



Design and Shielding Calculations for a New White Beam Beamline at DESY

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HELMHOLTZ



Out line

- Deutsches **Elektronen-Synchrotron** (DESY)
- PETRA III: Overview
- PETRA III: Beamlines
- P25 Beamline: PETRA IV Test Beamline, Bio-med. Imaging, Powder XRD Beamline
- Design and Shielding Calculations for P25 Experimental Hutches
- Summary
- PETRA IV: The Future

Deutsches Elektronen-Synchrotron (DESY)

- Deutsches Elektronen-Synchrotron
- Research center of the Helmholtz Association
- Founded on December 18, 1959
- Two locations:
 - Hamburg
 - Zeuthen (near Berlin)
- Basic budget: 350 million euros
- 3000 employees (including 1300 scientists) from 60 nations
- Over 3000 guest researchers from over 40 nations every year

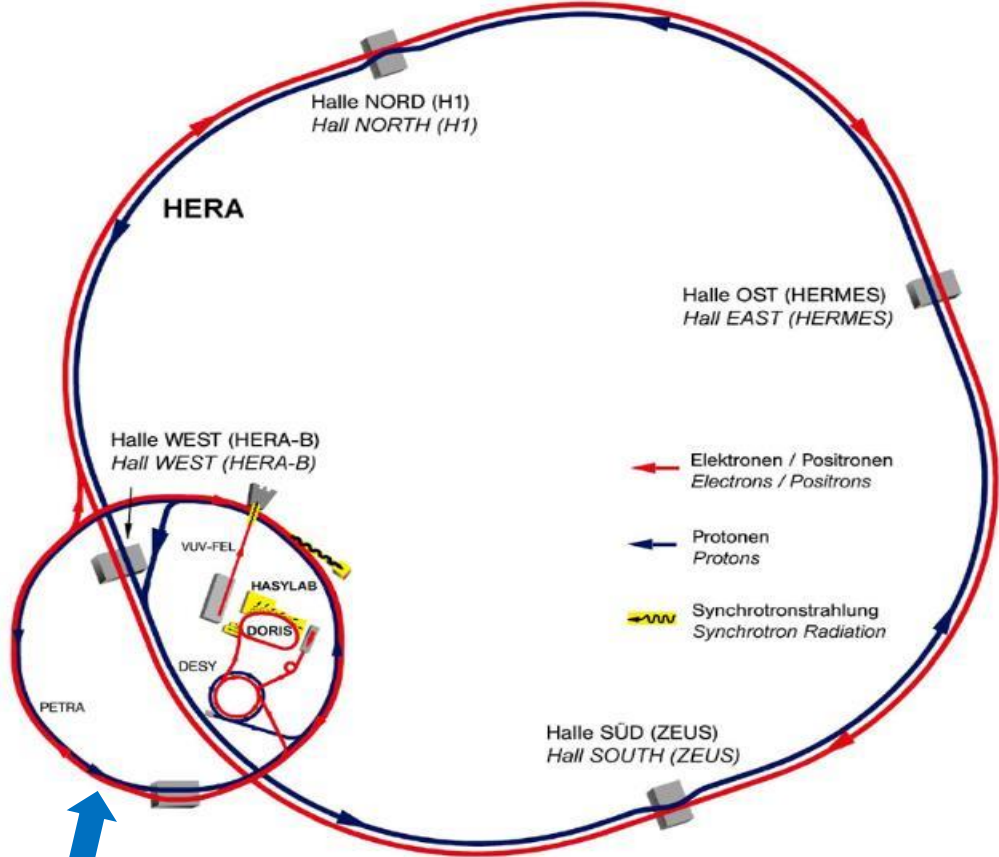


Deutsches Elektronen-Synchrotron (DESY)

At DESY we have a unique combination of analytical tools



HERA and PETRA



- PETRA (Positron-Electron-Tandem-Ring-Anlage) was pre-accelerator for HERA



- HERA: Hadron-Electron Ring Anlage
- HERA was operated from 1992 to 2007
- HERA tunnel runs 10 to 25 m below ground level and has a circumference of 6.3 km

PETRA III Overview: DESY's Brilliant Synchrotron Radiation Source

Timeline of PETRA:

1978: **PETRA I** for particle physics (gluon discovery)

1988: **PETRA II** as pre-accelerator for HERA

2010: **PETRA III** as 3. generation synchrotron radiation source (High Brilliance X-ray Source for Nano Science)

2010: PETRA III start of user operation with the first three beamlines

2016: PETRA III extension project starts users operation with the first two beamlines

2021: PETRA III extension project almost complete

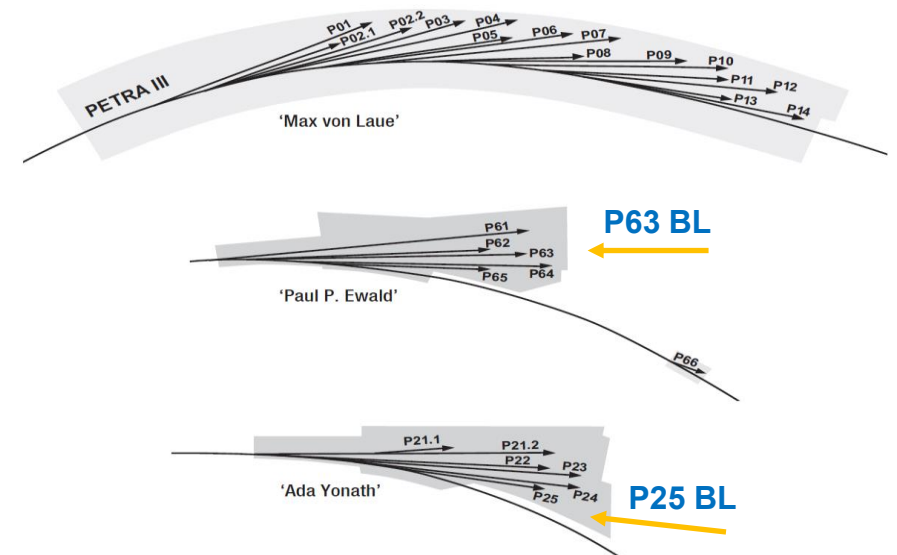
2023: P25 BL construction was started

2025: P25 BL commissioning is planned and also P63 BL will be built
➤ **planned**

End of 2029: **shutdown of PETRA III for upgrade to 4. generation synchrotron radiation source PETRA IV**

2032: PETRA IV operating (the Ultimate 3D X-ray Microscope)

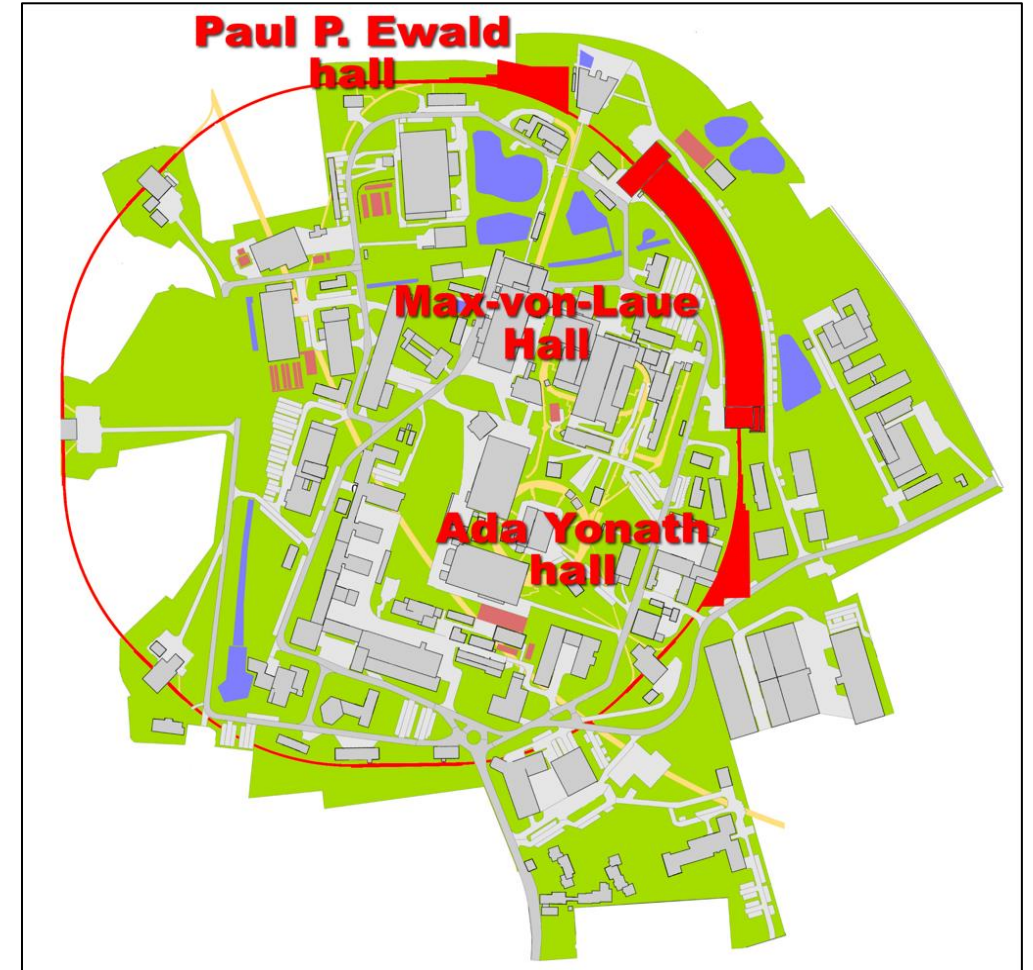
The PETRA III experimental hall „Max von Laue“



PETRA III: DESY's Brilliant Synchrotron Radiation Source

Parameters:

- Electron energy 6 GeV
- Stored current 100 / 120 mA (1% top-up)
- Emittance ($h \times v$) 1.3 nmrad \times 13 pmrad
- Circumference 2304 m
- Photon energy range 4-40eV, 250 eV - 200 keV
- Beamlines in operation 25
- Beamlines under construction 1 (P25)
- Beamlines in planning 1 (P63)
- User operation (hours/year) 5000
- Bunch separation 192 ns or 16 ns



PETRA III

User statistics and availability in 2024

- Users: 3476 from 46 countries

Numbers include:

On-site visits

Mail-in services

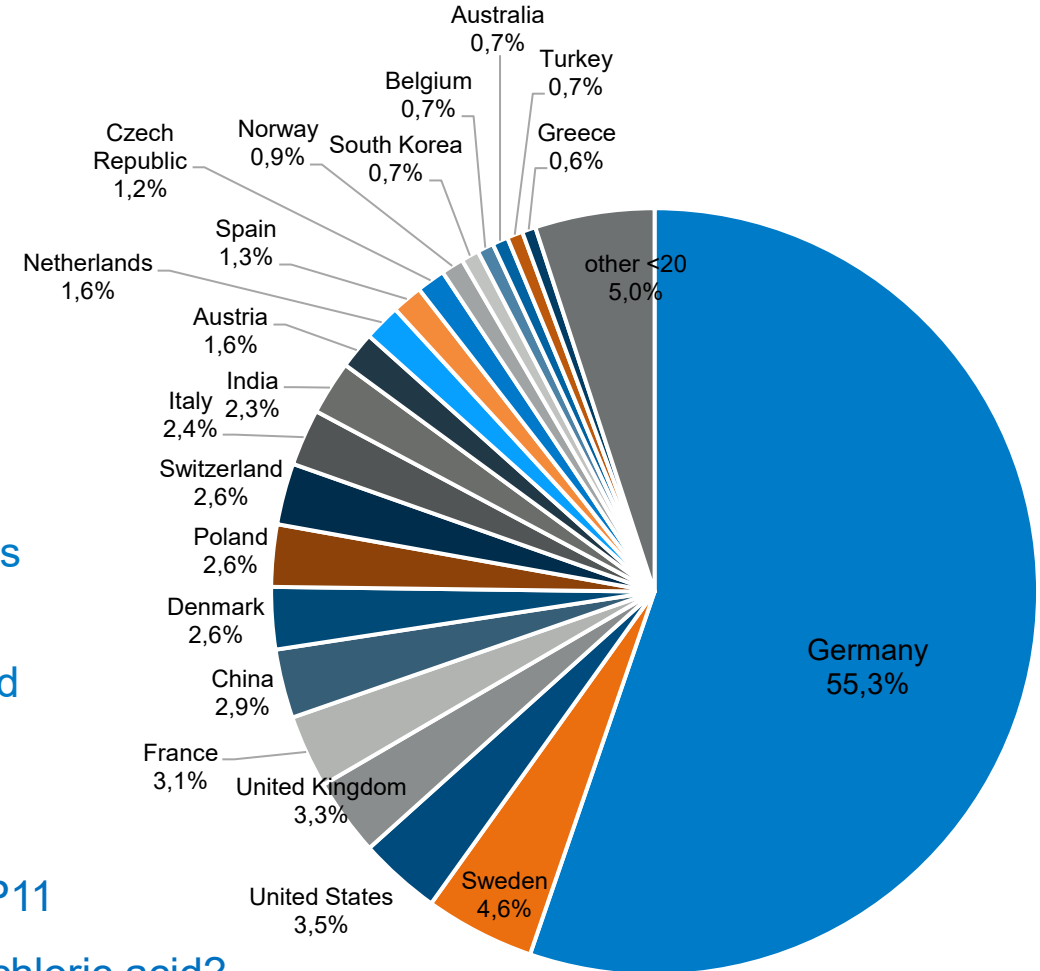
Remote access

- Mission: support solving grand societal challenges in various fields of science
- Over 3500 scientist (over 7900 visits) from all over the world visit PETRA III every year to solve their scientific

Highlight research experiments :

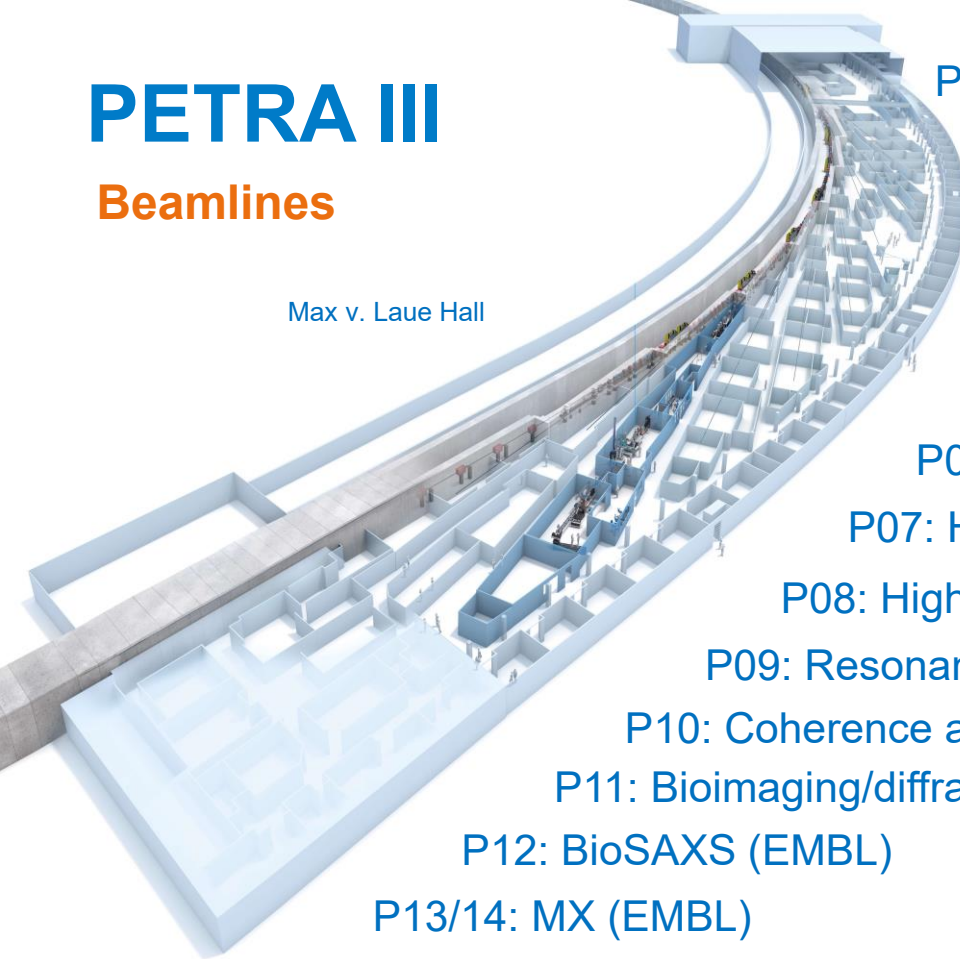
- Using PETRA III to watch disabling of a penicillin killer at P11
- How many water molecules does it take to dissolve hydrochloric acid?
- Possible early diagnosis of Parkinson's disease at P06

