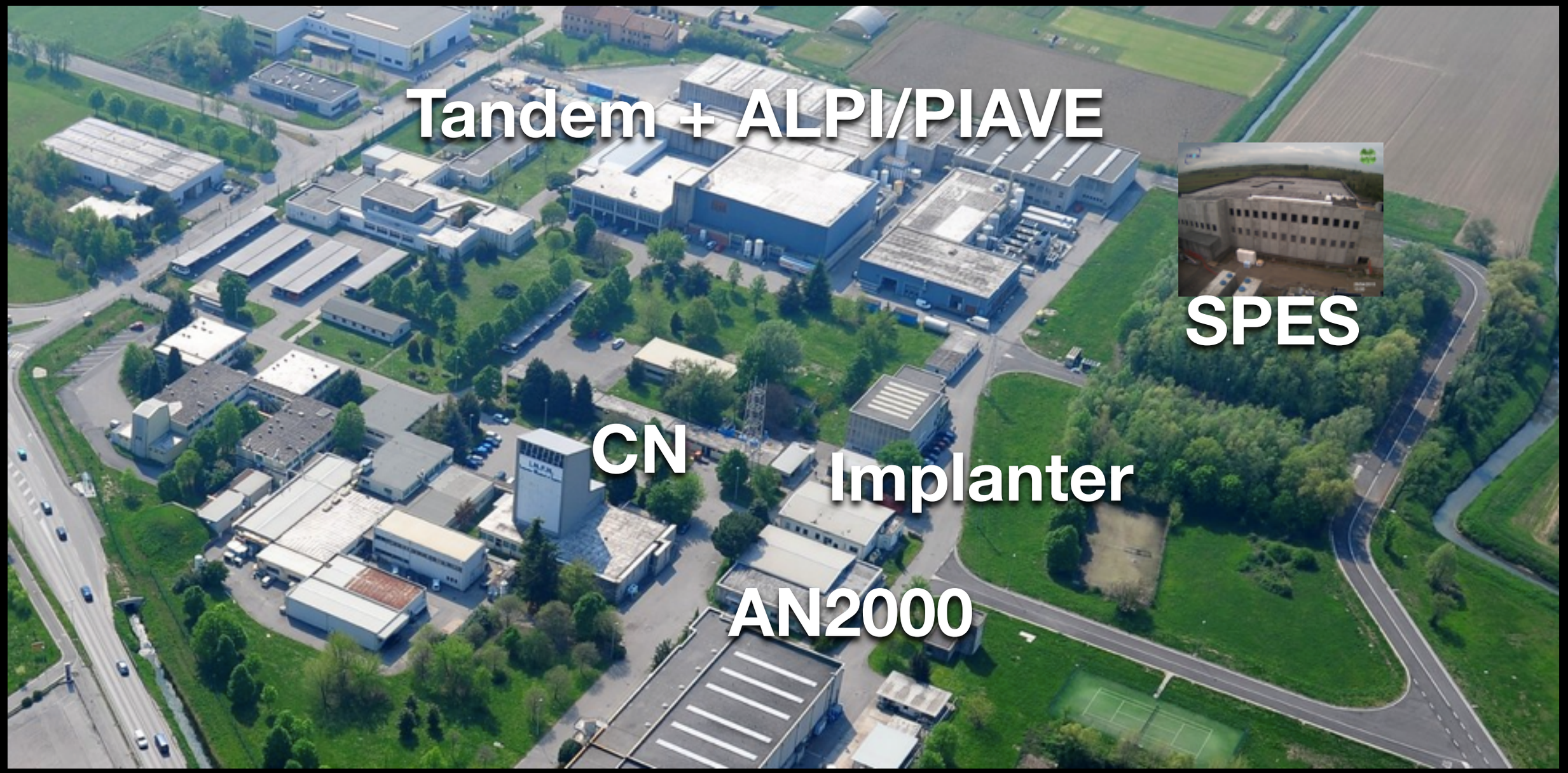


Low Energy Nuclear Astrophysics at LNL

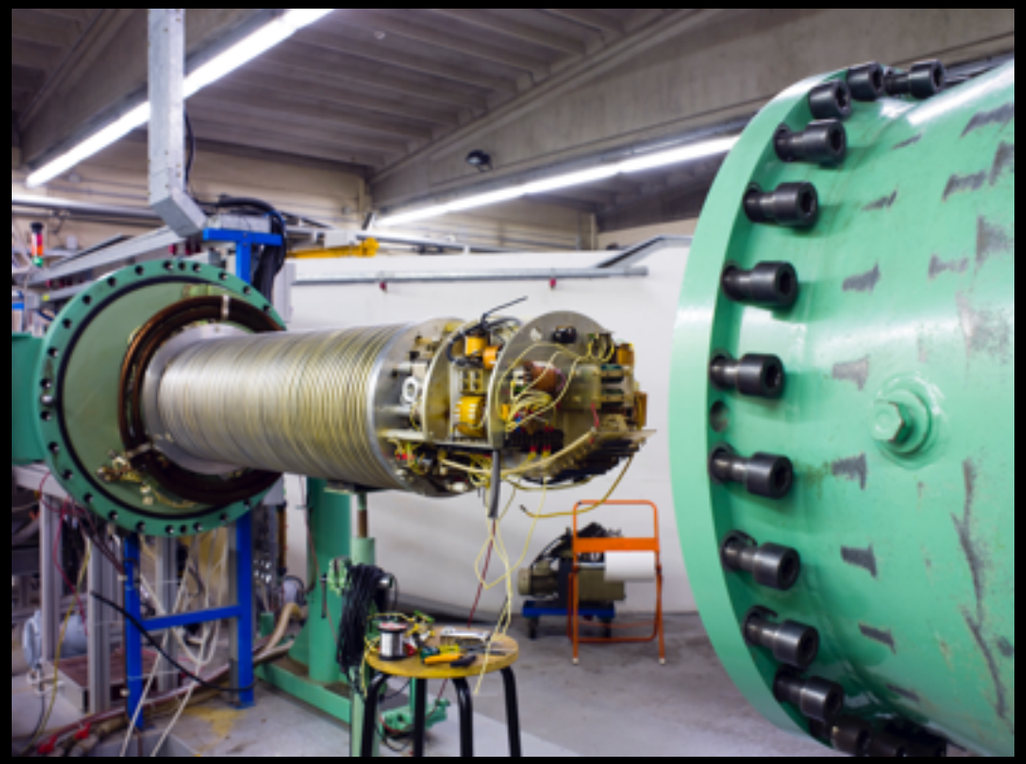
Antonio Caciolli
INFN - LNL and University of Padua

AN2000

2 MV single ended
Beams: p, α, deuterium

IBA, Nuclear Astrophysics, target characterisation, geological studies

$^{10}B(p,\alpha)^{7}Be$, $^{19}F(p,\alpha)^{16}O$ and ^{25}MgO andTa_2O_5 target characterisation



CN Van de Graaf

Terminal ~ 7 MV
Beams: H,^{2}H,$^{3/4}He$,N (Continuous and pulsed beam)

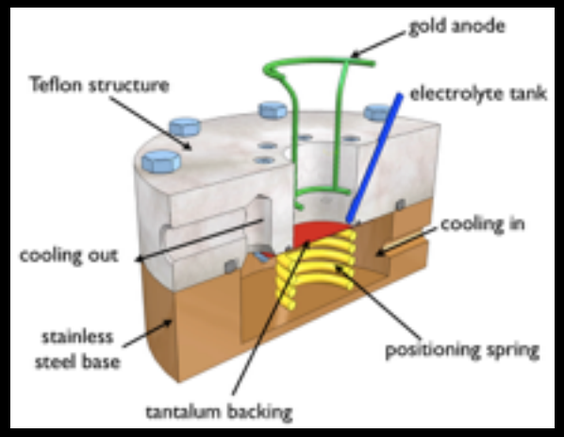
7 channels for different purposes:
IBA, Nuclear Astrophysics, ….

Astro^{25}Mg, CARTA, LENOS

Target Preparation and Analysis

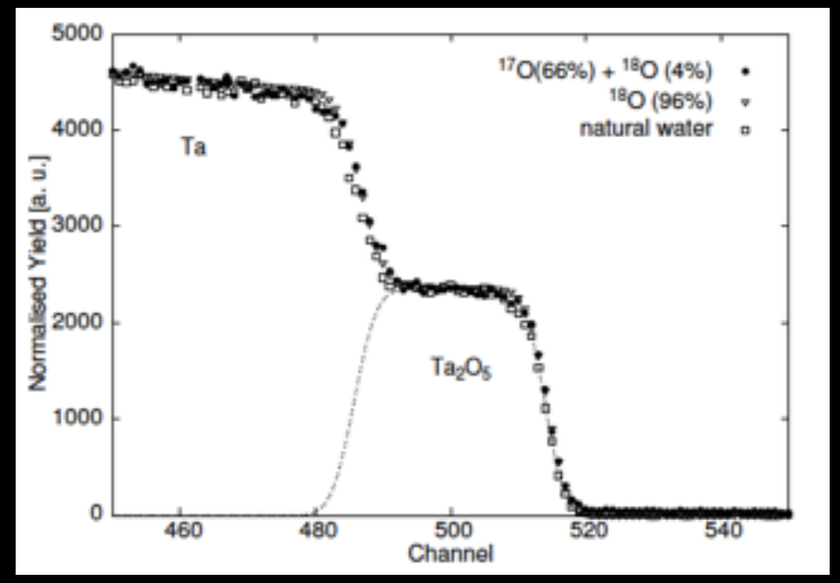
- Target lab (M. Loriggiola) can provide several target compounds with the evaporation technique
- Accelerator devoted to implantation that was used to create ^{22}Ne targets one year ago with good results
- Reactive Sputtering setup
- RBS, NRA, ERDA, Micro-beam facilities at AN2000, and CN accelerators to study the target properties
- SIMS facility at the Padua University

Ta_2O_5 : for the study of $^{17/18}O(p,\gamma)$ and $^{17/18}O(p,\alpha)$ at LUNA



