“Beam Dynamics meets Magnets”

G. Franchetti, GSI

1st EuCARD-2 Annual Meeting

19-23 May 2014, DESY

Overview

- Introduction
- Beam dynamics meets Magnets
- Highlights
- Summary/Outlook

Introduction:
starting from a realistic view

Accelerators were born within science

Basic research

Beam dynamics

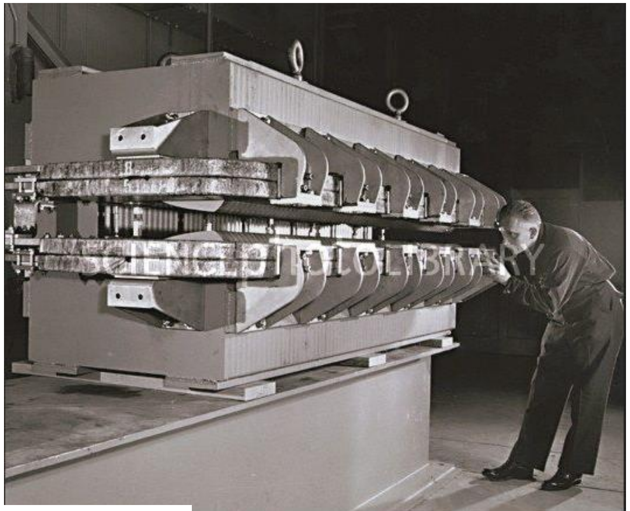
Magnets

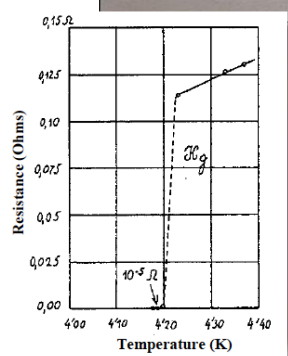
increase of energy / intensity

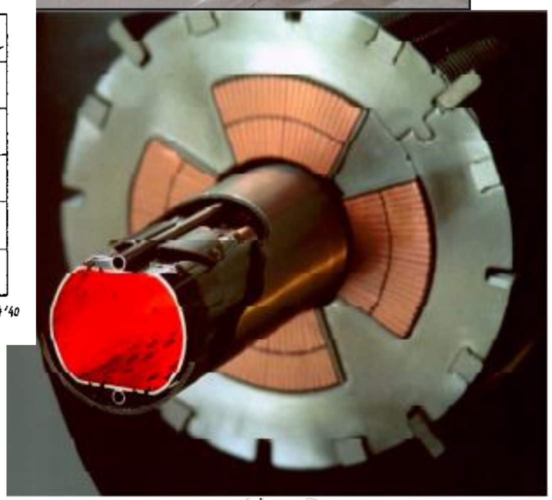
increase of complexity

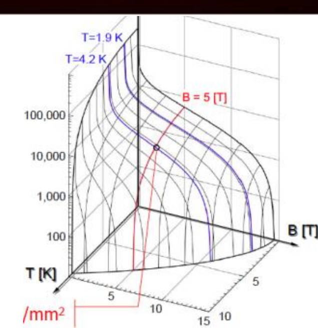
Fragmentation in areas of competence

Magnets

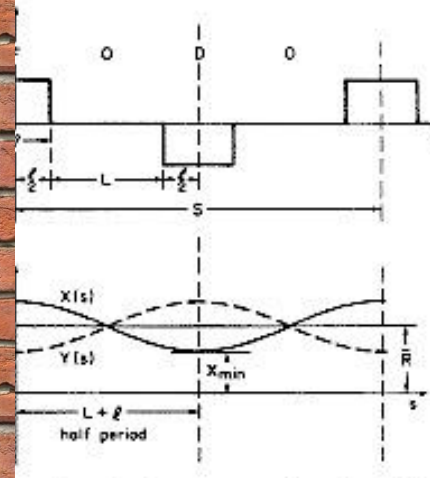


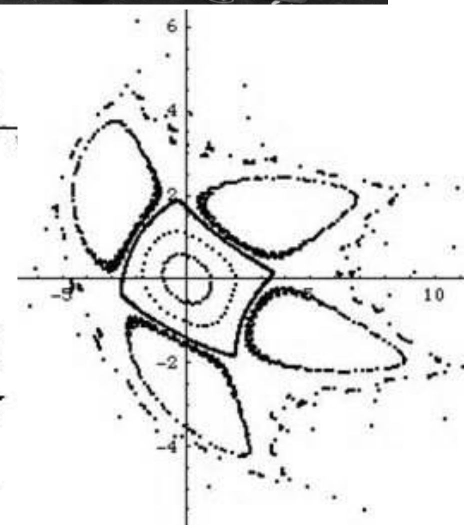


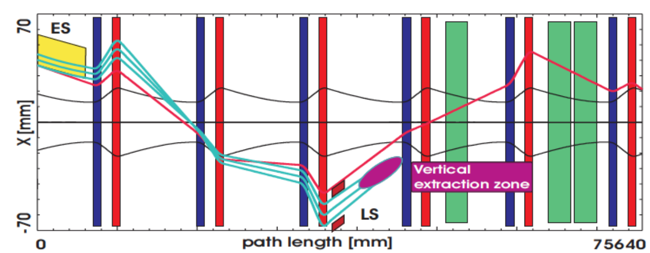




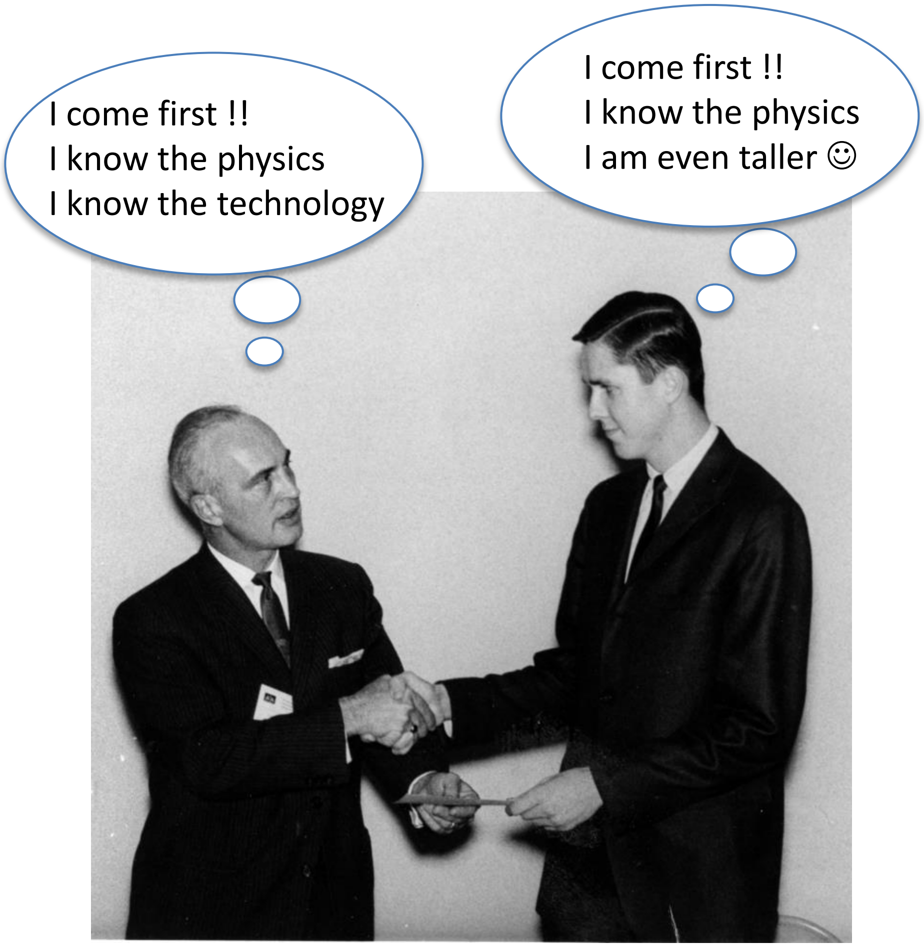
Beam Dynamics



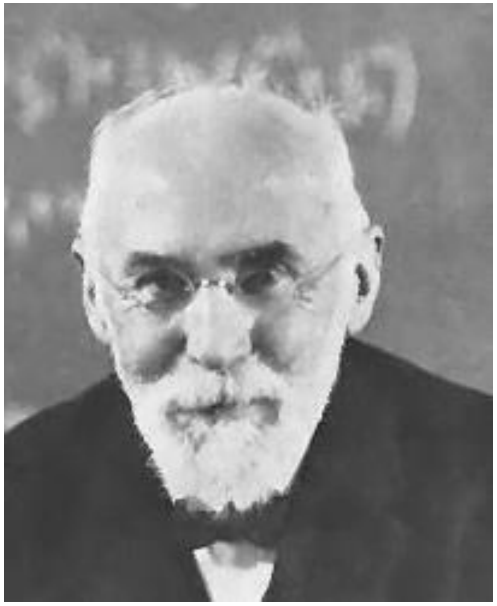




Beam Dynamics & Magnets
Who comes first?



