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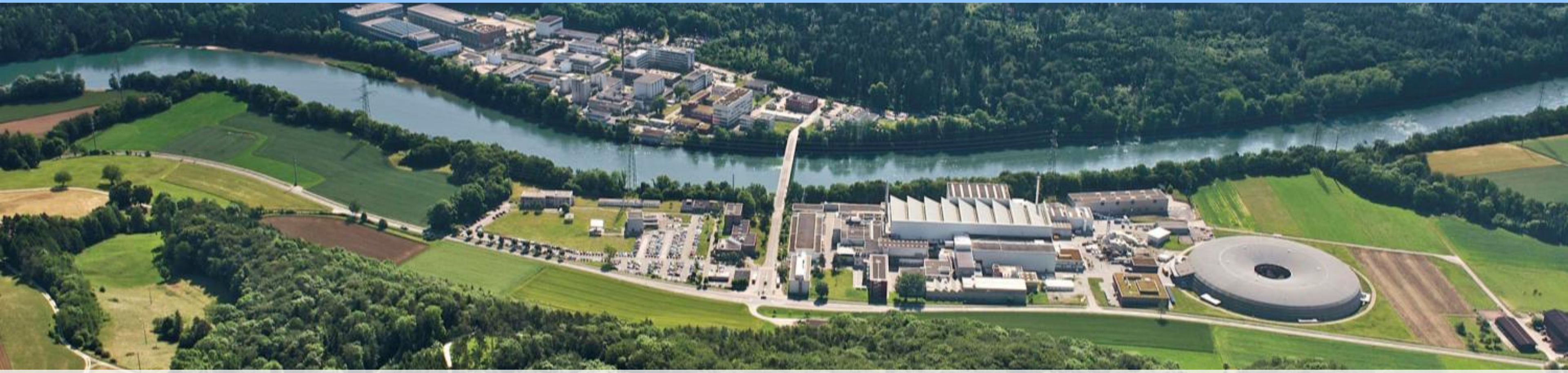


Wir schaffen Wissen – heute für morgen

Overview and challenges of the magnet activities at the Paul Scherrer Institut

Stéphane Sanfilippo on behalf the PSI magnet section

M. Buzio, O. Dunkel & L. Walckiers (CERN)

Overview

Overview of the PSI accelerators and next projects

Magnetic measurement systems: Recent developments

Spare magnet program

Challenges for the measurements of the SwissFEL magnets

- Accurate measurements of small aperture quadrupoles
- Integrated H/V steering dipoles in a common yoke
- Stability of the magnetic axis du to thermal effects

Flux-meter to measure the CCL of the ITER torroidal coils

Summary and challenges (2013-2014)

Three existing top class accelerators at PSI

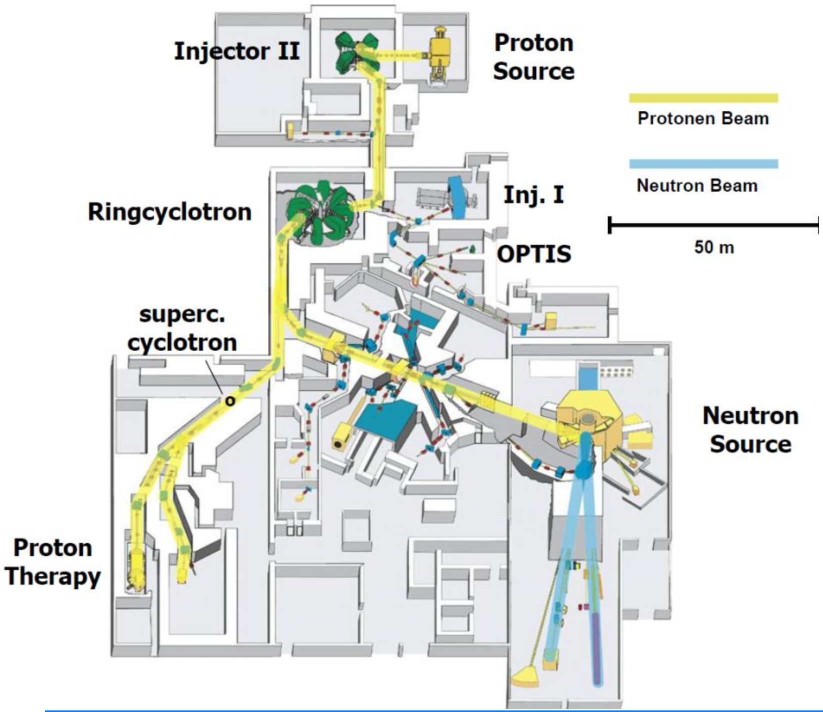
Ring-Cyclotron
590 MeV Protons

1.3 MW average beam power
(world record!)

most intense
Muon Beams
$5 \cdot 10^8\ \mu^+/s$, $10^8\ \mu^-/s$

Spallation-Neutron-Source
10^{14} n/s

corresponds to

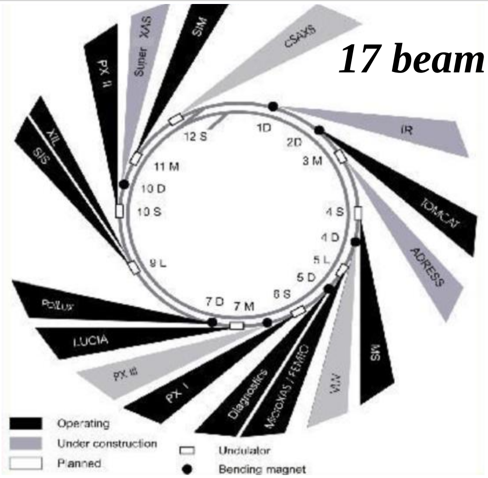


superconducting Cyclotron
250 MeV Protons
for Tumour Therapy

Eye Tumours

deeply seated Tumours
2 rotating Gantries
3D-Spot Scanning

Swiss Light Source (SLS)
2.4 GeV Electron Storage Ring



17 beam lines in operation

Next project (1): Swiss Free Electron laser

Two FEL Beamlines:

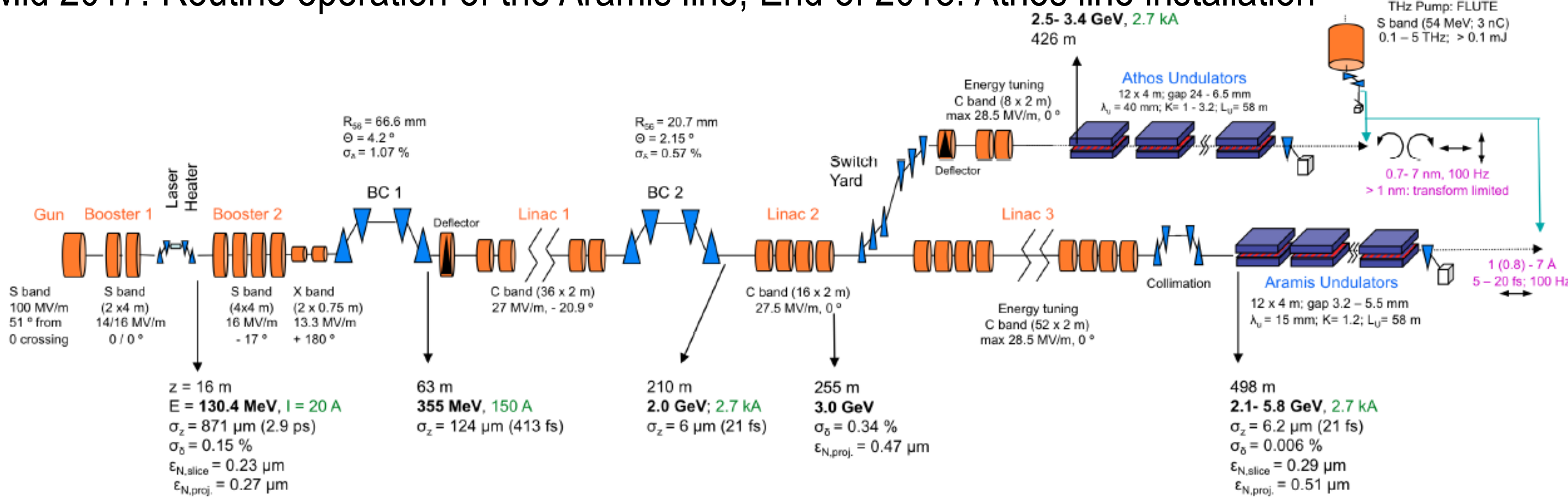
- Hard X-ray Beamline Aramis: SASE FEL (1 – 7 Å), tuning mostly by energy
- Soft X-ray Beamline Athos: SASE FEL (7 – 70 Å), seeded FEL (10 – 70 Å), tuning by gap and energy

One injector , two bunch compressor chicanes, three linacs for a beam energy up to 3.4 GeV

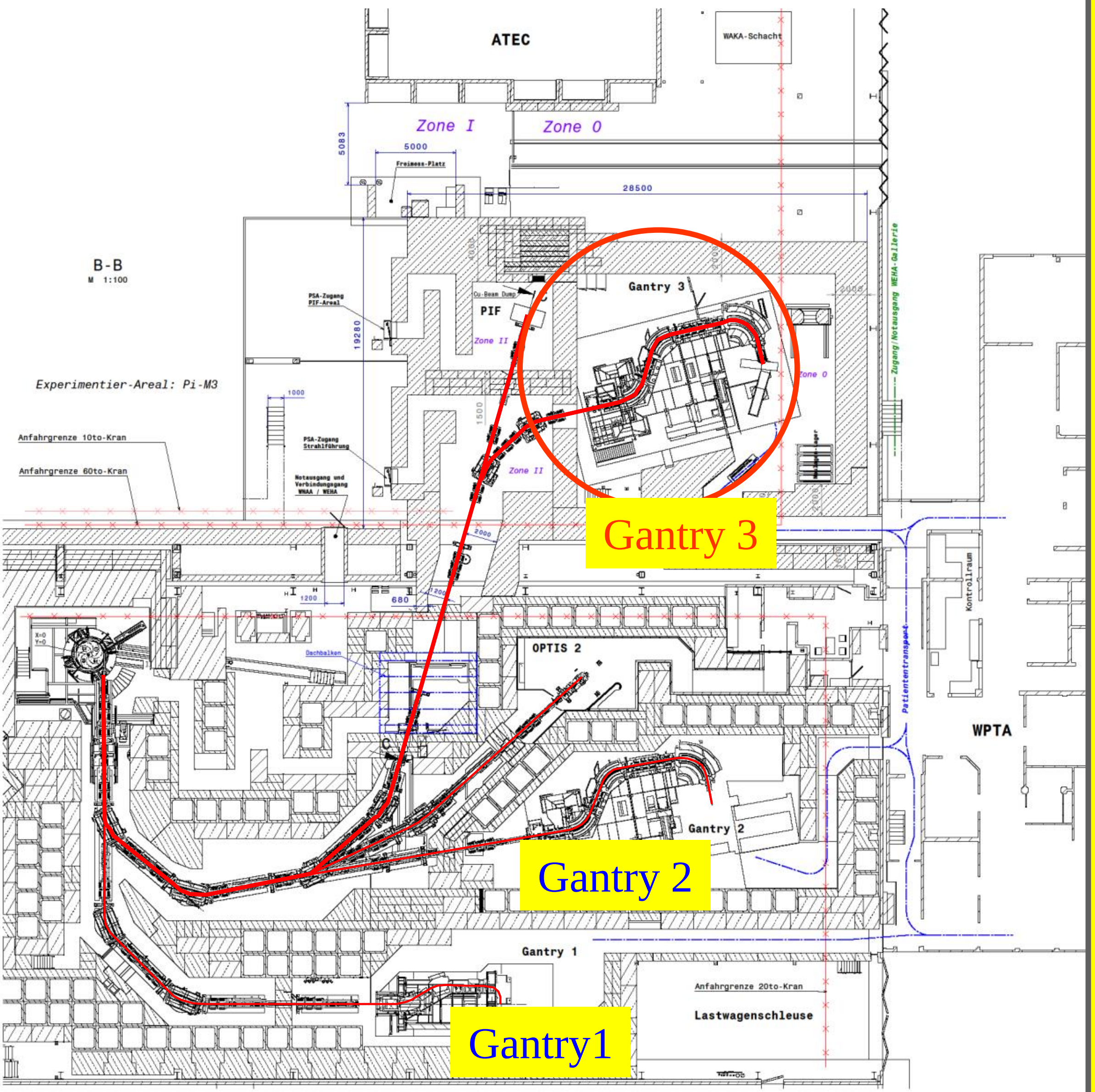
- Aramis line (2016) : 12 x 4 m long, variable gap 3.2-5.5 mm, λ_u=15 mm, K=1.2 undulators
- Athos line (2018) : 12 x 4 m long, variable gap 2.4-6.5 mm, λ_u=40 mm, K=1-3.2 undulators

