Fast Magnetic Measurement Equipment
FAME Project

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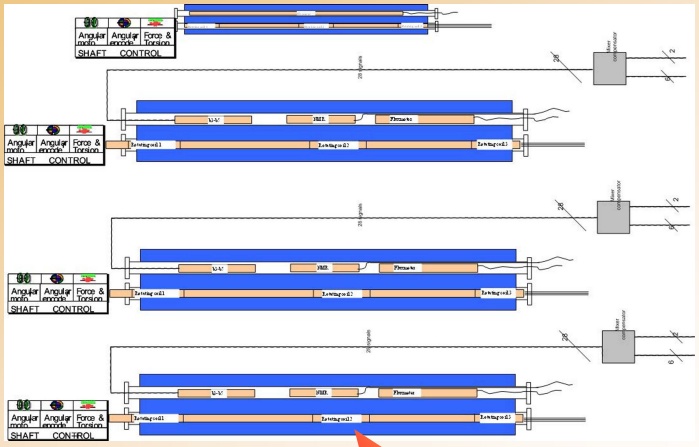
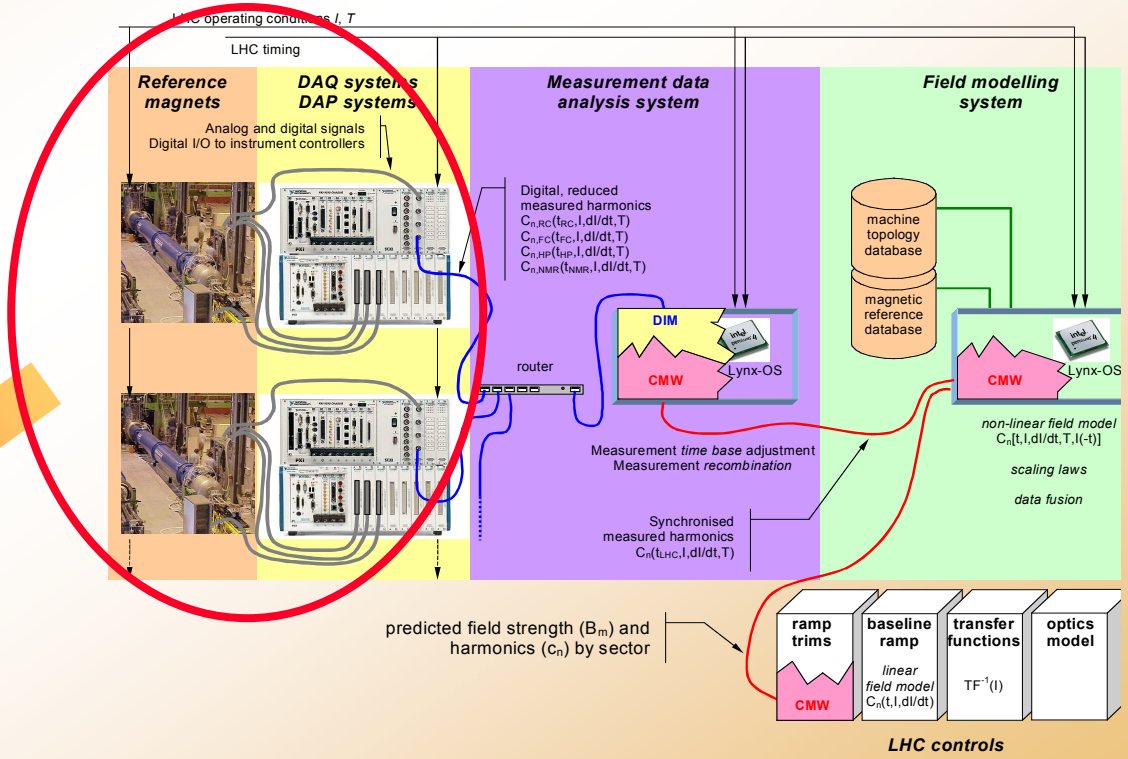
Overview

- Introduction: system architecture
- System requirements for MB/MQ
- Equipment: planning, status and R&D
  - Infrastructure
  - Rotating coils
  - Fixed coils
  - Fast Digital Integrators
  - New Rotating Unit
- Conclusions