- User run: 4821 h
- Availability: 98.4 %



PETRA III

Beamlines



Max v. Laue Hall

P01: Dynamics beamline, IXS, NRS

P02.1: Powder diffraction & total scattering

P02.2: Extreme conditions

P03: Micro-, nano-SAXS, WAXS (DESY, Hereon)

P04: Variable polarisation XUV

P05: Micro-, nano-tomography (Hereon)

P06: Hard X-ray micro-, nanoprobe

P07: High-energy materials sci. (Hereon, DESY)

P08: High-resolution diffraction

P09: Resonant scattering/diffraction

P10: Coherence applications **25 specialized beamlines**

P11: Bioimaging/diffraction

P12: BioSAXS (EMBL)

P13/14: MX (EMBL)

P21: Swedish materials science beamline

P21.1 High-energy broad band diffraction

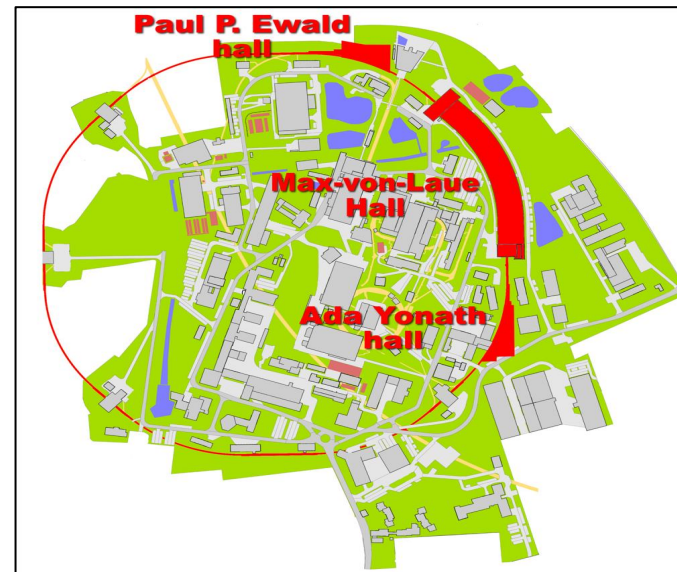
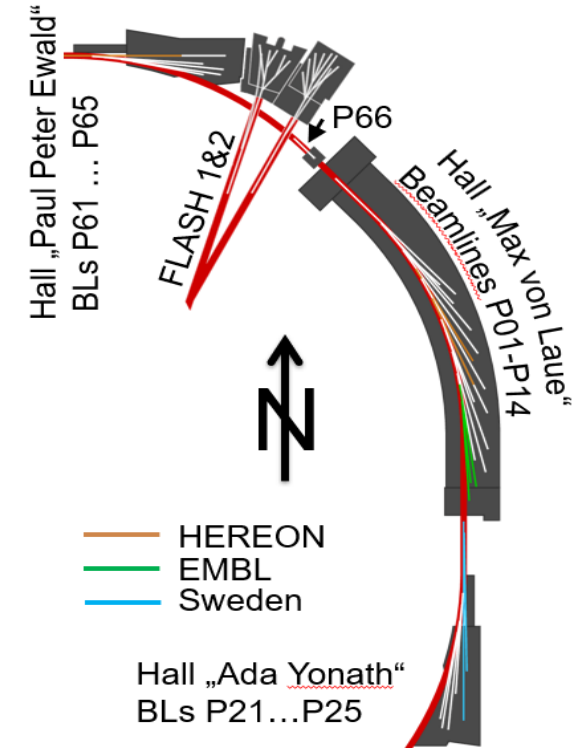
P21.2 High-energy diffraction and imaging

P22: Hard X-ray photoelectron spectroscopy

P23: In-situ and nano diffraction (DESY, KIT)

P24: Chemical crystallography

P25: Bio-med. imaging, Powder XRD, Innovation



P61: High-energy wiggler beamline (Hereon, DESY)

P62: Small-angle X-ray scattering

P63: in planning

P64: Advanced XAFS

P65: Applied XAFS

P66: Time-resolved luminescence spectroscopy

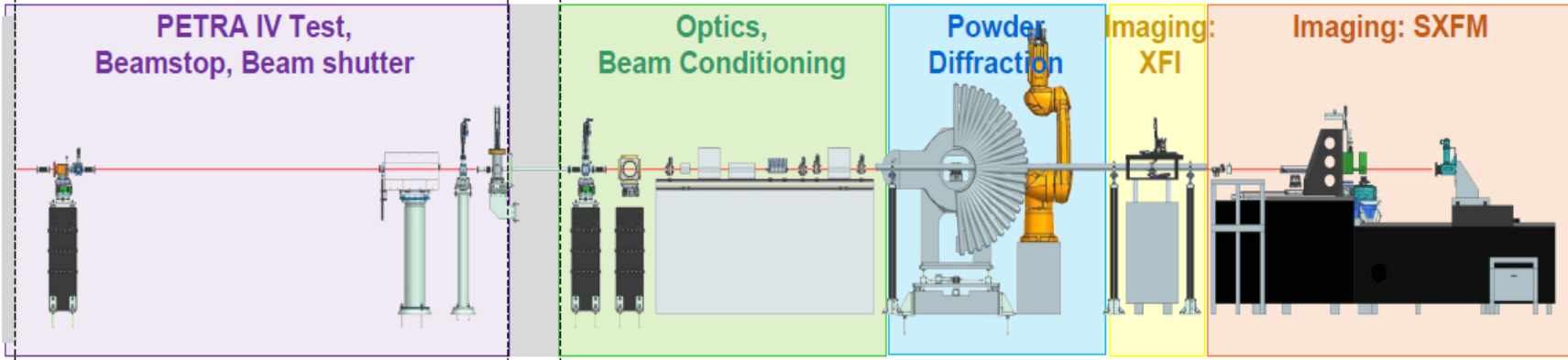
PETRAIII Beamline P25

Beamline for Applied Bio-Medical Imaging, Powder Diffraction and Innovation

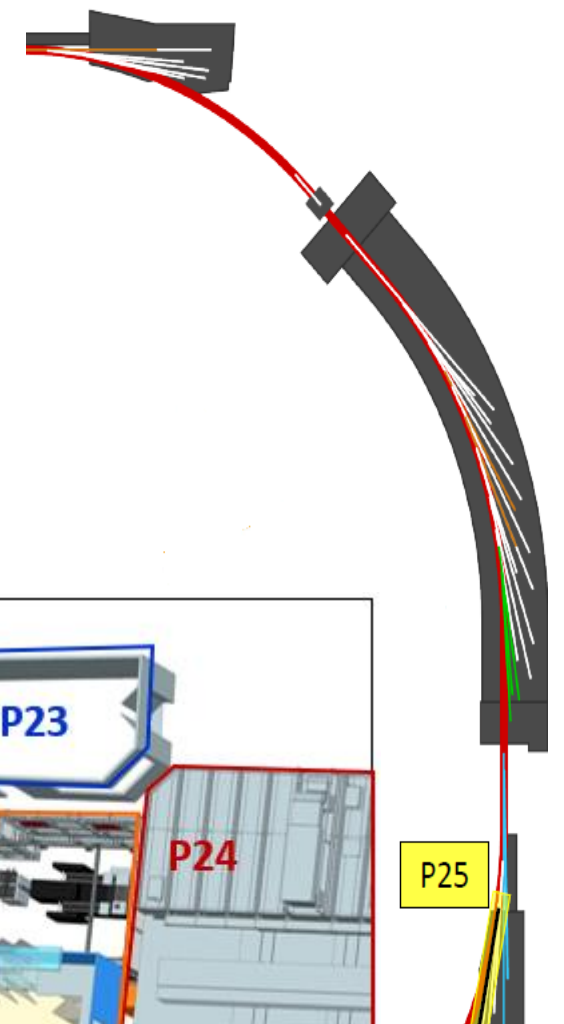
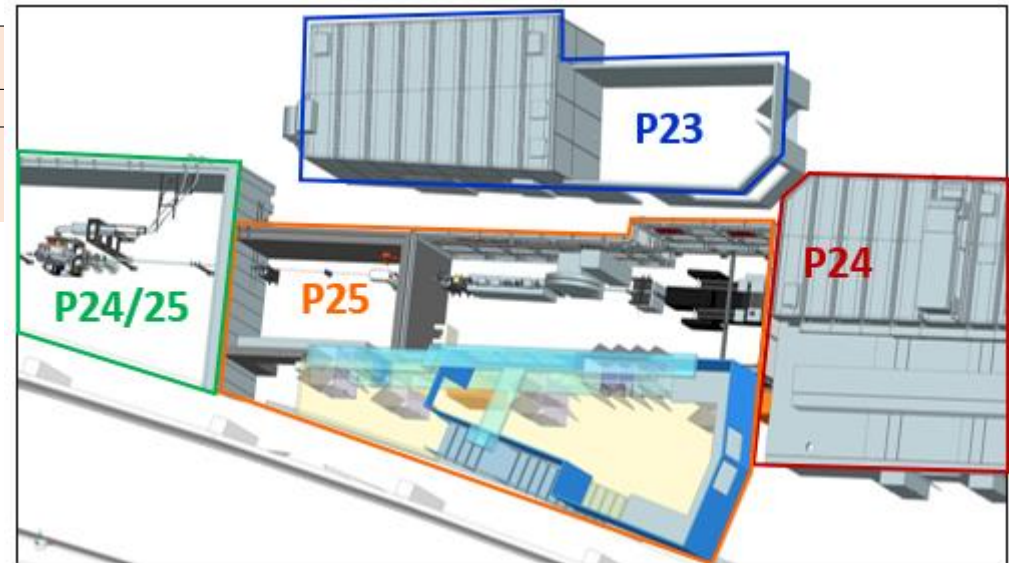
White and Monochromatic Beam Beamline

OH2: Test (White & Monochromatic Beam)

EH: Experimental Endstations (Monochromatic Beam)



	Test	PD	XFI	SXFM
Energy	White & Mono	15 – 35 keV	50 – 60 keV	10 – 40 keV
Beamsize		50 μm^2 to 1.5 x 0.5 mm^2	0.2 - 1 mm^2	$\sim 1 \mu\text{m}^2$

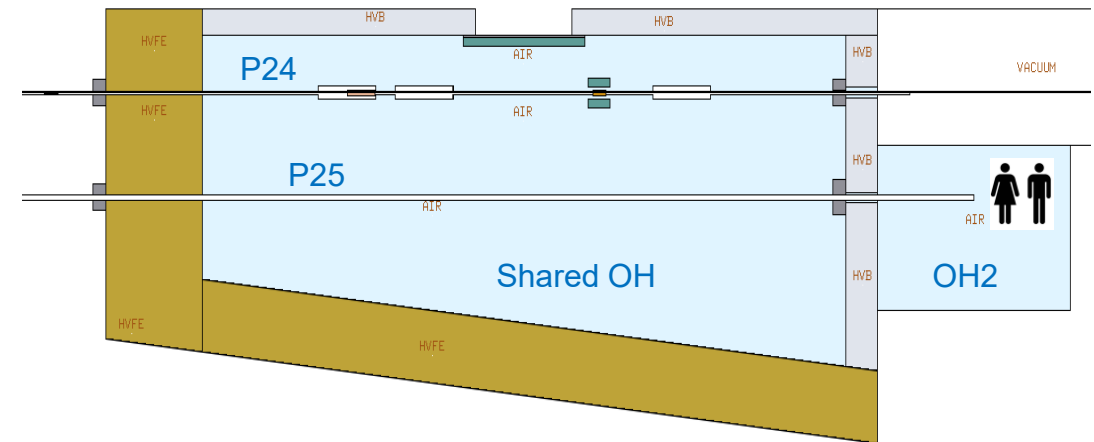
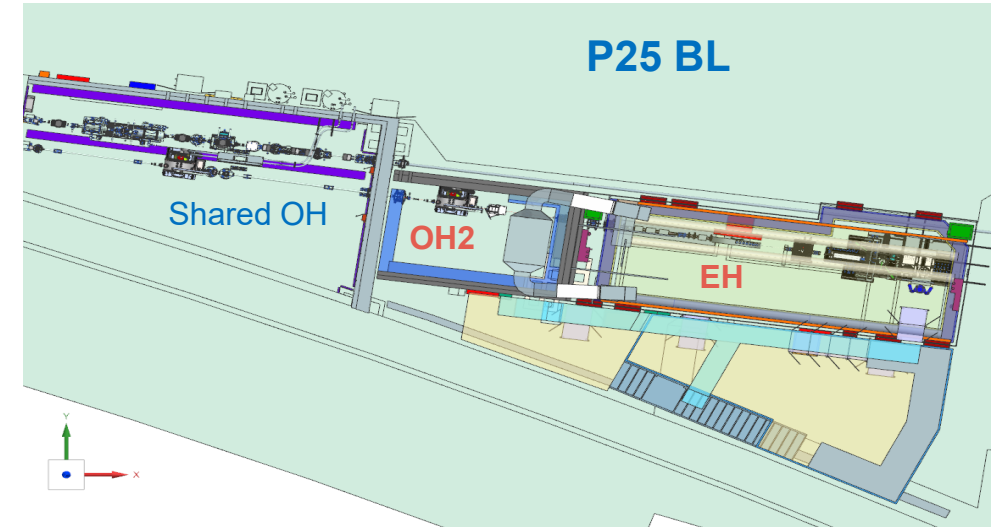


- User target groups: Industrial users
Impact-driven project
Applied bio-medical research

Challenges to Build Beamline P25

Design and Layout

- Space (last beamline in PXE hall, shared sector with P24)
- Initial layout conflicted with radiation safety
- No beam shutter at the end of shared OH between P24 and P25
- The monochromator is set up at OH2 to avoid interrupting the operation of the neighboring beamline
- White beam in air
- Use of White beam and Monochromatic beam



PETRA III Shielding Policy

- Personal dosimeters are not required for employees, visitors and users at DESY.
- Supervised areas at DESY are operational zones where individuals are exposed to an effective dose of less than 1 mSv annually, controlled areas at DESY are zones where individuals may receive an effective dose exceeding 1 mSv within a calendar year. This corresponds to a local dose rate of 0.5 $\mu\text{Sv/h}$ for an annual exposure of 2000 hours.
- Avoid any local shield
- Assume 0.01% BW for monochromatic beam hutches, and 1% BW for pink beam hutches
- Use of lead material for mono and pink beams, heavy concrete for white beam hutches

