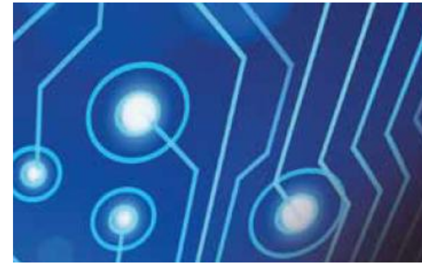
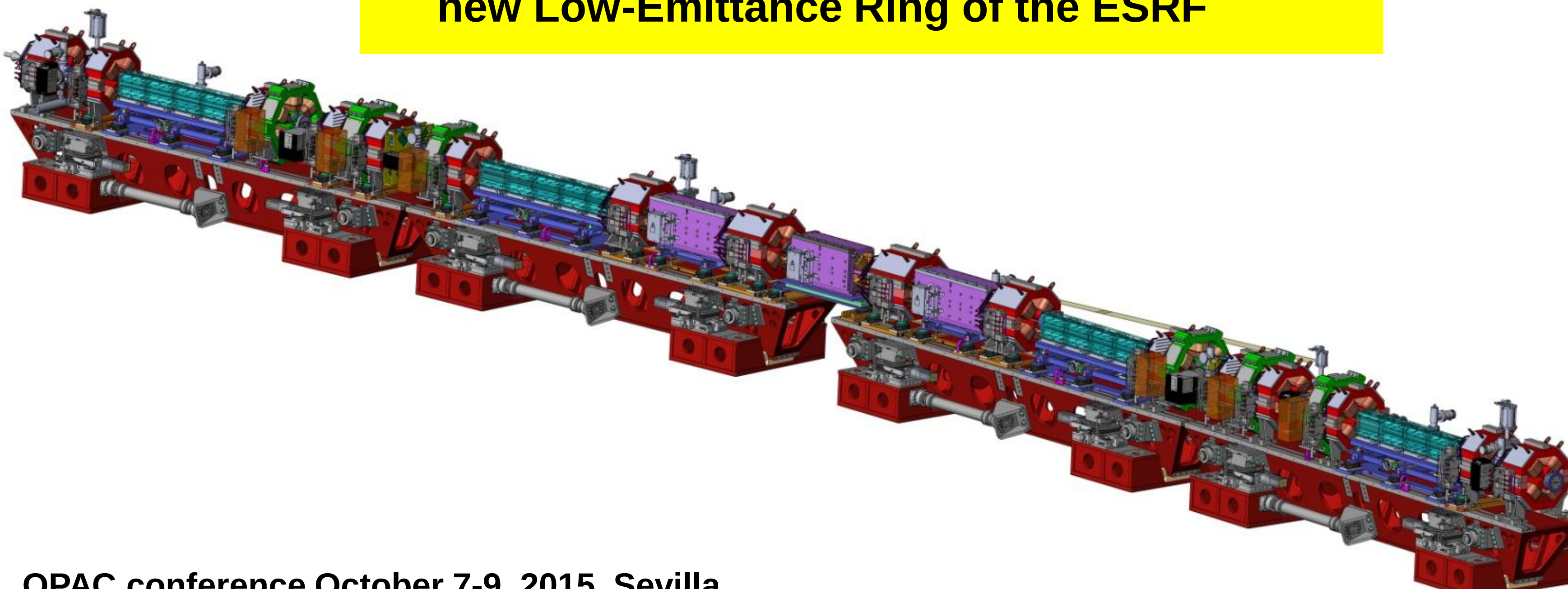
ESRF | The European Synchrotron



Kees Scheidt
Diagnostics Group
Accelerator & Source Division

diagnostics and feedback requirements for the new Low-Emittance Ring of the ESRF



OPAC conference October 7-9 2015 Sevilla

OUTLINE

1) introduction to "low emittance" synchrotron light source

2) scientific motivation for lower horizontal emittance

3) new low emittance Storage Ring for the ESRF : constraints of its implementation (2019)

4) lattice layout & properties after the final optimizations

5) the real challenges & difficulties : - Beam-Dynamics, Magnets ,
   - Vacuum Chambers , Girders

6) the Diagnostics : the BPMs,
   the emittance monitors
   the beam loss monitors

7) the Diagnostics : a list of all devices & planning & status

WHAT IS A "LOW EMITTANCE" STORAGE RING ??

many (circular) synchrotron light sources worldwide, all based on a Storage Ring of electrons, typically 3 to 8 GeV, and circumferences 0.3 to 1Km

WHAT IS A "LOW EMITTANCE" STORAGE RING ??

the horizontal emittance is determined by the lattice design (the magnets configuration)
among these magnet are the dipoles (for making the beam go round … i.e. 360^{o})

Simplistically : with a limited number but strong dipoles (e.g. 60 of 6^{o}) this emittance is NOT minimized
but with more but weaker dipoles (e.g. 360 of 1^{o}) this emittance can be reduced.

However, a drastic minimization of this horizontal emittance increases the complexity & challenges of :

- the lattice design (beam dynamics),
- the magnet designs (field strength & quality)
- the vacuum chambers

almost all today's synchrotrons did not pursue an ultra-low (horizontal) emittance design :
the objectives were to avoid risks and to produce (quickly) a reliable photon source for the scientific users

examples of **today's** horizontal emittances :

		[nm·rad]
France	ESRF	4.00
Spain	ALBA	4.58
Japan	Spring-8	3.70
USA	APS	3.1
Germany	Petra-3	1.0
USA	NSLS-2	2.1 / 0.6
UK	DLS	2.75

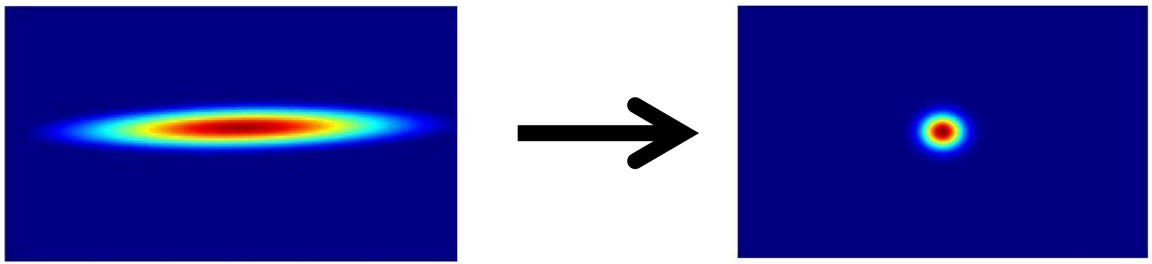
aims of **new** (LE) synchrotrons :

		[nm·rad]	when ?
	ESRF	0.15	2020, in progress
	Spring-8	< 0.2	2022 ? to be decided
	APS	< 0.1	2022 ? to be decided
Sweden	MAX-4	0.34	2016, now commissioning !

LOW-EMITTANCE RING AT THE ESRF : WHY ?

Motivation :

reduce the **horizontal** emittance from **4nm** to **0.15nm**

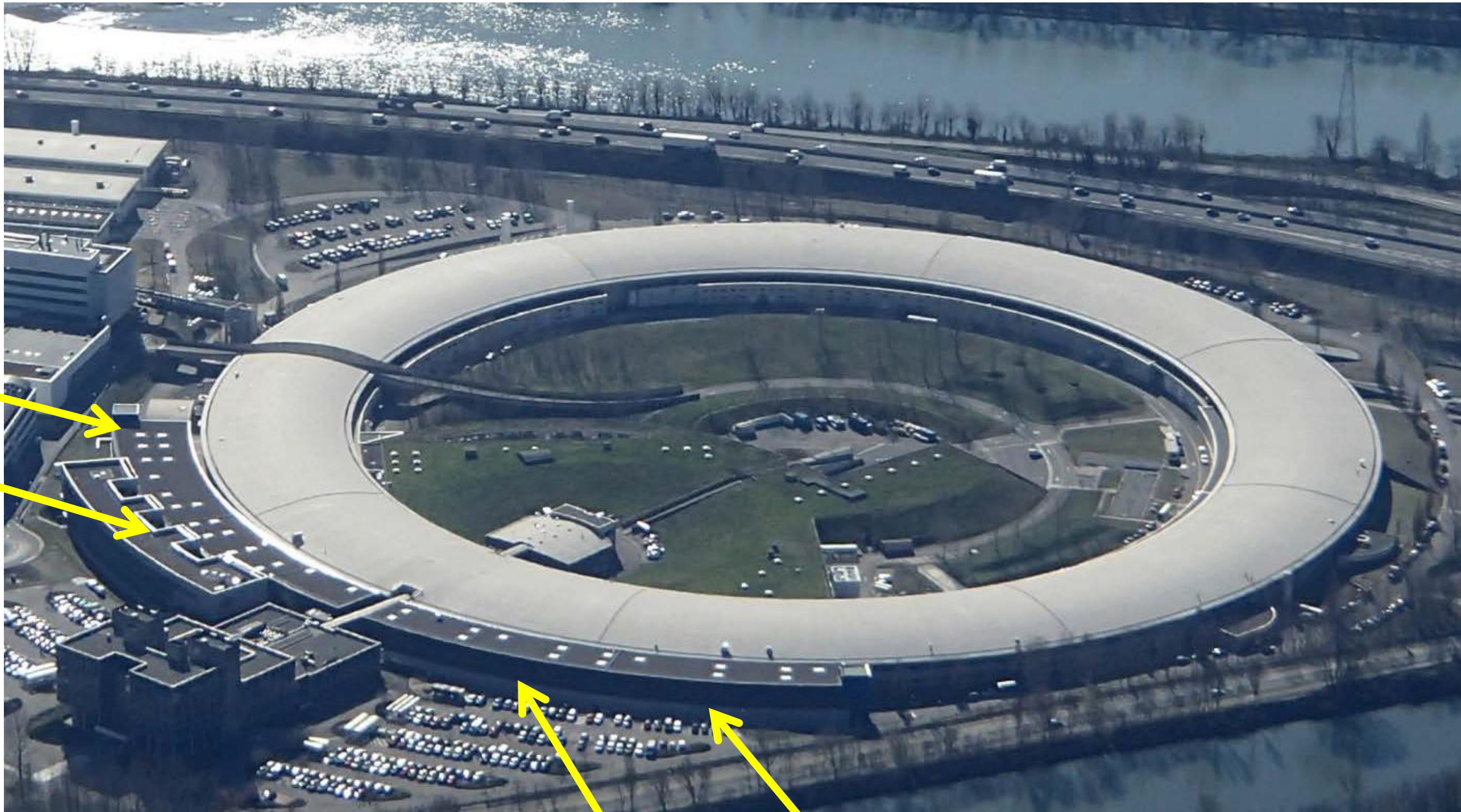


beam-line experiments can benefit from : an increase in brilliance

an increase of coherence

(the coherent fraction, in hor. plane)

