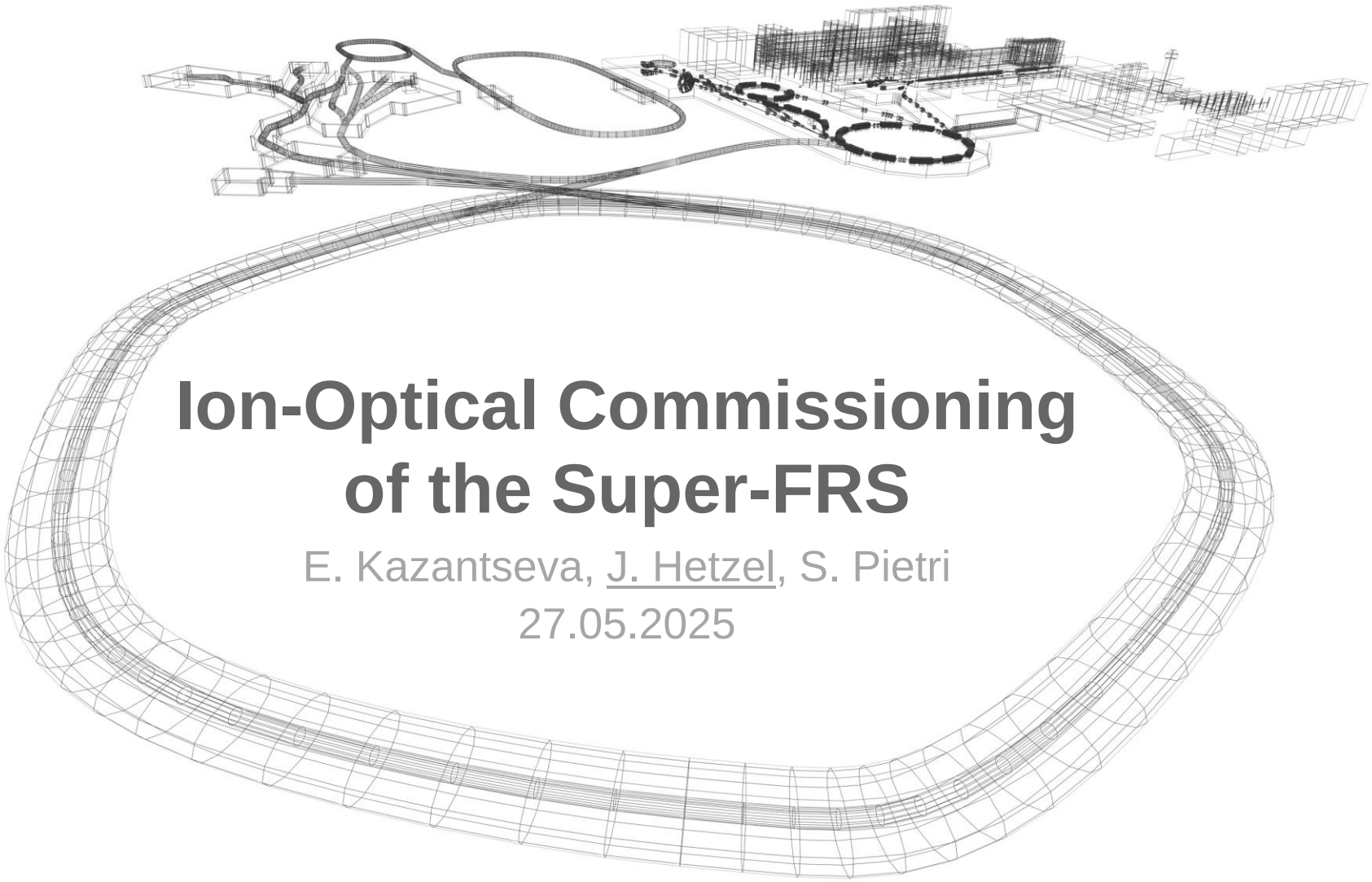


Ion-Optical Commissioning of the Super-FRS

E. Kazantseva, J. Hetzel, S. Pietri

27.05.2025

Ion Optics in a Nutshell

- Ion optics defines the path of of the ions throug the accelerator as infulenced by (electro-)magnetic fields & matter.