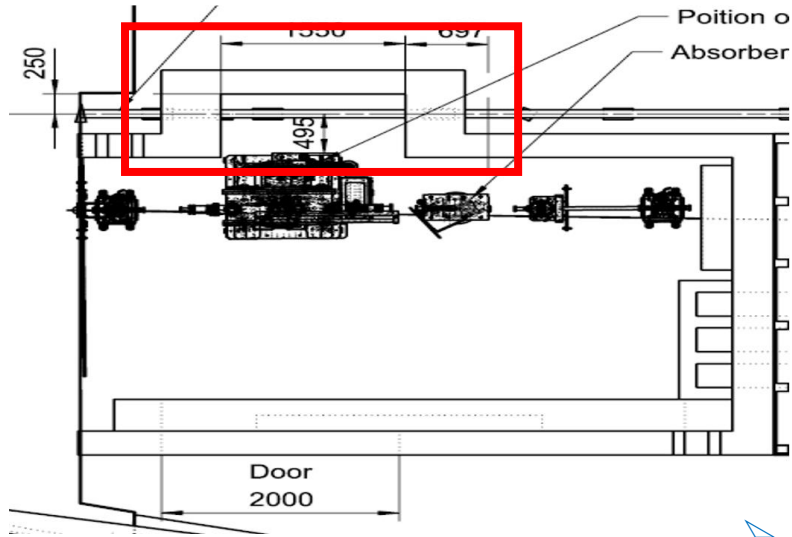
Computational Tools and Expert Implementation

Determination of wall thickness

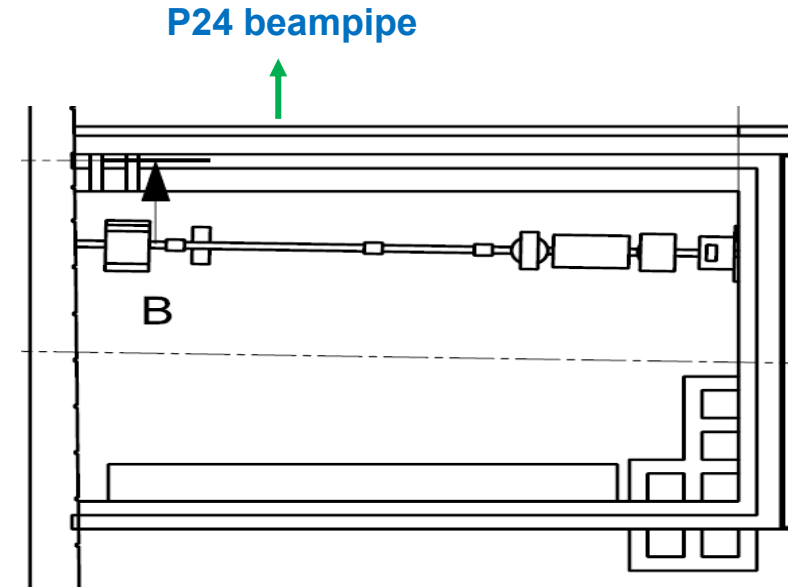
- FLUKA Monte Carlo code
 - Used for first enclosure shielding calculations
 - Used for synchrotron radiation source (Spectrum from Undulator group) to compare with STAC8 results
- STAC8
 - Used for experimental hutches shielding calculations
 - To calculate reflected beam flux
- FS-US (Undulator group at photon science)
 - Compute the synchrotron radiation source term to compare with STAC8
- Beamline scientist
 - Compute the synchrotron radiation source term
 - Beamline alignment, optic components

Challenges to build Beamline P25

- The first concept of OH1 layout



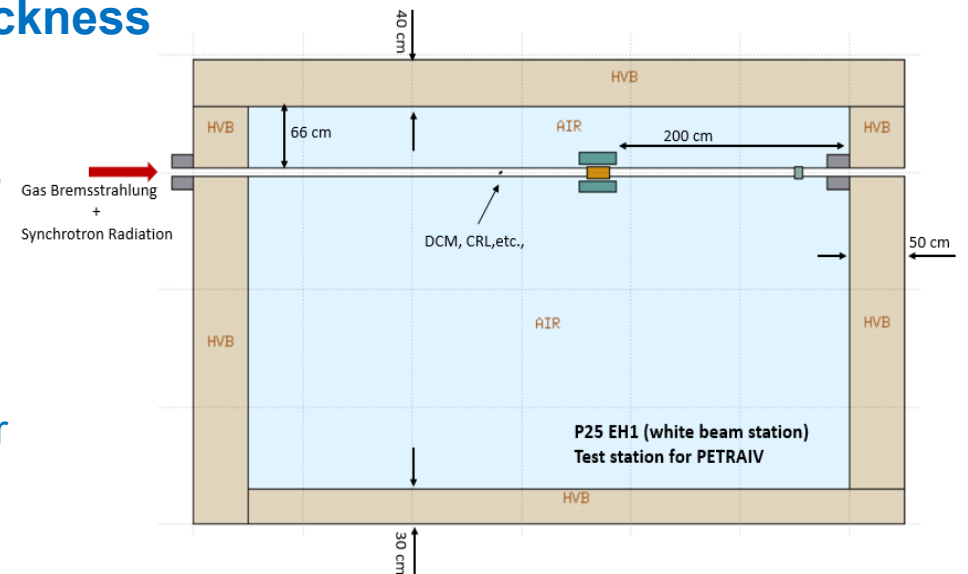
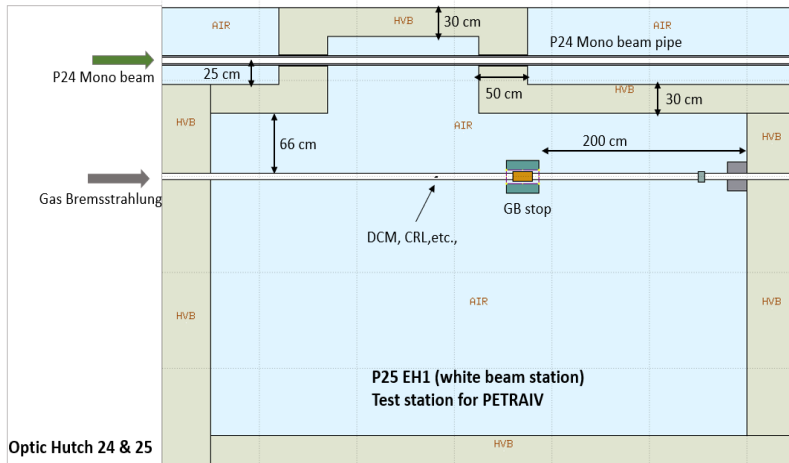
➤ To prevent local shielding issues and minimize the risk of radiation leakage



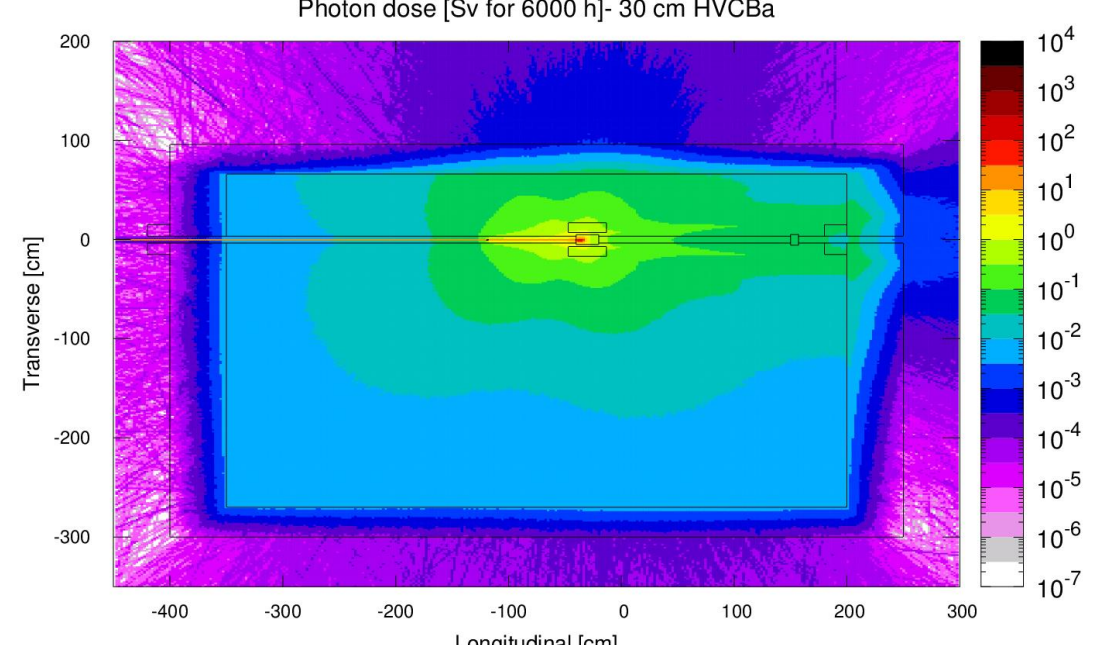
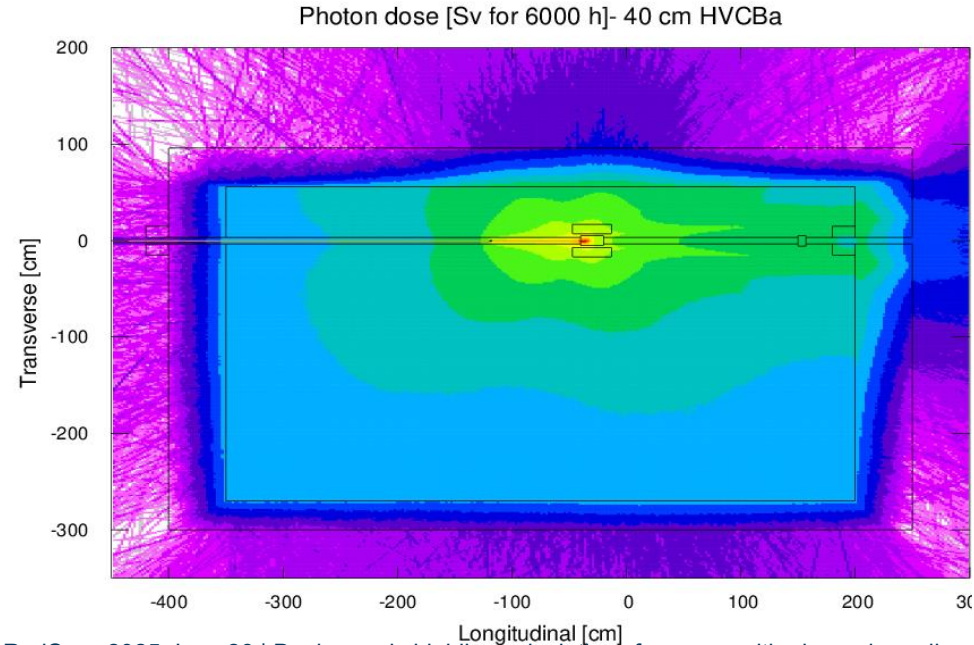
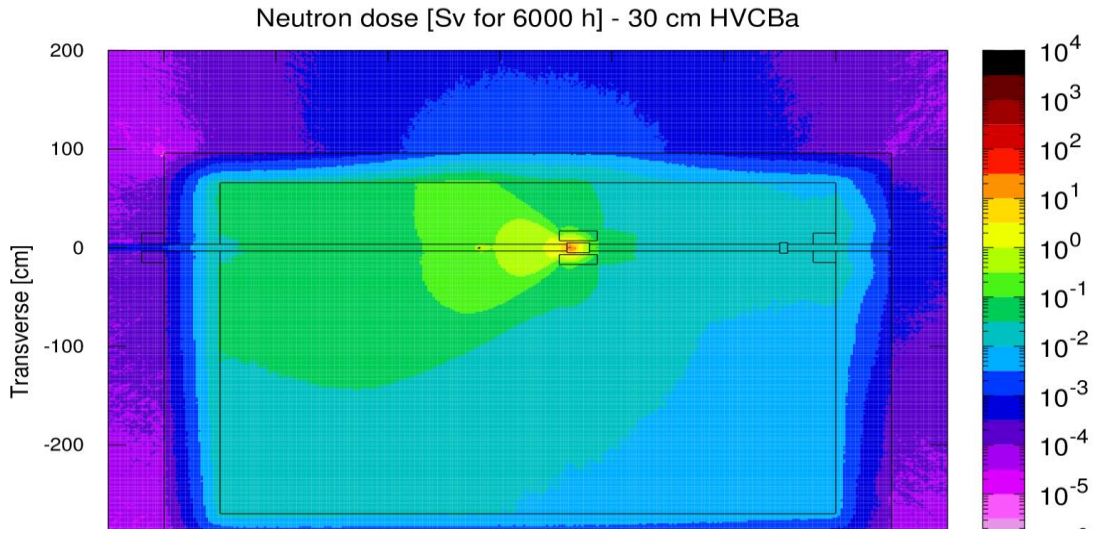
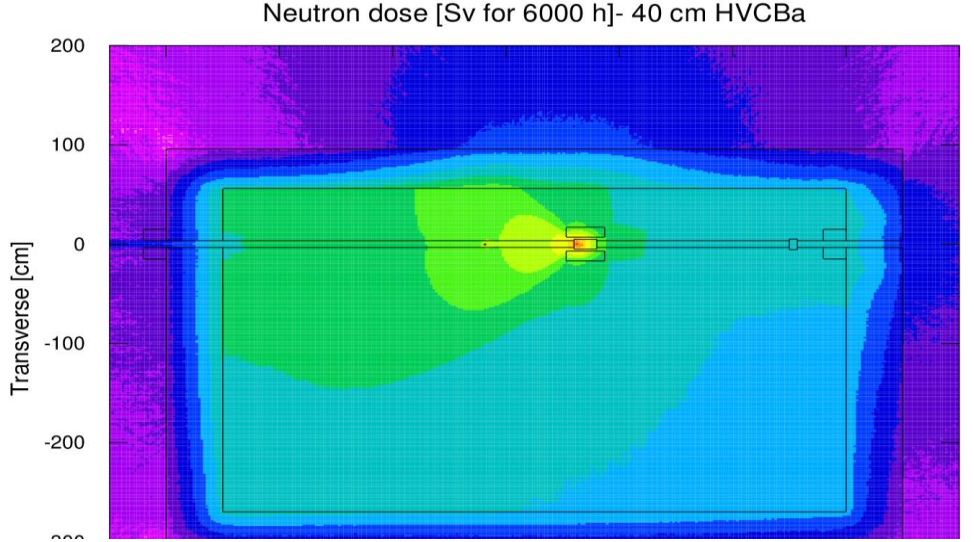
➤ To define the Side Wall Thickness

FLUKA calculations parameters

- Electron energy: 6 GeV
- Operation time: 6000 h
- Beam current: 200 mA
- Length of ID section: 14.5 m
- Vacuum pressure: $1.7e^{-08}$ mbar
- Gas: Air

