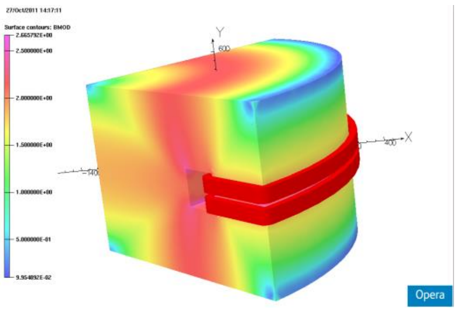
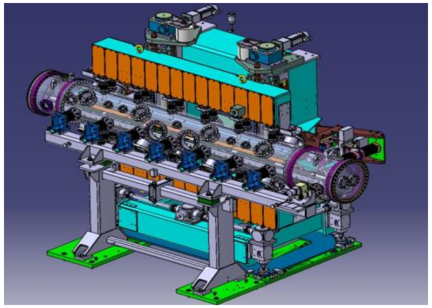
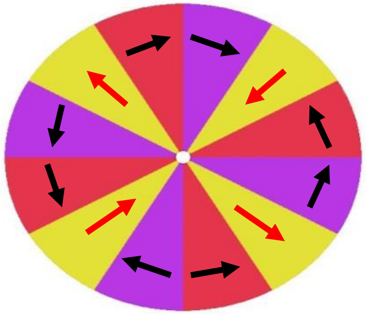
Undulators and magnetic elements of LUNEX5







Chamseddine Benabderrahmane

Synchrotron SOLEIL, France

FEL 2012 NARA

34th International Free Electron Laser Conference

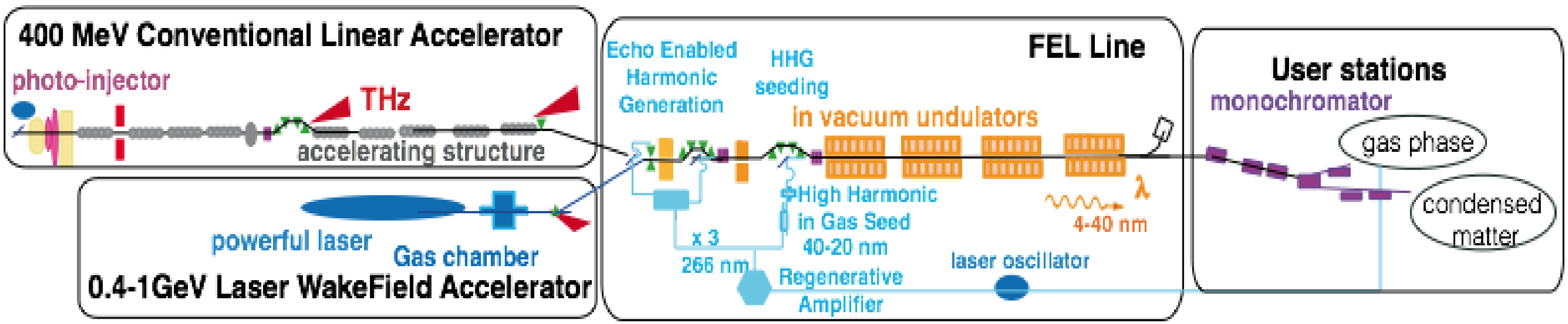
26-31 August 2012

Nara Prefectural New Public Hall, Nara, Japan

LUNEX 5 Project

LUNEX5

free electron Laser Using a New accelerator for the Exploitation of X-ray radiation of 5th generation



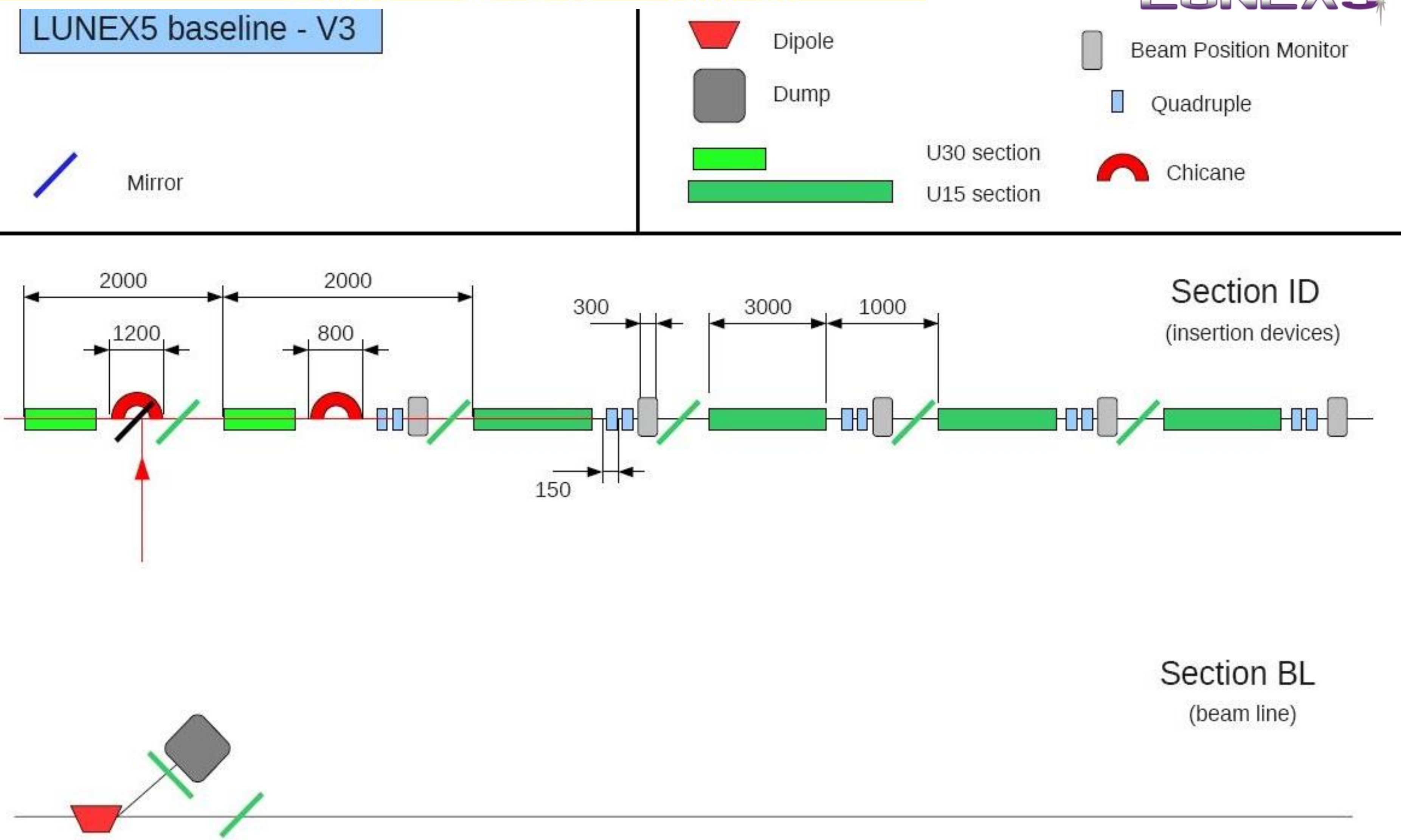
0.4-1 GeV, emittance 1 π nmrad, 1 ps - 10 fs

