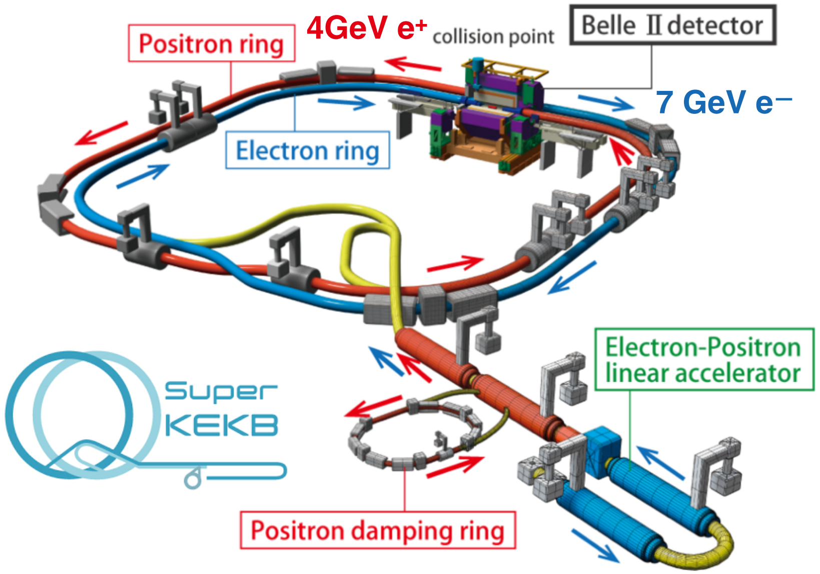
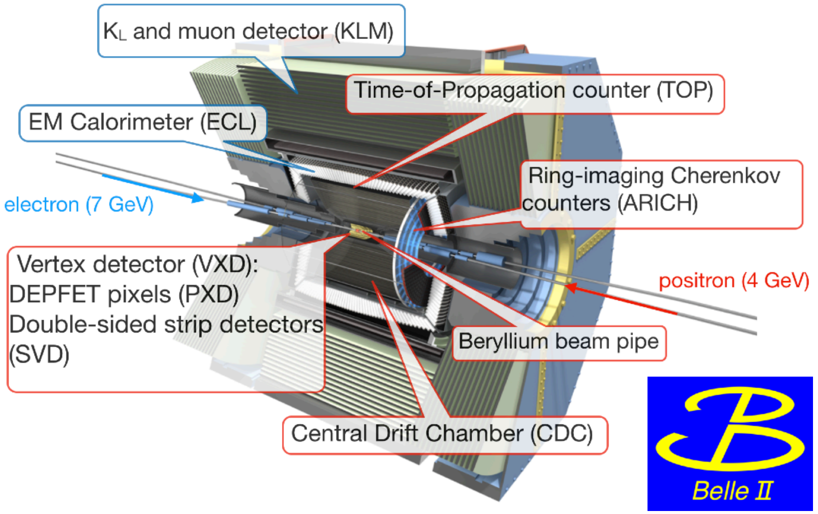
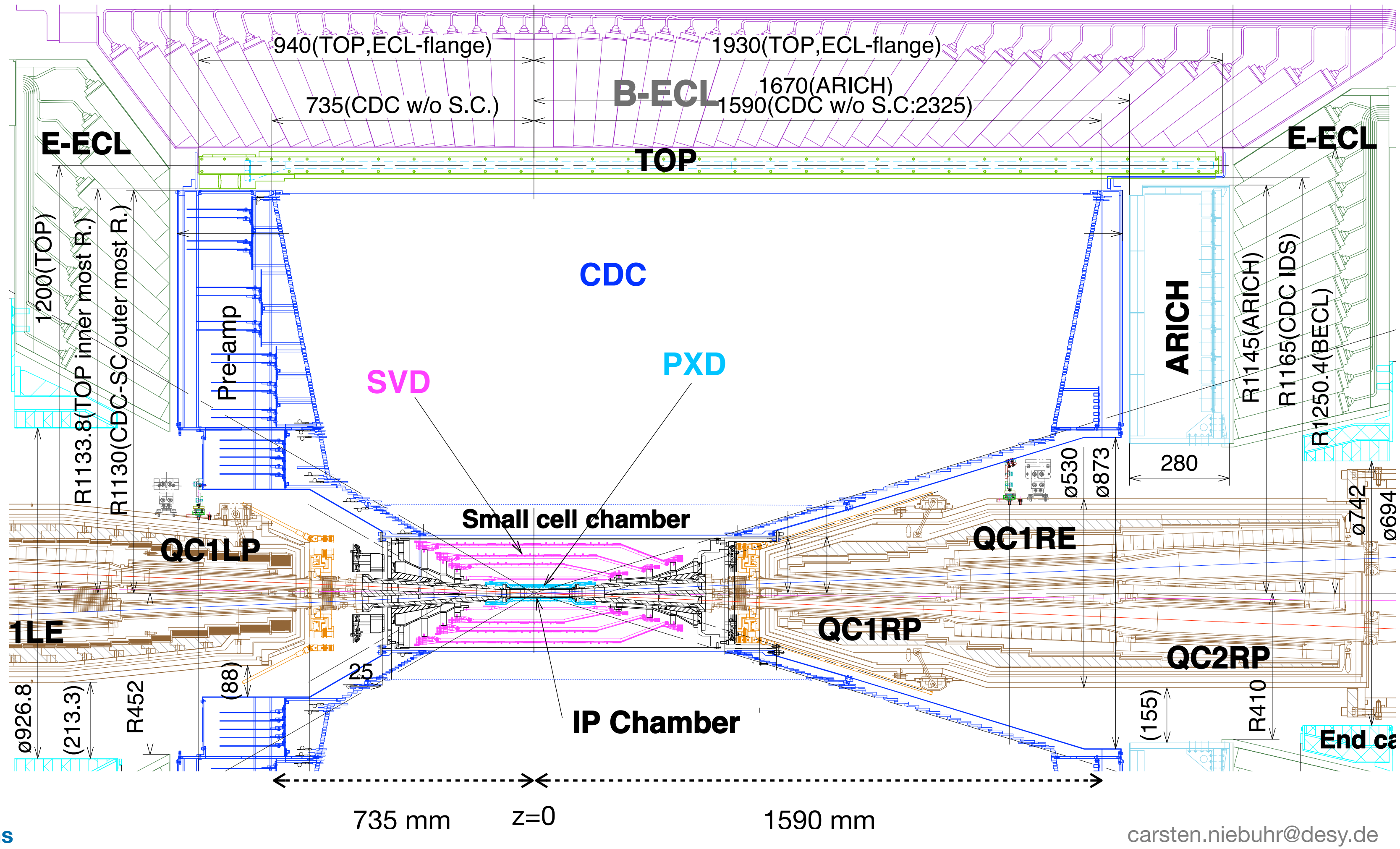
Belle II Mock-up Studies

Overview of Belle II at SuperKEKB





- Central IP chamber
  - reduced ID of 20 mm
  - two concentric Be pipes (d=0.6 & 0.4 mm)
  - 1 mm gap for paraffin cooling
- Belle II tracking devices (17° to 150°)
  - PXD Pixel Vertex Detector (@ r=14 & 22 mm)
  - SVD Strip Vertex Detector (4 layers DSSD)
  - CDC Central Drift Chamber



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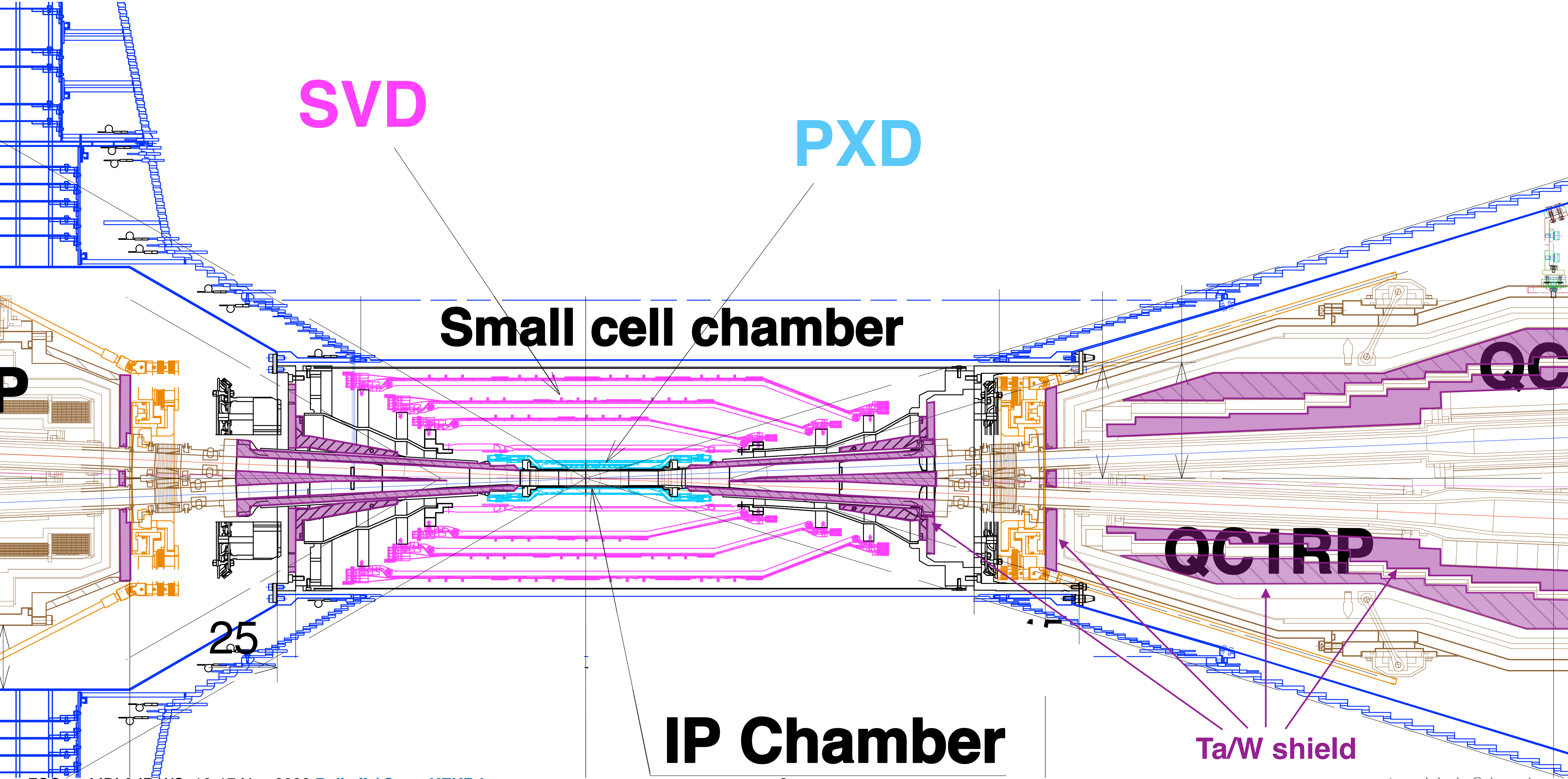
Taking a closer Look at the IR



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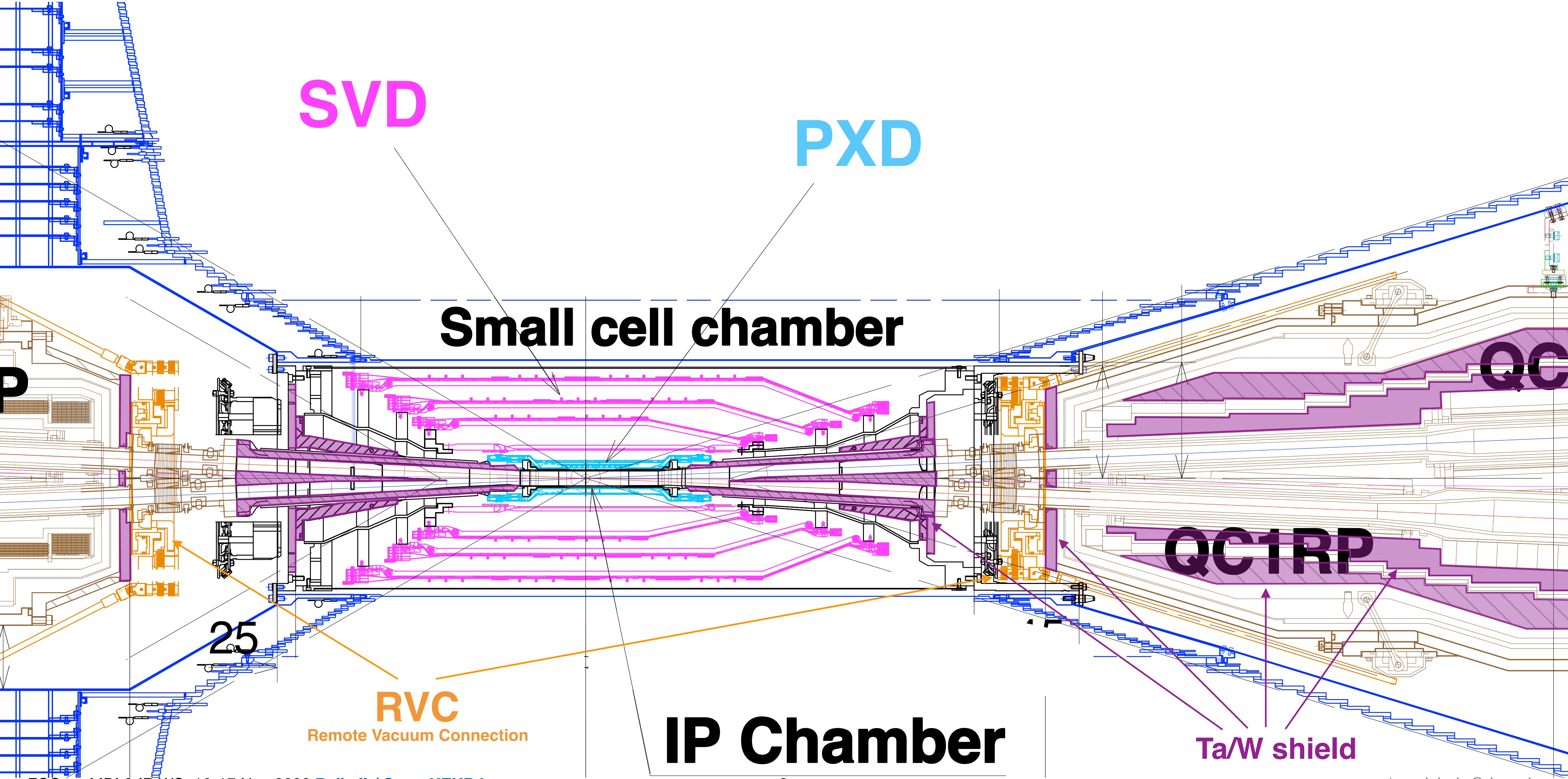

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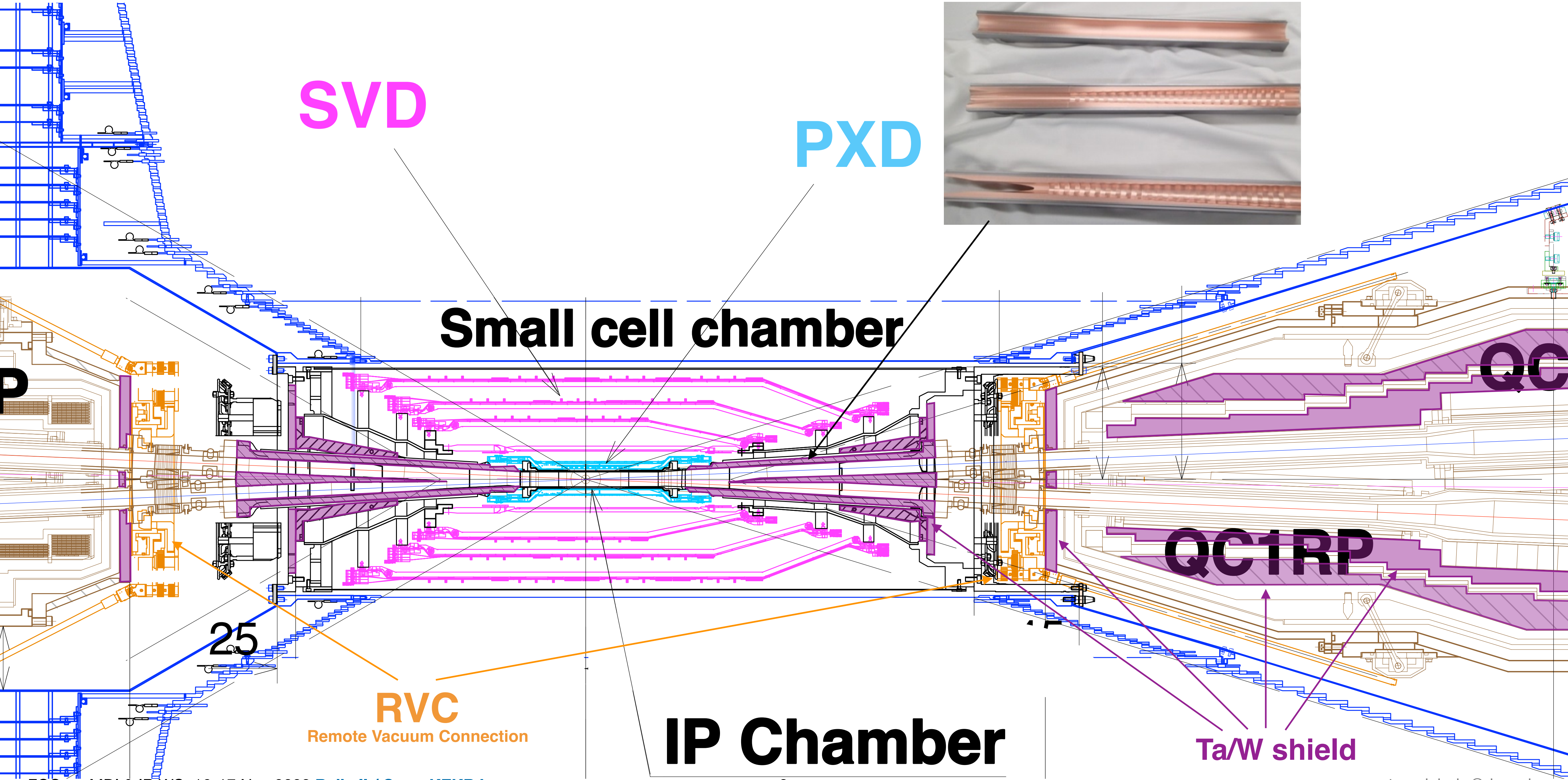


SVD

PXD

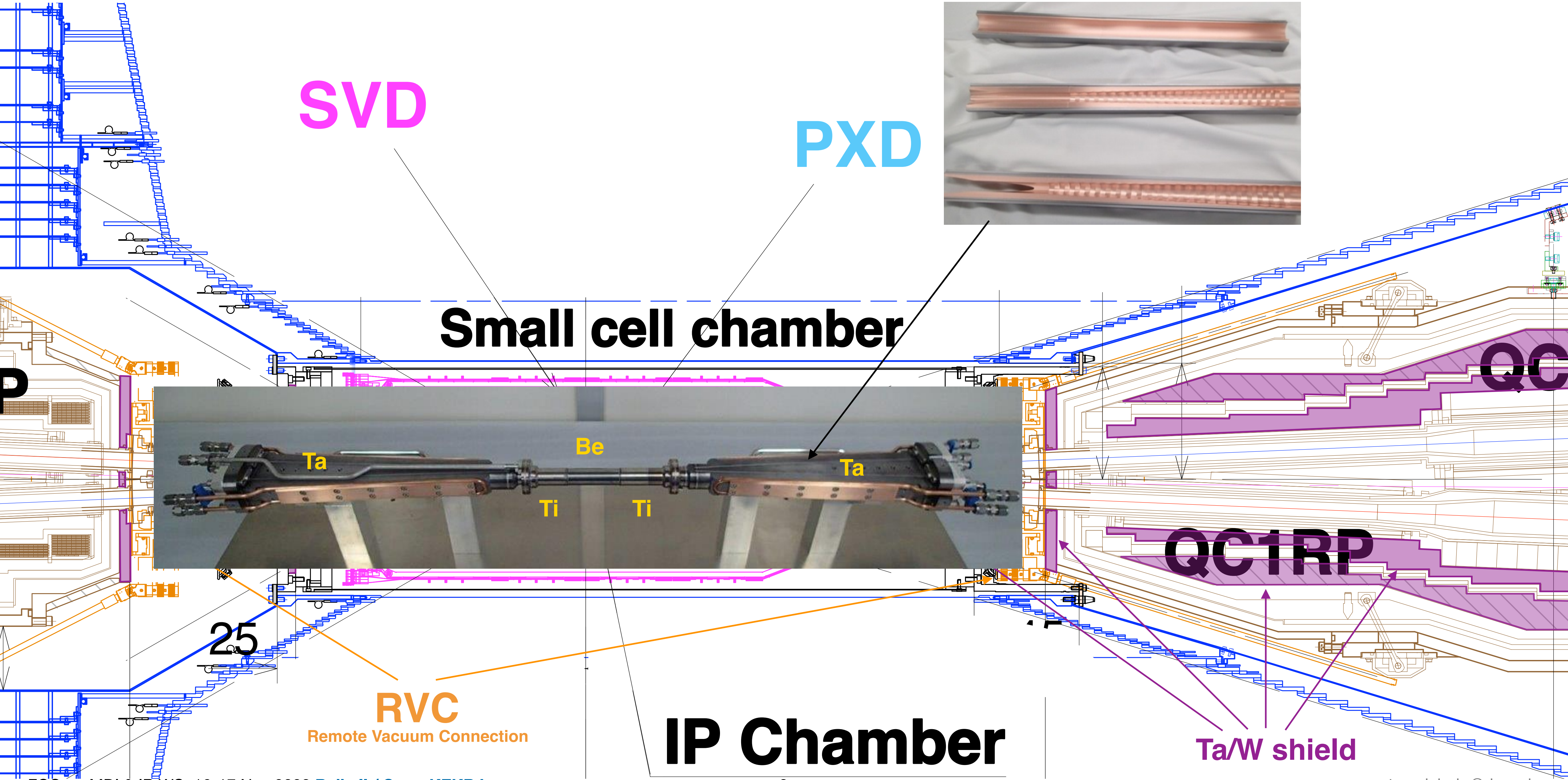
Small cell chamber

RVC
Remote Vacuum Connection

IP Chamber

Ta/W shield

Taking a closer Look at the IR



SVD

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Small cell chamber

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Be

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Remote Vacuum Connection

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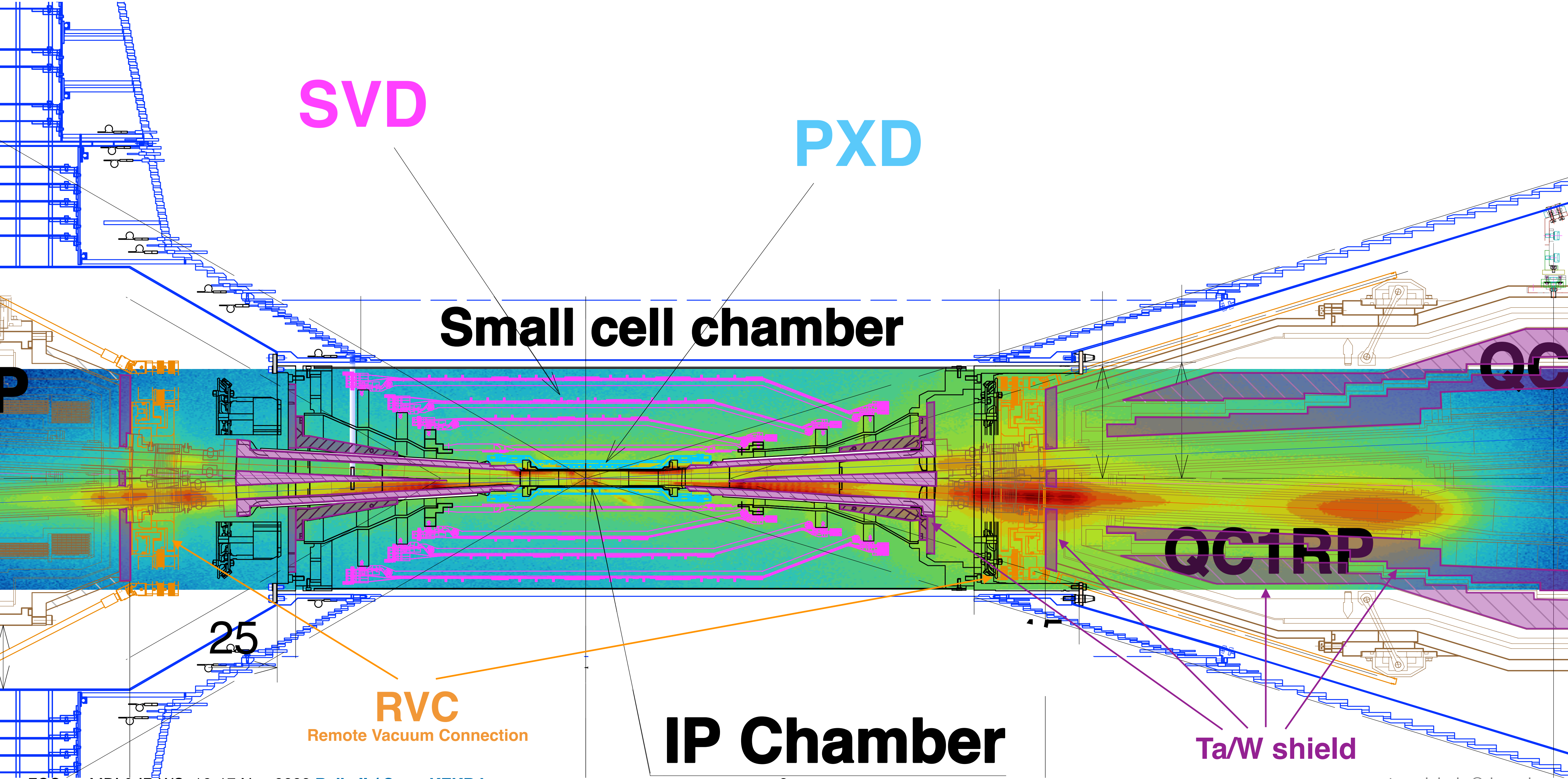
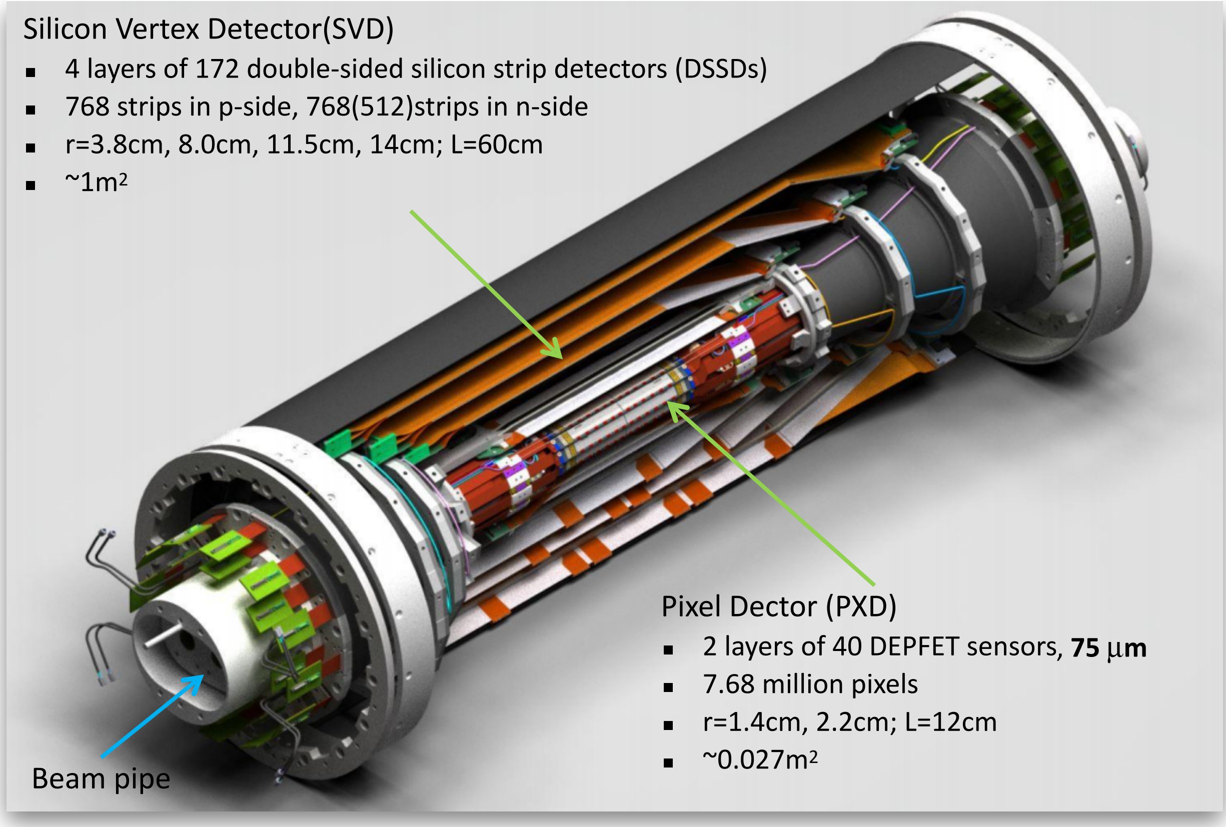


Belle II Vertex Detector VXD

CAD view without services



Silicon Vertex Detector(SVD)

- 4 layers of 172 double-sided silicon strip detectors (DSSDs)
- 768 strips in p-side, 768(512)strips in n-side
- r=3.8cm, 8.0cm, 11.5cm, 14cm; L=60cm
- ~1m^2