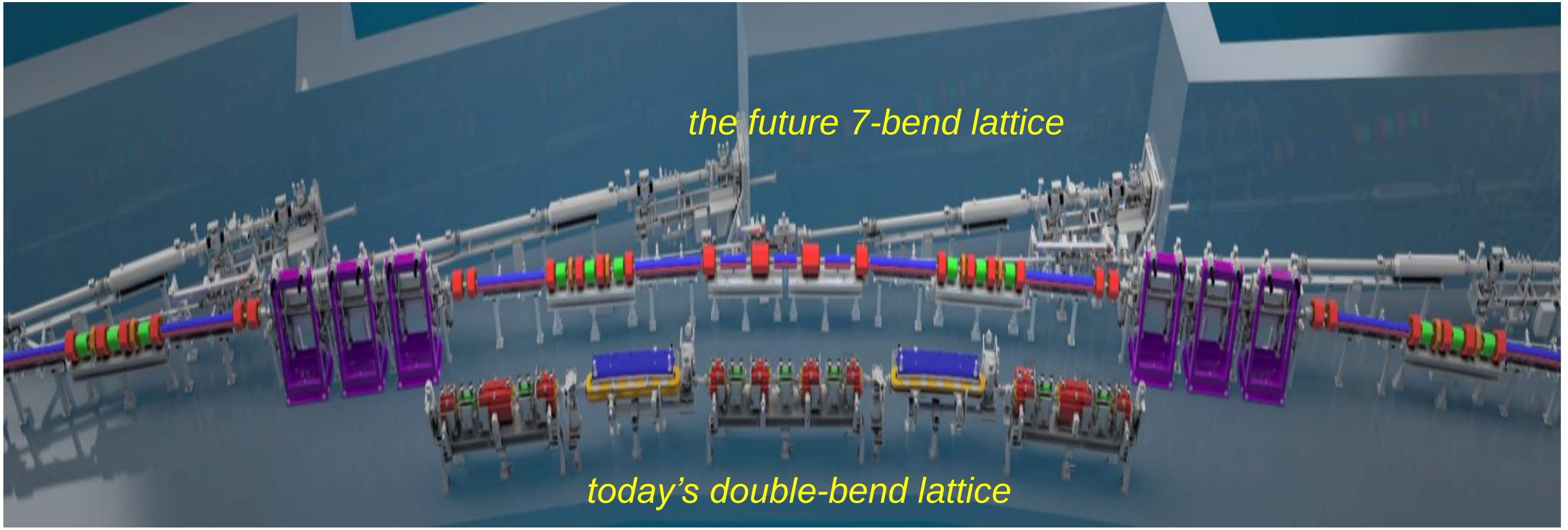
ESRF : > 20 YEARS OF SERVICE AND VARIOUS UPGRADES



Experimental Hall Extension

Experimental Hall Extension

LOW-EMITTANCE RING AT THE ESRF : CONSTRAINTS & PLANNING



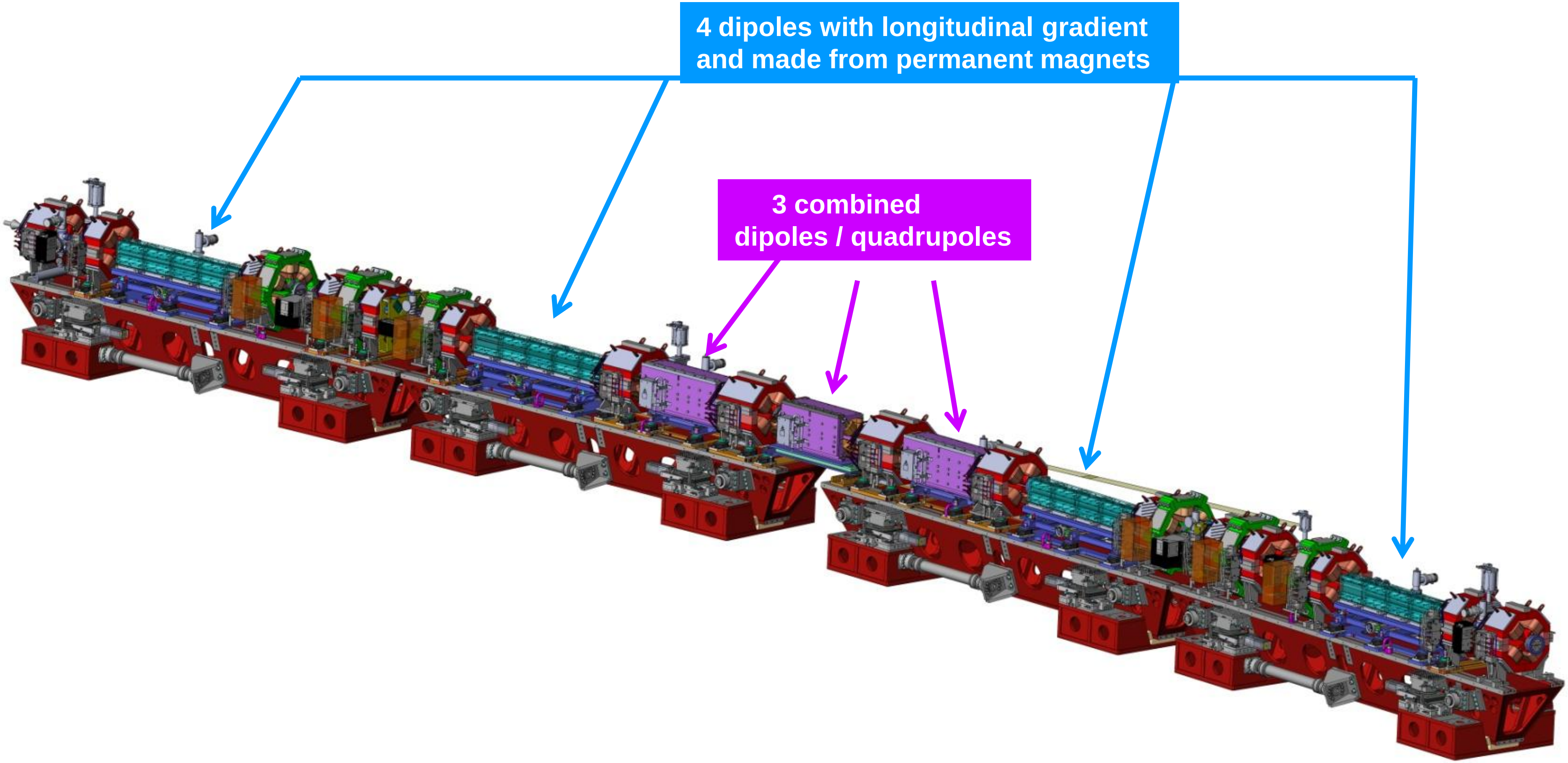
when : 2019 → the full year to dismantle the old ring and to install the new

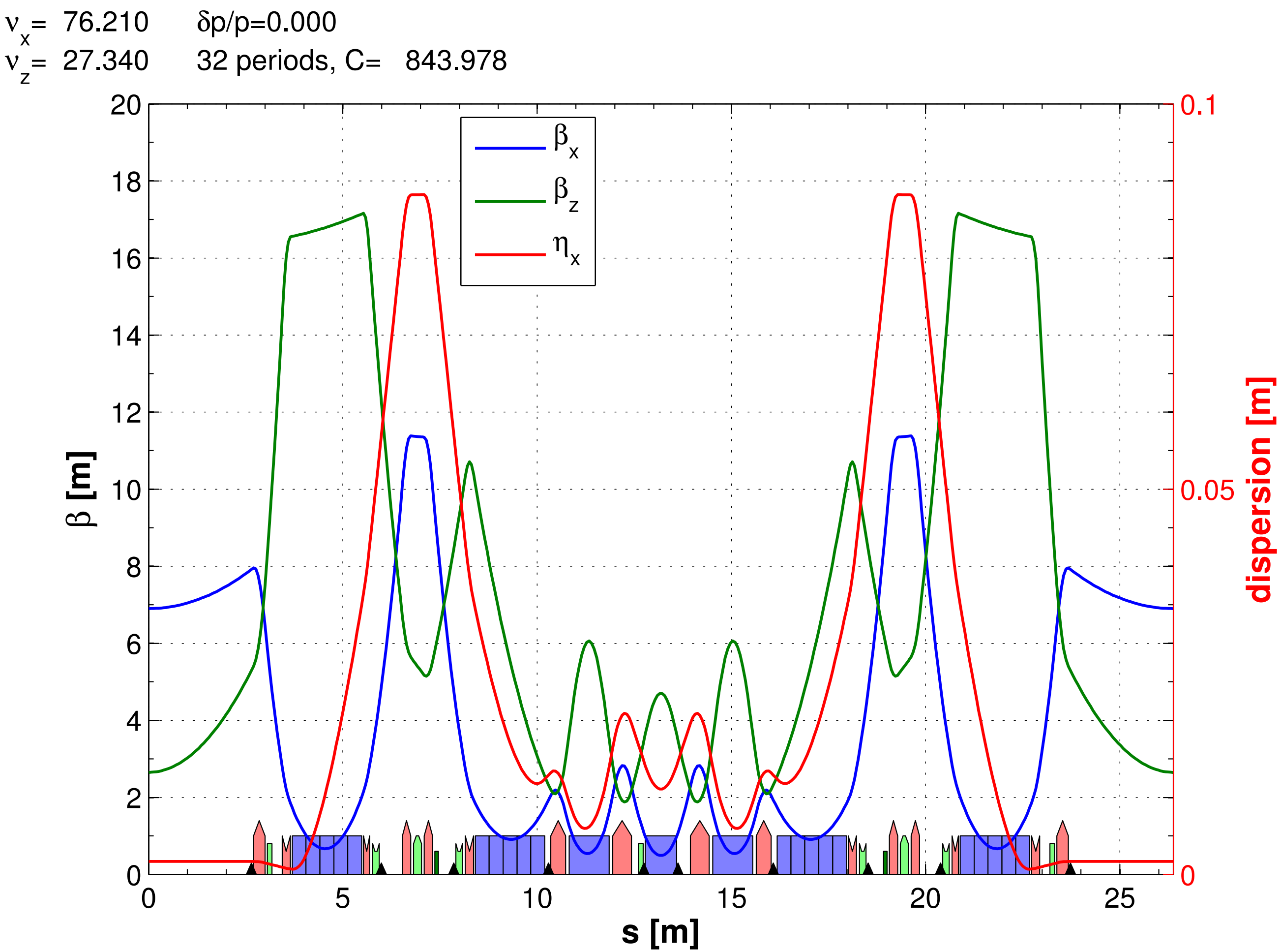
major constraint : keep all X-ray beamlines at the same location

and : keep all Users happy until last day (December 2018)

back for Users : June 2020

ESRF NEW LATTICE : ONE CELL WITH 7 DIPOLES





30 identical cells (+2 injection cells)

natural equilibrium emittance :

$$\varepsilon_{x0} = 134 \text{ pm}$$

emittances with 5 pm coupled into the vertical plane and 0.5 MV radiation losses from IDs:

$$\varepsilon_x = 107 \text{ pm}$$

$$\varepsilon_z = 5 \text{ pm}$$

THE LATTICE LAYOUT & PROPERTIES AFTER FINAL OPTIMIZATIONS

linear and non-linear optimizations carried-out with the multi-objective genetic algorithm NSGA-II, to maximize Touschek lifetime and dynamic aperture.

