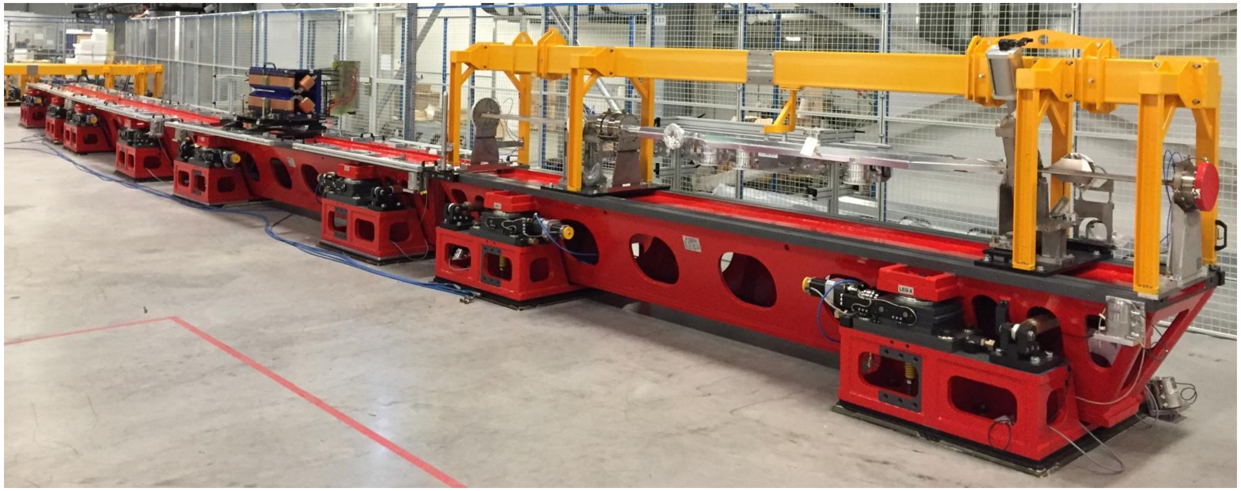
ESRF Operations and Machine Upgrade

BNL, April 26-28 2017

Pantaleo Raimondi

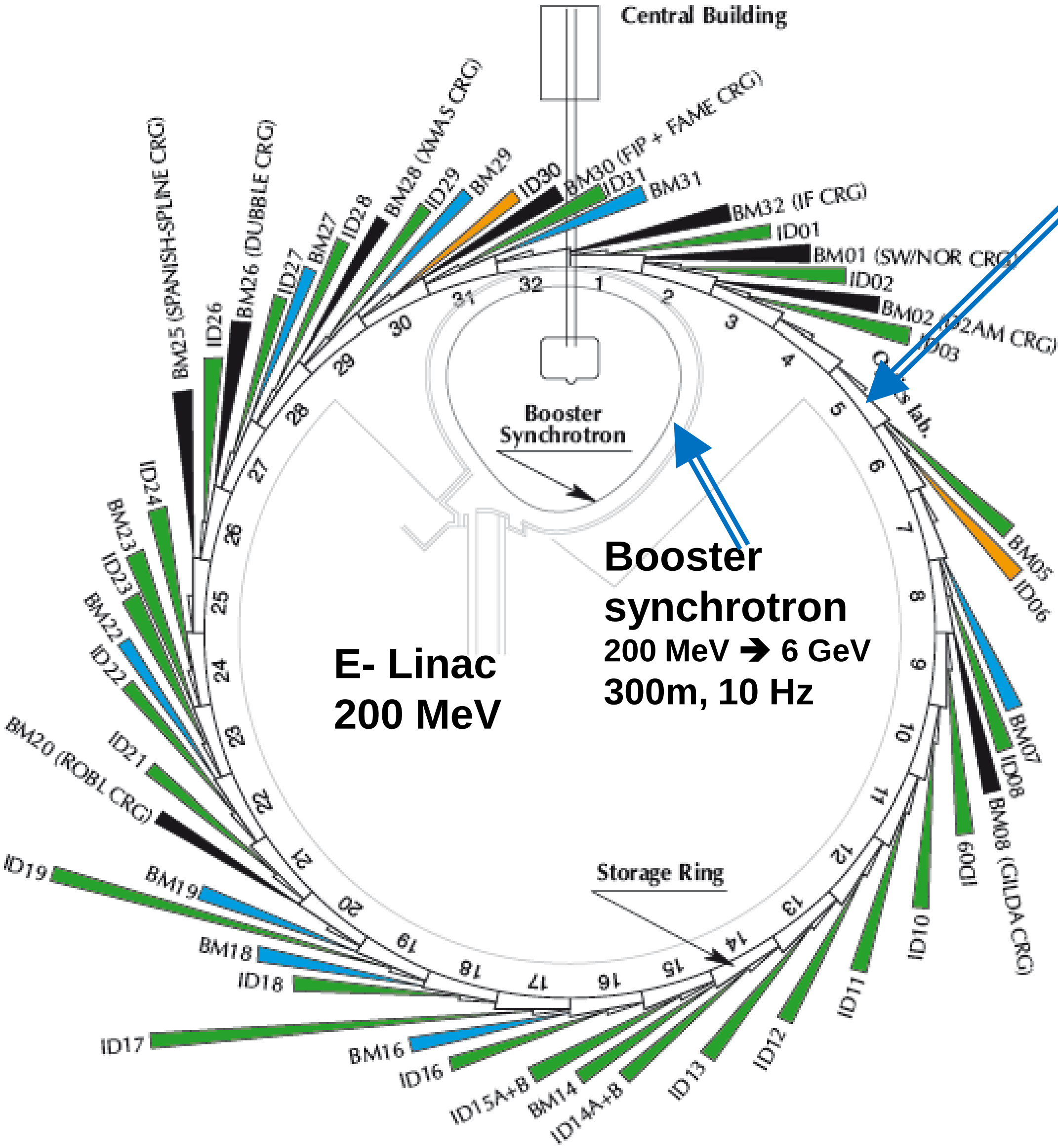
On behalf of the Accelerator Project Phase II Team



ESRF | The European Synchrotron

ESRF TODAY

Storage ring
6GeV, 844 m



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

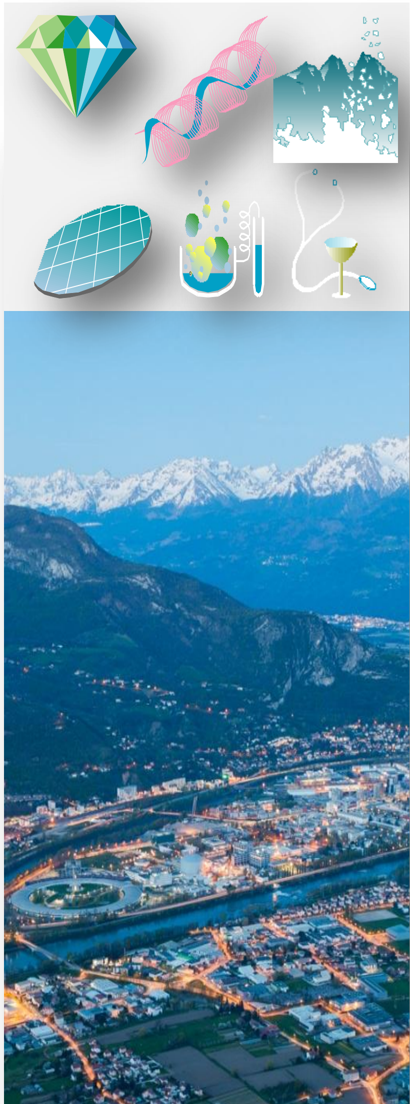
The Accelerator Upgrade Phase II aims to:

- 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



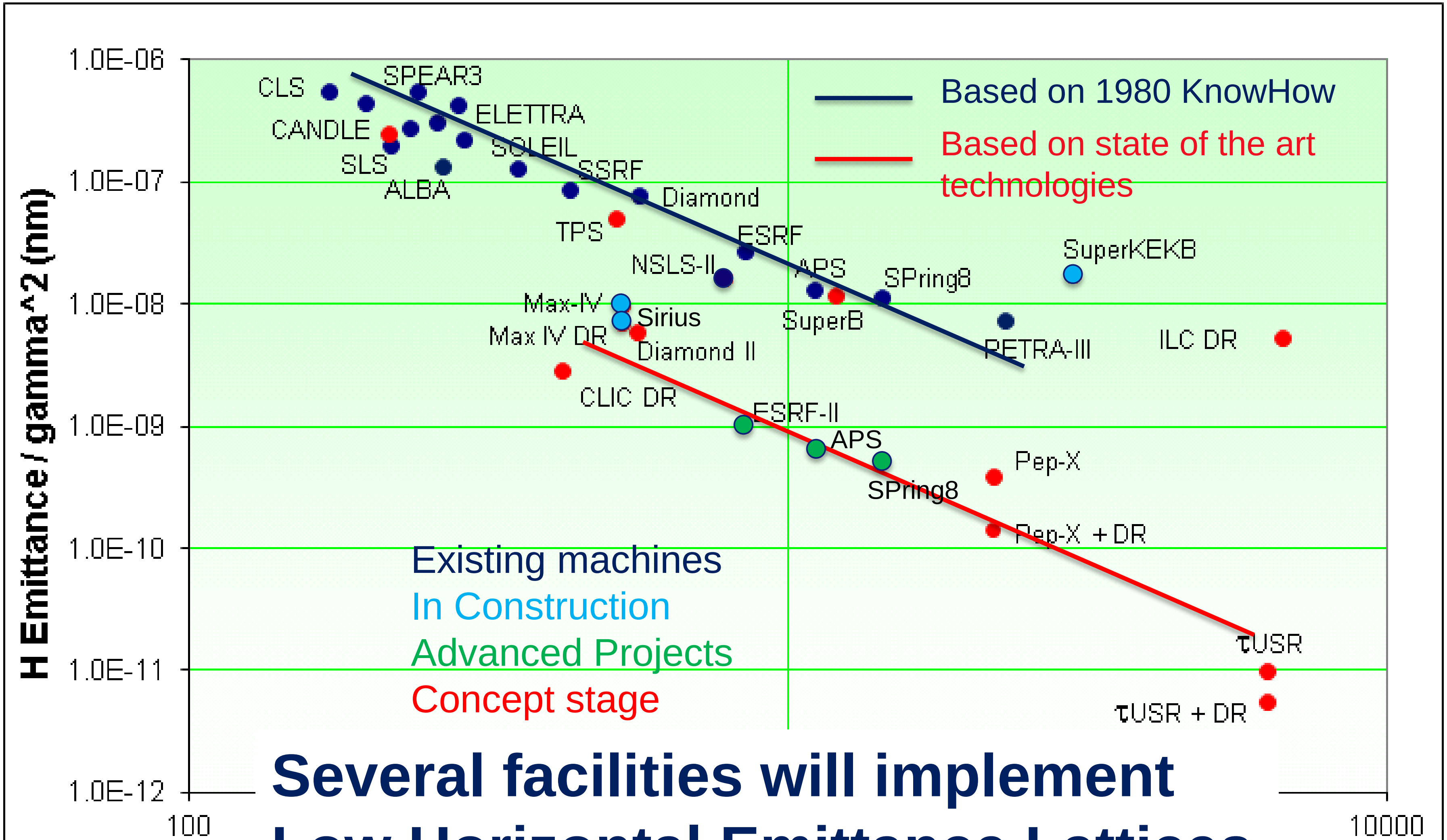
Machine Statistics for 2014-2017 at the ESRF

During 2016, ESRF has delivered 5485 hours of beamtime to its users, out of the 5537 planned

	2014	2015	2016	2017
Availability (%)	99.11	98.53	99.06	**97.93**
Mean Time Between Failures (hrs)	105.5	93.6	93.8	**60.50**
Mean duration of a failure (hrs)	0.94	1.37	0.88	**0.87**

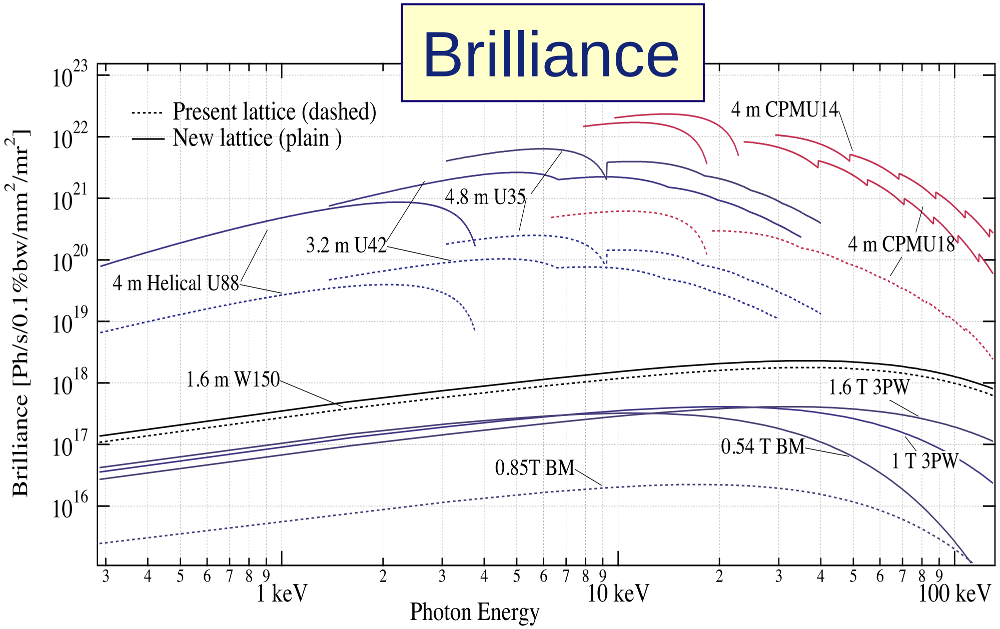
(Until March 2017)

LOW EMITTANCE RINGS TREND



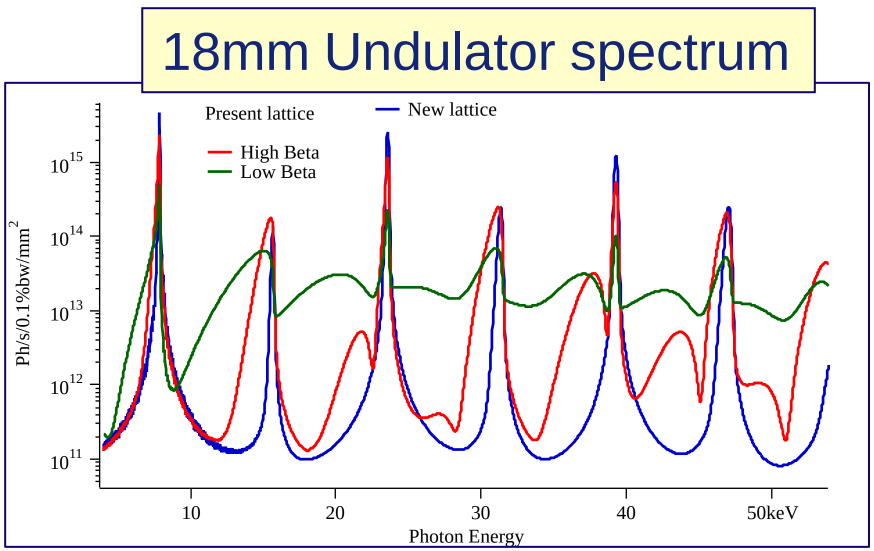
Several facilities will implement Low Horizontal Emittance Lattices by the next decade

BRILLIANCE AND COHERENCE INCREASE

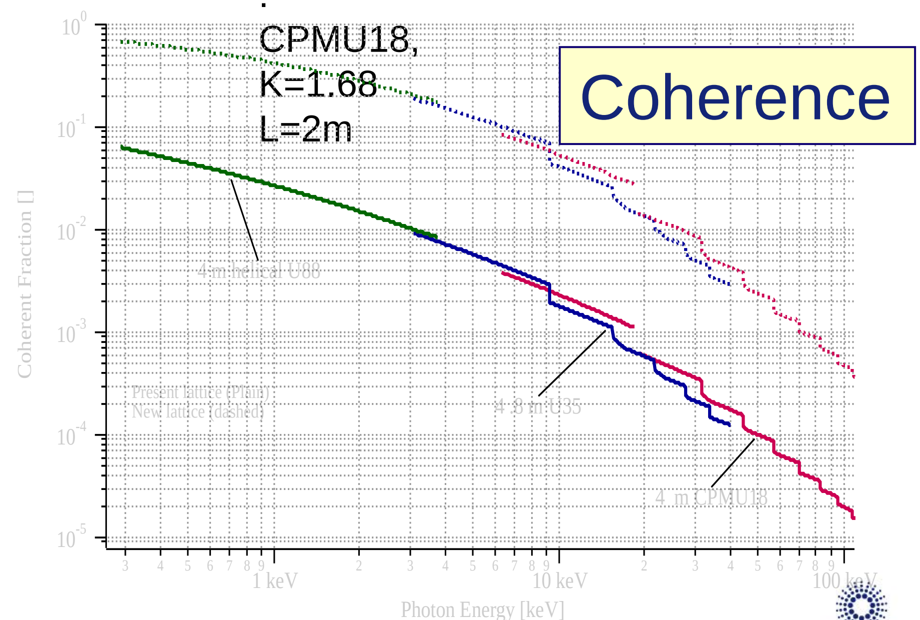


Hor. Emittance [nm]	4	0.135
Vert. Emittance [pm]	4	5
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

