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NUCLEAR DATA MEASUREMENTS WITH COLLIMATED FAST NEUTRON BEAMS GENERATED ON U-120M CYCLOTRON

Nuclear Physics Institute of the ASCR
public research institution

Center of Accelerators and Nuclear Analytical Methods (CANAM)

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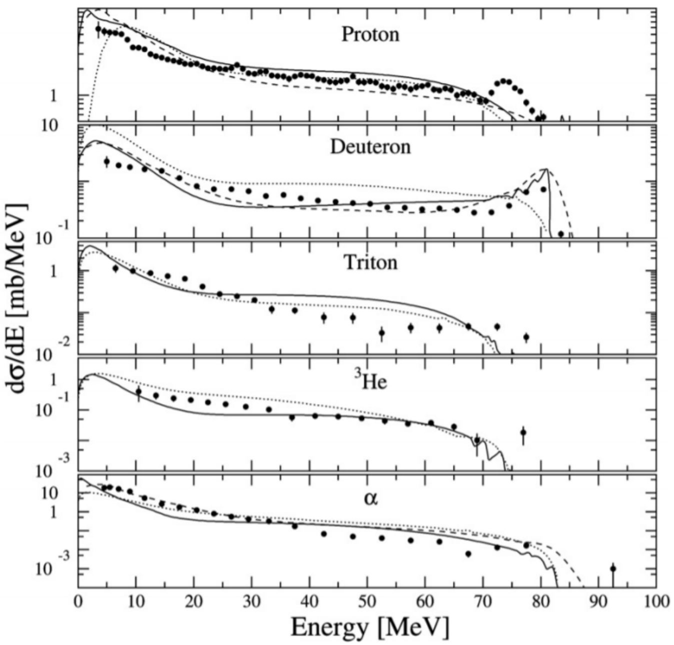
Cross-sections for Reactions Induced by Fast Neutrons

- Fast neutrons – at NPI it means energy region 1-33 MeV
- In long-term materials are activated and damaged by fast neutron irradiation
- Energy region above 20 MeV – Few experimental data
- Testing and validation of construction materials for usage in future projects (fusion -ITER, DEMO, IFMIF; ADS; spallation neutron sources)
- Physics of nuclear reactions induced by fast neutrons – Double-Differential CS for (n, cp) reactions

