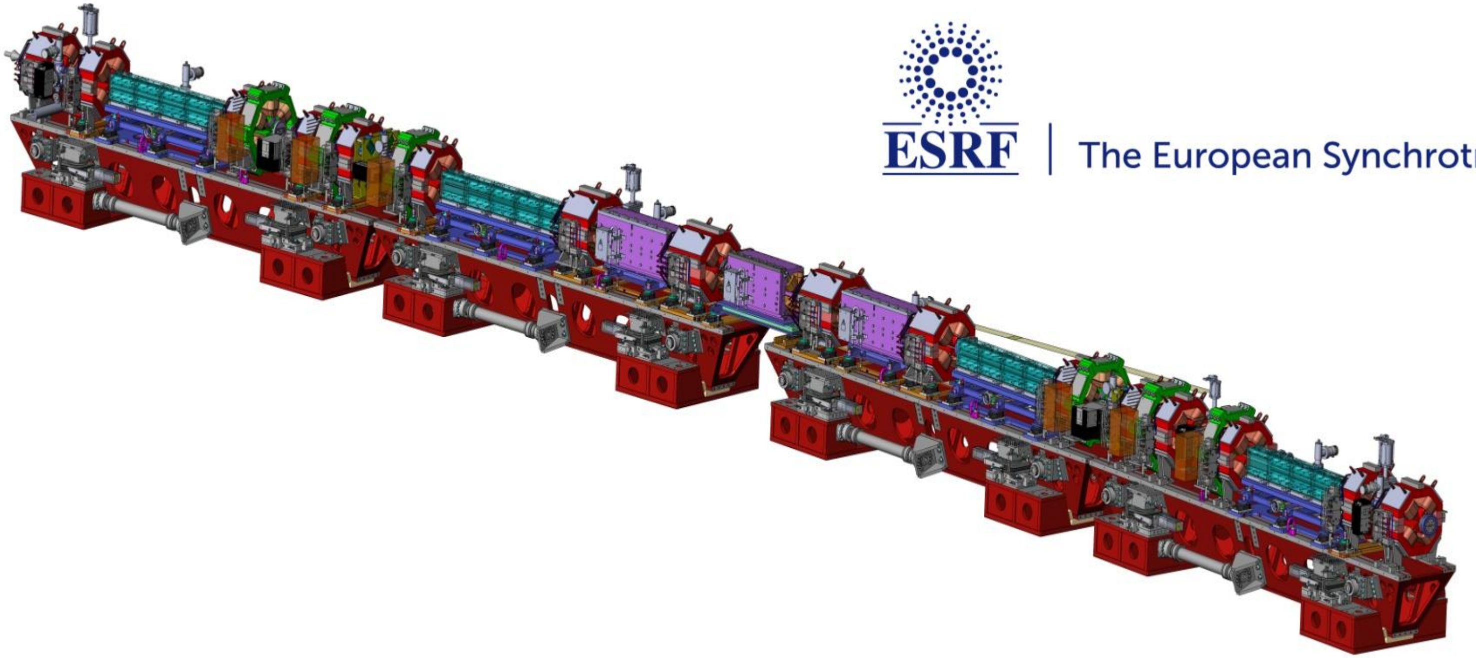
ESRF EBS Accelerator Upgrade

PSI, January 18th 2016

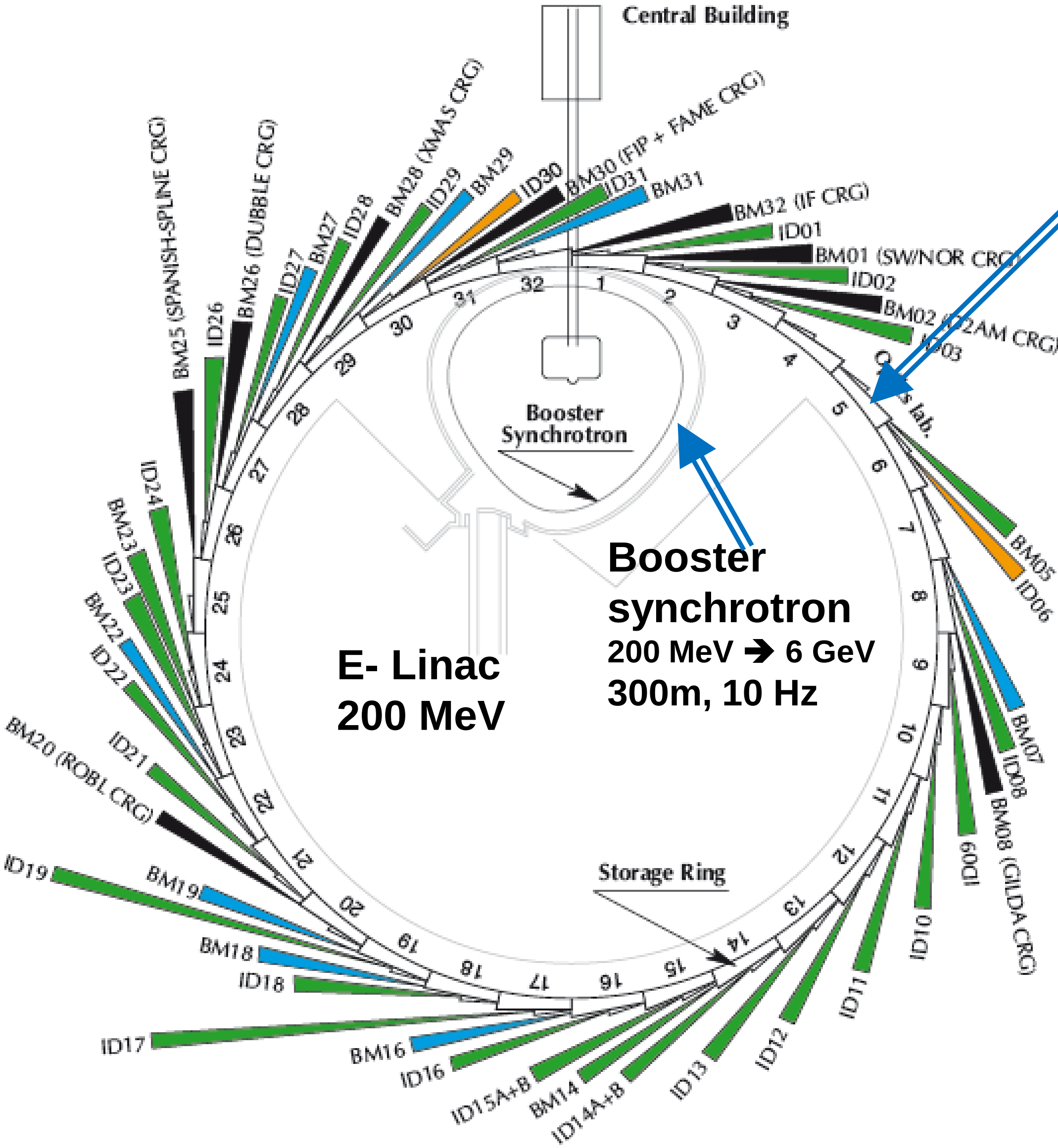
Pantaleo Raimondi

On behalf of the Accelerator Project Phase II Team



ESRF | The European Synchrotron

ESRF TODAY



Storage ring
6GeV, 844 m

Booster synchrotron
200 MeV ➔ 6 GeV
300m, 10 Hz

E- Linac
200 MeV

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:

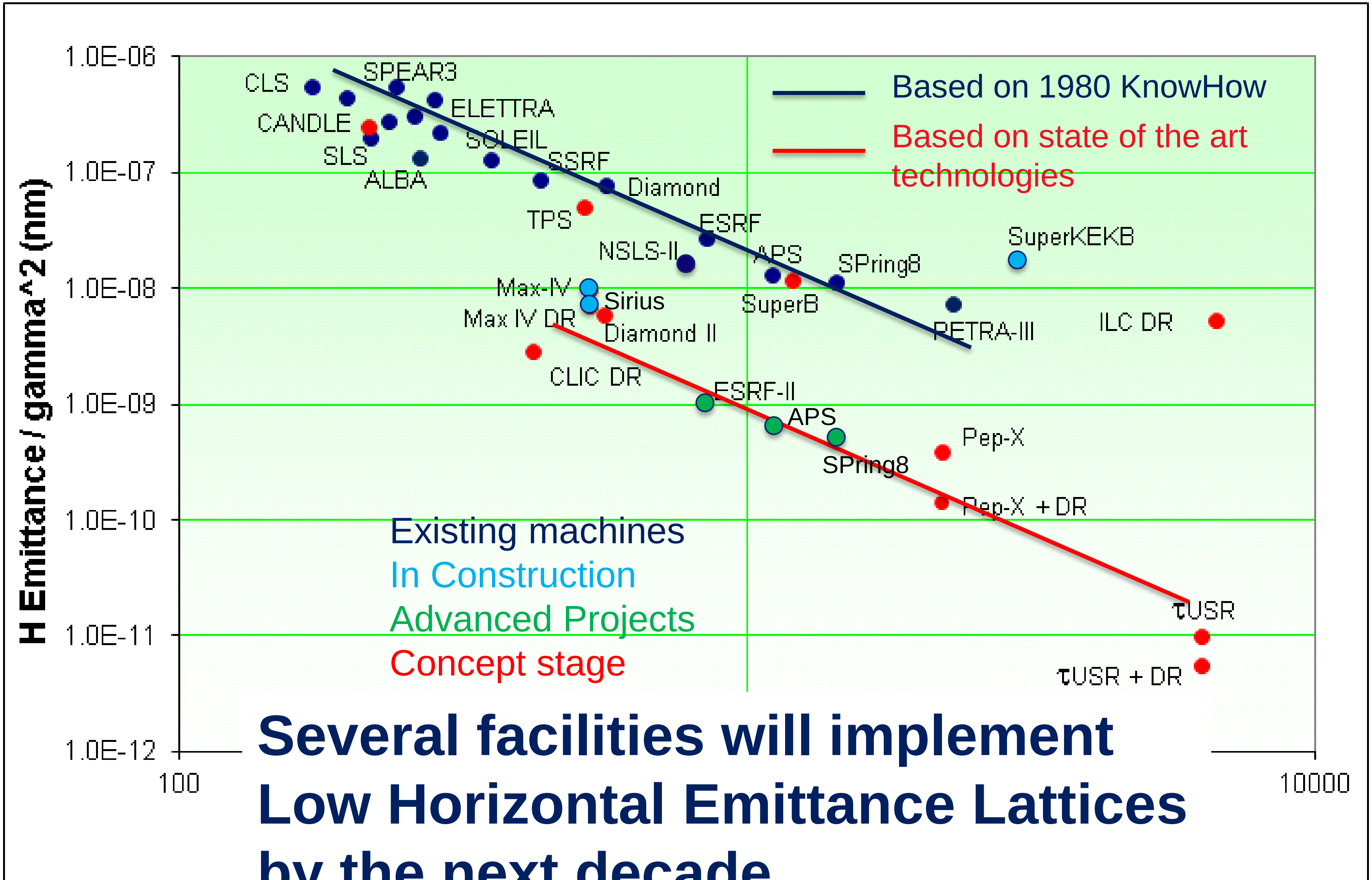
- Substantially decrease the Store Ring Equilibrium Horizontal Emittance
- Increase the source brilliance
- Increase its coherent fraction

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.

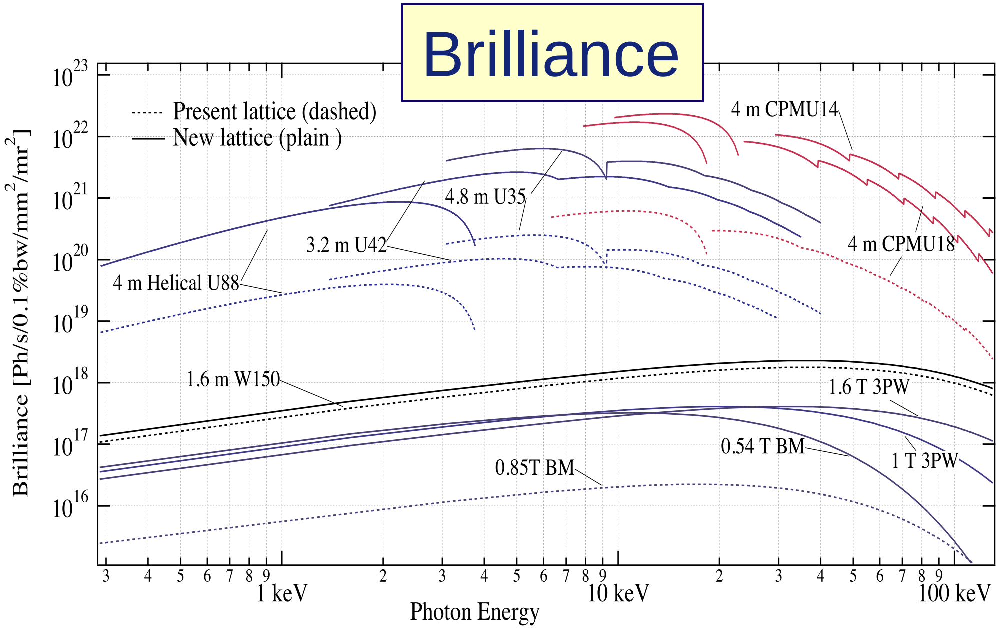
Maintain standard User-Mode Operations until the day of shut-down for installation

LOW EMITTANCE RINGS TREND



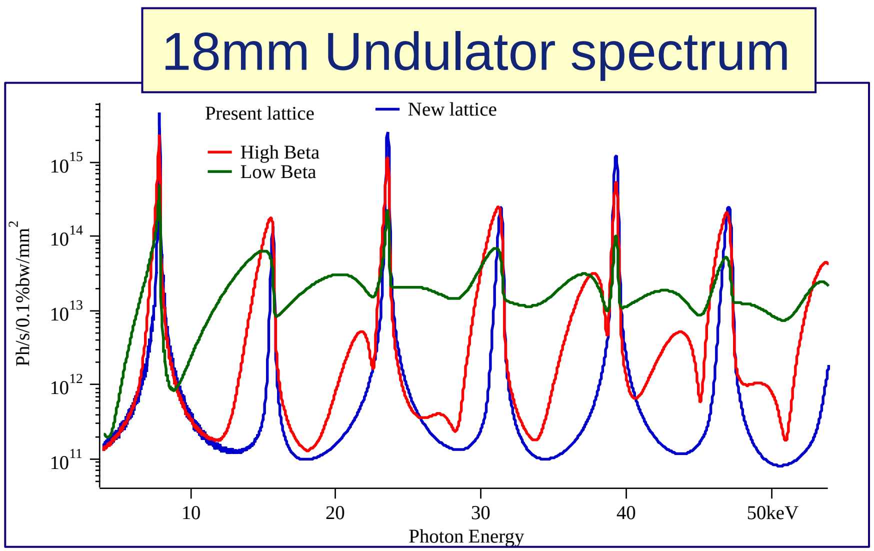
Several facilities will implement Low Horizontal Emittance Lattices by the next decade

