Il Tandem dei LNS: storia ed attualità dopo 35 anni di attività.

Giacomo Cuttone

INFN – Laboratori Nazionali del Sud, Catania, Italy

Workshop on basic research and interdisciplinary applications with small accelerators

Napoli 17 Gennaio 2017

UNIVERSITA' DEGLI STUDI DI CATANIA

FACOLTA' DI SCIENZE MATEMATICHE FISICHE E NATURALI

CORSO DI LAUREA IN FISICA

GIACOMO CUTTONE

OTTICA DEI FASCI DI IONI NELL'ACCELERATORE TANDEM SMP: PROBLEMI E POSSIBILI SVILUPPI

TESI DI LAUREA

Relatori:
Prof. E. MIGNECO
Dott. L. CALABRETTA

ANNO ACCADEMICO 1981 - 82

Accelerator equipment for ion beam production

450 KV injector
2 sputtering sources

Normal conducting ECR source CAESAR

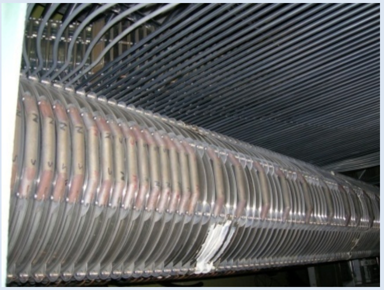
Superconducting ECR source SERSE

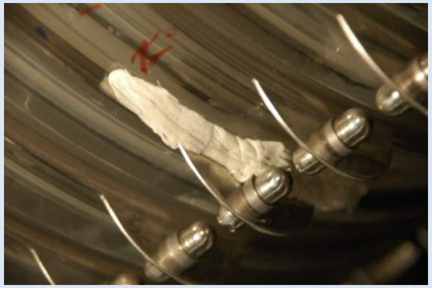
Tandem upgrade

Vacuum losses in the first accelerating tube

high residual pressure in the Low Energy section: $4 \cdot 10^{-6}$ mbar

- **difficult to be located <$5 \cdot 10^{-5}$ mbar•lt/s (limited access)**
- **once roughly located, fixed by means of a vacuum sealant**
- **done three times - after few months the problem appears again**





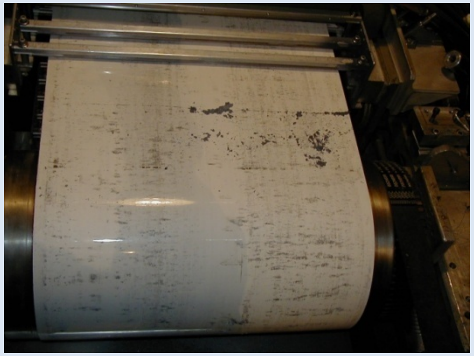
Replacement of the first accelerating tube - Order to VIVIRAD dated December 20th 2013: 237.000,00 € - project LNS Nuclear Astrophysics - delivered end of May 2014 – installed September 2014

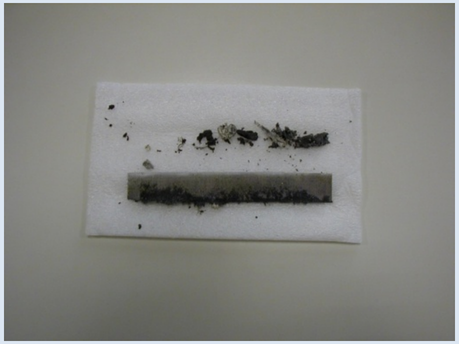
Tandem upgrade

Charging system

Original (HVEC) belts are not any longer available

Several attempts with belts produced by different companies





Another attempt ………… after only few weeks

Tandem upgrade

Charging system

The insulating material does not resist to temperature and discharges

The belt must have good mechanical and electrical characteristics - No company available to improve them

Alternative to the belt : Pelletron by NEC

Order to NEC dated July 25, 2013: 598.845,50 $ project - LNS Nuclear Astrophysics - Delivered on January 6, 2015. Installed on January 19, 2015 in 3 weeks

From the belt

to the Pelletron

Very good performance
Ripple 1•10^{-4}

LNS experimental resources upgradining for excellence researches in Nuclear Astrophysics, with stable and radioactive beams (Progetto Premiale)

Radioactive Ion Beams + Virtual Neutron & Trojan Horse

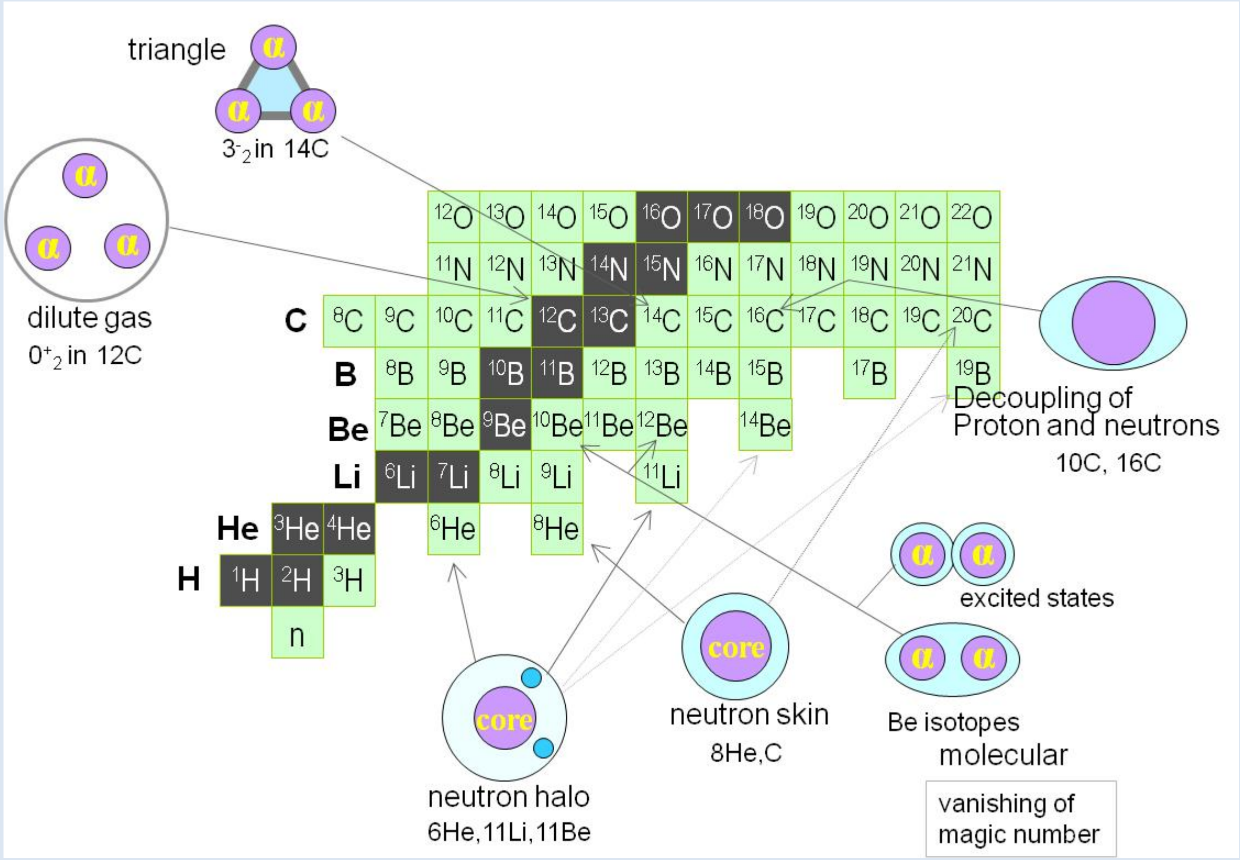
=

LNS is the first lab where it is possible to study reactions between neutrons and instable nuclei, both for Nuclear Astrophysics and Nuclear Structure and Reaction Mechanism Studies

The aim of this project is to perform "bare" nucleus cross sections measurements of key astrophysics reactions in the astrophysics energy range and thermonuclear fusions reactions that concern the fusion energy production.

For example, to know the $^{10}B(p,\alpha 0)^{7}Be$ cross section it is crucial to understand the natural B usability as clean fuel but even to study the nuclear reaction chain in the Sun.

Reazioni indotte da nuclei leggeri alle energie del TANDEM



Gli effetti quantistici fanno si’ che negli stati fondamentali dei nuclei leggeri siano presenti strutture molto particolari: vari tipi di clustering, aloni nucleari e skin di neutroni.

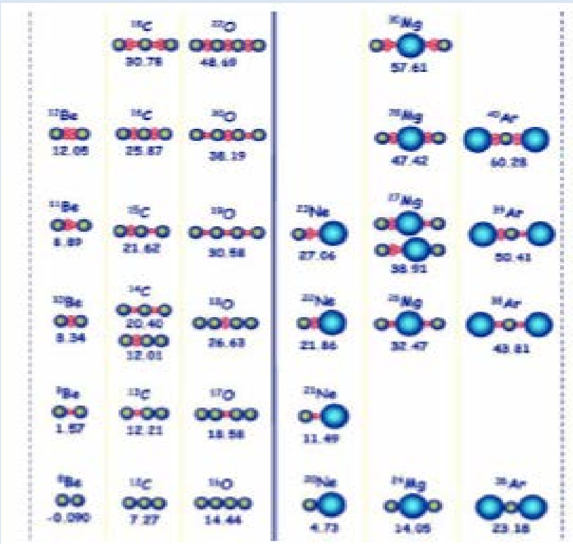
La presenza di tali strutture inficia la dinamica di reazione soprattutto a bassa energia (attorno ed al di sotto della barriera Coulombiana).

L’energia ottimale per lo studio di tali particolari strutture e degli effetti sulla dinamica di reazione e’ l’energia tipica degli acceleratori TANDEM.

Clustering nei nuclei

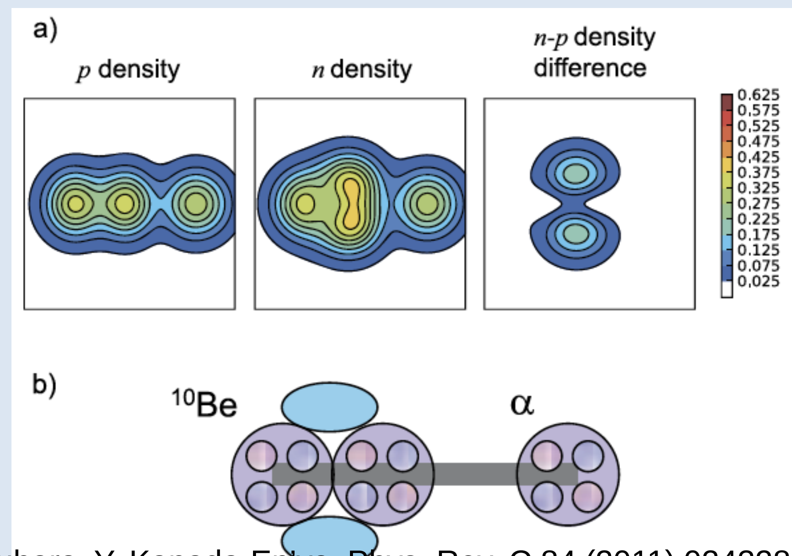
La struttura a cluster è caratteristica di molti nuclei leggeri, sia nello stato fondamentale che in stati eccitati

Molecole nucleari



Nei nuclei n-rich previste formazioni di “**molecole**” composte da particelle α legate da *neutroni* e/o *protoni*

Catena lineare prevista nel ^{14}C del tipo: $^{10}Be + \alpha$.



