This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

WP1 High Dynamic Range Current Measurement

I.FAST REX Collaboration Meeting 2022-02-17

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Goals

- I.FAST proposal: measure current to $\frac{\Delta I}{I_{\mathrm{DC}}} < 10^{-6}$
- Later communication: measure current to $\frac{\Delta I}{I_{\mathrm{DC}}} \approx 10^{-7}$,

  AC resolution $\frac{\Delta I}{I_{\mathrm{AC}}} \approx 10^{-5}$

  => dynamic range 100dB without range switching

- Challenges: very high resolution, very high dynamic range,

  presence of very high DC currents (up to 10kA)
  => saturation of magnetic materials

Actions

- I.FAST REX Kick-Off meeting 2021-02-8/9
- First discussions on requirements and constraints
- Specification meeting I.FAST REX WG1 2021-05-28
- Extensive email exchange
- Outcome: a large table and the comprehension that the measurement system has to be adaptable to very different situations.
- We still do not know specifications of all magnets where the current measurement system shall be installed.
- Nevertheless, we started working on something.

Specifications

	Magnet 1 Main Quad SIS100	Magnet 2 Fast Quad SIS100	Magnet 3 Main Quad SIS18	Magnet 4 Fast Quad SIS18	Magnet 5 MedAustron	Magnet 6
Magnet Current Specifications						
DC current minimum $I_{DC,min}$	1000 A	130 A	170 A	30 A	0 A	
DC current maximum $I_{DC,max}$	11000 A	2000 A	2000 A	600 A		
DC current polarity	pos, neg	pos, neg	pos, neg	pos, neg		
DC current ramp gradient r_I	6000 A/s					
DC current flat-top length $t_{flat\text{-}top}$						
AC modulation minimum rel. $I_{AC,min}/I_{DC}$ or abs. $I_{AC,min}$	10^{-4}					
AC modulation maximum rel. $I_{AC,max}/I_{DC}$ or abs. $I_{AC,max}$	10^{-2}					
Ramp end to extraction time Δt_{ext}	100 ms					
Ramp repetition rate f_{ramp}						
Measurement Requirements						
Bandwidth f_{min} to f_{max}	10 Hz – 40 kHz				0 Hz – 40 kHz	
Resolution flat-top rel. $\sigma_{I,FT}/I_{DC}$ or abs. $\sigma_{I,FT}$	10^{-7}					
Resolution ramp rel. $\sigma_{I,Ramp}/I_{DC}$ or abs. $\sigma_{I,Ramp}$	not required	not required	not required	not required		
Dynamic range total	>120 dB					
Dynamic range per range setting	>100 dB					
Measurement uncertainty u_I	0.1% - 1%					
Measurement duration t_{meas}						
Temperature coefficient c_T	??? %/K					

Specifications

	Magnet 1 Main Quad SIS100	Magnet 2 Fast Quad SIS100	Magnet 3 Main Quad SIS18	Magnet 4 Fast Quad SIS18	Magnet 5 MedAustron	Magnet 6
Geometrical and Mechanical Requirements						
Aperture Diameter *D*	100 mm	43 mm	43 mm	30 mm		
Outer Length *L*	<= 20 cm					
Outer Width *W*						
Outer Hight *H*						
Weight *M*						
Other Requirements						
Power Consumption						
Insulation breakdown voltage U_{max}						
EMI at installation position	??? mT					
ADC ENOB	>=17 bit					
ADC sampling rate	>80000 S/s					

Development Objective

- Fulfill the SIS100 main quad specifications,
  we have its specs and it is the magnet with the highest current.

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  we have its specs and it is the magnet with the highest current.

- For 10kA DC, 10^{-7} relative resolution means 1mA absolute resolution, which remains a nicely measurable signal level.
- What about the magnets with low DC current?
- If we get too close to µA resolution,
  we may have some more challenges to tackle.

Specifications

- We need specifications for the magnet with the lowest DC current, i.e. the magnet with the smallest absolute resolution requirement!

- It would be nice to have specifications of all magnets and the required current measurement performance.