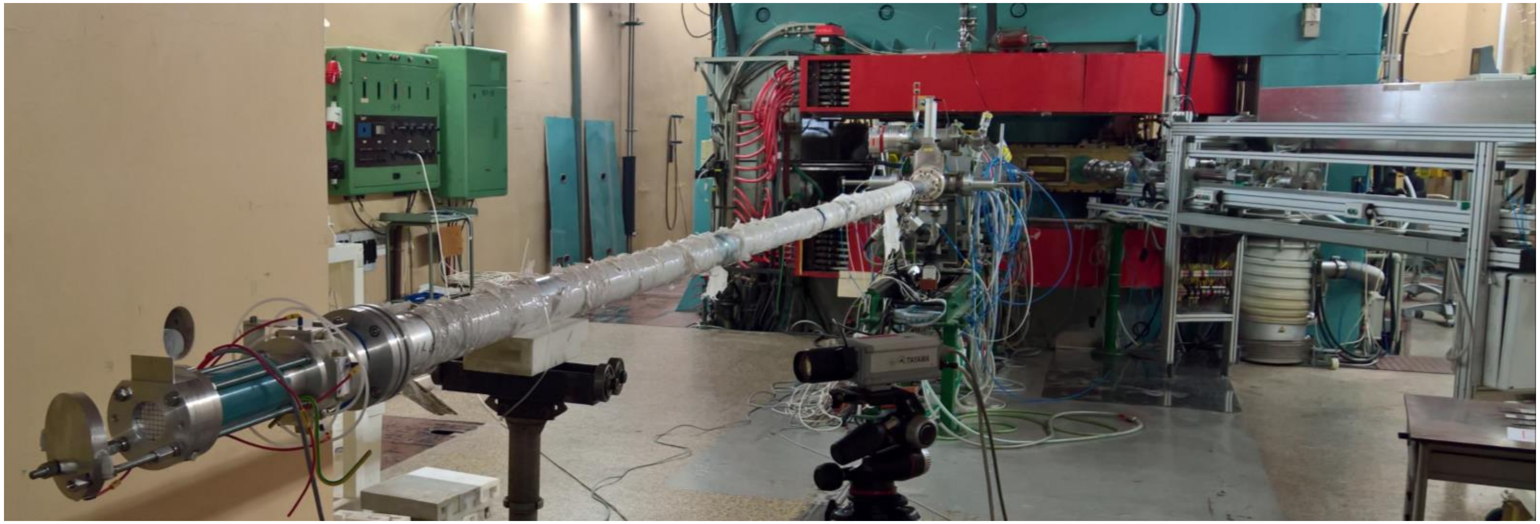


Double-differential cross sections and kerma coefficients for light-charged particles produced by 96 MeV neutrons on carbon

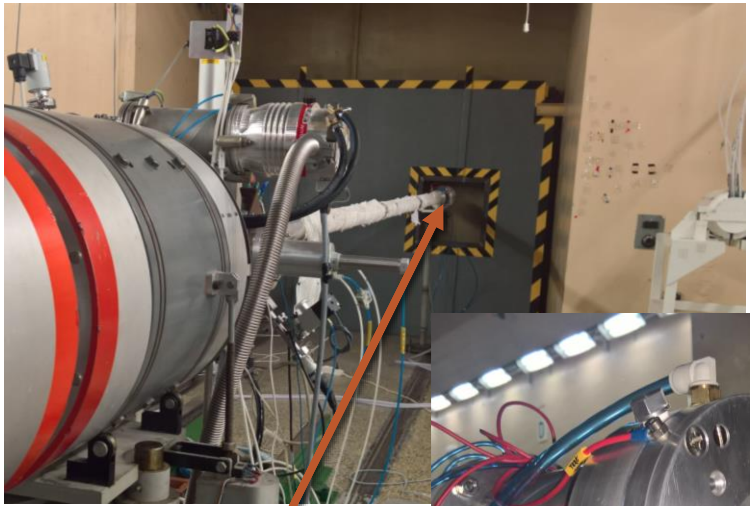
U. Tippawan [a, b], S. Pomp [b], J. Blomgren [b], S. Dangtip [a, b], C. Gustavsson [b], J. Klug [b], P. Nadel-Turonski [b, c], M. Österlund [b], L. Nilsson [b], N. Olsson [b, e], O. Jonsson [d], A.V. Prokofiev [d], V. Corcalciuc [f], A.J. Koning [g], Y. Watanabe [h]

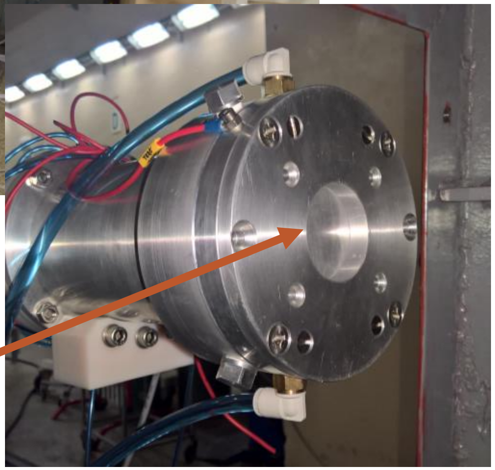
Laboratory of fast neutron generators

- Isochronous cyclotron U-120M - p, d, He, alpha ~ 1-35 AMeV
- Production of fast neutrons in reactions $p+^{7}Li$, $p+^{9}Be$
- Quasi-Monoenergetic or white energy neutron spectra are produced
- Maximum kinetic energies range 18 - 33 MeV
- Collimated neutron beams coupled with semiconductor detectors for on-beam measurements