Fascio di ^{10}Be prodotto al TANDEM dei LNS

Suhara, Y. Kanada-En'yo, Phys. Rev. C 84 (2011) 024328

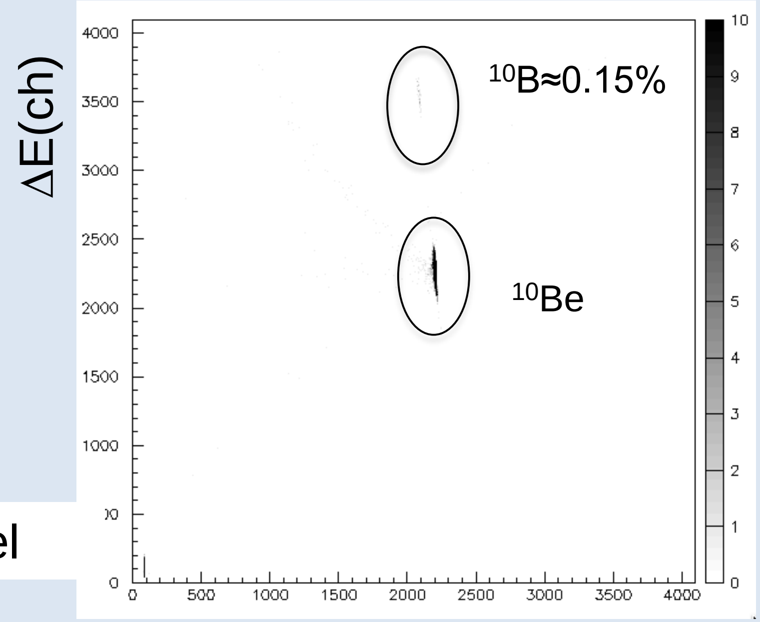
T. Suhara, Y. Kanada-En'yo, Phys. Rev. C 82 (2010) 04430

Produzione di un fascio radioattivo di ^{10}Be in batch-mode ai LNS

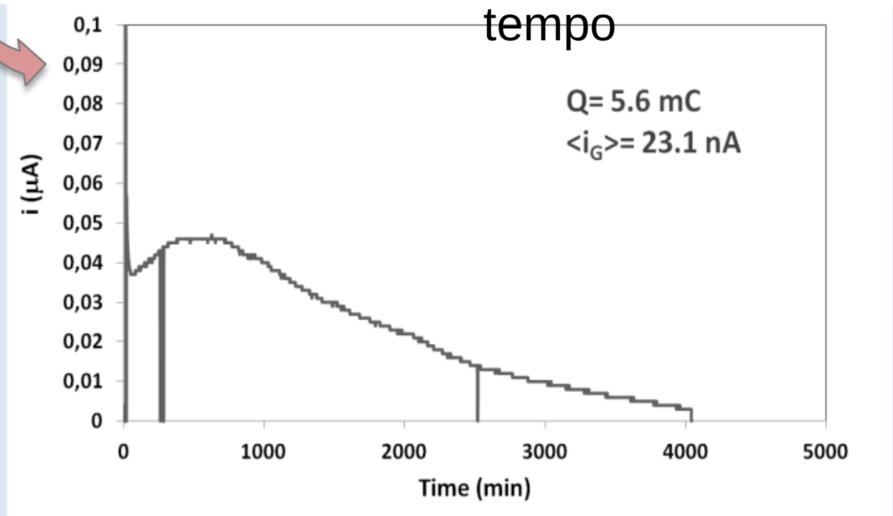
Catodi contenenti ^{10}BeO (^{10}Be $T_{1/2}=1.39\times10^6$ y) preparati al PSI (Zurigo).
Collaborazione con il laboratorio CIRCE di Caserta.

Preparazioni testate

Cathode	Dimensions (mm x mm)	BeO:Ag	Ag ADDING	Q(mC)	<i> nA
A	2X2	1:10	1/3 added bef. 2/3 after glowing	1,21	17,20
B	2X1	1:10	1/3 added bef. 2/3 after glowing	1,36	15,30
C	2X1	1:10	Ag added before glowing	2,41	27,50
D	2X2	1:10	1/3 added bef. 2/3 after glowing		
E	2X2	1:35	1/3 added bef. 2/3 after glowing	2,92	15,90
F	2X1	1:35	1/3 added bef. 2/3 after glowing		
G	2X2	1:35	Ag added before glowing	5,59	23,20
H	2X1	1:35	Ag added before glowing	3,61	43,60



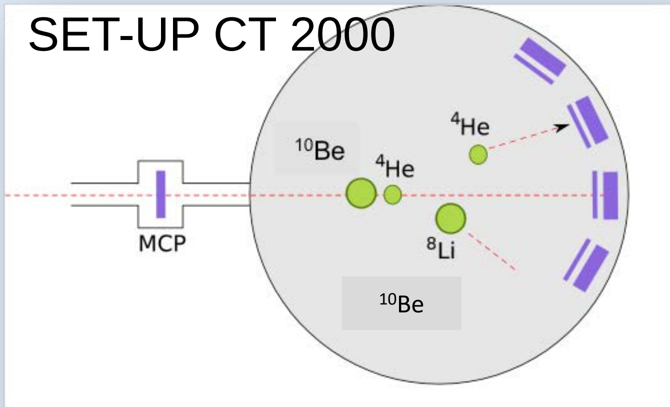
Intensita' in sorgente TANDEM in funzione del tempo



^{10}Be^{4+} @ 47 MeV
i≅10 nAe per alcuni giorni
Contaminazione di ^{10}B < 0.2%

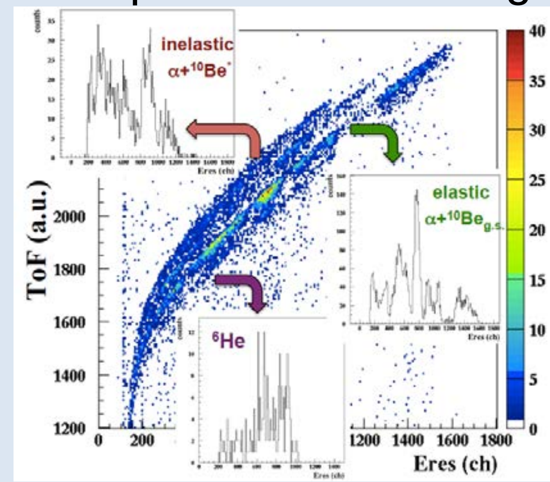
$^{10}Be+\alpha$ resonant elastic scattering ai LNS

Misura dello scattering risonante $^{10}Be+^{4}He$ allo scopo di studiare stati a catena α nel ^{14}C.
Intensita' del fascio radioattivo da 10^3 a 10^5 volte superiore a quello ottenuto negli esperimenti precedenti in altre facility →migliore qualita' dei dati

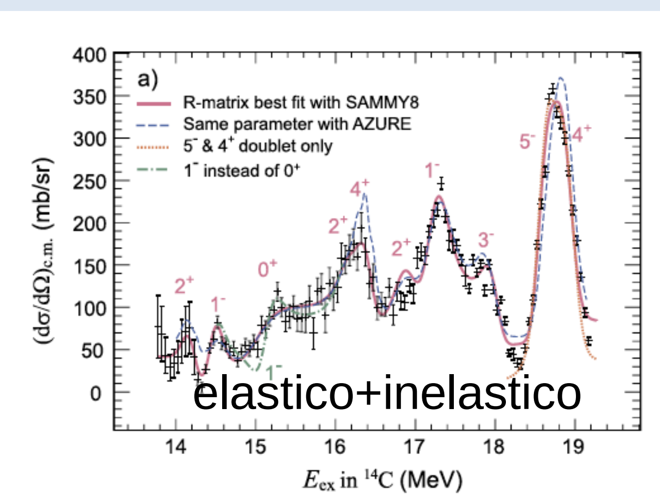


Per la prima volta si sono discriminati I contributi di scattering elastico ed inelastico.

Tempo di volo *vs* energia

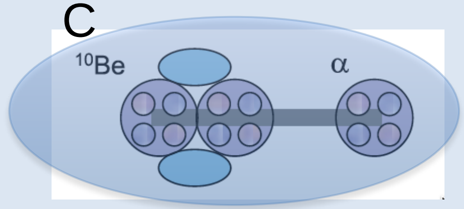


^{14}C: funzione di eccitazione misurata a CRIB- RIKEN



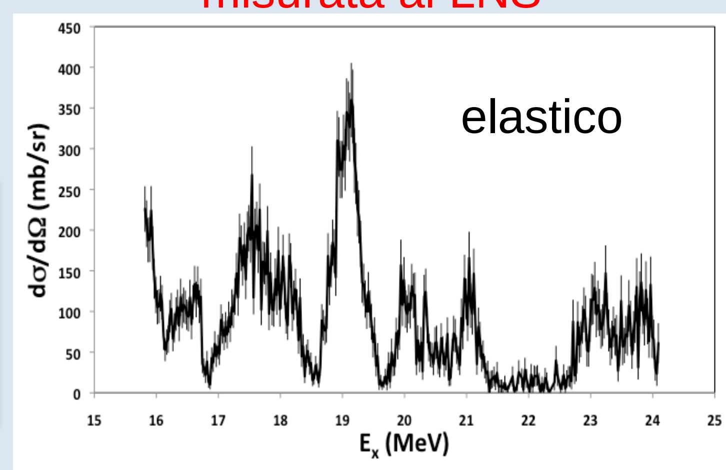
H. Yamaguchi et al. / Physics Letters B 766 (2017) 11

14
C

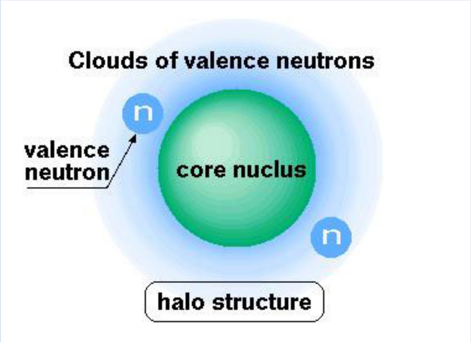


Il claim dell'esistenza della catena lineare va rivisto

^{14}C: funzione di eccitazione misurata ai LNS

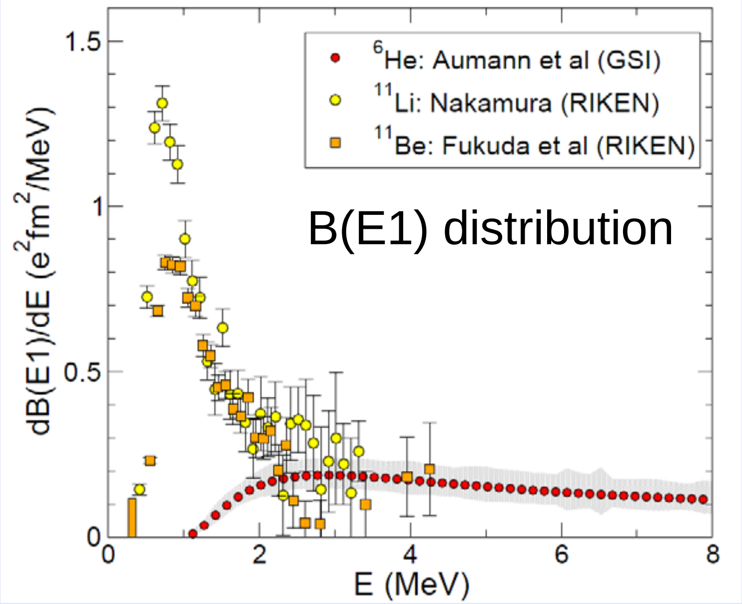


Nuclei con alone: e.g. ^{11}Li, ^{11}Be, ^{6}He ….



- Piccola energia di legame (elevata probabilita' di break-up)
- Facilmente polarizzabili (grande B(E1) a bassa energia)
- Grande raggio (barriera Coulombiana ridotta)
- Alta probabilita' di transfer

Sono attesi effetti sulla dinamica di reazione

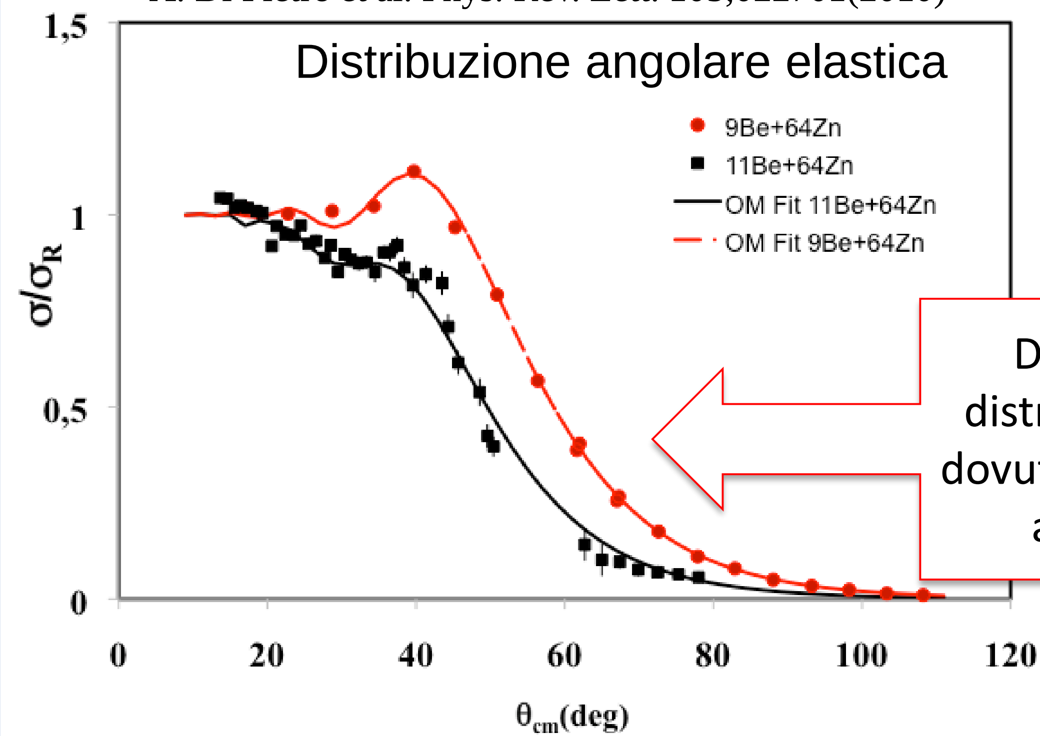


T. Nakamura et al., Phys. Rev. Lett. 96, 252502 (2006).
T. Aumann et al., Phys. Rev. C 59, 1252 (1999).
N. Fukuda et al., Phys. Rev. C70, 054606 (2004).

