The muEDM experiment at PSI

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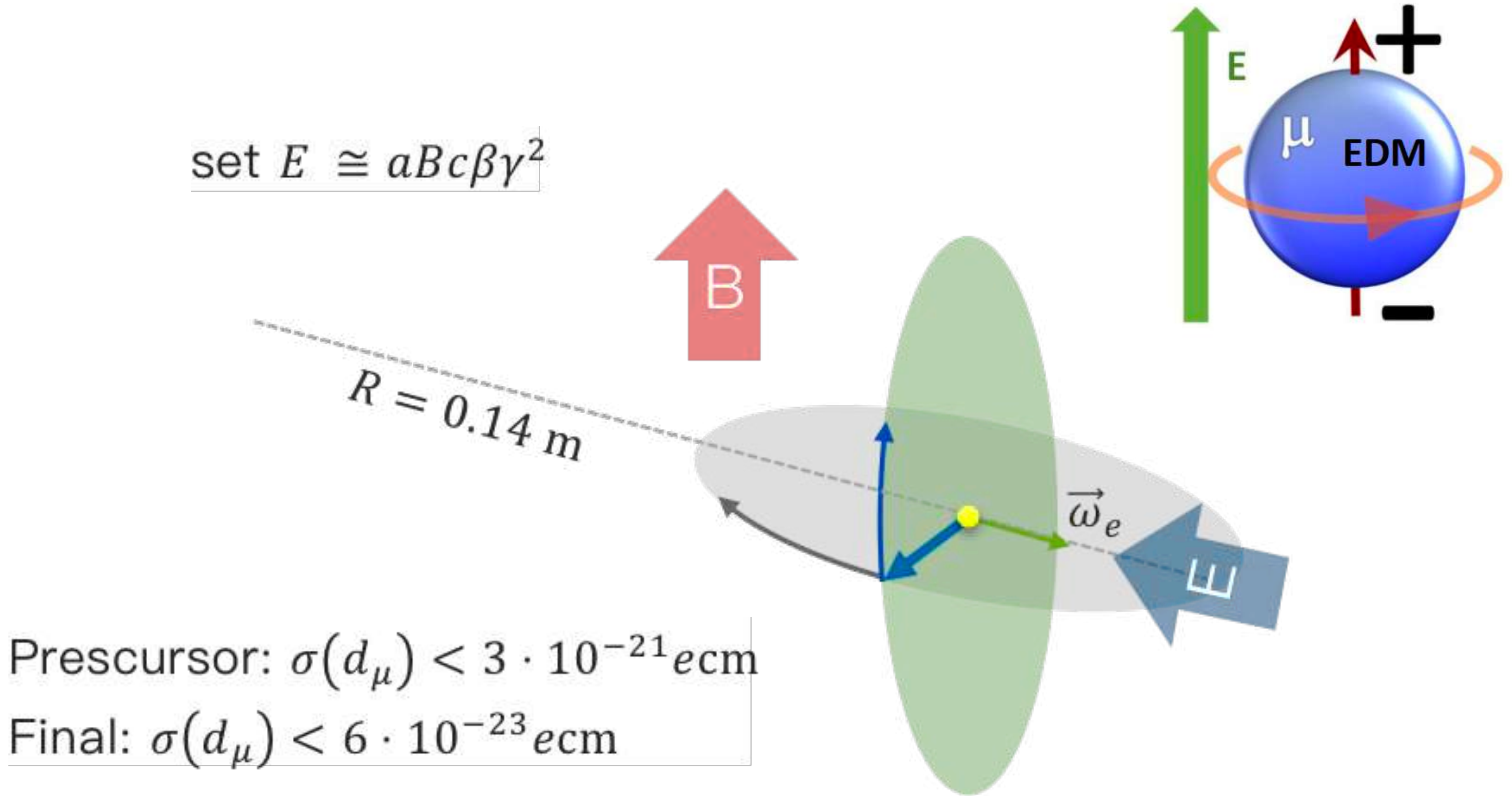

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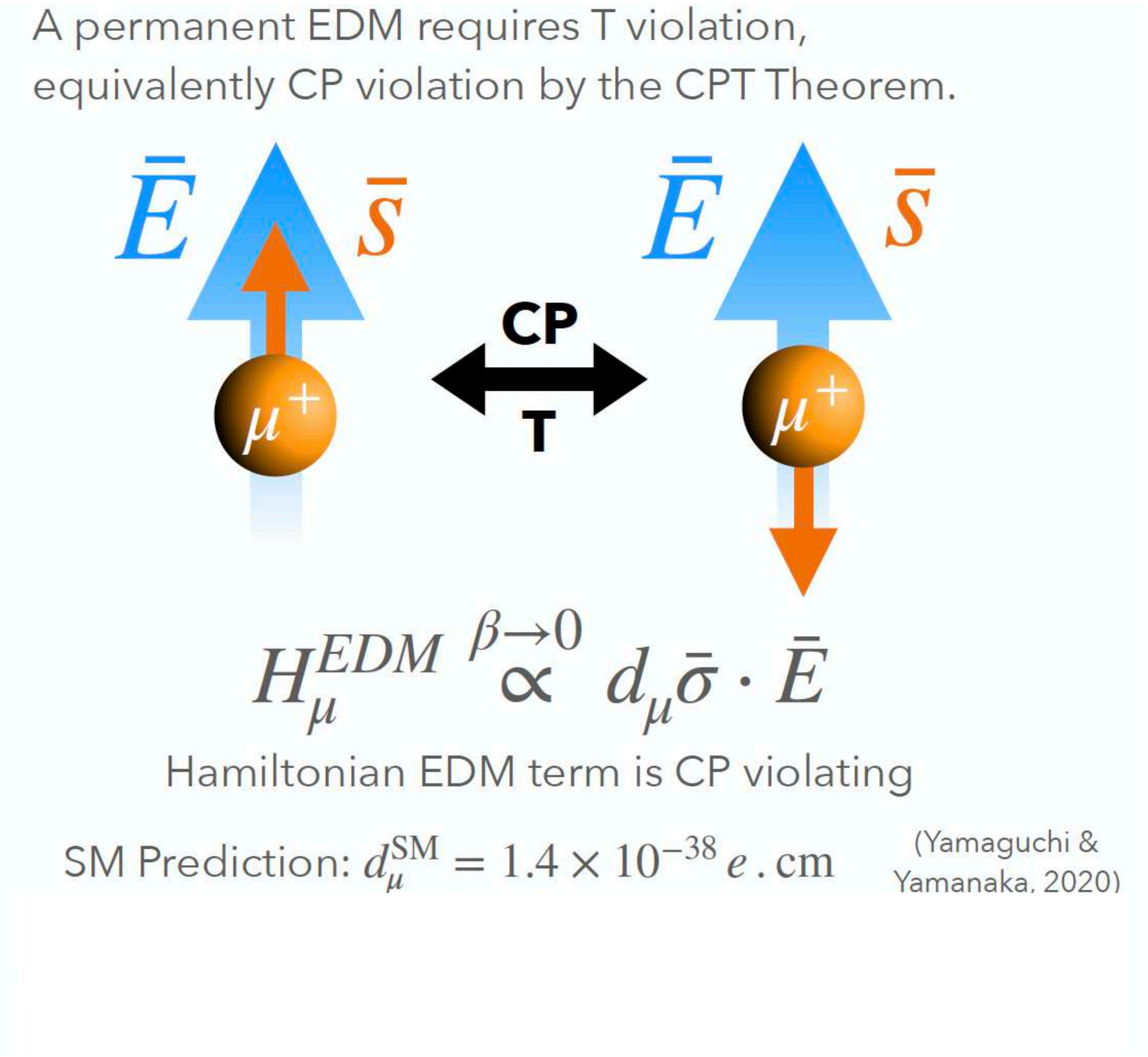
Content

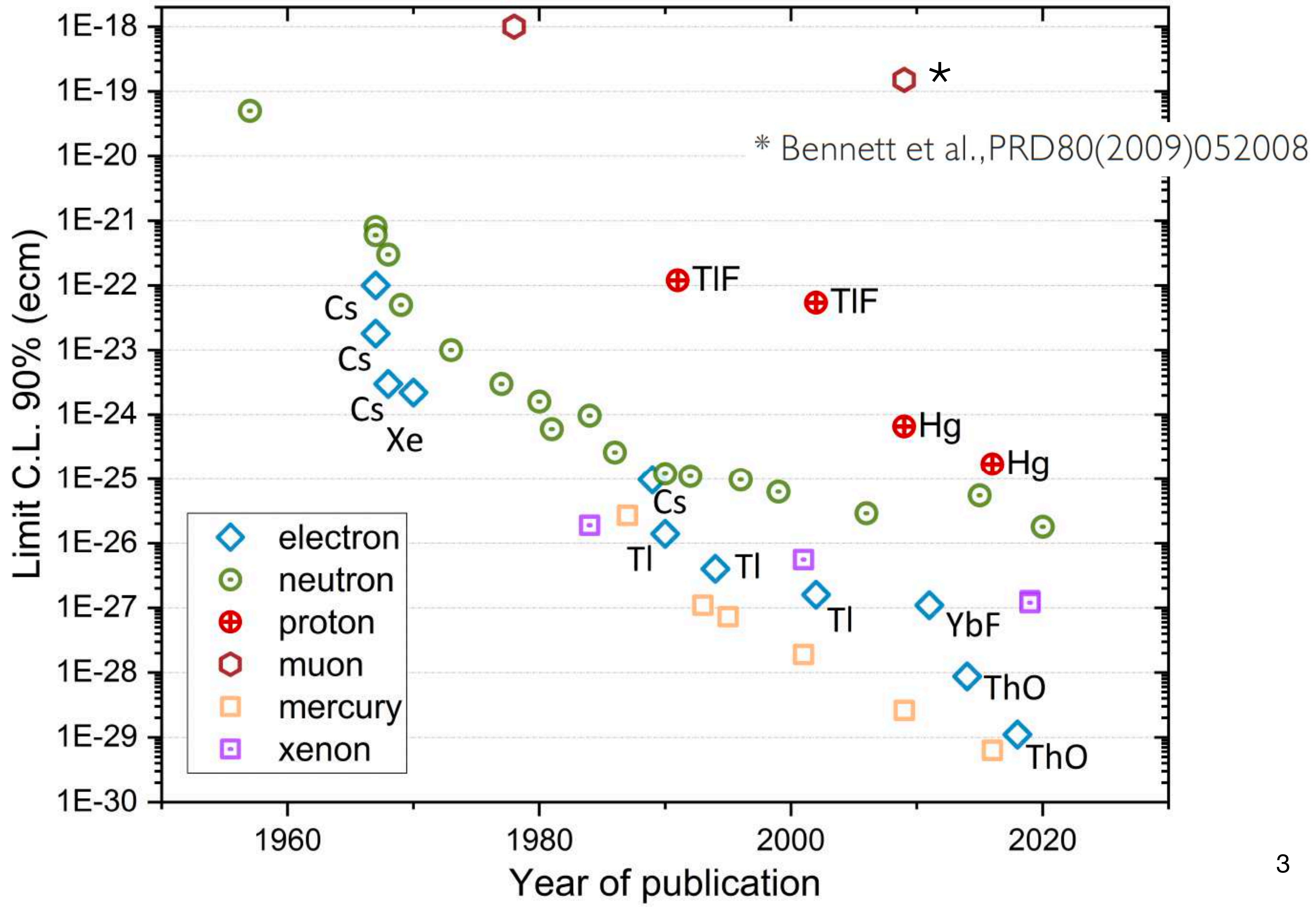
- Physics Motivation
- The experimental concept
- The experiment status
- Schedule
- Conclusions

muEDM dedicated search: Current status and Motivations

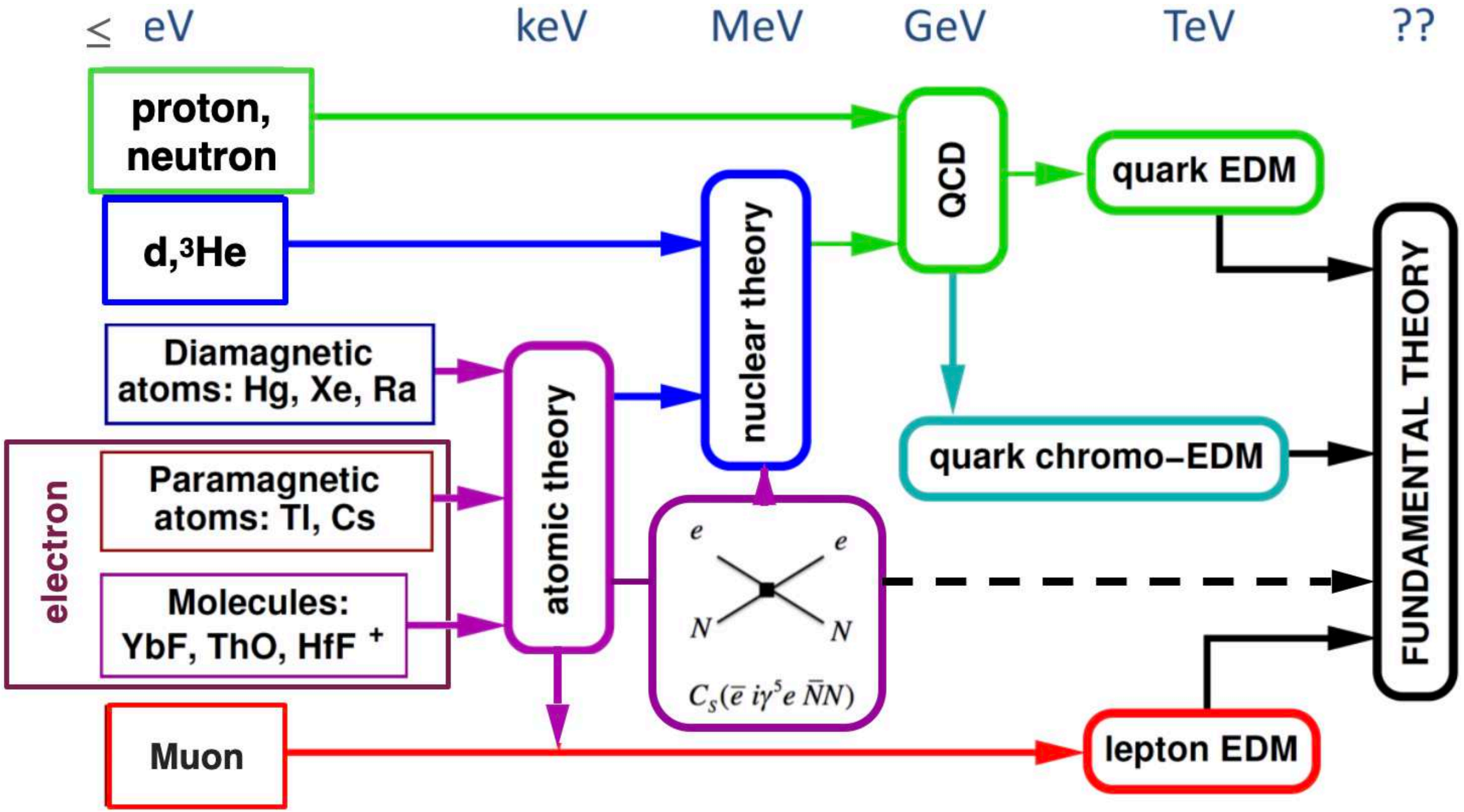
- EDMs of fundamental particles are intimately connected to the **violation** of time invariance **T** and the combined symmetry of charge and parity **CP**
- The different EDM searches are sensitive to **different**, **specific** combinations of underlying **CPV sources**
- **Muon unique** feature: the only currently direct accessible EDM of a **naked** fundamental particle

Quite poor current direct limit
d_μ **<1.5×10^{-19} $e$cm (CL 90%)**

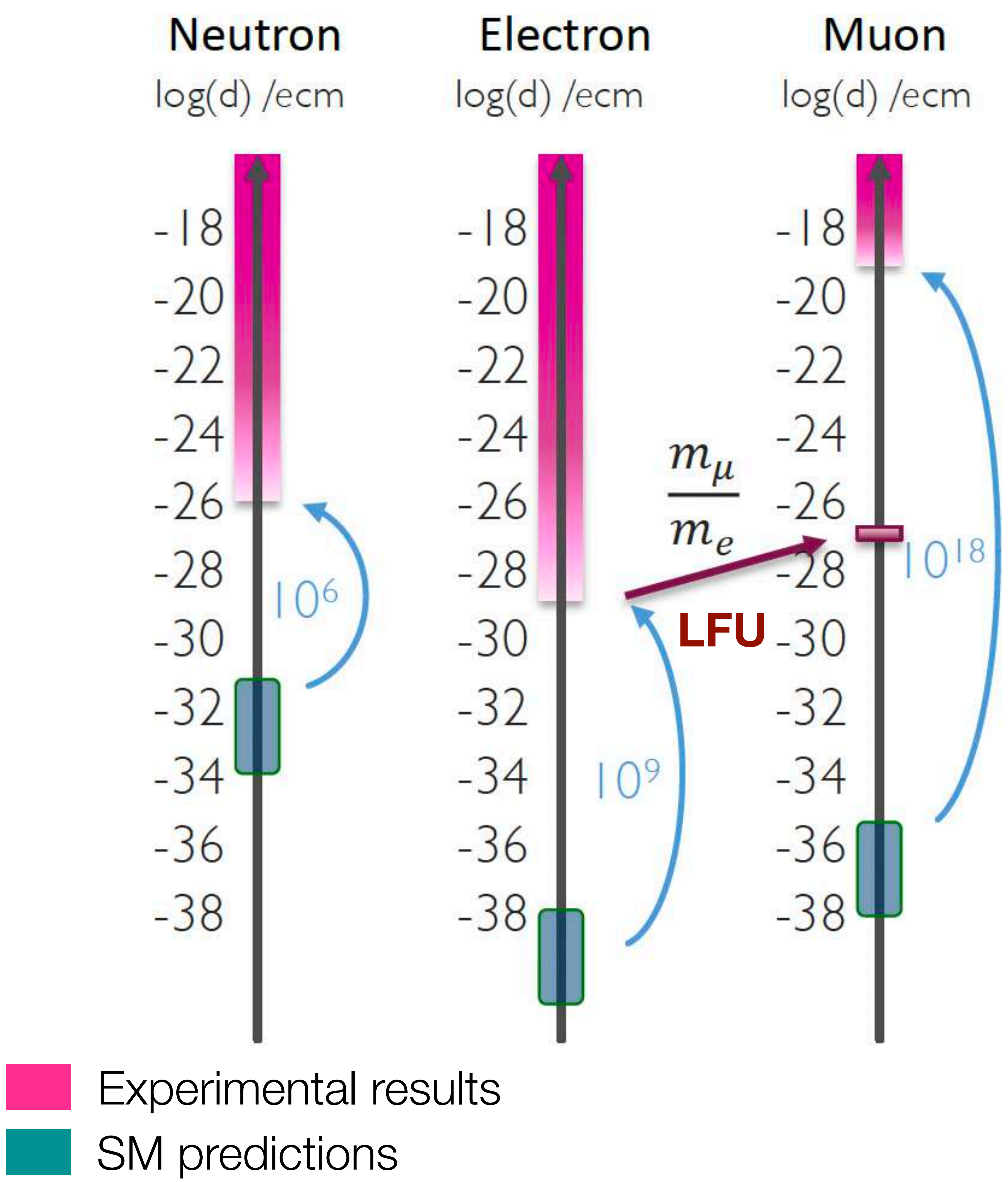




Complementarity of EDM searches



muEDM direct search: Why now?



- FNAL/JPARC g-2 experiments aims at d_μ ~ O(10^{-21}) ecm (via g-2)
- **Direct muEDM search at PSI in stages:**
  - **Precursors: $d_\mu < 3\times10^{-21}$ ecm**
  - **Final: $d_\mu < 6\times10^{-23}$ ecm**

Reminder: g-2 experimental approaches

In uniform magnetic field, muon spin rotates ahead of momentum due to g-2 = 0

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

BNL E821 approach
γ=30 (P=3 GeV/c)

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

Continuation at **FNAL** with **0.1ppm** precision

J-PARC approach
E = 0 at any γ

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

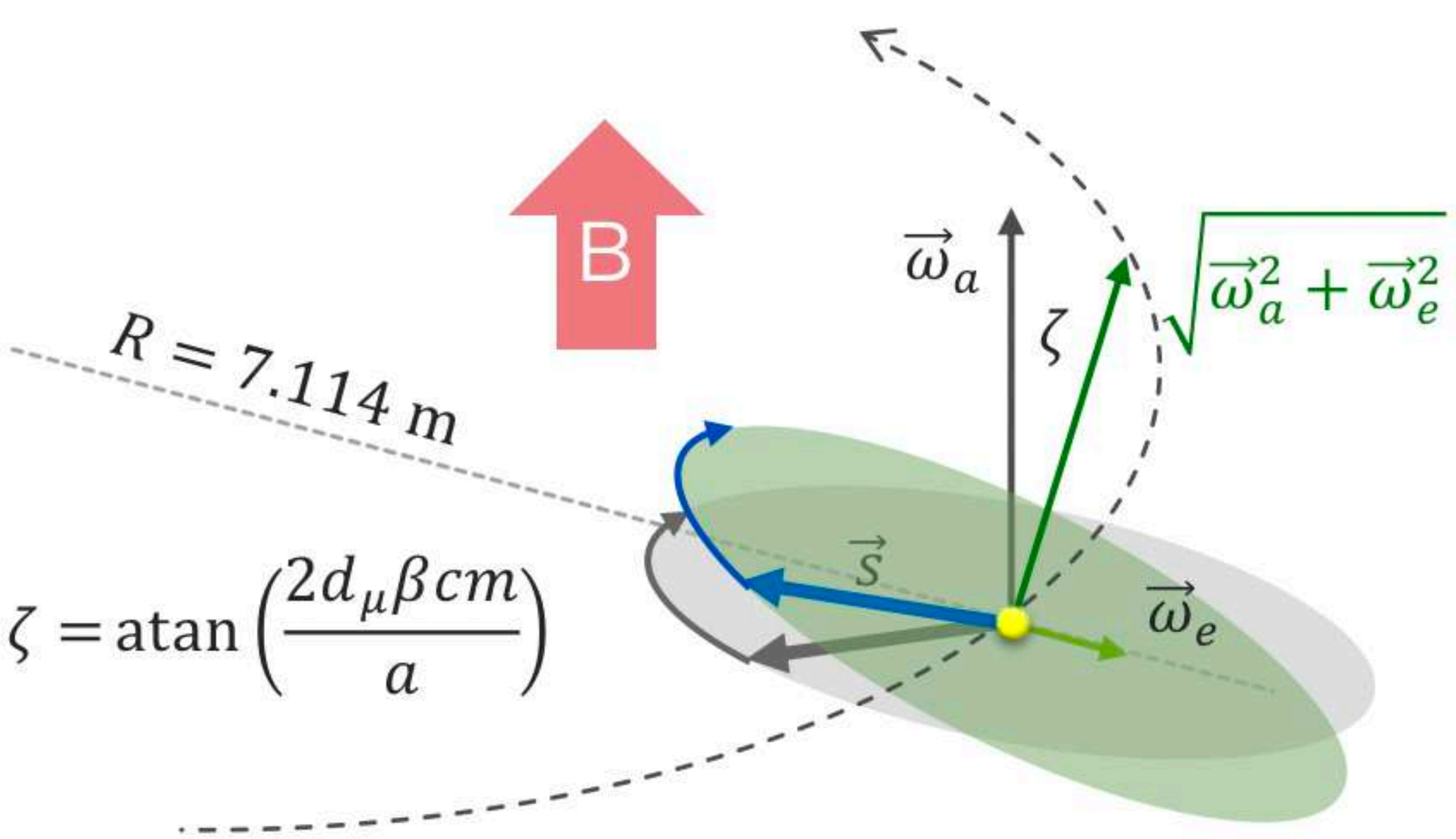
Proposed at **J-PARC** with **0.1ppm** precision

EDM search: From the “frequency” approach…

$$\vec{\omega} = \frac{q}{m}\left[a\vec{B} - \left(a + \frac{1}{1-\gamma^2}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right] + \frac{q}{m}\frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)$$

ω_a ω_e

- i.e. FNAL: The decay positrons are recorded using calorimeters and straw tube trackers inside the storage ring
- The sensitivity to a muon EDM is limited by the resolution of the vertical amplitude, proportional to ζ, of the oscillation in the tilted precession plane
- i.e. J-PARC: even if the technique is different the sensitivity to an EDM is limited by the resolution of the vertical amplitude



…to the frozen-spin technique

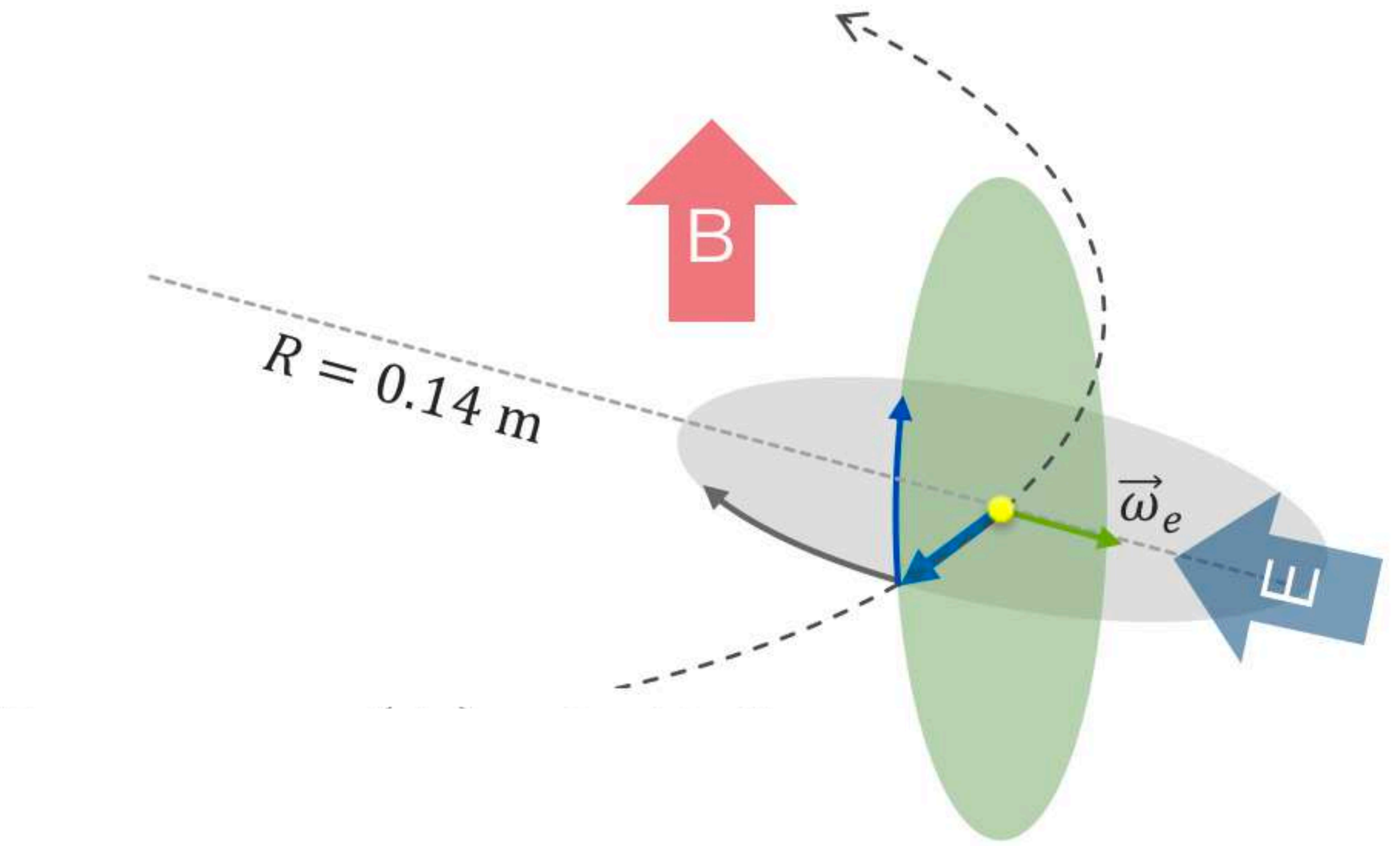
$$\vec{\omega} = \underbrace{\cancel{\frac{q}{m}\left[a\vec{B} - \left(a + \frac{1}{1-\gamma^2}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]}}_{\omega_a} + \underbrace{\frac{q}{m}\frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)}_{\omega_e}$$

- The frozen-spin technique uses an Electric field perpendicular to the moving particle and magnetic field, fulfilling the condition:

$$a\vec{B} = \left(a - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}_f}{c}$$

- Without EDM, $\omega = 0$, the spin follows the momentum vector as for an ideal Dirac spin-1/2 particle, while with an EDM it will result in a precession of the spin with $\omega_e \parallel E$

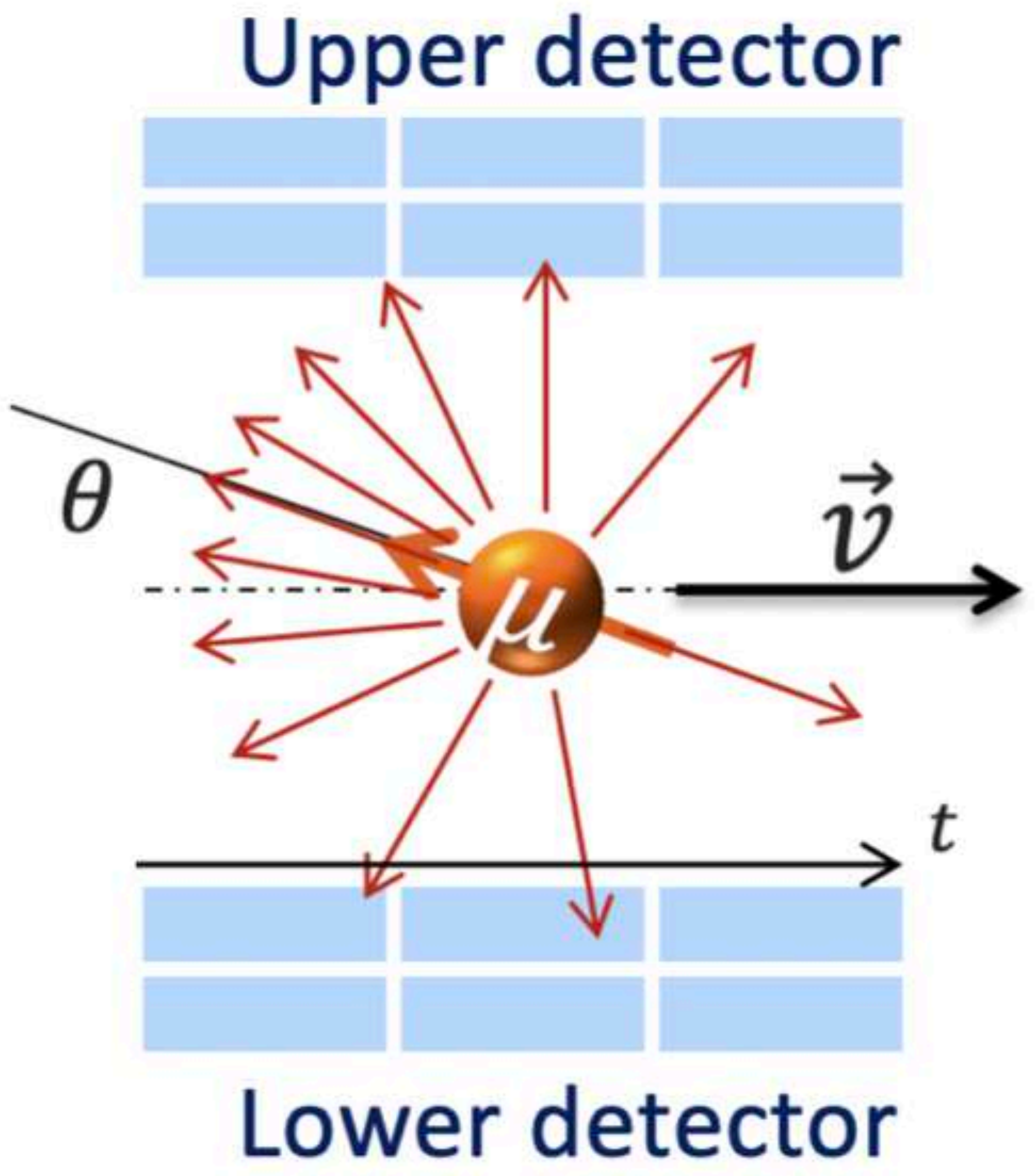
- The sensitivity to a muon EDM is given by the asymmetry up/down of the positron from the muon decay

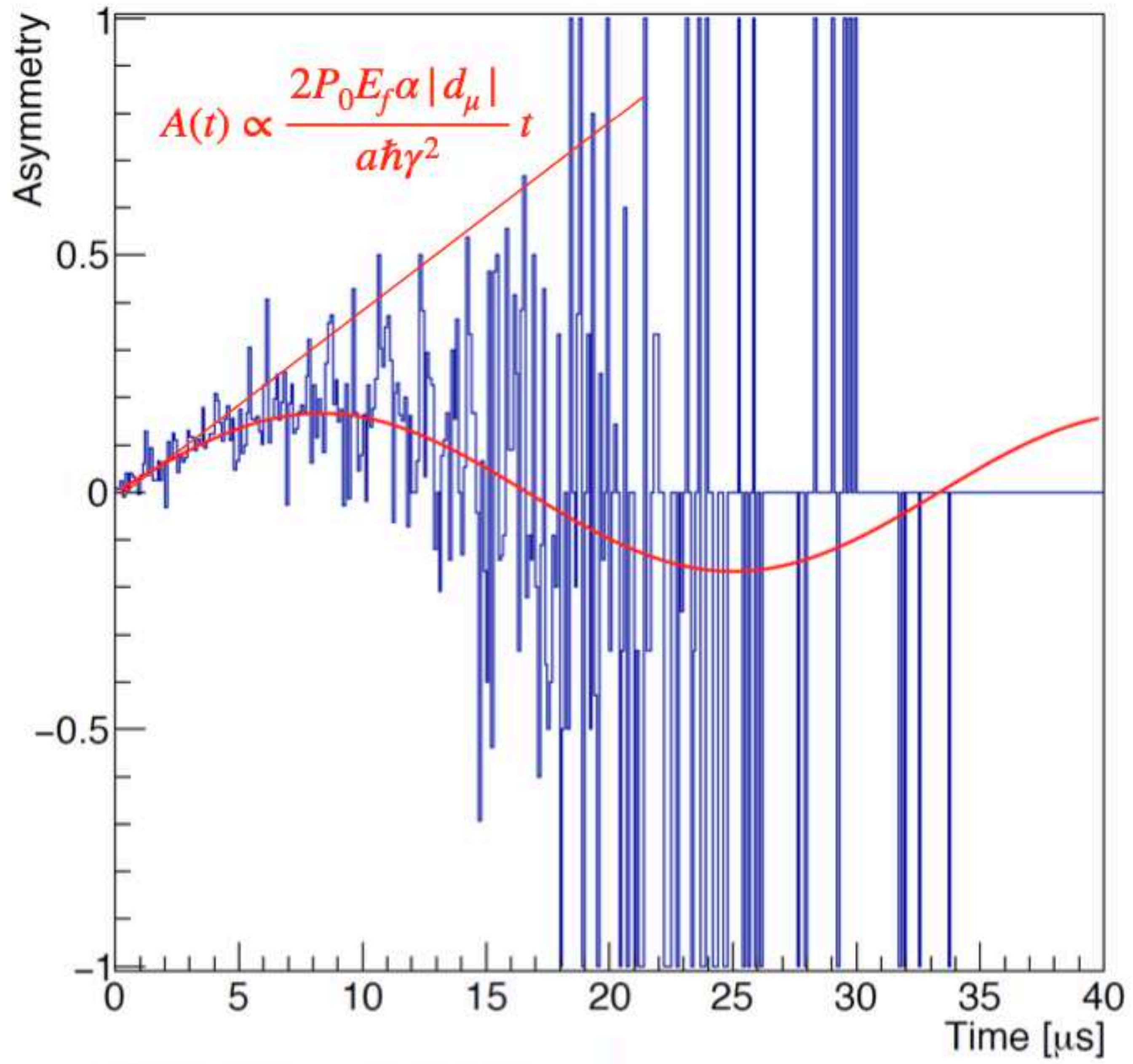


$$E_f \approx aBc\beta\gamma^2$$

Signal: asymmetry up/down positron tracks

- Positron are emitted predominantly along the muon spin direction
- The sensitivity to muon EDM is extracted from the **asymmetry up/down** of the **positron** from the muon decay, averaged over the muon decay time distribution (lifetime = $\gamma\tau_\mu$)





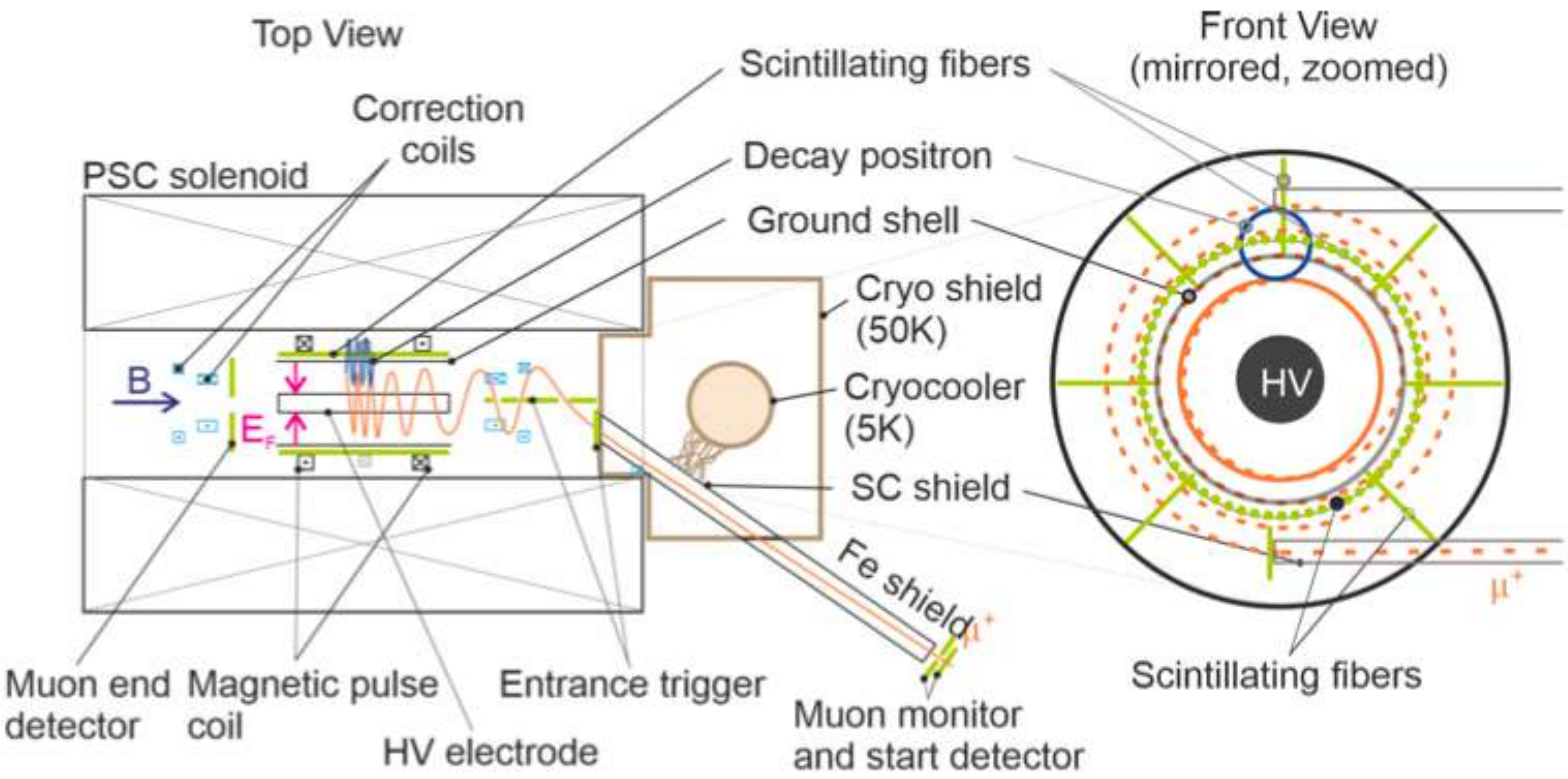
- P_0 = initial muon polarisation
- E_f = electric field in the lab frame
- N = number of observed decays
- τ_μ = muon lifetime
- α = mean decay asymmetry (~ 0.3)
- a = anomalous magnetic moment
- γ = gamma factor of the muon

$$A(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)} \propto \frac{2P_0E_f\alpha|d_\mu|}{a\hbar\gamma^2}t$$

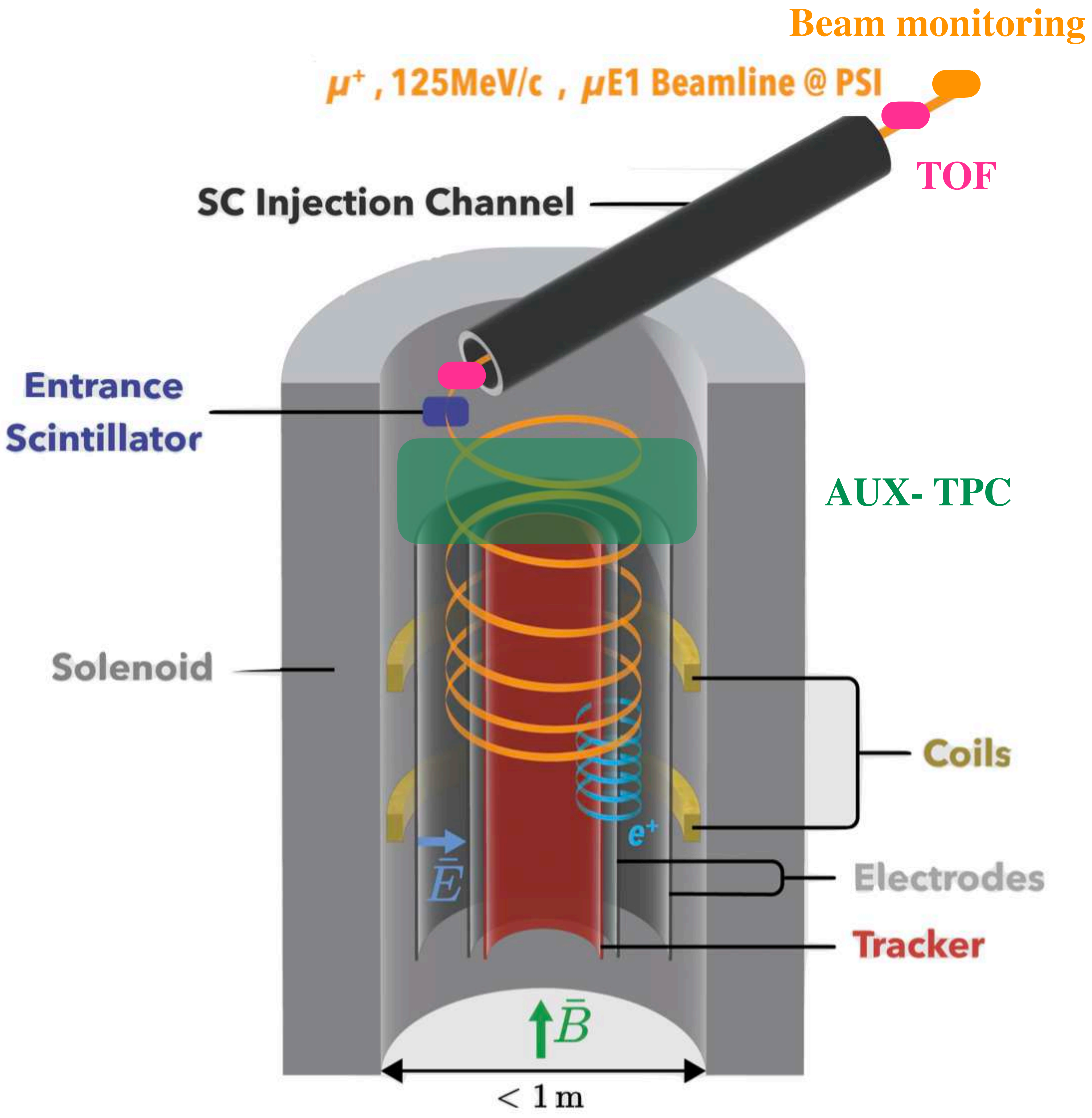
$$\sigma(|d_\mu|) = \frac{d|d_\mu|}{d\bar{A}}\sigma(\bar{A}) \sim \frac{a\hbar\gamma}{2P_0E_f\sqrt{N}\tau_\mu\alpha}$$

The general experimental idea

- Muons enter the **uniform magnetic** field region via **SC injection lines. Correction coils** are used to increased the storage efficiency
- A **radial magnetic** field pulse stops them within **a weakly focusing** where they are **stored**
- **Radial electric** field **“freezes” the spin** so that the precession due to the magnetic dipole moment is cancelled

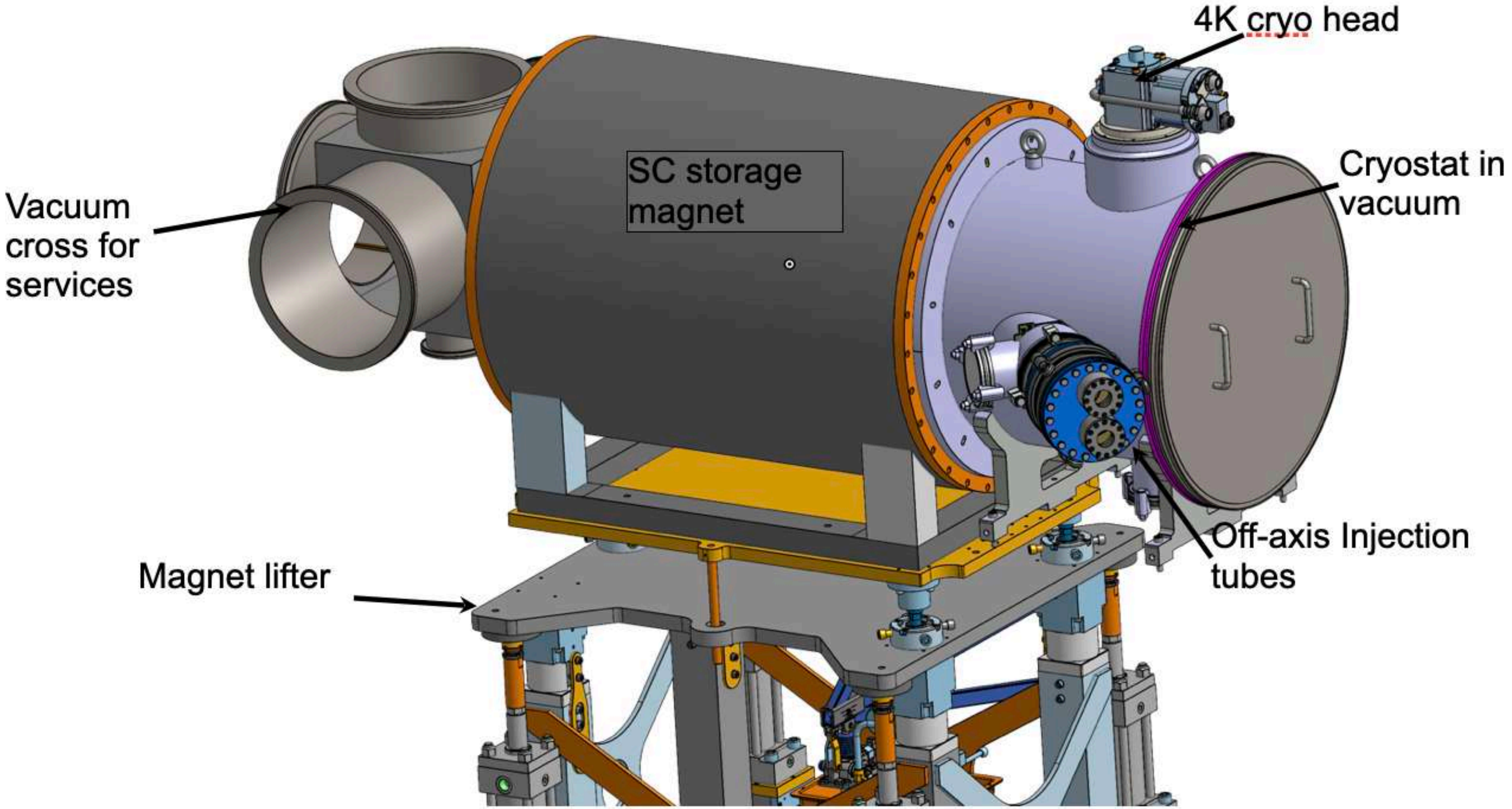


The general experimental idea: The item list

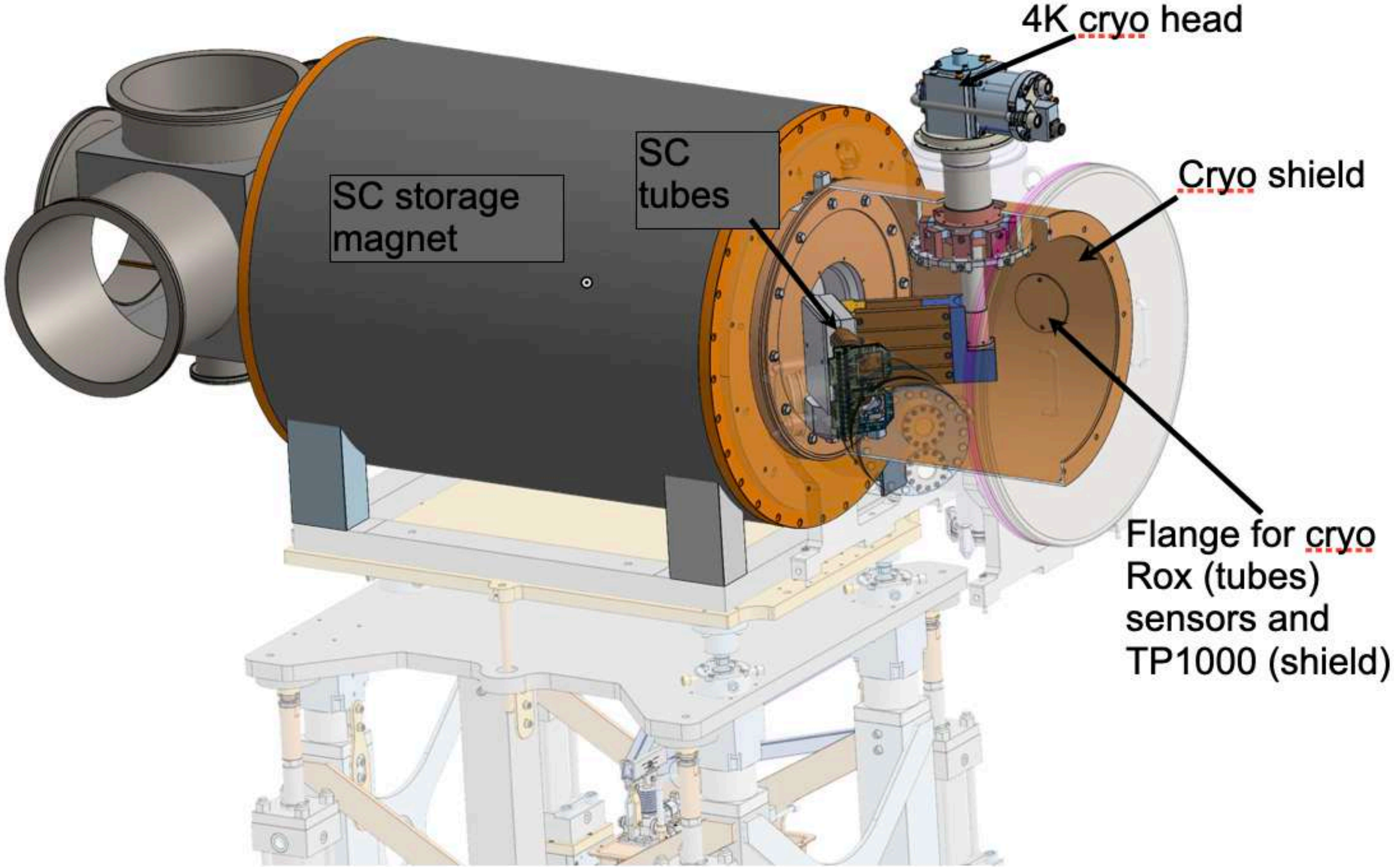


- Muons from pion-decays >> high polarisation p ~95%
- Injection through superconductor channels
- Compensation coils
- Muon beam detector
- Time of Flight detector for the systematics
- Entrance detector for the kicker
- Magnetic kicker and weekly focusing coil
- Thin electrodes for the frozen spin
- Positron detector for the g-2 and muEDM signature
- AUX detectors (i.e. TPC for the initial experimental settings)
- TDAQ
- MC/Analysis

