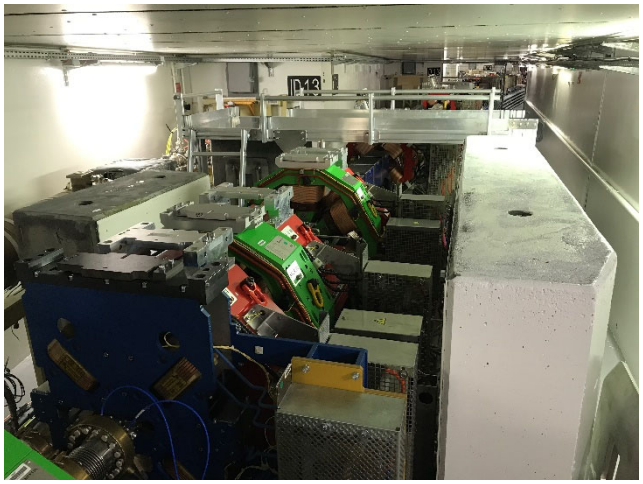
RADSYNCH 2023

ESRF, 30 May – 2 June 2023

The ESRF Extremely Brilliant Source (EBS)

Paul Berkvens, Patrick Colomp

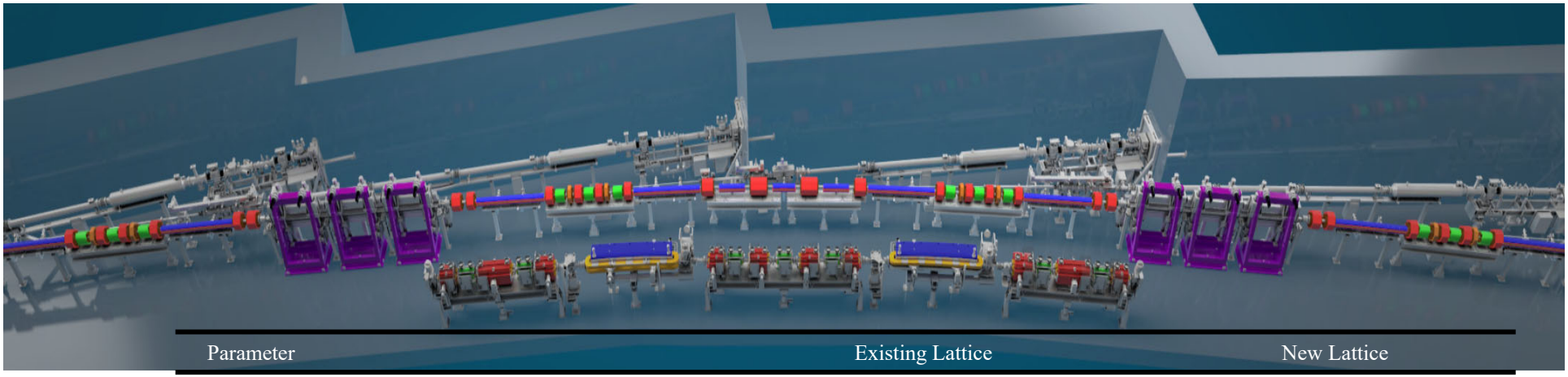


ESRF | The European Synchrotron

THE ESRF EXTREMELY BRILLIANT LIGHT SOURCE (EBS)

1. Introduction
2. Overview of commissioning
3. Validation of shielding calculations
    1. Storage ring
    2. Beamlines
4. Radiation damage in storage ring tunnel

THE ESRF EBS STORAGE RING



Parameter	Existing Lattice	New Lattice
Energy, *E* [GeV]	6.04	6.04
Circumference, *C* [m]	844	844
RF frequency, *fRF* [MHz]	352	352
Beam current [mA]	200	200
Horizontal Emittance [pm ·rad]	**4000**	**150**
Vertical Emittance [pm ·rad]	4	3
Beta at ID center, β*x* , β*y* [m]	37.6 , 3.0 (high β) 0.35 , 3.0 (low β)	3.6 , 3.6
Beam size at ID center, σ*x* , σ*y* [μm]	413 , 3.9 (high β) 50 , 3.9 (low β)	24 , 3.3
Beam div. at ID center, σ*x'* , σ*y'* [μrad]	10 , 1.3 (high β) 107, 1.3 (low β)	6.4 , 0.91

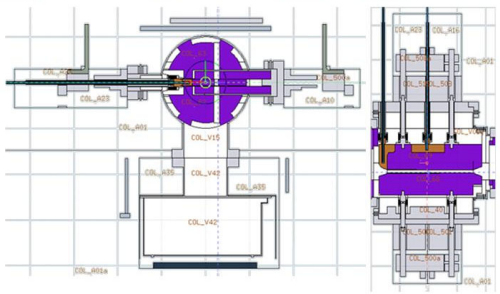
THE ESRF EBS STORAGE RING

$$\int_{4\ hours} \frac{dE}{dt} \cdot dt < 0.5\ \mu Sv/h \times 4\ h = 2\ \mu Sv$$

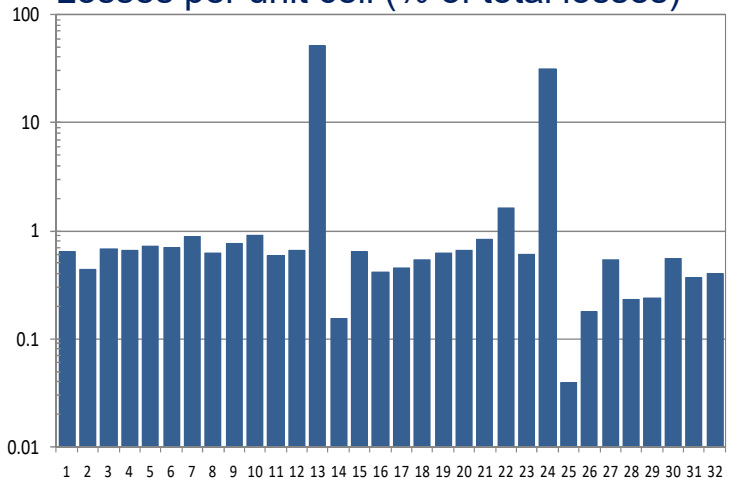
Main challenge:

e^- losses ×10 ⟺ use existing storage ring shielding

→ two dedicated beam loss collimators + local shielding



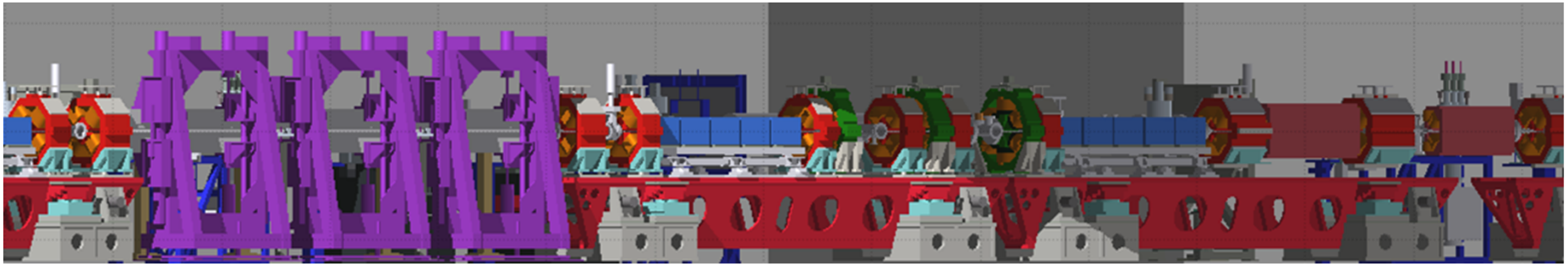
Losses per unit cell (% of total losses)

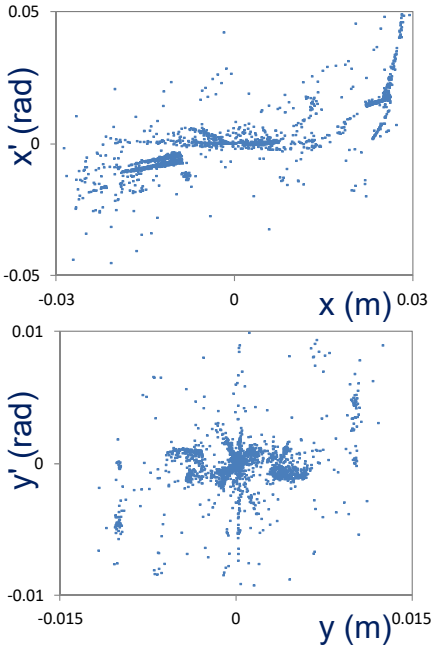


Distribution of beam losses along the storage ring lattice

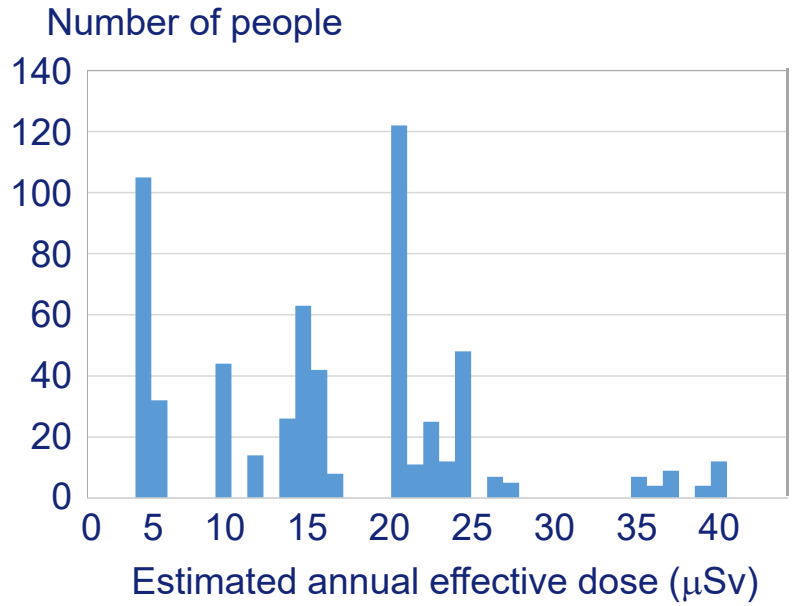
Mode	Stored beam (mA)	Lifetime (h)		Beam losses (e/s)	
		ESRF 1	EBS	ESRF 1	EBS
Multi-bunch	200	45	19.3	$2.2\ 10^7$	$5.1\ 10^7$
16 bunch	92	16	1.8	$2.8\ 10^7$	$2.5\ 10^8$
4 bunch	40	9	1.2	$2.2\ 10^7$	$1.6\ 10^8$

