ESRF | The European Synchrotron

Design, commissioning and operation of the collimation for the ESRF-EBS

I.FAST Low Emittance Rings Workshop 2024

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Reine Versteegen

On behalf of ESRF-EBS Team

INTRODUCTION

- ESRF used to operate with **distributed losses** and no dedicated beam dump area before the upgrade project

- The ESRF storage ring upgrade required to **minimize modifications** on the radiation shielding (request from the French Nuclear Safety Authority, ASN)

- Preliminary calculations showed that without a strategy for beam losses collimation
  - **Tunnel roof** shielding would have to be re-enforced
  - Lead would be added on the **walls**
  - **New access policy** with the extension of interlocked area, and forbidden access to the tunnel roof during operation

- Goal of the collimation project in 2014
  - maintain the **non exposed worker** policy at ESRF
  - ensure the **validation of the upgrade** project by the ASN

OUTLINE

I. Collimators design

- Specifications (beam losses, radioprotection)
- Mechanical design

II. Collimation and EBS Commissioning

- ESRF restart
- Collimation efficiency

III. Collimation and Machine Operation

- Collimators tuning and protection
- Impact on machine operation safety

I. Collimators design

I.1. COLLIMATION SCHEME (1/2)

Ref [1], [2], [3]

Objective: localize beam losses in well shielded areas for radiation protection

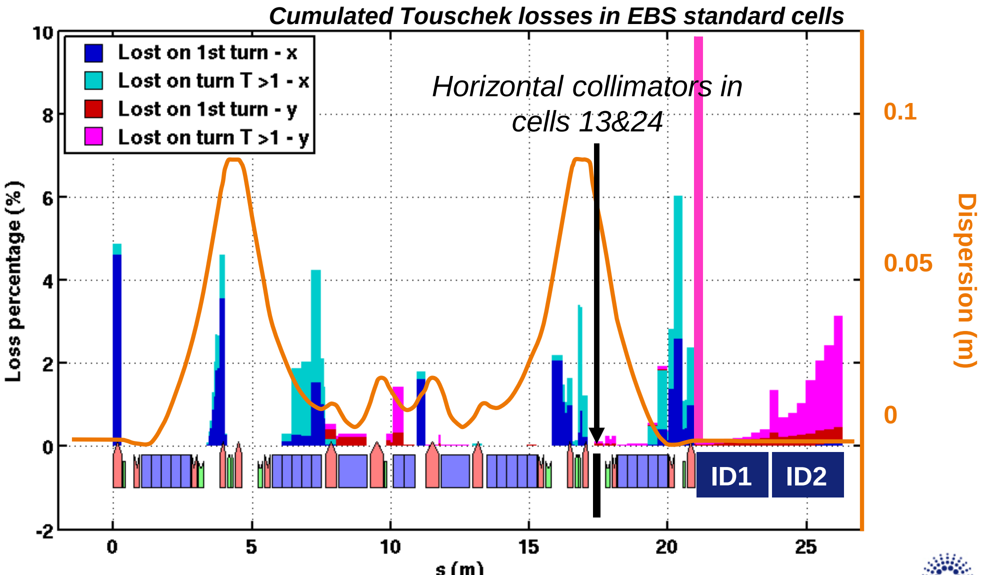
- Focus on **Touschek scattering** as the main limitation for beam lifetime

  - Particle tracking: beam losses concentrated in the straight sections
  - High risk of **Insertion Devices demagnetization**

  → Additional motivation for collimation

- Collimators intercept **off-momentum particles** before their transfer to the vertical plane thanks to the dispersion bumps

- **Residual gas** interactions: collimators can intercept off-energy electrons (Bremsstrahlung) but have poor efficiency on large angle scattered particles without affecting strongly the lifetime (elastic scattering)



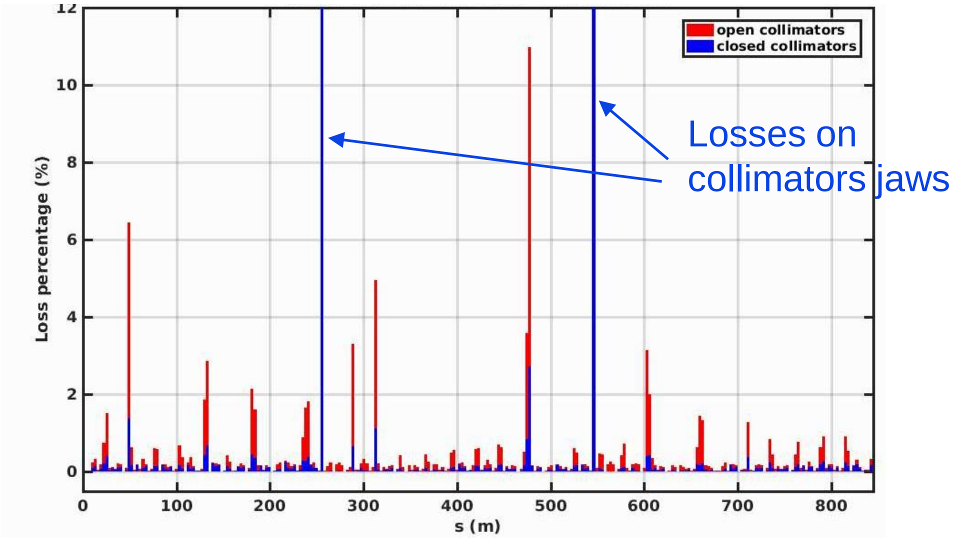
I.1. COLLIMATION SCHEME (2/2)

Ref [1], [2], [3]

