SPS Beam Dump Facility target prototype tests results

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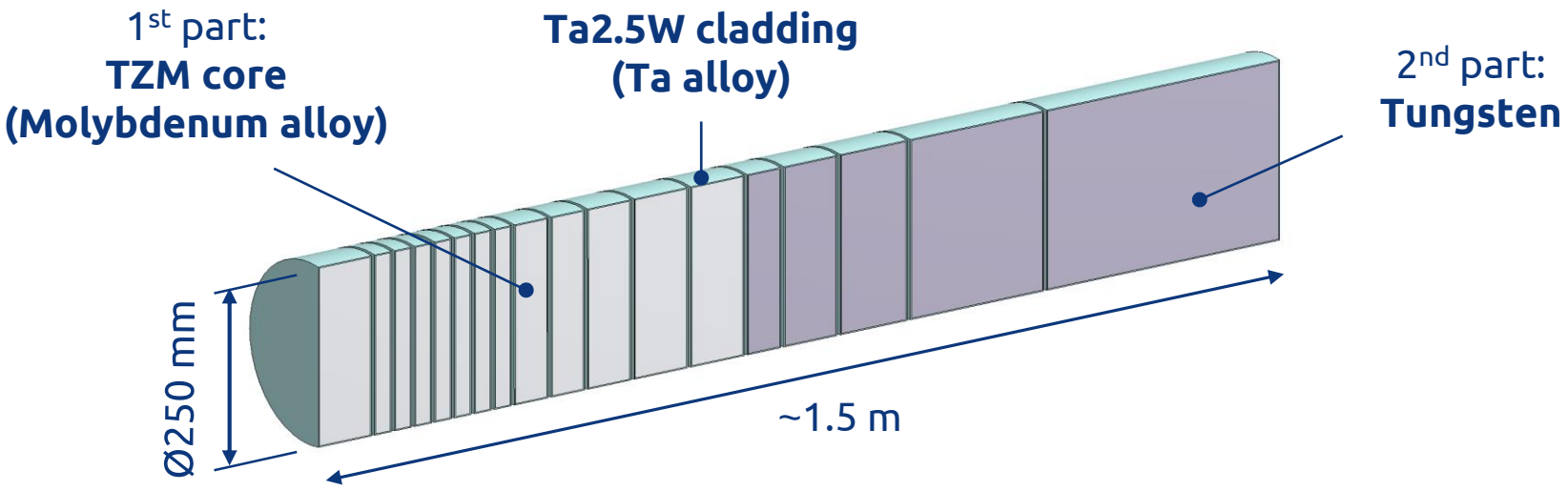
on behalf of the BDF Target & Target Complex WG

CERN | EN ENGINEERING DEPARTMENT

MSWG Meeting 2019 #4

Introduction – BDF target

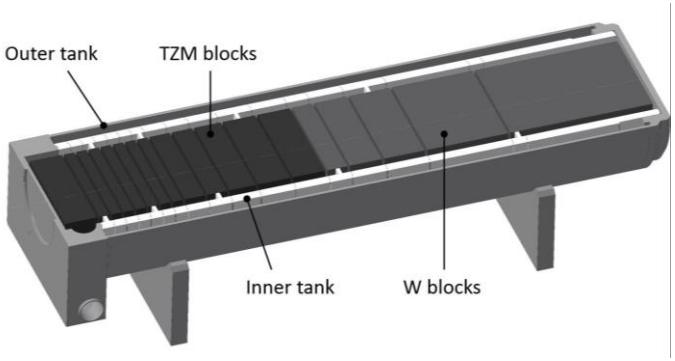
- Requirement: high-Z materials + short interaction length



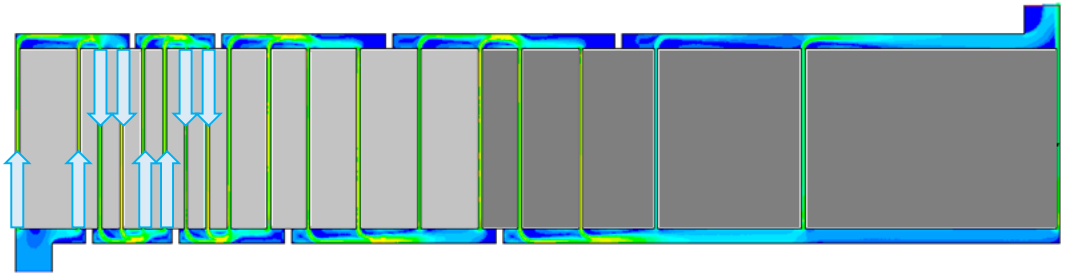
- **320 kW on target** → Optimized segmentation, water cooling
- Tantalum alloy cladding to avoid corrosion/erosion effects

Introduction – BDF target challenges

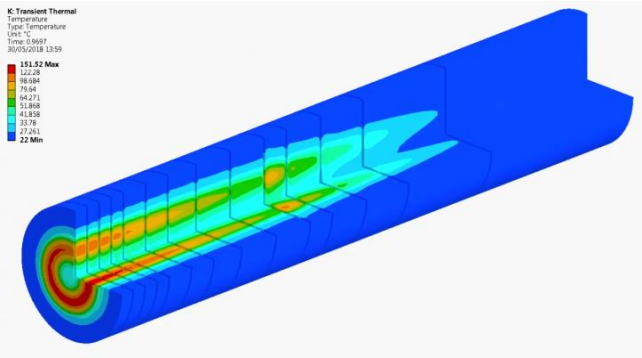
Target mechanical design



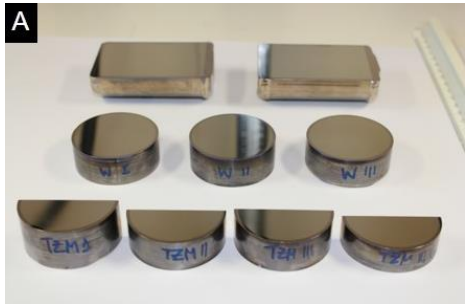
Cooling system



Target simulations



Material R&D

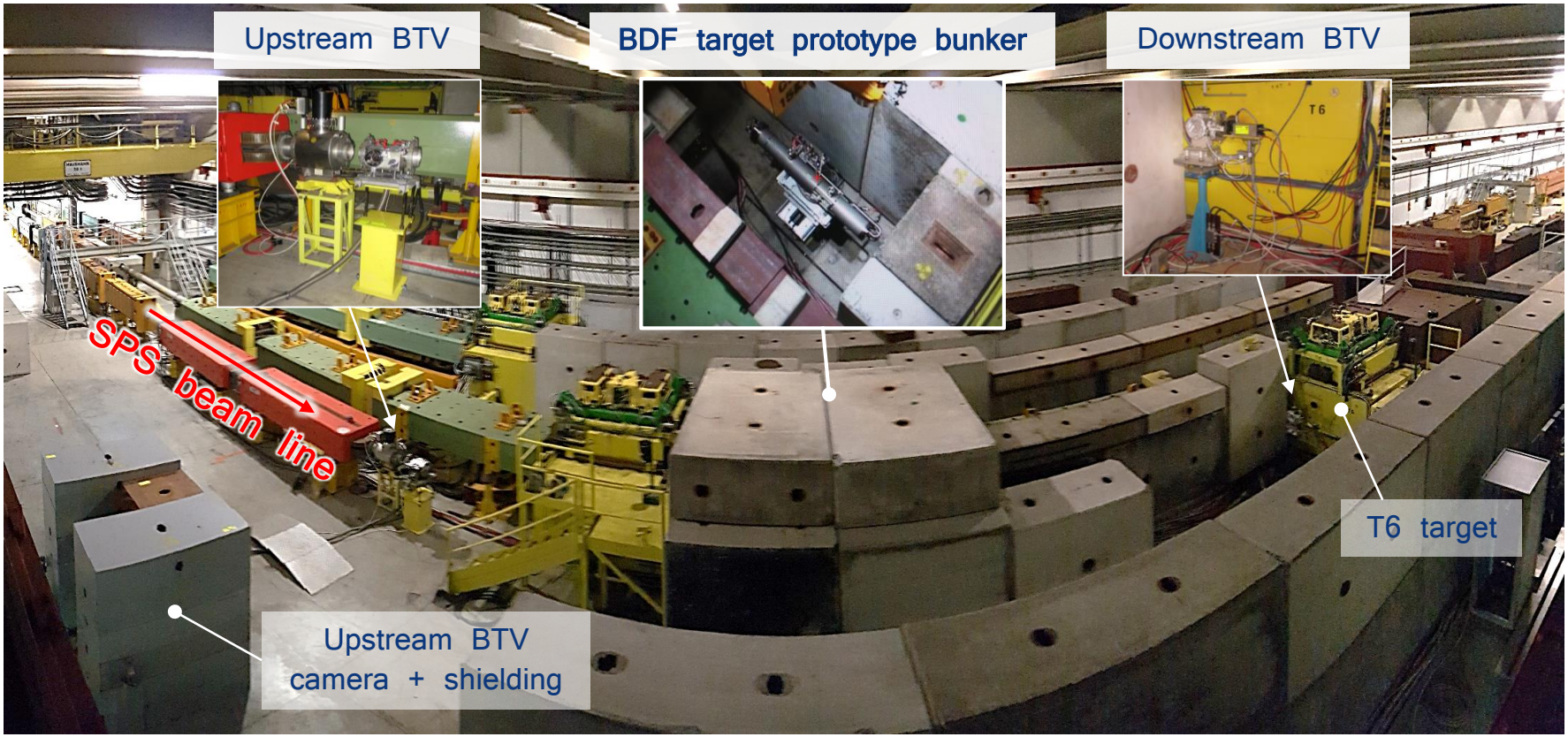


More details:
arxiv.org/abs/1904.03074
Paper submitted to Physical Review of Accelerators and Beams