Where we are NOW: Construction and integration phase



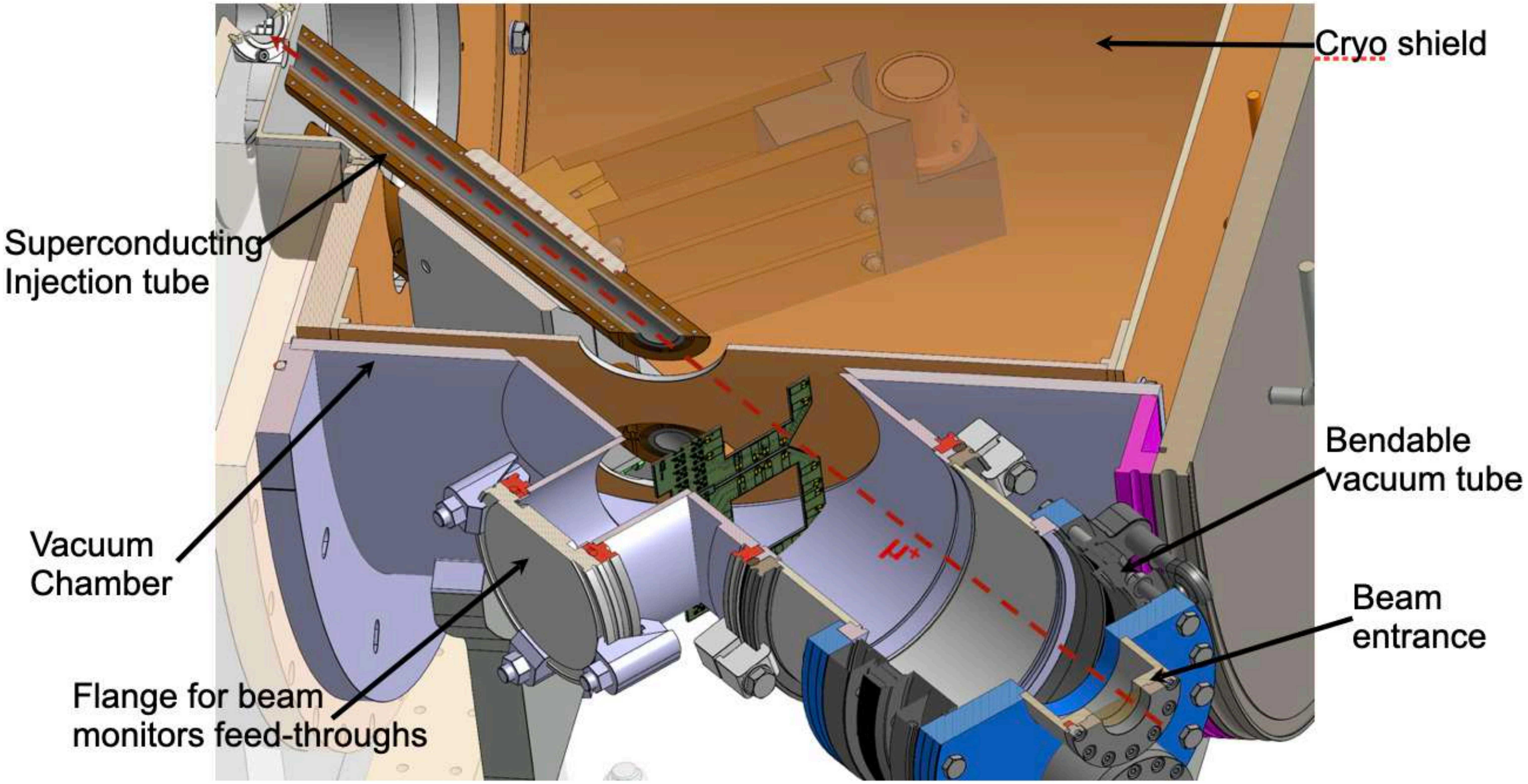
Where we are NOW: Construction and integration phase

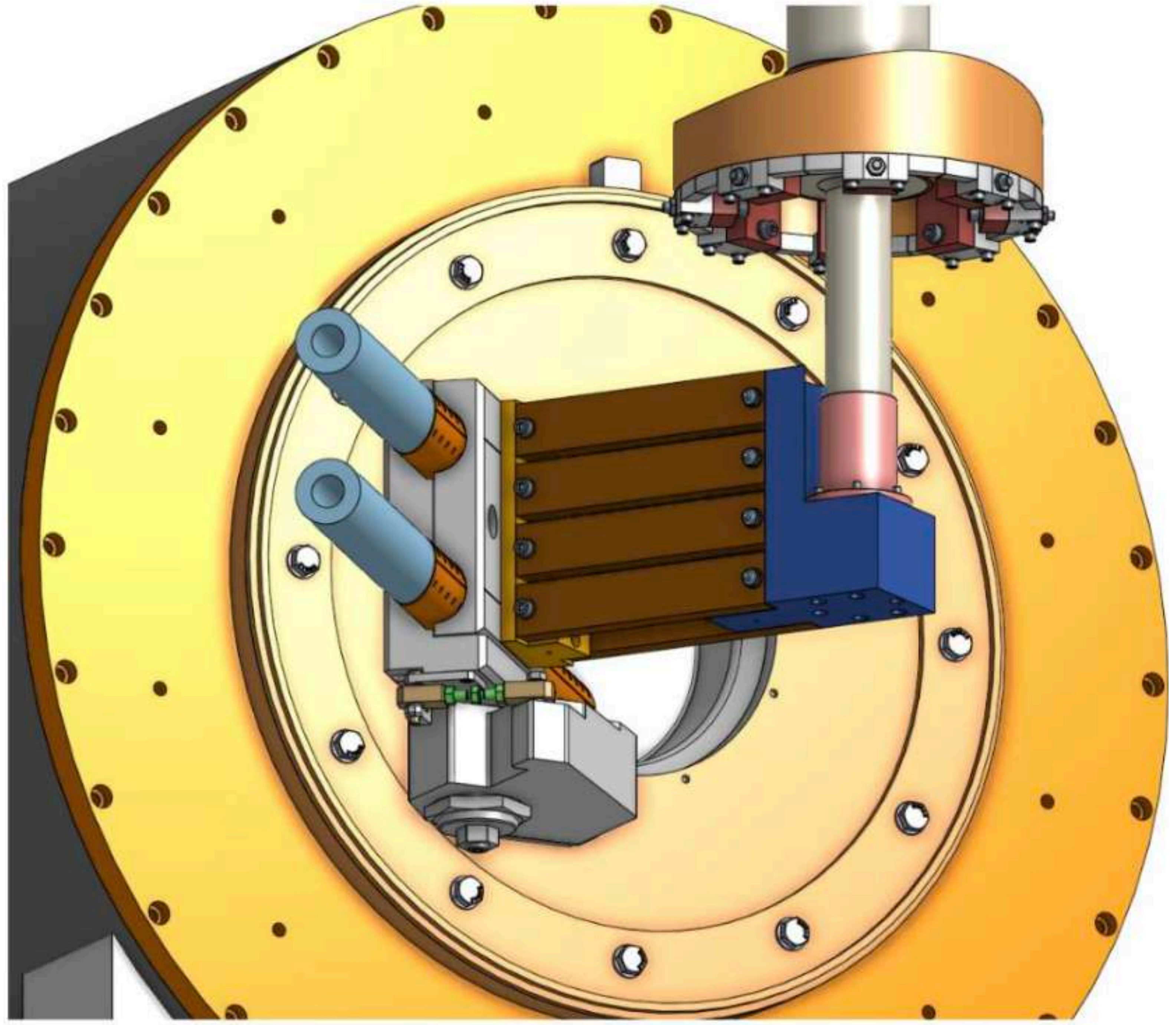


Muon injection: Super-conducting lines + Cryo Head

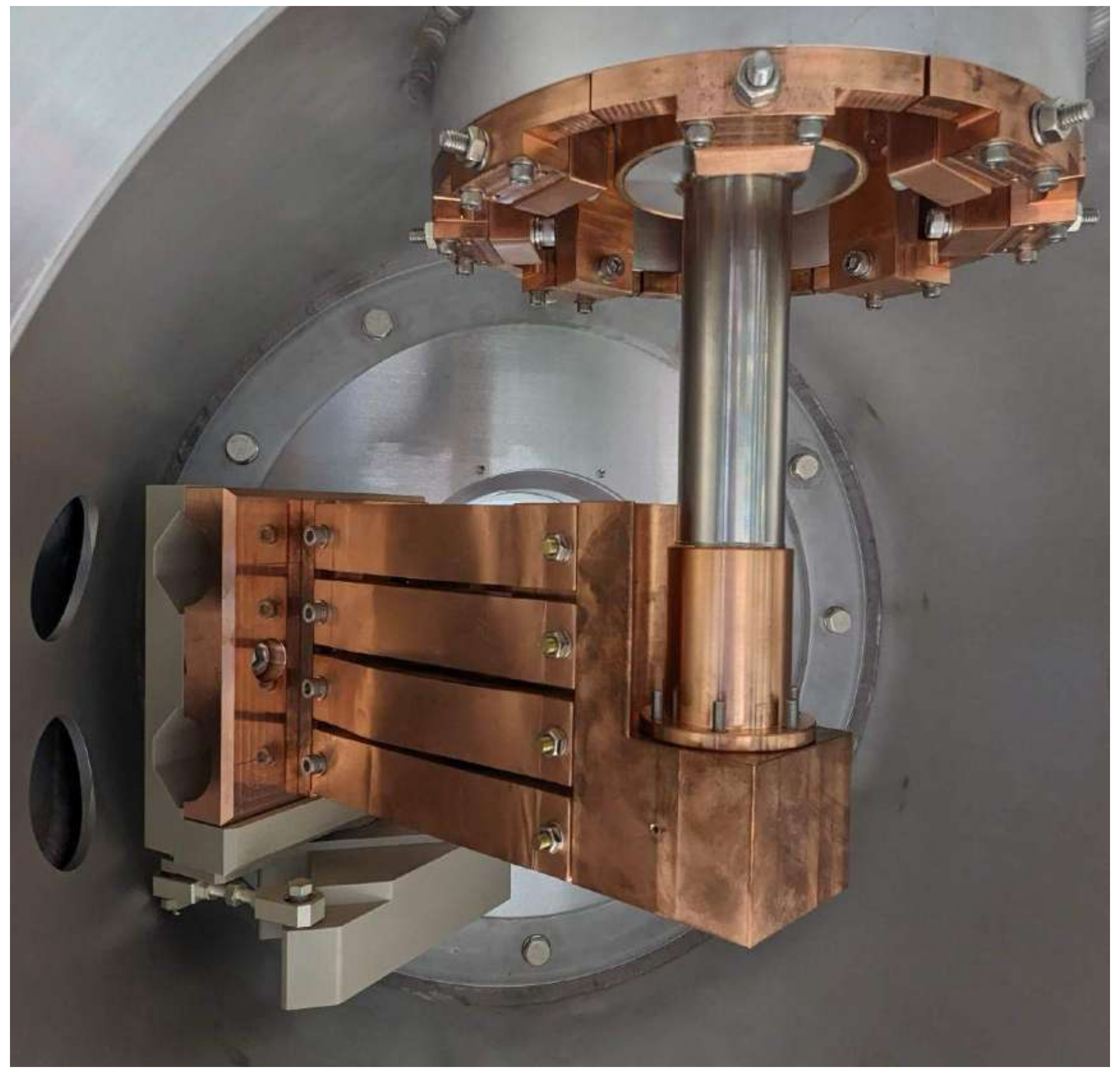
Muon transport into the solenoid bore through **superconducting (SC) injection tubes**

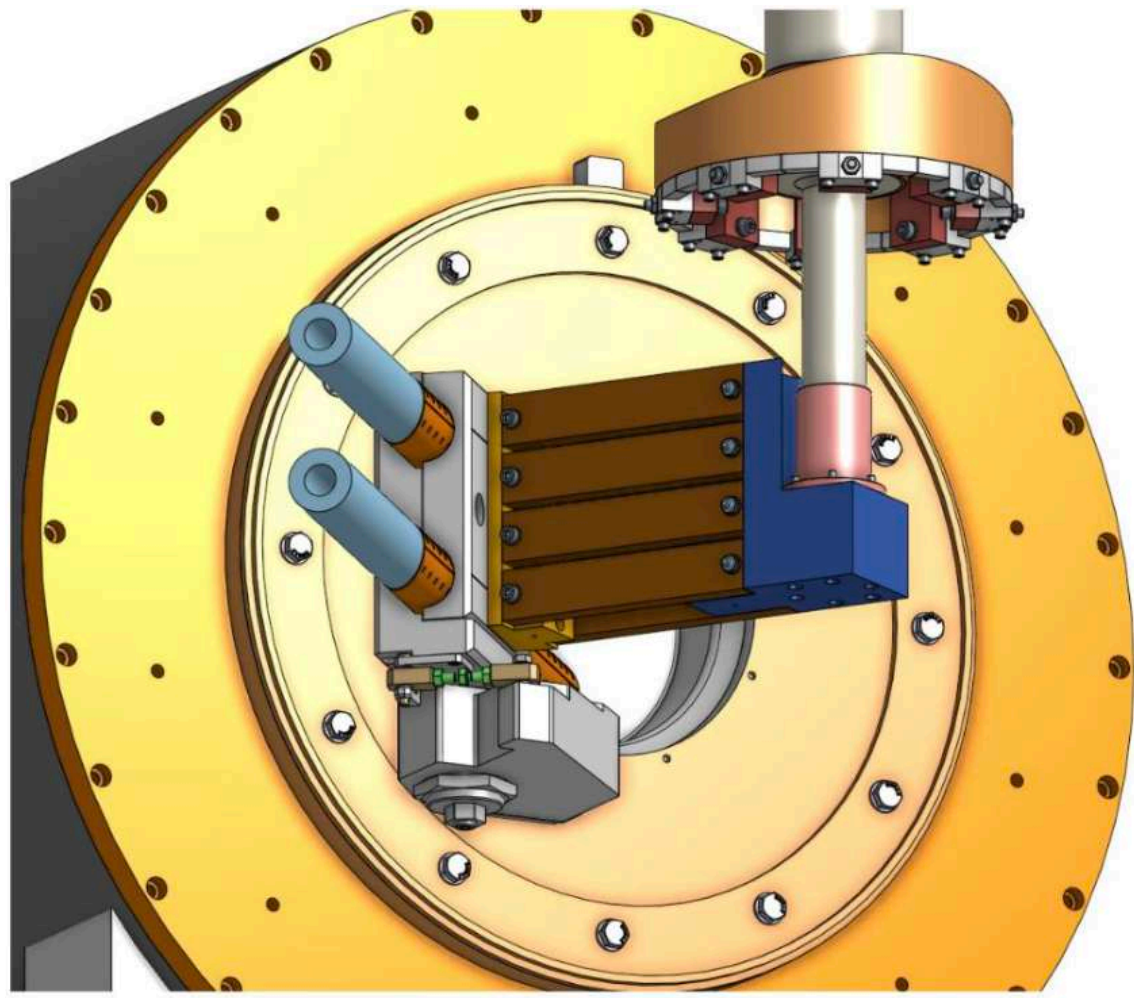
- **Shielding from the fringe magnetic** field to make the deflection negligible ($B_{\perp}$<10 mT, $B_{\parallel}$< 1 T)
- Transmission about 3% • 4 types of SC shields available
- tested BSCCO2223, NbTi, HTS REBCO ‣ **NbTi/Nb/Cu sheets** most promising (~3.1 T) - in preparation for the end-of-year test beam



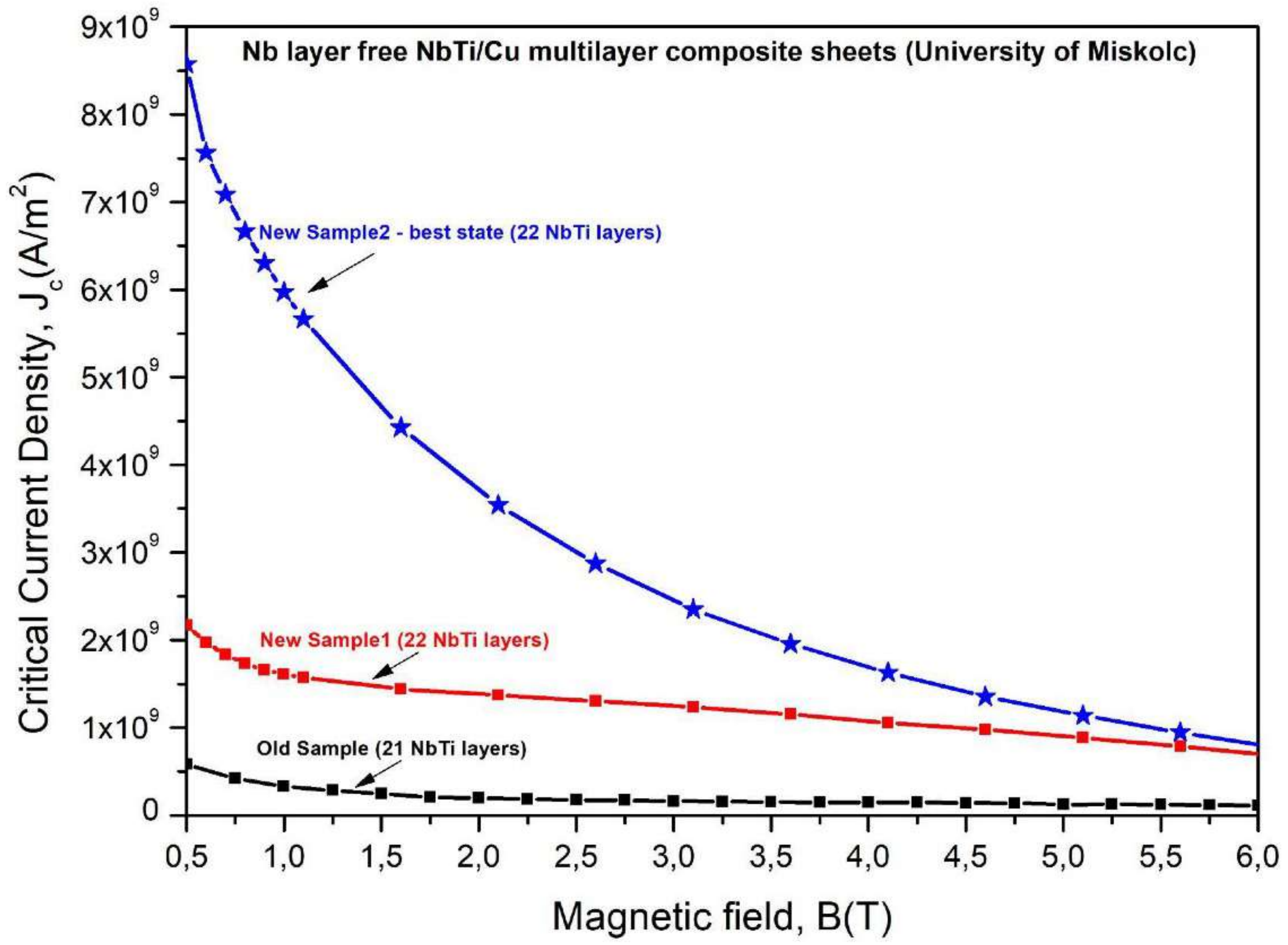


Super-conducting injection lines + Cryo Head in reality





- Arrived on 23.05.2025
- Internal parts, cold head fit✅
- All internal parts cleaned for UHV✅
- Vacuum ✅
- Transported to experimental hall ✅
- Temperature monitoring system ✅
  - 4 x ROX temperature sensors
  - 5 x PT-1000 temperature sensors
  - 2 x Lakeshore model 340
- Reached ~10e-6 mBar ✅
- **First cool down planned before July 10th**



- The NbTi/Nb/Cu sheets are ready to be rolled into slitted cylinders @PSI ✅
  - These sheets have shielded up to 3.1 T see arXiv:1809.04330
- Sheet rolling technique has been tested on a steel sheet with identical dimensions ✅
- Superconducting channel holders (inner tube and clamps) **arrive on July 15th**
- Magnetic field Hall sensors for shielding measurements ✅
- Additionally working on implementing new Nb layer free sc sheets (labeled *New Sample2*) from University of Miskolc. The sheets are expected to heavily outperform our current sheets and could be used for Phase II.

Muon entrance trigger and TOF

Trigger the kicker for storable muons

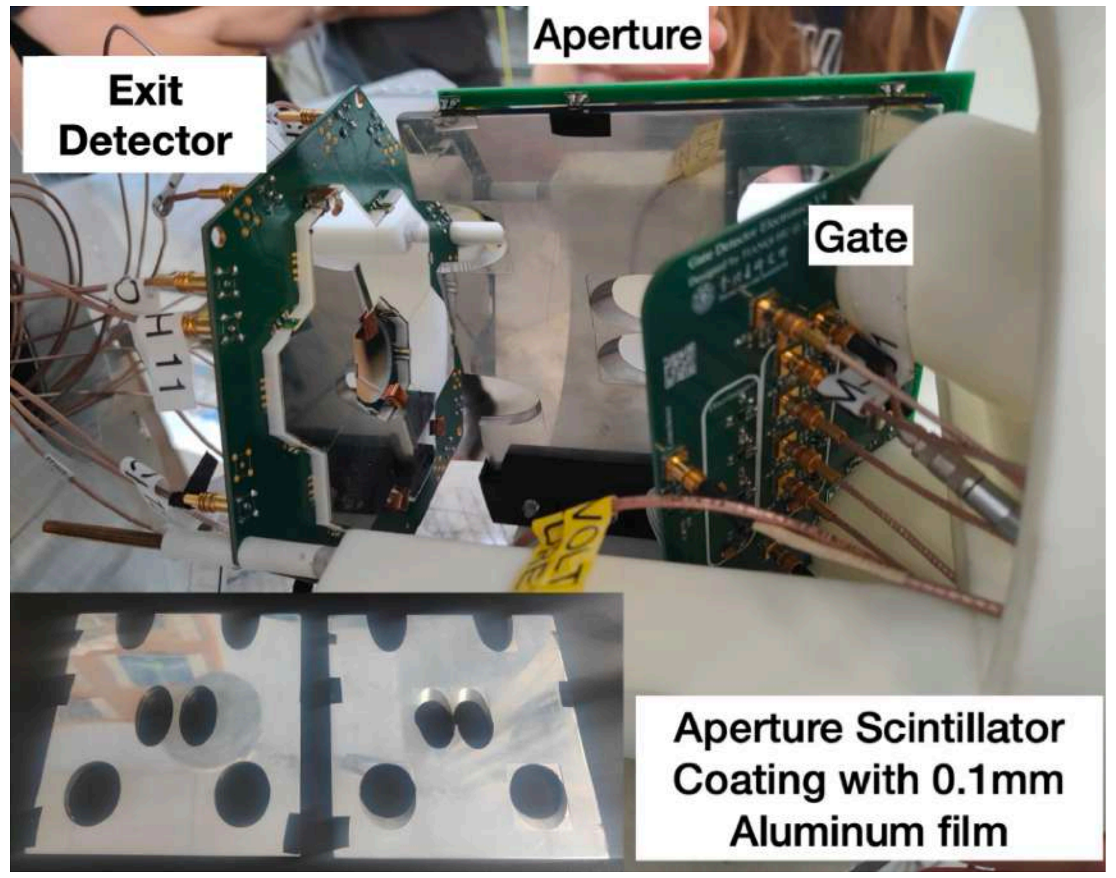
- ~1% of the incoming μ are in the acceptance phase space
- Thin entrance scintillator with active aperture as veto

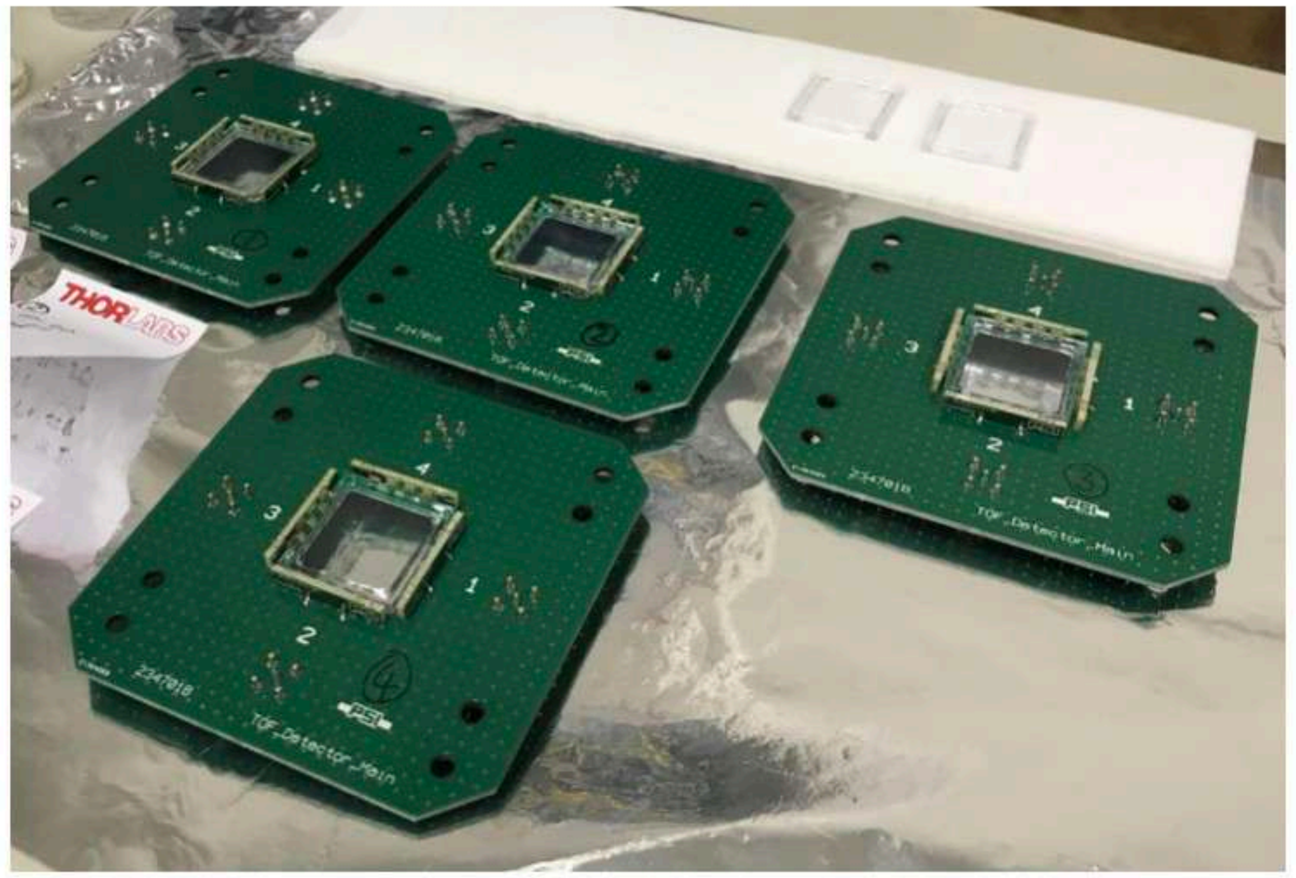
Time of Flight (ToF) detectors for measure the muon momentum

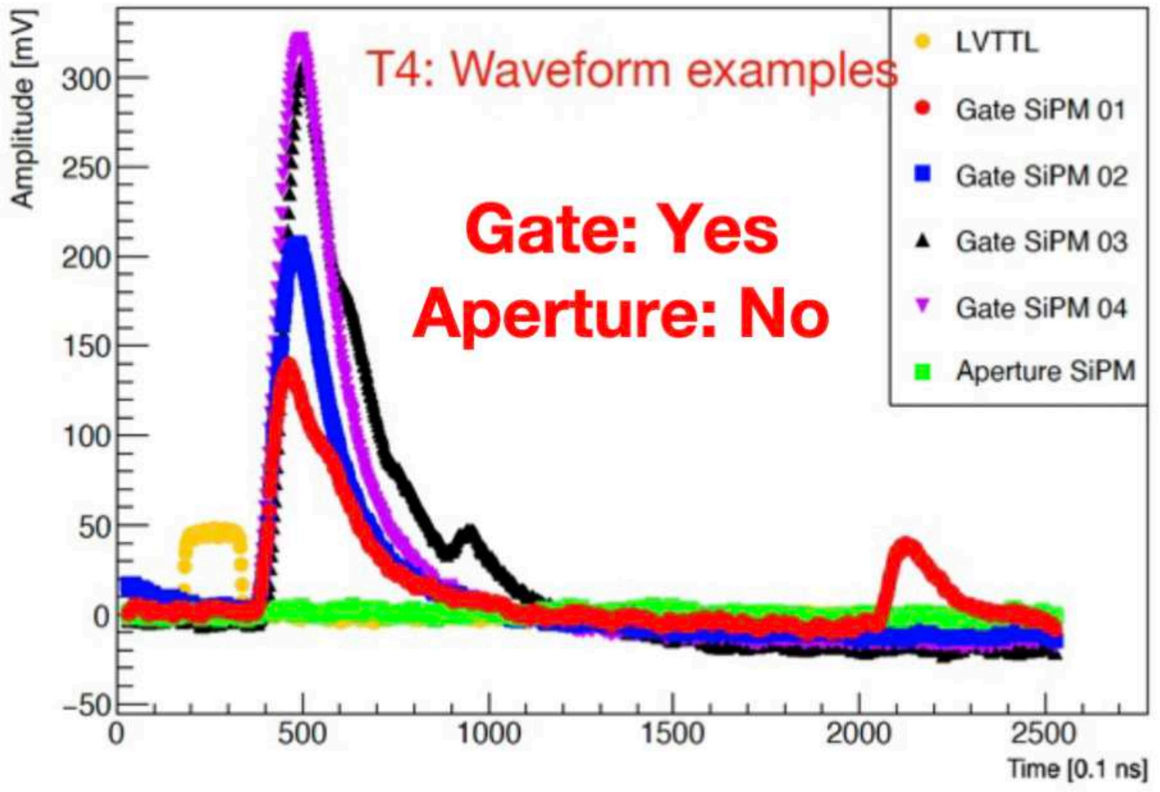
- <1% essential for controlling the main systematic uncertainties (alignment of the electric field with respect to the magnetic field)

Good performance in 2024 beam test

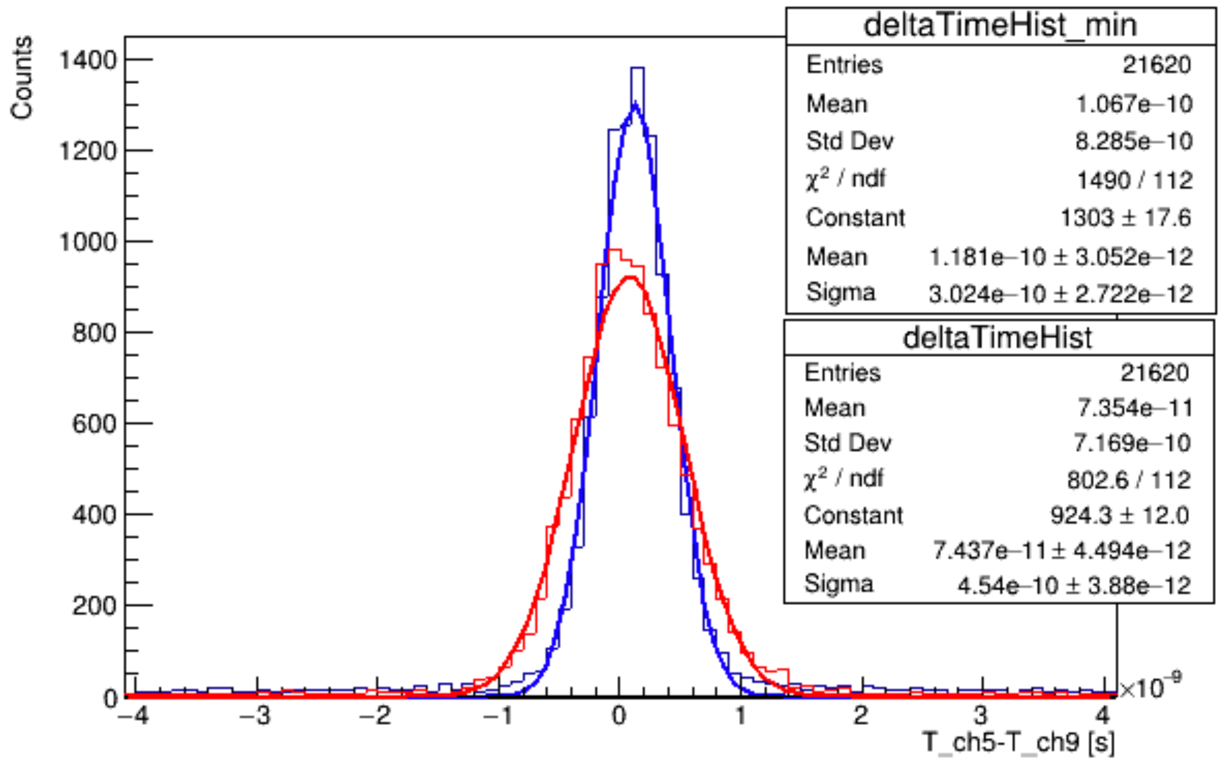
- Detection efficiency: >95% ‣ Anti-coincidence efficiency: >99% ‣ Propagation delay <10 ns







A good muon (with TTL signal)



O(300) ps, as expected

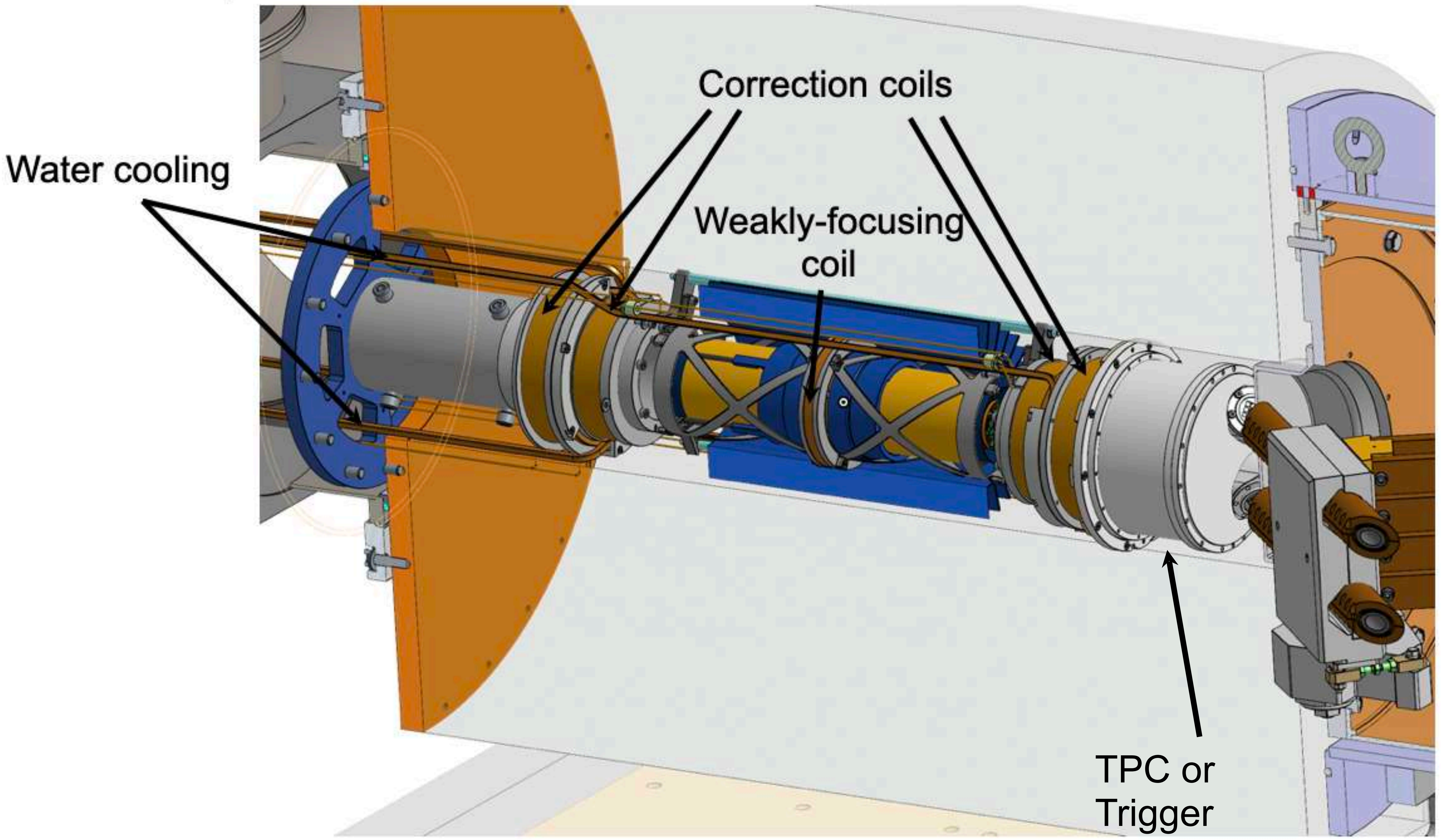
Muon storing acceptance: TPC and Correction and weakly focusing coils

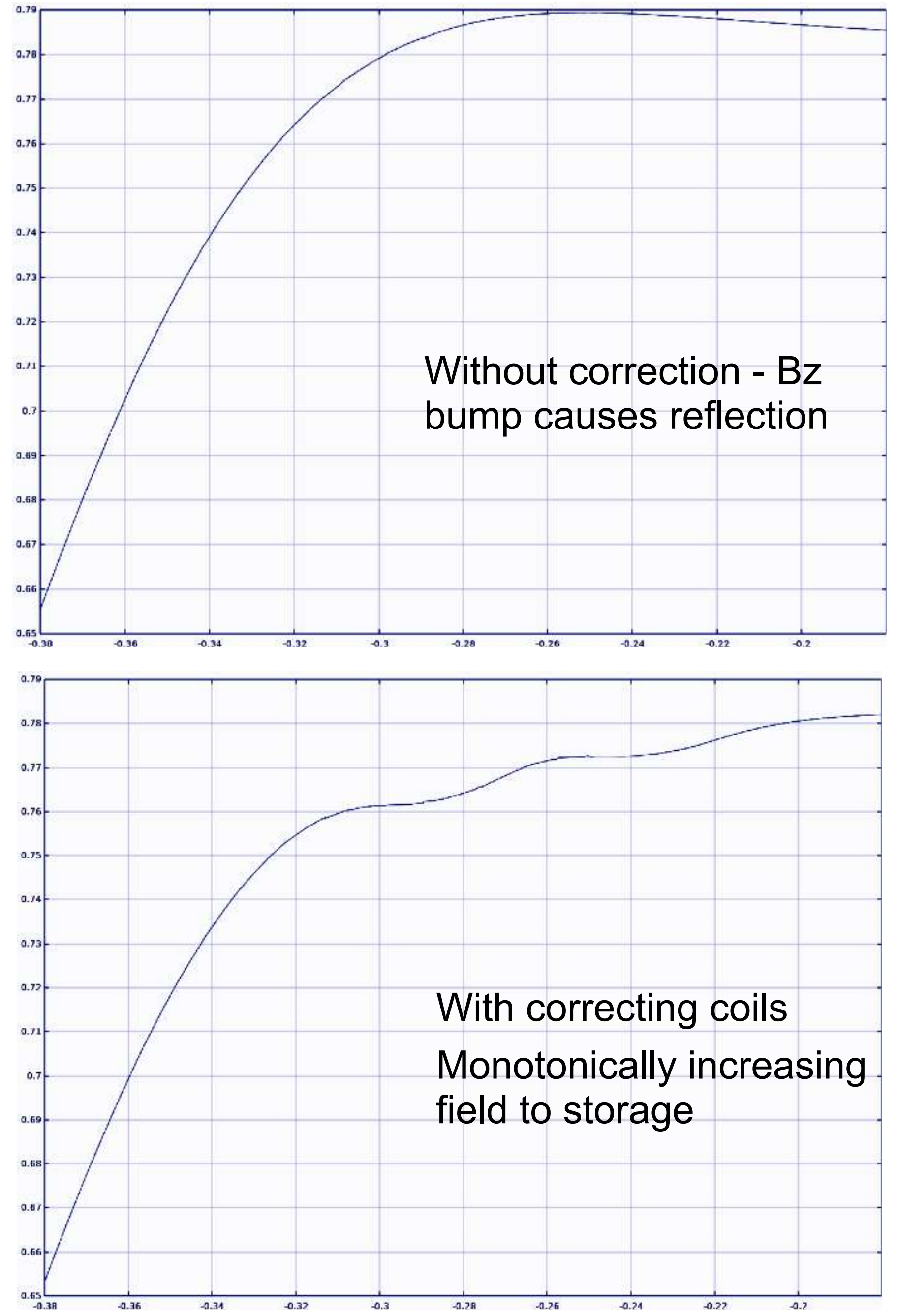
Correction and weakly focusing coils

- Improve muon acceptance and storage

TPC

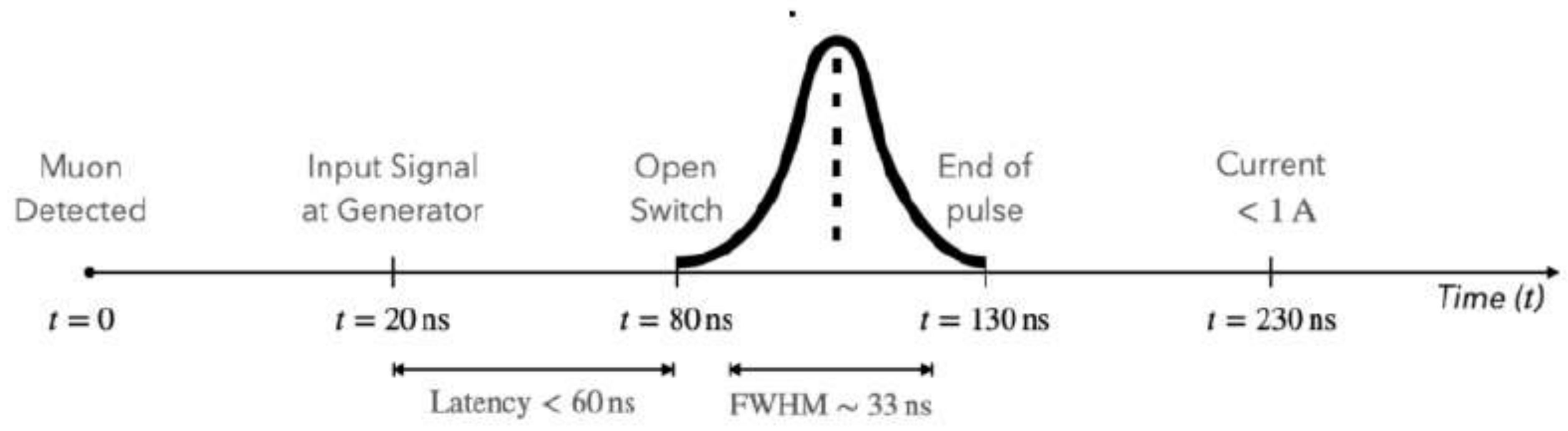
- 0.5% precision measurement of muon momentum difference between clockwise (CW) and counter-clockwise (CCW) injection —> essential for the control of the systematic uncertainties
- Determination of the phase space at the entrance of the magnet —> cross-check the alignment of beam, injection channels and magnet





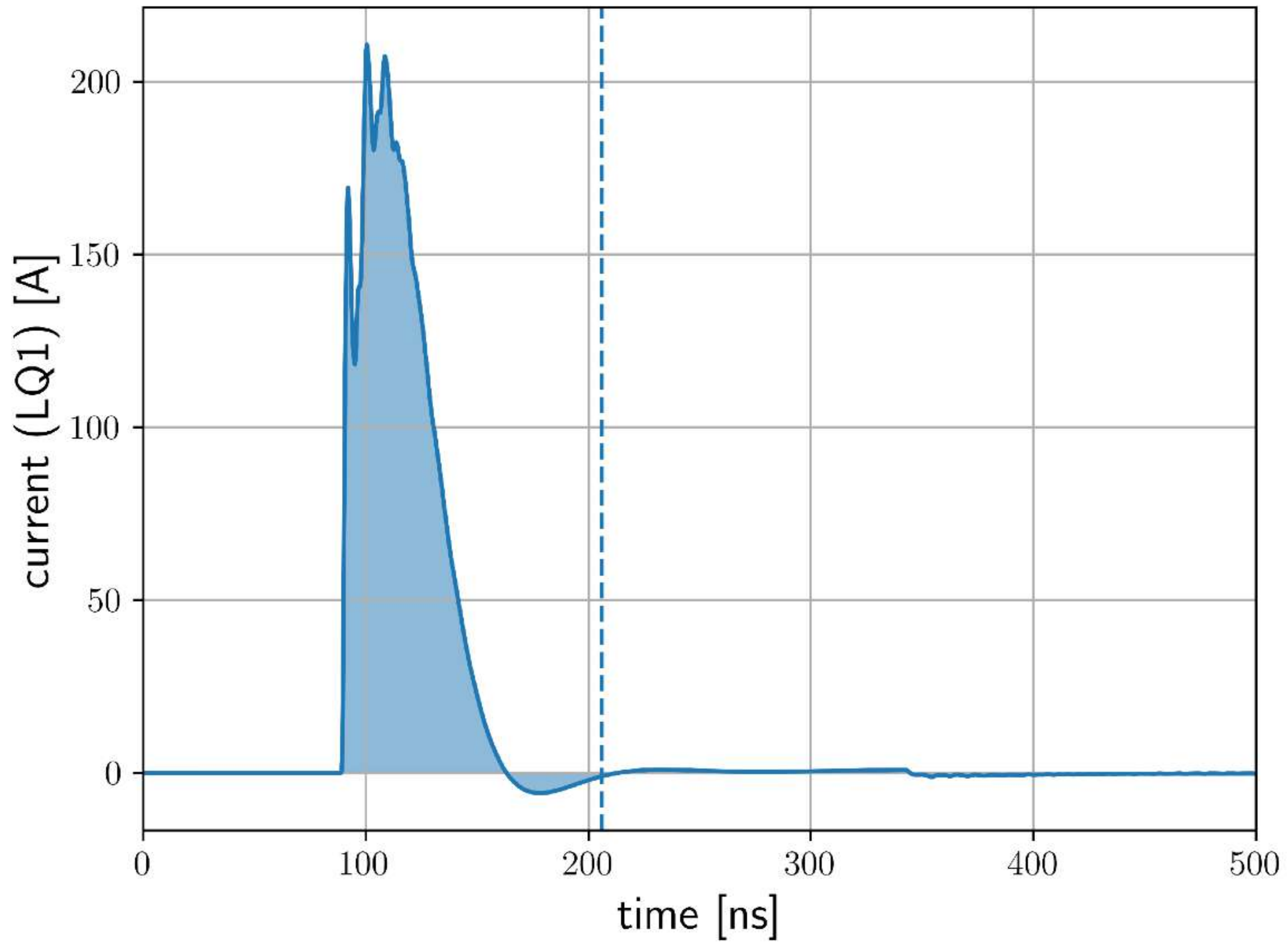
- Coils and services in production ✅
- The coils dissipate between 1 W and 4 W. With a flow of water of at least 10 ml/s, the temperature stays below 30^{o}C ✅
- **Delivery at PSI planned end of July**