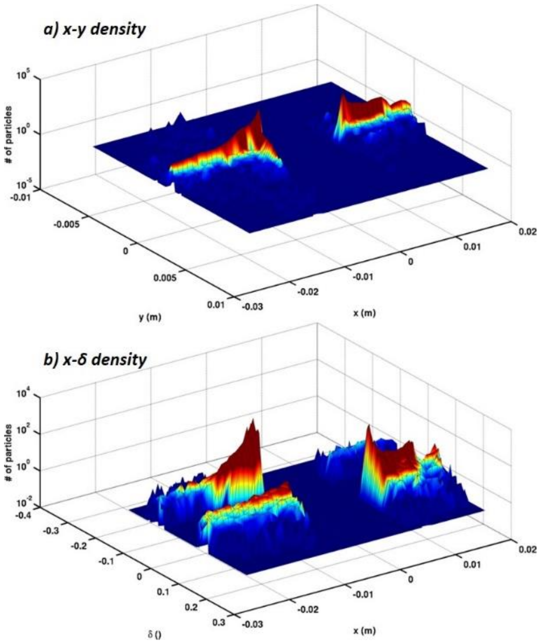
Objective: localize beam losses in well shielded areas for radiation protection

- Tracking of Touschek lost particles

→ **80% of losses relocated** in 2 horizontal collimators in dispersive regions, impact on lifetime **< 10%**



- 6D coordinates of lost electrons as input for **shielding simulations** (decay, beam loss, injection…)



Lost particles distribution on a collimator aperture

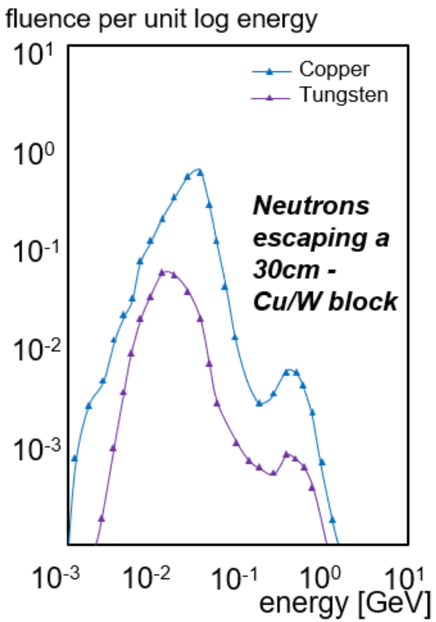
I.2. RADIATION PROTECTION (1/2)

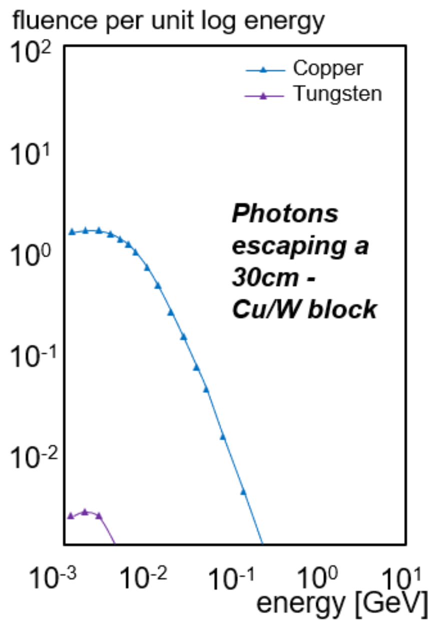
Ref [4], [5], [6]

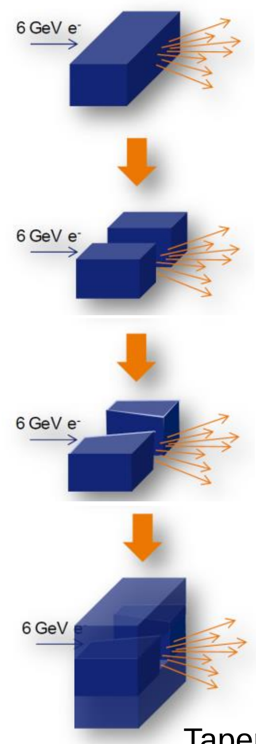
Objective: maintain free access in the experimental hall for all workers

- FLUKA simulations : **material** and **geometry** optimization for neutrons and photons shielding

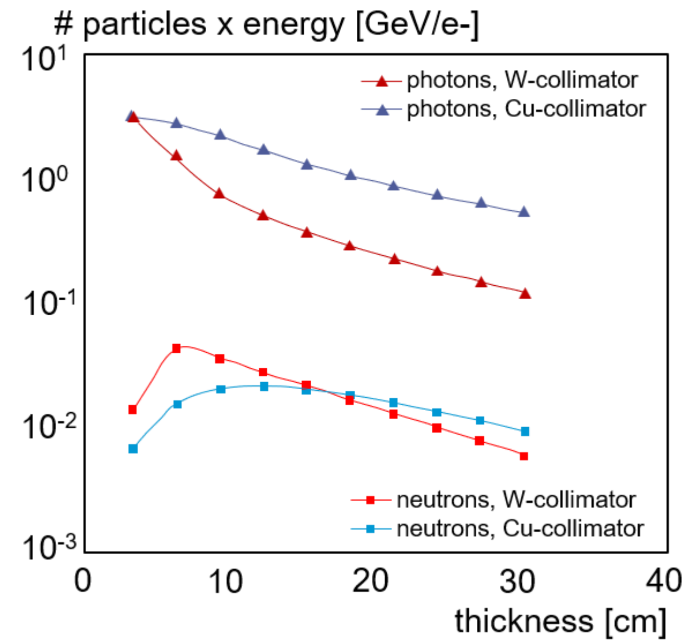
Copper vs Tungsten block







Tapered collimator



Courtesy P. Berkvens

Tapered jaws are needed to fit to the decreasing β-function.