Lifetime and dynamic aperture are computed on 10 different errors seeds.

Sextupoles: from 6 to 3 families

Octupoles: now 1 family only

Tunes: 76.21 27.34

Linear matching parameters: $\beta_{x\ ID}$ = 6.9m

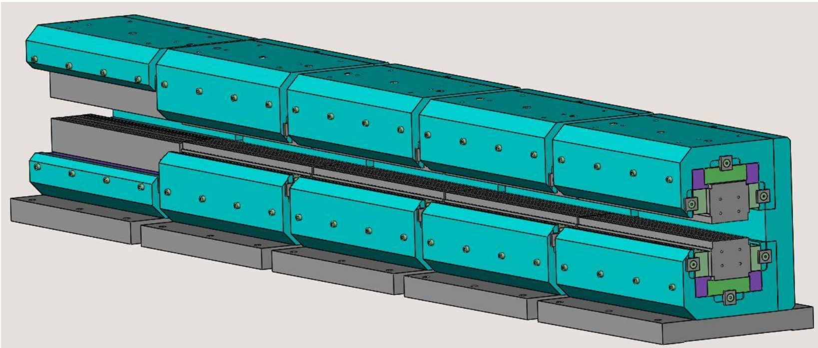
Chromaticities: 6, 4

dyn.aperture -10mm @Septum

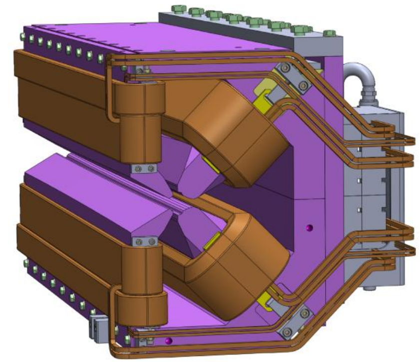
Touschek-Lifetime ~ 21h

vert. emit =5pm	ESRF-now	Low-Emittance-ESRF
7/8 multi-bunch	64 h	21 h
16 bunch	6 h	2.1 h
4 bunch	4 h	1.4 h

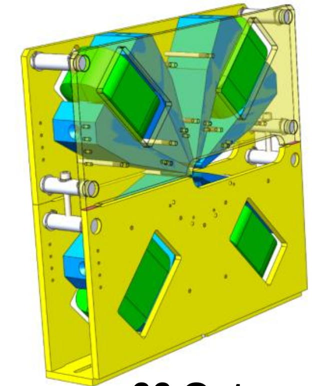
LOW-EMITTANCE RING : CHALLENGES → THE MAGNETS



132 Dipoles

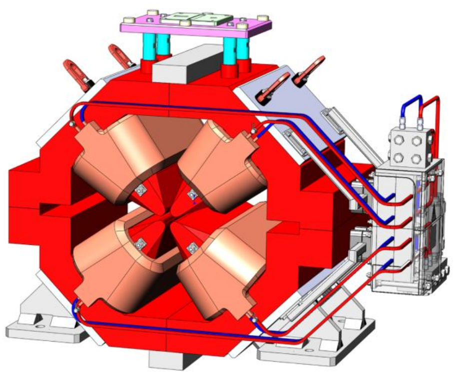


99 Dipole-quadrupoles

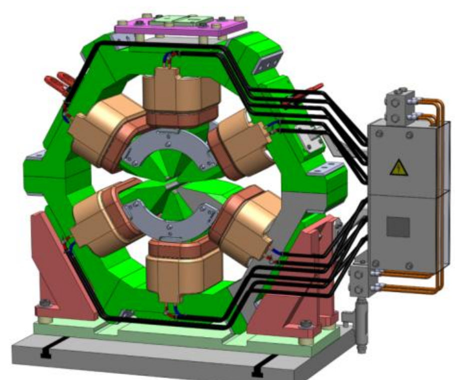


66 Octupoles

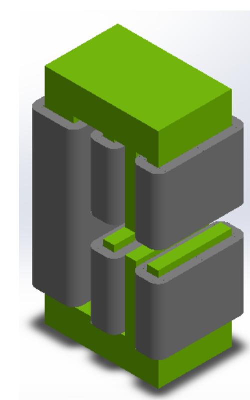
> 1000 Magnets to procure & handle in < 3 years



528 Quadrupoles

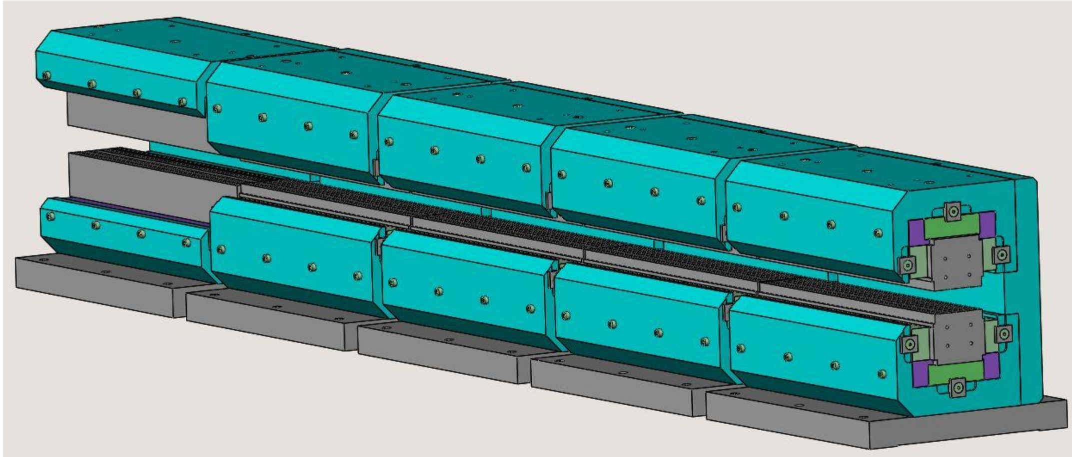


196 Sextupoles



100 Correctors

PERMANENT DIPOLE MAGNETS



dipole magnet made from permanent magnets assembly

with a longitudinal gradient in 5 sections from 0.17 to 0.67 T

- **low procurement costs**
- **no running (energy-consumption) costs**
- **strong in-house experience in permanent magnet assemblies**
- **approx. 6000 kg material (Sm_2Co_{17}) of permanent magnet (=12769 magnet pieces) to be delivered**

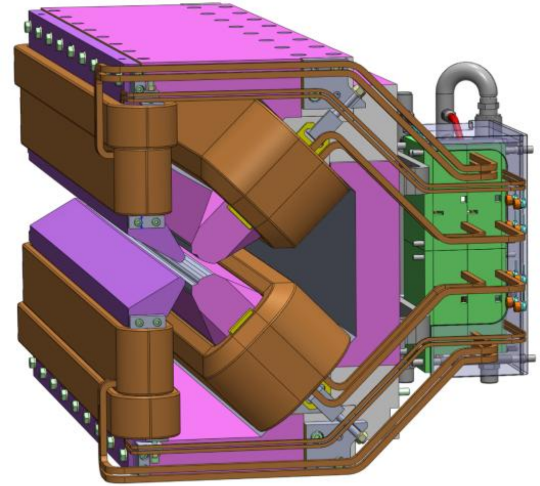
COMBINED DIPOLE - QUADRUPOLES

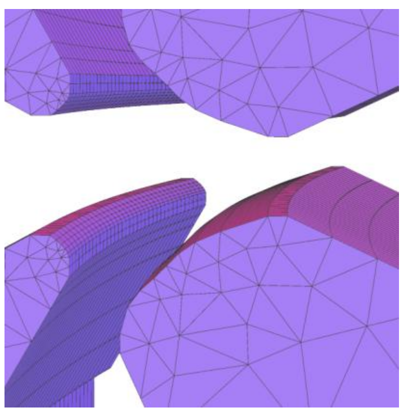
Specifications :	length	dipole	quadr.
• DQ1 :	1.028 m	0.57 T	37.1 T/m
• DQ2 :	0.800 m	0.39 T	31.4 T/m

- $\Delta G/G$ < 1% (GFR radius 7 mm)

