ESRF-EBS: The Extremely Brilliant Source Project

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On behalf of the EBS Accelerator Project Team

SLS / PSI, 24 July 2017

ESRF-EBS

Extremely Brilliant Source

ESRF | The European Synchrotron

ACKNOWLEDGEMENTS

This presentation has been contributed to by many ESRF staff.

With thanks to:

JC Biasci, P Raimondi, D Einfeld, K Scheidt, J Chavanne, L Farvacque, S White,

C Benabderrahmane, G LeBec, J Jacob, Q. Brioulet, P Renaud, S Liuzzo,

JF Bouteille

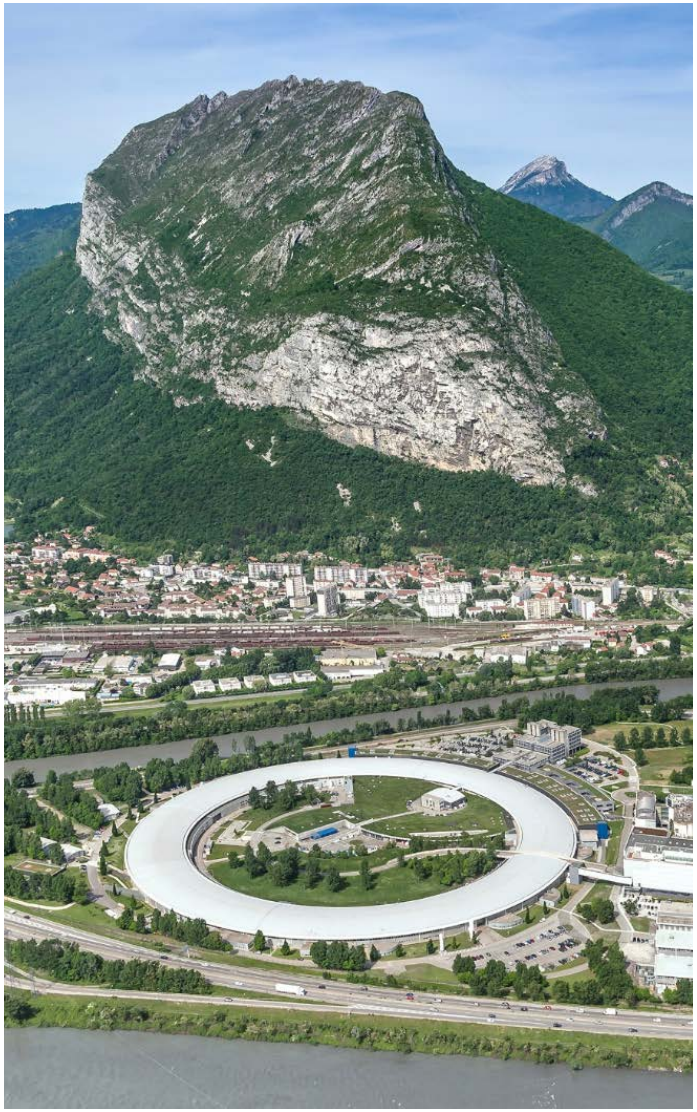
ISDD engineering group.

I Leconte, L Hardy

OUTLINE

- Introduction to the ESRF
- Operation performance
- ERSF/EBS project overview
- Schedule 2015-2020
- Project design & procurement status
- Assembly & Installation Phase

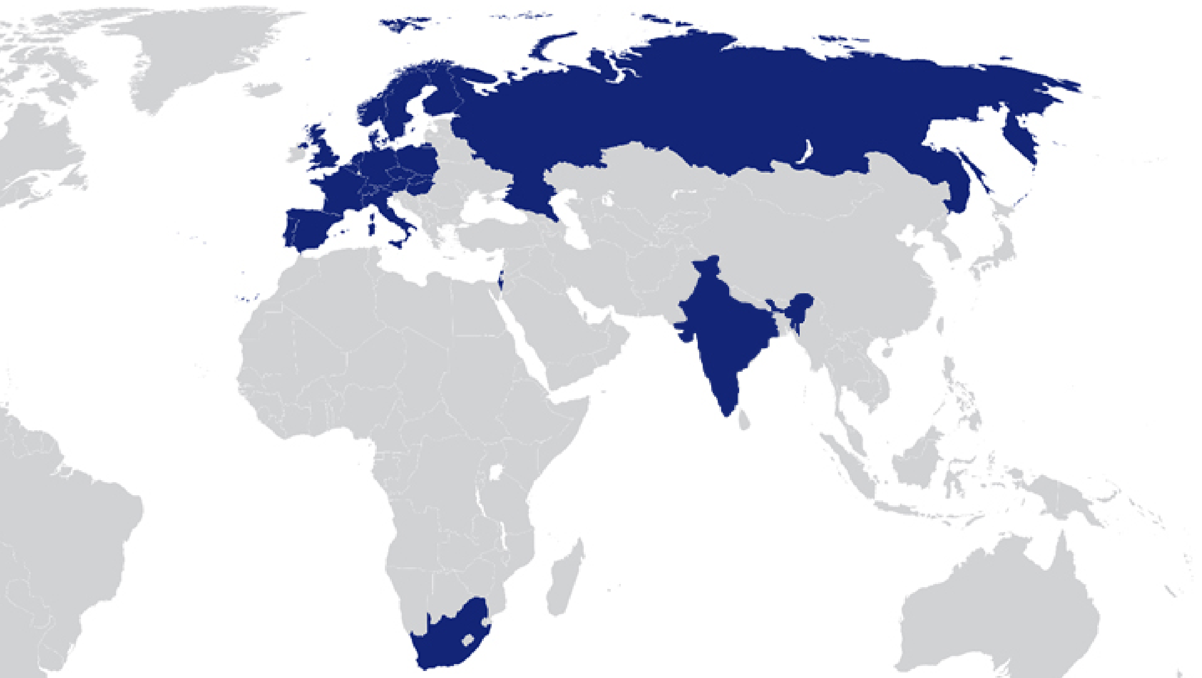
THE ESRF TODAY



ESRF

The European Synchrotron Radiation Facility Grenoble, France

A MODEL OF INTERNATIONAL COOPERATION: 22 PARTNER NATIONS

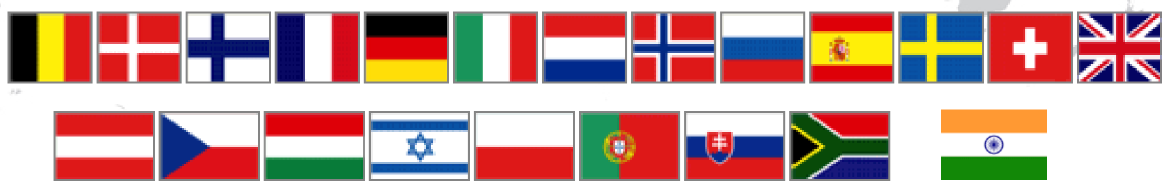


13 Member states:

France	27.5 %
Germany	24 %
Italy	13.2 %
United Kingdom	10.5 %
Russia	6 %
Benesync (Belgium, The Netherlands)	5.8 %
Nordsync (Denmark, Finland, Norway, Sweden)	5 %
Spain	4 %
Switzerland	4 %

9 Associate countries:

Israel	1.5 %
Austria	1.3 %
Centralsync (Czech Republic, Hungary, Slovakia)	1.05 %
Poland	1 %
Portugal	1 %
India	0.66 %
South Africa	0.3 %



22 partner nations
Annual budget: **100 million euros**
Staff: **630 people, 40 different nationalities**
Legal status: **Private civil company subject to French law**

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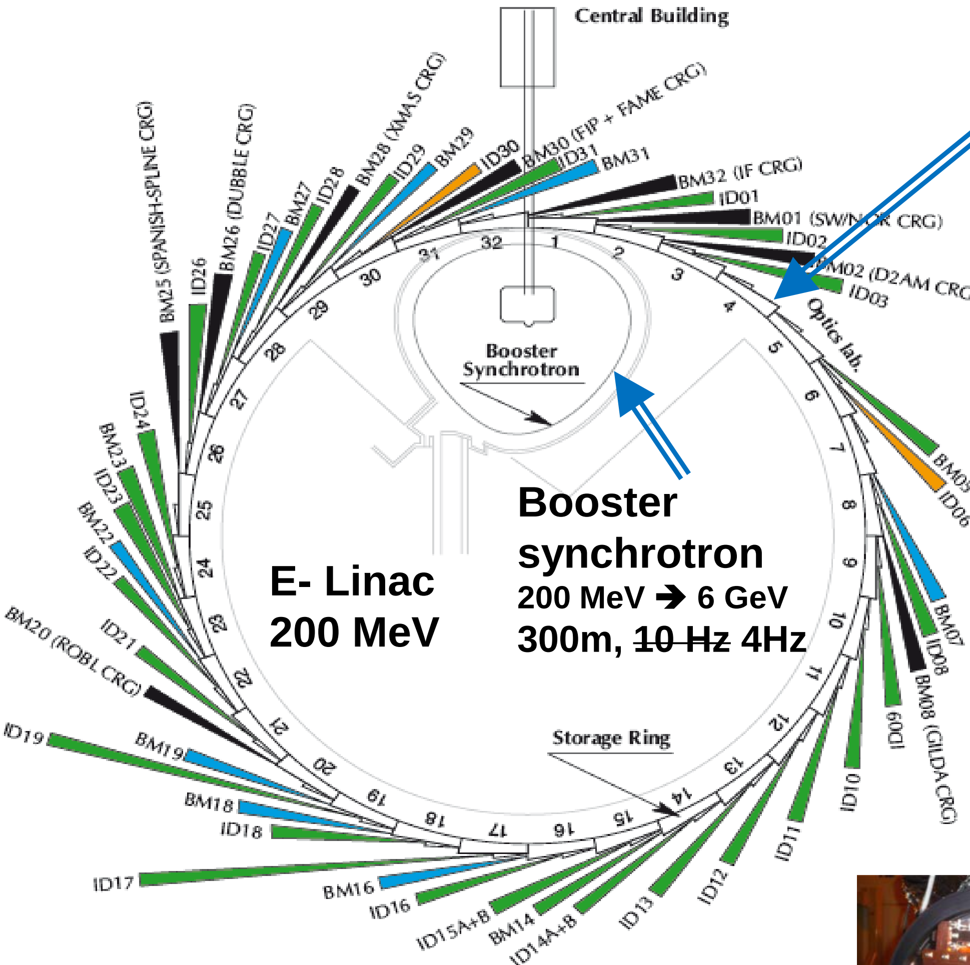
ESRF TODAY