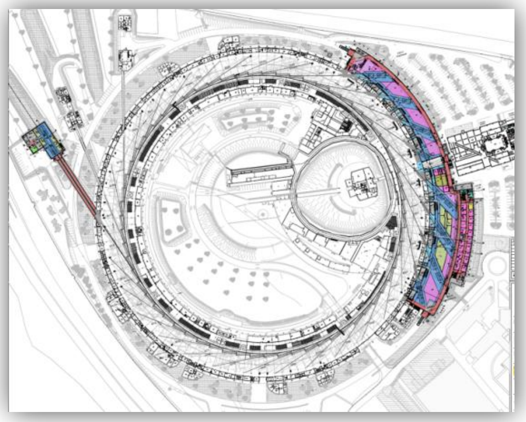
Source performances will improve by a factor 50 to100

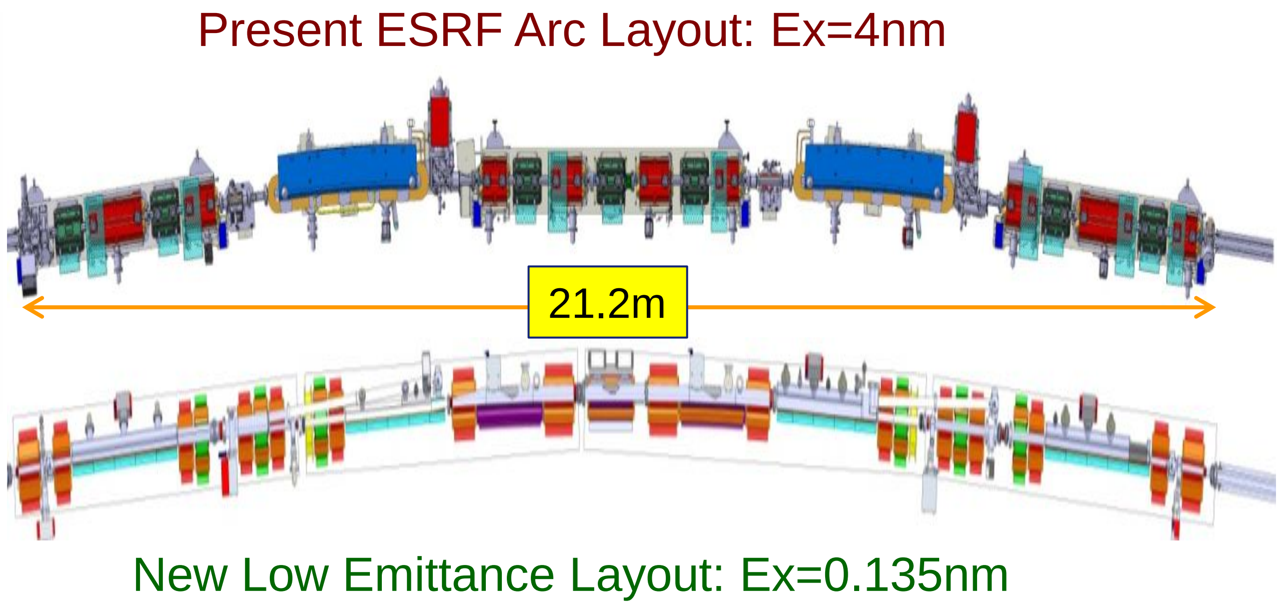


Undulator
:
CPMU18,
K=1.68
L=2m



ESRF Phase II Upgrade at the Bone





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

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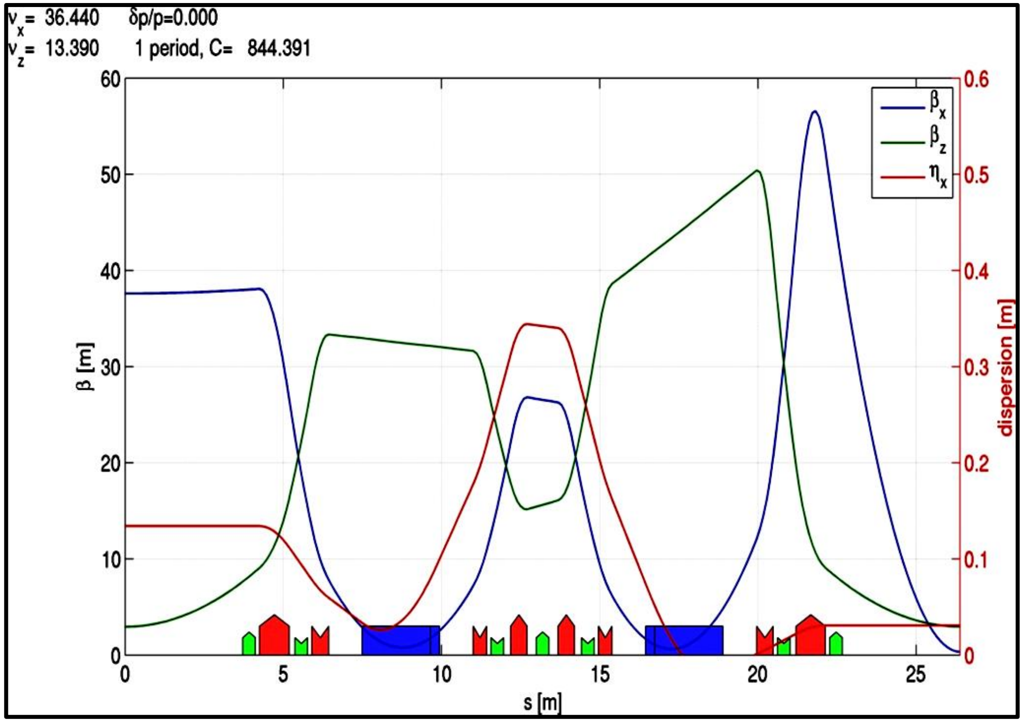
THE EVOLUTION TO MULTI-BEND LATTICE



Double-Bend Achromat (DBA)

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

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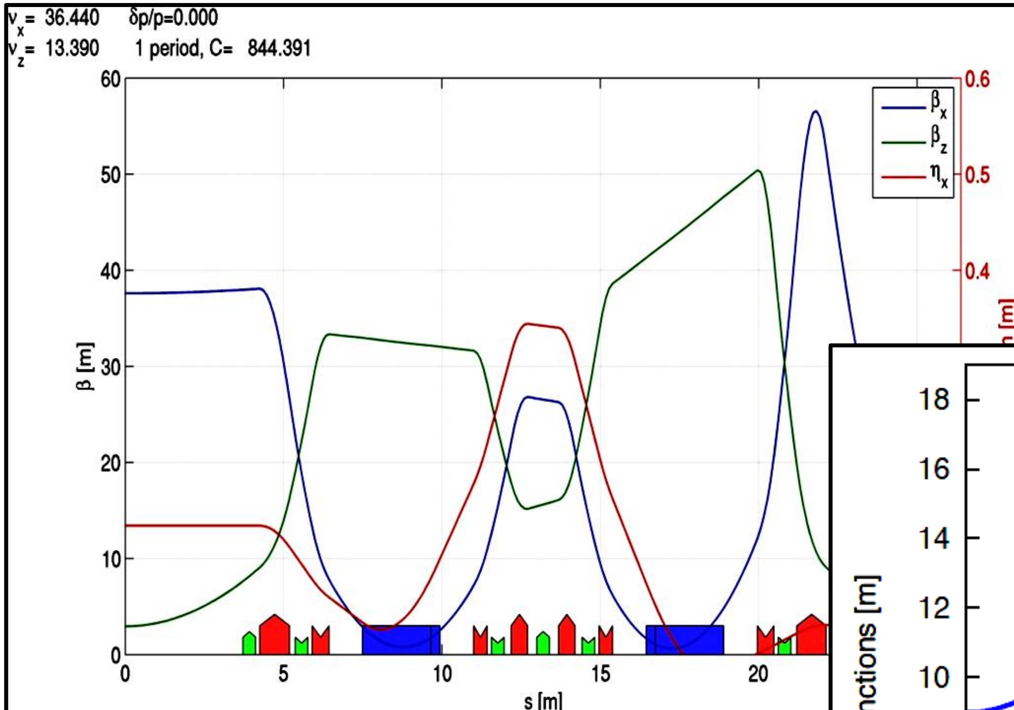

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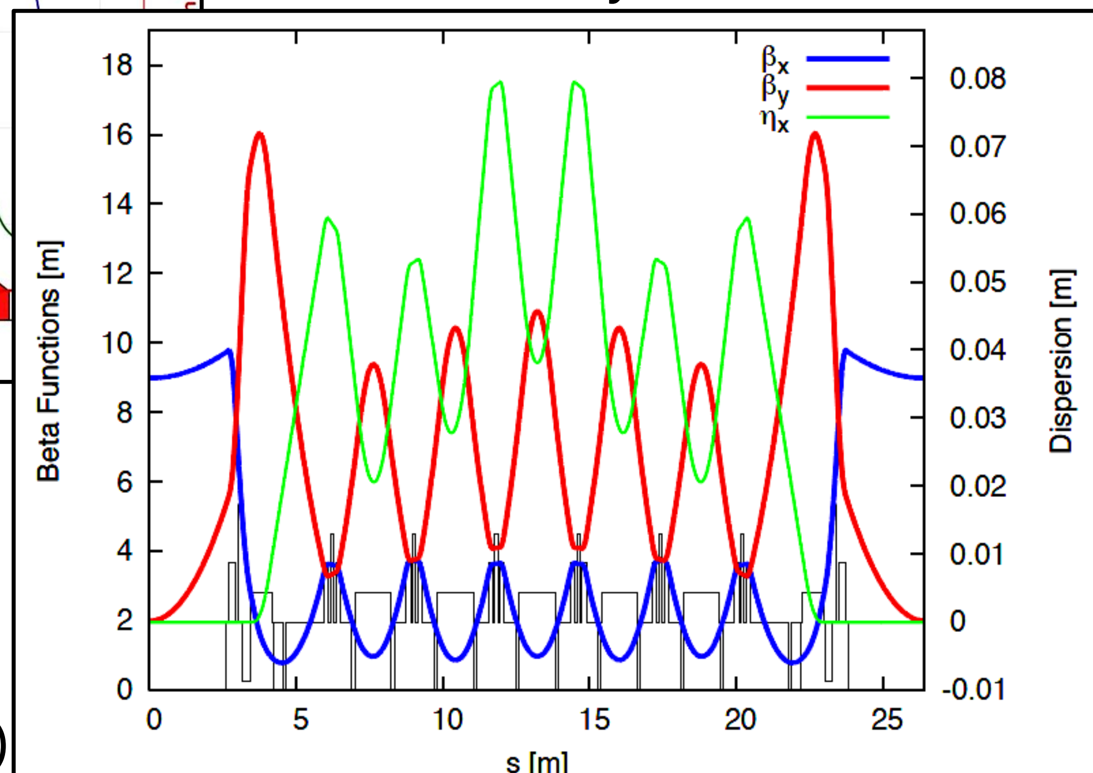
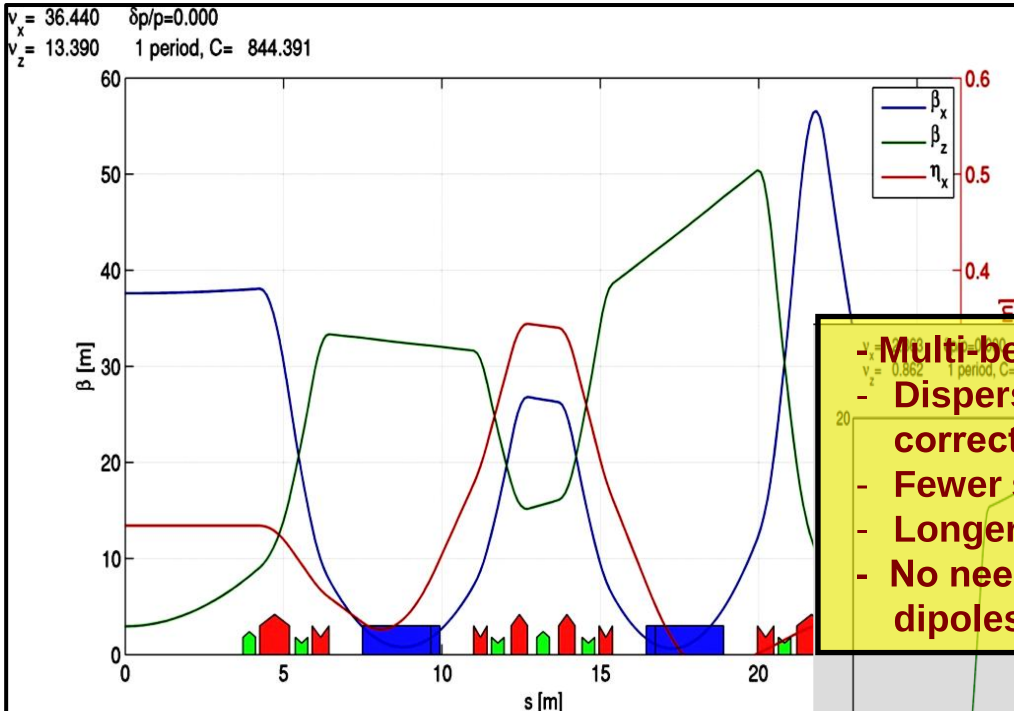


Multi-Bend Achromat (MBA)