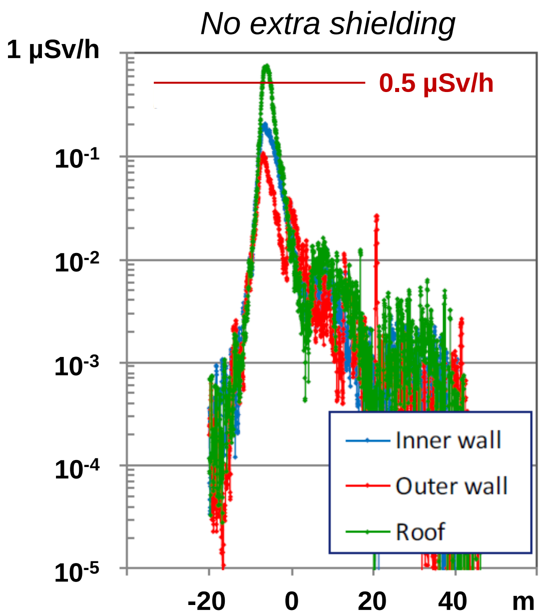
I.2. RADIATION PROTECTION (2/2)

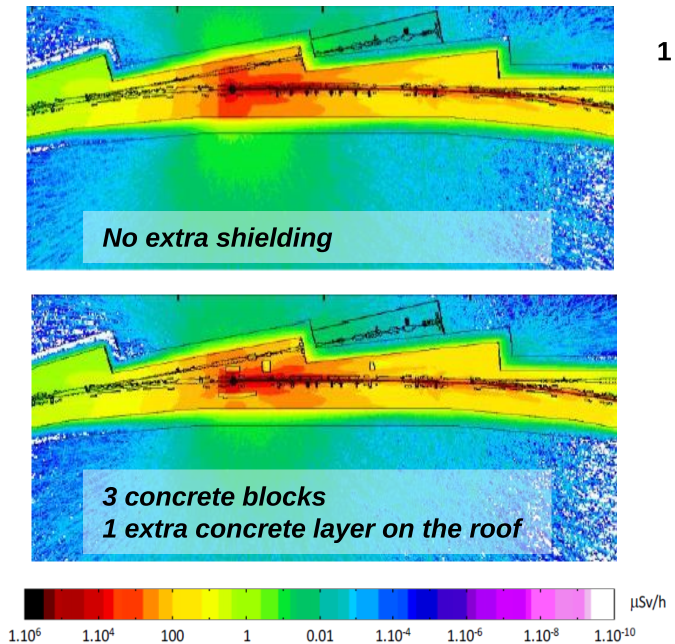
Ref [4], [5], [6]

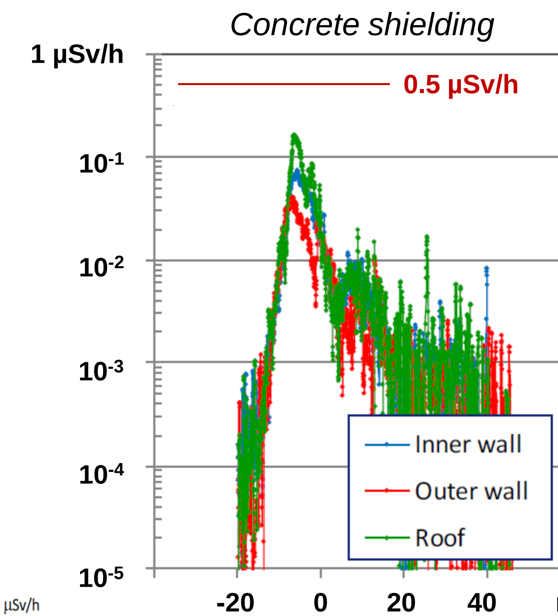
Objective: maintain free access in the experimental hall for all workers

- FLUKA simulations : radiation dose outside the tunnel **< 0.5 μSv/h**

  shielding for normal loss, injection, full beam loss







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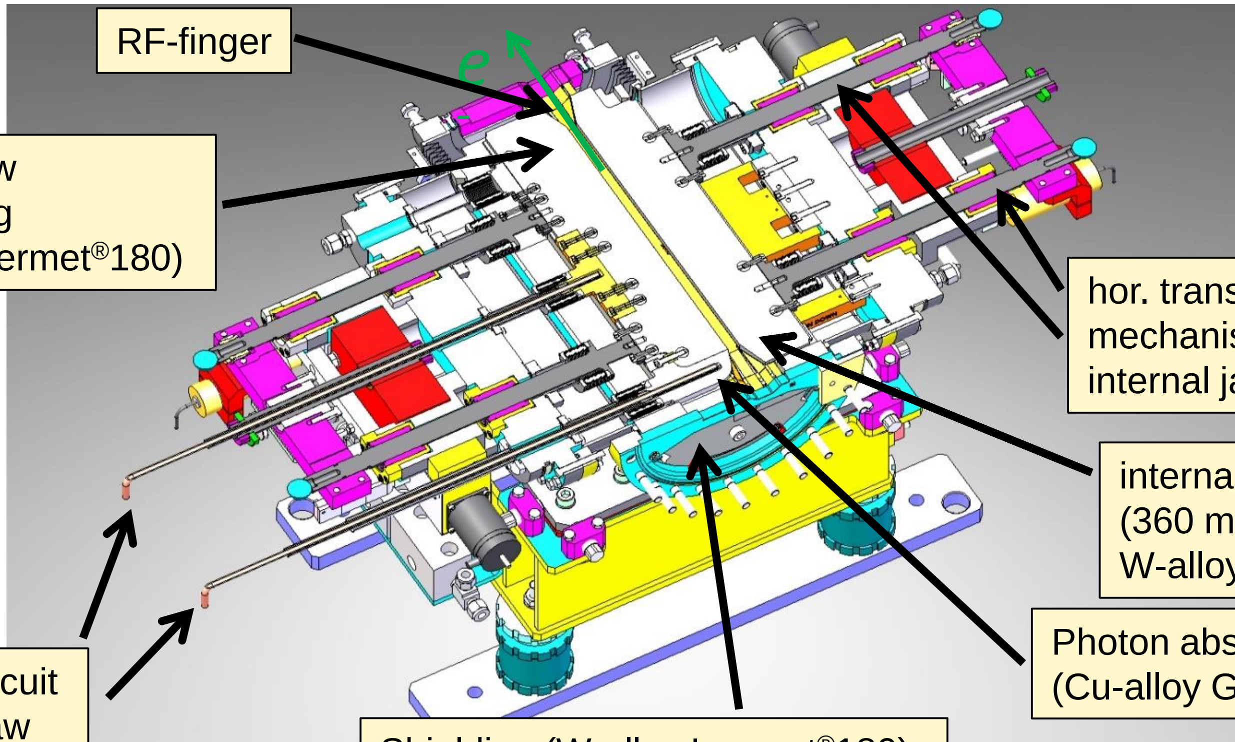
I.3. MECHANICAL DESIGN (1/3)

