



Vertical Neutron Camera

WPSA ENH mid-term progress meeting

2026-10-23

Lukasz Swiderski

and the NCBJ, UU, UniMiB, ISTP and F4E teams



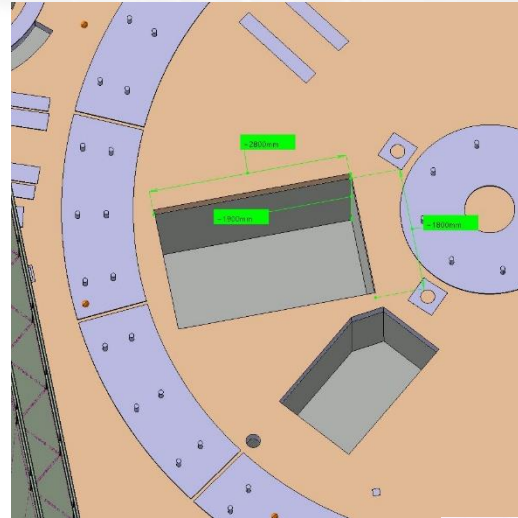
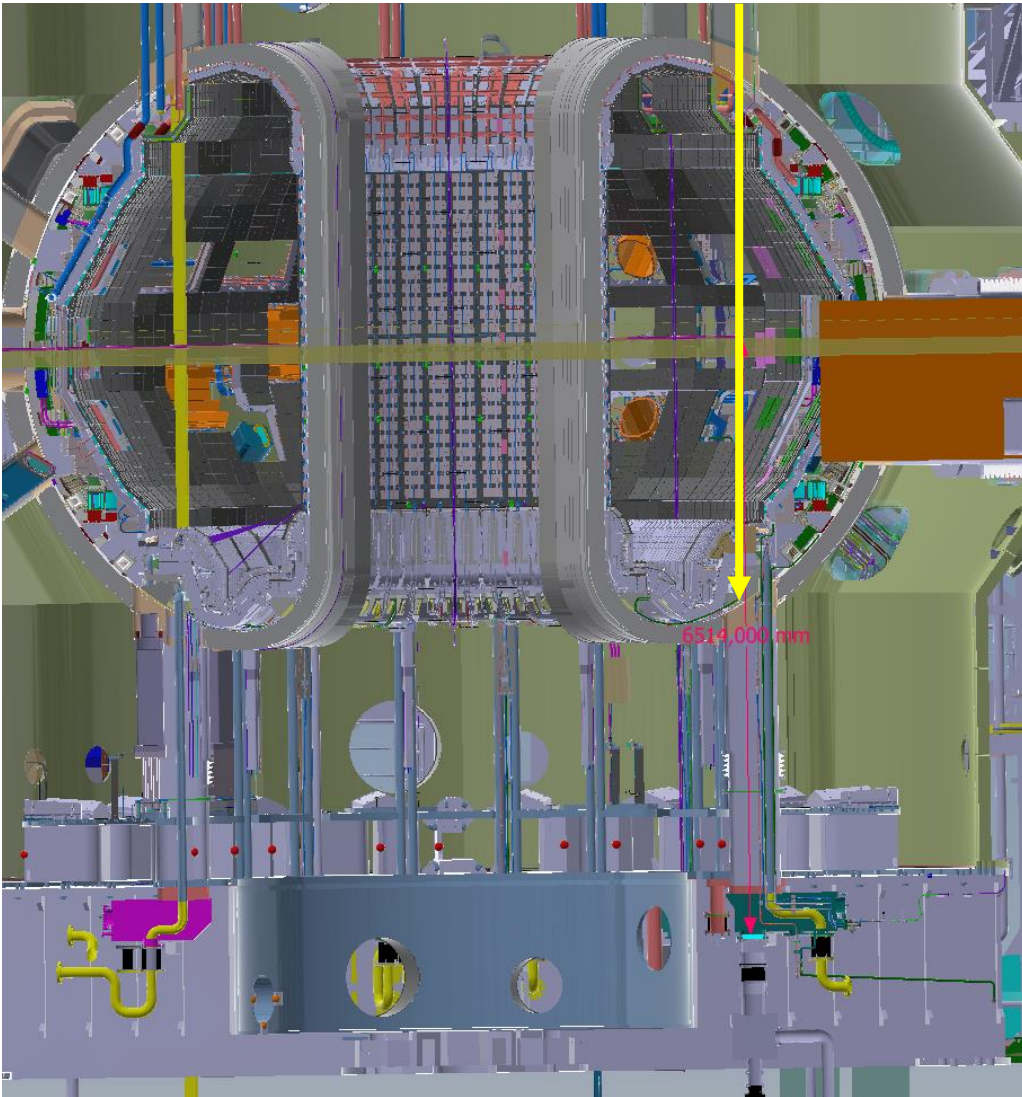
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Vertical Neutron Camera

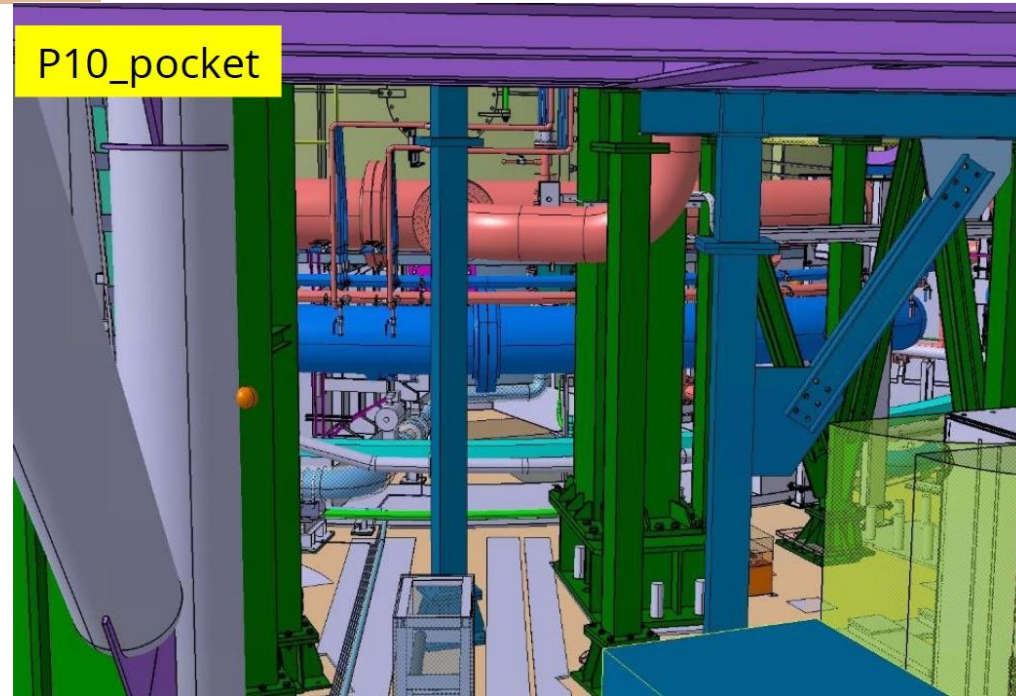
1. status of the project

VNC in P10-lower port

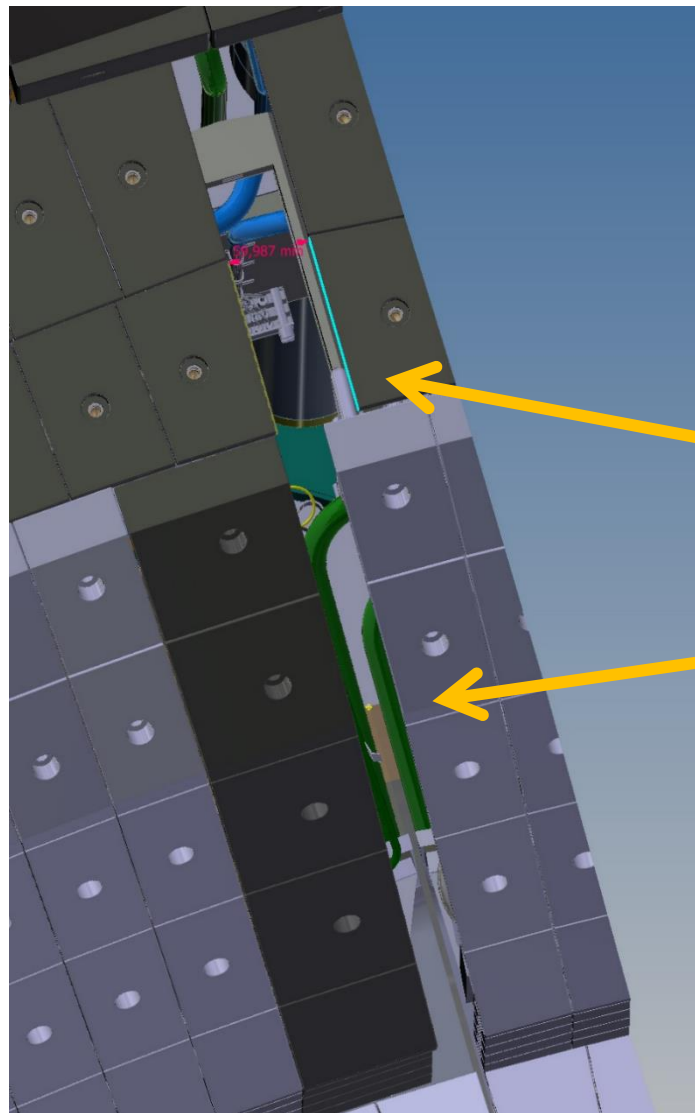


Requirements (from Sumida et al.,
Rev. Sci. Instrum., 91 (2020) 113504):

