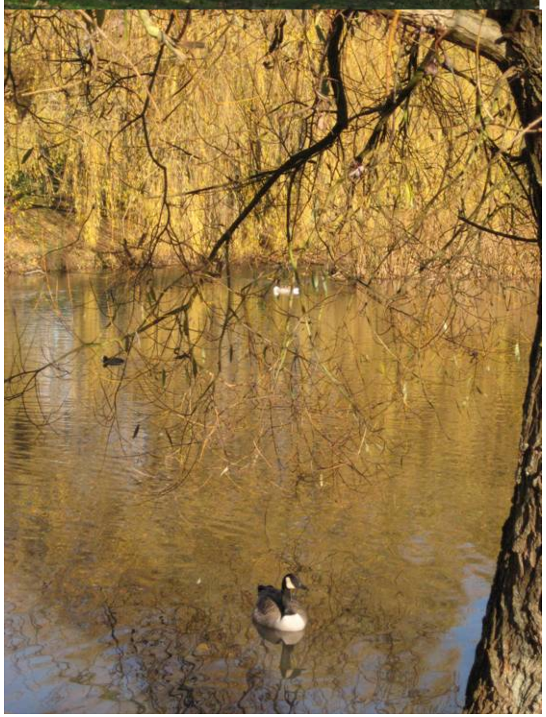

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"Nuclear reaction cross-section measurement capability in the UK: the Surrey Facility"

Nuclear Cross Sections Analysis and R-matrix tools
Friday May 10th 2012

J.L. Colaux & C. Jeynes

Ion Beam Centre

University of Surrey

www.surreyibc.ac.uk

Content

- Ion beam facilities at the IBC
  - **Danfysik**
  - **2MV Ion Implanter**
  - **2MV tandem accelerator**
- Existing systems of detection
- 2MV tandem accelerator
  - **Energy spread**
  - **V_t setting precision**
  - **Energy calibration**
- Possible applications
  - ***S* factor determinations**
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- Conclusions

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Danfysik Ion Implanter

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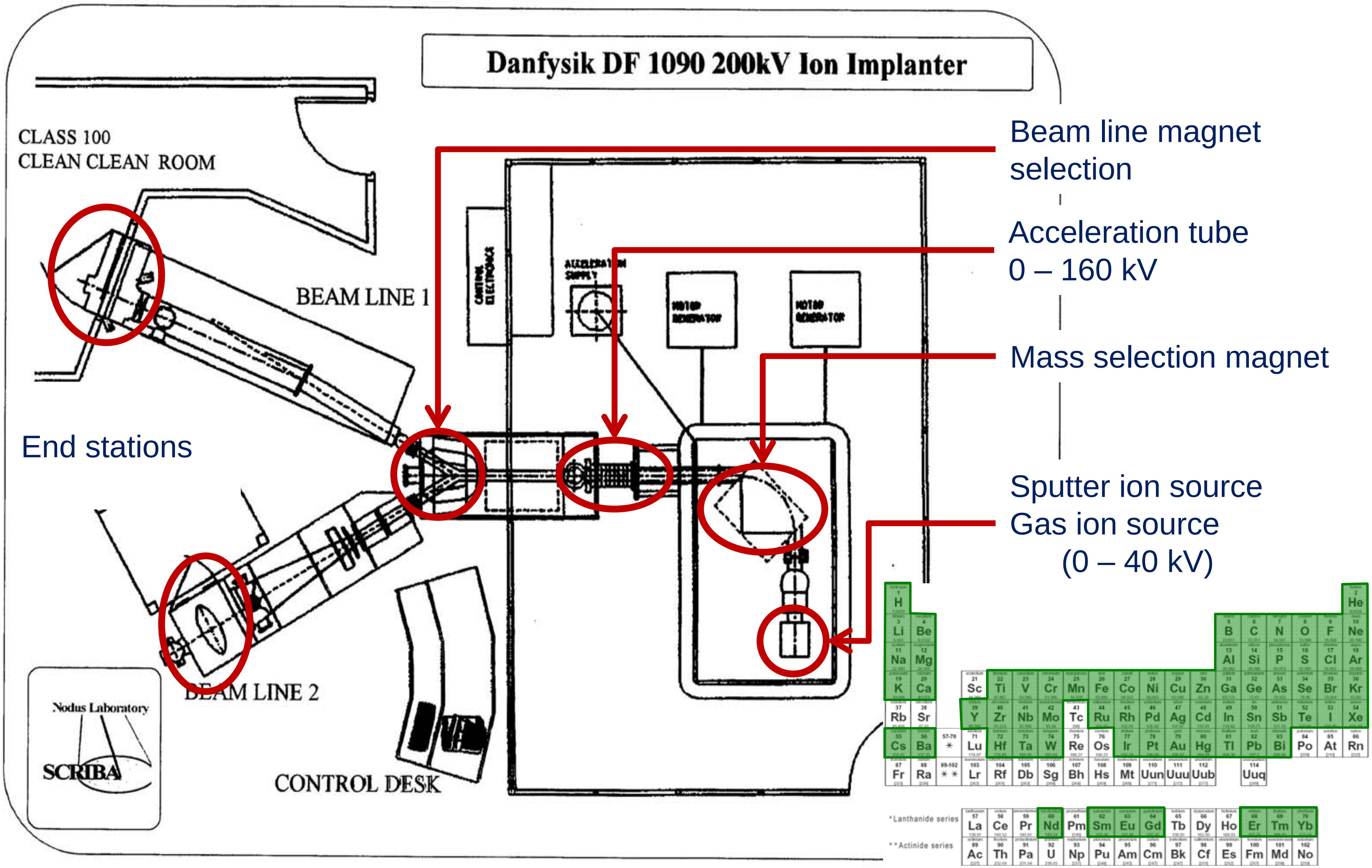
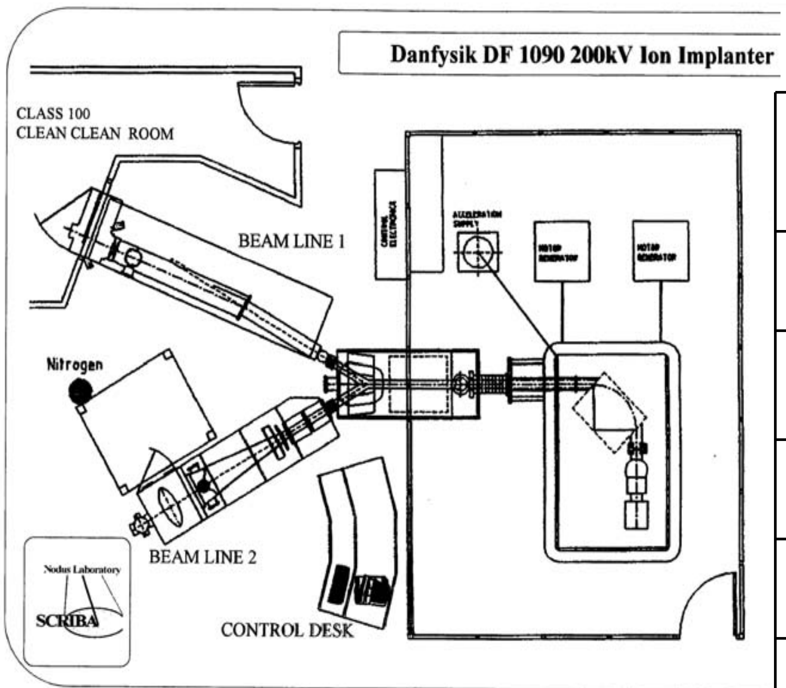


