1- ESRF today

2- Upgrade context

3-ID developments

4- Summary

J.Chavanne

On behalf the ESRF ID group

ESRF IDs todays

89 magnetic assemblies

39 standard 1.6 m/1.4 m devices

17 revolver type undulators

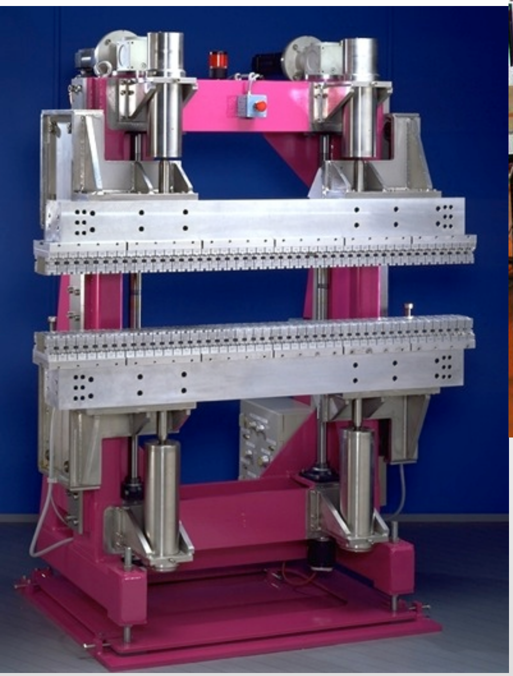
12 in-vacuum undulator/CPMUs

4 helical undulators (ESRF and APPLE II type)

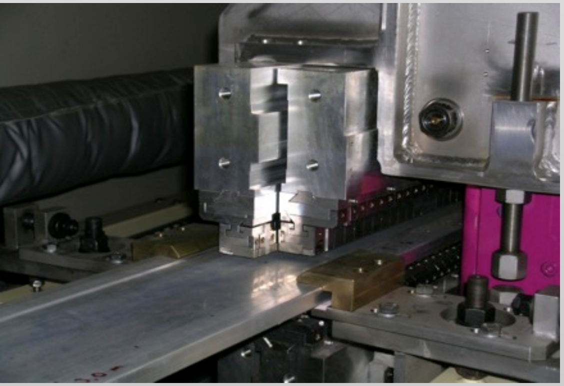
Permanent evolution of IDs since since more than 15 years