We all are interconnected

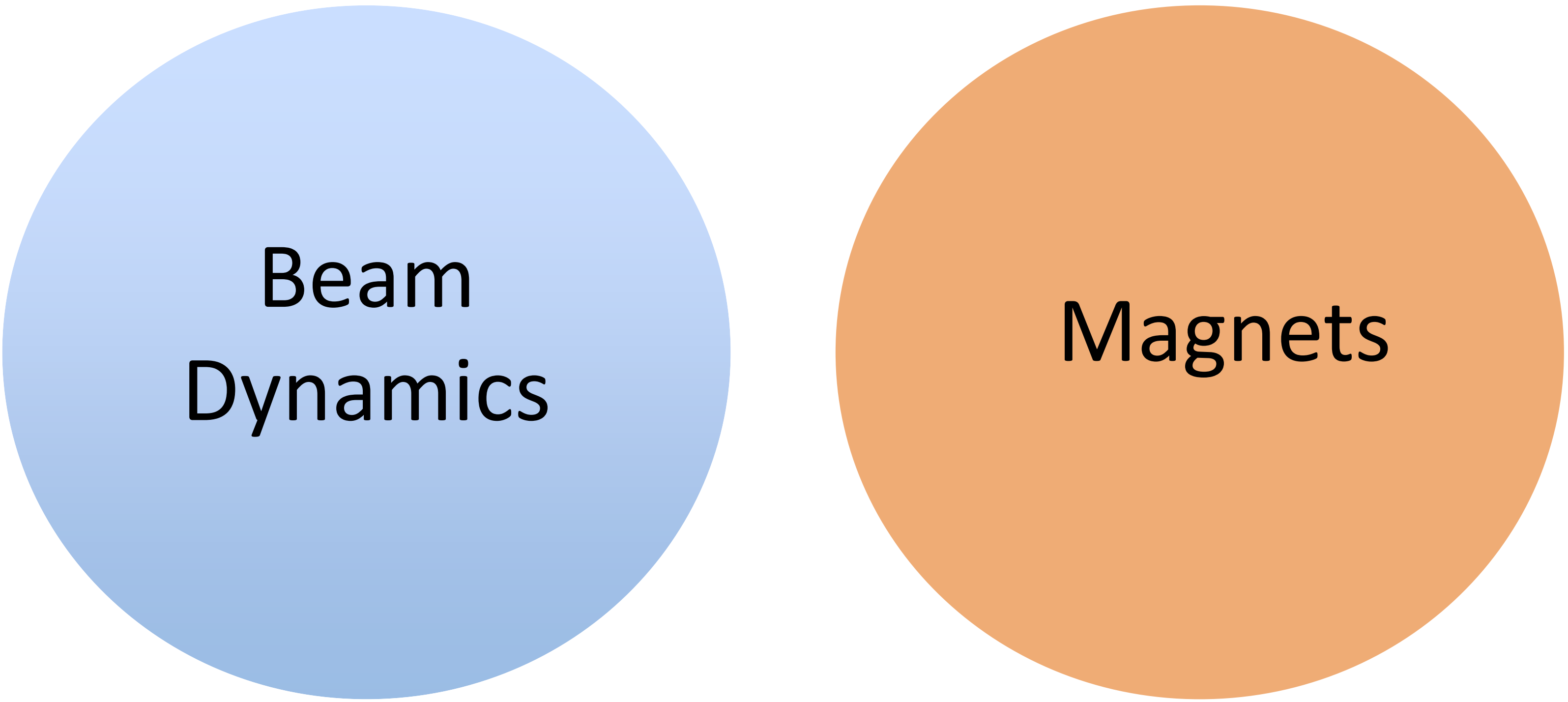


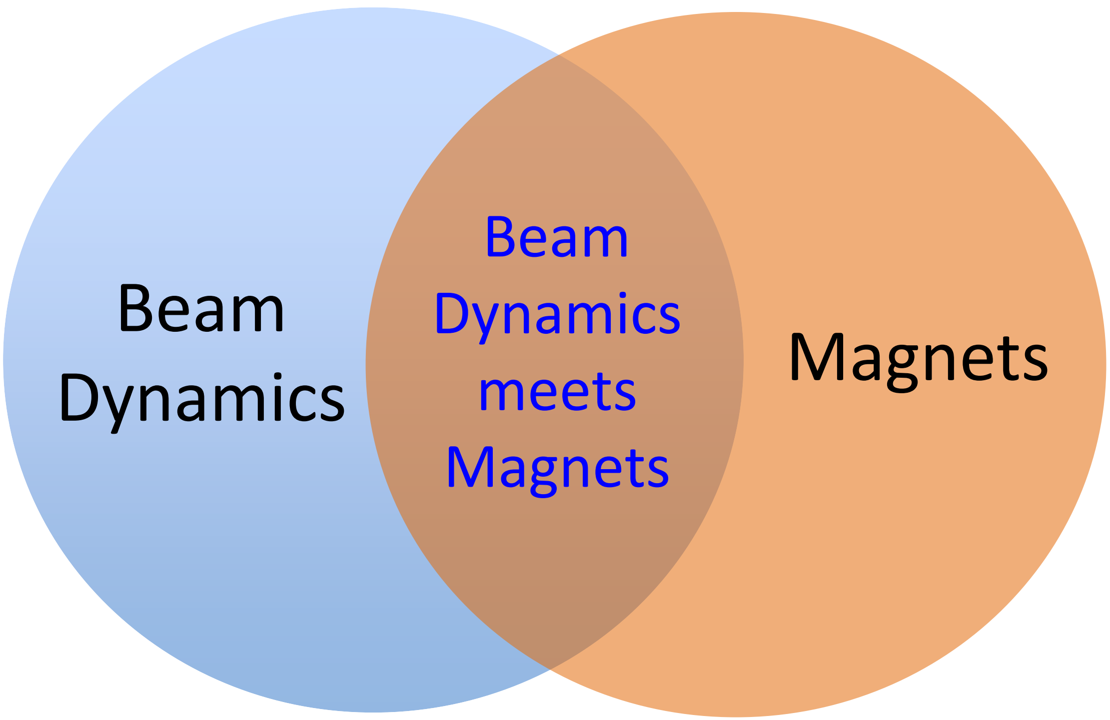
$$\frac{d\vec{p}}{dt} = q(\vec{E} + \vec{v} \times \vec{B})$$

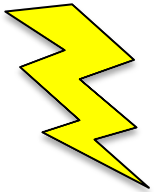
Task 5.3: Extreme performance rings (XRING)

GSI will coordinate XRING and integrate the activities of the accelerator, nuclear and particle physics communities towards reaching the optimum performance of FAIR, ISIS and PSI-HIPA, and helping guide the upgrade strategy for the LHC injector complex. Ultimate limitations for the aforementioned projects will be identified. XRING will also support studies on critical beam diagnostics (e.g. continuous emittance & beam-loss measurements) and on advanced FFAGs designs, including machine experiments at EMMA in the UK. XRING will create strong synergies across communities, countries and continents. XRING will be THE European forum for discussing performance limitations of high-intensity high-brightness hadron rings, and for analyzing and optimizing the proposed upgrade paths of several European facilities. XRING will bring together experts in beam dynamics with specialists of magnets and collimation to arrive at optimum upgrade solutions with risk mitigation. XRING will integrate the efforts of large laboratories, smaller institutes and universities, and it will form and maintain a community capable of advancing the technical realization & scientific exploitation of the European high-power hadron-ring facilities. Task participants will attend and contribute to events addressing high-intensity hadron beams and participate in beam experiments, e.g. at PSI, ISIS, and EMMA. The following institutes have expressed interest in the EUROLUMI activities: CNRS-LPSC, UJF (FR), GSI (DE), Unibo (IT), CERN (INO), JAEA, KEK (JP), UM (MT), CINVESTAV (MX), IHEP, JINR (RU), PSI (CH), RHUL, STFC, UNIMAN and ULANC as Cockroft Institute, UOXF (UK), BNL, and FNAL (US).