M.E. Couprie Talk FROA03

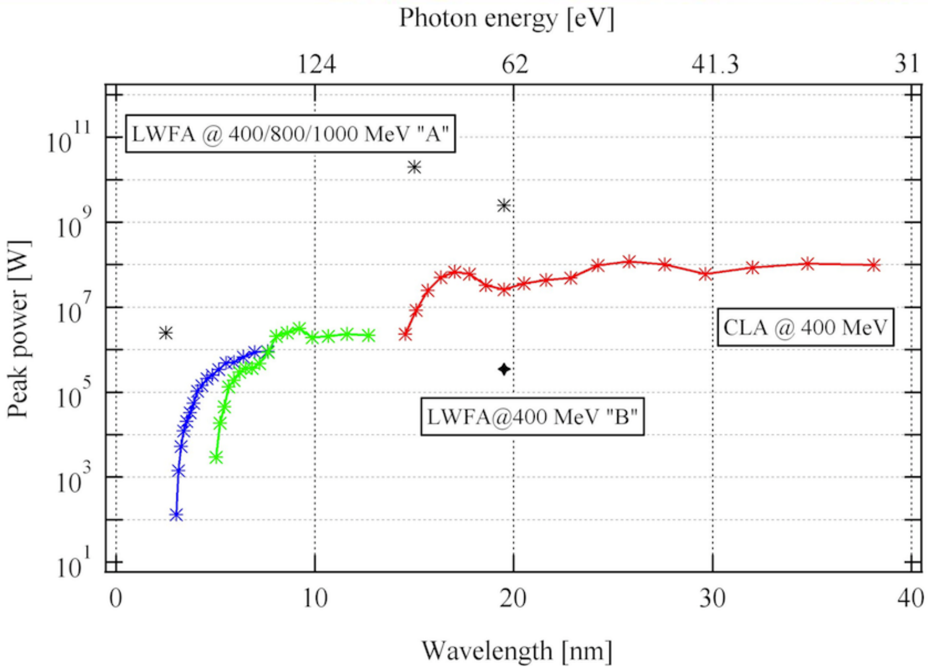
- Low energy FEL beam → Short period high field undulators
- High diverging LWFA beam → Compact high gradient quadrupôles

M.E. Couprie et al., IPAC 2011, Proced. 13th International Conference on X-ray Lasers, Paris, June 11-15, 2012

Undulator Implementation scheme



LUNEX 5 undulators



400 MeV
slice energy spread CLA : 0.02 %, LWFA : 0.1 %
1.5 π mm.mrad emittance : CLA : 1.5, LWFA 1
peak current : CLA : 400 A, LWFA : 10 kA, 50 pC
electron bunch length : CLA : 1 ps, LWFA : 2 fs

$$\lambda = \frac{\lambda_0}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

M. Labat talk FROBI01
C. Evain poster WEPD14
T. Tanikawa poster TUPD05

For low energy FEL beam 400 MeV

To reach short wavelength energy we need to use short period high field undulators

In-vacuum and cryogenic undulators

M.E. Couprie et al., IPAC 2011, Proced. 13th International Conference on X-ray Lasers, Paris, June 11-15, 2012

Cryogenic undulators

- CPMU (Proposed by SPring-8) takes benefit from improved magnetic properties of $RE_2Fe_{14}B$ at cryogenic temperatures.

- Cooling down permanent magnet increases the remnant magnetisation and the intrinsic coercivity

  - The increase of $Nd_2Fe_{14}B$ remnant magnetisation is limited by the appearance of Spin Reorientation Transition phenomenon. CPMU working temperature is around 140 K.
  - The increase of $Pr_2Fe_{14}B$ remnant magnetisation is not limited because of the absence of SRT phenomenon. CPMU working temperature is at liquid nitrogen one 77 K.

  C. Benabderrahmane et al., $Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnets characterisation and modelling for Cryogenic Permanent Magnet Undulator applications. ***Nucl. Instr. And Meth. (2012) A 669, 1-6***

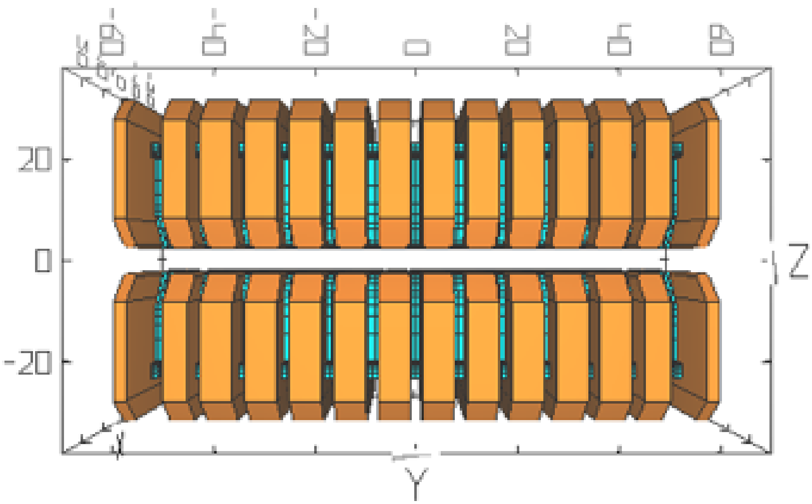
- CPMU is an adaptation of an in vacuum undulator with a cooling system and a dedicated low temperature magnetic bench