Overall FAME architecture

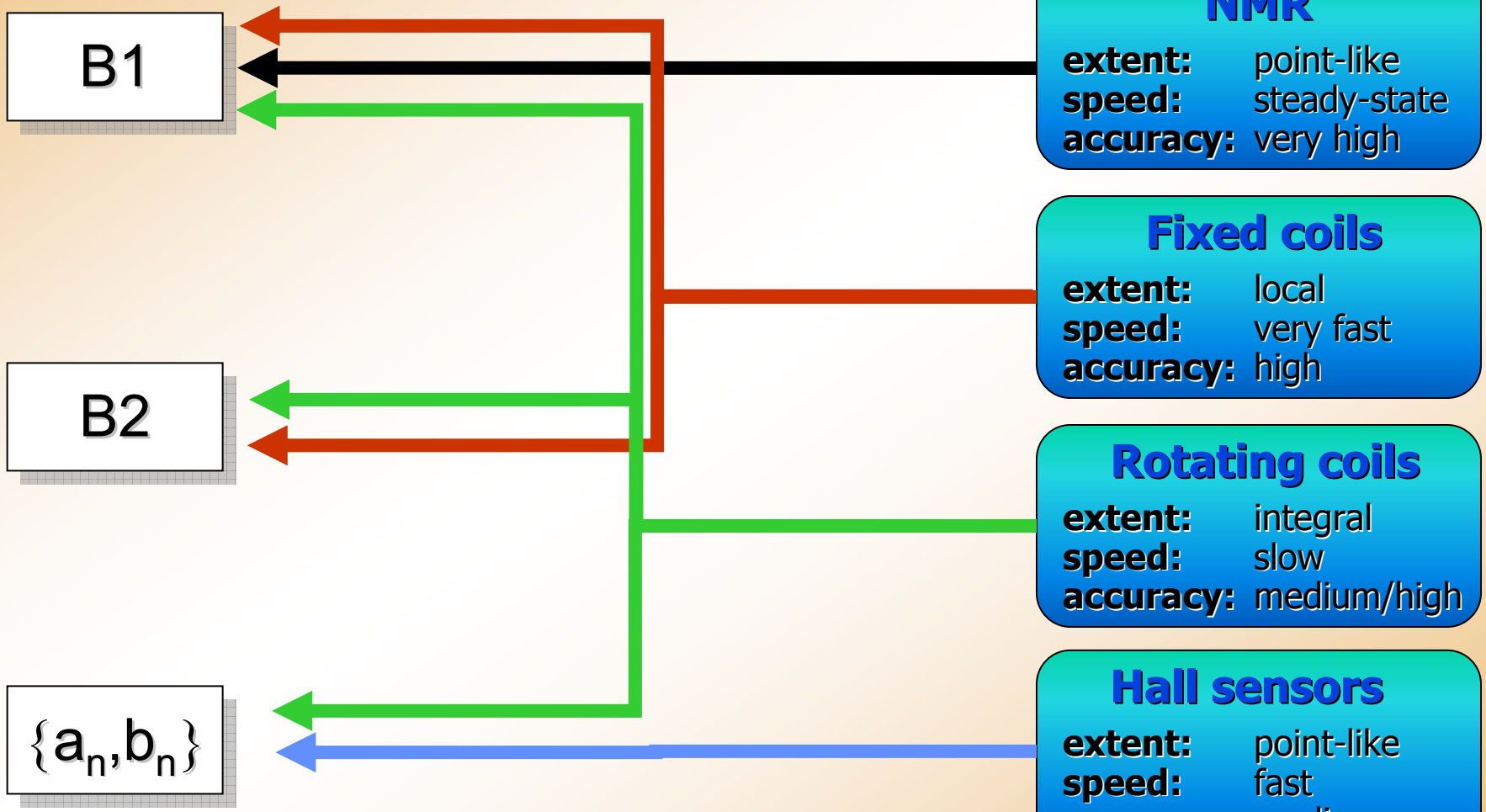




Overall FAME architecture

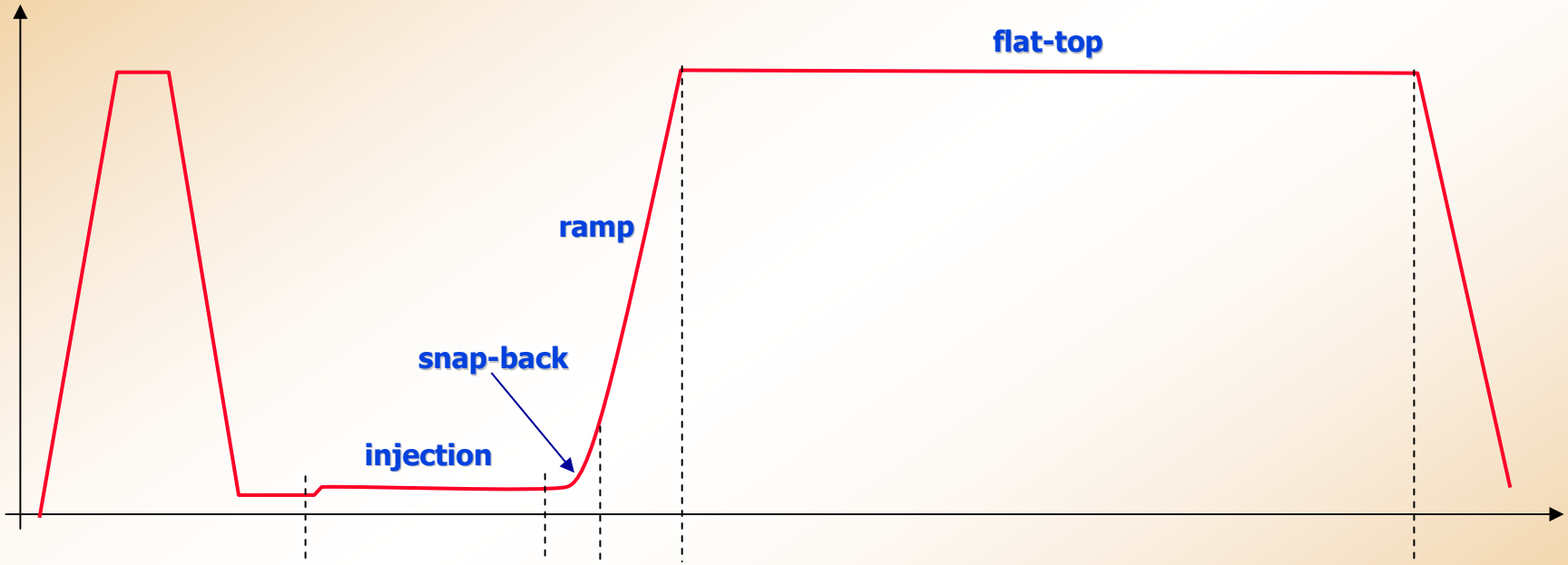
machine requirements:

available methods:



Overall FAME architecture

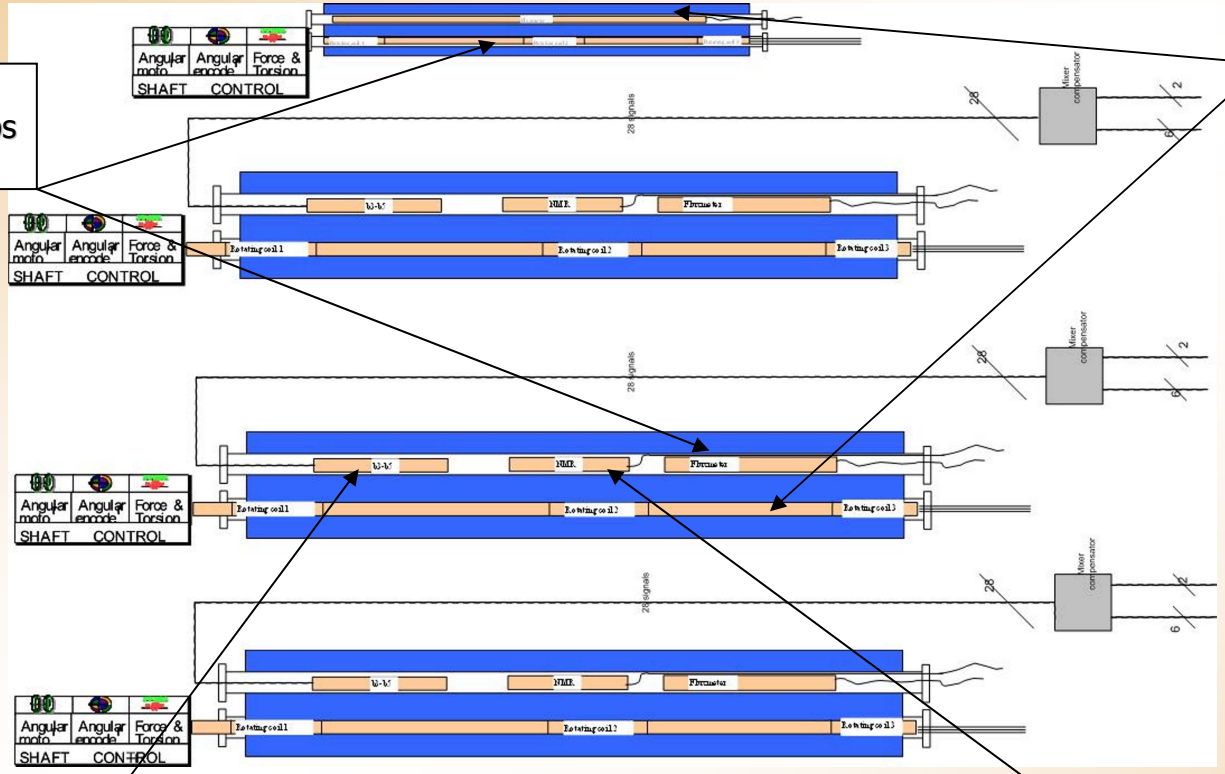
different measurement systems are palnned for different parts of the cycle according to spec range



rotating coils	✓	✓	✓	✓
fixed coils			✓	
Hall probes		✓		
NMR	✓			✓

FAME layout – 2 MB + 2 SSS

fixed coils
local B1/B2 during ramps
(to be extrapolated)



long coil shafts
integral of all harmonics,
one aperture

Hall probe
local B3/B5 during snapback
(to be extrapolated)

