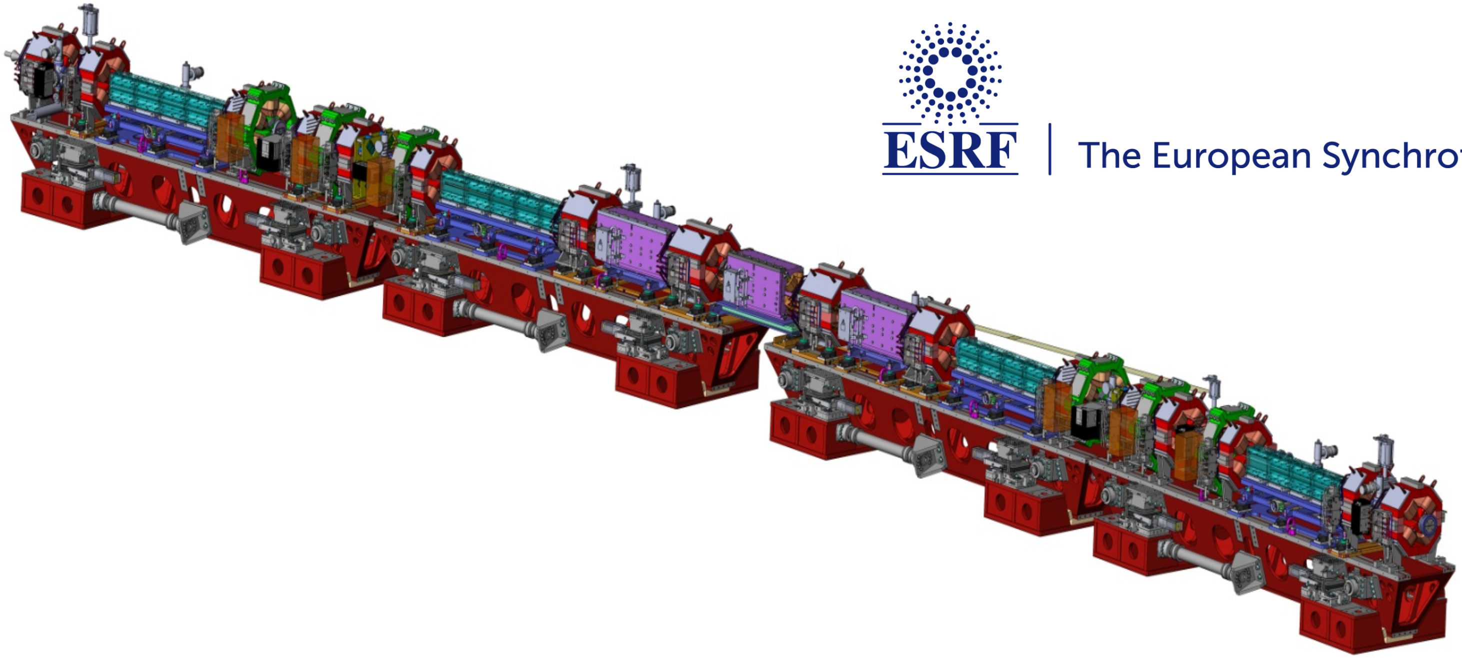
ESRF EBS Accelerator Upgrade

Busan, May 10th 2016

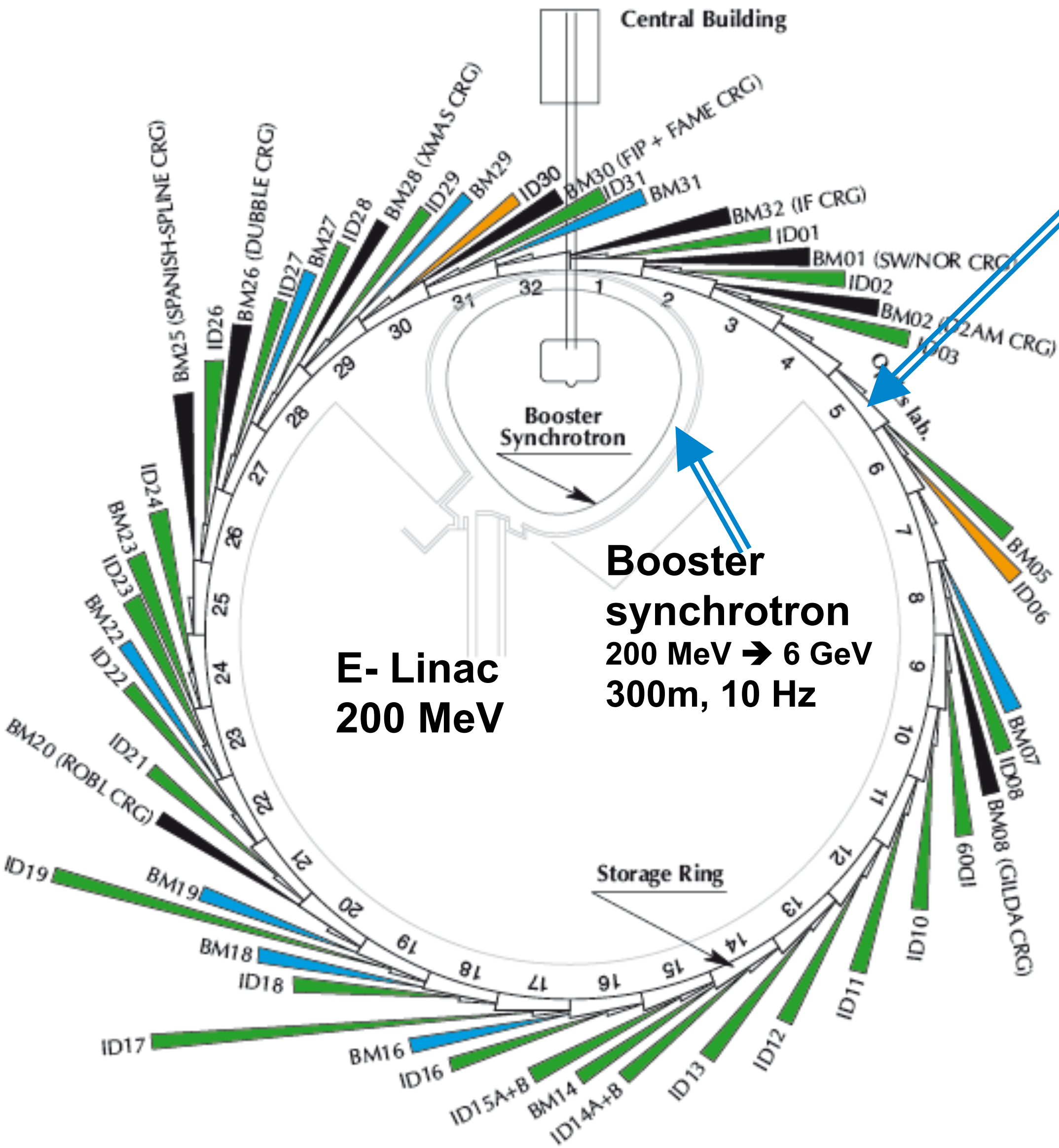
Pantaleo Raimondi

On behalf of the Accelerator Project Phase II Team



ESRF | The European Synchrotron

ESRF TODAY



Energy	GeV	6.04
Multibunch Current	mA	200
Horizontal emittance	nm	4
Vertical emittance	pm	3.5

32 straight sections

DBA lattice

42 Beamlines

12 on dipoles

30 on insertion devices

72 insertion devices:
55 in-air undulators, 6 wigglers,
11 in-vacuum undulators,
including 2 cryogenic

Extremely Brilliant Source: Accelerator Upgrade

The Accelerator Upgrade Phase II aims to:

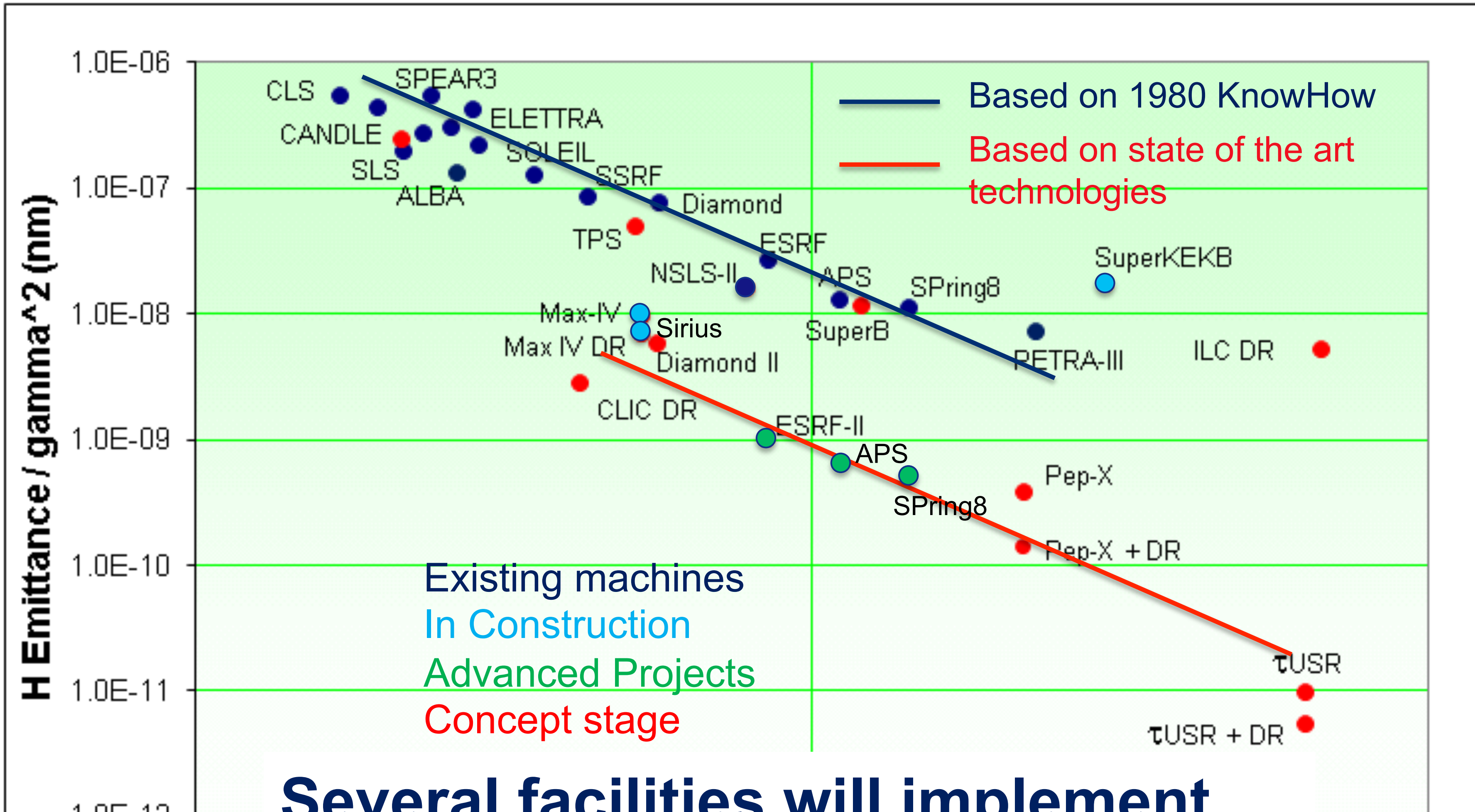
- Substantially decrease the Store Ring Equilibrium Horizontal Emittance
- Increase the source brilliance
- Increase its coherent fraction

In the context of the R&D on "Ultimate Storage Ring", the ESRF has developed a solution, based on the following requirements and constraints:

- Reduce the horizontal equilibrium emittance from 4 nm to less than 140 pm
- Maintain the existing ID straights 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, particularly wall-plug power
- Limit the downtime for installation and commissioning to less than 18 months.

Maintain standard User-Mode Operations until the day of shut-down for installation

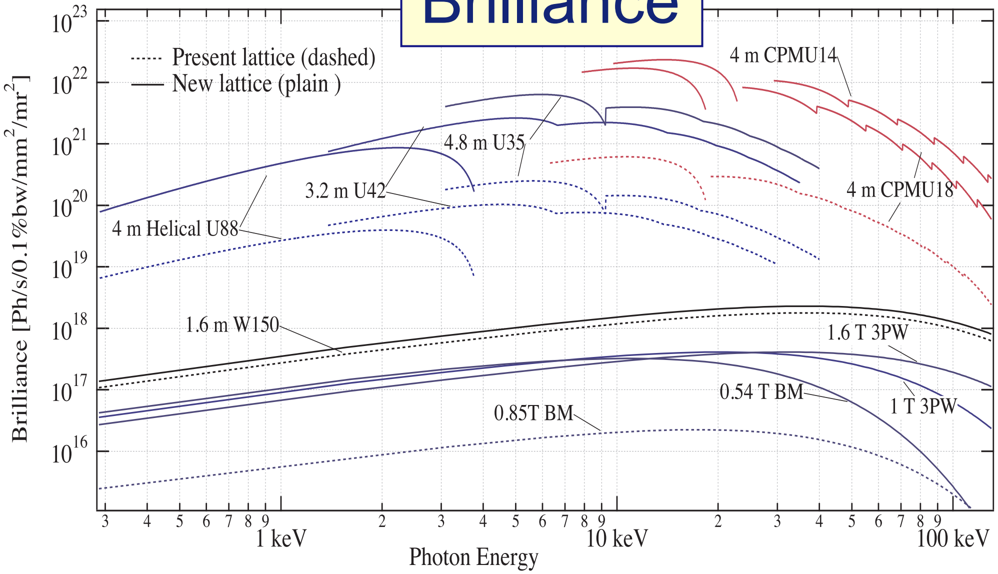
LOW EMITTANCE RINGS TREND



Several facilities will implement Low Horizontal Emittance Lattices by the next decade

BRILLIANCE AND COHERENCE INCREASE

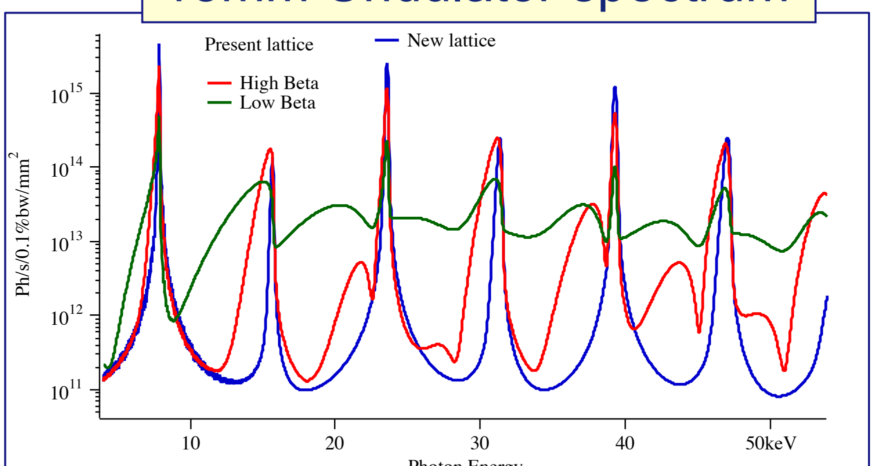
Brilliance



Hor. Emittance [nm]	4	0.135
Vert. Emittance [pm]	4	5
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

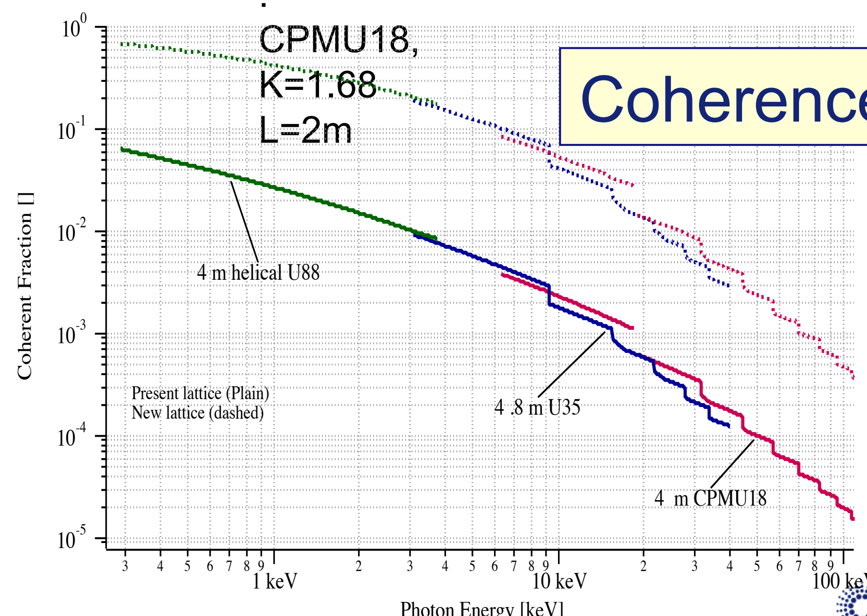
Source performances will improve by a factor 50 to100

18mm Undulator spectrum



Coherence

Undulator: CPMU18, K=1.68 L=2m



BENDING MAGNETS SOURCE: 2-POLE, 3-POLE OR SHORT WIGGLERS

All new projects of diffraction limited storage rings have to deal with:

Increased number of bending magnets / cell => BM field reduction

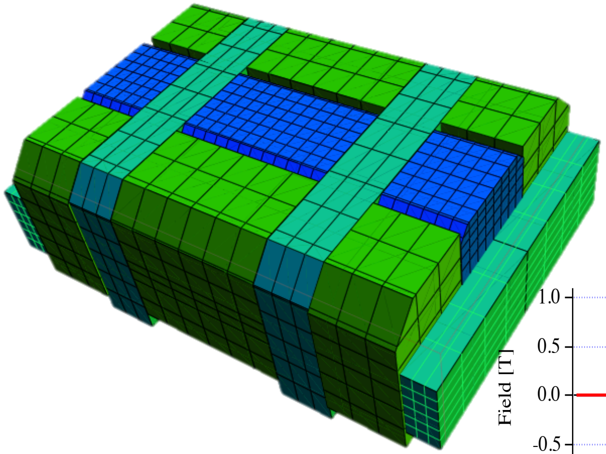
Conflict with hard X-ray demand from BM beamlines

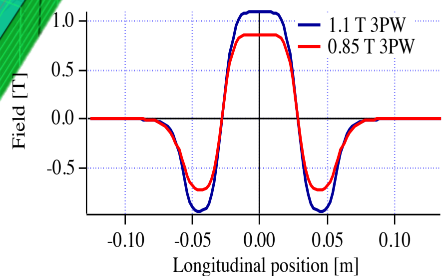
ESRF will go from 0.85 T BM to 0.54 T BM

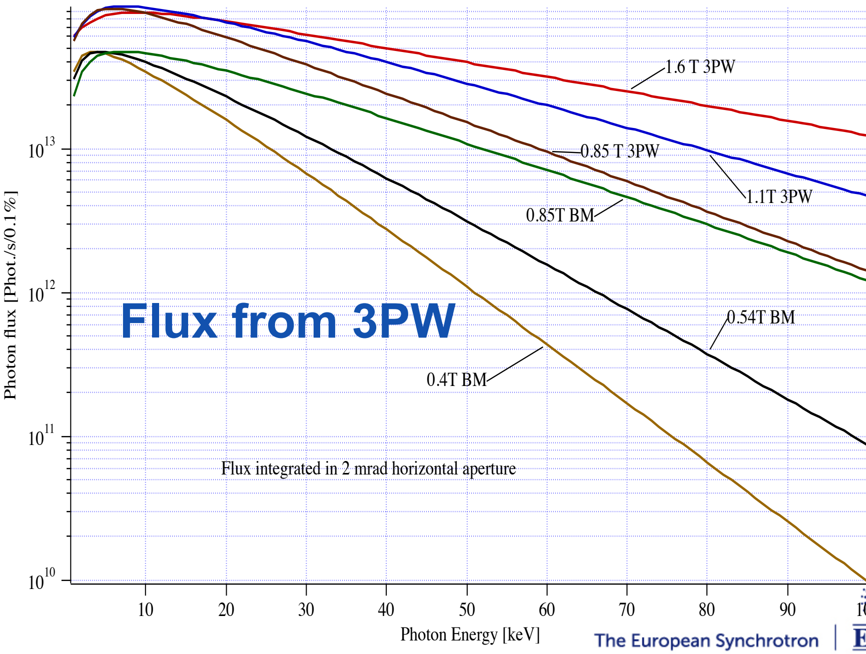
The BM Sources will be replaced by dedicated 2-Pole or 3-Pole Wigglers

- Field Customized
- Large fan with flat top field
- 2 mrad feasible for 1.1 T 3PW
- Mechanical length ≤ 150 mm

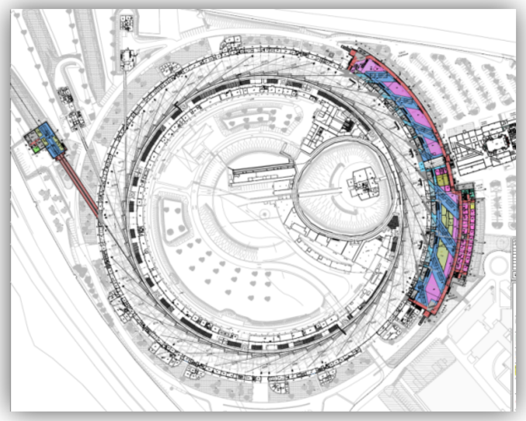
- Source shifts longitudinally by ~3m
- Source shifts horizontally by ~1-2cm



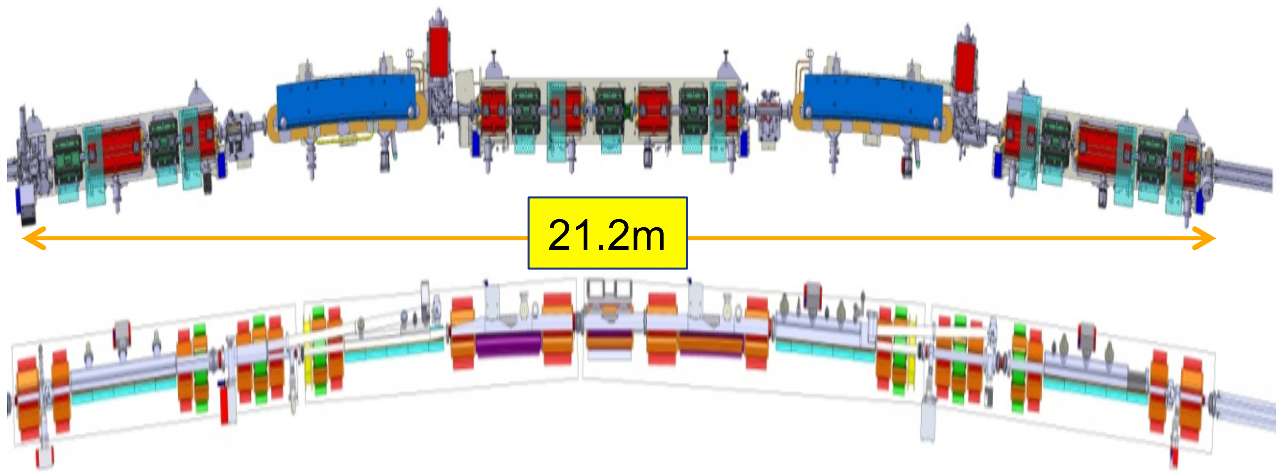




ESRF Phase II Upgrade at the Bone



Present ESRF Arc Layout: Ex=4nm



New Low Emittance Layout: Ex=0.135nm

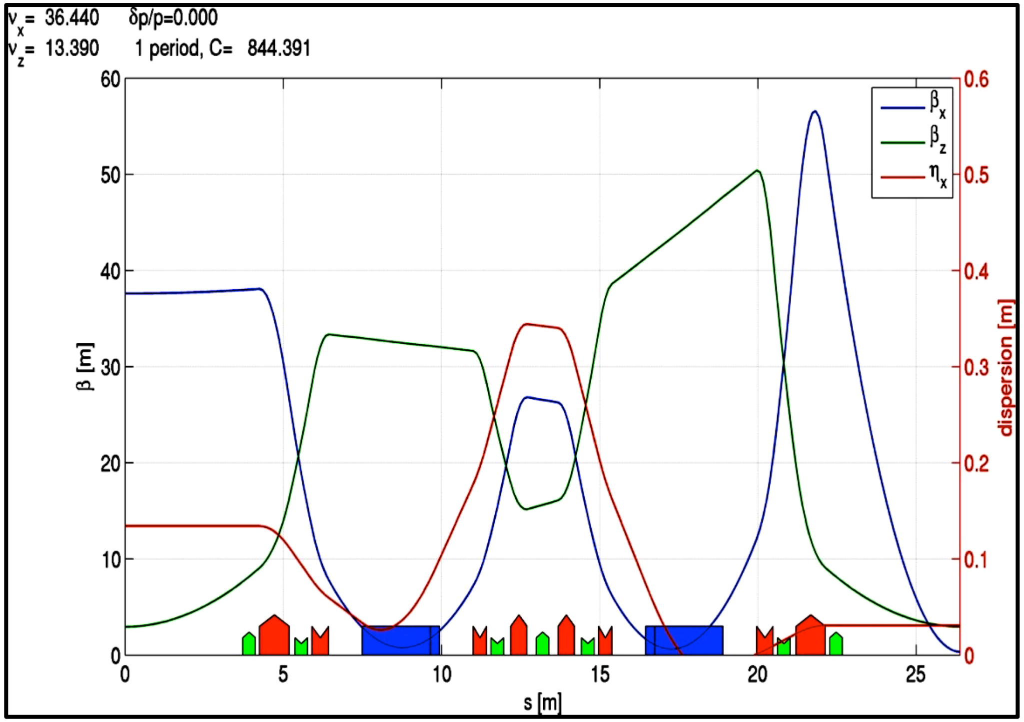
The 844m Accelerator ring consists of:

- 32 identical Arcs 21.2m long
- 32 straight sections 5.2m long equipped with undulators and RF

Each Arc is composed by a well defined sequence of Magnets (dipoles, quadrupoles etc), Vacuum Components (vacuum vessel, vacuum pumps etc), Diagnostic (Beam Position Monitors etc) etc.

All the Arcs will be replaced by a completely new Layout

THE EVOLUTION TO MULTI-BEND LATTICE



Double-Bend Achromat (DBA)

- Many 3rd gen. SR sources
- Local dispersion bump (originally closed) for chromaticity correction

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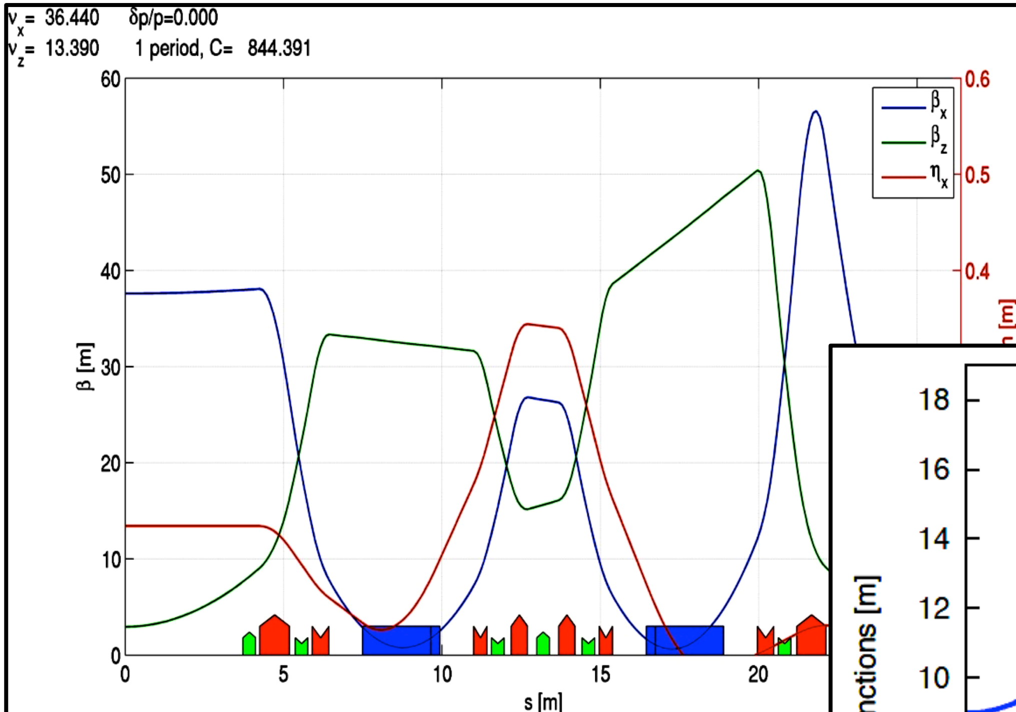

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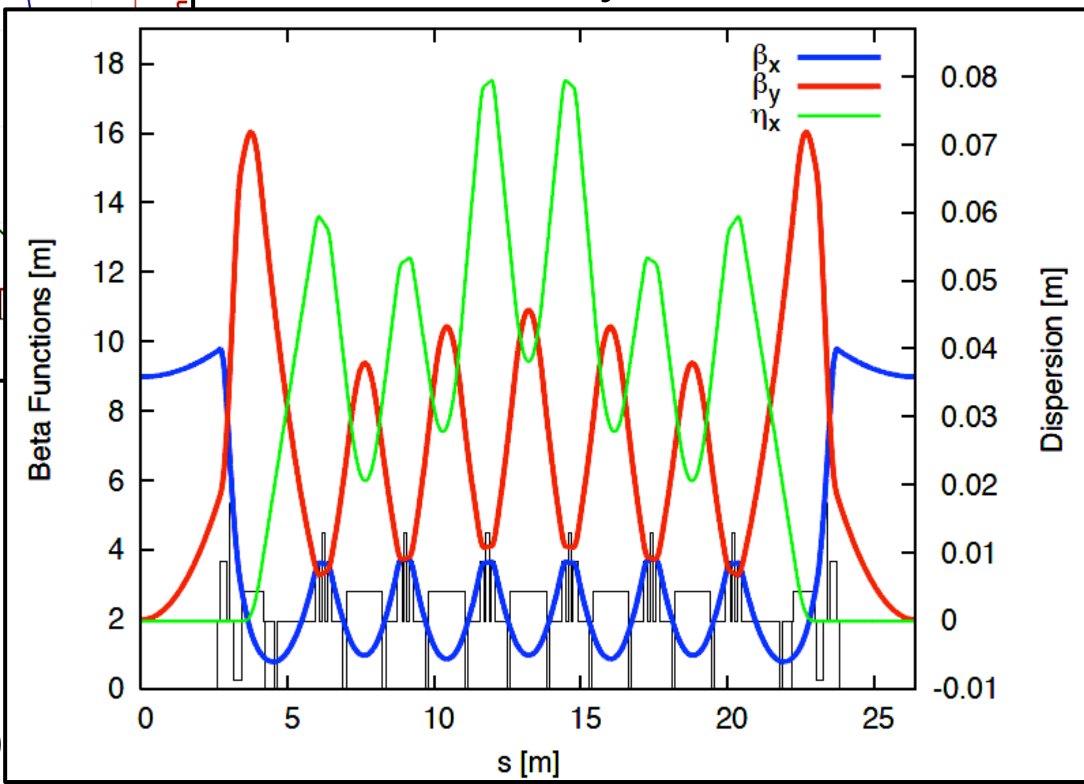
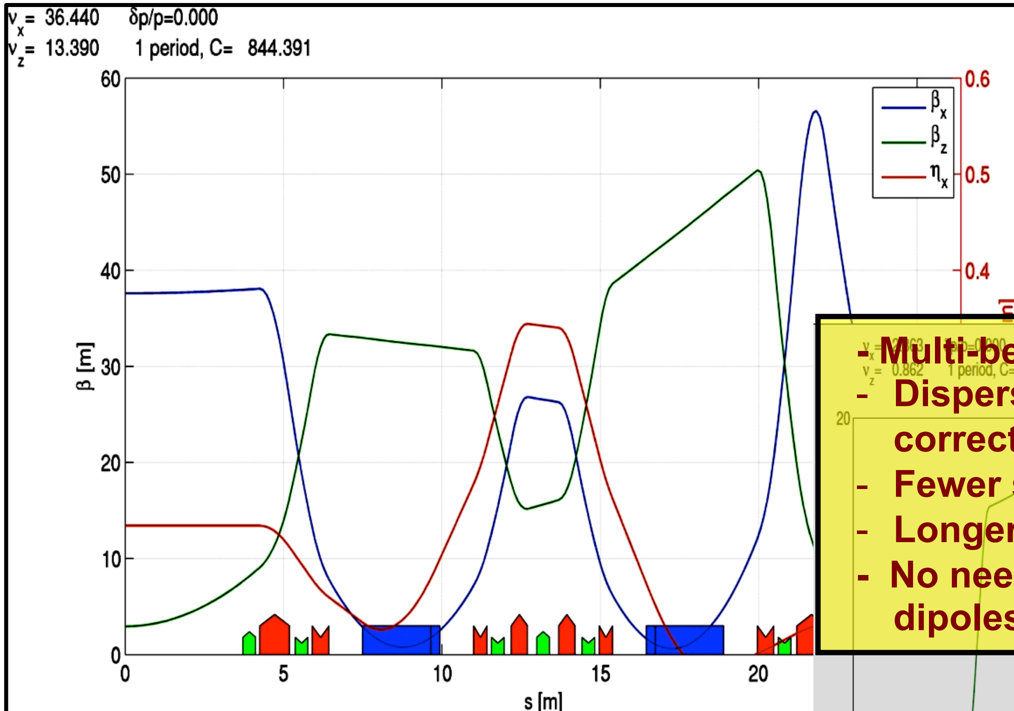


Multi-Bend Achromat (MBA)

- MAX IV and other USRs
- No dispersion bump, its value is a trade-off between emittance and sextupoles (DA)

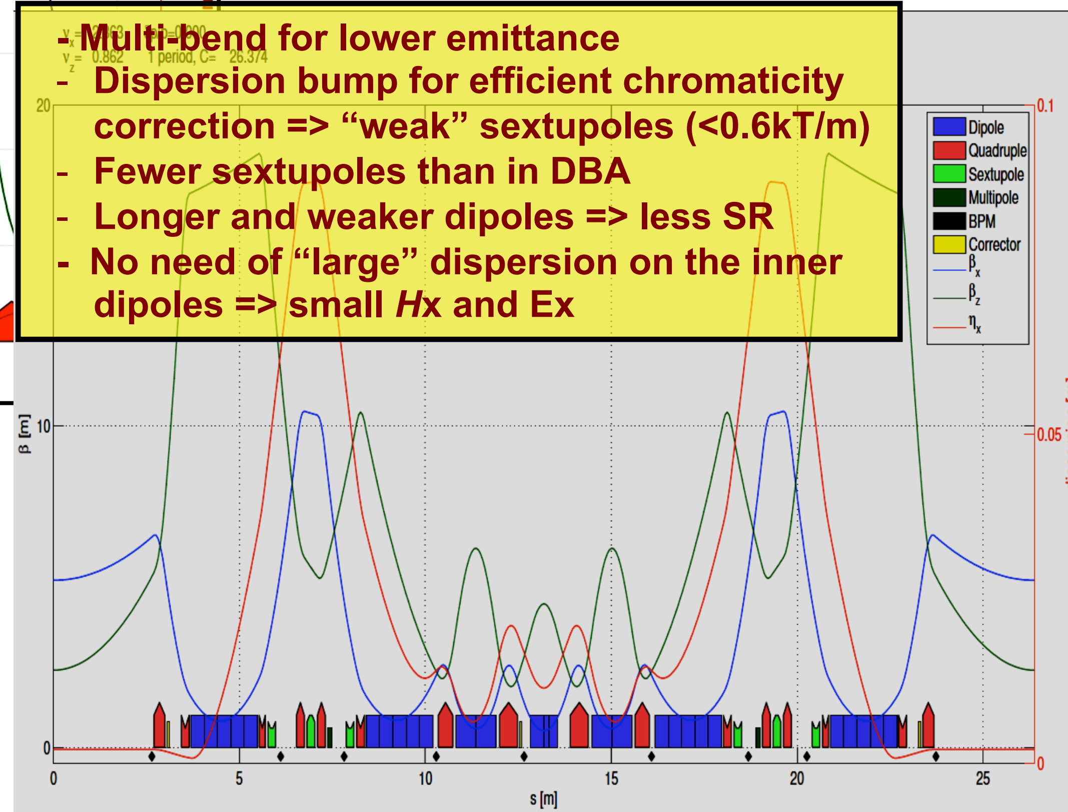
THE HYBRID MULTI-BEND (HMB) LATTICE



ESRF existing (DBA) cell

- Ex = 4 nm•rad
- tunes (36.44,13.39)
- nat. chromaticity (-130, -58)

- Multi-bend for lower emittance
- Dispersion bump for efficient chromaticity correction => "weak" sextupoles (<0.6kT/m)
- Fewer sextupoles than in DBA
- Longer and weaker dipoles => less SR
- No need of "large" dispersion on the inner dipoles => small *Hx* and Ex



Proposed HMB cell

- Ex = 140 pm•rad
- tunes (76.21, 27.34)
- nat. chromaticity (-99, -82)

LINEAR AND NONLINEAR OPTIMIZATIONS

Linear and nonlinear optimizations have been done 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.