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

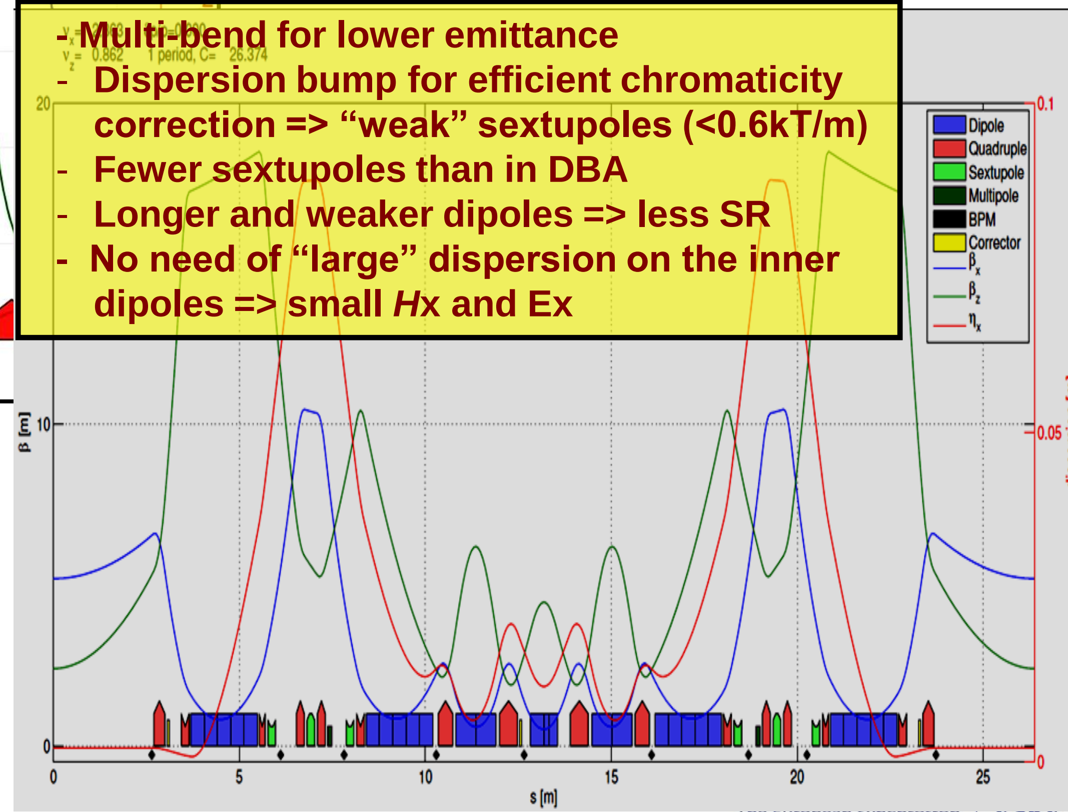
THE HYBRID MULTI-BEND (HMB) LATTICE



ESRF existing (DBA) cell

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

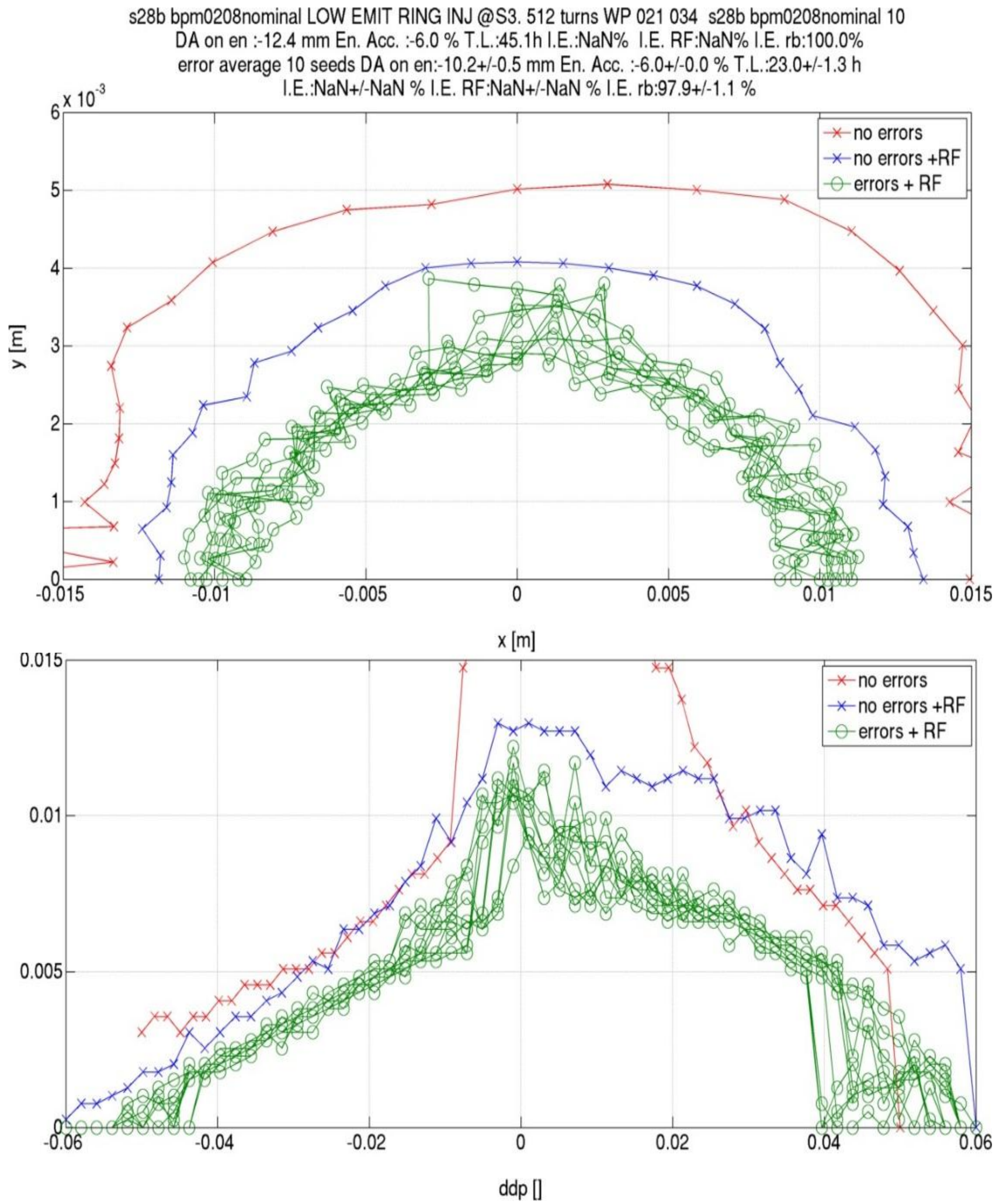
- Multi-bend for lower emittance
- Dispersion bump for efficient chromaticity correction => “weak” sextupoles (<0.6kT/m)
- Fewer sextupoles than in DBA
- Longer and weaker dipoles => less SR
- No need of “large” dispersion on the inner dipoles => small *H*x and Ex



Proposed HMB cell

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

LIFETIME OF S28B

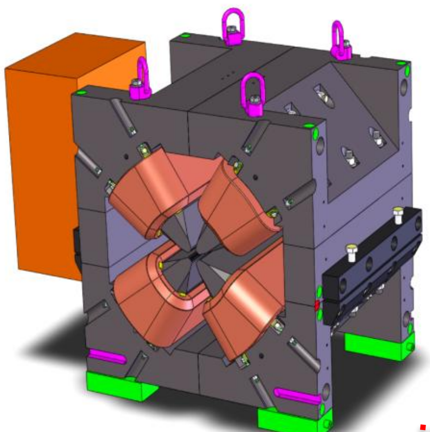


S28A
DA -8.1mm@S3
TLT ~ 13h.

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

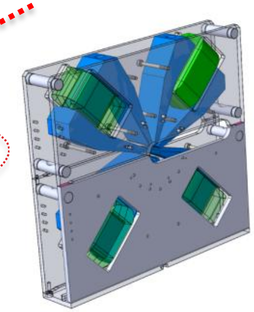
Technical challenge: Magnets System

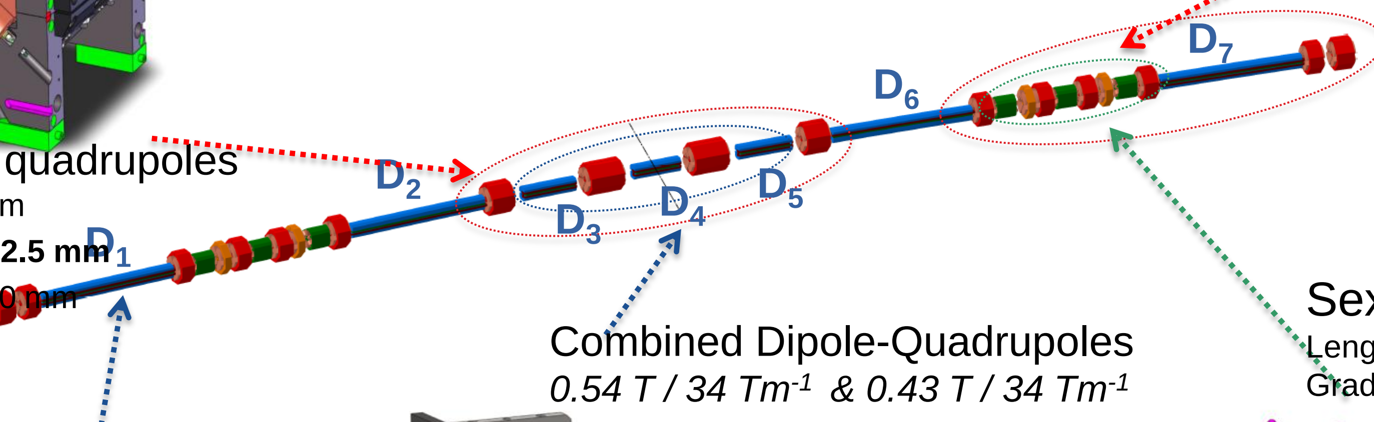


Mechanical design final drawing phase

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

Quadrupole
Around 52Tm^{-1}





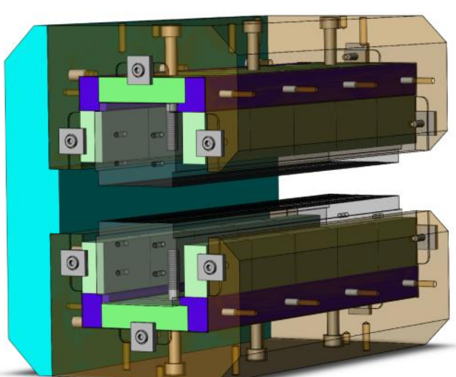
High gradient quadrupoles

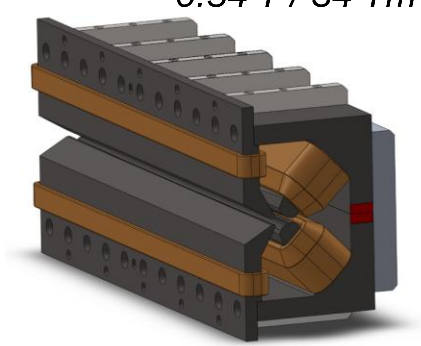
- Gradient: 90 T/m
- **Bore radius: 12.5 mm**
- Length: 390/490 mm
- Power: 1-2 kW

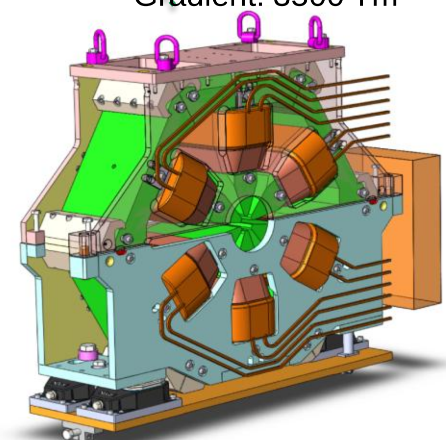
Octupoles

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

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





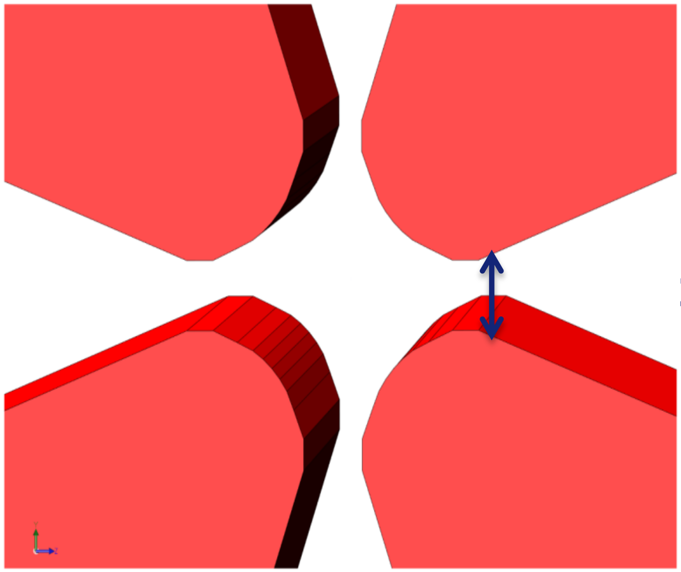


Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 – 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

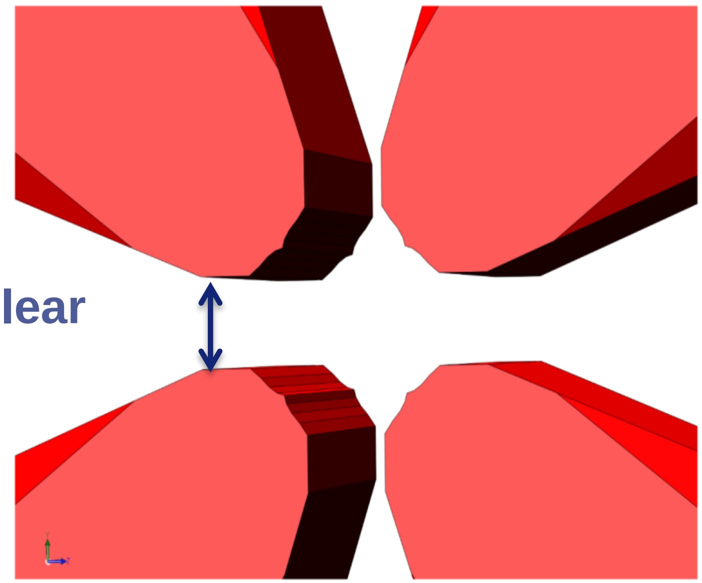
Gael Le Bec

Pole shape optimization

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

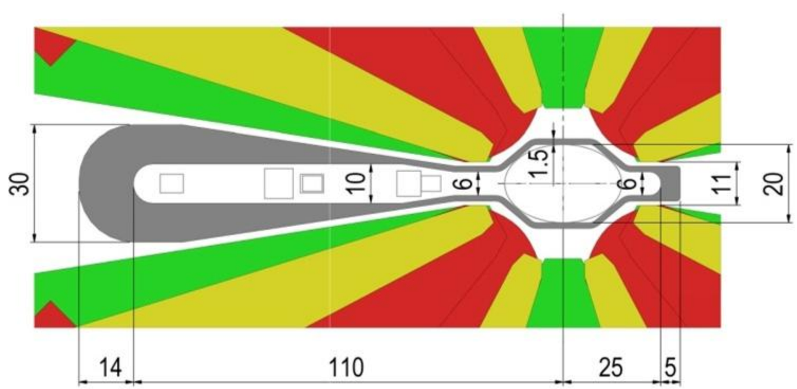


11mm stay clear



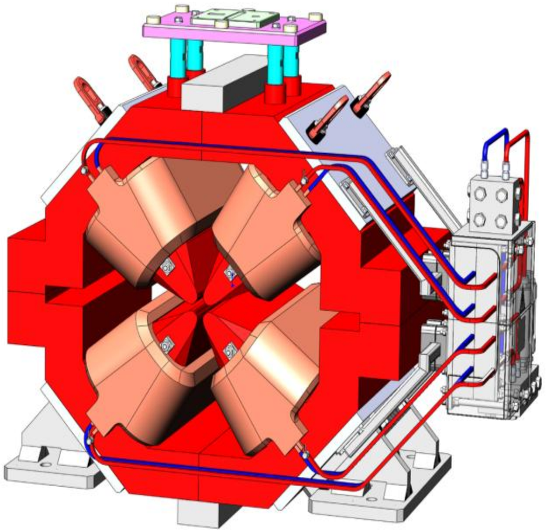
Low gradient pole profile

High gradient pole profile



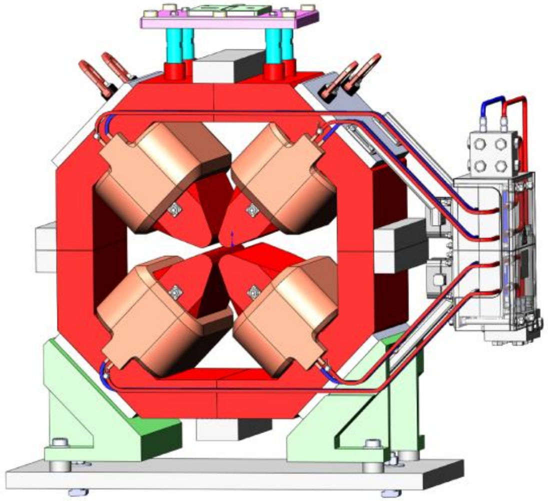
Vacuum chamber and magnets sections

QUADRUPOLES



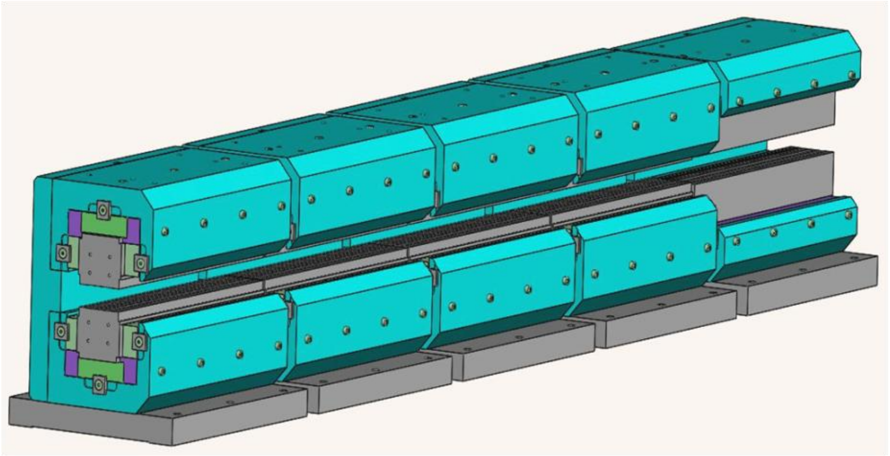
High Gradient

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



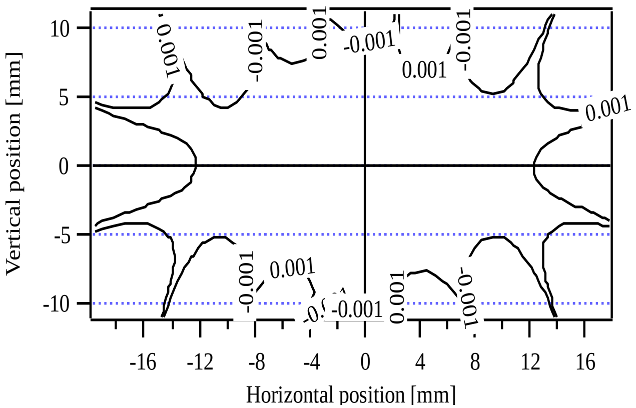
Moderate Gradient

- 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

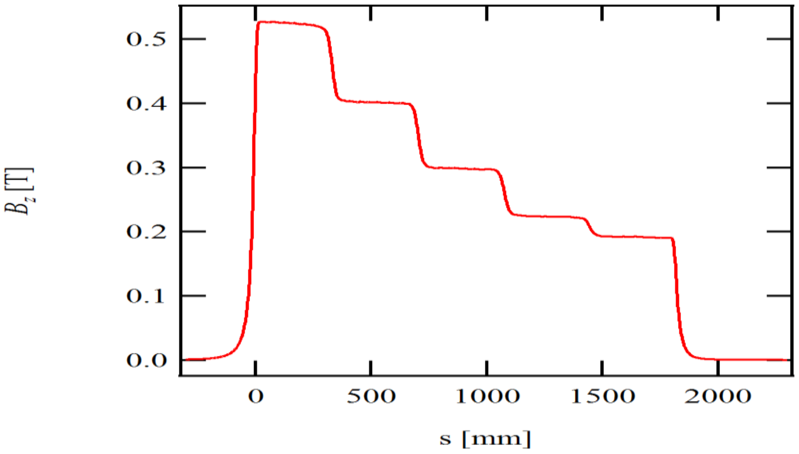


Specifications

- 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

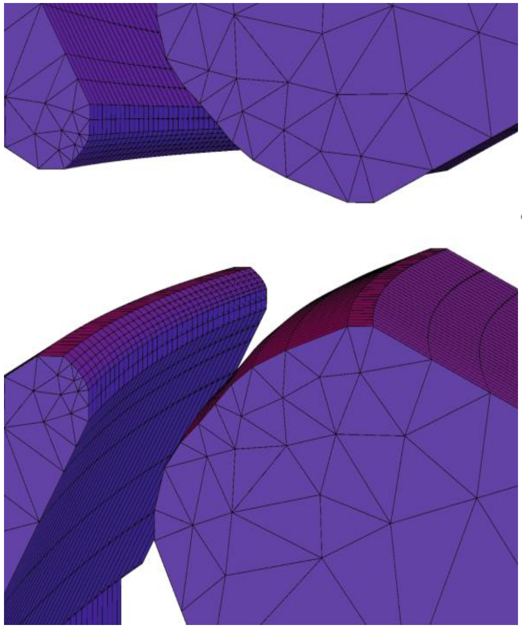


Measured field integral homogeneity (one module)

