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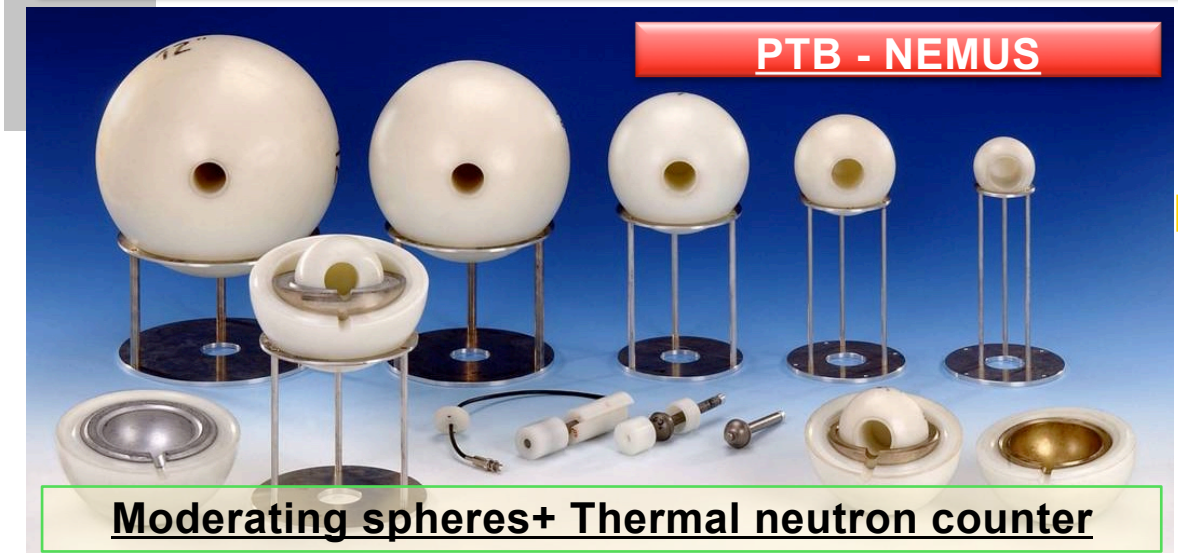
Fast neutron spectrum and distribution measurement at ChipIr at ISIS (14. – 18.06.2019)

ISTSI 2019 29th June 2019

Bonner Sphere Spectrometer (BSS)

Neutron spectrum in a broad energy range with coarse energy resolution
: **12 order of magnitude (1 meV – 20 MeV)** → possible extension ~ **100GeV**



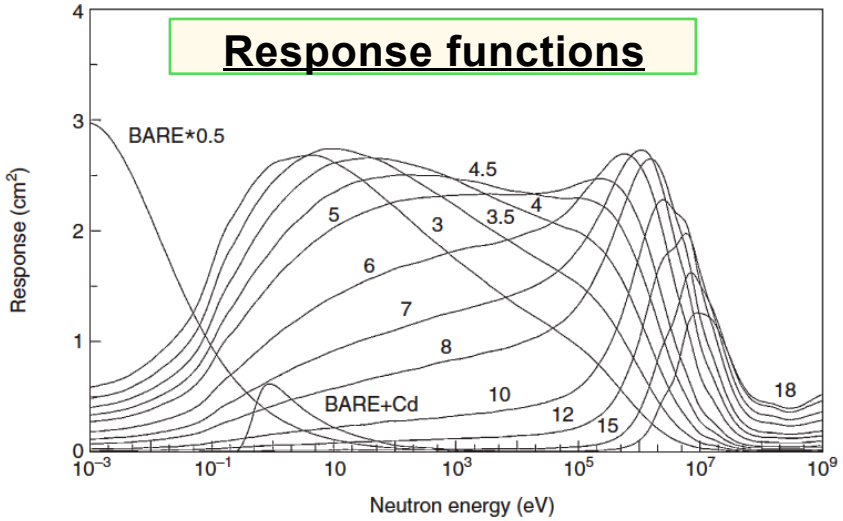
Moderating spheres+ Thermal neutron counter

Measurement: count rate suite

$$N_i = \int R_i(E)\phi(E)dE \qquad (i = 3, 3.5, ,, , 12)$$

N_i [n/s] : Count rate
R_i [cm^2] : Response func.
ϕ [n/s/cm^2] : Spectrum

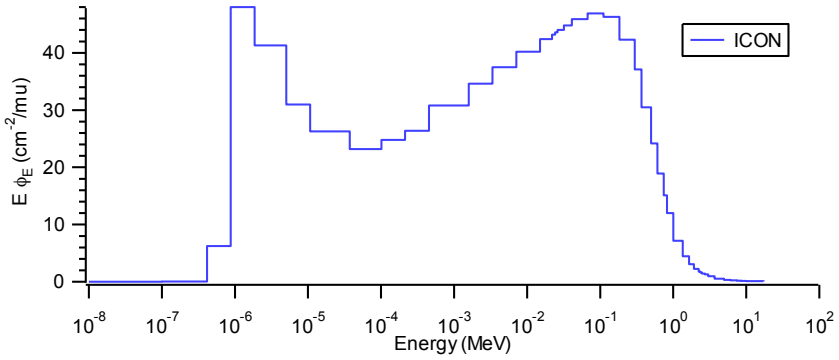
Response functions



B. Wiegel, A.V.Alevra, NIMA 476 (2002) p.36

Unfolding a spectrum using a guess spectrum

- **Maximum Entropy Method**
- **Bayesian Parameter Estimation method**



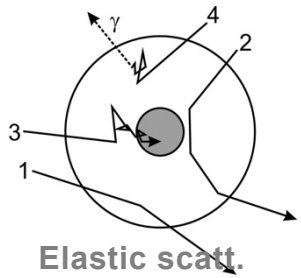
Extending the application of BSS

Background
at reactor sources

ex. Power plants, reactor source, medical facilities

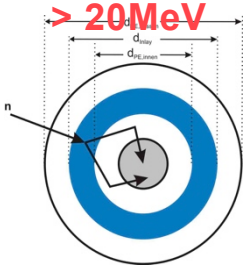
- < 20MeV
- homogeneous fields
- CW fields (low count rate)

Polyethylene(PE)
< 20 MeV

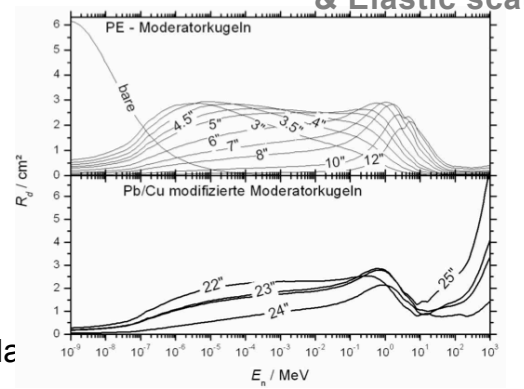


Elastic scatt.

