Laser cooling at the SIS100

4th SIS100 Workshop Procurement & Installation
Kloster Eberbach
22 – 24 September 2025

Danyal Winters

Laser cooling collaboration

- GSI Darmstadt

  Sebastian Klammes, Thomas Kühl, Peter Spiller, Thomas Stöhlker[1], **Danyal Winters**
  ([1]also HI Jena & Uni Jena)

- HZDR, TU Dresden

  Michael Bussmann[2], Mathias Siebold, Ulrich Schramm
  ([2]also CASUS Görlitz)

- TU Darmstadt

  Aleksandar Dimitrov, Lewin Eidam, Jens Gumm, Tamina Grunwitz, Benedikt Langfeld, Denise Schwarz, **Thomas Walther**[3]
  ([3]also HFHF Campus Darmstadt)

PhD in 2025

- Uni Münster

  Volker Hannen, Ken Ueberholz, Christian Weinheimer

- IMP-CAS, Lanzhou, China

  Dongyang Chen, Zhongkui Huang, Xinwen Ma, Hanbing Wang, **Weiqiang Wen**

Contents

Motivations for the FAIR SIS100

- create **worldwide unique** laser cooling facility @ FAIR SIS100
- **first application of laser cooling at a large synchrotron** using novel cw & pulsed laser and detection systems
- possibility to **deliver very cold & very short ion bunches** to FAIR experiments (*e.g.* plasma physics)

- “efficiency” of laser cooling increases with ion beam energy (γ)
- highly relativistic ion energies of the SIS100 allow **cooling of many ion species** by exploiting the huge Doppler shift (γ up to 13): Z = 10 – 54

- laser spectroscopy of the electronic structure of heavy ions

Contents

1. Motivations for laser cooling
2. New simulations
3. Laser systems
4. Laser Beamline (part 1 & 2)
5. Laser Lab

and for the SIS100 :

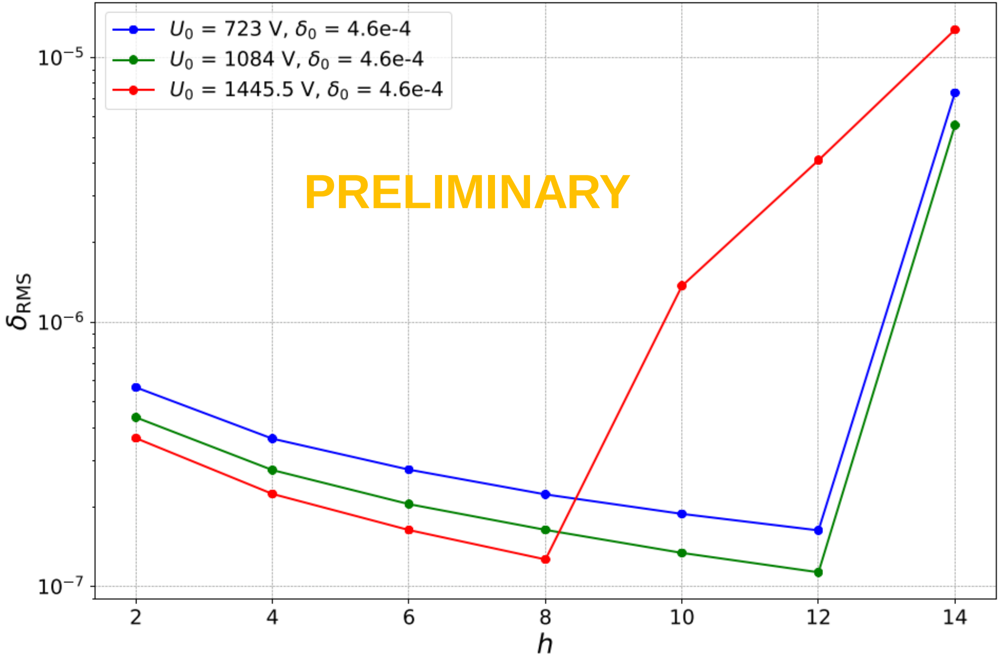


Figure 5.12: Dependence of δ_{RMS} on the bunching number h and the RF amplitude U_0. Different colors represent different values for U_0. δ_0 is the initial relative longitudinal momentum spread.

1 scanning CW laser

no particle interactions

Simulations by Aleksandar Dimitrov

and for the SIS100 :

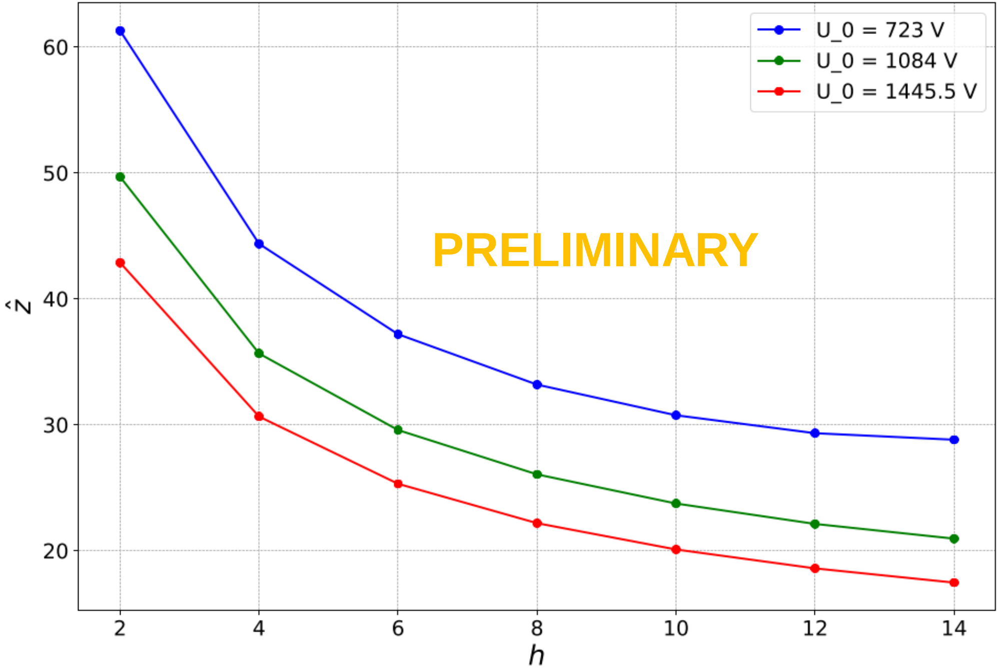


Figure 5.13: Dependence of the bunch length $\hat{z}$ on h and U_0. Different colors represent different U_0 values. The initial relative longitudinal momentum spread is $\delta_0 = 4.6 \times 10^{-4}$.

1 scanning CW laser

no particle interactions

Simulations by Aleksandar Dimitrov

and for the SIS100 :

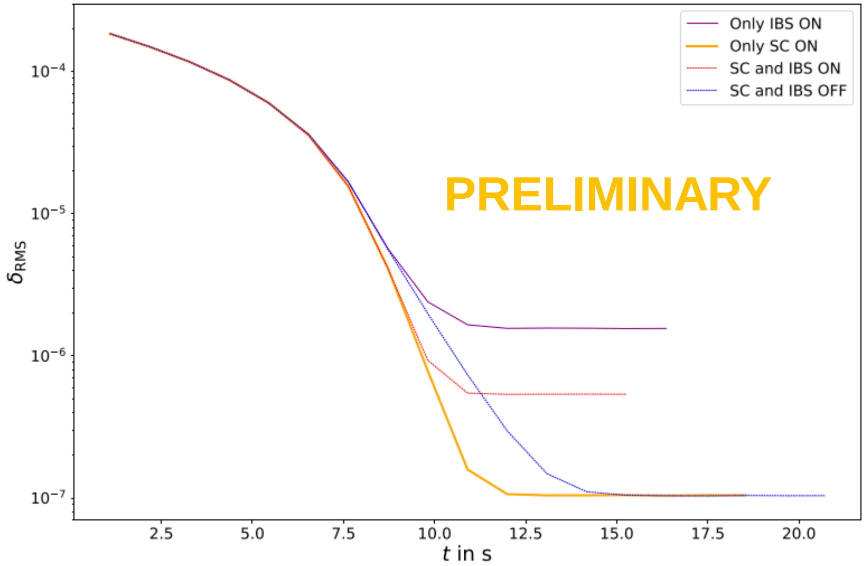


Figure 5.22: Time evolution of the cooling process with two pulsed laser systems at optimized power with particle interactions turned on and off individually. The thin, dashed lines shows the previous results without interaction and with both effects implemented, and are included for a direct comparison.

2 pulsed lasers

with particle interactions

Simulations by Aleksandar Dimitrov

and for the SIS100 :

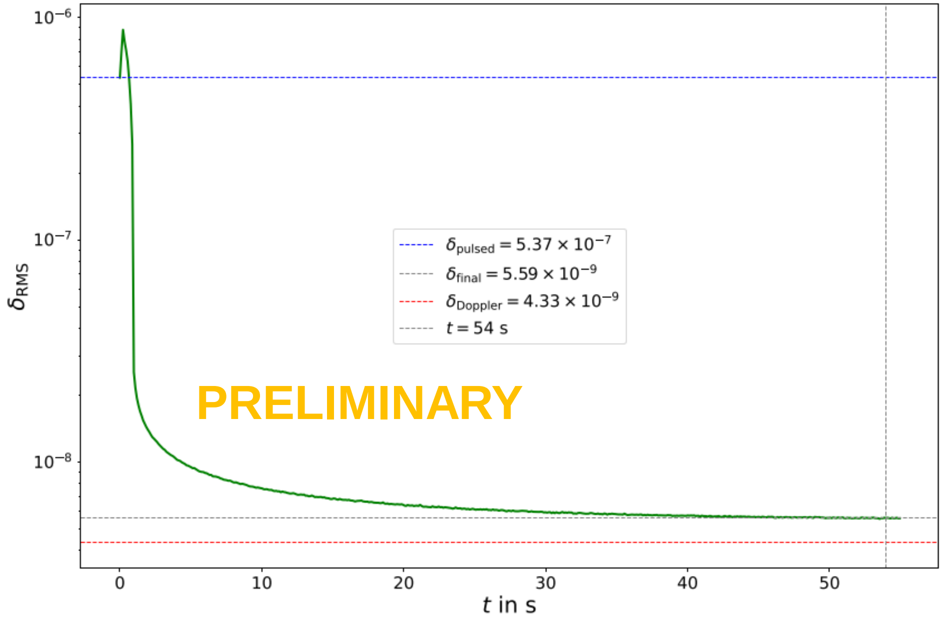


Figure 5.24: Secondary cooling progress using a fixed cw laser, applied after the pulsed lasers have established a pre-cooled state with $\delta_{\text{Pulsed}} = 5.37 \times 10^{-7}$ at $t = 11$ s

1 scanning CW laser

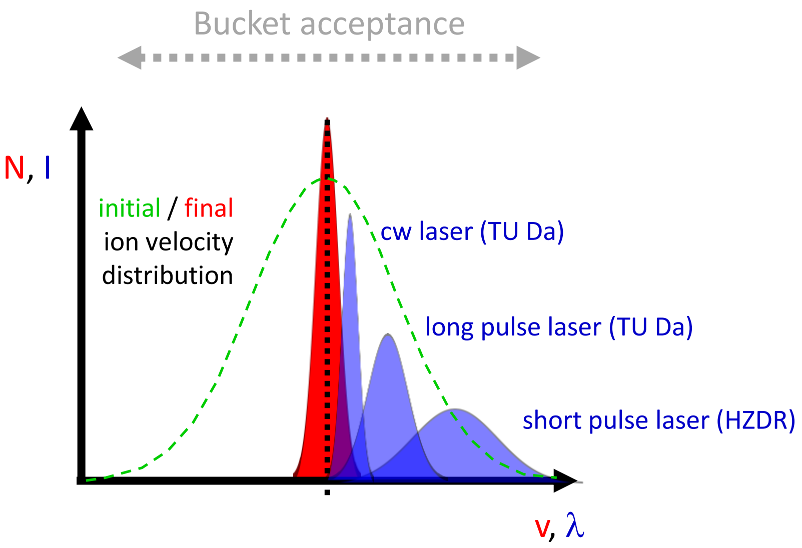
after 2 pulsed lasers

with particle interactions

Simulations by Aleksandar Dimitrov

Contents

3-beam laser cooling at the SIS100



Using **three** laser systems at the SIS100 simultaneously combines the advantages of:

- covering a large ion velocity range
- suppressing heating effects like IBS
- fast cooling (order of seconds)
- lowest possible longitudinal ion momentum spread $\Delta p/p \sim 10^{-7}$
- shortest ion bunch lengths (order of ~10 ns)

But … requires overlap of ion and laser beams in space, time & energy !