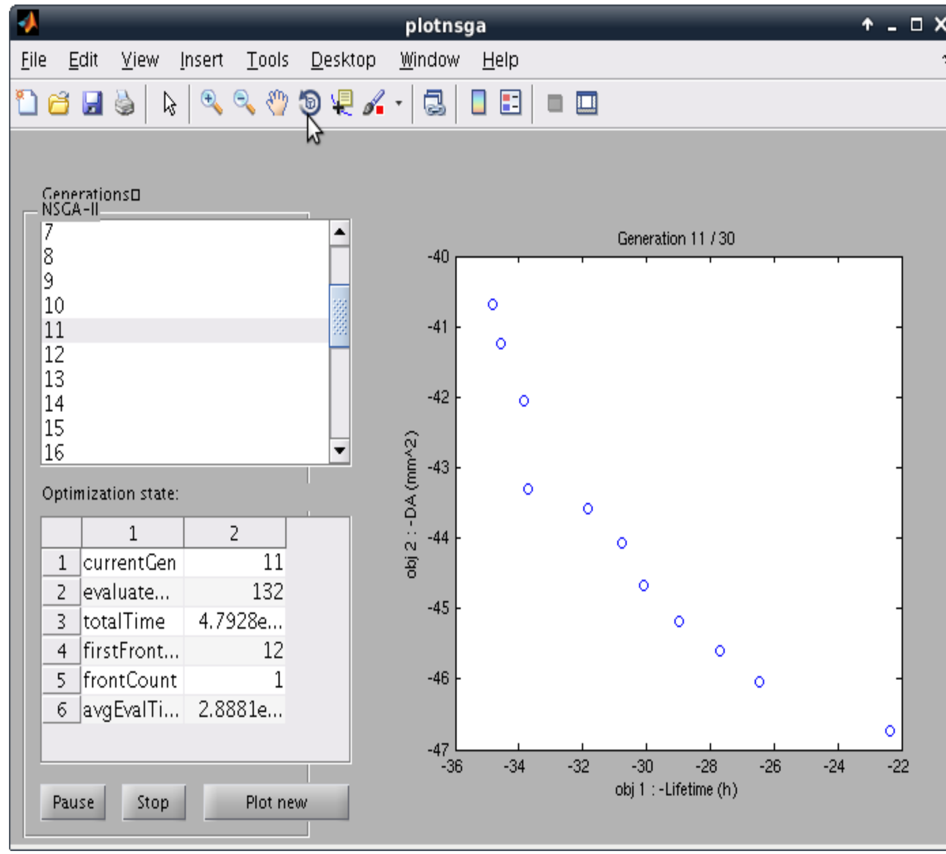
Sextupoles: from 6 to 3 families, weaker and shorter.

Octupoles: from 2 to 1 family, weaker and shorter.

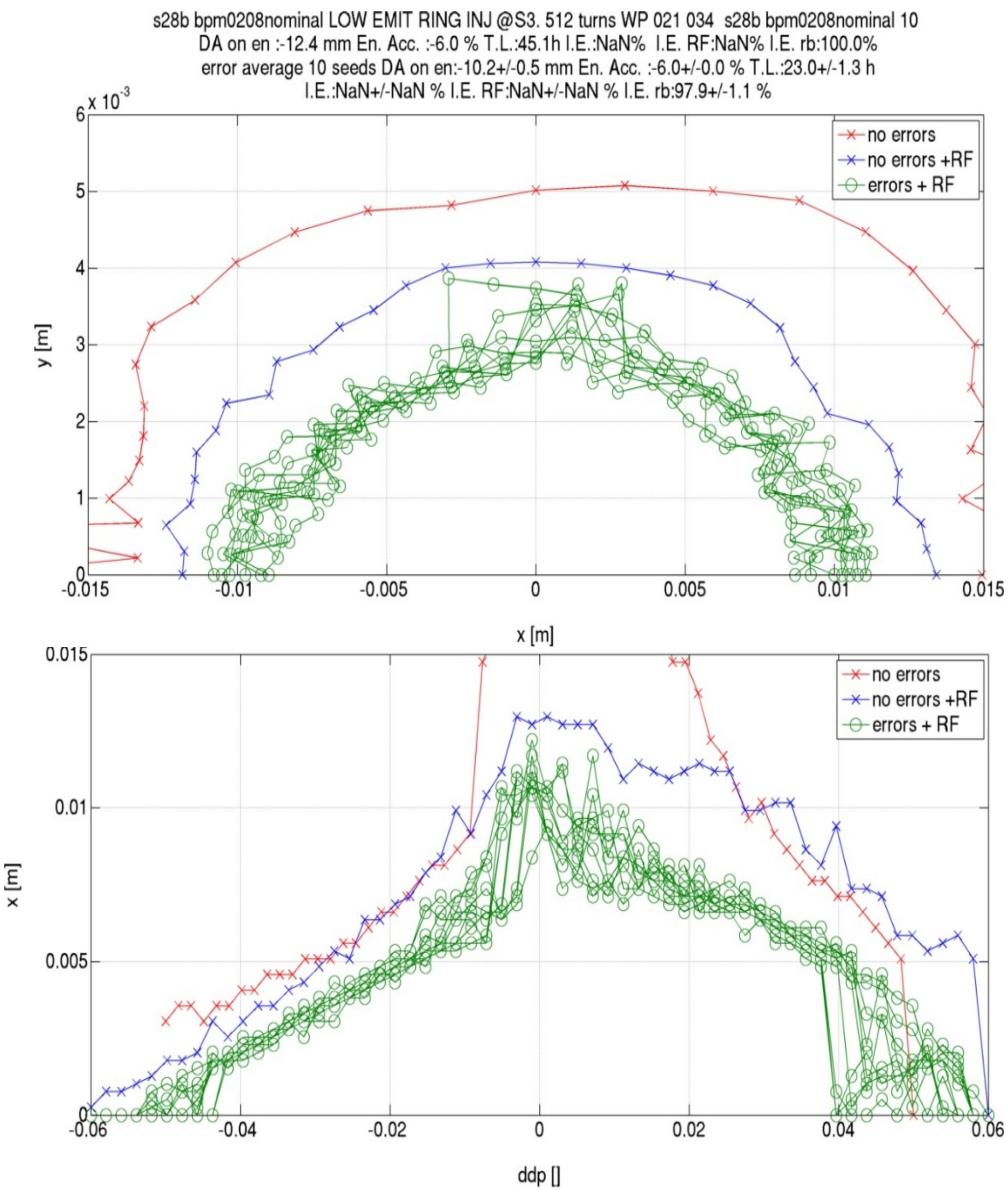
Tunes: 76.21 27.34

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

Chromaticities: 6, 4



LIFETIME OF S28B

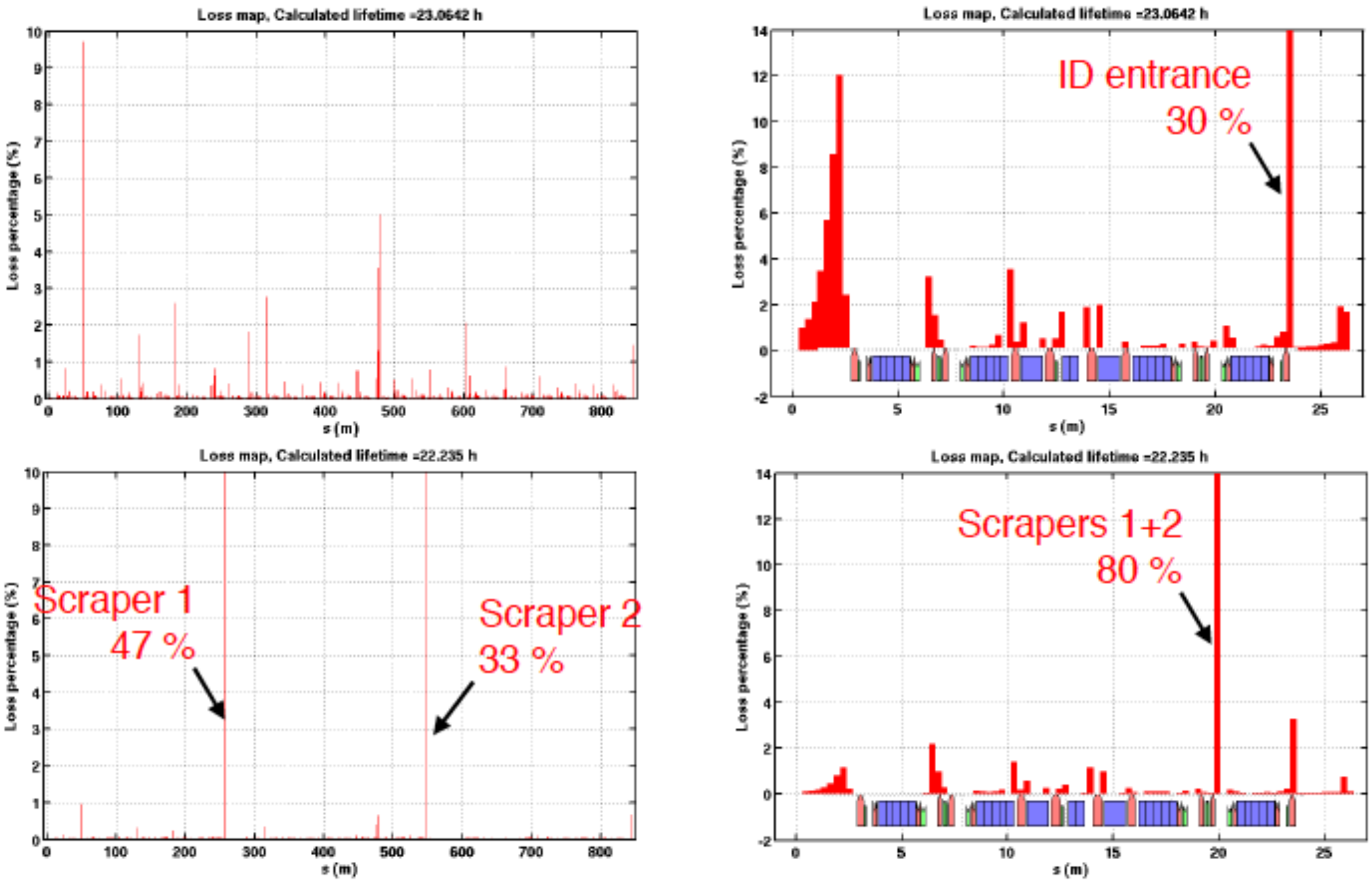


S28A
DA -8.1mm@S3
TLT ~ 13h.

S28B
DA -10mm@S3
TLT ~ 21h

e_y=5pm	ESRF	Upgrade
Multibunch	64 h	21 h
16 bunch	6 h	2.1 h
4 bunch	4 h	1.4 h

80% of the losses are relocated on the scrapers for 4% lifetime reduction:

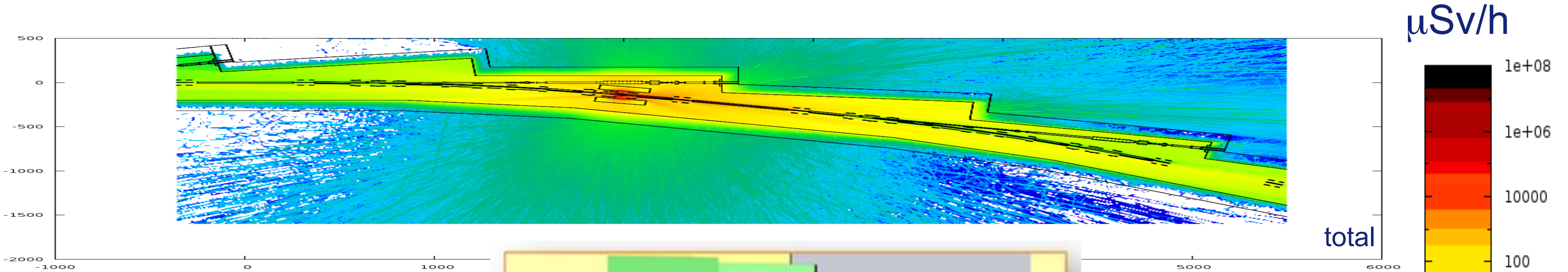


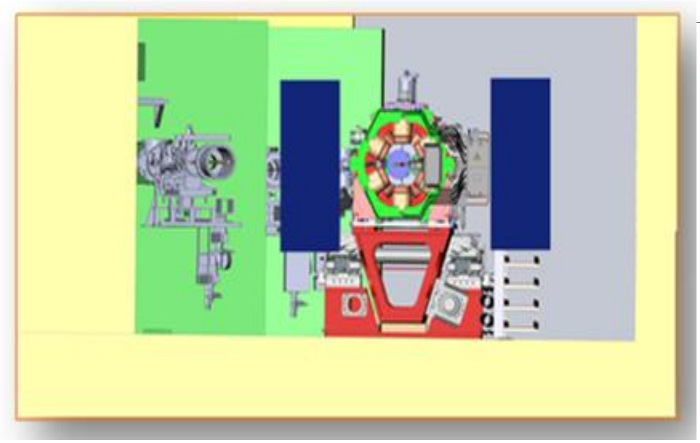
No scrapers

Two scrapers in DR_37 of cells 13 and 24

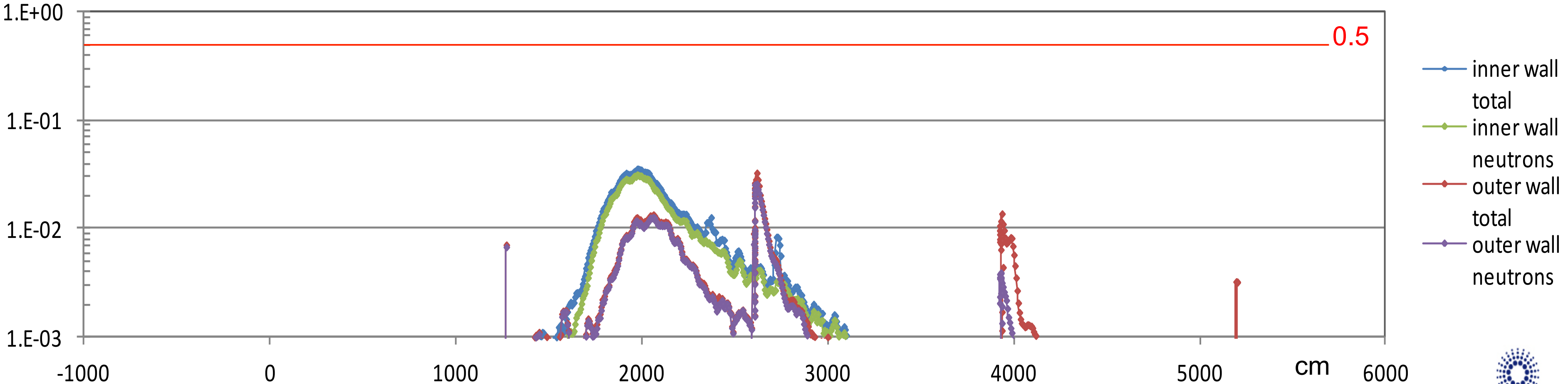
COLLIMATOR SHIELDING

50 CM LEAD LOCAL SHIELDING





ambient dose equivalent rate (μSv/h)