BRILLIANCE AND COHERENCE INCREASE

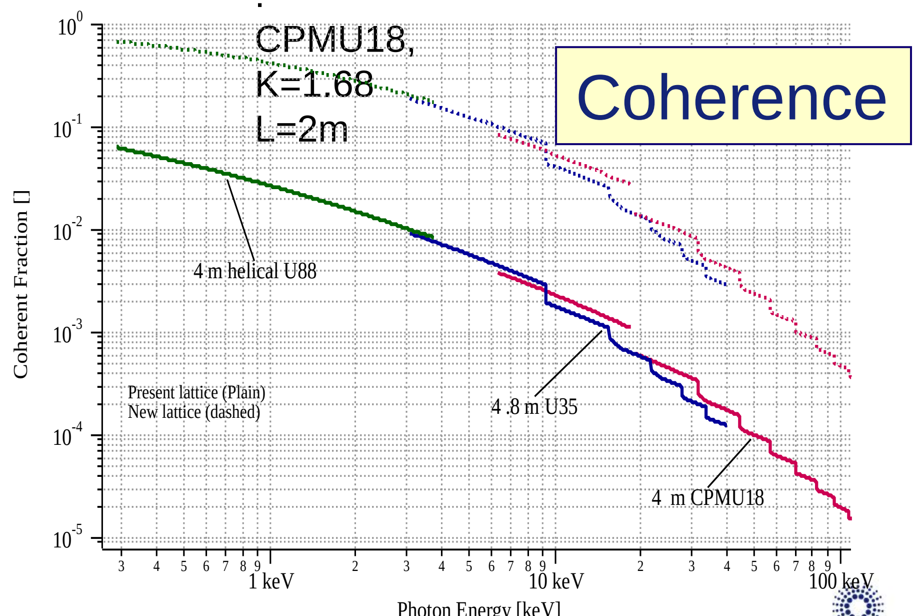


Hor. Emittance [nm]	4	0.135
Vert. Emittance [pm]	4	5
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

Source performances will improve by a factor 50 to100



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

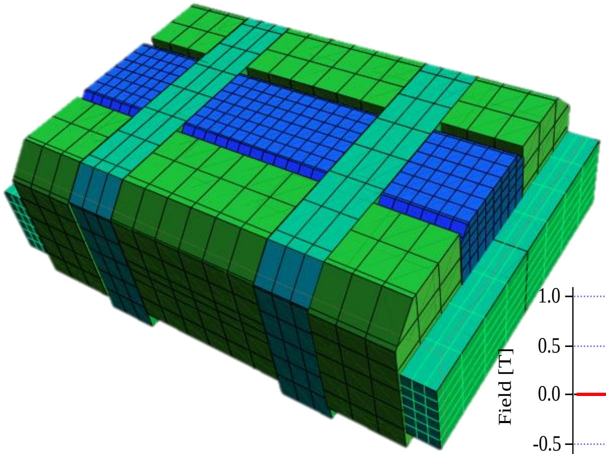
Conflict with hard X-ray demand from BM beamlines

ESRF will go from 0.85 T BM to 0.54 T BM

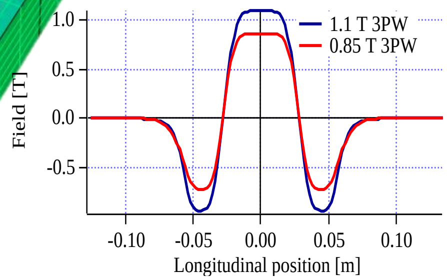
The BM Sources will be replaced by dedicated 2-Pole or 3-Pole Wigglers

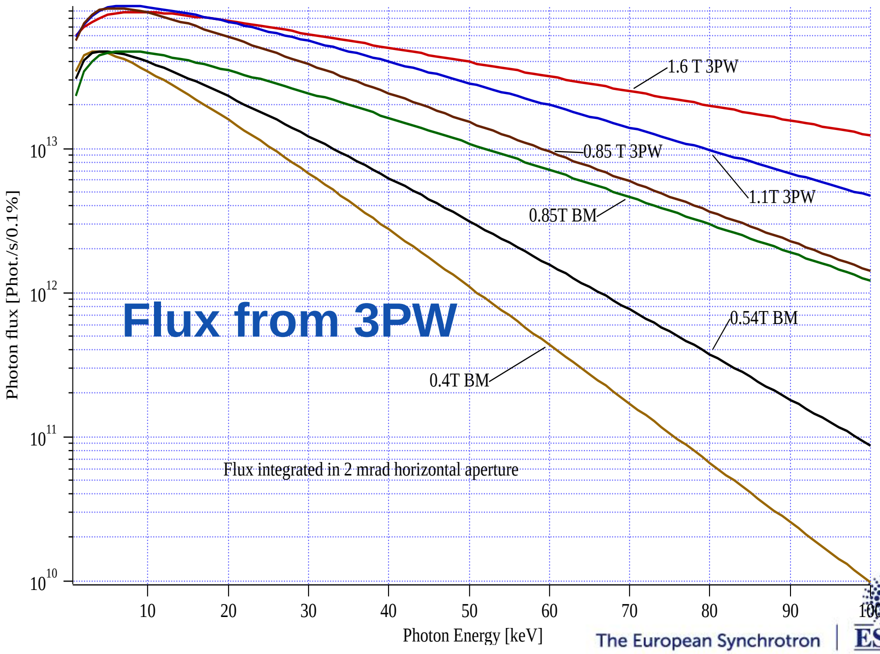
- Field Customized
- Large fan with flat top field
- 2 mrad feasible for 1.1 T 3PW
- Mechanical length ≤ 150 mm

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

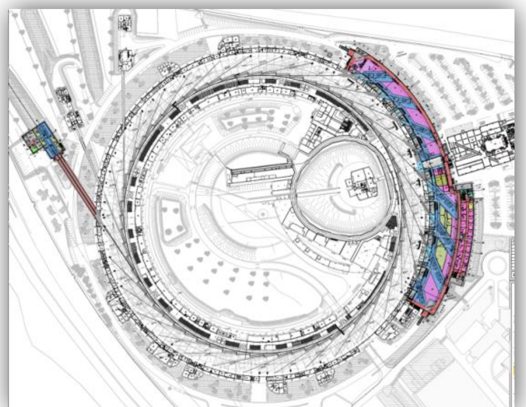


Half assembly

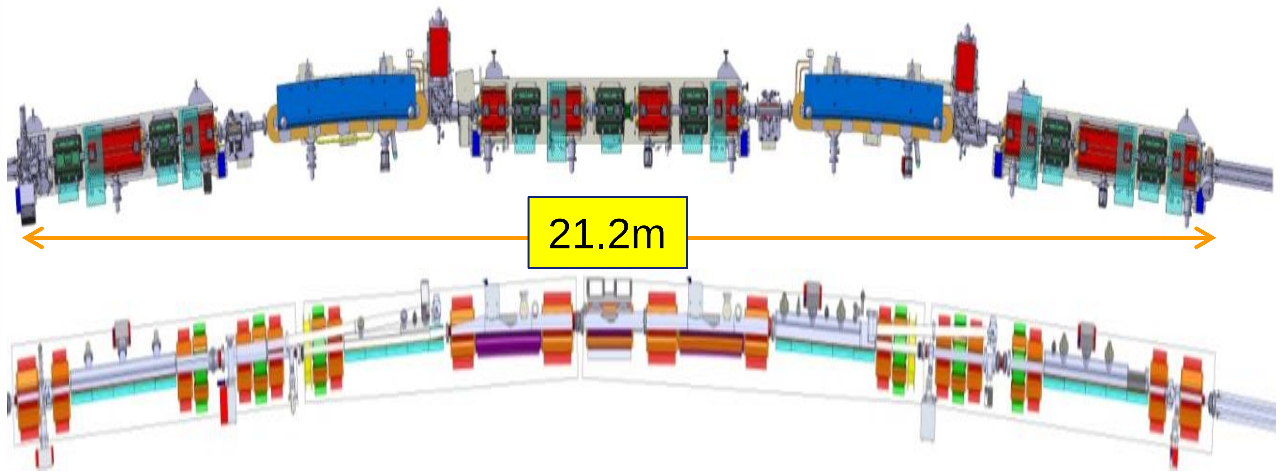




ESRF Phase II Upgrade at the Bone



Present ESRF Arc Layout: Ex=4nm

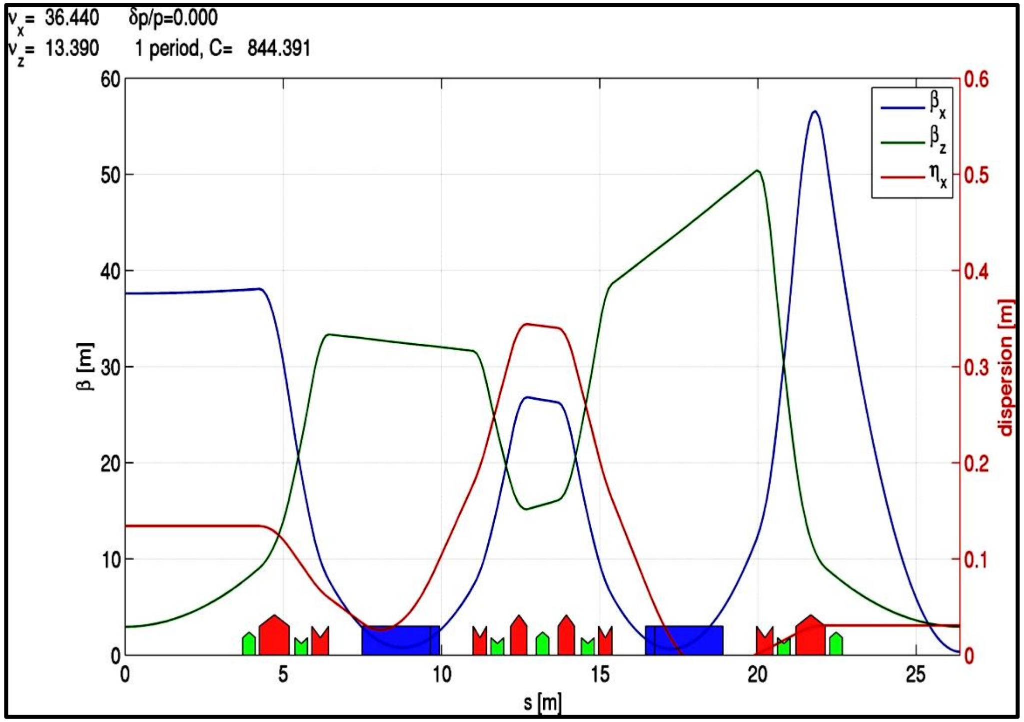


New Low Emittance Layout: Ex=0.135nm

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.

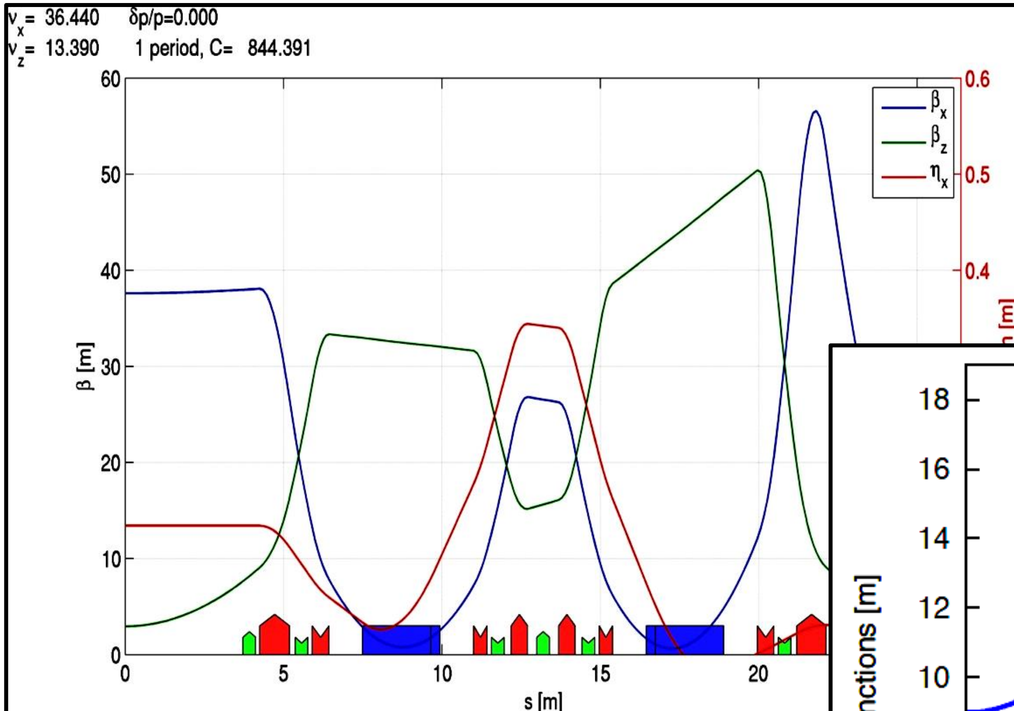
All the Arcs will be replaced by a completely new Layout



Double-Bend Achromat (DBA)

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

THE EVOLUTION TO MULTI-BEND LATTICE



Double-Bend Achromat (DBA)

- Many 3rd gen. SR sources
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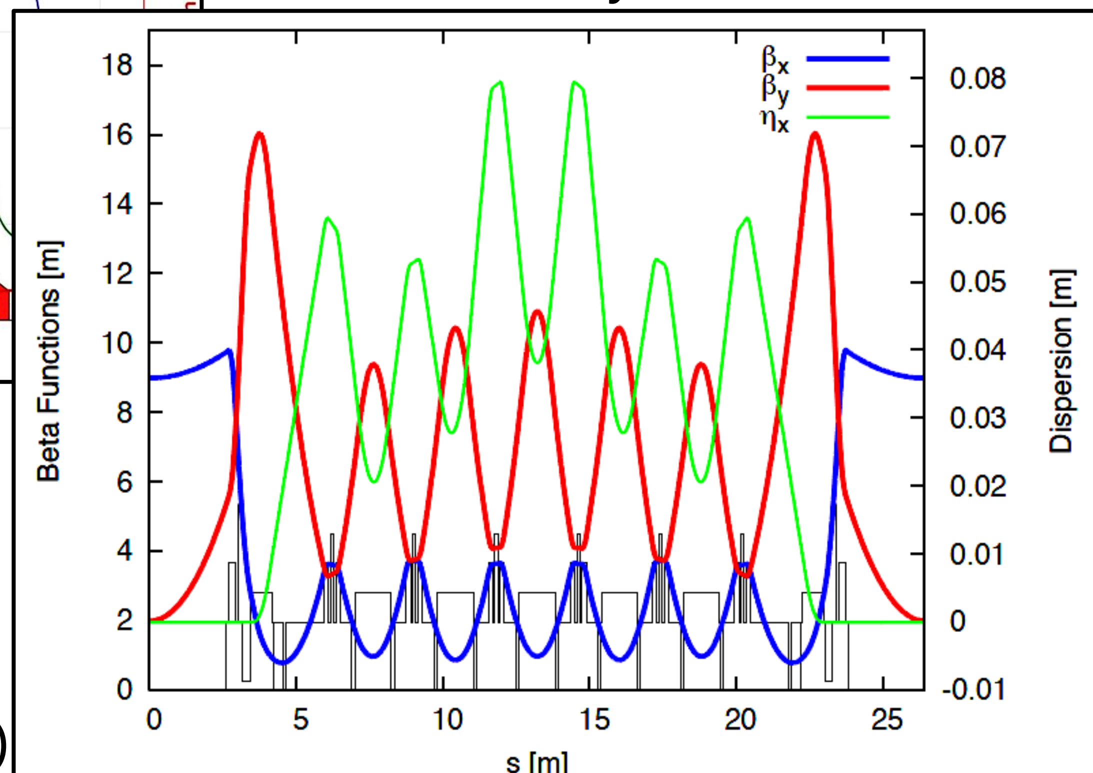
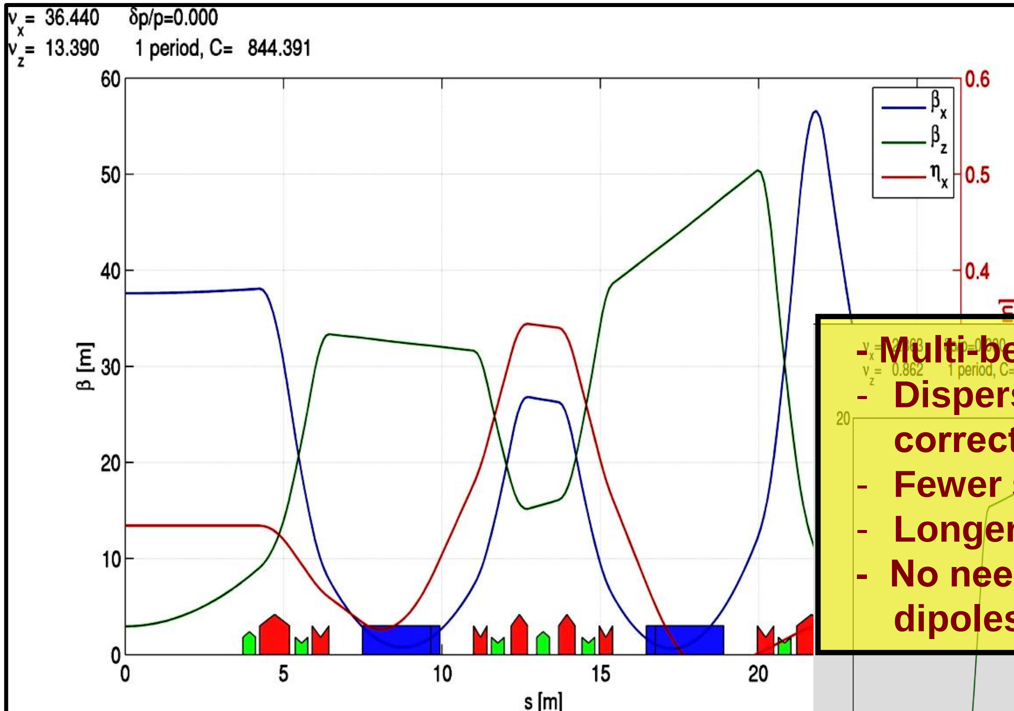