Example of ID types

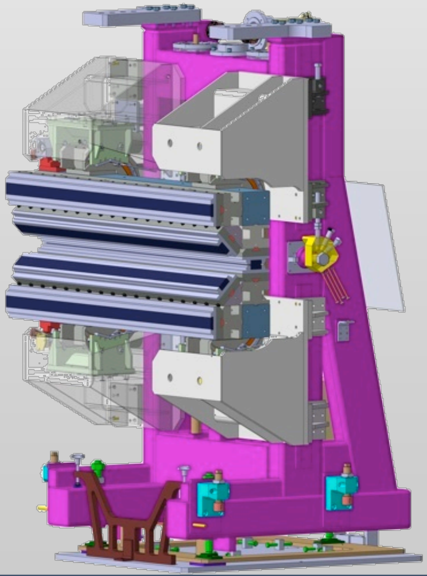
Standard undulator

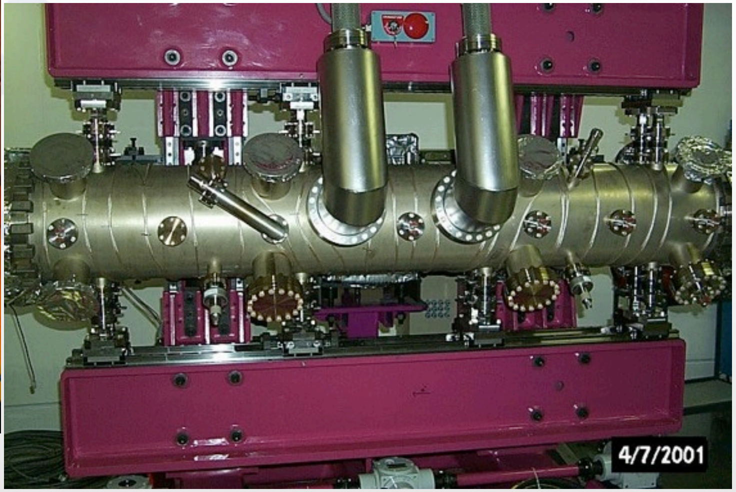


Helical undulators

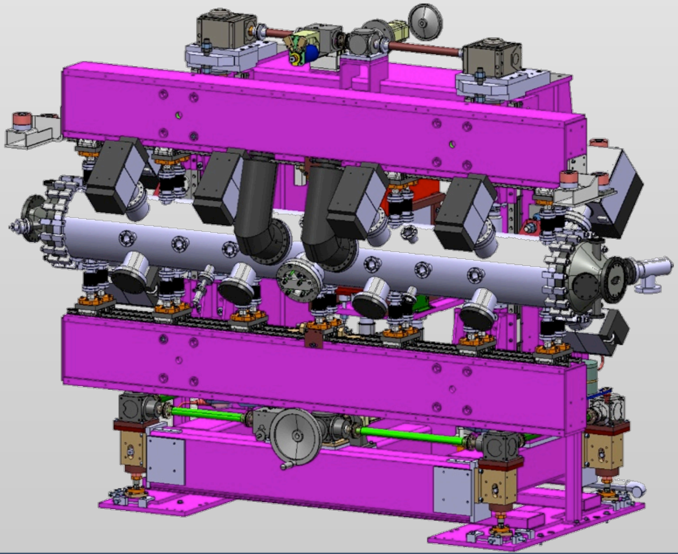


Revolver undulators

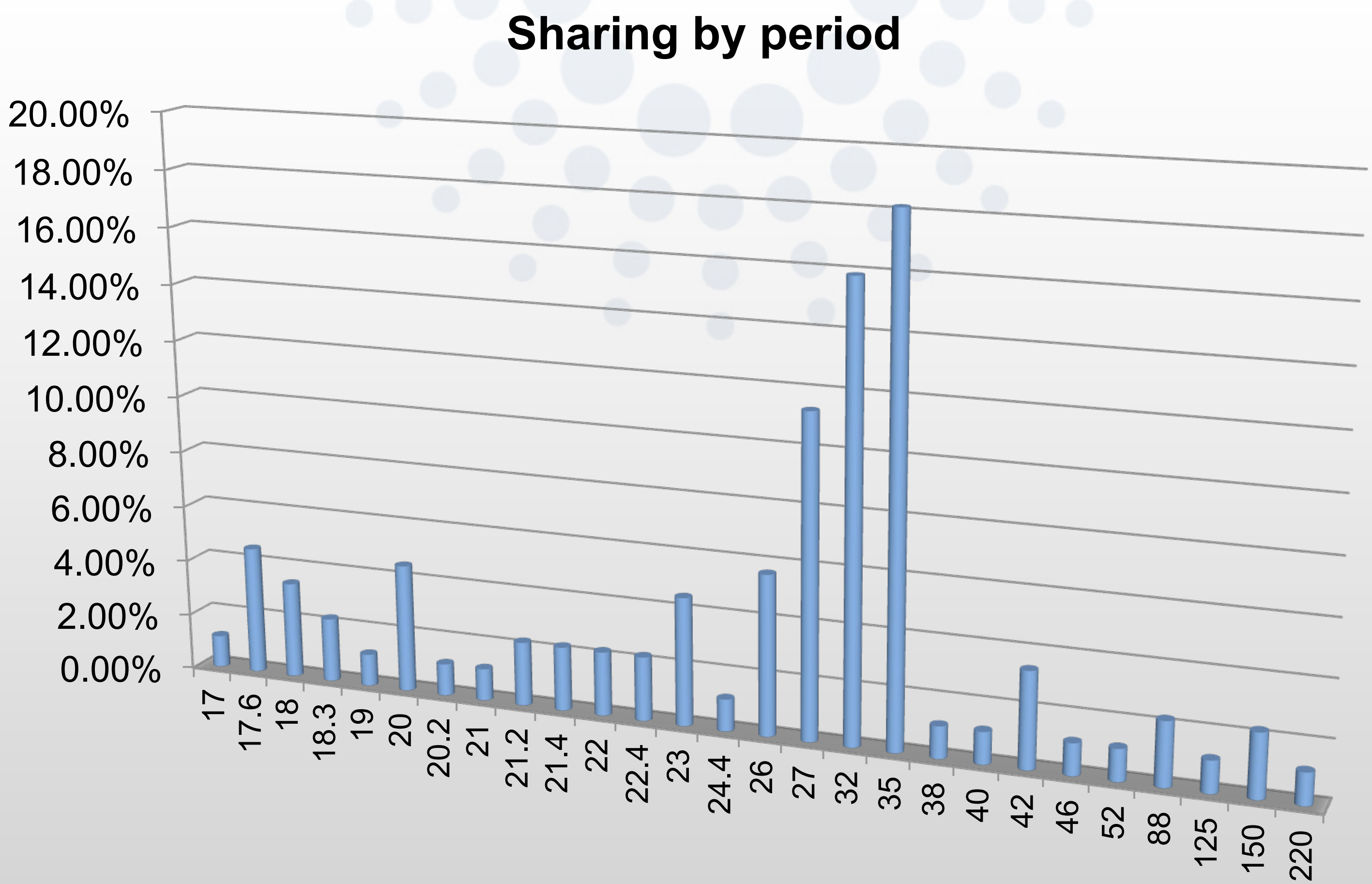




In-vacuum undulators



IDs need to be "specialized"

