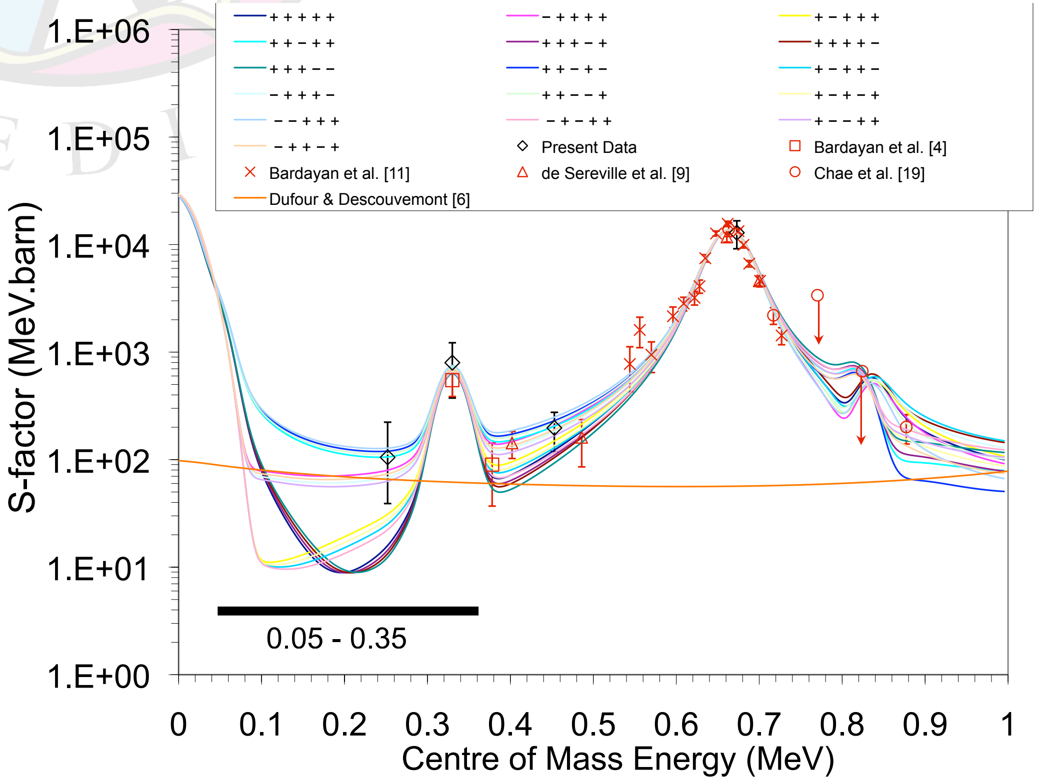


Rare event searches!



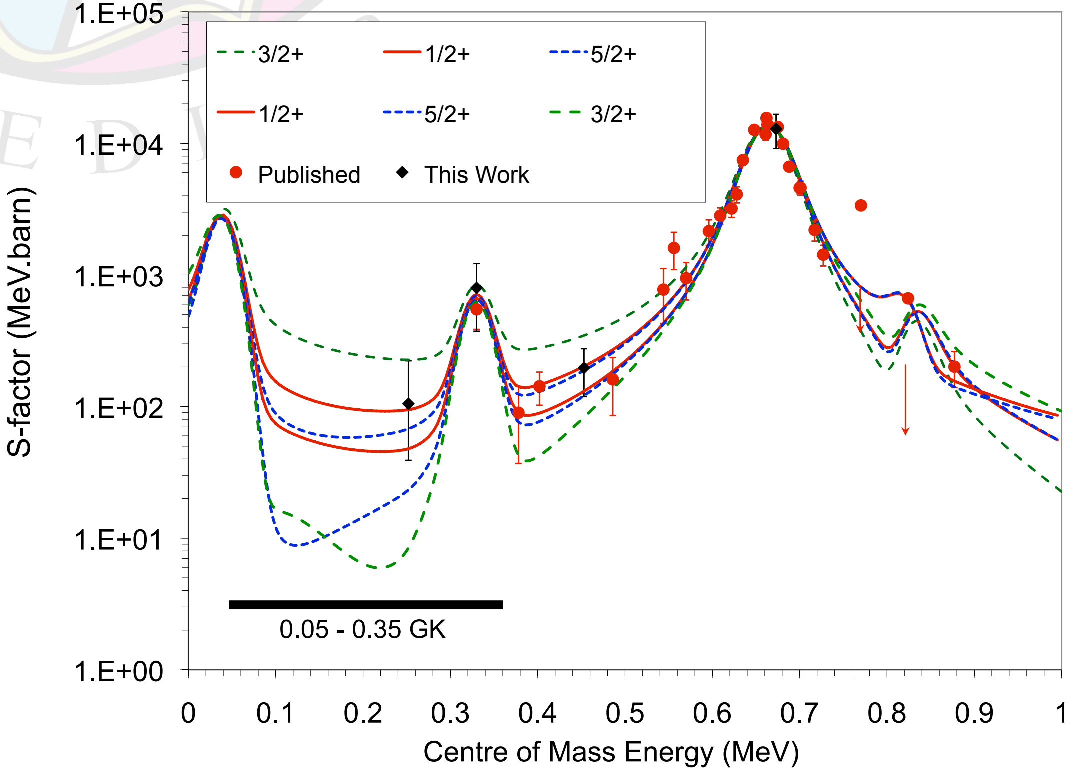
Two Ecm=250 keV events! No background!!

