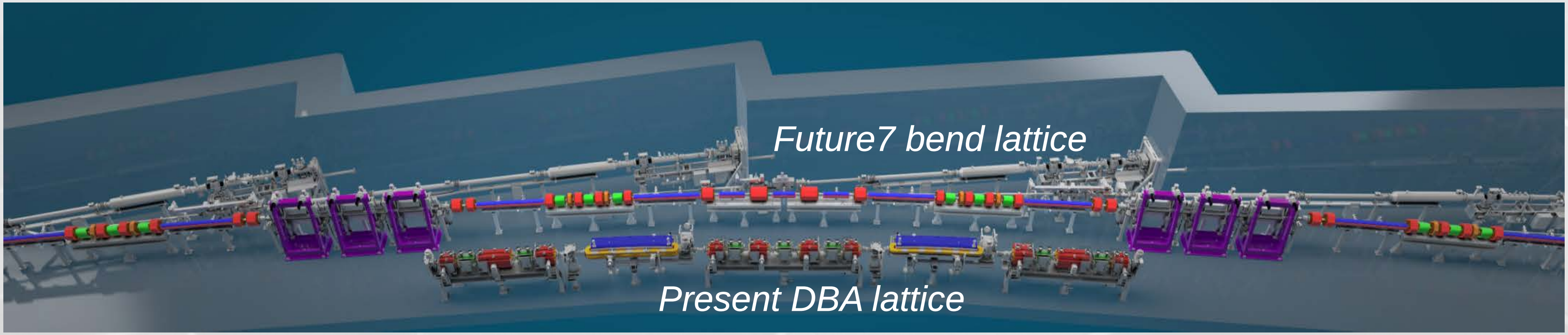
A Light for Science

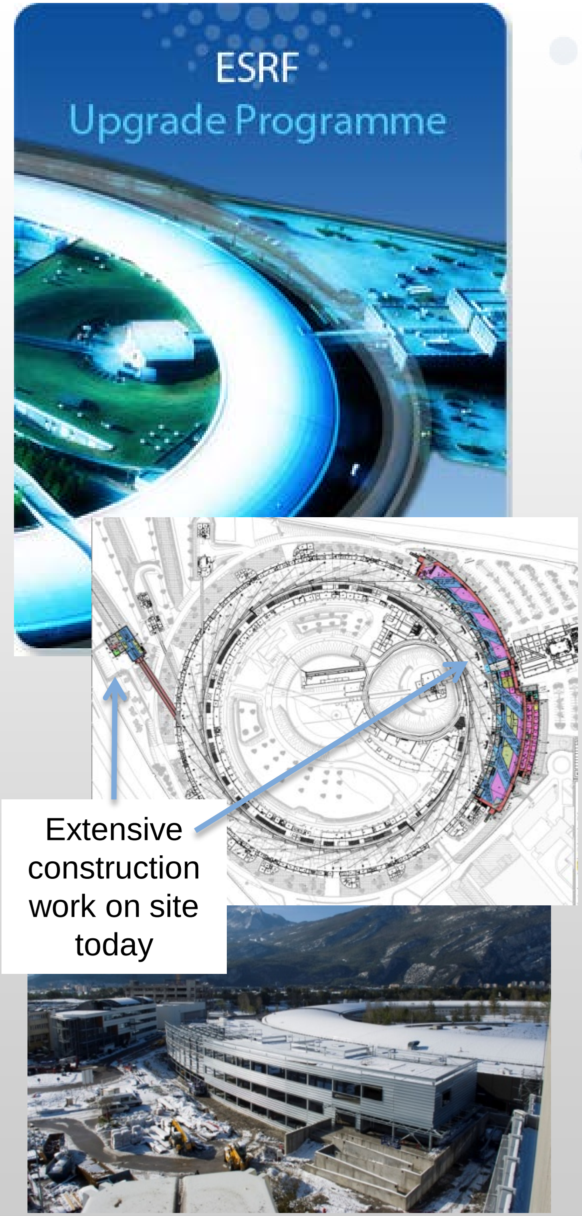


ESRF Upgrade Phase II

P. Raimondi
On behalf of the
Accelerator & Source Division

August 1, 2013

The Upgrade Programme



@ Phase I (from 2009 to 2015)

- Eight new beamlines
- Extension of the experimental hall
- Refurbishment of many existing beamlines
- Developments in synchrotron radiation instrumentation

- Upgrade of the X ray source for availability, stability, capacity and brilliance

@ Phase II (from 2015 to 2019)

- Four new beamlines
- Developments in instrumentation and support facilities

- Increase the brillance and the coherence of the source
    - ➔ implementation of a low emittance lattice
    - ➔ horizontal emittance reduced from 4nm to 150pm

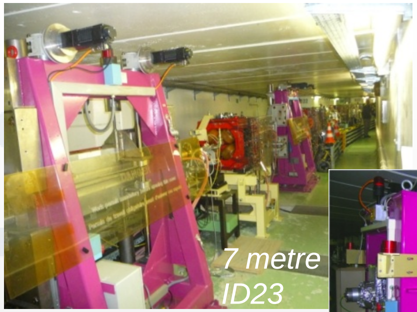
Project endorsed by the ESRF council in November 2012

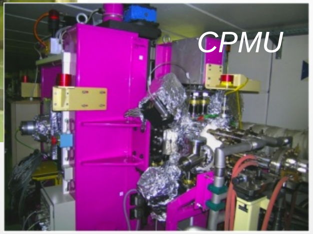
Technical Design Study due for October 2014

