How ATLAS Supports the Heavens

outline

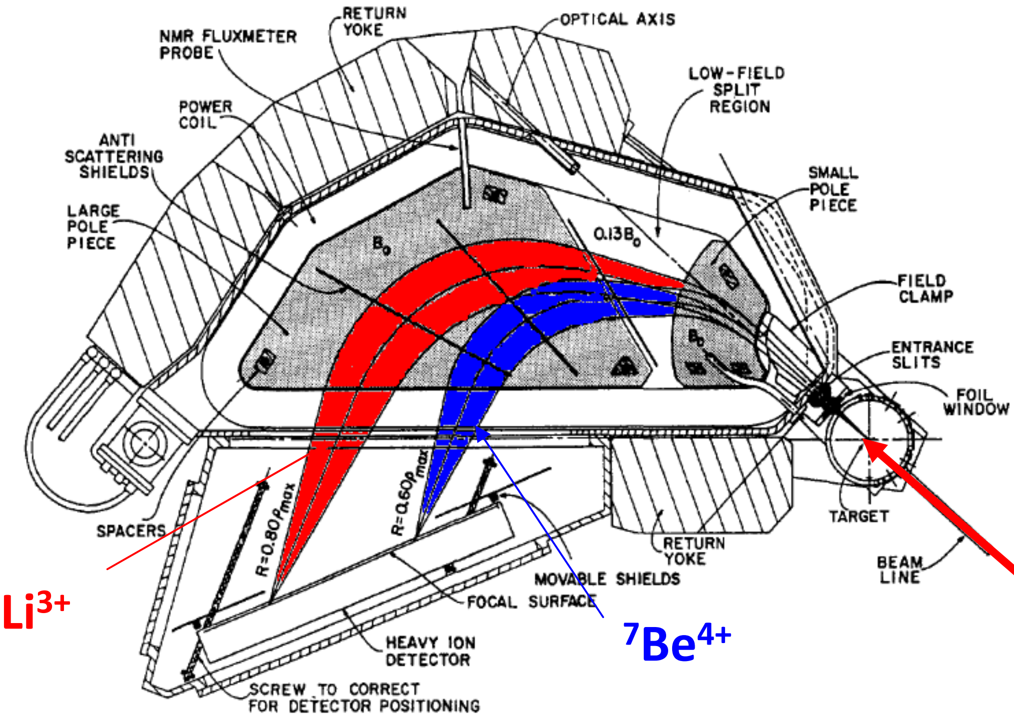
- History of the ‘In-Flight’ production program
- Some examples from the ‘Heavens’
- Future plans in nuclear astrophysics at ATLAS

The Argonne In-Flight Program: First use: 1982

PHYSICAL REVIEW C VOLUME 28, NUMBER 2 AUGUST 1983

Branching ratio in the electron-capture decay of ^{7}Be

C. N. Davids, A. J. Elwyn,* B. W. Filippone,† S. B. Kaufman, K. E. Rehm, and J. P. Schiffer
Argonne National Laboratory, Argonne, Illinois 60439
(Received 25 March 1983)



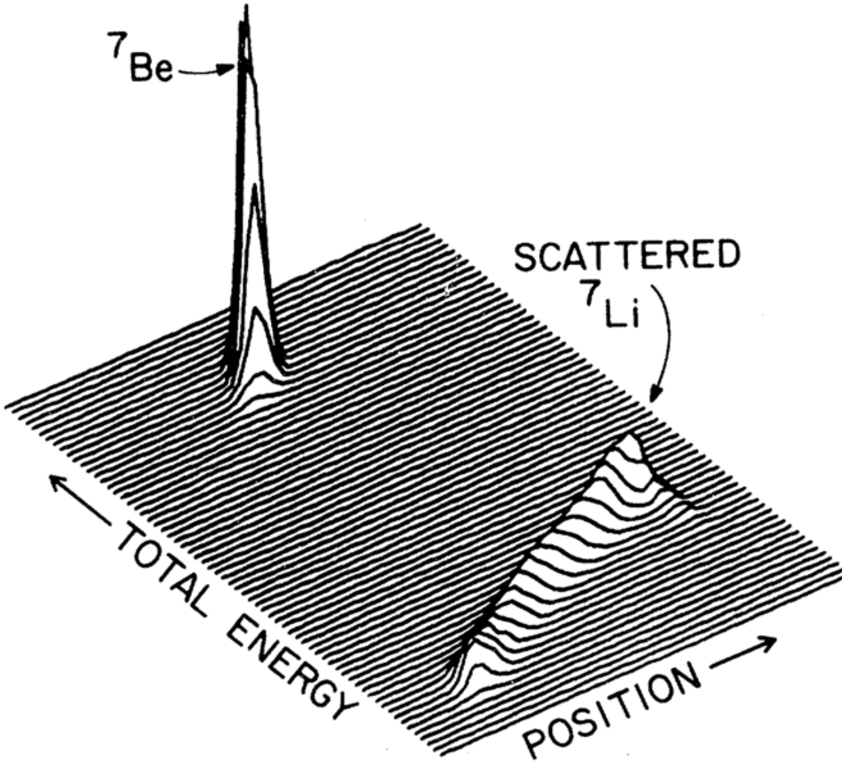
$^{7}Li^{3+}$

$^{7}Be^{4+}$

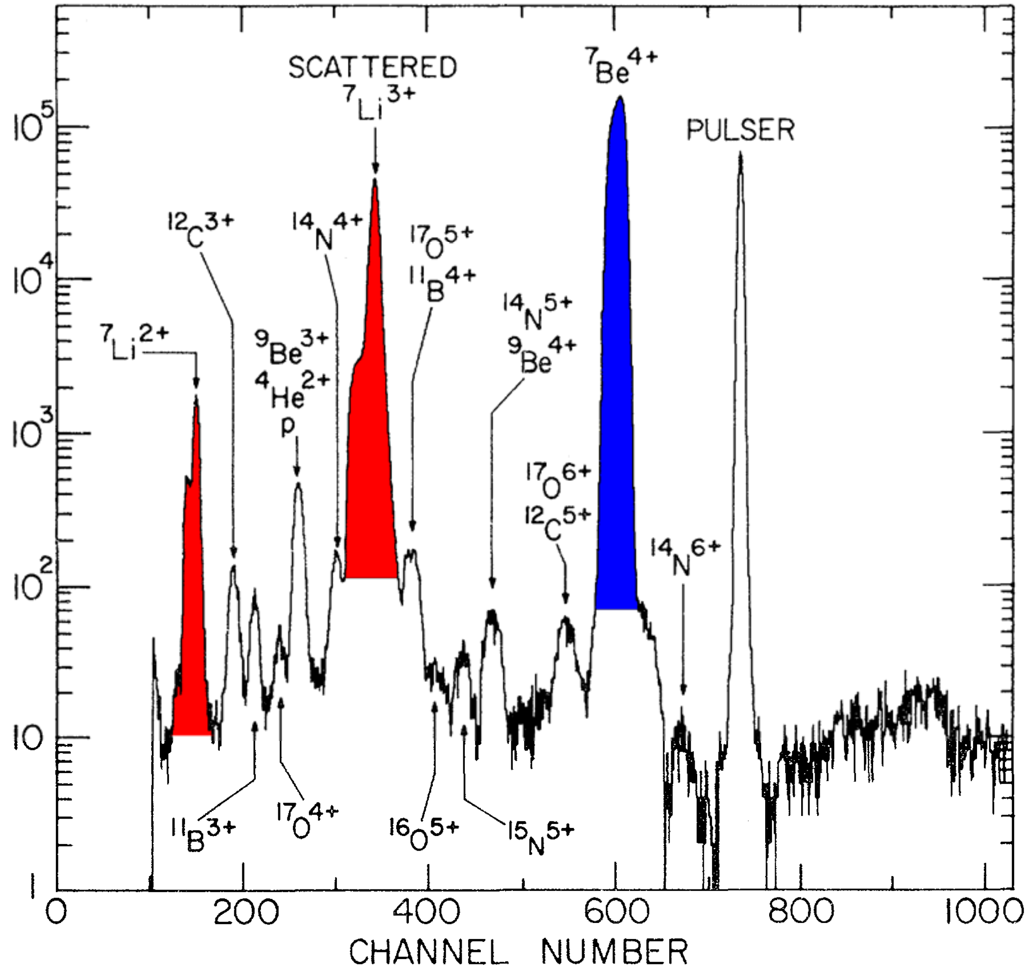
$^{1}H(^{7}Li,^{7}Be)n$ ~10^{3} ^{7}Be/sec

50 μg/cm^{2} of LiH target

15 pnA of ^{7}Li beam



7Be
SCATTERED 7Li
TOTAL ENERGY
POSITION

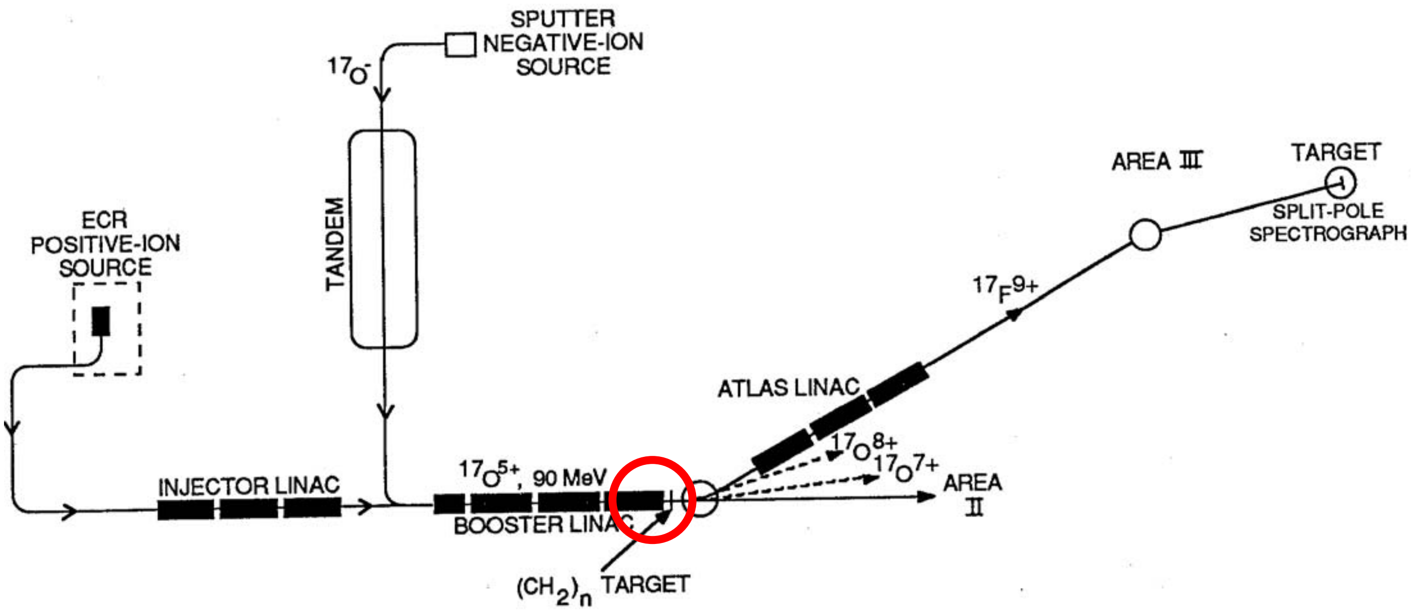


SCATTERED 7Li3+
7Be4+
PULSER
12C3+
14N4+
17O5+
11B4+
14N5+
9Be4+
7Li2+
9Be3+
4He2+
p
17O6+
12C5+
14N6+
11B3+
17O4+
16O5+
15N5+
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
CHANNEL NUMBER

The Argonne In-Flight Program: 2nd attempt: 1990

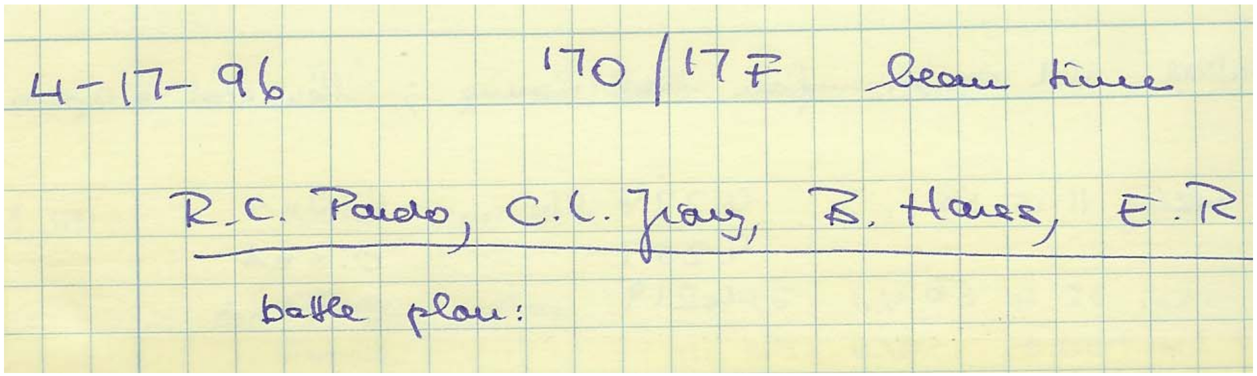
ANL Annual Report 1991

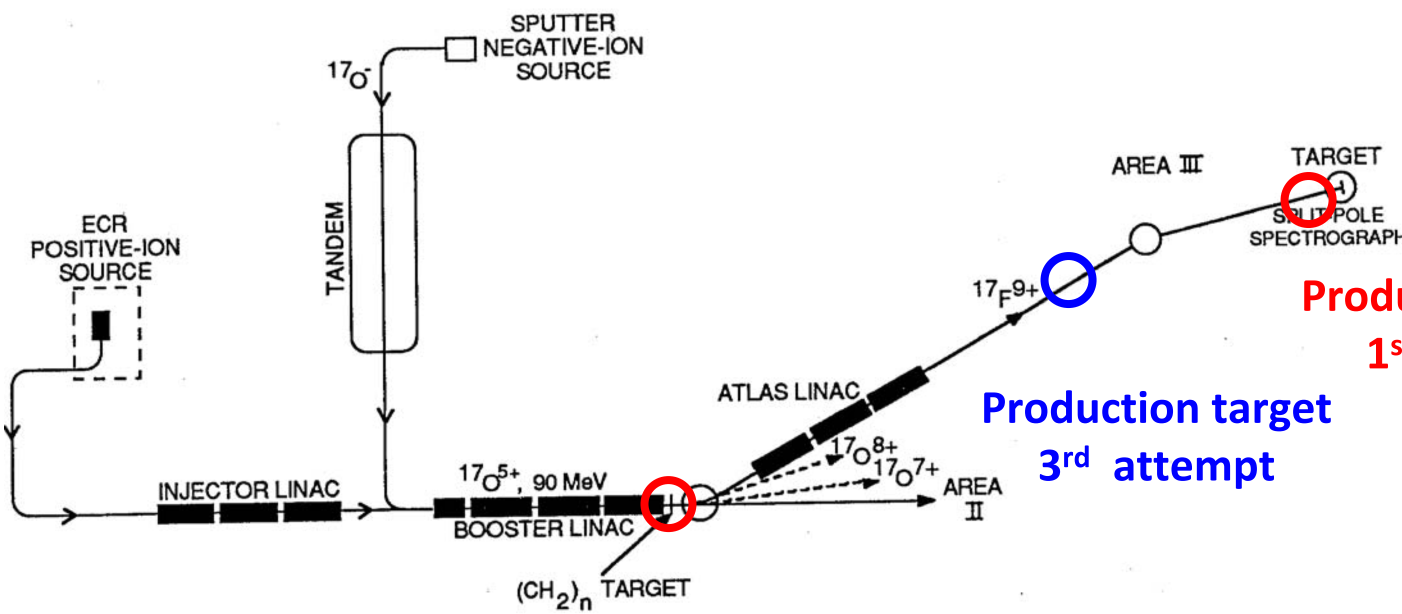
Secondary Beam Development via the H(^{17}O,^{17}F)n Reaction (W. Kutschera, D. Berkovits,† B. G. Glagola, R. C. Pardo, K. E. Rehm, J. P. Schiffer, B. Schneck,* M. Paul,† and T. F. Wang†)



Parameter	Achieved	Hoped-for Improvement	Goal
$^{17}O^{5+}$ beam	2.5 pnA	10^3	2.5 pμA
$(CH_2)_n$ target	905 μg/cm^2 130 μg/cm^2 H	7	1 mg/cm^2 H
cross section	100 mb	1	100 mb
fraction of phase space accepted for ^{17}F	$\frac{1}{200}$ (est.)	10^2	0.5
$^{17}F^{9+}$ stripping fraction	0.5	1	0.5
transmission from target to spectrograph	0.1	1	0.1
$^{17}F^{9+}$ beam at spectrograph	11 pps (30 est.)	$7x10^5$	$8x10^6$ pps