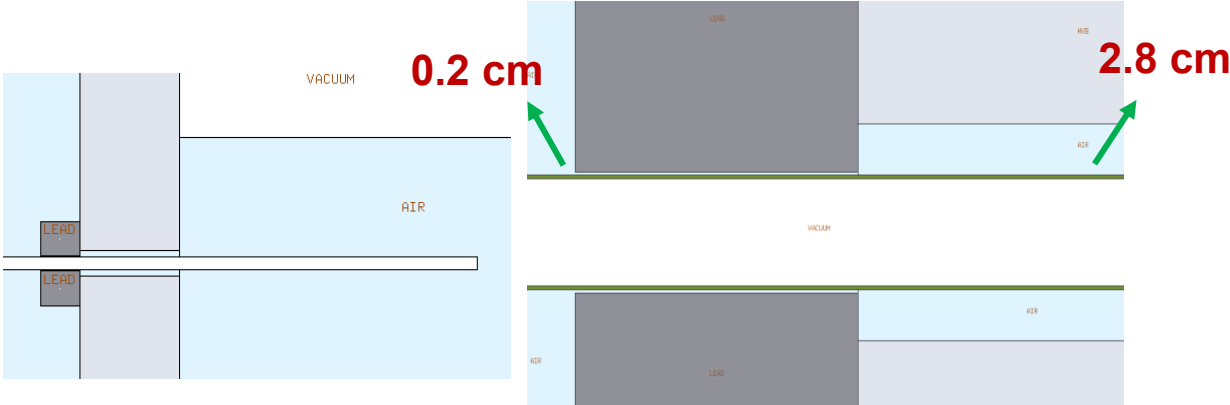
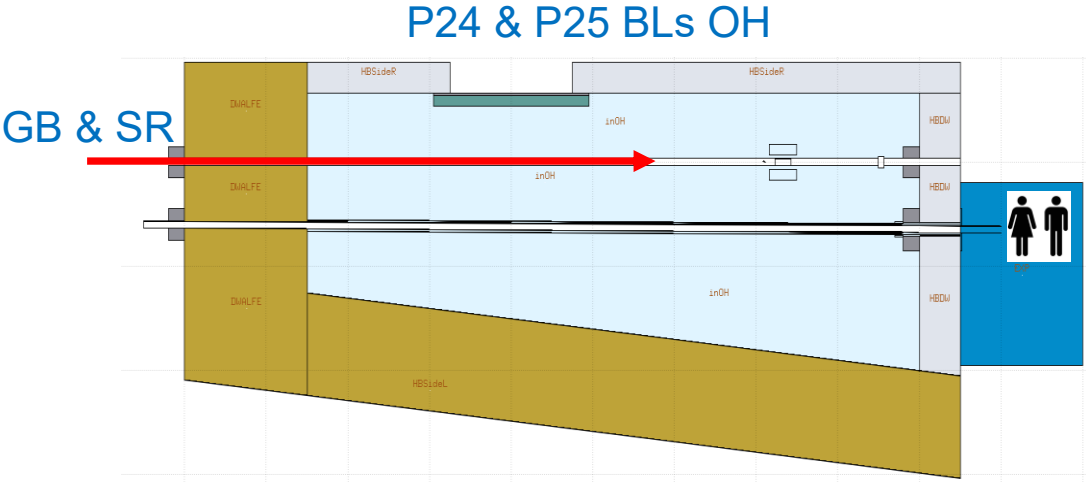
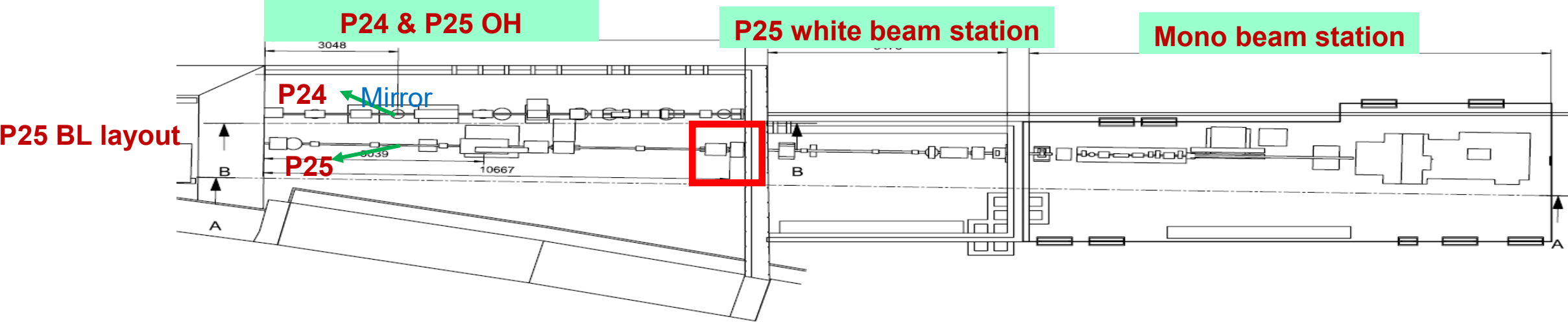


Neutron and Photon Dose from Gas Bremsstrahlung



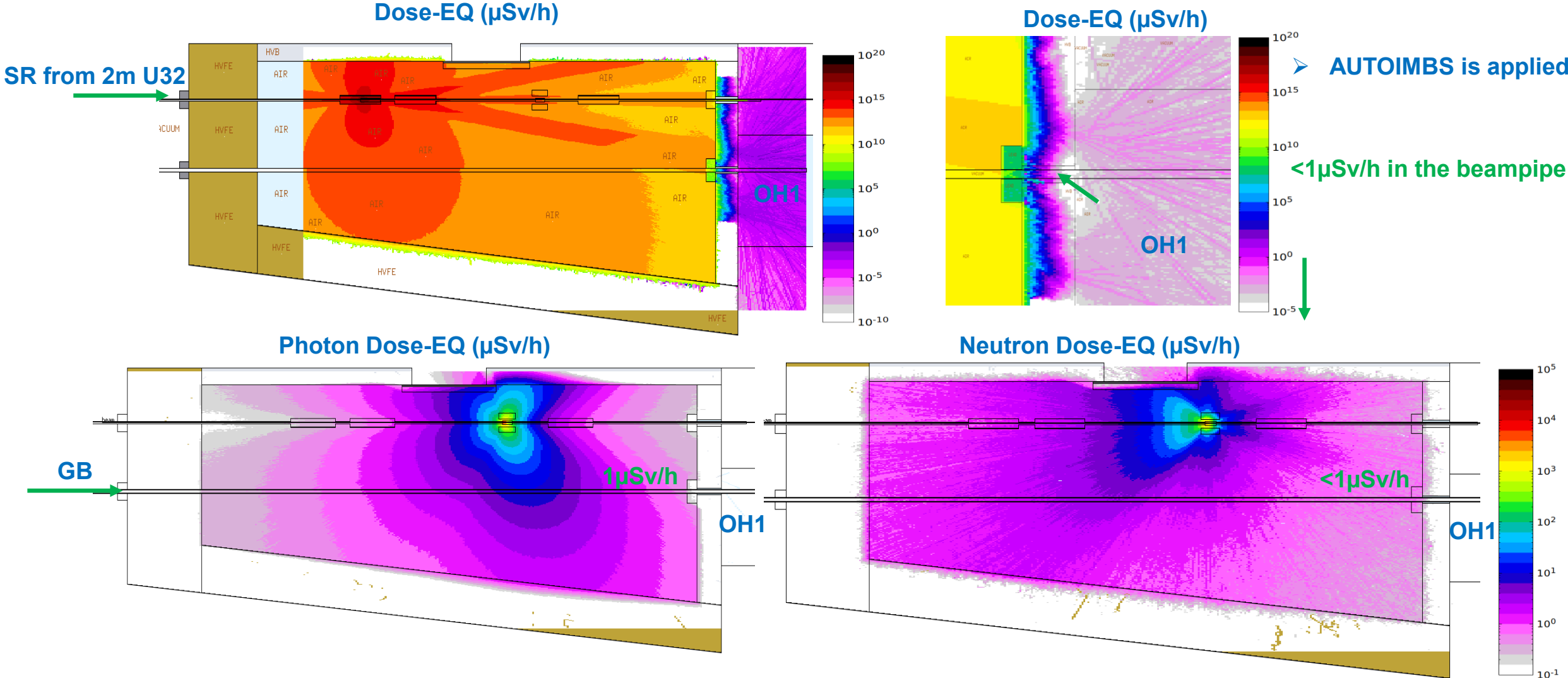
Challenges to build Beamline P25

➤ There is no beam shutter at the P25 beamline at the end of optic hutch



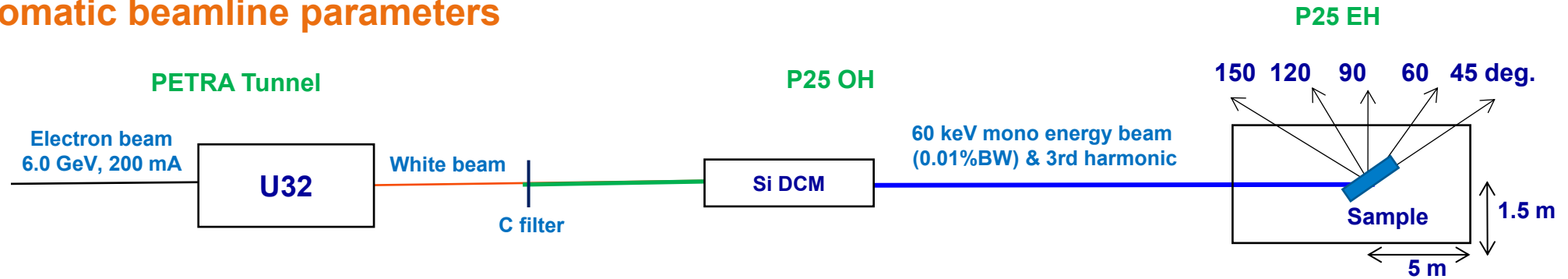
- The Gap between beampipe and collimator is 0.2cm
- The Gap between beampipe and concrete is 2.8 cm

Leakage dose into the OH1 at P25



STAC8 Shielding Calculation for Monochromatic Beam Hutch

Monochromatic beamline parameters



- **Key parameters of electron beam**

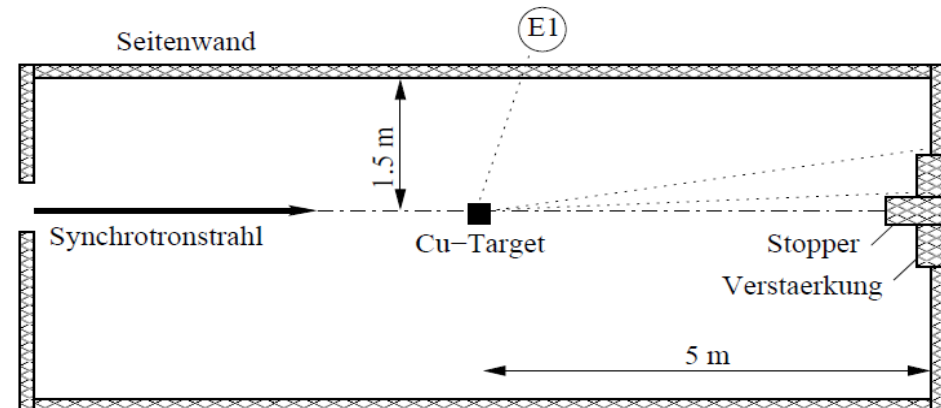
- Electron energy: 6 GeV
- Electron beam current: 200 mA

- **Key parameters of SR source**

- Undulator length: 2 m U32
- Period length: 32.8 mm
- Number of full periods: 62
- Peak field: 0.9 T

- **Key parameters of photon beam at EH**

- Maximum photon energy: 60 keV
- Maximum bandwidth: 0.01% (60 keV)
- Maximum 50 keV photon flux reaches the sample: $7.64E12$ photon/s



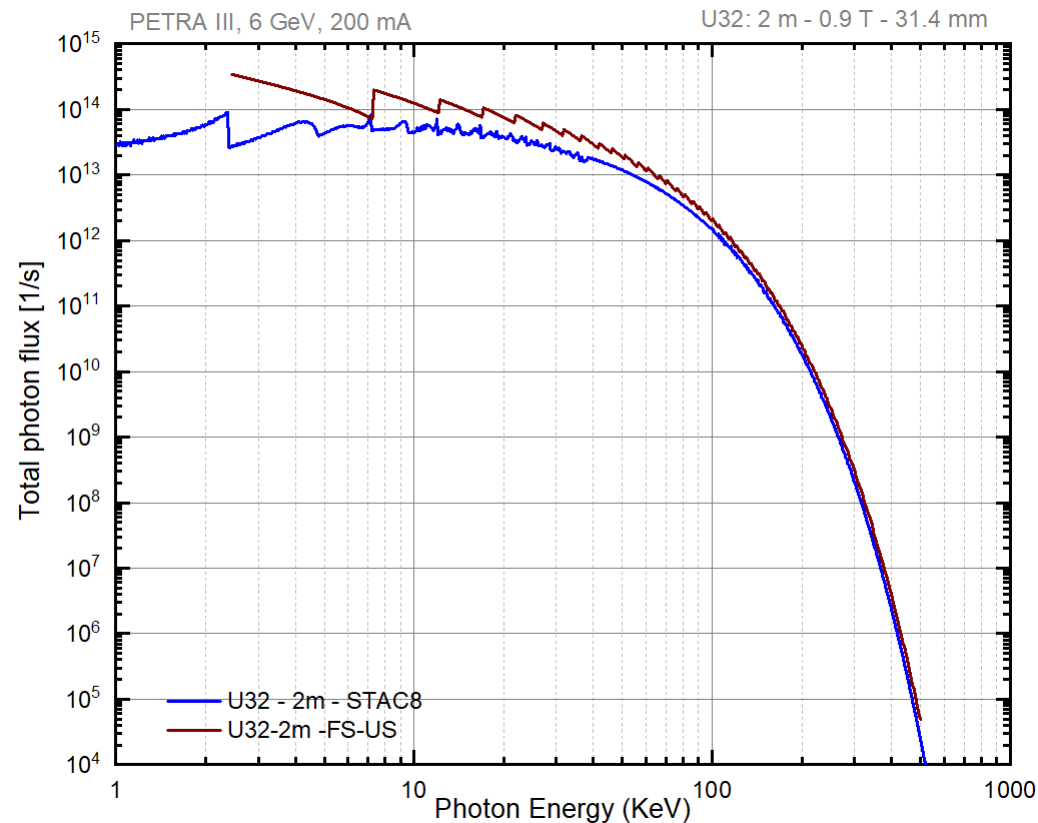
STAC8 Shielding Calculation for Monochromatic Beam Hutch