Development

- Directions we could take to improve measurement resolution:

    1) totally new idea and development
    2) push NPCT (DCCT) to higher DC currents
    3) wrap ACCT in a DC compensating feedback coil

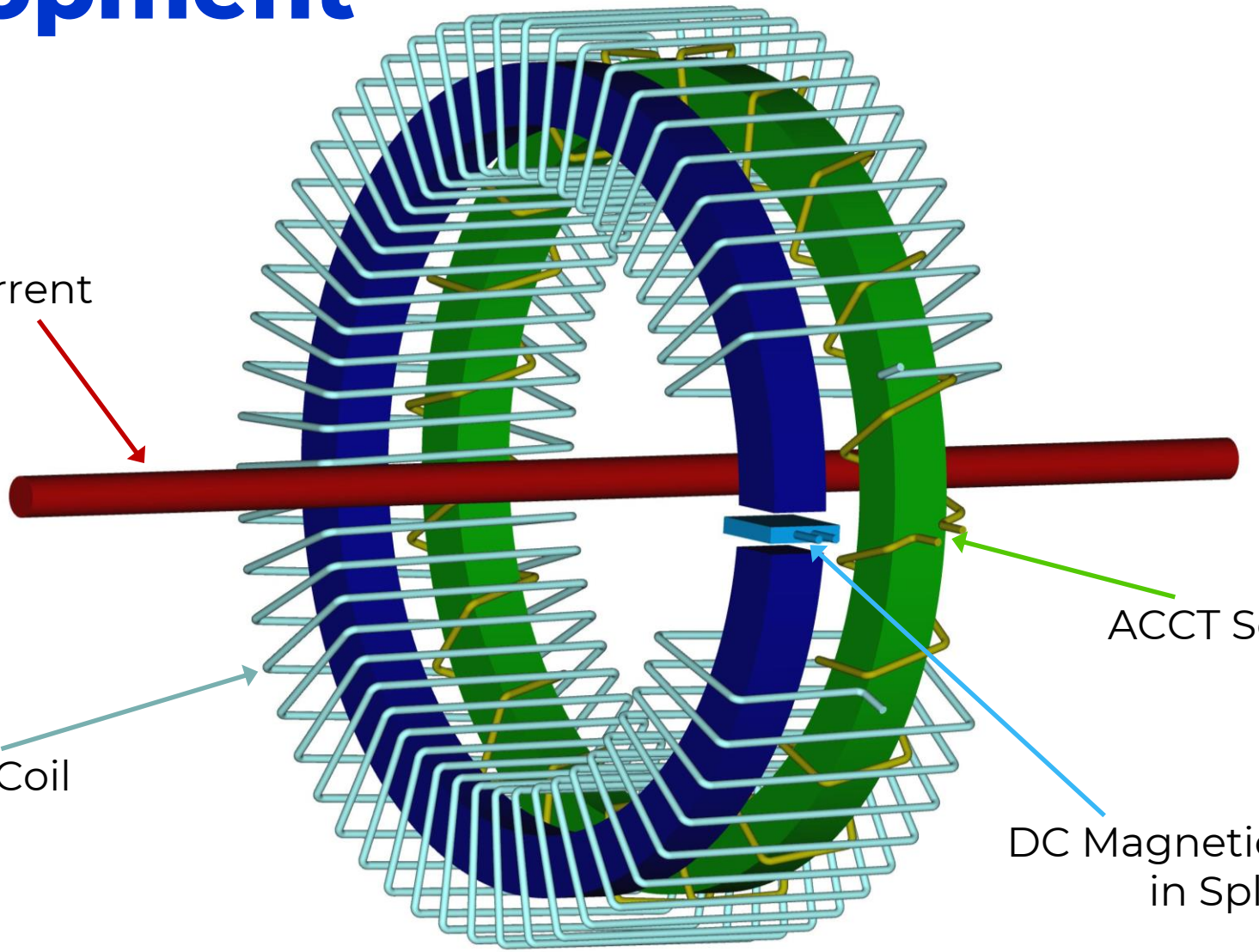
Development

- Directions we could take to improve measurement resolution:

