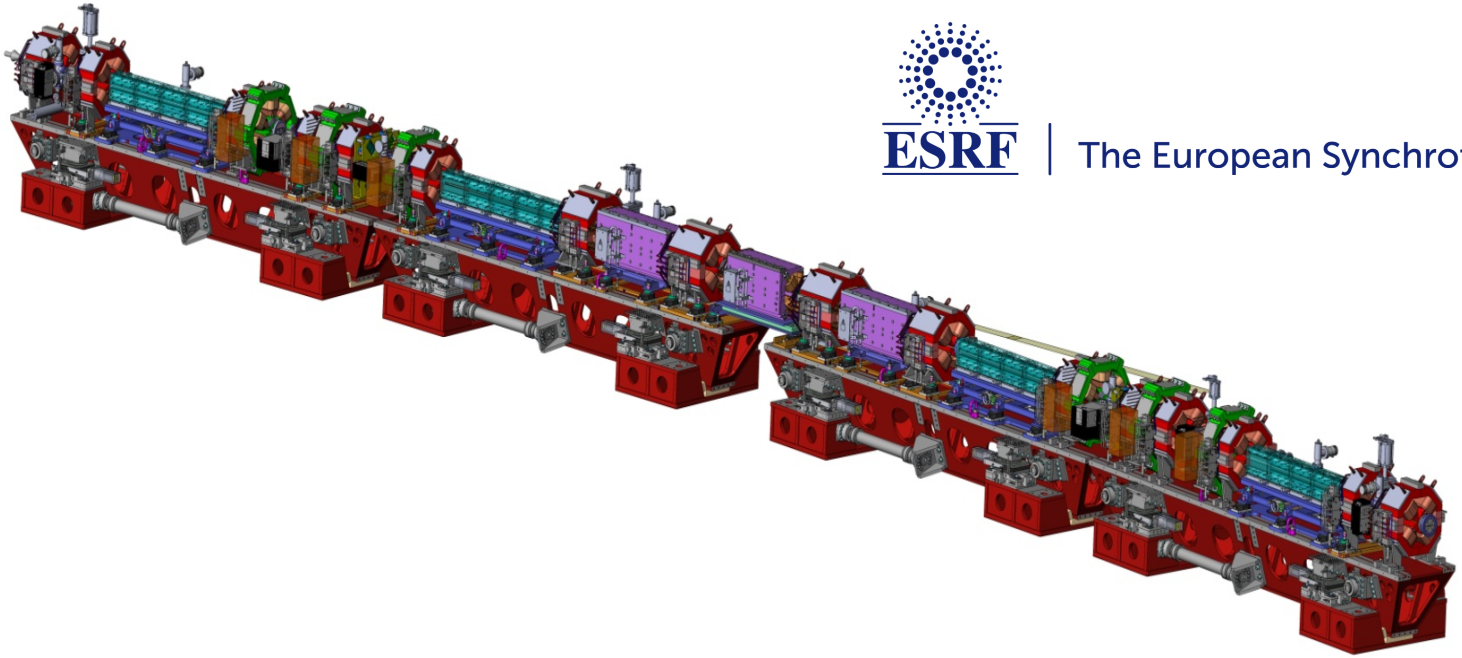
ESRF EBS Accelerator Upgrade

Paris, March 21th 2017

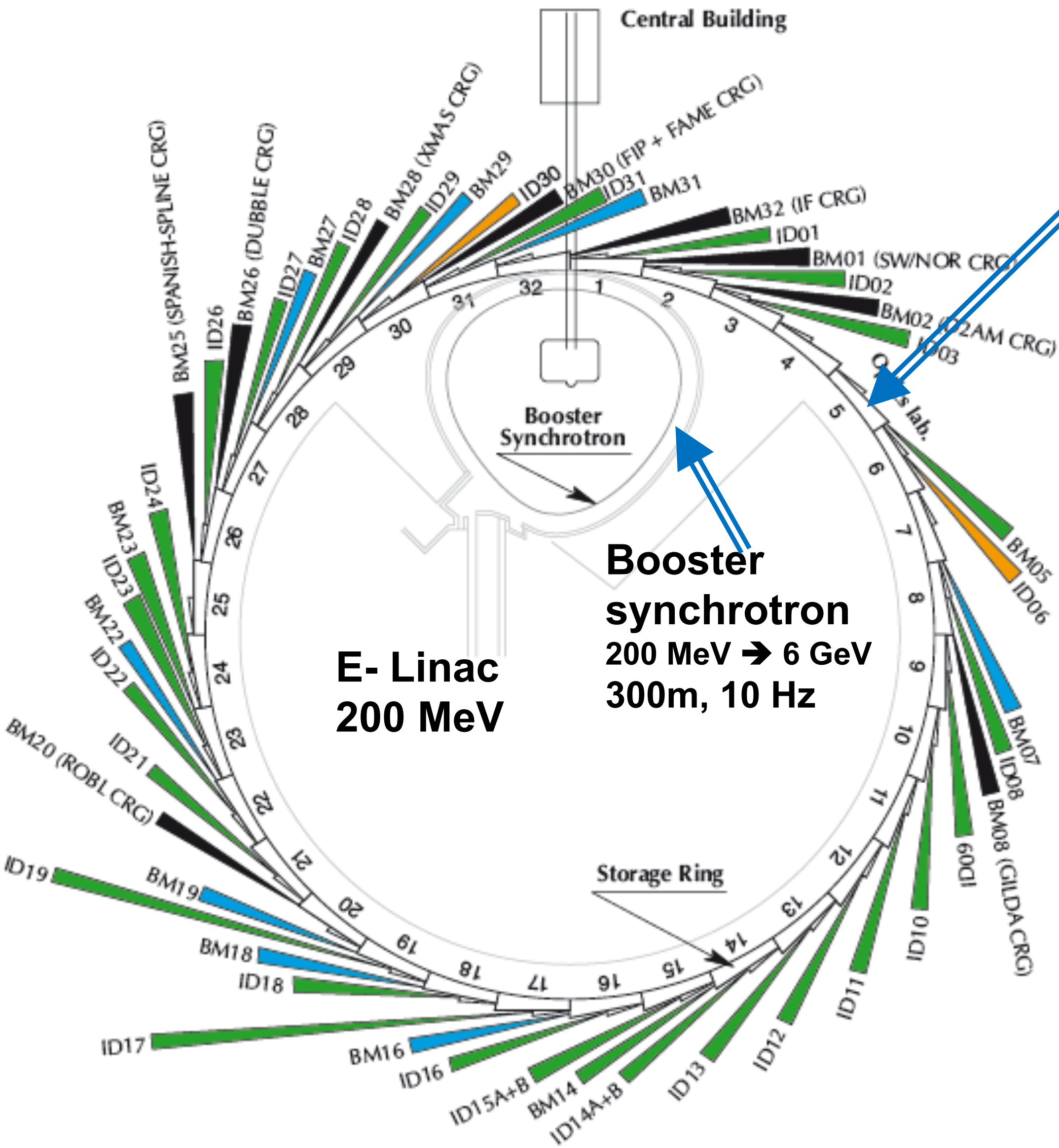
Pantaleo Raimondi

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:

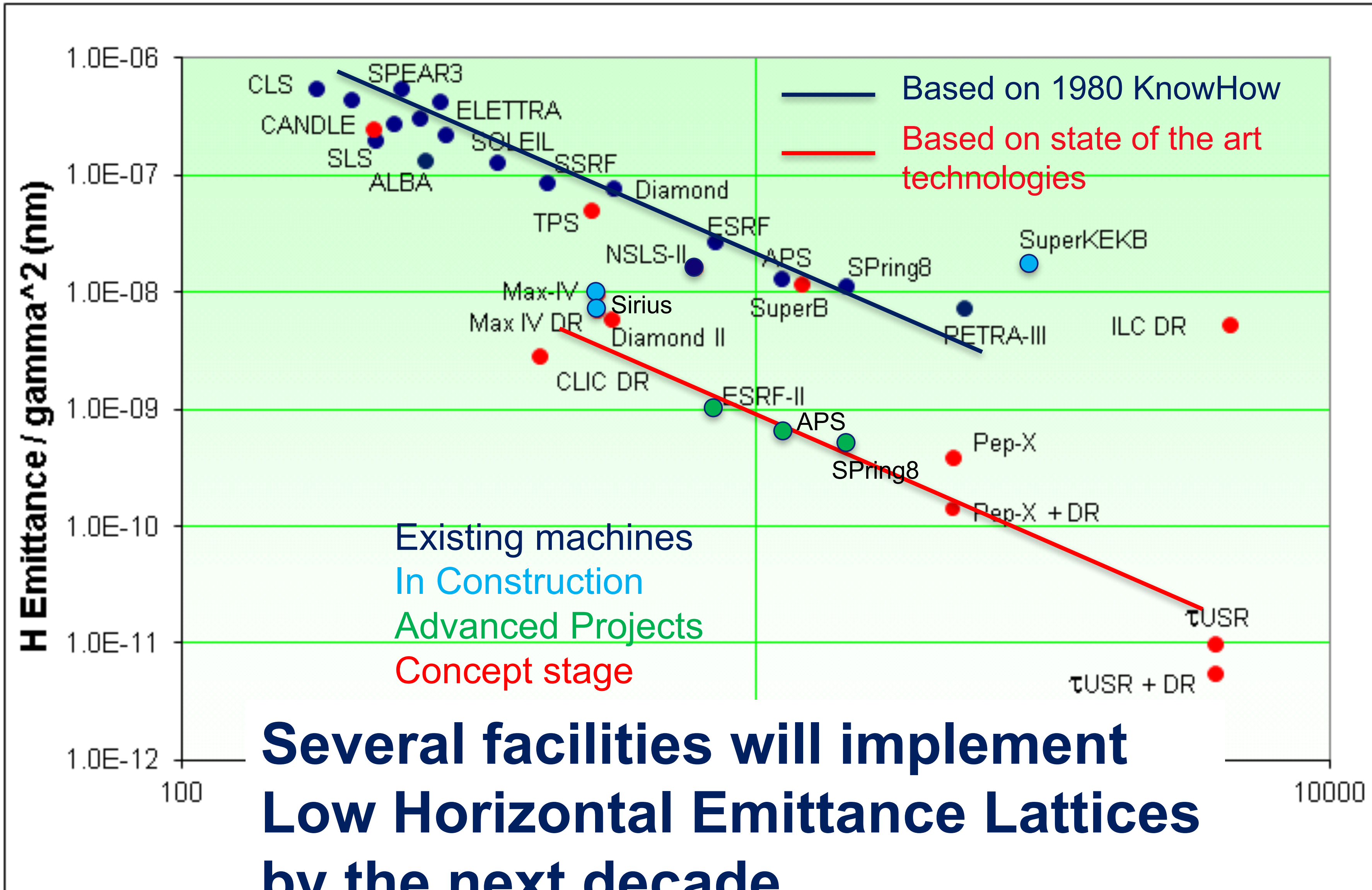
- Substantially decrease the Store Ring Equilibrium Horizontal Emittance
- Increase the source brilliance
- Increase its coherent fraction

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.

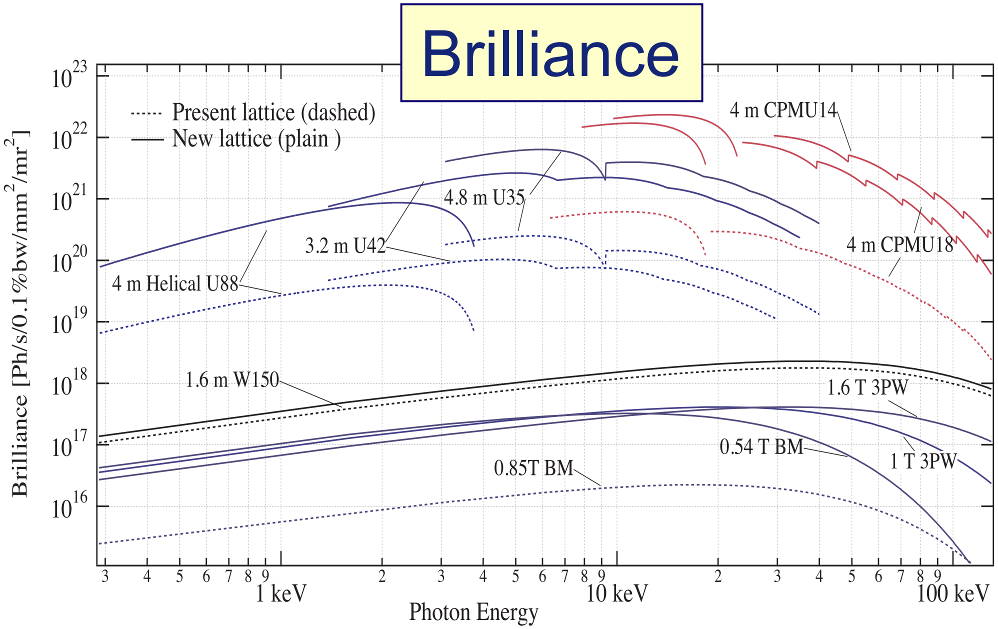
Maintain standard User-Mode Operations until the day of shut-down for installation

LOW EMITTANCE RINGS TREND



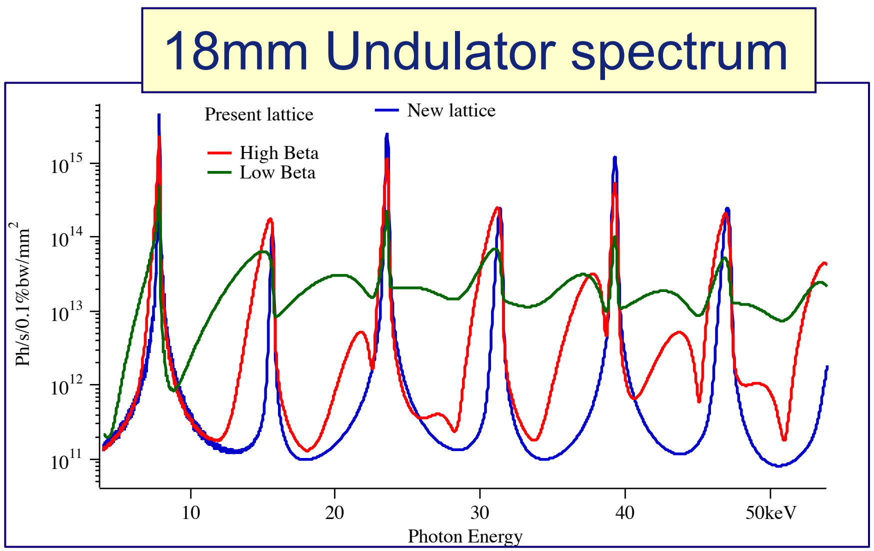
Several facilities will implement Low Horizontal Emittance Lattices by the next decade

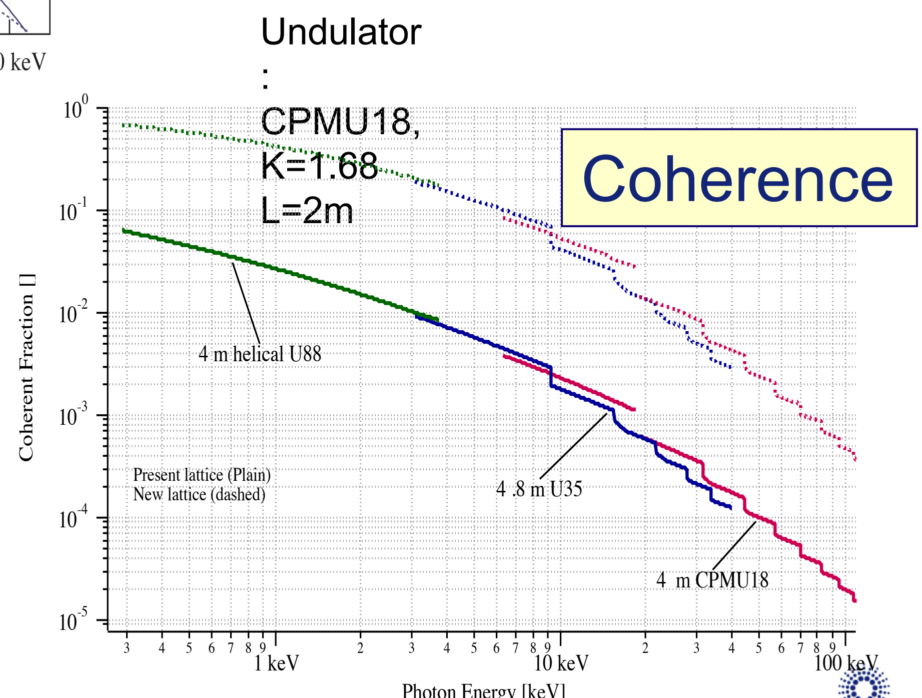
BRILLIANCE AND COHERENCE INCREASE



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





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

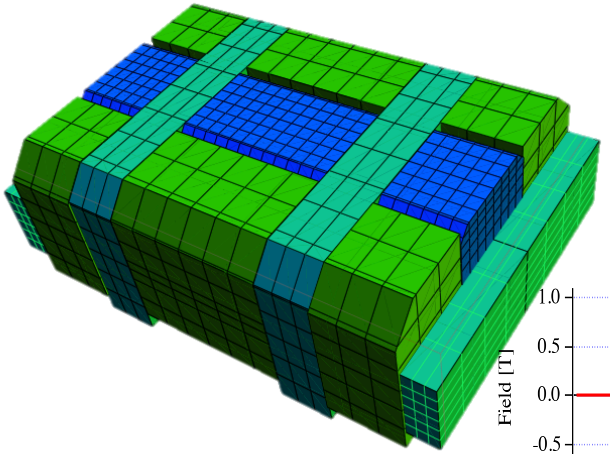
Conflict with hard X-ray demand from BM beamlines

ESRF will go from 0.85 T BM to 0.54 T BM

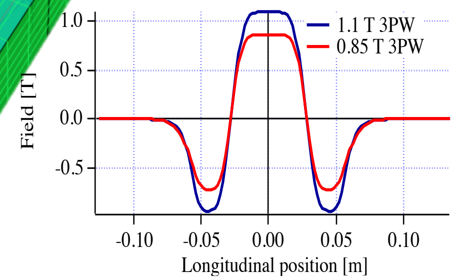
The BM Sources will be replaced by dedicated 2-Pole or 3-Pole Wigglers

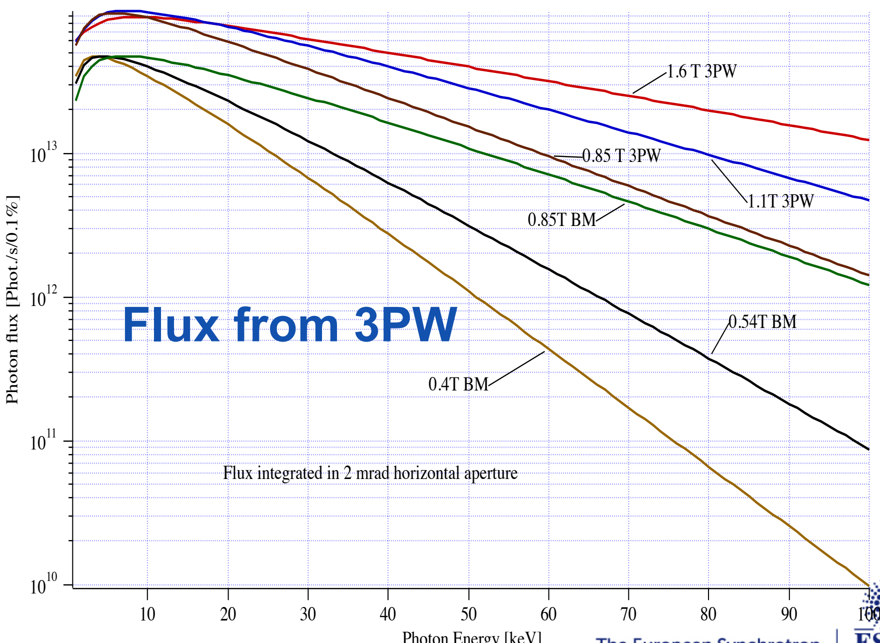
- Field Customized
- Large fan with flat top field
- 2 mrad feasible for 1.1 T 3PW
- Mechanical length ≤ 150 mm