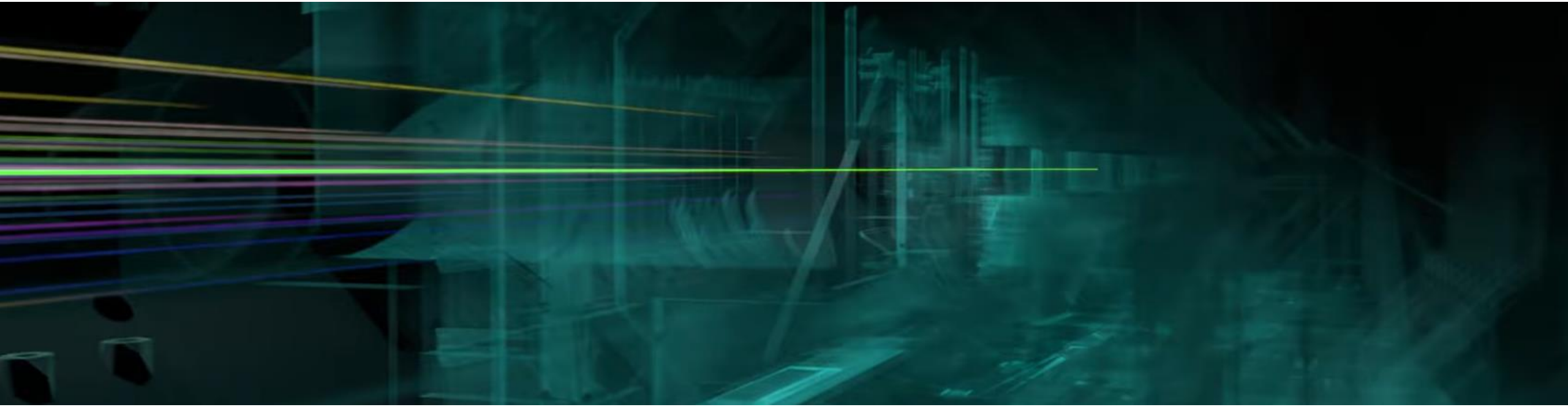


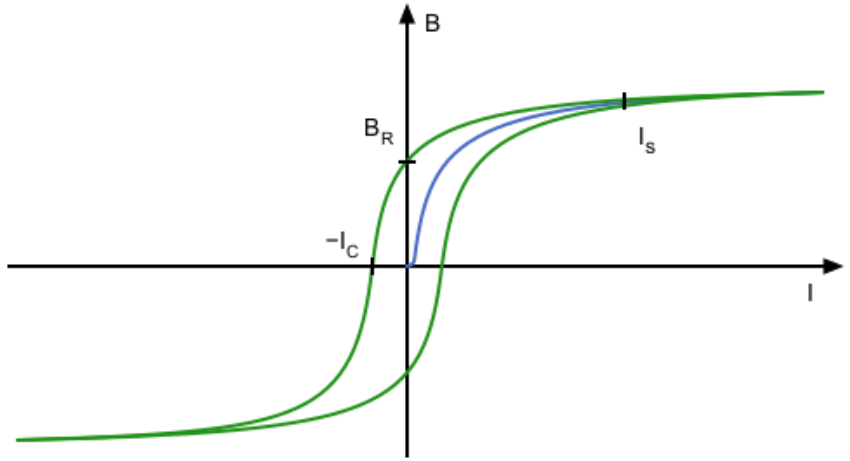
Image taken from: “FAIR Trailer: The Particles' Journey throught the Accelerator Facility”

→ precise knowledge of magnetic fields crucial for precise steering of the beam

Challenges at the Super-FRS

→ Precise control of magnetic fields crucial

- Measurement of B(I) in advance
  Challenge: Magnetic hysteresis
- Measurement of B during operation
  Challenge: Measurement locally, necesary for ion optics global field - over a (group of) element(s) (B_local vs B_global)
- Magnetic field influenced by neighbouring magnets (cross-talk)
- Findings on cross talk and calibration of the probes to be incorporated in the Control System (LSA)
  Set value: I(B)