Two different areas
Two different communities







Crazy idea → high risk

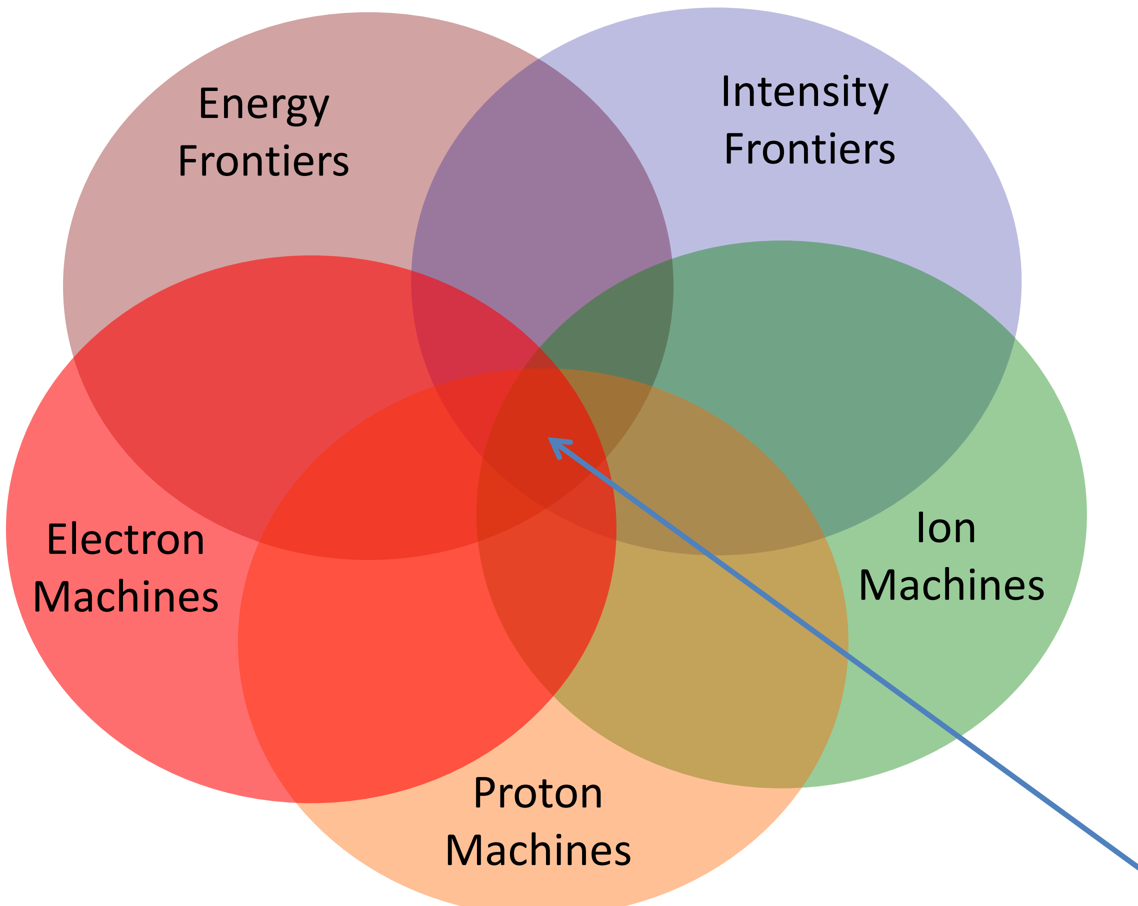
Thanks to EuCARD-2 we took the risk.

Beam Dynamics meet Magnets


Beam Dynamics meets Magnets
1st XBEAM-XRING Workshop
2-4 December 2013
Darmstadt, Germany
Chair G. Franchetti
Workshop Secretary I. De Caluwe
International Advisory Committee
P. Fabbricatore INFN
E. Fischer GSI
H.G. Khodzhibagiyan JINR
S. Russenschuck CERN
C. Spencer SLAC
O. Boine-Frankenheim TUD/GSI
S. Machida RAL
K. Ohmi KEK
F. Schmidt CERN
F. Zimmermann CERN
TOPICS
Magnet field mapping
Multipole measurements
Magnetic field in elliptical chambers
3D vs. 2D description
Magnet design
Mathematical models
Nonlinear dynamics
Emittance growth
Beam loss
Space charge
Lattice modeling
Tracking and multipoles
GSI
FAIR
EuCARD2
X BEAM RING
HIC for FAIR
Helmholtz International Center
TECHNISCHE UNIVERSITÄT DARMSTADT
web page: https://indico.gsi.de/conferenceDisplay.py?confId=2352

Beam Dynamics *meets* Magnets

CERN	22
GSI	20
STFC	7
Goethe U Ffm	6
TU Darmstadt	4
PSI	3
ISIS	3
FZ Jülich	2
KEK	2
KIT	2
ASTeC	1
BNL	1
Cockcroft I.	1
FAIR	1
Imperial College	1
INFN	1
KU Leuven	1
JPARC	1
LNL	1
MedAustron	1
MSU	1
SLAC	1
Tokyo U.	1



Unparalleled participation of institutions representing a large spectrum of the accelerator community

Beam Dynamics *meets* Magnets

Beam Dynamics *meets* Magnets

1st XBEAM-XRING Workshop

Darmstadt, December 2-4th, 2013

	Monday 2nd	Tuesday 3rd	Wednesday 4th	
8:00 8:30	Registration			
8:30 9:00	**G. Franchetti, O. Boine-Frankenheim, O. Kester,** Welcome address			
9:00 9:20	**Peter Spiller (GSI).** FAIR challenges to beam dynamics and to magnets	**Thomas Taylor (CERN).** Magnets in accelerators: a Historical Overview	**Martin Berz (MSU).** 3D dynamics vs. dynamics with kicks	9:00 9:30
9:20 9:40	**Wolfram Fischer (BNL).** Beam Dynamics in Accelerators: nonlinear dynamics and experiments		**Suzie Sheehy (ASTeC).** Helical coil magnets: advantages and challenges from the PAMELA medical FFAG design study	9:30 9:50
9:40 10:00		**Cherrill Spencer (SLAC).** Procuring the ATF2 magnets: new and recycled	**Jean-Baptiste Lagrange (Imperial College).** FFAG the working marriage of magnets and dynamics	9:50 10:10
10:00 10:30	**Sergei Litvinov (GSI).** Nonlinear Dynamics of the Collector Ring	**Rogelio Tomas (CERN).** The ATF2 Story	**Martin Droba (Goethe University).** Beam Dynamics in the Figure-8 magnetic fields	10:10 10:30
10:30 11:00	Coffee Break	Coffee Break	Coffee Break	10:30 11:00
11:00 11:25	**Pierre Schnizer (GSI).** Advanced Multipoles for Accelerator Magnets and Their Measurement	**Vassili Marusov (GSI).** Measurement of a dynamic field by rotating coil	**Joint Discussion and Summary**	11:00 12:00
11:25 11:45	**Anna Mierau (GSI).** Measuring the SIS100 Dipole Magnets	**Sebastian Schöps (TUD).** Approaches for the Quantification of Uncertainties in Stochastic Magnet Design		
11:45 12:00		**Kei Sugita (GSI).** Special Design Aspects of the Superconducting Corrector Magnets of SIS100		
12:00 14:00	Lunch	Lunch		
14:00 14:25	**Frank Schmidt (CERN).** The LHC dynamic aperture experiment	**Yukiyoshi Onishi (KEK).** Effect of IR optics error on SuperKEKB luminosity performance		
14:25 14:50	**Massimo Giovannozzi (CERN).** Sorting of the LHC magnets and lessons learned	**Susumu Igarashi (KEK).** J-PARC optics, space charge and magnet alignment		
14:50 15:20	**Stephan Russenschuck (CERN).** Establishing C^3, the coherence between beam physics requirements, magnet manufacture and measurements	**Hiroyuki Harada (J-PARC).** RCS optics, space charge, and magnet alignment		
15:20 15:40	**Marco Buzio, (L. Fiscarelli) (CERN).** Overview on measurement techniques, precision and accuracy	**Ulrich Dorda (MedAustron).** Requirement on small machines		
15:40 16:00	**Stefano Sanfilippo (PSI).** Field quality and warm-cold correlations: The experience of LHC dipoles and quadrupoles	**Ben Pine (STFC):** Experiments, Simulations and Magnets for the ISIS Ring		
16:00 16:30	Coffee Break	Coffee Break		
16:30 16:55	**Herbert de Gersem (KU Leuven).** State of the art and the limitations of simulations.	**Ingo Hofmann (TUD).** Comparison of quadrupole and solenoids dynamics		
16:55 17:15	Discussion + short talks	Discussion + short talks		
17:15 17:30				
17:30 17:45				
17:45 18:00				
18:00 18:15				
18:15 18:30				
18:30 19:00	Discussion + short talks	Discussion + short talks		
19:00 22:00		**Buffet-Dinner:** "Beam Dynamics eats with Magnets"		