Kicker

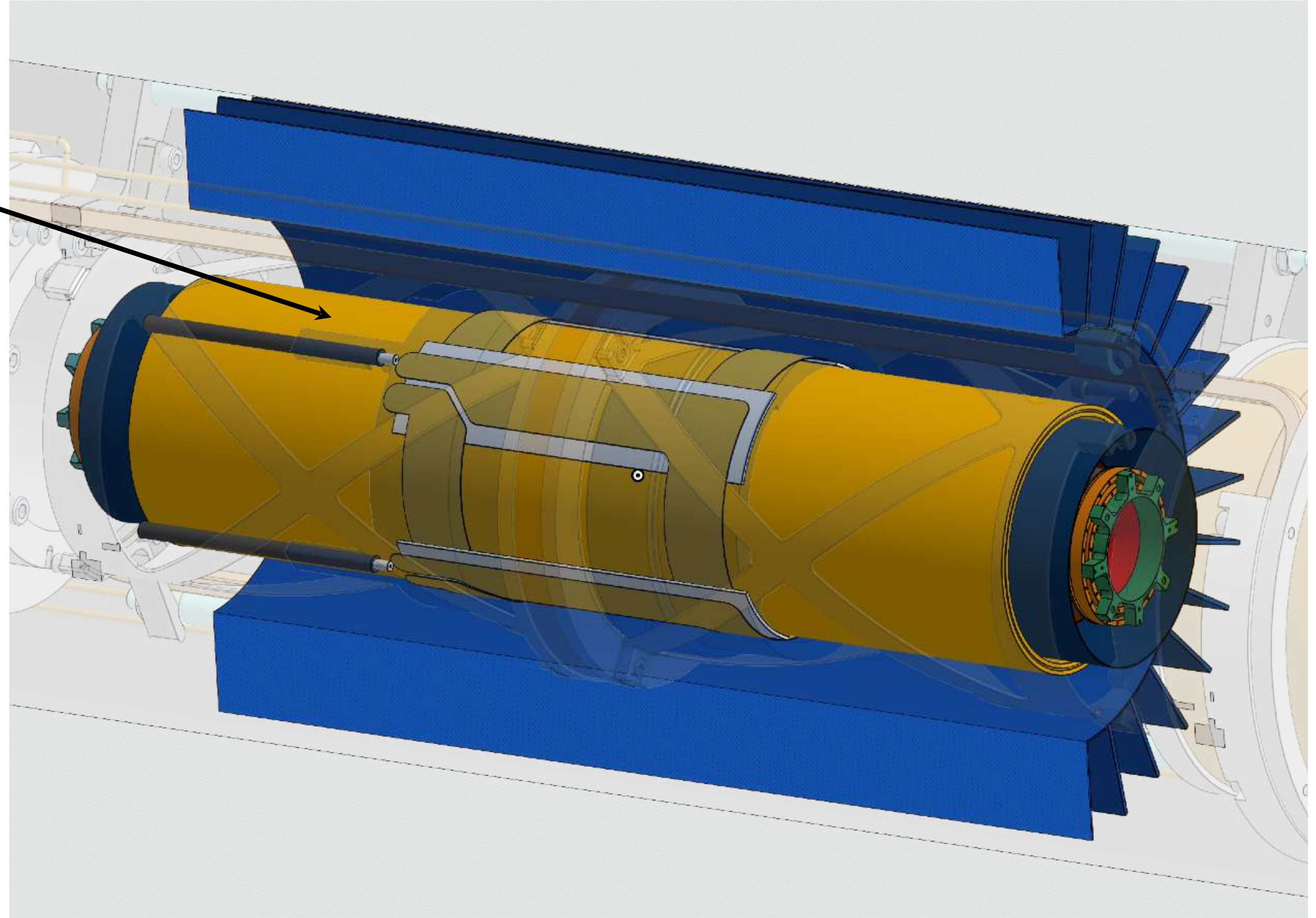


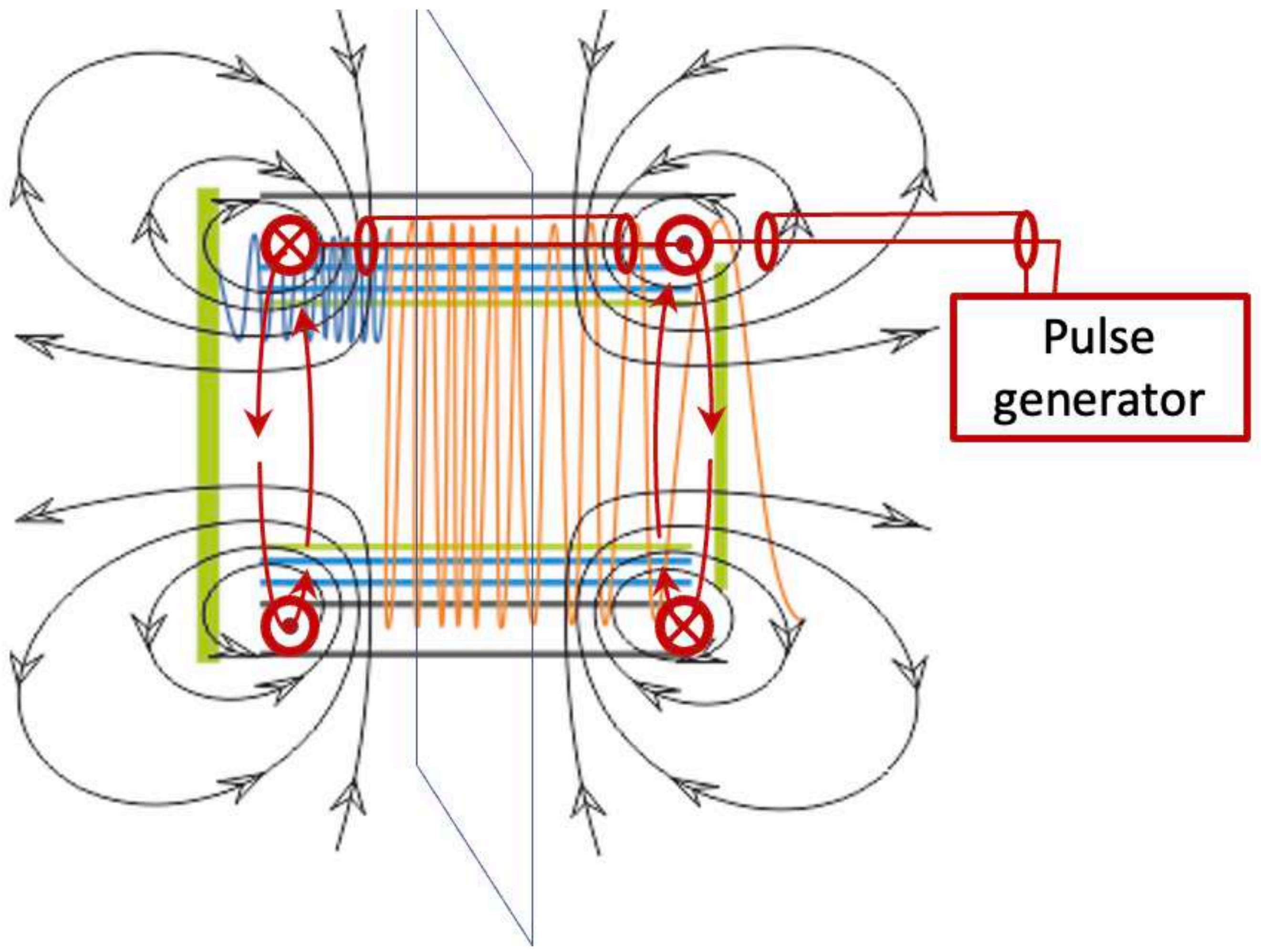
Magnetic pulse (kicker) to stop the z-motion of muons and store them in the centre of the solenoid

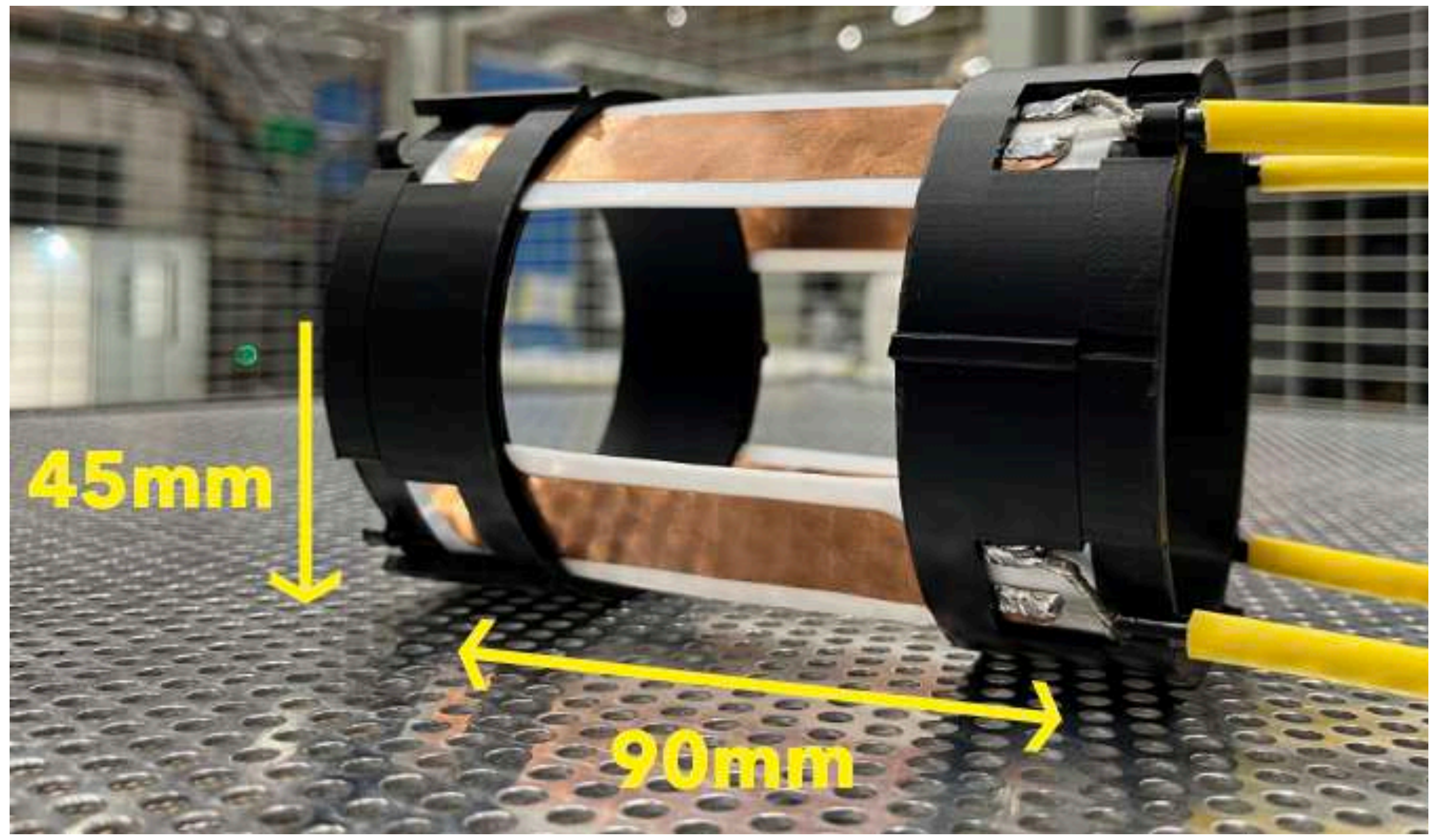
- Kicker coil: ‣ 4-quadrant anti-Helmholtz made of 100 µm Cu
- **200 A** to be released for **~100 ns after ~ 80 ns** from the trigger



Kicker-coil







Kicker coil

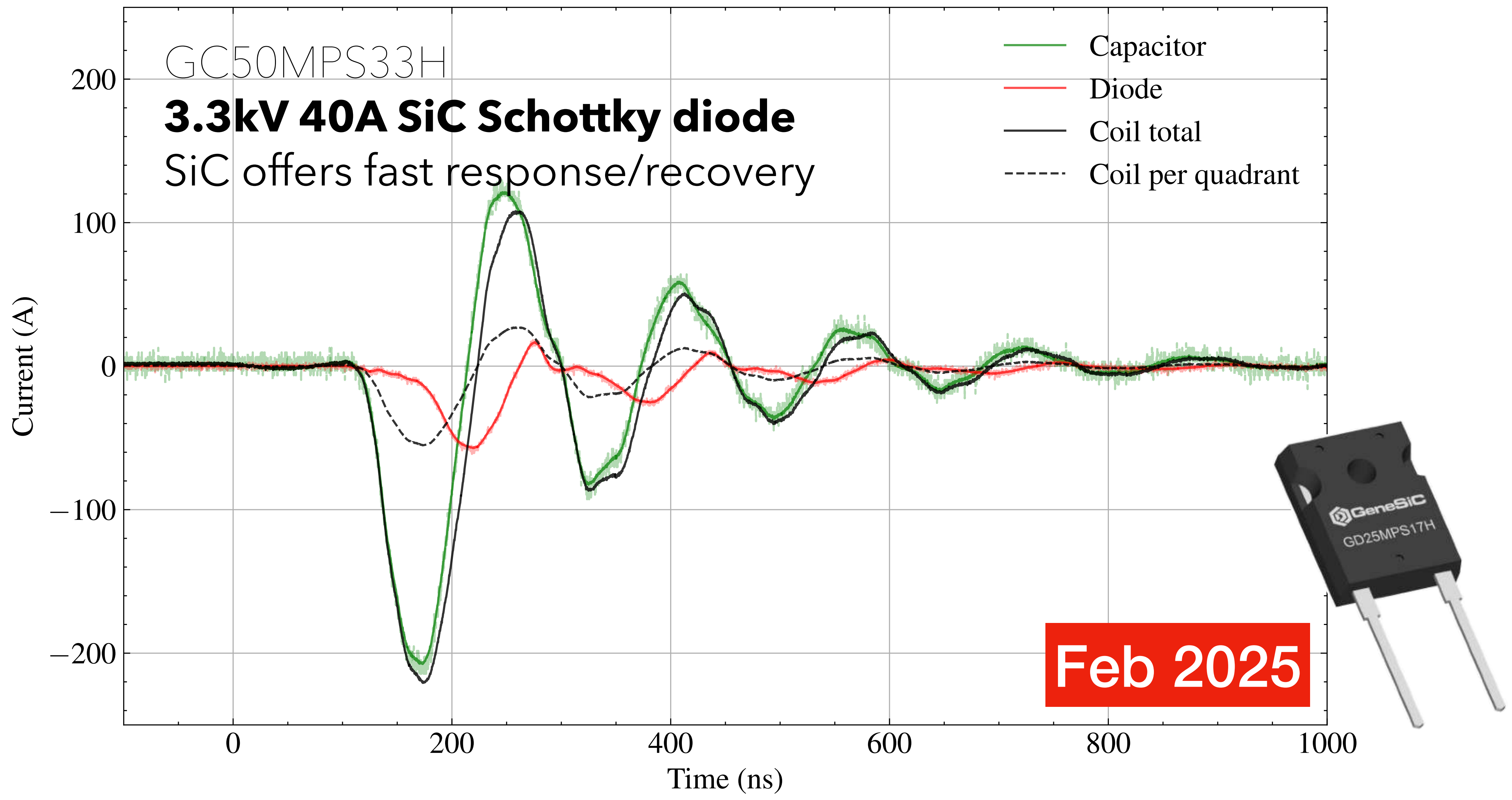
- **Beam time 2025** will employ an intermediate pulsed power system developed at PSI to enable the first attempt at muon storage builds upon the system successfully implemented in the **Beam time 2024**
- **Sept 2024 testbeam:** 5nF capacitor at 1.5kV discharged over kicker coil quadrants with single MOSFET to switch up to **32A/quadrant** undamped oscillation

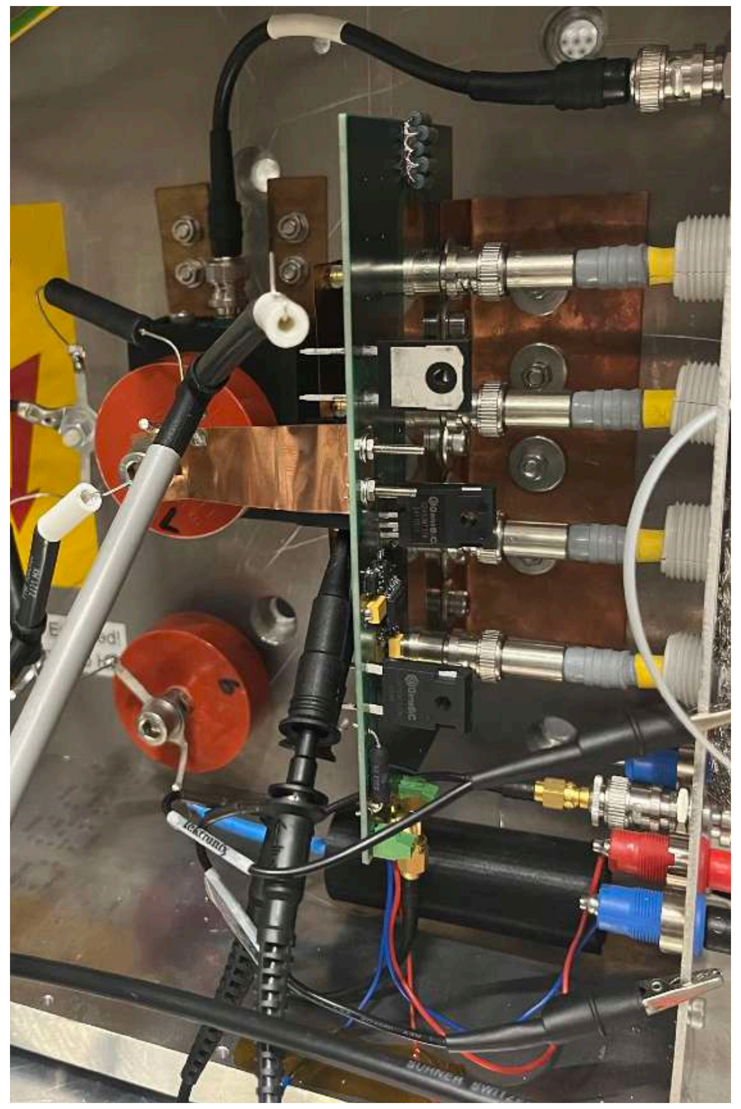
Upgrade in view of the Beam time 2025

- 4 MOSFETs (right) increased peak up to **55A/quadrant**
- **Diode used to damp oscillation (below)**
- Isolated trigger (floating switch) s.t. coils held grounded for in-vacuum operation
- July: test with 3.3kV MOSFET to push **>100A/quadrant**
- August: prepare vacuum feedthrough

PSI Kicker: **~0.1%** efficiency (wrt **0.4%** of the final)

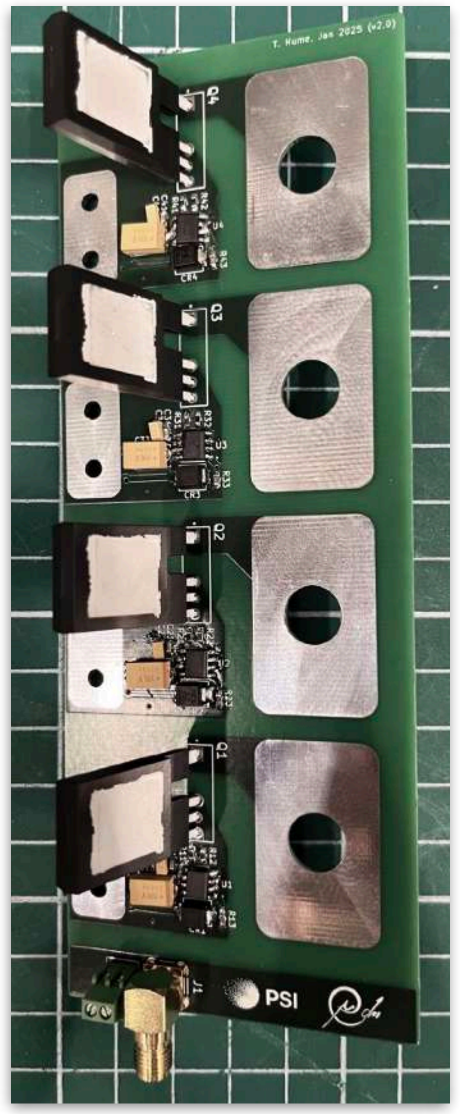
KIT Kicker: in preparation. Delivery at PSI first quarter of **2026**





June 2025
(tests in progress)

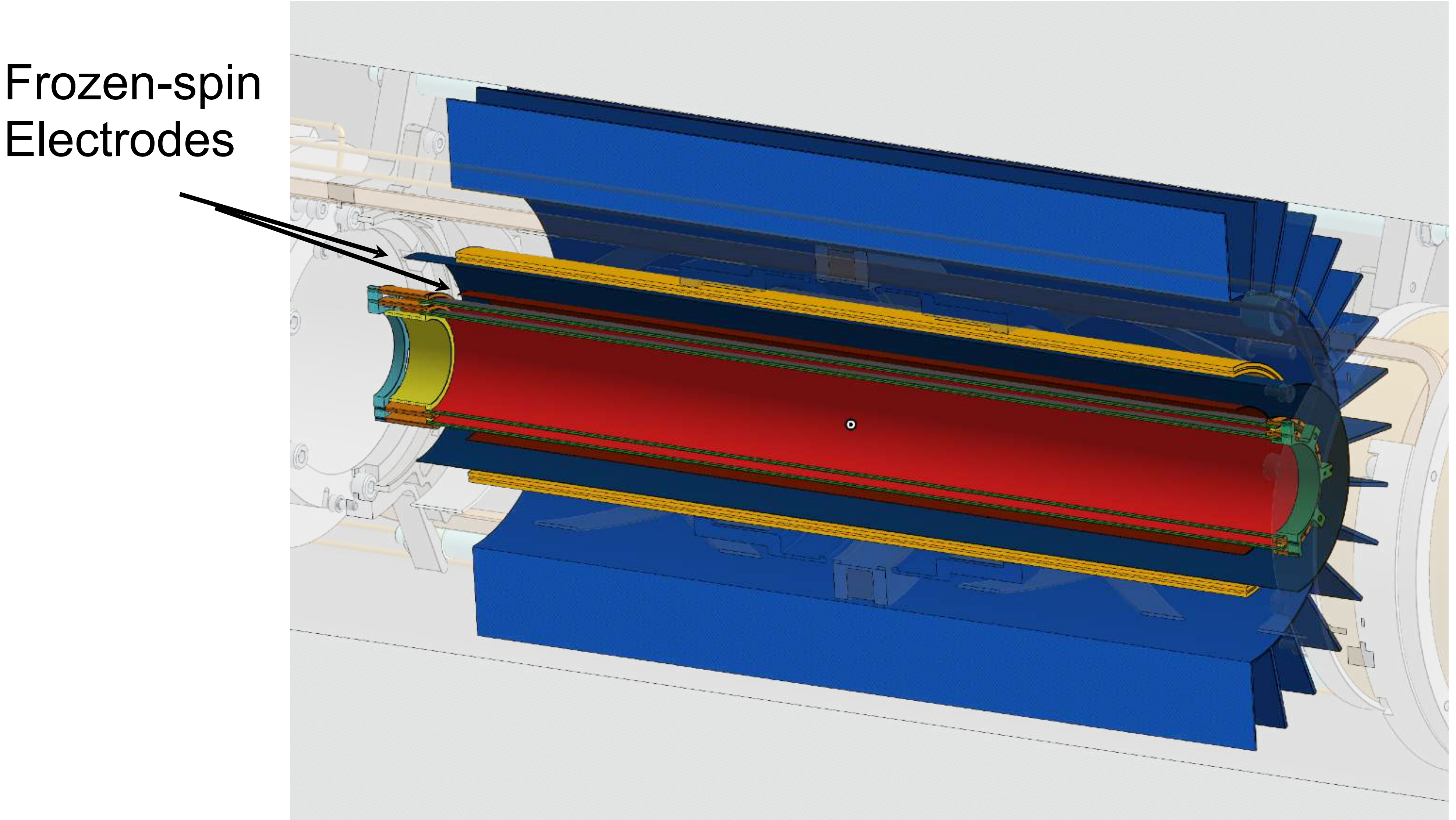
Capacitive isolation (ISOW7721) of trigger signal +6ns delay
Total delay ~70ns

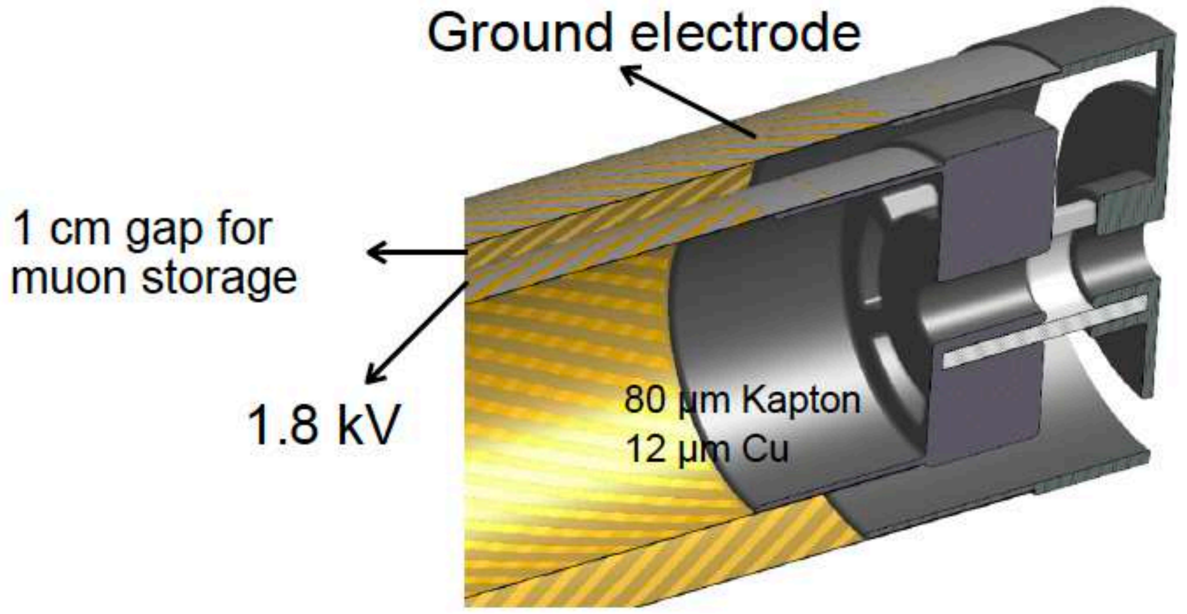


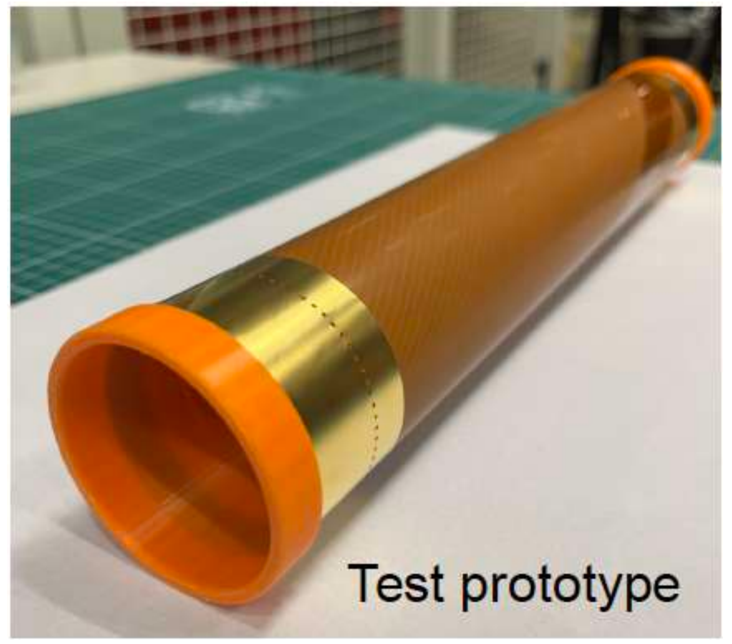
Frozen spin electrodes

Tuning of $\vec{E}_f$ such that it freezes the spin to the $\vec{p}(\mu)$

- **Very thin (<100 µm)** to reduce the multiple scattering
- **Striped Cu** segmentation to reduce the shielding of the magnetic kick due to the eddy currents
- HV test: September 2025

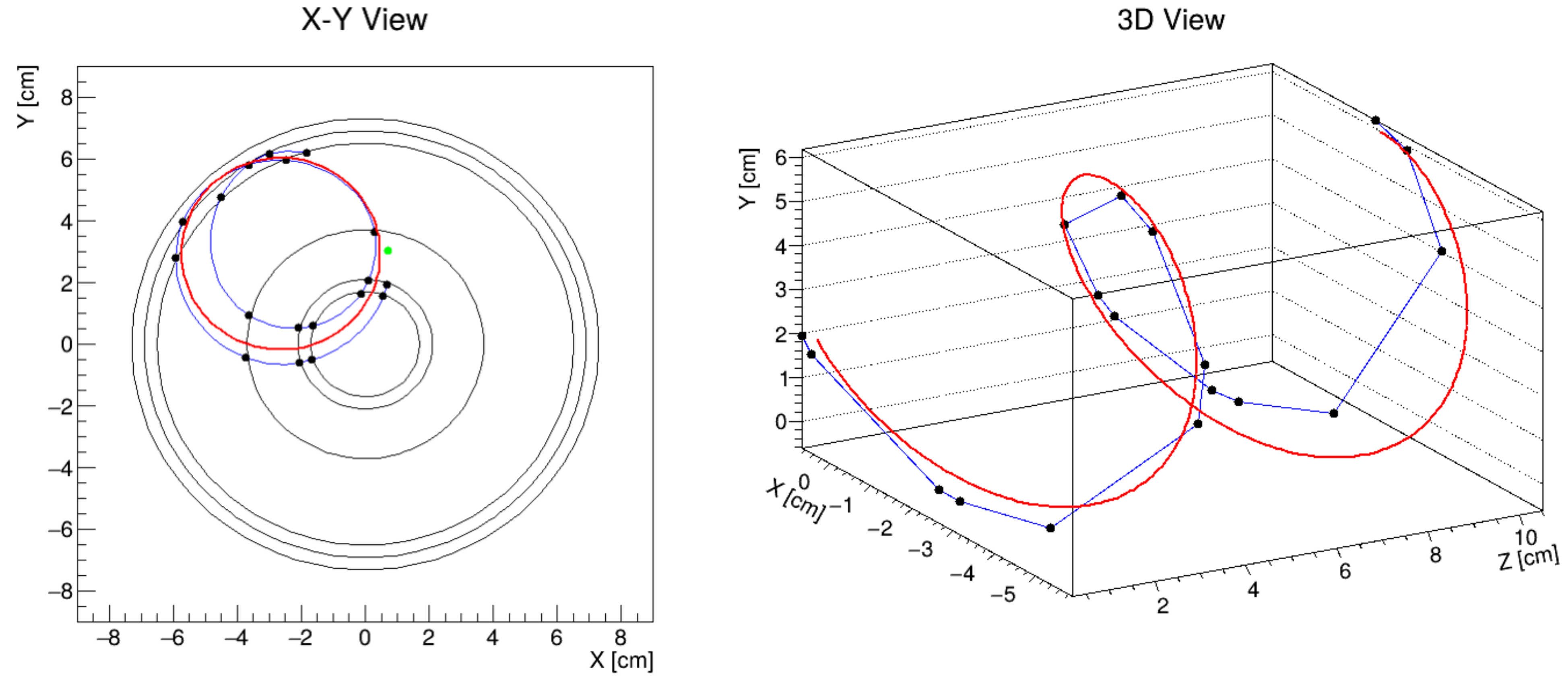




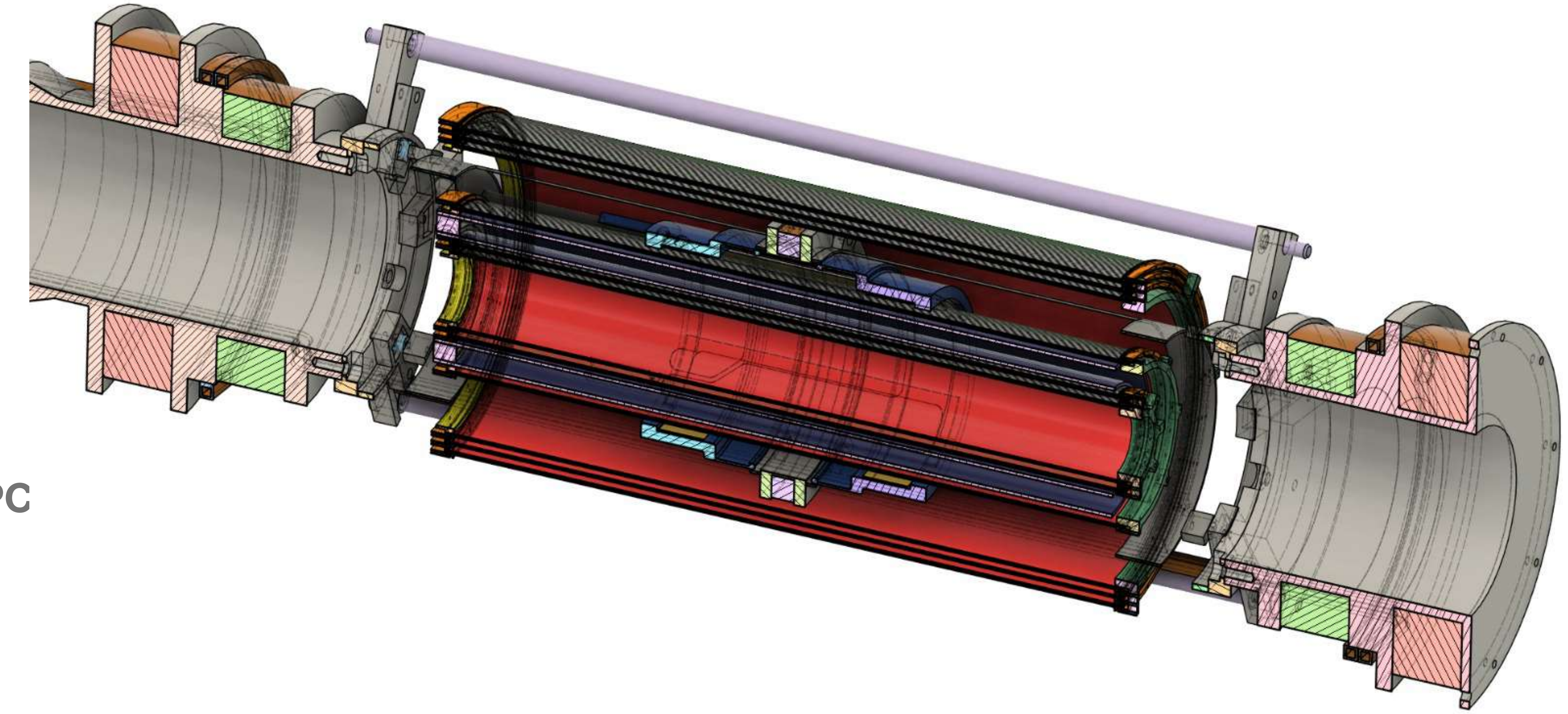


The positron tracker: CHeT

Measure the direction and momentum of decay positrons

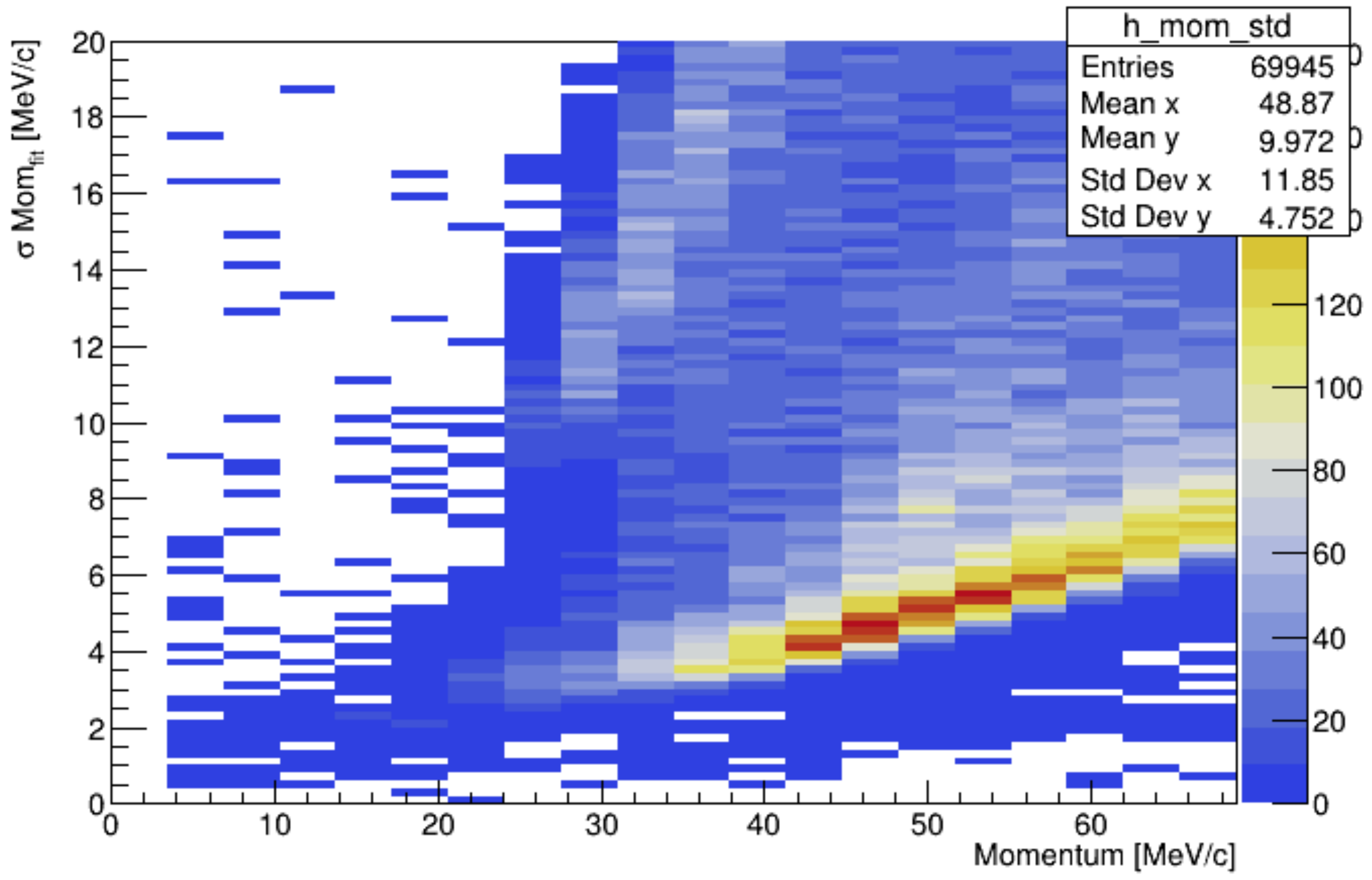


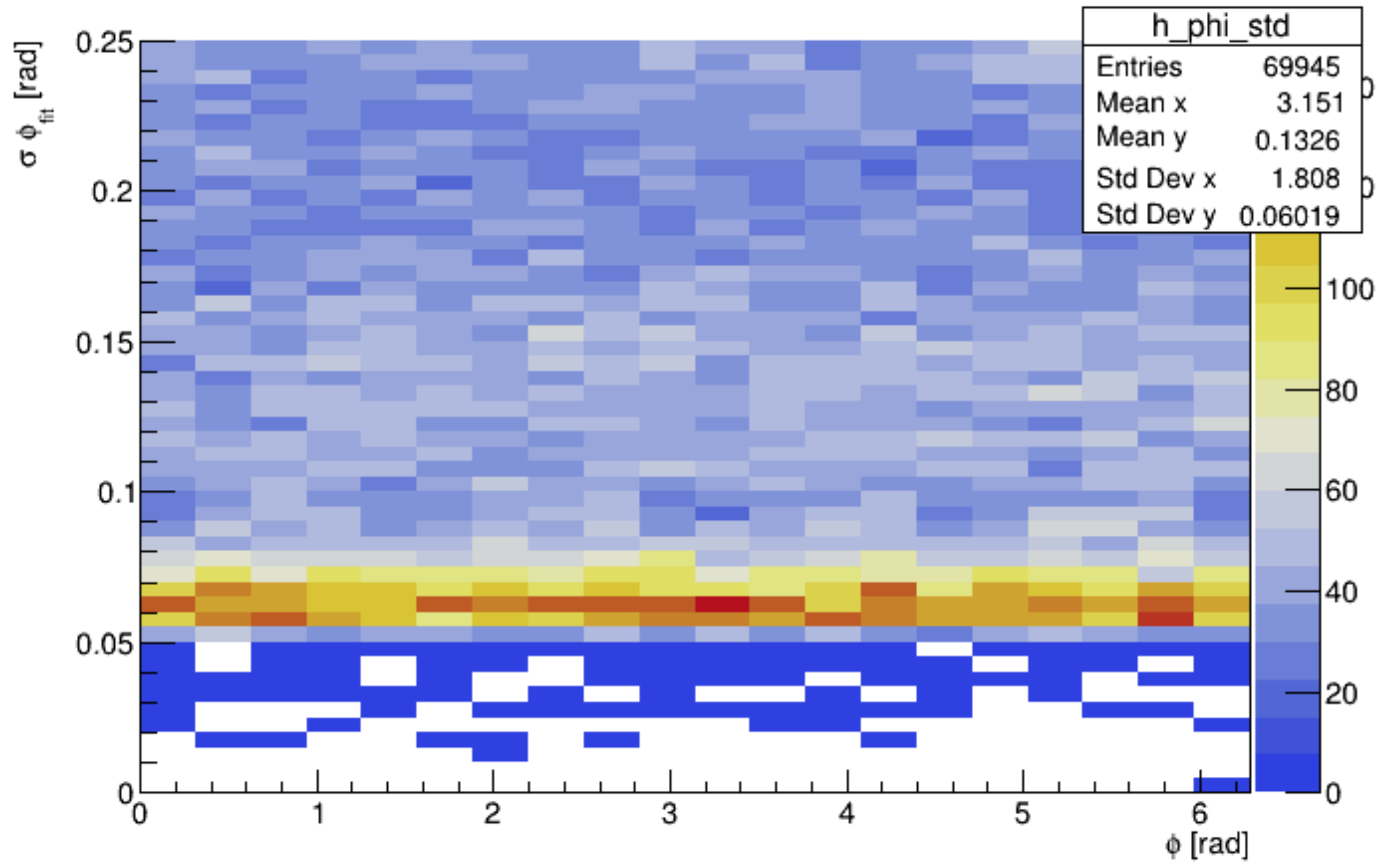
- Very thin (~ **0.1% X_0**) scintillating fibre detector coupled to MPPC for the **g-2** and **EDM** measurement
- Spatial Constraint: 5T magnet bore diameter = **20 cm**
- Detector requirements
  - Position resolution: **O(1) mm,** Timing resolution **< 1 ns**
  - Detection efficiency **O(50%)**
- Track parameters
  - g-2: Need to measure particles emitted with small theta
  - EDM: Need to measure particles emitted with theta ~pi/2
- Geometry
  - **Cylindrical** detector: **6** Cylindres. Stereo fibres
- Technology
  - **500um** fibres group in 2x/4x and coupled to **1.3 x 1.3 MPPC** (Hamamatsu S13360-50PE)
  - Readout: **CAEN FERS**
  - Number of channels: **O(2000)**

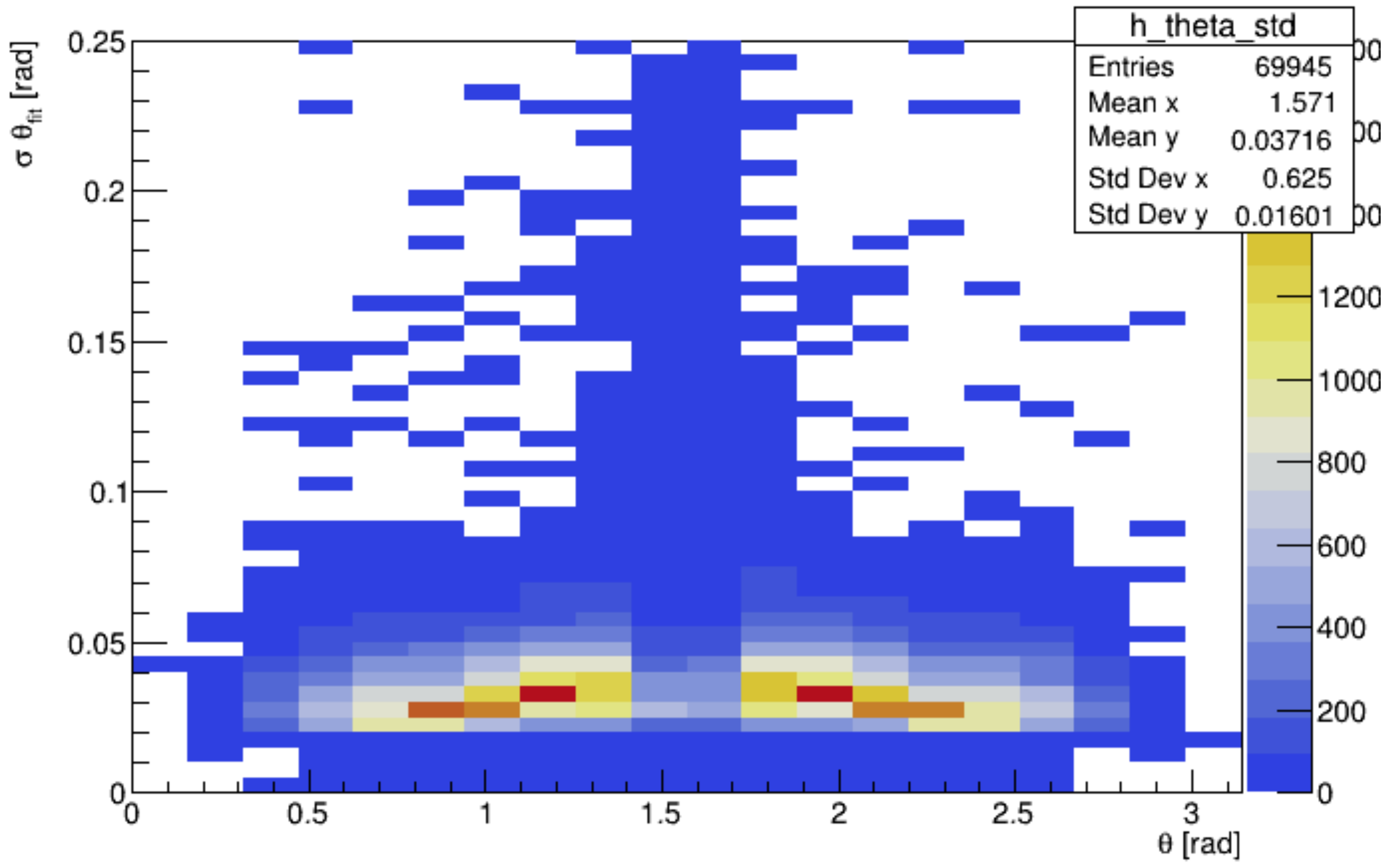


CheT: Resolutions

- Achieved typical (using the mode of the distribution instead of the average, which is influenced by bad reconstructed tracks) resolutions of:
  - $\sigma_p \approx$ 0.1 MeV x p
  - $\sigma_\theta \approx$ 50-100 mrad, worsening for particles emitted along the z axis
  - $\sigma_\varphi \approx$ 10-50 mrad