- spatial resolution:
 $< 0.1a$ (20 cm)
- statistical resolution:
 $< 3\%$ (10^3 counts / timebin)
- temporal resolution:
 < 100 ms ($@10^5$ cps)



Vertical Neutron Camera in P10-lower port



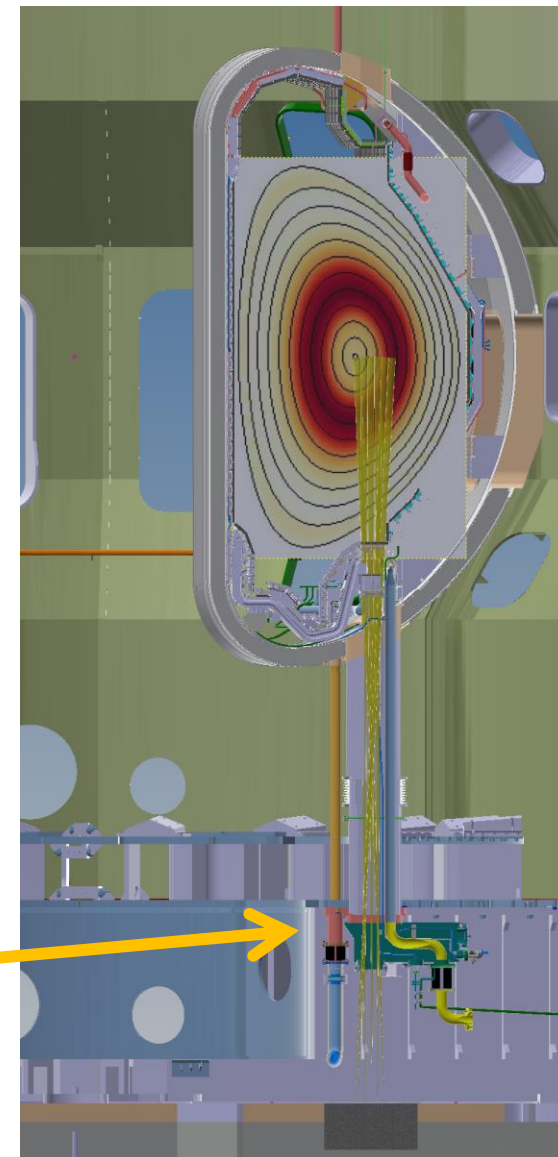
Main issues:

Narrow divertor slit above P10-lower port
and the flange inside restrict FoV

60 mm

34 mm

Flange inside
P10-lower port

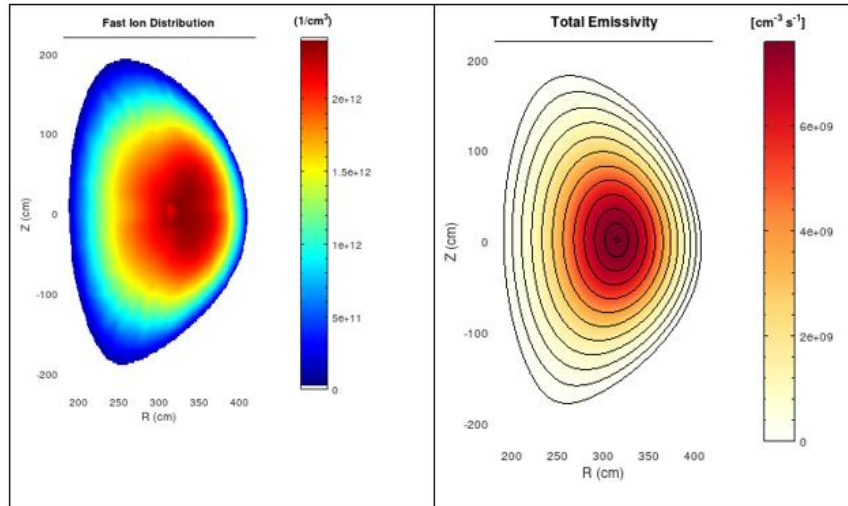


TRANSP/NUBEAM simulations

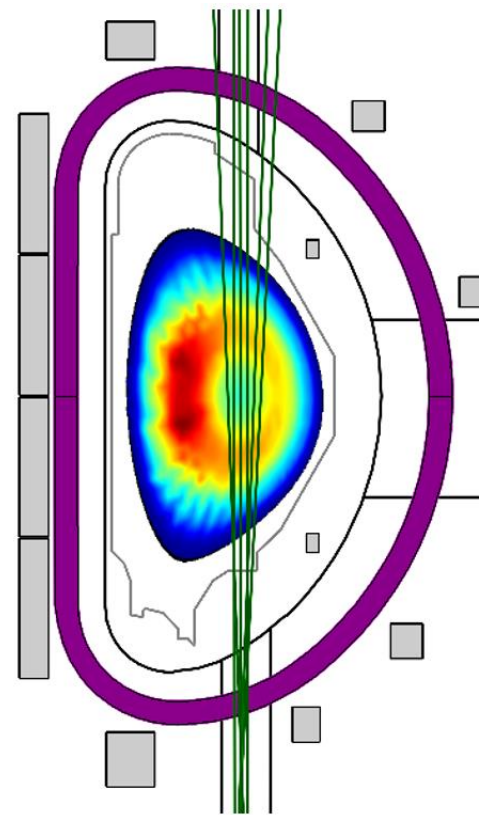
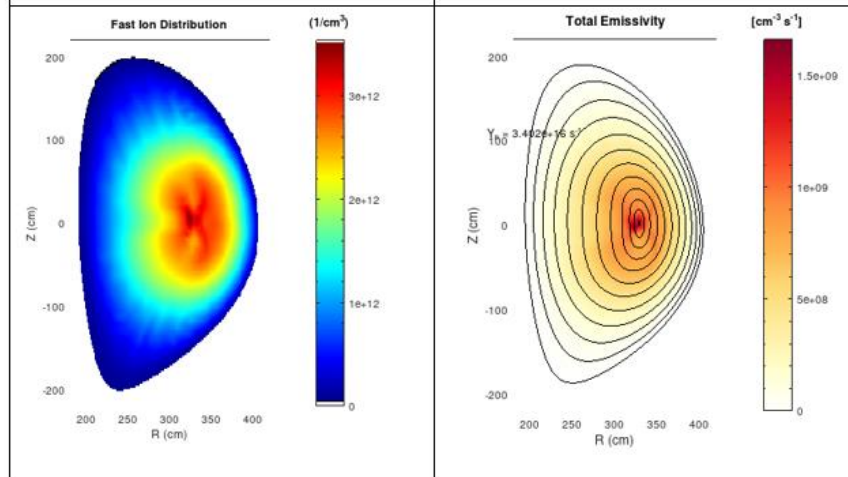
FID and neutron emissivity

