Neutron beams for low energy accelerators

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INFN- Laboratori Nazionali di legnaro

Ricerca di base ed interdisciplinare con fasci di ioni di bassa energia

Why compact neutron sources are required?

1. Place where trial or idea stage studies for new developments can be carried out
2. have an Easy access (fundamental to increase the neutron users).
3. On demand or quick experiments can be done; indispensable for many of industrial applications and industrial users.
4. Have flexibility in experiment setup
5. Perform education and training for young people
6. Low costs (construction, maintenance and access)
7. To maintain a culture of neutron science in each country needs to have at least a small local facility
8. Useful in prototype development

CANS are the support and the complement of the large neutron facilities

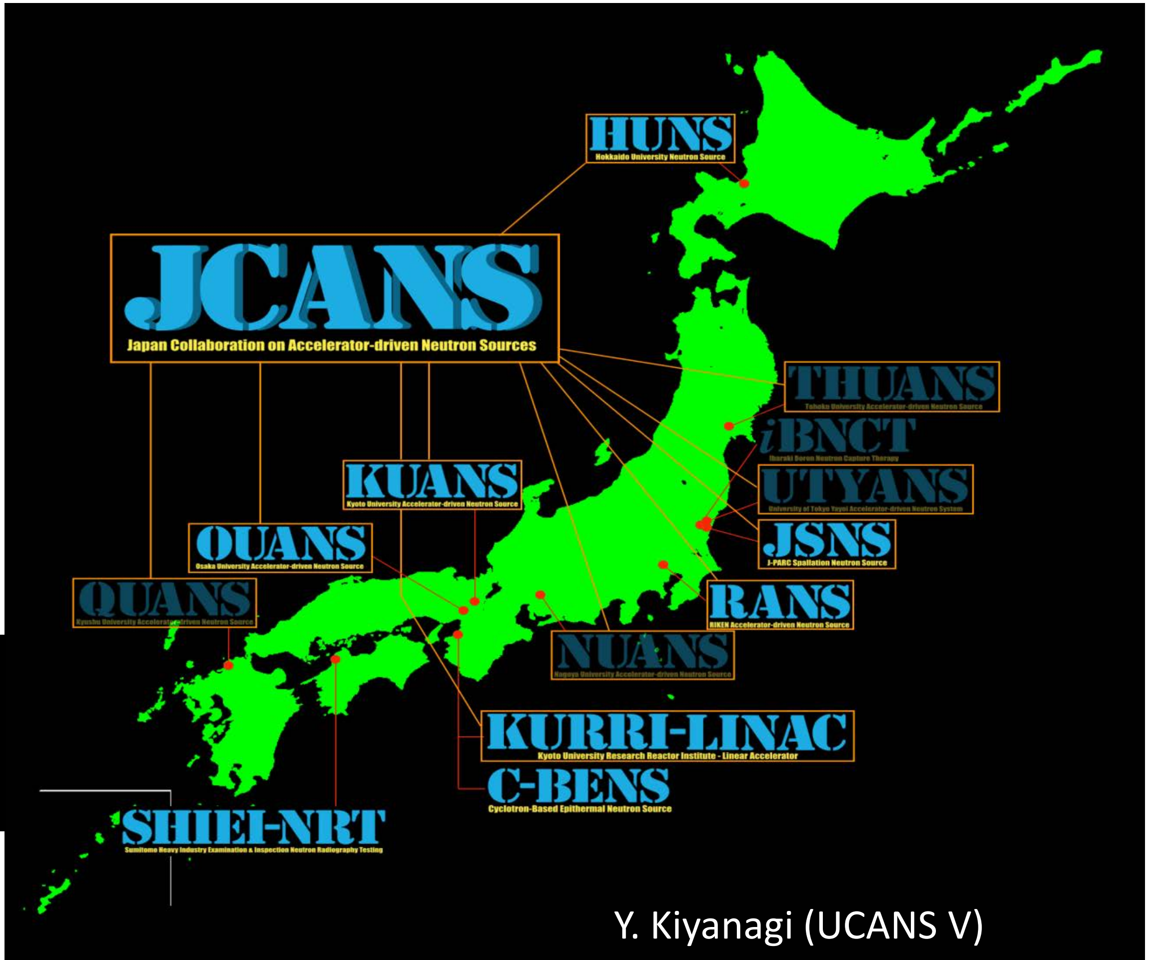
New oportunity in EUROPE THANKS TO EUFRAT and CHANDA network

UCANS

Next UCANS VII, March, Bariloche, Argentina.

Japan Collaboration on Accelerator-driven Neutron Sources
It is part of UCANS

Opaque logotypes indicate facilities already in operation for neutron production, and semitransparent ones those under construction, discussion and consideration.



Y. Kiyanagi (UCANS V)

In Europe few CANS available and mostly disconnected
Needs for ECANS ?

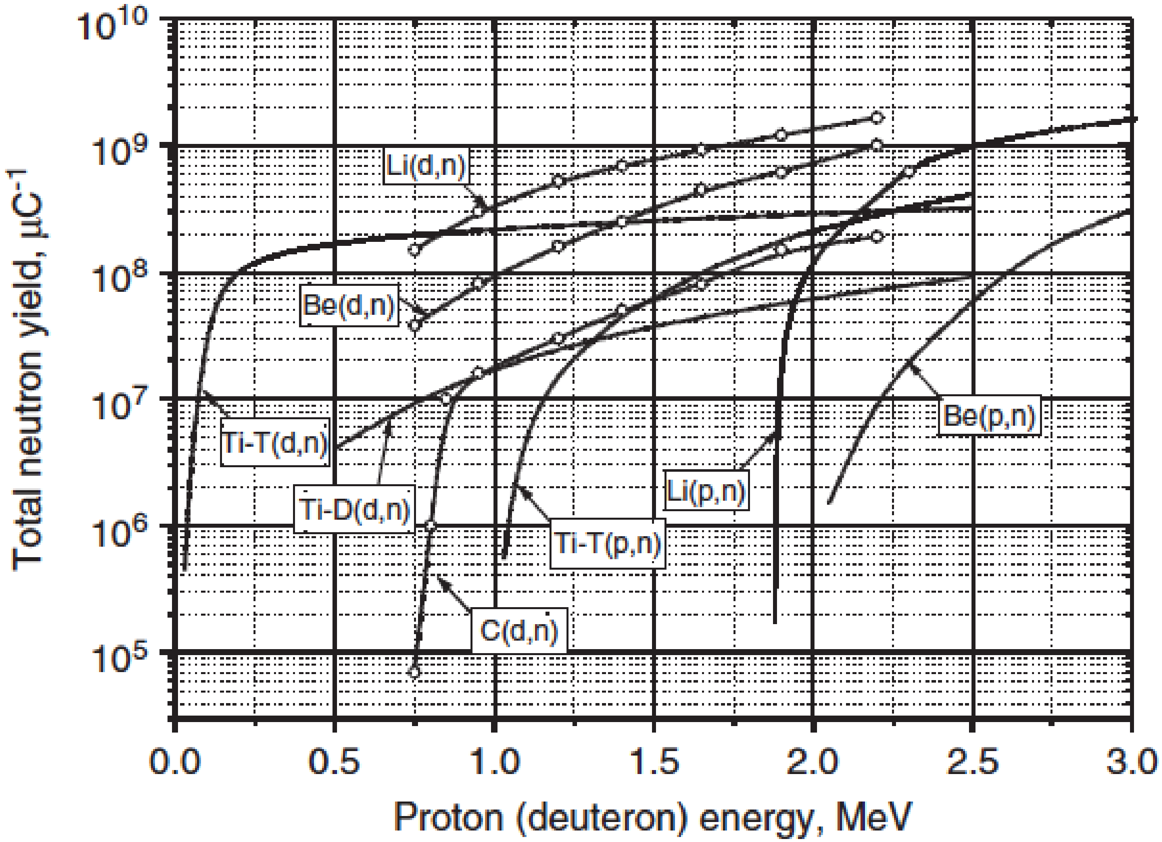
Low-Energy Nuclear Reactions Optimized for CANS