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

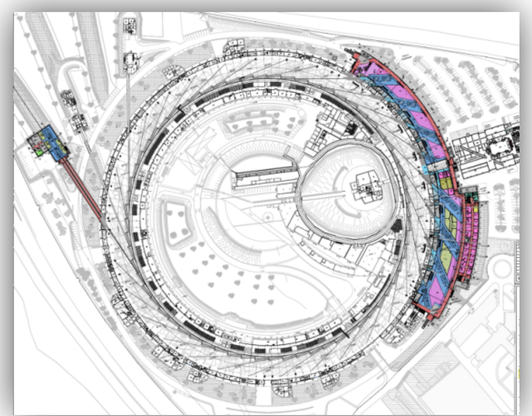


Half assembly

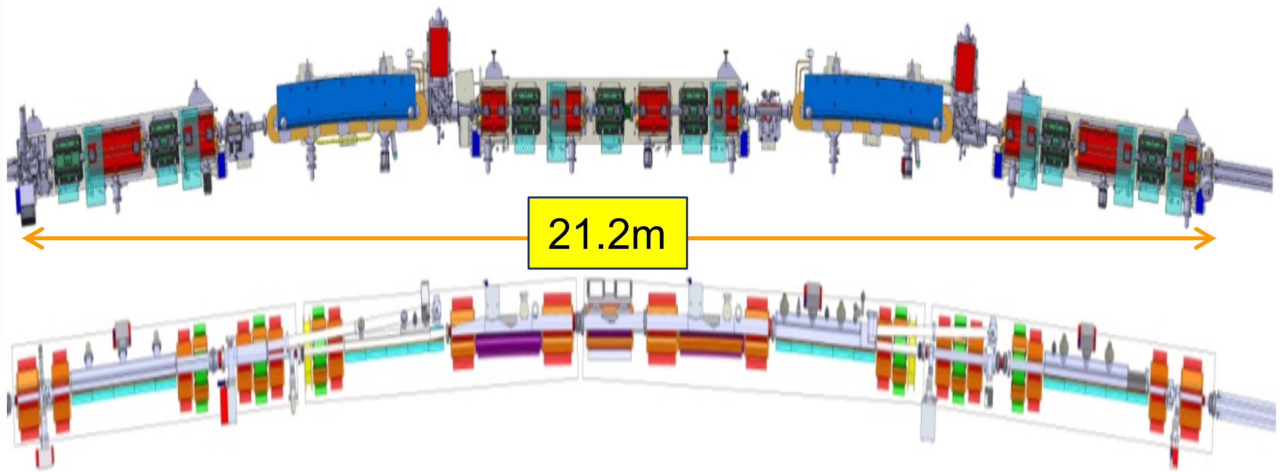




ESRF Phase II Upgrade at the Bone



Present ESRF Arc Layout: Ex=4nm



New Low Emittance Layout: Ex=0.135nm

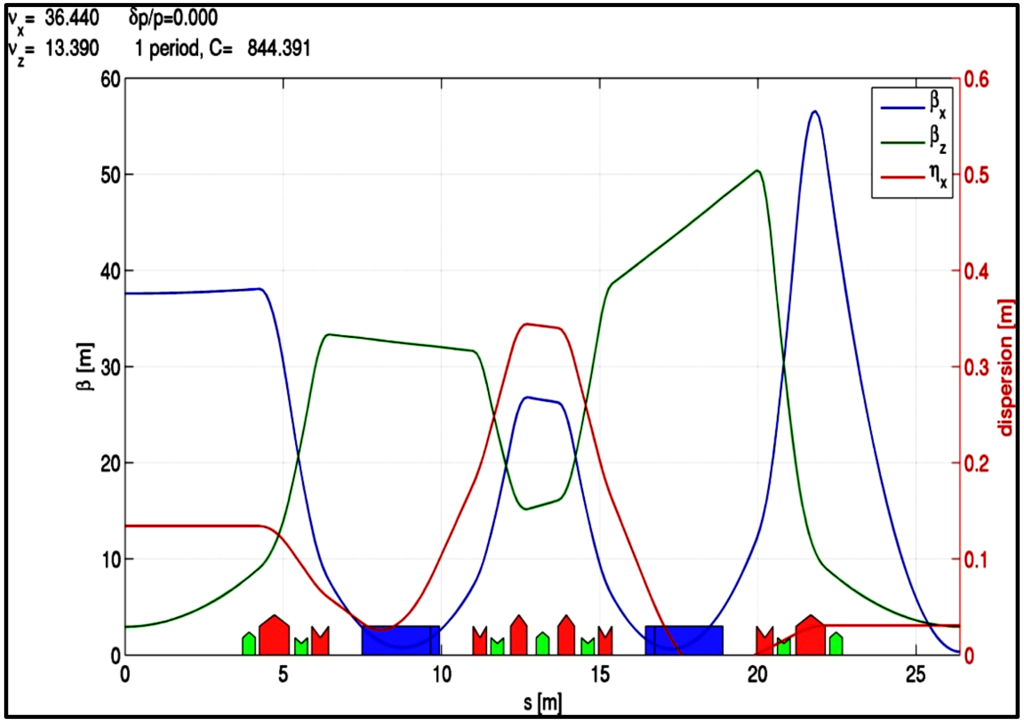
The 844m Accelerator ring consists of:

- 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.

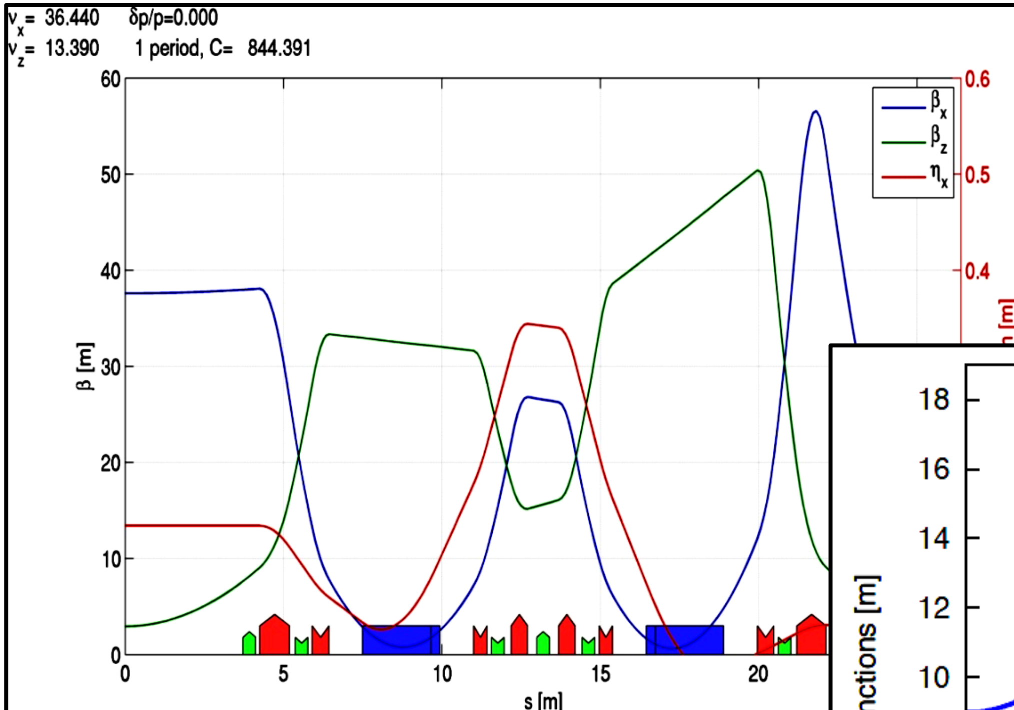
All the Arcs will be replaced by a completely new Layout

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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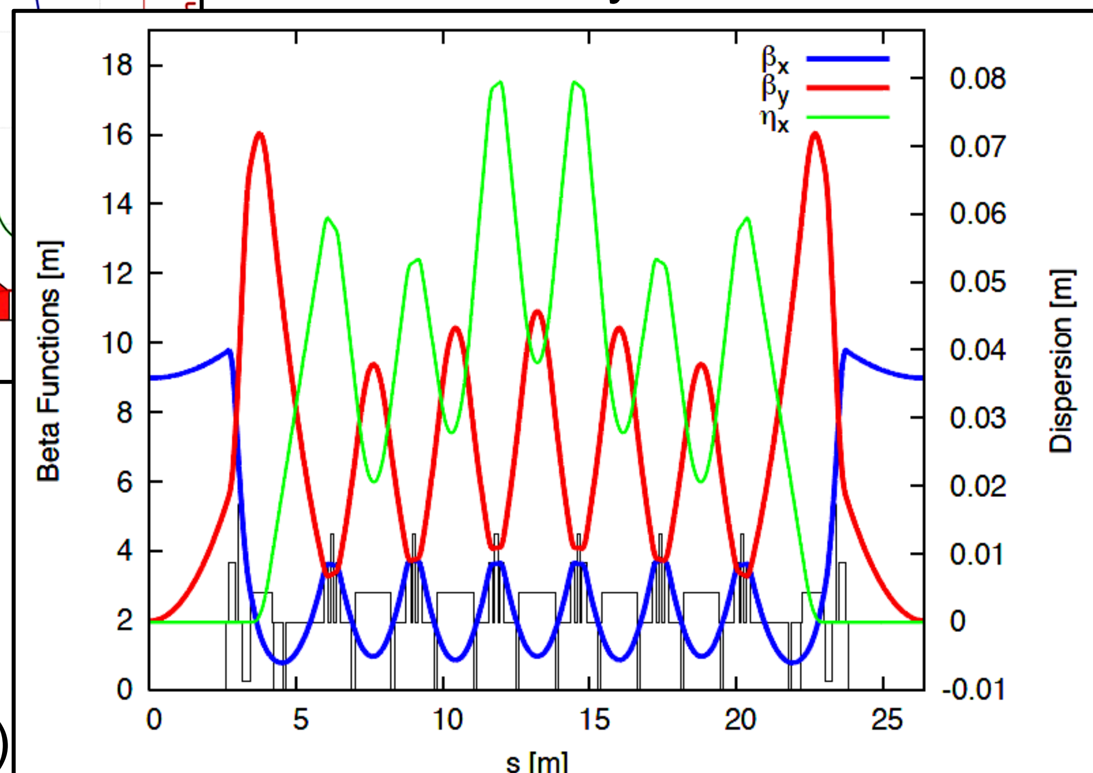
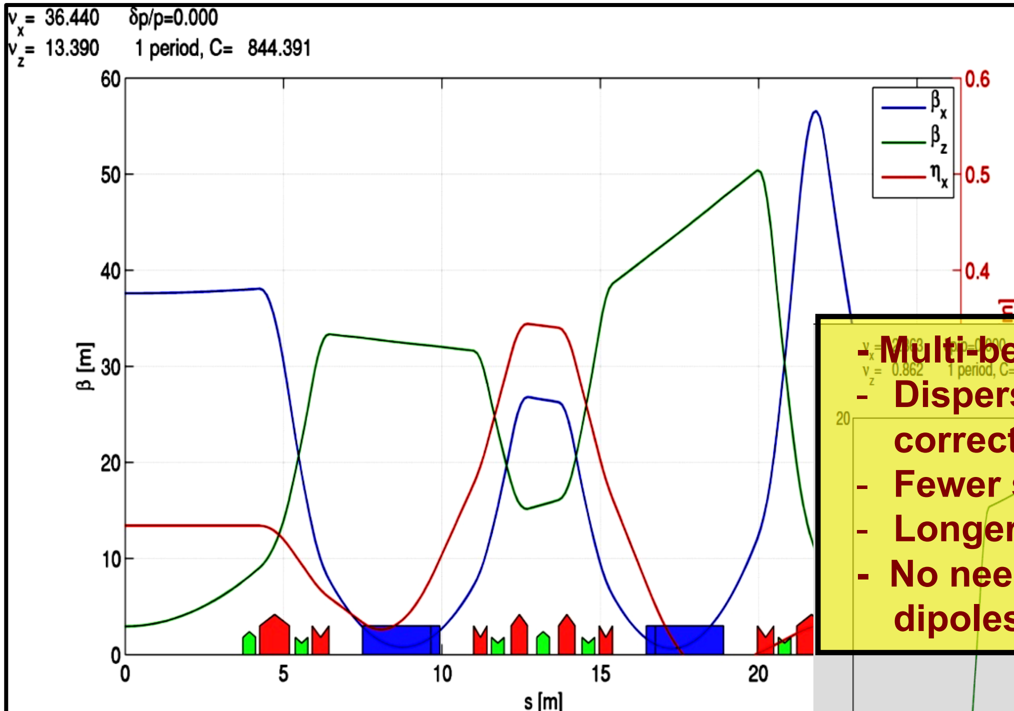


Multi-Bend Achromat (MBA)

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

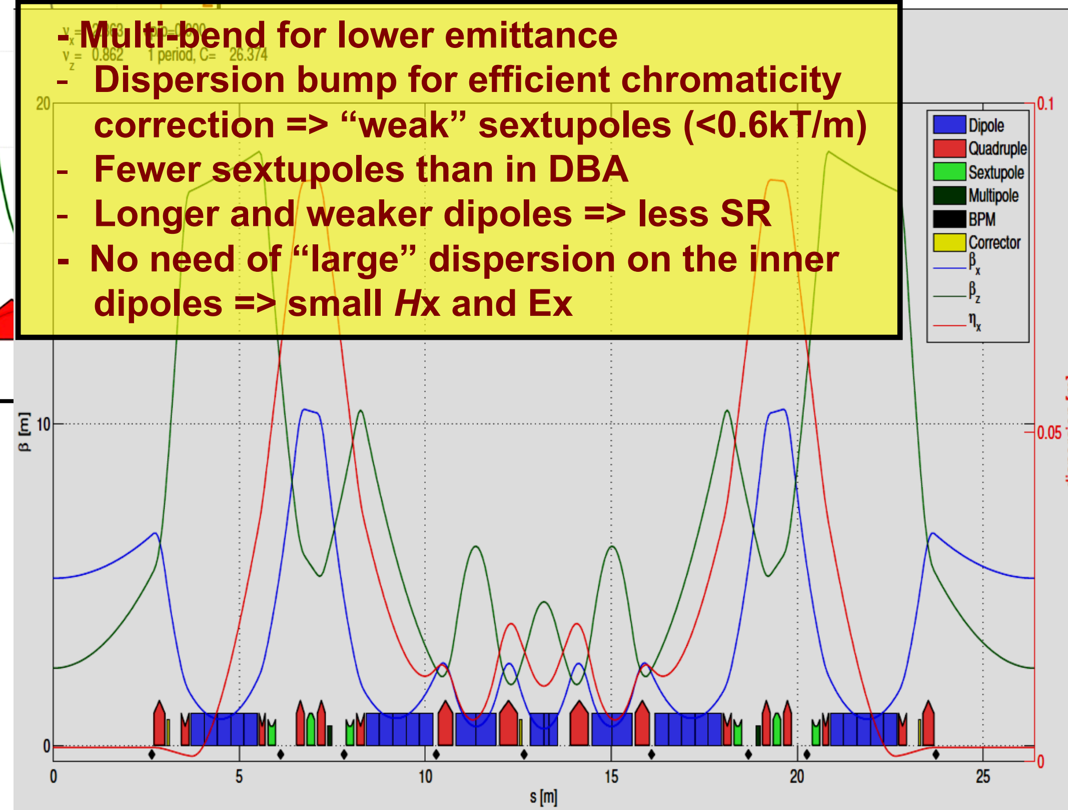
THE HYBRID MULTI-BEND (HMB) LATTICE



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.

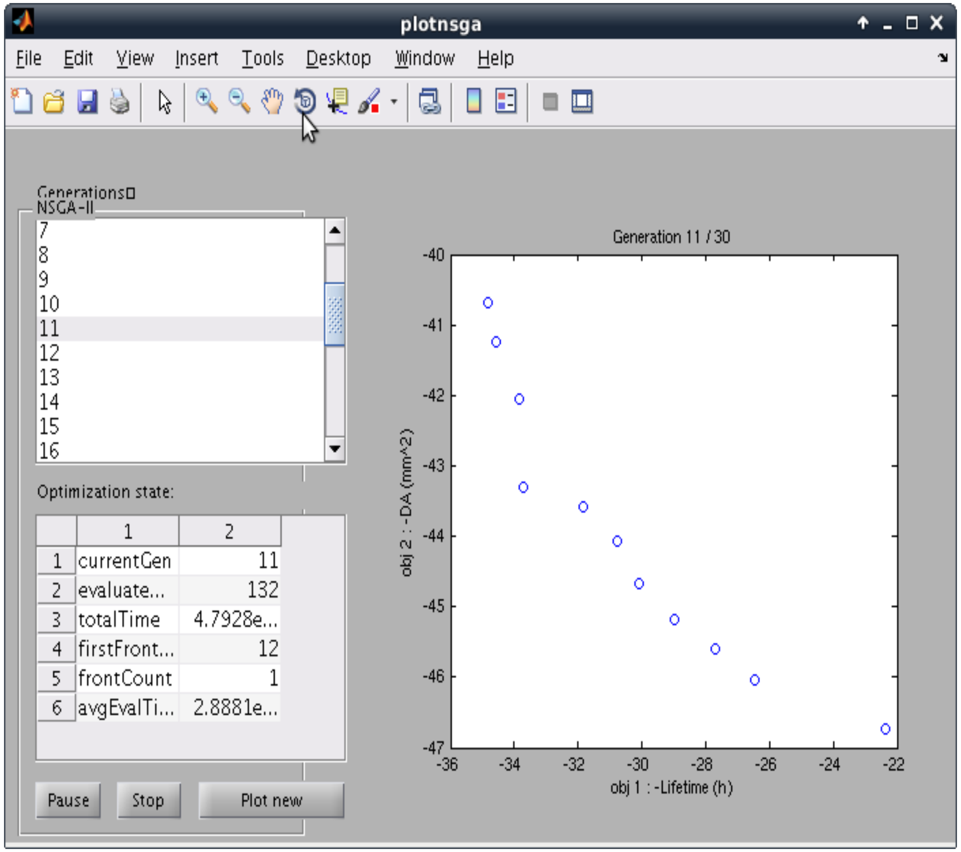
Sextupoles: from 6 to 3 families, weaker and shorter.