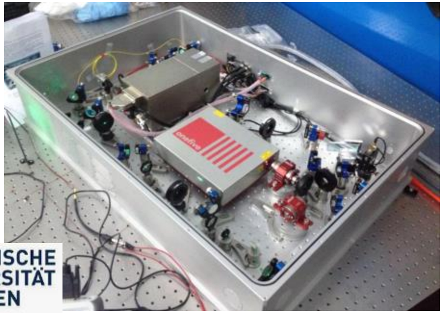
2024 – 2027: Full „FAIR Core Invest“ funding of 3 laser systems for SIS100 laser cooling

Federal Ministry of Education and Research

„Verbundforschung“

„short“ pulse laser system

- pulse duration: 10 – 100 ps
- repetition rate: up to 5 MHz
- power: up to 10 W @ 1028 nm
  up to 100 mW @ 257 nm

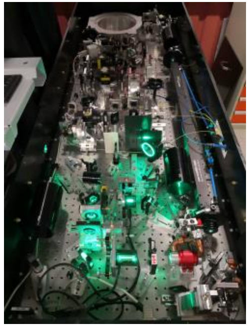


HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

TECHNISCHE UNIVERSITÄT DRESDEN

„long“ pulse laser system

- pulse duration: 50 – 740 ps
- repetition rate: up to 10 MHz
- power: up to 60 W @ 1028 nm
  up to 4 W @ 257 nm



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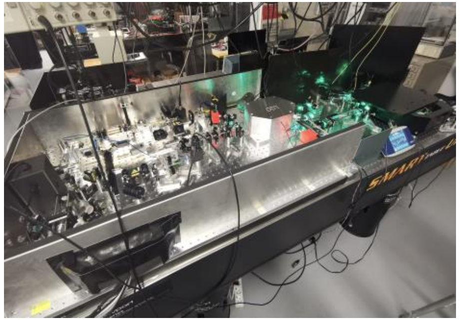
continuous wave laser system

- narrow linewidth
- mode hop free scanning over 20 GHz (50 Hz scan rate) @ 257 nm
- power: up to 1.6 W @ 257 nm



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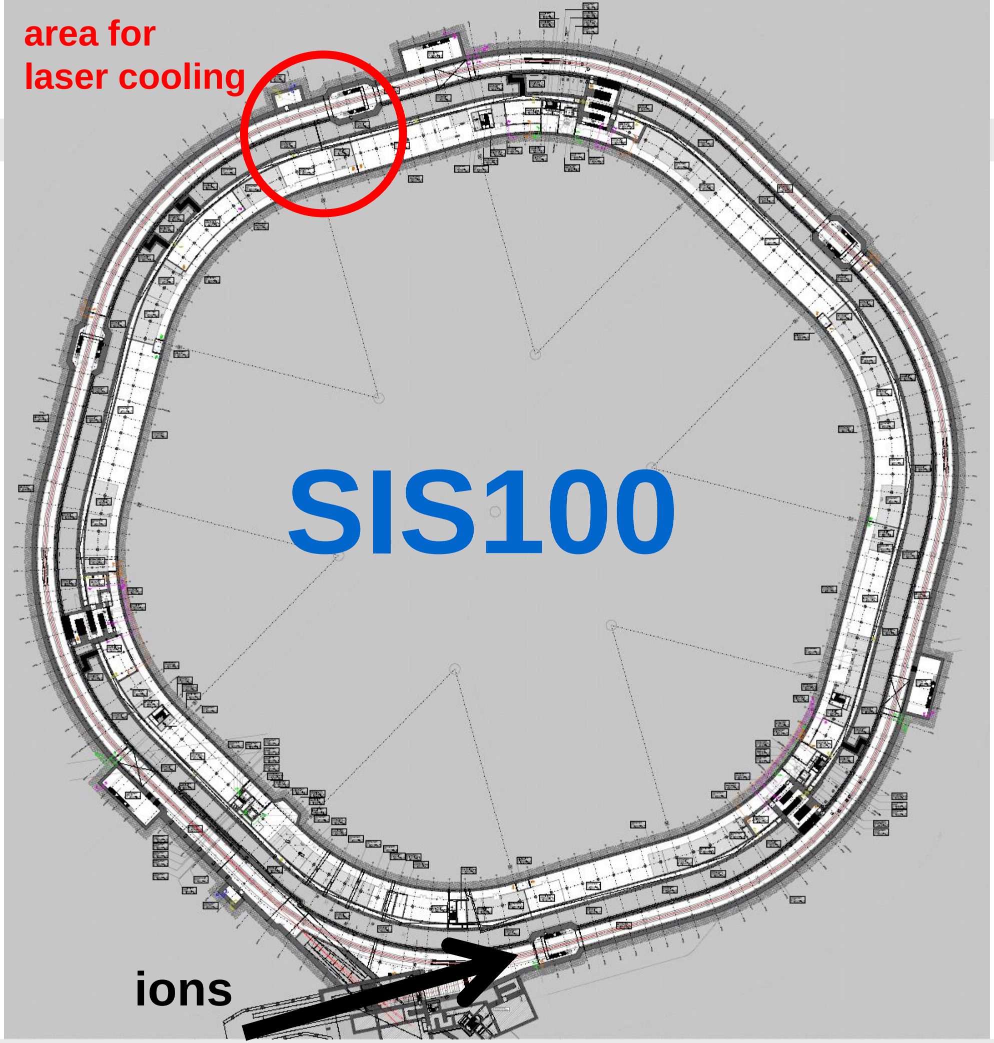
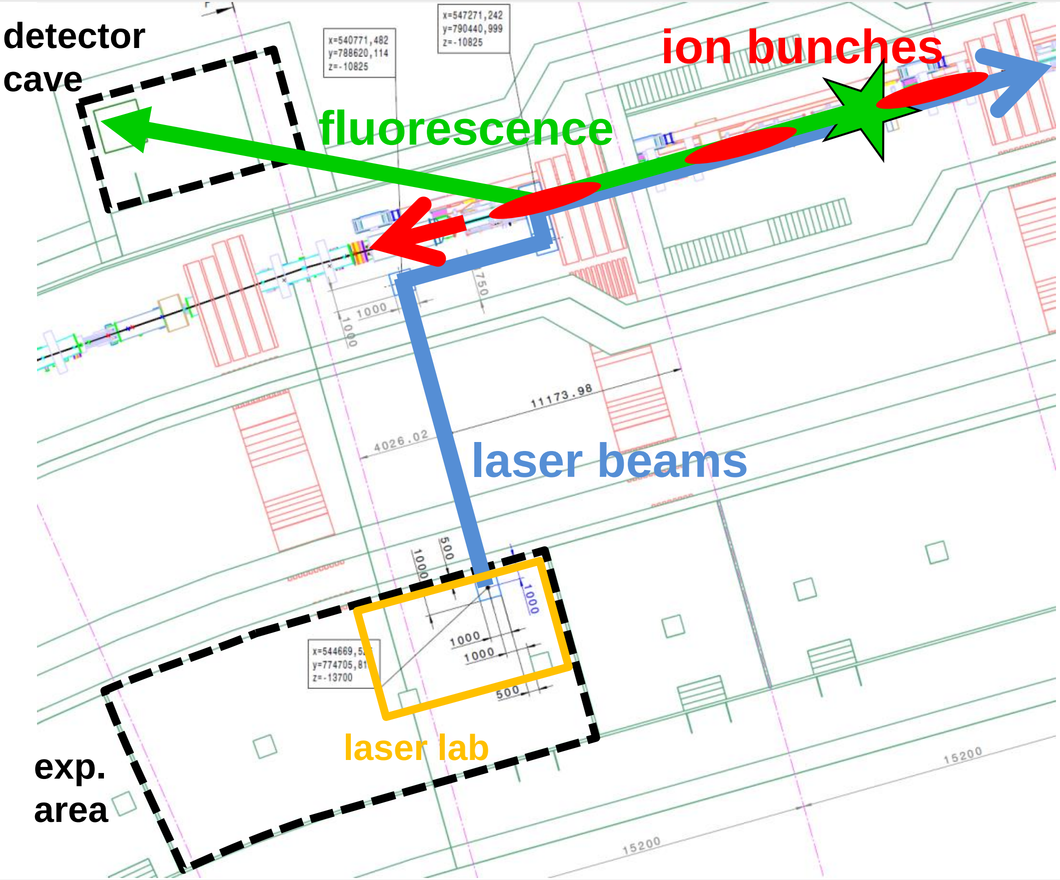
Note: All laser systems use two frequency doubling stages: 1028 nm → 514 nm → 257 nm

Contents

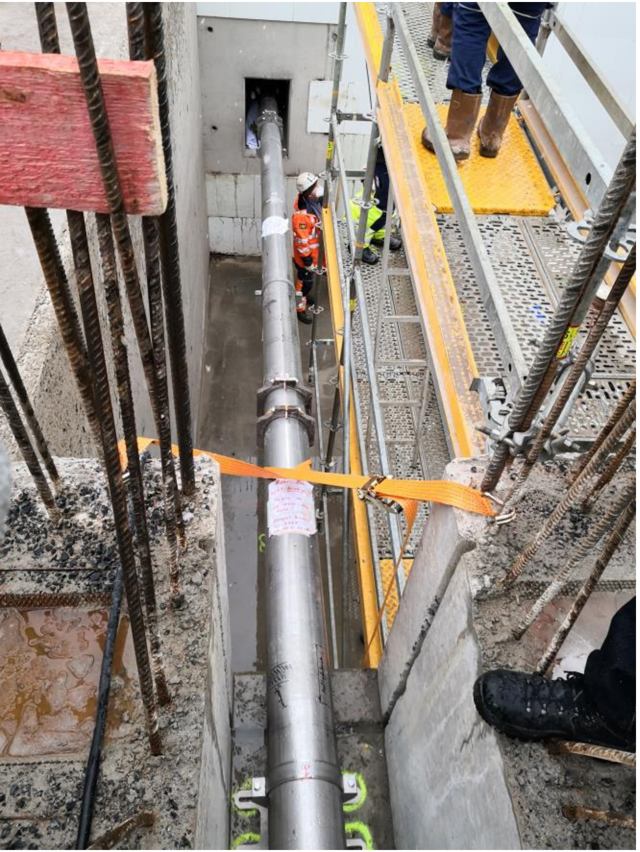
The facility

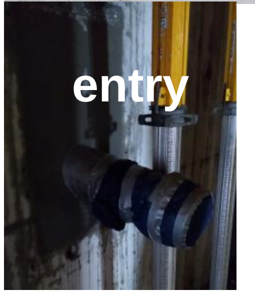


The beams

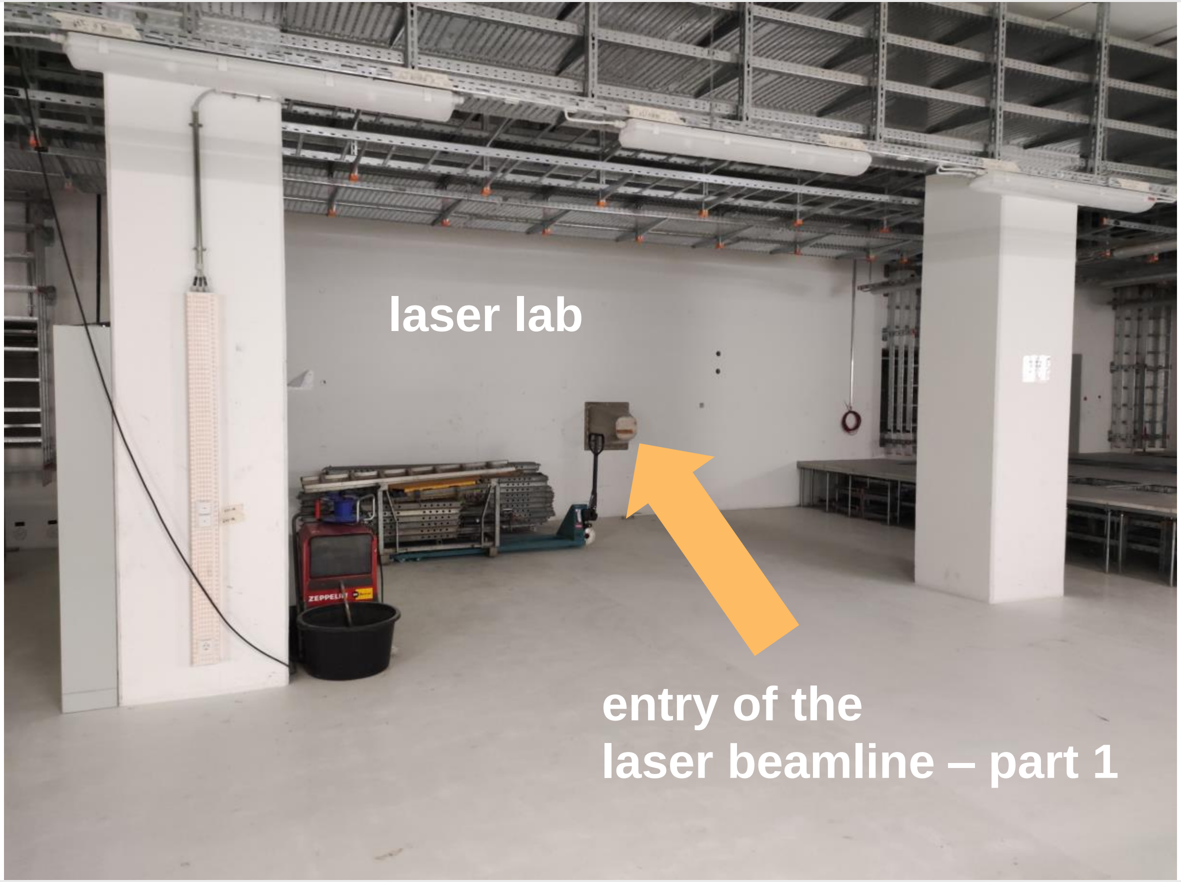

detector
cave
fluorescence
ion bunches
laser beams
laser lab
exp.
area
1000
1000
750
11173.98
4026.02
500
1000
1000
1000
500
15200
15200