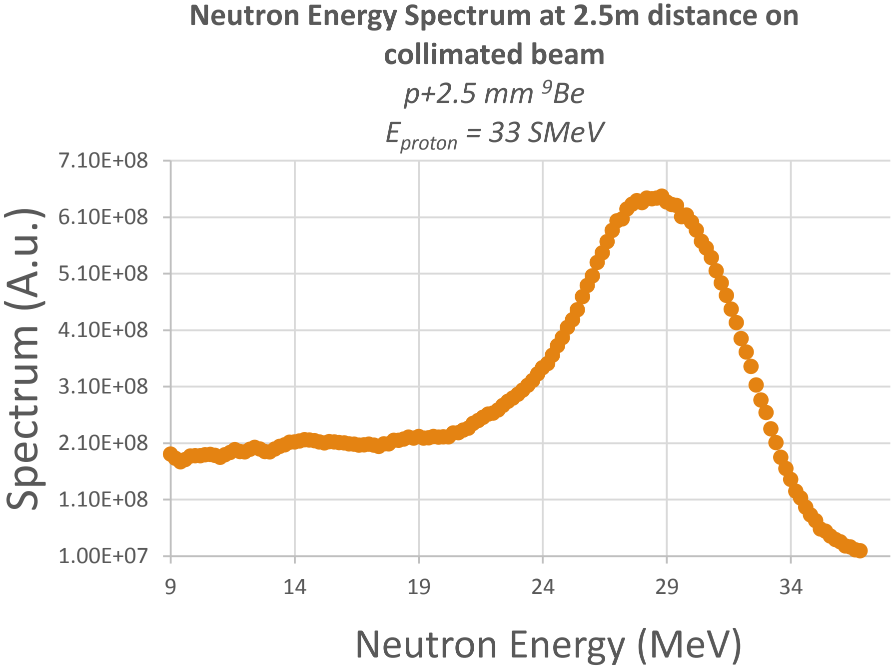


New thin-Be FNG driven by U-120M cyclotron





2.5 mm Be foil backed with Graphite beam stoper, cooled with demineralized water.



Detection Systems for Collimated Beams of Fast Neutrons at NPI

- ToF Technique for energy spectra determination with organic scintillators
- Array of four HPGe detectors for on-beam gamma spectroscopy – (n, γ) (see talk of Mr Koliadko):
  - prompt gammas
  - Delayed gammas -isotopes with decay times down to ms
- Vacuum chamber for light ion detection - (n,cp)
- Transmission experiments with total neutron cross-section extraction - (n, tot)

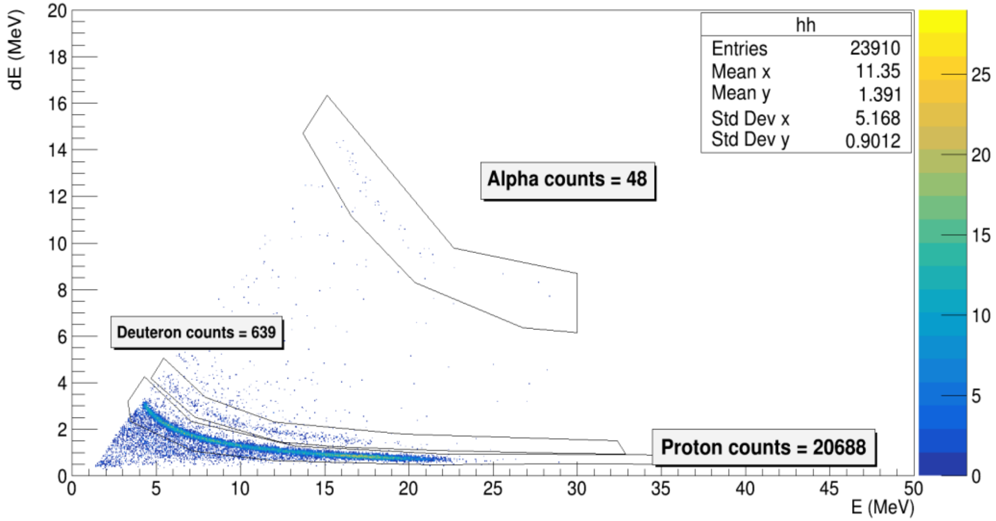
NPI Chamber for Light Ion Detection – „CLIDevice“