Effetti di struttura sulla dinamica di reazione: come la struttura ad "alone-nucleare" inficia lo scattering elastico?

Scattering elastico: Nuclei "normali" *vs* nuclei con "alone"

A. Di Pietro et al. Phys. Rev. Lett. 105,022701(2010)



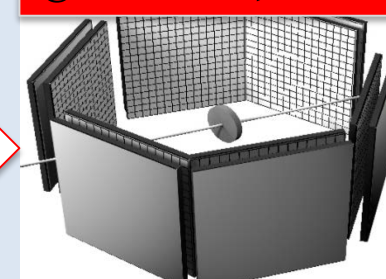
Differenza tra le distribuzioni angolari dovuta alla struttura ad alone del ^{11}Be

Confronto tra esperimenti con:

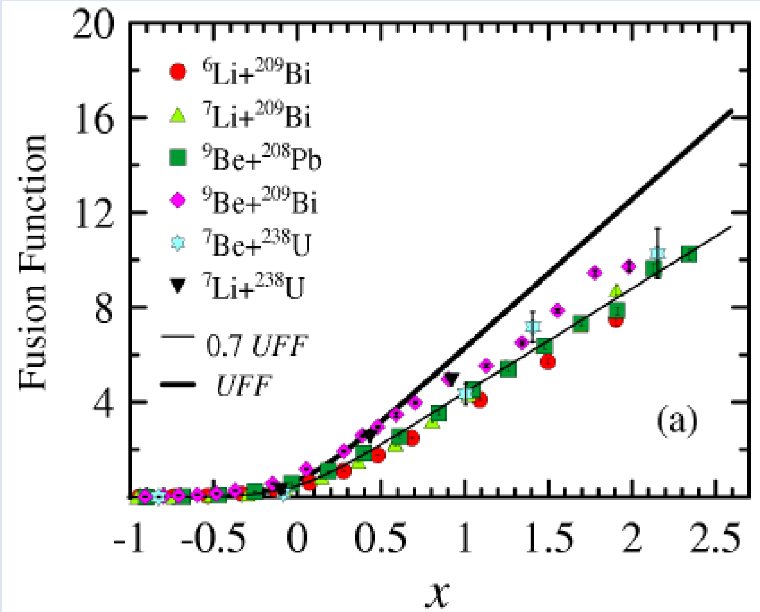
Fasci stabili

Fasci radioattivi

^{10,11}Be+^{64}Zn @ Rex-Isolde, CERN



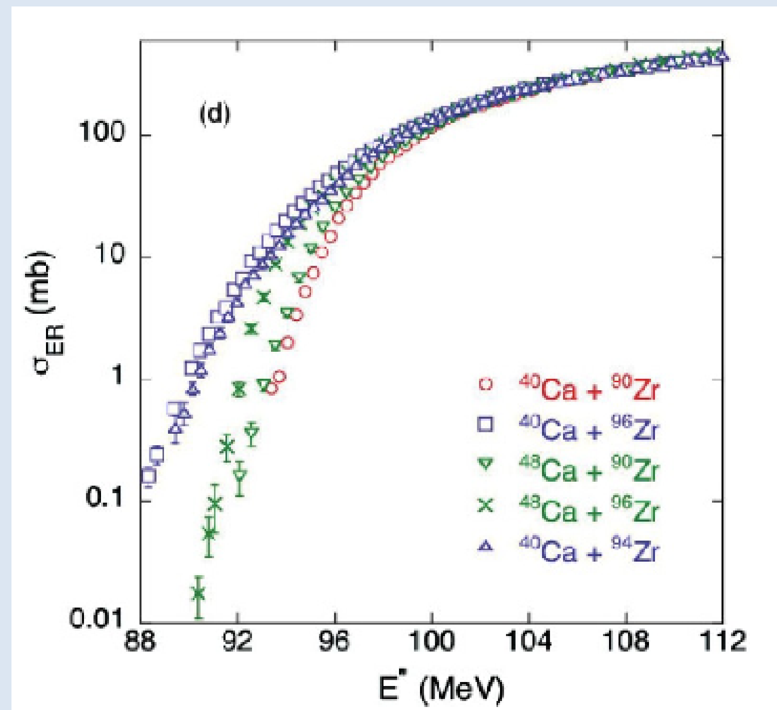
Effetti di struttura nucleare sul processo di Fusione Completa



L .F. Canto , Nucl. Phys. A 821 (2009) 51

Sezione d'urto di fusione sopra barriera soppressa se reazione indotta da nuclei debolmente legati

La sezione d'urto di fusione sotto barriera sembra dipendere dal segno del Q n-trafer. Enhancement se Q n-trasfer>0

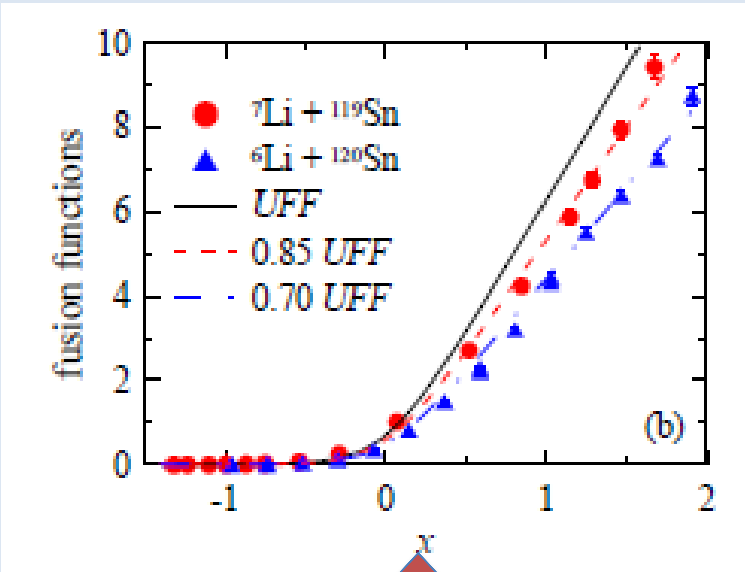


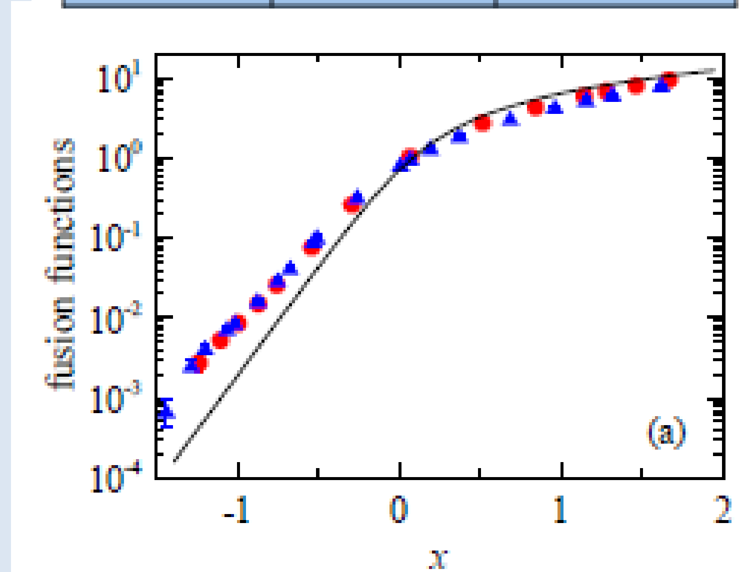
Stefanini et al., PRC76(2007)014610

System	+1n	+2n	+3n	+4n	+5n	+6n
^{40}Ca+^{90}Zr	−3.61	−1.44	−5.86	−4.17	−9.65	−9.05
^{40}Ca+^{94}Zr	+0.14	+4.89	+4.19	+8.12	+3.57	+4.65
^{40}Ca+^{96}Zr	+0.51	+5.53	+5.24	+9.64	+8.42	+11.62
^{48}Ca+^{90}Zr	−6.82	−9.79	−17.73	−22.67	−31.93	−37.60
^{48}Ca+^{96}Zr	−2.71	−2.82	−6.63	−8.69	−13.87	−17.00

^{6,7}Li+^{120,119}Sn @ LNS TANDEM:effetti di struttura nucleare sul processo di Fusione Completa

	Q (1n)	Q (2n)
^{6}Li +^{120}Sn	0.51 MeV	-12.3 MeV
^{7}Li +^{119}Sn	1.858 MeV	2.36 MeV





Soppressione della sezione d’urto sopra barriera. Dipendenza dall’energia di legame dei nuclei collidenti (maggiore soppressione nel caso del ^{6}Li nucleo piu’ debolmente legato)

Nessun effetto dovuto al Q n-trafer

M. Fisichella et al. Phys. Rev. C 92, 064611 (2015) e Phys. Rev. C 95, 034617 (2017)

Radiation Protection Dosimetry
Vol. 85, Nos. 1–4, pp. 353–356 (1999)
Nuclear Technology Publishing

RESPONSE CHARACTERISTICS OF THERMOLUMINESCENCE AND ALANINE-BASED DOSEMETERS TO 16 AND 25 MeV PROTON BEAMS

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[(5)]Istituto Scientifico dei Tumori di Genova, Sezione Messina, via Consolare Valeria, 98125 Italy

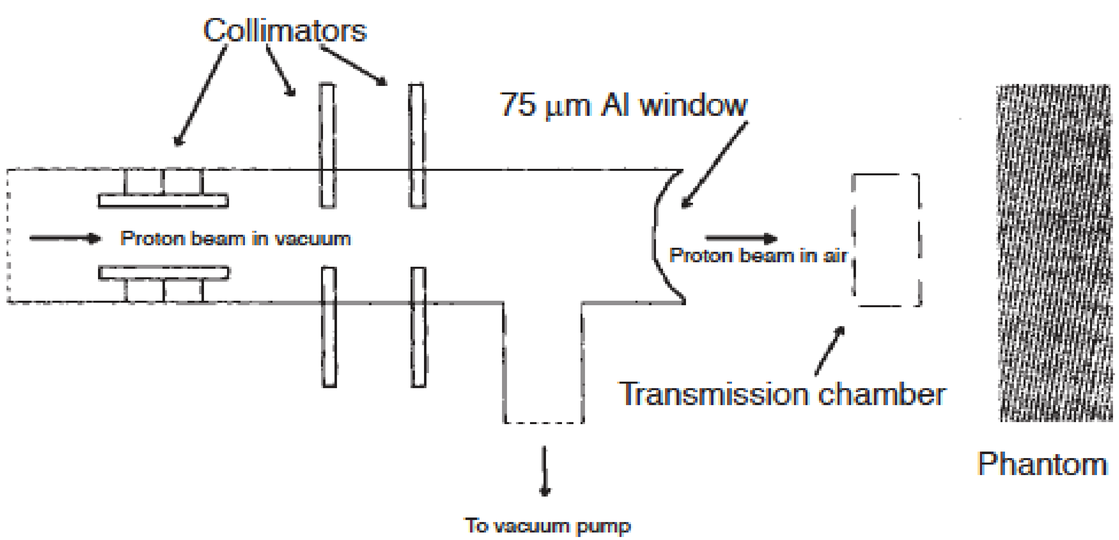

Figure 1. Experimental set-up for proton beam irradiation.

Systematic small differences, up to a maximum of −2%, were observed between dose values evaluated

Table 1. Dose measurements with ISS alanine dosemeters, TLD-100 and Markus ionisation chamber with the 24.9 MeV proton beam; the reported values are absorbed doses in gray, obtained as the average of three repeated measurements.

