Measurement Challenges for the Magnet Projects at CERN

S. Russenschuck for the TE-MSC-MM Section
and the Magnet Design Teams at CERN
and the collaborating institutes

20.09.2011

Approved Projects and Studies

- CLIC
- Linac4
  - Permanent magnet quadrupoles
  - Axis of RF drift tube
- LHC consolidation
  - Refurbished main dipoles and quadrupoles
  - Exchange of magnets in the next shutdown
- LHC upgrade
  - Wide aperture insertion quadrupoles
  - High field magnets (11 T separation dipole, FRESCA2, HQ)
- *Med*Austron, Ion-Therapy Project
  - Strongly curved dipole magnets
- LHeC

Small apertures, PCB Coil, Vibrating wire

Flexible Framework for Magnetic Measurements (FFMM)

Quench Antenna

PCB Fluxmeter, Field description for strongly curved magnets

Recurrent

- Injector maintenance and upgrade
  - PS (Multi -turn extraction), SPS
  - Booster
  - Elena
  - High Intensity ISOLDE
  - Fast Cycling Magnet (FCM) for PS2
- Controls and Instrumentation of accelerators
  - B-train (Booster, PS, AD, SPS, Leir)
  - Fidel and tracking tests
- Field computation and analysis of measurements
  - Magnetic model of the LHC (FIDeL)
- Magnetic measurements on materials

Analysis and controls for compensation of saturation

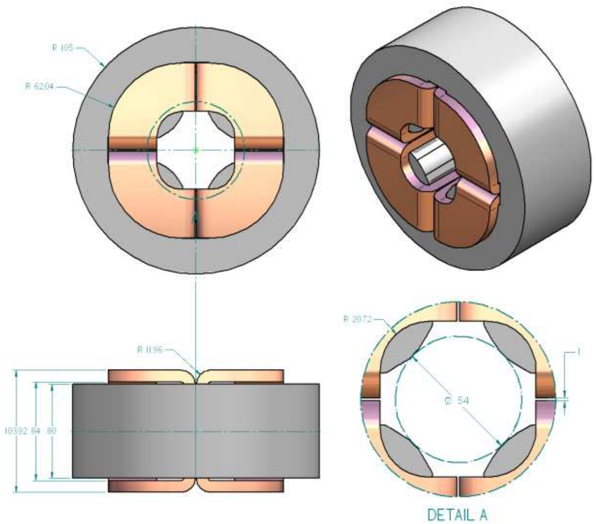
Strongly curved magnets

Eddy currents, end-effects and hysteresis

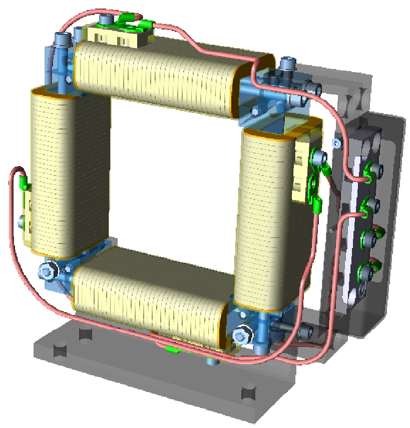
Ferrimagnetic Resonance Marker

Fast Rotating Measurement equipment (FAME), Fast Digital Integrator

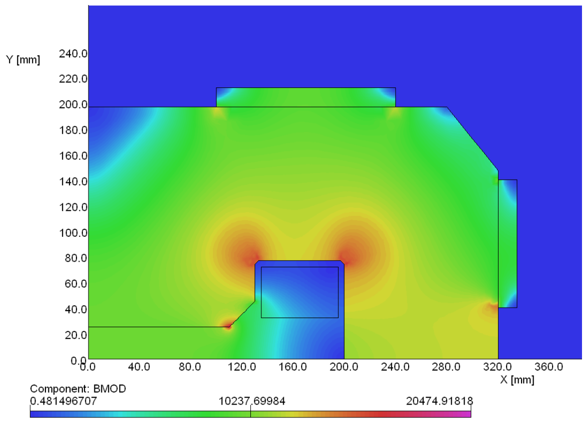
LINAC4 (Replacing Linac2 as Injector to the PS Booster)

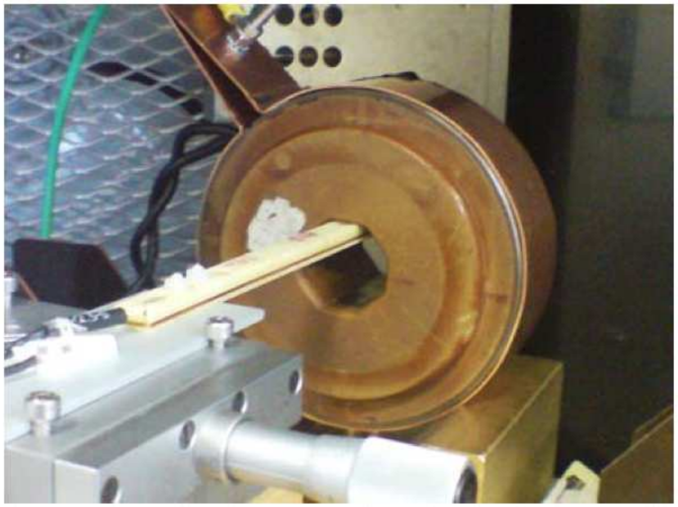


Linac quadrupoles



Transfer line steerers



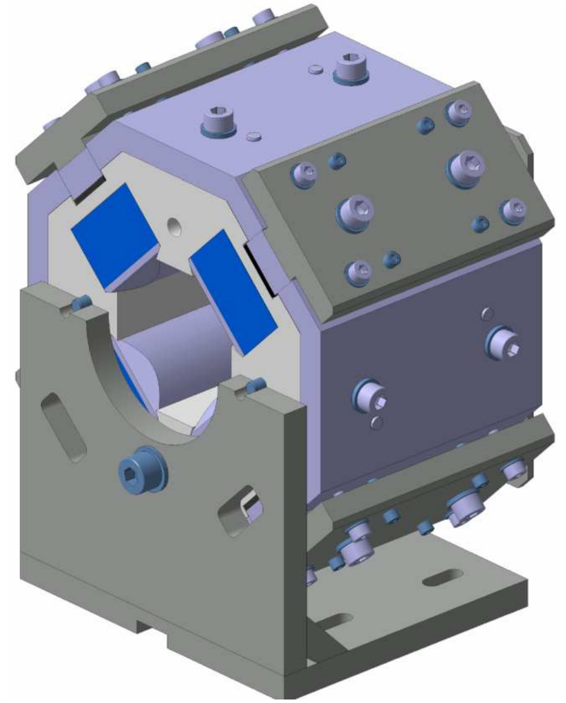


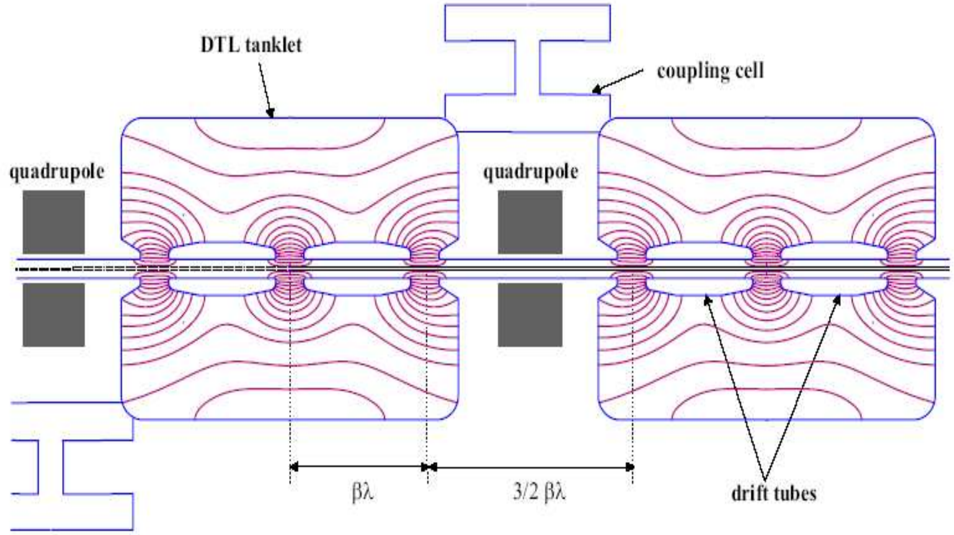
Fast-pulsed magnets; 0.2 ms rise time:

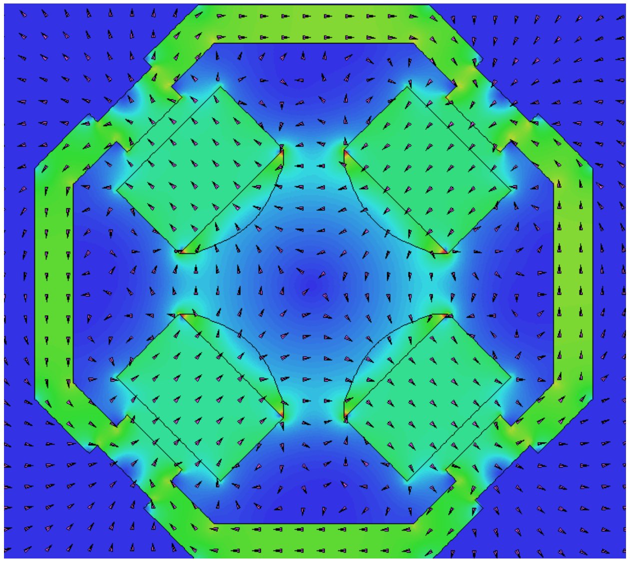
Hysteresis and power supply stability
Eddy currents
High angular precision in measurement

Arpaia et al., 2010 I2TMC Conference

LINAC4





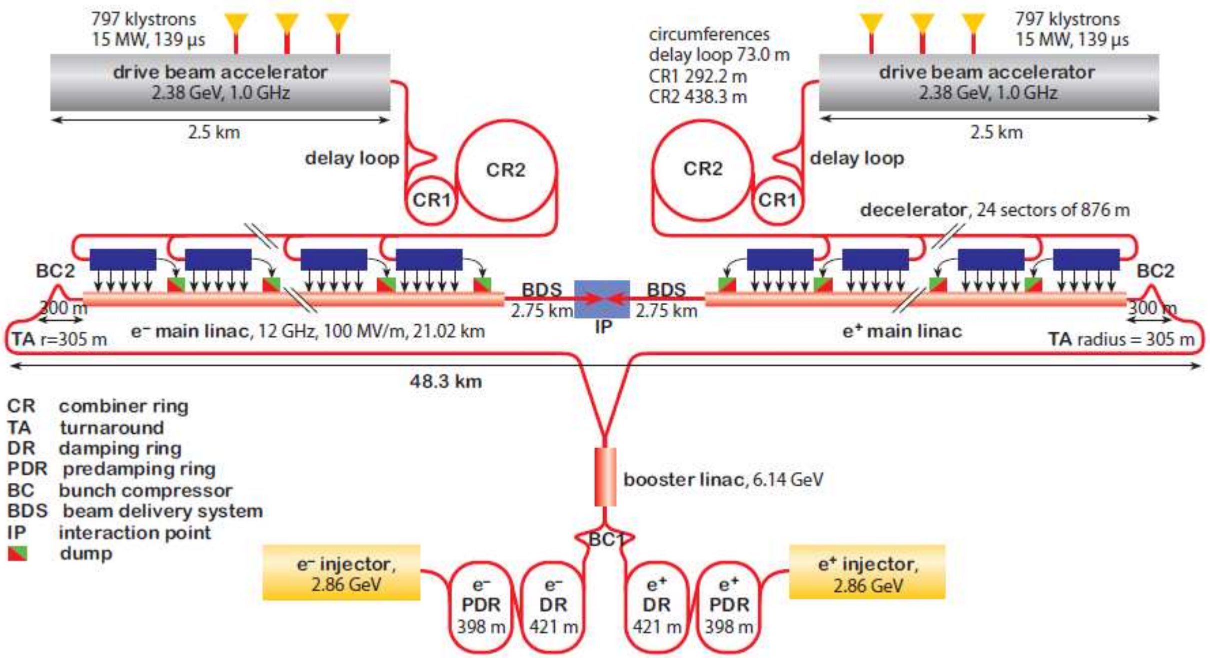


Limited space in Cell-Coupled Drift-Tube Linac (DTL) modules
Samarium Cobalt permanent magnets
Integrated gradient of 1.3-1.6 Tesla
45 mm aperture, Field quality tuning with iron shims