Transport and installation of the laser beamline





SIS100 maintenance tunnel taken 2024

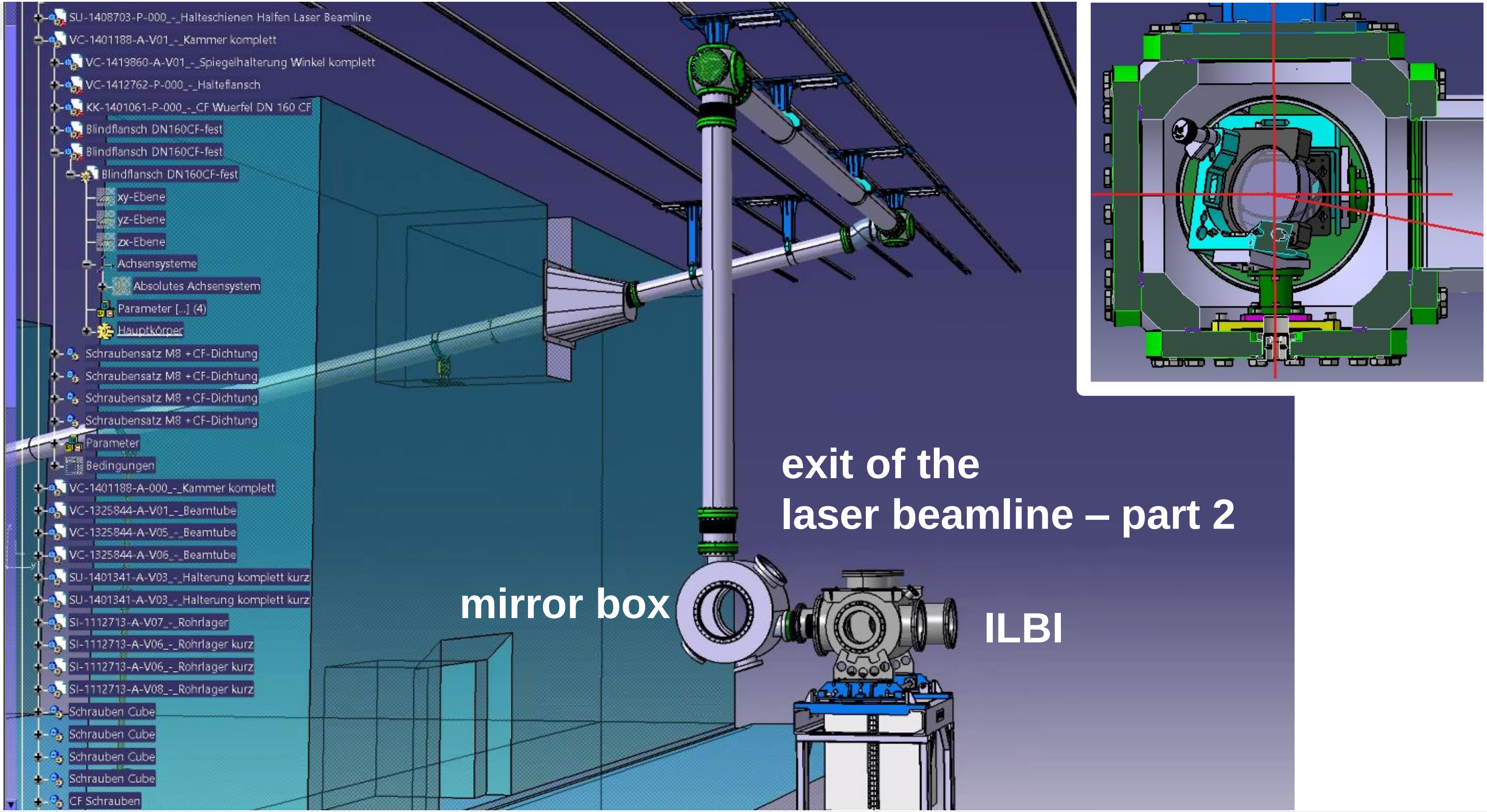


SIS100 accelerator tunnel

taken 2024

commissioning of the
laser beamline – part 1
Fri. 13 June 2025

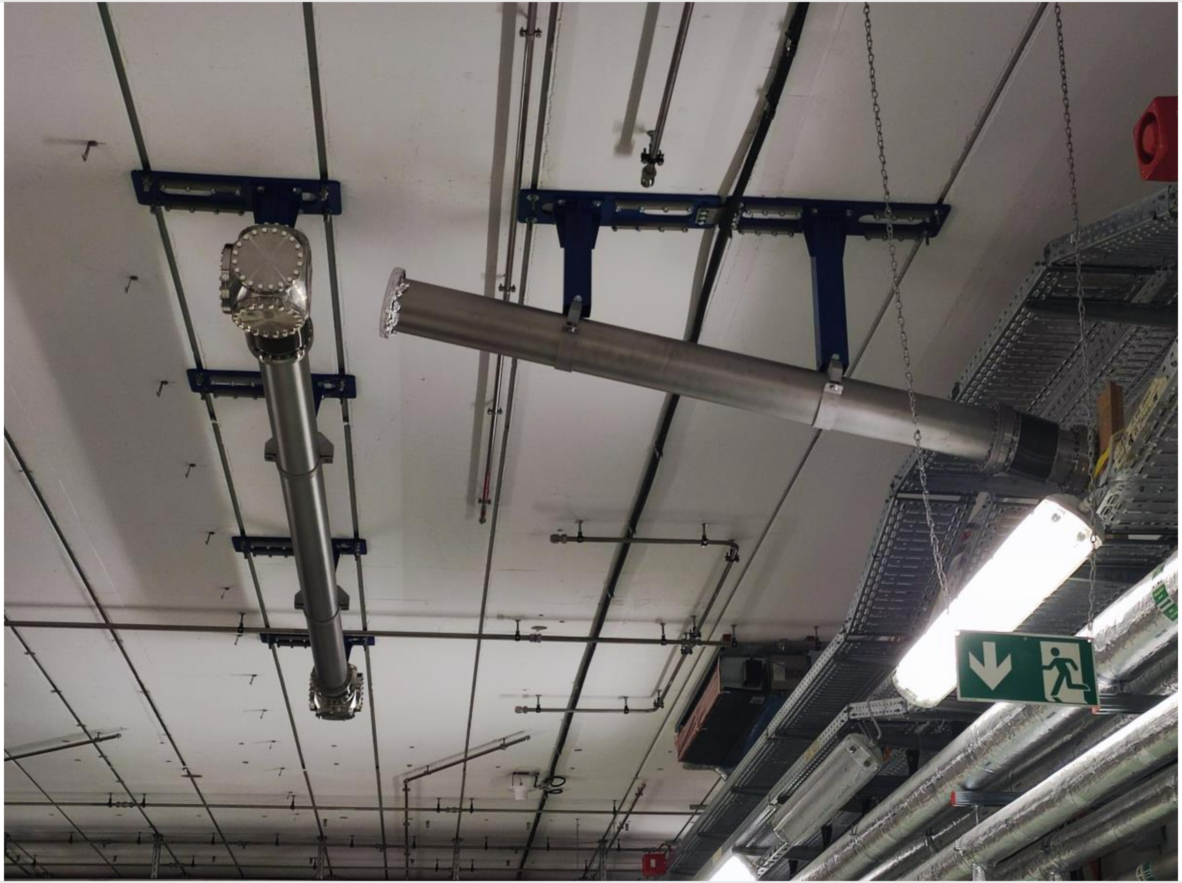
SIS100 laser beamline – part 2

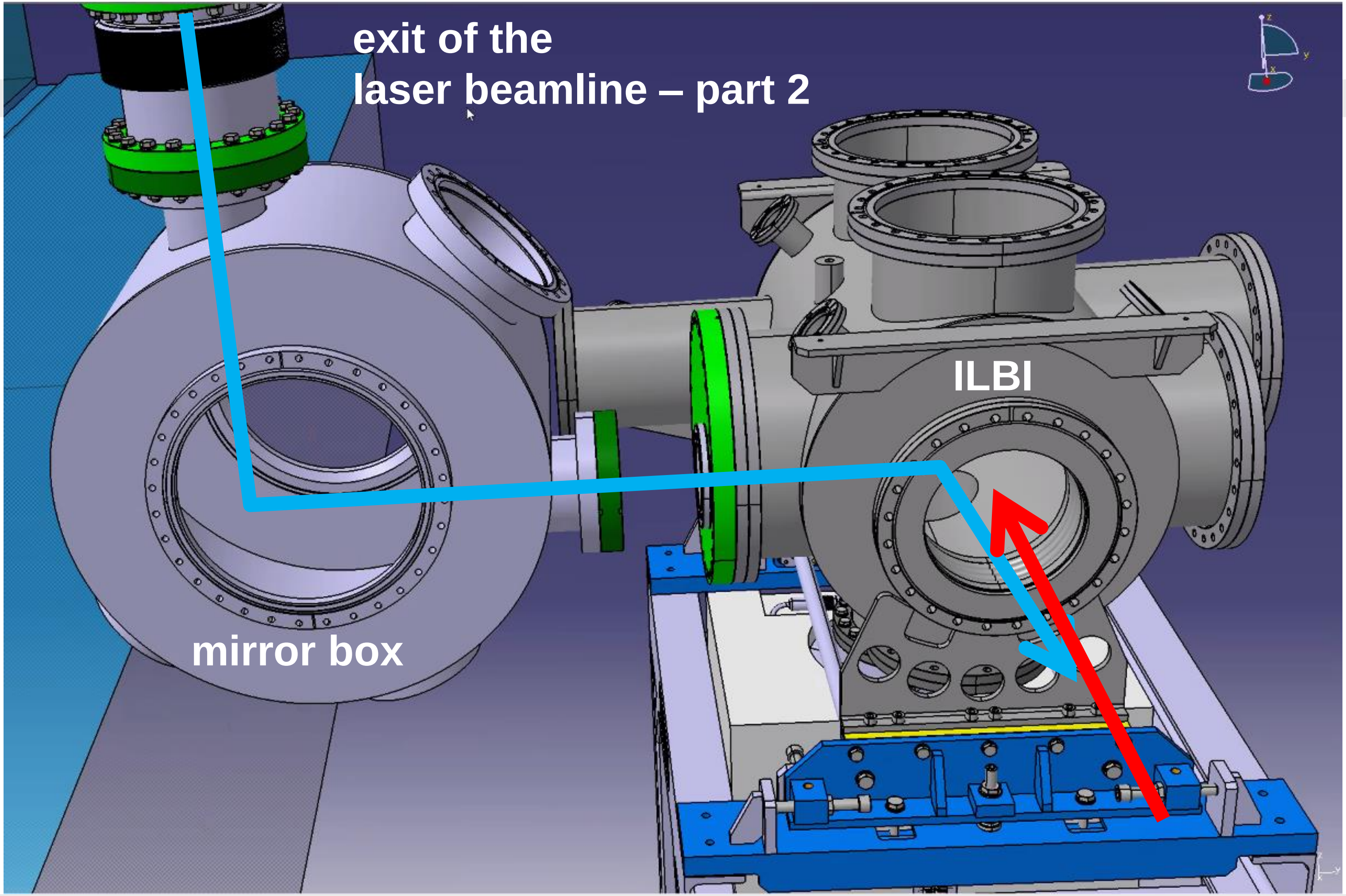


SIS100 laser beamline – part 2

SIS100 laser beamline – part 2

SIS100 laser beamline – part 2



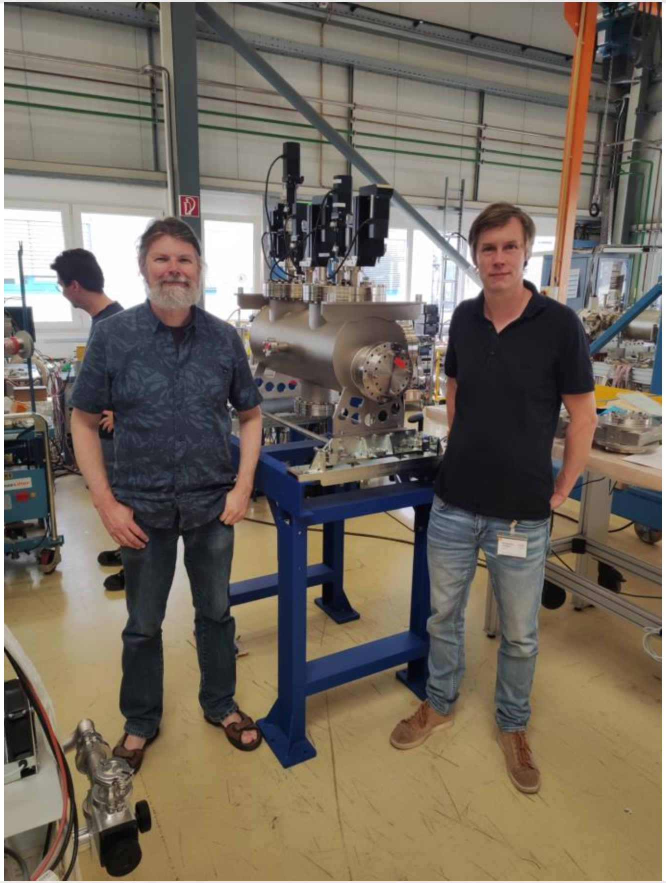

exit of the
laser beamline – part 2
ILBI
mirror box

two experiment vacuum chambers

Special thanks to
Ivan Pongrac !!!

