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Neutron Detectors for Gamma Beam Intensity and Polarization at ELI-NP

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outline

- Gamma Beam System parameters & protocols
- beam diagnostics overview & instruments
- the method based on d(γ,n)p reaction
- prototype tests & experiments
- other ideas & development

ELI-NP large equipment

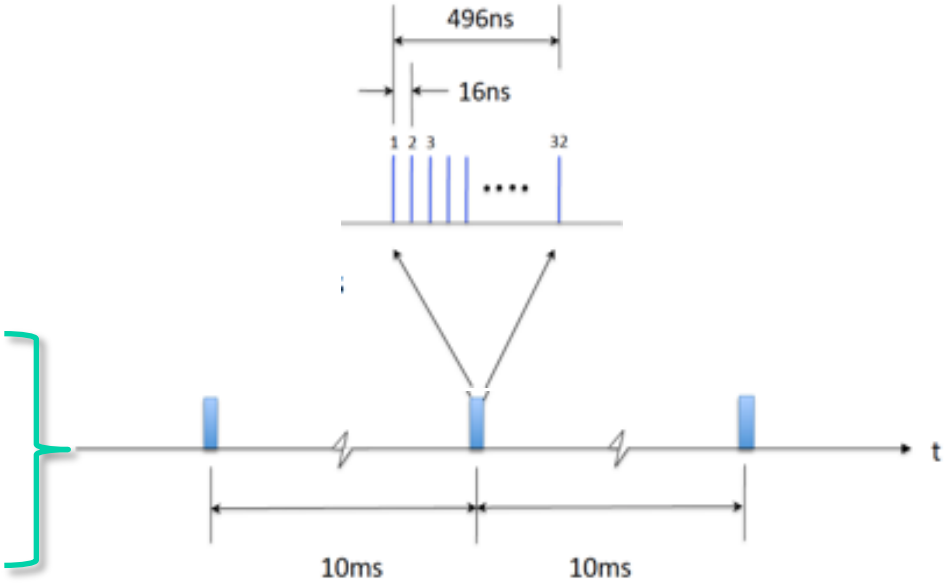
- **High Power Laser System** - 2 x 10 PW maximum power
  - *contracted by Thales Optronique SA*
- **Gamma Beam System** - high intensity, tunable energy up to 20MeV
  - *contracted by EuroGammaS Consortium led by INFN Rome*

The Gamma Beam System (GBS)

Parameter [units]	Value
Photon energy [MeV]	0.2 – 19.5
Spectral density [ph/s/eV]	> 10^4
Bandwidth	< 0.5 %
# photons / shot FWHM bdw.	1.0 – 4.0·10^5
# photons/sec FWHM bdw.	2.0 – 8.0·10^8
Source rms size [μm]	10 – 30
Source rms divergence [μrad]	25 – 250
Peak brill. [N_{ph}/sec·mm²mrad²·0.1%]	10^{22}– 10^{24}
Radiation pulse length [ps]	0.7 – 1.5
Linear polarization	> 99 %
Macro repetition rate [Hz]	100
# of pulses per macropulse	>31
Pulse–to–pulse separation [ns]	16

Low–energy stage: Eγ < 3.5 MeV

High–energy stage: Eγ < 19.5 MeV



what to remember

- beam size: 1 mm at 10 m away from collimator
- energy spread: 50 keV at E_γ=10 MeV
- time structure: micropulses at 16 ns
- photons/pulse: 10^5
- photons/macro-pulse: $32x10^5=3x10^6$
- photons/s: $3x10^8$

GBS Parameters and Protocols

spatial & temporal parameters

Spatial Parameters	Description & Measurement
Source diameter	Basic definition of source diameter at FWHM
Beam width	Beam diameter (FWHM) at certain location z (e.g. 10 m)
Beam divergence	Angular measurement of beam expansion (beam diameter increase) over its propagation. $$\theta_x = 2\, arctan \frac{d\sigma_x^2(z)}{dz}$$
Beam instability	Pointing and centering. Beam drift and jitter.

Temporal Parameters	Description & Measurement
Micropulse duration	Basic definition of pulse duration at FWHM
Micropulse separation	Time separation between pulse peaks
Number of micropulses per train	Number given
Macropulse separation	Time separation between macropulses

spectral parameters

Spectral Parameters	Description & Measurement
Beam polarization	Polarization of the electric field vector denotes the direction in which it oscillates during its propagation
Beam bandwidth	Defined as the ratio of FWHM of the energy distribution and the given energy. $$BW = \frac{\Delta E_{FWHM}}{E}$$

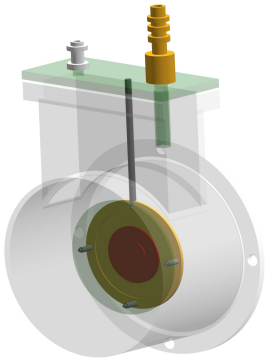
power parameters

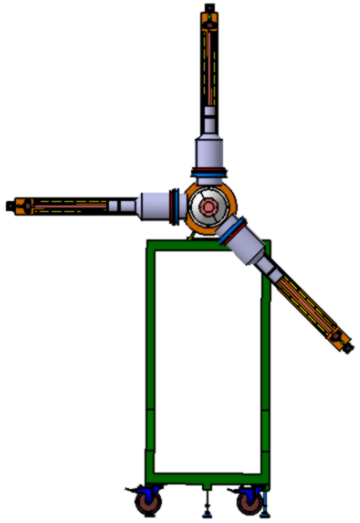
Power Parameters	Description & Measurement
Average brilliance at peak energy	Definition of brilliance: number of photons emitted by the source in unit time in a unit solid angle, per unit surface of the source, and in a unit bandwidth of frequencies around the given one (units photons/s/mm2/mrad2/0.1%BW). $$B_{av} = \frac{\phi_{av}}{\Delta\Omega\ 0.1\%BW}$$
Peak brilliance at peak energy	Instantaneous brilliance $$B = \frac{\phi}{\Delta\Omega\ 0.1\%BW}$$
Time-average spectral density at peak energy	Definition of spectral density: number of photons emitted by the source in unit time and per unit energy. $$S_{\gamma,av} = \frac{I_{av}}{E}$$
Time-average spectral density at off-peak energy	Spectral density off-peak $$S_{\gamma,bkgr} = \frac{I}{E}$$