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

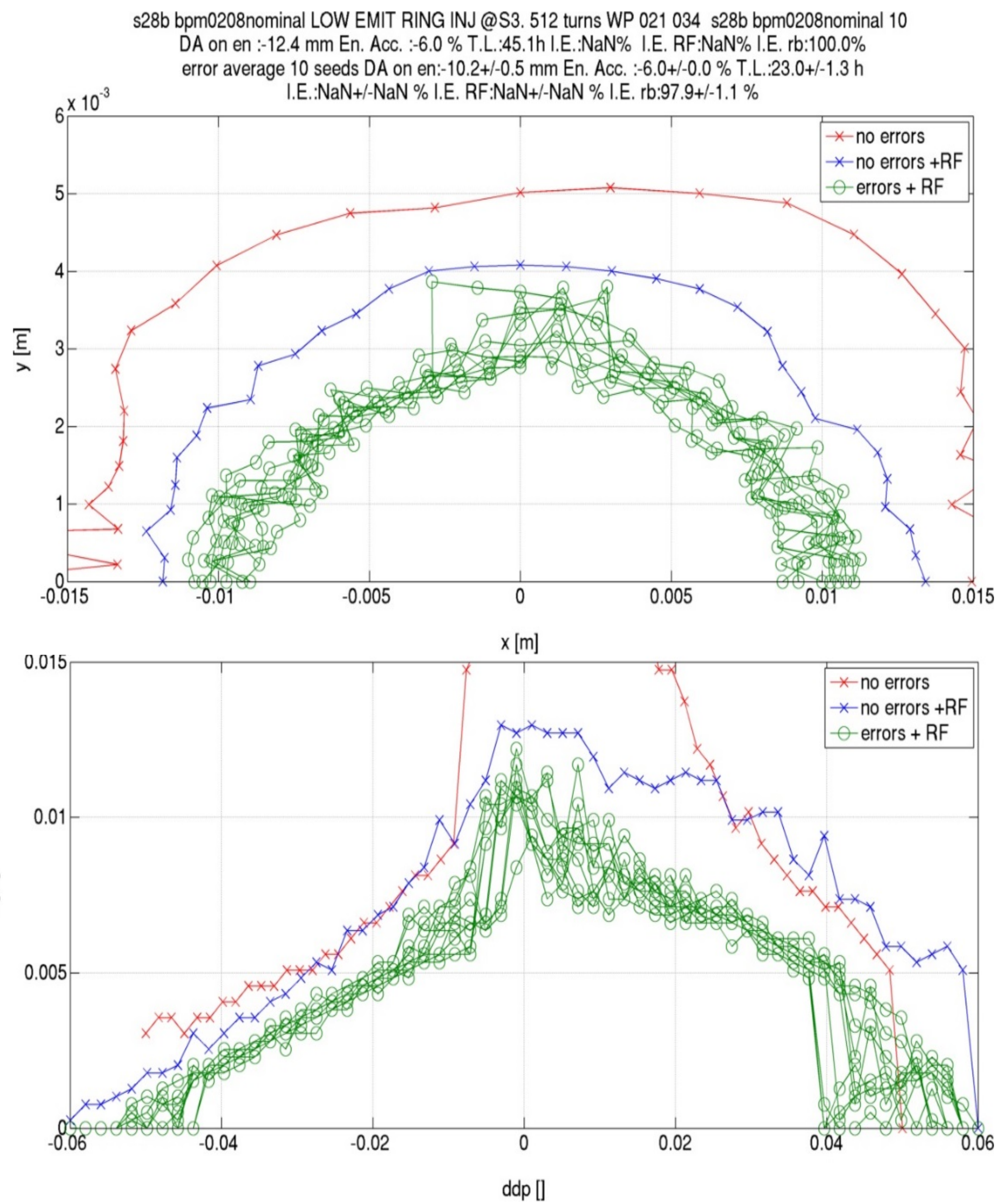
Tunes: 76.21 27.34

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

Chromaticities: 6, 4



LIFETIME OF S28B



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

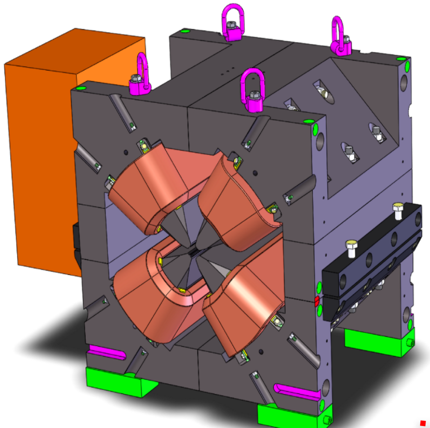
S28B
DA -10mm@S3
TLT ~ 21h

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

Technical challenge: Magnets System

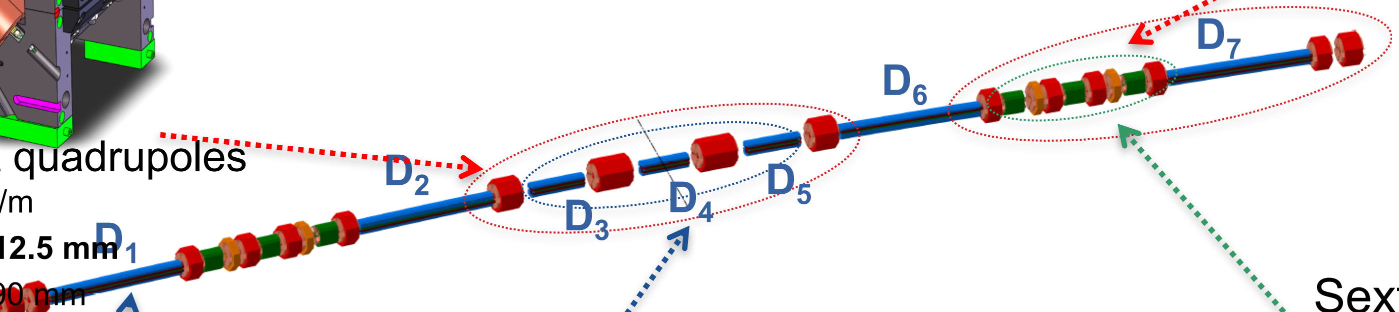
Mechanical design final drawing phase

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

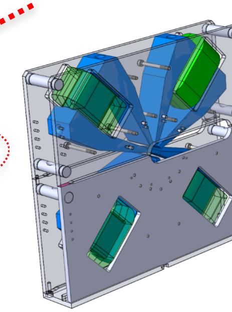


High gradient quadrupoles

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



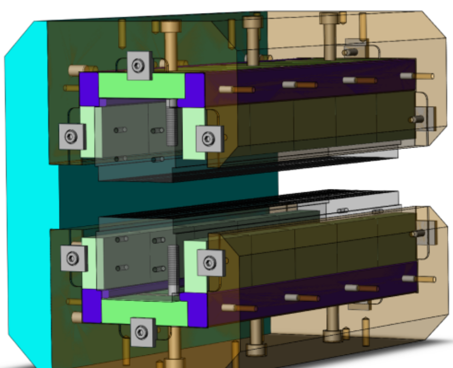
Quadrupole
Around 52Tm^{-1}

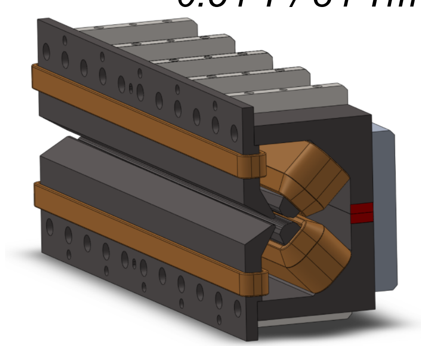


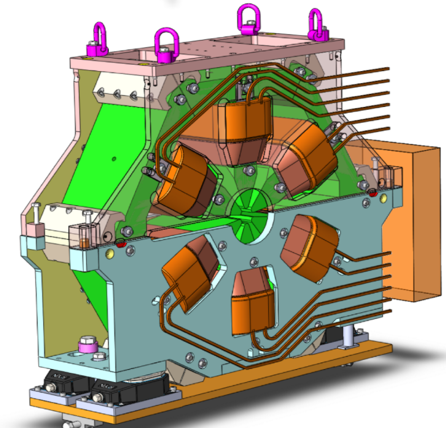
Octupoles

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

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







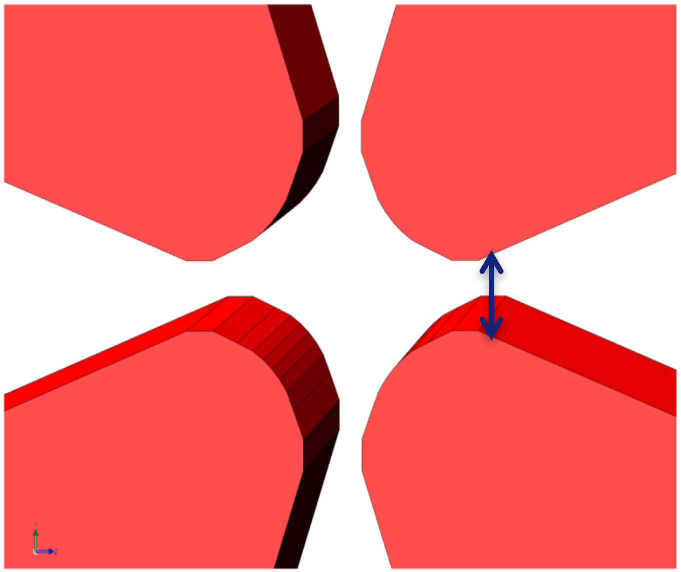
Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 – 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

Gael Le Bec

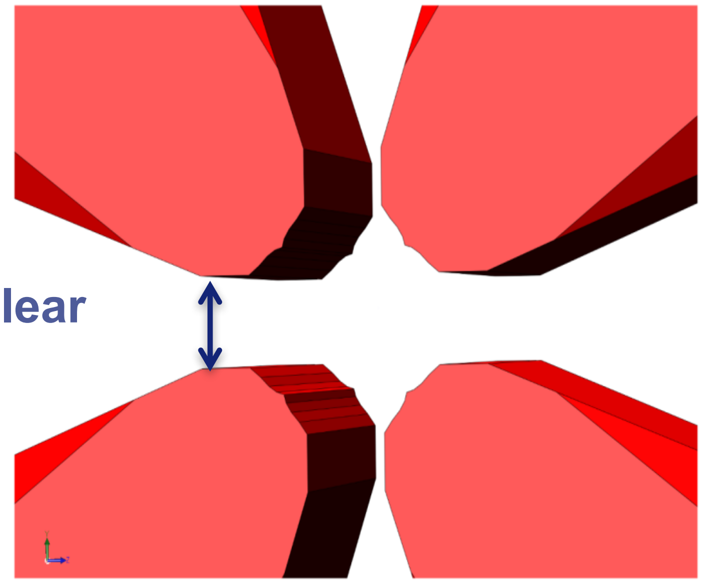
QUADRUPOLES DESIGN

Pole shape optimization

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

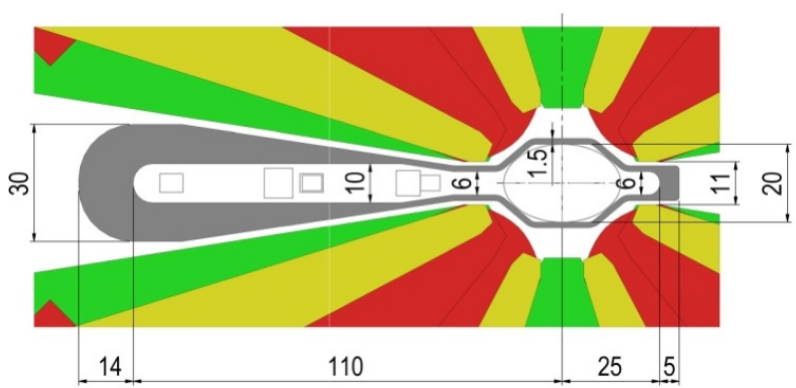


11mm stay clear



Low gradient pole profile

High gradient pole profile

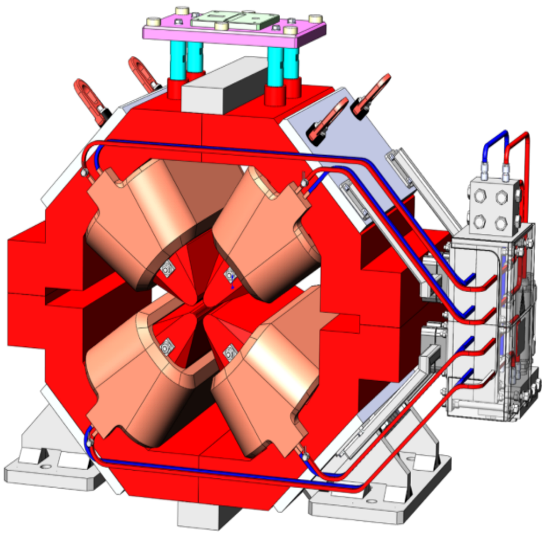


Vacuum chamber and magnets sections

QUADRUPOLES

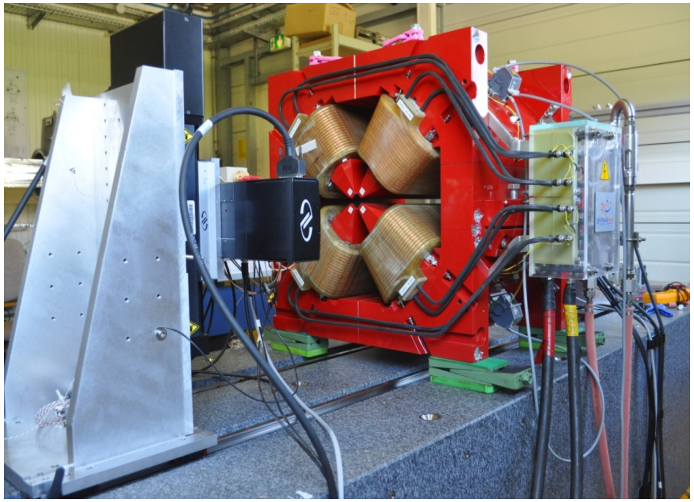
High Gradient

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



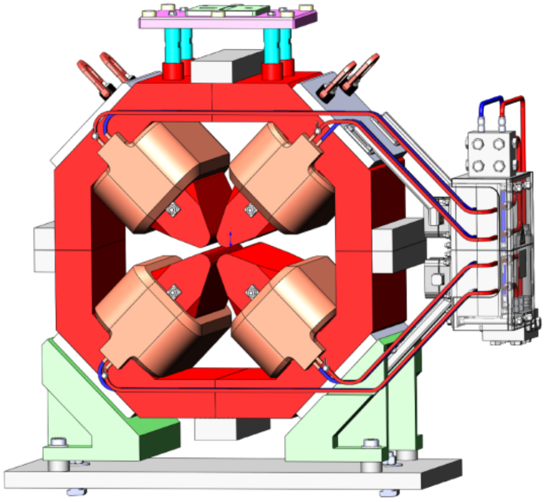
HG Prototype

+/-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



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

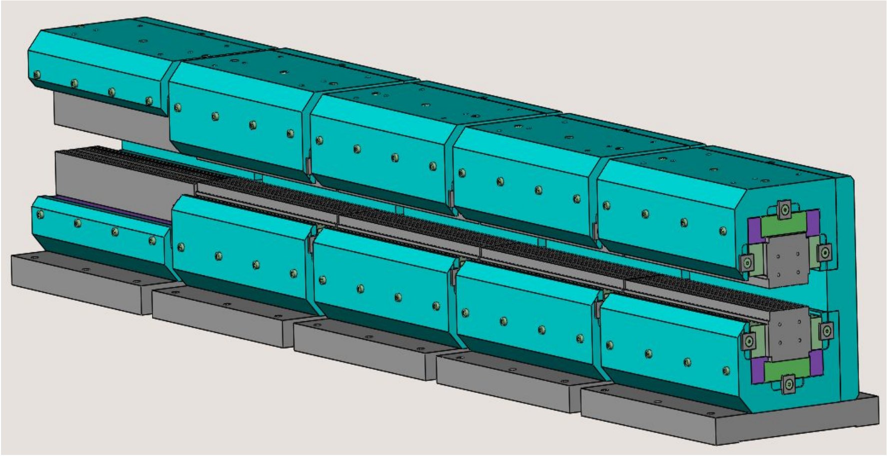
Engineering design

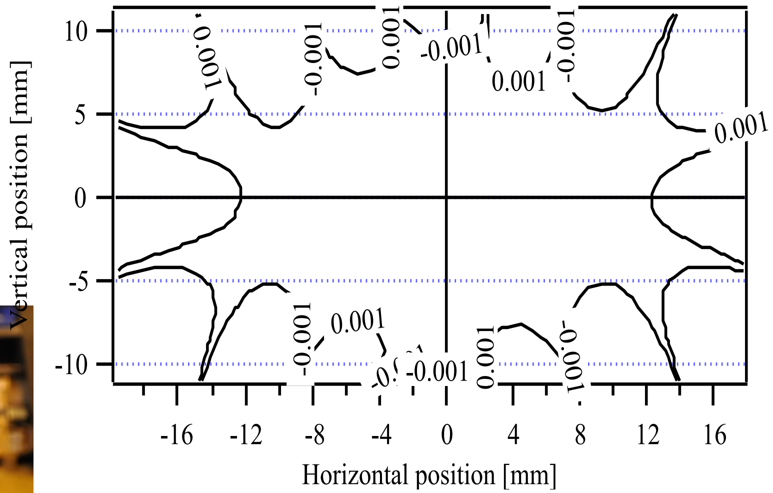
- Completed

Prototyping

- Completed

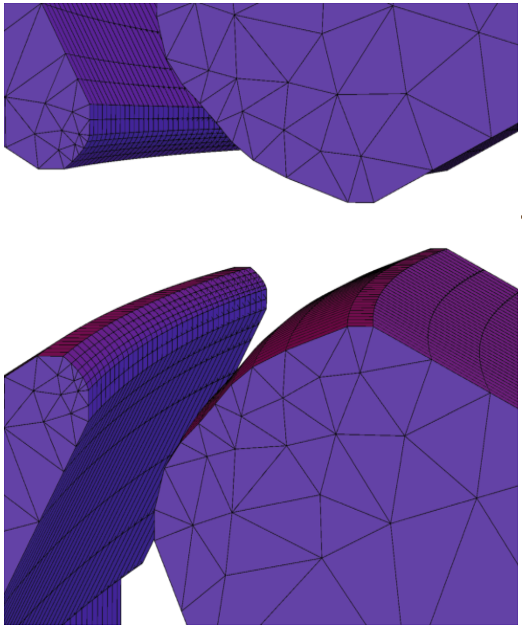
The DLs will be build by ESRF



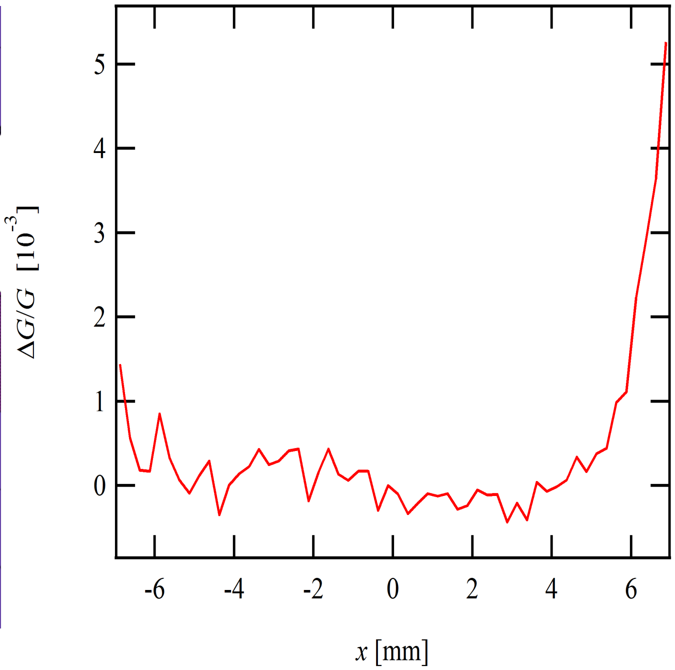


Measured field integral homogeneity (one module)

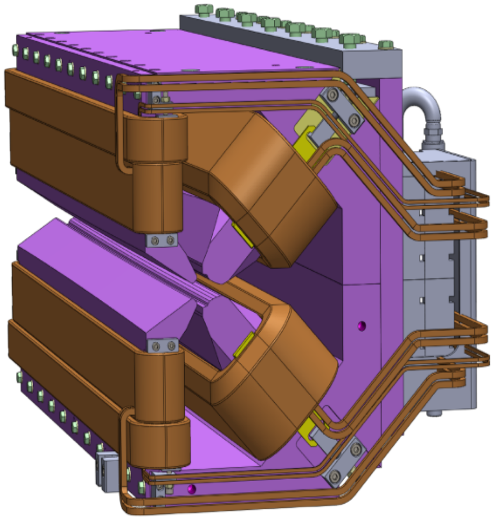
DIPOLE QUADRUPOLES



DQ1 pole shape



DQ1 gradient homogeneity:
Integration of trajectory along an arc



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

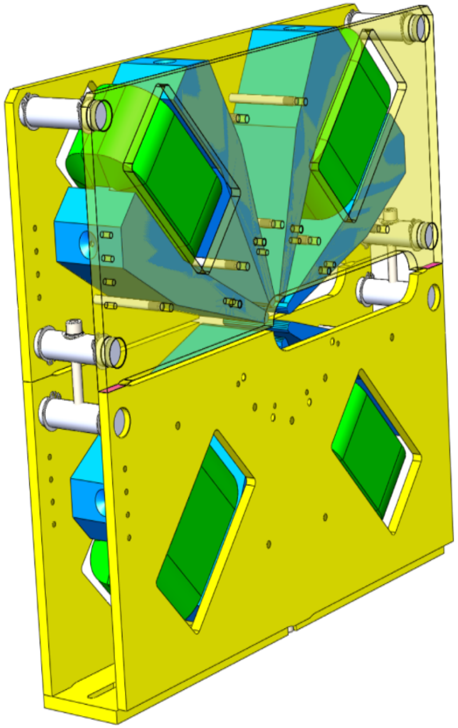
$\Delta G/G$ < 1% (GFR radius 7 mm)