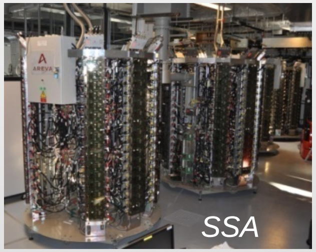
Accelerator Upgrade Phase I

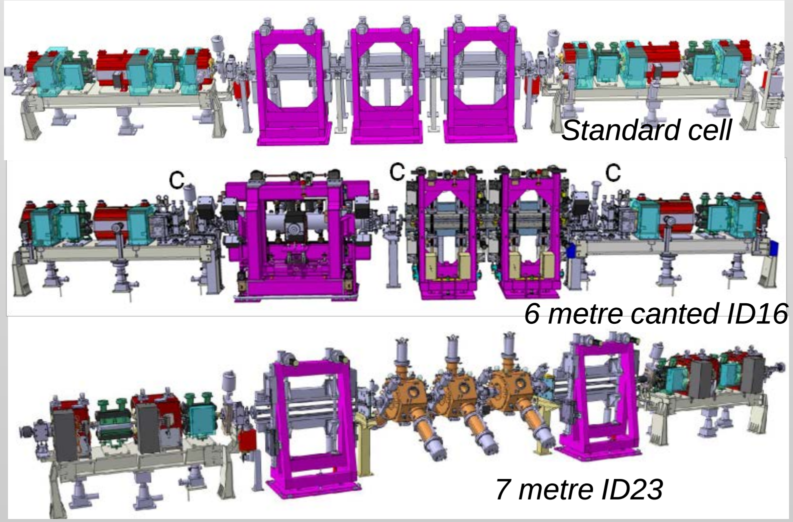
See: Poster MOPEA009

- Upgrade of BPM electronics ✓ Done
  - Improvement of the beam position stability ✓ Done
  - Coupling reduction ✓ Done *(4pm)*
- 6 m long straight sections ✓ Done *(Four operational)*
- Cryogenic in-vacuum undulators ✓ Done (Two CPMUs)
- 7 m straight sections ✓ Done *(One in winter 2012)*
- New RF SSA Transmitters ✓ Done for the booster
- New RF Cavities ✓ Three prototypes under test
- Top-up operation ✓ Project ongoing
- Studies for the reduction of the horizontal emittance ✓ TDS in progress

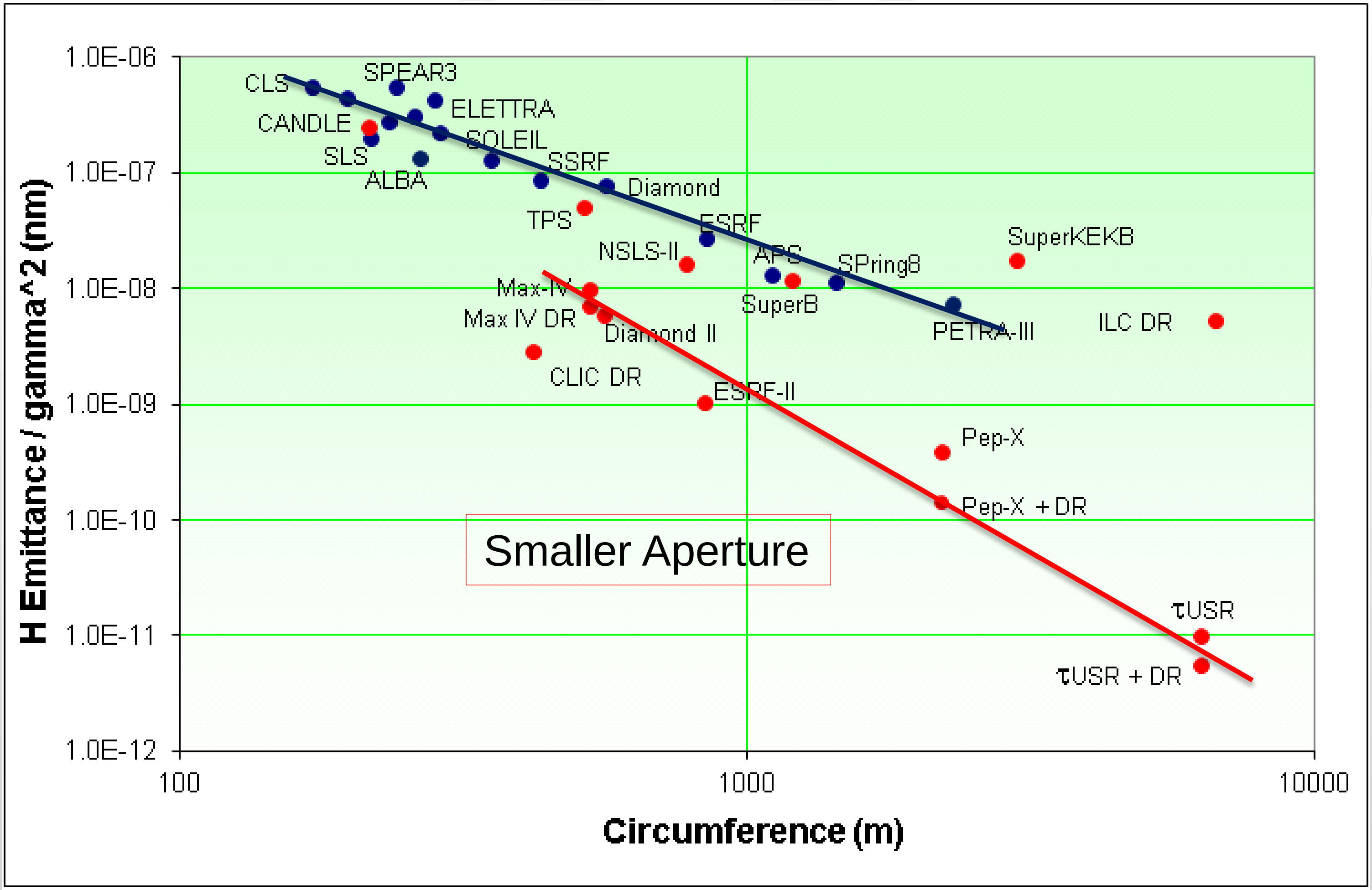








Low Emittance Rings Trend



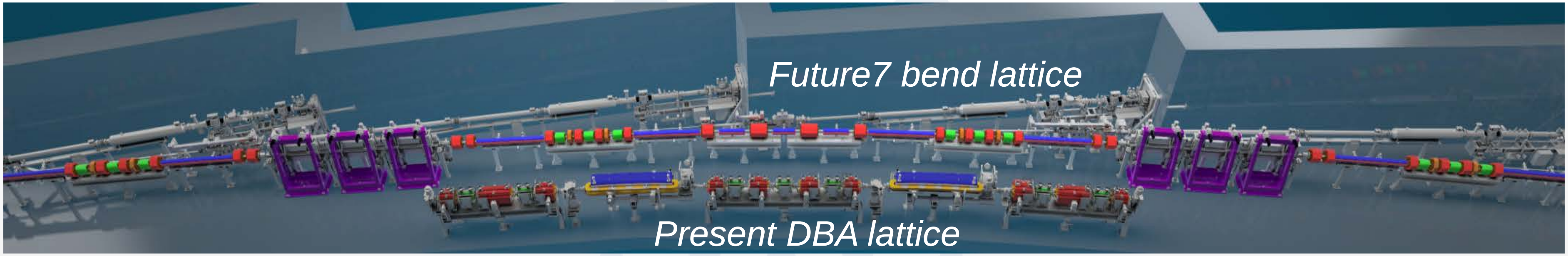
Storage ring performance (current and future sources)

horizontal emittance

• ESRF	2BA	**4000** pm – 6 GeV, operational
• PETRA III	2BA	**1000** pm – 6 GeV, operational
• NSLS II	2BA	**~350** pm – 3 GeV, construction
• MAX IV	7BA	**~300** pm – 3 GeV, construction
• Sirius	5BA	**~250** pm – 3 GeV, in planning
• Spring-8	6BA	**~70** pm – 6 GeV, in planning
• ESRF	7BA	**~150** pm – 6 GeV, in planning