VNC Line of sights from P-10 lower port

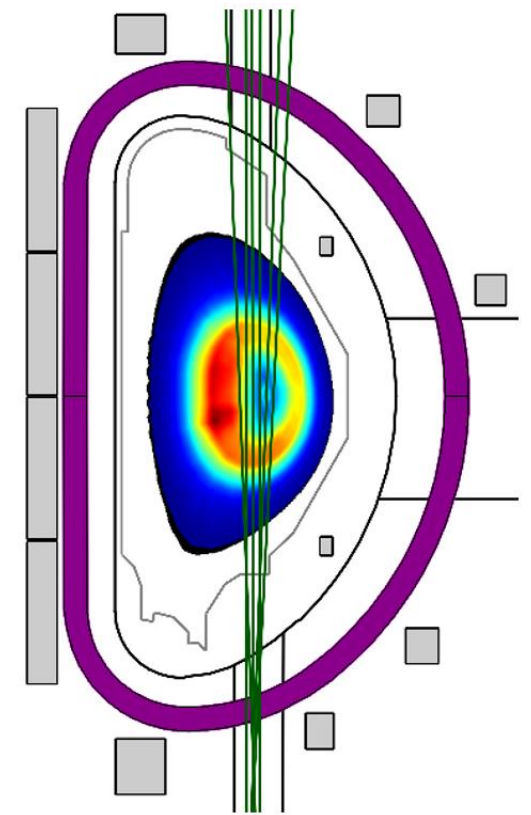
S2



S5



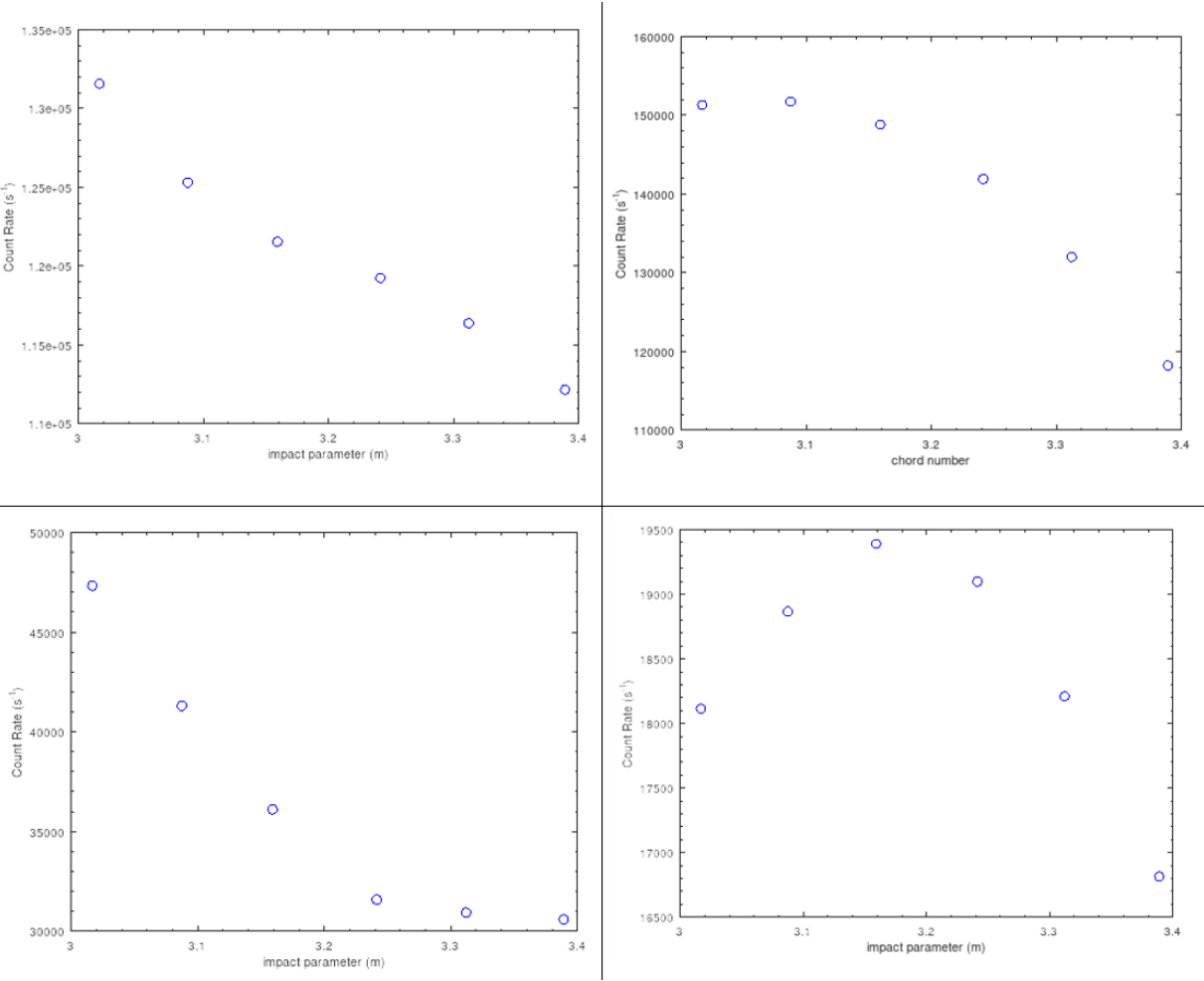
S2



S5

countrate evaluation

liquid scintillator: Ø6×60mm
DD neutron detection eff: 12.4%
energy threshold: 1.8 MeV



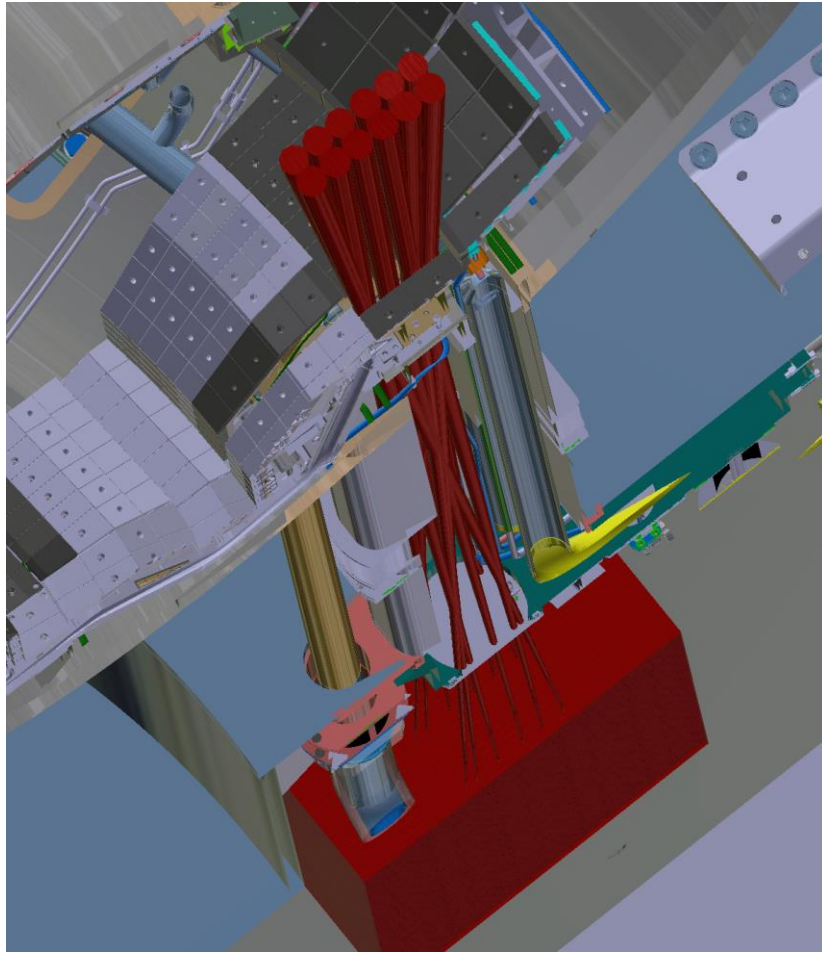
	DD neutrons		DT neutrons	
Scenario	Average CR (1/s)	Time resolution for 10% statistical uncertainty (ms)	Average CR (1/s)	Time resolution for 10% statistical uncertainty (ms)
S2	1.21×10^5	0.83	1.11×10^4	9
S2 with anomalous fast ion diffusion	0.89×10^5	1.12	1.85×10^2	500
S5	3.63×10^4	2.75	2.1×10^3	48
S5 with anomalous fast ion diffusion	1.84×10^4	5.43	2.4×10^1	4800