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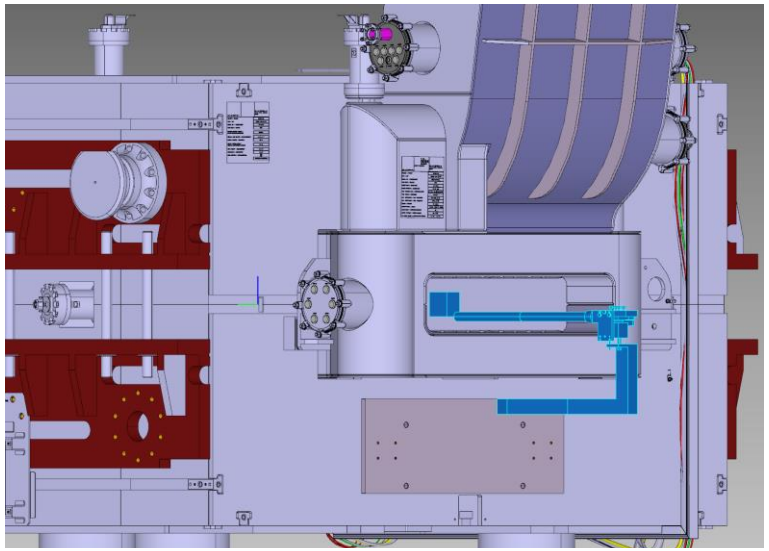

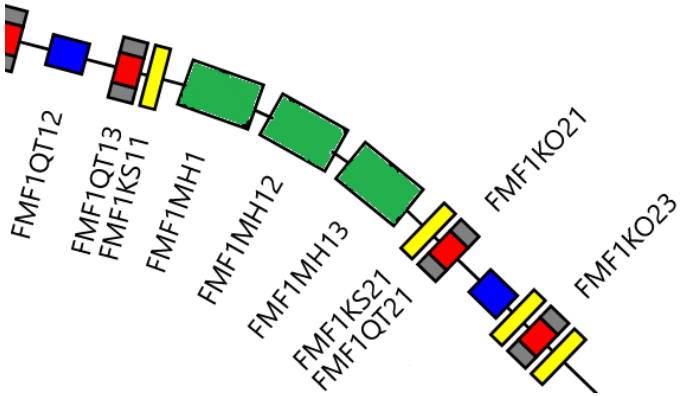

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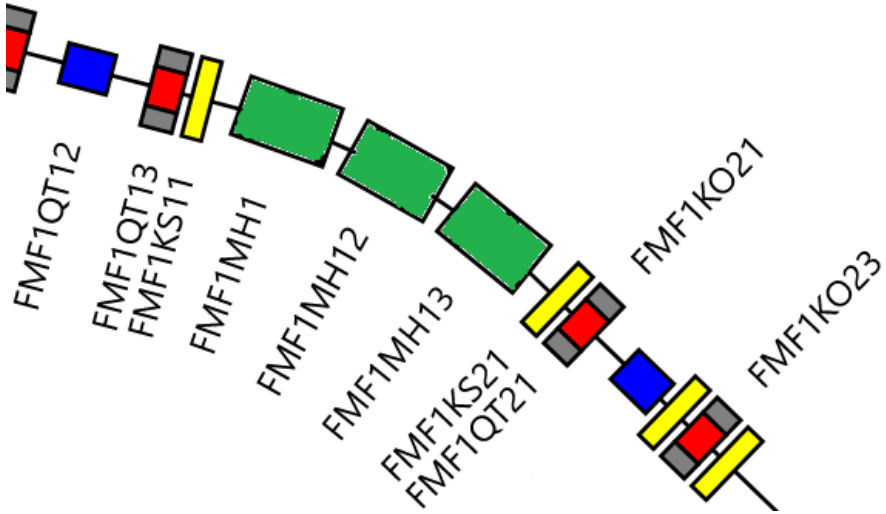

