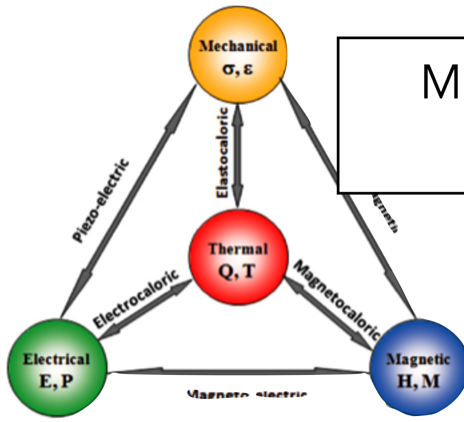
MAGiC: polarized single crystal diffractometer for magnetism

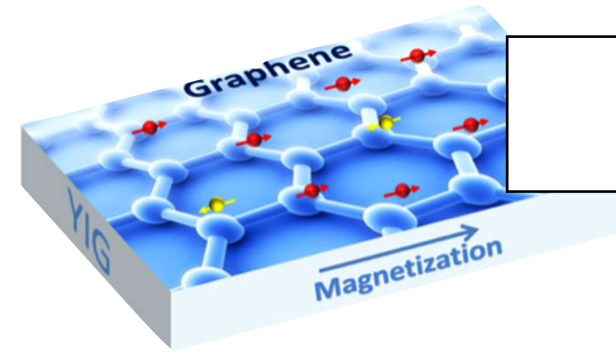
LLB: **X. Fabrèges**, S. Klimko, A. Goukassov
JCNS: W. Schweika, P. Harbott
PSI: U. Filges, M. Kenzelmann

The science behind MAGiC

Multi-functional materials

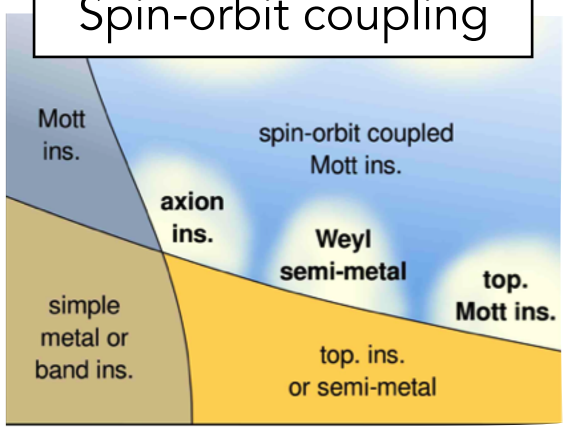


Magnetism at interfaces
Thin films



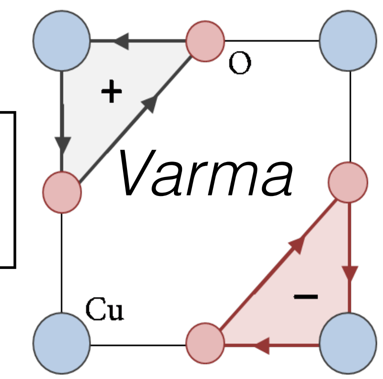
Phys. Rev. Lett. **114**, 016603

Spin-orbit coupling

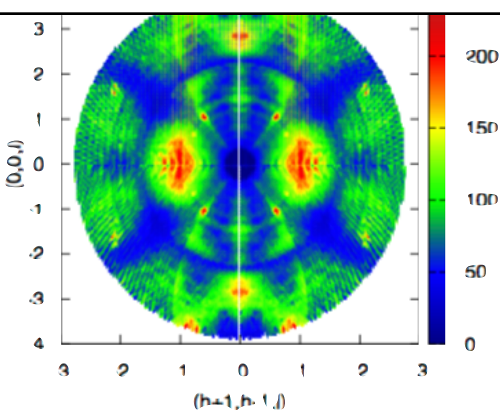


arXiv:1305.2193v2

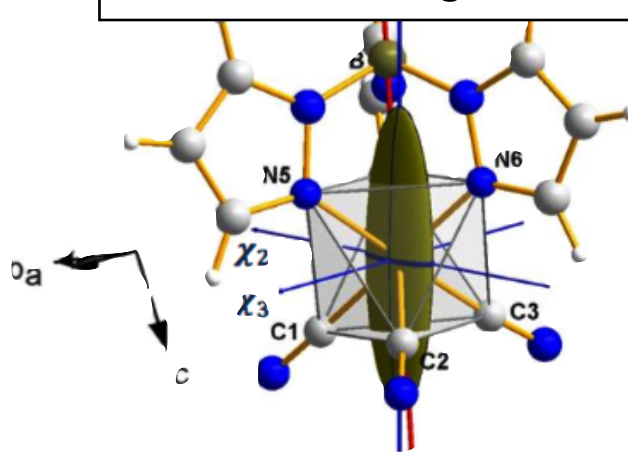
Superconductivity and magnetism



Fundamental magnetism and theory (Coulomb, Kitaev, …)

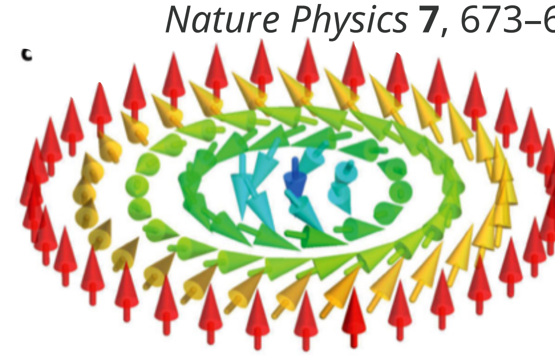


Molecular magnetism



Long range magnetic states (skyrmions, multiferroics, …)

Nature Physics **7**, 673–674 (2011)

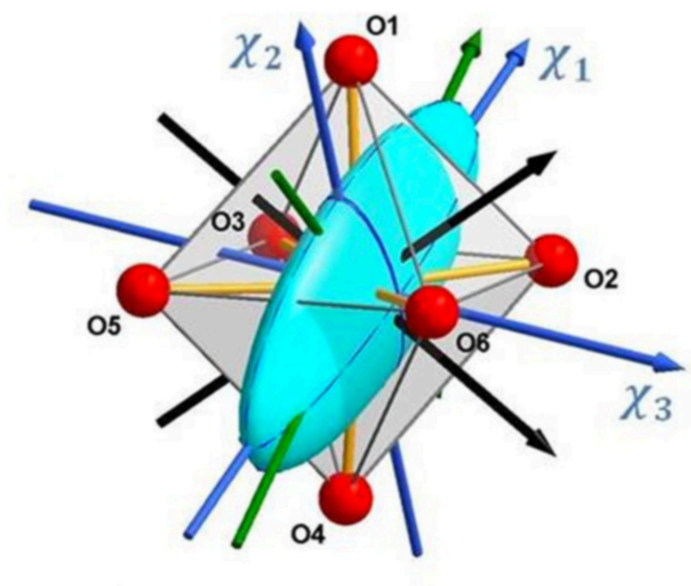


Anisotropy in molecular magnets

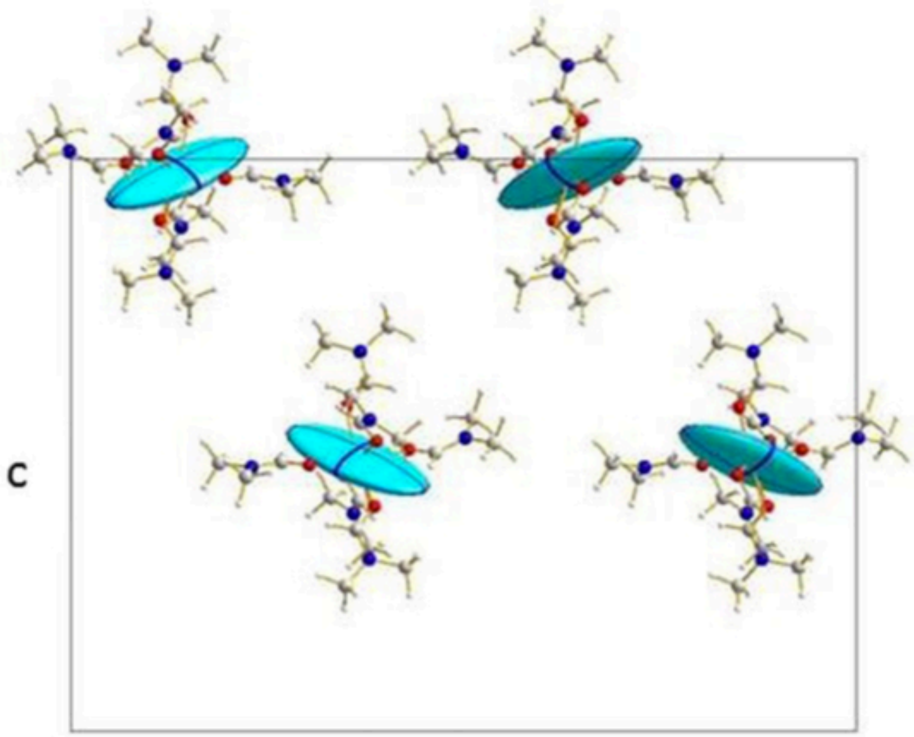
Data storage at molecular level
High density: >10^{14} bit/in^2

Magnetic state can be manipulated (photo-excitation)
No coupling between the cells
Strong anisotropy to retain information vs time.

(a)



(b)



Magnetism Studies |*Hot Paper*|

Polarized Neutron Diffraction as a Tool for Mapping Molecular Magnetic Anisotropy: Local Susceptibility Tensors in Co^{II} Complexes

Karl Ridier,[a, f] Béatrice Gillon,*[a] Arsen Gukasov,[a] Grégory Chaboussant,[a] Alain Cousson,[a] Dominique Luneau,*[b] Ana Borta,[b, g] Jean-François Jacquot,[c] Ruben Checa,[b] Yukako Chiba,[d] Hiroshi Sakiyama,[d] and Masahiro Mikuriya[e]

Neutrons are sensitive to local magnetization ➜ local SQUID !

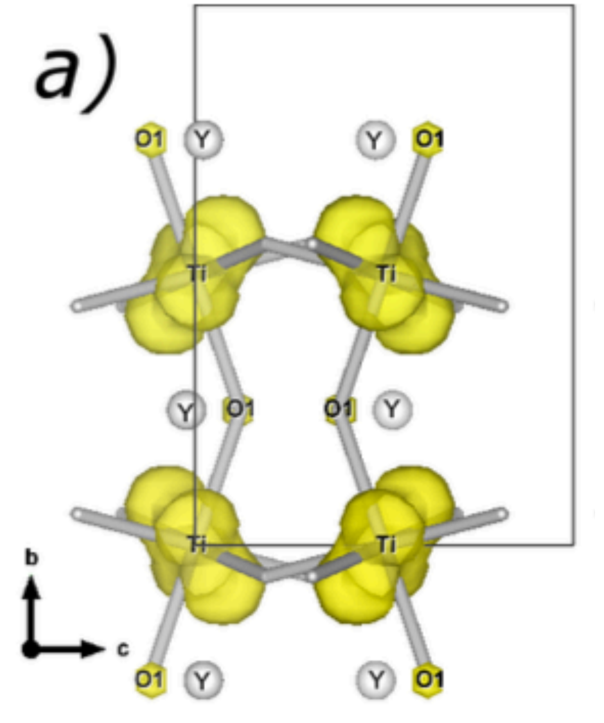
Orbital order through spin density

Orbital ordering is playing a key role in the onset of perovskite magnetic properties.

$YTiO_3$ is a good candidate: ferromagnetic insulator with predicted AF orbital ordering.

$$FR_{PND} = \frac{I^+}{I^-} = \frac{F_N^2 + 2pq^2 F_N F_M + q^2 F_M^2}{F_N^2 - 2peq^2 F_N F_M + q^2 F_M^2}$$

$$Q_{max} \propto \frac{\sin(\theta)}{\lambda}$$



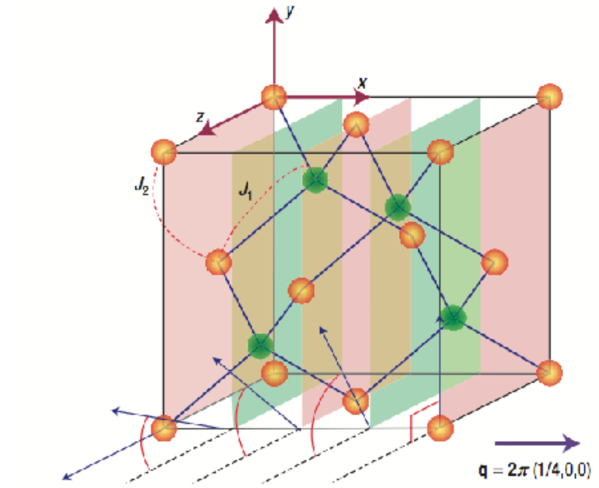
X-rays Magnetic Diffraction adds details to the obtained shape

Joint refinement

New magnetic states

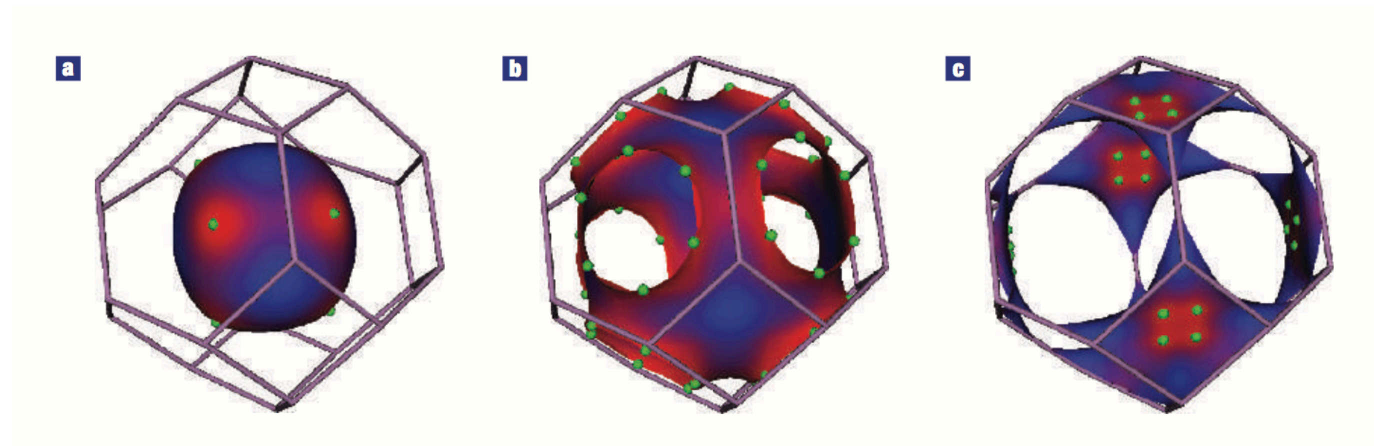
Spiral spin-liquids

Predicted in spinels AB_2O_4



Order-by-disorder and spiral spin-liquid in frustrated diamond-lattice antiferromagnets

DORON BERGMAN[1]*, JASON ALICEA[1], EMANUEL GULL[2], SIMON TREBST[3] AND LEON BALENTS[1]



New magnetic states

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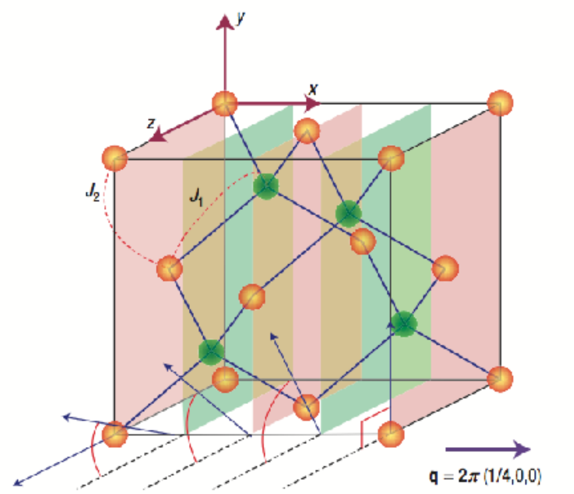

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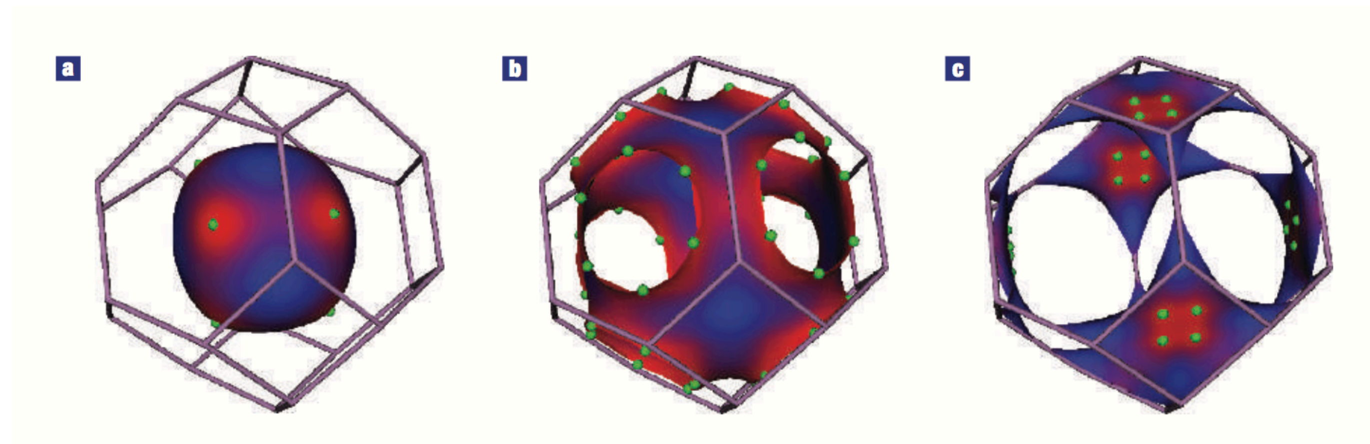
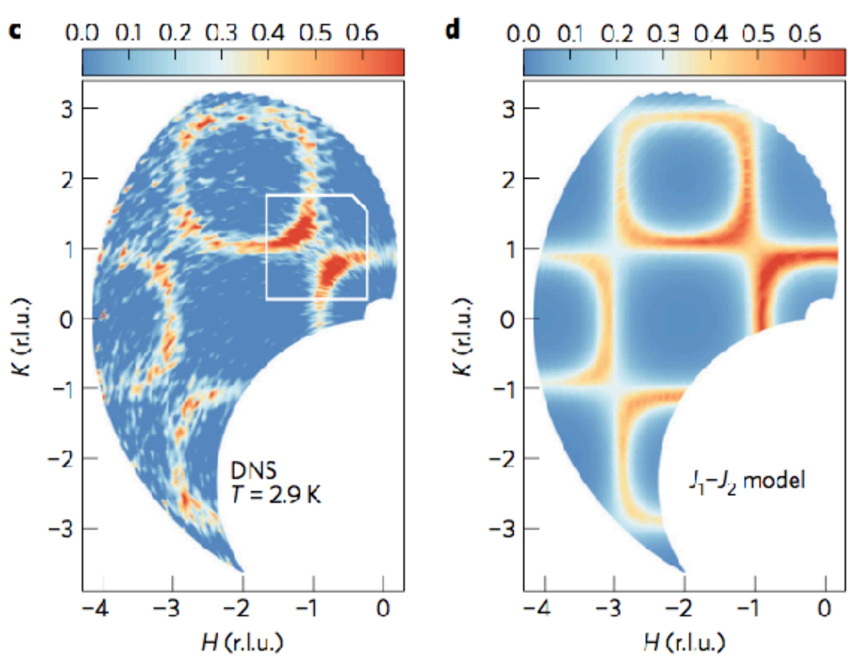


Observed in $MnSc_2S_4$ using polarized neutron diffraction !



Spiral spin-liquid and the emergence of a vortex-like state in $MnSc_2S_4$

Shang Gao[1,2], Oksana Zaharko[1*], Vladimir Tsurkan[3,4], Yixi Su[5], Jonathan S. White[1], Gregory S. Tucker[1,6], Bertrand Roessli[1], Frederic Bourdarot[7], Romain Sibille[1,8], Dmitry Chernyshov[9], Tom Fennell[1], Alois Loidl[3] and Christian Rüegg[1,2]

Building for tomorrow

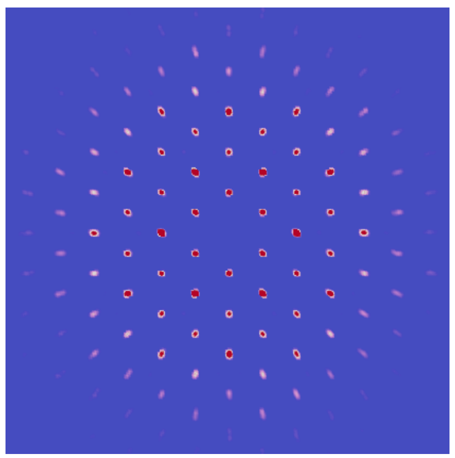
- New scientific trends will emerge in the next decades

- Open land: difficult to predict
- 20 years ago: no spin-liquids, multiferroics, spintronic …
- Today: first observation of Discrete Time Crystal

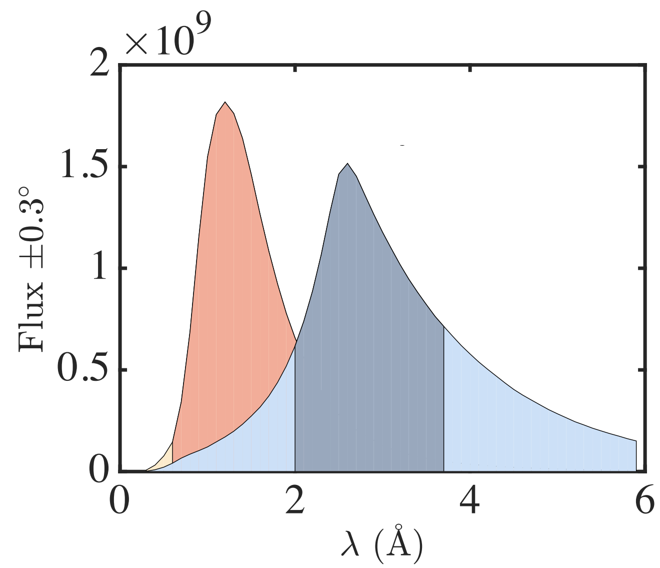
- Instrument needs flexibility/adaptability

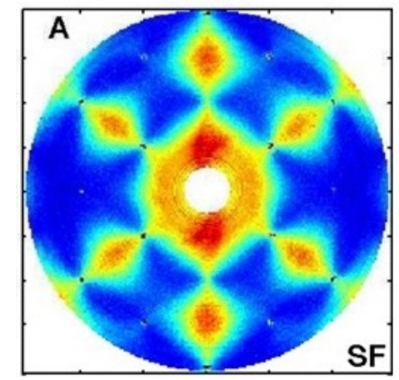
Functional requirements

Spectrum: thermal & cold



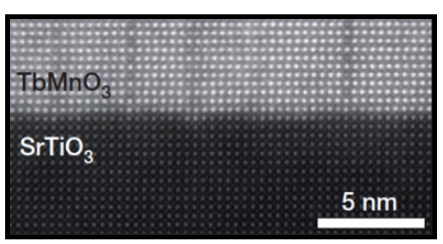
Crystal & magnetic structures
Spin-lattice coupling

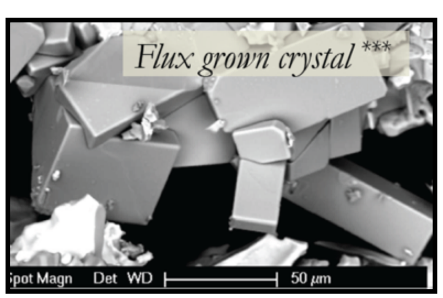




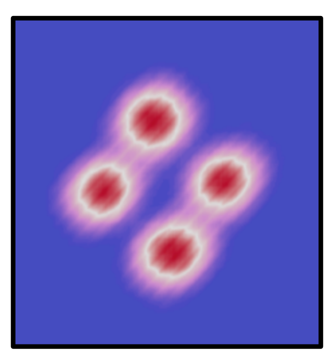
Fundamental magnetism
Diffuse scattering

