Nuclear Physics Institute Řež

LA150H library for the reaction $^{7}Li(p,n)$ and new experimental data on neutron production

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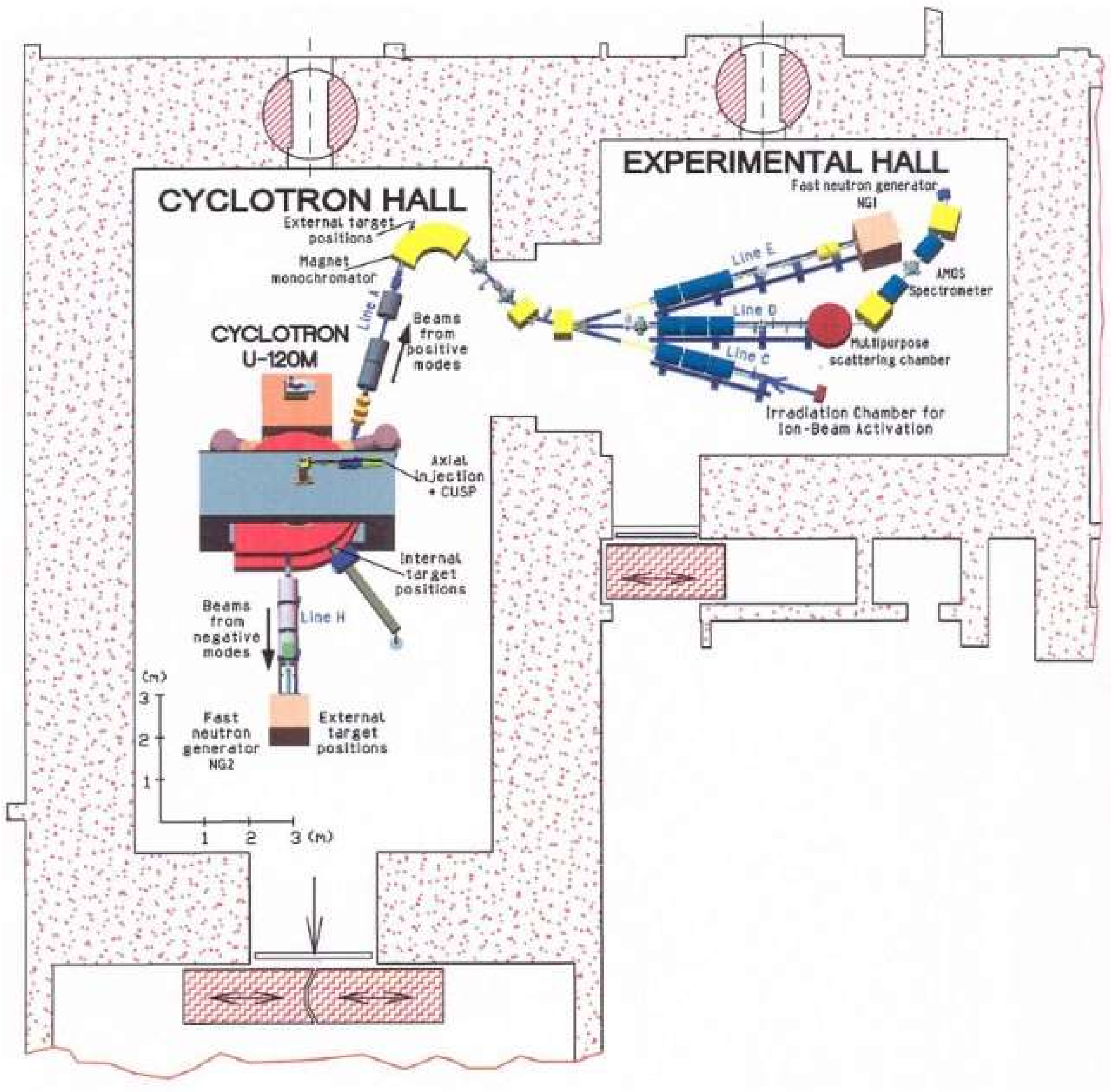
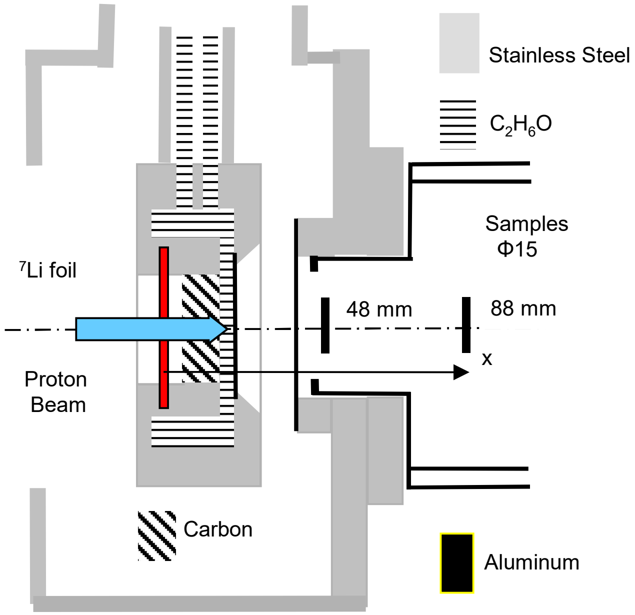
NPI neutron source target stations



Why do we need QM source?