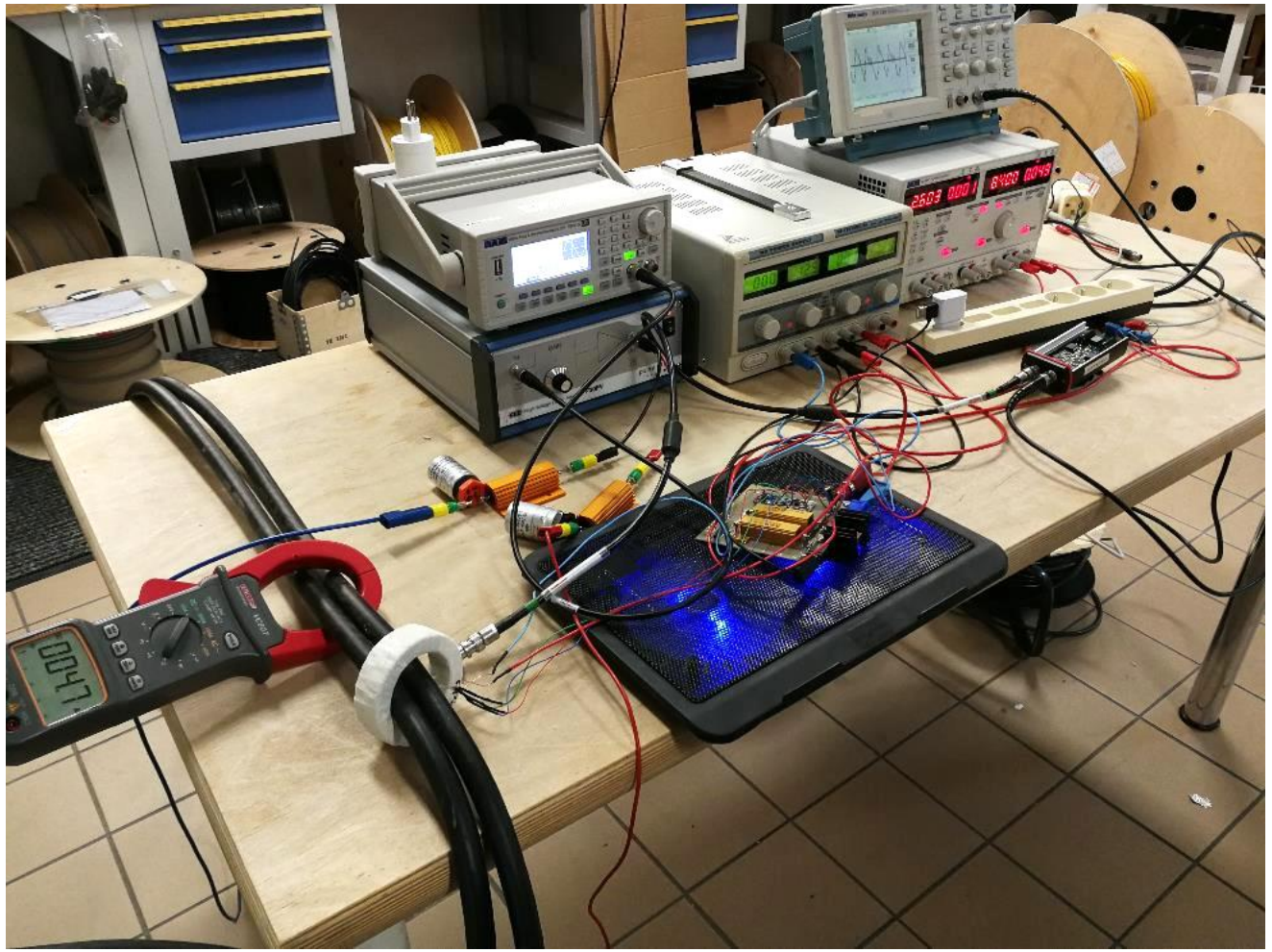
1) totally new idea and development
2) push NPCT (DCCT) to higher DC currents
3) wrap ACCT in a DC compensating feedback coil

ACCT bandwidth 1Hz - 1MHz
ACCT resolution $<5\times10^{-5}$ rel. to full scale current

Development



Development



Development

- As a proof-of-principle, we tried a first sensor with up to 400Adc plus ~10^{-3} power supply ripple
  and a small sine induced intentionally.
- It works!
- But still a lot work to do:
  - improve ACCT resolution
  - develop a proper feedback electronics
  - set up a test bench allowing
    accurate performance qualification

Summary

- The challenge is sufficiently well defined to start development.
- Nevertheless, we would like to fill the specifications table further.
- Most importantly, we need to know the lowest absolute signal level to be measured.