Storage ring
6GeV, 844 m

E- Linac
200 MeV

Booster synchrotron
200 MeV → 6 GeV
300m, ~~10 Hz~~ 4Hz

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

32 straight sections

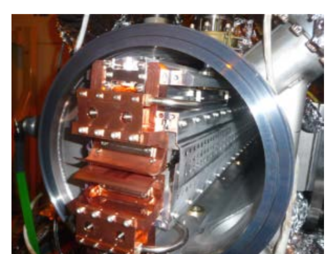
DBA lattice

42 Beamlines

12 on dipoles

30 on insertion devices

72 insertion devices:
55 in-air undulators, 6 wigglers,
10 in-vacuum undulators,
including 3 cryogenic



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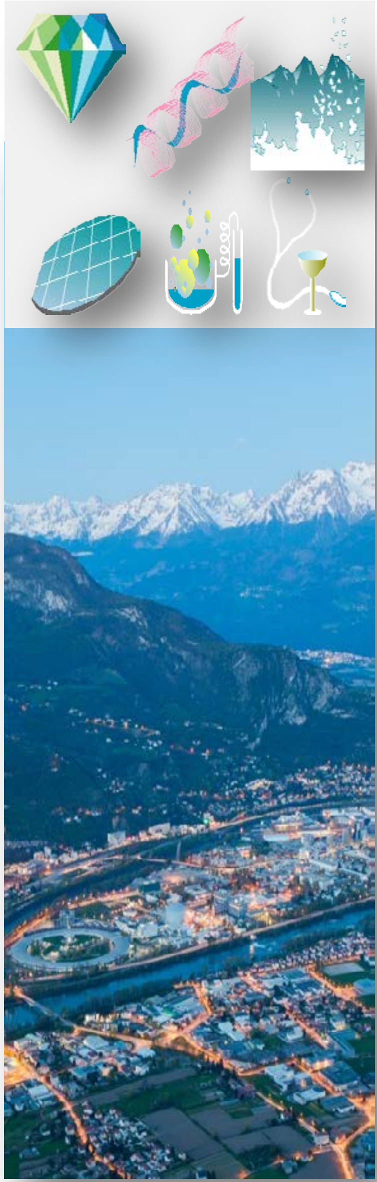


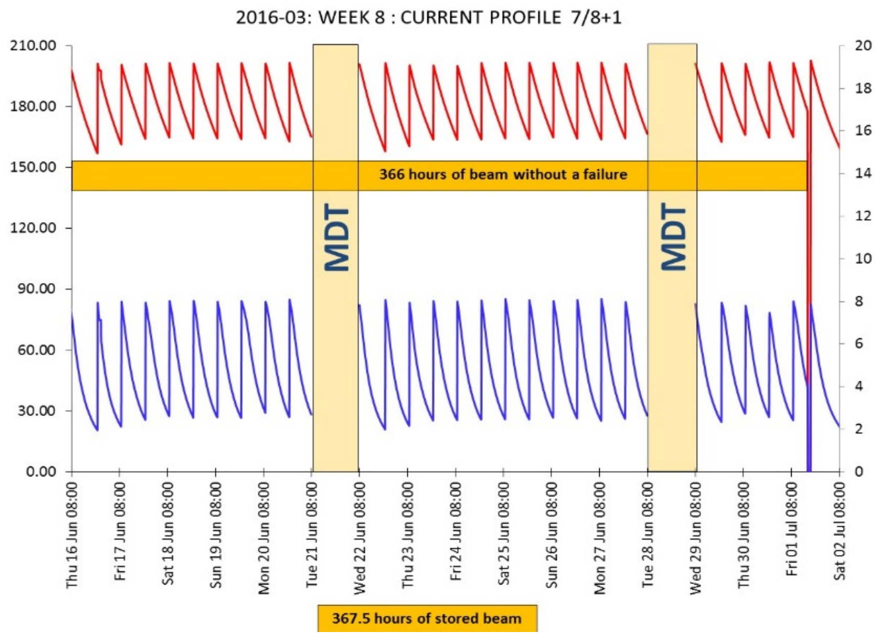
Throughout 2016, the ESRF delivered 5485 hours of beamtime to its users, out of the 5537 planned

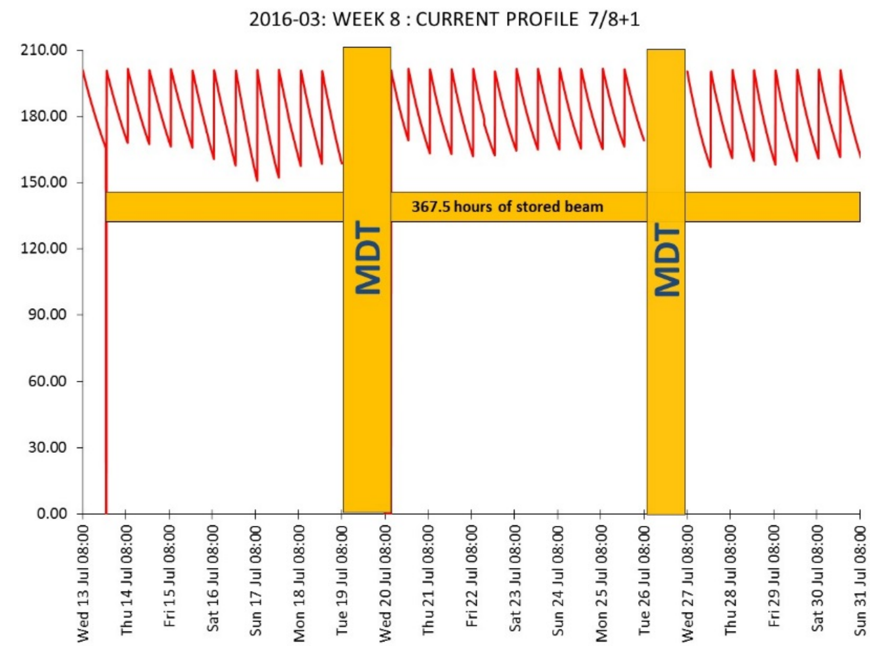
	2014	2015	2016	2017 *(until June)*
Availability (%)	99.11	98.53	99.06	**98.6**
Mean Time Between Failures (hrs)	105.5	93.6	93.8	**62.4**
Mean duration of a failure (hrs)	0.94	1.37	0.88	**0.87**

2014: 52 Failures / 2015: 59 Failures / 2016: 59 Failures

OPERATION : MACHINE

JUNE – JULY 2016: long periods of deliveries without any failures





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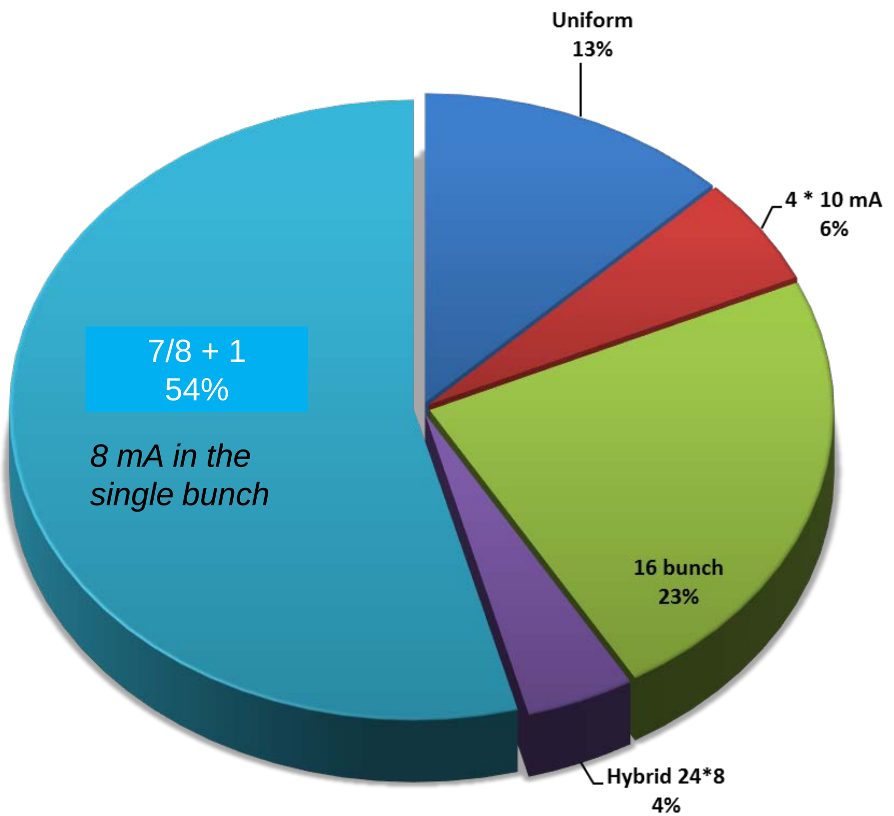
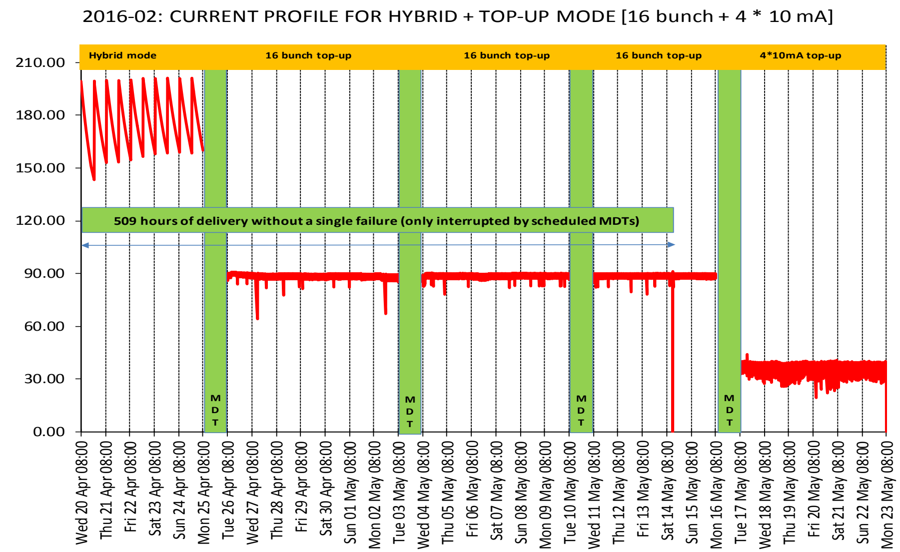
OPERATION: FILLING MODES IN 2016