The Argonne In-Flight Program: 3rd attempt: 1996



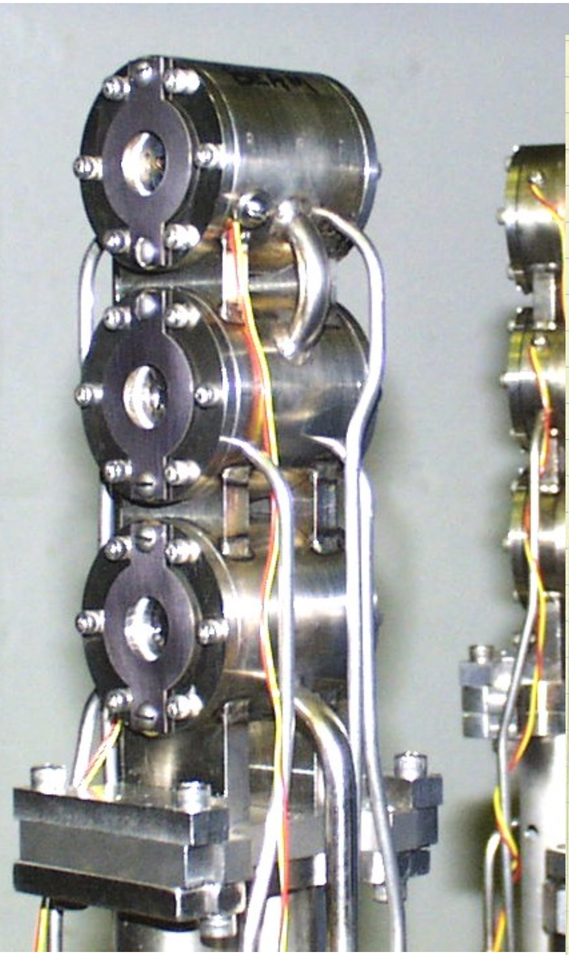


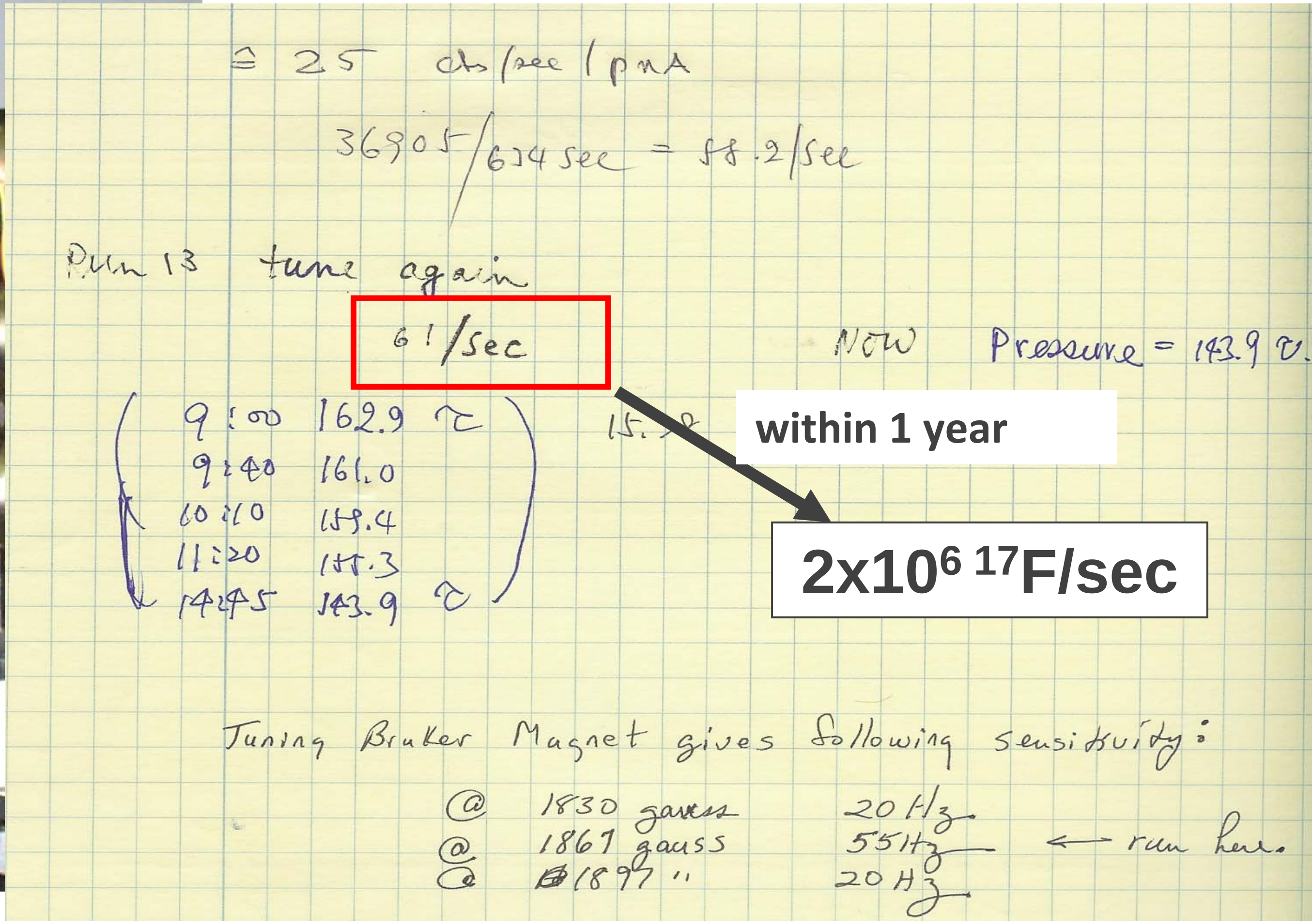
Production target 1st attempt

Production target 3rd attempt

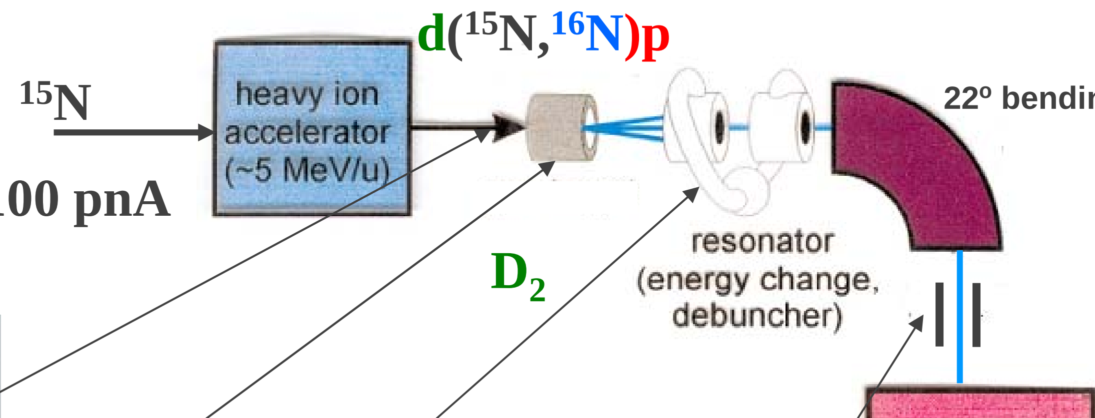
Production target 2nd attempt

Use H_2 gas cell target





The In-Flight Technique Today



I~10⁴ - 5x10⁶ /sec

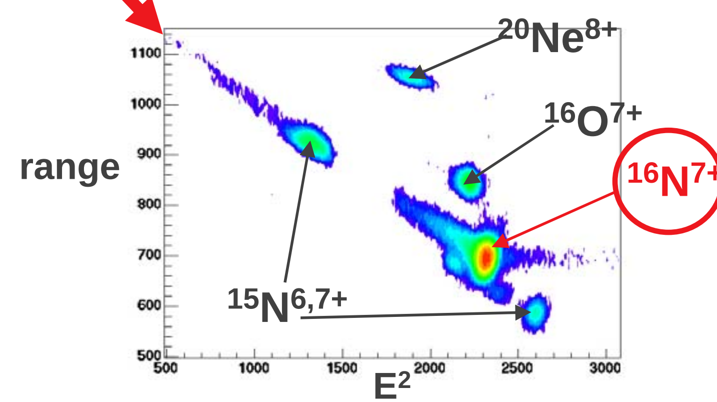
Multiple gas cells

Superconducting solenoid

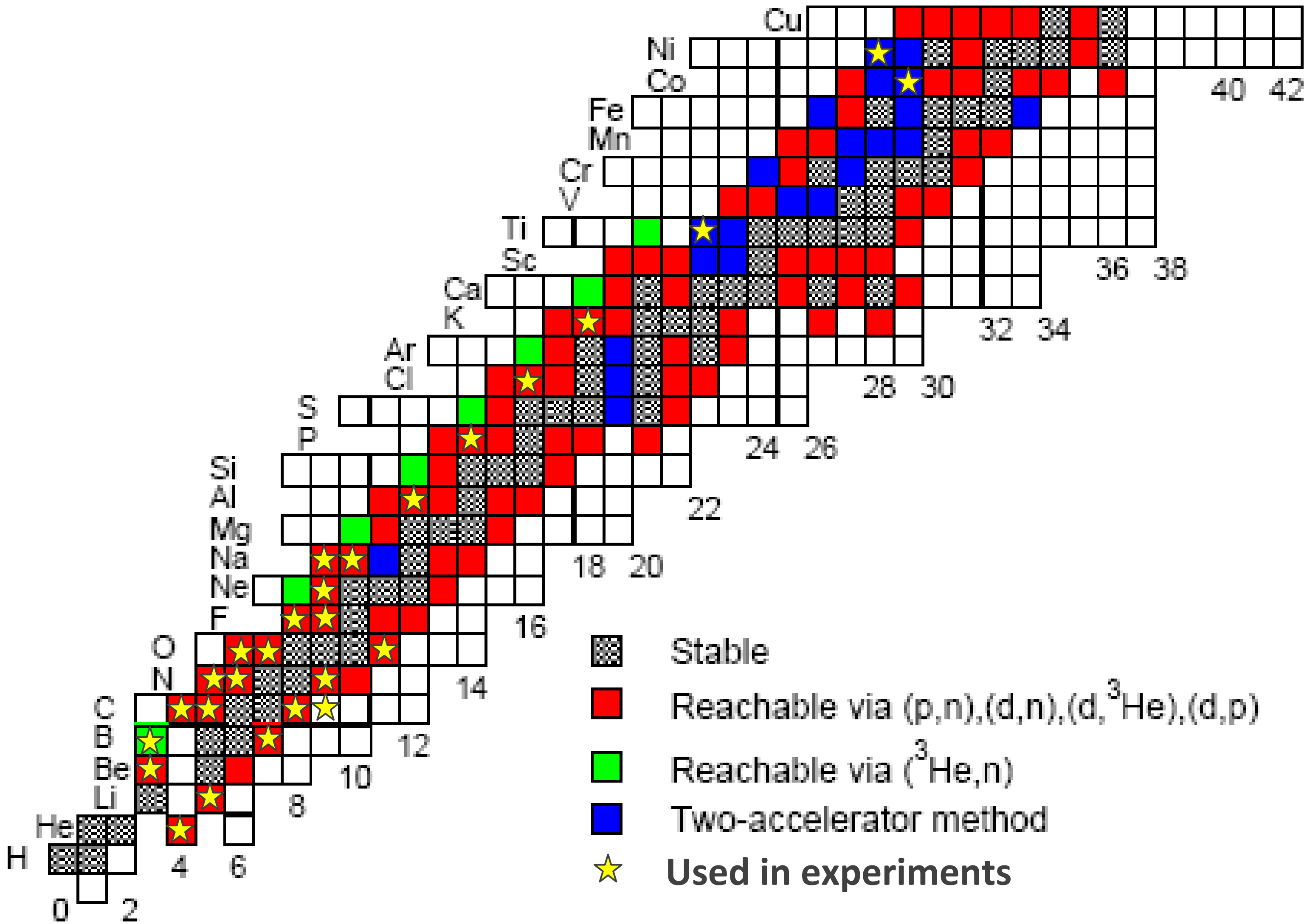
Debunching resonator

rf sweeper

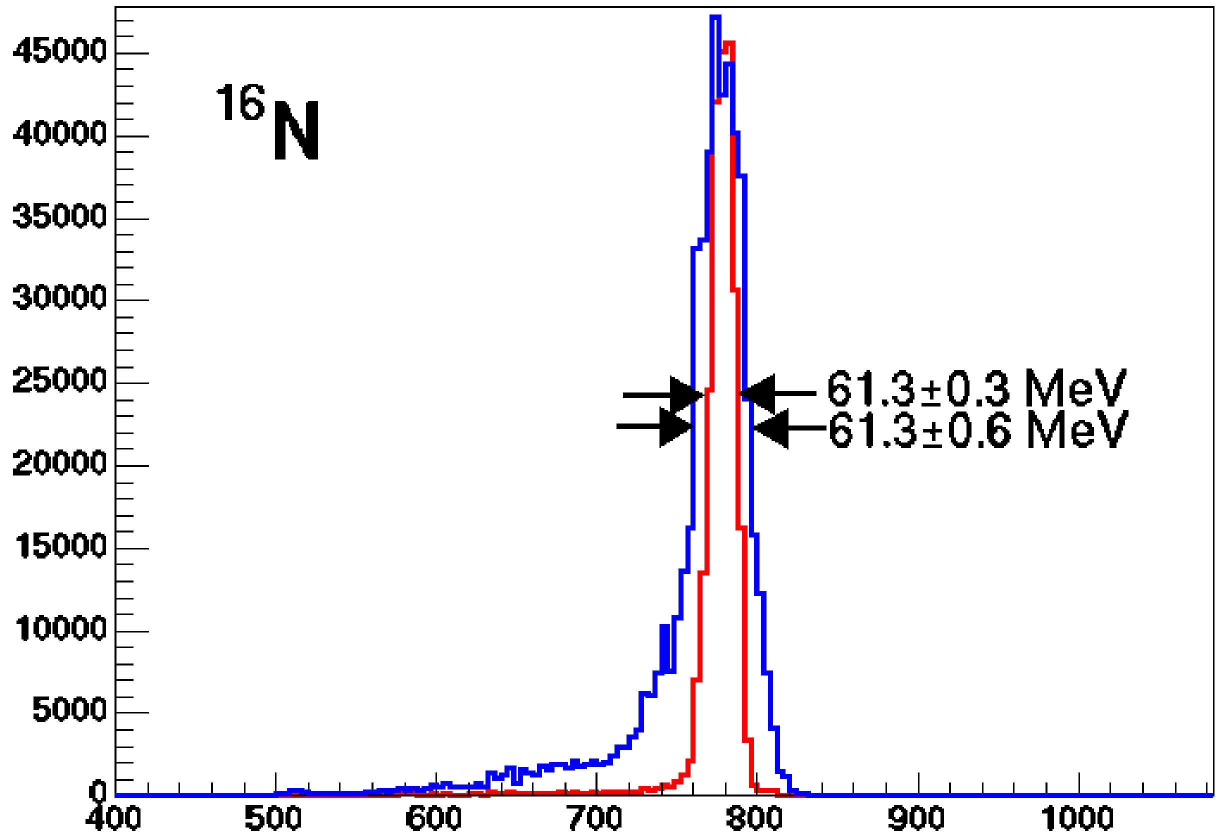
Particle identification



Secondary Beams that can be Produced at ATLAS



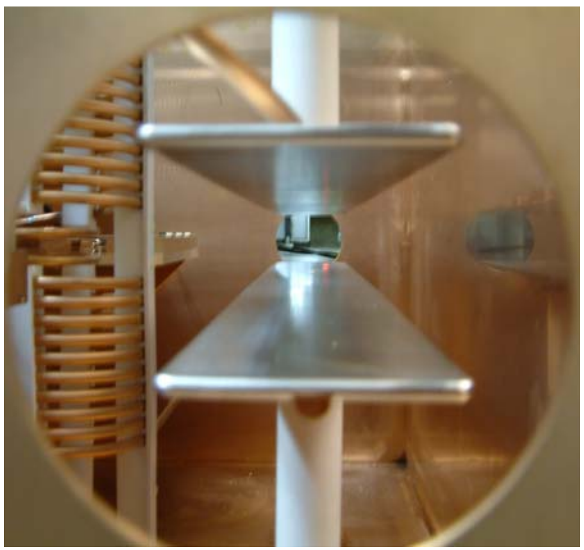
Improvement of the energy resolution with debunching

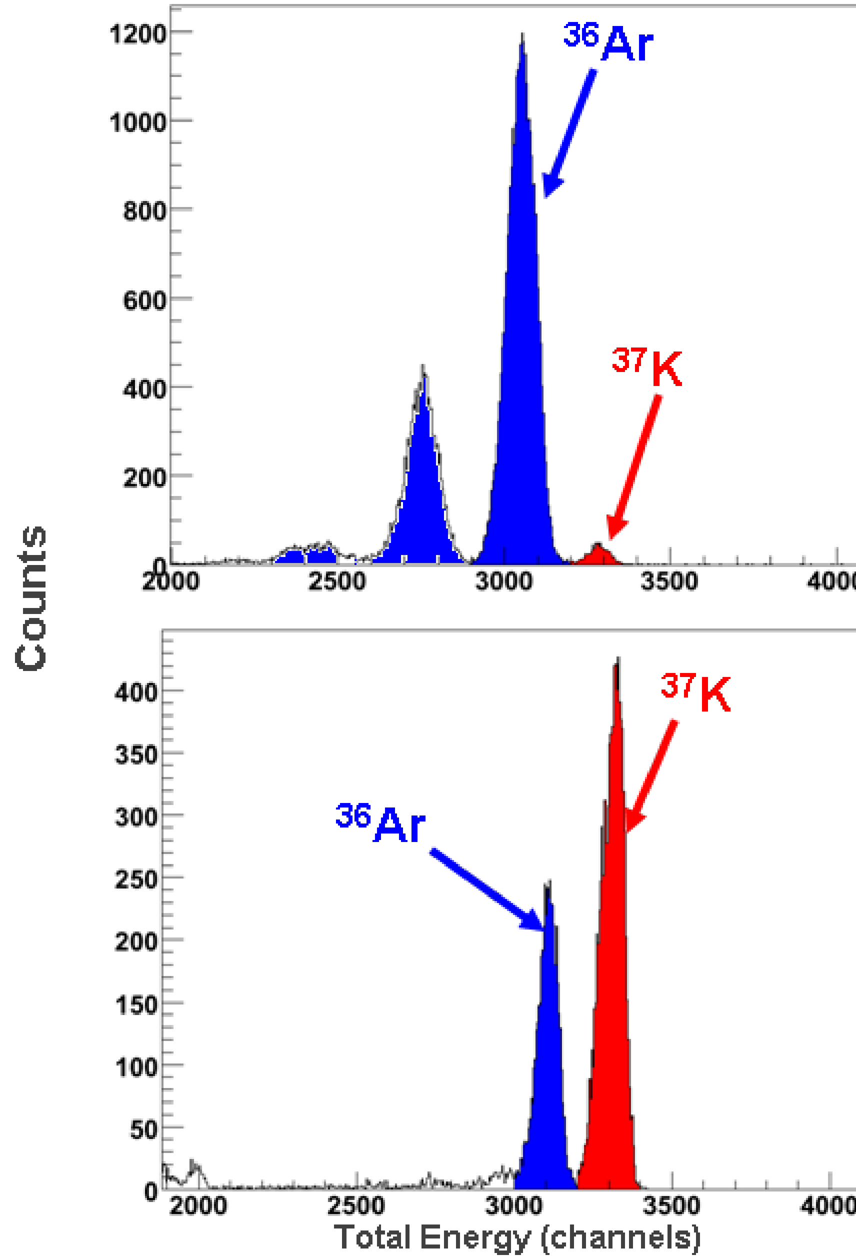


Improvement of the beam puritv with the rf sweeper

d(^{36}Ar,^{37}K

- Without RF sweep





- With RF sweeper

How ATLAS Supports the Heavens

- Measurements of critical half lives

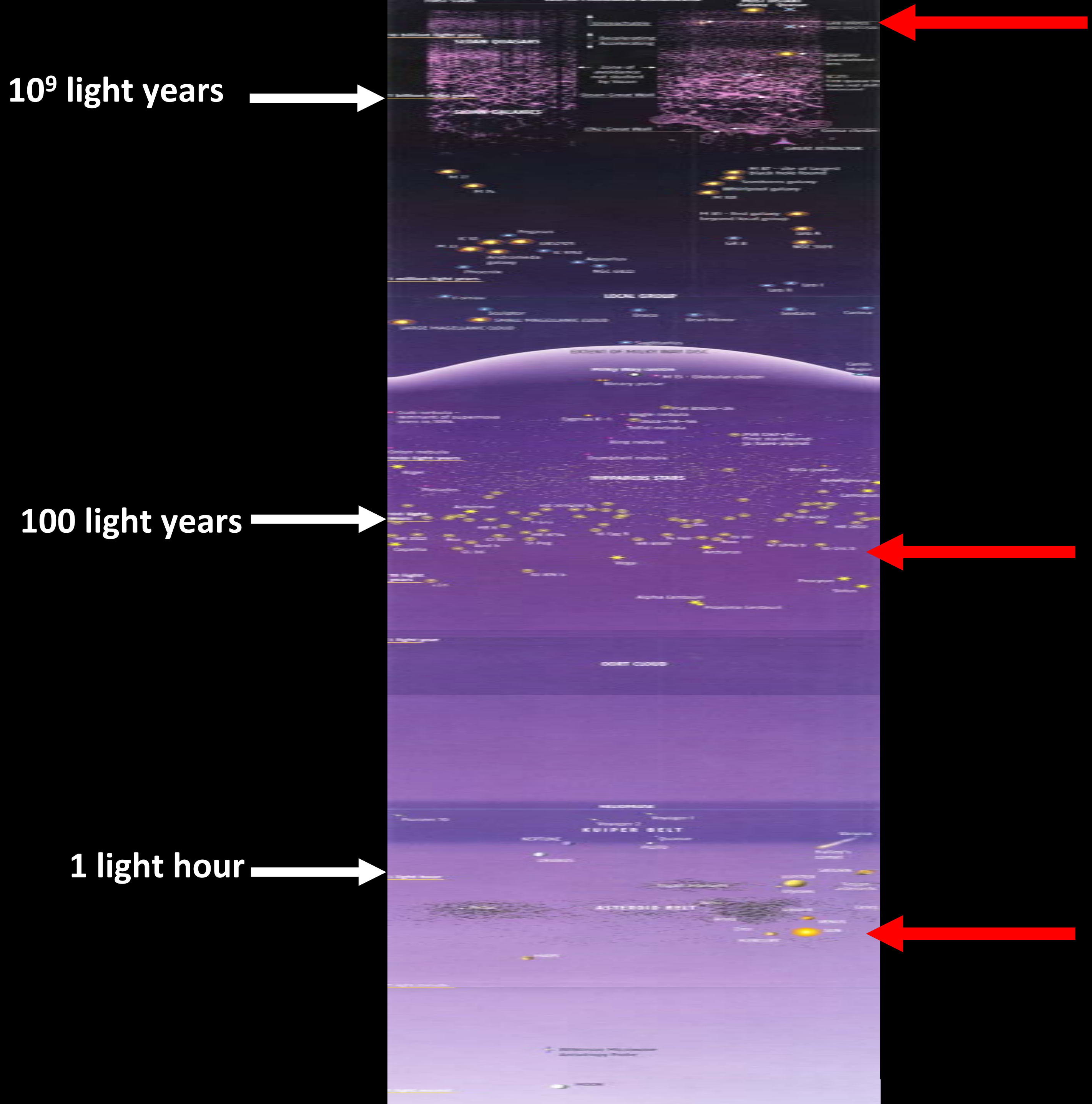
  ^{44}Ti, ^{60}Fe, ^{146}Sm,..