Focusing



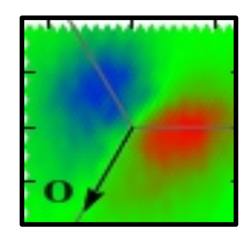


Flexible Q-resolution

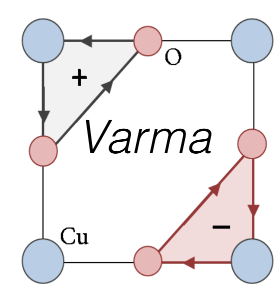


$\Delta Q \sim 10^{-2} \ldots 10^{-3} \text{Å}^{-1}$

Polarised

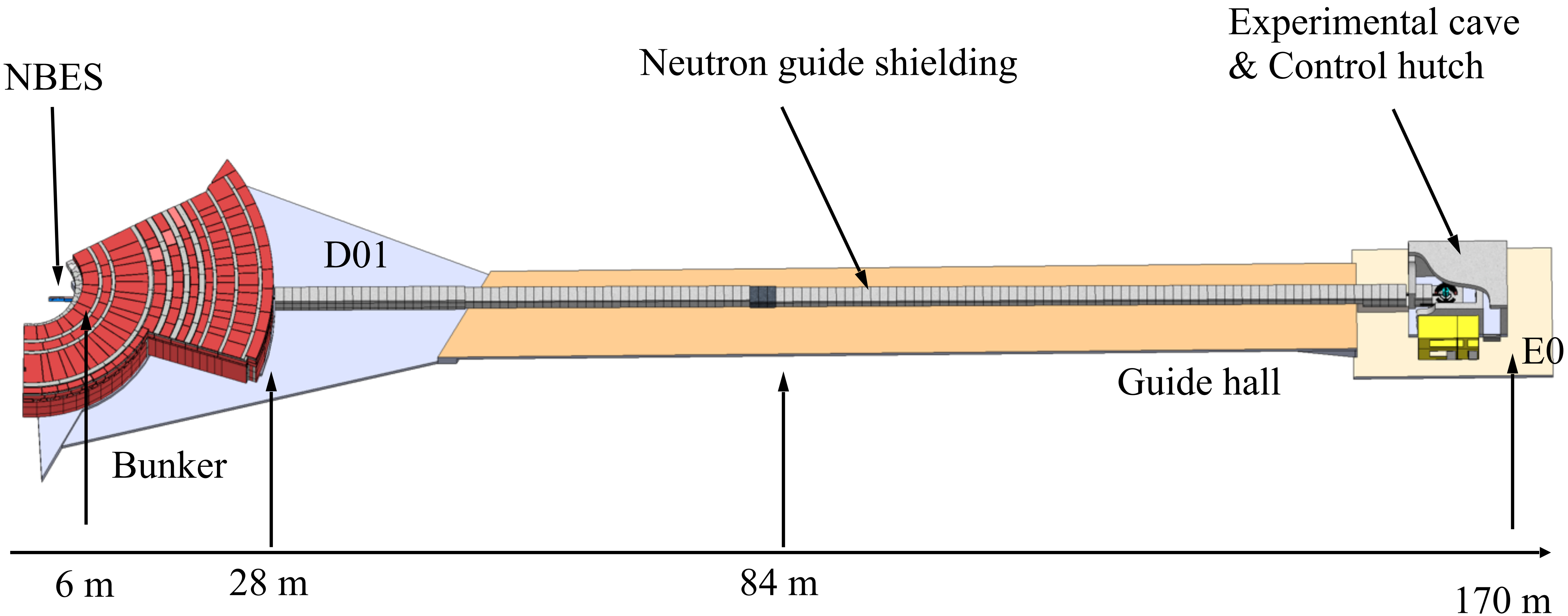


Vector properties
Chirality

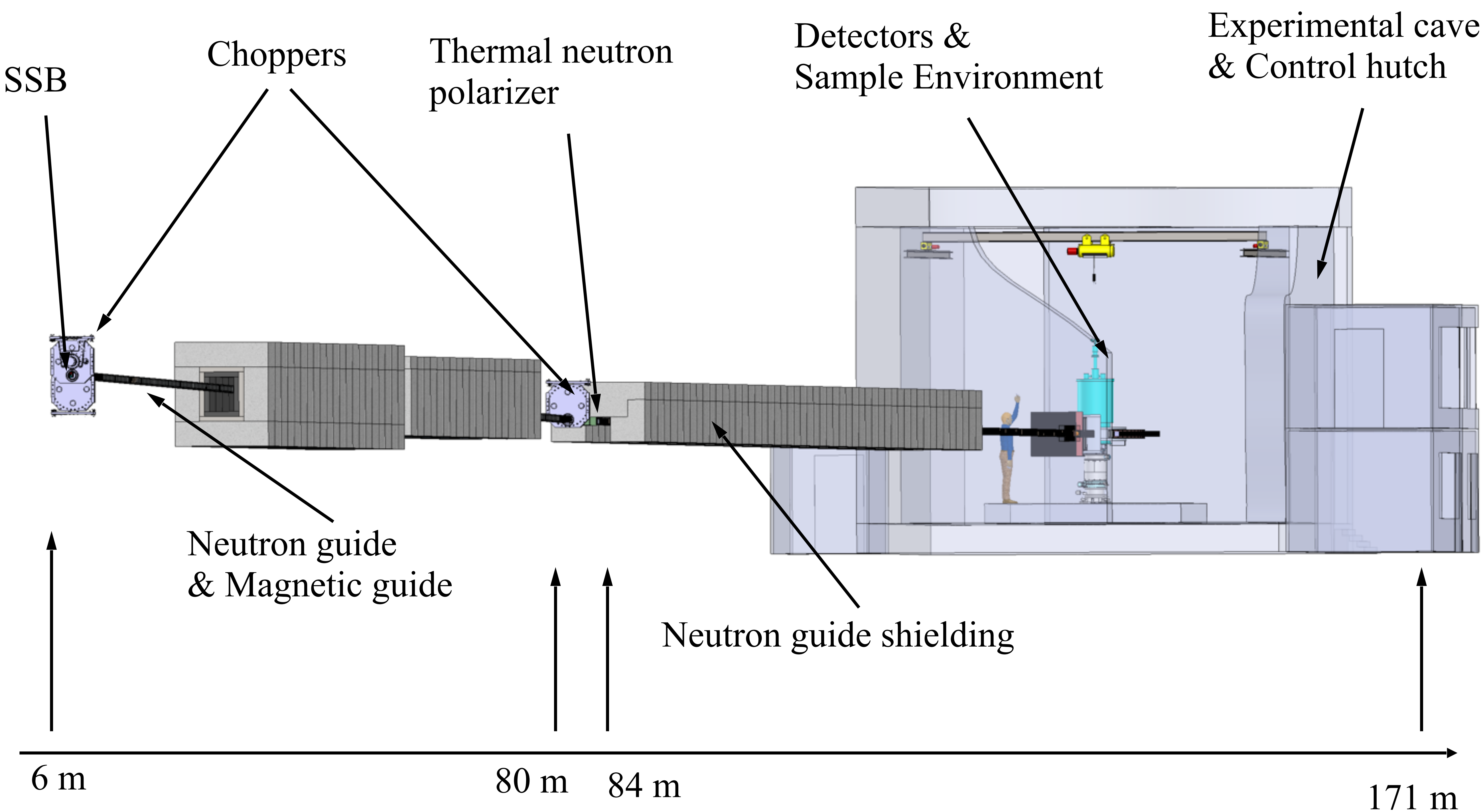


Separation of weak
Magnetic from nuclear
contributions

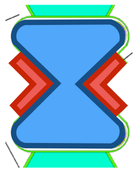
MAGiC layout



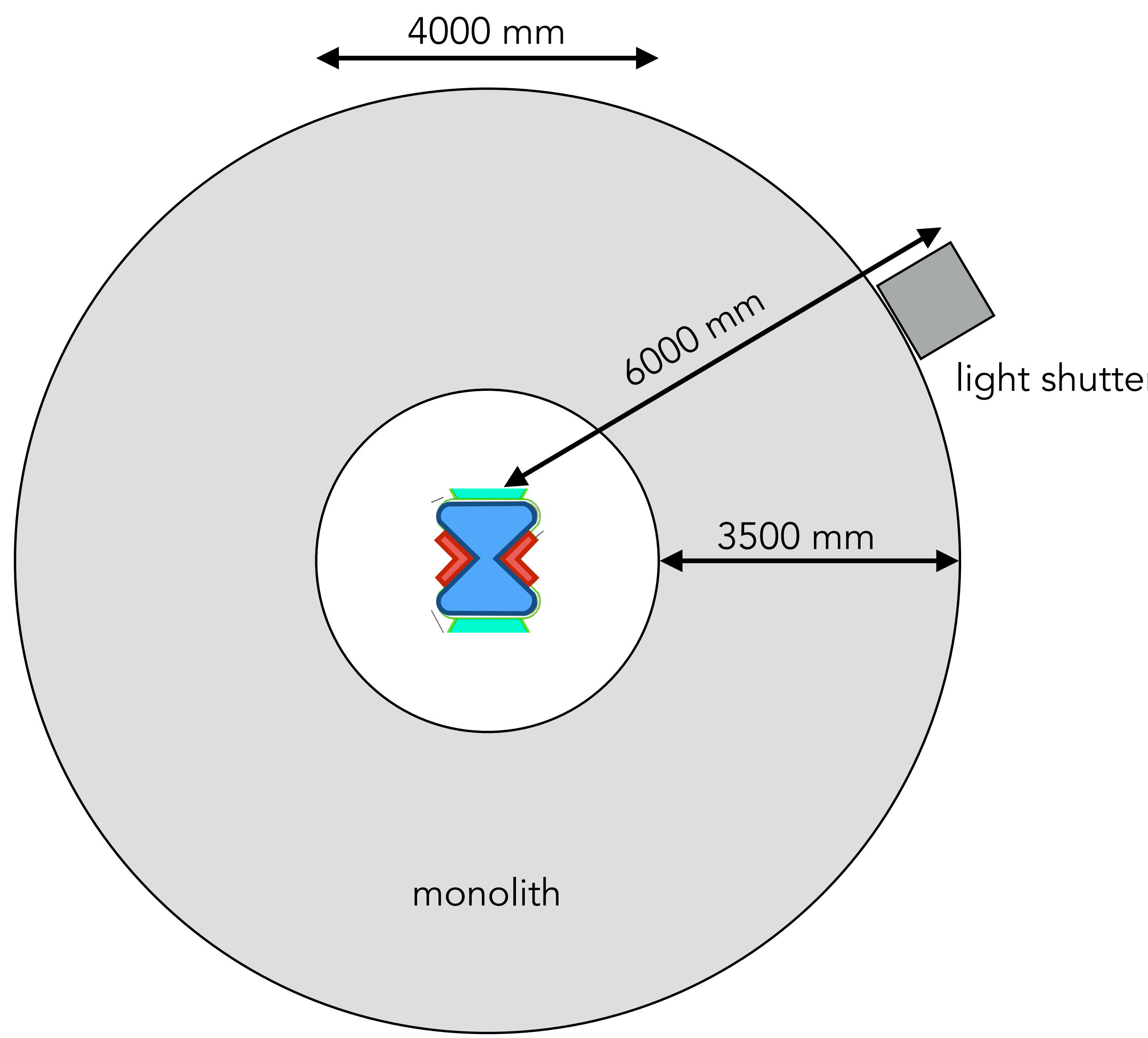
MAGiC layout



Moderator & Monolith



Moderator & Monolith



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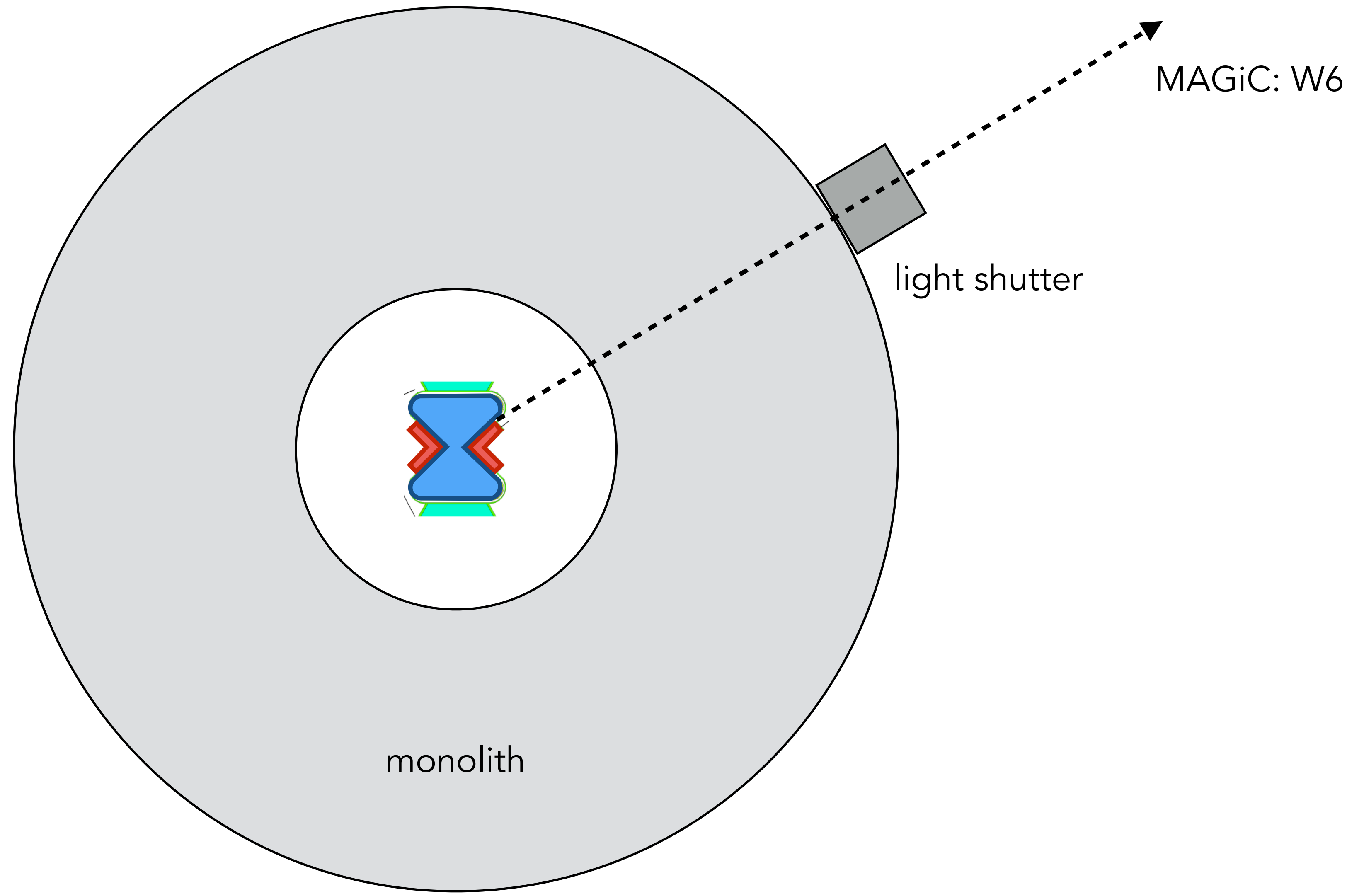
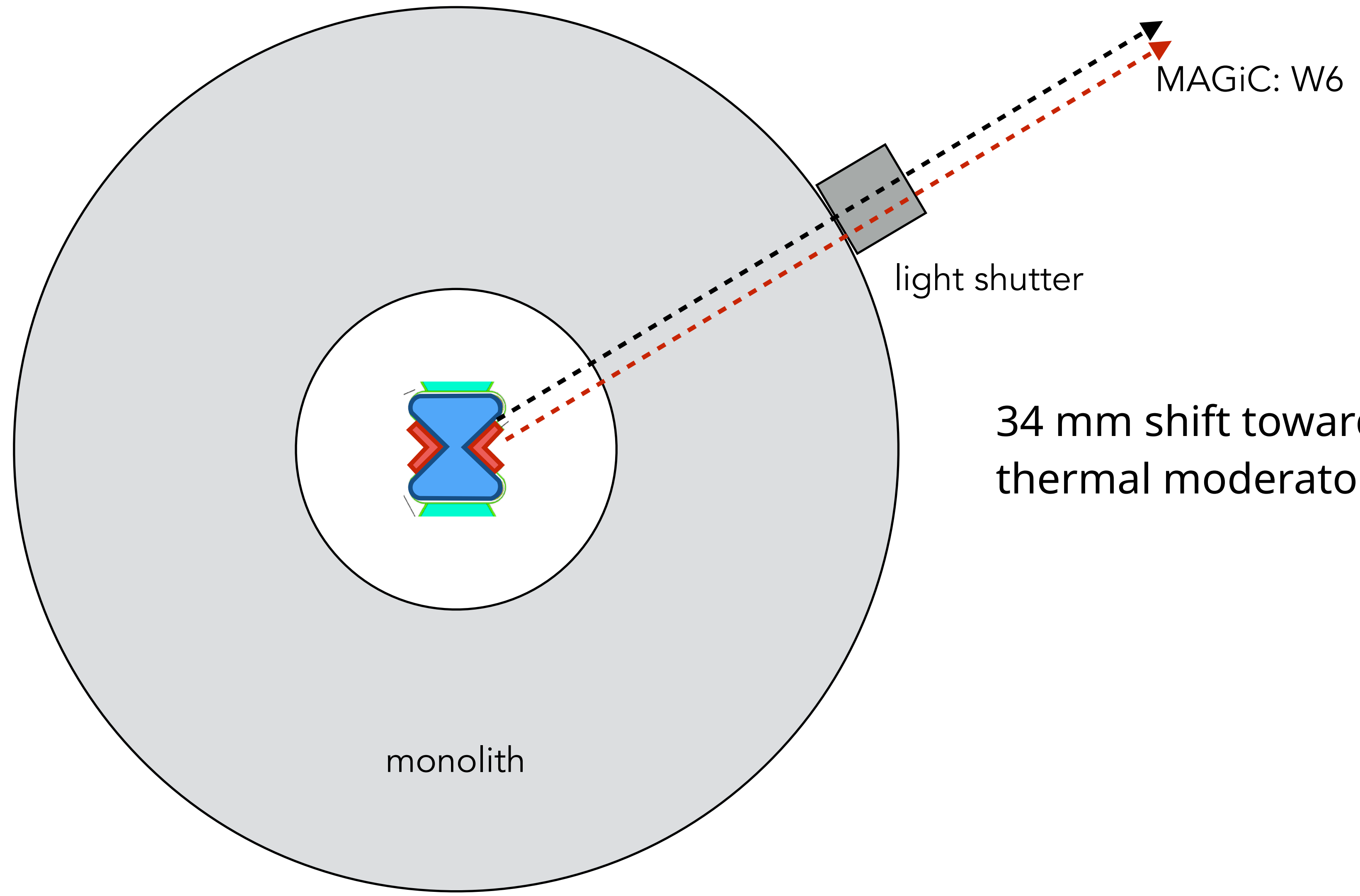
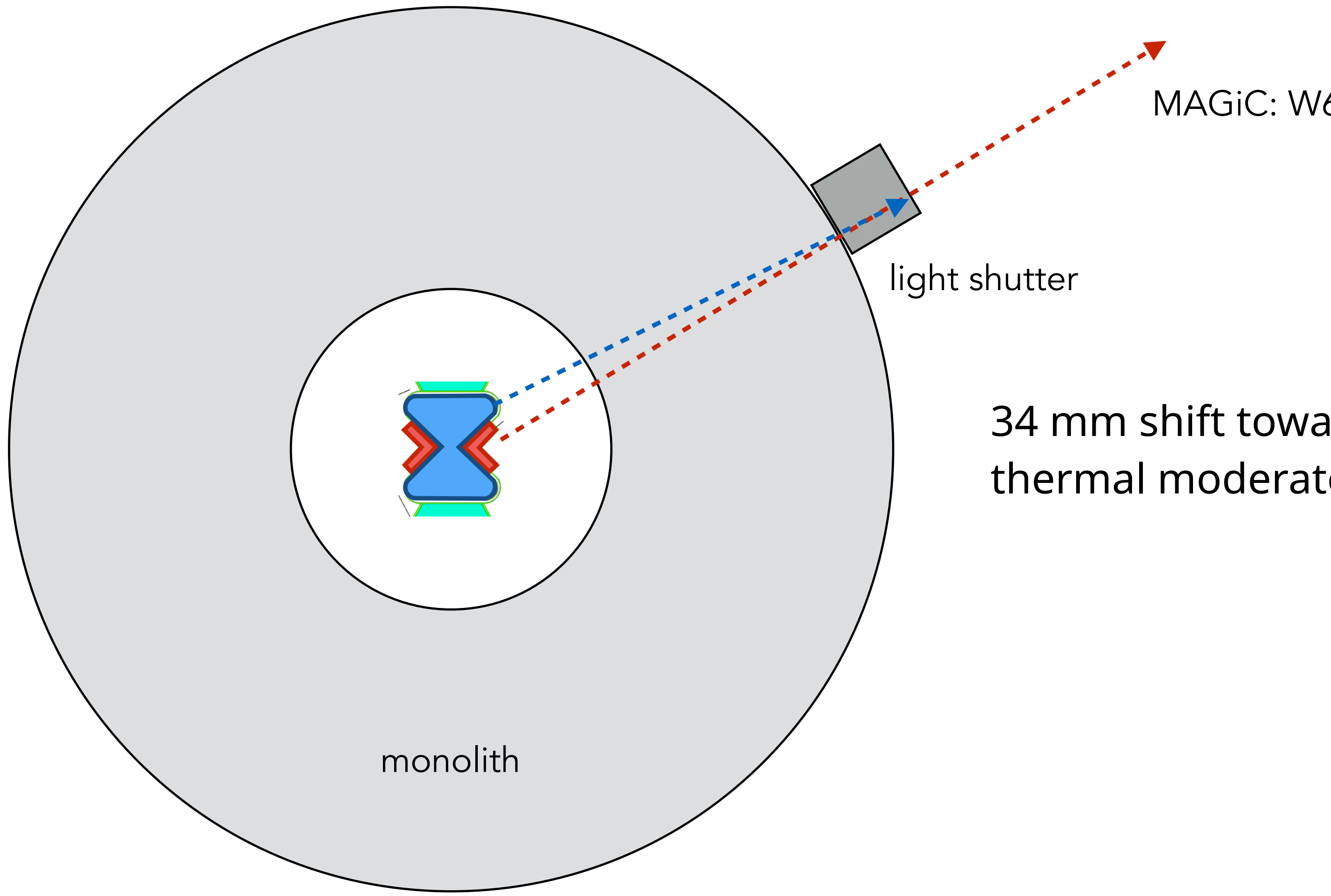


Moderator & Monolith



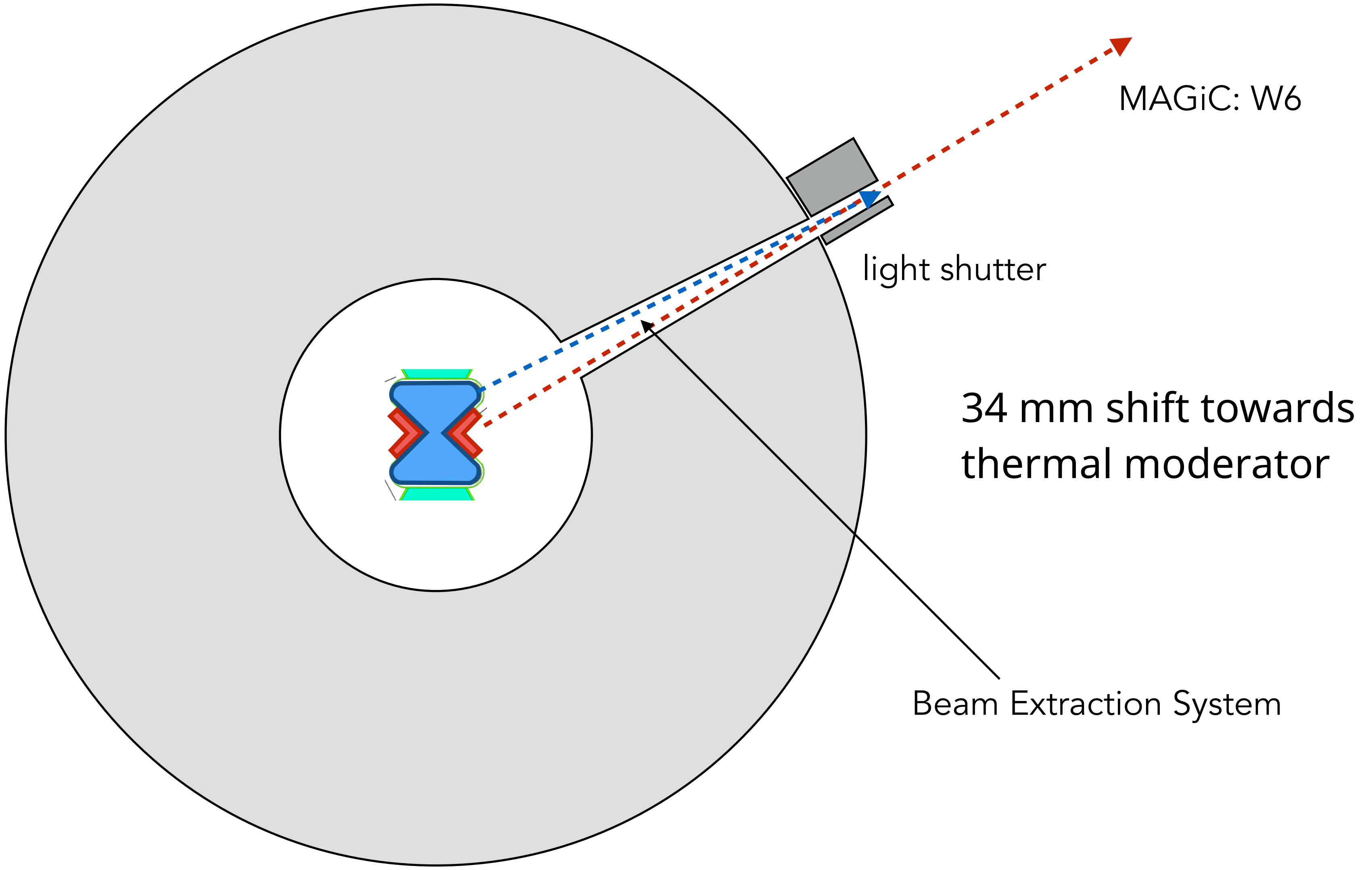
34 mm shift towards thermal moderator

Moderator & Monolith

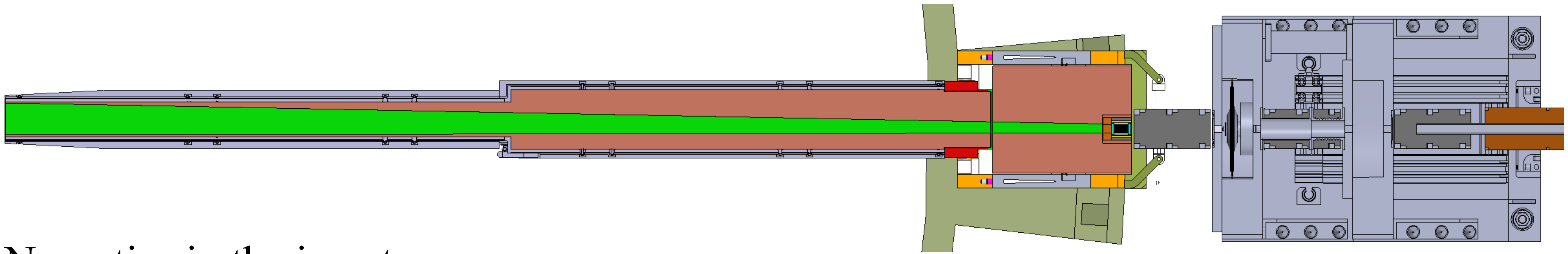


34 mm shift towards thermal moderator

Moderator & Monolith

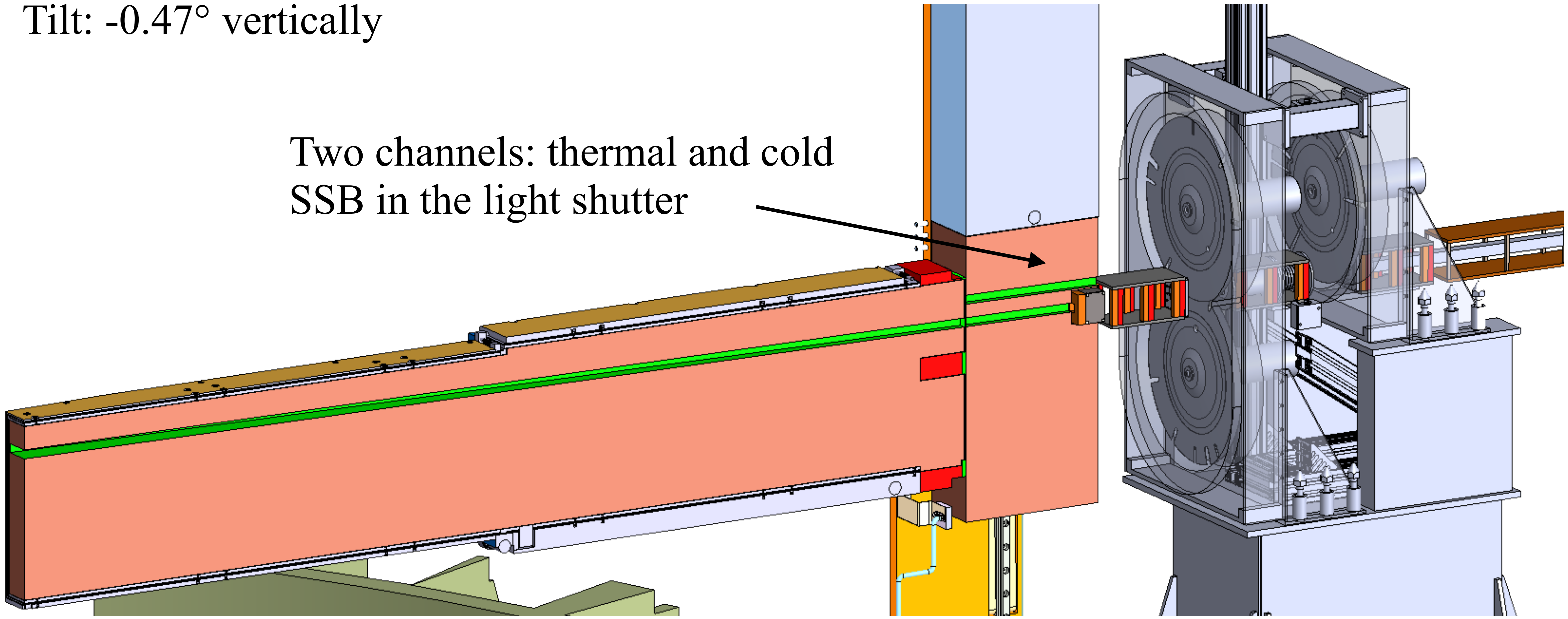


Neutron Beam Extraction

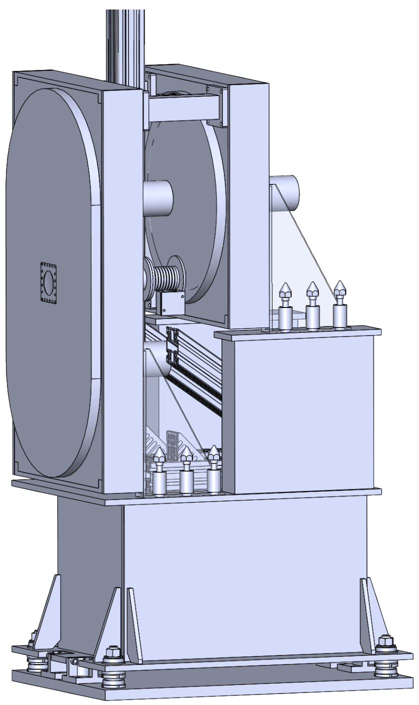


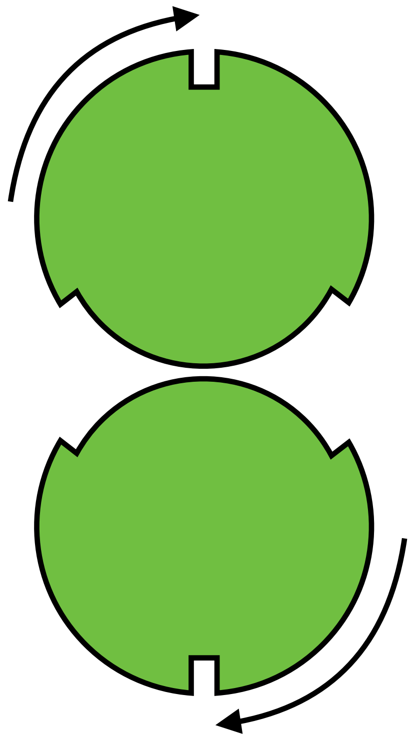
No optics in the insert
Dimensions @ 2.0 m: 124x30 mm
Dimensions @ 5.5 m: 38x30 mm
Tilt: -0.47° vertically