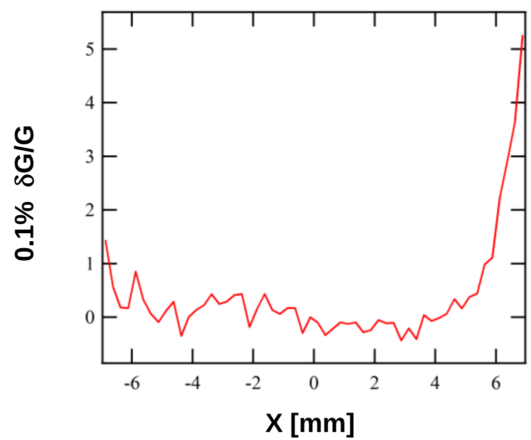
Pole shape optimization

- machined in 7 laminated iron plates

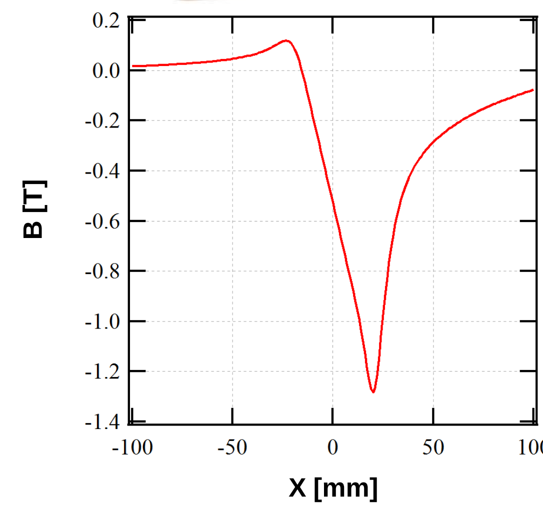




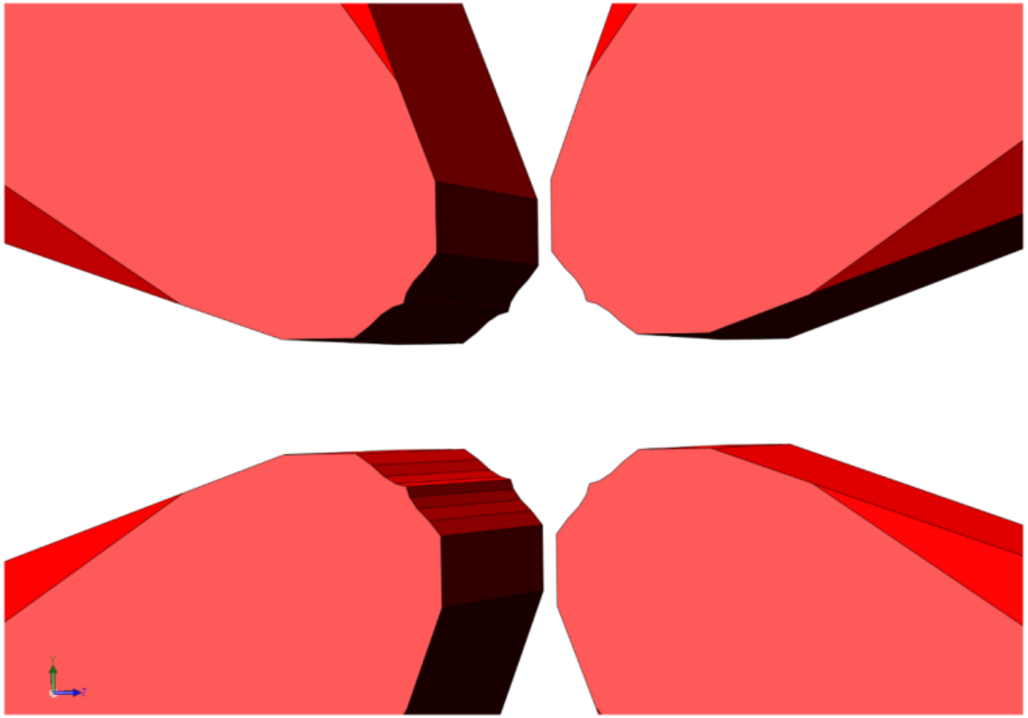
pole-shape (detail)