- Measurement of masses

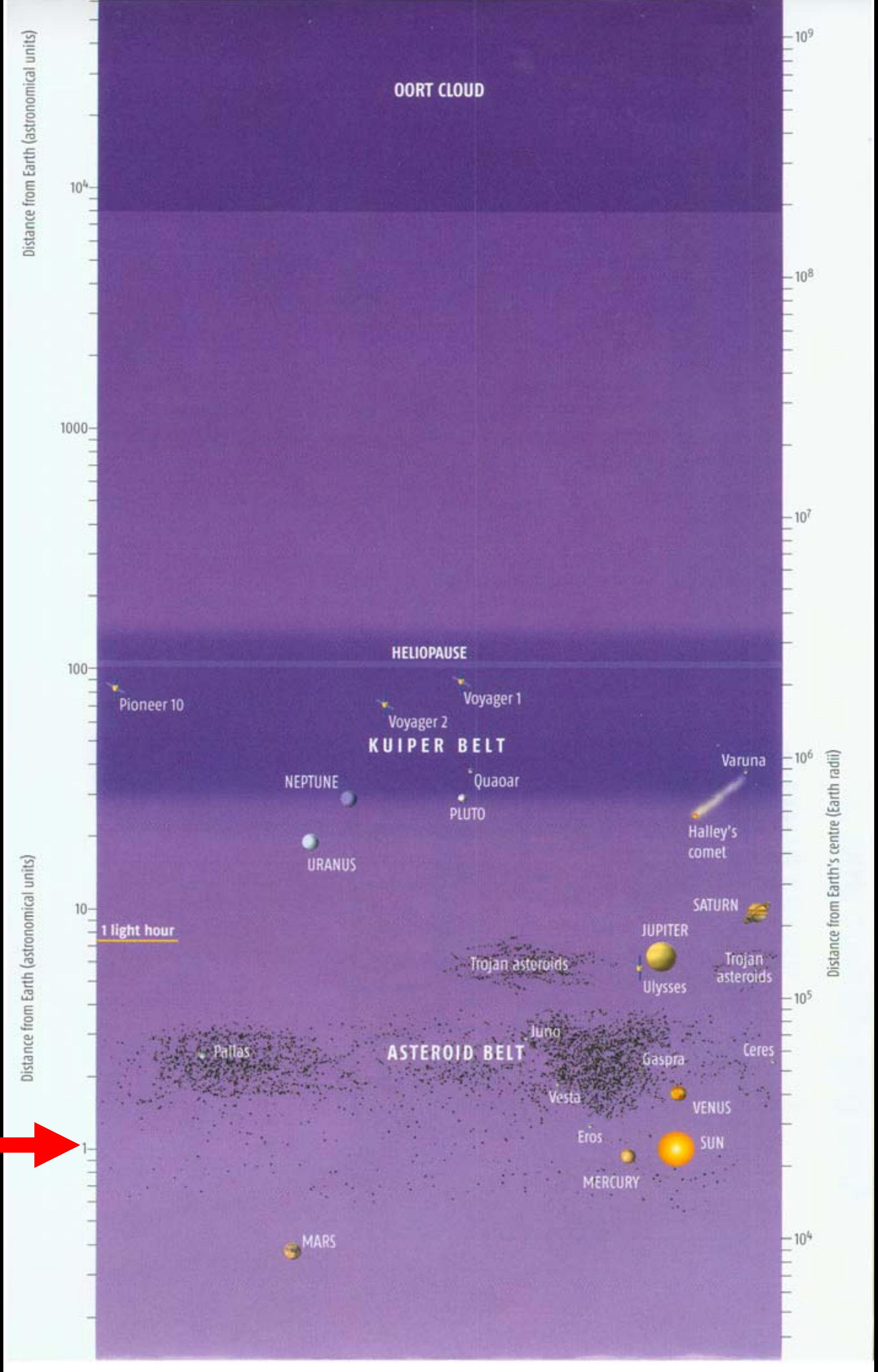
  r-process, rp-process

- Measurement of critical reaction rates

~30 % of beam time

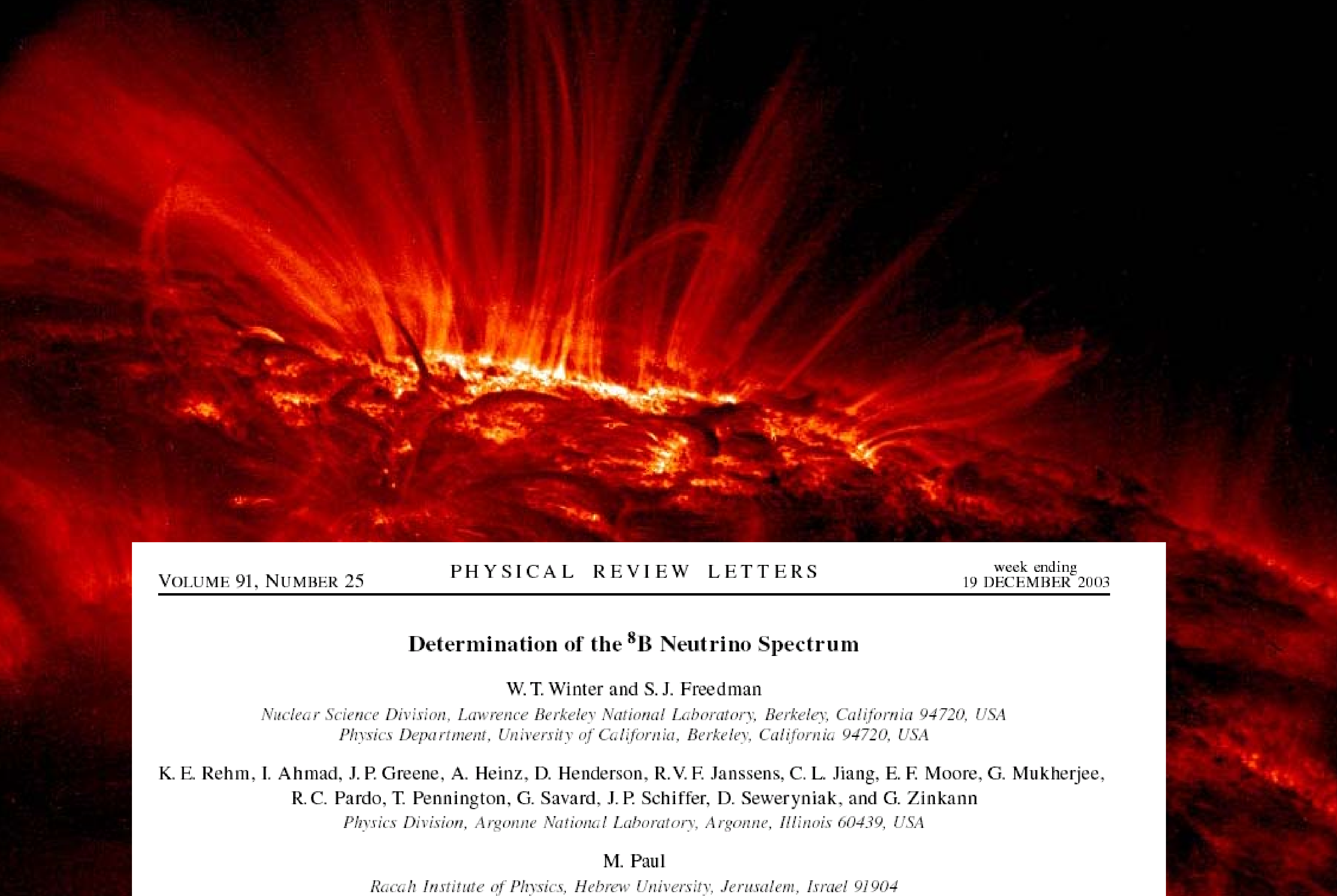


10^9 light years
100 light years
1 light hour



Solar neutrino spectrum

Neutrinos from the Sun



VOLUME 91, NUMBER 25 PHYSICAL REVIEW LETTERS week ending 19 DECEMBER 2003

Determination of the ^{8}B Neutrino Spectrum

W. T. Winter and S. J. Freedman

Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
Physics Department, University of California, Berkeley, California 94720, USA

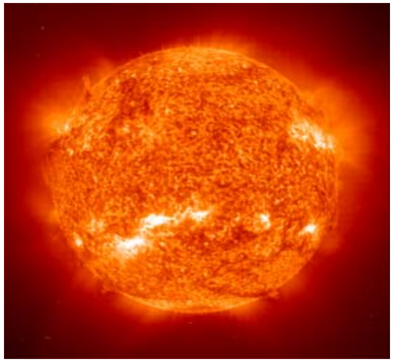
K. E. Rehm, I. Ahmad, J. P. Greene, A. Heinz, D. Henderson, R. V. F. Janssens, C. L. Jiang, E. F. Moore, G. Mukherjee, R. C. Pardo, T. Pennington, G. Savard, J. P. Schiffer, D. Seweryniak, and G. Zinkann

Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

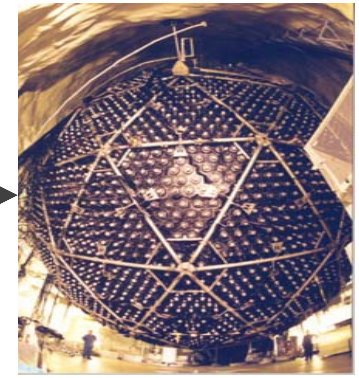
M. Paul

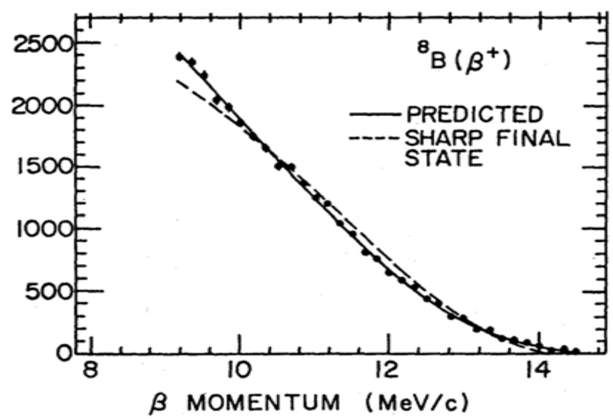
Racah Institute of Physics, Hebrew University, Jerusalem, Israel 91904

Study of the ^{8}B β-spectrum



ν





PRC36, 298(87)

^{8}B

β^{+}

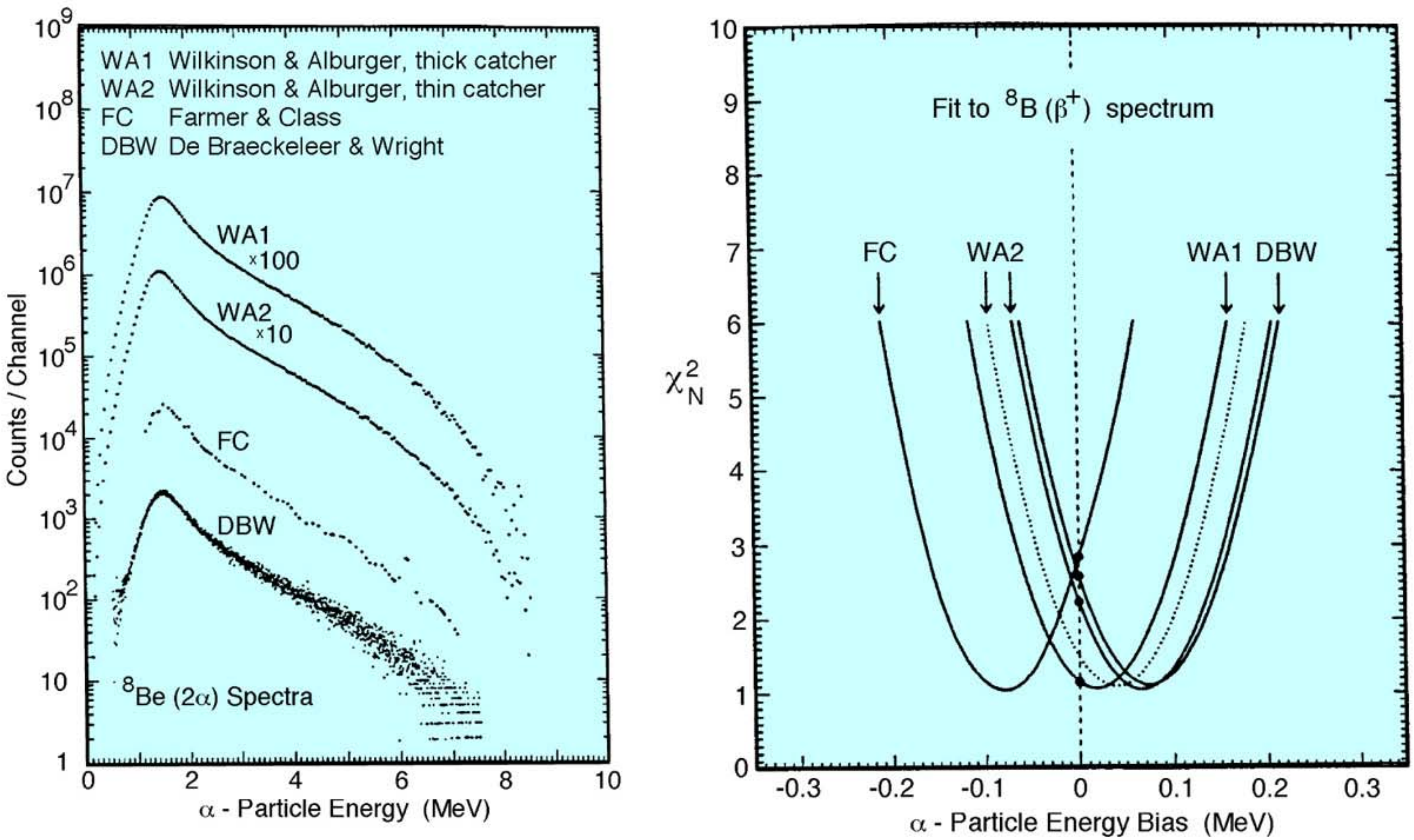
2^{+}

^{8}Be

$2\ \alpha$

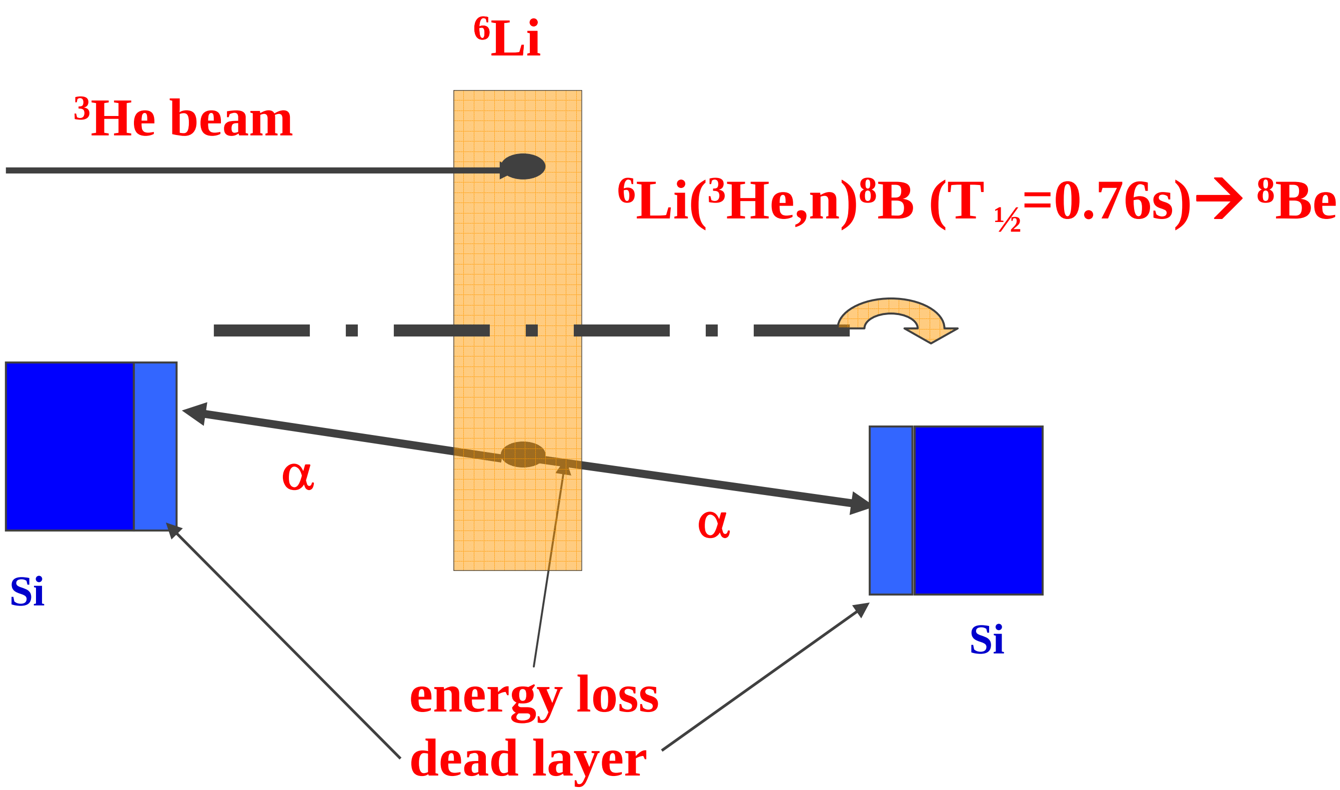
$^{8}B \rightarrow {}^{8}Be \rightarrow 2\alpha$