Metal inlay
> 20MeV



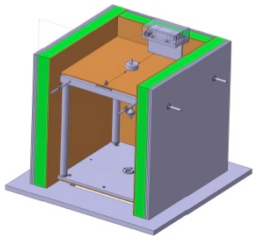
(n,2n), (n,3n), (n,xn)
& Elastic scatt.



In-beam and Background
at large scientific facilities

ex. SINQ, Swiss FEL, HIPA, ISIS, ESS

- Transportable system
- Energy extension ~ 100GeV
- directional field
  - – shielding box
- localized field
  - – modified res. func.
  - – fast neutron imaging
- Intense filed
  - – low efficient counters (10^{-2})
- time structure (pulsed)
  - – fast det. and DAQ system

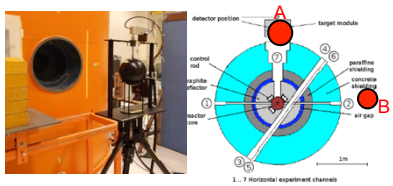


Measurements at neutron facilities

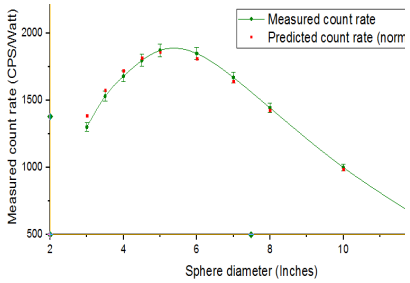
Measurement at AKR, TU-Dresden (low-intensity source)

Neutron source

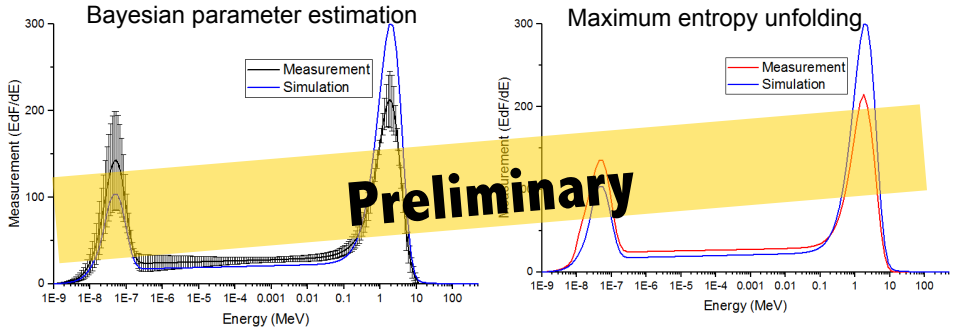
- AKR-2 of the TU Dresden, Educational reactor:
  The thermal, homogeneous, solid material moderated zero power reactor with maximum continuous power of 2 Watt.



Measured count rates of Pos. A



Unfolded spectra of Pos. A (by Roman Galeev)

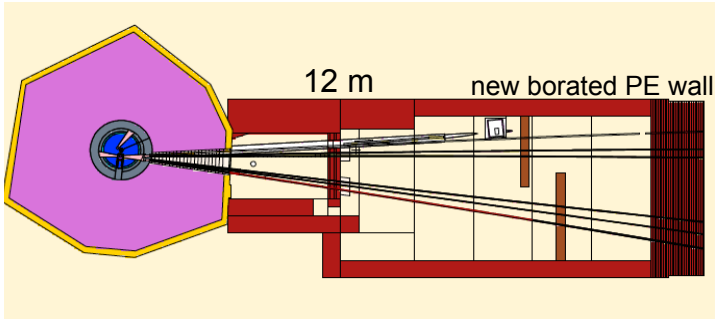


Measurement in the neutron guide bunker in SINQ, PSI (middle-intensity source

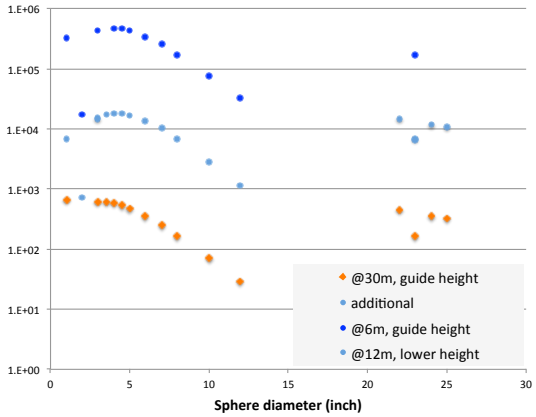
Goal of SINQ-upgrade

increase of the S/N ratio (by improved shielding) in the instrument detectors (neutron guide hall) up to a factor of 2

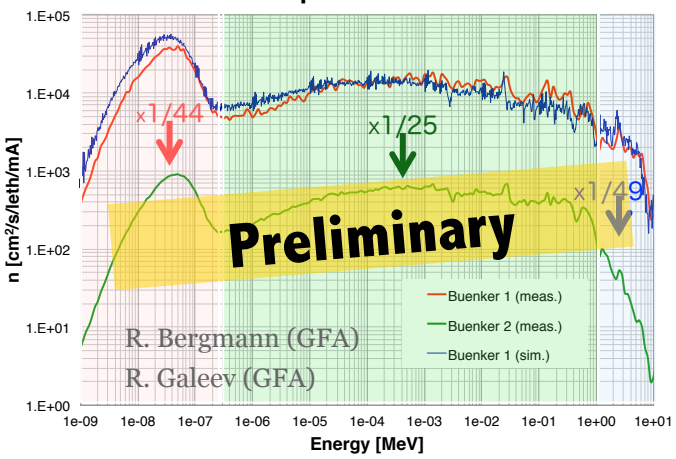
- reduction of fast-neutron BG in the detector
- avoiding of cross talk



Measured count rates in the bunker



Unfolded spectra in the bunker

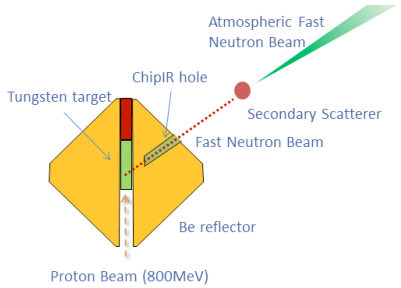


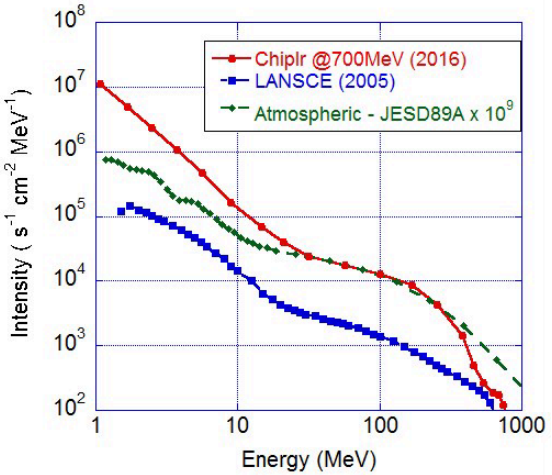
Measurements at the pulsed, high-intensity source

Measurement at ChipIr in TS2, ISIS (WP8)

ChipIr

The fast neutron beam line dedicated to accelerated testing of microelectronics. It is designed to replicate **an atomospheri-like neutron spectrum** to study the **Single Event Effect** in microelectronics.