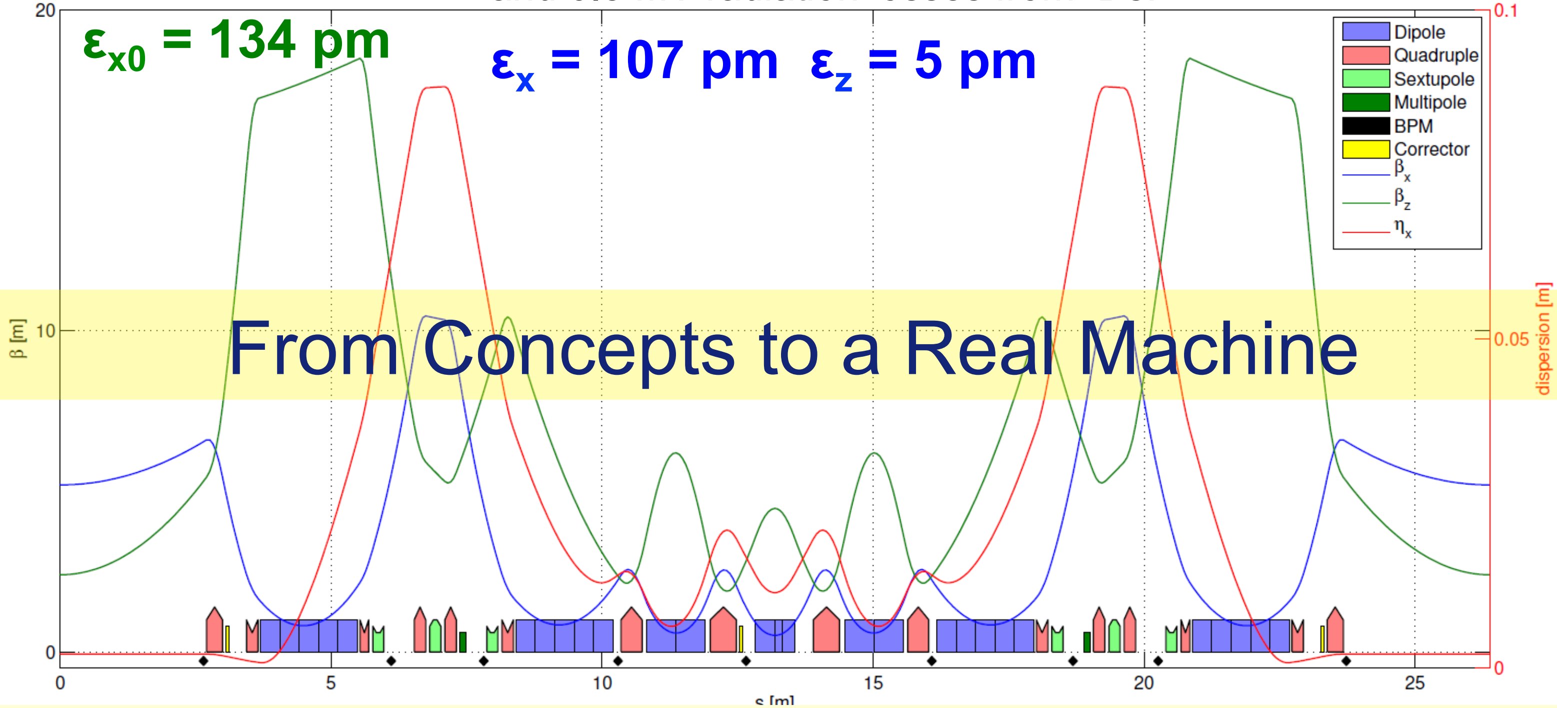
The ESRF Low Emittance Lattice

Natural emittance:

ε_{x0} = 134 pm

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

ε_x = 107 pm ε_z = 5 pm

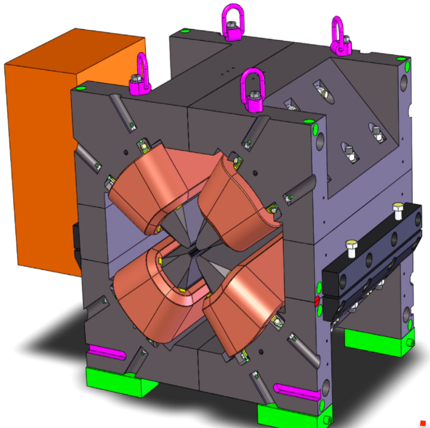


From Concepts to a Real Machine

Several iterations made between:

- Optics optimization: general performances in terms of emittance, dynamic aperture, energy spread etc…
- Magnets requirements: felds, gradients…
- Vacuum system requirements: chambers, absorbers, pumping etc
- Diagnostic requirements
- Bending beam lines source

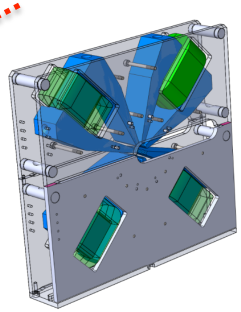
Technical challenge: Magnets System



Mechanical design final drawing phase

- Large positioning pins for opening repeatability
- Tight tolerances on pole profiles
- Prototypes delivered in the period September 2014-Spring 2015

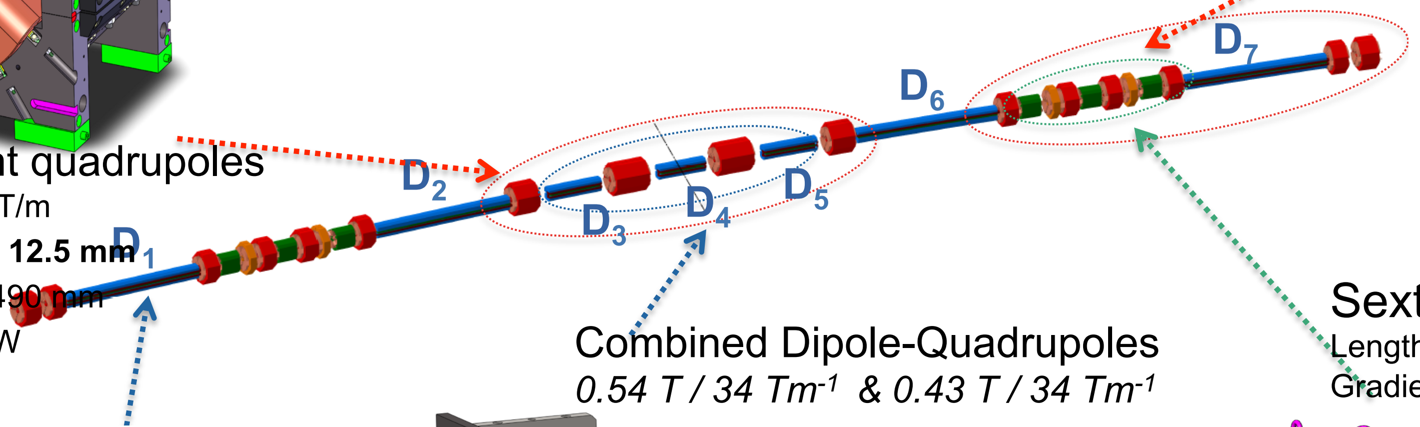
Quadrupole
Around 52Tm^{-1}



Octupoles

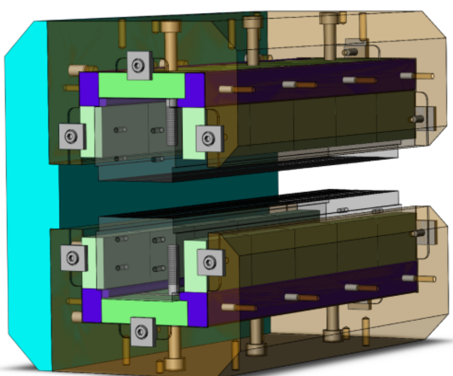
High gradient quadrupoles

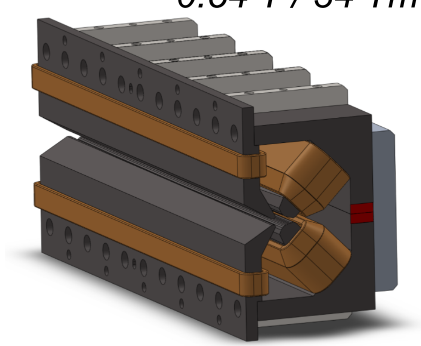
- Gradient: 90 T/m
- **Bore radius: 12.5 mm**
- Length: 390/490 mm
- Power: 1-2 kW

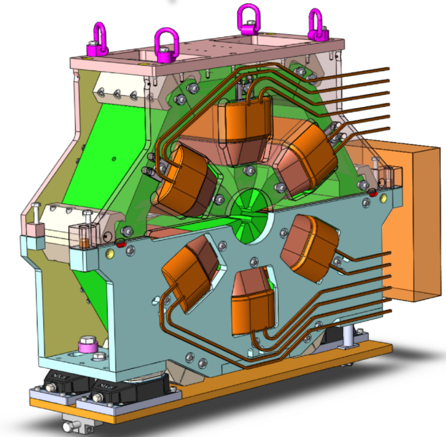


Combined Dipole-Quadrupoles
0.54 T / 34 Tm^{-1} & 0.43 T / 34 Tm^{-1}

Sextupoles
Length 200mm
Gradient: 3500 Tm^{-2}





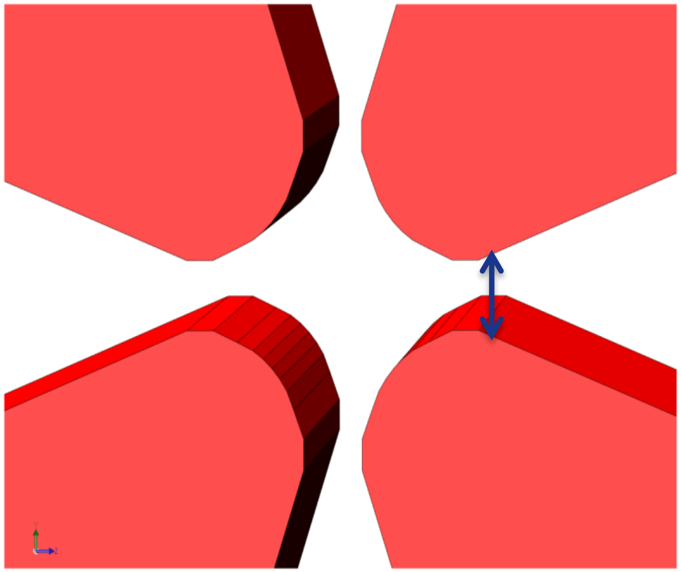


Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 - 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

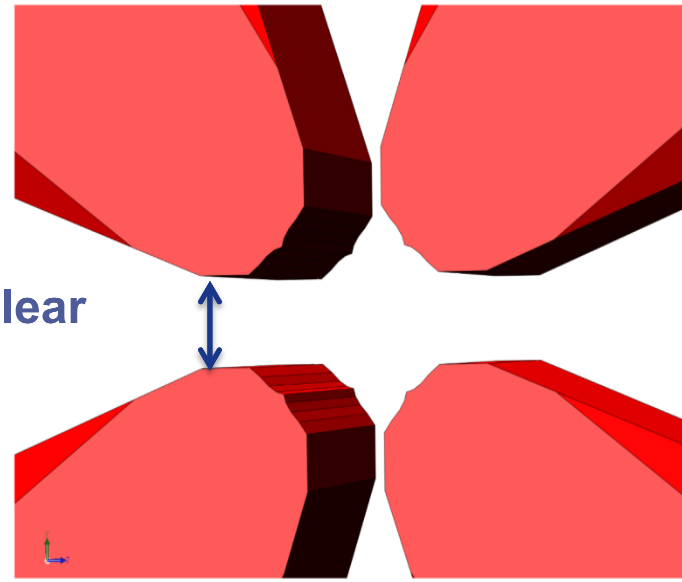
Gael Le Bec

Pole shape optimization

Imposed 11mm stay clear from pole to pole for all magnets for optimal synchrotron radiation handling

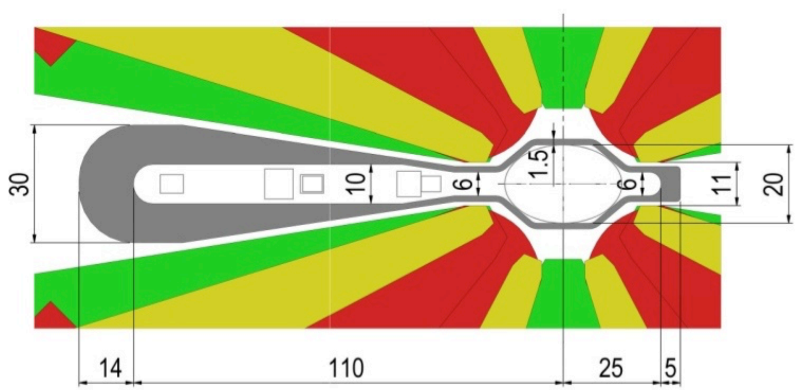


11mm stay clear



Low gradient pole profile

High gradient pole profile

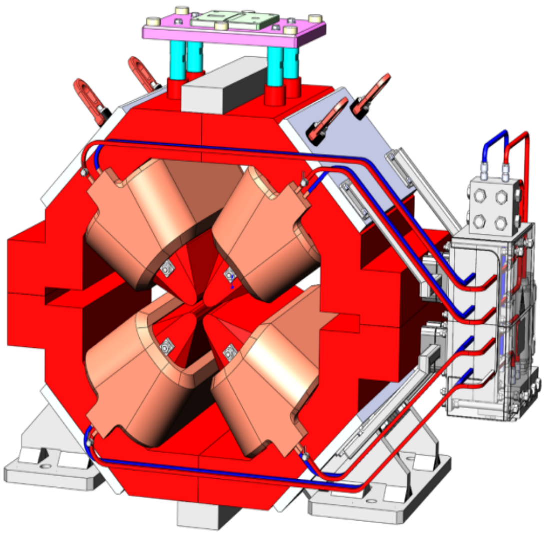


Vacuum chamber and magnets sections

QUADRUPOLES

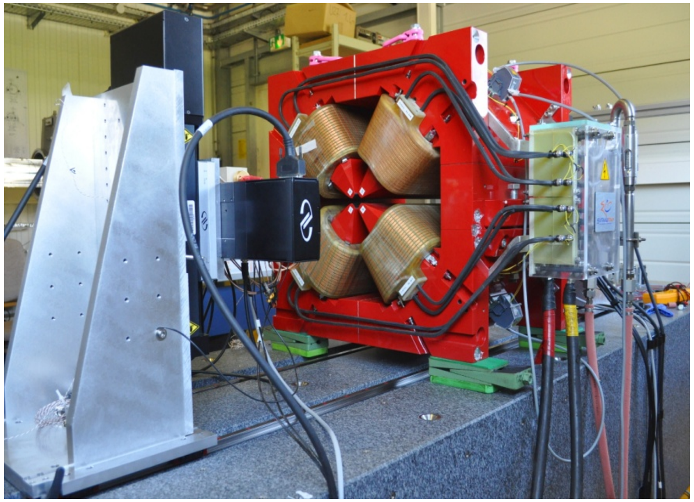
High Gradient

- 91 T/m gradient, 388 - 484 mm length
- 12.7 mm bore radius, 11 mm vertical gap
- 1.4 - 1.6 kW power consumption



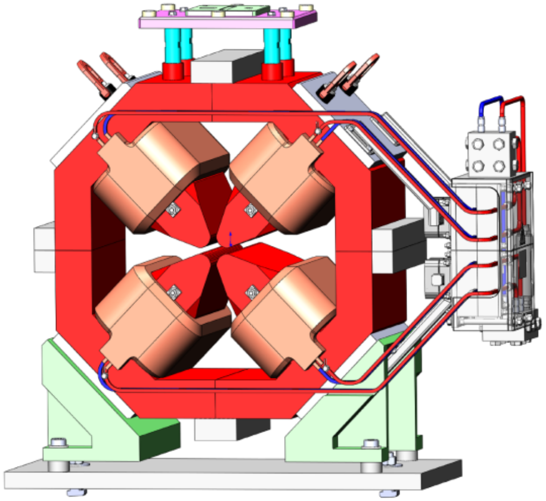
HG Prototype

+/-20um pole accuracy



Moderate Gradient

- Up to 58 T/m gradient, 162- 295 mm length
- 16.4 mm bore radius, 11 mm vertical gap
- 0.7 - 1.0 kW power consumption



DIPOLE WITH LONGITUDINAL GRADIENT

Specifications

- 0.17 - 0.67 T field
- 5 modules of 357 mm each
- Larger gap for the low field module
- Allows the installation of an absorber