Vertical Neutron Camera

1. status of the project

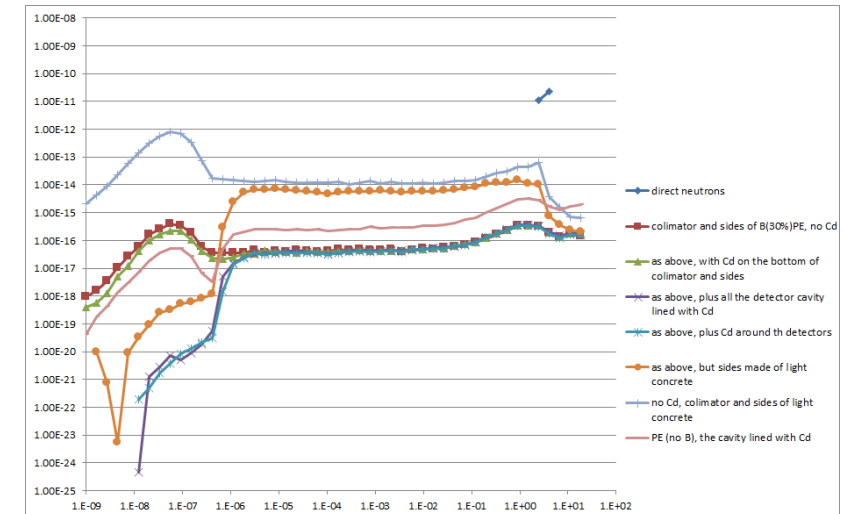
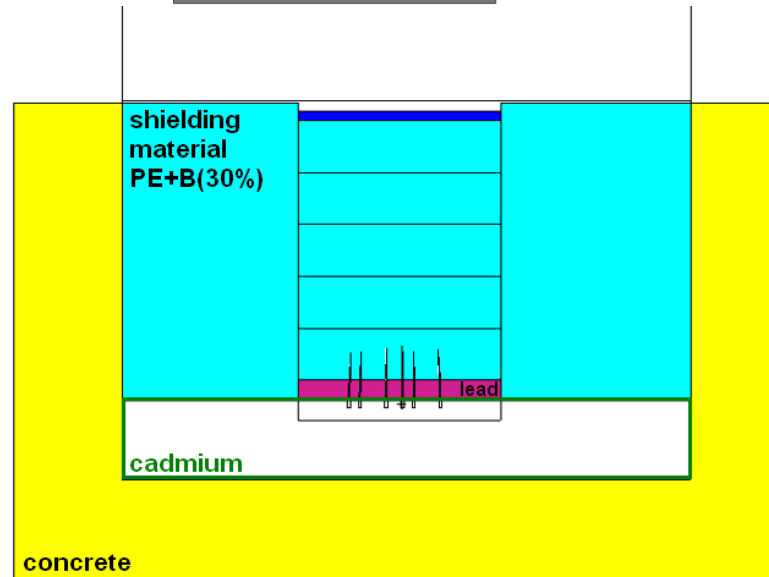
Proposed solution:

2 rows × 6 channels (Ø6.6 mm)

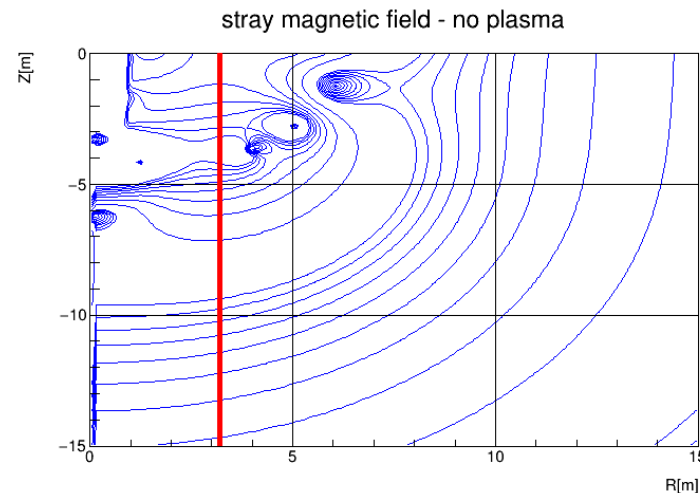
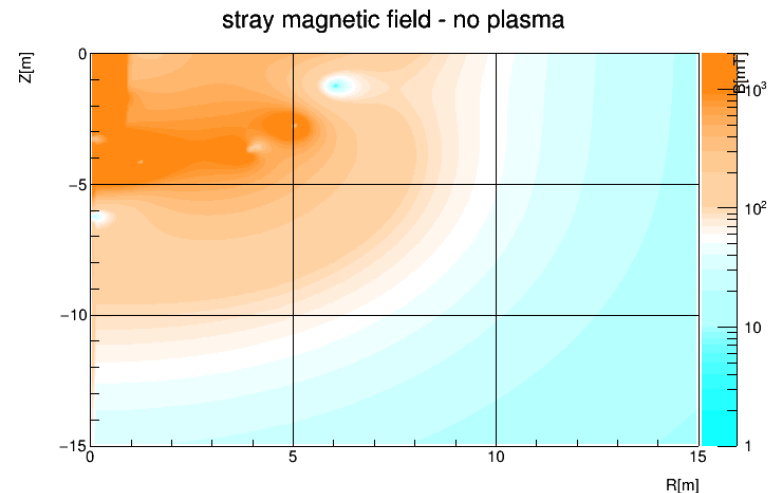
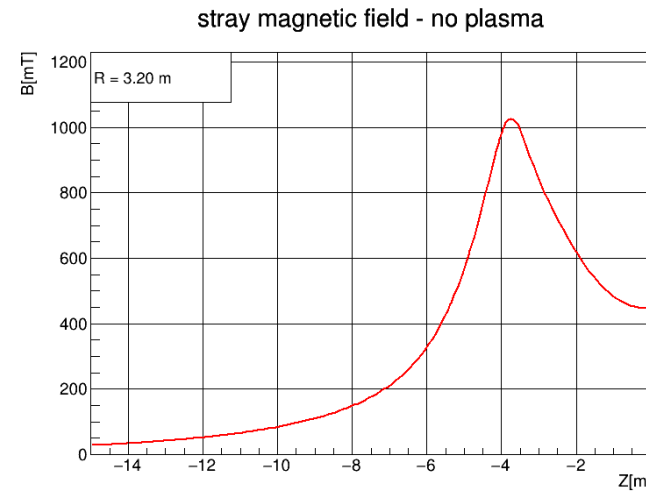
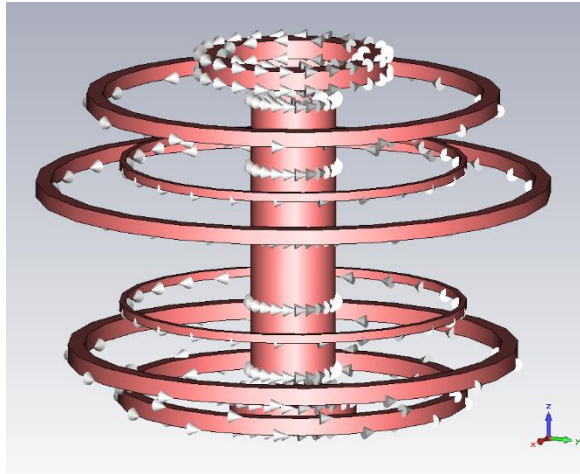


Vertical Neutron Camera in P10-lower port simplified model with 2.45 MeV isotropic neutron source

- Collimator thickness in total is 150 cm, composed of shielding material made with:
- polyethylene with boron-10 at 30% (5 blocks with thickness 26 cm + sides),
 - lead plate above the detectors (thickness 10 cm),
 - cadmium sheet around the detectors pocket (thickness 2 mm).