16 Bunch in top-up since 26 April 2016

I max = 90 mA,
Refill every 20 mins, delta I = 5 mA,
Vertical emittance < 10 pm

skipped refills <2%

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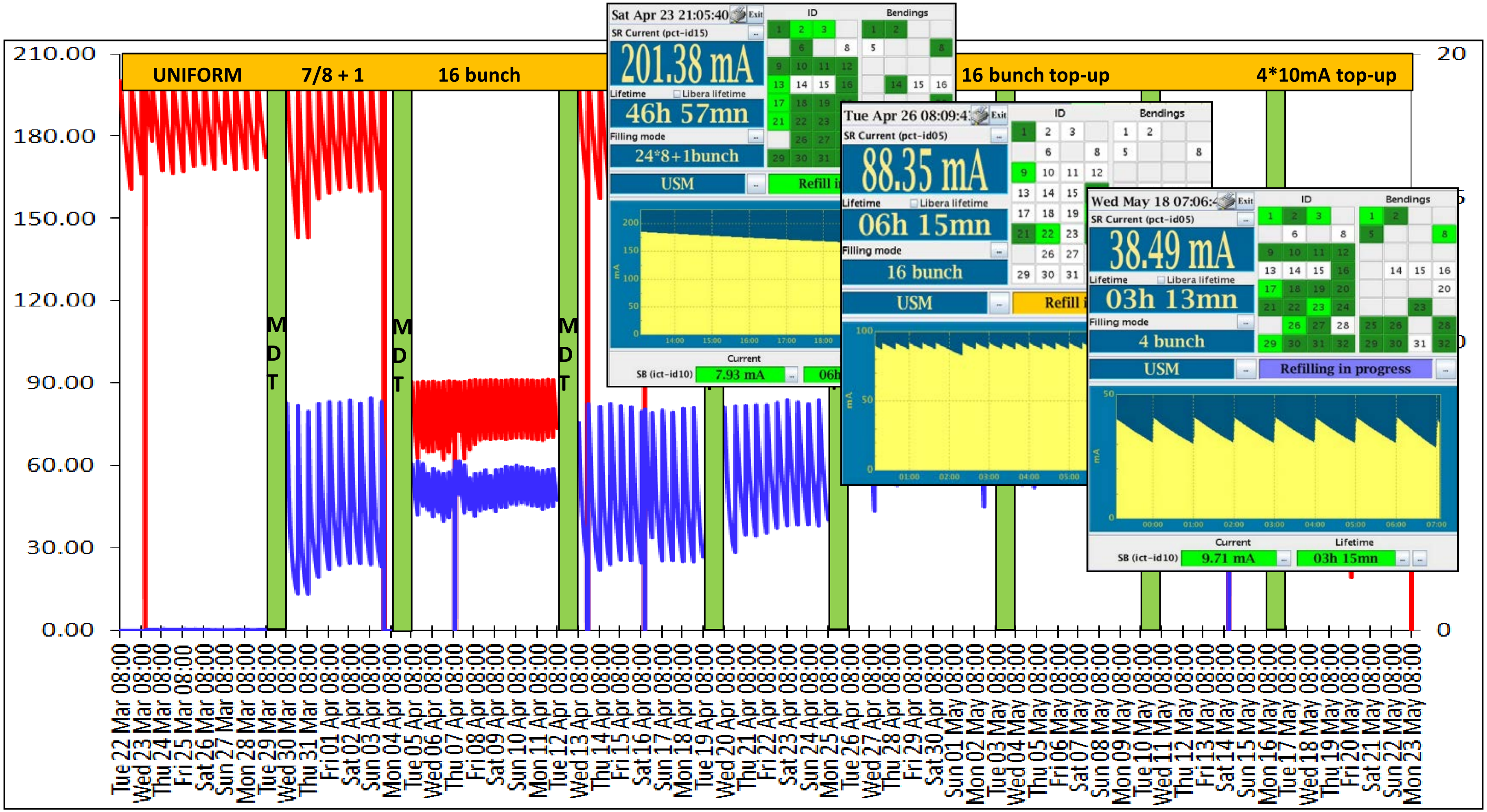
OPERATION : MACHINE



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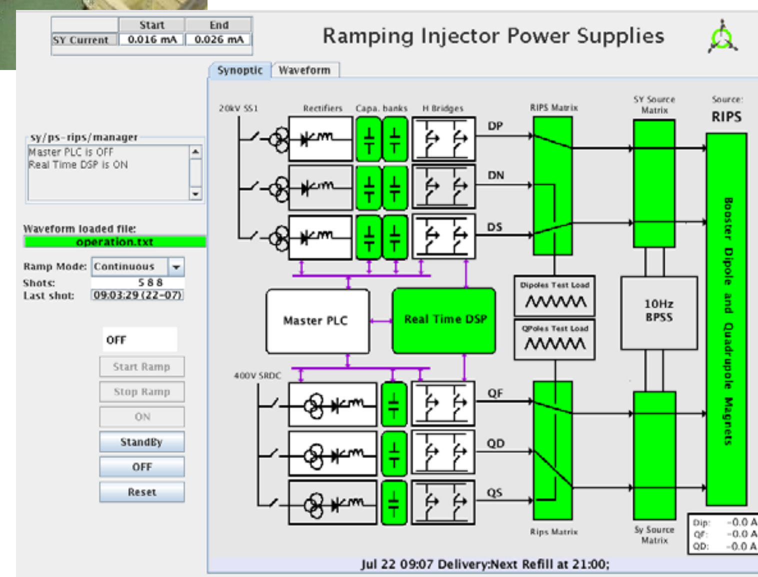
OPERATION: TOP-UP

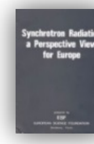
After a long period with minimum intervention, the injection underwent <u>major upgrades </u> for top-up operation and the EBS project

- New Libera Beam Position Monitor electronics
- Quadrupole movers
- Two additional RF cavities
- Linac: New→ gun, pre-buncher, buncher
  Third modulator (for redundancy)
- **A new booster Ramped Injection Power Supply (RIPS)**
- New power supplies for the septum magnets
- Bunch cleaning system
- … etc



The injection will be reused for the EBS

ESRF: MORE THAN 20 YEARS OF SUCCESS AND EXCELLENCE



- **1988** 11 member states sign the creation of the ESRF
- **1992** 1st electron beam in the storage ring
- **1994** Inauguration: 15 beamlines on time and within budget
- **1998** 40 beamlines on time and within budget

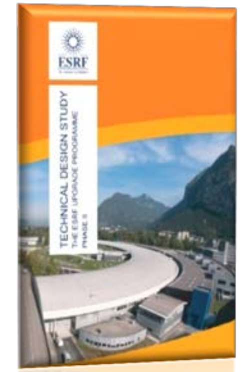
- **2009-2015** Upgrade Programme Phase I on time and within budget

- **2012** New design for the storage ring

- **2015** Upgrade Programme Phase II: ESRF-EBS

ESRF UPGRADE PROGRAMME:
AN AMBITIOUS PROGRAMME TO PREPARE THE FUTURE

Purple Book January 2008



Orange Book January 2015

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI ROADMAP 2006-2016
ON TIME – WITHIN BUDGET

- 19 new beamlines, many specialised in *nano*-beam science
- Upgrade and renewal of facilities and support laboratories

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EXTREMELY BRILLIANT SOURCE

ESFRI

European Commission

ESRF-EBS
Extremely Brilliant Source
150 M€ (2015-2022):
ESFRI LANDMARK (2016)

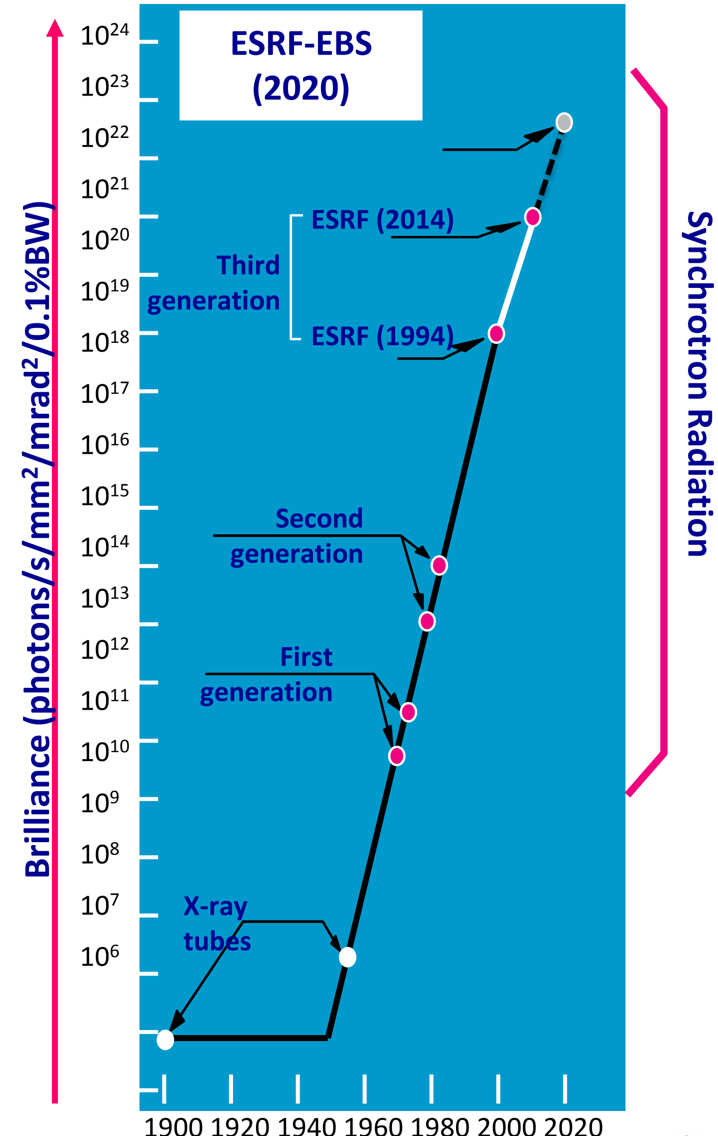
Revolutionary design for a new generation of synchrotron source storage rings

ESRF-EBS: AN AMBITIOUS NEW STANDARD FOR SYNCHROTRON STORAGE RINGS

ESRF-EBS
Extremely Brilliant Source

ESRF Extremely Brilliant Source
ESRF-EBS – 150 M€ (2015-2022)

- ~100 times more brilliant and coherent X-rays
- Programme to exploit the qualities of this new and unique extremely brilliant X-ray source:
  - Creation of new beamlines
  - Innovative detector programme
  - « Data as a Service » strategy