Two channels: thermal and cold
SSB in the light shutter

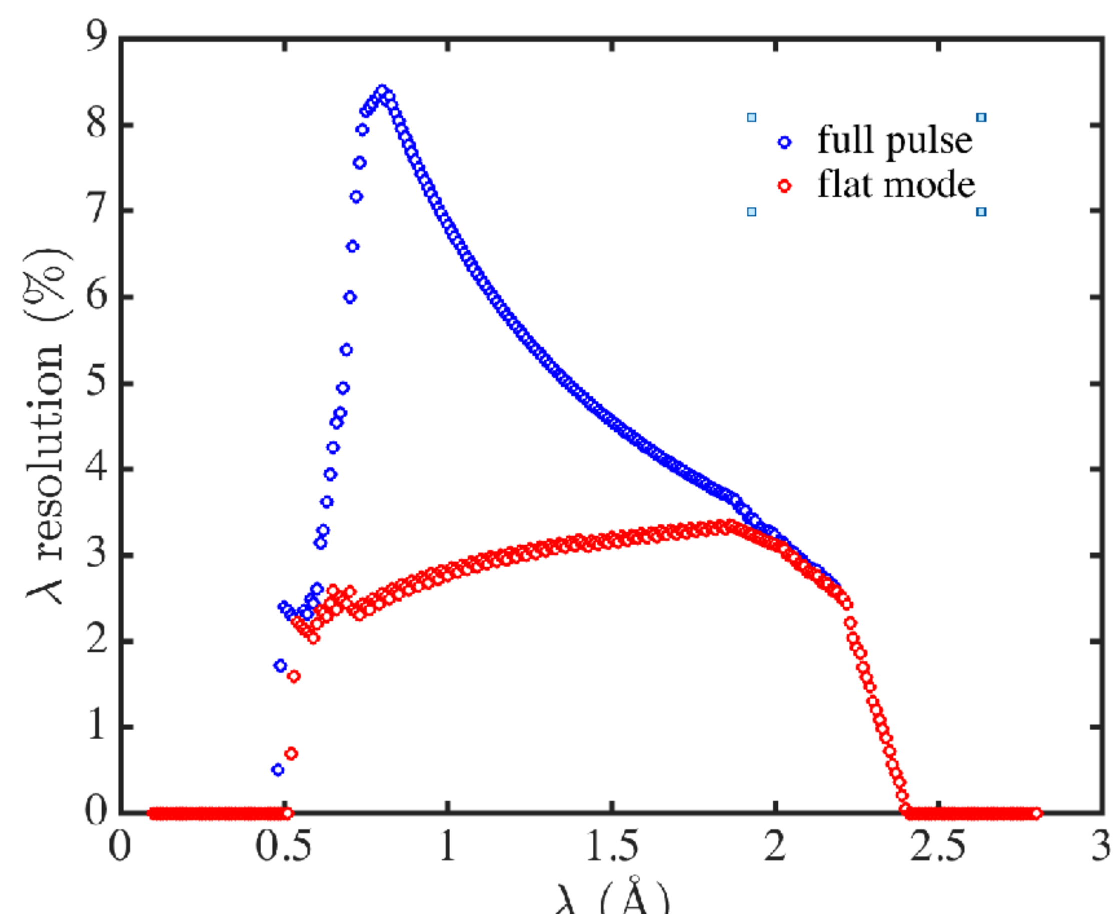


Choppers



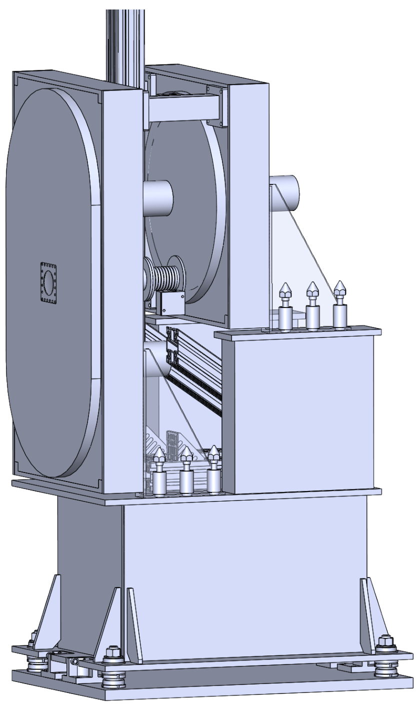


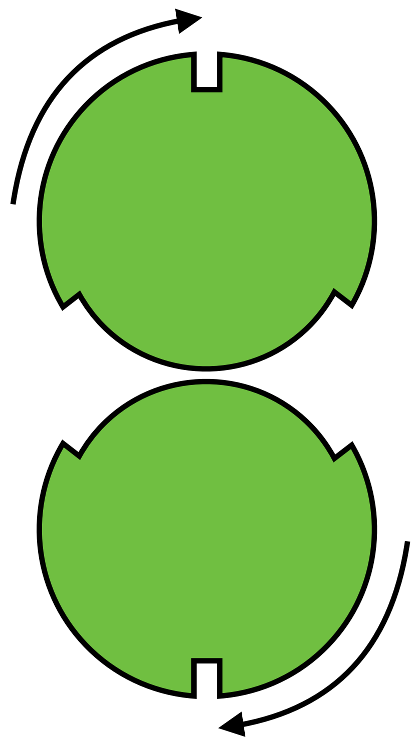
- Pulse Shaping Choppers : select $\delta\lambda/\lambda$ resolution
  - ⁎ Small slit: 8.6° ➜ 120 µs pulse length
  - ⁎ Large slit: 105° ➜ λ dependent pulse length
    - ⁎ Thermal spectrum: $\delta\lambda/\lambda$ = 3,0% — $F=0{,}63xF_t$
    - ⁎ Cold spectrum: $\delta\lambda/\lambda$ = 1,9% — $F=0{,}77xF_c$



- Disks diameter = 600 mm
- Frequency < 140 Hz
- Opening time: 60 µs @ 112 Hz

Choppers





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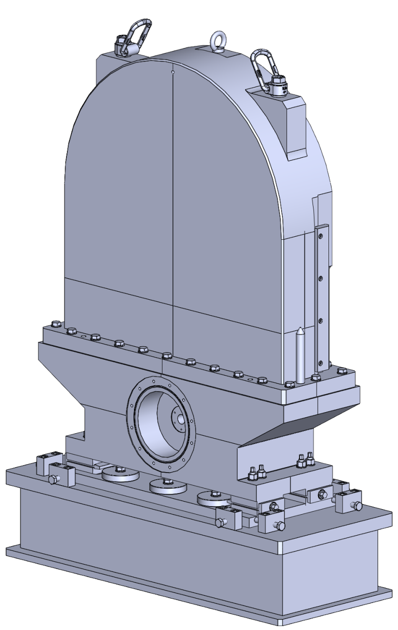
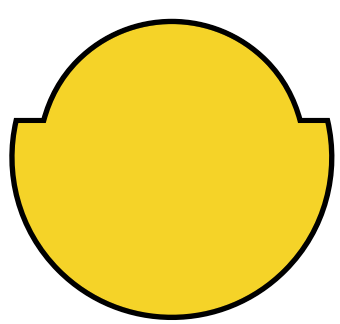
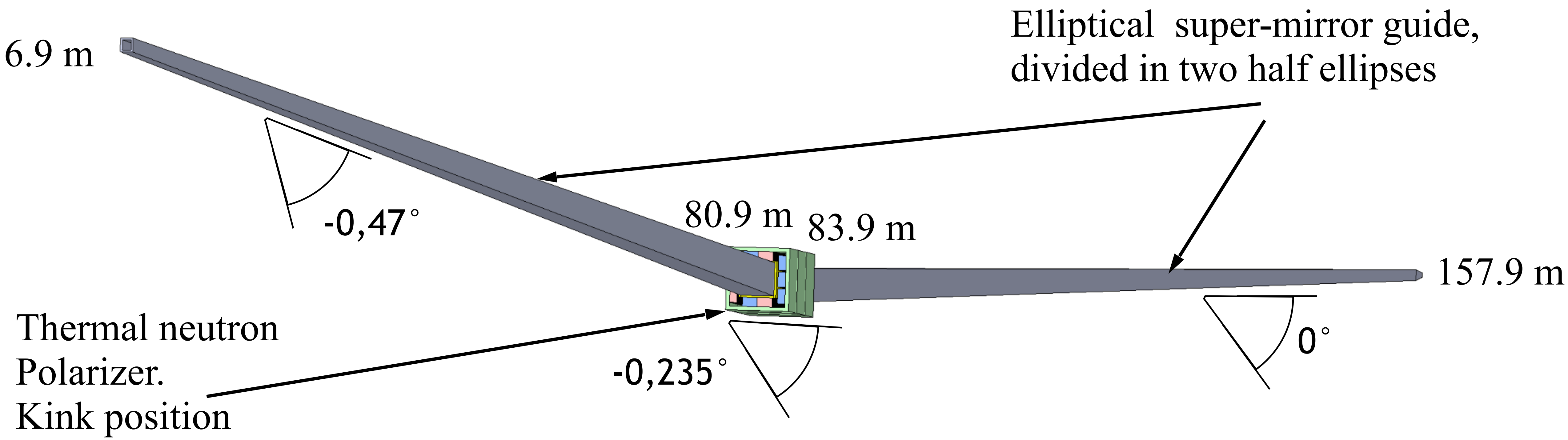




- SC (14 Hz): eliminate sub-pulses from PSC
  - 20.6° ➜ 1.1 ms opening
  - D = 600 mm
- BC (14 Hz): select wavelength range @~80 m
  - 180° ➜ 2.6 ms opening
  - D = 750 mm

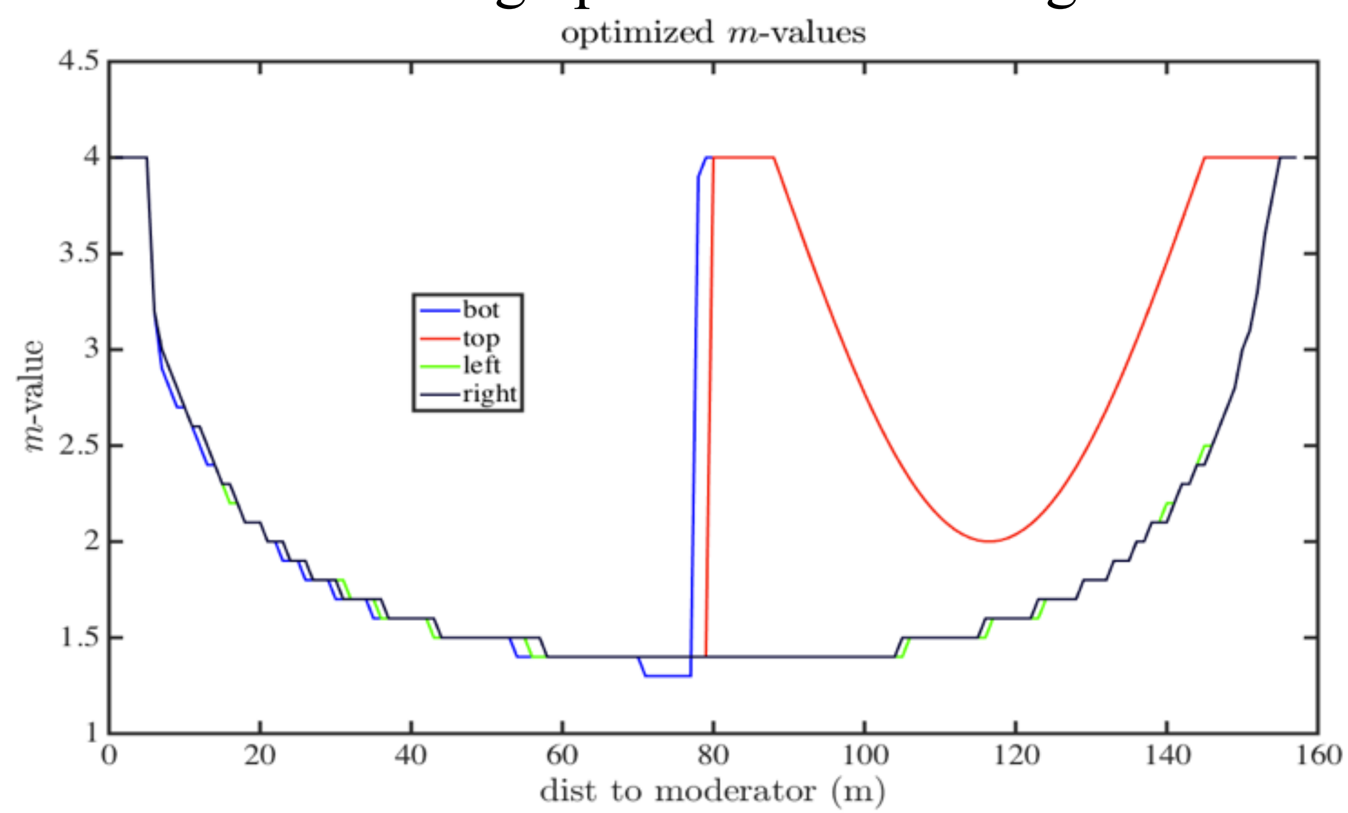
Neutron optics



FoM for optimisation:

Brilliance Transfer on a 5x5 mm^2 area within +/- 0.3°x0.3° divergence

m-coating optimization of the guide



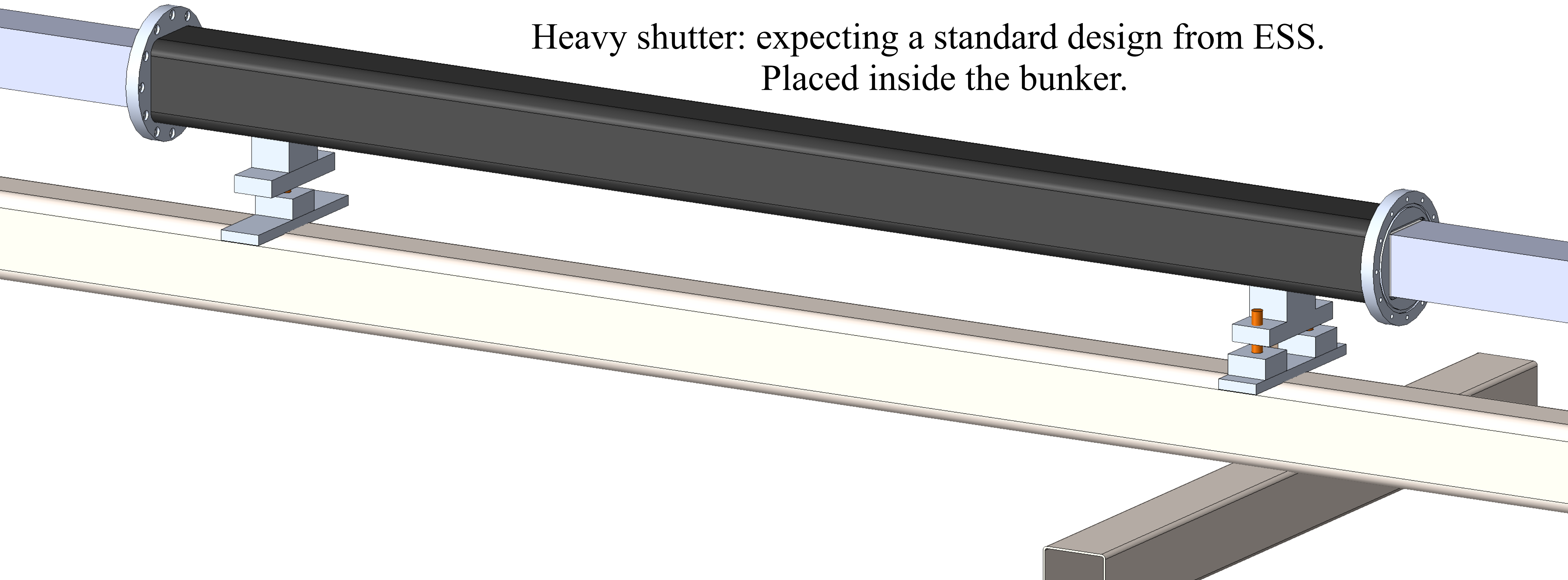
In-bunker guide

6900 mm ➜ 24500 mm
Inclination: -0.469°

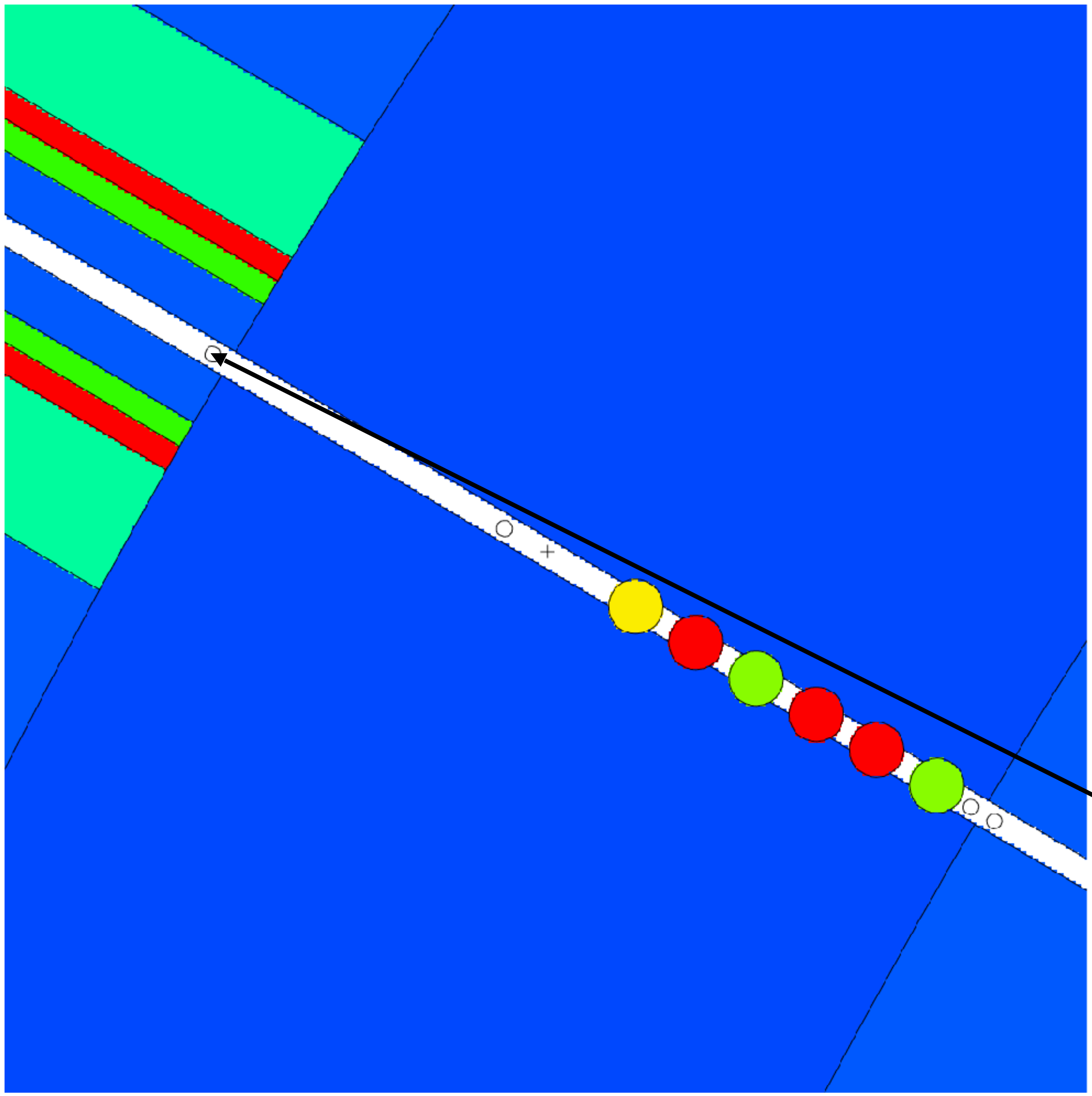
Substrate: aluminum
Vacuum housing: ensured by the substrate ➜ 10^{-3} mbar

5 mm B_4C layer around the guide to reduce activation
30-60 Gauss magnetic guide field (cost vs standardisation)

Heavy shutter: expecting a standard design from ESS.
Placed inside the bunker.



High energy shutter setup



6 drums are positioned within the neutron bunker wall.

Drum Sequence:

1. Borax (50% epoxy / 50% B_4C)
2. Standard steel
3. Standard steel
4. Borax
5. Standard steel
6. Tungsten/parafin (density 11.8 g/cm^3)

Effective thickness: each drum 20 cm

n-dose rate: 15.2 µSv/h
g-dose rate: 0.5 µSv/h
(only prompt gammas from the drums)

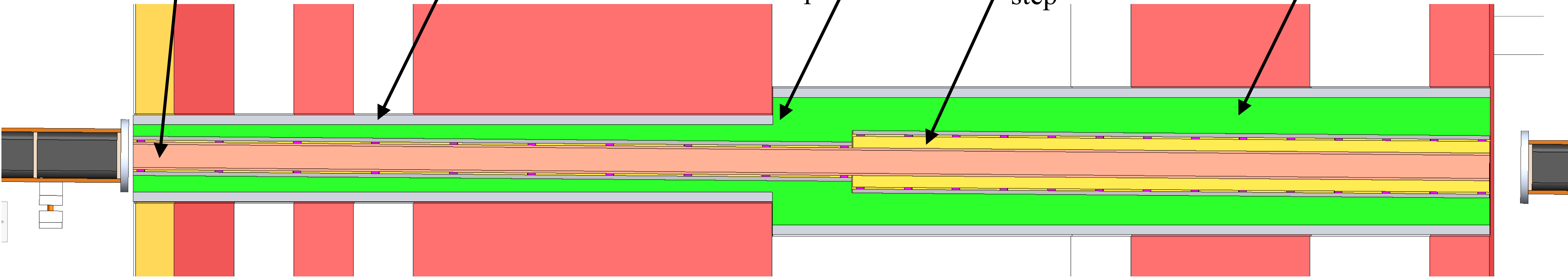
N-Dose rate can be reduced more by replacing steel with tungsten drums.

Bunker wall

24500 mm ➜ 28000 mm
Inclination: -0.469°

Substrate: copper
Vacuum housing: ensured by the substrate ➜ 10^{-3} mbar

Bronze C86300 anti-streaming volume (checked with Gabor).



End 1st half-ellipse

28000 mm ➜ 80000 mm
Inclination: -0.469°

Substrate: BK7
Vacuum housing: 5 mm aluminum pipe ➜ 10^{-3} mbar

5 mm B_4C layer around the housing to reduce activation
30-60 Gauss magnetic guide field (cost vs standardisation)

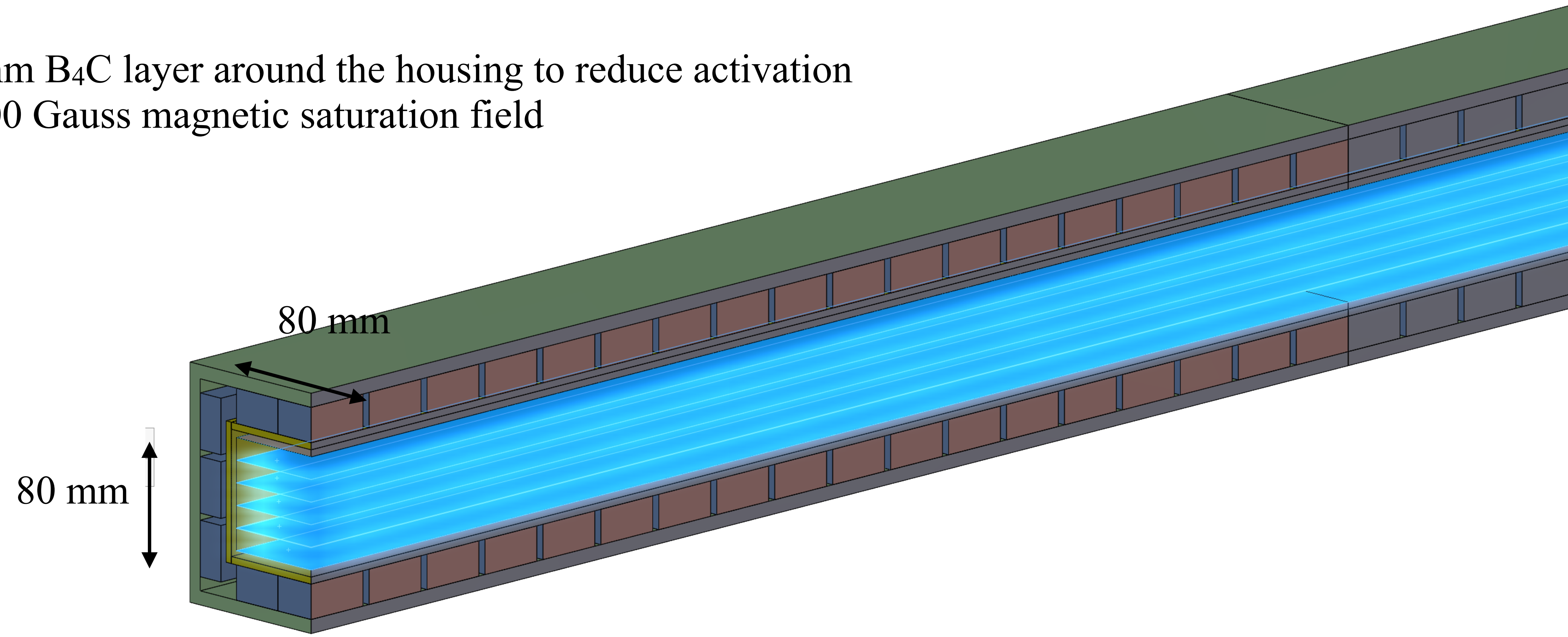
Total drop: 650 mm from Beam Center Line

Straight element

80900 mm ➜ 83900 mm
Inclination: -0.235°

Substrate: BK7
Vacuum housing: 5 mm aluminum pipe ➜ 10^{-3} mbar
6 horizontal channels: 300µm thick FeSi coated Si layer

5 mm B_4C layer around the housing to reduce activation
1000 Gauss magnetic saturation field

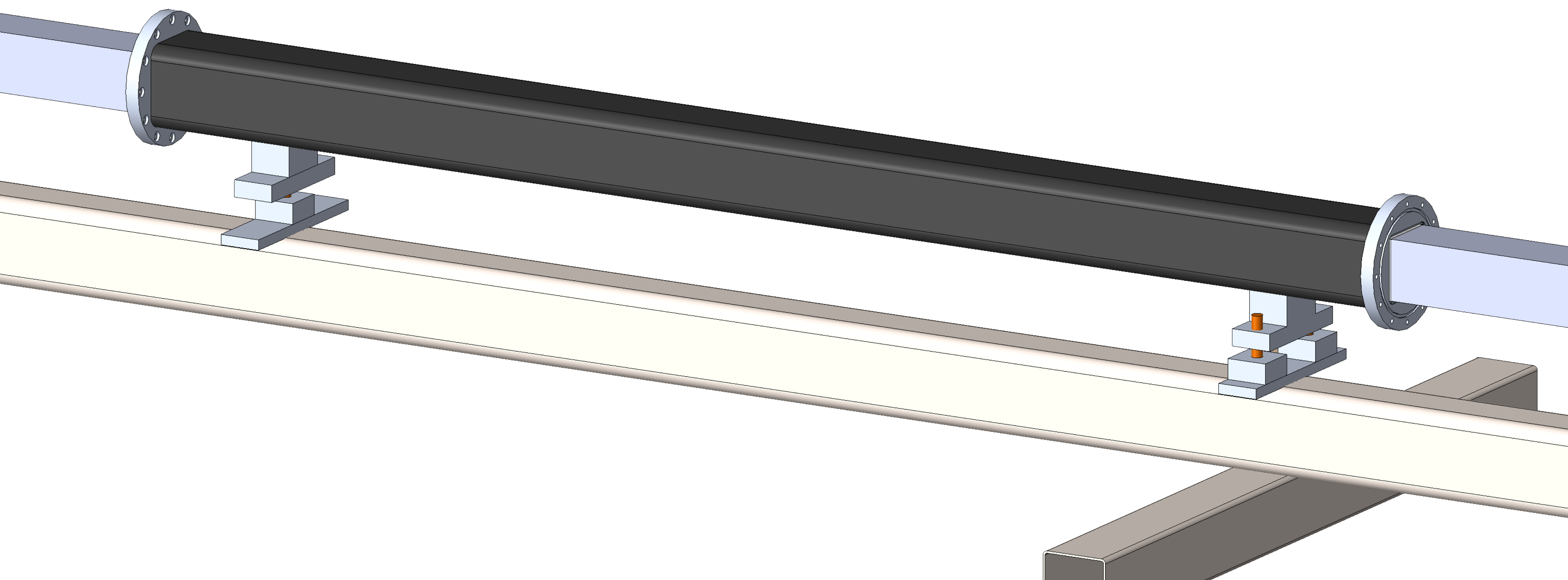


2^{nd} half-ellipse

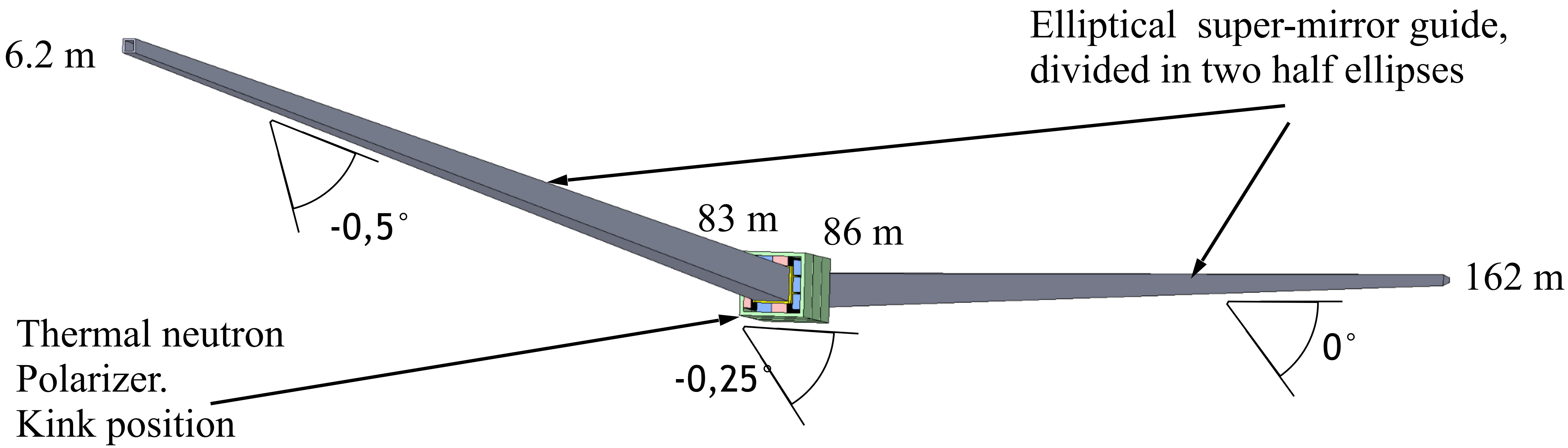
83900 mm ➜ 157900 mm
Inclination: 0°

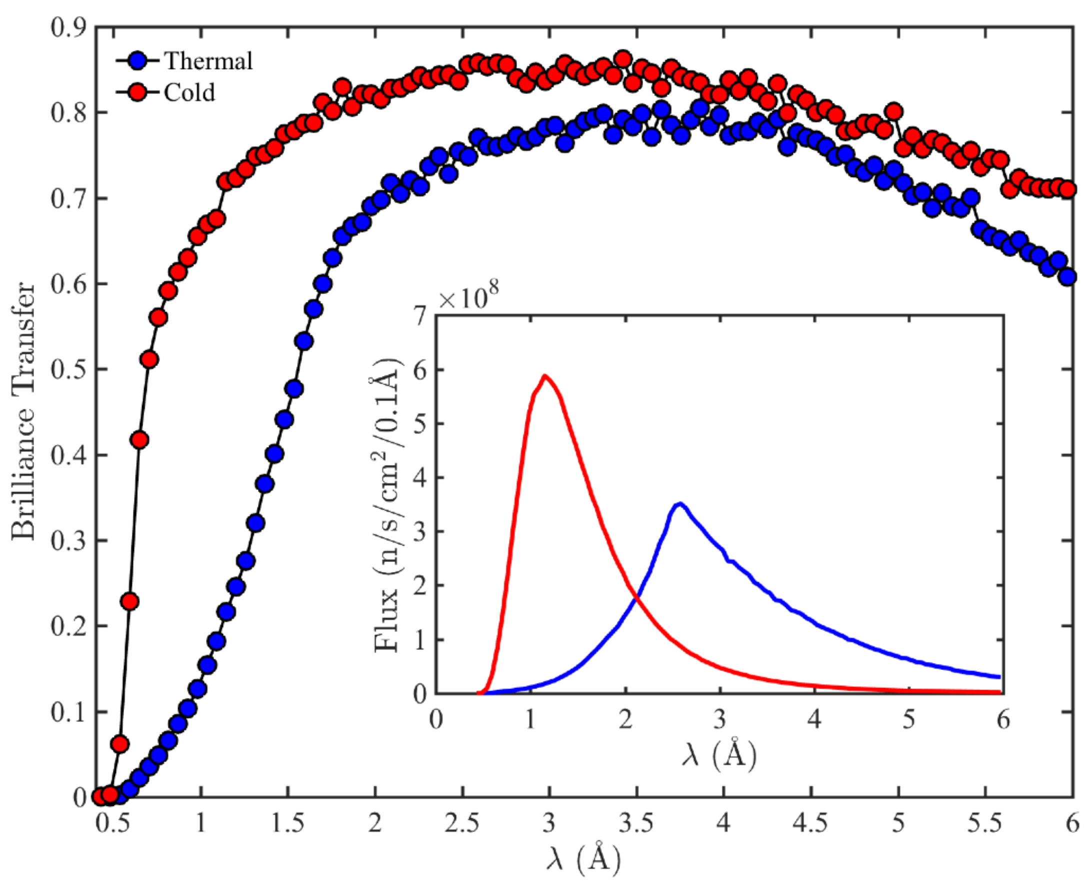
Substrate: BK7
Vacuum housing: 5 mm aluminum pipe ➜ 10^{-3} mbar