^{17}O up to 69% (5% ^{18}O)

problems: stoichiometry Ta:O and isotopic ratio $^{17}O/^{18}O$

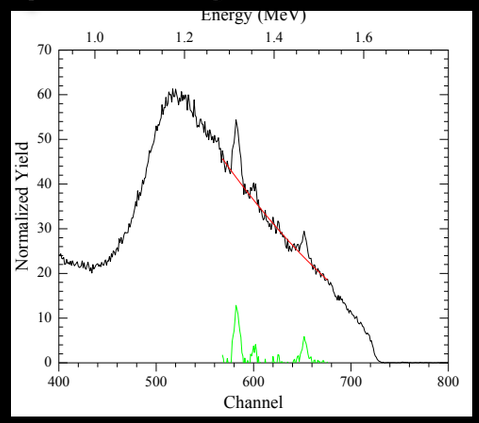


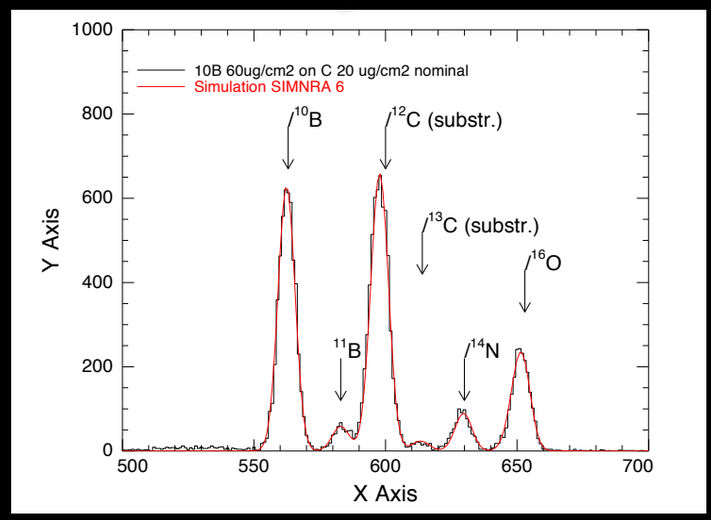
Caciolli et al., EPJA 48 (2012) 144

Ta:O = 2:5 verified within 3% with RBS
SIMS measurements for isotopic ratio

$^{10}B(p,\alpha)^{7}Be$ study: $^{10}B/C$ or B_4C/Si samples analysis
Both typology has been analysed with RBS and NRA techniques in order to characterise the targets completely

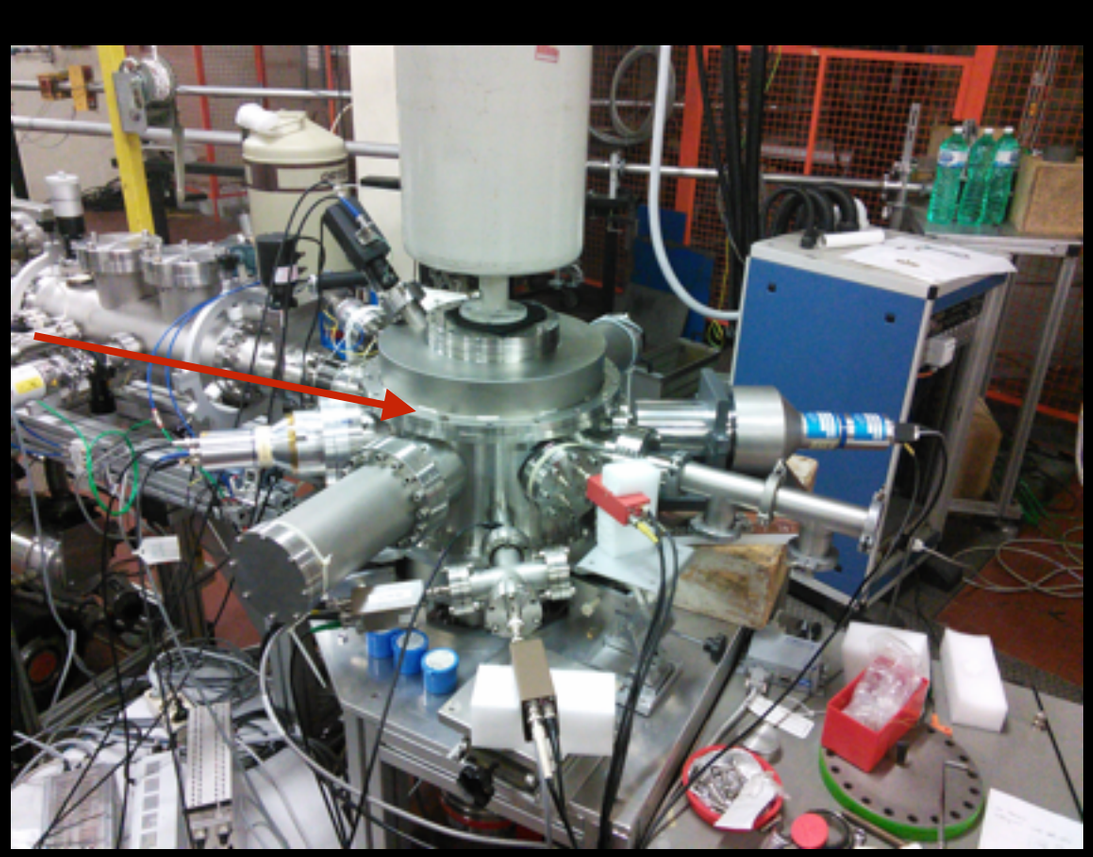
the analysis is necessary to also understand target contaminants

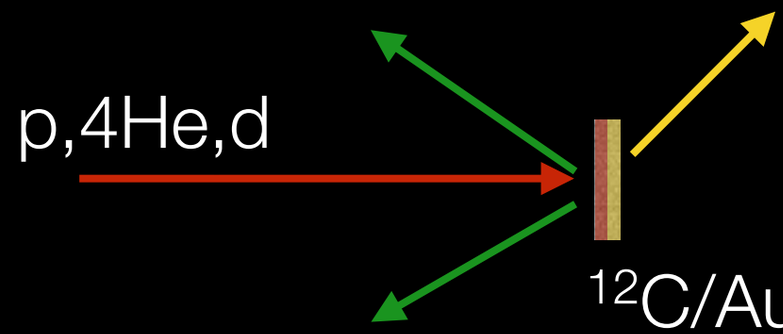




CARTA: CARbon TArget

dedicated to study ^{12}C target with a isotopic ratio $^{12}C/^{13}C$ above 10^5 to be used at LUNA-MV to study the $^{12}C(\alpha,\gamma)^{16}O$ reaction



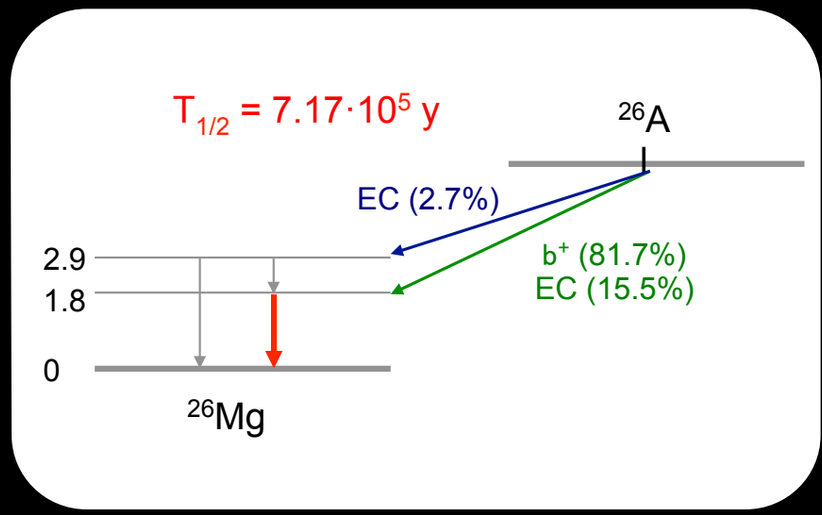


Ion Beam Analysis with charged particle and gamma detectors is used to characterise the target produced at Sidonie. **Preliminary tests reached a sensitivity of 10^5** for the isotopic ratio and a samples analysis is planned for late 2014

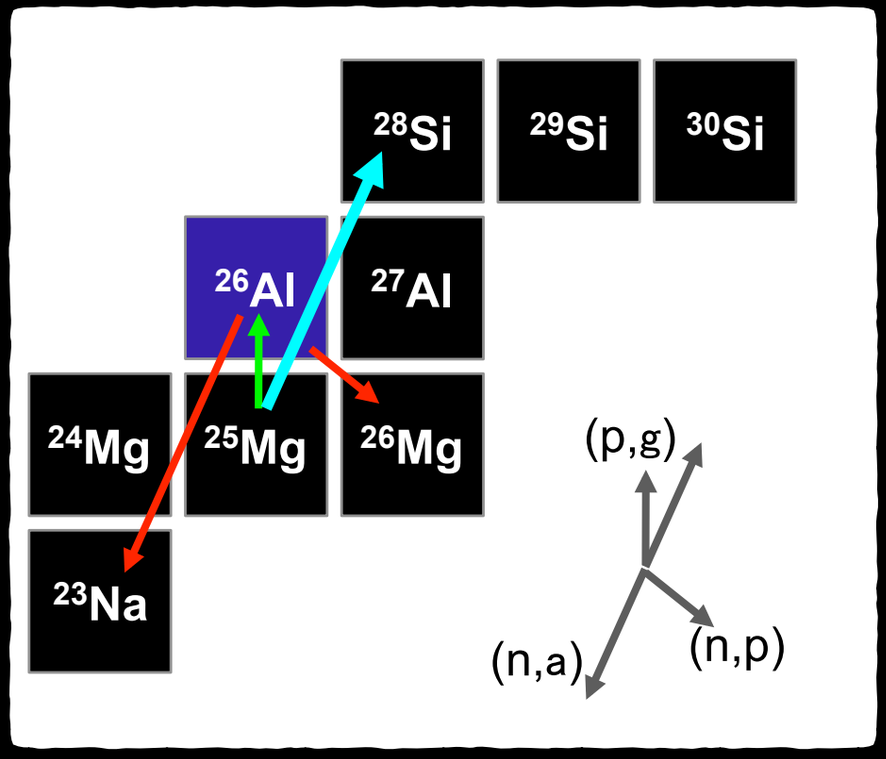
Study of $^{25}Mg(\alpha,n)^{28}Si$

- The detection of ^{26}Al in our Galaxy and in pre-solar meteorites is a direct proof of “recent” nucleosynthesis
- ^{26}Al is mainly produced by explosive C/Ne burning in stars with M > 8 $M_\odot$ (Limongi and Chieffi 2006)