Ref [7], [8]

Challenges:
- compactness
- movable blades
- smooth RF transitions omega-rectangular shaped aperture
- photon absorber integration
- cooling



3 units built :
2 in operation
+1 spare

J. Borel, et al.

I.3. MECHANICAL DESIGN (2/3)

Ref [7], [8]

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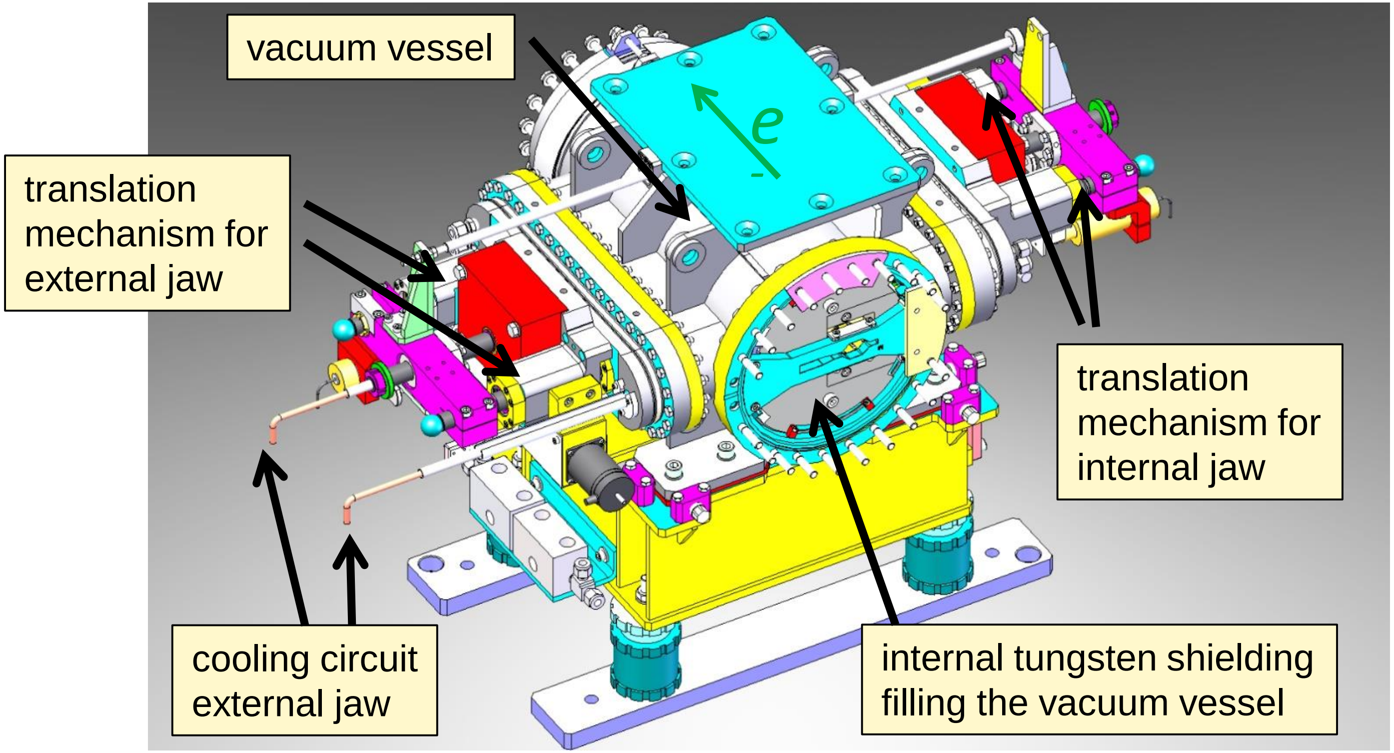
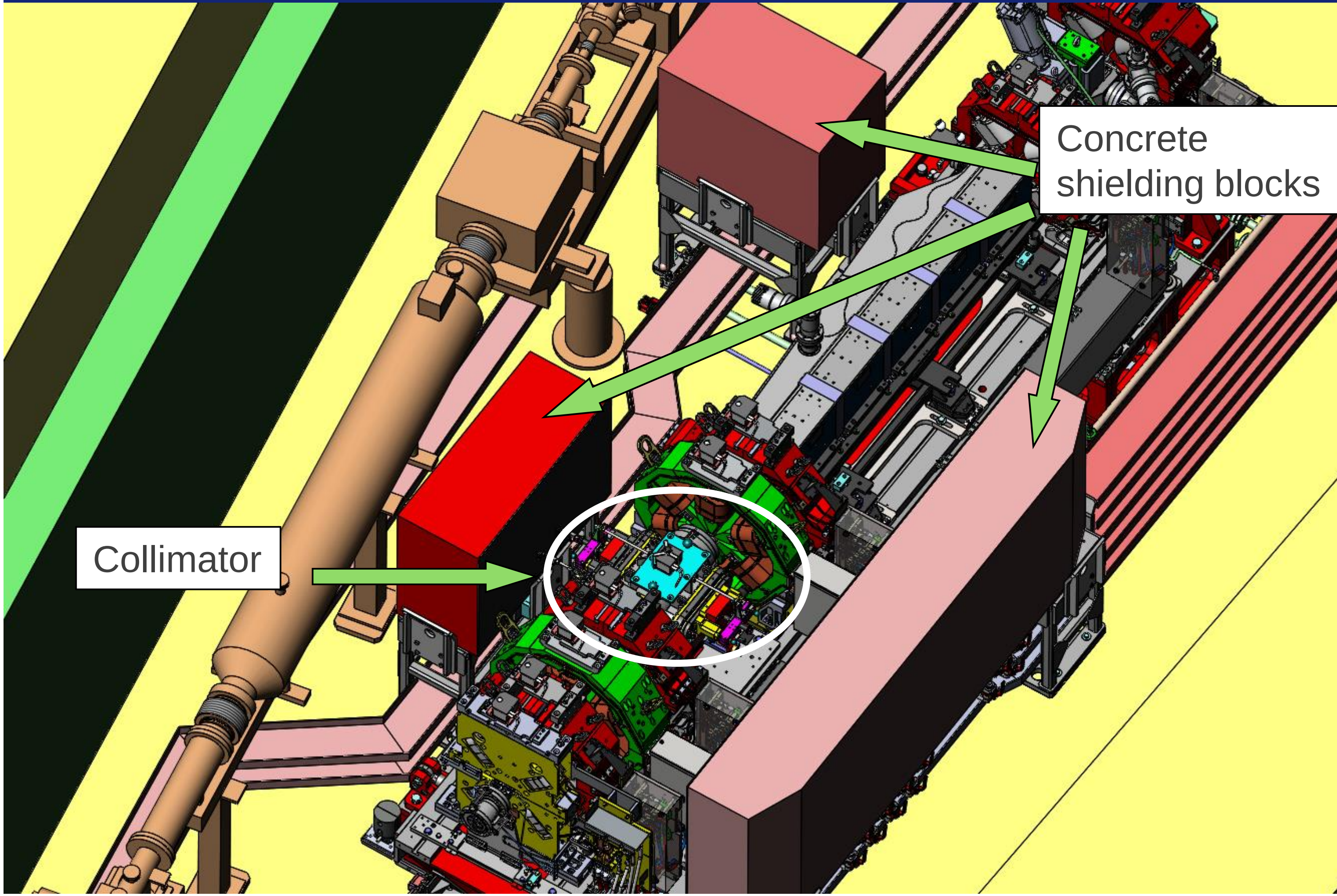