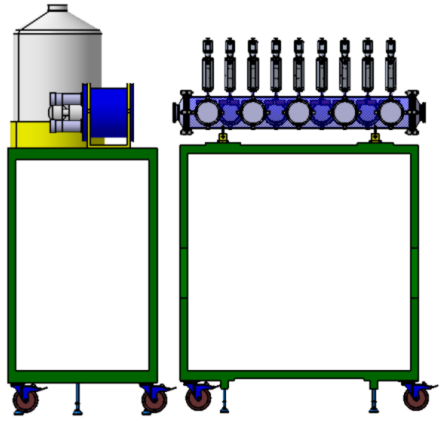
Diagnostics instruments @ ELI-NP

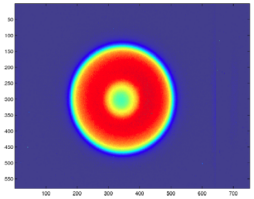
diagnostics overview

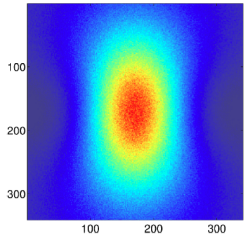
- **Intensity/Polarization monitoring**
  - deuteron photodisintegration
- **Intensity monitoring**
  - photo-fission of ^{238}U
- **Energy monitoring**
  - HPGe + anti-Compton shield
  - LaBr3 + anti-Compton shield
- **Time structure monitoring**
  - small plastic/LaBr3
- **Spatial structure monitoring**
  - CCD camera





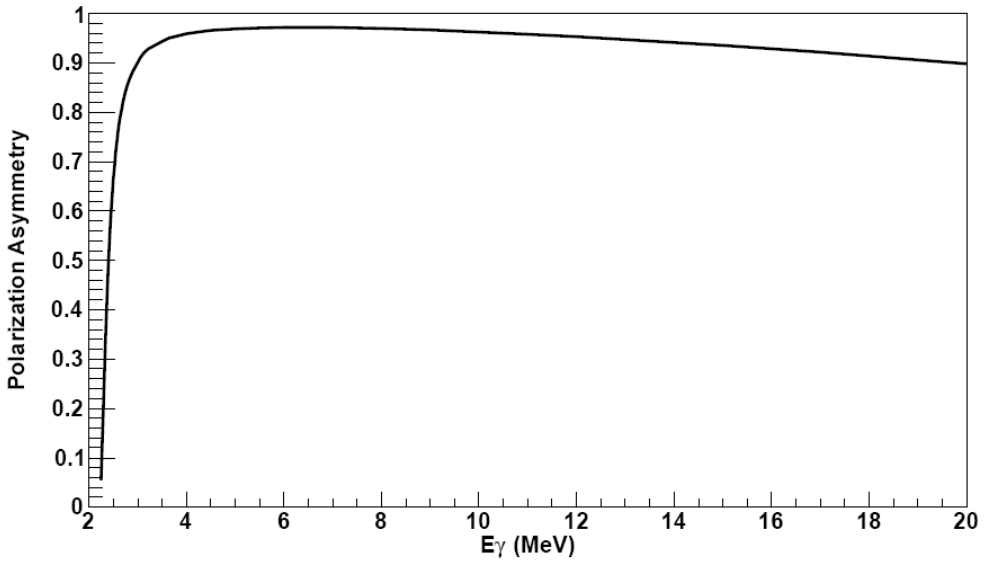


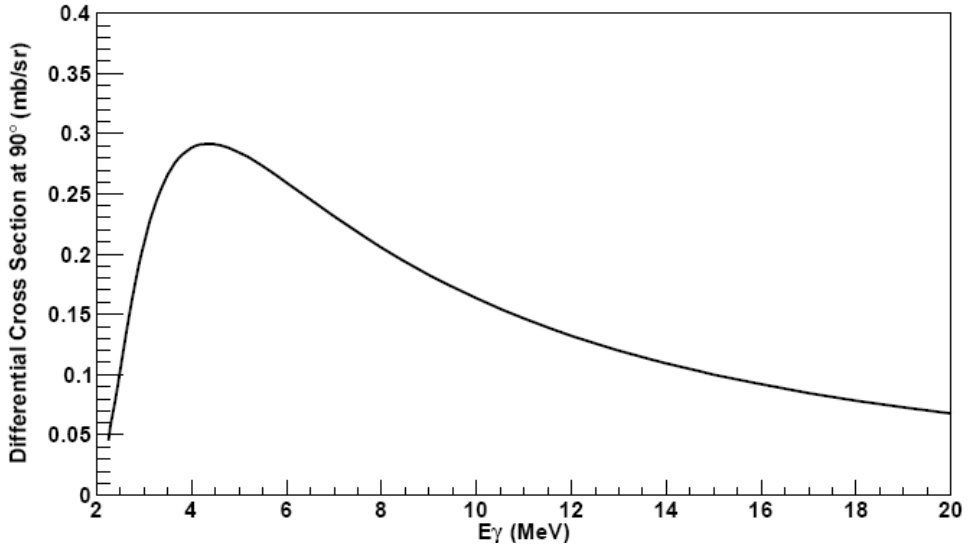




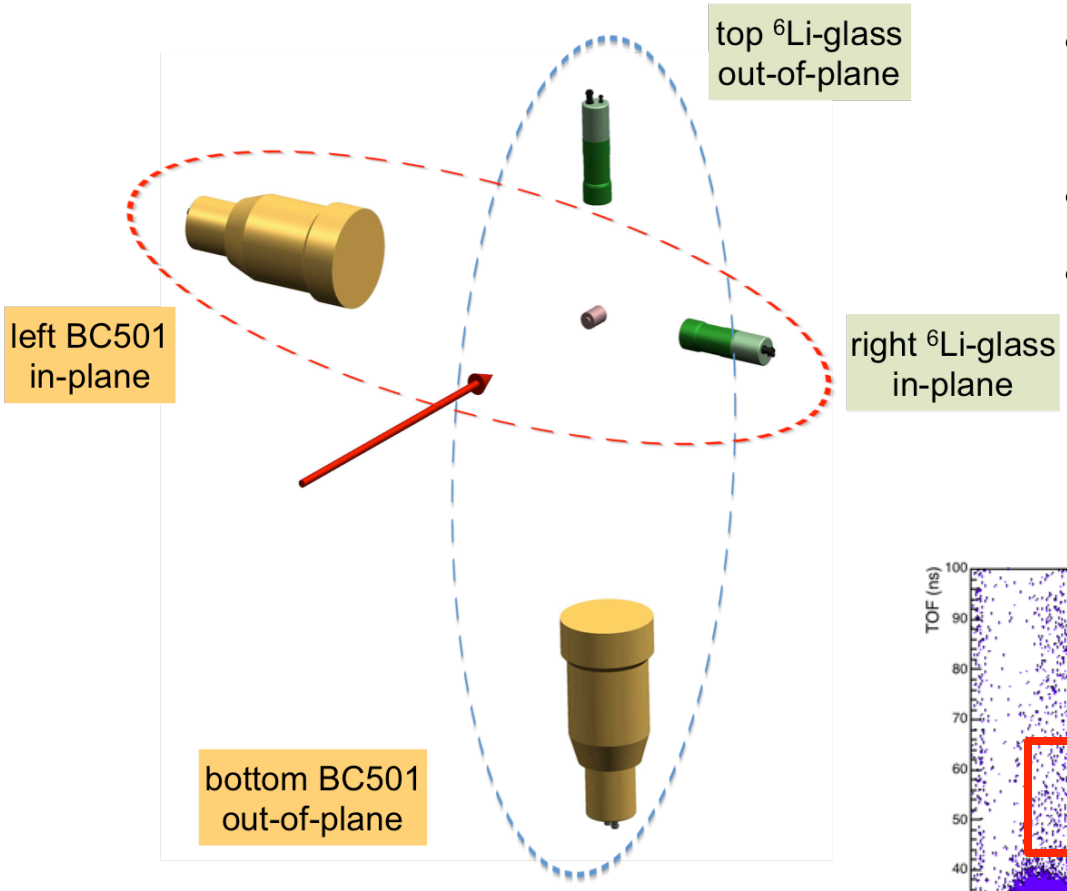
Beam Intensity & Polarization w/ d(γ,n)p reaction