x-ray/xuv fluorescence detection (Münster)

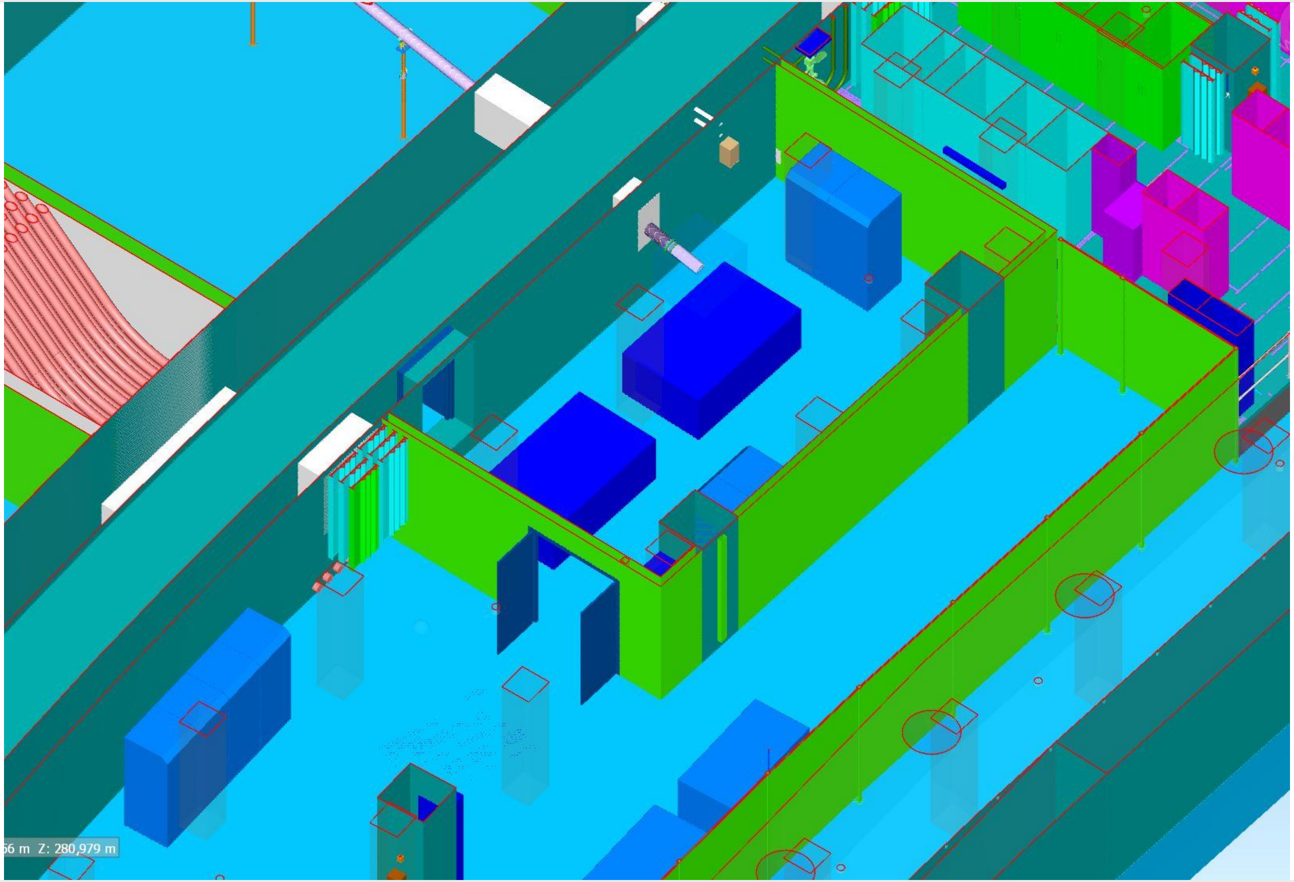
18. June 2025



MoU between
Münster University
and GSI / FAIR.

Contents

The SIS100 laser lab



Start
Dec ´25

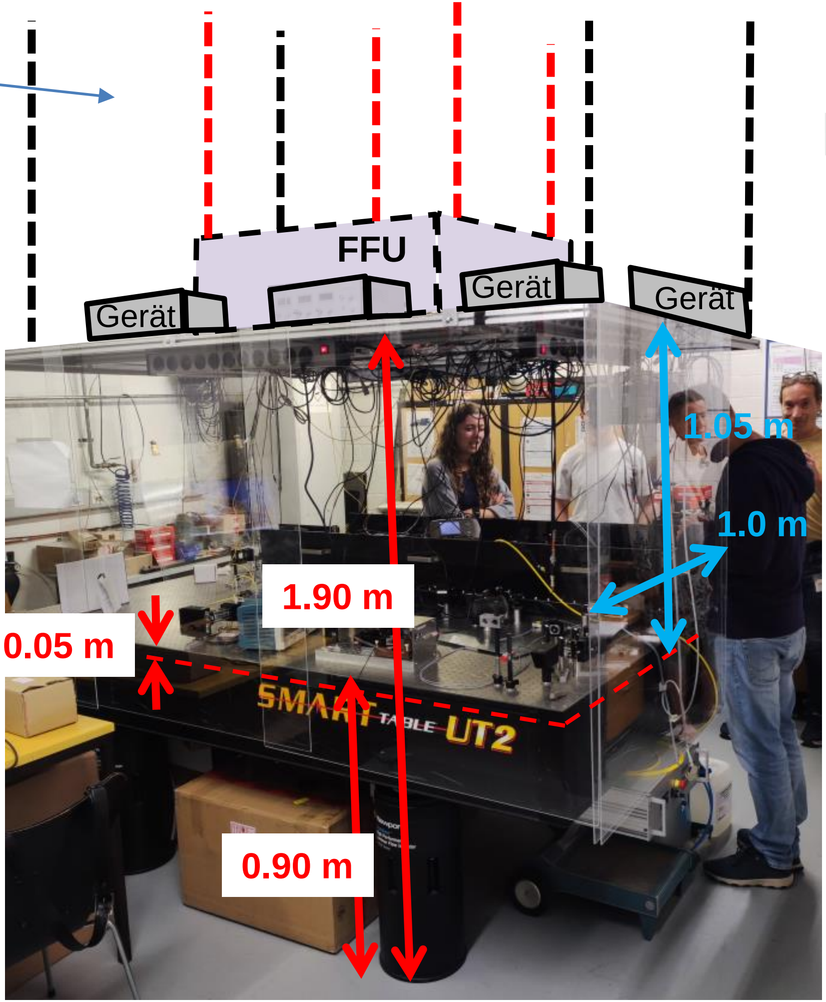
Finished
Aug ´26

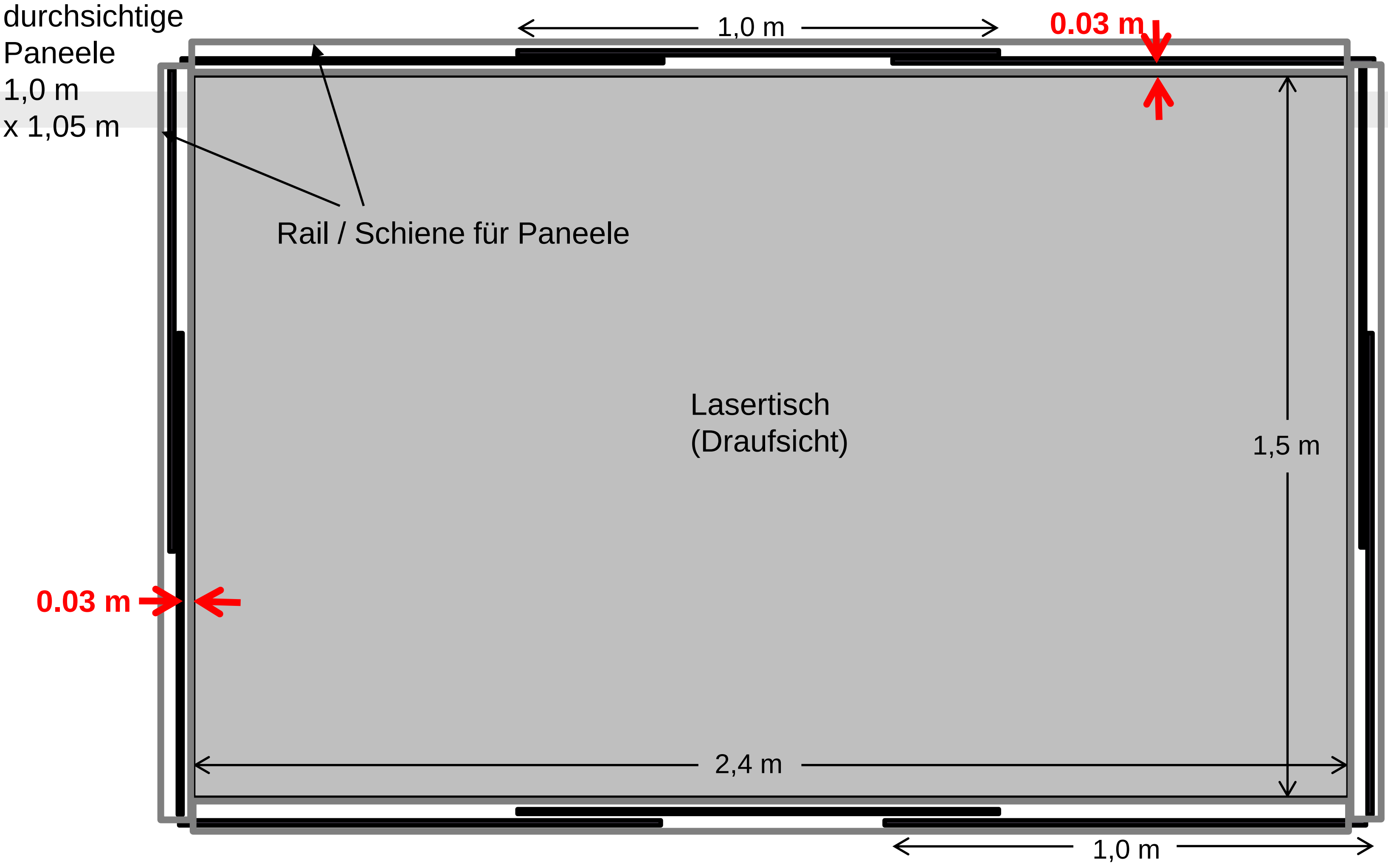
Wie viele Ketten/Seile?
4, 6 oder 8?

1 Regal mit 1 FFU (1,2m x 0,6m) drin und
eine Bürstenleiste um FFU herum
(um Kabel und Faser durchzuführen)

Regal auf Höhe 1,9 m (Unterkante)

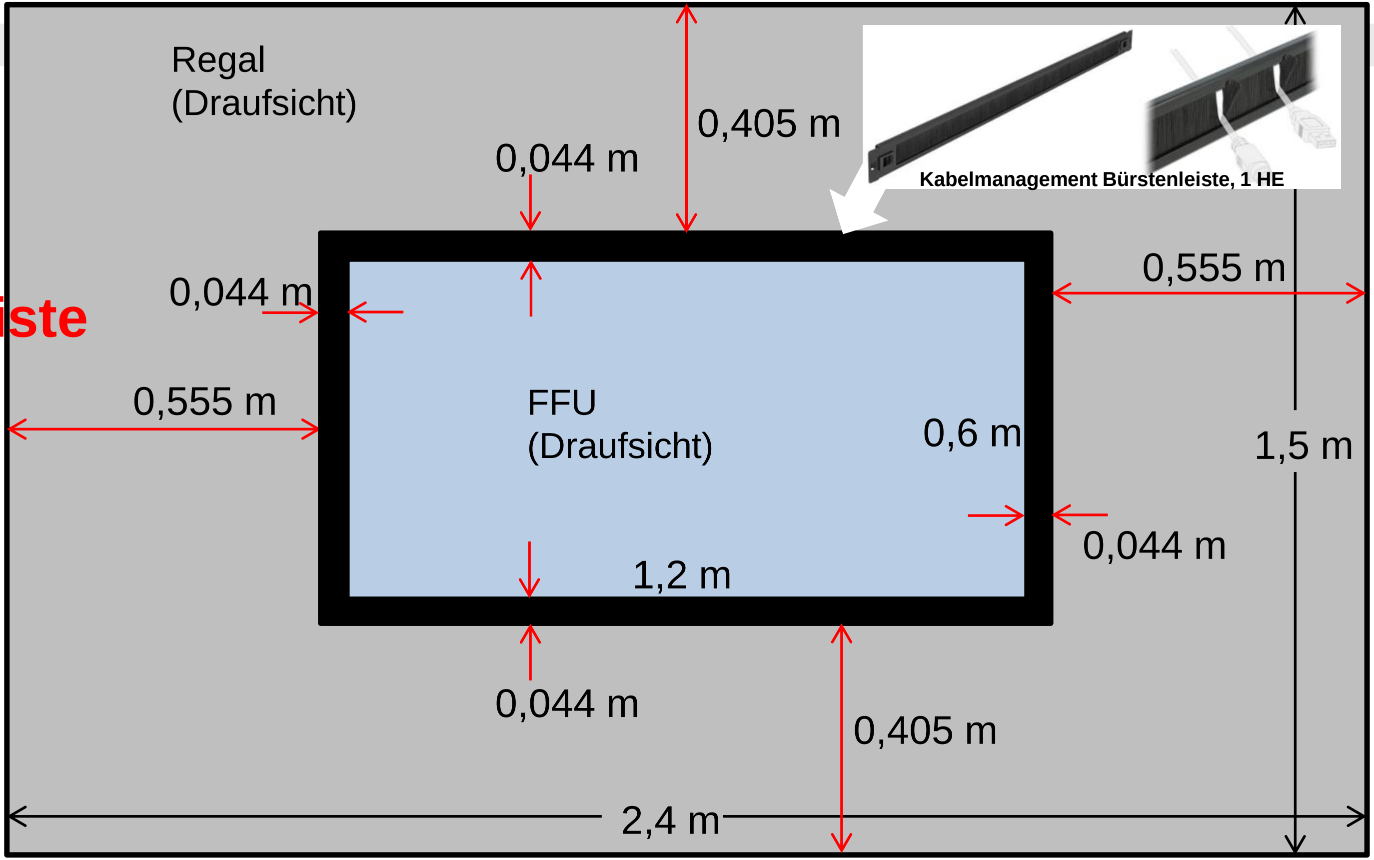
Kunststoff Paneele (durchsichtig)
Maßen: 1,0m x 1,05m x 3 mm Dicke