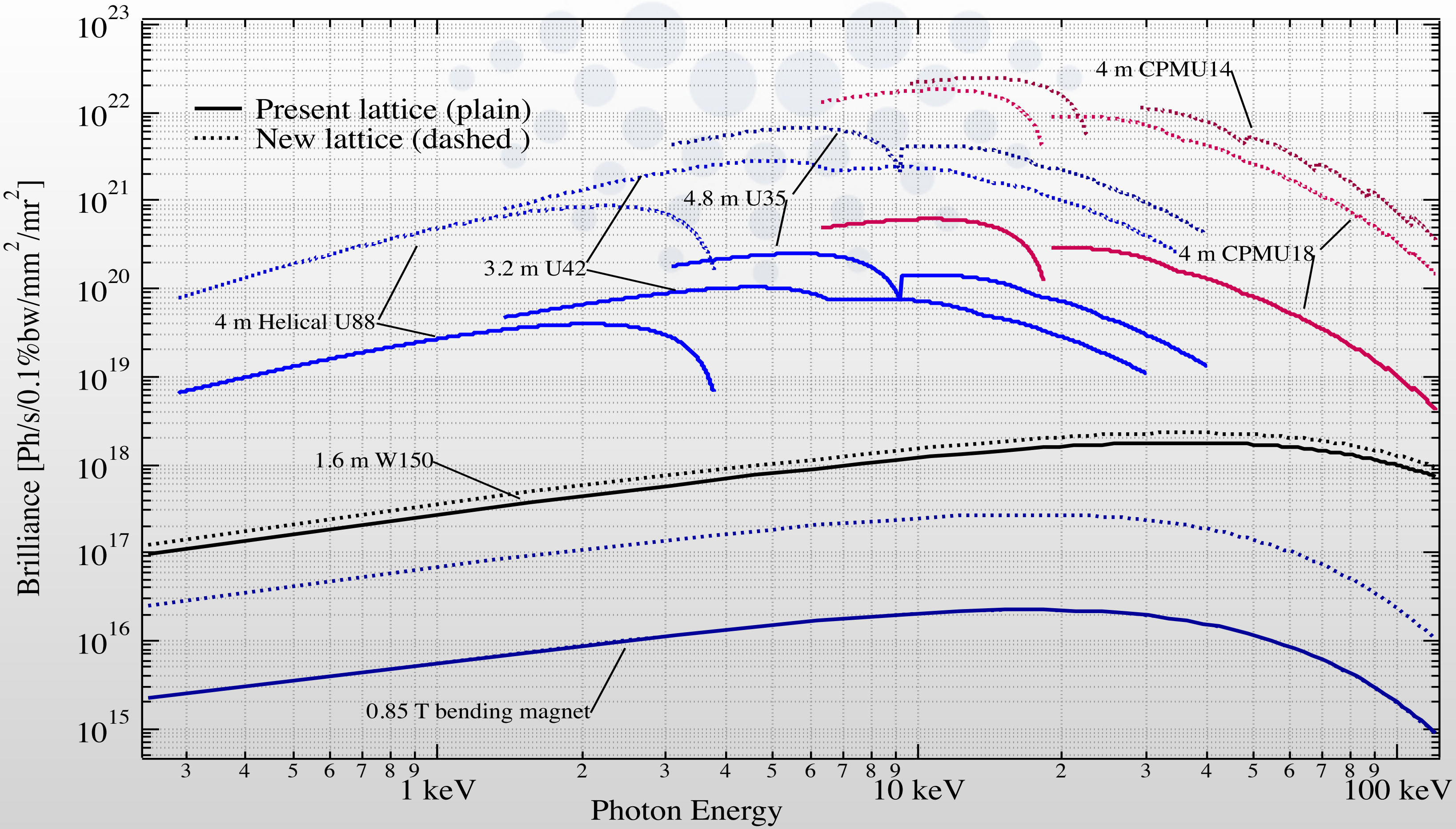


ESRF has a large range of ID period (require flexible designs)

A logical consequence of beamline specialization

Brilliance

Billiance improved by a factor higher than 28 above 10 keV



	Emittance	Coupling [%]	Energy spread [%]
Present	4 nm	1.2	0.1
New lattice	0.15	2	0.1

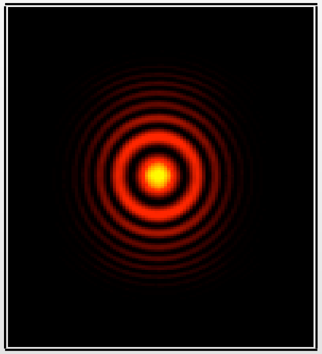
Electron beam:
6 GeV
I=0.2 A

Few comments on photon beamsize,divergence, emittance …

Up to now :

Single electron emission from undulators generally described as Gaussian beam

$\varepsilon_p = \frac{\lambda}{4\pi}$ is true if and only if beam is Gaussian



Undulator beam (single electron) is not Gaussian [1]

- has transverse interference pattern
- Often hidden by the electron beam emittance
- Need to be properly taken into account at some stage for future USRs
- **this has impact on the evaluation of the brilliance**

For an undulator, the photon beam emittance (single electron emission) depends strongly on detuning from on axis resonance , it is minimum close to resonance with a value approximately given by :

$$\varepsilon_p \approx \frac{\lambda}{2\pi}$$

[1] K.J Kim NIM A, 246, 71 (1986)

ID field quality (1)

Two classes of errors and associated corrections

- Impact on beam dynamics/ integrated multipoles shimming
- Impact of X-ray spectral quality for undulators/ phase shimming

Impact on beam dynamics random + systematic :
mostly COD (integrated dipoles) and vertical emittance perturbations (skew quads)

Closed orbit stabilized to about 1% of horizontal photon beam size
Using presently :
- high quality passive ID field correction
- active feed forward correction in some case (10%)
- orbit feedback

Users have caught the improvement, will probably not relax on this feature for new accelerators.

ID field quality (2)

Very small emittance rings

IDs & Beam stability

- ID field integrals specs can be too small to be reasonably achieved
- Will need systematic feed forward+ orbit feedback
- Helical undulators may need some more detailed investigations

Not discussed but possibly important:
Magnetic environment in straight section : background field, magnetic materials in ID & magnet fringe field, ion pumps … etc

  - Several issues already seen & cured at ESRF

X-ray spectral quality:

Present achievements (1-3 degree rms phase error) is sufficient for new low emittance machines:

- undulator spectral quality still largely dominated (on high harmonics ≥ 7) by emittance + energy spread.

Energy Spread

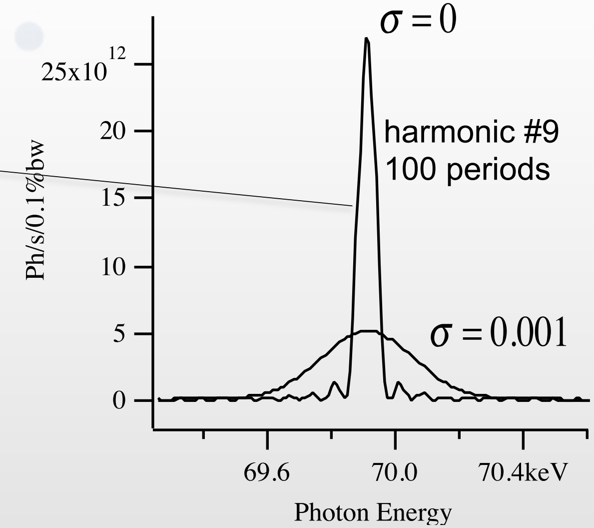
Is a limiting factor for using high undulator harmonics

Relative electron beam energy spread (rms) : $\sigma = \dfrac{\sigma_\gamma}{\gamma}$