gamma beam polarization – dgn reaction

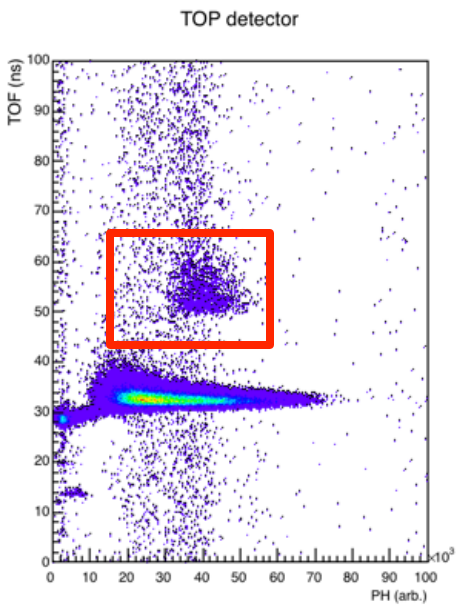


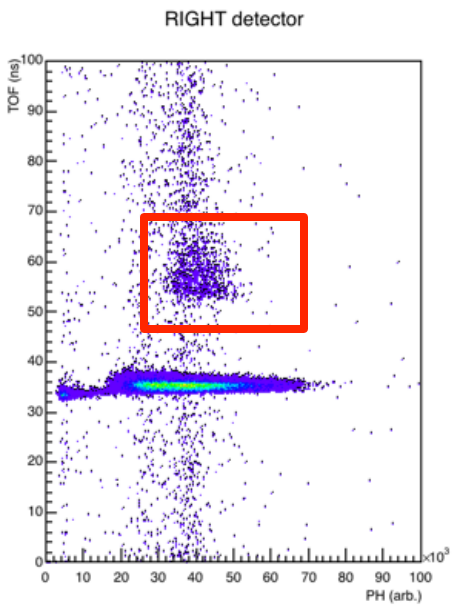


dgn @ HIGS – circular polarized beam

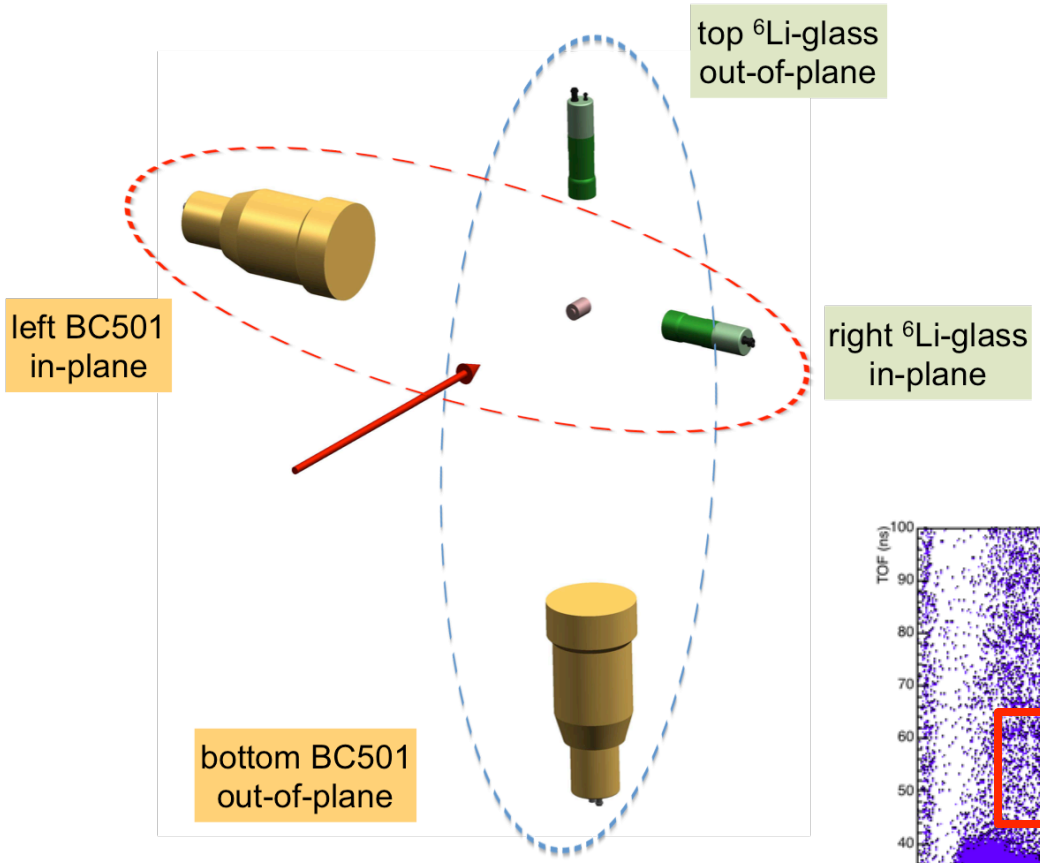


- E_γ= 3 MeV
- E_n=384 keV (ideal beam & target)
- Li-glass at 15 cm
- D_2O target (L=4 cm, Φ=3 cm)