WLAN:

SSID -> BEAM

password -> DYNAMICS

16:00 GSI Tour

TOPICS

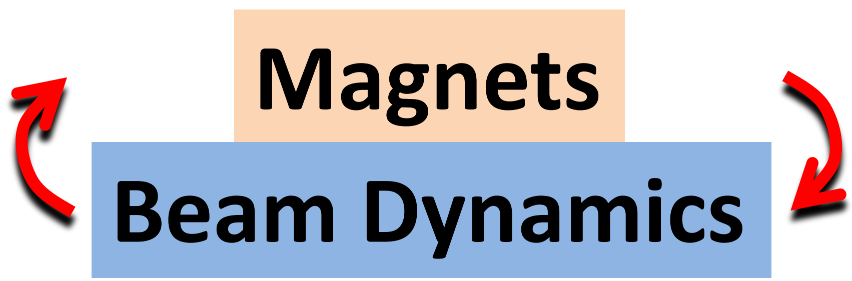
Beam Dynamics

Magnets

Unique opportunity to face issues that requires the expertise of magnet and beam dynamics

The workshop attempted to enhance the scientific-technical "project" experience:
in every project (LHC,FAIR,JPARC,ATF2,EMMA, etc...) the experience of the **communications** and **synergy** between "Beam Dynamics & Magnets" has developed differently.
This is due to project features, laboratory styles and traditions, people personalities and experiences.

Workflow of “beam dynamics” and “magnets” in different projects



Example:

How well should a magnet be measured for beam dynamics ?

Benchmarking experiments: beam dynamics <-> magnets

Beam Dynamics ⟷ *meets* Magnets

A Mixed approach

Beam Dynamics meets Magnets

audio/video package

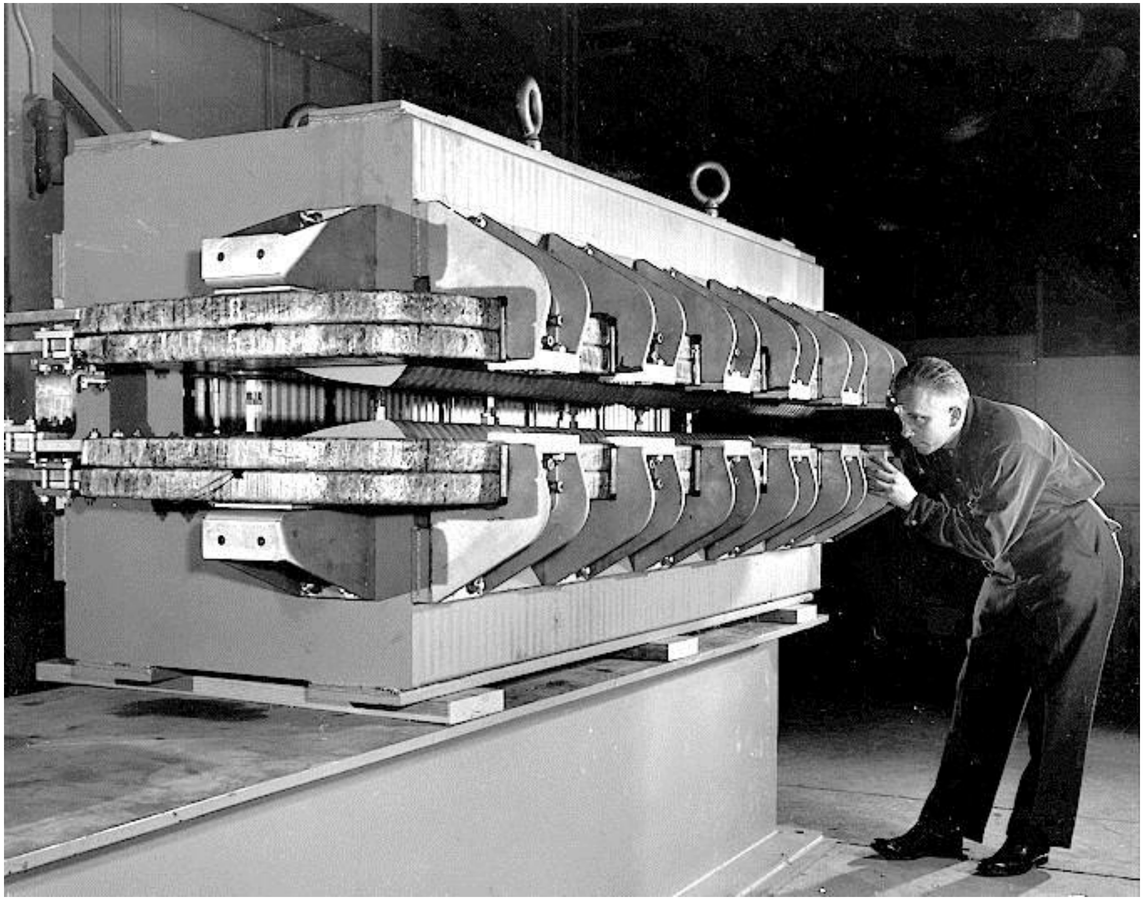
Darmstadtium negotiations

support of students

Highlights

T. Taylor

Historical overview: Strong focusing magnets – combined function



An AGS magnet

(PS, ISR are similar)

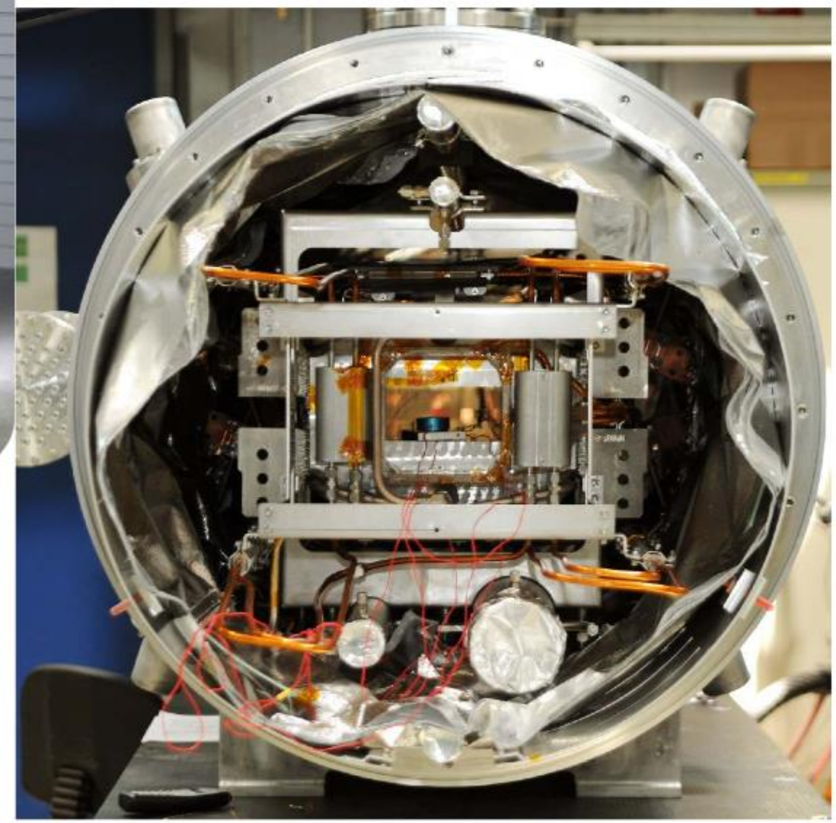
Accurate pole (2-D)
+ steel mixing
+ measurements
+ magnet sorting
+ poleface windings

(But finally ISR magnets were sorted by weight!)