Status and Milestones

- Project granted by the government (2012)
- Injector and booster test facility (250 MeV) in operation; Facility will be moved to SwissFEL in 2015
- End 2014: Building ready; Magnet installation planed from beginning 2015
- Mid 2017: Routine operation of the Aramis line; End of 2018: Athos line installation



Next project (2): PROSCAN+/Gantry 3



Design & implementation of an additional beam line (250 MeV) + Gantry magnet (part of the PROSCAN Facility)

- 23 Quadrupoles (3 types)
- 4 dipoles (2 types)
- 2 sextupoles
- 2 solenoids
- 4 steering magnets

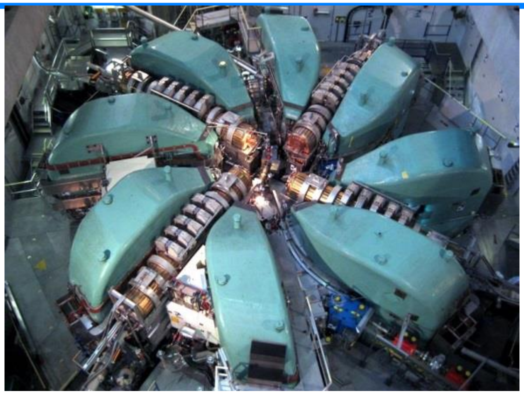
to be designed, procured and tested

- Design close to Proscan /Gantry 2 magnets
- Gantry 3 Magnet designed and procured by industry with the PSI support
- Operation start : Mid 2015

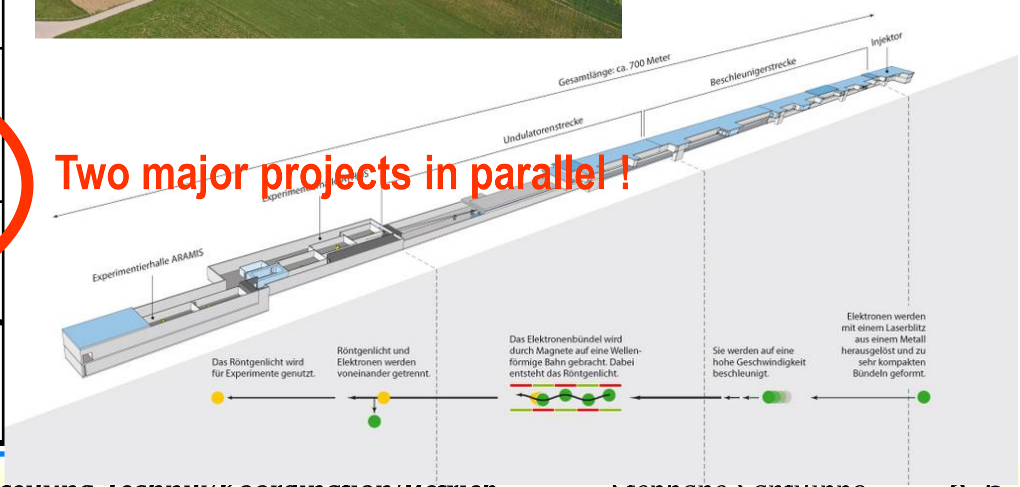
Magnets in Operation at PSI in 2017

Magnets in Operation at PSI

Machine	*Number of magnets*	*In operation since*
HIPA	300	1974 (Ring) 1984 (Inj. II) 1996 (SINQ)
SLS	350	2001
PROSCAN	100	2004
PROSCAN PLUS	*40*	*2015*
SwissFEL	*300*	*2017*
Total	*1000*	



Two major projects in parallel !



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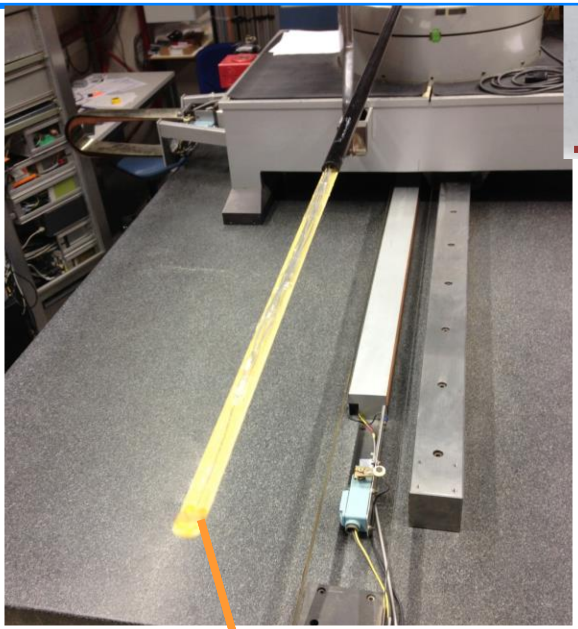
Magnetic measurement systems

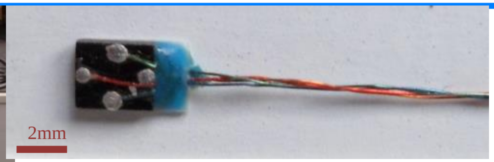
(Status May 2013)

Measurement equipments

Equipment	Unit	Aim	Status	Comments
Hall probe systems: -1 siemens probe -3 AREPOC probes	2	integral and local field in dipoles cross calibration of the GdI	second system operational since 2012	The second system will be used to cross-check the field integral of quads
3D Ga/As Hall probe	1	Accurate (0.01%) measurement of B_x, B_y, B_z	In construction Operational in 2014	PSI/ ETHZ/ EMPA METROLAB collaboration
∅ 45 mm rotating mole test bench	1	integral field gradient, harmonics and axis in large aperture quadrupoles	System operational	CERN / PSI collaboration
∅ 19 mm rotating mole test bench	1	integral field gradient, harmonics and axis in 19 mm aperture quadrupoles (linac)	System operational since 2012	CERN / PSI collaboration
∅ 8 mm rotating mole test bench	1	integral field gradient, harmonics and axis in 12 mm apertures quadrupoles	System operational since 2012	CERN / PSI collaboration
Vibrating Wire (+ FARO ARM)	1	magnetic axis of quadrupoles	System operational	Developed at PSI
Moving & Rotating Wire	1	Measurements & cross calibration of the GdI + harmonics	System fully operational end 2013	Only GdI for the moment
PCB AC Fluxmeter (+ laser tracker)	1	Magnetic determination of the CCL of the large wing packs	In construction Operational in 2014	PSI/ CERN /ITER collaboration

Hall probe bench for small apert. Quads *(V. Vrankovic, R. Deckardt)*

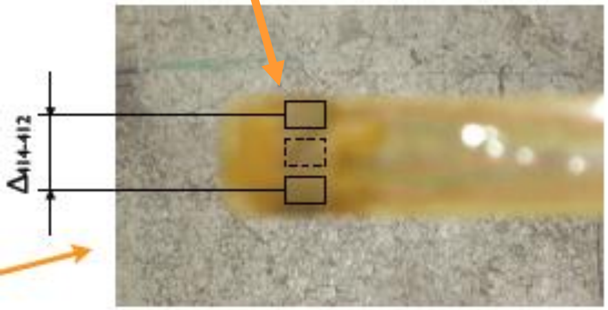




LHP Mu Probe
Active area : 0.01 mm²

AREPOC Probes

Parameter	Unit	Value
Magnetic field range	[T]	0 - 33
Temperature range	[K]	1.5 - 350
Nominal control current I_n	[mA]	20
Maximum control current	[mA]	50
Sensitivity at I_n	[mV/T]	> 5
Linearity error at 300 K, B = 0 - 1 T	[%]	< 0.2
Linearity error at 77 K, B = 0 - 0.2 T	[%]	< 0.1
Linearity error at 4.2 K, B = 0 - 5 T	[%]	< 1
Mean temp. coefficient of sensitivity at temperature range 4.2 - 77 K	[K^{-1}]	2.10^{-5}
Mean temp. coefficient of sensitivity at temperature range 77 - 300 K	[K^{-1}]	3.10^{-5}
Residual voltage	[μV]	< 100
Temperature coefficient of residual voltage	[μV/K]	< 0.02
Input resistance at 4,2 K (in zero field, including leads)	[Ω]	1.8
Input resistance at 77 K (in zero field, including leads)	[Ω]	2.2
Input resistance at 300 K (in zero field, including leads)	[Ω]	4
Output resistance at 4,2 K (in zero field, including leads)	[Ω]	1.9
Output resistance at 77 K (in zero field, including leads)	[Ω]	2.6
Output resistance at 300 K (in zero field, including leads)	[Ω]	6
Quantum oscillations beginning at 4.2 K	[T]	> 2
Amplitude of quantum oscillations at 4.2 K, B = 0 - 5 T	[%]	< 0.1
Active area	[mm²]	0.01
Control current leads (green, black)	[mm]	∅ 0.1
Hall voltage leads (orange, red)	[mm]	∅ 0.08



Arepoc Hall probes 412-413-414
CONSTANT $\Delta_{414-412}$ = 6.294±0.030 mm

Three AREPOC hall Probes (2 used for the moment)

- Compact system for the 12 mm aperture
- Mounted to measure the same field component
- Calibrated at PSI (for I_{Probe}=20 mA, S~11mV/T,V_{offset}~8 μV)
- Direct measurement of the field gradient
- Longitudinal magnetic field homogeneity