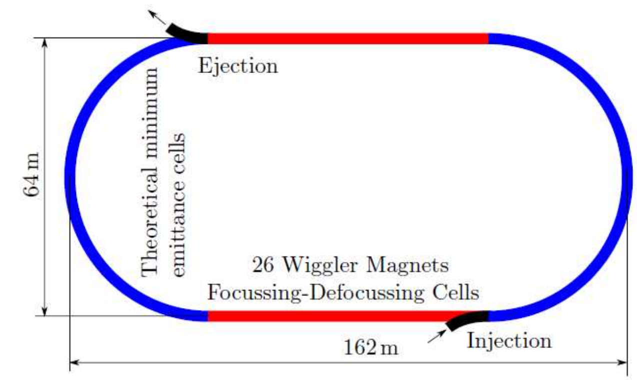
Axis, geometry, and harmonics measured
(Stretch wire, presentations by J. Garcia-Perez)

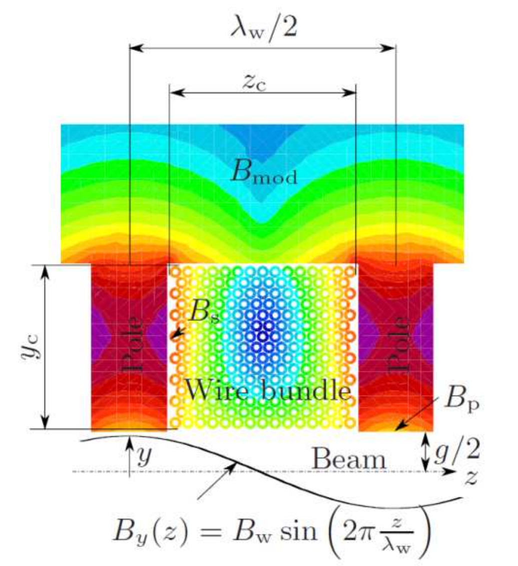
Status report by T. Zickler at IPAC 11

CLIC Layout and Damping Ring Wiggler R&D

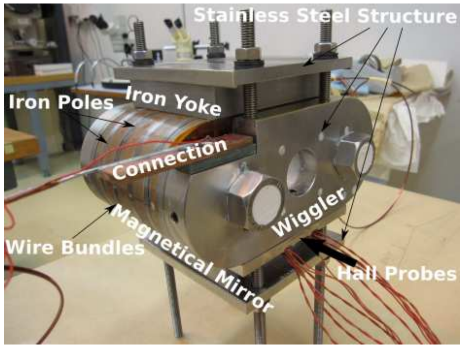


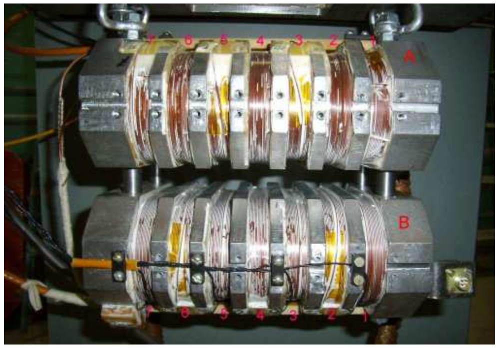
Collaboration with BNIP and KIT for the installation of complete, conduction cooled unit