J. Borel, et al.

I.3. MECHANICAL DESIGN (3/3)

Ref [7], [8]

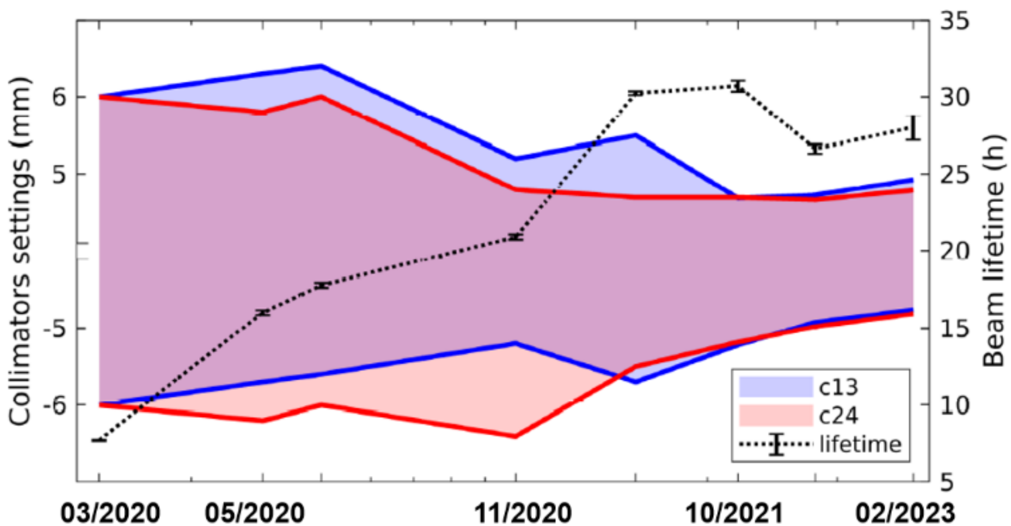


II. Collimation and EBS Commissioning

II.1. FIRST YEARS OF OPERATION

Ref [9],[10]

- January 2020 : First months of machine commissioning done with **symmetric intermediate** collimators' settings, open IDs gaps, strong vacuum losses
- Sept. 2020 : Start of users mode, **reduced** beam current in high intensity per bunch mode, **constraints on ID minimum gaps** depending on Beam Loss Detectors signals
- Mid. 2021 : **Touschek dominated** losses, automated collimators tuning procedure and **stabilization** of the blades' positions

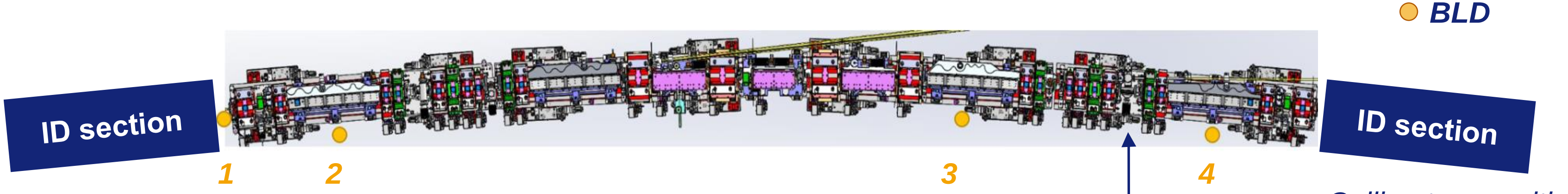


Collimators position versus beam lifetime in uniform mode during EBS start of operation

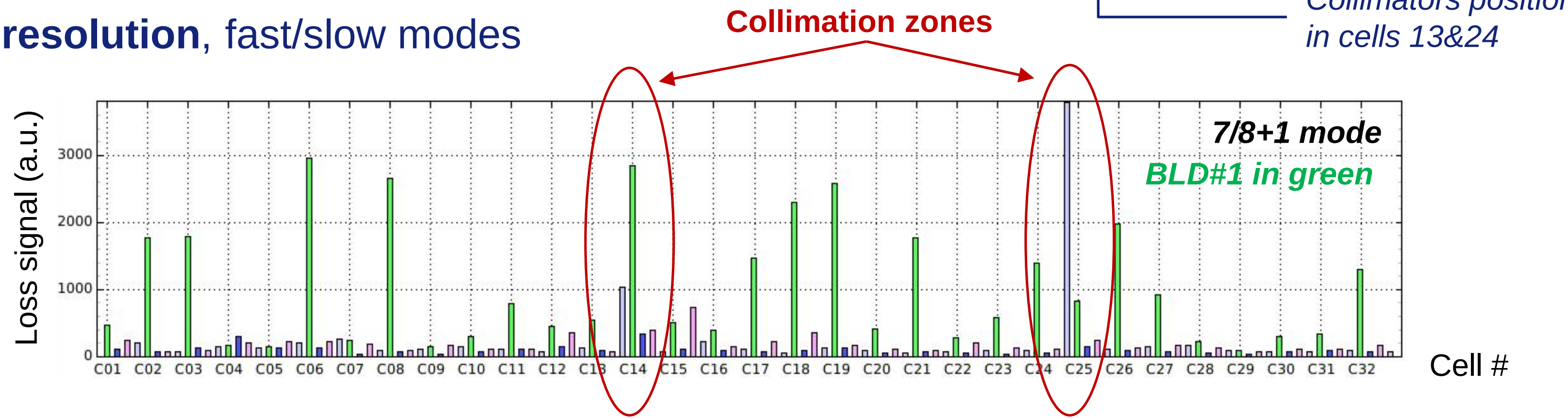
II.2. BEAM LOSS DETECTORS

Ref [11]