Carlo Cazzaniga and Christopher D. Frost, IOP Conf. Series: Journal of Physics: Conf. Series 1021 (2018) 012037

Beam angle (ver.) – 2.17°↑

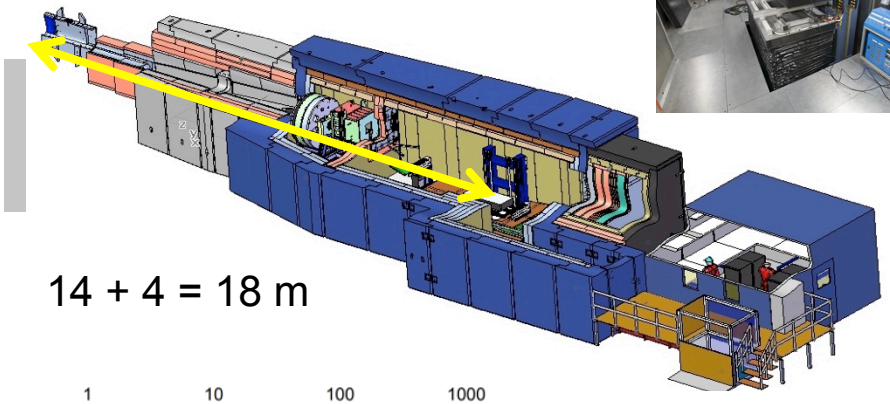
The basic model for MCNP exists and the spectrum has been calculated. But there are discrepancies between the model and the reality.

Purpose of the campaign (original)

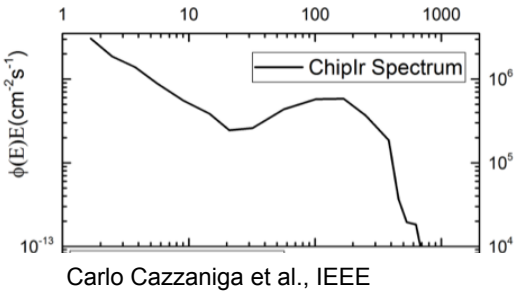
1. **Investigate the possible and useful setup for the mutual validation between BSS meas. and MCNP simulation**
2. **➔ Evaluate the shielding performance of the mineral cast**
3. **➔ Evaluate the shielding performance of the shielding box of PSI-BSS**

Fast neutron beam line- *ChipIr*, TS2, ISIS

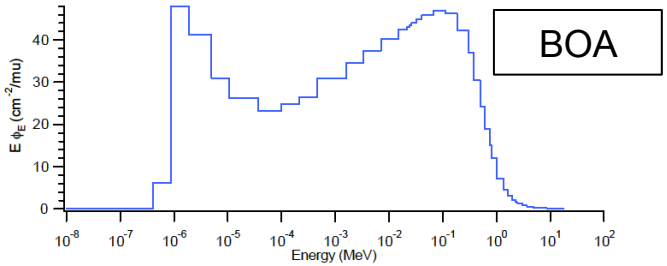
- Shutter – **2m**
- Collimator – **0.5m**
- Adjustable aperture – **0.5m** (ver) + **0.5m** (hor.)



14 + 4 = 18 m

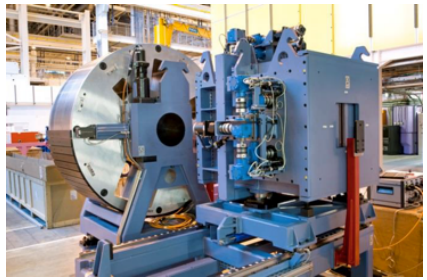


Carlo Cazzaniga et al., IEEE

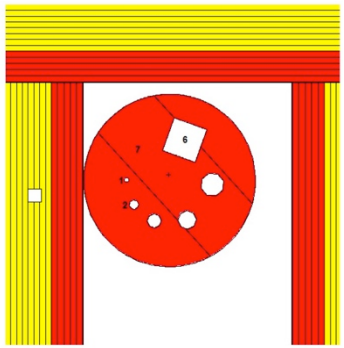


Beam angle (ver.) – 2.17°↑

Steel + (Ni, W)



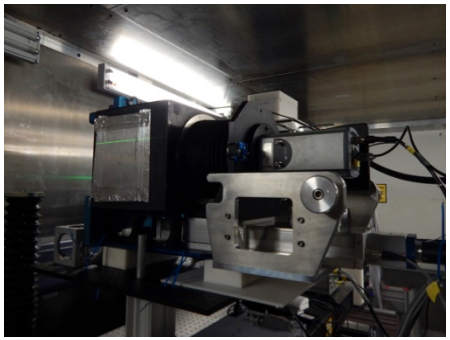
	ChipIr, ISIS	BOA, SINQ
Integrated flux >1MeV [n/s/cm2]	$6x10^6$ (< 1MeV) (800MW, 40uA)	10^4(< 1MeV) (0.8MW, 1.4mA)
time structure	Pulsed (70ns, 2-pulses, 10Hz)	CW
Beam size	$70x70mm^2$	$24x24mm^2$
count rate (differential)	(expected) $6x10^9$n/s/pulse ➔required reduction ~**$x10^{-6}$**	$1x10^4$n/s



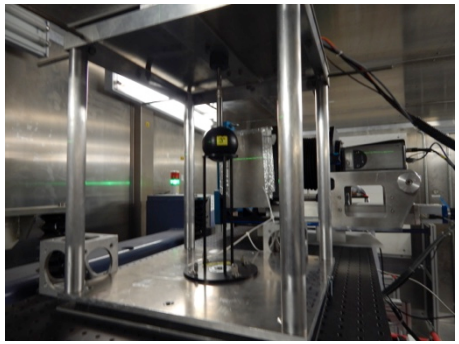
Setup combinations

Detector	Sphere	Shutter	Collimator	Beam size	Gamma-shield	Position
100%		Open	Open	70x60 mm^2	W (t700mm)	In-beam
↕	PE (3”, … 12”), Cu, Pb	↕	↕	↕	↕	↕
1%		Close	Close	10x10 mm^2	Close	away

- filter, attenuator (ex.BPE)