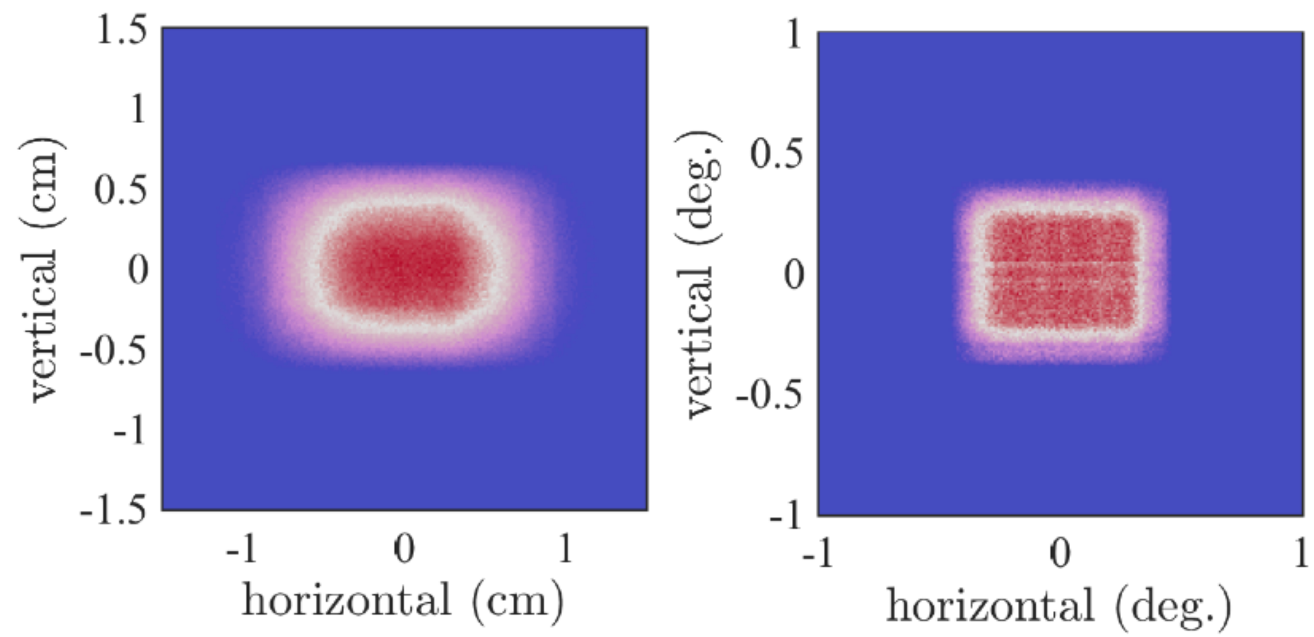
5 mm B_4C layer around the housing to reduce activation
30-60 Gauss magnetic guide field (cost vs standardisation)



Neutron optics

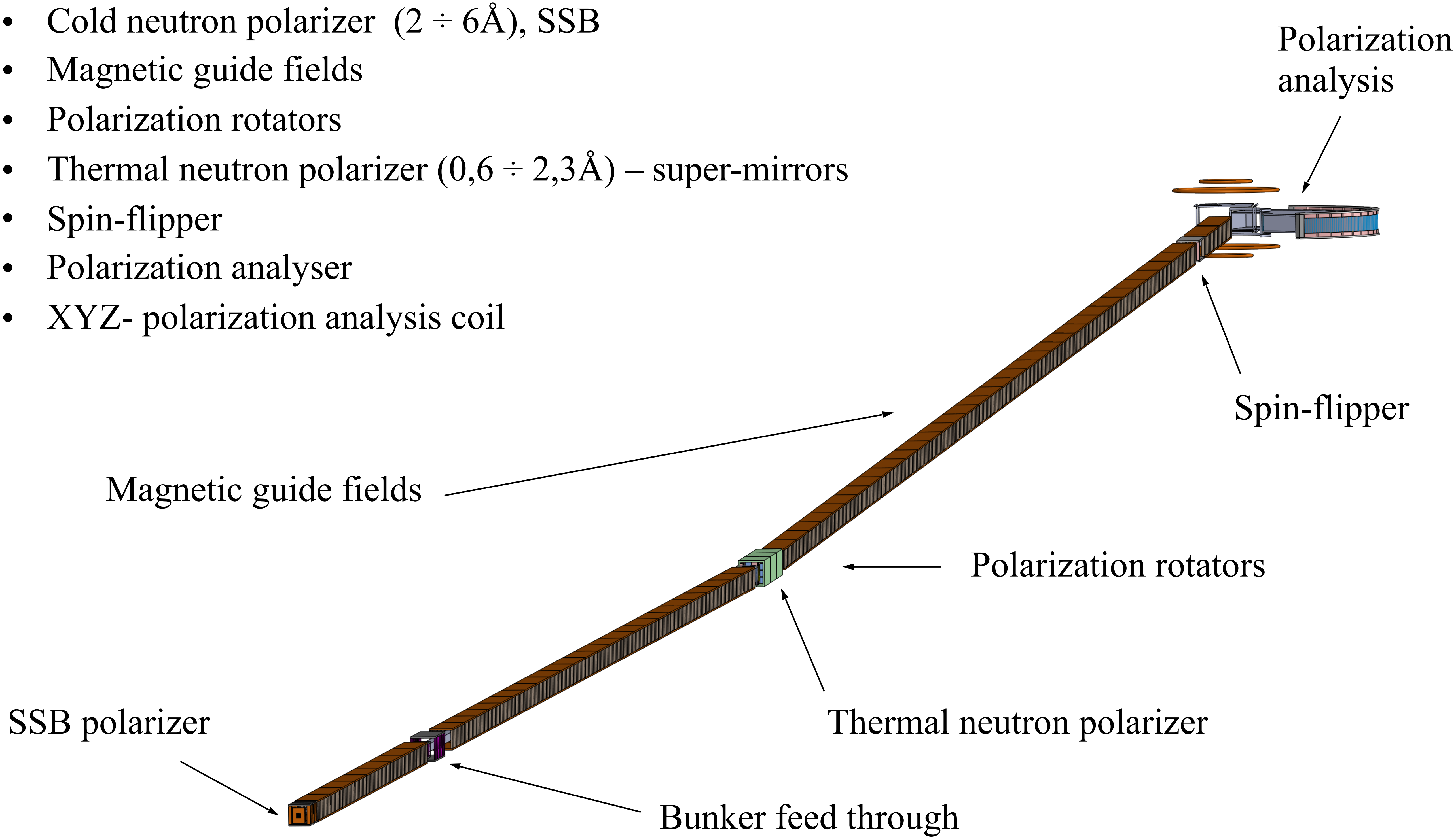






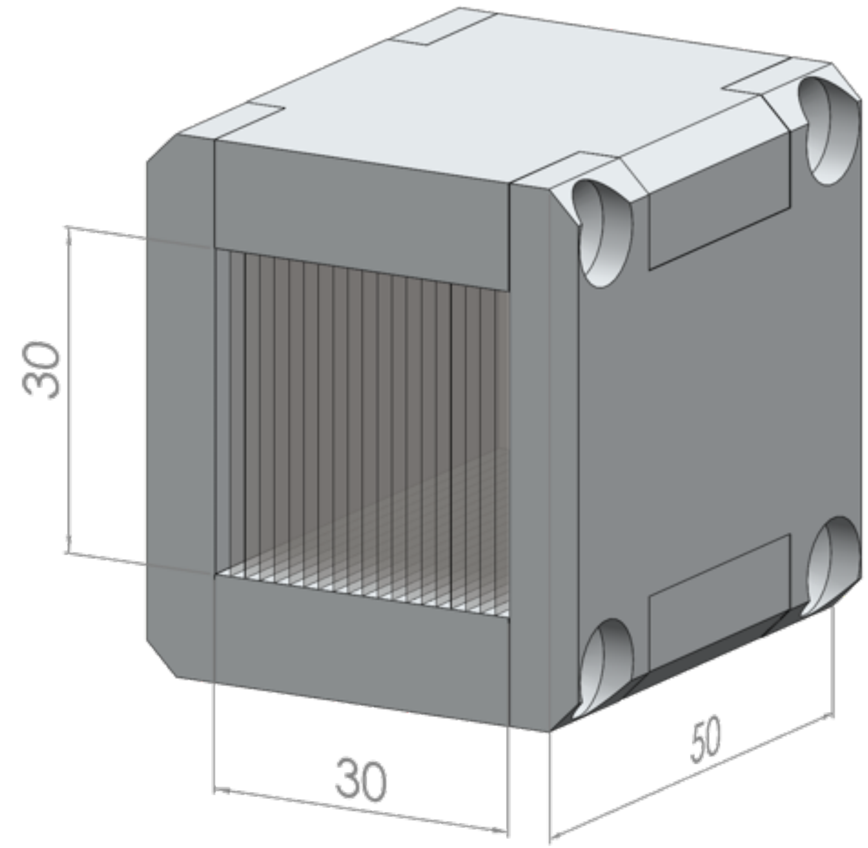
Neutron Polarization

- Cold neutron polarizer (2 ÷ 6Å), SSB
- Magnetic guide fields
- Polarization rotators
- Thermal neutron polarizer (0,6 ÷ 2,3Å) – super-mirrors
- Spin-flipper
- Polarization analyser
- XYZ- polarization analysis coil

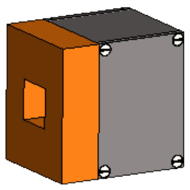


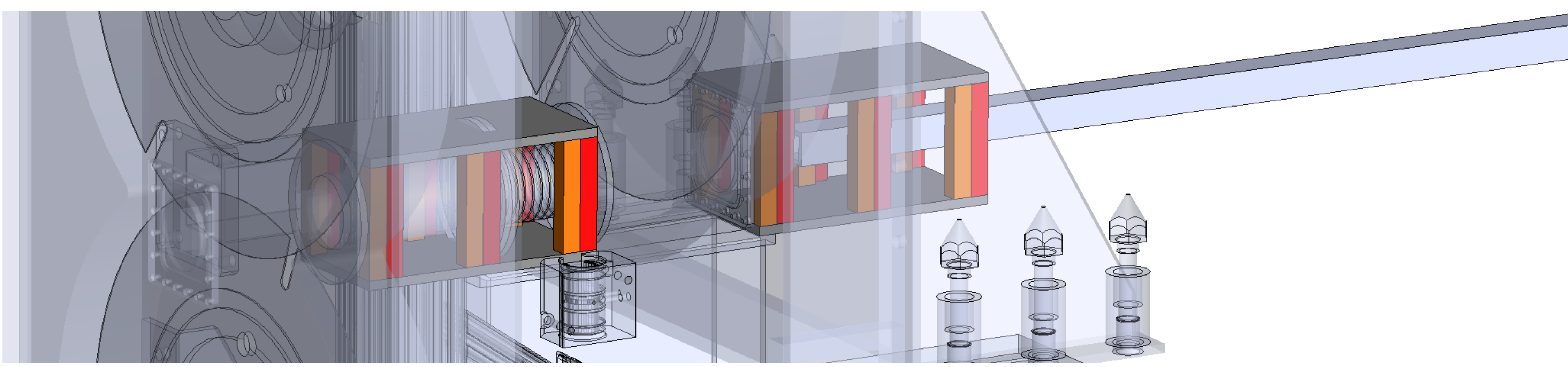
Cold neutron polarizer

- Position: in front of PSC
- Solid state bender (3m), 150 μm thick Si wafer coated with FeSi;
- Vertical saturation field of 1 kGauss;
- Mounted inside the light shutter to easily adjust and switch between thermal (0,6 ÷ 2,3Å) and cold (2 ÷ 6Å) polarized neutron beams;



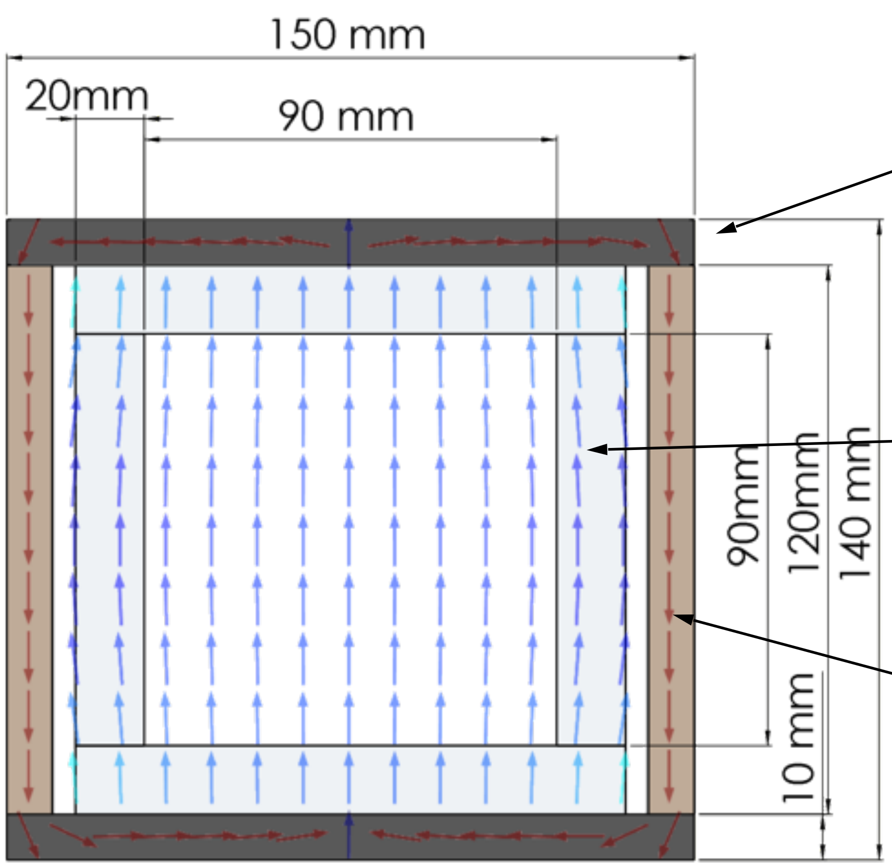
SSB polarizer

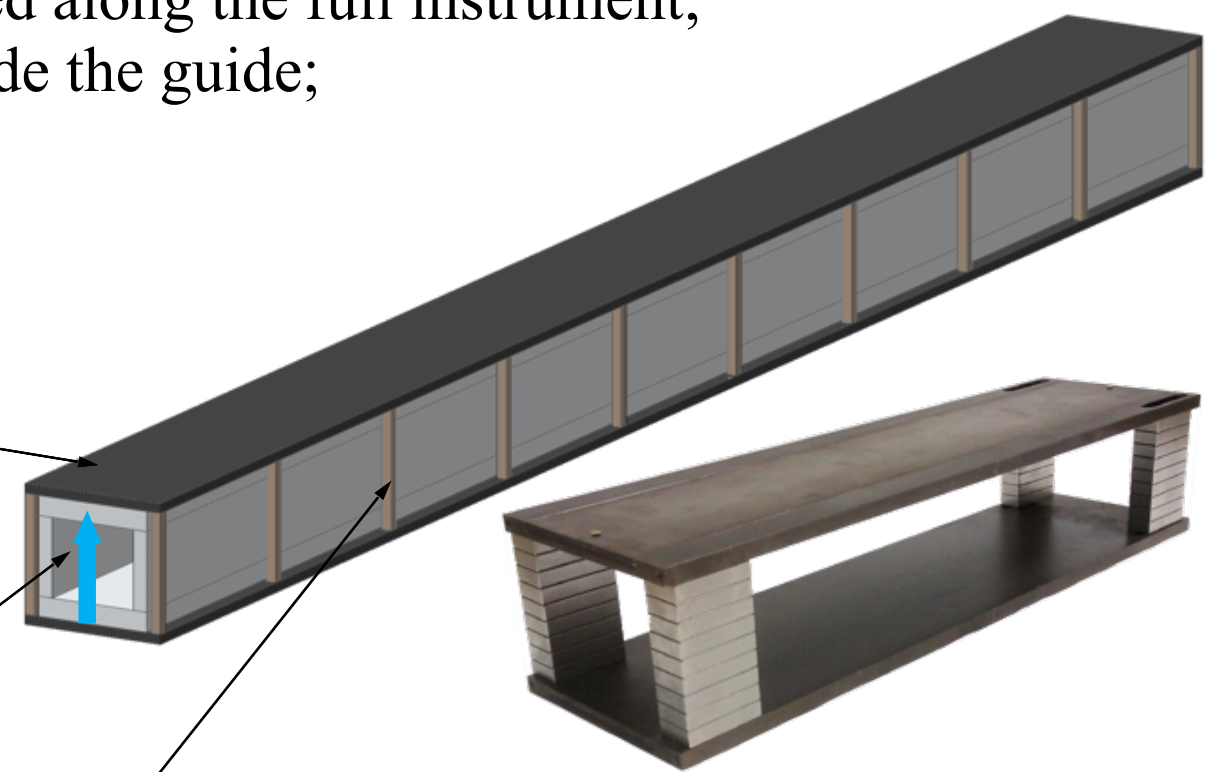


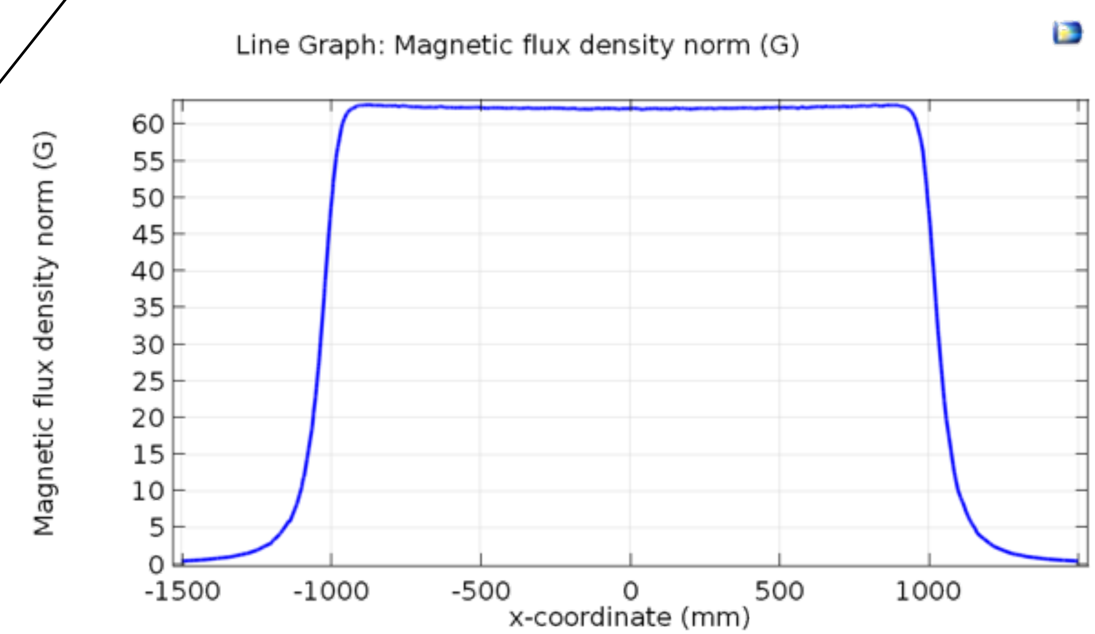


Magnetic guide field

- To keep polarization, magnetic guide field is applied along the full instrument;
- Homogeneous vertical guide field of 60 Gauss inside the guide;
- Soft iron plates + NdFeB magnets;







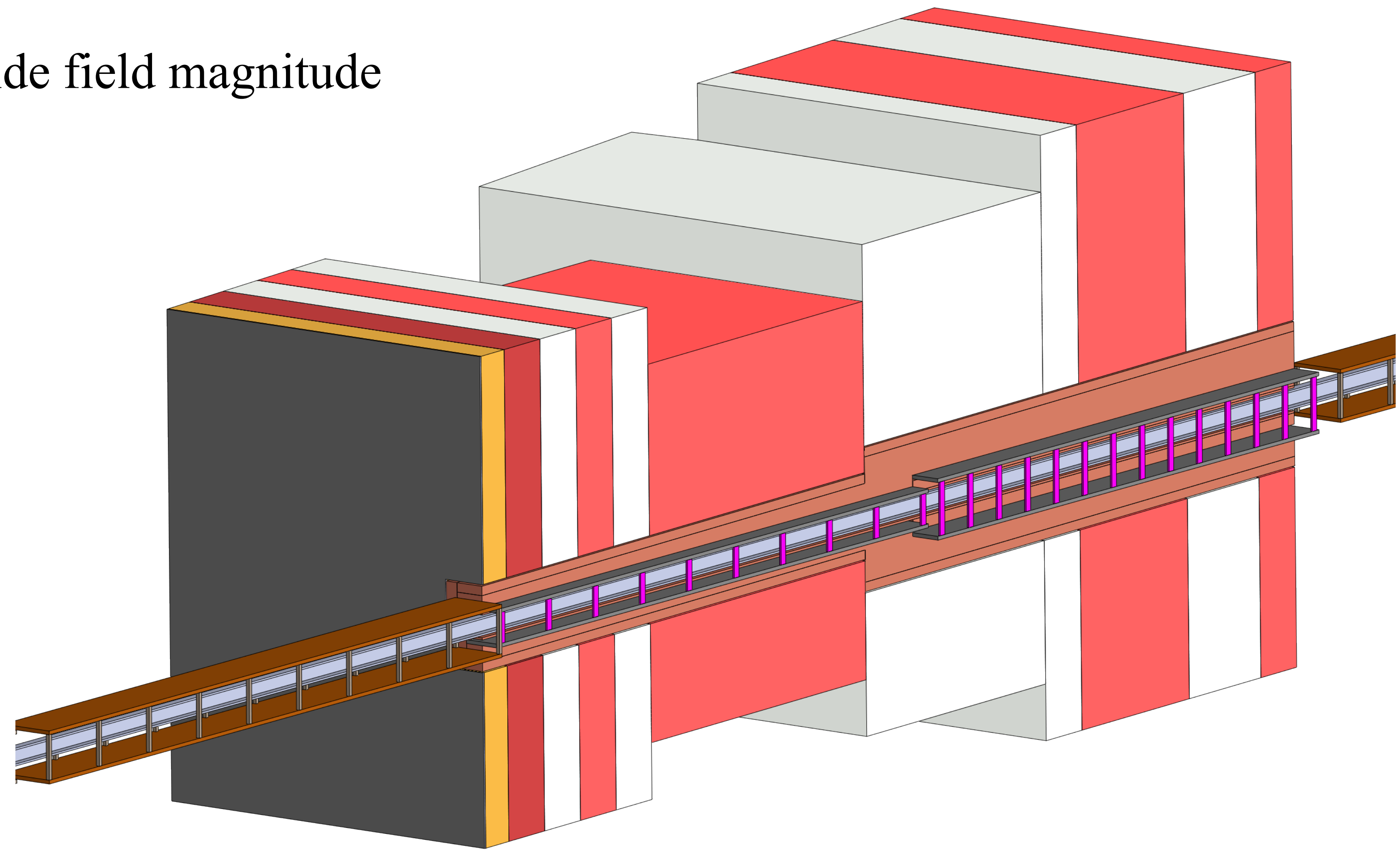
Magnetic guide field

- To keep polarization, magnetic guide field is applied along the full instrument;
- Homogeneous vertical guide field of 60 Gauss inside the guide;
- Soft iron plates + NdFeB magnets;

- Bunker reduces the guide field magnitude
- Permeability is not 0

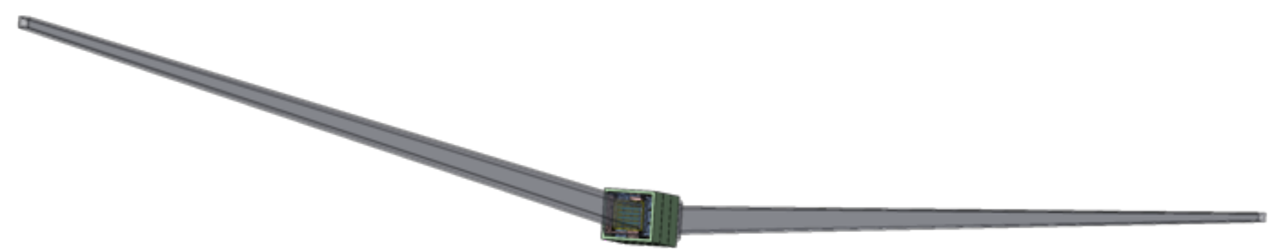
- Expected 20-30 Gauss
- OK for cold neutrons

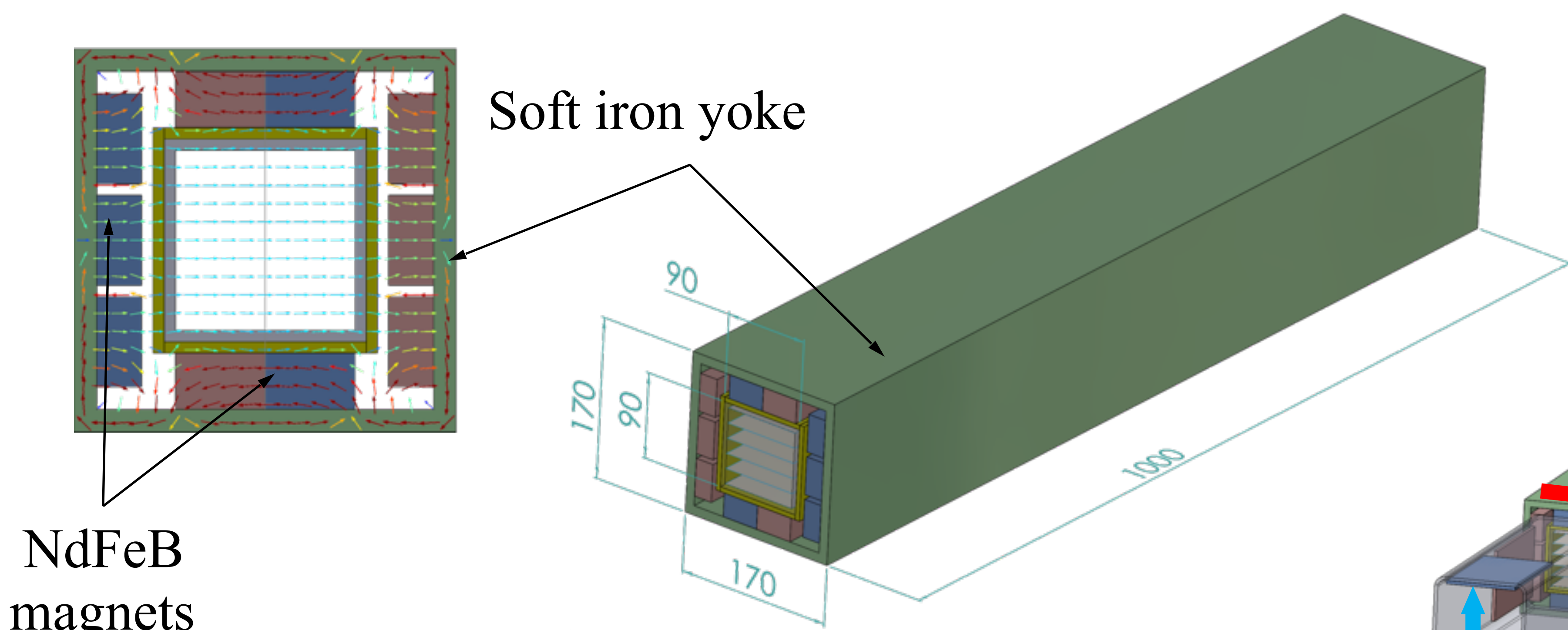
Deadline today !