NMR probe
(B1 calibration at center of magnet,
to be extrapolated)

multiple instruments combined in parallel to overcome individual shortcomings

Performance targets for FAME hardware (MB)

System	Goal		Resolution (units)		Bandwidth (Hz)	
	Harmonic	LHC cycle phase	now	target	now	target
rotating coil shafts	B_1	steady-state	0.05	0.05	0.1 →	3.0
	a_n, b_n, $n \geq 2$	steady-state	0.02	0.01		
		ramp	0.10 →	0.01		
fixed coils (flux loops)	B_1	ramp	0.10	0.10	10.0	10.0
Hall sensors	b_3, b_5	snap-back	0.05	0.05	10	10
NMR	B_1	steady-state	0.001	0.05	0.5 →	1.0

→ = improvement needs further R&D at CERN

Performance targets for FAME hardware (MQ)

System	Goal		Resolution (units)		Bandwidth (Hz)	
	Harmonic	LHC cycle phase	now	target	now	target
rotating coil shafts	B_2	steady-state	0.10	0.10	0.1 →	3.0
	a_n, b_n, $n \geq 3$	steady-state	0.02	0.02		
		ramp	>0.10 →	0.02		
fixed coils (flux loops)	B_2	ramp	0.10	0.10	10.0	10.0

→ = improvement needs further R&D at CERN

Infrastructure: SM18 test station

Rotating coil shaft system

Twin Rotating Unit

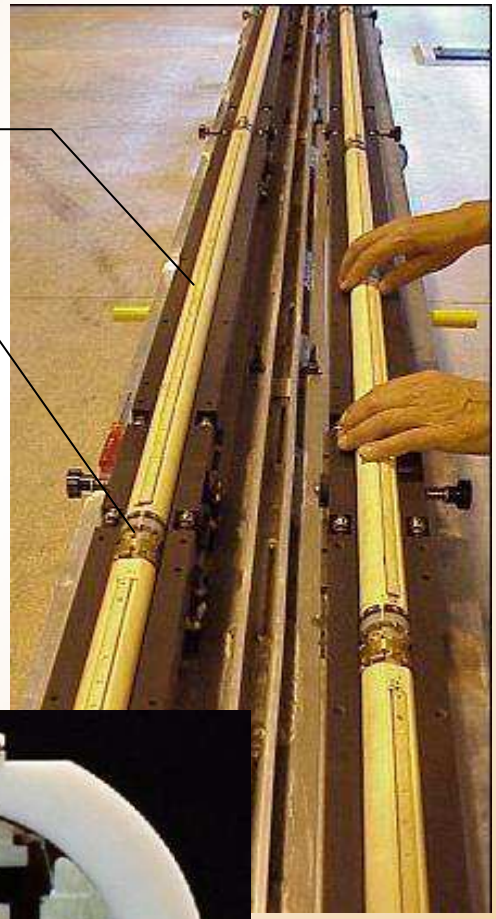
Twin ceramic coil shafts

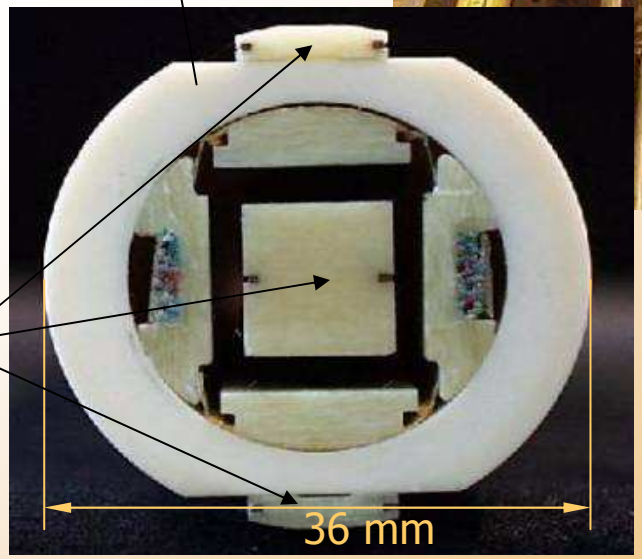
Stepping motor
angular encoder

CERN/Metrolab
VFC based digital
VME integrators

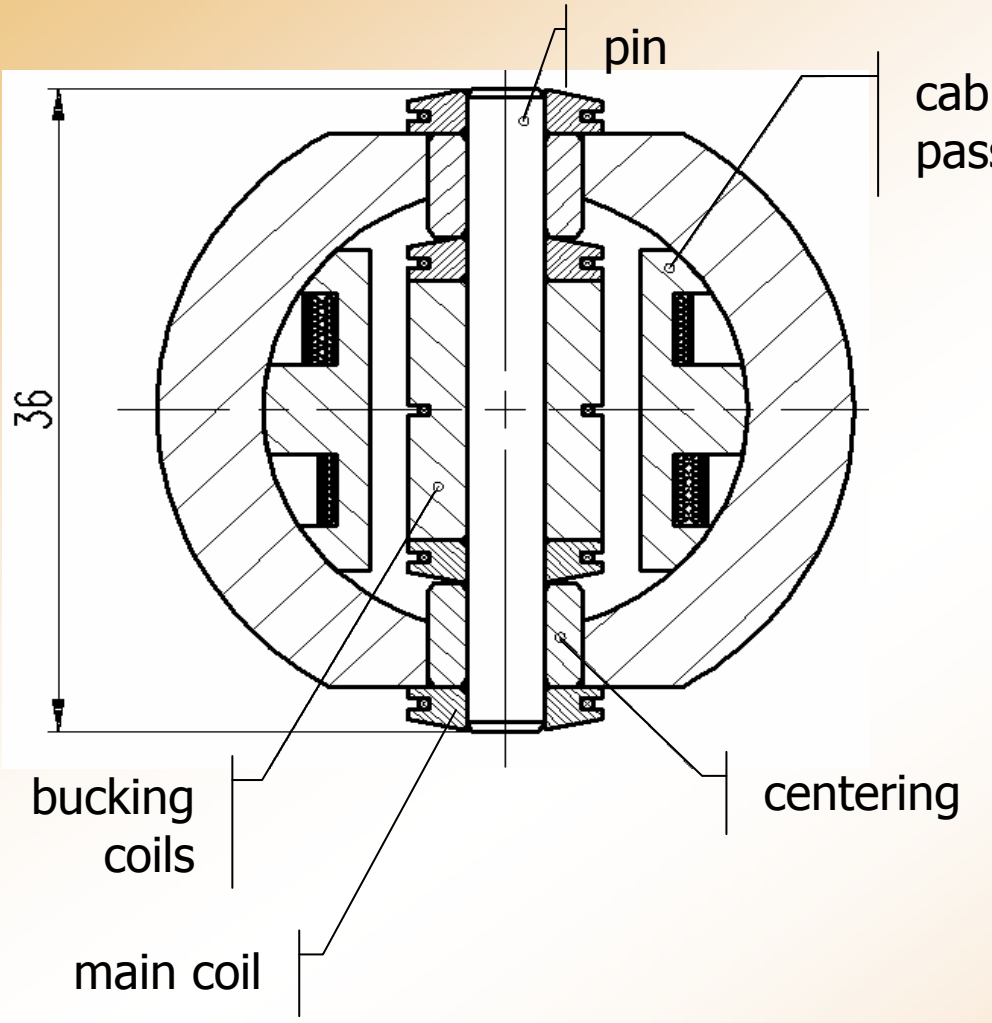
Rotating coil shaft system (MB)