- Four **scintillators-based** detectors per cell, i.e. 128 units around the ring



- **High resolution**, fast/slow modes



- **No absolute** calibration, but provides a reliable relative map of beam losses for beam modes and cell to cell **comparisons**,

- **References** and commissioning done before the long shutdown for EBS, with BLM#1 at the same position, same environment behind IDs

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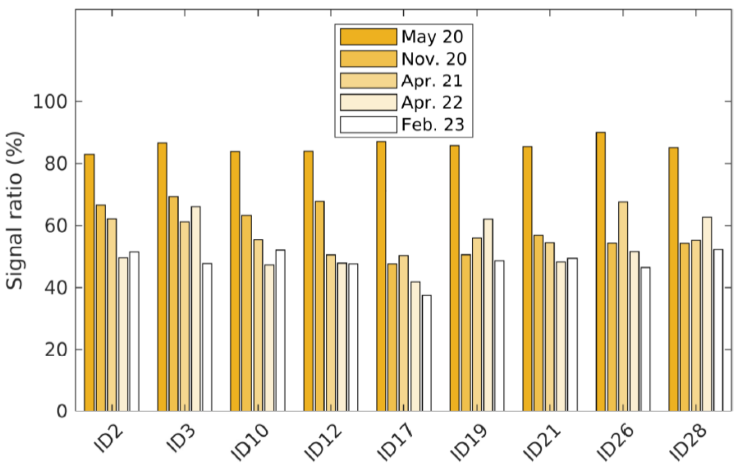
II.3. COLLIMATION EFFICIENCY

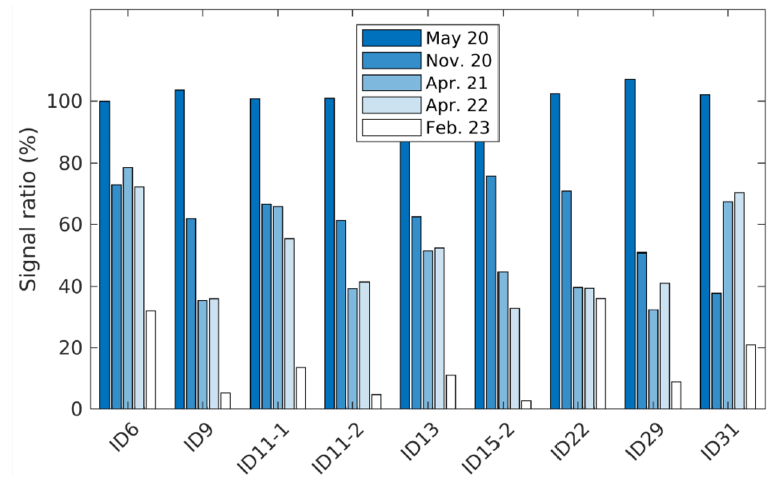
Ref [10]

- Quantified using the **signal of BLM#1** (smallest vertical aperture zones)
- **Between 95% and 50%** signal reduction depending on location and shielding environment
- No gain in 5m-chambers since Touschek dominates over residual gas interactions
- Different behavior for in-vacuum IDs depending on ID gaps and machine tuning – direct scraping and shielding of the electromagnetic shower by the device itself



5m-chambers - 8mm aperture

BLM signal: open collimators vs operation settings



in-vacuum devices at min. gap (5-6mm)

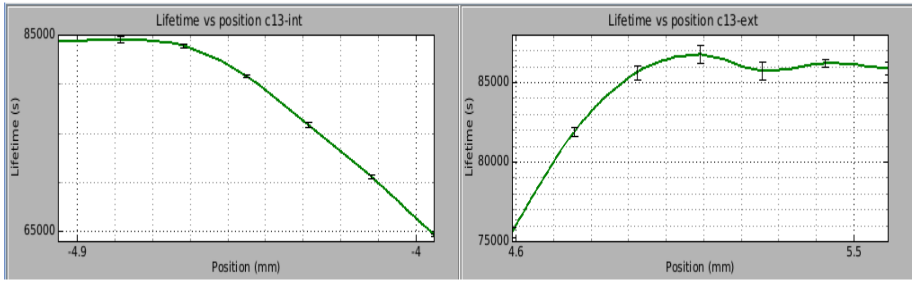
III. Collimation and Machine Operation

III.1. COLLIMATION AND MACHINE OPERATION

Ref [12]

- Collimators scans done after each machine tuning (change of beam mode)

  → **share** losses on 4 jaws
  → keep lifetime reduction **< 10%**
  → do not affect **injection efficiency**



B. Vedder

- **Validation of shielding computations** with radiation measurements

→ stored beam decay,
→ losses at injection,
→ beam dump on collimators

- **No intervention allowed** on collimators, one spare ready to install if needed

	FLUKA model		Measurements	
	1st week	2nd week	1st week	2nd week
background (0.11 nSv·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**