Magnetic field map:
simple coil model reproduces results from PID v4.5

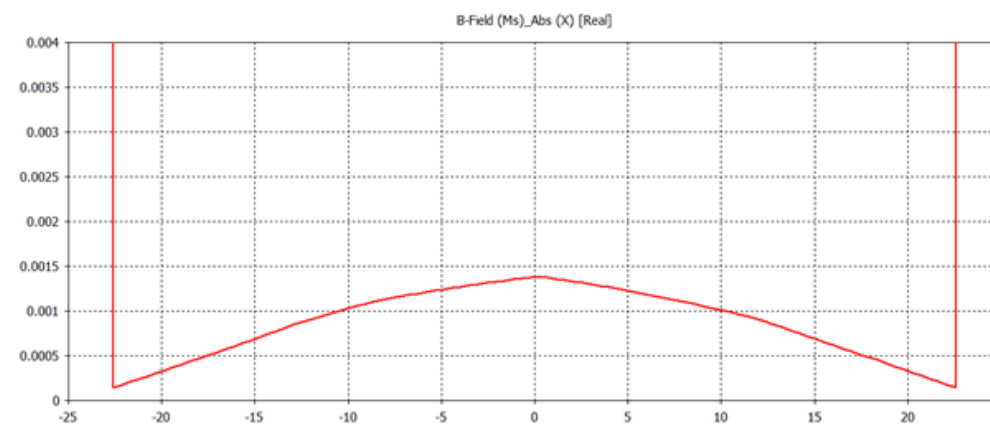
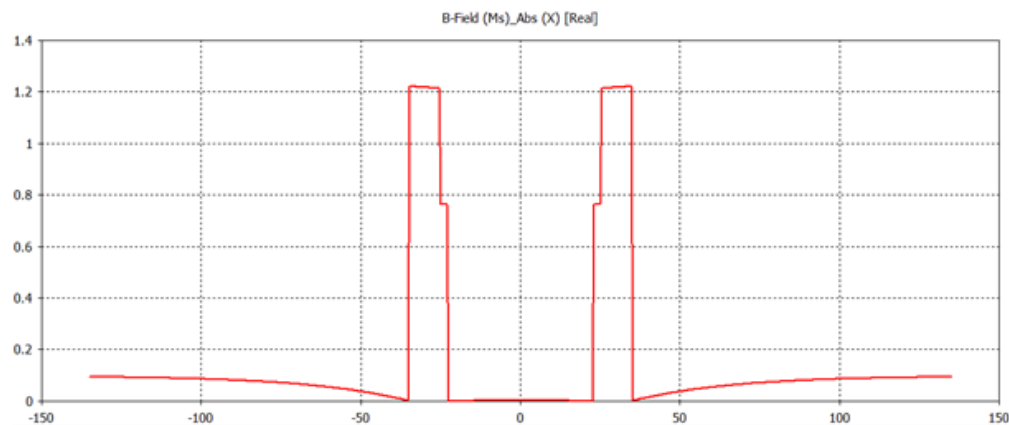
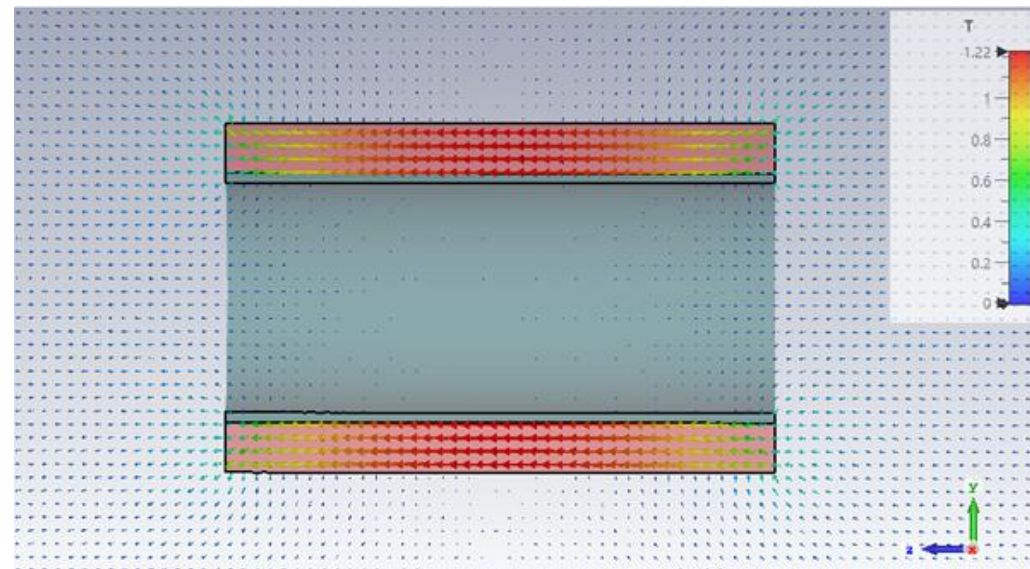
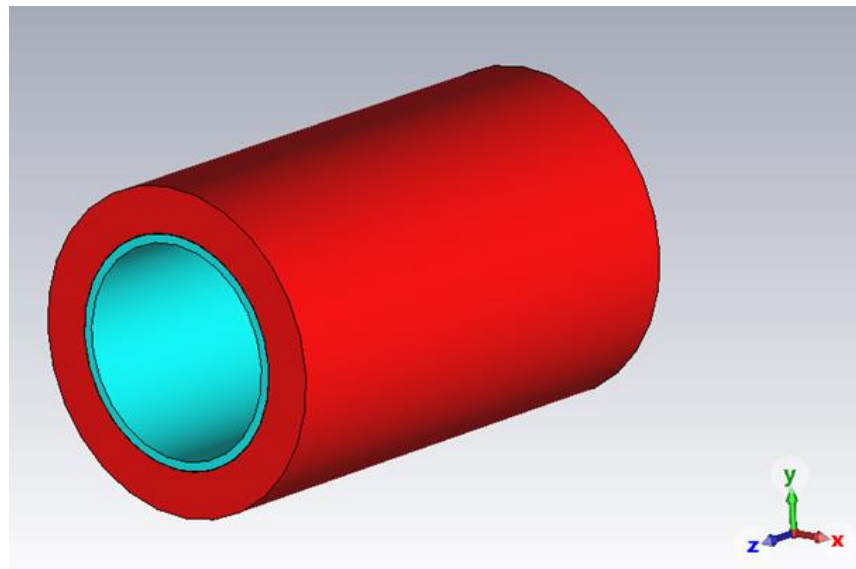


Stray B-field values:

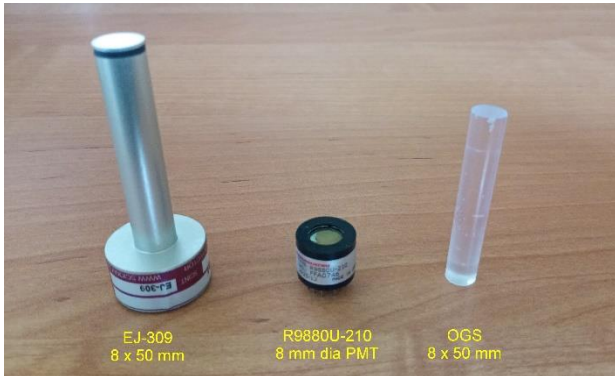
LHD (VNC)	~12 mT
HL-2A (HNC)	~18 mT
JT-60SA (HNC)	~40 mT
JT-60SA (VNC)	~100 mT

Vertical Neutron Camera

Magnetic shield design ($\varnothing 45 \times 110 \text{ mm}$): mu-metal (2mm) + iron (10mm)



$B < 2 \text{ mT}$

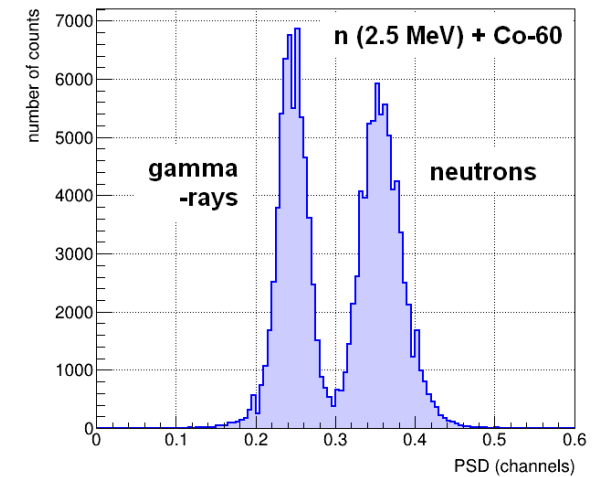
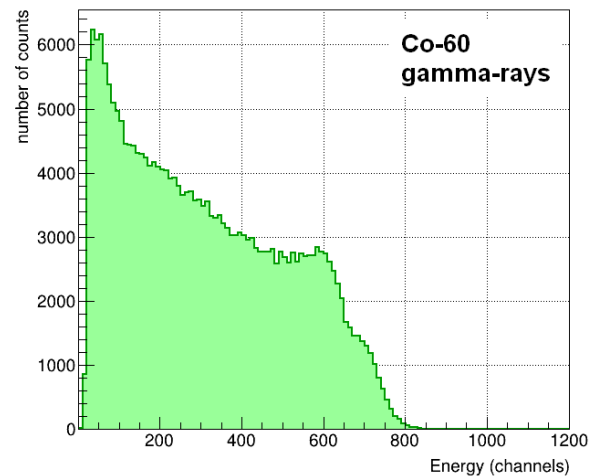
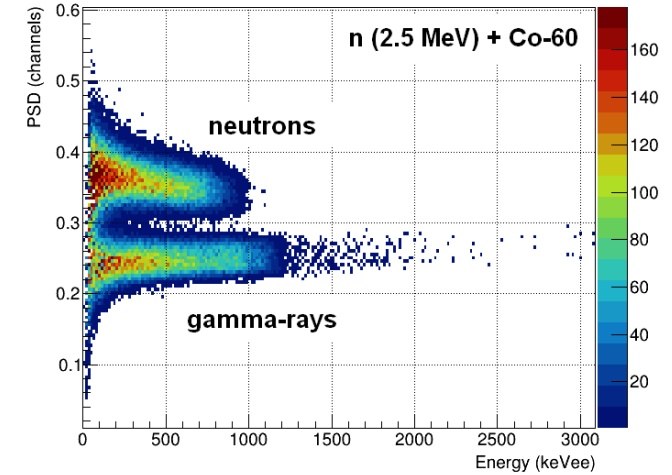
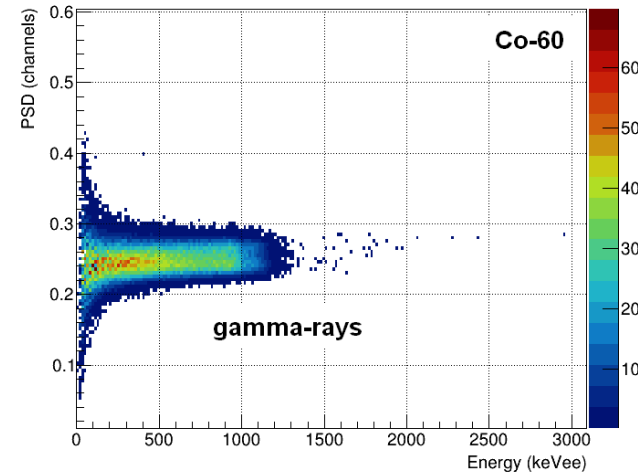


laboratory test:

OGS ($\varnothing$ 8mm $\times$ 25mm) + R9880U-210 (PMT $\varnothing$ 8mm)



DD neutron
generator



Vertical Neutron Camera

3. n/ γ detection (high CR)

laboratory test: OGS + R9880U-210 (PMT Ø8mm) + act.VD
Pu-Be + Cs-137 (~250 MBq)

How to raise countrate in laboratory?

- add high activity gamma emitter
Cs-137 (~250 MBq)

~12 kcps

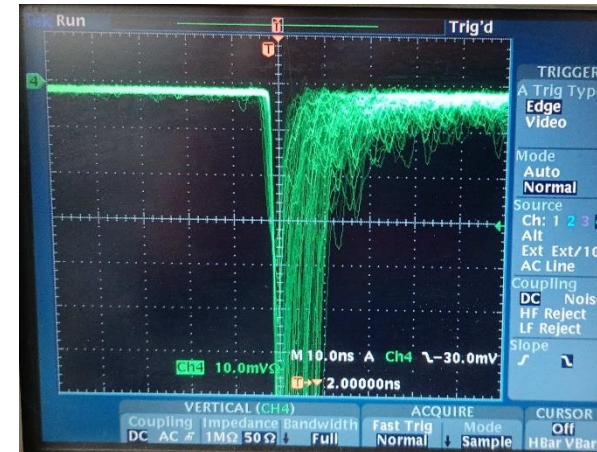
- increase sample size
(Ø8mm × 25mm)

↓
(Ø25mm × 25mm)

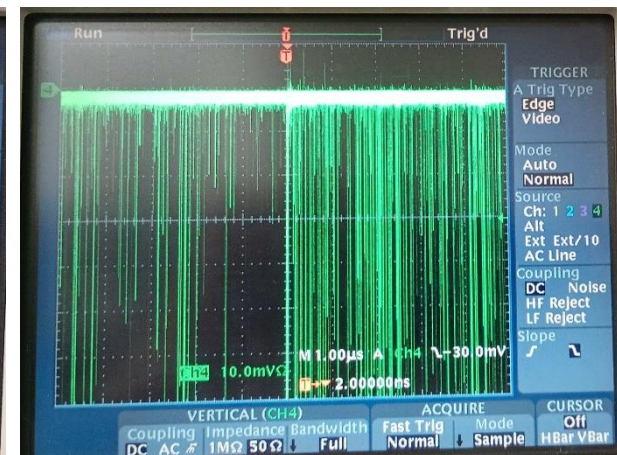
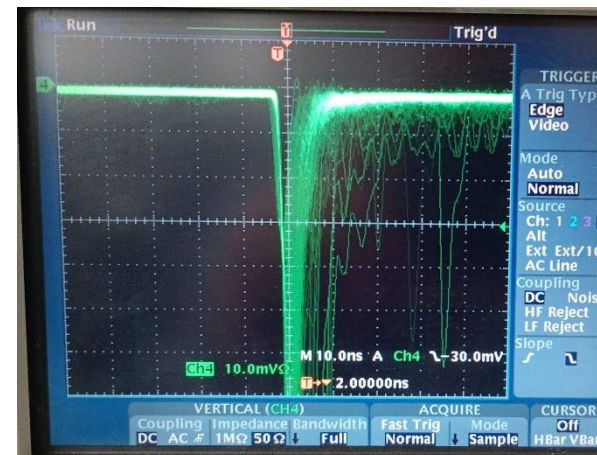
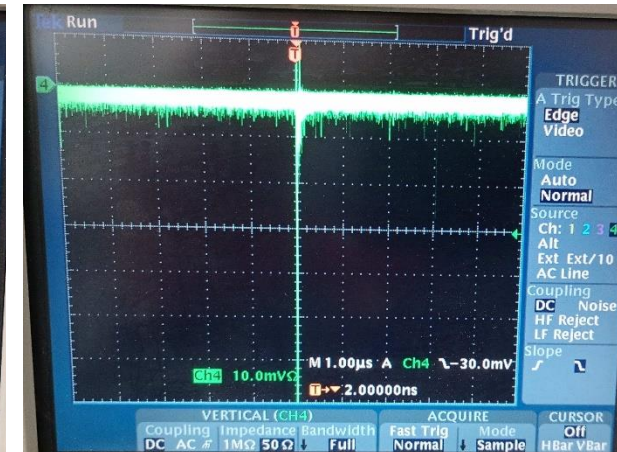
~120 kcps

Active VD makes the job!

range: 1 μ s



range: 10 μ s



Vertical Neutron Camera

3. n/γ detection (high CR)

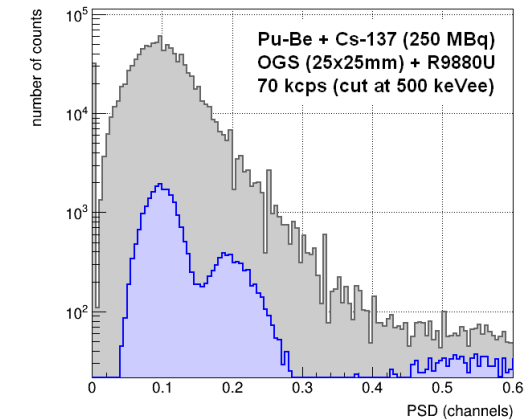
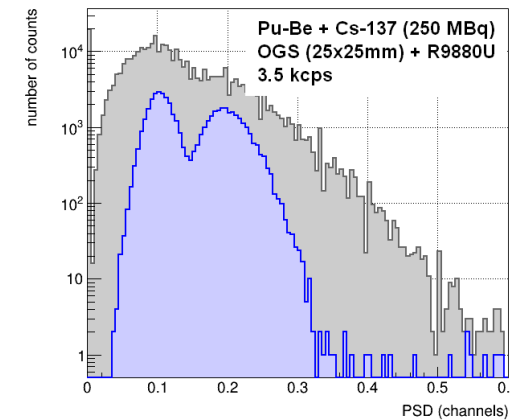
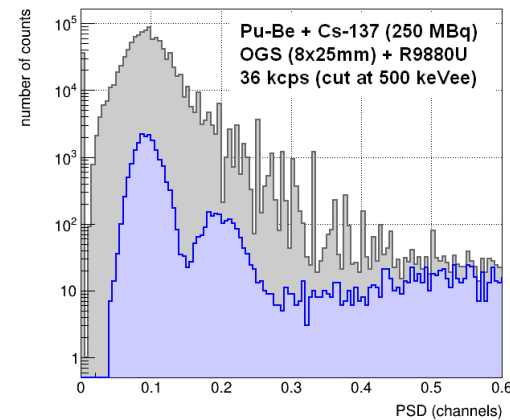
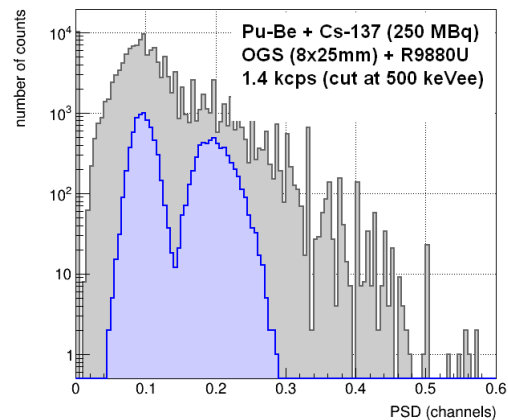
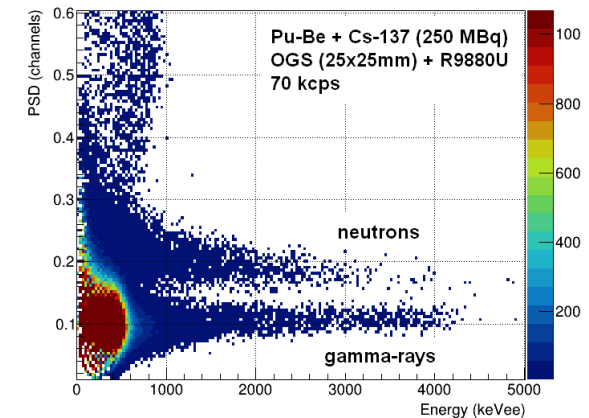
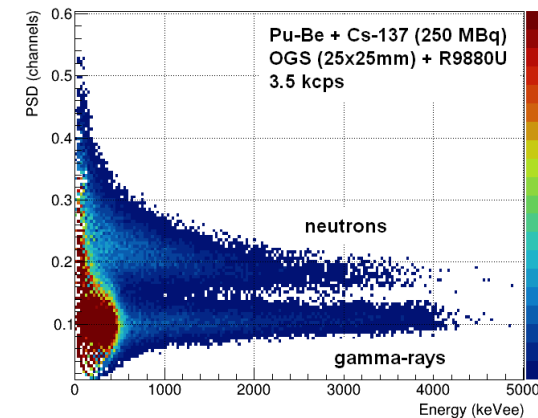
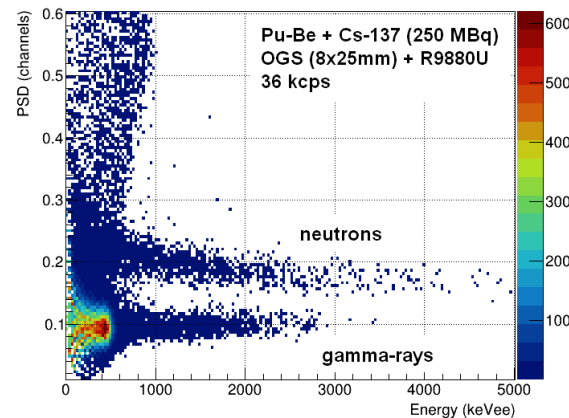
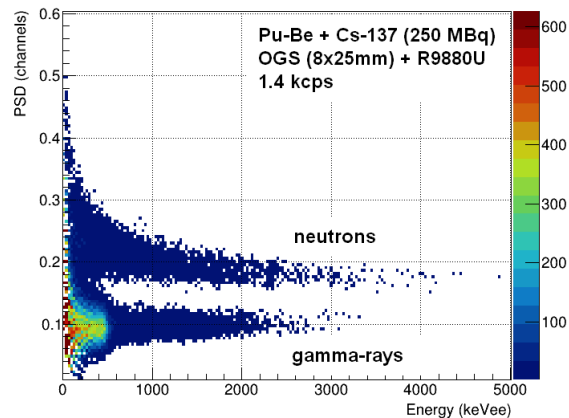
laboratory test: OGS + R9880U-210 (PMT Ø8mm) + act.VD