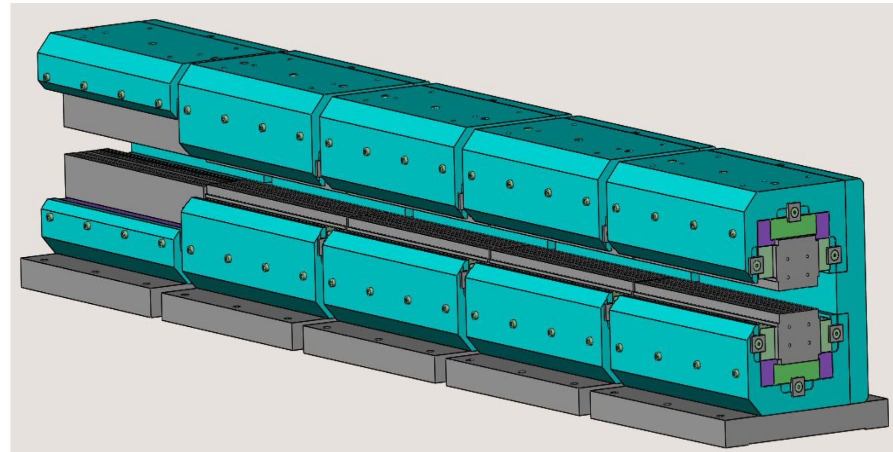
Engineering design

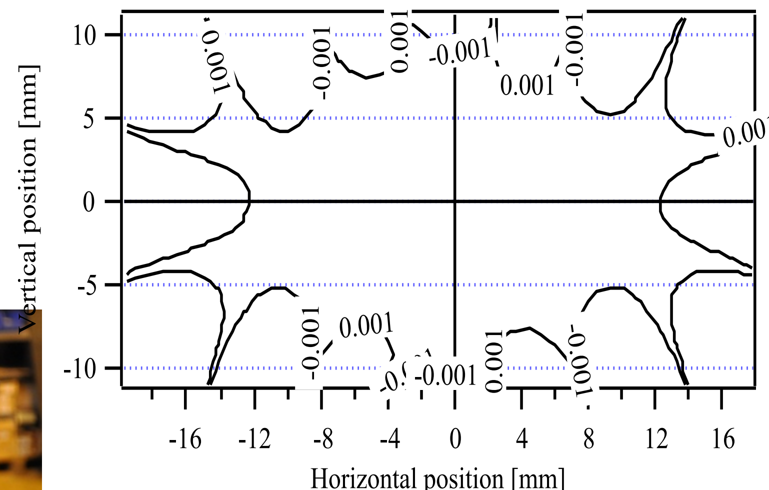
- Completed

Prototyping

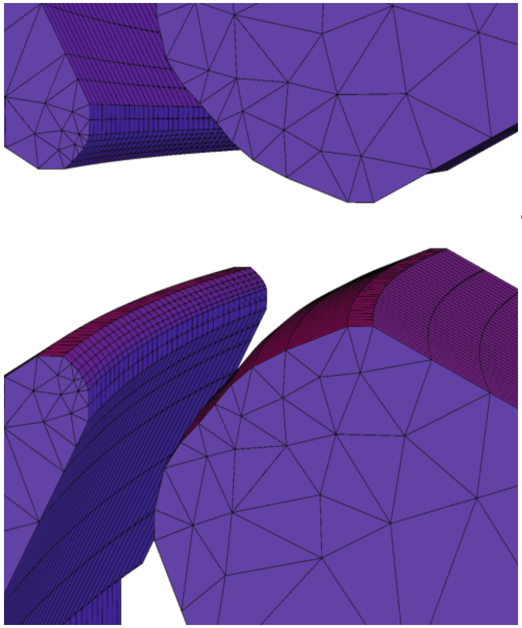
- Completed

The DLs will be build by ESRF

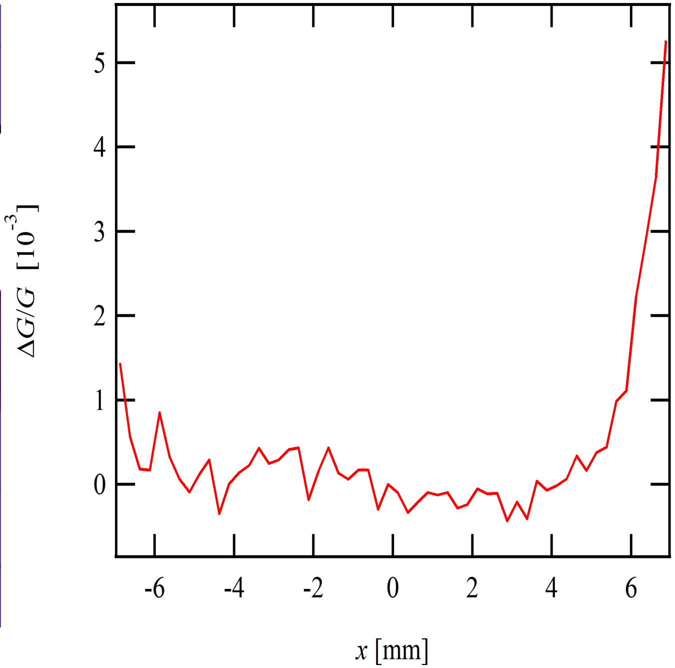


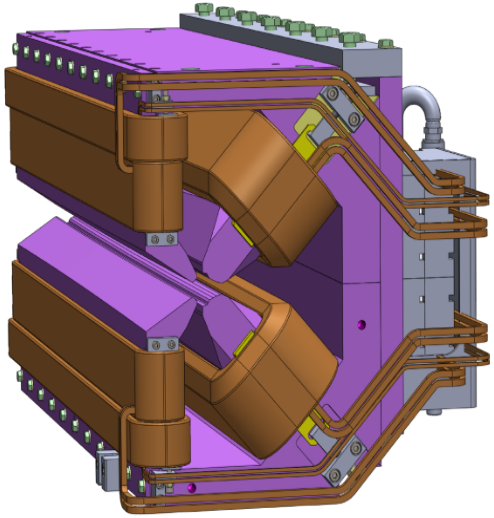


Measured field integral homogeneity (one module)



DQ1 pole shape





DQ1 gradient homogeneity:
Integration of trajectory along an arc

DQ1: 1.028 m, 0.57 T, 37.1 T/m

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

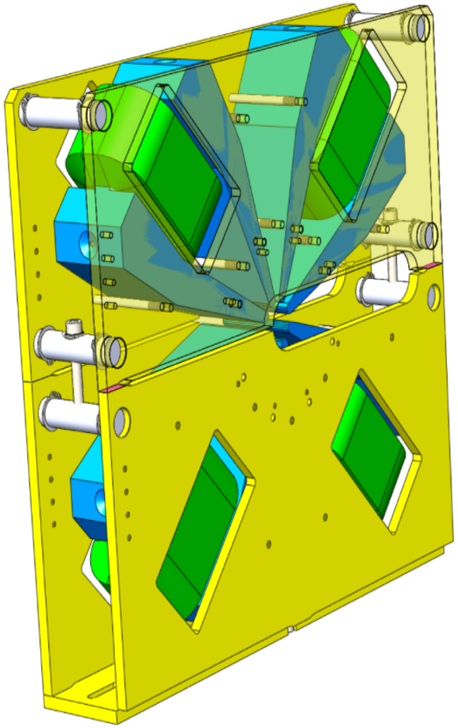
DQs are machined in 7 solid iron plates

Poles curved longitudinally for maximum stay clear and good field region

OCTUPOLES

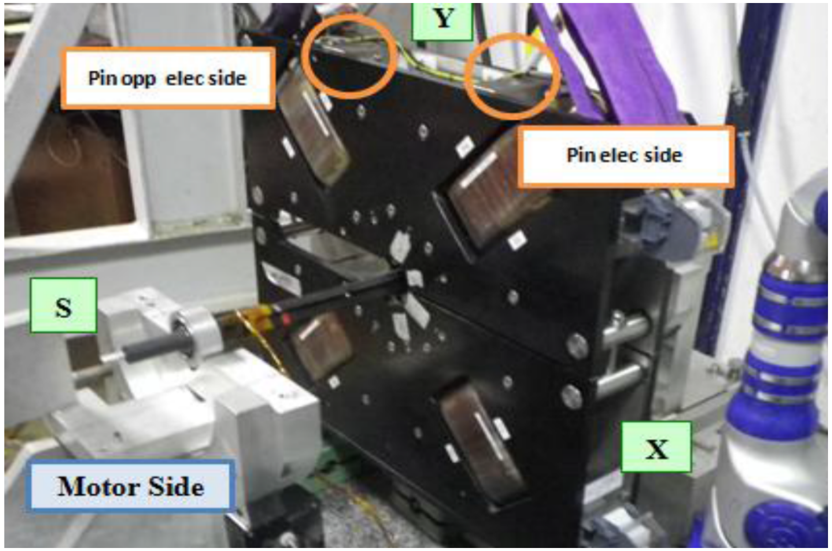
S28b specifications

- 48 kT/m^3 nominal strength (70 kT/m^3 maximum)
- 90 mm length
- 4 Water cooled coils at the return-field yoke
- Allows for the required stay-clear for Synchrotron Radiation fans



Prototyping

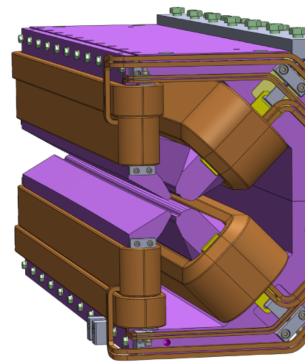
- Air cooled prototype measured



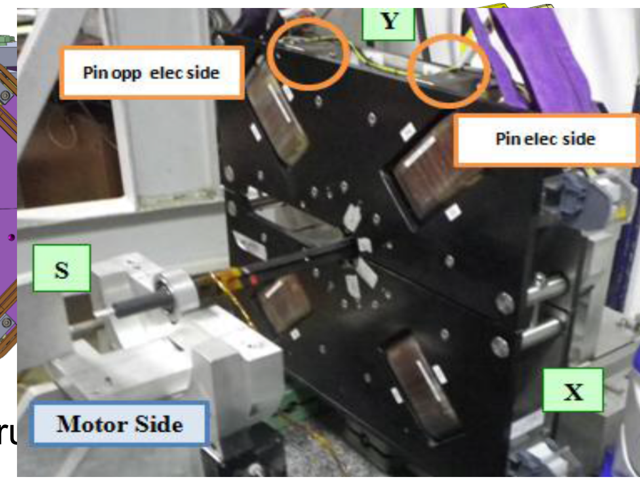
PROCUREMENT: MAGNETS

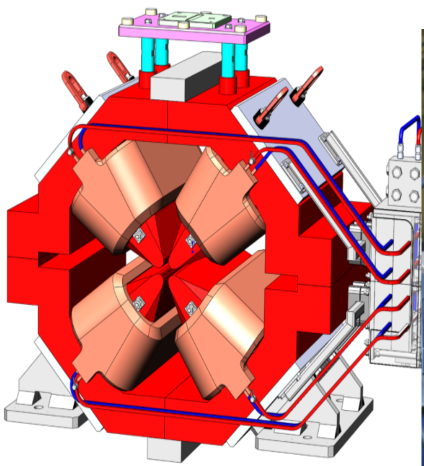
More than 1000 Magnets to be procured by the end of 2018