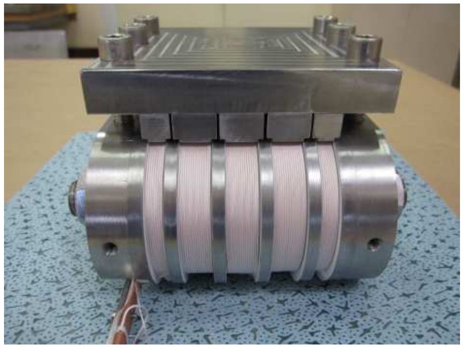




First and second field integrals with stretch wire

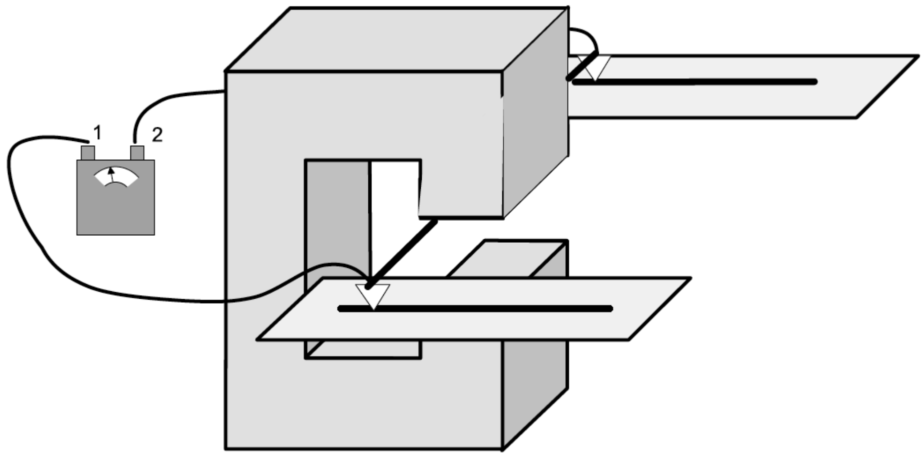


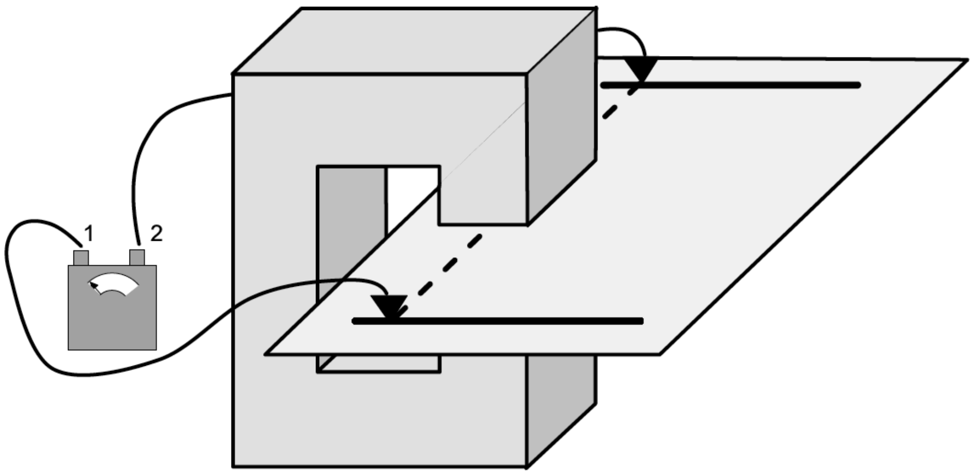


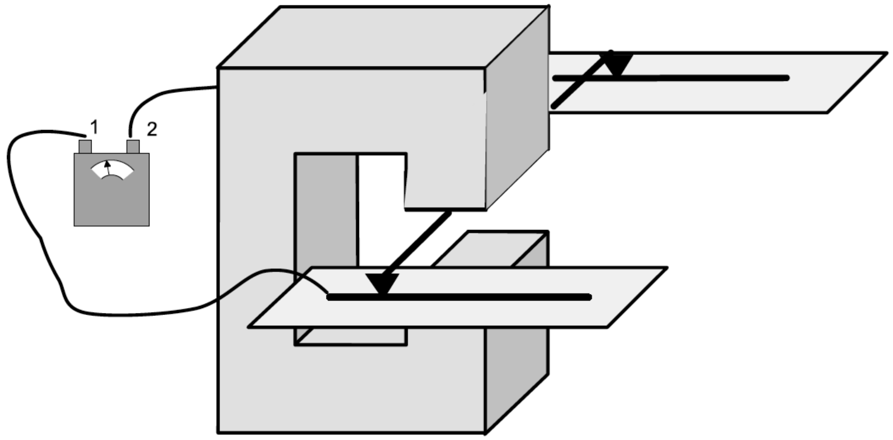


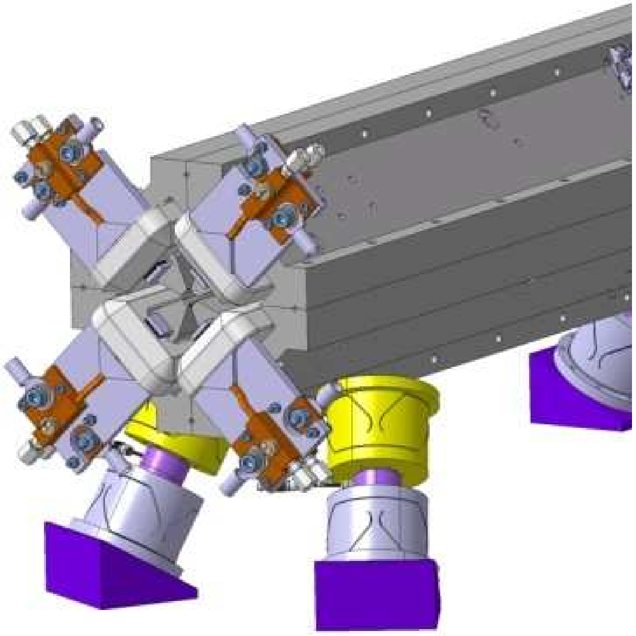
Short model magnets

Stretch Wire Measurements and the Faraday Paradox

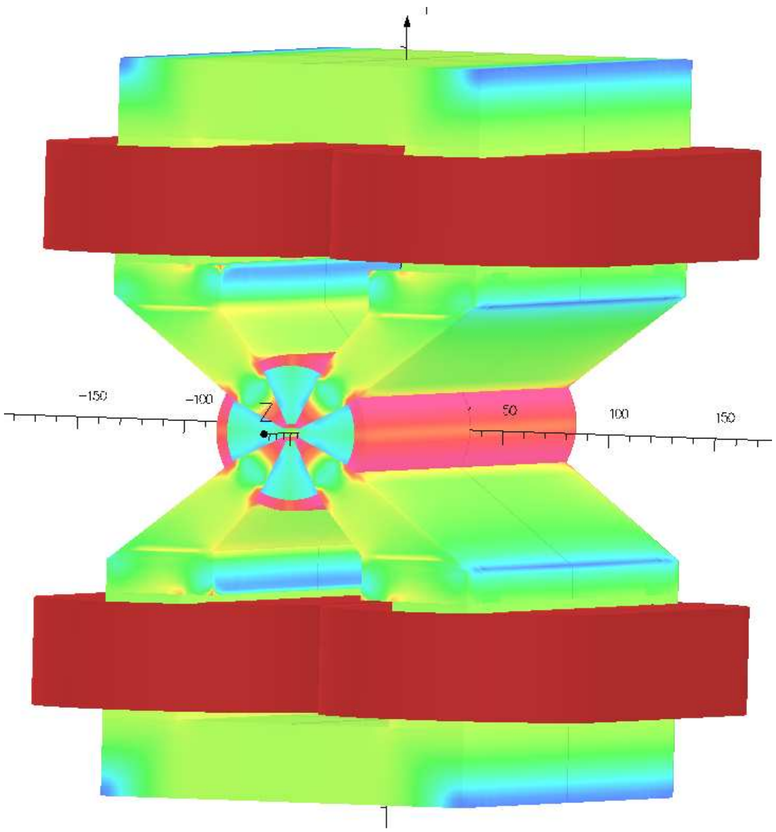








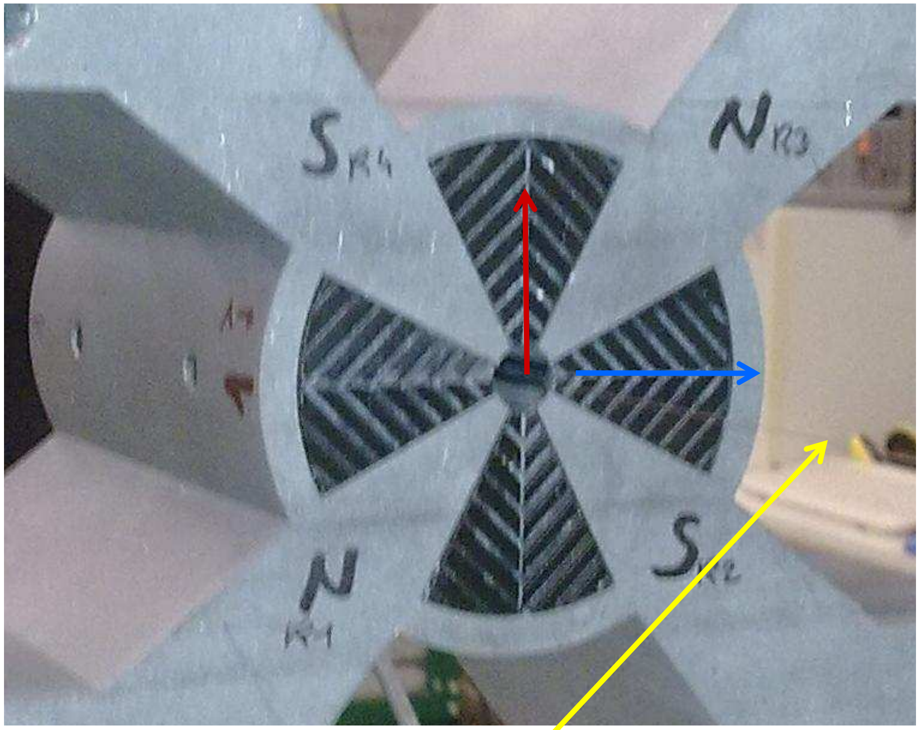
Main Beam Quadrupole



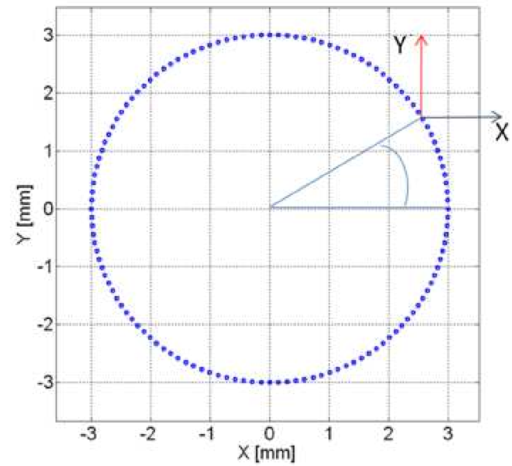
Final Focus Quad, Gradient: > 530 T/m, Aperture Ø: 8.25 mm

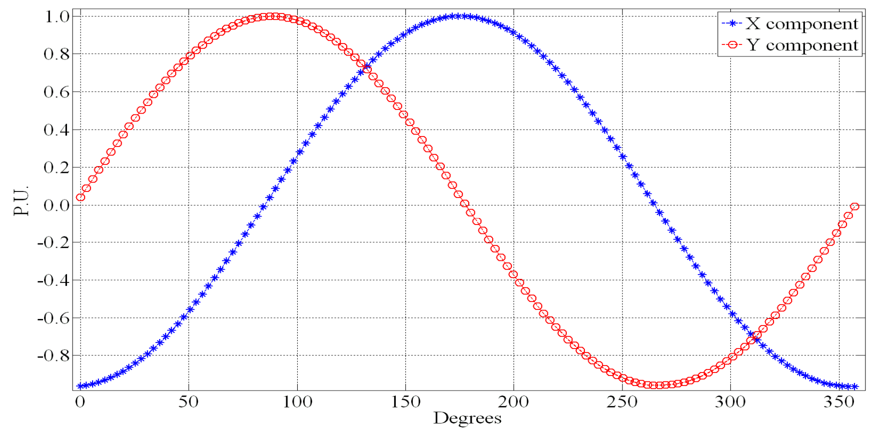
Procurement of one long and two short Main Beam Quad prototypes
Manufacture of a Hybrid Quadrupole for the Final Focus
Procurement of several Drive Beam Quadrupole units

CLIC Quadrupole Field Measurement with Vibrating Wire



wire Ø 0.125 mm

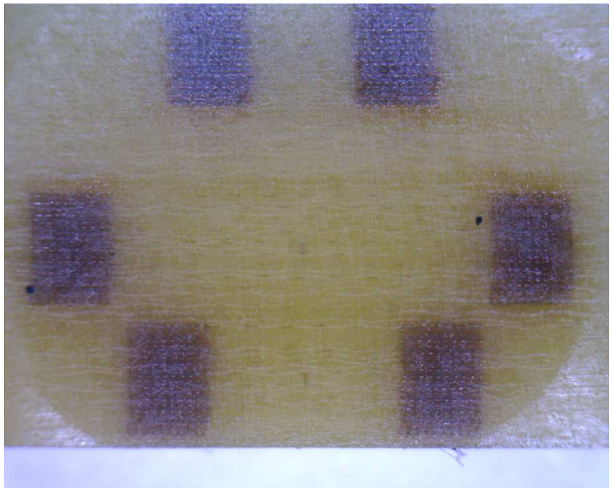




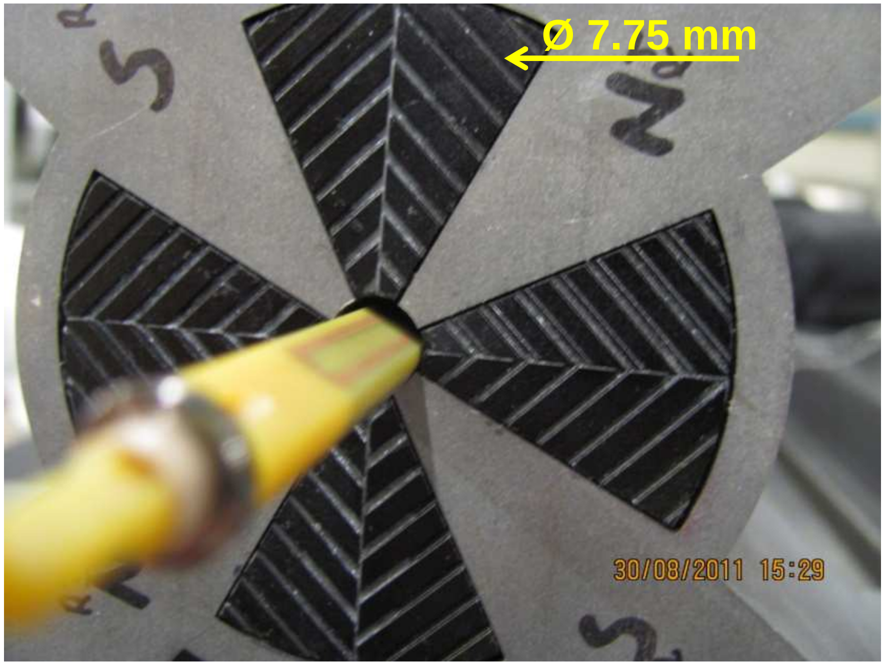
Presentation
By C. Petrone

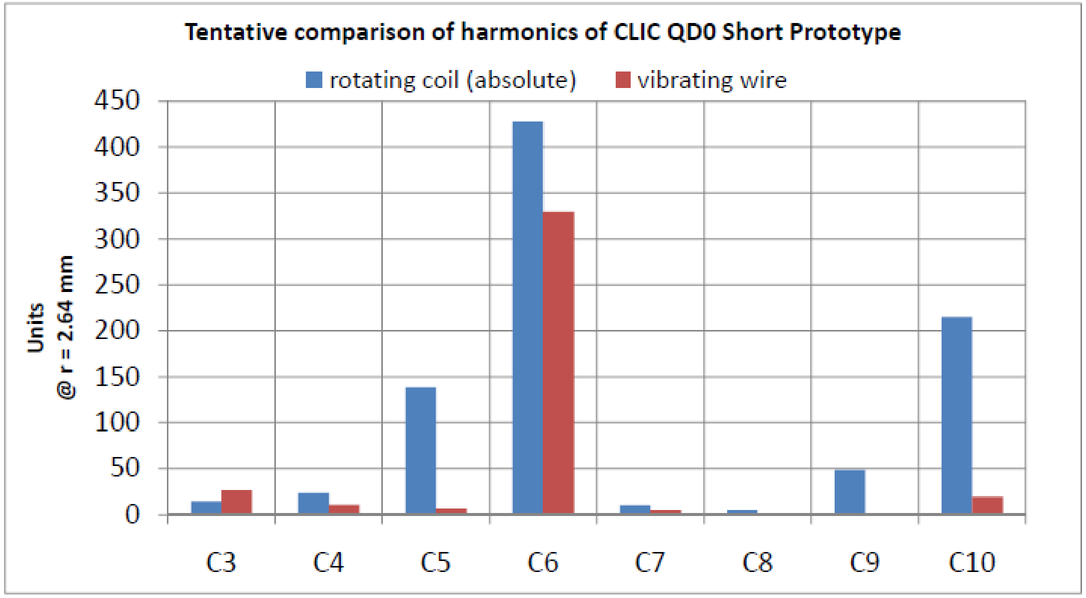
AC current (40 Hz for 2-m-long wire). Phototransistors acquire the amplitudes Ax and Ay of the wire oscillation in x and y directions, which are proportional to the magnetic field components B_x and B_y.

PCB Rotating Coil Array for CLIC Magnetic Measurements



Printed Circuit Board Technology for coil Manufacture with 7.75 mm in diameter





First harmonic measurements

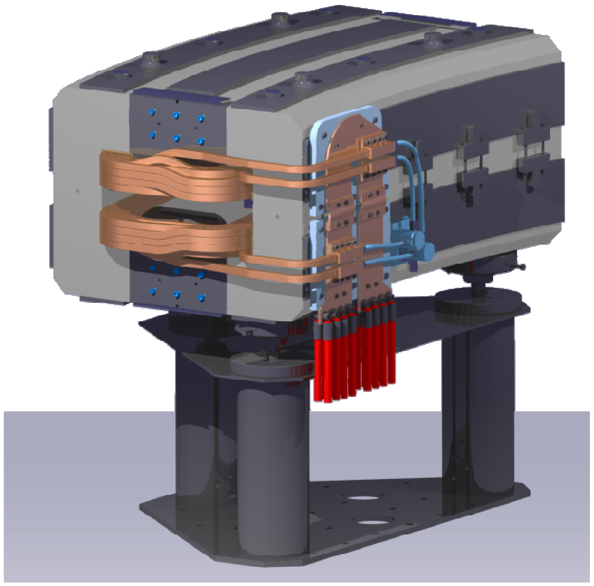
Presentations by O. Dunkel

*Med*Austron

*Med*Austron: Centre for ion therapy and research in Wiener Neustadt, Austria

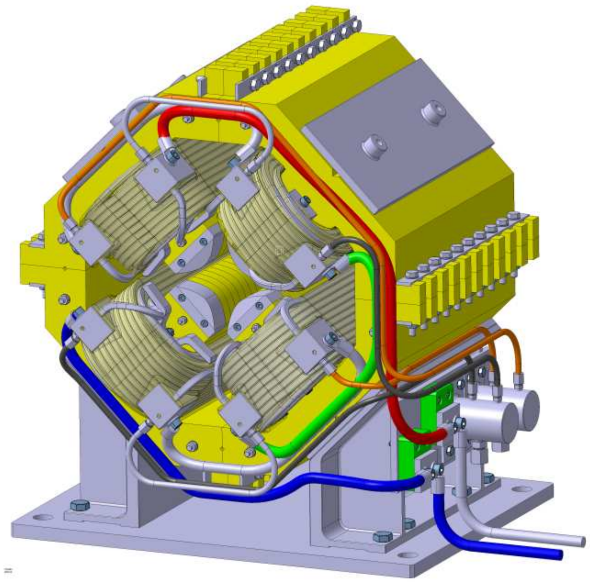
Consists of 3 ion sources, a synchrotron, 4 treatment rooms, incl. a p-Gantry