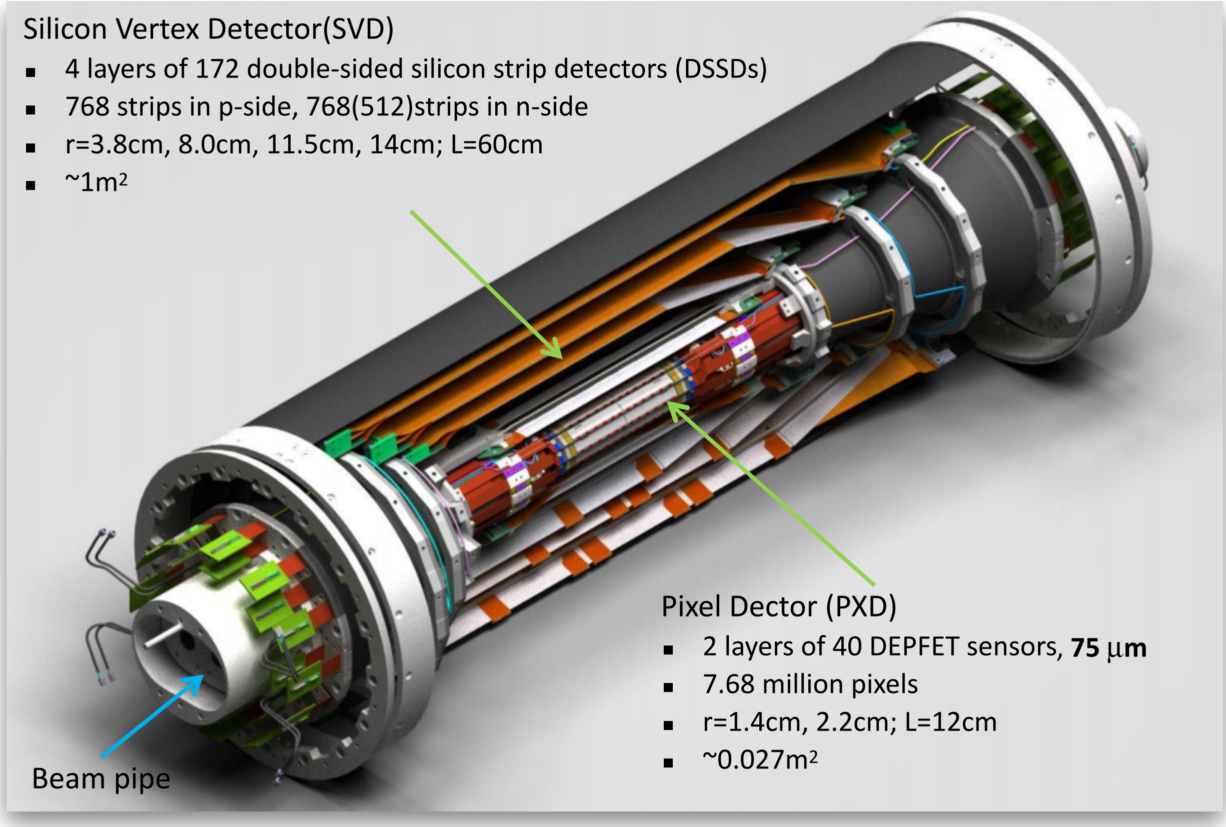
Pixel Dector (PXD)

- 2 layers of 40 DEPFET sensors, **75 μm**
- 7.68 million pixels
- r=1.4cm, 2.2cm; L=12cm
- ~0.027m^2

Beam pipe

Belle II Vertex Detector VXD

CAD view without services



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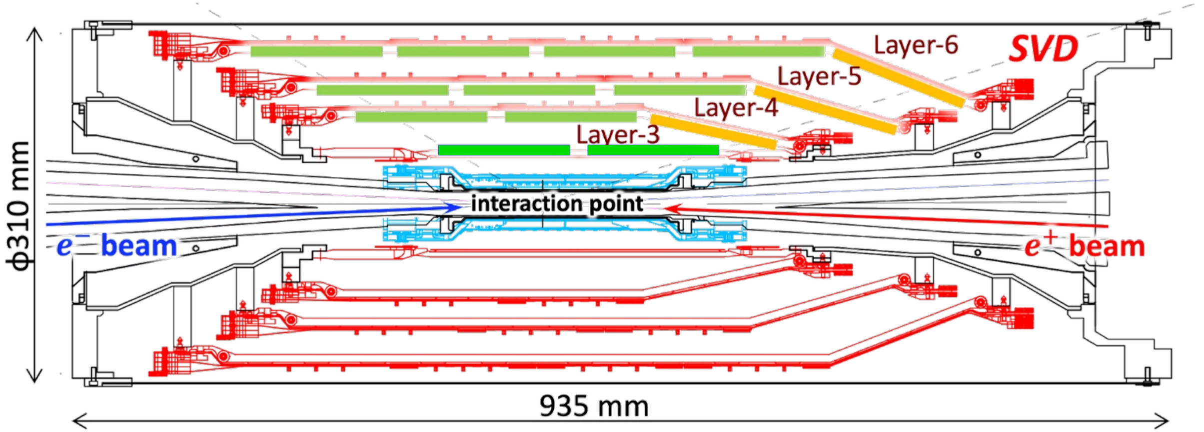
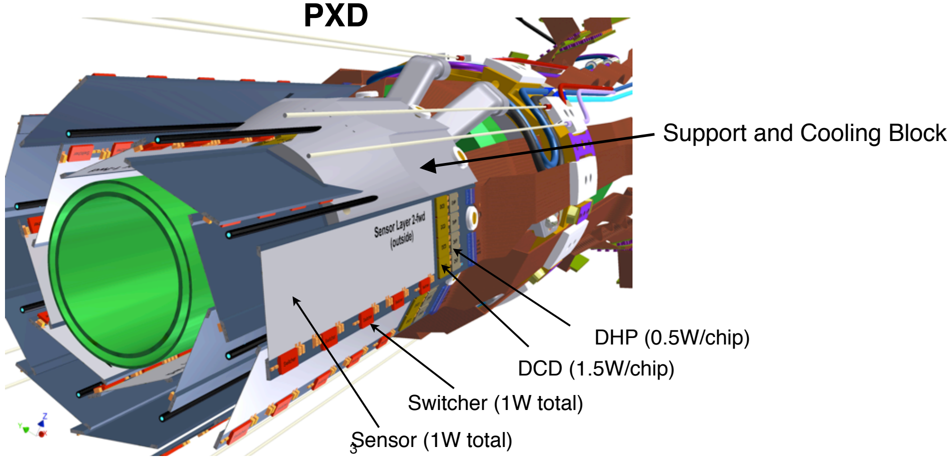
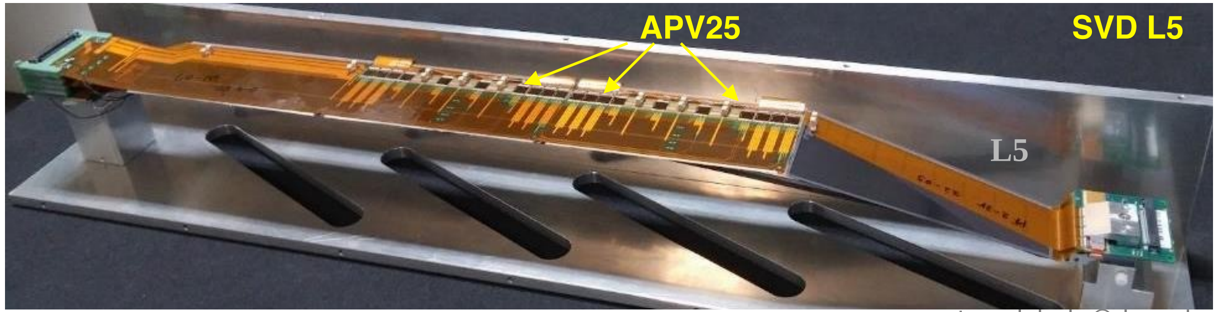
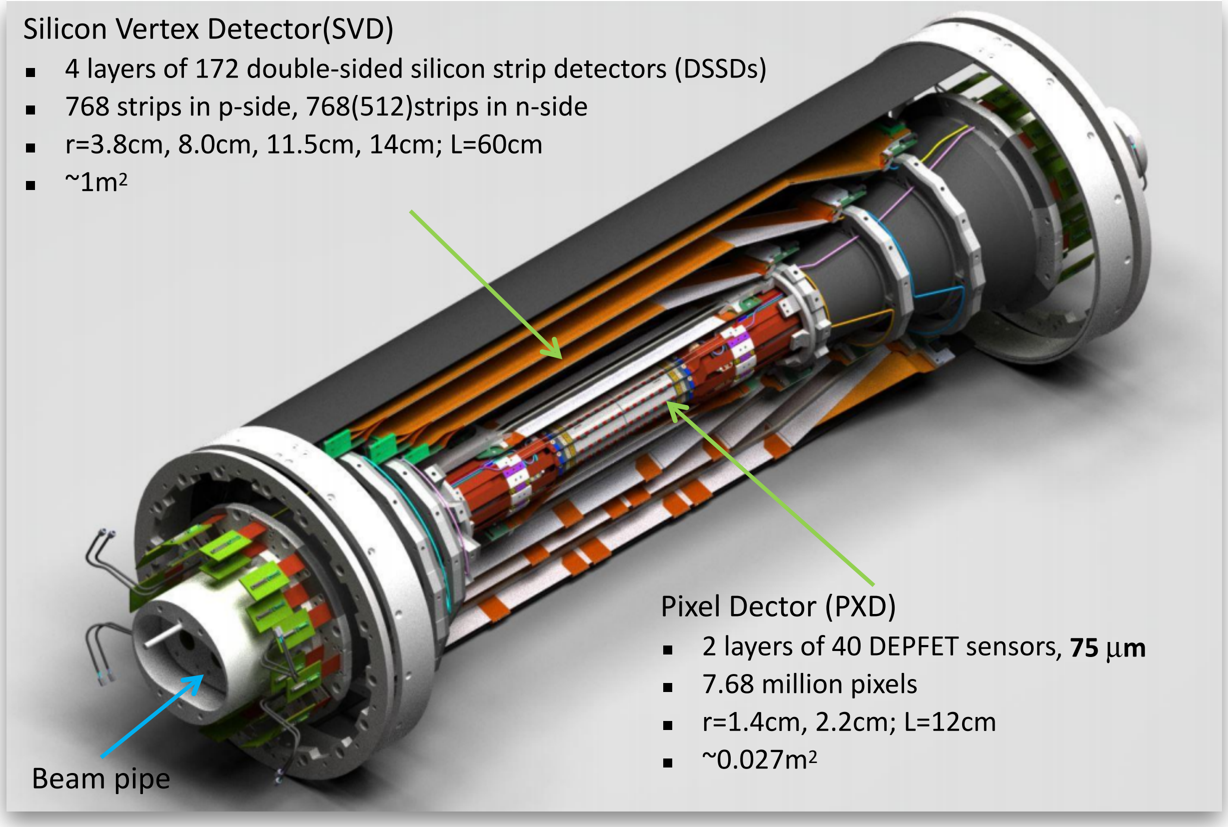






Belle II Vertex Detector VXD

CAD view without services



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- 2 layers of 40 DEPFET sensors, **75 μm**
- 7.68 million pixels
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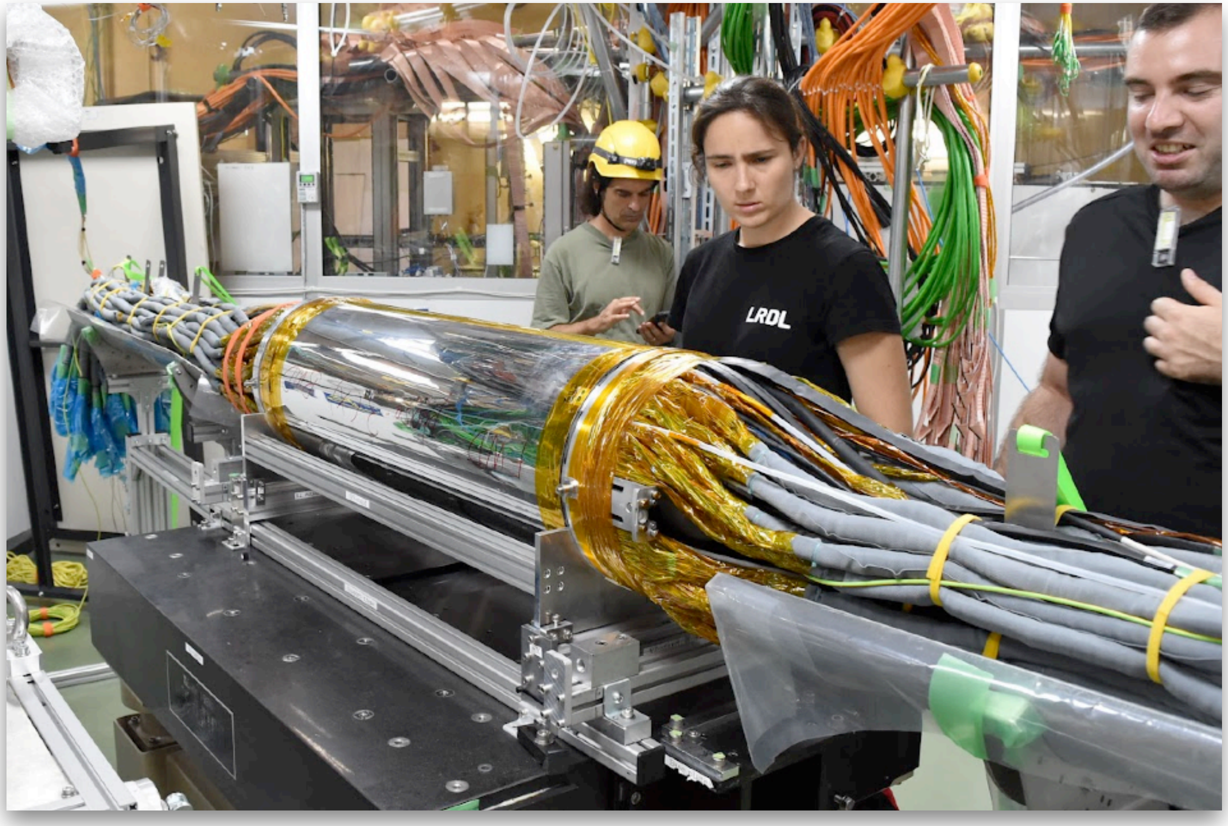
VXD ready for installation into Belle II



Large amount of services for:
Signal cables, beam diagnostics,
beam pipe&detector cooling

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Thermal Mockup

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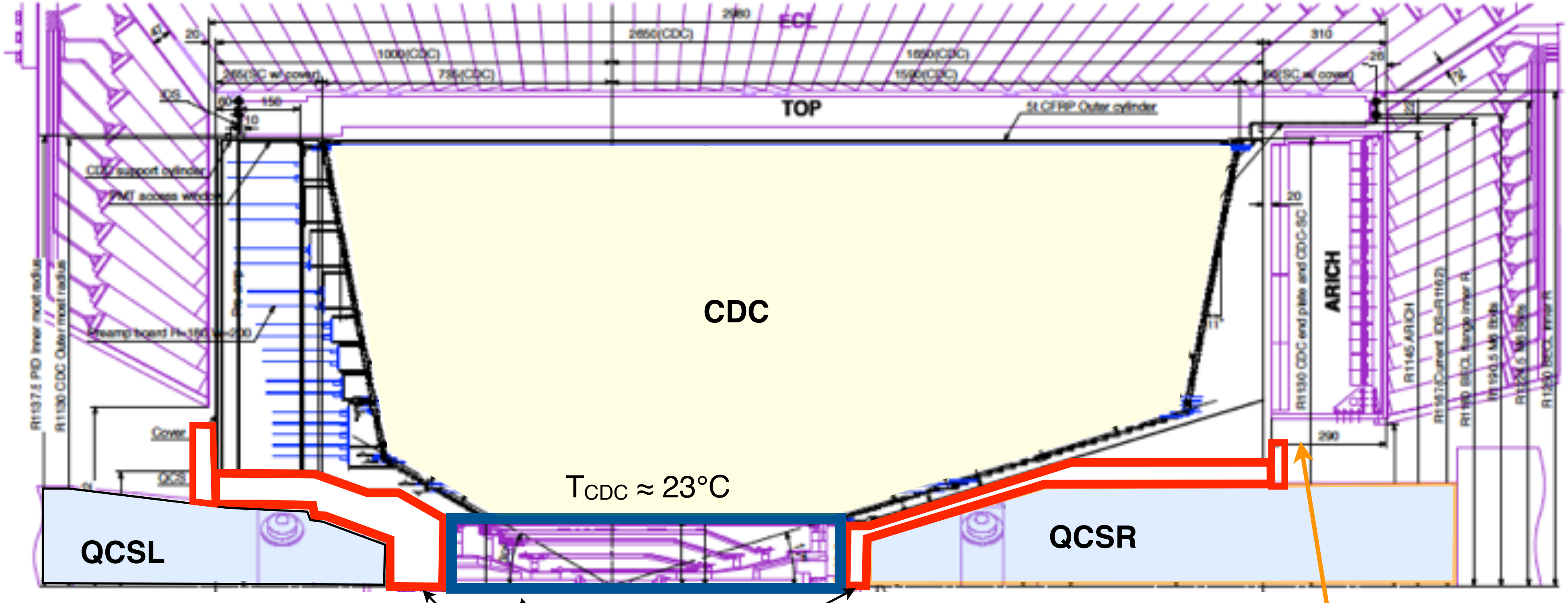
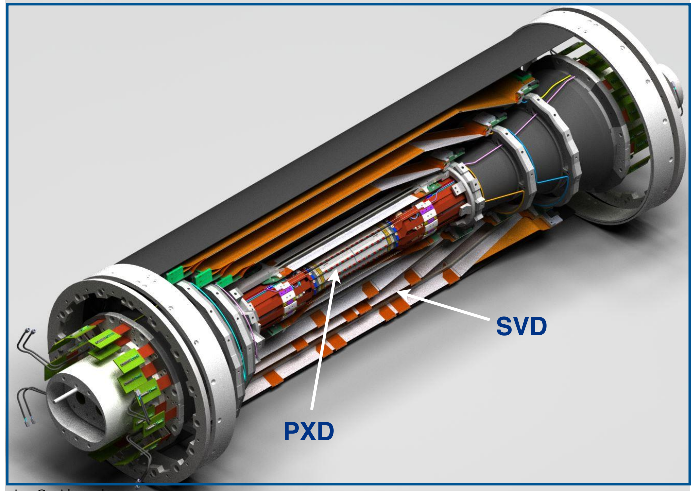
VXD Cooling Environment



$T_{BP} \approx 15°C$

Warm / cold dry volumes

Dock boxes



- VXD cooling concept based on
  - two-phase CO_2 @-20°C
  - forced N_2 flow
- Specific detector geometry requires heterogeneous layout of CO_2 cooling circuits

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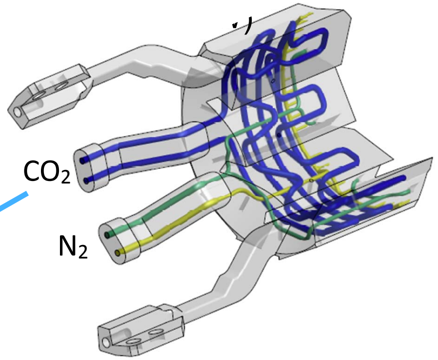
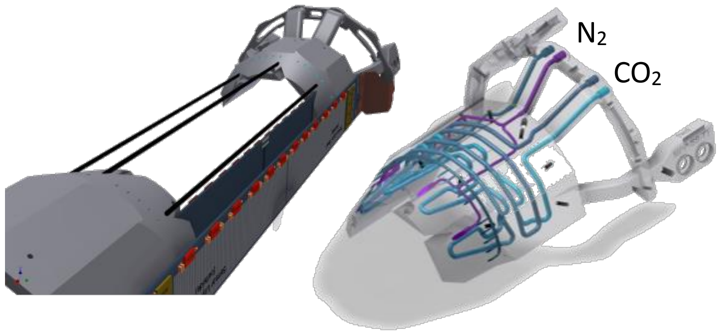
VXD Heat Dissipation and CO_2 Cooling Circuits

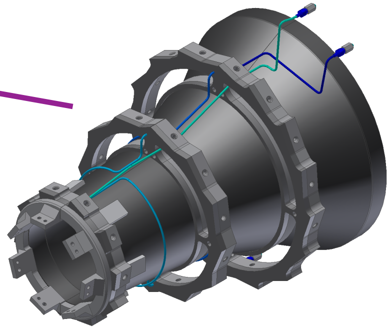
CO_2 Circuit	Detector	Half	Layer	Type	Side	Power [W]
1	PXD	up	1&2	endring	bwd	90
2			1&2	endring	fwd	90
3		down	1&2	endring	bwd	90
4			1&2	endring	fwd	90
sum PXD						360
5	SVD	left	3-6	endring	bwd	93
6		right	3-6	endring	bwd	93
7		left	3-6	endring	fwd	93
8		right	3-6	endring	fwd	93
9		left	4&5	origami	bwd	68
10		right	4&5	origami	bwd	68
11		left	6	origami	bwd	96
12		right	6	origami	bwd	96
sum SVD						700
sum VXD						1060

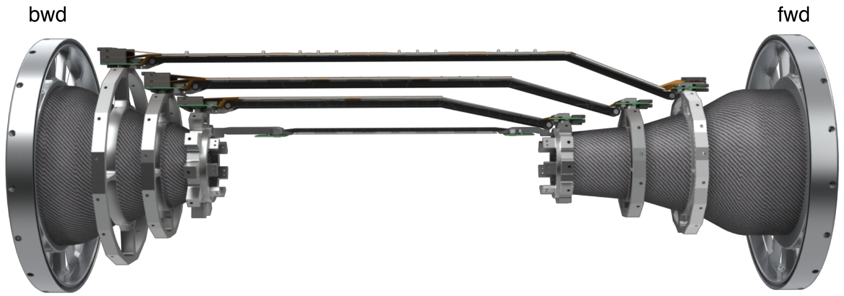
plus parasitic heat load
from the environment





Combined Support Cooling Block (SCB), manufactured using 3D printing technology, with CO_2 and *N2* channels inside.





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CO_2 Circuit	Detector	Half	Layer	Type	Side	Power [W]
1	PXD	up	1&2	endring	bwd	90
2			1&2	endring	fwd	90
3		down	1&2	endring	bwd	90
4			1&2	endring	fwd	90
					sum PXD	360
5	SVD	left	3-6	endring	bwd	93
6		right	3-6	endring	bwd	93
7		left	3-6	endring	fwd	93
8		right	3-6	endring	fwd	93
9		left	4&5	origami	bwd	68
10		right	4&5	origami	bwd	68
11		left	6	origami	bwd	96
12		right	6	origami	bwd	96
					sum SVD	700
					sum VXD	1060

plus parasitic heat load
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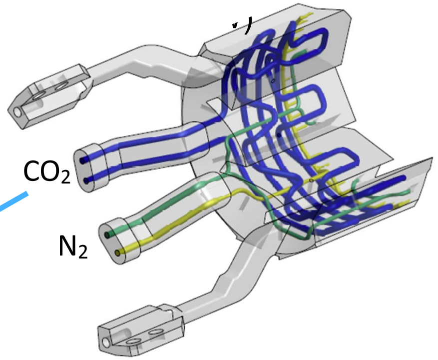

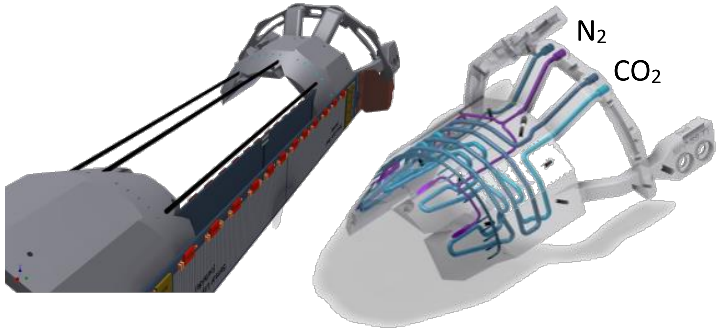

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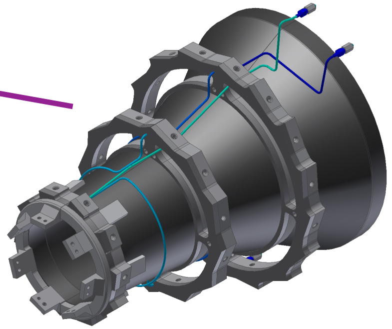
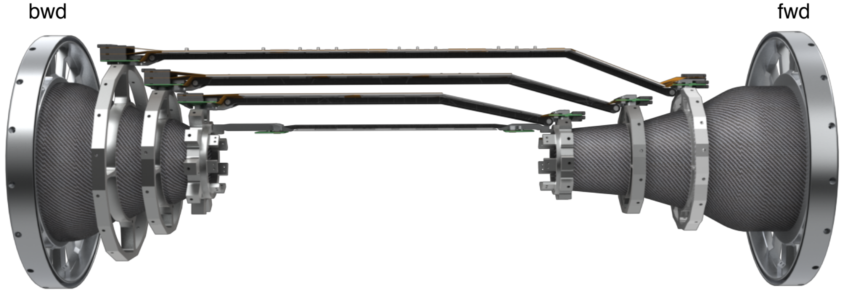
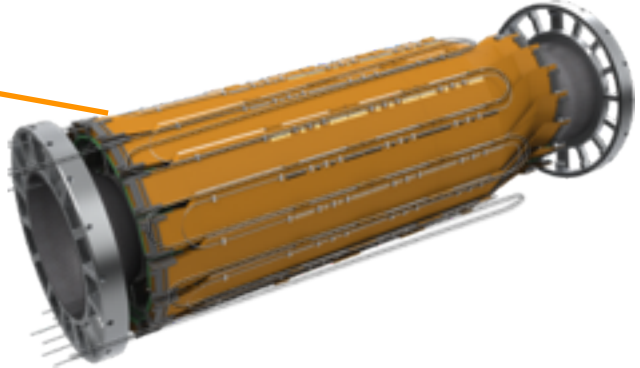
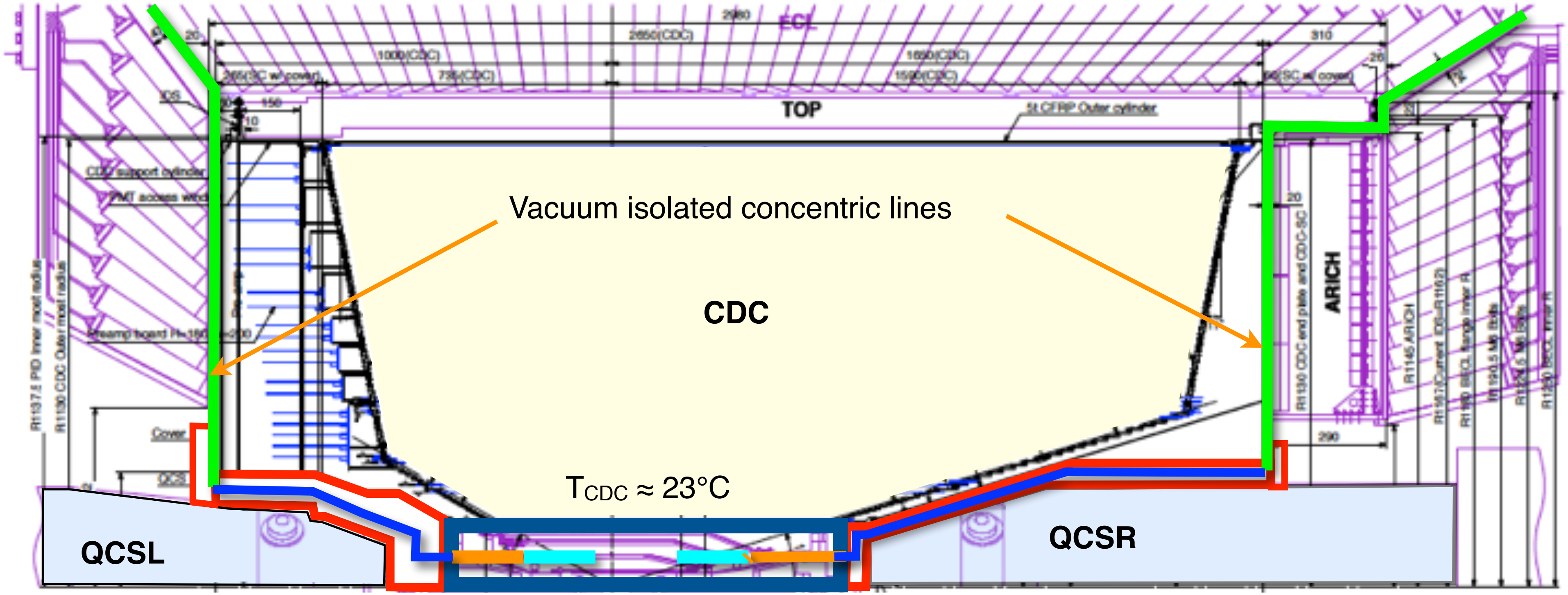






VXD Cooling Circuit Parameters



Vacuum isolated concentric lines

$T_{CDC} \approx 23°C$

PXD		Endring		Origami L45		Origami L6	
L/mm	ø/mm	L/mm	ø/mm	L/mm	ø/mm	L/mm	ø/mm
7120	1	7120	1	7120	1	7120	1
660	1	660	1	660	1	660	1
575	1						
533	1,2	2078	1,5	2282 3013	1,4 1,4	4909	1,4
575	1,2						
660	2	660	2	660	2	660	2
7120	3	7120	3	7120	3	7120	3

PXD		Endring	
L/mm	ø/mm	L/mm	ø/mm
7390	1	7390	1
1180	1	1180	1
600	1		
580	1,2	1585	1,5
600	1,2		
1180	2	1180	2
7390	3	7390	3

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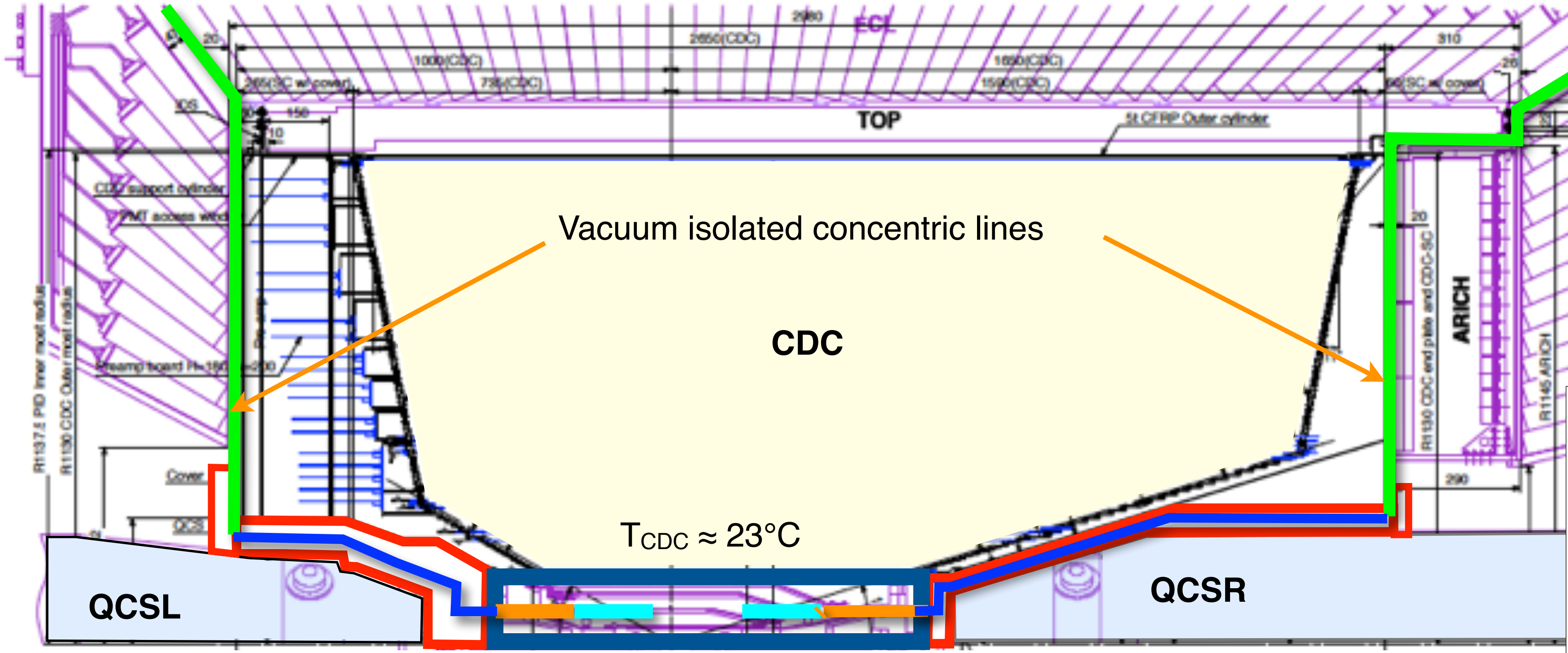
VXD Cooling Circuit Parameters