Idea of using punched laminations to obtain accurate pole profile over whole length

Talks on FAIR magnets

A. Mierau



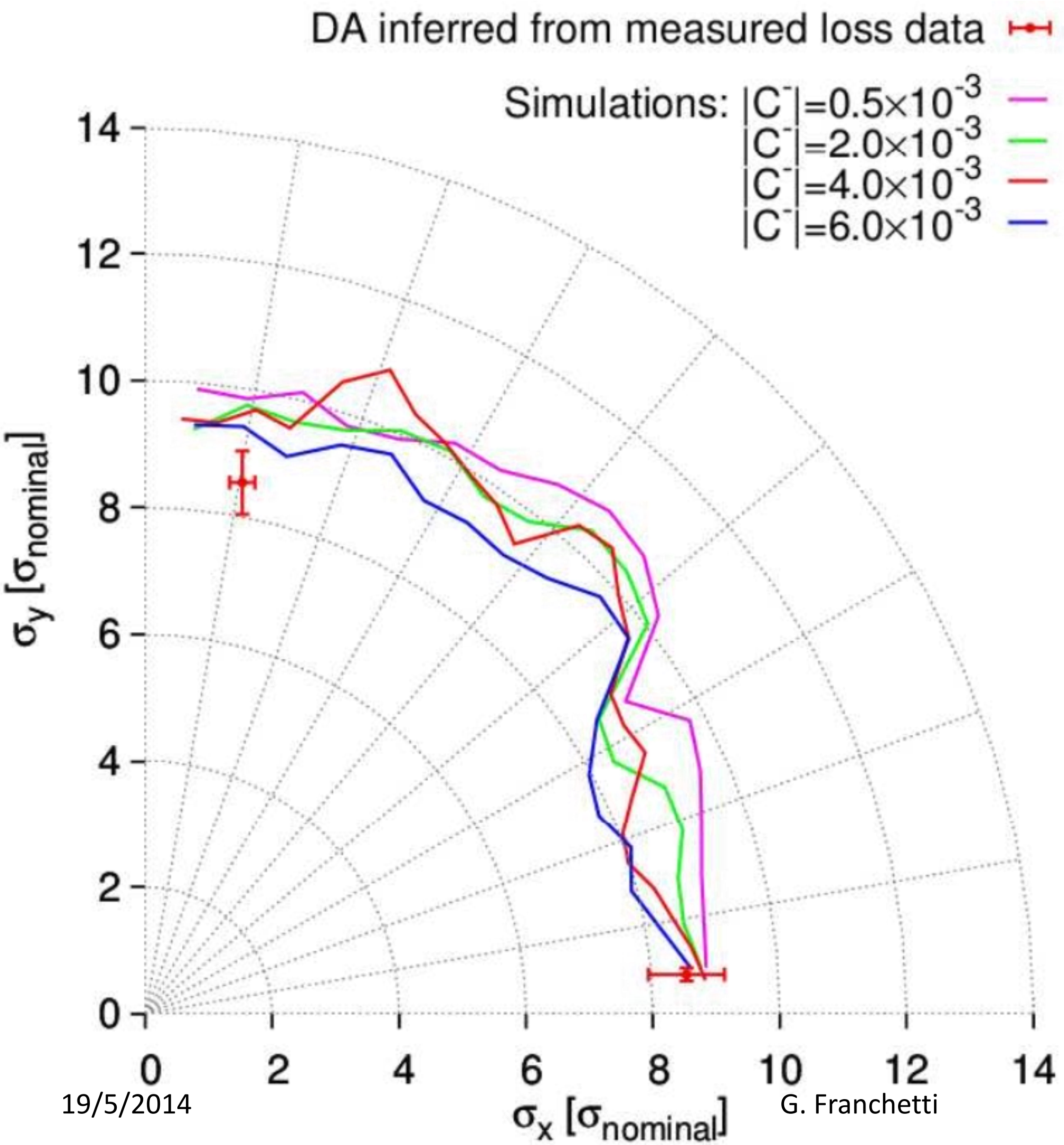
B_{min}	T	0.228
B_{max}	T	1.9
Effective length L_{eff}	m	3.062
Usable aperture	mm x mm	60 x 120
Bending angle	°	3 1/3
Bending radius	m	52.632