^{26}Al abundance: 2.8+-0.8 M⊙ (INTEGRAL)



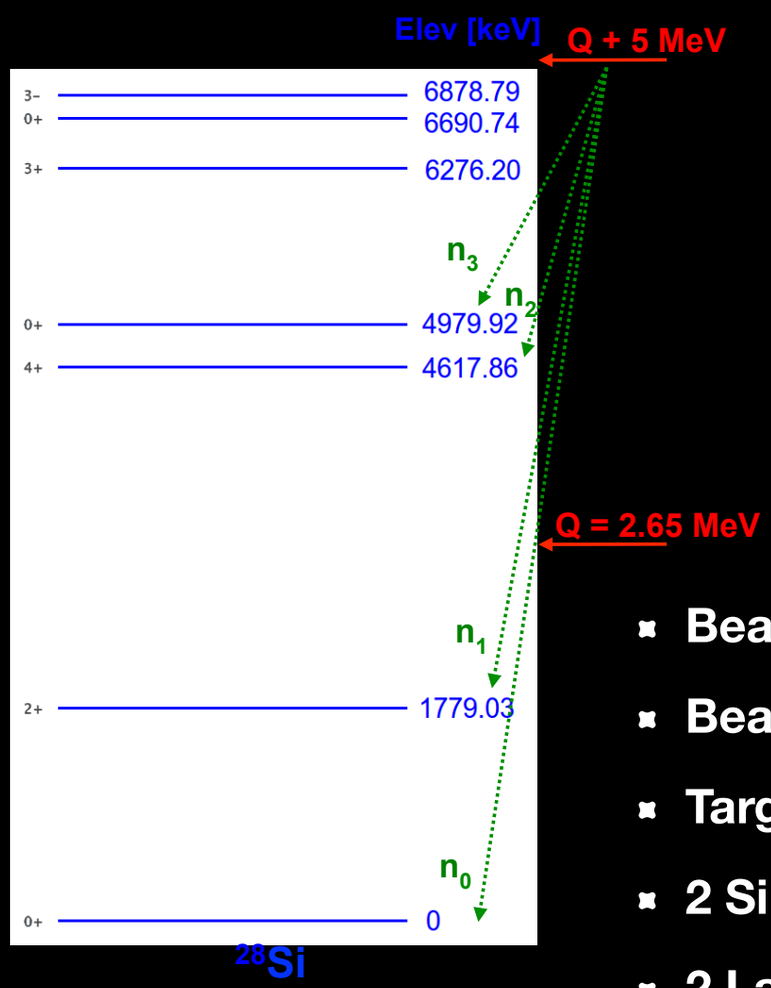
^{26}Mg excess in solar grains

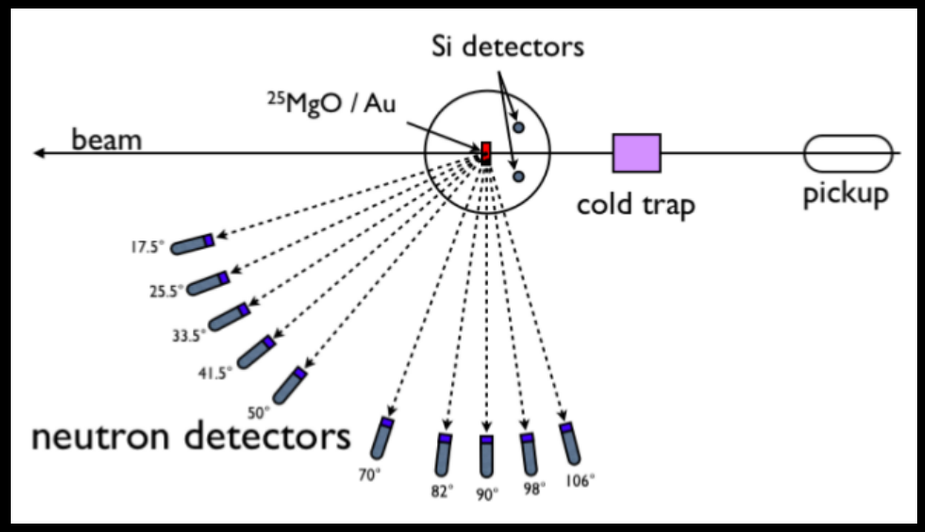


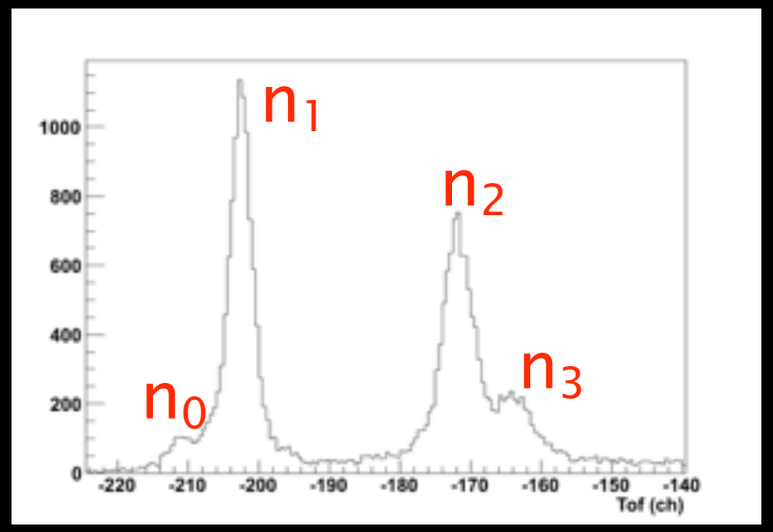
Reaction[b]	Rate Multiplied By				Source[c]	Uncertainty[d]
	10	2	0.5	0.1		
$^{25}Mg(\alpha,n)^{28}Si$	0.10	0.49	1.8	4.0	nacr	18%
$^{24}Mg(n,\gamma)^{25}Mg$	5.2	1.6	0.61	0.24	ka02	
$^{26}Al^t(n,p)^{26}Mg$	0.14	0.58	1.6	3.2	present	
$^{25}Mg(p,\gamma)^{26}Al^t$	1.7	1.4	0.58	0.14	il10	4%
$^{30}Si(p,\gamma)^{31}P$	0.51	0.77	1.3	2.0	il10	14%
$^{20}Ne(\alpha,\gamma)^{24}Mg$	1.8	1.4	0.64	0.28	il10	11%

Iliadis et al, APJSS 2011

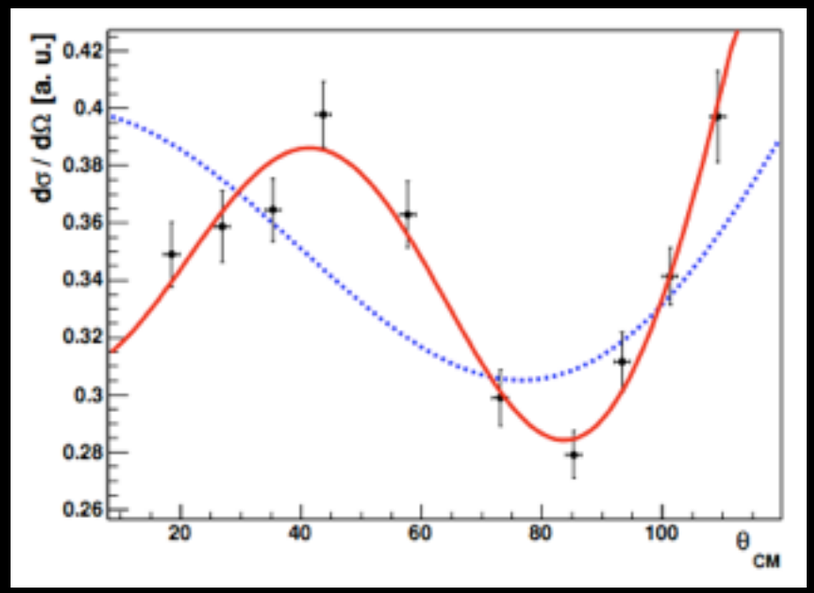
The setup with RIPEN detectors







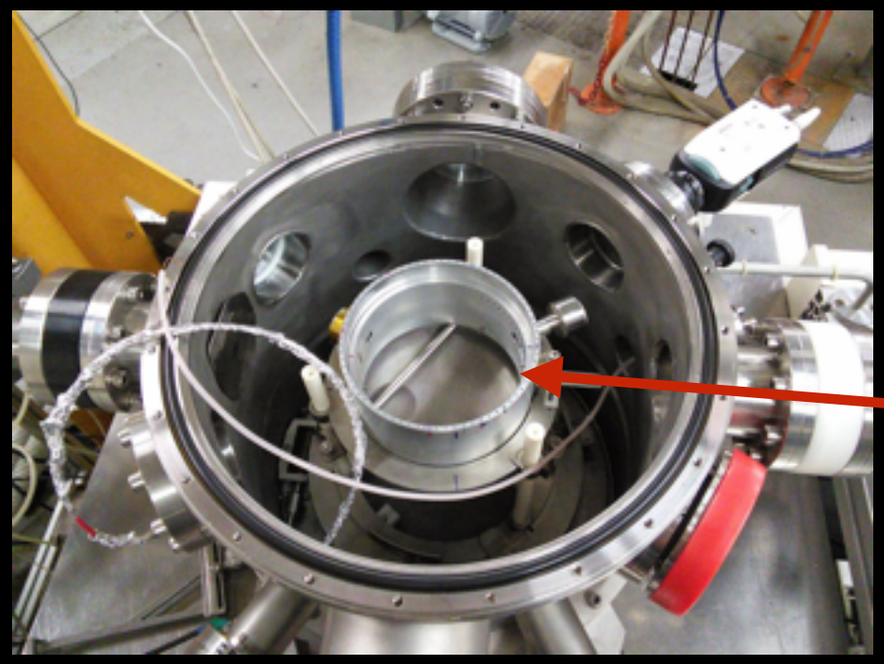
- **Beam Energy: 3, 3.5, 4, 4.5, 5 MeV**
- **Beam Current: 200 pnA pulsed beam**
- **Target MgO/Au (70μg/cm², ^{25}Mg 95.75%)**
- **2 Si detectors @ 150°**
- **2 $LaBr_3$(Cr) for γ-detection**
- **RIPEN placed from 17.5° to 106°**