PXD		Endring		Origami L45		Origami L6	
L/mm	ø/mm	L/mm	ø/mm	L/mm	ø/mm	L/mm	ø/mm
7120	1	7120	1	7120	1	7120	1
660	1	660	1	660	1	660	1
575	1						
533	1,2	2078	1,5	2282	1,4	4909	1,4
				3013	1,4		
575	1,2						
660	2	660	2	660	2	660	2
7120	3	7120	3	7120	3	7120	3

PXD		Endring	
L/mm	ø/mm	L/mm	ø/mm
7390	1	7390	1
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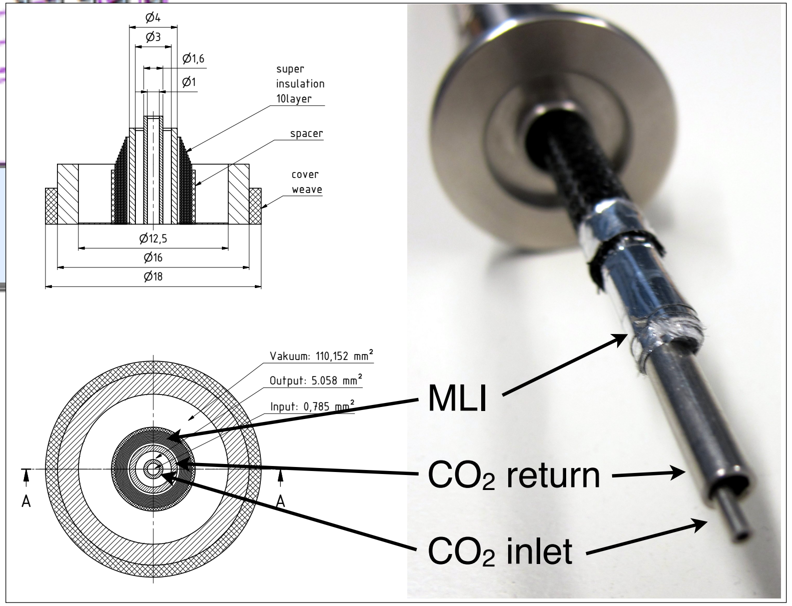
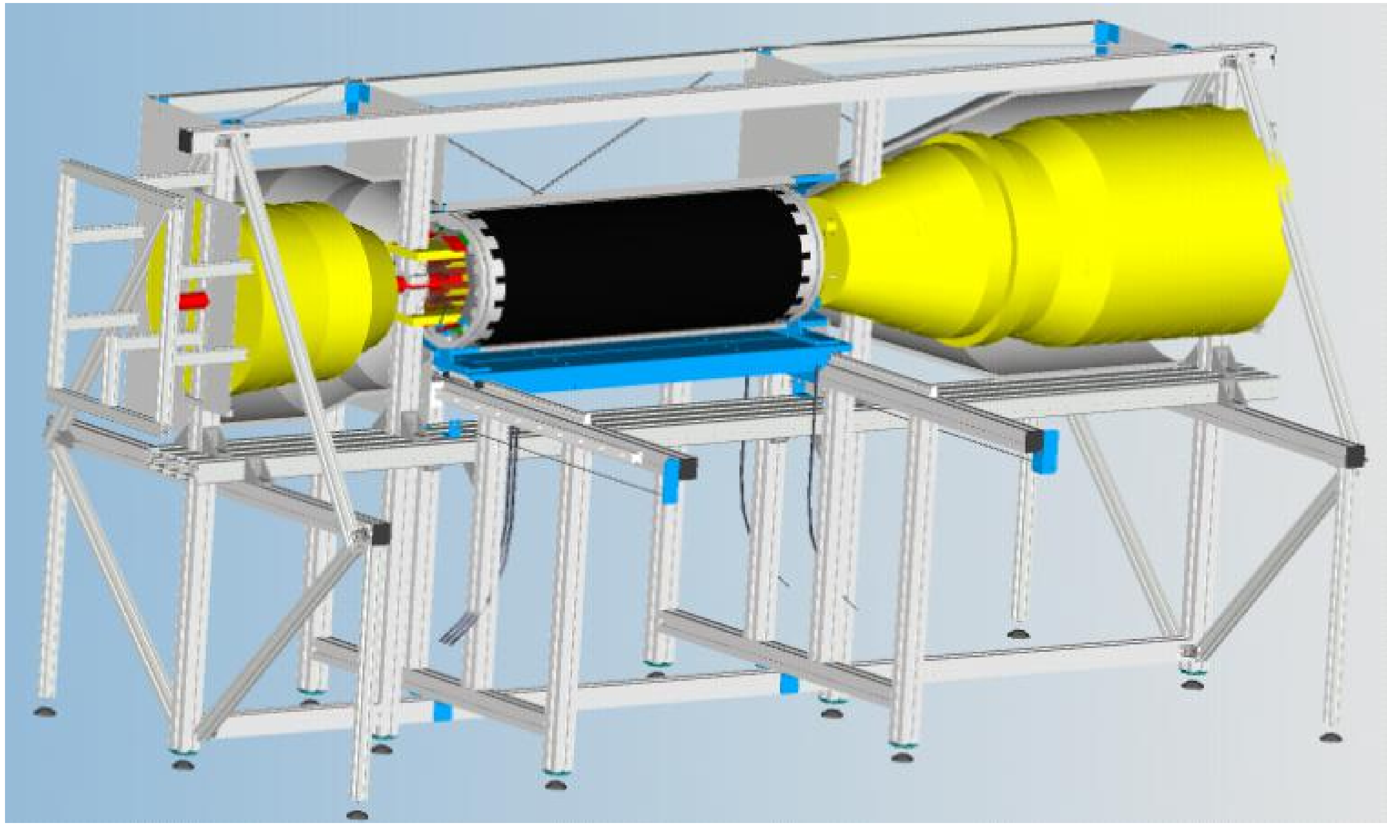
600	1		
580	1,2	1585	1,5
600	1,2		
1180	2	1180	2
7390	3	7390	3



Vacuum isolated concentric CO_2 transfer lines
ATLAS-IBL design

VXD Cooling Requirements and Thermal Mockup

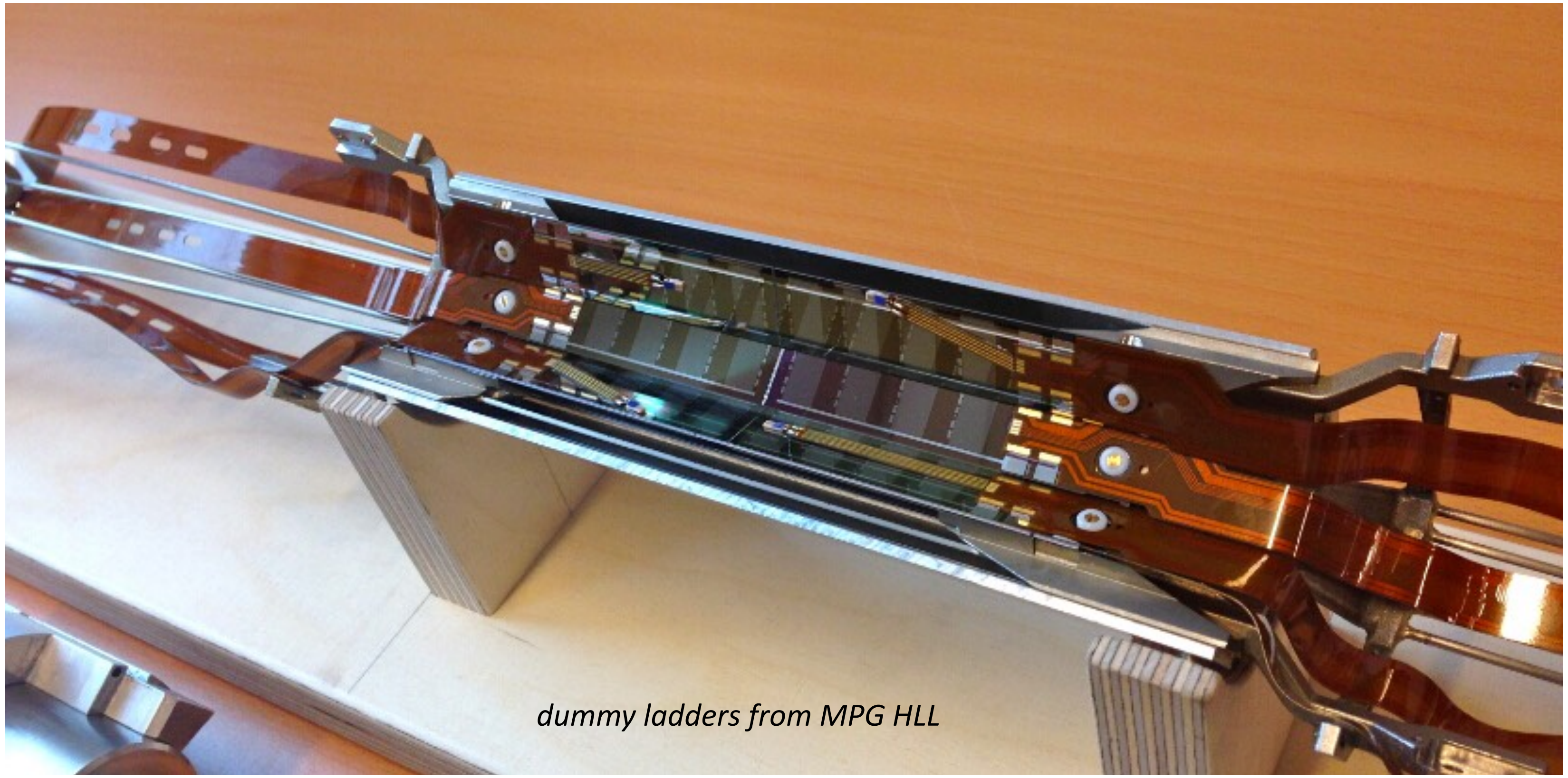
- Power consumption
  - PXD 360W
  - SVD 700W
  - required cooling capacity of ~ 2-3kW
- In total need 12 independent cooling circuits
  - 4 PXD SCBs (90W)
  - 4 SVD endrings (93W)
  - 4 SVD origami cool. pipes (68/96W)
- Constant temperature at inner surface of CDC is important for stable calibration and dE/dx performance
  - minimise thermal effects of VXD



For a number of VXD components, the construction of the mock-up has served as a very useful and important exercise in the pilot assembly process

PXD Thermal Dummy Ladders

- The fragile 75µm thick dummy sensors are made of silicon, like the real detector, to study their thermal performance
- Resistive dummy loads are integrated to simulate the power distribution in the working ladder
  - main power dissipation of read-out ASICs at end of stave (EOS) outside of physics acceptance
  - integrated NTC sensors to monitor temperatures at EOS and in sensor region
- An additional power of 25 W is applied to the Kapton cables to simulate their power dissipation



dummy ladders from MPG HLL

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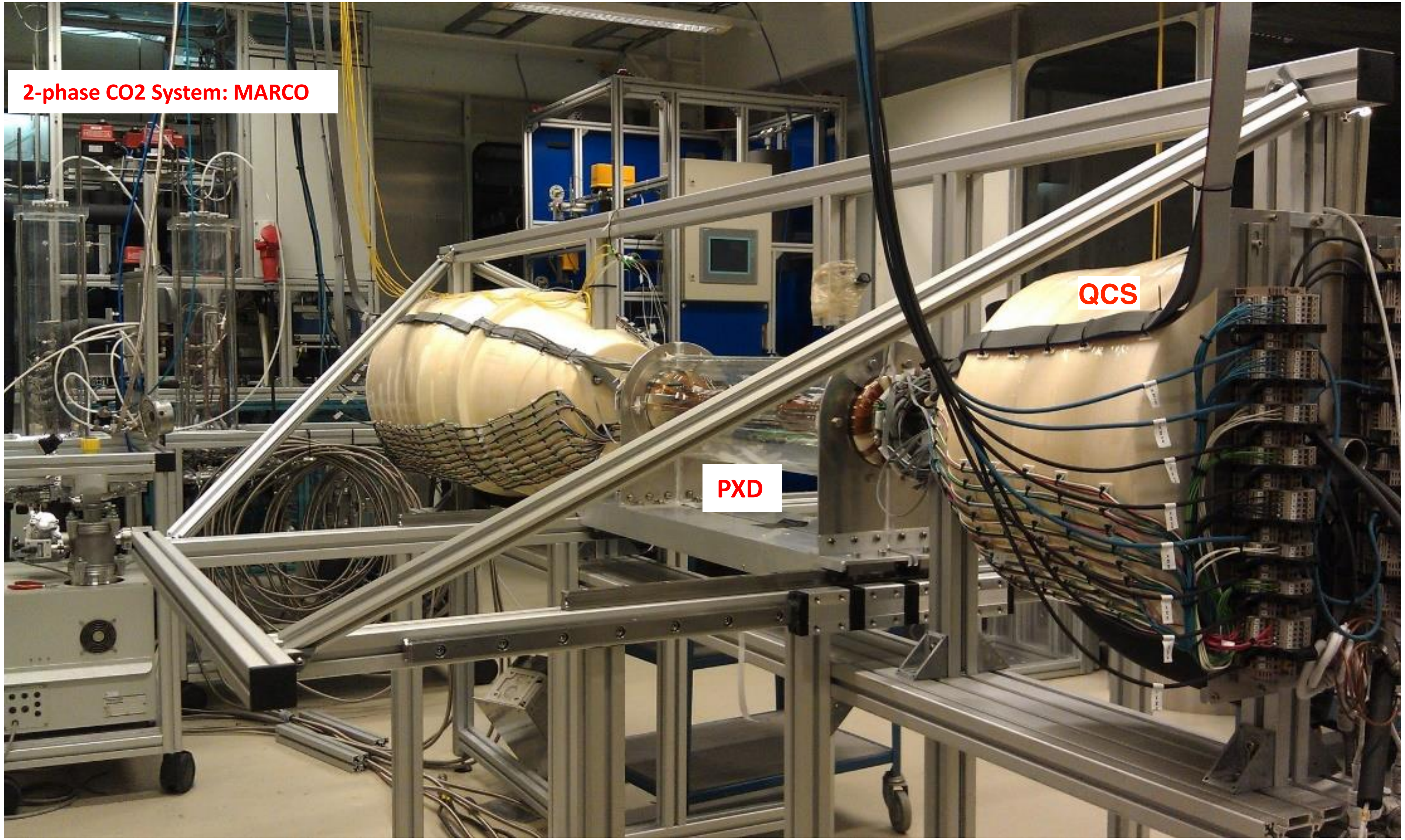
PXD Thermal Mock-up



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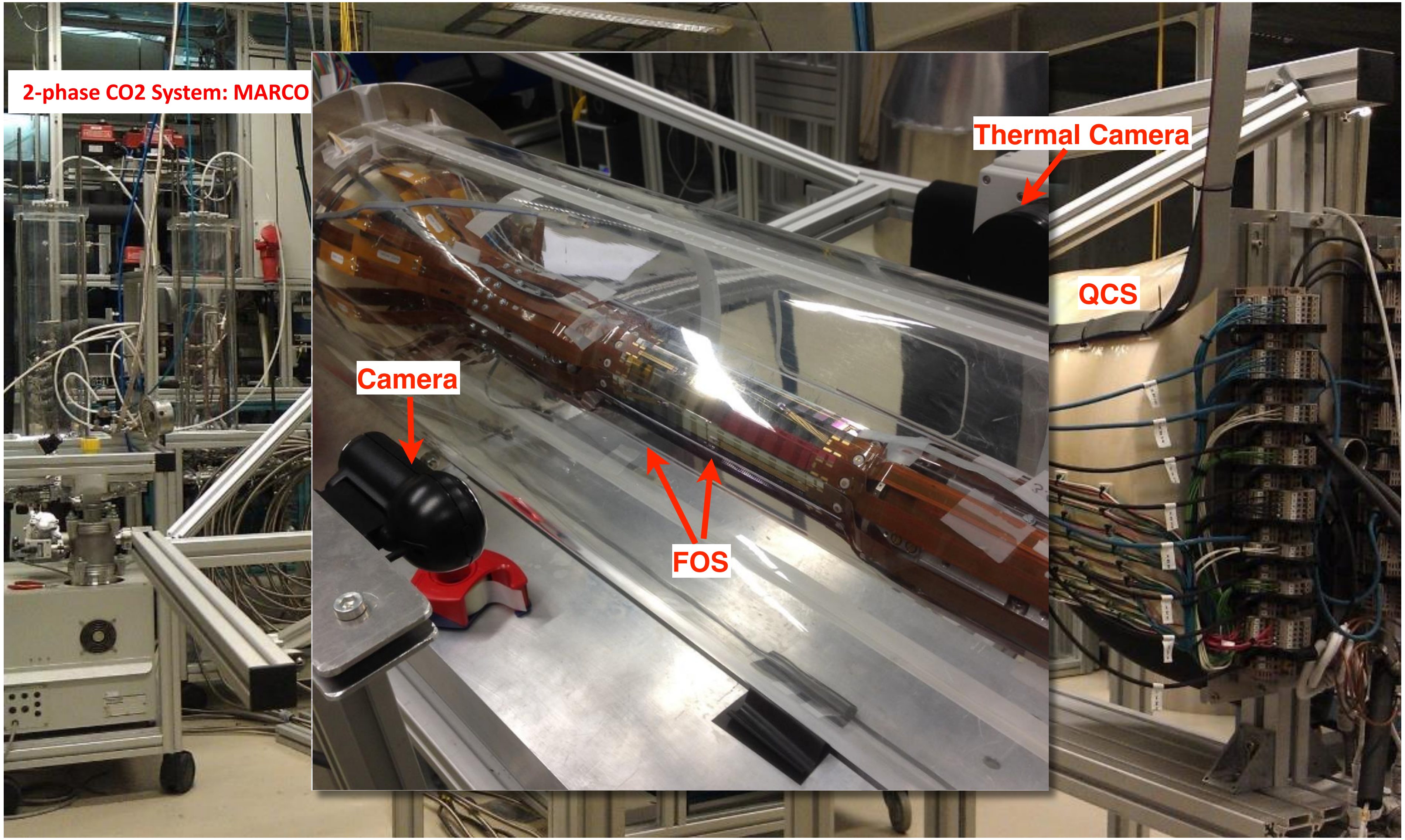
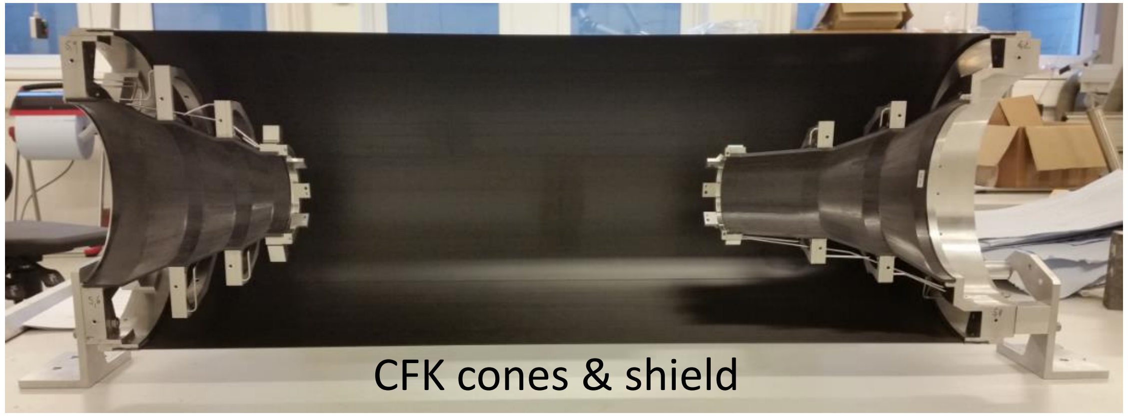
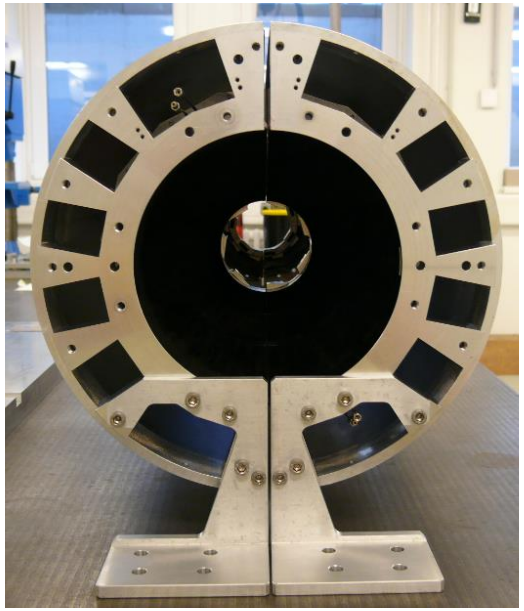
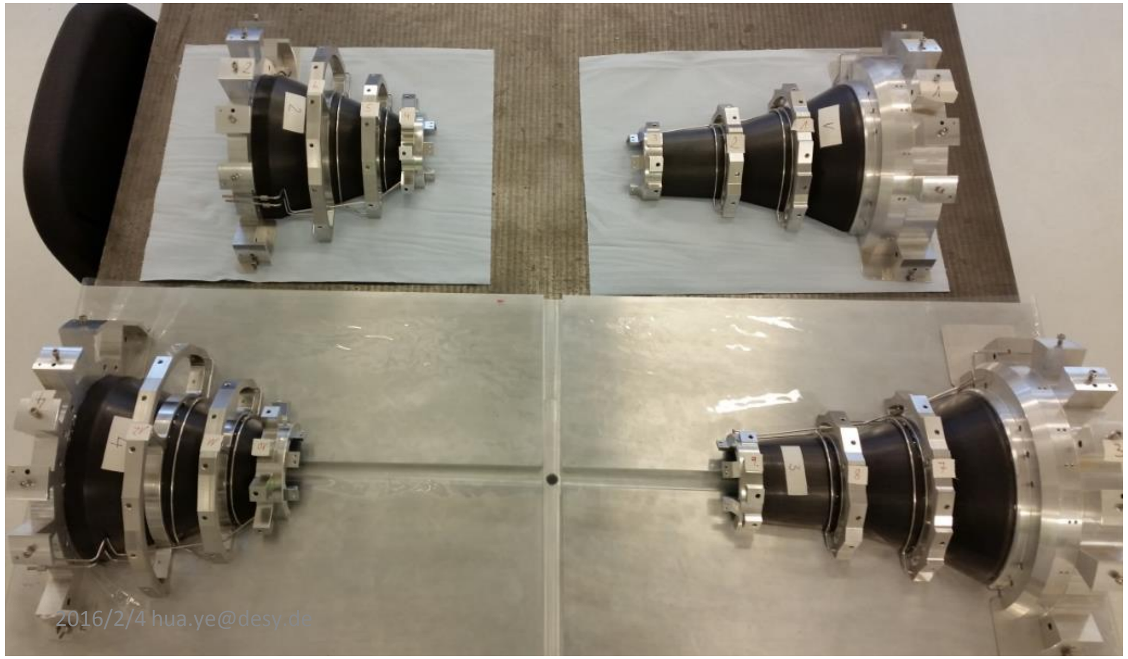


SVD Thermal Mock-up Components


CFK cones & shield




2016/2/4 hua.ye@desy.de

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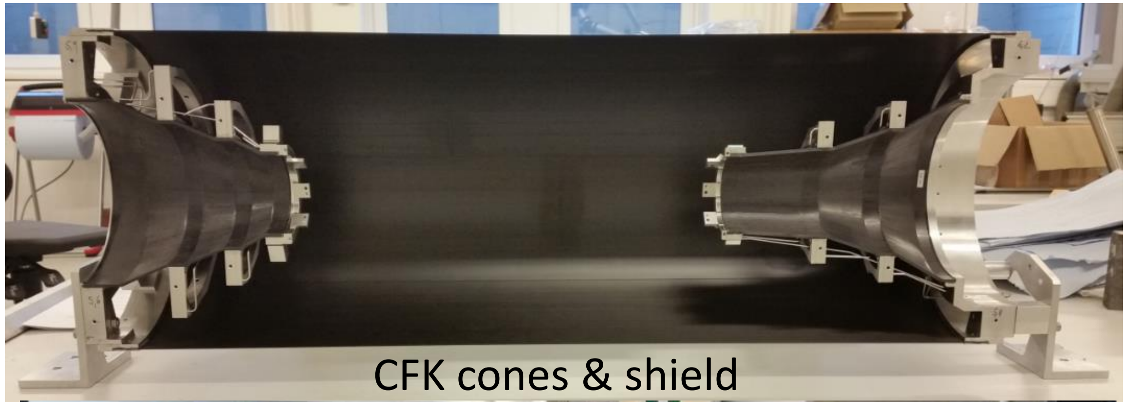

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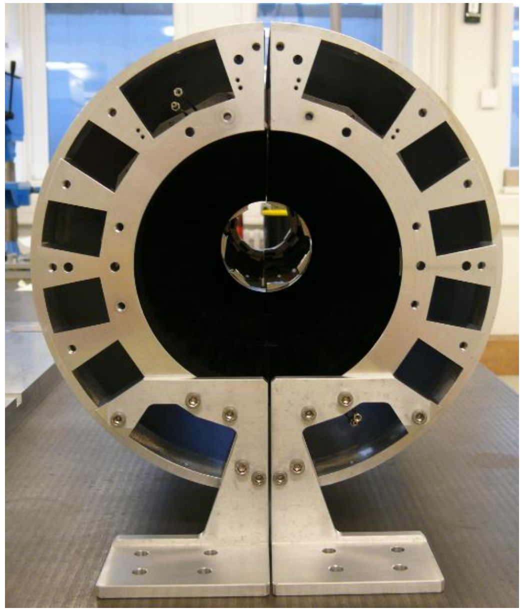
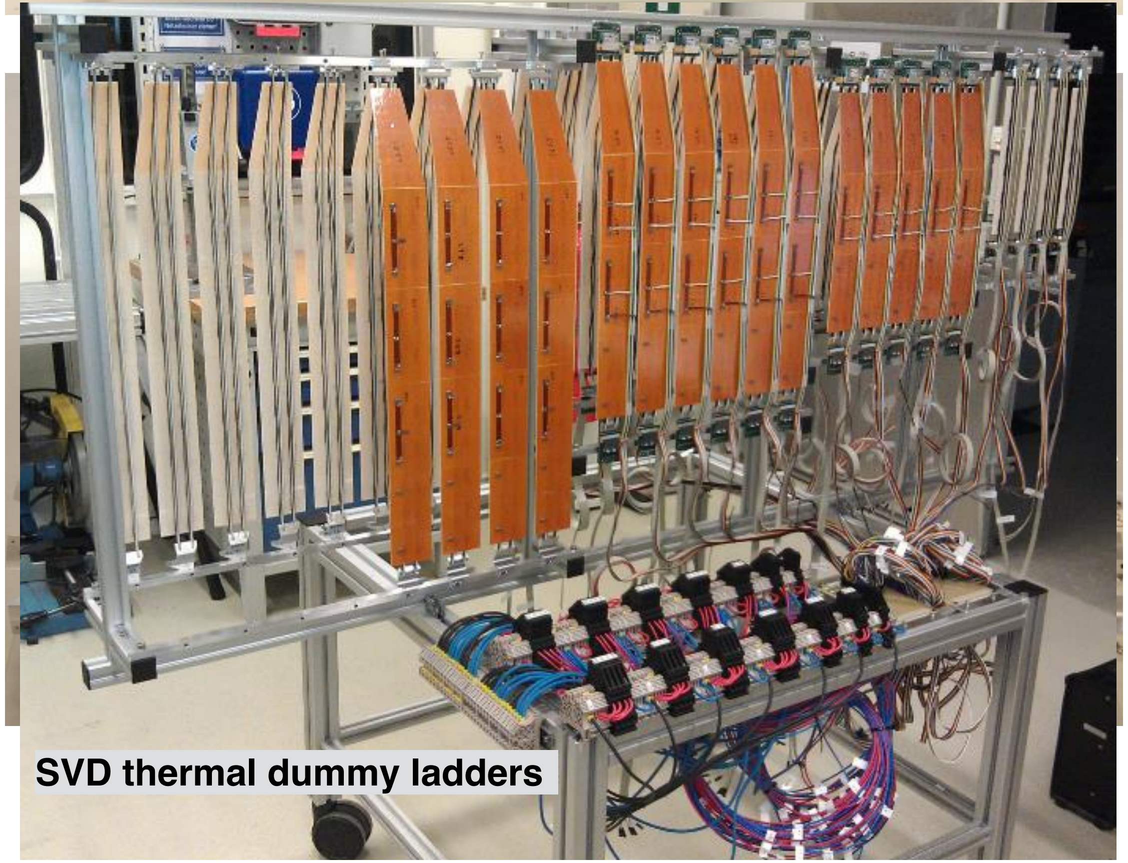
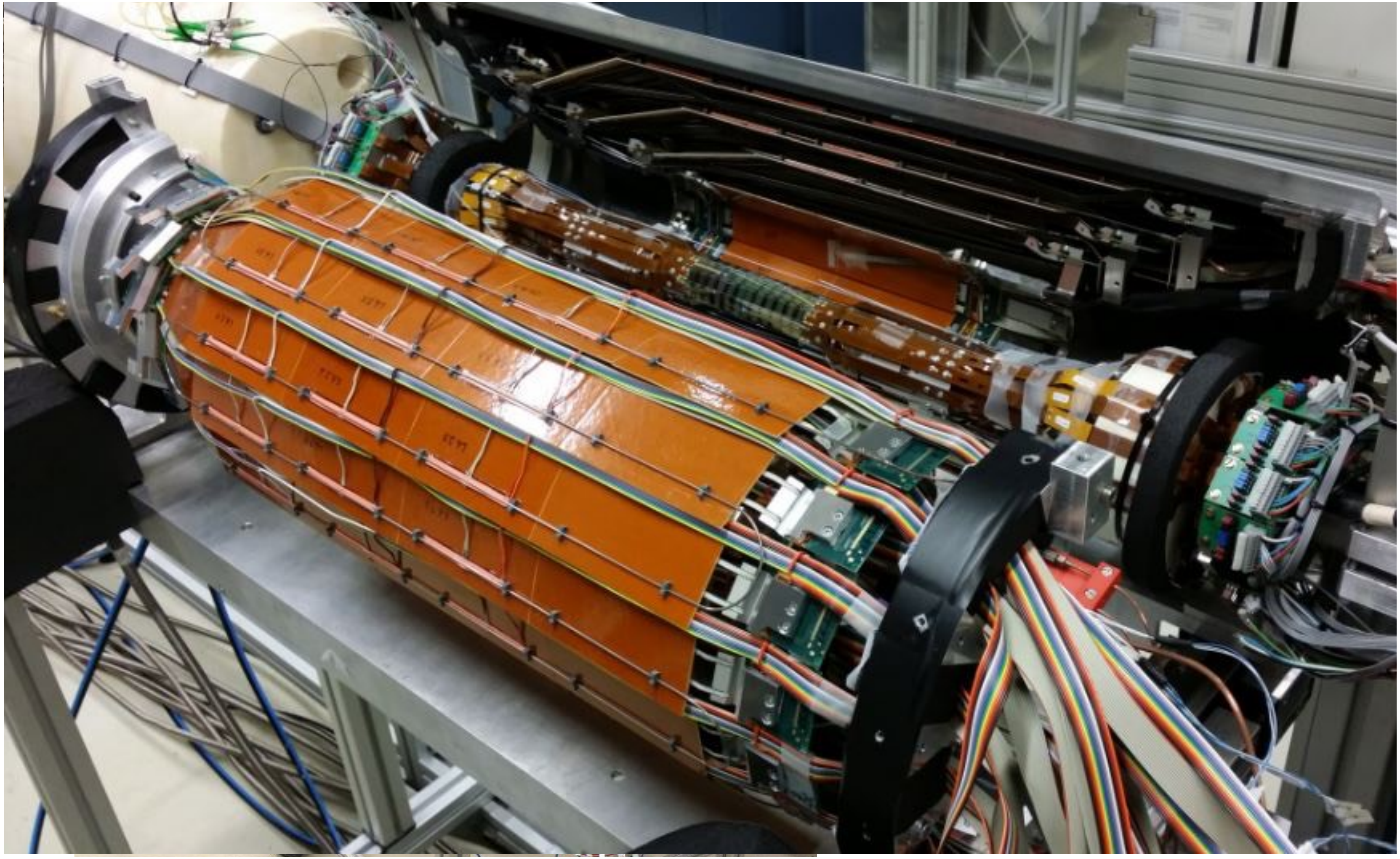