- 13 x 1260 mm modules
- rollers and ceramic ball bearings result in 110 mm gaps between modules (compensated by interpolation)
- ≈18 m length (including a 1460 mm *rallonge*)
- simultaneous measurement of two complete magnet apertures in one rotation
- 2 + 1 dipole-compensated coils per module





Rotating coil shaft system (SSS)



- 6 x 810 mm modules
- 110 mm gaps between modules (as for MB)
- ≈8 m length (including two 1460 mm *rallonges*)
- 5 longitudinal positions for measurement of MQ, MSCB, MO/MQT/MQS
- 4+1 quadrupole-compensated coils per module
- *compatible cabling* between SSS/MB for modularity/flexibility

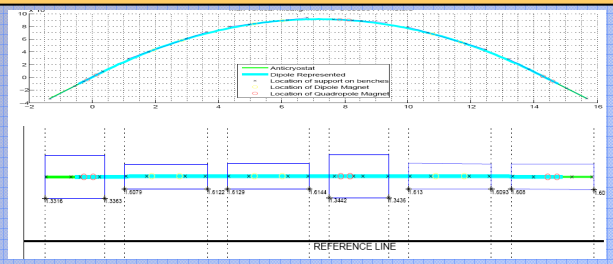
Rotating coils: developments needed

- Hardware
  - **Coil shafts:** modify existing shafts by connecting in series groups of contiguous coils (lower total channel count – 3 super segments).
  - **New shafts:** to reduce the signal amplitude due to high rotation speed and series connection of segments new coils with ¼ of # of turns (effective surface).
  - **Rotation unit:** New rotating unit lighter and with slip rings to allow continuous rotation in one direction at around 2-4 Hz limited by mechanical vibrations.
  - **Digital integrators:** faster ADC/DSP-based digital integrators.
  - **Acquisition system**: new real-time computer system for higher data throughput.
- Software
  - **Embedded code**: low-level logic to drive DSP integration (+ possibly harmonic analysis)
  - **Acquisition and control code:** real-time software to drive the instruments and to carry out continuous harmonic analysis
  - **Harmonics analysis:** new algorithm to increase precision during ramps, taking into account the variation of current with time (if necessary with sliding-window FFT for faster interpolation)
  - **Integration**: interface with overall FAME system

FAME Rotating Unit - Project Planning

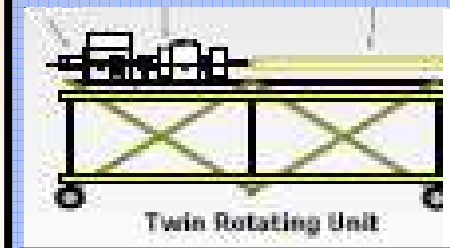
Investigation & Characterization of Obstacles to FAME Rotating Unit

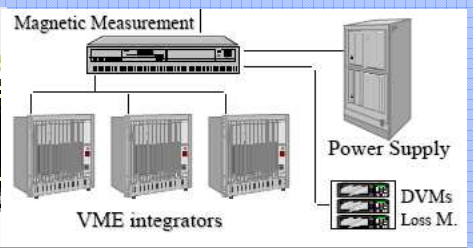
I8 Test Bench Replicating MB



Experimental Tests

Vibrations
Signal Quality
Alignment
Stability





TRU & Measurement System Retrofitted for Continuous Fast Rotation

Analysis of
Slip Ring
Lifetime
Performance

Prototype of FAME Rotating Unit

Analyze Data

Optimized Component Selection

Motor
Slip Rings
Encoder
Couplings

Design, Construct, & Test

- Sub-Project for TS-MME
- Satisfy FAME targets
- Maintenance-free for minimum of 10^8 rotations
- Reduced bulk of rotating unit
- Integration with other FAME hardware

FAME - Project Status

- **Modified TRU (achieved)**
  - Up to 600 rpm (10 Hertz)
  - Motor (2 Phase Hybrid Stepper & Brushless DC)
  - Slip rings (Continuous rotation in either direction)
- **Test Bed (achieved)**
  - Layout replicates curvature of LHC long dipole magnets
  - Dipole and Quadrupole magnets used to analyze system performance
  - Endurance test successful of 430 hours at 8 Hz (Over 12M rotations)
- **Measurement System (achieved)**
  - QIMM measurement system modified for FAME rotating unit
  - Modified LabView PDI application developed for previous tests in SM18
  - Testing at SM18 on real LHC dipoles (at warm & cold)
- **Rotating Coils (in progress)**
  - 12 segments electrically connected in 3 main groups (2 exterior and 1 center). Precision of the coils for absolute B1 smaller than 5 units, better than dispersion between dipoles.
- **New Rotation unit (in progress)**
  - Up to 54 channels (3 slip rings of 18 channels)
  - Much lighter support (attached to end of magnet without supporting chariot)
  - Fast and easy to align, dismount and reconfigure