THE ESRF EBS STORAGE RING

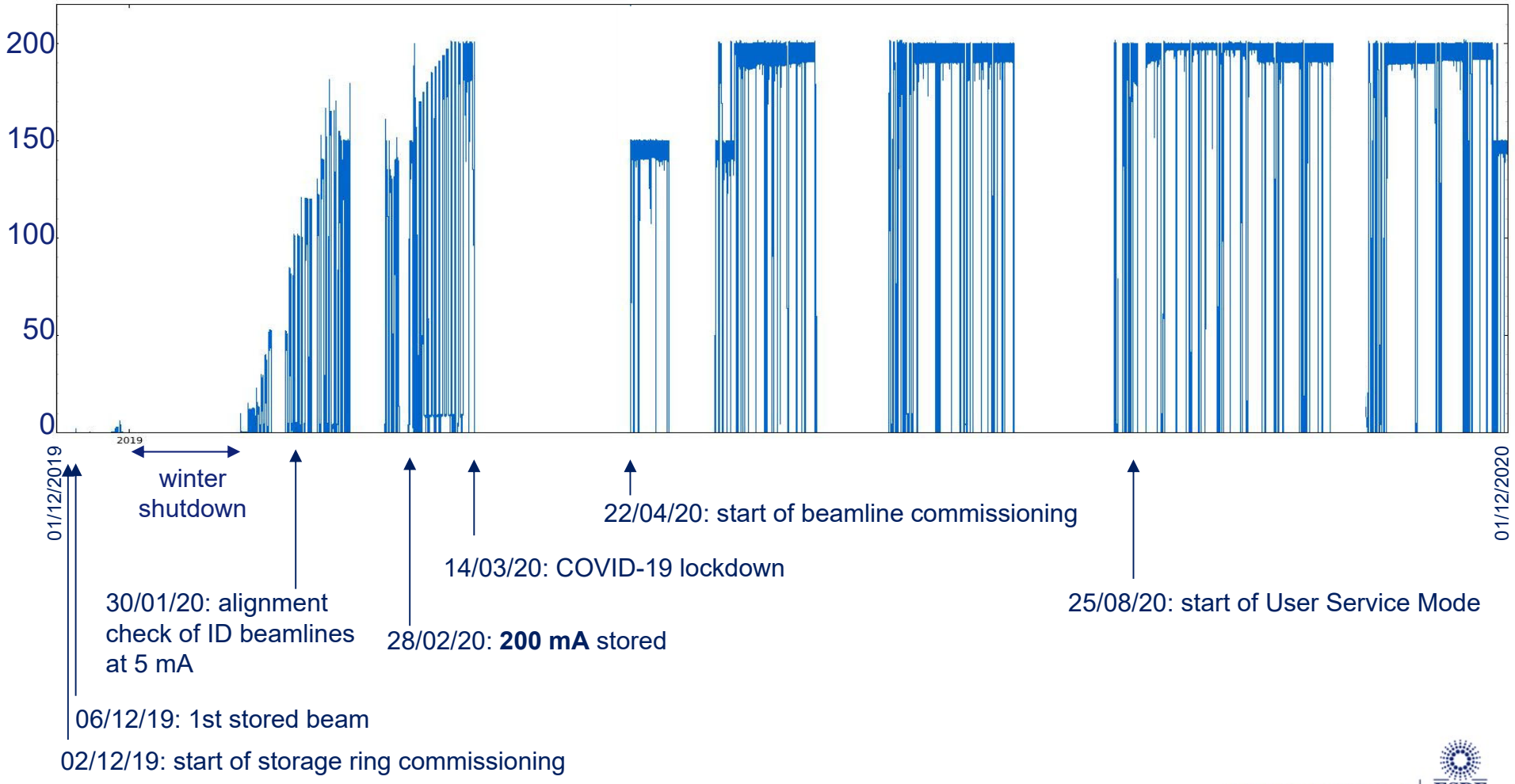




FLUKA
+
Beam loss
phase space files



STORAGE RING AND BEAMLINE COMMISSIONING



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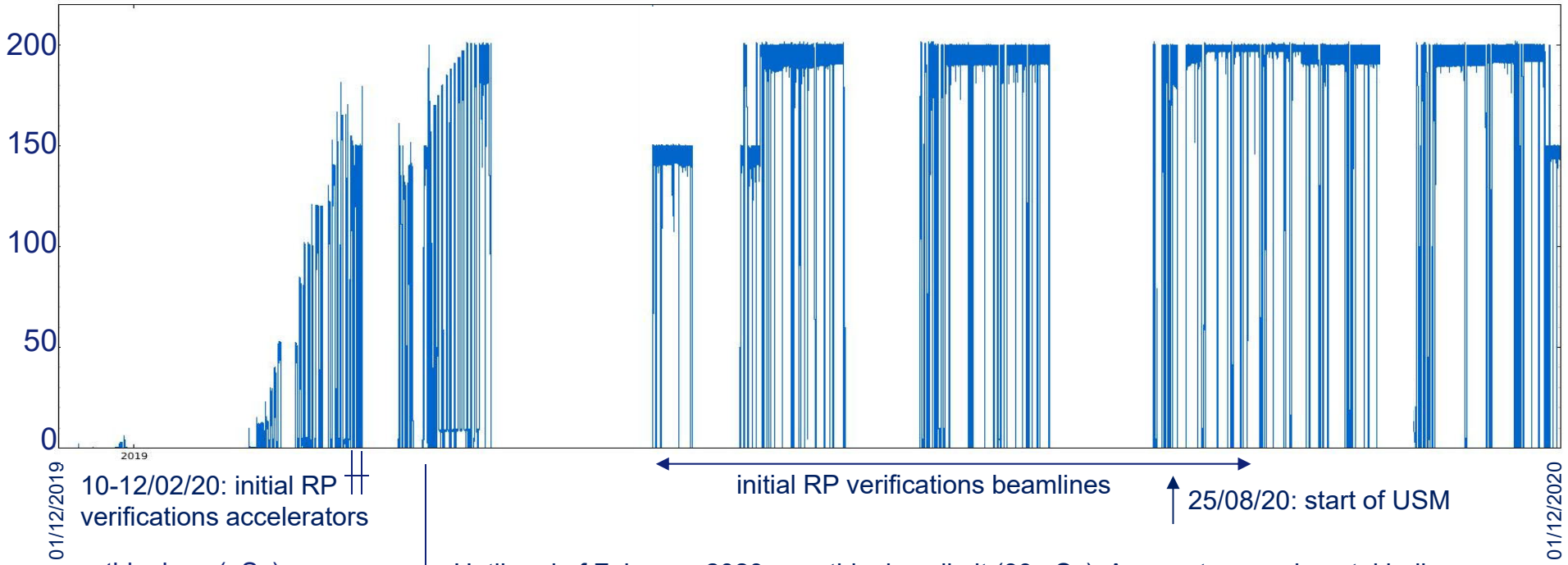
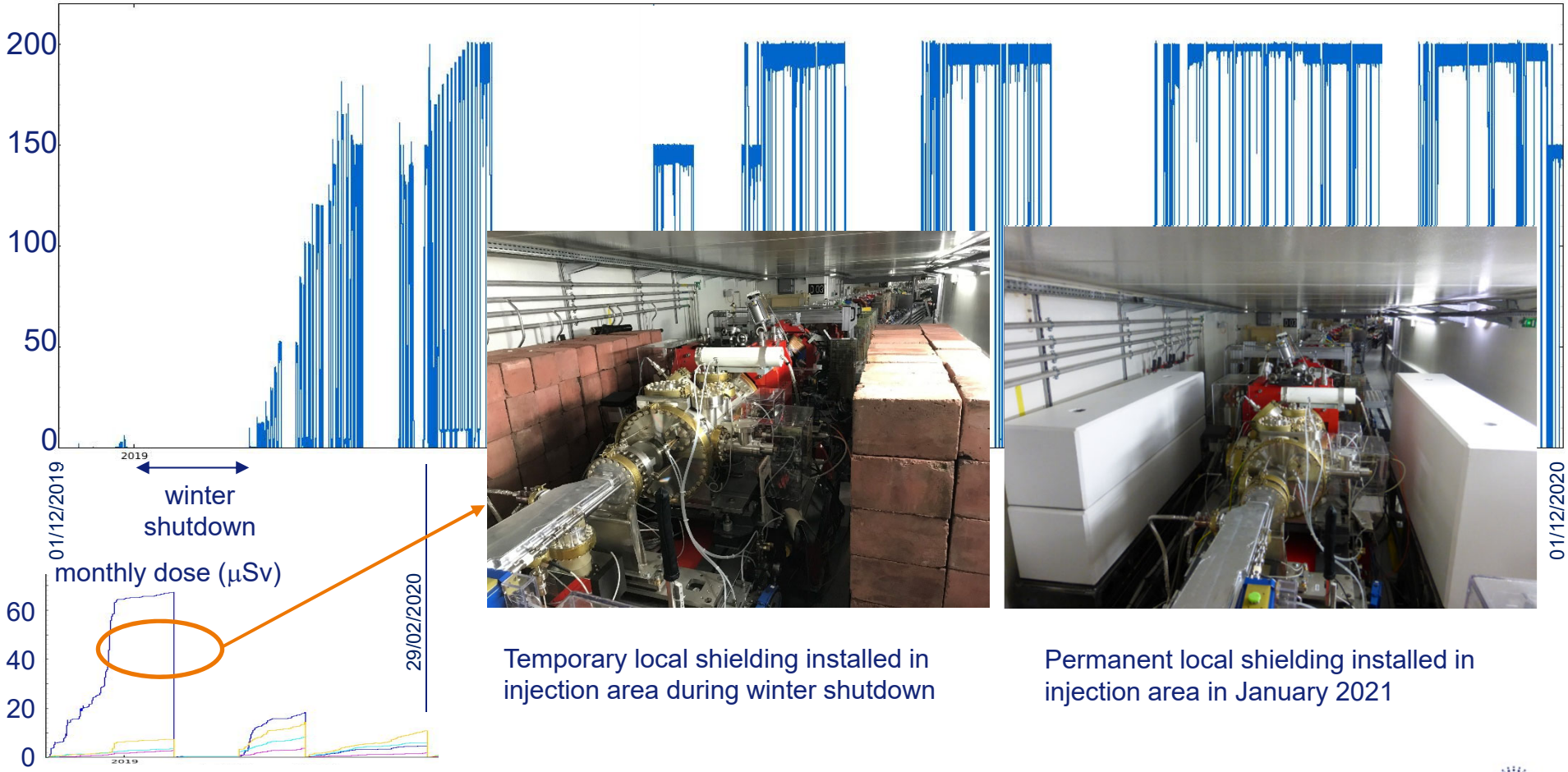


Until end of February 2020: monthly dose limit (80 μSv). Access to experimental hall limited to ESRF + CRG staff and a limited number of contractors, permanently on site.

From 1st of March 2020 : 4-hours dose limit (2 μSv) → official end of the EBS storage ring commissioning.

STORAGE RING AND BEAMLINE COMMISSIONING



Temporary local shielding installed in injection area during winter shutdown

Permanent local shielding installed in injection area in January 2021

CONSERVATIVE ASSUMPTIONS OF SHIELDING STUDY

EBS shielding study:

Maximum dose rates: 16-bunch: 92 mA, 1.8 h lifetime.

Safety envelope: 1200 μC injected in storage ring per year.

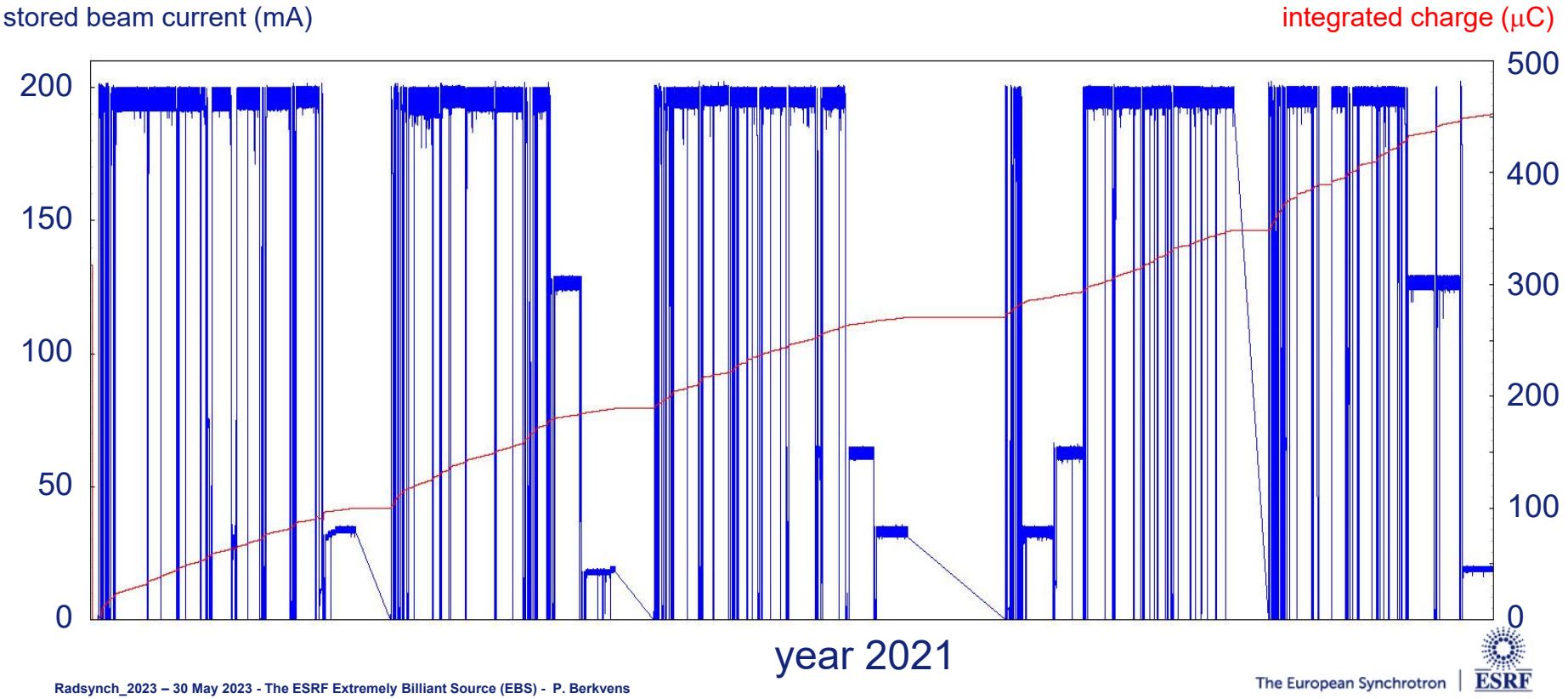
So far:
16-bunch maximum current limited to 75 mA, with 5 h lifetime.