Field gradient, field homogeneity and longitudinal profile of the small aperture quadrupoles

The system is operational since Autumn 2012

3 D HallCube project

Motivation : novel Hall sensor for highly accurate (~0.01%) 3D magnetic field measurements

CTI funded PhD project

PHD STUDENT: C. Wouters (PSI)

PHD SUPERVISOR: Prof. Dr. C. Hierold (ETHZ)
LEAD RESEARCH PARTNER: Prof. Dr. J. Gobrecht (PSI)
MENTOR: V. Vranković (PSI)
PROJECT MANAGER: Dr. S. Sanfilippo

Prof. Dr. K. Ensslin (ETHZ)
Prof. Dr. W. Wegscheider (ETHZ)
Dr. P. Reimann (Universität Basel)
Dr. K. Jefimovs (EMPA)

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

UNI BASEL

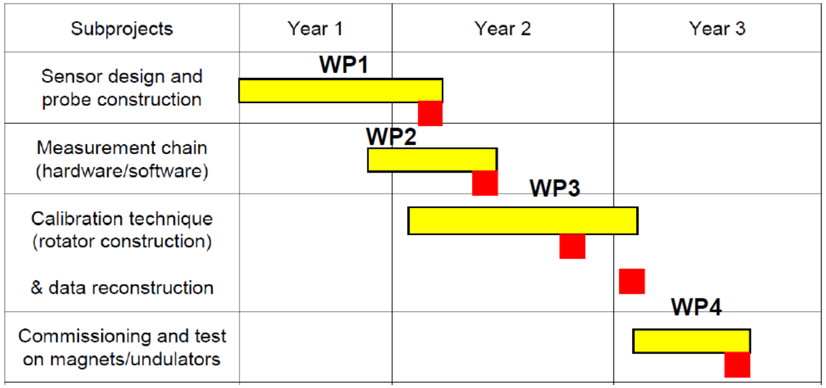
PAUL SCHERRER INSTITUT PSI

EMPA

Metrolab

Presentation of C. Wouters

Time schedule :2012-2014



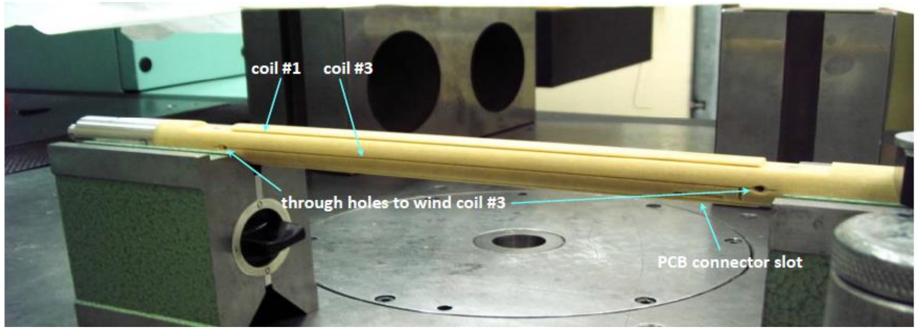
Parameters

- Sensitivity : >20 mV / T for I=10 mA;
- Accuracy : 0.01% (on the axis),0.1% in any field direction
- DC Resolution (at 1 T) : 50 μT
- Field SensitiveVolume (inner cube volume)< 200x200x200*μm^3
- Target field range up to 1.5 -2 T;
- Non linearity at high magnetic field <0.2%
- Temperature dependence of the sensitivity< 0.02 %K^{-1}

System operational in 2014

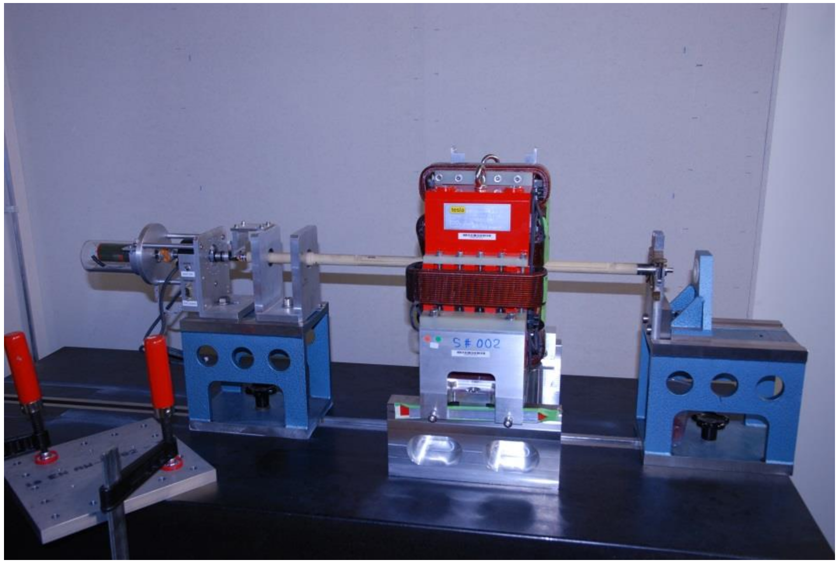
Ø 19 mm CERN Rotating coil (PSI/CERN collaboration)

CERN"linac 4" coil (second generation)



Target performance

Ø 19 mm coil	Field gradient	Multipoles
Accuracy	0.1%	
Reproducibility	<0.05 %	0.02 %



3 coils to reject dipole and quadrupole components

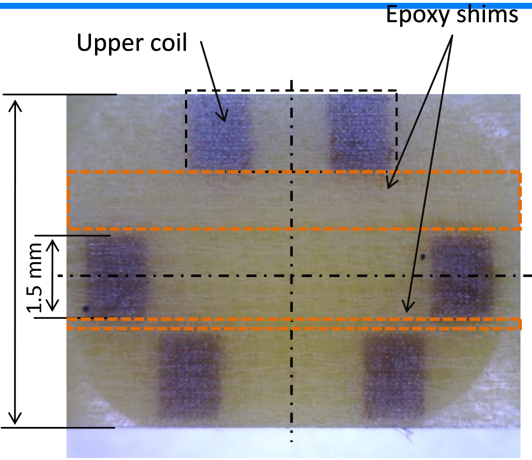
- ø19 mm x 400 mm coil head
- 3 tangential coils with b1 and b2 bucking
- Monolithic design
- Higher sensitivity (multiwire flat cable)

M. Buzio et al. "Calibration and performance of the rotating coil system for CERN Linac4", IMMW18

Goals: Measure the harmonics and the field gradient of the 22 mm aperture quadrupoles for SwissFEL linac and matching sections

System operational since April 2012

Ø 8 mm CERN Rotating coil (PSI/CERN collaboration)

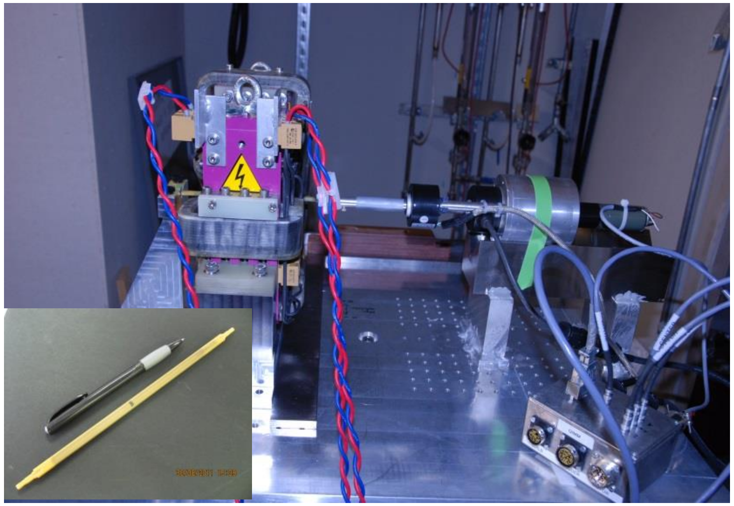


Cross section of a 3-coil-array

Coils :Monobloc PCB technology

- One coil =10 double layers+ 9 insulation pre-pregs
- 20 tracks connected in series in 1 double layer
- Copper track width: 50 µm
- Copper track thickness: 5 µm

O. Dunkel et al., IMMW17 (2011)



The shaft:

- Ø7.8 mm x 150 mm coil head
- 3 coils, 200 turns each

(b1 and b2 bucking)

- Plate coil array machined to a rotating shaft

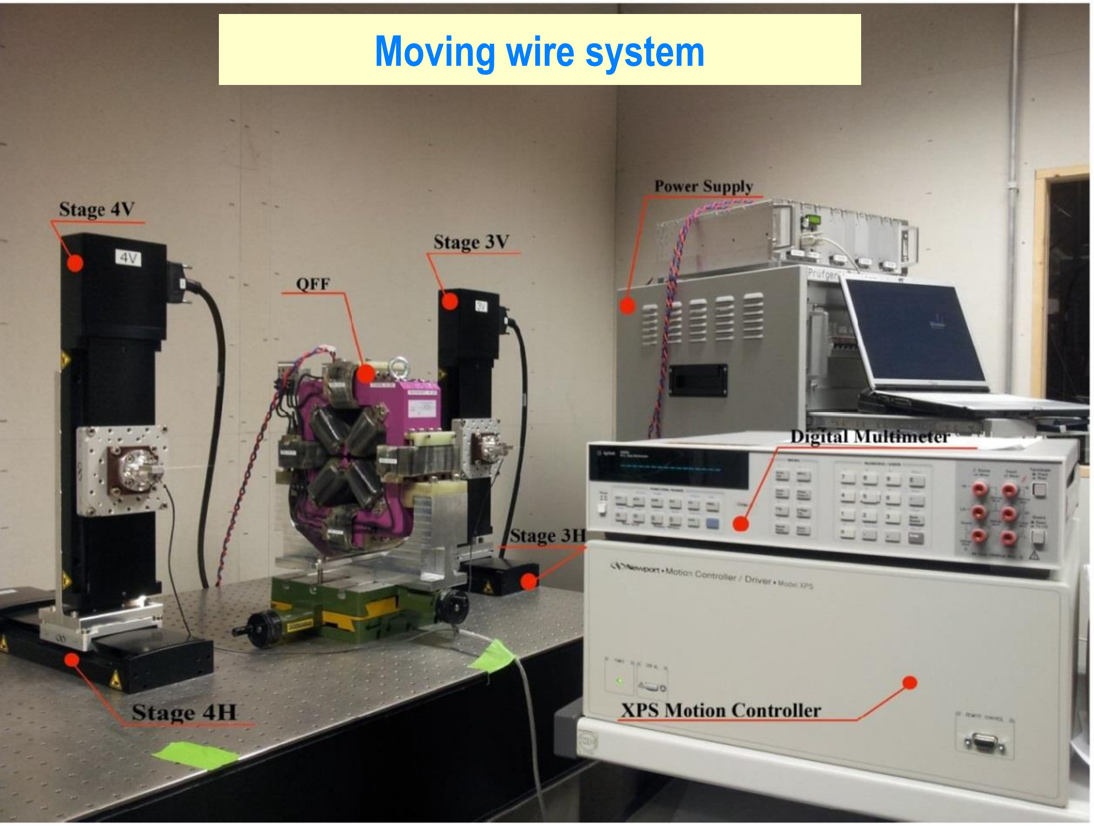
Target performance

Ø 8 mm coil	Field gradient	Multipoles
Accuracy	0.1 %	
Reproducibility	<0.05 %	<0.02 %

Goals: Measure the harmonics and the field gradient of the 12 mm aperture quadrupoles in the SwissFEL undulator lines

System operational since November 2012

Moving (rotating) wire system (V. Vrankovic, I. Gorgishyan , P.Tchesov)



System characteristics

- Longitudinal & circular trajectories
- 4 ML-ILS150 CC stages from Newport (1 μm accuracy) controlled by a Newport XPS controller
- $Cu_{98}Be_2$ wire, 1 m long
- Agilent digital Multimeter 3458A (DMM) (accuracy of 5 nV in the 0.1-1 mV meas. range)
- Communication, DMM & XPS via EPICS
- Python environment for the EPICS channel
- For every trigger, voltage reading time is 20 ms

- Longitudinal trajectories : Integrated field Gradient $$L_m.G = \frac{\Phi_H^+ + \Phi_H^-}{D^2} = \frac{\Phi_V^+ + \Phi_V^-}{D^2}$$

- Circular trajectories: Multipoles related to the FFT coefficients of induced voltages
  But no bucking of b_2 : multipoles accuracy ~1-2%

Goals: Check the field gradient and harmonic for small aperture quadrupoles

Status : Commissioning for field gradient measurements
Harmonics : Work needs to be completed with bucking of b_2 (2013?)