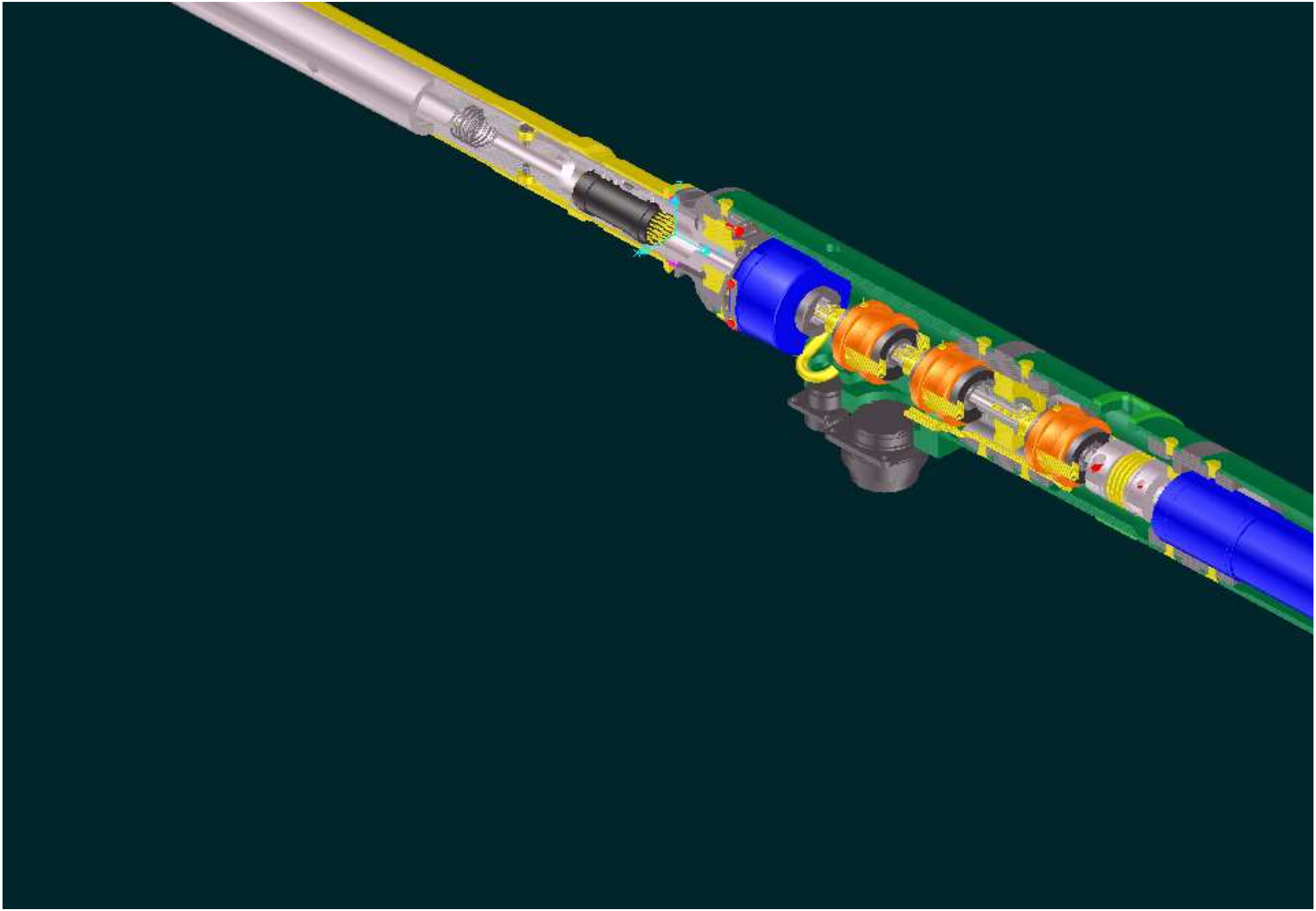
New digital integrators for rotating/fixed coils
Fast Digital Integrator (FDI)

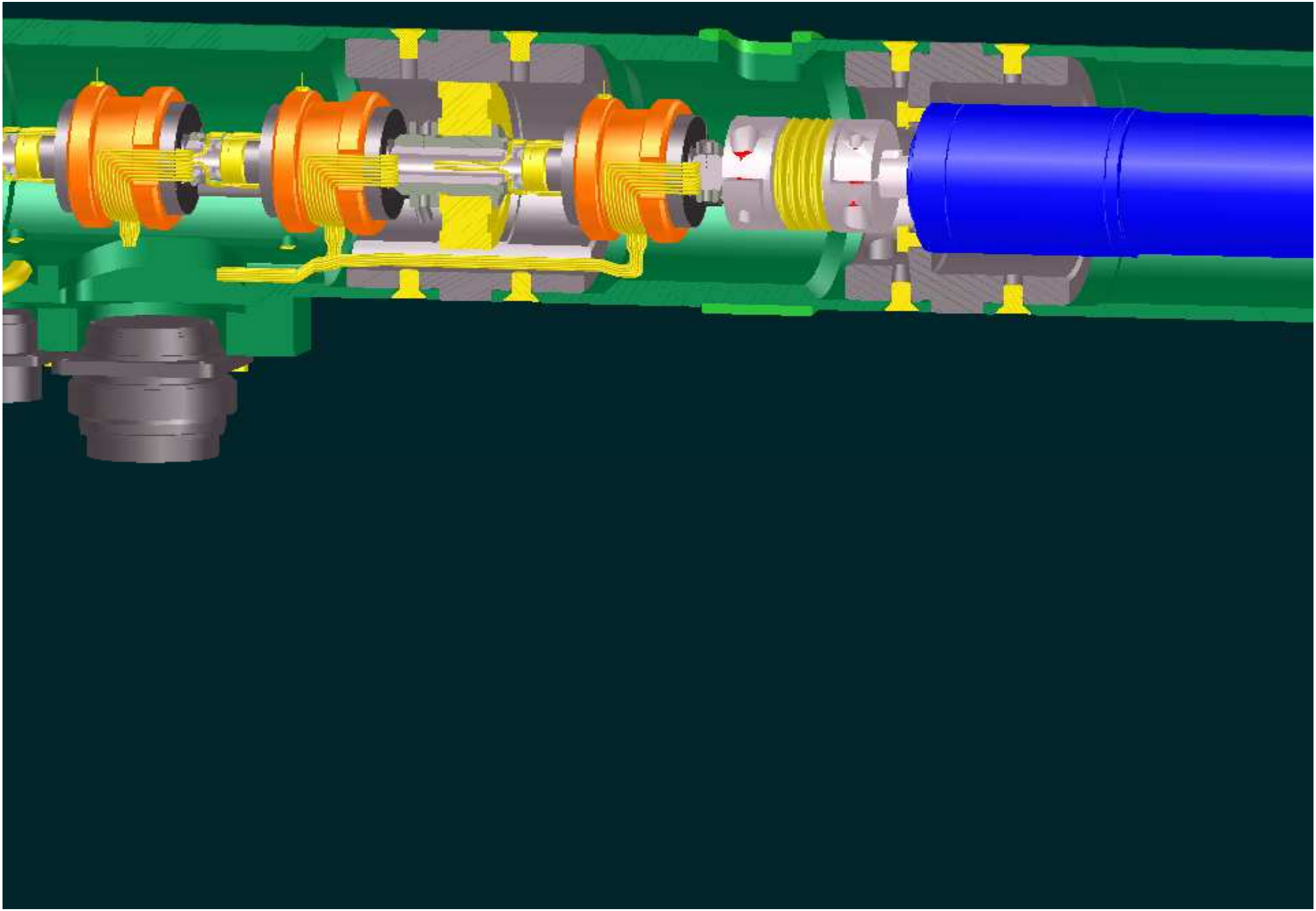
- limitation of current system: low precision at > 256 integrations/s, low overall data rates, sensitive to input offset
- new digital integrators taking advantage of recent progresses, based on fast ADC to sample the input + on-board DSP to carry out numerical integration/FFT + time measurement to improve the time stamp precision
- programmable pre-amplifiers to follow dynamic range during LHC cycle + anti-aliasing input filters
- optoelectronic angular encoder interface to synch integration intervals to the coil angular position (256 flux increments/turn)
- auto-recalibration between cycles
- possibility of hosting algorithms to improve performance
- PXI interface