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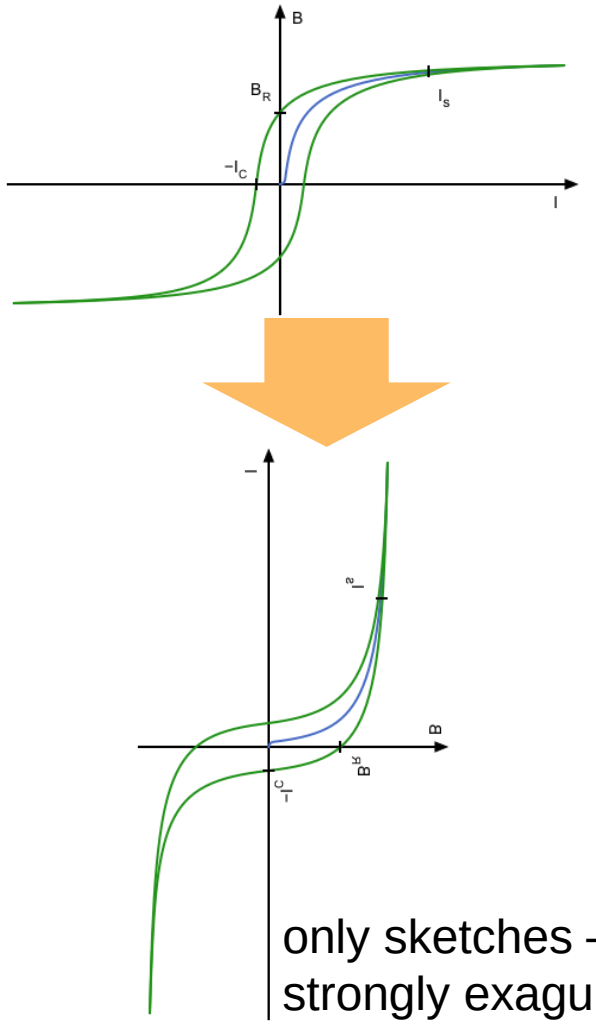

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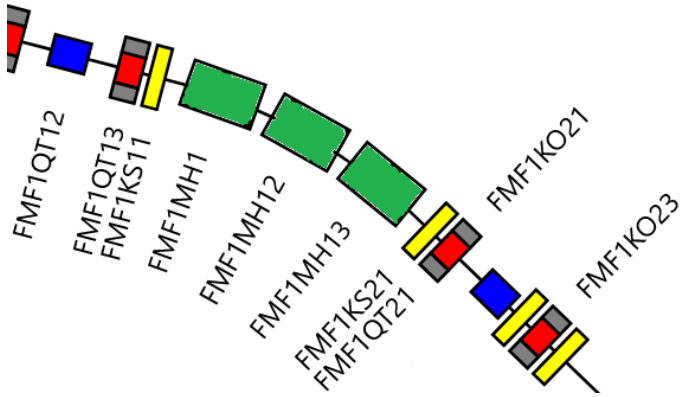
$$^{p}/_{q} = B\rho$$

„Brho“



Goals of the Ion Optical Comissioning

After ion-optical commissioning we should:

- Be able to operate SFRS safely
- Be able to know where the beam is in every section and every magnet
- Be able to scale the settings for different Brho-values quickly without manual retuning
- Have a reliable knowledge about transfer maps of each section and methods to remeasure them quickly
- Reach the design performance for the standard optics: transmission, resolution

Required steps

IO commissioning without beam:

1. Optimize measurement performance of each NMR probe
2. Measure the "calibration" curves for NMR probes (I), Hall probes (B(NMR), I)

Required: Automated setup of magnets and readout of probe data by algorithms

IO commissioning with beam:

1. **Measure ion-optical parameters of the system**
2. Optimize (finetune) the focus properties at focal planes.
3. In planes with full PID measurements (e.g. FMF1), apply optical correction of PID data

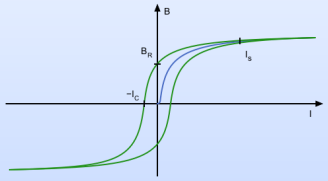
Required: Automated setup of magnets and readout detector data