Danfysik Ion Implanter



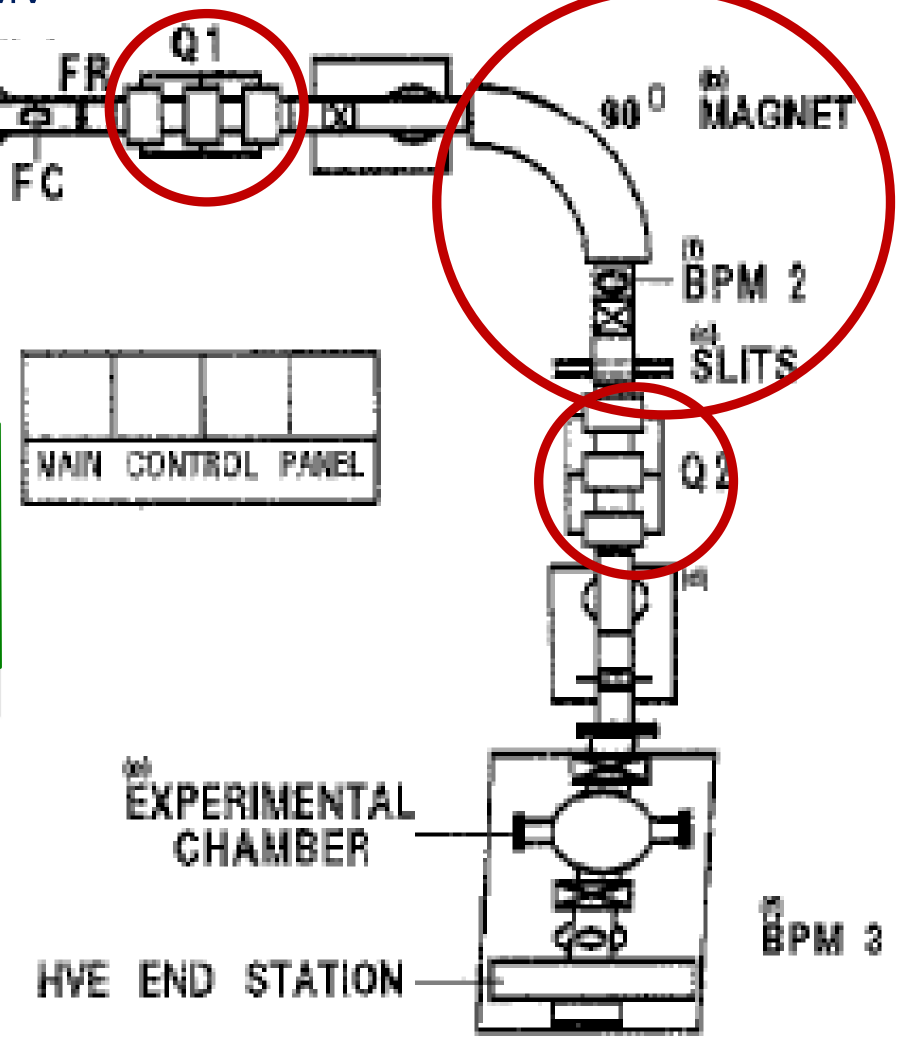
Typical values for Beam line 1

Ion species	Energy (keV)	Beam on target (p μA)
H_2^+	80	140
He^+	50 140	40 300
Li^+	30	15
Be^+	60	10
B^+	120	125
C^+	50	25
N^+	80	110

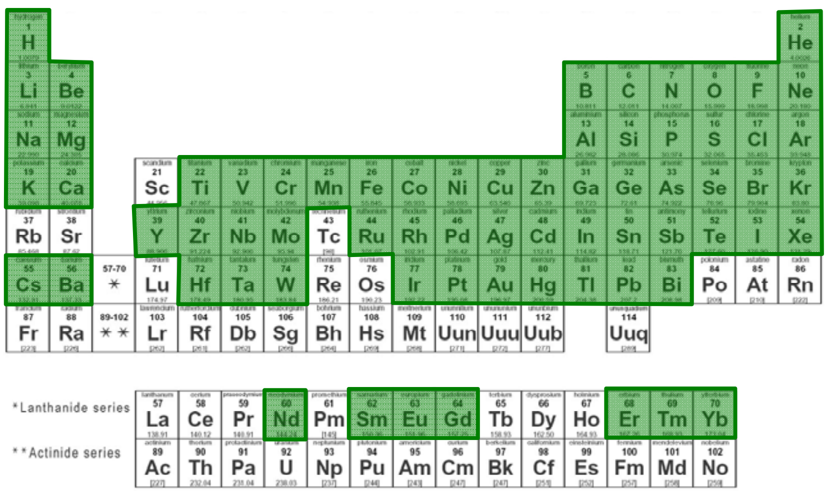
Beam intensities are much higher for Beam line 2

2MV Ion Implanter

Acceleration tube: 0.4 – 2.0 MV

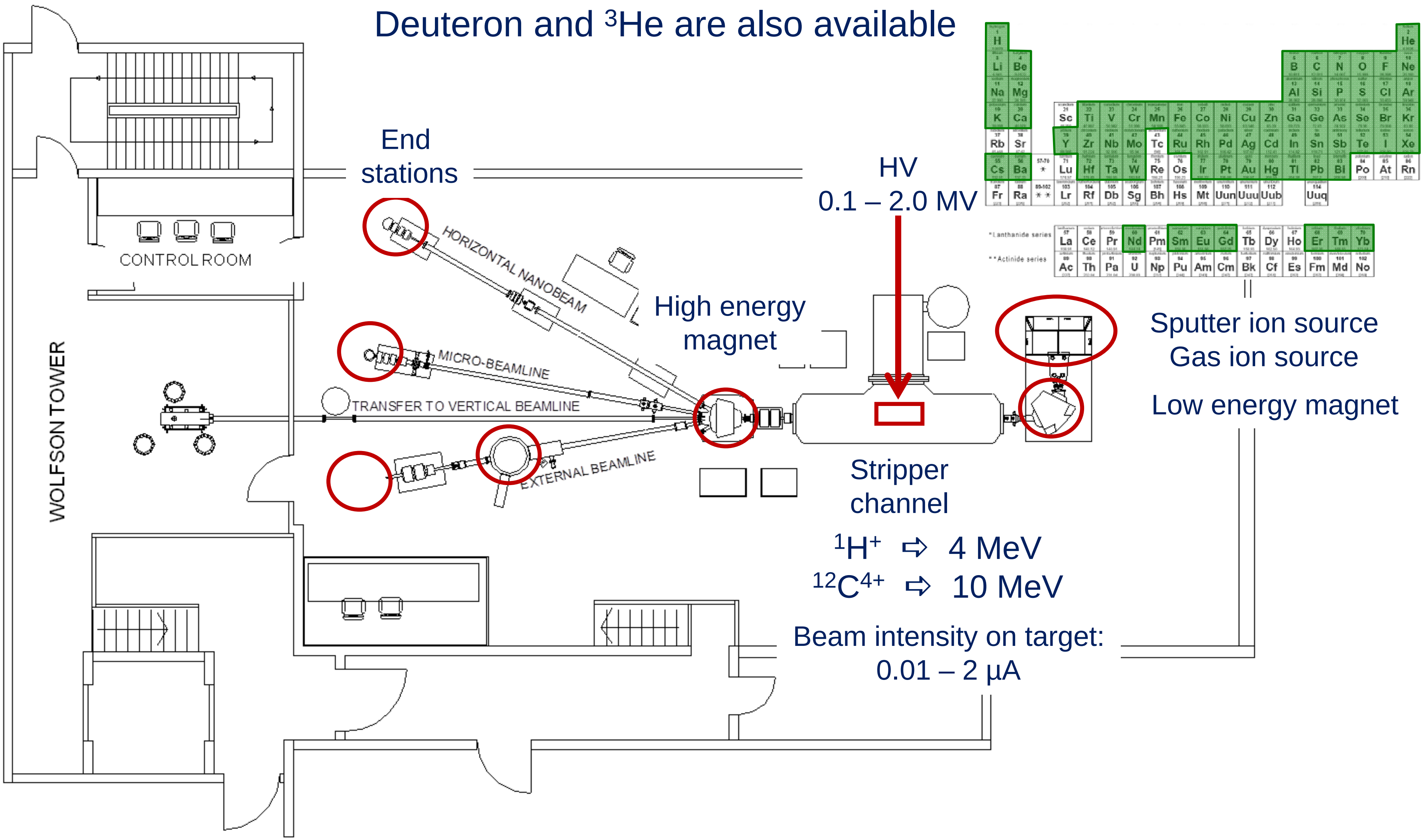
Sputter ion source
Oven ion source
Cold penning ion source
Hot penning ion source



$^{1}H^{+}$ ⇨ 2 MeV
$^{12}C^{2+}$ ⇨ 4 MeV

Beam intensity: 1 – 20 μA

2MV tandem accelerator



Ion beam facilities at the IBC

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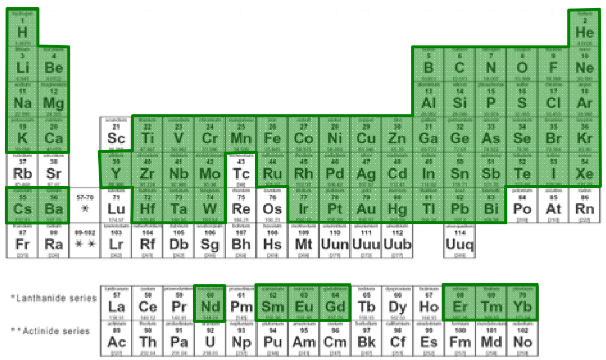
Facility	Energy range (keV)	Ion species available	Beam intensity on target (µA)
Danfysik	2 – 200		10 – 1000
2M Ion Implanter	300 – 4000		1 – 20
2M tandem accelerator	150 – (q + 1) × 2000		0.01 – 2