→ Beam losses 3.4 times smaller.

CONSERVATIVE ASSUMPTIONS OF SHIELDING STUDY

EBS shielding study:
Safety envelope: 1200 μC
injected in storage ring per year.

So far: less than 500 μC per year
→ Annual doses reduced by more than a factor 2.



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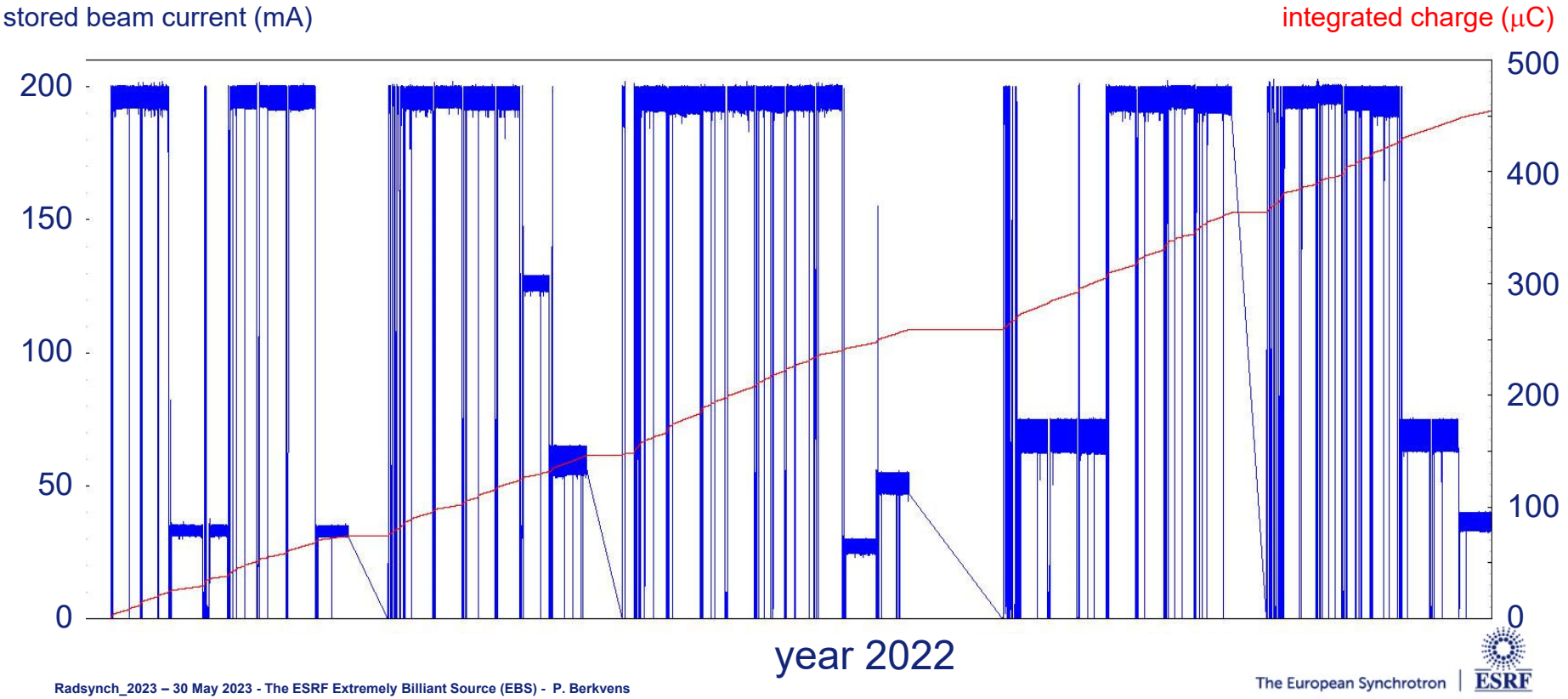
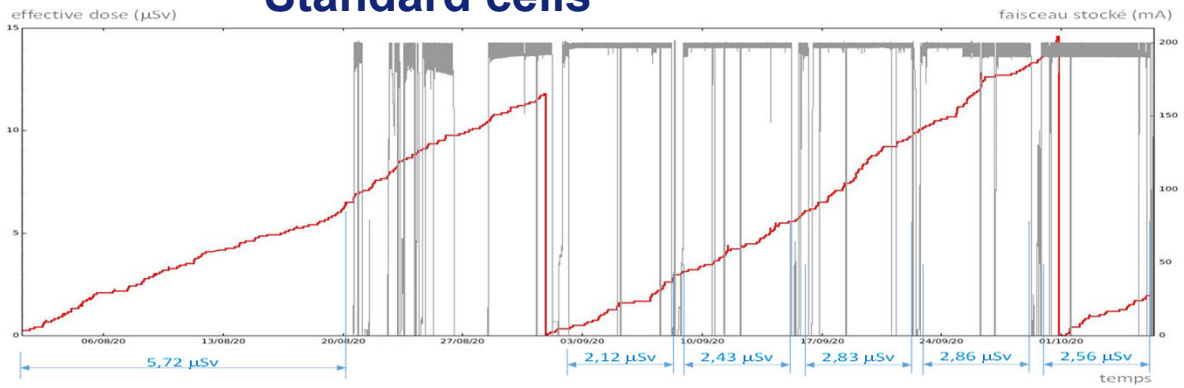
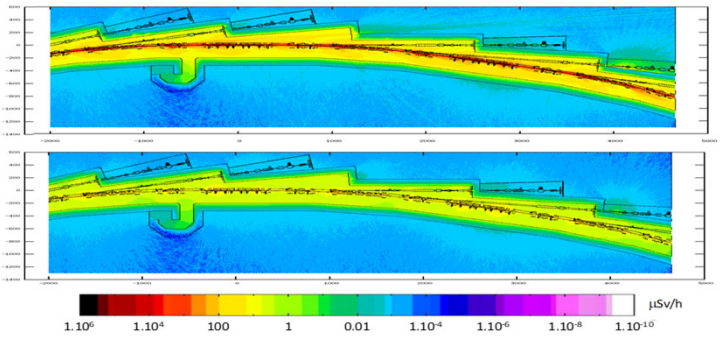


VALIDATION OF SHIELDING STUDY: STORED BEAM DOSE RATES

Standard cells

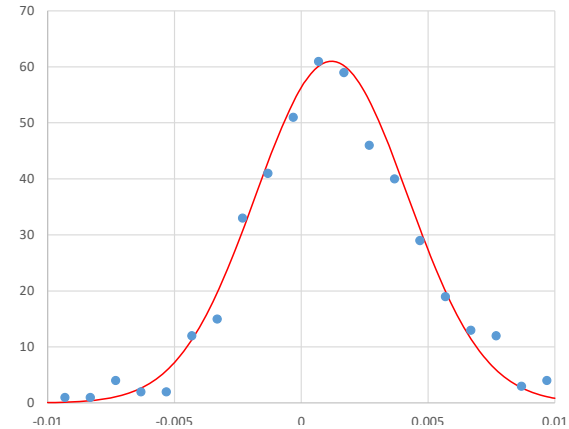


Typical measurement by one of the neutron monitors on the roof of the storage ring during the period from 1 August to 6 October 2020. Red curve: monthly dose integrated by the monitor. Grey curve: stored beam current.



FLUKA shielding study: 196 mA stored beam with 20 h lifetime

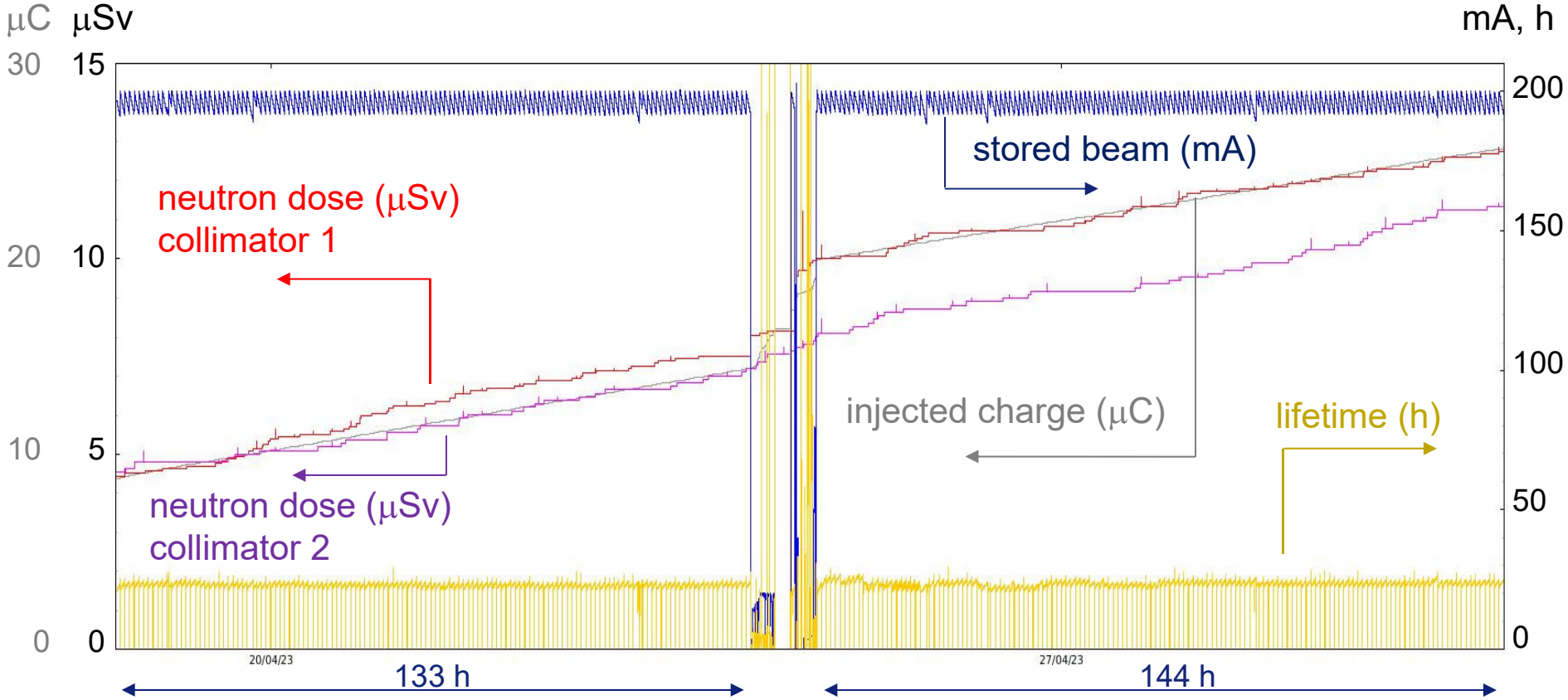
→ **1 nSv·h^{-1}**.



Distribution of 6-day-period measurements during USM, as a function of the average net effective dose rate during the 6 days. Points: measurements – Curve: Gaussian fit with μ = **1.1 nSv·h^{-1}** and σ = 3 nSv·h^{-1}.

Measured background, averaged over all monitors : **11 nSv·h^{-1}**.