132 dipoles

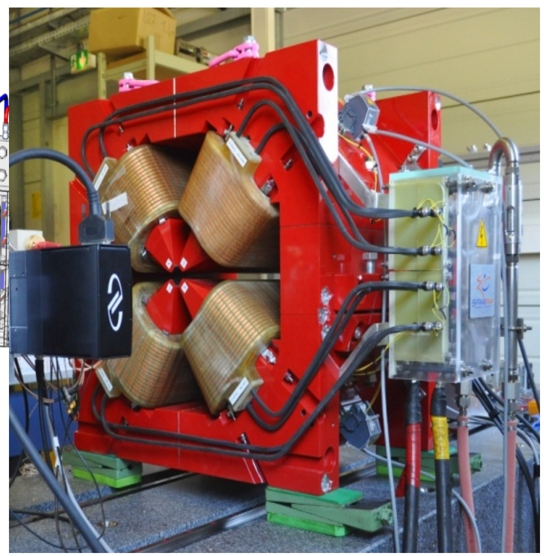


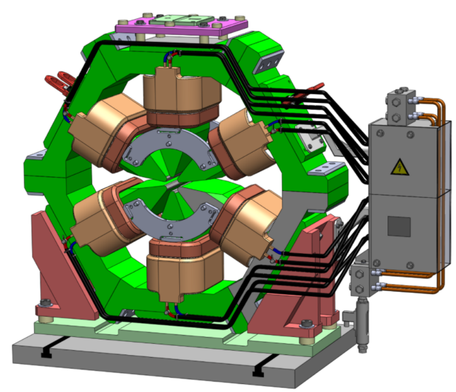
99 dipole-quadru



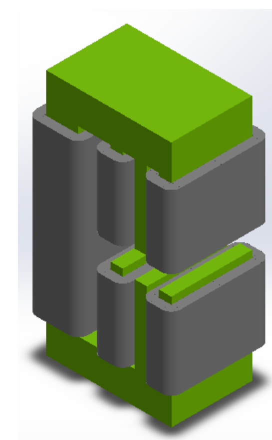


398 mod gradient quadrupoles





196 sextupoles

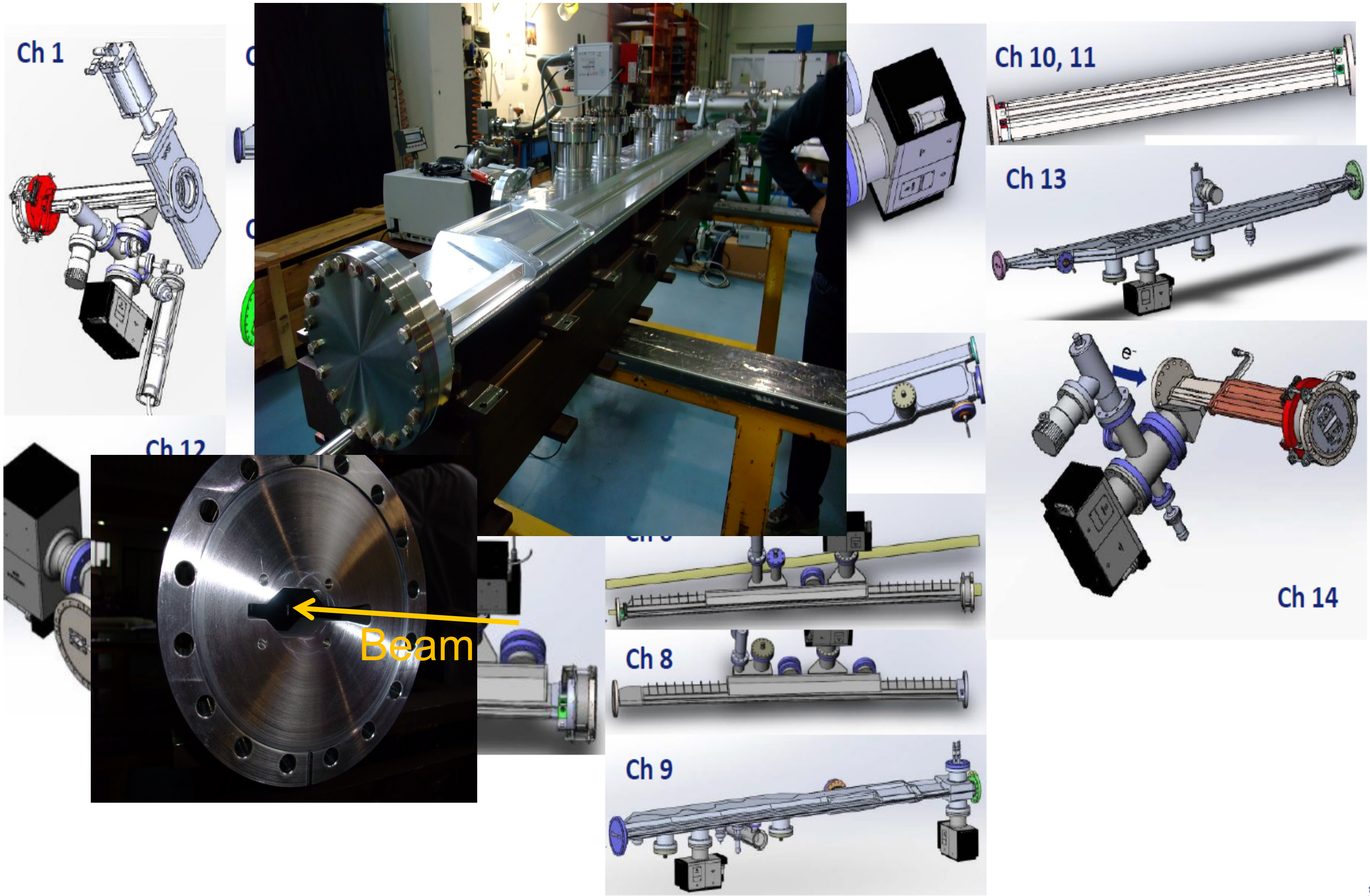


100 correctors

Courtesy of ASD-IDM & ISDD-MEG

PROCUREMENT: VACUUM CHAMBERS

Vacuum chambers: more than 450 chambers to be procured in less than 3 years



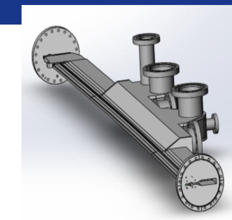
Courtesy of ASD-FE, ISDD-MEG & TID-VG

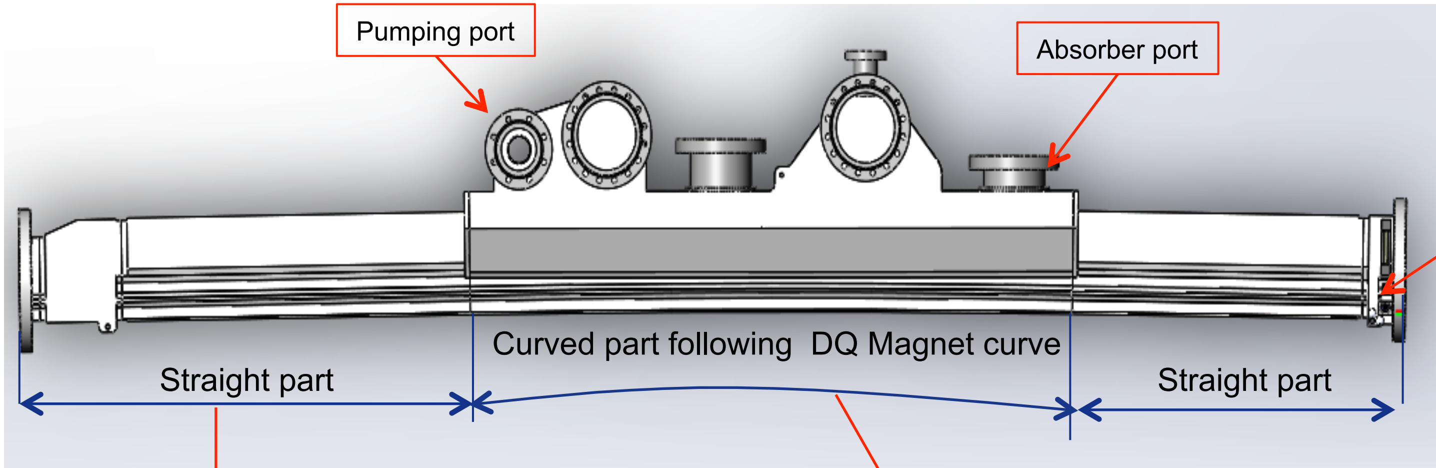
The European Synchrotron | ESRF

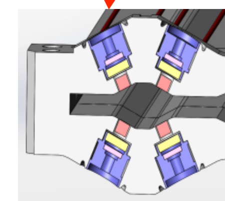
FAMILY 3: LOW PROFILE STAINLESS STEEL CHAMBERS

Material : 316 LN

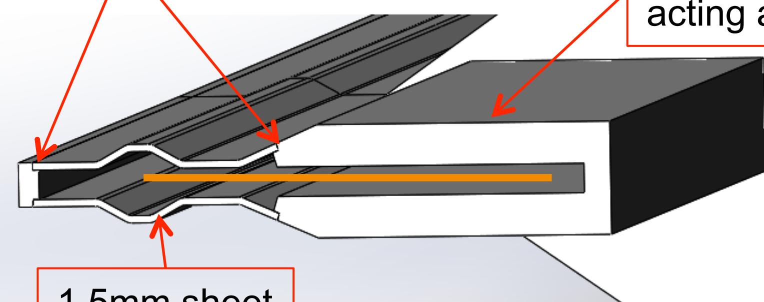
Curved Chambers

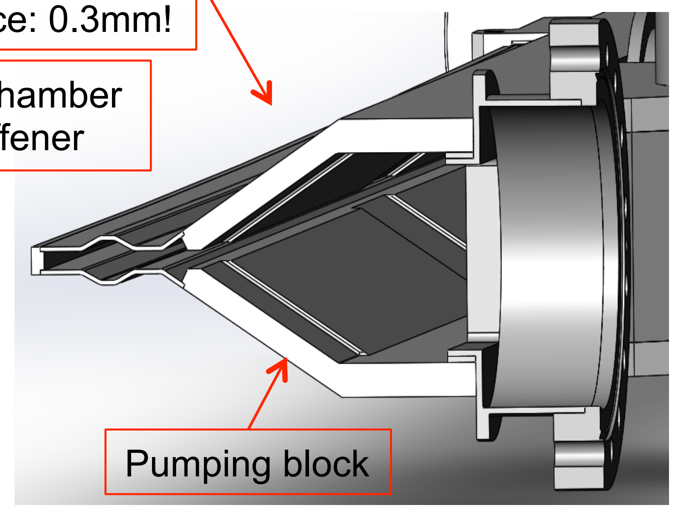


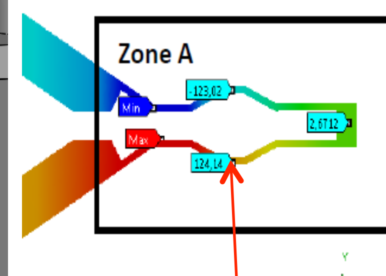




Requested shape tolerance: 0.3mm!





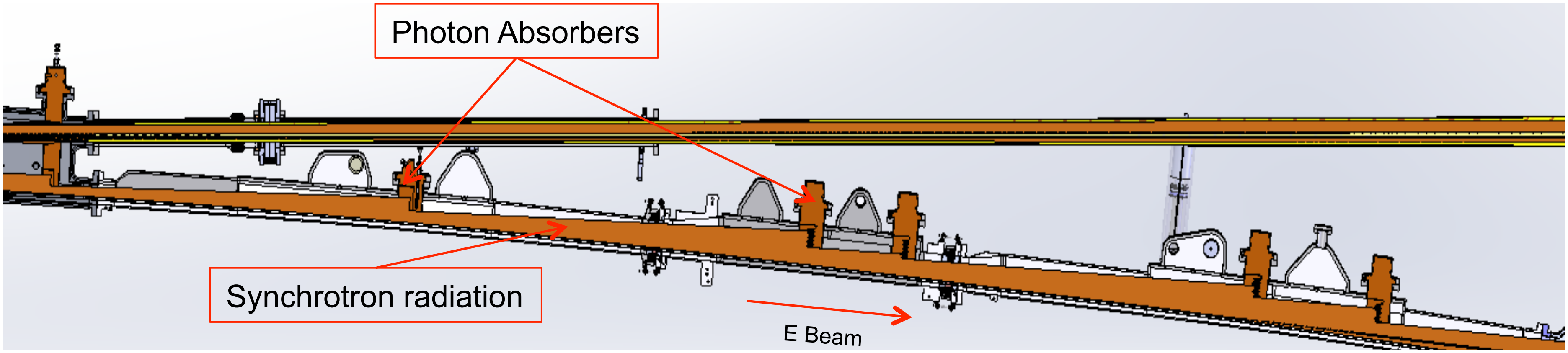


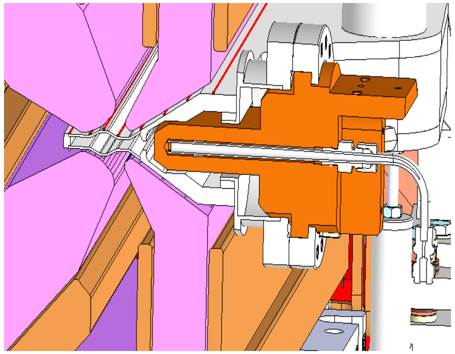
Deformation at the Beam area 0.125mm

Joel Pasquaud

ESB PHOTON ABSORBERS

- ~391 absorbers (including crotch absorbers, without injection cell specials)
- Total power to be absorbed: 504.5 kW (30 x 15.795 kW + 2x 15.314) kW
- Power density: 10 to 110 W/mm2 (normal to beam)
- => moderate power parameters compared to current ESRF
- Scattered radiation blocked in the absorber to avoid chamber cooling





Absorber flange mounted on the ante-chamber

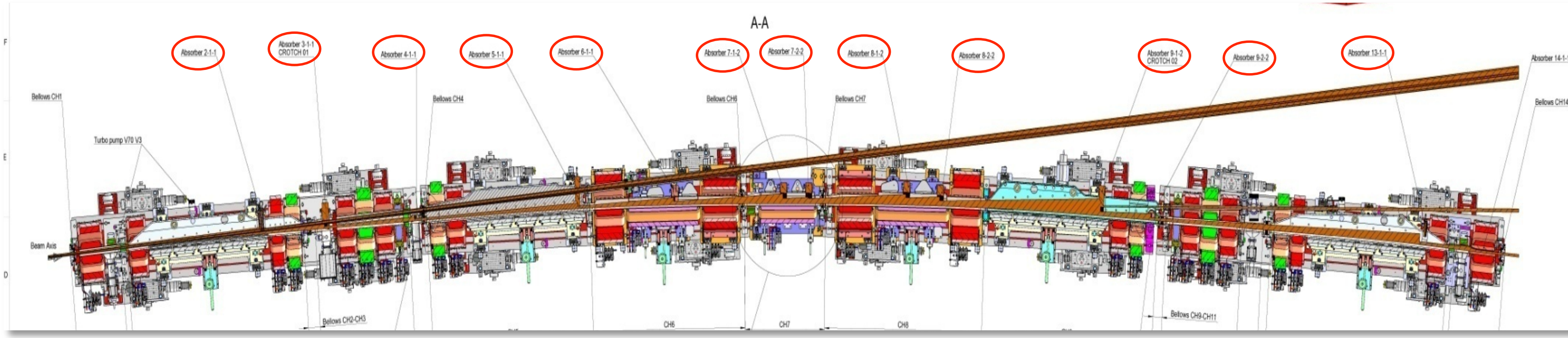
Tight space constraints

-CuCr1Zr as an alternative to Glidcop

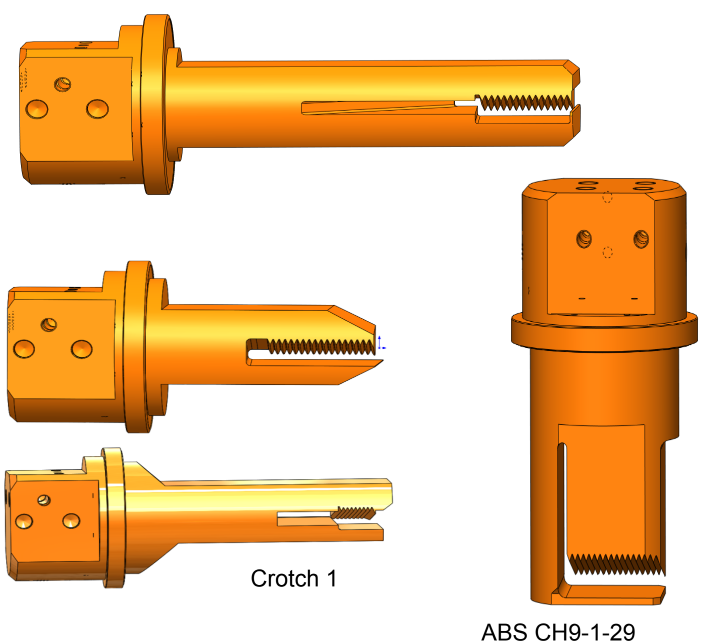
- Integrate the CF flange in the CuCr1Zr absorber body

D. Coulon, Y. Dabin, Th. Ducoing, E. Gagliardini, Ph. Marion, F. Thomas

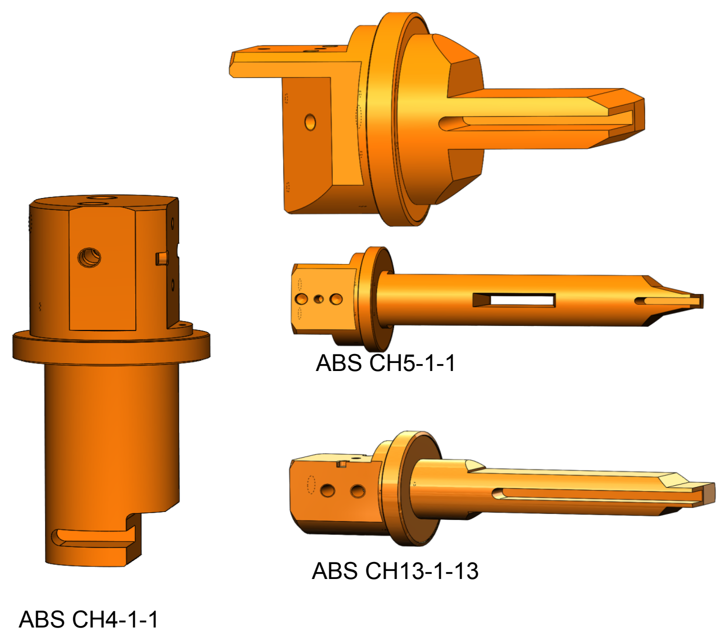
ABSORBERS DESIGN : TWO FAMILIES



Family Teeth (up to 110 W/mm^2)



Family Frontal (up to 50 W/mm^2)

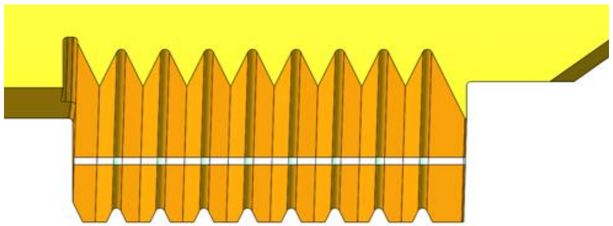


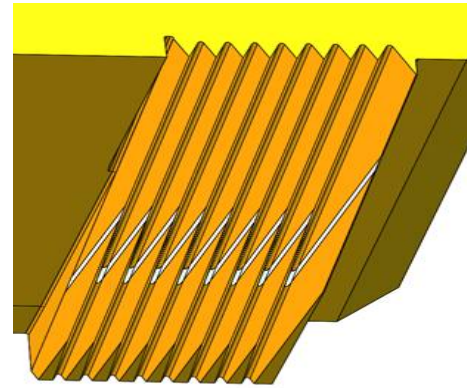
D. Coulon, Y. Dabin, Th. Ducoing, E. Gagliardini, Ph. Marion, F. Thomas

No weld, no braze

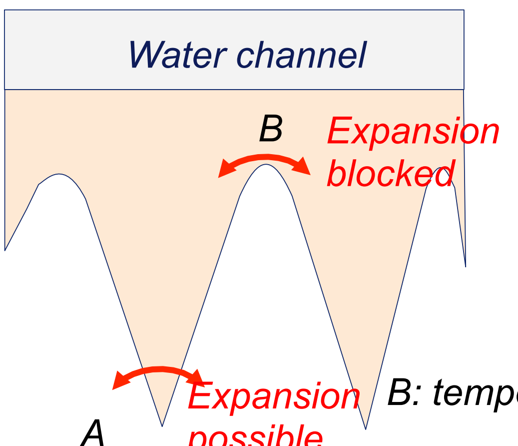
ABSORBERS WITH TEETH OPTIMIZED TO REDUCE THERMAL STRESSES

Teeth distribute the heat over a larger area

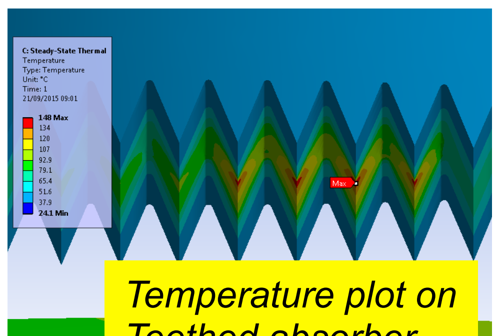




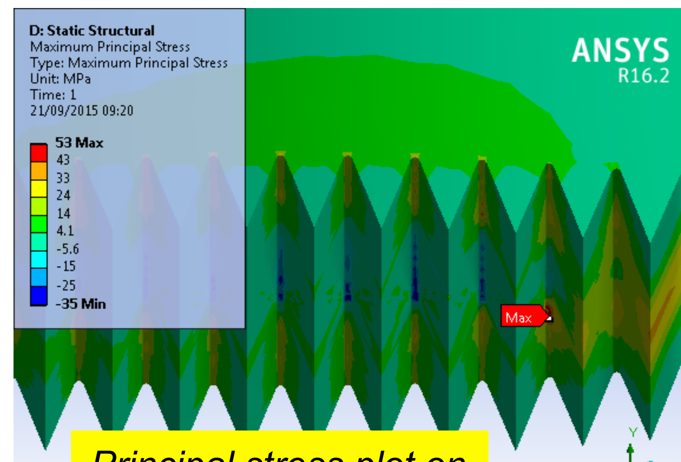
Teeth geometry optimized to reduce thermal stresses



B: temperature is min Stress is max



Temperature plot on Teethed absorber



Principal stress plot on Teethed absorber

A: temperature is max Stress is min

D. Coulon, Y. Dabin, Th. Ducoing, E. Gagliardini, Ph. Marion, F. Thomas

Stress criteria < Yield strength

1000 LARGE POWER SUPPLIES AND 1000 SMALL POWER SUPPLIES

Type	Name	quantity per cell	NOMINAL FIELD VALUES Length [m]	dB/dx [T/m]	lattice	Electrical design Power [kW]	Voltage [V]	Current [A]	PS OVdesign factor	Imax	Watts Pnom	Watts Pmax	nom Watts cell	maxWatt P total cell
Quadrupole, mod. gradient	QF1	2	0.349	53.7		1.06	12.1	87.5	1.2	102	1167	1576	2334	3152
Quadrupole, mod. gradient	QD2	2	0.266	51.5		0.86	9.8	87.5	1.2	106	966	1418	1932	2836
Quadrupole, mod. gradient	QD3	2	0.216	46.5		0.74	8.4	87.5	1.2	117	843	1519	1687	3037
Quadrupole, mod. gradient	QF4	4	0.216	51.5		0.74	8.4	87.5	1.2	106	843	1238	3373	4952
Quadrupole, mod. gradient	QD5	2	0.212	52.5		0.86	9.8	87.5	1.2	104	966	1364	1932	2729
Total		**12**											**11257**	**16705**
Quadrupole, high gradient	QF6	2	0.36	95.2		1.42	15.7	90.4	1.1	99	1535	1857	3070	3714
Quadrupole, high gradient	QF8	2	0.48	96.2		1.66	18.6	89	1.1	98	1767	2139	3535	4277
Total		**4**											**6605**	**7992**
Dipole-Quadrupole, high field	DQ1	2	1.11	37.54	33.9	1.59	15.75	100.7	1.2	121	1729	2490	3458	4980
Dipole-Quadrupole, mod field	DQ2	1	0.77	37.04	33.7	1.38	17.0	81.0	1.2	97	1469	2116	1469	2116
Total		**3**											**4928**	**7096**
Sextupole, long	SD	4		4500	4300	1.01	11.7	86	1.1	95	1111	1344	4444	5377
Sextupole, long	SF	2				1.01	11.7	86	1.1	95	1111	1344	2222	2689
Total		**6**											**6666**	**8066**
Octupole	OF1-2	2	0.1			0.30	3.2	94	1.2	113	426	613	852	1226
Total		**2**											**852**	**1226**
		27	Total PS power for **one cell** for main electromagnets										**30.3** KW	**41.1** KVA

	magnet	coils	type
corrector AC+DC (5 independent coils)	3	5	AC+DC
Sextupole, short correctors	6	6	DC

Total number of coils/cell **51**

About 1000 DC-DC low voltage converters: the average channel power is around 1kW and a maximum of 2.3kW.