Time estimate - IO commissioning without beam

Optimize measurement performance of each NMR probe

- Move the holder including probe a bit to see if there is a spot with the best performance at maximal field. (20 min if magnet is not turned off during the movement, 1 h if it is turned off during the movement)
- Find good measurement parameters for about 10 points along the measurement range. (10 min/point if automatized, 0.5h/point if not)
- Time estimate: min **2h**/dipole, max **5.5h**/dipole. For 15 dipoles **4-10** days

Measure the "calibration" curves for NMR probes and Hall probes



- precycle each group of 3 dipoles (max **20 min**)
- for a given list of current set points I_set_i (about 30 points) measure B(I) and U_Hall(I):
  - measure at I_set_i ascending (max **4 min** per point)
  - go I_max, wait. (max **3 min**)
  - measure descending at I_set_i (max **4 min** per point)
  - go to I=0, wait. (max **3 min**)

  each measurement is conducted at all three magnets and includes a waiting time
- Time estimate in case all steps can be automatized: **7h** per group of 3 magnets, otherwise x 3.
  For 15 magnets: **5** days.

Total time estimate: 9 - **25** days

Time estimate - IO commissioning with beam

1. Finetune beam centering & focusing at the target: **2 h**
2. Estimate the 1st order transfer maps at every tracking detector positions, measuring x, a, y, b: **1 day**
3. Center and focus the primary beam from FPF0 to FHF1: **2 days day**

} to be done in || to detector commissioning

4. Measure misalignments of magnets and detectors section by section: **25 h** (x 3 if only partially automatized)
5. Measure the excitation curves of the groups of 3 dipoles, finding symmetric settings → Set I measure B_global with beam.
   - includes cross talk
   - during this we measure the B_local from NMR, gives the I(B_loc) calibration curve
   - ideally 2Tm to 18 Tm
   - This measurement must be repeated for at least 25 points of I for allowing accurate interpolation
   - The beam has to be centered up to the group of considered dipoles
   - Time estimate 0.5 h per group per I level: **23 days** in total
6. Measure the path length of reference particle in ToF measurement sections: **2 h**
7. Measure higher order transfer maps, compare to the simulations (no additional beamtime, just additional analysis)
8. Validate the cross-talk corrections **2 days**

required: automatic DAQ tested during control system commisioning and available for IO comissioning

optional:

1. Finetune the focus properties at focal planes
   - refine optimization for set of Brho's for each section.
   - store settings including interpolation functions for Brhos between the measurement points with proper documentation and access. Do it for all ES optics
   - Time estimate: **1 day** per optics setting
2. In planes with full PID measurements (e.g. FMF1), try out online optical correction of PID histograms (no additional beamtime, just additional analysis)
   - for this, transfer map of FPF0-FMF1 shall be known.
   - applying inverse transfer map to the measured in FMF1 phase space one can get initial phase space at FPF0.
   - Having it known, we can subtract from each plane the undesired high order aberrations to resolve better different fragments.

Total time estimate: 40 days

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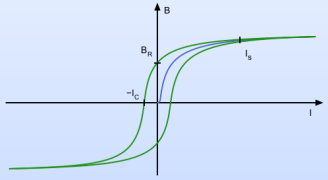

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Total time estimate: 9 - **25** days

Prerequisite: automatization framework

SFRS Control systems specific application and commissioning specific applications for SFRS for automated access by algorithms

- setting/reading out the magnet status (all **94** HEB magnets + **12** FS magnets)
- probe handling: set parameters, measure, switch probes (**30** NMR probes, **15** Hall probes)
- setting/reading out the status of each drive: **few 10** of drives

➢ **About 200 items:** if everything is well prepared* 2 min/item, otherwise x 5.

*about **6** months with **3** FTEs for preparation before the commissioning

Total time estimate: 1 - **4** days

Summary

- Automatization framework is crucial
- Preparation of 6 month with 3 FTEs is desired for successful IO commissioning
- Up to 4 (autmatization) + 25 (probes) days without beam and 40 days with beam are essential to cover all main aspects of IO commissioning