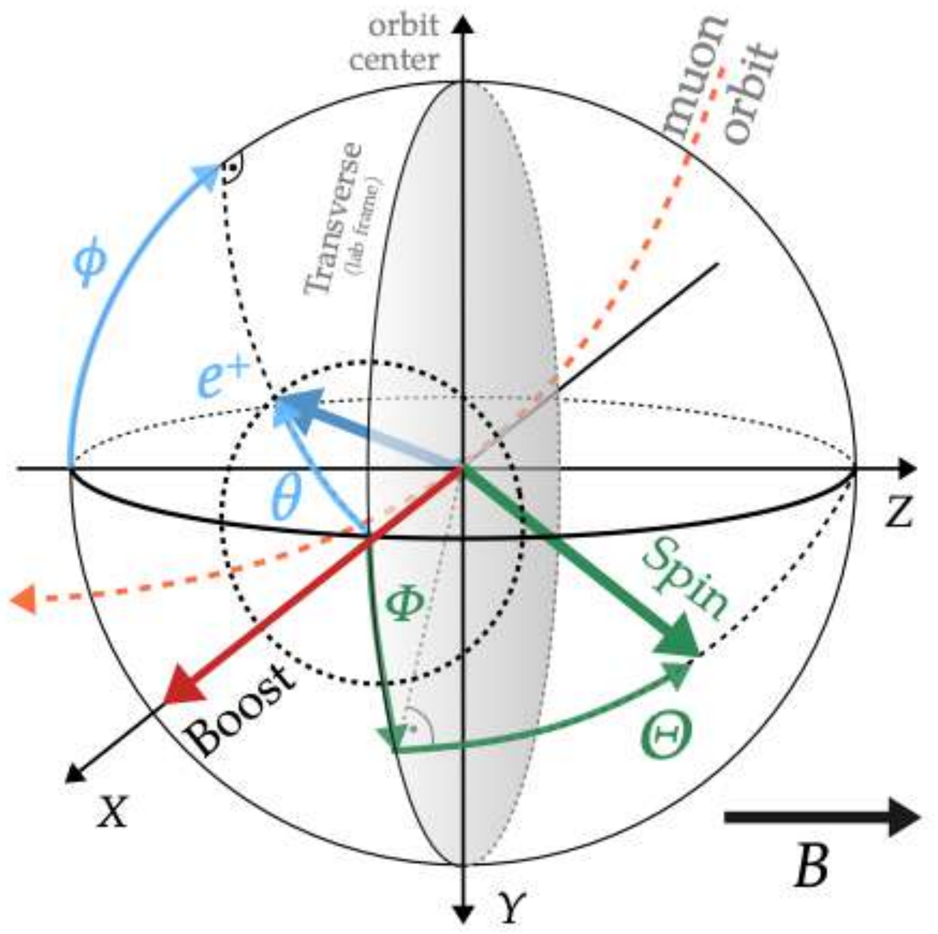




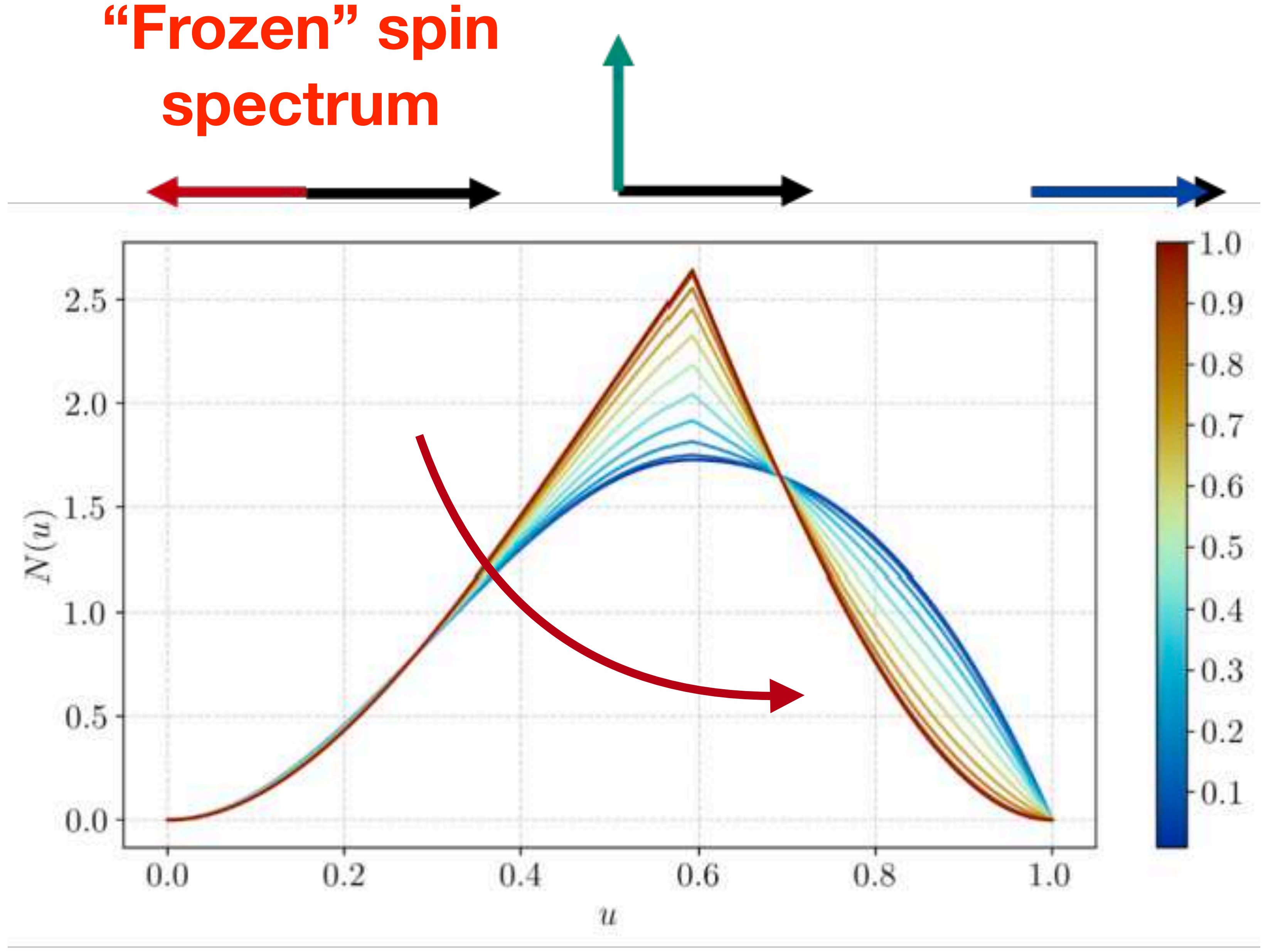


The positron tracker: CHeT

- Some positrons bring more EDM info then others:
  - EDM figure of merit for the Phase I of the experiment
- The CHeT design is optimized for a maximal detection efficiency for those “more sensitive EDM” positrons

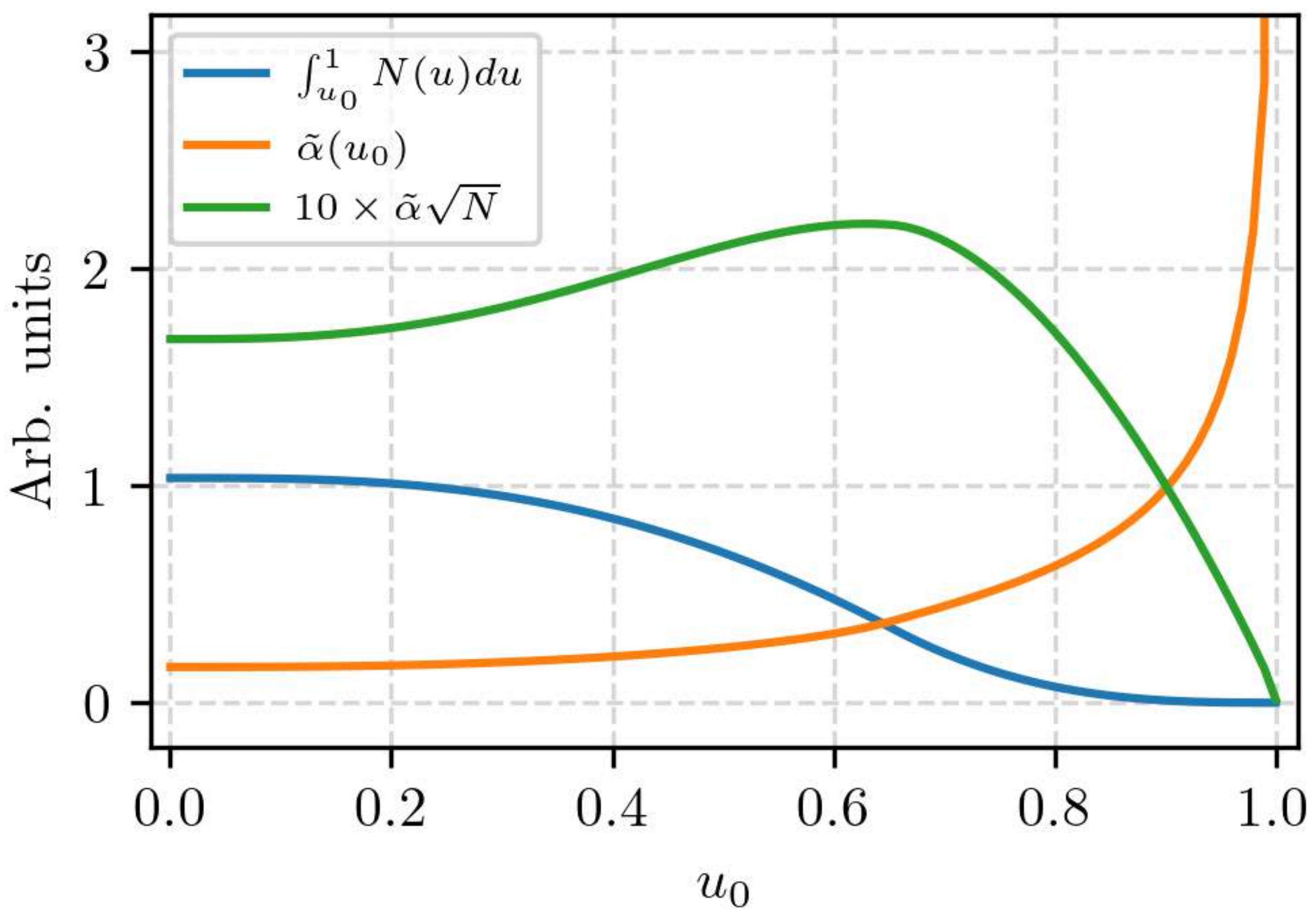


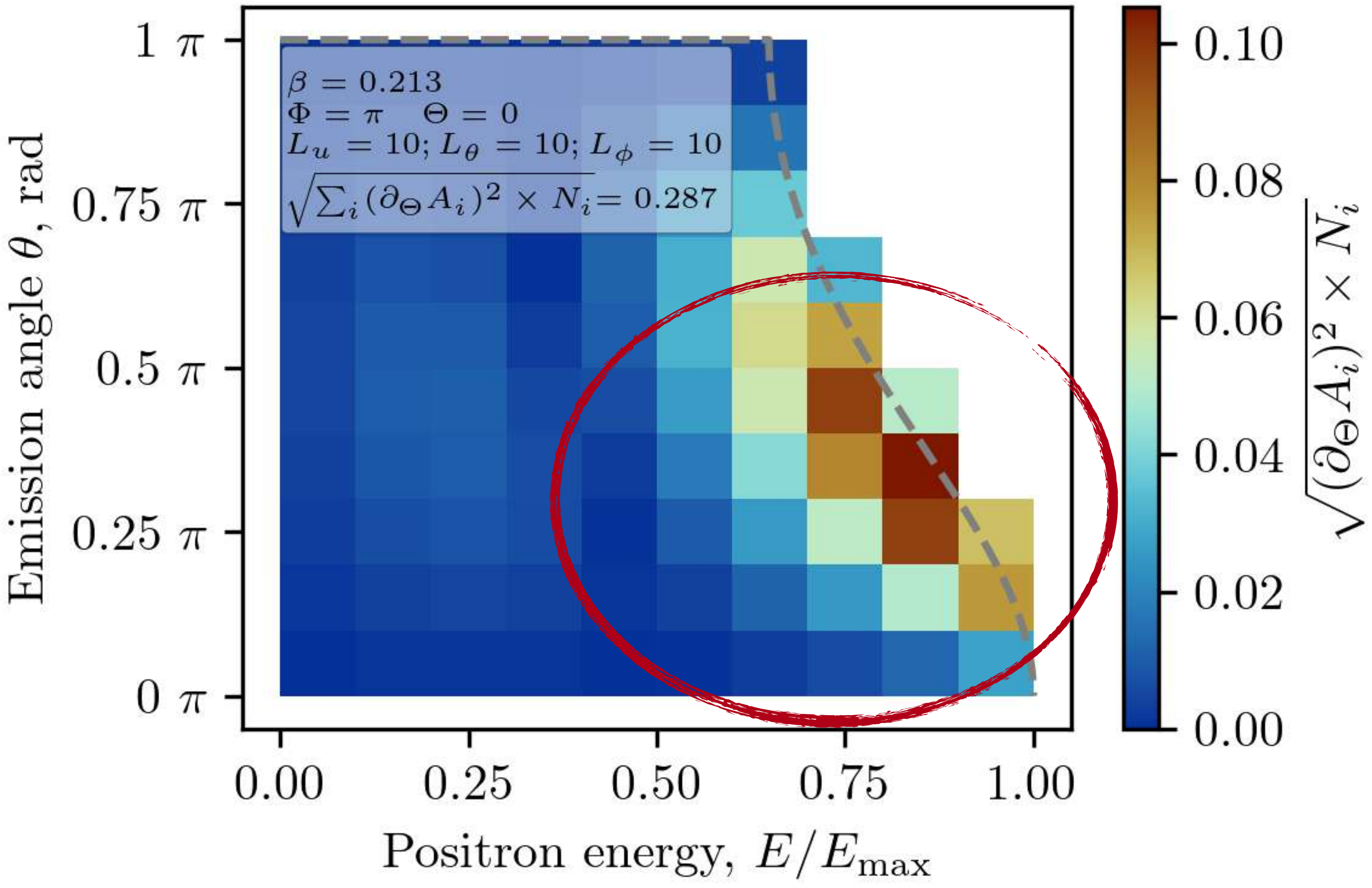
“Frozen” spin spectrum



Positron energy distribution as a function of the angle between the muon spin and momentum. u= E/Emax.

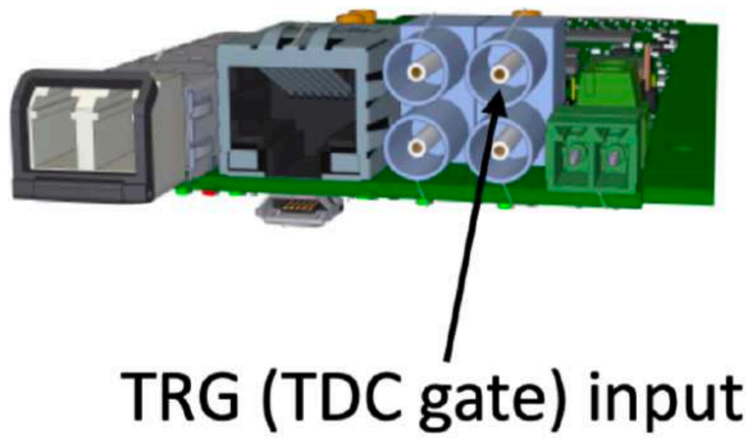
Emax = 68.9 MeV

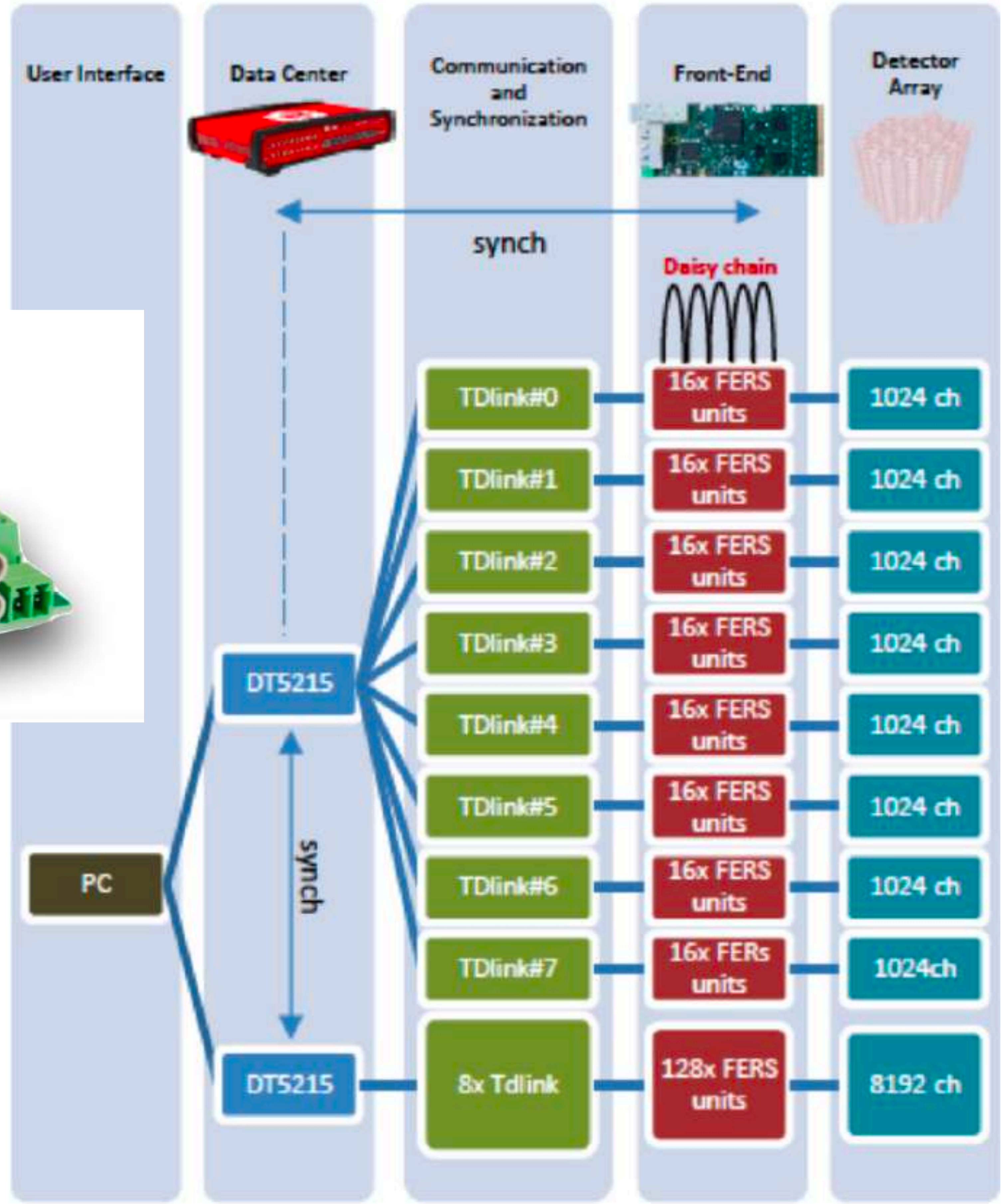




DAQ: CAEN FERS 5200

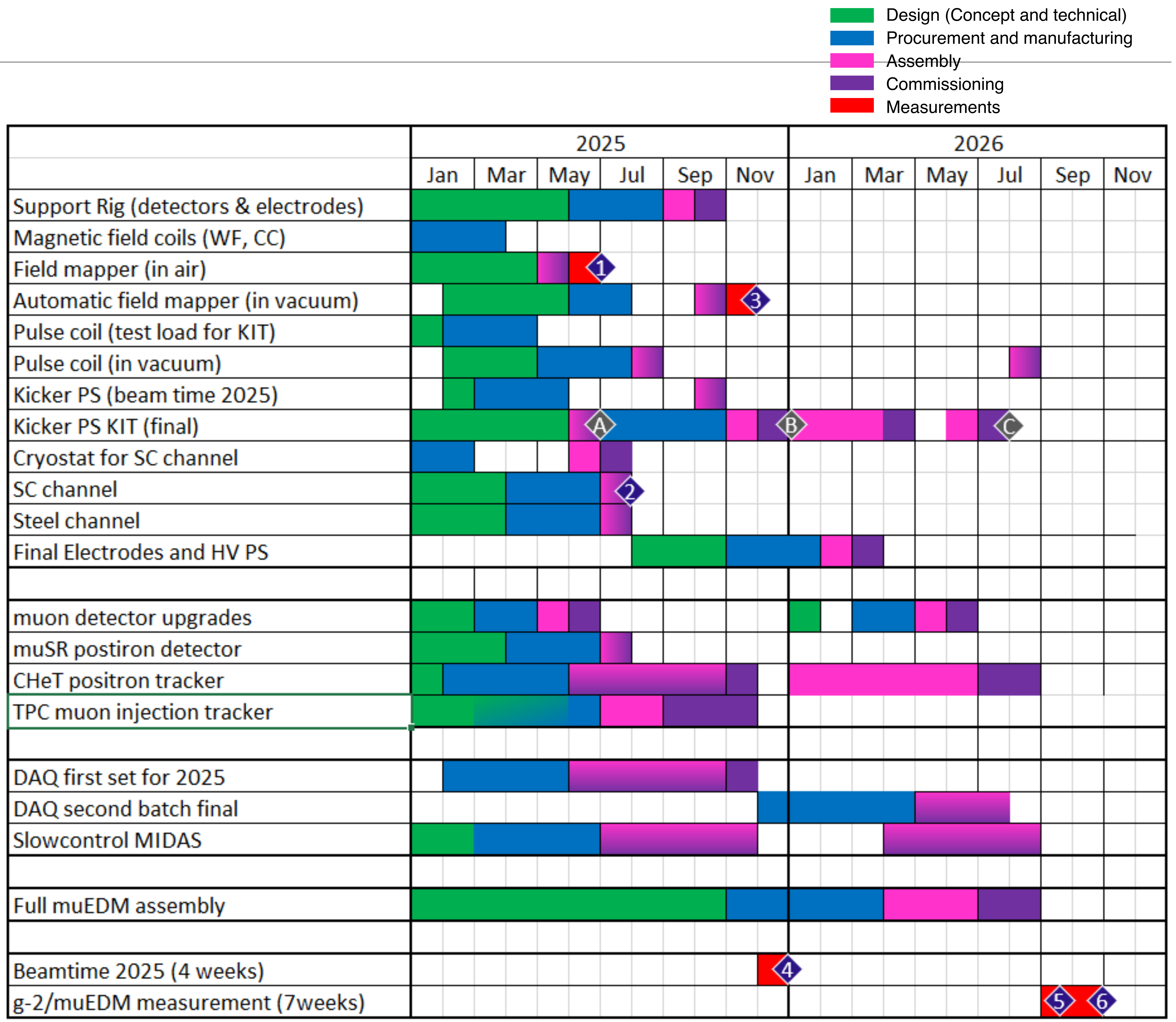
- Platform for the readout of large arrays of detectors including services (i.e. MPPC bias and front-end amplification)
- **Modular** (A520x FERS units- 64/128 channels) + DT5215 Concentrator Board. **Scalability**: from a single standalone FERS units to **8192** channels with Concentrator Board. **Easy-synch**: up to 128 FERS units can be easily managed and synchronized by a single DT5215 Concentrator Board
- Timing**@200ps** level
    - **Time Over Threshold** available
- Read out up > **100 KHz**
- **CHeT**
    - **2000** channels default configuration
    - Trigger signal to open a 20 us gate looking for hits in the fibre-tracker (common start)
        - The signal is received on one of the LEMO input
    - Hits sent in push mode
- **Trigger signal distribution to be designed**
    - **32** copies are needed for **2048** readout channels





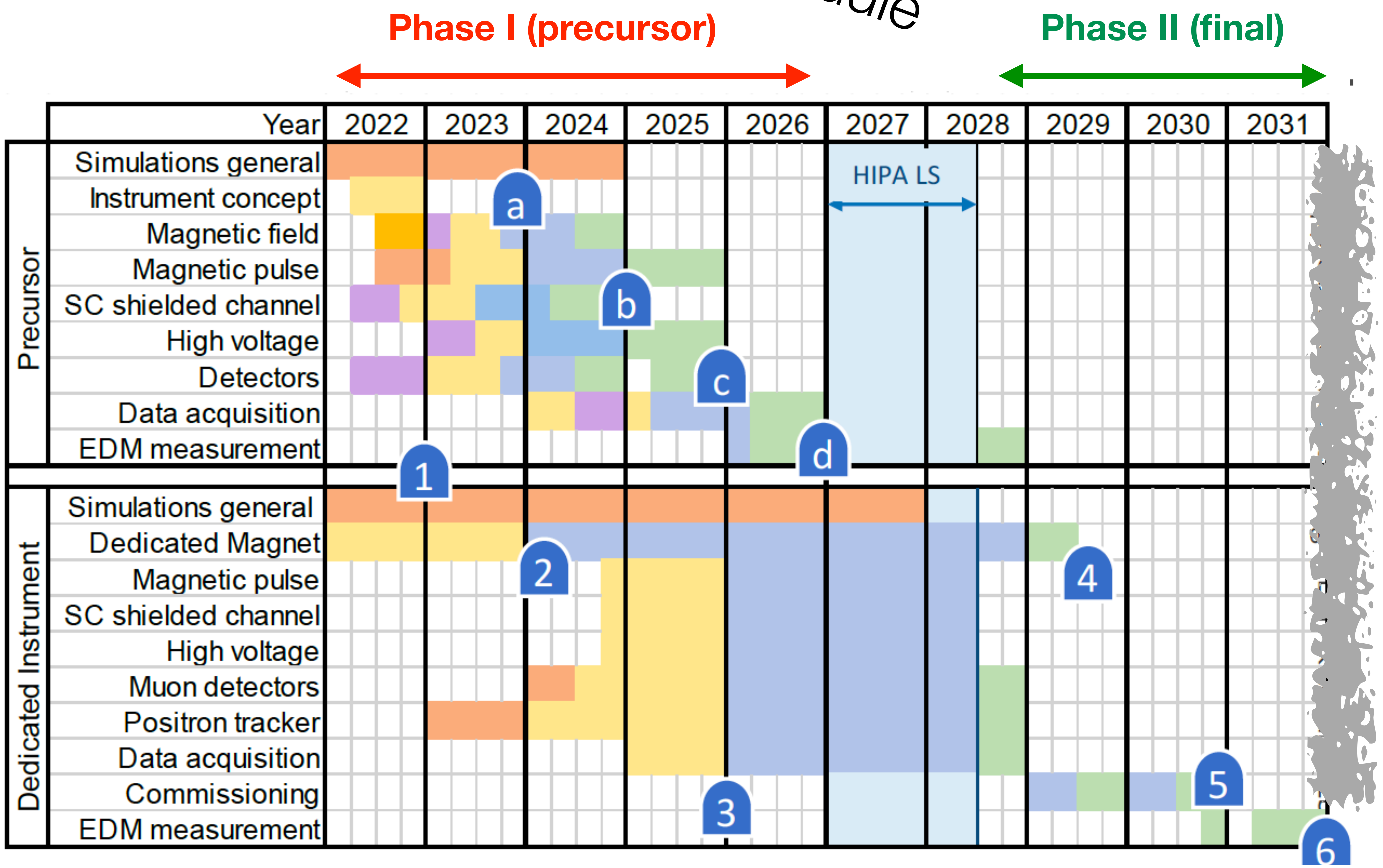
Milestones 2025

- Demonstration of all critical methods and techniques
  - cryogenic injection
  - final magnetic field (compensation coils + weekly focusing)
  - kicker field (Kicker-PSI)
  - positron tracker (partial)
  - FERS DAQ system (partial)
  - TPC injection tracker



muEDM schedule

Up to now…in schedule



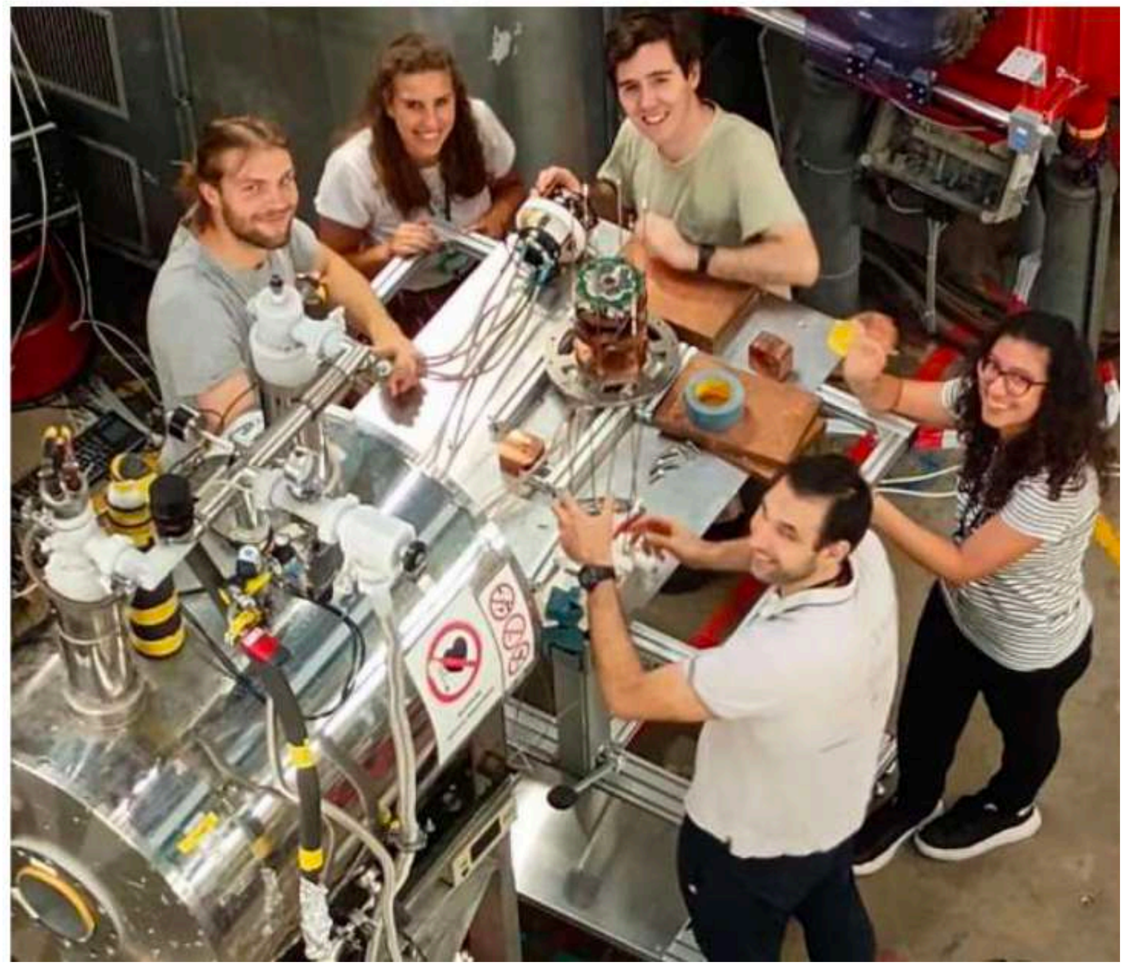
- Simulations
- Conception/Design
- Prototyping
- Acquisition/Assembly
- Tests/Measurements

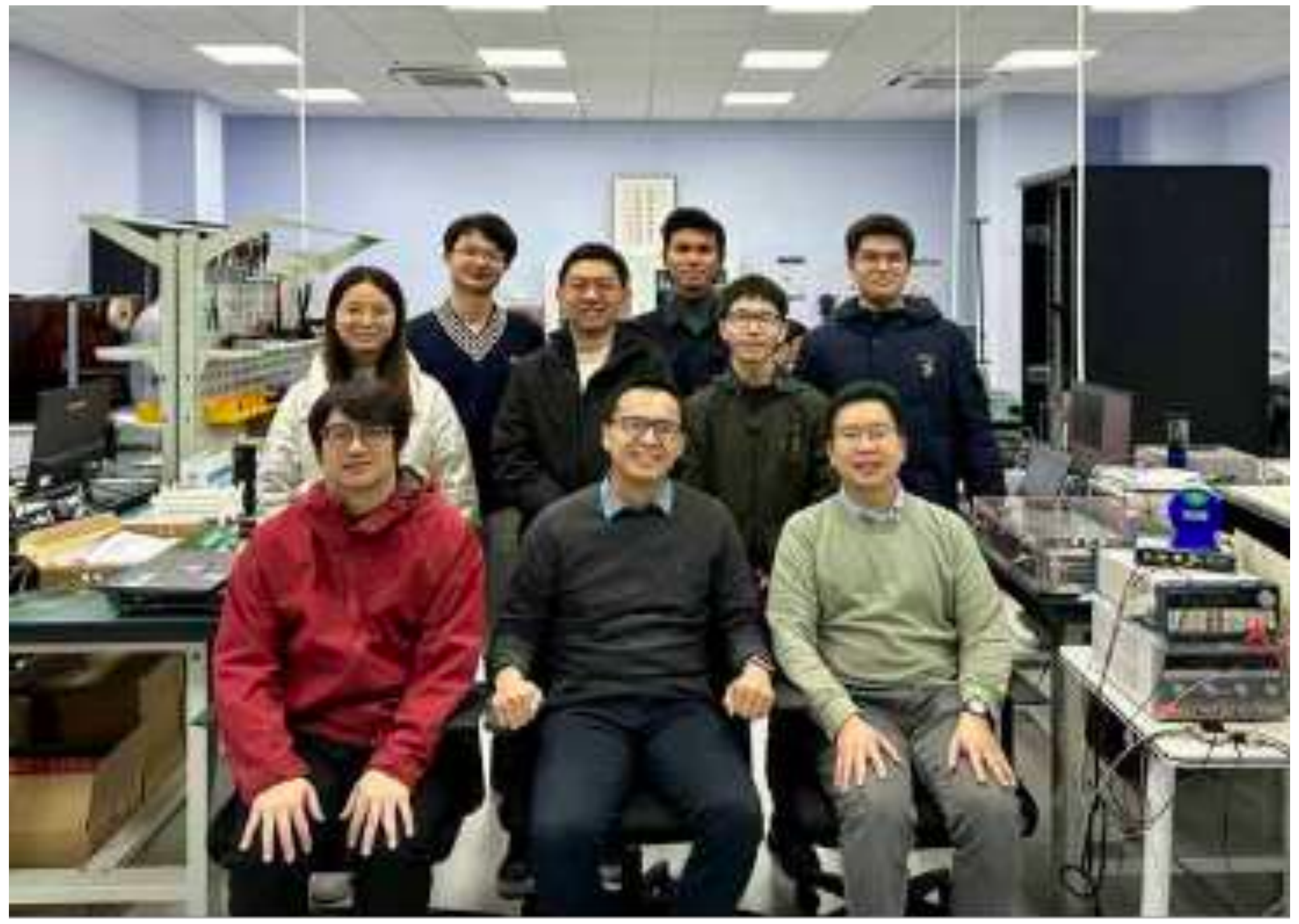
1 Full proposal for both phases to CHRISP committee
2/a Magnet call for tender / precursor design fix
b Precursor ready for assembly/commissioning
3/c Technical design report / frozen spin demonstration
d First data for precursor muEDM
4 Magnet delivered, characterized and accepted
5 Successful commissioning / start of data taking
6 End of data acquistion for muEDM

Conclusions

- Very successful 2024 and 2025 (up to now) in view of the construction and commissioning of the muEDM Phase I experiment
- Research proposal very attractive for students
- Looking for more collaborators. Please do not hesitate us: angela.papa@psi.ch, philipp.schmidt-wellenburg@psi.ch

Thanks a lot for your attention !!!





Back-up

Signal: asymmetry up/down positron tracks

- Positron are emitted predominantly along the muon spin direction
- The sensitivity to muon EDM is extracted from the **asymmetry up/down** of the **positron** from the muon decay, averaged over the muon decay time distribution (lifetime = $\gamma\tau_\mu$)

Final muEDM Experiment Sensitivity

μE1 Beamline Flux $2 \times 10^8 \mu^+/s$

Momenta $\gamma = 1.55$

Polarisation $P_0 \approx 0.95$

Av. Decay Asymmetry $A \approx 0.3$

Electric Field $E_f = 2\,\mathrm{MV/m}$

$$\sigma(d_\mu) = \frac{a\hbar\gamma}{2P_0E_f\sqrt{N}\tau_\mu A}$$

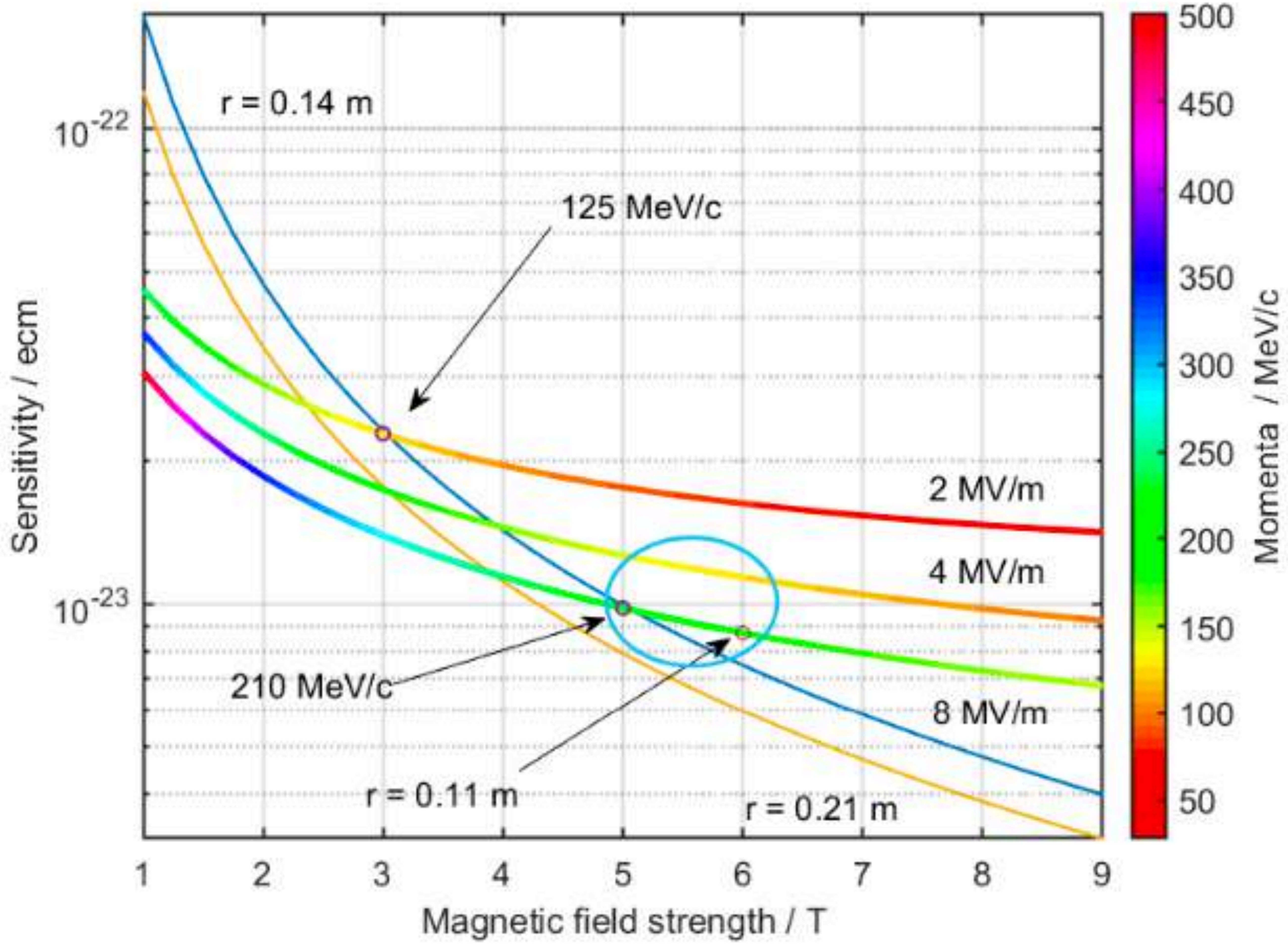
$$\sim 6 \times 10^{-23} e\,.\,\mathrm{cm}$$

(with $N = 200$ days)

muEDM projected sensitivity phase I and II

	π**E1**	μ**E1**
Muon flux (μ^+/s)	4×10^6	1.2×10^8
Channel transmission	0.03	0.005
Injection efficiency	0.003	0.60
Muon storage rate (1/s)	400	360×10^3
Gamma factor γ	1.04	1.56
e^+ detection rate (1/s)	300	90×10^3
Detections per 200 days	8.64×10^9	1.5×10^{12}
Mean decay asymmetry A	0.45	0.3
Initial polarization P_0	0.95	0.95
Sensitivity in one year ($e \cdot$cm)	$<3 \times 10^{-21}$	$< 6 \times 10^{-23}$

Sensitivity vs B and Momentum

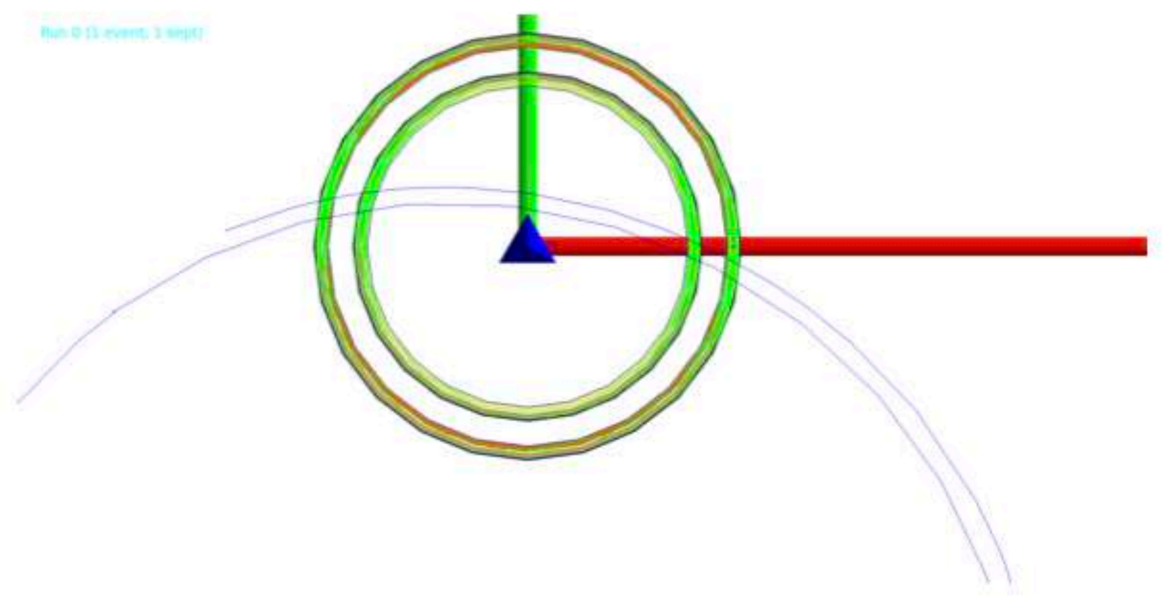


Systematic effect summary

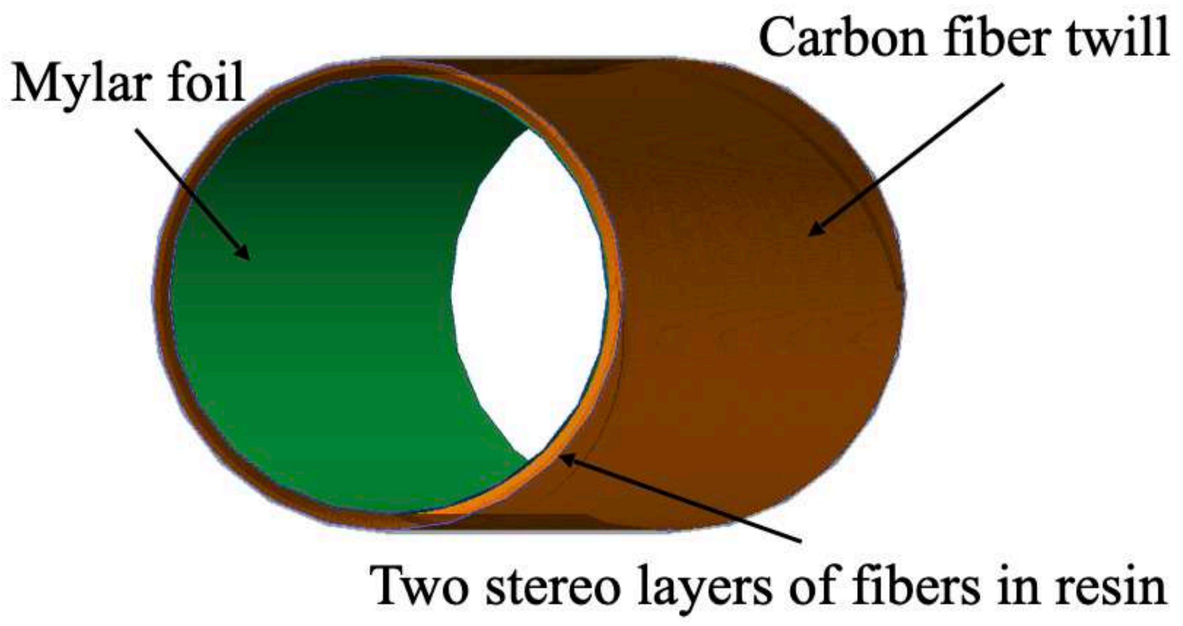
Systematic effect	Phase I		Phase II	
	Expected value (Limit value)	Syst. 10^{-21} $e\cdot$cm	Expected value (Limit value)	Syst. 10^{-23} $e\cdot$cm
Radial B-field (ii) @100 kHz	5 µT (140 µT)	0.03	20 µT (40 µT)	0.75
Current flowing through orbit (iii)	< 10 mA (250 mA)	$< 10^{-2}$	< 10 mA (40 mA)	0.3
Longitudinal E-field E_z, (v)	$< 10^{-4} E_\mathrm{f}$	–	$< 1.5 \times 10^{-5} E_\mathrm{f}$	–
Mean momentum difference Δp, (vi)	0.2% (0.5%)	–	(0.1)%	–
Difference in initial polarisation, (vii)	25 mrad	–	5 mrad	–
Radial E-field adjustment, $(viii)$	0.1%	–	0.01%	–
Main B-field adjustment, $(viii)$	0.01%	–	0.001%	–
CW/CCW orbit displacement	1 mm	–	1 mm	–
$\partial_x E_z$, $\partial_y E_z$	(0.56 kV/m/m)	–	(0.15 kV/m/m)	–
E-field related systematics	–	0.75	–	1.5
Resonant geometrical phase accumulation (xi)	Pitch $<$ 1 mrad Offset $<$ 2 mm	2×10^{-2}	Pitch $<$ 1 mrad Offset $<$ 2 mm	0.15
TOTAL		0.75		1.70

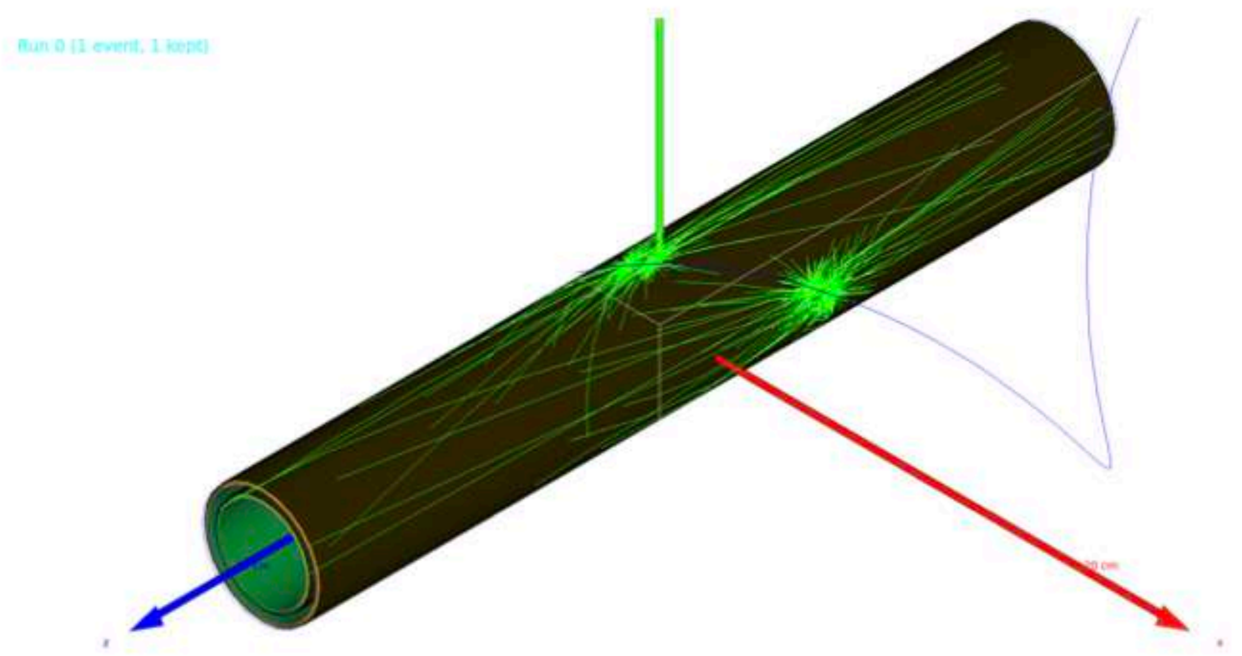
CheT: MC simulation and reconstruction

- MC framework based on Geant4
  - Technical details exported from the experiment CAD
    - To be implemented: Services, cables and support of all items
  - Single fiber implementation and response as measured in the lab
    - To be done: MPPC and electronic to provide the final signal
  - Reconstruction based on GENFIT



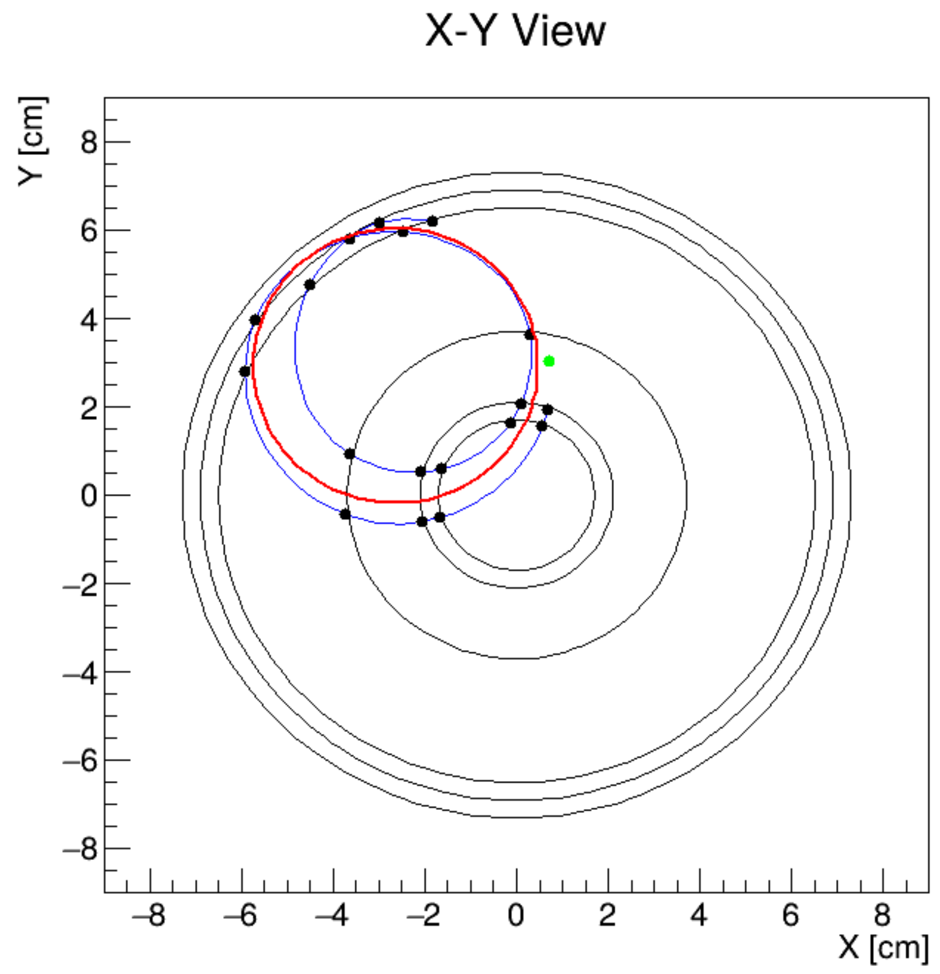
➢ In the "single" fibers simulation mode, scintillating planes are replaced with:

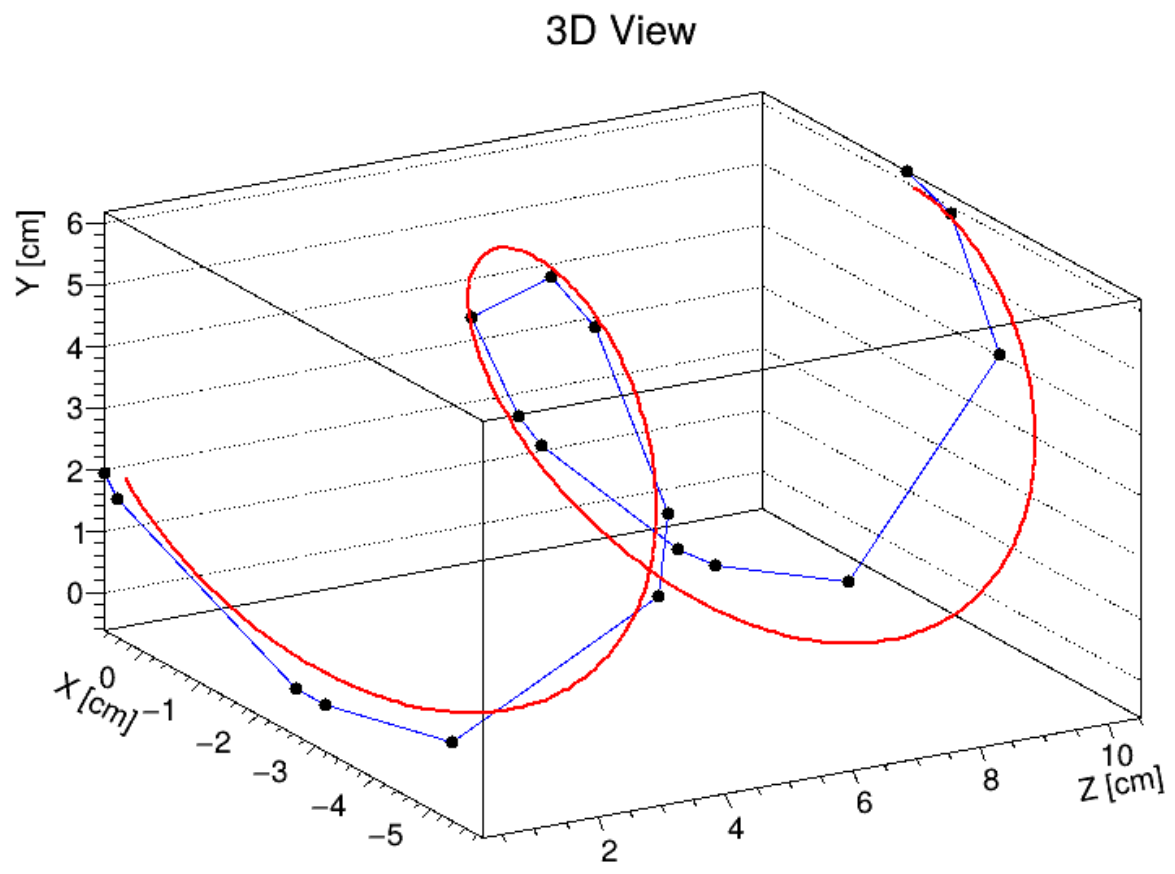


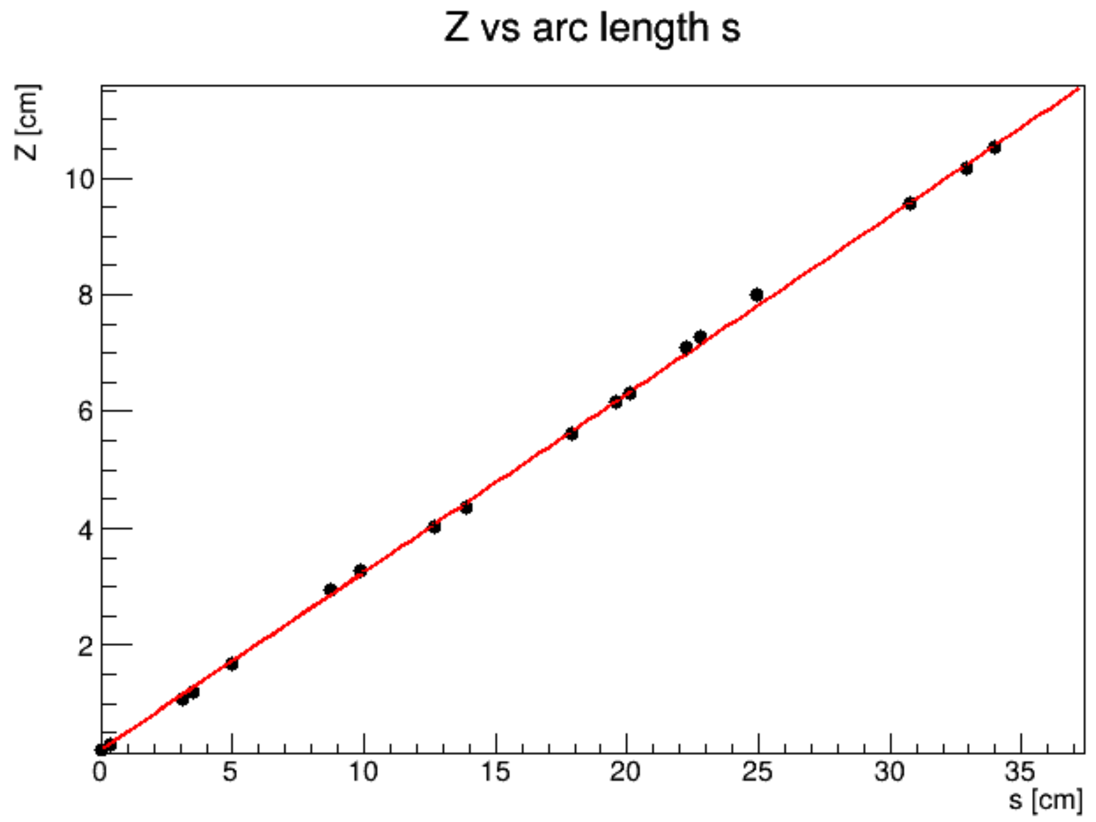


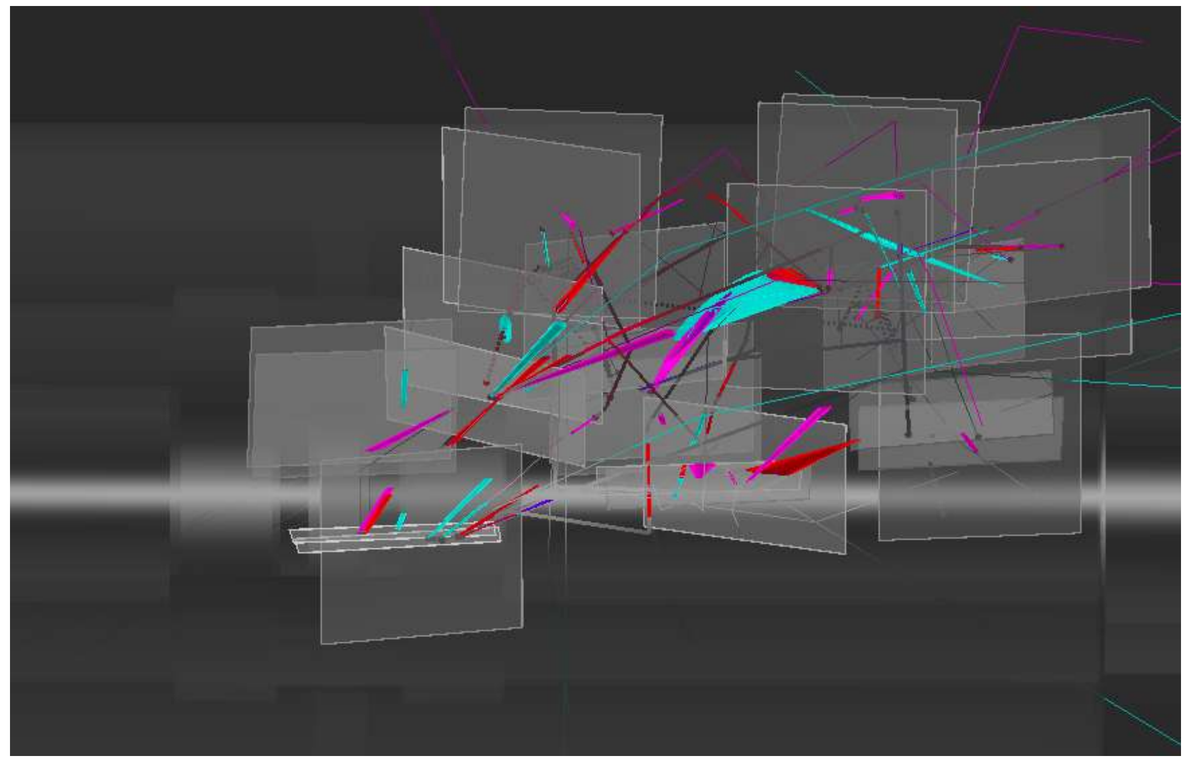
Ex. of improvement on the track-fitting algorithm

- The built-in Kalman filter in GenFit **struggles** to reconstruct tracks **when hits are too far apart**
- To address this limitation, the algorithm is extended with a **stable and efficient helix pre-fitter:**
  - ➢ Circle Riemann fit in the transverse plane → $\{x_C, y_C, R\}$
  - ➢ Linear fit of Z as a function of arc length → $\{z0, \tan\lambda\}$

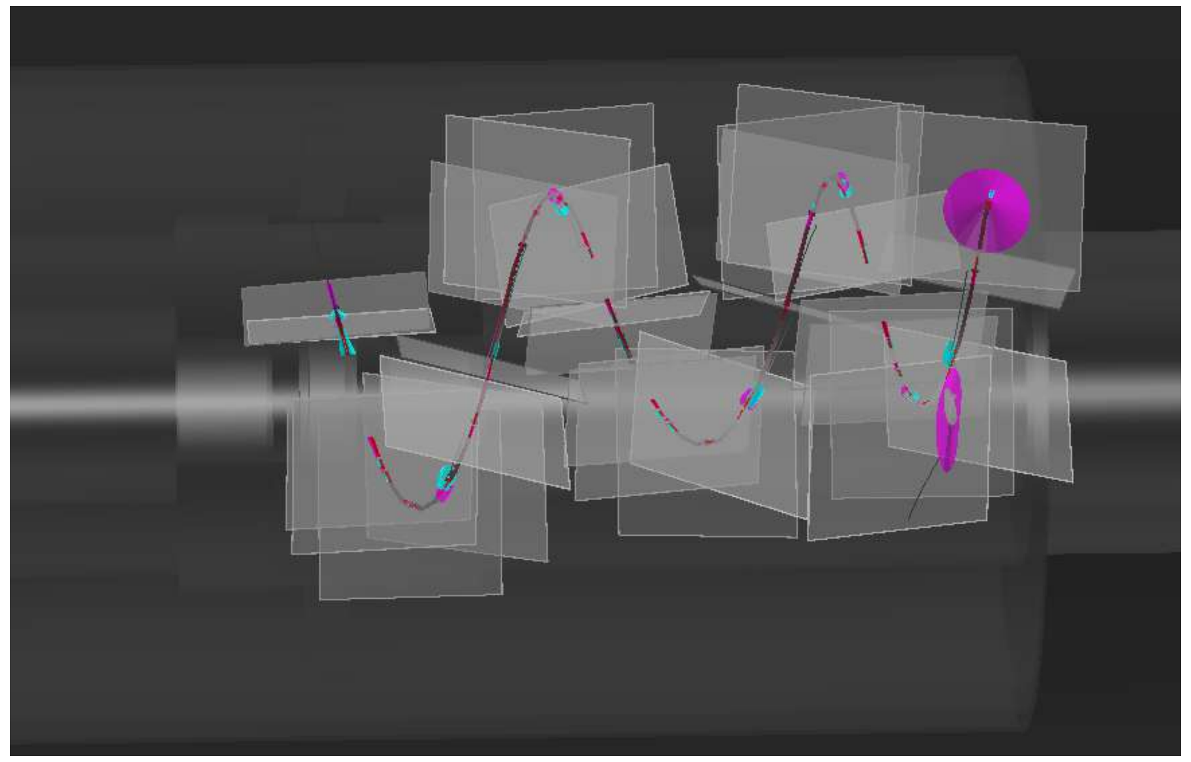








w/ pre-fitter

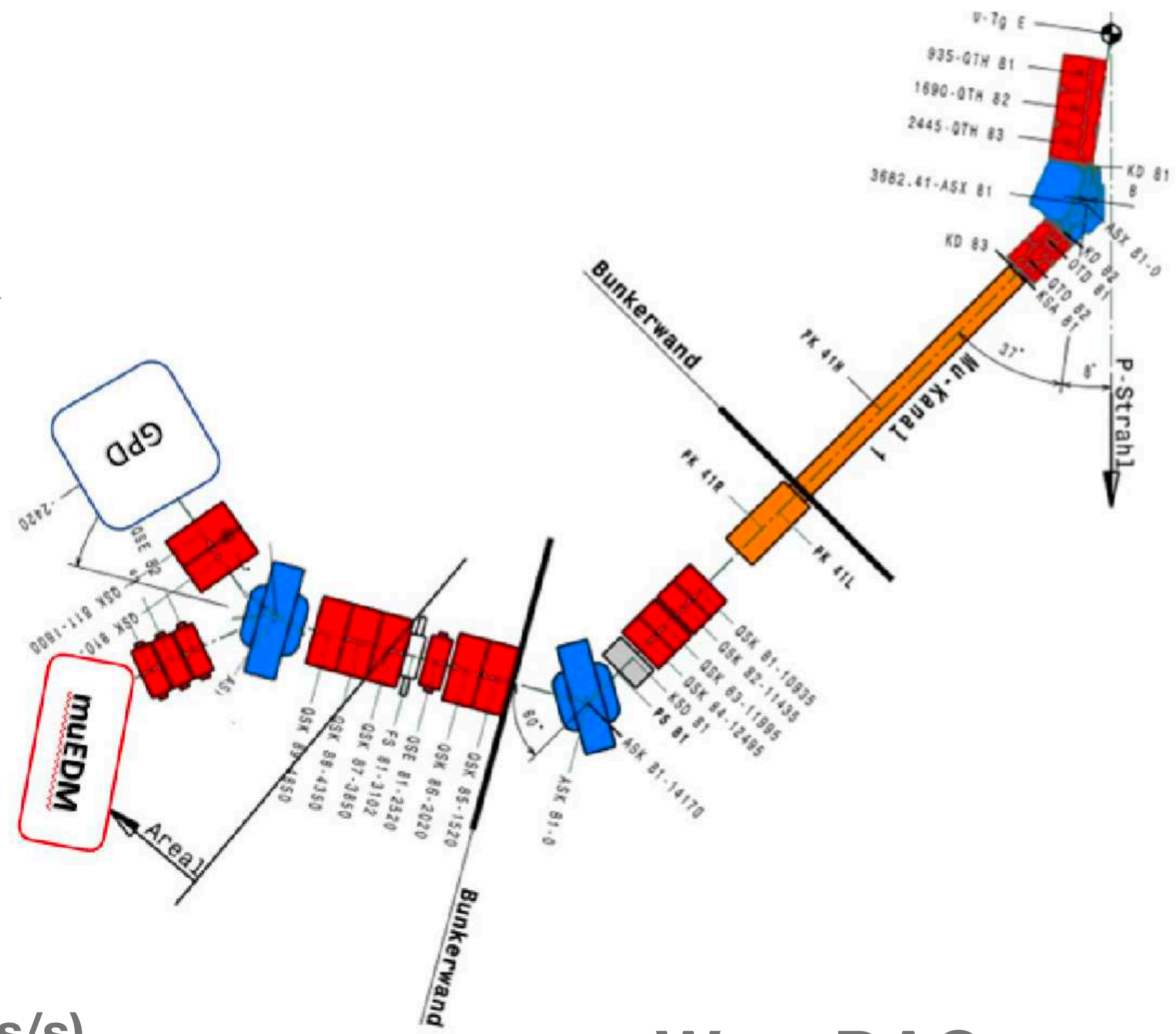


Fitter \ nTurns fitted	1	2	3
w/o pre-fitter	64%	60%	59%
w/ pre-fitter	76%	71%	69%

Beam time 2024: All (three) successfully accomplished

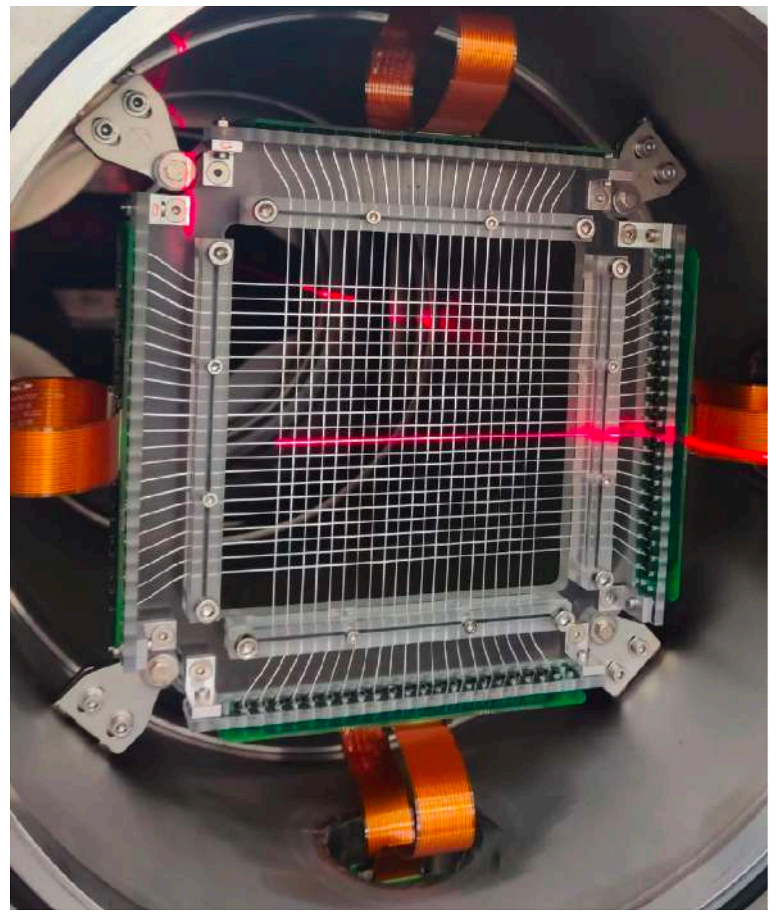
- μE1 Beamline Study
- Magnetic Kicker Systematic Study at πM1
- Triggering System Test with Low Magnetic Field Injection at πE1

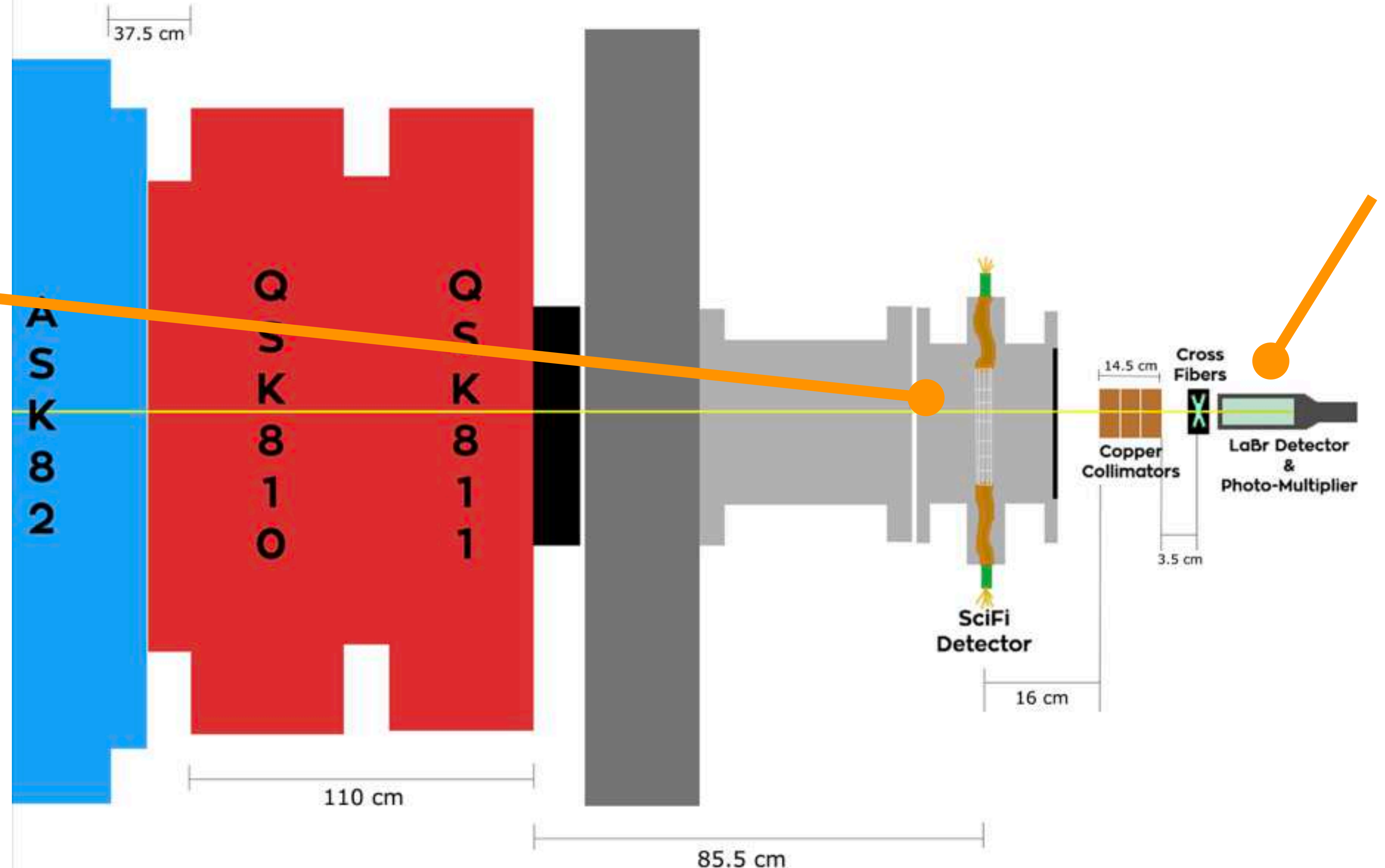
Beam time 2024 - 1: µE1 Beamline Study



- Goal: Characterize the **phase space of the muE1** beam in Z-configuration
- Z-configuration permits operation of the
  - GPD muSR instrument - GIANT instrument
  - and the **future muEDM** on the same beam line
- **Very successful:** Data analysis ongoing
  - **Our contributions**
    - Measurement **technique proposal** (6D phase space + RF reference)
    - **SciFi+BC400X+LaBr** detectors readout with **WaveDAQ** (Trigger+DAQ settings)
  - **Main result:** improved the beam quality and increased the beam intensity **by 30% (~1.2 x 10^8 muons/s)** wrt previous tuning at 125 MeV/c [our interested momentum value]

SciFi



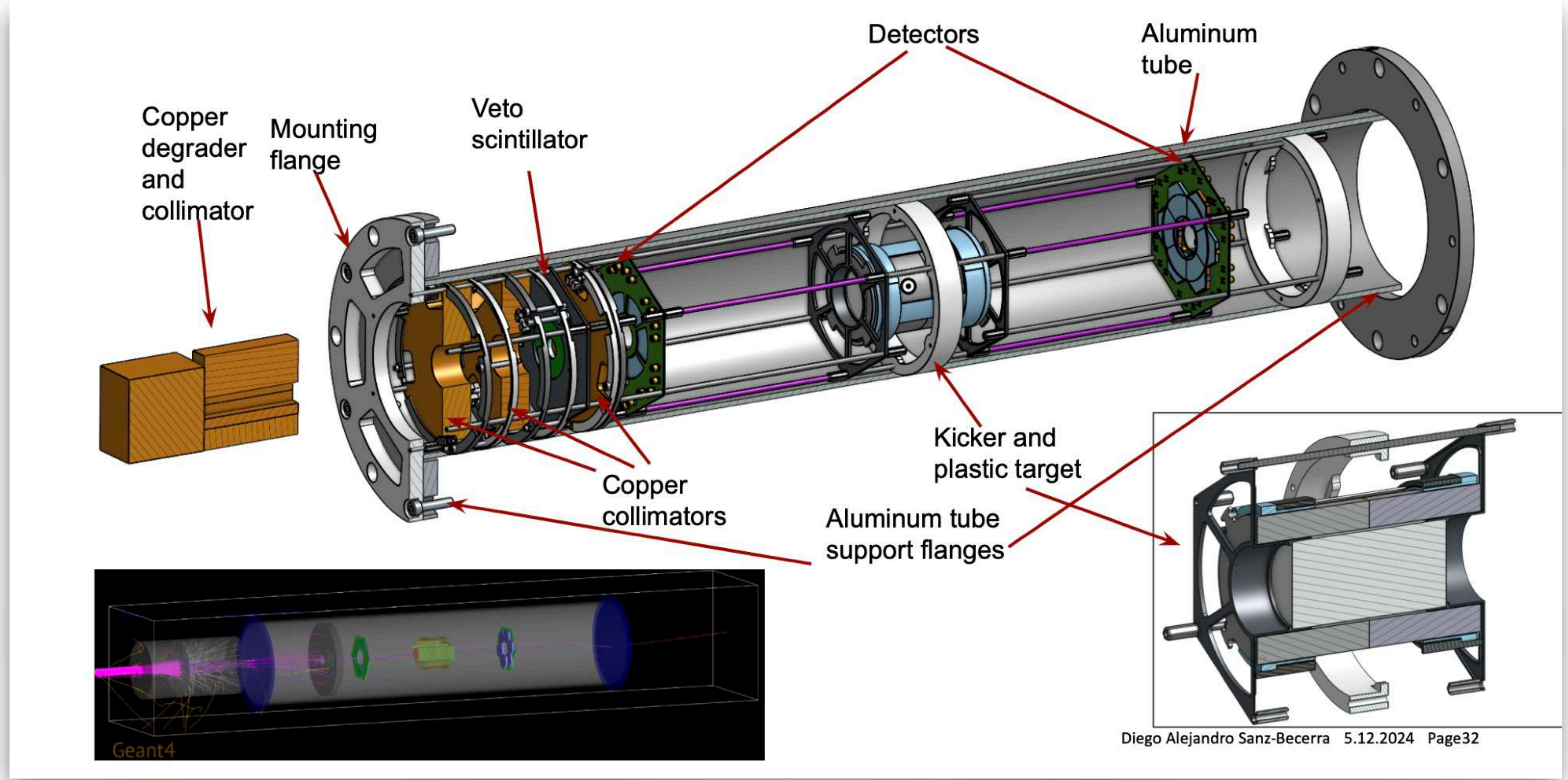


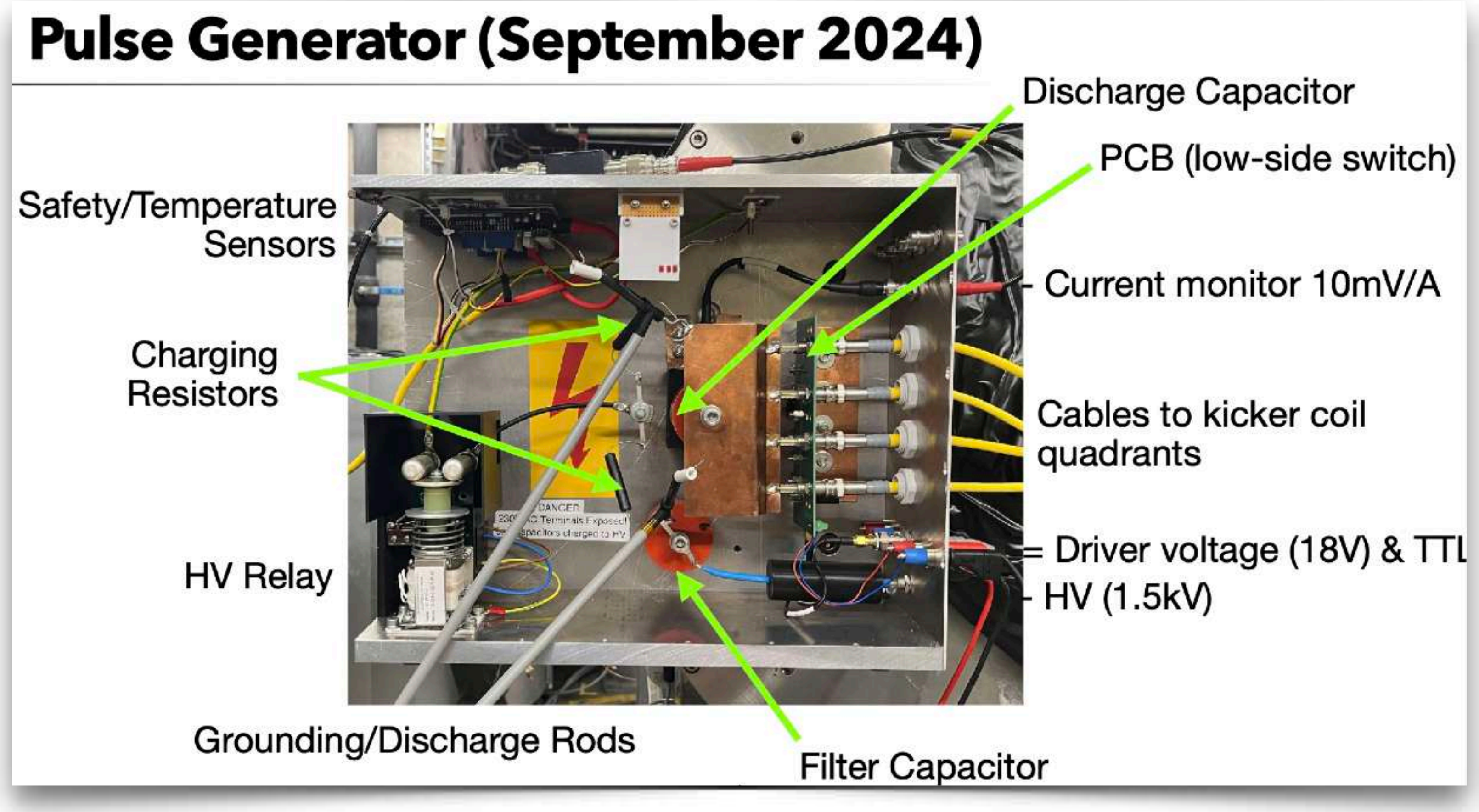
BC400-X & LaBr

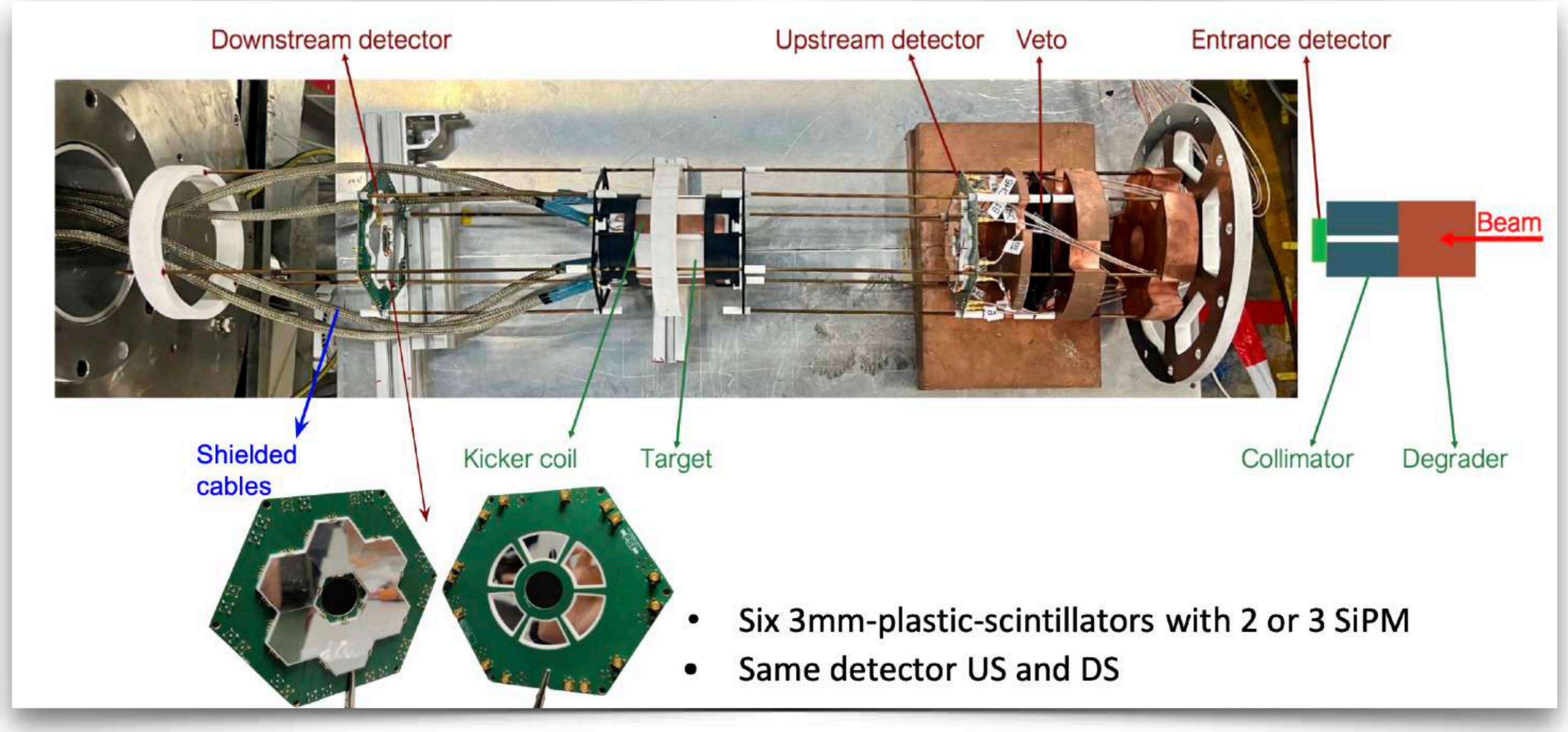
WaveDAQ

Beam time 2024 - 2: Magnetic Kicker Systematic Study at πM1

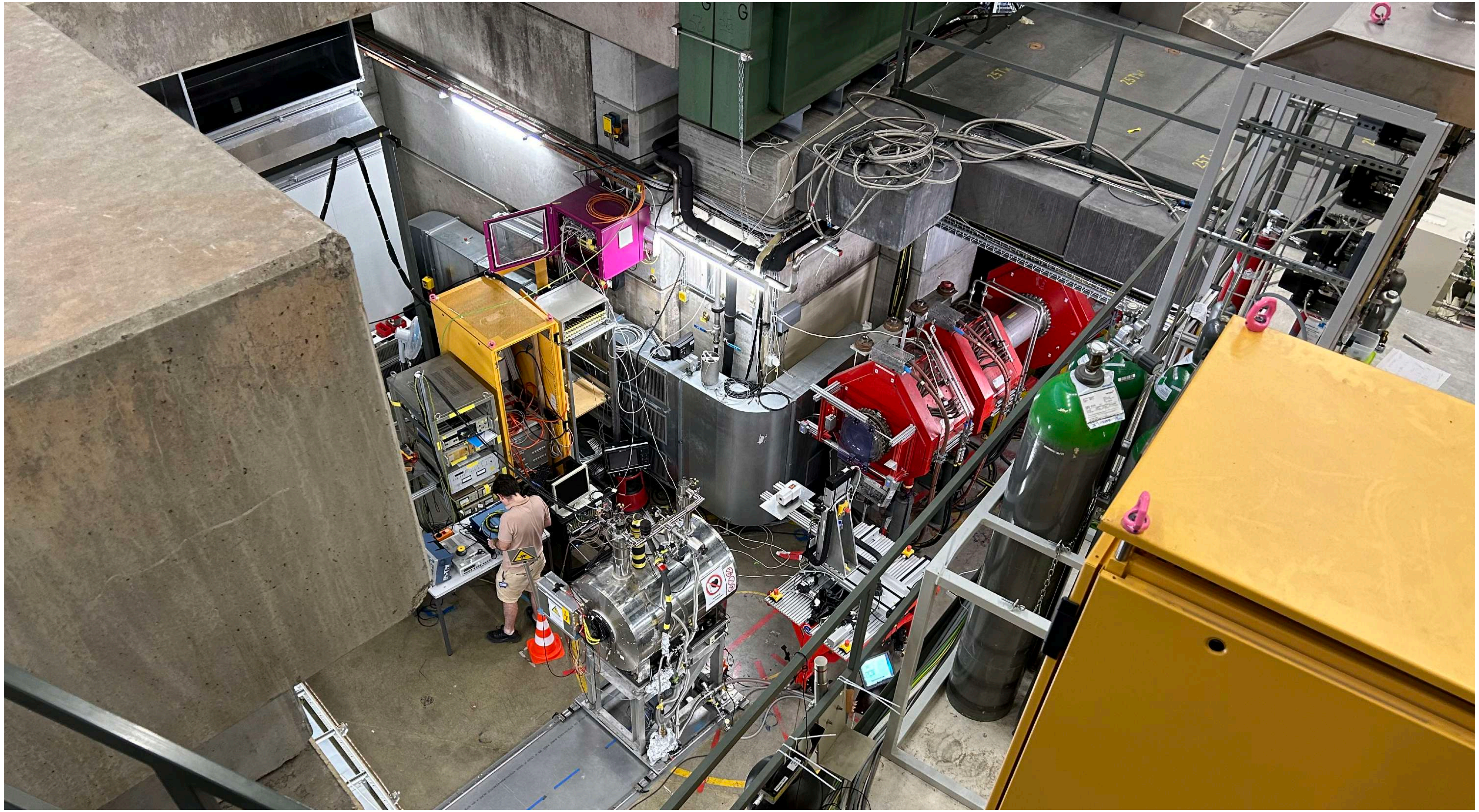
- Test prototype of magnetic kicker
  - Current pulses amplitude close to Phase-1 design
  - Current pulse persistent for O(μs) (not as Phase-1 design O(100ns))
- Study effects of magnetic kicker on scintillating detectors based on SiPMs
- Test of the Exit detector
- The role of this detector in experiment
- Optimise the correction coil and kicker current for the best muon spiral injection
- Detect not stored muons







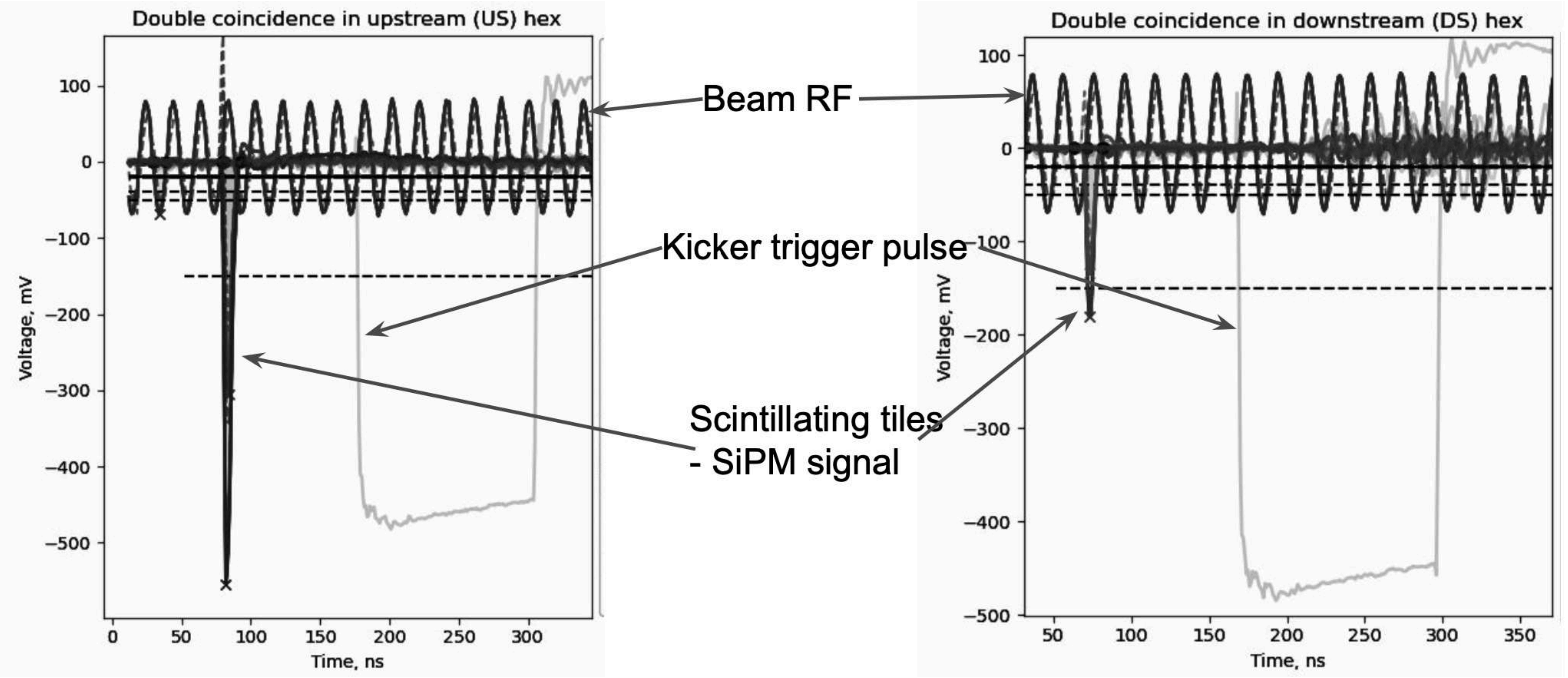
Beam time 2024 - 2: Magnetic Kicker Systematic Study at πM1



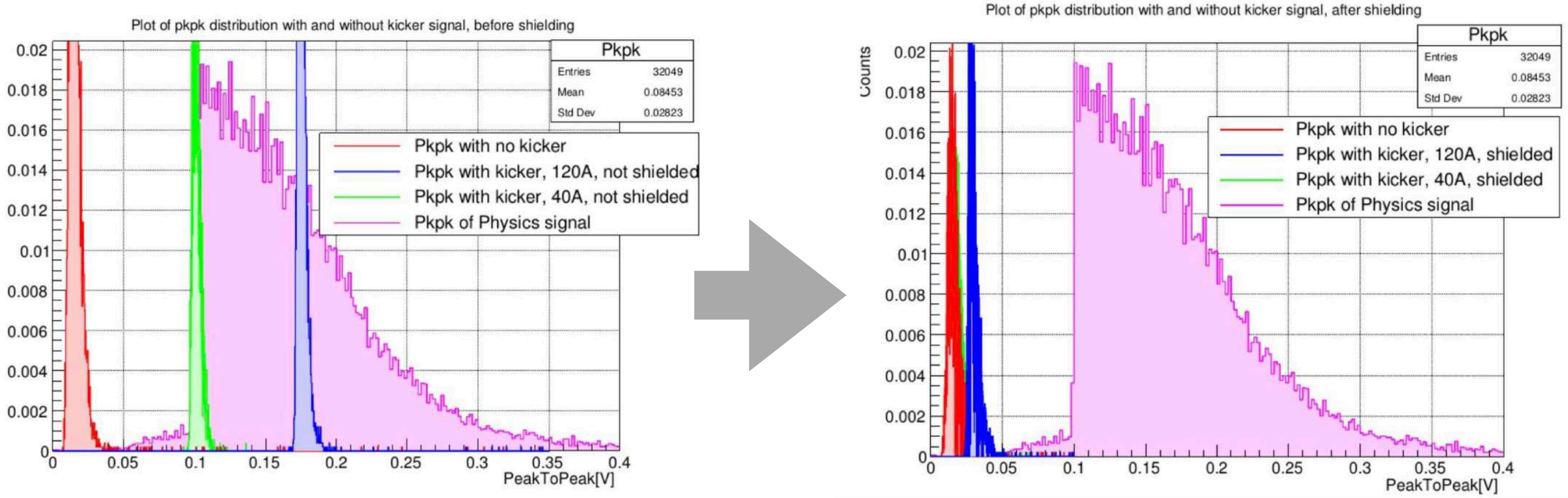
Beam time 2024 - 2: Magnetic Kicker Systematic Study at πM1

Beam time 2024 - 2: Magnetic Kicker Systematic Study at πM1

- **Accomplished:** Data analysis ongoing
  - Kicker operated at
    - “High frequency” and “High current” modes: 40 A @ 300 Hz, 120 A @ 19 Hz
  - Our contributions
    - Measurement **proposal** with particles at different momenta
    - **WaveDAQ** (Trigger+DAQ settings)
    - Installation, beam tuning, Data taking, Data analysis and Shifts



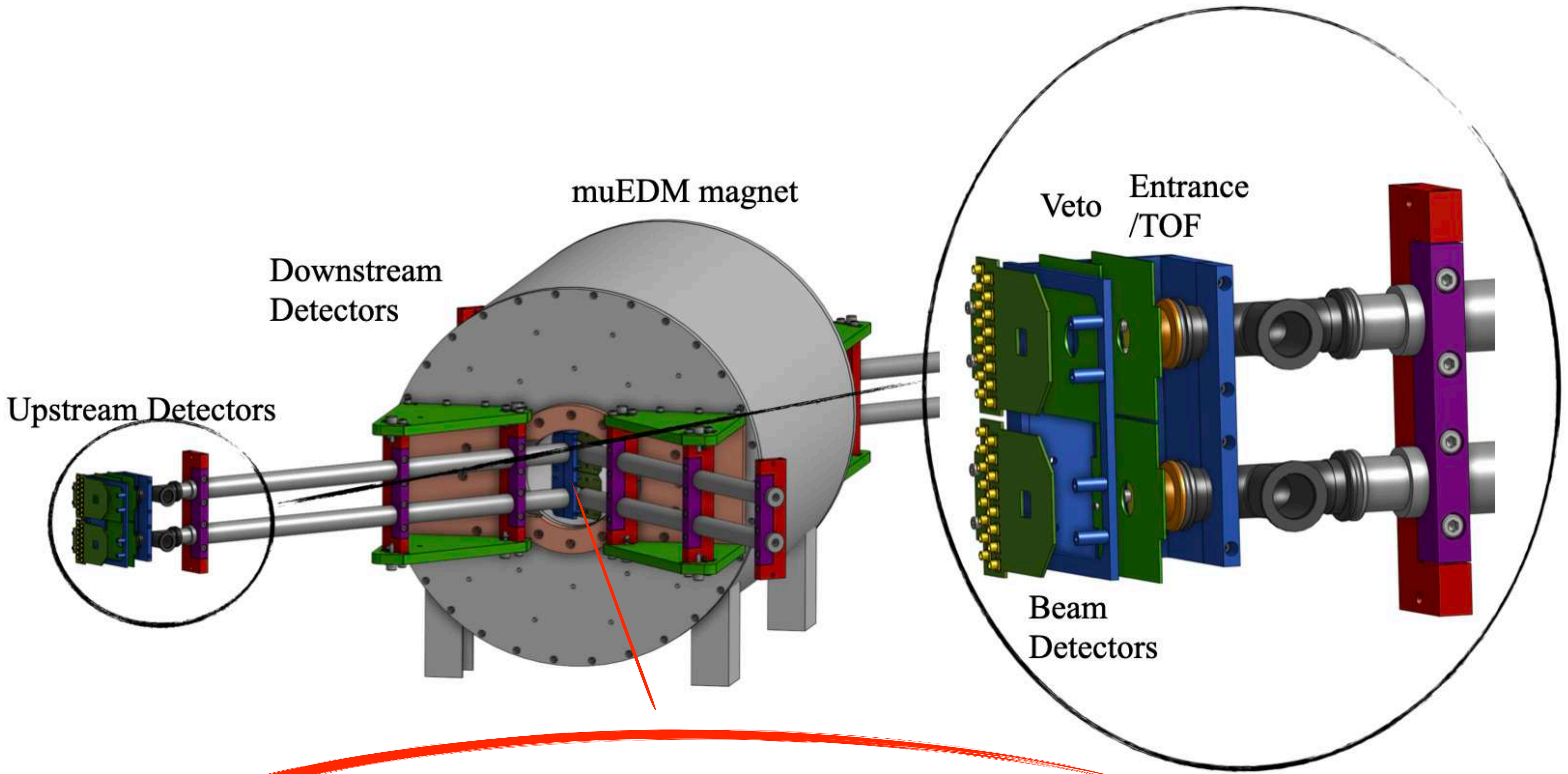
Before/after the extra cabling shielding