Bahcall et al. Phys. Rev. C54, 411 (1996)



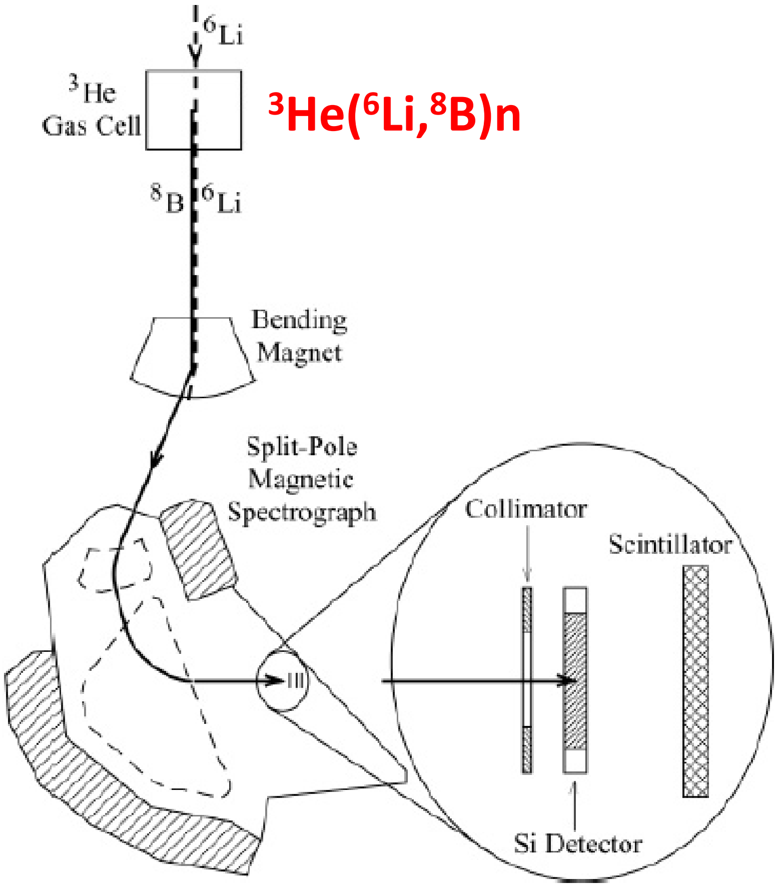
ΔE~ ±100 keV

Techniques to measure the decay of $^8B \rightarrow {}^8Be \rightarrow 2\alpha$



corrections needed for: $E_\alpha = 1.5$ MeV

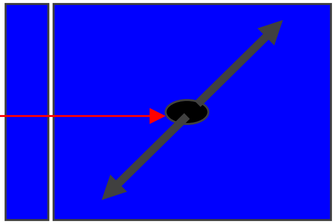
Stop an <u>energetic</u> ^{8}B beam in the middle of a Si detector



$^{3}He(^{6}Li,^{8}B)n$

^{8}B, 27 MeV

$T_{1/2}$=0.76s



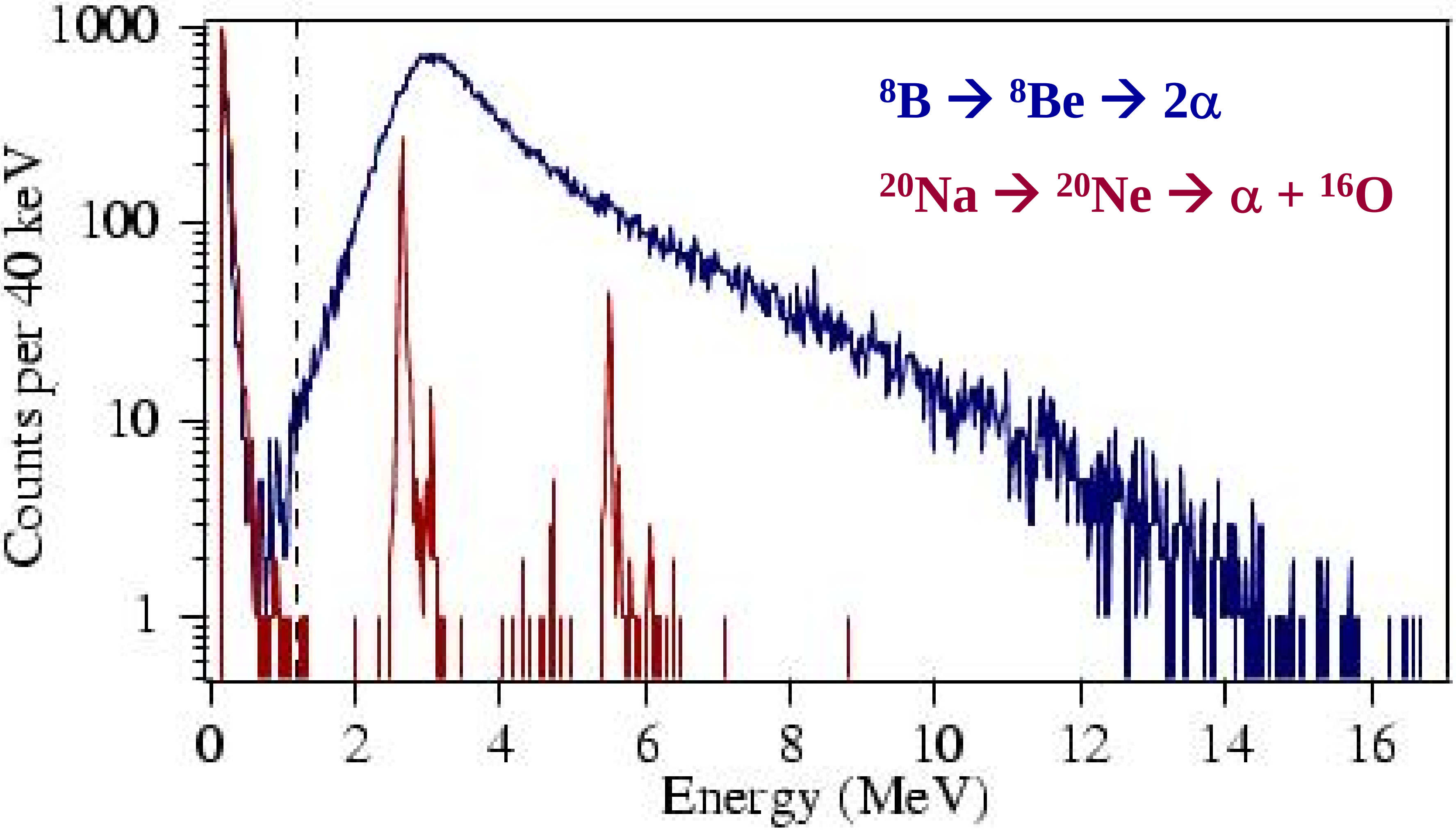
Si detector

90 μ thick

Beam on 1.5s

Beam off 1.5s

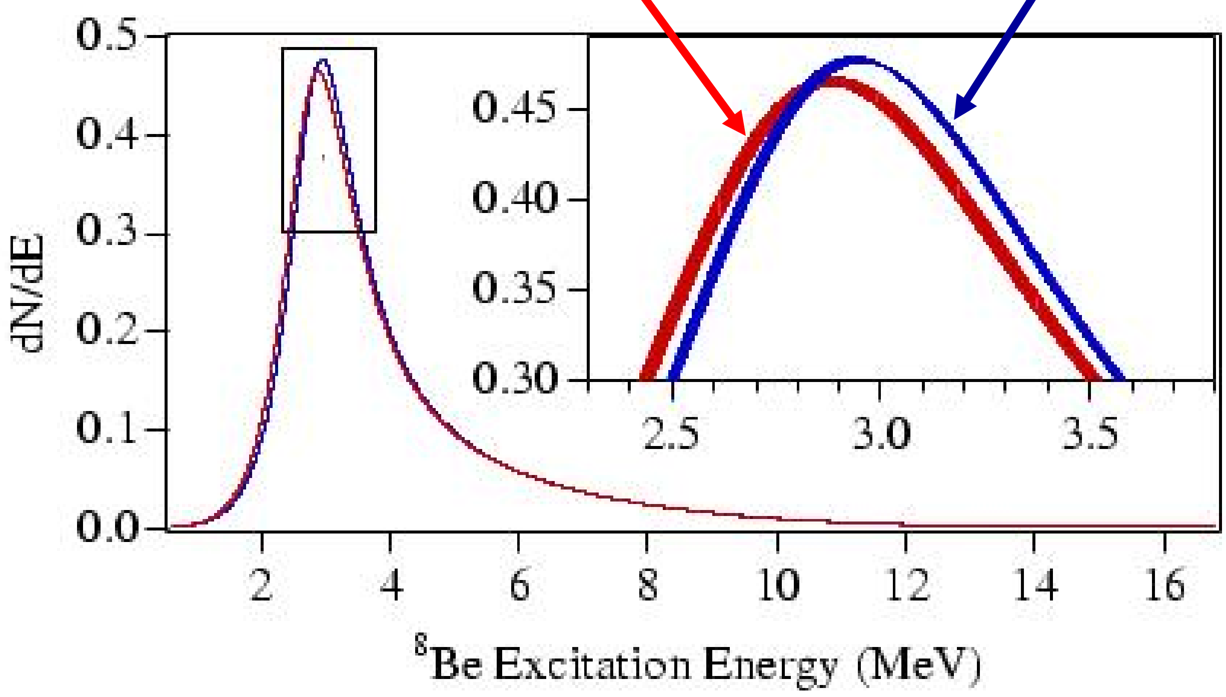
Experimental Results



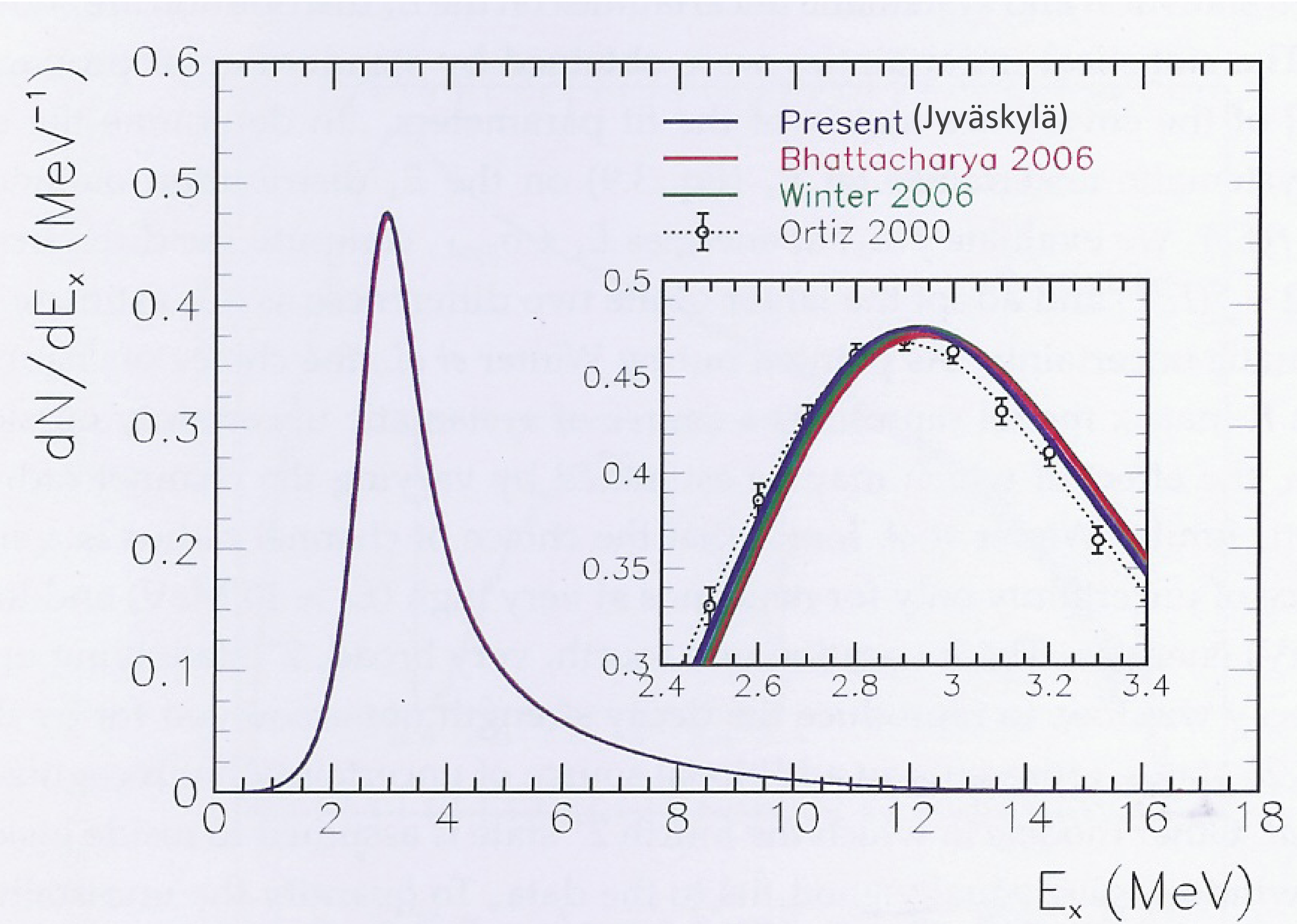
+ Pulse height effects, β summing,..

used by SNO and
SuperK collaborations

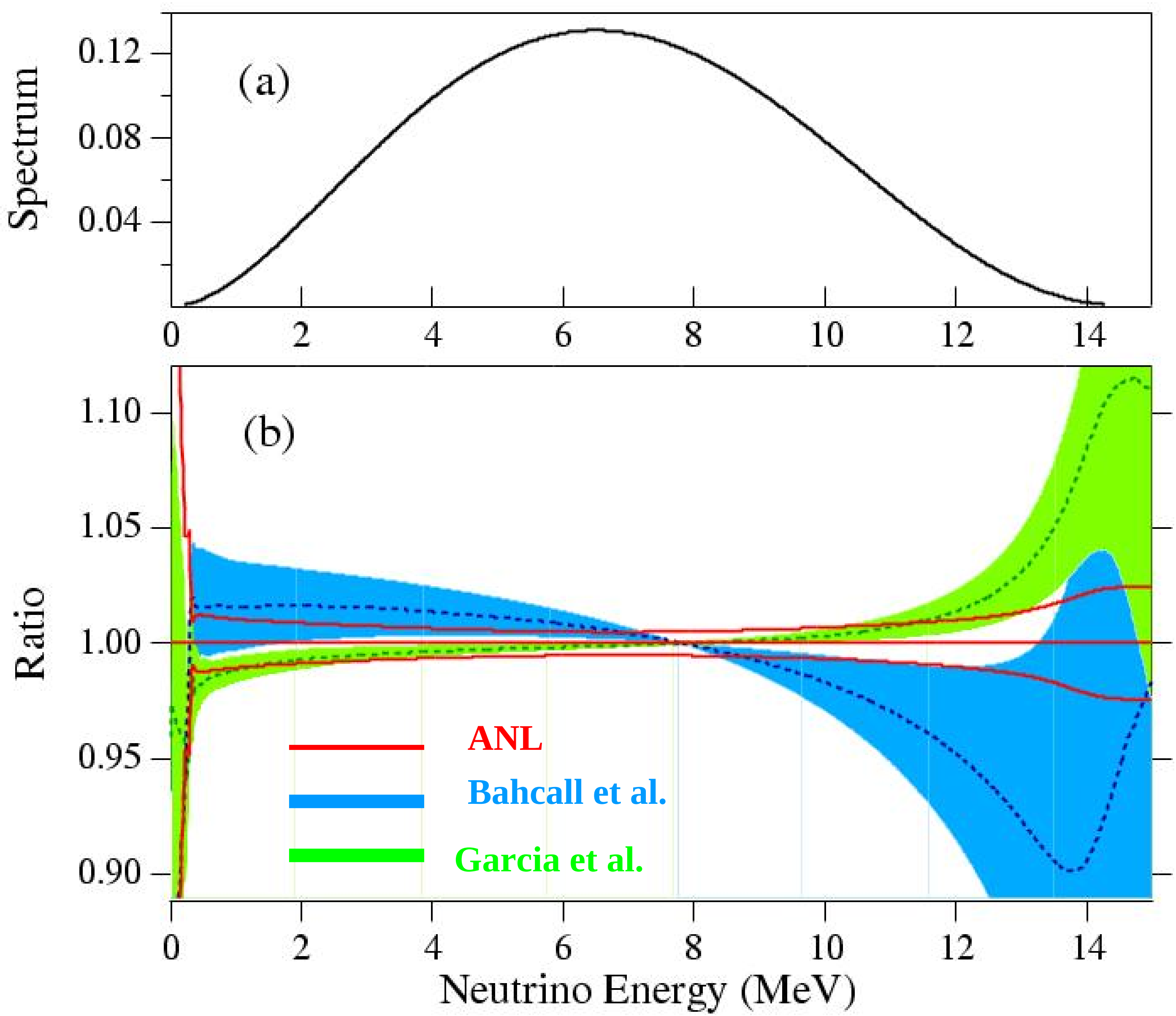
ANL



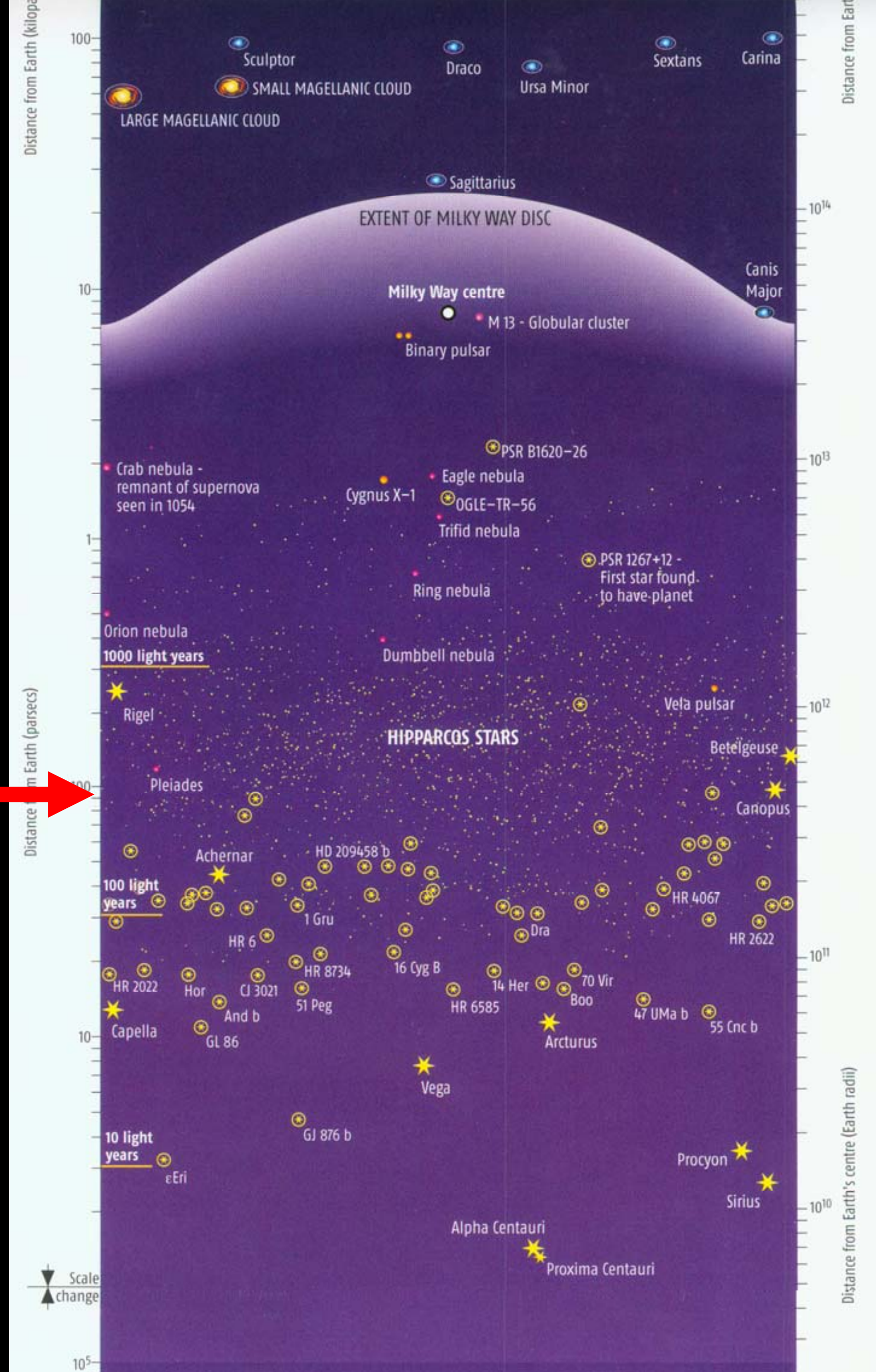
ΔE ~ 7 keV


dN/dE$_x$ (MeV^{-1})
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
E$_x$ (MeV)
Present (Jyväskylä)
Bhattacharya 2006
Winter 2006
Ortiz 2000
0.5
0.45
0.4
0.35
0.3
2.4
2.6
2.8
3
3.2
3.4