Table 1 Neutron production from low-energy nuclear reactions

Reaction types	Examples	Neutron yield per event	Heat Deposit (MeV)	Residual Products & radiation
(p/d, xn)	$^{7}Li(p,n)^{7}Be$ $^{9}Be(p,n)^{9}B$ $^{9}Be(d,n)^{10}B$	$\sim 10^{-3}$-10^{-2} n/p or n/d	~2000	Mostly γ, possibly t and accumulation of hydrogen
Fusion	$^{2}H(d,n)^{3}He$ $^{3}H(d,n)^{4}He$	$\sim 10^{-5}$ n/d	>3000	Mainly γ
Photonuclear	35 MeV e^- on a W target	$\sim 10^{-2}$ n/e	~2000	Mainly γ

Beside, monochromatic neutron beams

Neutron Yields for Various Charged-Particle induced Reactions



The low-energy reactions all require dissipating most of the incident charged-particle energy as heat, amounting to ~ 1000 MeV per useful neutron: Fission, ~ 200 MeV/n; spallation, ~ 30 MeV/n).

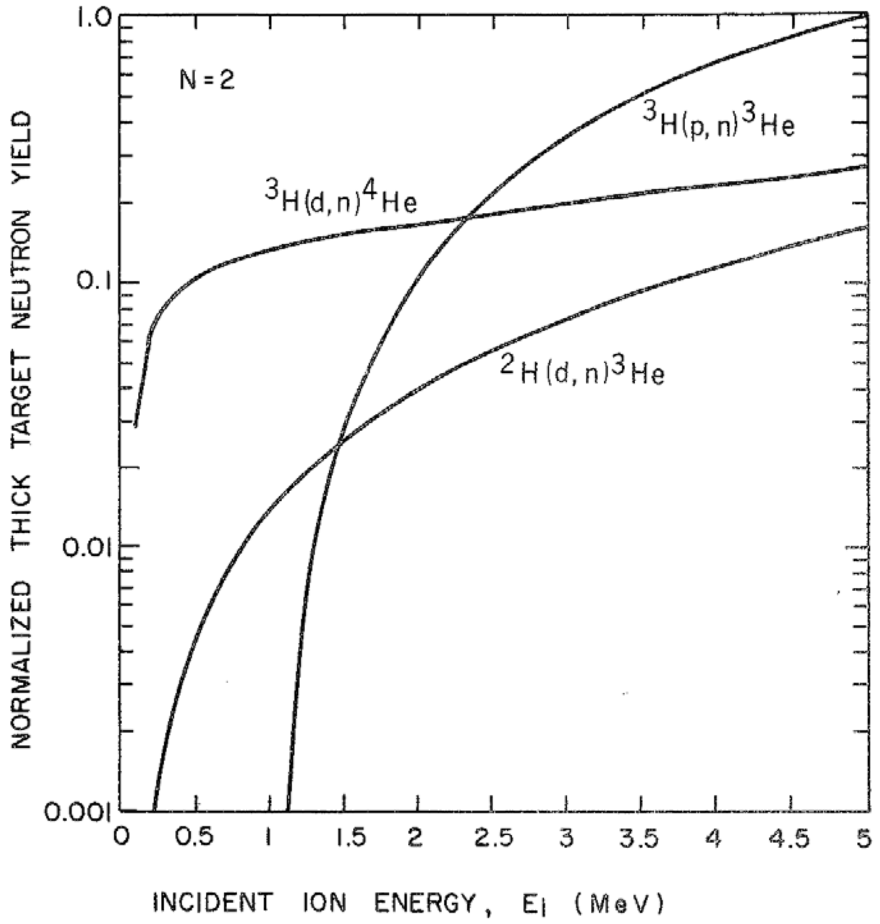
Hydrogen Isotope Reactions

J. Carpenter (UCANS V)

Since the neutron yield depends from cross section and
stopping power, Hydrogen ions (p,d,t as a projectile or target)
give the highest flux.

$^{3}H(d,n)^{4}He$, has highest yield and produces 14.-MeV neutrons. Useful for neutron cross section for fusion reactors

$^{2}H(d,n)^{3}He$ produces 2.2 MeV neutrons.



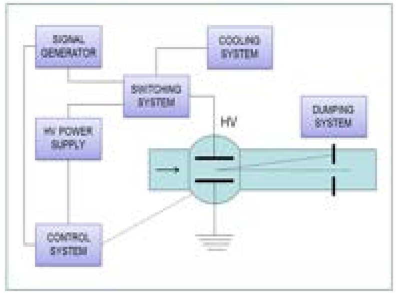
Mostly D-D and D-T tubes are used

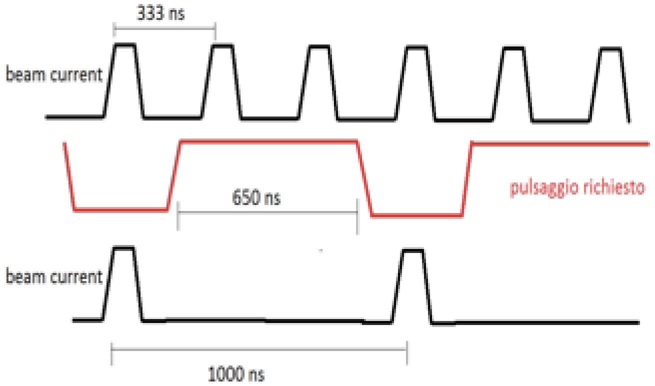
BELINA facility: CN 7 MV Van der Graaf

Pulsed beam:

- 3 MHz rf pulsing system on the high voltage terminal.
- 1 ns pulse width.
- Only 3 MHz operating: no adequate for neutron TOF measurement in the energy range of interest.

We have developed, installed and tested a switching system able to provide 1 ns pulse at 1 MHz, 625 kHz…. (*) low Rep rate available now for TOF measurements

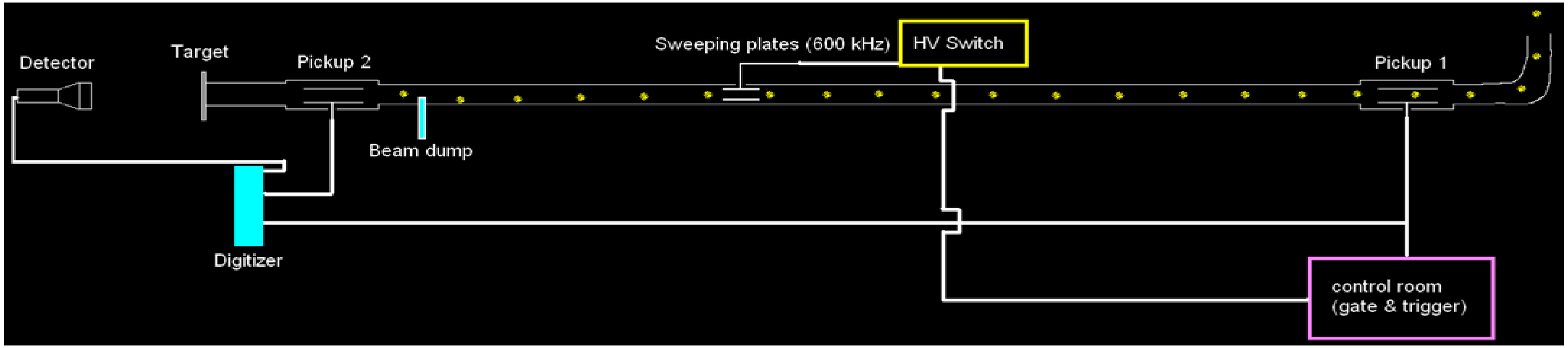




[*] P. Mastinu *et al.*, TALES Report (2013).