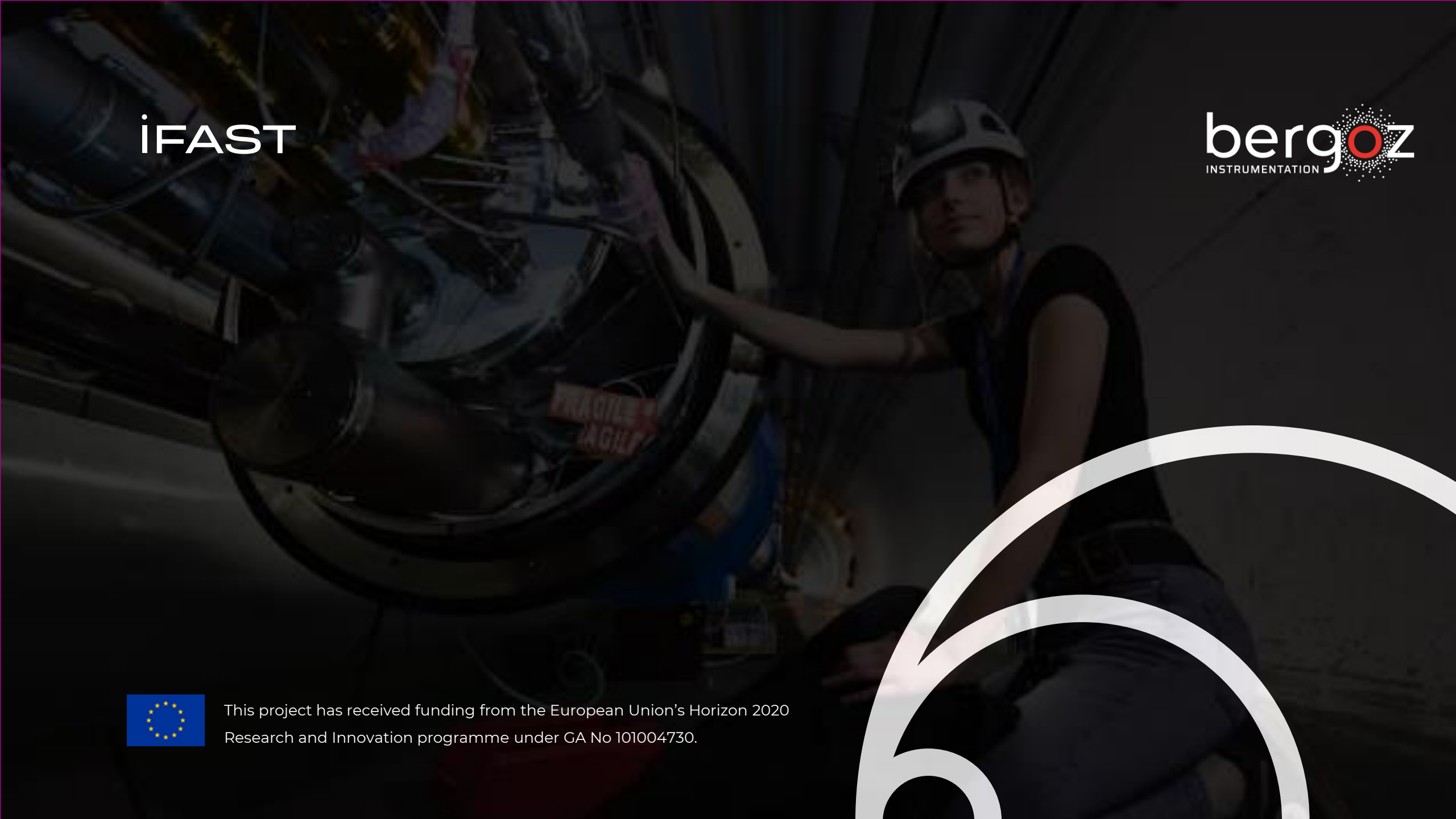
- A first test sensor has been assembled.
- First tests are promising.

Next Steps

- We know which parameters we have to improve and also how we can improve them (at least partially).

- We should discuss what we want to have ready for the collaboration meeting in May 2022 (the “Mock-Up”).

- We need to define what we want to have ready for the milestone April 2023 (the “Prototype”).



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