DQs are machined in 7 solid iron plates

Poles curved longitudinally for maximum stay clear and good field region

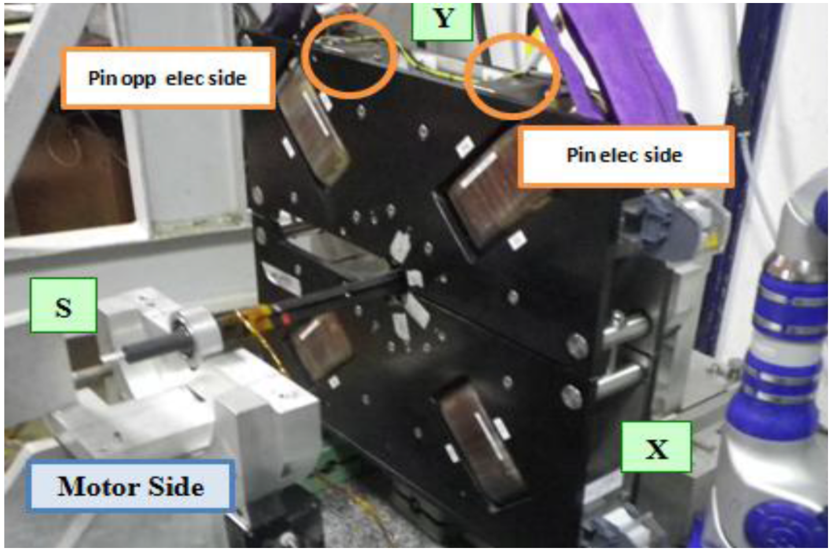
S28b specifications

- 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



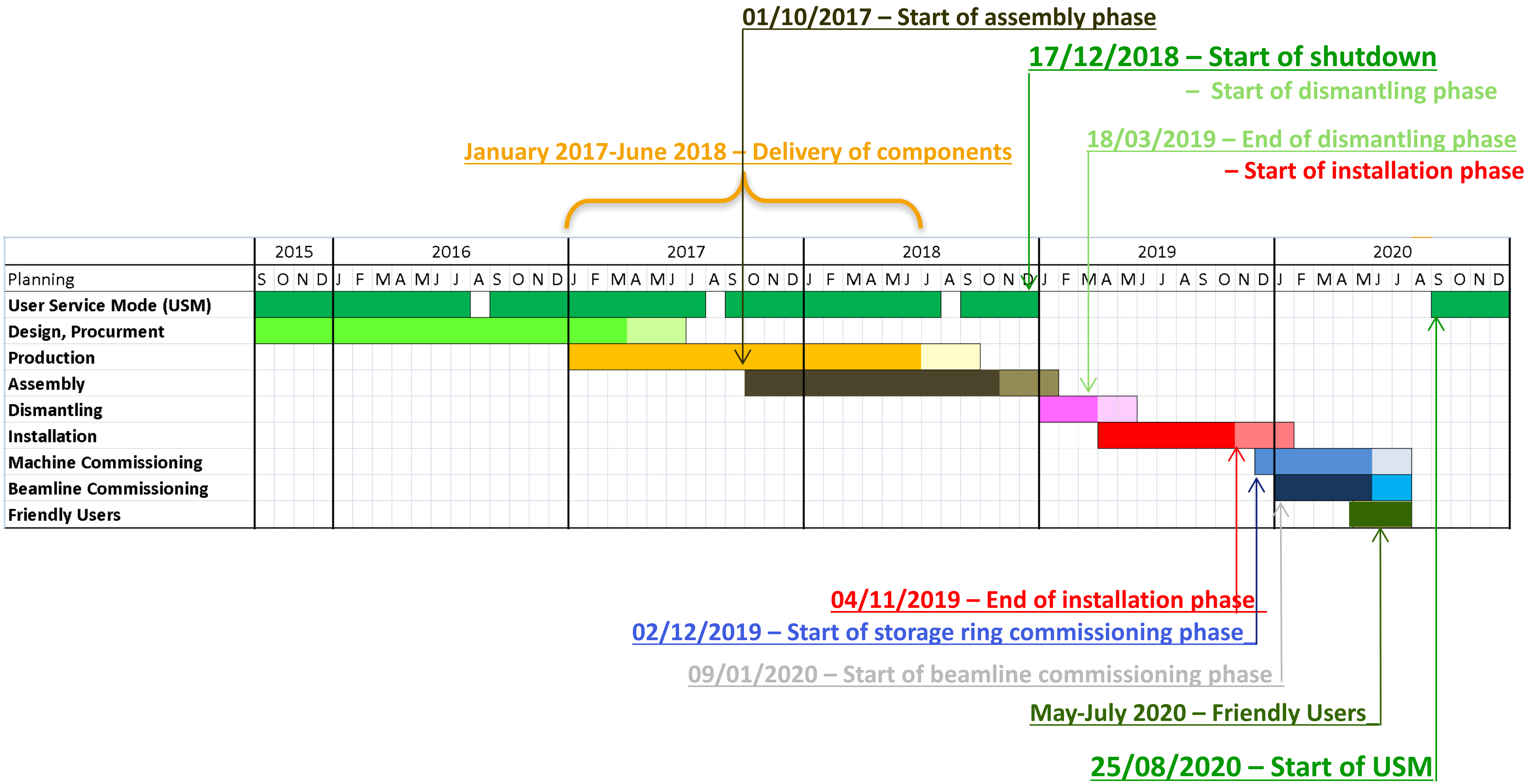
Prototyping

- Air cooled prototype measured



EBS MASTER PLAN (2015-2020)

Master Plan and Major Milestones



PROGRESS STATUS: 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 and requirements

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

PROGRESS STATUS: PROCUREMENT

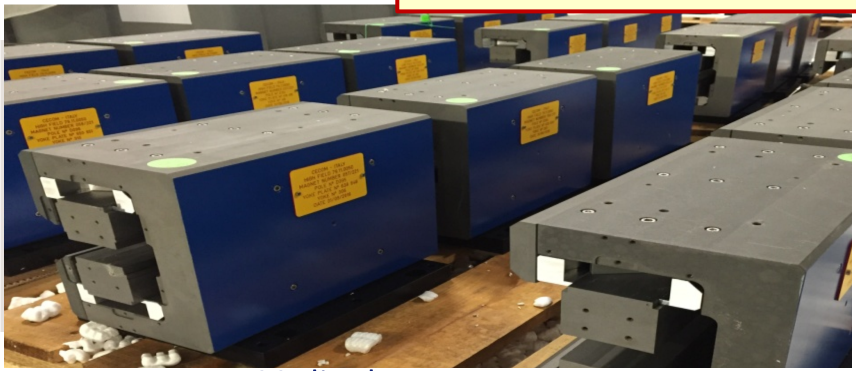
- All contracts for serial production magnets in place
- All contracts for vacuum chambers in place
- Girder contracts in place
- Infrastructure adaptations critical contracts in place
- All large scale procurement in place by December-2016

Delivery of serial components has started will last about 2 years

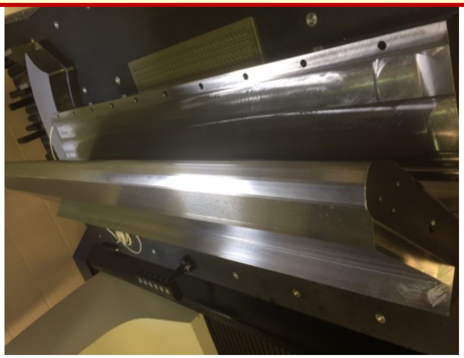
ADM very heavily involved for
- Budget and Financing
- Procurement
- Personnel

ESRF EBS (2015-2022): MAGNETS PROCUREMENT

All contracts in place, magnets in fabrication
FAT for HG-Quads, Sextupoles and correctors last week
All FAT should be completed by December
More than 1000 Magnets to be procured by the end of 2018



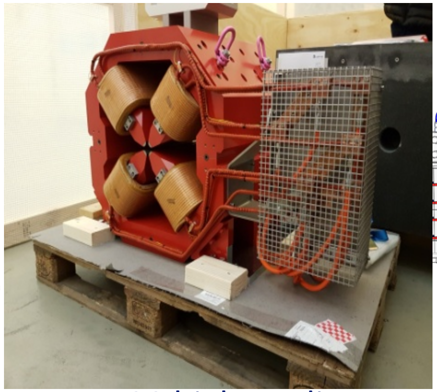
132 dipoles



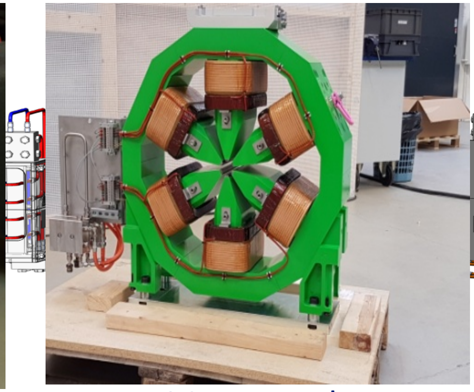
99 dipole-quadrupoles

66 octupoles

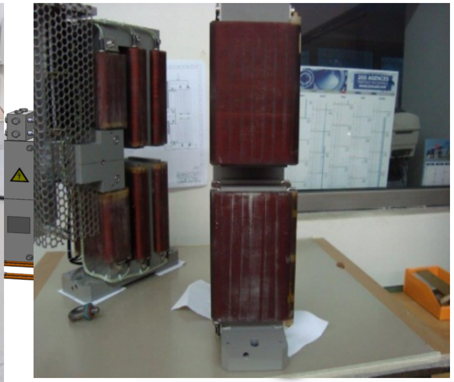
398 moderate gradient quadrupoles



130 high gradient quadrupoles



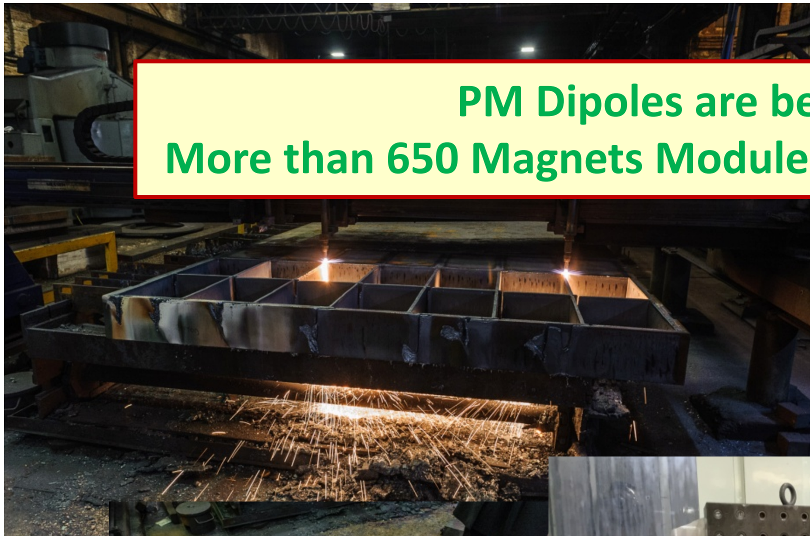
196 sextupoles

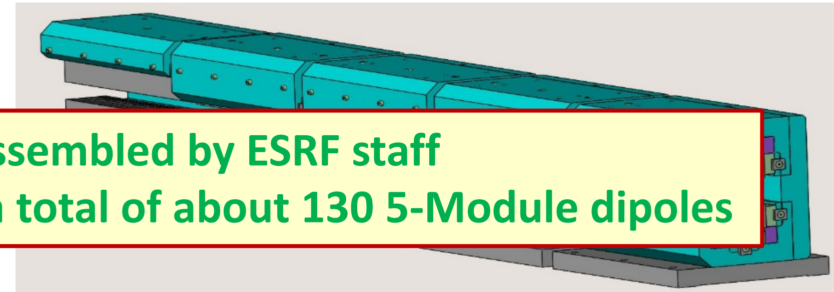


100 correctors

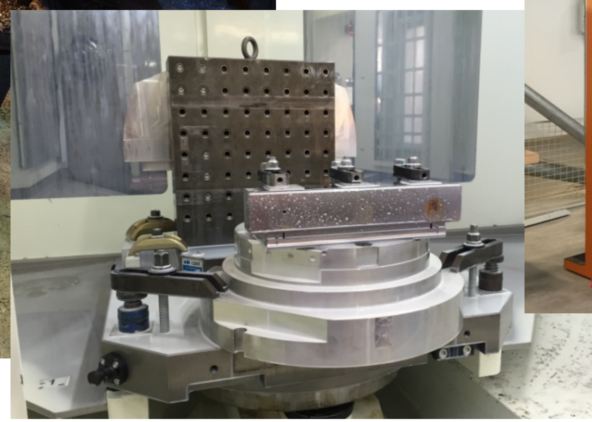
Courtesy of ASD-IDM & ISDD-MEG

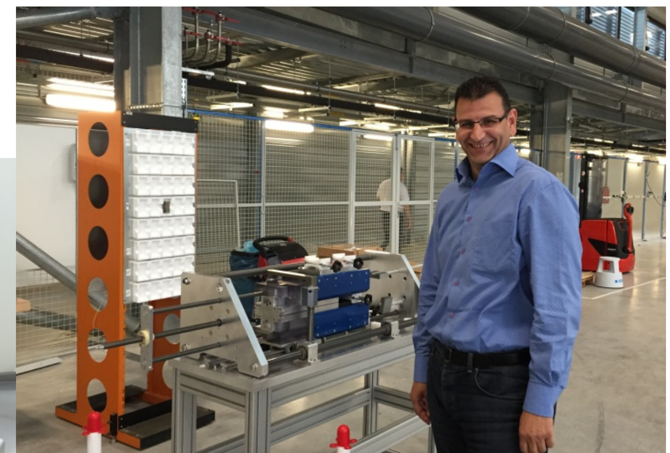
ESRF EBS (2015-2022): PM DIPOLES FABRICATION





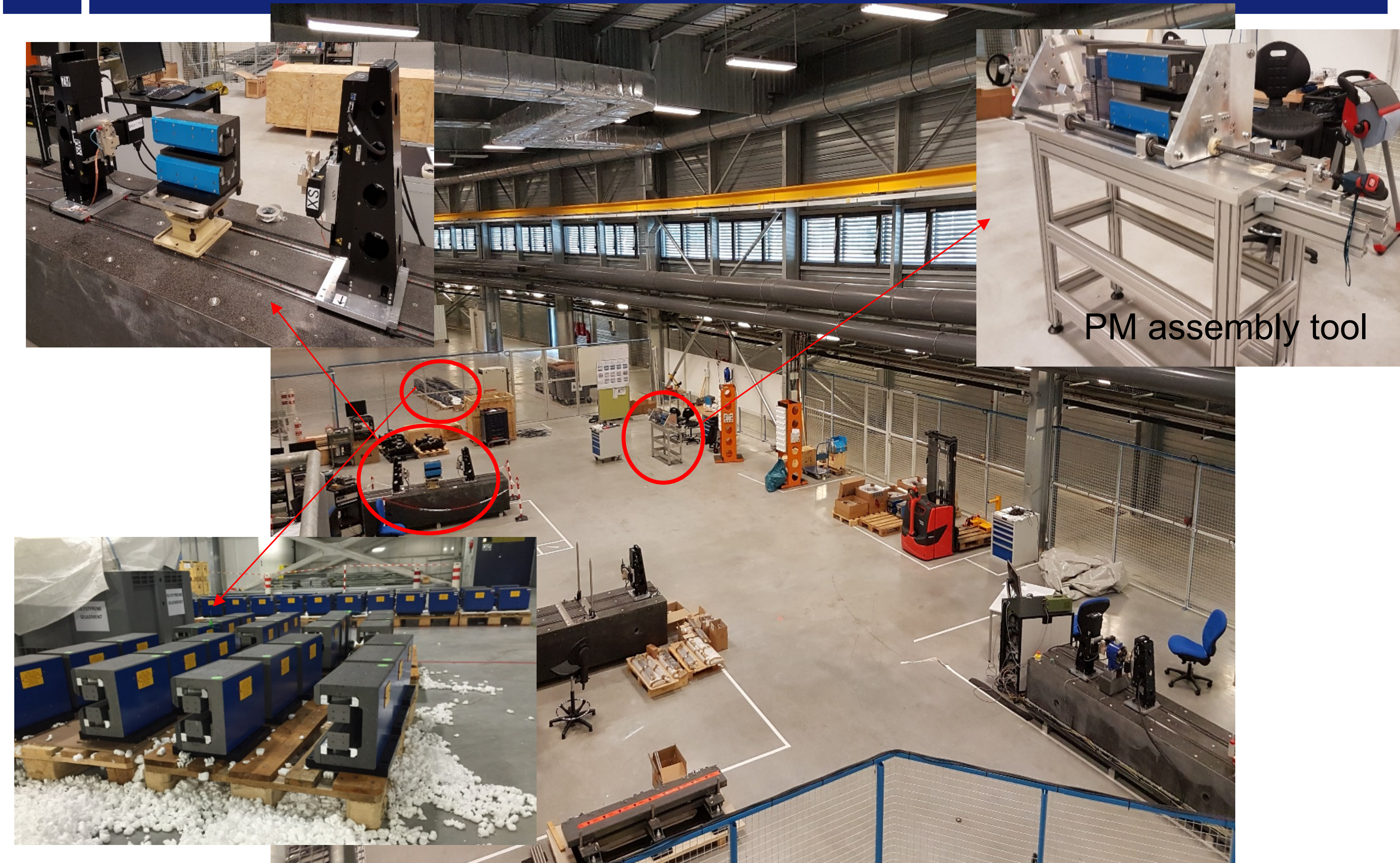
PM Dipoles are being assembled by ESRF staff
More than 650 Magnets Modules for a total of about 130 5-Module dipoles





Courtesy of ASD-IDM & ISDD-MEG

IMPLEMENTATION IN CHARTREUSE HALL



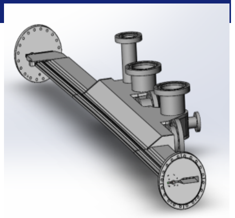
Dipole assembly area

Module's Yokes

All contracts in place, chambers in fabrication
FAT for aluminium chambers in November
All FAT should be completed by December
More than 450 Vacuum Chambers to be procured by the end of 2018

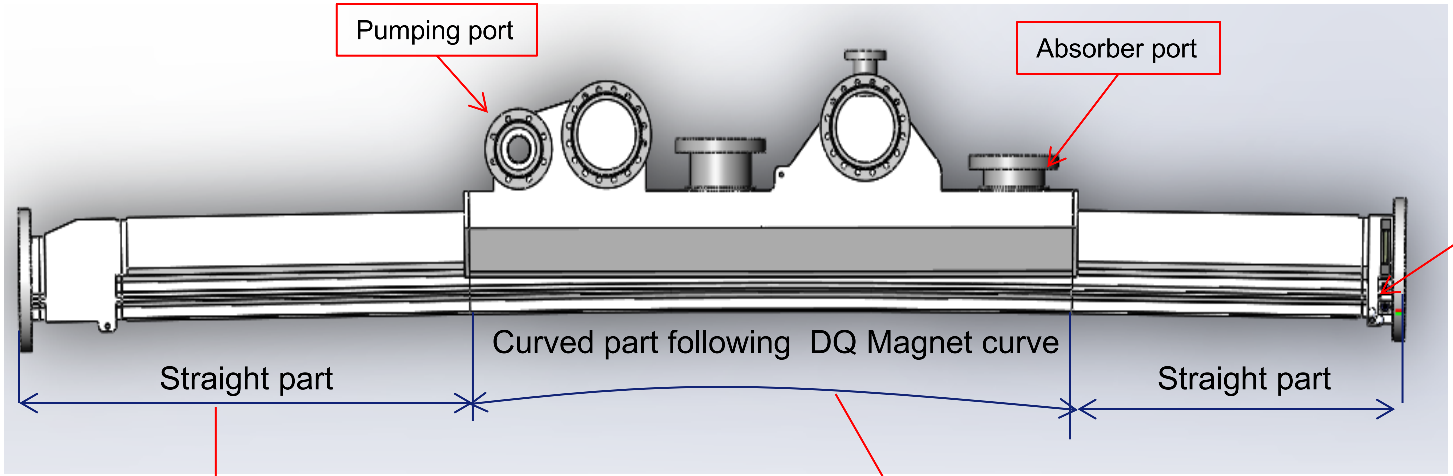
Courtesy of ASD-FE, ISDD-MEG & TID-VG

FAMILY 3: LOW PROFILE STAINLESS STEEL CHAMBERS

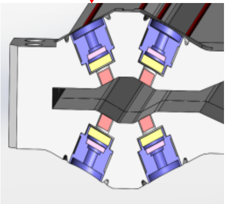


Material : 316 LN

Curved Chambers

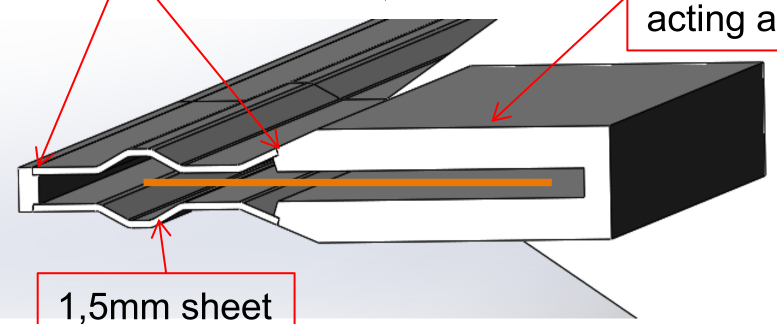


BPM Block



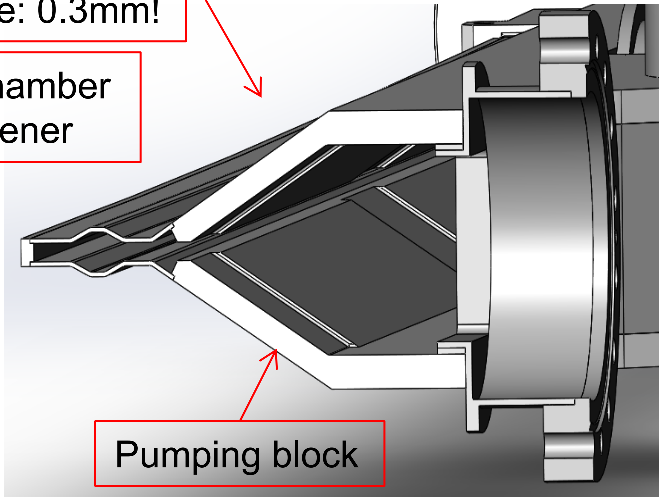
Requested shape tolerance: 0.3mm!