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Systems of detection

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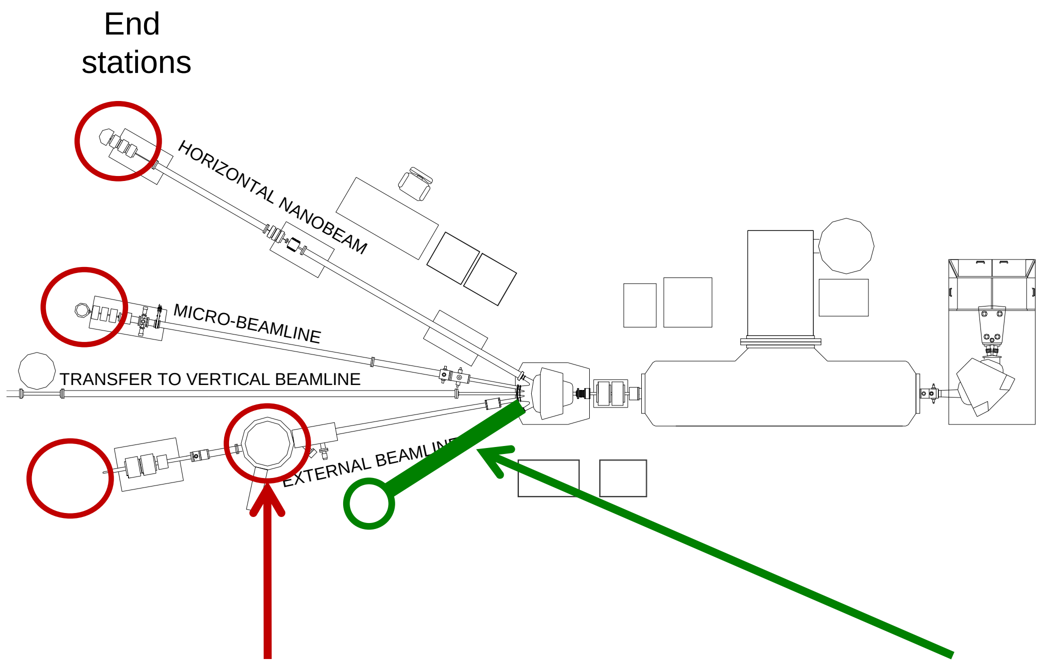


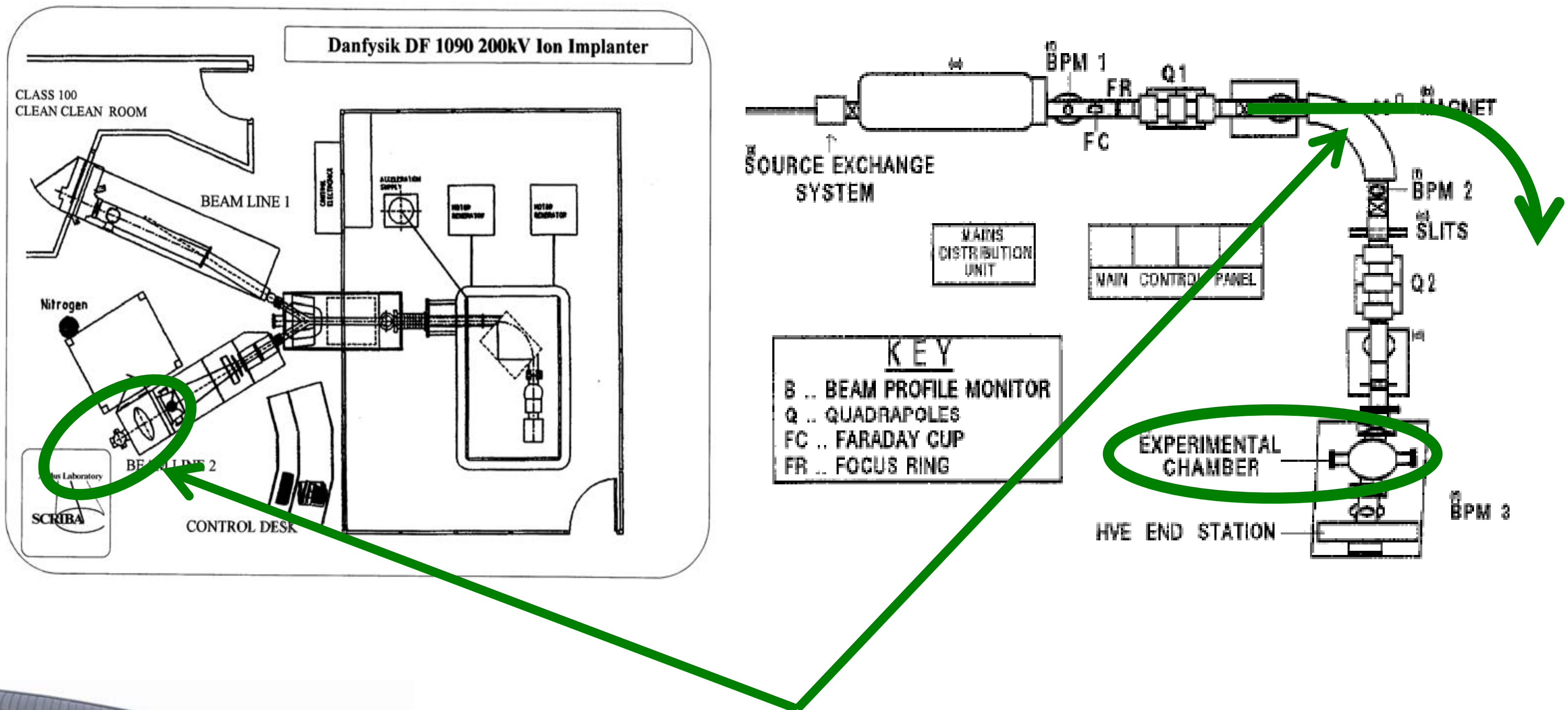
Broad-beam chamber
Angular distribution studies

Fifth line:
To be developed…

Detectors available:

- -PIPS (particles)
- -SiLi (X-rays)
- -SDD (X-rays)
- -HPGe (γ-rays)
- -NaI(Tl) (γ-rays)

Systems of detection



To be developed…

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Content

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2MV tandem accelerator
Energy spread & V_t precision

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SPECIFICATIONS

Model No.		4110	4117	4120	4130	4140	4150	4160
Beam current version*		MC MC⁺ HC	MC MC⁺ HC	MC MC⁺ HC	MC MC⁺ HC	MC MC⁺ HC	MC MC⁺ HC	MC MC⁺ HC
Terminal voltage range	MV	0.1 - 1.0	0.1 - 1.7	0.1 - 2.0	0.2 - 3.0	0.2 - 4.0	0.3 - 5.0	0.3 - 6.0
Terminal voltage stability								
. standard system (GVM)**	⁺/₋ V	150	200	200	300	400	500	600
. with slit stabilisation***	⁺/₋ V	30	30	30	30	30	30	30
Terminal voltage ripple**								
. standard system	V_{pp}	100	100	100	200	300	400	500
. with de-rippling kit	V_{pp}	25	25	25	30	40	50	60
X-ray level****	μSv/hr	<2	<2	<2	<2	<2	<2	<2

Beam currents***** (eμA)

Ion source	Ion	4110 q	MC	MC⁺	HC	4117 q	MC	MC⁺	HC	4120 q	MC	MC⁺	HC	4130 q	MC	MC⁺	HC
. Ion source Model 860A	^{11}B	2+	10	15	15	2+	10	20	20	3+	10	20	20	3+	5	20	20
	^{16}O	2+	25	50	80	2+	25	40	80	3+	25	50	100	3+	20	40	100
	^{28}Si	2+	35	50	100	2+	40	50	140	3+	40	50	150	3+	20	40	125
	^{31}P	2+	15	25	25	2+	15	35	35	3+	15	35	35	3+	10	40	40
	^{58}Ni	2+	3	6	6	2+	5	10	10	2+	5	10	10	3+	3	8	8
	^{63}Cu	2+	5	10	10	2+	5	15	15	2+	5	15	15	2+	3	10	10
	^{197}Au	1+	10	50	50	2+	20	50	60	2+	20	50	60	2+	10	40	40
. Ion source Model 358	^{1}H	1+	5	20	20	1+	5	25	25	1+	5	25	25	1+	4	25	25
	^{4}He	2+	0,5	1	1	2+	1	2	2	2+	1	2	2	2+	0,7	2	2
. Ion source Model 173	^{4}He	2+	0,2	0,5	0,5	2+	0,5	1	1	2+	0,5	1	1	2+	0,3	1	1

Ion source	Ion	4140 q	MC	MC⁺	HC	4150 q	MC	MC⁺	HC	4160 q	MC	MC⁺	HC
. Ion source Model 860A	^{11}B	3+	5	20	20	3+	5	15	15	3+	4	10	10
	^{16}O	4+	15	30	100	4+	15	30	100	4+	15	30	80
	^{28}Si	4+	15	30	125	4+	15	30	125	4+	15	30	100
	^{31}P	4+	10	30	35	4+	10	30	35	4+	10	30	30
	^{58}Ni	3+	3	10	10	4+	3	10	10	4+	3	8	8
	^{63}Cu	3+	3	10	10	3+	3	10	10	4+	3	8	8
	^{197}Au	2+	8	30	40	3+	10	25	35	3+	10	20	30
. Ion source Model 358	^{1}H	1+	4	25	25	1+	4	20	20	1+	3	15	15
	^{4}He	2+	0,7	2	2	2+	0,7	1,5	1,5	2+	0,5	1	1
. Ion source Model 173	^{4}He	2+	0,3	1	1	2+	0,3	0,8	0,8	2+	0,3	0,5	0,5

* Medium current plus (MC⁺) version is a medium current (MC) version equipped with a (optional) stripper gas re-circulation pump.
High current (HC) version is a medium current plus (MC⁺) version equipped with a (optional) high current power supply.
** measured over one hour, after one hour of warming up, at 75% of maximum terminal voltage.
*** measured over one hour, after one hour of warming up, at the exit of a HVEE 90° 1500mm radius analyzing magnet, by means of the $^{7}Li(p,n)$ reaction at 1.881MeV.
**** measured at 1mtr from the tankwall, running a 1μA He beam at maximum terminal voltage.
***** measured at maximum terminal voltage in a Faraday cup after a HVEE high energy switching magnet.