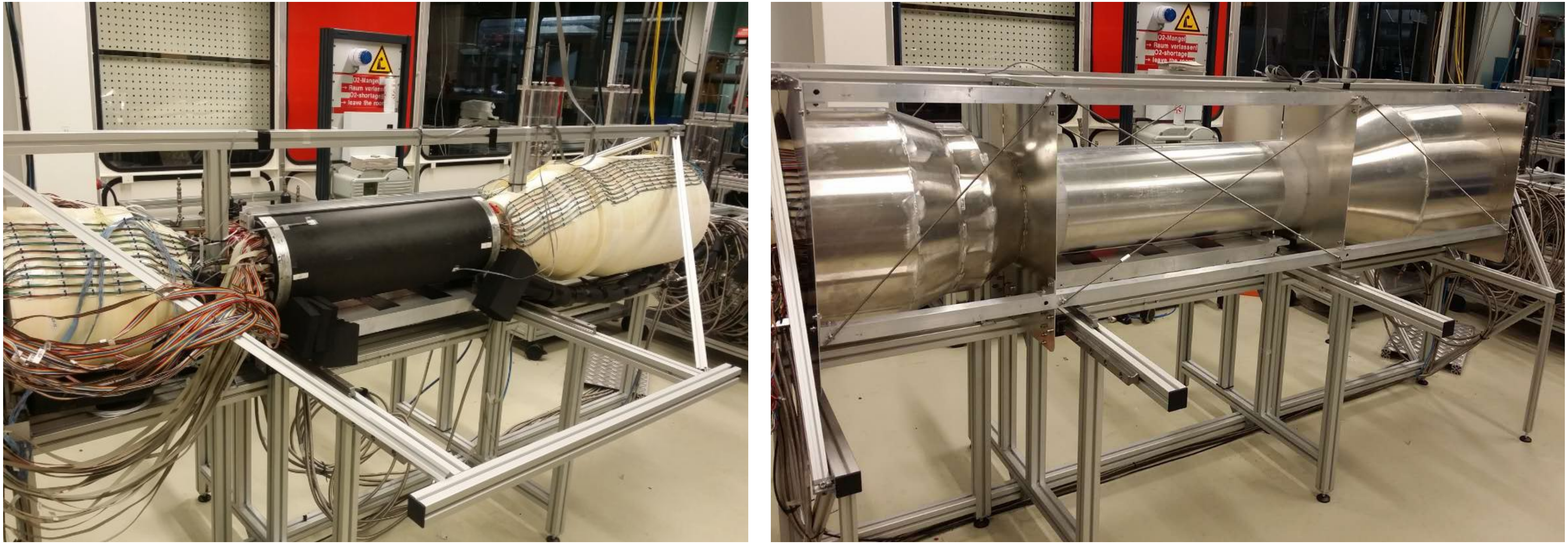


SVD thermal dummy ladders

SVD Thermal Mock-up Components

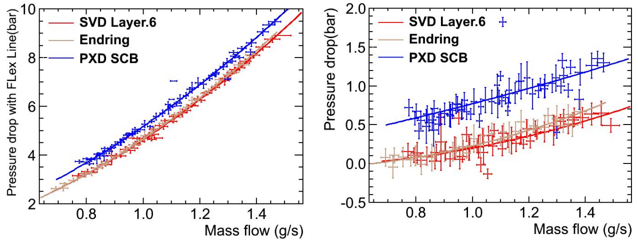


Emulating the inner CDC wall: Warm Dry Volume



Pressure Drop in Cooling Circuits

- ☐ The long and thin cooling lines cause relative high pressure drops, which cause temperature gradients.
- ☐ Relatively big contribution of pressure drop in transfer flex line, to ensure balanced CO_2 mass flow in each circuit.

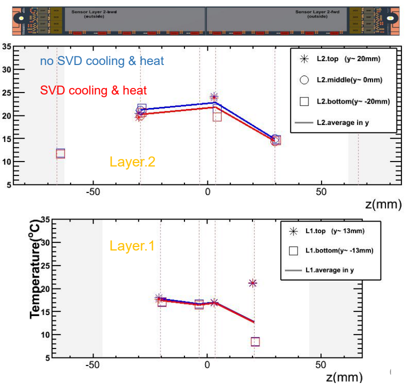


PXD Temperatures with fully operational VXD

CO2@-25°C, N_2 20L/min

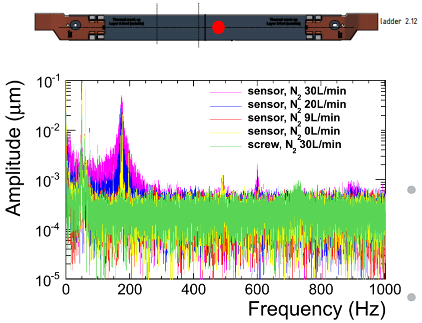
With SVD cooling and power on, temperature on PXD changes ~1-2°C.

asymmetric temperature along the PXD ladder is due to the heat dissipation in the volume (more space in FW side).



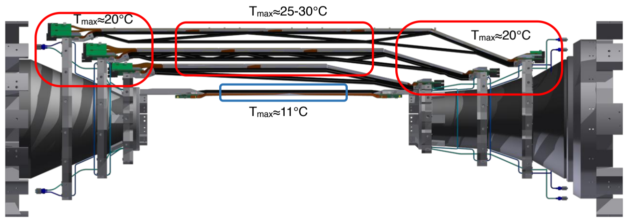
Vibration Studies

Using non-contact
capacitive (sensitivity of 0.05um, band width of 5kHz)
laser (sensitivity of 0.02um, band width of < 50kHz)
displacement sensors.



- Measure amplitude and frequency spectrum vs N₂ flow
  - frequency peak at 175 Hz
  - amplitude < 0.04 μm at a flow rate of 20-30 L/min
- Not a concern for PXD operation

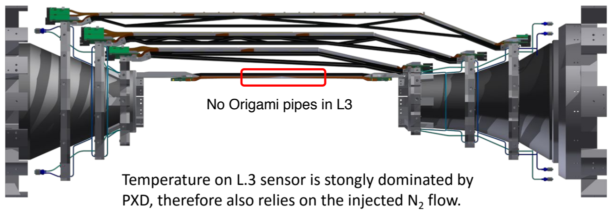
Temperature on SVD Ladders



CO2@-25°C:
Temperature in the middle of L.3 sensor is 11°C, it's strongly influenced by PXD, therefore relies on the injected N_2 flow.

For L4/5/6, with nominal load, the maximum temperature on FW/BW edges and module ASICs reach about 25-30°C.

SVD L3 Sensor Temperature



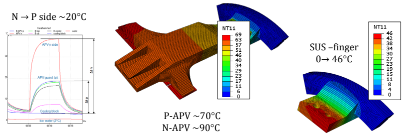
Temperature on L.3 sensor is stongly dominated by PXD, therefore also relies on the injected N_2 flow.

	PXD power off	PXD on, N2 20L/min	PXD on, N2 30L/min
$T_{average}$(PXD L2) /°C	-25	20	16
T(SVD L3 sensor) /°C	-7	11	10

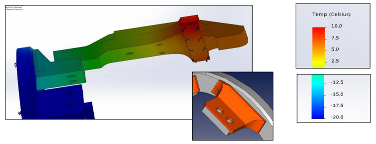
After PXD powered up, temperature at L.3 ASICS increase about 1°C

L3 Thermal Management Problem

FEA analysis on L3- after DESY BEAM test Apr.16 - confirmed a thermal gradient from cooling pipe to FW-APV about 90°C



Most of the gradient (~45°C) is in the endring finger, made of stainless steel.

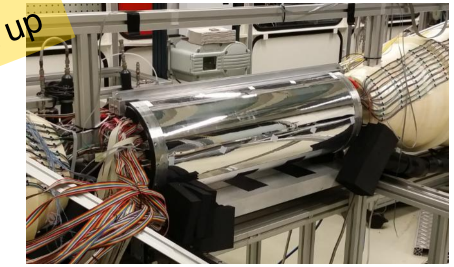


A first draft of the insert (K.Gadow) and thermal analysis (M.Friedl) confirmed the functionality of this solution.

Selected topics studied using the thermal mock up

Thermal Radiation

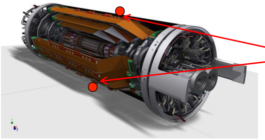
A reflecting foil covers the out surface of VXD shield.



With the foil,
- Temperatures on the inner/outer surface of CFRP shield decreases by ~0.5°C
- No influence on temperatures on the ladders

Temperature on CFRP & CDC Inner Cylinder

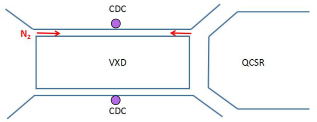
About 5°C's gradient on the top/bottom of inner side of CFRP shield . ●



CO2@-25°C, 20L/min N2 to SCB.

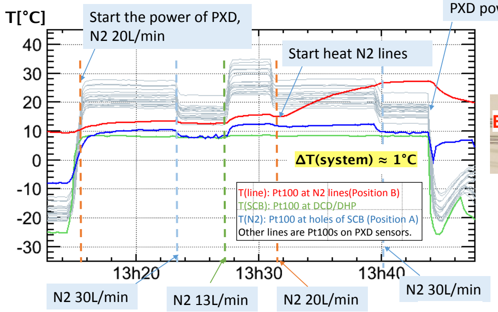
20L/min N2 to SCB, VXD heat on	
top	10
bottom	4

Temperature on CDC inner cover ●



14L/min N2 to Dry Volume			
top BW	12	top FW	14
bottom BW	7	bottom FW	8
25L/min N2			
top BW	13	top FW	15
bottom BW	8	bottom FW	8

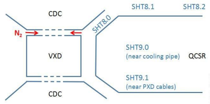
Study Influence of N₂-Line Temperature



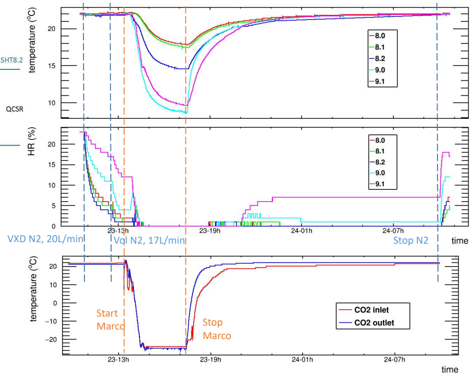
- PXD temperature largely independent of N₂ input temperature at SCB
  - SCB cooling of N₂ is quite efficient
- N₂ flow rate plays the dominant role

Humidity with N₂ Flow in Dry Volume

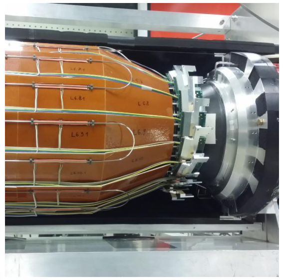
Introduce 17L/min N_2 to the dry volume

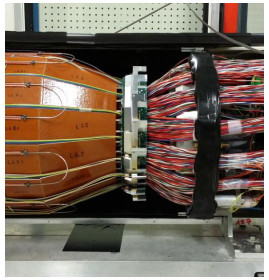


- ☐ When CO2 setpoint is reached, the humidity in dry volume will reduce to ~0%.



Heat Transfer through Cables

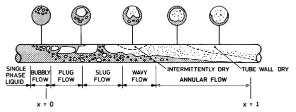




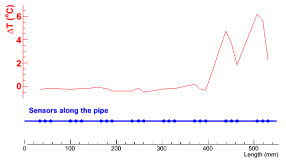
Electronic cables are insert to FW -x half endring, contacting L.5, L.6 endrings.
No significant temperature change at the endflange is observed.
→ Little influence from cables' thermal conductivity.

Study Onset of Dry-out

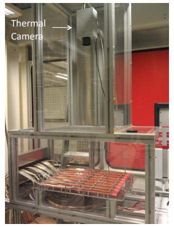
When the vapor quality gets too high, there will be no liquid film on the capillary walls, then result in a shape increase of the cooling block temperature.



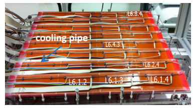
Dry out



The dry out happens in the last 6 sensors



SVD Layer.6 in flat arrangement



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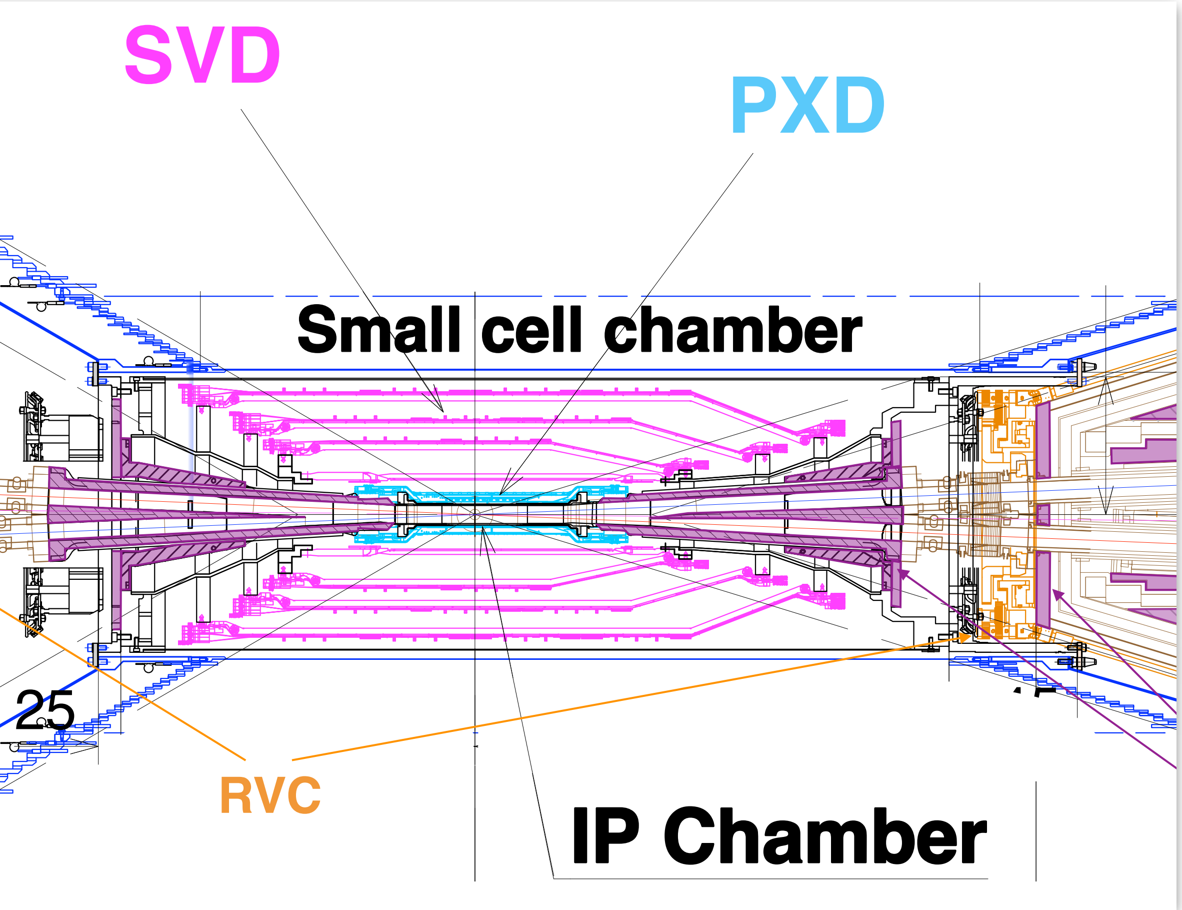
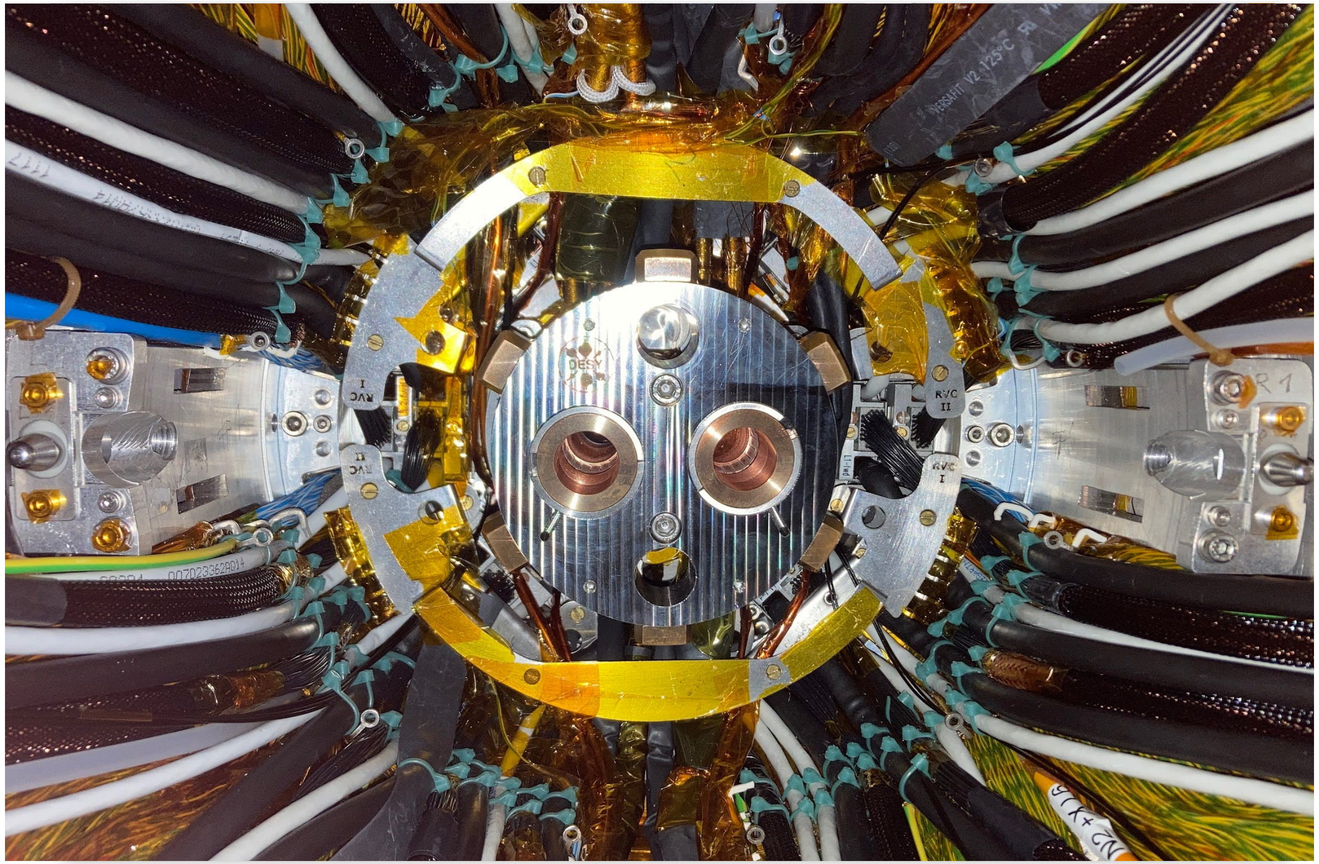
RVC Mock-up

Establishing Vacuum Connection in an inaccessible Area





Front end flange view prior to QCS insertion

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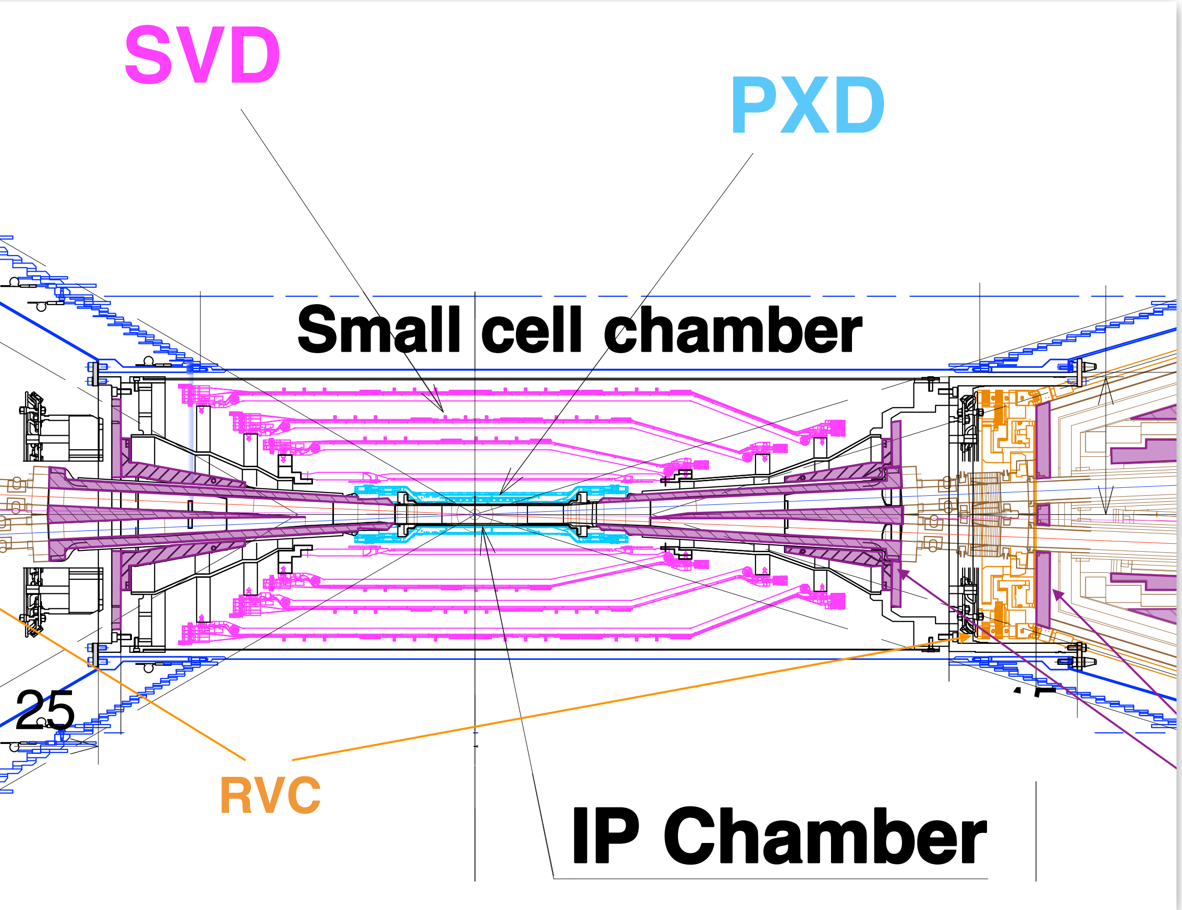
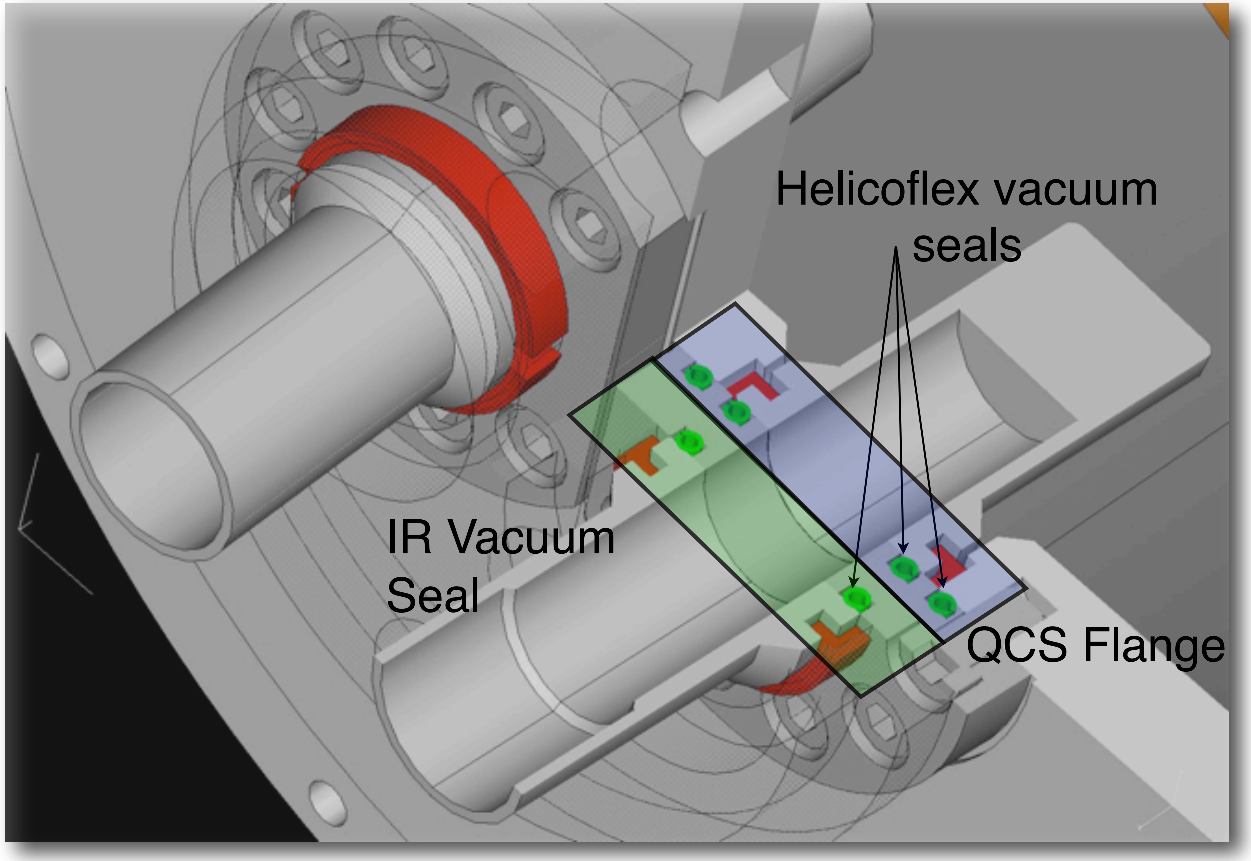
Establishing Vacuum Connection in an inaccessible Area





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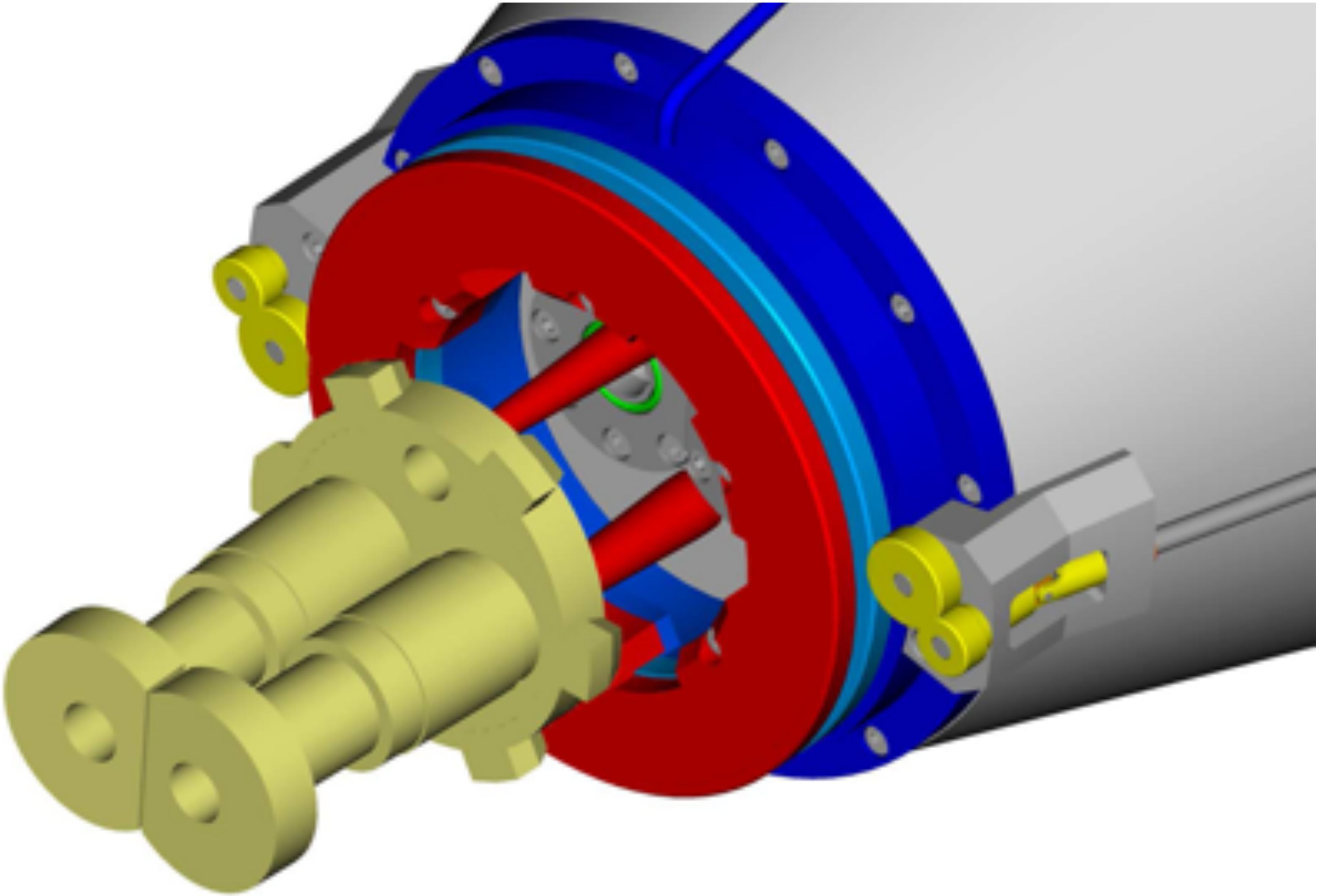
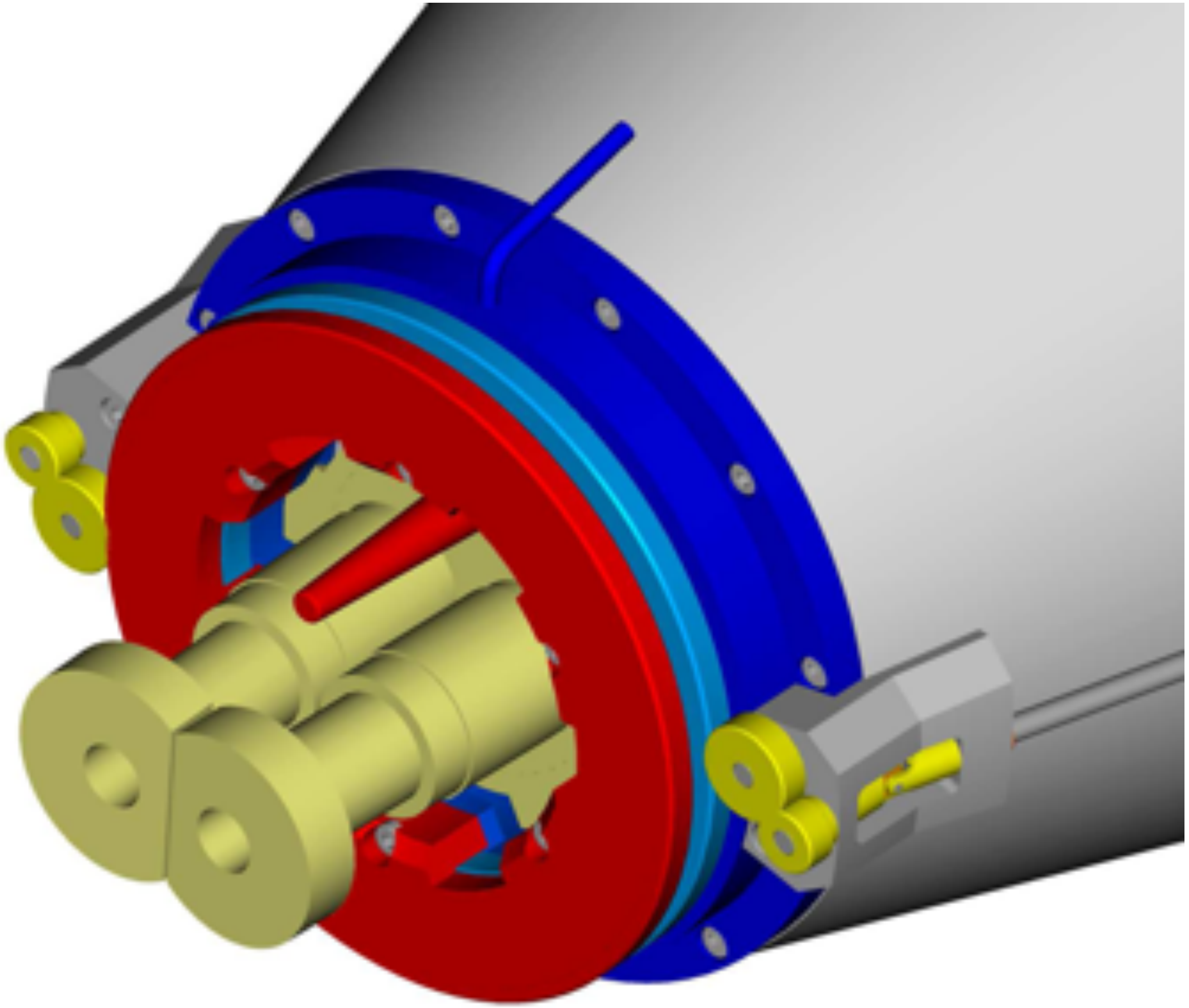
Basic Principle