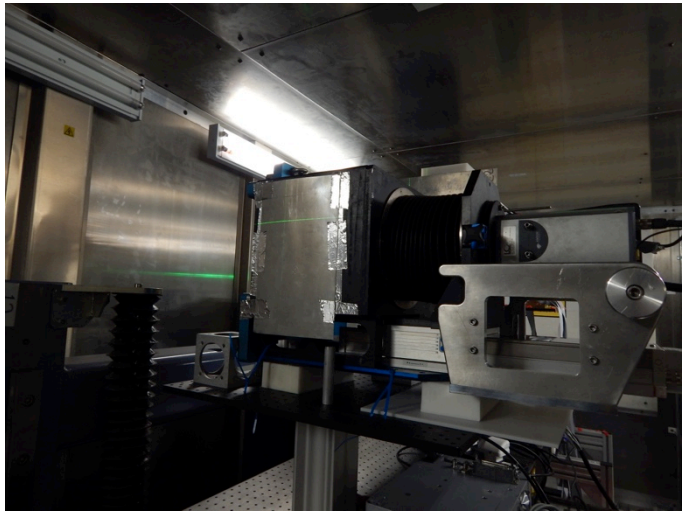
➔ Spatial beam profile with imaging
- homogeneity
- cross sections
- (essential for response functions)



➔ Signals in BSS
- Law signals in oscilloscope (saturation)
- PHA (gamma contribution)
- Count rates

Imaging setup

imaging	Scintillator	sensitive energy
Fast	PP/ZnS:Cu (t2.4mm)	> 0.8 MeV
Epi-thermal	Li^6F/ZnS (t100um) +Cd	> 0.4eV
Thermal (subtract Epi-th)	Li^6F/ZnS (t100um)	< 0.4eV

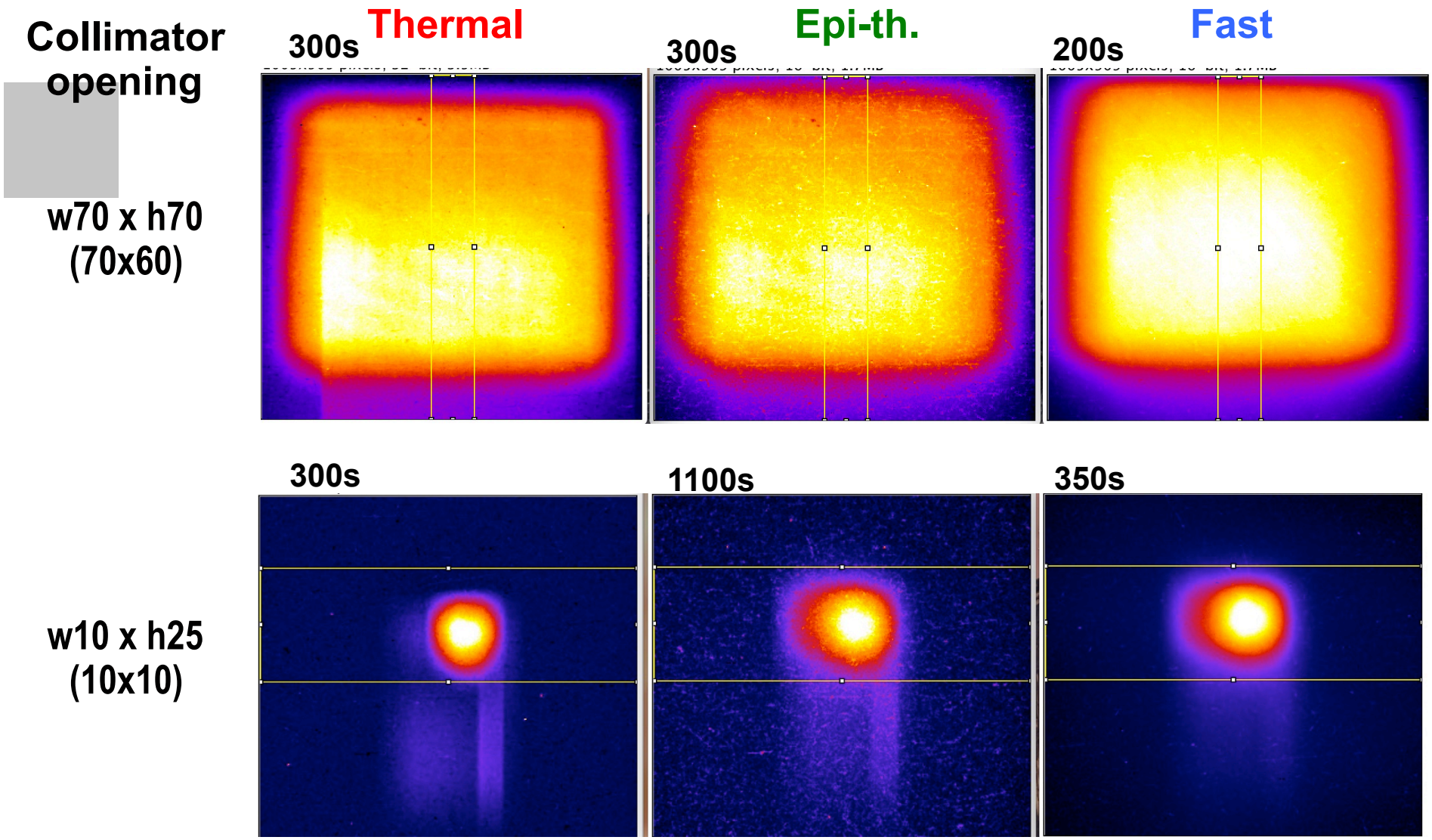


MIDI-box

(PSI-standard neutron imaging system)

- CCD camera
  : ANDOR iKON-M operated at -90°C
- Objective : f-50mm
  - FOV : 10.6 x 10.6 (cm)