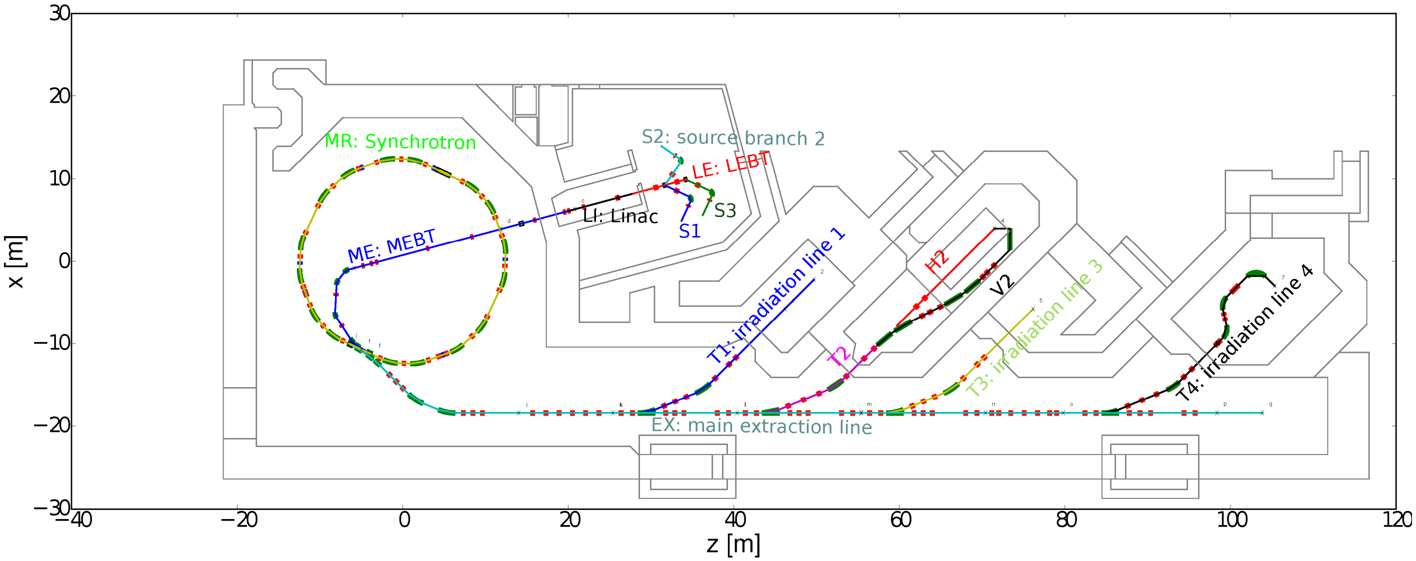
About 300 magnets of 26



Synchrotron main bending magnet assembly

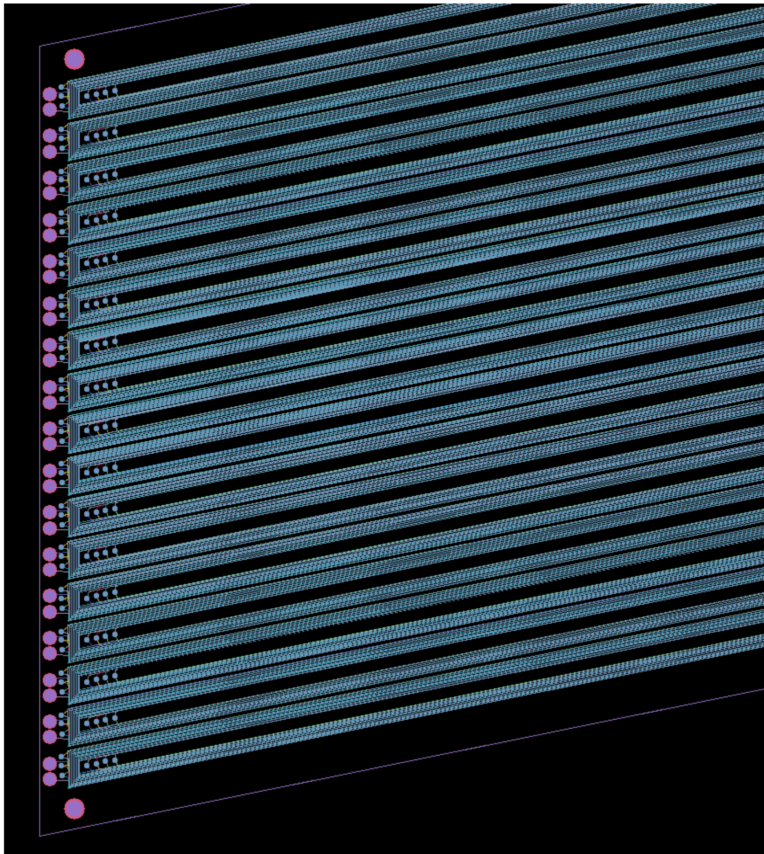
HEBT quadrupole magnet assembly

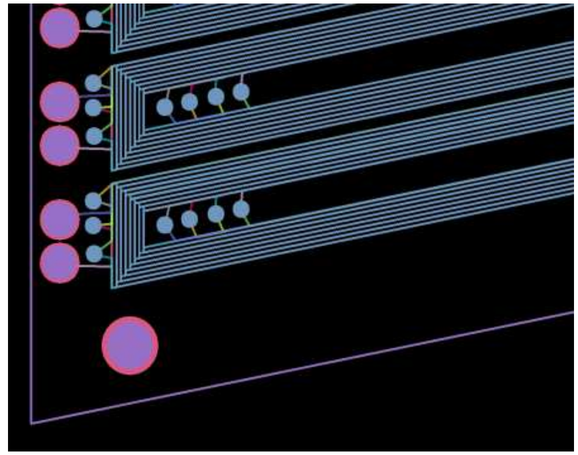




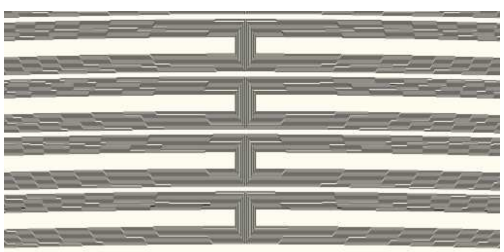
Presentation by T. Zickler

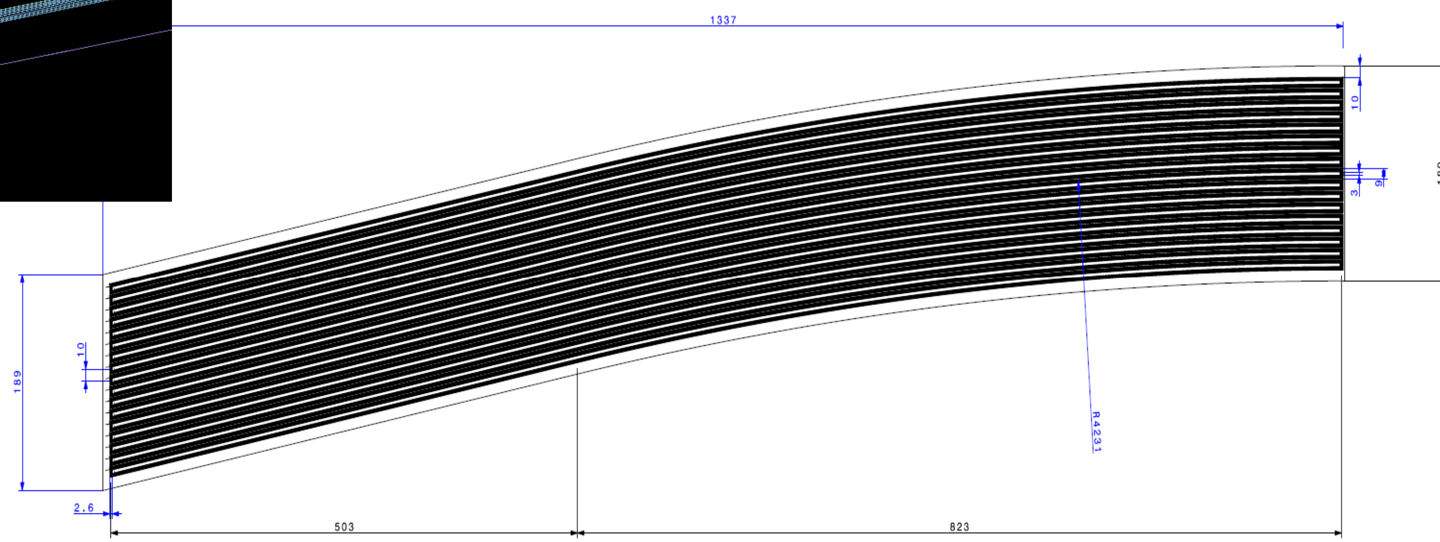
Printed Circuit Boad (PCB) for Curved Fluxmeter





Presentation by
A. Beaumont





ELENA (Extra Low Energy Antiprotons)

2.1 Bending magnet 0.36[T]

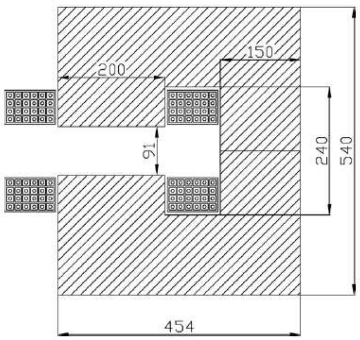


Fig 2. Bending magnet cross-section

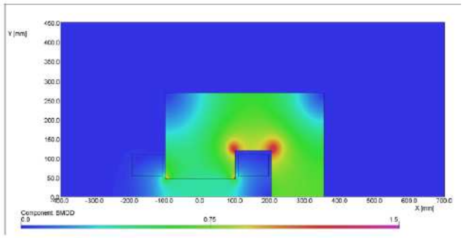
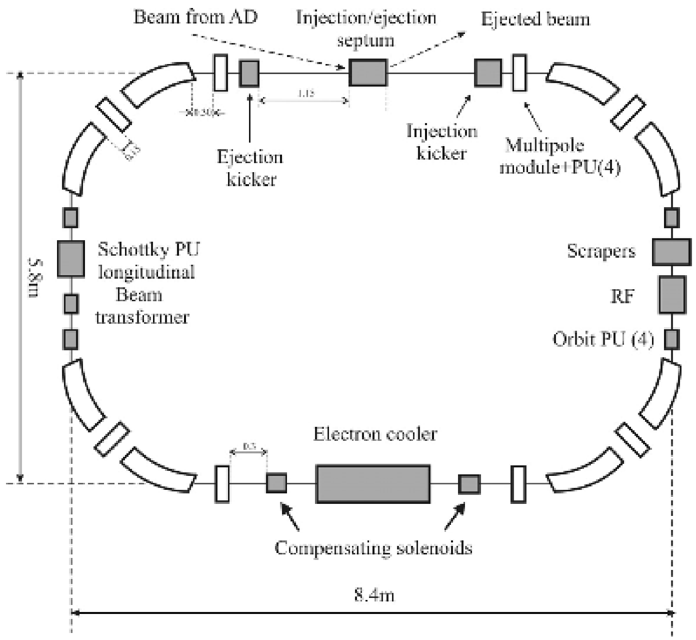
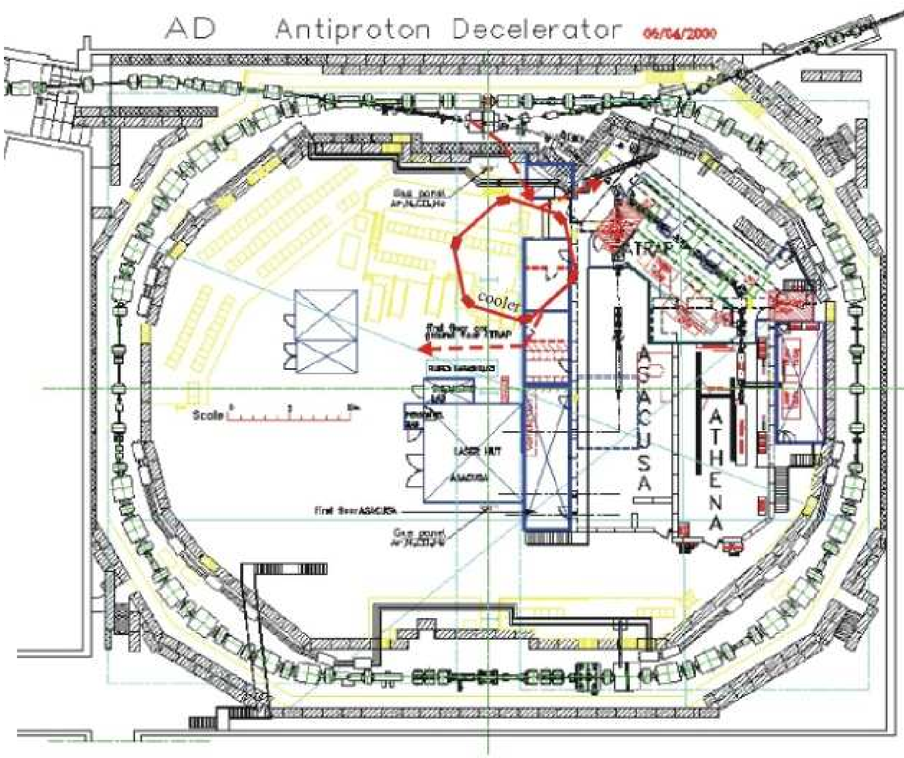