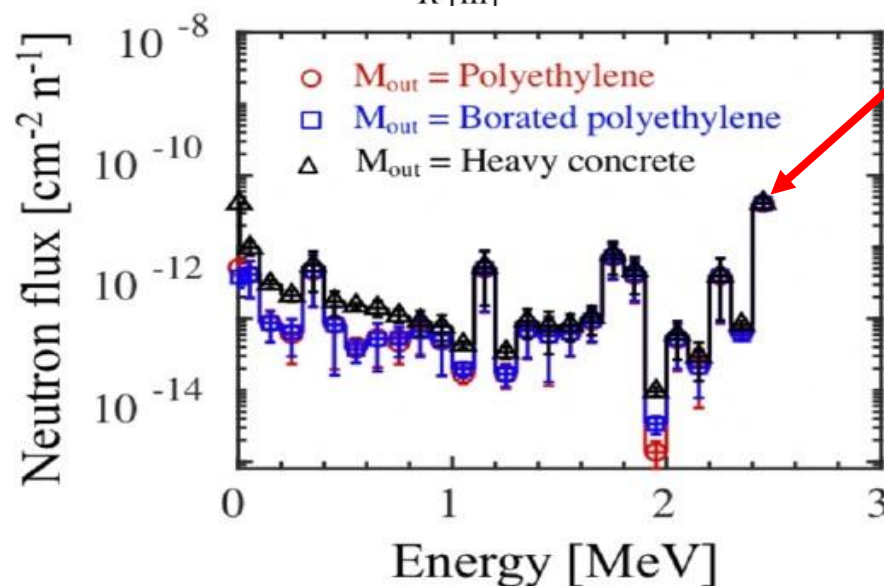
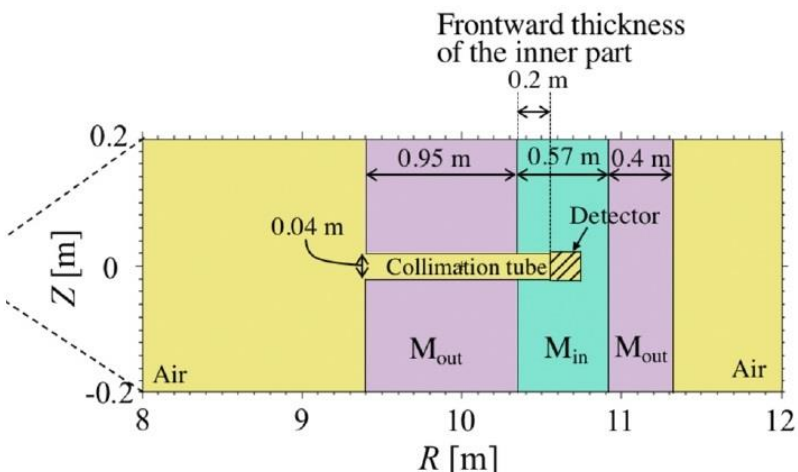
Pu-Be + Cs-137 (~250 MBq)

CAEN DT5730

(Ø8mm × 25mm)

(Ø25mm × 25mm)





MCNP simulation

model: section of tokamak + collimator

source: torus shape, discrete energy, isotropic emission

E_{cutoff} : 10^{-5} eV

coll dia: $\varnothing 40\text{mm}$

distance: $\sim 7\text{m}$

**direct neutron peak
at detector
(~ 2.5 MeV)**

results:

n_{yield} : 5×10^{15} n/s

n_{flux} : $\sim 4 \times 10^{-11}$ /cm²/n

S_{det} : 7 cm²

th_{det} : 10 mm

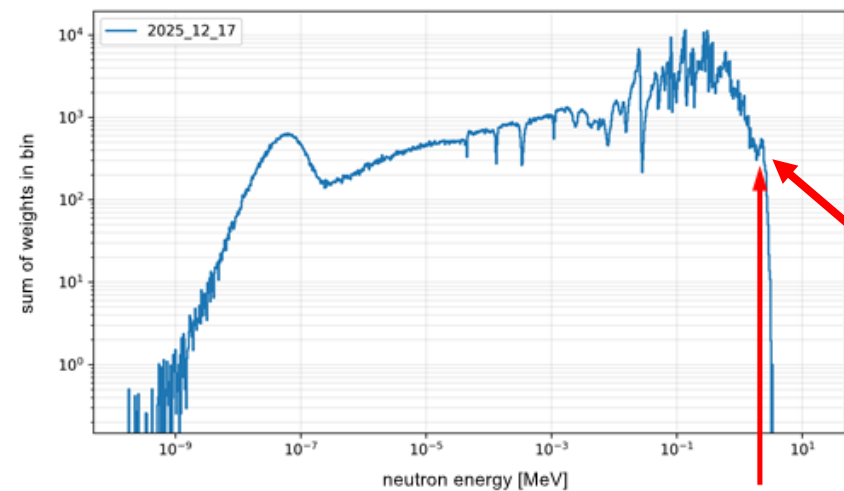
E_{thr} : 0.1 MeV_{ee}

det_eff: $\sim 10\%$

n_{CR} : $\sim 2.2 \times 10^5$ n/s (my est. $\sim 1.4 \times 10^5$ n/s)

Sumida et al.