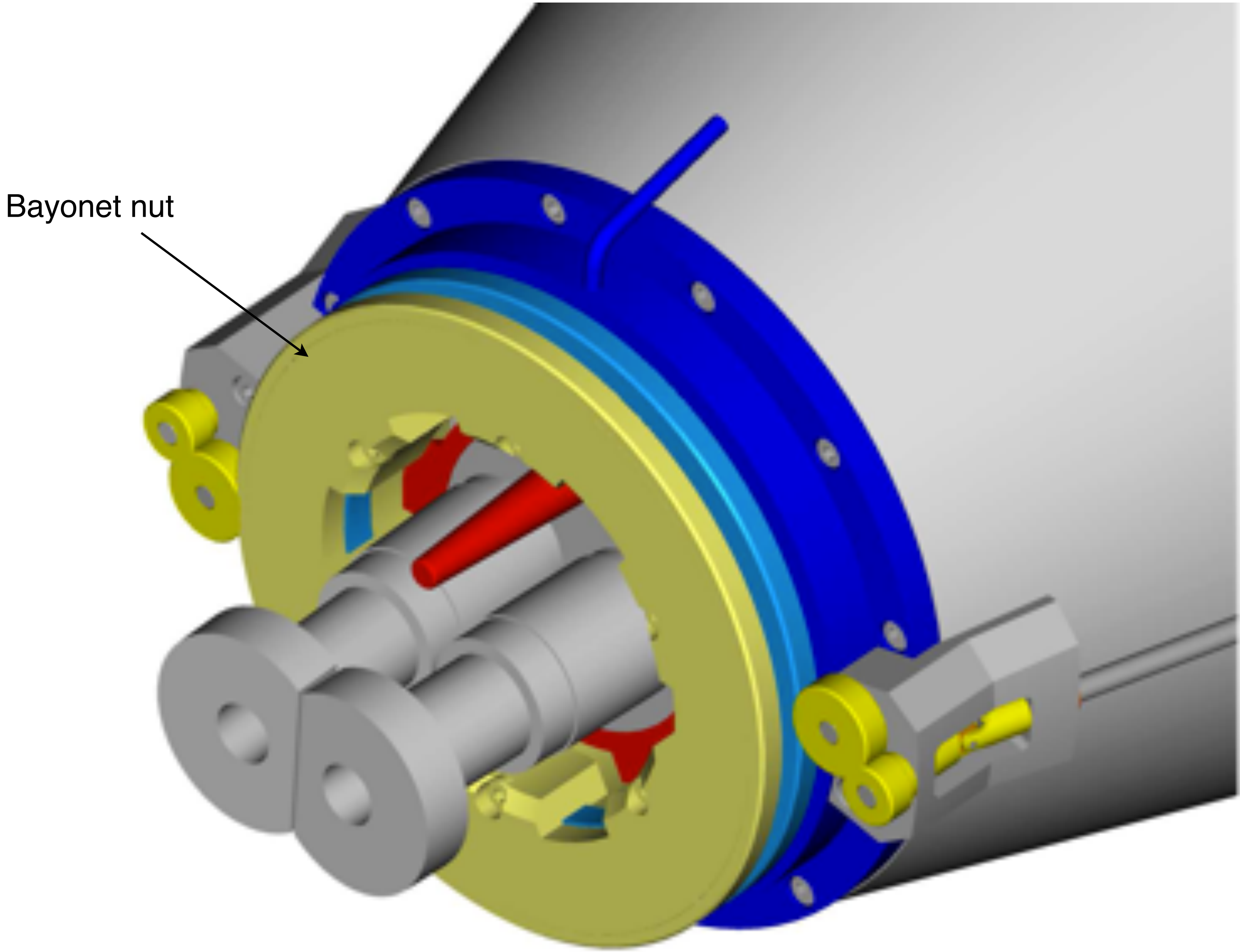


Basic Principle

QCS moving in

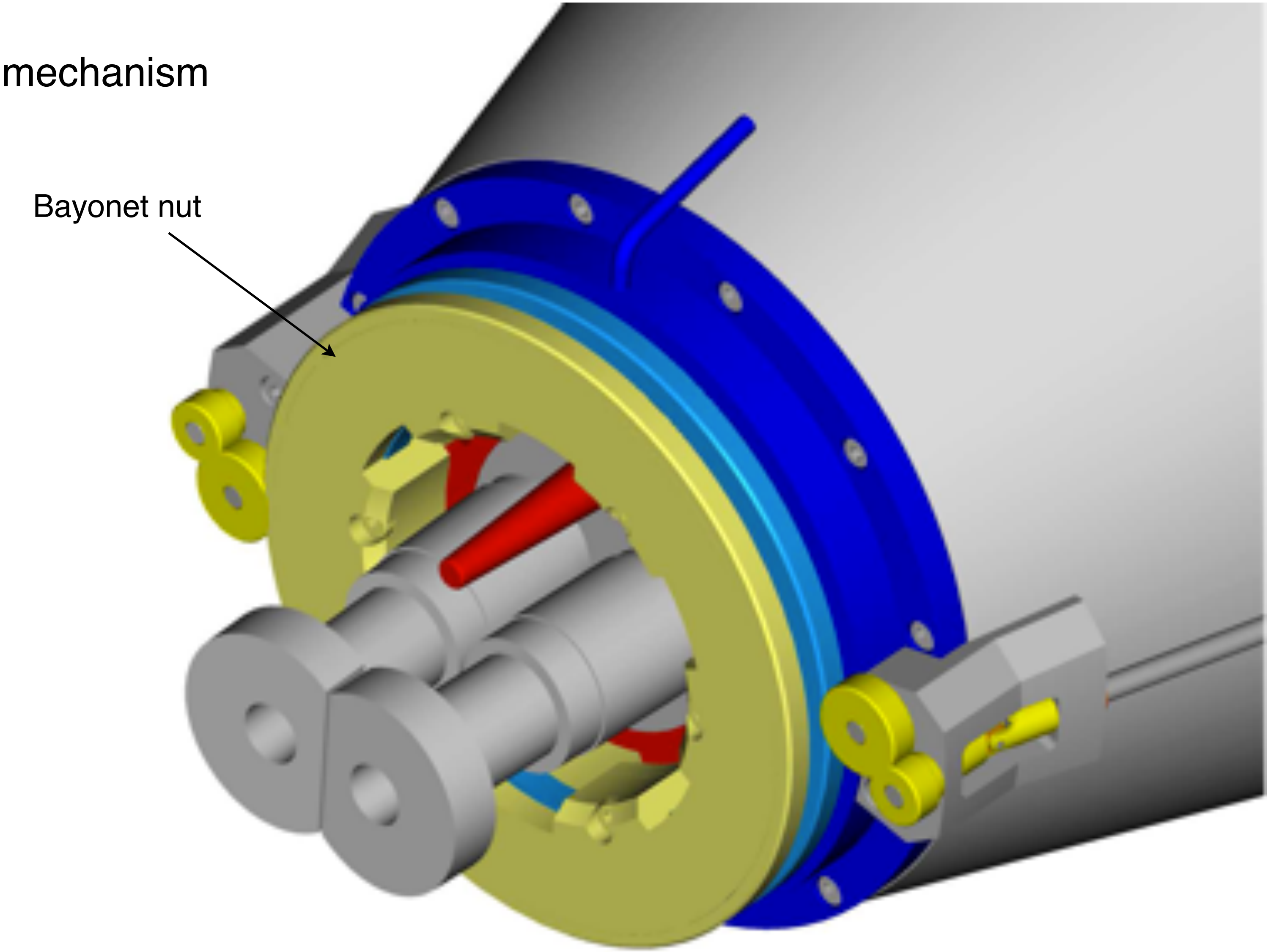


Basic Principle



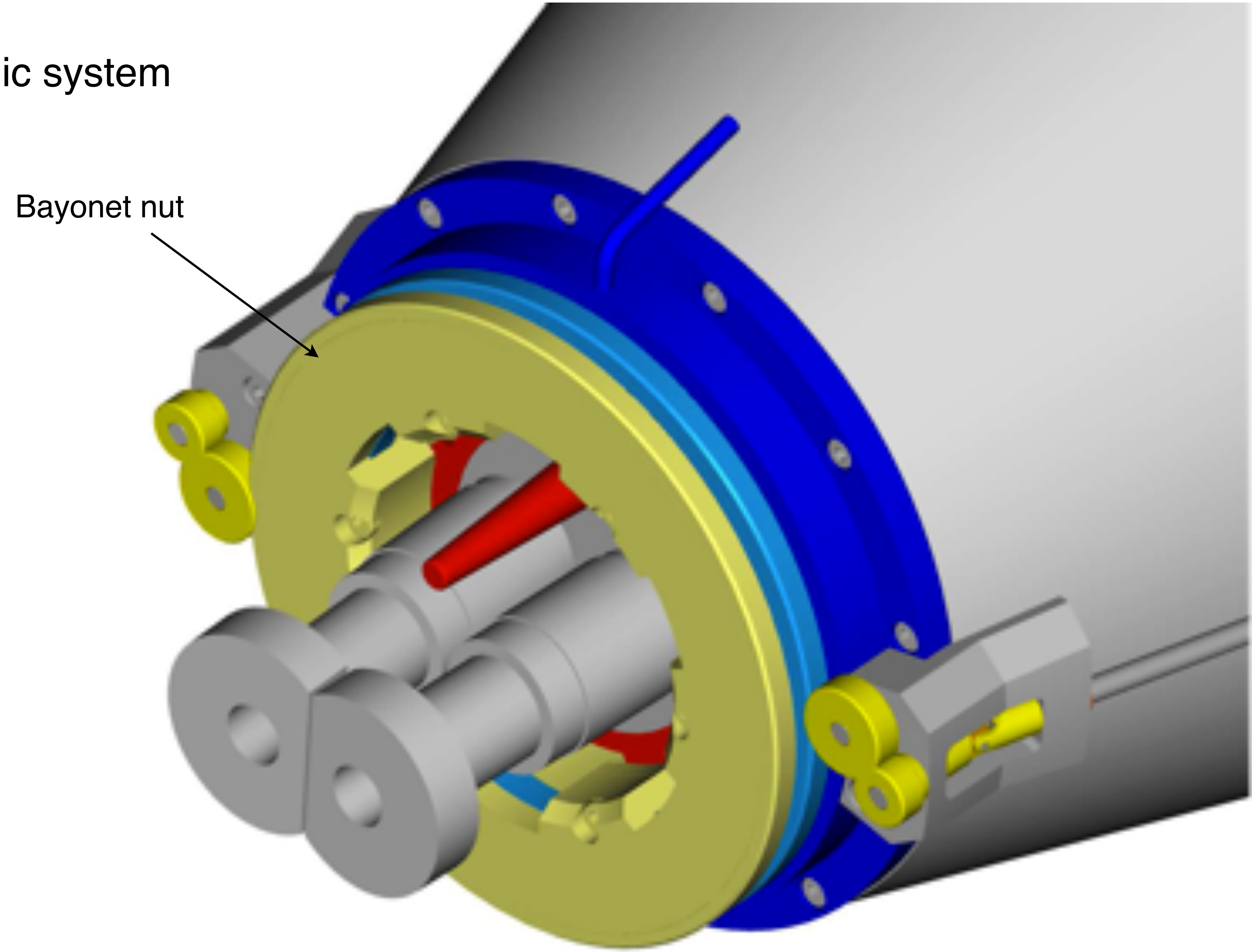
Basic Principle

Closing bayonet mechanism

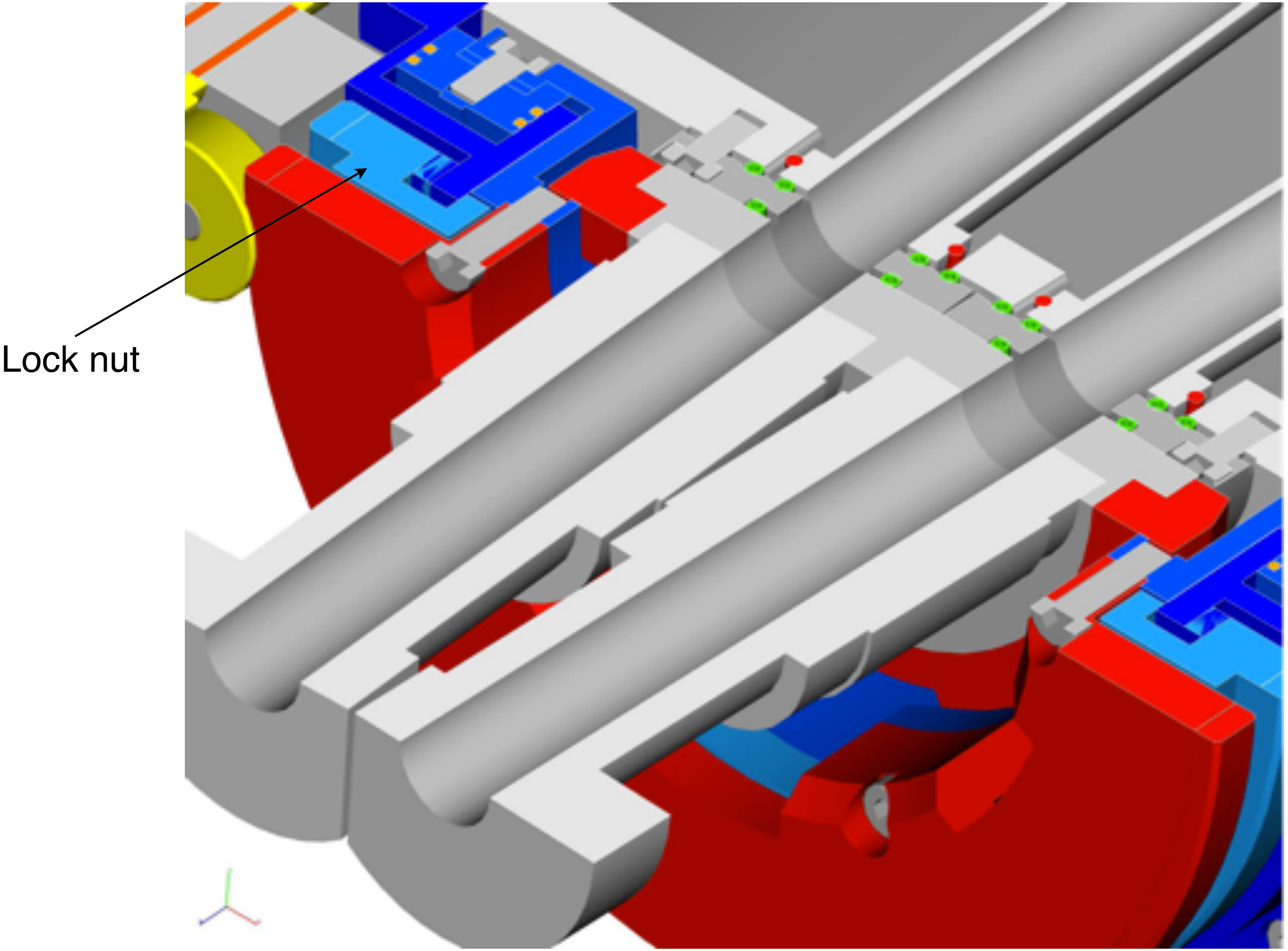


Basic Principle

Activating hydraulic system

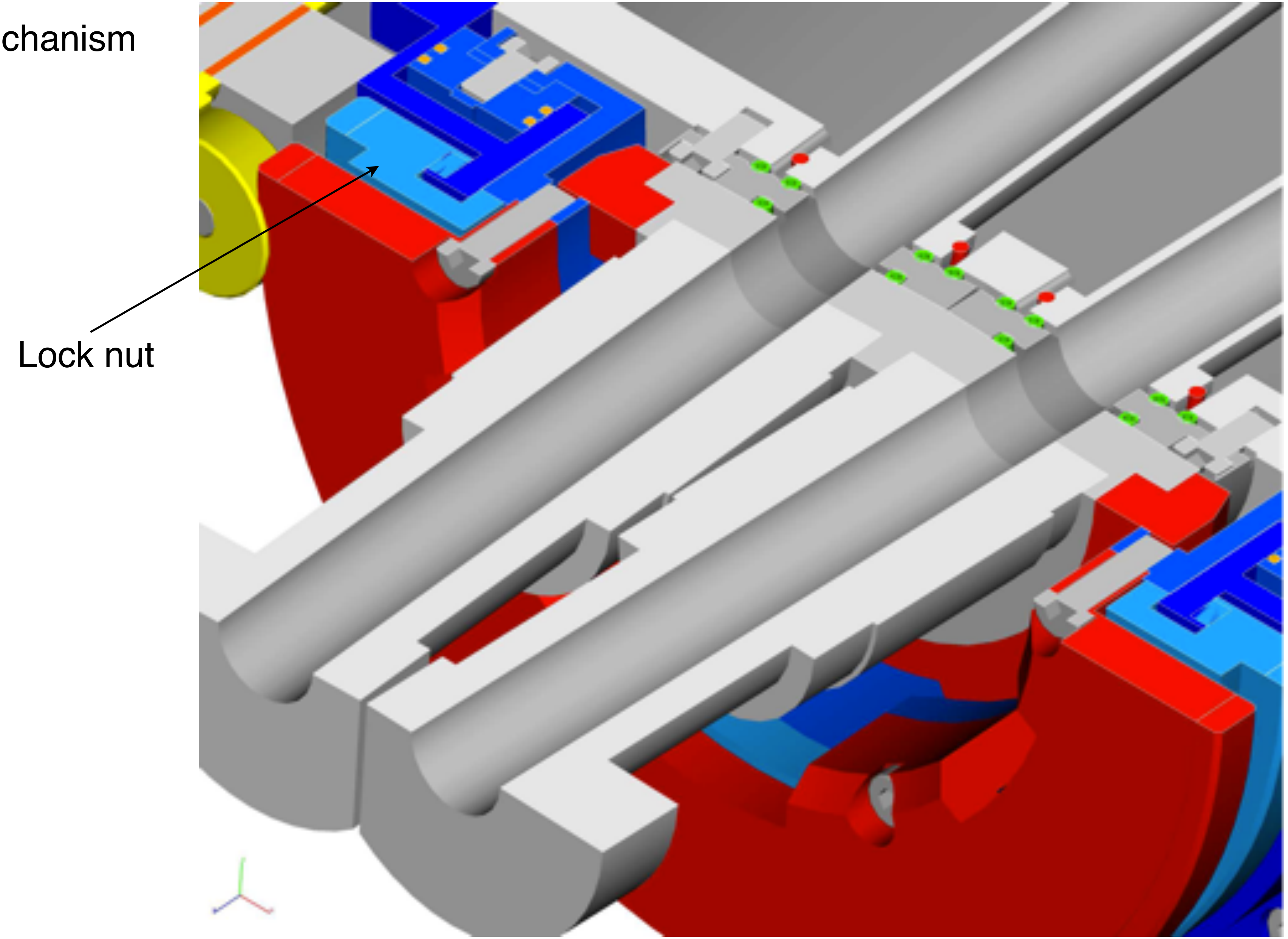


Basic Principle



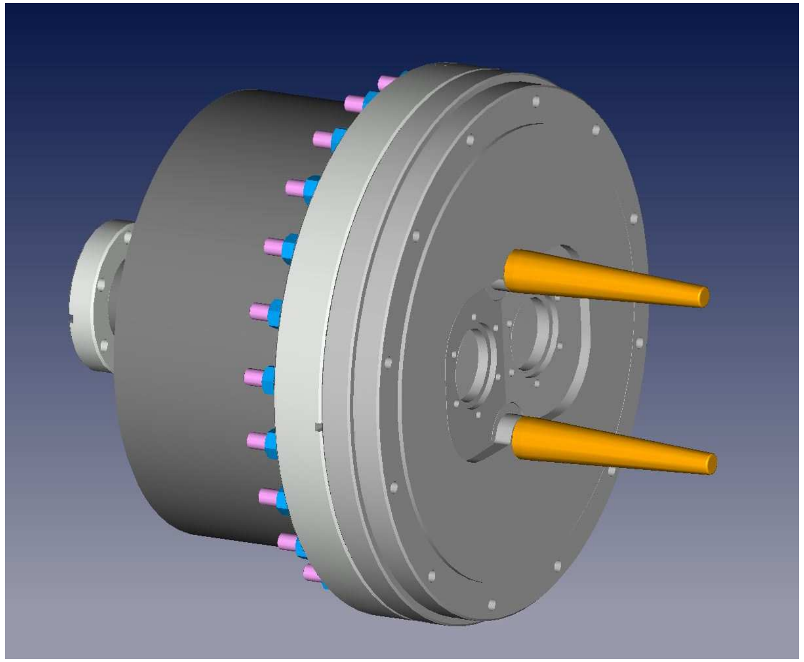
Basic Principle

Locking mechanism engaged

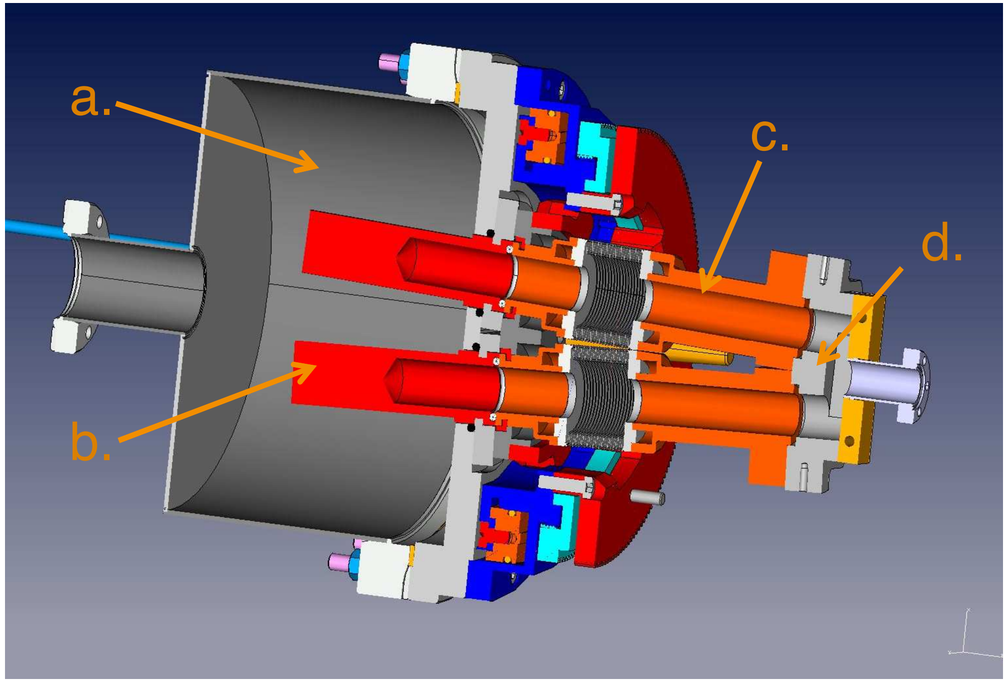


Lock nut

RVC Mock-up Design

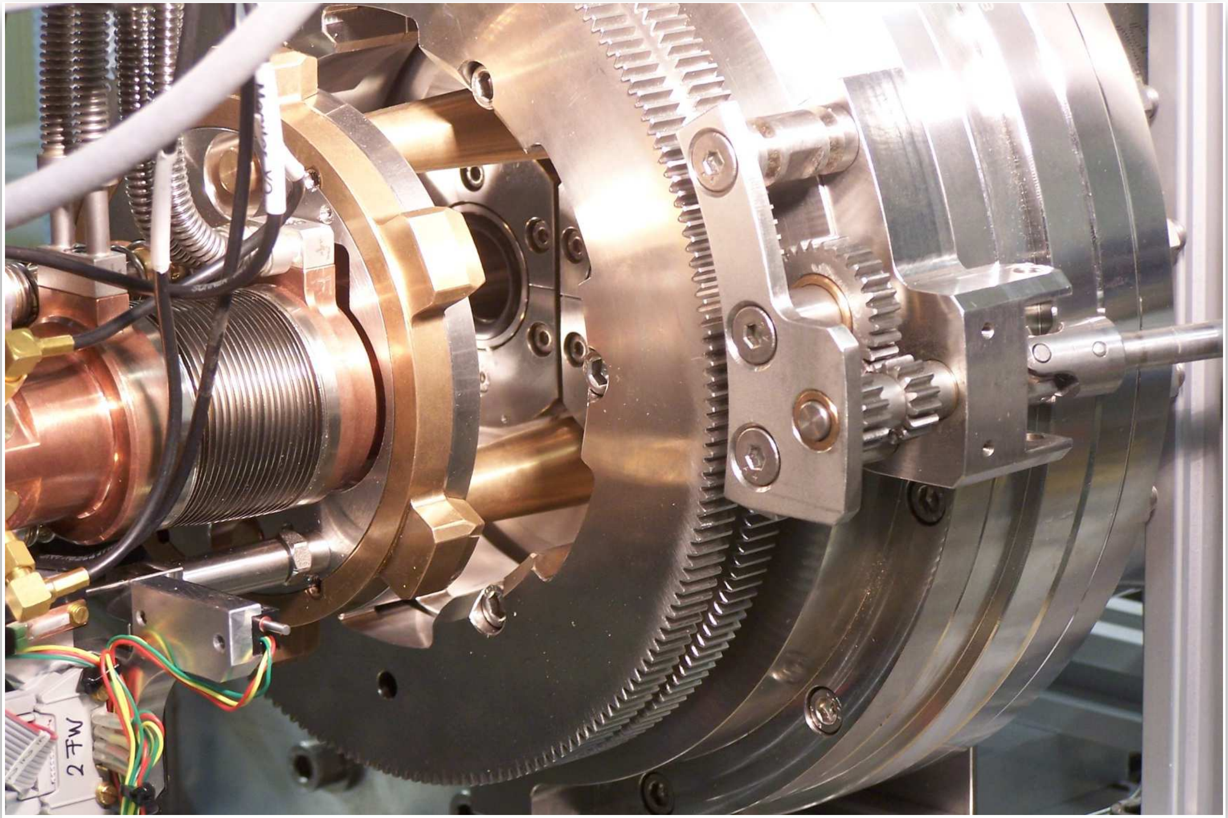


a. QCS vacuum vessel
b. QCS beam pipe
c. beam pipe bellow parts
d. crotch beam pipe flange