durchsichtige
Paneele
1,0 m
x 1,05 m
1,0 m
0.03 m
Rail / Schiene für Paneele
Lasertisch
(Draufsicht)
1,5 m
0.03 m
2,4 m
1,0 m

https://www.reichelt.de/de/de/shop/produkt/19_kabelmanagement_buerstenleiste_1_he_schwarz-279918

1 Regal mit 1 FFU und Bürstenleiste



Nylonbürsten
schwarz
Metall
Maße (LxBxH):
ca. 482,0 x 44,2 x 10,0 mm

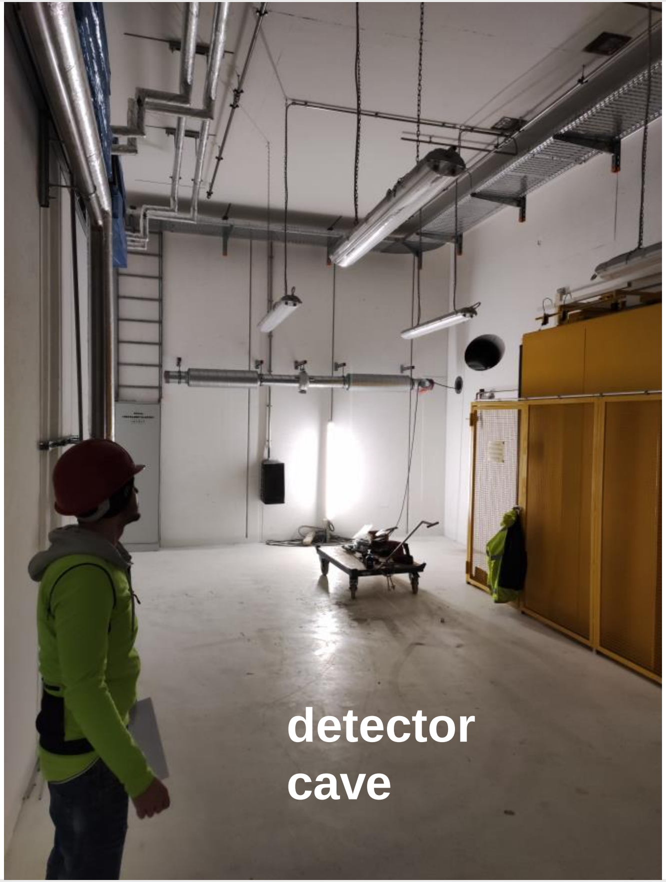
Meeting Darmstadt & Dresden: 6 – 7 August 2025

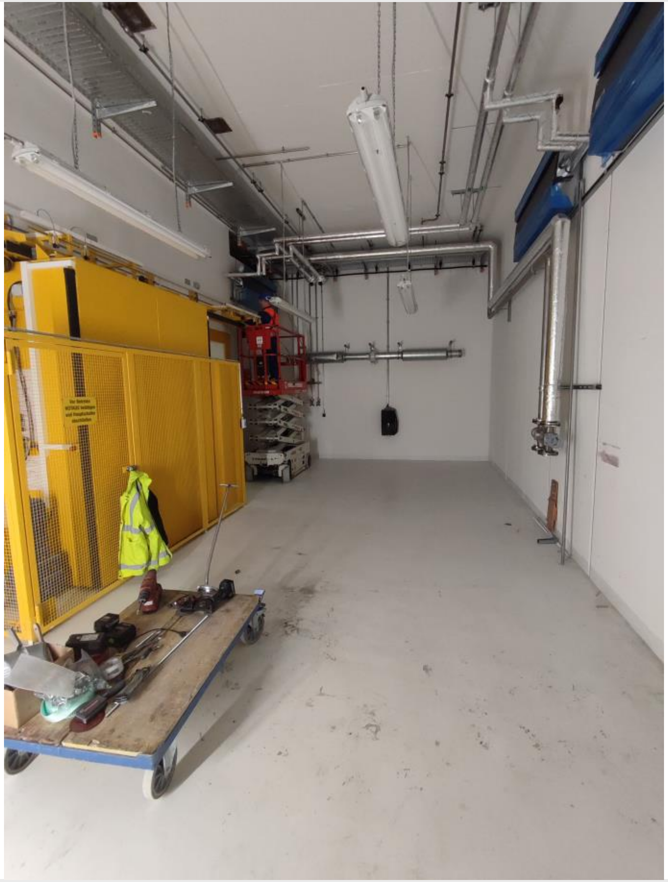
Thank you for your attention!

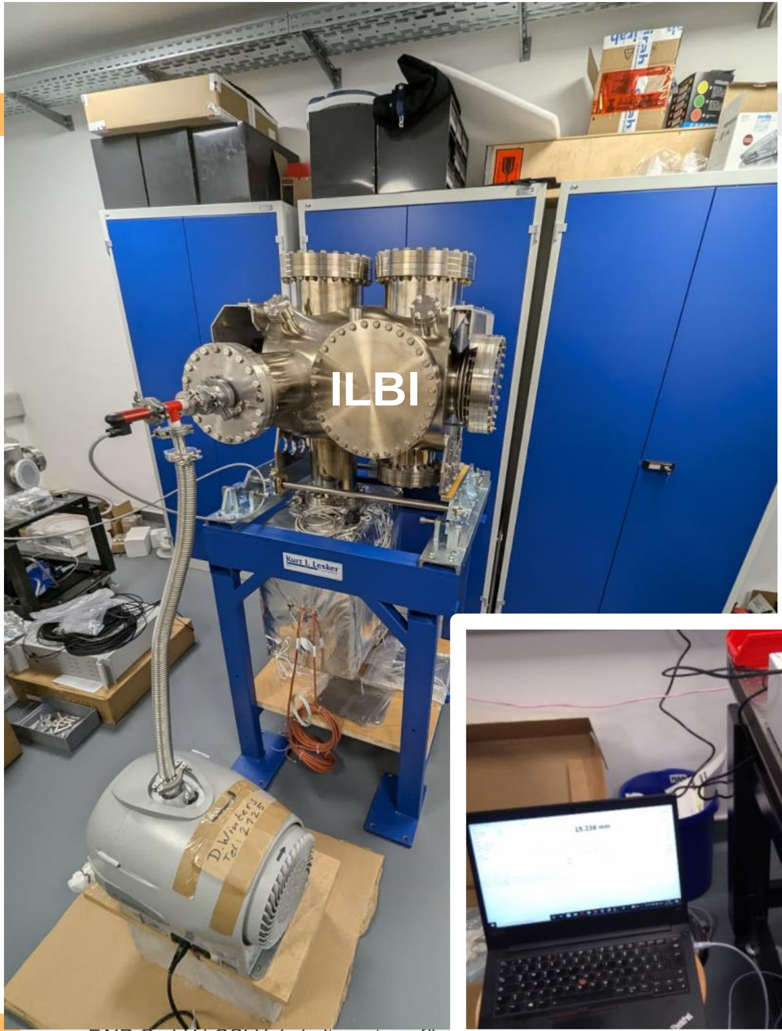
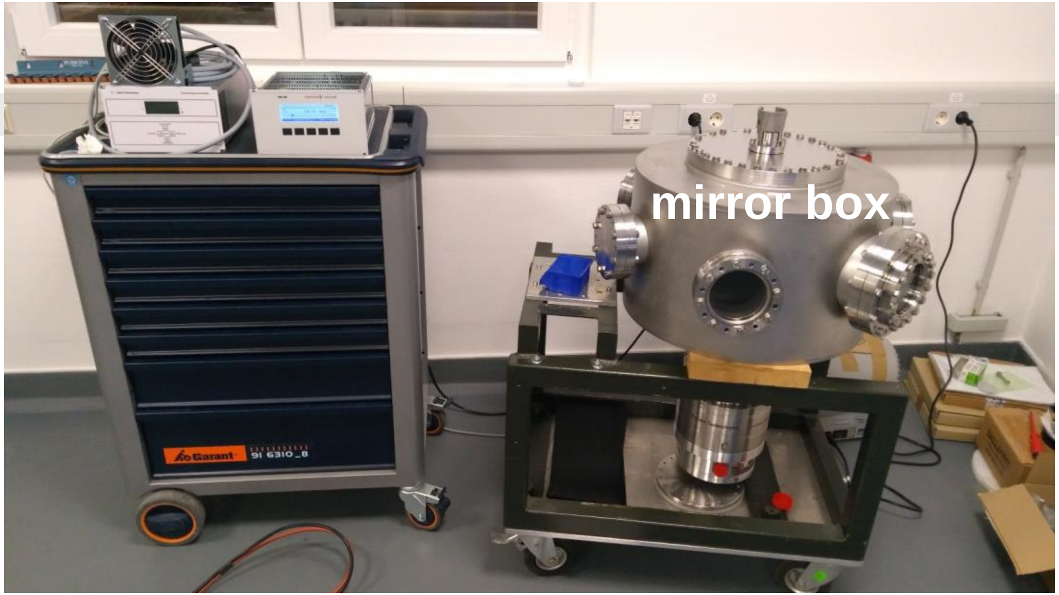
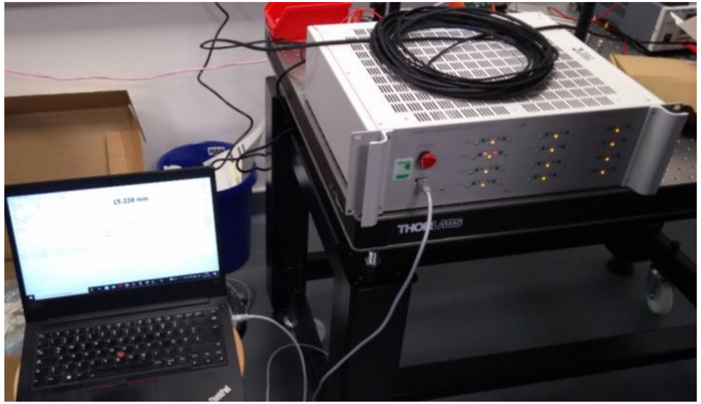
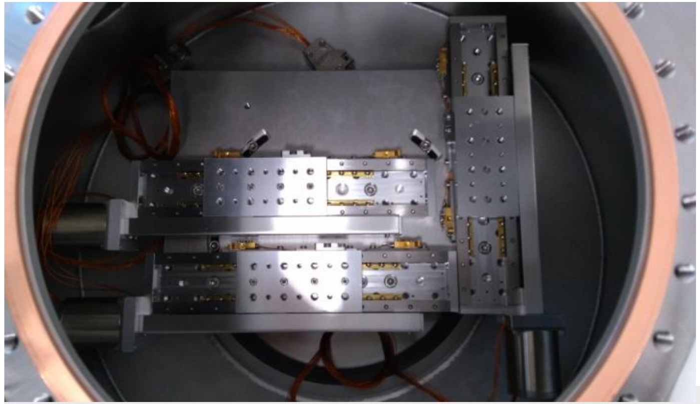
EXTRA SLIDES