Multi-Bend Achromat (MBA)

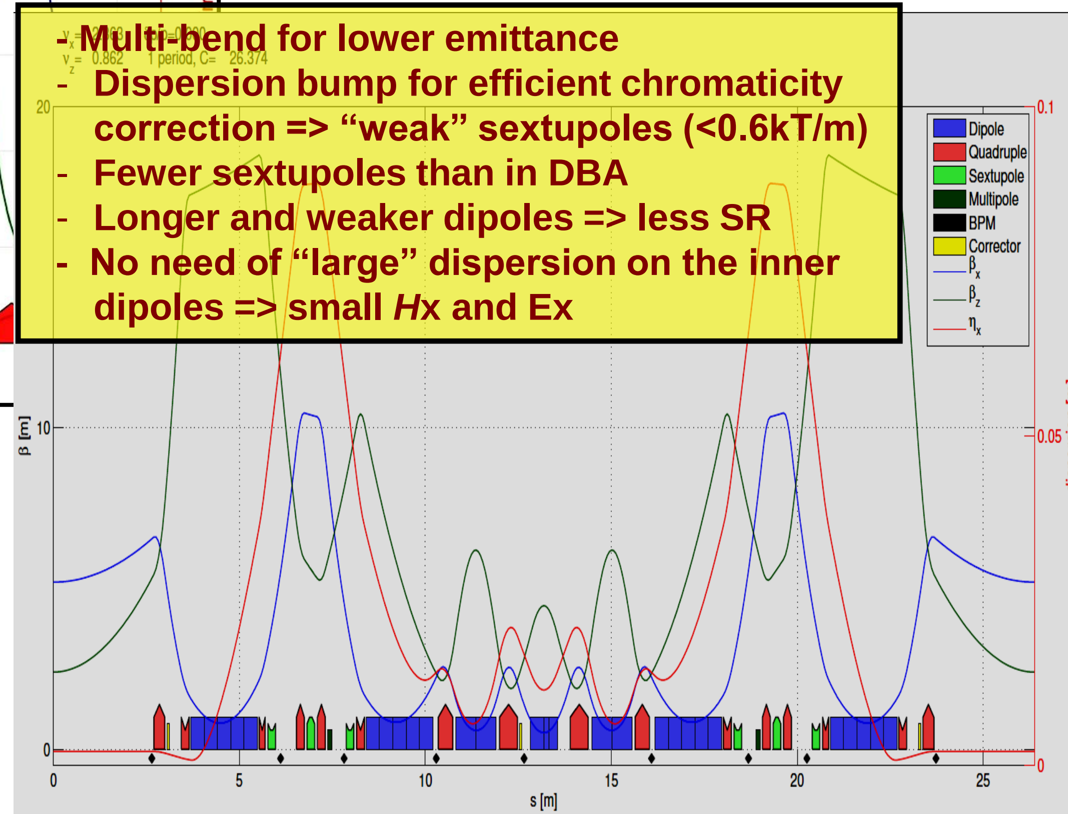
- MAX IV and other USRs
- No dispersion bump, its value is a trade-off between emittance and sextupoles (DA)

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)

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.

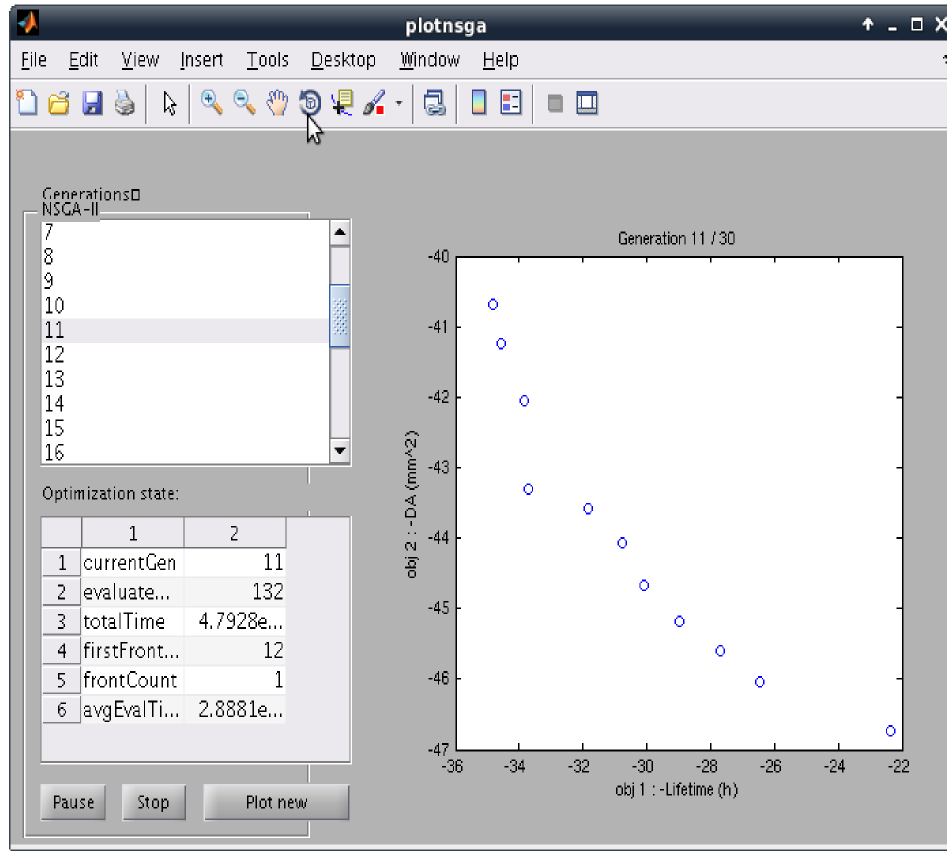
Sextupoles: from 6 to 3 families, weaker and shorter.

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

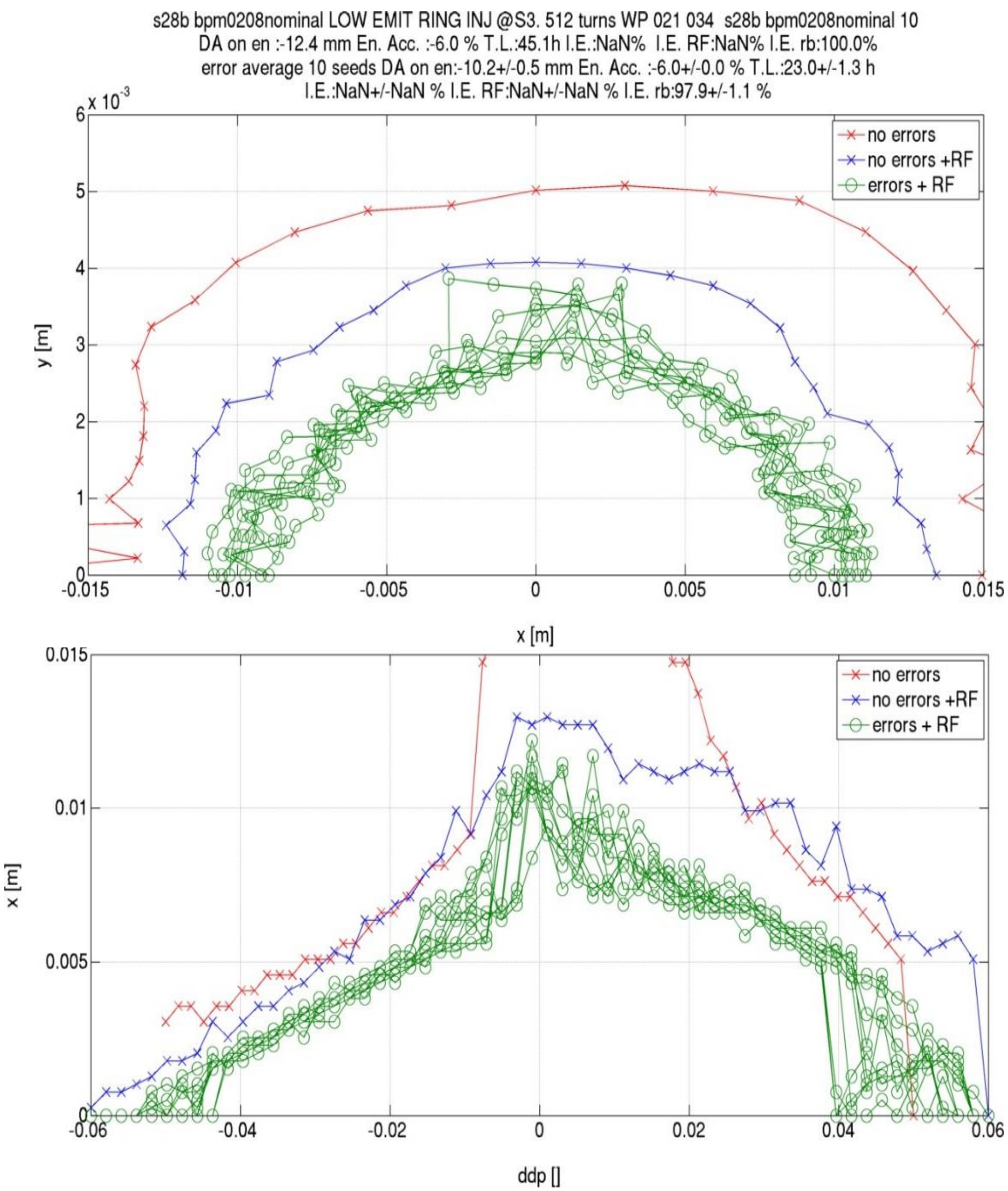
Tunes: 76.21 27.34

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

Chromaticities: 6, 4



LIFETIME OF S28B



S28A

DA -8.1mm@S3

TLT ~ 13h.

S28B

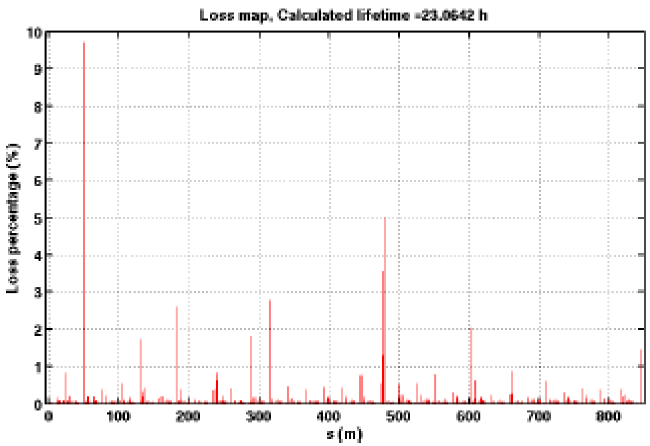
DA -10mm@S3

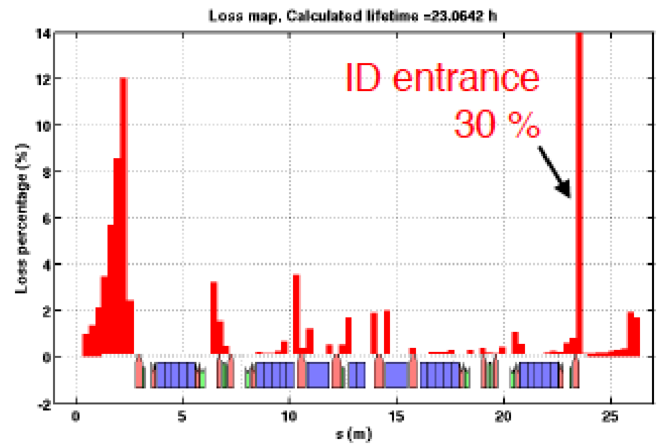
TLT ~ 21h

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

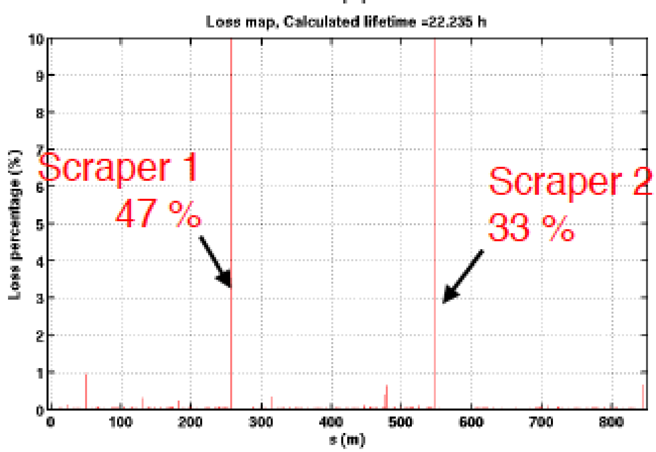
COLLIMATION OPTIMIZATION TO DECREASE LOSSES IN THE IDS

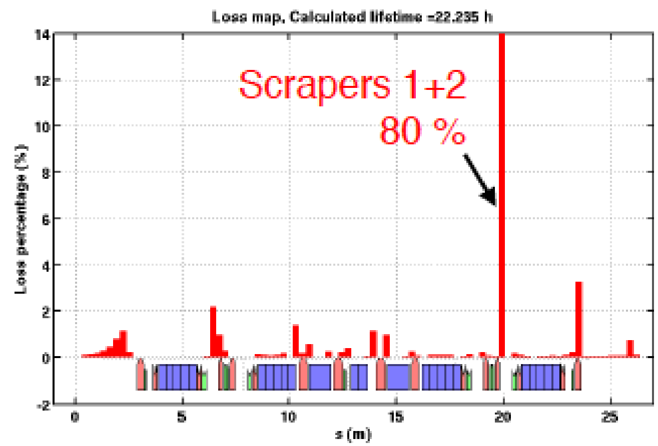
80% of the losses are relocated on the scrapers for 4% lifetime reduction:





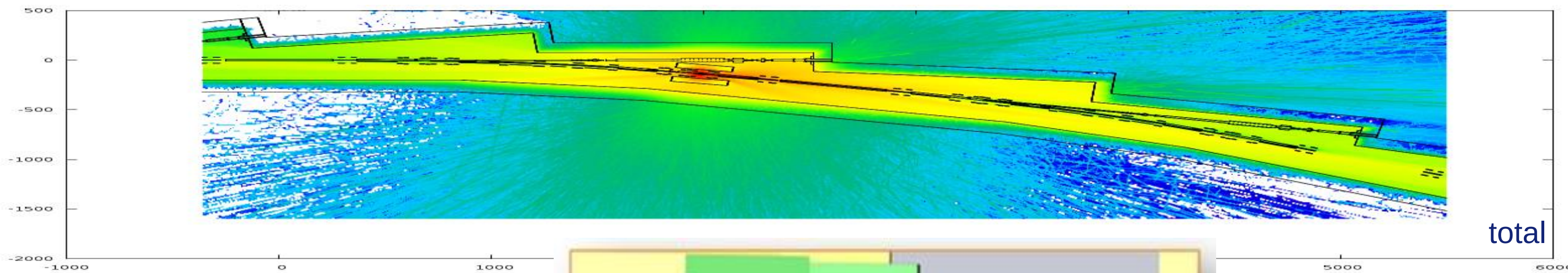
No scrapers

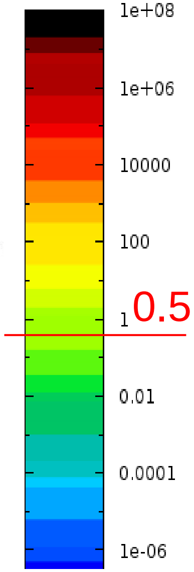


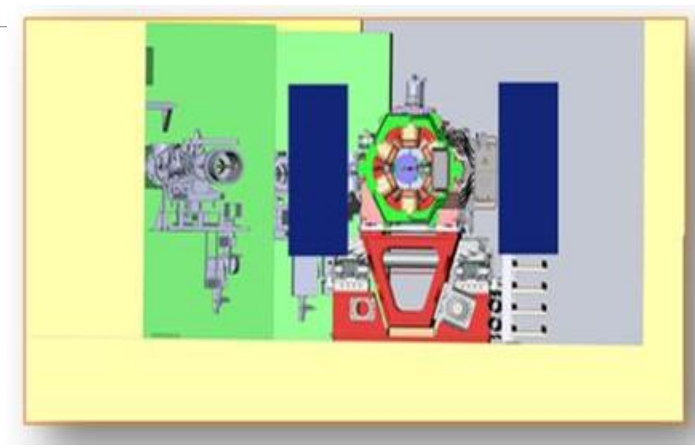


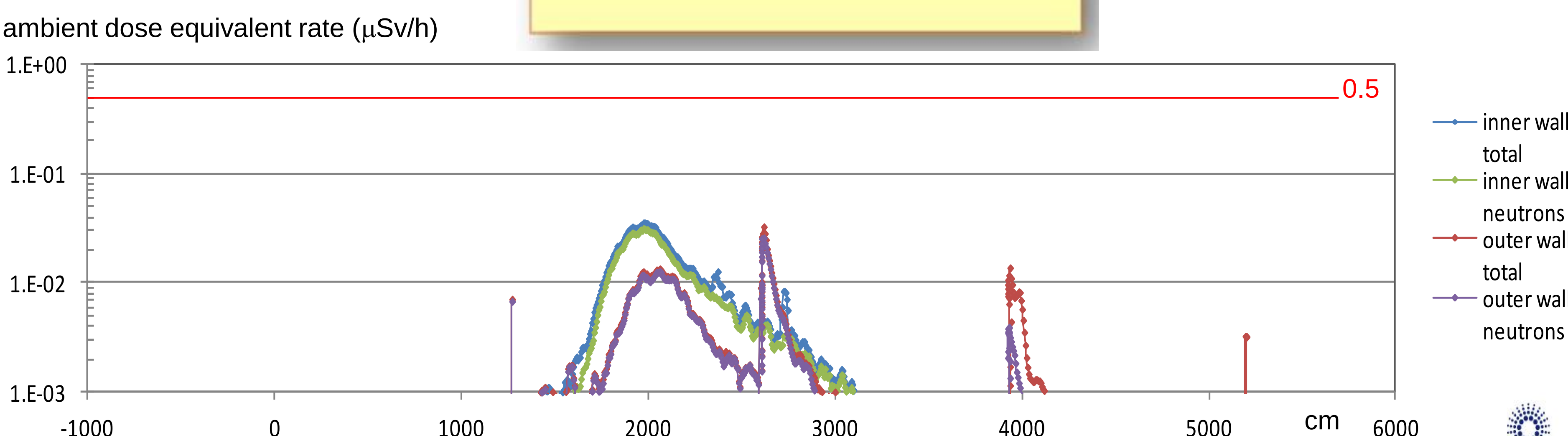
Two scrapers in DR_37 of cells 13 and 24

50 CM LEAD LOCAL SHIELDING









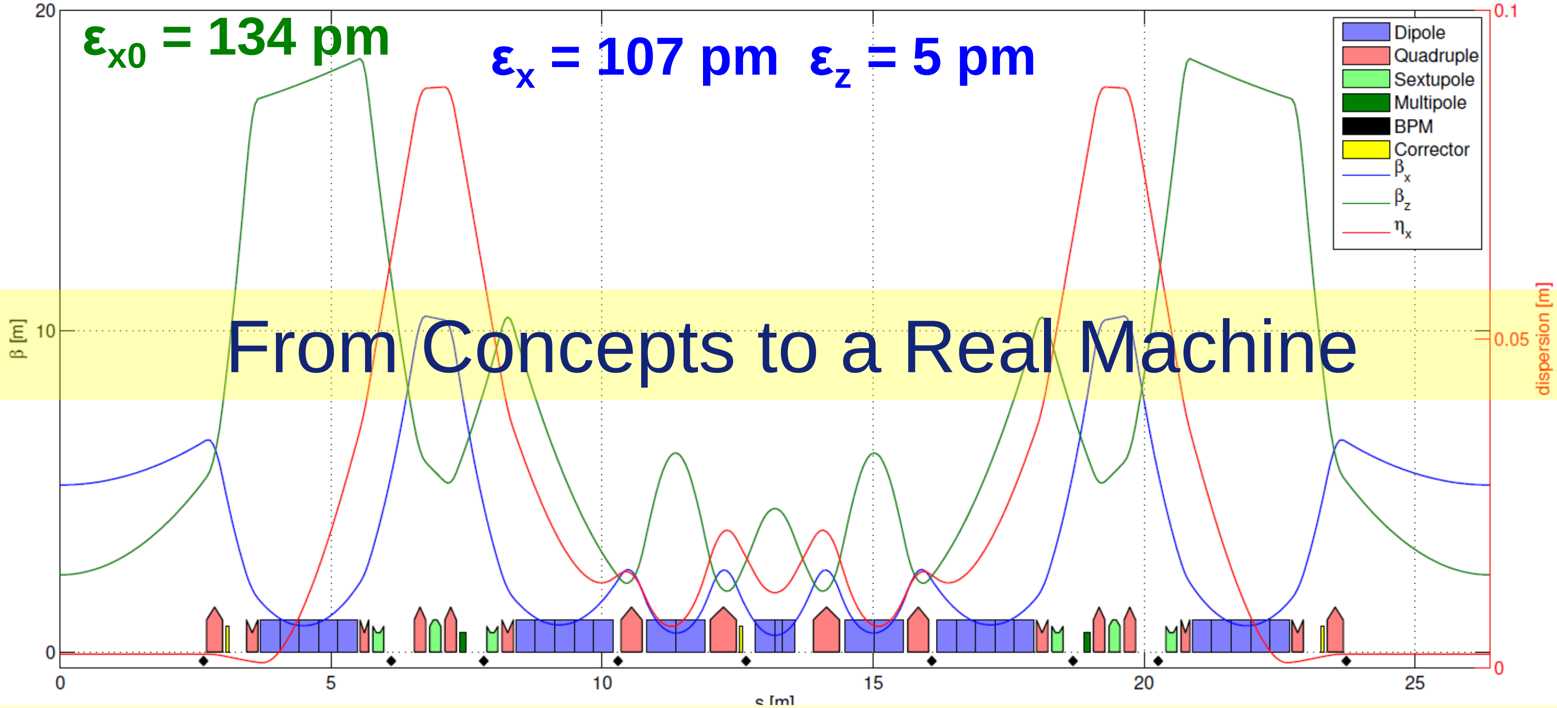
The ESRF Low Emittance Lattice

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

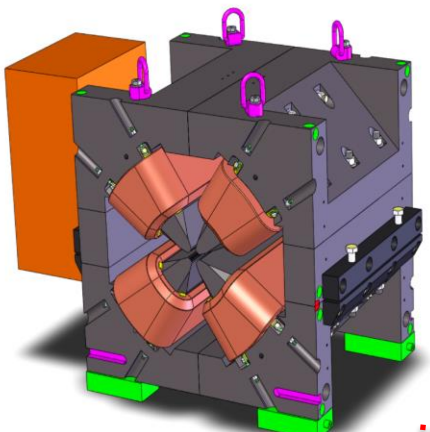


From Concepts to a Real Machine

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

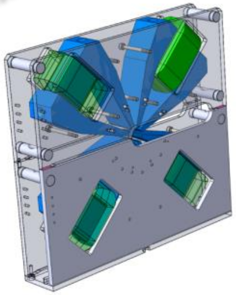
Technical challenge: Magnets System

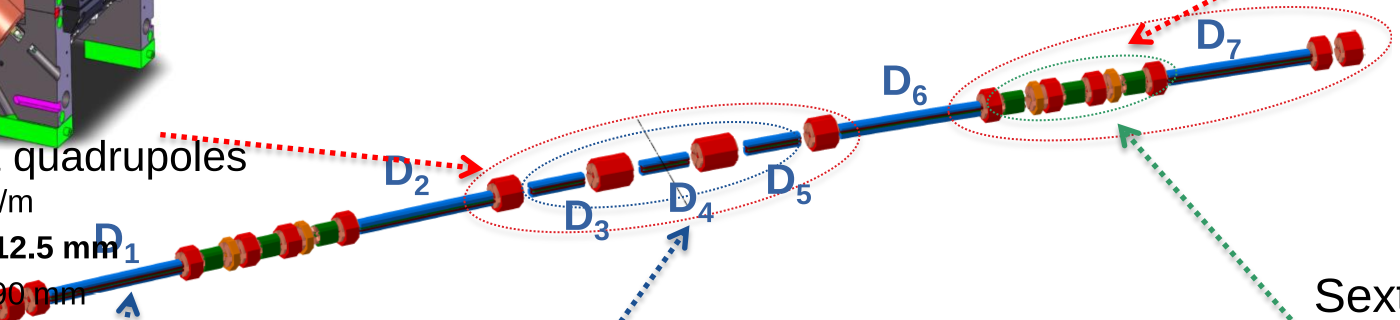


Mechanical design final drawing phase

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

Quadrupole
Around 52Tm^{-1}





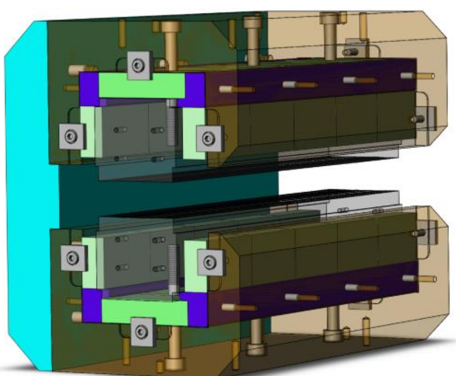
High gradient quadrupoles

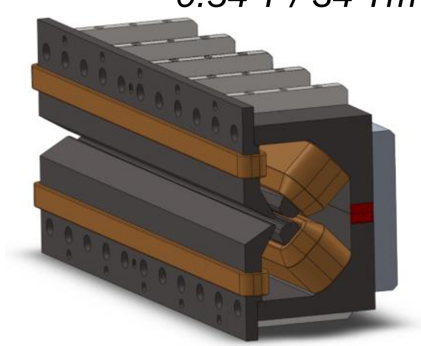
- Gradient: 90 T/m
- **Bore radius: 12.5 mm**
- Length: 390/490 mm
- Power: 1-2 kW

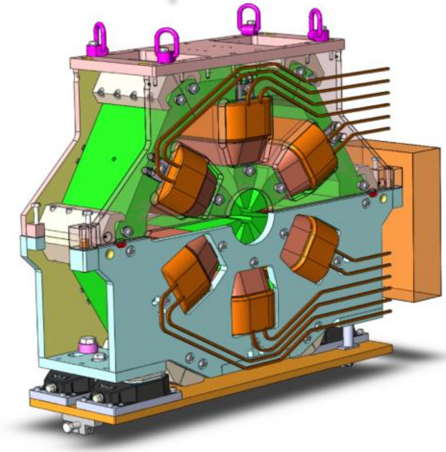
Octupoles

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

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







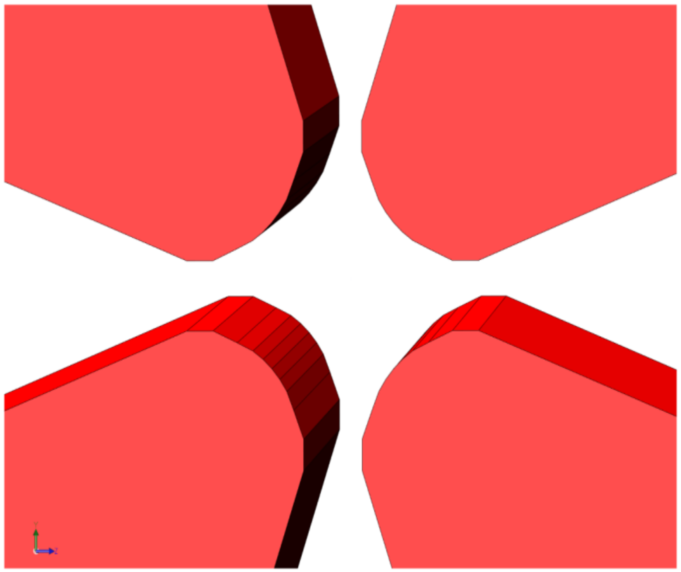
Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 – 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