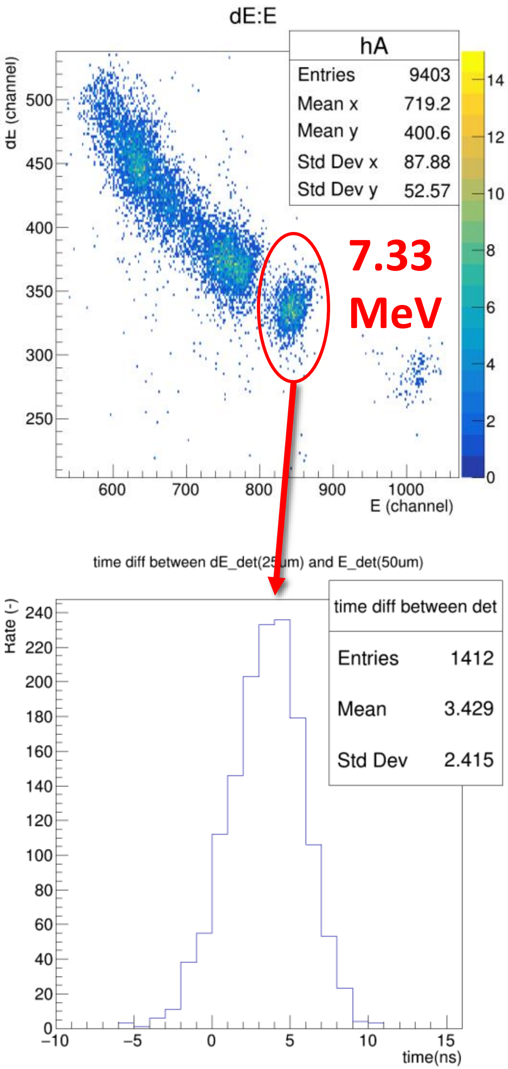
- Detection of light ion particles (p, d, t, ^{3}He, α) produced in nuclear reactions induced by fast neutrons
- Measurements of double-differential cross sections for reactions (n, cp) with Time-of-Flight method
- Equipped with dE-E Si-detector telescopes for distinguishing between cp types
- Digitalized data acquisition
- Since October 2019 operated in test mode
- High degree of automation

First tests with CLIDevice

- Beam of collimated neutrons (collimator diam. 3 cm) from p(34 MeV)+Be (2.5 mm) reaction
- Two Silicon detectors mounted on the remote-controlled table in vacuum chamber
- The PE target foil (thickness of 180 um, diam 3 cm) was mounted into the central position - $^{1}H(n,p)$, $^{12}C(n,p/d/t/\alpha)$
- Irradiation time 5h 50min

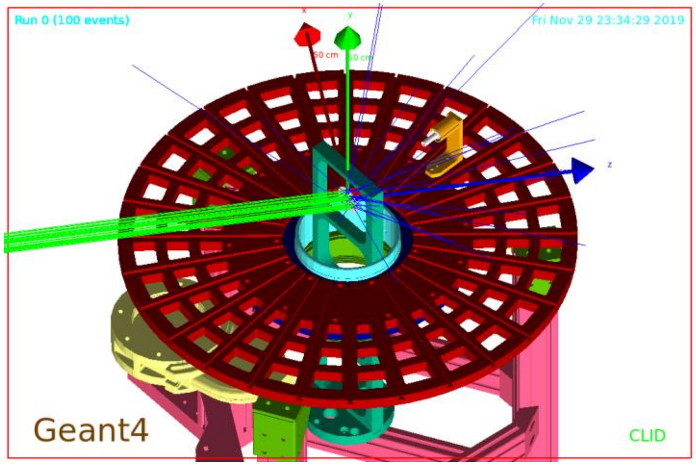
Telescope n. 2 (Si dets 150um + 5mm, Angle 36.4°):