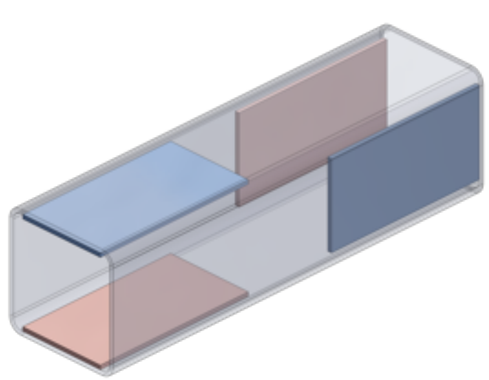


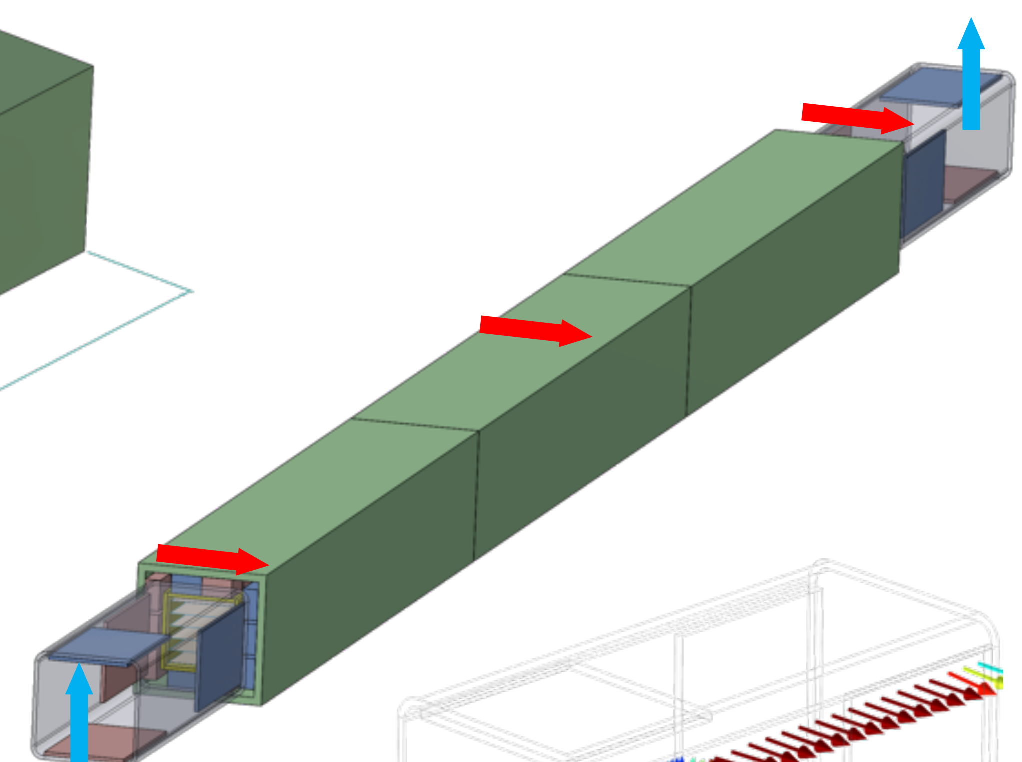
Thermal neutron polarizer

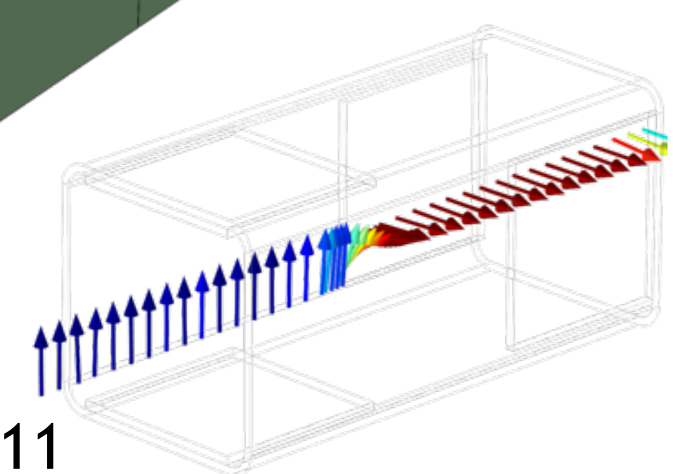
- 6 channels FeSi super-mirror polarizer; 3 section by 1m long;
- Horizontal saturation field of 1 kGauss;
- Soft iron yoke + NdFeB magnets;
- Polarization rotator – turn polarization 90°;





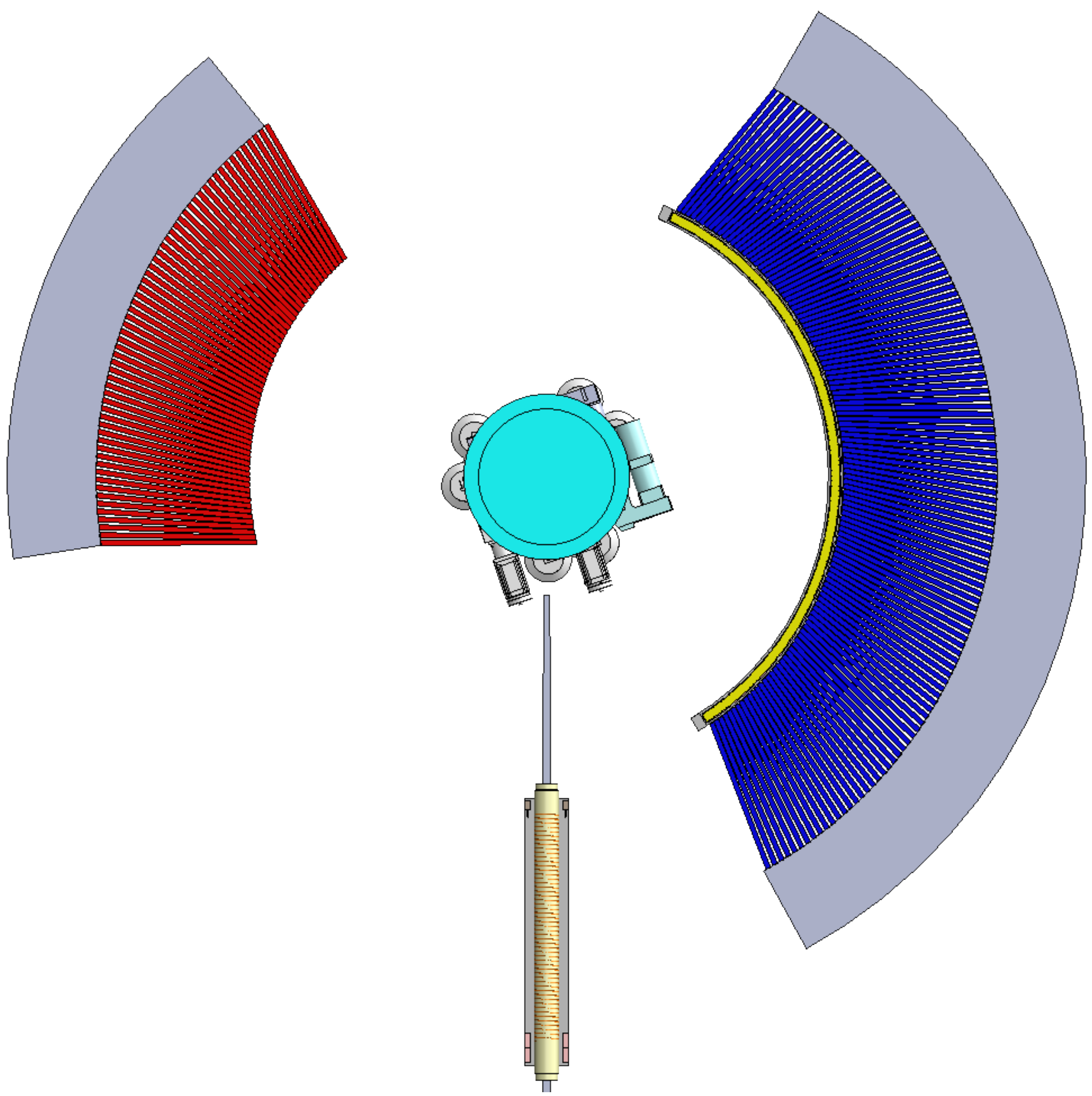


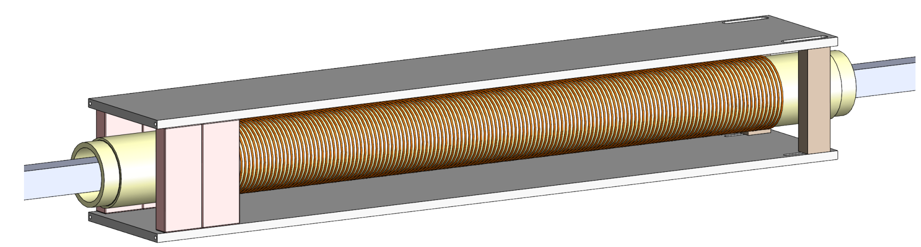


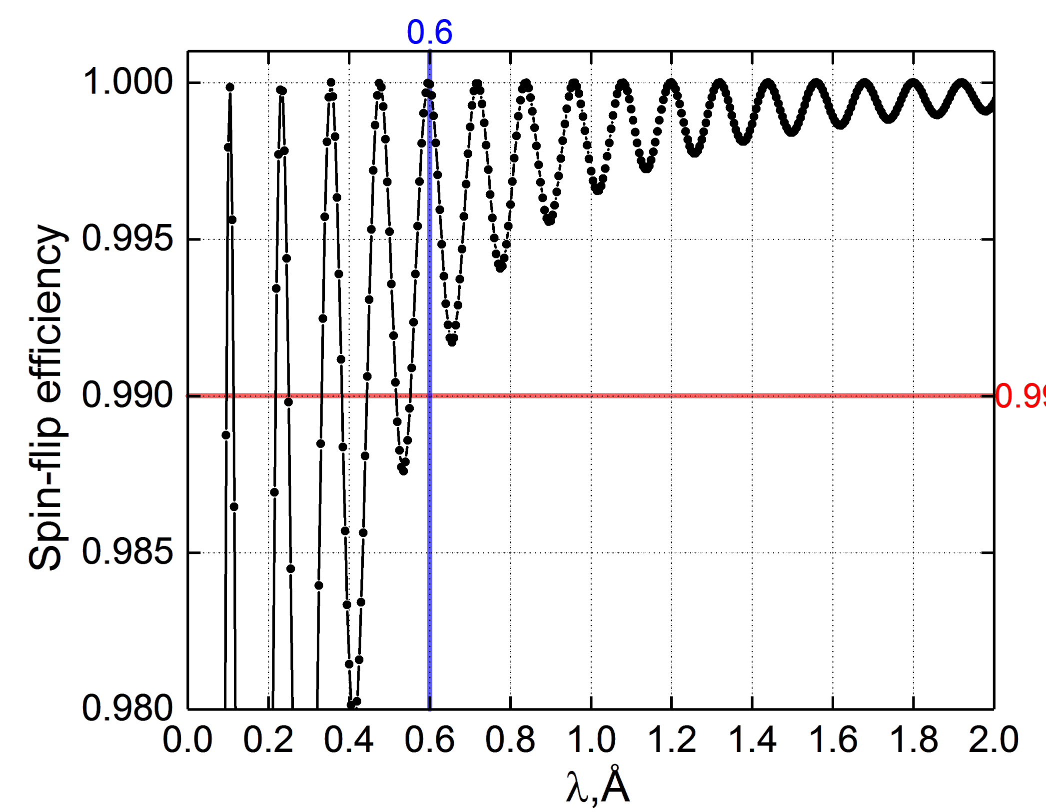


Adiabatic spin flipper

- Adiabatic spin flipper will be installed in the second guide section at distance from the sample position to limit stray field from 10 T magnet;
- Spin-flip efficiency is ~1 from 0,6Å to higher wavelength;

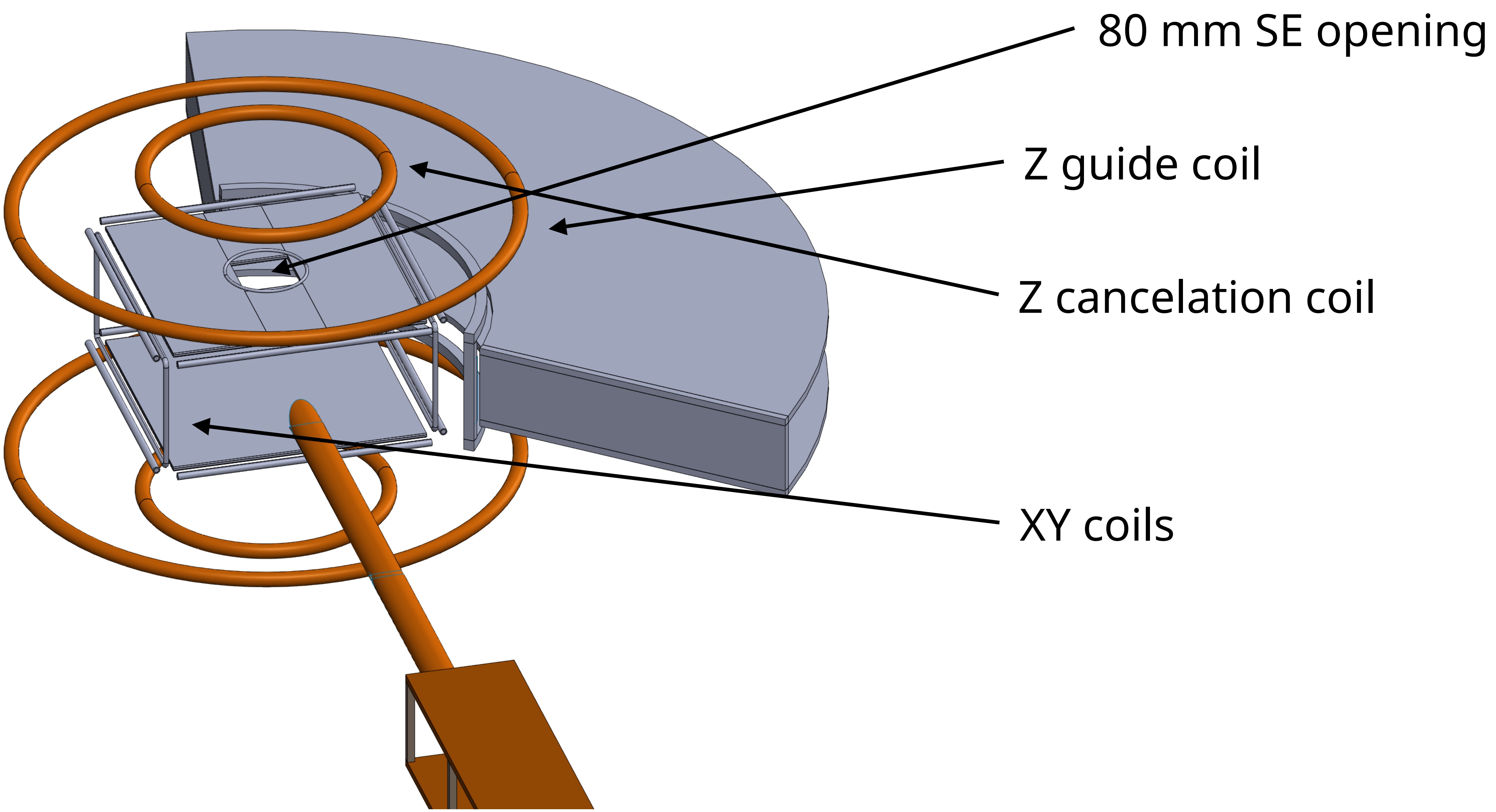






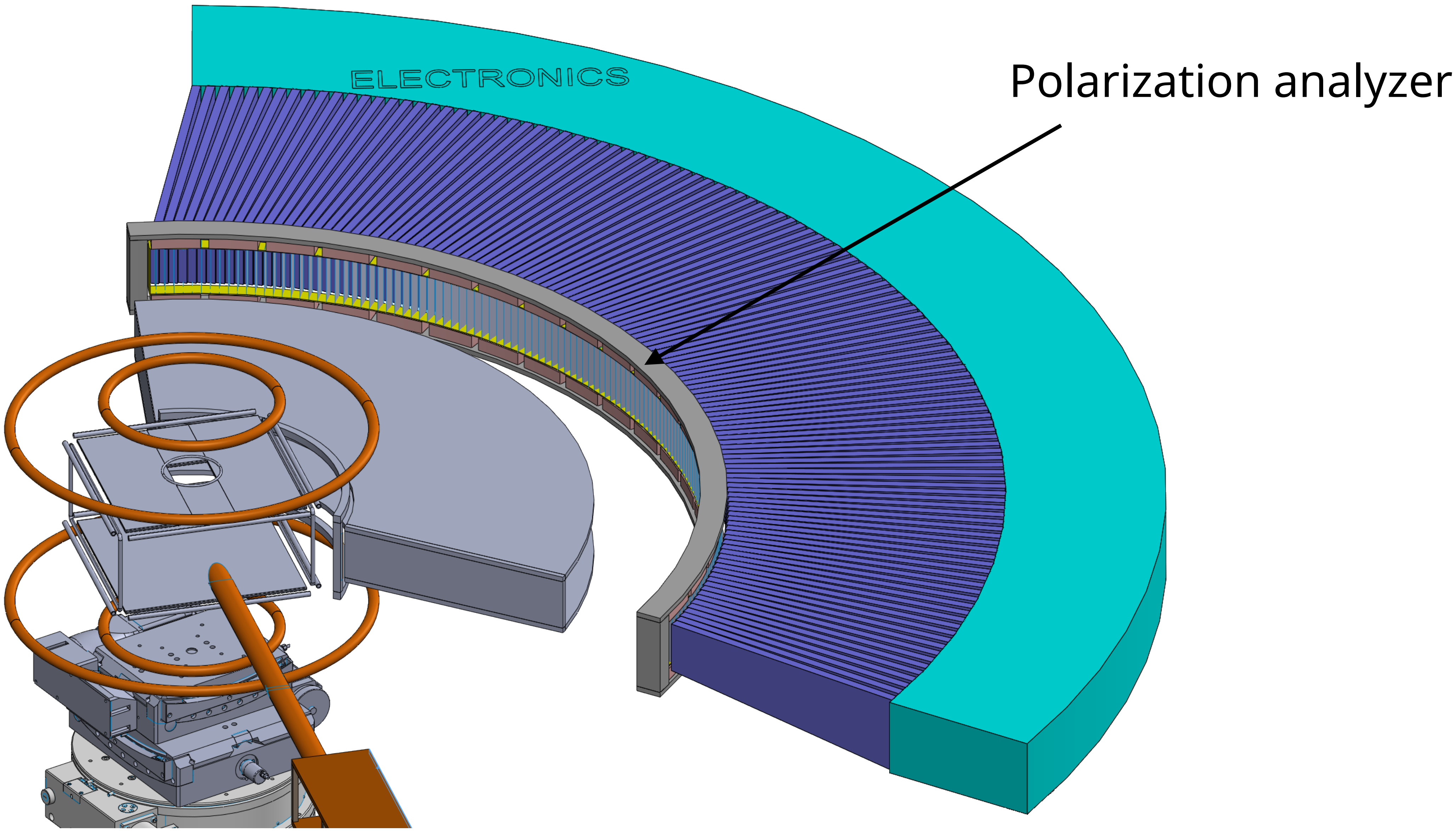
XYZ polarization

- Set of XYZ coils to manipulate the guide field at sample position;
- PASTIS like coil geometry



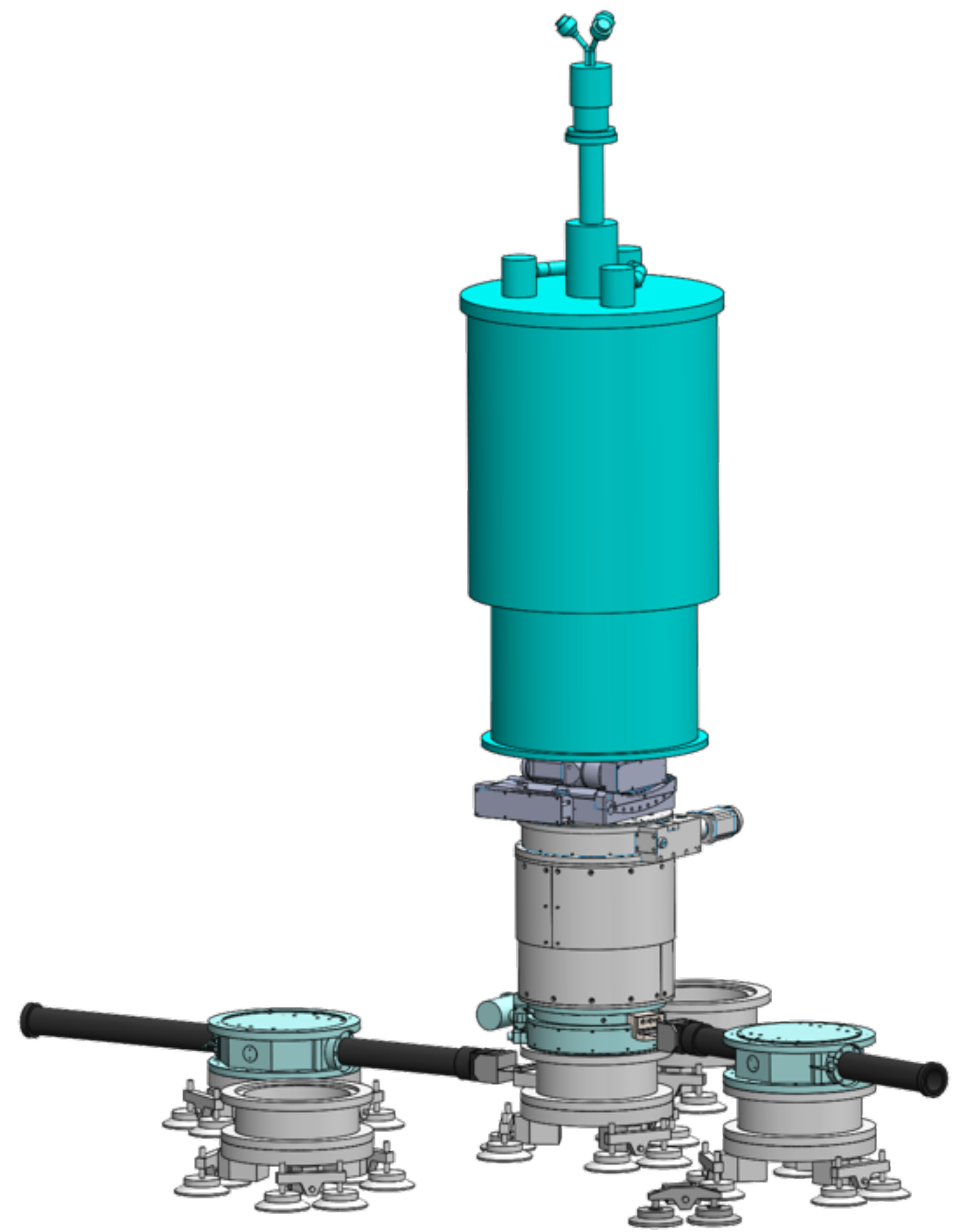
Polarization analyzer

- Solid state analyser, 150 μm thick Si wafer coated with FeSi;
- 120° horizontal angular aperture, 6° vertical aperture;



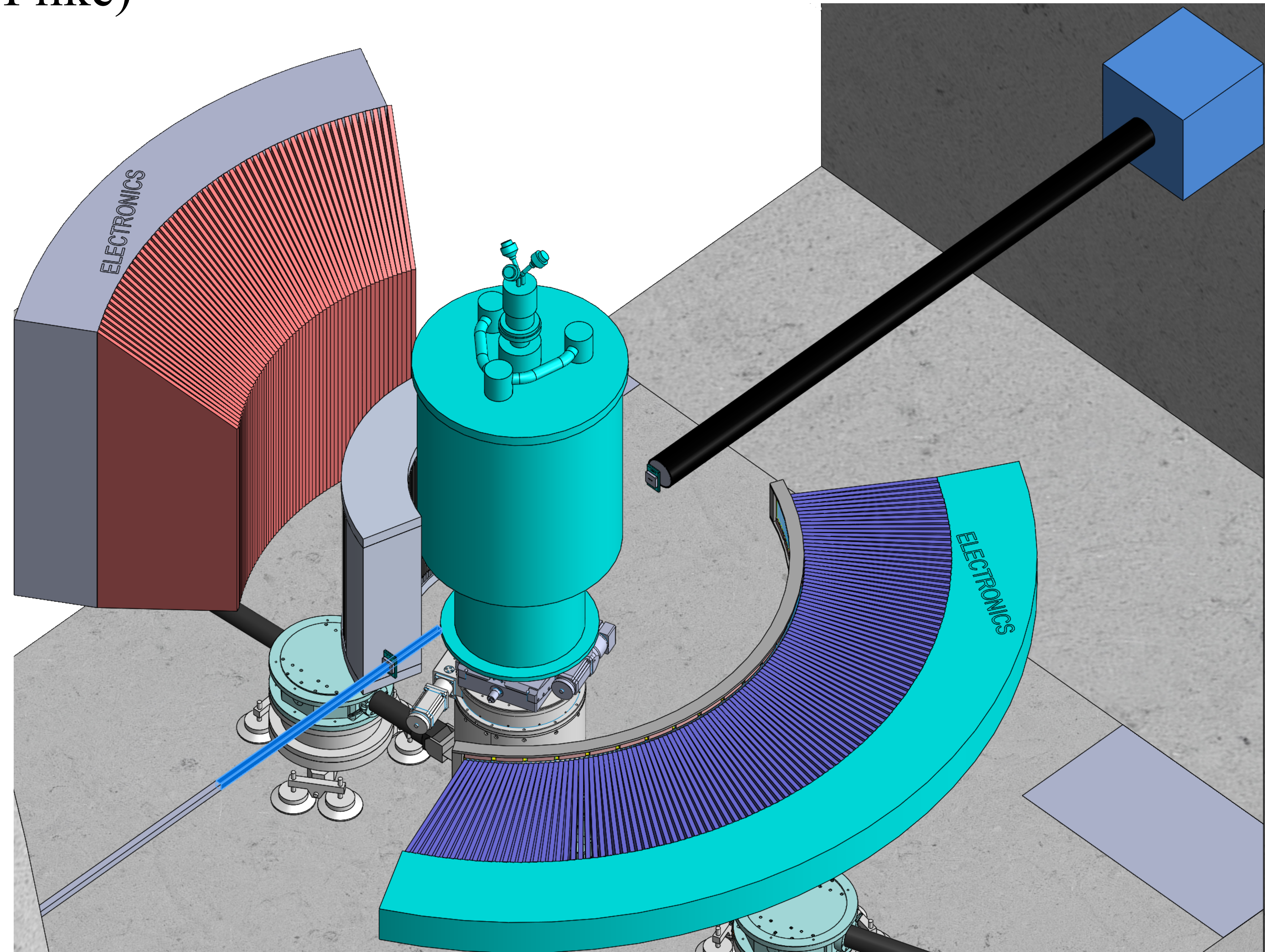
Sample exposure system

- Sample table
- Cryostat
- Piezo positioning system Attocube



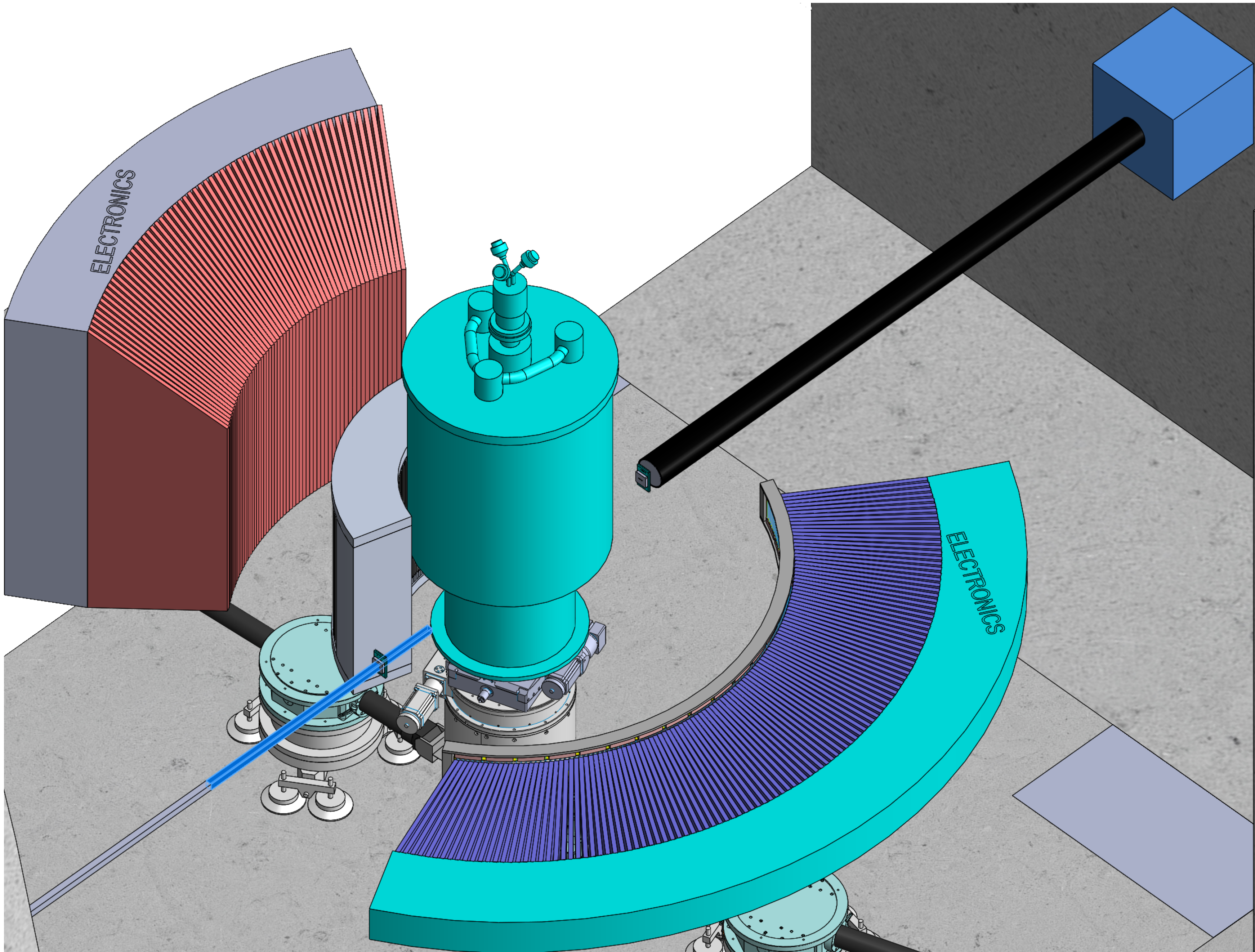
Beam shaping at sample position

- Beam focusing, SM m=6: gain ~ 4
- 1 Radial Collimator 120ºx48º Euro collimators
- Collimation slits (DREAM like)