Monochromatic beamline

Necessary thickness of P25 EH walls & ceiling

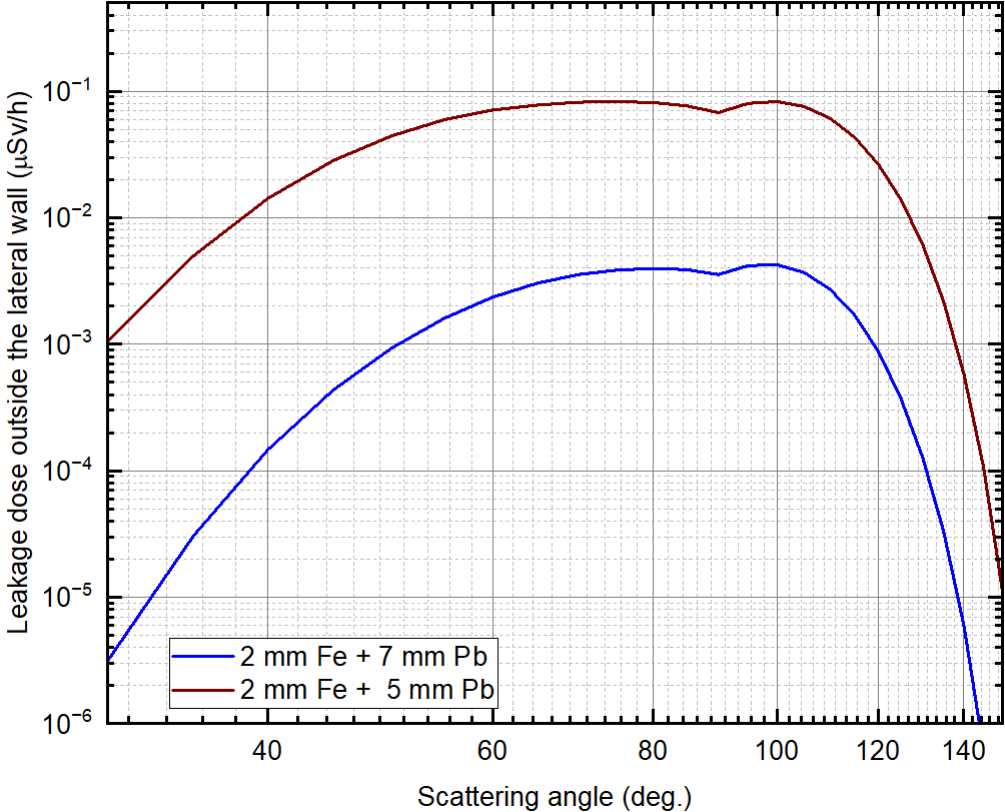
Shield case	Necessary shield thickness [mm]
Downstream wall	11
Ceiling	7
Upstream wall	
Lateral wall	
Lead layer on the floor	6

Synchrotron Radiation from Undulator



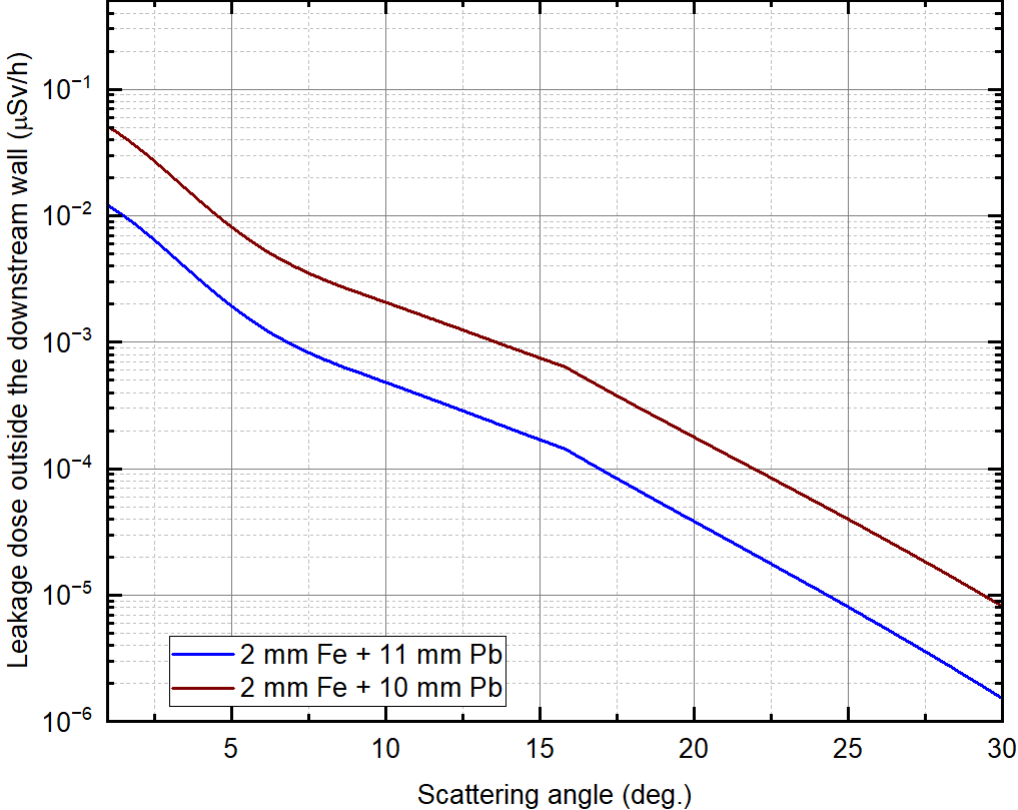
Effective dose outside the walls

Side wall



0.1 μSv/h outside the sidewalls

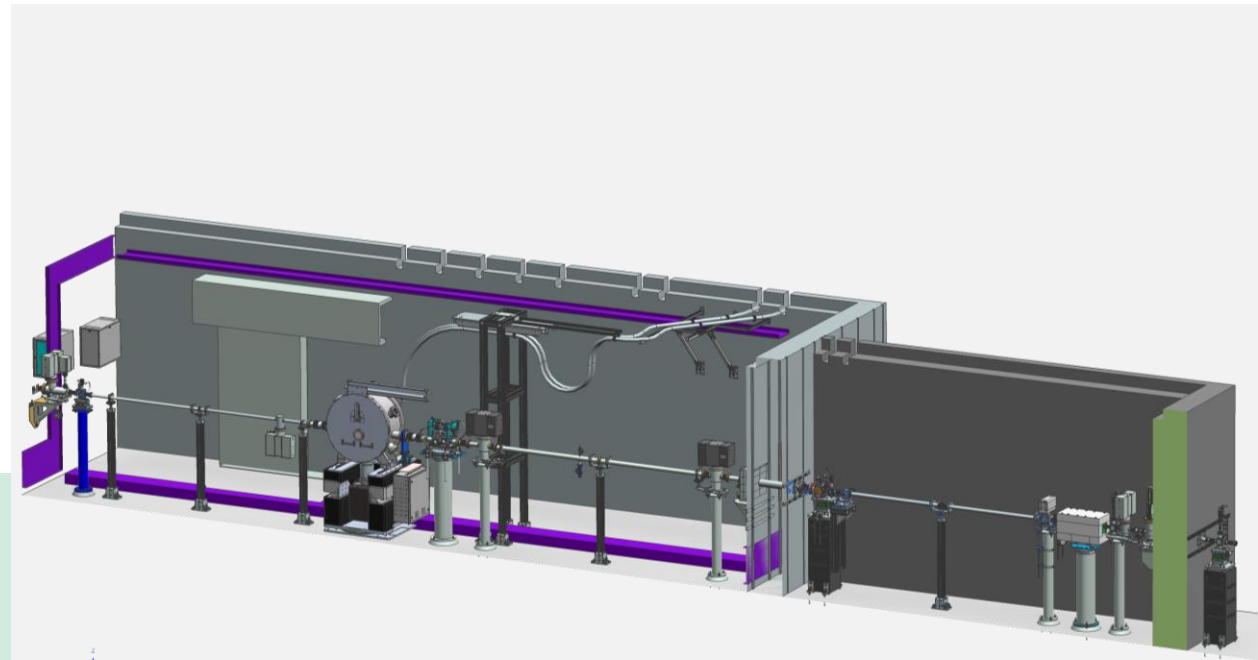
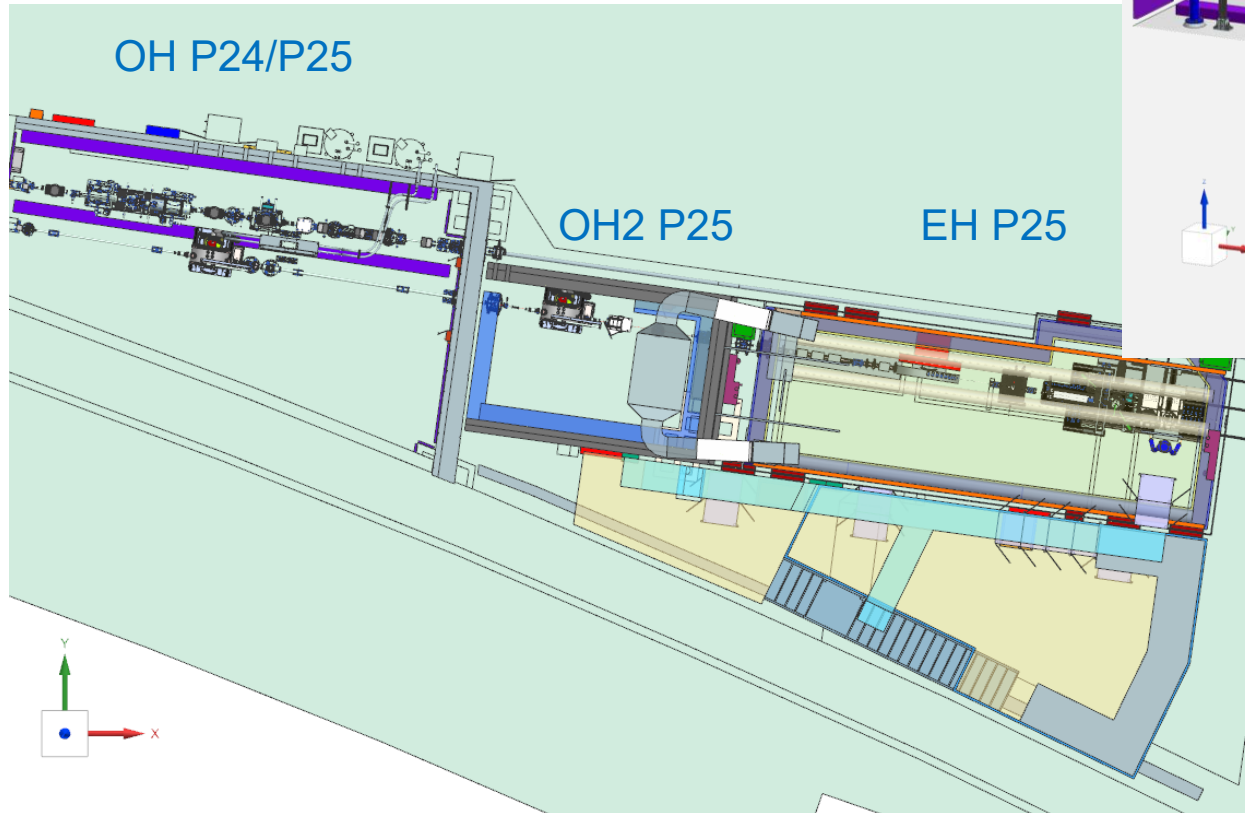
Downstream wall



Calculation without Beamstop at the end of the hutch

Final layout of P25

3D model with components



OH P24/P25

OH2 P25

Position	Costs rounded in kEuro
Front end	200
Shared optics hutch OH1	850
White beam hutch OH2	300
Experimental hutch EH	1.000
Powder diffraction endstation	1.300
XFI endstation	250
SXFM endstation	1.500
Media, radiation safety, beam transport	1.000
Beamline infrastructure	400
Control hutch	400
Lab infrastructure	300
In-vivo infrastructure/lab	350
SUM	7.850 €

Summary

Beamline P25 construction process at DESY



- Commissioning will start in autumn with 1mA run and monochromatic beam

PETRA IV.

Ultimate 4D X-Ray Microscope for Physical, Chemical, and Biological Processes

- What makes PETRA IV stand out?
- How does it transform our view on nature & technology?
- Understanding biological systems for fighting disease
- Understanding materials and processes for a sustainable future

➤ PETRA IV Budget: 1.7 B €

PETRA IV.

Outstanding Beam

Hard and high-energy X-rays from PETRA IV:

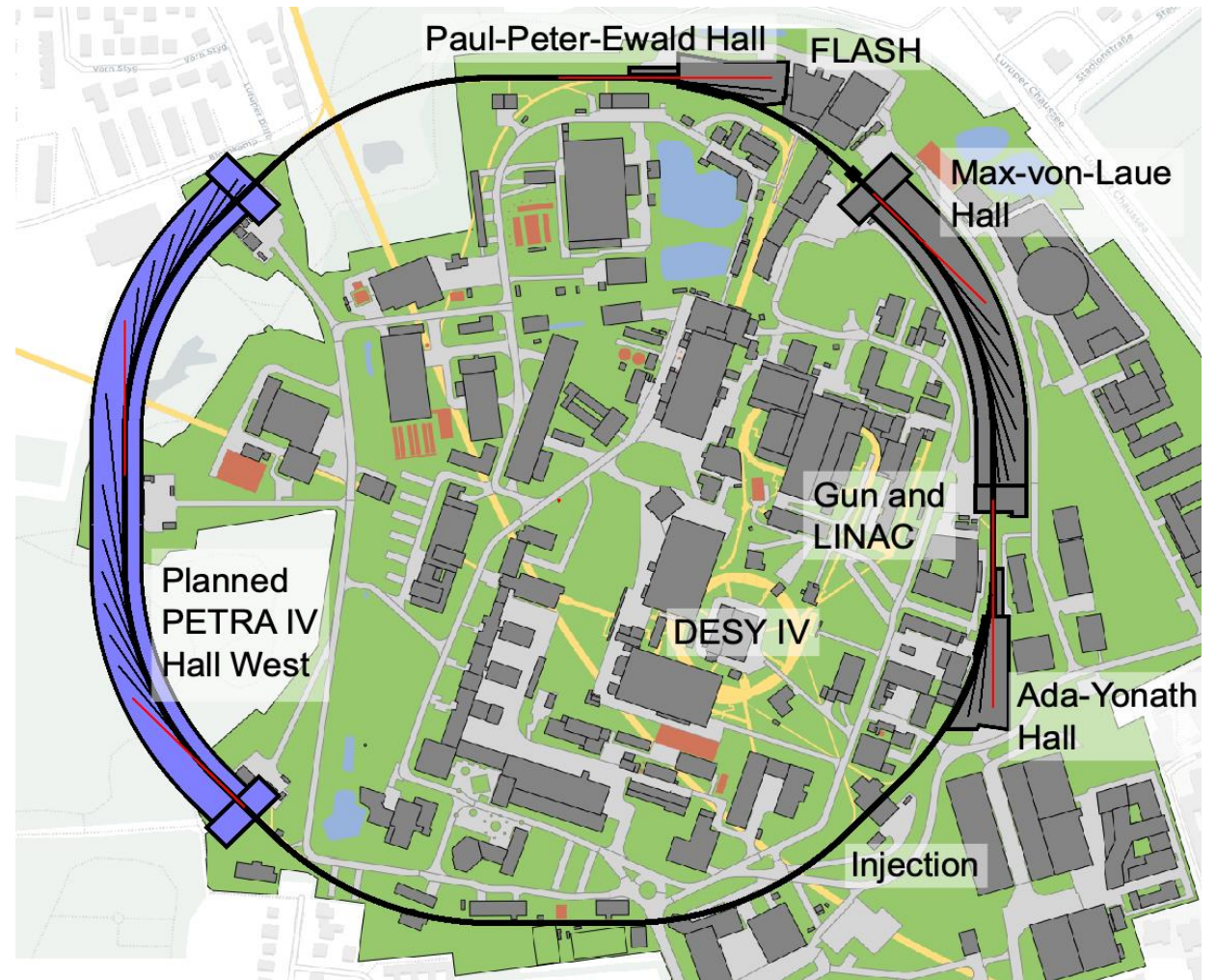
→ simultaneous **quantitative measurements** of physical and chemical properties:

- structural
- chemical
- electronic
- magnetic
- ...

