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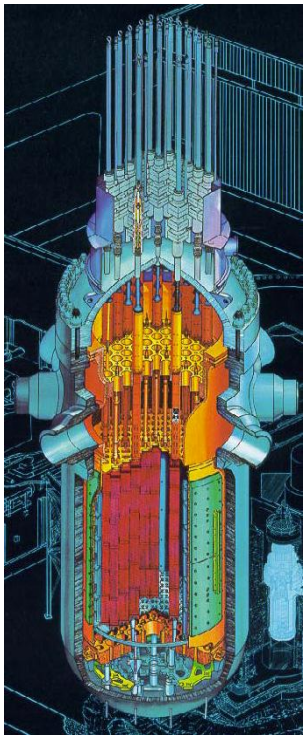
Use of NEUTON at the EPFL zero power research reactor CROCUS

ADAMAS Workshop, December 13th 2018, Vienna, Austria

Outline

- Motivations behind the use of diamond detectors in CROCUS
- Installation & Testing of NEUTON in CROCUS
- Modelling of NEUTON (preliminary results)
- Perspectives

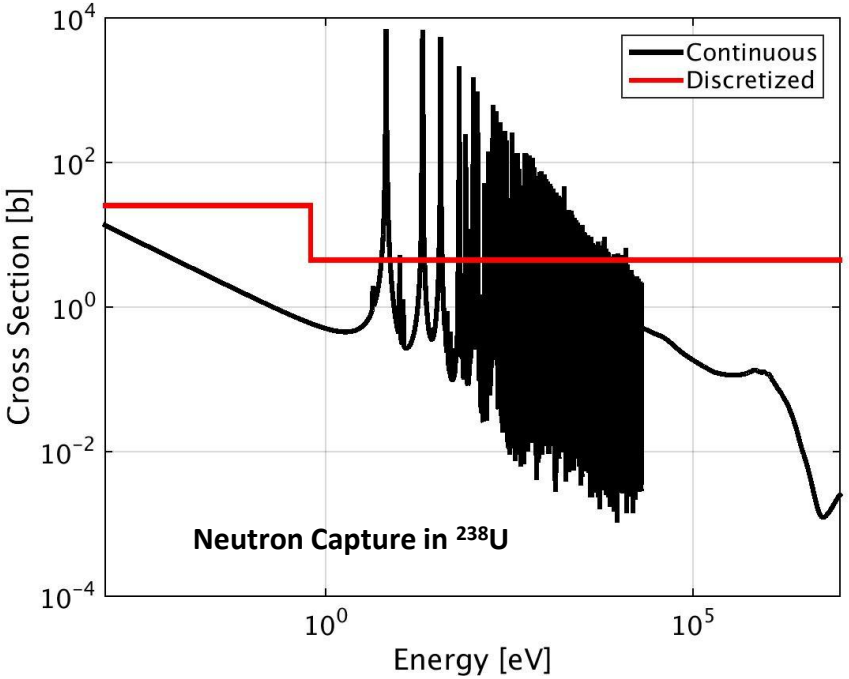
Simulation of Nuclear Reactors



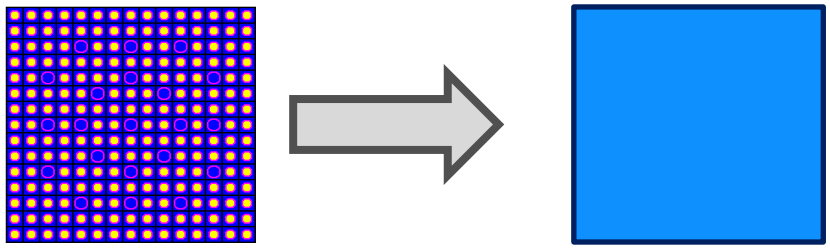
Reactor Vessel

Fuel Pellet

- Complex probability of interaction



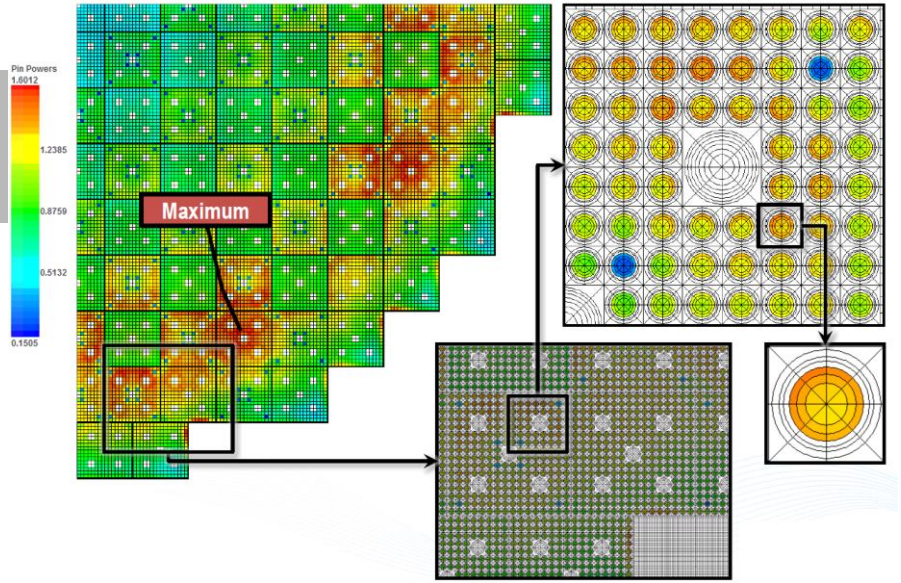
- Approximations used for modeling lead to “conservative methods”

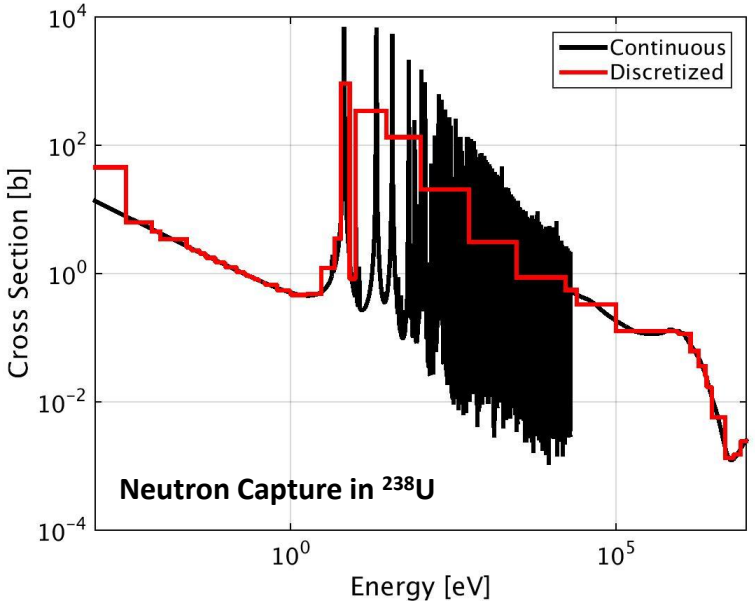


Example of Goesgen Kernkraftwerk:

- Core
  - 3.4m diameter x 4m height
  - 107.7 tons of UO_2
- 51’000 fuel rods and over 16M fuel pellets in the core of the reactor

Improvement to Simulation Tools





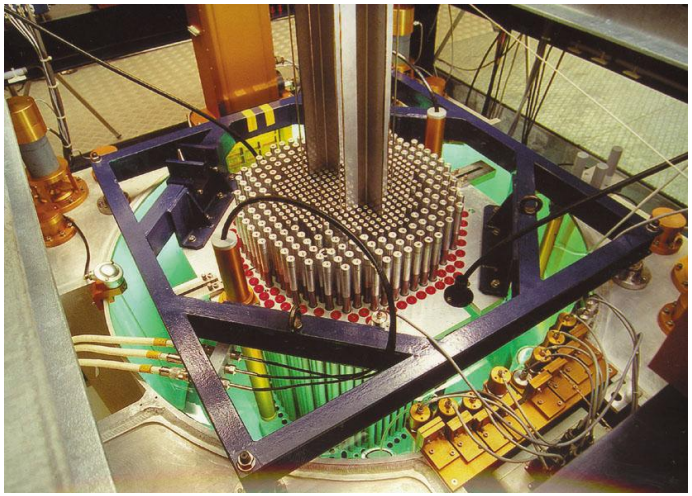
Swiss National Supercomputing Centre

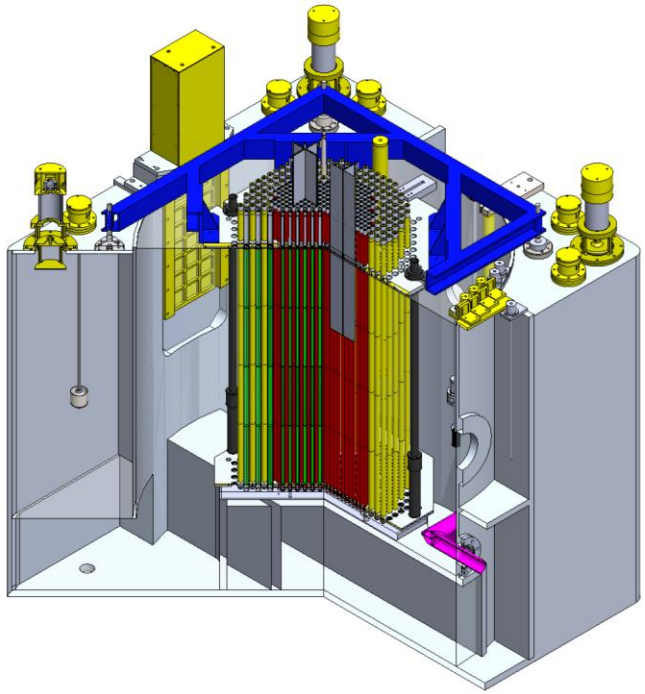
- Improved knowledge about local quantities
- Better measurements are needed
  - Small detectors
  - Capable of neutron spectroscopy

Diamond detectors!

CROCUS zero power research reactor

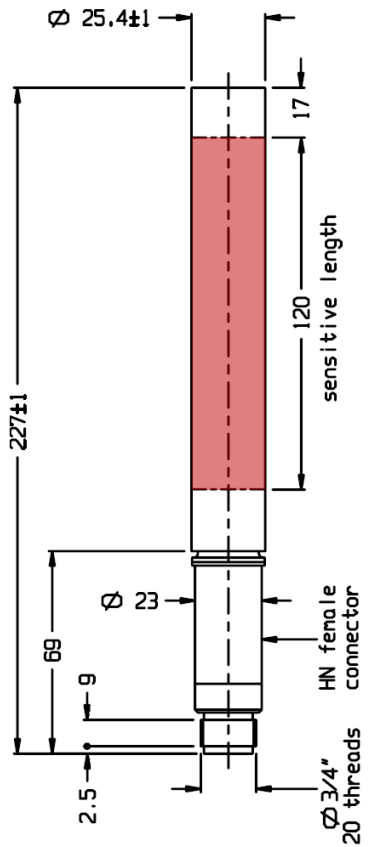
- Last research reactor in CH
  - Education
  - Restarting research programs
- Zero power light water reactor
  - Room conditions
  - Pocket reactor - 0.6 m x 1 m
  - Max power 100W
  - $\Phi \sim 10^{7}.cm^{-2}W^{-1}$
- CROCUS strengths
  - Easy access /space available
  - Neutron and gamma spectra are characterized
    - Monte Carlo modeling
    - On-going dosimetry