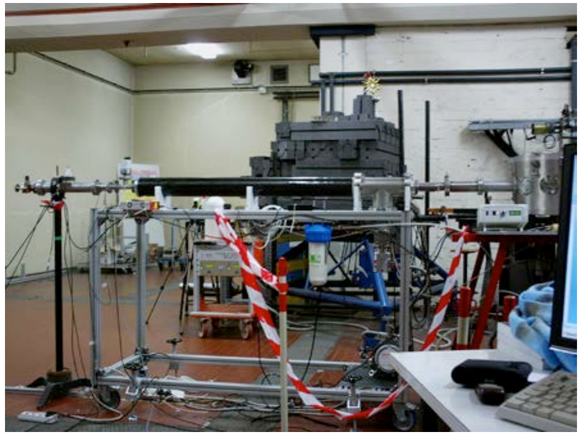
Typical BELINA setup

Parameter	Value
Beam line	0 degree (BELINA setup)
Target	Natural Li metal
Beam	H+
Pulse width	<2 ns
Pulse frequency	100 Hz-600 kHz-1 MHz
Flight path	70 cm
Proton current	50-110 nA (averaged)
Beam diameter	<3 mm



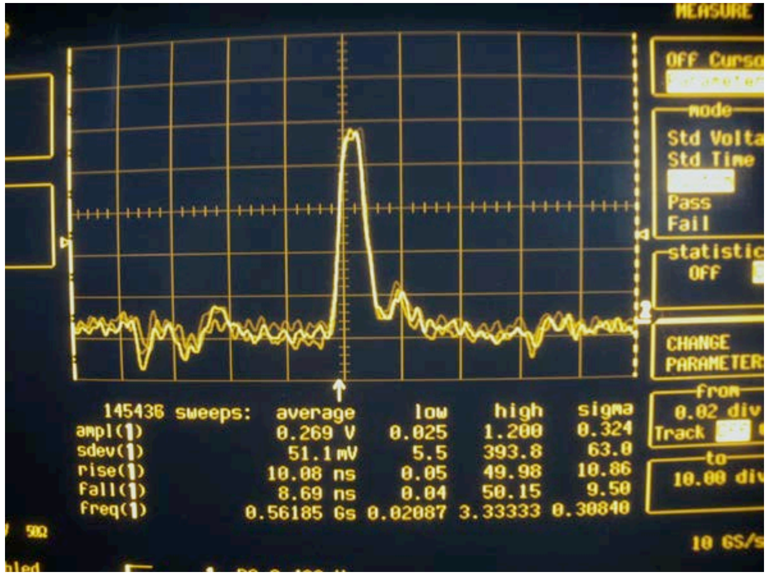
CN Performances

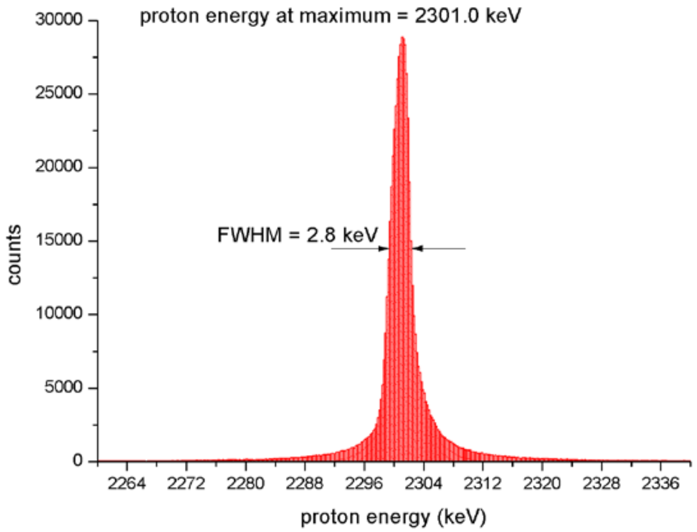
On-line TOF measurement of proton beam energy distribution (13m FP)



Low mass setup

1-2 ns time resolution of proton beam





Achievable energy resolution about 0.1% (about 200 ps time resolution)

BELINA: neutron beam line at CN VdG

We have constructed the different parts of the setup and the DAQ system:

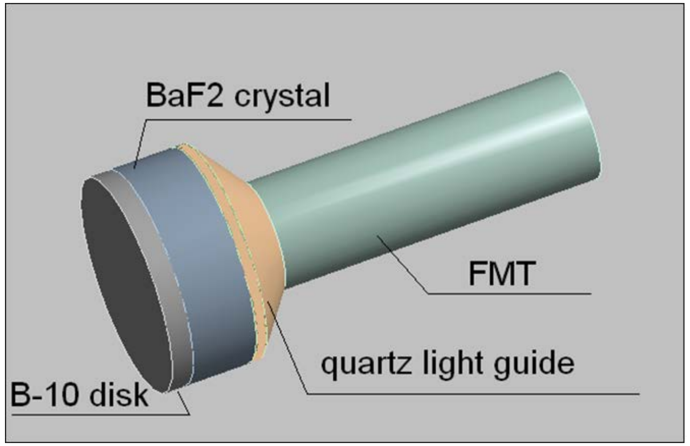
- ^{10}B-BaF_2 detector, ^{6}Li-glass detector, Li evaporation system, self made low mass metal Li-Target
- DAQ based on CAEN Digitizer (1-2 GHz sampling rate).: waveform or list mode
- Low mass neutron beam line and goniometer
- Up to 5 MeV neutron energy collimator with different apertures

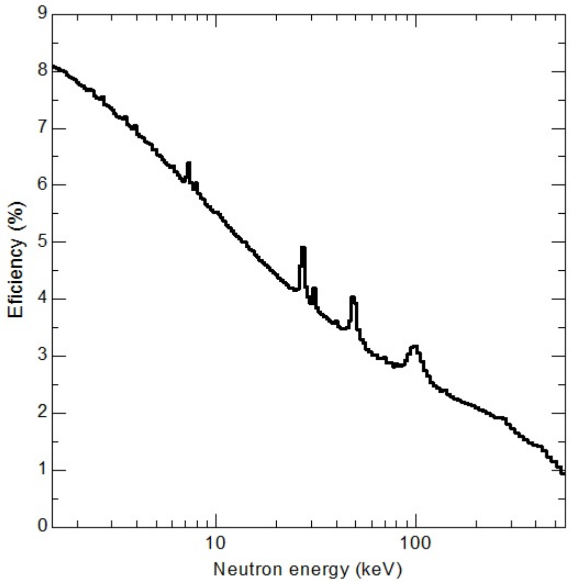
Different detectors available:

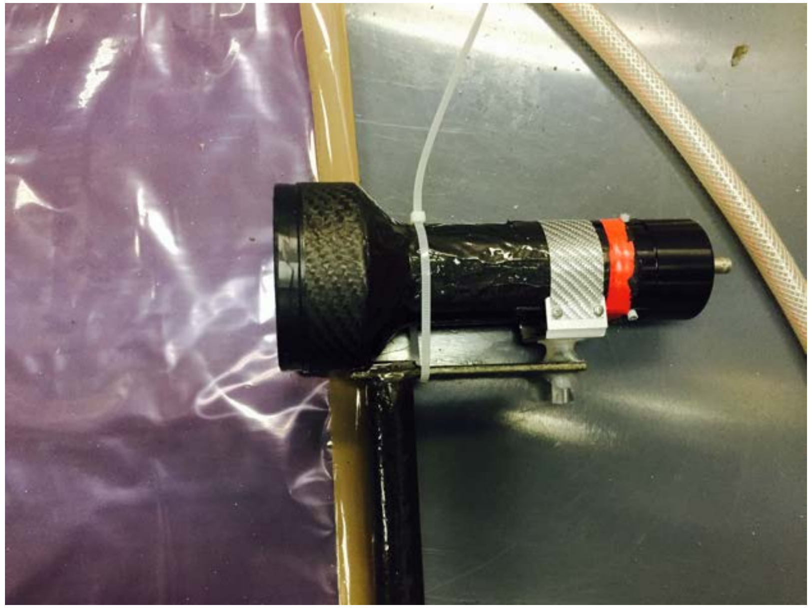
- ^{6}Li-Glass of different thickness
- BC501a
- BF_3

The new, High efficiency, High resolution TOF neutron detector

Detector: BaF_2 with ^{10}B removable capsule. Neutrons detected via 480 keV gamma from ^{10}B capture. High efficiency





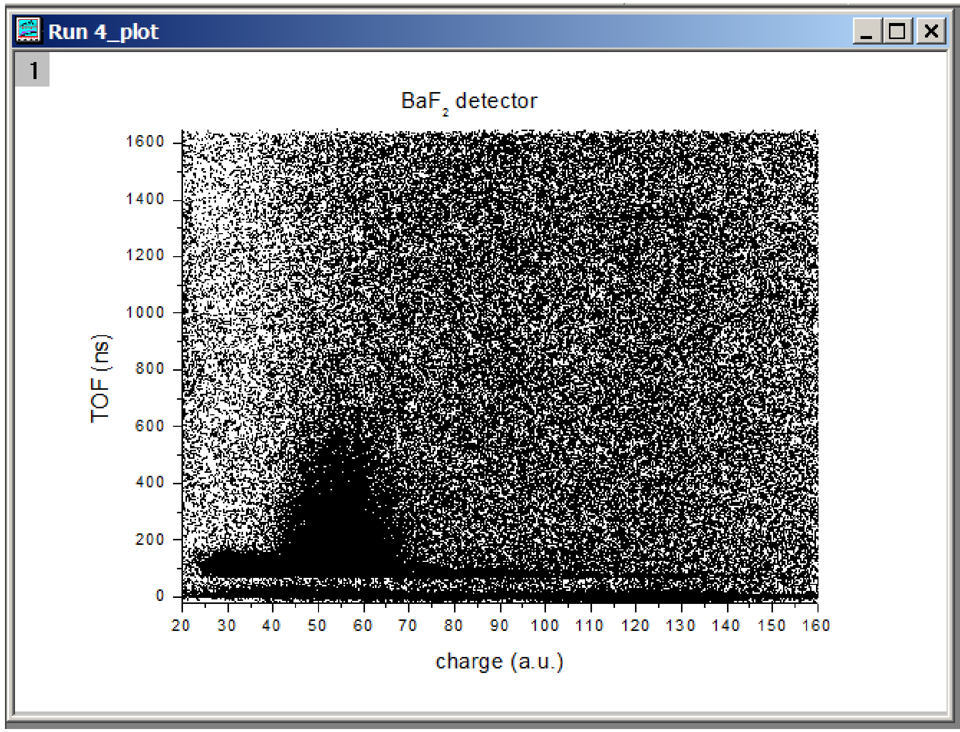


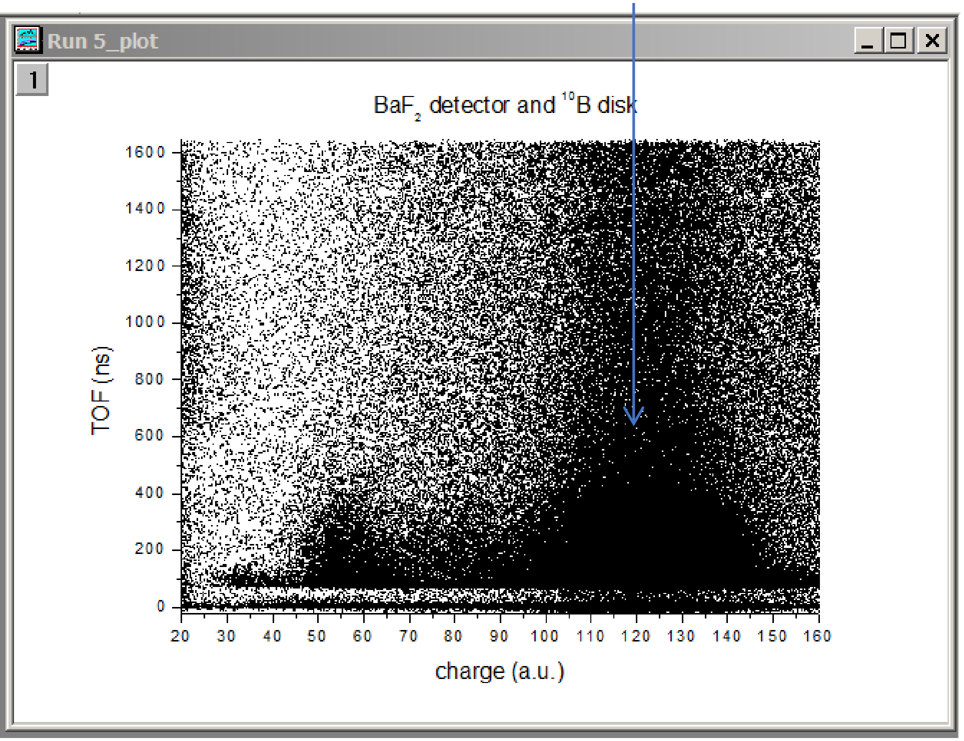
Setup and routine for data analysis

We have already characterized tested and used out new detector, since we have already performed a similar TOF experiment at CN-LNL

