11TH INTERNATIONAL WORKSHOP ON RADIATION SAFETY AT SYNCHROTRON RADIATION SOURCES

Shielding Considerations for BEATS beamline (SESAME)

Iyad Zahran*, María-José García-Fusté **, Adli Hamad*

* SESAME synchrotron

** ALBA synchrotron

Introduction

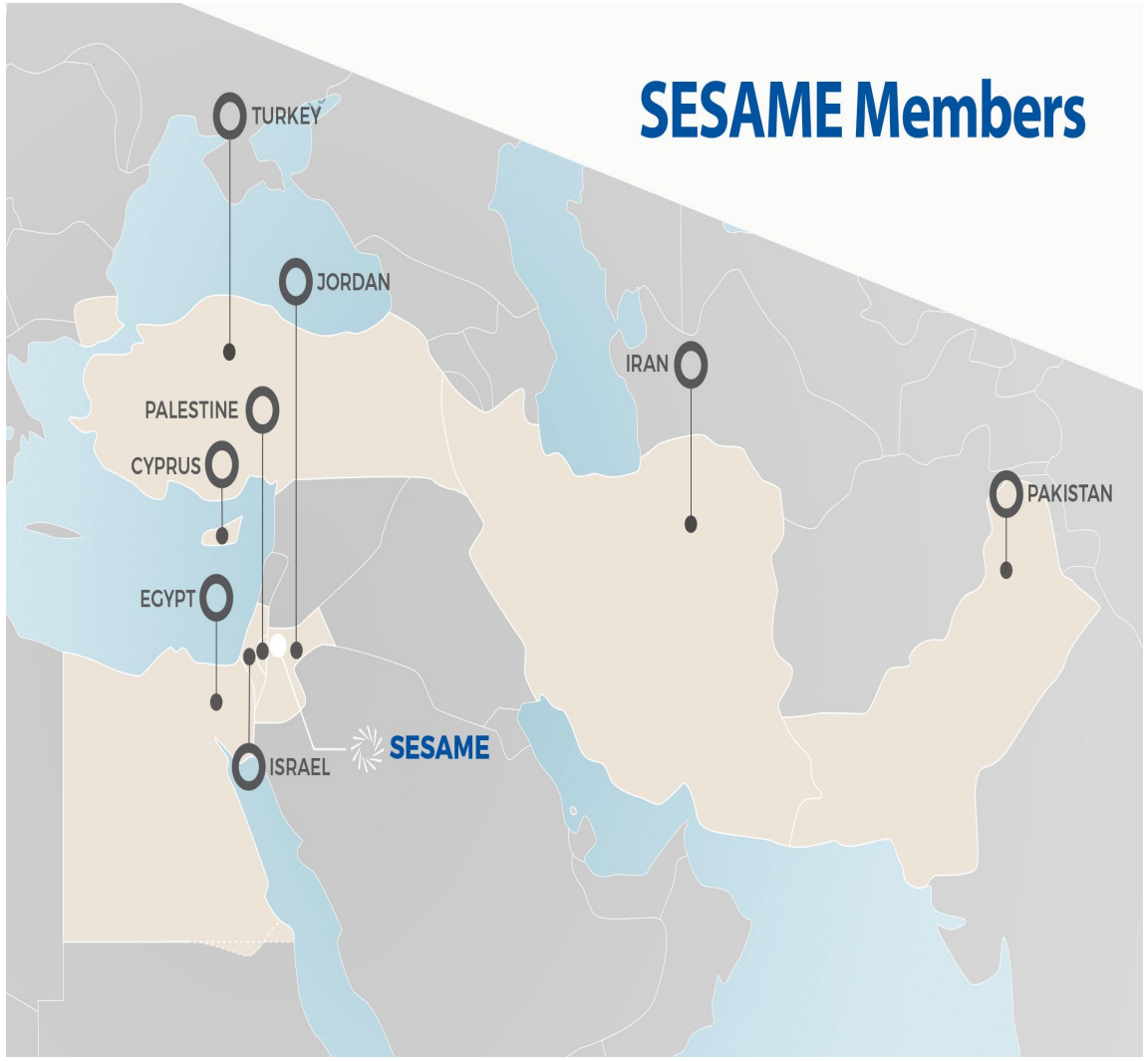
The Synchrotron-Light for Experimental Science and Applications in the Middle East (**SESAME**) is an independent laboratory located in Allan in the Balqa governorate of Jordan, created under the auspices of UNESCO on 30 May 2002.

Solar power plant, which makes SESAME the first accelerator in the world to be powered by renewable energy.

SESAME is composed of:

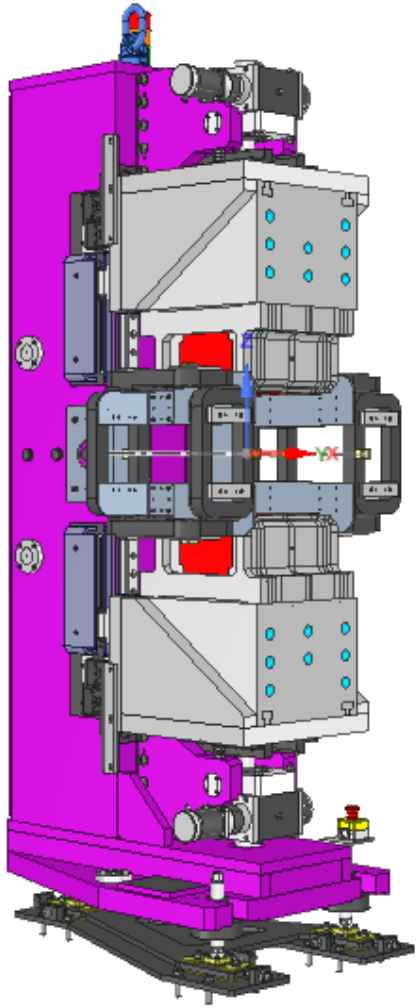
- A 22.5 MeV microtron,
- A 800 MeV booster synchrotron, with a repetition rate of 1 Hz,
- A 2.5 GeV, 400 mA electron storage ring, with a circumference of 133.2 m,
- Beamlines utilizing radiation extracted by the storage ring through bending magnet (BM) and insertion device (ID) sources.

To date, three beamlines are operative at SESAME: IR, XAFS/XRF and Material Science. Two new beamlines dedicated to hard X-ray tomography (BEATS) and soft X-ray spectroscopy HESEB) are under commissioning.



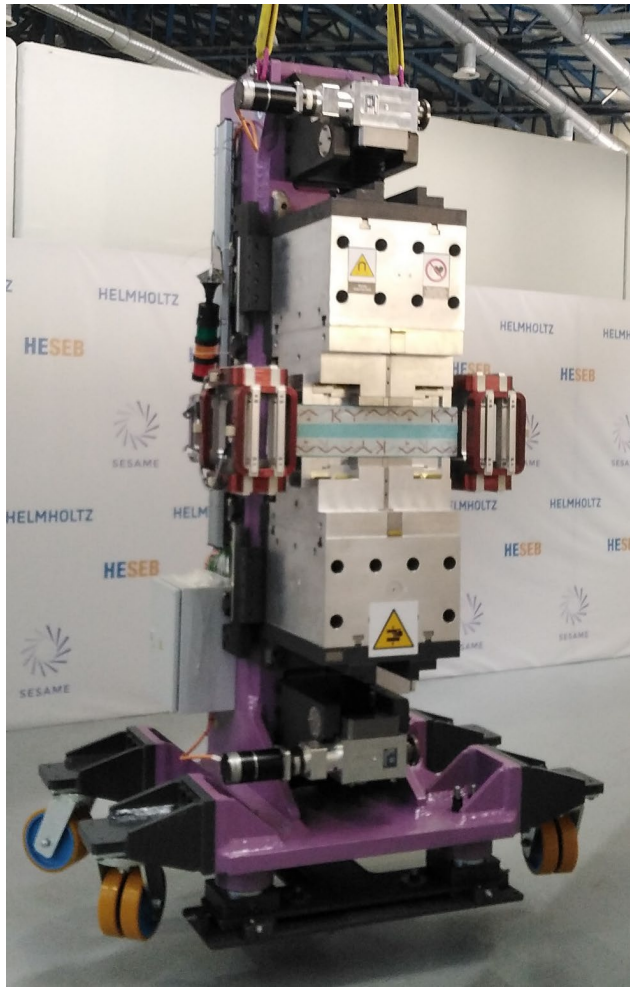
BEATS Beamline

BEATS project has received funding from the EU's H2020 framework programme for research and innovation under grant agreement n°822535.

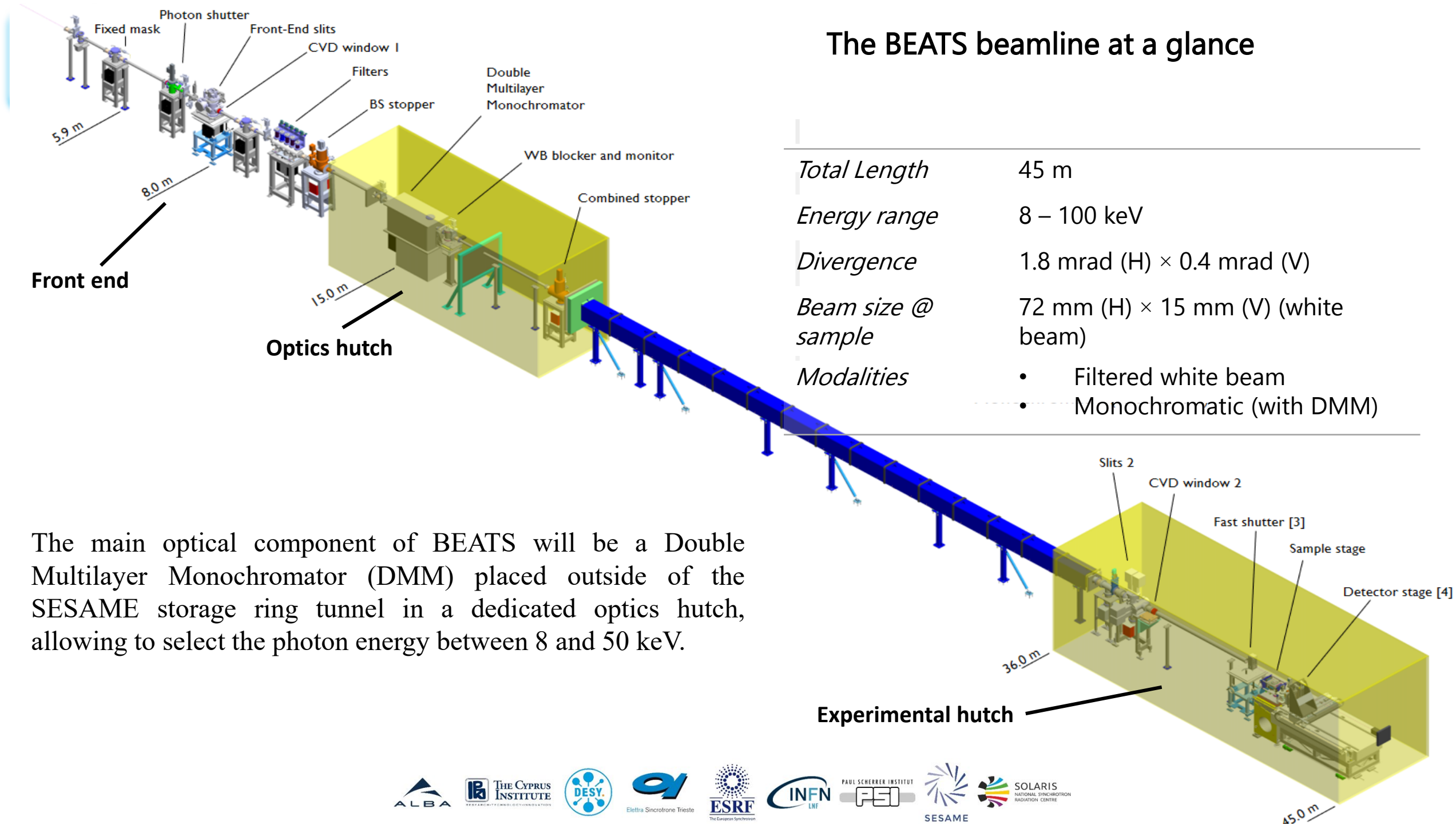


BEATS involves leading research facilities in the Middle East (SESAME and the Cyprus Institute), and European synchrotron radiation facilities ALBA-CELLS (Spain), DESY (Germany), the ESRF (France), Elettra (Italy), INFN (Italy), PSI (Switzerland), SESAME (Jordan) and SOLARIS (Poland).

BEATS beamline has a 3T 3-pole-wiggler as insertion device located on a short straight section of the SESAME storage ring



The BEATS beamline at a glance



Total Length	45 m
Energy range	8 – 100 keV
Divergence	1.8 mrad (H) × 0.4 mrad (V)
Beam size @ sample	72 mm (H) × 15 mm (V) (white beam)
Modalities	• Filtered white beam • Monochromatic (with DMM)

The main optical component of BEATS will be a Double Multilayer Monochromator (DMM) placed outside of the SESAME storage ring tunnel in a dedicated optics hutch, allowing to select the photon energy between 8 and 50 keV.