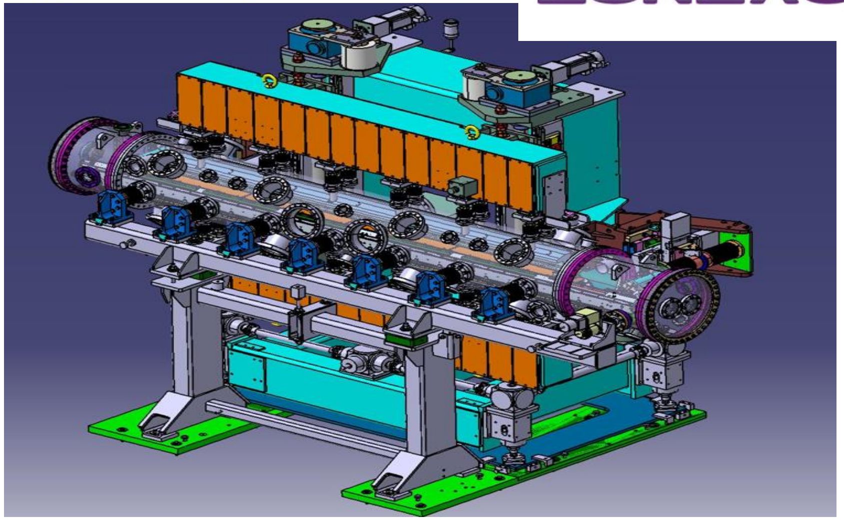
Cryogenic undulator state of the art

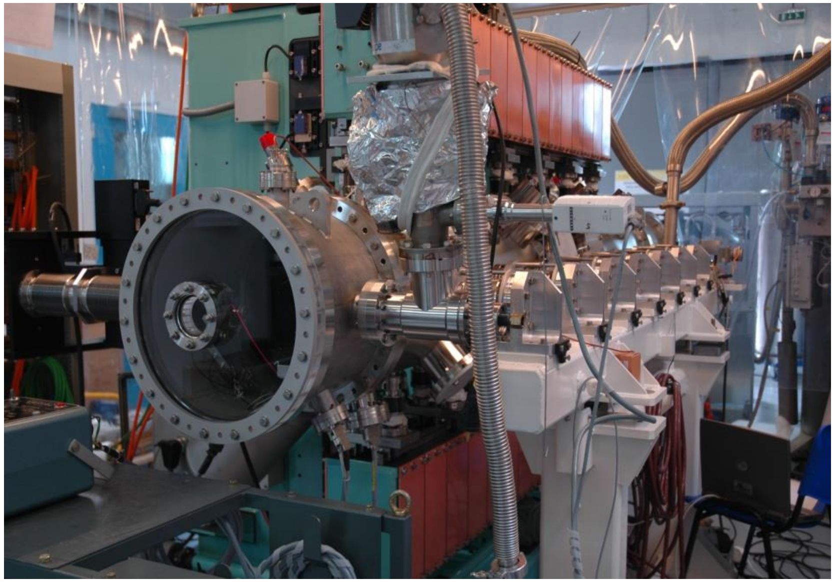
	λ_u (mm)	type	PM	B_r (T)	H_{cj} (kA/m)	L (m)	Baking	T (K)
ESRF* (1)	18	FS	$Nd_2Fe_{14}B$	1.18	2400	2	Yes	**150**
ESRF*(2)	18	FS	$Nd_2Fe_{14}B$	1.37	1355	2	No	**150**
Danfysik*/Diamond	17.7	FS	$Nd_2Fe_{14}B$	1.31	1670	2	No	**150**
SPring-8*/SLS	14	FS	$Nd_2Fe_{14}B$	1.33	1670	2	No	**135**
SOLEIL*	18	FS	$Pr_2Fe_{14}B$	1.35	1355	2	No	**77**
SPring-8***	15	P	$Nd_2Fe_{14}B$	1.41	1114	0.6	No	**135**
SOLEIL***	20	P	$Nd_2Fe_{14}B$	1.41	1114	0.1	No	**145**
SOLEIL***	18	P	$Pr_2Fe_{14}B$	1.35	1355	0.1	No	**77**
NSLS II***		P	$Pr_2Fe_{14}B$				No	
UCLA/BESSY***	**9**	**P**	**$(Pr_{0.8}Nd_{0.2})Fe_{14}B$**	**1.41**	**1040**	**0.18**	**No**	**30**

* constructed in house   *** Laboratory prototypes

2 m $Pr_2Fe_{14}B$ Cryogenic undulator



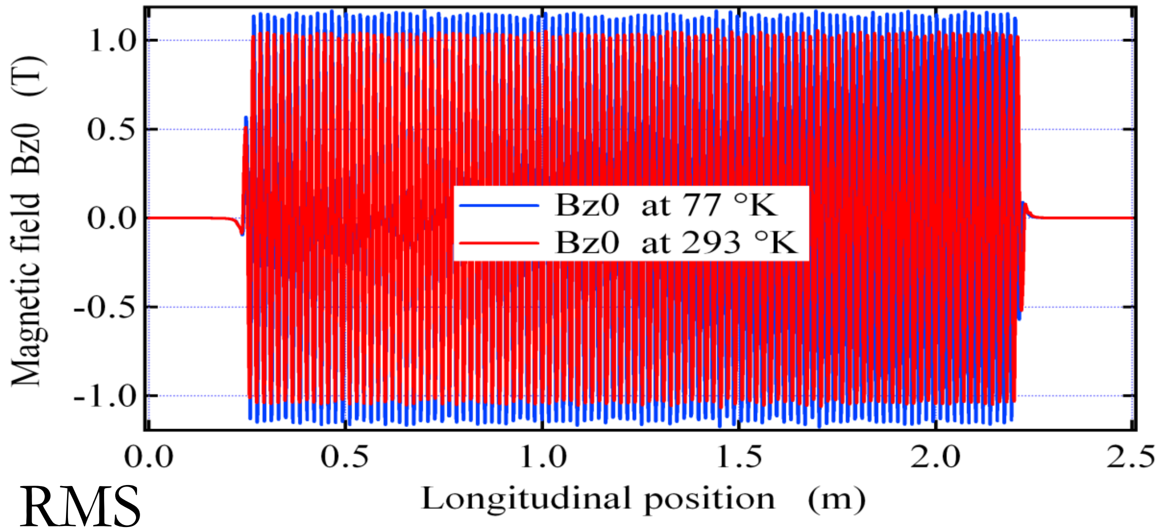




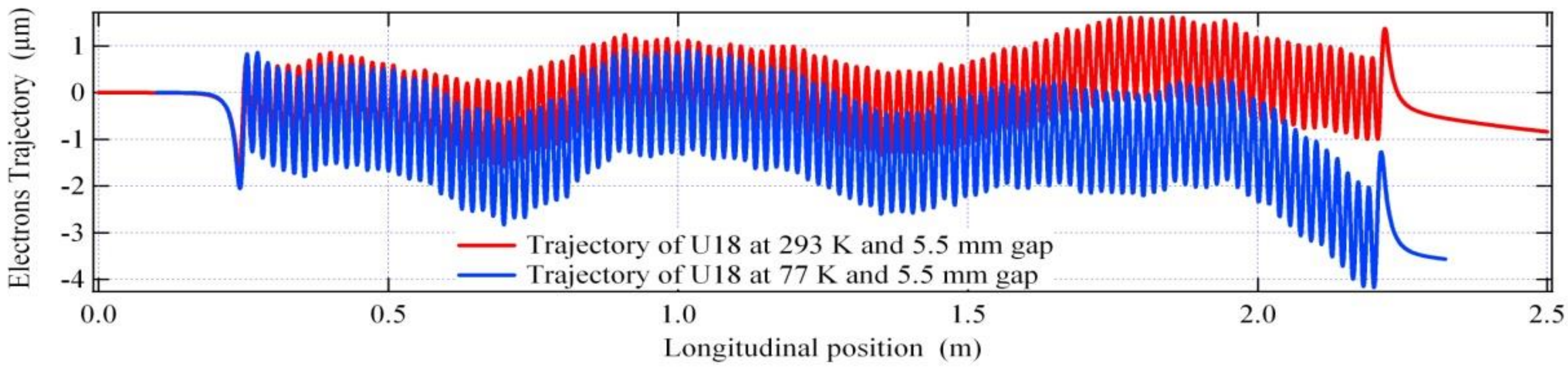
PM	$Pr_2Fe_{14}B$
Pole	Vanadium P
Period:	18 mm
N° periods:	107
Bz_0:	1.15 T à 77 K
K:	1.9
Gap min:	5.5 mm