Spatial distributions of the beam

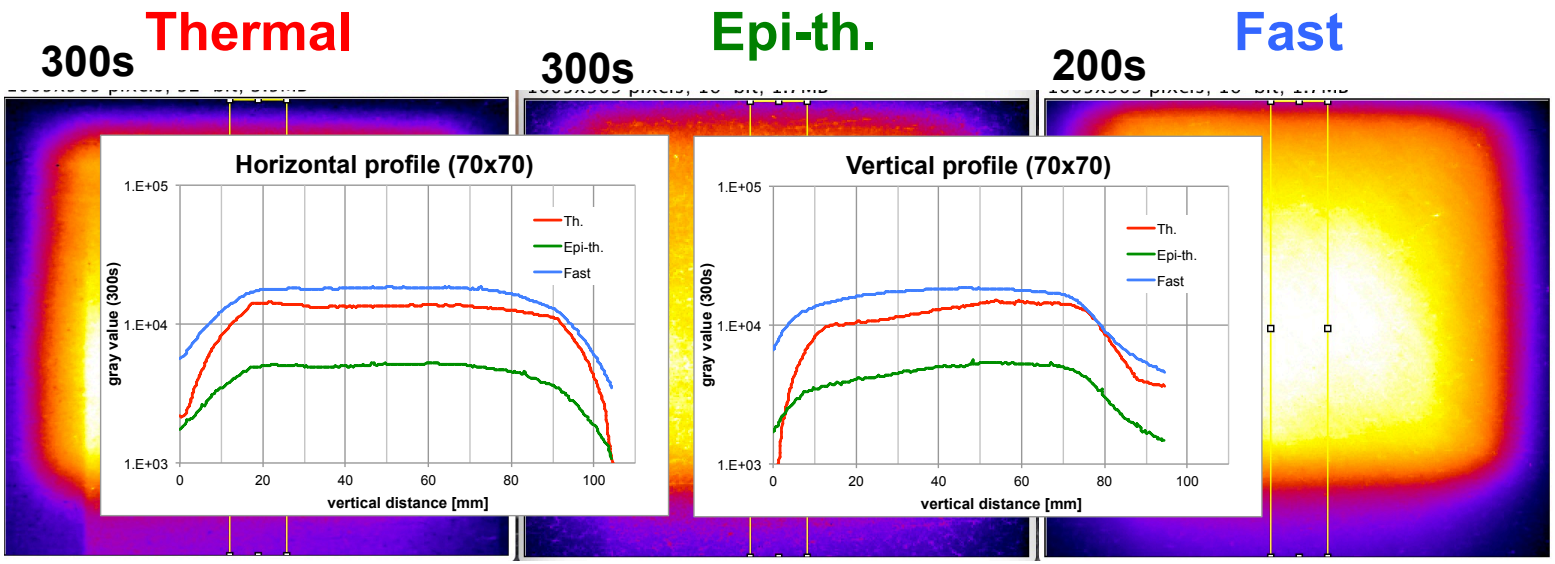


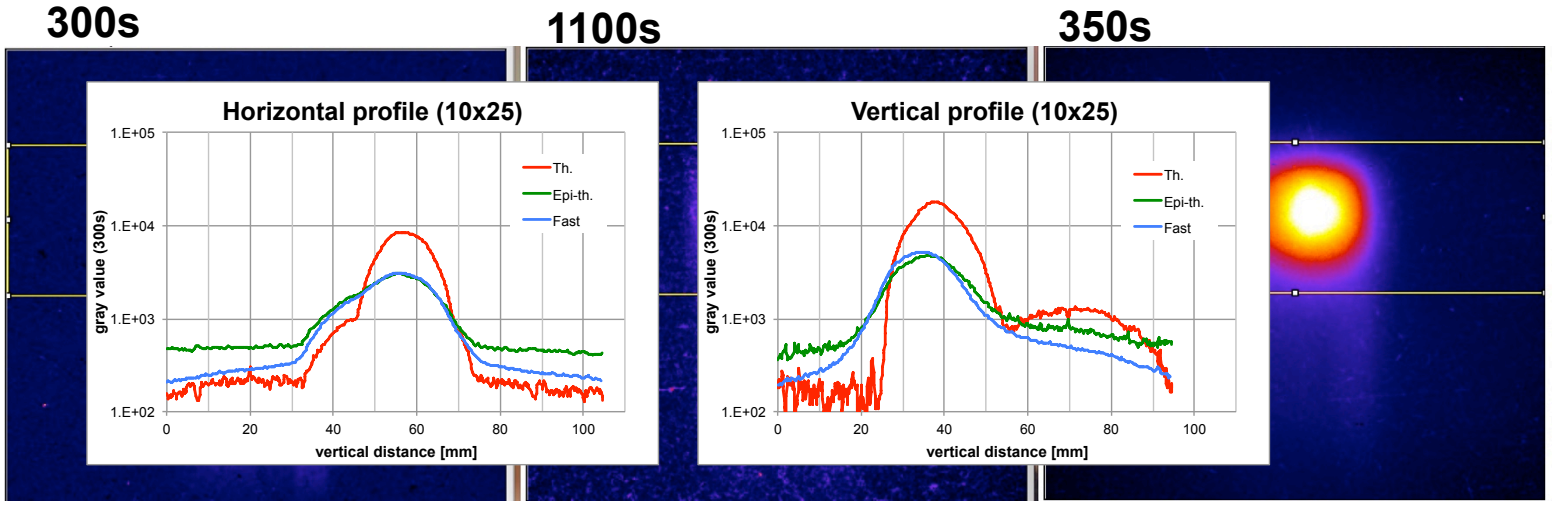
Spatial distributions of the beam

Collimator opening

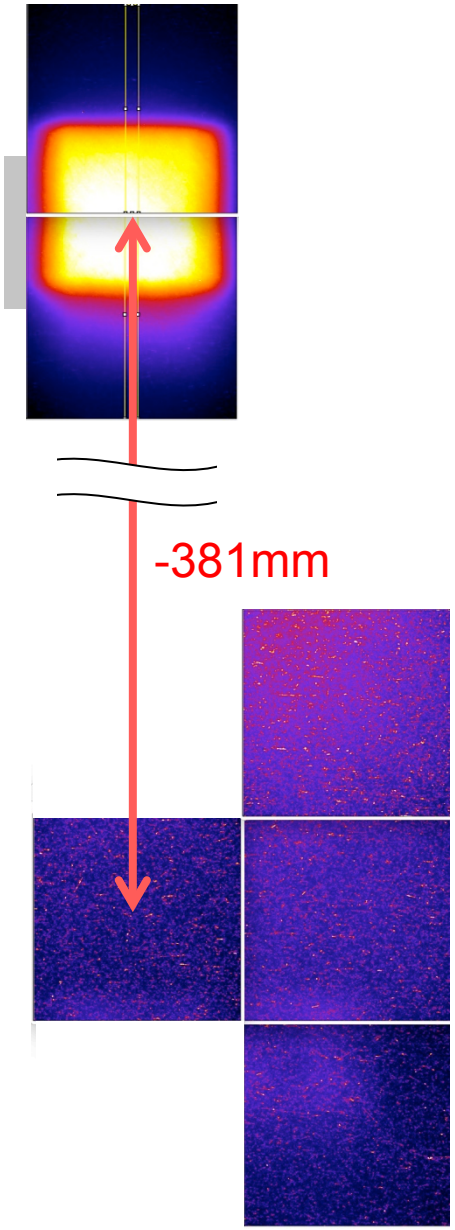
w70 x h70 (70x60)