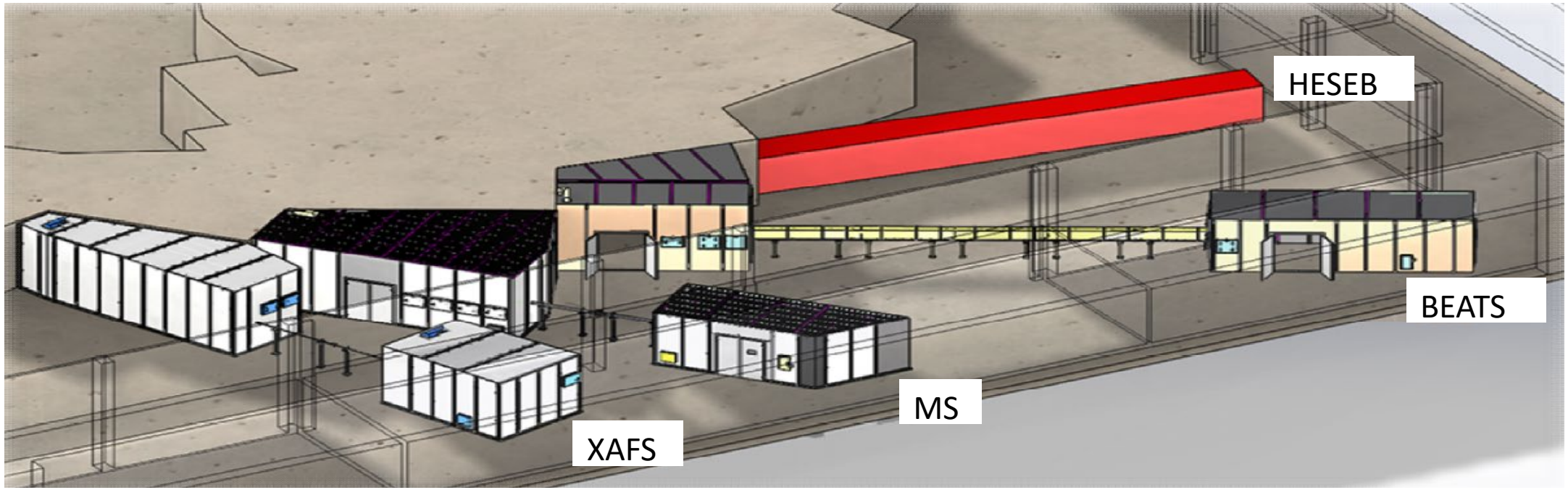
Objective

To describe the results of the shielding calculations made for the BEATS Beamline at SESAME to guarantee public zone levels outside its shielding during operation.

For the public zone level to be reached at SESAME's experimental hall dose rates must be below 0.5 μSv/h, this limit value is established from the dose limit for non-exposed workers, assuming 2000 working hours per year.

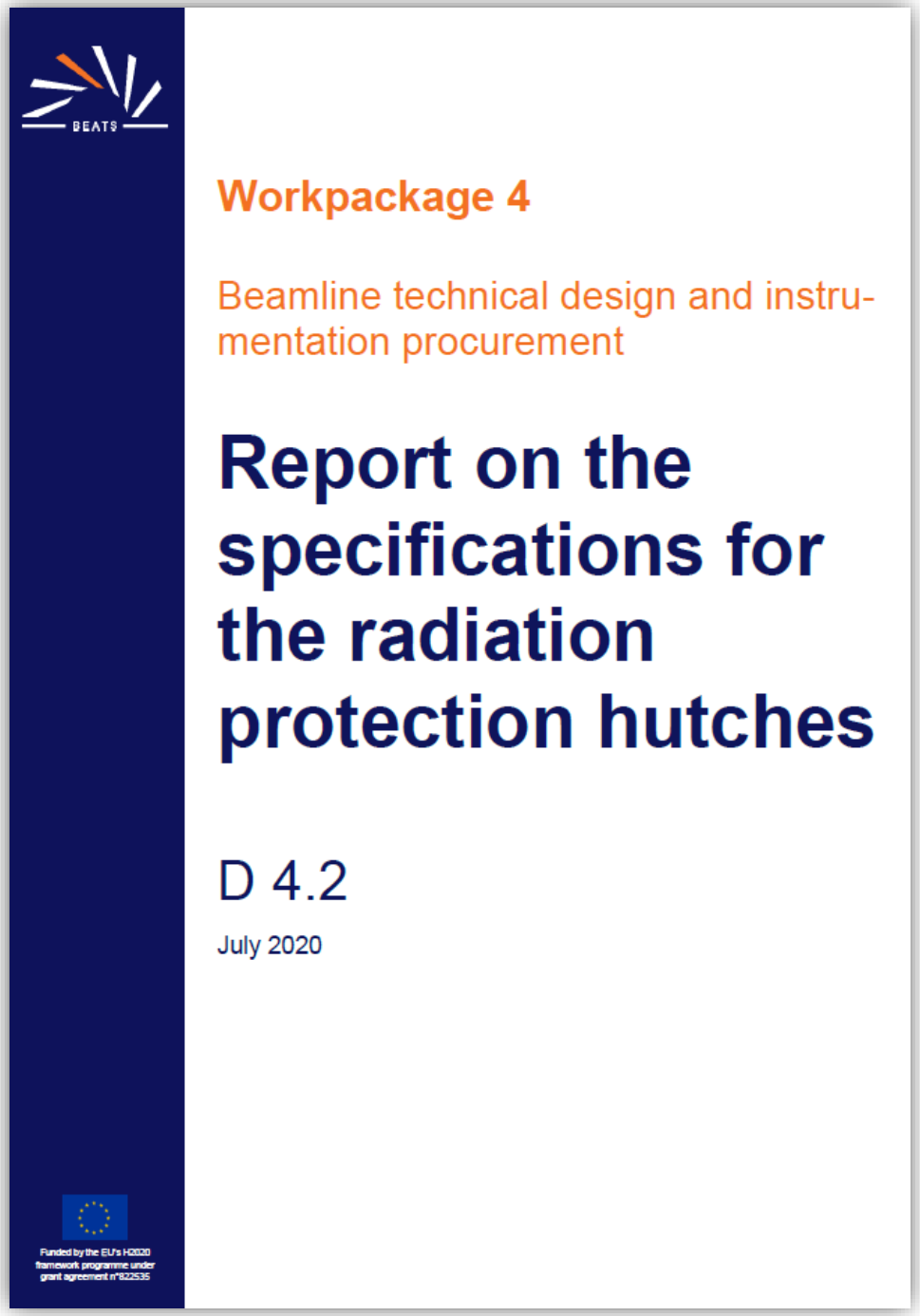
Consequently, the dose rates produced by BEATS shall be near the natural background levels during normal operation conditions.

BEATS will be installed in the Experimental Hall of SESAME.



Reference

- July 2020 (month 19) – Submitted
  María-José García-Fusté (ALBA), safety office (SESAME)
  - Gas bremsstrahlung source calculations
    - White beam or mirrorless operation mode
    - Monochromatic beam operation mode
    - Safety shutter behaviour
    - Transfer line behaviour in a vacuum accident situation
    - Sample environment inside experimental hutch
  - ID source calculations
    - White beam or mirrorless operation mode
    - Monochromatic beam operation mode
    - Transfer line behaviour in a vacuum accident situation
    - Sample environment inside experimental hutch
  - Limiting raytracing -> transfer pipe size; collimators design



Hypothesis for the shielding calculations

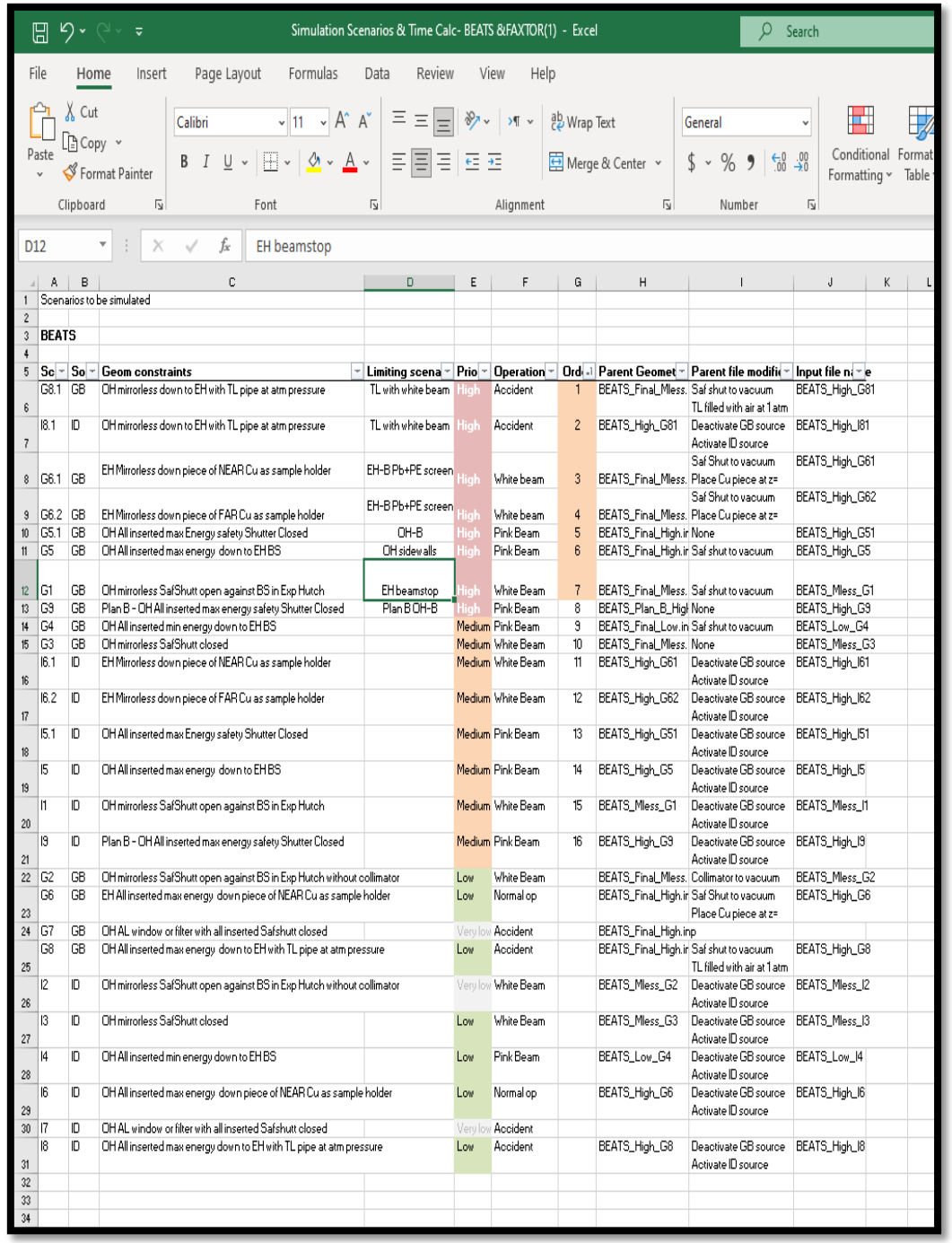
- The calculations were done using FLUKA Monte Carlo code

Following the general methodology in use at other synchrotrons, and in particular at ALBA for this type of shielding calculations ,the following parameters are used for the calculations:

- Electron energy: 2.5 GeV
- Current of the stored beam: 400 mA
- Length of the straight section (dipole to dipole): 5.05 m
- Average pressure in the straight section: 5.0×10^{-9} mbar, with the residual gas composition given in Table (next slide).

All shielding calculations for the BEATS Beamline are performed with an average pressure in the straight section of 5×10^{-9} mbar, and maximum permitted total dose rates outside the shielding below 0.5 μSv/h. This will guarantee that at the design pressure of 1.4×10^{-9} mbar.

The simulations were be run at ALBA cluster.