^{8}B Neutrino spectrum



Waiting points in X-ray bursts



X-ray bursts –

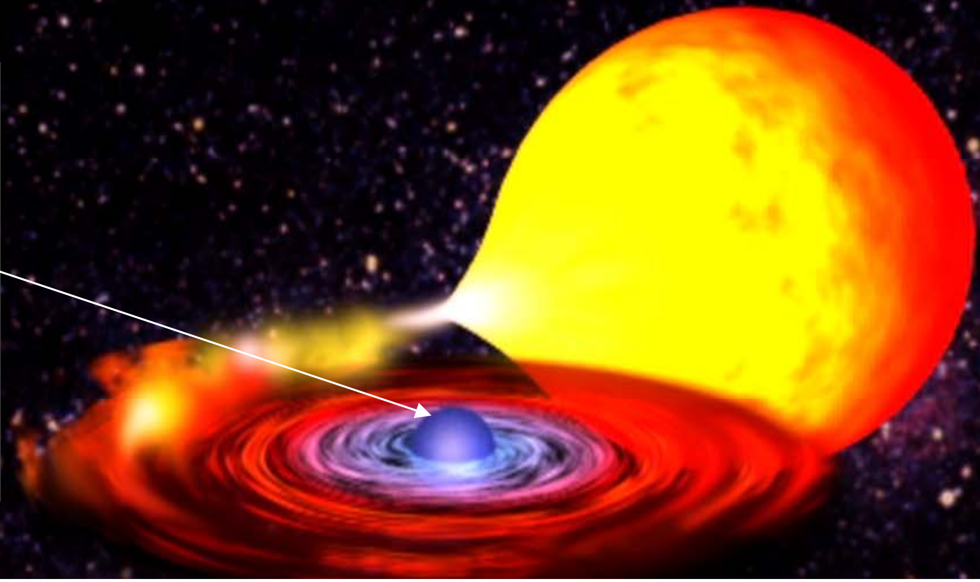
Thermonuclear explosions on the surface of a neutron star

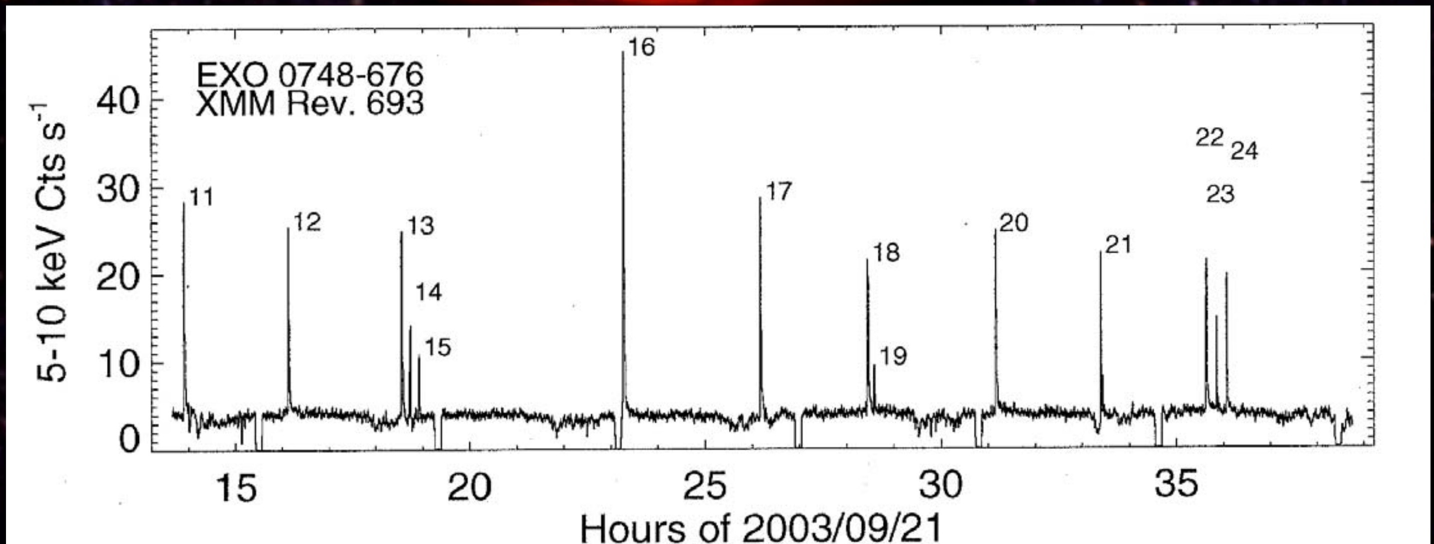
~1.5 $M_\odot$

radius ~ 10 km

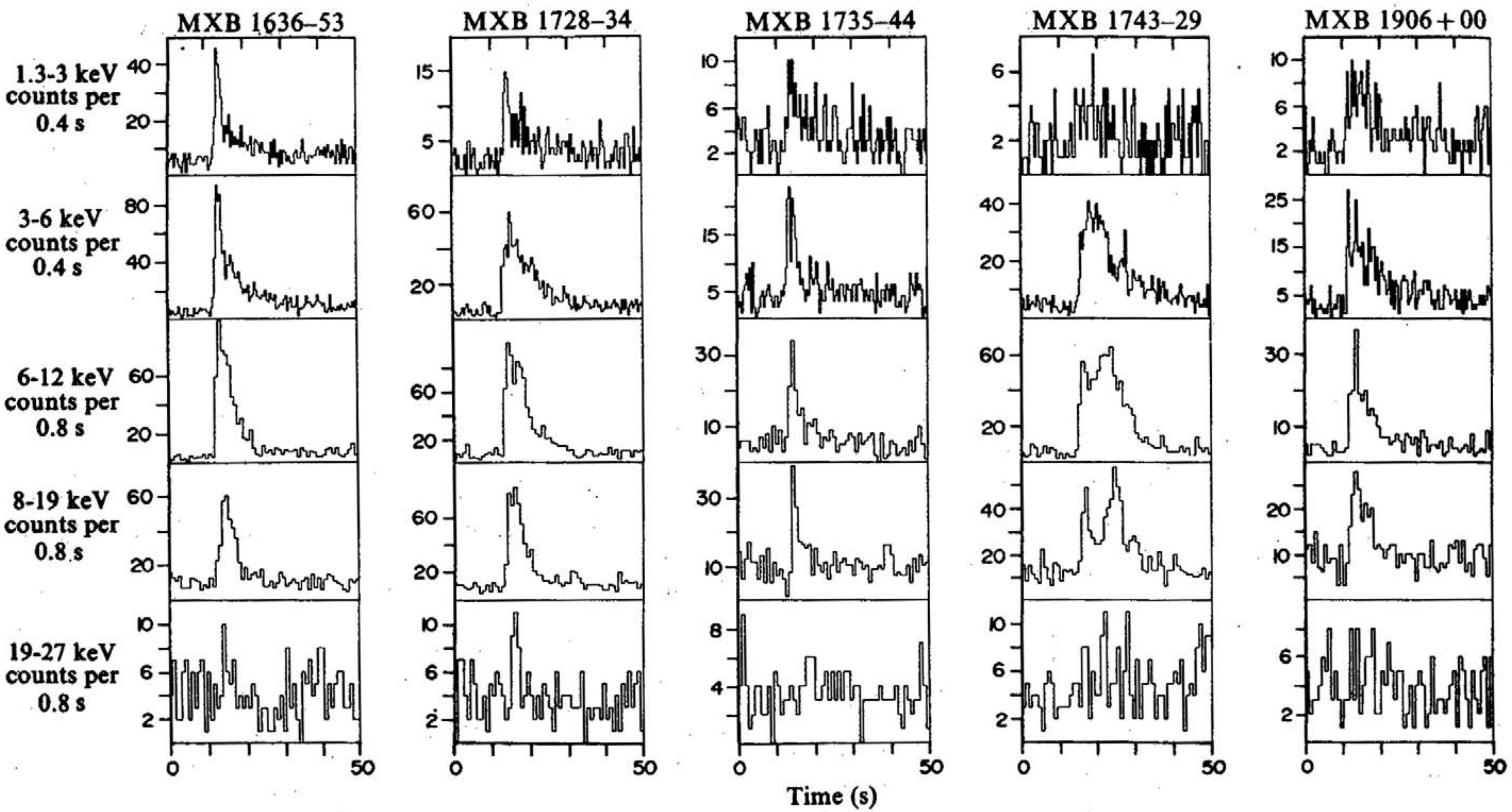
ρ~ $10^{6\text{-}14}$ g/cm^3

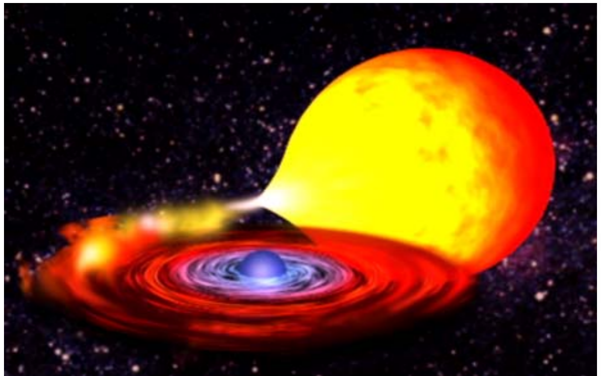
T ~ 10^7 K





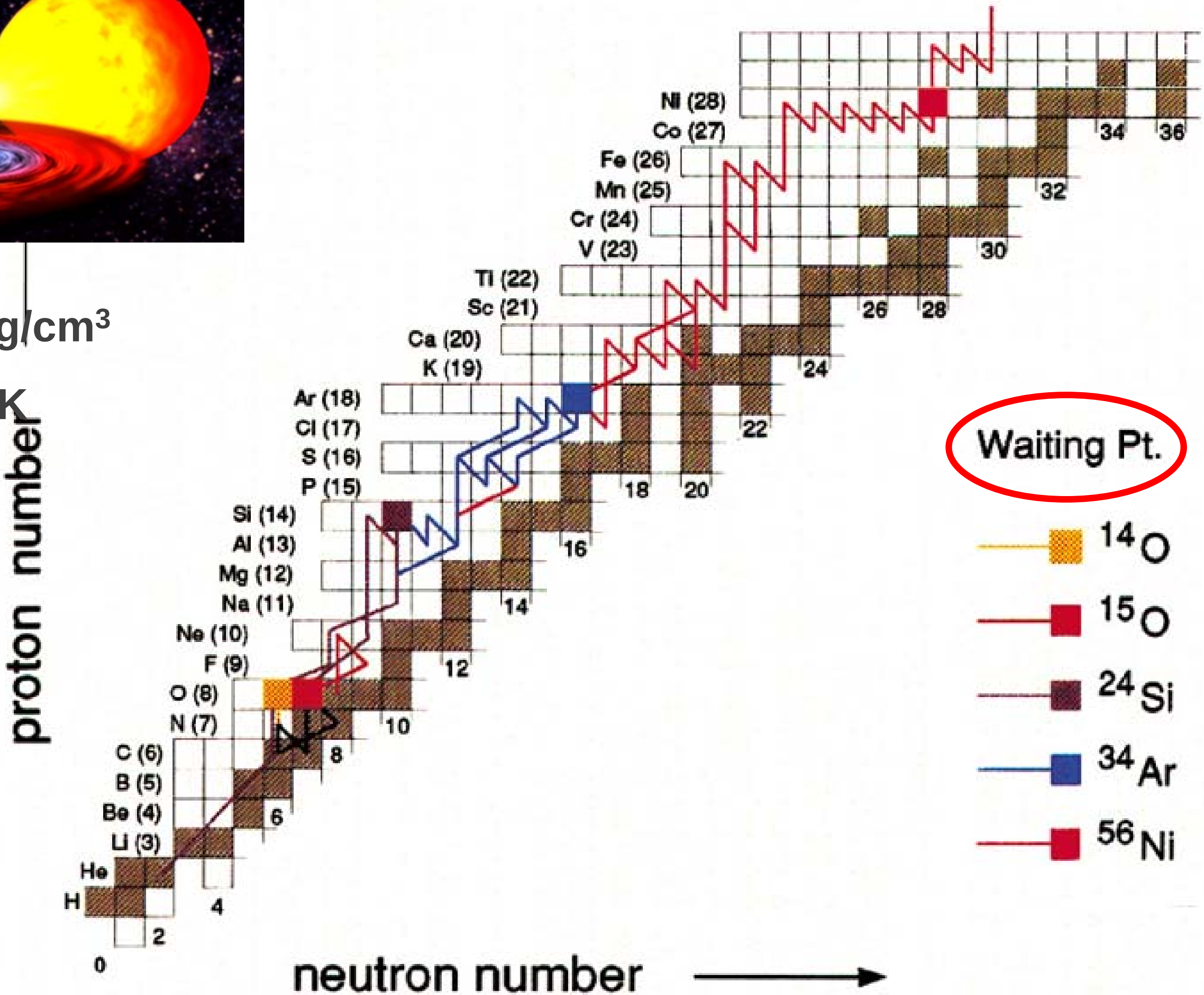
observables





$\rho \sim 10^6 - 10^9$ g/cm^3

$T \sim 10^8 - 10^9$ K



- ^{56}Ni (p,γ)^{57}Cu ~ ^{56}Ni(^{3}He,d)^{57}Cu ~ ^{56}Ni(d,p)^{57}Ni

VOLUME 80, NUMBER 4 PHYSICAL REVIEW LETTERS 26 JANUARY 1998

Study of the ^{56}Ni(d,p)^{57}Ni Reaction and the Astrophysical ^{56}Ni(p,γ)^{57}Cu Reaction Rate

K. E. Rehm,[1] F. Borasi,[1] C. L. Jiang,[1] D. Ackermann,[1] I. Ahmad,[1] B. A. Brown,[2] F. Brumwell,[1] C. N. Davids,[1]
P. Decrock,[1] S. M. Fischer,[1] J. Görres,[3] J. Greene,[1] G. Hackmann,[1] B. Harss,[1] D. Henderson,[1] W. Henning,[1]
R. V. F. Janssens,[1] G. McMichael,[1] V. Nanal,[1] D. Nisius,[1] J. Nolen,[1] R. C. Pardo,[1] M. Paul,[4] P. Reiter,[1] J. P. Schiffer,[1]
D. Seweryniak,[1] R. E. Segel,[5] M. Wiescher,[3] and A. H. Wuosmaa[1]

PHYSICAL REVIEW C **80**, 044613 (2009)

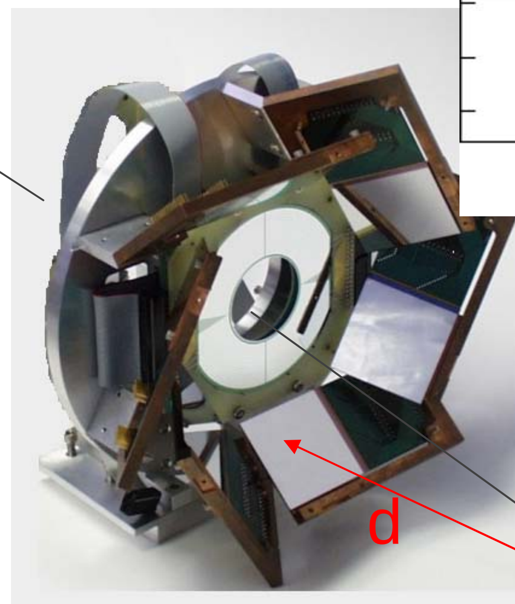
Experimental study of the ^{56}Ni(^{3}He,d)^{57}Cu reaction in inverse kinematics

C. L. Jiang, K. E. Rehm, D. Ackermann,[*] I. Ahmad, J. P. Greene, B. Harss,[†] D. Henderson, W. F. Henning,
R. V. F. Janssens, J. Nolen, R. C. Pardo, P. Reiter,[‡] J. P. Schiffer, D. Seweryniak, A. Sonzogni,[§]
J. Uusitalo,[‖] I. Wiedenhöver,[¶] and A. H. Wuosmaa[**]
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