Direct measurement: Results



The higher cross section interference possibilities are favoured by the new data

Or...

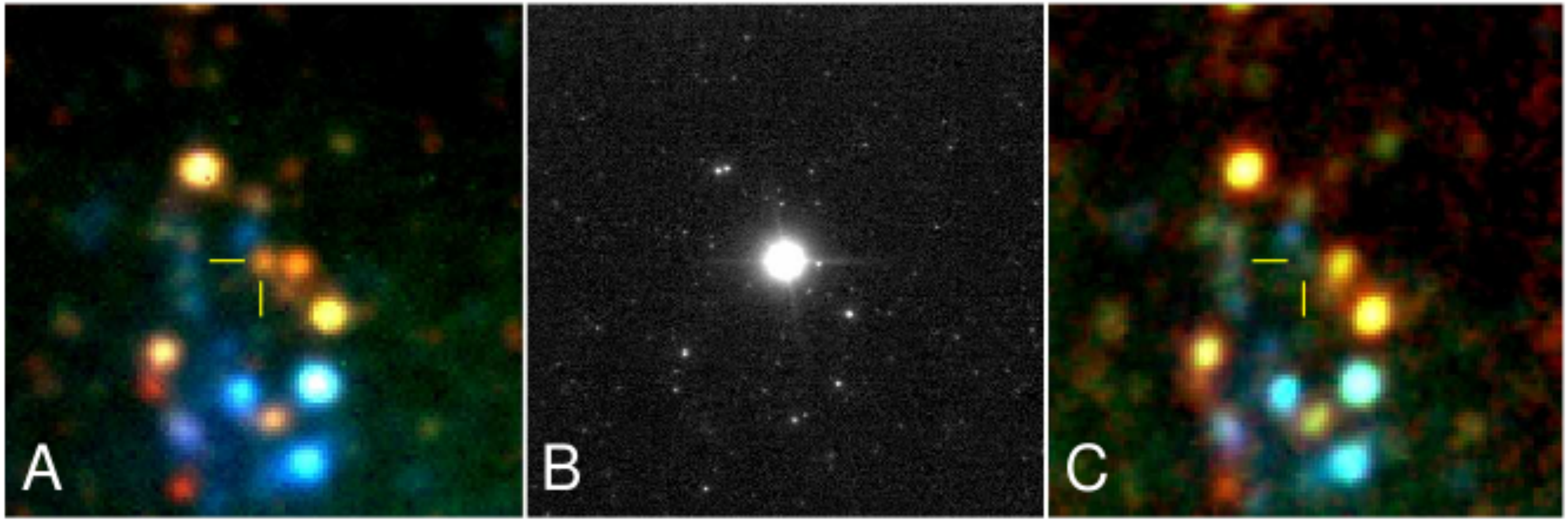


It could be we are seeing the contribution from a sub-threshold state...