- Neutron cross-sections at energies higher than few MeVs are becoming increasingly important in the future energy production:
  - fusion
  - Accelerator Driven Systems.
- The experimentally measured CS data for neutrons with energies above some 20 MeV are rare.
- Irradiation with the known neutron spectrum and the subsequent activity measurement is commonly used to determine the reaction CS.
- Monoenergetic neutron beams from the d+t reaction are commonly used below some 20 MeV neutron energy, while above this energy only quasi-monoenergetic (QM) beams are available.

p+thin ^{7}Li QM neutron generator

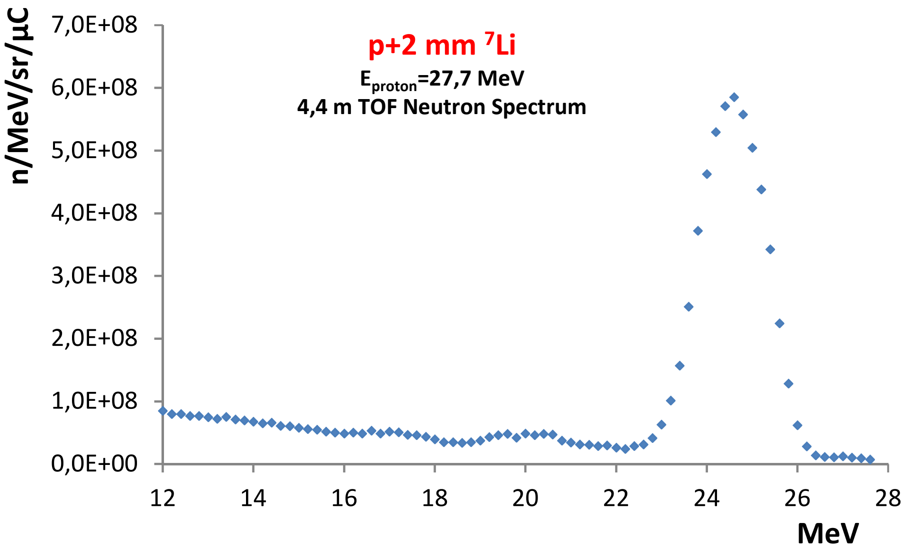


The p+Li reaction is the most used QM neutron generator.

- ^{7}Li(p,n) reaction on thin lithium target
- carbon beam stopper
- 20–37 MeV proton beam is used
- The neutron flux up to 3.10^{8} n/cm^{2}/s for the 37 MeV/5 μA proton beam and for the target-to-sample distance of 50 mm.

^{7}Li(p,xn) characteristics

- E_p = 1.9 ~ 2.4 MeV
  - Only ^{7}Li(p,n)^{7}Be$_{g.s.}$. Neutrons are monoenergetic, the reaction cross section is large. Source of neutrons n_0.
- E_p > 2.4 MeV
  - The ^{7}Li(p,n)^{7}Be, where ^{7}Be is in the first excited state at 0.43 MeV, contributes to the neutron spectrum. Below 5 MeV the zero-degree yield < 10 % of the ground state yield. Above 7 MeV, it is > 25 %. Source of neutrons n_1.
- E_p > 3.68 MeV
  - ^{7}Li(p,n^{3}He)^{4}He – 3-body breakup. The zero-degree neutron spectra are very broad.
- E_p > 7.06 MeV
  - The ^{7}Li(p,n)^{7}Be, where ^{7}Be is in the second excited state. The contribution is not significant. Source of neutrons n_2.



The n_0 and n_1 neutron yields are strongly forward peaked.

The zero-degree differential CS of ^{7}Li(p,n$_0$)^{7}Be and ^{7}Li(p,n$_1$)^{7}Be increases monotonically with increasing E_p , whereas the integral CS decreases monotonically above 5 MeV.

LA150H library extended by Mashnik et al.

Mashnik et al. [2000]

extends the ENDF-formatted cross section data library for protons on ^{7}Li, incident proton energies up to 150 MeV.

Experimental background

$^{7}Li(p,xn)$

- Threshold – 8 MeV: Meadows and Smith, using the Argonne Fast-Neutron Generator
- 10 – 20 MeV: Anderson *et al.,* at Lawrence Radiation Laboratory
- 4.3 – 26 MeV: Poppe *et al.,* Van de Graaff, cyclotron at Livermore, summarized all measurements before 1976
- 15, 20, and 30 MeV: McNaughton *et al., at* the Croker Nuclear Laboratory
- Above 20 MeV: number of other groups
- 18 – 38 MeV: Uwamino et al. **not included !**

LA150H library extended by Mashnik et al.