	A	B	C	D	E	F	G	H	I	J
1	Scenarios to be simulated									
2										
3	BEATS									
4										
5	Sc	So	Geom constraints	Limiting scena	Prio	Operation	Ord	Parent Geomet	Parent file modifi	Input file n
6	G8.1	GB	OH mirrorless down to EH with TL pipe at atm pressure	TL with white beam	High	Accident	1	BEATS_Final_Mless.	Saf shut to vacuum TL filled with air at 1 atm	BEATS_High_G81
7	I8.1	ID	OH mirrorless down to EH with TL pipe at atm pressure	TL with white beam	High	Accident	2	BEATS_High_G81	Deactivate GB source Activate ID source	BEATS_High_I81
8	G6.1	GB	EH Mirrorless down piece of NEAR Cu as sample holder	EH-B Pb+PE screen	High	White beam	3	BEATS_Final_Mless.	Saf Shut to vacuum Place Cu piece at z=	BEATS_High_G61
9	G6.2	GB	EH Mirrorless down piece of FAR Cu as sample holder	EH-B Pb+PE screen	High	White beam	4	BEATS_Final_Mless.	Saf Shut to vacuum Place Cu piece at z=	BEATS_High_G62
10	G5.1	GB	OH All inserted max Energy safety Shutter Closed	OH-B	High	Pink Beam	5	BEATS_Final_High.ir	None	BEATS_High_G51
11	G5	GB	OH All inserted max energy down to EH BS	OH sidewalls	High	Pink Beam	6	BEATS_Final_High.ir	Saf shut to vacuum	BEATS_High_G5
12	G1	GB	OH mirrorless SafShutt open against BS in Exp Hutch	EH beamstop	High	White Beam	7	BEATS_Final_Mless.	Saf shut to vacuum	BEATS_Mless_G1
13	G9	GB	Plan B - OH All inserted max energy safety Shutter Closed	Plan B OH-B	High	Pink Beam	8	BEATS_Plan_B_High	None	BEATS_High_G9
14	G4	GB	OH All inserted min energy down to EH BS		Medium	Pink Beam	9	BEATS_Final_Low.in	Saf shut to vacuum	BEATS_Low_G4
15	G3	GB	OH mirrorless SafShutt closed		Medium	White Beam	10	BEATS_Final_Mless.	None	BEATS_Mless_G3
16	I6.1	ID	EH Mirrorless down piece of NEAR Cu as sample holder		Medium	White Beam	11	BEATS_High_G61	Deactivate GB source Activate ID source	BEATS_High_I61
17	I6.2	ID	EH Mirrorless down piece of FAR Cu as sample holder		Medium	White Beam	12	BEATS_High_G62	Deactivate GB source Activate ID source	BEATS_High_I62
18	I5.1	ID	OH All inserted max Energy safety Shutter Closed		Medium	Pink Beam	13	BEATS_High_G51	Deactivate GB source Activate ID source	BEATS_High_I51
19	I5	ID	OH All inserted max energy down to EH BS		Medium	Pink Beam	14	BEATS_High_G5	Deactivate GB source Activate ID source	BEATS_High_I5
20	I1	ID	OH mirrorless SafShutt open against BS in Exp Hutch		Medium	White Beam	15	BEATS_Mless_G1	Deactivate GB source Activate ID source	BEATS_Mless_I1
21	I9	ID	Plan B - OH All inserted max energy safety Shutter Closed		Medium	Pink Beam	16	BEATS_High_G9	Deactivate GB source Activate ID source	BEATS_High_I9
22	G2	GB	OH mirrorless SafShutt open against BS in Exp Hutch without collimator		Low	White Beam		BEATS_Final_Mless.	Collimator to vacuum	BEATS_Mless_G2
23	G6	GB	EH All inserted max energy down piece of NEAR Cu as sample holder		Low	Normal op		BEATS_Final_High.ir	Saf Shut to vacuum Place Cu piece at z=	BEATS_High_G6
24	G7	GB	OH AL window or filter with all inserted Safshutt closed		Very low	Accident		BEATS_Final_High.inp		
25	G8	GB	OH All inserted max energy down to EH with TL pipe at atm pressure		Low	Accident		BEATS_Final_High.ir	Saf shut to vacuum TL filled with air at 1 atm	BEATS_High_G8
26	I2	ID	OH mirrorless SafShutt open against BS in Exp Hutch without collimator		Very low	White Beam		BEATS_Mless_G2	Deactivate GB source Activate ID source	BEATS_Mless_I2
27	I3	ID	OH mirrorless SafShutt closed		Low	White Beam		BEATS_Mless_G3	Deactivate GB source Activate ID source	BEATS_Mless_I3
28	I4	ID	OH All inserted min energy down to EH BS		Low	Pink Beam		BEATS_Low_G4	Deactivate GB source Activate ID source	BEATS_Low_I4
29	I6	ID	OH All inserted max energy down piece of NEAR Cu as sample holder		Low	Normal op		BEATS_High_G6	Deactivate GB source Activate ID source	BEATS_High_I6
30	I7	ID	OH AL window or filter with all inserted Safshutt closed		Very low	Accident				
31	I8	ID	OH All inserted max energy down to EH with TL pipe at atm pressure		Low	Accident		BEATS_High_G8	Deactivate GB source Activate ID source	BEATS_High_I8
32										
33										
34										

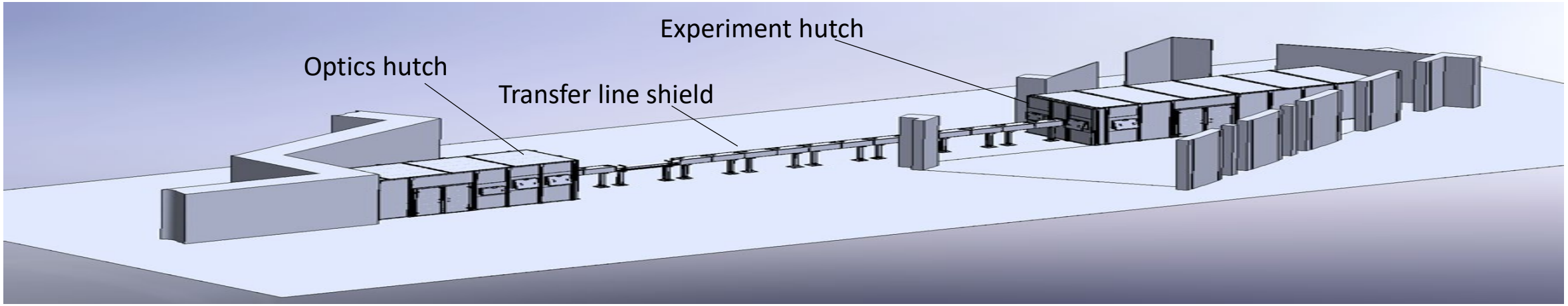
Shielding estimations from ALBA hard X-ray Beamlines

BEATS is similar from a radiological point of view to other hard X-ray Beamlines designed and installed at ALBA, and particularly similar to FaXtor, ALBA's tomography beamline,

The parameters of ALBA's storage ring and vacuum are basically equivalent to those of SESAME. These facts allow the establishment of shielding requirements estimations making use of ALBA's prior designs and experience.

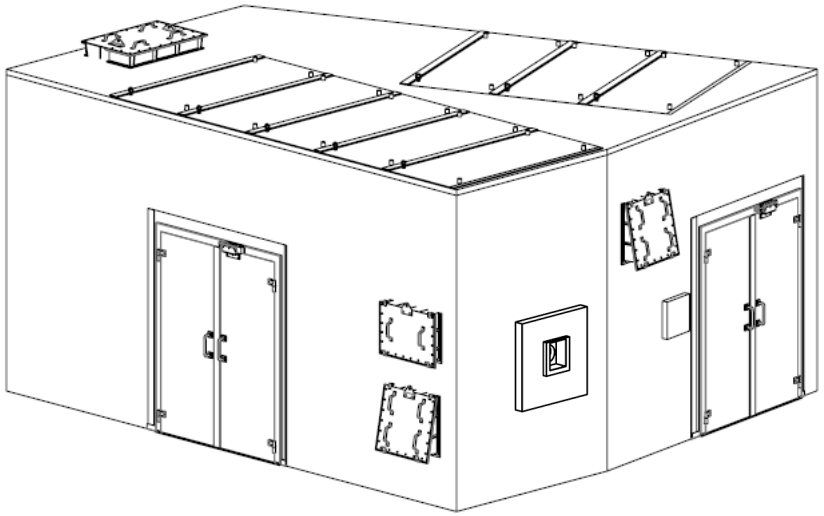
Molecule	Relative pressure (%)	Partial pressure (mbar)
H_2	80	1.12×10^{-9}
CO	10	1.4×10^{-10}
CO_2	5	7×10^{-11}
Noble gases	3	4.2×10^{-11}
H_2O	2	2.8×10^{-11}

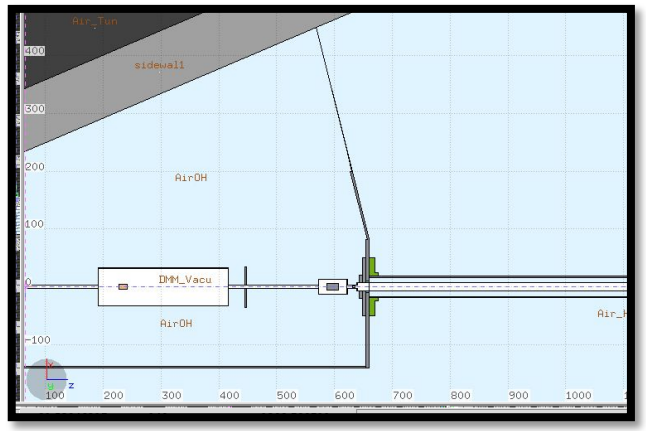
Radiation safety – Lead hutches



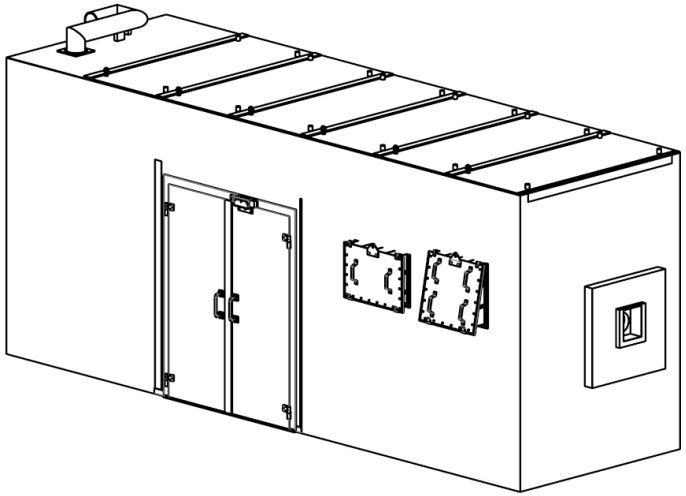
BEATS Beamline Optical Hutch

- Version A: common hutch with neighboring BM beamline

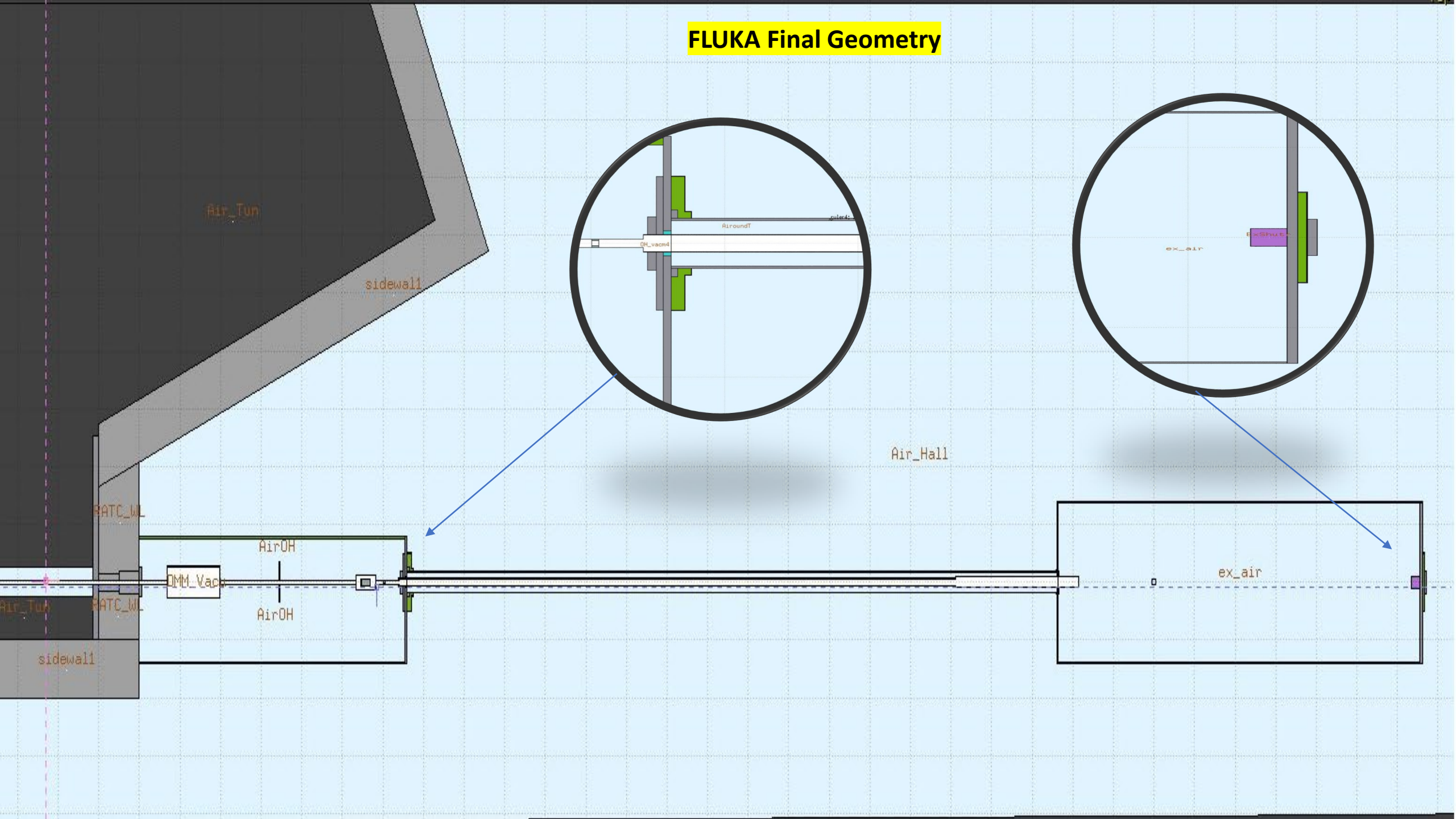




- Version B: BEATS beamline only



FLUKA Final Geometry



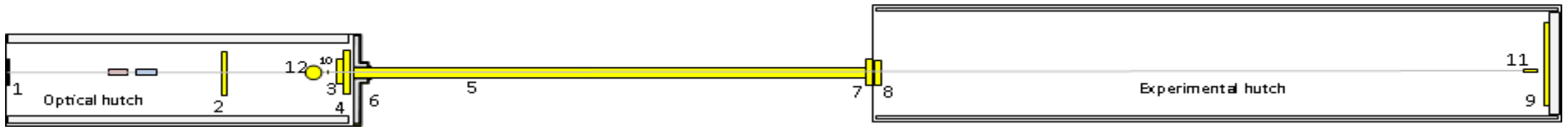
BEATS SHIELDING ELEMENTS

Structural shielding

Element	Material and thickness
Sidewall OH-I	Pb 15 mm +PE 50 mm
Sidewall OH-0	Pb 10 mm
Backwall OH-B	Pb 60 mm +PE 100+Pb 5
Roof OH	Pb 5 mm
Frontwall EH Sidewall EH-I Sidewall EH-O	Pb 20 mm
Backwall EH-B	Pb 60 mm
Roof EH	Pb 20 mm