Experimental validation required in view of ESPP submission

BDF target prototype

- Representative beam tests → **SPS high intensity beam**
- Slow extraction required (1 second spill)
  - Fully dedicated experimental setup in TCC2 (NA)



Prototype timeline

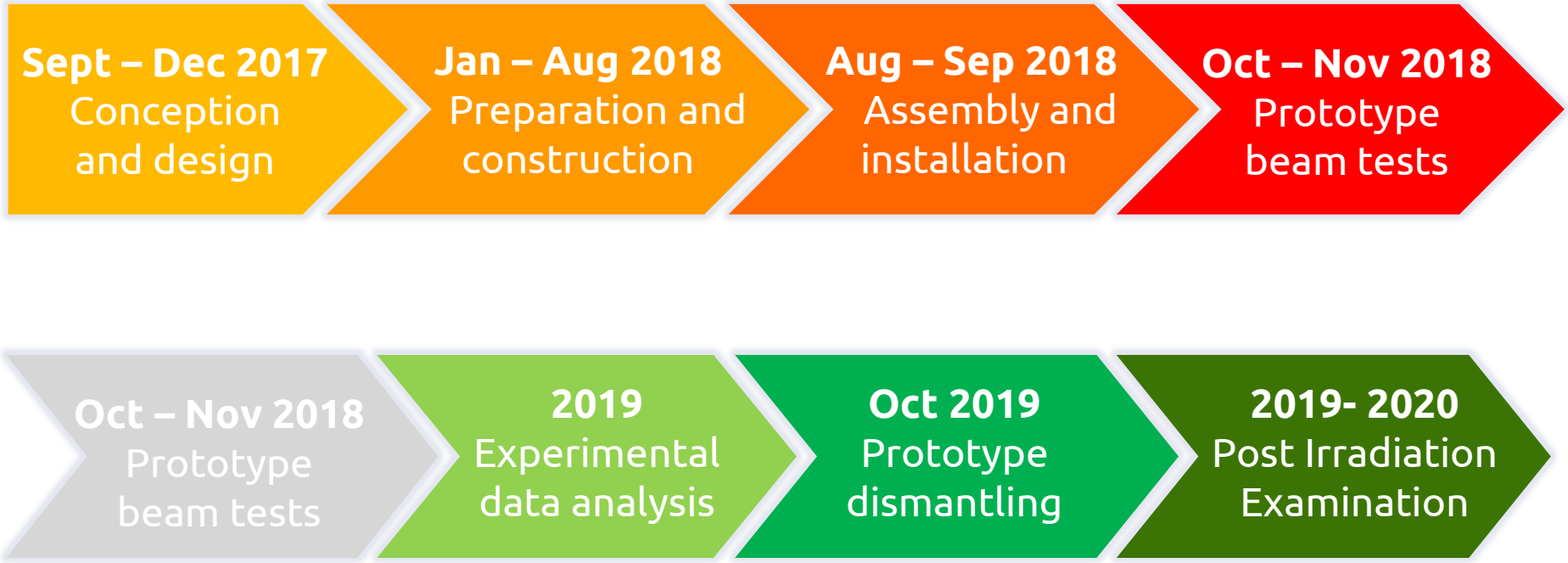
- Conception of the experiment
- Design of the prototype
- FEM simulations

- **YETS 2017/18** Preparation of the area
- Manufacture of prototype parts
- Procurement of core blocks
- Instrumentation of the blocks

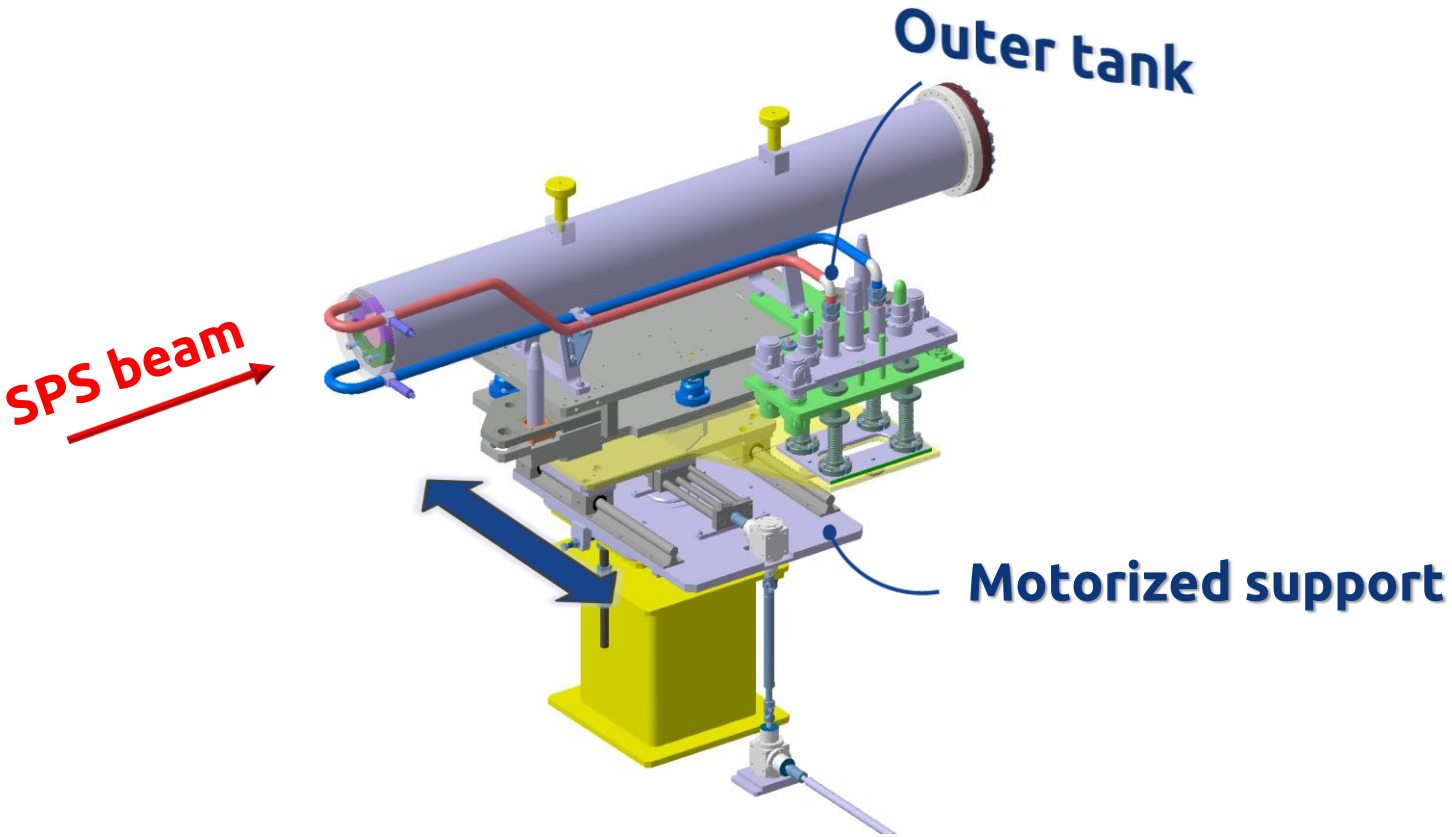
- Assembly of the prototype
- **September 2018** Installation in TCC2

- **3 MD days** Prototype test under beam

Prototype timeline



Sept – Dec 2017 Design | **Jan – Aug 2018** Construction | **Aug – Sep 2018** Installation | **Oct – Nov 2018** Beam tests