Almost linear increase of brightness and coherence fraction down to 50-100pm
For lower emittance the gain becomes less than linear due to:
- the diffraction limit
- mismatch of the electron beam with the X-ray beam

Accelerator Upgrade Phase II



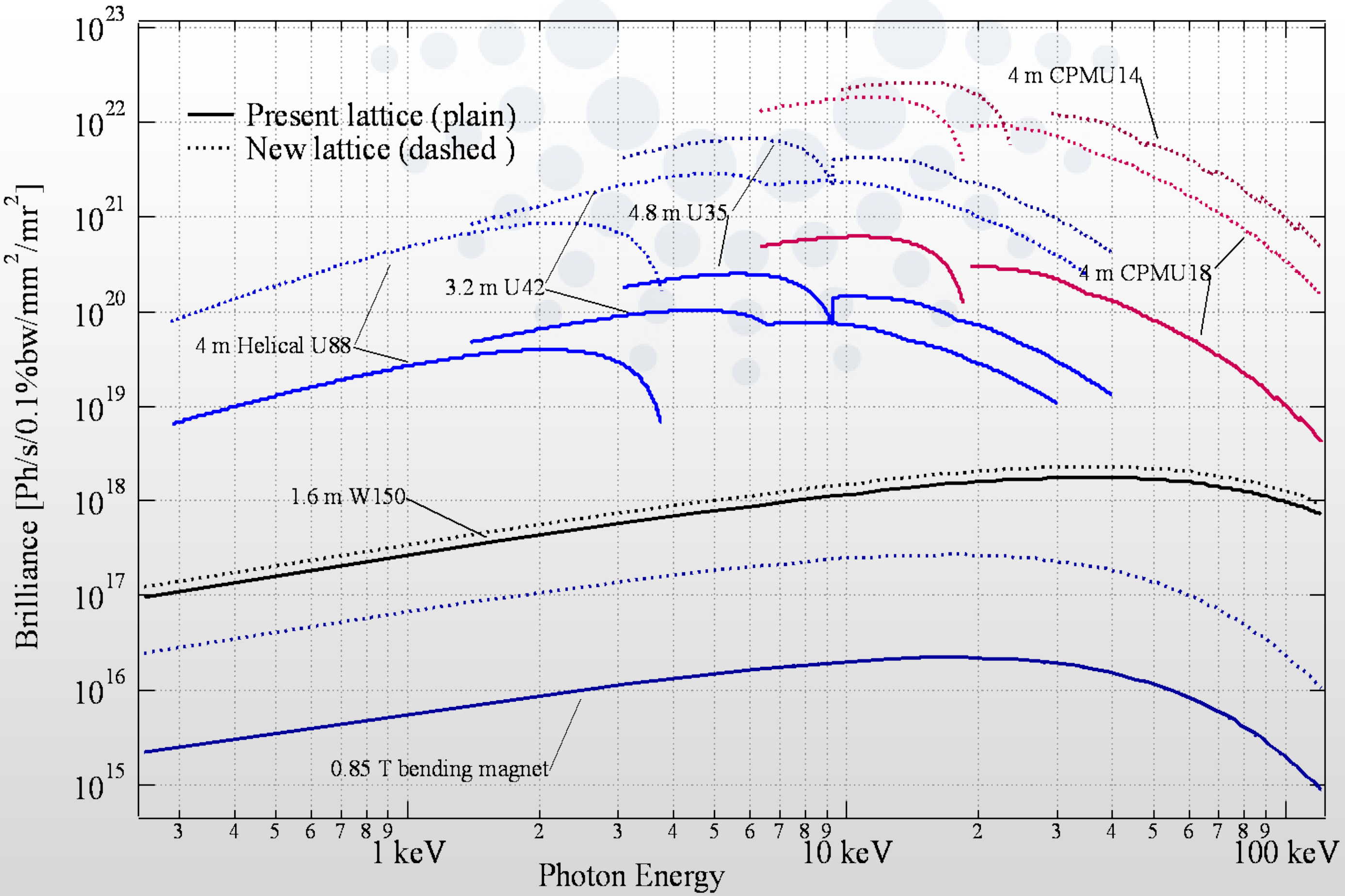
A recurrent request from ESRF beamlines is a **reduction of the horizontal emittance**

…..*with the strong constraint of re-using the same tunnel and infrastructure*

Thanks to the worldwide efforts made to develop an Ultimate Storage Ring, the ESRF is re-addressing the question, with the following requirements:

- Reduce the horizontal equilibrium emittance from 4 nm to less than 150 pm
- Maintain the existing ID straights and beamlines
- Maintain the existing bending magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Keep the present injector complex
- Reuse, as much as possible, existing hardware
- Minimize the energy lost in synchrotron radiation
- Minimize operation costs, mainly wall-plug power
- Limit the downtime for installation and commissioning to about one year.