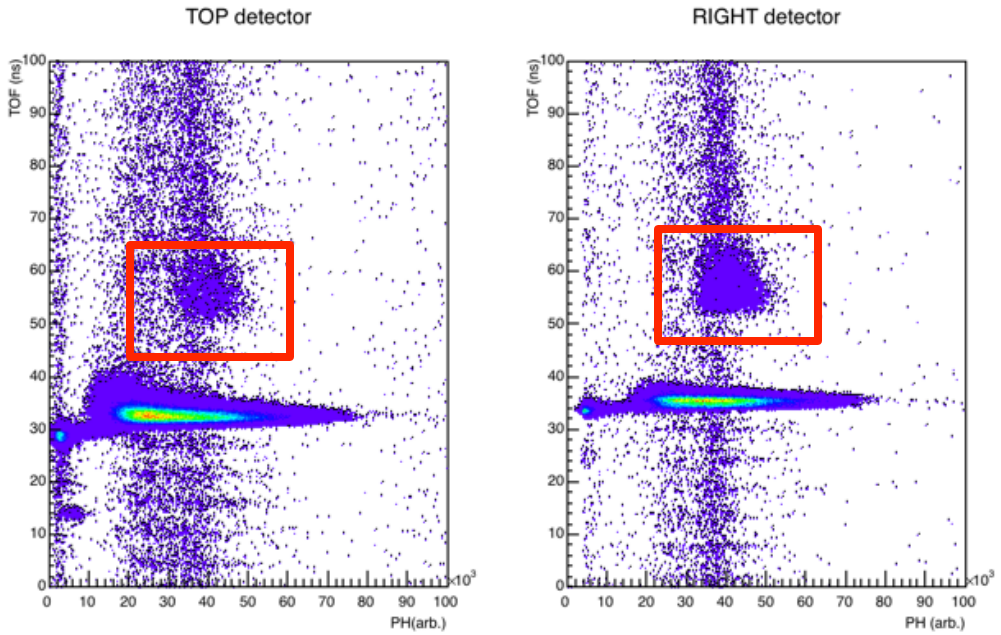




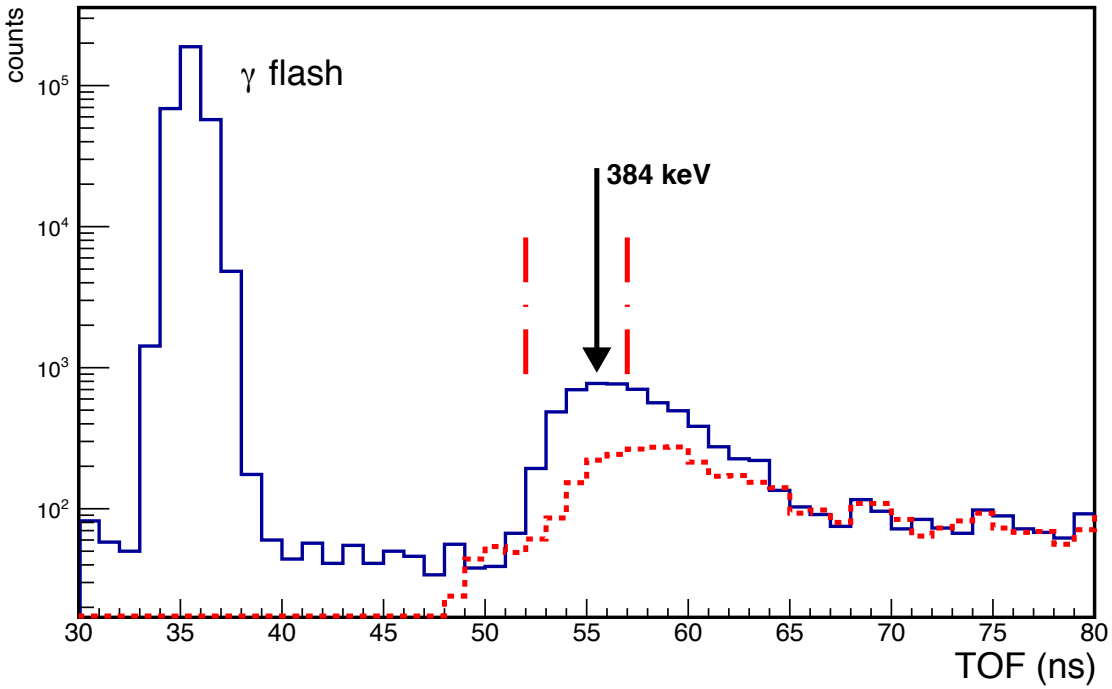
dgn @ HIGS – linear polarized beam



- E_γ= 3 MeV
- E_n=384 keV (ideal beam & target)
- Li-glass at 15 cm
- D_2O target (L=4 cm, Φ=3 cm)



gamma beam polarization – dgn reaction



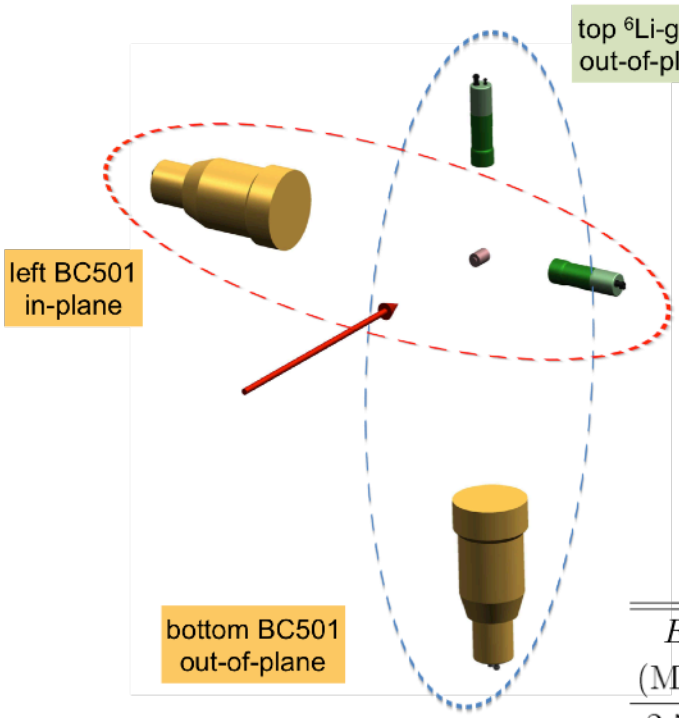
$$B_{pol} = \frac{A_{pol}^{\text{measured}}}{A_{pol}^{\text{expected}}}$$

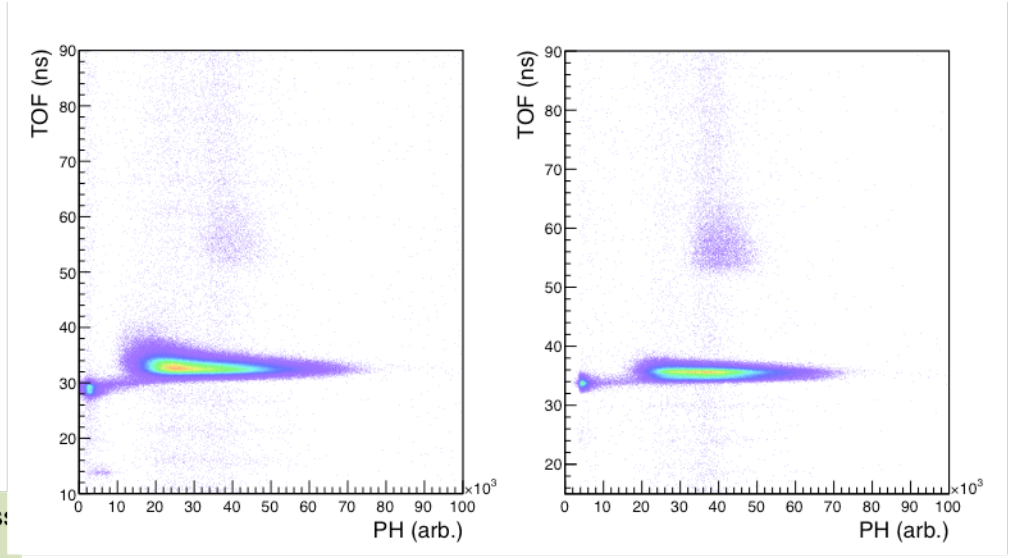
$$B_{pol} = \frac{0.89}{0.9} = 98.9\%$$

Linear polarization, in-plane vs. out-of-plane

$$A_{pol} = \frac{\sum_{in-plane} \frac{Y^L}{Y^C} - \sum_{out-plane} \frac{Y^L}{Y^C}}{\sum_{in-plane} \frac{Y^L}{Y^C} + \sum_{out-plane} \frac{Y^L}{Y^C}} = \frac{\frac{2650-330}{430} - \frac{710-420}{892}}{\frac{2320}{430} + \frac{290}{892}} = 0.89$$