Spare Magnet Program

(Status May 2013)

Spare magnet program-challenges

Core activity : Reduce the down-time of the operating PSI accelerators
Maintenance, repair and spare magnet/coil program (some magnets are more than 35 years old)

- **Criticality:** Analysis of magnet failures and impact on accelerator operations based on its position, function, operation years and regular inspections
- **Radiation:** **High Radiation area :** Measuring or estimating lifetime activation; establishing which parts can be reused, and whether work can be performed on site or not

  see "Radiation Hard Magnet at the Paul Scherrer Institut",
  J. Duppich, A. Gabard, D. George, IPAC 2012
- **Spare policy (prioritizing):** Primary beam/beam for medical treatment/experiment schedules
- **Preventive v.s reactive maintenance:** compromise between costs and benefits
- **Complexity:** required amount of resources for redesign (redundancy principle for hard radiation magnets), manufacturing and **magnetic tests**
- **Documentation:** Inventory, missing quality control documents, specifications, (electronic) drawings, PSI magnet-database
- **Construction and storage :** workshop reorganization/ storage place management

Spare magnet program-Actions since 2008

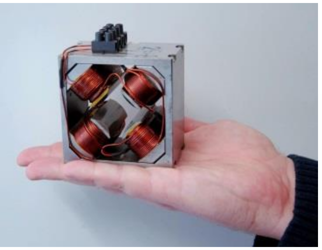
Diversity

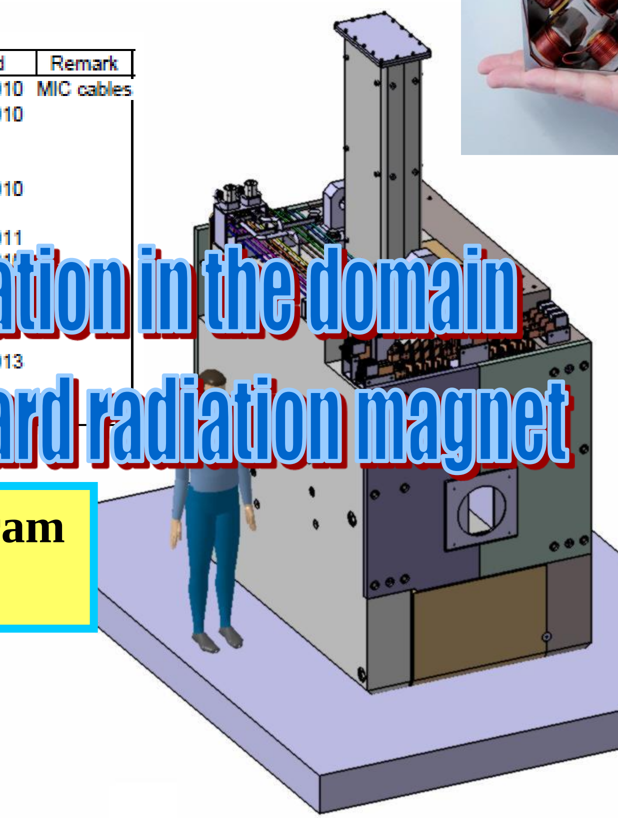
Action on 78 coils or magnets concerning all PSI accelerators and beam lines

Name	Type	coils	Magnets	Position	New design	Assembly & tests	Period	Remark
AHL	Dipole	2		SINQ	Yes	No	2007-2010	MIC cables
AHB	Dipole	4	1	Cyclotron	Yes	Yes	2008-2010	
AWA/AWB	Dipole	6		Injector cyclotron	No		2009	
WVB	Solenoid		2	CW cyclotron	No	Yes	2009	
QWB doublet	Quadrupole		1	Injector cyclotron	No	Yes	2009-2010	
AWC/AWD	Dipole	2	2	Injector cyclotron	No	Yes	2010	
AHC	Dipole		1	Cyclotron	No	Yes	2009-2011	
AWK	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ANC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WEU/WEP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
UCN Kicker	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Linac Solenoids	Solenoids	27+6		Linac SLS	Yes	Yes	2012-2013	
AHC_2	Dipole	4		Cyclotron	[illegible]	this year	[illegible]	
QSN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Call for an international collaboration in the domain of spare magnet availability and hard radiation magnet construction

Yearly average resources for the sp[illegible]ram since 2009 : 25 [illegible]





- 48 tons
- estimated 10-100 Sv/h

Magnetic measurements challenges for the SwissFEL magnets

(Status May 2013)

SwissFEL Magnets (phase 1)

Total : 319 magnets

31 dipoles 174 quadrupoles 10 solenoids 96 correctors

Dipole

SHA	1
AFL	6
AFBC2	4
AFBC3	14
AFSS	4
AFD1+2	2

Quads (+ skew)

QFA	0 + 1
QFD	128 + 3
QFM	18
QFF	24

Corr. Quads

QFCOR	2
QFC	3
QFB	3 + 3

11 corr. quads

Solenoide

WFB	1
WFG	1
WFS	8

Sextupole

HFA	13

Corrector magnets

SFB,DD	6
SFC	16
SFQFM	34
SFU	40

Green: existing magnets

Linac and beam line magnets : Status March 2013

Magnet type	Design	Prototypes	Series production	Delivery after meas.
Linac quad QFD (QFS)	**OK**	**OK (4)**	Ordered	Mid 2015
Undulator Quads QFF	**OK**	**OK (4)**		End 2014
Matching Quads QFM	**OK**	**No**	Ordered	Mid 2014
Laser Heater dipoles AFL	**OK**	**No**	Ordered	Mid 2013
BC2 dipoles AFBC3	**OK**	**No**		End 2014

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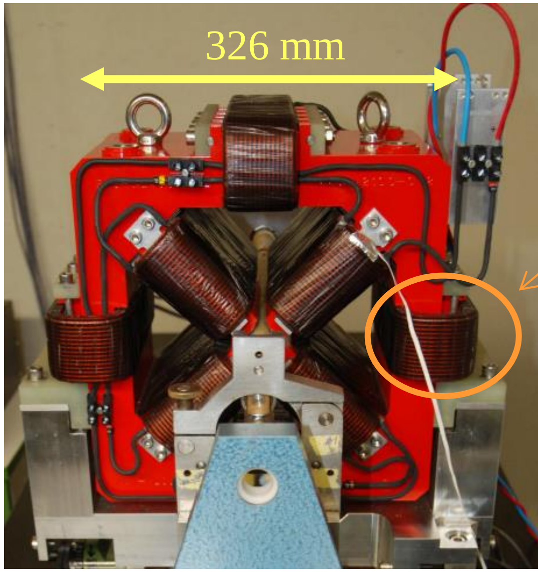
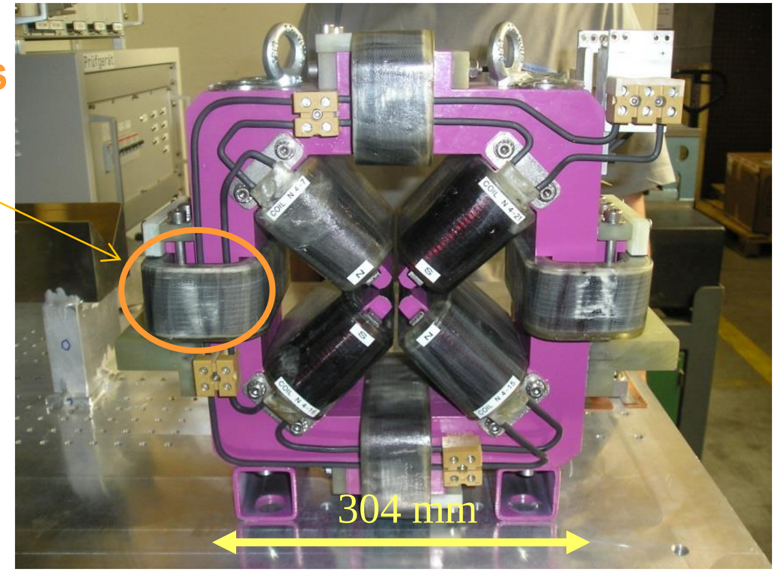
Focus : SwissFEL Linac and undulator quadrupoles

QFD (linac) : 4 prototypes



Steering dipoles

QFF (Aramis) : 4 prototypes



Aperture :22 mm
Gradient : 20 T/m
Pole Tip field : 220 mT
Max current : 10 A (air cooled)
Yoke length: 0.150 m
H/V Steering dipoles (integrated): 10 A
Steering max field : 30 mT
Size (mm), weight (kg): (326x326x204);80
Yoke laminations : 0.5 mm thick

Aperture :12 mm
Gradient : 50 T/m
Pole Tip field : 300 mT
Max current : 10 A (air cooled)
Yoke length: 0.08 m
H/V Steering dipoles (integrated): 10 A
Steering max field : 50 mT
Size (mm), weight (kg): (304x304x130);32
Yoke laminations : 0.5 mm thick

Measurement program on QFD/QFF prototypes

Goals : Check the field quality and validate the magnetic & mechanical design

Measurement type	Measurement systems
Quadrupole excitation curve	Rotating coil / Hall probe
Steerer excitation curves	Rotating coil / Hall probe
Quadrupole Harmonic measurements	Rotating coils
Steerer Harmonic measurements	Rotating coils
Quadrupole roll angle	Rotating coils/vibrating wire
Hysteresis Cyle (B vs I) & degaussing	Rotating coil / Hall probe
Magnetic axis measurements	Vibrating wire
Temperature effects on quadrupole axis	Vibrating wire
Quad. Axis displacement due to steerer hysteresis	Rotating coils

Why is it difficult to measure accurately small quadrupoles?