Gael Le Bec

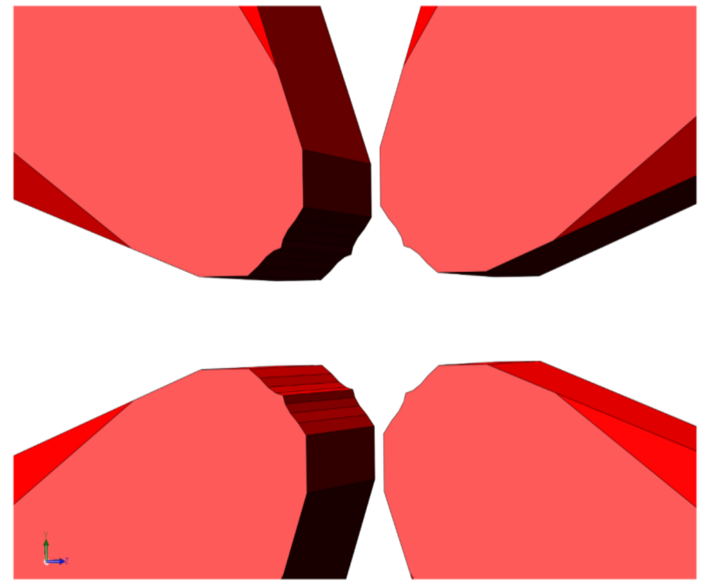
QUADRUPOLES DESIGN

Pole shape optimization

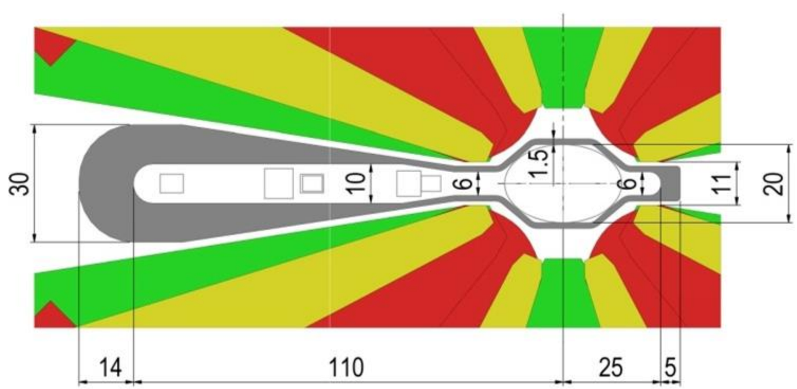
Imposed 11mm stay clear from pole to pole for all magnets for optimal synchrotron radiation handling



Low gradient pole profile



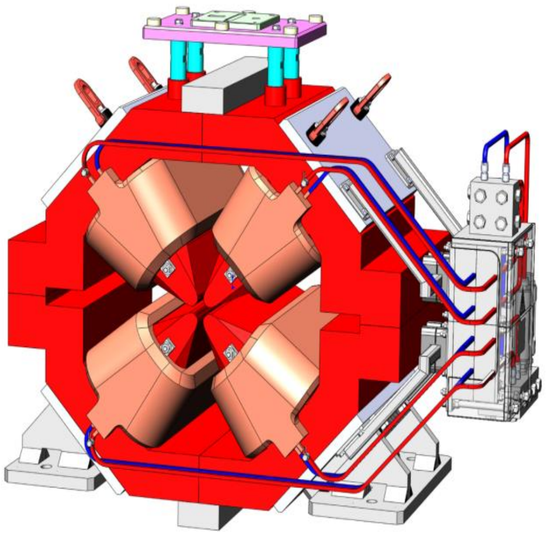
High gradient pole profile



Vacuum chamber and magnets sections

QUADRUPOLES

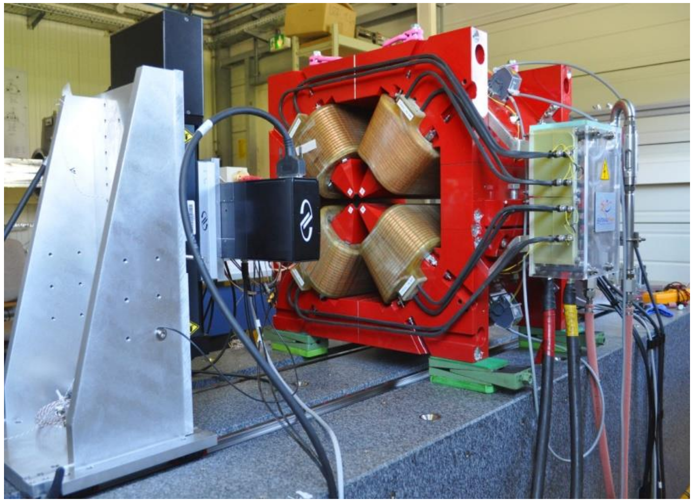
High Gradient



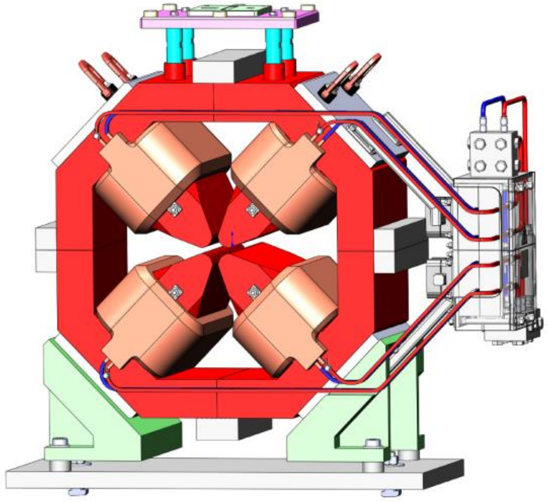
- 91 T/m gradient, 388 – 484 mm length
- 12.7 mm bore radius, 11 mm vertical gap
- 1.4 – 1.6 kW power consumption

HG Prototype

+/-20um pole accuracy



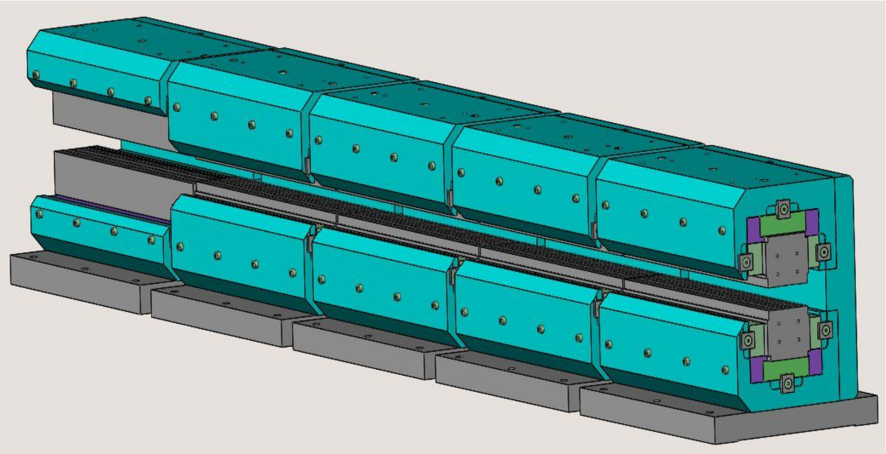
Moderate Gradient



- 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

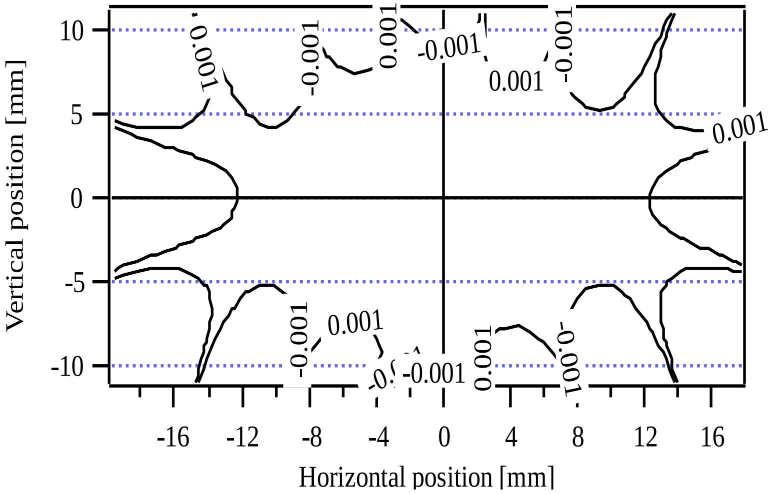


Engineering design

- Final drawings produced

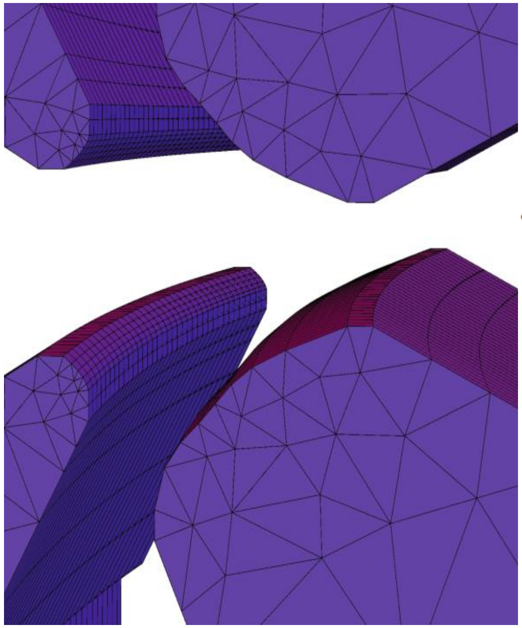
Prototyping

- Final prototype to be build in the coming months

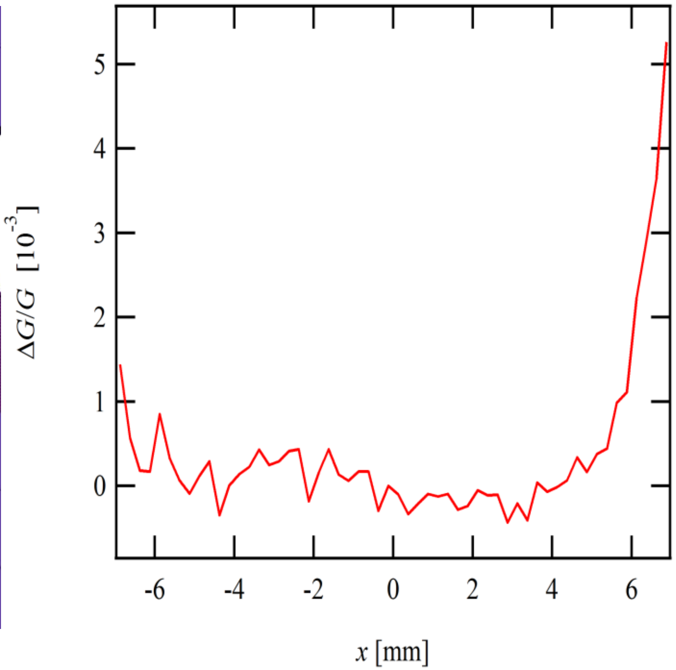


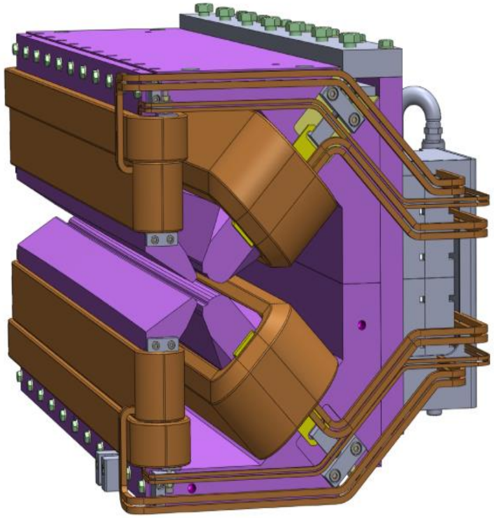
Measured field integral homogeneity (one module)

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

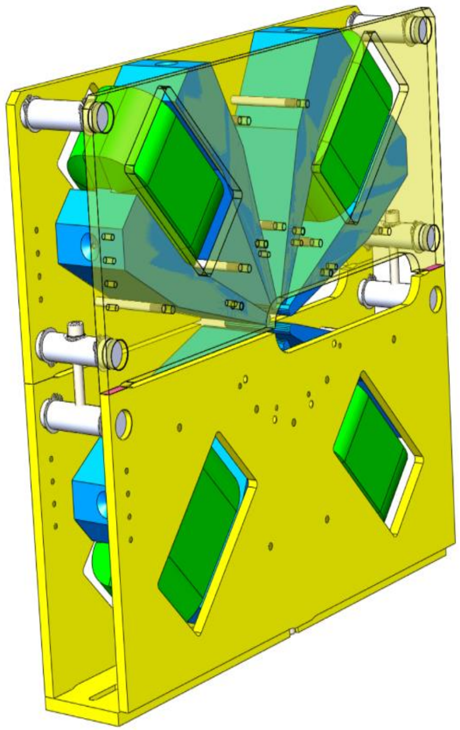
$\Delta G/G$ < 1% (GFR radius 7 mm)

DQs are machined in 7 laminated iron plates

OCTUPOLES

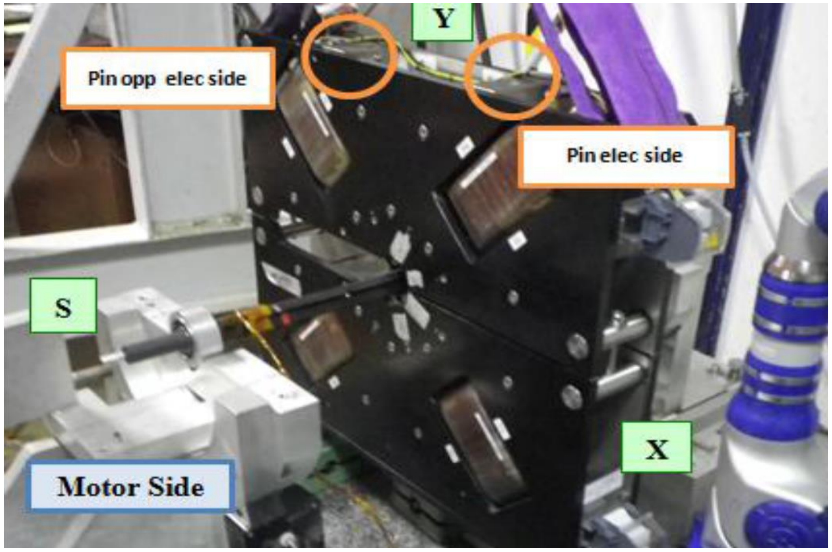
S28b specifications

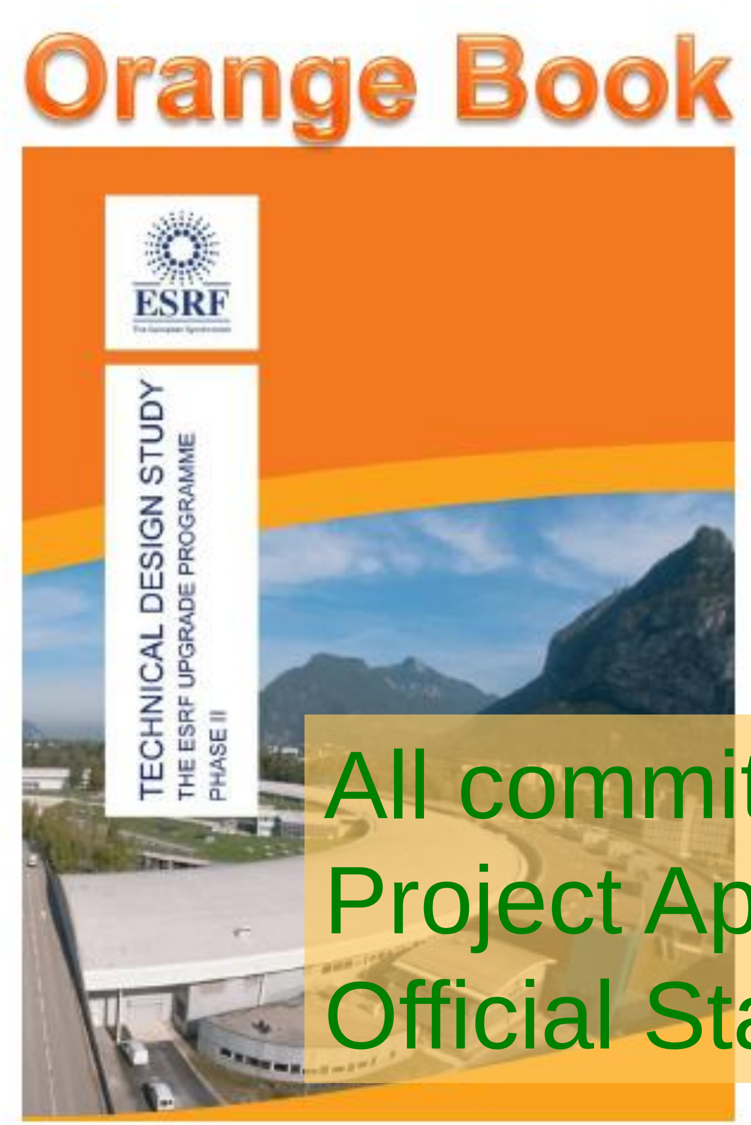
- 48 kT/m^3 nominal strength (70 kT/m^3 maximum)
- 90 mm length
- 4 Water cooled coils at the return-field yoke
- Allows for the required stay-clear for Synchrotron Radiation fans