Dosemeter type	Markus dose (Gy)	Measured dose (Gy)	Deviation (%)
Alanine	52.8	50.5	−4
	162	152	−6
	244	237	−3
TLD-100	1.93	1.66	−14
	2.02	1.81	−10
	3.50	3.08	−12
	5.00	4.71	−6

Table 2. Dose measurements with ISS alanine dosemeters, TLD-100 and Markus ionisation chamber, with the 15.6 MeV proton beam; the reported values are absorbed doses in gray, obtained as the average of three repeated measurements.

Dosemeter type	Markus dose (Gy)	Measured dose (Gy)	Deviation (%)
Alanine	40.0	36.4	−8
	80.7	71.8	−10
	120	111	−7
TLD-100	0.97	0.84	−14
	1.93	1.63	−16
	2.70	2.51	−7

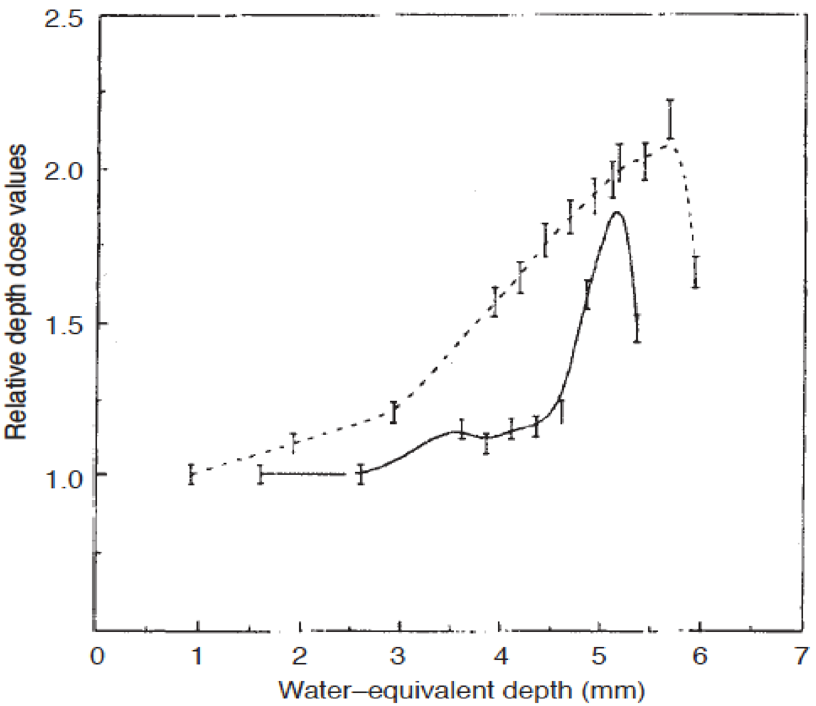

Figure 2. Depth dose values (26.6 MeV protons) measured with alanine (solid line) and TLD-100 (dashed line) dosemeters; the continuous curves were obtained with a smoothing technique. A peak position of 5.7 mm and of 6.1 mm was obtained with the Markus chamber and with TRIM simulation, respectively.

Table 3. Relative effectiveness (RE) of alanine and TLD-100 dosemeters. The effective energy (E_{eff}) was evaluated at the effective point of measurement. The dosemeter entrance, E_e, and output, E_o, proton energies are also reported.

	Alanine		TLD-100	
E_{eff}(MeV)	23.6	13.7	22.8	12.6
RE	0.96	0.92	0.90	0.88
E_e	24.9	15.6	24.9	15.6
E_o	22.2	11.5	20.7	9.1

Radiation Protection Dosimetry
Vol. 101, Nos. 1–4, pp. 461–464 (2002)
Nuclear Technology Publishing

PRELIMINARY RESULTS ON A DEDICATED SILICON DIODE DETECTOR FOR PROTON DOSIMETRY

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Abstract — The present work reports preliminary measurements on the behaviour of a new p-type stereotactic silicon diode, Hi-pSi, produced by Scanditronix and dedicated to proton dosimetry. Diode response was investigated in low-energy proton beams (26.7 MeV and 12 MeV nominal energy), mainly with attention to stability, linearity, dose rate and energy dependence of the detector response. Three different Hi-pSi diodes of the same type were investigated. The diode response was linear with dose and the standard deviation of repeated readings was less than 2.5%. A marked dependence on dose rate was observed for one of the diodes (a response increase of 47% in the 0.7–11 Gy.min^{-1} range). After the dose rate and water to silicon mass collision stopping power ratio correction of the diode response in the depth dose measurements, the difference, at the Bragg peak, with respect to the reference chamber was about 4%, ascribed to poor knowledge of the materials in front of the sensitive volume. The diode response was also nearly independent of linear energy transfer (LET) in the 9.6–21.5 MeV effective energy range.

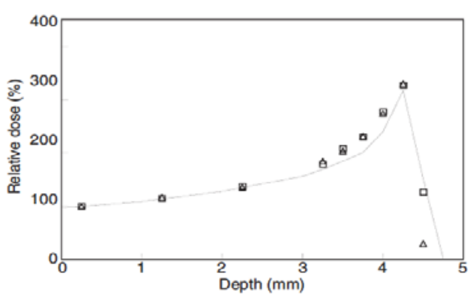
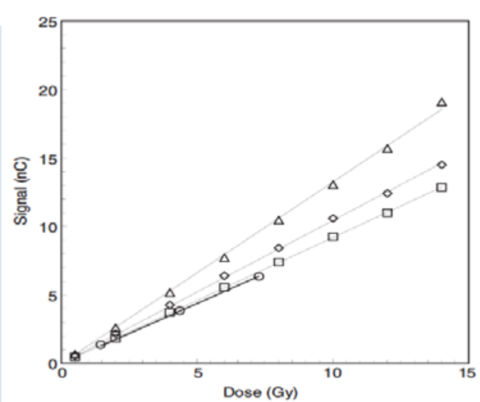
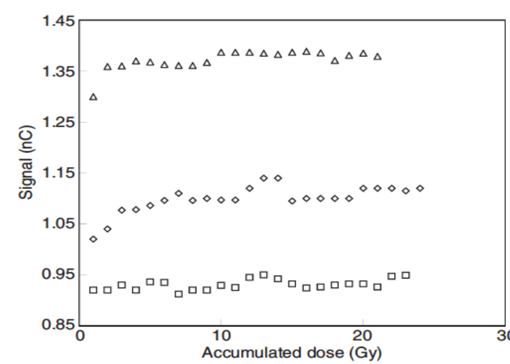


Figure 3. Depth–dose curves in plastic water for ISS (□) and LNS1 (Δ) diodes. For comparison, the Markus chamber depth dose curve (full curve) is also reported.





ELSEVIER

Physica C 341–348 (2000) 1263–1264

PHYSICA C

www.elsevier.nl/locate/physc

Control of the flux regime in BSCCO tapes by means of surface columnar defects.

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[a] INFM – UdR Torino-Politecnico; INFN-Sez.Torino; Dept. of Physics, Politecnico di Torino, c.so Duca degli Abruzzi 24, 10129 Torino, Italy

[b] ENEL-SRI, Milano, Italy

[c] INFN – L.N.S., Laboratori Nazionali del Sud, Catania, Italy

Surface columnar defects (SCDs) are produced in high quality Ag/BSCCO tapes by irradiating them with 0.25 GeV gold ions only on a top layer up to 10% of the full volume. The ion beam is orthogonal to the tape plane. In the low current regime, the irreversibility lines (ILs) with the applied field either parallel to the tracks or tilted are shifted towards higher fields and temperatures. Moreover, SCDs do not damage the superconducting properties when the magnetic field is applied perpendicularly to the tracks. It can be shown that, as a consequence, the IL anisotropy falls to zero (or is strongly reduced) in a quite controllable range of magnetic fields near the dose equivalent field.

Inhibition of human melanoma cell growth by proton irradiation

By: Ristic-Fira, A et Al.

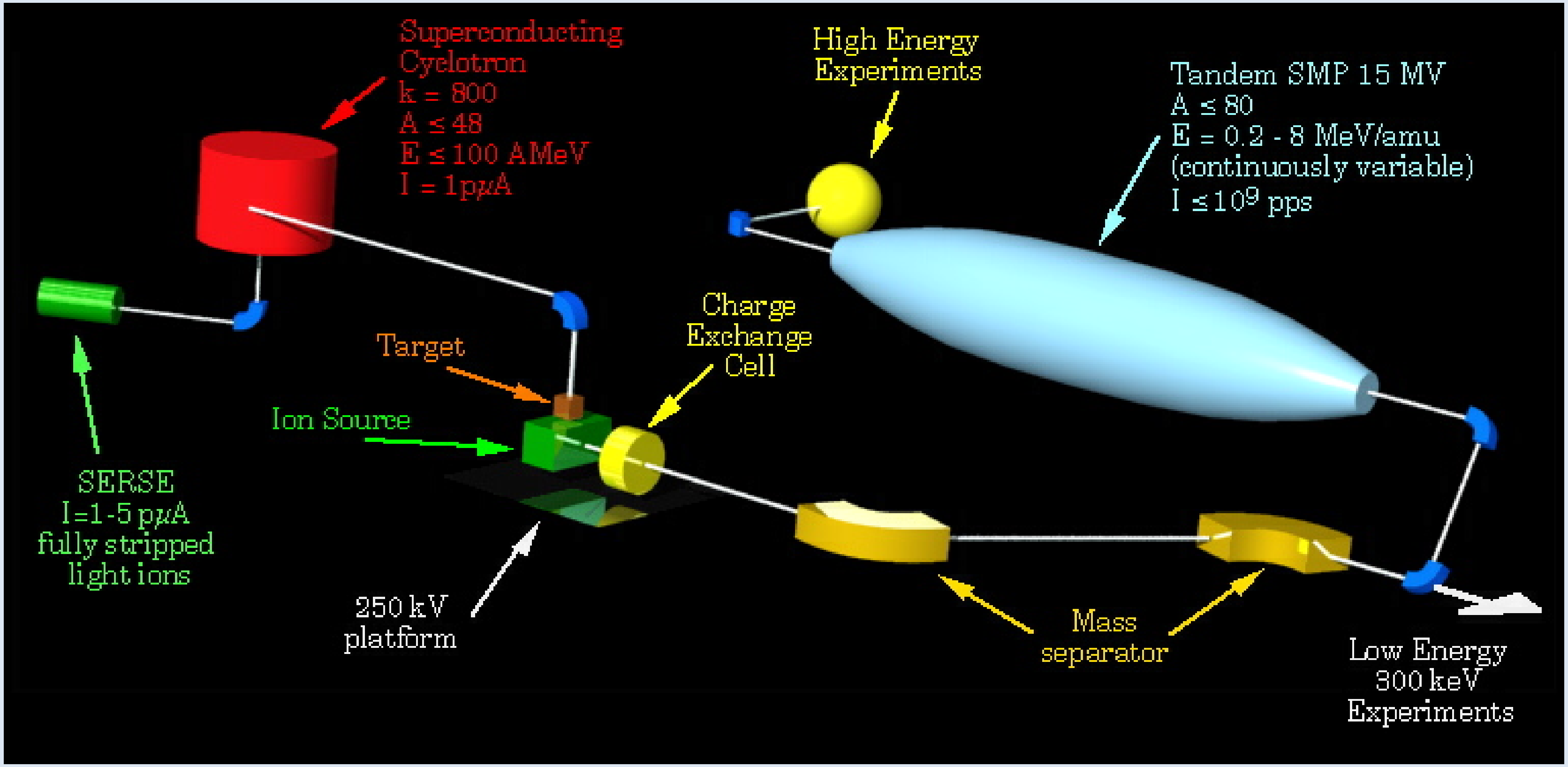
PHYSICA MEDICA-EUROPEAN JOURNAL OF MEDICAL PHYSICS

Volume: 17, **Pages:** 71-75 **Supplement:** 3 **Published:** 2001

The aim of this work is the in vitro study of human melanoma cell growth modulation after irradiation with protons. Confluent cell monolayers were irradiated with single doses ranging from 1 to 20 Gy, using proton beams having energy of 22.6 MeV at the target. 48 hours after irradiation, cell growth, cell cycle analyses and initiation of cell death were followed. The obtained results were compared with the effects of glucocorticoid hormones.

The inhibition of melanoma cell growth was observed, especially after single application of 12 and 16 Gy. Cell cycle analyses of melanomas after proton irradiation, have shown the G2/M arrest of irradiated cells corresponding with the increase of applied dose. The flow cytometric analysis has shown presence of apoptotic nuclei. Glucocorticoid treatment has shown modest melanoma cell growth inhibition, cell cycle arrest in G2/M phase and 'ladder' pattern on agarose gel electrophoresis.