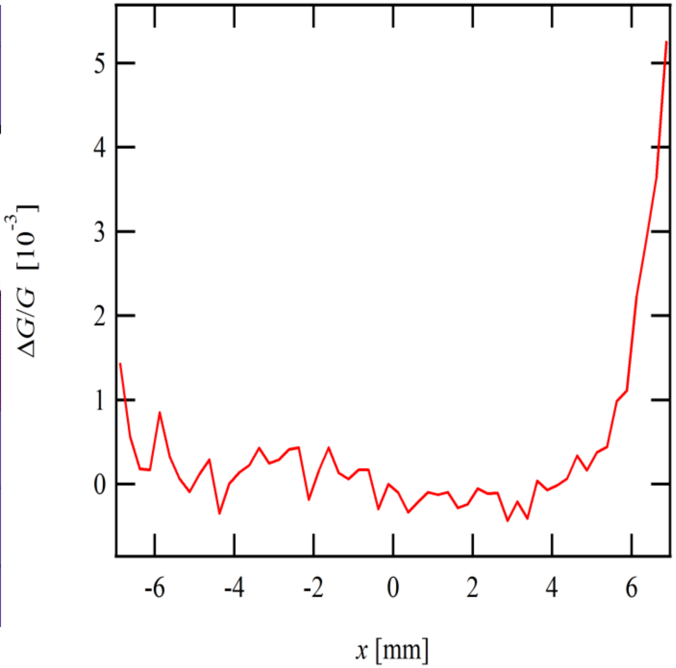


Longitudinal field distribution

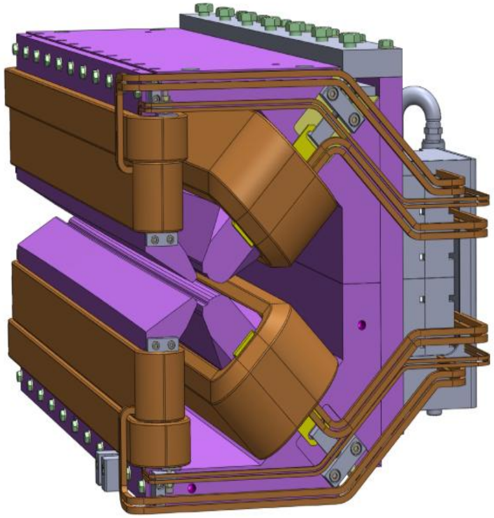
DIPOLE QUADRUPOLES



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)

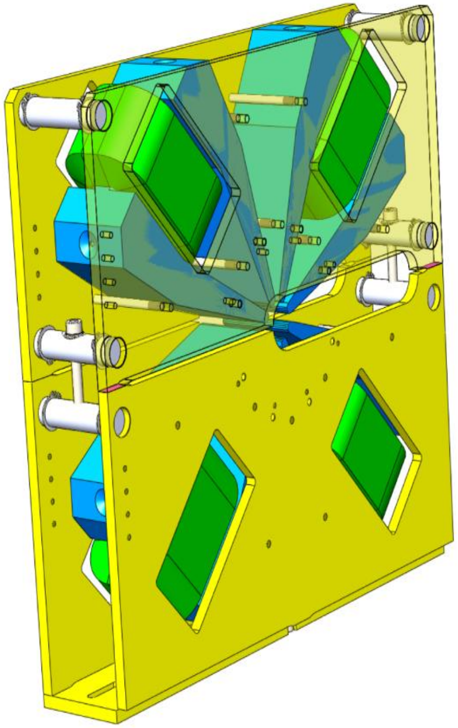
DQs are machined in 7 solid iron plates

Poles curved longitudinally for maximum stay clear and good field region

OCTUPOLES

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



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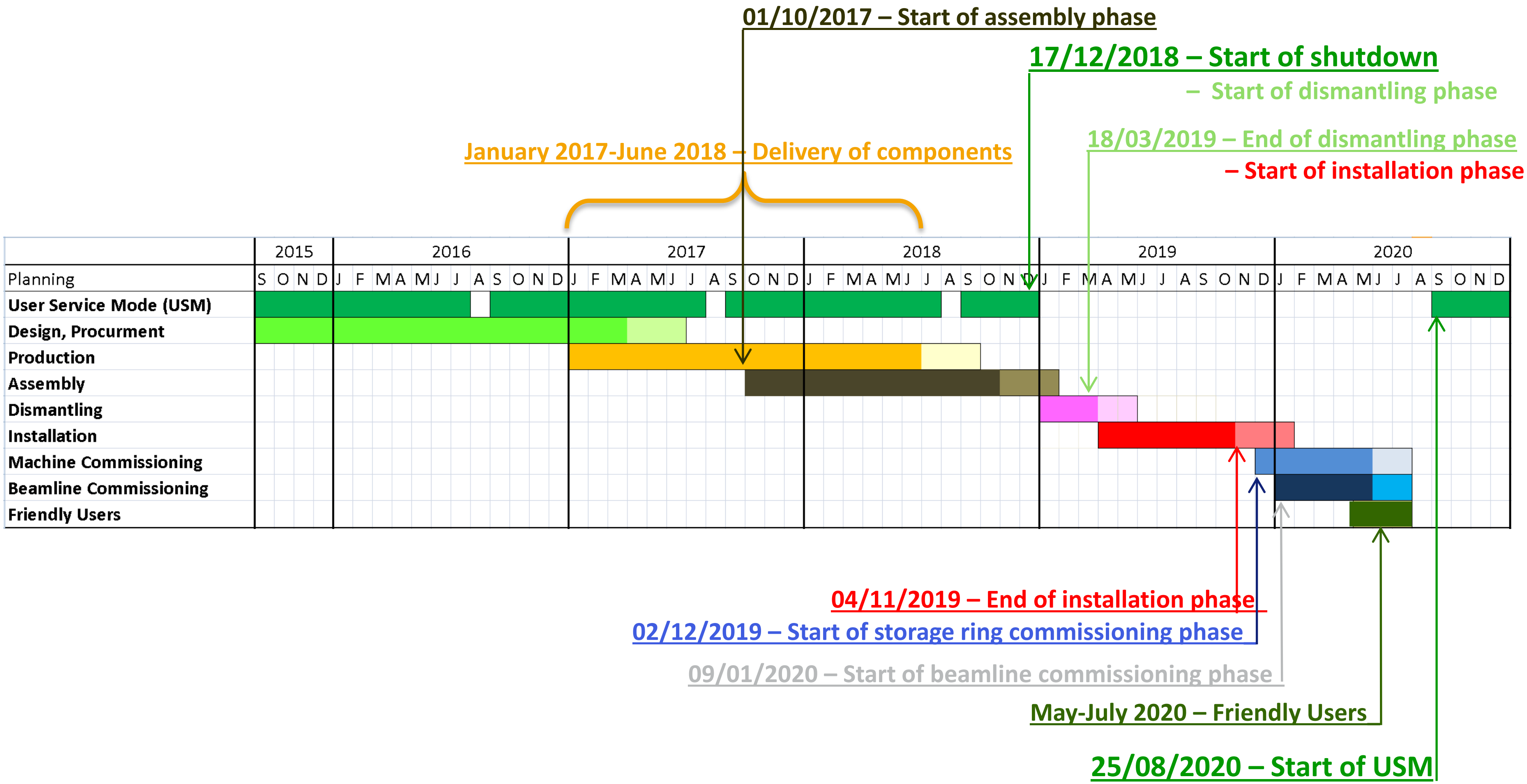
EBS MASTER PLAN (2015-2020)

Master Plan and Major Milestones



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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

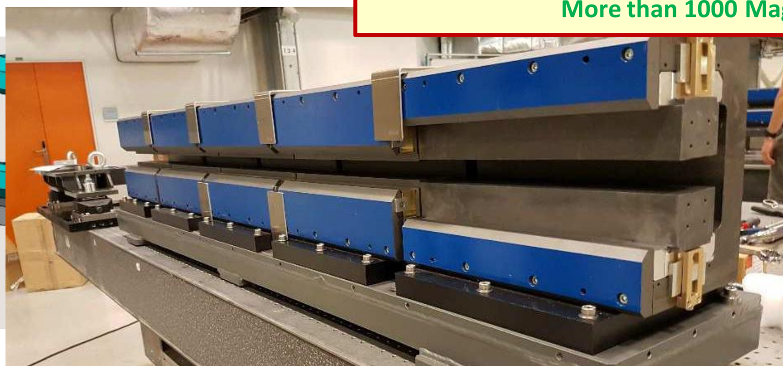
PROGRESS STATUS: PROCUREMENT

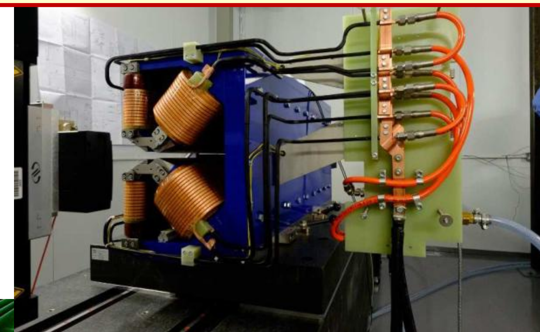
- All contracts for serial production magnets in place
- All contracts for vacuum chambers in place
- Girder contracts in place
- Infrastructure adaptations critical contracts in place
- All large scale procurement in place by December-2016

Delivery of serial components has started will last about 2 years

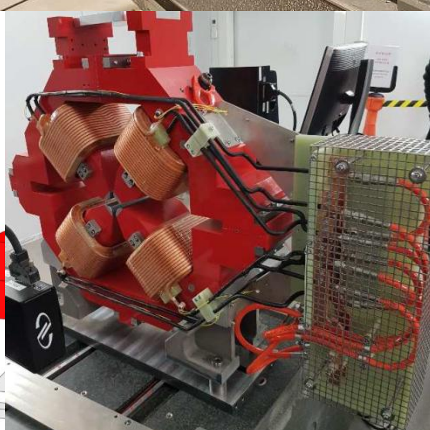
ESRF EBS (2015-2022): MAGNETS PROCUREMENT

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





66 octupoles



398 moderate gradient quadrupoles

130 high gradient quadrupoles

196 sextupoles

100 correctors

IMPLEMENTATION IN CHARTREUSE HALL

PM Dipoles are being assembled by ESRF staff

More than 650 Magnets Modules for a total of about 130 5-Module dipoles

Dipole assembly area

Module’s Yokes

ESRF EBS (2015-2022): VACUUM CHAMBERS PROCUREMENT

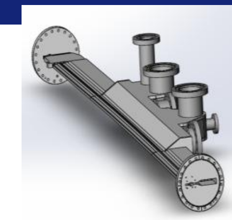
All contracts in place, chambers in fabrication
FAT for aluminium chambers in November
All FAT should be completed by December
More than 450 Vacuum Chambers to be procured by the end of 2018

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

FAMILY 3: LOW PROFILE STAINLESS STEEL CHAMBERS

Material : 316 LN

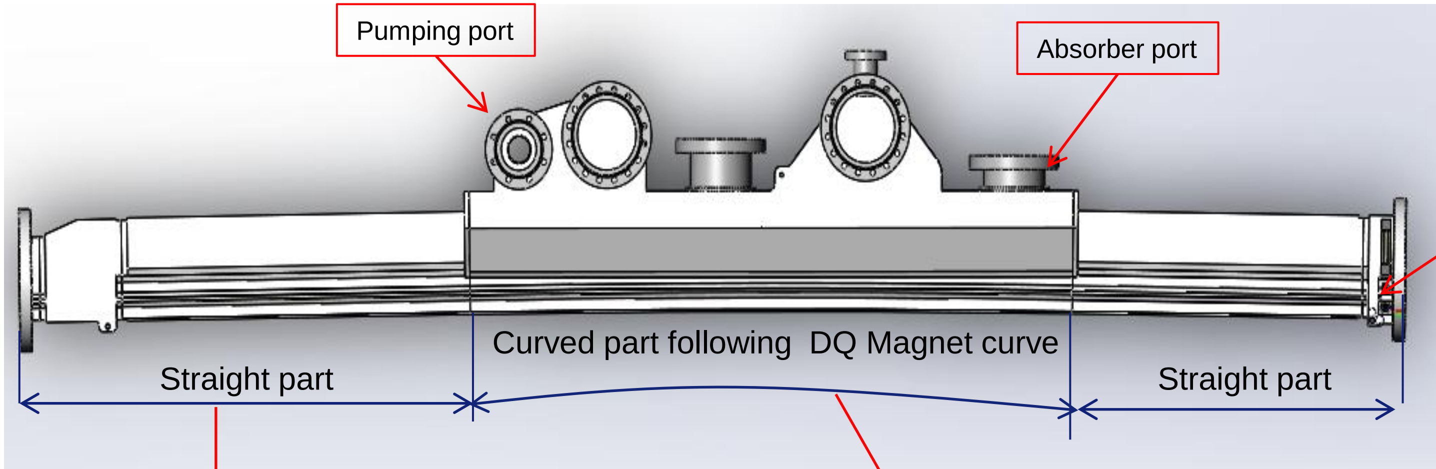
Curved Chambers



Pumping port

Absorber port

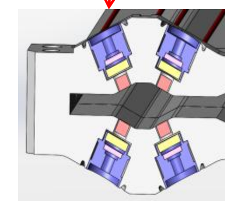
BPM Block



Curved part following DQ Magnet curve

Straight part

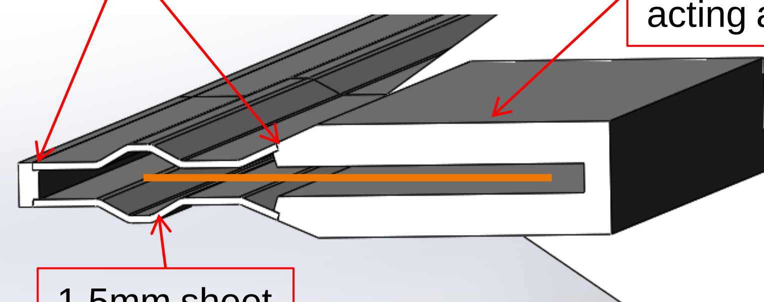
Straight part



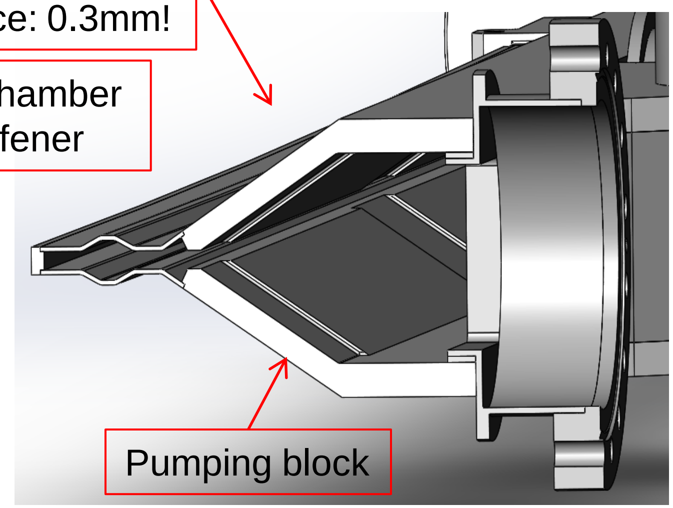
Requested shape tolerance: 0.3mm!