Fig 3. Bending magnet OPERA 2D model view

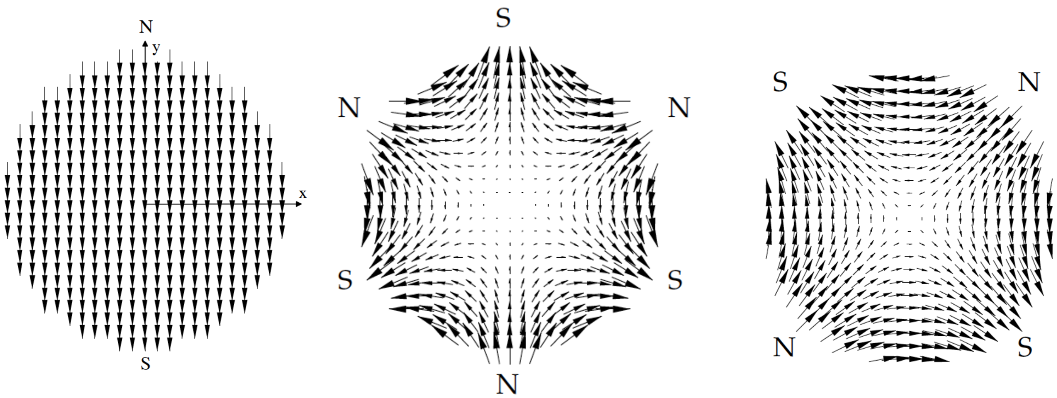




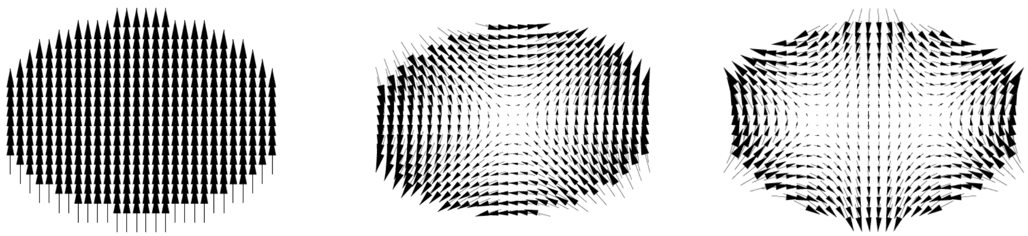
Upgrade to the Antiproton Decelerator (AD) to 100 keV (now 5.3 MeV) to serve

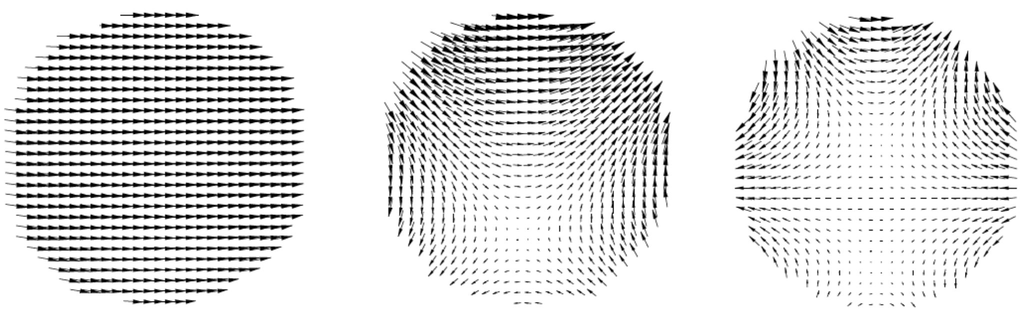
Serves several experiments (ASACUSA, ALPHA, AEGIS, PAX)

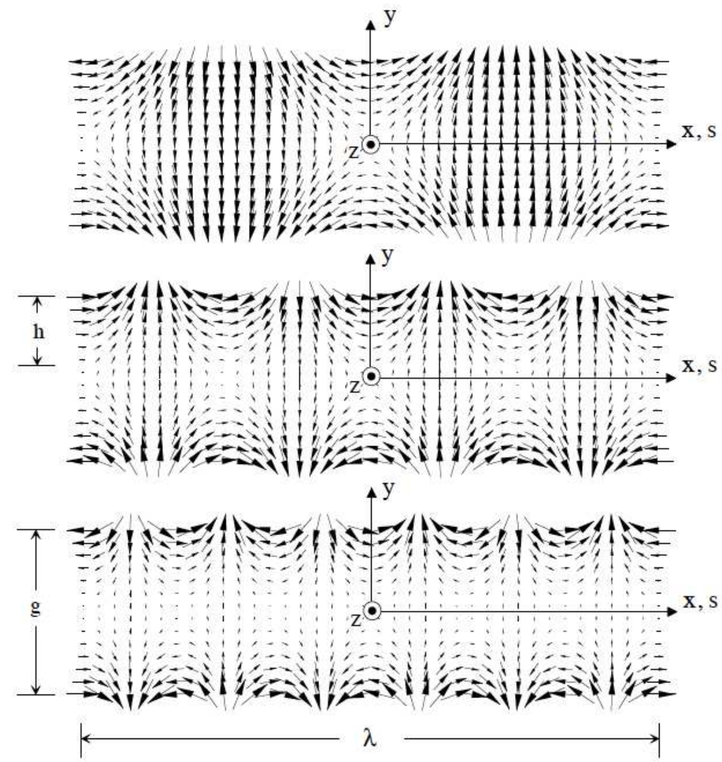
Eigensolutions in Circular, Elliptic, Bipolar, Cartesian Coordinates



Elliptic: Wide aperture





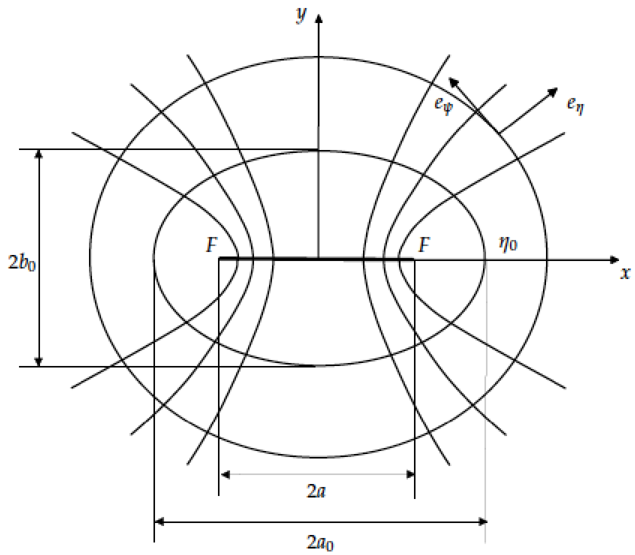


Cartesian: Wiggler

Bipolar: 2d approximation of curved magnets

What if we Develop the Differential Form ?

$$B_\eta(\eta,\psi) = \frac{1}{h_2}\sum_{n=1}^{\infty}(n\,\mathcal{A}_n \sinh n\eta \cos n\psi - n\,\mathcal{B}_n \cosh n\eta \sin n\psi)$$



$$B_\eta(\eta_0,\psi) = \sum_{n=1}^{\infty}(B_n(\eta_0)\sin n\psi + A_n(\eta_0)\cos n\psi),$$

$$B_\eta = \frac{1}{h_2}\frac{\partial A_z}{\partial \psi} = \frac{1}{a\sqrt{\cosh^2\eta - \cos^2\psi}}\frac{\partial A_z}{\partial \psi}$$

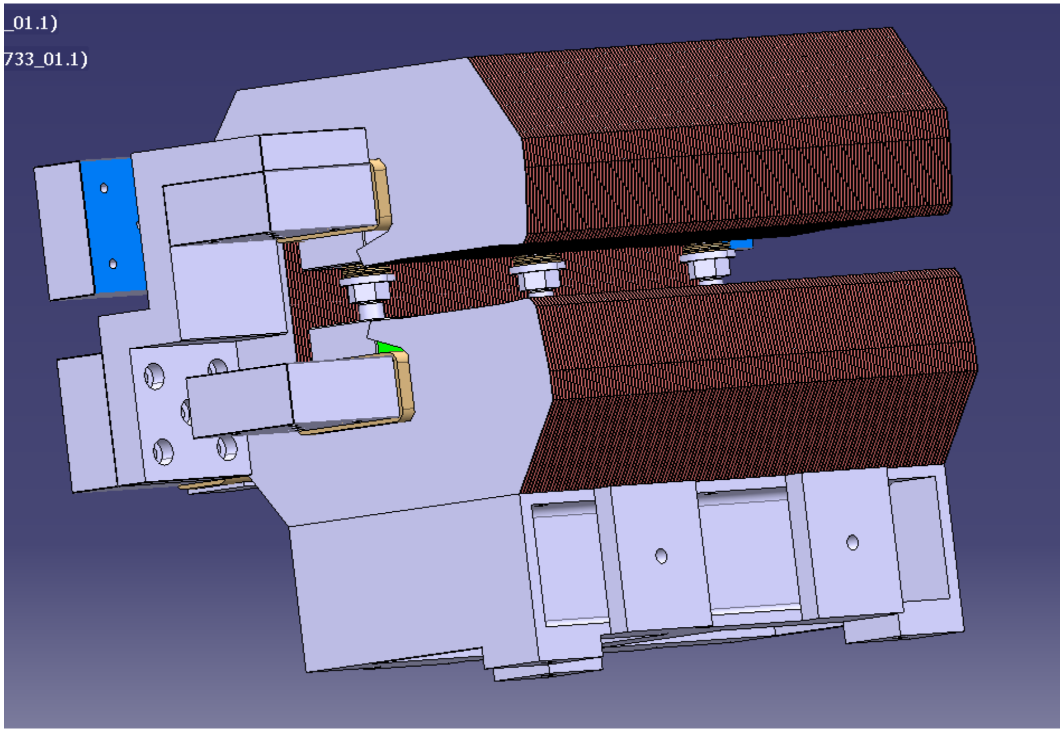
$$\tilde{B}_\eta = \frac{\partial A_z}{\partial \psi}$$

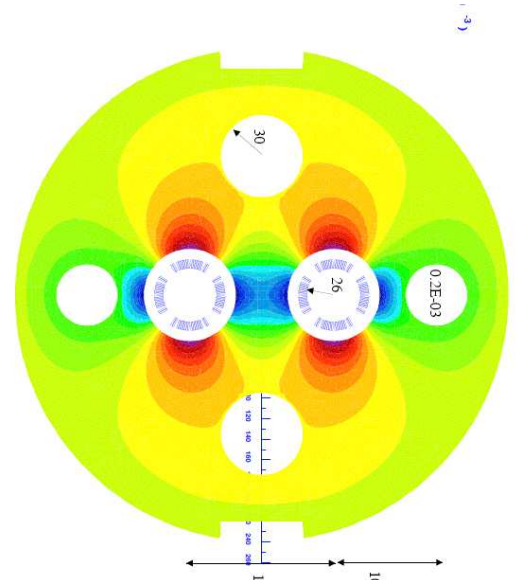
$$B_\eta(\eta,\psi) = \frac{1}{h_2}\sum_{n=1}^{\infty}\left(\tilde{B}_n(\eta_0)\frac{\cosh n\eta}{\cosh n\eta_0}\sin n\psi + \tilde{A}_n(\eta_0)\frac{\sinh n\eta}{\sinh n\eta_0}\cos n\psi\right)$$