Facility Layout



Maximun Energy: 2.5 ÷ 150 MeV (***preacceleration energy up to 300 keV***)

Low emittance (<0.5 π mm.mrad): clear-cut beam spot e low angular spread

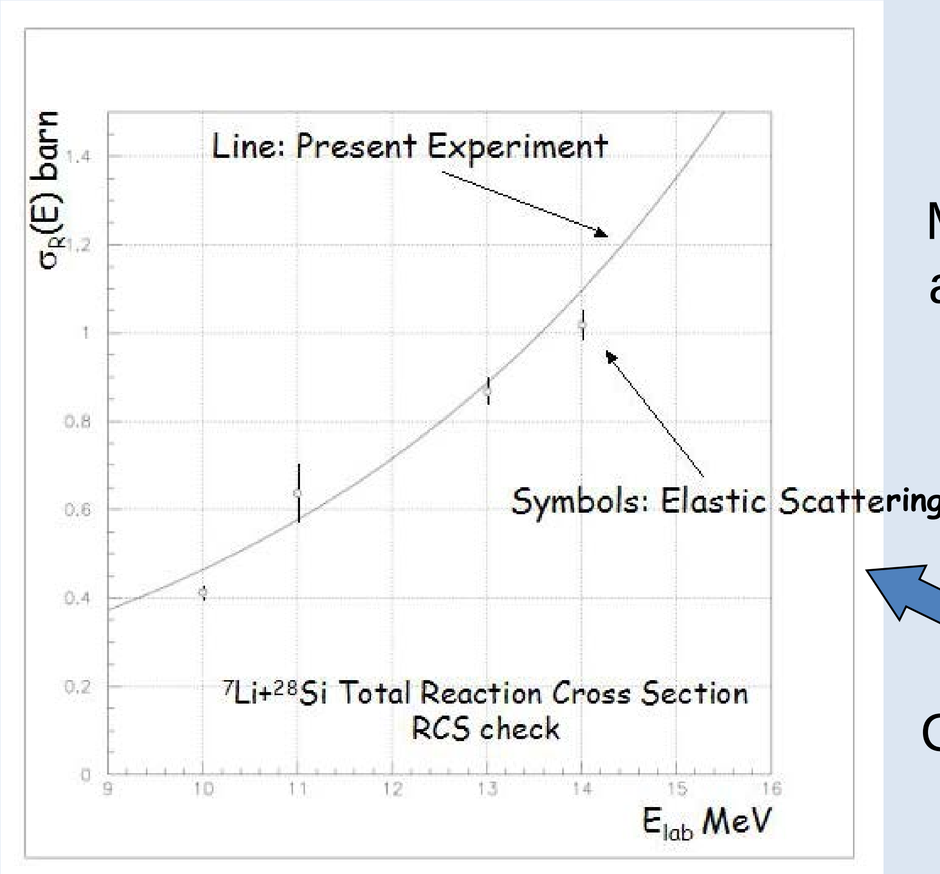
Easy variable beam energy (excitation function study)

***Low energy spread*: ΔE/E = 10-4.**

Beam lines to the Tandem

TANDEM

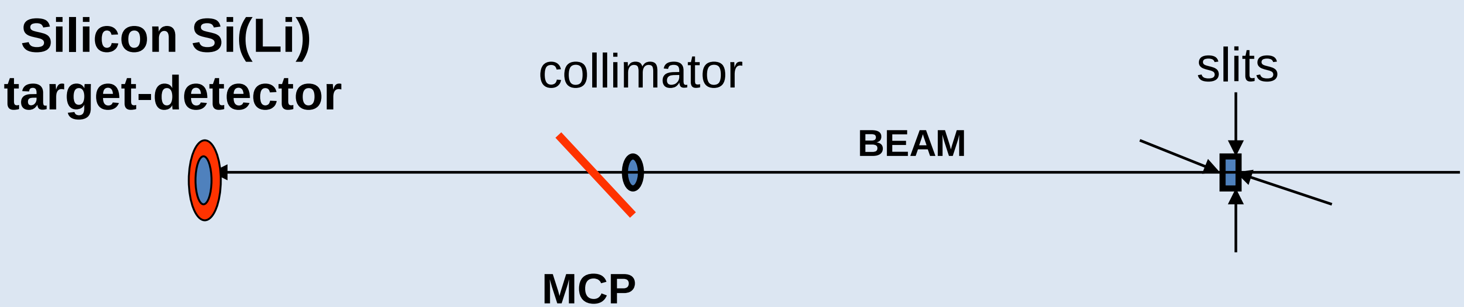
Experimental rooms



RCS Experiment: A. Musumarra et al.

Measuring total reaction cross-sections at energies around the coulomb barrier by using the active target method
- RCS experiment at LNS -

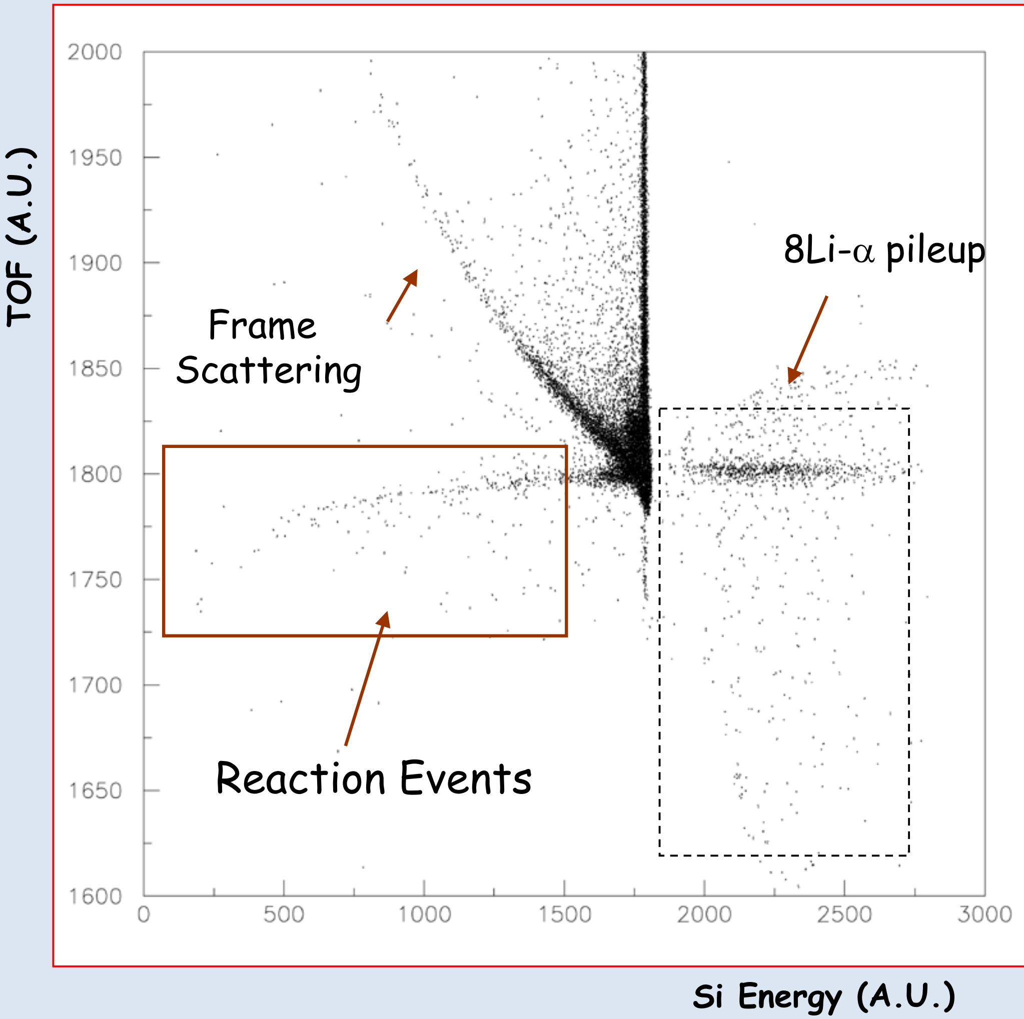
Technique succesfully tested for the 7Li+28Si stable system.
Comparison with optical model analysis of elastic scattering.



Simple set-up: frame scattering and decay rejection by TOF (MCP-Si)

Preliminary short run by using the first beam delivered by EXCYT-LNS (**8Li**).

Preliminary data



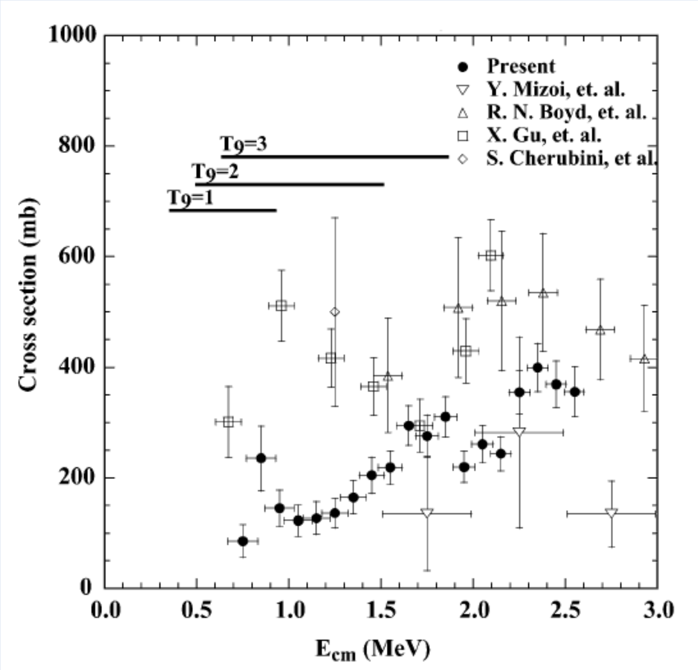
8Li+28Si E_{lab}=14.56 MeV

Interaction probability η was extracted for *Q-value* < -2 MeV and compared with 7Li+28Si system at the same beam energy

η_{8Li}=6.8·10-5

η_{7Li}=6.9·10-5

By using a technical improvement of the experimental setup we will reject the residual 8Li-α pileup. More informatios ask to A.Musumarra

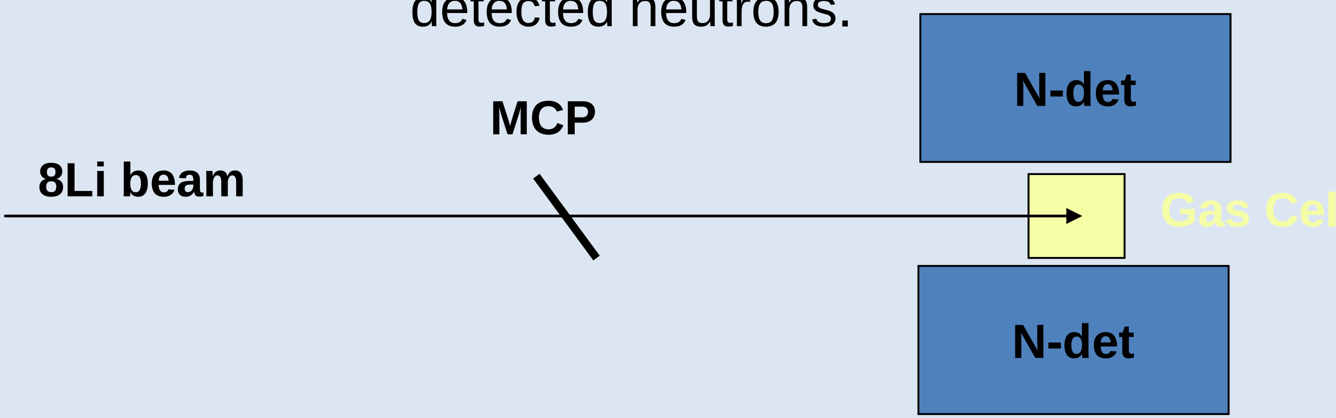


BIG-BANG (P. Figuera et al.)

Due to its astrophysical interest, the ***8Li(α,n)11B*** reaction has been measured by different groups obtaining excitation functions covering a wide cross-section range.