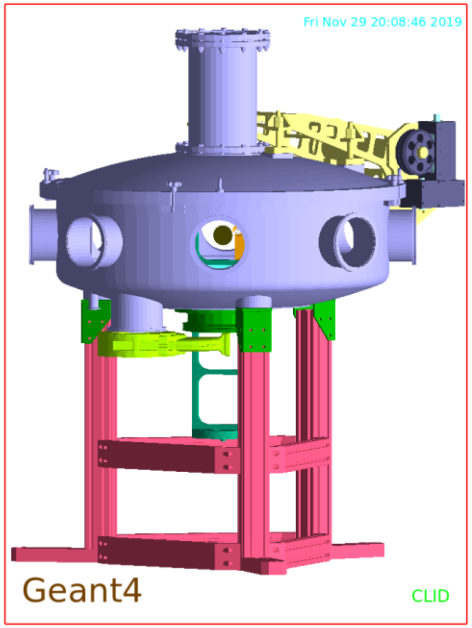




Time resolution of Si dE-E telescopes

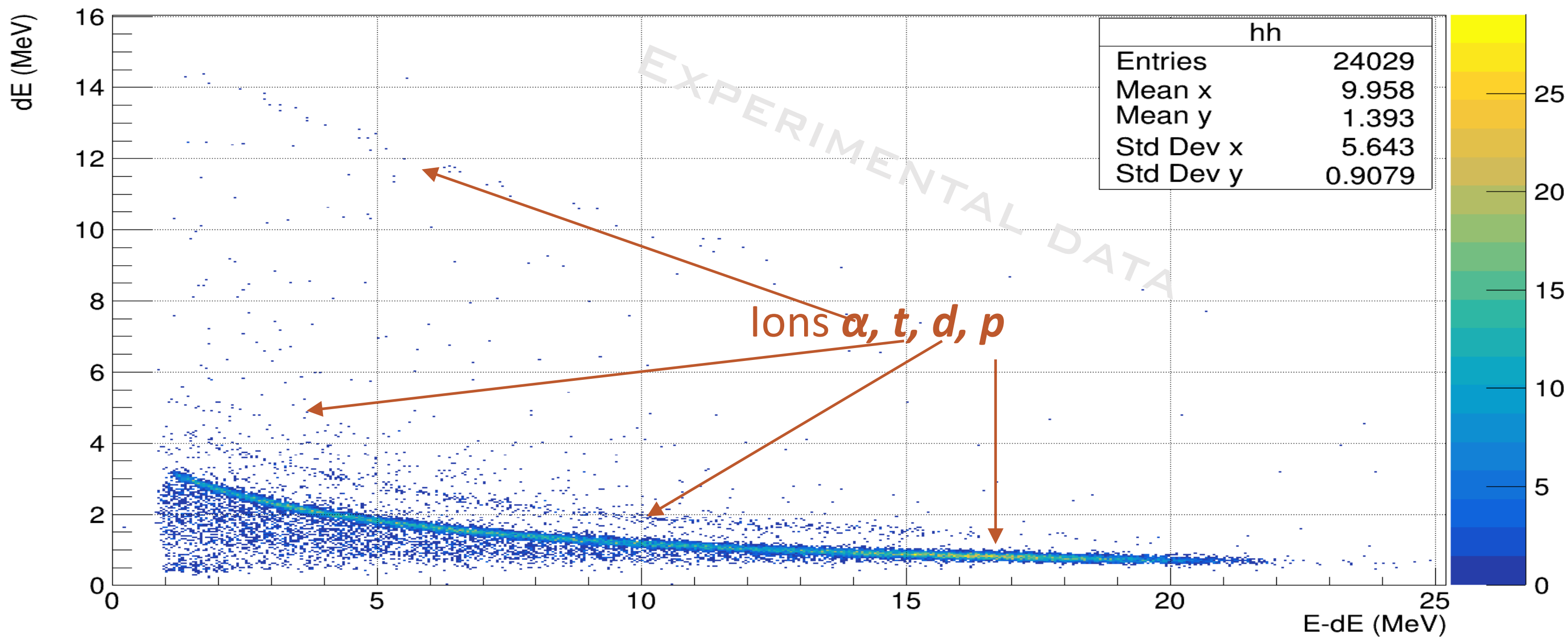
- Tested with alpha source
- Estimation of Upper limit for time resolution
- Measurement of trigger-time difference between two detectors in one telescope (time diff between dE_det(25um) and E_det(50um))
- $FWHM_{max} = \mathrm{Std} \div \sqrt{2} \times 2.355 \ \cong 4.0\ ns$
- Possible resolution enhancement with offline analysis of the sampled signal