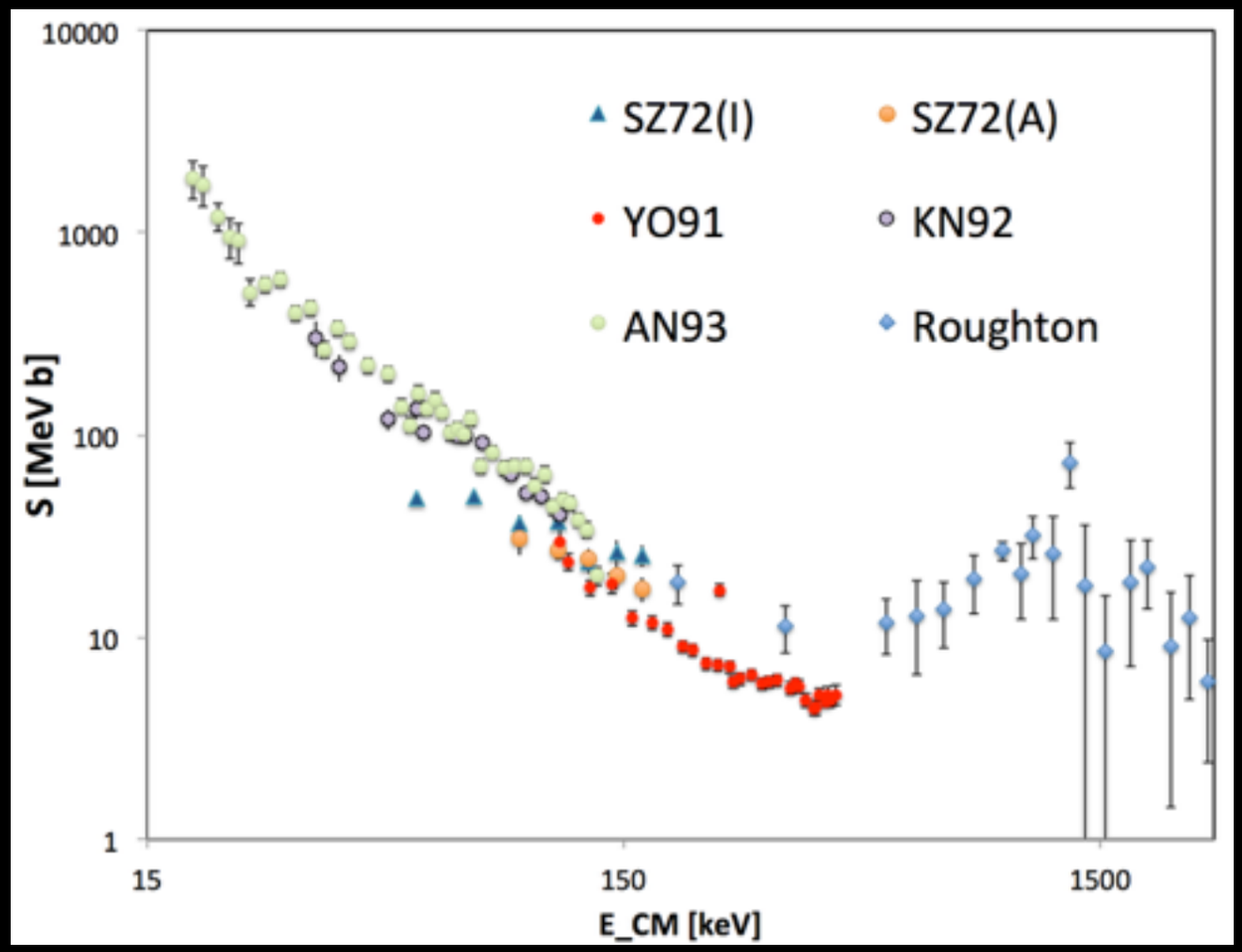
Setup realised by experts of the LUNA, RIPEN and Orione collaborations from LNL and Padua

Study of $^{10}B(p,\alpha)^{7}Be$

- Motivation: BBN, nuclear fuels, Trojan Horse Method normalization
- Goal: cross section obtained with activation and direct detection techniques from 1 MeV down to 300 keV



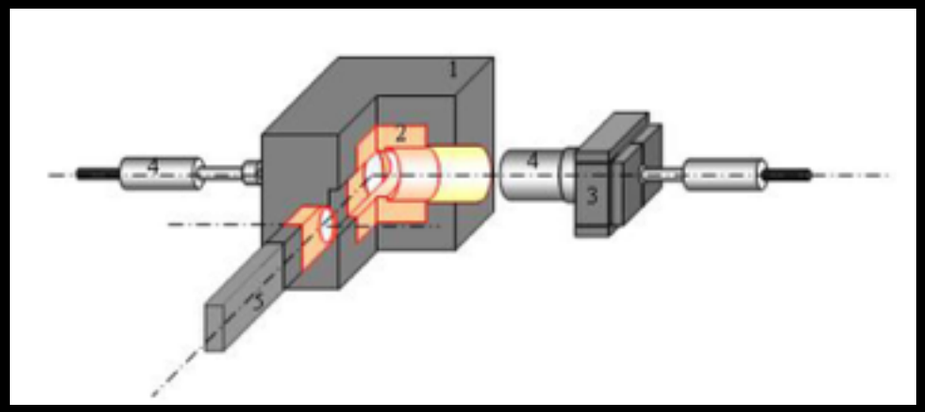
data taking in Dec 2014



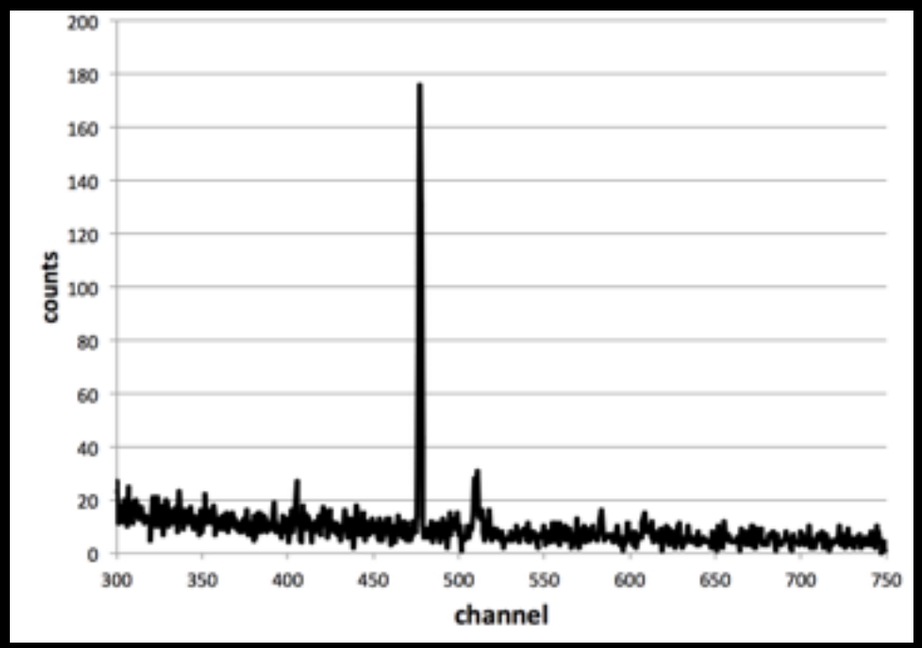
- target done in LNL by Loriggiola
- activation technique with the low counting facility of the LNL
- measure in collaboration with ASFIN group