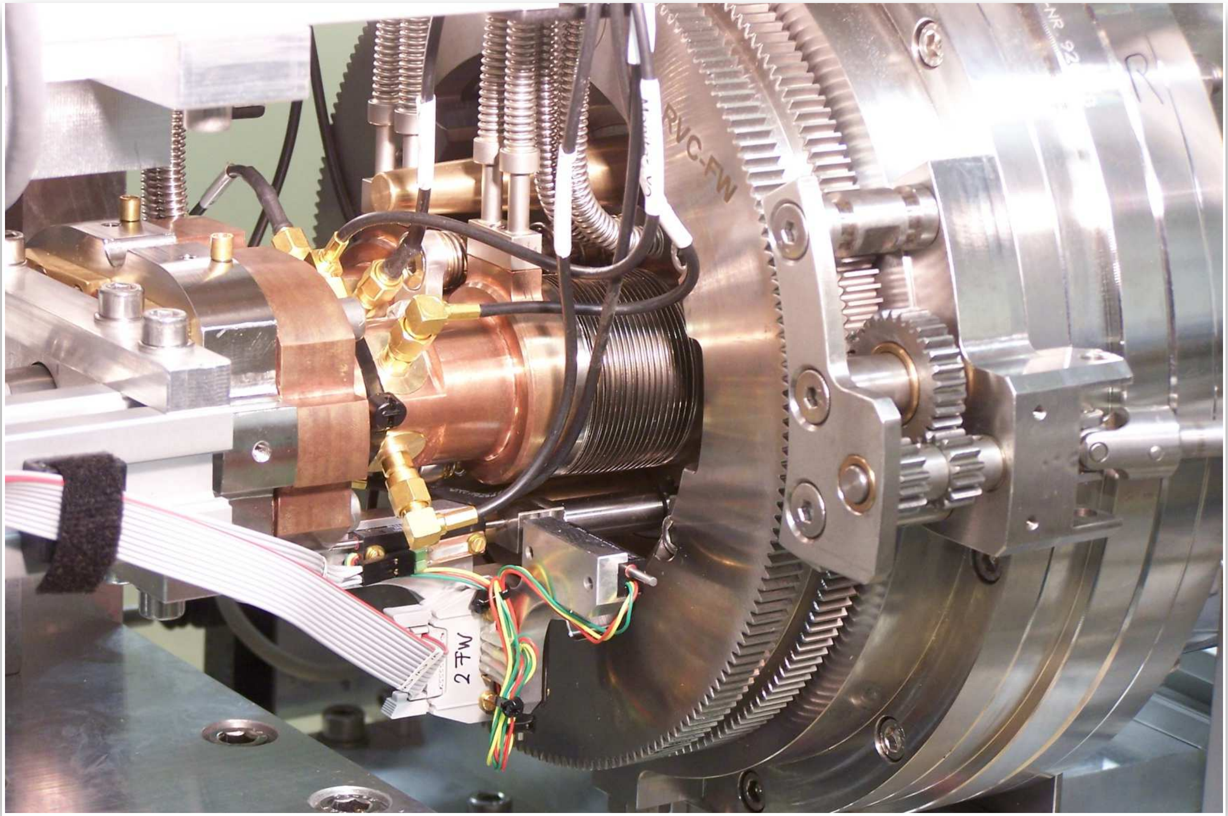
RVC Operation

Before closing



← IP QCS→

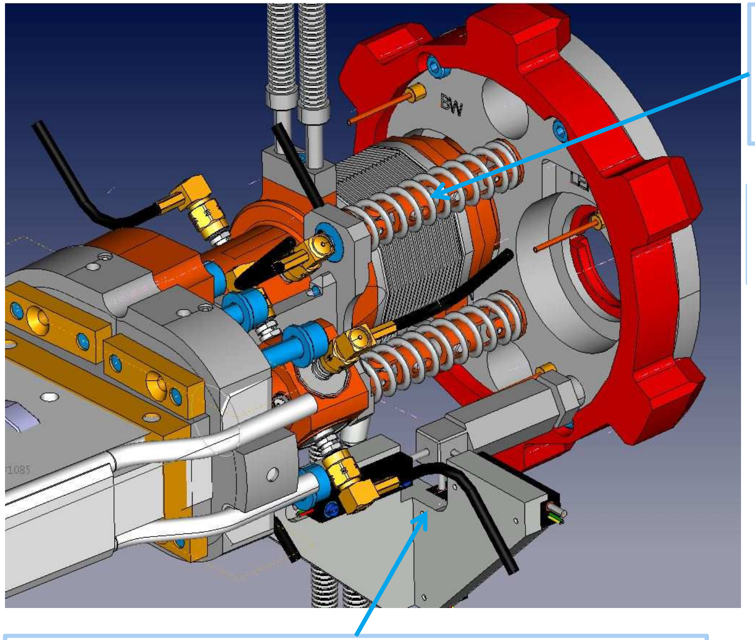
After closing



← IP QCS→

In the real system at KEK, can watch the QCS approach with a camera attached to the VXD end flange

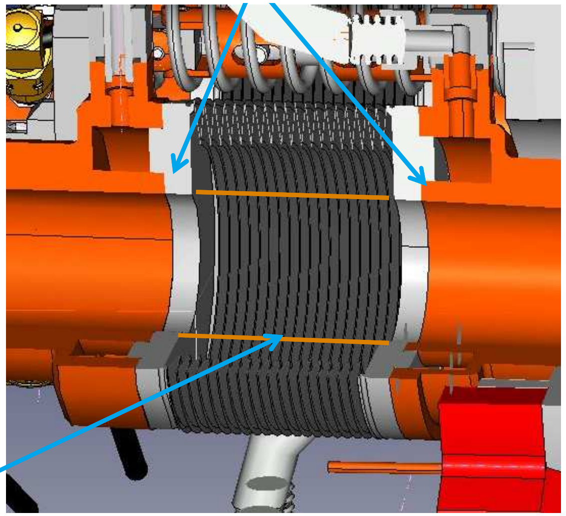
Travel Limiter

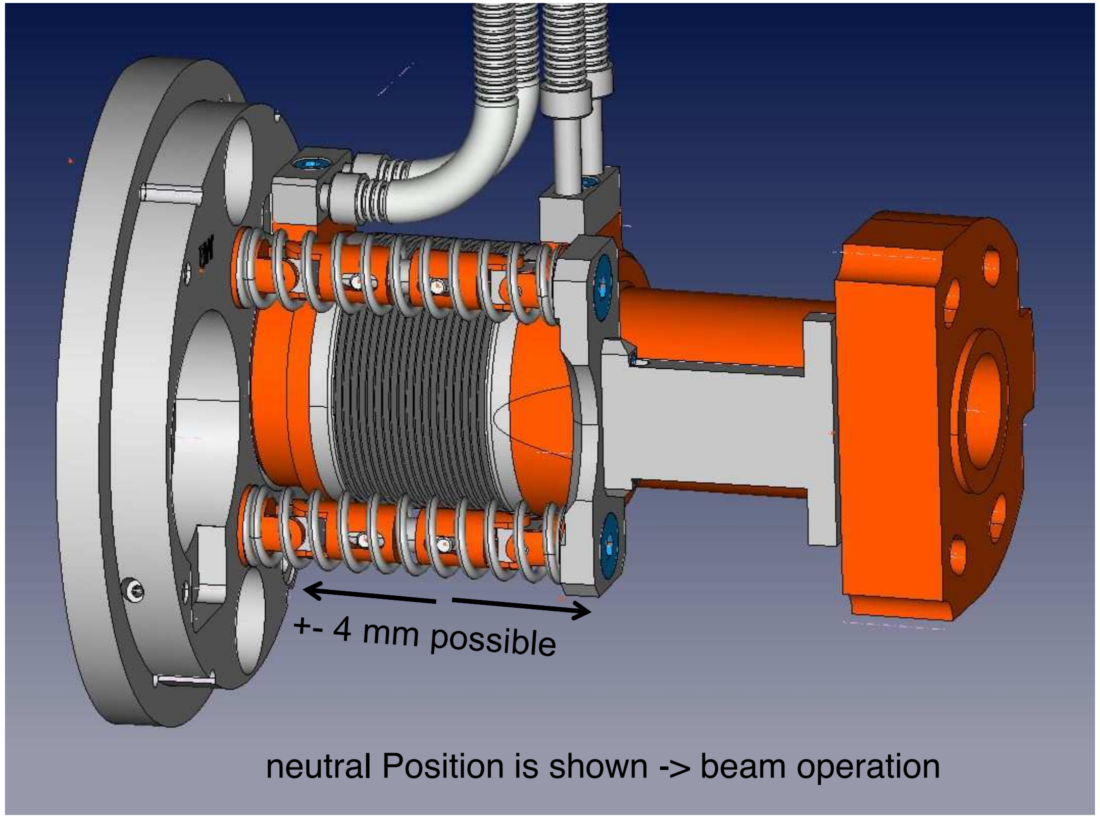


Travel Limiter to keep RVC flange in connection position and secure RF bridge

Potentiometer to measure 3D displacement

RF fingers have to be kept in position





+- 4 mm possible

neutral Position is shown -> beam operation

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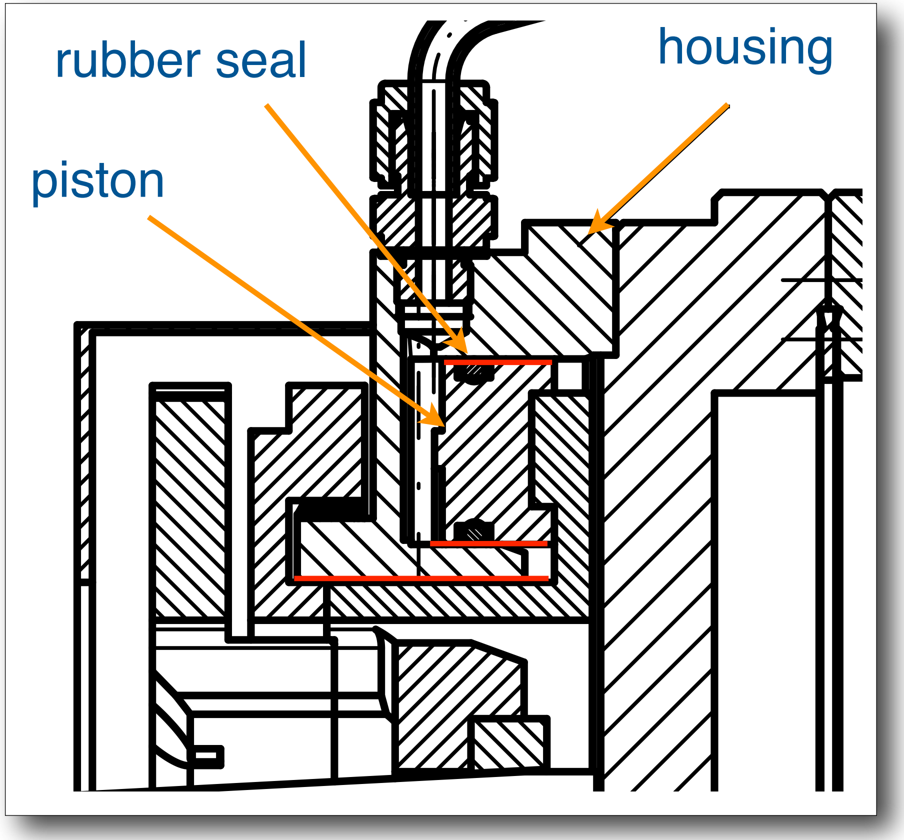
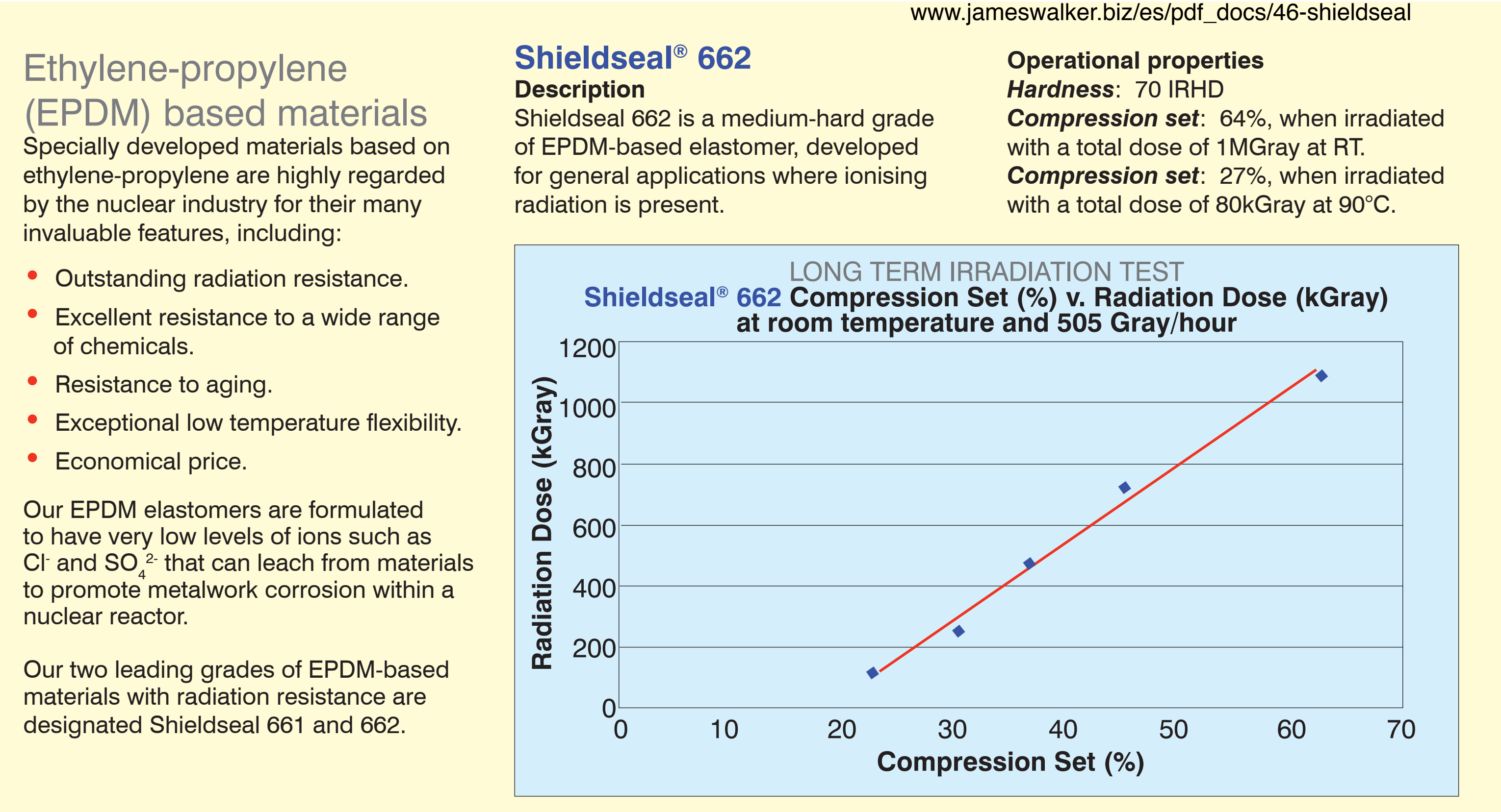
Other Reliability Issues

- Initial design included use of hydraulic oil
  - first version of mock-up used NBR (nitrile-based) as seal material due to its excellent resistance to hydraulic fluids
  - however, uncertain whether the rubber seal used in the hydraulic system would retain its mechanical properties under intense radiation
- Decided to move to 60 bar operation with N_2
  - allows the use of EPDM based material



Radiation Hard Elastomer Seals



www.jameswalker.biz/es/pdf_docs/46-shieldseal

Ethylene-propylene (EPDM) based materials

Specially developed materials based on ethylene-propylene are highly regarded by the nuclear industry for their many invaluable features, including:

- Outstanding radiation resistance.
- Excellent resistance to a wide range of chemicals.
- Resistance to aging.
- Exceptional low temperature flexibility.
- Economical price.

Our EPDM elastomers are formulated to have very low levels of ions such as Cl^- and SO_4^{2-} that can leach from materials to promote metalwork corrosion within a nuclear reactor.

Our two leading grades of EPDM-based materials with radiation resistance are designated Shieldseal 661 and 662.

Shieldseal® 662

Description

Shieldseal 662 is a medium-hard grade of EPDM-based elastomer, developed for general applications where ionising radiation is present.

Operational properties

Hardness: 70 IRHD

Compression set: 64%, when irradiated with a total dose of 1MGray at RT.

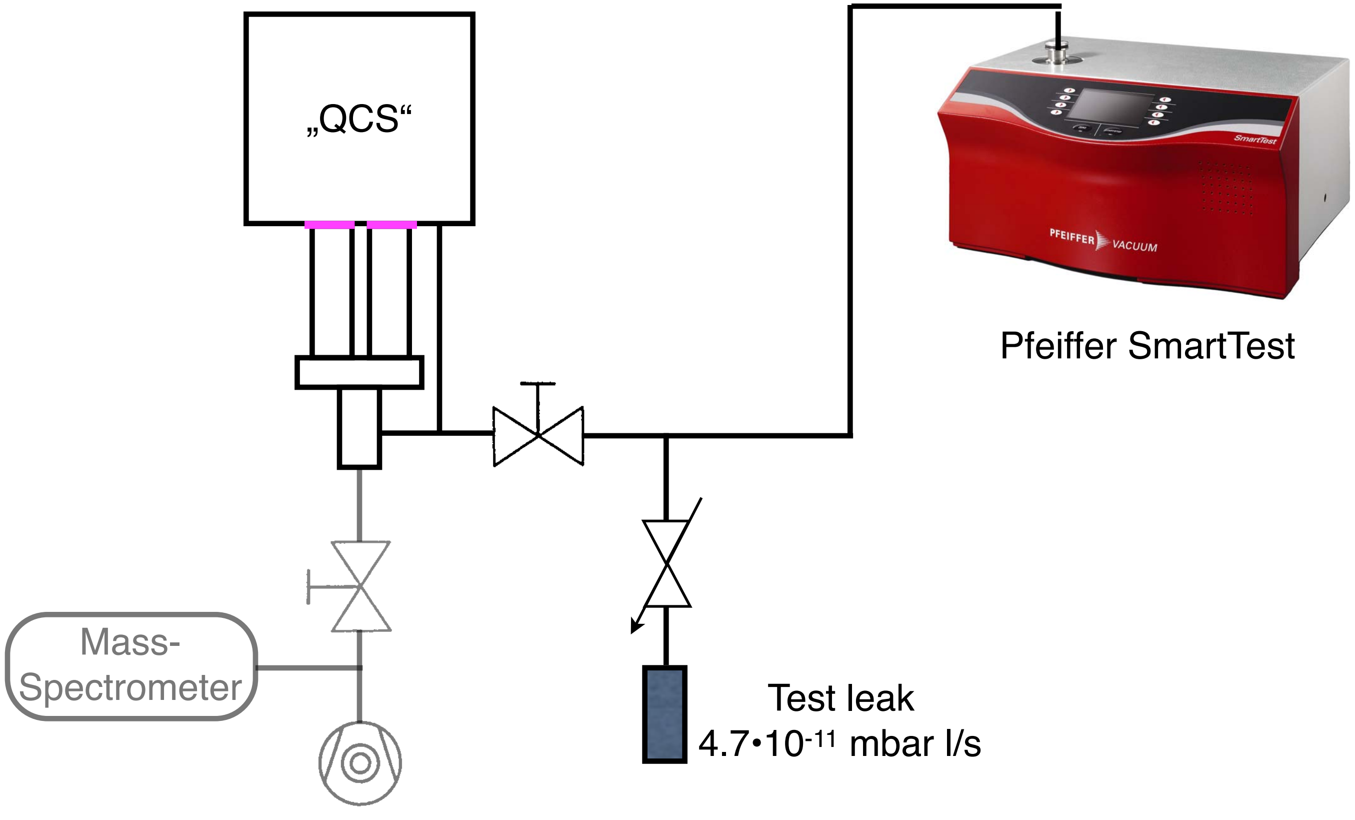
Compression set: 27%, when irradiated with a total dose of 80kGray at 90°C.

LONG TERM IRRADIATION TEST

Shieldseal® 662 Compression Set (%) v. Radiation Dose (kGray) at room temperature and 505 Gray/hour

- EPDM seals certified up to 1 MGray at room temperature
- Comparing mechanical properties (compression set) before and after irradiation at Synergy Health Radeberg 0.5 / 1 MGray @ 1.5 kGray/h