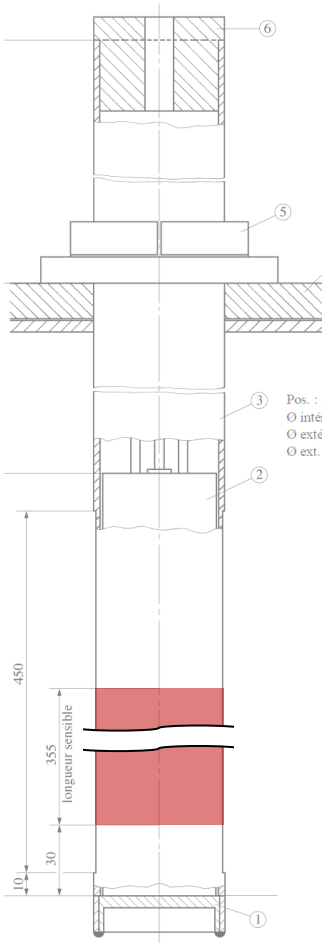




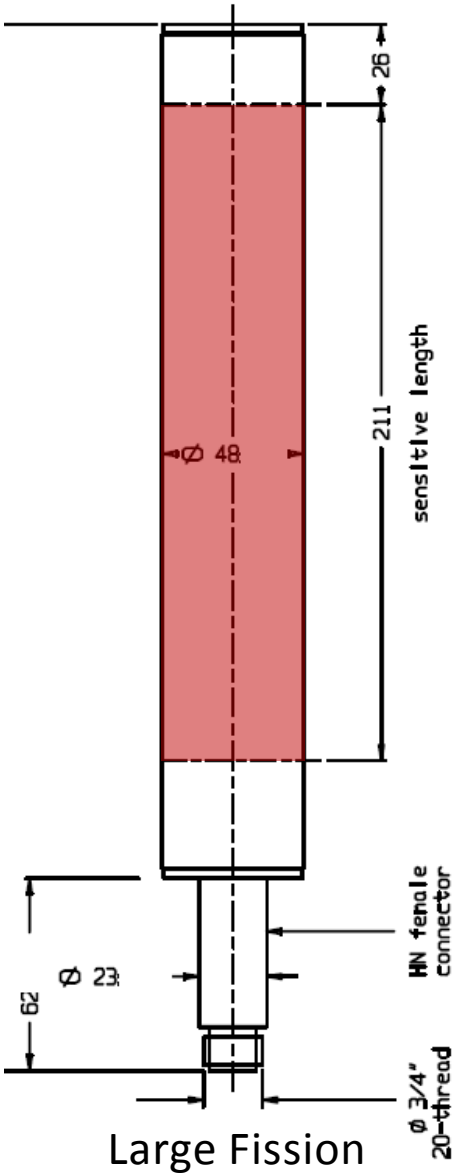
Typical Instrumentation in CROCUS

^3He, BF_3 detectors

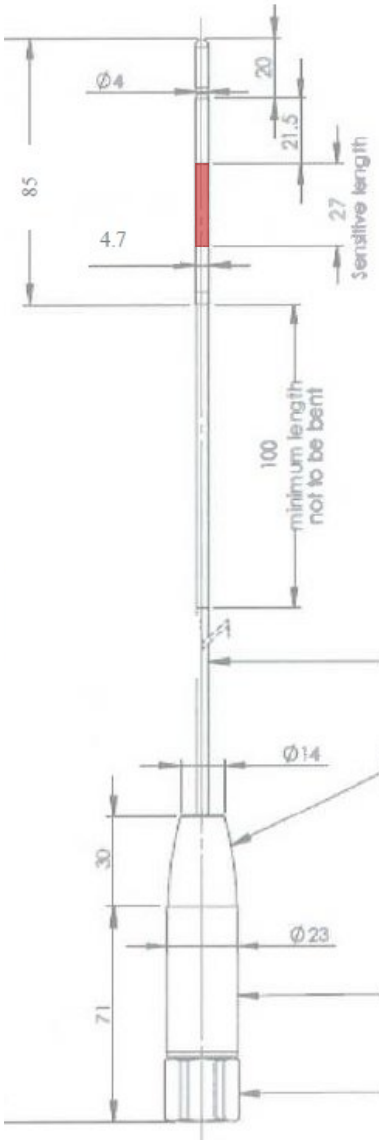




Boron Coated Chambers



Large Fission Chambers



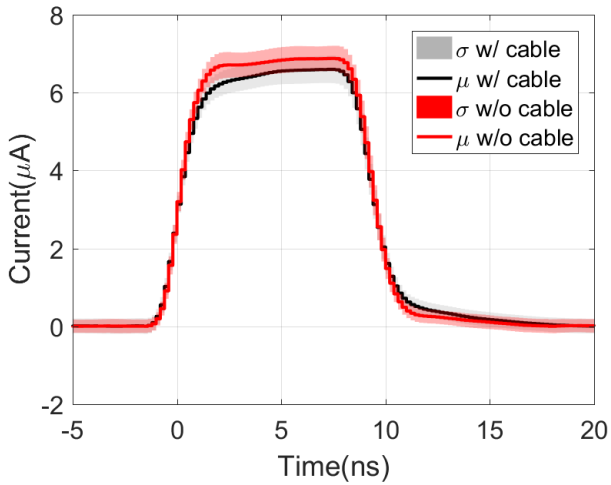
Miniature Fission Chambers (MFC)

NEUTON detector (CIVIDEC)

B6-C like
4x4 mm^2 & 500µm thick
Removable ^{6}Li foil

3m long cable
(50Ω)

30 m
(out of CROCUS containment)