$^{10}B(p,\alpha)^{7}Be$ preliminary results

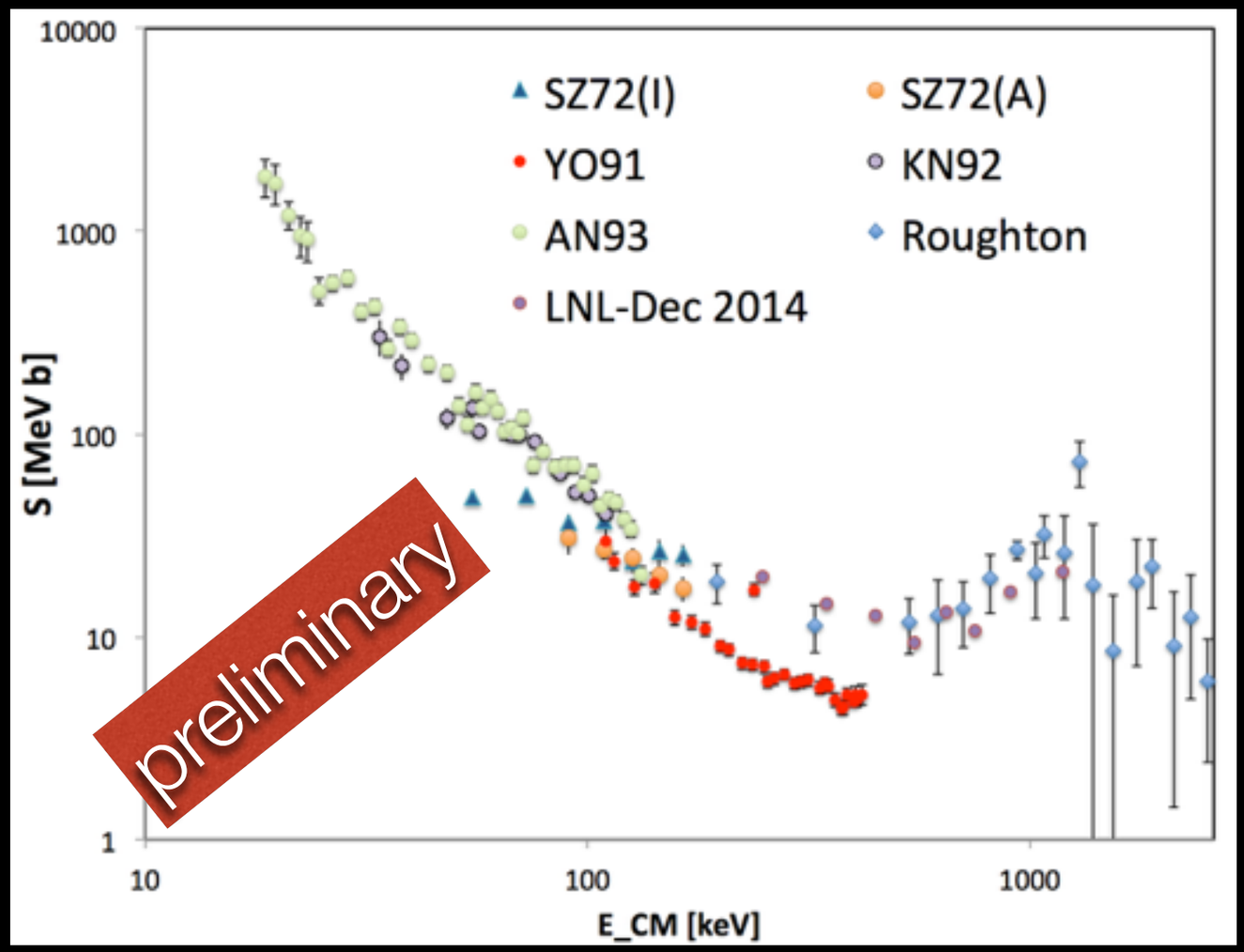
^{7}Be decay counted in the low counting facility of LNL



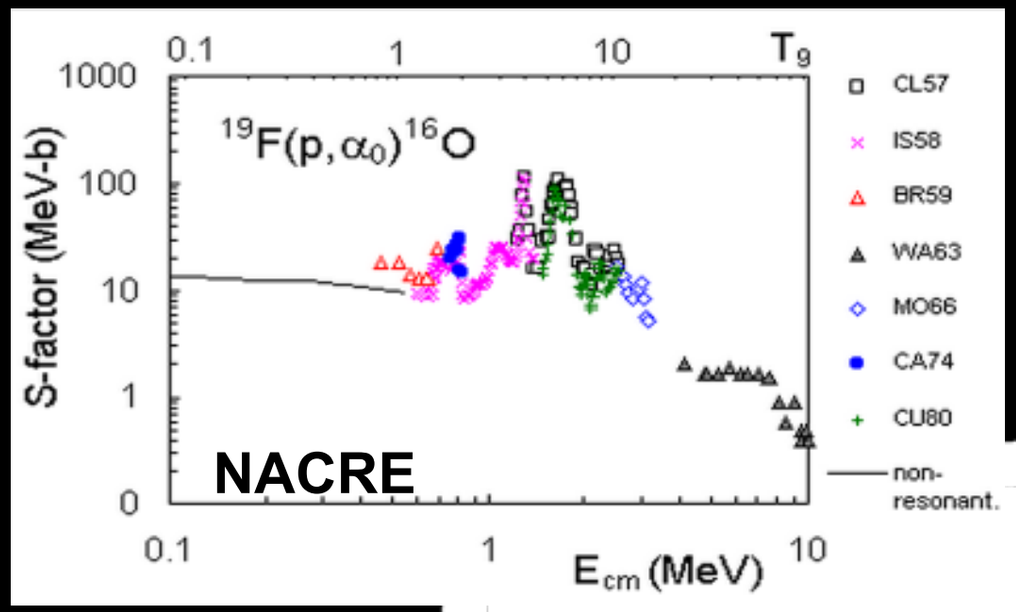
bck in ROI ~ 0.01 cps



bck reduction ~ a factor of 100



$^{19}F(p,\alpha_0)^{16}O$ - E ~ 0.2 - 0.6 MeV

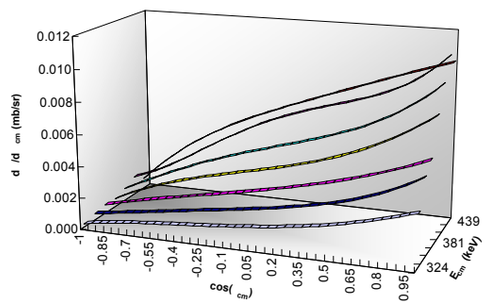


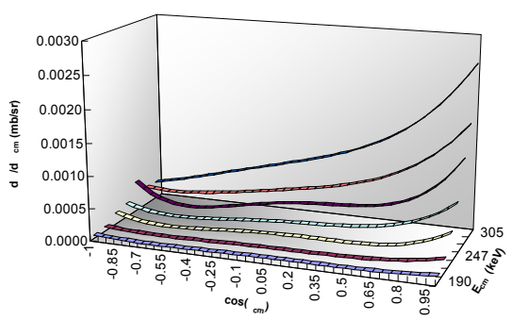
No existing data at energies below 600 keV

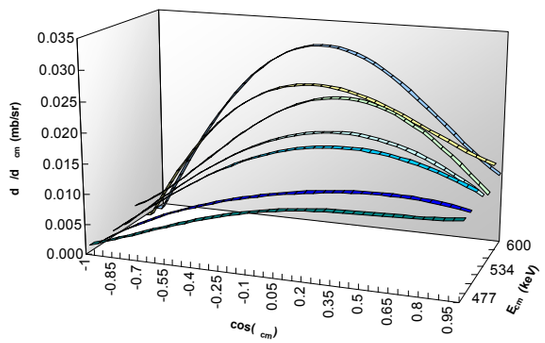
New experiment **at the AN-2000 accelerator in Legnaro (NASPENA)**

I. Lombardo, D. Dell'Aquila, A. Di Leva, I. Indelicato, M. La Cognata, M. La Commara, A. Ordine, V. Rigato, M. Romoli, E. Rosato, G. Spadaccini, C. Spitaleri, A. Tumino and M. Vigilante

Importance of measuring *angular distributions*! (12 angles)