EB Welding

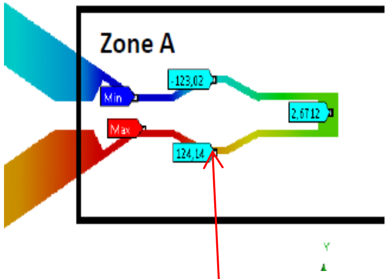


Thick ante-chamber acting as stiffener

1,5mm sheet



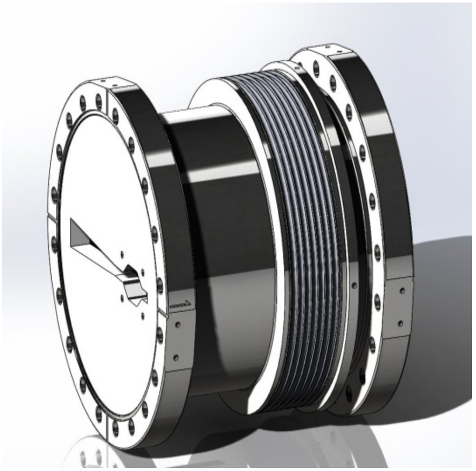
Pumping block



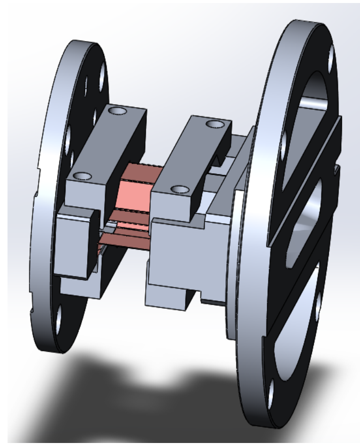
Deformation at the Beam area 0.125mm

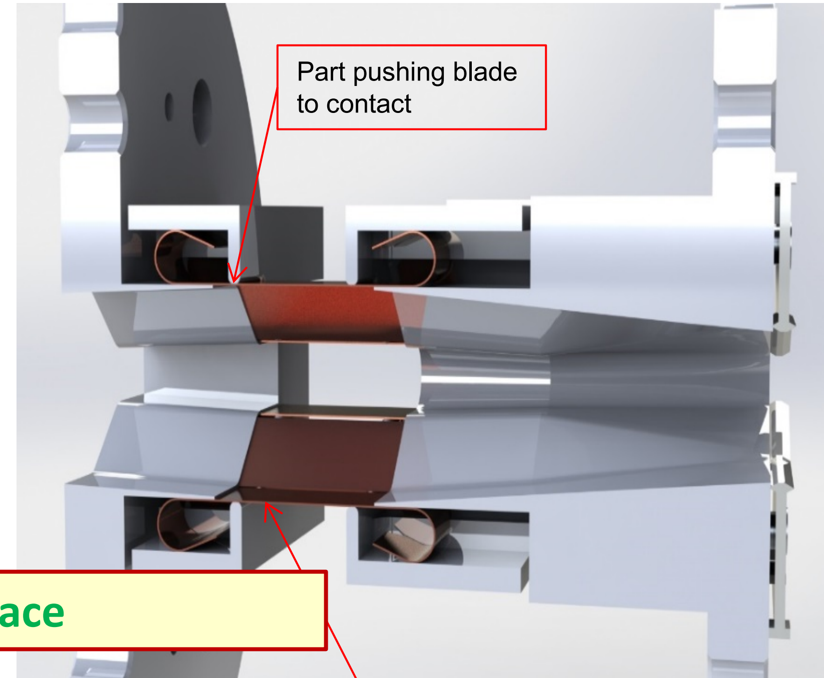
Joel Pasquaud

BELLOW RF FINGERS: ESRF DESIGN PATENTED



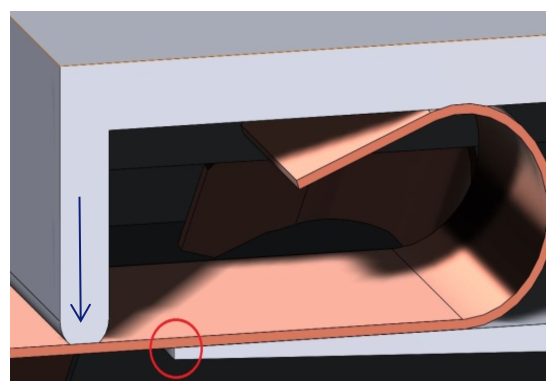
Bellow assembly





Contract in place

Blade contact



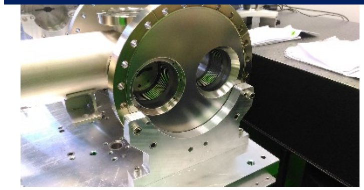
- Smooth transitions between profiles
- No change of the profile inside the RF fingers

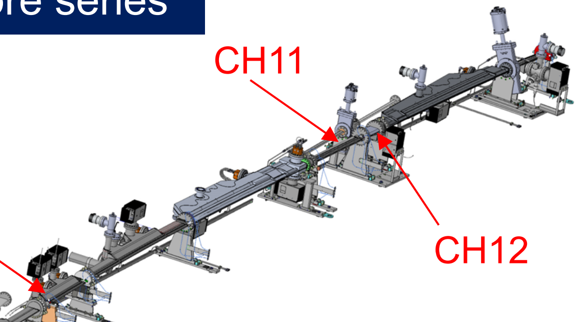
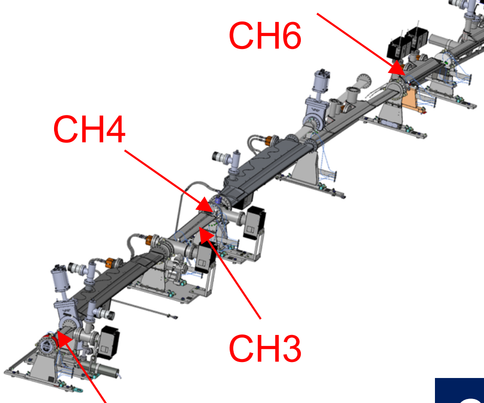
Courtesy of P Brumund,
L Eybert, L Goirand

PRODUCTION – VACUUM CHAMBERS (STAINLESS STEEL)

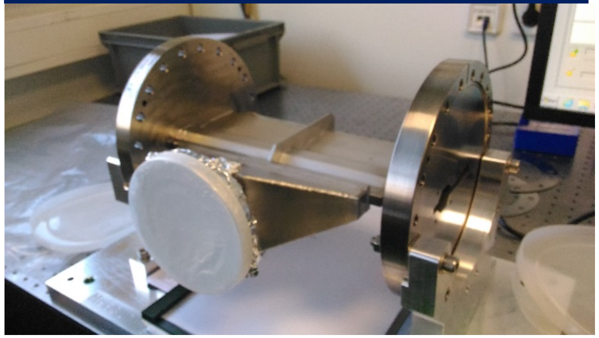
Stainless steel chambers: 2 contracts FMB (D)
CH14: 1 contract PINK (D)

CH4 high profile pre series



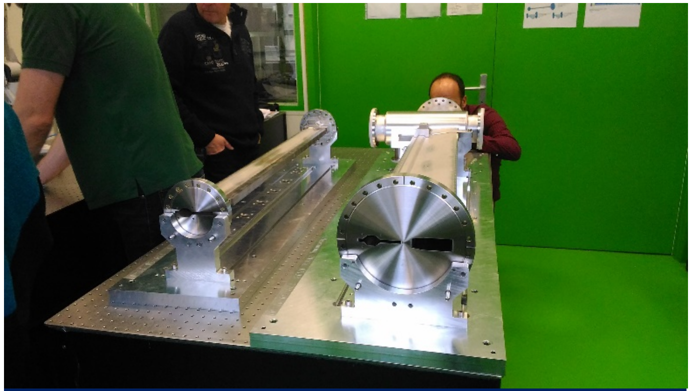
CH12 high profile pre series



CH1 high profile pre series

Pre-series still in progress

CH7 low profile pre series in progress

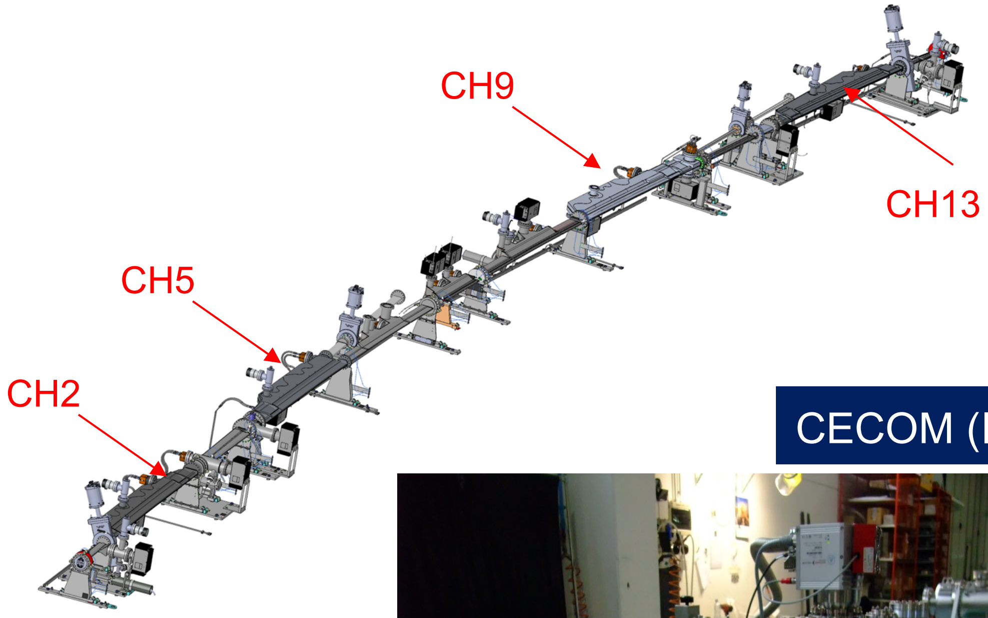


CH3 & 11 high profile pre series

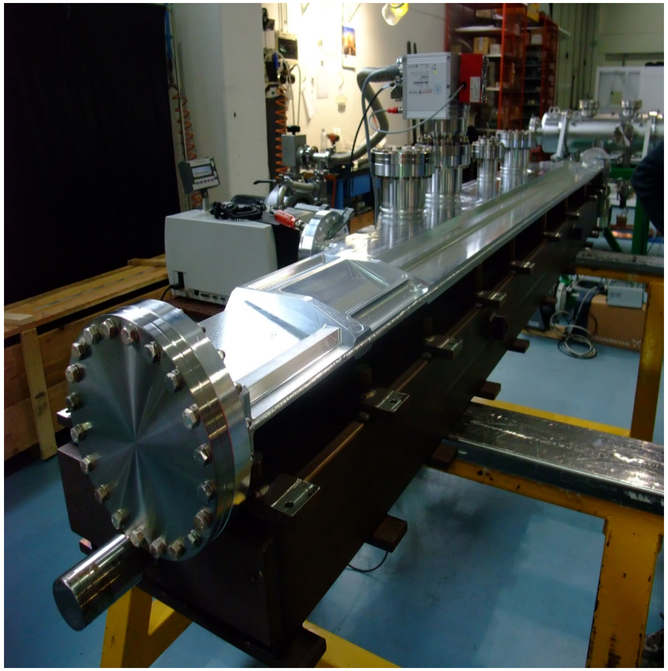
Courtesy of P Van Vaerenbergh, J Pasquaud, L Goirand

PRODUCTION – VACUUM CHAMBERS & OTHERS

Aluminium Vacuum chambers pre-series: still in progress



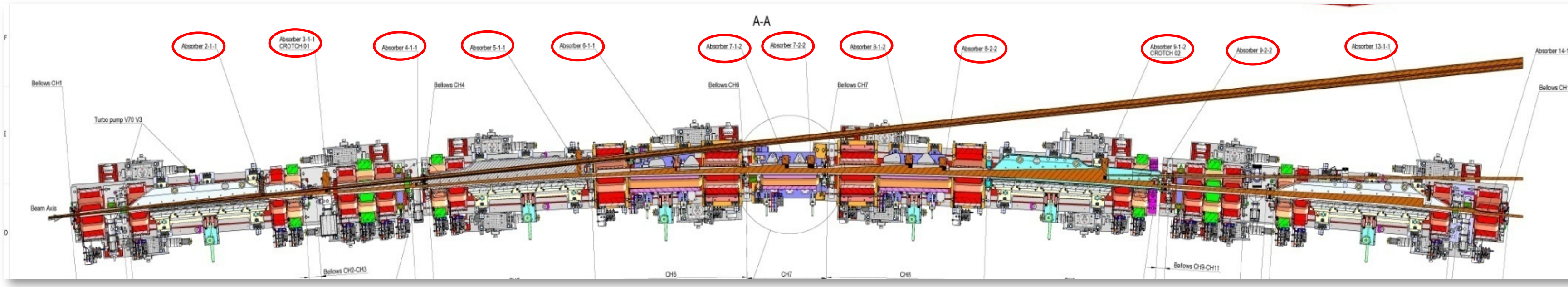
CECOM (IT)



January 2017
Factory acceptance for;

- Photon absorbers

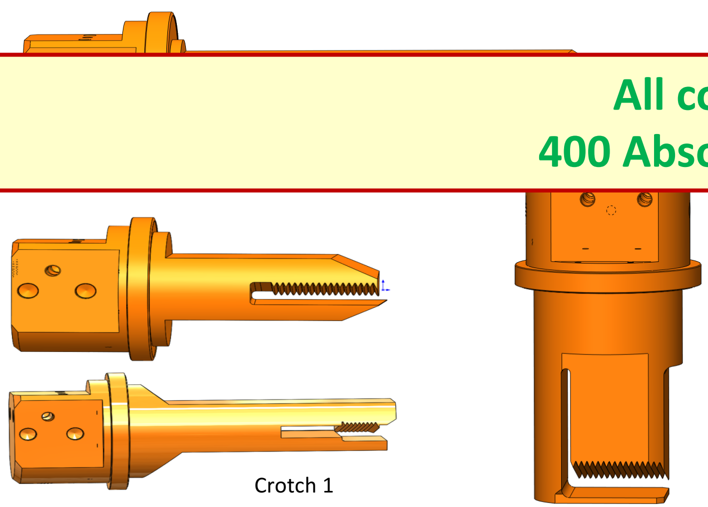
ESRF EBS (2015-2022): ABSORBERS PROCUREMENT

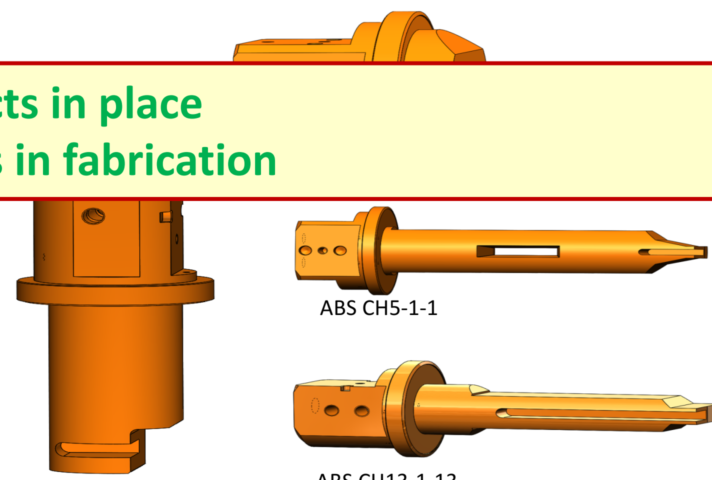


Family Teeth (up to 110 W/mm^2)