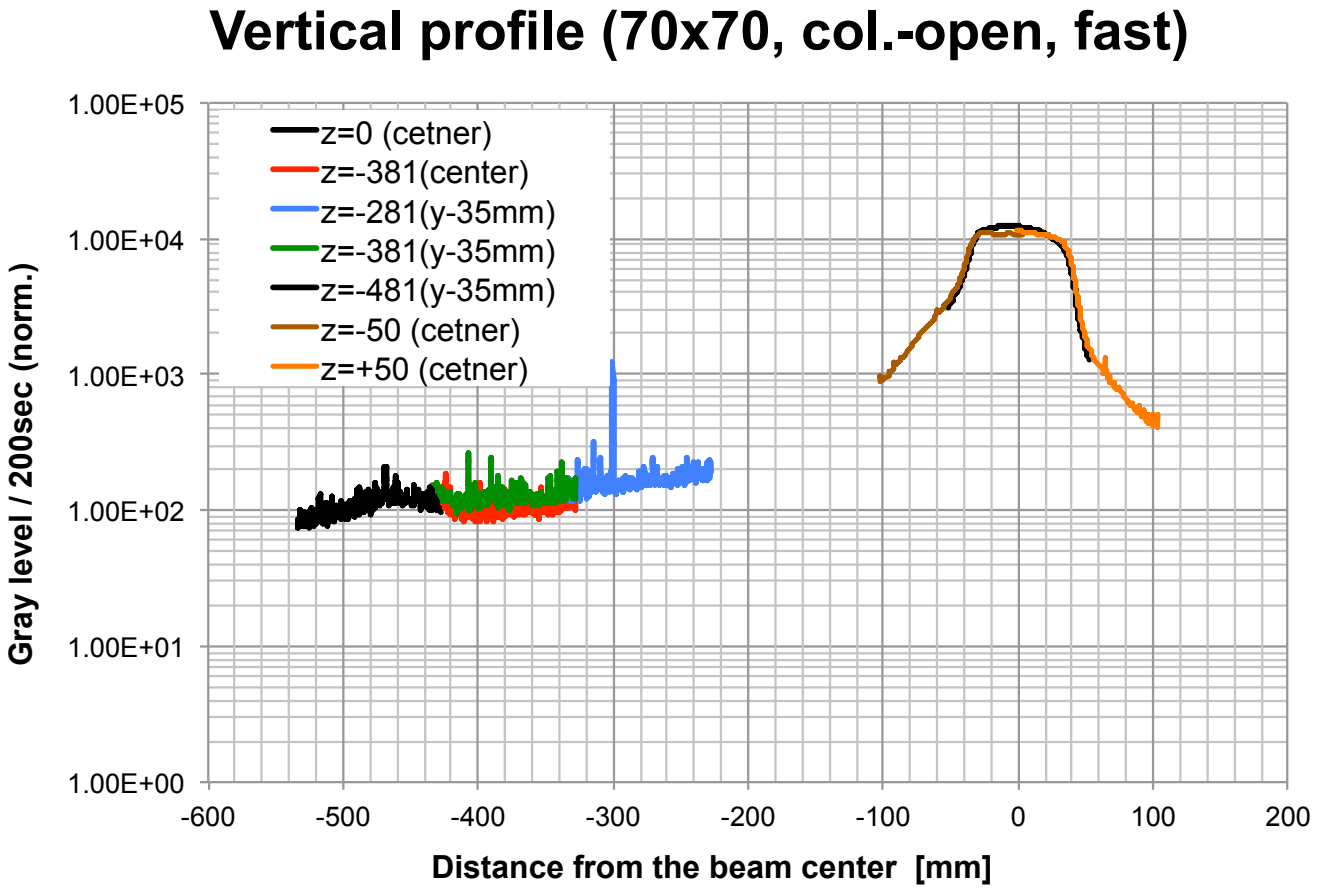
w10 x h25 (10x10)





Spatial distributions away from the beam

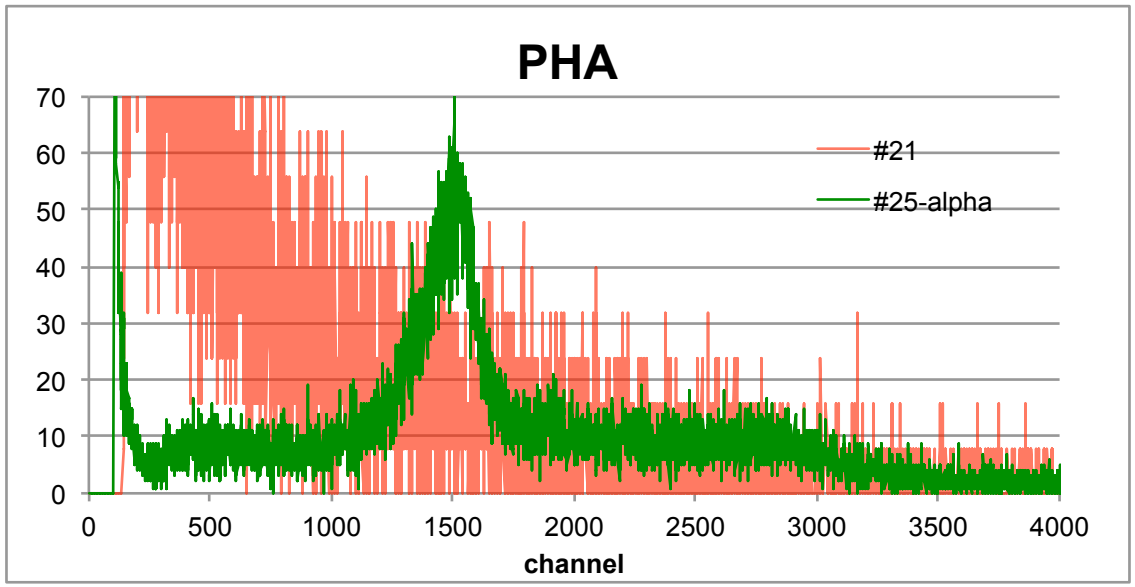


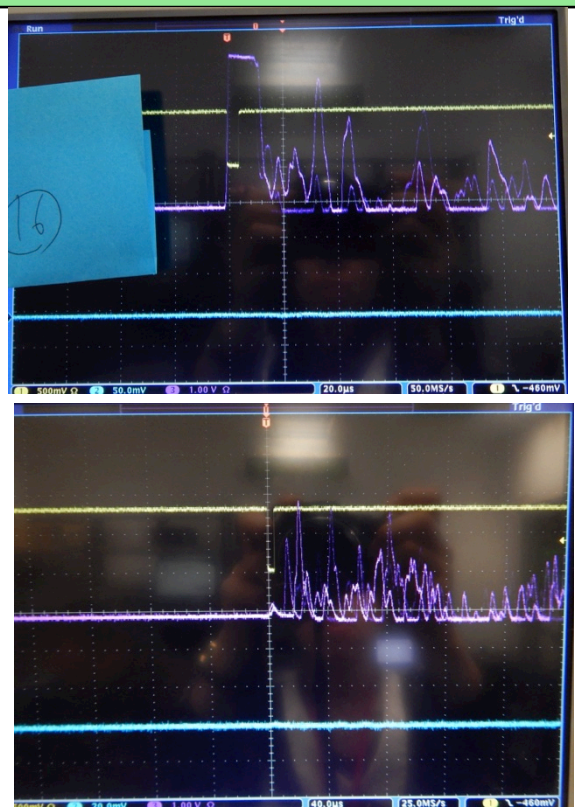


- We can use the homogeneus field, which is 400 mm away from the beam center
- reduction x1/100