The center-of-mass measured angular distributions of both the n_0 and n_1 neutrons were fitted using Legendre polynomials,

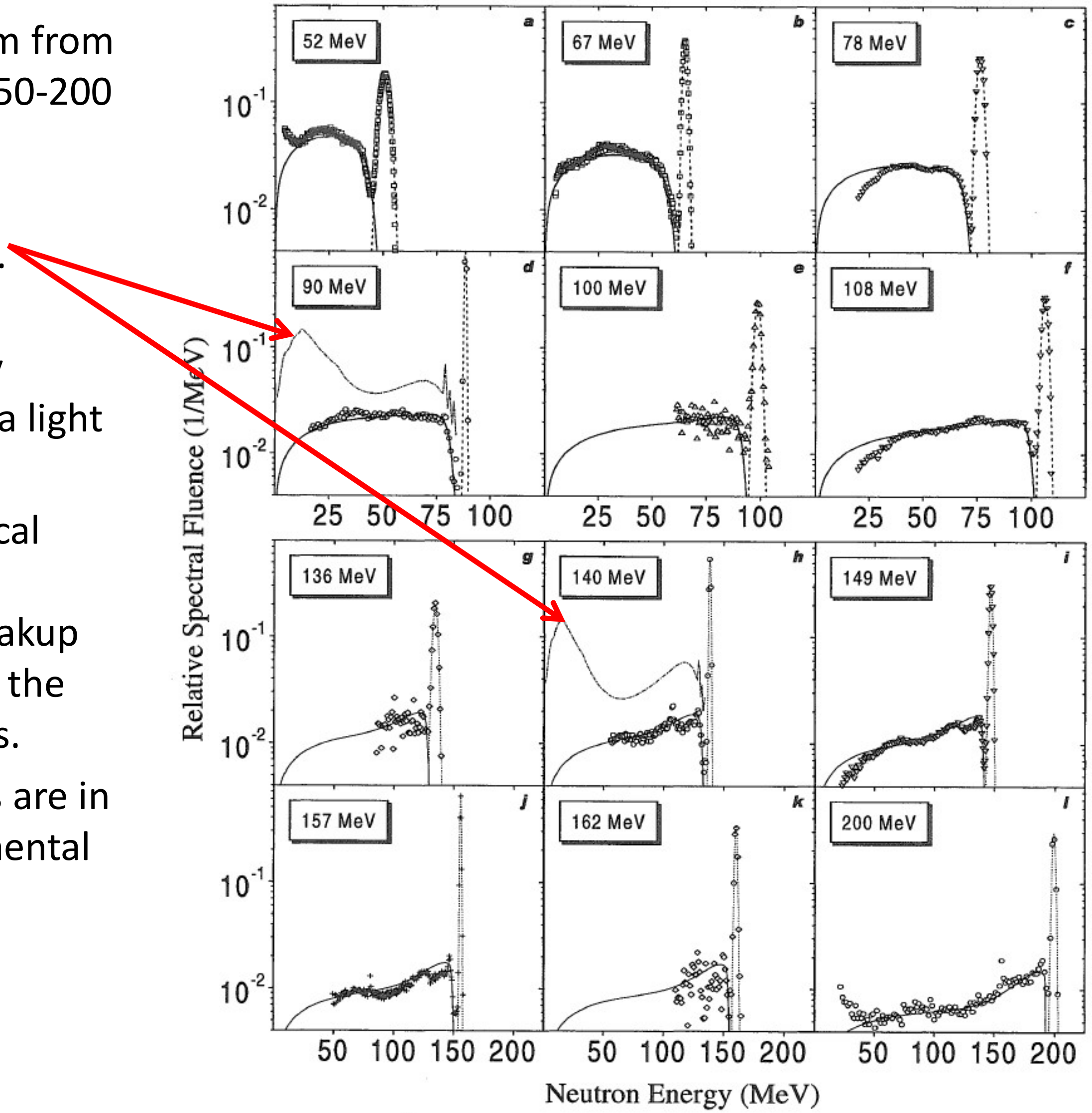
$$\frac{d\sigma_{c.m.}}{d\Omega} = \sum_{n=0}^{N} A_n P_n(\cos\theta)$$

The remaining part of the neutron flux is estimated by preequilibrium and Hauser-Feshbach calculation using the GNASH code.

- The input optical potentials were modified.
- The utility code for GNASH modification was used for exclusion of n_0 and n_1 neutron emission contribution. The inclusion of the n_0 and n_1 neutron emission contribution is based on measurements.