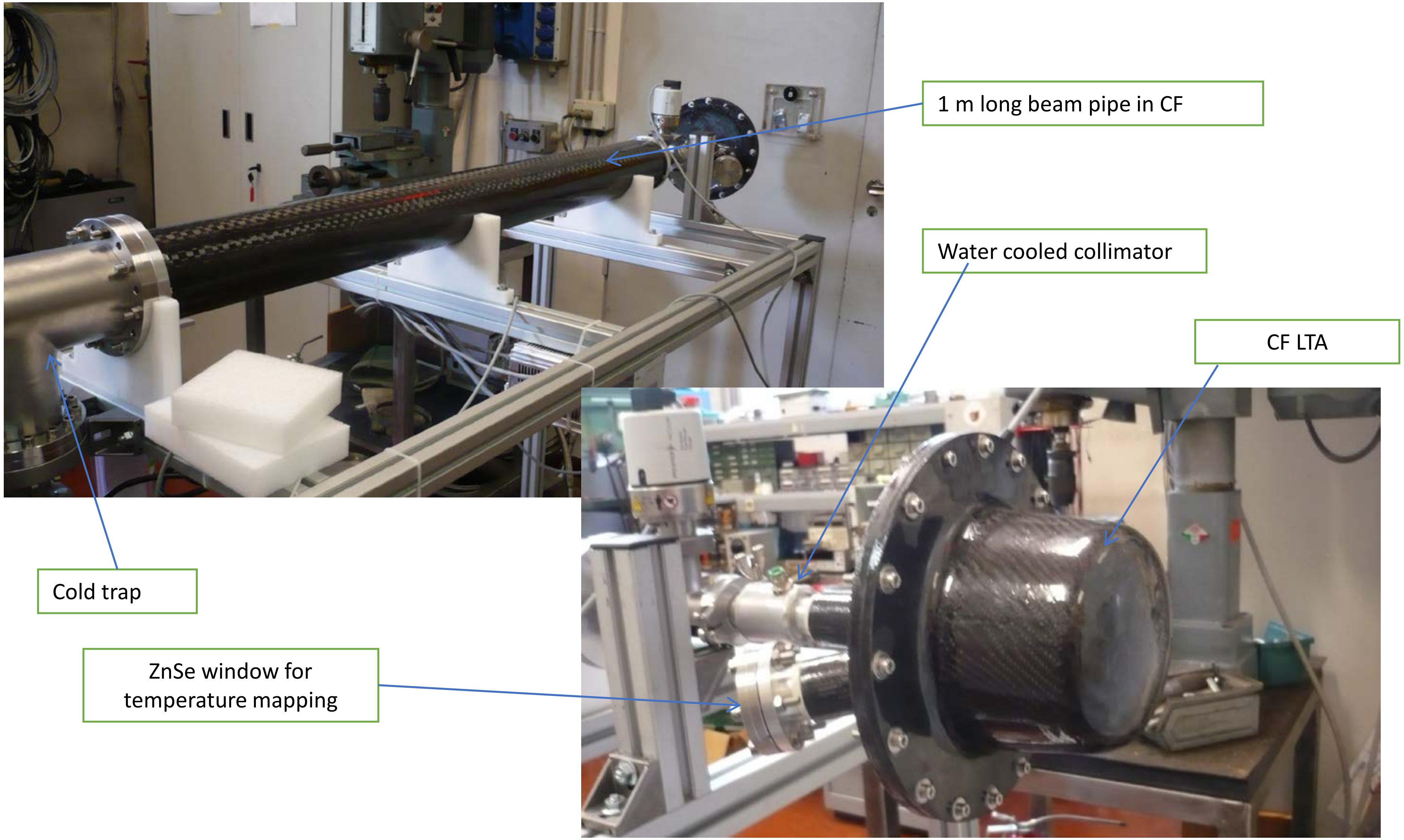
NO ^{10}B capsule
(background mesurement only)

With ^{10}B capsule
(neutrons selected trought 480 keV energy line)



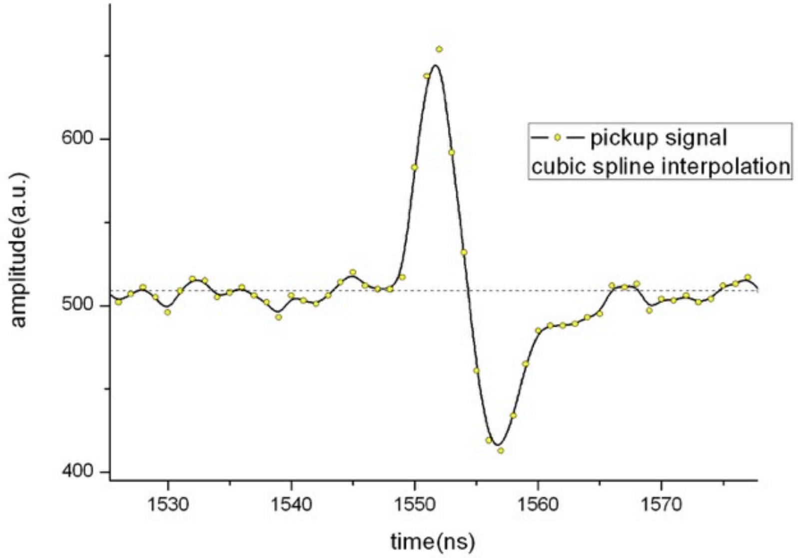


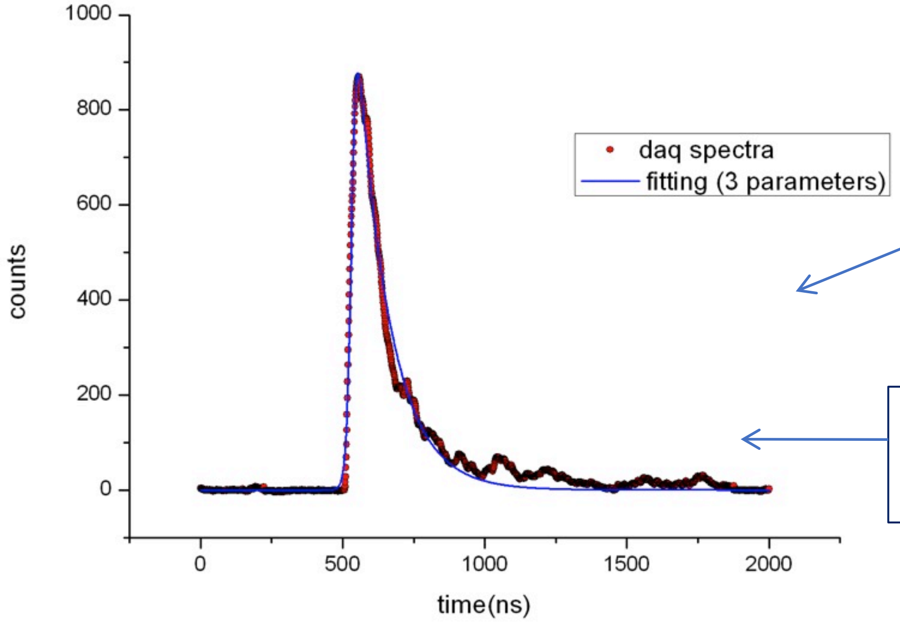
Lithium Target Assembly in CF



LENOS: MBNS at kT=30 keV. DAQ signal fitting.