SIS100 accelerator tunnel

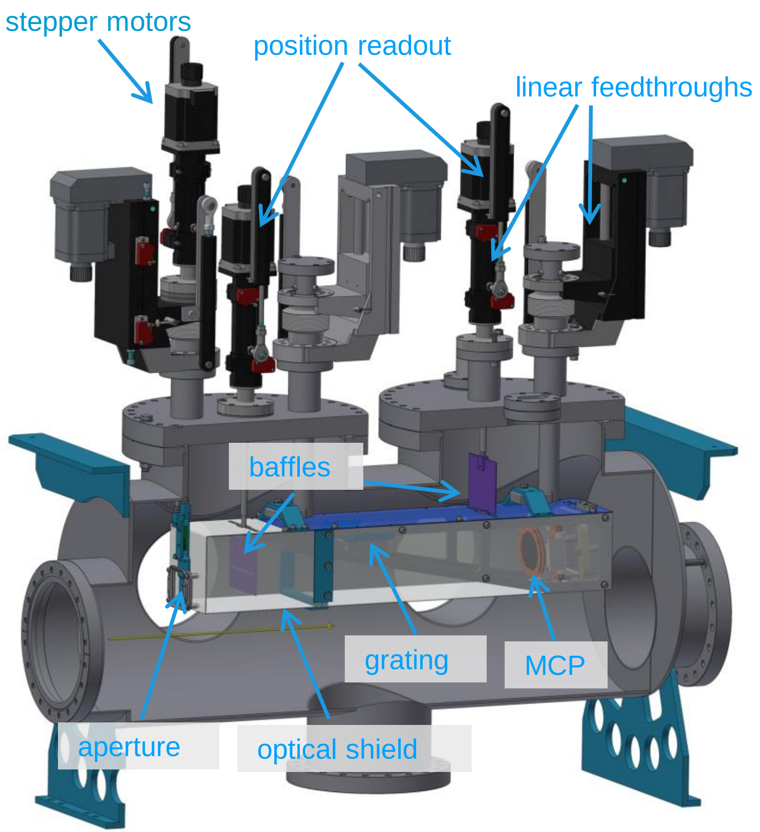
taken 2024

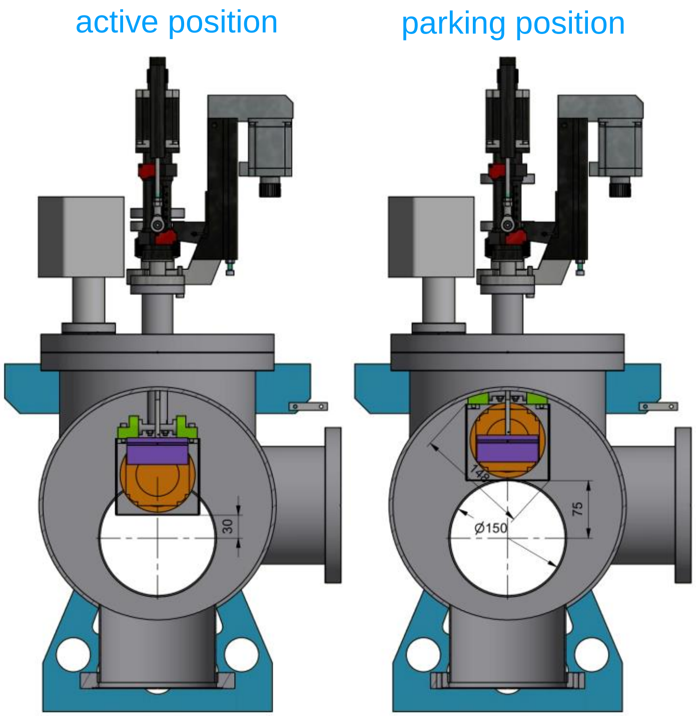




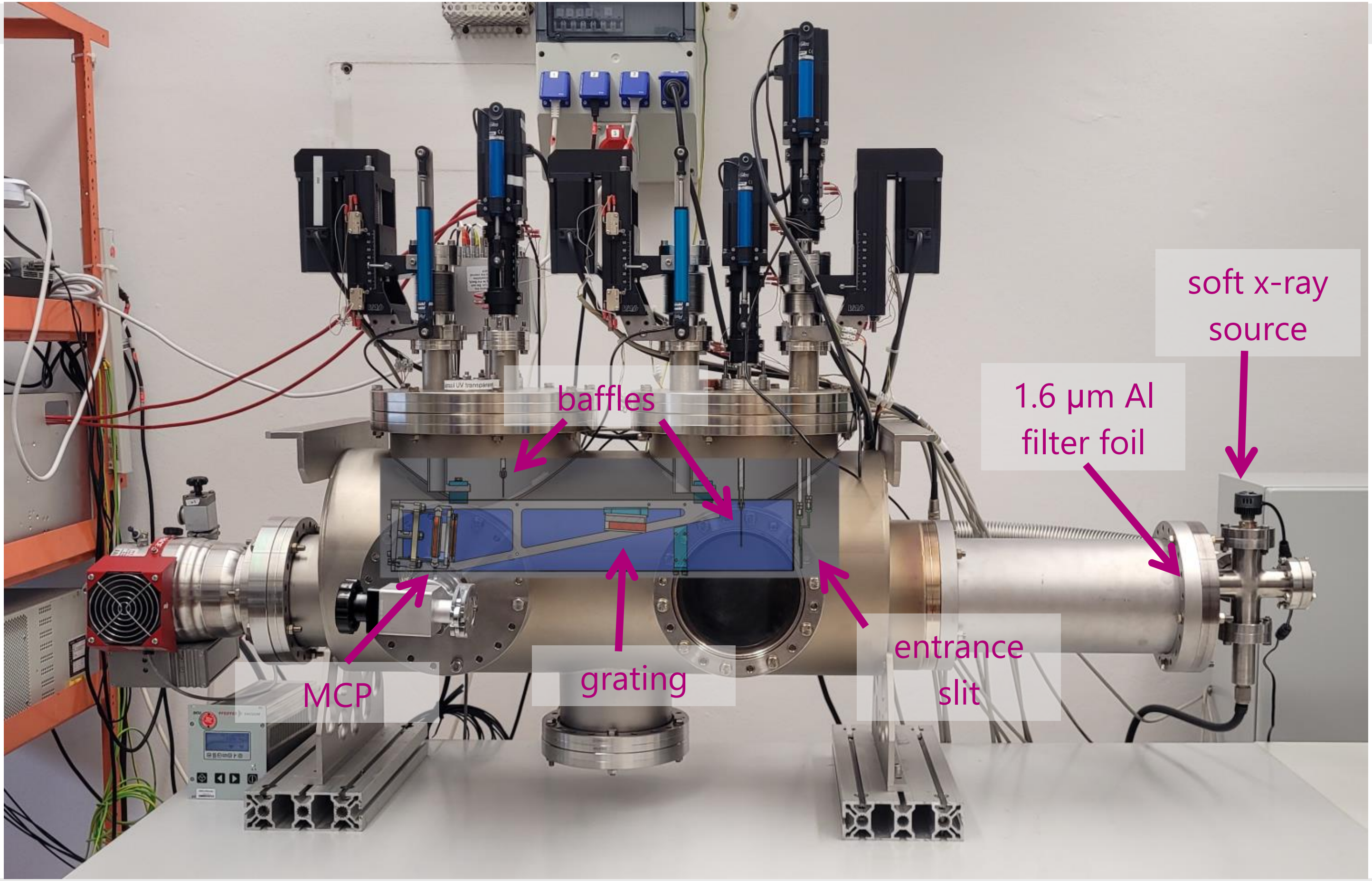

ILBI
Kurt J. Lesker

mirror box
Garant
91 6310_8



x-ray/xuv fluorescence detection (Münster)





x-ray/xuv fluorescence detection (Münster)

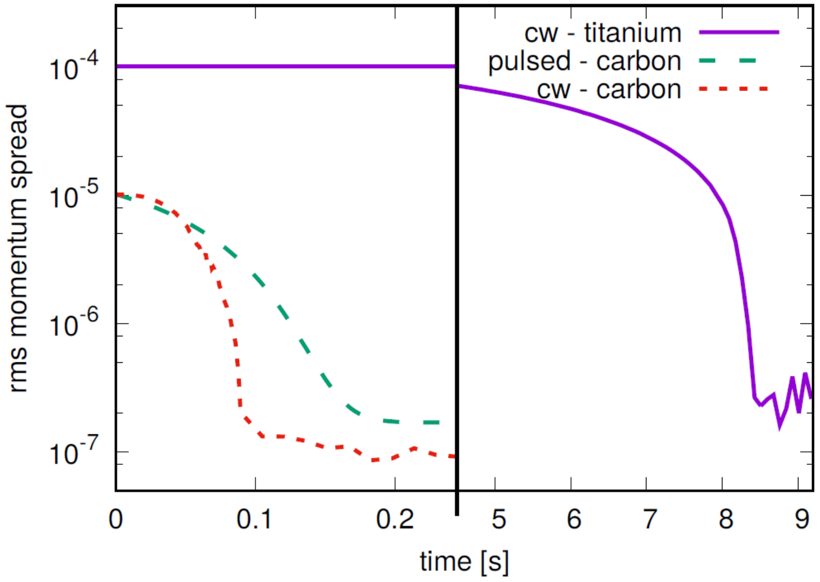


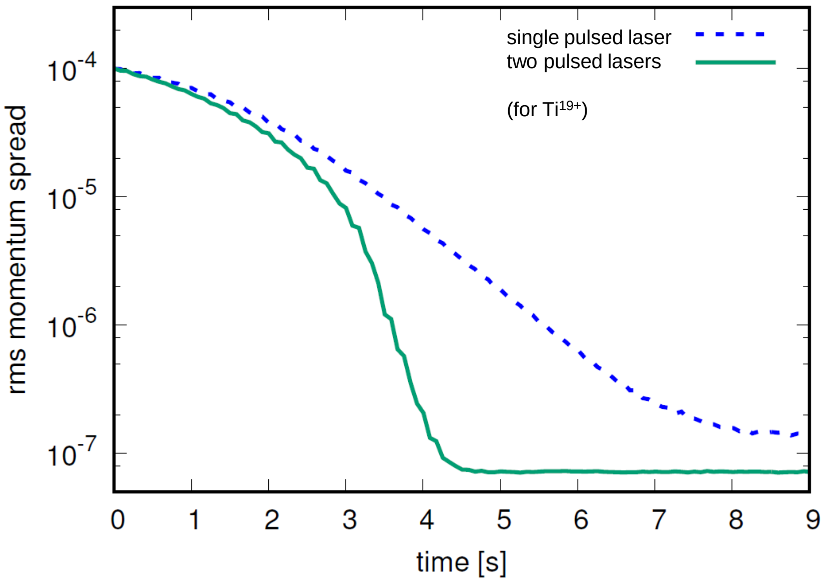
x-ray/xuv fluorescence detection (Münster)

Universität
Münster

2. September 2025

Expected cooling times and momentum spreads





L. Eidam, „Laser Cooling of Intense Relativistic Ion Beams“, Dissertation, 2017

@ESR @SIS100 @SIS100

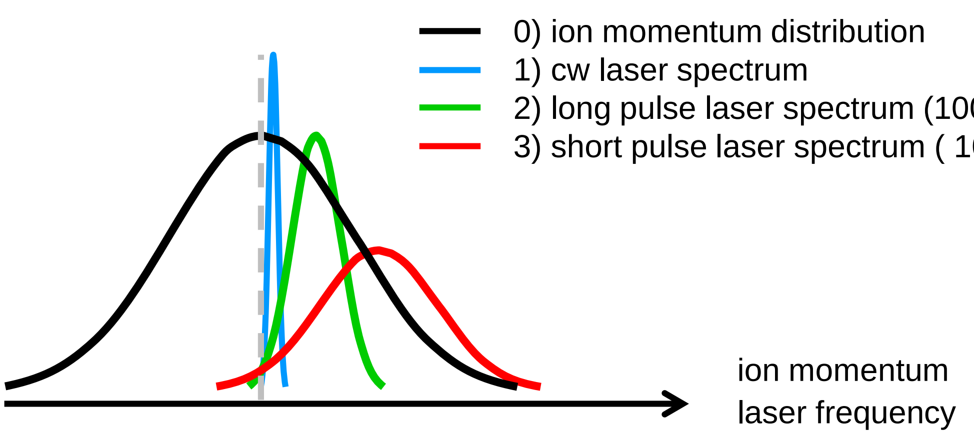
Simulations by Lewin Eidam

Why is our laser cooling interesting?

- laser cooling is frequently applied to atoms/ions in small traps (~cm)
- normally, several laser beams are used coming from different directions → 3D
- the laser light is mostly continuous (cw)
- typically, light atoms/ions (singly charged) are used (Be, Na, Mg, Ca …)
- the velocities of the atoms/ions is usually low

extreme

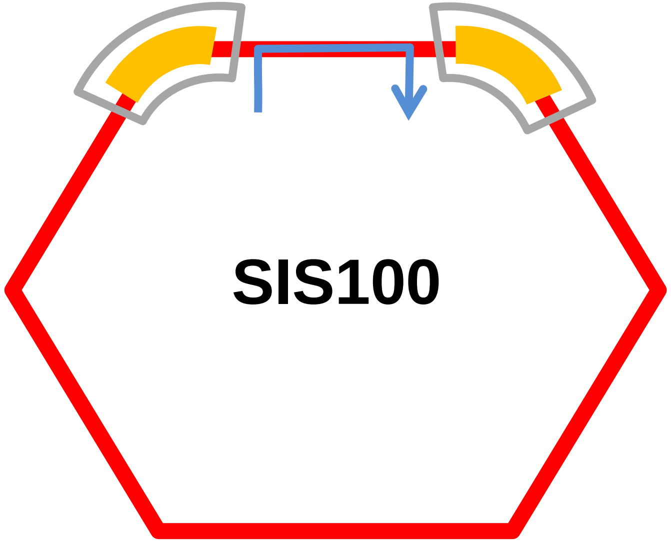
New approach for laser cooling



The combination of one cw and two pulsed (MHz rep. rate) UV laser systems allows for simultaneous and fast laser cooling of a broad ion momentum distribution.