- The classical problems with the rotating coils e.g. static and dynamic deformations, vibrations and alignment are more difficult to control
- Mechanical manufacturing tolerances of the coils are fixed=f(tooling) → the relative uncertainty on the coil sensitivity $\kappa_n \sim 1/r$ (r=outer rotation radius)

•Signal/Noise ratio:

Size : the number of turns available for small coils ∝ signal→ ∝ r^2
Signal level grows with linked flux variation → ∝ r^1 (e.g. radial coil),
(field/gradient strength, rotation/translation speed, length, etc. being equal)

for quadrupole measurements: S/N ratio ∝ r^3, systematic errors ∝ 1/r

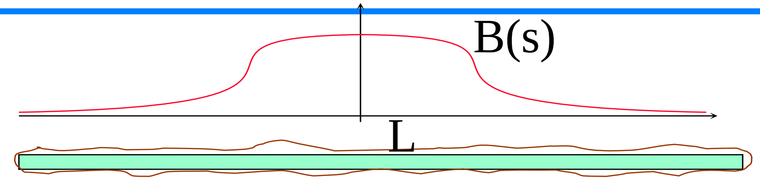
The accuracy depends strongly on the calibration (measurement) process

- "In situ calibration process" (calibration with the magnet under test) to optimize the (field gradient , harmonic)
- Magnet flipping around the axes to correct the systematic offsets for roll angles measurements and magnetic axis location

"A polyvalent harmonic coil testing method for small aperture magnets"
P. Arpaia , M. Buzio, G. Gollucio and L. Walckiers
Rev. Scient. Instr. 83,013306 (2012)

Magnet length << coil length: "In situ" calibration of rotating coils

- Manufacturing errors induce a non regular longitudinal geometry (surface, radius)
- Classical magnetic calibration (surface A_0, radius R_0) with reference dipoles and quads is not sufficient for magnets shorter that rot. coil in lengths



The area that is important is : average of the area weighted with the field for a type of magnet

$$\Psi = N_T \int_0^L w(s)B(s)ds = Lw_{eff}\,B_{average} = A_{eff}\,B_{average}$$

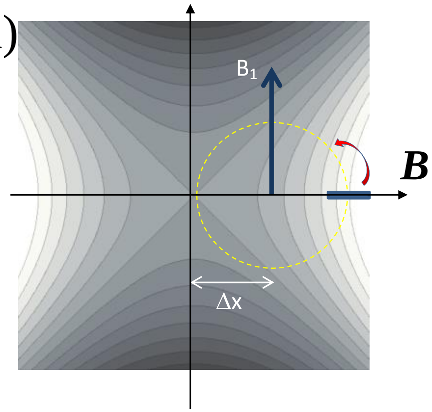
In situ calibration procedure:

Calibration of the geometrical parameters equivalent magnetic area A_{eff} and the equivalent rotation radius R_{eff}, averaged using the field profile as a weight

(a) : Translation of the coil in the magnet by a precisely known Δx $\rightarrow$ generation by feed-down of dipole B_1^{meas} in the quadrupole field B_2^{meas}

(b) : Quadrupole Field integral ∫Gdl measured independently (by stretched wire or Hall probe)

(a)



$$B_1^{meas} = \frac{\Delta x}{r_{ref}} B_2^{meas}$$

(b) Independent reference measurement of B_2

$$\int Gdl = \frac{B_2}{r_{ref}} L_{wire}$$

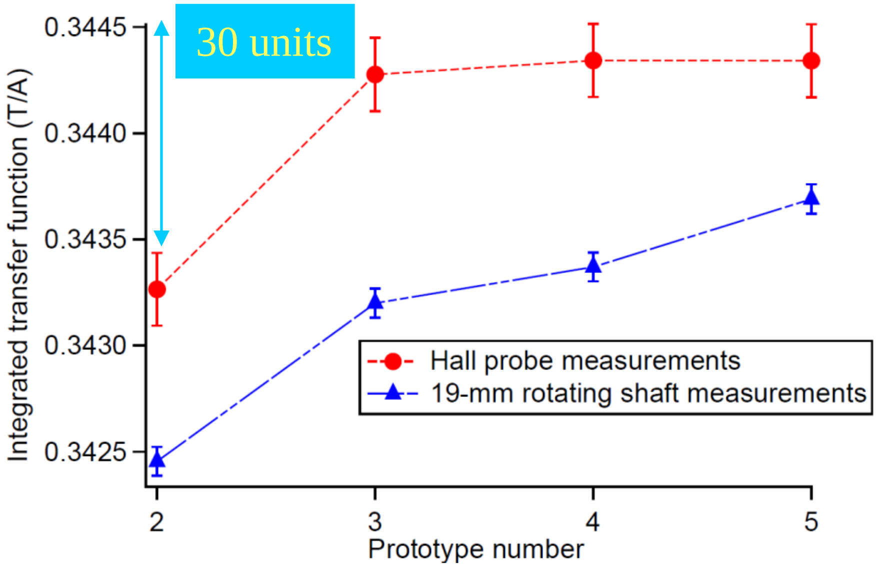
New κ_n ⟸

$$\begin{cases} R_{eff} = \dfrac{\Delta x}{r_{ref}} \dfrac{B_2^{meas}}{B_1^{meas}} R_0 \\[2ex] A_{eff} = \dfrac{r_{ref}}{\Delta x} \dfrac{B_1^{meas}}{B_2} A_0 \end{cases}$$

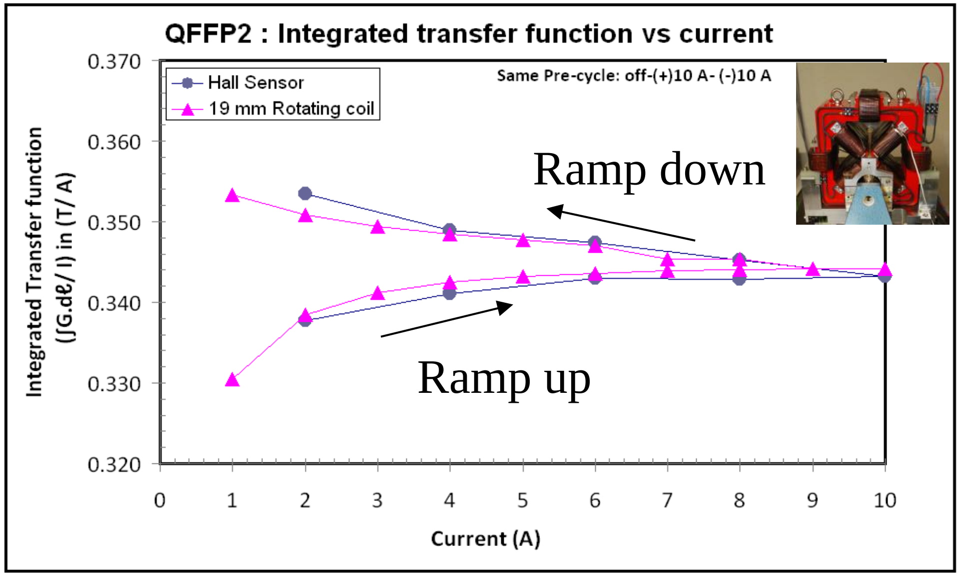
Procedure developed at CERN. Double-check performed for the 19 mm and 8 mm rotating coils at PSI using Hall probe measurements

22 mm aperture quads : Field gradient double-check

Transfer function at 10 A with HP and RC



Case of magnet QFDP2

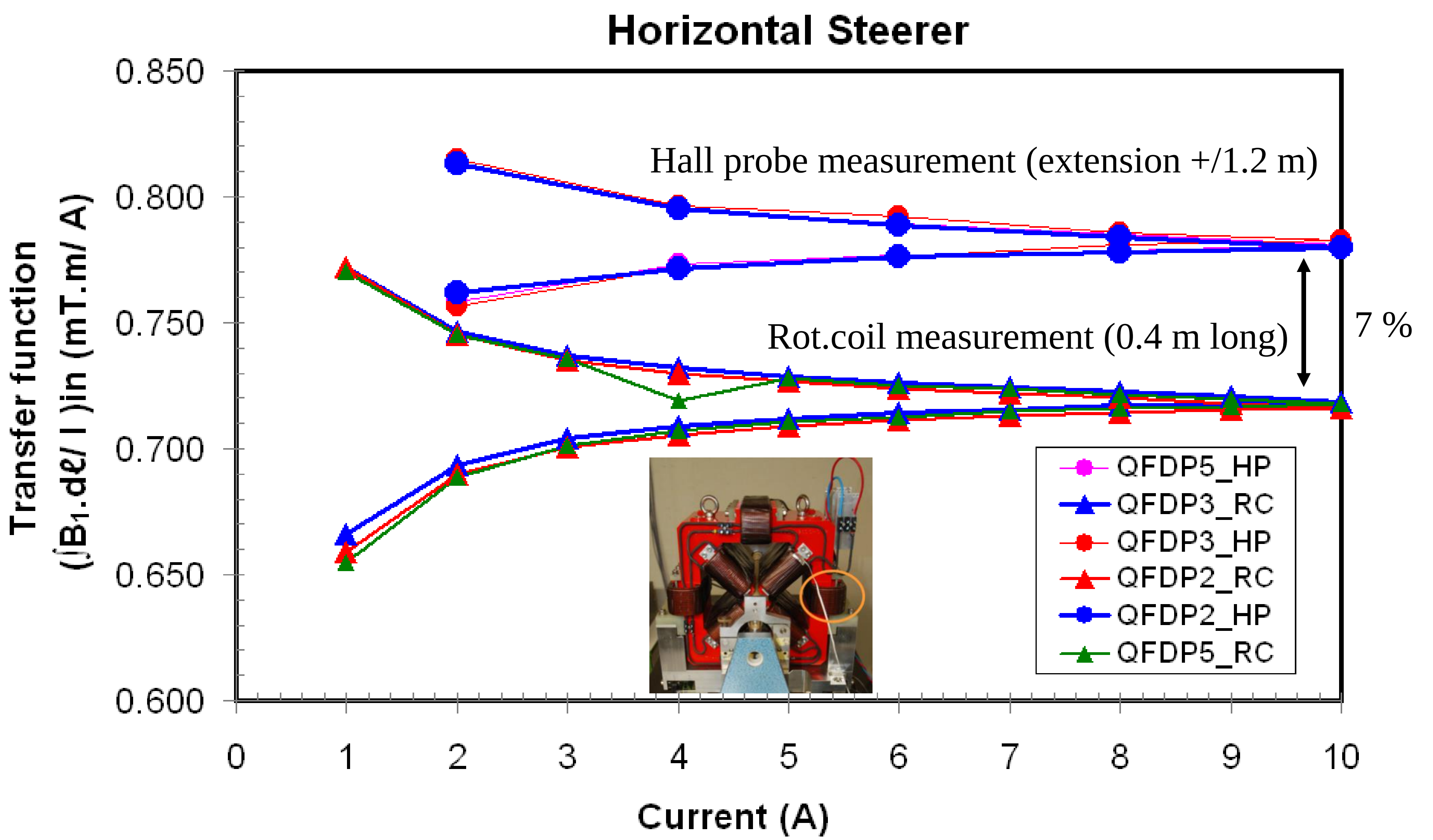


Guide-line : Correct the measured field integral value of the rotating coil by optimizing the κ_2 coefficient to match the field integral value from the Hall probe (or the moving wire)