Pickup signal. Cubic Spline fitting.
Base line crossing taken as time mark

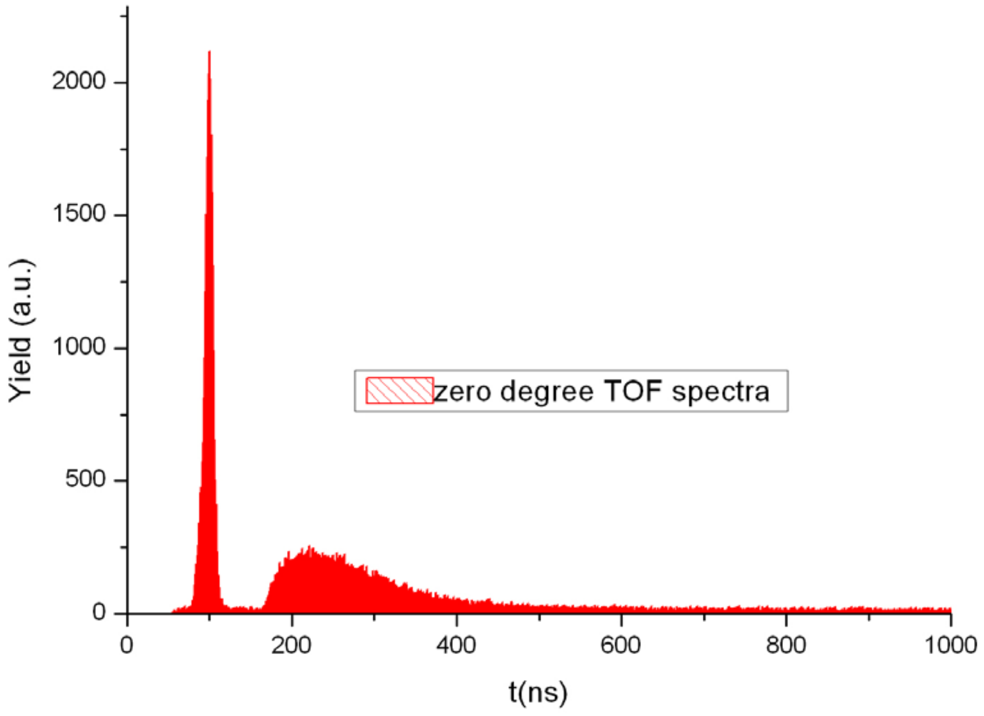


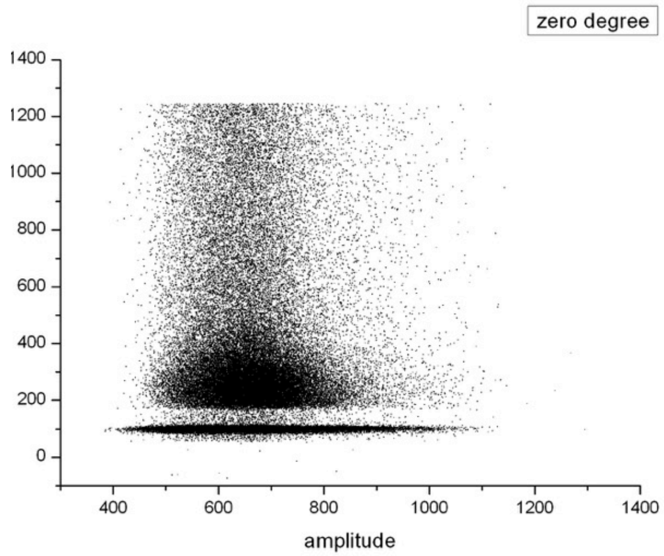


Li-glass Detector Signals shaped and amplified (Ortec TFA)

Detector signal fitted (minuit D506 CERNLIB)
Time at half maximum taken as time mark

Measurement MBNS at kT=30 keV: 0^o spectra.



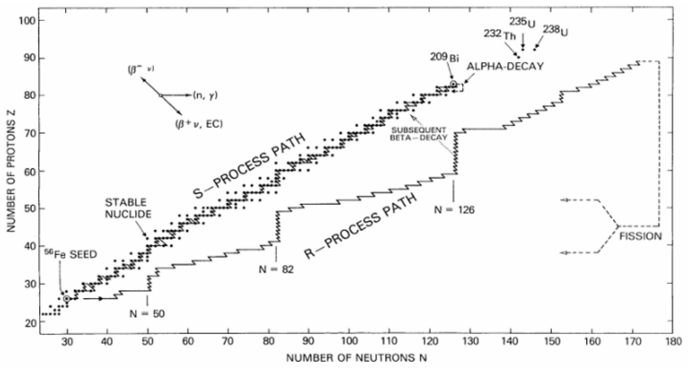


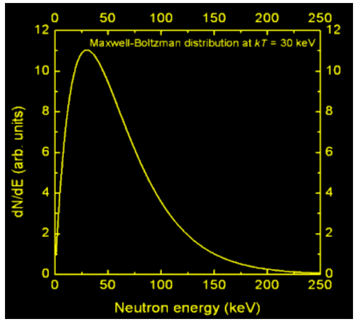
Good discrimination of gamma and neutrons.
2 ns width the gamma-flash peak.
Flat background.

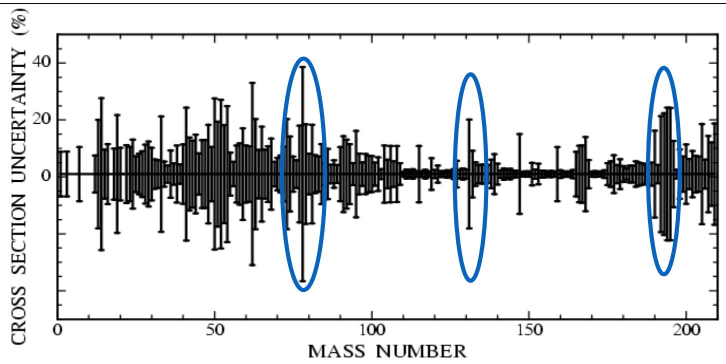
Physics motivations: Astrophysics

Nucleosynthesis of elements beyond Fe (B=8.8 MeV/A) are produced in stars by successive (n,ɣ) and β- decays.

The stellar velocity neutron spectrum is a Maxwell-Boltzmann distribution. Depending on the stellar site and the evolutionary stage of the star the most important kT are 8, 30 or 90keV, being 30 keV the standard temperature of reference.







$$\frac{dN_A(t)}{dt} = N_{A-1}(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_{A-1} - N_A(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_A - \lambda_\beta(t)N_A(t)$$

$$MACS \equiv \langle\sigma\rangle = \frac{\langle\sigma\cdot v\rangle_A}{v_T}$$

→ **MACS (Maxwellian Averaged Cross Section)**

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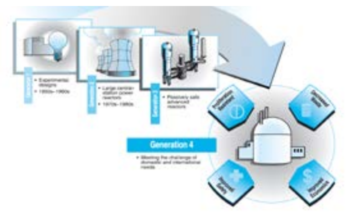
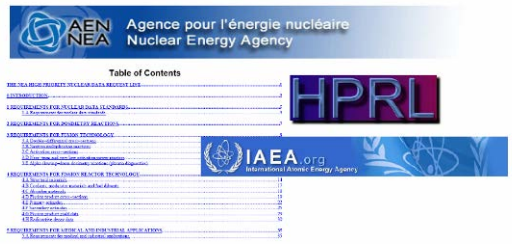
Motivations:
Validation of Evaluated Nuclear Data





Large request of data from the most important agencies (IAEA, NEA).
Some actinides for AFC and Gen-IV:
- Pu-239 fission in 1 keV – 1 MeV
- Pu-241 fission in 1 keV – 1 MeV
- U-238 capture in 2 – 200 keV
- Am-243 capture in fast and thermal energy range
- Am-241fission in fast energy range

P. Oblozinsky, NNDC

Often large discrepancies between data bases (ENDF, JENDL, JEFF, BRONDL) for many already measured isotopes.
No measurements for some important isotopes (mainly radioactive).
Integral measurements are accurate. The epithermal integral measurement can be performed using a well-characterized neutron spectrum (for example, Maxwell-Boltzmann like).