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

All contracts in place
400 Absorbers in fabrication



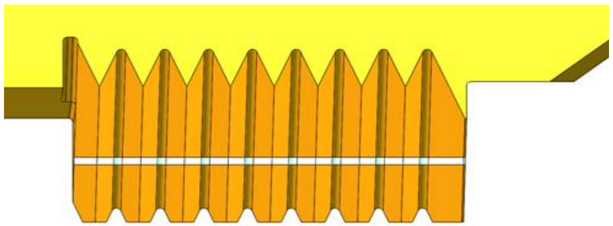


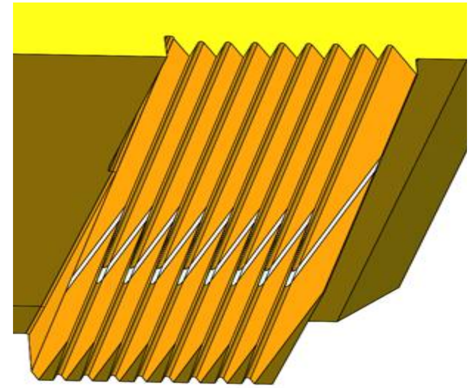
No weld, no braze

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

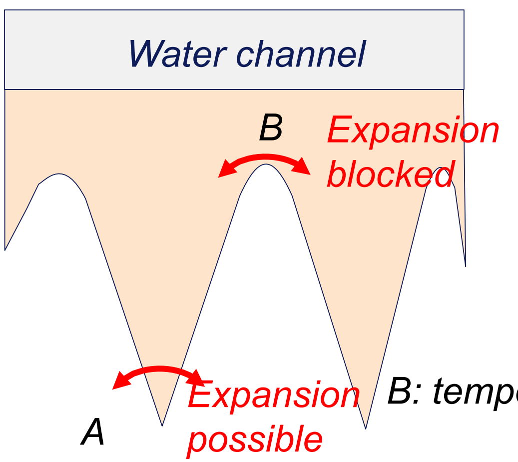
ABSORBERS WITH TEETH OPTIMIZED TO REDUCE THERMAL STRESSES

Teeth distribute the heat over a larger area



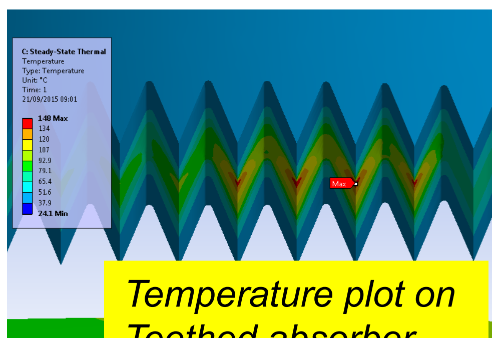


Teeth geometry optimized to reduce thermal stresses

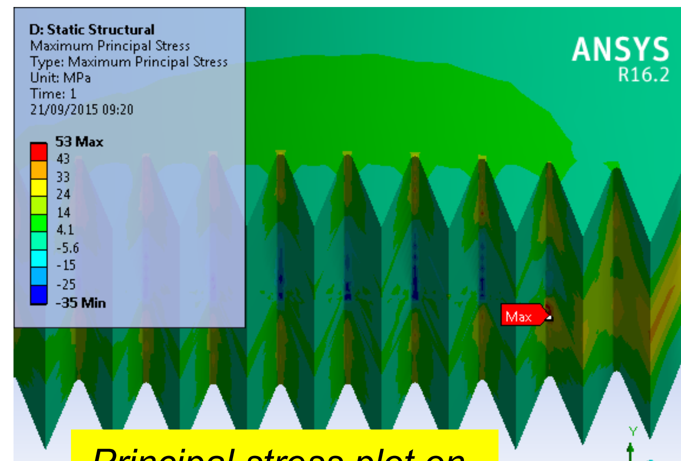


B: temperature is min Stress is max

A: temperature is max Stress is min



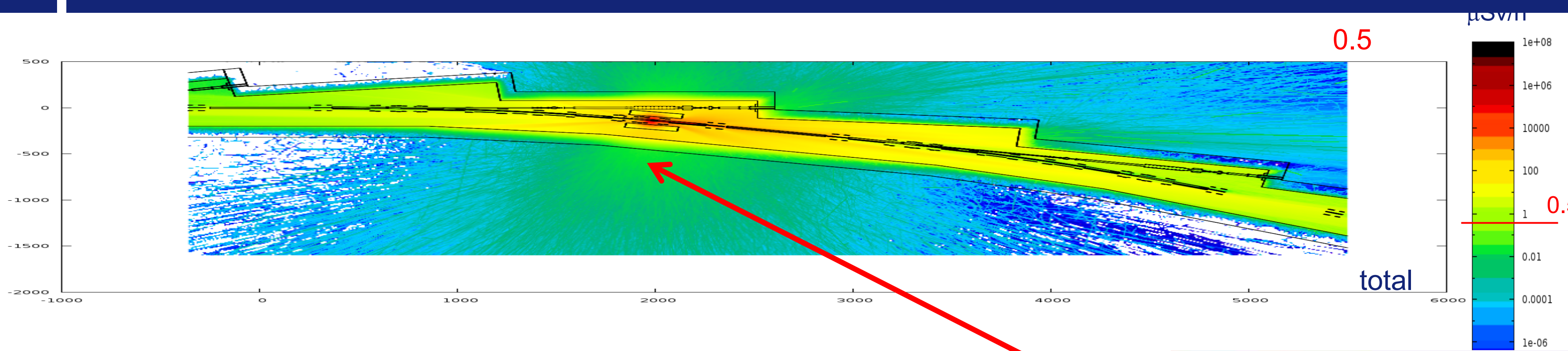
Temperature plot on Teethed absorber

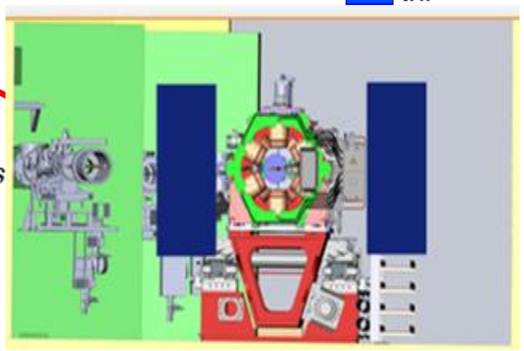


Principal stress plot on Teethed absorber

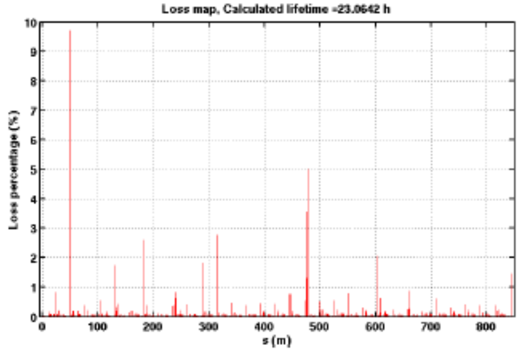
D. Coulon, Y. Dabin, Th. Ducoing, E. Gagliardini, Ph. Marion, F. Thomas

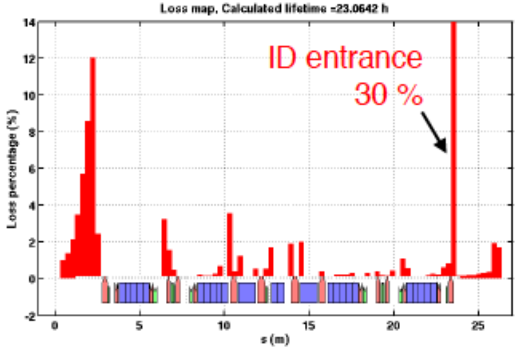
Stress criteria < Yield strength



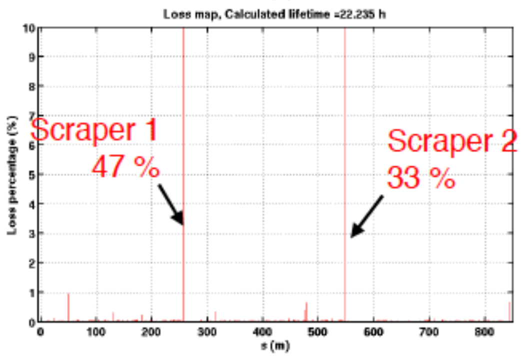


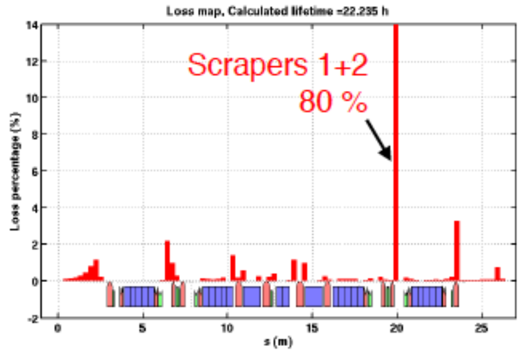
80% of the losses are relocated on the scrapers for 4% lifetime reduction:





No scrapers

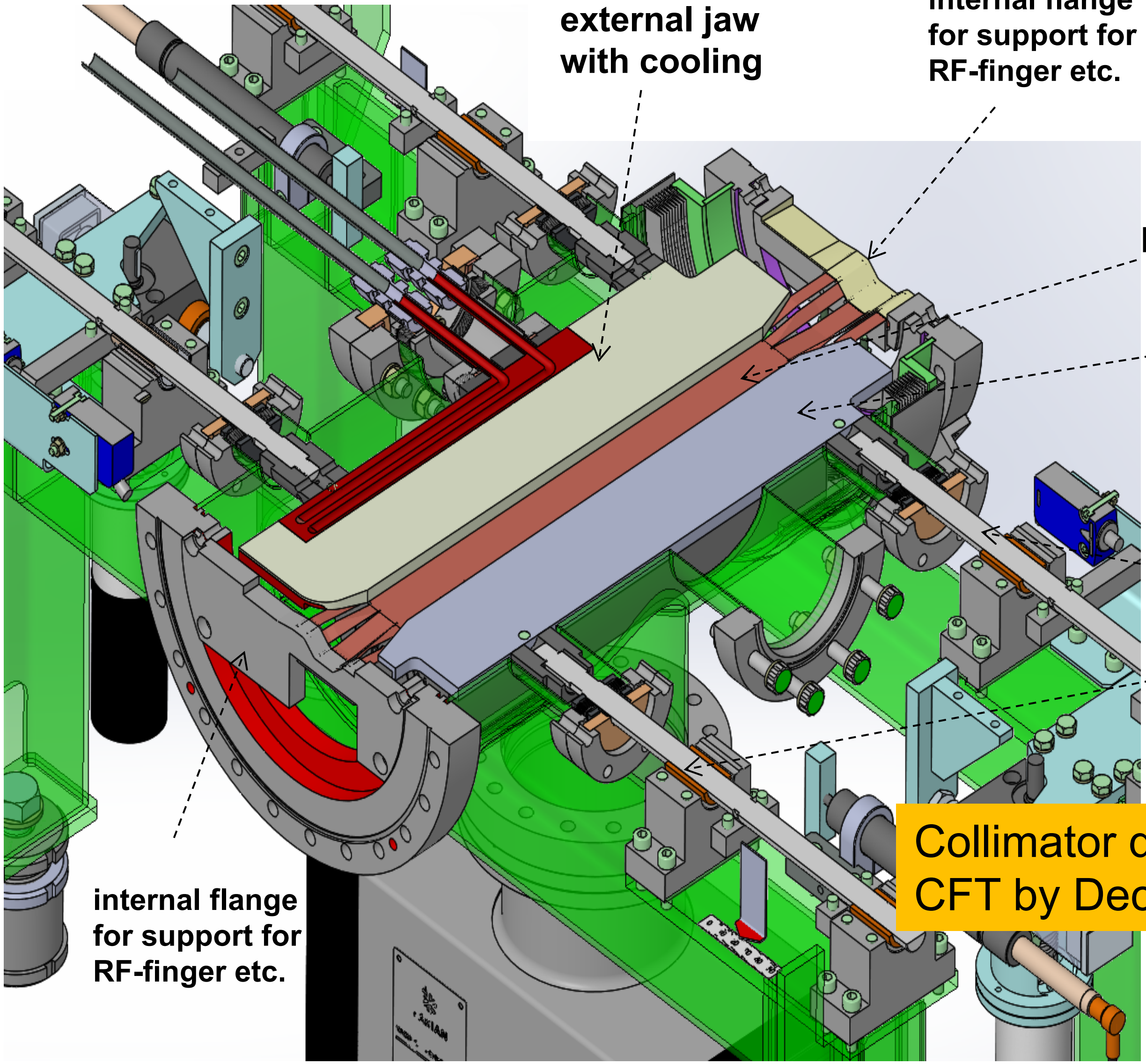




Two scrapers in DR_37 of cells 13 and 24

cm

COLLIMATOR FOR CH.#12 IN CELLS 13 AND 24



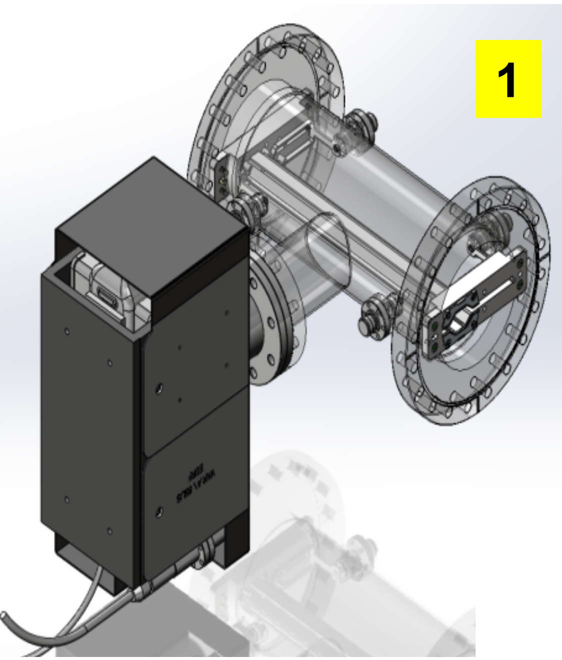
Collimator design nearly completed
CFT by Dec 2016

CURRENT TRANSFORMER & STRIPLINES

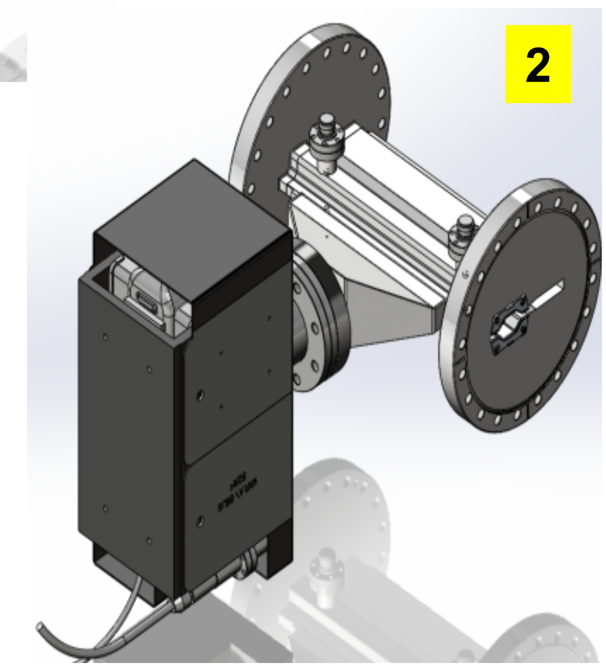
all in Ch.#12

1. H stripline
2. V stripline
3. Current transformer

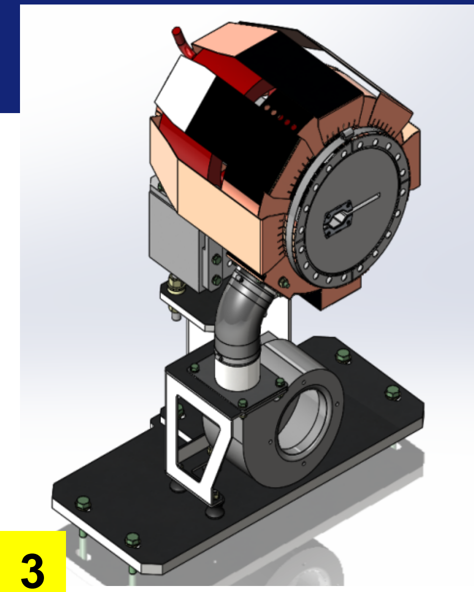
all detailed designs ready
CFTs by December 2016

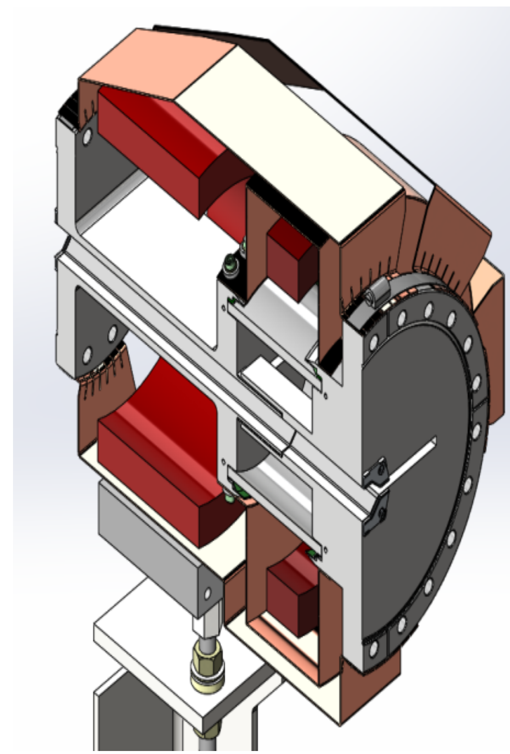


1



2

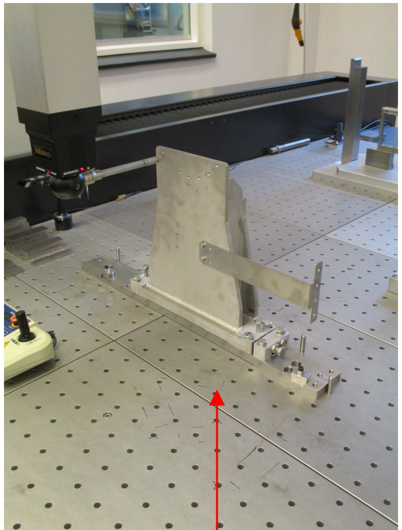




3

ESRF

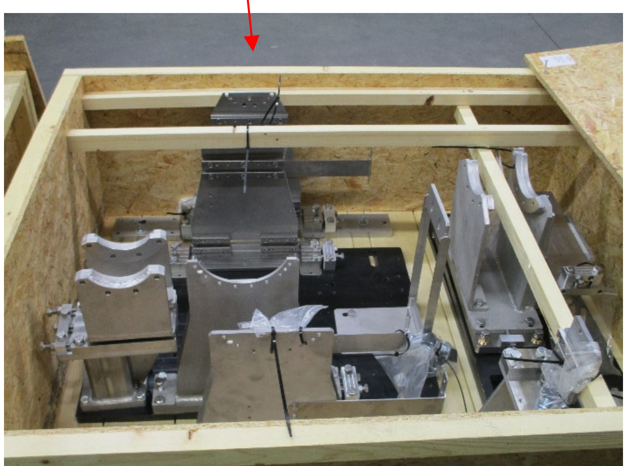
PRODUCTION - SUPPORTS



All supports in Production phase

Dipole supports KINKELE (D)

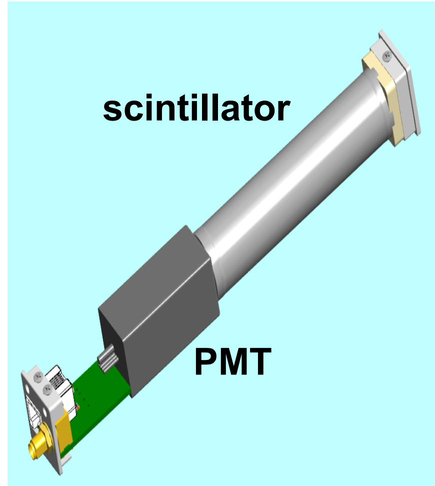
Vacuum Chambers supports KURSTERS & BOSCH (NL)



Magnets supports CASTELLINI (IT)

Courtesy of L EYBERT

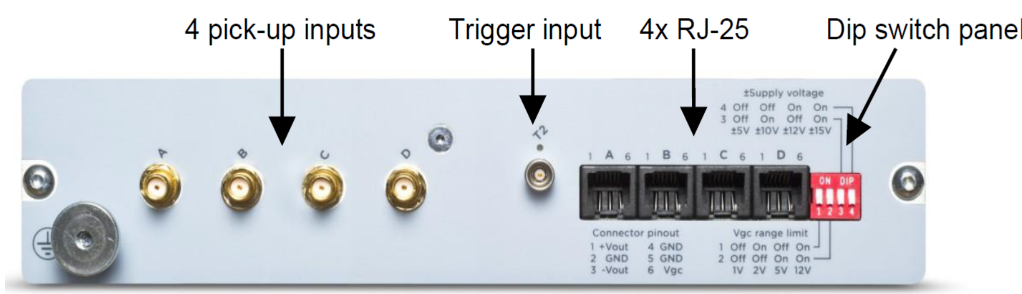
BEAM LOSS MONITORS : COMPACT, CHEAP, PERFORMING



connectors
sma & RJ-25

compact BLD is an in-house design
extensively tested & optimized
for ESRF usage
160 units in procurement
costs: <550 € per unit

BLM is the full control & signal acquisition
for 4 BLDs → 40 units in procurement



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														
Sextu														
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

Contracts in place by December 2016

	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**

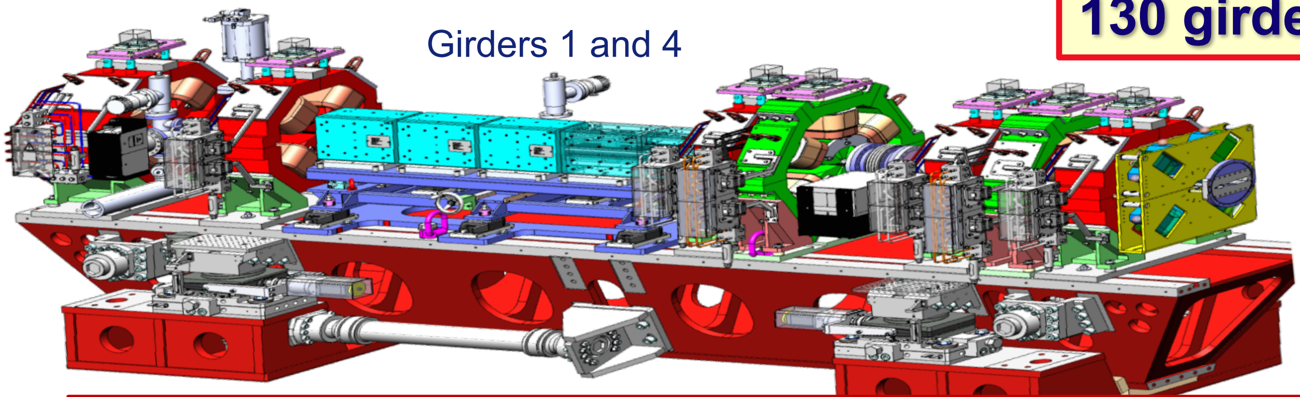
About 1000 DC-DC low voltage converters: the average channel power is around 1kW and a maximum of 2.3kW.