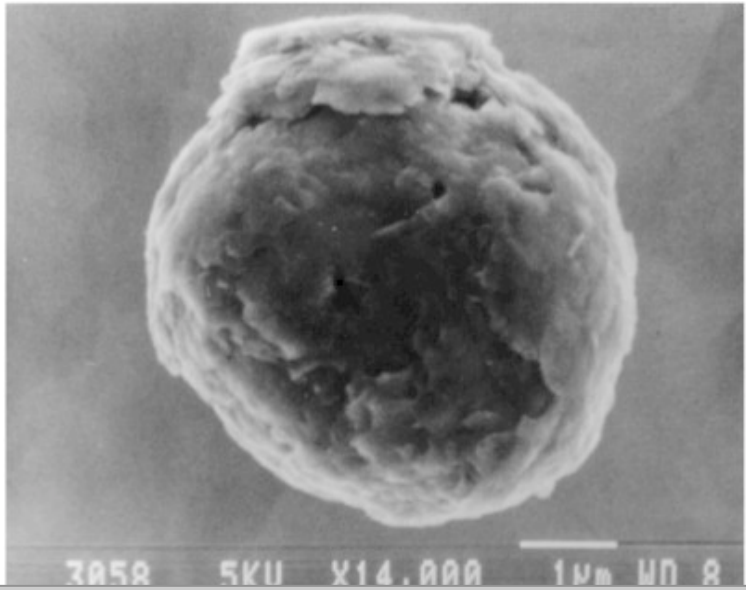
^{44}Ti and Core Collapse Supernovae

The Disappearance of the Red Supergiant Progenitor of Supernova 2008bk

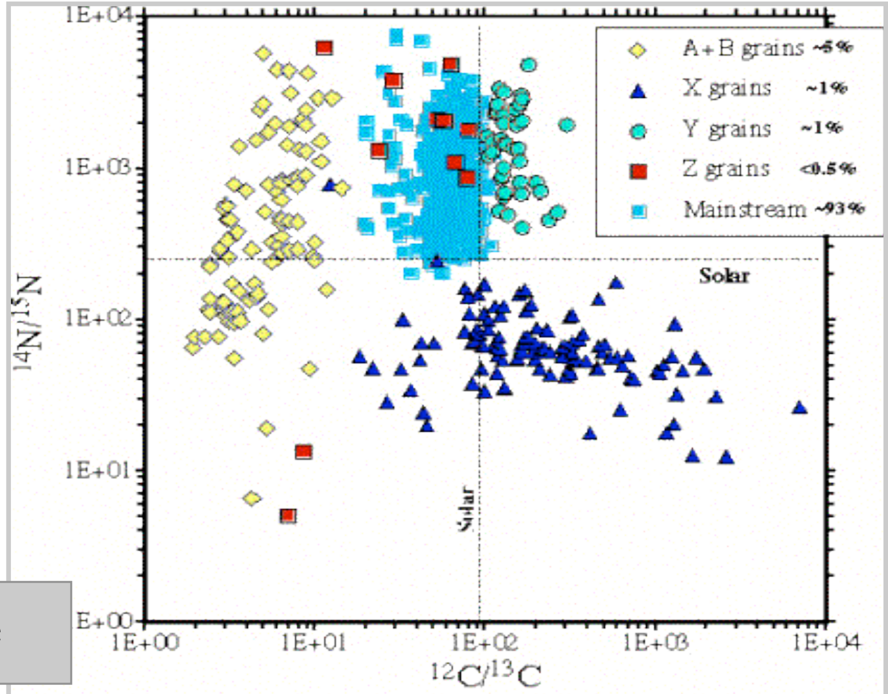
Seppo Mattila,[1,2*] Stephen Smartt,[3] Justyn Maund,[4,5] Stefano Benetti,[6] Mattias Ergon[1]