Undulator with N periods

$$\left(\frac{Sin(\pi N\Delta E / E_1)}{\pi N \Delta E / E_1}\right)^2$$

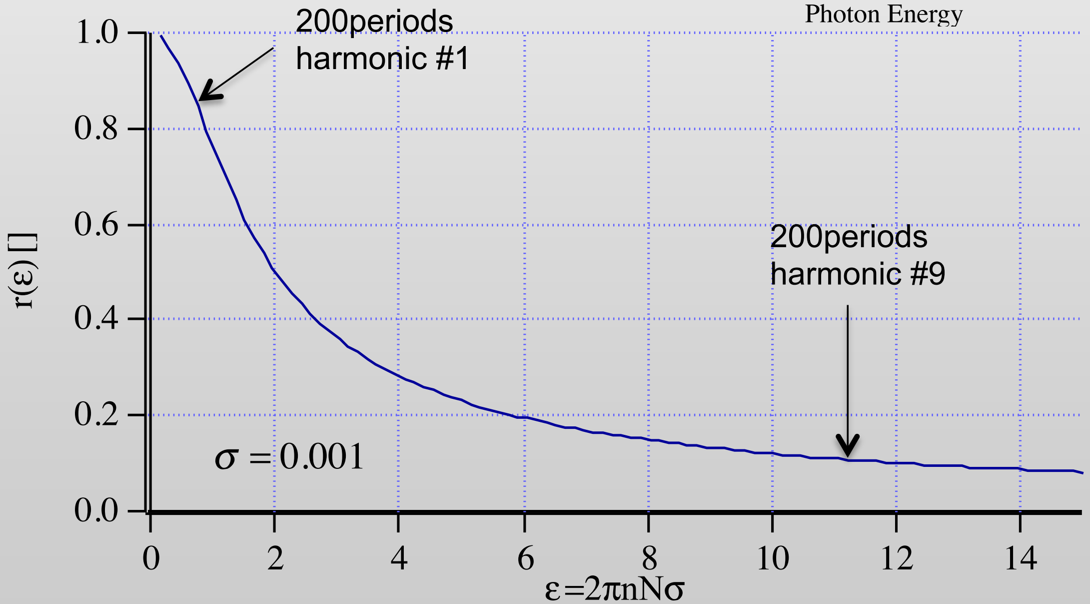
$$\Delta E = E - nE_1$$



Reduction factor at harmonic n due to energy spread:

$$r(\varepsilon) = \frac{e^{-2\varepsilon^2} + \sqrt{2\pi}\varepsilon Erf[\sqrt{2}\varepsilon] - 1}{2\varepsilon^2}$$

$$\varepsilon = 2\pi n N \sigma$$



Heat load aspects

Does smaller electron beam emittance means higher heat load?

Critical parameter is the power density of the white beam from undulators

→ Heat load on first optical components (i.e Silicon monochromators)

The size of the white photon beam has weak dependence on emittance

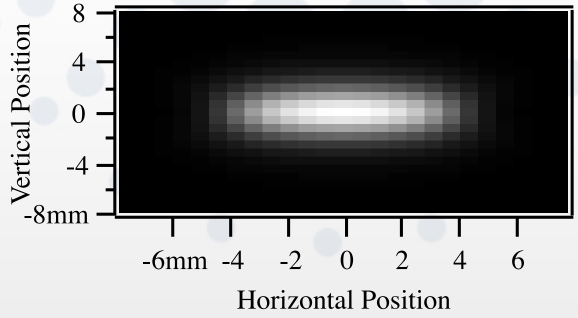
Primarily dominated by
- Undulator K value

Generally much larger divergence than electron beam divergence

Example

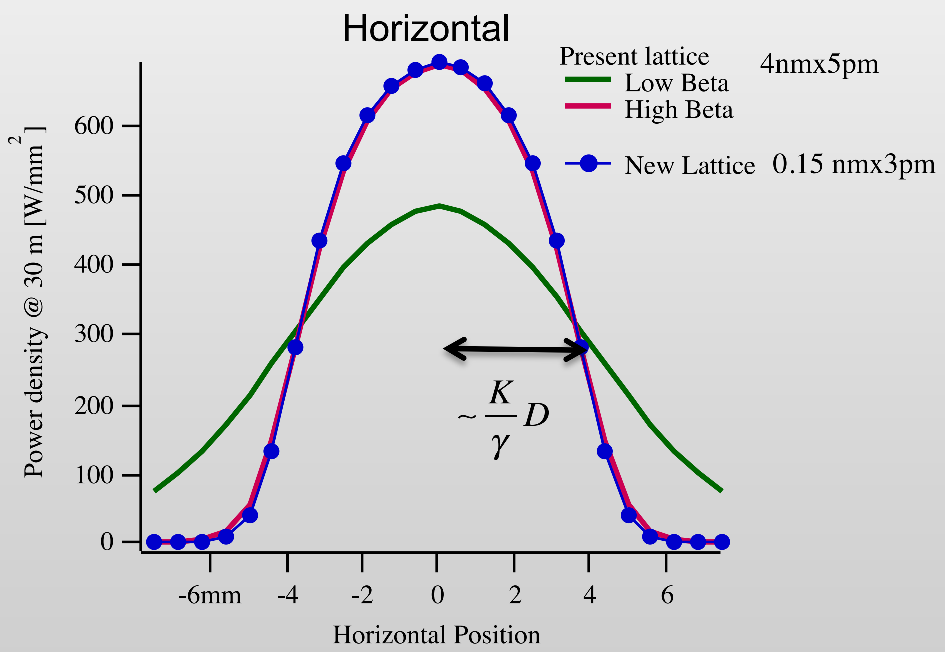
Change in power density due to evolution to new lattice (much smaller emittance)

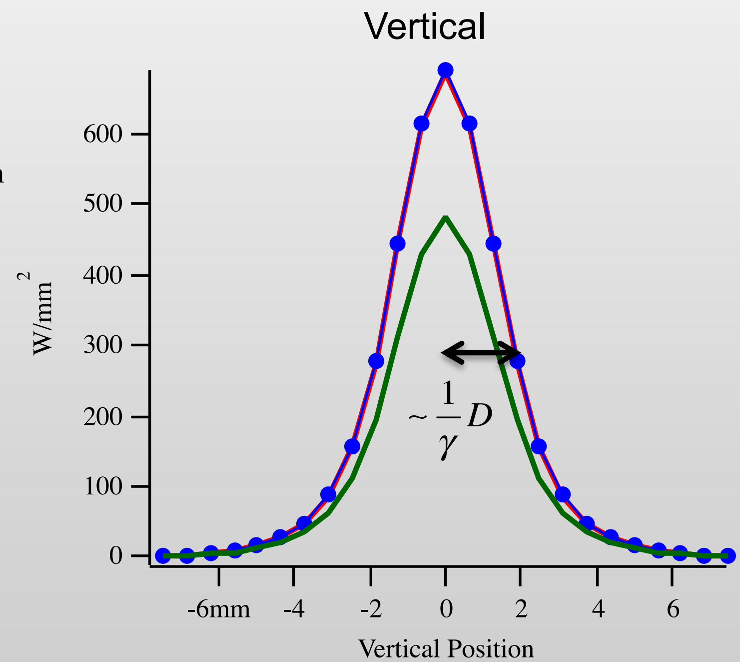
Undulator:
Period 18mm
Length: 2m
K=1.67
D=30 m