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

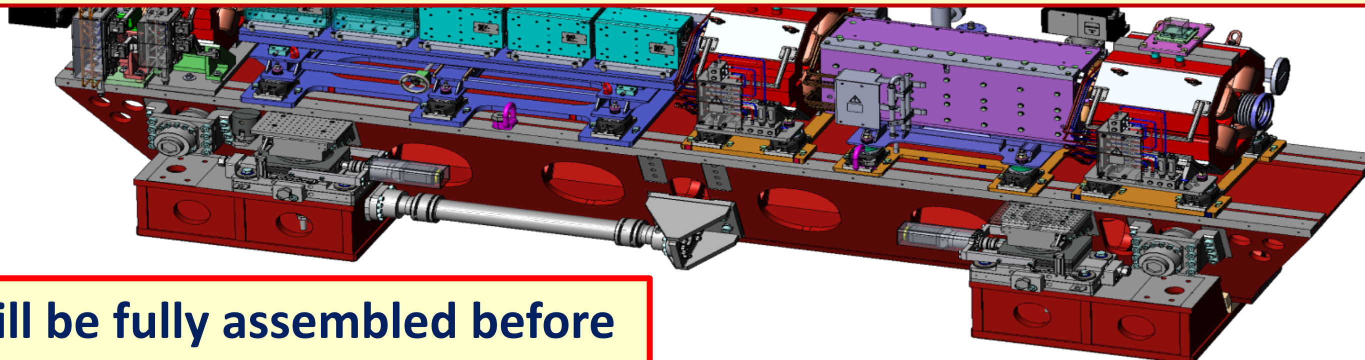
The integration in 32 cabinets will be designed with the Computer Services for redundancy and HOT-Swappability

ESRF EBS (2015-2022): GIRDERS PROCUREMENT

130 girders,10-12t each



All contracts in place, girders in fabrication (first one arrived last week)
130 girders



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

PRODUCTION - GIRDERS

NORTEMECANICA (SP) 65

← Pre-series girders delivered

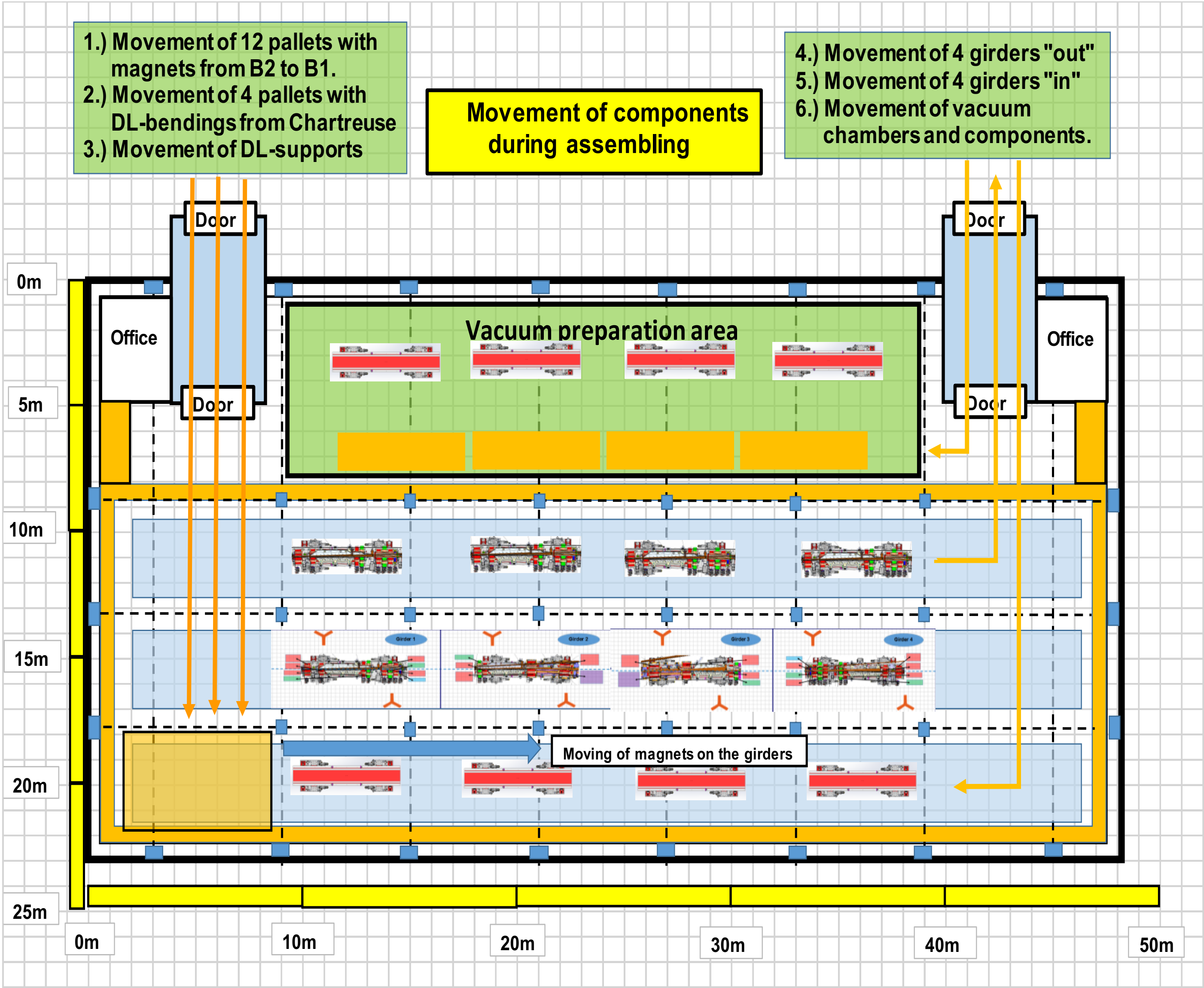
Series girder, 2 contracts

production 8 every 5 weeks (total 129+1 spare)

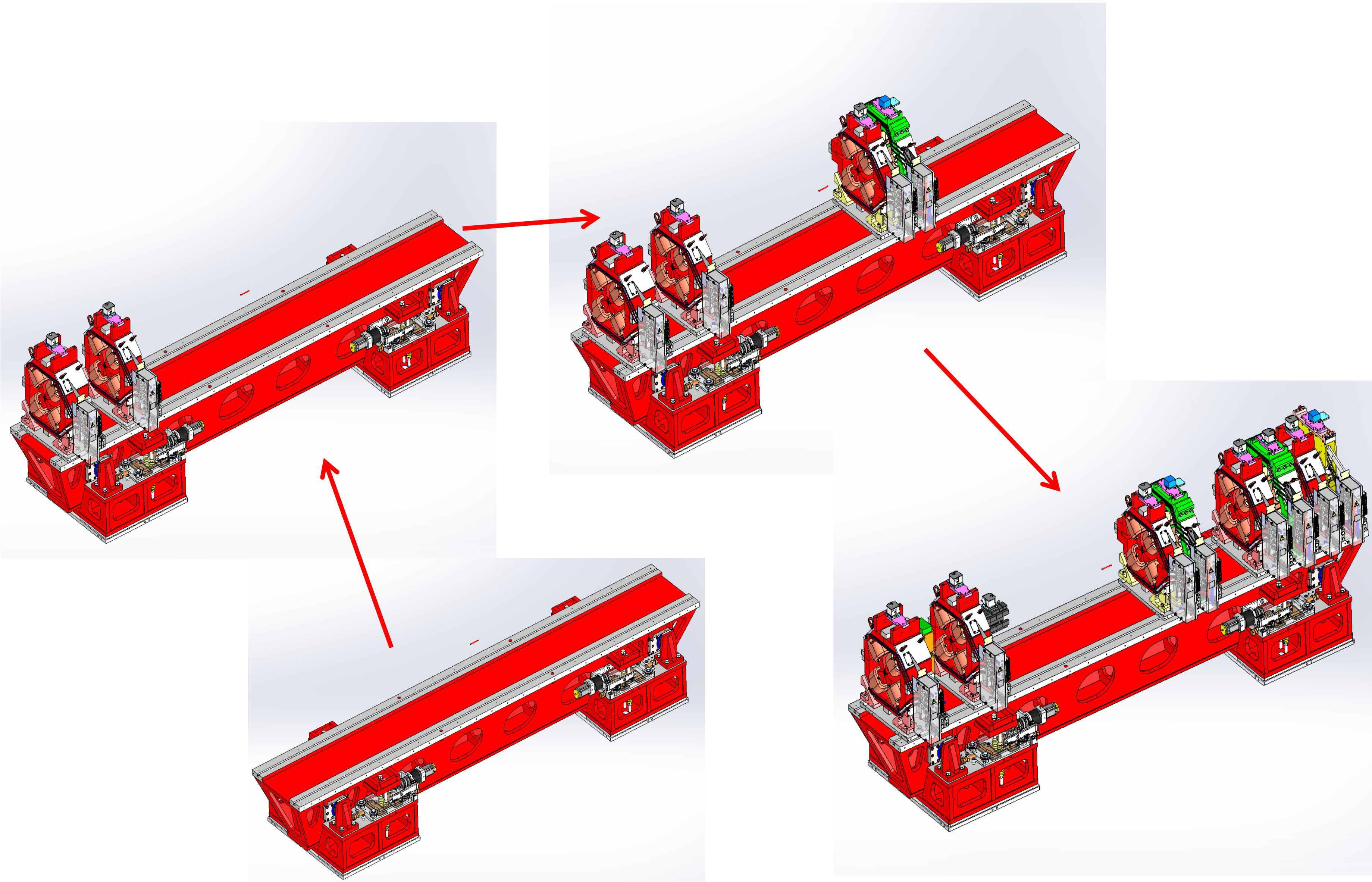
AVS (SP) 65

Courtesy of T Brochard, F Cianciosi

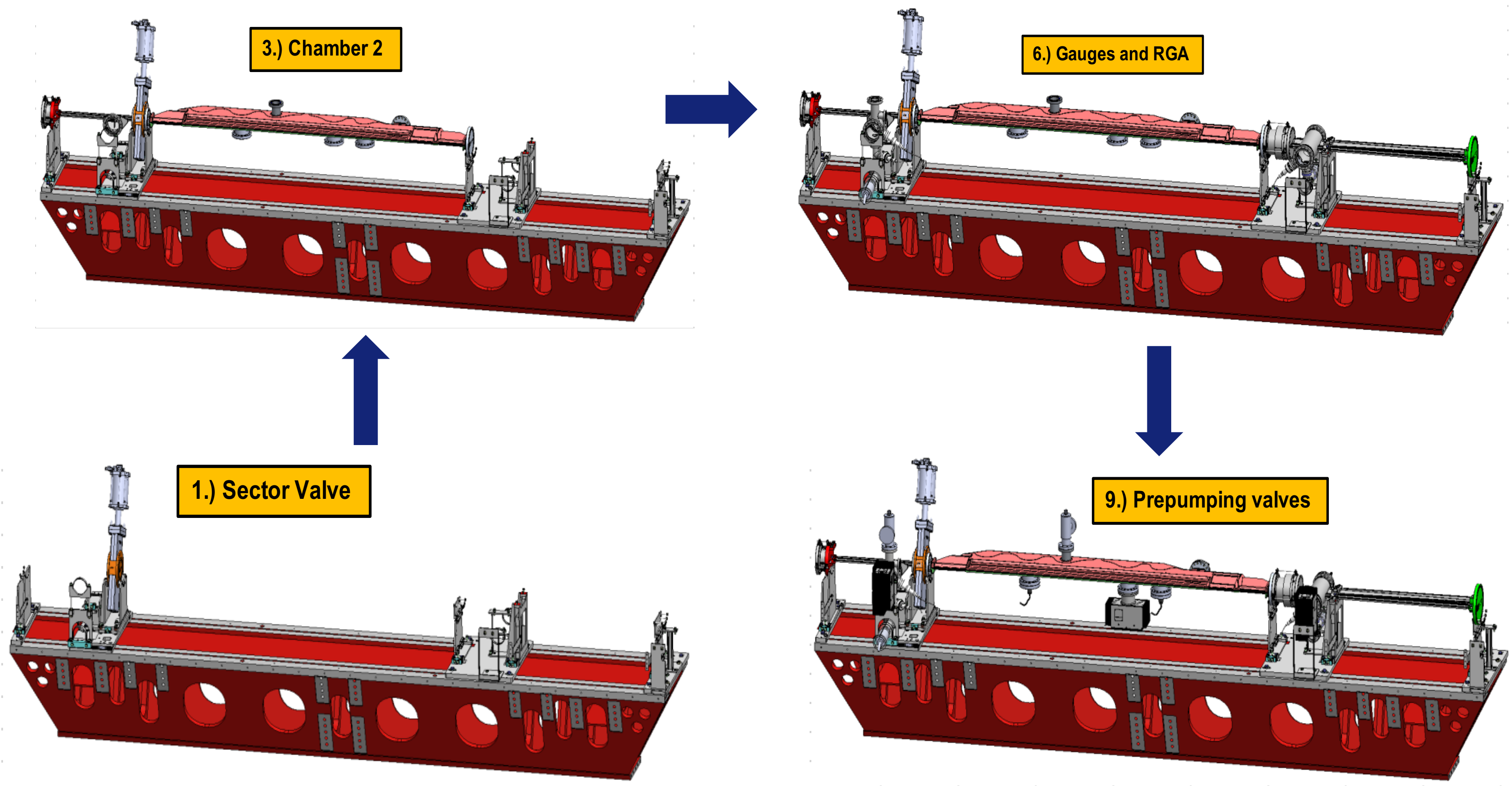
GIRDERS ASSEMBLY



SEQUENCE OF MAGNET INSTALLATION

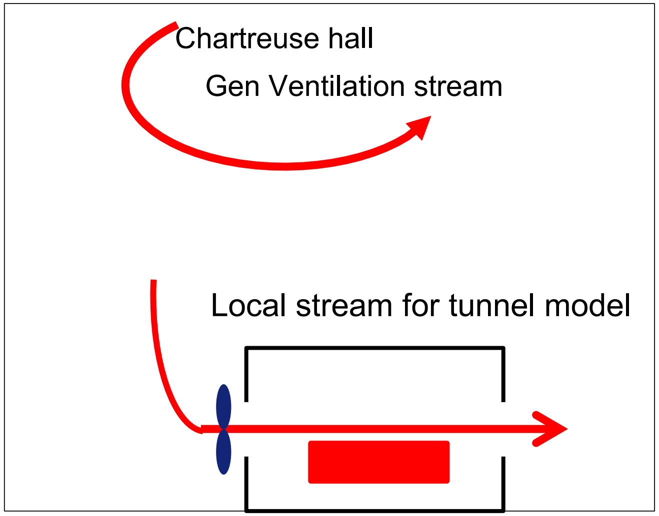


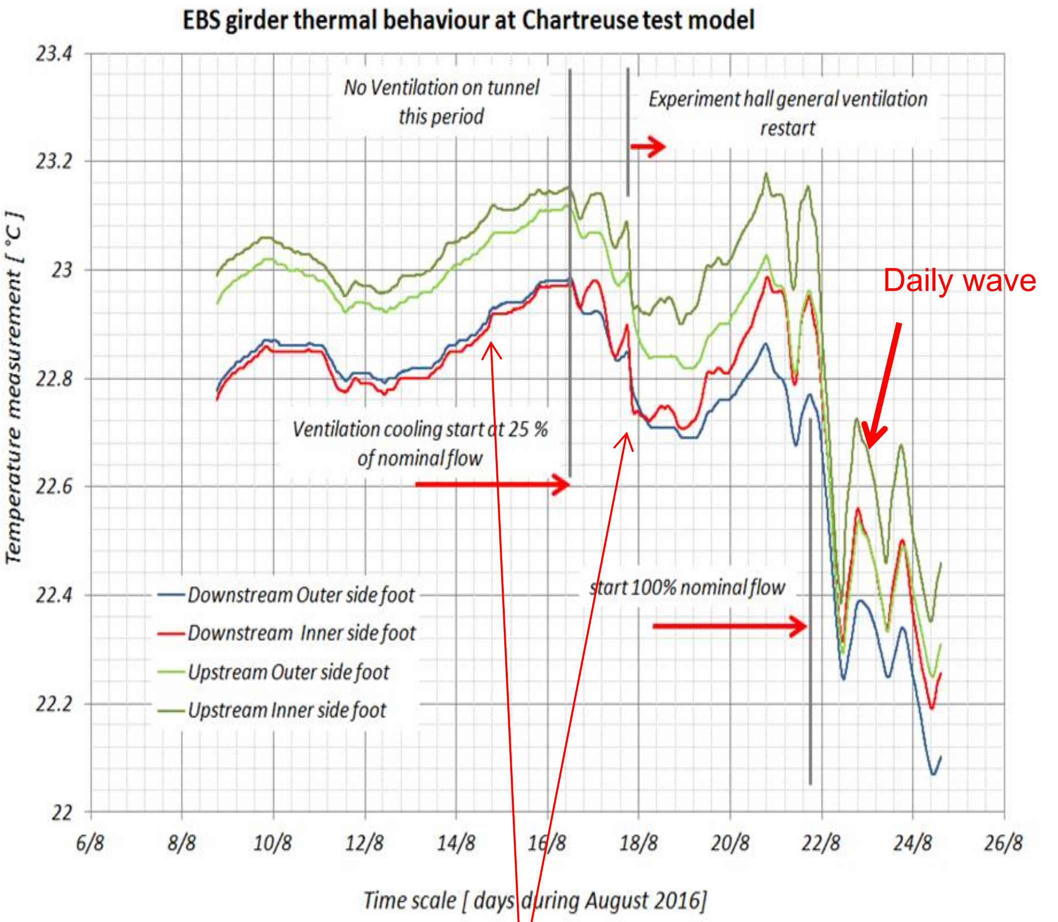
SEQUENCE OF VACUUM ASSEMBLY



CHARTREUSE TEST MODEL

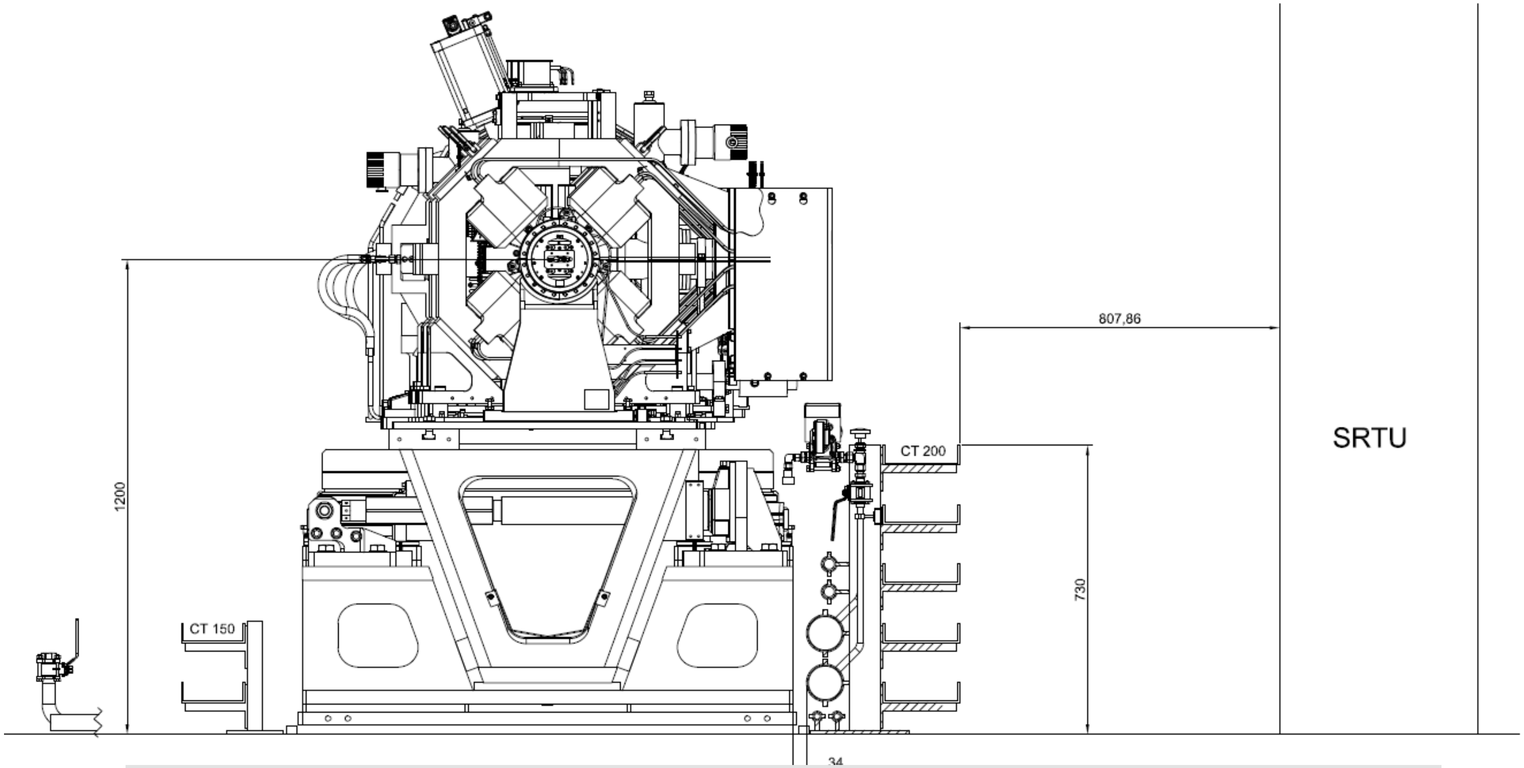
The girder thermal behaviour is recorded
In permanent and transient modes