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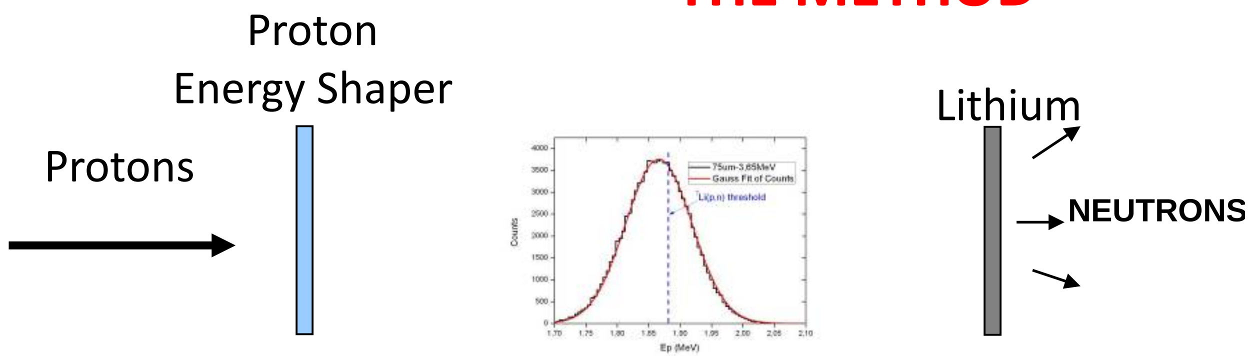
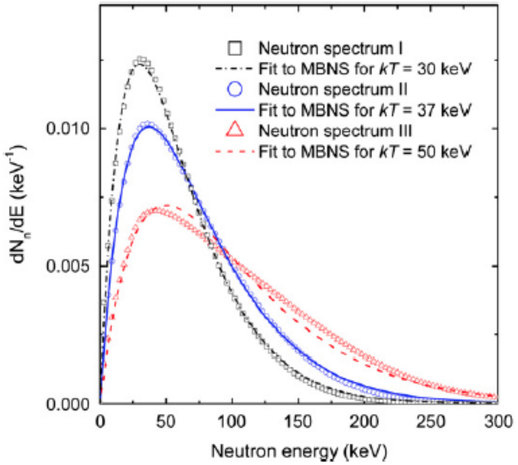
Physics case: Maxwell-Boltzmann Neutron Spectra (30-70 keV)

- Integral cross-sections in MBNS can also be used for the validation of evaluated data for the next IRDFF-2 database.
- MACS of large number of istopes meets the need in different fields (Nuclear astrphisycs, nuclear data for fast reactors, medical physics….)

THE METHOD



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

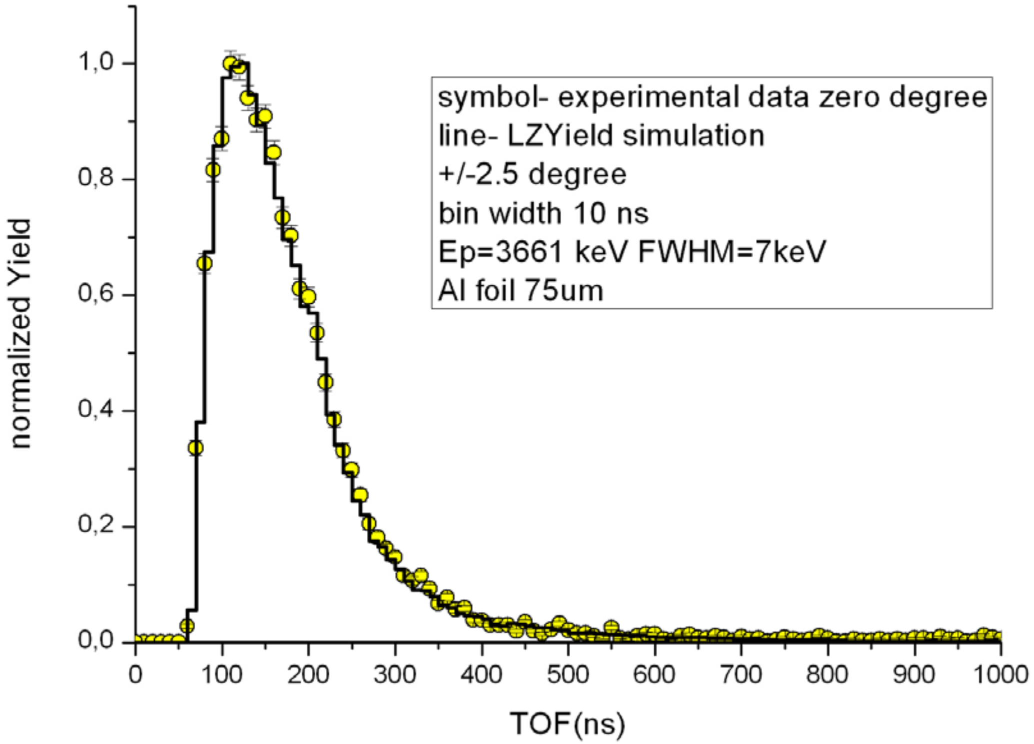


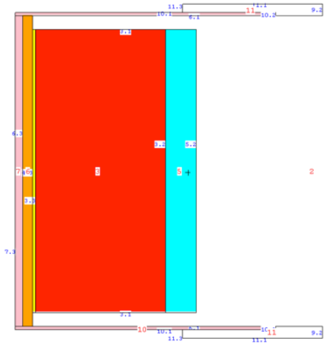
ARI *70 (2012) pg 1583-1589*

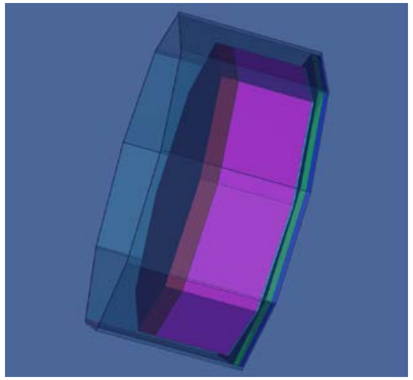
P.F. Mastinu *et al.*, NIM A 601, 333 (2009).

There are several combinations of proton energy, shaper thickness and material suitable for this method, as well as target to sample distance.
The first measurement is focused in the production of MBNS at kT=30 keV with Ep=3.666 MeV, 75 um thickness Al as proton energy shaper.