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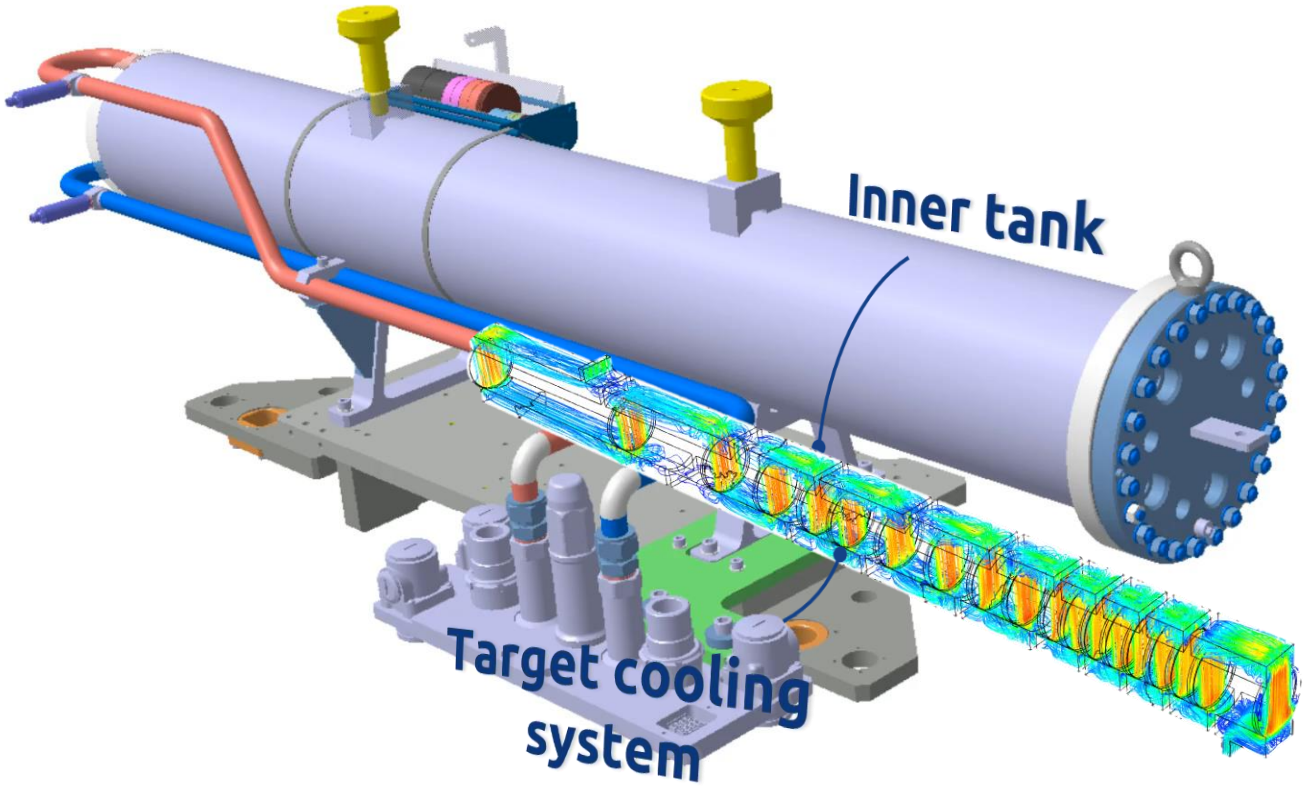
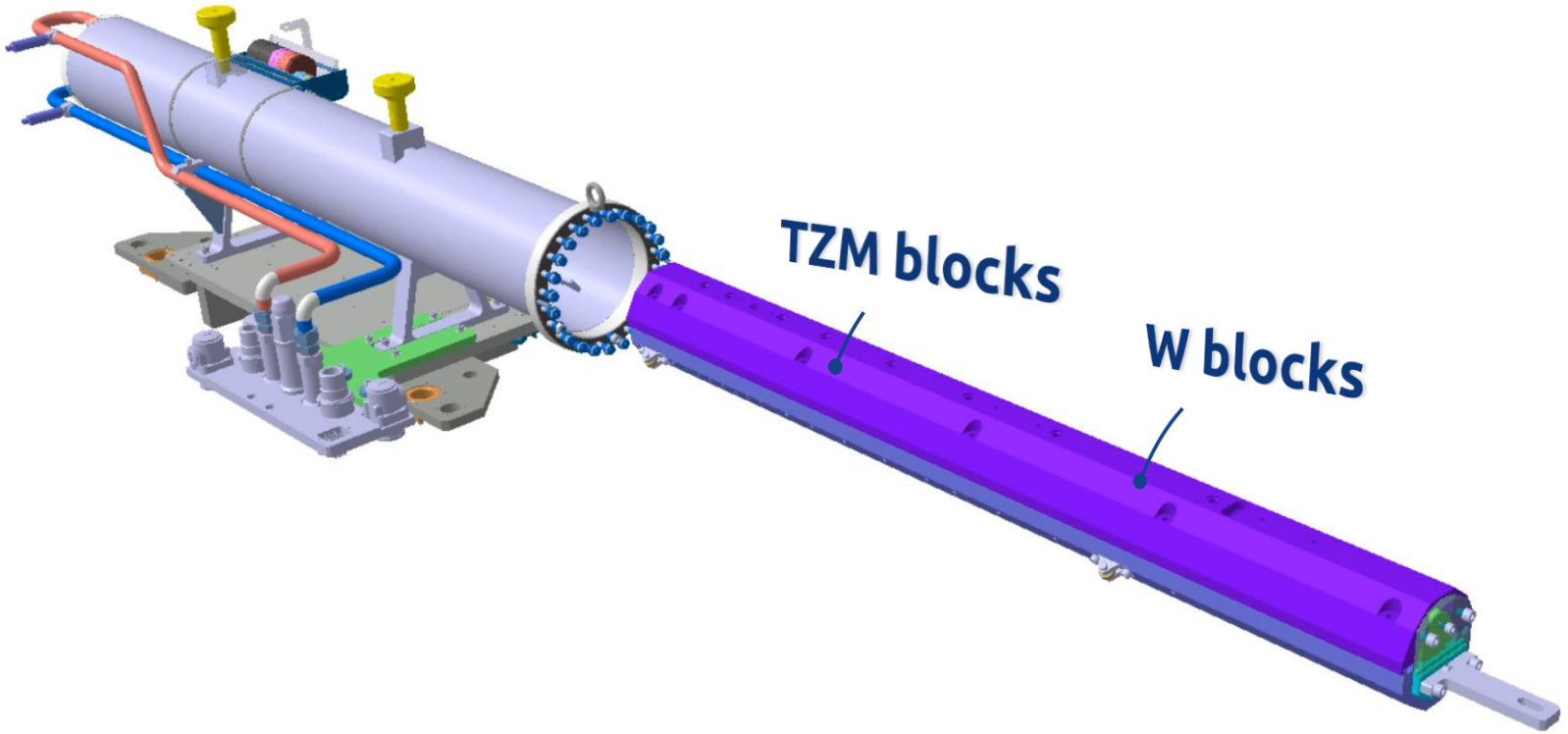
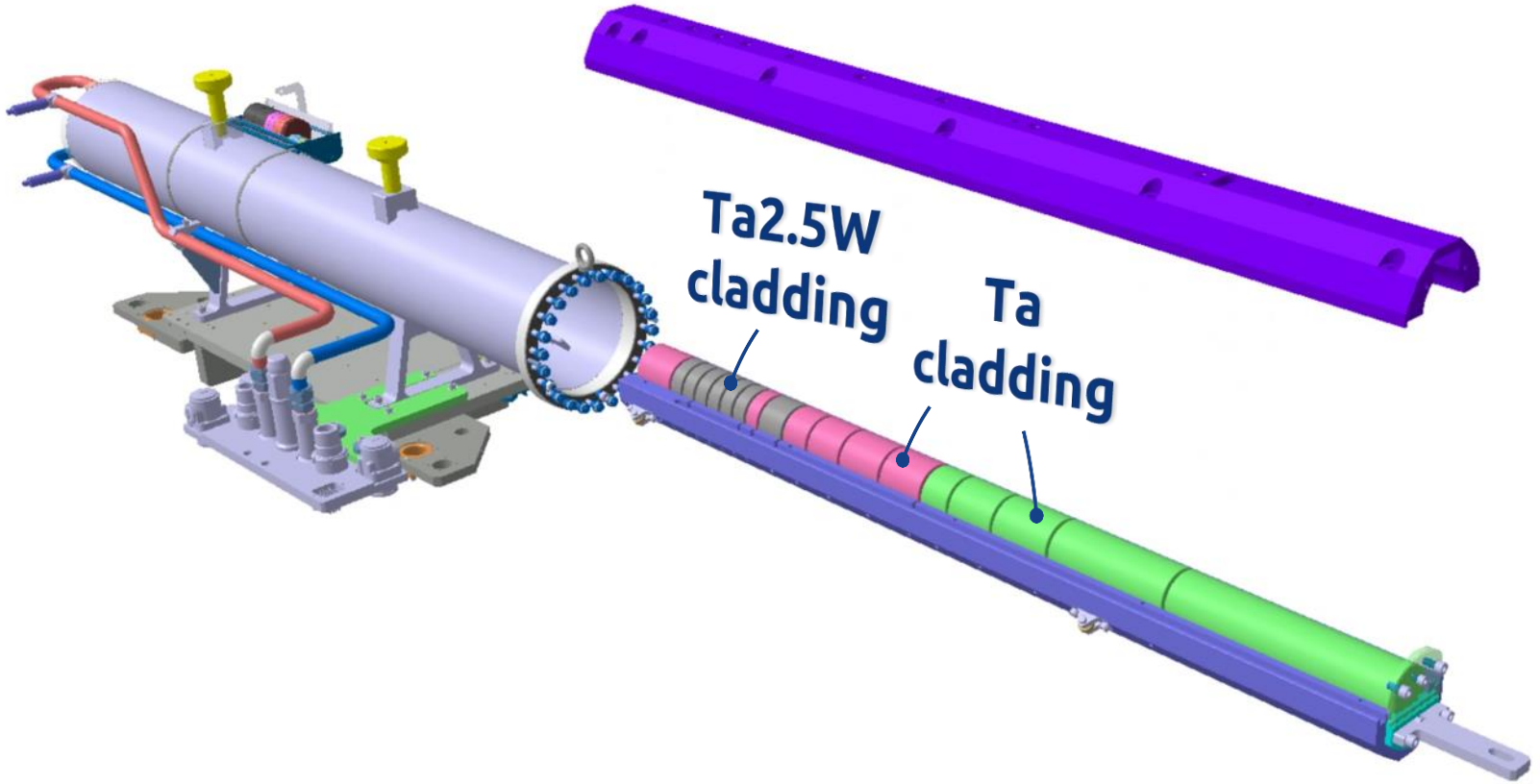
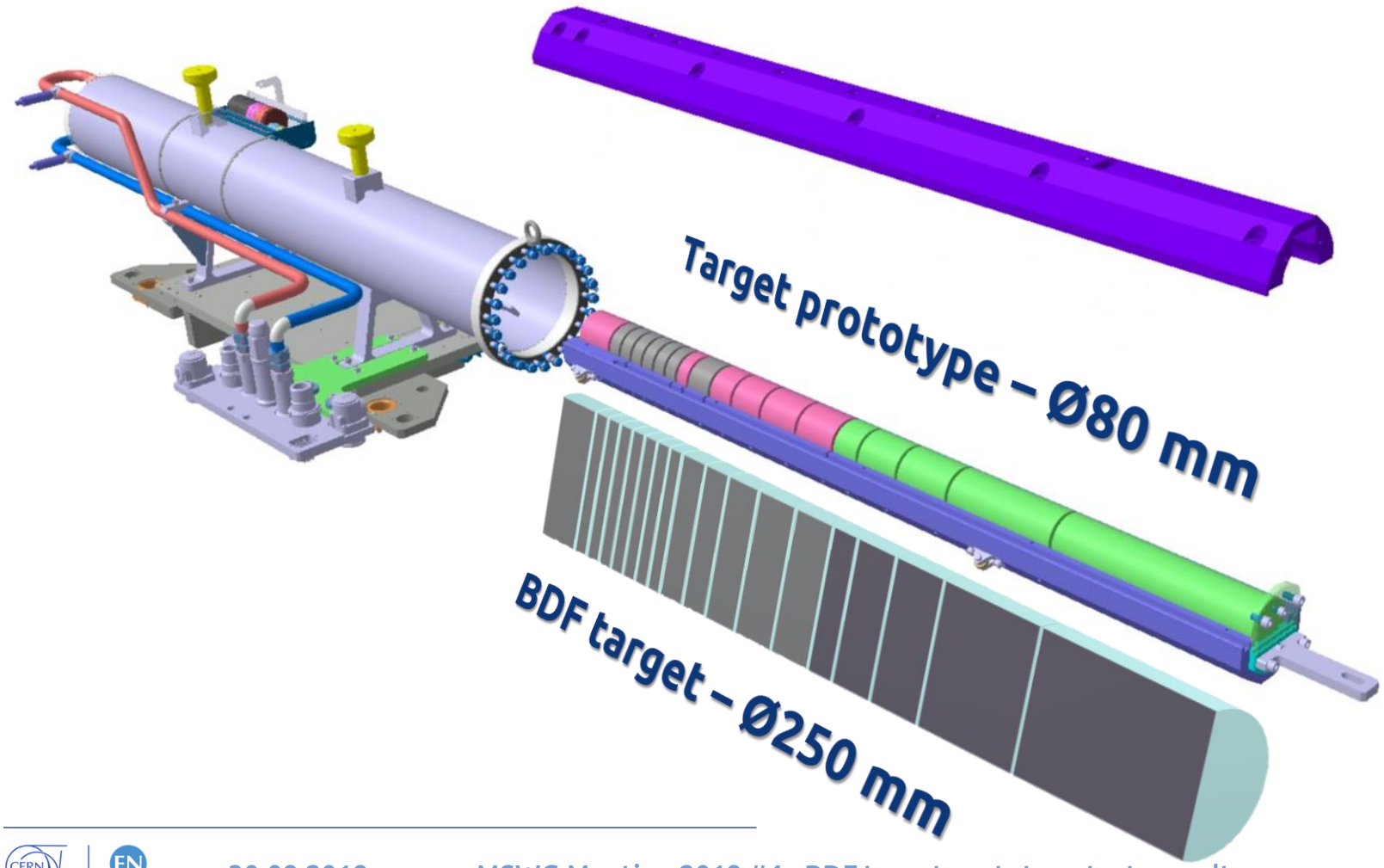