A. Mierau Workshop beam dynamics meets magnets. 2 - 4 December 2013, Darmstadt.

HELMHOLTZ GEMEINSCHAFT GSI FAIR 6

DA verification in LHC

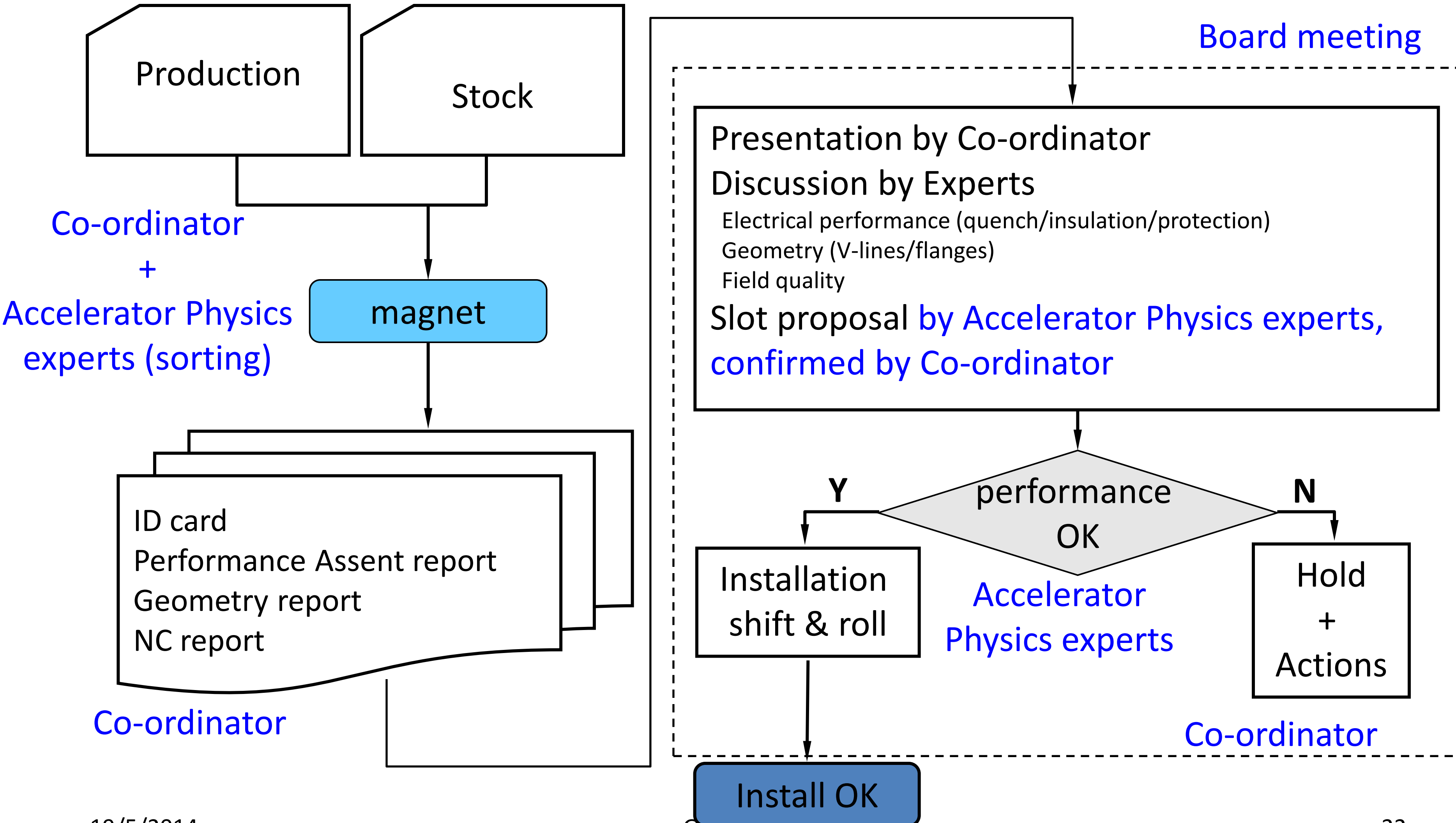
F. Schmidt



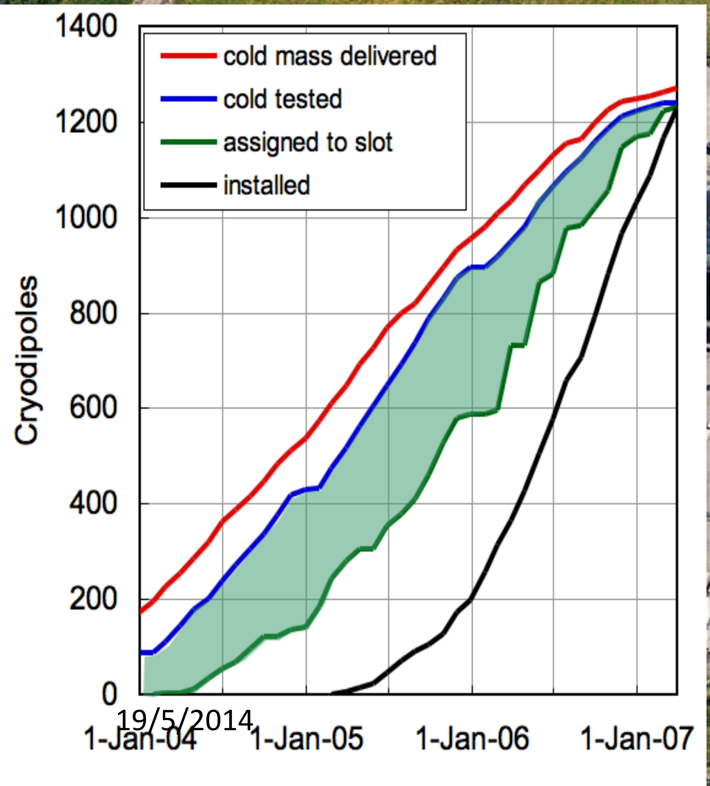
E.H. Maclean, R. Tomàs, F. Schmidt, and T.H.B. Persson.

The LHC magnet sorting experience
MEB Workflow Diagram

M. Giovannozzi

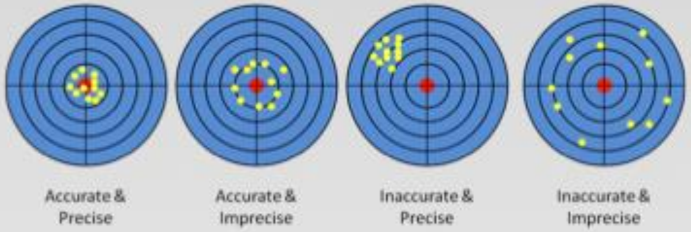


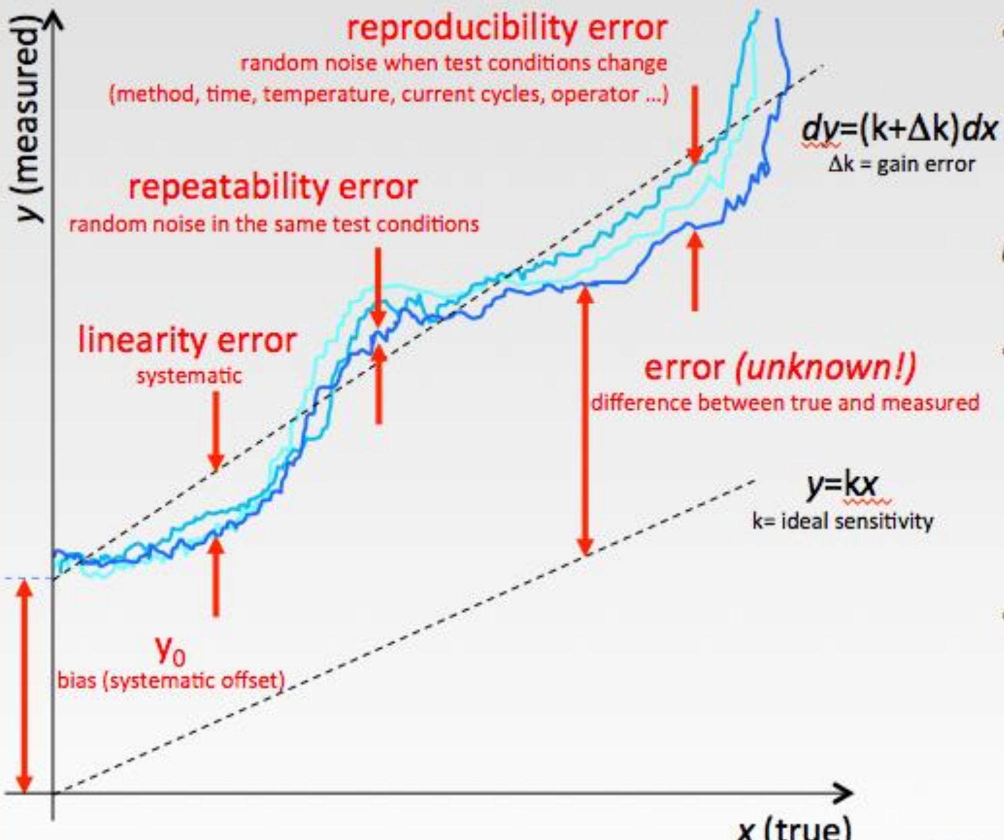
Slot allocation for MB’s



Comfortable stock for sorting: maximum of 300 MB’s by end 2005, tapered down in 2006

Metrology recap





qualitative terms (to be avoided)

- **precision:** measure of dispersion
- **accuracy:** closeness of agreement between measured (average) and true value
- **resolution:** smallest detectable change

use instead:

- **estimated standard deviation** σ
  measure of dispersion ("*noise*") obtained from a finite sample : $\sigma^2 = 1/n \sum (x-x)^2$
  NB: all sources of dispersion add <u>quadratically</u>

- **standard measurement uncertainty *u***
  quantitative parameter of the dispersion of a measurement result $\bar{x}$: $u = \pm\sigma/\sqrt{n}$

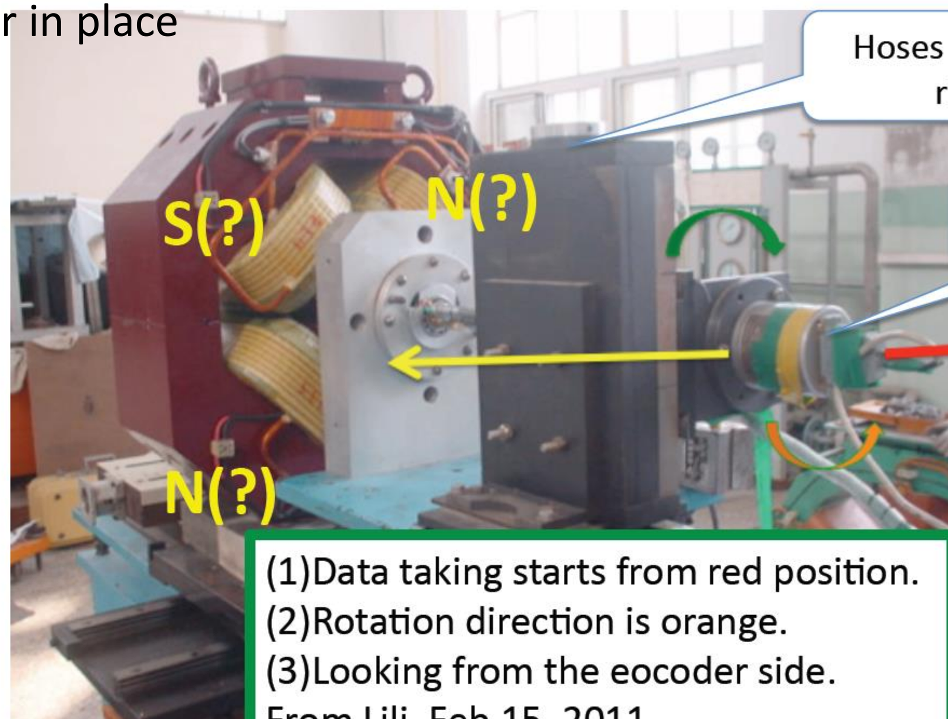
Reference: ISO GUM (*Guide to the Expression of Uncertainty in Measurement*)

Marco Buzio

Needed to understand the polarities of the multipoles, had to recall which way

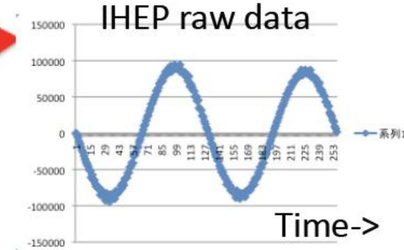
IHEP magnetic measurement apparatus. No longer in place

Cherrill Spencer



Hoses (not visible) are on the right in this photo.