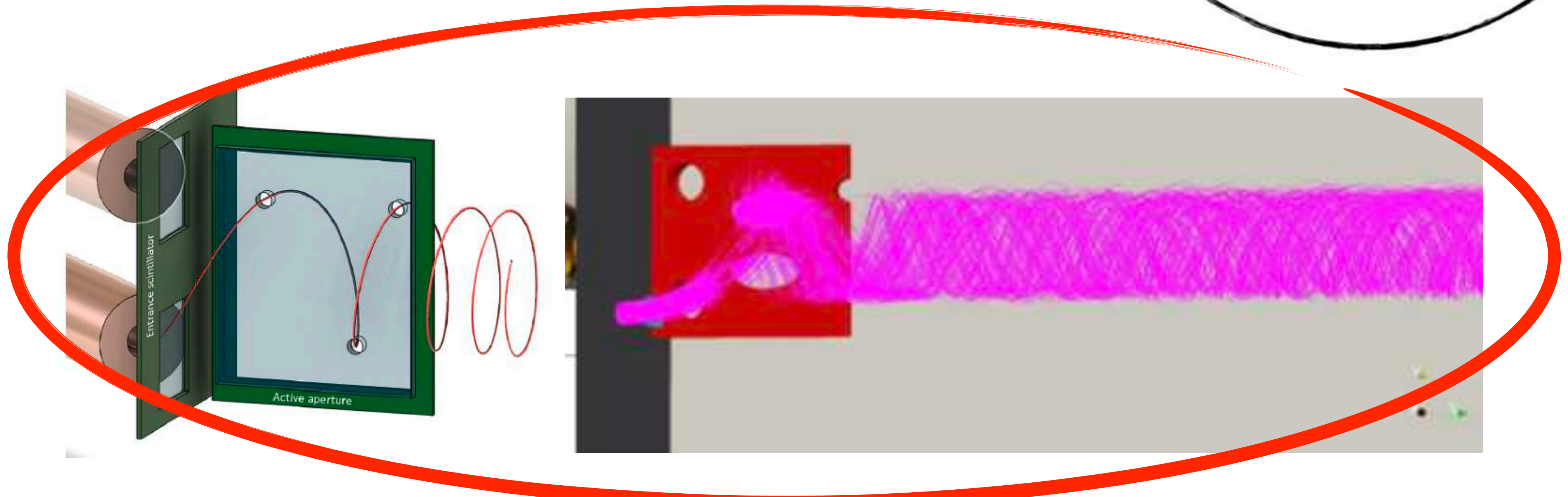


- **Main results:**
  - Big reduction of non-physical signals with extra shielding of cables and SiPMs
  - No observed asymmetry on US/DS detectors
  - Kicker-PSI successfully operated: Room for improvements allowed to promote it as back-up solution for the main one (Kicker-KIT)

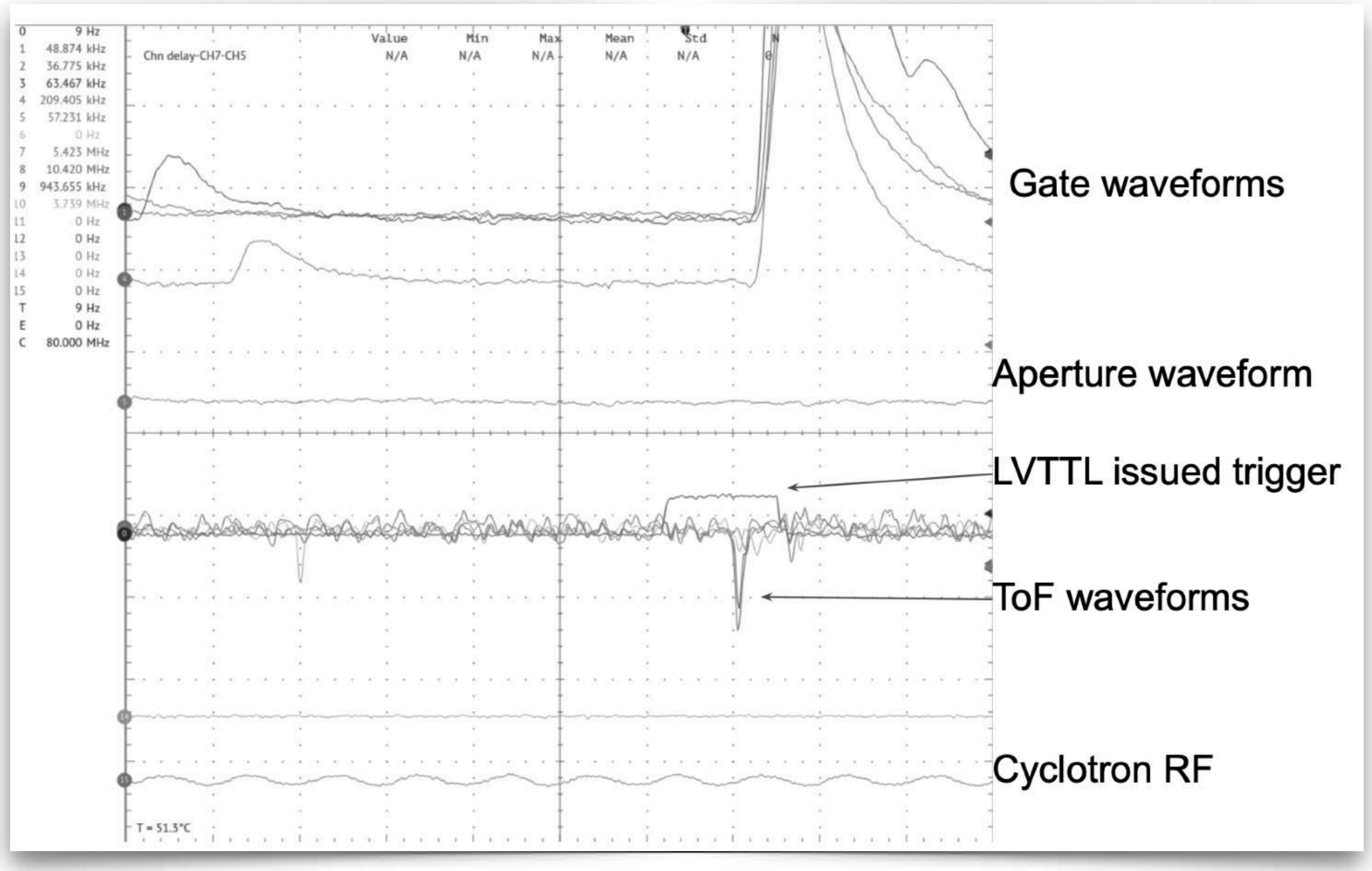
Beam time 2024 - 3:
Triggering System Test with Low Magnetic Field Injection at πE1

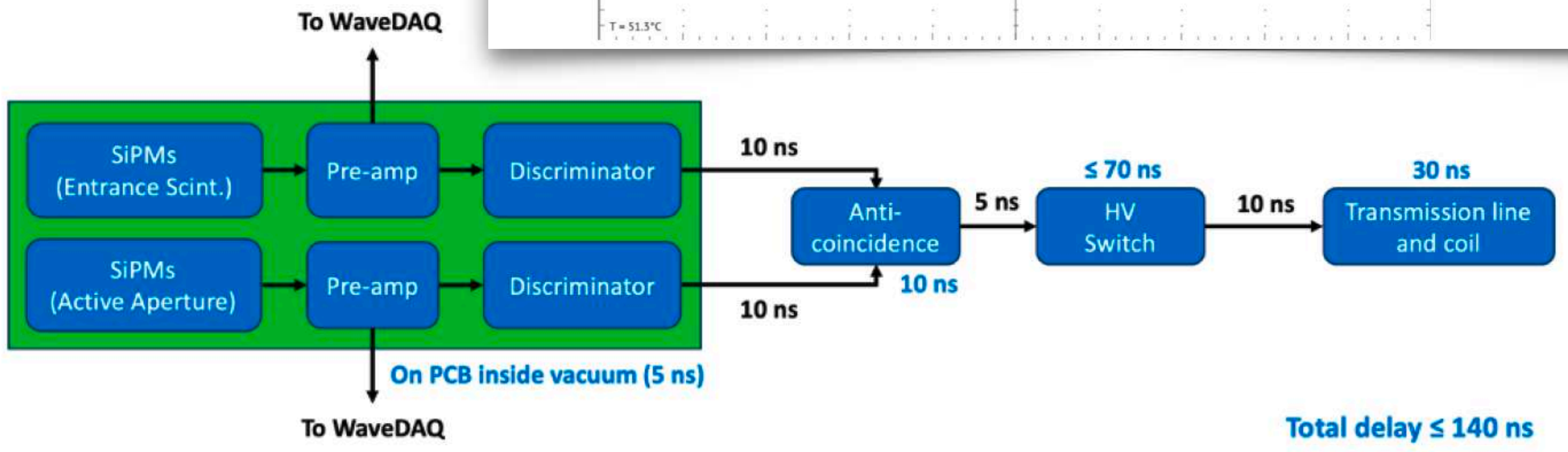
- Test the double spiral injection for the CW and CCW injection (including the precise movement of the magnet up/down)
  - Detectors: Beam monitoring/TOF/Complete Entrance Detectors (including the anti-coincidence)
- Test the Entrance (kicker trigger) detector and its fast electronics



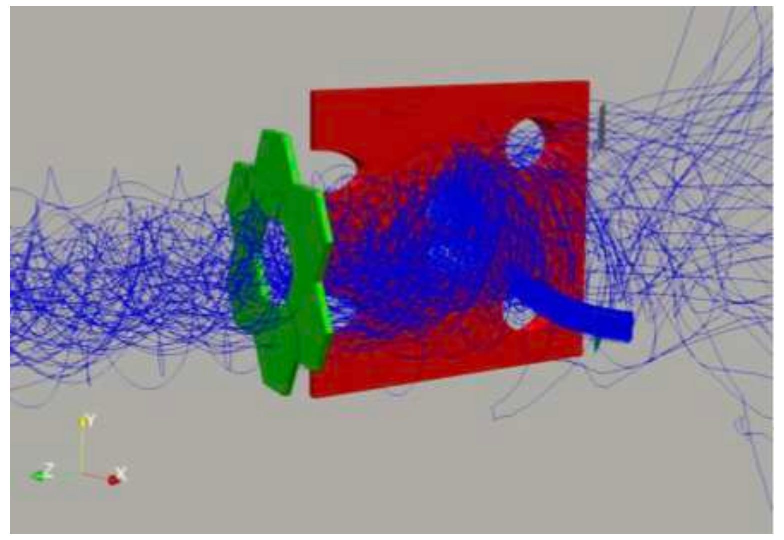


Data



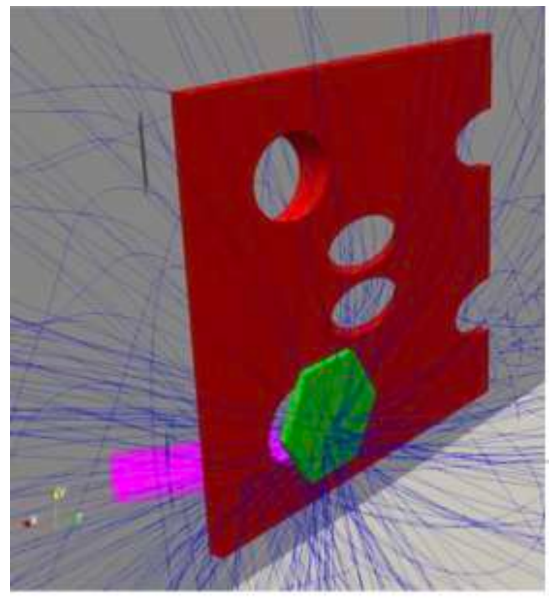


Beam time 2024 - 3:
Triggering System Test with Low Magnetic Field Injection at πE1



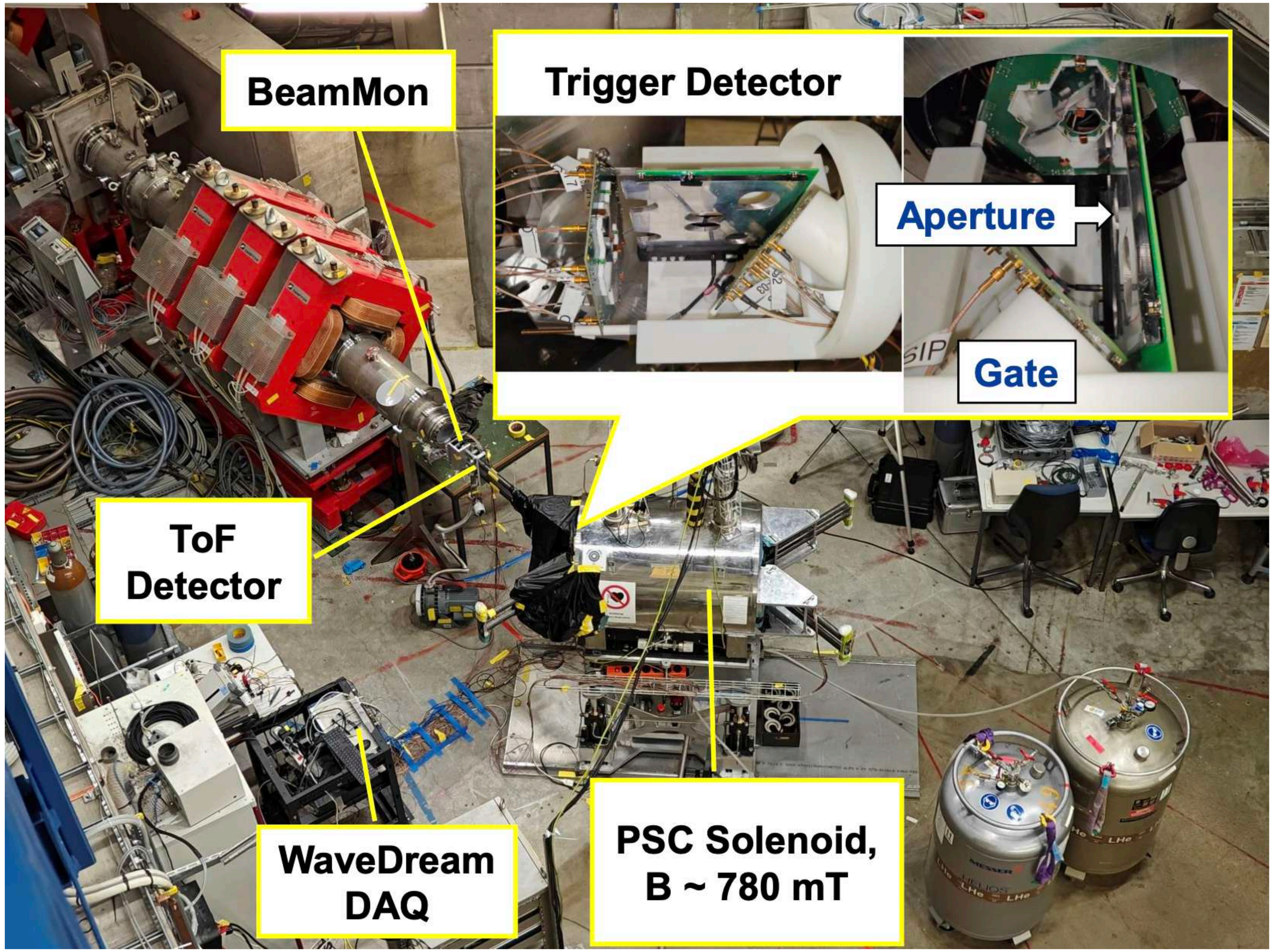
e+ beam at 10 MeV/c

- Spiral trajectory reaches exit detector
- Full test of the trigger + anti coincidence with all openings



μ+ beam at 22.5 MeV/c

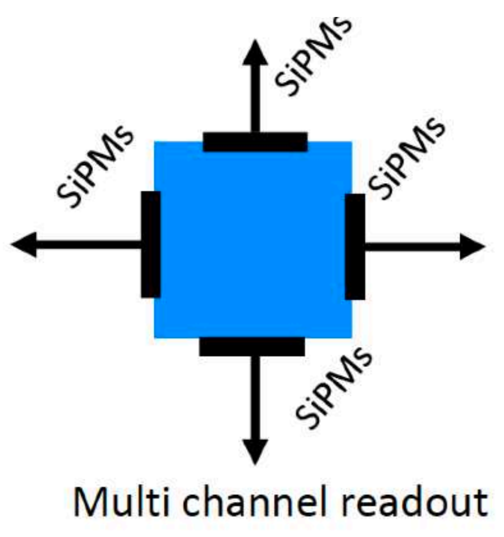
- Test of the entrance detector with muons
- Test of the trigger + anti coincidence with one aperture opening

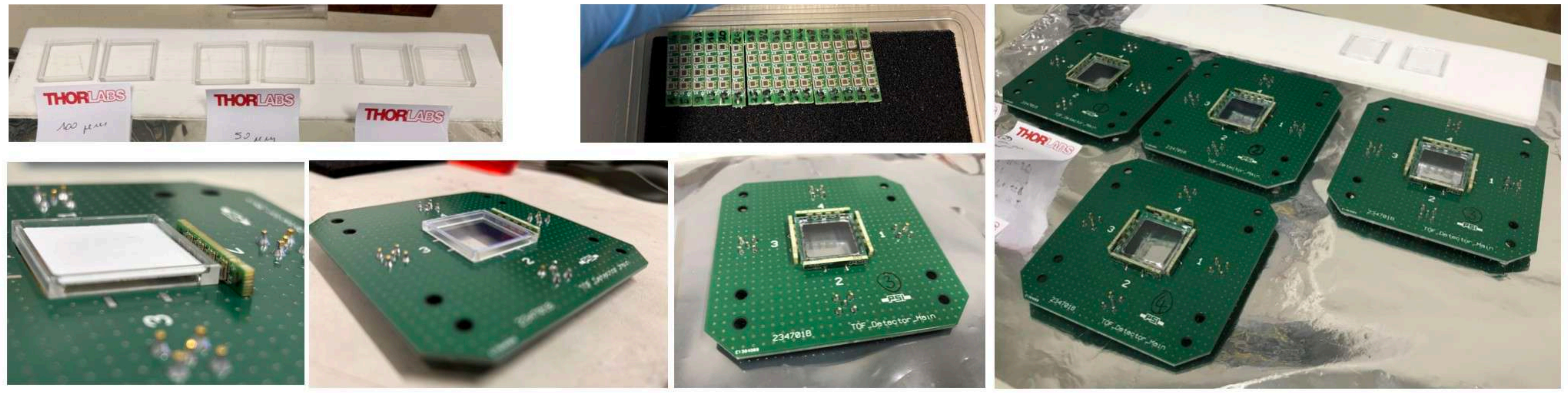


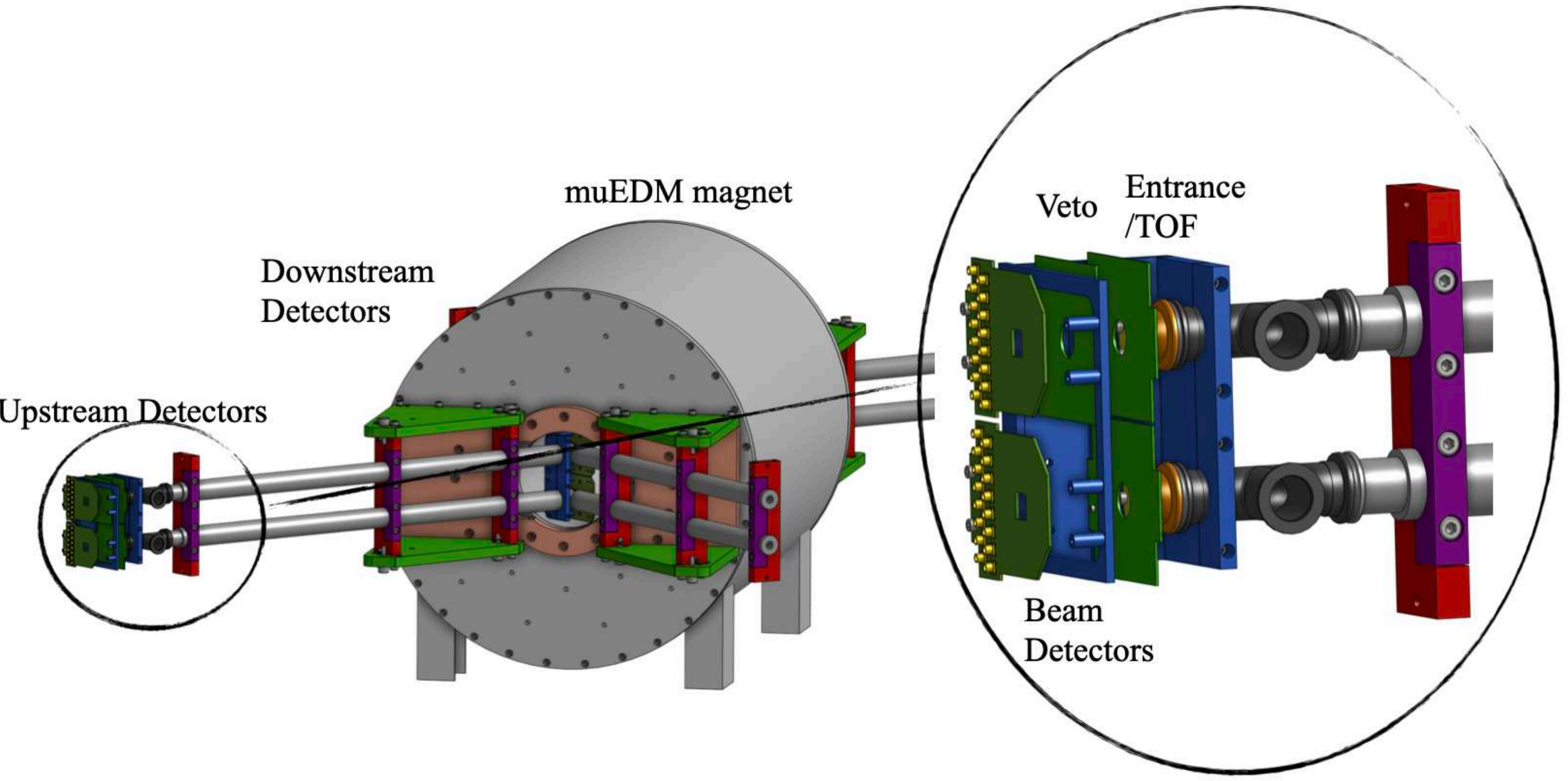
- **Very successful:** Data analysis ongoing
  - Our contributions
    - Measurement proposal with positron and muons at different momenta
    - **TOF** detectors, **WaveDAQ** (Trigger+DAQ settings)
    - Beam tuning, Data taking and Shifts

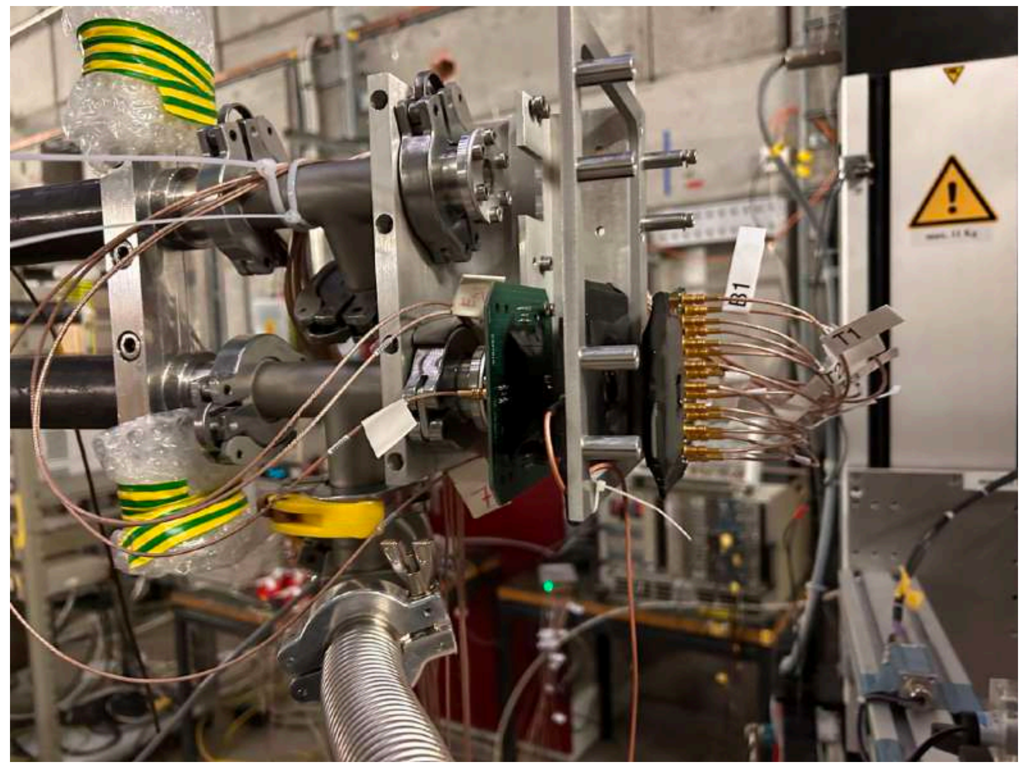
TOF/Entrance detectors v2.0

- The Time of Flight (ToF) detectors are used to measure the muon momentum of the particle that will be stored inside the magnet
    - It is essential for controlling the main systematic uncertainties related to the alignment of the electric field with respect to the magnetic field
- Detector performances tested along the beam (beam time 2023 and 2024)
    - Detection efficiency > 98% (100 um), >90% (50 um)
    - TOF detector experiment requirements: **Addressed.** R&D: **Completed!**

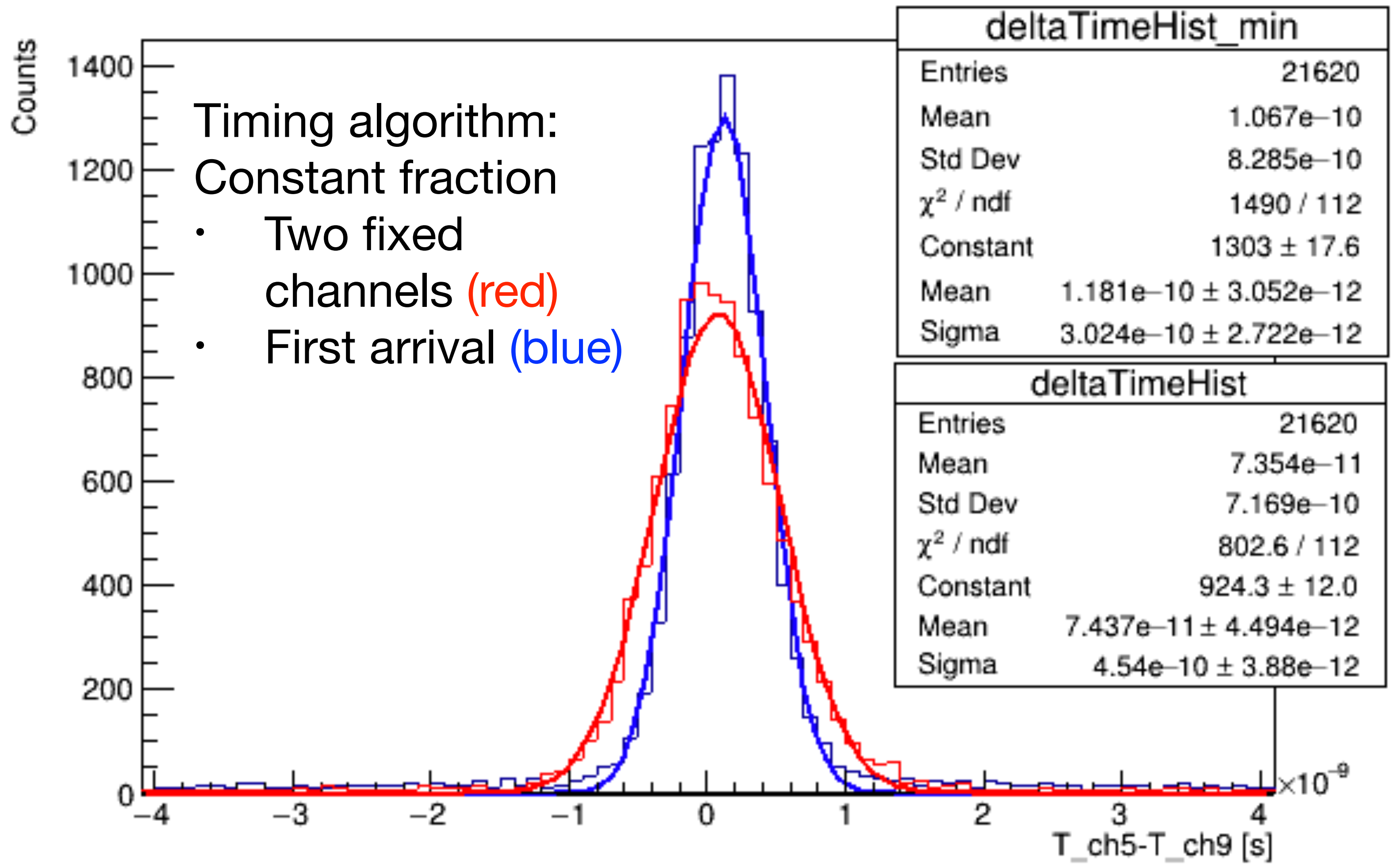






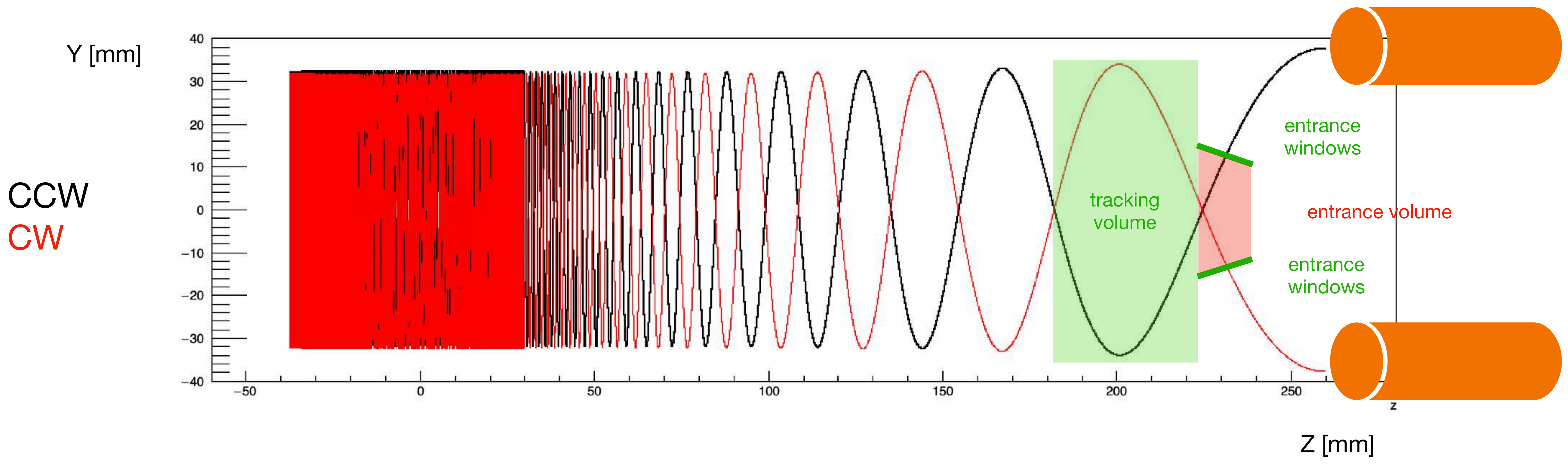


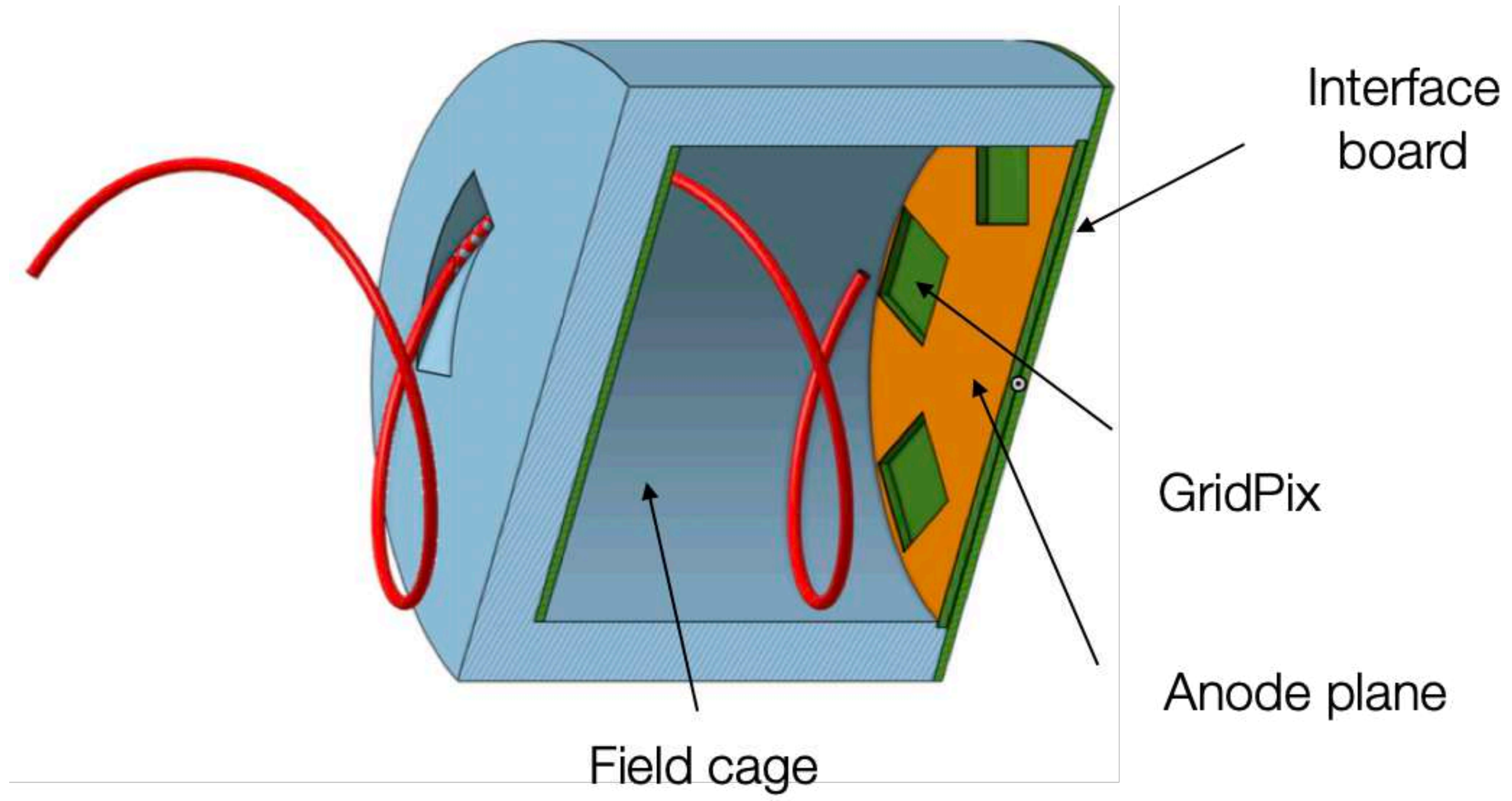
Measured “intrinsic” time resolution: **O(300) ps, as expected!**



AUX detector: A TPC for muon trajectory characterisation

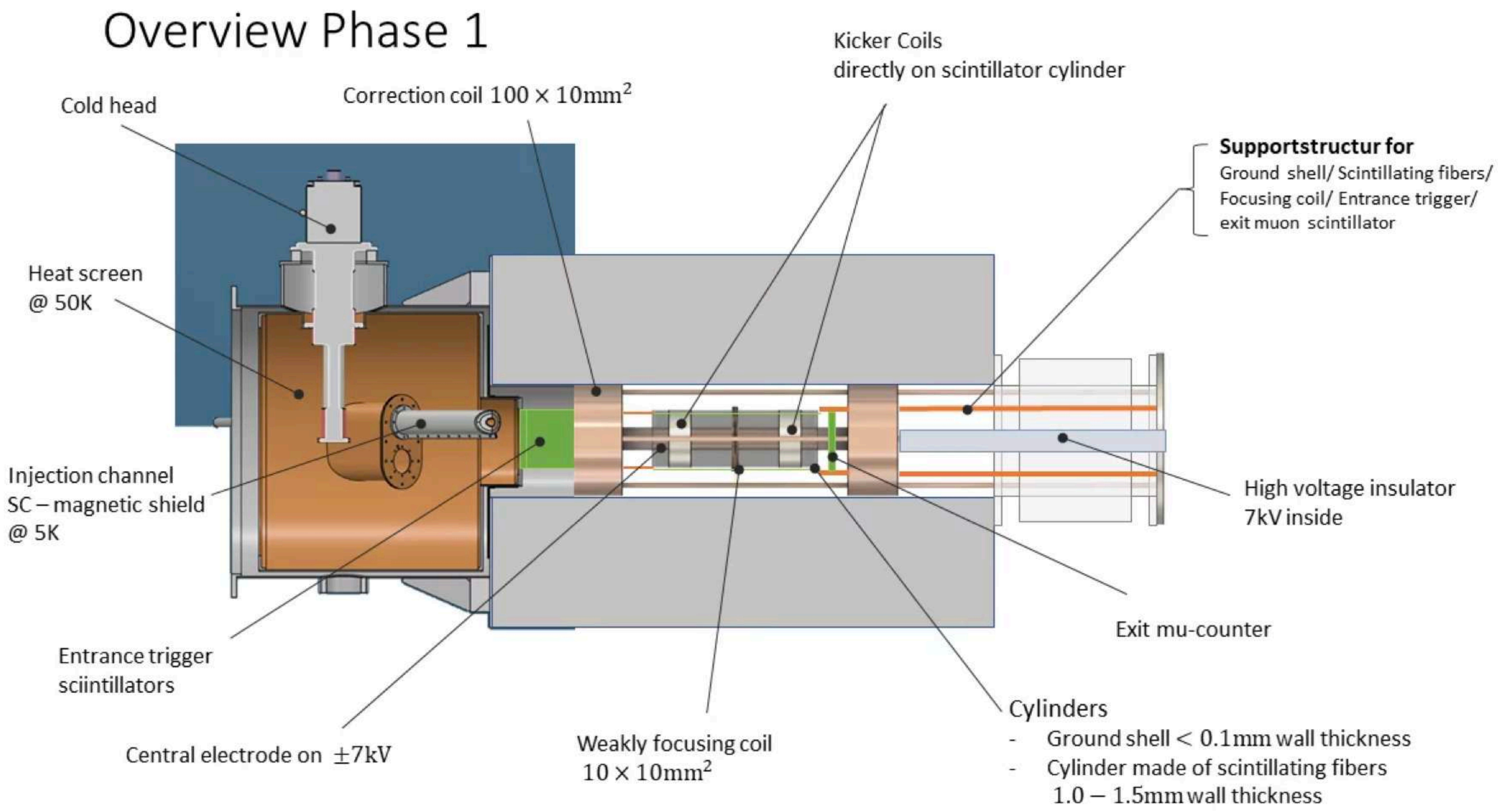
- Determination of the muon momentum difference between clockwise (CW) and counter-clockwise (CCW) injection within 0.5% precision —> essential for the control of the systematic uncertainties
- Determination of the phase space at the entrance of the magnet —> cross-check the alignment of beam, injection channels and magnet
- Schedule. Construction + commissioning: 2/4+3/4 of 2025. Beam characterisation: 4/4 of 2025





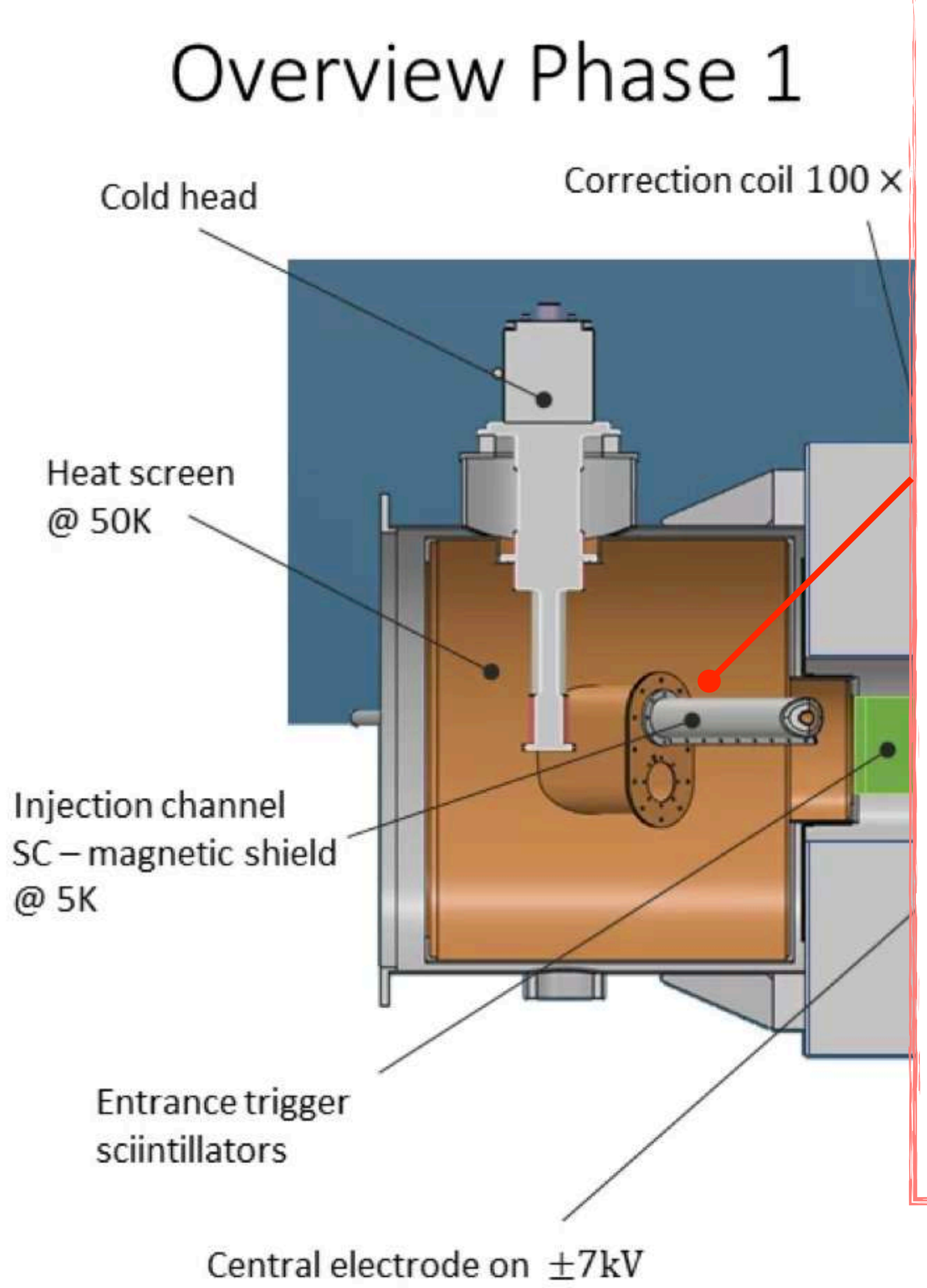
- Small TPC (few cm drift) with GridPix readout in two configurations:
  - longitudinal (optimized for momentum) and radial (optimized for angles)
- Extremely light material budget:
  - 400 nm silicon nitride windows, light helium-based gas mixture

Summary

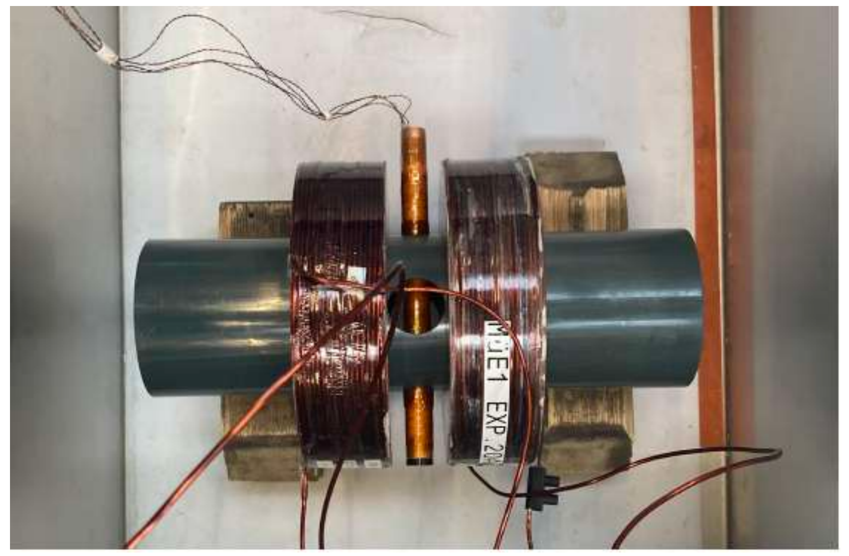

Overview Phase 1
Cold head
Correction coil $100 \times 10\text{mm}^2$
Kicker Coils
directly on scintillator cylinder
Supportstructur for
Ground shell/ Scintillating fibers/
Focusing coil/ Entrance trigger/
exit muon scintillator
Heat screen
@ 50K
Injection channel
SC – magnetic shield
@ 5K
High voltage insulator
7kV inside
Exit mu-counter
Entrance trigger
sciintillators
Central electrode on $\pm 7\text{kV}$
Weakly focusing coil
$10 \times 10\text{mm}^2$
Cylinders
- Ground shell $< 0.1\text{mm}$ wall thickness
- Cylinder made of scintillating fibers
$1.0 - 1.5\text{mm}$ wall thickness

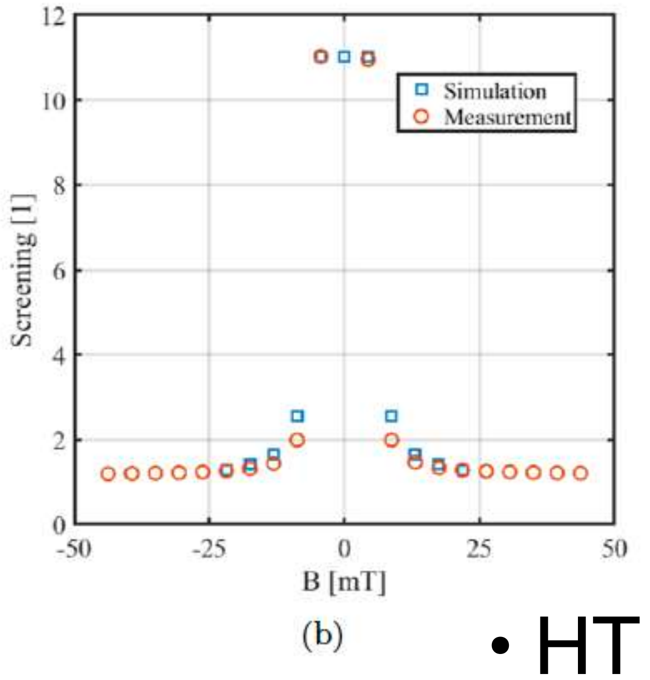
Summary

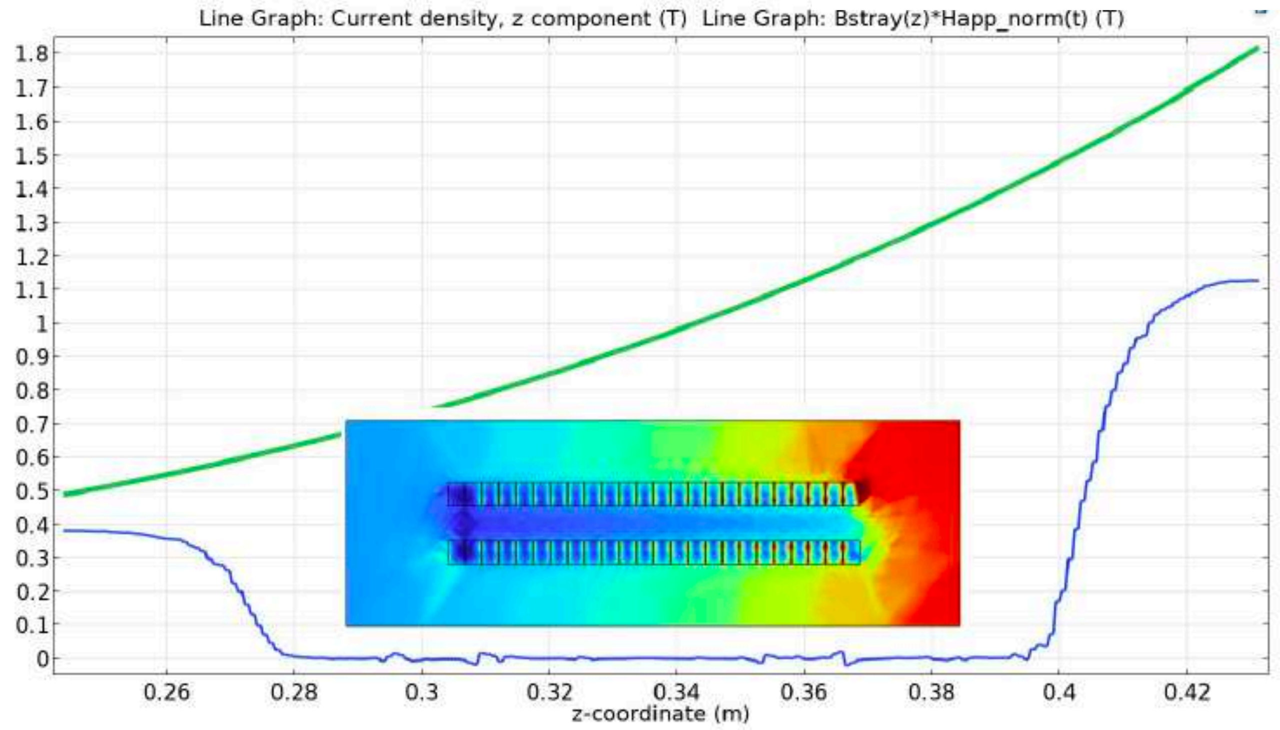
Overview Phase 1



First SC-prototypes test





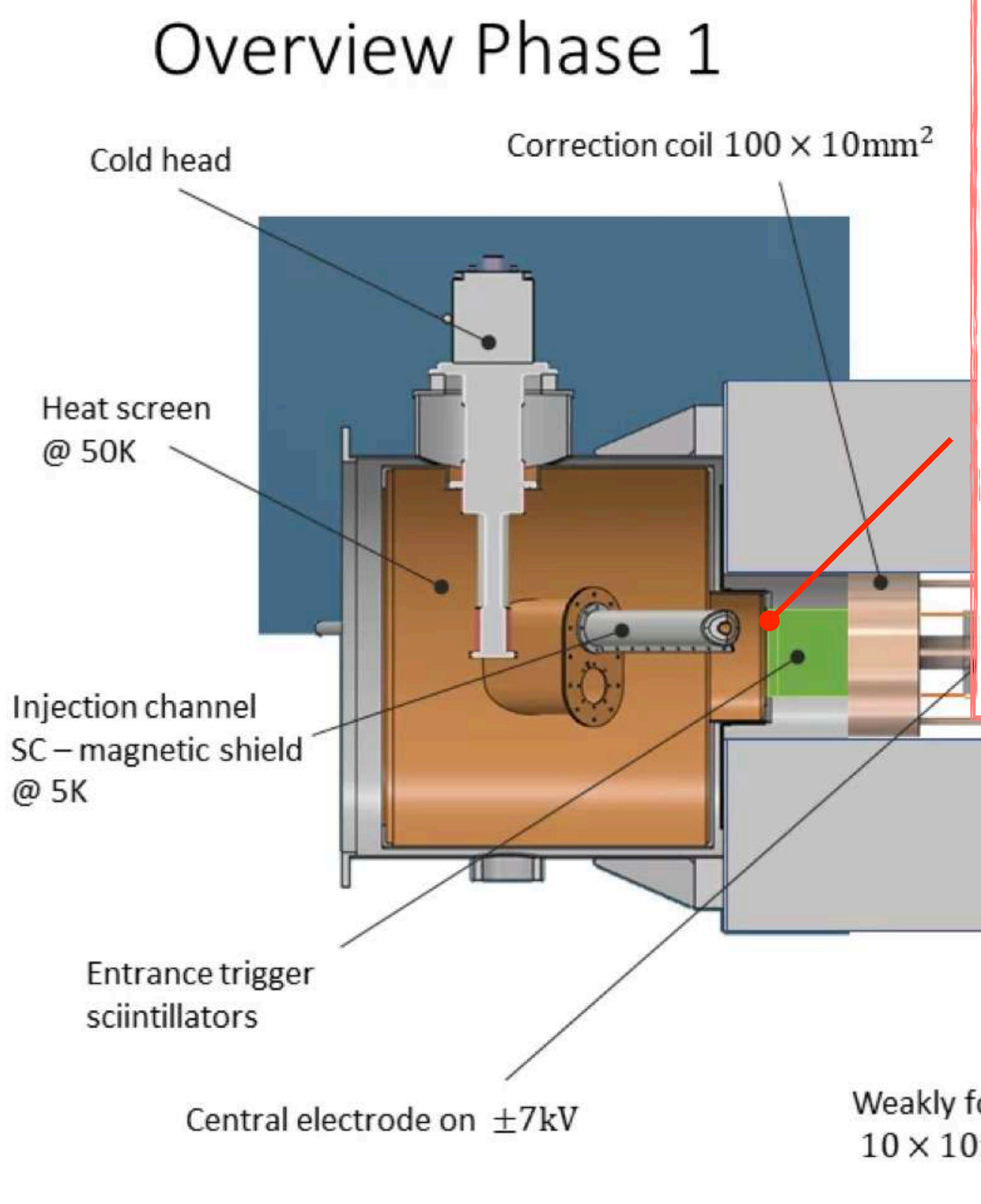


- HT SC YBCO-tape
- HT SC Bi-2223
- Shielding factor demonstrated and in agreement with MC
- Final: HT Bi-2223 + REBCO disks
- Other option: LT Nb-Ti/Nb/Cu SC sheet
- Cryo-cooler: Expected for Feb2025