EB Welding

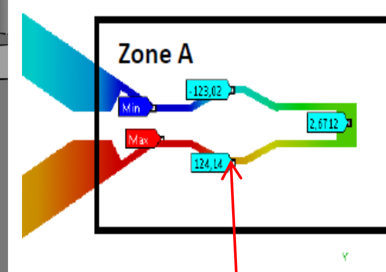
Thick ante-chamber acting as stiffener



1,5mm sheet

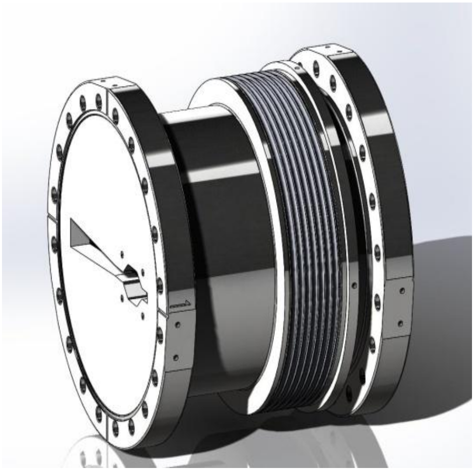


Pumping block

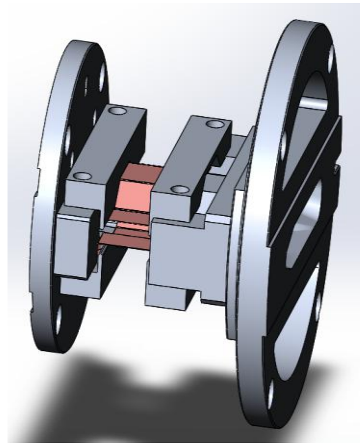


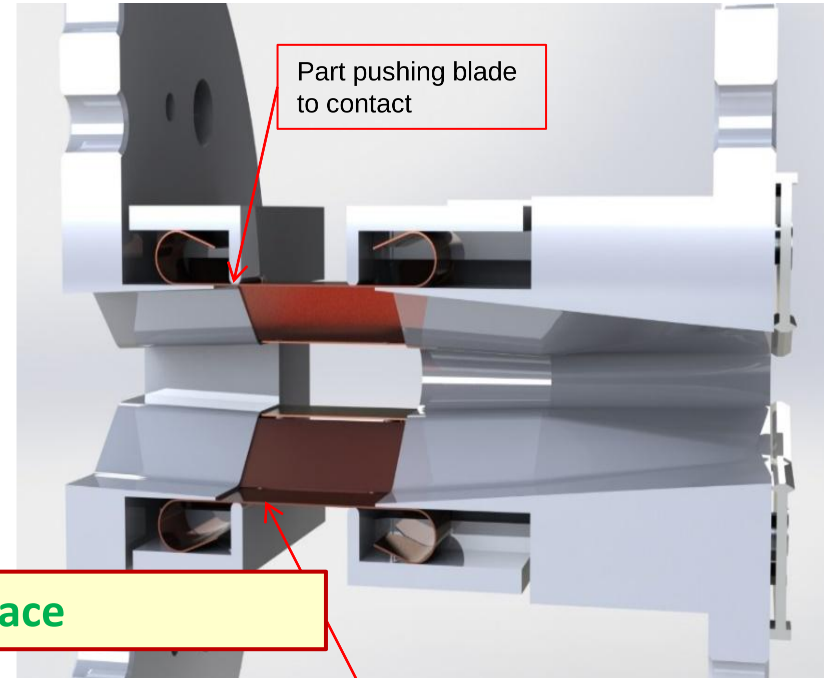
Deformation at the Beam area 0.125mm

Joel Pasquaud



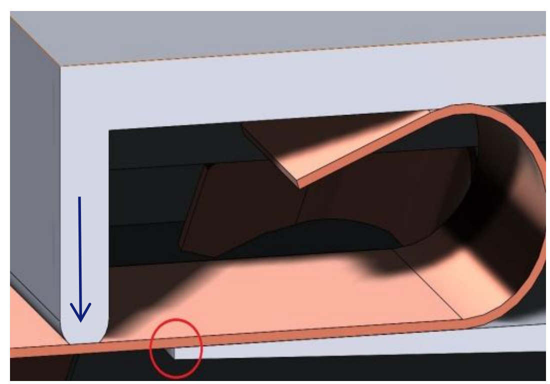
Bellow assembly





Contract in place

Blade contact



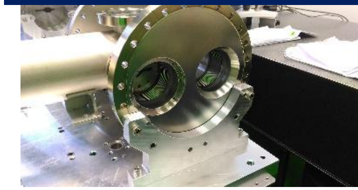
- Smooth transitions between profiles
- No change of the profile inside the RF fingers

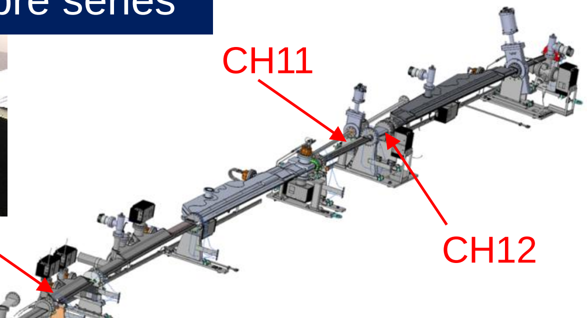
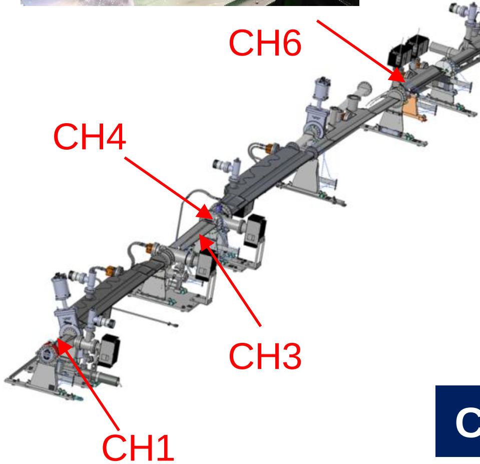
Courtesy of P Brumund, L Eybert, L Goirand

PRODUCTION – VACUUM CHAMBERS (STAINLESS STEEL)

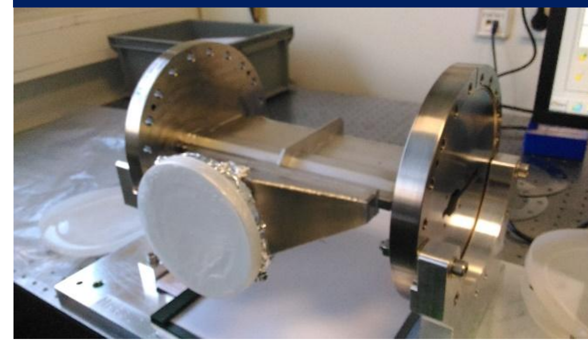
Stainless steel chambers: 2 contracts FMB (D)
CH14: 1 contract PINK (D)

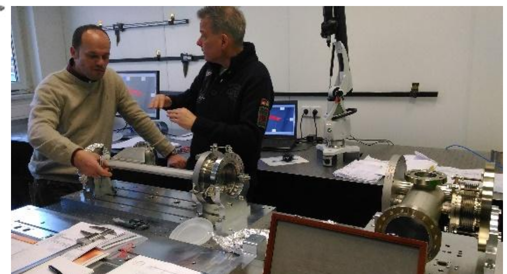
CH4 high profile pre series



CH12 high profile pre series

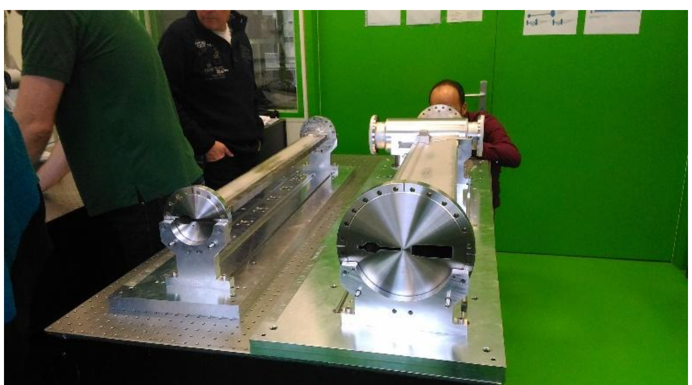




CH1 high profile pre series

Pre-series still in progress

CH7 low profile pre series in progress

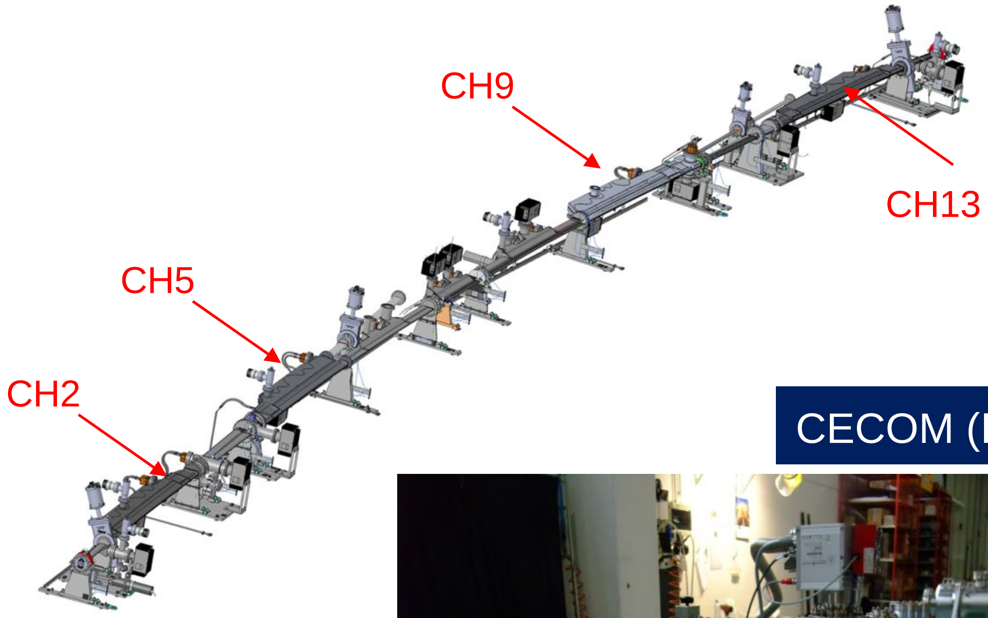


CH3 & 11 high profile pre series

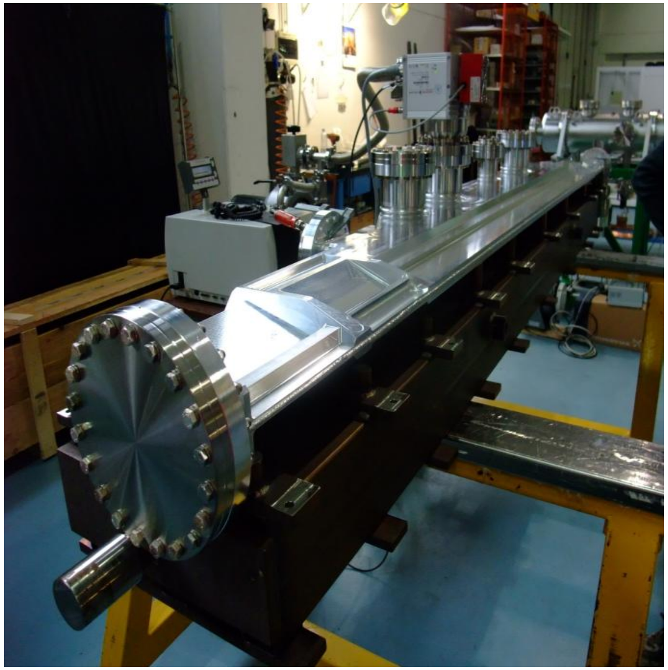
Courtesy of P Van Vaerenbergh, J Pasquaud, L Goirand

PRODUCTION – VACUUM CHAMBERS & OTHERS

Aluminium Vacuum chambers pre-series: still in progress



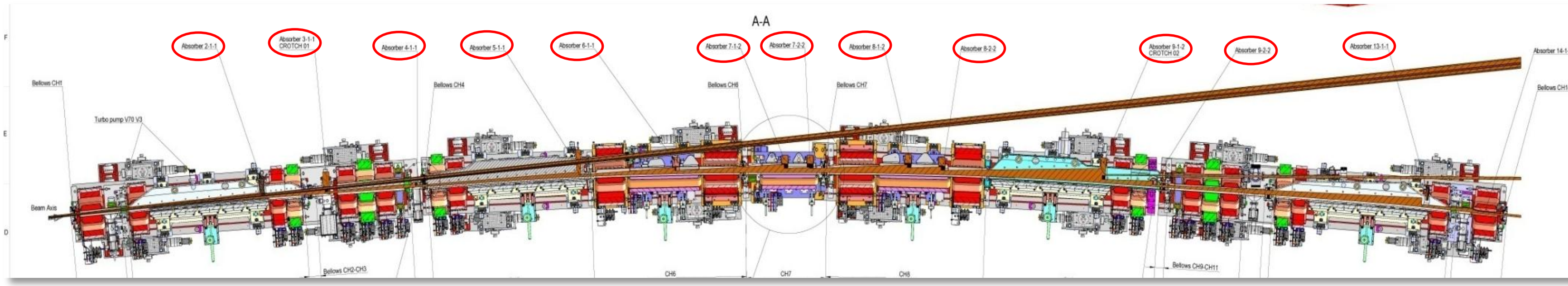
CECOM (IT)



January 2017
Factory acceptance for;

- Photon absorbers

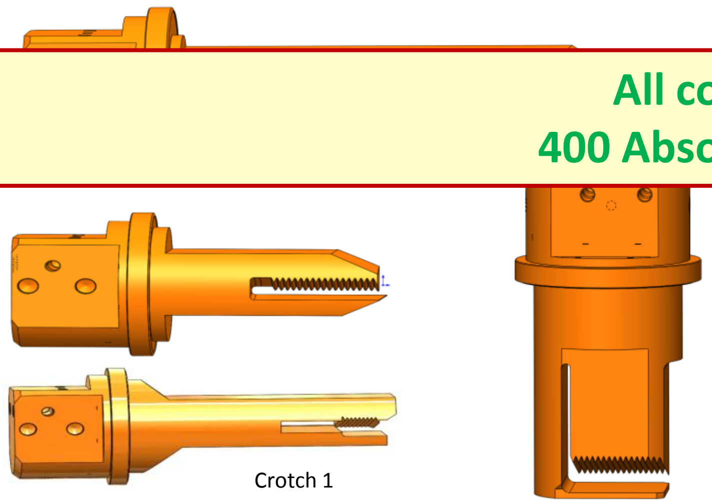
ESRF EBS (2015-2022): ABSORBERS PROCUREMENT



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

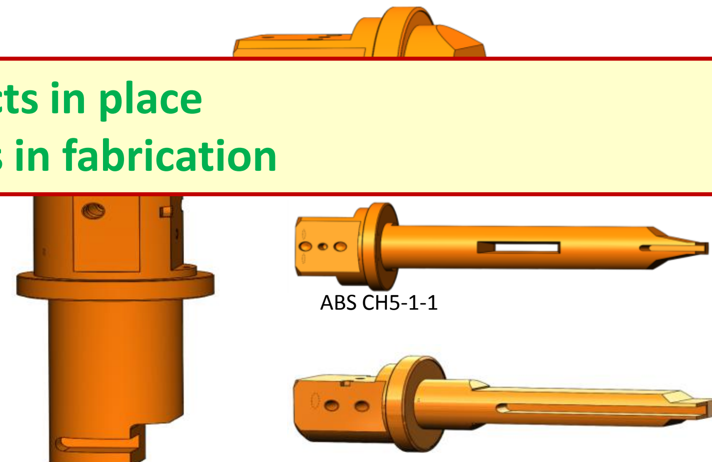
Family Frontal (up to 50 W/mm^2)

All contracts in place
400 Absorbers in fabrication



Crotch 1

ABS CH9-1-29



ABS CH4-1-1

ABS CH5-1-1

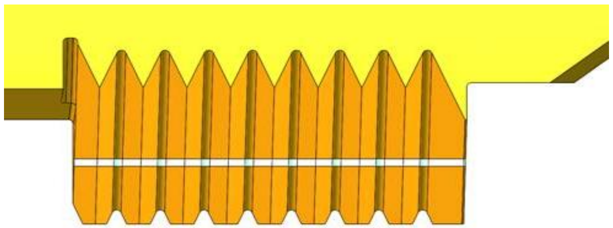
ABS CH13-1-13

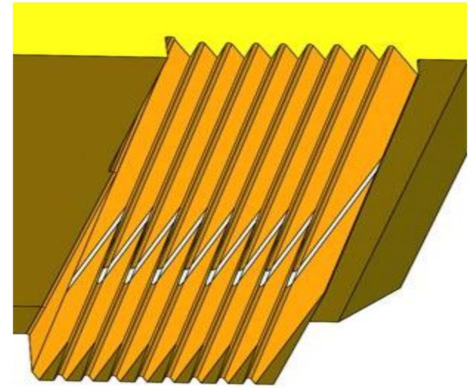
No weld, no braze

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

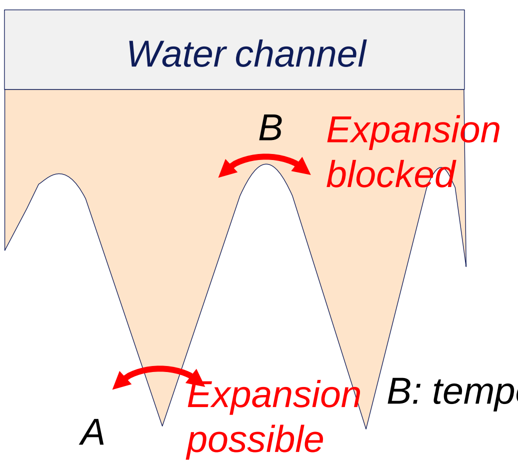
ABSORBERS WITH TEETH OPTIMIZED TO REDUCE THERMAL STRESSES

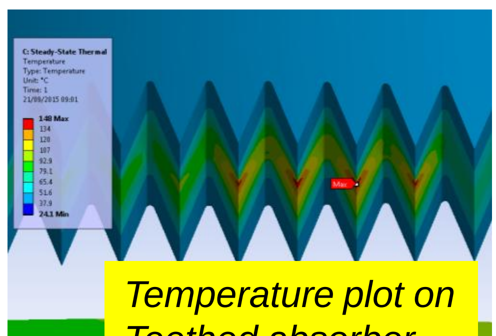
Teeth distribute the heat over a larger area