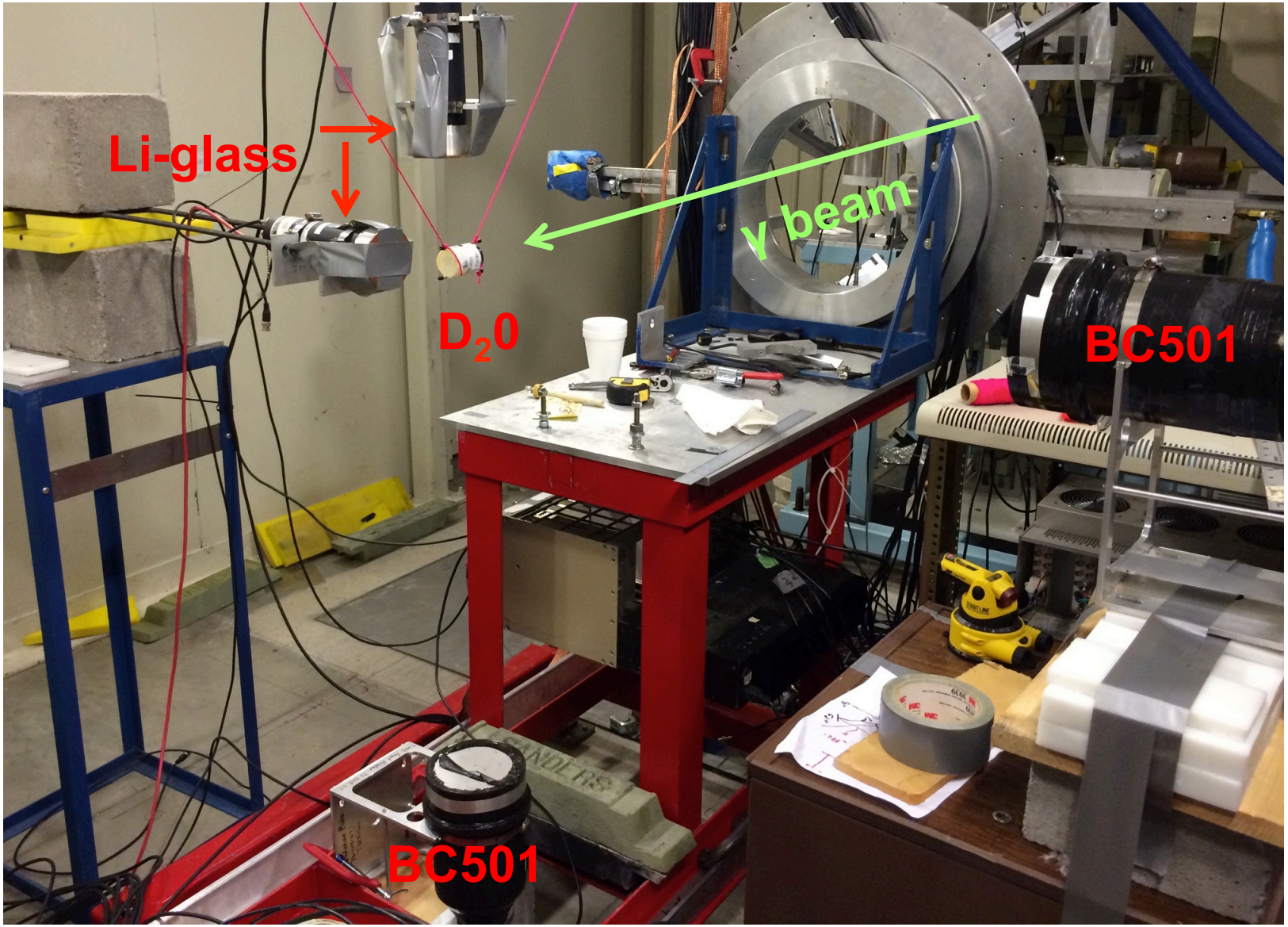
gamma beam intensity – dgn reaction





E_γ (MeV)	Beam intensity ($\times 10^7$ s^{-1})	Time (min)	Expected Asymmetry	Measured Asymmetry	Beam Polarization	Uncertainty Stat. & Syst.
2.50[a]	1.2	60	0.693	0.688	99.3%	7.3 & 8.2 %
2.75[a]	1.5	60	0.846	0.848	100.2%*	1.4 & 1.5 %
3.00[a]	1.7	55	0.903	0.903	100.0%	1.8 & 2.6 %
3.00[b]	0.7	78	0.903	0.912	101.0%*	2.5 & 1.3 %

prototype setup @ HIGS



gamma beam polarization – dgn reaction

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Investigation of the d(γ,n)p reaction for gamma beam monitoring at ELI-NP