ESRF Electron beam

I=0.2 A
E=6 GeV

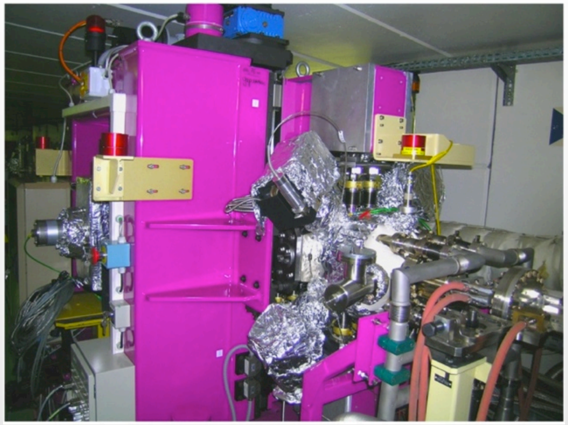




No change for present ESRF high beta
~ 30% more expected for low beta straight section

R&D on IDs @ ESRF

CPMU: Cryogenic Permanent Magnet Undulator



Why?
Affordable evolution of IVUs:

Cryogenic cooling of permanent magnet arrays:

- possible use of high performance magnets
- high resistance to demagnetization
- ~ 35 % gain in peak field vs standard IVUs

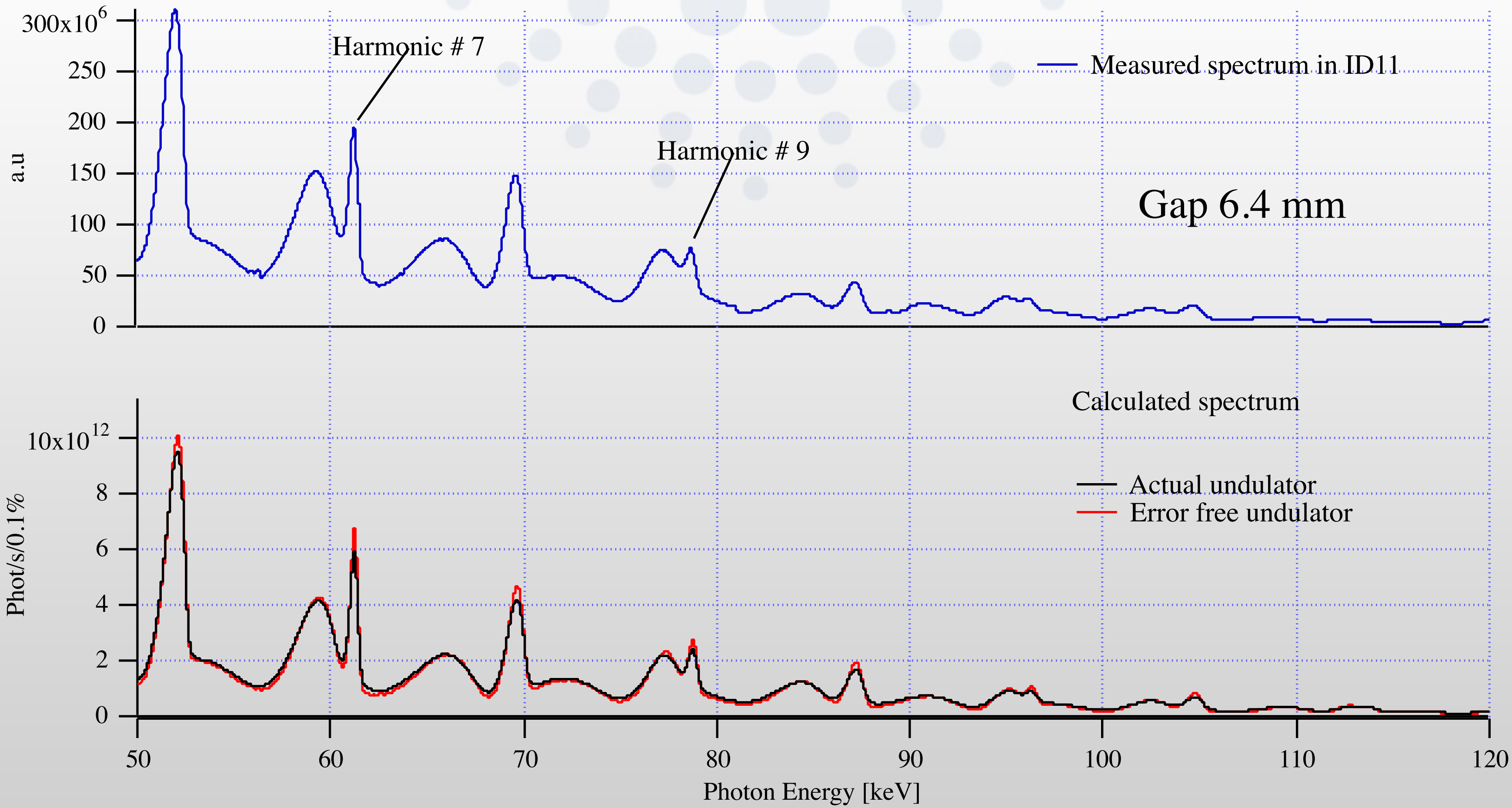
First device installed and operated at ESRF