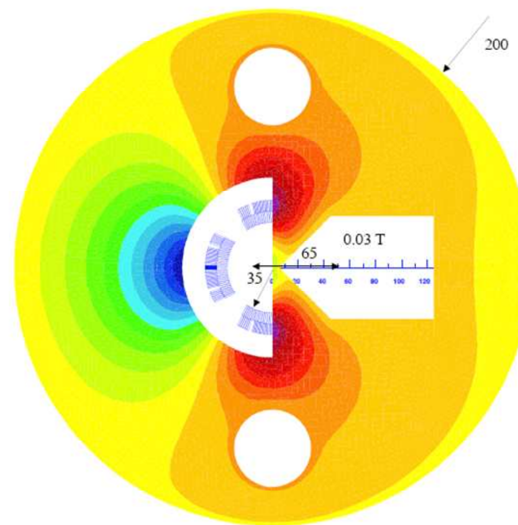
LHeC

Technology Department

Inner triplet quadrupoles







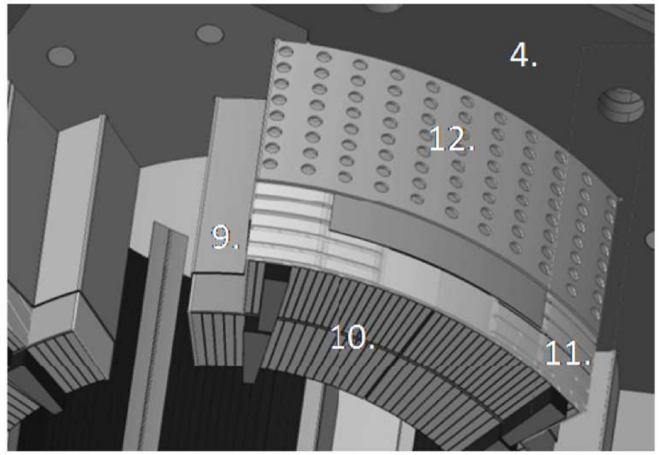
Ring-Ring and Linac-Ring Options
CDR issued

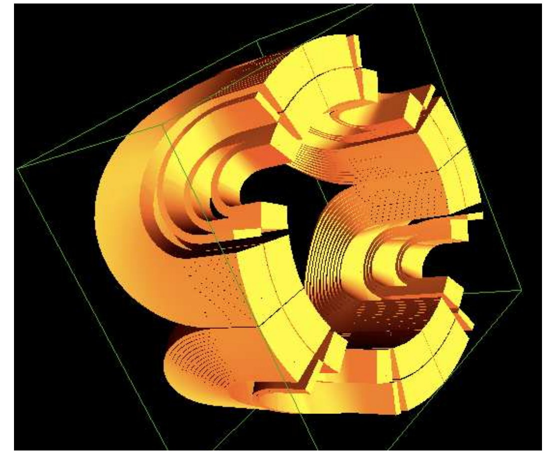
Prototype magnets with three different materials for the yoke laminations measured

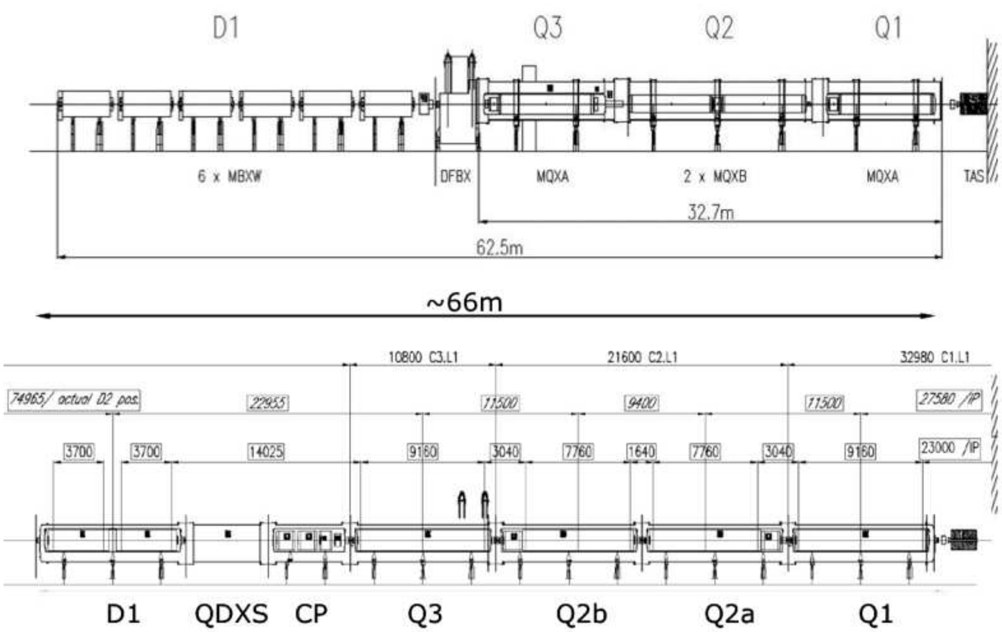
Wide Aperture Insertion Quadrupole in Nb-Ti

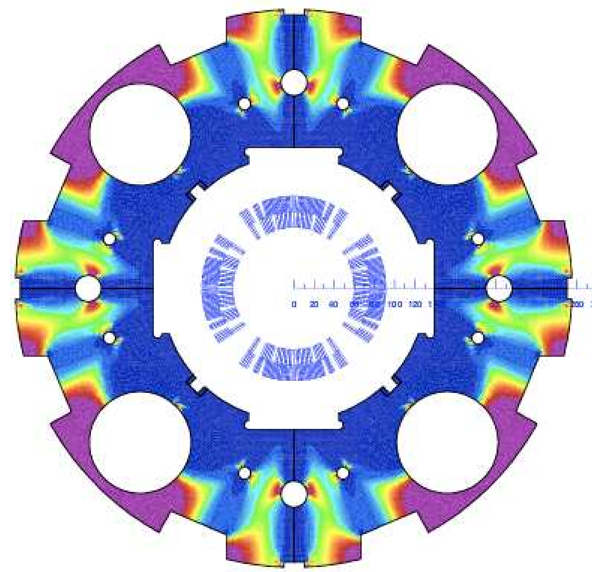
Presently: beta* = 55 cm,
Aperture 70 mm

Phase 1: 40-50 cm, 120 mm

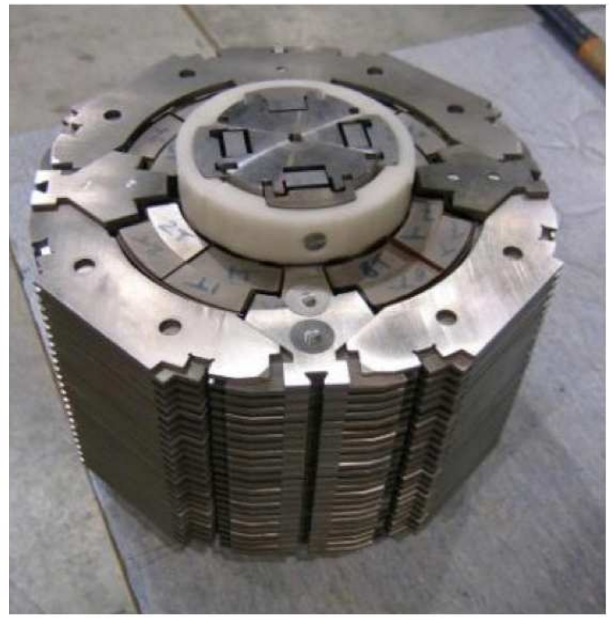








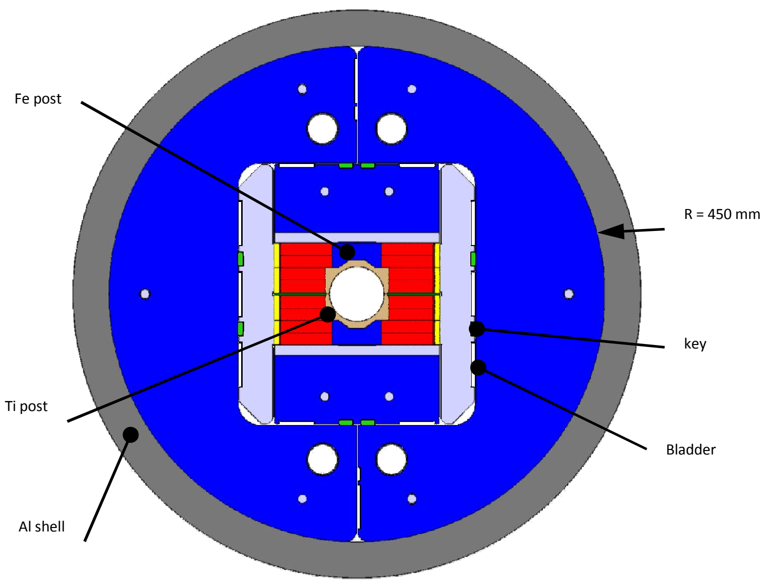
Wide Aperture Insertion Quadrupole in Nb-Ti

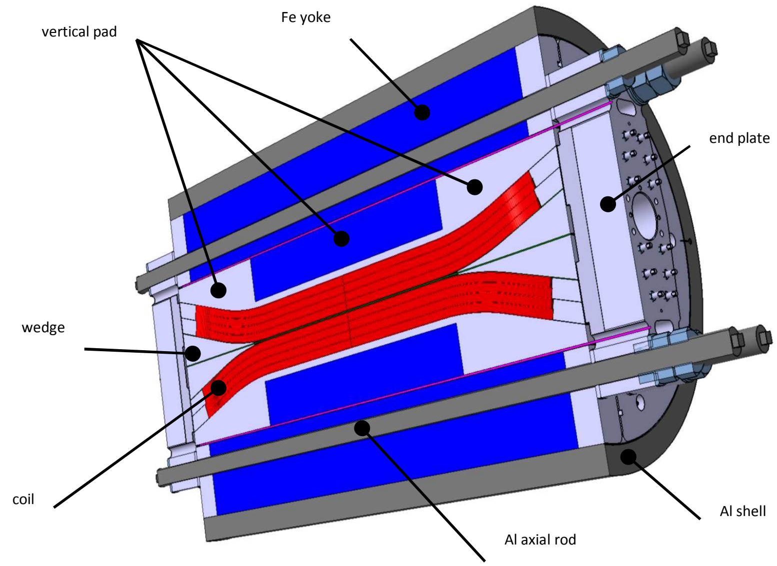


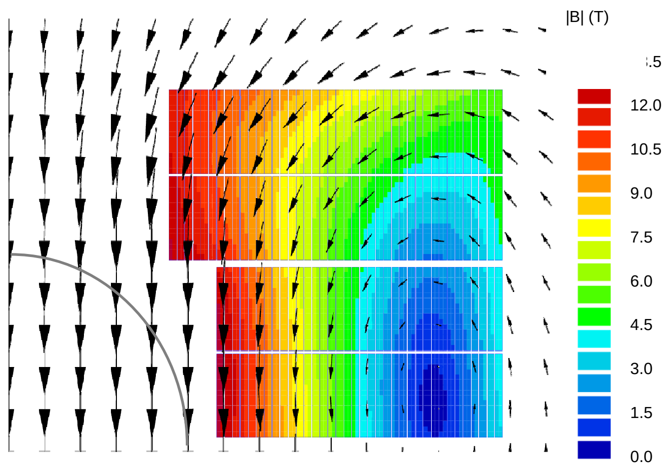
To be measured in vertical cryostat by summer 2012.