Setup combinations with BSS

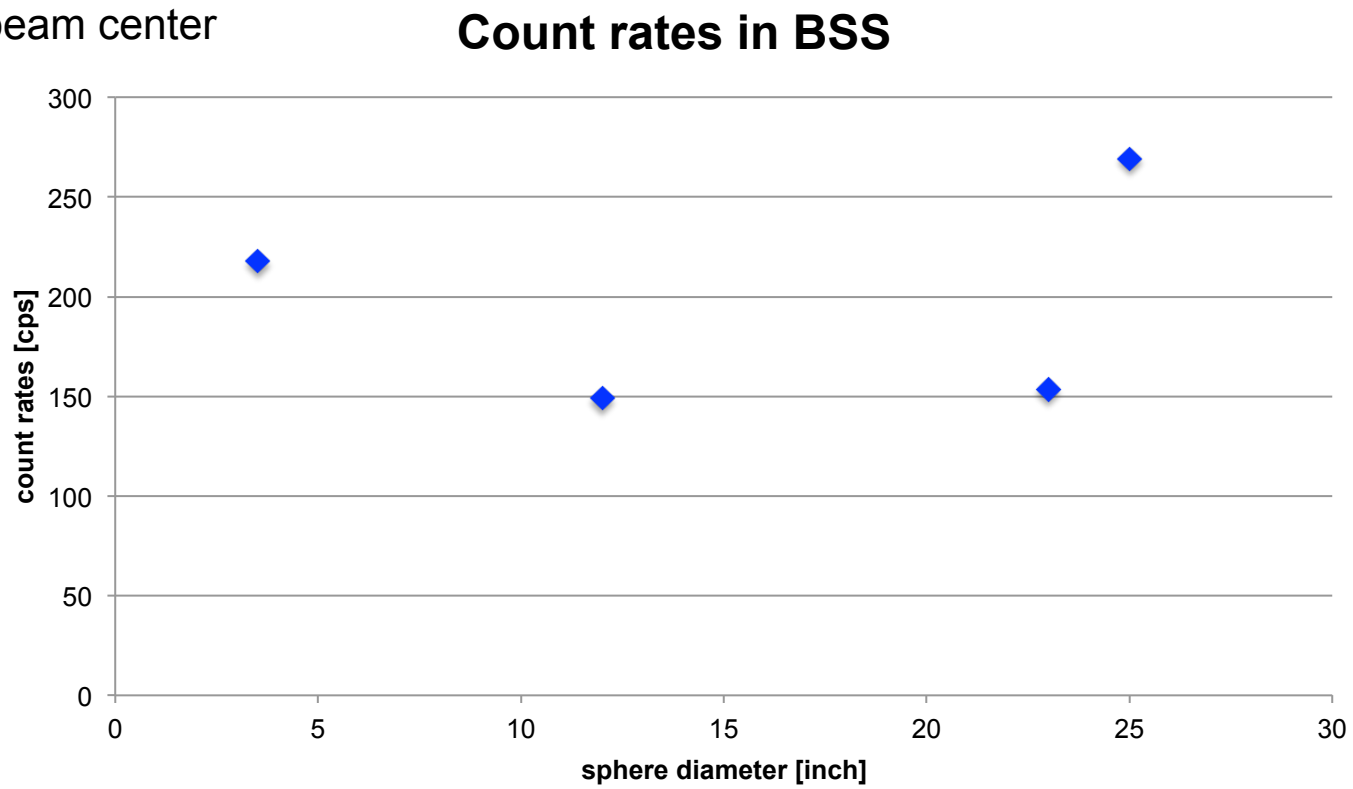
Detector	Sphere	Shutter	Collimator	Beam size	Gamma-shield	Position
100% / 1%	PE (3", … 12"), Cu, Pb	Open / Close	Open / Close	70x60 mm^2 / 10x10 mm^2	w/ / w/o W (t700mm)	In-beam / away
100%	Pb(25")	open	close	10x10	w/	-400
1%	Pb(25")	open	close	closed	w/	0



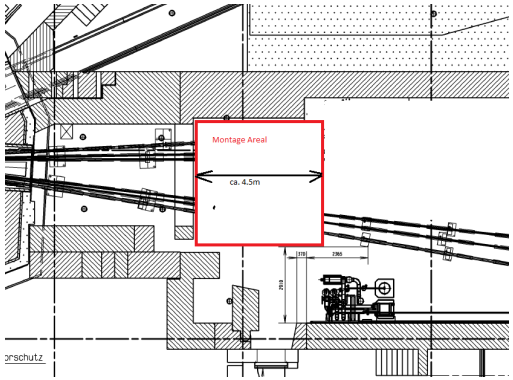


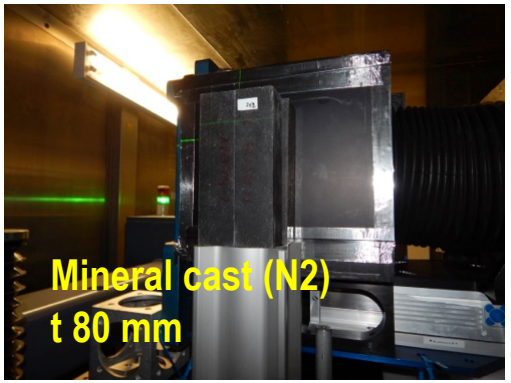
Measured count rates in BSS at ChipIr

- Detector – 1%
- Shutter – open
- Collimator – close
- Aperture – 10 x 10
- w/ W-blocks (t700mm)
- Position
  - at the beam center