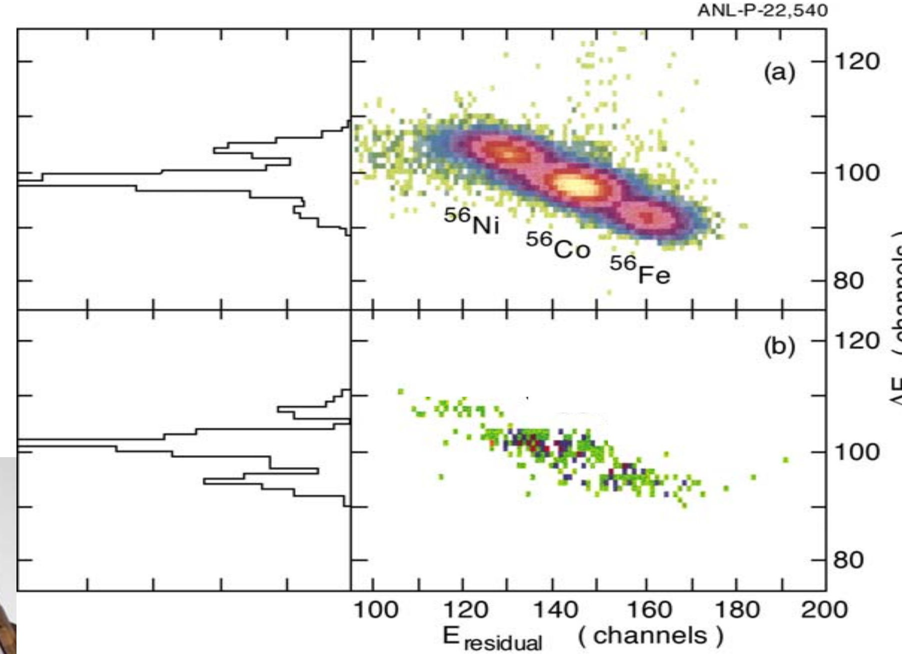
FMA

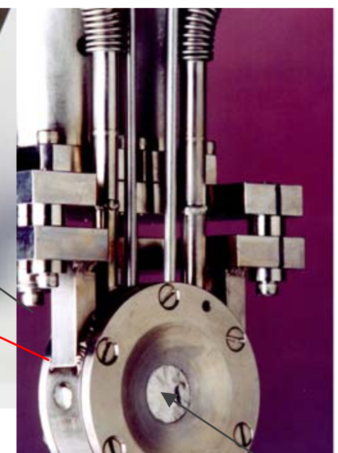
^{57}Cu,
^{57}Ni,
^{57}Co

Si detector array



d





^{3}He gas cell,
t=50 $\mu g/cm^2$

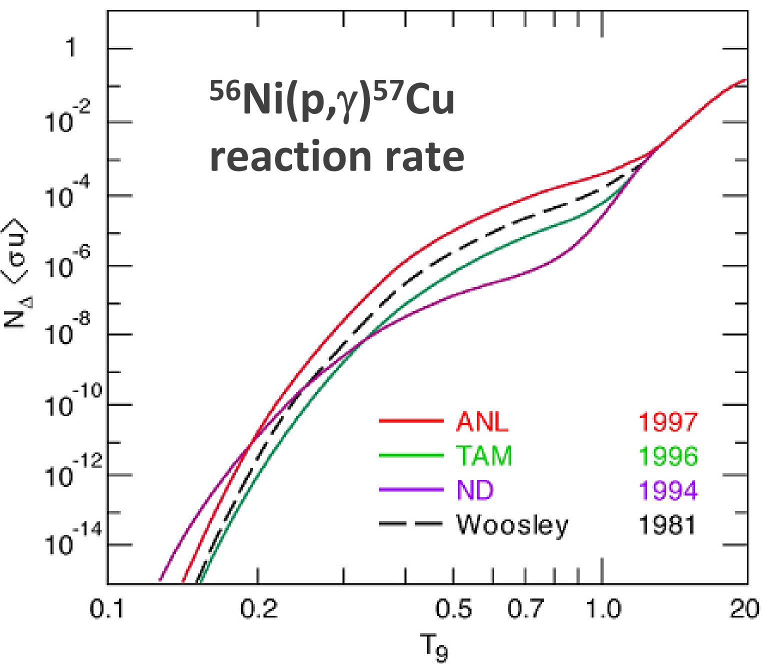
^{56}Ni ($T_{1/2}$=6.1d)

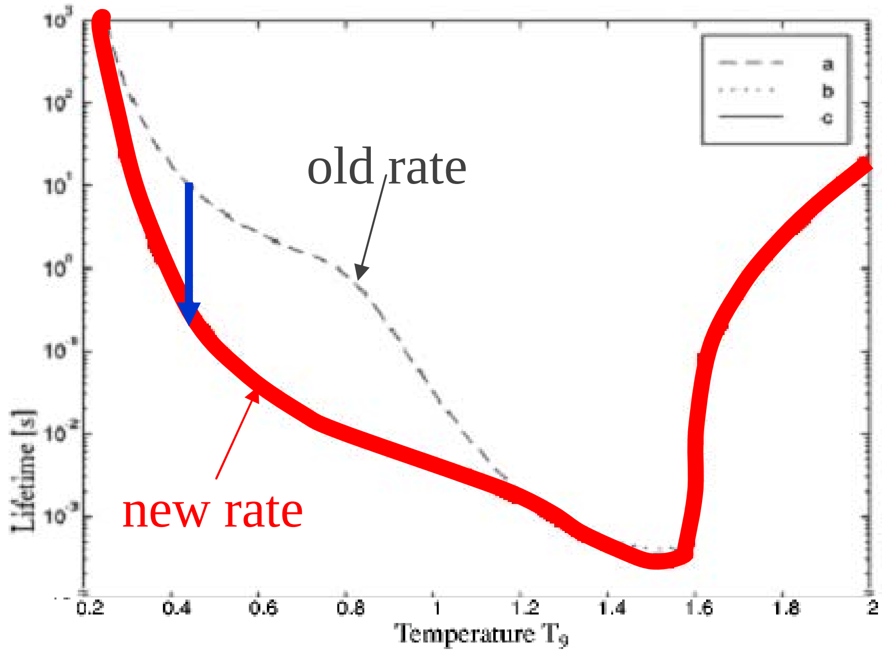
+ ^{56}Co,^{56}Fe

Produced at the IPNS

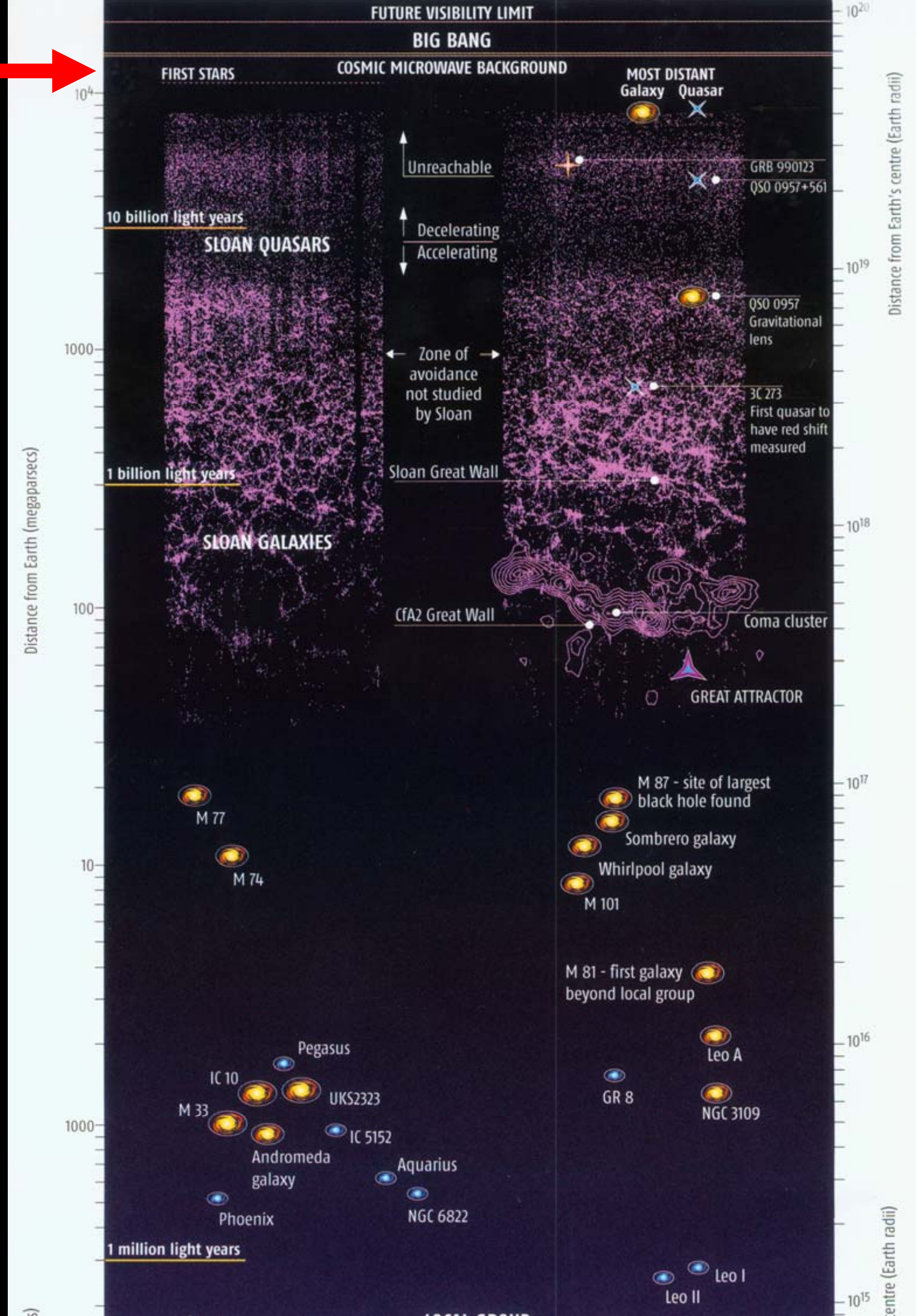
I_{Ni}~3x10^4/s

Effect of the new reaction rate on the ^{56}Ni waiting point





Bypassing the triple α reaction in super-massive stars



SCIENCE DIRECT

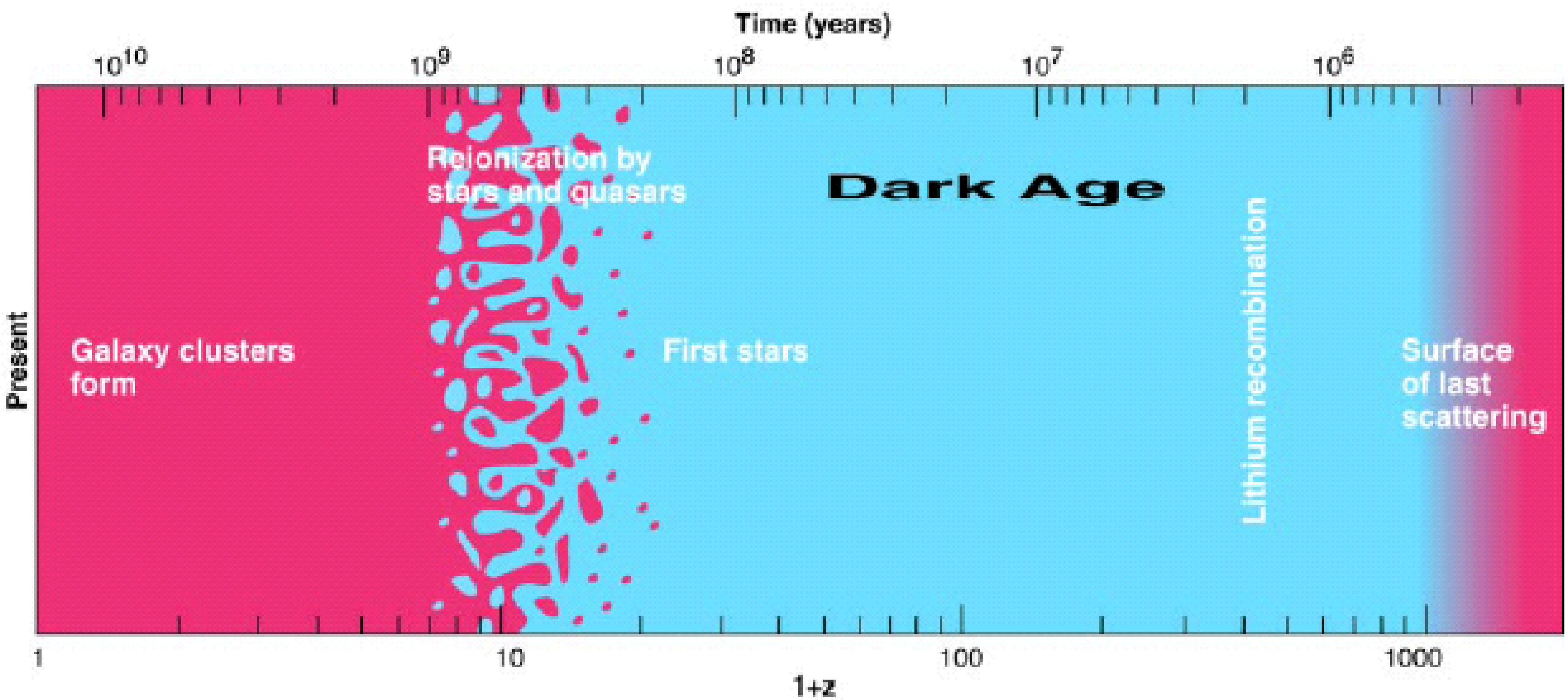
ELSEVIER

NUCLEAR PHYSICS A

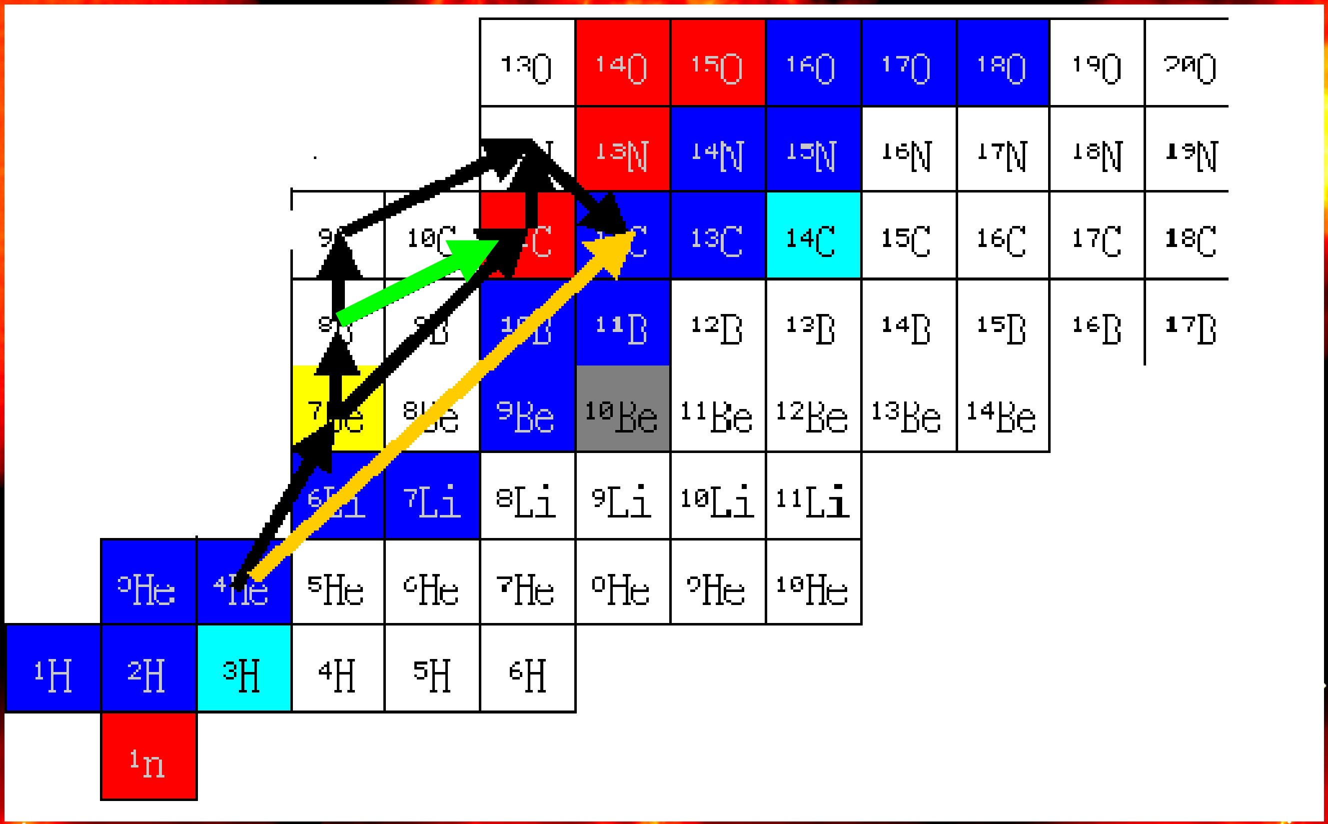
Nuclear Physics A 746 (2004) 354c–358c

First studies of the $^{8}B(\alpha,p)^{11}C$ reaction

K. E. Rehm[a], C. L. Jiang[a], J. P. Greene[a], D. Henderson[a], R.V.F. Janssens[a], E. F. Moore[a], G. Mukherjee[a], R.C. Pardo[a], T. Pennington[a], J. P. Schiffer[a], S. Sinha[a], X. D. Tang[a], R. H. Siemssen[b], L. Jisonna[c], R. E. Segel[c], A. H. Wuosmaa[d]



UK Astrophysical Fluids Facility
UK Astrophysical Fluids Facility



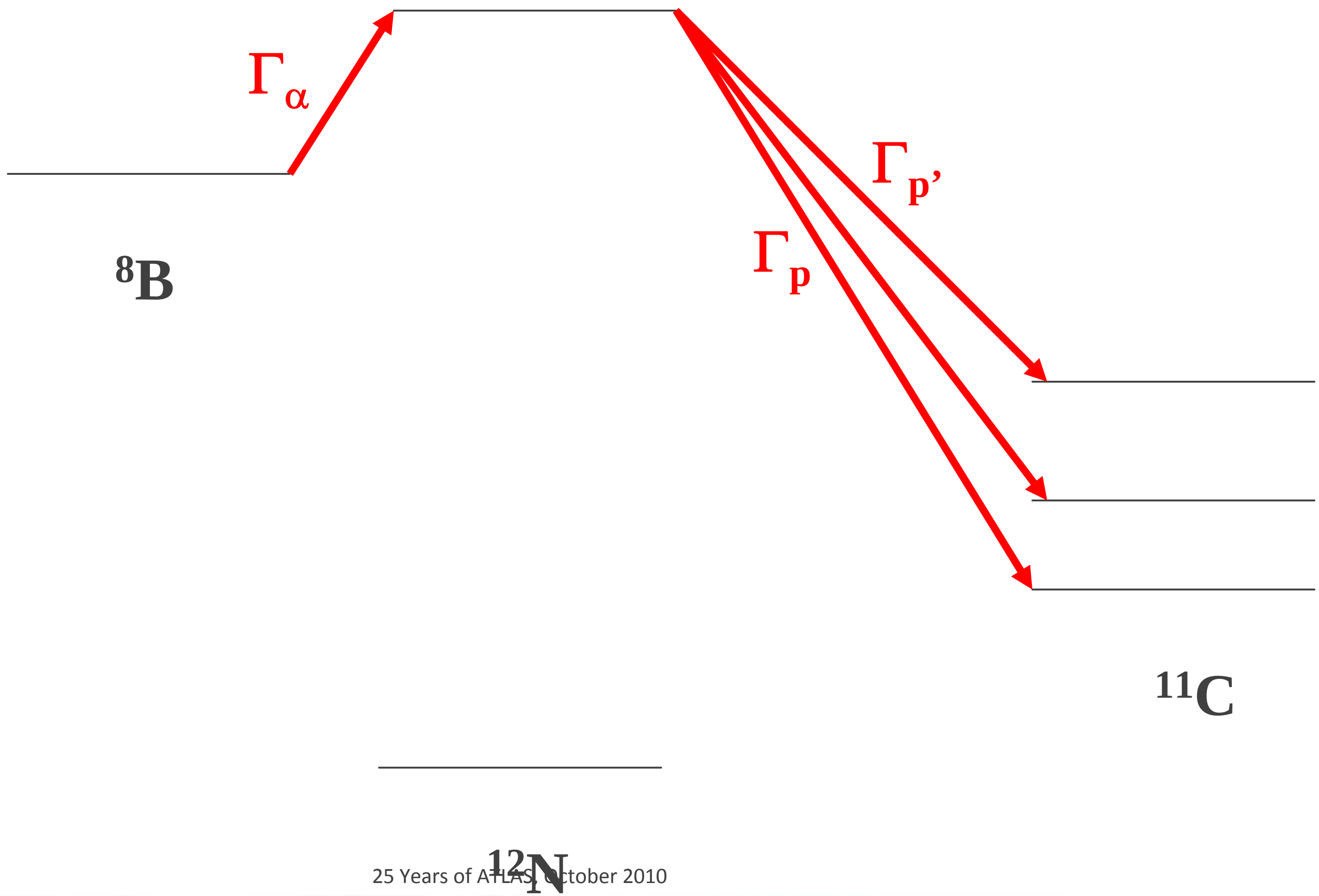
Creating the first 'metals' bypassing the triple α process