High Voltage Engineering Europa B.V. reserves the right to change specifications and features without prior notice, unless part of a quotation or order.

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HIGH VOLTAGE ENGINEERING EUROPA B.V.
Amsterdamseweg 63, 3812 RR Amersfoort, P.O.Box 99, 3800 AB Amersfoort, The Netherlands
Phone: +31 33 4619741 Fax: +31 33 4615291 E-mail: info@highvolteng.com Web: www.highvolteng.com

Energy spread is ~(1 + q) 25 eV

V_t precision setting is better than 0.2 kV

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2MV tandem accelerator Energy calibration

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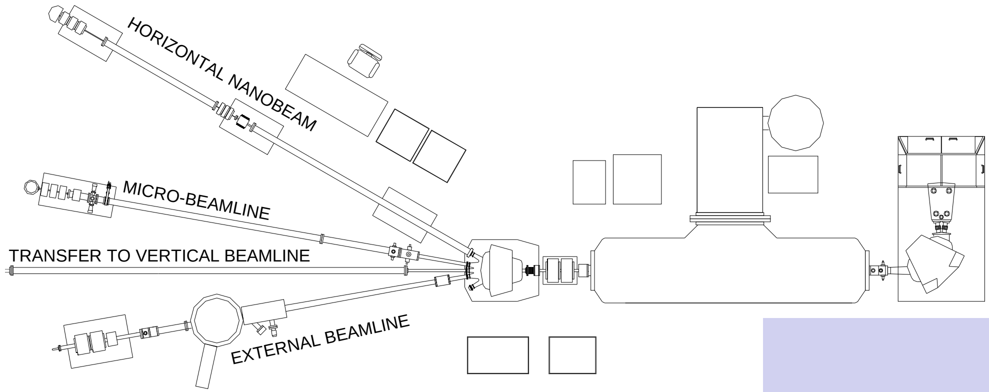


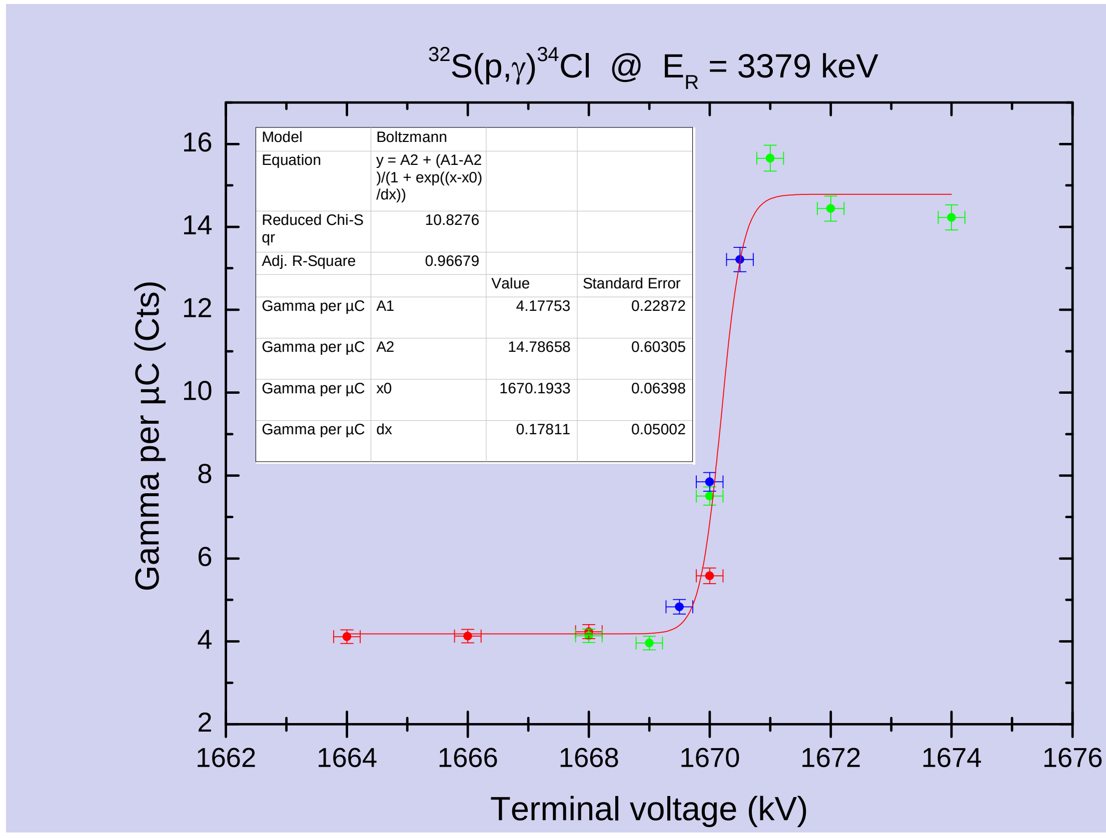
?

$$E = eV_{ext} + (1+q)\,a\,V_t$$

$$^{13}C(p,\gamma)^{14}N \ @ \ E_R = 1747.6 \pm 0.9\ keV$$

$$^{27}Al(p,\gamma)^{28}Si \ @ \ E_R = 991.9 \pm 0.04\ keV$$

$$^{32}S(p,\gamma)^{33}Cl \ @ \ E_R = 3379 \pm 1\ keV$$



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2MV tandem accelerator Energy calibration

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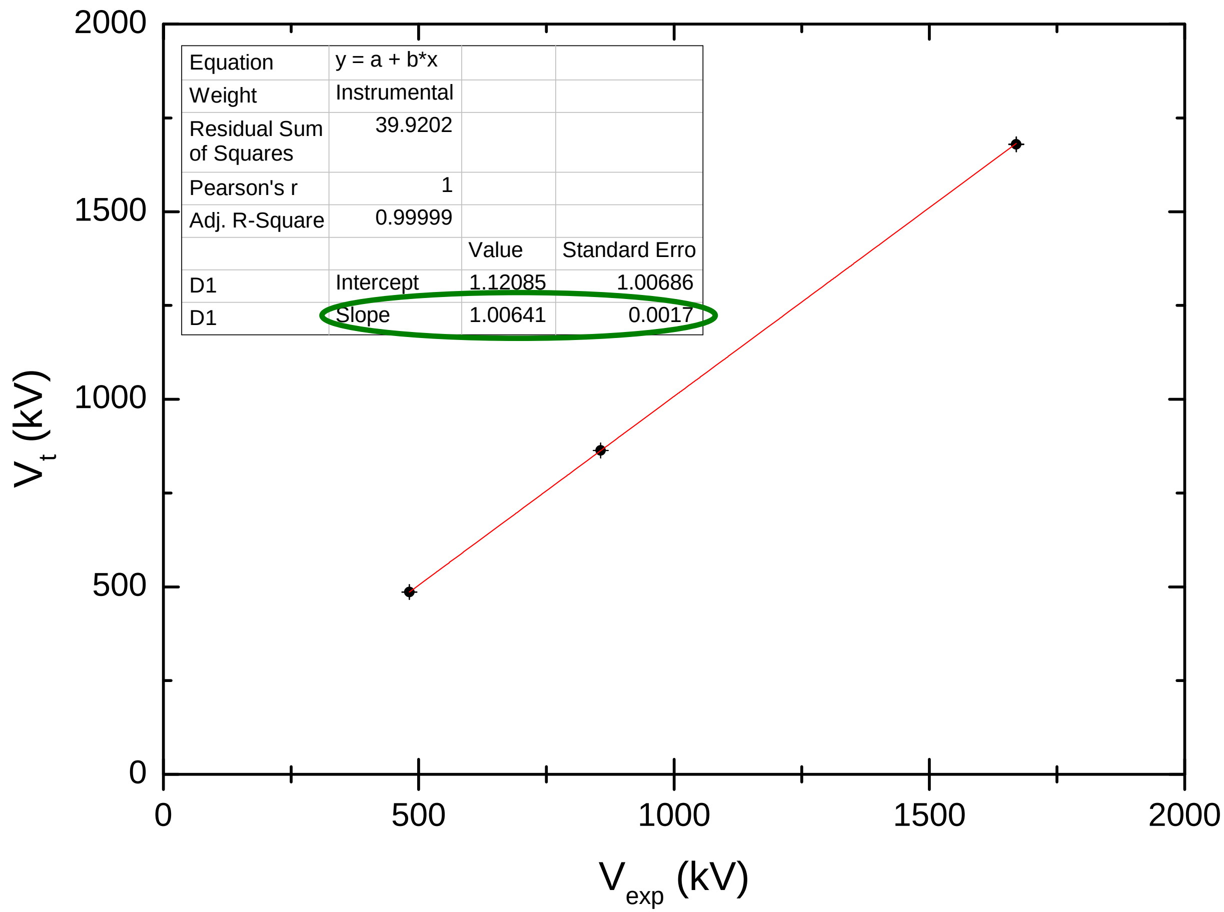
$$E = eV_{ext} + (1+q)\,a\,V_t$$

Calibration uncertainty < 0.2%

Energy spread (1 + q) 25 eV

V_t precision better than 0.2 kV



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S factor determinations

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Nuclear Instruments and Methods in Physics Research B 268 (2010) 1523–1528