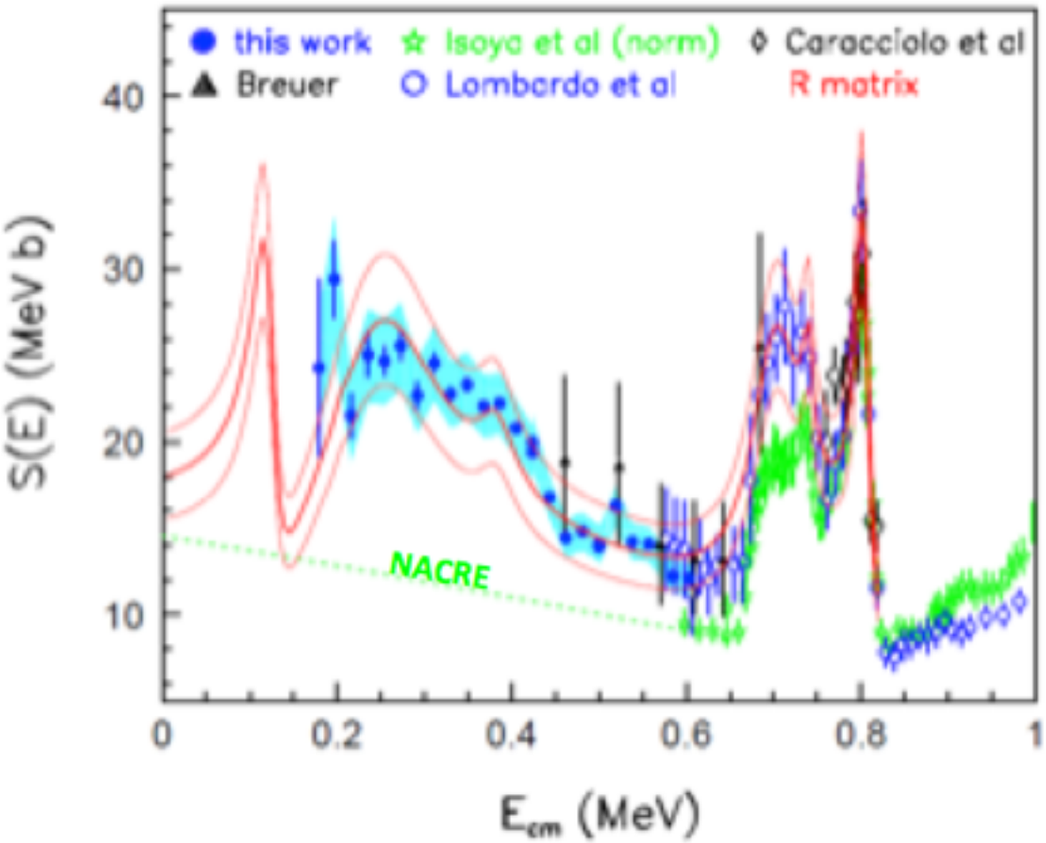




thanks to I. Lombardo

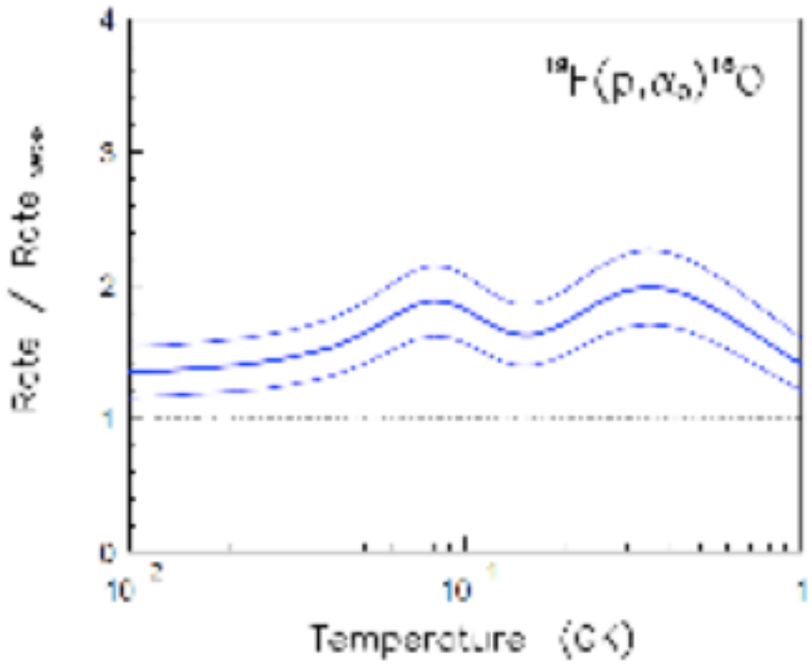
$^{19}F(p,\alpha_0)^{16}O$ - E ~ 0.2 - 0.6 MeV

S – factor **at** ***low energies*** **→** ***non-resonant*** **extrapolations (NACRE) based on** ***high energy*** **data**
→ ***large ambiguities*** **(≈ 50%) on the** ***reaction rate*** **at stellar energies**



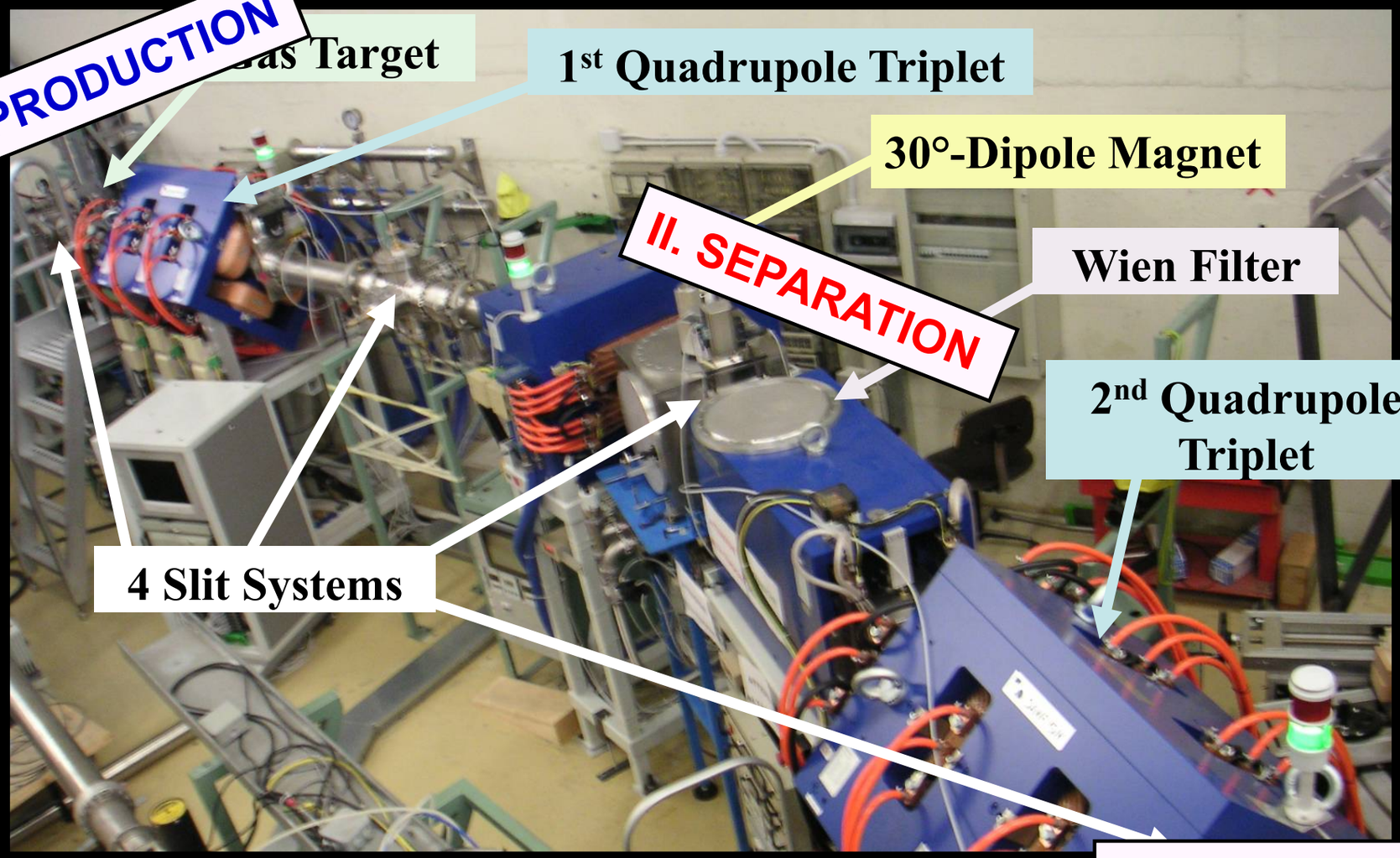
Bumps **at:**

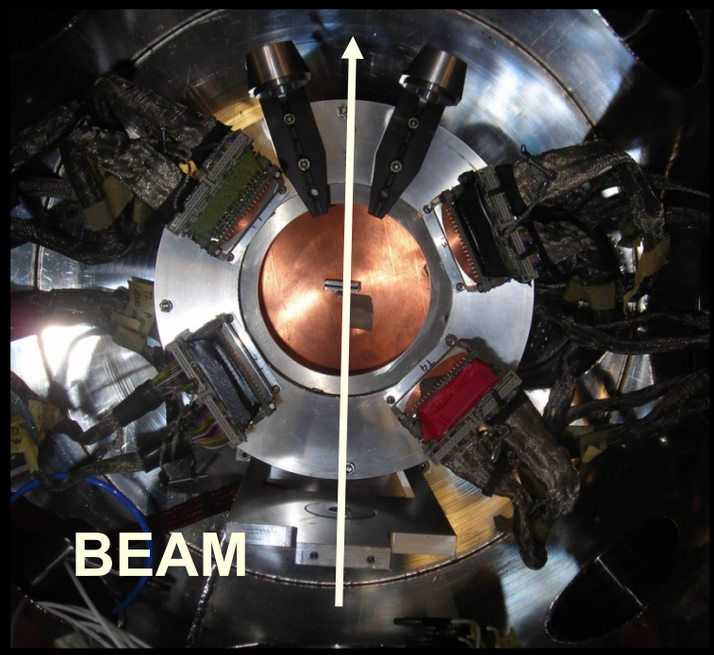
- **≈ 0.38 MeV → Breuer+THM**
- **≈ 0.25 MeV 2^+ → $^{16}O(\alpha,\alpha_{0\pi})$**
- **0.2 MeV → THM**
- ***interference*** **between 2^+ states at 0.2 and 0.25 MeV**

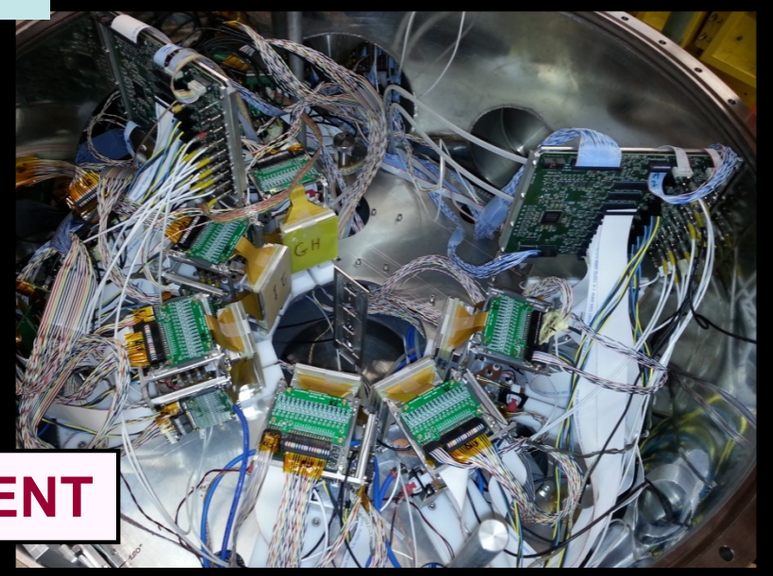


Experimental ***S-factor*** ***much larger*** **than the** ***non-resonant*** ***extrapolation*** **from NACRE → consequences in the** ***Reaction Rate*** **determination (1.5 – 2 times larger)**