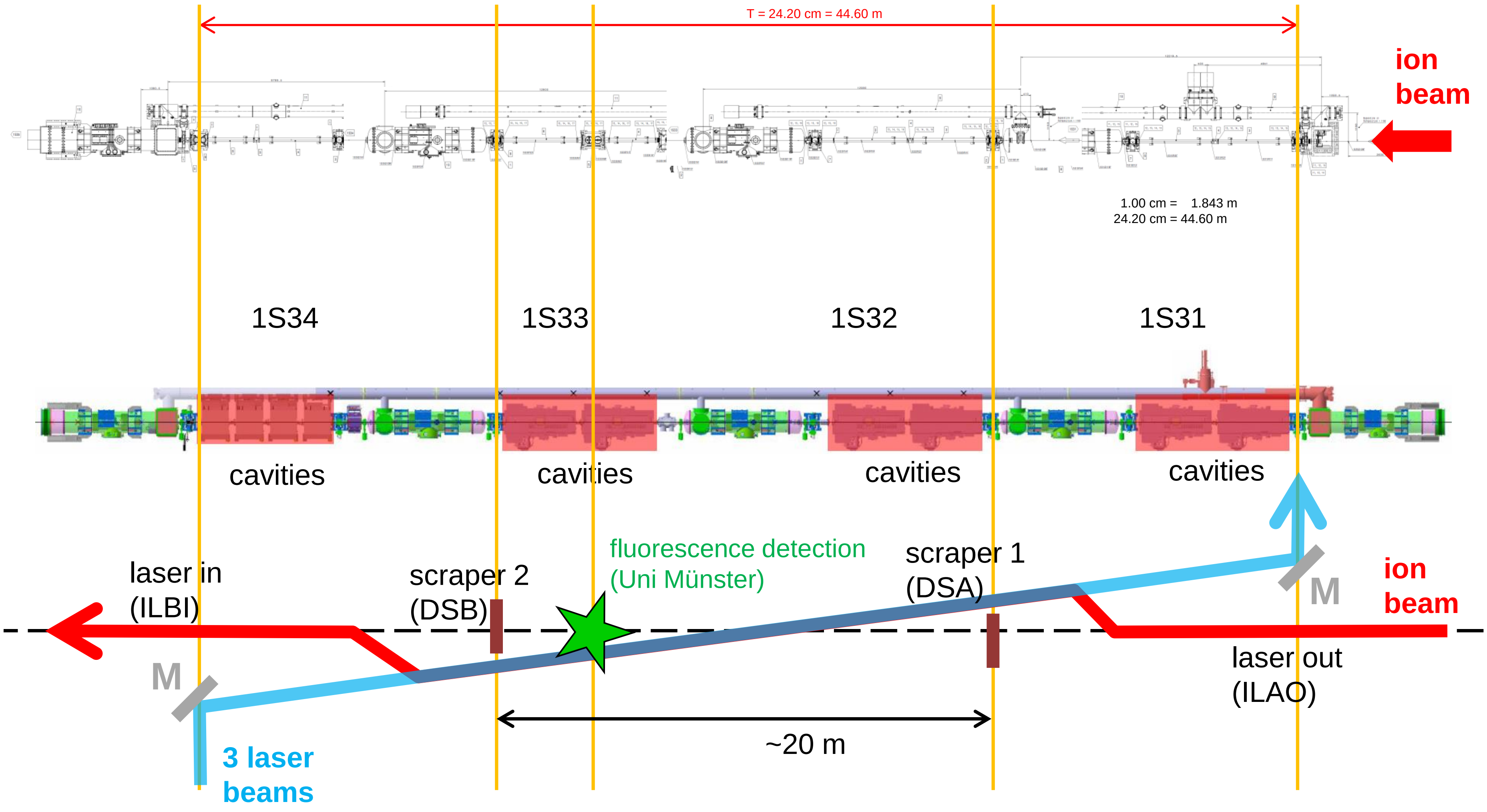
picture taken from: Technical Report (TDR) for the design, construction and commissioning of the SPARC laser systems for laser cooling at the FAIR SIS100, Oct 2020.

Differences between ESR and SIS100



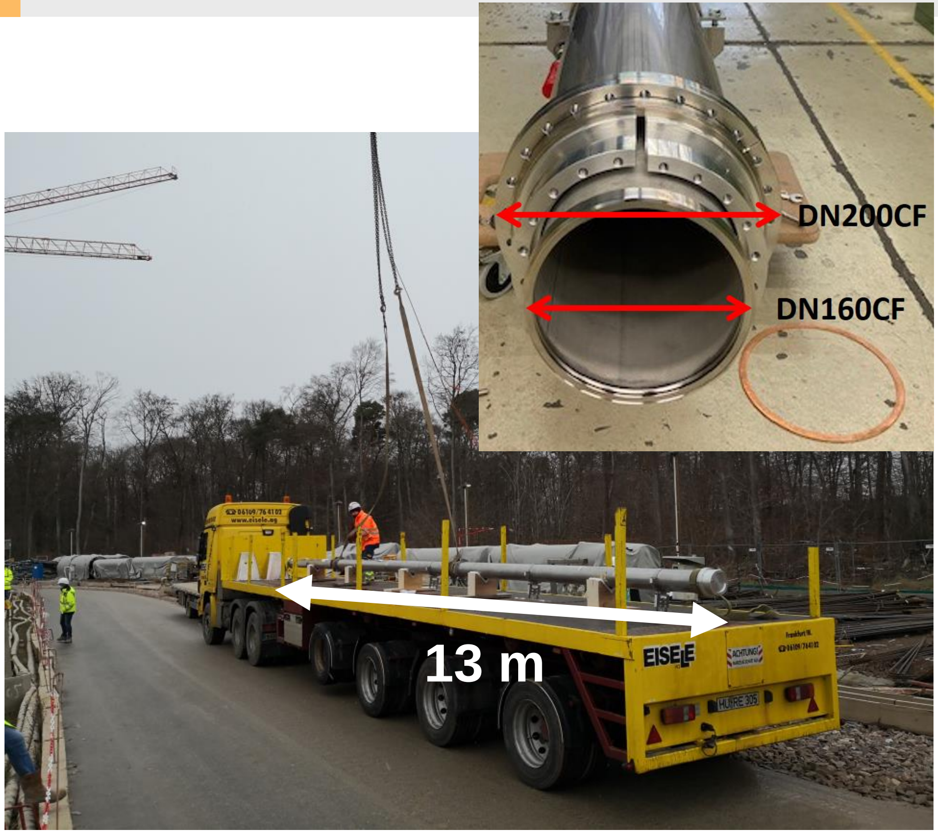
- normal conducting magnets (open, warm)
- laser beam enters within dipole magnets
- ion beam bends away, laser beam goes straight
- laser beam enters & exits via quartz viewports which are in-line with ion beam pipe
- no mirrors in UHV

- superconducting magnets (closed, cold)
- laser beam enters in between dipole magnets
- ion beam goes straight, laser beam bends away
- laser beam enters & exits via quartz viewports which are perpendicular to ion beam pipe
- (moveable) aluminium mirrors in UHV

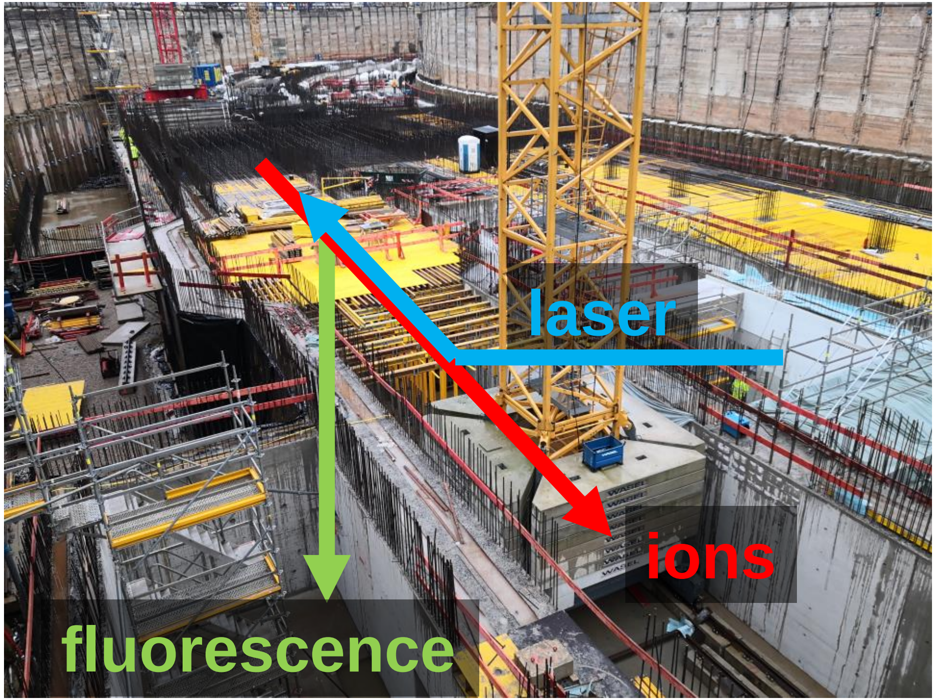


T = 24.20 cm = 44.60 m
ion beam
1.00 cm = 1.843 m
24.20 cm = 44.60 m
1S34
1S33
1S32
1S31
cavities
cavities
cavities
cavities
fluorescence detection
(Uni Münster)
scraper 1
(DSA)
scraper 2
(DSB)
laser in
(ILBI)
M
M
ion beam
laser out
(ILAO)
~20 m
3 laser beams

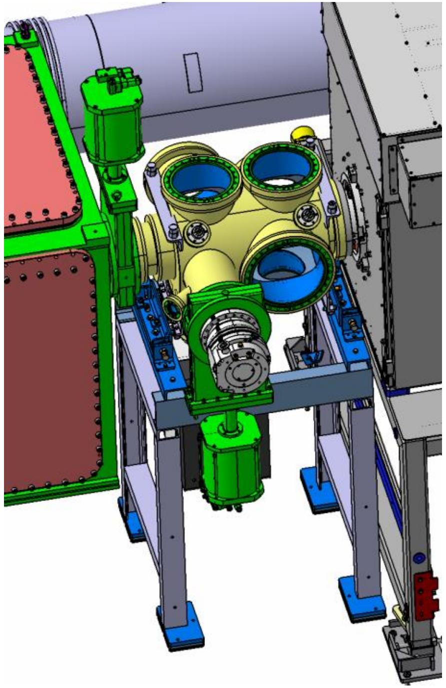
Transport and installation of the laser beamline