- Systematic offset of 0.25 % for I=10 A;
- After correction, rotating coils will match with the Hall Probe within 0.05% (in the specs)
- Tests performed on only 4 magnets;

The first QFD series magnets have to be tested by the two systems to confirm the correction

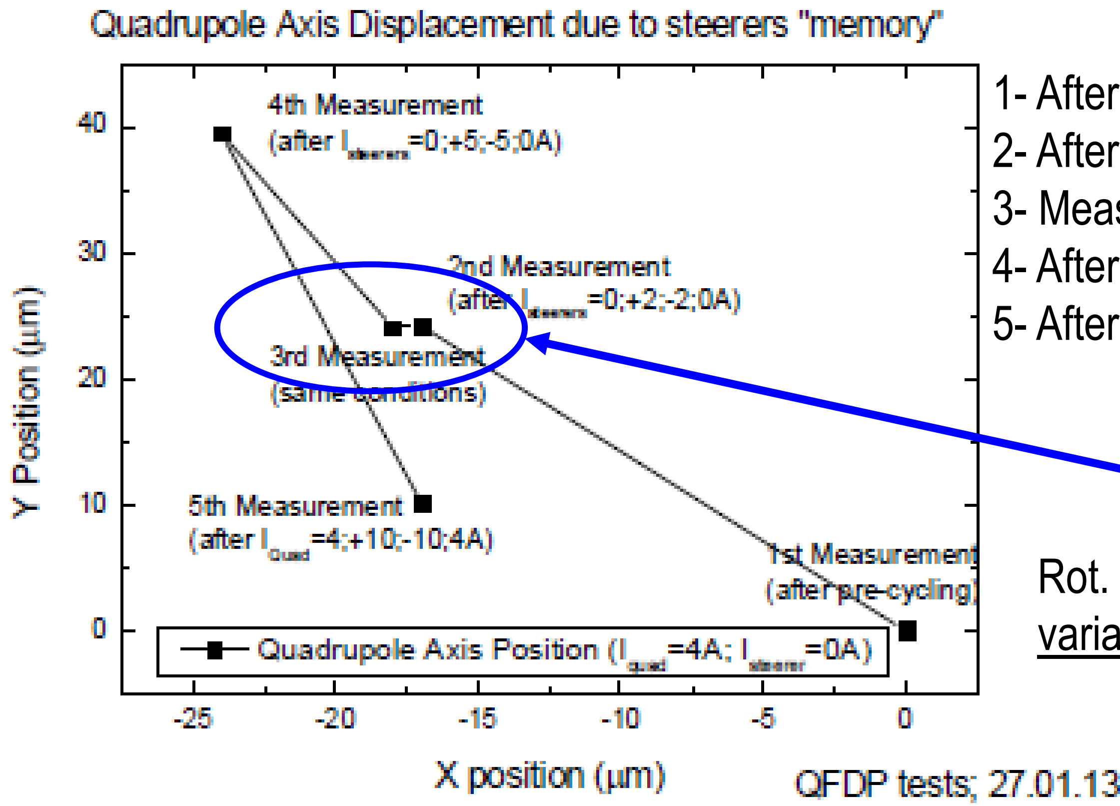
22 mm aperture quads: Integrated transfer function of steerers



Very long fringe field from the horizontal steerer : Rot coil is only 400 mm long (L_{mag}~150 mm, Ø22 mm)

Impact of the steerers' memory on the Quad. Magnetic Axis (22 mm aperture)

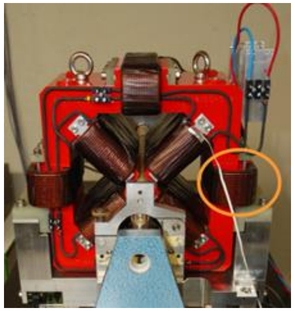
Change of the magnetic axis position for I_{quad}=4 A, $I_{steerers}$ =0 :



1- After pre-cycle : I_{quad} → 10 A →-10 A →0 (ref)
2- After $I_{steerers}$: 0→ 2 A →-2 A →0
3- Measurement 2 repeated
4- After $I_{steerers}$: 0→ 5 A →-5 A →0
5- After I_{quad} : 4→ 10 A →-10 A →4 A

Measurement reproducibility

Rot. Coils measure accurately the relative variation of the magnetic axis.



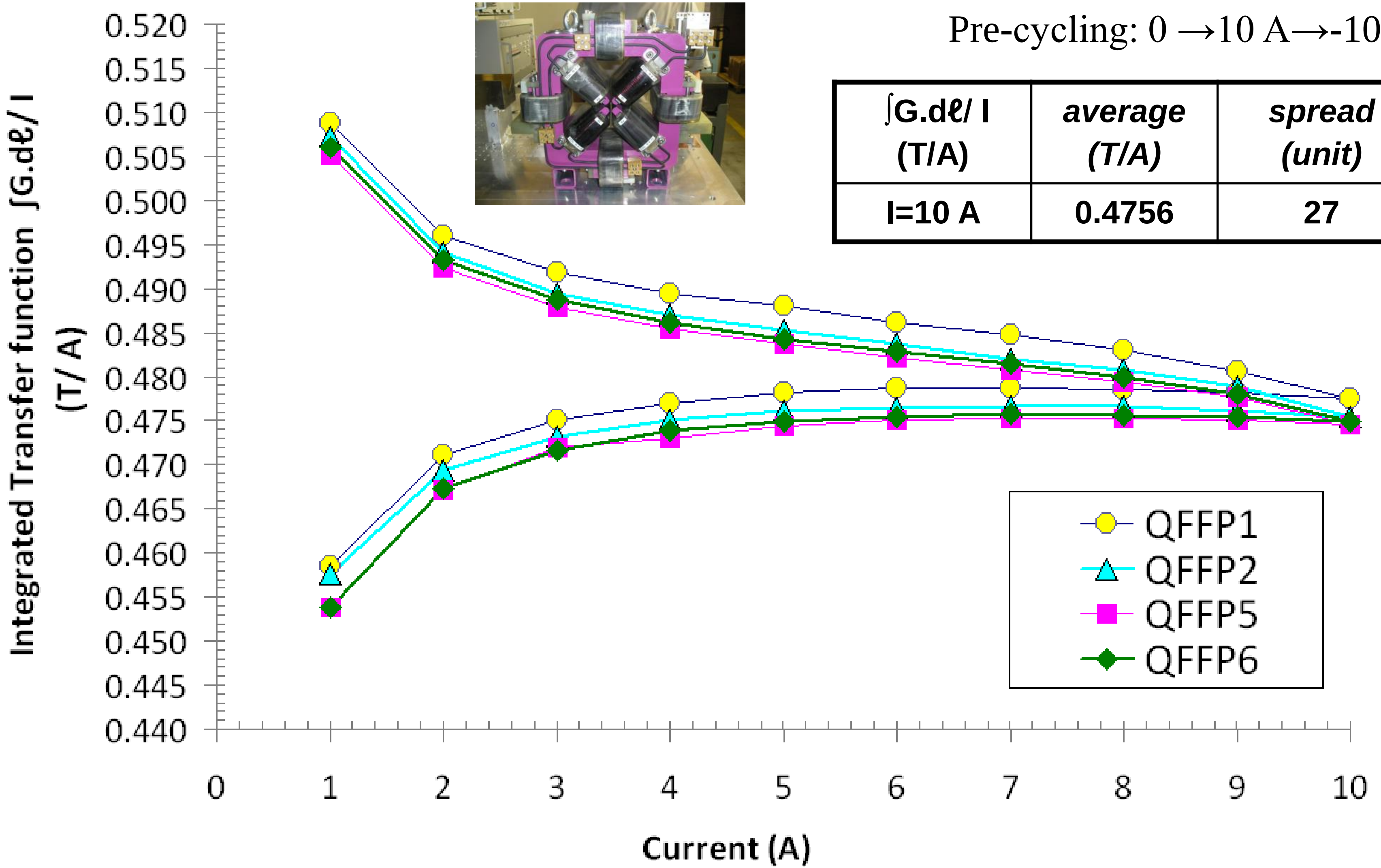
Deckardt, Felder, Ganter, Aiba (29.01.2013)

Quadrupole magnetic axis varies by <40 µm due to steerers' history

12 mm apertures prototype : Field gradient measured with rotating coils

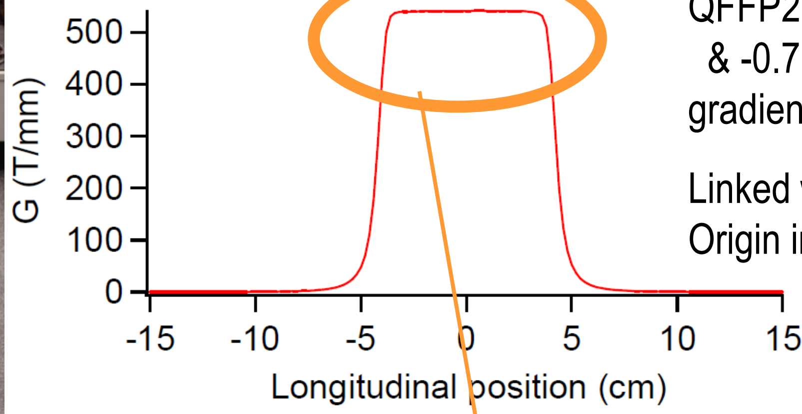
Pre-cycling: 0 →10 A→-10 A

∫G.dℓ/ I (T/A)	*average (T/A)*	*spread (unit)*
I=10 A	**0.4756**	**27**



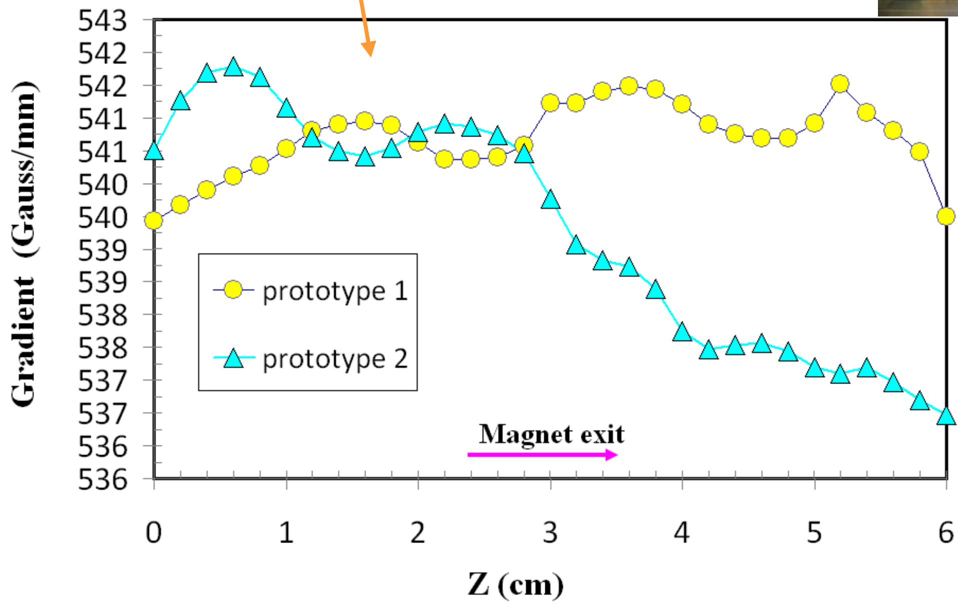
The transfer function integrated along the quadrupole is 0.4 % higher for QFFP1 at 10 A