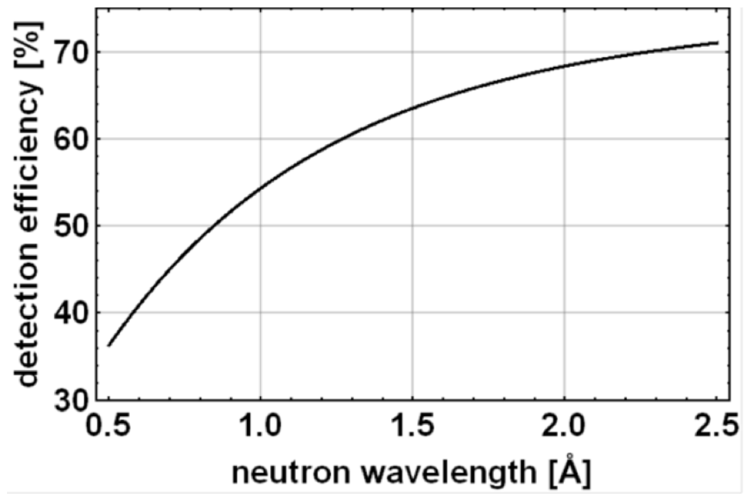
Detectors

- ^{10}B Jalousie Detector 60ºx48º
- ^{10}B Jalousie Detector 120ºx6º   Cascade Detector Technology

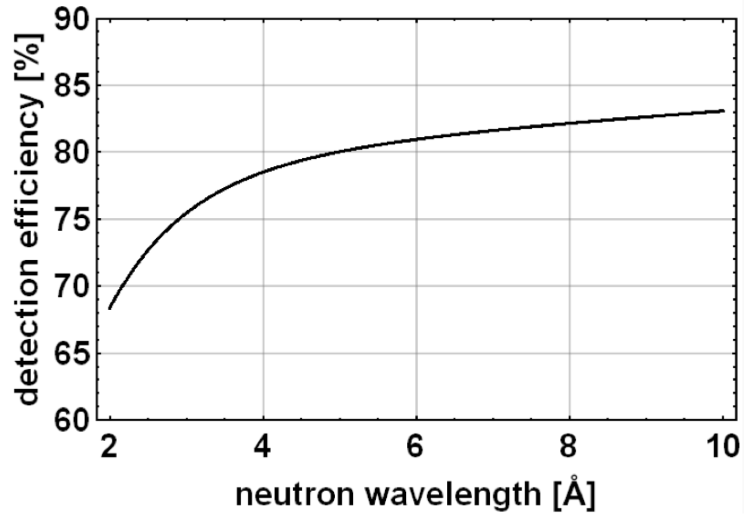


Detectors

- ^{10}B Jalousie Detector 60ºx48º
  - Inclination: 10°
  - Length: 520 mm (32 channels) ➜ 2.1 mm
  - Height: 902 mm (128 channels) ➜ 5.6 mm
  - Efficiency ➜

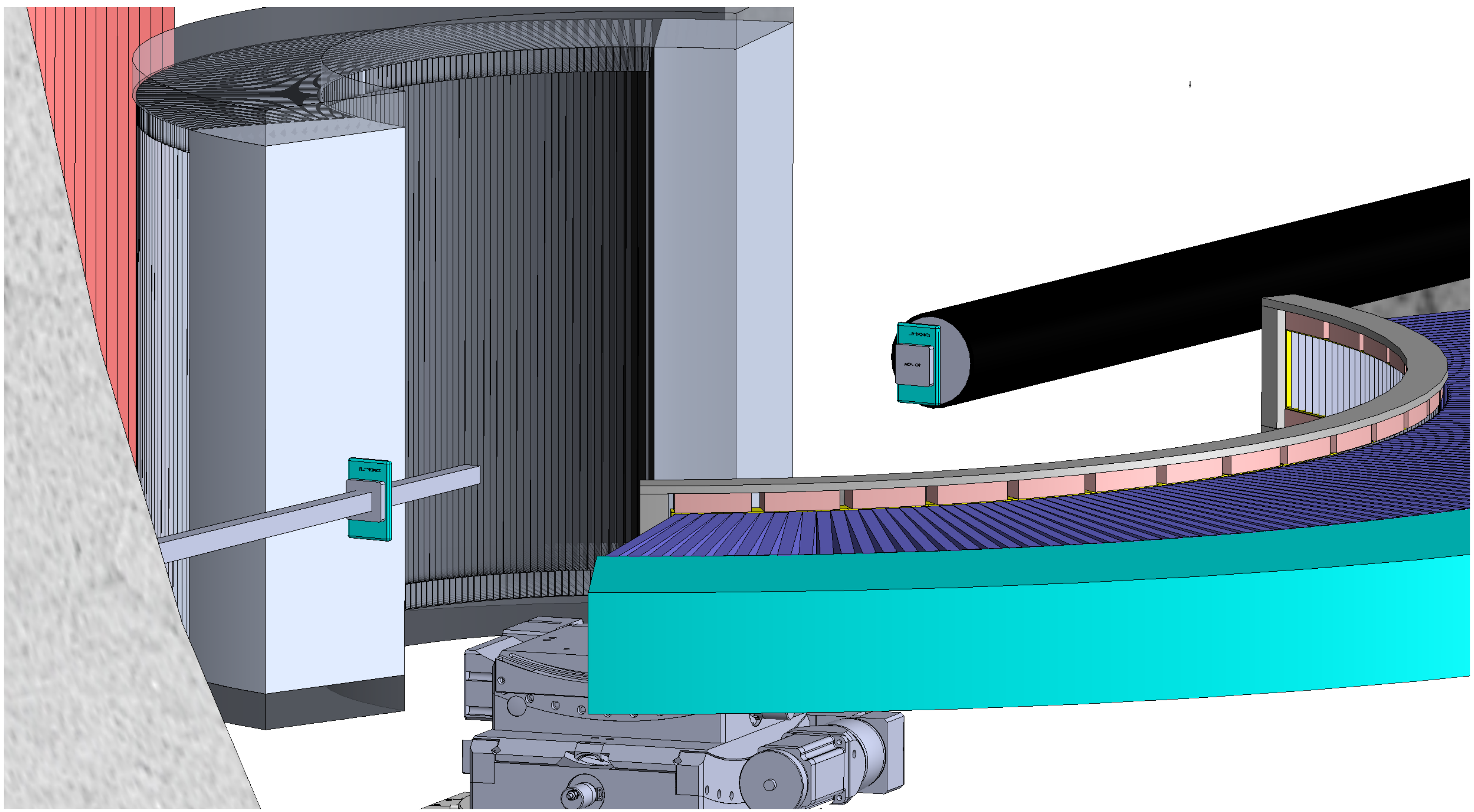


- ^{10}B Jalousie Detector 120ºx6º:
  - Inclination: 10°
  - Length: 500 mm (32 channels) ➜ 1.9 mm
  - Height: 100 mm (16 channels) ➜ 5.4 mm
  - Efficiency ➜



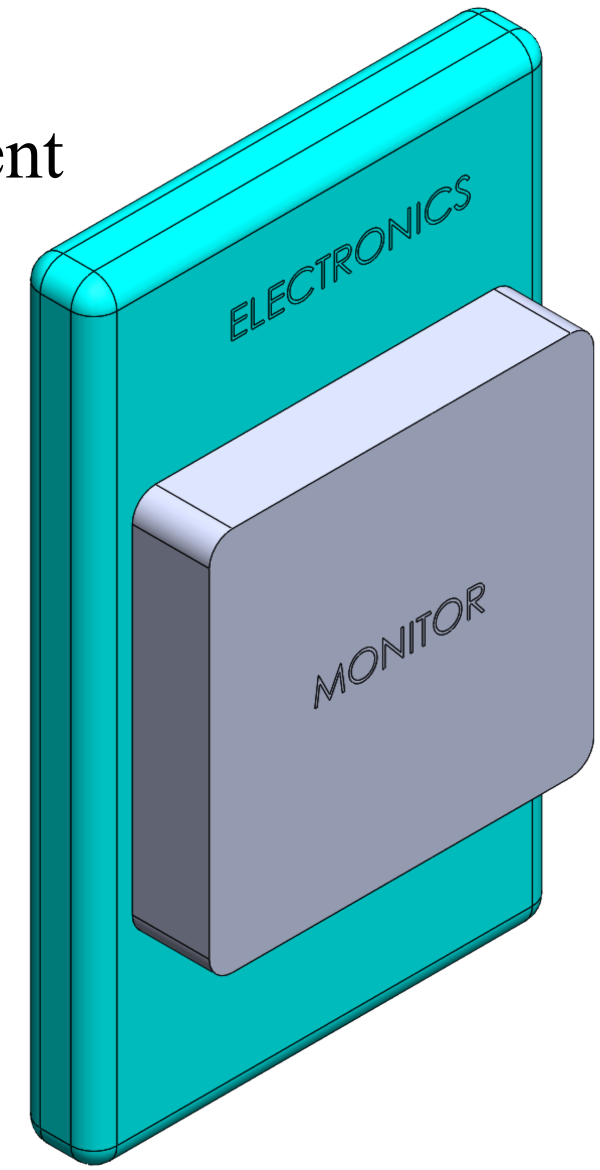
Monitors

- 2 monitors on incident and transmitted beam

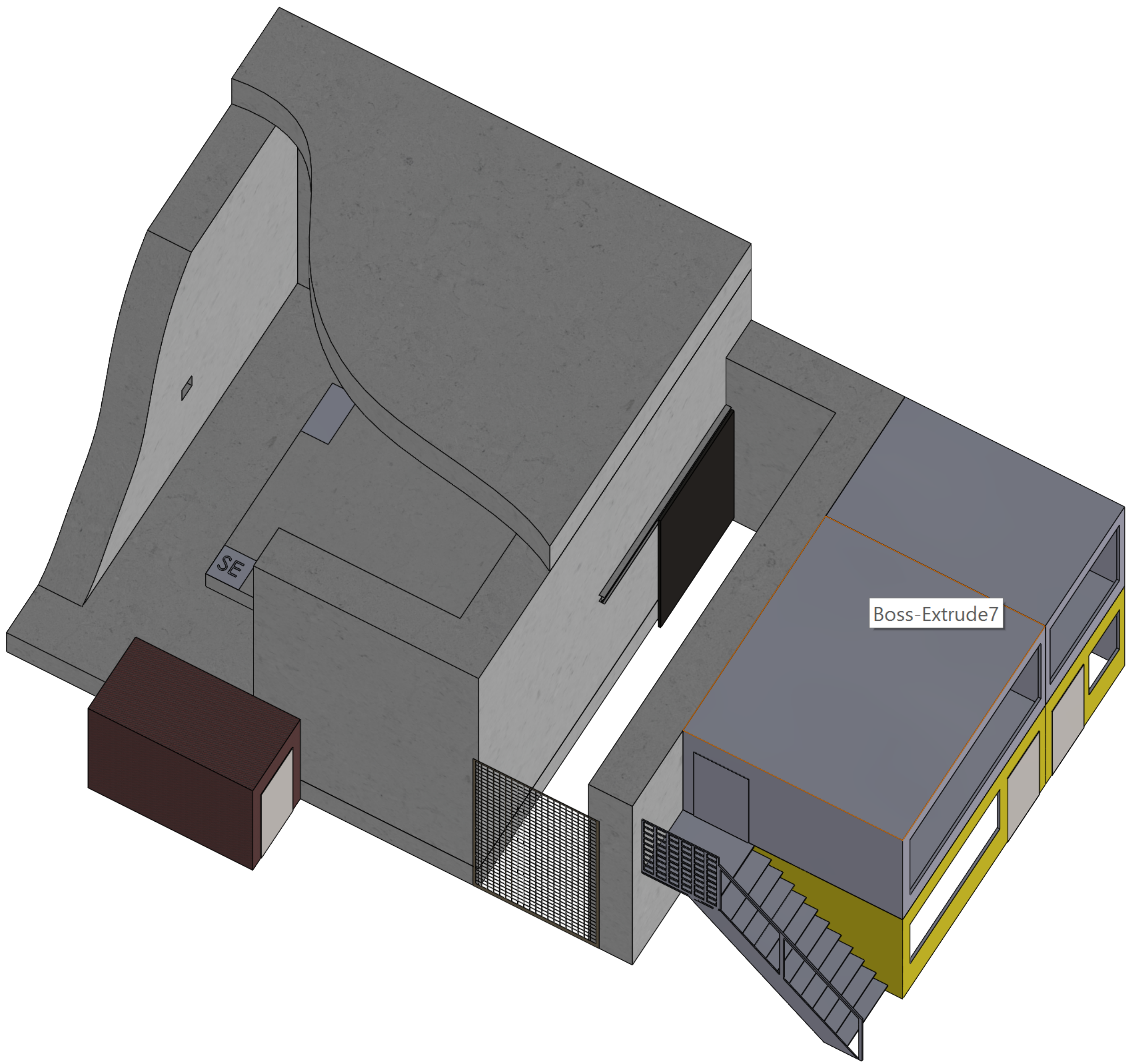


Monitors

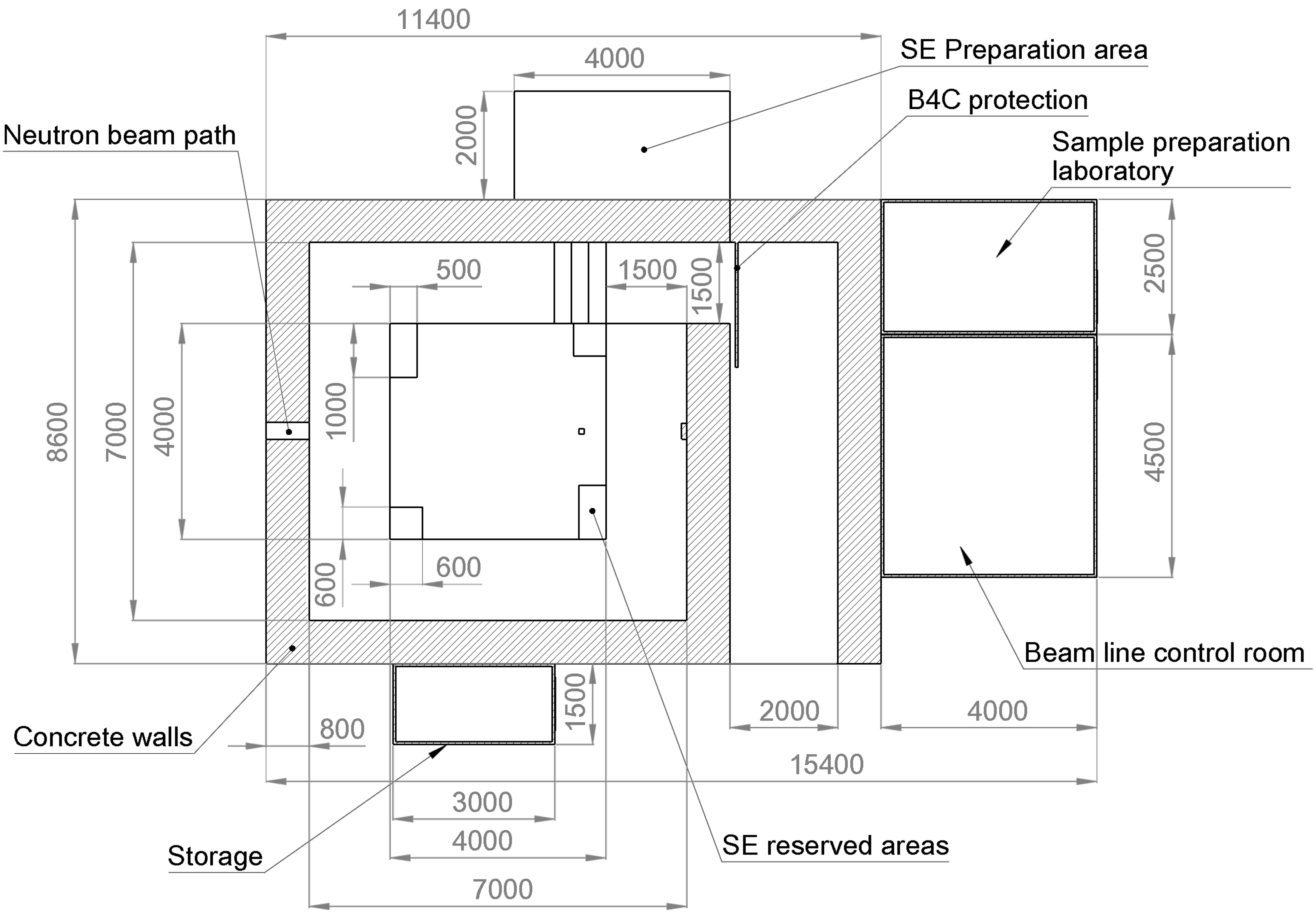
- 2 monitors on incident and transmitted beam
- Current status: micro-Bulk technology derived from CERN beam monitoring: copper micro mesh on Kapton layer
- Efficiency: 10^{-4} with 10 nm ^{10}B capture layer
  - Could be reduced using only N_2 as capture element
- up to 200µm resolution !
- 20 k€ cost/monitor + electronics



Experimental cave



Experimental cave

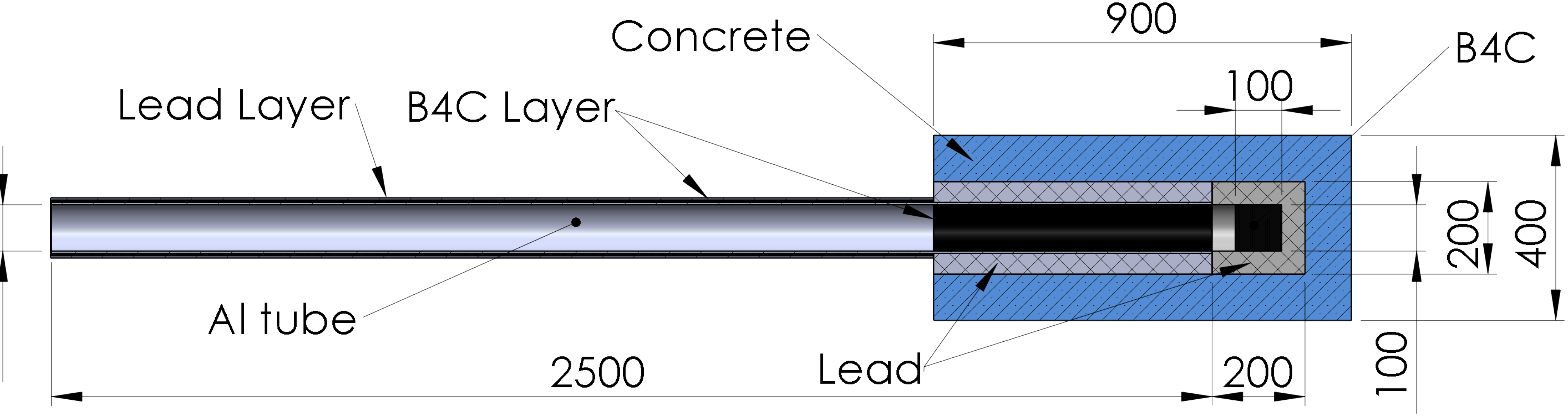


Experimental cave

Wall thickness calculated for H2 event
52 cm optimized thickness required
60 cm used (safety factor = 2)

5 mm B_4C on the walls
Calculated for graphite monochromator in beam

Beamstop (updated)
Thermal beam only !

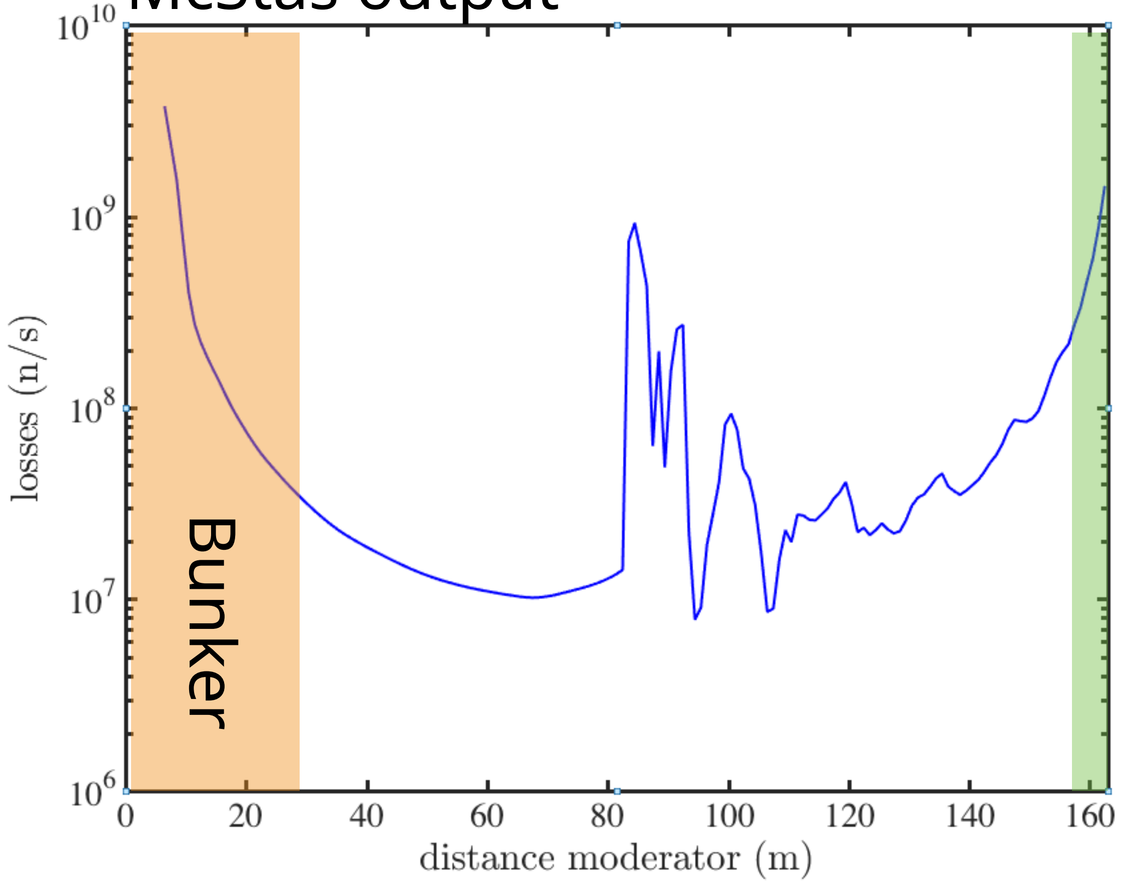


Beamline shielding

Beam losses inside the guide:

- Boron carbide
- Concrete
- Steel in hotspots

McStas output



Beamline shielding

Beam losses inside the guide:

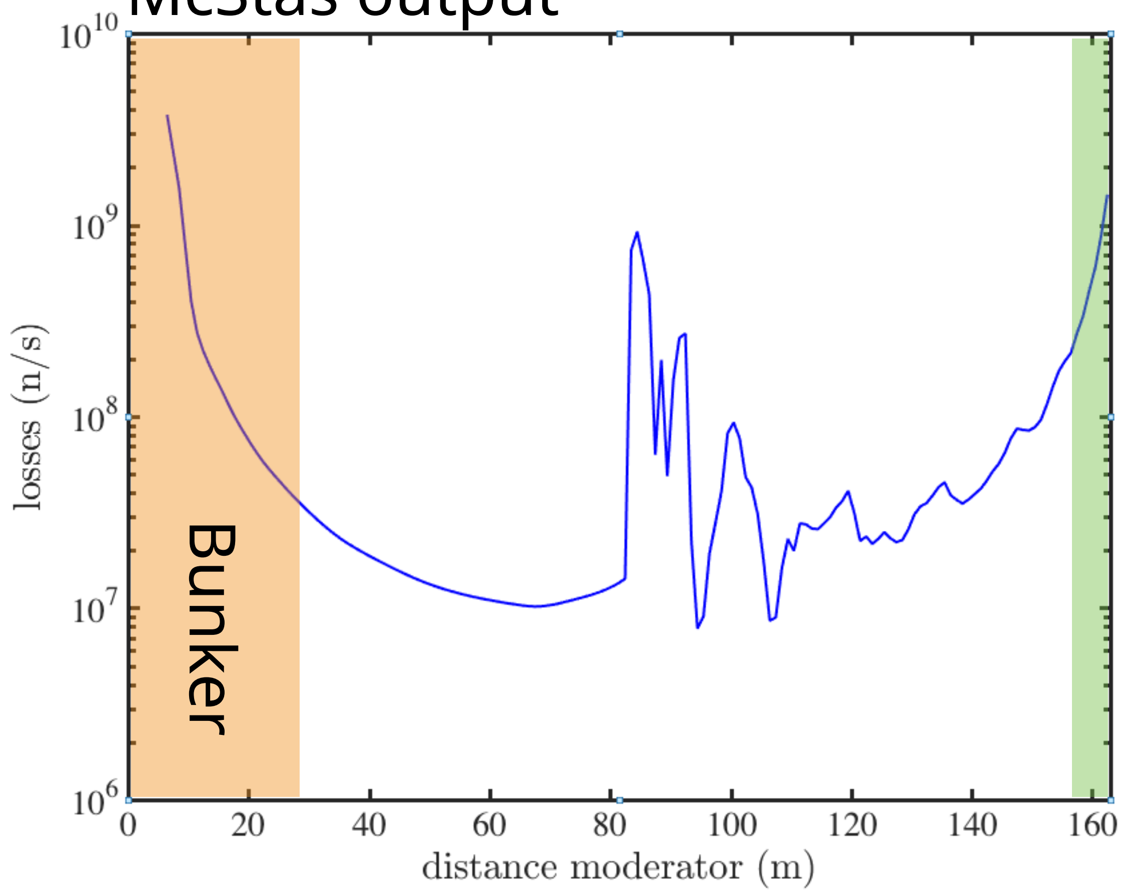
- Boron carbide
- Concrete
- Steel in hotspots

$^{10}B + n_{th} \rightarrow {}^{7}Li^{3+} + {}^{4}He^{2+} + \gamma$ (0.48 MeV)