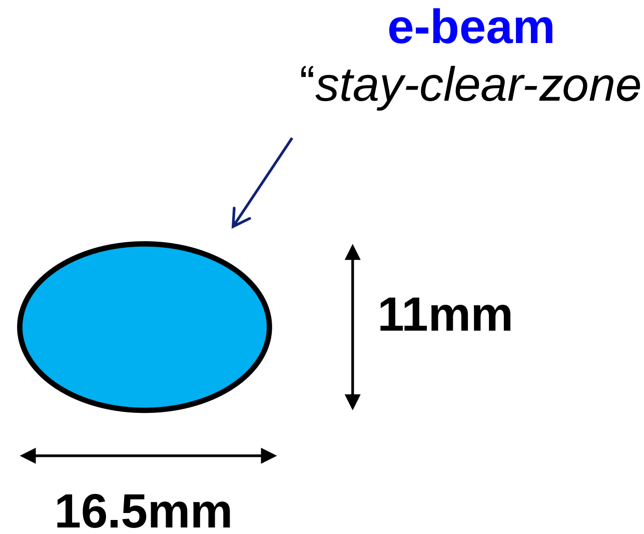
gradient homogeneity



VACUUM CHAMBERS : VERY LIMITED SPACE TRANSVERSELY

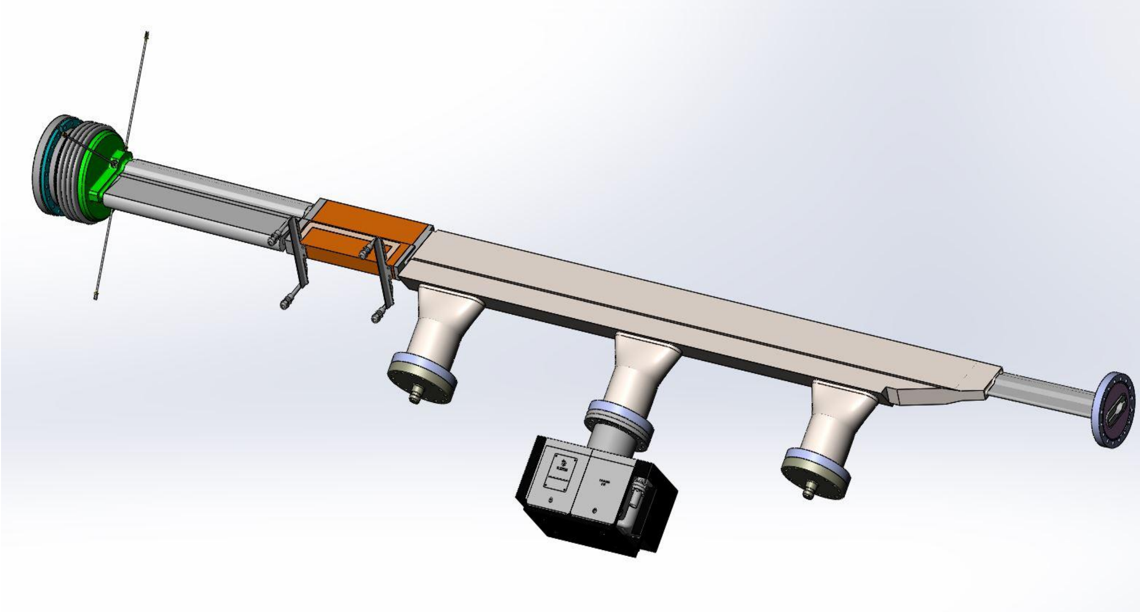


strong gradient fields → poles at short distance

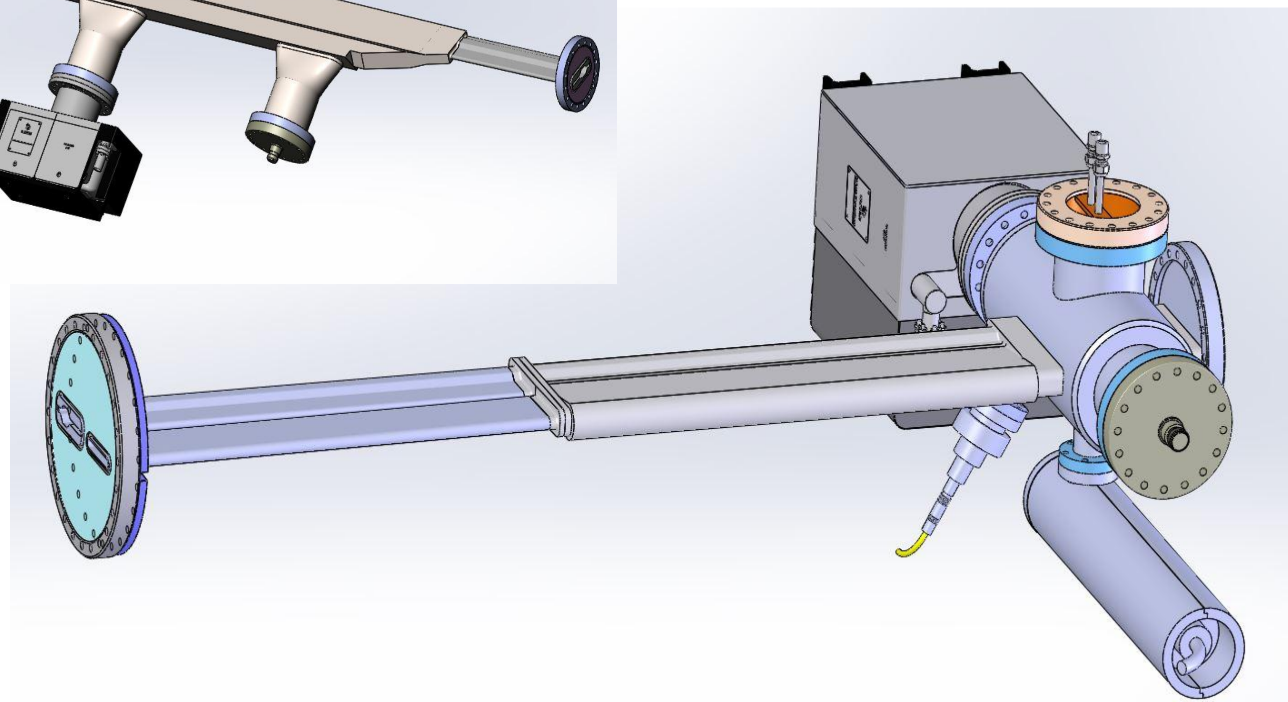


little space (thickness) for
the vacuum chamber wall,
→ most chambers from Steel

CHALLENGES : A TOTAL OF 14 *COMPLEX* VACUUM CHAMBERS PER CELL



two examples shown

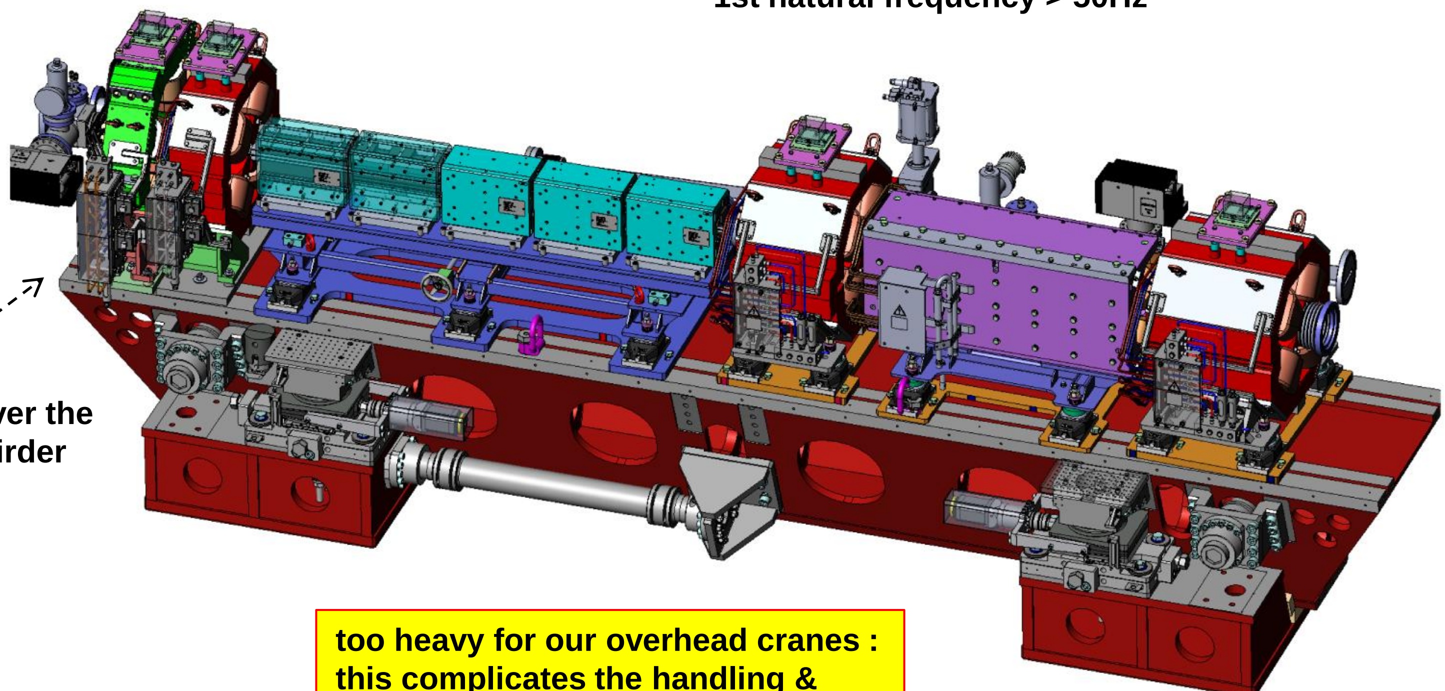


ESRF LOW-EMITTANCE RING : THE CHALLENGES : GIRDERS & TRANSPORT

orthogonal heptapod

- 4 motorized adjustable supports in vertical direction
- 3 manual horizontal jacks (1 longit. and 2 radial)
- Girder material: carbon steel
- Typical thickness: 30mm (20-50)
- Piece junction: full penetration and continous welding

- Girder length = 5.1m
- Girder weight ~ 3500kg
- magnets weight ~ 6000kg
- motorized Z adjustment resolution 5µm
- manual Y adjustment resolution 5µm
- 1st natural frequency > 50Hz

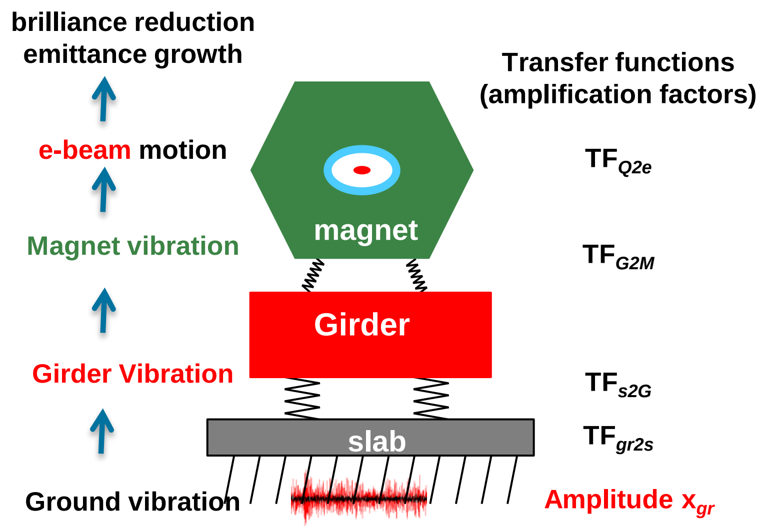


+/- 50um flatness over the full surface of the girder

too heavy for our overhead cranes : this complicates the handling & transportation & installation

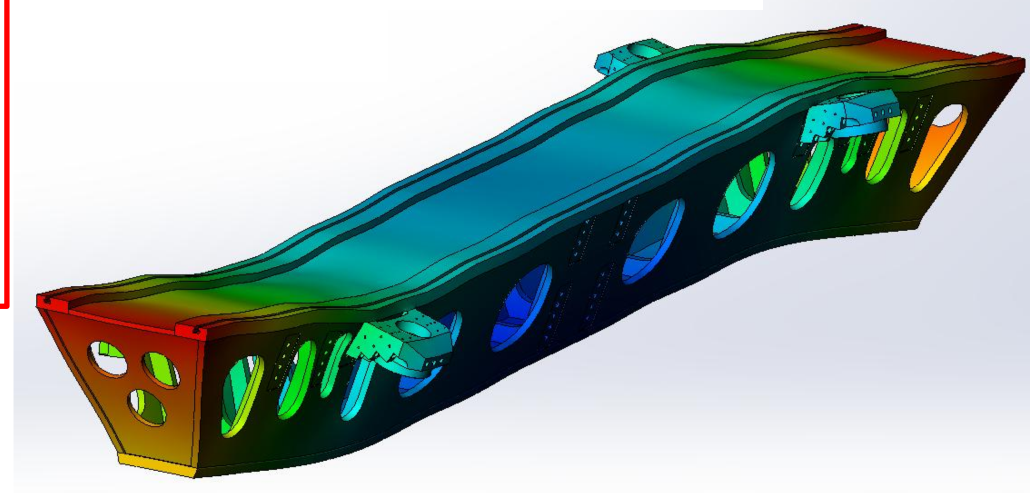
GIRDERS : STIFFNESS CALCULATIONS

vibration amplification ground to beam

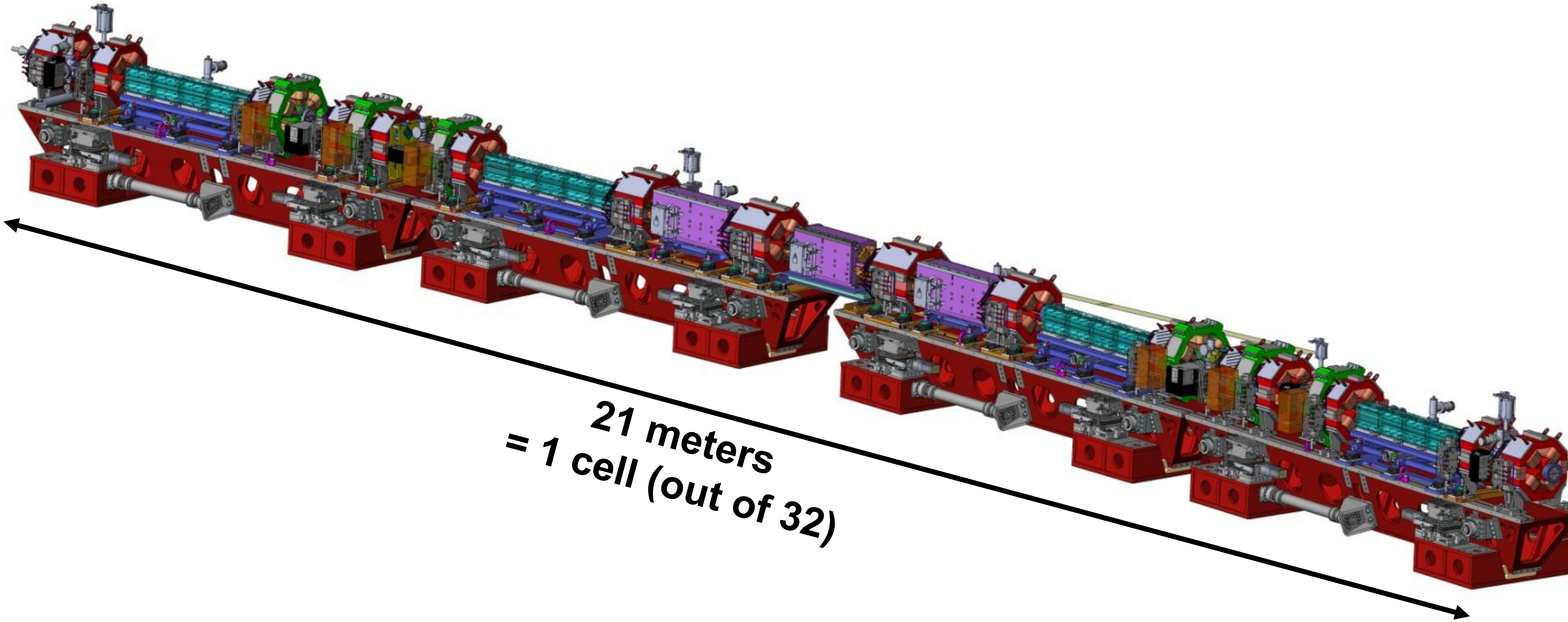


real measurements will be performed with the girder loaded with dummy magnets (of real weight)