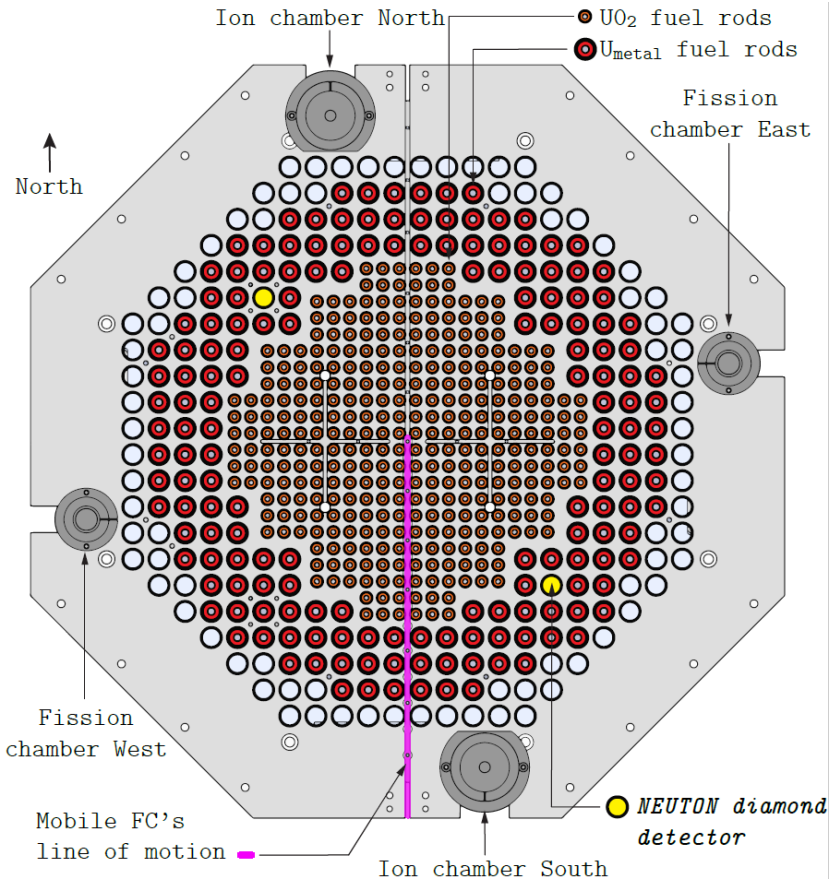


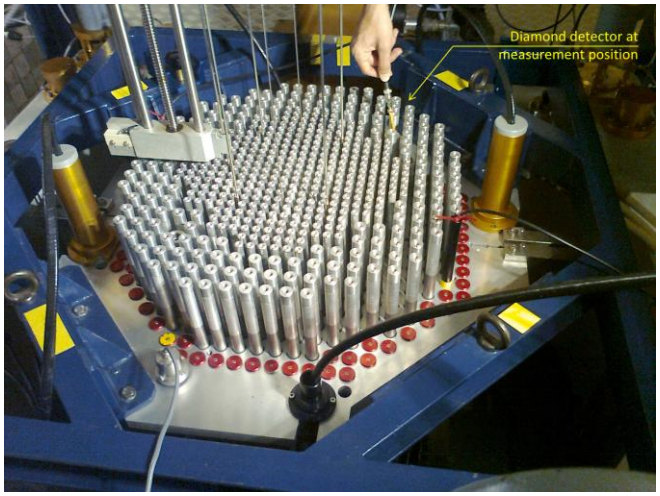
Transient-current technique

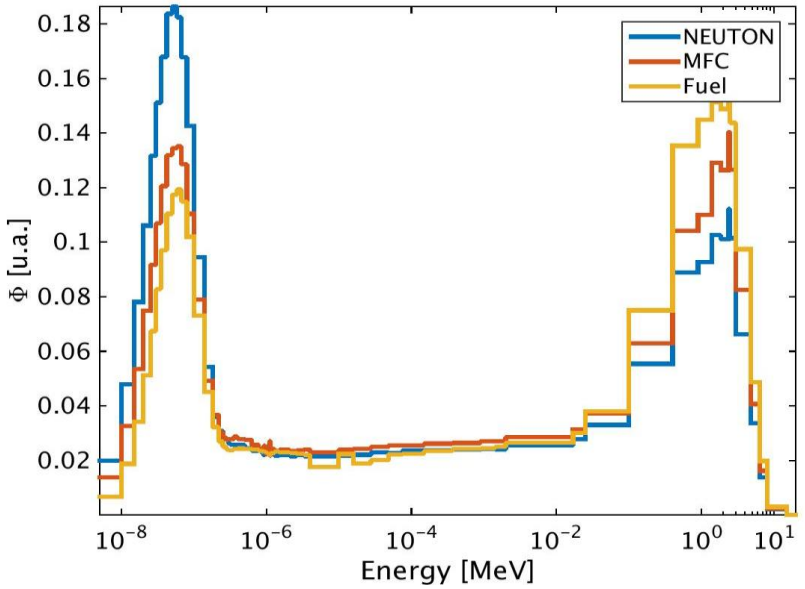
- Amplitude / Area / Width of pulses recorded in real-time
- Pulse selections based on multi-criteria
- Possibility to record full pulses (not in real time)

Installation of NEUTON in CROCUS

- Mixed radiation field
  - Thermal/fast neutrons
  - Prompt/delayed gammas

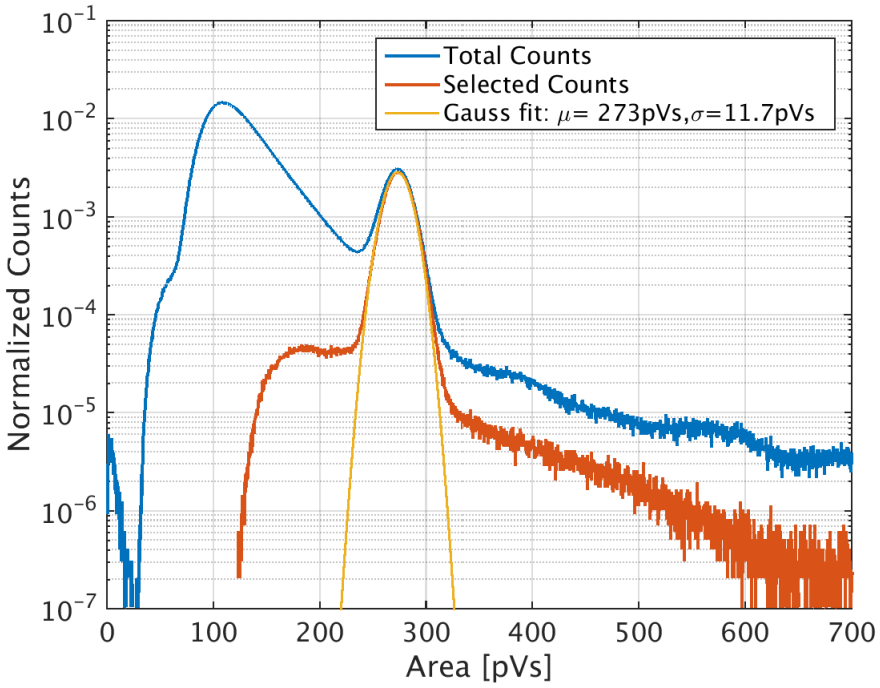


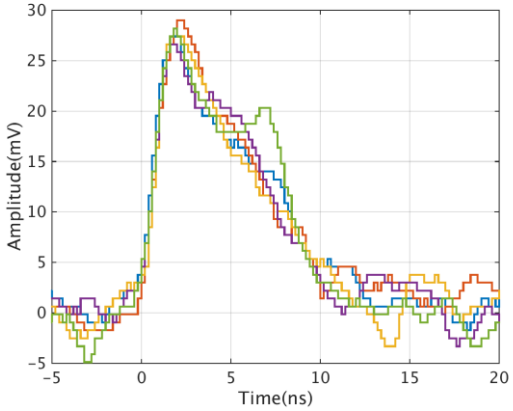




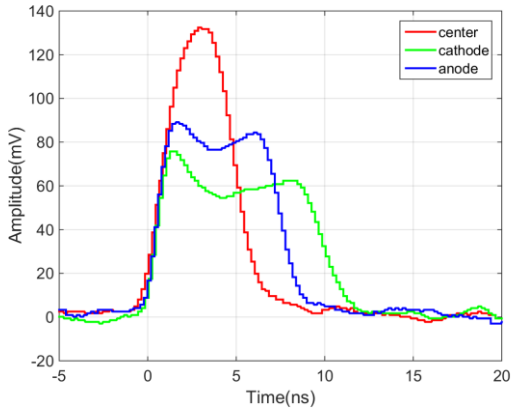
Hursin et al. (2018). Testing of a sCVD diamond detection system in the CROCUS reactor. *European Physical Journal A*, *54*(82), 179–184.