→ large penetration depth:
observe *in situ*, *operando*, and *in vivo*

→ extreme brightness:
highest resolution and sensitivity

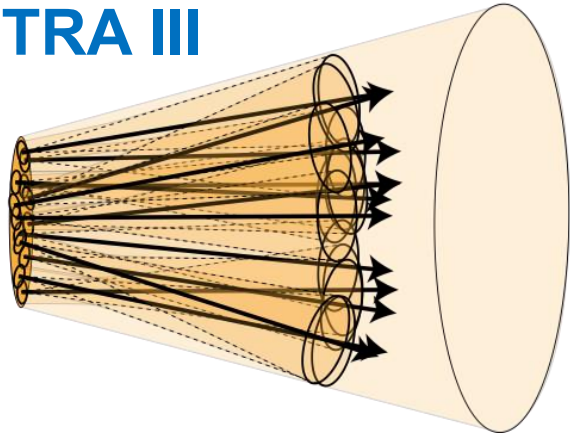
→ access to all relevant length and time scales



PETRA IV.

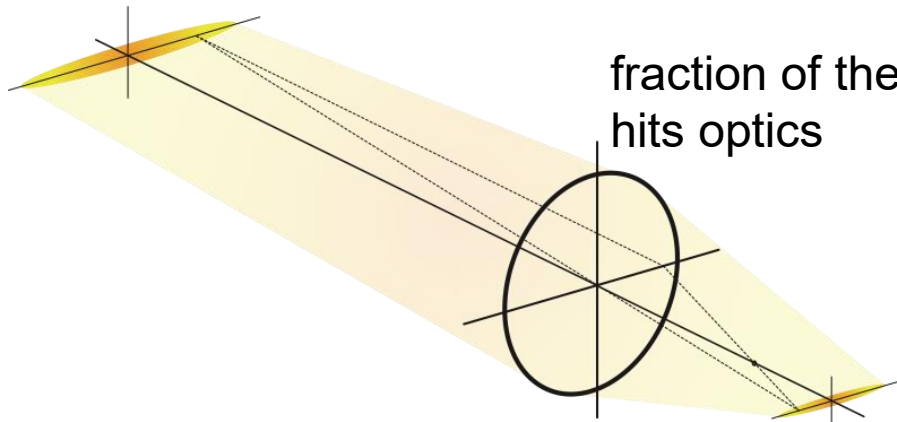
What makes the difference...

PETRA III



broad beam

extended source

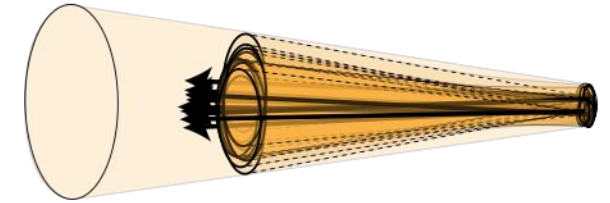


fraction of the light hits optics

extended focus

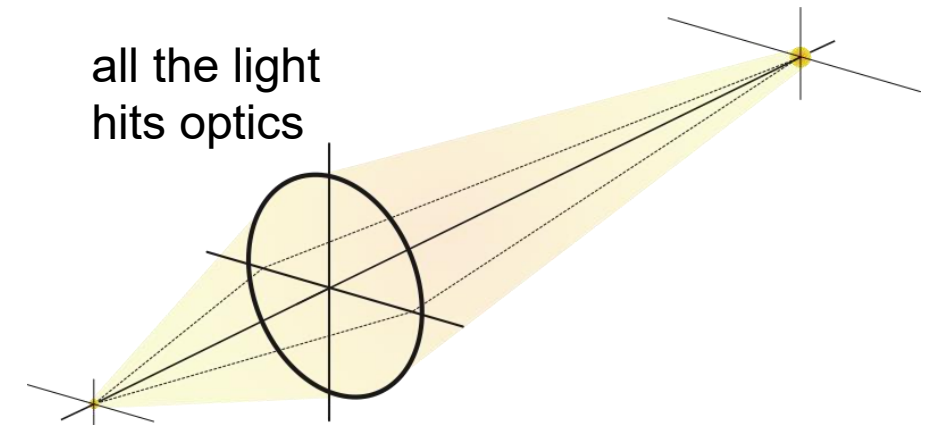
65 x lower emittance
optimised source size

PETRA IV



directed beam

point source

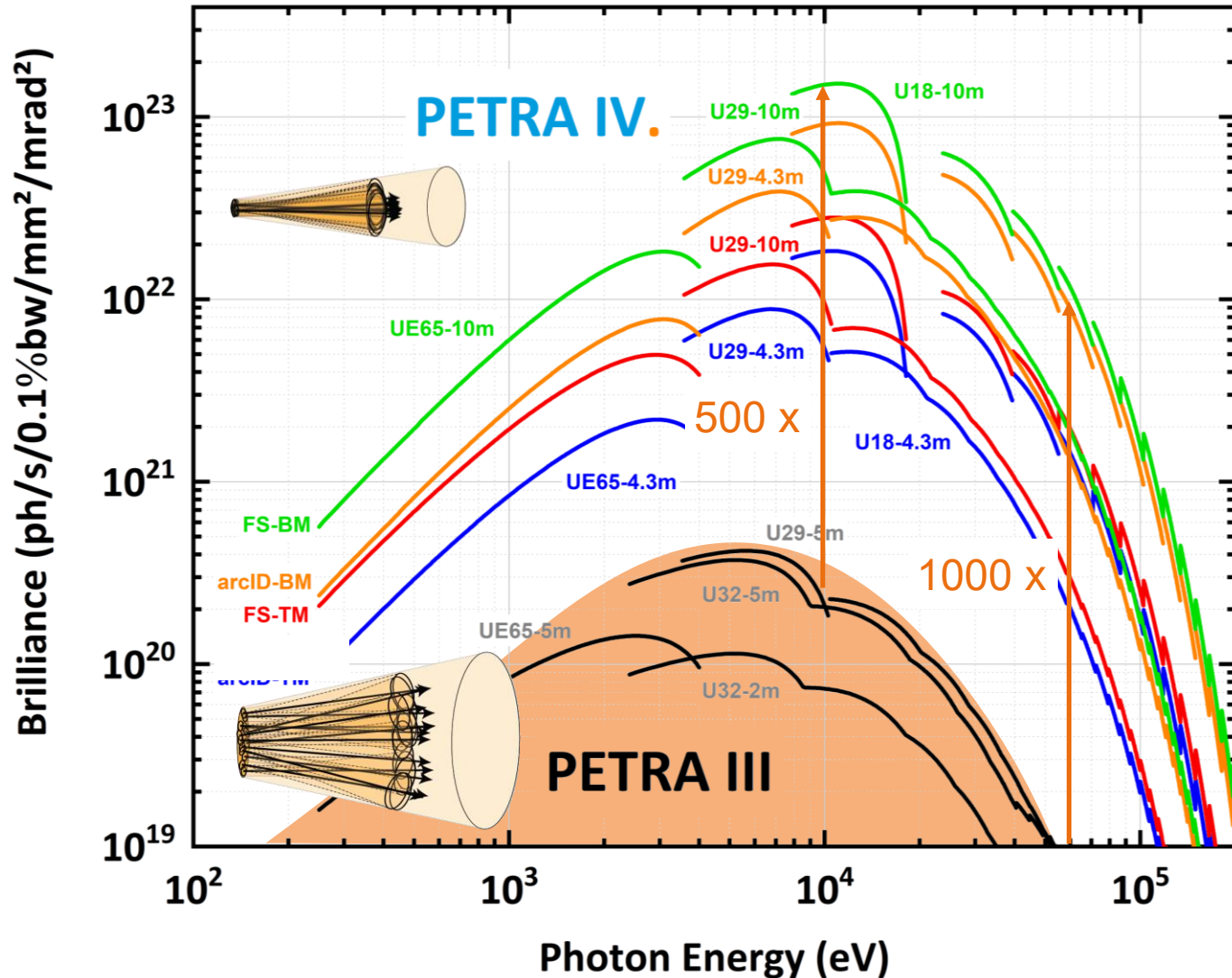


all the light hits optics

point focus
(diffraction limited)

PETRA IV.

Outstanding Beam



A factor 1000 is not just a factor!

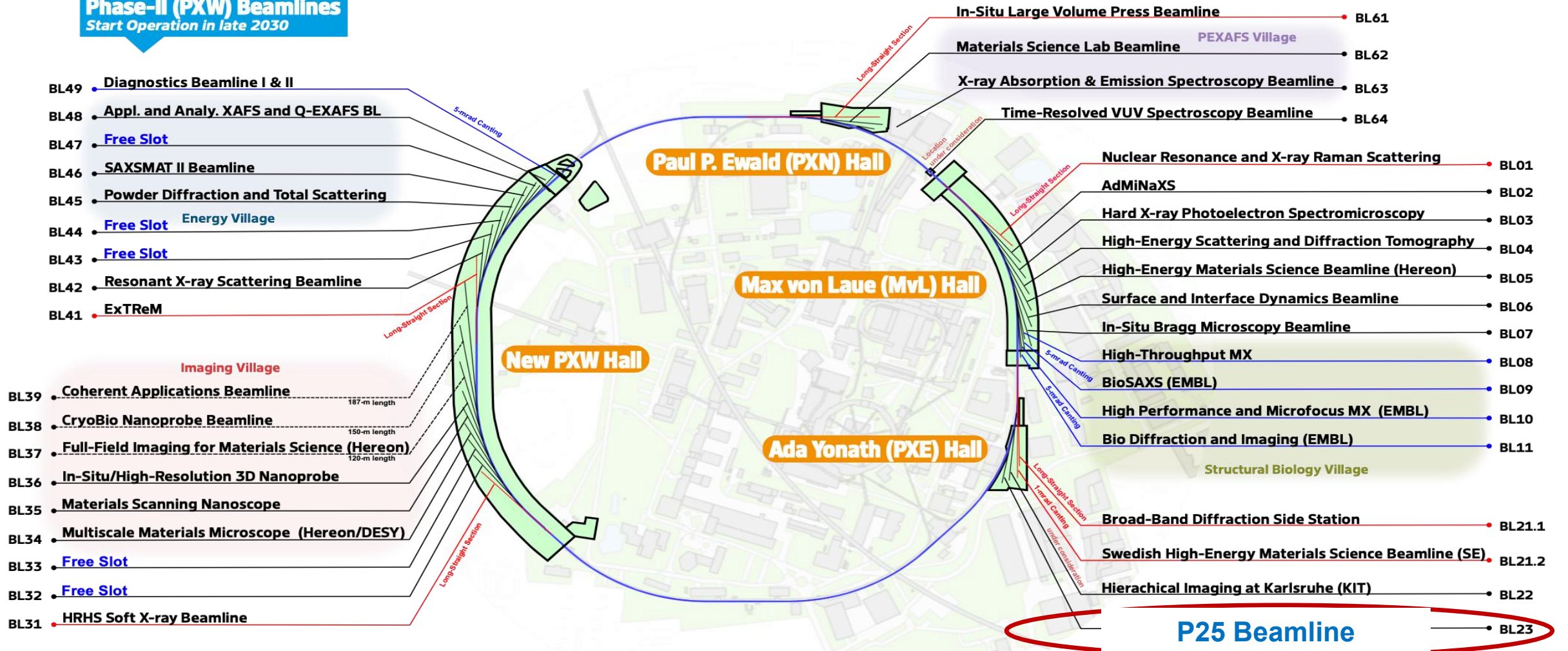
- It changes the way we can do experiments
- Transformative change towards following processes in nature and technology:
 - Watch things live as they happen...
 - Observe matter in detail from atomic dimensions to the macroscopic world...

PETRA IV.

Beamline portfolio

Phase-I Beamlines
Start Operation in 2029

Phase-II (PXW) Beamlines
Start Operation in late 2030



Plan for PETRA IV Optic and Experimental Hutches

Shielding Policy Scenario

- Ensure shielding of all enclosures are adequate with the strongest undulator source for worst case scenarios
- Assume twice reflection or 0.01% BW for monochromatic beams
- Assume 1% BW or assume once reflection scenario for pink beam
- Heavy concrete with iron may be utilized in constructing optic hutches rather than heave concrete with barium
- Goal is to limit the experimental hutch designs with the wall thickness
- To provide a category for experimental hutches.
- The category depends on the ID devices parameters and optic components

Wall thickness of experimental hutches

PETRA Halls	Straight section	Undulator Wiggler Bending magnet	Insertion device length [m]	period length [mm]	Peak Field [T]	Max. Energy [keV]	Bandwith [keV]	Energy of calculation [keV]	Lateral wall [mm]	Downstream wall [mm] 120 cm x 120 cm R > 115 cm R < 115 cm [mm]		Roof [mm]	Beam stop @ Downstream 30 x 30 cm ² (mm)	Beryllium Box 10 x 10 x 10 cm ³ (mm)	Beam pipe 20 cm x 100 cm (mm)
47C Hall	P01	U36-10 m	10 (2 x 5 m)	36	0.91	73	0.01 %		13	28	28	13	75		
	P02-1	U23	2	23	0.61	60	0.01 %		14	16	16	14	30		
	P02-2					100	0.01 %		16	30	30	16	80		
	P03	U29	2	29	0.81	25	1 %	25; 3.Harmon. 75	6.5	7	7	6.5	20	8.5	3;1
	P04	UE65-APPLE	5	65.6	1.1	3		3; 3.Harmon. 9	No Shielded EXP Hutch			No Beam Stop			
	P05	U29	2	29	0.81	50	1 %	50; 3.Harmon. 150	10	11	11	10	20		
	P06	U32	2	31.4	0.91	120	1 %	100; 3.Harmon.300	16	30	45	16	80		
	P07	IVU-21	4	21.2	0.7	300	1 %	300; 3.Harmon.900	10	20	30	10	60		
	P08	U29	2	29	0.81	30	0.01 %	30; 3.Harmon. 90	5	11	11	5	30		
	P09	U32	2	31.4	0.91	50	0.01 %	50; 3.Harmon. 150	5	11	11	5	30		
	P10	U29-5 m	5	29	0.81	25	1 %	25; 3.Harmon. 75	7	6	7	7	20		20
	P11	U32	2	31.4	0.91	25	0.01 %	25; 3.Harmon. 75	4.5	5	5	4.5	20		
	P12	U29	2	29	0.81	20	1 %	20; 3.Harmon. 60	3.5	3.5	3.5	3.5	20		20
	P13	U29	2	29	0.81	35	1 %	35; 3.Harmon. 105	14	18	18	14	30		
P14	U29	2	29	0.81	35	1 %	35; 3.Harmon. 105	14	18	18	14	30			
East Extension Hall	P21-1 (b)	U29	2	29	0.81	100	0.1 %		10	10	10	10	60		
	P21-2 (a)	IVU-21	4	21.2	0.7	150	0.01 %	300; 3.Harmon.900	10	20	25	10	60		14
	P21-OH2								11	20	25	10			
	P22	U32	2	31.4	0.91	50	0.01 %	50; 3.Harmon. 150	6	6	6	6	30		12
	P23	U32	2	31.4	0.91	50 (29)	0.01% (1%)	50; 3.Harmon. 150	6	6	6	6	30		12
	P24	U29	2	29	0.81	50	0.01 %	50; 3.Harmon. 150	6	6	6	6	30		12
	P25	U32	2	31.4	0.91	60	0.01 %	60; 3.Harmon. 180	7	11	11	7			
	P25	U32	2	31.4	0.91		white Beam	Heavy Concrete Hutch				200			
North Extension Hall	P61	Damping wiggler	40 (10 x 4)	200	1.52		white Beam	Heavy Concrete Hutch				200			
	P62	U32	2	31.4	0.91	35	0.01 %	30; 3.Harmon. 90	6	6	6	6	30		
	P63	U29	4	29	0.91	60	0 %	65; 3.Harmon. 195	7	11	11	7	80		
	P64	U33	2	32.8	0.9	50	0.01 %	50; 3.Harmon. 150	6	11	11		30		12
	P65	U33	0.38 (11 or 12 period)	31.4	0.91	50	0.01 %	50; 3.Harmon. 150	7	11	11		30		
47K (Superlum)	P66	Bending magnet	1	1	0.87	0.04		UV-VUV	No Shielded EXP Hutch			No Beam Stop			