Material for large rotating coil ordered.

Design of the EuCARD High Field Model Dipole Magnet FRESCA2







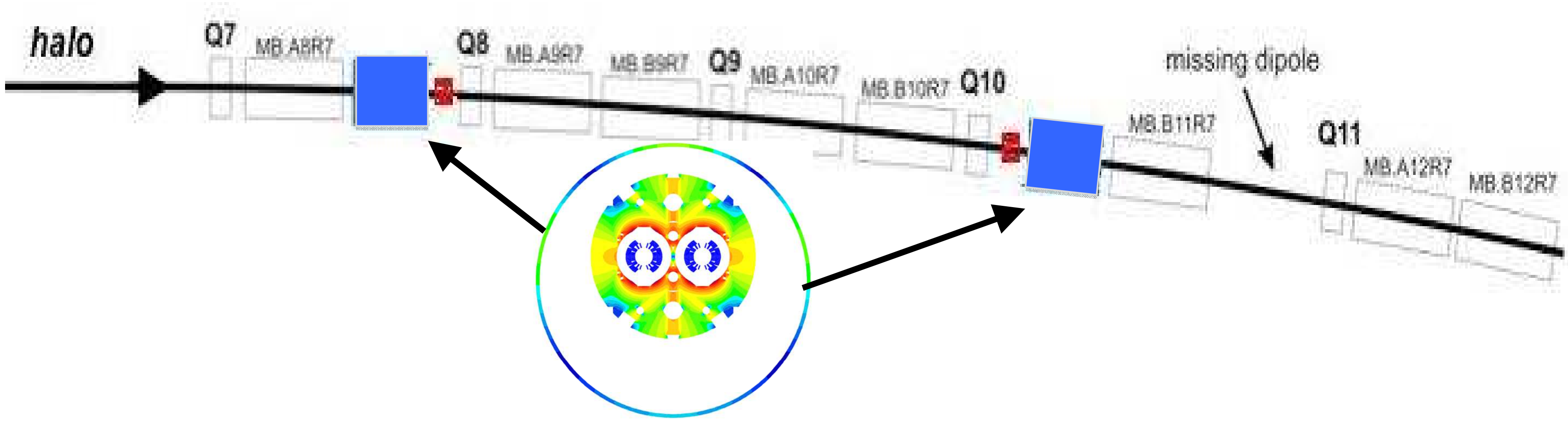
European Coordination for Accelerator Research – High field superconducting magnets

Coil field of 13 T, 100 mm aperture

To be used in the Cable Test Facility at CERN
Field quality not an issue
Accelerator quality magnet?

LHC Upgrade: 11 T Dispersion Suppressor Dipole

New ~3.5..4 m shorter Nb_3Sn Dipoles (2 per DS)



Replace an MB with a strong Nb3Sn dipole to accommodate the Cryo-collimator (L ≈ 3 m):

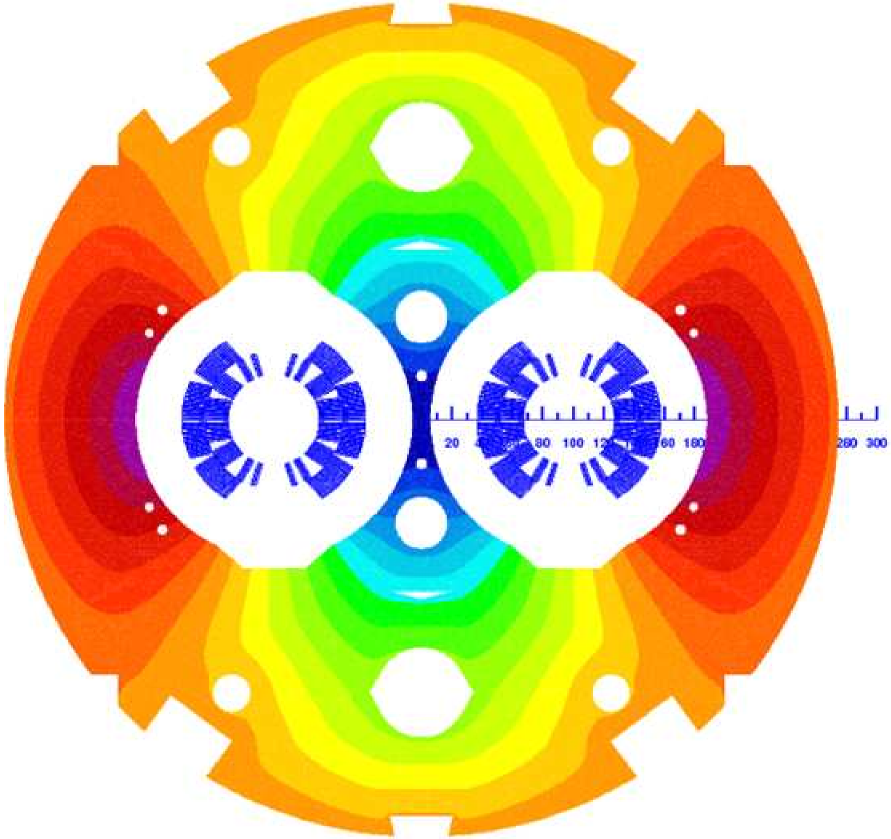
➔1 x (11.2 T x 10.6 m) magnet, $L_{coldmass}$ ≈ 11 m, **(MB -4.2 m)**

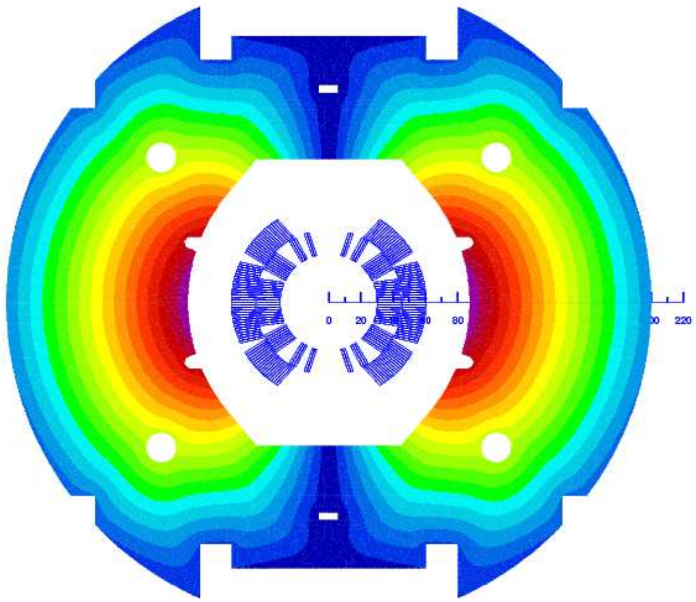
=> 8 coldmass + 2 spares = 10 CM by 2017

➔2 x (11.2 T x 5.3 m) magnets, $L_{coldmass}$ ≈ 11.5 m, **(MB -3.7 m)**

=> 16 coldmass + 4 spares = 20 CM by 2017

2-in-1 & 1-in-1 Models





B_0(11.85 kA) = 10.86 T

B_0(11.85 kA) = 11.21 T

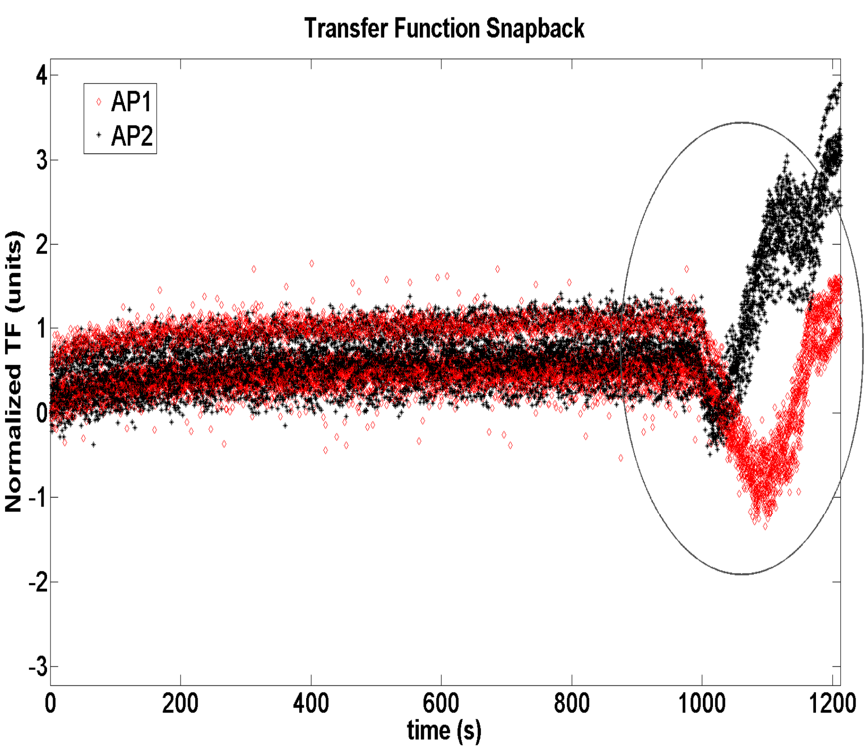
To be measured in 2012. Dynamic effects, quench antenna

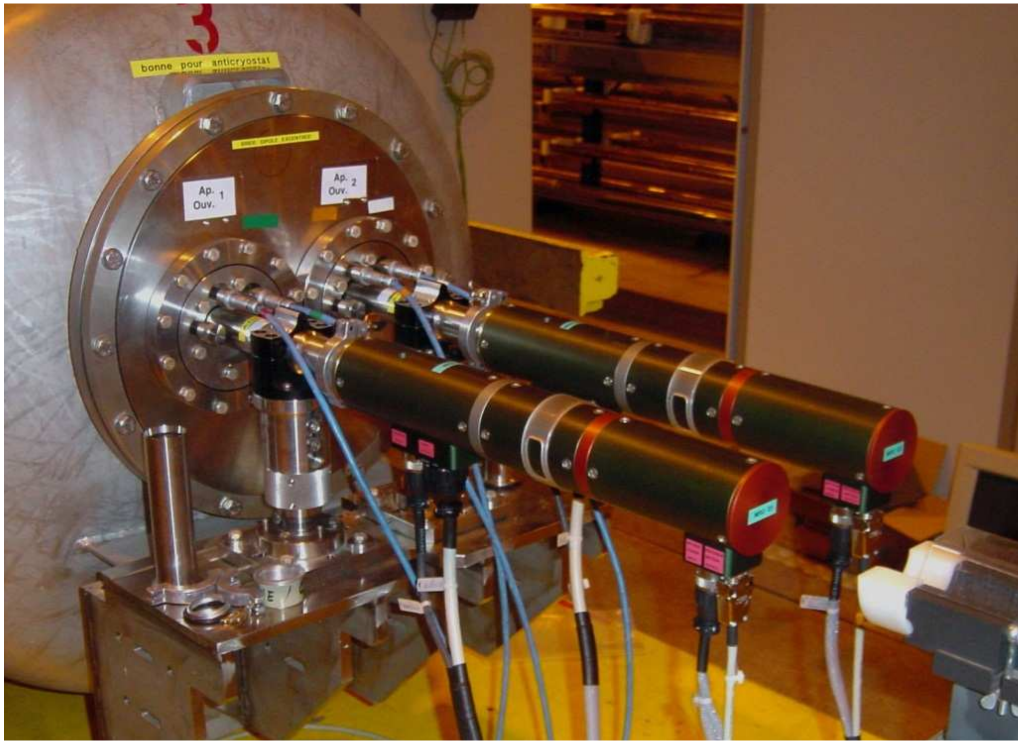
Tracking Test on LHC Main Dipoles

Verify the whole chain: Measurements => FiDeL => LSA
Address non perfect b3 compensation by MCS corrector