Prototyping

- Air cooled prototype measured





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
Official Start: Jan 1st 2015

PLANNING AND BUDGET

<u>Global Schedule</u>

Nov 2012	White paper
Nov 2012- Nov 2014	Technical Design Study / Orange Book
Jun 2014	Council Approval
Jan 2015	Start of the project
Jan 2015 – July 2016	Engineering Design
Jul 2015 – Jun 2018	Procurement
Sep 2017 – Oct 2018	Girder Assembly
Dec 2018	Start of the shutdown
Dec 2018 – Nov 2019	Dismantling and Installation
Dec 2019 – Jun 2020	Accelerator and Beamlines Commissioning
Jun 2020	Start of User Mode Operations

Budget:

100 M€ Construction of the new storage ring lattice

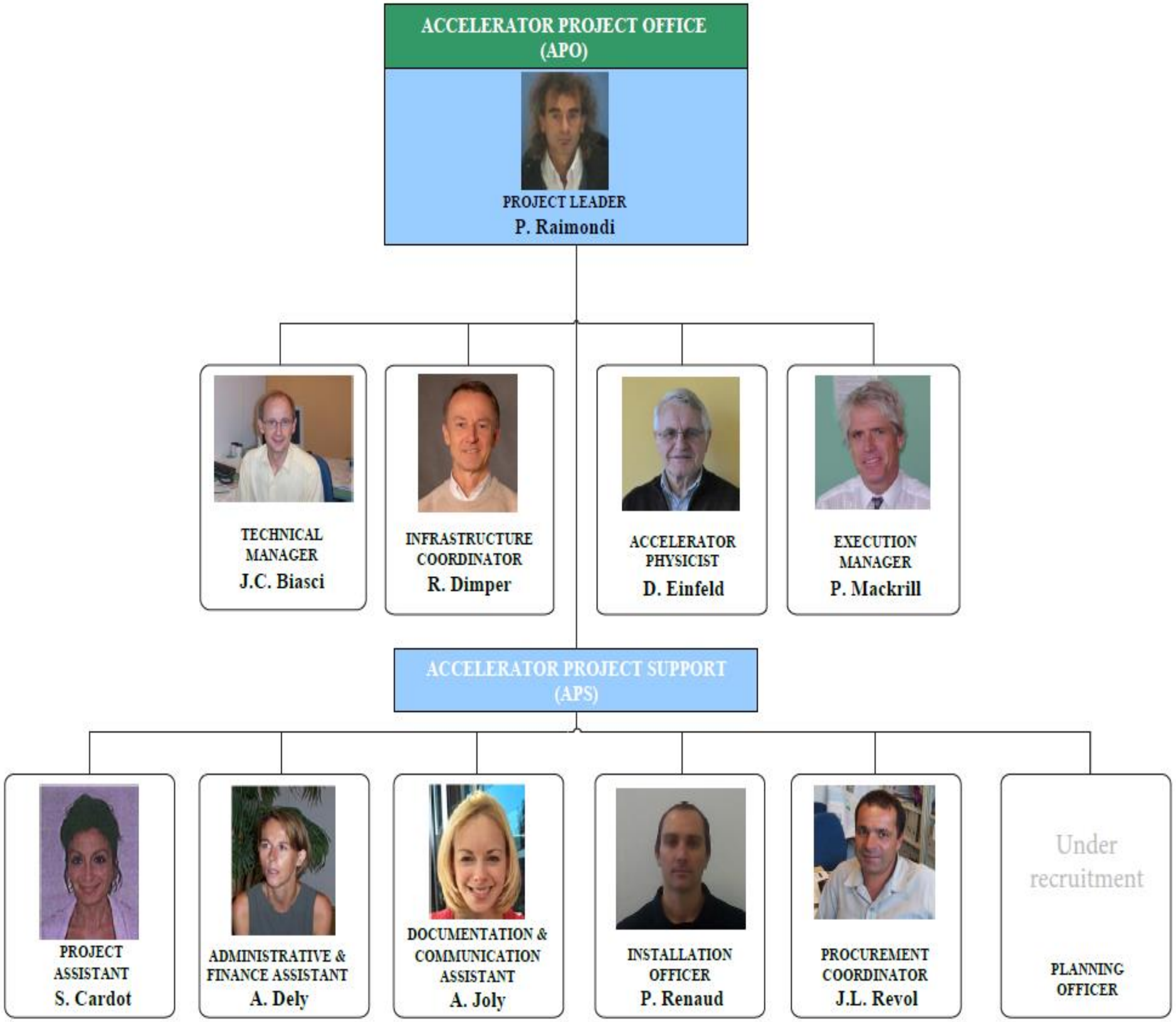
3.5 M€ Building programme for storage and pre-assembly

STATUS PROGRESS: GENERAL

- Project Organization and Project Management finalized
- WPs deliverables reviewed
- WPs budgets and spending profiles reviewed and finalized
- Master Schedule finalized
- Design phase nearly completed
- Procurement phase started
- 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

ORGANIZATION: ACCELERATOR PROJECT OFFICE



ESRF - EBS
Project Management Organisation Chart
25 November 2015

ACCELERATOR PROJECT MANAGEMENT STRUCTURE

Accelerator Project Office

WP-0 **Management** P. Mackrill	WP-5 * **Radio Frequency** J. Jacob	WP-10 **Vacuum** M. Hahn
WP-1 **Beam Dynamics** L. Farvacque	WP-6 **Control System** J.-M. Chaize	WP-11 **Buildings & Infrastructure** T. Marchial
WP-2 **Magnets** G. LeBec	WP-7 **Diagnostics & Feedbacks** K. Scheidt	WP-12 **Reliability & Operation** L. Hardy
WP-3 **Accelerator Engineering** J.-C. Biasci	WP-8 **Photon Source** J. Chavanne	WP-13 **Radiation Safety** P. Berkvens
WP-4 * **Power Supply & Elec. Engineering** J.-F. Bouteille	WP-9 * **Injector Upgrade** T. Perron	

* WP 4, 5 and 9 have both Phase I and Phase II deliverables (and budgets).

WP0, WP3, WP6, WP11, WP12, WP13 are highly transversal

STATUS PROGRESS: DESIGN

➢ **Design of all the components being finalized:**

- Magnets	**~95% (correctors, in progress)**
- Vacuum System	**~90% (one-of-a-kind chambers, in progress)**
- Absorbers	**~90%**
- Girders	**~100%**
- Supports	**~95%**
- Diagnostics	**~80% (Collimators, special chambers)**
- Power Supplies	**~80% (sizing optimization and hot-swap implementation)**

➢ **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

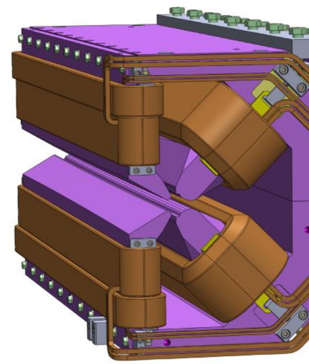
- Pre-Qualifications of companies has been performed for magnets and vacuum chambers
- No other components do require PQs
- All contracts for magnets expected by Spring 2016 (2 contracts placed in 2015)
- All contracts for vacuum chambers expected by Spring 2016 (several CFTs already launched)
- Girders contract(s) expected by March 2016
- Infrastructure adaptations finalized, CFTs expected by March 2016
- **All large scale procurements in place by mid 2016**
- Delivery will start by the end of 2016 for about 2 years

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

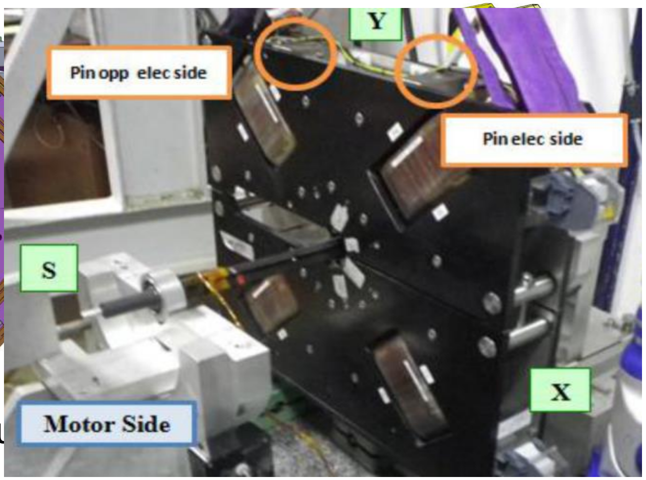
PROCUREMENT: MAGNETS

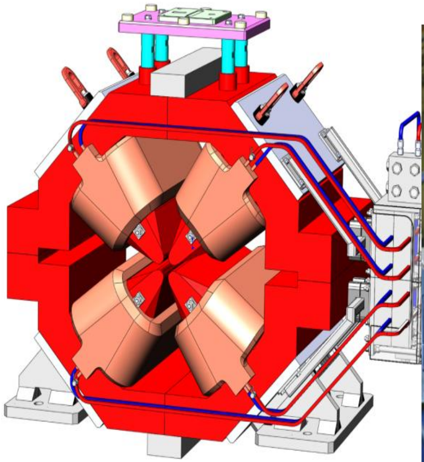
More than 1000 Magnets to be procured by the end of 2018

132 dipoles

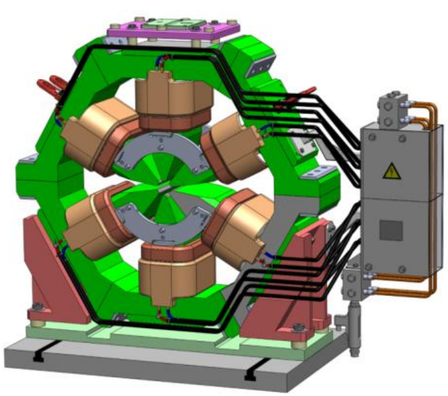


99 dipole-quadru

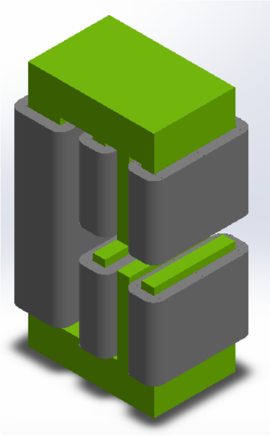




398 mod gradient quadrupoles



196 sextupoles

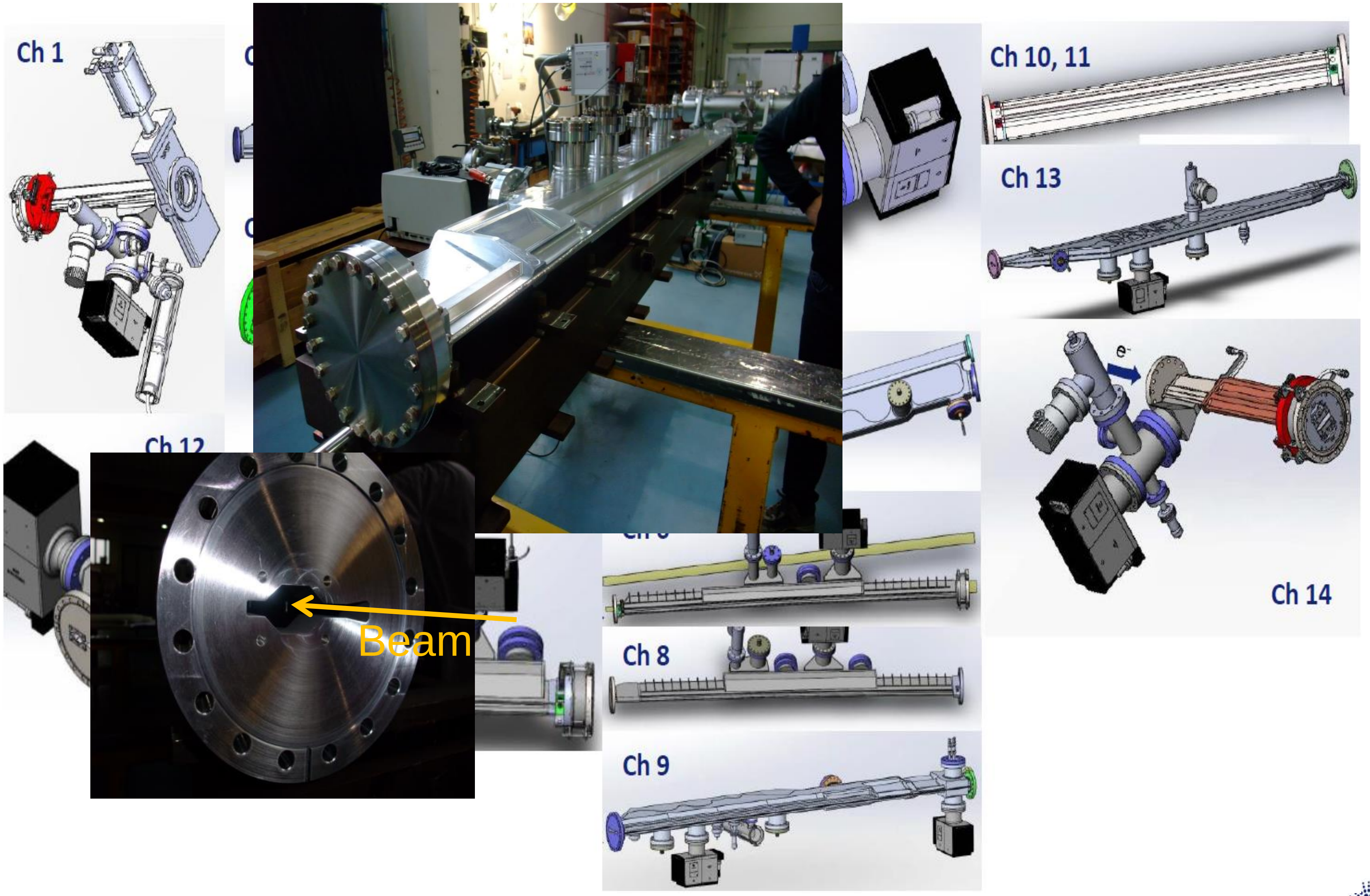


100 correctors

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

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.