Second device completed & successfully tested in ID11 BL

- period 18 mm
- peak field 1 T @ 145 K, gap 6 mm

Measured Spectrum

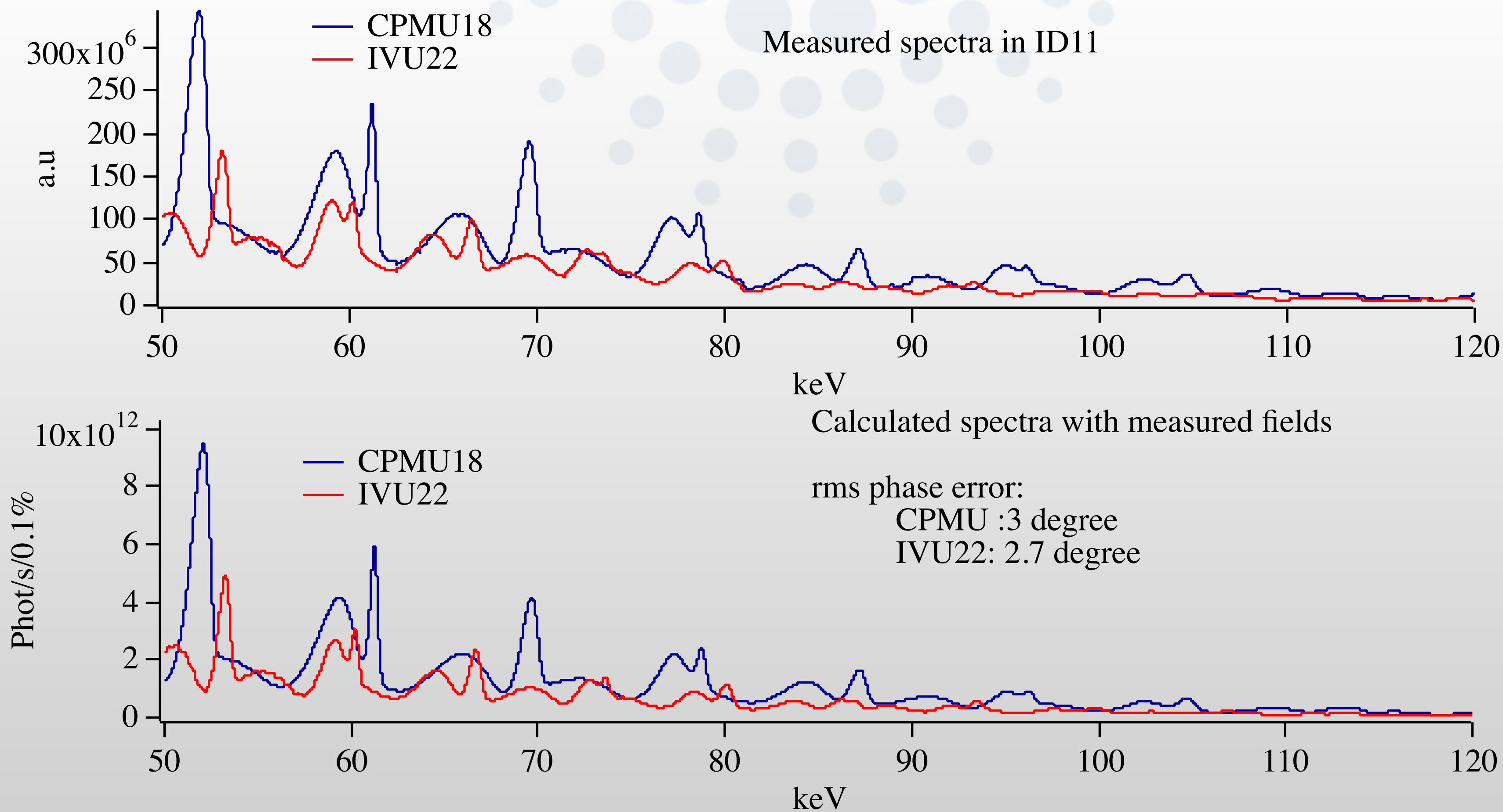
Photon flux in 0.6 mm x 0.6 mm @ 30 m in ID11 (G. Vaughan, J. Wright)



Robust consistency between magnetic design - field measurements - observation in beamline