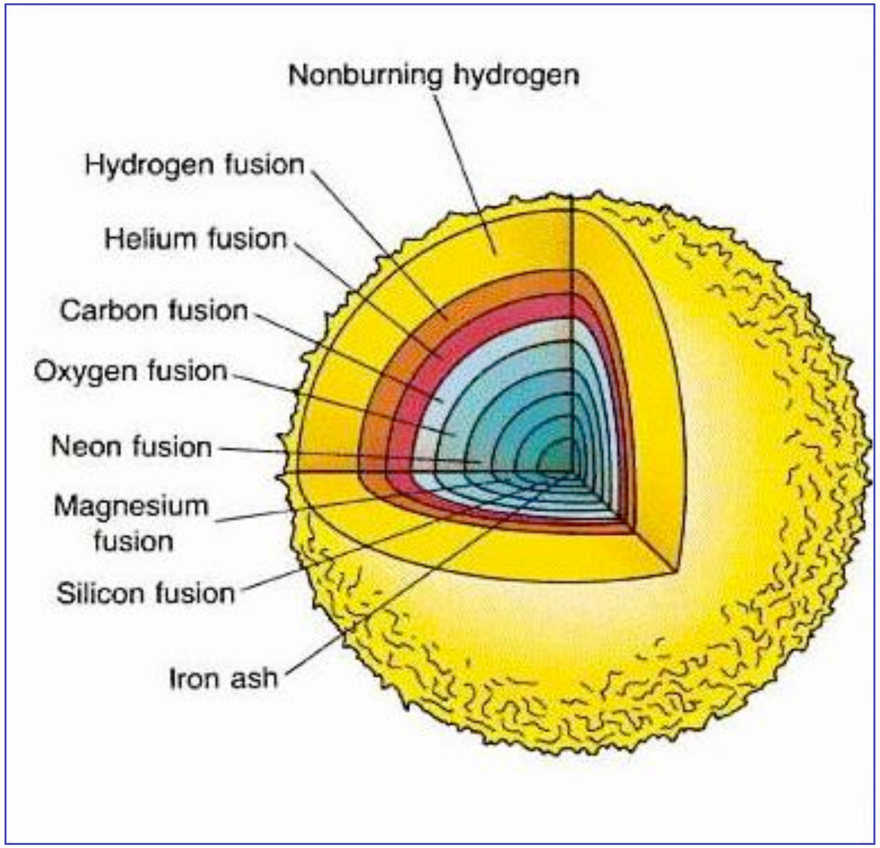
Presolar grains

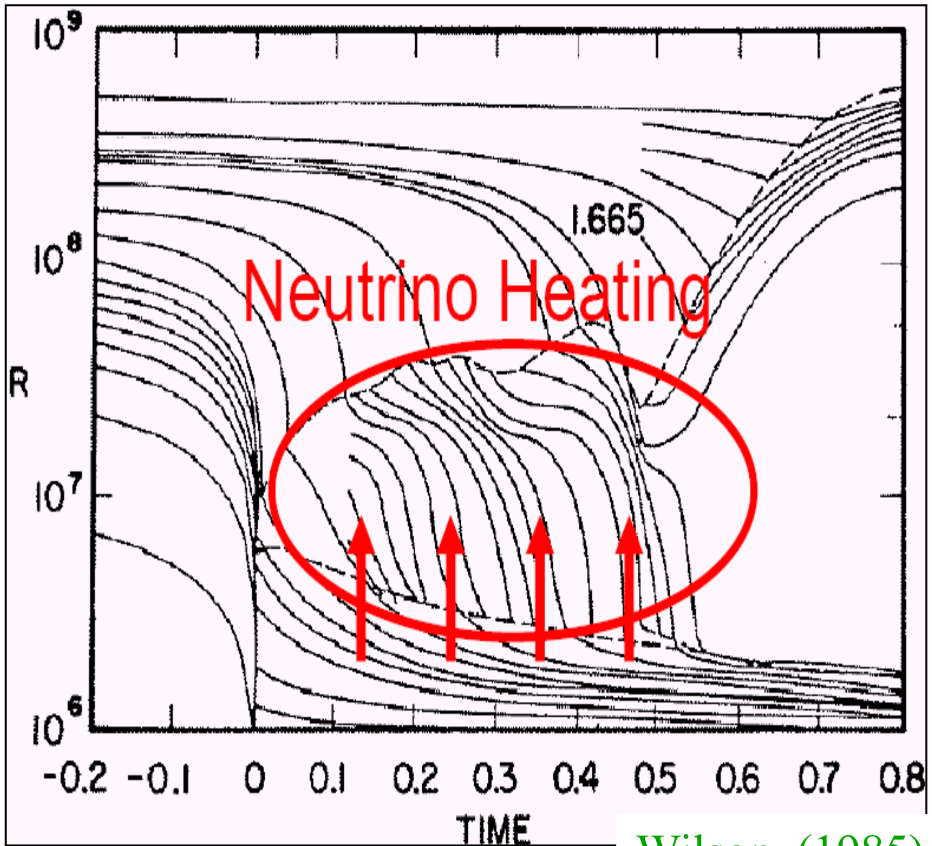


A grain from the Murchison Meteorite



The Neutrino Mechanism

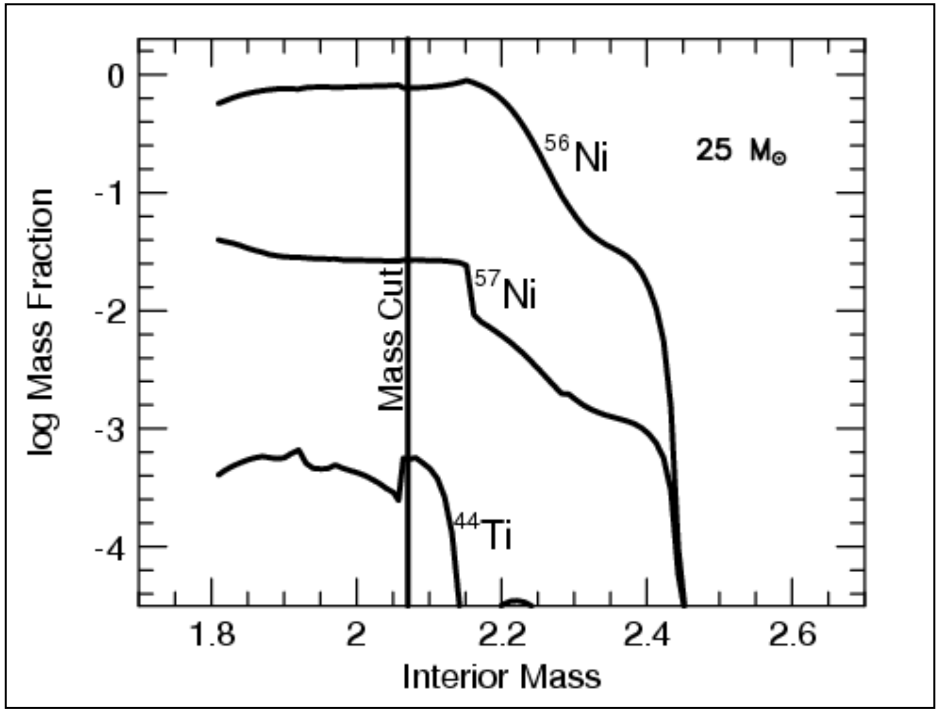




Wilson. (1985)

^{44}Ti production as a diagnostic

- Amount ejected sensitively depends on location of the 'mass cut'
  - Material that 'falls back' is not available for detection
- ^{44}Ti yield a sensitive diagnostic of the explosion mechanism
- Thus, very useful for models to make comparisons against



Timmes *et al.* (1996)