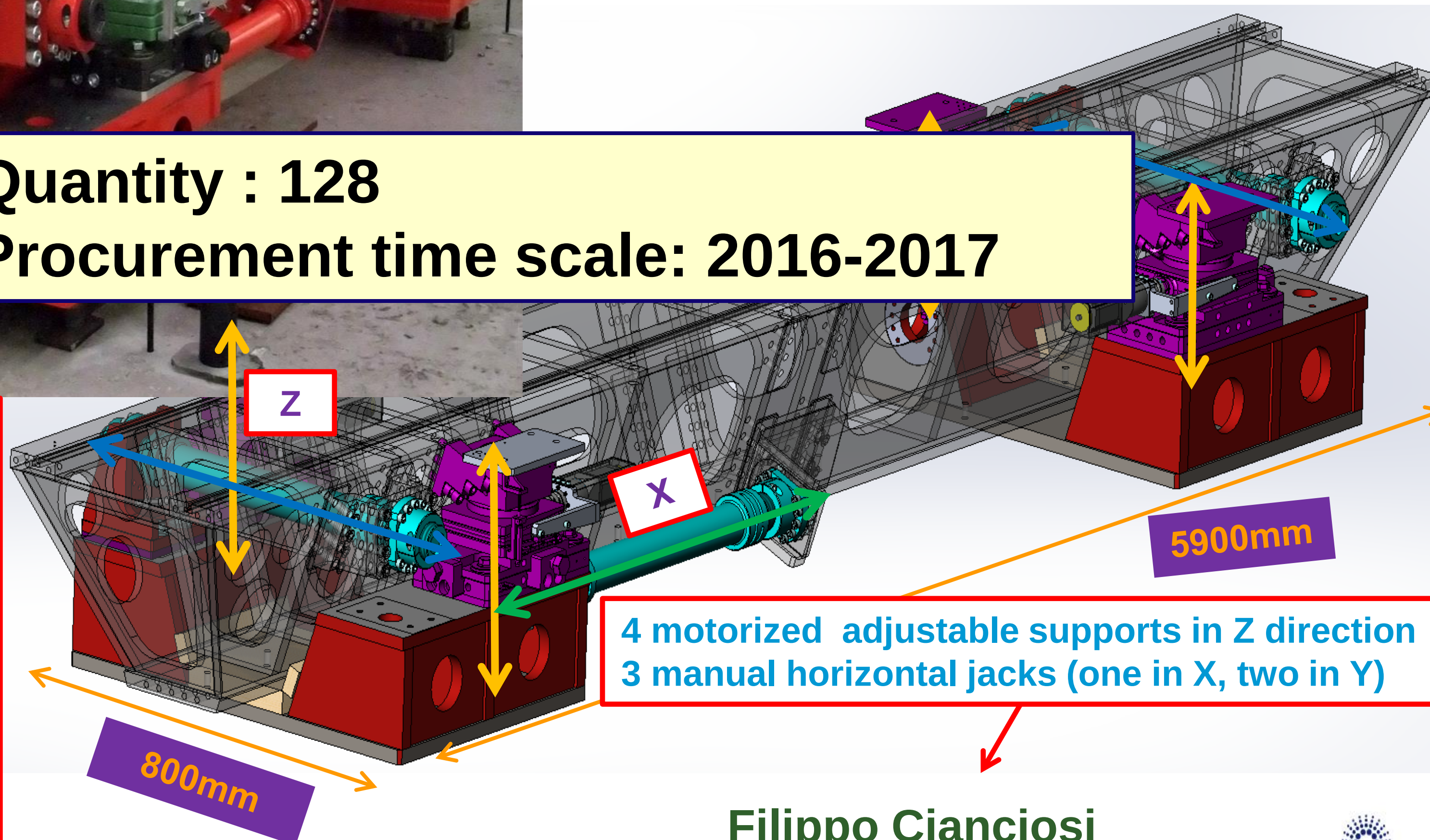
The stability requested will be 15ppm with a MTBF of more than 400 000 hours.

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

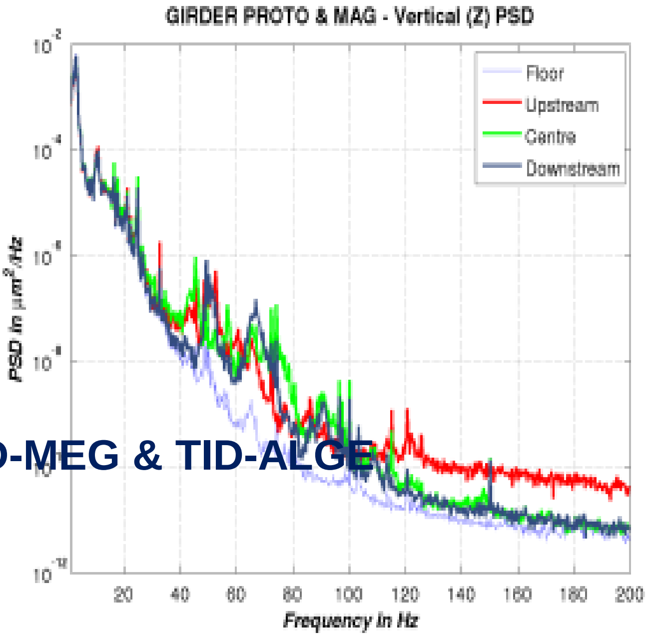
4 motorized adjustable supports in Z direction
3 manual horizontal jacks (one in X, two in Y)

Filippo Cianciosi

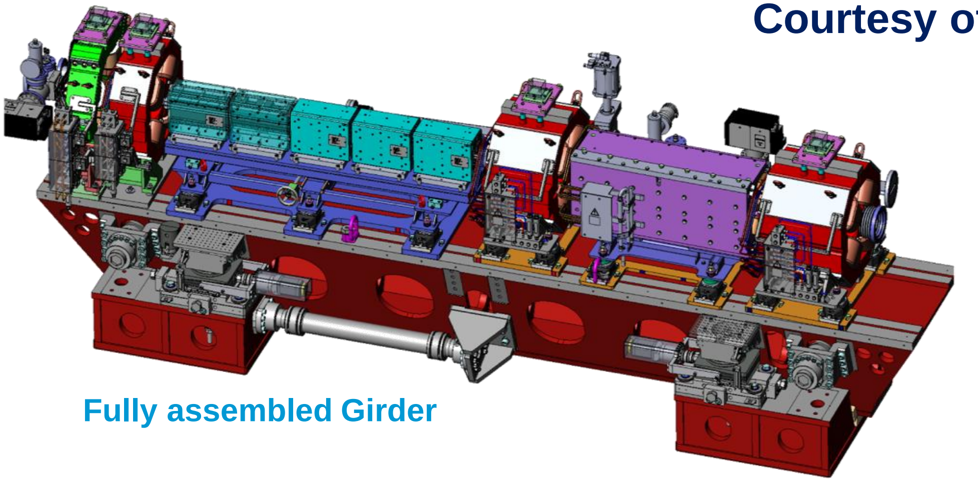
GIRDER PROTOTYPE TESTS

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

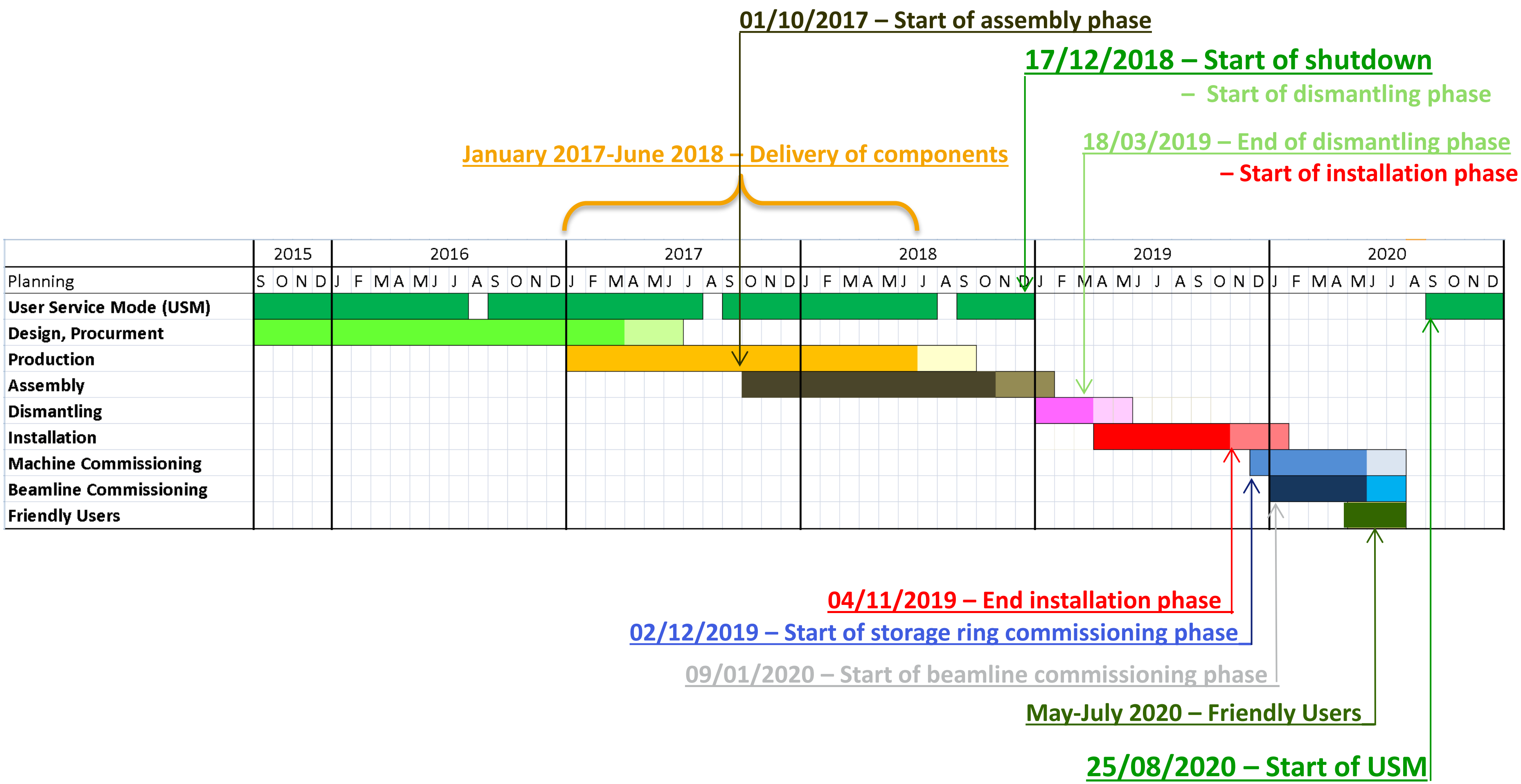
OVERALL PLAN STRATEGY

- All actions sequenced as much as possible
- Design phase nearly completed
- Procurement phase has started
- Assembly overlaps with procurement
- About 3 months time contingency for procurement phase
- About 3 months time contingency for assembly
- About 3 months time contingency for installation
- About 3 months time contingency for commissioning

ExpD will contribute to:
- Assembly
- Installation

EBS MASTER PLAN (2015-2020)