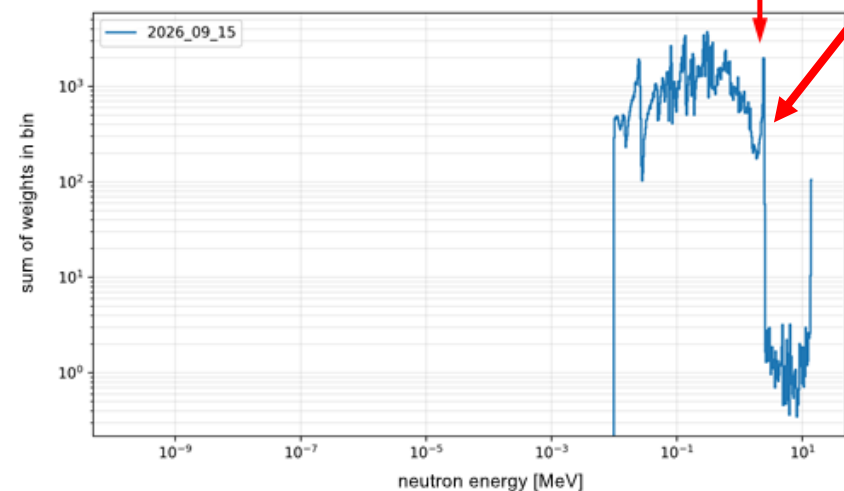
Rev. Sci. Instrum. **91**, 113504 (2020); doi: 10.1063/5.0025902



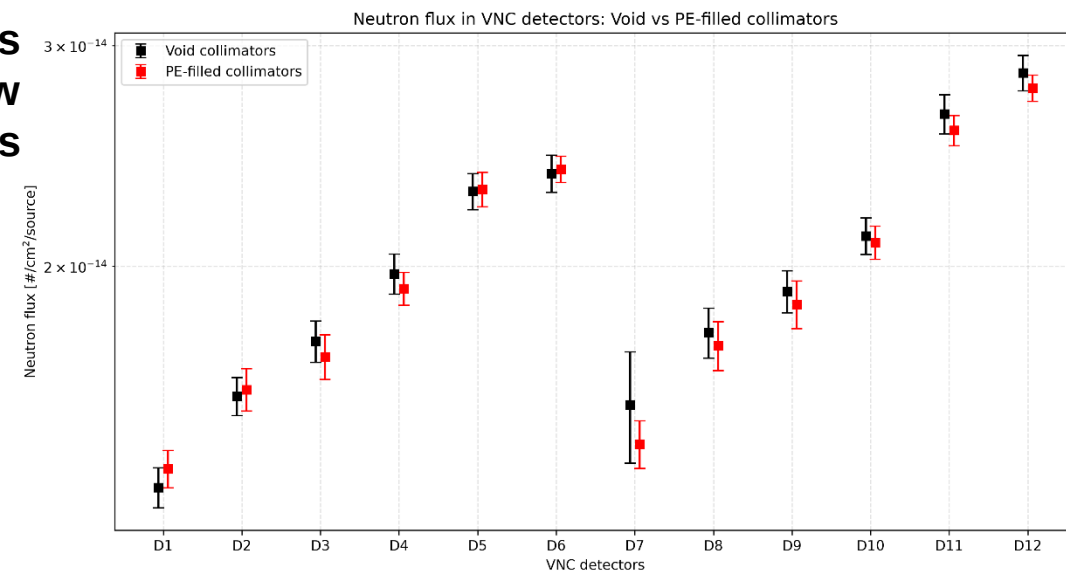
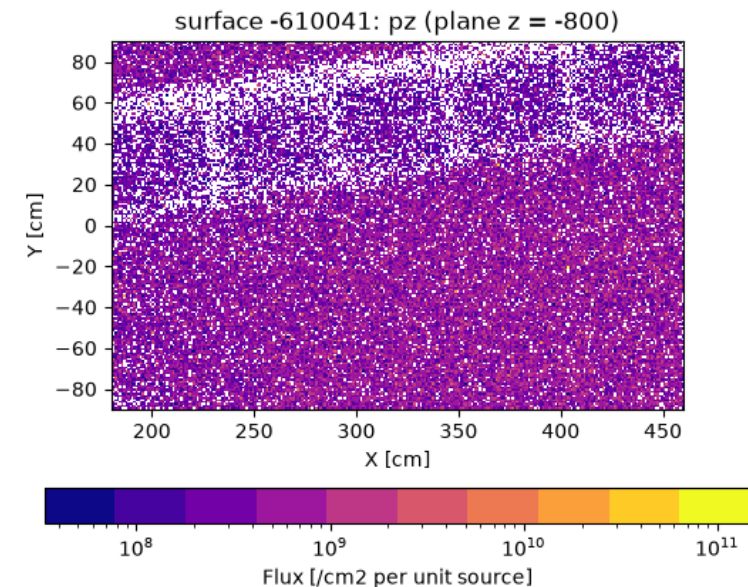
Full-scale simulation for SSW file
(Alvaro Cubi and F4E team)
RSSA run: $10^9 \rightarrow 10^{10}$ histories

we observe
direct neutron peak
at collimator entrance,
but...

2.45 MeV



...still, no direct neutrons
pass through narrow
collimator channels

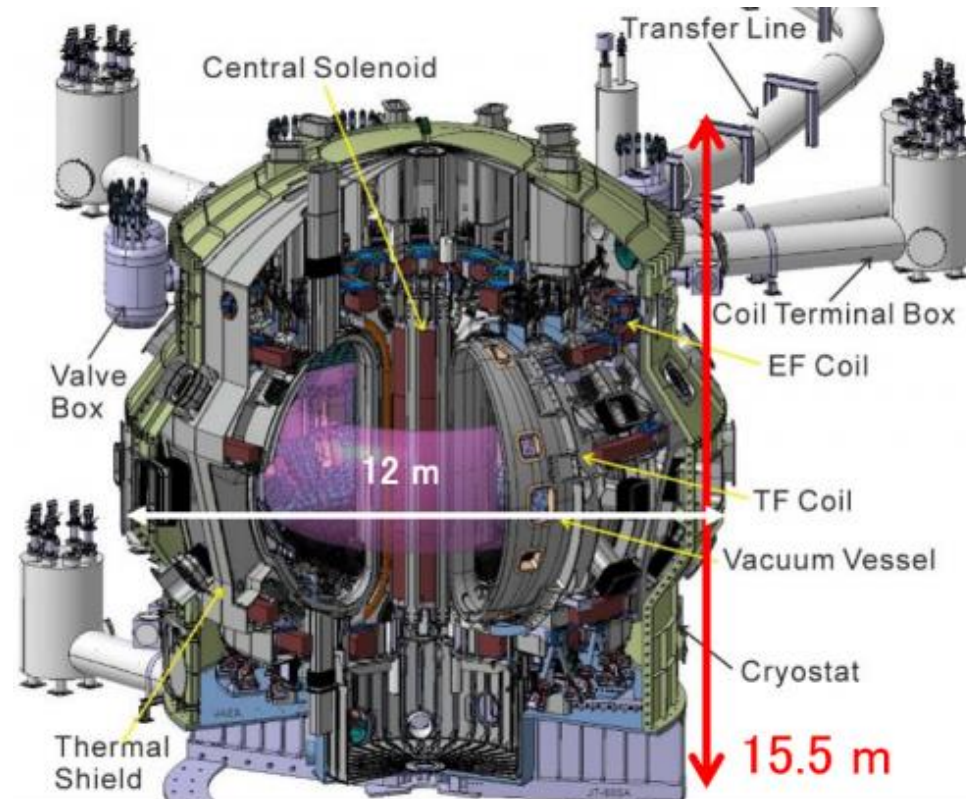


	HNC	VNC	CR ratio
source	5×10^{15} n/s	5×10^{15} n/s	1
no. of histories	?	10^{10}	---
plasma-det. dist.	~7m	~10m	0.5
det. dia	30 mm	6.6 mm	0.05
det. thickness	10 mm	50 mm	---
energy threshold	0.1 MeVee	1 MeVee	---
det. efficiency	10%	26%	2.6
det. CR	2.2×10^5 nps	---	0.065

How to increase direct neutrons at detectors in the case of:

- MCNP: more simulated neutrons ($10^{10} \rightarrow 10^{12}$) $\times 100$
- experiment: larger detector surface (6.6 mm $\rightarrow$ 20 mm) $\times 10$

Vertical Neutron Camera



thank you for attention!

Workplan 2026

Tasks towards completion of Conceptual Design Report

Calculations:

yields at detector location for selected collimator configurations:

- direct 2.5 MeV neutrons
- scattered neutron background
- γ /X-ray background
- calculations for other scenarios than S2 & S5
- tomography reconstruction

Hardware:

detector tests to verify neutron response:

- in magnetic field (μ -shield design)
- under high counting rate (active VD)
- comparison with SiPM photodetector readout

Design:

- VNC performance assessment
- cost evaluation

Vertical Neutron Camera

- identification of direct DD neutrons at the P-10 lower pocket entrance
- optimizing collimator diameter for required direct neutron countrate

<u>collimator diameter</u> [mm]	spatial resolution at equator plane [mm]	<u>FoV</u> fraction without interference
6.6	75	100 %
8	93	92 %
10	116	78 %
12	140	67 %

collimator diameter extended to **12 mm**:
33% of FoV interfering with the divertor