2 m $Pr_2Fe_{14}B$ Cryogenic undulator

Gain of 10 %
on the magnetic peak field
between 293 K and 77 K

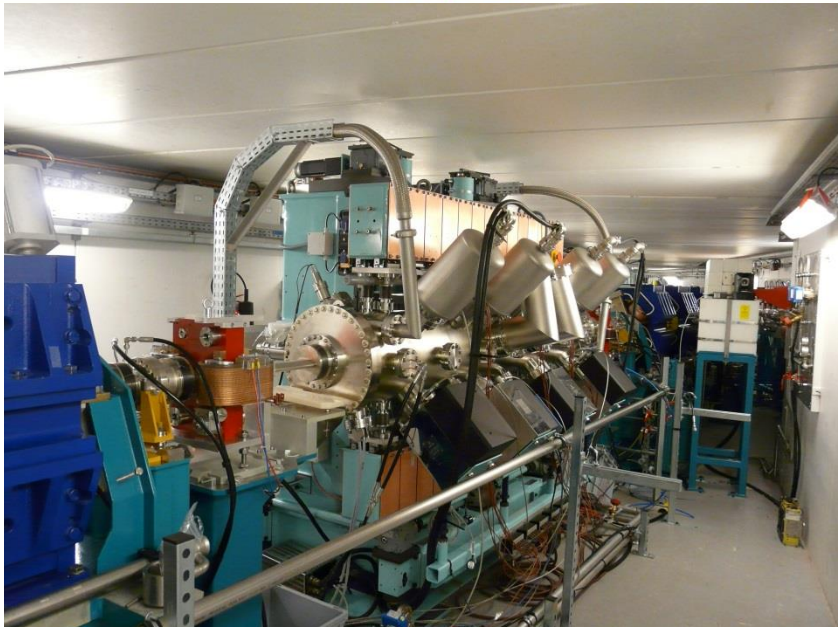


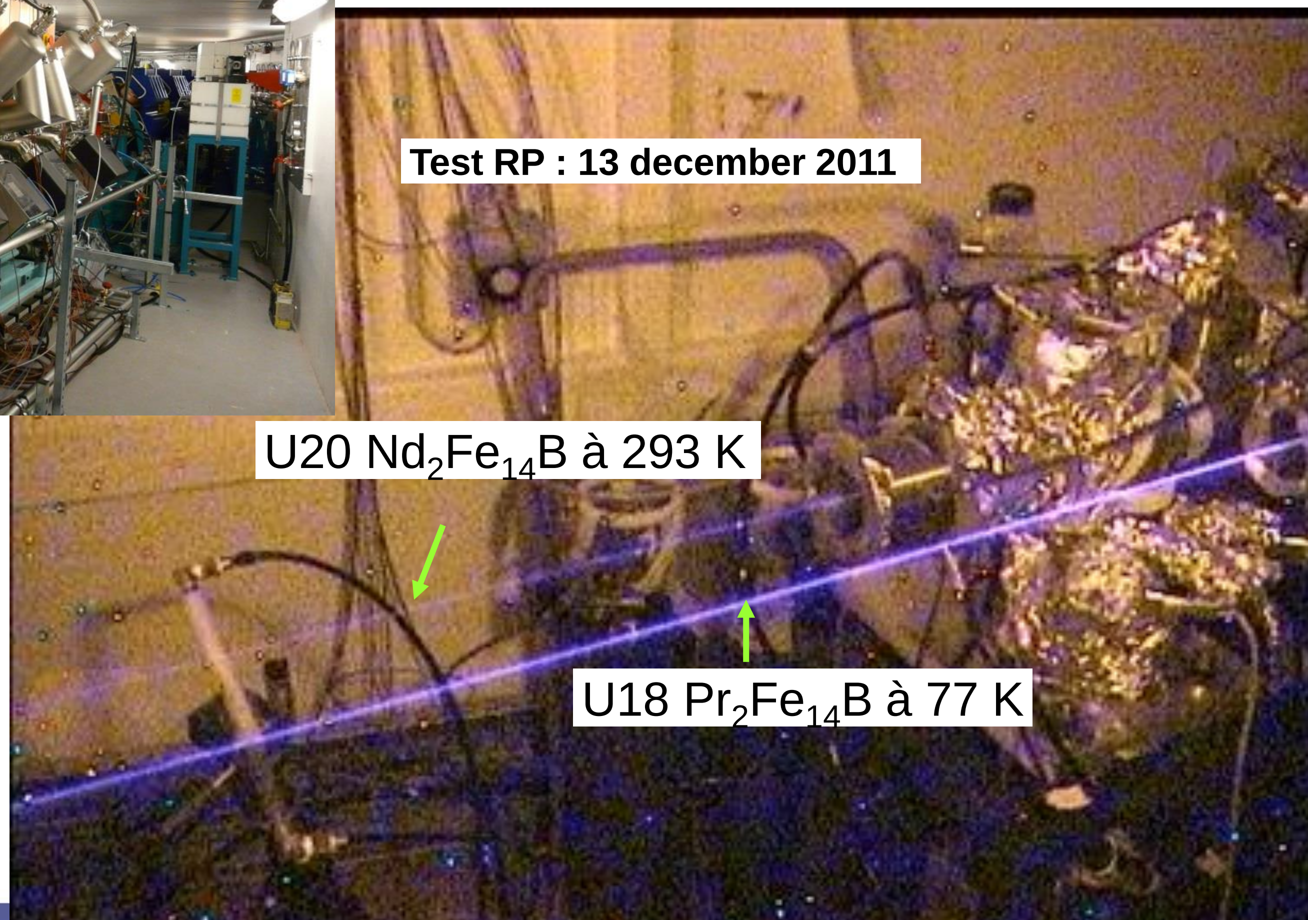
Phase error at 77 K is 3° RMS



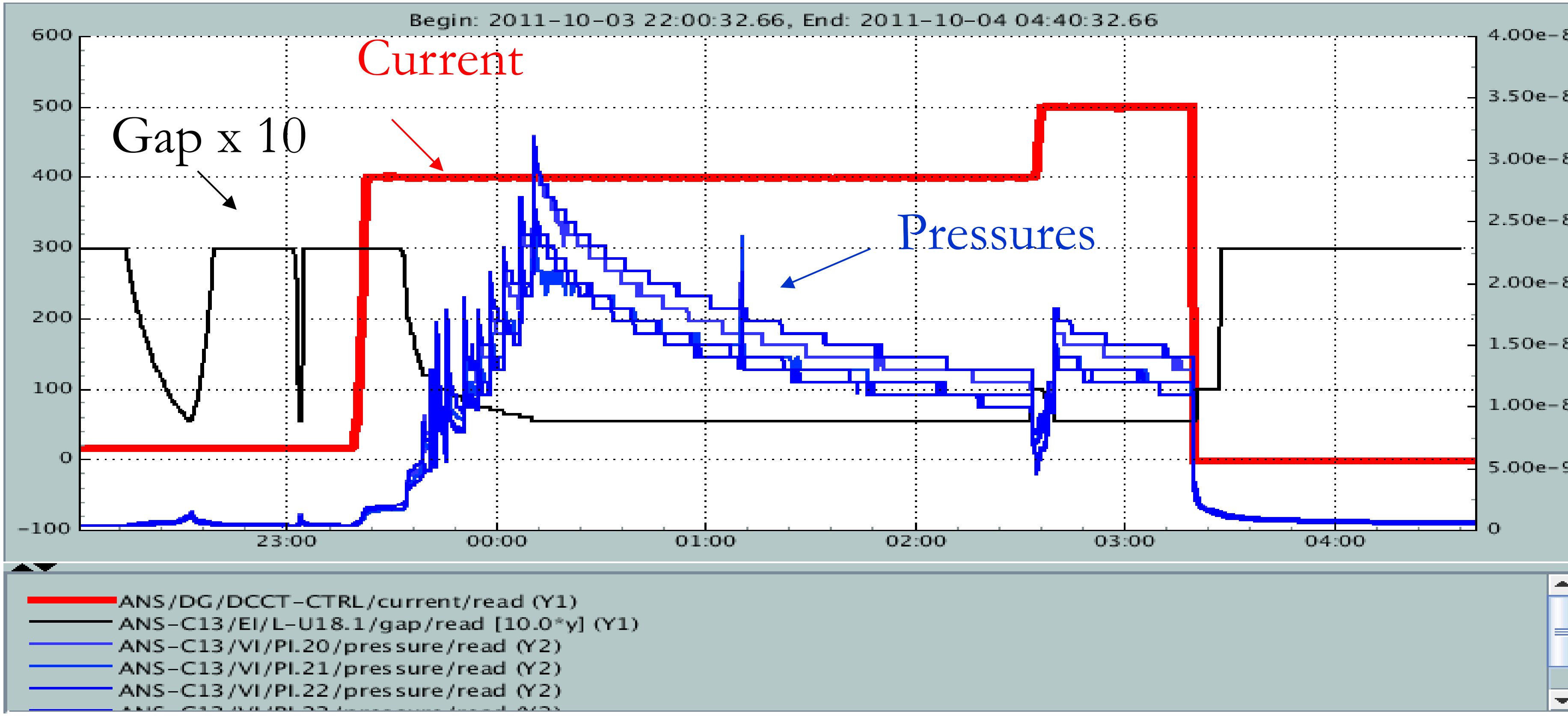
Correction of the electron trajectory angle (9 µm) at 77 K