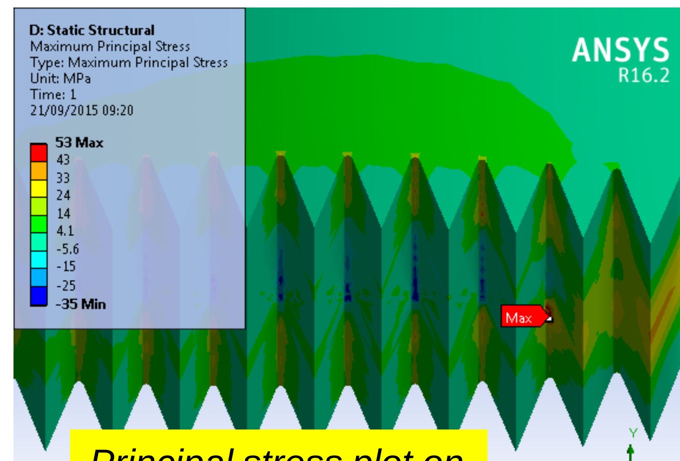


Teeth geometry optimized to reduce thermal stresses





Temperature plot on Teethed absorber



Principal stress plot on Teethed absorber

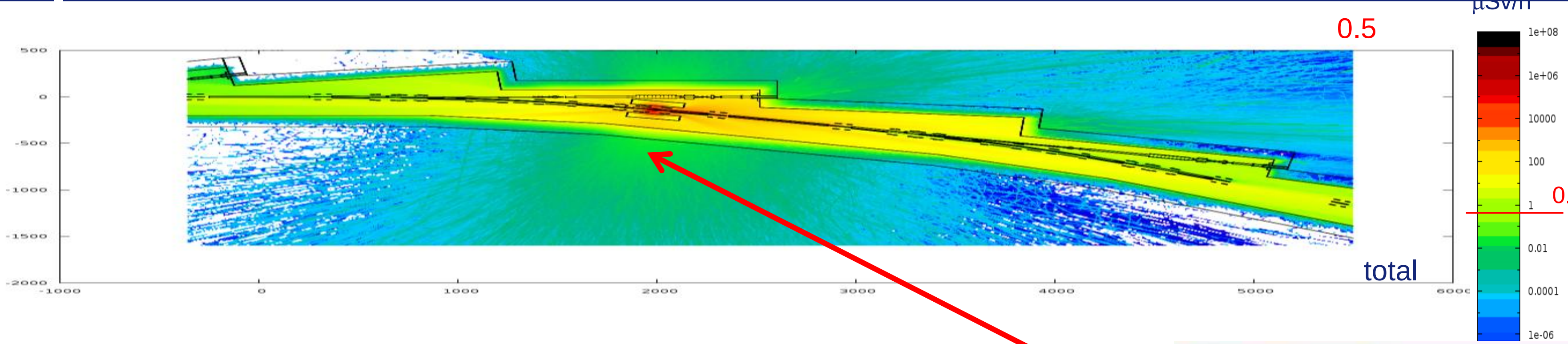
B: temperature is min Stress is max

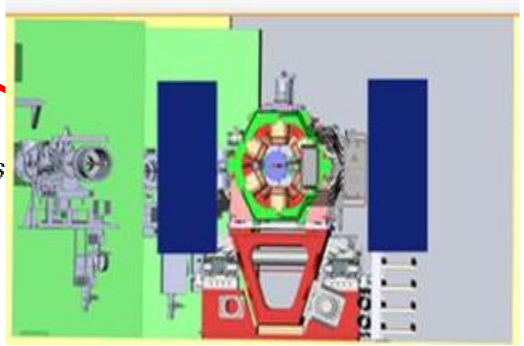
A: temperature is max Stress is min

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

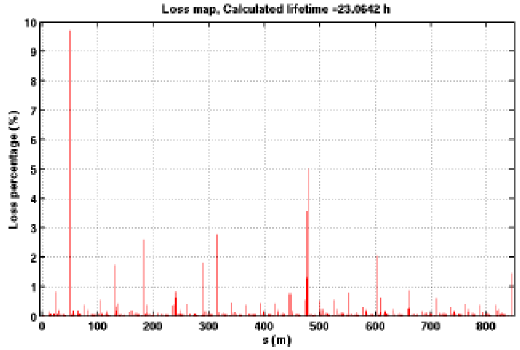
Stress criteria < Yield strength

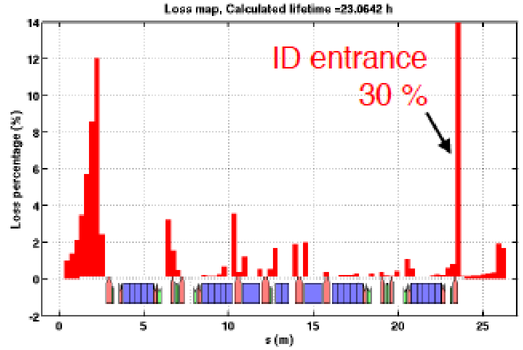
50 CM LEAD LOCAL SHIELDING



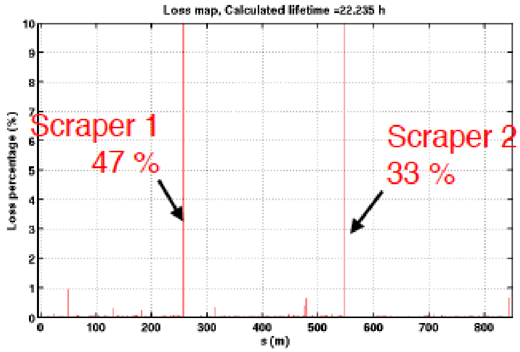


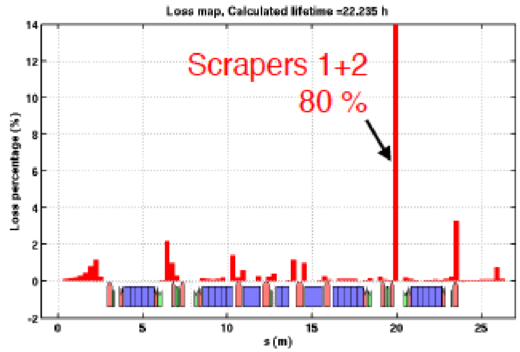
80% of the losses are relocated on the scrapers for 4% lifetime reduction:





No scrapers

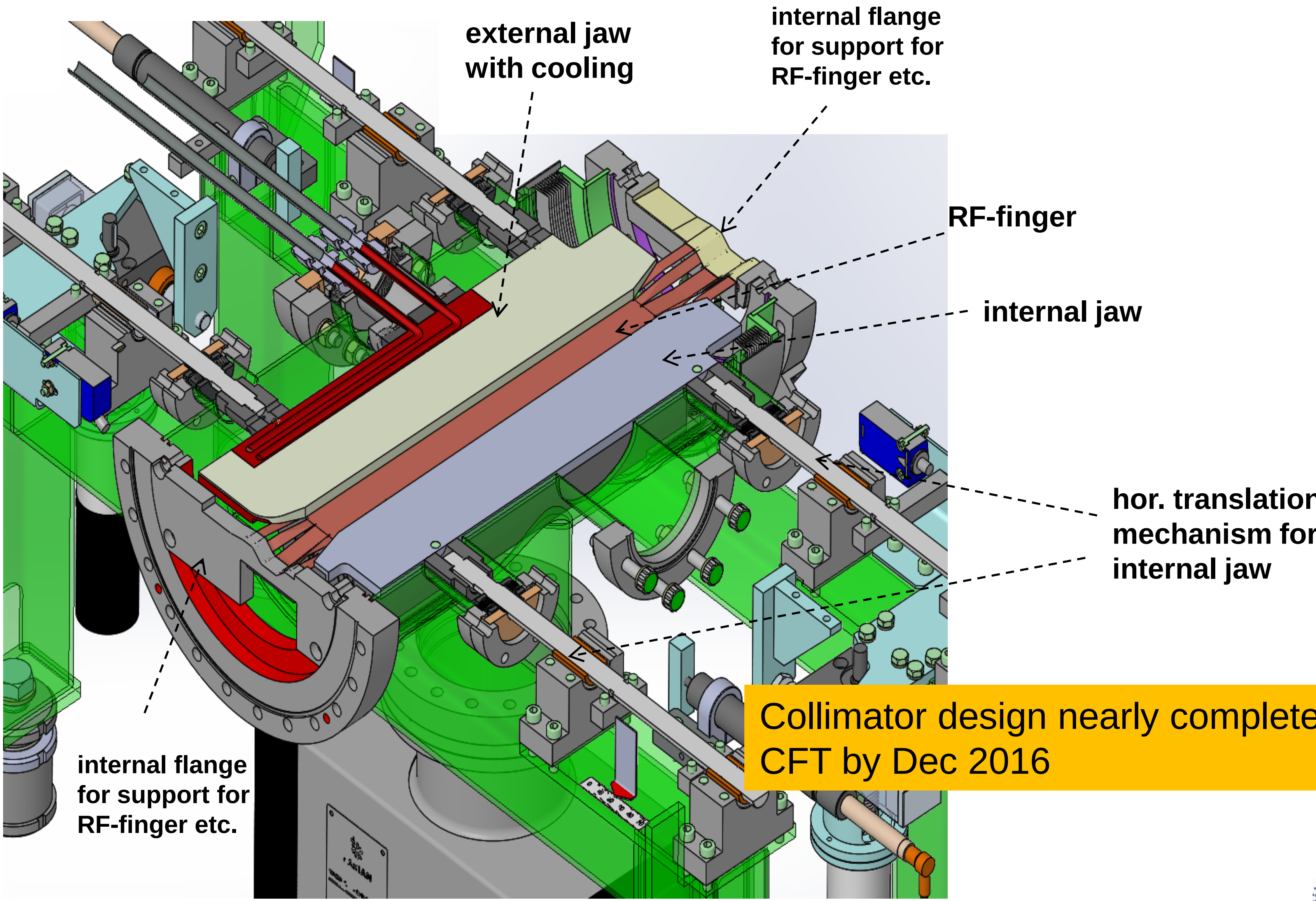




Two scrapers in DR_37 of cells 13 and 24

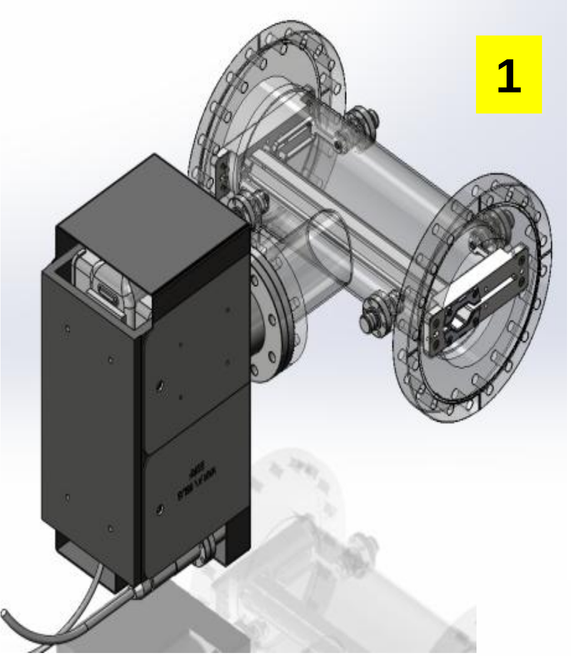
cm

COLLIMATOR FOR CH.#12 IN CELLS 13 AND 24



Collimator design nearly completed
CFT by Dec 2016

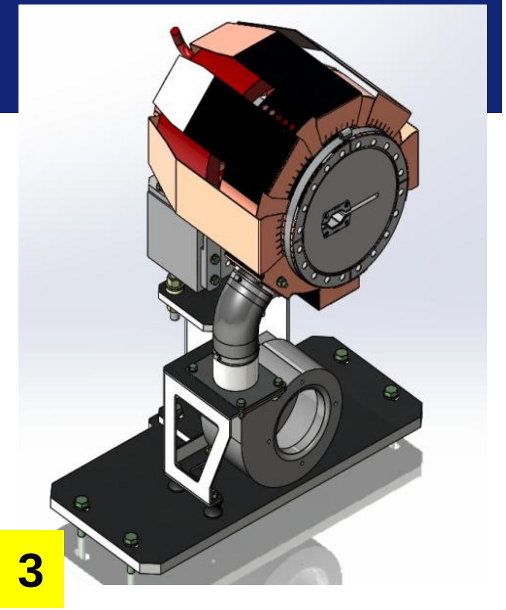
CURRENT TRANSFORMER & STRIPLINES

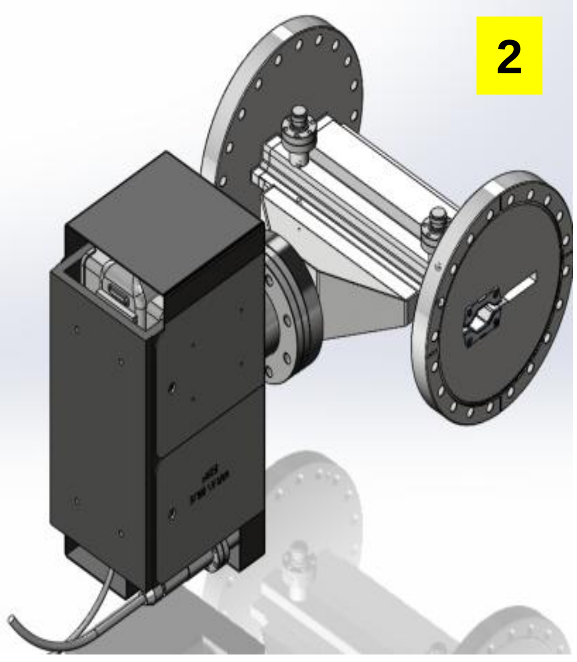


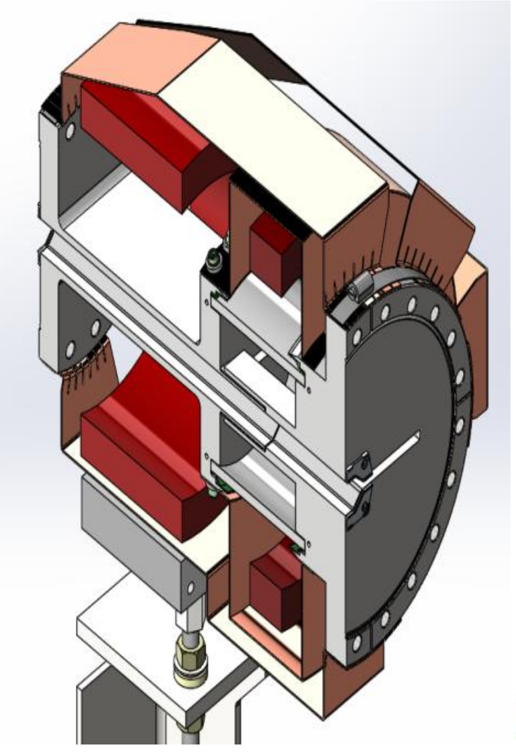
all in Ch.#12

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

all detailed designs ready
CFTs by December 2016

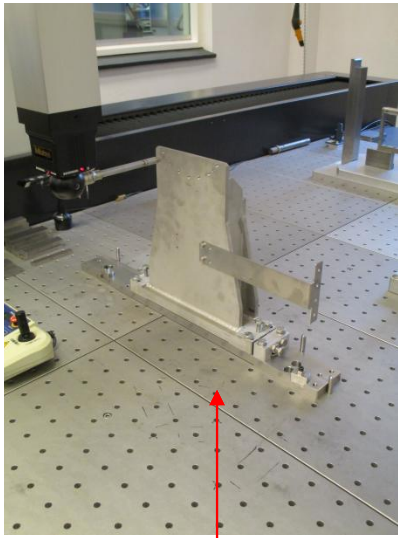






ESRF

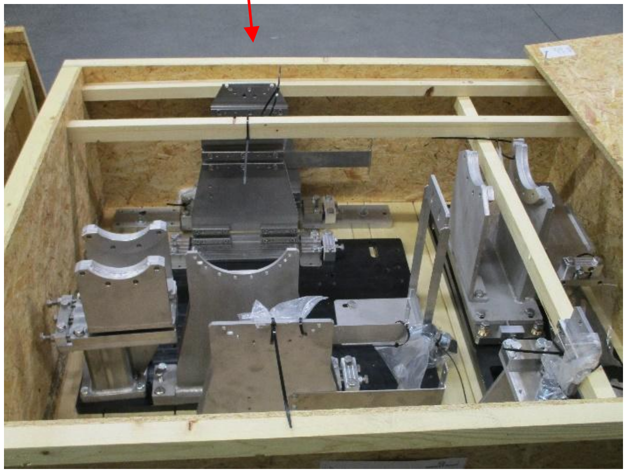
PRODUCTION - SUPPORTS



All supports in Production phase

Dipole supports KINKELE (D)