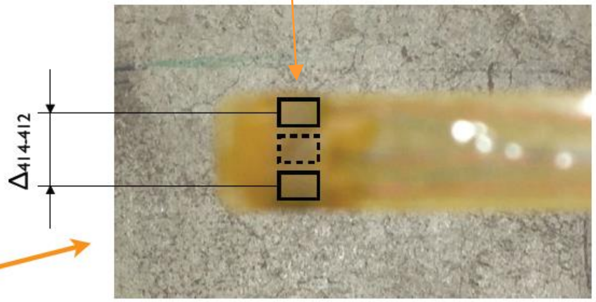
12 mm apertures prototype 1 and 2: Field gradient w.r.t longitudinal position



QFFP2: ΔTF confirmed;
& -0.7 % variation of the field gradient value along the axis

Linked with aperture dimensions?
Origin in investigation



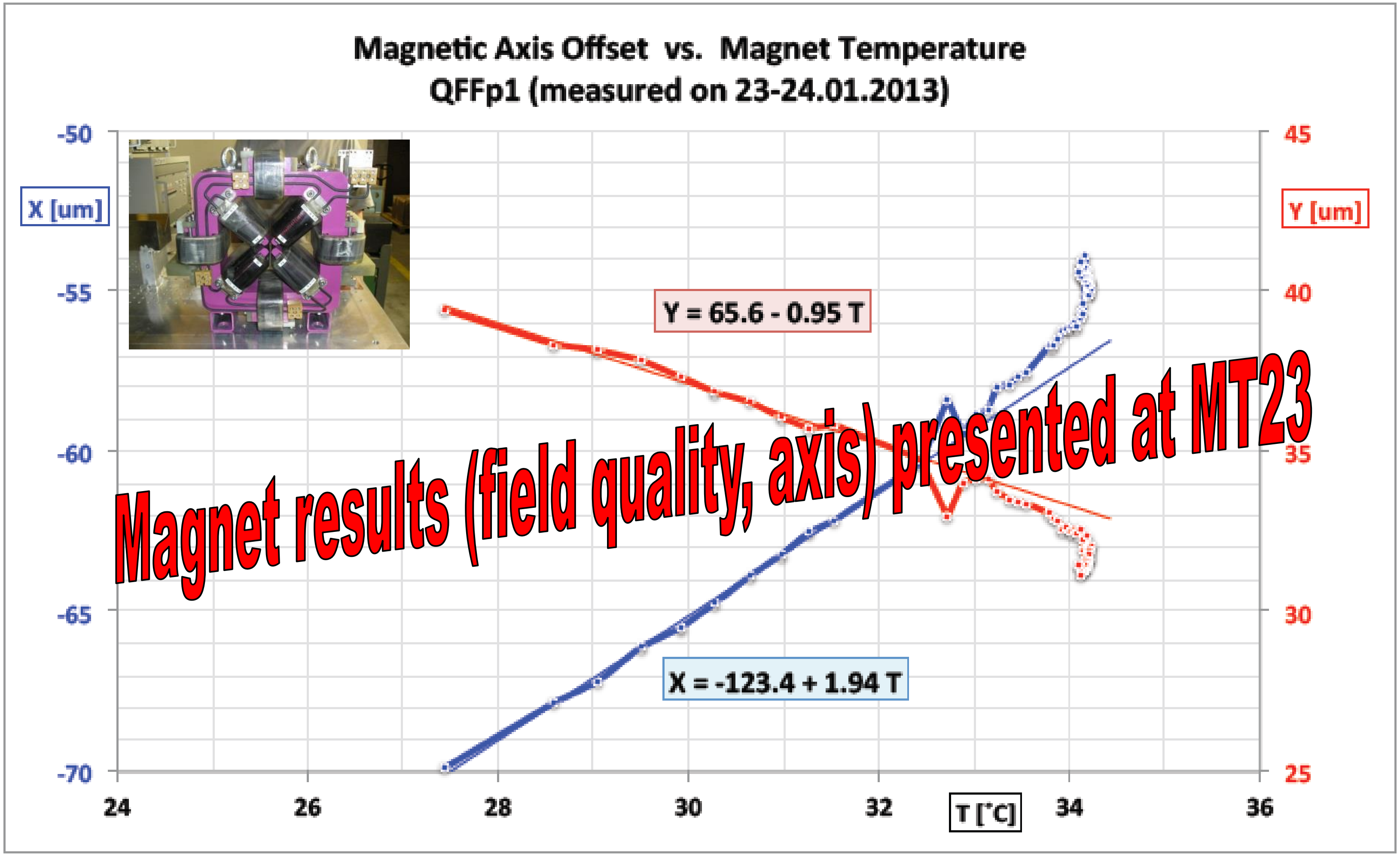


Arepoc Hall probes 412-413-414
CONSTANT $\Delta_{414-412}$ = 6.294±0.030 mm

Hall probe measurements are essential to complement RC measurements

Air cooled quads: Magnetic axis location change with time

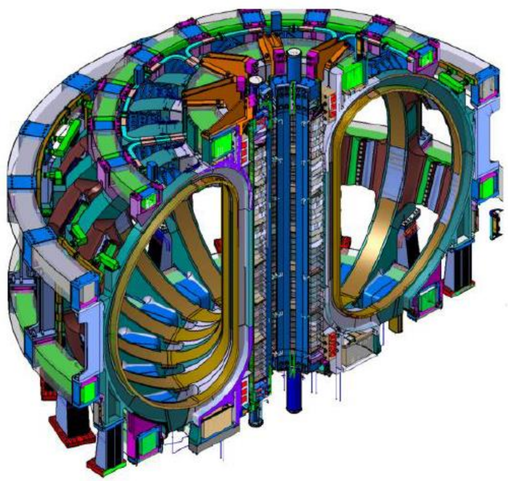
Case of a 12 mm aperture Quadrupole



See "A method for the sub-micron accurate finding of quadrupole magnetic axis" from V. Vrankovic et al., submitted to MT23 , Boston , July 2013

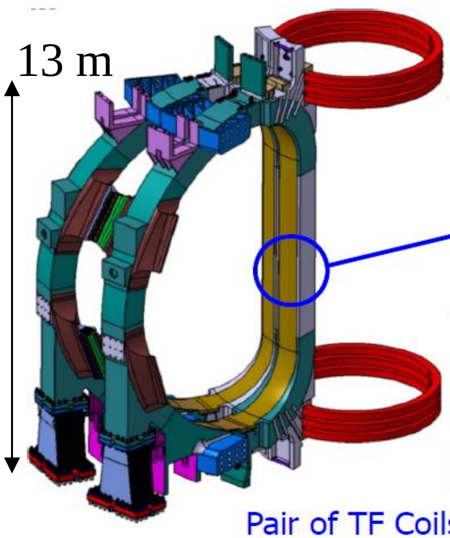
The magnetic determination of the Current Center Line (CCL) of the ITER TF-coils

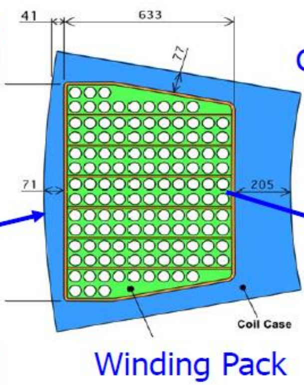
A.Gabard, Ph. Lerch & S. Sanfilippo @ PSI, M. Buzio @ CERN
A. Foussat ITER Organisation
Project granted by I.O. for 2013-2014

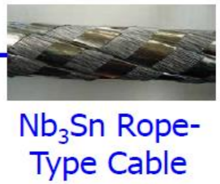


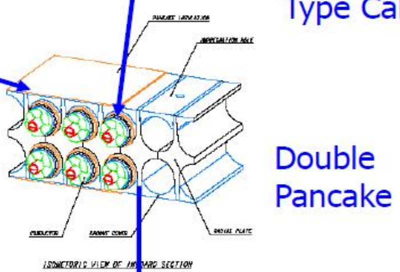
18 Toroidal Field coils

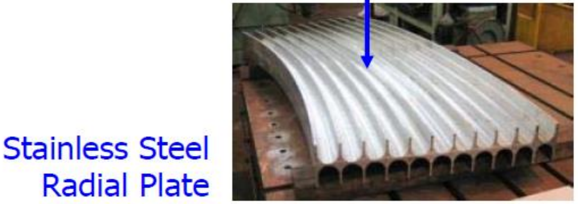
Status of ITER magnets
A. Devred , Dec 2012











- Main assembly steps: wind, react, transfer and impregnate.

Motivations

The CCL firstly defined as the geometrical barycenter of the conductors

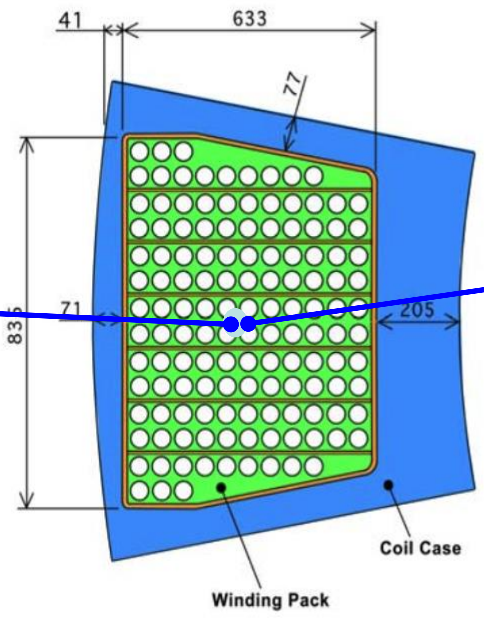
geometrical *deformations*
fabrication *tolerances*
assembly *errors*
→ magnetic field *perturbations* → *degrade* plasma confinement

TF coil positioning based from one part on CCL of each TF Coil inner leg in the best possible radial position relative to the array of TF Coils