Brilliance at lower horizontal emittance

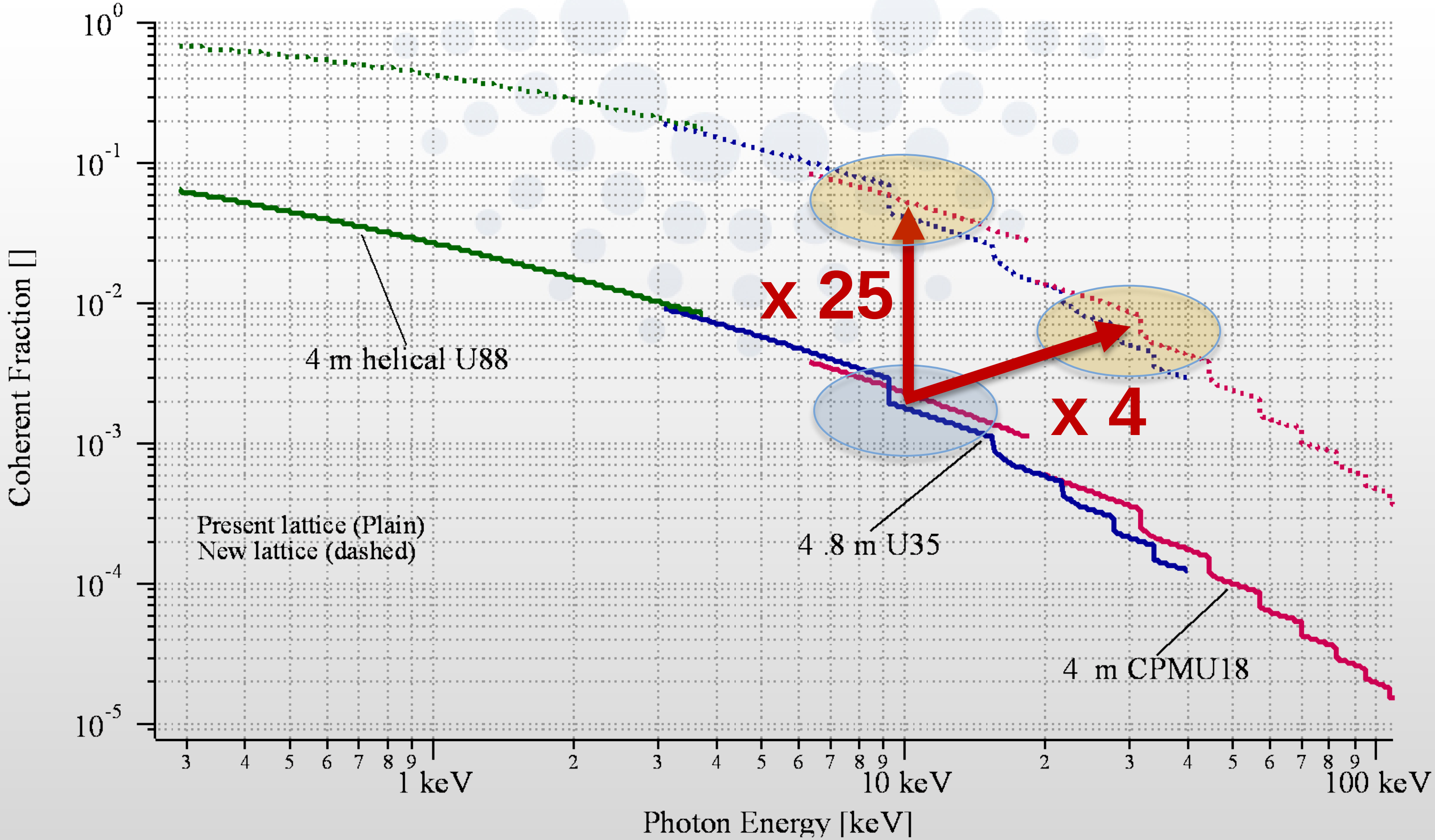


Hor. Emittance [nm]	4	0.15
Vert. Emittance [pm]	3	2
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	3.4/2.8

E = 6.04 GeV
I = 200 mA

Coherence at lower horizontal emittance

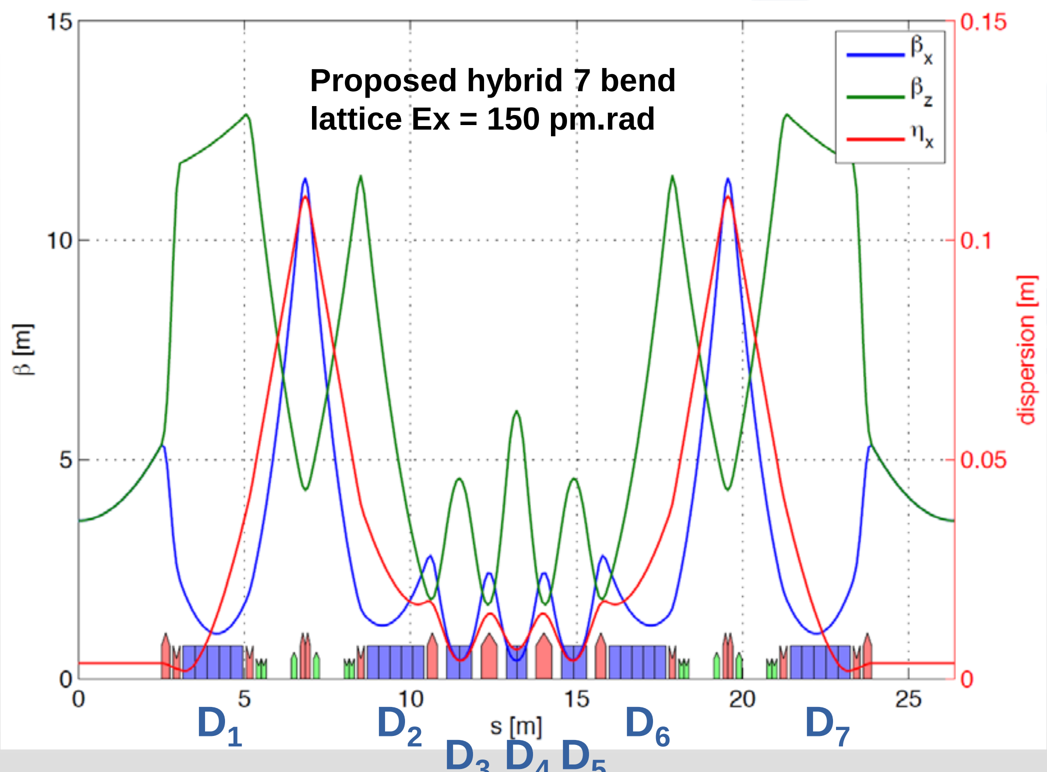
A light for Science

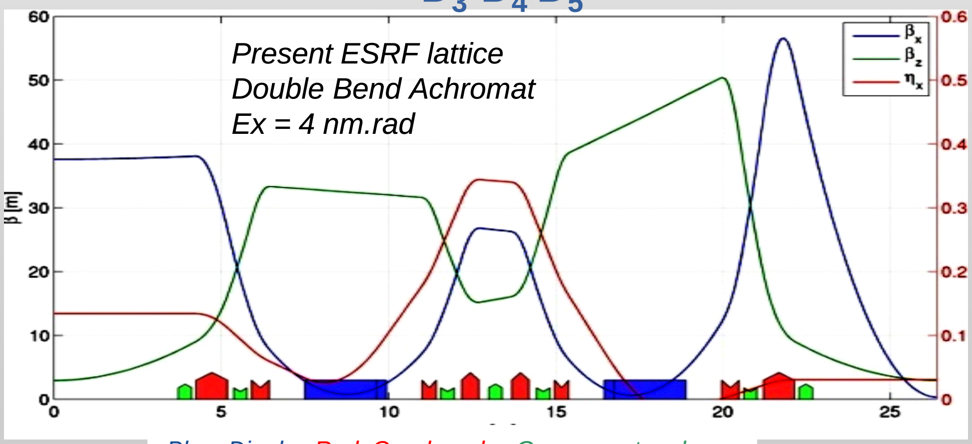


Hor. Emittance [nm]	**4**	**0.15**
Vert. Emittance [pm]	**3**	**2**
Energy spread [%]	**0.1**	**0.09**
β_x[m]/β_z [m]	**37/3**	**6/2**