Non-structural shielding

Shielding Elements	Height (cm)	Width (cm)	Thickness (cm)	Material
Tunnel-to-OH guillotine	50	50	5	Pb
Local Pb screen behind DMM	100	70	2	Pb
OH_backwall-to-TL guillotine	40	40	6.5	Pb
OH backwall central reinforcement	100	100	5	Pb
Collar around TL	-	-	2	Pb
OH-backwall neutron central shield	100	100	10+0.5	PE + Pb
Extension of OH-backwall neutron shield over the TL collar	Along the first 15.5 cm of TL		5+0.5	PE + Pb
OH-B to ExpHall	-	-	5	Pb
TL to EX guillotine	40	40	2	Pb
ExpHall-to-EH guillotine	54	42	2	Pb
EH-B beamstop	20	12	20	W
EH-B neutron central reinforcement on outer side	100	100	5+0.5	PE+Pb
EH-B central reinforcement after neutron shield	40	40	5	Pb

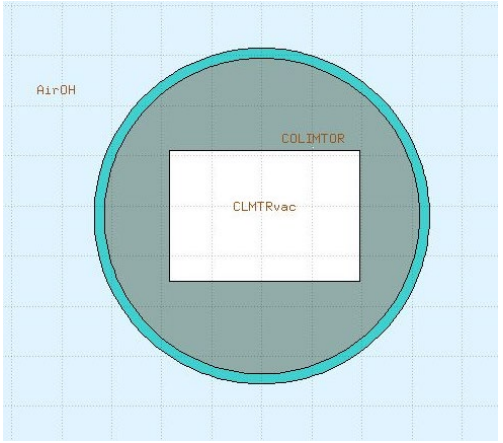


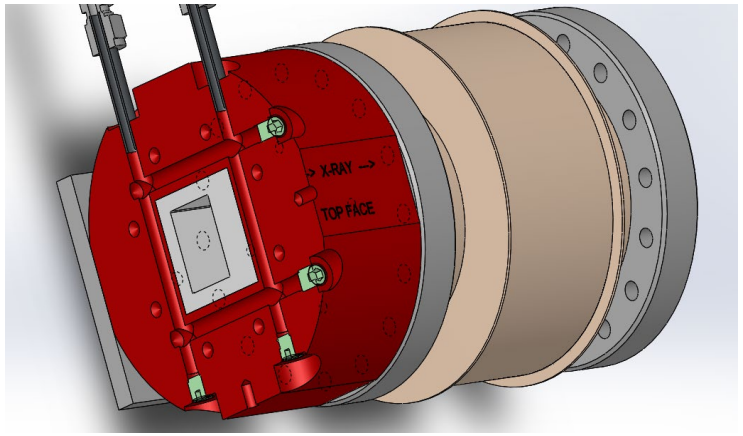
Collimator

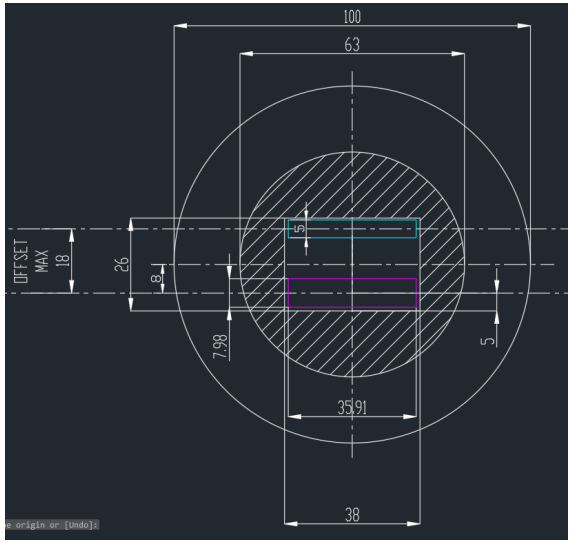
To ensure that no ray will hit the TL and reduce the total photon flux reaching the Experimental Hutch.

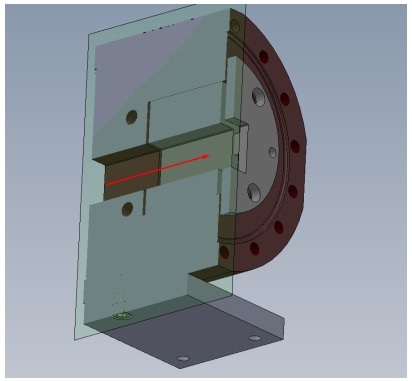
Single tungsten collimator placed 29.3 cm upstream the OH back wall. Aperture of 22 (h) x 26 (v) mm^2 and fill the entire vacuum chamber.

The use of a collimator adds a scattering element inside the OH, thus incrementing the radiation level at this hutch, but allows for a dose rate reduction of a factor 5 inside the Experimental Hutch.

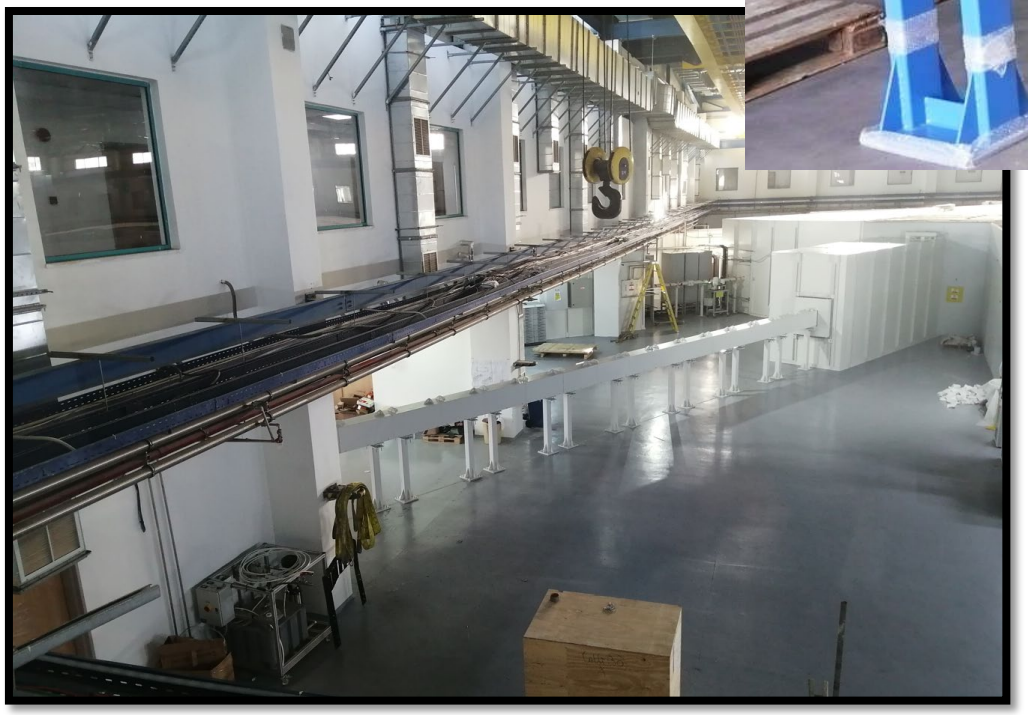


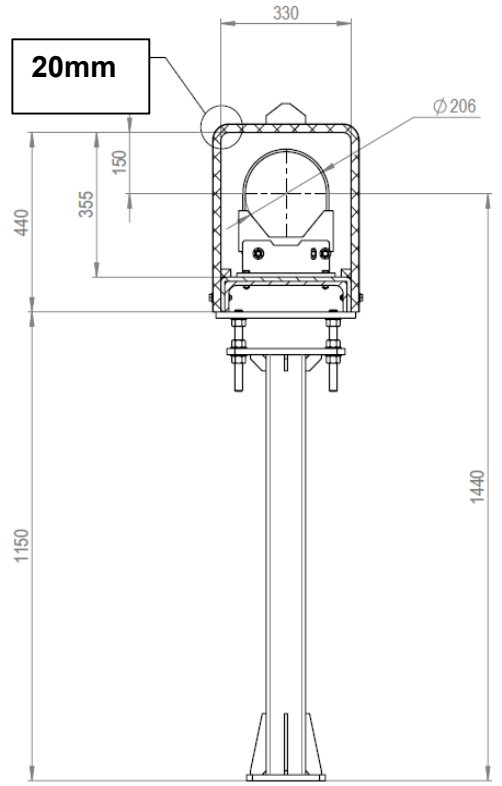


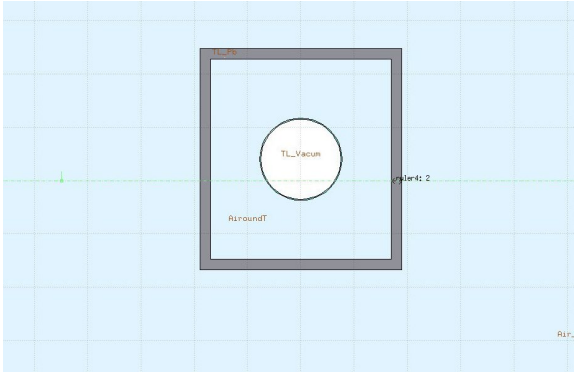




Transfer line Shielding

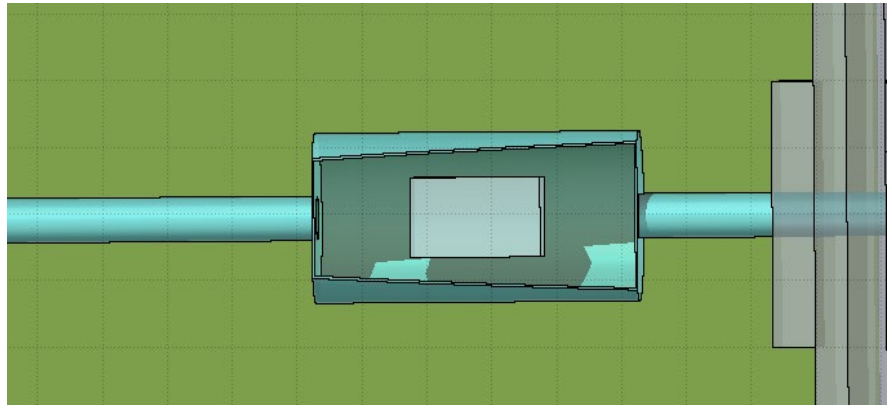






Safety Shutter

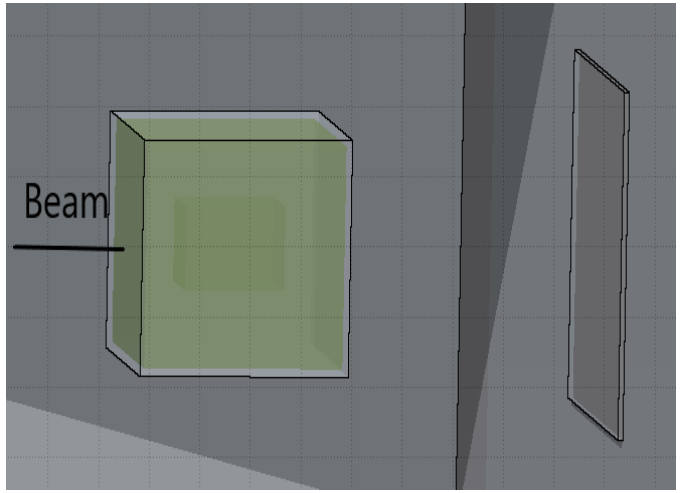
located at the end of the optical hutch, to allow access to the experimental hutch when there is beam inside the optics hutch



Shielding Element	Height (cm)	Width (cm)	Thickness (cm)	Material
Safety Shutter	12	12	20	Tungsten

Beam Stopper

A bremsstrahlung stop is needed at the end of the experimental hutch to absorb all the flux coming from the OH through the TL in any beamline configuration. This beam stop must deal with the neutron production induced by the primary photons.



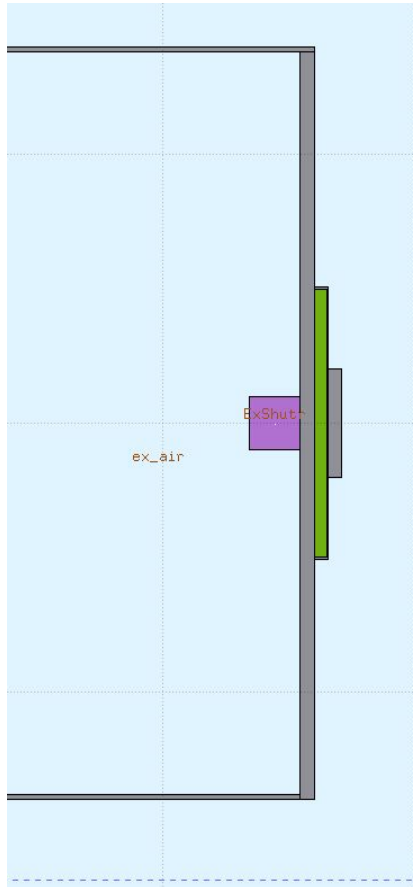
Beam Stopper

A 200 mm × 120 mm × 200 mm (h × w × t) Tungsten beamstop must installed inside EH on EH-B at the nominal beam height of 1400 mm.