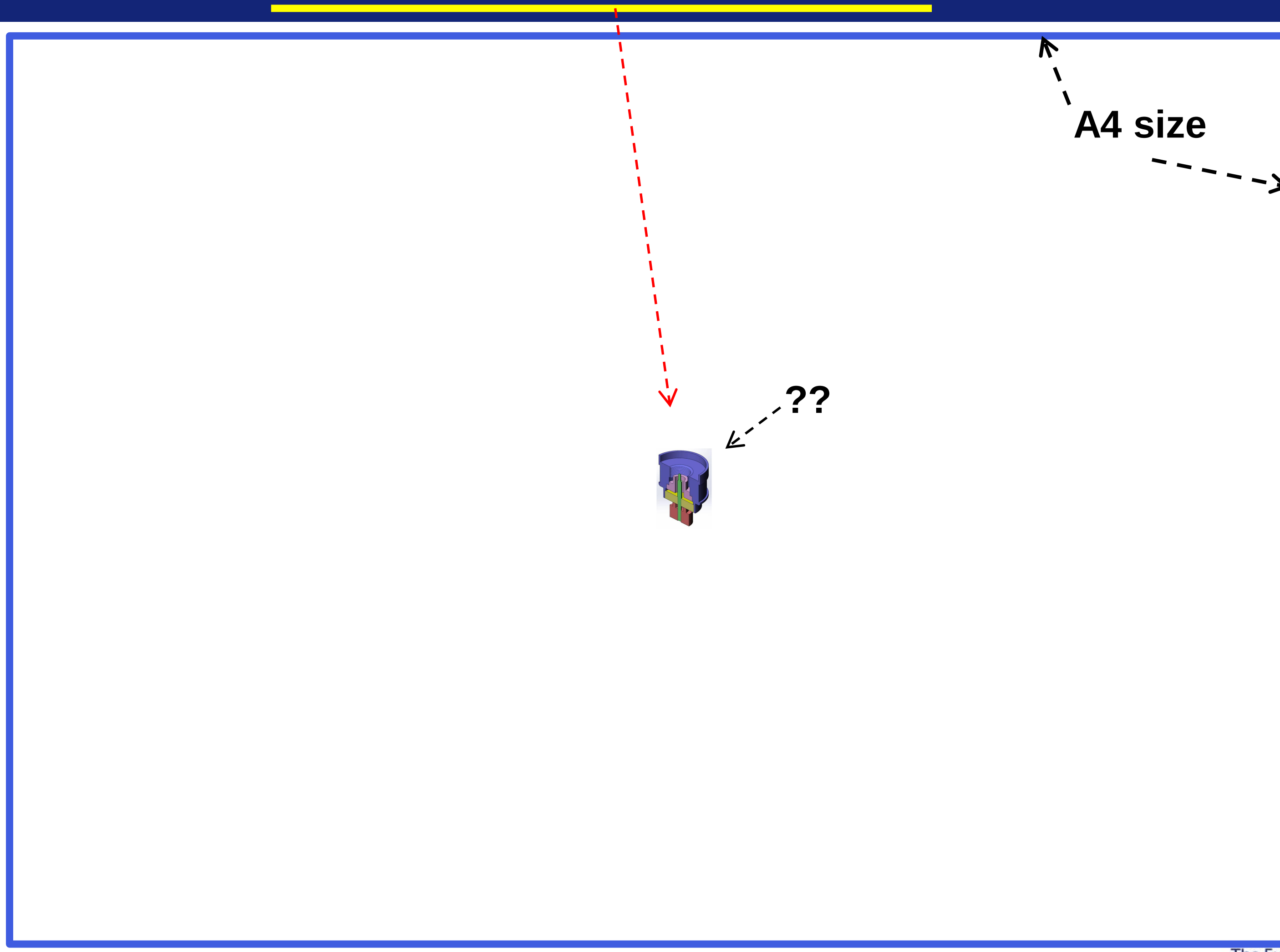
output from modal analysis,
1rst natural frequency about 50Hz



NOW LET'S SHOW THE DIAGNOSTICS : WHERE ARE THEY ?



DIAGNOSTICS : THE MOST CRUCIAL COMPONENT ….



BPM BUTTONS : BPM-BUTTON-UHV-FEEDTHROUGH

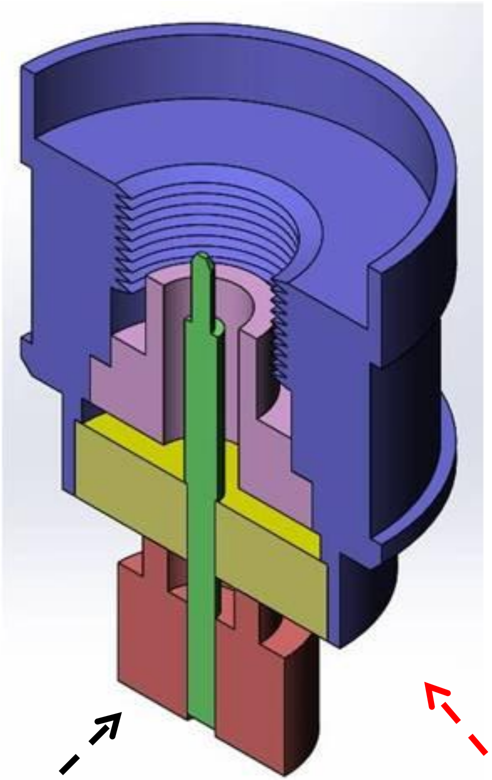
prototype & C-f-T process done in 2014/15

contract with manufacturer now in process

delivery (1500 units) expected early 2016

total costs : roughly 350 KEuros

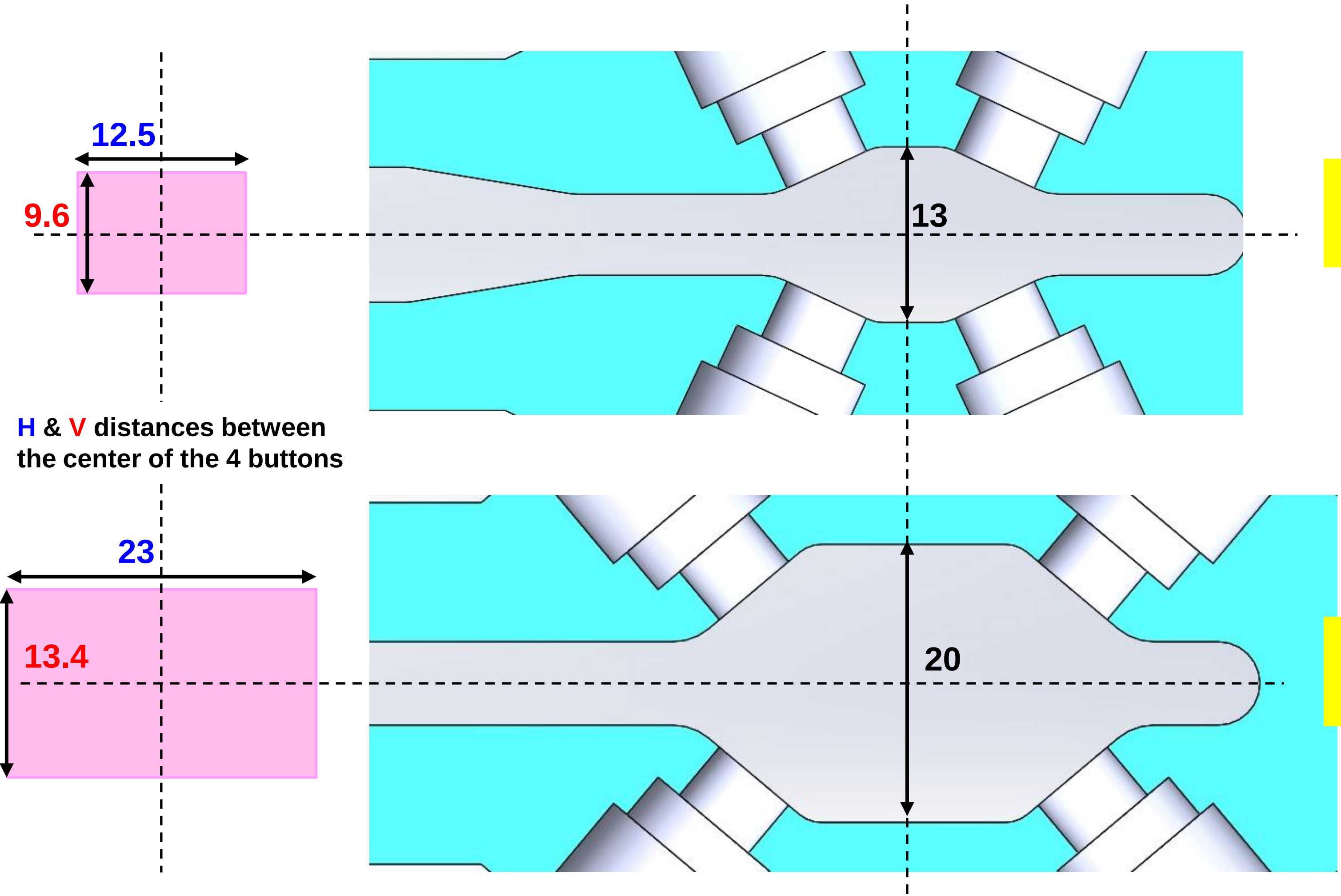
in total in the Ring :
320 BPMs = 1280 buttons



1500 { 600 with 6mm
900 with 8mm }

tolerances down to 20um

BPM BLOCKS : 2 DISTINCT GEOMETRIES



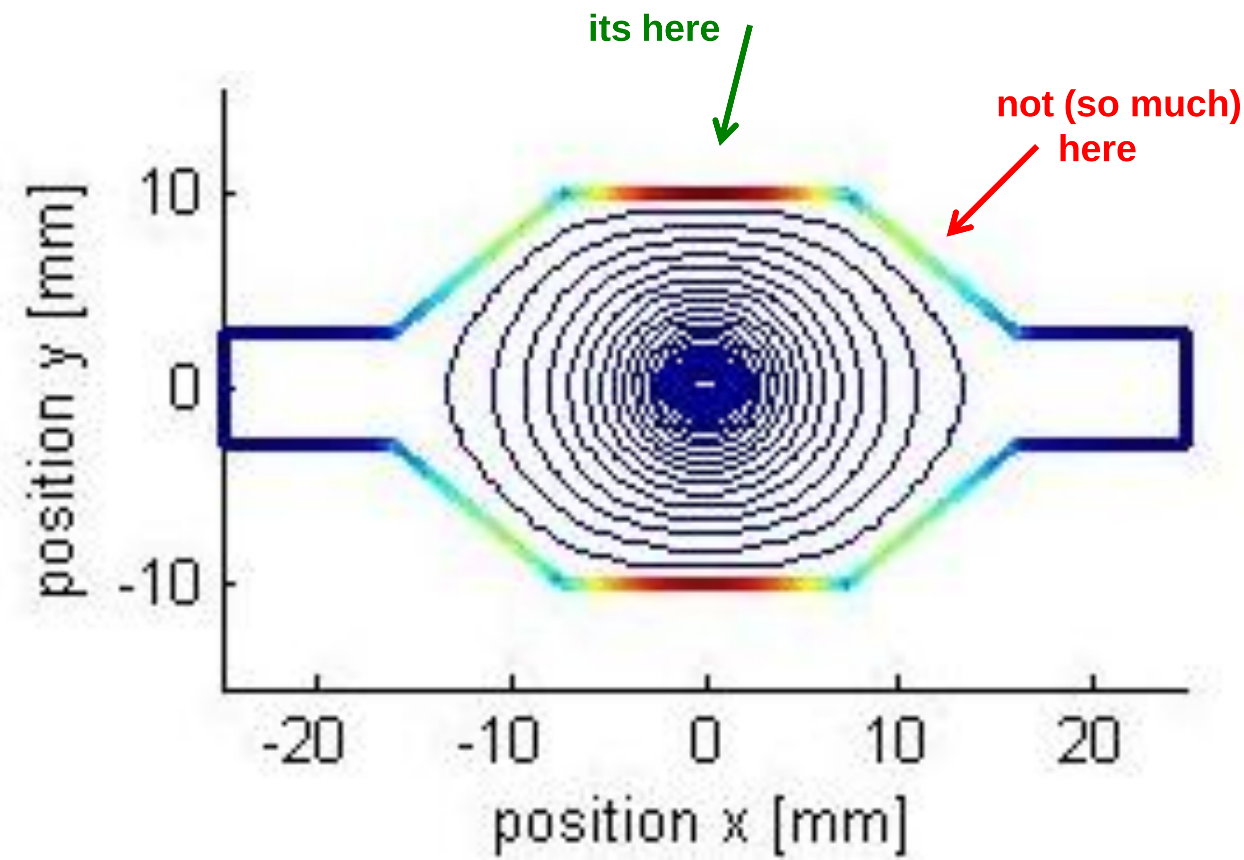
Kx= 4.7
Kz= 7.4

BPM no.
4 5 6 7

Kx= 6.5
Kz= 16.4 . . .