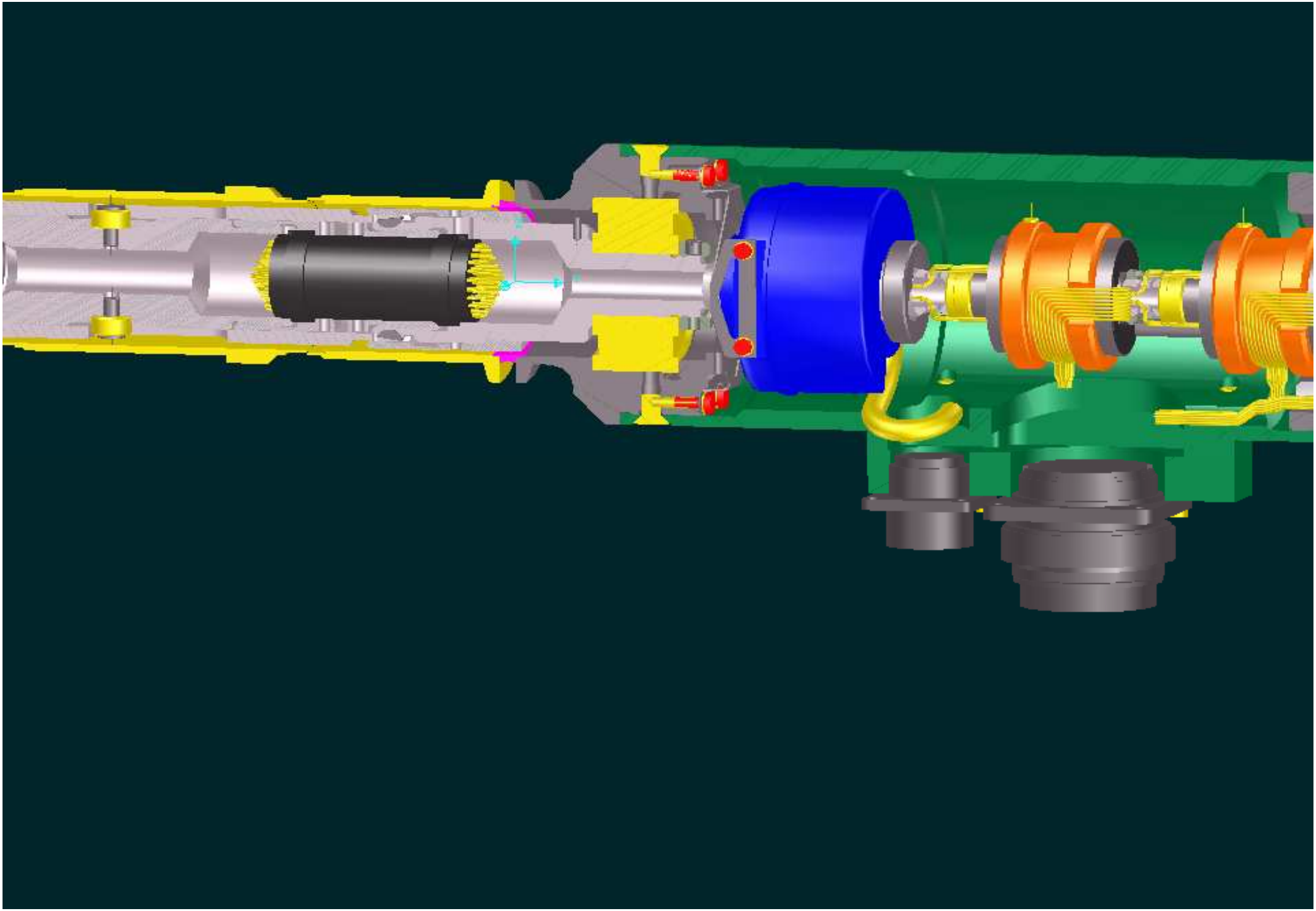
N. of channels/bench	7
Input range (V)	± 5.0
Input gain	0.1 - 100
Gain switching time (ms)	<50
Integrations/s	>1024
Integrator accuracy (Vs)	$\pm 10^{-5}$
ADC Sampling Rate (S/s)	$0.8\ 10^{6}$
ADC Resolution (bit)	18
Temperature range (°C)	0-50

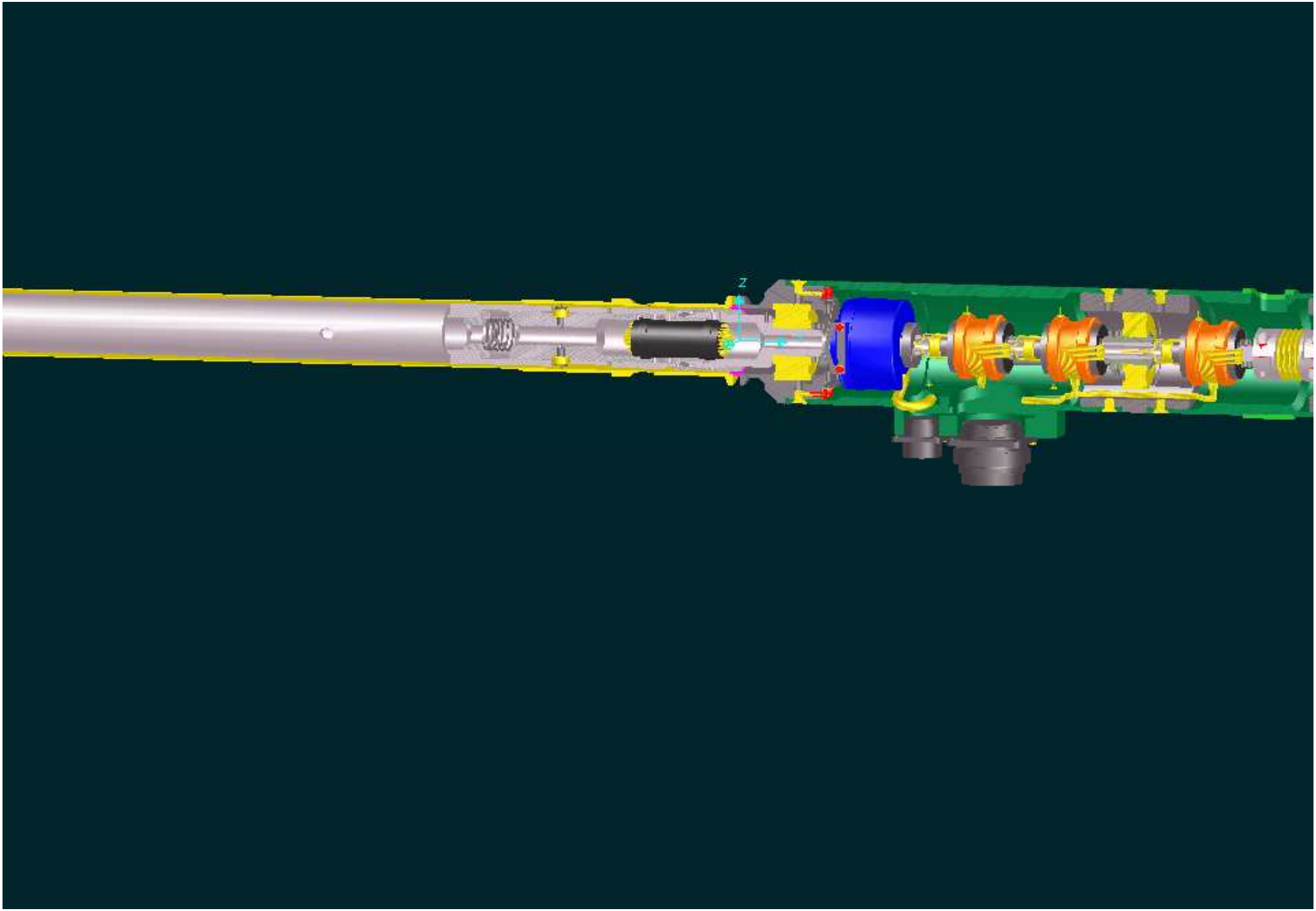
New Mini Rotation Unit

- A new mini rotation unit has been developed
- Smaller (~0.5 m), lighter(~5 Kg) and easily aligned to magnet anticryostat
- Prototype has been produced and is being mounted
- Eliminates the heavy and cumbersome old TRU support
- Up to 54 channels (dipole shafts needs 4x12)
- Selection of segments within a super-segment is done externally, at the level of PCI-PXI crate