VALIDATION OF SHIELDING STUDY: COLLIMATOR CELLS



neutron dose 1: 3.05 μSv
neutron dose 2: 2.56 μSv
injected charge: 5.66 μC

stored beam: 196 mA
lifetime: 24 h
injection efficiency: 56%

neutron dose 1: 2.67 μSv
neutron dose 2: 3.24 μSv
injected charge: 5.68 μC

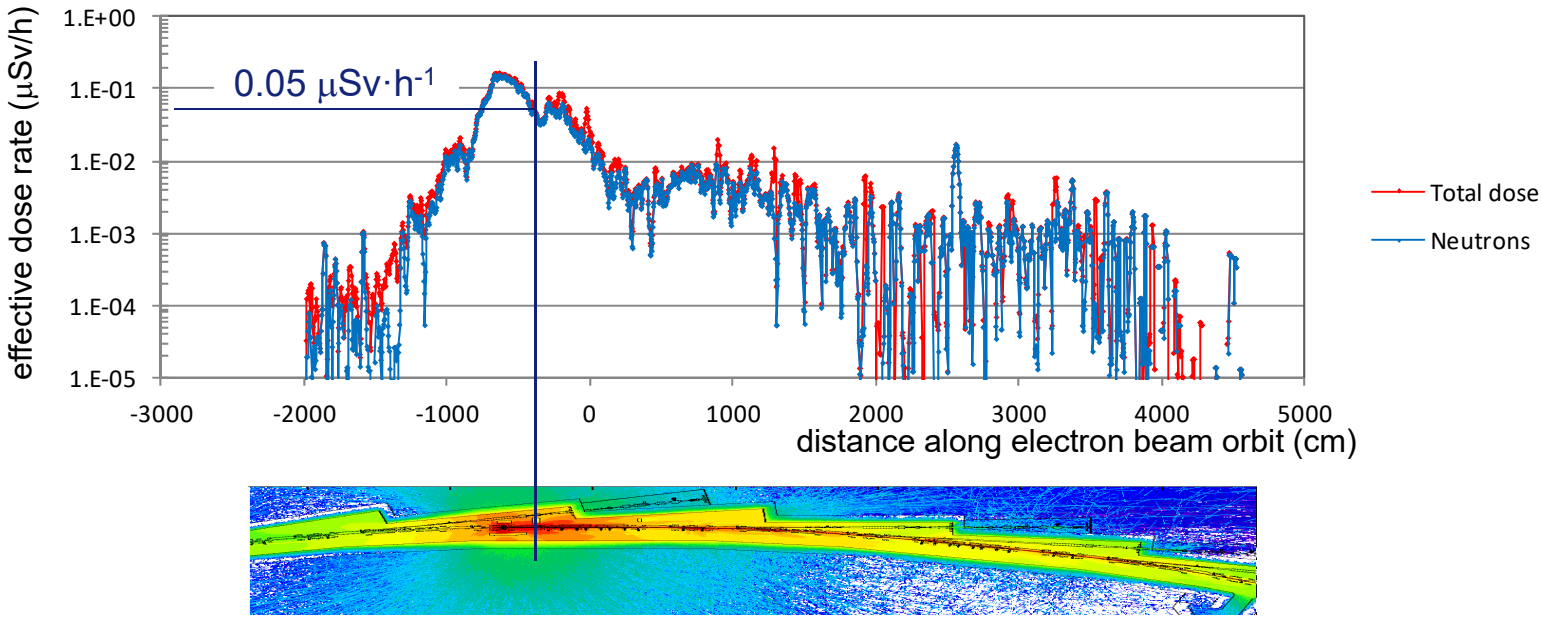
stored beam: 196 mA
lifetime: 24 h
inj. eff.: 60%

$\Delta t_{injection}$ = 1 h

VALIDATION OF SHIELDING STUDY: COLLIMATOR CELLS

Stored beam dose rates on tunnel roof - collimator cells
Conditions: 92 mA stored beam, 1.8 h lifetime

Neutron dose rate at detector position: 0.05 μSv·h^{-1}
→ 196 mA, 24 h lifetime: **0.0082 μSv·h^{-1}**
→ 133 h: integrated dose = 1.063 μSv
→ 144 h: integrated dose = 1.150 μSv



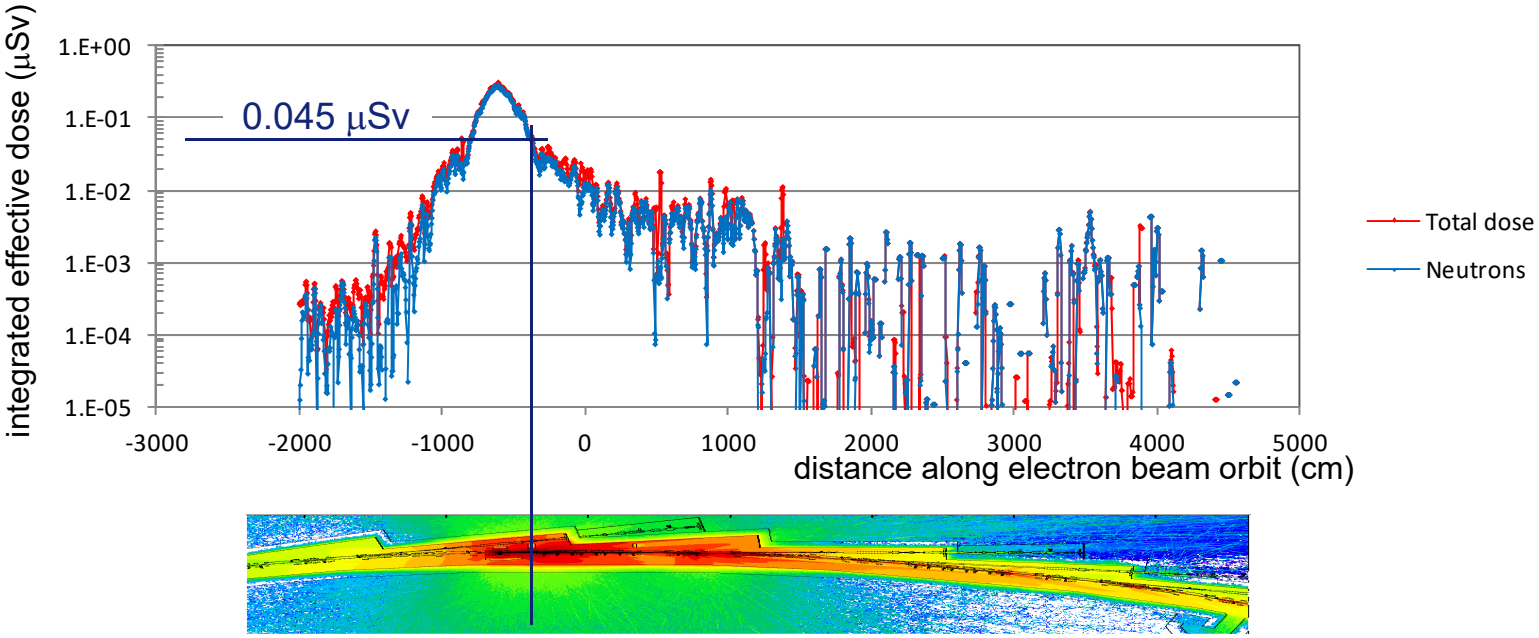
VALIDATION OF SHIELDING STUDY: COLLIMATOR CELLS

Integrated dose on tunnel roof during injection - collimator cells
Conditions: full 200 mA injection, 50 % injection efficiency

Neutron dose at detector position: 0.045 μSv

→ 1st week, integrated dose due to injection losses: **0.21 μSv**

→ 2nd week, integrated dose due to injection losses: **0.22 μSv**

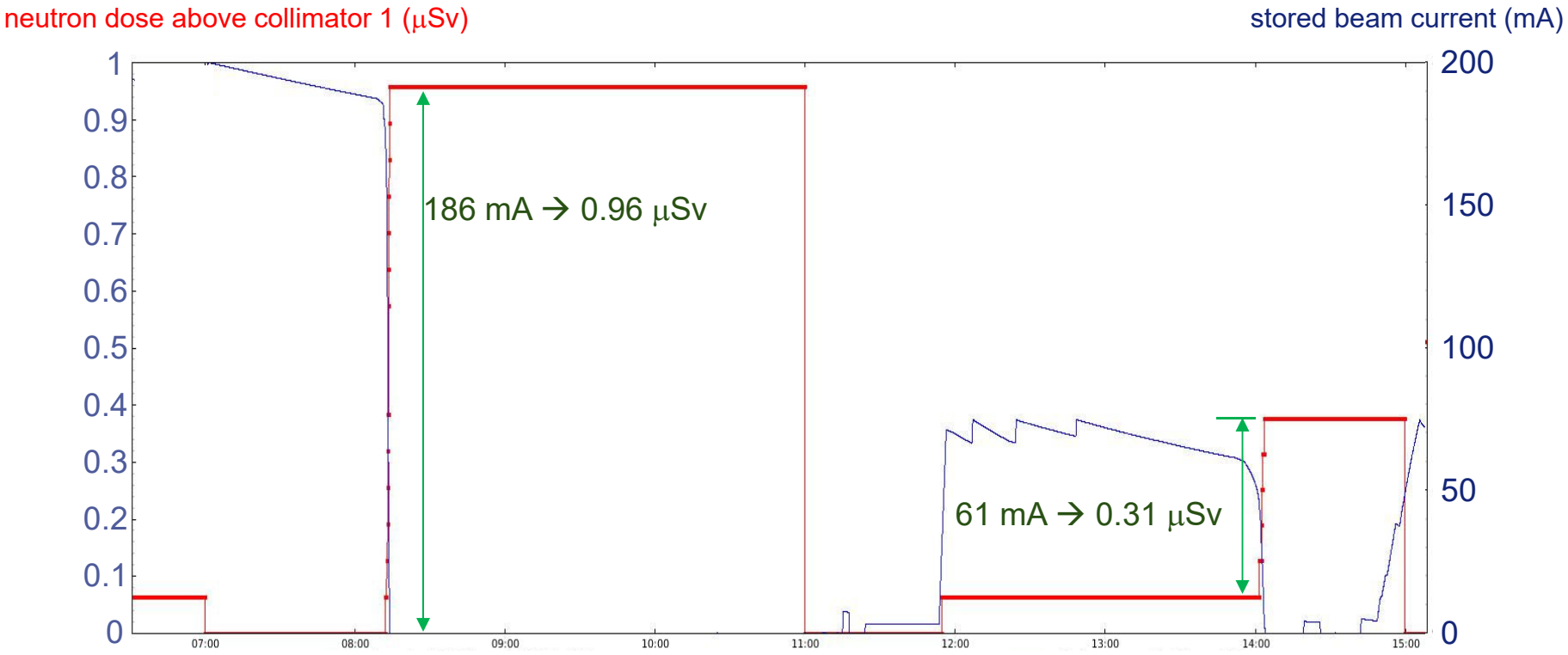


VALIDATION OF SHIELDING STUDY: COLLIMATOR CELLS

FLUKA model			Measurements	
	1st week	2nd week	1st week	2nd week
background ($0.11\ nSv \cdot h^{-1}$)	1.463 μSv	1.584 μSv		
dose during decay	1.062 μSv	1.150 μSv		
dose during injection	0.210 μSv	0.217 μSv		
total neutron dose on tunnel roof	**2.735 μSv**	**2.951 μSv**	collimator 1: 3.05 μSv collimator 2: 2.56 μSv average: **2.81 μSv**	collimator 1: 2.67 μSv collimator 2: 3.24 μSv average: **2.95 μSv**