BPM no.
1 2 3 8 9 10

<u>WHERE IS THE CHARGE</u> IN THAT BPM ???

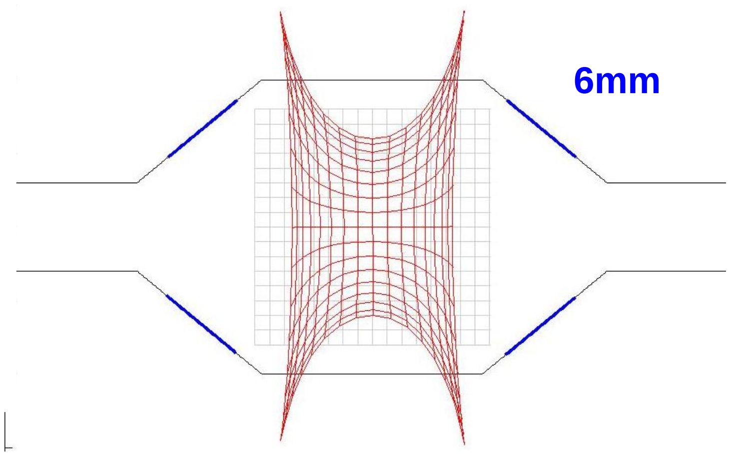


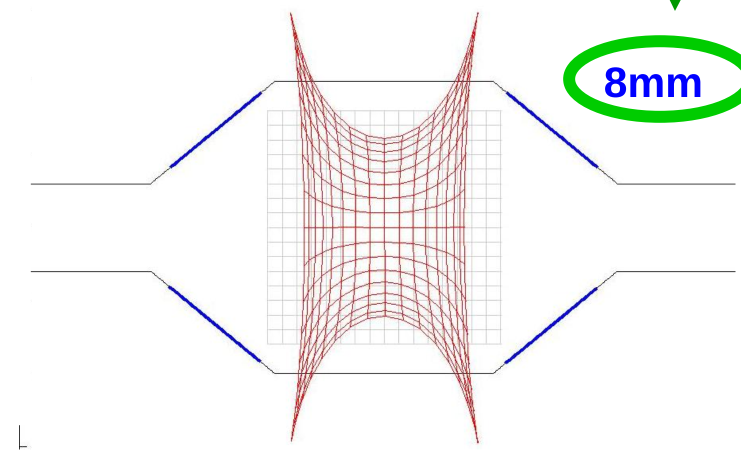
with courtesy to G.Rehm (DLS, UK)

BPM GEOMETRY , MAPPING, BUTTON DIAMETER

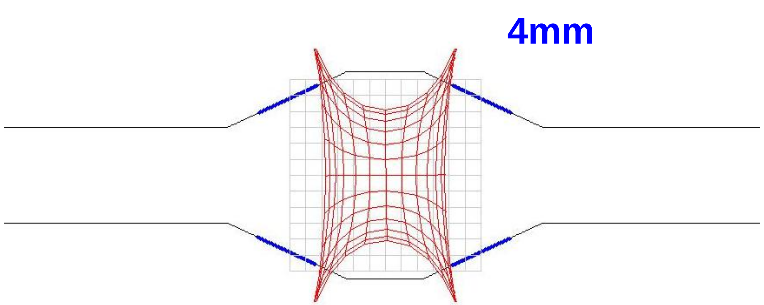
optimization of button diameters (for RF signal strength)

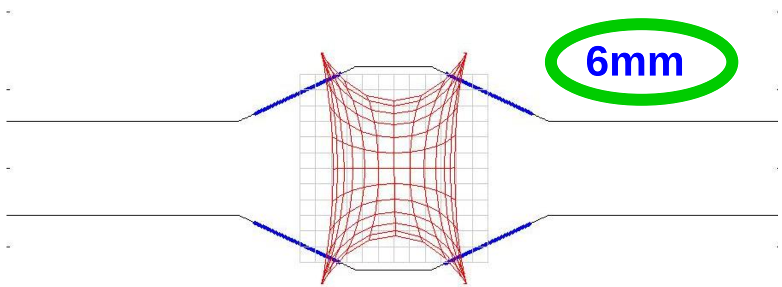
BIG 6/10





small 4/10





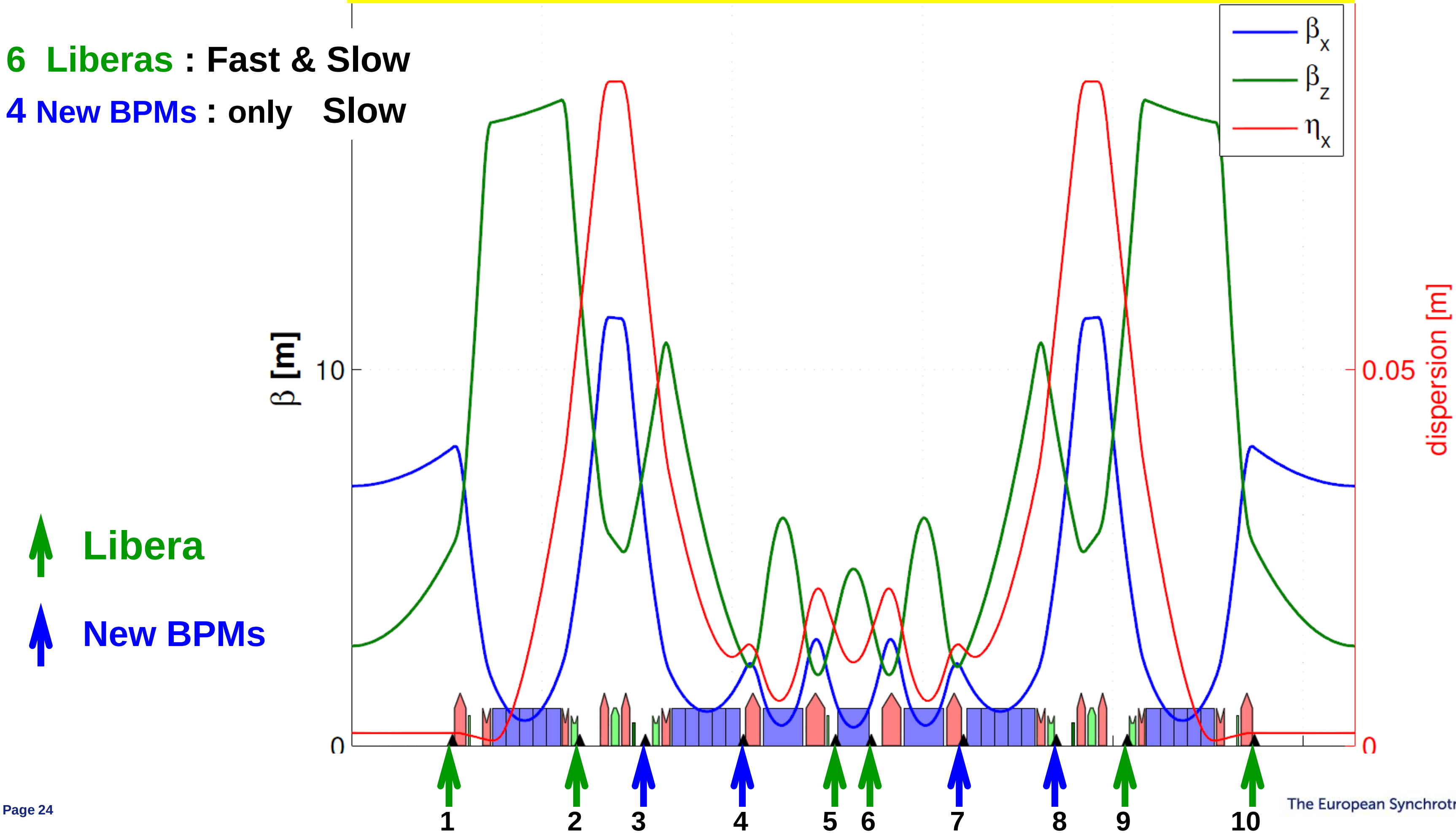
with courtesy to G.Rehm, DLS

FAST & SLOW ORBIT CORRECTION : 6 LIBERAS & 4 NEW BPMS PER CELL

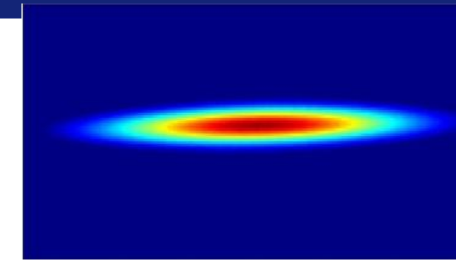
X-ray beam stability for users will be identical to that of today

6 Liberas : Fast & Slow

4 New BPMs : only Slow



DIAGNOSTICS : EMITTANCE MONITORS → X-RAY PINHOLE SYSTEMS



resolution limits

2 units using X-rays produced by a dipole DL1A_5 at 0.68T → 1.5 pm

3 units using X-rays produced by a dipole DQ1D at 0.56T → 10 pm

both systems together offer a good energy spread monitor
(at 2 positions of different dispersion)