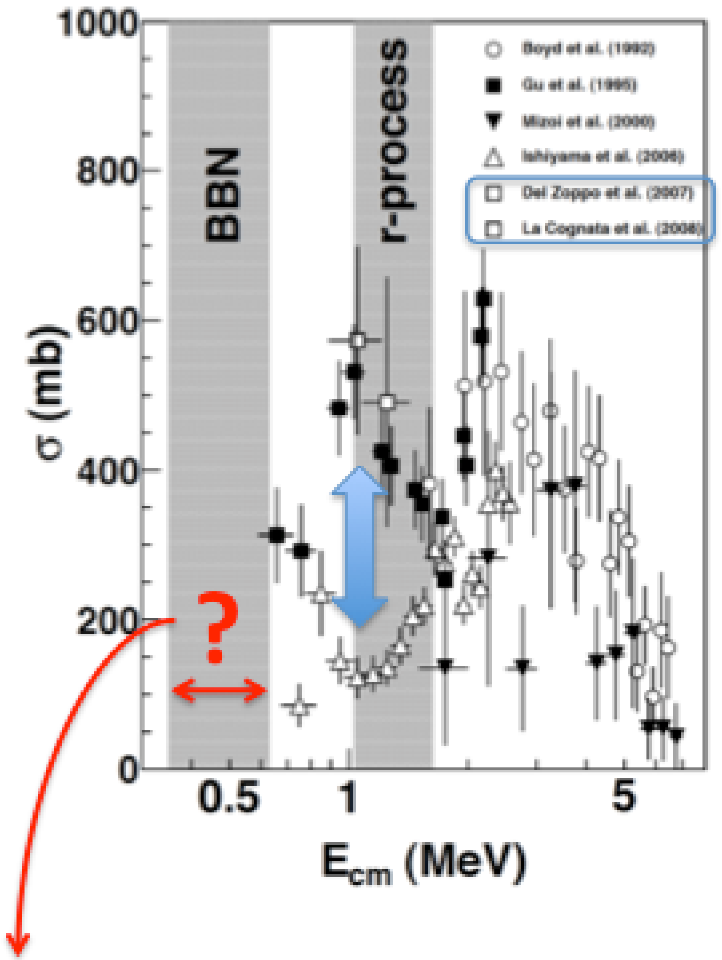
In the figure
taken from *H. Ishiyama et al. PLB 640(2006)82*
data from different authors are reported

By using the 8Li provided by EXCYT and a 4π neutron thermalization detector we measured the ***8Li(α,n)11B*** reaction cross section by a novel technique analizing the time correlation between the incoming 8Li and the detected neutrons.



Results with EXCYT

The $^{8}Li(^{4}He,n)^{11}B$ reaction cross section



Factor of 5 discrepancy at r-process energies solved
La Cognata et al., The Astrophysical Journal Letters 706(2009)251

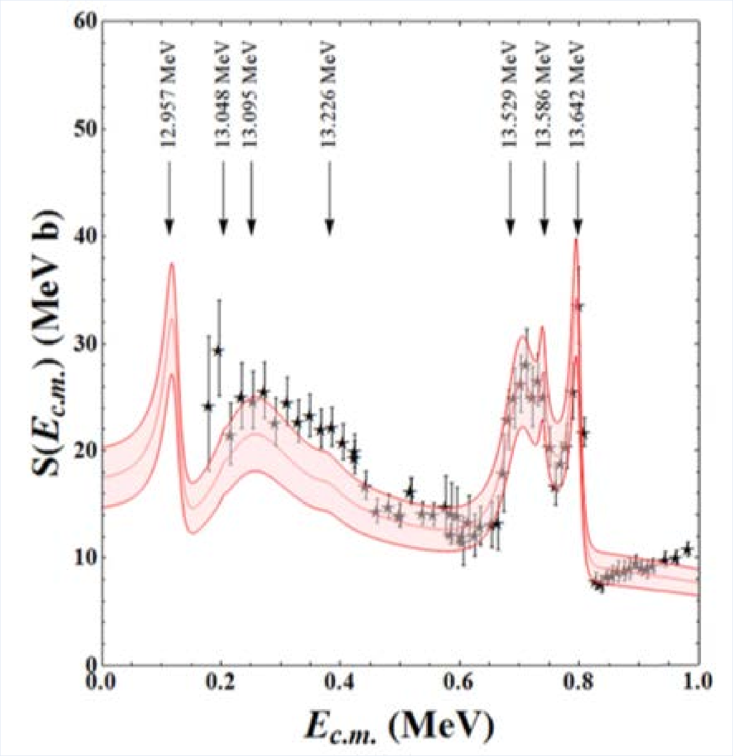
Recommended rate
La Cognata & Del Zoppo, The Astrophysical Journal 736(2011)148

LNS results have been selected by A. Coc et al. [The Astrophysical Journal 744(2012)158] to estimate the recommended rate in the frame of a new and extended nuclear network for Big Bang nucleosynthesis (BBN).

The ASFIN research activity mainly focuses on cross section measurements of reactions of astrophysical interest induced by stable/unstable nuclei and neutrons by means of indirect methods (THM-ANC)

→ A few key recent results:

Results confirmed by a new THM measurement



Red band: new THM S-factor

I. Indelicato et al., ApJ 845 (2017) 19

A new THM measurement has been carried out to investigate the origin of the discrepancy. Improved energy resolution allowed for

- **better level separation**
- **angular distribution analysis**

The basic feature → 113 keV resonance is confirmed

Interference is also confirmed

What next? Exploring the role of ^{16}O excited states → high resolution necessary
New experiment performed at the 2000 mm chamber @ LNS

APJ 836 (2017) 57

10.3847/1538-4357/836/1/57

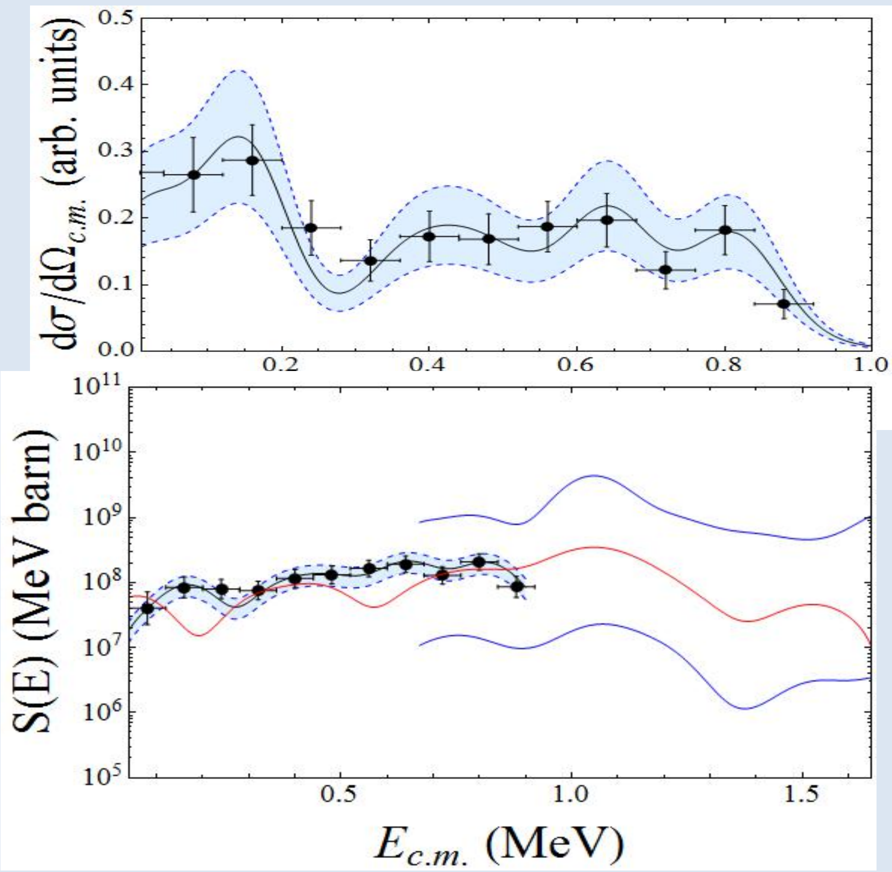
CrossMark

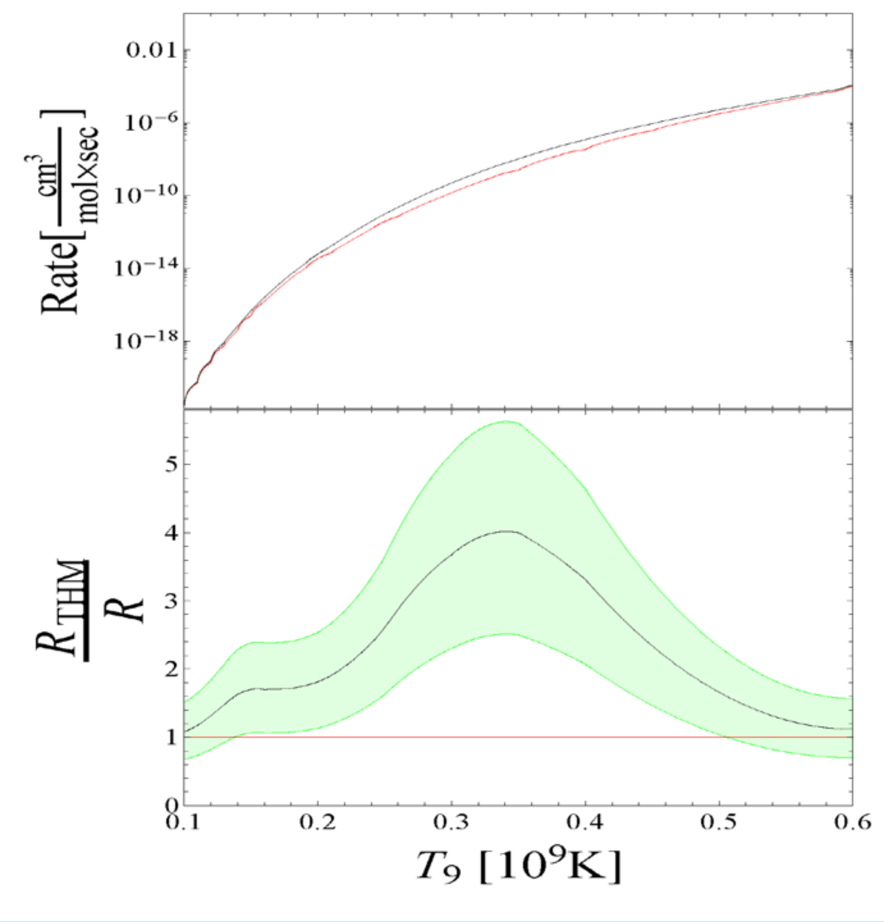
First Measurement of the $^{19}F(\alpha, p)^{22}Ne$ Reaction at Energies of Astrophysical Relevance

$^{19}F(\alpha, p)^{22}Ne$

R. G. Pizzone[1], G. D'Agata[1,2], M. La Cognata[1], I. Indelicato[1], C. Spitaleri[1,2], S. Blagus[3], S. Cherubini[1,2], P. Figuera[1], L. Grassi[3], G. L. Guardo[1], M. Gulino[1,4], S. Hayakawa[1,5], R. Kshetri[1,6], L. Lamia[1,2], M. Lattuada[1,2], T. Mijatović[3], M. Milin[7], Đ. Miljanić D.[3,8], L. Prepolec[3], G. G. Rapisarda[1], S. Romano[1,2], M. L. Sergi[1], N. Skukan[3], N. Soić[3], V. Tokić[3], A. Tumino[1,4], and M. Uroić[3]

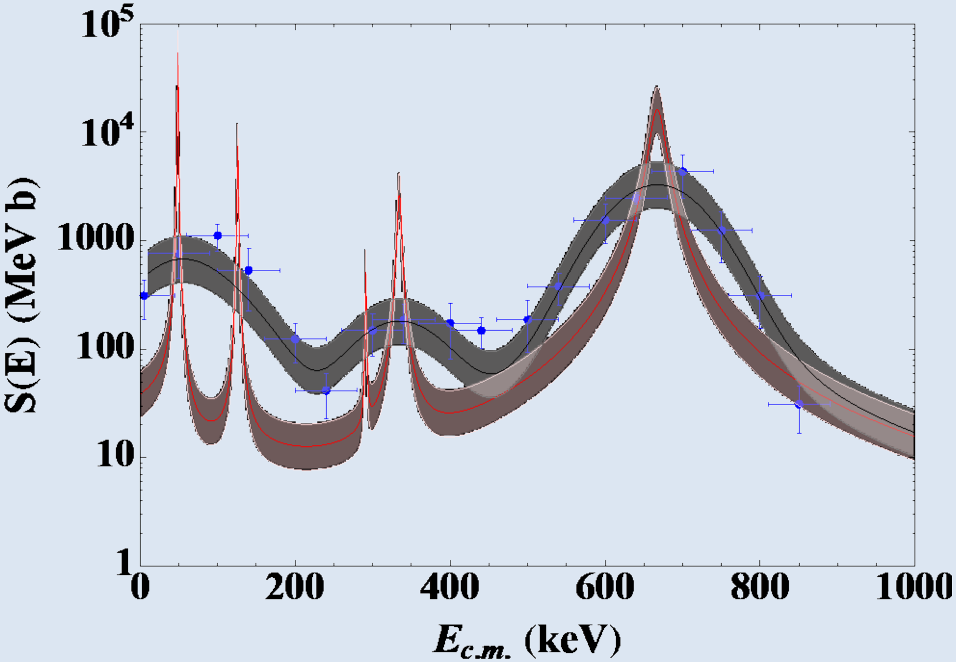
- Cross-section measurements at astrophysical energies
- Important in the AGB nucleosynthesis
- Performed at the Rudjer Boskovic Institute (Zagreb) in December 2012
- Coming: Astrophysical implications