VALIDATION OF SHIELDING STUDY: STORED BEAM DUMPS

Beam scraping with 1st collimator

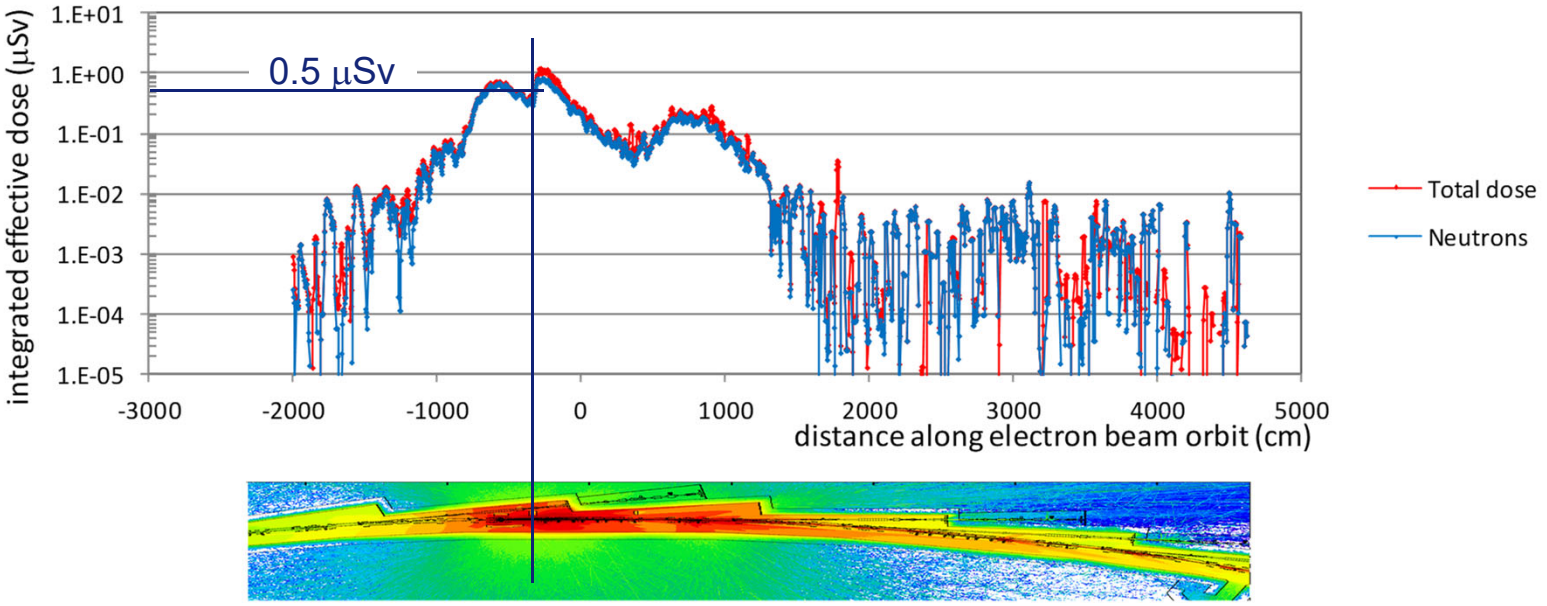


VALIDATION OF SHIELDING STUDY: STORED BEAM DUMPS

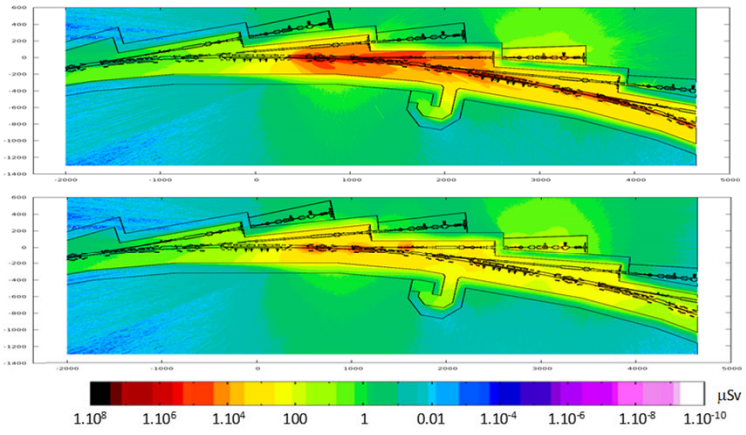
Integrated dose on tunnel roof during beam dump - collimator cells
Conditions: 200 mA dump, 50 % loss on each collimator
→ expected dose when scraping 200 mA beam with a single collimator: **1 μSv**

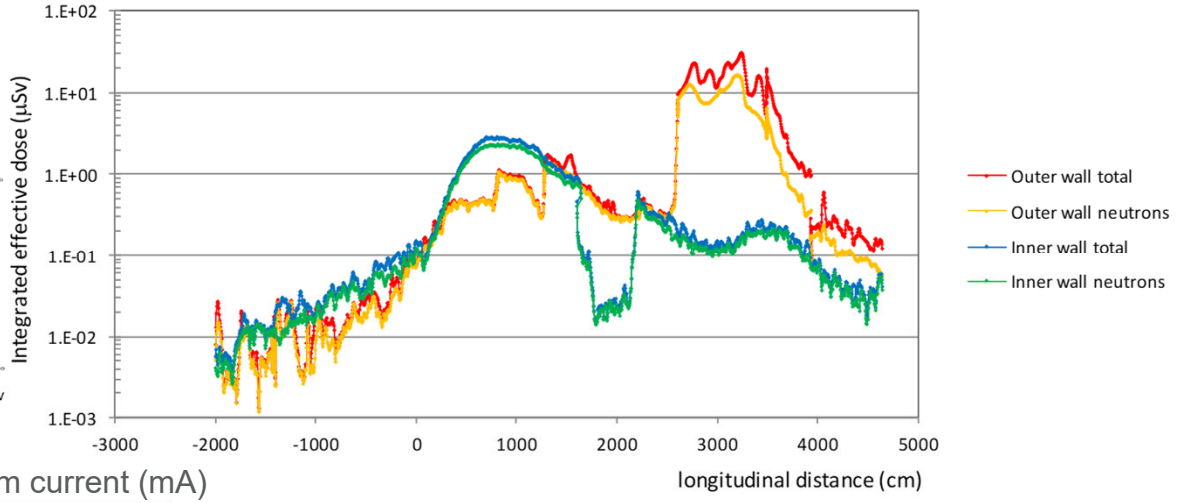
186 mA, 0.96 μSv → **1.03 μSv** for 200 mA dump

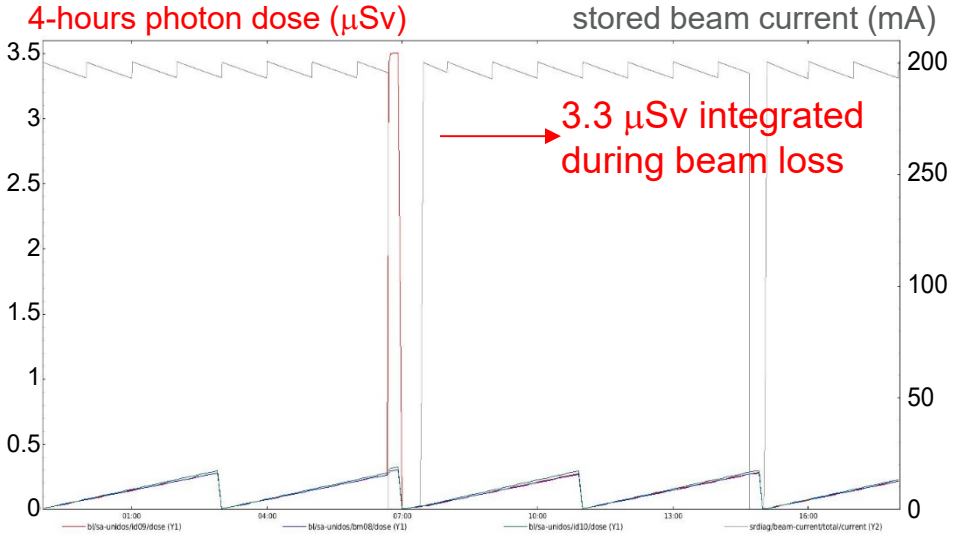
61 mA, 0.31 μSv → **1.02 μSv** for 200 mA dump



VALIDATION OF SHIELDING STUDY: STORED BEAM LOSS ON CLOSING VACUUM VALVE







Stored beam loss on closing vacuum valve (envelope scenario for stored beam accidents). Dose outside downstream optics hutch for 200 mA loss: **28 µSv**.

On 19/11/2021, the beam was accidentally lost due to closing vacuum valve(s).

An integrated dose of **3.3 µSv** due to the beam loss was measured outside the downstream hutch.

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BEAMLINE COMMISSIONING

FLUKA calculations

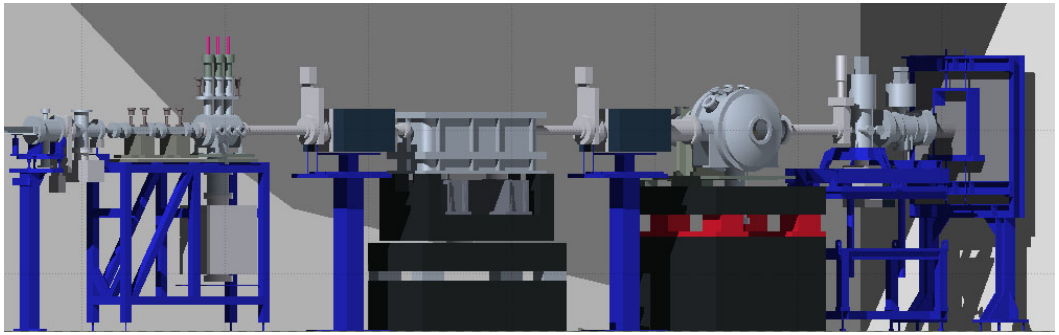
- Use of generic model for optics hutches.
- Shorter than standard hutch → conservative results.

Insertion device beamlines

- No change in synchrotron radiation source.
- Length straight section (dipole to dipole) divided by two.
- Straight section ID vessel reused → conditioning done.

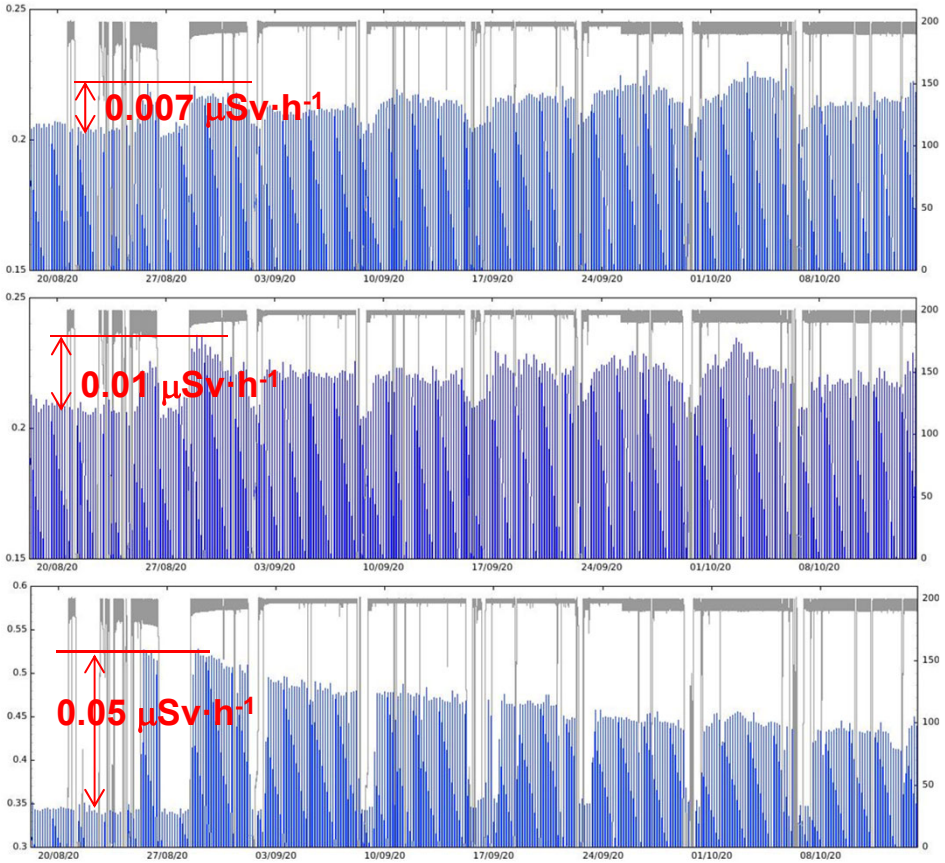
Bending magnet beamlines

- Change of synchrotron radiation sources (short bends, 2-pole or 3-pole wigglers)
- Increased gas-bremsstrahlung source.
- Freeways next to BM optics hutches interlocked.