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BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Development of a low-level setup for gamma spectroscopy: Application for nuclear astrophysics using reverse kinematics

G. Genard *, V.E. Nuttens, V. Bouchat, G. Terwagne

Research Centre in Physics of Matter and Radiation (PMR), Laboratoire d'Analyses par Réactions Nucléaires (LARN), University of Namur (FUNDP), Rue de Bruxelles, 61, B-5000 Namur, Belgium

A R T I C L E I N F O

Article history:
Received 18 July 2009
Received in revised form 4 January 2010
Available online 4 February 2010

Keywords:
Nuclear astrophysics
Reverse kinematics
Radiative proton capture
Hydrogen standard
Ion implantation
Low-level gamma-ray spectroscopy

A B S T R A C T

It is more and more necessary to improve the sensitivity of gamma-ray spectroscopy systems, especially in nuclear astrophysics. In the case of radiative proton capture reactions, one means is to avoid the reactions on the target impurities by using reverse kinematics. This technique is possible with the LARN accelerator and can provide very clean cross-section measurements. For that purpose, a hydrogen standard has been carried out by means of ion implantation in silicon. In addition, a low-level setup has been put in place on a new beam line of the accelerator. A high efficiency and high resolution germanium detector is used conjointly with a double shielding. A passive lead castle shielding system is used to reduce the natural radioactivity and an active shielding consisting of an anti-cosmic veto is provided by an anticoincidence between the plastic scintillator and the gamma-ray detector. The setup allows a reduction of 70% of the background interference and provides an approximately 200 fold sensitivity gain of between 600 and 3000 keV. Some other developments have also been carried out to optimize the setup. The entire setup and the reverse kinematics have been validated by measuring the cross-section of the $^{13}C(p,\gamma)^{14}N$ and $^{15}N(p,\gamma)^{16}O$ reactions that present some astrophysical interest.

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S factor determinations

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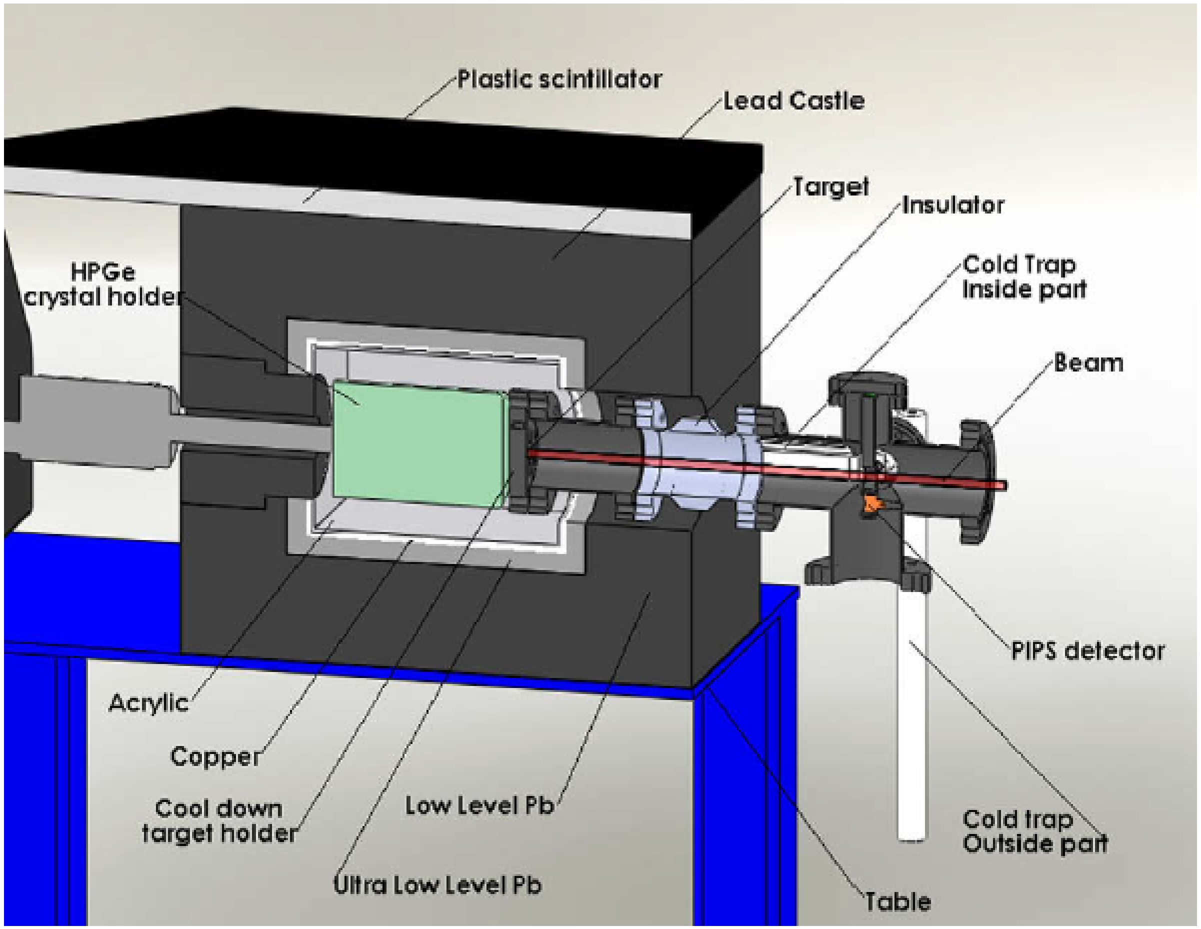

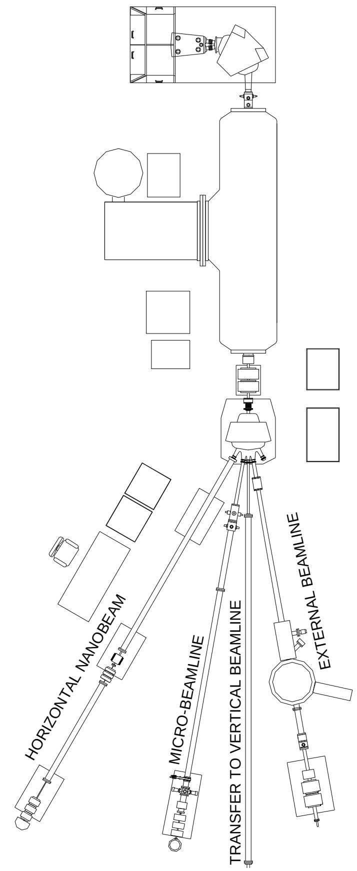

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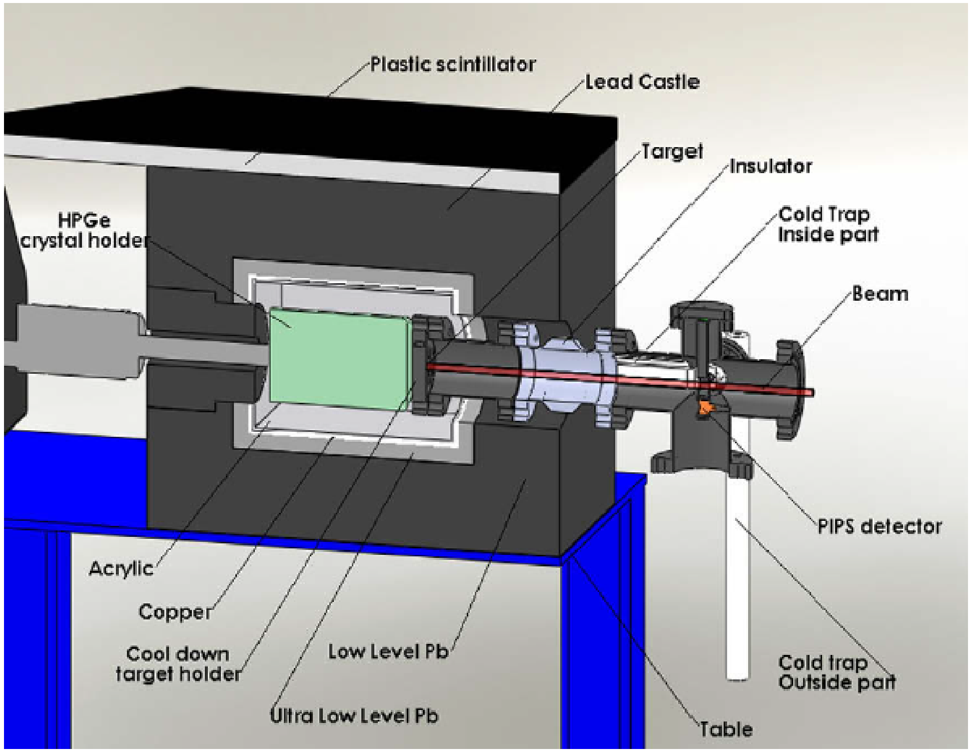