Budget for the source only: 104 M€

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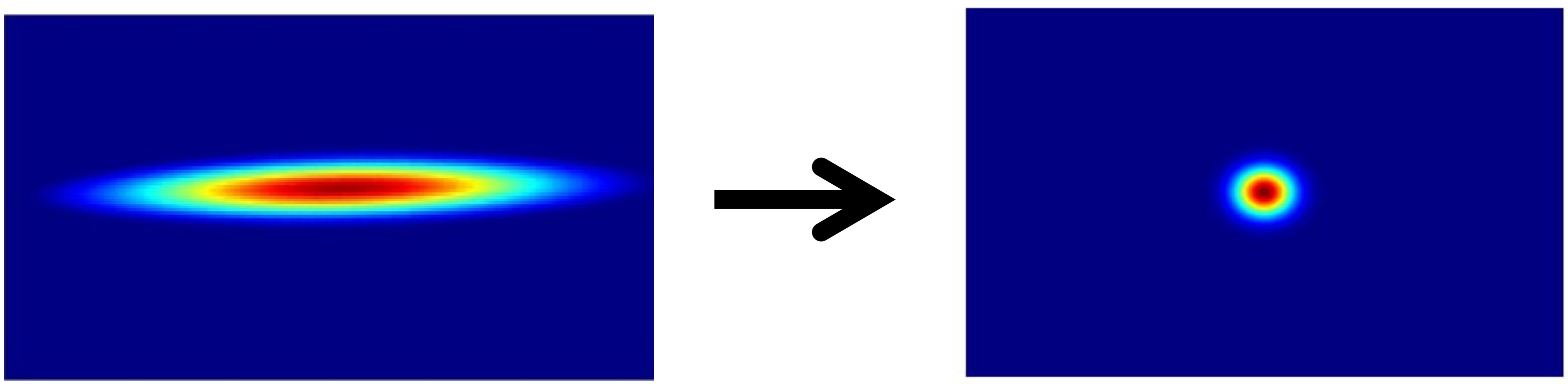
Reduce the **horizontal** emittance from **4nm** to **0.14nm**

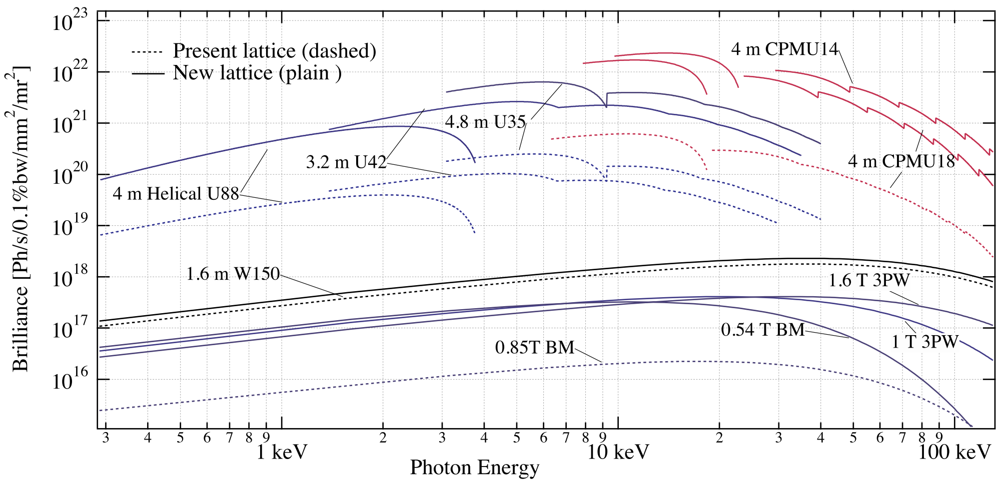


Beam-line experiments can benefit from :

an increase in brilliance
an increase of coherence
(the coherent fraction, in hor. plane)

BRILLIANCE AND COHERENCE INCREASE

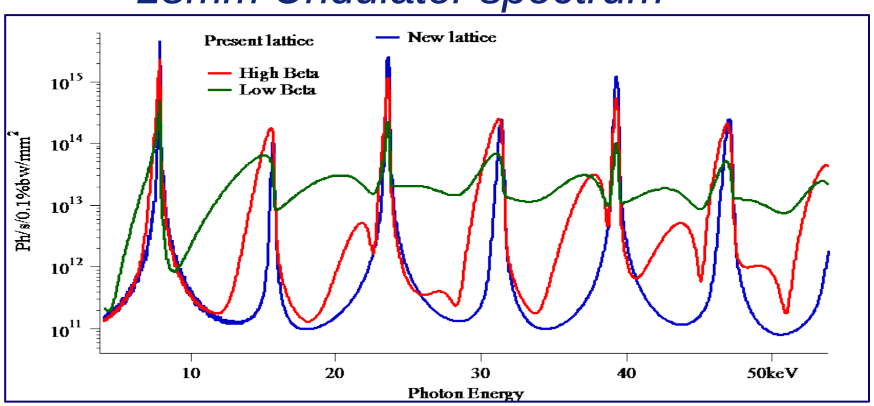
Brilliance



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

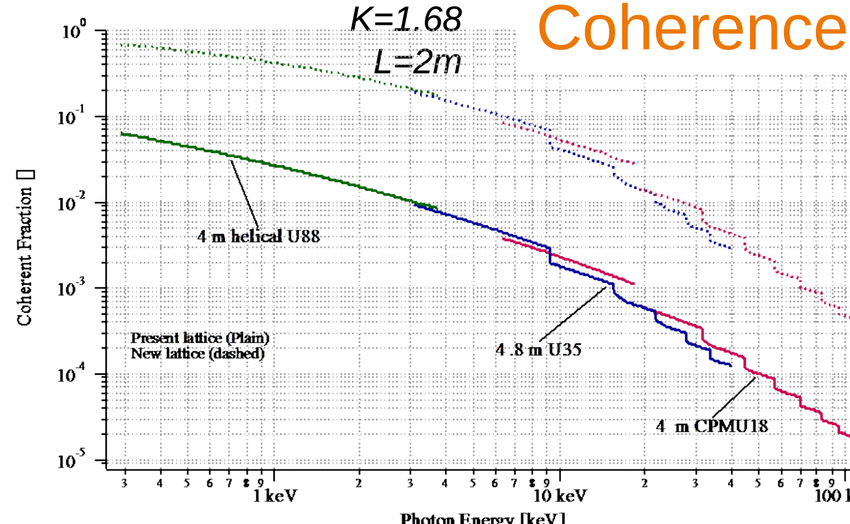
Source performances will improve by a factor 50 to100

18mm Undulator spectrum



Undulator: CPMU18, K=1.68 L=2m

Coherence



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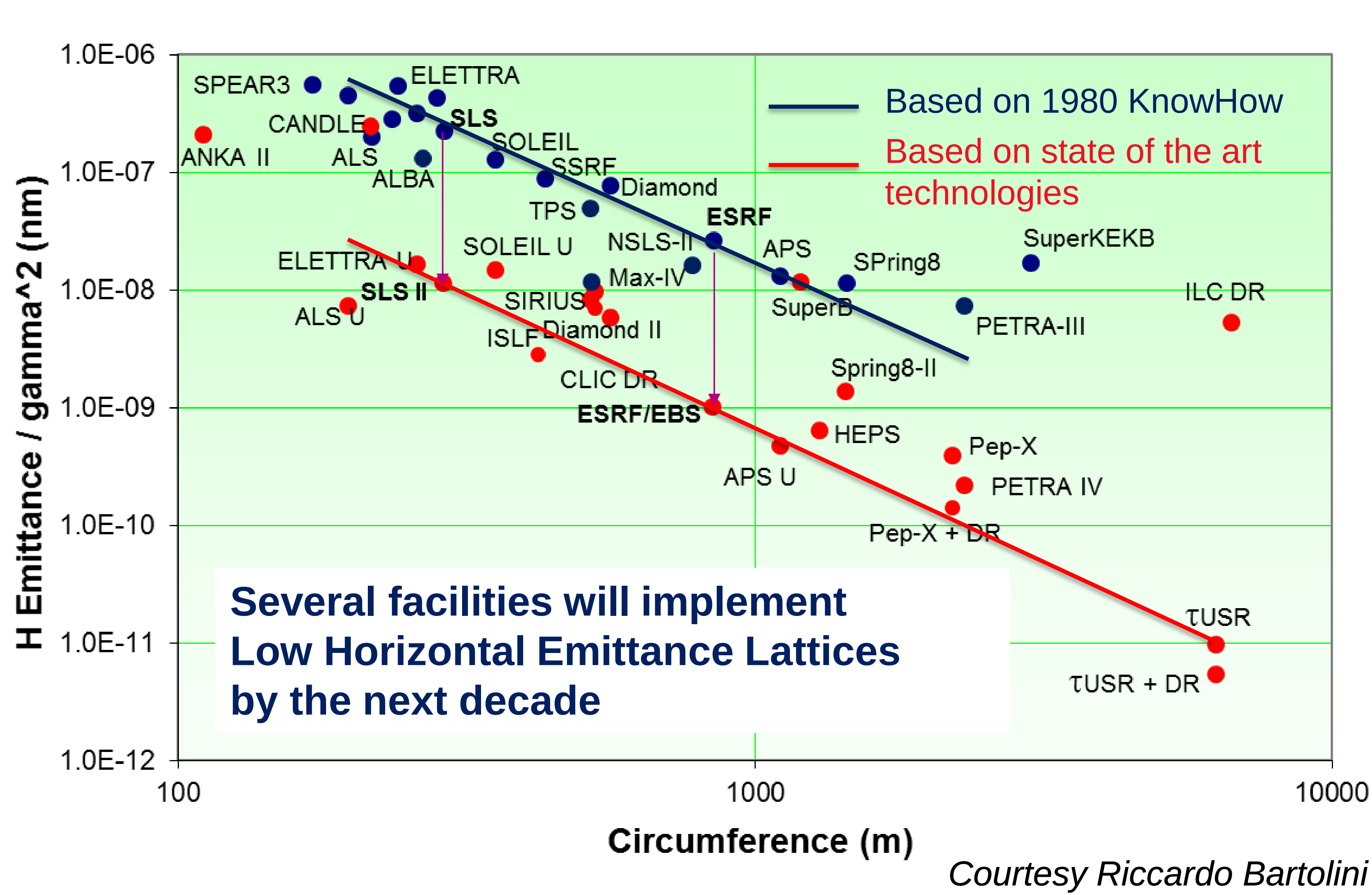
LOW EMITTANCE RINGS TREND



EXTREMELY BRILLIANT SOURCE: ACCELERATOR UPGRADE

The Extremely Brilliant Source Project aims to:

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

- Must fit in the same tunnel: same circumference as much as possible
- Keep the electron energy (6 GeV)
- IDs at same locations: keep Beamlines where they are
- Maintain the existing bending magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Re-use injector complex
- 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