NEUTON measurements in CROCUS

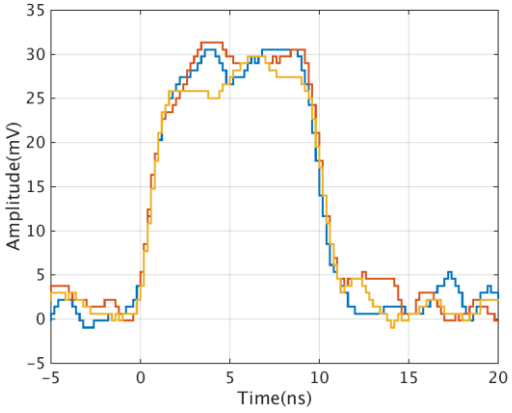




Gamma interactions



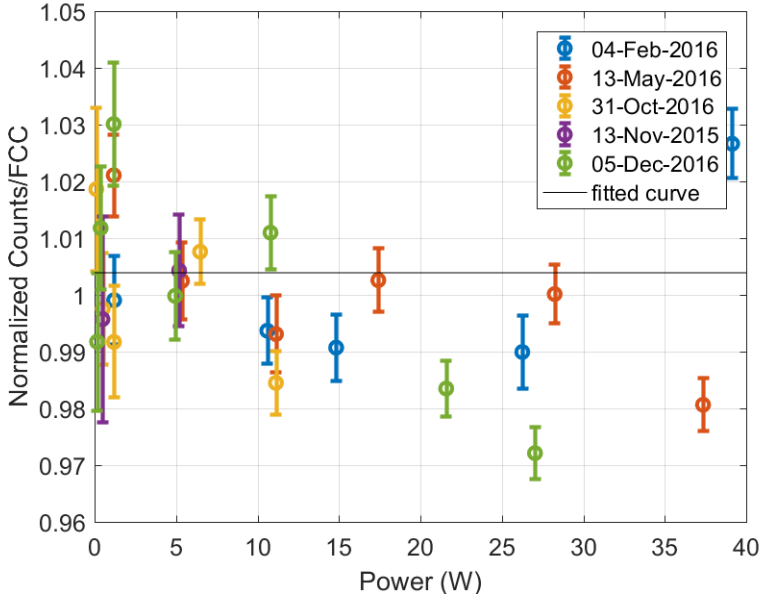
Fast neutron interactions

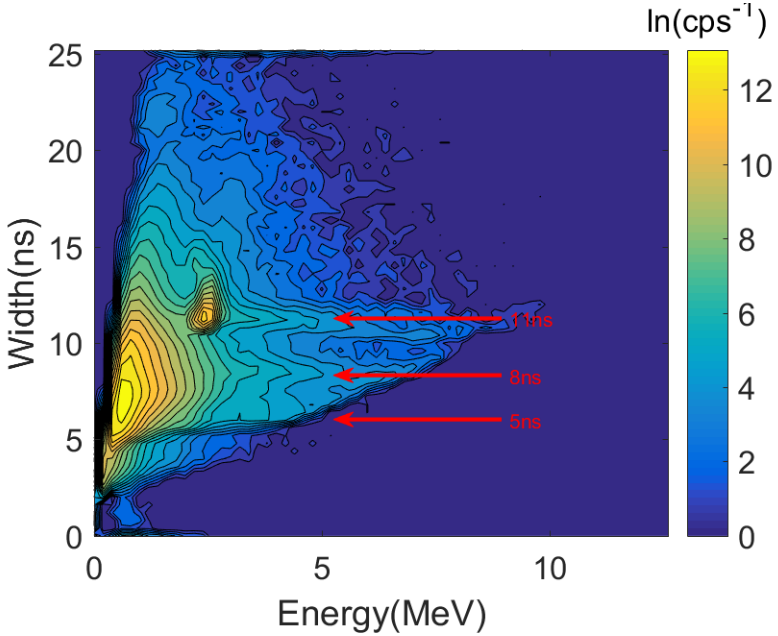


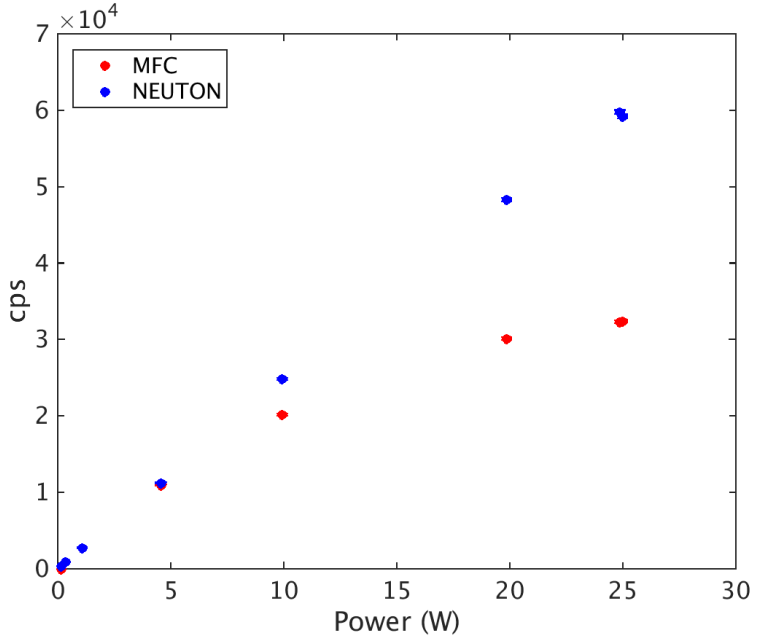
Thermal neutron interactions

Testing of NEUTON in CROCUS

- 6%/94% neutrons/gammas detections
- Linearity of response with reactor power
- Sensitivity ~3.10^{-5} per thermal neutron
- Can accommodate for high count rate
- Detection of fast neutrons