On the outer side of EH-B, a central 50-mm-thick neutron shielding in polyethylene with a surface of 1 m × 1 m must be installed at the nominal beam height of 1400 mm.

The neutron reinforcement is followed by a 400 mm × 400 mm rectangular screen with minimum lead thickness of 50 mm.

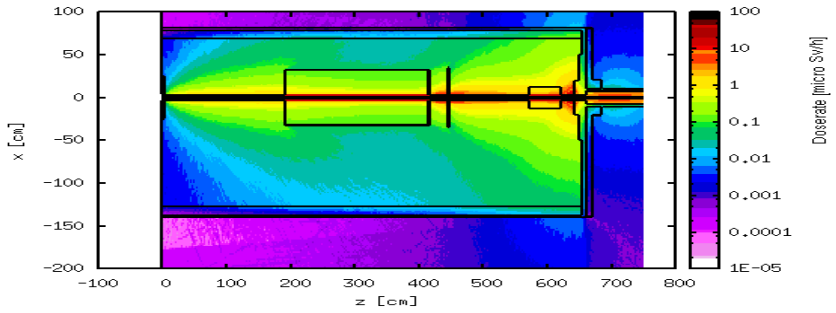
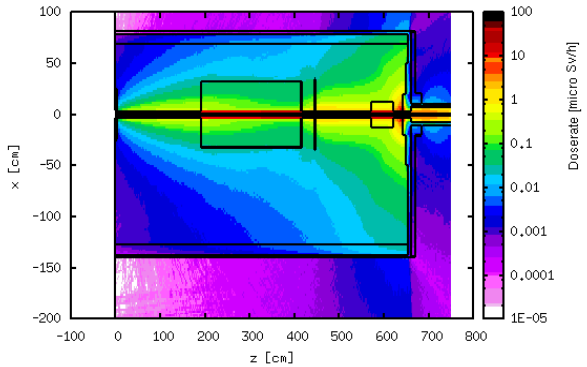
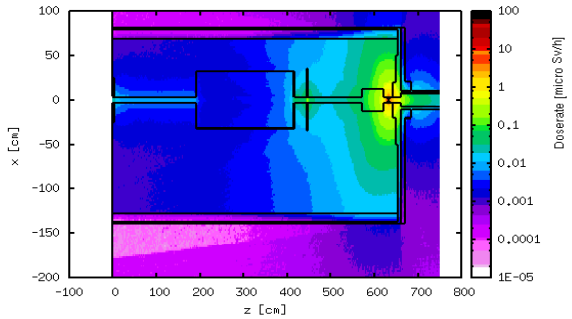
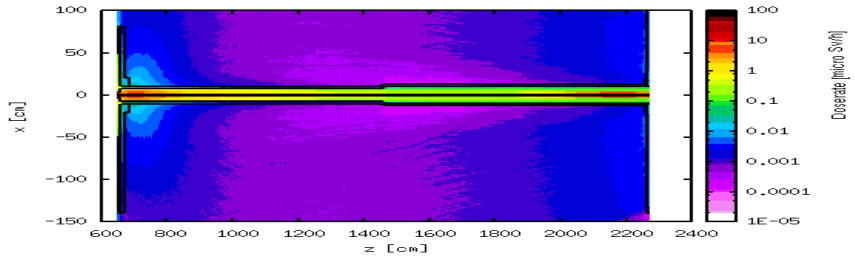
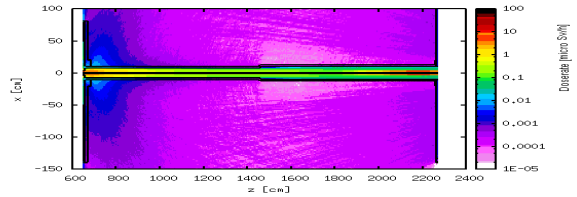
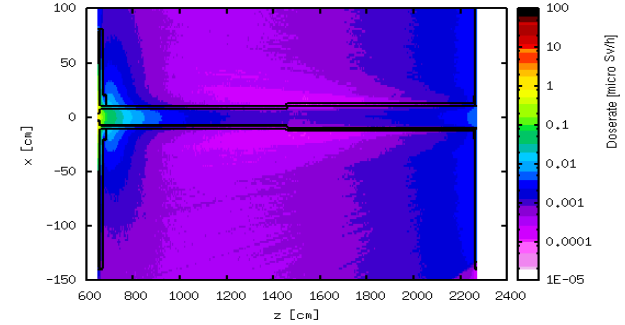
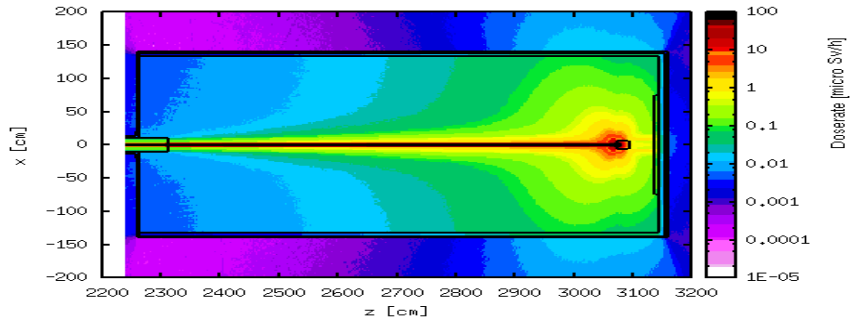
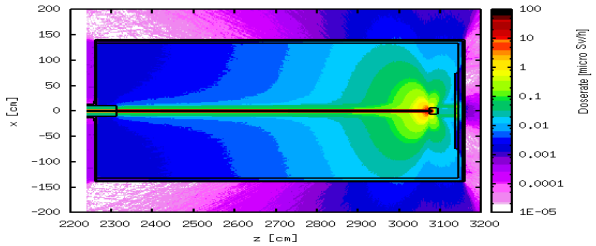
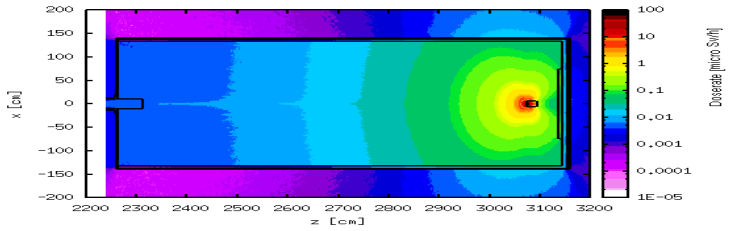
The surface of the polyethylene layer which is not in contact with the lead screen must be covered with a 5-mm-thick lead wrapping.



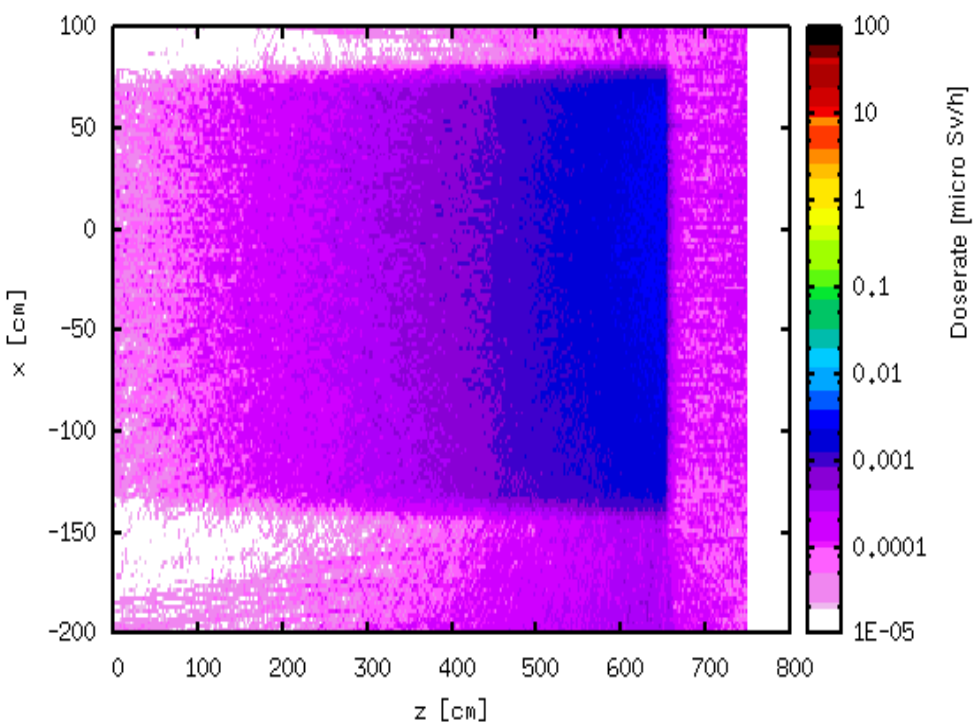
12	EH beam stop - Photon stop	cm H=20	cm W=12	cm t=20	Lead
	- Neutron stop	5 cm in all directions			Polyethylene
	- External layer	0.5 cm in all directions			Lead

Gas bremsstrahlung source calculations

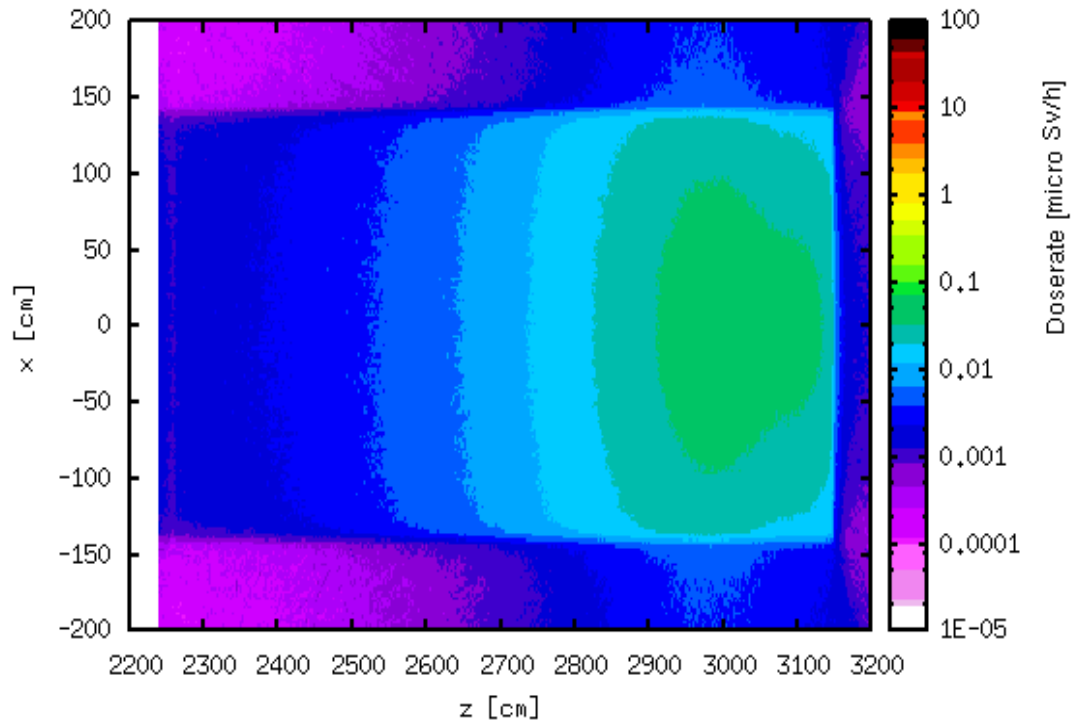
OH mirrorless Safety Shutter open against B.Stopper in Exp Hutch