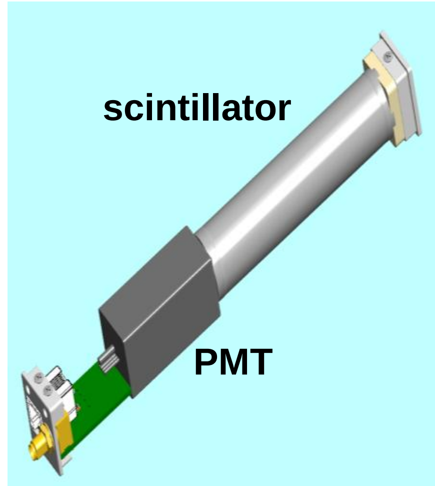
Vacuum Chambers supports
KURSTERS & BOSCH (NL)



Magnets supports CASTELLINI (IT)

Courtesy of L EYBERT

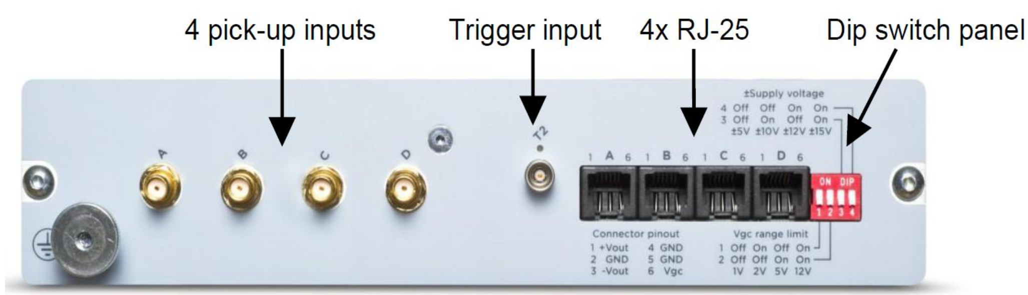
BEAM LOSS MONITORS : COMPACT, CHEAP, PERFORMING



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		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sextu[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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.

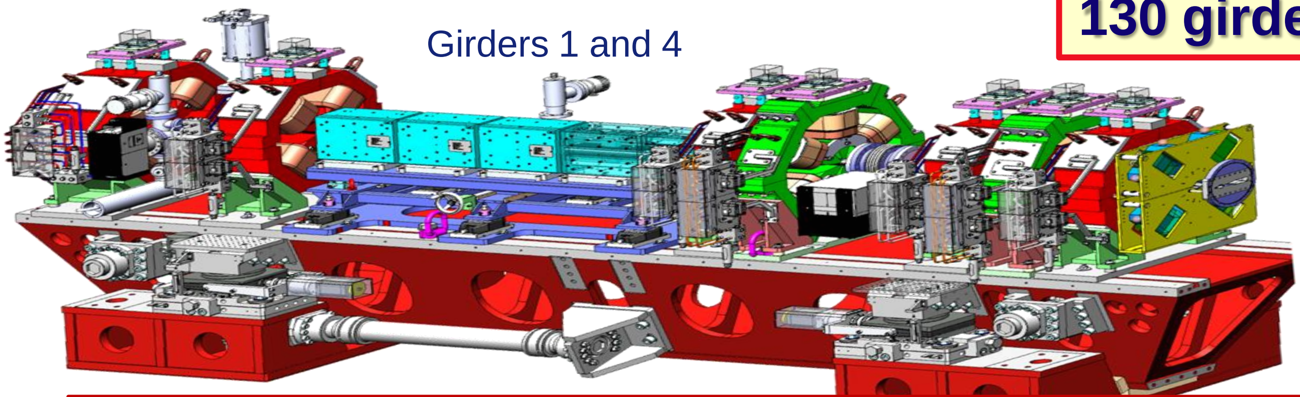
The stability requested will be 15ppm with a MTBF of more than 400 000 hours.

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

ESRF EBS (2015-2022): GIRDERS PROCUREMENT

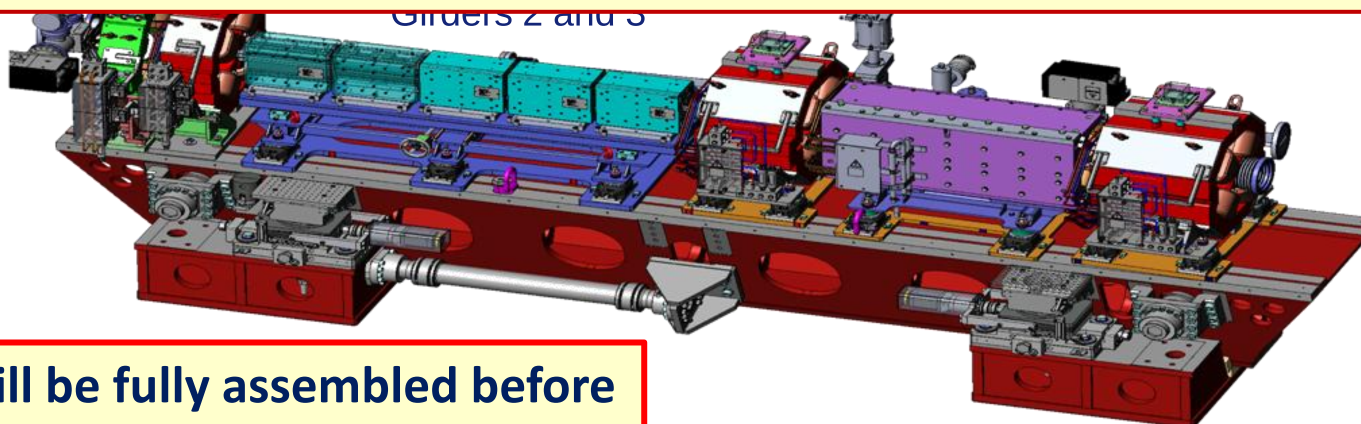
130 girders,10-12t each

Girders 1 and 4



All contracts in place, girders in fabrication

Girders 2 and 3



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

PRODUCTION - GIRDERS

NORTEMECANICA (SP) 65

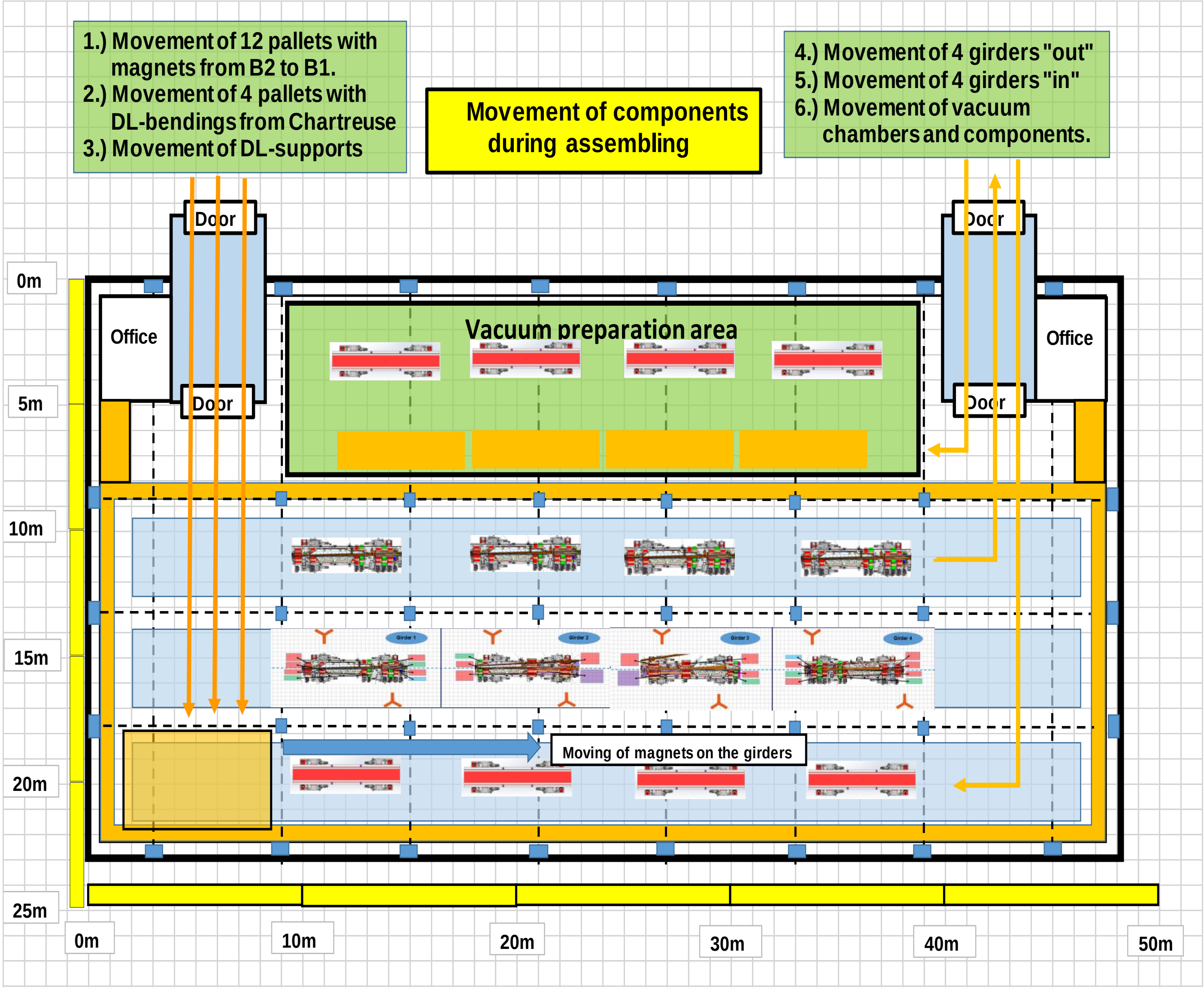
Pre-series girders delivered

Series girder, 2 contracts
production 8 every 5 weeks (total 129+1 spare)