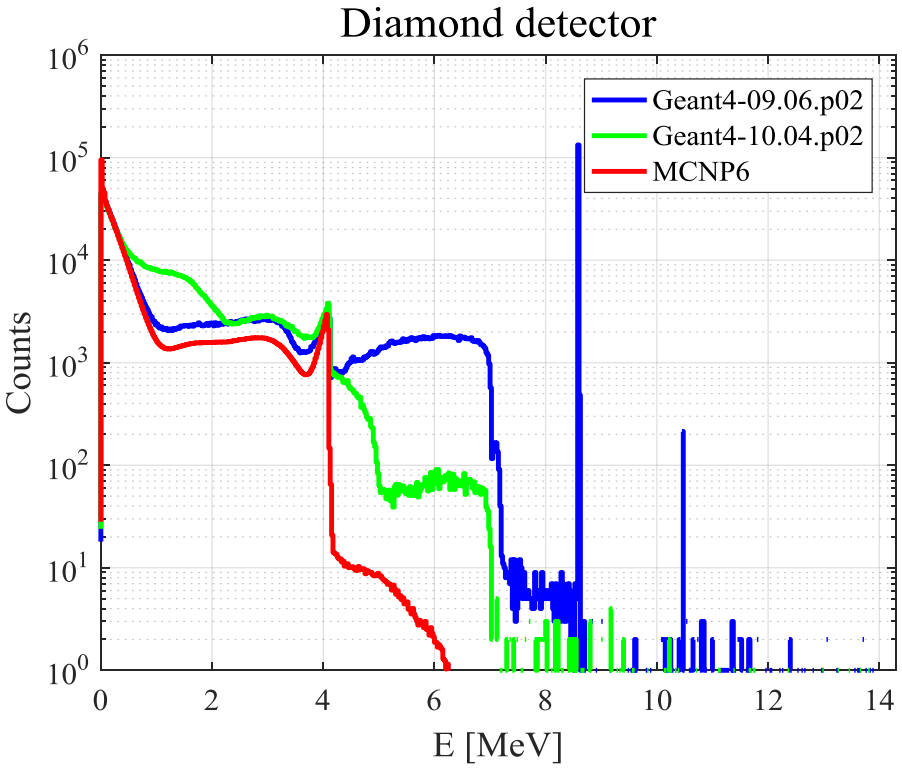






Modeling NEUTON with Monte Carlo codes

- 14 MeV neutrons impinging on diamond crystal
- Geant4 results
  - differences due to neutron library (inelastic scattering)
- MCNP6 results
  - responses above 4 MeV are missing:
    - $^{12}C(n,n+2\alpha)\alpha$
    - $^{12}C(n,\alpha)^{9}Be$
    - $^{13}C(n,\alpha)^{10}Be$