	Total	Photons	Neutrons
OH			
TL			
EH			

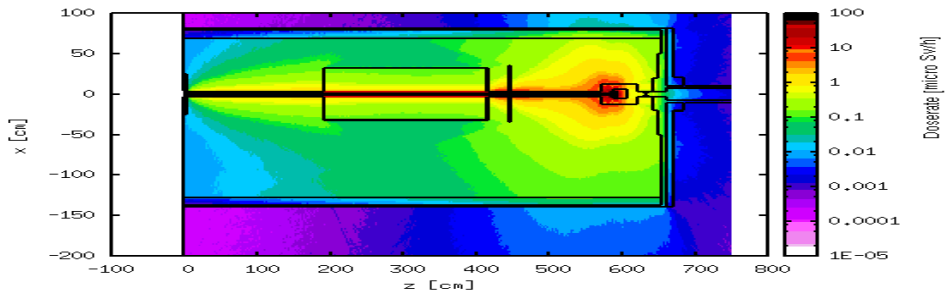
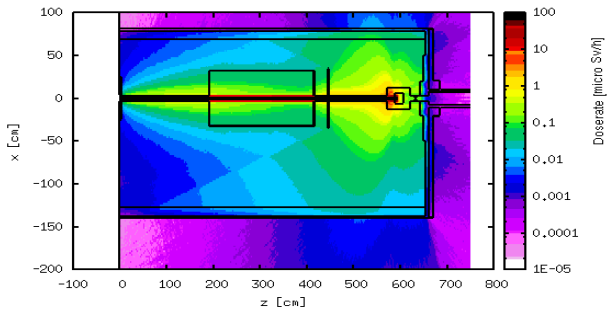
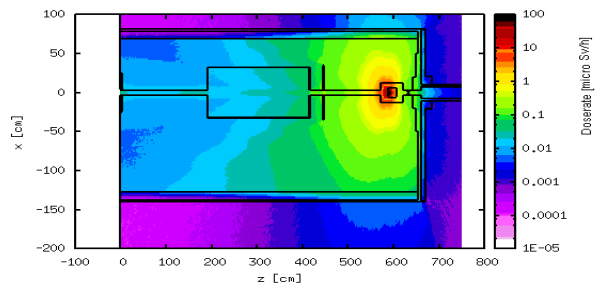
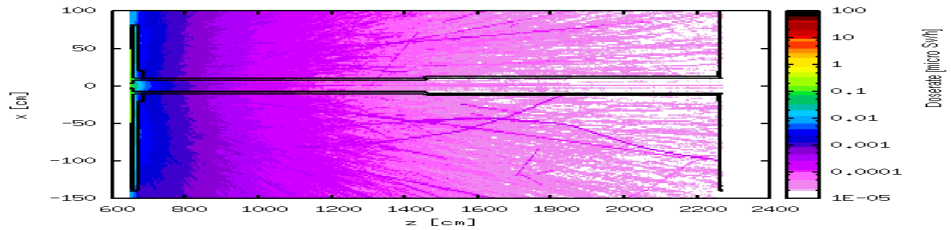
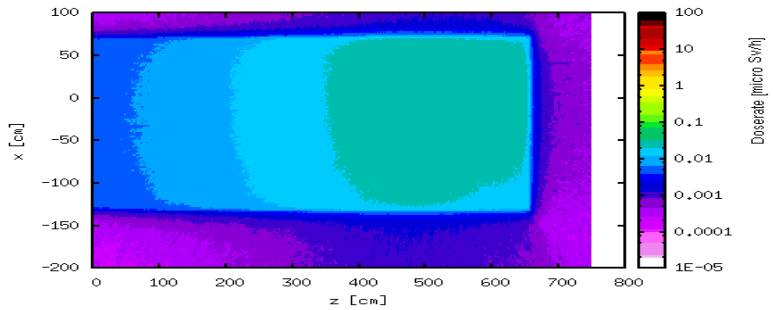
Total Dose OH Roof



Total Dose EH Roof



OH mirrorless Safety Shutter closed

	Total	Photons	Neutrons
OH			
TL			
OH- Roof			

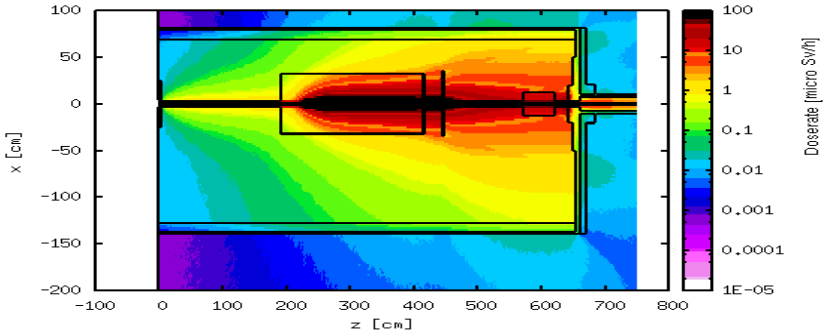
OH All inserted max energy down to EH B.Stopper