Key Reactions

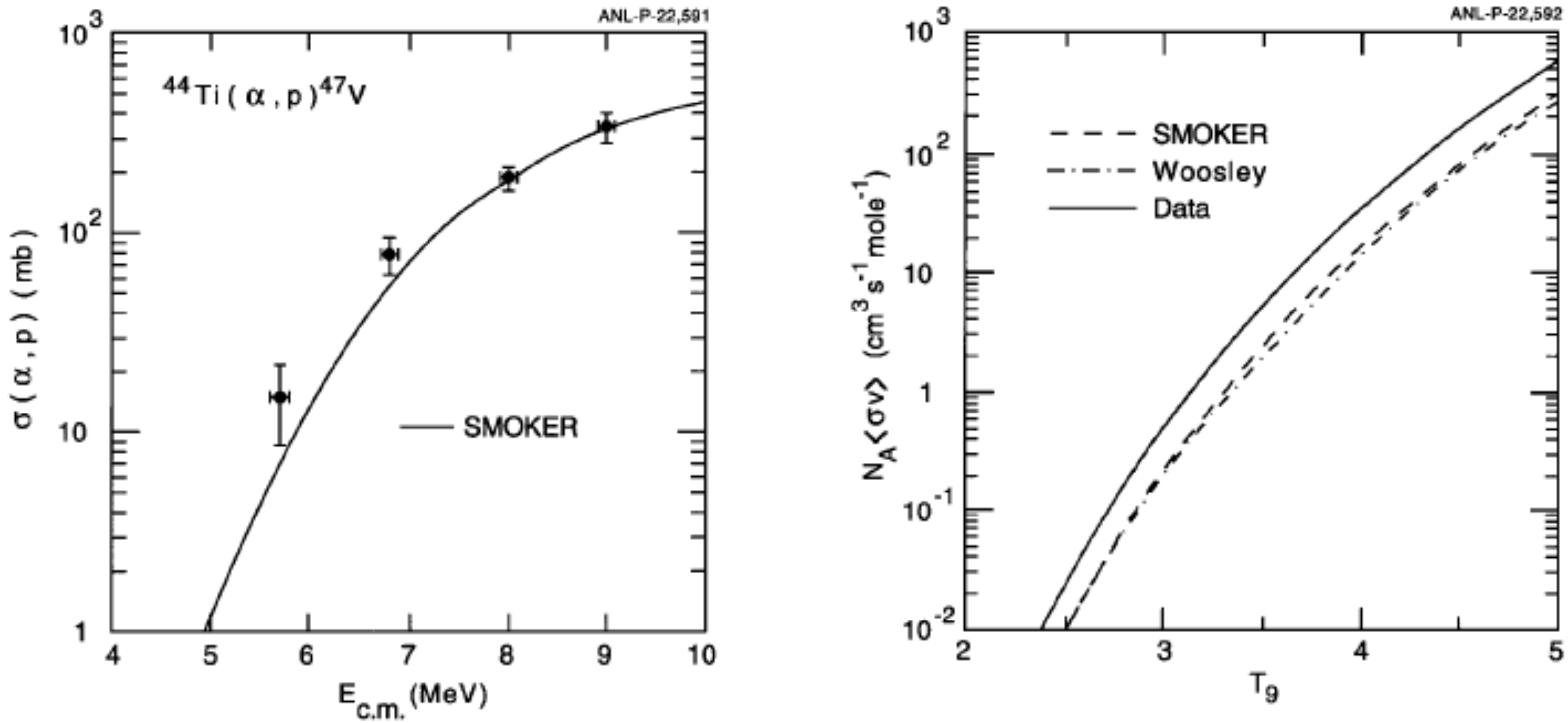
L.S. The et al. ApJ 504 (1998) 500

- $^{40}Ca(\alpha,\gamma)$
  - Recent from Nassar *et al.* *(PRL 96 (2006) 041102)*
  - Results from Vockenhuber *et al.* (*PRC **76** (2007) 035801*)

DONE!

- Triple–α
  - Ubiquitous; not the focus here
- $^{44}Ti(\alpha,p)$
  - Sonzogni *et al.* PRL 84 (2000) 1651: Measured above Gamow window
- $^{44}Ti(\alpha,\gamma)$
  - No relevant data
- $^{45}V(p,\gamma)^{46}Cr$
  - Interesting, no relevant data, hard...