E = 6.04 GeV
I = 200 mA

The ESRF low emittance lattice





Bleu: Dipoles Red: Quadrupoles Green: sextupoles

@ 7 bending magnets D_{1to7}
➔ reduce the horizontal emittance

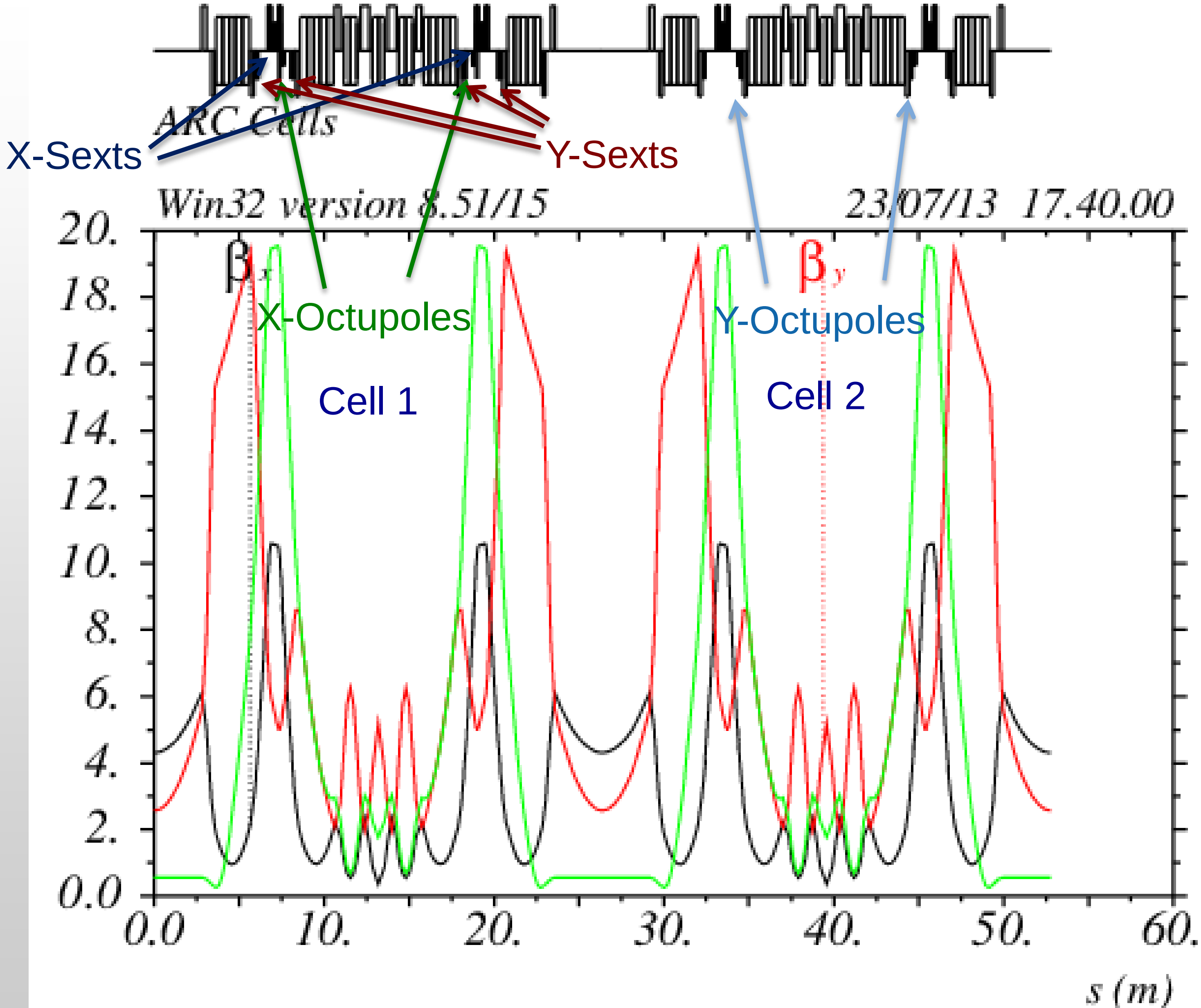
@ Space between D_1-D_2 and D_6-D_7
β-functions and dispersion allowed to grow
➔ chromaticity correction
with efficient sextupoles

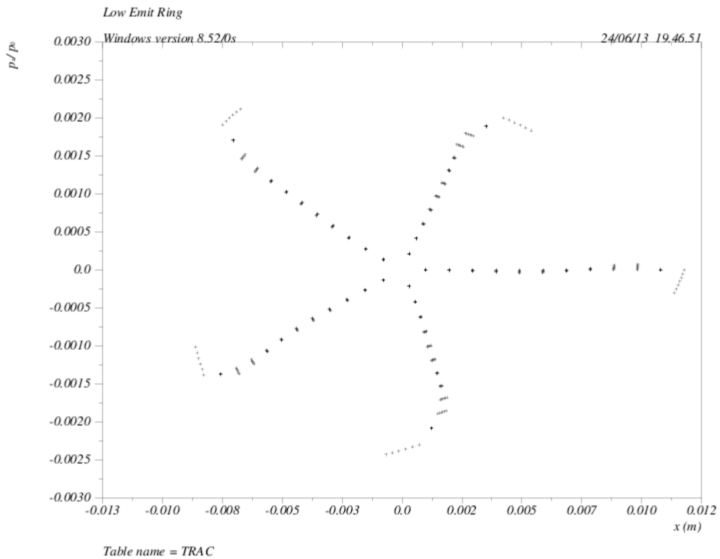
@ Dipoles D_1, D_2, D_6, D_7
➔ longitudinally varying field to further reduce emittance