UK Astrophysical Fluids Facility
Matthew Bate
University of Exeter
Matthew Bate
University of Exeter
Matthew Bate
University of Exeter

In a star:

$^{8}B(\alpha,p)^{11}C$

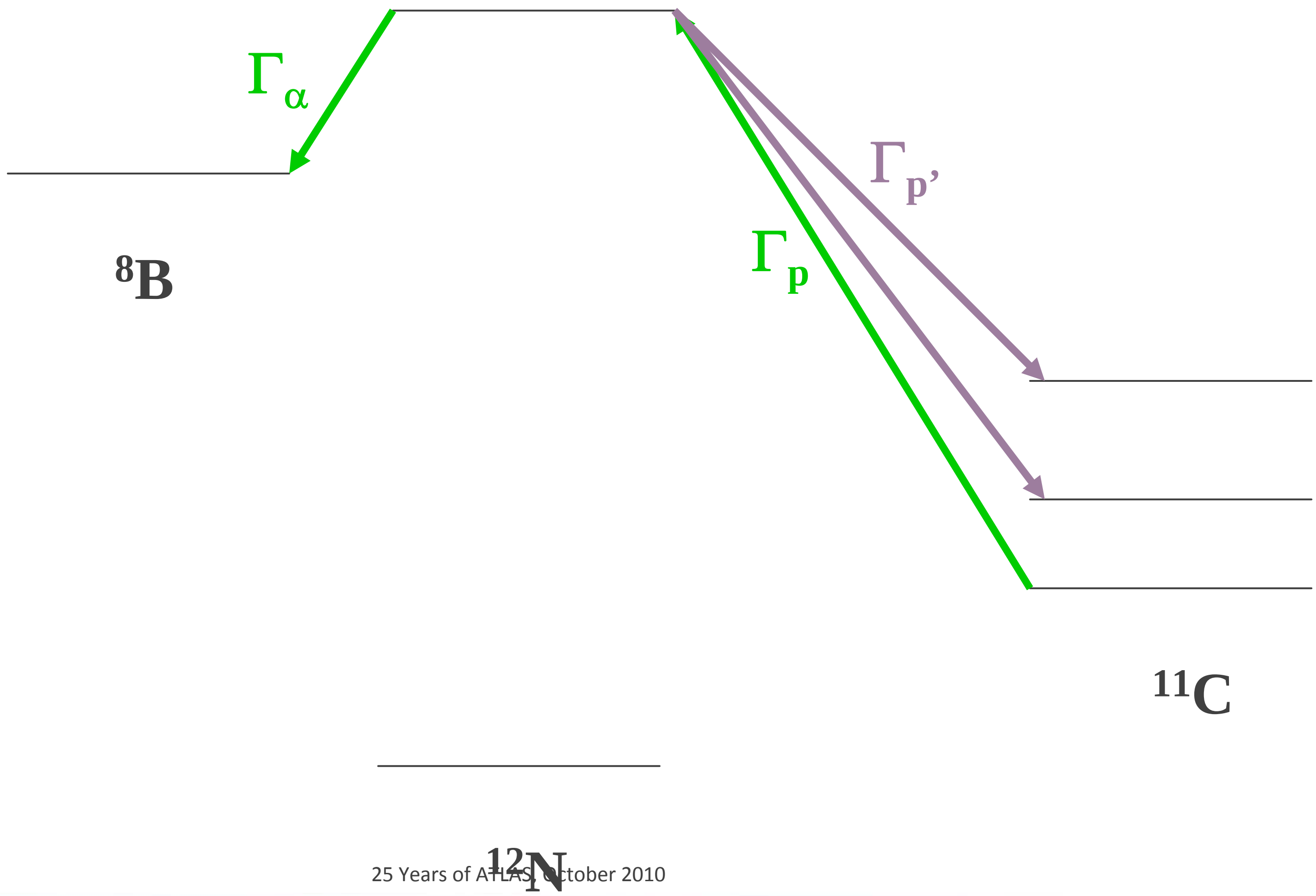
(gives $\Sigma\, \Gamma_{\alpha}\Gamma_{p'}$)



In the laboratory:

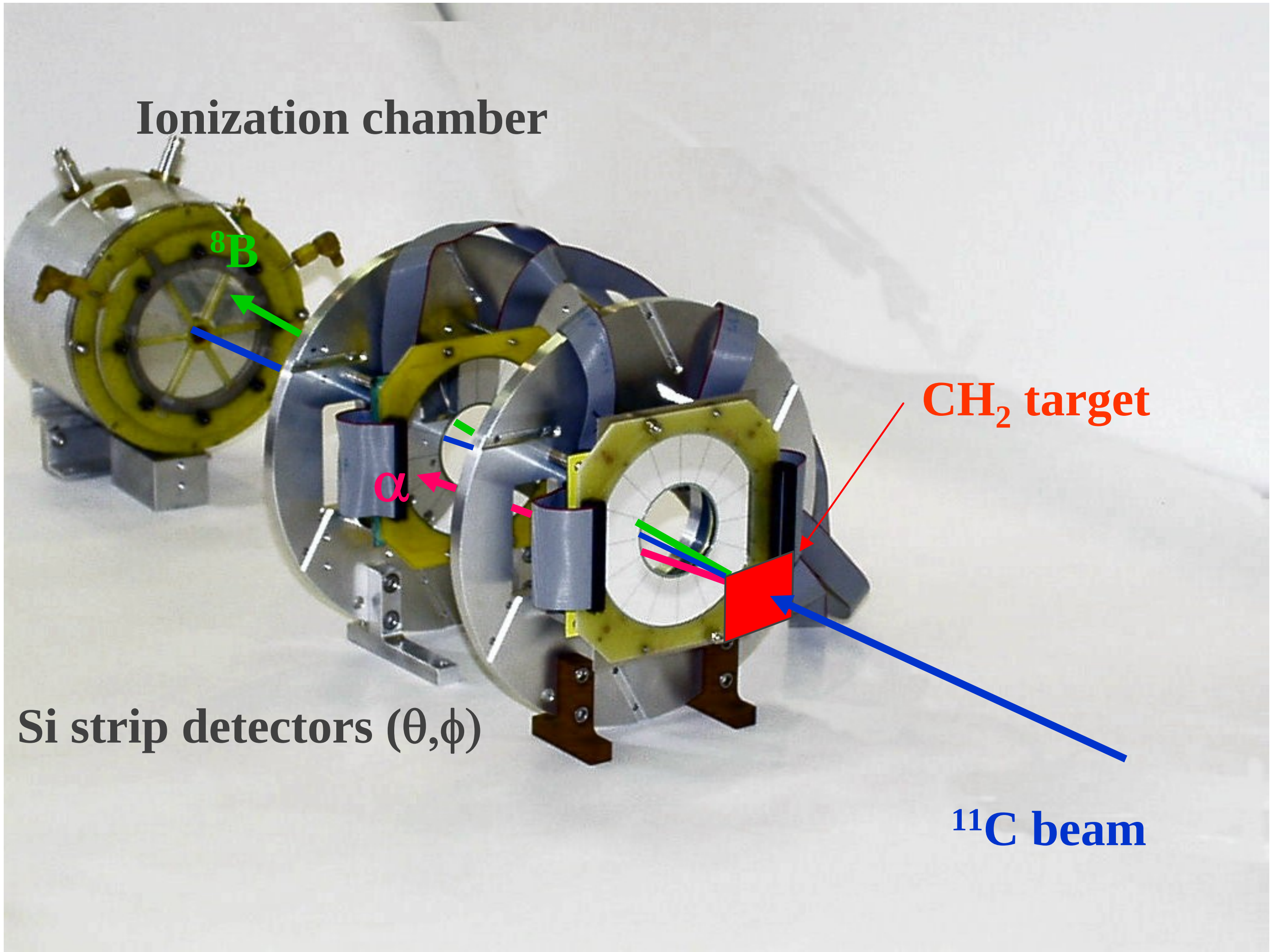
$^{11}C(p,\alpha)^{8}B$ (gives $\Gamma_\alpha \Gamma_p$)

$^{11}C(p,p')^{11}C$ (gives $\Sigma \Gamma_p \Gamma_{p'}$)

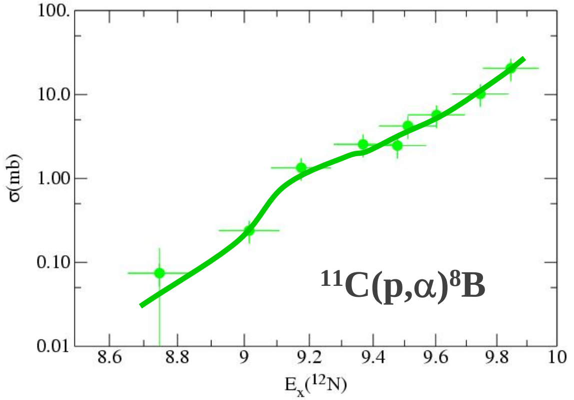


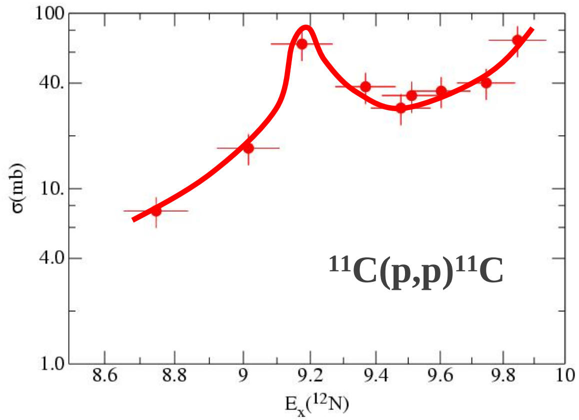
Experimental setup for (p,α) experiment

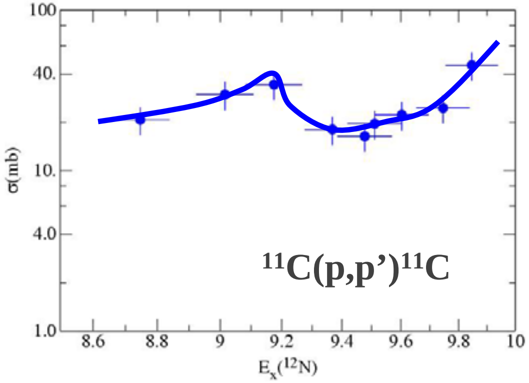
^{11}C beam produced via the $^{1}H(^{11}B,^{11}C)n$ reaction



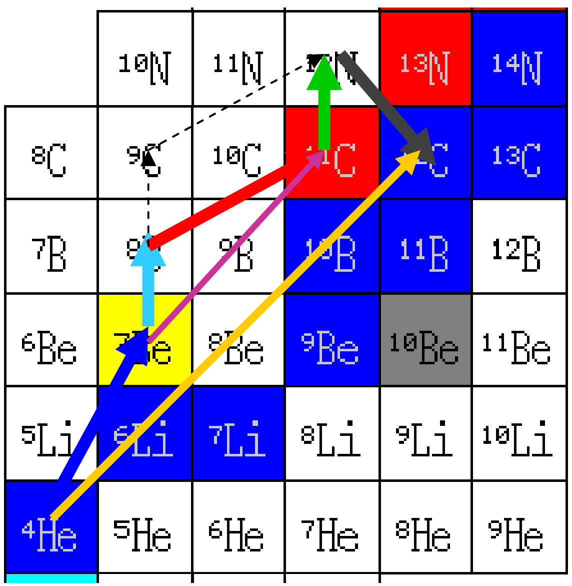
Experimental Results

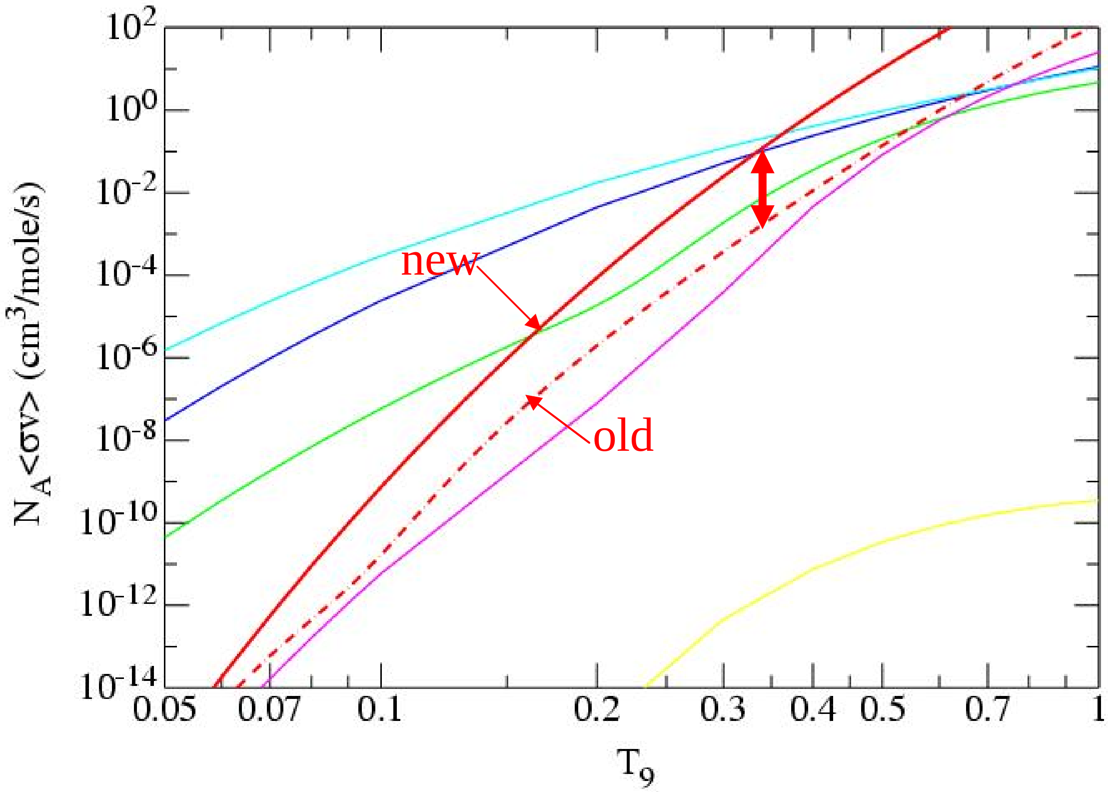






Bypassing the triple–α reaction



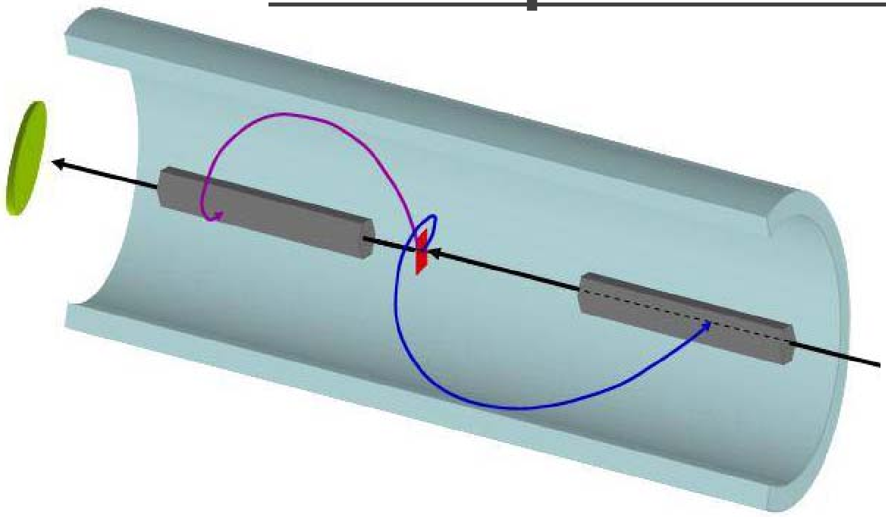


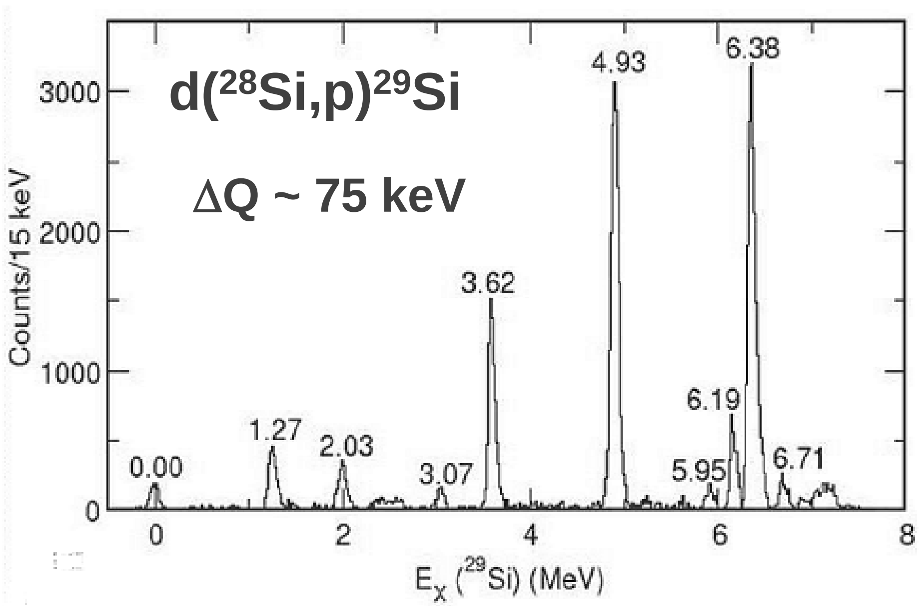
Bottleneck reaction $^{8}B(\alpha,p)^{11}C$ is 50 times stronger than previously assumed