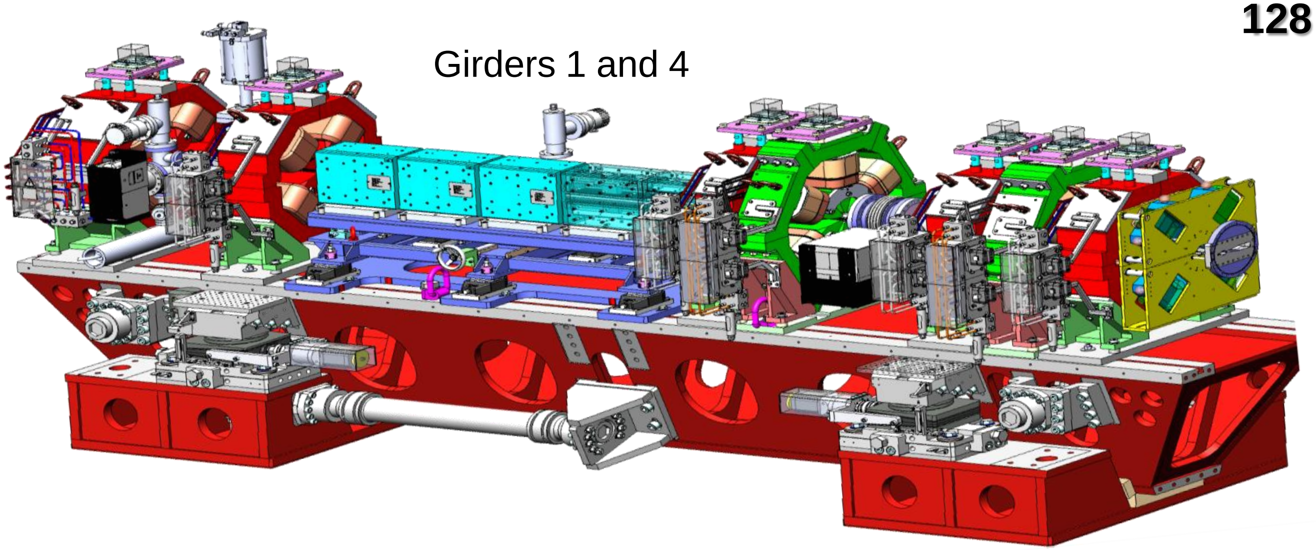
Master Plan and Major Milestones



GIRDER ASSEMBLIES

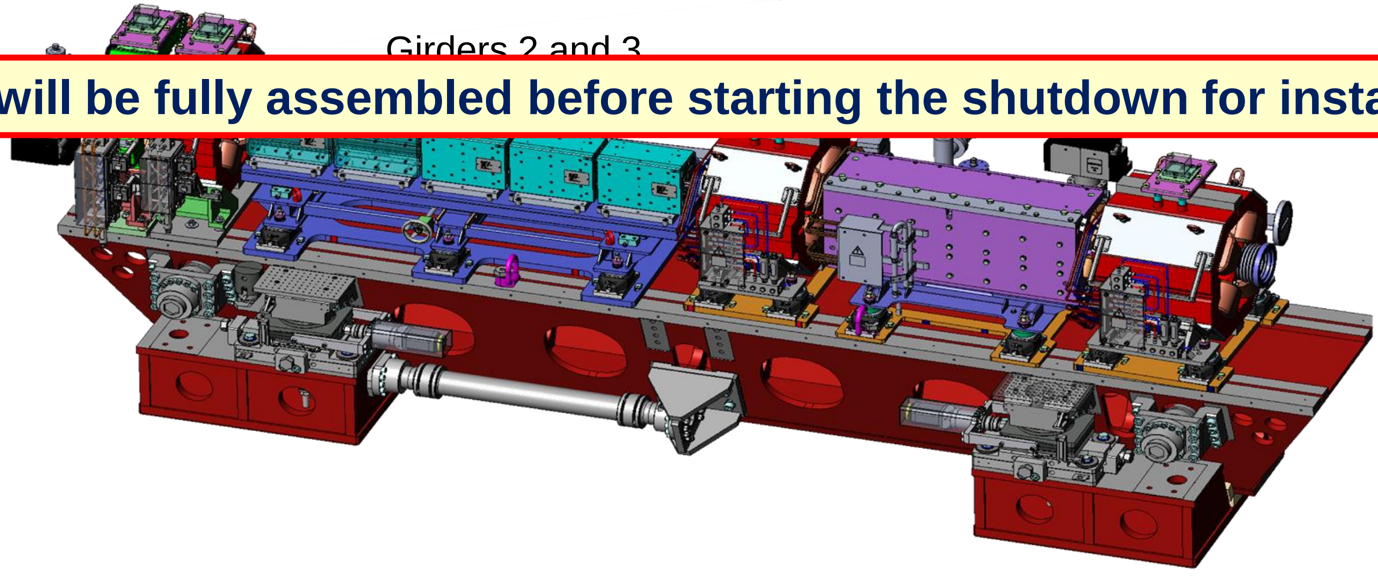
128 girders,10-12t each

Girders 1 and 4

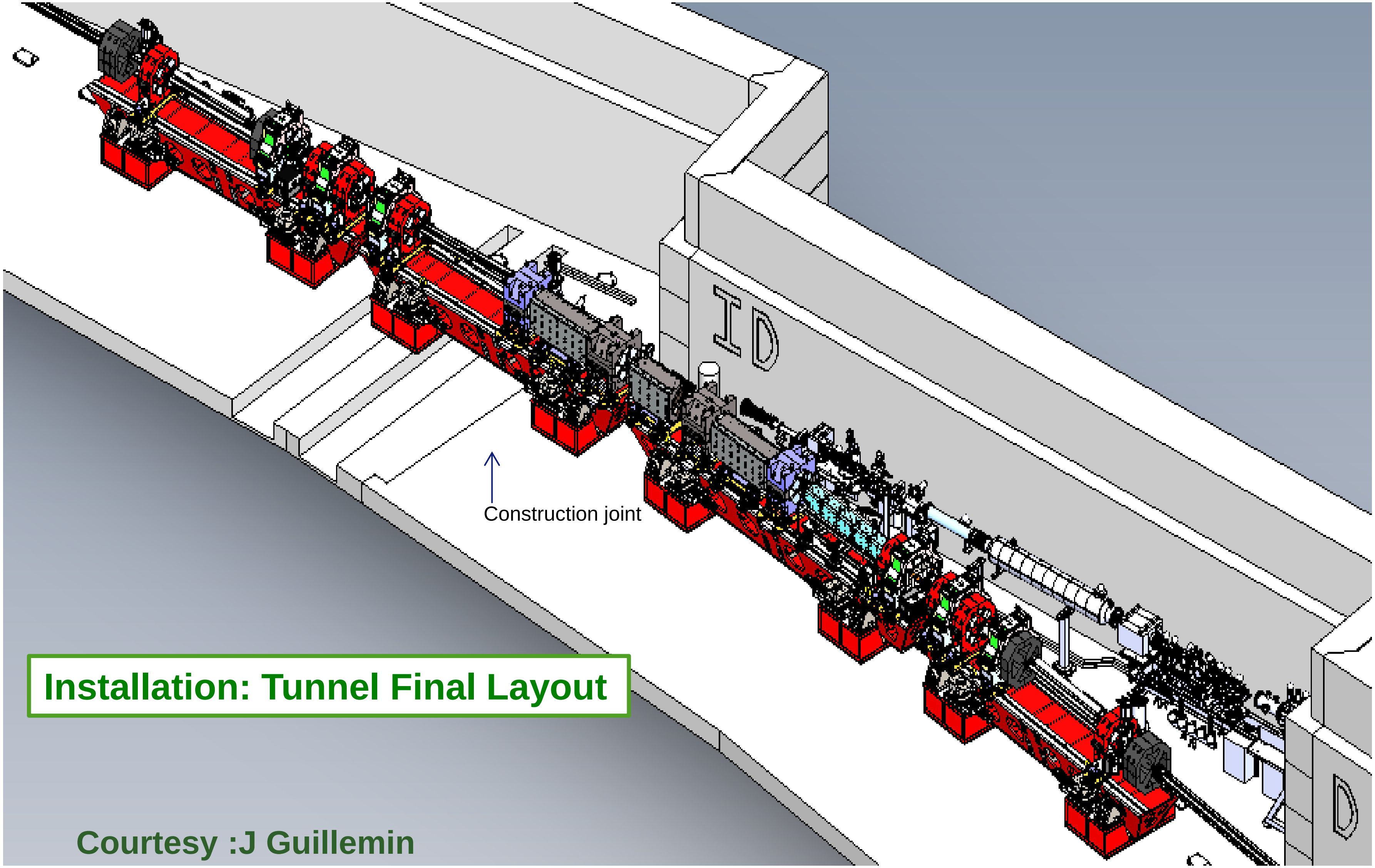


Girders 2 and 3

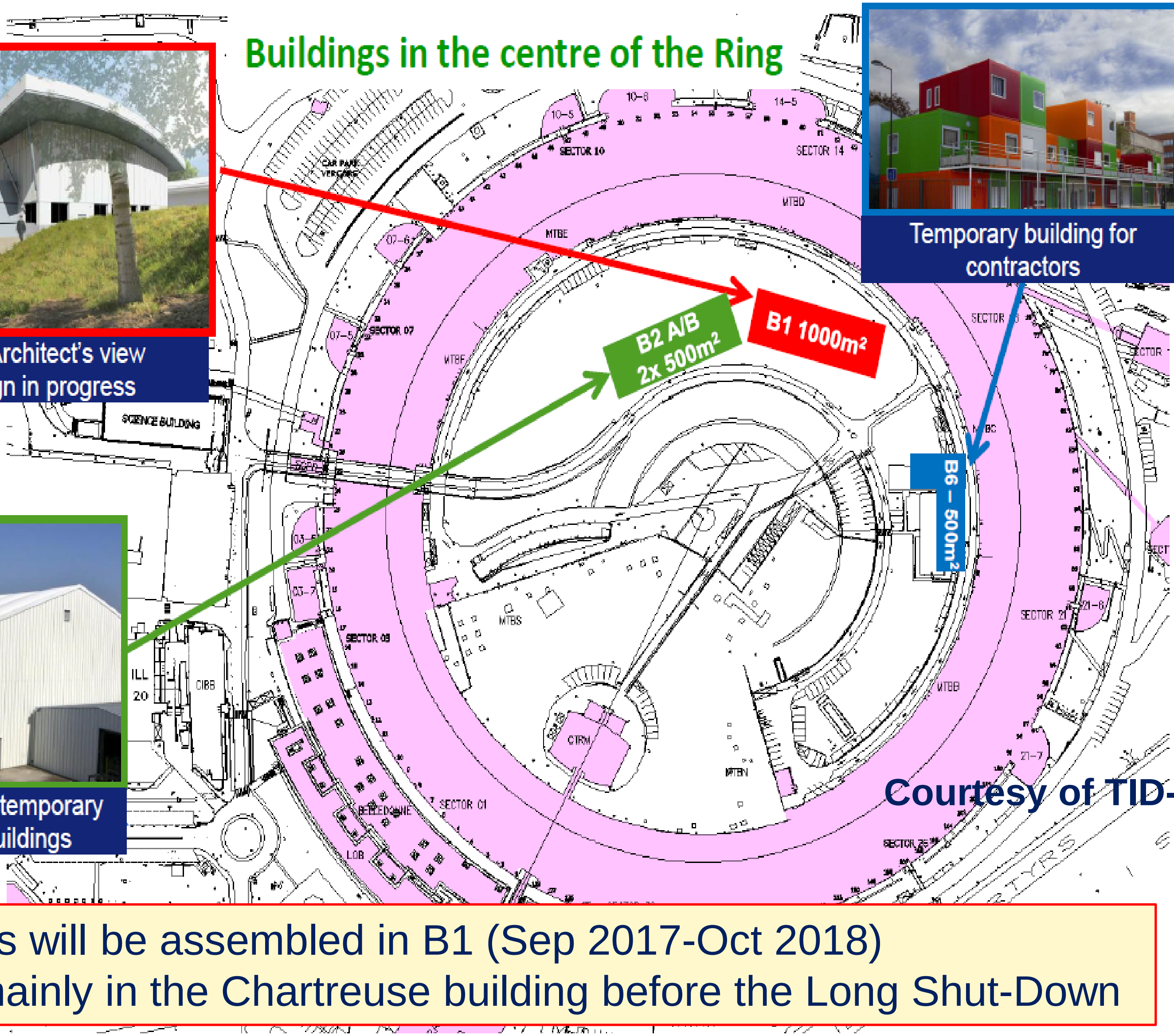
All girders will be fully assembled before starting the shutdown for installation



SYSTEM INTEGRATION – MACHINE LAYOUT IN THE TUNNEL



BUILDINGS FOR THE ASSEMBLY PHASE



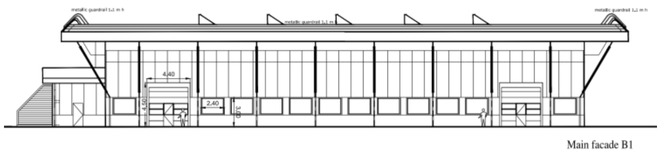
B1 – Architect's view
Design in progress

B2 A and B– temporary storage buildings

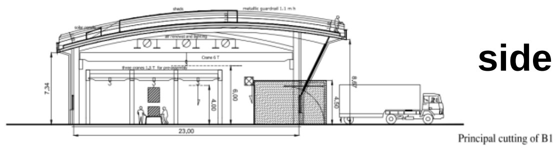
Temporary building for contractors

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

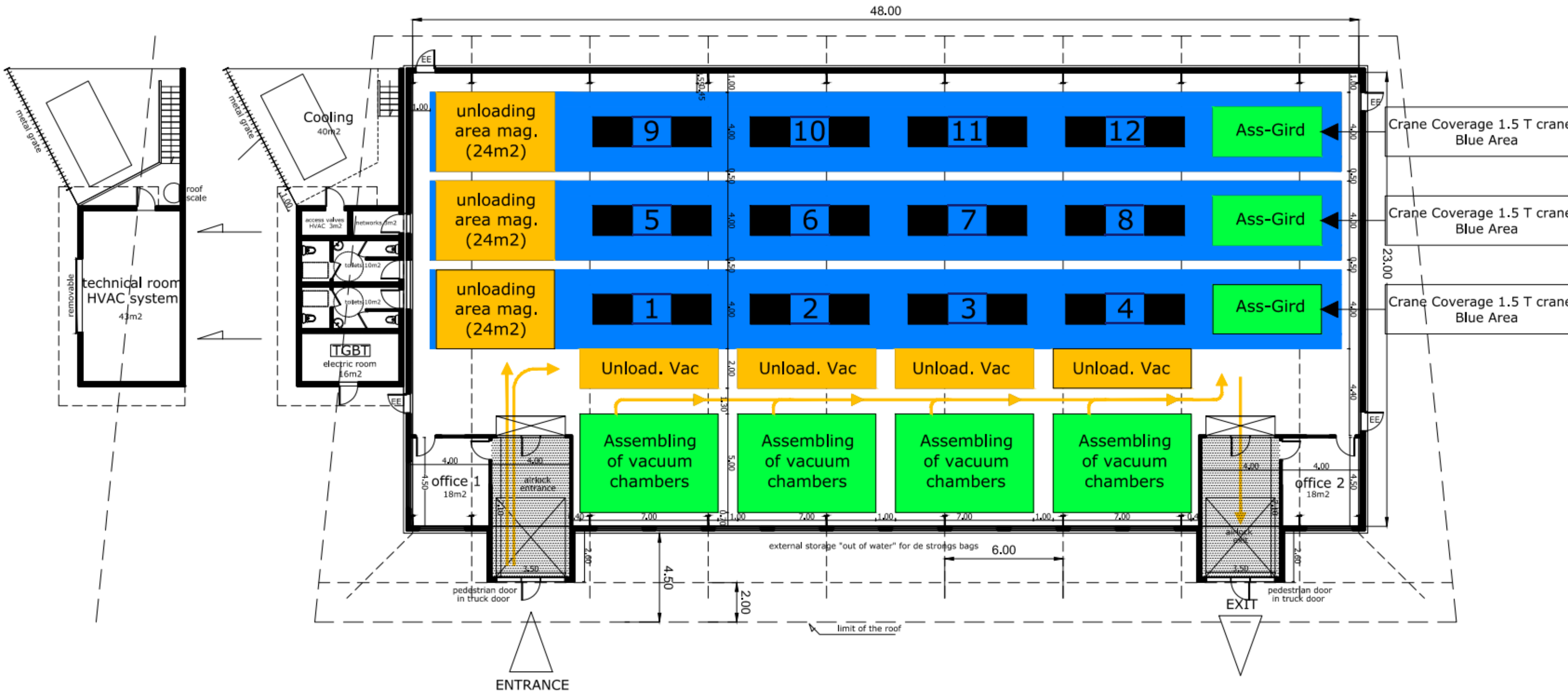


front view



side view

top view



Courtesy of TID-BIG

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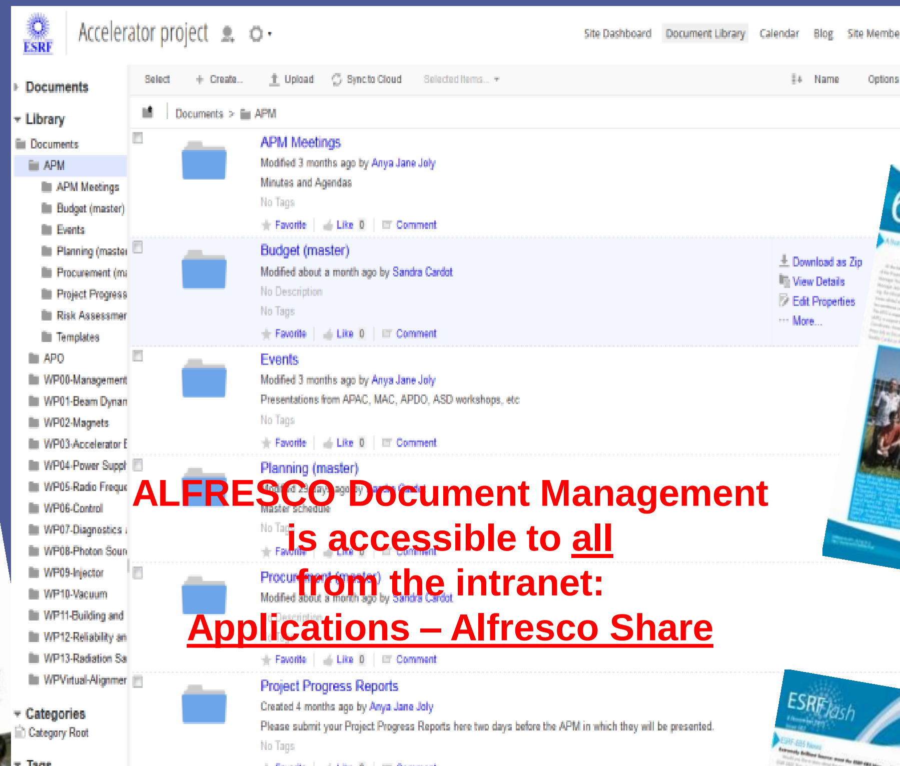
EBS PROJECT COMMUNICATION

EBS Blog:
www.esrf.fr/ebs



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ESRFlash

Courtesy of A.Joly & Communication Group

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CONCLUSION

EBS officially started on January 1st 2015

Planned project execution progression:

- **20% completed by the end of 2015: Engineering Design**
- **40% expected to be completed by the end of 2016: Delivery of Preseries components**
- **60% by the end of 2017: Delivery of >50% of components**
- **80% by the end of 2018: Completion of the Assembly**
- **100% by the end of 2019: Completion of Installation**

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

And looking forward for the very exciting work ahead of us.

MANY THANKS FOR YOUR ATTENTION