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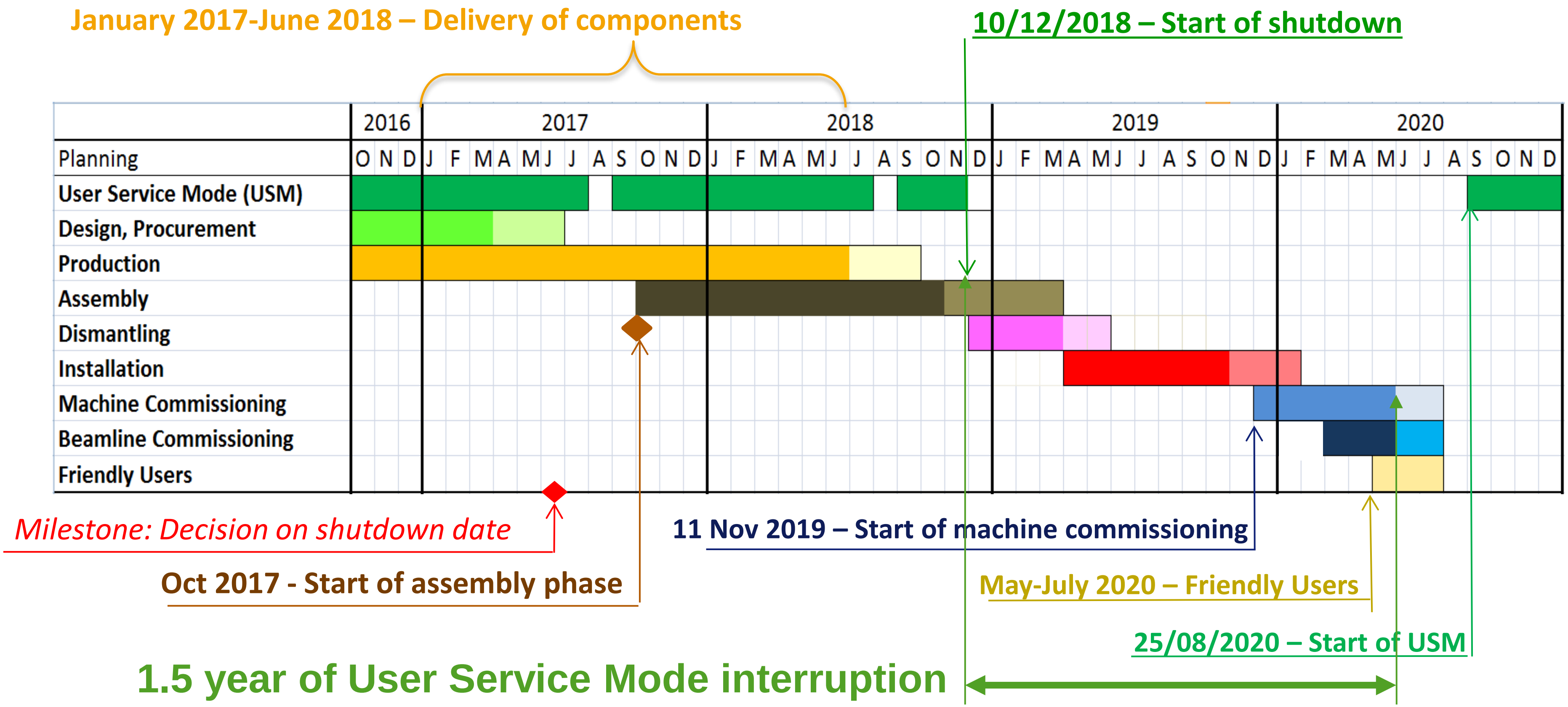
OPERATION AND EBS PROJECT PLAN (2015-2020)



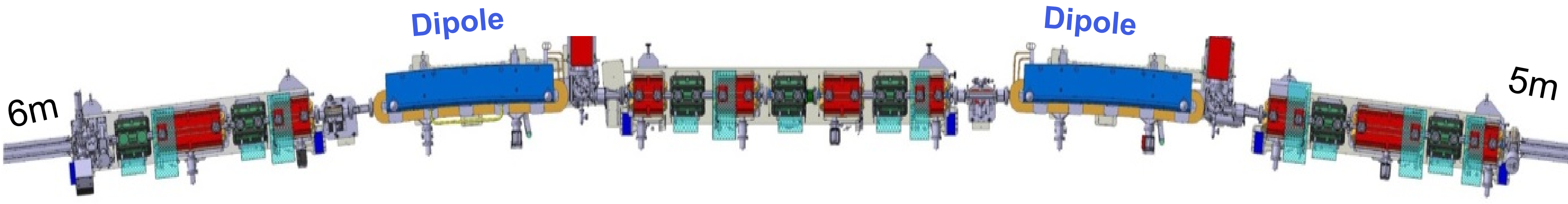
2018 is a normal year for Operation

October	2017	Start of the girder assembly (estimated duration 1 year)
10 December	2018	Start of the long shutdown, dismantling starts
December	2019	Accelerator commissioning
March	2020	Beamline commissioning starts
25 August	2020	Back to USM

NEW LATTICE VS PRESENT ESRF LATTICE

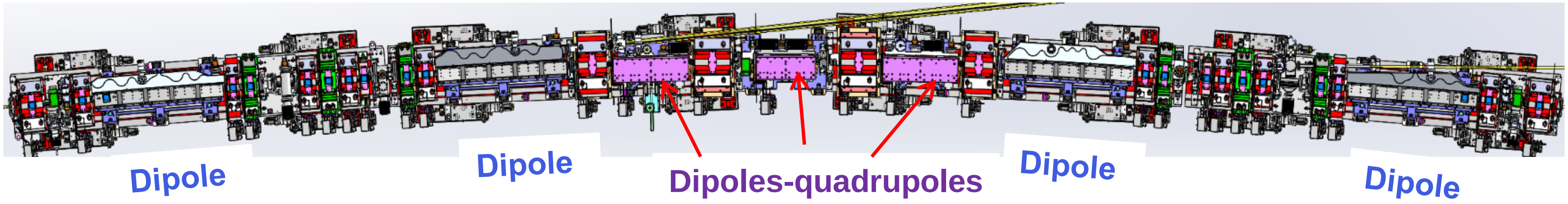
- **Present ESRF lattice**

32 cells, Double Bend Achromat = (2 dipoles + 15 quad. sext.) per cell
ID length = 5 m (standard) / 6m / 7m



- **ESRF EBS lattice**

Hybrid 7 Bend Achromat = (4 dipoles + 3 dipoles-quad + 24 quad., sext., oct.) per cell
32 identical arcs 21.2 m long, ID length = 5 m



31 magnets per cell instead of 17 currently
Free space between magnets (total for one cell): **3.4m** instead of **8m** today !!

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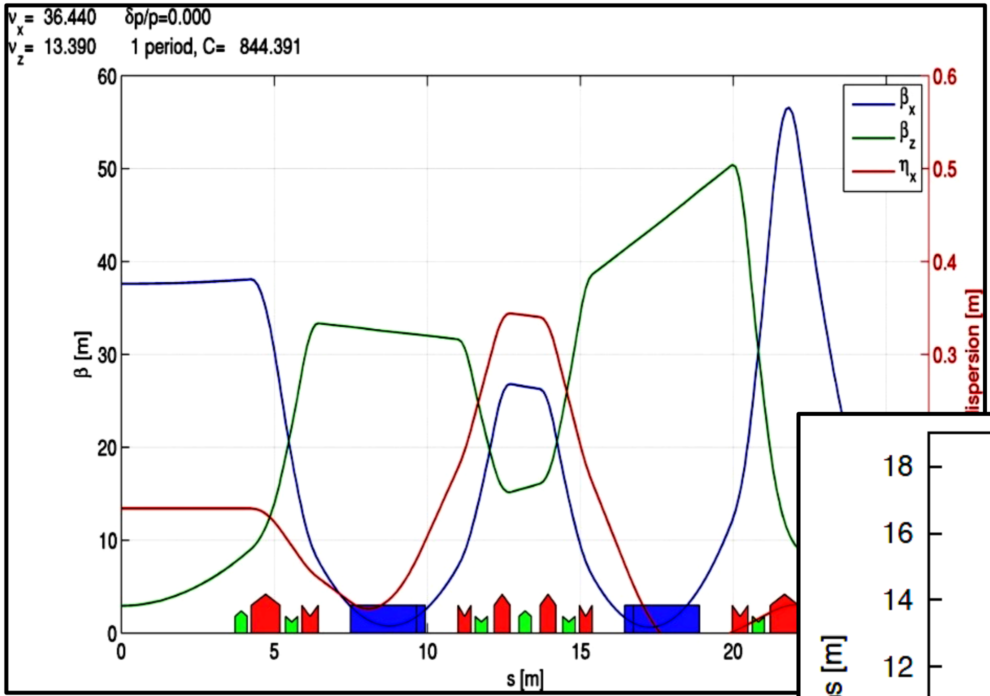
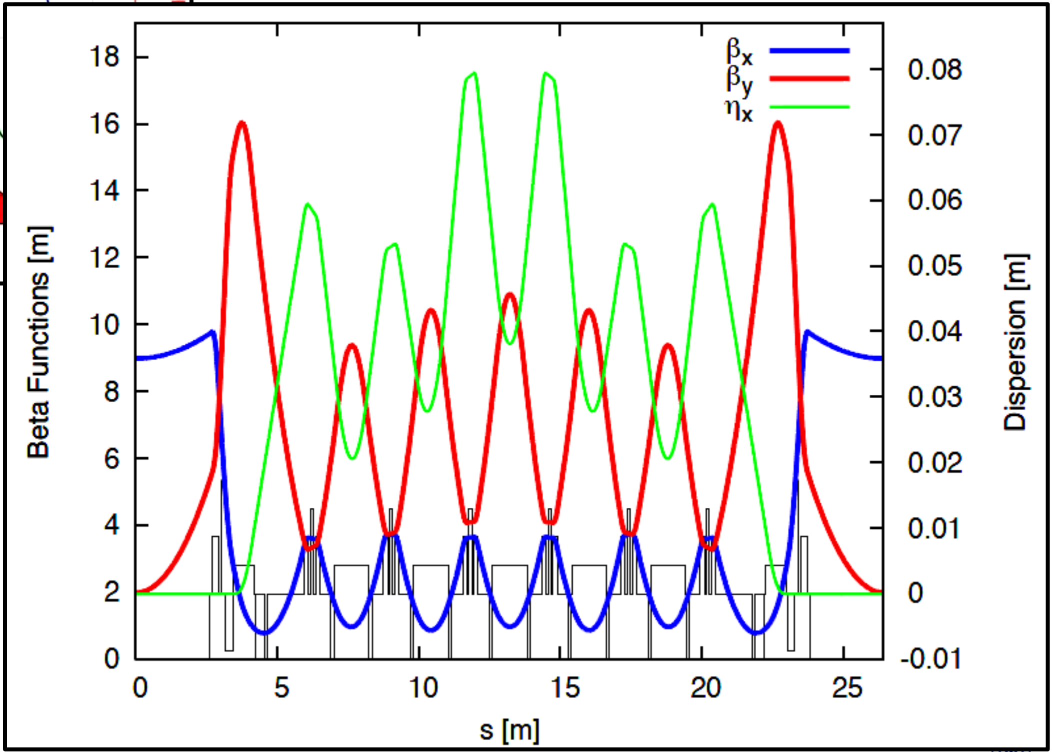
THE EVOLUTION TO MULTI-BEND LATTICE