2 m $Pr_2Fe_{14}B$ Cryogenic undulator



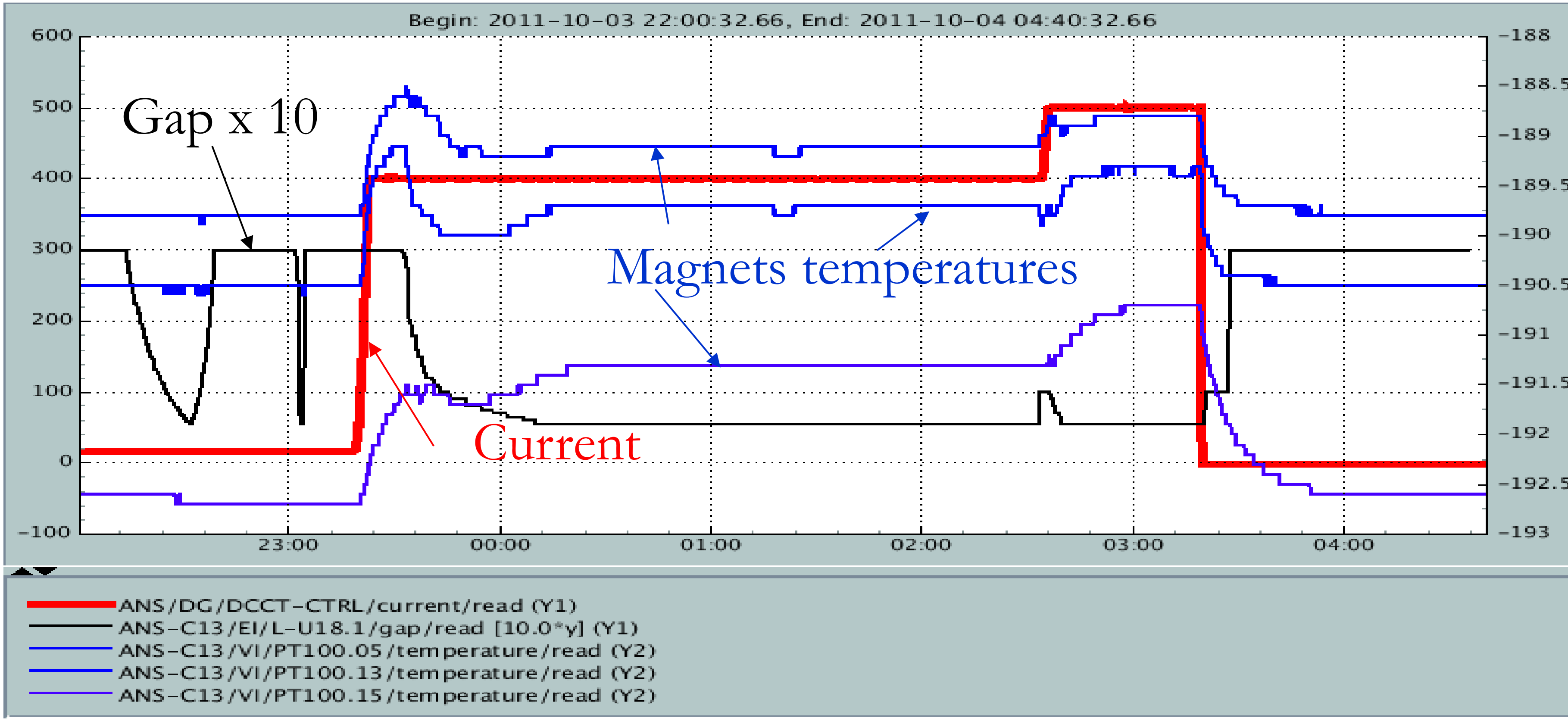


Commissioning



- No baked CPMU with low vacuum pressure due to the cryo pumping
- Gap closed for the first time with in 40 min (Beam 400 mA)
- Vacuum pressure grows when the temperature increases