Proof of Vacuum Tightness



„QCS“

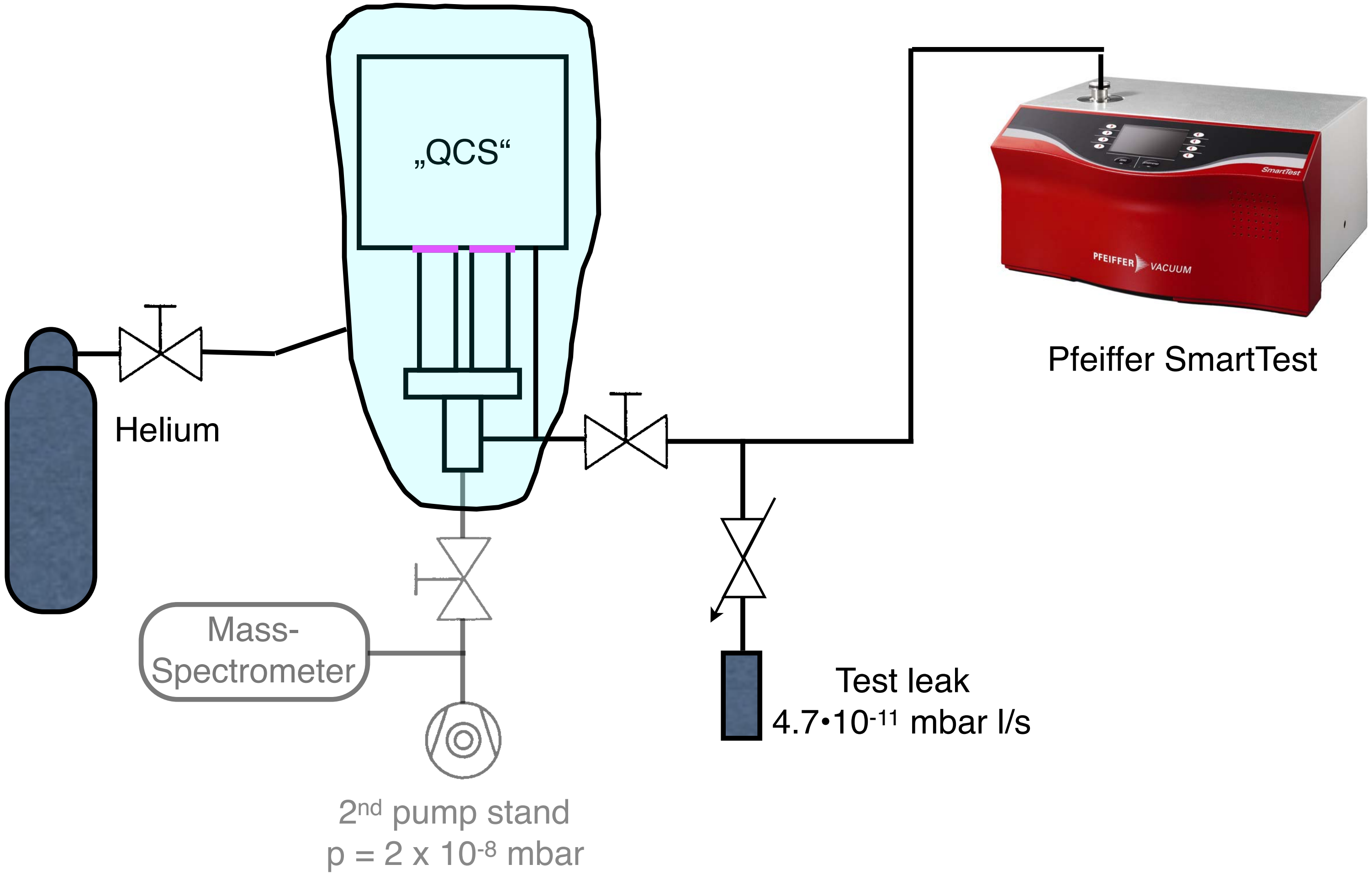
Pfeiffer SmartTest

Mass-Spectrometer

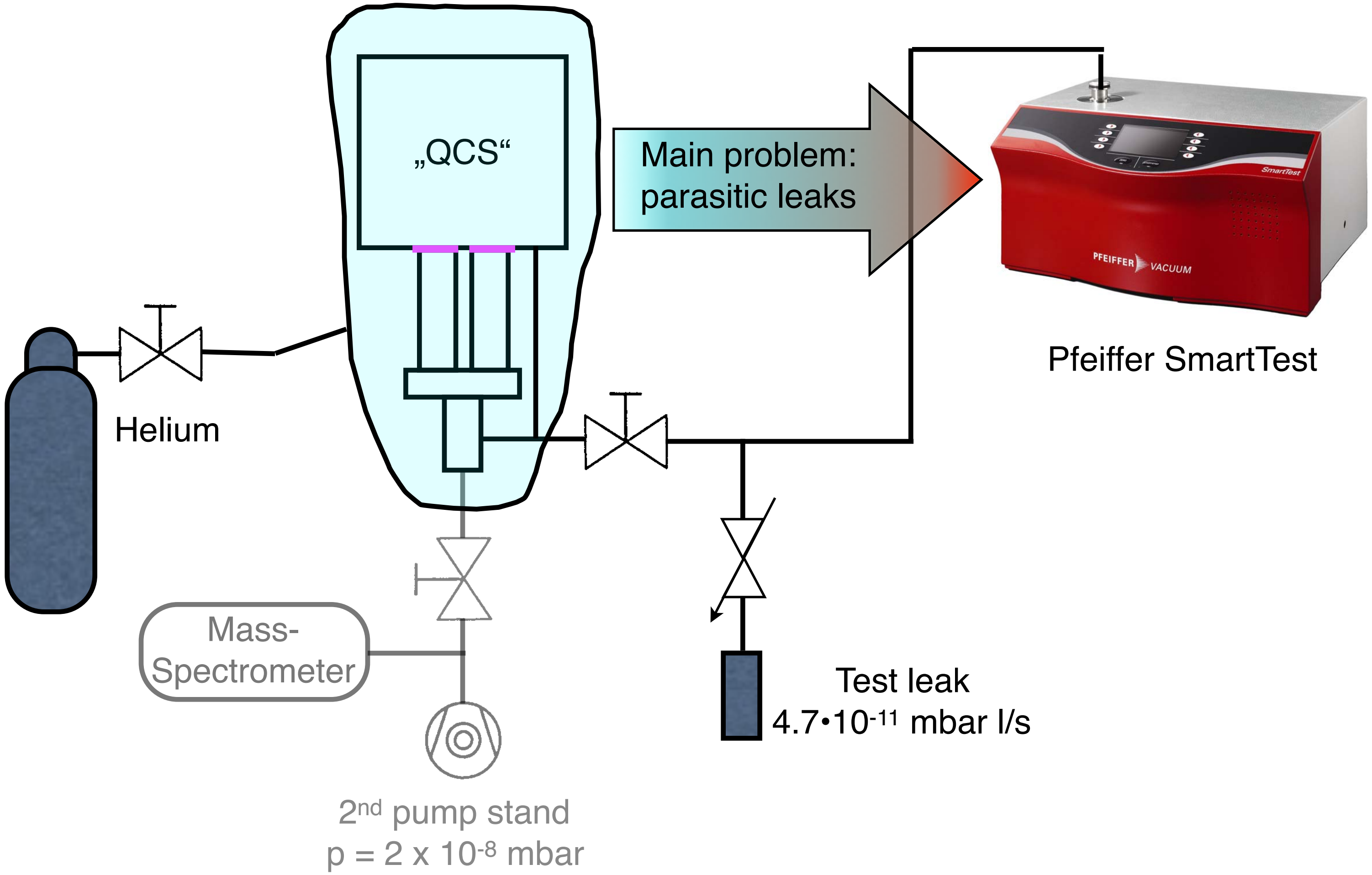
Test leak
4.7•10^{-11} mbar l/s

2^{nd} pump stand
p = 2 x 10^{-8} mbar

Proof of Vacuum Tightness



Proof of Vacuum Tightness



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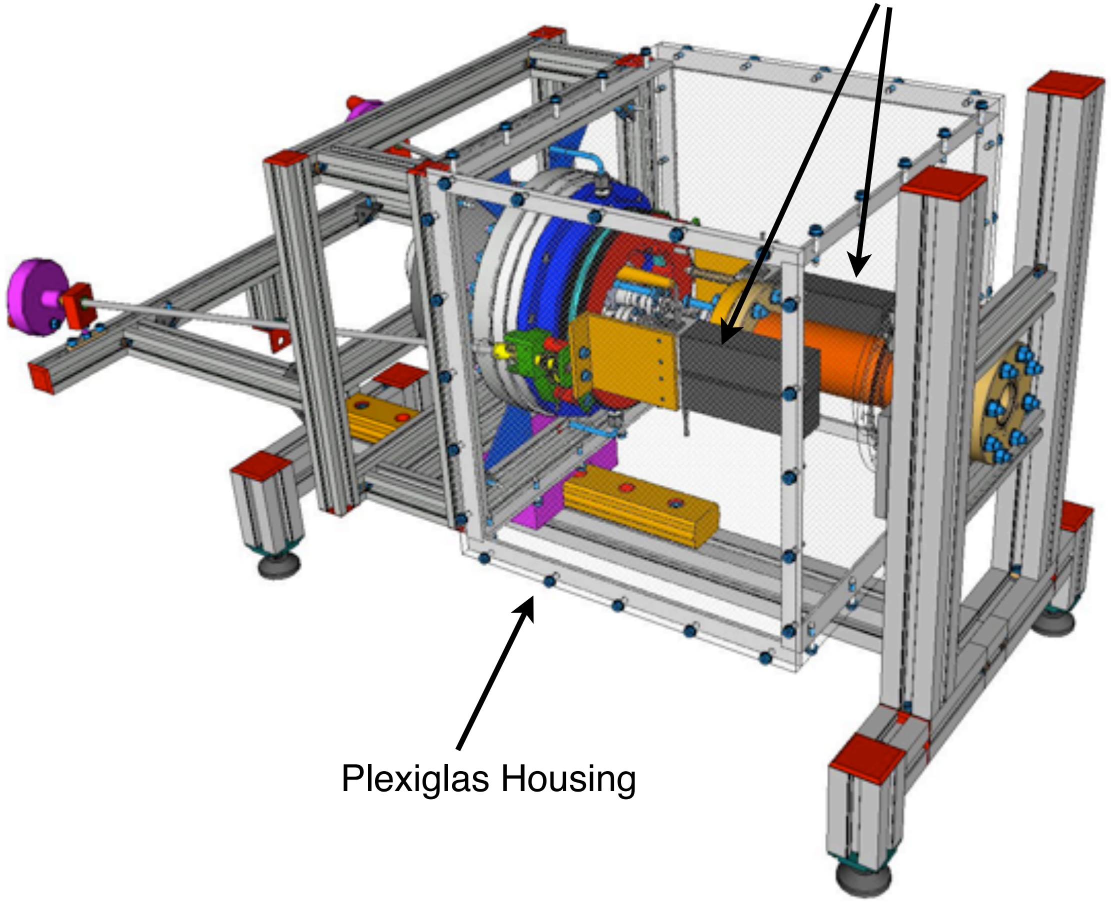
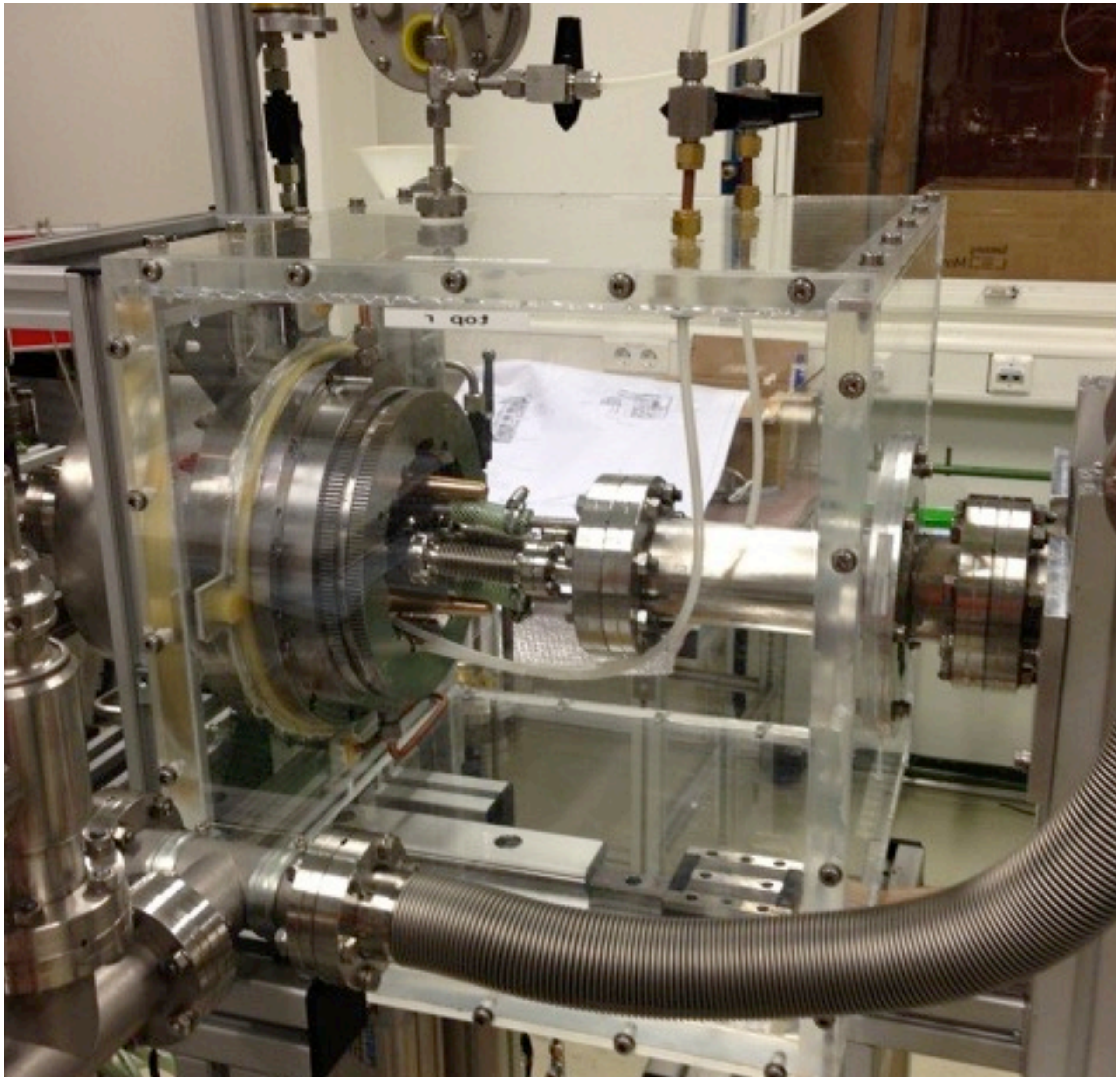
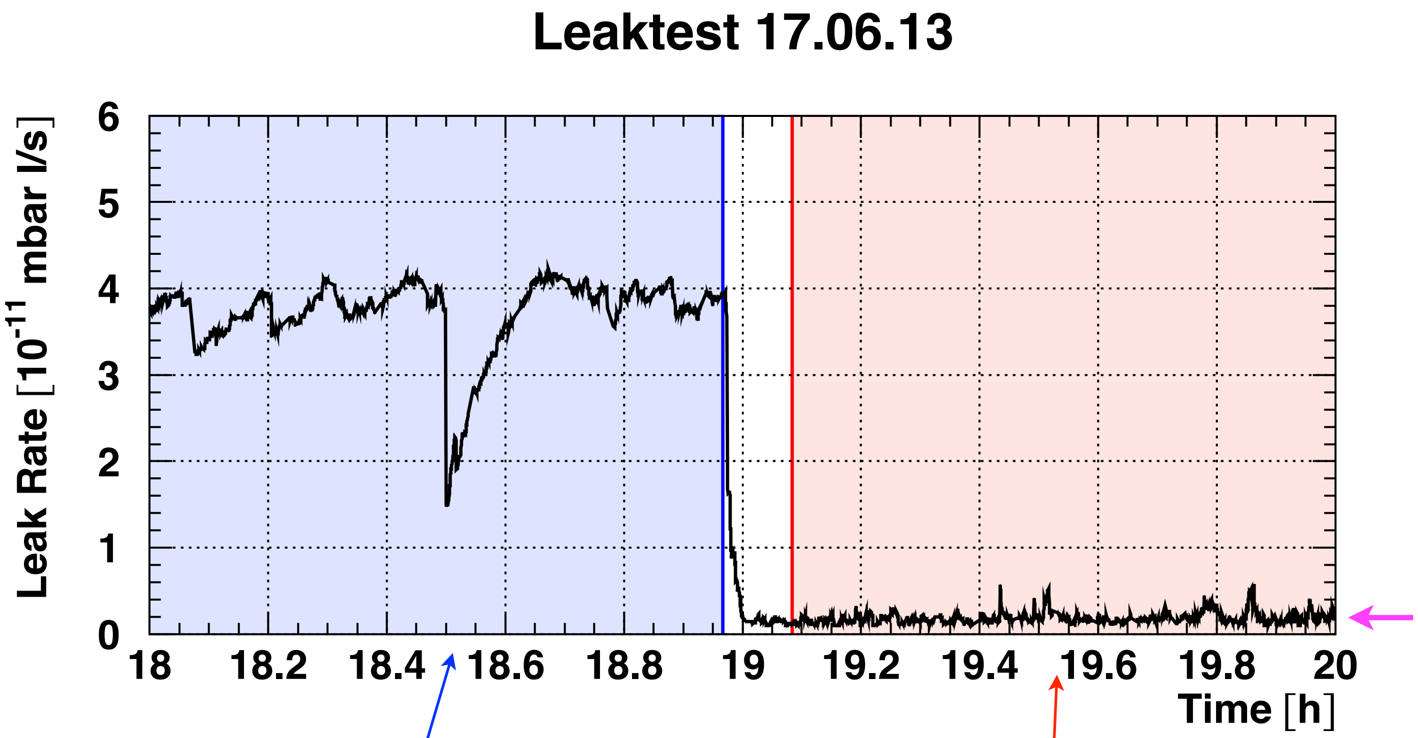
Proof of Vacuum Tightness





Result of Integral Helium Leak Test



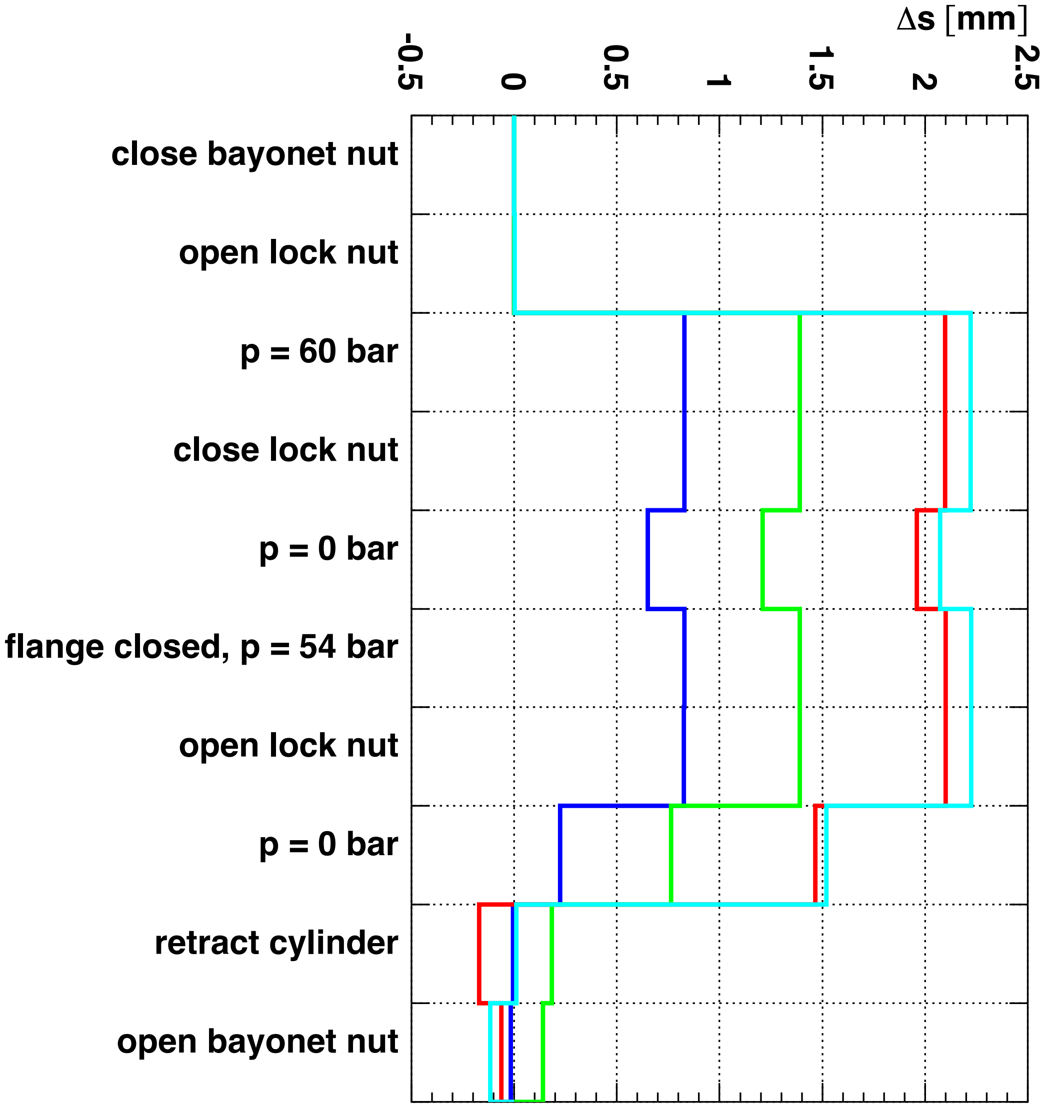
$2\ 10^{-12}$ mbar l/s

Test Leak @ 4.6 10^{-11} mbar l/s

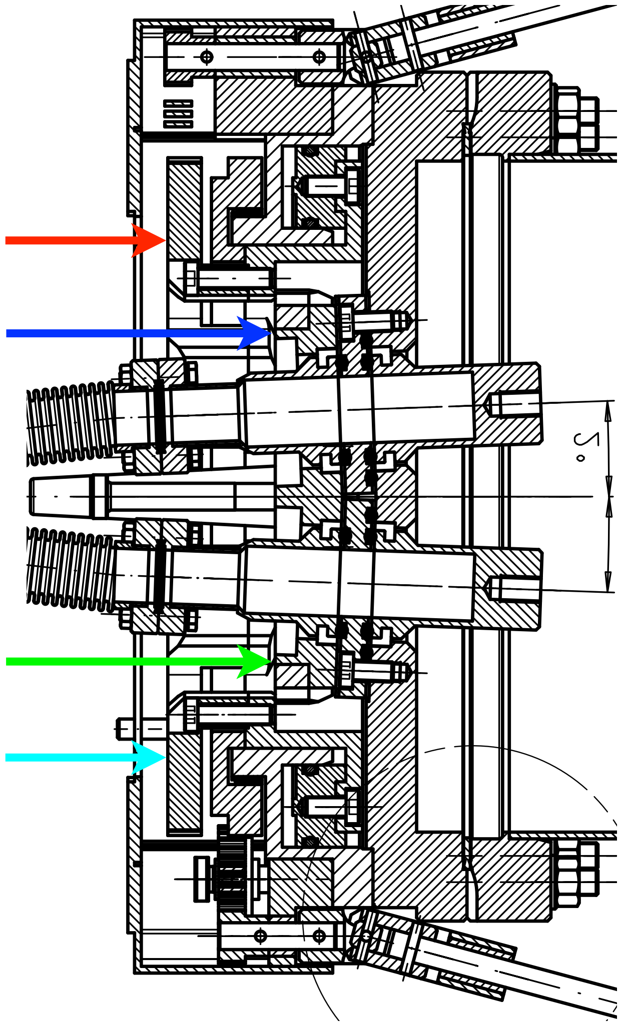
He @ ~10 mbar

- Result of „longterm test“
  - vacuum seal still Helium-tight after 6 weeks: leak rate below 3×10^{-12} mbar l/s
  - continuation problematic since we had to return leak tester to vacuum group

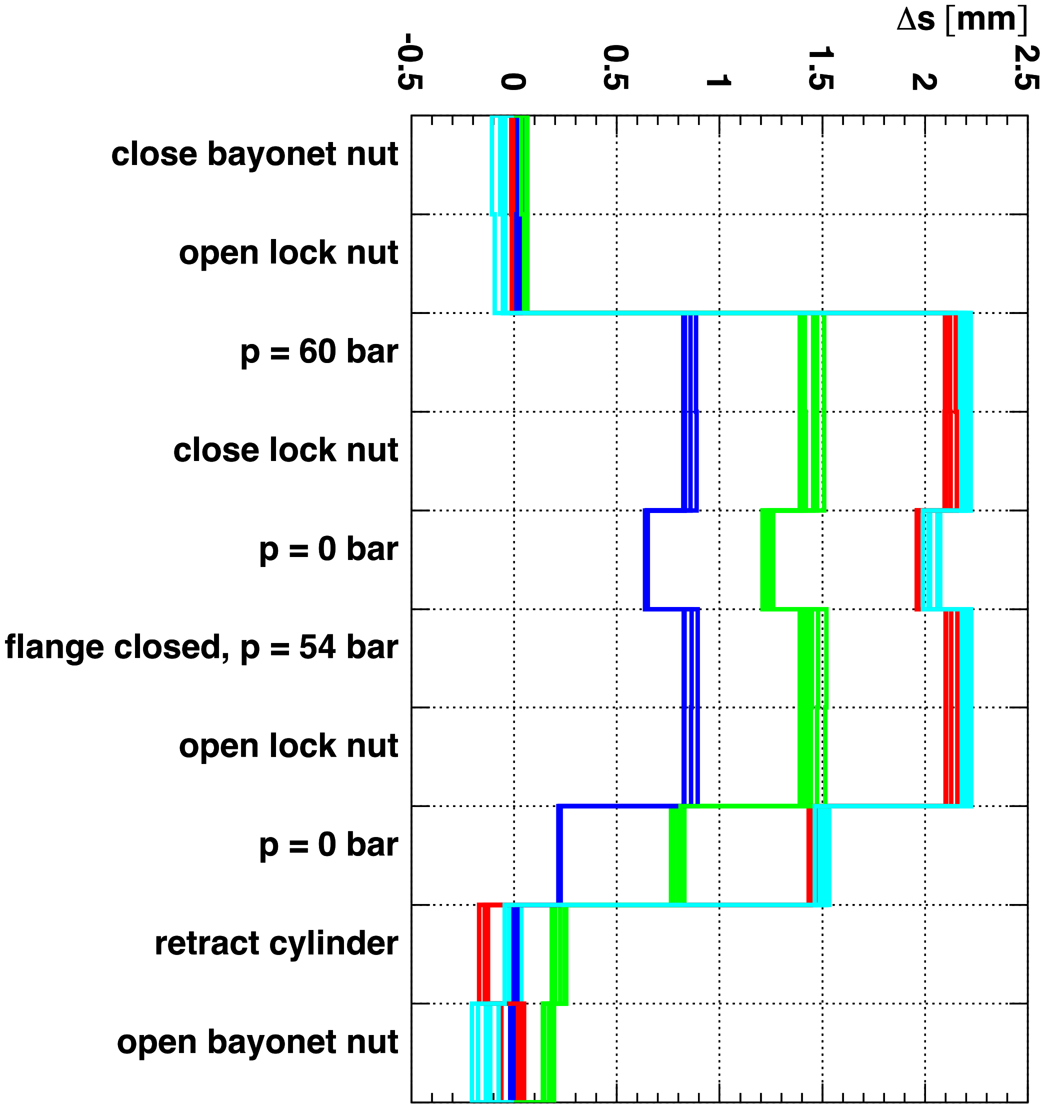
Verification of mechanical Repeatability and Reproducibility



Position Encoder

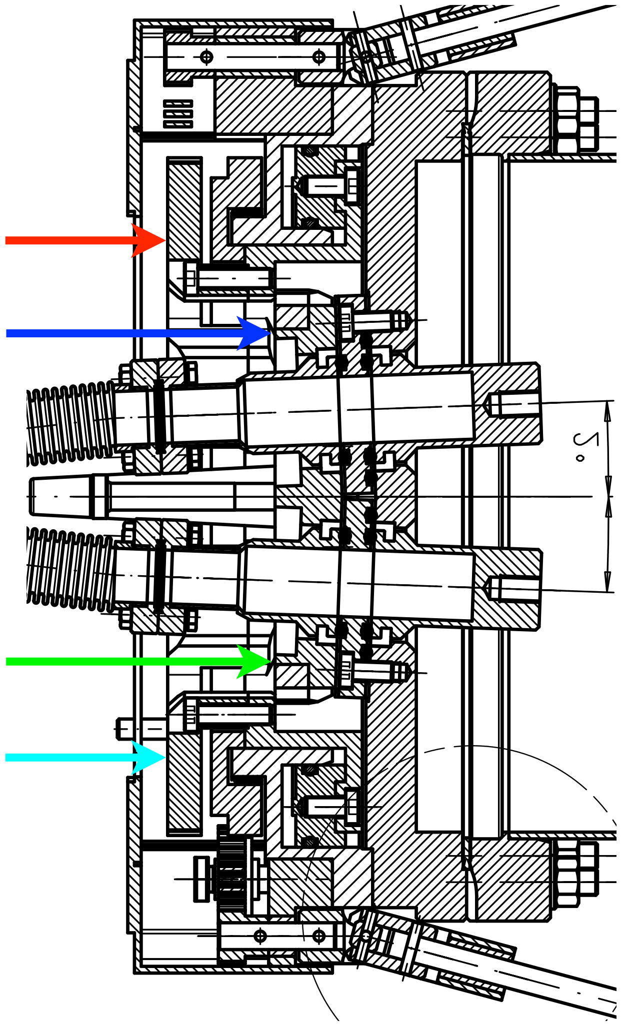


Verification of mechanical Repeatability and Reproducibility

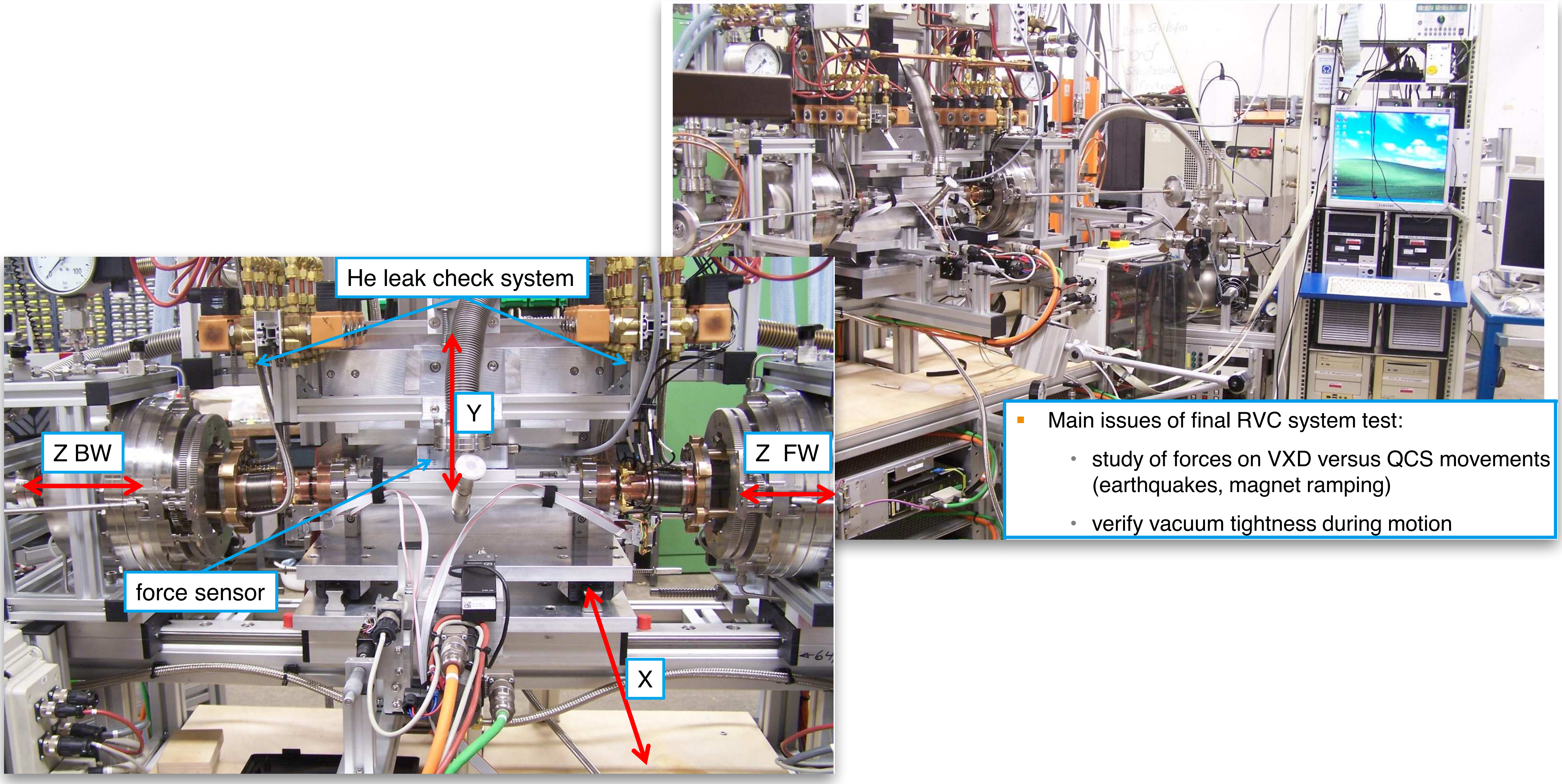


Opening and closing repeated 10 times

Position Encoder



Other mechanical Tests



- Main issues of final RVC system test:
  - study of forces on VXD versus QCS movements (earthquakes, magnet ramping)
  - verify vacuum tightness during motion

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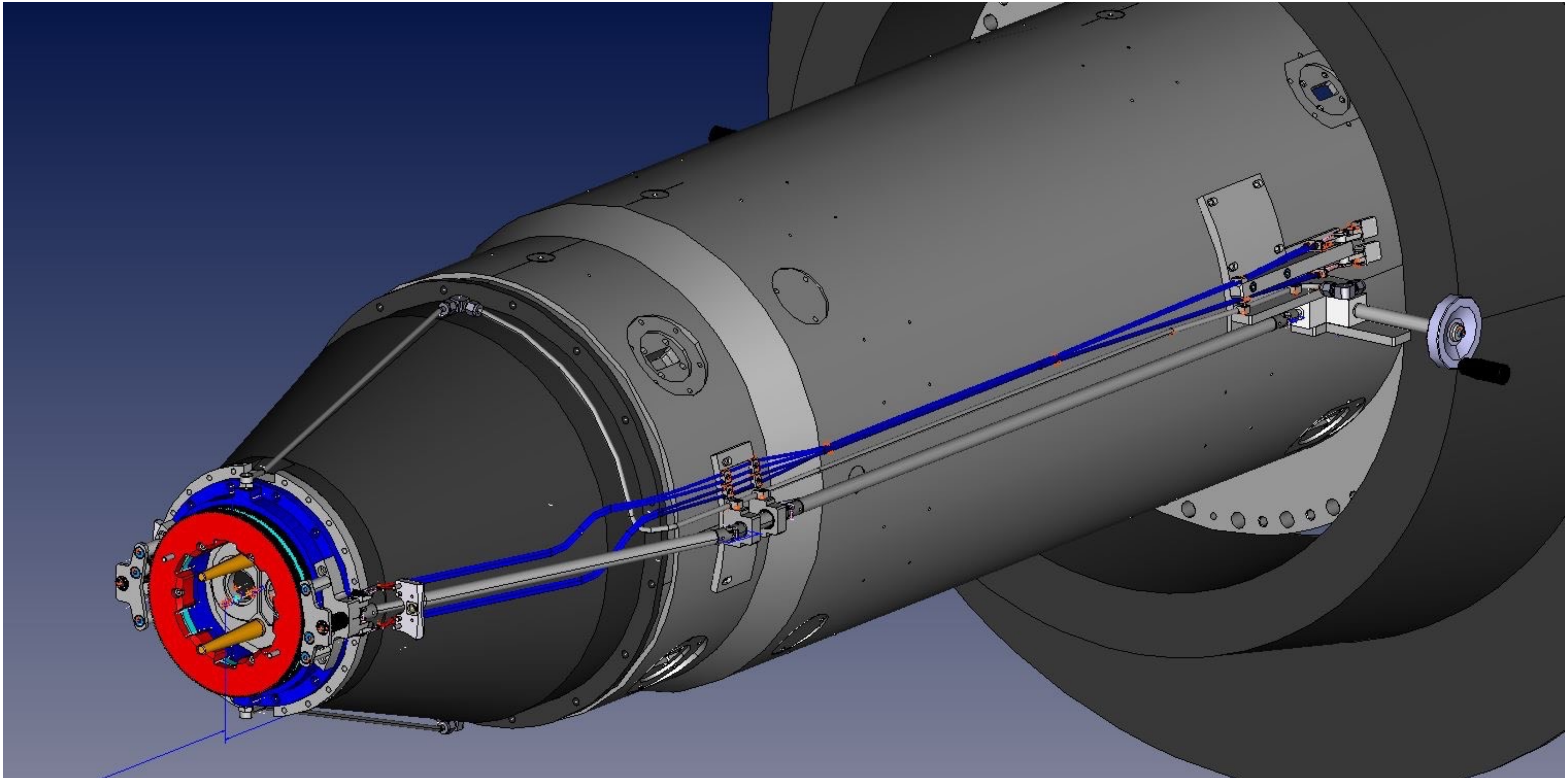
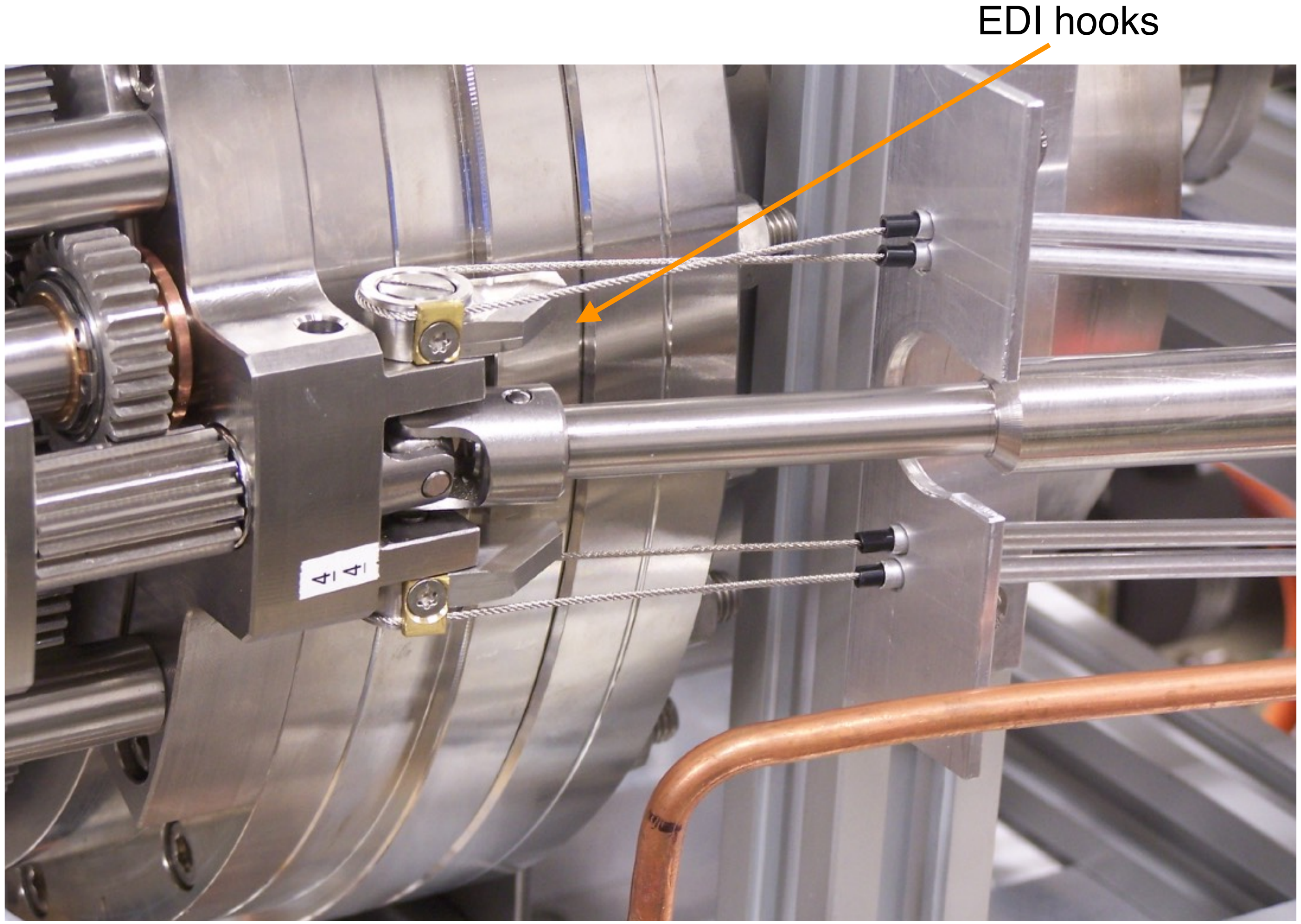
Verification of the Emergency De-Installation Concept



Verification of the Emergency De-Installation Concept



- In the event of RVC failure on QCSR, a mechanism is required to extract QCSR together with VXD in forward direction
- Implement a simple Bowden mechanism that can be used to pull out the VXD
  - if RVC fails simultaneously on QCSL, vacuum connection can still be opened due to reduced space requirements

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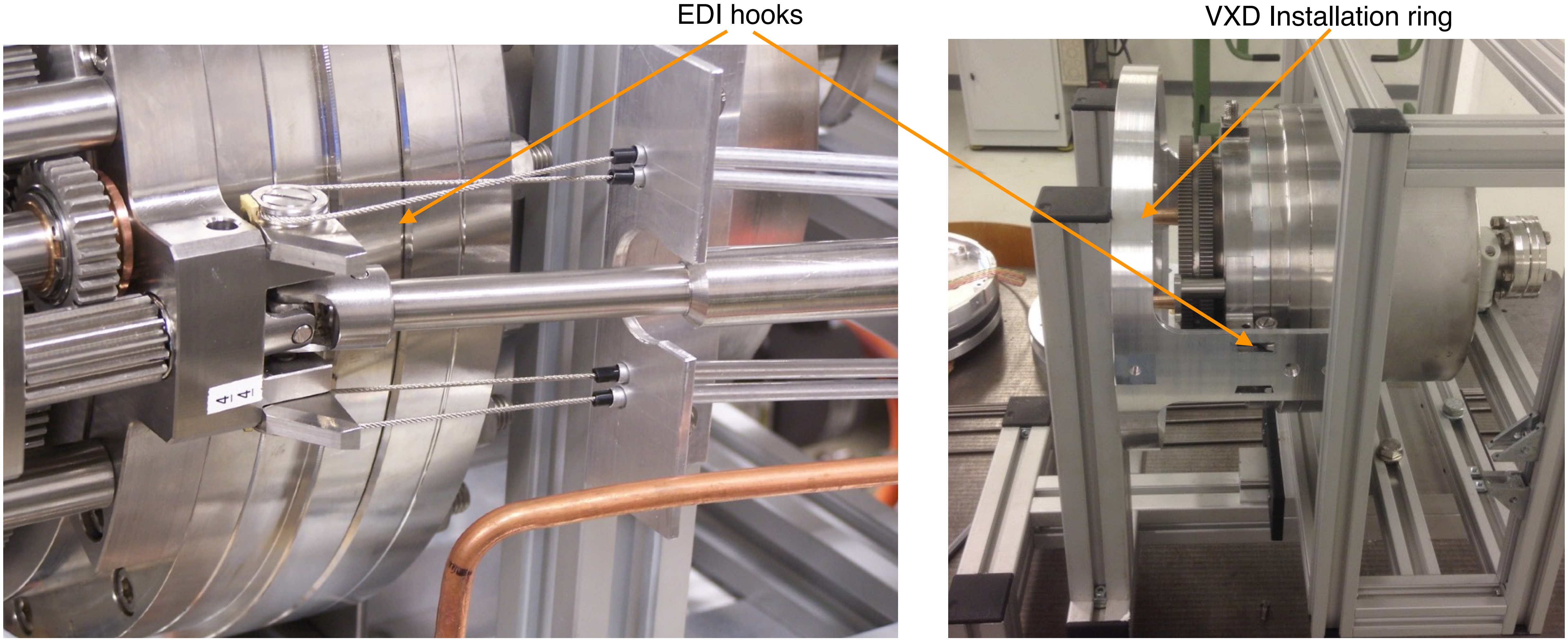
Verification of the Emergency De-Installation Concept