@ Central part alternating
➔combined dipole-quadrupoles$D_{3\text{-}4\text{-}5}$
➔high-gradient focusing quadrupoles
@ D_4 (0.34T) and D_5 (0.85T)
➔Source points for BM beamlines have same fields, positions and angles

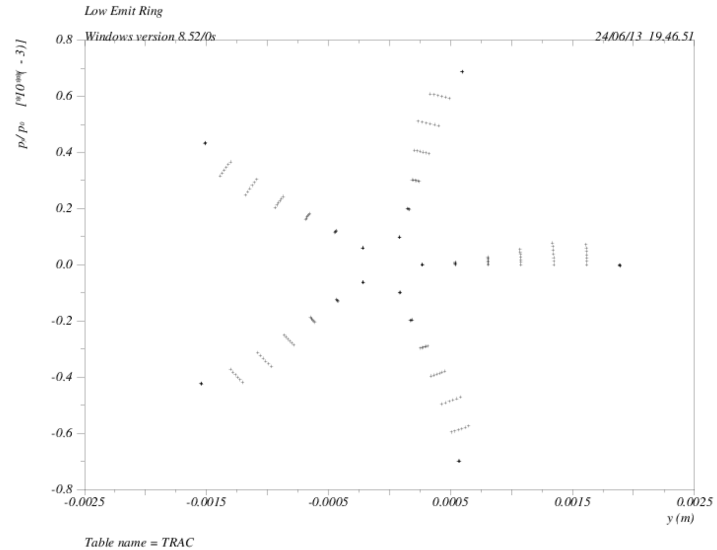
Dynamic Aperture Optimization

- Two sextupoles families (cells 1-2-1-2…) are used to zero the second order chromaticity
- Sextupoles are paired but interleaved, resulting in horizonal and vertical detuning with amplitude
- Optimized a solution with octupoles in the Chromatic Correction Section area, looking for symplicity and effectivness
- Best combination found by only one pair of octupoles per cell. Two families of octupoles (cells 1-2-1-2), are chosen to minimize as much as possible the horizonta dechoerence
- The y-detuning is zeroed by a proper value of alfa_y at the middle of the X-sextupoles
- The R12 and R34 between the x-sextupoles is about 0.5, reducing the overall octupoles strenght. Negligible impact on DA, apart distorting the x-phase space.

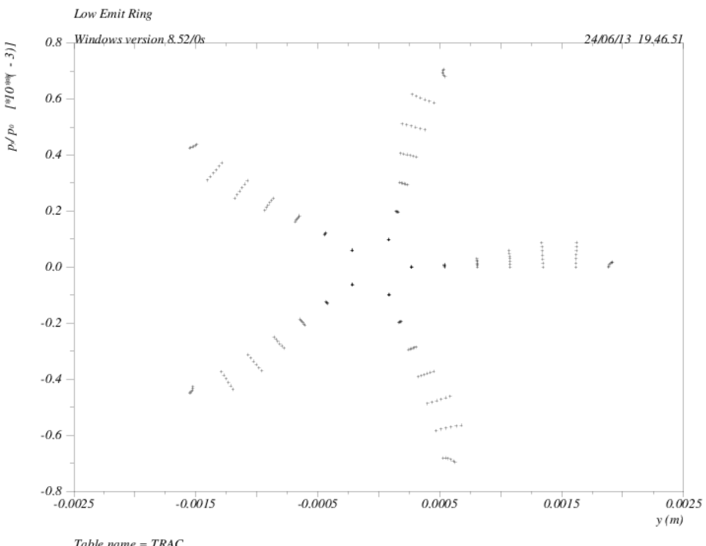

ARC Cells
X-Sexts
Y-Sexts
Win32 version 8.51/15
23/07/13 17.40.00
β x
β y
X-Octupoles
Y-Octupoles
Cell 1
Cell 2
20.
18.
16.
14.
12.
10.
8.
6.
4.
2.
0.0
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
0.0
10.
20.
30.
40.
50.
60.
s (m)