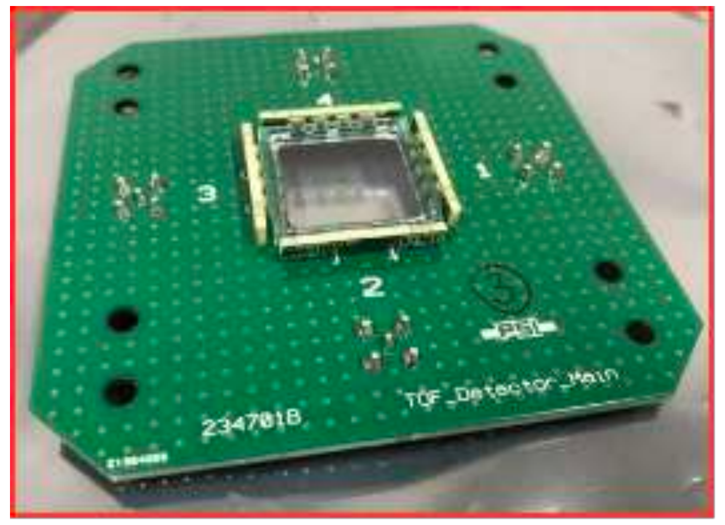
Weakly focusing coil
$10 \times 10\text{mm}^2$

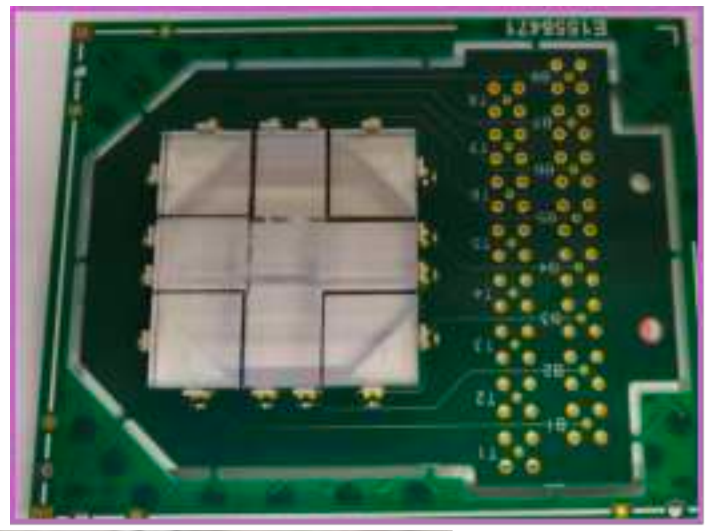
- Ground shell < 0.1mm wall thickness
- Cylinder made of scintillating fibers $1.0 - 1.5$mm wall thickness

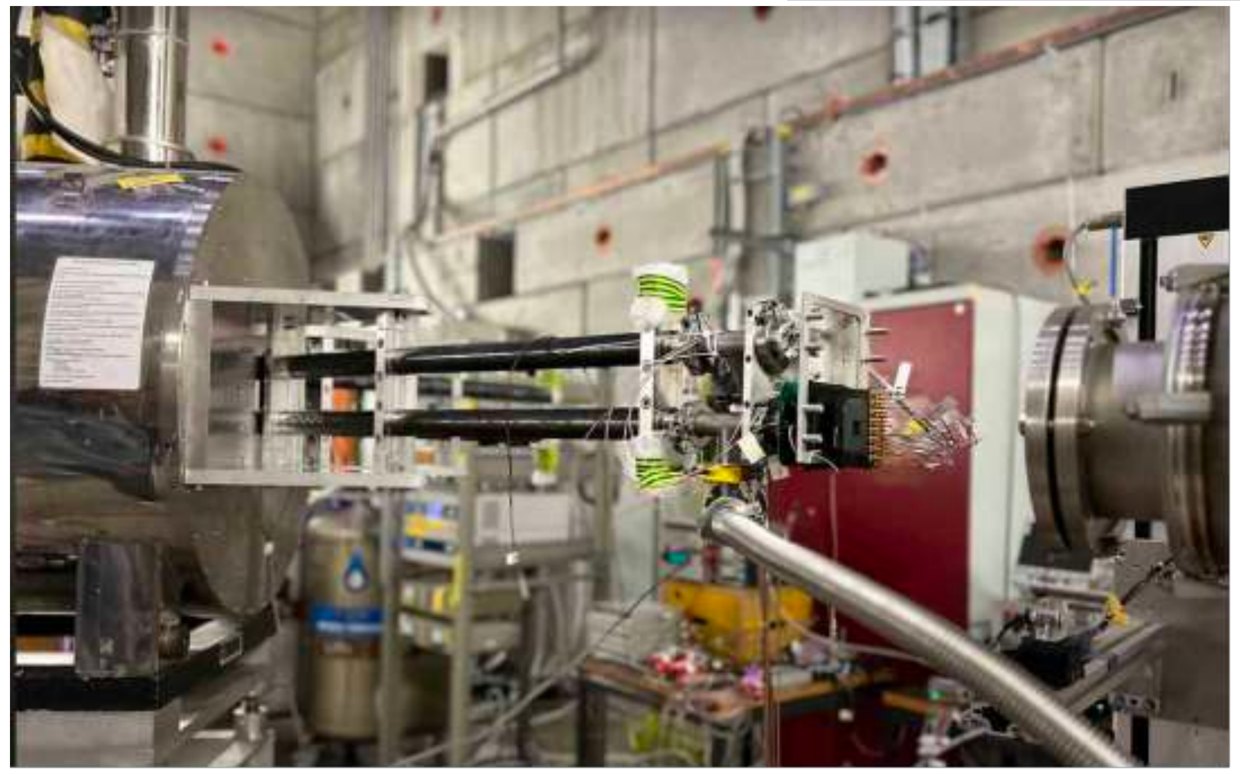
Summary

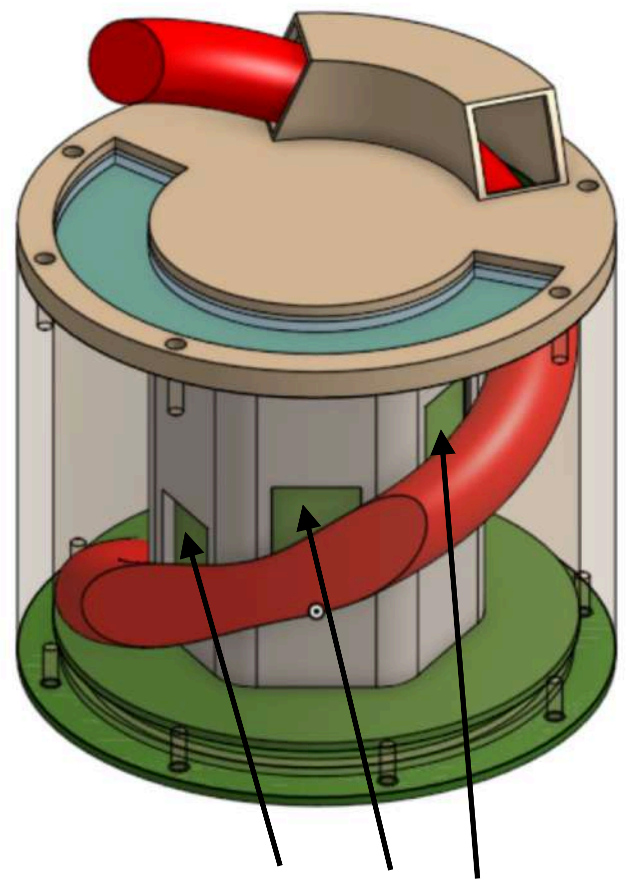


Beam monitoring/Entrance/TOF/ Muon Chamber







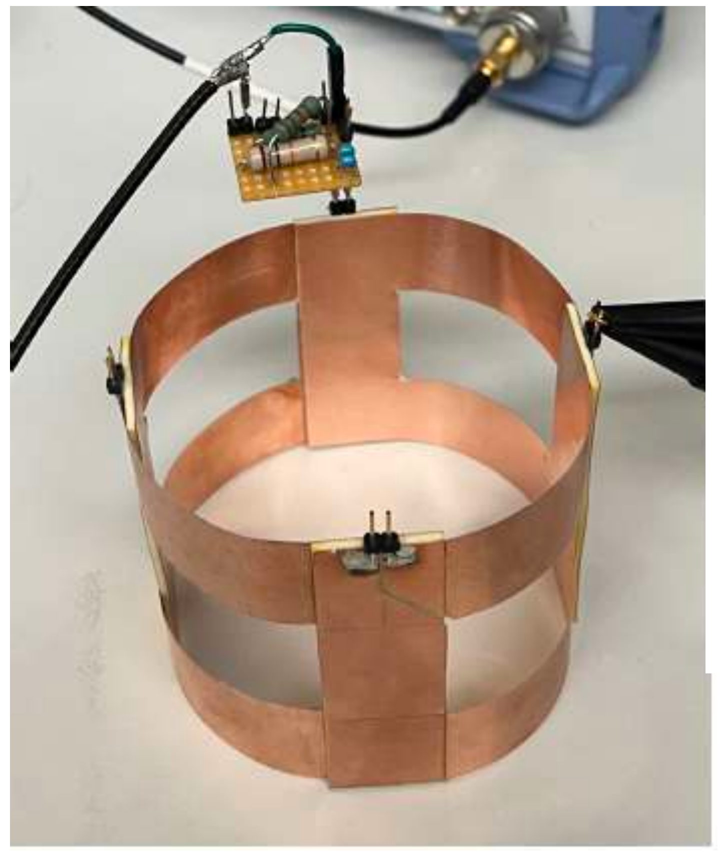


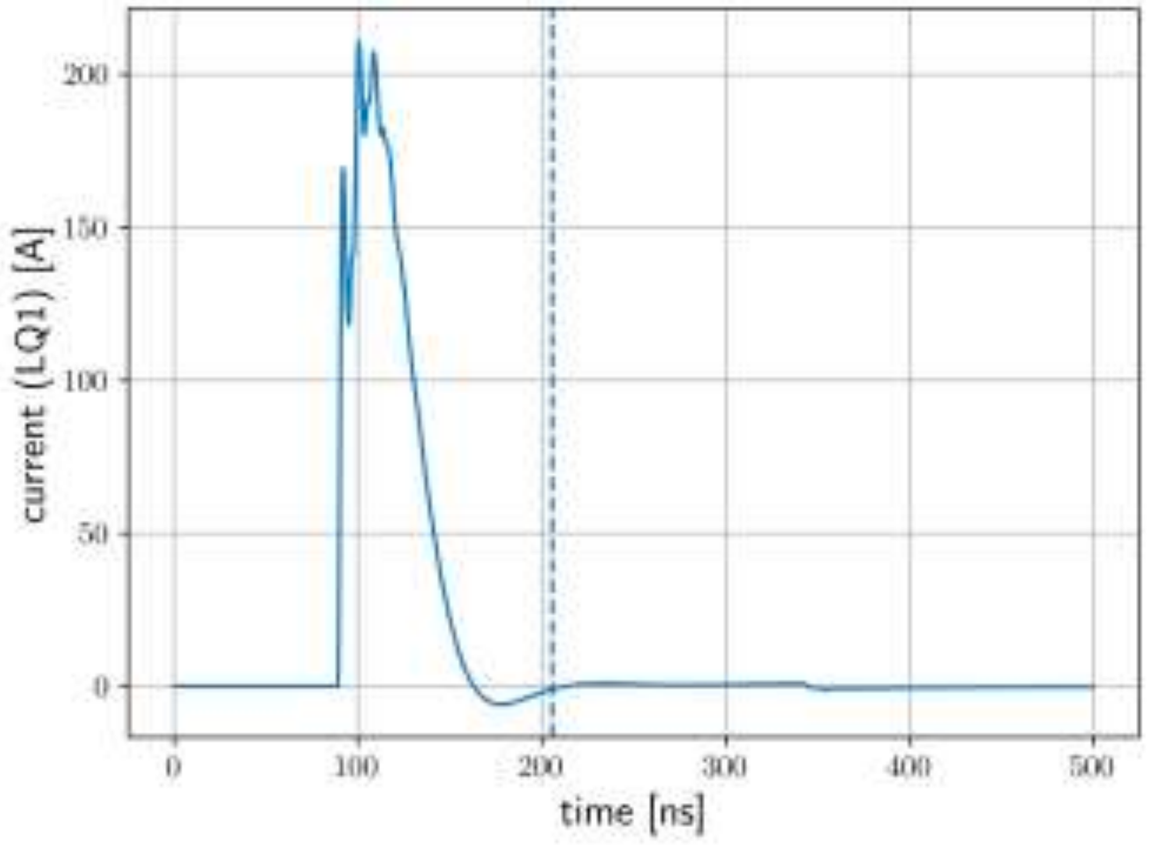
GridPix sensors
(to be duplicated for symmetric CW/CCW tracking)

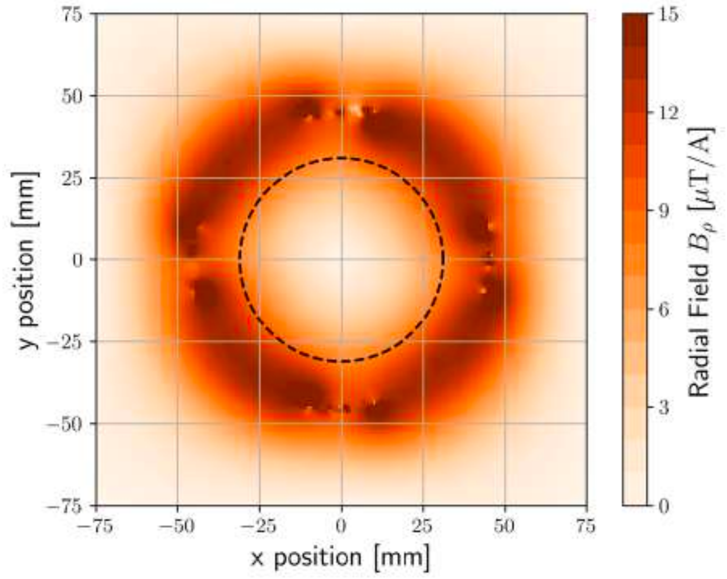
- R&D completed
- Ready for final construction

Summary

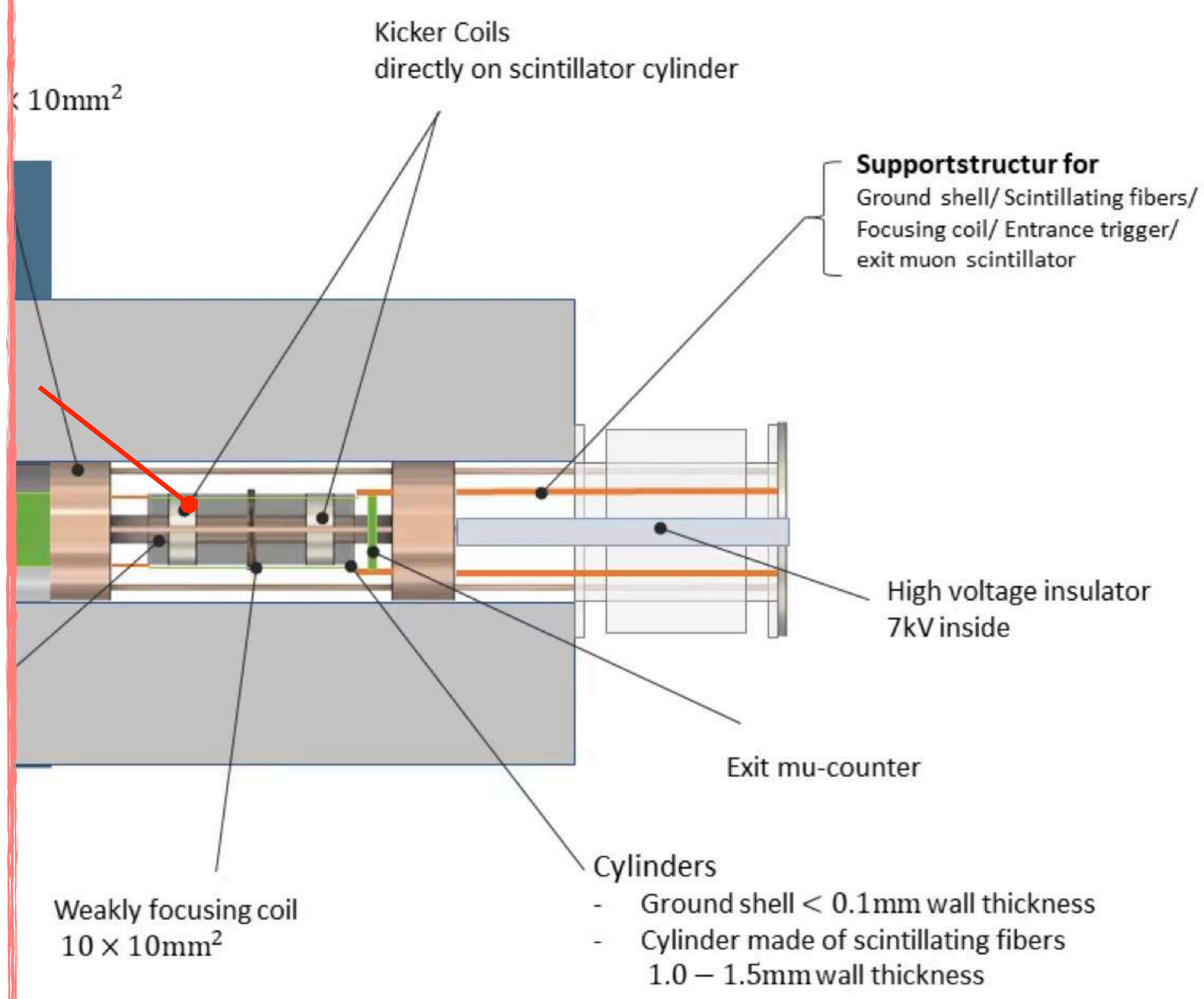
Kicker coils







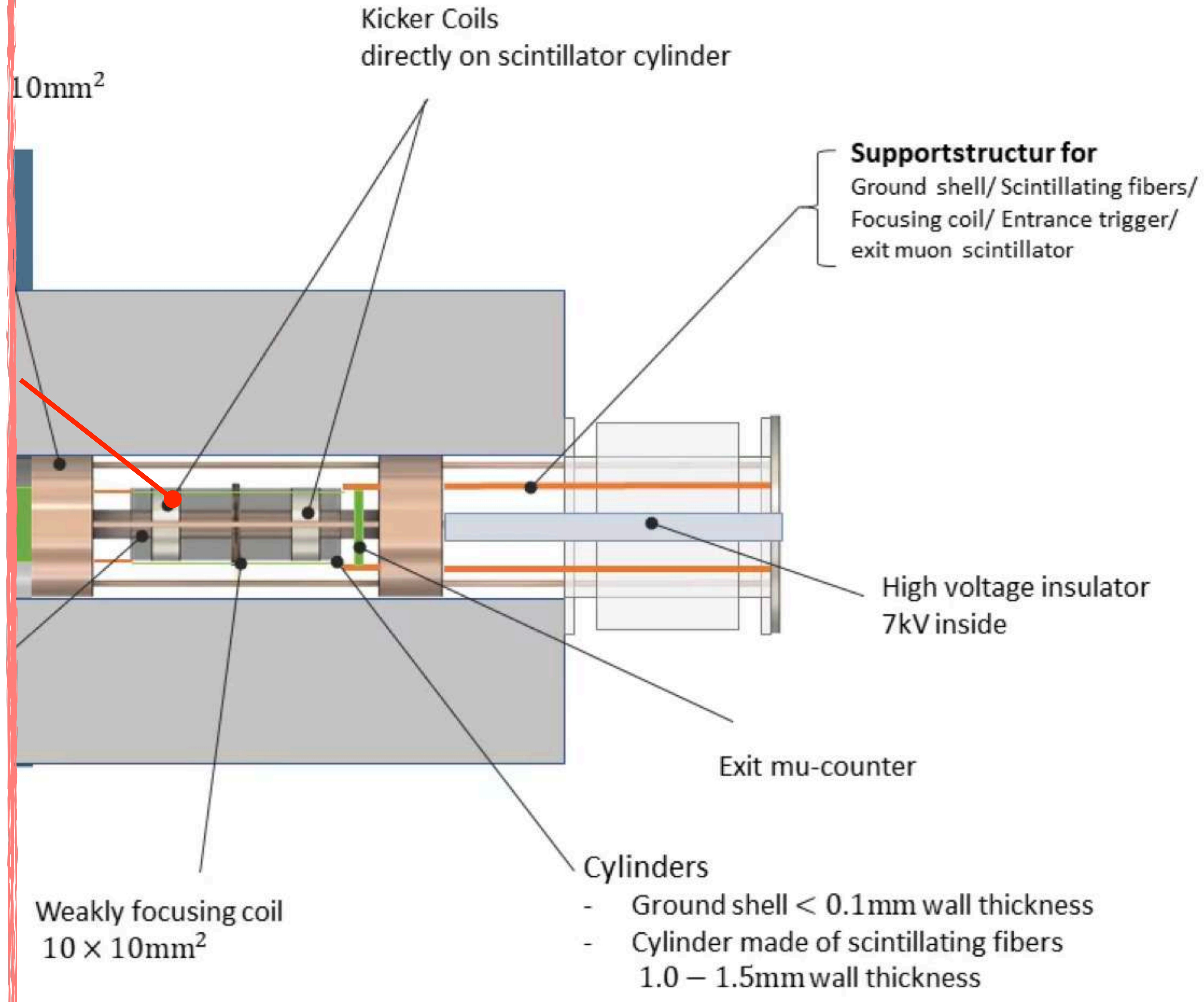
- Coil prototype: built
- Fast kicker circuit in construction: 200 A to be released for ~ 100 ns after ~ 80 ns from the trigger
- Expected “disturbance” test during BT2024
- Kicker final PS: Beginning 2026



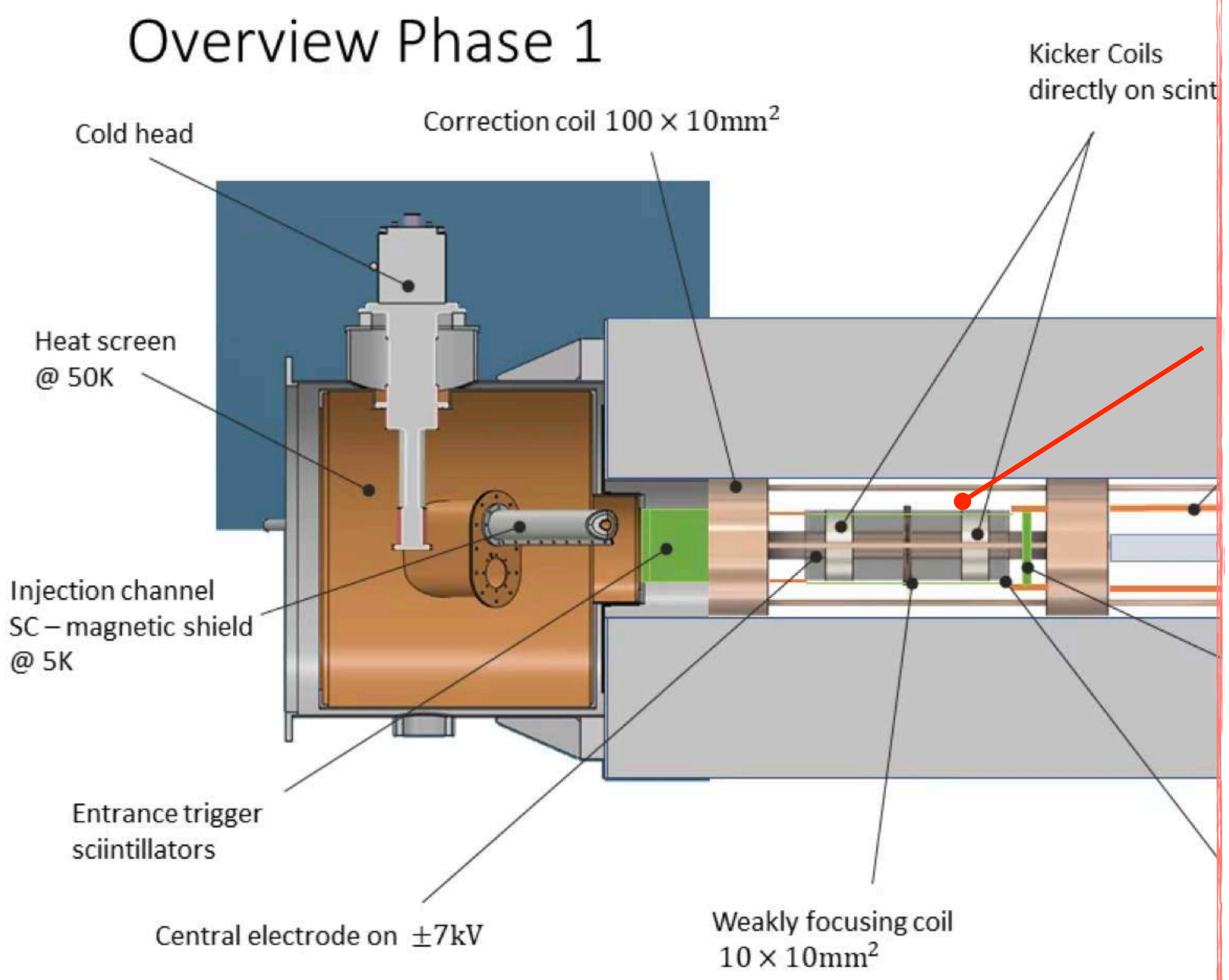
Summary

Frozen-spin electrodes

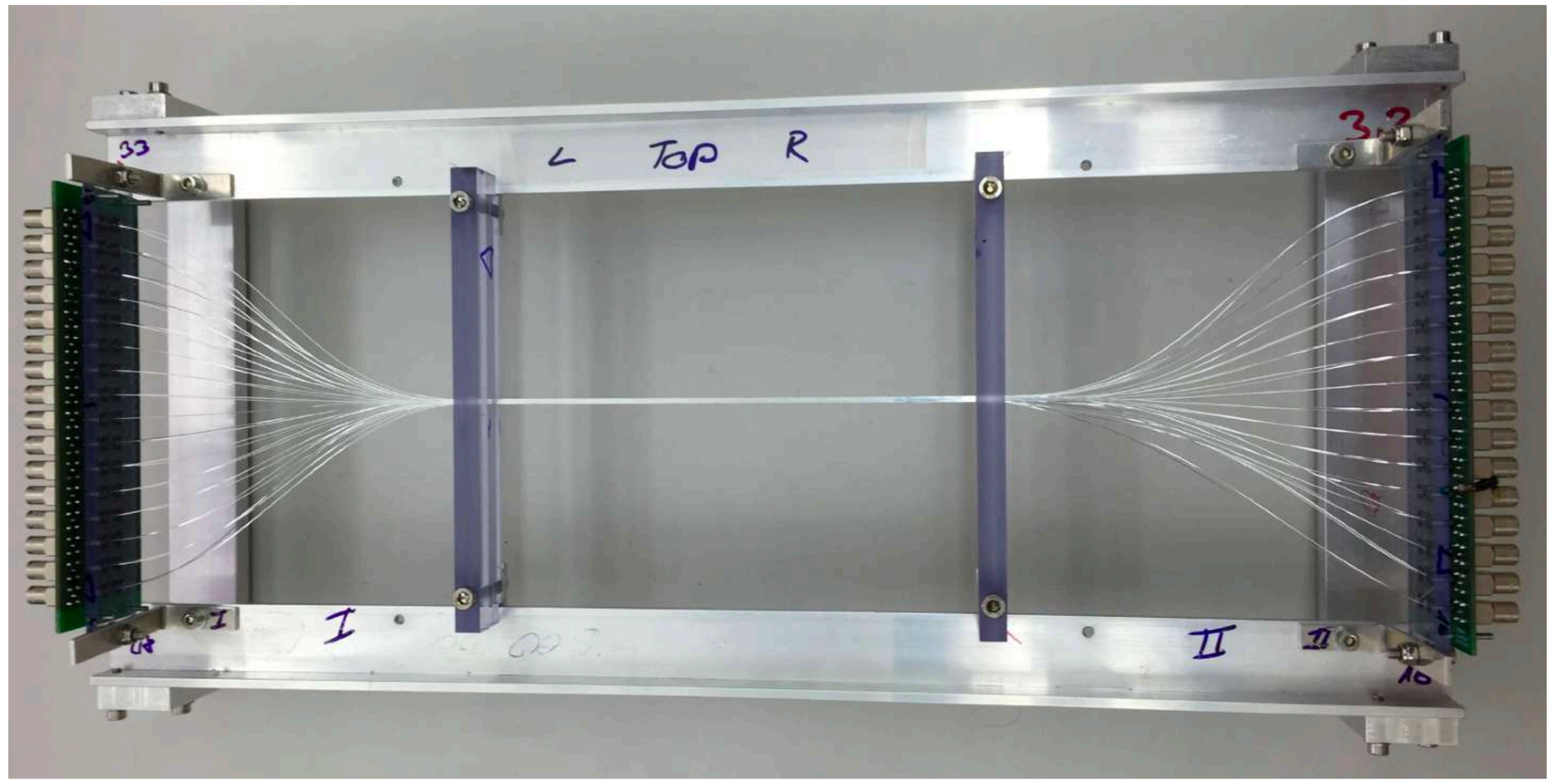
- Electrode prototype: built
- PS: Received
- Dedicated space vere to perform HV test (SLS)
- Assembly of the setup: ongoing
- Test: Beginning of 2025



Summary

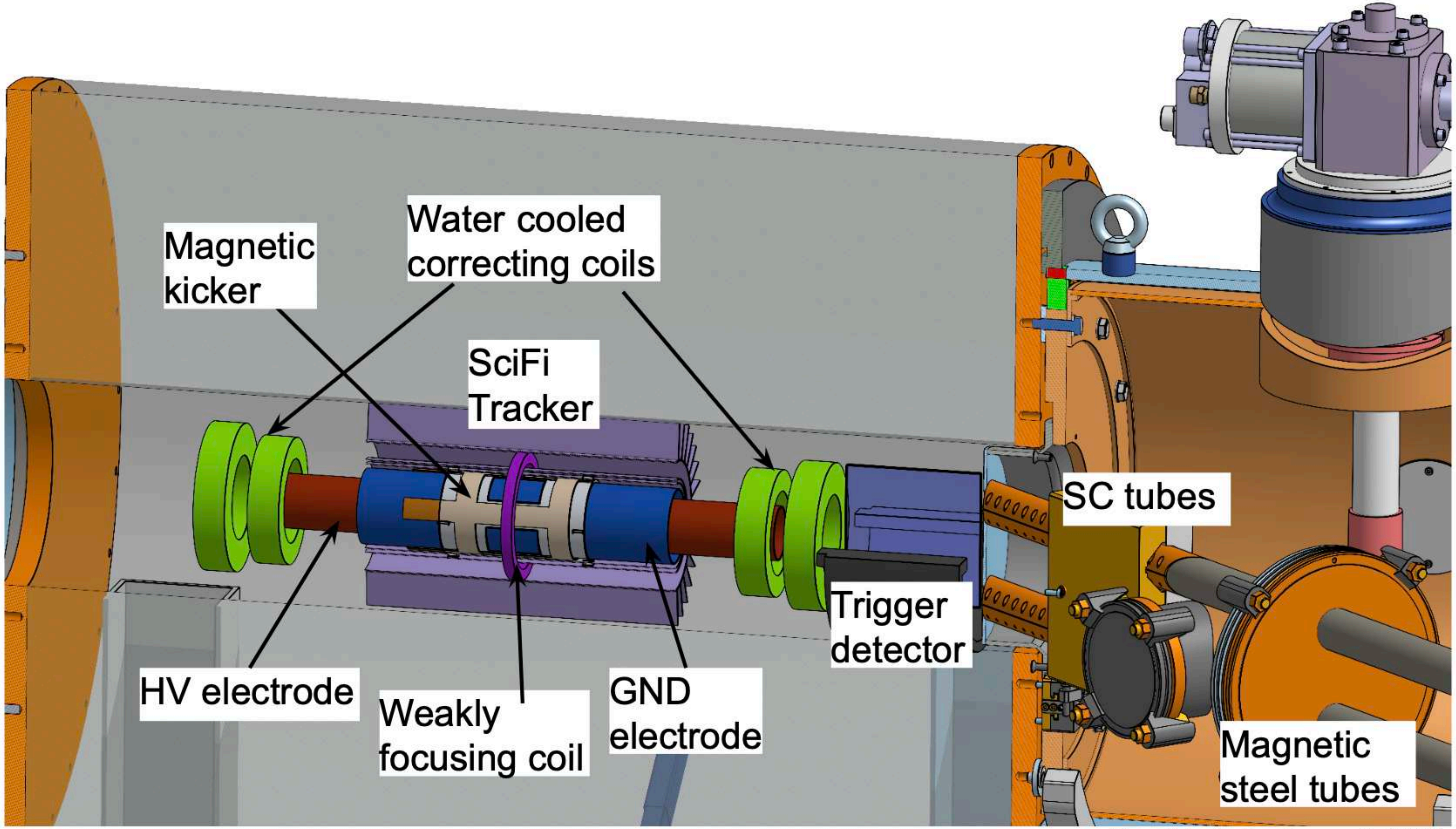


CHeT detector



- CHeT prototype: tested
- New fibers + new DAQ: by 2024
- Technical Design: by 2024/beginning 2025
- Material procurement for the final detector: Ongoing/first quarter of 2025
- Modules and commissioning: by 2025

Where we are: construction and integration phase

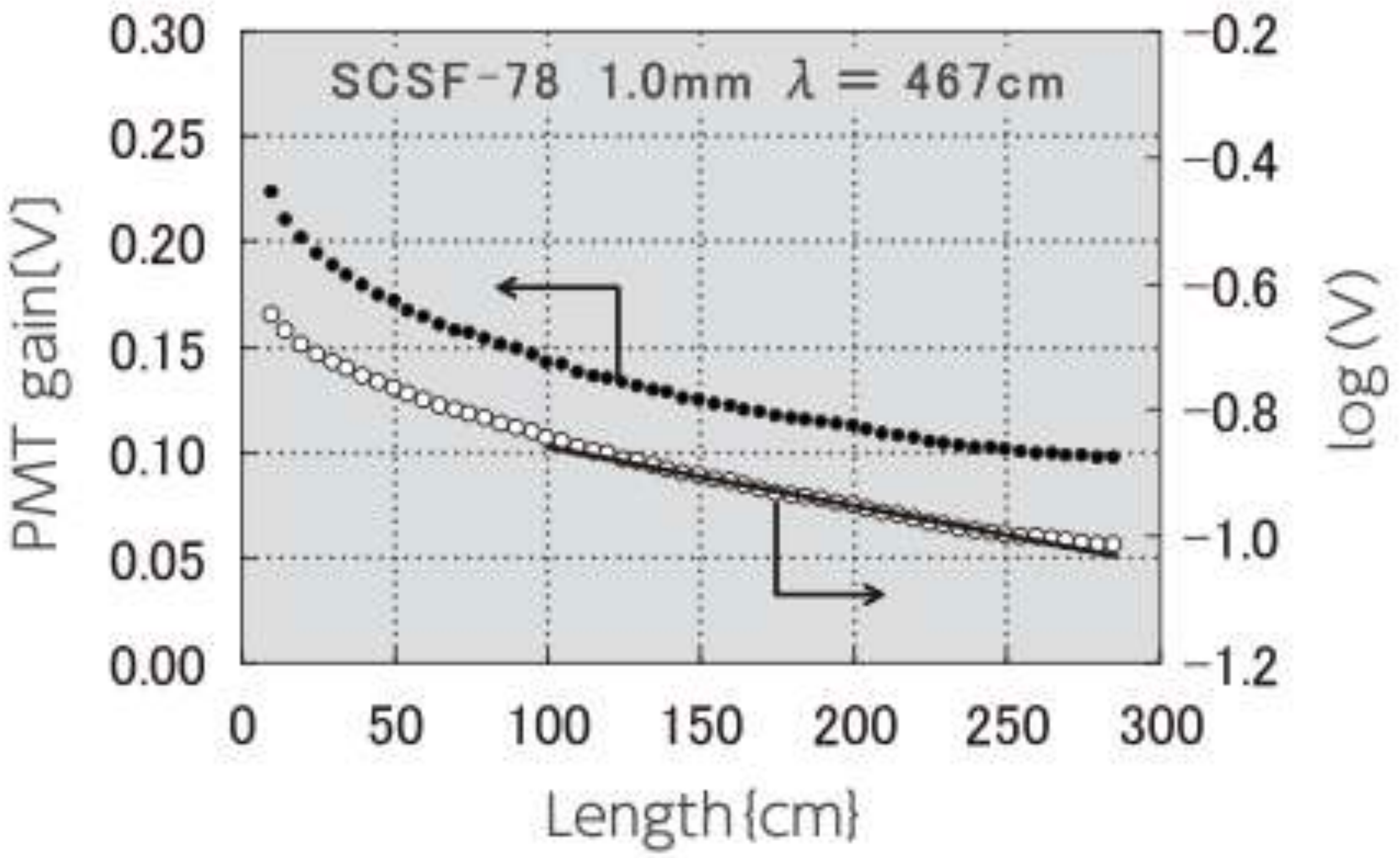


Material procurement: Fibres

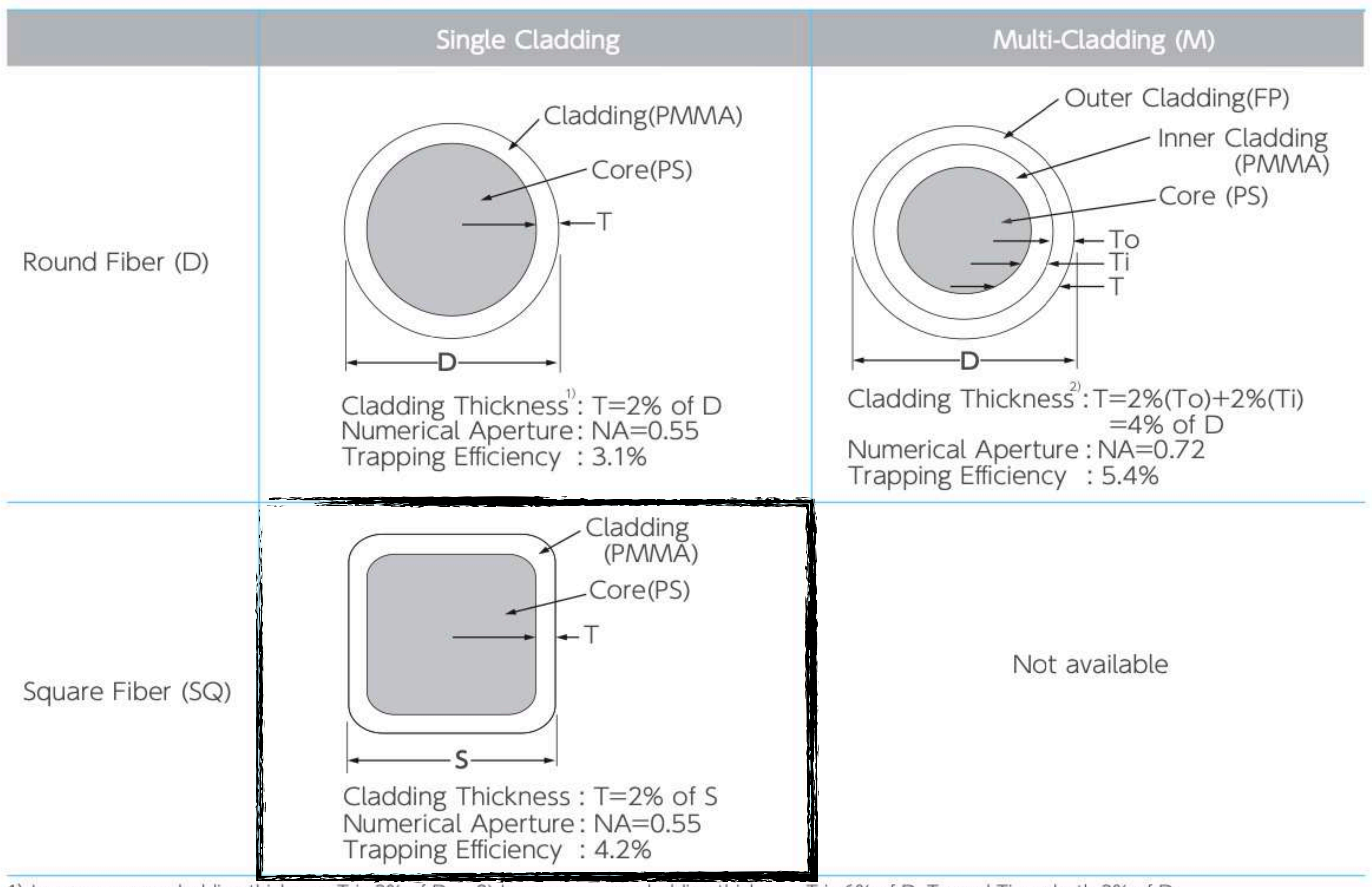
- Fibres: **Received**
- SCSF-78, Square Single Cladding, S-type
- Quantity : MOQ **0.25mm = 3.200m** & **0.5mm=1.200 m**

Formulations[1)]

Description	Emission Color	Emission Spectra	Emission Peak[nm]	Decay Time [ns]	Att.Leng.[2)] [m]	Characteristics
SCSF-78	blue	See the following figure	450	2.8	>4.0	Long Att. Length and High Light Yield
SCSF-81	blue		437	2.4	>3.5	Long Attenuation Length
SCSF-3HF(1500)	green		530	7	>4.5	3HF formulation for Radiation Hardness



Cross-section and Cladding Thickness

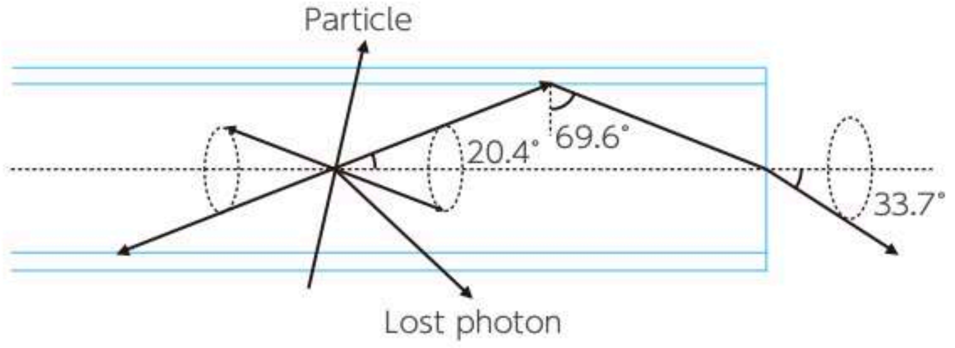


1) In some cases, cladding thickness T is 3% of D. 2) In some cases, cladding thickness T is 6% of D, To and Ti are both 3% of D.

Cladding and Transmission Mechanism

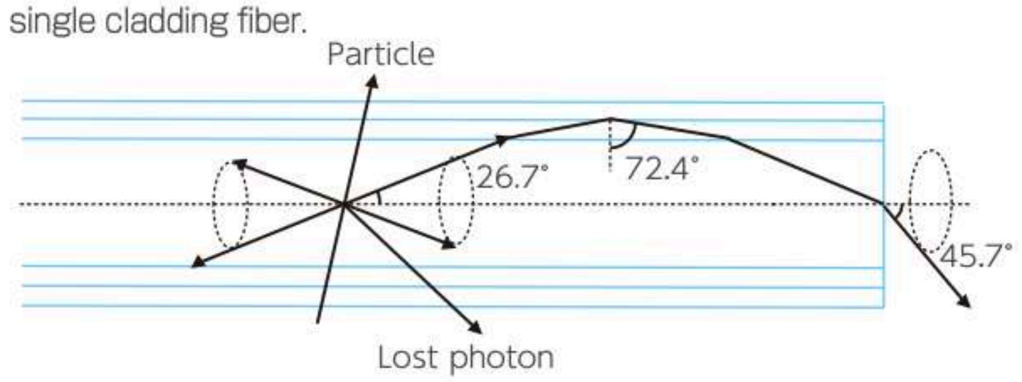
Single cladding

Single cladding fiber is standard type of cladding.



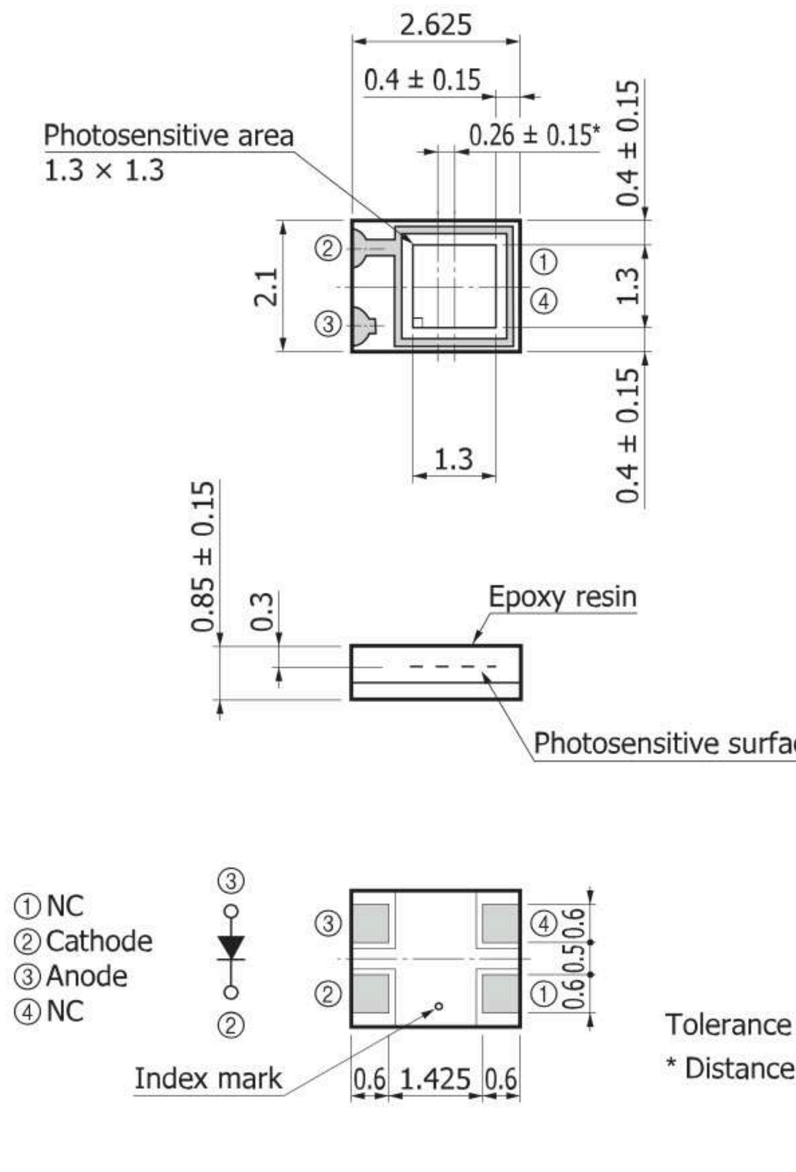
Multi-cladding

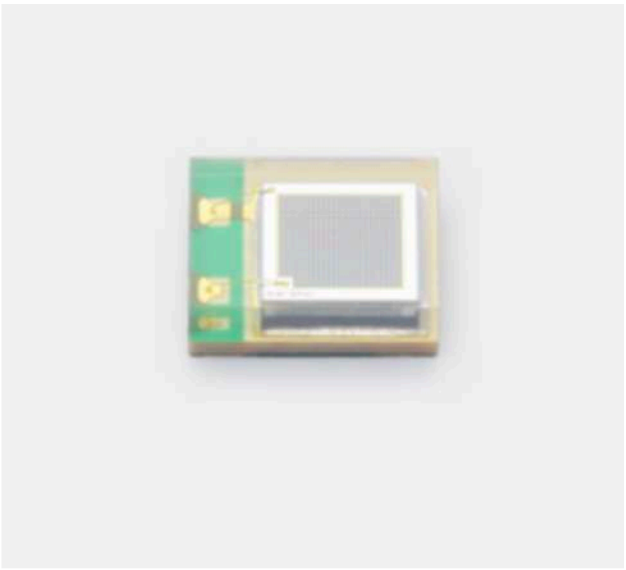
Multi-cladding fiber(M) has higher light yield than single cladding fiber because of large trapping efficiency.
Clear-PS fiber of this cladding has extremely higher NA than conventional PMMA or PS fiber, and very useful as light guide fiber.
Multi-cladding fiber has long attenuation length equal to single cladding fiber.