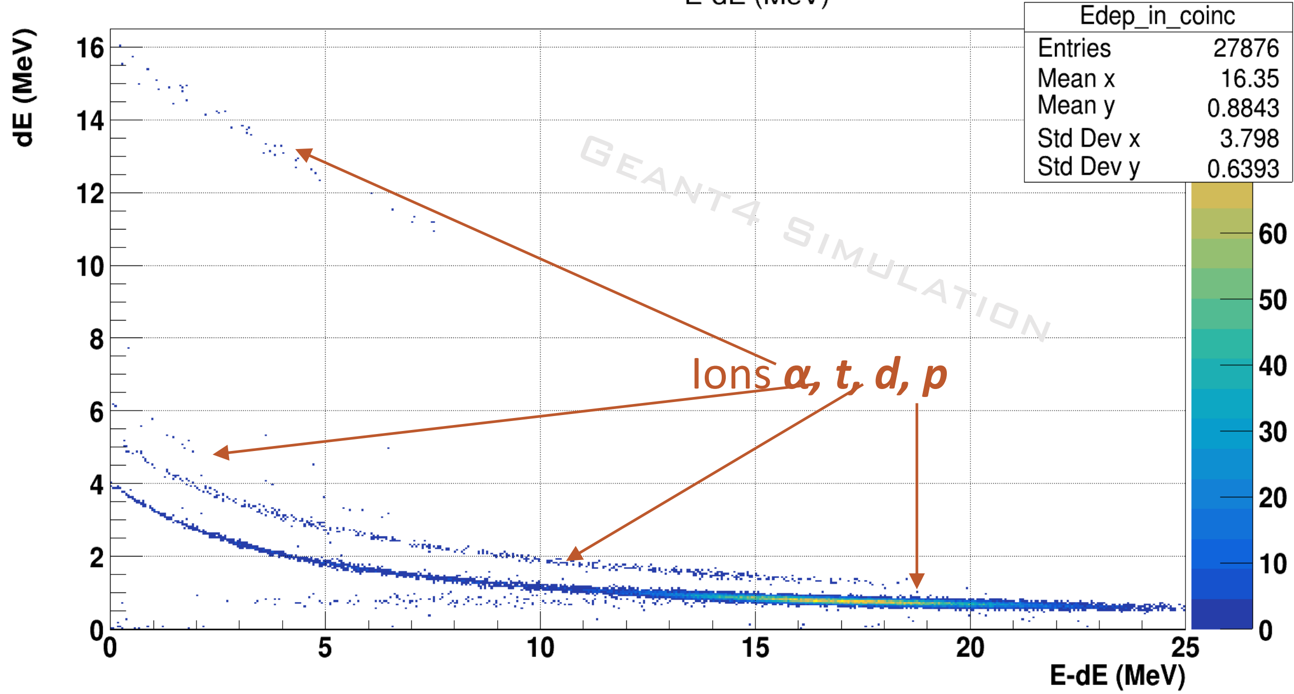




Complex Geant4 model

- Based on CAD drawings of chamber
- Precise representation of the real-world chamber structure
- Model is prepared for simulations of whole experiments with neutron induced reactions
- Modular C++ environment of the Geant4 framework preserves ability to implement whatever new is needed in the future
- Geant4 has well implemented neutronics (transport) up to 20 MeV – evaluated CS for neutrons
- In region above 20 MeV the general models for nucleon interactions are used





- Simulation vs. Experiment comparison
- Qualitative comparison shows good ability to predict experimental data
- Investigation and estimation of various effects in data acquisition
- Future possibility for tuning parameters of nuclear reaction models to get better agreements with specific experimental data