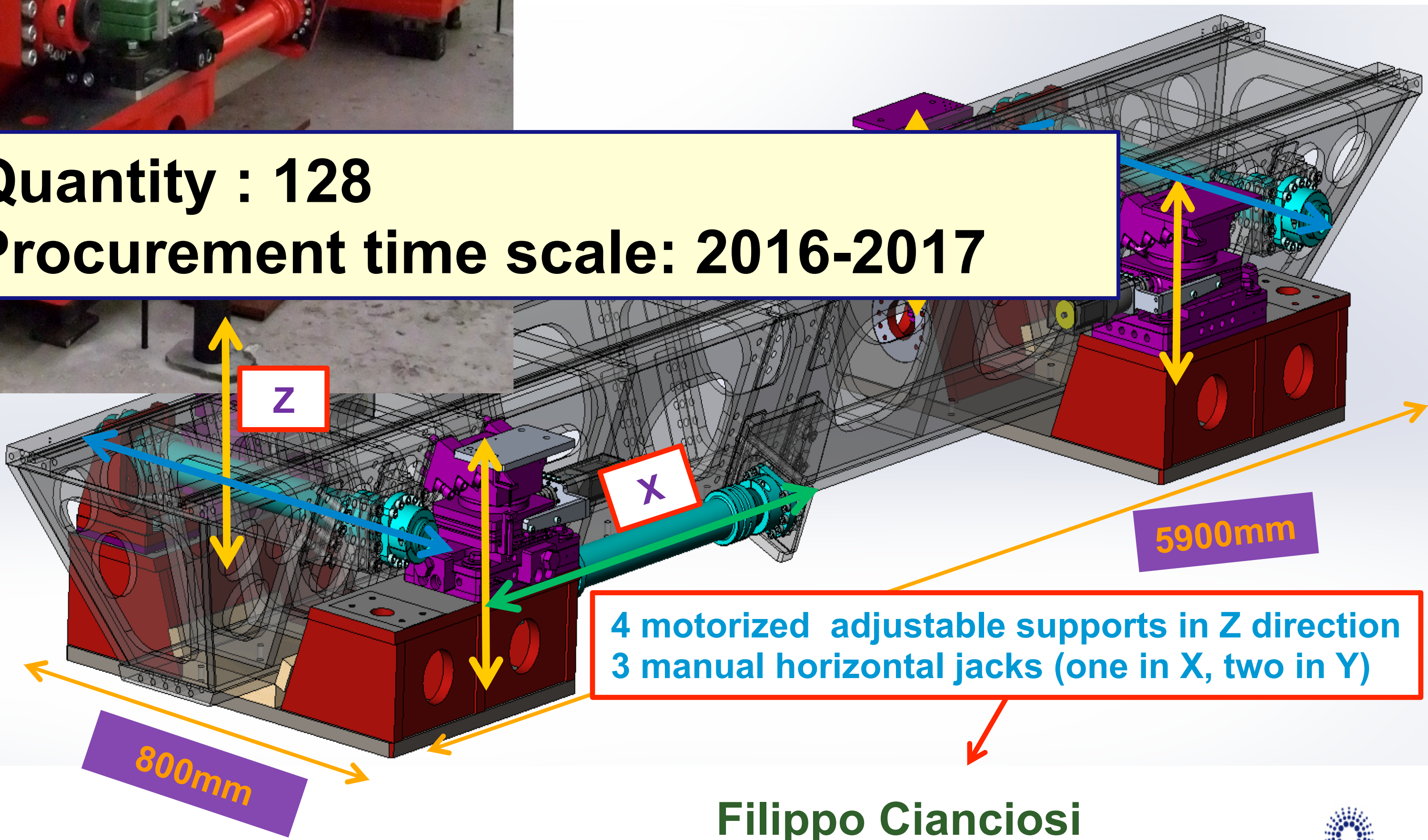
The stability requested will be 15ppm with a MTBF of more than 400 000 hours.

The integration in 32 cabinets will be designed with the Computer Services for redundancy and HOT-Swappability

GIRDER DESIGN, THE ORTHOGONAL HEPTAPOD

Mass:
Magnets: ~ 5-6 T
Magnet supports: ~ 1 T
Girders: ~ 3-3.5 T
Vacuum chamber, pumping etc: ~ 0.5T
Total weight: ~9-11T

Quantity : 128
Procurement time scale: 2016-2017



Technology:
Girder material:
carbon steel
Typical tickness:
30mm (20-50)
Piece junction:
full penetration and
continous welding
Rails flatness: ± 30
micrometers

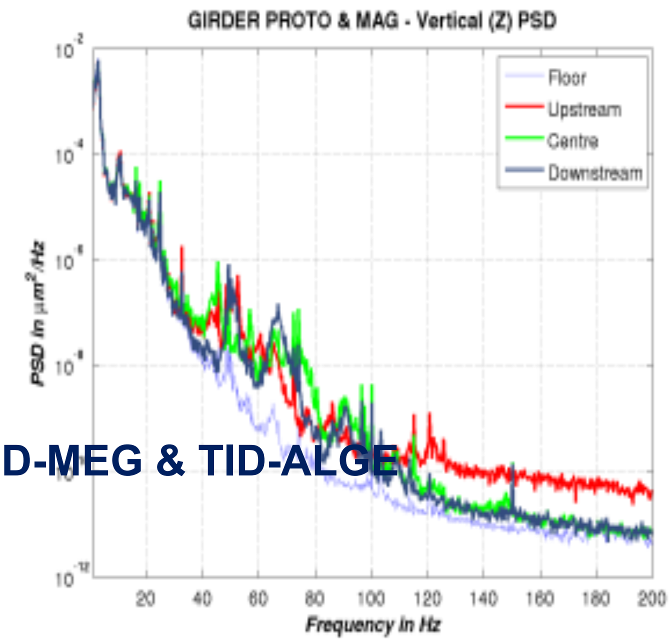
4 motorized adjustable supports in Z direction
3 manual horizontal jacks (one in X, two in Y)

Filippo Cianciosi

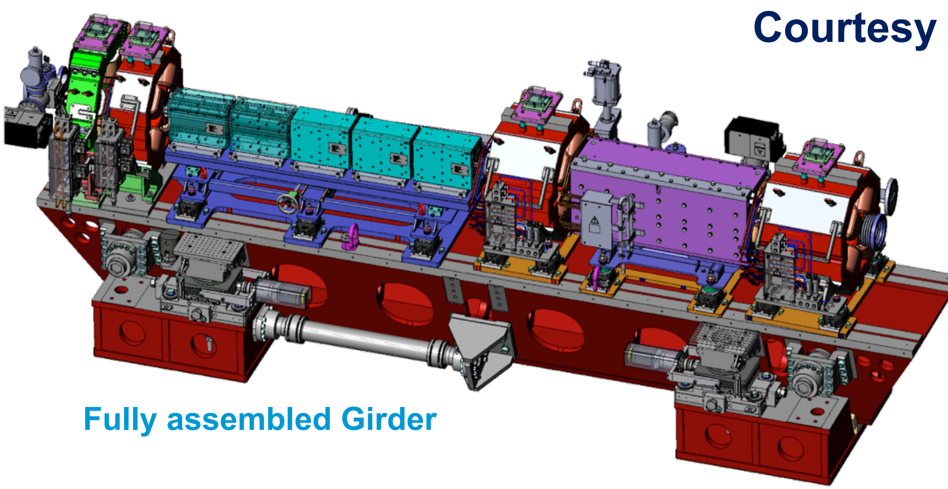
GIRDER PROTOTYPE TESTS

Girder prototype with dummy magnets:

Mechanical tests



Courtesy of ISDD-MEG & TID-ALGE

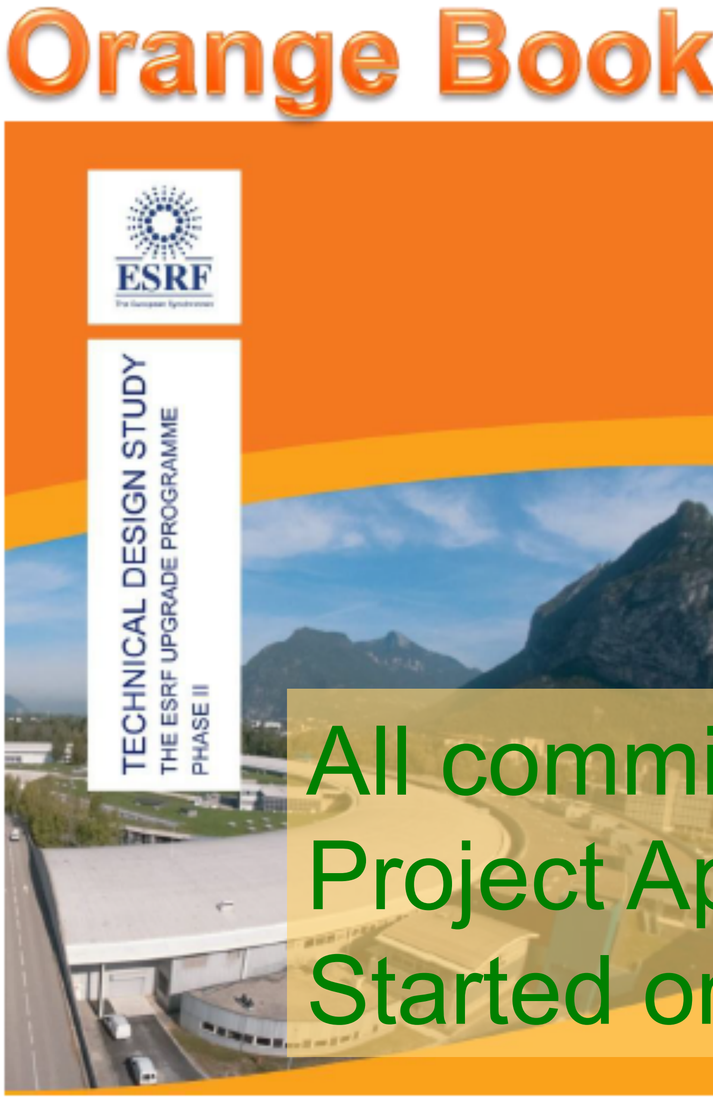


Fully assembled Girder

First vibrational mode at 40 Hz

Virtually no amplification of natural ground motion

PREPARING THE EBS UPGRADE



Technical Design Study (TDS)
Completed on May-2014
and submitted to:

Science Advisory Committee (SAC)

Accelerator Project Advisory Committee (APAC)

Cost Review Panel (CRP)

ESRF Council

All committees very positive
Project Approved and Funded
Started on Jan 1st 2015

STATUS PROGRESS: GENERAL

- Master Schedule finalized
- Design phase completed
- Procurement phase launched
- Fully resource loaded Assembly Phase planning is ongoing
- Fully resource loaded Installation Phase planning is ongoing
- Staffing, CDI 100% completed, CDD/COD 75% complete

ASD extremely involved in all the phases
All the other Divisions are fully committed as well

STATUS PROGRESS: DESIGN

- Design of all the components nearly completed:

 - Magnets ~95% (Kickers and PM-septa in progress)

 - Vacuum System ~95% (One-of-a-kind chambers in injection section in progress)

 - Absorbers ~100%

 - Girders ~100%

 - Supports ~100%

 - Diagnostics ~80% (Collimators, Special chambers in progress)

 - Power Supplies ~90% (Sizing optimization and hot-swap implementation in progress)

- All elements have been fully integrated and are consistent with the overall specifications

ISDD and TID very heavily involved for
- Design finalization
- System integration
- Logistic

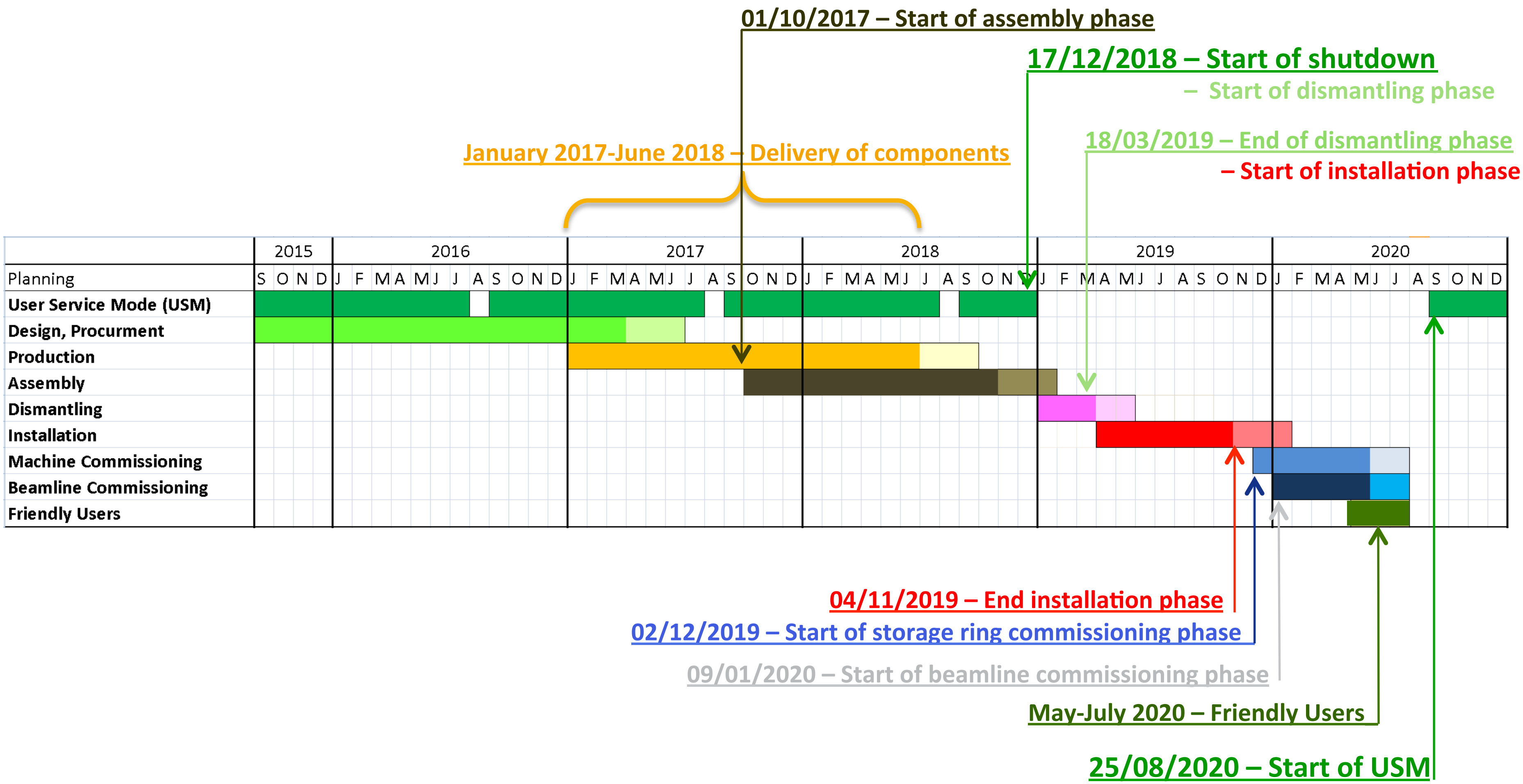
STATUS PROGRESS: PROCUREMENT

- All contracts for magnets in place
- All contracts for vacuum chambers expected by Spring 2016
  (all CFTs launched, ~50% contracts in place)
- Girders contract(s) expected by March 2016
- Infrastructure adaptations finalized, CFTs in progress
- All large scale procurements in place by mid 2016
- Serial components delivery will start by the end of 2016 and will last about 2 years

ADM very heavily involved for
- Budget and Financing
- Procurement
- Personnel

EBS MASTER PLAN (2015-2020)