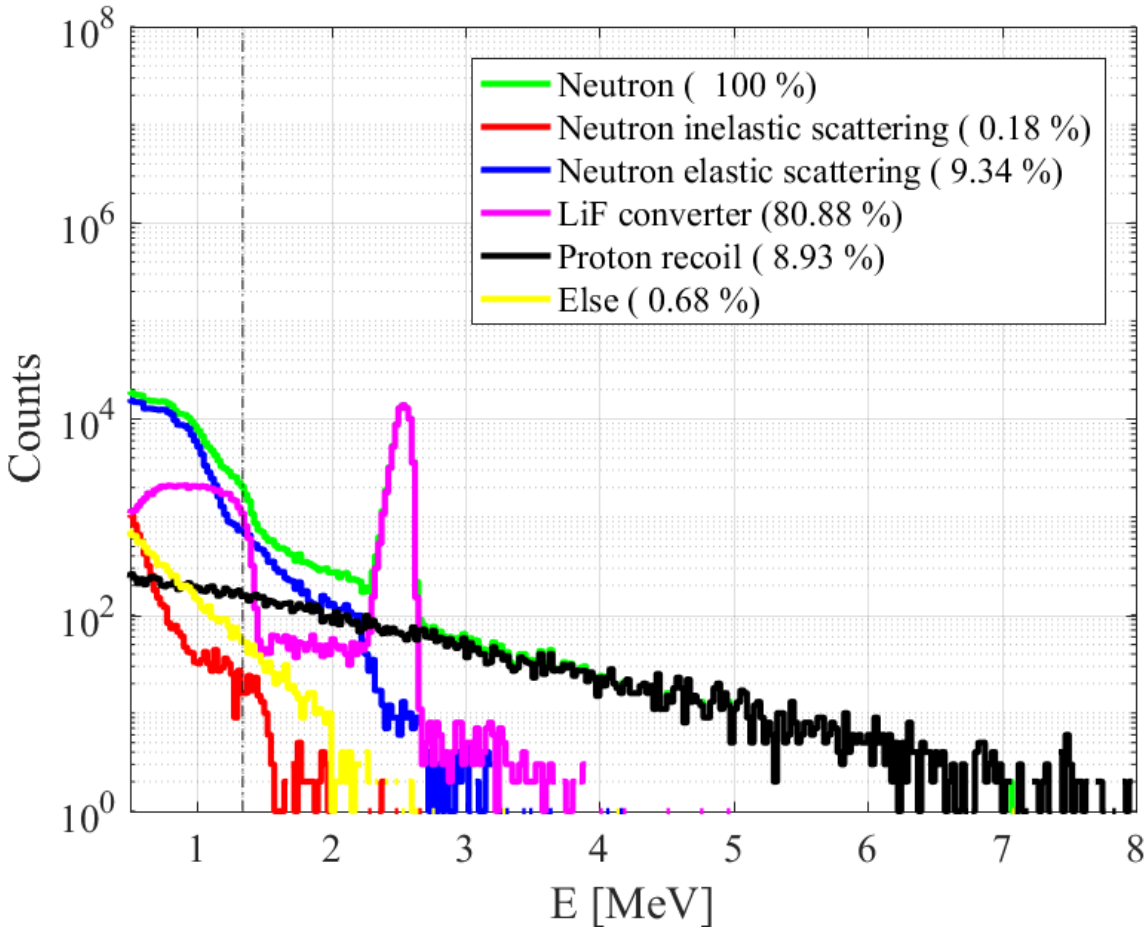
Modeling NEUTON response in CROCUS

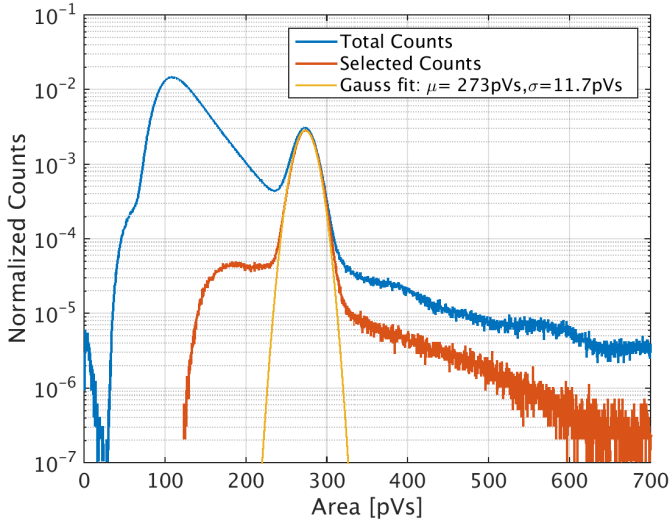
- Two-steps approach
  1. Determination of (n, g) spectra at the location of interest in CROCUS with MCNP6
  2. Modeling of NEUTON with Geant4
  - Only neutron for now. Gamma later…
  - 25 calculations with 2.10^9 neutron histories each (uncertainty)
  - Interaction of n with ^{6}Li and diamond crystal
  - Transport of secondary particles (α,t,e^-)

- Record location, energy deposited & type of interaction

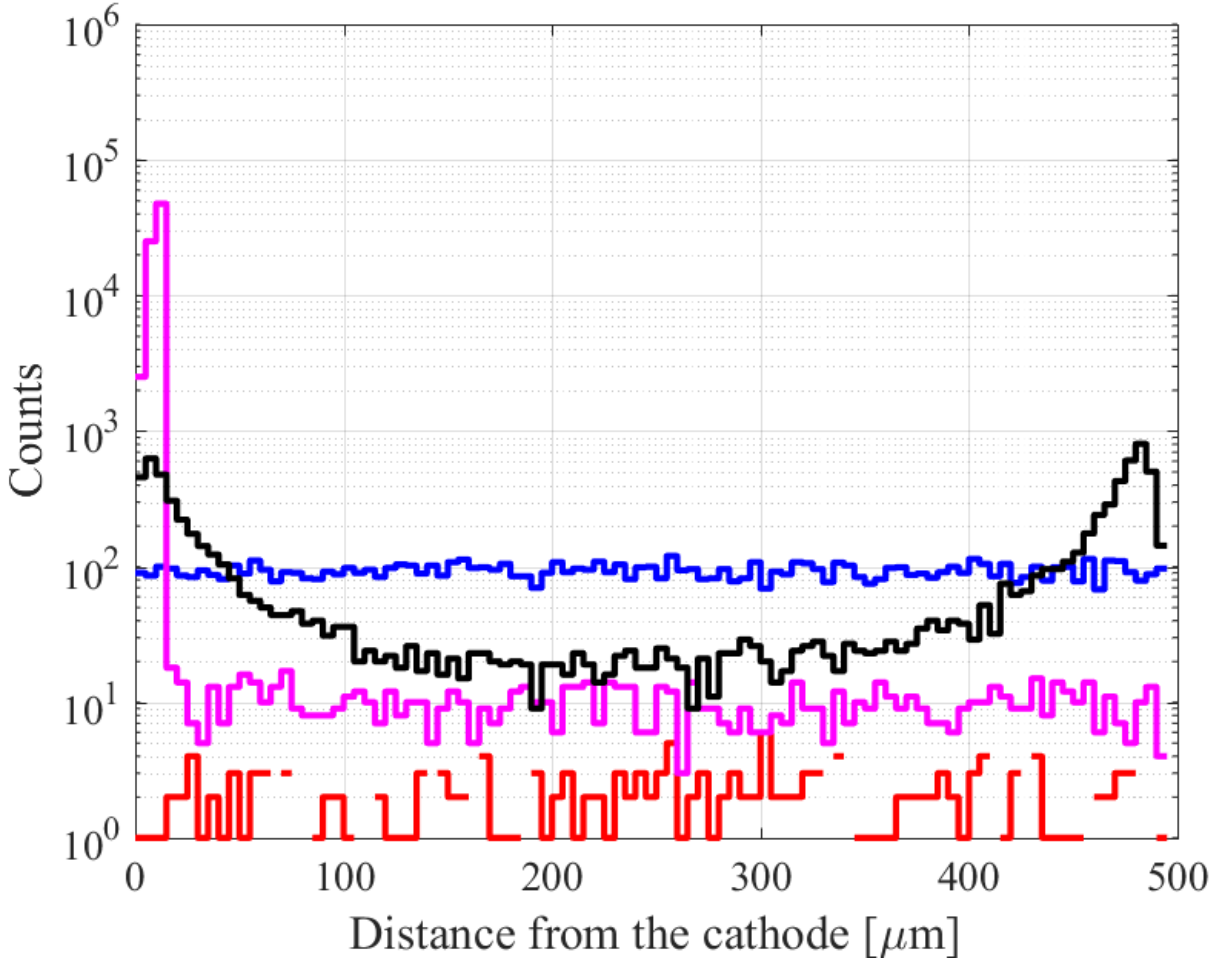
- Reconstruction of an ideal pulse shape based on interaction location & deposited energy
  - RC constant is not taken into account
  - No energy loss in the system