$^{7}Be(n,a)^{4}He$ with EXOTIC

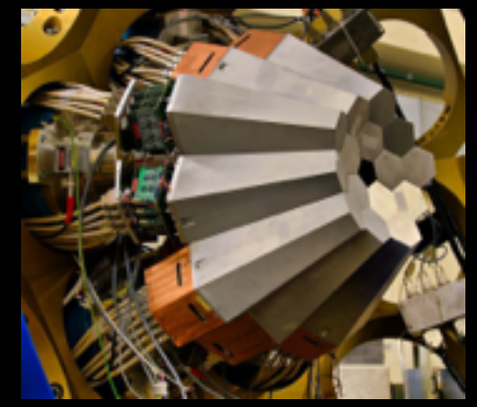


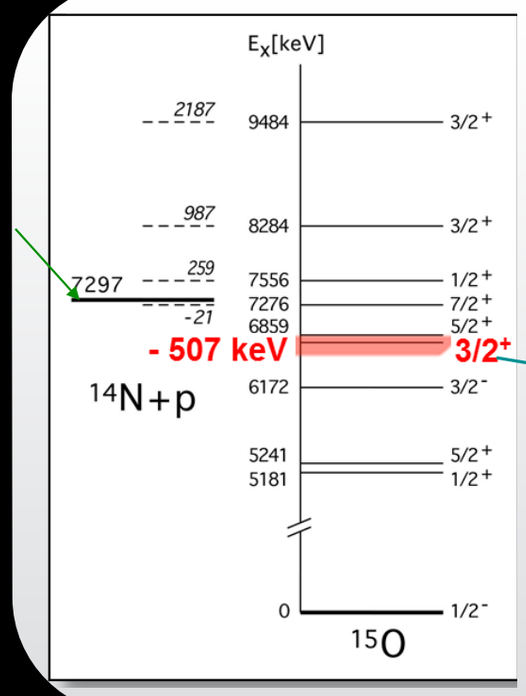


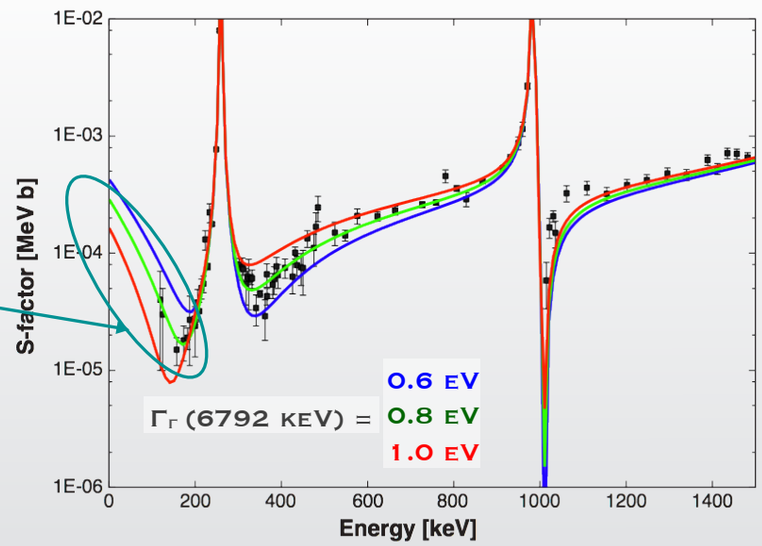


^{7}Be beam ~ 2* 10^{5} ions

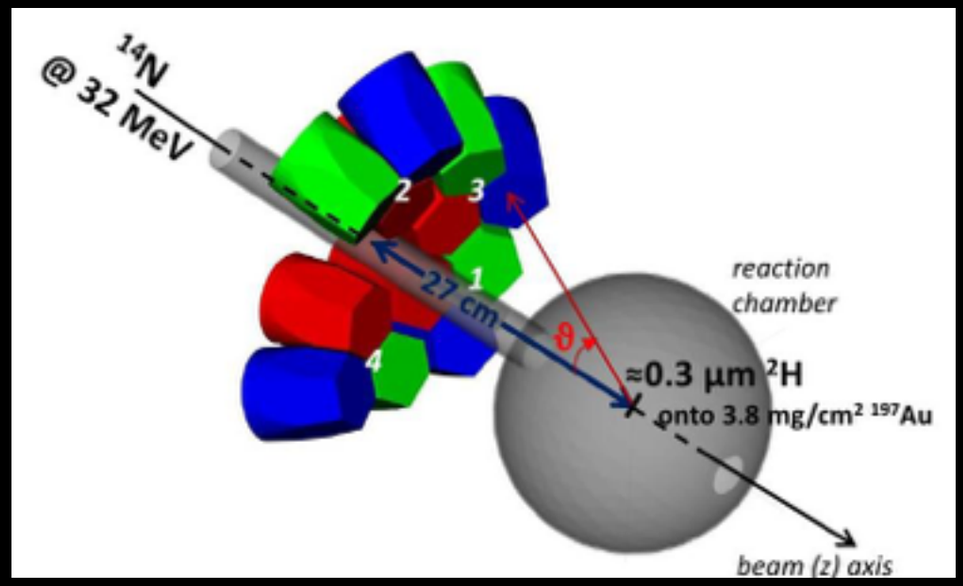
^{15}O experiment at AGATA

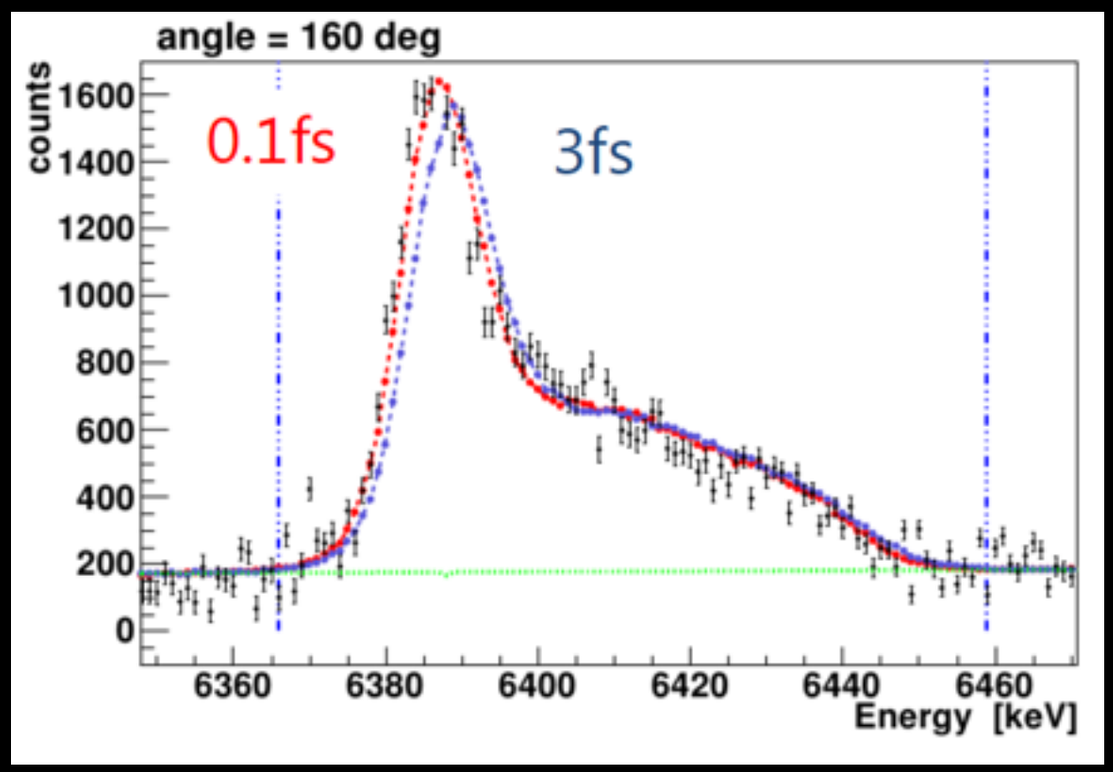






H.P. Trautvetter et al., JPG 35 (2008)