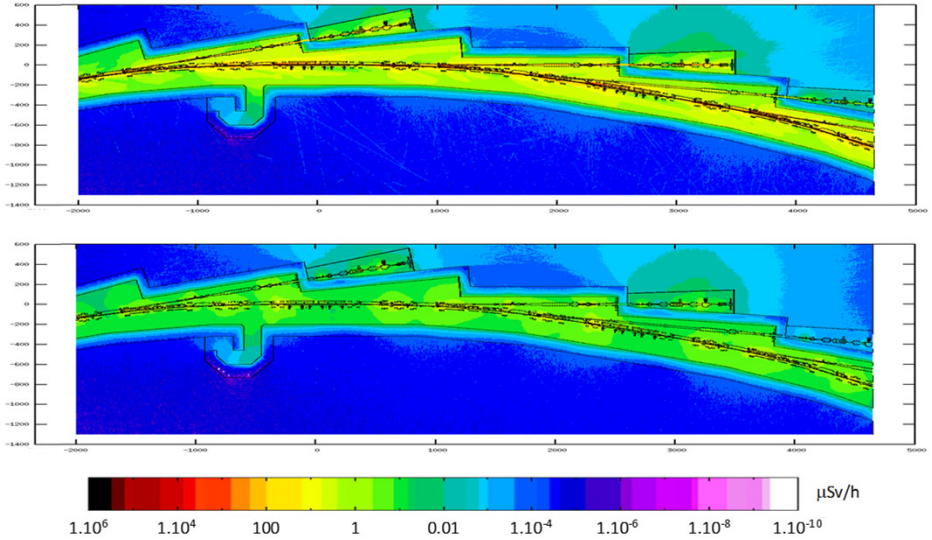


Generic FLUKA model of optics hutch

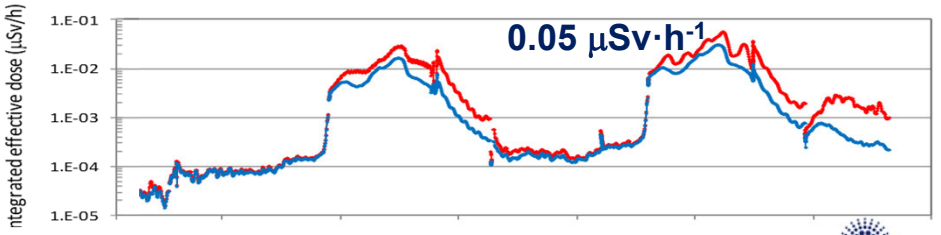
BEAMLINE COMMISSIONING: ID BEAMLINES



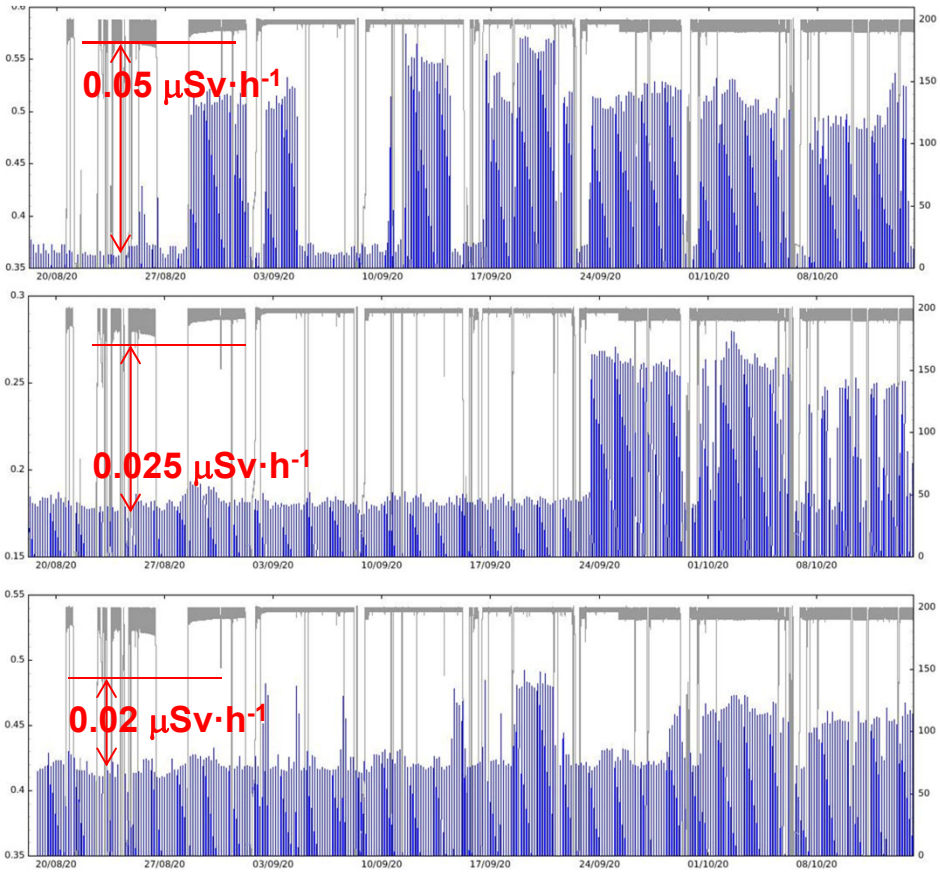
Effective dose over 4 h, measured with ionisation chambers outside three optics hutches: ID06 (top), ID20 (middle) et ID02 (bottom). Blue curve: integrated dose; grey curve: stored beam current (20/08 to 15/10/2020).



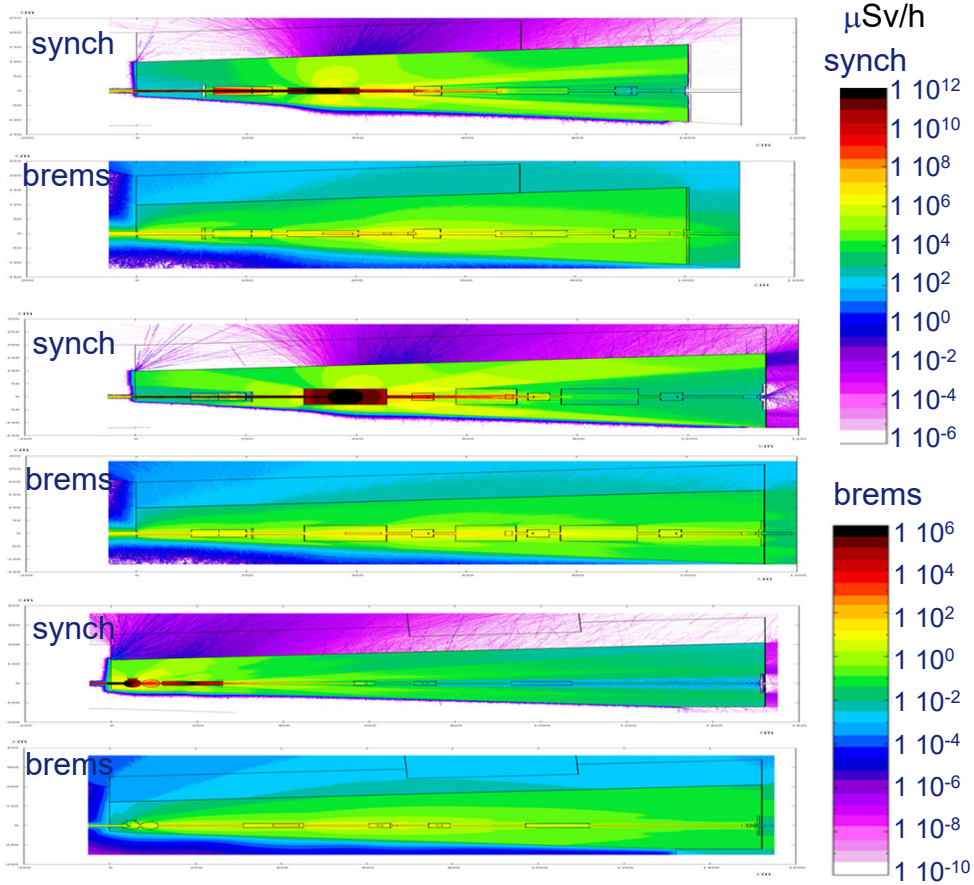
Effective dose rate distribution due to gas-bremsstrahlung beam losses in a horizontal plane at beam height. 200 mA stored beam, 500 A·h conditioning. Top: total dose – Bottom: neutron dose.



BEAMLINE COMMISSIONING: BM BEAMLINES



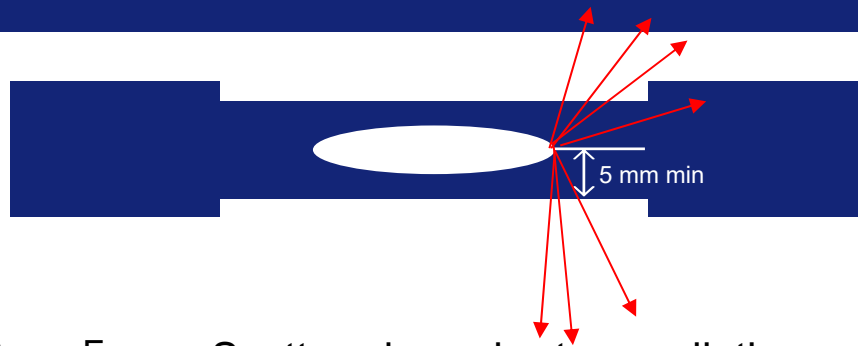
Effective dose over 4 h, measured with ionisation chambers outside three optics hutches: BM02 (top), BM20 (middle) and BM25 (bottom). Blue curve: integrated dose; grey curve: stored beam current (20/08 to 15/10/2020).



Measured net dose values between 0.01 and 0.05 µSv/h for all BM beamlines (inside interlocked freeway). Calculated values between 20 % and 100 % higher than measured ones.

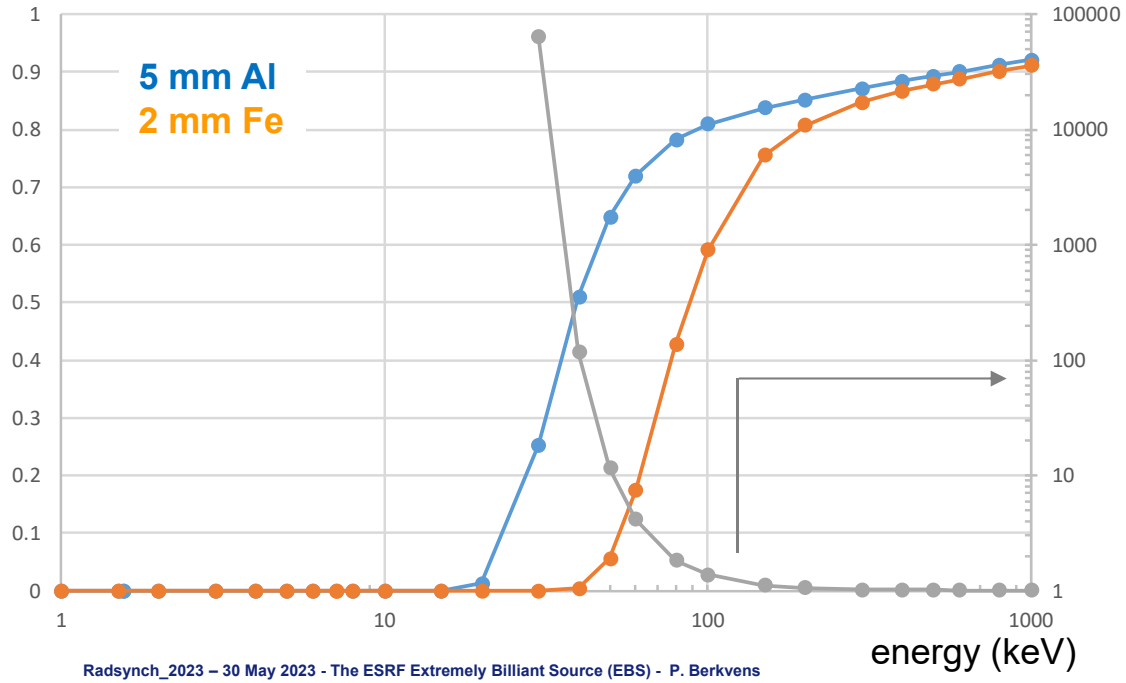
RADIATION DAMAGE INSIDE STORAGE RING TUNNEL