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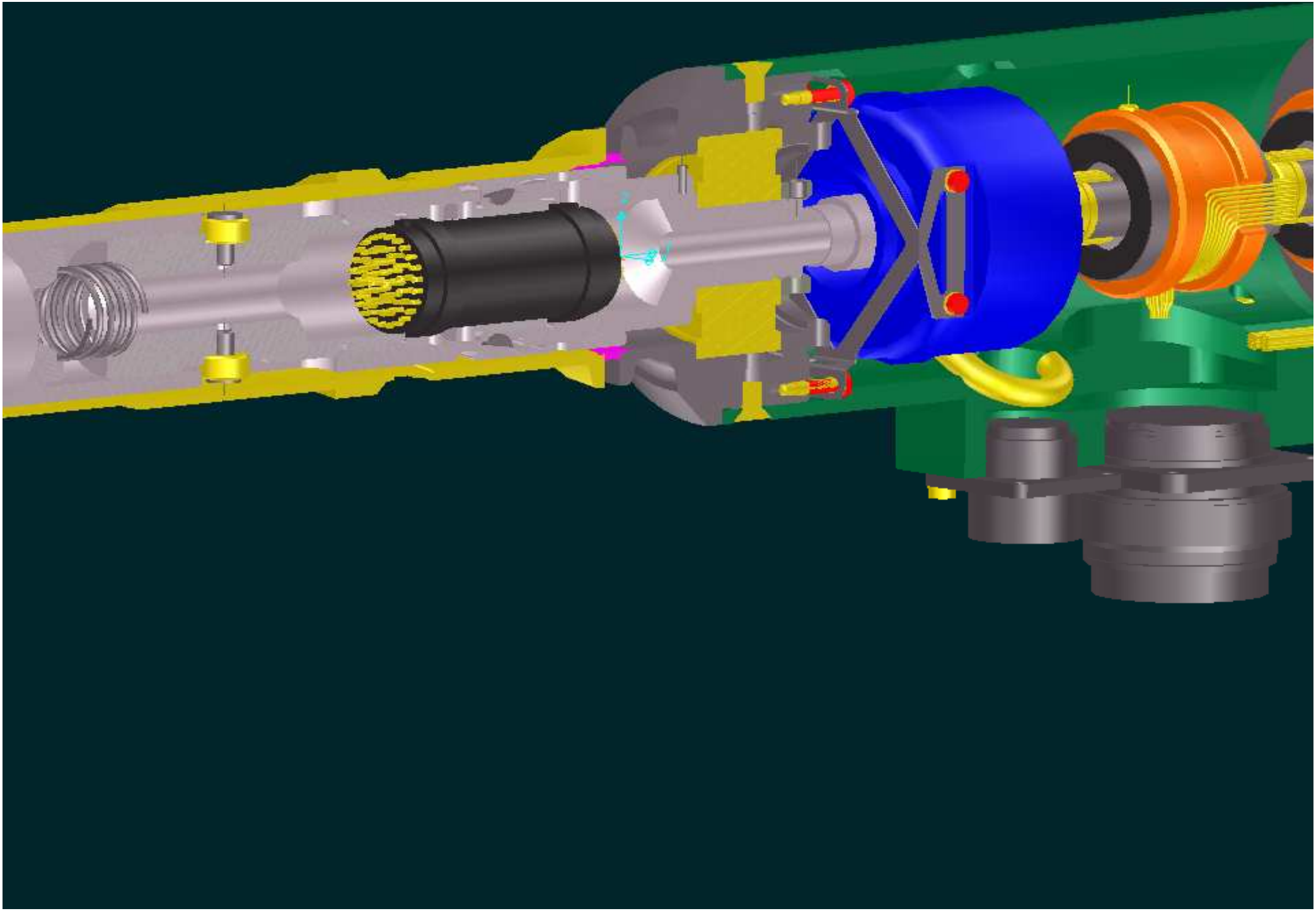
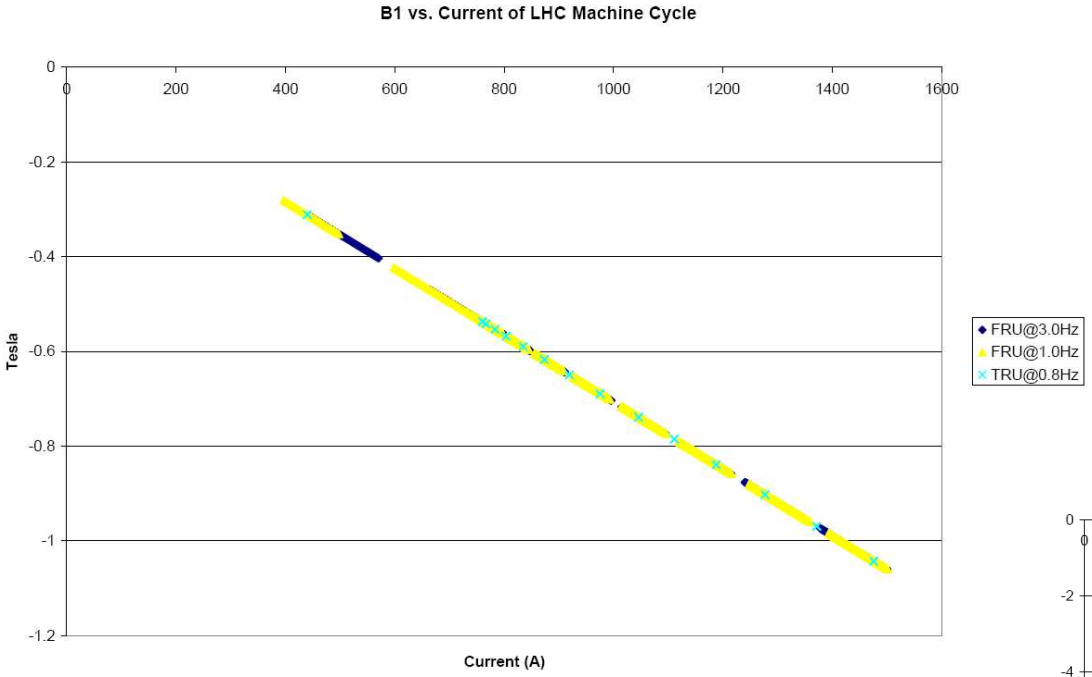
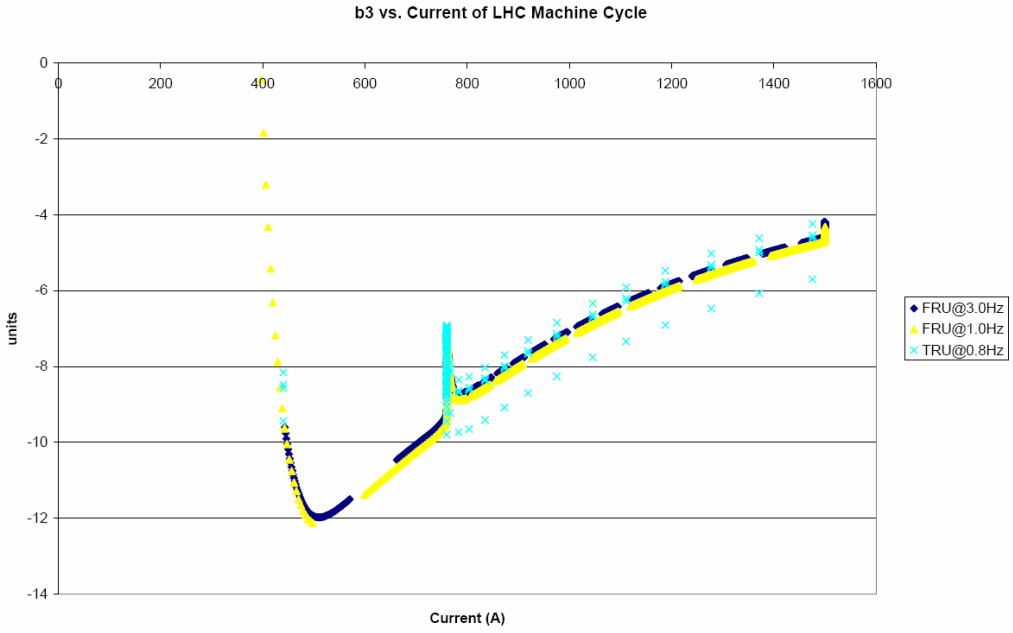