TZM blocks
W blocks

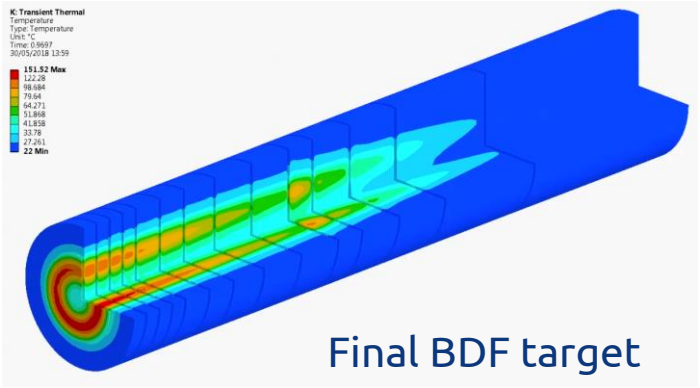

Ta2.5W cladding
Ta cladding

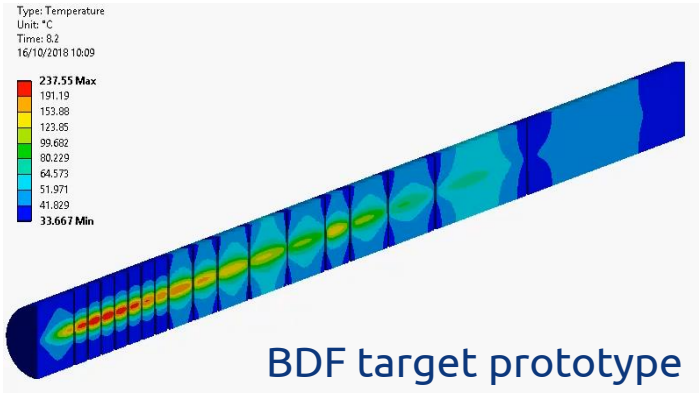

Target prototype – Ø80 mm
BDF target – Ø250 mm

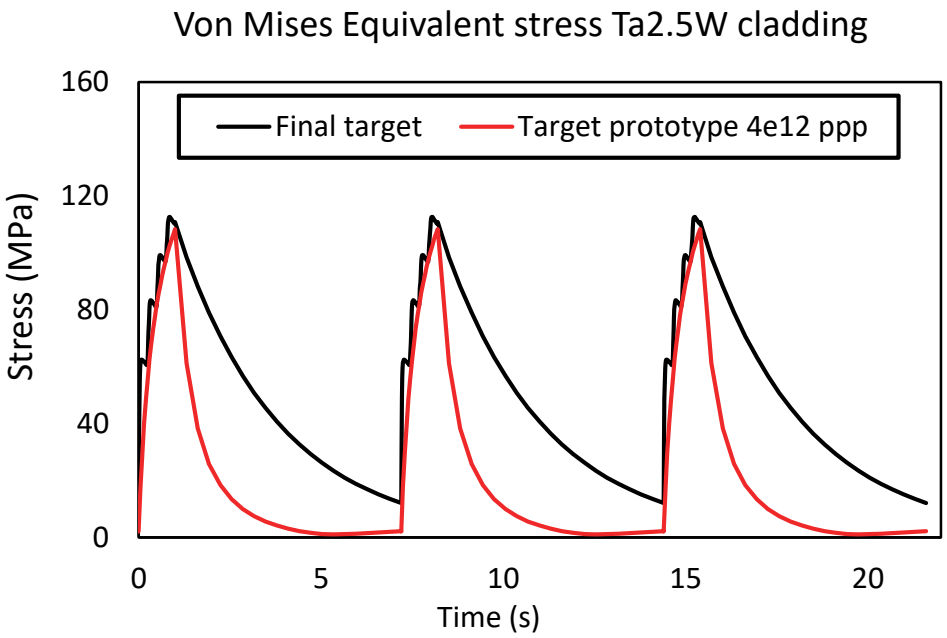
Sept – Dec 2017 Design → Jan – Aug 2018 Construction → Aug – Sep 2018 Installation → Oct – Nov 2018 Beam tests

Baseline characteristics	Final BDF target	Target prototype
Proton momentum [GeV/c]	400	
Beam intensity [p+/cycle]	**$4.0 \cdot 10^{13}$**	**$3.0 - 4.0 \cdot 10^{12}$**
Beam dilution	**4 circular sweeps / s**	**No**
Cycle length [s]	**7.2**	
Spill duration [s]	**1.0** (SX)	
Beam size (H/V) [mm]	**8/8**	**3/2.5**
Average beam power [kW]	350	35
Average beam power/spill [MW]	2.56	0.26
Power density / spill [MW/m^3]	18	

Reach representative level of temperatures and stresses despite lower intensity & lack of dilution

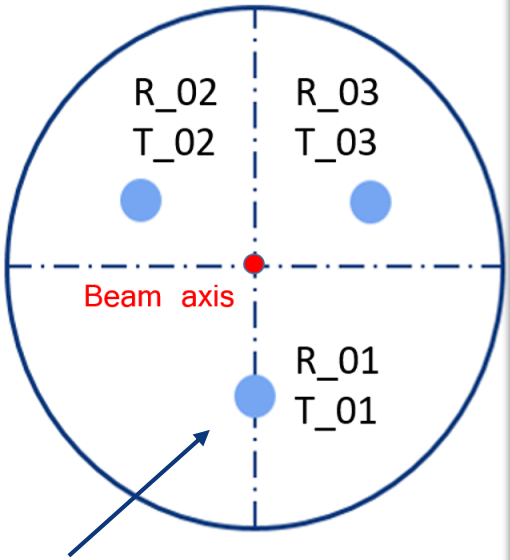






Reasonable approximation of the level of stresses in the core and cladding materials, despite lack of dilution and lower intensity