Comparison with conventional IVUs

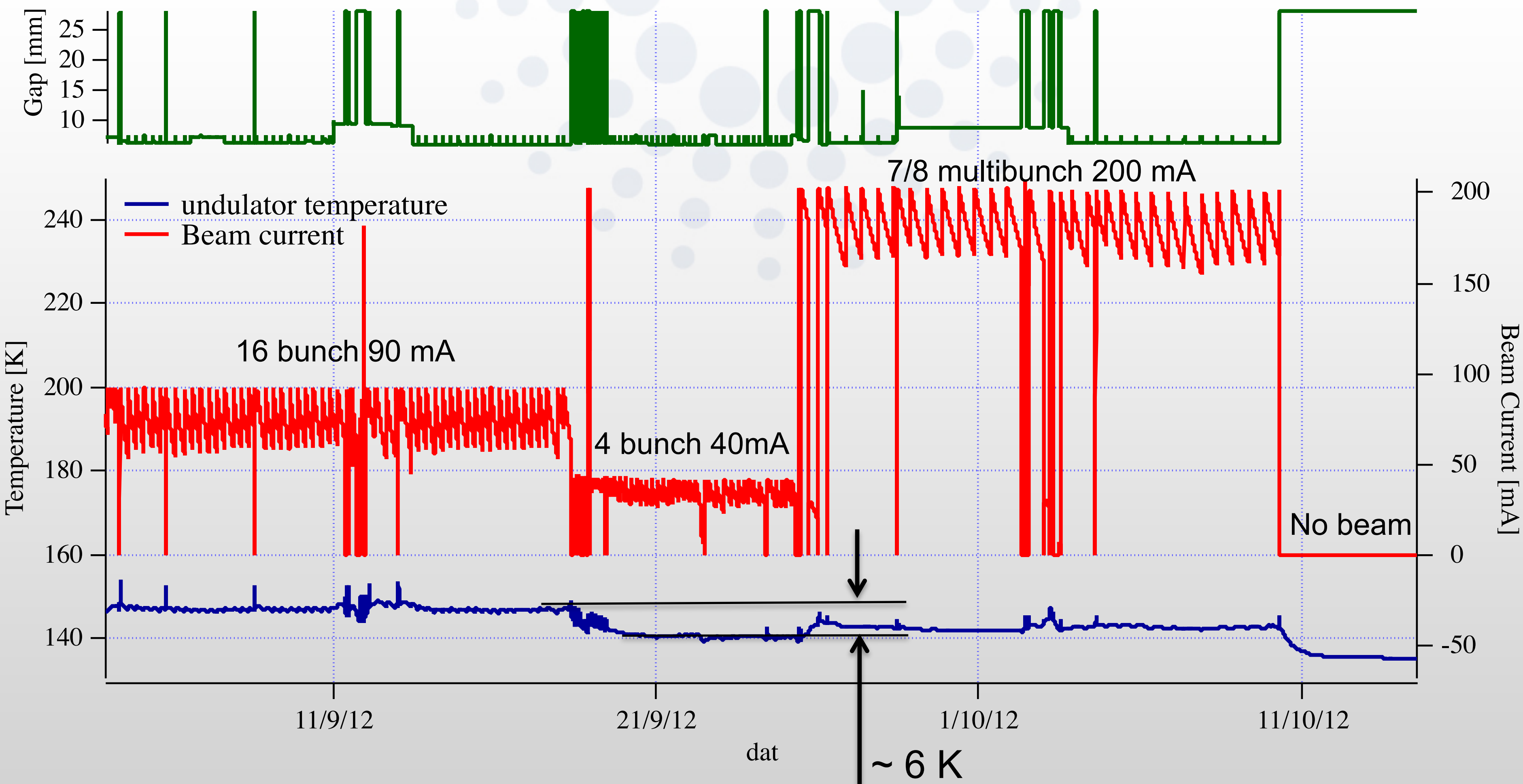
Check CPMU performance wrt conventional IVU22 in ID11



Photon flux in 0.6 mmx 0.6 mm @ 30 m, gap 6.4 mm

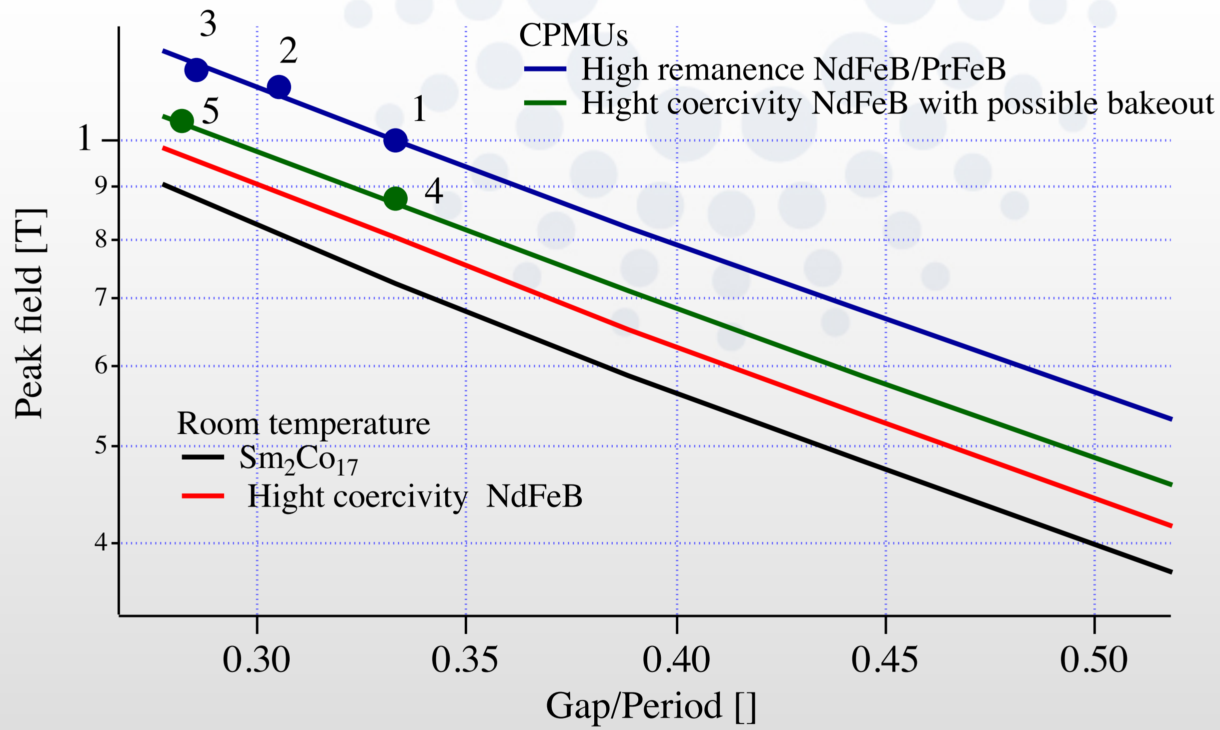
Gain in photon flux ~ 2 @ 60 keV, ~3 above 90 keV as expected

CPMU operational aspects



ID11 CPMU: stable optimum temperature (140K- 146 K) in different filling mode
Very stable spectral output