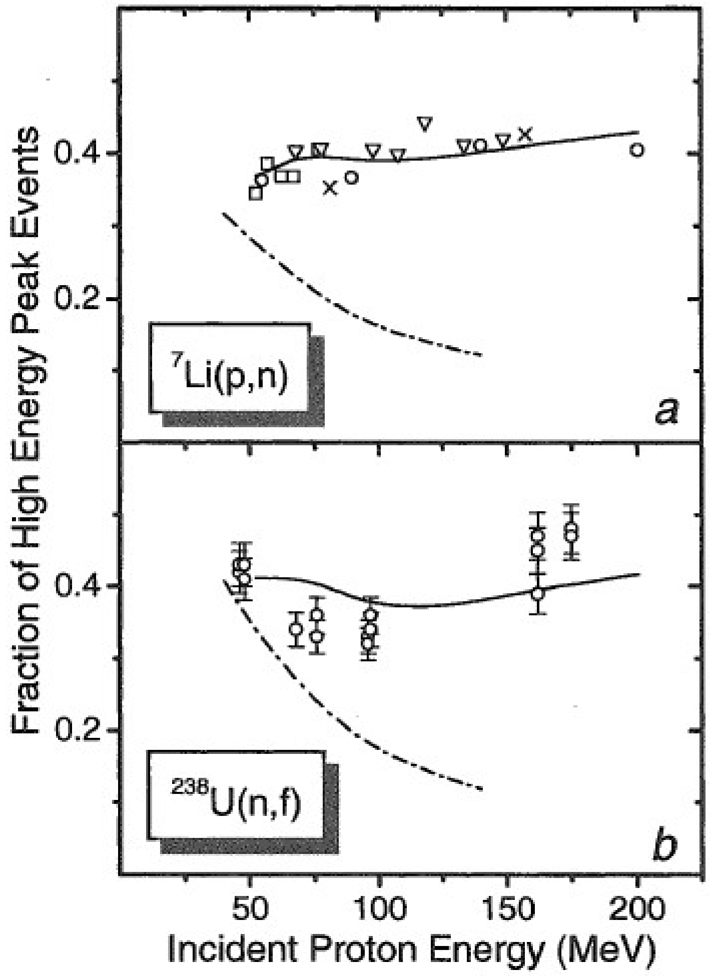
Development of nuclear data library by Prokofiev et al.

- The spectral fluence of the n spectrum from the ^{7}Li(p,n) reaction at 0 deg for E_p = 50-200 MeV was assessed.
- The simulation using LA150H library disagrees with the experimental data.
- The model calculations based on the preequilibrium and equilibrium decay theories may be inadequate for such a light nucleus as ^{7}Li.
- Prokofiev developed the semi-empirical systematics based on a phase-space distribution corresponding to the breakup process ^{7}Li(p,n^{3}He)α, completed with the correction on the experimental points.
- The Prokofiev systematics predictions are in good overall agreement with experimental data.
- The missing part of the experimental spectrum was reconstructed.



Development of nuclear data library by Prokofiev et al.

- The fraction of high-energy peak has been calculated on the basis of
  - Prokofiev model (solid line)
  - LA150H library simulation (dash-dotted line)
  - experimental data
- Event distributions of the neutron-induced fission of ^{238}U nucleus were used for calculation of the fraction of fission induced by high-energy peak neutrons.
- Fractions calculated using the Prokofiev model reasonably agrees with the experimental results.
- Results of the similar calculations from the LA150H library are in disagreement with the experiment.
- The Prokofiev systematics should be used with caution al lower neutron energies.



Further development of the ^{7}Li-proton file in the LA150 library is needed.

^{7}Li(p,n) measured by Uwamino et al.

- Differential CS for E_p = 20, 30 and 40 MeV measured, for E_p between 25 and 800 MeV collected to get universal curve.
- The $n_0 + n_1$ neutron fluence in the forward direction

$$\phi_{\text{peak},\theta=0} = N_{\text{Be}-7} R \quad (\text{n sr}^{-1}),$$

$N_{\text{Be}-7}$ number of the produced ^{7}Be nuclei in the Li target

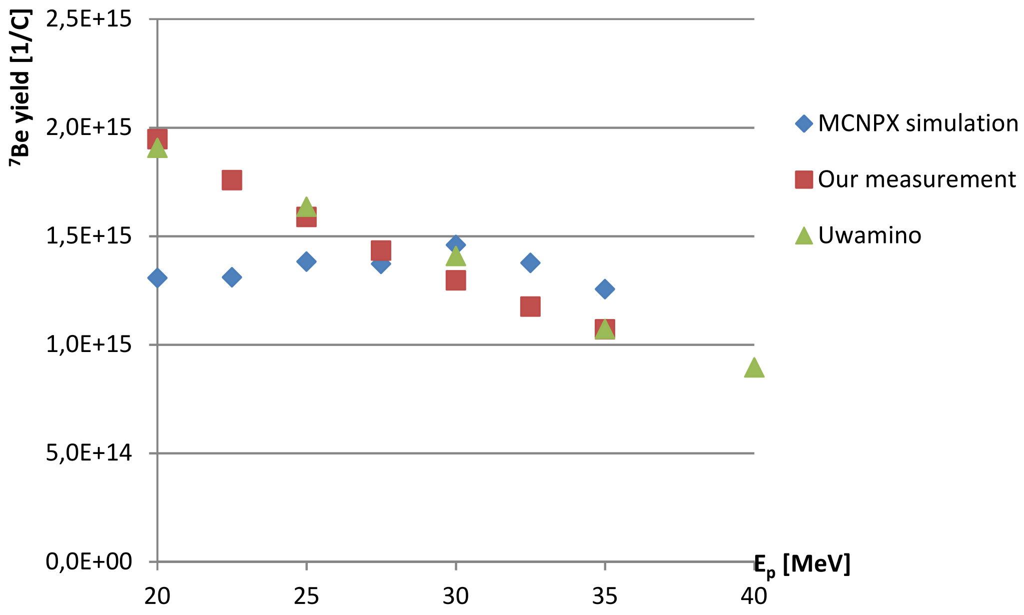
$$R = \frac{(\mathrm{d}\sigma/\mathrm{d}\Omega)_{\theta=0}}{\int_{4\pi} (\mathrm{d}\sigma/\mathrm{d}\Omega)\mathrm{d}\Omega} \quad (\text{sr}^{-1}),$$