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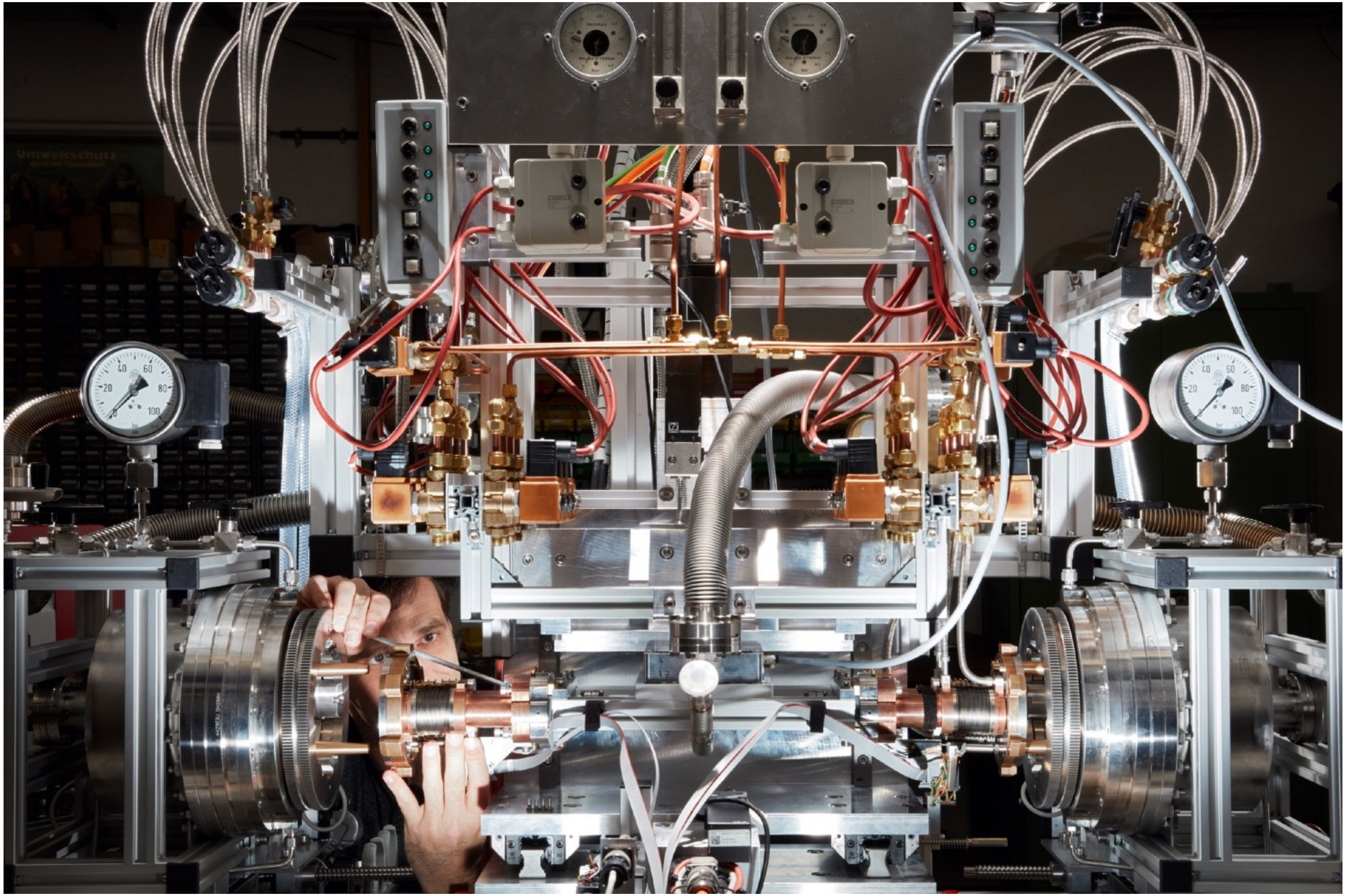
RVC Test Setup in full Glory



Summary

- For the successful installation and operation of the Belle II Vertex Detector in the challenging environment of SuperKEKB, the design, construction and optimisation of various mock-ups proved to be essential

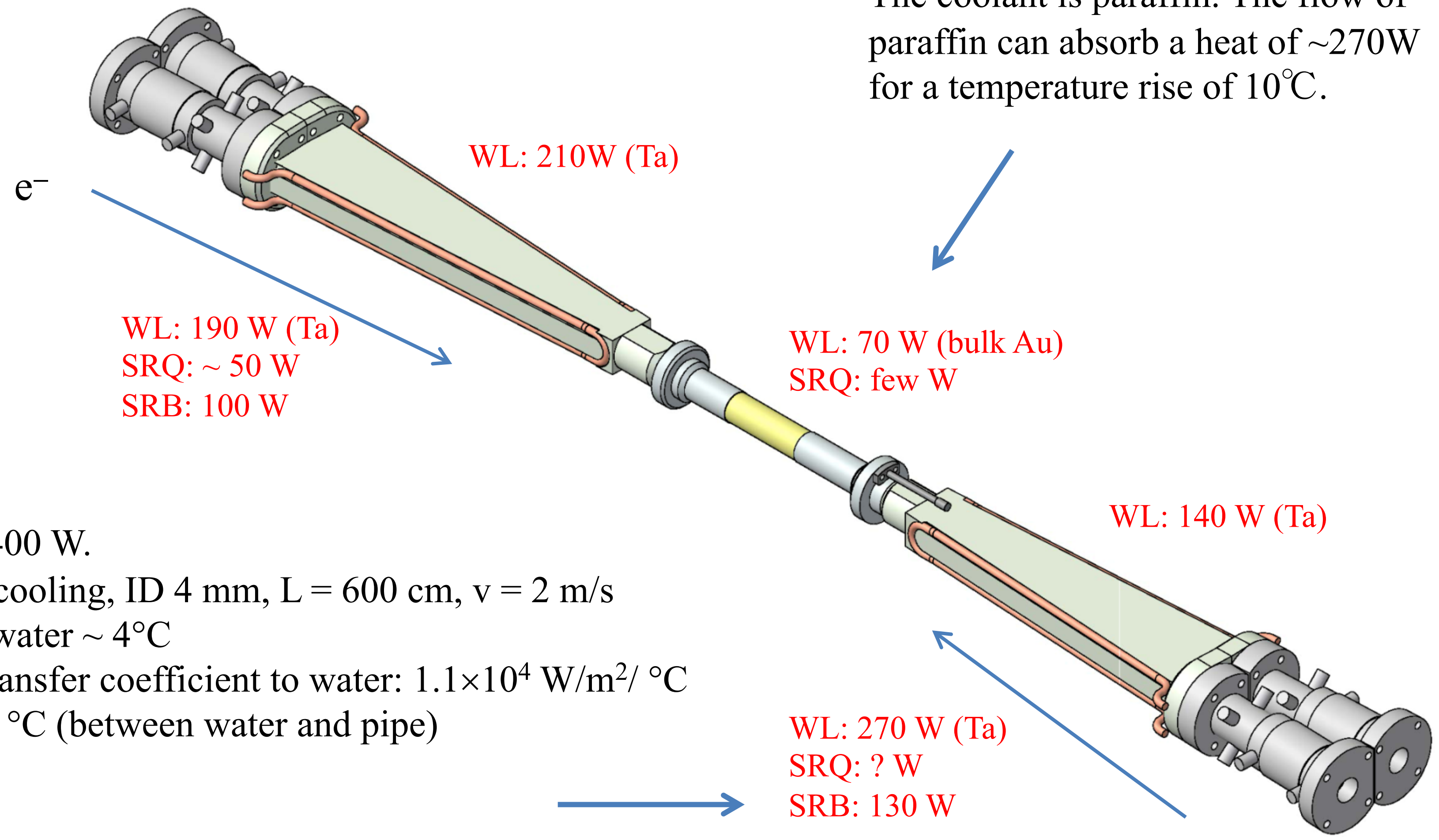
- A complete and realistic VXD thermal mock-up was used to validate the planned cooling concept
  - manufacture and installation of a number of critical components could be practised for the first time under realistic conditions
  - operating parameters could be established prior to installation of the real detector
  - operation of the mock-up helped to identify a design flaw that could be corrected

- The Remote Vacuum Connection mock-up was absolutely crucial to optimise the design and to prove that the concept was applicable to SuperKEKB

Backup

Expected Heat Load on IP Chamber

The coolant is paraffin. The flow of paraffin can absorb a heat of ~270W for a temperature rise of 10℃.



WL: 210W (Ta)

WL: 190 W (Ta)
SRQ: ~ 50 W
SRB: 100 W

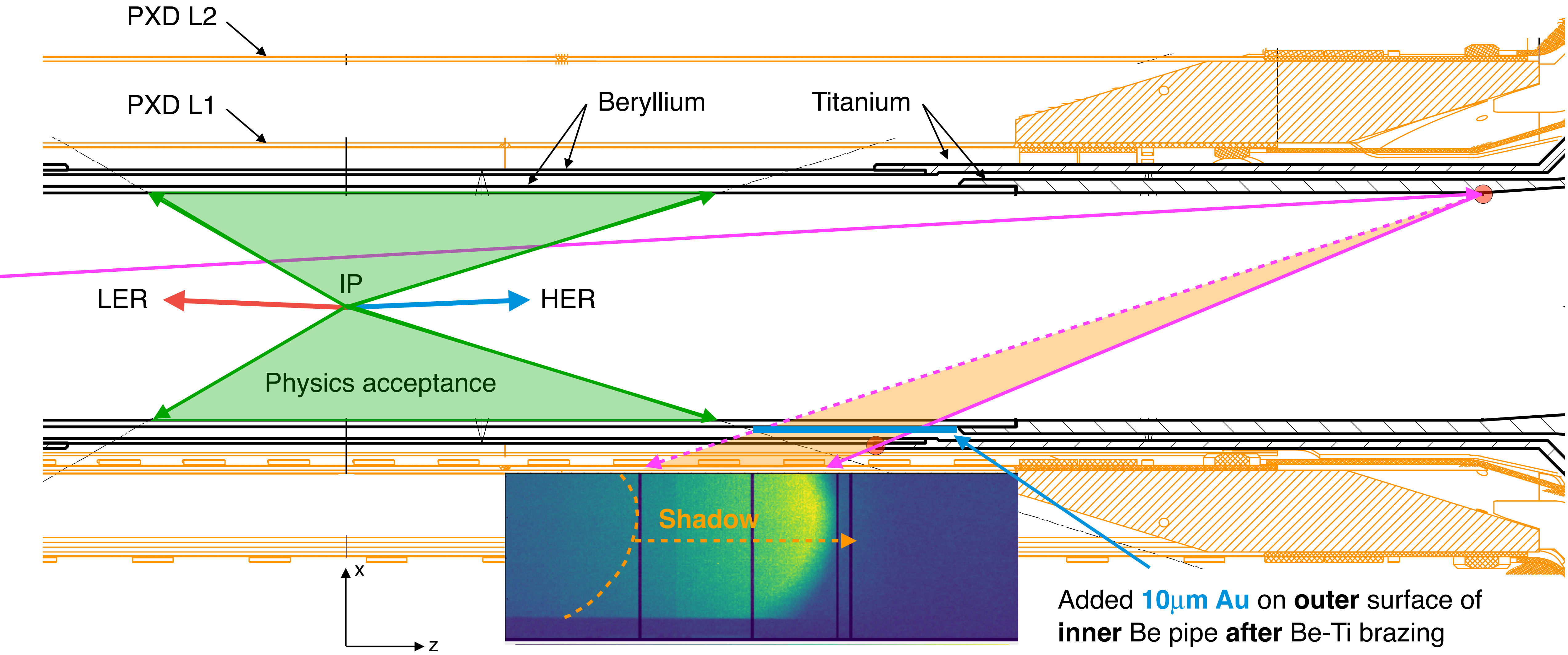
WL: 70 W (bulk Au)
SRQ: few W

WL: 140 W (Ta)

WL: 270 W (Ta)
SRQ: ? W
SRB: 130 W

Heat: 400 W.
Water cooling, ID 4 mm, L = 600 cm, v = 2 m/s
ΔT of water ~ 4°C
Heat transfer coefficient to water: 1.1×10^4 W/m^2/ °C
ΔT ~ 5 °C (between water and pipe)

Modification of Beam Pipe



Added **10µm Au** on **outer** surface of **inner** Be pipe **after** Be-Ti brazing

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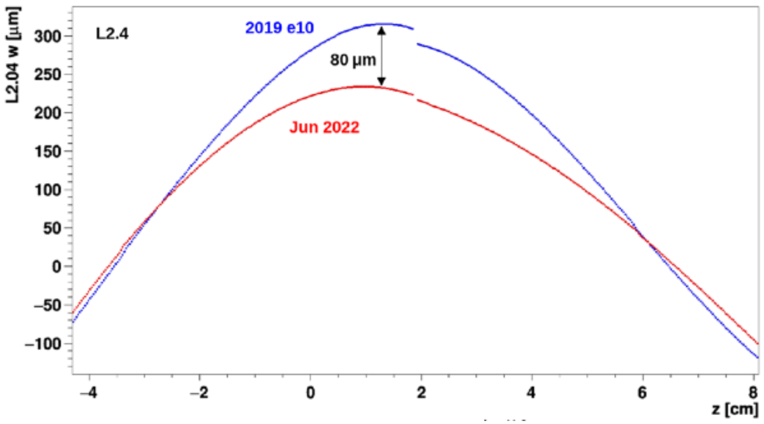
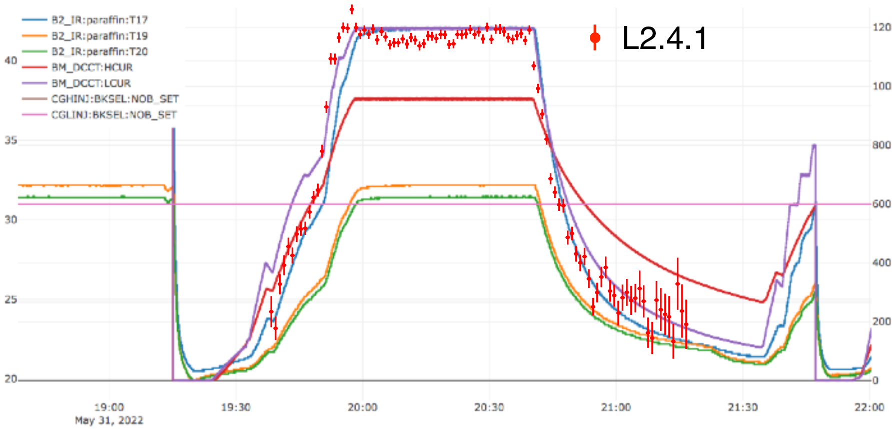
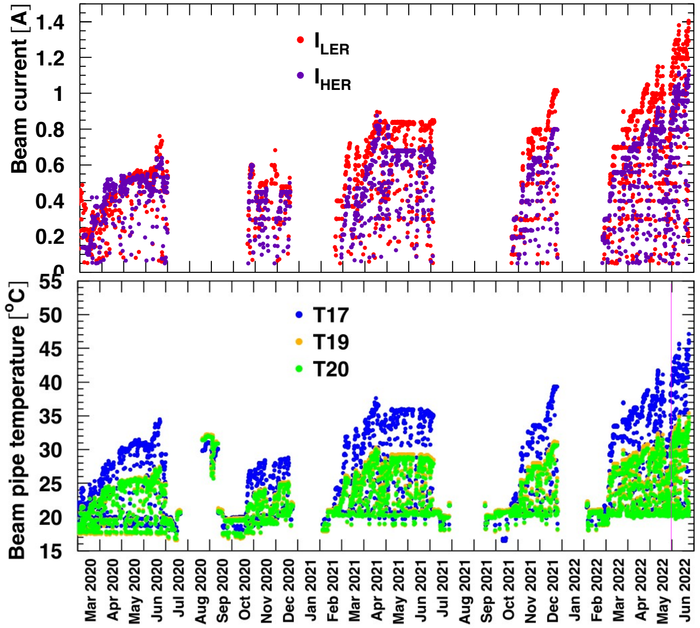
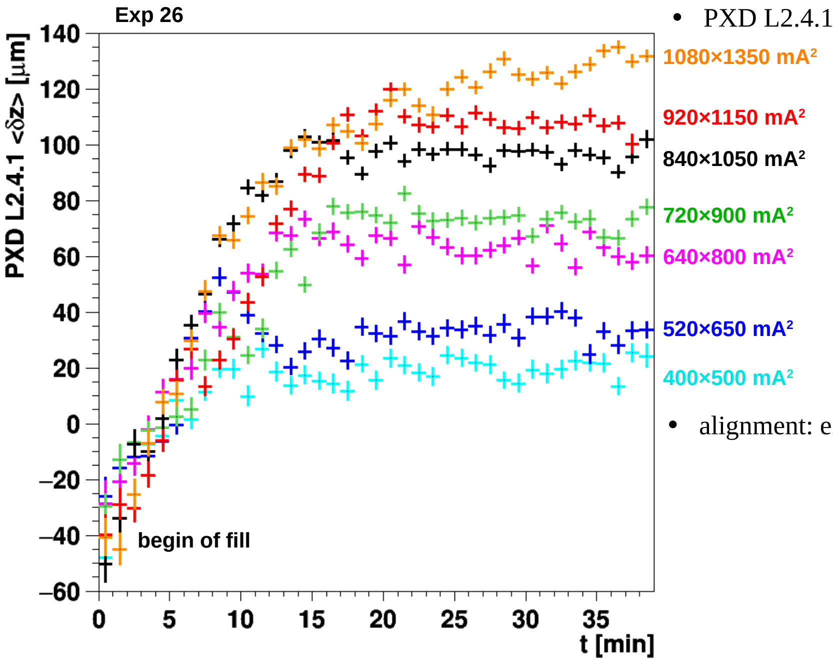
Ladder Bowing in PXD1 due to Beampipe Heating



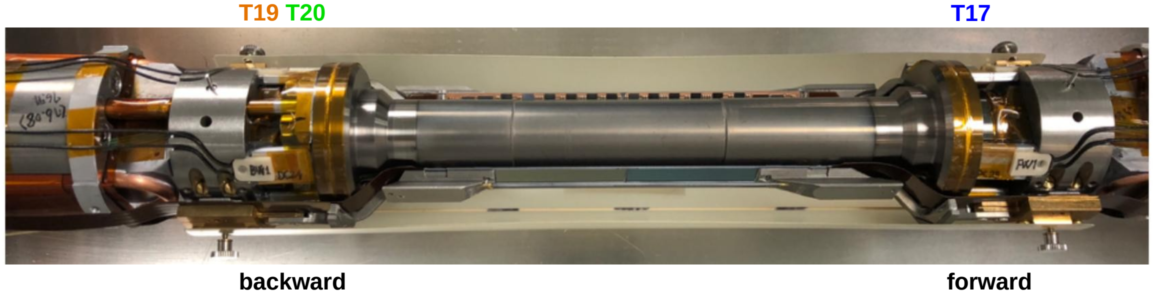






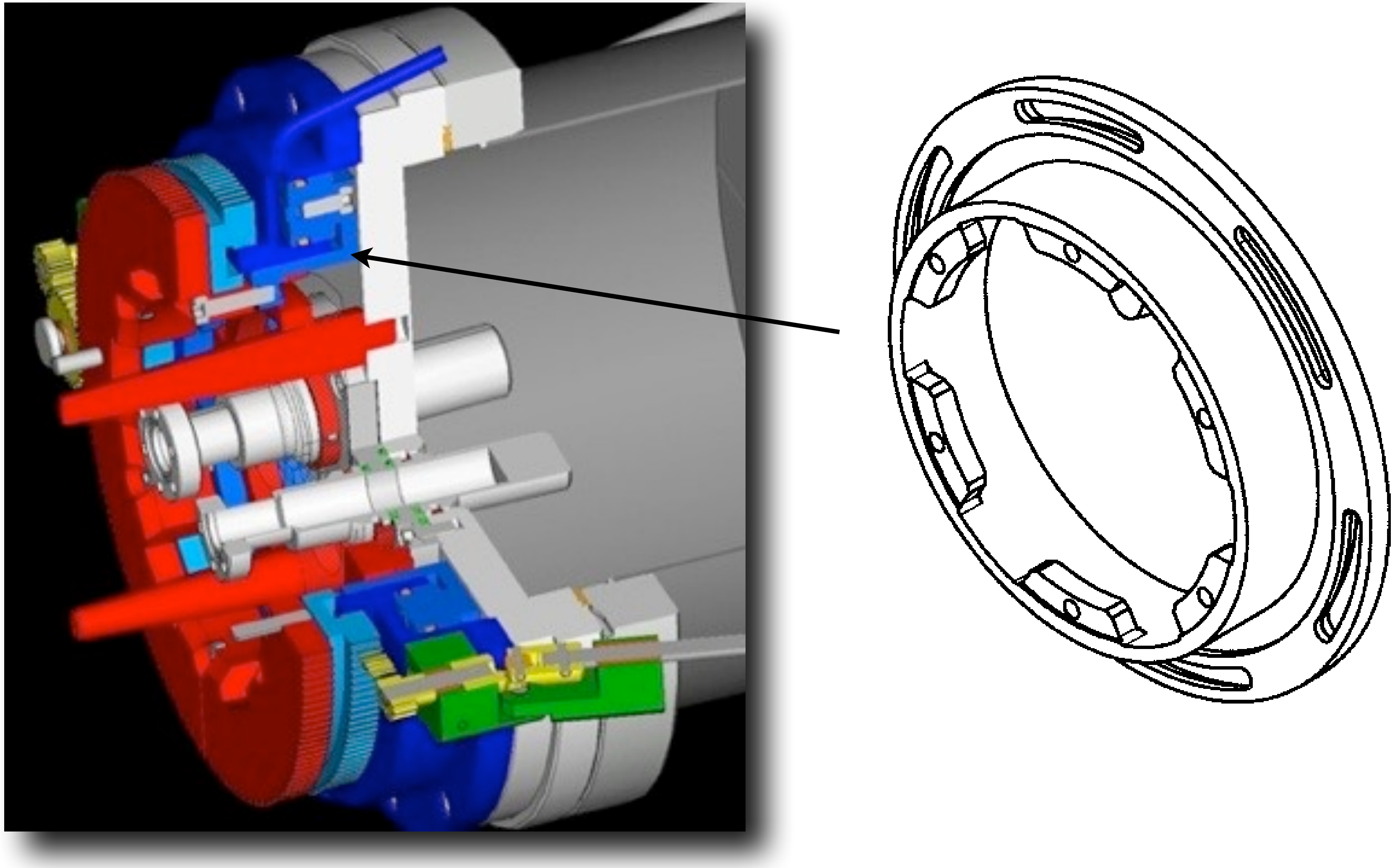
- PXD L2.4.1 vs SVD tracks: -δz
- alignment: e26 at 160×200 mA²

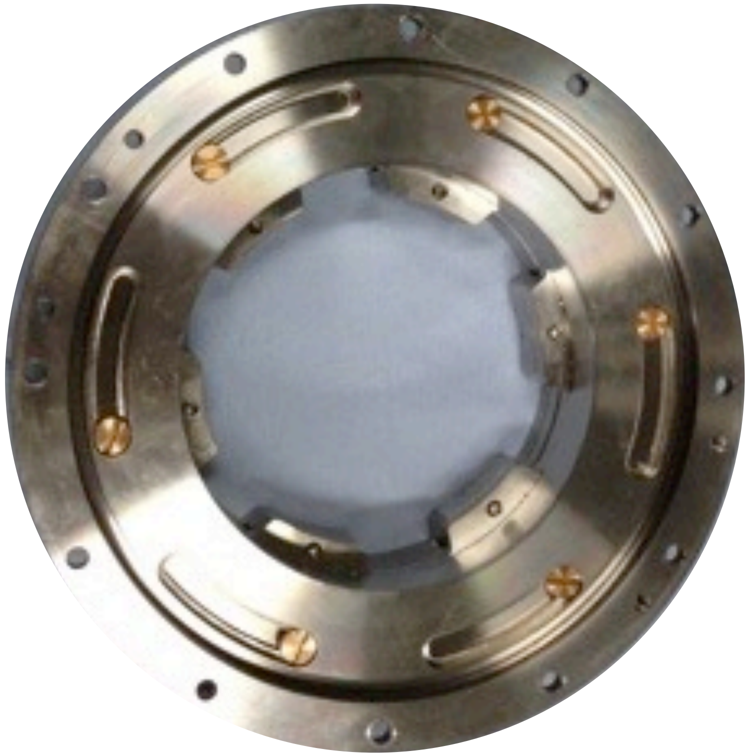
at run start: ≈constant **lumi state: depends on beams**



Improved beampipe cooling in preparation → see presentation bei Shuji Tanaka

Modified Bayonet Structure





- Modification allows independent rotation of bayonet part and piston
  ⇒ avoid friction between rubber seal and cylinder housing

Background Extrapolation before and after LS2

Setup	Before LS2	Target	Design
β^*_y(LER/HER) [mm]	0.6/0.6	0.27/0.3	0.27/0.3
β^*_x(LER/HER) [mm]	60/60	32/25	32/25
$\mathcal{L}$ [$\times 10^{35}$ cm^{-2}s^{-1}]	2.8	6.0	8.0
I(LER/HER) [A]	2.52/1.82	2.80/2.00	3.6/2.6
$\bar{P}_{\text{eff.}}$(LER/HER) [nPa]	48/17	52/18	133/133
n_b [bunches]	1576	1761	2500
ε_x(LER/HER) [nm]	4.6/4.5	3.2/4.6	3.2/4.6
$\varepsilon_y/\varepsilon_x$(LER/HER) [%]	1/1	0.27/0.28	0.27/0.28
σ_z(LER/HER) [mm]	8.27/7.60	8.25/7.58	6.0/6.0
CW	ON	OFF	OFF

- By continuing to improve our MC simulation, we have achieved good agreement between measured and simulated beam-induced backgrounds
  - This allows us to predict background levels reasonably well up to LS2
- However, no optics yet available for post-LS2 machine setup
  - Different scaling factors of scenarios account for associated uncertainties

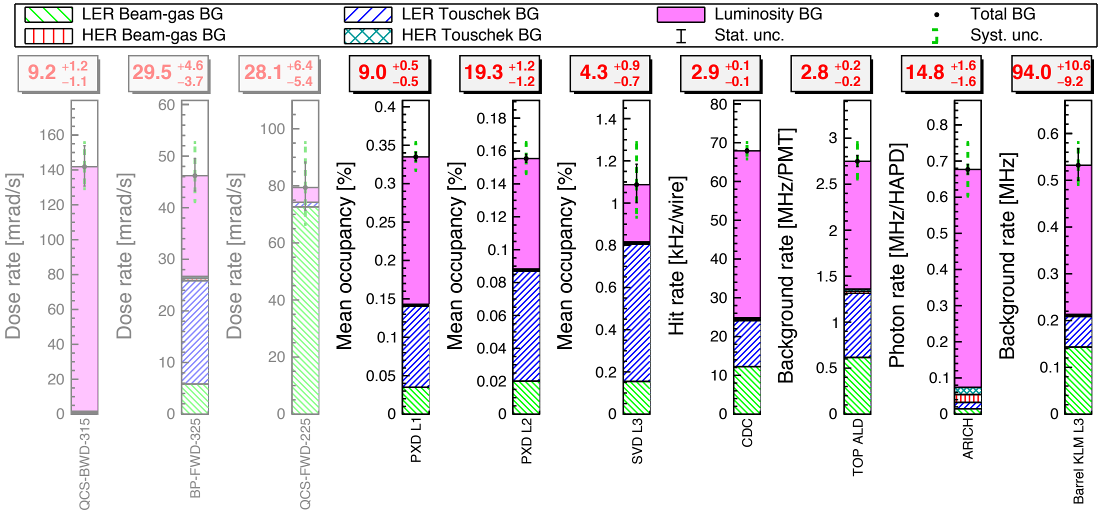


Figure 3.4: Estimated Belle II background composition for predicted beam parameters Before LS2. Each column is a stacked histogram of BG rates from dedicated MC samples scaled with average Data/MC ratios listed in Table 3.3. The red numbers in rectangles are detector safety factors, showing that Belle II should be able to operate safely until a luminosity of 2.8×10^{35} cm^{-2} s^{-1} with some important caveats, discussed in the text.

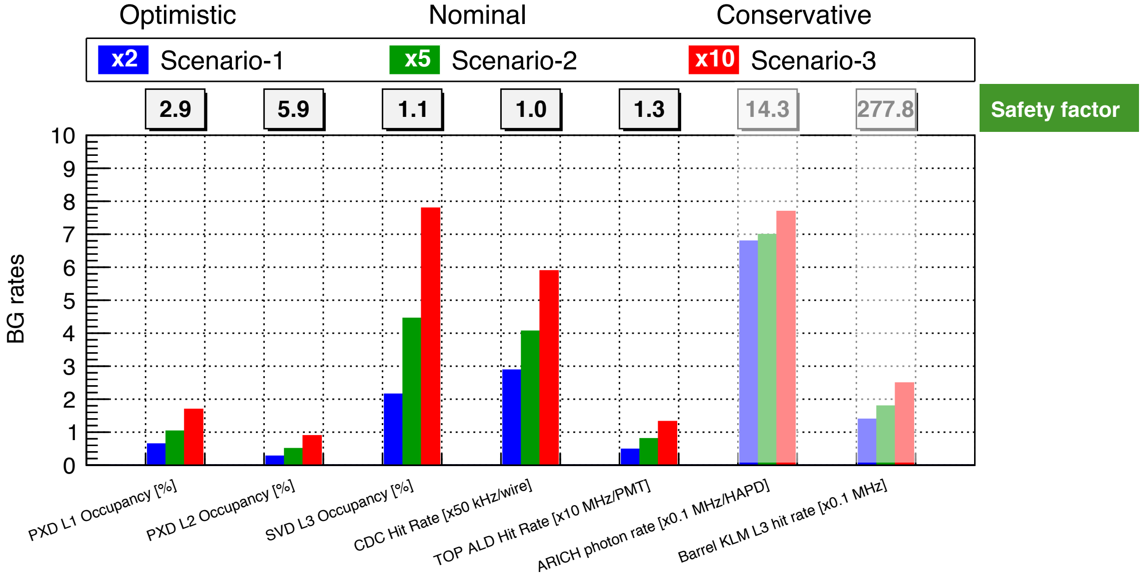


Figure 3.5: Estimated beam background rates in Belle II for After LS2 operation at luminosity of 6.0×10^{35} cm^{-2} s^{-1}. The numbers in rectangles are detector safety factors for Scenario-2.