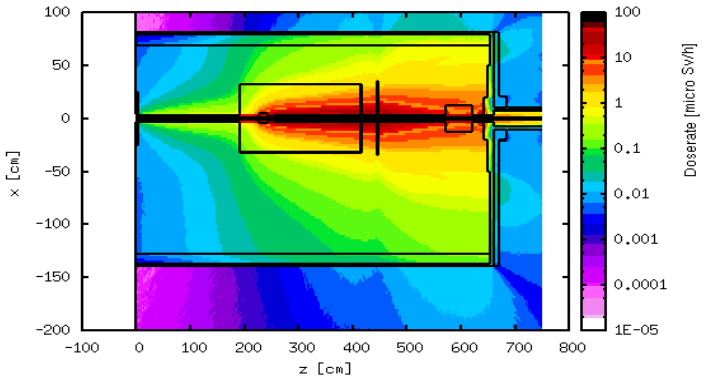
Total

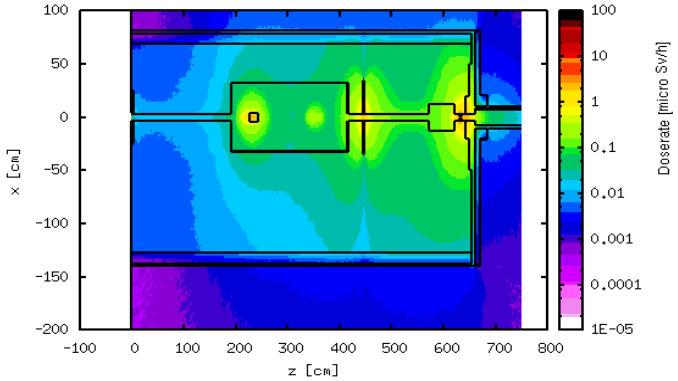
Photons

Neutrons

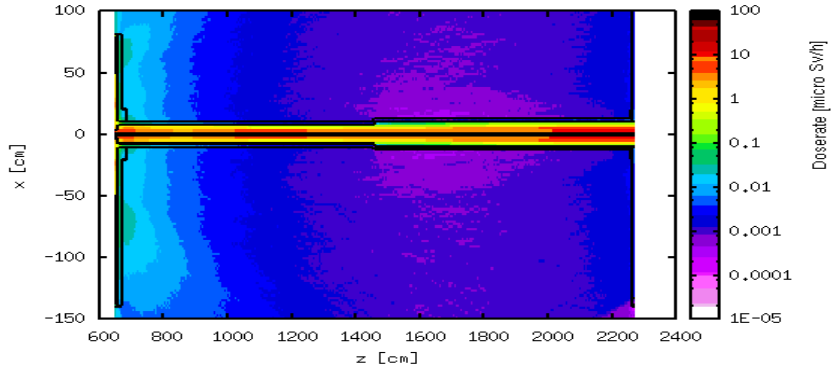
OH

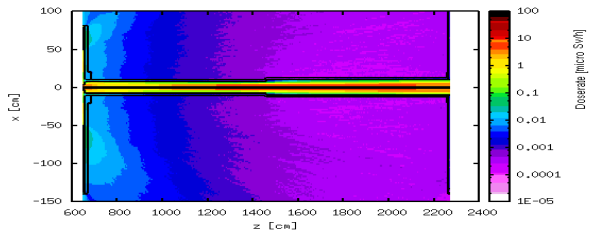


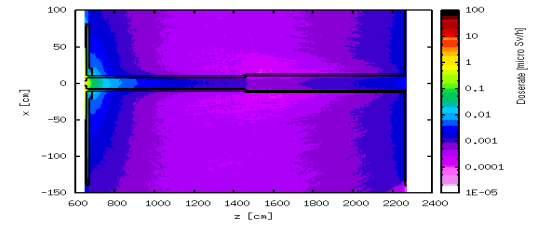




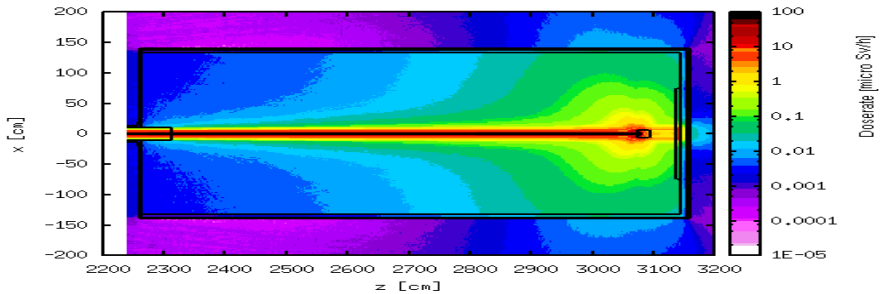
TL

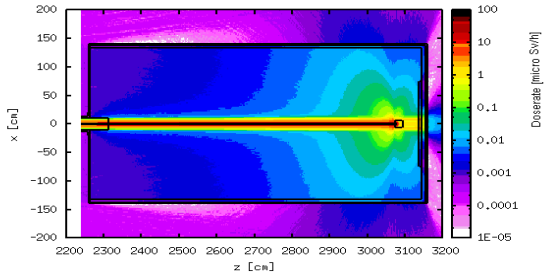


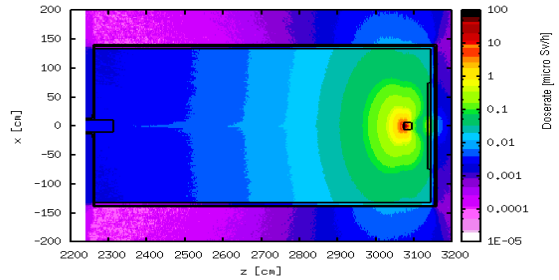




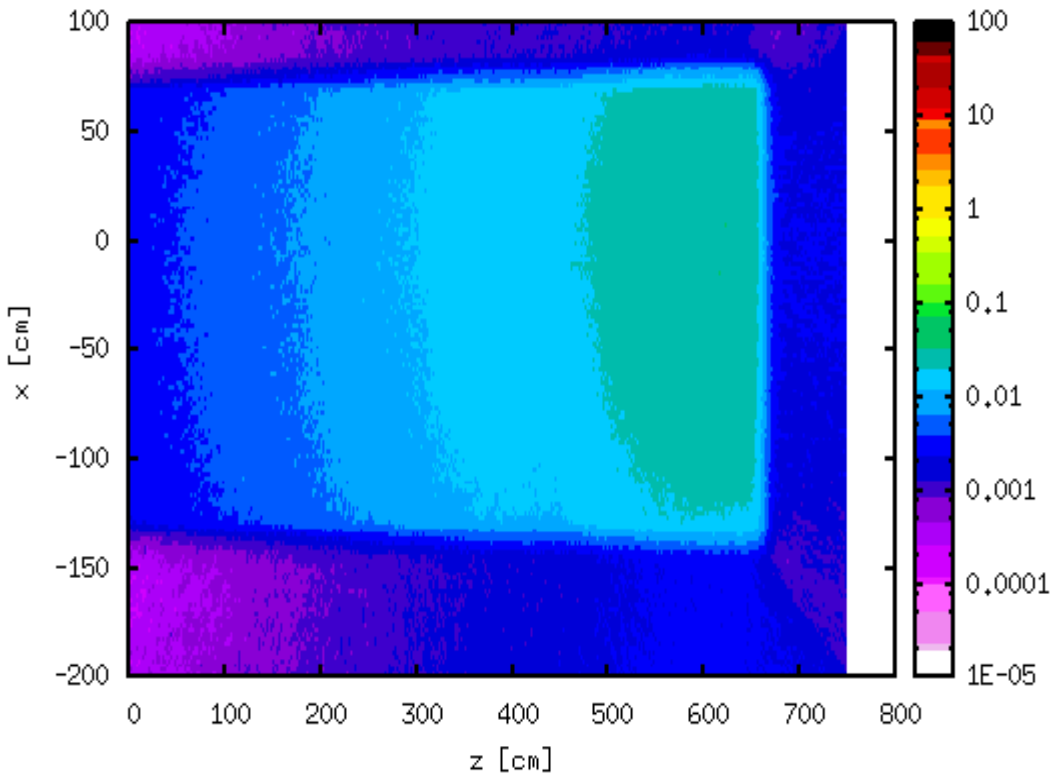
EH



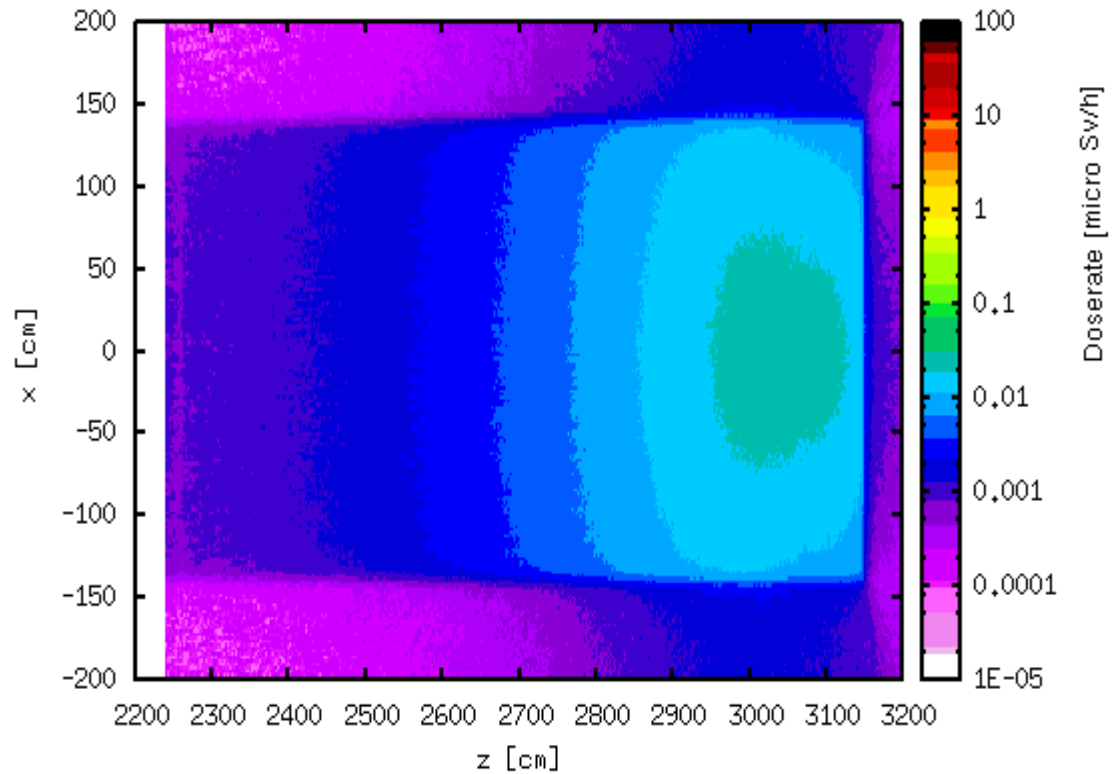




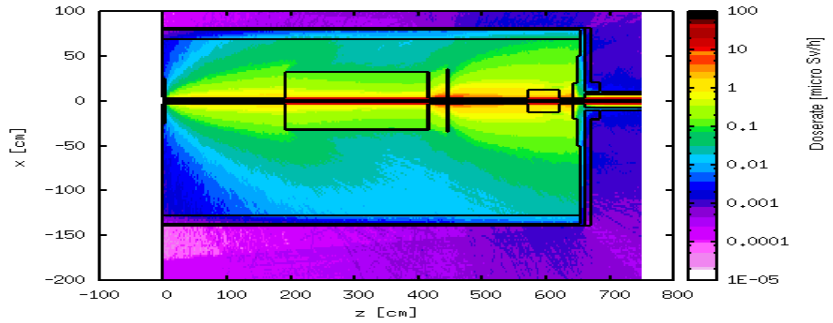
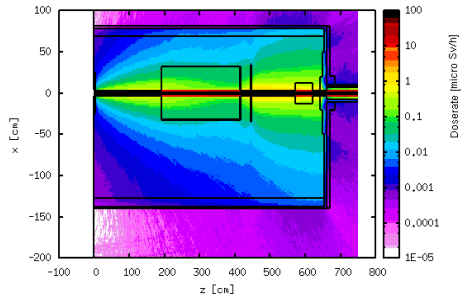
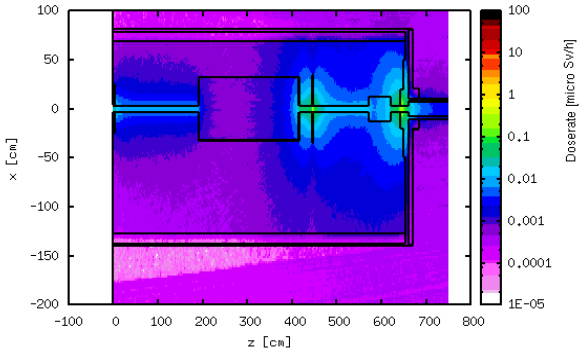
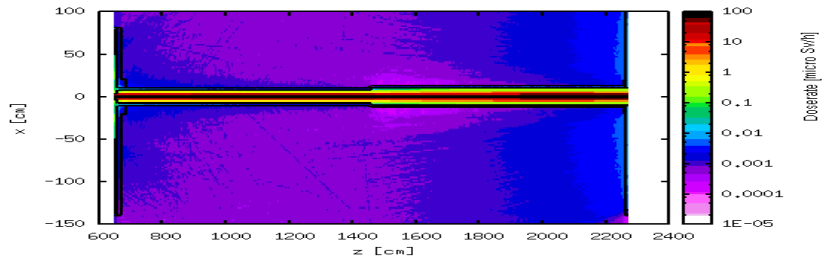
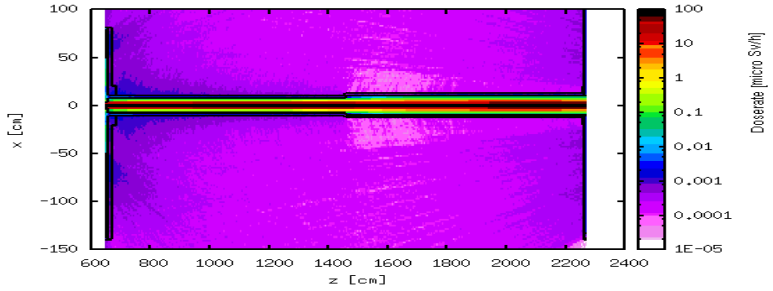
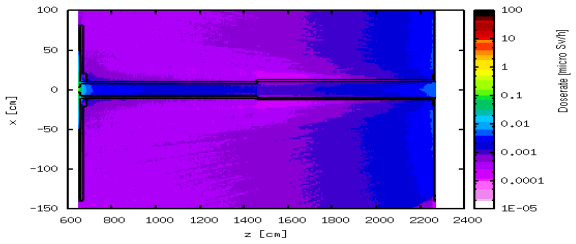
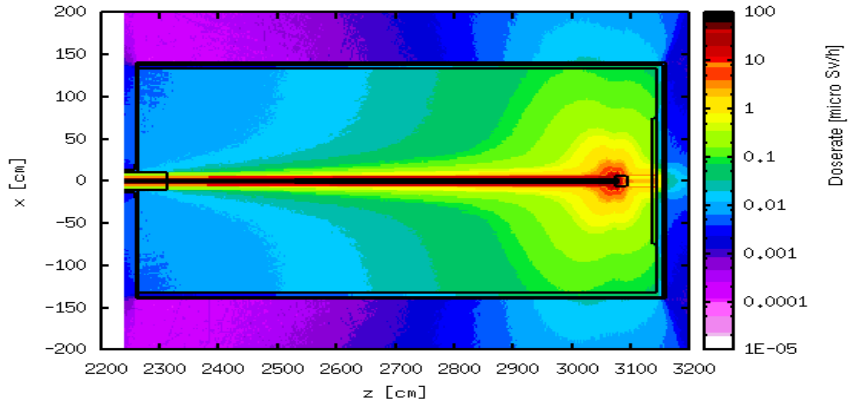
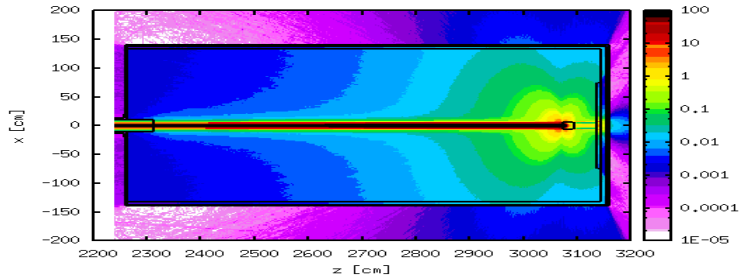
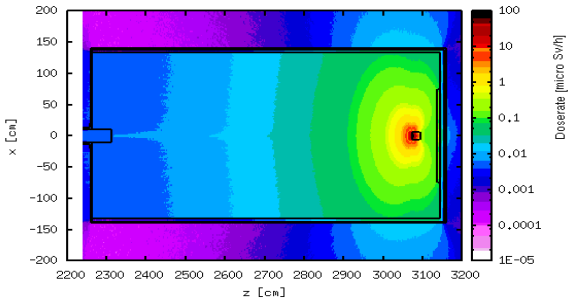
Total Dose OH Roof



EH Total Dose Roof

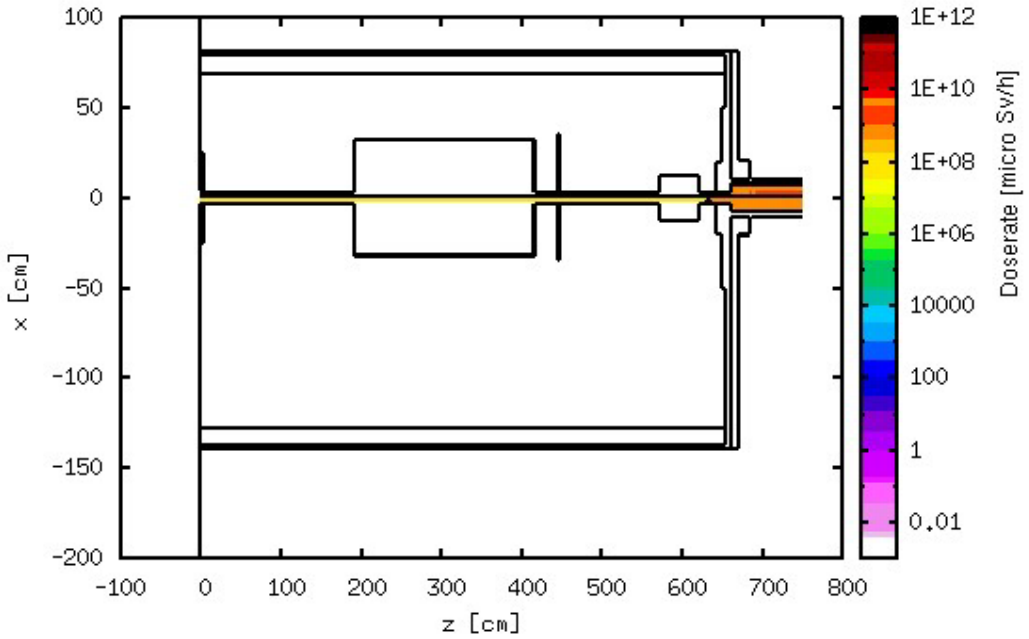


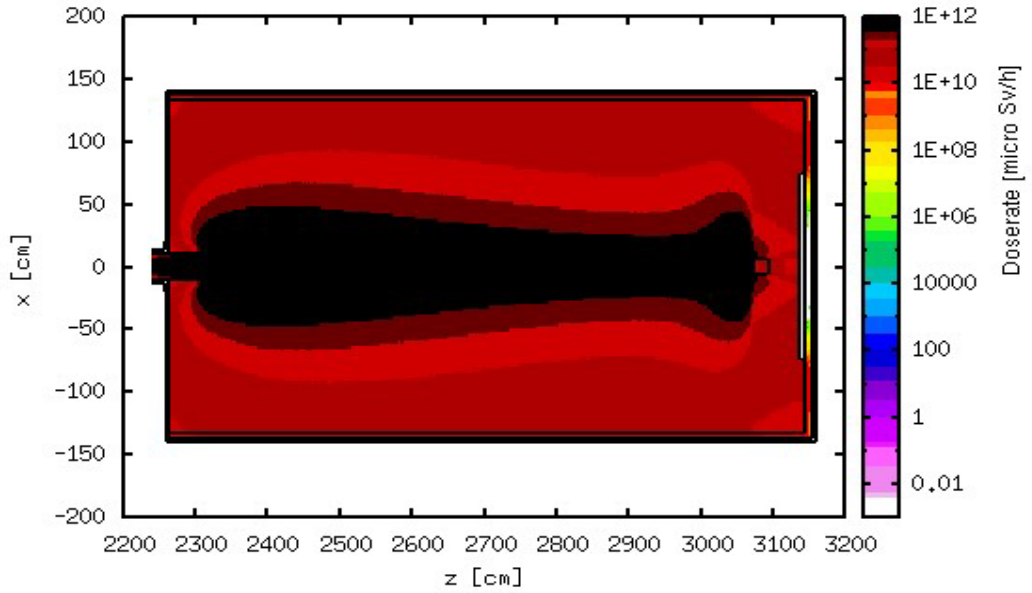
OH mirrorless SafShutt open against BS in Exp Hutch without collimator