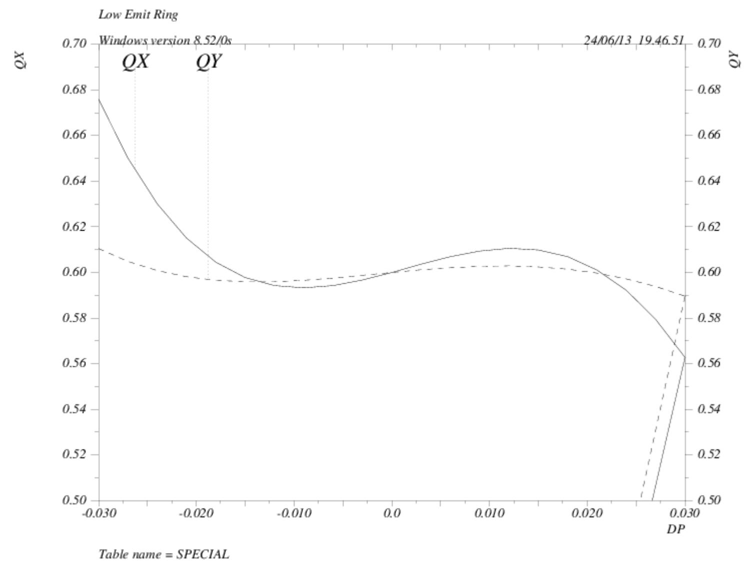
X Tracking, Qx=0.6



Y Tracking, Qy=0.6

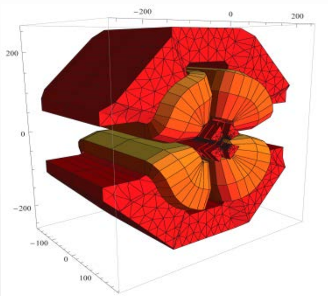


Y Tracking, with also initial x offset



X & Y Chromaticity

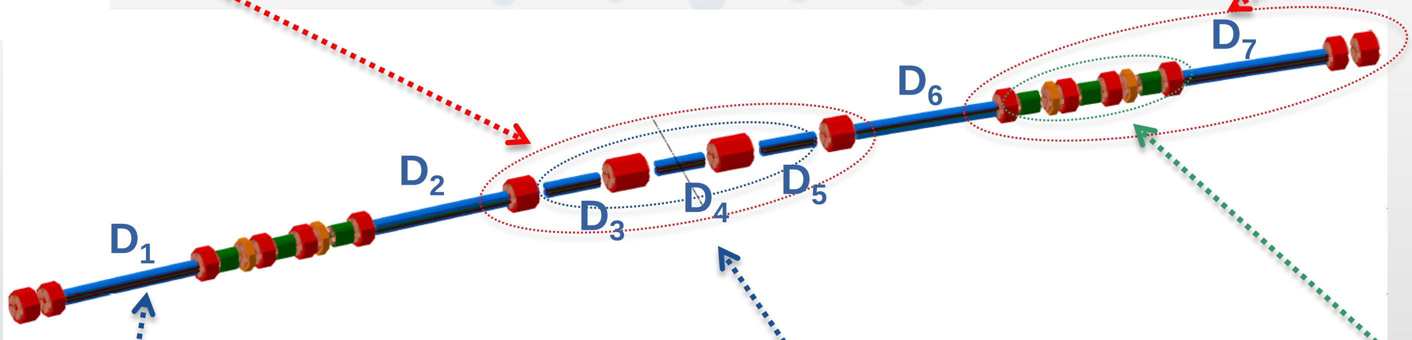
Technical challenge: magnet system



High gradient quadrupoles 100 Tm^{-1}

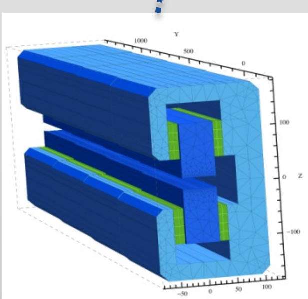
- Spec:100 T/m x 335 mm
- **Bore radius: 11 mm**
- Mechanical length: 360 mm
- 1 kW

Quadrupole
Around 50Tm^{-1}



Combined dipole quadrupoles
0.85 T / 45 Tm^{-1} & 0.34 T / 50 Tm^{-1}

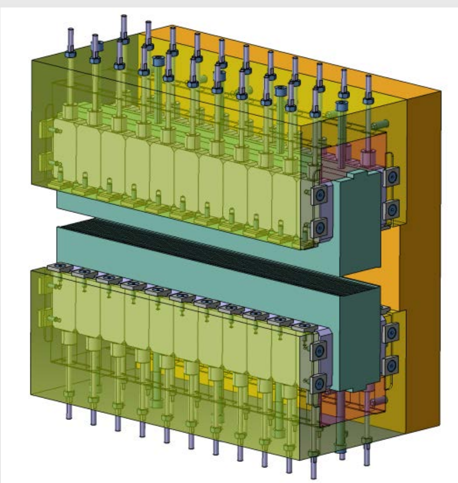
Sextupoles
300mm
1500 Tm^{-2}



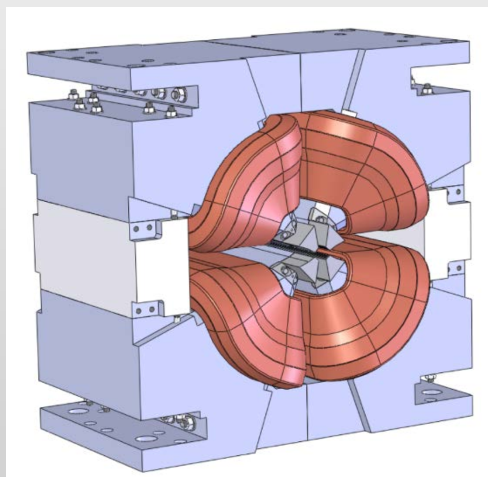
Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 – 0.6 T, magnetic gap 22 mm
2 metre long, 5 modules
With a small tuning coil 1%

Magnet Design Status

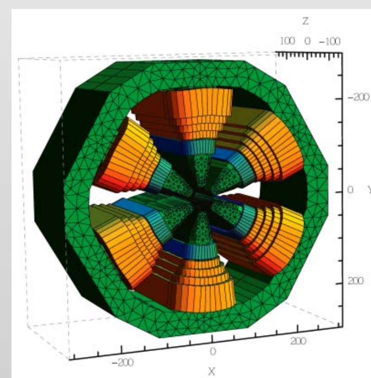
- Dipole, quadrupole, sextupole and octupole are well advanced
- Combined dipole-quadrupole in progress
- Prototyping will start soon



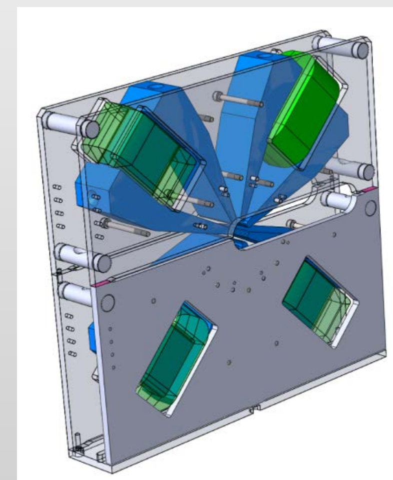
PM dipole module



High gradient quadrupole



Sextupole



Octupole

See J. Chavanne Talk

Technical challenges: compactness

@ **Mechanical design very challenging due to the compactness**

only 3.4 metre of drift tube per cell instead of today's 8m

@ Vacuum: Low vacuum conductance due to reduced aperture of the chambers

Main chambers made from extruded aluminium with NEG coating with localised pumping

Lump absorbers to collect the radiation from dipole magnets

@ Energy efficient source: >30% less power consumption of the SR

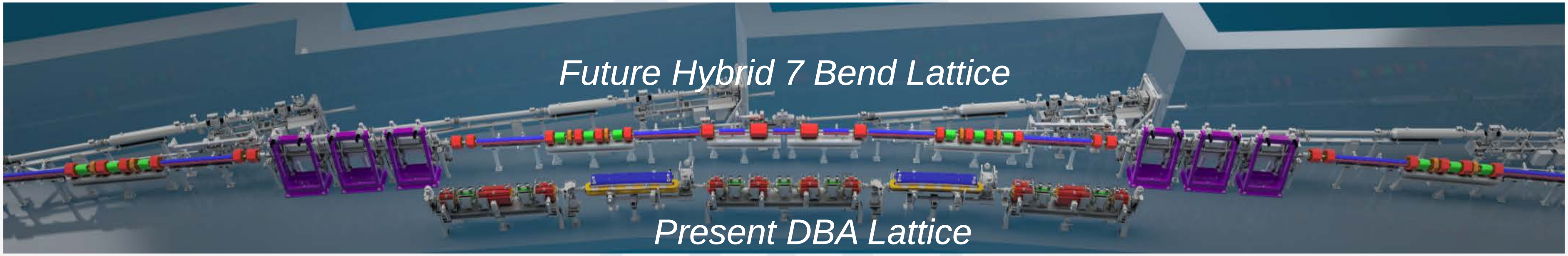
➔ Increase efficiency of the production of magnetic field

➔ RF systems tailored to the reduced losses per turn from 5.4 to about 3.8 MeV/turn, including 0.5 MeV ID radiation

New lattice is more sensitive to longitudinal coupled-bunch instabilities (a factor two).