Double-Bend Achromat (DBA)

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



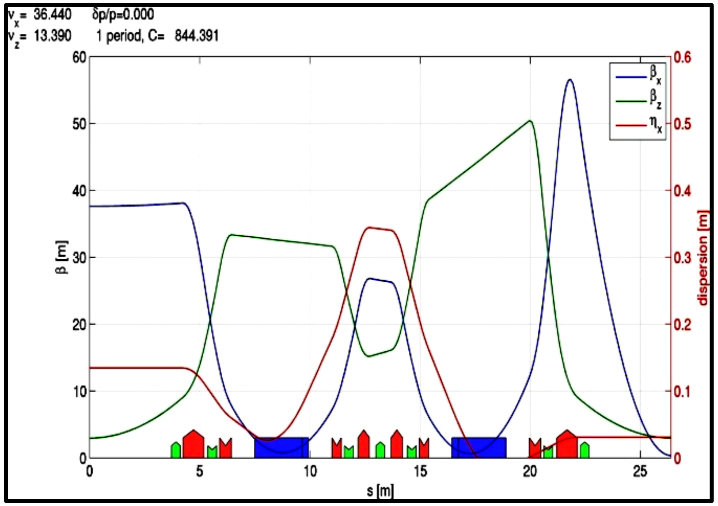
Multi-Bend Achromat (MBA)

- 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

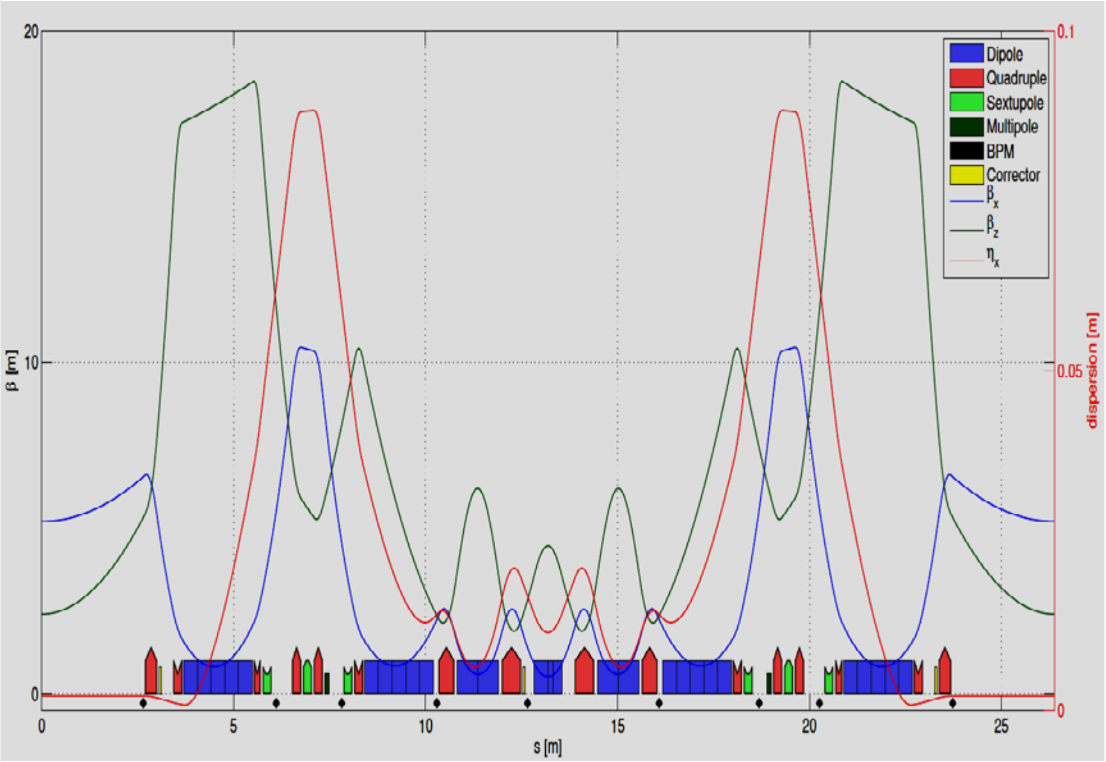
- Ex = 4 nm•rad
- tunes (36.44,13.39)
- nat. chromaticity (-130, -58)



- 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

ESRF HMB cell

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



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PROGRESS STATUS: DESIGN

➢ Design of all the components nearly completed:

- Magnets ~95% (including Kickers and PM-septa)
- Vacuum System ~95% (including one-of-a-kind chambers in injection section)
- Absorbers ~100%
- Girders ~100%
- Supports ~100%
- Diagnostics ~80% (Collimators, Special chambers)
- Power Supplies ~90% (Optimisation and hot-swap implementation in progress)

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

PROGRESS STATUS: PROCUREMENT

- <u>**All large scale procurement in place**</u>

- **All contracts for serial production magnets in place**
- **All contracts for vacuum chambers in place**
- **Girder contracts in place**
- **Infrastructure & logistics critical contracts in place**

Delivery of serial components has started and will last about 2 years

Pre-series components delivered for almost all contracts

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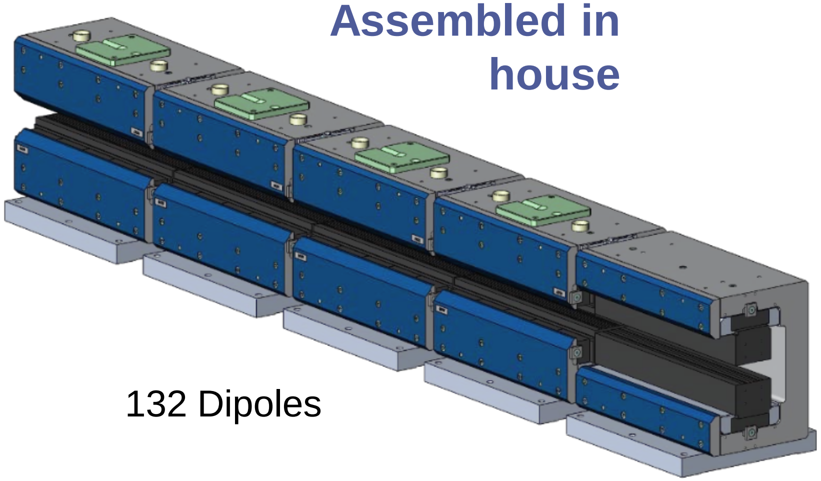
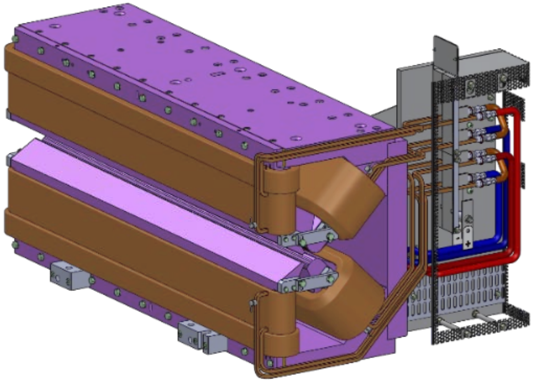
MAGNETS

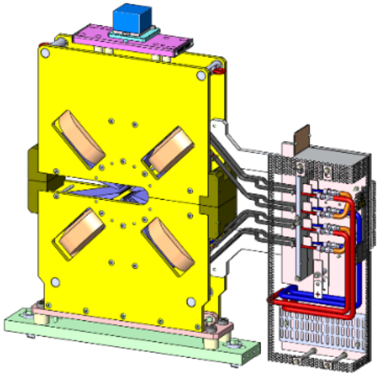
Assembled in house



132 Dipoles



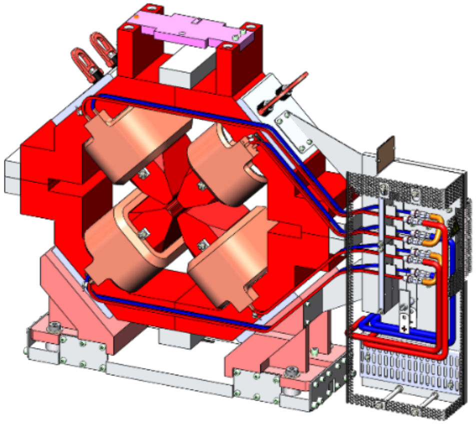
100 Dipole-quadrupoles

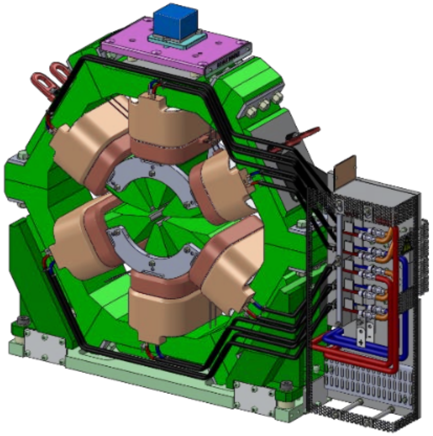


66 Octupoles

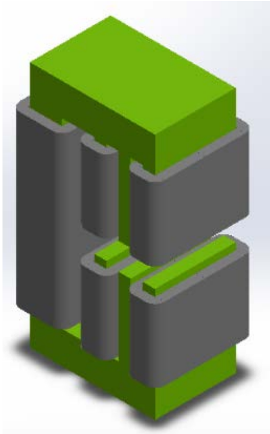
More than 1000 Magnets to procure in less than 3 years