Experimental data: 0^o time spectra

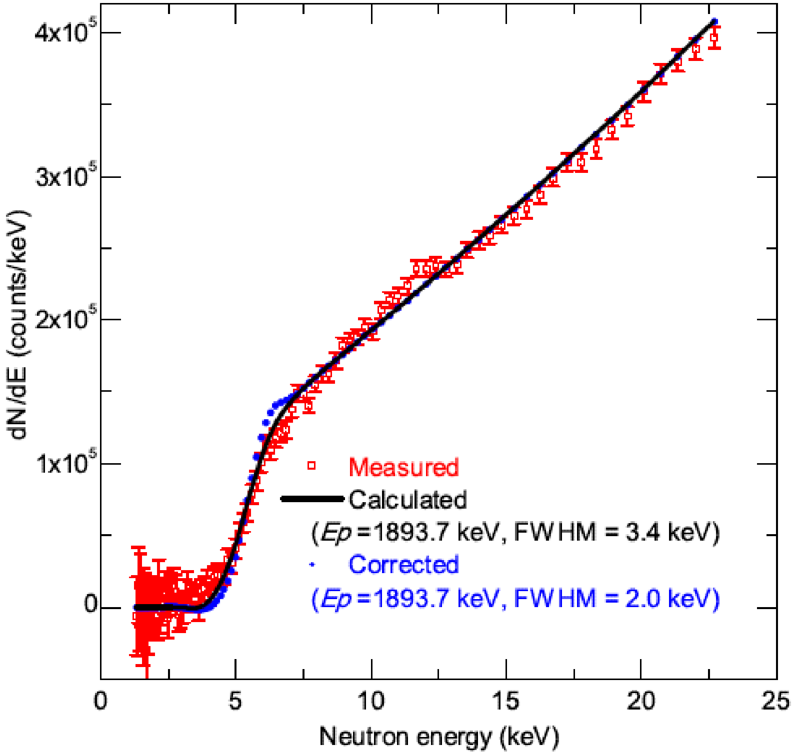


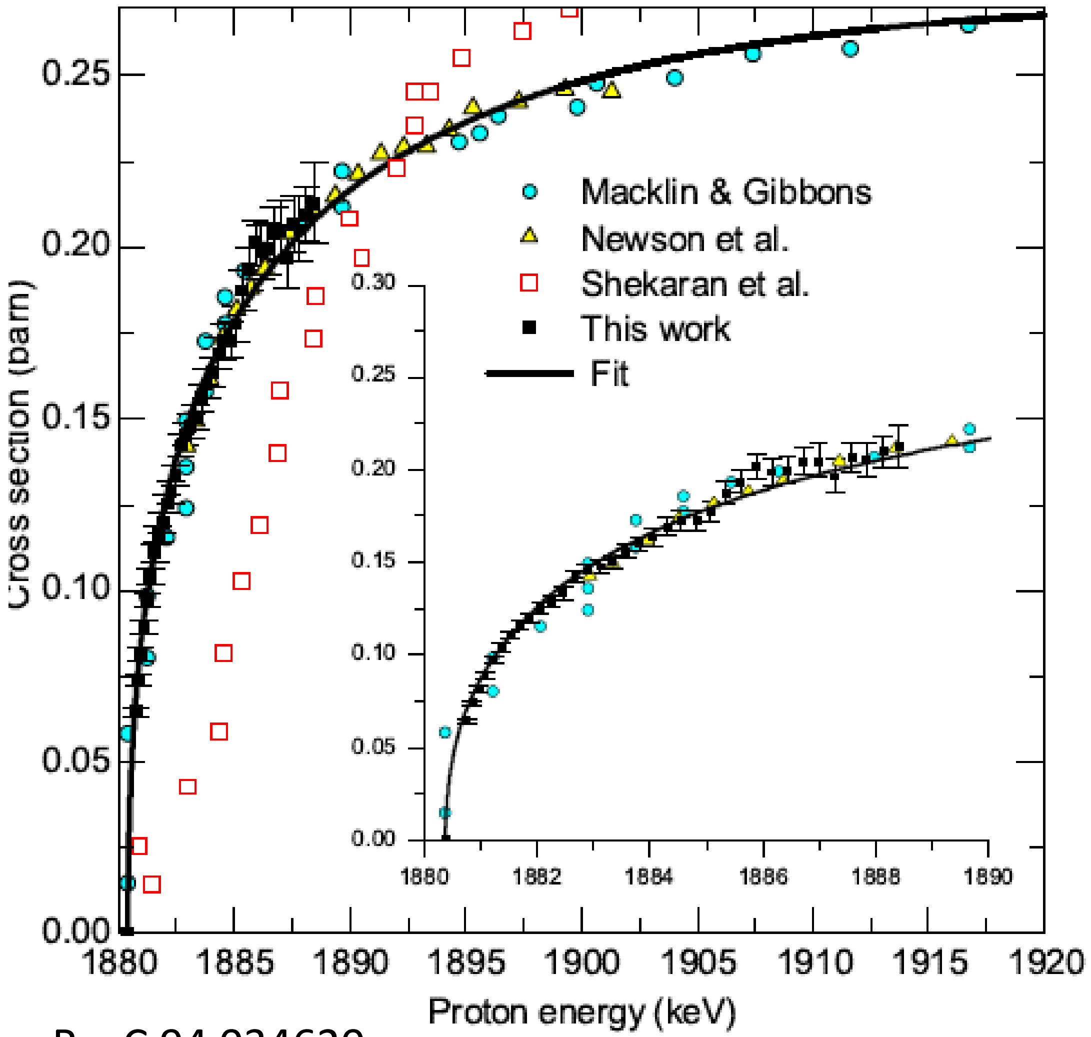




Yellow points are our experimental data at 0^o.
Black line is the simulated neutron spectra with our code LZYield/MCNPX.
detailed MCNPX geometry of the setup.

Near treshold $^7Li(p,n)$ reaction exitation function shape and neutron spectra



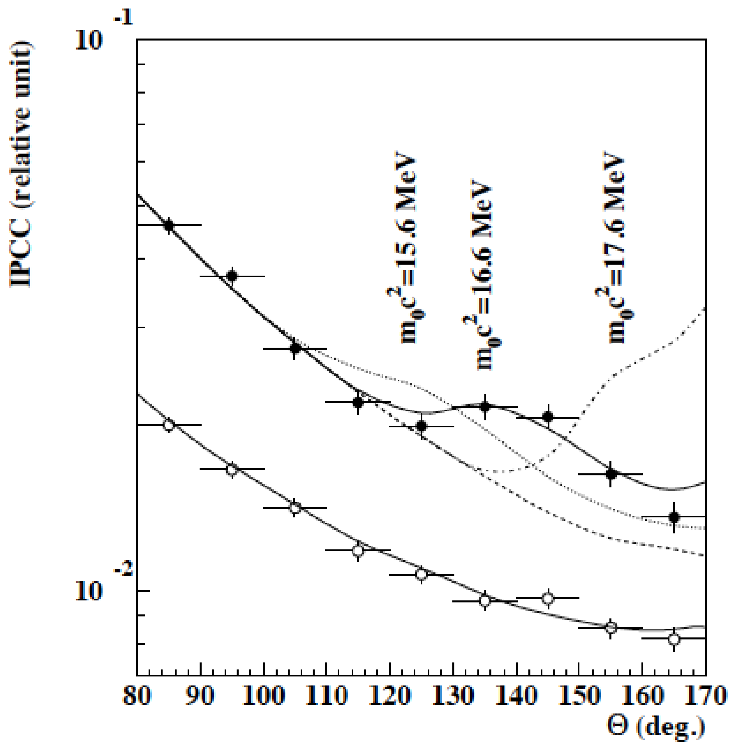


Phys RevC 94 034620

Searching for dark matter

Observation of Anomalous Internal Pair Creation in 8Be: A Possible Signature of a Light, Neutral Boson

1. Krasznahorkay,∗ M. Csatl´os, L. Csige, Z. G´acsi, J. Guly´as, M. Hunyadi,
1. Kuti, B.M. Nyako´, L. Stuhl, J. Tima´r, T.G. Tornyi, and Zs. Vajta
nstitute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki),



Searching for anomalous angular distribution in e+e-

Other interesting topics

- Measurement of gold MACS using 1.912 MeV $^{7}Li(p,n)$ relative to $^{235}U(n,f)$
- Delayed neutron emission
- Activation measurements for validation of nuclear data for dosimetry (IRDFF2 standard), both in epithermal and fast neutron energy range
- Mono and quasi-mono energetic neutron beams for detector calibration and response function
- Surrogate reaction methods
- Thomography with fast neutrons (pulsed beams) 7Li(p,n)
- 235U(n,f) neutron spectra
- Education, education, education (SNRI, etc...)

- Thank you for your attention