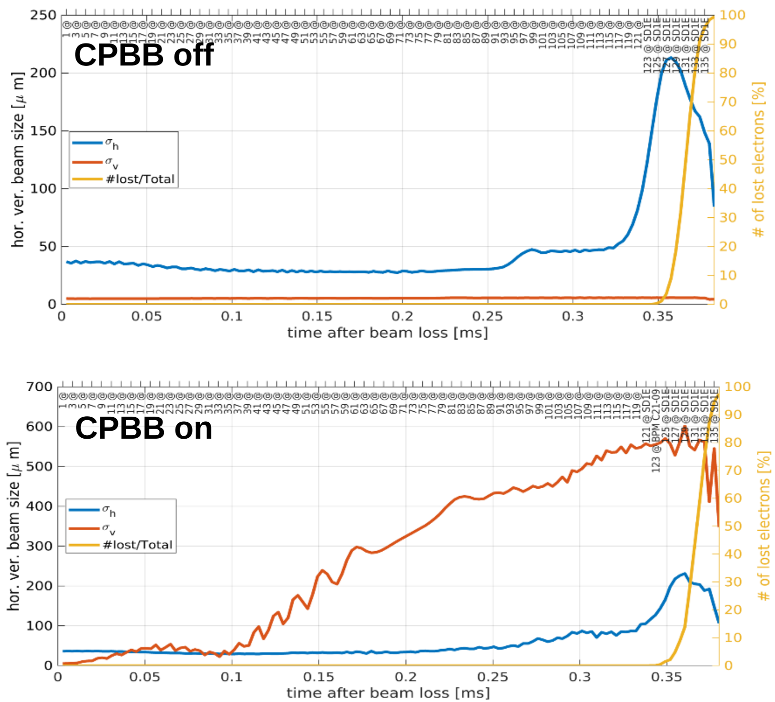
Neutron detector measurements versus FLUKA simulation in April 2021 (collimator cells, 196mA, 24h lifetime) (P. Berkvens)

III.2. COLLIMATORS PROTECTION

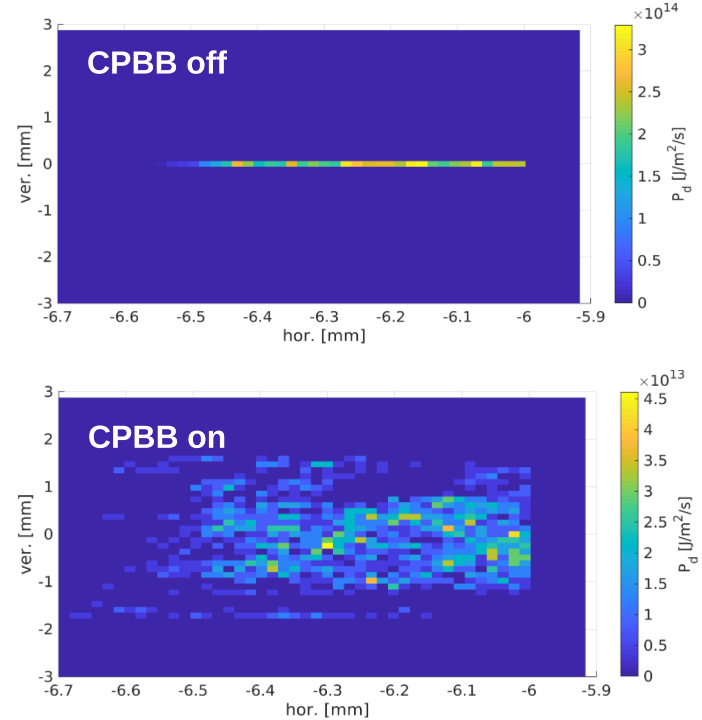
Ref [13]

- Collimator Protection Beam Blower system for interlocks and uncontrolled beam losses
  → **fast vertical blow up** with dedicated shaker to spread the energy deposition

Vertical blow up simulation after an RF trip



Power deposition on one blade for (4b, 40 mA)