Box with liquid O_2 sample

Empty box

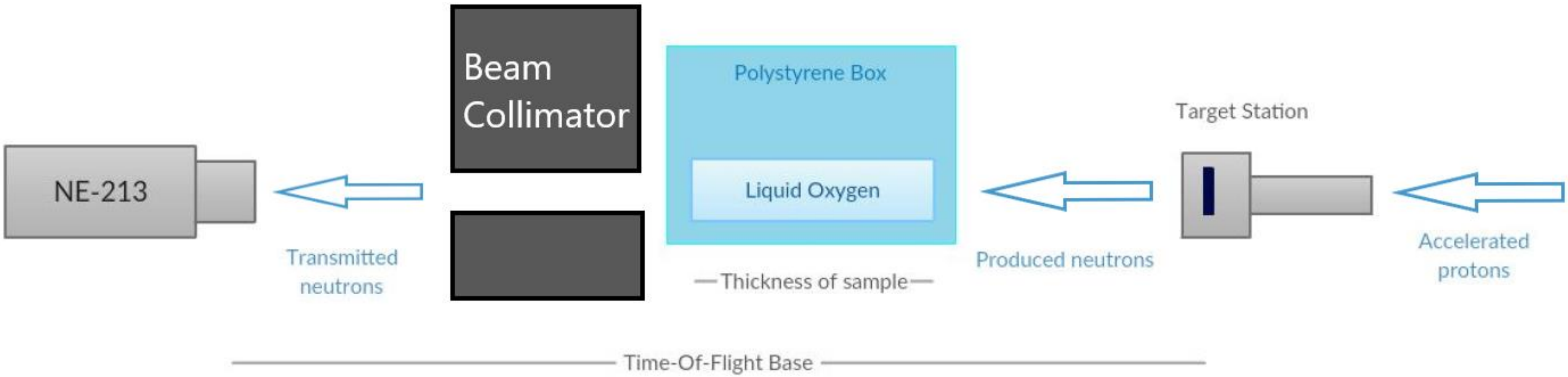
Transmission measurements with liquid oxygen

- Repeated experiment with improved approach
- White neutron spectrum produced on thick beryllium target
- Two measurements with continuous neutron spectra with energies up to 21 MeV and 33 MeV
- Sample with liquid oxygen was placed in polystyrene box and remotely manipulated during irradiation – In and Out
- TOF neutron energy spectrum with/without box filled with liquid O_2 is measured
- Decrease in neutron energy spectrum is calculated as transmission coefficient
- (n,tot) reaction cross-section is calculated based on the transmission T_{lo2}, known density ρ_{lo2} and sample thickness l:

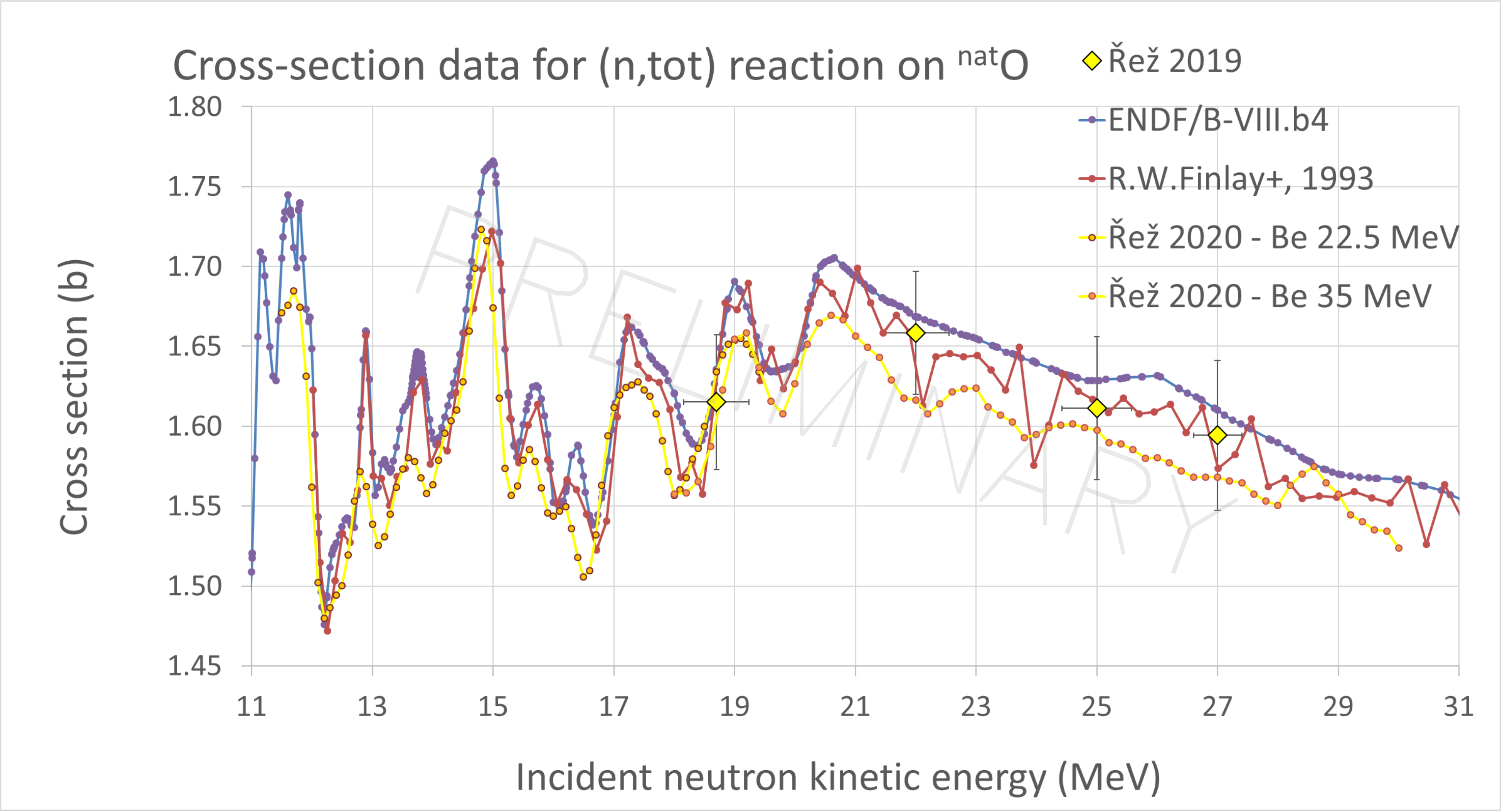
$$\sigma_{tot} = -\frac{1}{nl} \cdot \ln T_{lo2} \qquad n = \frac{N_A}{M} \rho_{lo2}$$

Experimental set-up

- Liquid oxygen with natural abundance of its isotopes
- Polystyrene box (inner dimensions: 16 × 21 cm; 3 cm thick walls) with liquid oxygen
- Scintillator NE-213 with standard 2″ × 2″ cylindrical active volume
- Collimated beam of fast neutrons with continuous
- Flight path over 9 meters



Preliminary Results



Corrections and Uncertainties

- Two main effects of fast neutron interacting in matter:
  - Neutron is excluded from the collimated beam by an interaction in matter
  - Neutron scatters on sample nuclei but still reaches by the detector without sufficient kinetic energy loss (so-called „In-Detector-Scattered effect“)
- In-Detector-Scattered effect - underestimating the CS results, corrections ranges from 0.2 to 1 % (depending on kinetic energy and box orientation)
- Corrections on Pile-Up and Dead-Time (saturated digitizer) during ToF measurements
- Transmision experiments are based on comparison of relative values which is advantage for uncertainty analysis
- Main sources of uncertainties are
  - Time-resolution of accelerated proton bunches, bunch duration up to few nanoseconds, standard deviation up to 1.5 ns
  - Energy calibration during ToF technique

Conclusion

- Collimated beams of fast neutrons are accessible at NPI (up to 33 MeV)
- New detection systems (HPGe - (n, γx), Si dE-E – (n, cp)) are in final stage of development, tuning of acquisition
- (n, tot) cross-section measurements with transmission technique has been successfully used with liquid samples of oxygen - ^{nat}O(n,tot)

We are looking for new colleagues (employees, postdocs, students…:-)

Visit http://www.ujf.cas.cz or email on ansorge@ujf.cas.cz in case of any questions

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Thank you for your attention

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