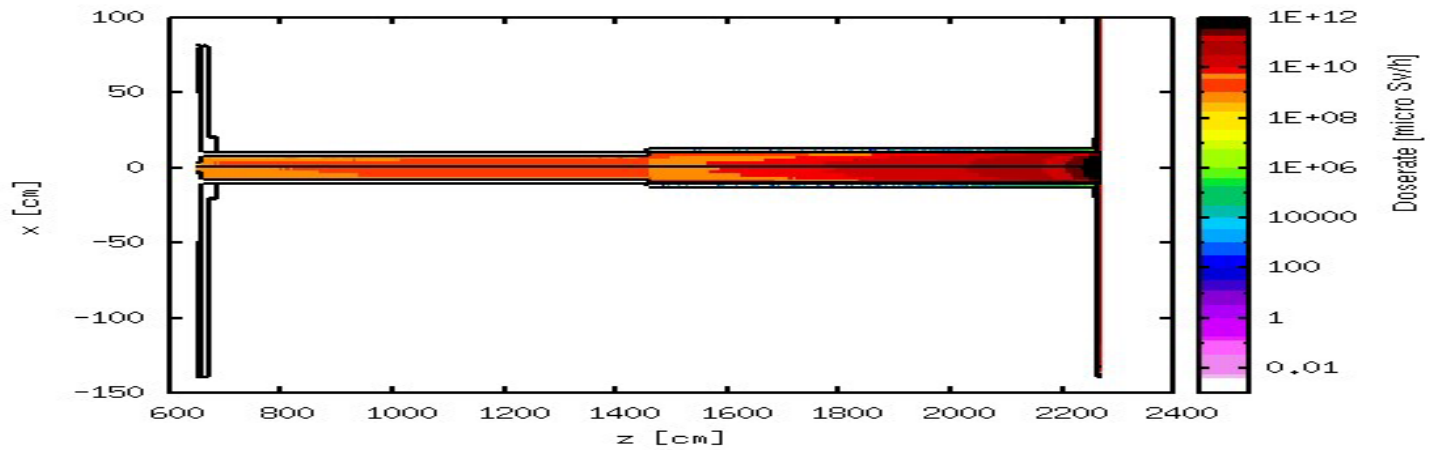
	Total	Photons	Neutrons
OH			
TL			
EH			

ID source calculations

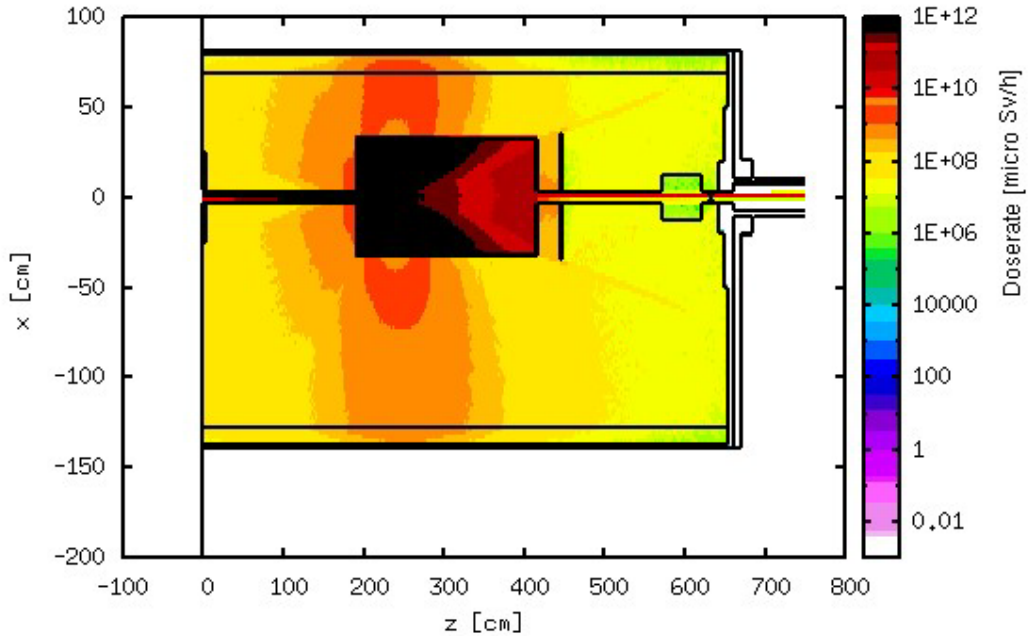
OH mirrorless Safety Shutter open against B.Stopper in Exp Hutch

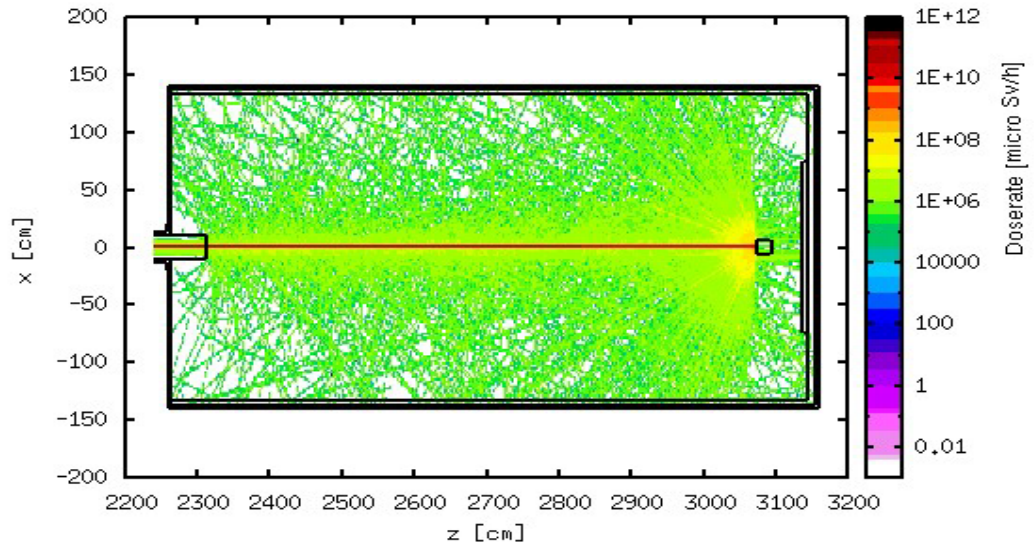


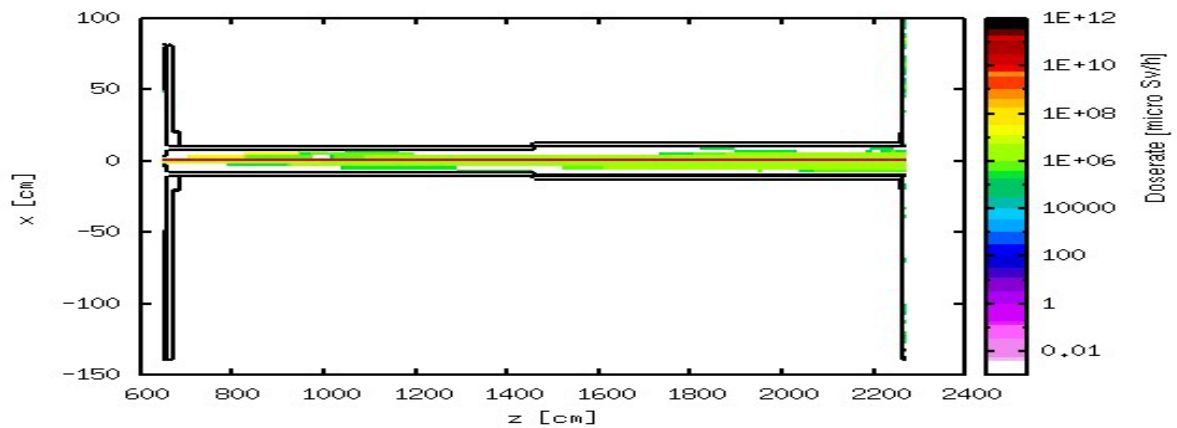




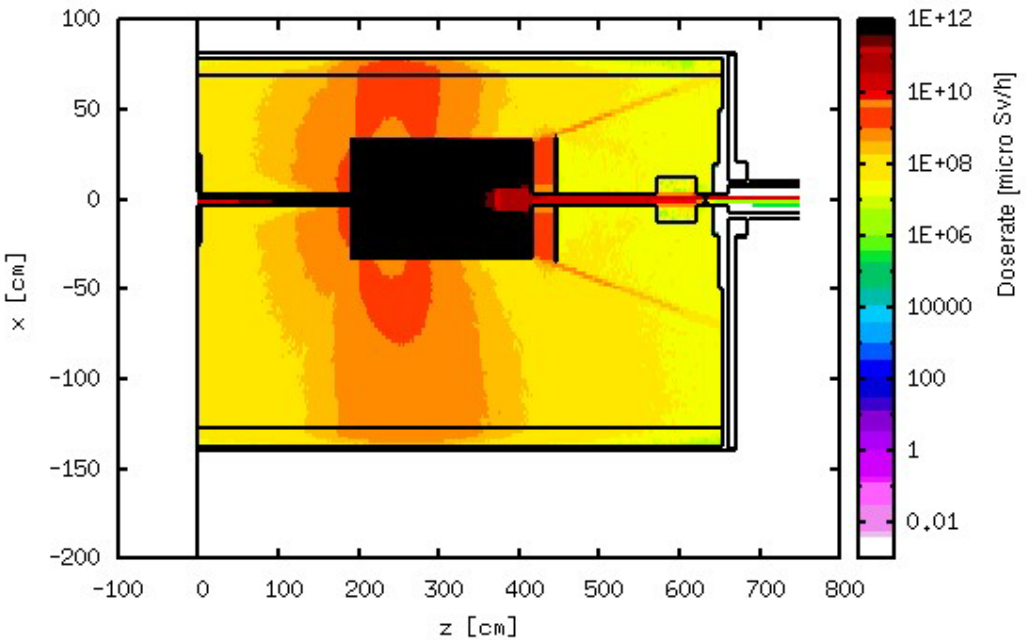
OH All inserted min energy down to EH B.Stopper

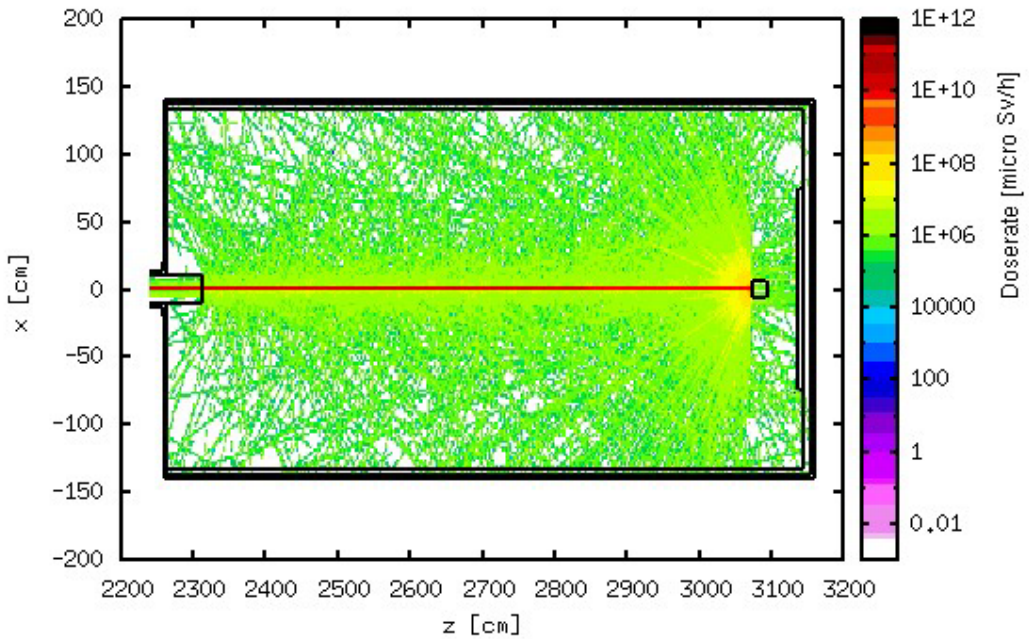


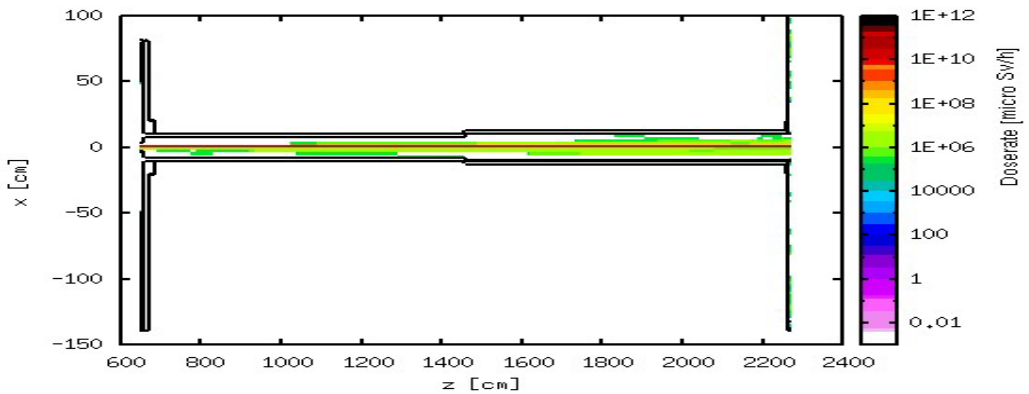




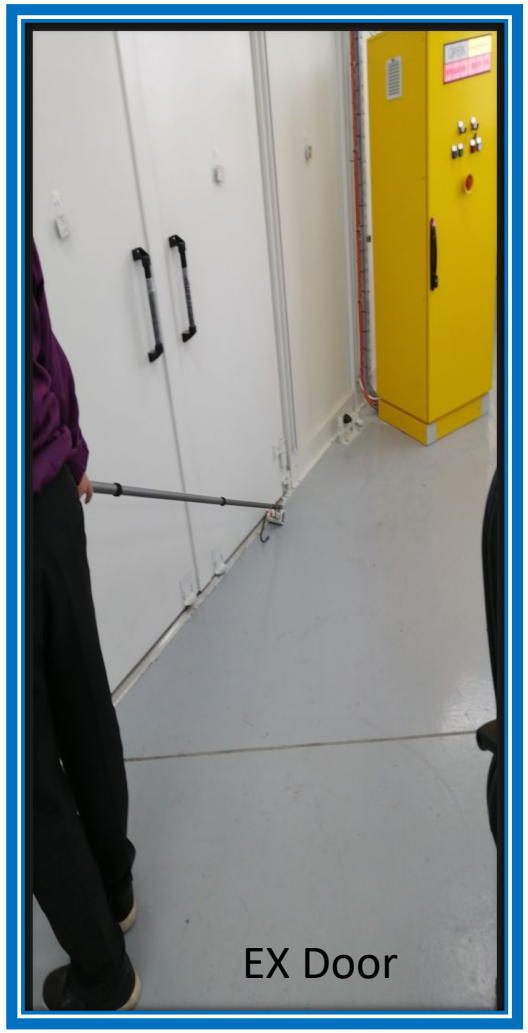
OH All inserted max energy down to EH B.Stopper







BEATS Beamline Commissioning



The Measurement values were within Background

Agree with the simulations .

Acknowledgment

SESAME is thankful to ALBA synchrotron, María-José García-Fusté, for:

Supporting, Training, Using ALBA's cluster and Supervising radiation calculations of BEATS beamline.

Thank you for listening