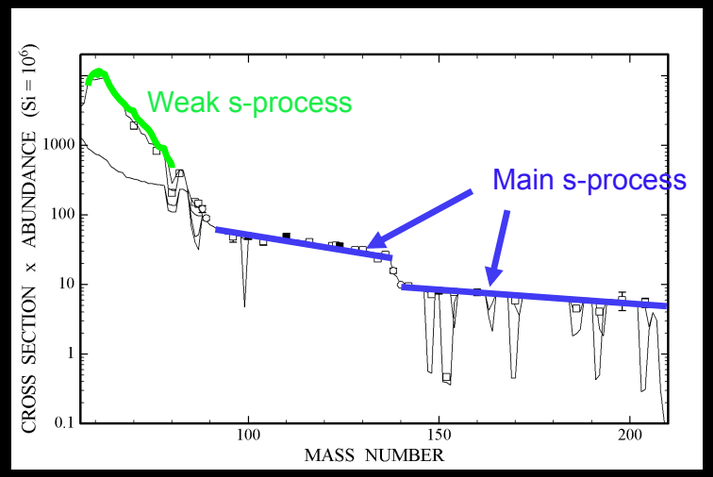
collaboration with the GAMMA group

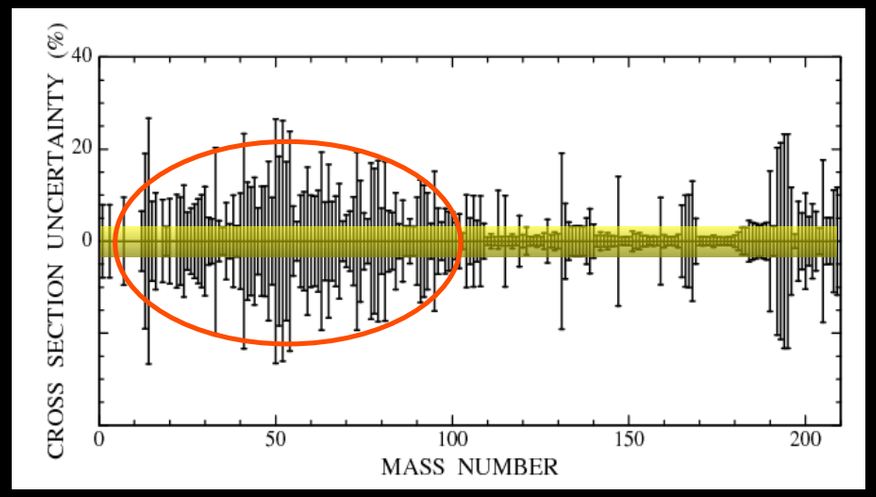
DSAM sensitivity below 1 fs

Michelagnoli et al, submitted to PRL

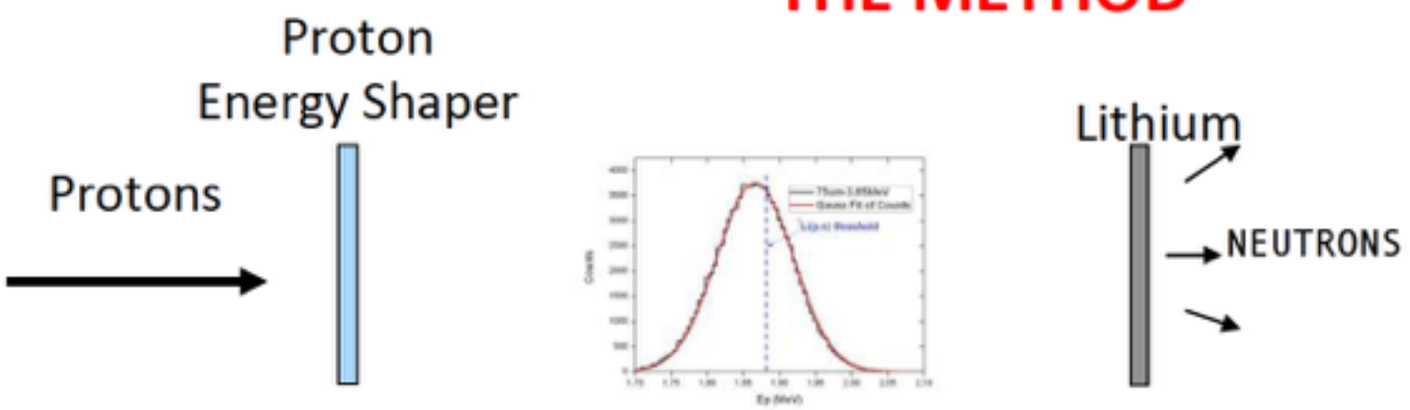
Legnaro Neutron Source

At present strong needs of low energy facility with suitable pulsed beam for neutron TOF measurement.

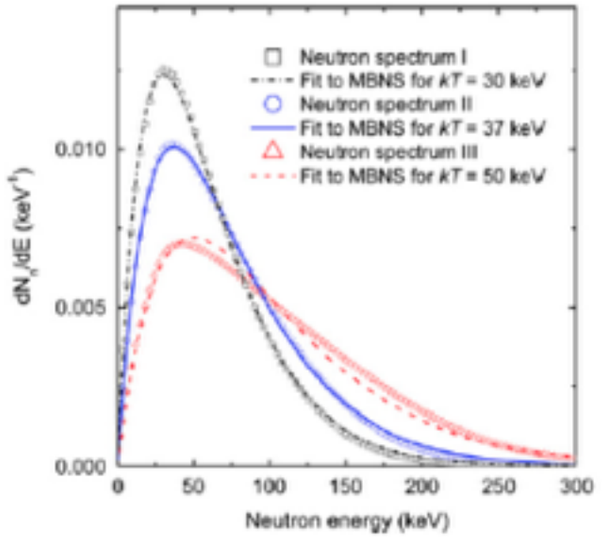




THE METHOD



Shaped Proton distribution. Dot line:
$^{7}Li(p,n)$ threshold (1.88 MeV)

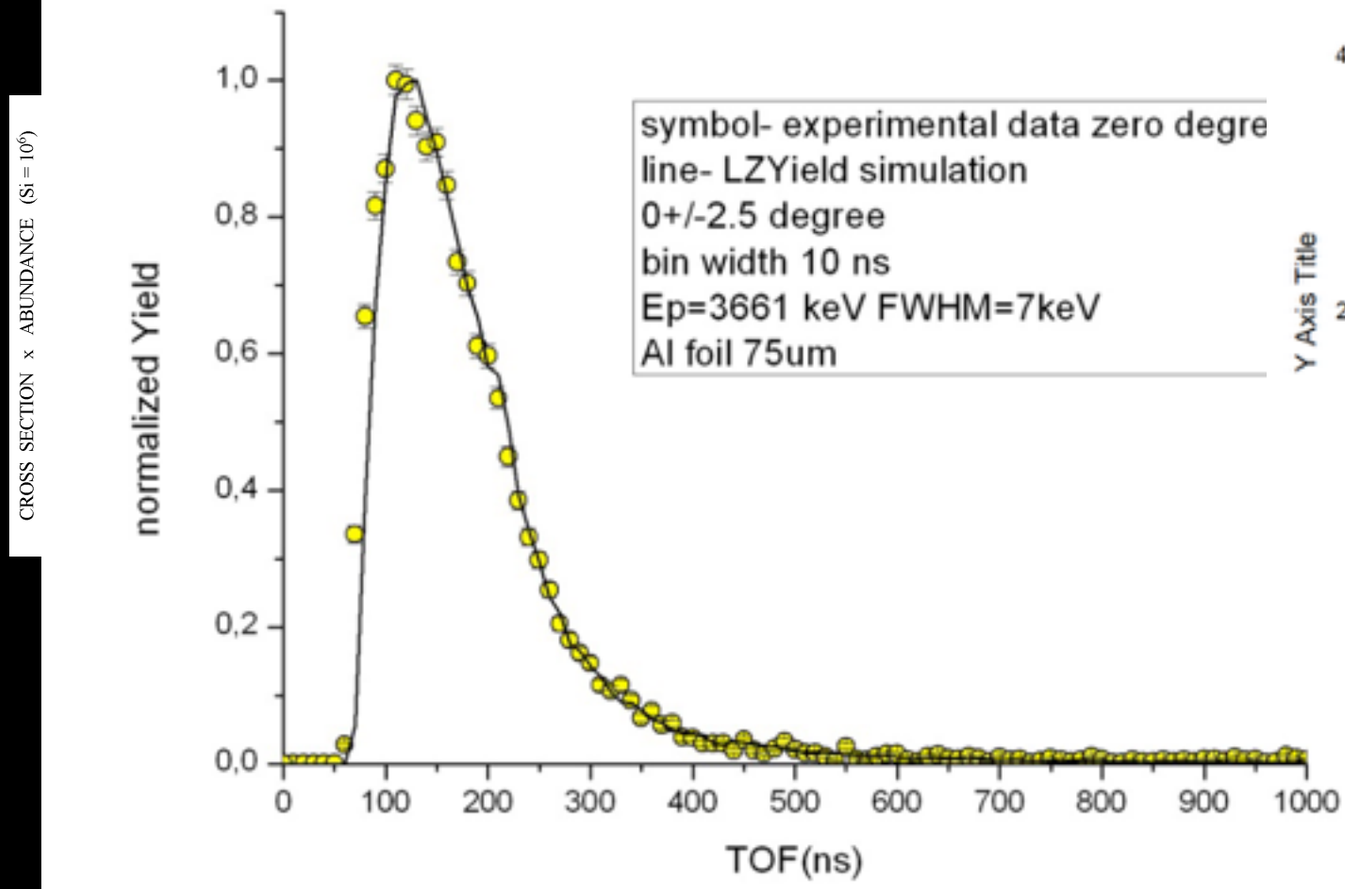


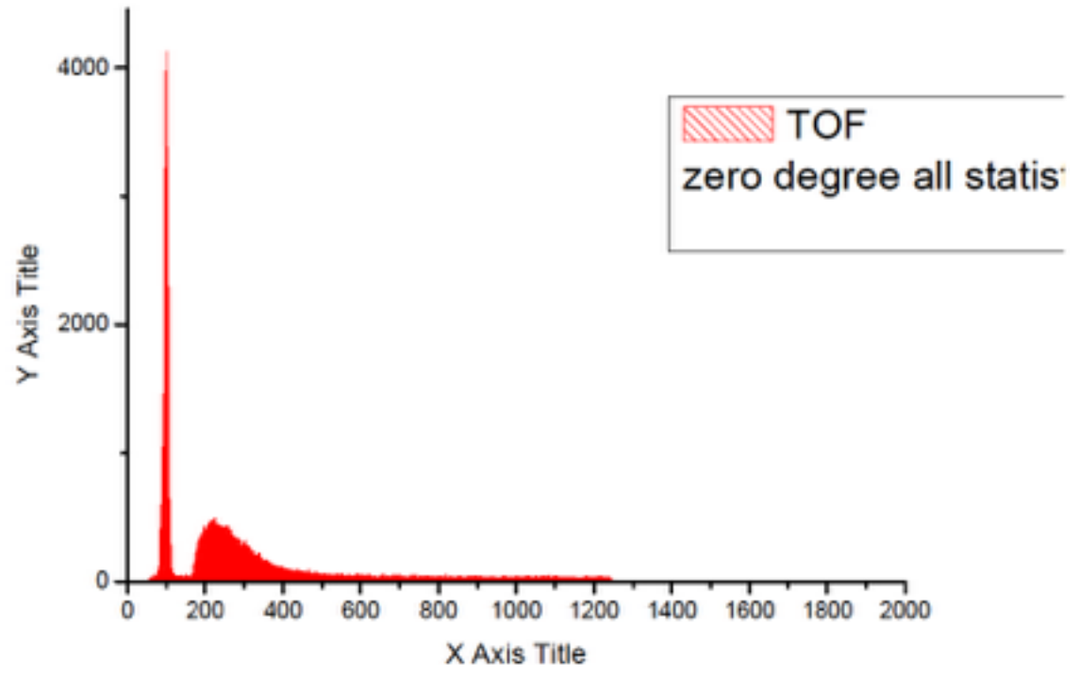
ARI *70 (2012) pg 1583-1589*

P.F. Mastinu *et al.*, NIM A 601, 333 (2009).

4

Legnaro Neutron Source





Yellow points are our experimental data at 0°.
Black line is the simulated neutron spectra with our code LZYield/MCNPX.
We have calculated the response matrix with a detailed MCNPX calculations.

ask P. Mastinu (INFN- LNL) for details

Conclusion

- LNL has long tradition in Nuclear Physics and IBA
- Target production lab and facility to characterise the targets
- Low counting facility for activation measurements
- Two accelerators with energies below 7 MeV (next call deadline 3 June 2015)