Courtesy S. Liuzzo, B. Roche

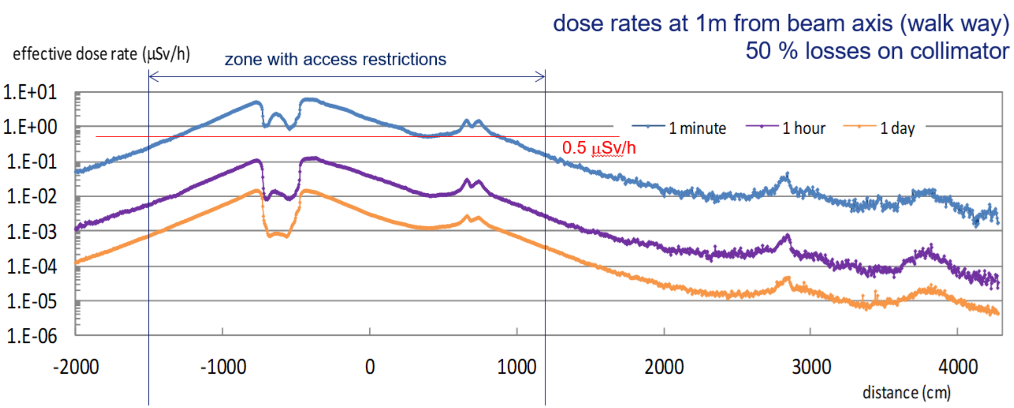
III.3. TUNNEL ACCESS

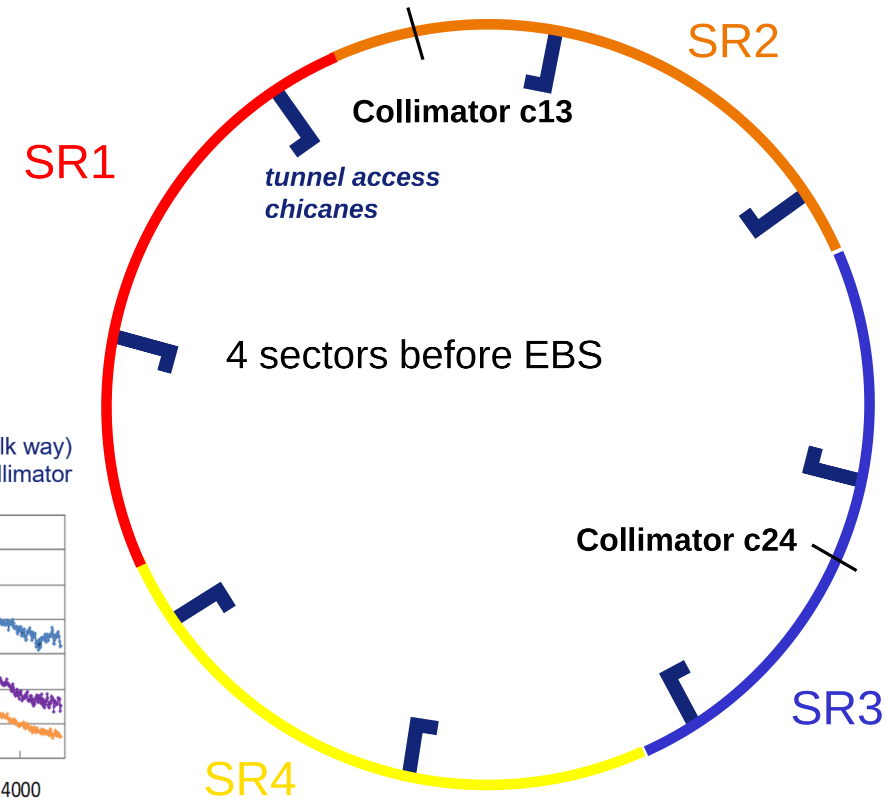
- Tunnel access authorization were modified because of the collimation sections

→ temporary **restricted access zones** after beam dump, impacts on short interventions

→ **beam kill** with one or both collimators depending on access requests

→ additional doors and **modification of the Personal Safety System** needed





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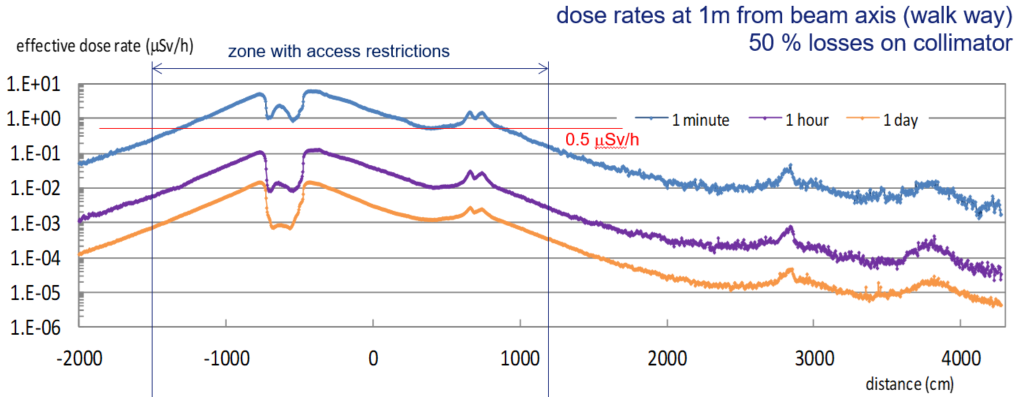

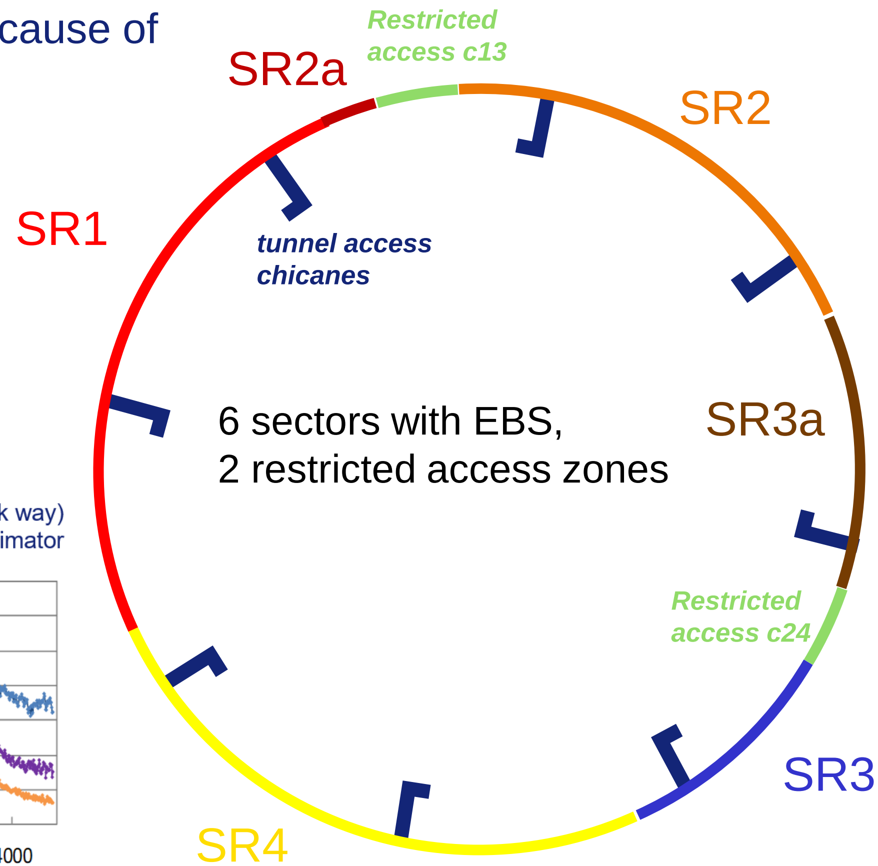

Courtesy P. Berkvens

CONCLUSION

- The shielding study for ESRF-EBS design required a **detailed simulation** of beam loss processes
- In addition to the safety motivation, the **protection of Insertion Devices** became a strong argument in favor of beam collimation
- ESRF collimators have been designed to **guarantee the non exposed worker** condition (dose < 0.5µSv/h) on the roof and outside the ring tunnel during operation, while minimizing the impact on machine operation
- Beam losses monitored in the tunnel showed a good **convergence of the collimation efficiency** as the vacuum conditioning was progressing
- Beam losses levels are **comparable** as measured in the previous machine
- Radiation measurements in operation **validate the shielding model** and hence the collimation and shielding design

Thank you for your attention

Thanks to all people involved from the Beam Dynamics, Diagnostics, Mechanical Engineering, Safety, Vacuum Groups

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