"geometrical" CCL through
the successive WP manufacturing steps

error field budget *Knaster et al, ITER_D_23DVQU*

RP	steps	in-plane	out-of-plane
RP	grooves	+/- 0.4 mm	
RP	assembly	+/- 0.5 mm	
DP	flatness		+/- 0.5 mm
DP	bending weld		+/- 0.5 mm
DP	cable location	+/- 0.9 mm	
WP	WP assembly	+/- 0.6 mm	+/- 1.0 mm



magnetic CCL measurement *required*

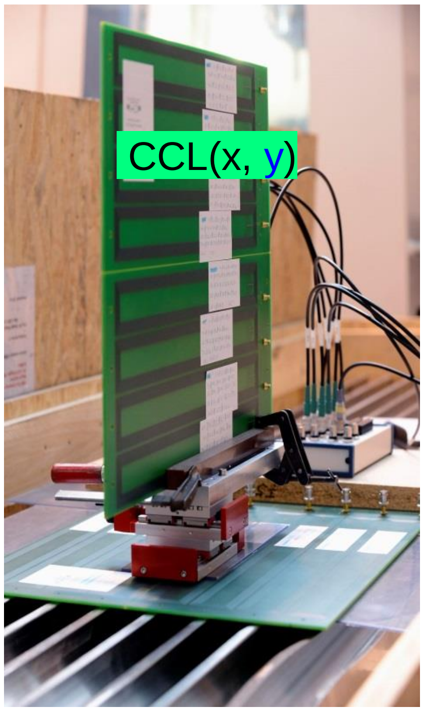
magnetic CCL
Deniau et al, CERN-ATS-2012-048
Knaster et al IEEE Appl. Super. 20, 1475 (2010)

Magnetic representation of the winding pack to "refine" the location of the CCL of each coil within uncertainty of 1 mm

Magnetic measurement system: AC Flux-meter

low frequency *ac* excitation <1 Hz

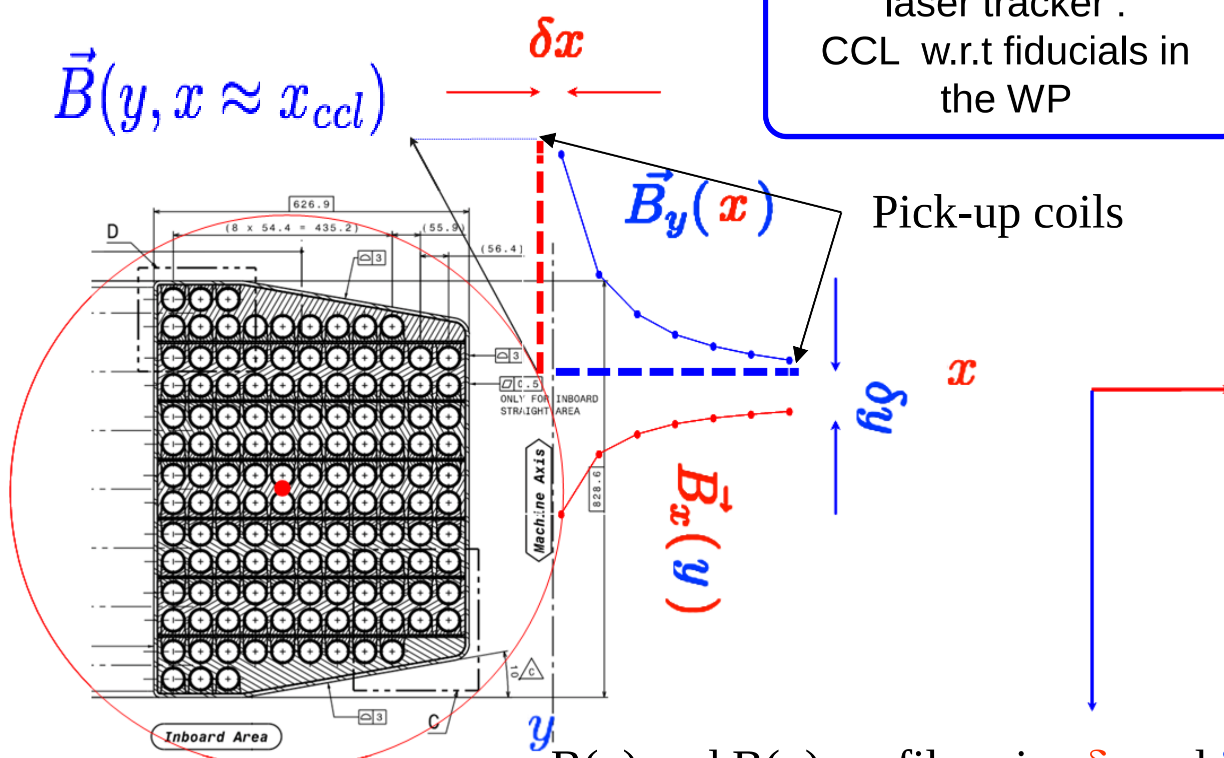
measure B(x) and B(y) profiles with PCB coil arrays



Crossed PCB coils+ lock-in detection gives ccl (x) line

calibrated gradiometer gives ccl (y) line

laser tracker : CCL w.r.t fiducials in the WP

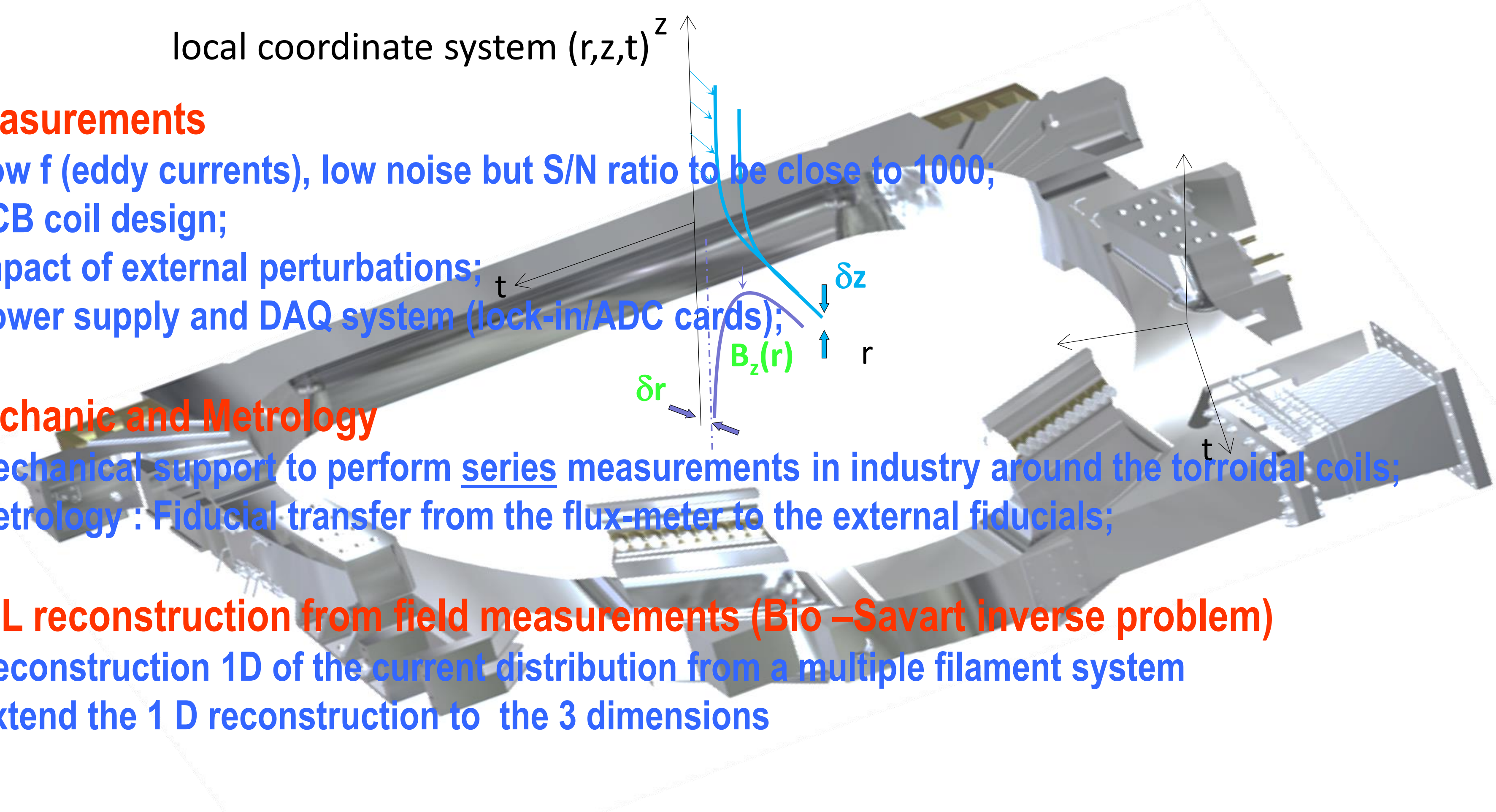


$\vec{B}(-y, x \approx x_{ccl})$

B(x) and B(y) profiles give δ_x and δ_y

Inverse biot savart law

Magnetic measurement system to find the CCL - challenges



Measurements

- Low f (eddy currents), low noise but S/N ratio to be close to 1000;
- PCB coil design;
- Impact of external perturbations;
- Power supply and DAQ system (lock-in/ADC cards);

Mechanic and Metrology

- Mechanical support to perform series measurements in industry around the torroidal coils;
- Metrology : Fiducial transfer from the flux-meter to the external fiducials;

CCL reconstruction from field measurements (Bio –Savart inverse problem)

- Reconstruction 1D of the current distribution from a multiple filament system
- Extend the 1 D reconstruction to the 3 dimensions

See "Room temperature magnetic determination of the Current Center Line for the ITER TF coils" from Ph. Lerch et al.,
submitted to MT23 , Boston , July 2013

Magnet section activity

- The magnet section is facing the challenge to design, measure and deliver magnets for two major projects running practically in parallel in 2014/2015 : SwissFEL & Gantry 3
- A spare magnet /coil program was launched in 2009 is an important part of the magnet section activity. It will be pursued with the same intensity in the next decade.
- SwissFEL : the strategy of series measurements includes the tests of 100% of magnets & double-check measurements with reference systems as a statistical basis. The ordering of the magnets will be finished in 2013. Series-tests will start in October 2013.
- Battery of measurements systems (2 wires, 3 rotating coils, 3 Hall probes). Most of them are fully operational. Collaborations with Swiss Institutes/companies, ITER and CERN aim to develop accurate and original magnetic measurement systems
- Accurate magnetic measurements in small aperture air cooled quadrupoles used for the SwissFEL remain a challenge. The integration of steerers in the magnet cross section increases the measurement complexity.
- 8 mm and 19 mm-aperture rotating coils were built at CERN, calibrated & commissioned at CERN and PSI to measure the small aperture series quadrupoles. They show a very good reproducibility for the field gradient and the harmonic measurements.

Next challenges (2013-2014)

Improvement of our existing systems

- Rotating wire : Accurate harmonic measurements is the next goal
- Magnetic axis measurement within 20 μm using the Ø-8 mm rotating coil
- Protocols for series measurements are on-going, finished in mid 2013

Next developments

- HallCube : 3 D Hall probe with a small practical calibration system (Metrolab)
- AC Fluxmeter: Prototype and 2 industrial devices for series measurement of the 18 ITER torroidal coils
- Rotating coil: Long (1.2 m) and large aperture (70 mm) for Ø-100 mm series quadrupoles for the project Gantry 3 in 2014.

Thank you for your attention

Questions?