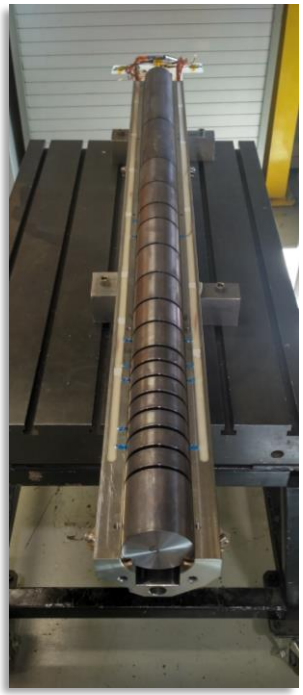
- **Target prototype instrumentation**
- 4 instrumented blocks

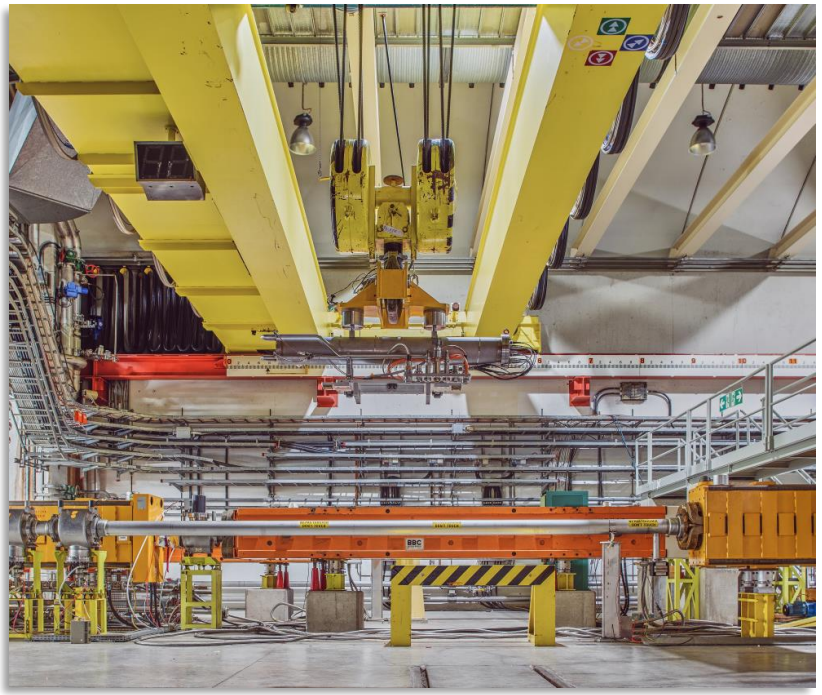


Strain gauges
(radial and transversal)

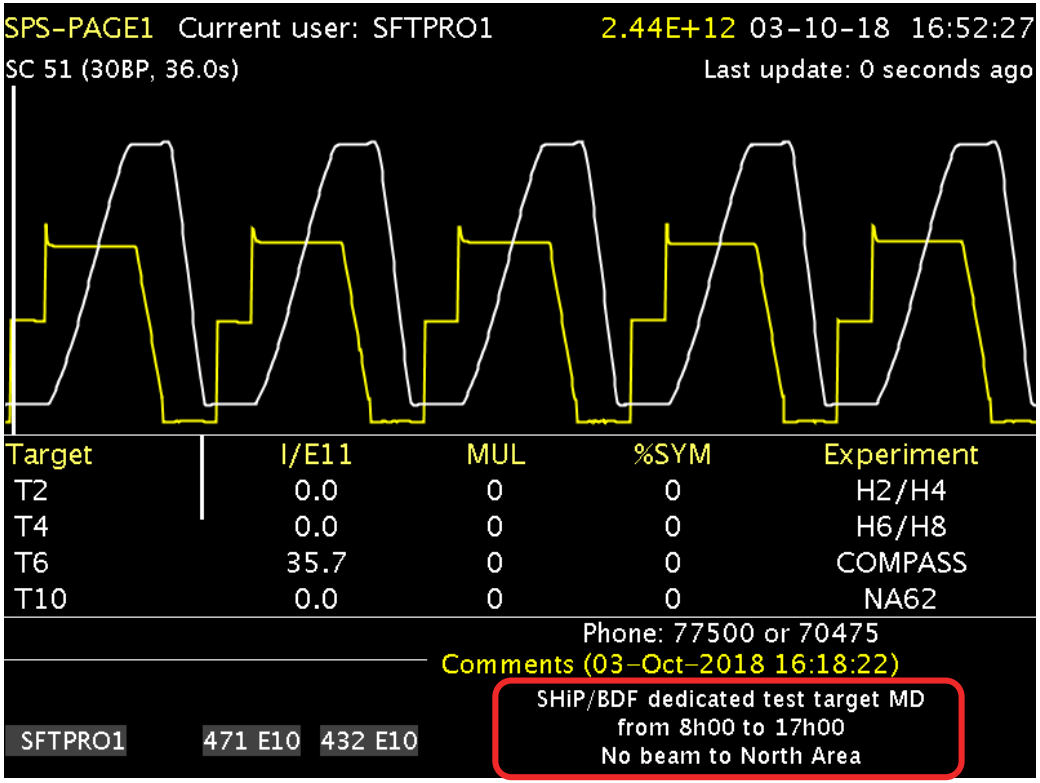
M. Guinchard, L. Bianchi (EN/MME)

- Target prototype assembly
- Fully remote installation in TCC2 during TS





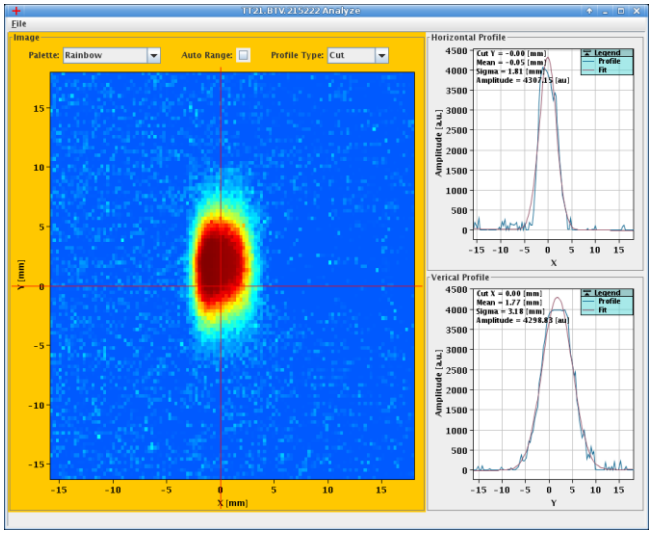
1st MD day – Successful target operation

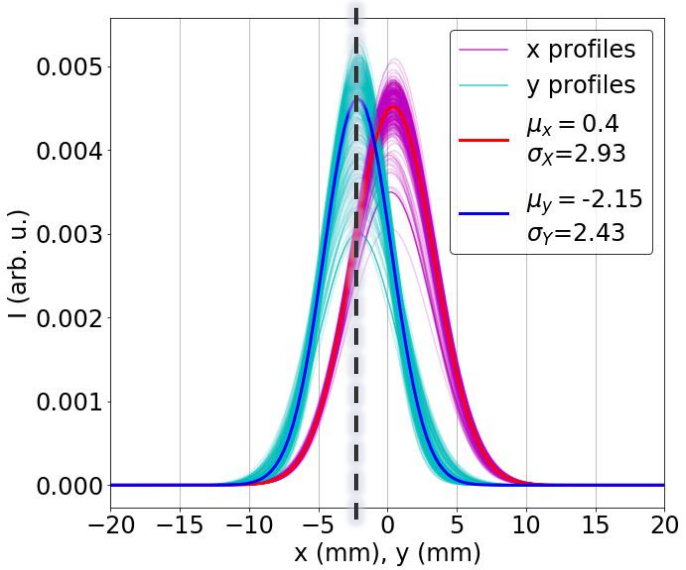


Dedicated SPS supercycle

- **SHiP cycle achieved** (1 sec spill, 7.2 sec pulse)
- > 6h of dedicated beam
- ~$1 \cdot 10^{16}$ POT
- Maximum power on target = **33 kW**

1st MD day – Successful target operation



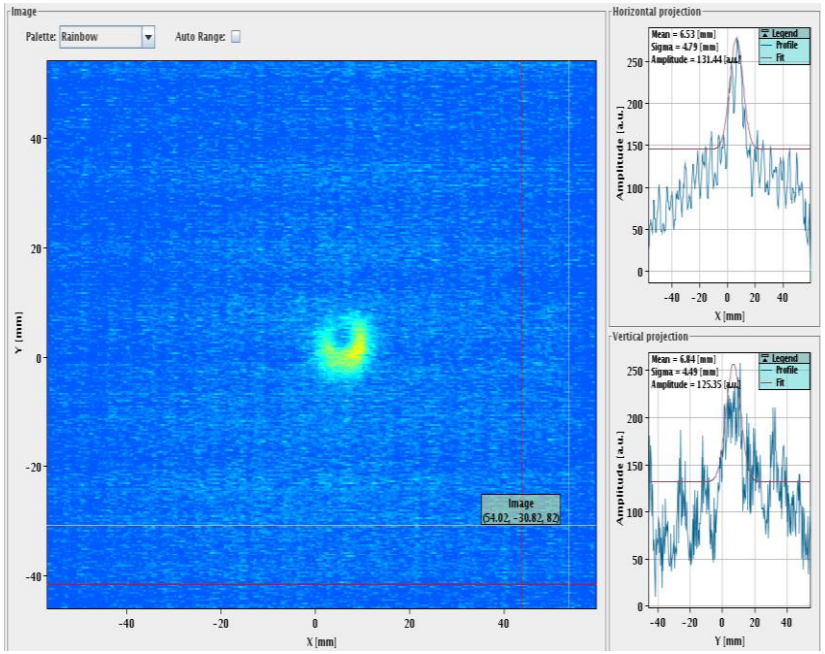


Upstream and downstream BTV key for beam tuning

- Beam 2 – 3 mm down from target center
- Average beam size ≈ 2.9 x 2.4 mm (expected = 3 x 2.5 mm) ✓