Some probes behave oppositely when ventilation is activated

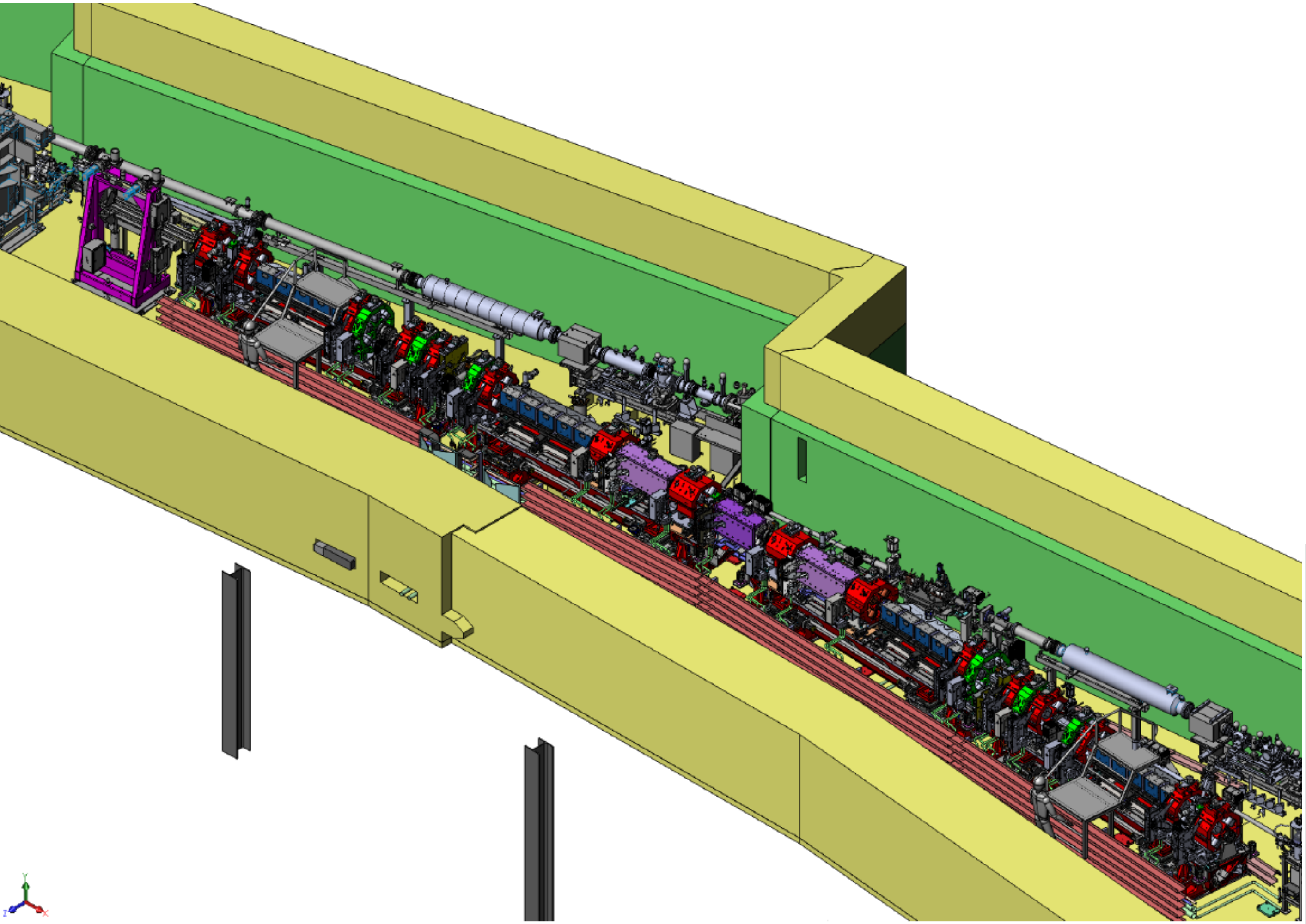
CABLING AND PIPING IN THE SRTU – CROSS SECTION



Fluids' and cabling distribution: next optimization

- ✓ Optimization of the diameter for the SRE network (D80 to D50) to be confirmed
- ✓ Position of cabling according to services
- ✓ Cable trays Number of level
- ✓ Protection of cable trays on the upper part (footboards)
- ✓ Finalization of footbridges
- ✓ Support of baking facilities
- ✓ Final optimization of the mechanical support for cabling and piping

OVERVIEW OF THE INFRASTRUCTURE IN THE TUNNEL (AS OF 22-09-2016)



“Standard cells”
Design in progress

“Specific cells”
C5 – C7 – C25 (RF)

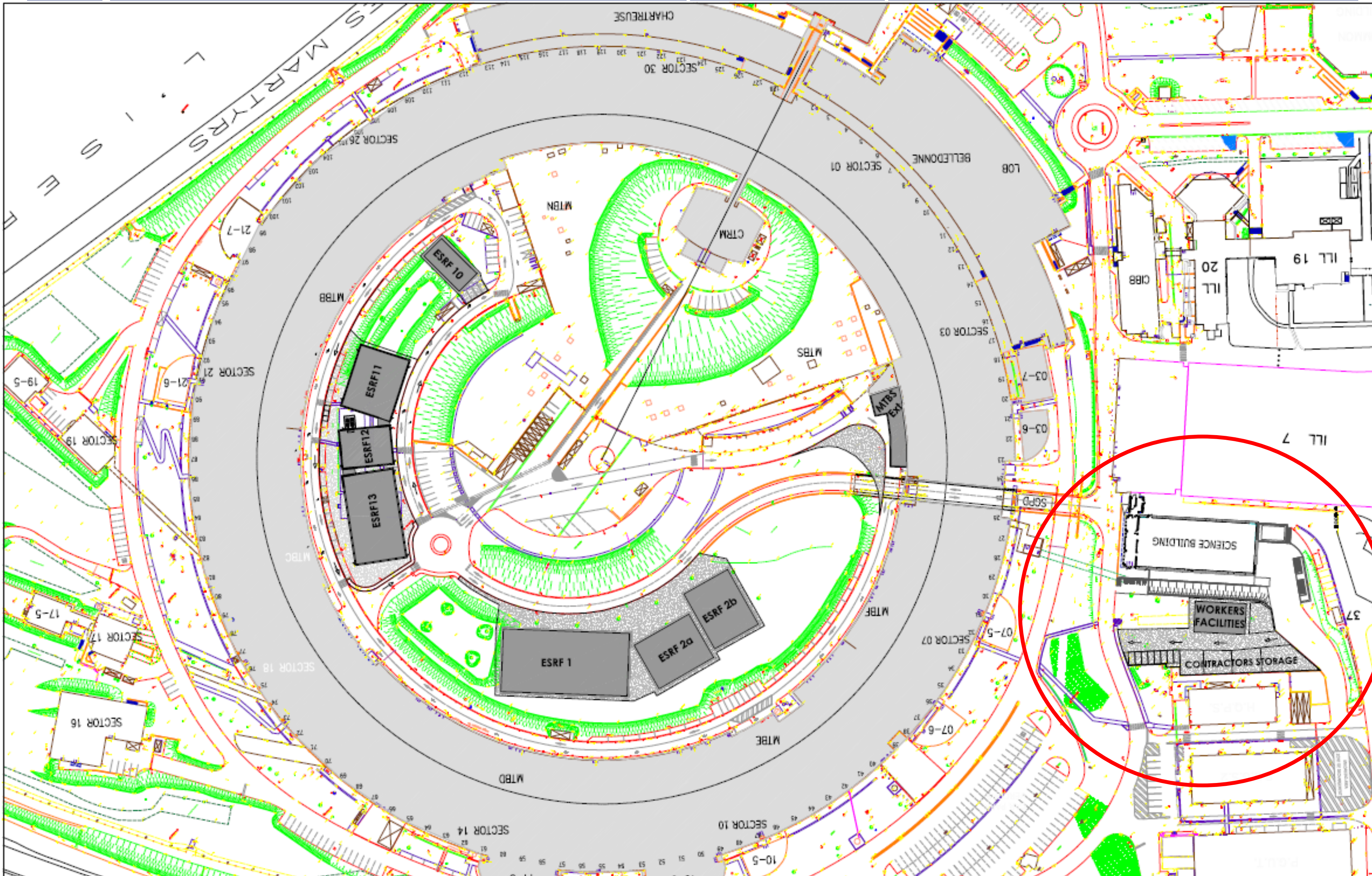
“Specific cells”
C13 - C24 (Collimator)

Injection zone TL2

3D layout in progress (MEG)
3D - Girders
3D - Front end
3 D - Straight section

And then drawings :
For the piping
For the cable trays

GENERAL OVERVIEW OF BUILDINGS (AS OF MAC4)



BUILDINGS FOR LOGISTICS : RESUME

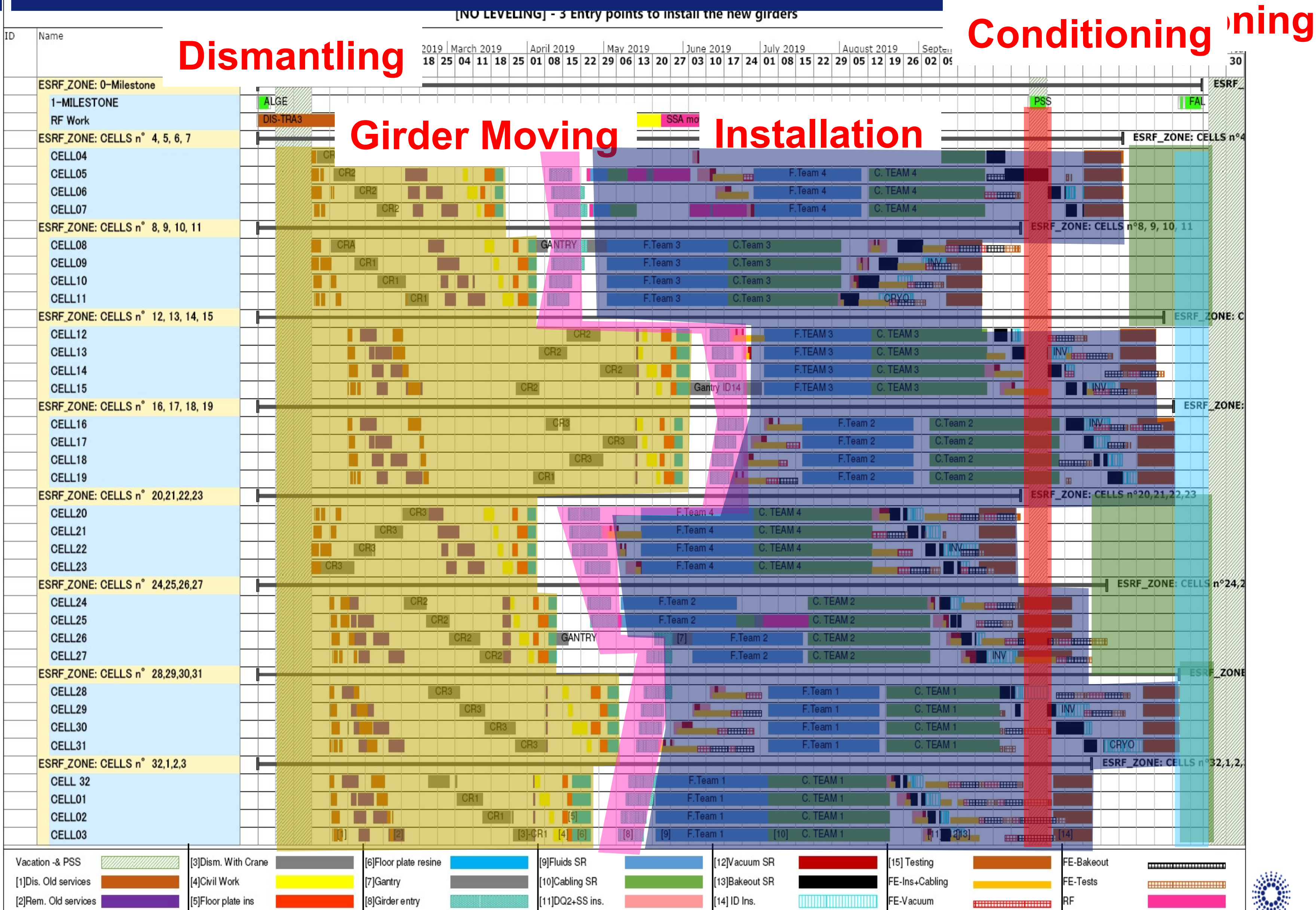
	Building	Surface (m²)	Duration	Main function
Creation of new buildings and services for storage, assembly and workers' areas	ESRF1	~1100	Permanent	Pre-assembly, then Radio protection measurements + storage pending ASN decision After this stage: building suitable for storage or workshops
	ESRF2 (A and B)	2 x 500 m²	Temporary	Storage of components
	ESRFx – Workers facilities	500	Temporary ~14 months rental during long shut down	Contractors' premises Surface for 50 people
Chartreuse hall is ready to be used	Chartreuse	1170	For the project	Pre-assembly of Dipoles Storage of girders after pre-assembly in B1
ID14 is available	ID14	440	For the project	Storage or test zone
ID08 is available and used by the RF group	ID8	300	For the project	Storage or test zone
These areas must be prepared just before the long SD	BM7 – BM24 – ID14	250	For the long shut down	Entrance point for transfer of girders from EXPH to the SRTU
Only in case of problems	B3 - Off site storage (if required)	500	Temporary	Off-site storage of components
Storage of old devices, before the shutdown	ESRF10	200	Temporary	Temporary storage of old devices (currently stored in the TZ)
Storage – radio activation measurements	ESRF11-12-13	1500	Temporary	Except for ESRF12
Storage - RF Test stand	MTBS extension	300	Permanent	New RF test stand + storage

ESRF01 – ESRF02 A/B – WORKS IN PROGRESS

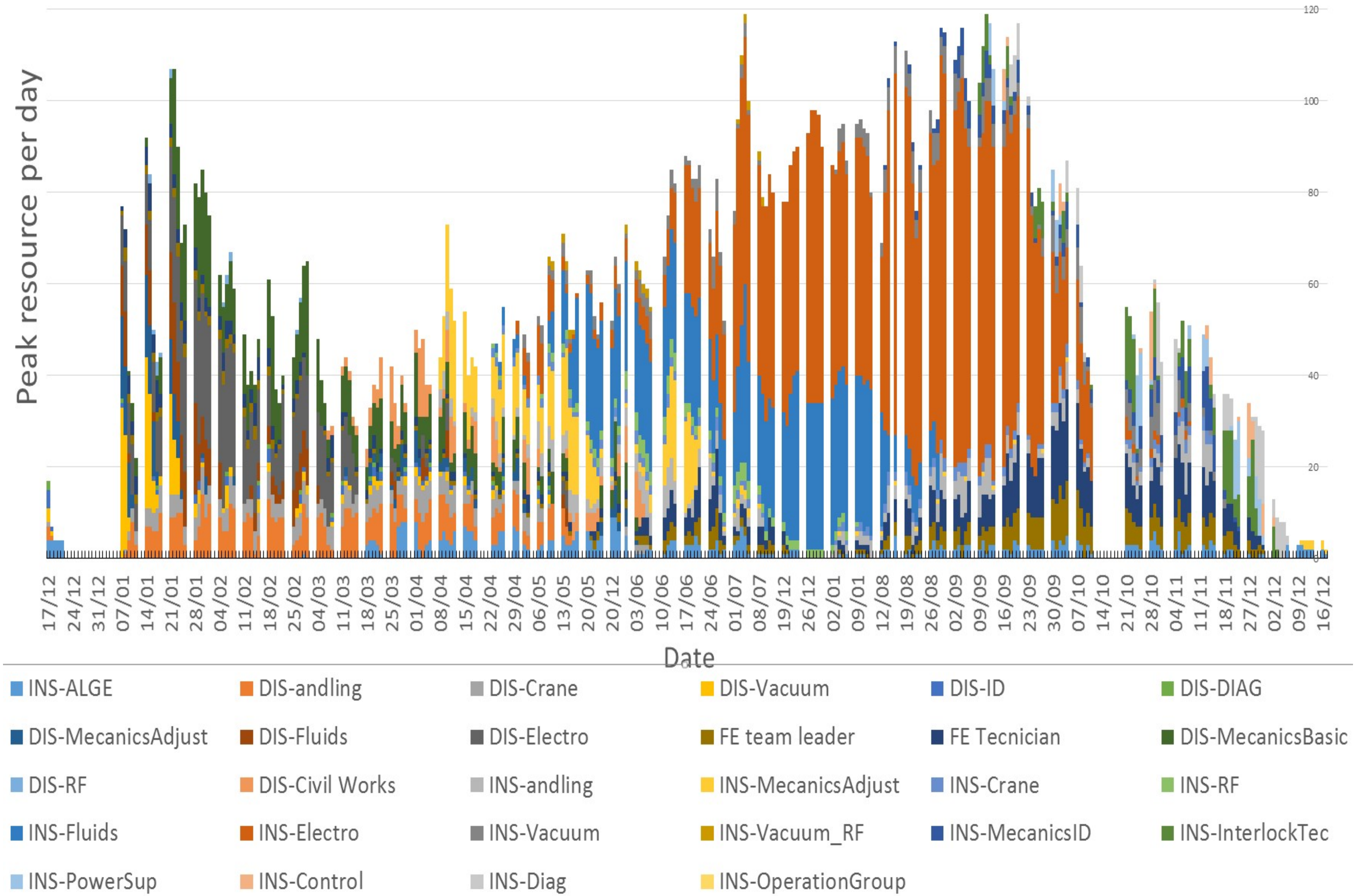
CIVIL WORKS IN PROGRESS

ESRF 1 & 2 - ASSEMBLY & STORAGE AREAS

DISMANTLING – INSTALLATION – PLANNING OVERVIEW



DISMANTLING + INSTALLATION HUMAN RESOURCES – ALL WORKS



PROGRESS IN THE PROCUREMENT (CONTRACTS)

		Contract signed & CFT in progress Sept. 2016 *In budget fraction*
WP0	Management	41%
WP1	Beam dynamics	
WP2	Magnets	99%
WP3	Engineering	91%
WP4	Power suplies	48%
WP5	Radio-frequency *(Big orders done in phase1)*	17%
WP6	Control	12%
WP7	Diagnostics	28%
WP8	Photon source	16%
WP9	Injector *(EBS budget part)*	65%
WP10	Vacuum	93%
WP11	Building & infrastrucure	18%
WP12	Reliability	0%
WP13	Safety	0%
	Sub total	***64.1%***

CONCLUSION

- Engineering Design virtually completed
- Procurement in full swing
- Delivery of all pre-series components almost completed (4 vacuum chambers still missing)
- Serial production for many components (magnets, vacuum components, supports, absorbers, girders etc…) proceeding well
- Many installation activities (cabling, buildings etc) are being anticipated
- Schedule now heavily linked to external manufacturers!
- Logistic activities proceeding very well

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

MANY THANKS FOR YOUR ATTENTION