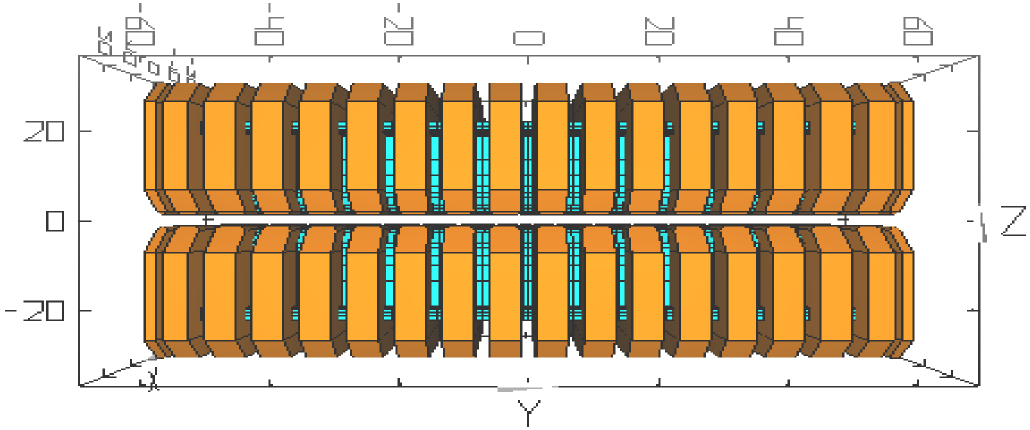
Commissioning

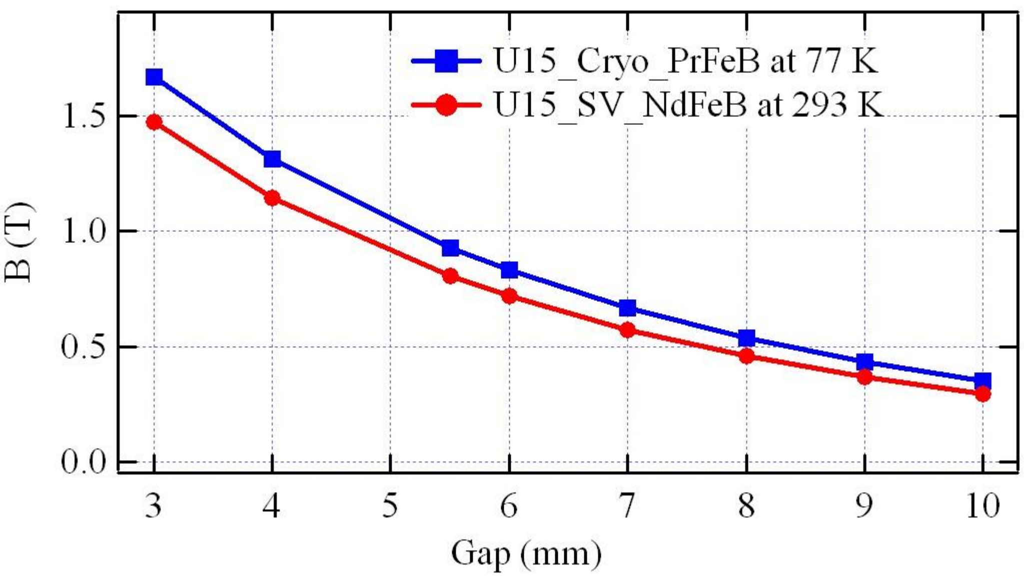


Thermal gradient on the magnetic system **< 1.5 K/m**

Total temperature variation due to electron beam (400 mA) and gap variation **< 2.5 K**

Radiator Undulators

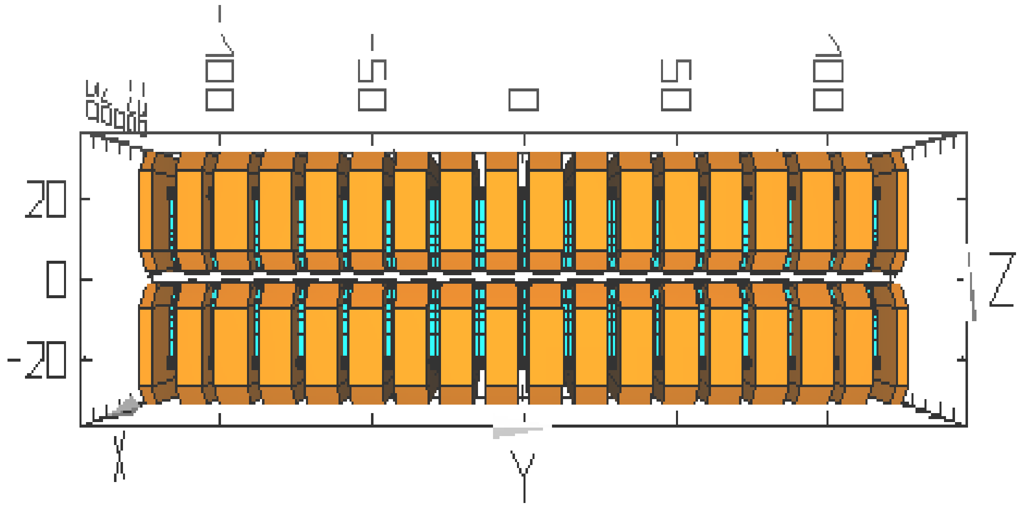


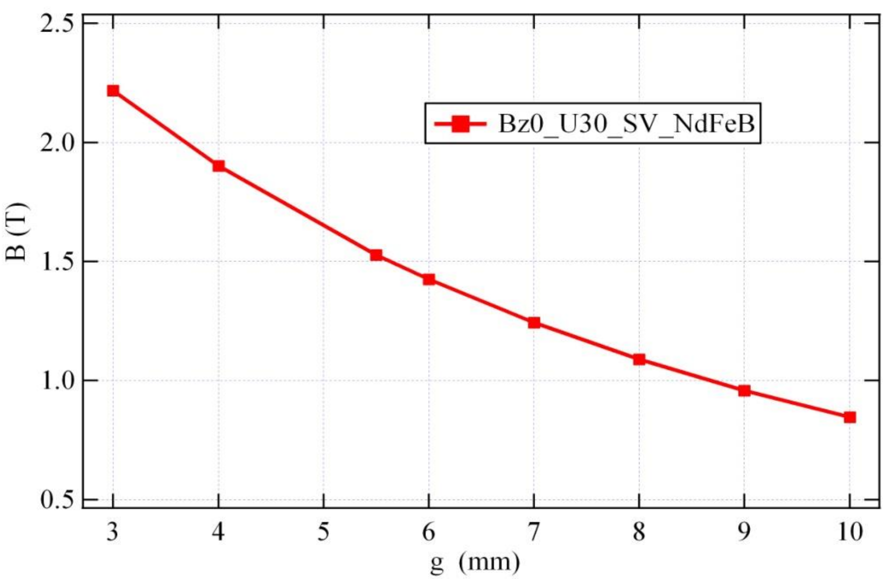


Type	In- vacuum
PM	$Nd_2Fe_{14}B$
Pole	Vanadium P
Period:	15 mm
N° periods:	200
Bz_0:	1.5 T
K:	2.10
Gap min:	3 mm
Magnetic length:	3000 mm
Number:	4