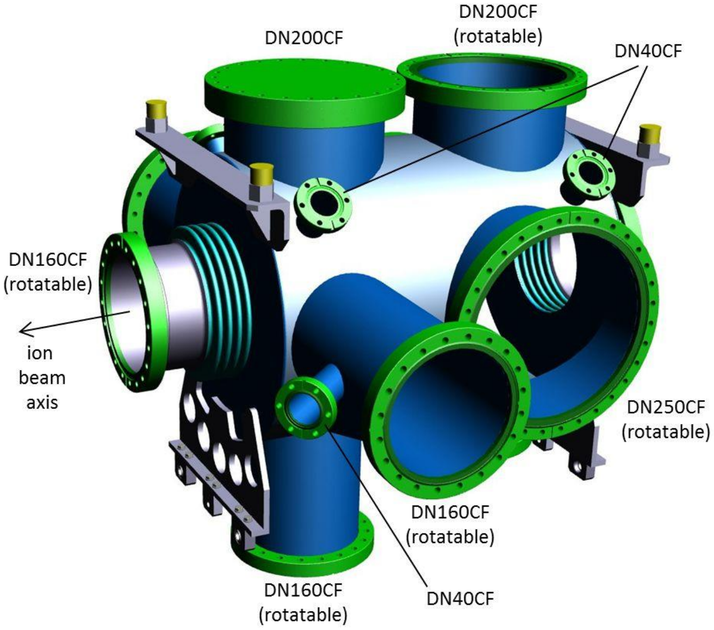


January 2021



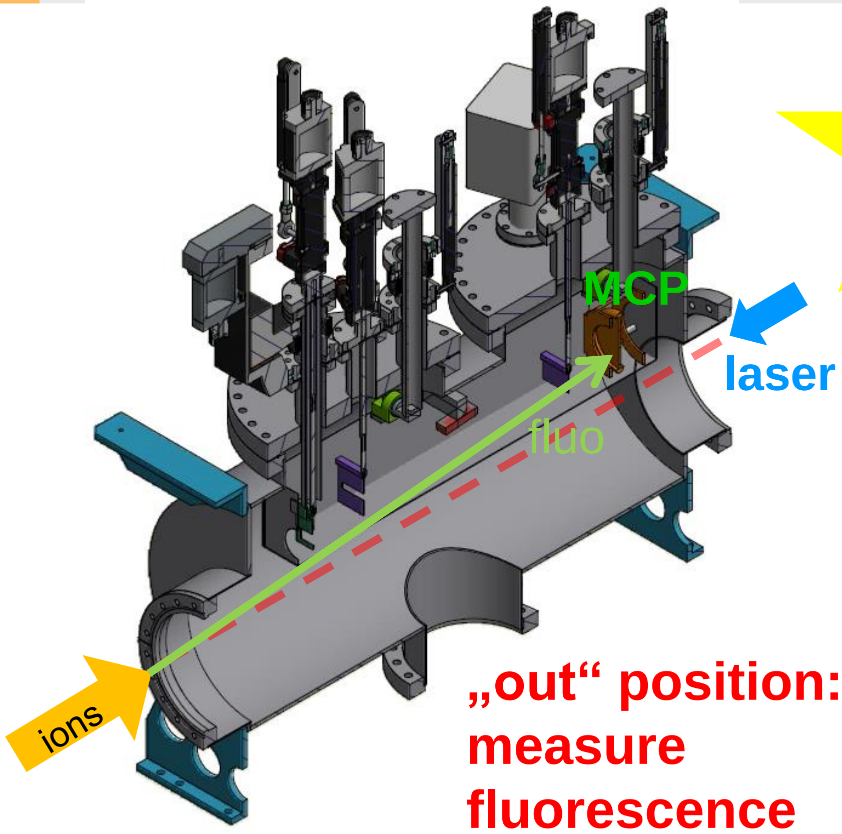
SIS100 laser-detector chamber



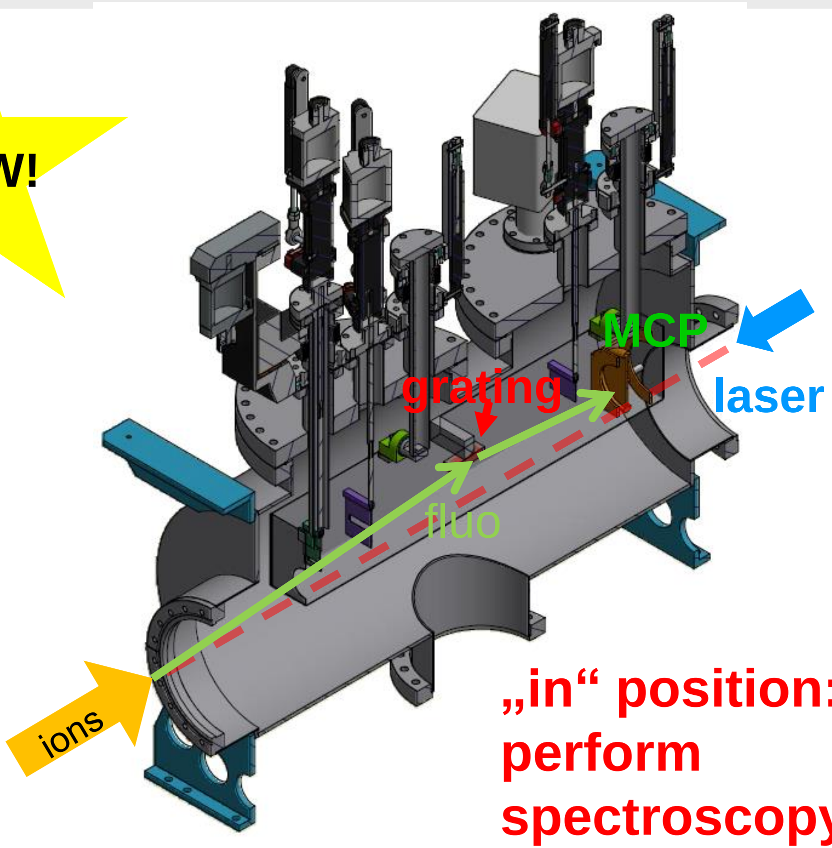


fluorescence detection system @ SIS100

NEW!

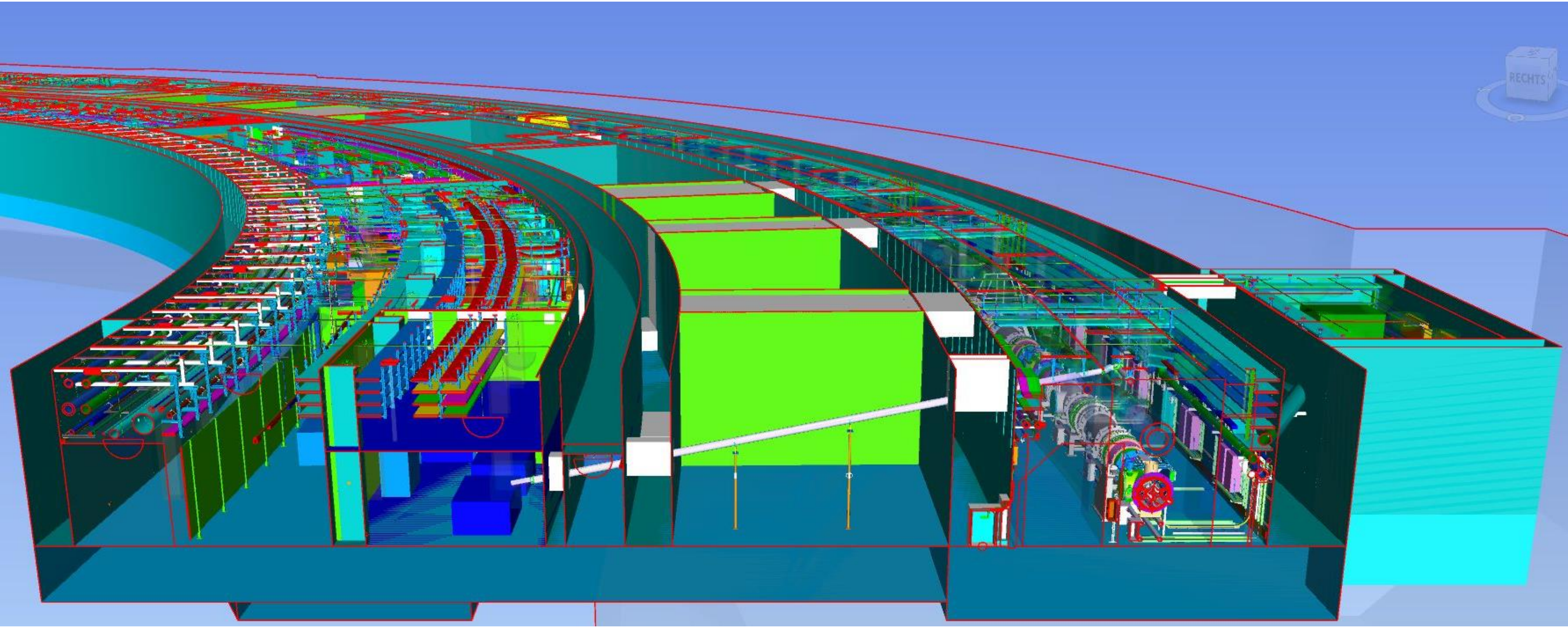


„out“ position:
measure fluorescence

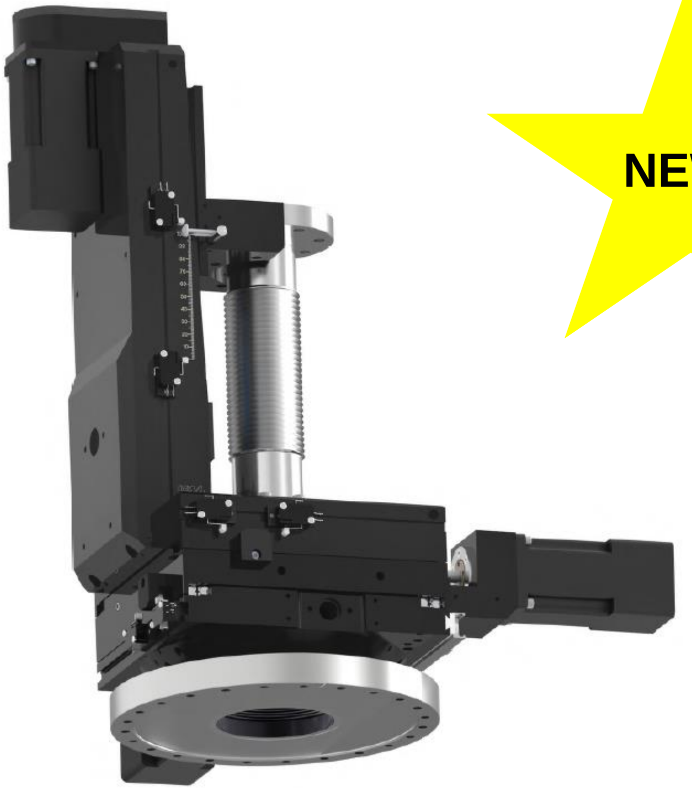


„in“ position:
perform spectroscopy

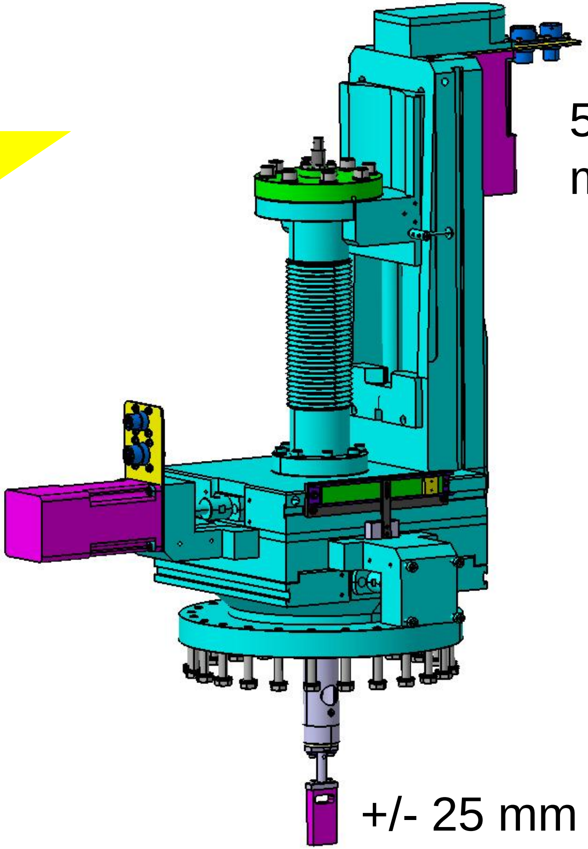
The SIS100 laser lab



SIS100 scraper system (for ion & laser beam alignment)



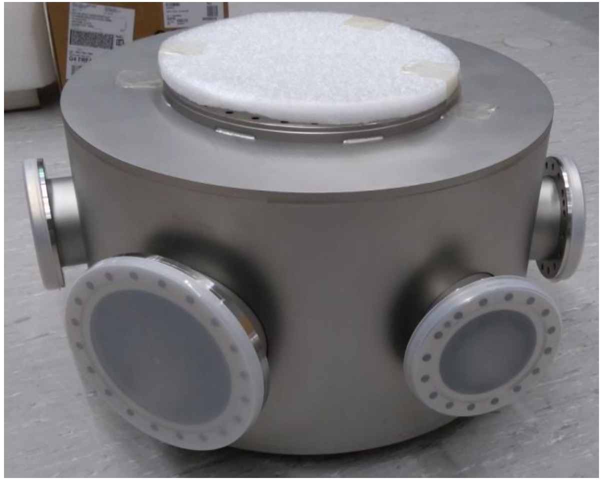
NEW!

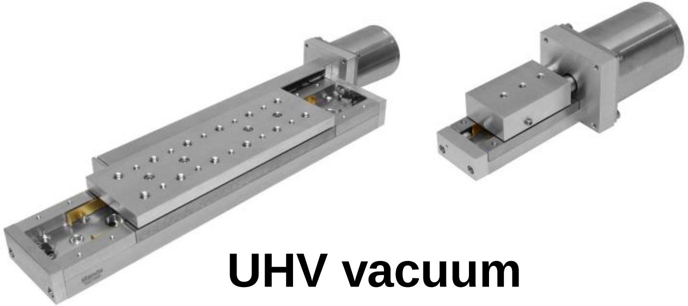


SIS100 laser beamline - components

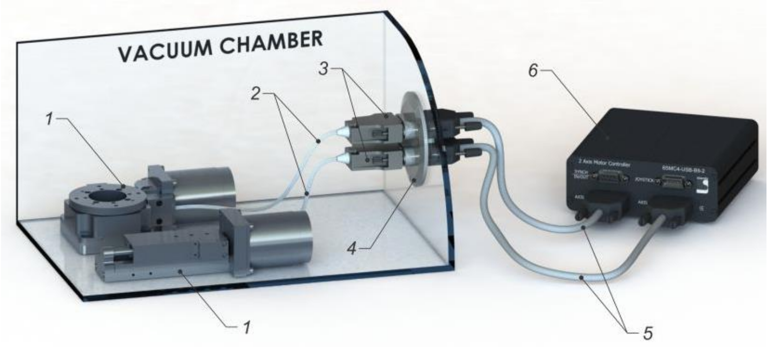
CF cube

mirror box





UHV vacuum linear translator stages and controller



SIS100 accelerator tunnel

photo 2022