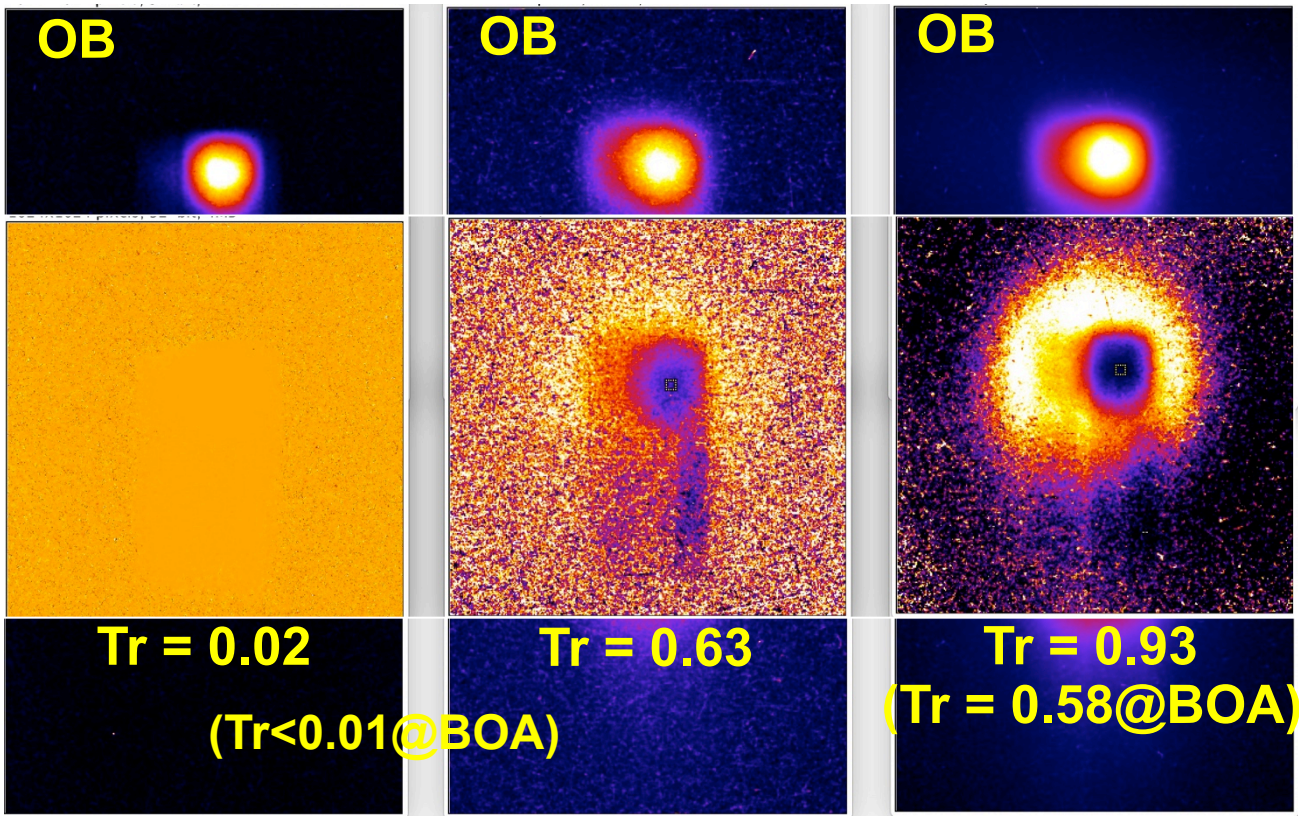


Transmission of Mineral cast (N2)



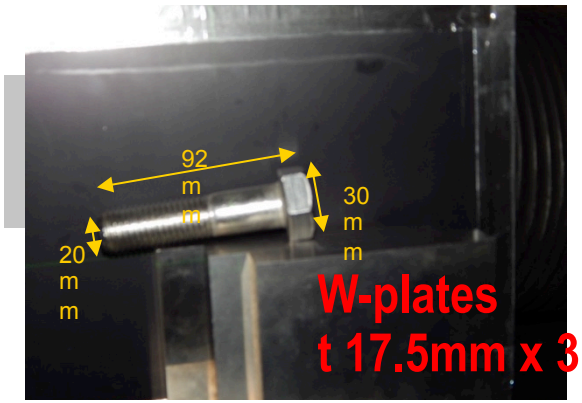


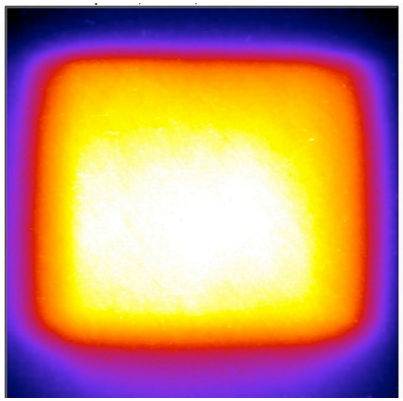
Thermal **Epi-th.** **Fast**

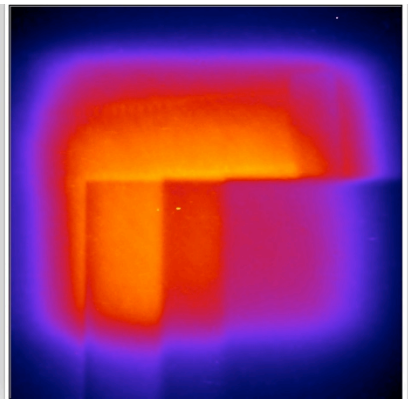


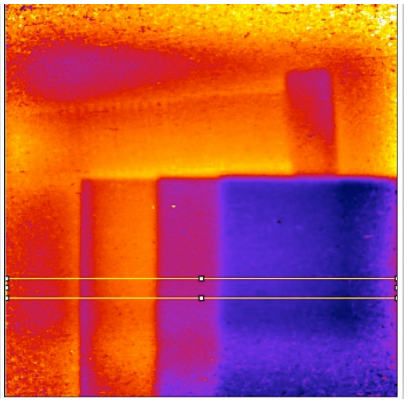
- The spectrum information is essential to assess the shielding performance of N2 in different energy ranges.
- The gamma contribution should be treated using the simulation results.

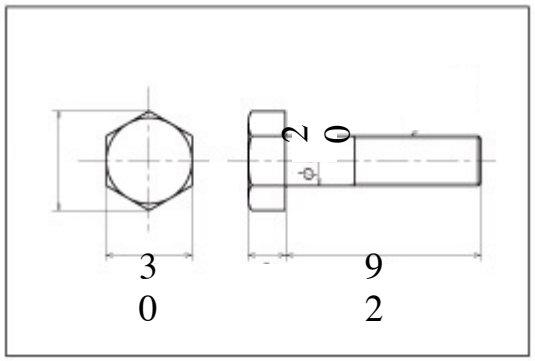
Example of imaging with fast neutrons

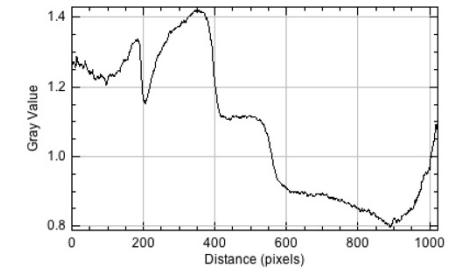












- The thread is recognizable.
- The **afterglow** by very fast neutrons should be studied further.
- It will be better to keep distance between sample and the scintillator to discard **scattered** neutron by sample.
- The **gamma contribution** should be studied and treated properly.

Summary

1. **PSI-ERBSS (the extended-range BSS) is up running for the low-/middle- flux sources.**

2. **We are trying to extend the application to the high-flux, pulsed sources under the SINE2020 WP8. The first measurement at ChipIr were conducted between 14. – 18.06.2019.**

    - ISIS is providing the fast neutron beam time, ChipIr, and the MCNP model of the beam line.
    - PSI is conducting the measurement and improving the system to adapt to high-pulsed-flux source.
    - ESS-Bilbao will perform the simulations for this various setups in this campaign.

3. **The next step is to discuss with the simulation team. Not only neutron but photon (gamma) should be simulated to treat the measured data better.**

4. **The current BSS setup is not able to cope with such high differential count rates. The detector should be replaced by the faster detector (ex. ^{235}U fission chamber), which is gamma-insensitive, and can be very low efficiency.**

5. **We are aiming to conduct another measurement at ChipIr within one year with modified PSI-BSS system.**

Thank you for your attention