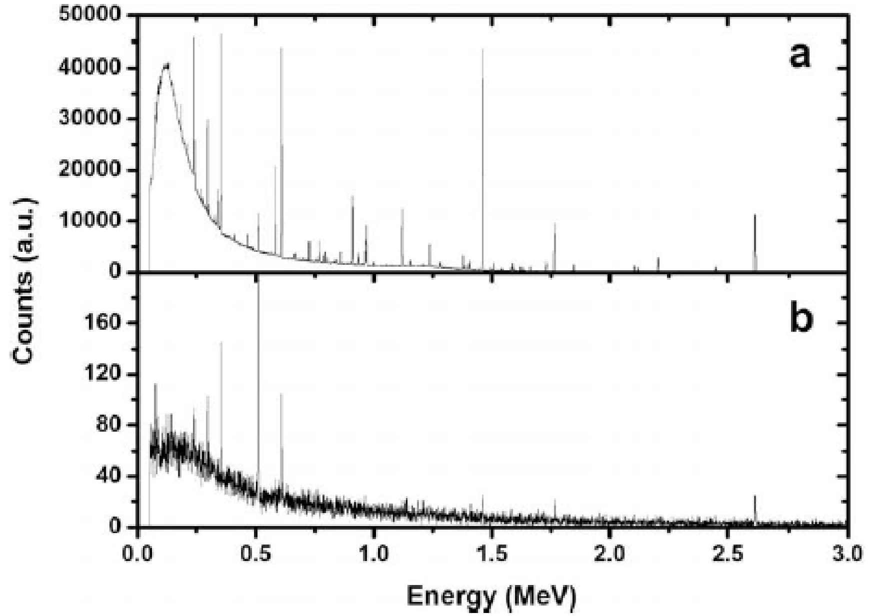

Fig. 2. Comparison of two background spectra acquired with the HPGe detector with (b), and without (a) lead castle. The acquisition time is 51,120 s (more than 14 h).

Counting rate is 200 times lower

S factor determinations

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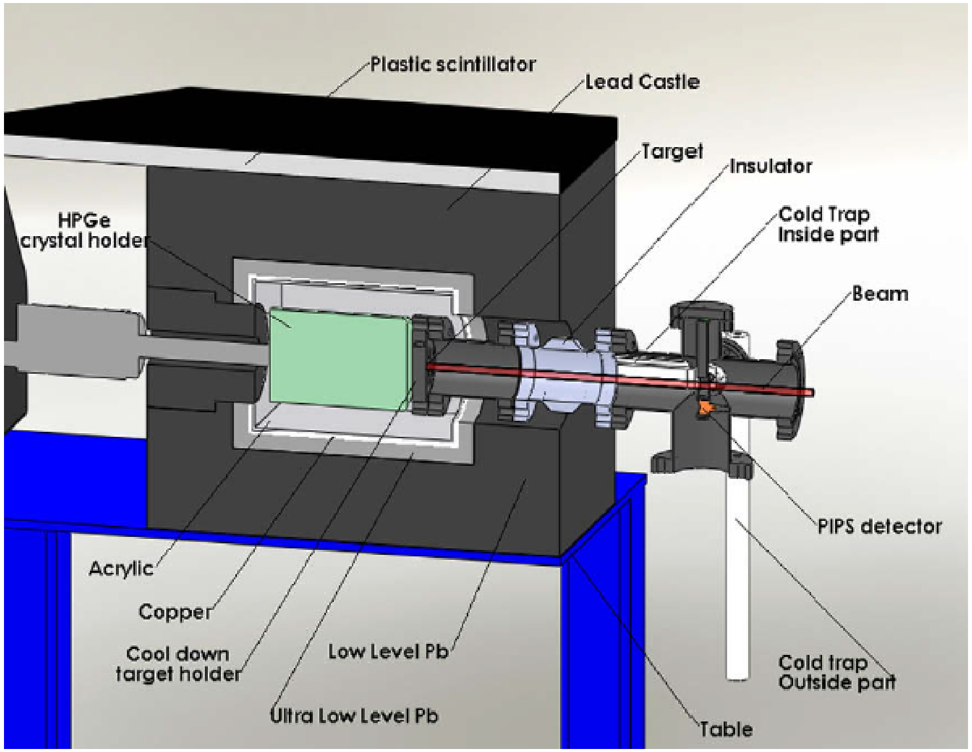

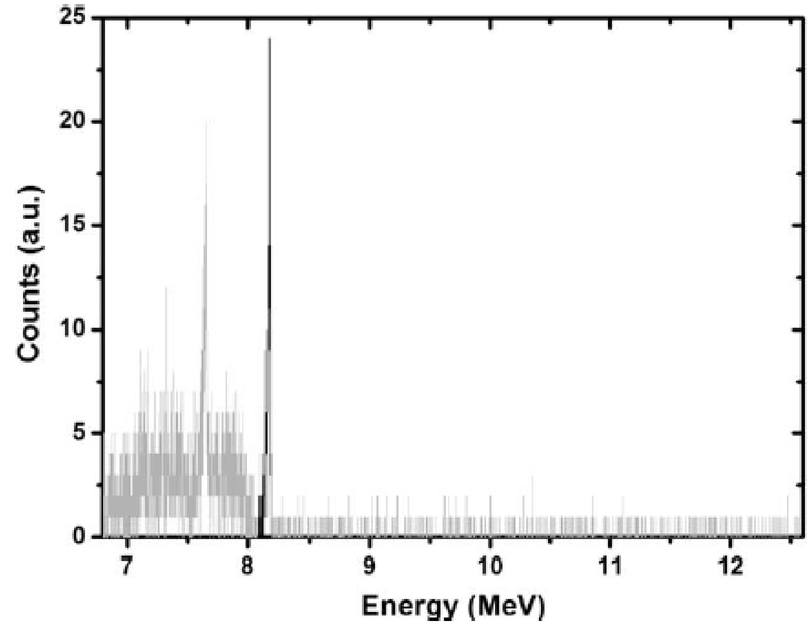

Fig. 3. Spectrum acquired during the $^1H(^{13}C,\gamma)^{14}N$ cross-section measurement at E_{CM} = 400 keV. The ROI on the full-energy peak is in black. No gamma-ray line is observed at higher energy, only cosmic rays. The acquisition time is less than 5 h and the signal to noise ratio is 40.

Reverse kinematics: $^1H(^{13}C,\gamma)^{14}N$

S factor determinations

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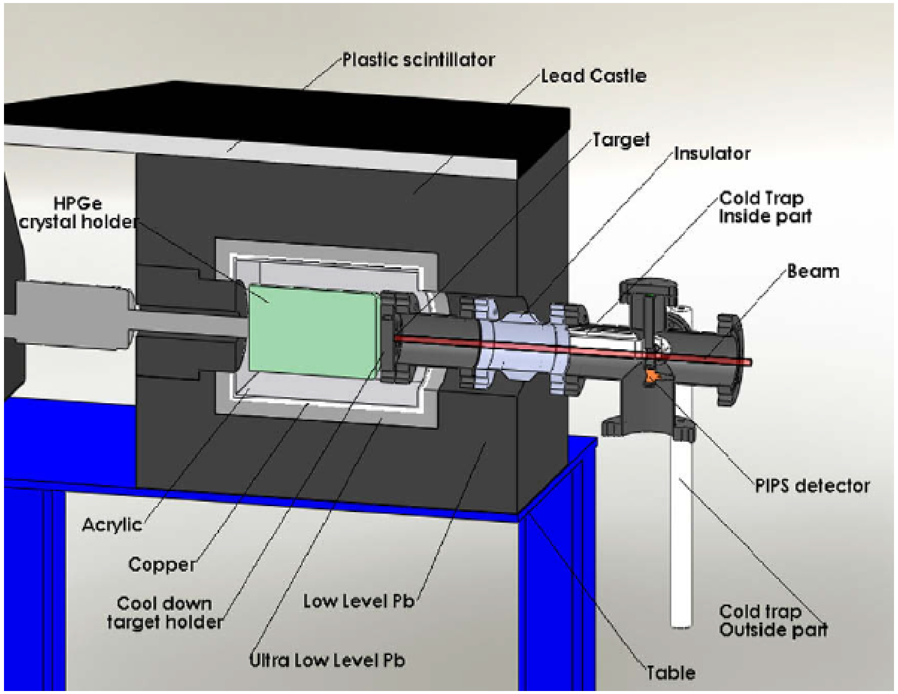

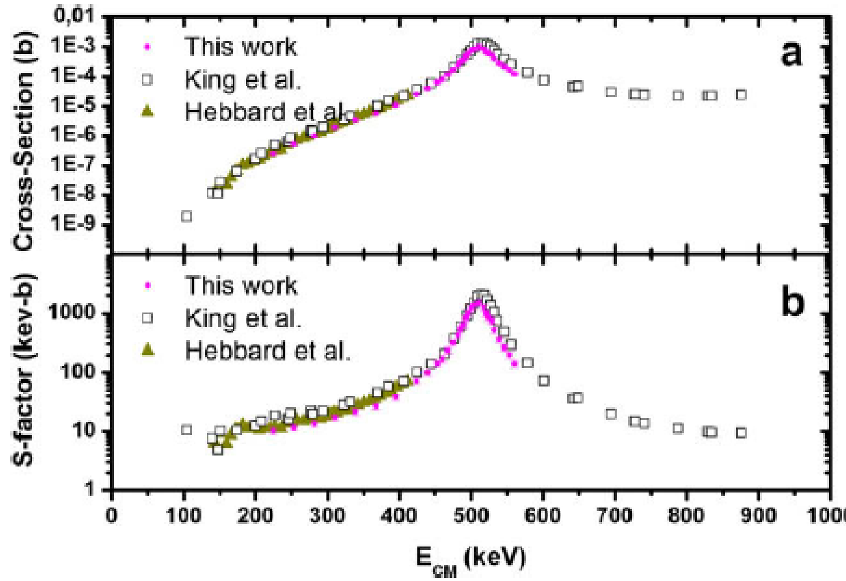

Fig. 4. Results of the measurement of the $^{13}C(p,\gamma)^{14}N$ reaction: the total cross-section (a) and the *S*-factor (b). A re-normalization factor of 1.23 has been applied to the cross-section in order to take into account all the de-excitation channels of the 511 keV resonant level. They are compared to those of King et al. [33] and Hebbard et al. [8].