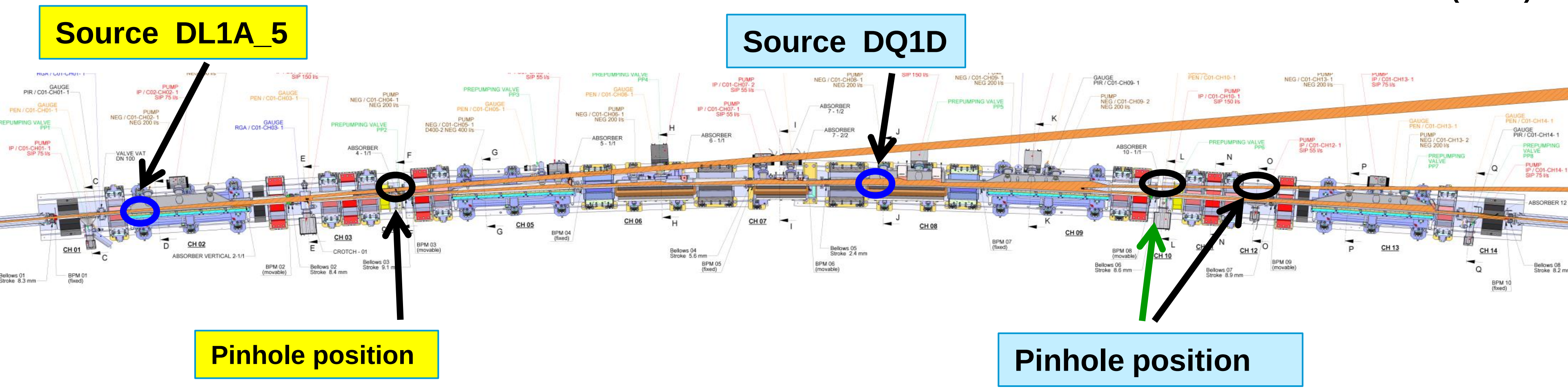
layouts now globally determined

UHV components : special absorbers and Aluminium beamport window

non-UHV parts : pinhole made from Tungsten blades, motorizations
standard X-ray imager

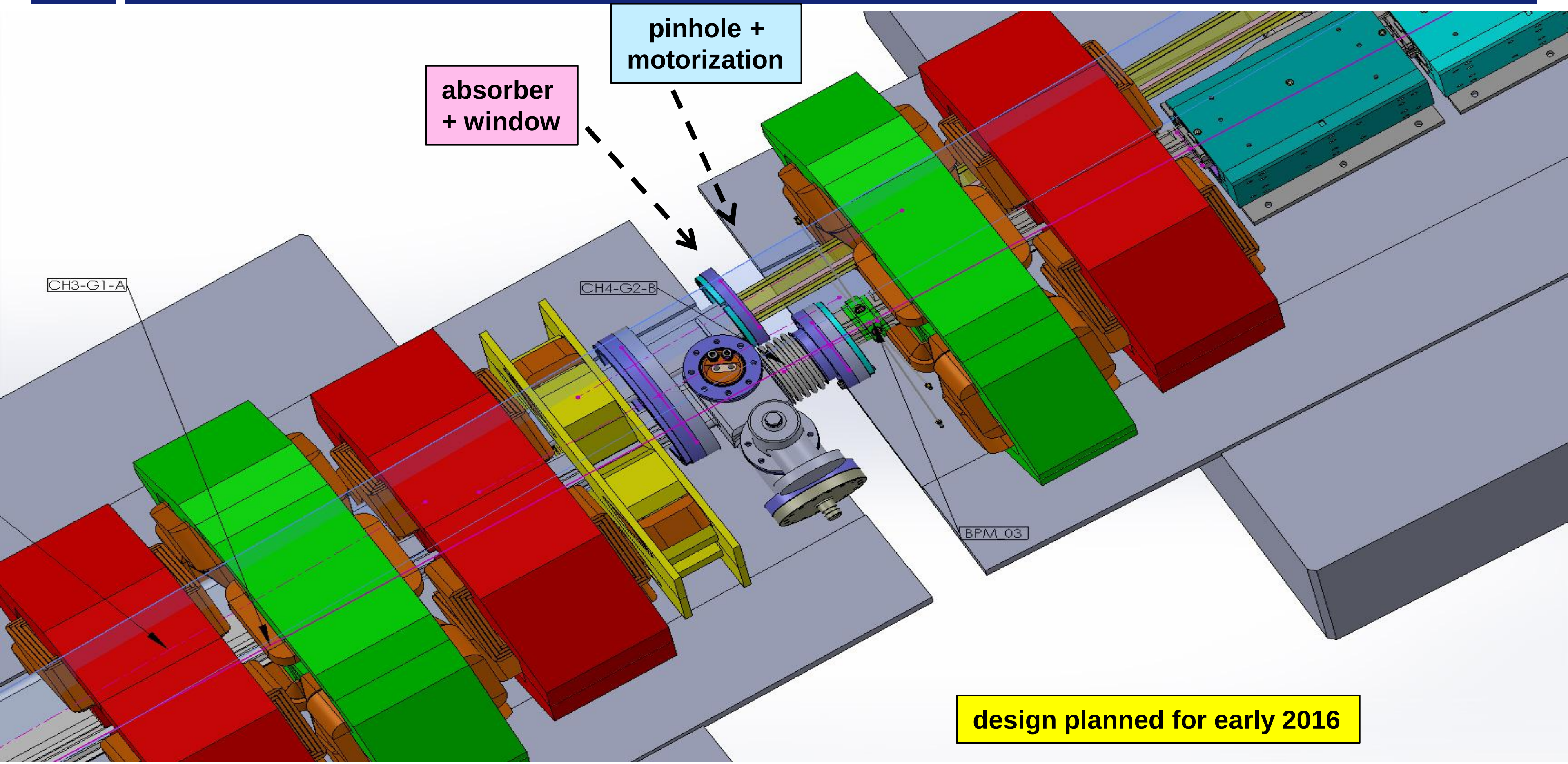
DIAGNOSTICS : EMITTANCE MONITORS LAYOUT

(S28A)

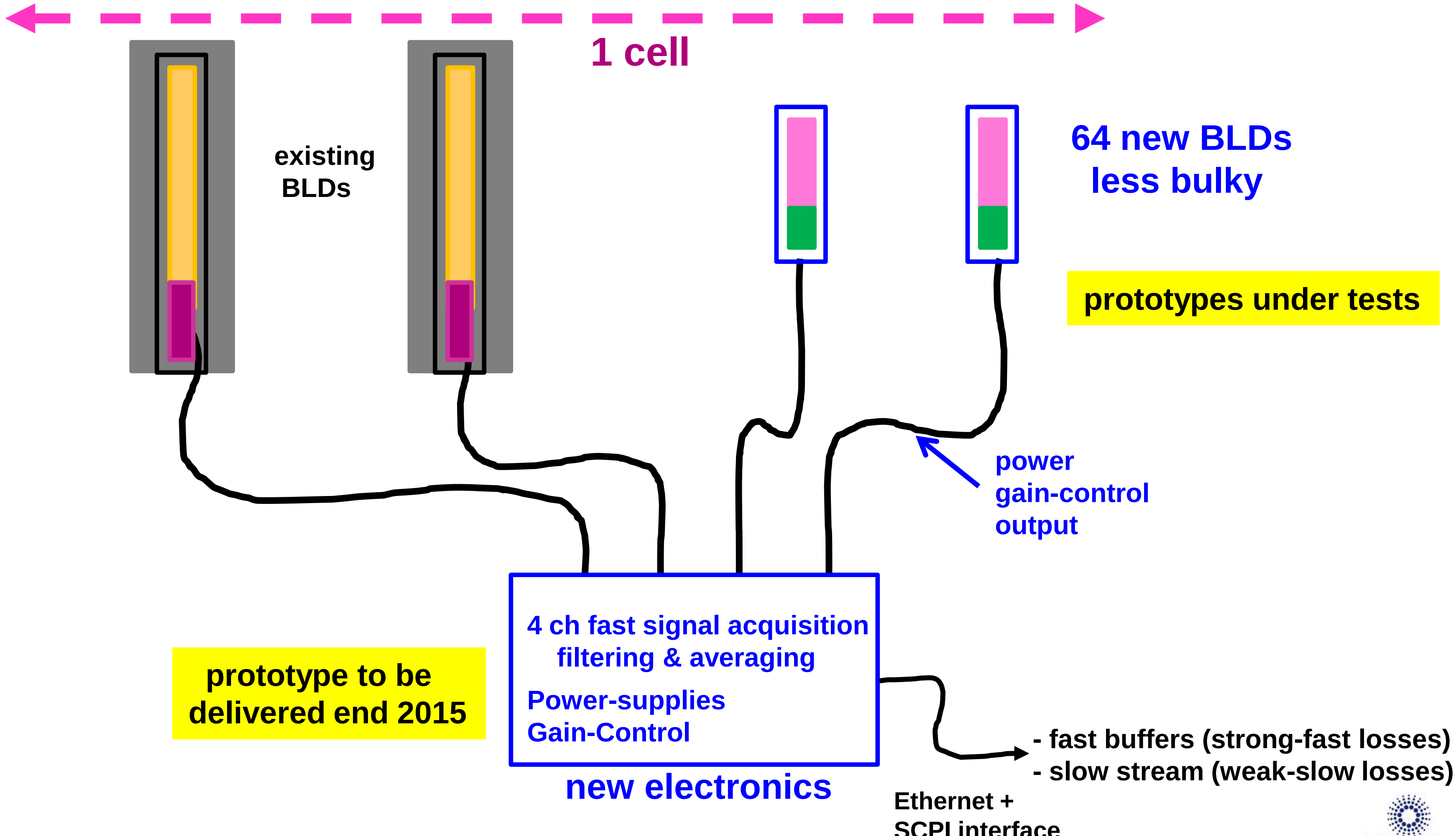


	ID-beamport		BM-beamport	
distance source–pinhole	*d = 3.76 m*		*d = 5.4 m*	*or 4.2 m*
distance pinhole–screen	*D = 16.4 m*		*D = 17.7 m*	*or 18.9 m*
magnification	*M = 4.3*		*M = 3.3*	*or 4.5*

DIAGNOSTICS : EMITTANCE MONITORS , THE PARTS IN & BEHIND UHV



DIAGNOSTICS : BEAM LOSS MONITORS → TOTAL OF 128 UNITS



DIAGNOSTICS & FEEDBACKS : OVERVIEW & PLANNING

BPMs & Fast Orbit Correction :	architecture & functionality determined
buttons :	C-f-T in process
blocks :	geometries and supports & fixation now defined
extra electronics :	upgraded prototype under tests
Emittance Monitors :	quantity, type and layout now globally determined detailed design (of the UHV parts) in early 2016
Current Transformers :	design nearly finalized
Striplines :	design nearly finalized
Scrapers :	design still to be done
BeamLoss Monitors :	prototypes of BLD-head under tests / evaluation, signal acquisition prototype purchased, delivery autumn
Visible Light Extraction :	feasibility needs to be fully confirmed, radiation protection etc. to be decided, implementation of the Mirror in UHV to be designed

thank you for your attention