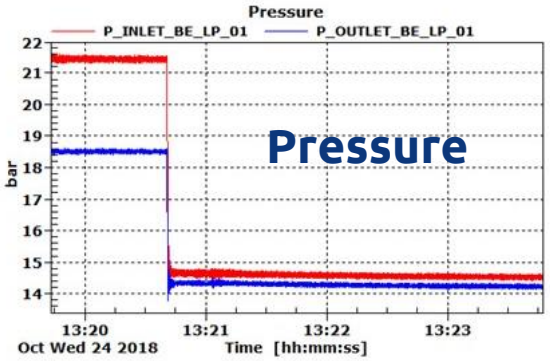
- 2nd MD day
  - **Upstream BTV camera failed** (radiation exposure)

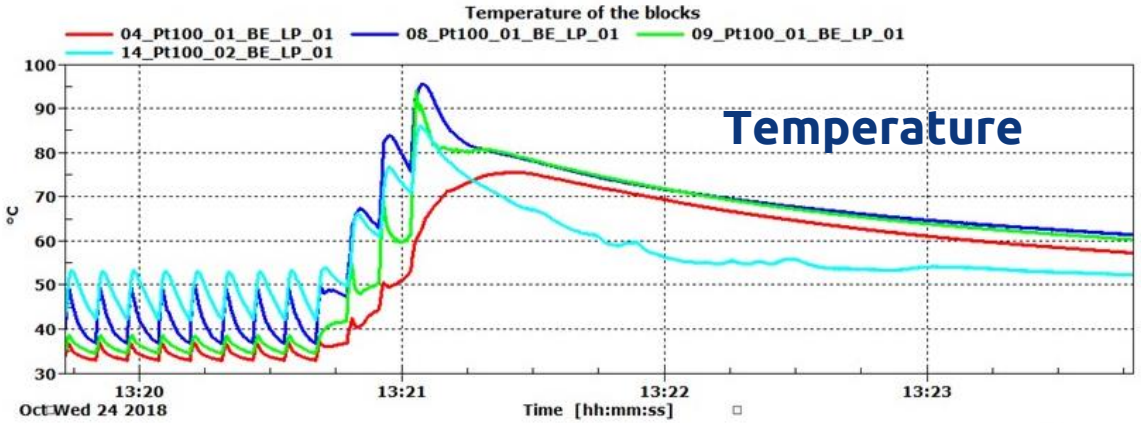
    → Beam tuning performed with downstream BTV

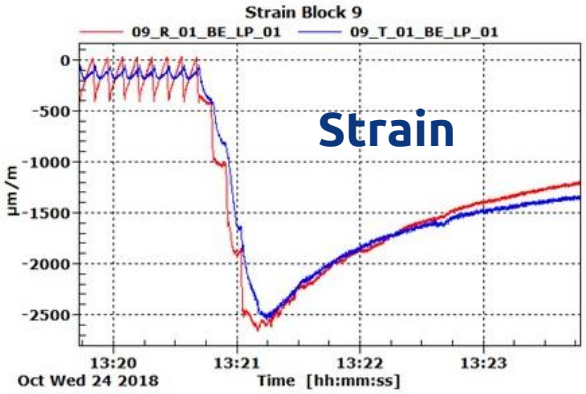


- > 5h of dedicated beam
- ~1.5·10^{16} POT
- Maximum power on target = **45 kW**

- **2nd MD day**
  - **Cooling skid pump failure** (Loss Of Coolant Accident)



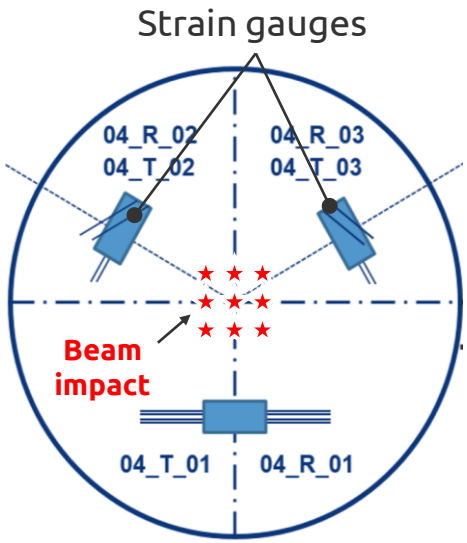


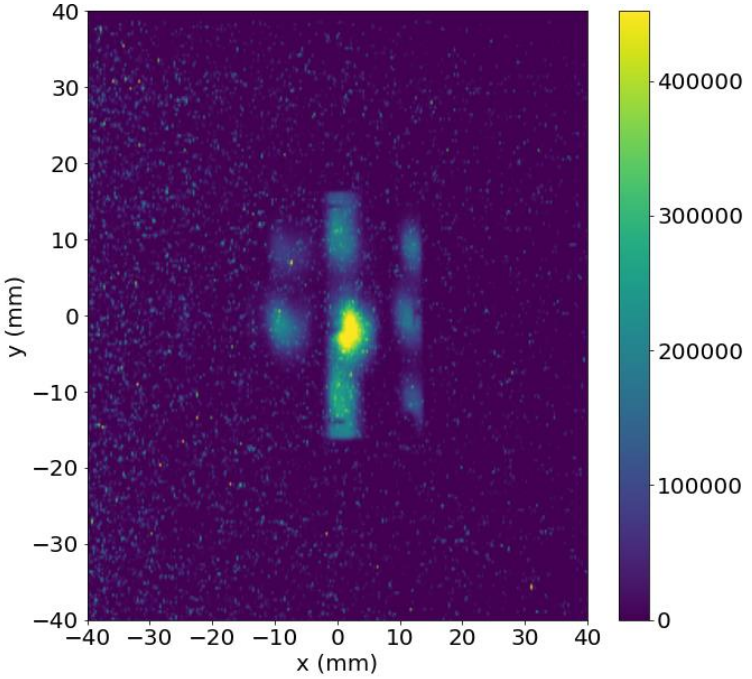


Beam interlocked after **4 pulses on target without cooling**

3rd MD day

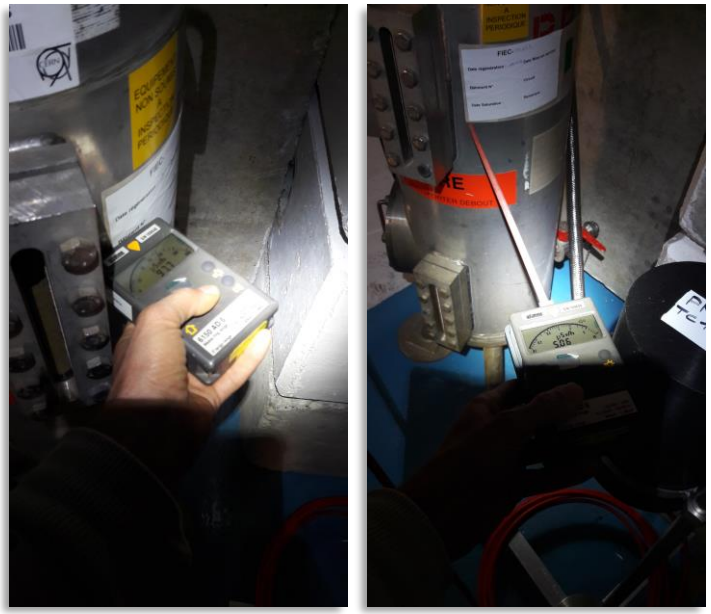
- Exchange of upstream BTV → "Sensitivity" tests





- **RP situation**
  - **Dose rate measurements**
    - Good agreement with simulations
    - Expected after 1 year: **~Sv/h @ contact**