524 Quadrupoles
(132 HG, 392 MG)





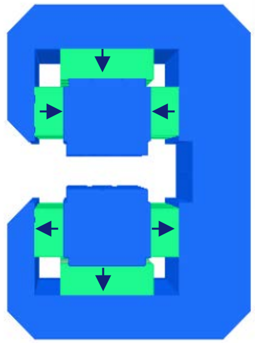
196 Sextupoles

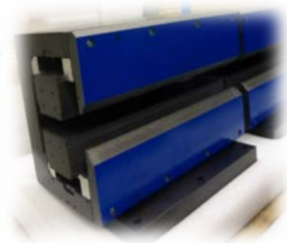


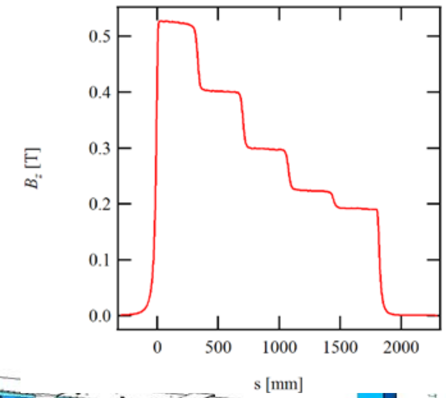
98 Correctors

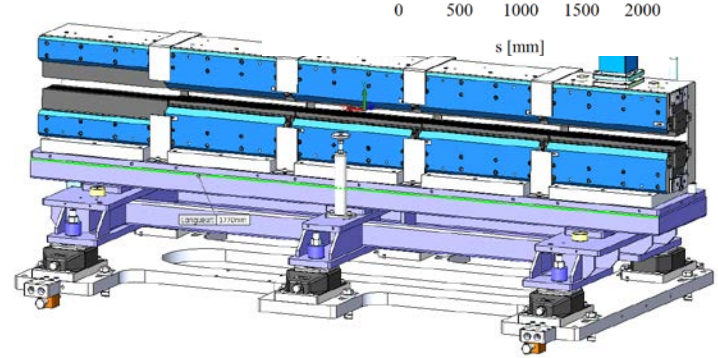
DIPOLES WITH LONGITUDINAL GRADIENT [132]

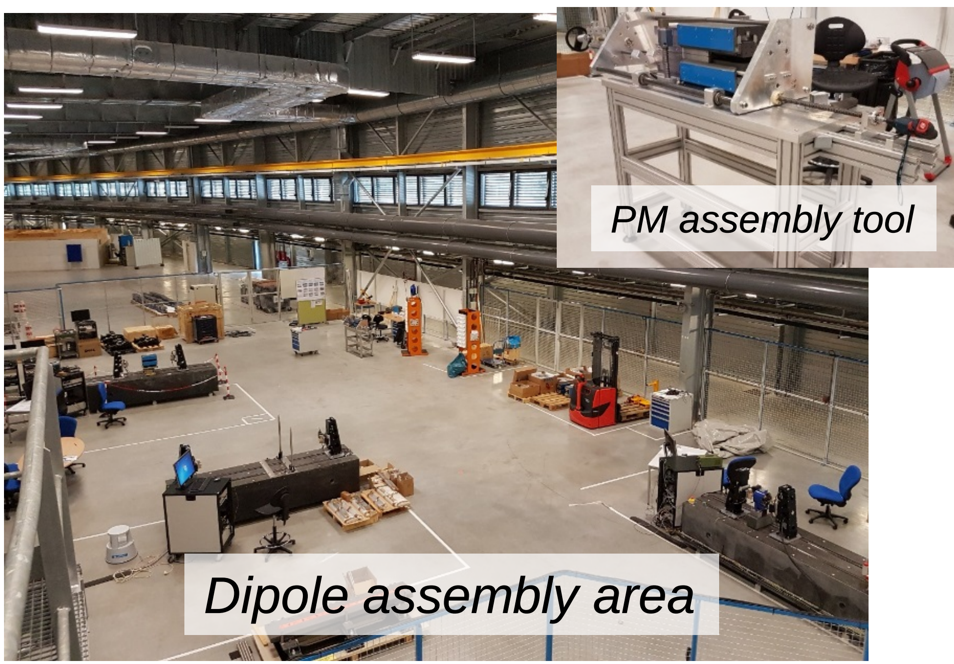
- Each dipole based on 5 PM modules
- Strength 0.67-0.17 T &
- Iron length 1788 mm
- 25.5 – 30.5 mm GAP
- Iron: Pure Iron
- Permanent magnet Sm_2Co_{17}











Dipole assembly area

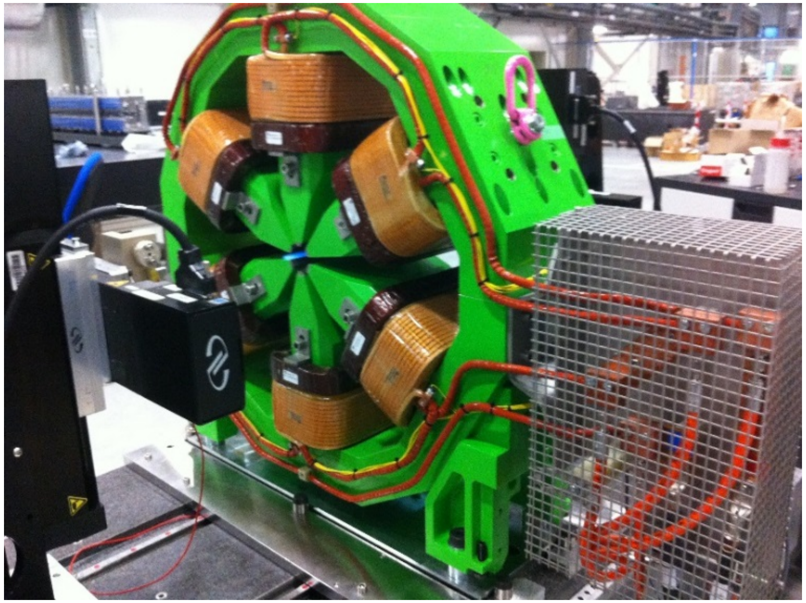
PM assembly tool

Around 6000kg of PM, 660 Iron modules,
Half of the 128 magnets already assembled

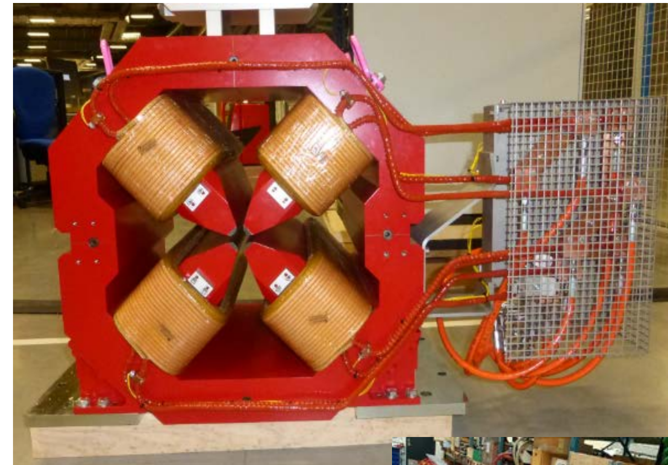
SEXTUPOLES [196]

- 2 types
- 1700 T/m^2 gradient, 166 – 200 mm length
- 19.2 mm bore radius
- 0.5 kW power consumption
- Including additional correction coils

First series magnet batch delivered



QUADRUPOLES



High Gradient *[130]*

- 2 types
- 89 & 87 T/m gradient
- 388 – 484 mm length
- 12.7 mm bore radius
- 1.9 & 1.7 kW power consumption

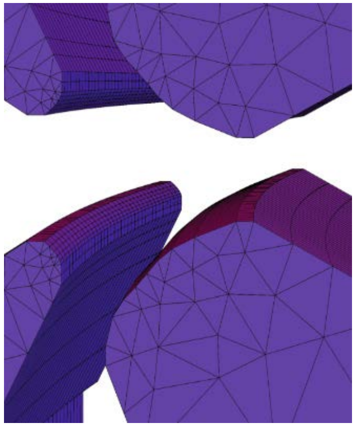
First series magnet batch delivered

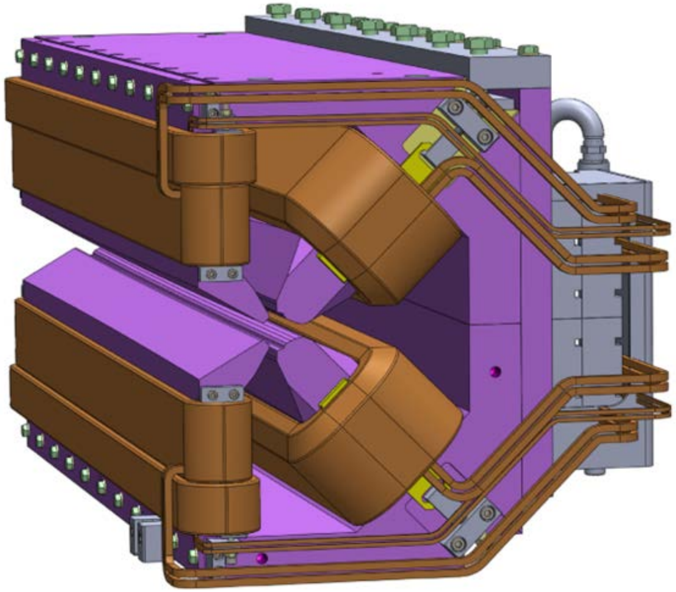
Moderate Gradient *[398]*

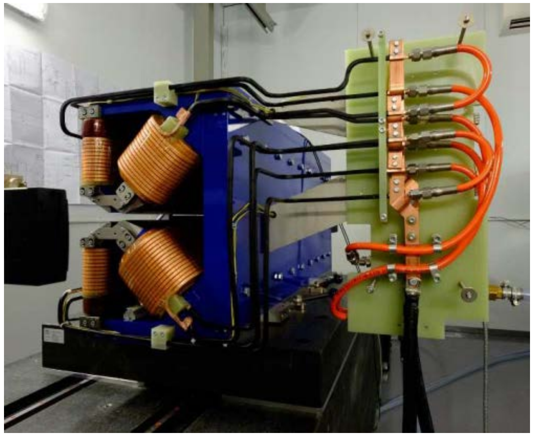
- 4 types
- Up to 54 T/m gradient, 162– 295 mm length
- 16.4 mm bore radius
- 0.7 – 1.1 kW power consumption