R index of forwardness

$$R = -5.155 \times 10^{-13} E_p^4 + 4.409 \times 10^{-9} E_p^3 + 2.483 \times 10^{-5} E_p^2 + 6.521 \times 10^{-2} E_p - 0.8636,$$

Comparison of the measured and LA150H obtained CS of the $^{7}Li(p,n)^{7}Be$ reaction

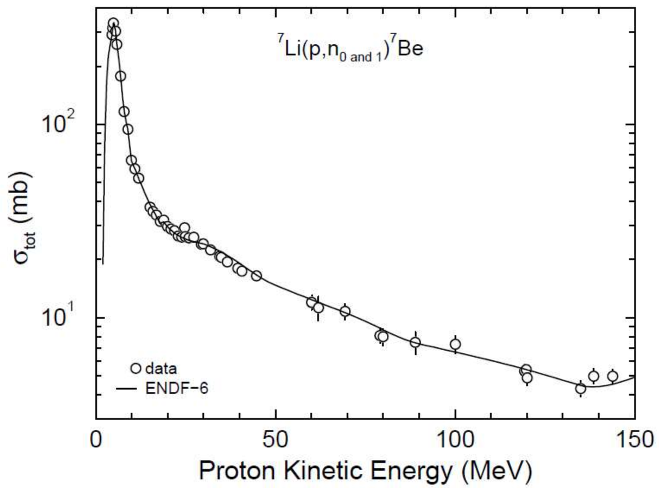
- 2-mm Li target bombarded by protons at energies between 20 and 35 MeV was chosen as the input data for simulation.
- The MCNPX simulation of the $n_0 + n_1$ neutron flux in the forward direction using LA150H was performed.
- The MCNPX calculated neutron flux was divided by R to obtain ^{7}Be yield.

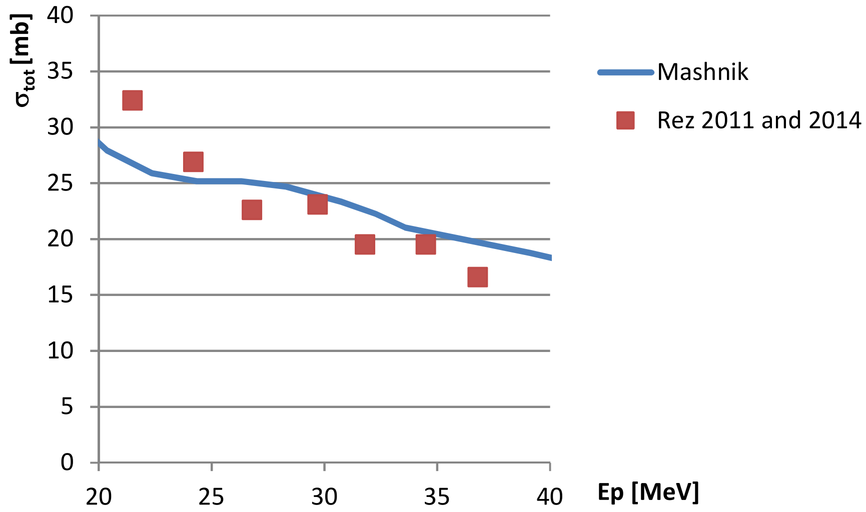


The comparison of ^{7}Be yield, obtained by the MCNPX, with our measured data shows the LA150H data discrepancy with experiment.

Comparison of the measured and LA150H obtained CS of the $^{7}Li(p,n)^{7}Be$ reaction

Part of the $n_0 + n_1$ CS data collected and fitted by Mashnik was compared with CS obtained in our measurements.