Encoder

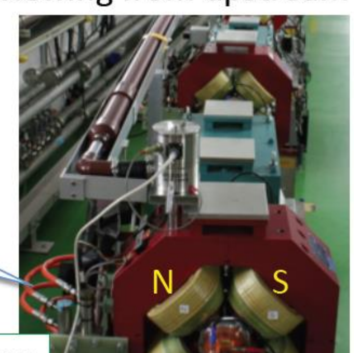


(1)Data taking starts from red position.
(2)Rotation direction is orange.
(3)Looking from the eocoder side.
From Lili, Feb.15, 2011

ATF2 beam line viewing from upstream

Power cable connection @ field measurements: Left terminal is +.

Hoses are on the left in this photo.



QM16

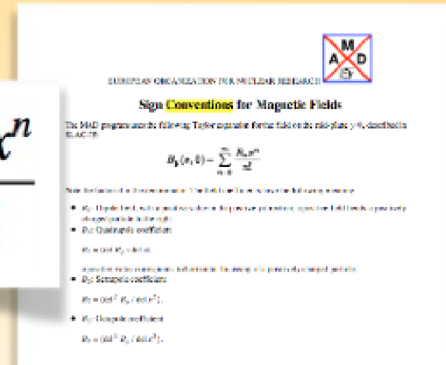
The issue of different notations!

Sugita Kei

Do you know the difference of *magnetic multipole representation*?

$$\mathbf{B} = B_y + iB_x = \sum_{n=1}^{\infty}(B_n + iA_n)\left(\frac{x+iy}{r_0}\right)^{n-1}$$

$$B_y(x,0) = \sum_{n=0}^{\infty}\frac{B_n x^n}{n!}$$


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Sign Conventions for Magnetic Fields

Magnet design: dipole n=1

Beam dynamics: dipole n=0

Exclude "n!" from Bn in beam dynamics definition

Both units T/m^n (T/m^{n-1}) is same!

n!

Dipole 0!=1

Quadrupole 1!=1

Sextupole 2! = 2

Octupole 3! = 6

We should respect each other!

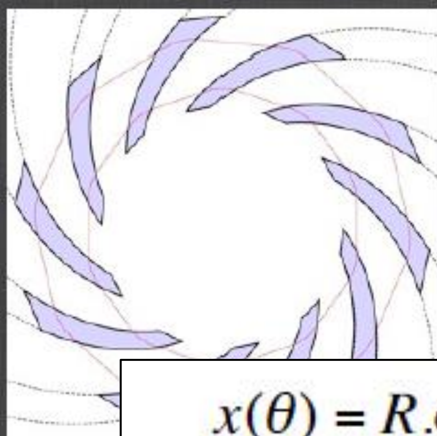
The definition should be described in the docs, specs.

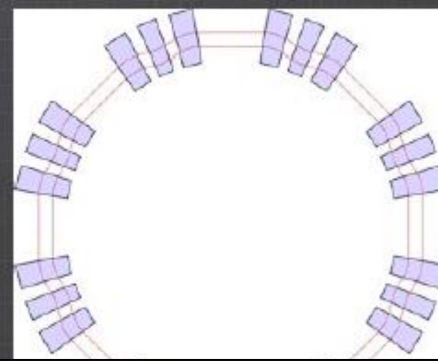
FFAG the working marriage of magnets and beam dynamics

J-B. Lagrange

Geometrical field index: $k = \frac{R}{\bar{B}}\frac{d\bar{B}}{dR}$

$$B(r,\theta) = B_0 \left(\frac{r}{r_0}\right)^k \cdot \mathcal{F}(\theta - \tan\zeta \ln \frac{r}{r_0})$$



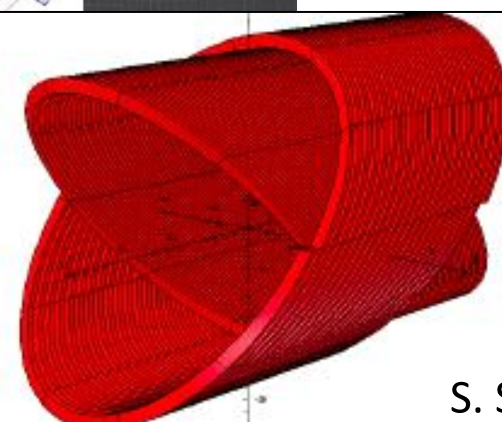


Spiral

$$x(\theta) = R.\cos(\theta)$$

$$y(\theta) = R.\sin(\theta)$$

$$z(\theta) = \frac{h\theta}{2\pi} + \frac{R}{\tan\alpha}\sin(n\theta + \varphi_0)$$

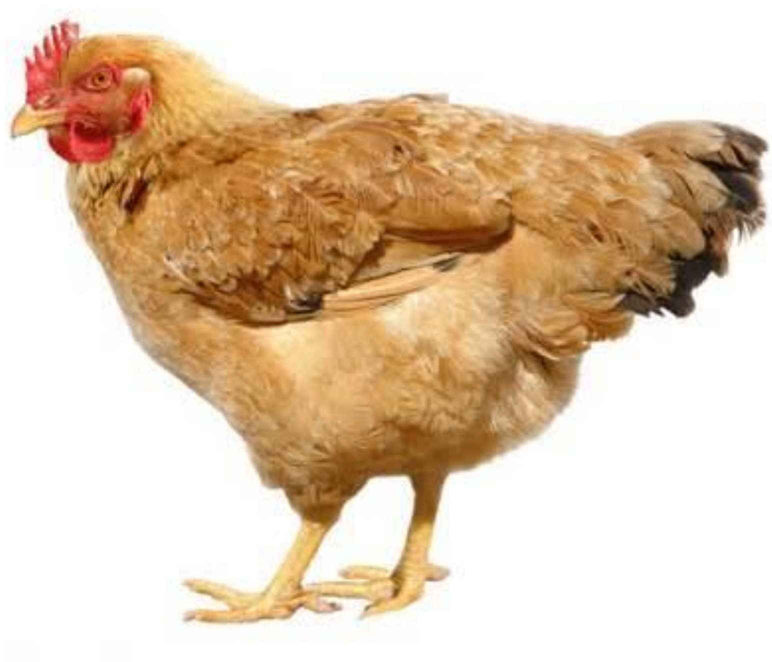


S. Sheehy

PAMELA Project Experience: superconducting helical coils

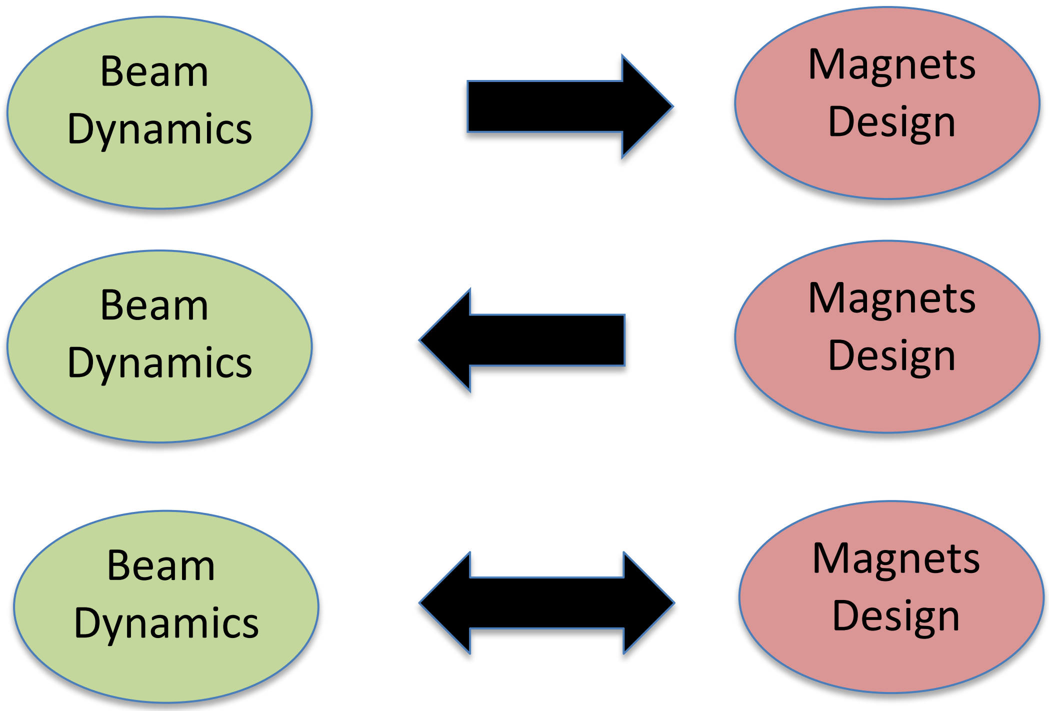
Summary

Which came first, the chicken or the egg ?