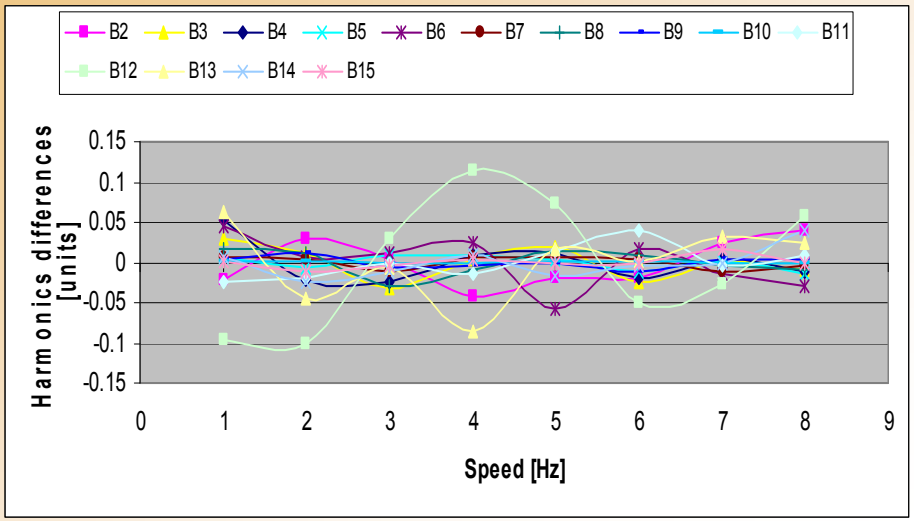
Results with Fast Rotating Unit

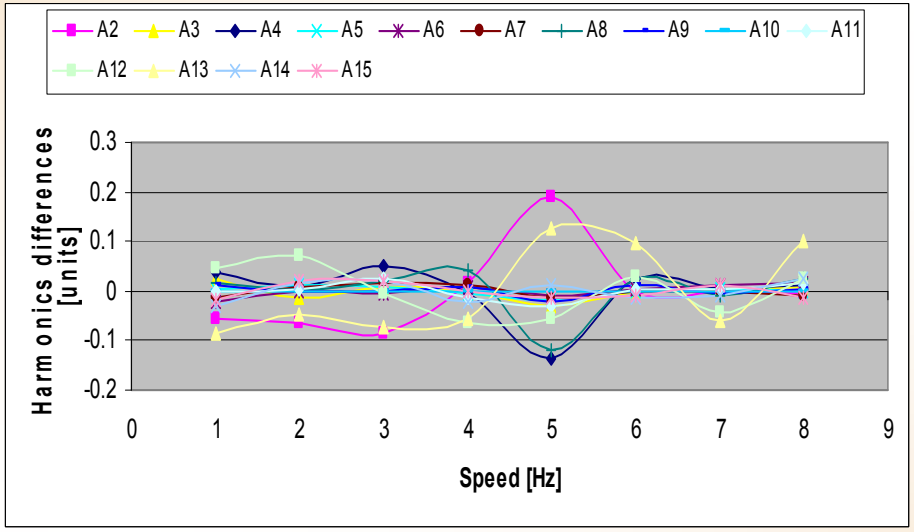


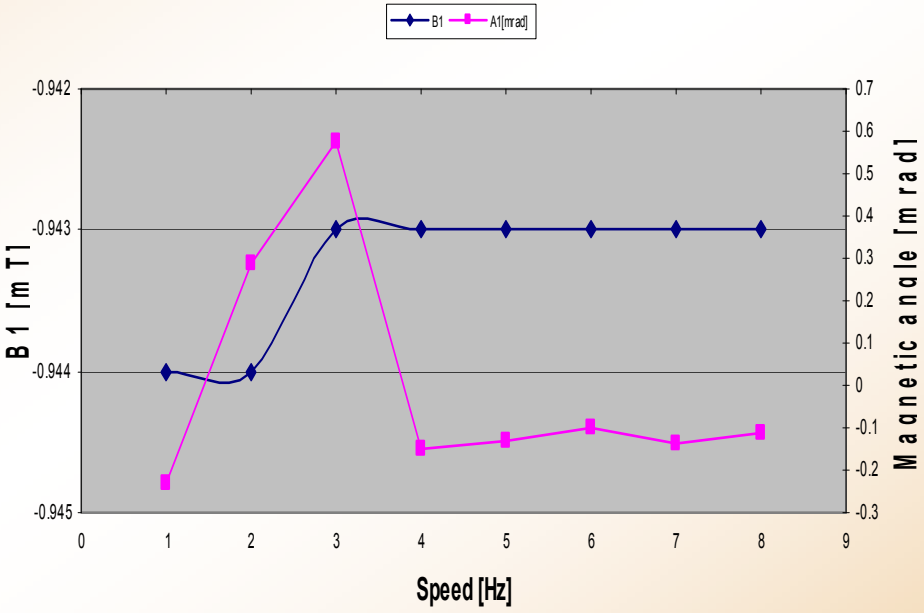
- Old electronics and modified old rotation unit used



Preliminary results of harmonics on a dipole







- Results from a central super-segment analysis
- 10 A current at warm on a LHC dipole
- No sign of harmonics change with the speed
- Small change in magnetic angle, and B1 stable

Conclusions

- FAME project is on its final phase
- Mechanics of the rotating coils has proven its ability to turn at around 9 Hz without disturbances
- New rotation unit designed and produced in short time to be tested soon
- New Digital Integrators are in prototype production phase and feature very good results
- New shaft with smaller surface are well advanced
- Final tests with all these new elements are programmed for this Autumn