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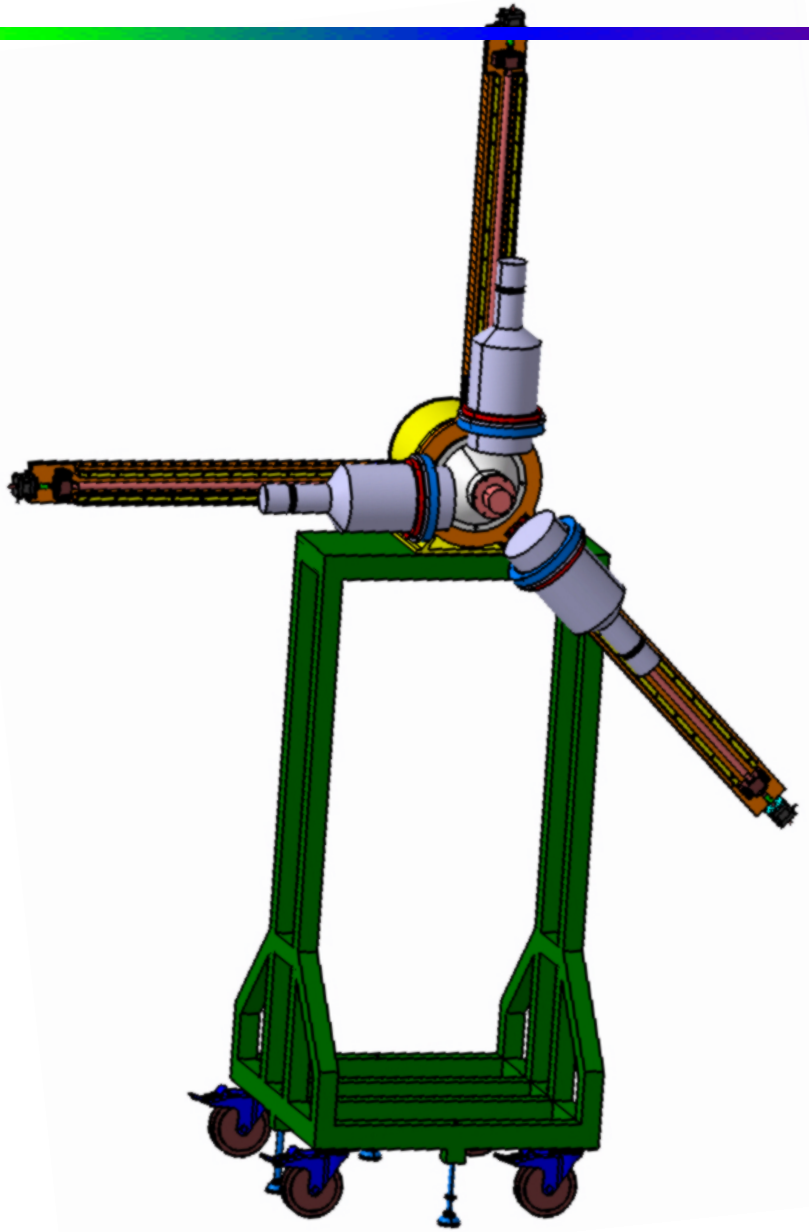
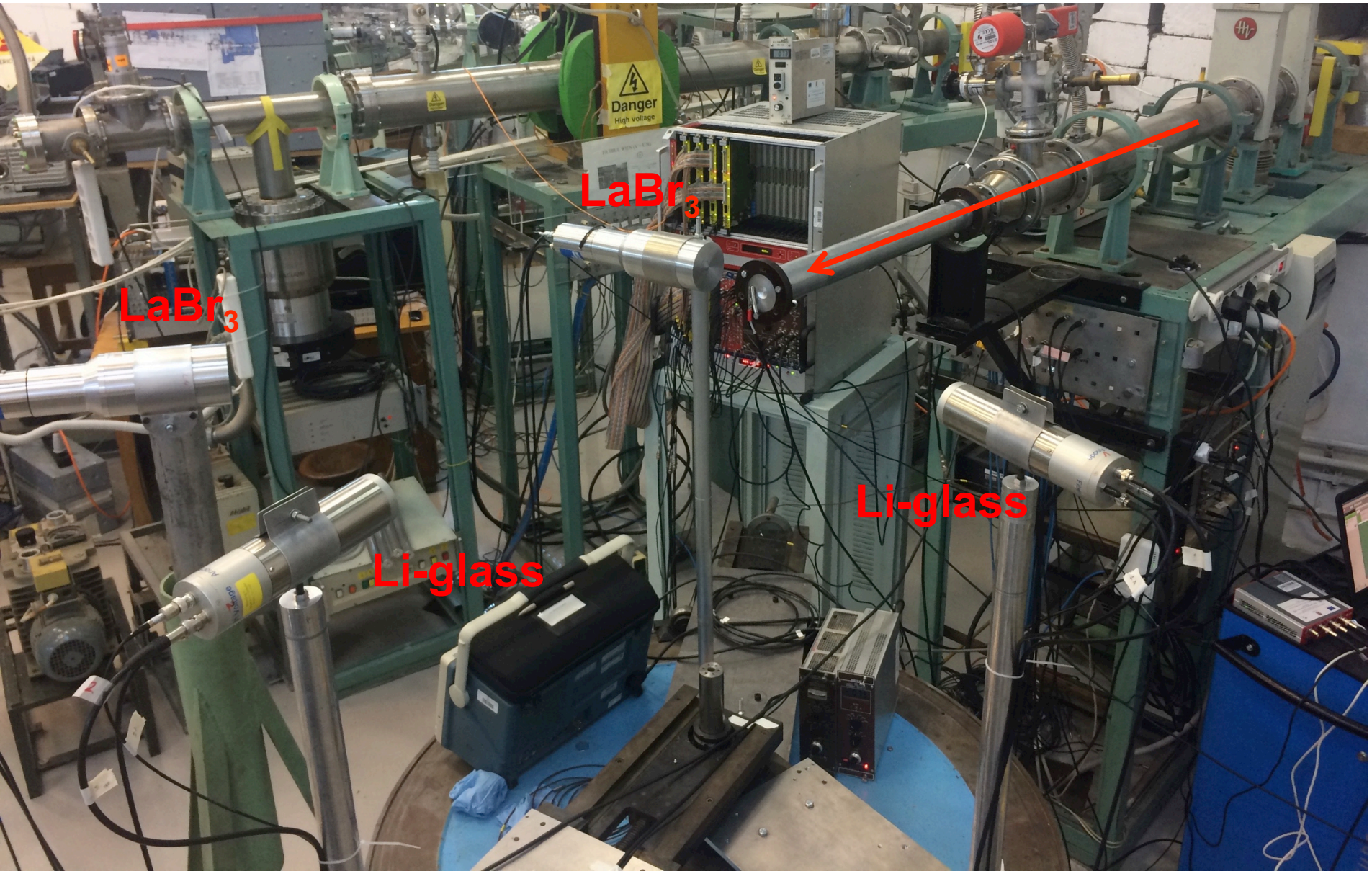
implementation @ ELI-NP

- D_2O cell – 4 cm long
- threshold reaction 2.5 MeV
- well known cross sections ~3%
- x3 neutron detectors
- Li-glass below 4 MeV
- NE213-type above 4 MeV
- beam fluence accurate to 5%

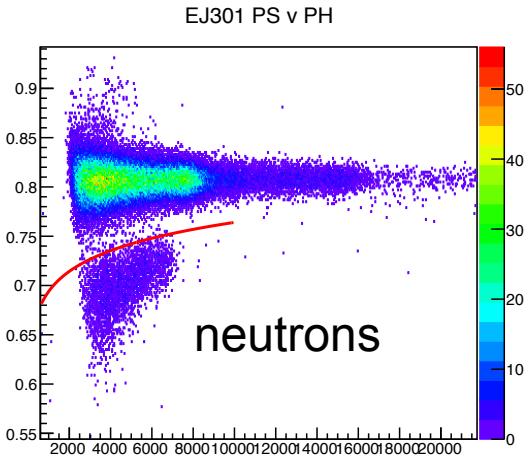


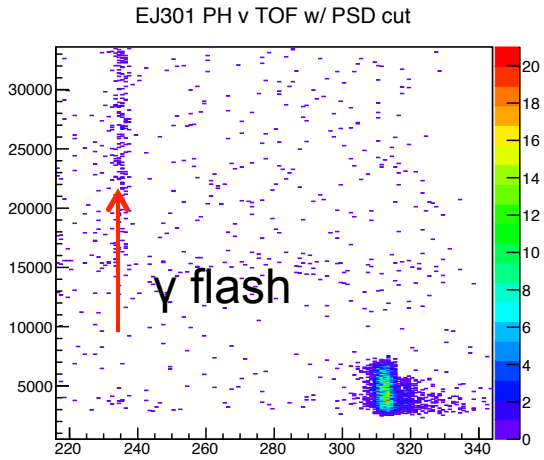
detector characterization & test experiments