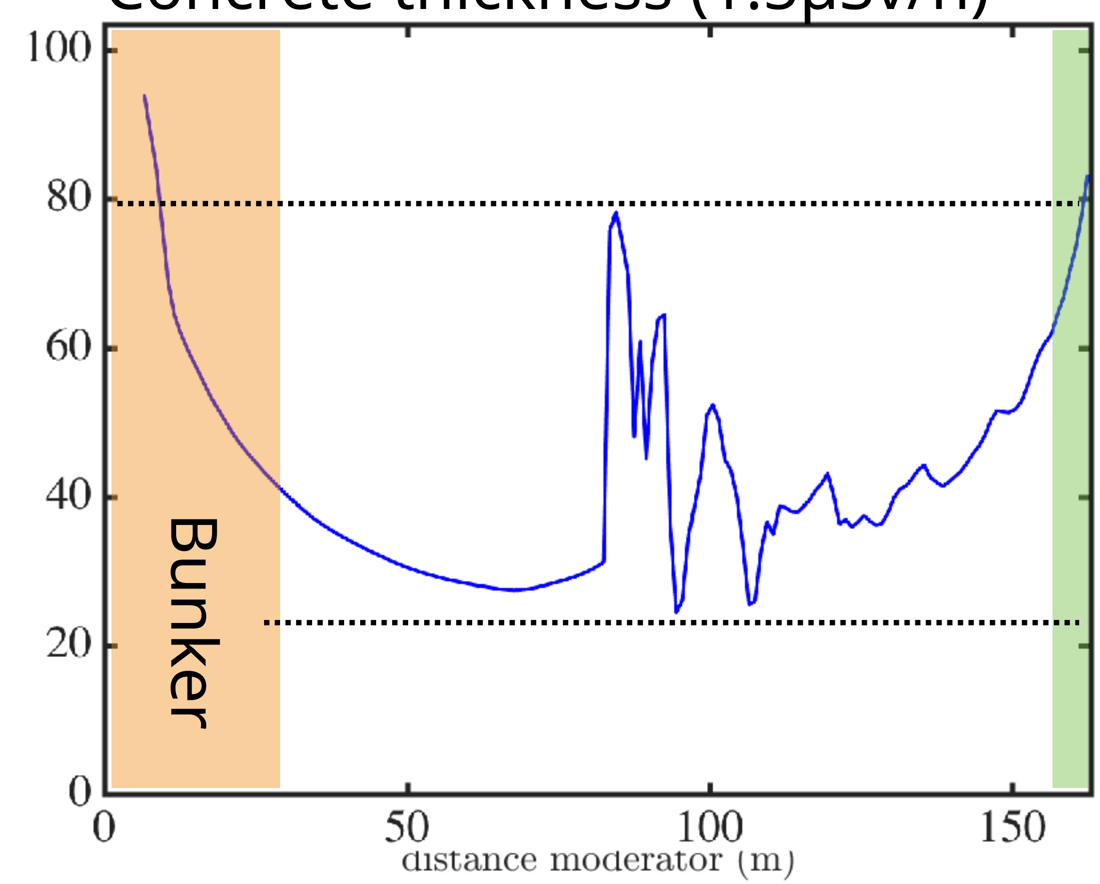
Min. thickness = 25 cm

Max. thickness = 80 cm

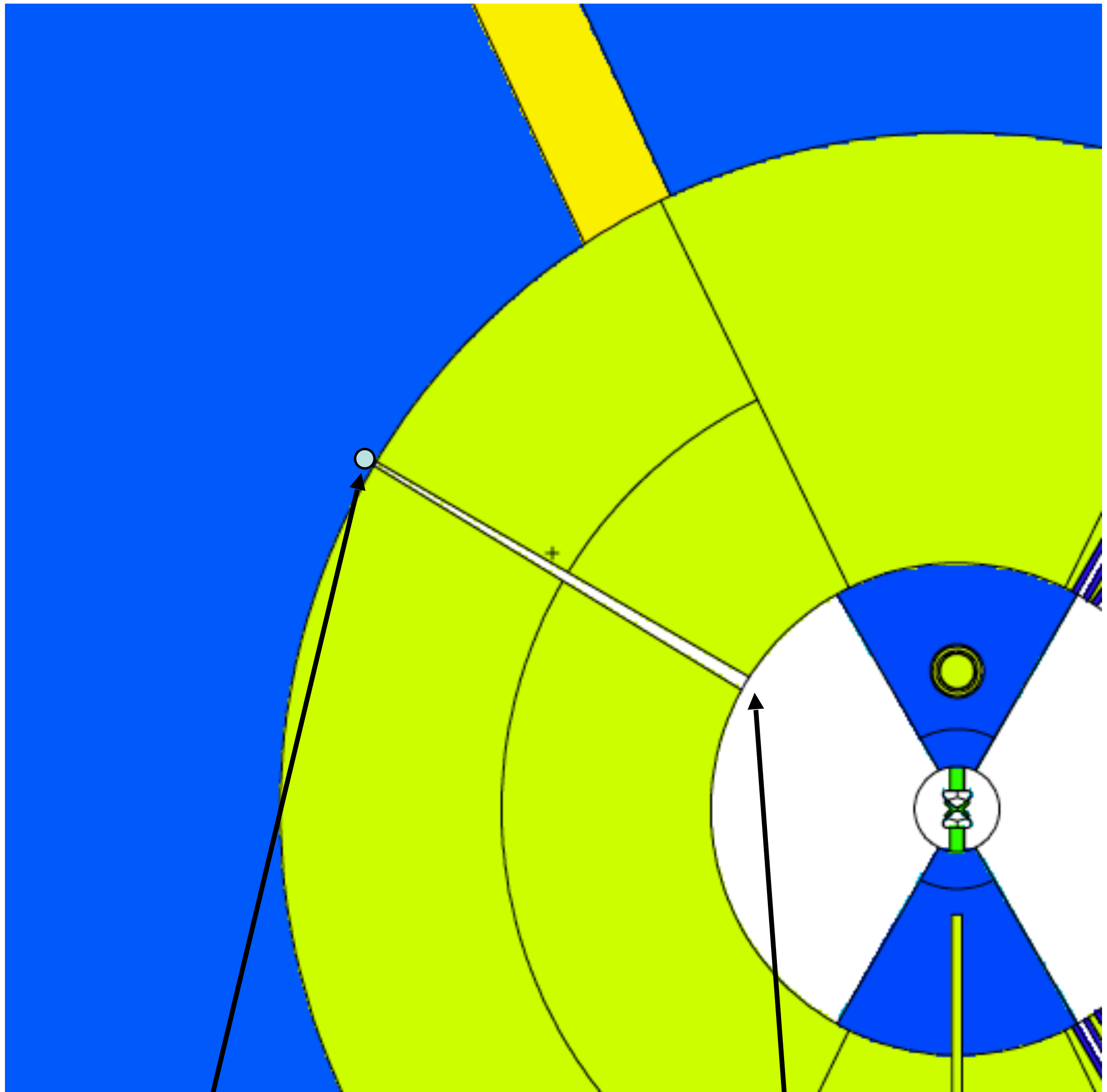
McStas output



Concrete thickness (1.5μSv/h)

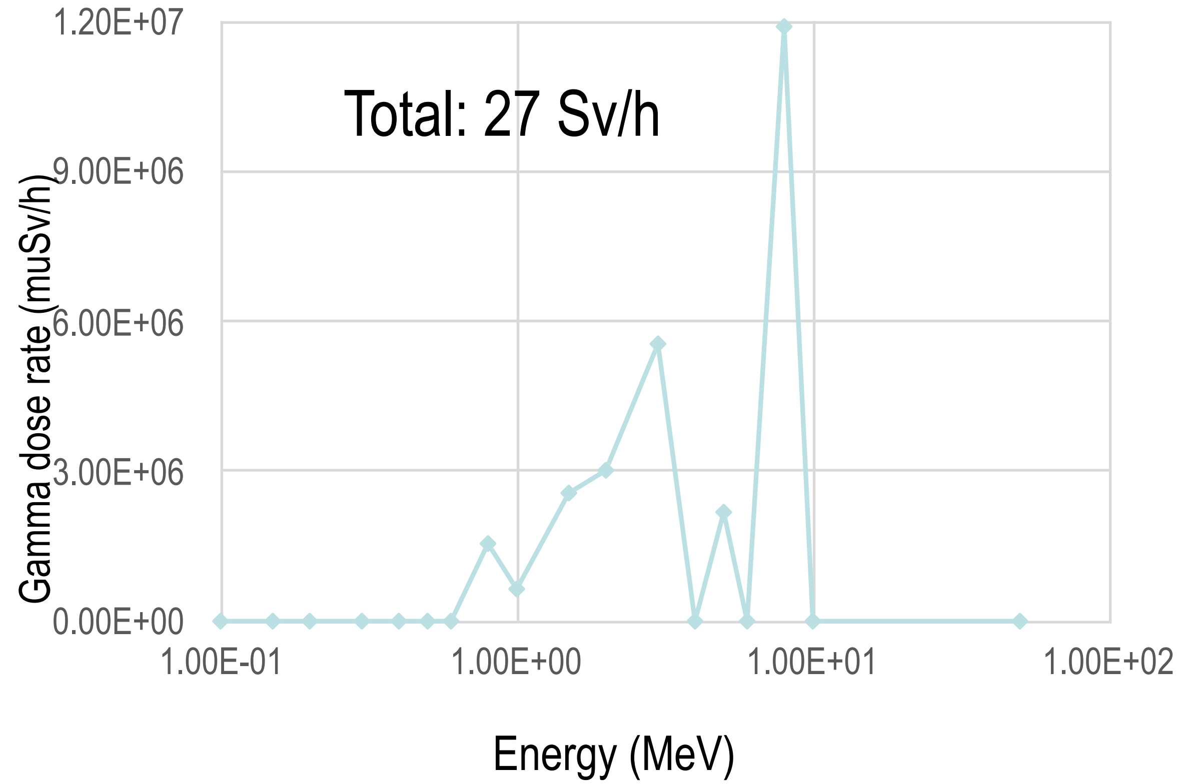


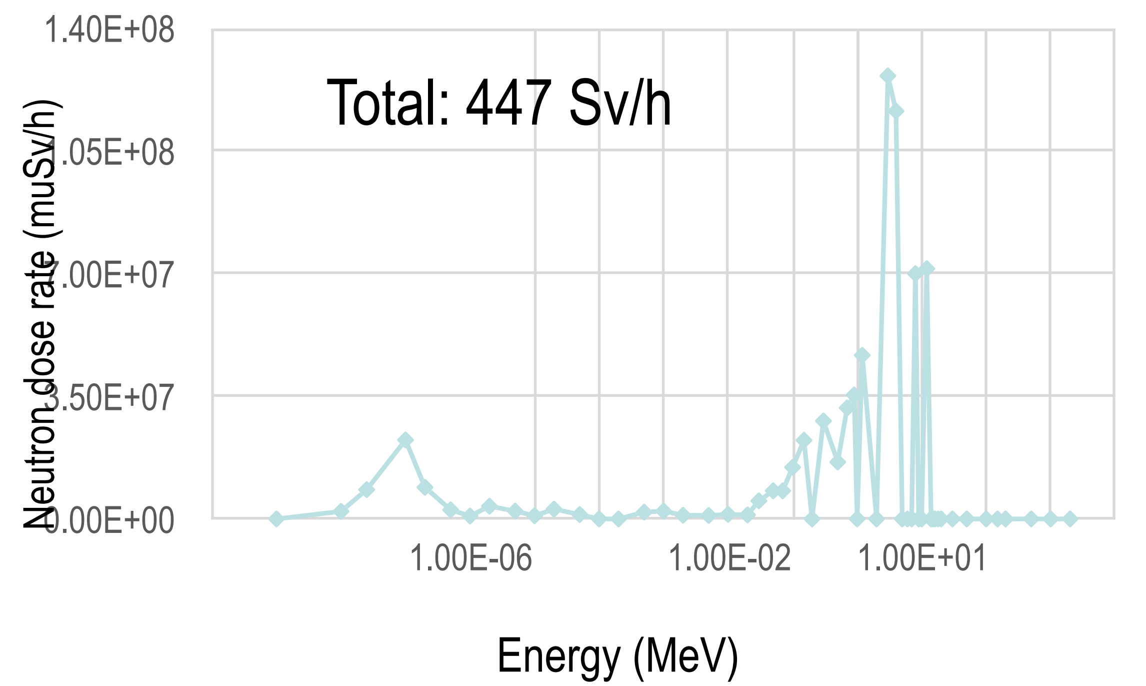
Neutron and prompt gamma dose rates at 5.5m (W6)



W6 – beam entrance 30 mm x 124 mm

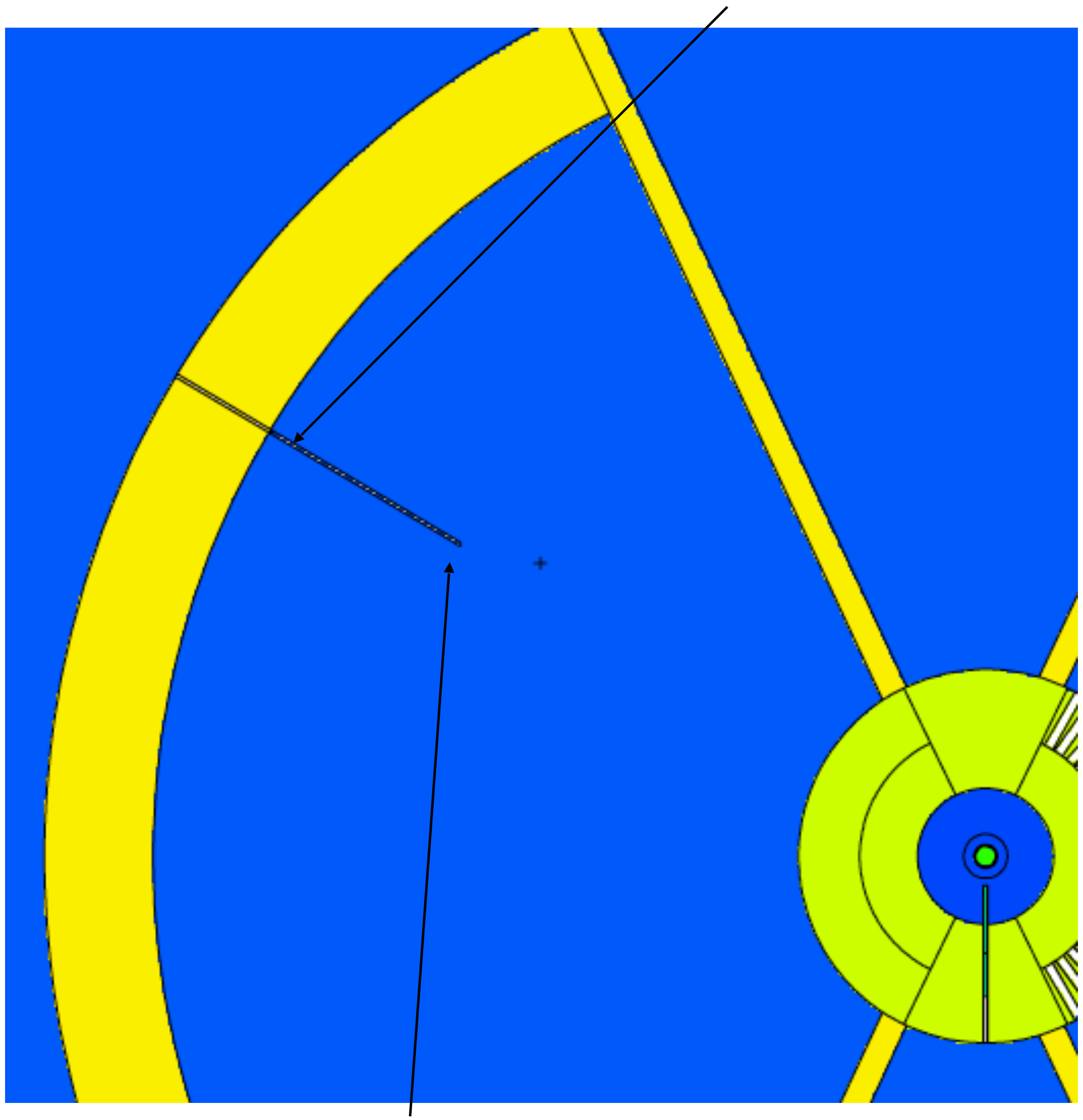
W6 – beam exit 30 mm x 38 mm



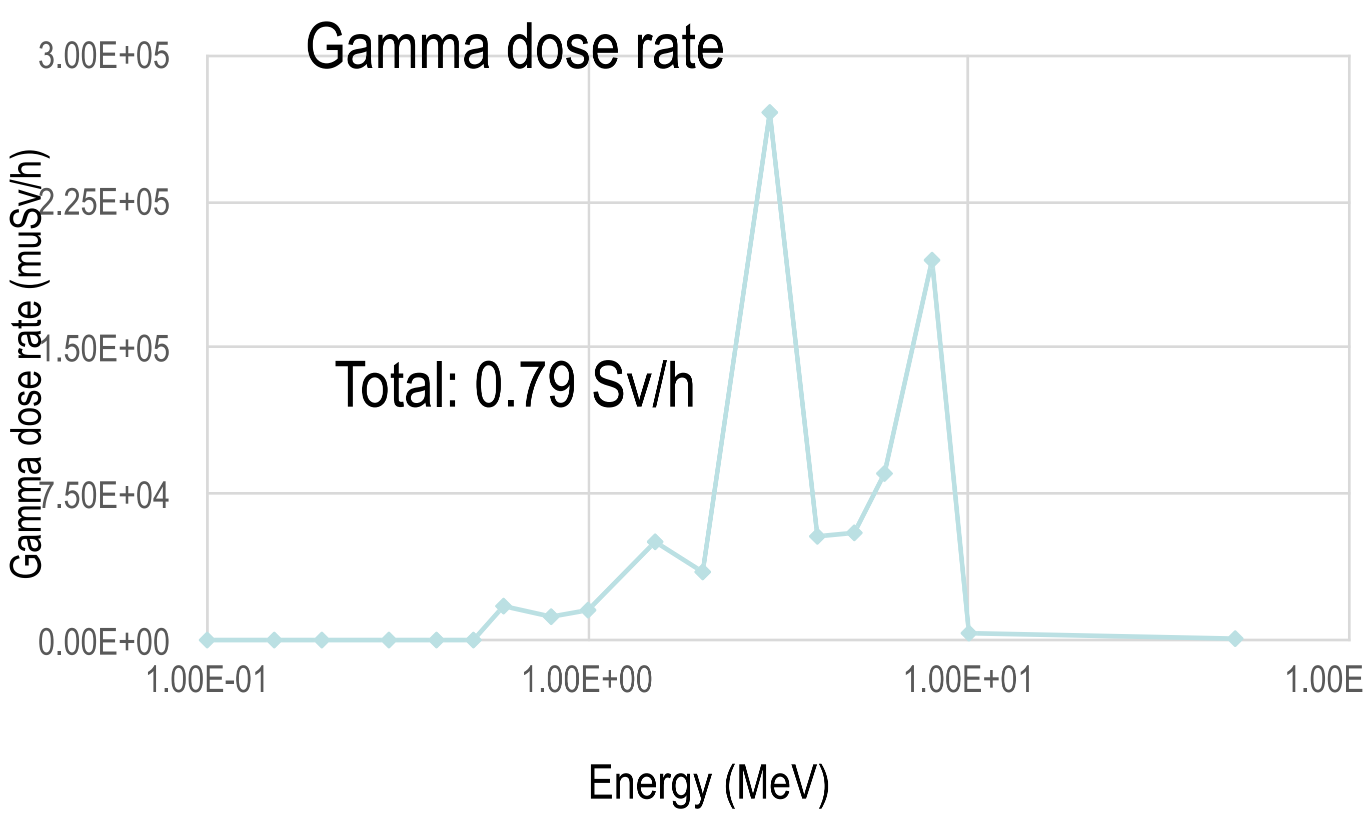


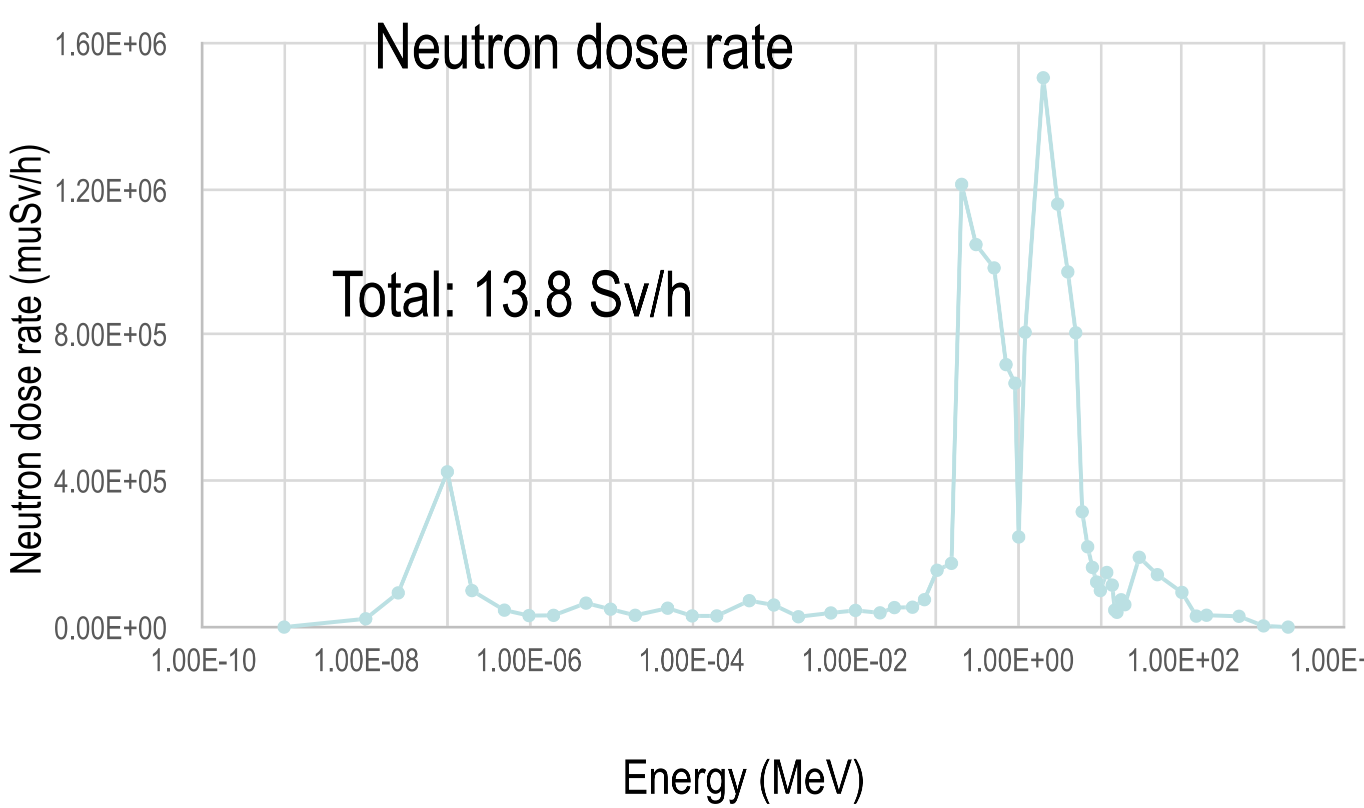
Note: no other beamports are modelled

Neutron and prompt gamma dose rates at 24.5 m (W6)



W6 – vacuum channel 10 cm x 10 cm (0.5 deg tilt)

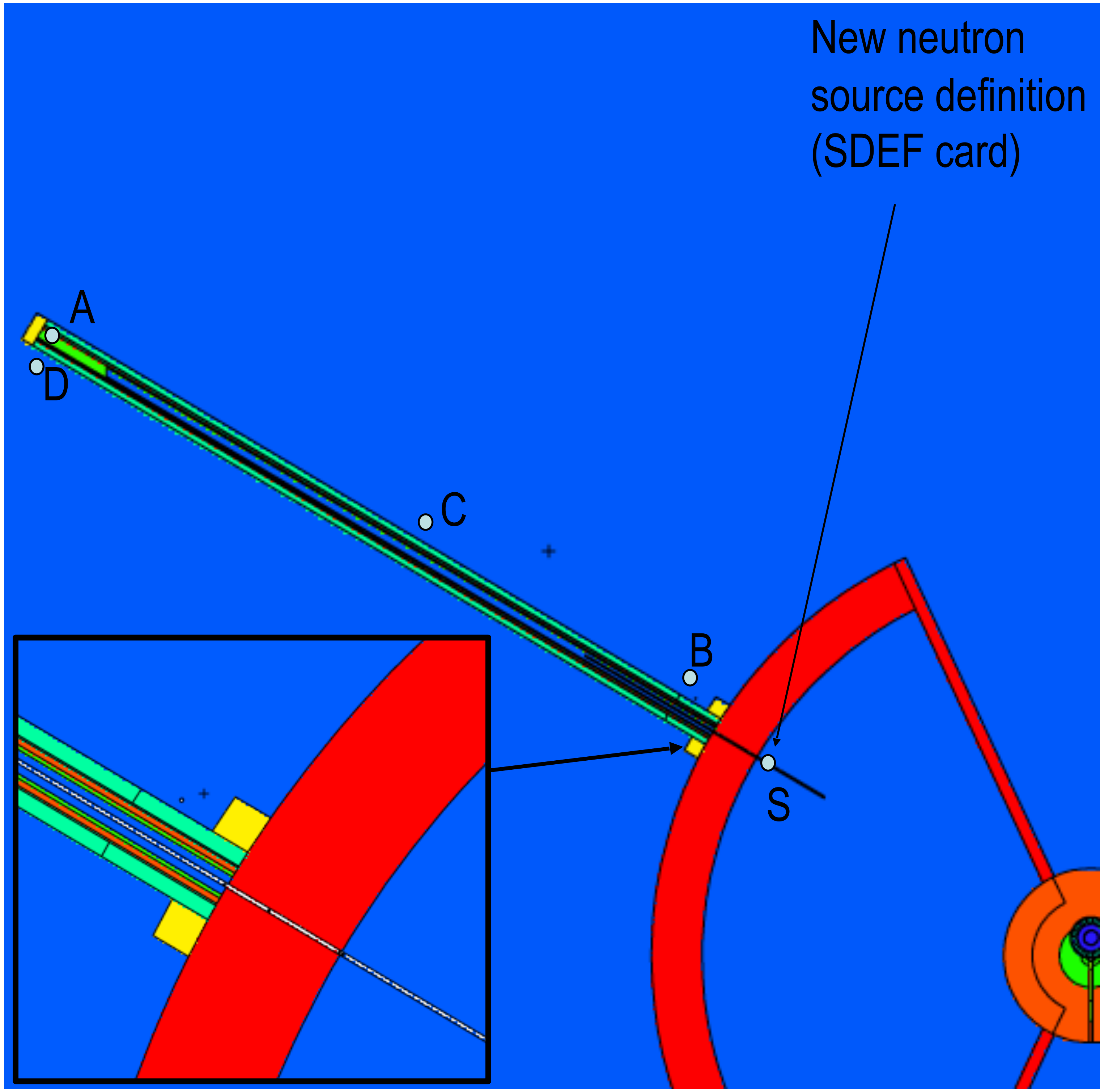




New SDEF-card defined for guide shielding calculations

Neutron dose rates along guide system (W6)

cross section inside shielding: 50 cm x 50cm



Shielding around guide:

10 cm borated concrete
10 cm standard steel
50 cm standard concrete

Source – tally S: 13.8 Sv/h

@77m - tally A: 8.8 mSv/h

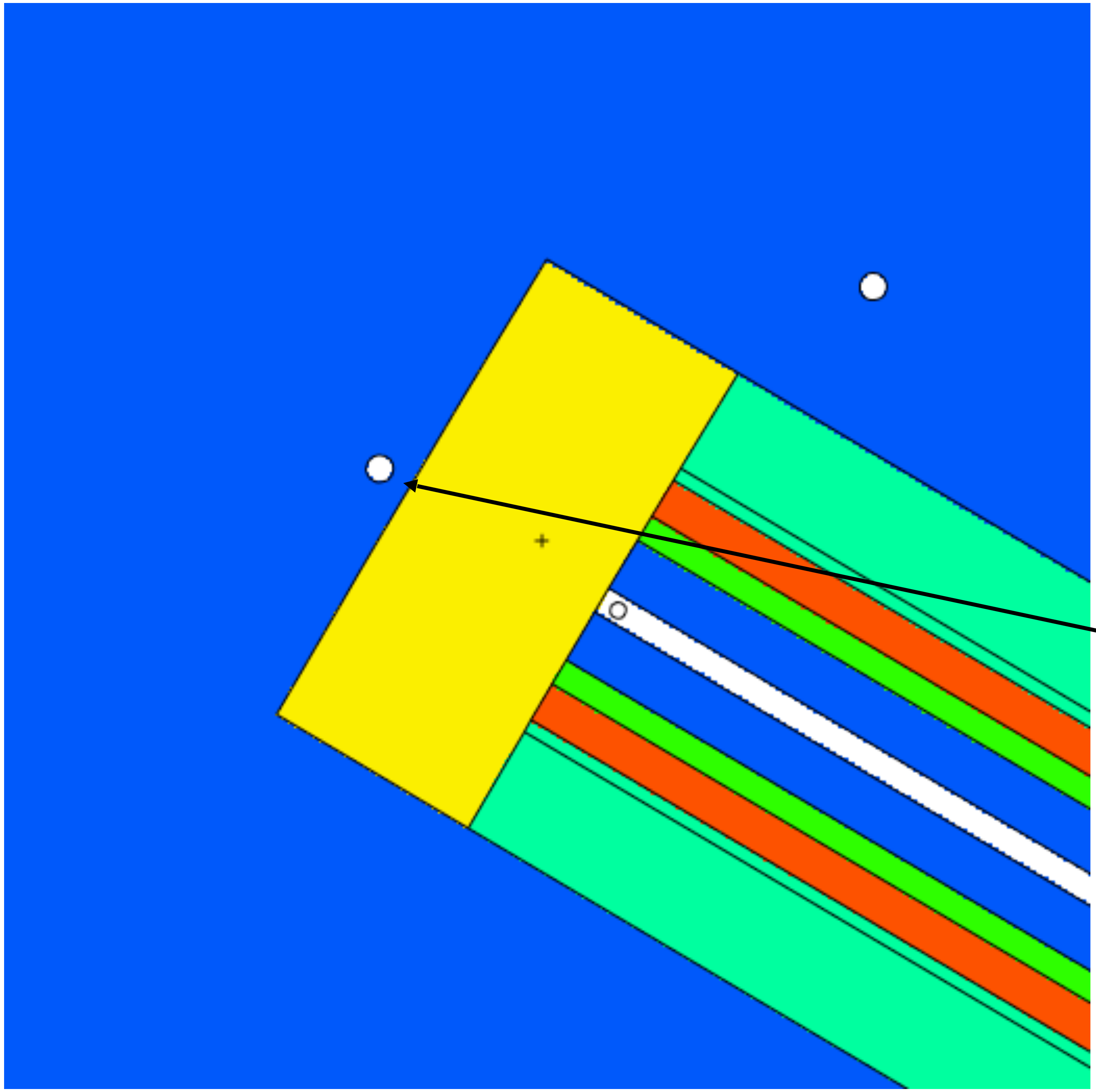
fast neutron flux: 4.7E4 n/cm^2/s

@30m – outside guide shielding
tally B: 3.4 μSv/h

@50m ouside guide shielding
tally C: 1.9 μSv/h

@77m ouside guide shielding
tally D: 1.1 μSv/h

Shielding the direct beam at 77m



Remember:
@77m center of beam: 8.8 mSv/h neutron dose rate

Beam dump consists of 50 cm heavy concrete (4.9 g/cm^3)