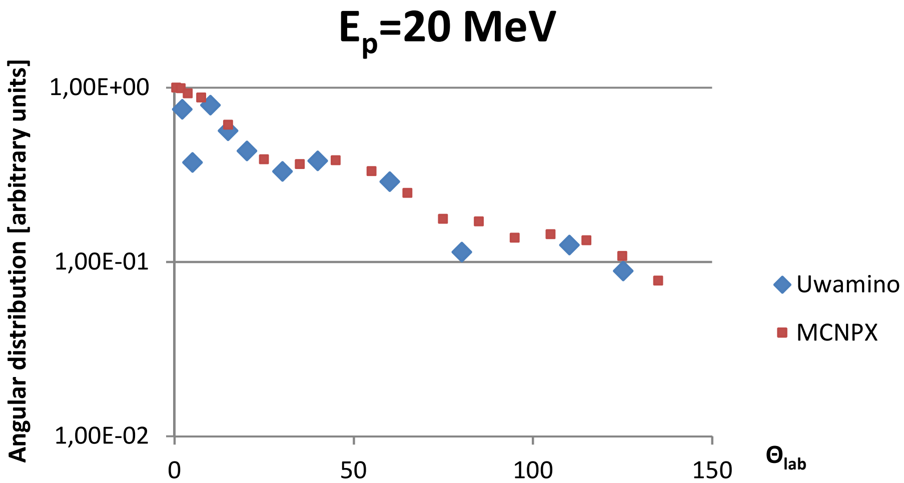


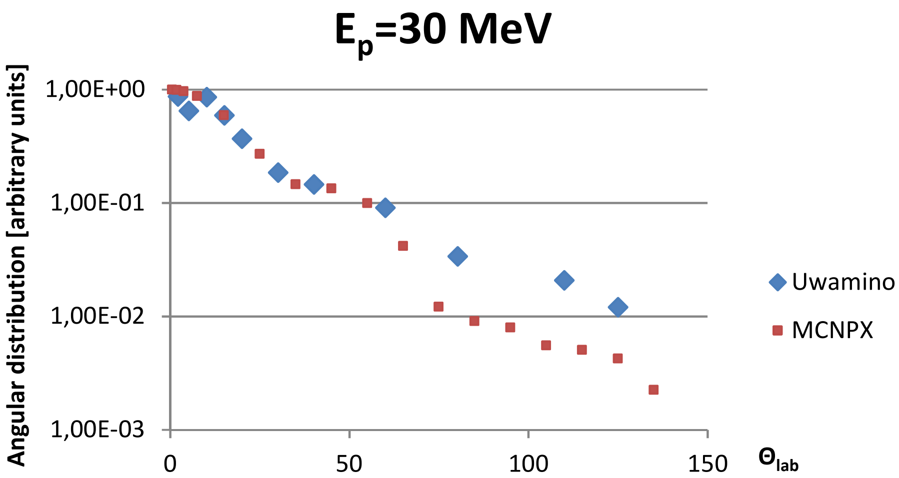


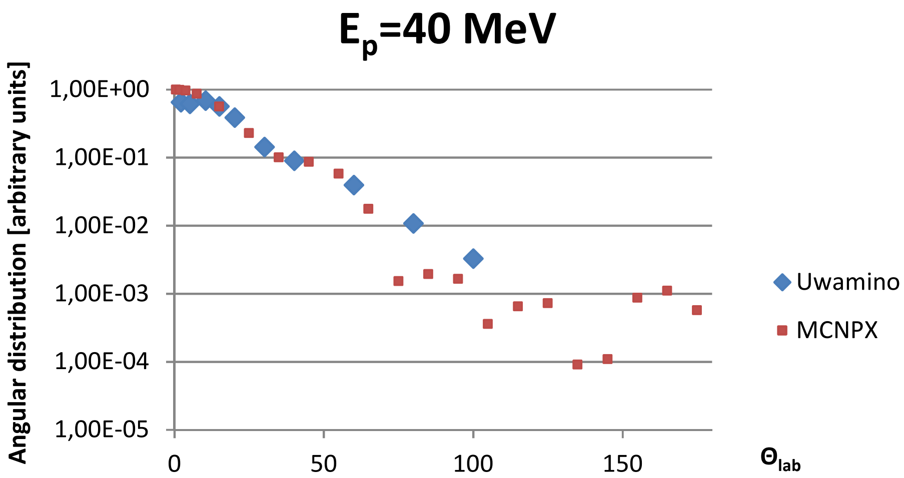
The comparison of the $n_0 + n_1$ CS data given by Mashnik with our measured data shows the LA150H data discrepancy with experiment.