Installed CPMUs in SR Facilities

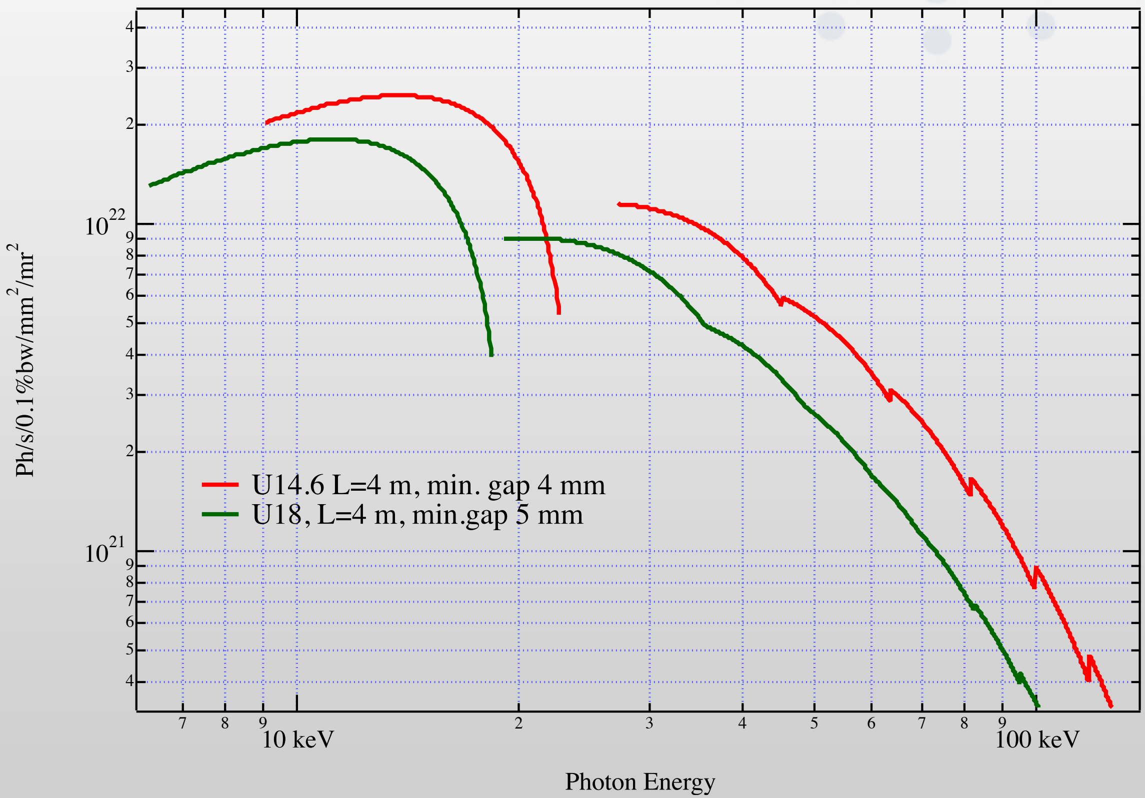


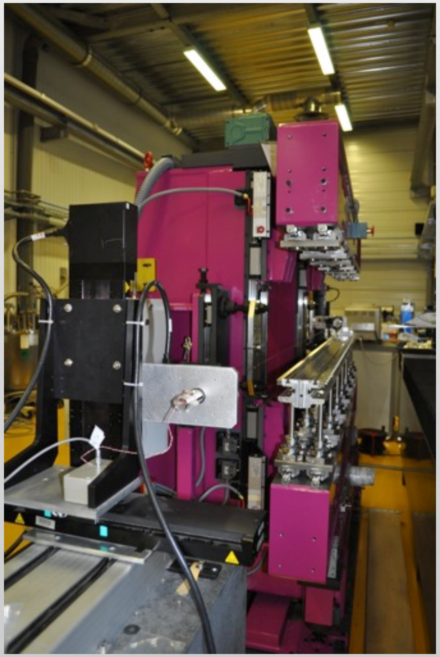
Device #	Period[mm]	min. Gap[mm]	Facility	P.M Material	Bake-out
1	18	6	ESRF	NdFeB	**n**
2	18	5.5	SOLEIL	PrFeB	**n**
3	14	4	SLS	NdFeB	**n**
4	18	6	ESRF	NdFeB	**y**
5	17.7	5	DIAMOND	NdFeB	**y/n**

CPMUs @ESRF

Taking advantage from gap reduction (mini betaz)

- Primarily for High photon energy (> 50 keV)





An ongoing development

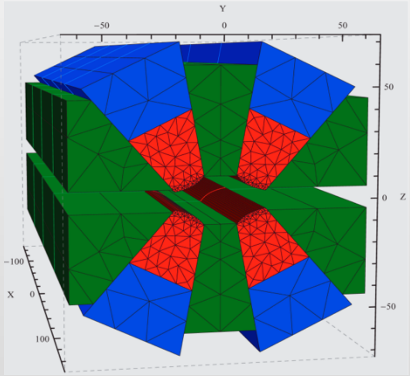
Possibility for Permanent Magnet Multipoles:

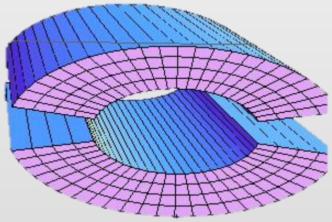
- Energy saving /Economy
- Magnetic performance
- Possible a future ingredient for USRs ?

High stability PM materials (Sm2Co17, very high coercivity NdFeB)

Main focal point is high gradient quadrupoles

- 100 T/m or more
- Possibility of very compact structures
- Likely Sm_2Co17 PM Material (Stability)
- Elliptical bore magnets
- 5~10% variable field (coils)



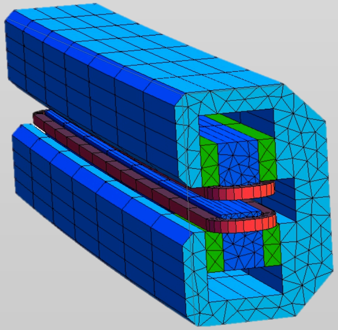


Constant field part of some sextupole

- ~ 5-10% variable with coils

Dipole magnets

- Space saving
- Longitudinal field gradient for ex.
- Include small fraction with variable field



Summary

- Upgraded ESRF ring will use existing IDs as starting point
- Present high quality IDs are suitable for USRs
  - Residual rms phase errors lower than 3 degree
  - Limits on Integrated dipole close to accuracy limit of magnetic measurements, need to be complemented by feed forward+ feedback layer
- Change in power density for undulator beams is not really an issue
- ID R&D is expected to be a recurrent task in future ultra low emittance rings
  - Shorter period/higher field devices fore sure
  - Probably new types of IDs ..