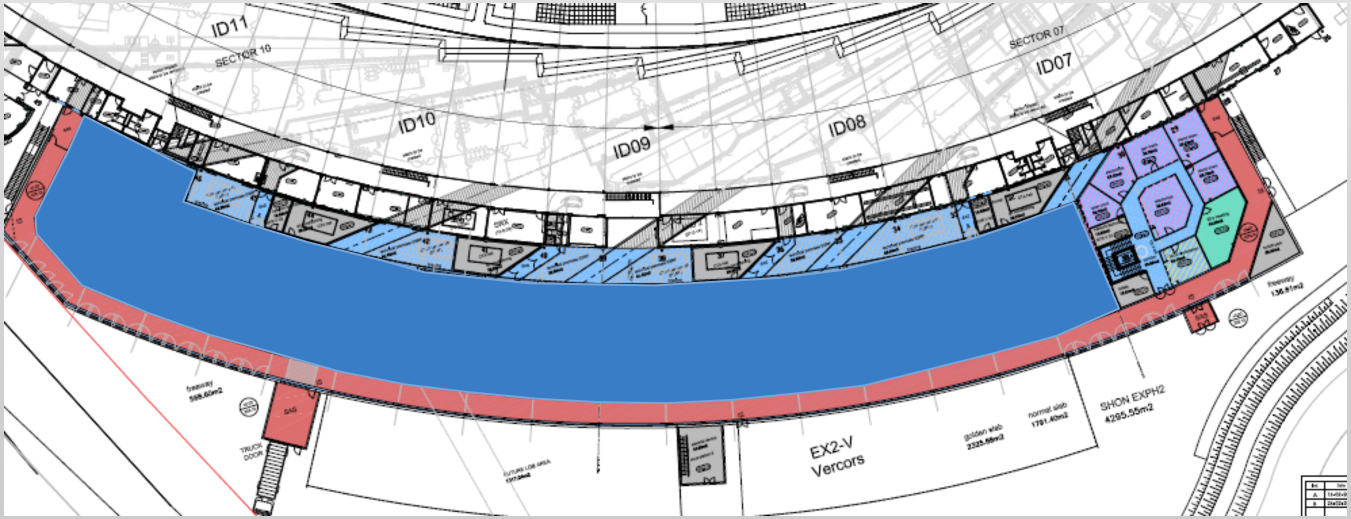
➔ Use 12 HOM-damped single-cell cavities developed during phase 1.

Implementation



@ Extension of the experimental hall to provide
2500 m2 of preparation and storage area

@ Dismount and reconstruct the whole storage ring in about
9 months in 3 sliding parallel working areas



Use the hall later for long beamlines and support facilities

Road map

<u>Schedule</u>:

◊ *Nov 2012*	White paper ✓ Done
Nov 2012- Nov 2014	Technical Design Study ✓ TDS in progress
◊ *Nov 2014*	Council decision
Jan 2015 – Aug 2018	Detailed design and procurement
◊ *End 2016*	Preparation and storage building
Aug 2018– Aug 2019	Shutdown for installation and commissioning
◊ *Autumn 2019*	Back to operation

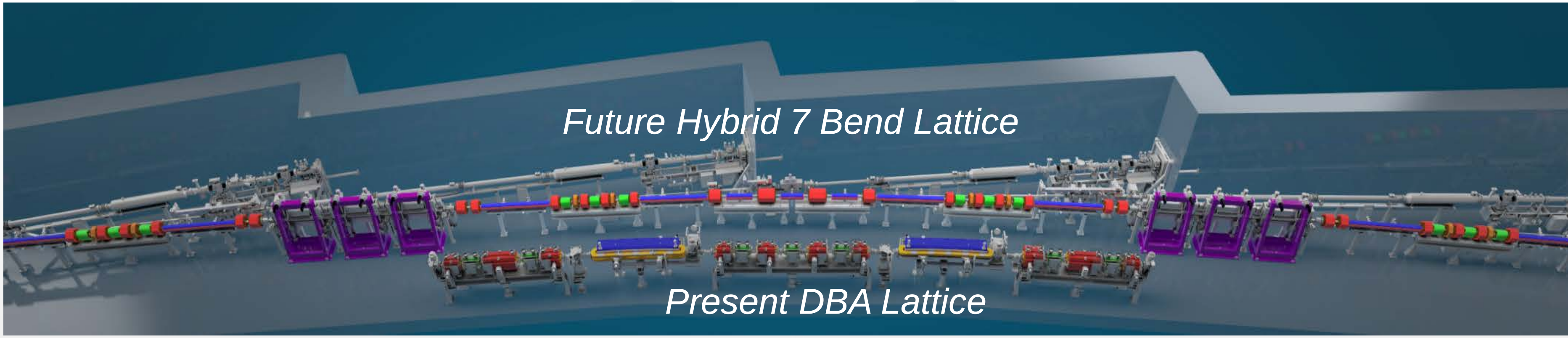
9 work packages defined for the TDS:

- *WP1: Beam dynamics*
- *WP2: Magnets*
- *WP3: Electron and photon beam transport*
- *WP4: Power supplies*
- *WP5: Radiofrequency*
- *WP6: Implementation*
- *WP7: Diagnostics and beam control*
- *WP8: Photon source and user interface*
- *WP9: Injector upgrade*

<u>Budget:</u>

100 M€	Construction and commissioning of the new storage ring lattice
10 M€	Extension for the experimental hall extension
20 M€	Four state of the art beamlines
20 M€	Instrumentation and support facilities

Conclusion



Thanks to the large expertise gained during ESRF UP phase 1 and the worldwide efforts to develop an Ultimate Storage Ring

ESRF Upgrade Phase II will be an excellent opportunity to:

- Drastically increase the brightness of our Light Source to maintain world-wide excellence for the next 1-2 decades

- Improve and expand the science reach of the SR-based light sources
- Enable new technologies
- Provide important know-how to continue the push for higher performances the SR-based Light Sources