^{44}Ti(α,p): Sonzogni data



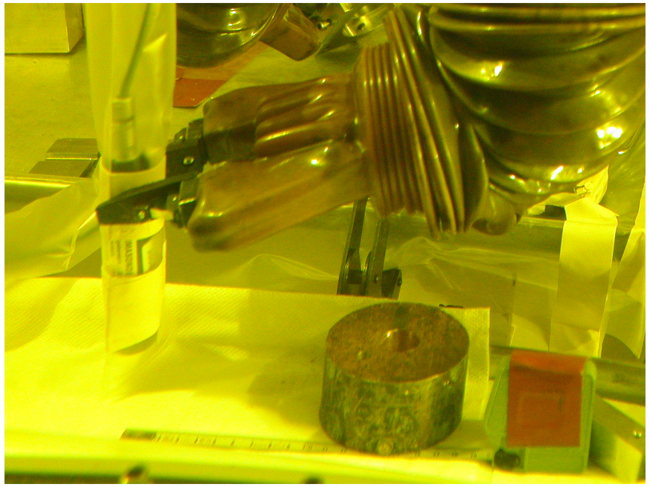
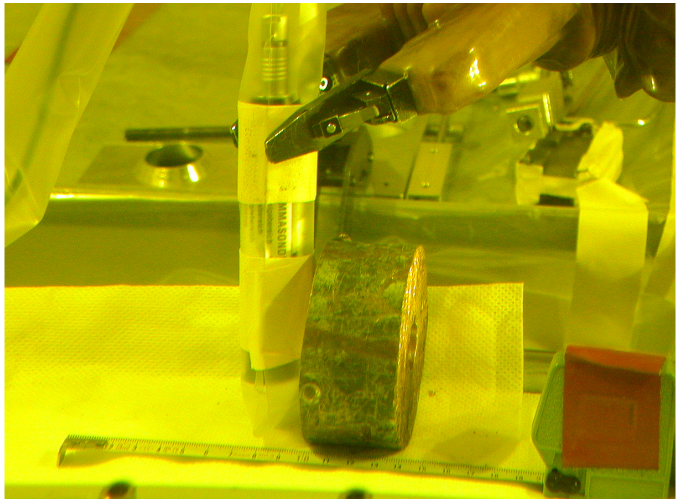
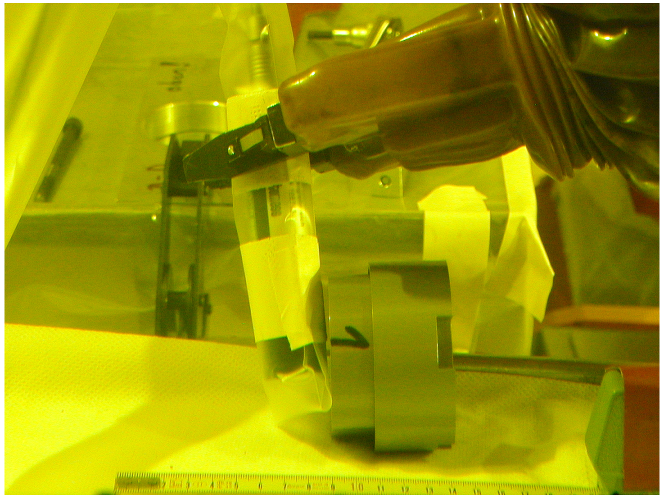
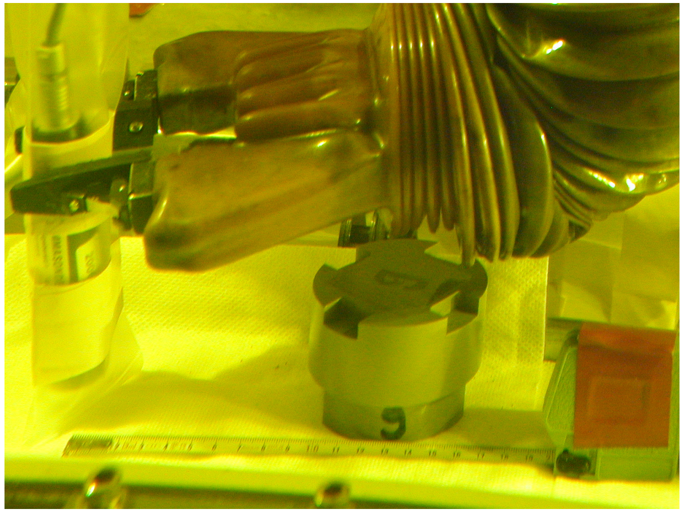
Note: Astrophysical region is ~1-4 MeV
Need to be able to access cross sections to <1 mb
Accuracy of HFSM reduces at lower energies

The ERAWAST Project

- “Exotic Radionuclei from Accelerator Waste”
- Nuclear Astrophysics, geophysics, medicine, industry, etc etc...
- 3.5 MBq presently available (~$2x10^{17}$ ions); 20 ml 1M HNO_3

- Hot Ti within SUPERNANOGAN?
- Impinge accelerated beam on to ^{4}He gas cell / windowless gas target
- Could consider making ^{44}Ti target

Reclaiming of ^{44}Ti

Proposals

S1289 ... ent of
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Spokes ... urphy

TRIUMF | Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

August 6, 2010

Dr. A.J. Murphy
University of Edinburgh
amurphy@ph.ed.ac.uk

Dear Dr. Murphy:

I am pleased to inform you that, at its meeting held July 29 & 30, 2010, the Subatomic Physics Experiments Evaluation Committee recommended that your experiment S1289 be given stage 1 approval at medium-high priority. Please see the committee recommendation on the next page.

As you are aware, your experiment will have to undergo a formal safety review by the TRIUMF Science Division Safety Committee before being allocated beam time. In addition, a Technical Review will be required outlining technical demands the experiment will place on TRIUMF (space, cryogenics and electrical support, machine shop, electronics shop, drawing office, detector facility, electronics pool, and wire chamber support). According to our policy, no experiments will be scheduled for beam without the relevant safety approvals and technical reviews.

At year-end, the TRIUMF Publications Office may request a report on your experiment for the TRIUMF Annual Report. We would also like to request that you give appropriate acknowledgement to TRIUMF in any of your talks or publications.