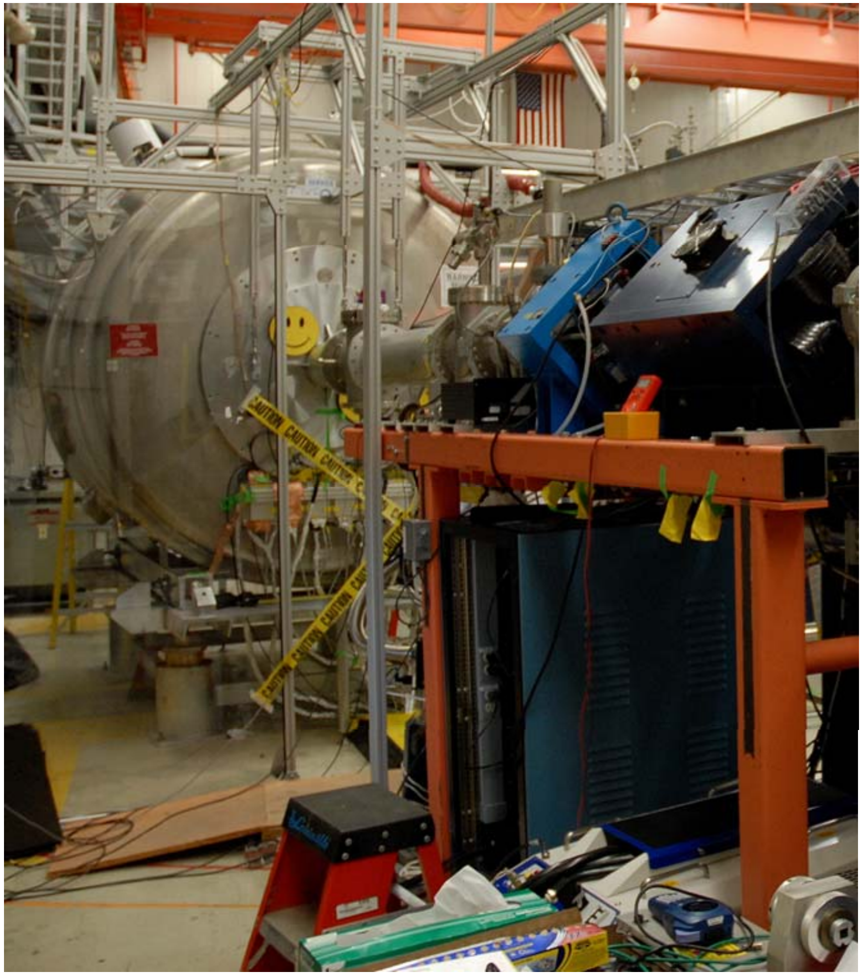
Future

- HELIOS
- CARIBU
- Energy upgrade
- Intensity upgrade

Future plans: HELIOS Spectrometer



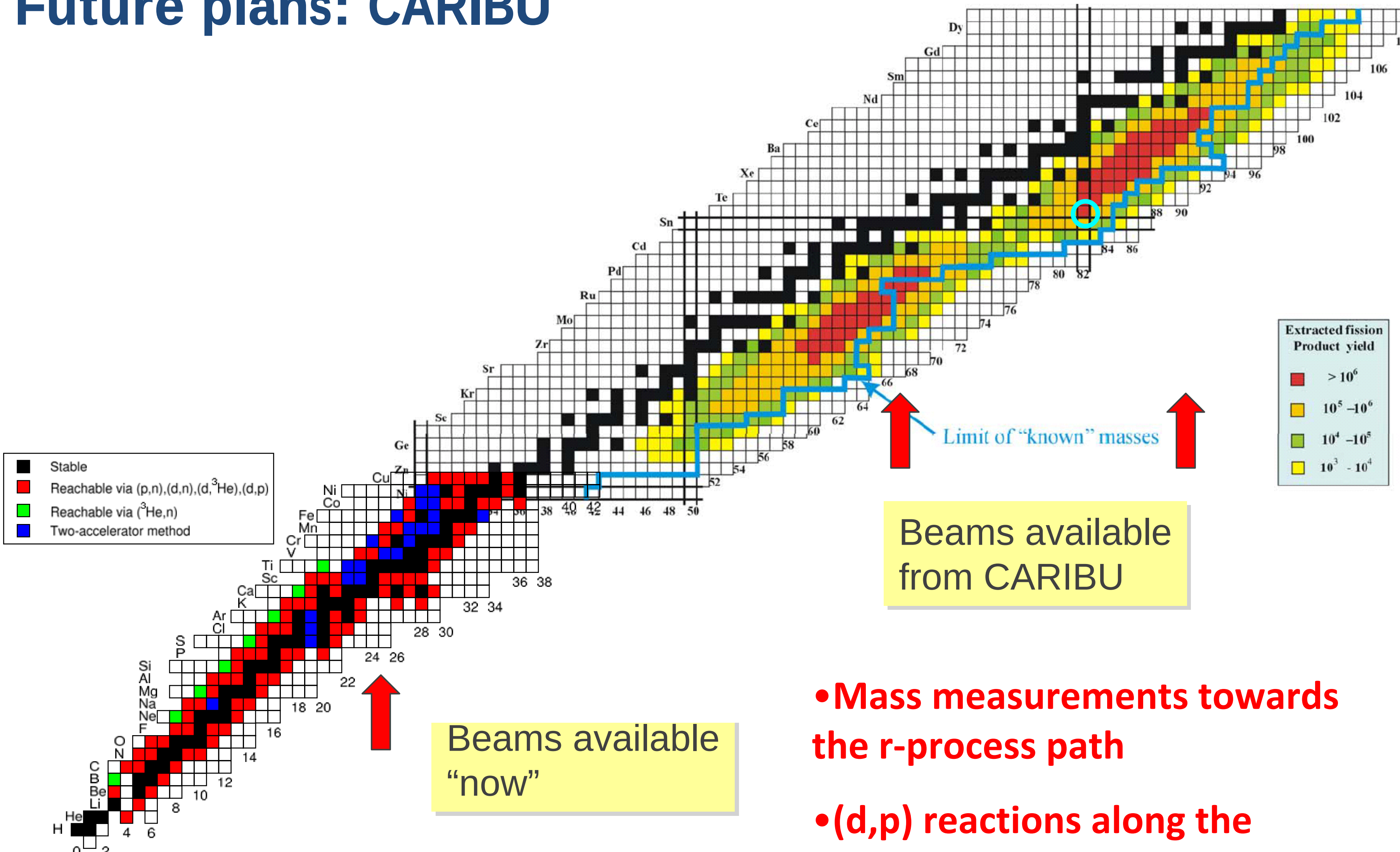




Possibilities with HELIOS for reactions in inverse kinematics

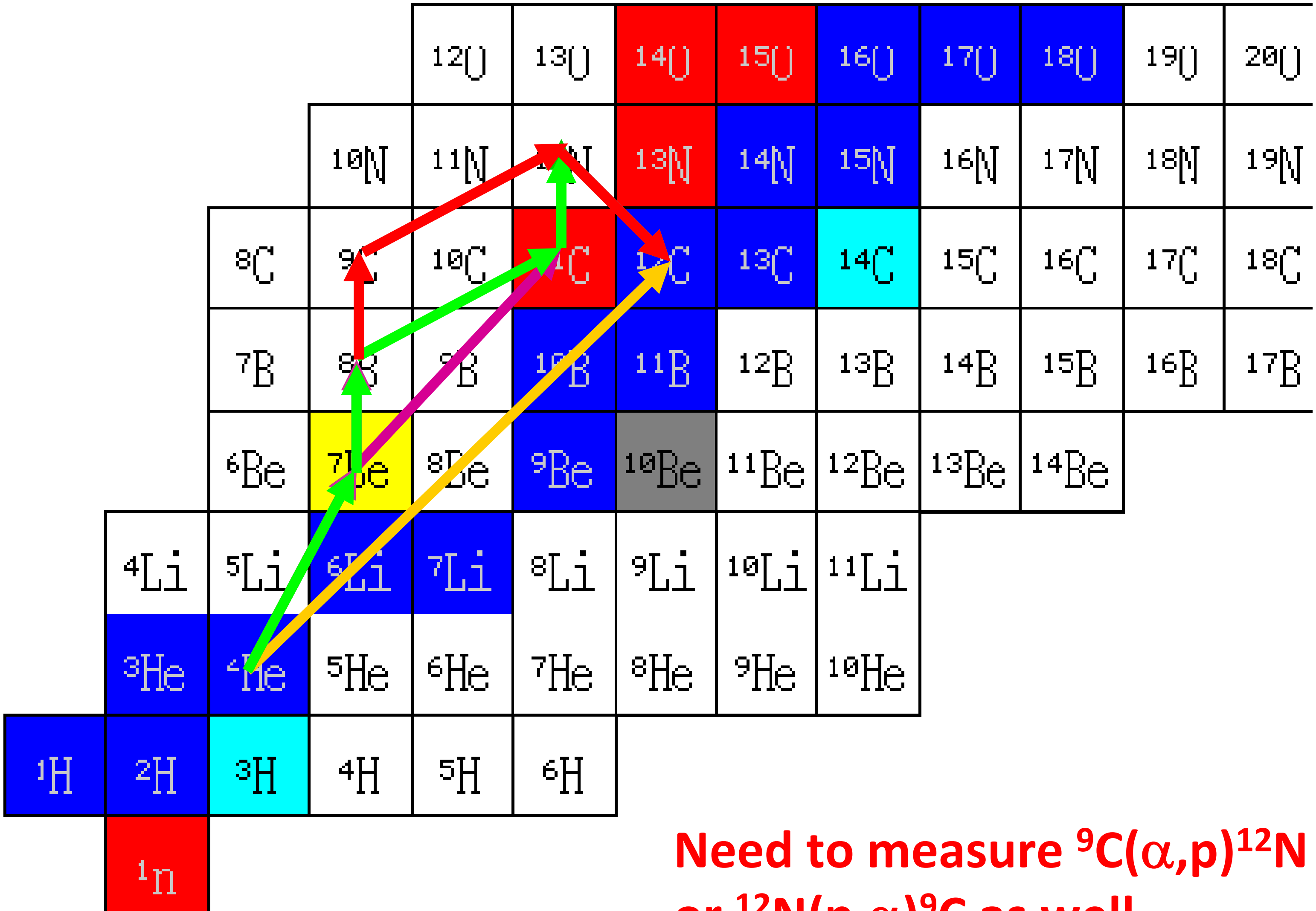
- Measurement of (^{3}He,d) reactions as a surrogate for (p,γ) measurements in the rp-process (see ^{56}Ni)
- Measurements of (d,p) reactions as a surrogate for (n,γ) reactions in the r-process
- Measurements of (α,p) reactions with high efficiency for the rp-process

Future plans: CARIBU



- **Mass measurements towards the r-process path**
- **(d,p) reactions along the N=82 neutron shell**

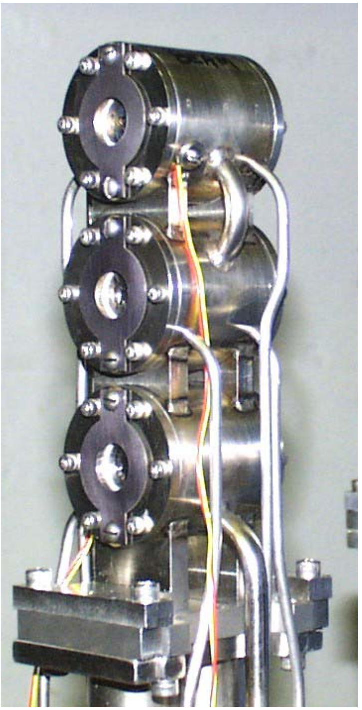
Future Plans: energy upgrade

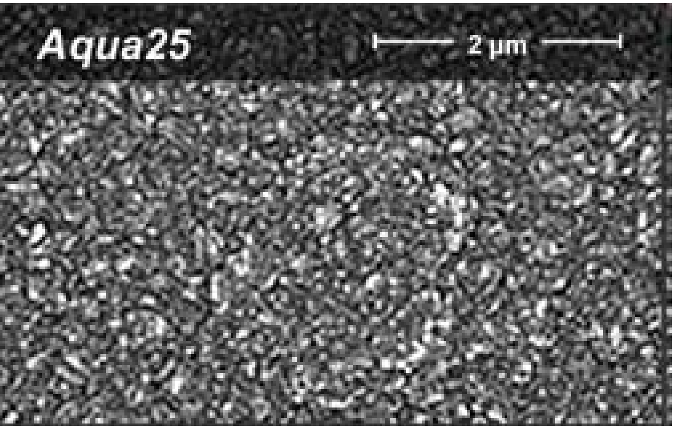


Need to measure $^{9}C(\alpha,p)^{12}N$ or $^{12}N(p,\alpha)^{9}C$ as well

Future Plans: intensity upgrade

New gas cell window material (~2x higher intensities)





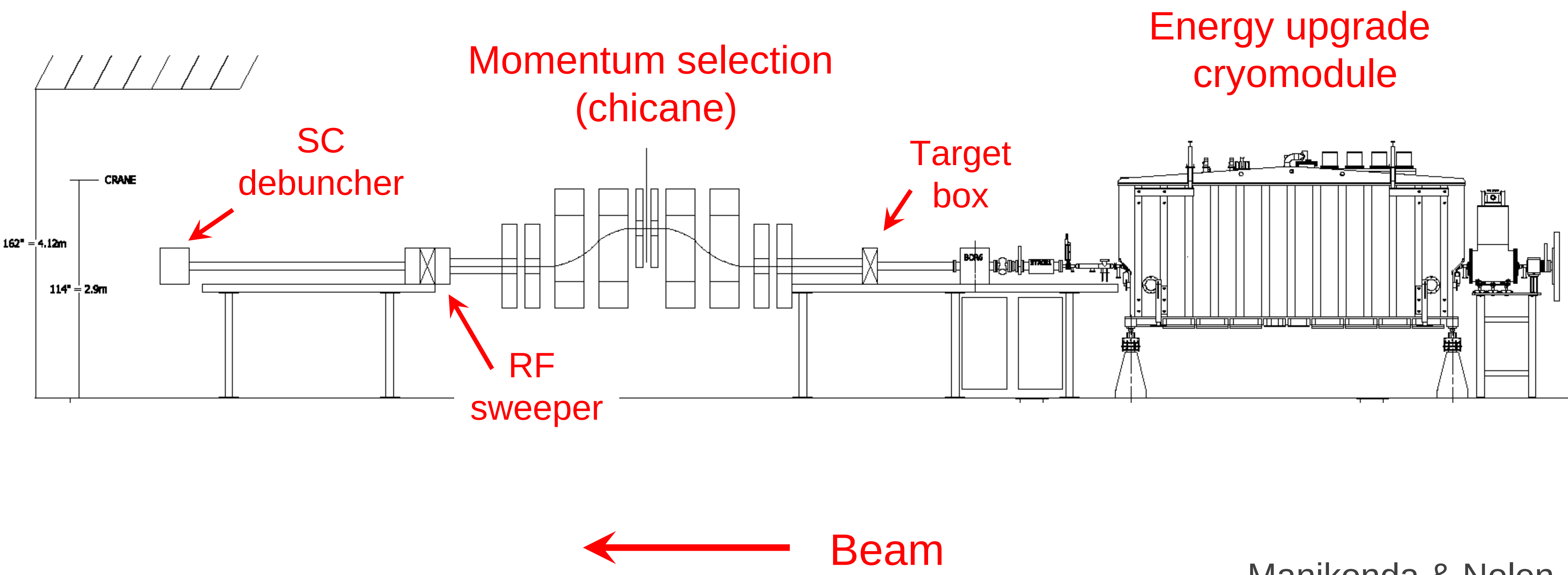
Nanocrystalline diamonds

Graphene, carbon nanotubes

Future Plans: intensity upgrade

Dedicated transport system (~50x higher intensities)

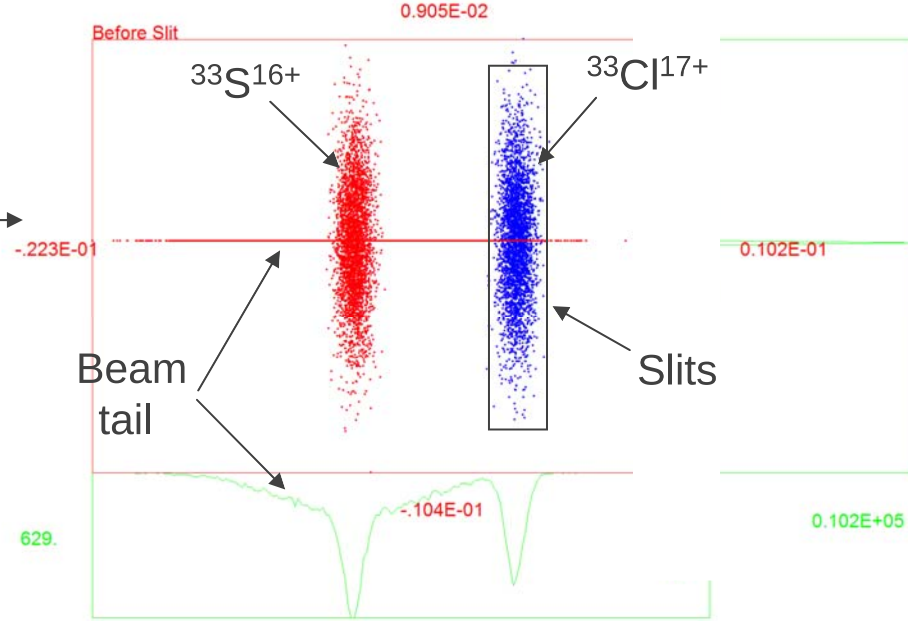
Conceptual layout of in-flight separator upgrade



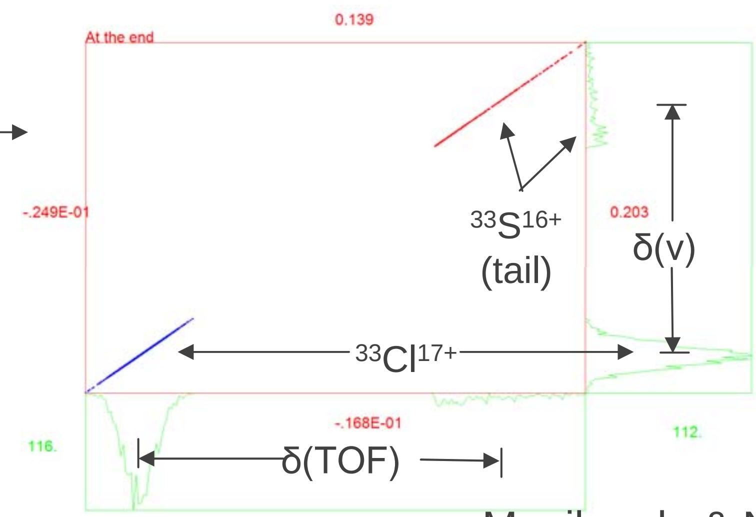
Manikonda & Nolen

Momentum and TOF separation

- Momentum selection



- TOF selection (RF sweeper)
- Followed by debuncher to reduce energy spread



Manikonda & Nolen

beam	f(charge state)	Opening cone (p,n)	Opening cone (d,n)	Expected beam
^{17}F	0.91	2.7	4.75	10^8
^{25}Al	0.79	1.6	3.35	$5x10^7$
^{33}Cl	0.61	1.03	2.53	$1x10^7$
^{45}Ti	0.37	1.	2.15	$4x10^6$
^{55}Co	0.16	0.32	1.61	$9x10^5$

Assuming 10 MeV/u and 100 mb cross section

Provides unstable beams to all experimental stations at ATLAS

Factor of 100 improvement

KK
IMPORTED
SUPER STRONG
ATLAS
BEER
12%
SERVE COOL
ATLAS BIRI, DAT N'A
IMPORTED
SUPER STRONG
ATLAS
BEER
SUPER STRONG
12%
SERVE COOL
500 ml
KK
GEIMPORTEERD
ATLAS
BIER
12%
KOEL SERVEREN
50 cl