Type	CPMU at 77 K
PM	$Pr_2Fe_{14}B$
Pole	Vanadium P

Modulator Undulators





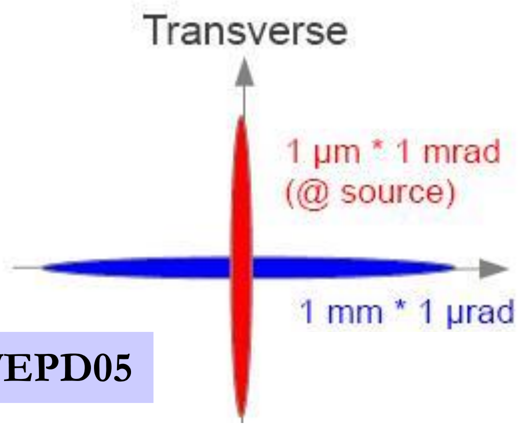
Type	In- vacuum
PM	$Nd_2Fe_{14}B$
Pole	Vanadium P
Period:	30 mm
N° periods:	9
Bz_0:	2.2 T
K:	6.25
Gap min:	3 mm
Magnetic length:	270 mm
Number:	2

LWFA-Undulator beam transport

Laser Wake Field Acceleration beam

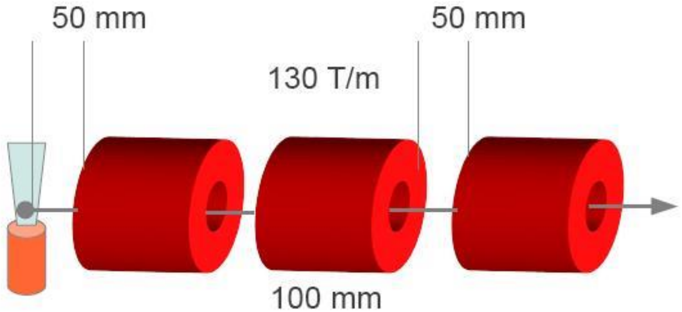
CLA/LWFA

- Very short
- Strongly diverging
- Large relative E-spread



Compact permanent magnets
Spaced by 50 mm

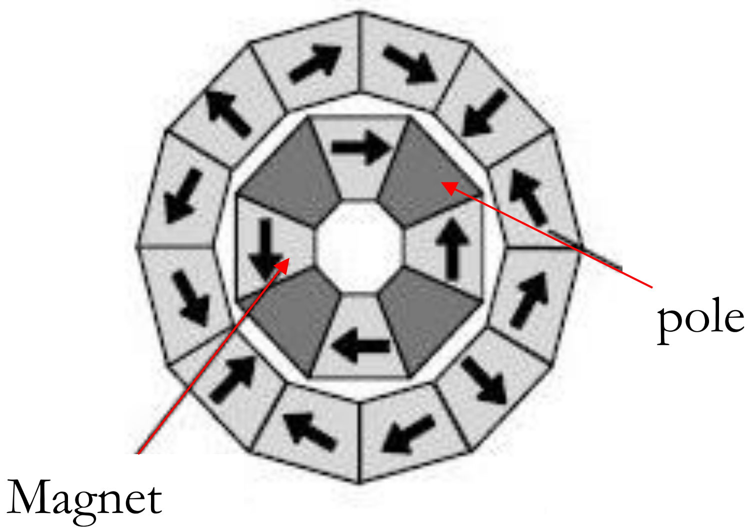
A. Loulergue poster WEPD05



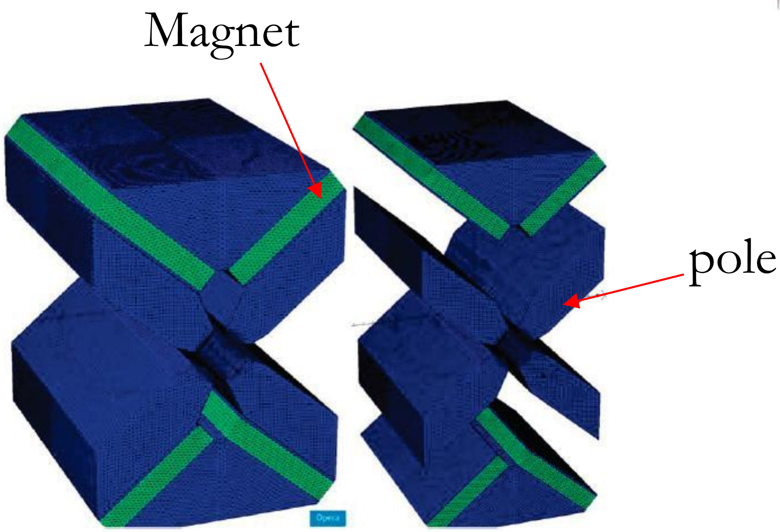
	Source	Normal quad layout	Compact quad layout
Norm. H emittance	1	23	6.7
Norm. V emittance	1	35	11
Length	2 fs	12 fs	4.2
Peak current	4 kA	1 kA	2.2 kA
Max gradient	-	20 T/m	120 T/m

Compact variable high gradient permanent magnet quadrupôle

Permanent magnet quadrupôle



Bore diameter: 20 mm
Gradient: 115 T/m – 17 T/m

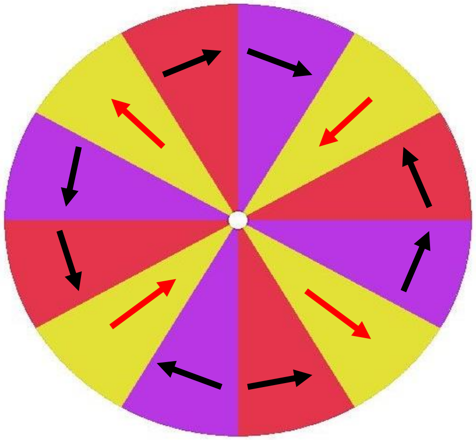


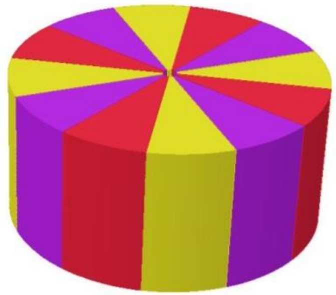
Bore diameter: 13.6 mm
Gradient: 60.4 T/m – 15 T/m