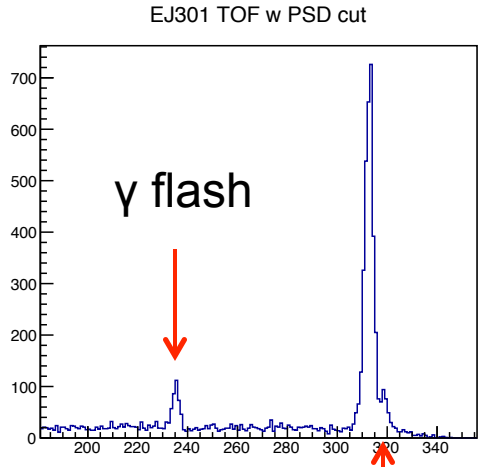
neutrons @ IFIN

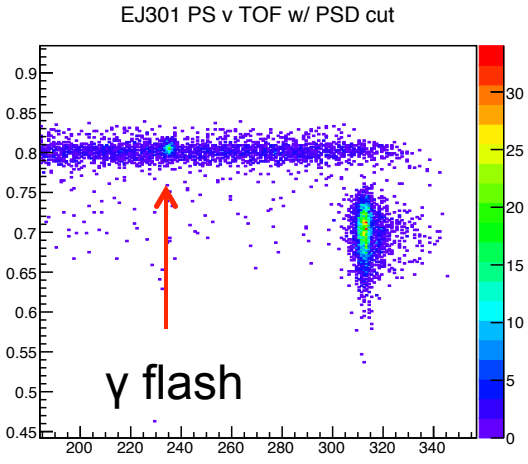


neutrons @ IFIN – EJ301 spectra







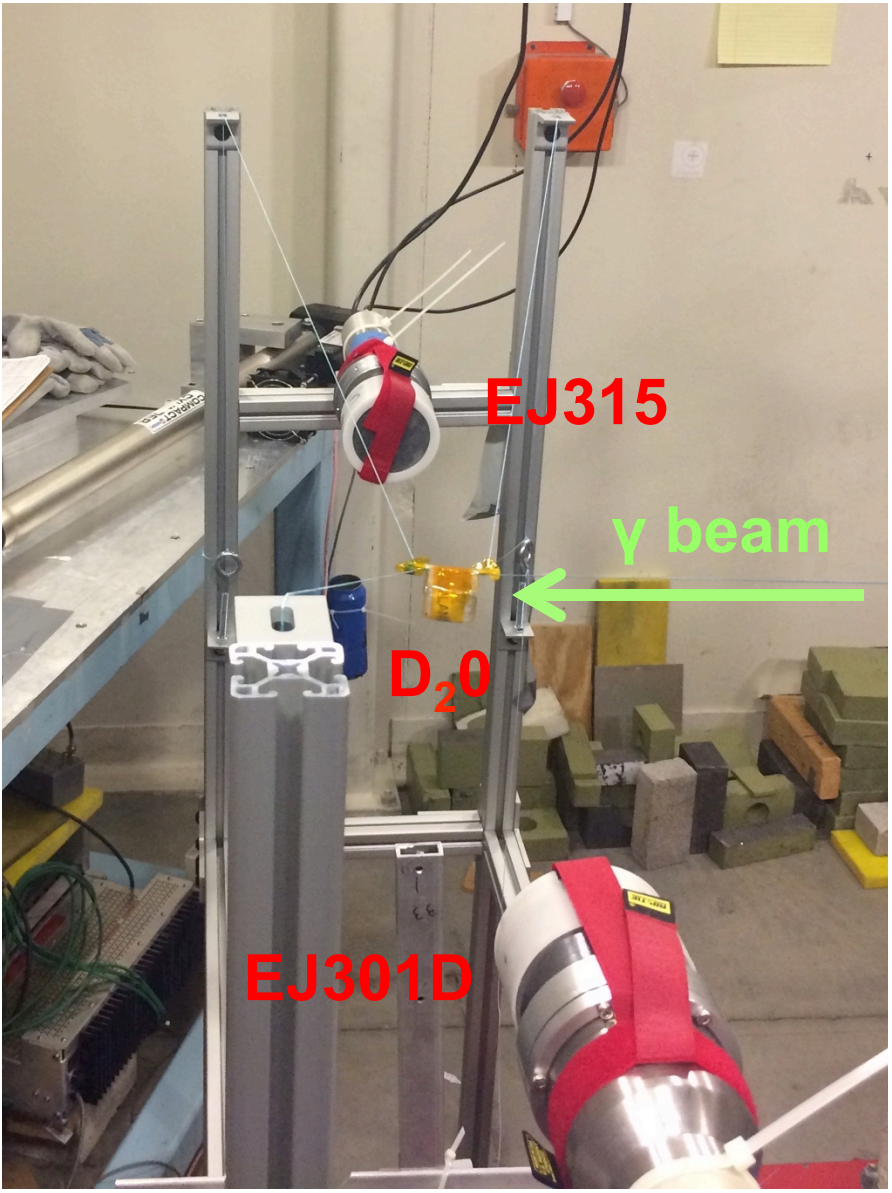


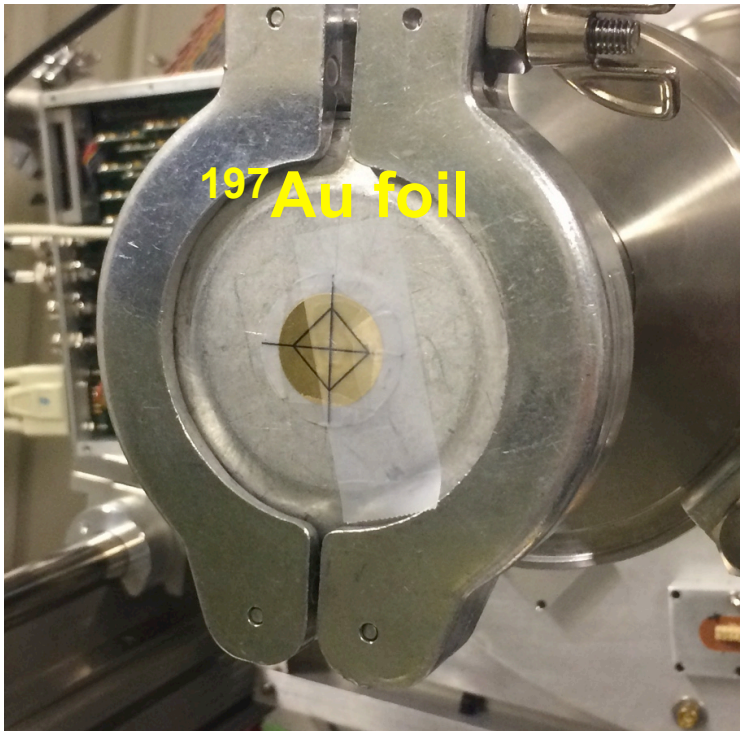
- $^{7}Li(p,n)^{7}Be$
- E_p= 5 MeV and below
- Li-glass at 75 cm
- EJ-301 at 210 cm