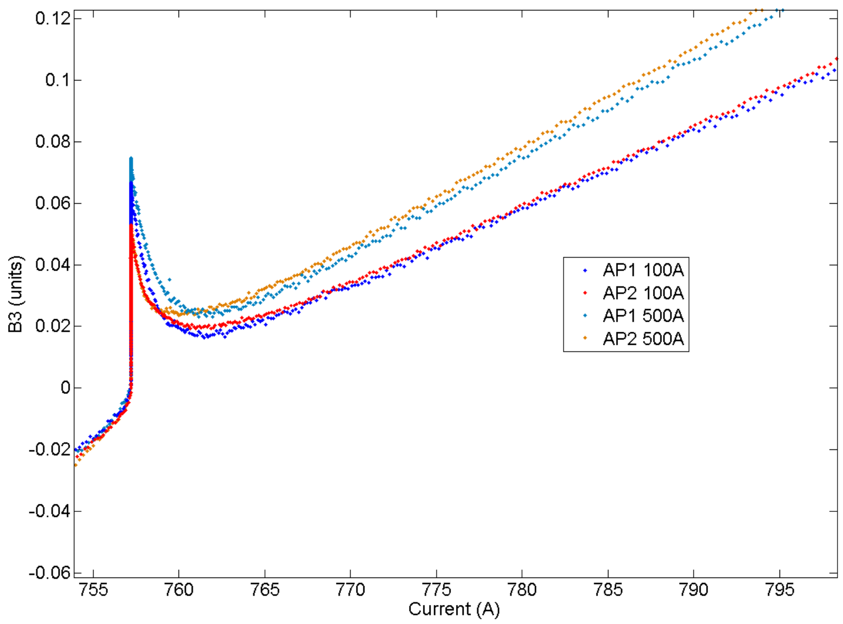
FDI (Fast Digital Integrator, Presentation by L. Fiscarelli)
MRU (Micro Rotating Unit) and shaft with 8 turns / second

The shaft is currently used for the vertical cryostat and to drive the CLIC rotating shaft

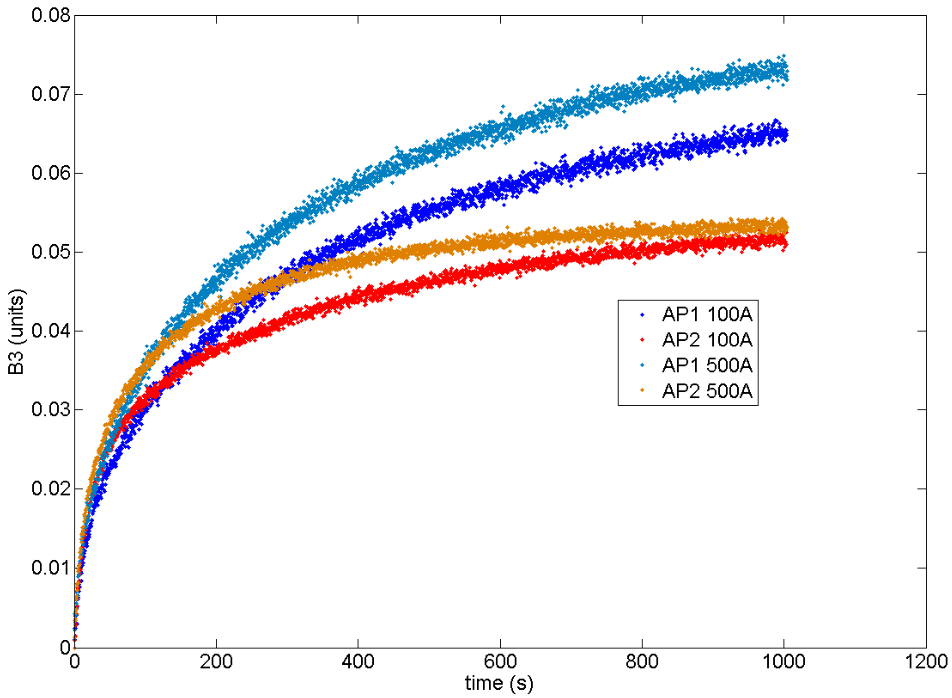




Resolution on Decay and Snapback Measurements



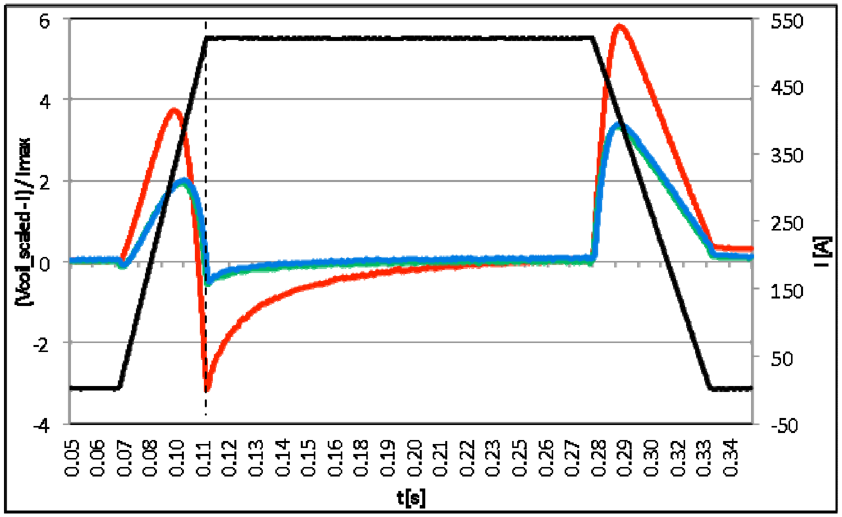
About 5 Points / second



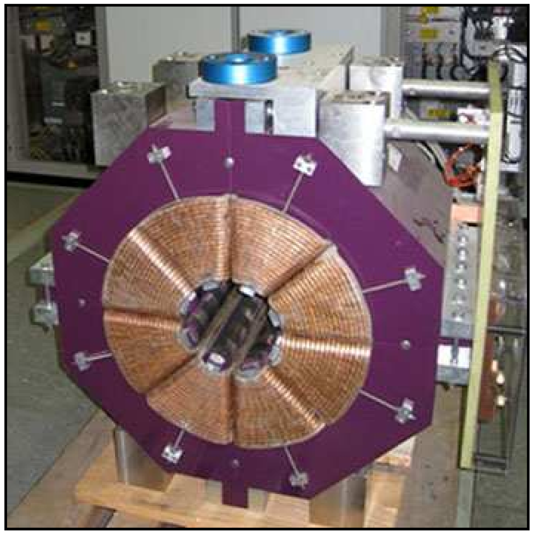
Saturation dependent eddy currents

PS-Booster dipoles at higher field levels

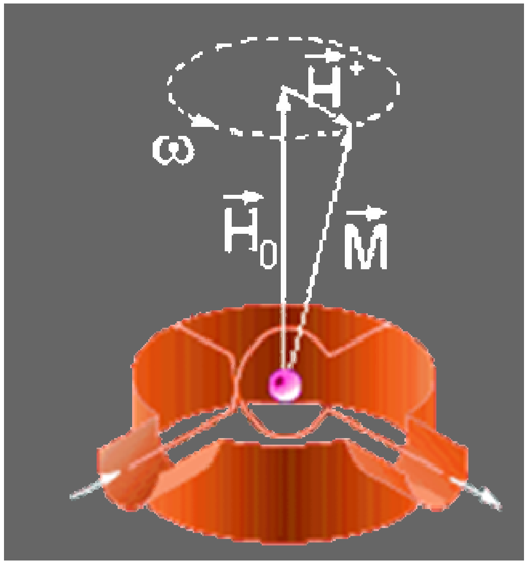
Presentation by R. Chritin

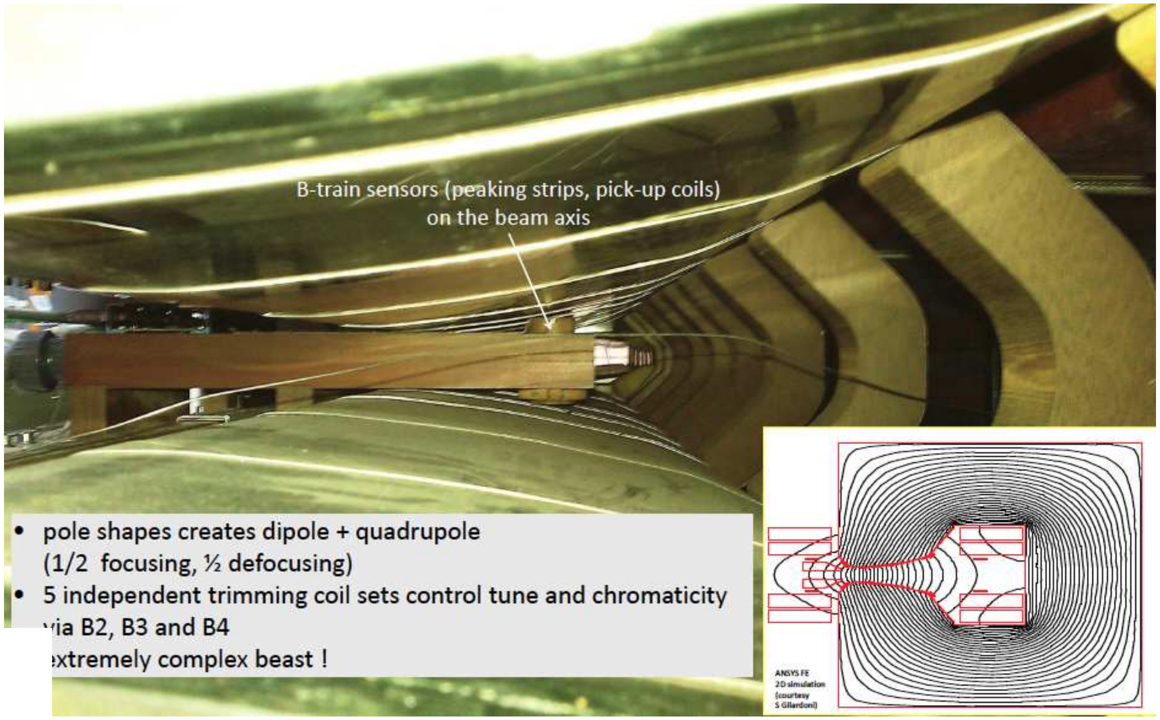


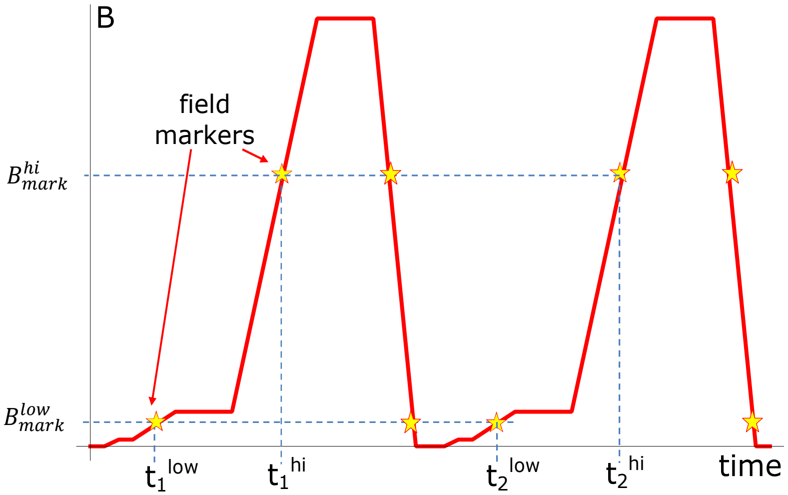
Remark: The calculation of these end-effects are at the forefront of numerical field-computation



PS- Multiturn extraction







Challenge: Marker to work at low and High field, low and high dB/dt

See Presentation by M. Buzio

Conclusion

- We have interesting and diverse projects for magnetic field measurements
  - Curved magnets (both NC and SC)
  - Fast ramping (both NC and SC)
  - Small and large apertures
  - Very high field magnets (dynamic effects and quench propagation)
- Application of diverse and sophisticated measurement techniques
  - Fast rotating probes, fast integrators
  - PCB technology shafts and fluxmeters
  - Software framework for data acquisition
- Hopefully we will have (be given) enough time for the development and testing of these new tools and methods, and for thorough analysis of the magnet performance
  - No need for large series measurements
  - However, not the amount of resources
- We intend to strengthen the link between simulations and measurements