Comparison of the measured and LA150H obtained angular distribution of the $^{7}Li(p,n)^{7}Be$ reaction

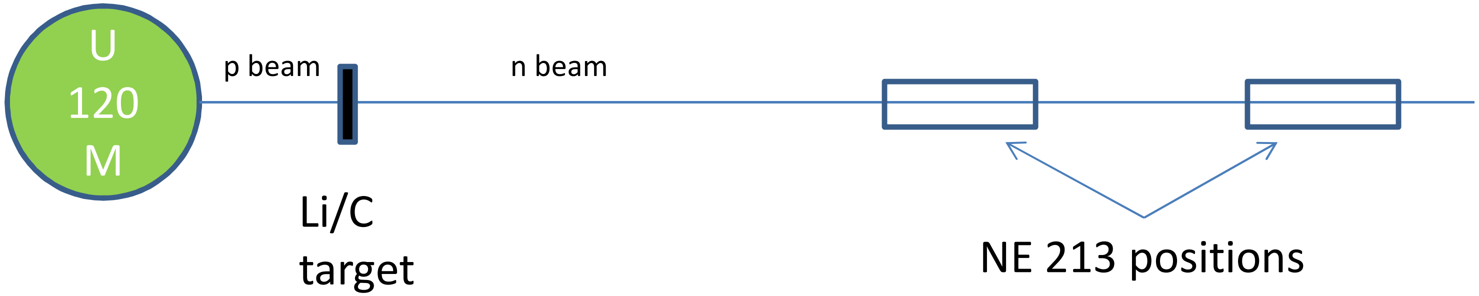
- Angular distribution discrepancies for Θ_{lab}>50 deg, namely at E_p = 30 and 40 MeV.
- Implausible points for Θ_{lab}<7,5 deg in the Uwamino angular distribution.

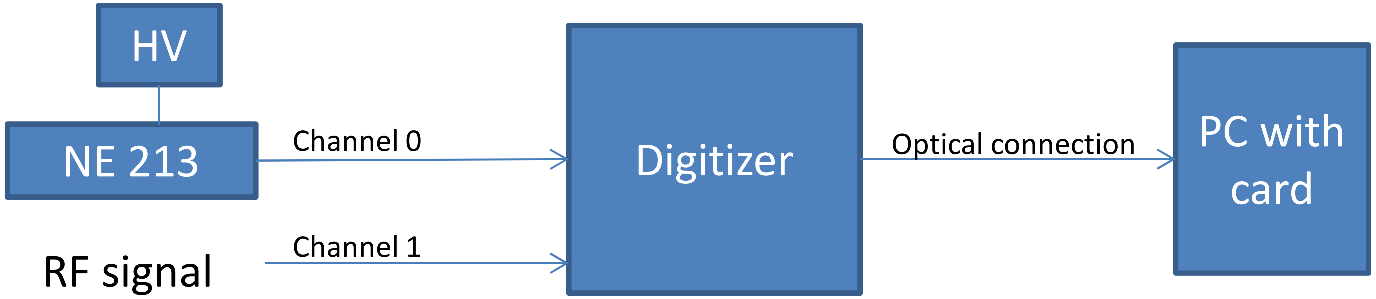






TOF measurement in NPI

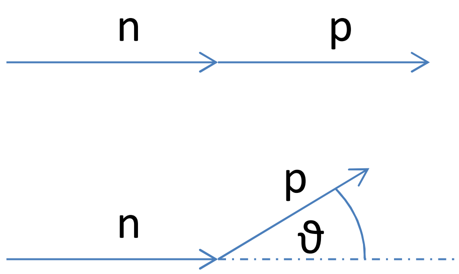




- CAEN V1751 digitizer: 1GHz sampling rate, 10 bits resolution
- Simultaneous sampling of the anode signal from the scintillation probe and the cyclotron accelerating frequency (RF)