THM IS working for RIB'S

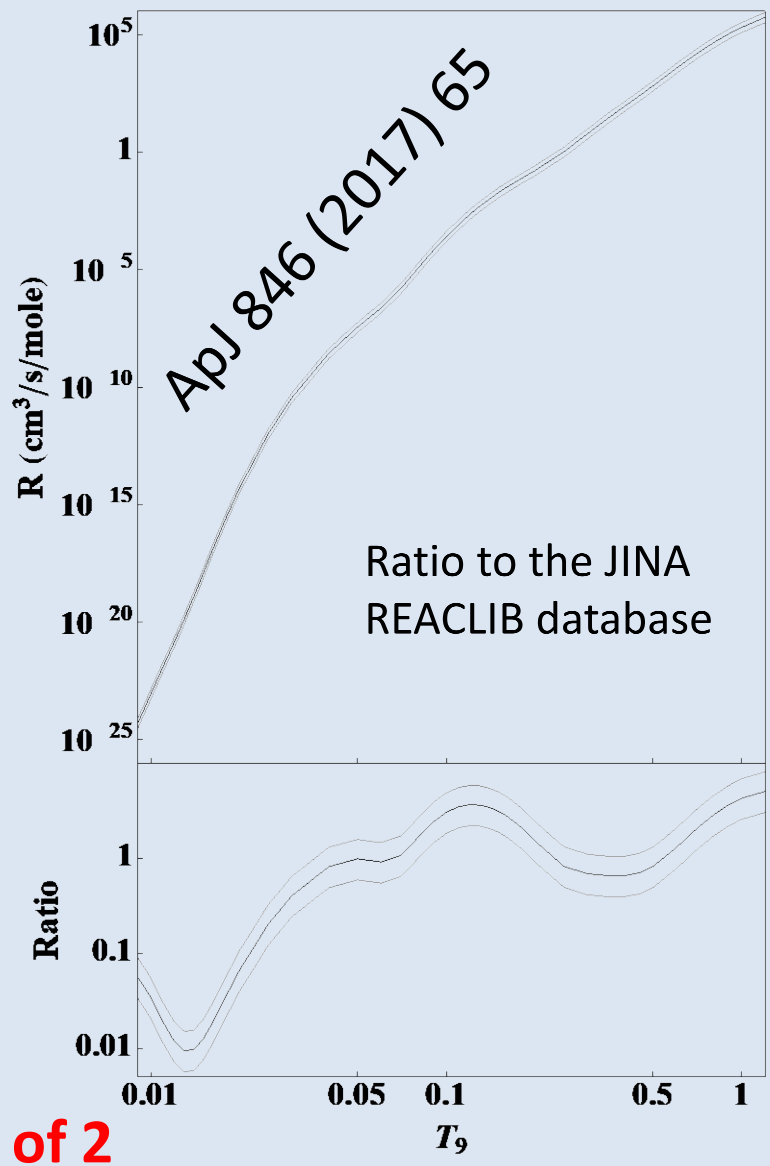
^{18}F(p,α)^{15}O: impact on Novae nucleosynthesis and observations



Experimental data down to ZERO energy!

No evidence of the 7 keV resonance
(3/2$^-$ state of ^{19}Ne at 6417 keV)

Evidence of the 126 keV resonance
(7/2$^+$ state of ^{19}Ne at 6537 keV)



REDUCTION of ^{18}F abundance by a factor of 2

IOP Publishing

Indirect techniques estabilished as determinant in many astrophysical applications

REPORTS ON PROGRESS IN PHYSICS		
Impact Factor		
12.933 (2015)	15.463 (5 year)	
JCR® Category	*Rank in Category*	*Quartile in Category*
PHYSICS, MULTIDISCIPLINARY	**4 of 79**	**Q1**

Data from the 2015 edition of Journal Citation Reports®

Table 5. Two-body reactions studied via the THM (first column). In the next columns, the THM reaction, the beam energy and the Q−value of the three-body reactions (Q_3) are shown, respectively. In the fifth column the THM nucleus and the transferred cluster are reported. Finally, in the last column the reference for each reaction is given.

Reaction	THM reaction	E_{beam} (MeV)	Q_3 (MeV)	THM nucleus (x-cluster)	Reference
^{7}Li(p,α)^{4}He	^{2}H(^{7}Li,$\alpha\alpha$)n	19–22, 28–48	15.122	^{2}H (p)	Zadro *et al* (1989)
					Spitaleri *et al* (1999)
					Lattuada *et al* (2001)
					Aliotta *et al* (2000)
^{7}Li(p,α)^{4}He	^{7}Li(^{3}He,$\alpha\alpha$)^{2}H	33	11.853	^{3}He (p)	Tumino *et al* (2006)
^{6}Li(p,α)^{3}He	^{2}H(^{6}Li,α^{3}He)n	14.25,	1.795	^{2}H (p)	Tumino *et al* (2003)
		21.6–33.6			Tumino *et al* (2004)
		25			Calvi *et al* (1990)
					Lamia *et al* (2013)
^{6}Li(d,α)^{4}He	^{6}Li(^{3}He,$\alpha\alpha$)^{1}H	17.5	16.879	^{3}He (p)	Pizzone *et al* (2011)
^{6}Li(d,α)^{4}He	^{6}Li(^{6}Li,$\alpha\alpha$)^{4}He	5	22.372	^{6}Li (d)	Cherubini *et al* (1996)
					Spitaleri *et al* (2001)
^{9}Be(p,α)^{6}Li	^{2}H(^{9}Be,α^{6}Li)n	22.35	−0.099	^{2}H (p)	Romano *et al* (2006)
					Wen *et al* (2008)
^{10}B(p,α)^{7}Be	^{2}H(^{10}B,α^{7}Be)n	27	−1.079	^{2}H (p)	Lamia *et al* (2009, 2010)
^{11}B(p,α)^{8}Be	^{2}H(^{11}B,α^{8}Be)n	27	6.366	^{2}H (p)	Spitaleri *et al* (2004)
					Lamia *et al* (2012a)
^{15}N(p,α)^{12}C	^{2}H(^{15}N,α^{12}C)n	60	2.741	^{2}H (p)	La Cognata *et al* (2006, 2007, 2009)
^{18}O(p,α)^{15}N	^{2}H(^{18}O,α^{15}N)n	54	1.755	^{2}H (p)	La Cognata *et al* (2008a, 2008b, 2010a, 2010b)
					Palmerini *et al* (2013)
^{19}F(p,α)^{16}O	^{2}H(^{19}F,α^{16}O)n	50	5.889	^{2}H (p)	La Cognata *et al* (2011)
^{17}O(p,α)^{14}N	^{2}H(^{17}O,α^{14}N)n	45	−1.033	^{2}H (p)	Sergi *et al* (2010)
					Palmerini *et al* (2013)
^{3}He(d,p)^{4}He	^{6}Li(^{3}He,pα)^{4}He	5.6	16.879	^{6}Li (d)	La Cognata *et al* (2005)
^{2}H(d,p)^{3}H	^{2}H(^{6}Li,p^{3}H)^{4}He	14	2.559	^{6}Li (d)	Rinollo *et al* (2005)
					Pizzone *et al* (2013)
^{2}H(d,p)^{3}H	^{2}H(^{3}He,p^{3}H)^{1}H	18	−1.461	^{3}He (d)	Tumino *et al* (2011)
^{2}H(d,n)^{3}He	^{2}H(^{3}He,n^{3}He)^{1}H	18	−2.225	^{3}He (d)	Tumino *et al* (2011)
^{12}C(α,α)^{12}C	^{6}Li(^{12}C,α^{12}C)^{2}H	16, 20	−1.474	^{6}Li (α)	Spitaleri *et al* (2000)
^{6}Li(n, α)^{3}H	^{2}H(^{6}Li,α^{3}H)^{1}H	14	2.559	^{2}H (n)	Tumino *et al* (2005)
					Gulino *et al* (2010)
^{17}O(n,α)^{14}C	^{2}H(^{17}O,α^{14}C)^{1}H	41, 43.5	−0.407	^{2}H (n)	Gulino *et al* (2013)
^{1}H(p,p)^{1}H	^{2}H(p,pp)n	5.6	2.224	^{2}H (p)	Tumino *et al* (2007, 2008)
^{12}C(^{12}C,α)^{20}Ne	^{12}C(^{16}O,α^{20}Ne)^{4}He	25	−2.545	^{16}O (^{12}C)	—
^{19}F(α,p)^{22}Ne	^{19}F(^{6}Li,p^{22}Ne)^{2}H	6	0.199	^{6}Li (α)	—
^{13}C(α,n)^{16}O	^{13}C(^{6}Li,n^{16}O)^{2}H	7.82	0.742	^{6}Li (α)	La Cognata *et al* (2012, 2013)

The Nuclear Astrophysics Group @ Catania

C.Spitaleri, A. Anzalone, A. Bonasera, S. Cherubini, A.Cvetinovic, G. D'Agata, GL Guardo, I. Indelicato, M.La Cognata, L.Lamia,R.G. Pizzone, S. Messina, S. Perrotta,S.M.R. Puglia, G.G. Rapisarda, S.Romano, M.L.Sergi, R. Spartà,

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  - RSE INP Alma Aty Kazakhstan: N. Burtibaiev
  - Rudjer Boskovic Institute Zagreb Croatia: N. Soic, M. Milin, D. Miljanic

REcoil Directionality

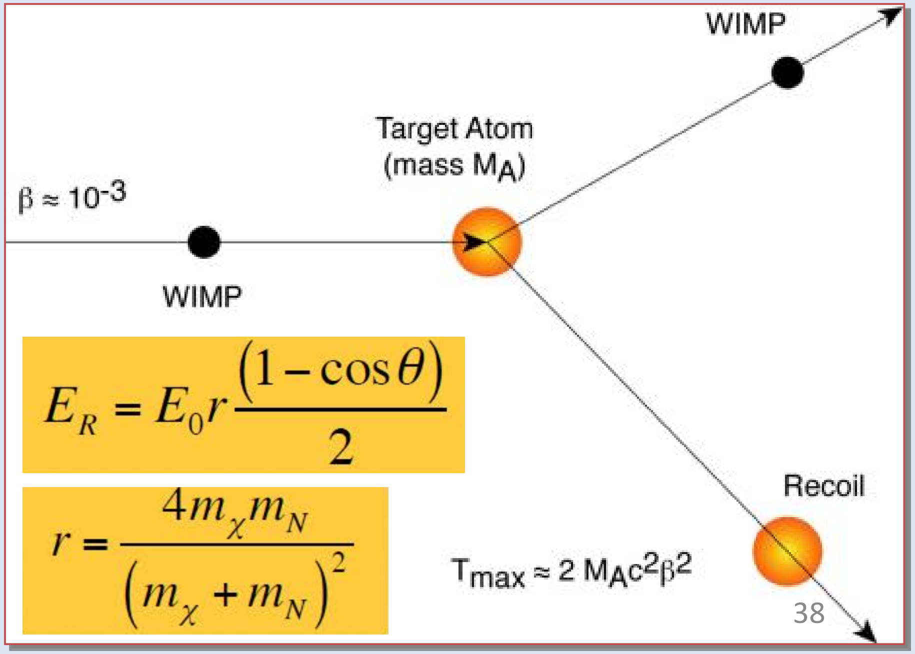
L. Pandola (LNS)
on behalf of the ReD Working Group
(DarkSide Collaboration)

darkside

Physics background

- Search for **dark matter** in the form of Weakly Interacting Massive Particles (WIMPs)
  - WIMP is a favourite candidate, but there are many others
- Signature: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering
  - Backgrounds: e^- recoils, neutron-induced recoils

- Global effort worldwide:
  - Rates in the range from 10^{-1} to 10^{-6} events / (kg·day)
  - next generation experiments should eventually reach **exposures** in the range of **kton· day**
  - Need very low background level (and underground site)