Origin of problem: relative transparency of Al for X-rays < 60 keV



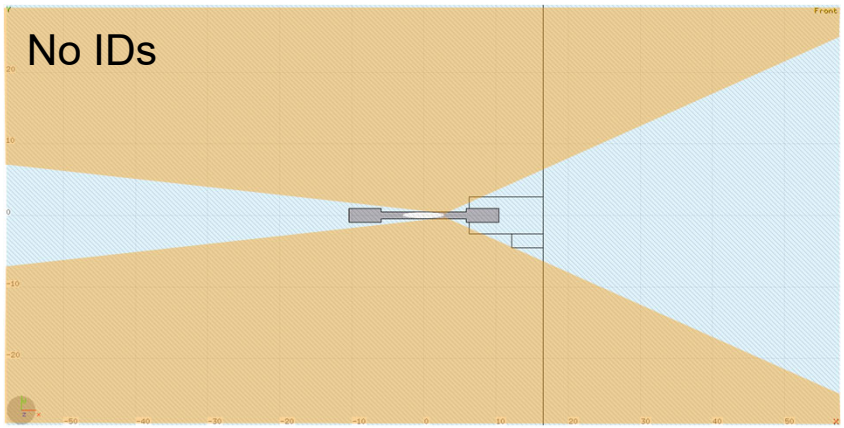
transmission

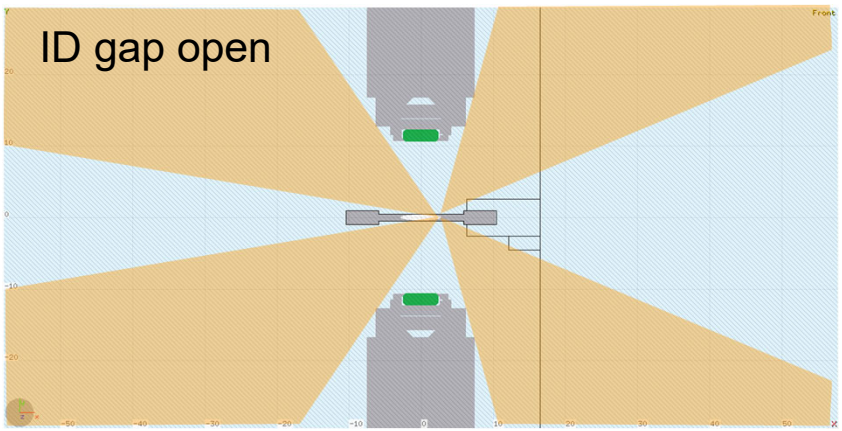
ratio transmission 5 mm Al / 2 mm Fe

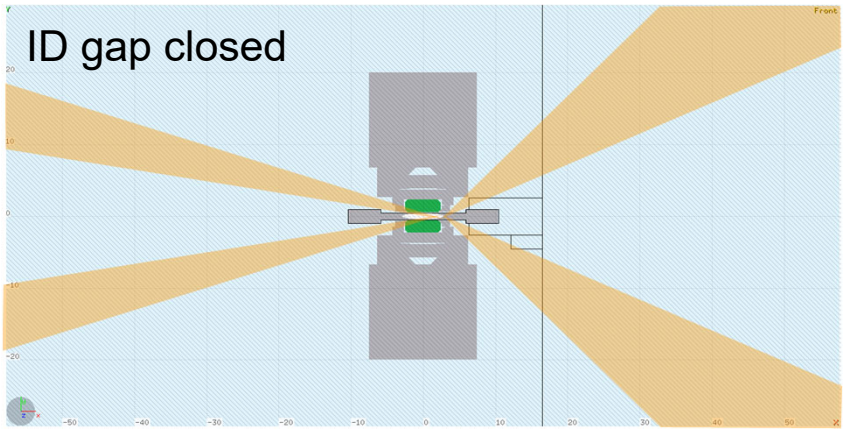


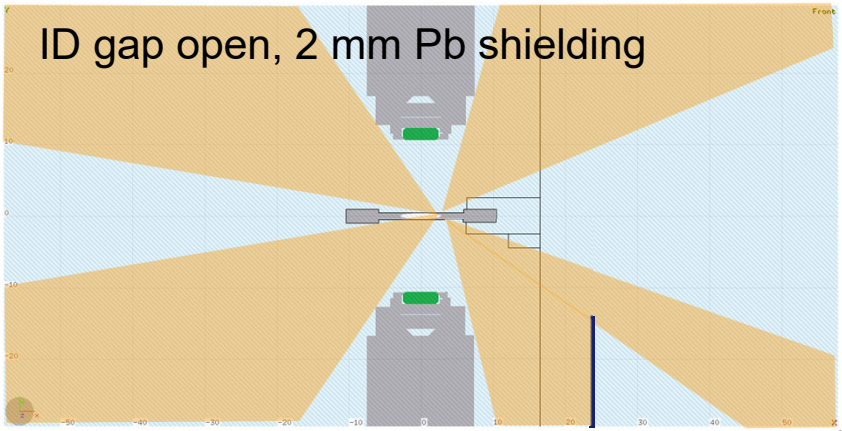
Scattered synchrotron radiation produced along 5 m long insertion device vacuum vessels.

RADIATION DAMAGE INSIDE STORAGE RING TUNNEL









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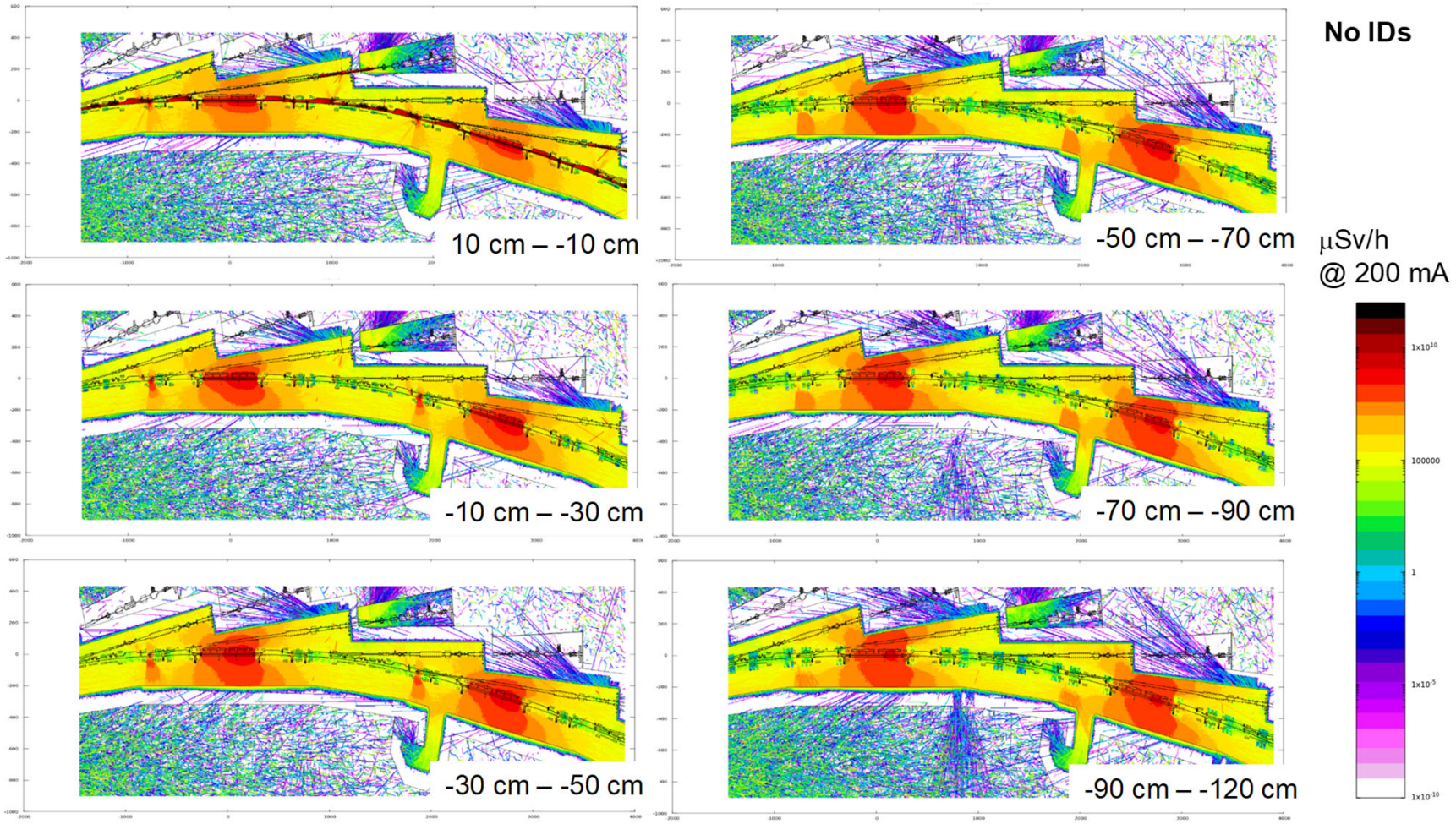

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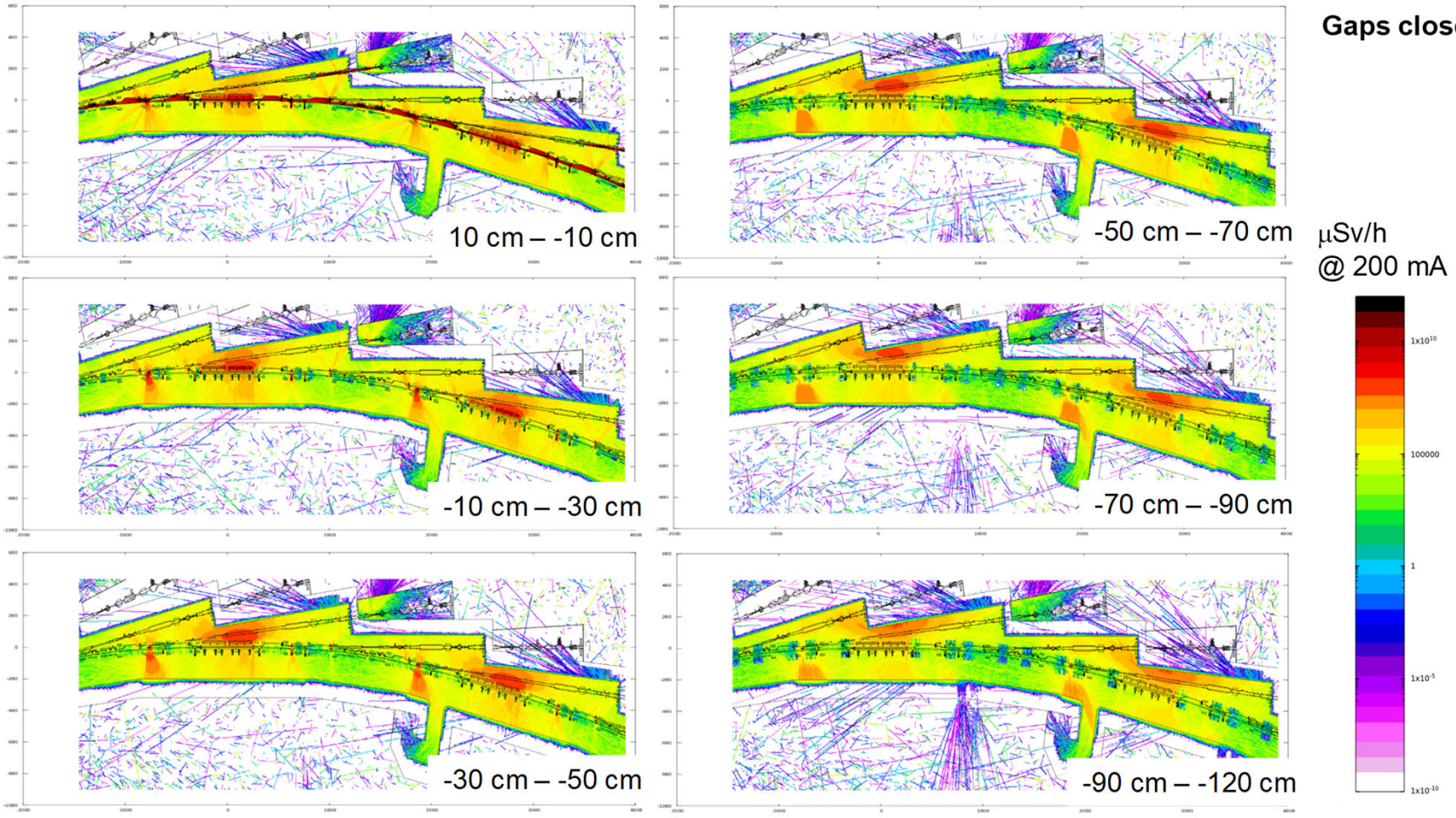