    → Fully remote dismantling

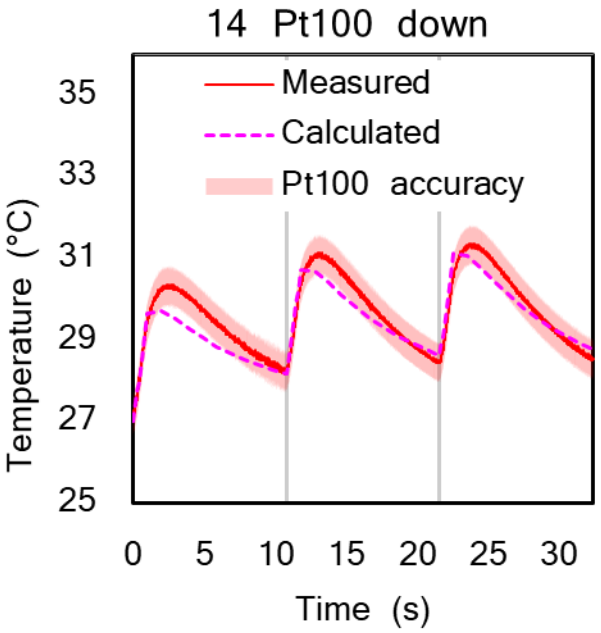


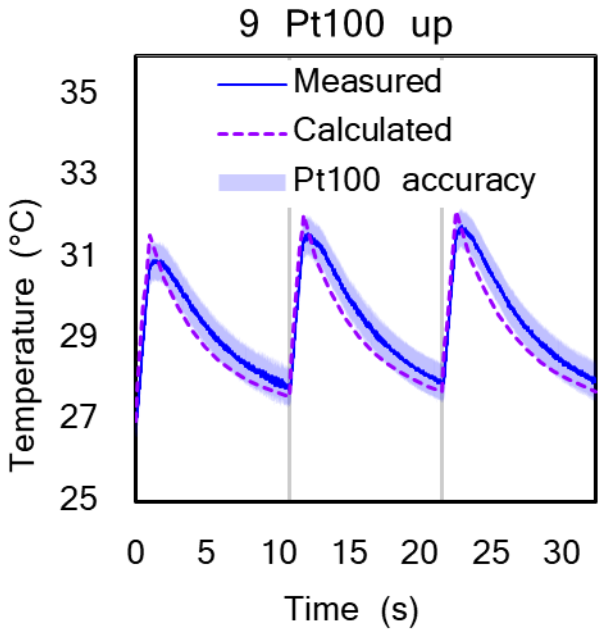
  - **Water activation and circuit contamination detected**
    - Probable cause: **debris from bronze wheels**
    - Good choice to have a **separate cooling circuit**

Data analysis

2019 Experimental data analysis → Oct 2019 Prototype dismantling → 2019- 2020 PIE

- **Temperature sensors vs. FEM (1st MD)**
  - Temperature evolution first beam pulses

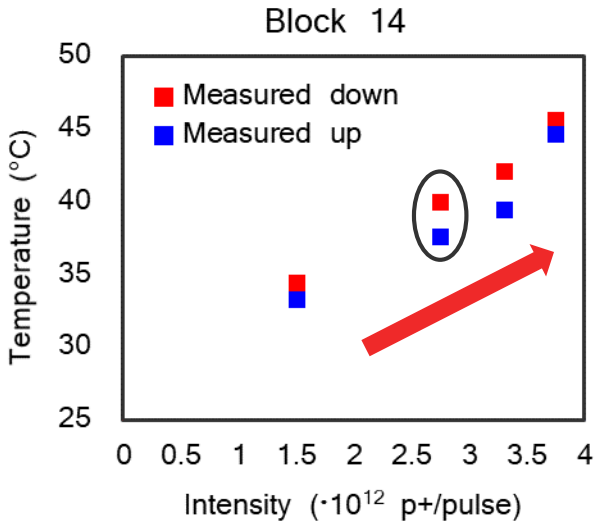




Accurate estimation of the trend ✓

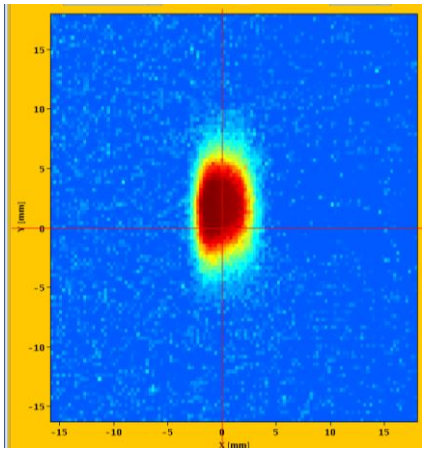
Data analysis

- **Temperature sensors vs. FEM (1st MD)**
  - Maximum temperature at different intensities



Beam offset 2 mm down

→ $T_{down} > T_{up}$



Data analysis

2019 Experimental data analysis → **Oct 2019** Prototype dismantling → **2019- 2020** PIE

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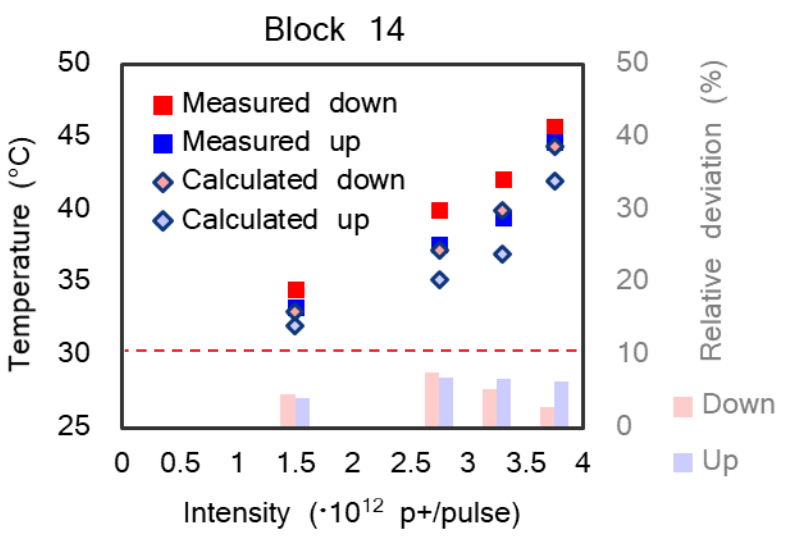
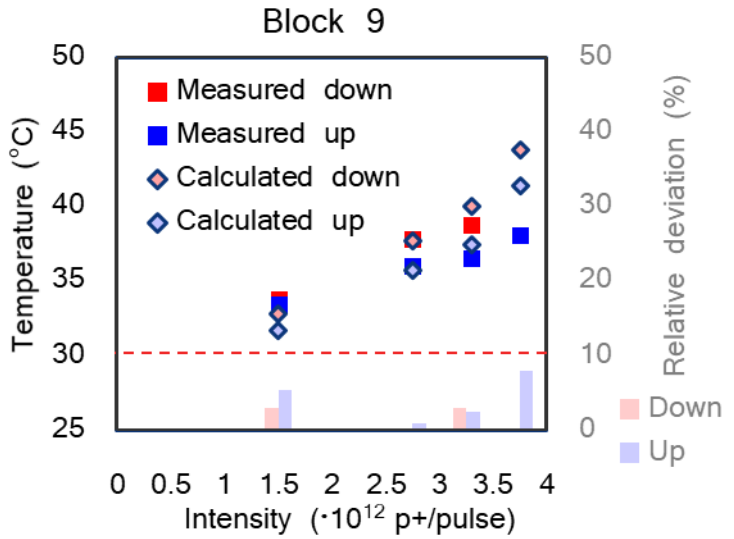




< 10% relative deviation ✓

Data analysis

2019 Experimental data analysis → Oct 2019 Prototype dismantling → 2019- 2020 PIE

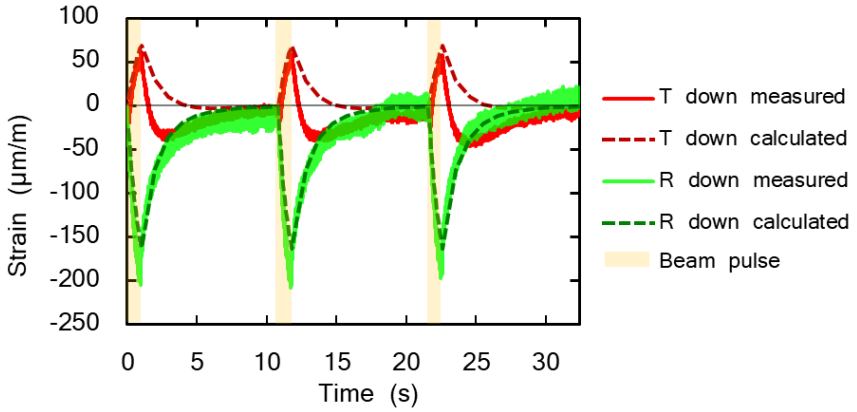
- Extrapolation to estimate maximum temperatures
- **Representative level of temperatures** assuming good correlation with FEM simulations (within 10% deviation)

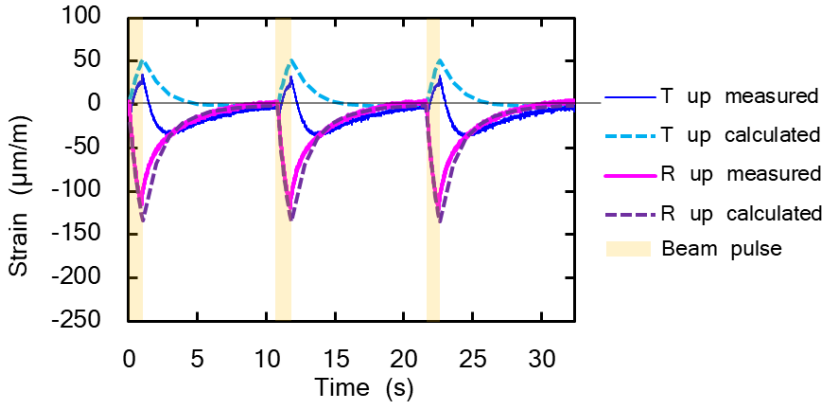
Material		Maximum temperature (°C)		
		Prototype target		Final BDF target
Core	TZM	**280**	>	180
	W	**160**	>	150
Cladding	Ta2.5W	**250**	>	160
	Ta	**195**		-

Data analysis

2019 Experimental data analysis → Oct 2019 Prototype dismantling → 2019- 2020 PIE

- **Strain sensors vs. FEM (1st MD)**
  - Strain evolution – First beam pulses (block 4)