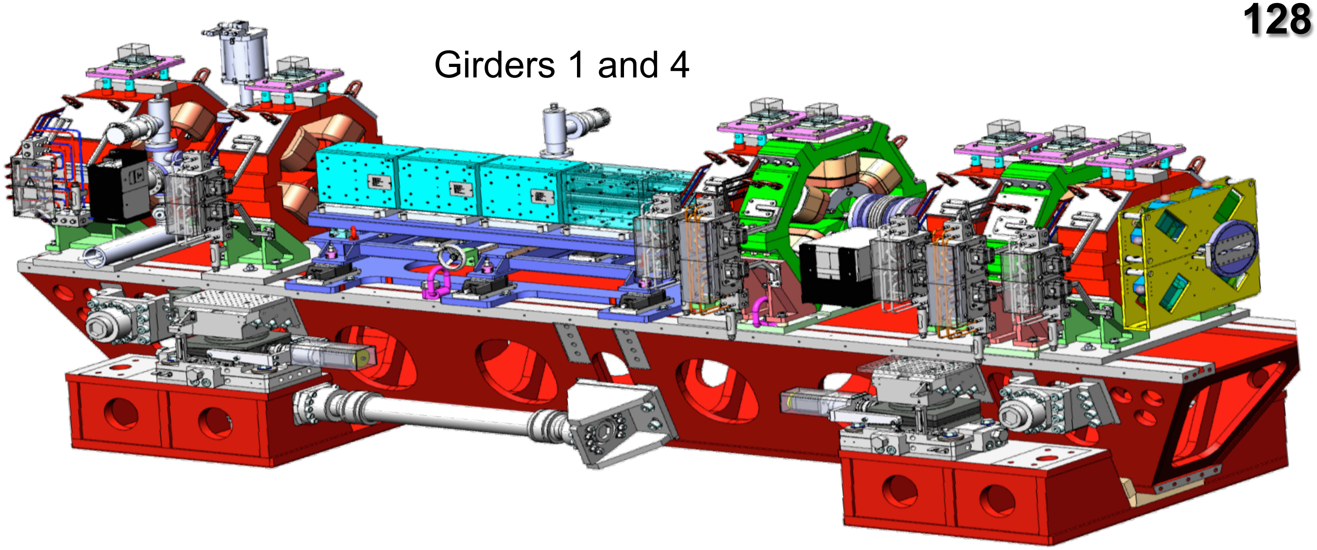
Master Plan and Major Milestones



GIRDER ASSEMBLIES

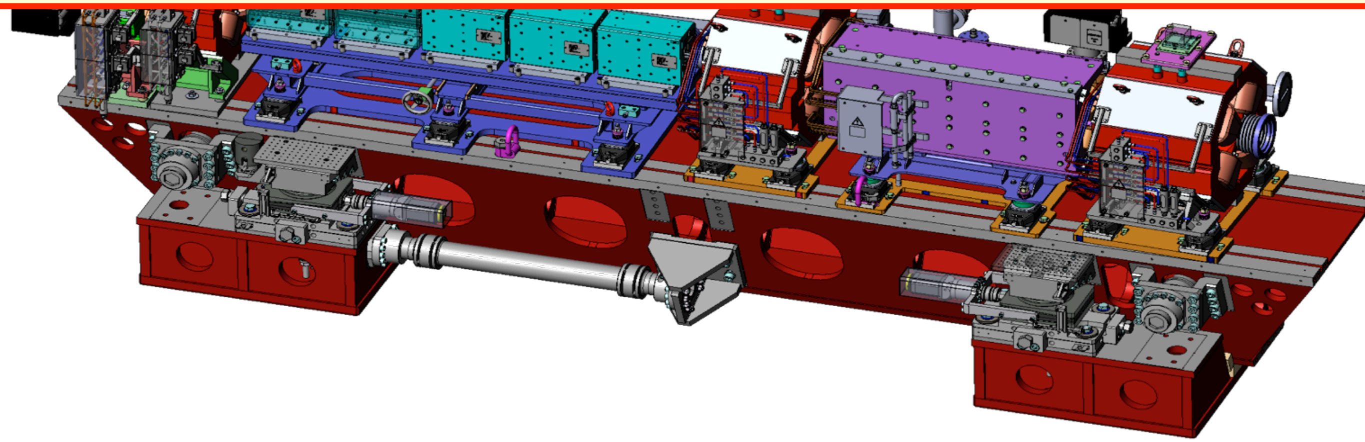
128 girders,10-12t each

Girders 1 and 4

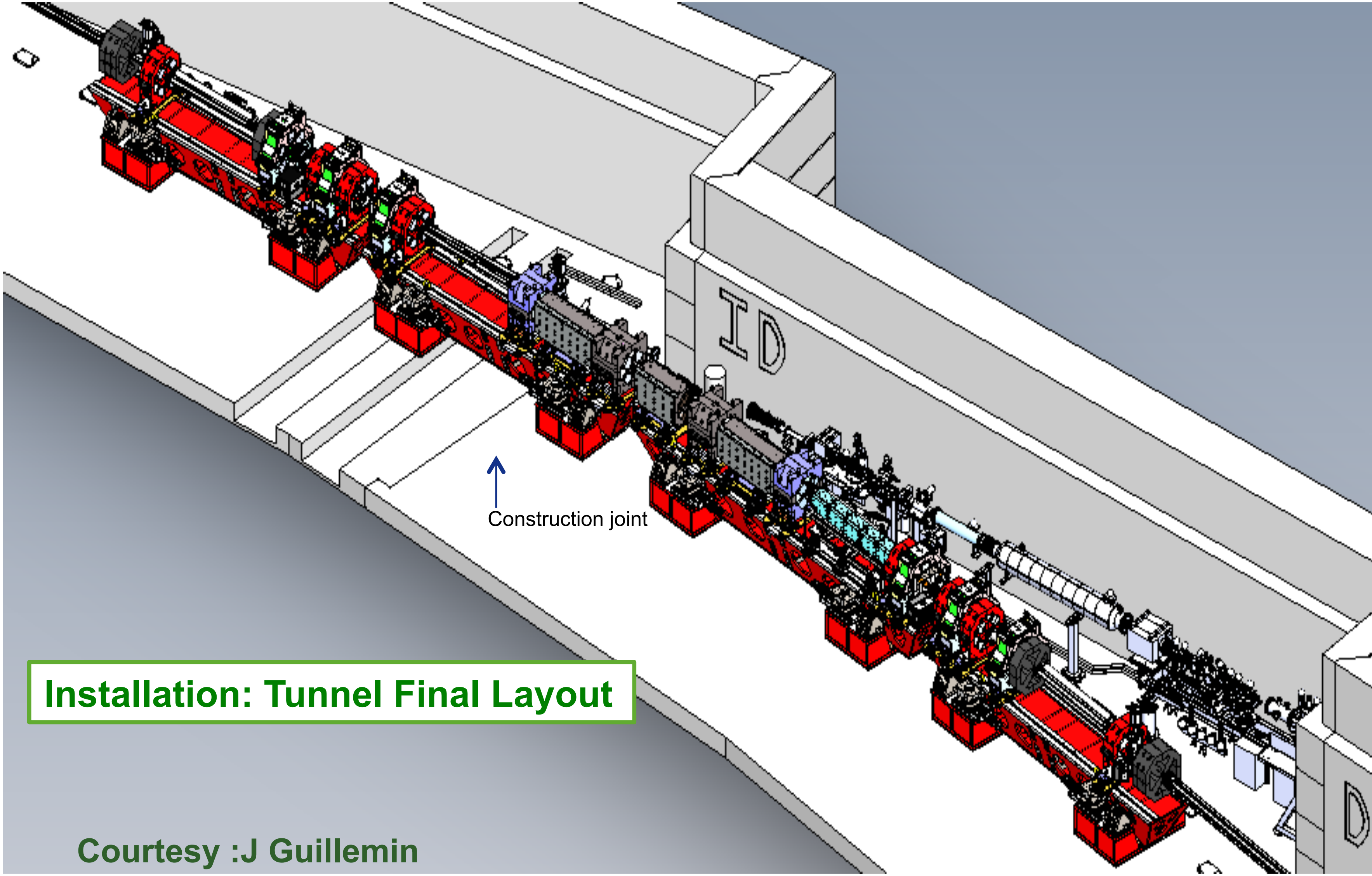


Girders 2 and 3

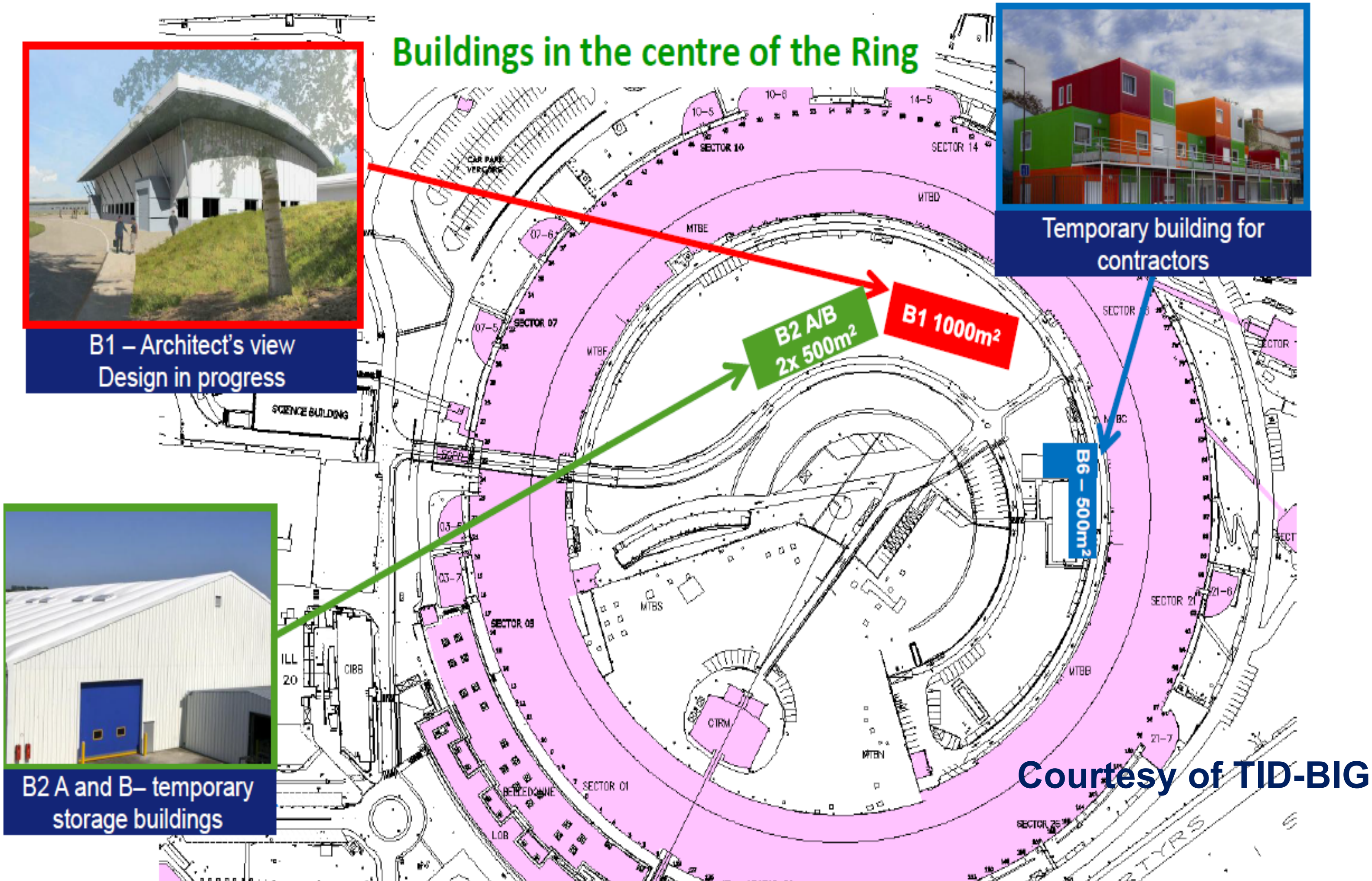
All girders will be fully assembled before starting the shutdown for installation



SYSTEM INTEGRATION – MACHINE LAYOUT IN THE TUNNEL

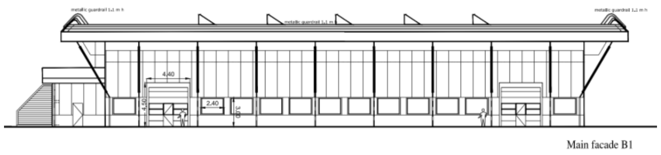


BUILDINGS FOR THE ASSEMBLY PHASE

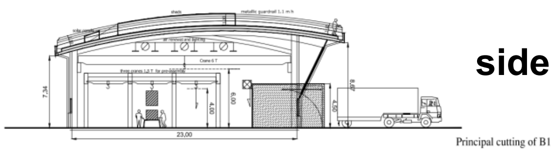


All the girders will be assembled in B1 (Sep 2017-Oct 2018)
and stored mainly in the Chartreuse building before the Long Shut-Down

ASSEMBLY BUILDING LAYOUT

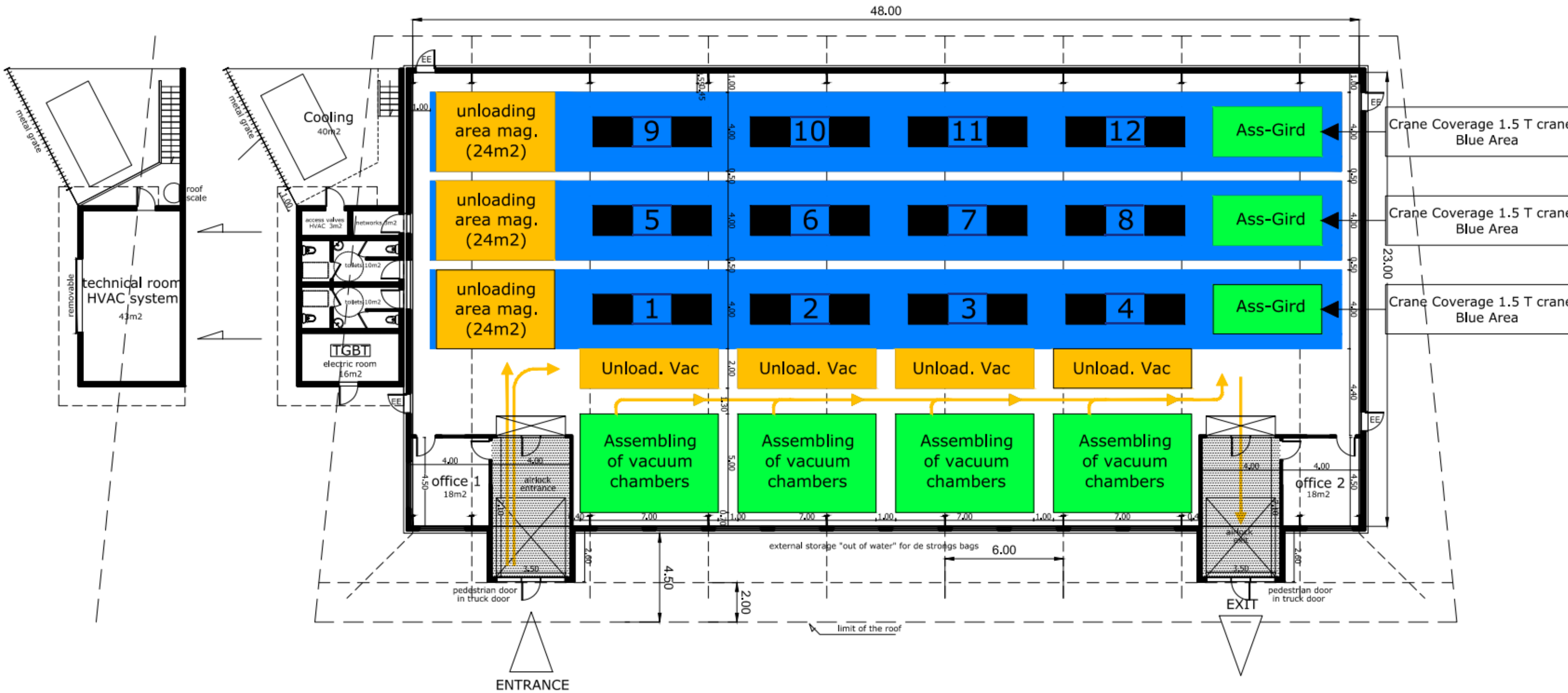


front view



side view

top view

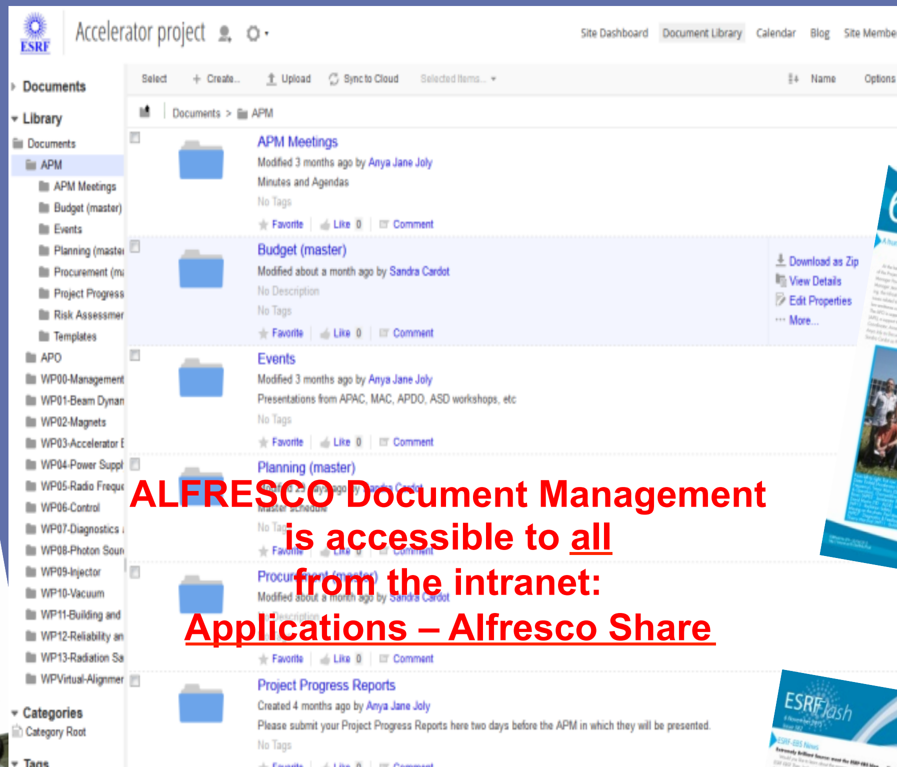


Courtesy of TID-BIG

The European Synchrotron | ESRF

EBS PROJECT COMMUNICATION

EBS Blog:
www.esrf.fr/ebs



ALFRESCO Document Management is accessible to all from the intranet:
Applications – Alfresco Share

ESRFlash

Courtesy of A.Joly & Communication Group

CONCLUSION

EBS officially started on January 1st 2015

Project execution progression:

- **Engineering Design virtually completed**
- **Procurement in full swing**
- **Delivery of all pre-series components expected by end of 2016**

Schedule now heavily linked to external manufacturers

Many thanks to all the ESRF staff for the great enthusiasm, support and achievements…

EBS is a significant step toward a DLSR but:

Another factor 10 reduction in the horizontal emittance is still needed in order to reach the diffraction limit (@10KeV)

MANY THANKS FOR YOUR ATTENTION