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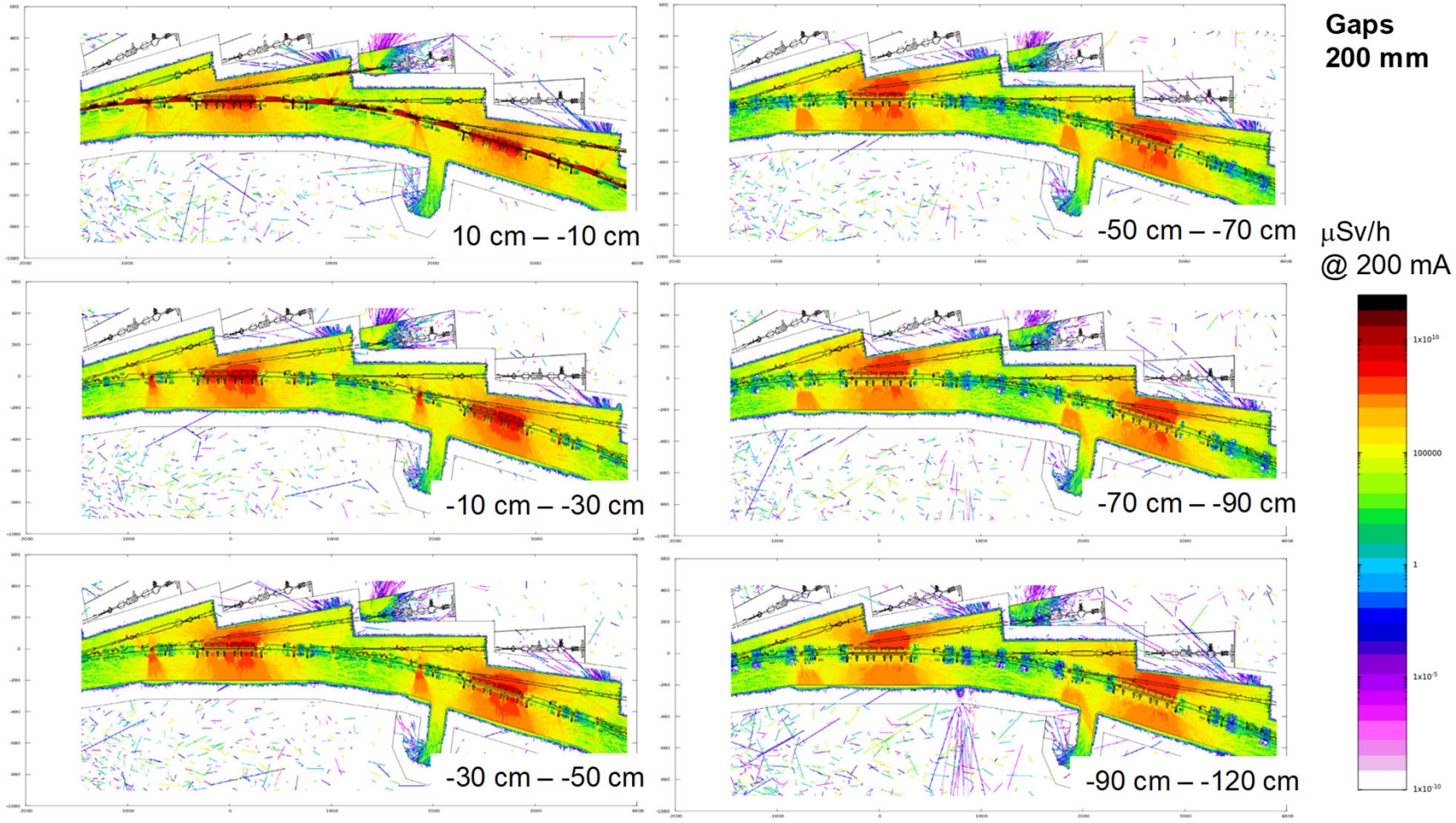

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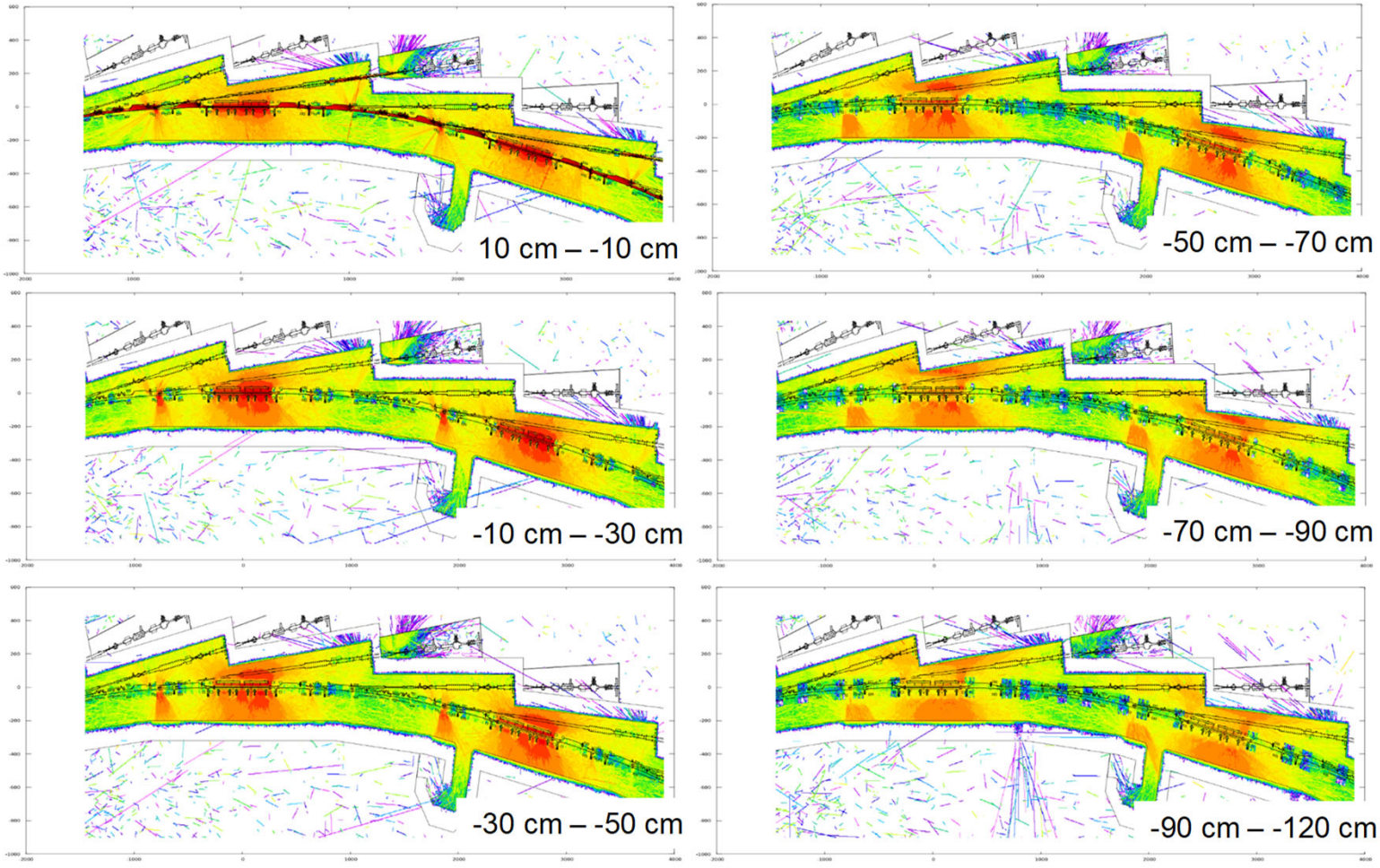

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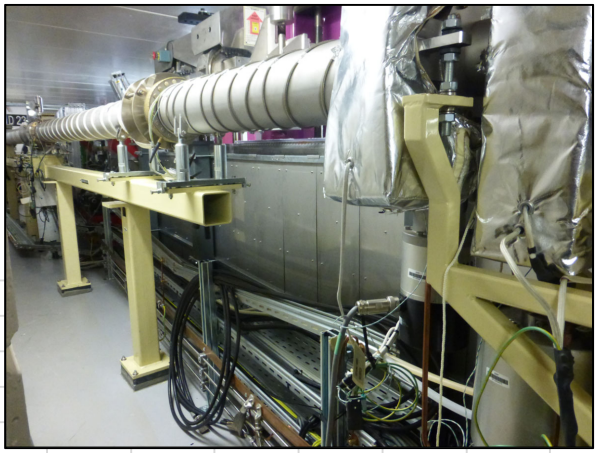

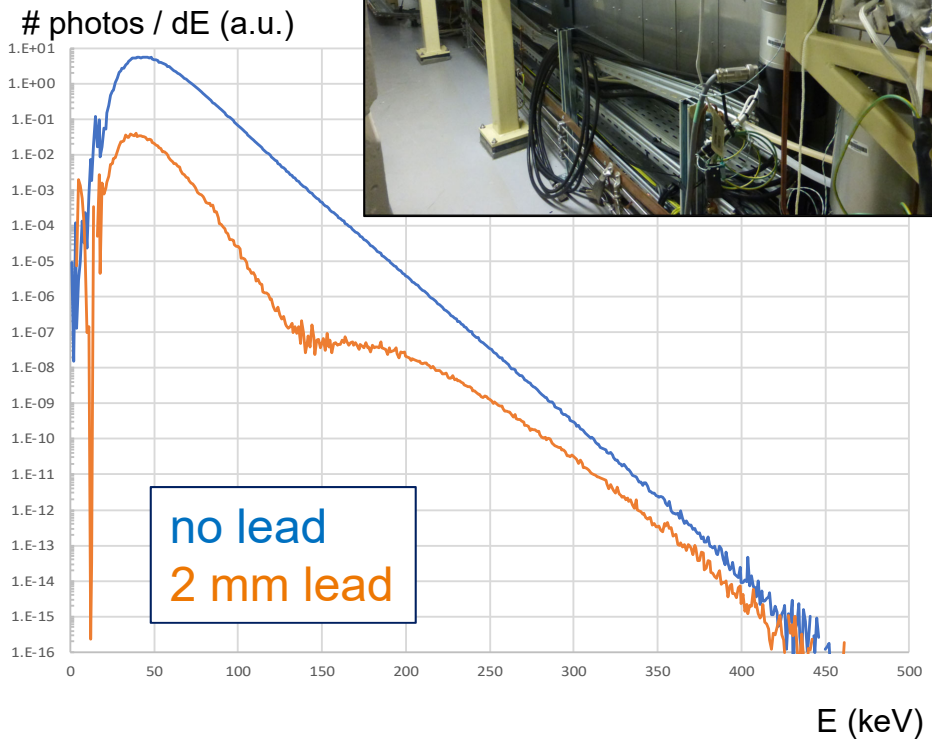

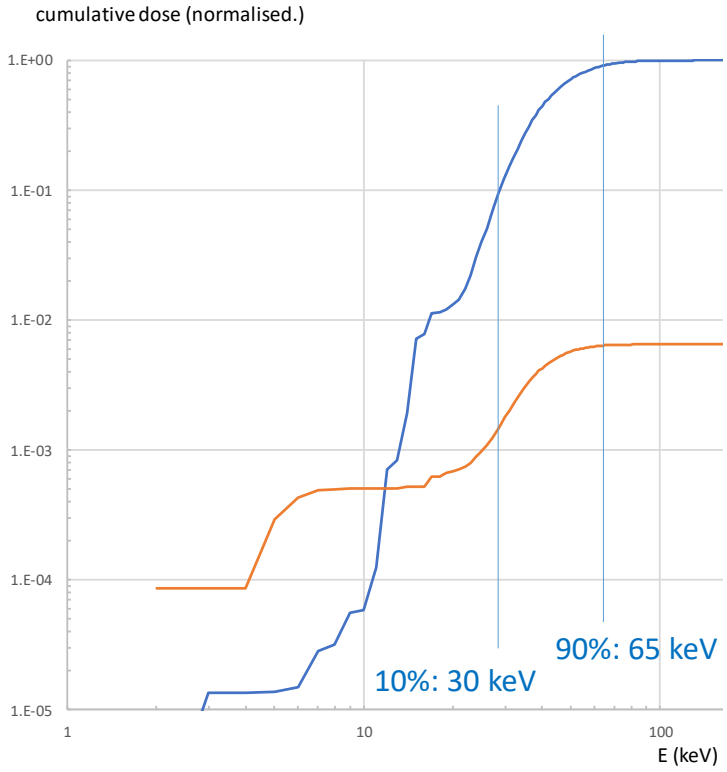

MANY THANKS FOR YOUR ATTENTION