Let me congratulate you and your colleagues, and wish you every success with your experiment. Please do not hesitate to contact me if I can be of help in any way.

Yours sincerely,

Richard Woloshyn

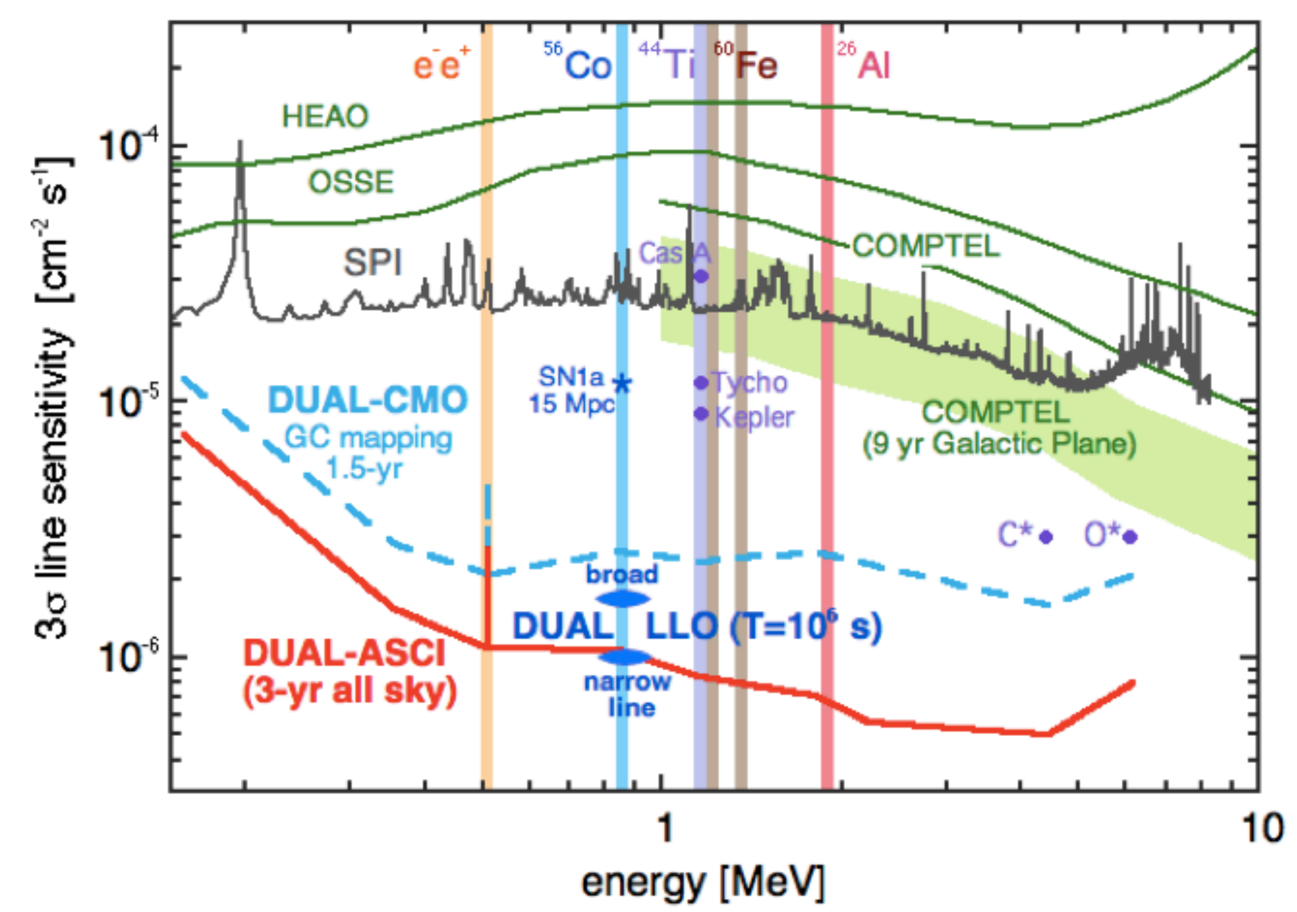
Richard Woloshyn
for Gordon C. Ball
Science Division Head

ERAWAST workshop

29 Aug - 2 Sept 2011

PSI

Rocket Science!



30x better narrow line sensitivity

J. Knödlseder (CESR)
B. Pirard (Canberra)
JP. Prost (TAS)

Thank you