PETRA IV. In the science city Hamburg

Timeline



International context



Science Case in Conceptual Design:



Thank you



Contact

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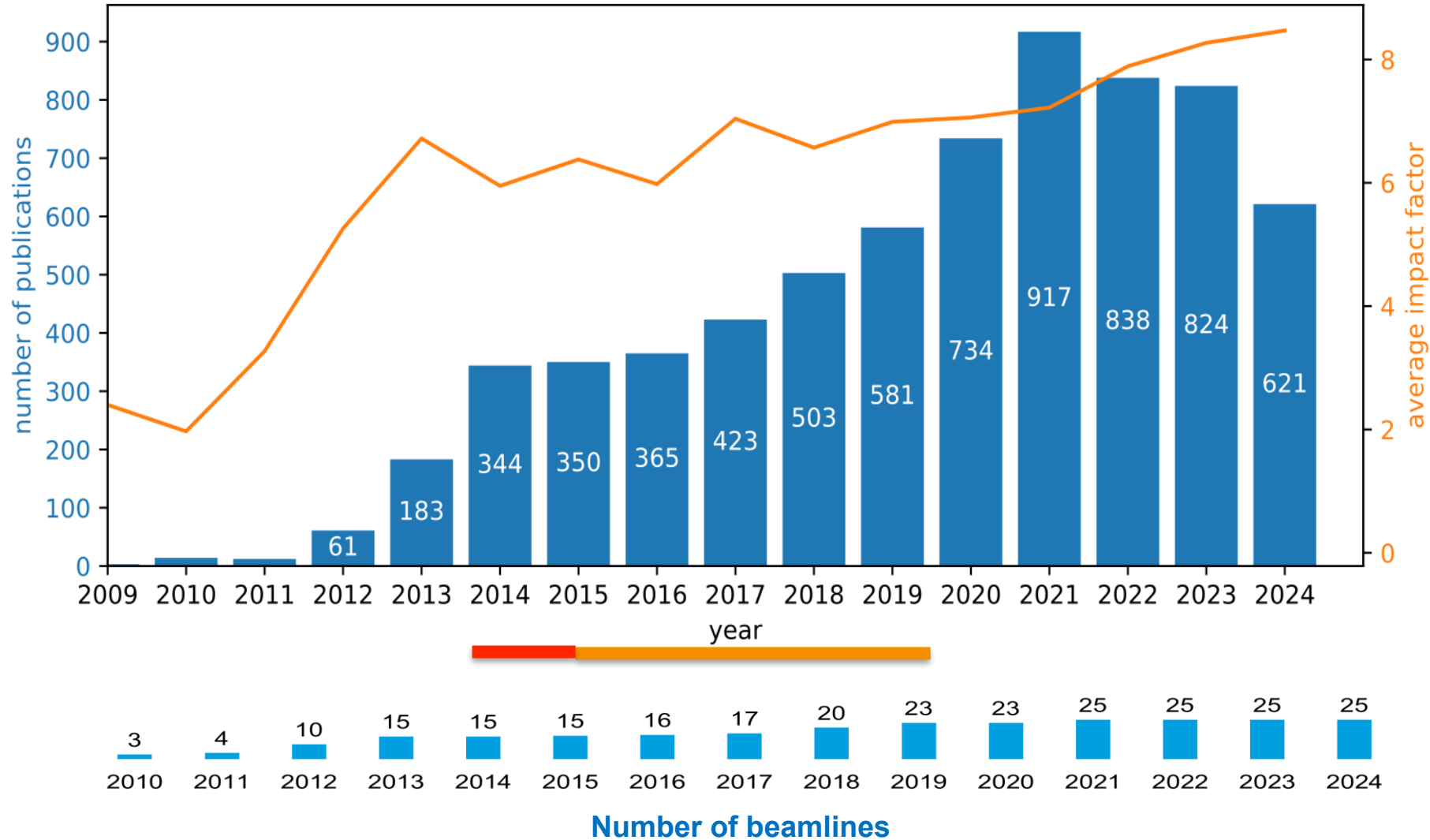
DESY. Deutsches Elektronen-Synchrotron
www.desy.de

Thanks to FS-TI, MPS and D3



PETRA III Publications

As of April 2025



WOS listed:

Publications: 6791

IF > 7: 2000 (29%)

Mean IF: 7.2

2024:

Publication: 823*

IF > 7: 249 (40%)

Mean IF: 8.5

pubdb.desy.de

* incomplete

Wall Thickness and Material of Optic Hutches

Wall Thickness and Material

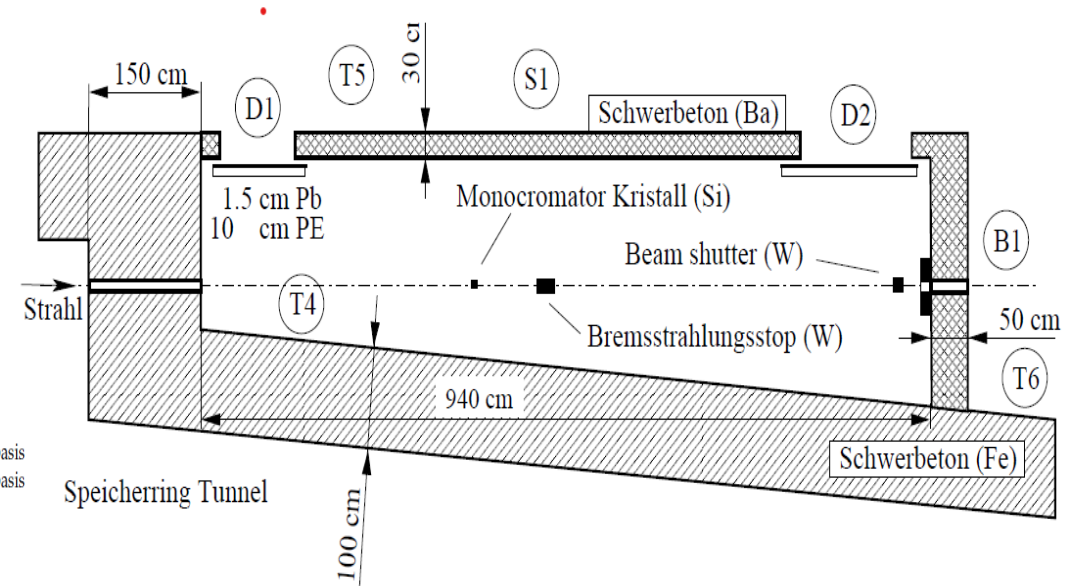
Optic Hutch: First enclosure after tunnel

- Wall Materials: Heavy concrete with barium and heavy concrete with iron
- Door: Lead and Polyethylene

Table 2 Compositions of the heavy concretes

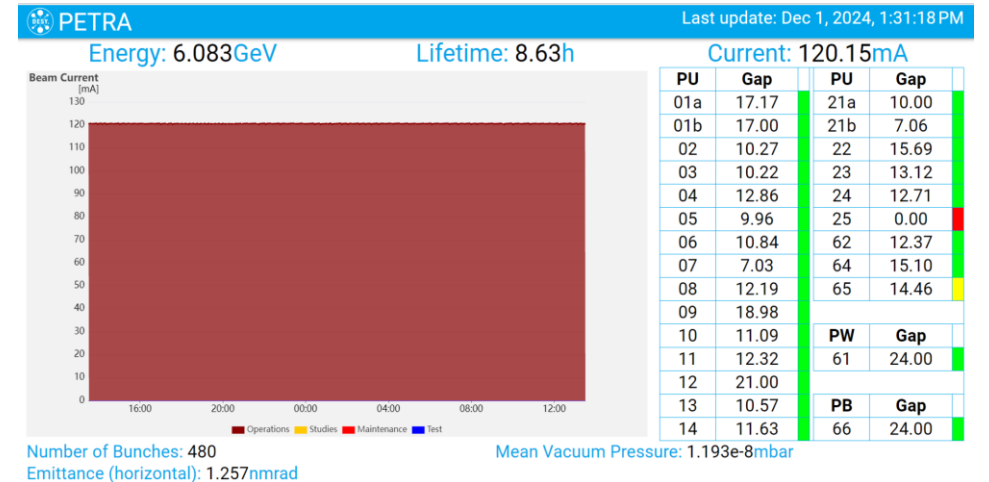
	Heavy concrete(Fe)	Heavy concrete(Ba)
Density	3.7 g/cm ³	3.35 g/cm ³
Composition(W/O)		
H	0.004	0.0036
O	0.345	0.3116
Mg	0.019	0.0012
Al	0.010	0.0042
Si	0.069	0.0105
F	-	0.1079
Ca	0.048	0.0502
Fe	0.505	0.0475
Ba	-	0.4633

Komponente	Dicke	Dichte	Material
Seitenwand	30 cm	3.35 g/cm ³	Schwerbeton auf Barytbasis
Rückwand	50 cm	3.35 g/cm ³	Schwerbeton auf Barytbasis
Bremsstrahlungsstop	Ø10 cm × 20 cm	17 g/cm ³	Wolfram (Densimet)
drumrum Neutronenabschirmung	10 cm	0.92 g/cm ³	Polyethylen
Tür, innere Lage	10 cm	0.92 g/cm ³	Polyethylen
Tür, äußere Lage	1.5 cm	11.3 g/cm ³	Blei



FLUKA calculations parameters

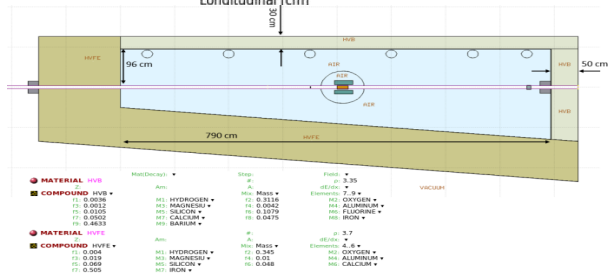
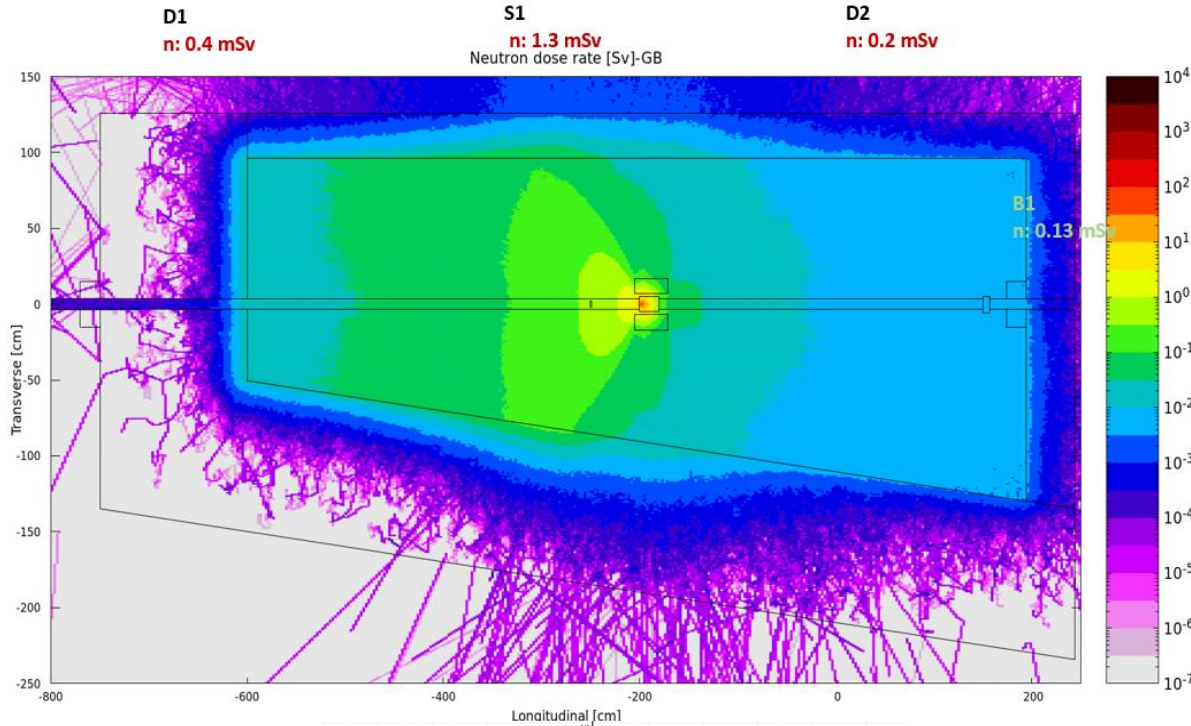
- Electron energy: 6 GeV
- Operation time: 6000 h
- Beam current: 200 mA
- Length of ID section: 14.5 m
- Vacuum pressure: 1.7E⁻⁰⁸ mbar
- Gas: Air



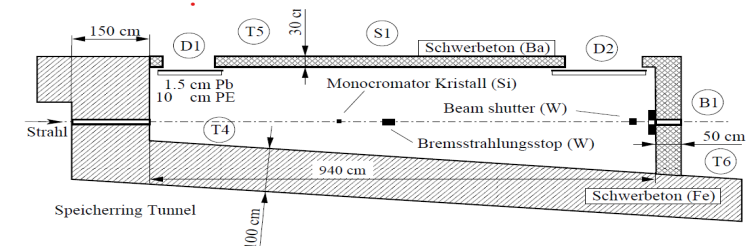
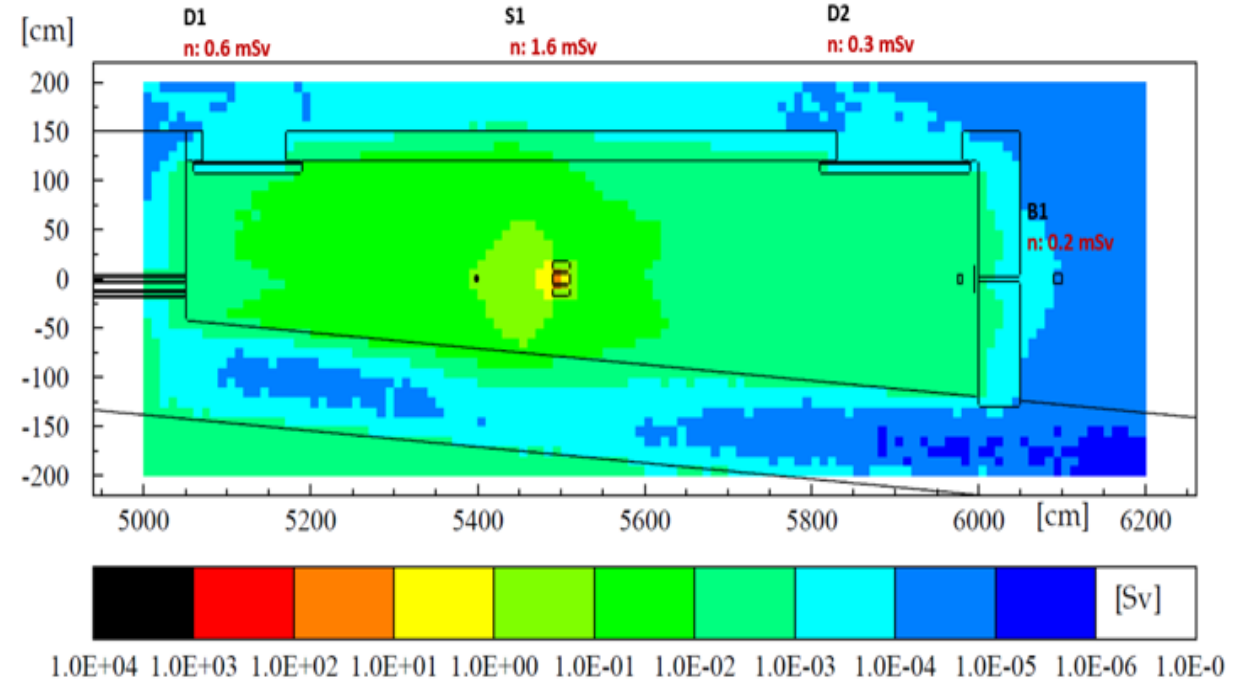
PETRA III Optic Hutches