Energy deposited by neutrons in the crystal

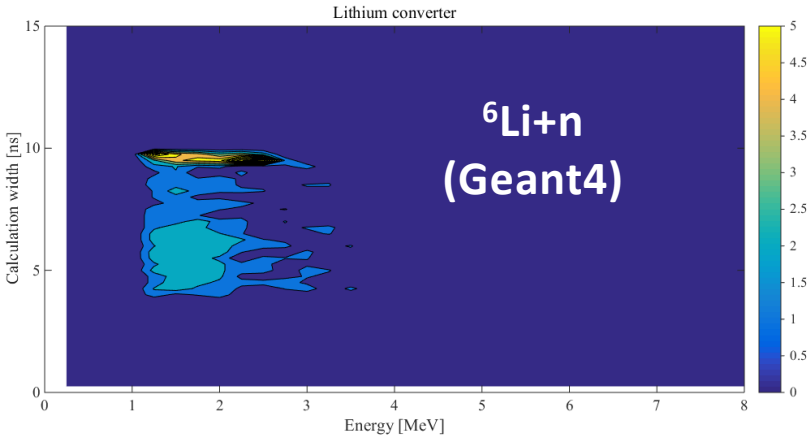


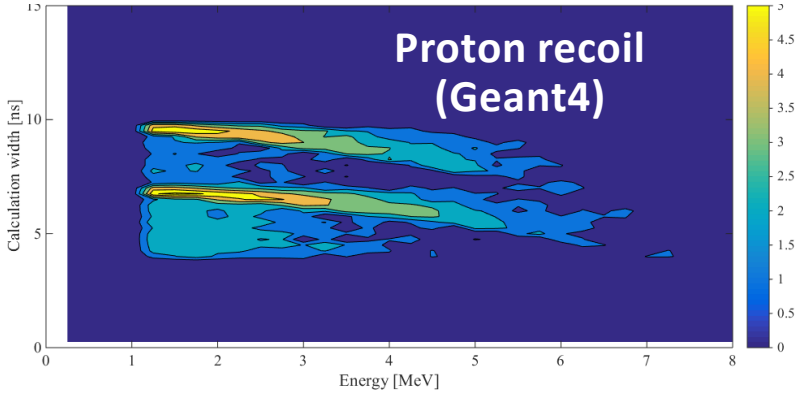


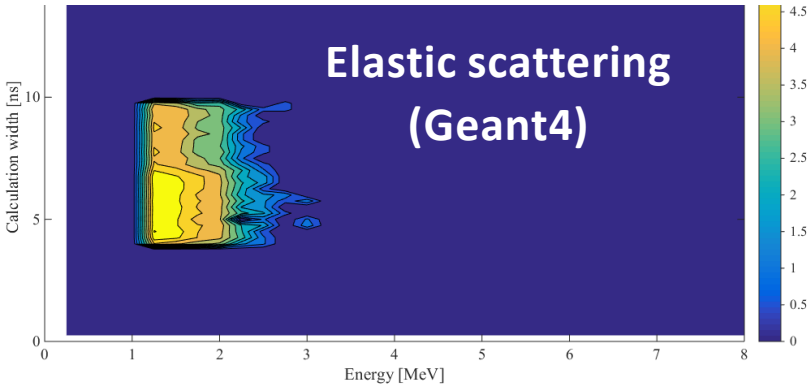
Location of energy deposition in the crystal

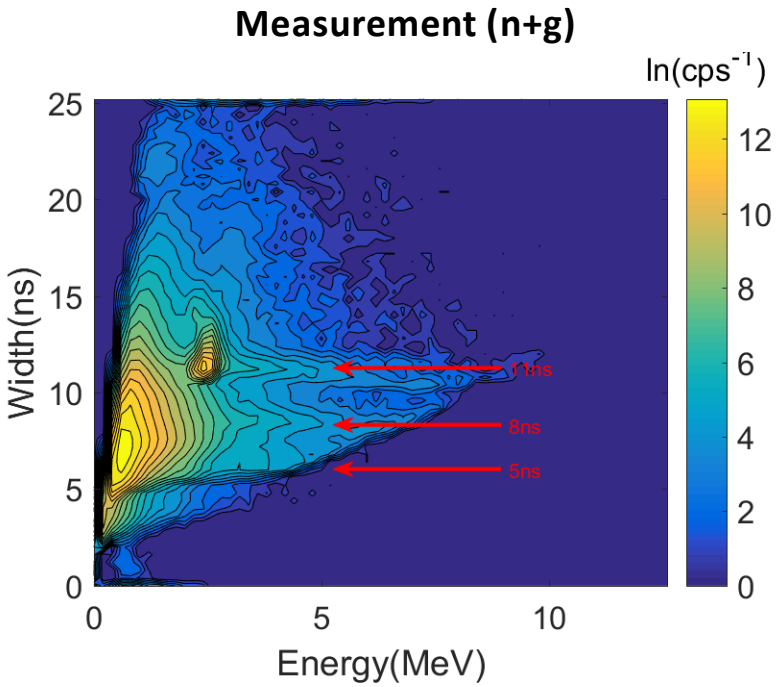


Geant4 vs. Measurements









Conclusions

- Successful installation and testing on NEUTON in CROCUS
  - Joint publication with CIVIDEC
  - Linearity of response with CROCUS power
  - Sensitivity is ~3.10^{-5} per thermal neutron
  - Qualitative detection of fast neutrons in CROCUS

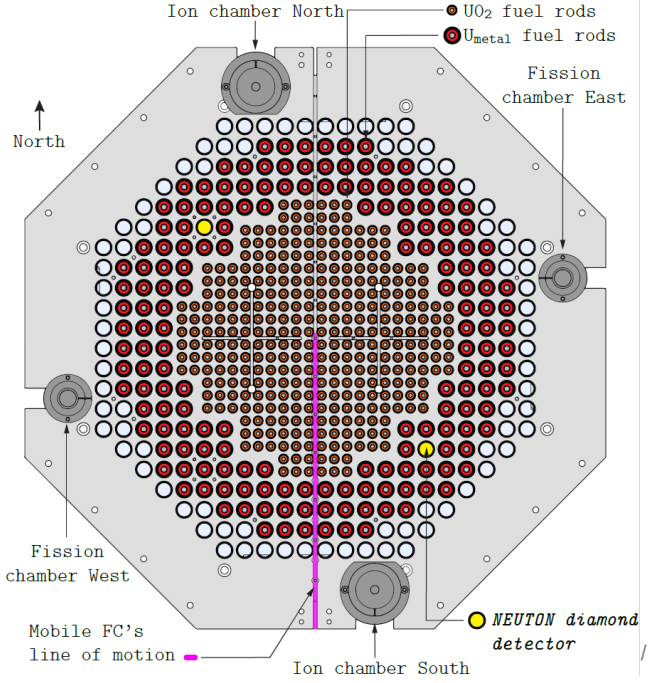
- Modeling of NEUTON with Geant4
  - Contribution of various reactions to overall n interactions quantified
  - High energy tail observed in area spectrum due to proton recoil
  - Structures at 7 and 10 ns & high energy in scatterplot due to proton recoil
  - Energy deposition through scattering is homogeneous

Perspectives for Future Activities

- Neutron Spectroscopy: Quantitative measurement of fast neutrons in CROCUS
  - Area/Amplitude/Width in real time is not enough
  - Upgrade of NEUTON acquisition setup required

- Spatial distribution of neutron flux: Azimuthal variation of the neutron flux near the reflector of CROCUS (on-going)

- Characterization of gamma spectrum in CROCUS by dosimetry / calculations (on-going)



PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Questions?