- first attempt at IFIN
- low intensity (20 nA)
- need NMI instrument for field characterization

two neutron groups: 3.2 & 2.75 MeV

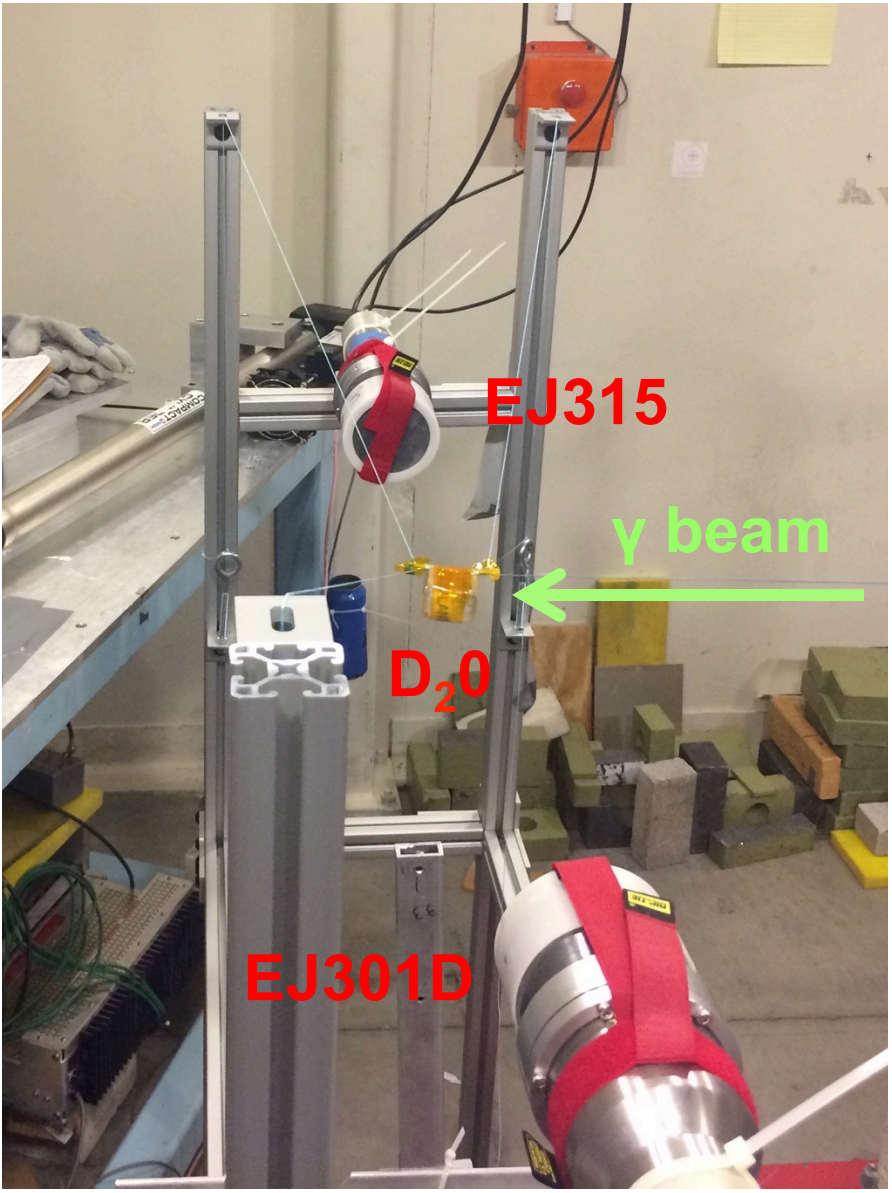
^{7}Li experiment @ HIGS

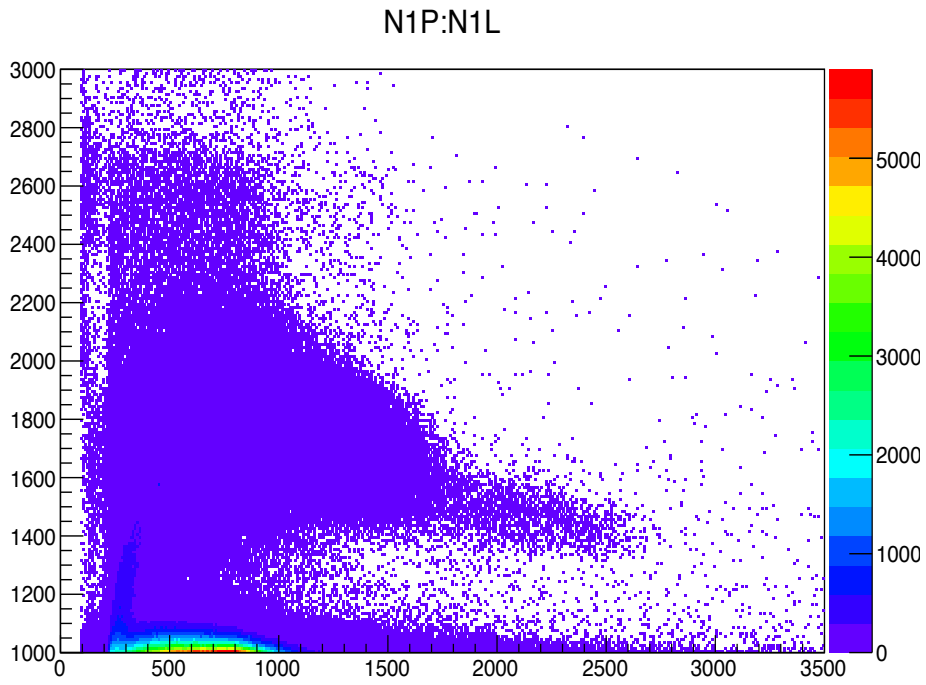




- ^{197}Au activation above 8 MeV
- d(γ,n)p w/ EJ301D & EJ315
- HPGe & collimator for Compton

^{7}Li experiment @ HIGS





- d(γ,n)p w/ EJ301D @ 9 MeV
- PS vs PH quite messy
- efficiency depends on threshold

summary GBS & diagnostics

- precise measurement of beam parameters is essential
- instruments need to be very well characterized
- multiple monitoring devices (the more, the better)
- it doesn’t stop here. more devices to be proposed
- beam transport is versatile / changes are possible