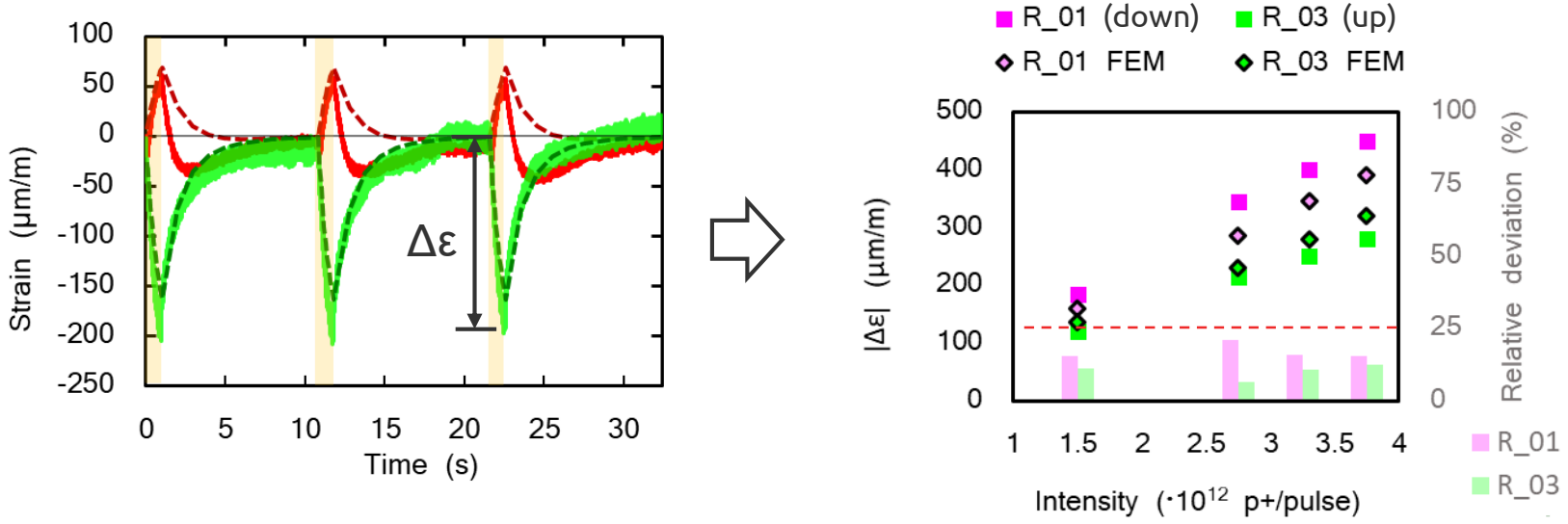


Good estimation of the trend

Larger uncertainties during cool-down phase – flow behavior, beam effects ✓

Data analysis

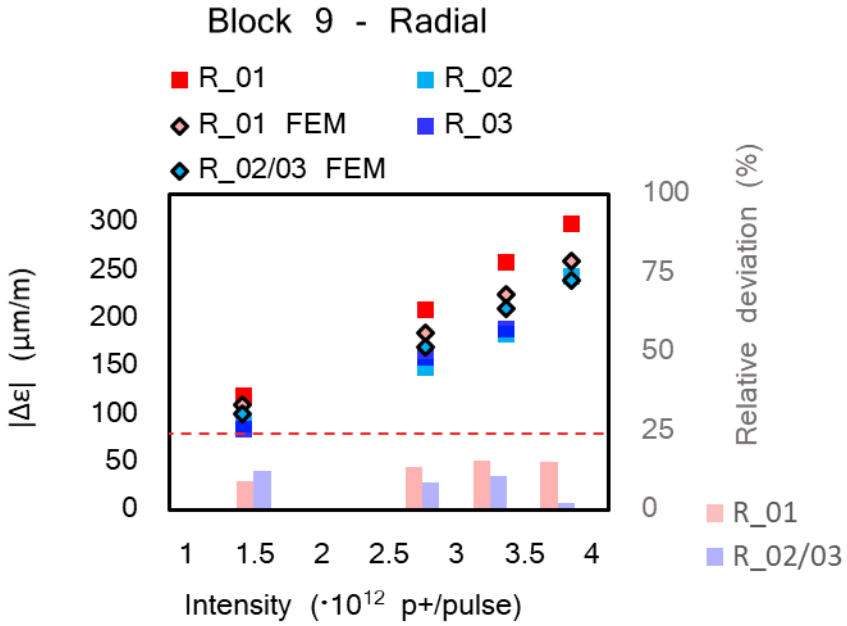
- **Strain sensors vs. FEM (1st MD)**
  - Δε after beam impact at different intensities

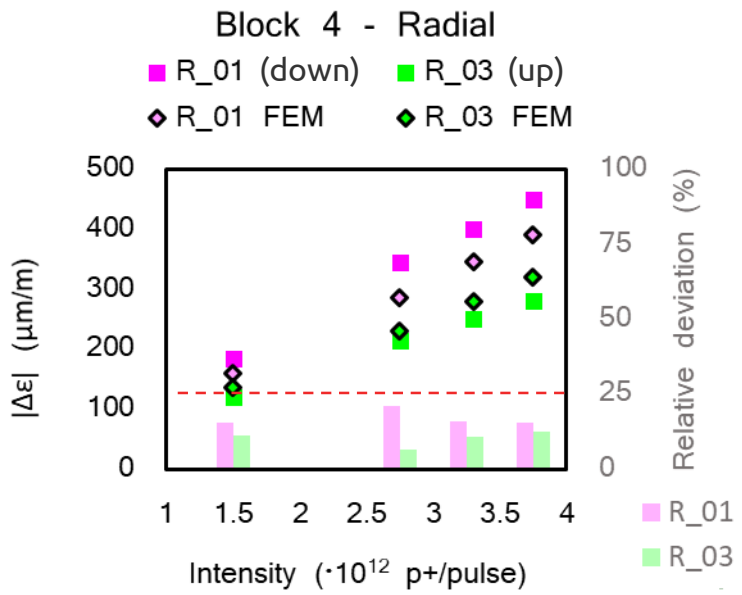


< 25% relative deviation ✓

Data analysis

- **Strain sensors vs. FEM (1st MD)**
  - Δε after beam impact at different intensities





< 25% relative deviation ✓

Data analysis

2019 Experimental data analysis → Oct 2019 Prototype dismantling → 2019- 2020 PIE

- **Representative level of stresses** assuming good correlation with FEM simulations

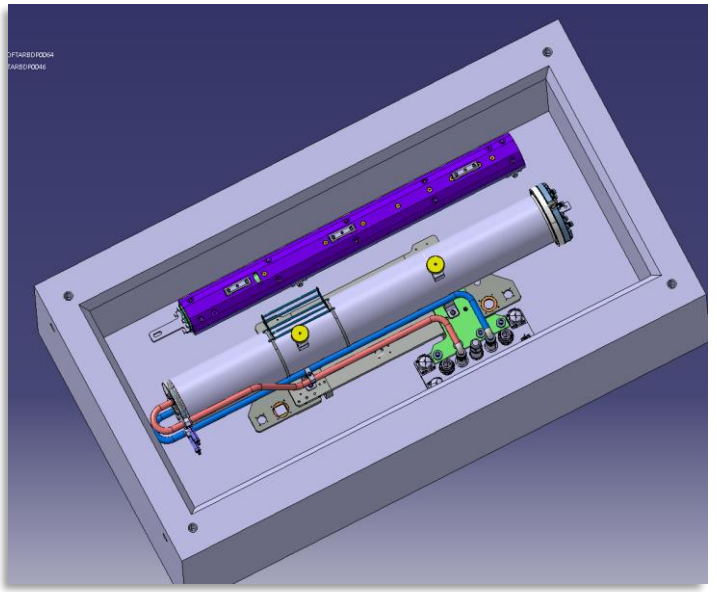
Material		Maximum stress (MPa)		
		Prototype target		Final BDF target
Core	TZM	**180**	>	130
	W	**115**	>	95
Cladding	Ta2.5W	**105**	>	95
	Ta	**75**		-

- **On-going paper preparation**: BDF target prototype tests and results analysis

Next steps

2019 Experimental data analysis → **Oct 2019 Prototype dismantling** → 2019- 2020 PIE

- **Fully remote target dismantling (ALARA 3)**
  - October – November 2019

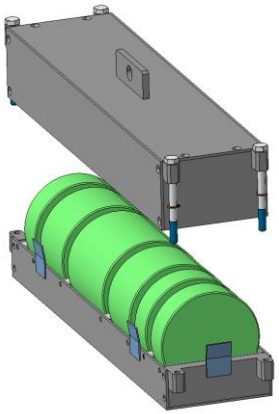


  - Discussing whether to keep the area as **slow extraction target test area**

Next steps

2019 Experimental data analysis → Oct 2019 Prototype dismantling → **2019- 2020 PIE**

- **Post Irradiation Examination (PIE)**
  - 6 irradiated blocks to be examined → **influence of stress, thermal cycles, cooling and irradiation** in material properties, interface bonding,…



- Metrology – microscopy
- Non-destructive testing
- Destructive testing

→ Critical for the BDF target assessment

Conclusions

- **Successful prototype** design, construction and operation under the SPS proton beam
- The target prototype is a **key development** for the assessment of the final BDF target
- **First analysis of the results completed**, good correlation with the FEM simulations and **representative level of temperatures and stresses** reached
- The **results of the PIE are crucial** for the validation of the final BDF target design

Thank you for your attention

Questions?