Low current tandem accelerator ⟺ ^{13}C beam intensity: 0.2 – 2.5 µA

Acquisition time: 20 min – 50 hours

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S factor determinations

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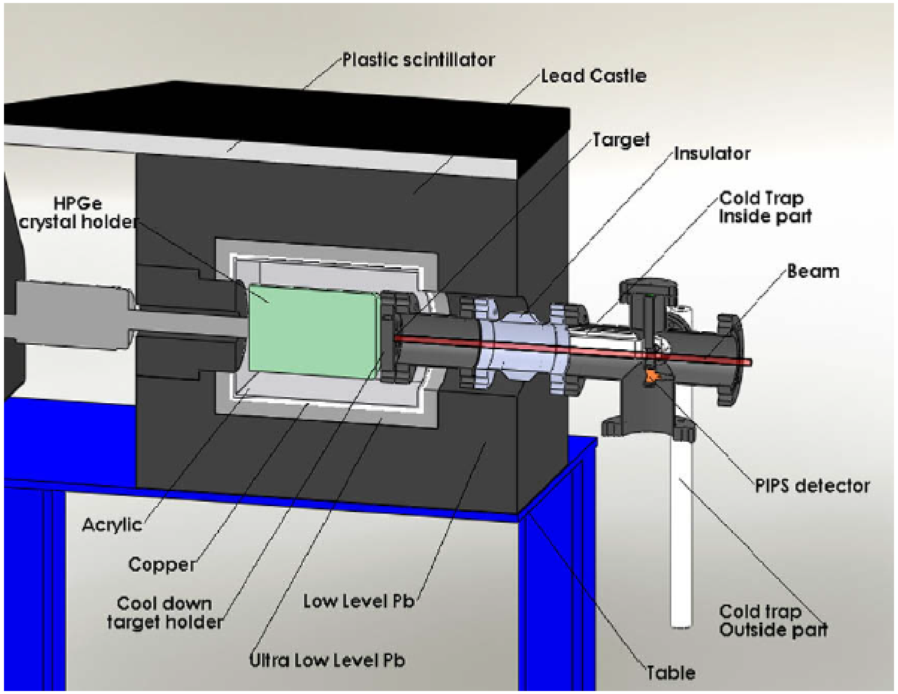

Nuclear Physics in Astrophysics IV — IOP Publishing
Journal of Physics: Conference Series **202** (2010) 012015 — doi:10.1088/1742-6596/202/1/012015

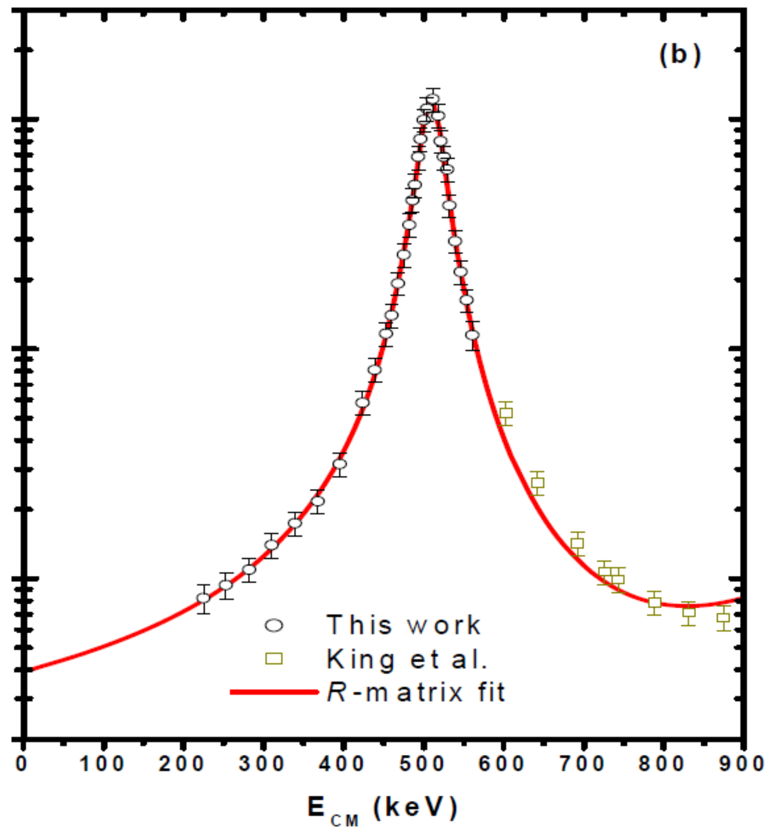

Figure 1. (b) Extrapolation of the *R*-matrix fit (circles). Some points of King et al. [3] (squares) are also shown.

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S factor determinations

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PHYSICAL REVIEW C **87**, 025806 (2013)

Cross section measurements of proton capture reactions relevant to the *p* process: The case of ^{89}Y(p,γ)^{90}Zr and ^{121,123}Sb(p,γ)^{122,124}Te

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J. W. Hammer and R. Kunz†
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DTL/RUBION, Ruhr-Universität Bochum, Universitätsstrasse 150, 40781 Bochum, Germany
(Received 16 June 2012; revised manuscript received 6 January 2013; published 27 February 2013)

The cross sections of the ^{89}Y(p,γ)^{90}Zr and the ^{121,123}Sb(p,γ)^{122,124}Te reactions were determined from γ-angular distribution measurements at beam energies from 1.6 to 3.4 MeV. In addition, angle-integrated cross sections were also measured at $E_p = 2, 3, 4,$ and 4.8 MeV for the ^{89}Y(p,γ)^{90}Zr reaction using the 4π γ-summing method. Astrophysical S factors and reaction rates were deduced from the measured cross sections. Statistical model calculations were performed using the nuclear-reaction code TALYS. The results from the comparison between theory and experiment are discussed in detail.

DOI: 10.1103/PhysRevC.87.025806 PACS number(s): 24.60.Dr, 25.40.Lw, 26.50.+x, 27.60.+j

^{1}H beam intensity: 5 – 10 μA

S factor determinations

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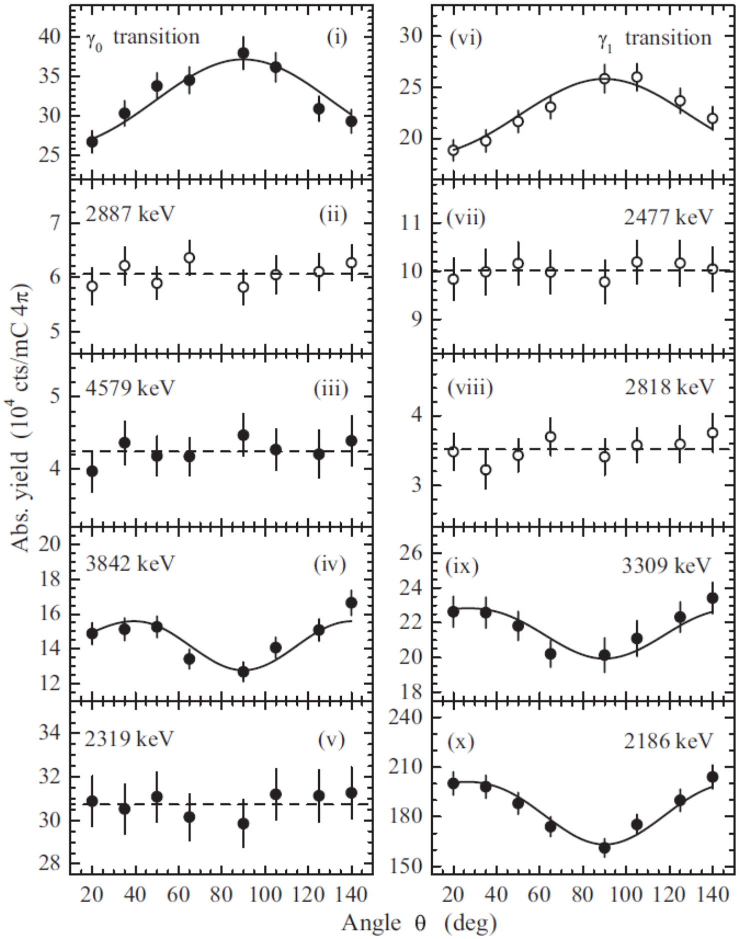

FIG. 5. Some typical angular distributions of γ transitions depopulating excited levels in the ^{90}Zr nucleus. The primaries from the entry level to the ground and first excited states, γ_0 and γ_1, respectively, are shown in the upper parts of the figure. Angular distributions plotted with open circles belong to γ rays feeding the first excited state, whereas those shown with filled ones to γ transitions populating the ground state (see also text).