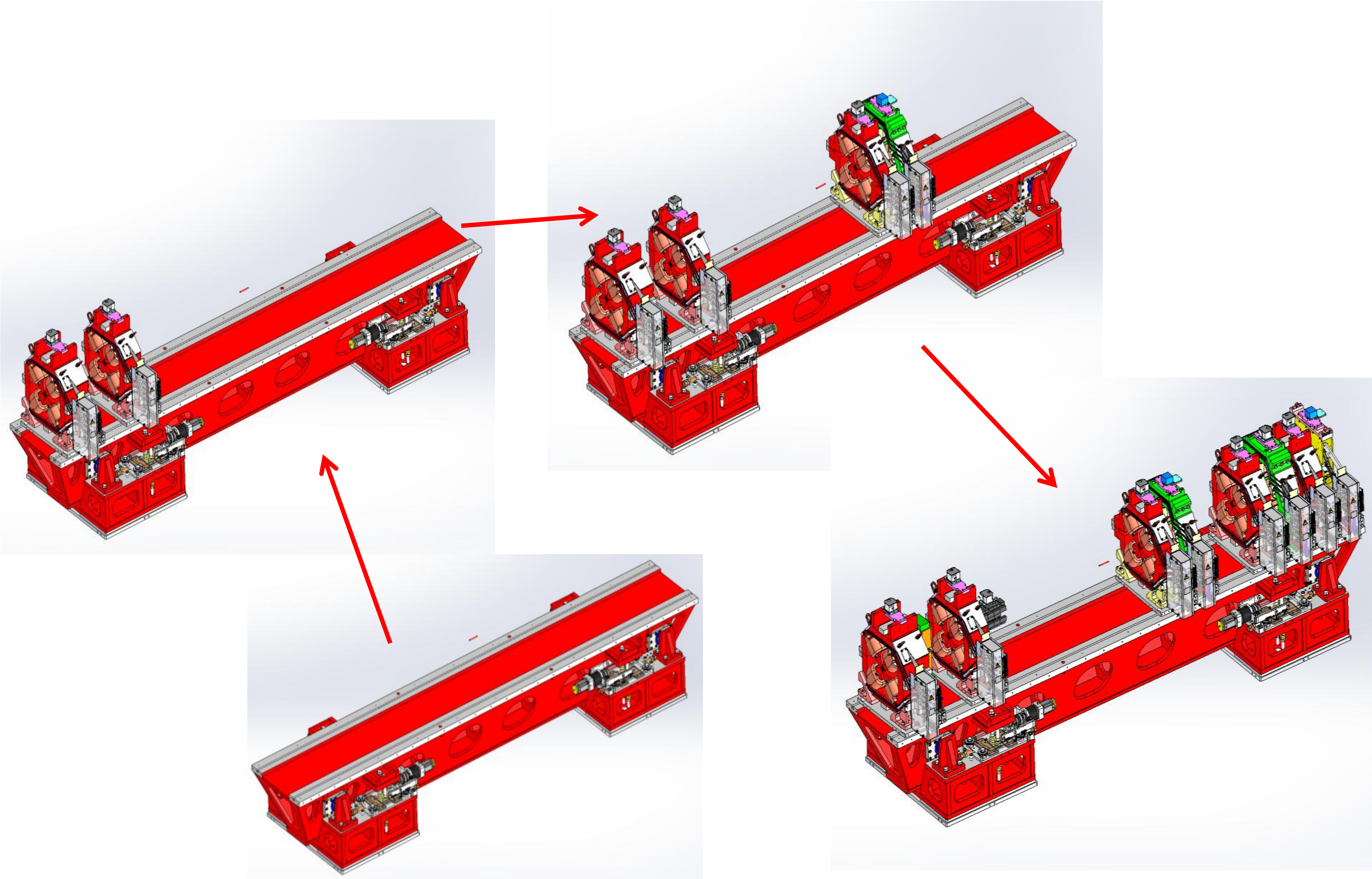
AVS (SP) 65

Courtesy of T Brochard, F Cianciosi

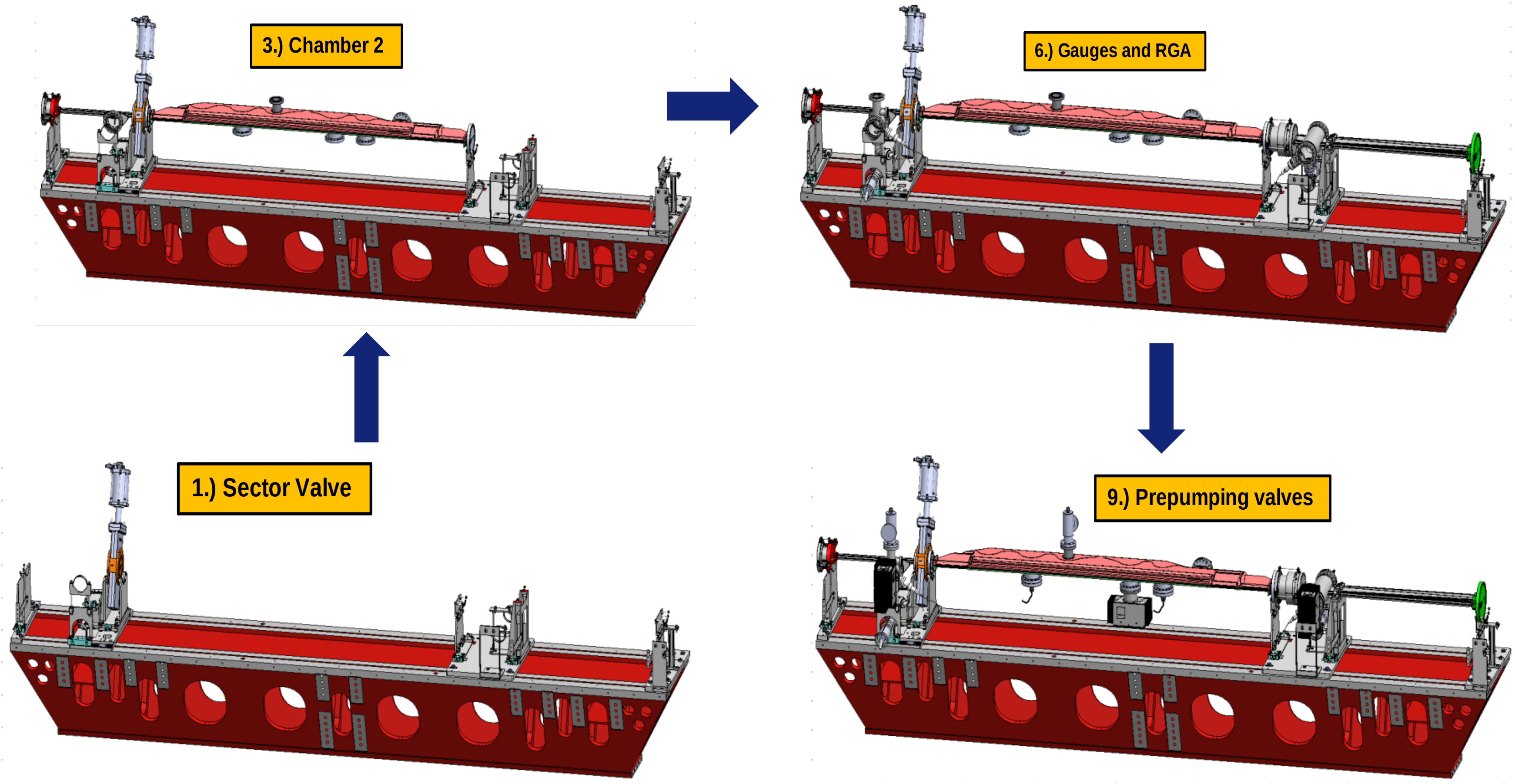
GIRDERS ASSEMBLY



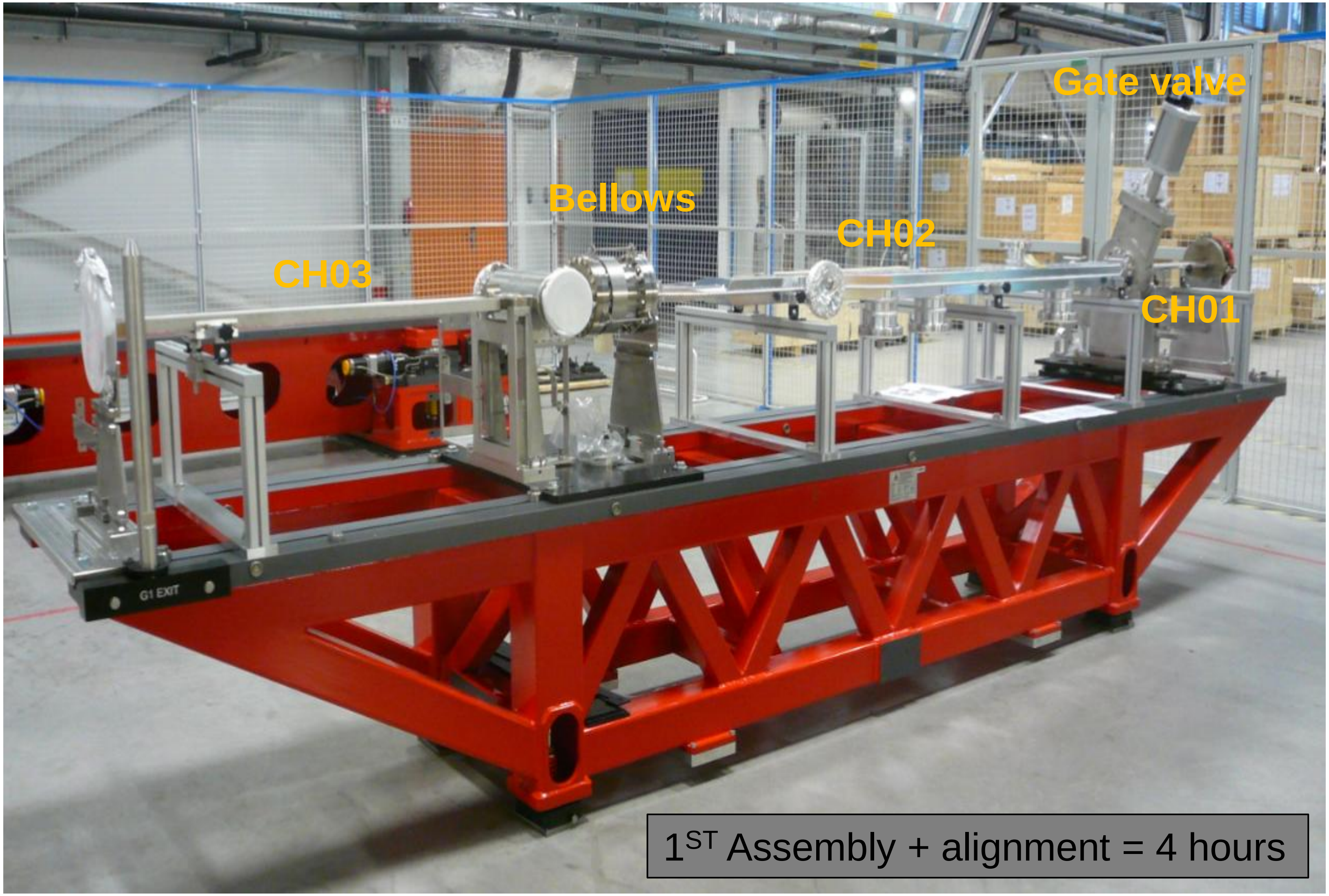
SEQUENCE OF MAGNET INSTALLATION



SEQUENCE OF VACUUM ASSEMBLY

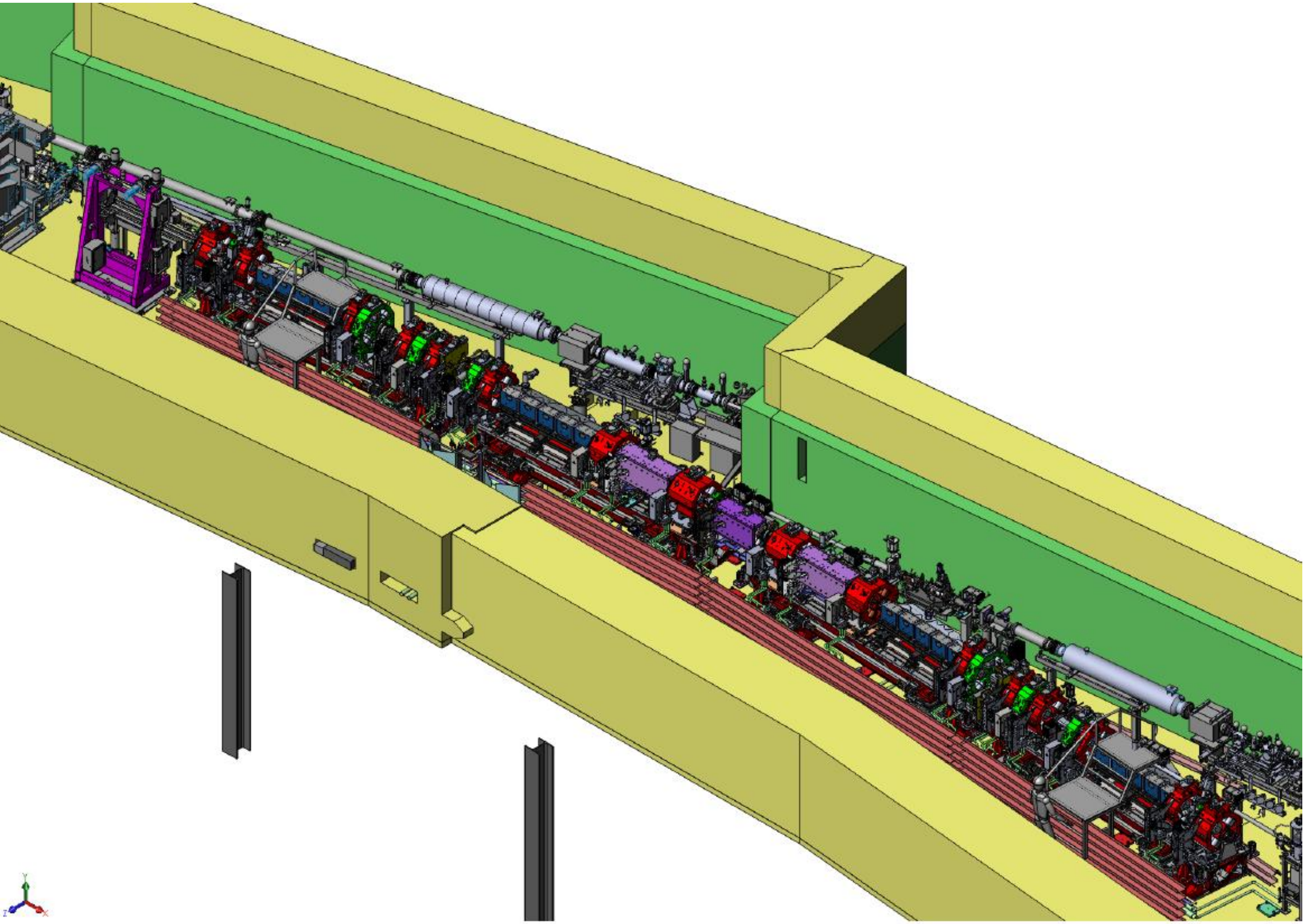


STATUS - VACUUM ASSEMBLY – GIRDER 1



1ST Assembly + alignment = 4 hours

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



“Standard cells”
Design in progress

“Specific cells”
C5 – C7 – C25 (RF)

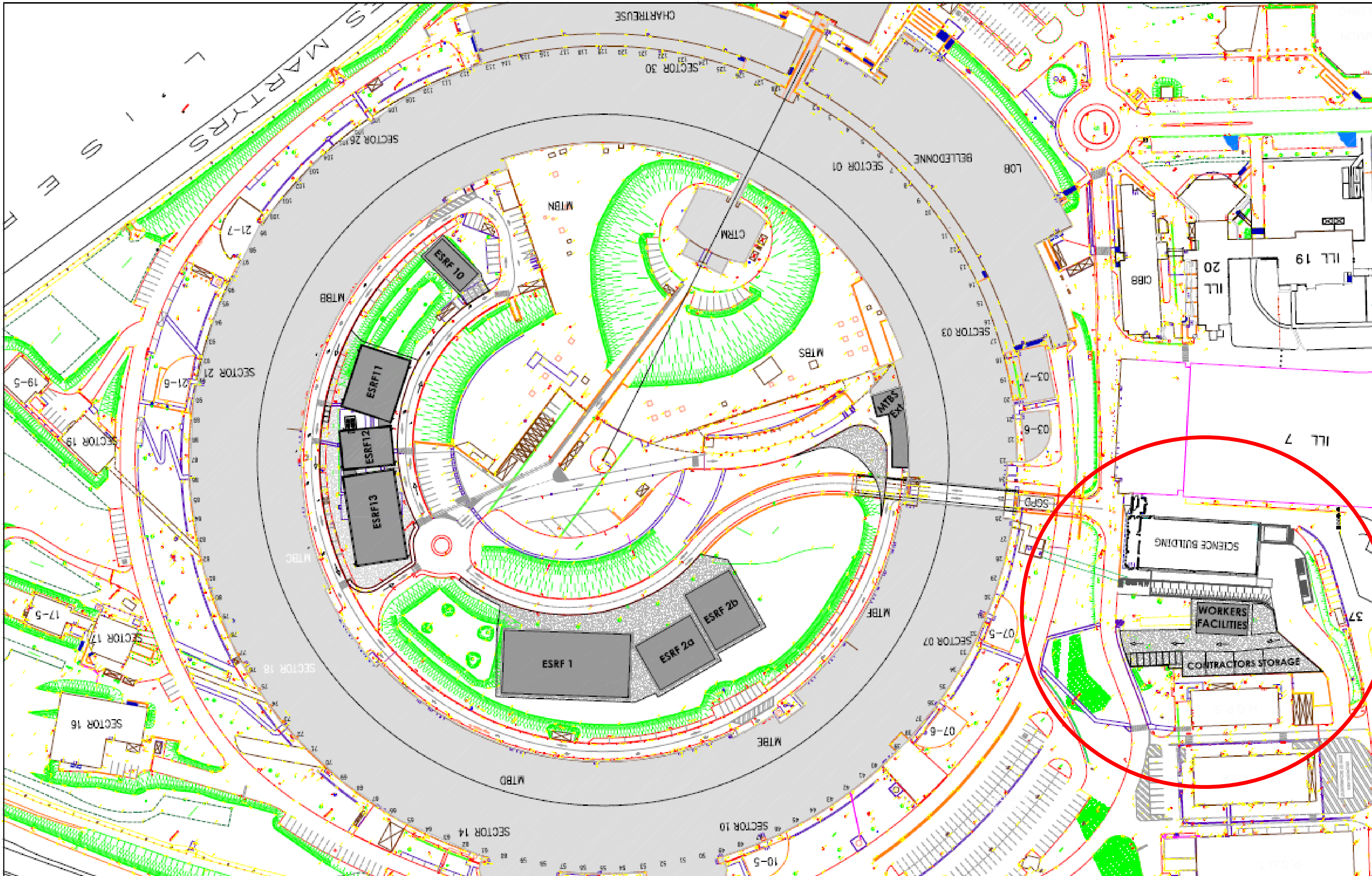
“Specific cells”
C13 - C24 (Collimator)

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)

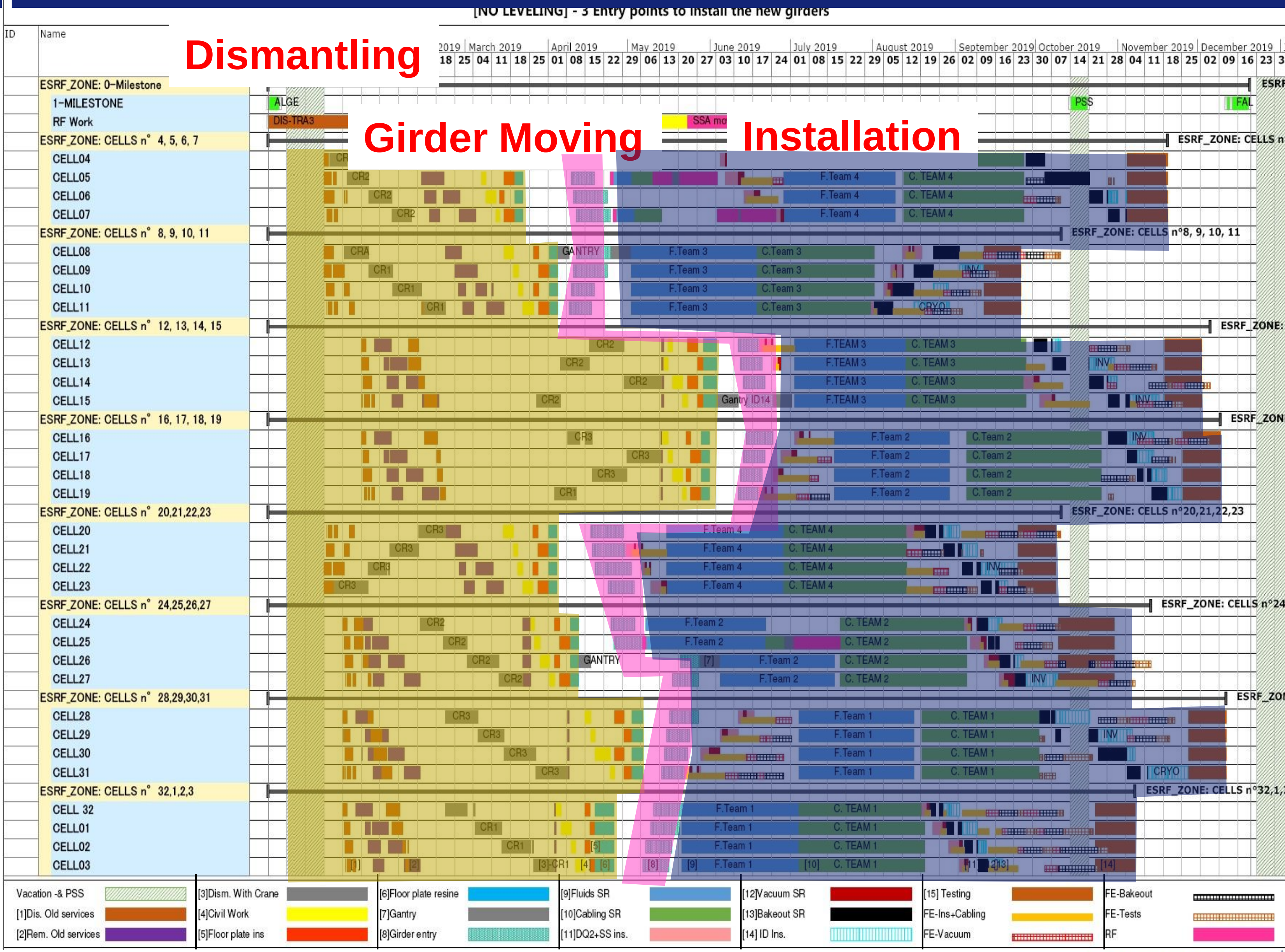


ESRF01 – ESRF02 A/B – WORKS IN PROGRESS

Main steps since the last MAC (4):

- Metallic structure
- Facade
- Overhead crane
- Ground preparation - Asphalt
- Concrete slab
- Facilities

DISMANTLING – INSTALLATION – PLANNING OVERVIEW



The European Synchrotron | ESRF

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