B.J.A. Shepherd et al, Construction and measurement of novel adjustable permanent magnet quadrupoles for CLIC, *Proceeding of IPAC 2012, New Orleans, USA*

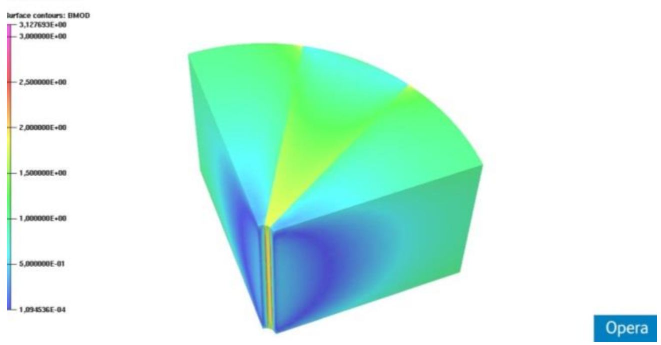
Y. Iwashita et al, Super strong adjustable permanent magnet quadrupole for the final focus in the linear Collider. *Proceeding of EPAC 2006, Edinburgh, Scotland*

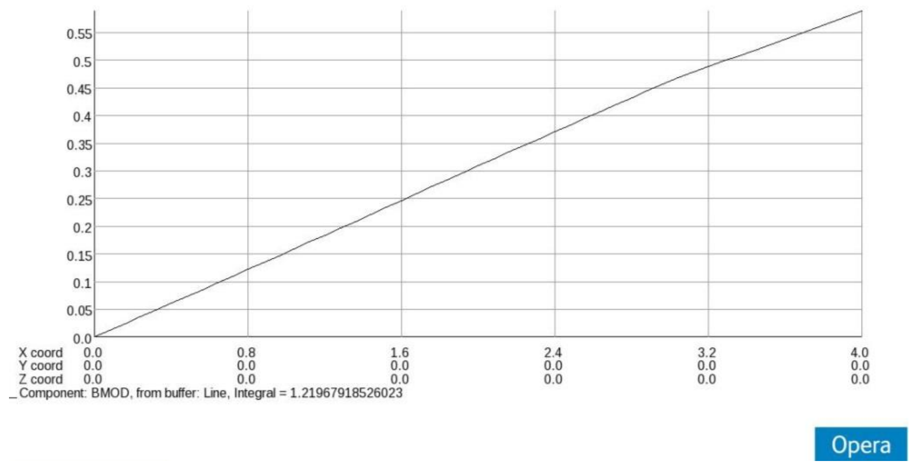
Permanent magnet quadrupôle





Permanent magnet quadrupôle
Based on HALBACH configuration
Inner diameter: 10 mm
Thickness: 100 mm
Height: 100 mm
Gradient 150 T/m



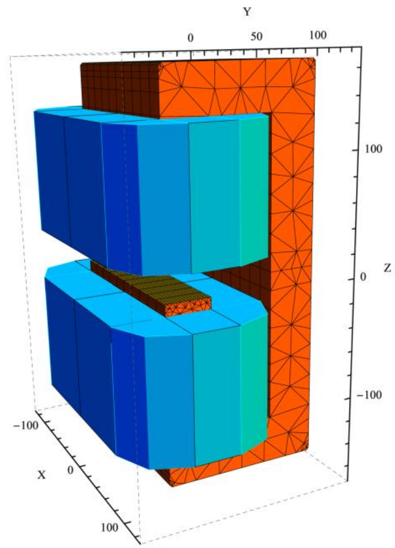


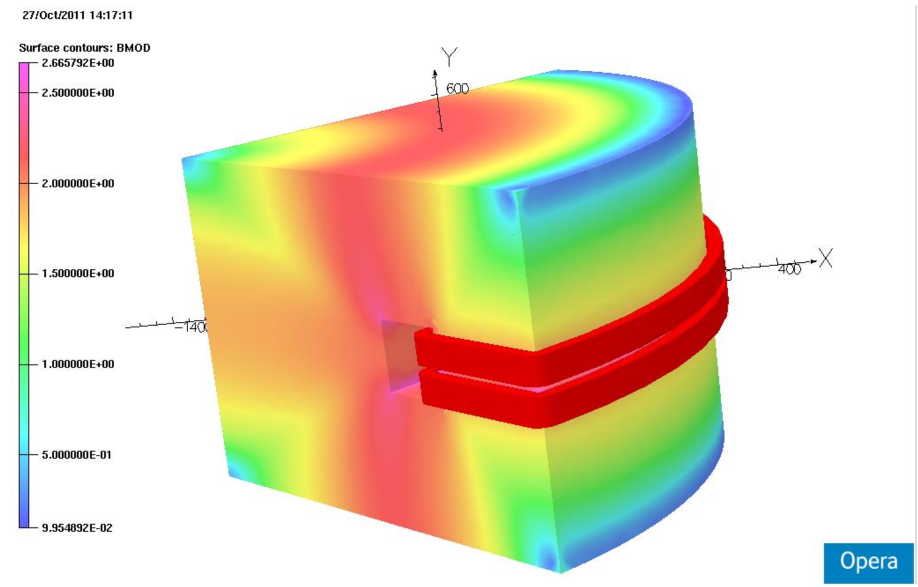
Founded from RTRA "Triangle de la physique" to develop a compact, strong and variable gradient permanent magnet quadrupole

Conventional magnetic elements

Chicane dipole

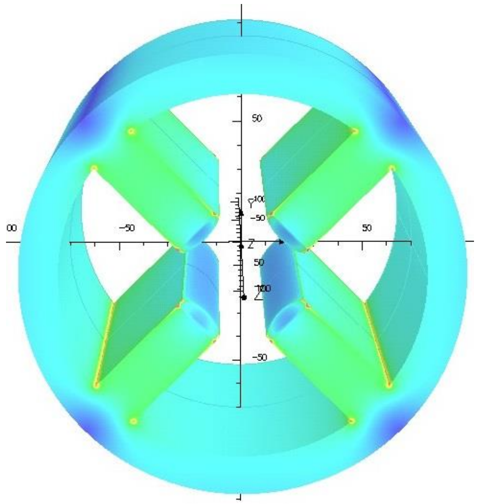
Air cooled dipole
Density = 1.5 A/mm²
B_{Z0} = 0.35 T





Quadrupoles

Tosca model
Gradient : 5 T/m



Beam dump dipole

Water cooled dipole
Density = 5 A/mm²
B_{Z0} = 1.6 T

Conclusion and perspectives

- Development of a 3 m Cryo-Ready in-vacuum undulator, design of magnetic system, carriage and adaptation of the vacuum chamber
- Characterisation of $(Nd_{1-x}Pr_x)_2Fe_{14}B$ permanent magnet
- Study of short period undulator between 15 mm and 12 mm
- Development of a variable gradient permanent magnet quadrupole
- Detailed design of dipoles, quadrupoles, chicanes and correctors

Thank you for your attention