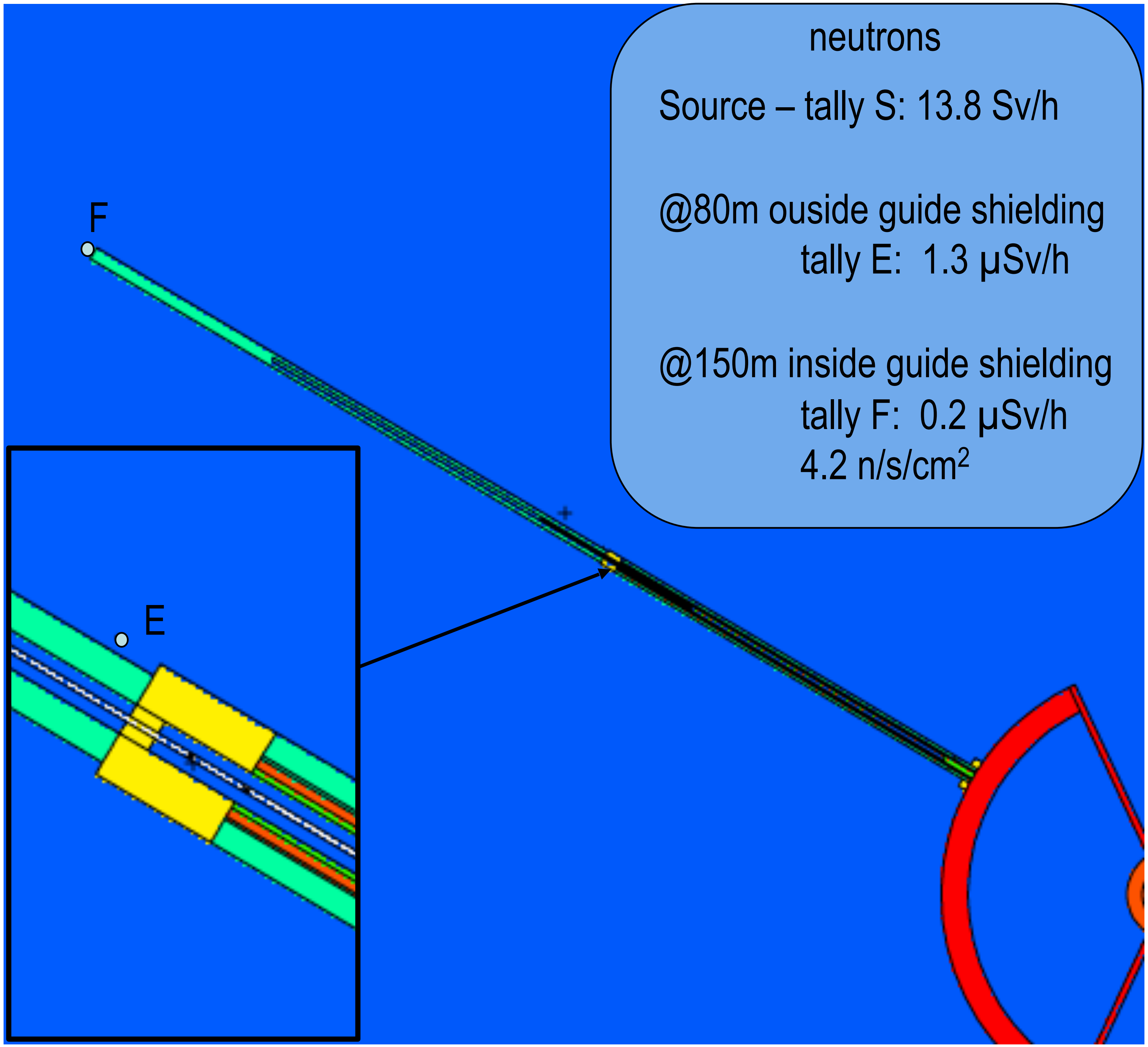
Concrete includes 5 % B_4C

Behind beam dump:
n-dose rate : 1.6 µSv/h
g-dose rate : < 0.1 µSv/h

30 n/s/cm^2

Detector size: d=6 cm

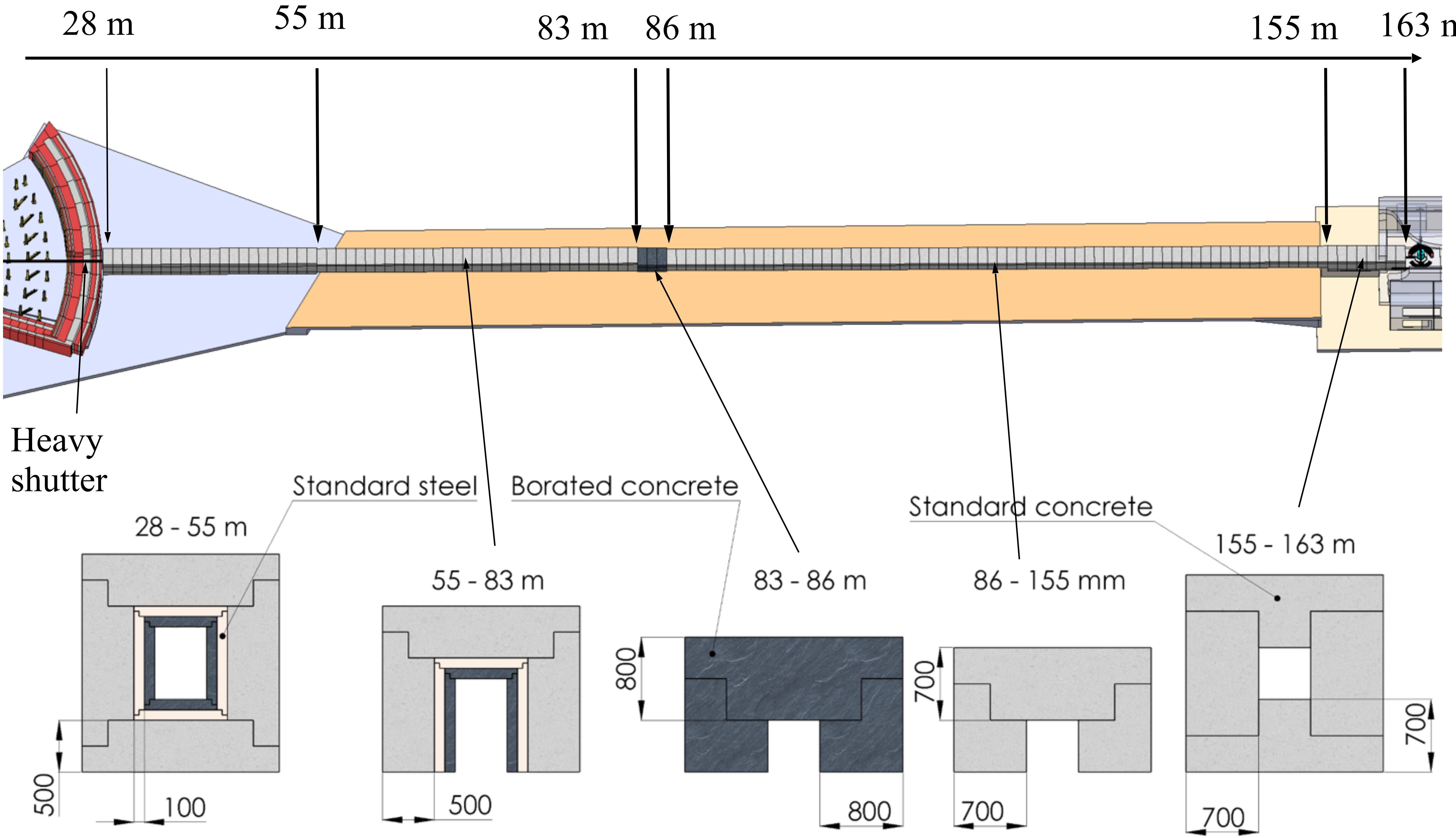
150m Guide Shielding



Shielding around guide behind 77m:

- 2m heavy concrete with vacuum tube belt
- 75m standard concrete (0.5 m thickness)

Shielding design

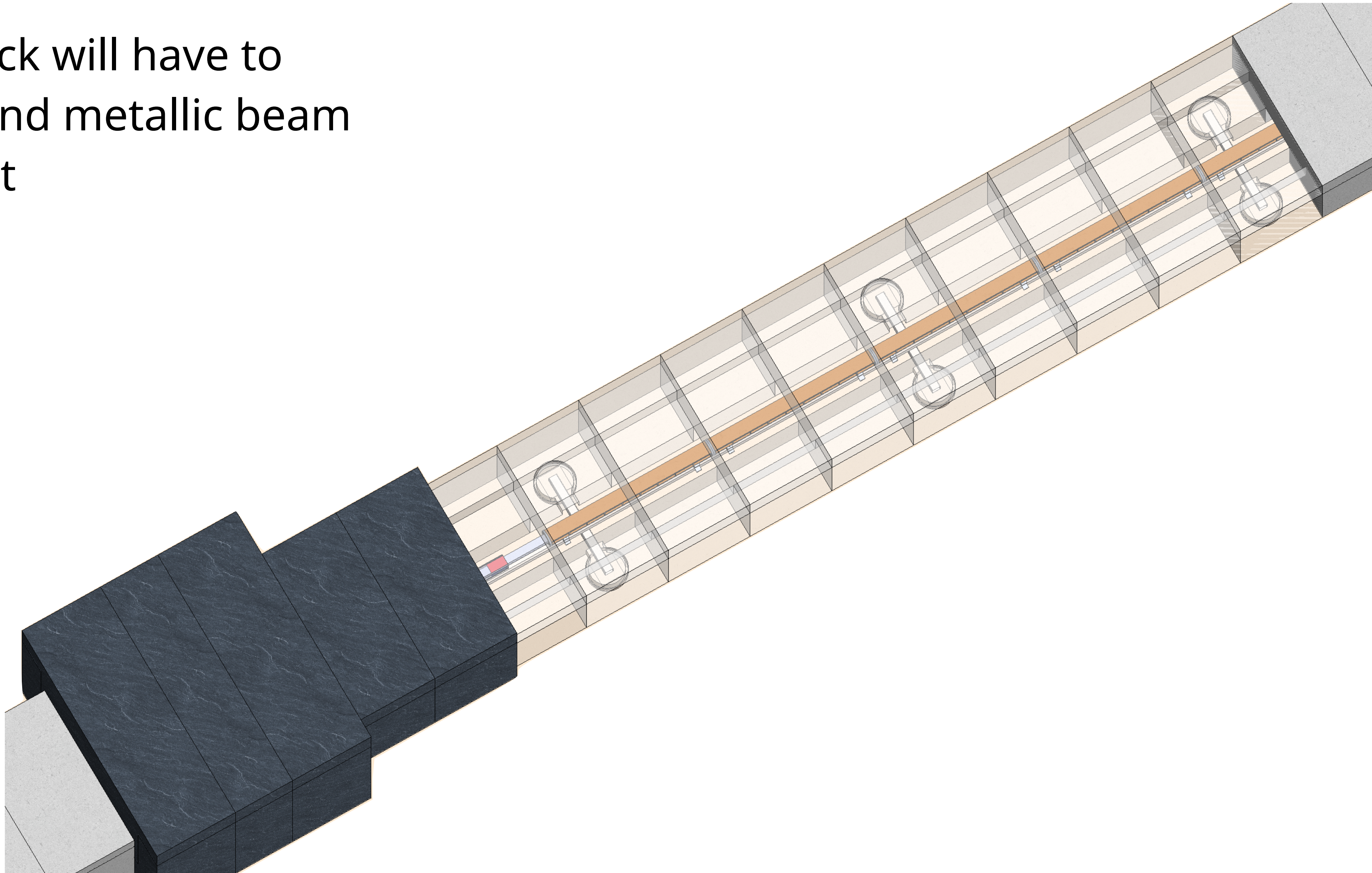


Dealing with pillars

Compact shielding !

Pillars in the guide hall have been cut to 10 cm height

1/4 shielding block will have to enclose a pillar and metallic beam for guide support



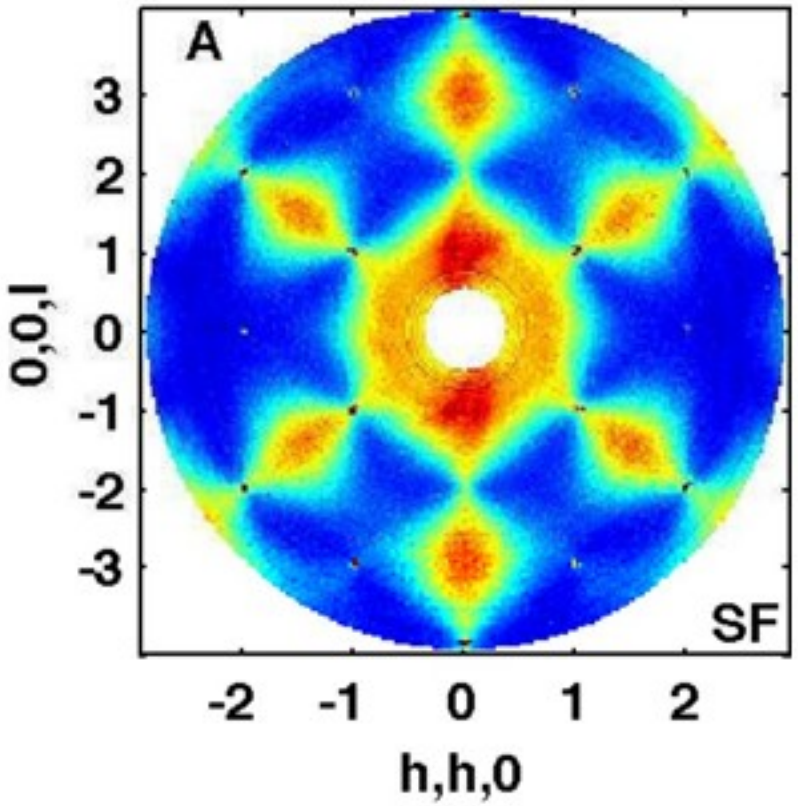
Performance at 2 MW

The full scientific case is covered by the instrument !

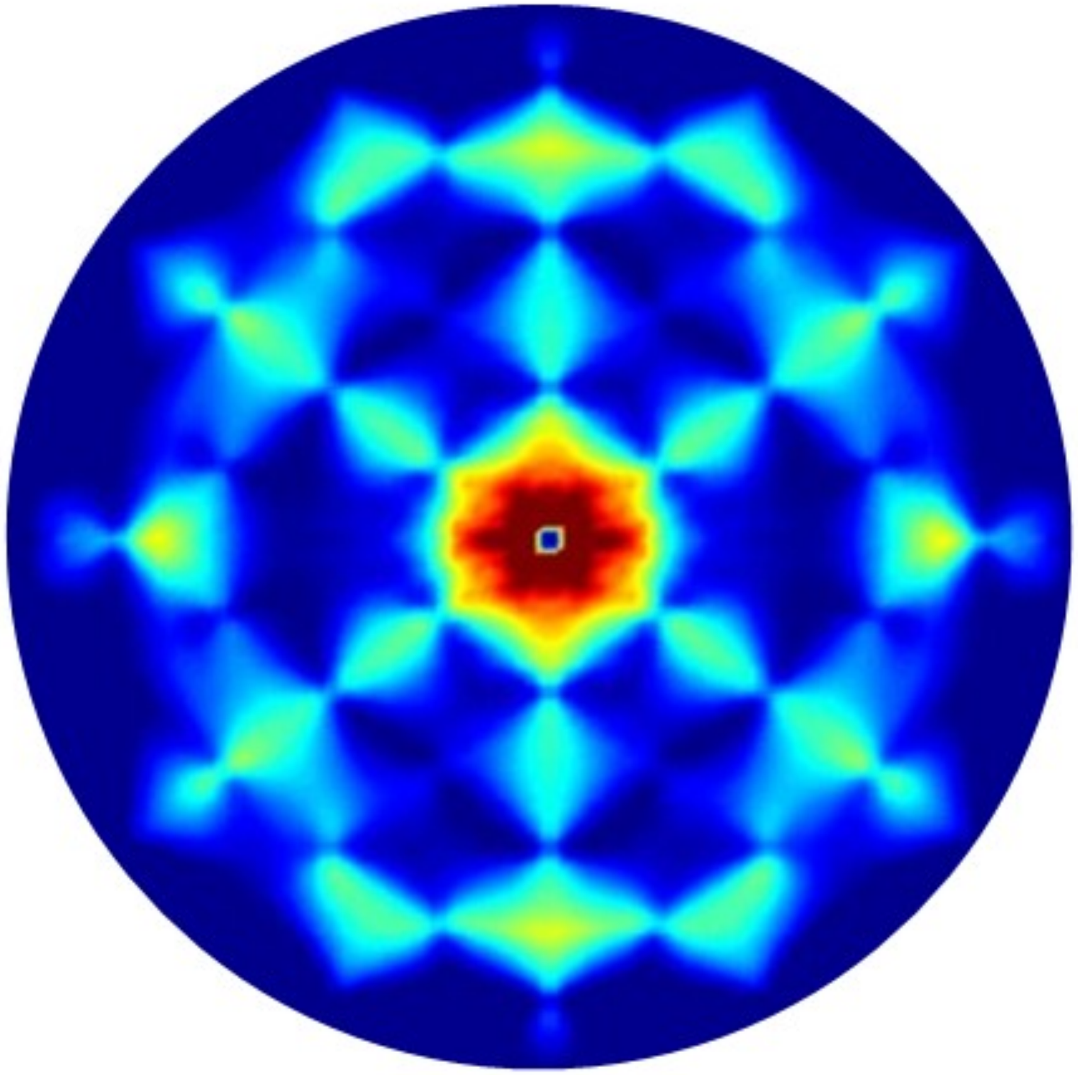
Performance at 2 MW

Polarization analysis

D7: 2.10^{6} n/s/cm^{2}



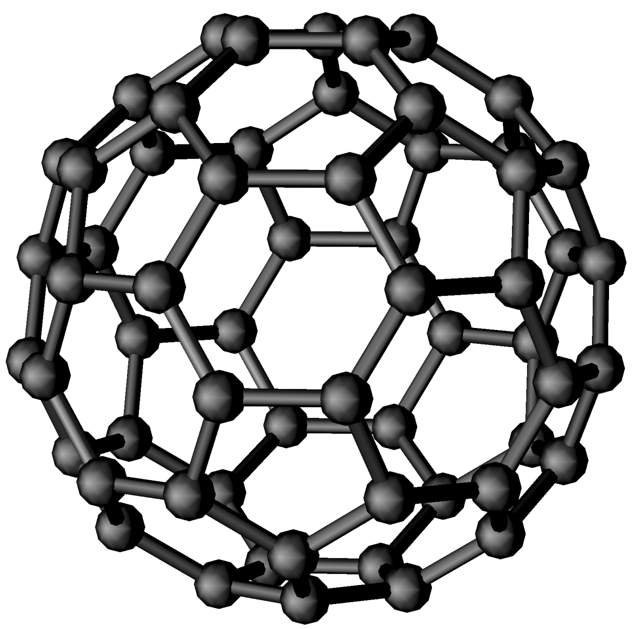
MAGiC: 7.10^{8} n/s/cm^{2}



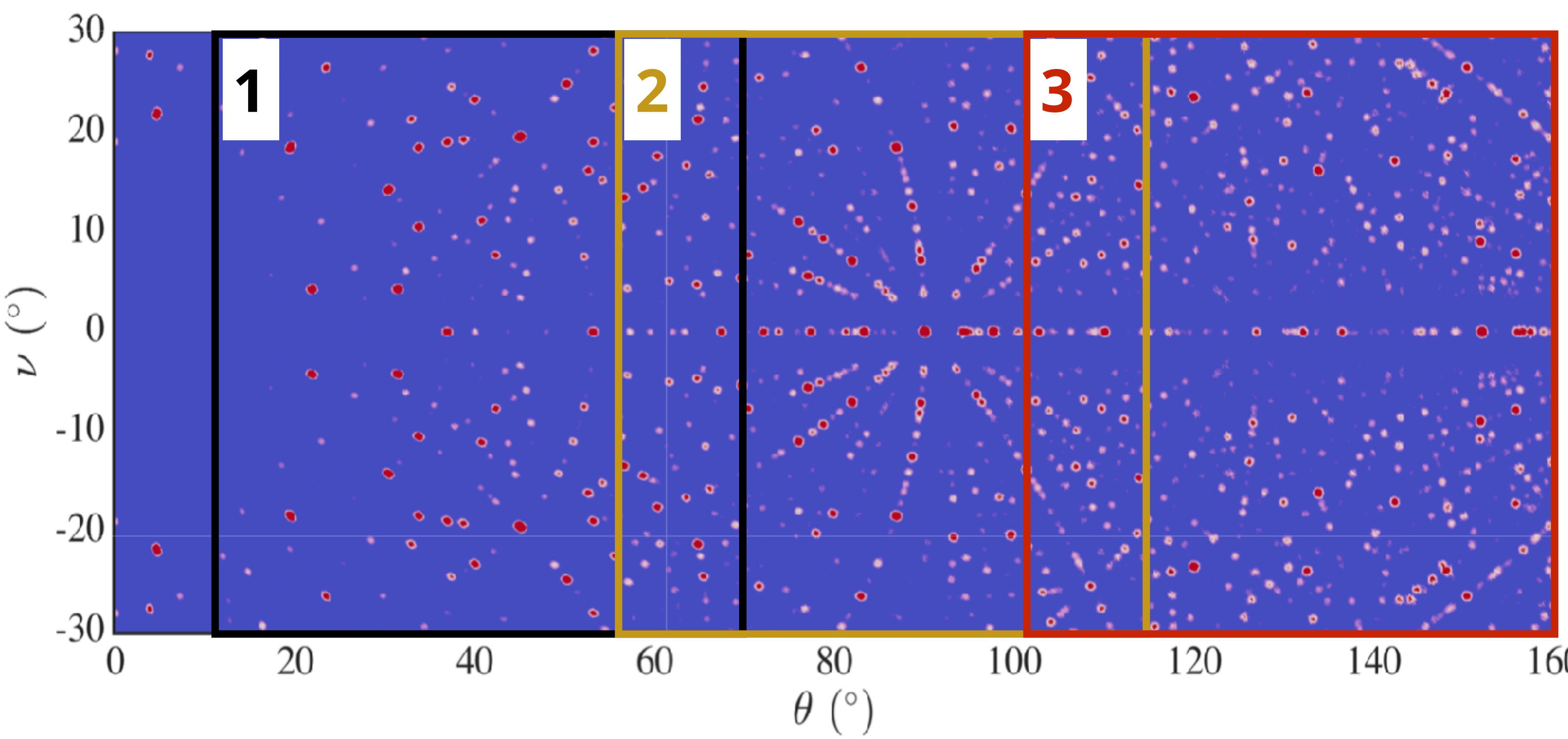
Expected gain: **300**

Performance at 2 MW

Thermal data collection



1 mm^3 sample



30 s per frame
60 frames per data collection

Full data collection ~ 30 mn

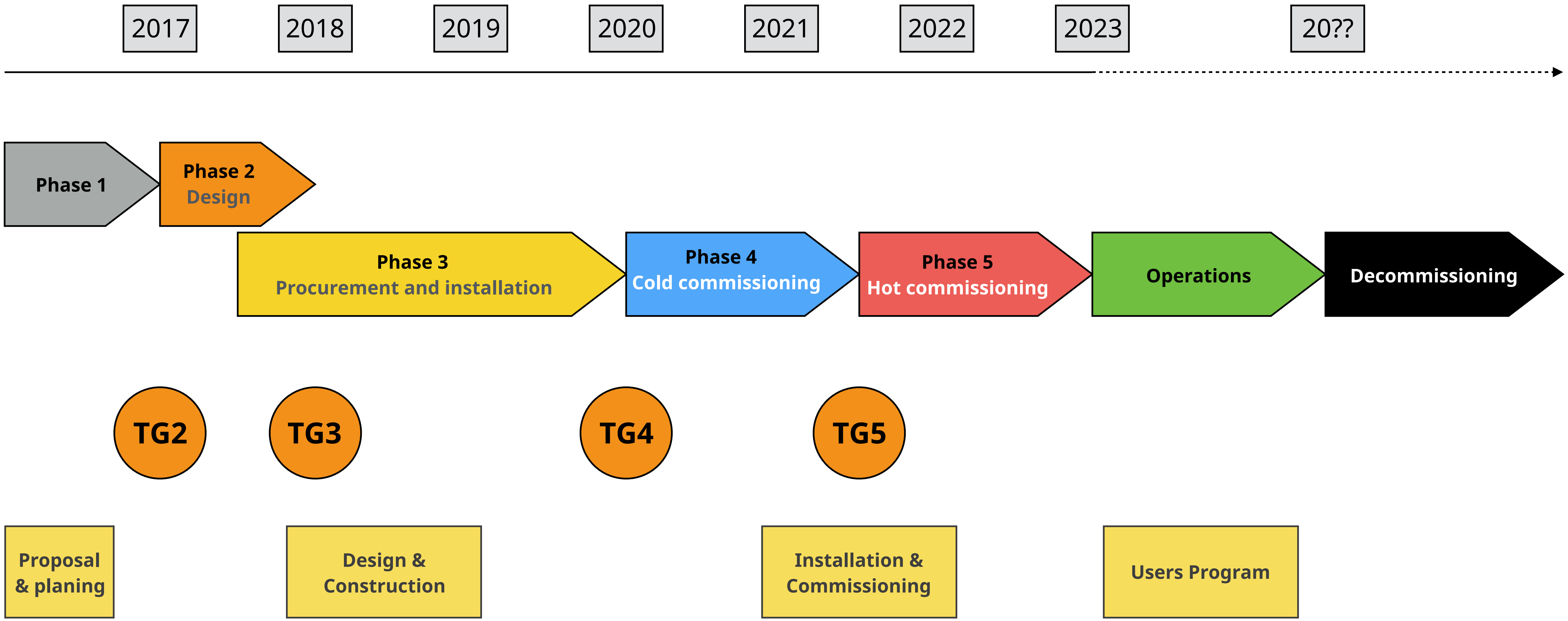
Topaz (SNS) : 12 hours

Expected gain: ~**20**

Instrument budget

	01 Phase 1	02 Phase 2	03 Phase 3	04 Phase 4	Total (k€)
Shielding & Cave					
	0	0	1269	142	**1411**
Neutrons Optics & Polarization					
	0	0	4484	496	**4980**
Choppers					
	0	0	675	75	**750**
Sample Environment					
	0	0	165	20	**185**
Detectors & Beam Monitors					
	0	0	1324	248	**1572**
Data Acquisition and Analysis					
	0	0	0	0	**0**
Motion Control & Automation					
	0	127	152	83	**362**
Instrument Specific Technical Equipment					
	415	439	493	830	**2187**
Instrument Infrastructure					
	0	0	365	140	**505**
Vacuum					
	0	0	0	0	**0**
Contingency					
					1154
Total					
					13103

Instrument lifecycle



Early procurement

Guide system:

- Design has been optimized
- Tendering process will take > 6 months
- Production up to 2 years
- First element to install on the instrument (inside the bunker)

Detectors:

- A first sector of the large detector is mandatory to check performances
- 200 k€ investment

Choppers:

- Pressure on choppers suppliers will be high
- Our concept is well defined and follows the guide design
- 2 years process and needed on day 1 of installation

Questions ?

Remarks ?

Comments ?