Equivalent dose due to neutrons caused by 1200 Ah and 1.7 μPa air in the undulator section

FLUKA 2022



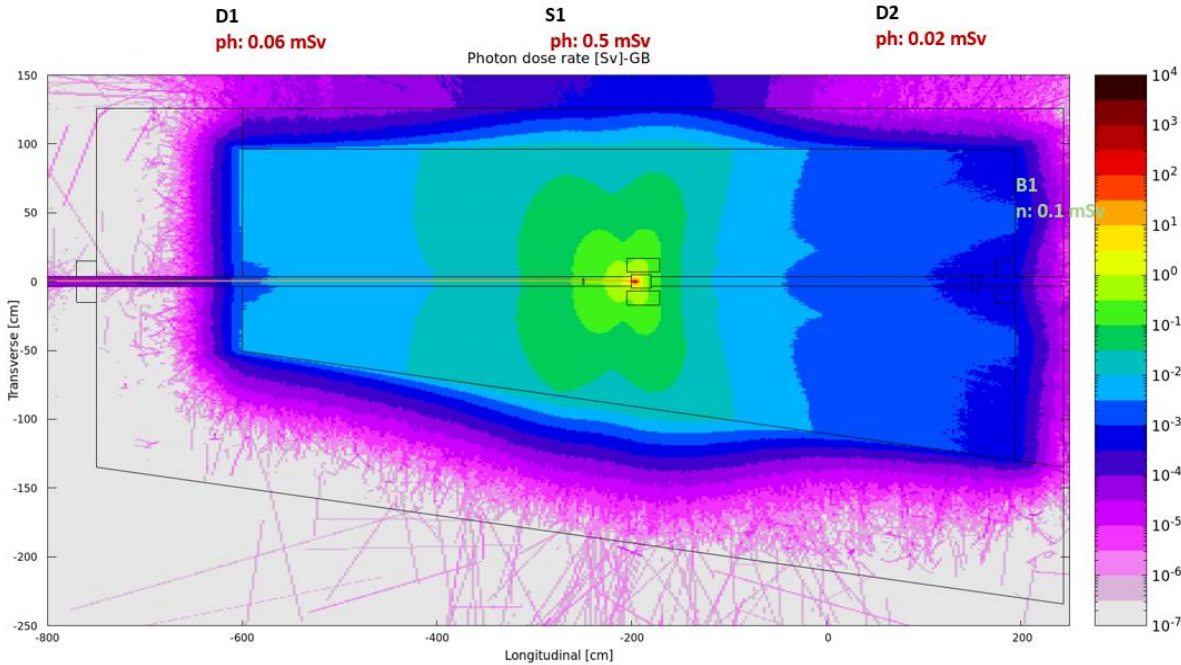
FLUKA 2006



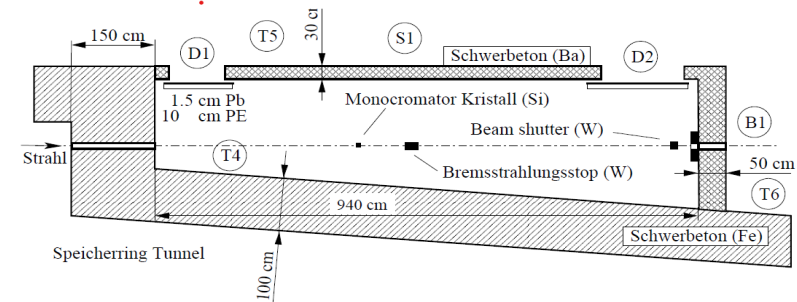
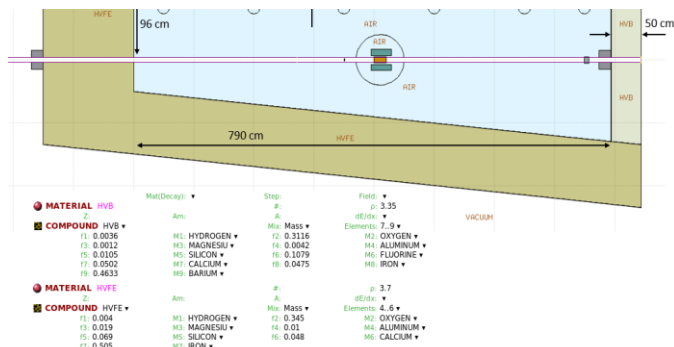
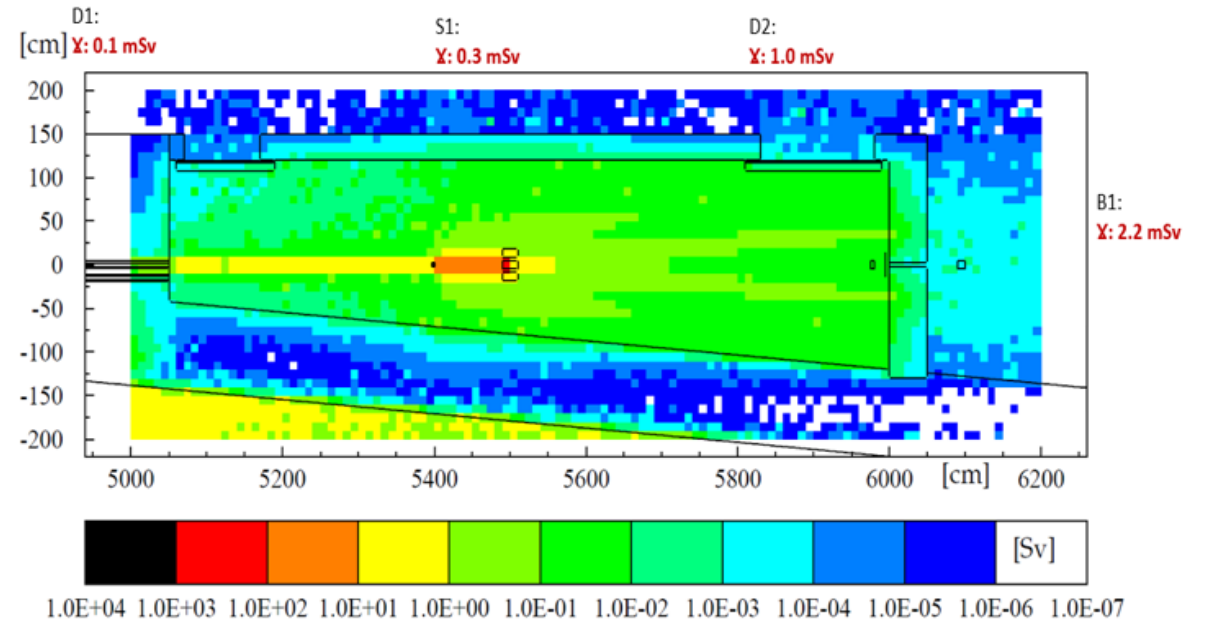
PETRA III Optic Hutches

Equivalent dose due to photons caused by 1200 Ah and 1.7 μPa air in the undulator section

FLUKA 2022

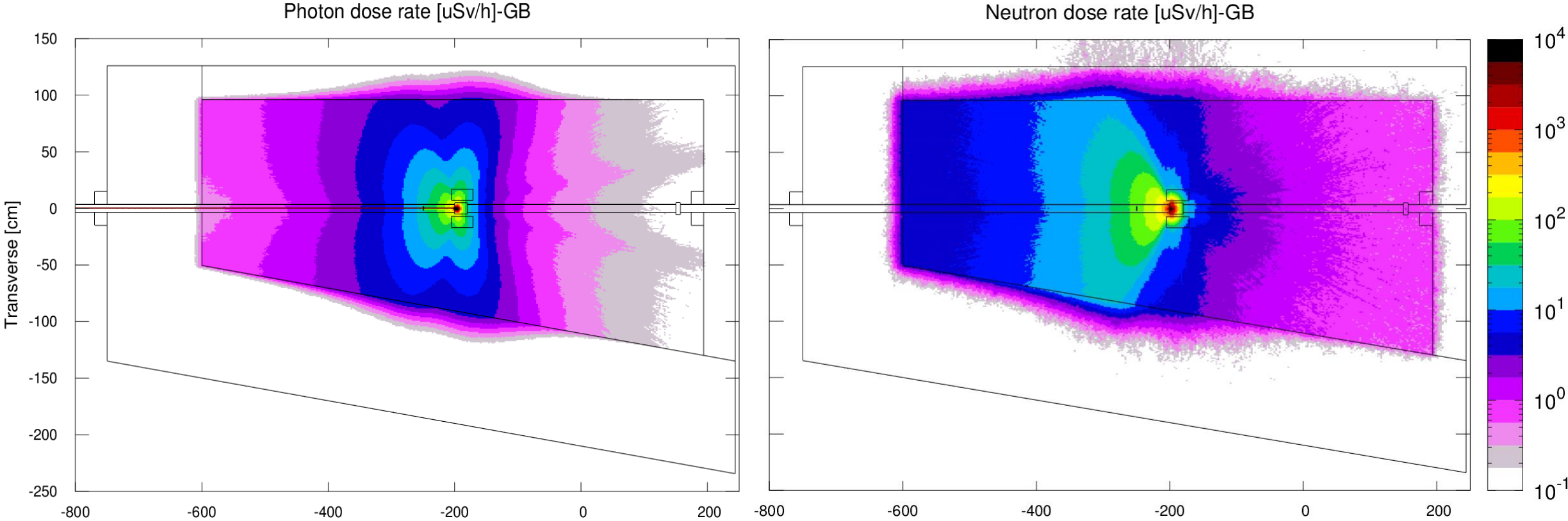


FLUKA 2006



PETRA III Optic Hutches

Equivalent dose due to neutrons and photons caused by 1200 Ah and 1.7 μPa air in the undulator section



FLUKA 2022

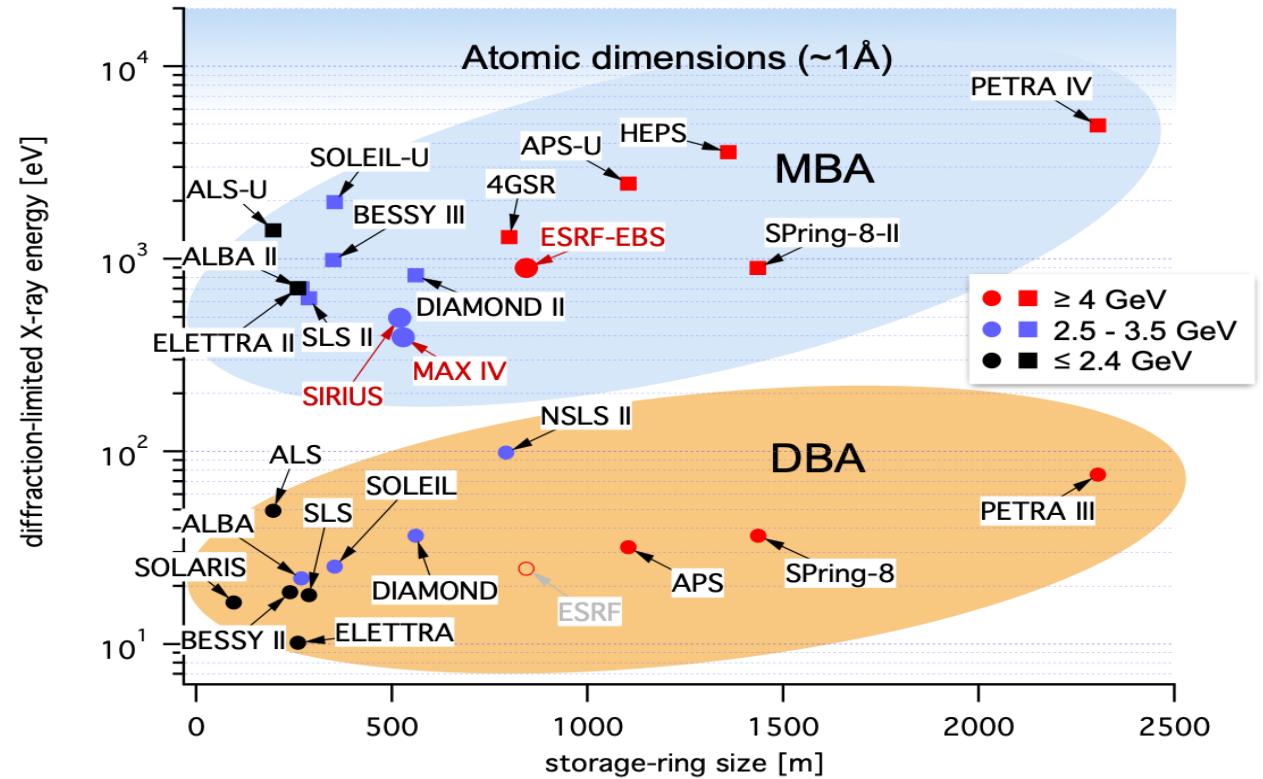
PETRA IV.

Outstanding Beam

	H6BA Technology		DBA Technology	
	PETRA IV	PETRA IV	PETRA III	PETRA III
Mode of Operation	brightness mode	timing mode	continuous	timing mode
Number of Bunches	1600 - 1920	80 (40)	480 - 960	40
Total current [mA]	200	80 (80)	120	100
Bunch current [mA]	0.125	1.0 (2.0)	0.25 - 0.125	2.5
Arc ID β_x/β_y [m]	2.2 / 2.2		high β : 20.0 / 4.0	
long ID β_x/β_y [m]	4.0 / 4.0		low β : 1.4 / 4.0	
Hor. Emittance ϵ_x [pmrad]	20	35 (38)	1300	
Vert. Emittance ϵ_y [pmrad]	5	7 (8)	10	
Bunch length σ_z [ps]	30	65 (75)	40	43
Bunch separation [ns]	4	96 (192)	16 - 8	192
Energy spread σ_p [10^{-3}]	0.9	1.2 (1.5)	1.3	1.3
Touschek lifetime τ [h]	> 10	> 5	9 - 13	1.5
Number of beamlines	29 + 5 + 1 VUV		26 + 1 VUV	

New storage-ring technology:

Most synchrotron radiation sources are moving to the 4th generation based on multi-bend achromats (MBAs)



PETRA IV needed for Germany and Europe:

- strengthen science & technology
- maintain technological sovereignty