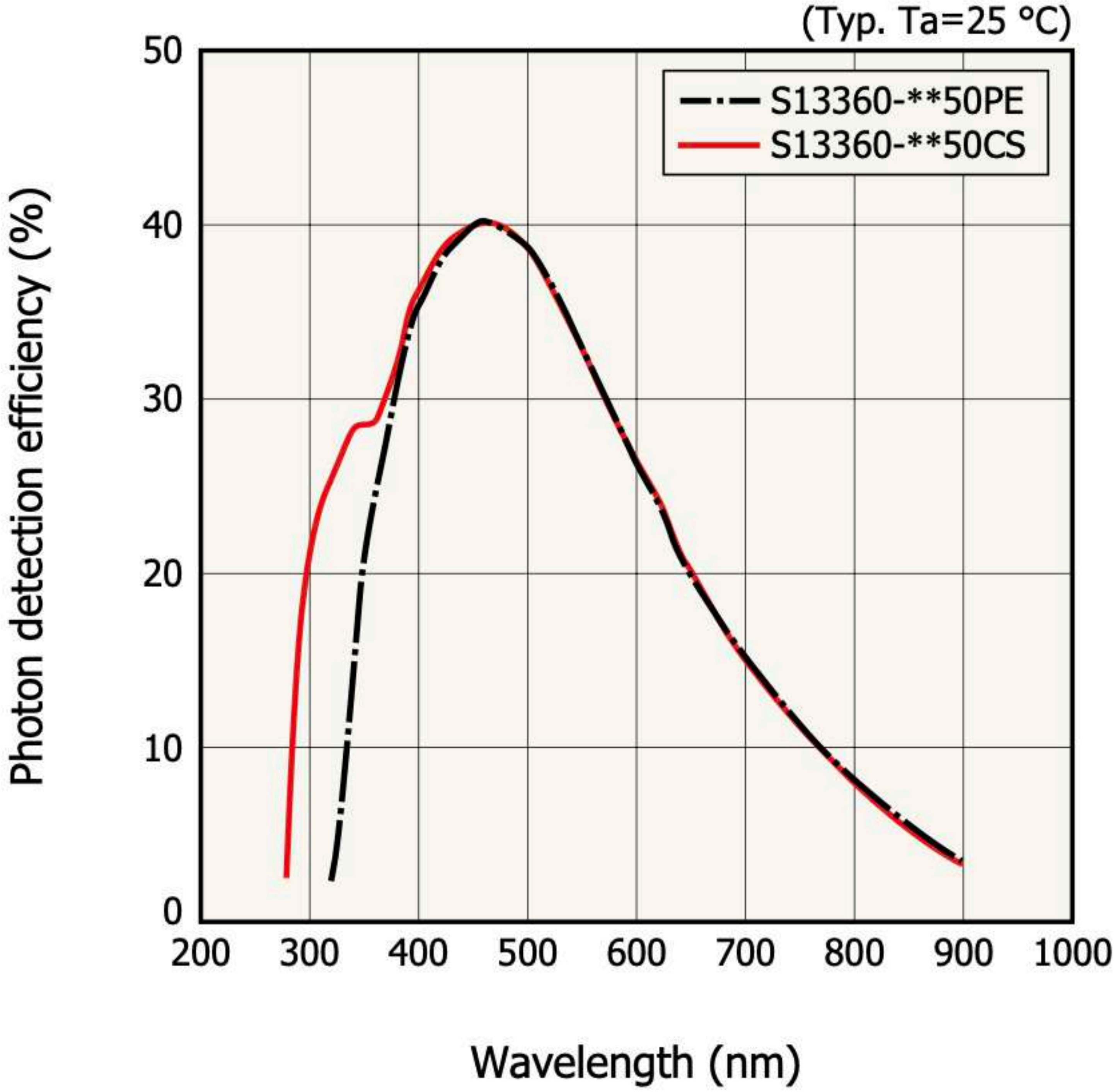


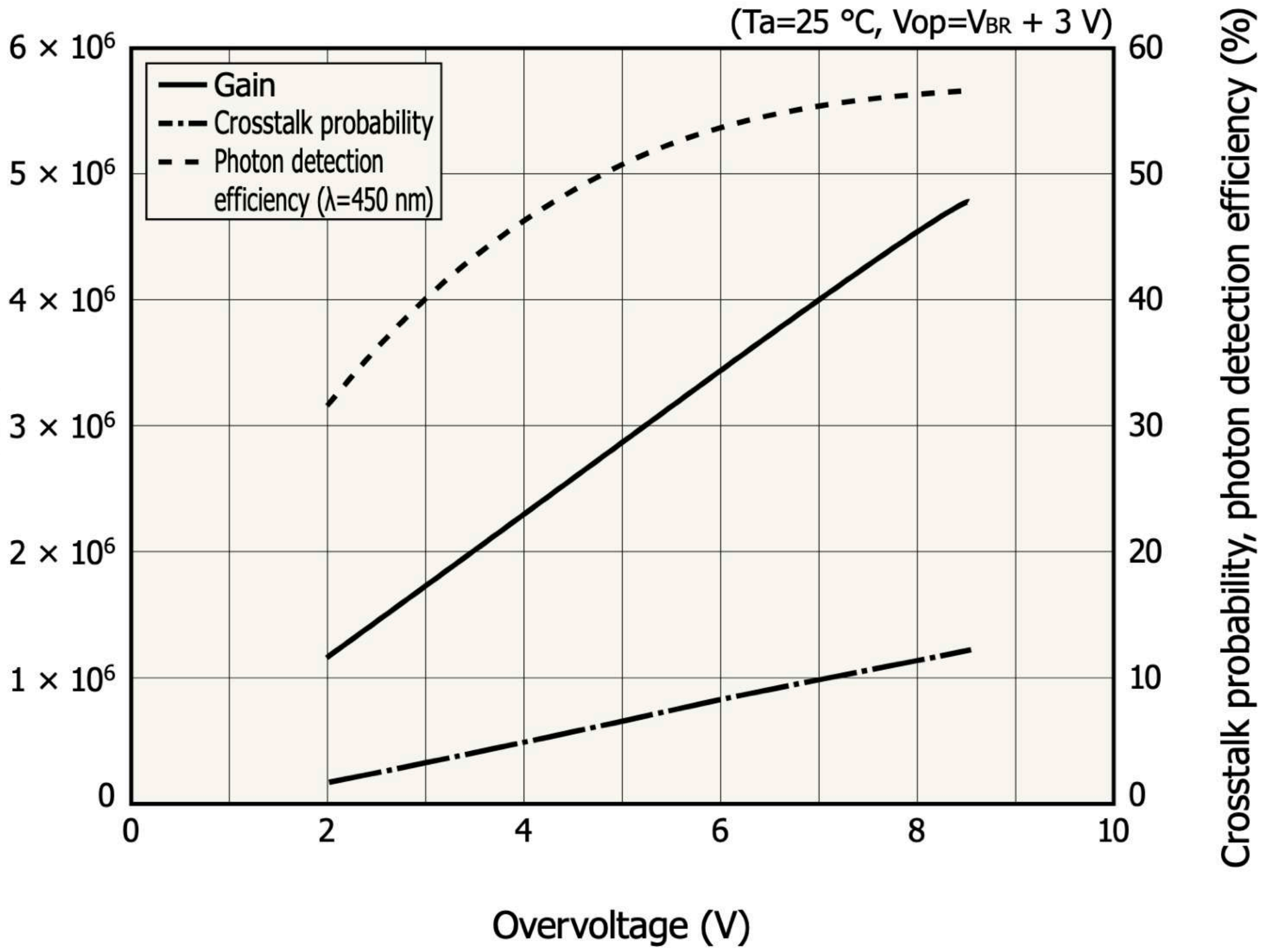
Material procurement: Sensors

- **2000 MPPC** 13360-1350 PE 1.3x1.3 50 um
- Status: **Received**



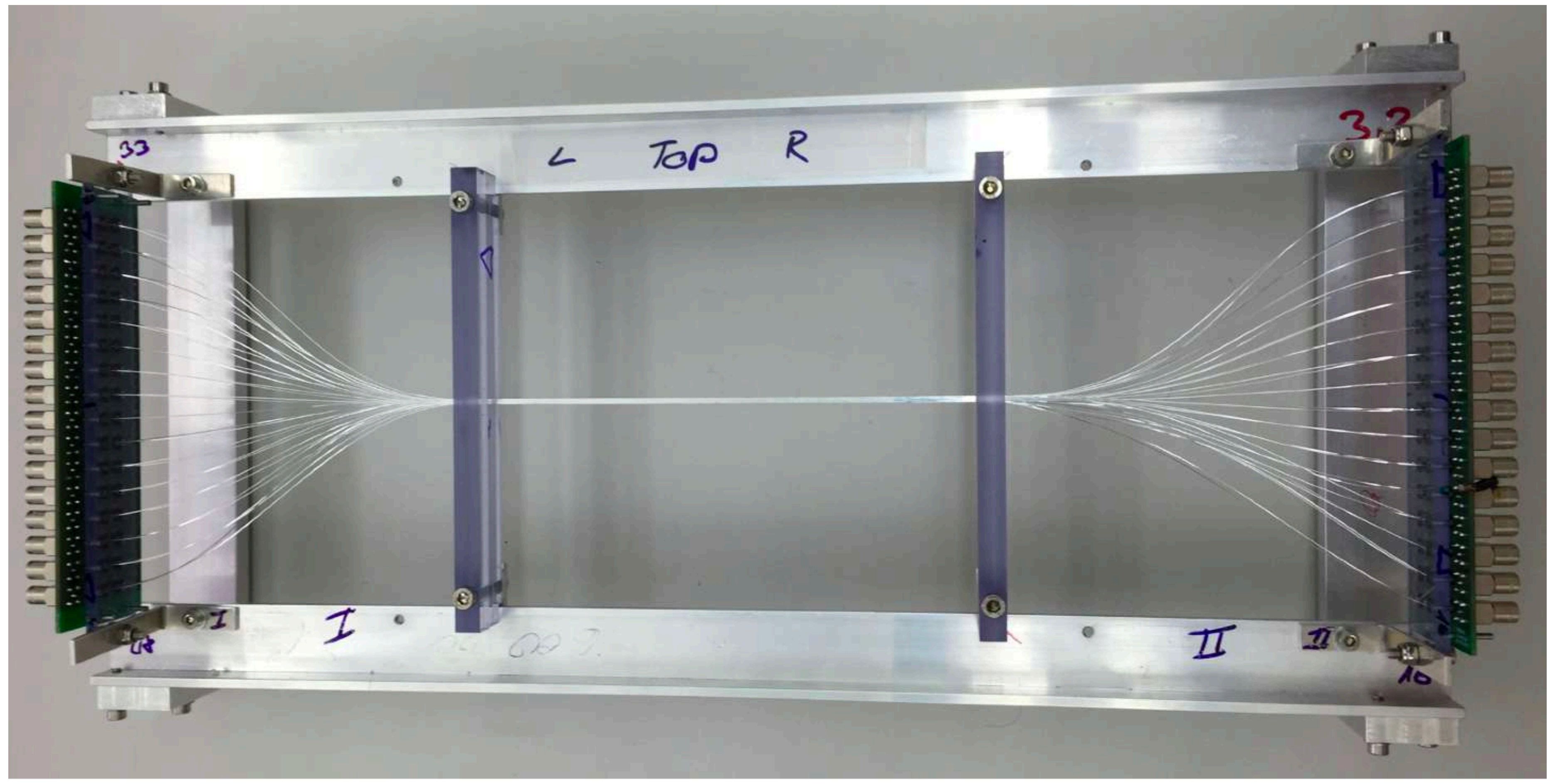






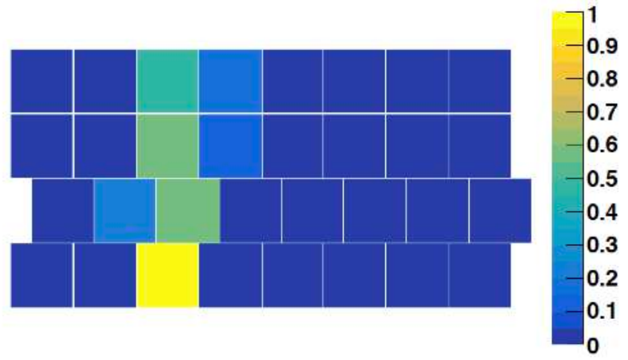
Fibre detector prototype: To assess the basics performances

- A fibre bundle (W = 2 mm, L = 300 mm) with a double read-out scheme (left-right)
- 0.25 mm BCF12 Saint Gobain fibre (Aluminum fiber coating)
- Hamamatsu S13360-1350CS SiPM
- DAQ: DRS (5 GSample/s)



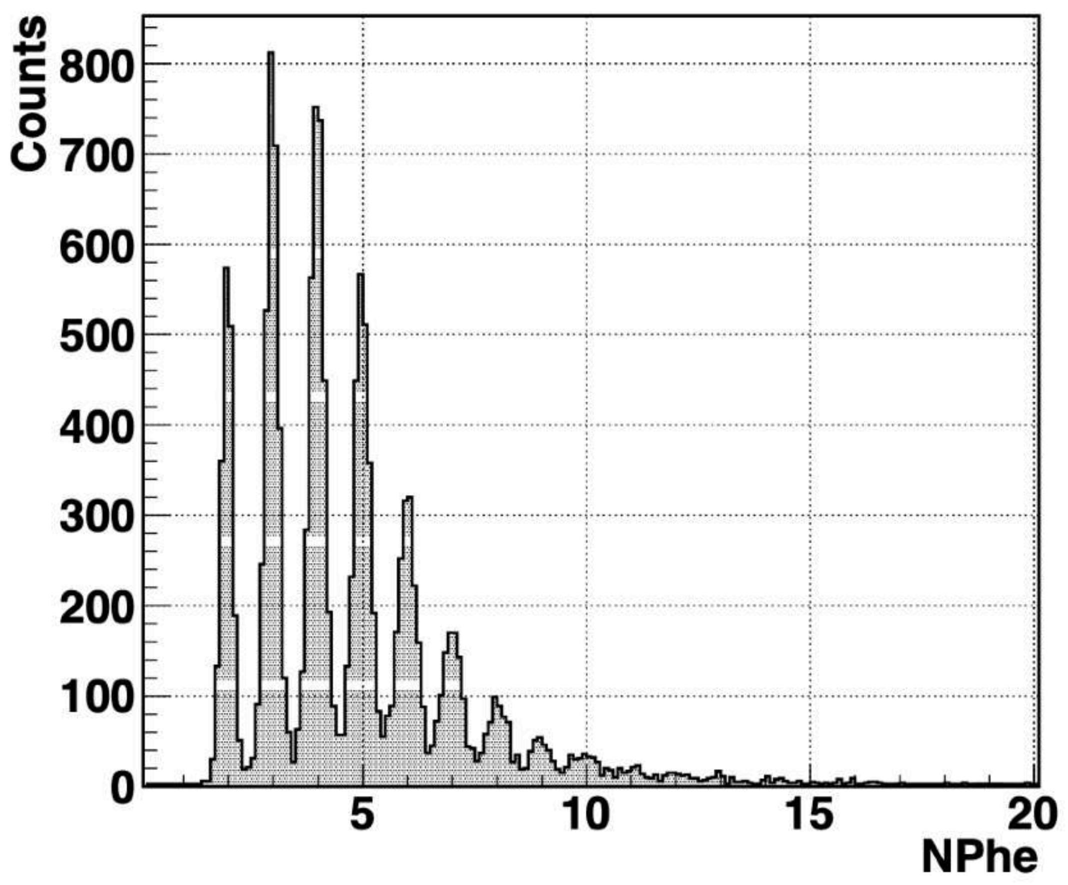
Trigger layer

Active layers



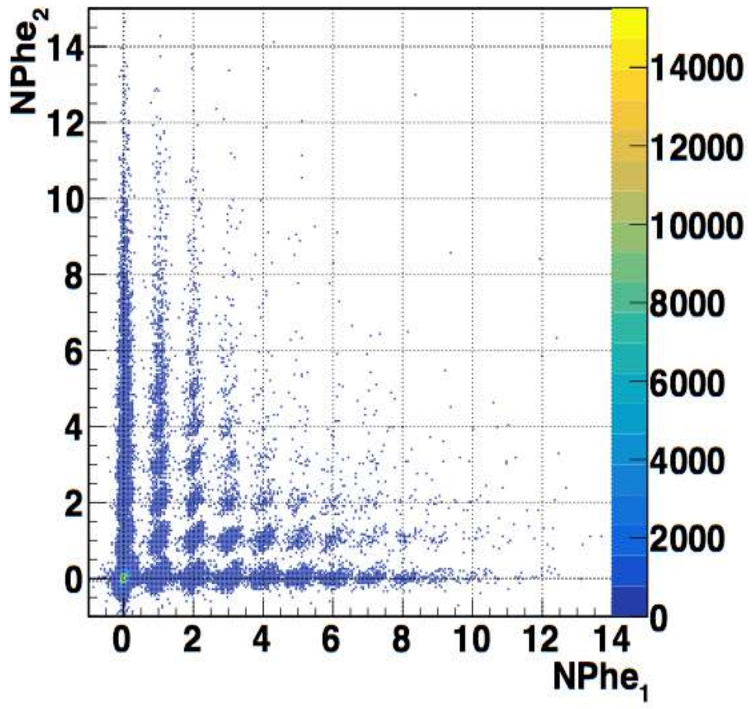
Fibre bundle transverse view

Collected charge/fibre

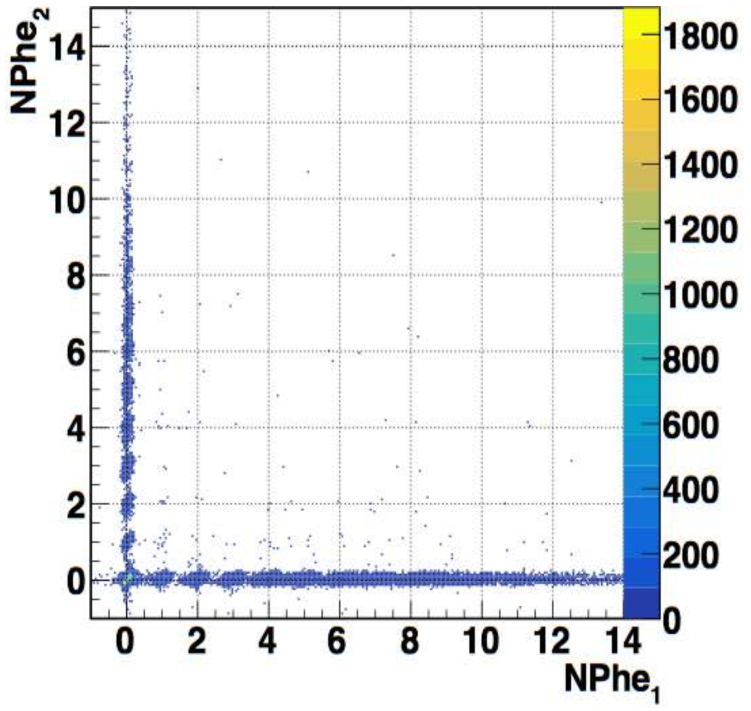


Fibre Optical cross-talk

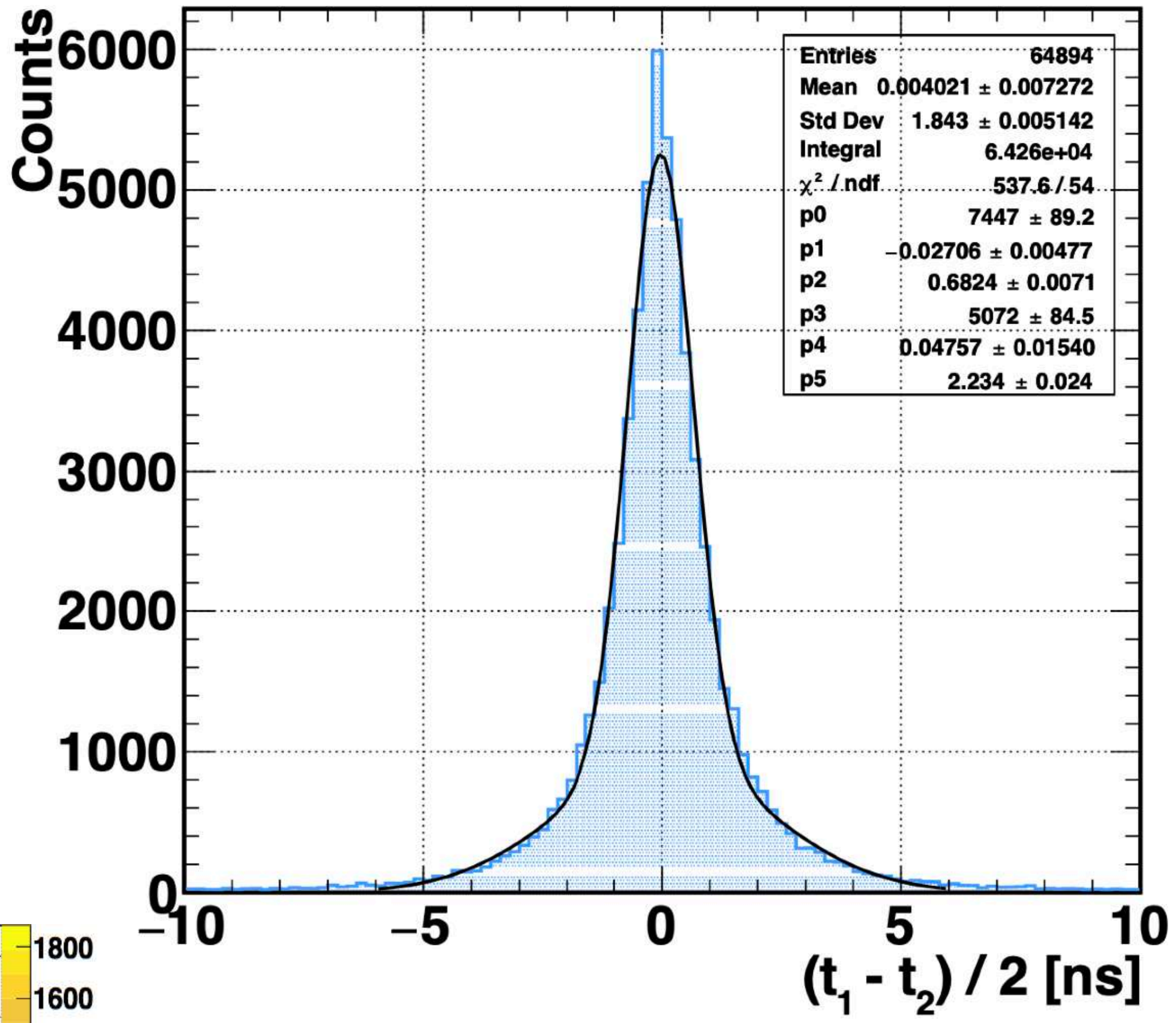
w/o Aluminum deposit



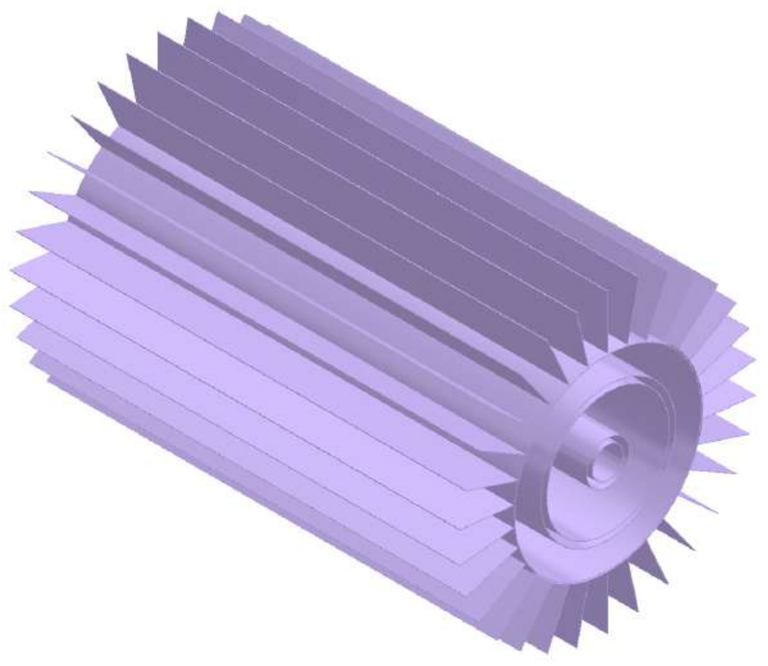
with Aluminum deposit



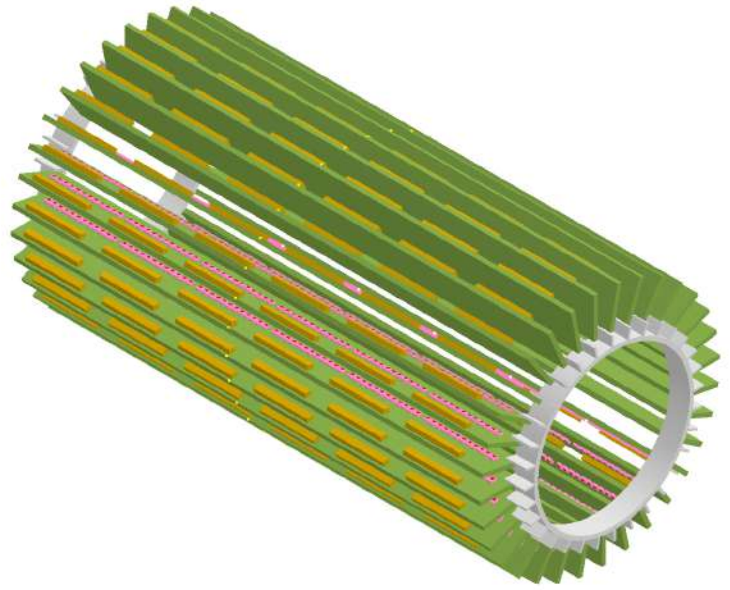
Time resolution [**< 1ns**]

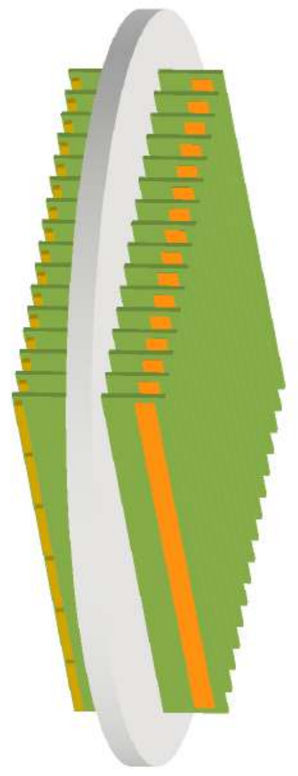


From the fibers to the DAQ



32 boards





16 boards/flange

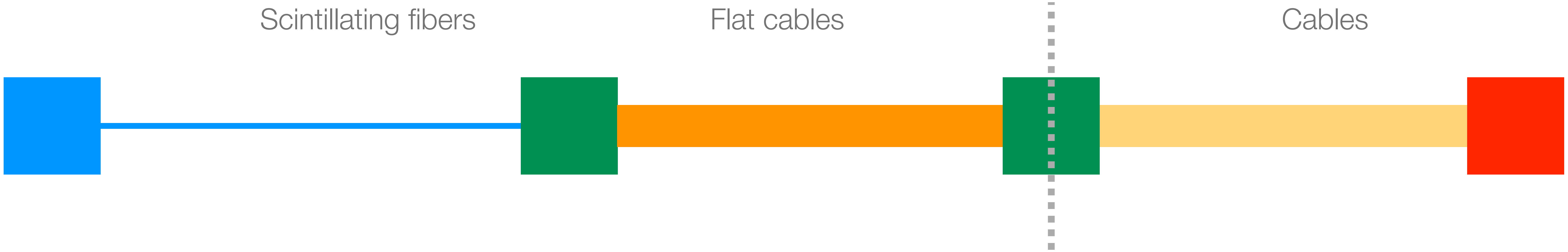
2 flanges

Detector/fiber → MPPC board → Feedthrough board → DAQ/FERS

Scintillating fibers

Flat cables

Cables

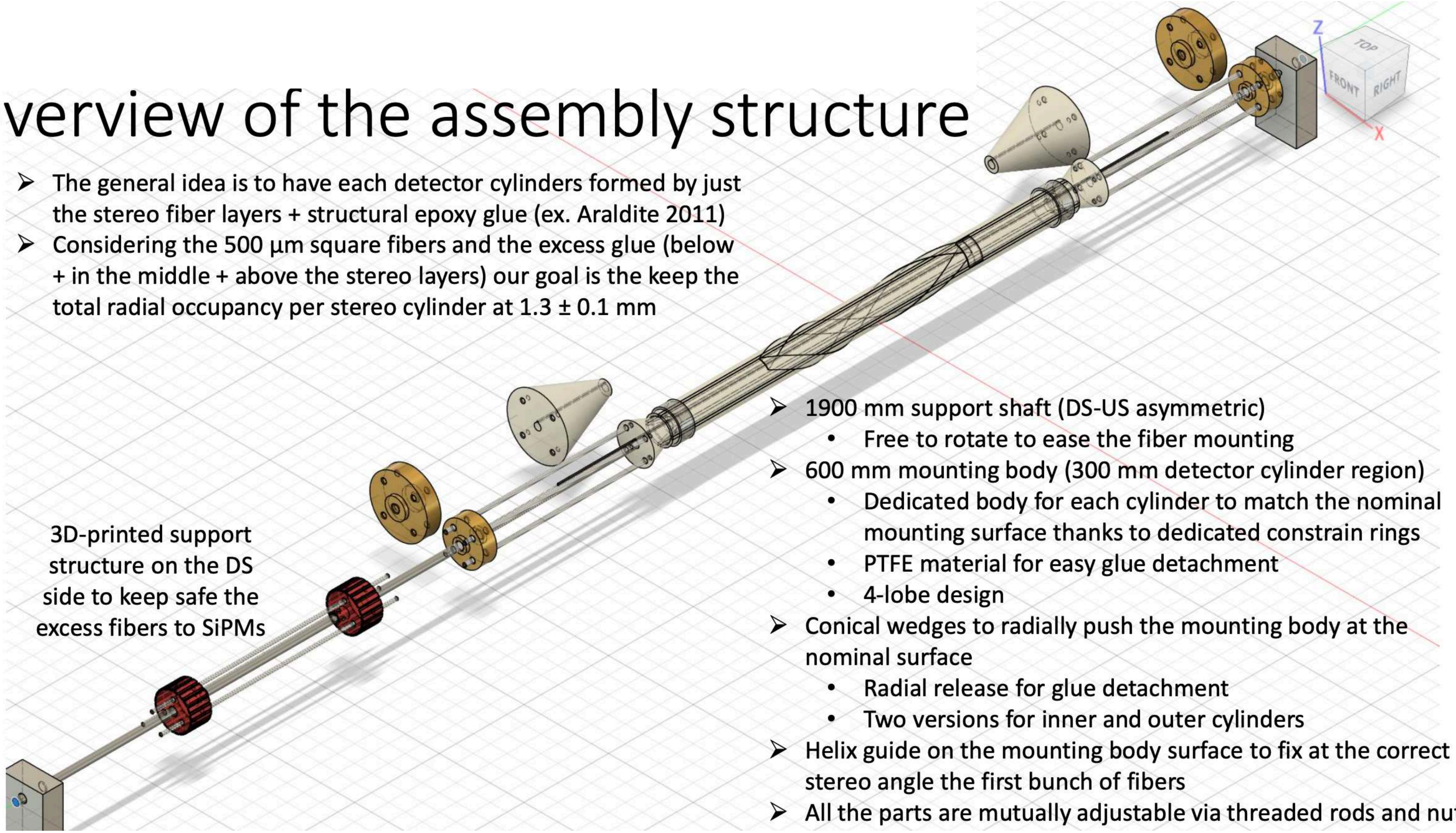


Vacuum Air

CHeT: Cylindrical detector production

Overview of the assembly structure

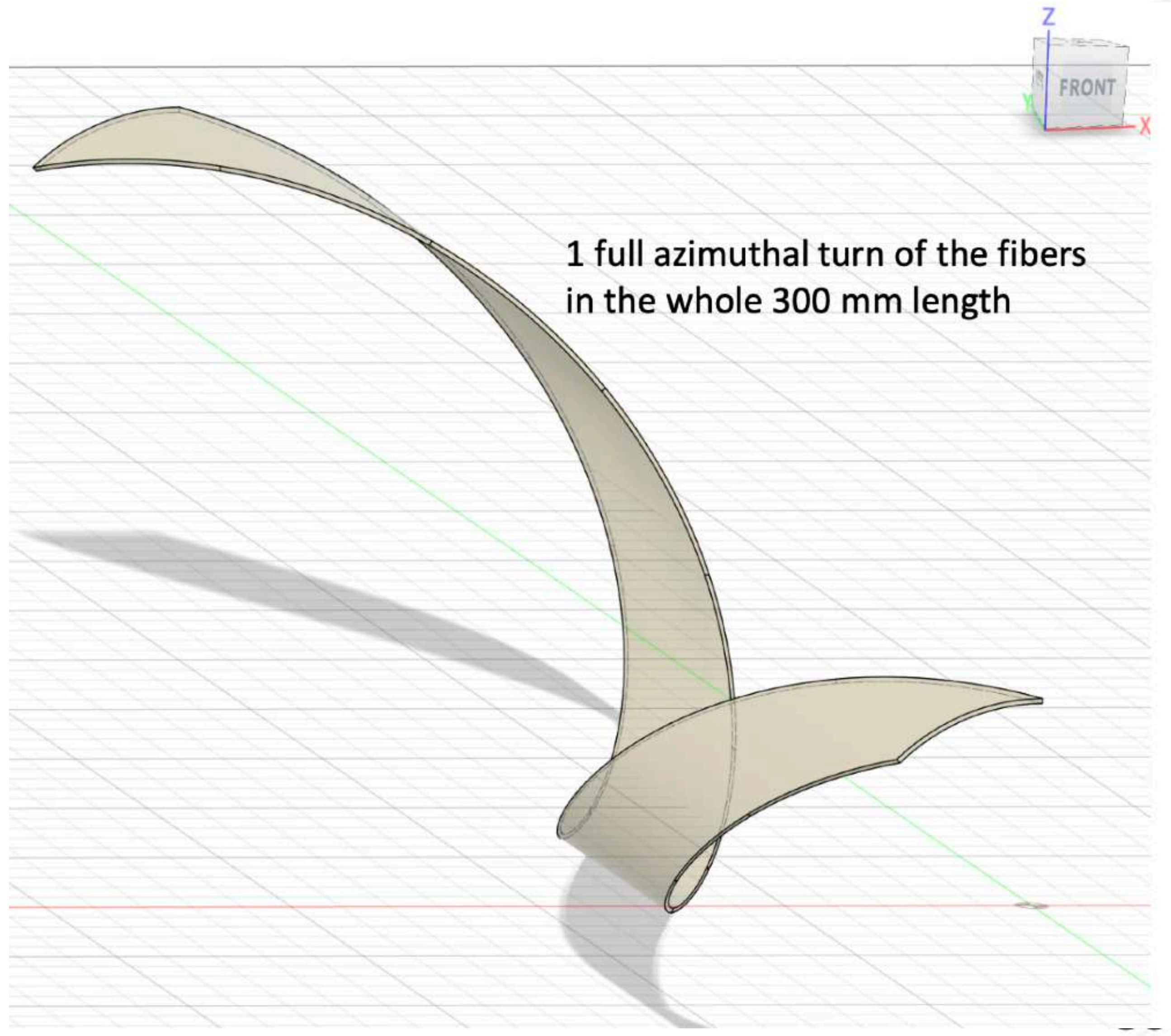
- The general idea is to have each detector cylinders formed by just the stereo fiber layers + structural epoxy glue (ex. Araldite 2011)
- Considering the 500 μm square fibers and the excess glue (below + in the middle + above the stereo layers) our goal is the keep the total radial occupancy per stereo cylinder at 1.3 ± 0.1 mm



3D-printed support structure on the DS side to keep safe the excess fibers to SiPMs

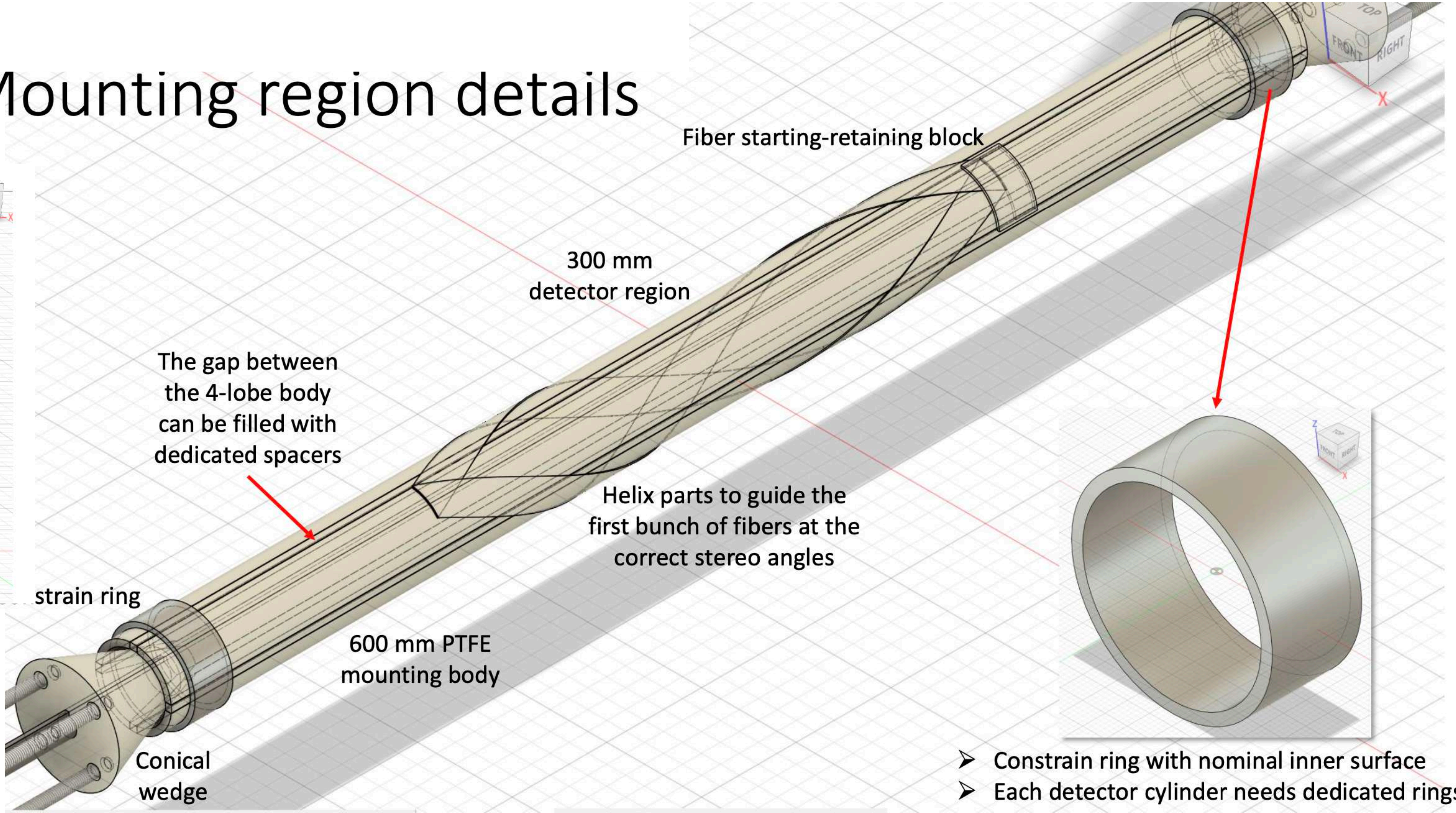
- 1900 mm support shaft (DS-US asymmetric)
  - Free to rotate to ease the fiber mounting
- 600 mm mounting body (300 mm detector cylinder region)
  - Dedicated body for each cylinder to match the nominal mounting surface thanks to dedicated constrain rings
  - PTFE material for easy glue detachment
  - 4-lobe design
- Conical wedges to radially push the mounting body at the nominal surface
  - Radial release for glue detachment
  - Two versions for inner and outer cylinders
- Helix guide on the mounting body surface to fix at the correct stereo angle the first bunch of fibers
- All the parts are mutually adjustable via threaded rods and nuts

CHeT: Cylindrical detector production zoom in



Helix guide

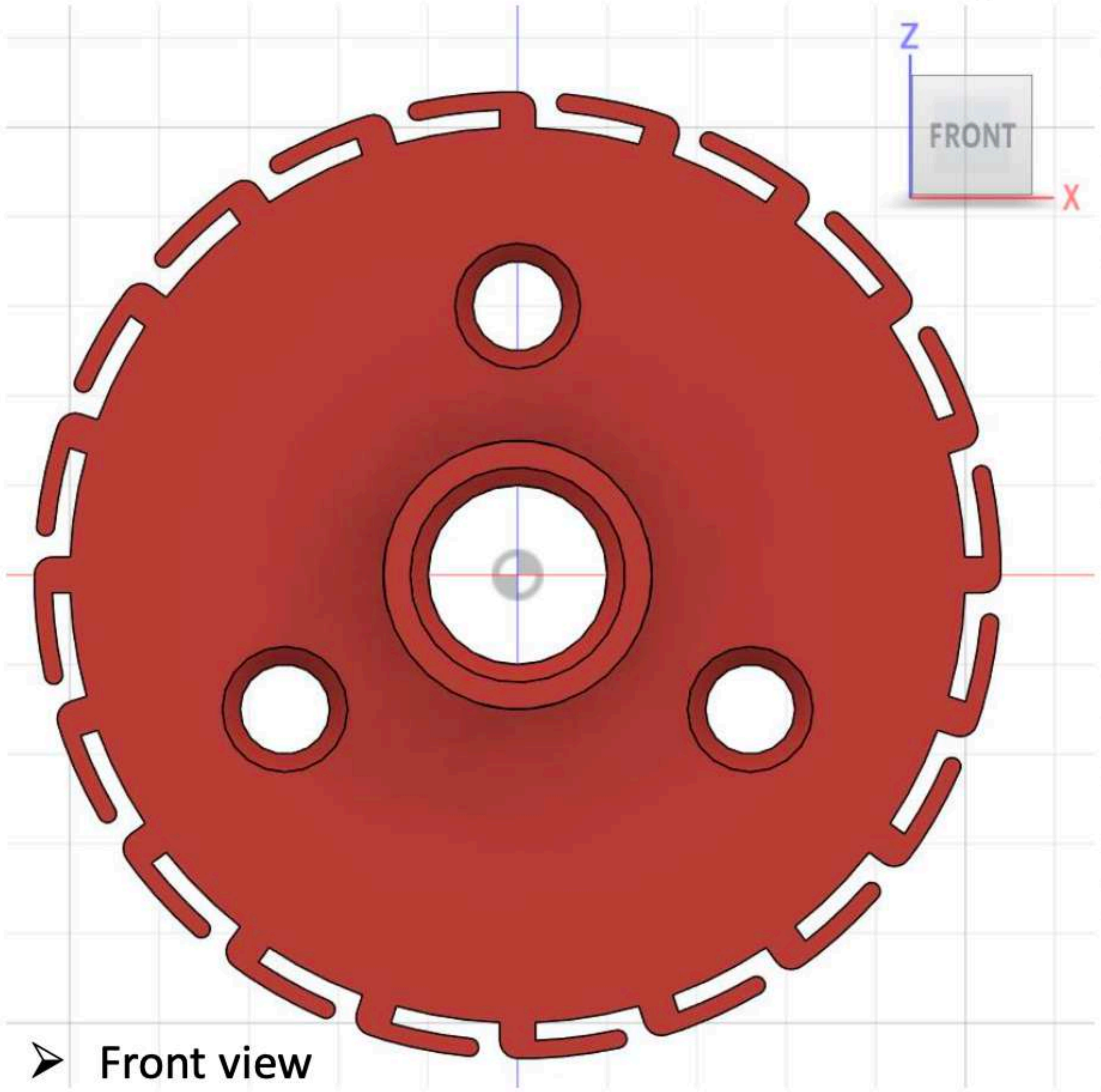
Mounting region details



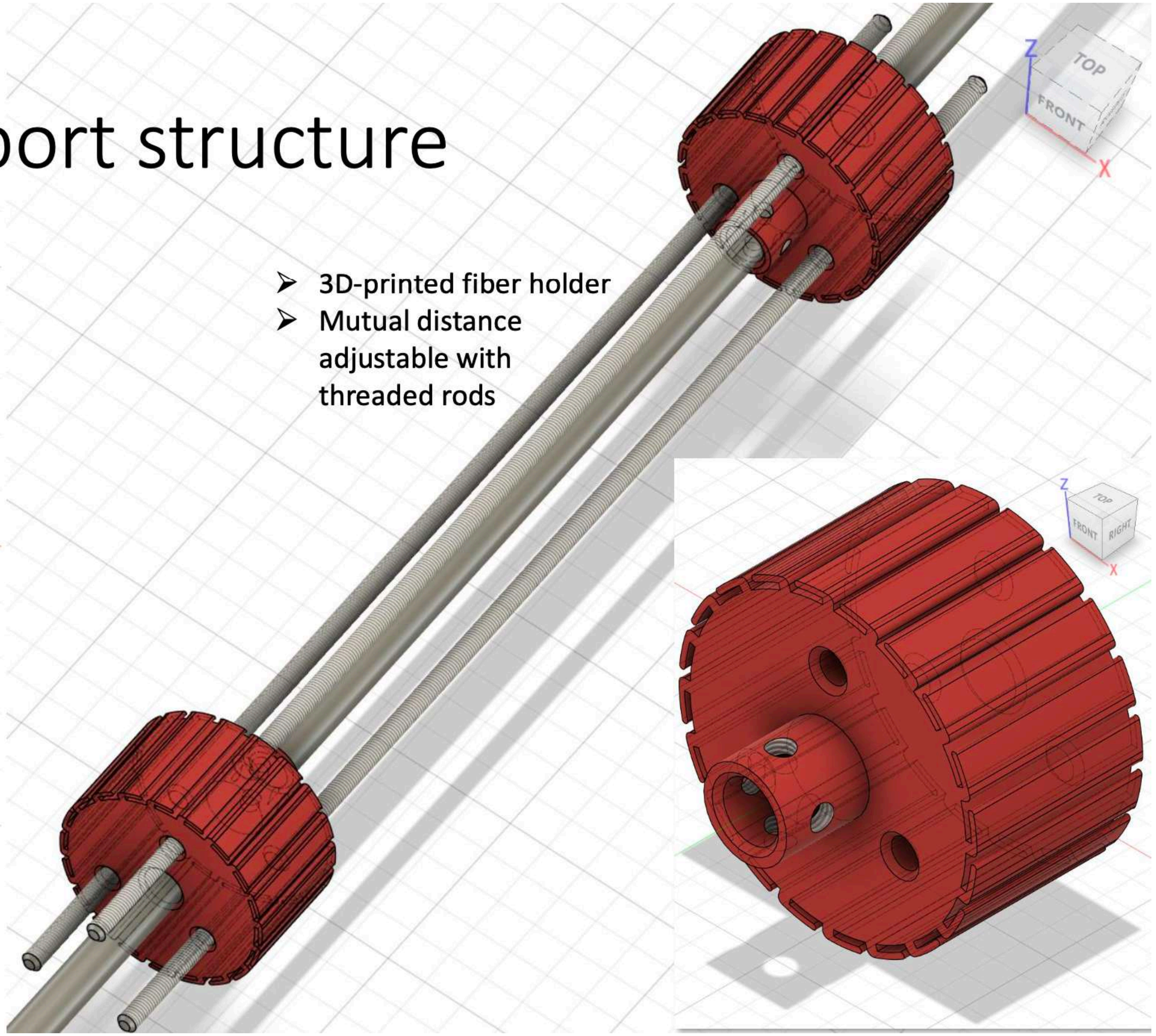
- Constrain ring with nominal inner surface
- Each detector cylinder needs dedicated rings

CHeT: Stereo fiber path

DS excess fiber support structure



- Front view
- Another mirror-symmetric piece secures the fibers and prevent them to fall down during the rotation



- 3D-printed fiber holder
- Mutual distance adjustable with threaded rods

CAEN FERS 5200: First tests in lab

- Janus software for board and DAQ control
- Started to become acquainted with one **borrowed board (INFN-MI)** meanwhile **“our”** has been **ordered** and **received**
  - Dark noise spectrum using the CHeT MPPC
  - Plastic scintillator BC200 10x10x5 + MPPC S13360-3050PE + Sr90 source (w/wo)
  - **CHeT full chain**: 500 um fiber (1 m length) + MPPC + FERS