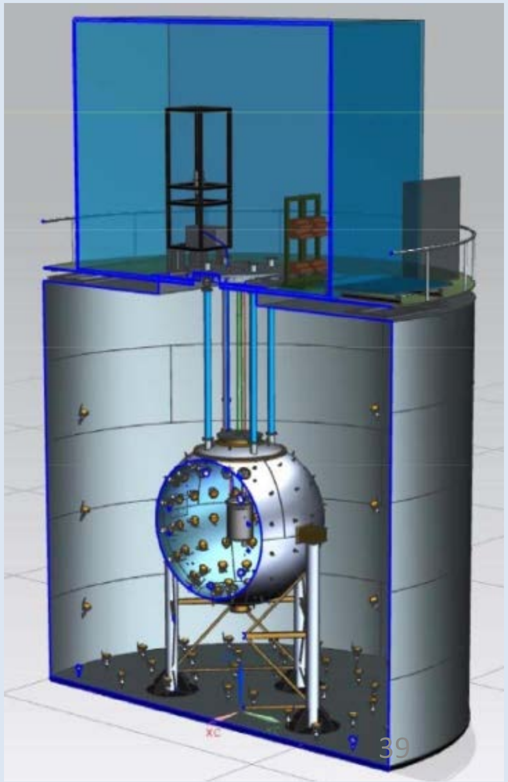


Physics background

- Electron/recoil discrimination currently achieved by "**dual technology**"
  - Measure **two** out of: scintillation, ionisation, heat
    - Electrons and recoils typically have different response in these channels
- Viable option: noble liquid detectors TPC (LAr, LXe)
  - Detect scintillation light and ionization
    - Charge drifted by E field and collected
  - Can use fiducialization and pulse shape analysis

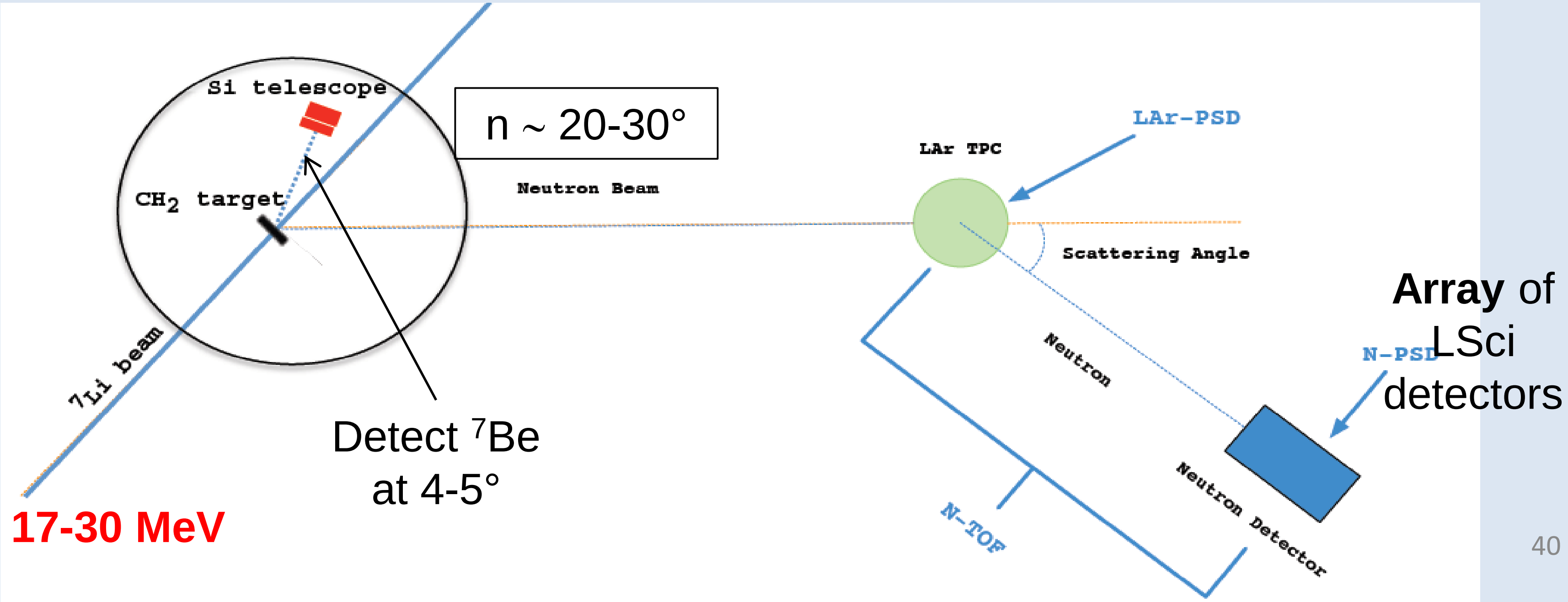
- **DarkSide project** at Gran Sasso Laboratory, using **LAr**
  - Operating now a 50 kg TPC, equipped with active neutron veto (DarkSide-50)
  - Next step: 20 ton LAr TPC (DarkSide-20k)
    - Light readout with SiPM
    - Low-radioctivity Ar

darkside



ReD: probe directional sensitivity

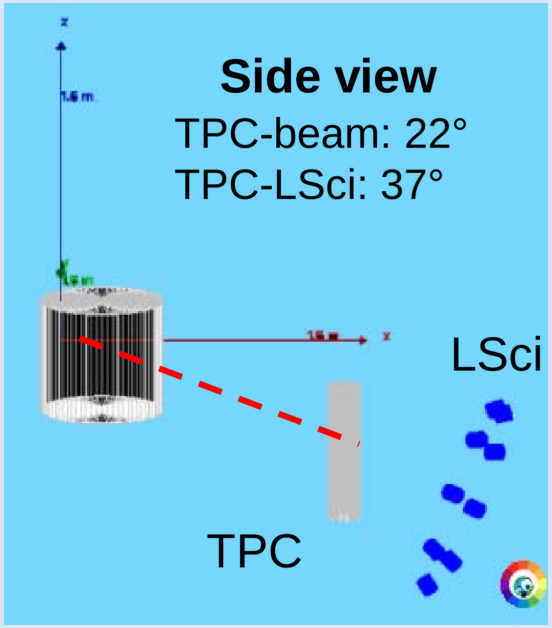
- Irradiate a (small) LAr TPC with **neutrons** and produce recoils parallel or orthogonal wrt the E field
  - Check for scintillation/ionization at fixed recoil energy
- Make neutron beam at the TANDEM, via **p(^{7}Li,n)**
  - Need neutrons ~few MeV, to have recoils **< 100 keV**
  - Design **a non-horizontal** configuration, to detect more recoils // E
  - Bonus: measure light yield (quenching) for nuclear recoils < 100 keV

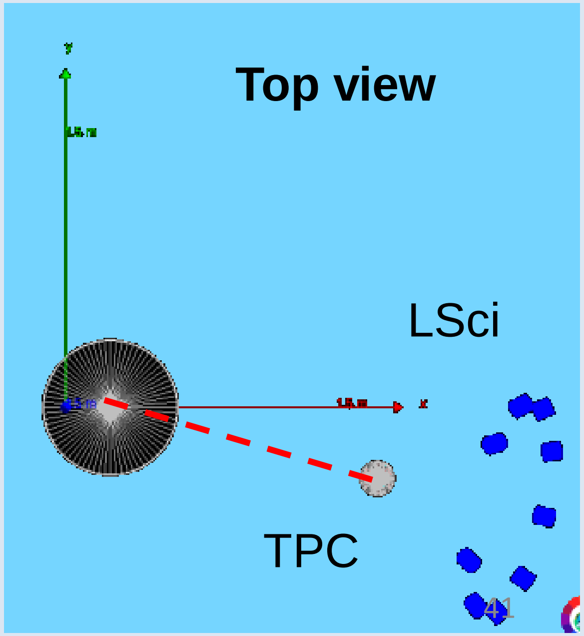


Basic design

- Detect the associate particle (^{7}Be) and ToF to **tag neutron energy** event by event (fixed by kinematics)
- Pay attention to arrange the setup such to tag nuclear recoils ~parallel and ~perpendicular to the E
  - Displace the TPC **vertically**, such that the (n,n') interaction plane is not "horizontal" (as in SCENE)
  - Deploy LSci to tag recoils of the same energy, but different angle with respect to the E

- Monte Carlo simulation in place
- Beam intensity limited by the ^{7}Be at small angle
- Beam/target such to produce a few 10^5 n/s
  - Signal rate **O(15 cph)**

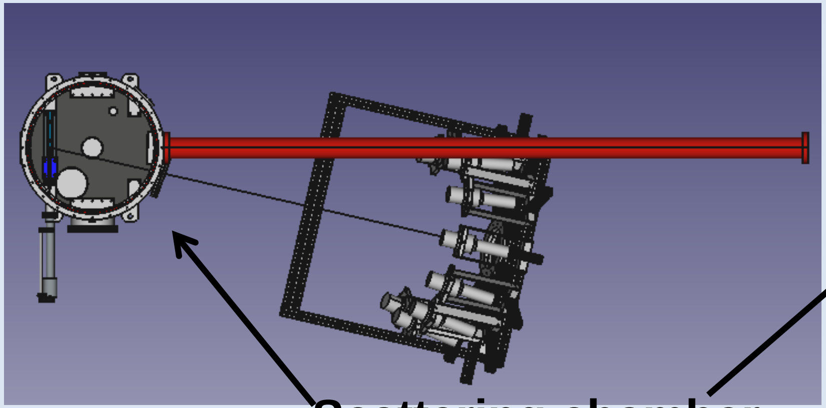




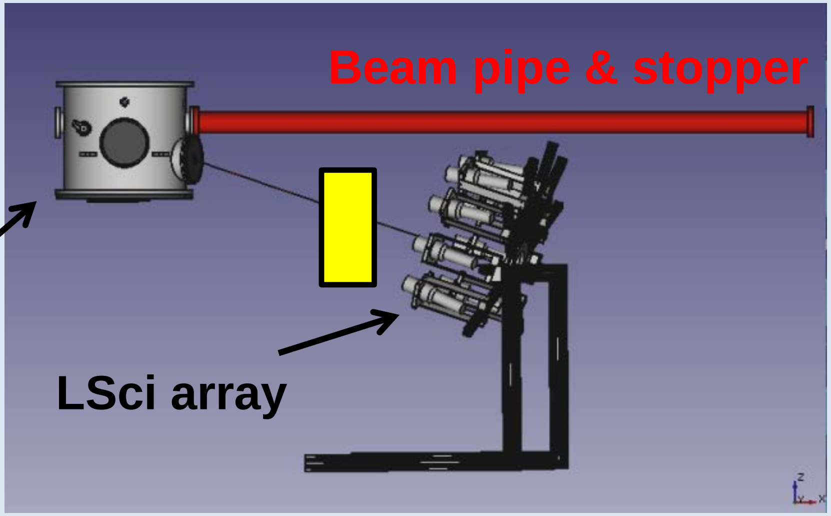
Layout of the setup at LNS

- Propose to use the **"80 deg" beamline**
  - Enough space to accommodate the TPC (+ cryogenic) and LSci's
- Equip beamline with a custom-made scattering chamber
  - Target at the **entrance point**
- Expected: 1 week beamtime for each value of the recoil enegy
  - Current: **2 pnA**; target **0.2 mg/cm^2 CH$_2$**; dσ/dΩ ~ 70 mb/sr
  - Span ~5 points between 20 keV and 100 keV

Top view



Side view



Scattering chamber

TPC to be integrated within the CAD drawing

UNA NUOVA LUCE SULLA STRUTTURA DEL CARBONIO, FONDAMENTO DELLA VITA

Ora, una nuova misura di altissima precisione, realizzata ai Laboratori Nazionali del Sud dell'INFN con l'acceleratore Tandem van de Graaf, ha permesso di fare luce sulla formazione e sulle proprietà della base fondamentale della vita, il nucleo di carbonio-12 (^{12}C). Il lavoro, frutto della collaborazione delle Sezioni INFN di Napoli e Catania, dei Laboratori Nazionali del Sud dell'INFN, delle Università di Napoli Federico II, Paris-Saclay, Catania, Enna e UNAM, è stato pubblicato su Physical Review Letters come Editors' Suggestion ed è accompagnato da un articolo di viewpoint sulla rivista Physics della American Physical Society.

Conclusions

- ReD project (DarkSide collaboration) aiming to scrutinize the current hint for directional sensitivity of a LAr dual-phase TPC
  - If confirmed, breaktrough for dark matter searches
- Dedicated TPC (readout with SiPM) irradiated with neutrons produced by the **TANDEM** via p(^{7}Li,n), @80° beamline
- Impressive acceleration in the preparation
  - System components could be shipped at LNS in ~March
  - Technical details being worked out
- Full measurement: 6 weeks of beamtime (= 126 BTU)
  - Can be fractioned in two-week bunches: *~one week per energy point*
- Goal: run at least **one full-scale test** (= yielding physics data) **before the summer**
  - **21 BTU in May-June**, the rest in the 2nd semester

APPROVED by LNS PAC