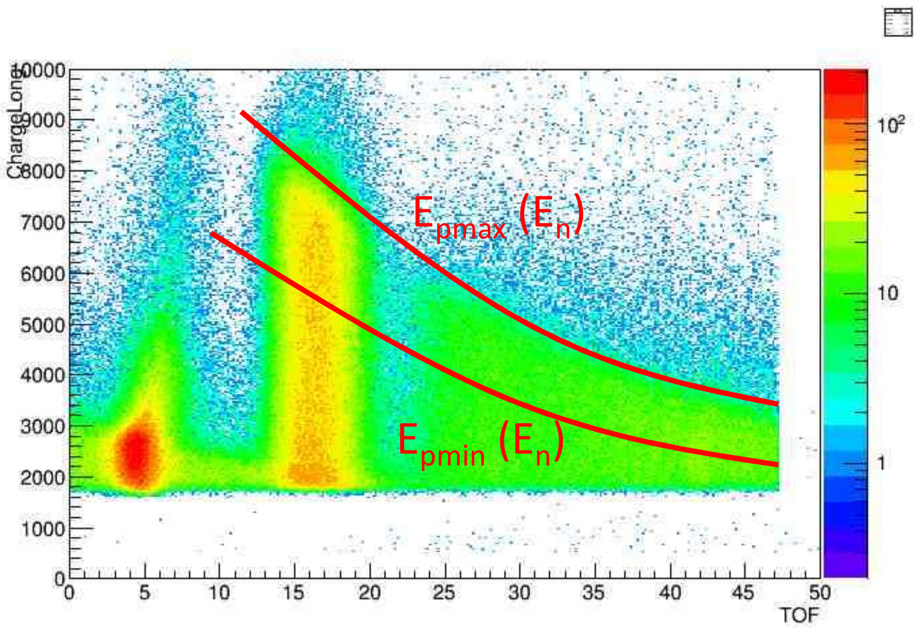
TOF measurement in NPI

Dynamic threshold method



$E_{pmax}\,(E_n) = E_p(E_n, 0) = E_n$

$E_{pmin}\,(E_n) = E_p(E_n, \vartheta_{max})$



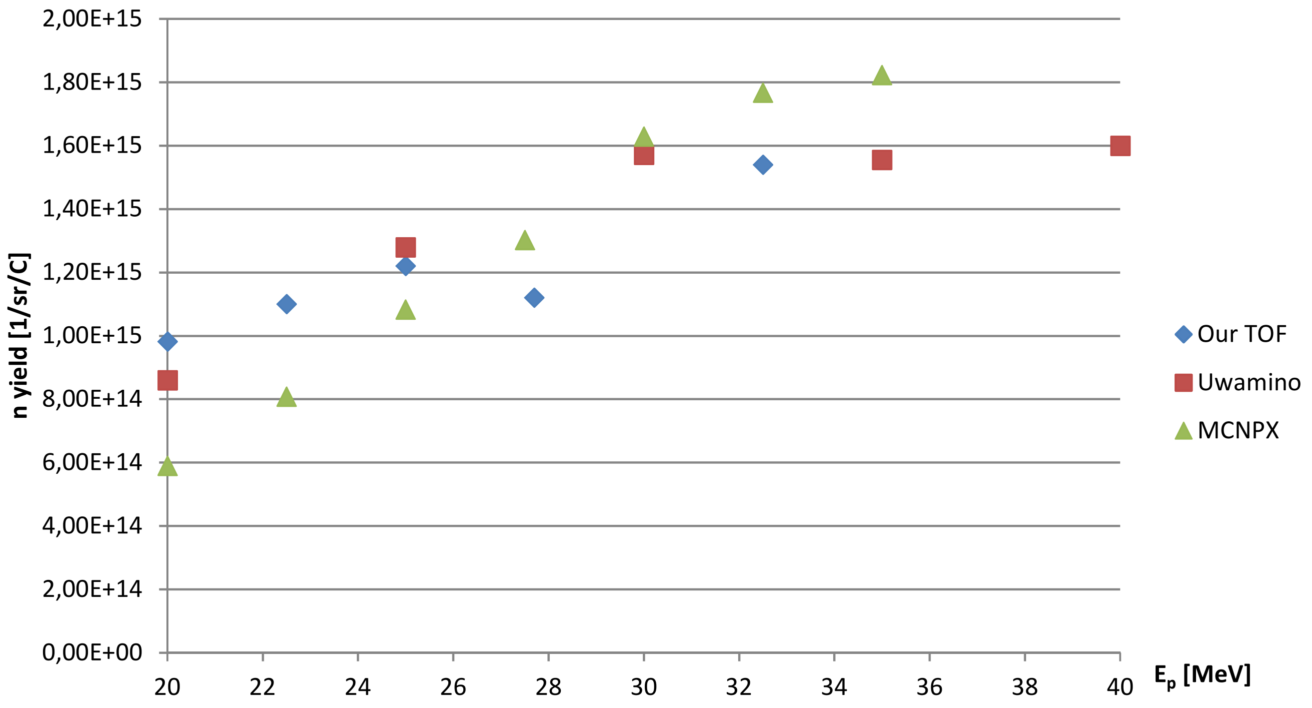
$$\frac{dN_n}{dE_n}(E_n) = \frac{\frac{dN}{dE_n}(E_p > E_{p\min}(E_n), E_n)}{\eta(E_p > E_{p\min}(E_n), E_n)}$$

$$\eta(E_p > E_{p\min}(E_n), E_n) = 2\pi\rho_S \int_0^{\vartheta_{\max}} \frac{d\sigma}{d\Omega} \sin(\vartheta)\, d\vartheta$$

\+ boundary effects

This approach removes the necessity to know the whole response function of the scintillator, the results are based only on the number of hydrogen atoms in the scintillator and on the cross-section of elastic scattering of neutrons on hydrogen, which are both accurately known.

Comparison of energy dependence of neutron yield



- Our TOF measurement is in good agreement with Uwamino
- The MCNPX calculated dependence markedly differs from our and Uwamino dependence.

Conclusions

- LA150H library does not contain Uwamino data.
- The simulations of neutron energy spectra for E_p = 50-200 MeV, using LA150H library, disagrees with the experimental data.
- The comparison of ^{7}Be yield, obtained by the LA150H based MCNPX calculation, with our and Uwamino measured data for E_p = 20-35 MeV shows the LA150H data discrepancy with experiment.
- CS data given by Mashnik does not agree with our measured data.
- Angular distributions obtained by the MCNPX calculation does not agree with angular distribution measured by Uwamino.
- The n_0+n_1 yield at 0 deg simulated by MCNPX disagrees with the our and Uwamino measurement.

Therefore

Further development of the ^{7}Li-proton file in the LA150 library is needed.

Thank you for your attention