Both come first !

Project interplay

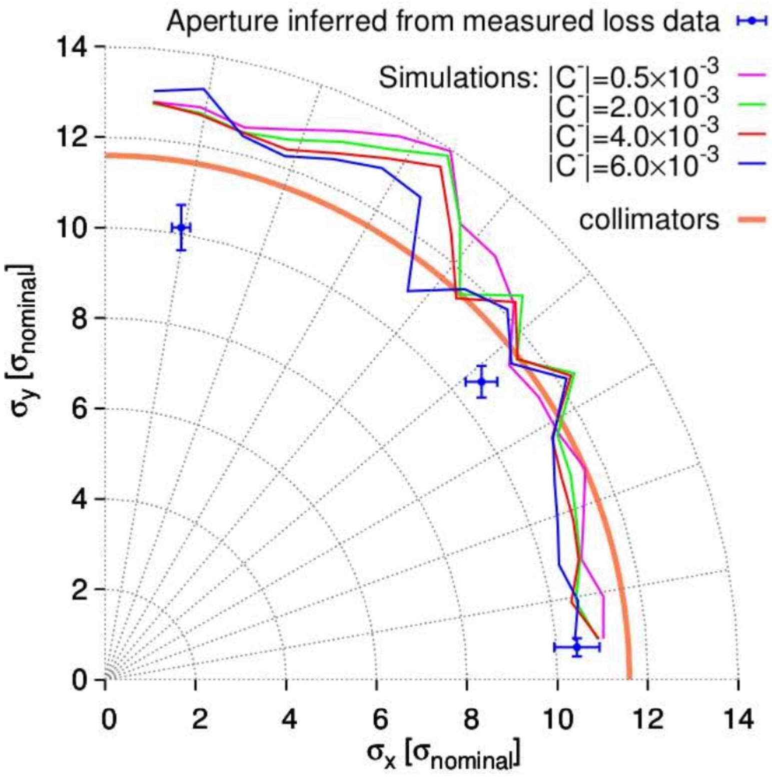


LHC

J-PARC, SIS100

ATF2

Beam Dynamics Verification



The LHC experience shows that
if all magnets are knows well, then
the dynamic aperture can be predicted
with very good accuracy

Theory can be trusted (physics works)

Strategies after magnets are ordered…

- High degree of competence and exchange of information
- Massive involvement of resources

Magnet sorting for LHC

ATF2

Quality assessment of magnets

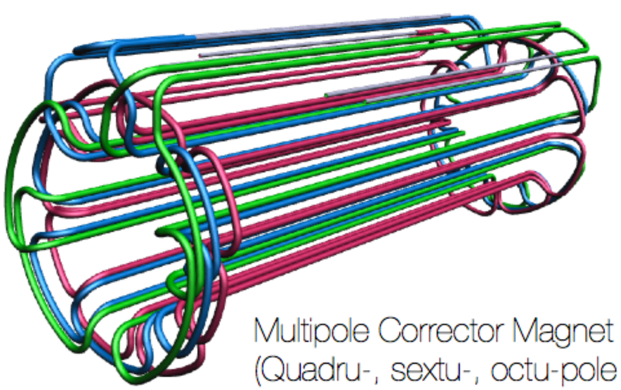
Magnets seen by two communities

For a Beam Dynamics person

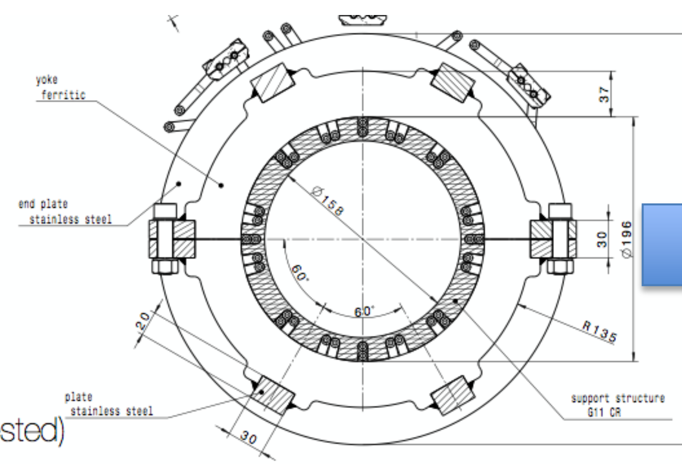
$$\begin{cases} \dfrac{d^2x}{ds^2} + \left(\dfrac{1}{\rho(s)^2} - k_1(s)\right)x = \mathrm{Re}\left[\displaystyle\sum_{n=2}^{M} \dfrac{k_n(s) + ij_n(s)}{n!}(x+iy)^n\right] \\ \\ \dfrac{d^2y}{ds^2} + k_1(s)y = -\mathrm{Im}\left[\displaystyle\sum_{n=2}^{M} \dfrac{k_n(s) + ij_n(s)}{n!}(x+iy)^n\right]. \end{cases}$$

→ k_n, j_n

For a Magnet person

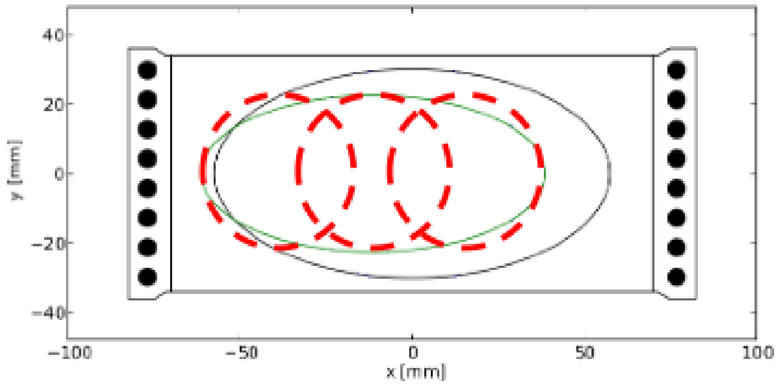


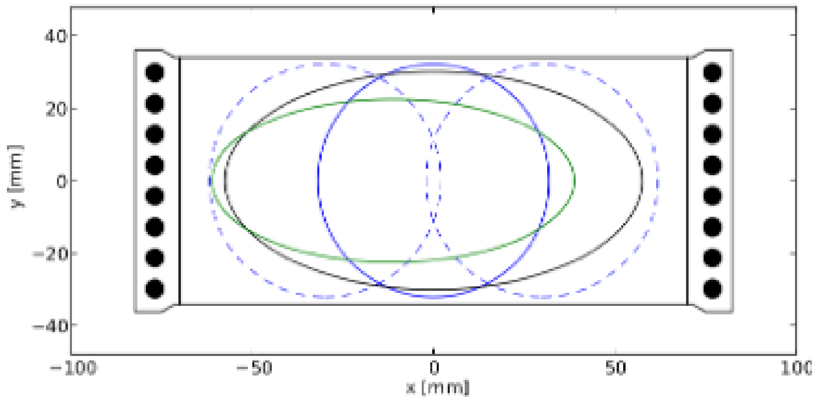
Multipole Corrector Magnet (Quadru-, sextu-, octu-pole nested)



→ B_x, B_y, B_z

Combining rotating coil probe measurements





Not a clear answer from the workshop

Outlook

There has been a general consensus that the discussion is not over and more aspects of the interplay between Beam Dynamics and Magnet should be commonly discussed

New workshop in 2014!
under the EuCARD-2 umbrella
but organized by the community

Thank you for the attention