R-matrix traitment

Resonances parameters

Quantum numbers

R-matrix traitment

Extrapolation to lower energies

(*S* factor – Gamow window)

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Nuclear spectroscopy

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PHYSICAL REVIEW C VOLUME 29, NUMBER 5 MAY 1984

Proton resonances in ^{28}Si from $E_x = 12.5$ to 13.4 MeV

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and Triangle Universities Nuclear Laboratory, Duke Station, Durham, North Carolina 27706

G. E. Mitchell
North Carolina State University, Raleigh, North Carolina 27695
and Triangle Universities Nuclear Laboratory, Duke Station, Durham, North Carolina 27706
(Received 19 December 1983)

The ^{27}Al(p,p) and (p,α_0) differential cross sections were measured in the range $E_p = 0.92$ to 1.85 MeV with an overall resolution of 350 to 400 eV (full width at half maximum.) Resonance parameters were extracted for 31 resonances with a multilevel, multichannel, *R*-matrix analysis code; these parameters include resonance energy, total angular momentum, partial elastic and inelastic widths, and channel spin and orbital angular momentum mixing ratios. Eleven analog states were identified, and the Coulomb displacement energies and spectroscopic factors were calculated. For the 2^+ resonance at $E_p = 1.37$ MeV the entrance orbital angular momentum mixing ratio was determined. The relevance of this mixing ratio to a previous test of time reversal invariance is discussed.

Nuclear spectroscopy

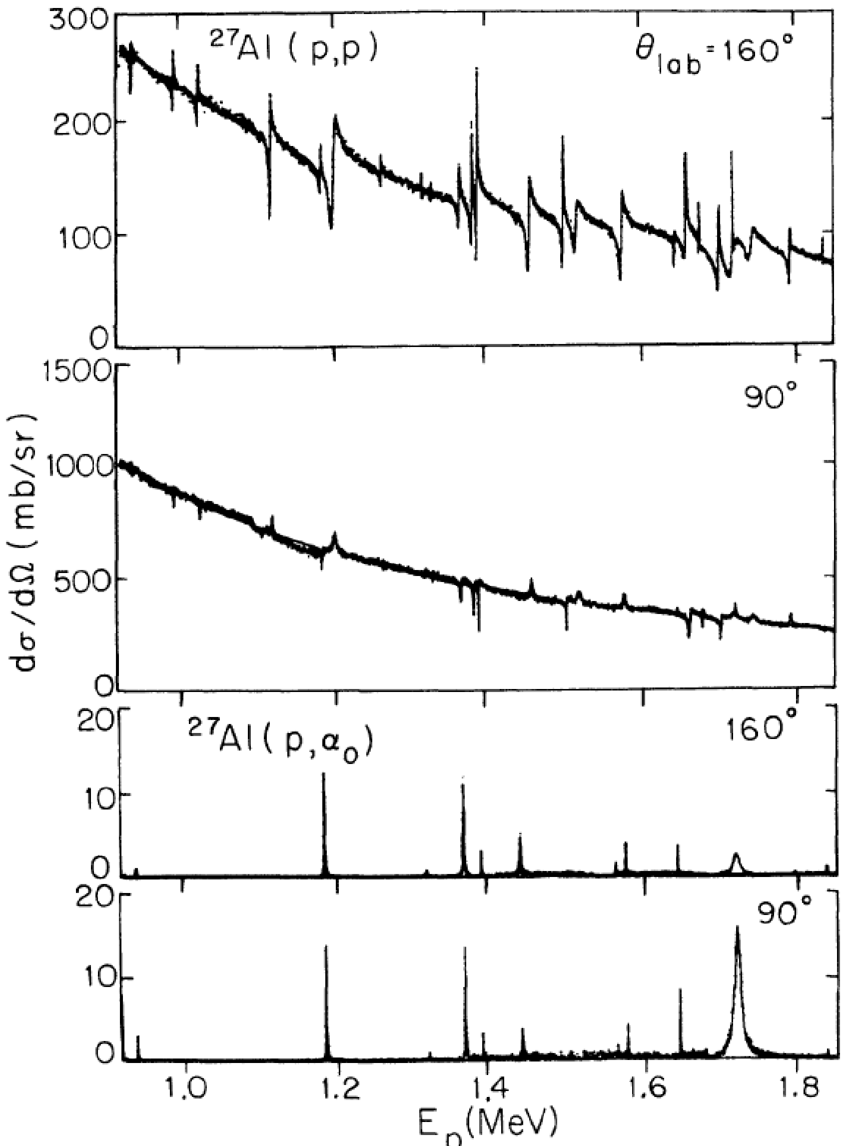

FIG. 3. The ^{27}Al(p,p) and (p,α_0) differential cross sections at two angles in the range E_p=0.92–1.85 MeV. The solid line is the *R*-matrix fit to the data. Background due to pulse pileup is seen in the α_0 excitation functions above E_p=1.4 MeV. There are no 160° α_0 data for the resonance near E_p=1.7 MeV due to the large contribution of pulse pileup from strong ^{12}C(p,p) resonances. Acceptable data were obtained at the three other angles. Uncorrected laboratory energies are plotted.

R-matrix → Resonances parameters

Quantum numbers

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Nuclear spectroscopy

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TABLE I. Resonance parameters for $^{27}Al(p,p)$ and $^{27}Al(p,\alpha_0)$.

E_p[a] (MeV)	J^{π}[b]	l[c]	ξ	ϕ_2[d] (deg)	ϕ_3[d] (deg)	Γ_p[e] (keV)	γ_p^2[f] (keV)	l_{α_0}	Γ_{α_0}[e] (keV)	$\gamma_{\alpha_0}^2$[f] (keV)
0.9370	3−	1	0.80	0	0	0.10	28.	3	0.008	17.
0.9919	(2)+	0	0.0	0		0.10	5.0			
	(3)+	0	1.0		0	0.070	3.5			
1.0253	2+	0	0.0	0		0.11	4.5			
1.1189	4−	1	1.0		0	0.70	62.			
1.1841	2+	0	0.0	0	0	0.25	34.	2	0.41	74.
1.2008	3−	1	0.0	0		5.4	320.	3	<0.005	3.2
		1	0.9	0	0	5.4	320.	3	<0.005	3.2
1.2637	3−	1	g	0	0	0.10	4.5			
1.3183	4+	2	1.0			0.030	9.6	4	0.005	11.
1.3300	(2)+	0	0.0	0		0.040	0.43			
	(3)+	0	1.0		0	0.030	0.32			
1.3656	2+	0	0.03	−6	90	0.55	11.	2	0.40	36.
1.3826	2+	0	0.0	0		0.78	7.0			
1.3893	3+	0	1.0		0	0.60	5.3			
1.3895	2+	0	0.0	0		0.20	1.7	2	0.030	2.5
1.4406	1−	1	0.0	0		0.25	5.7	1	1.45	42.
1.4575	4−	1	1.0		0	2.3	50.			
	(3)−	1	0.10	0	0	2.3	50.			
		1	0.75	0	0	2.3	50.			
1.5033	3+	0	1.0		0	0.55	3.4			
1.5196	2−	1	0.32	0	0	3.7	65.			
1.5660	4+	2	0.80			0.010	1.4	4	0.010	8.2
1.5784	4−	1	1.0		0	2.4	35.			
1.5788	2+	0	0.0	0		0.050	0.26	2	0.080	3.5
1.6472	3−	1	0.71	0	0	0.28	3.4	3	0.060	8.6
1.6625	2+	0	0.00	17		1.85	20.	2	<0.010	0.34
		0	0.09	0	90	1.85	20.	2	<0.010	0.34
1.6645	1+	2	g			0.45	38.			
1.6798	2+	0	0.0	0		0.21	0.84			
	(3)+	0	1.0		0	0.15	0.60			
1.7055	2+	0	0.0	0		1.1	4.2			
1.7234	3−	1	0.96	0	0	8.0	79.	3	1.6	153.
1.7243	5−	3	0.65			0.20	215.			
1.7481	2−	1	0.05	0	0	6.6	62.			
1.7974	(3)−	1	0.10	0	0	1.3	10.8			
		1	0.75	0	0	1.3	10.8			
	(4)−	1	1.0		0	1.1	9.1			
1.7998[h]	1+	2	g			0.20	11.			
1.8410	4+	2	0.7			0.55	2.7	4	0.006	1.9

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Content

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- Ion beam facilities at the IBC
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- 2MV tandem accelerator
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Conclusions

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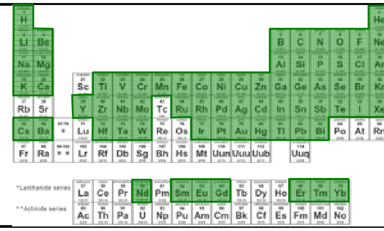
Facility	Energy range (keV)	Ion species available	Beam intensity on target (μA)
Danfysik	2 – 200		10 – 1000
2M Ion Implanter	300 – 4000		1 – 20
2M tandem accelerator	150 – (q + 1) × 2000		0.01 – 2

Calibration uncertainty < 0.2%

Energy spread (1 + q) 25 eV

V_t precision better than 0.2 kV

Instrument of choice for

Cross sections measurement

(Automated data collection)

R-matrix

Nuclear astrophysics

Nuclear spectroscopy

Ion Beam Analysis

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