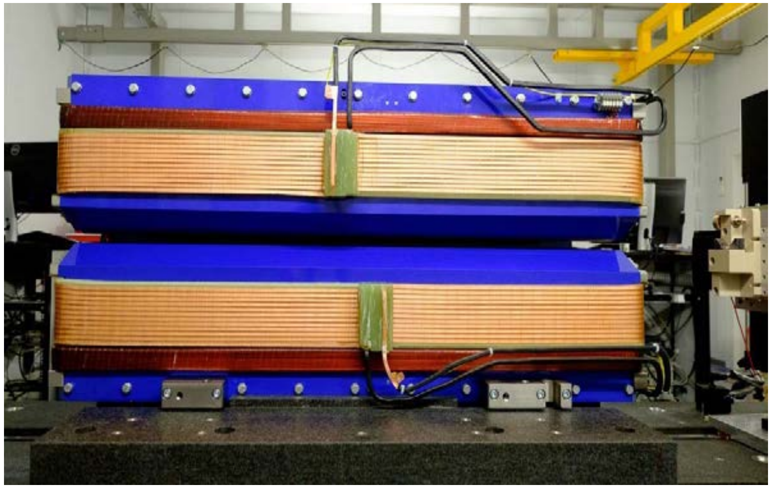
DIPOLE QUADRUPOLES [99]

- 2 types
- Nominal dipole 0.55 – 0.39 T
- Nominal gradient 36-39 T/m
- 1028-800 mm
- 18.6 mm bore radius
- 1.6- 1.2 kW power consumption
- Poles longitudinally curved





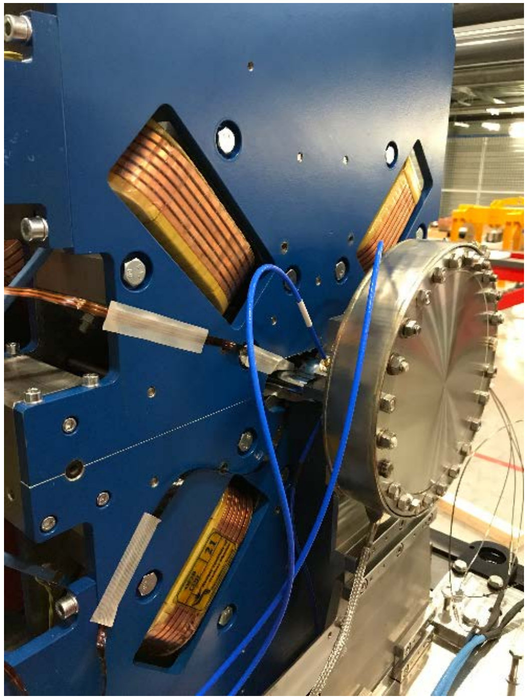


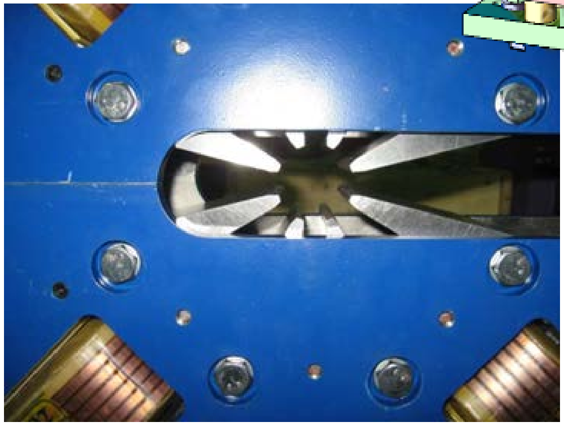


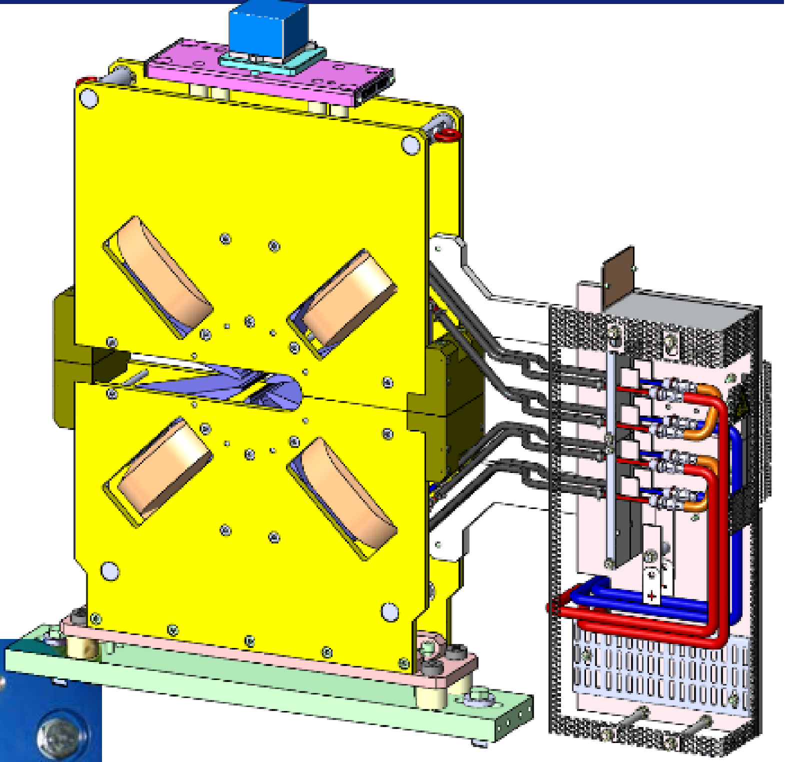
Pre-series magnet delivered

OCTUPOLES [66]

- 36900 T/m3 gradient, 90 mm length
- 18.6 mm bore radius
- 0.1 kW power consumption
- Allows the required stay clear for Synchrotron radiation fan







Series production

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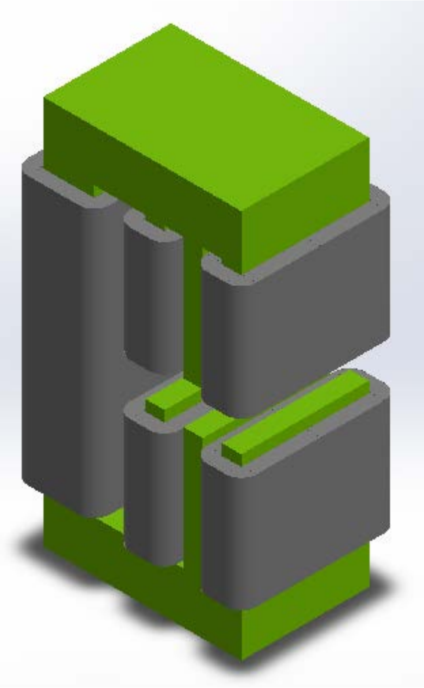
CORRECTORS [100]

- Horizontal: 0.1 T.mm
- Vertical 0.1 T.mm
- Skew quadrupole: 0.12 T
- 25.5 mm gap mm bore radius



Series production

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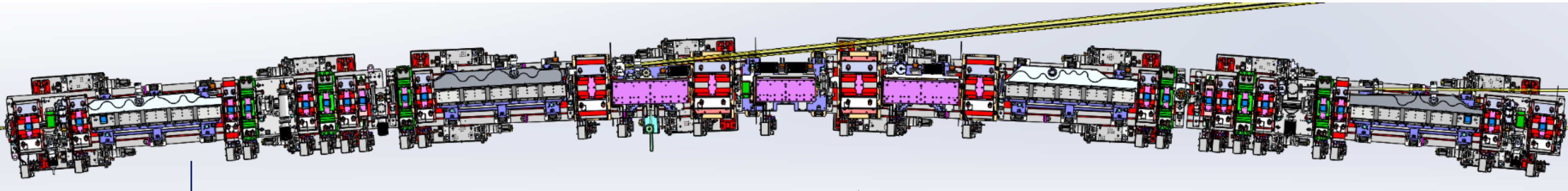
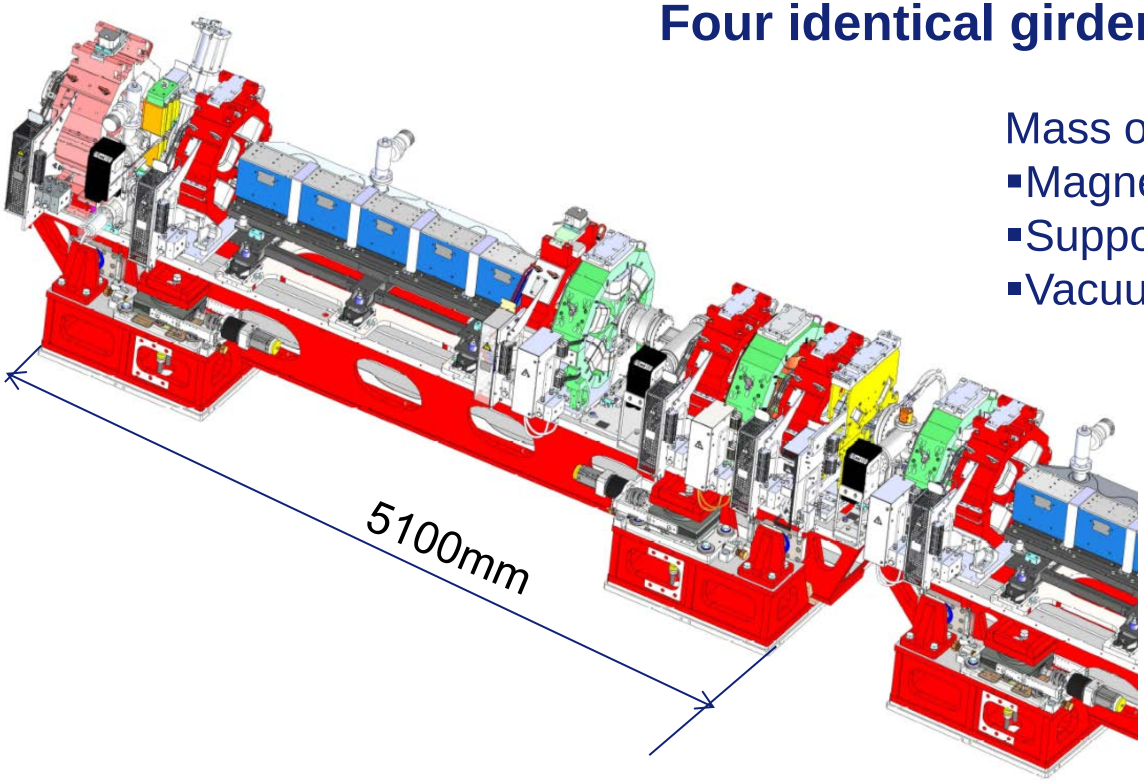
GIRDERS





Four identical girders per cell

Mass of:
- Magnetic elements
- Supports
- Vacuum equipements

6-7T/girder

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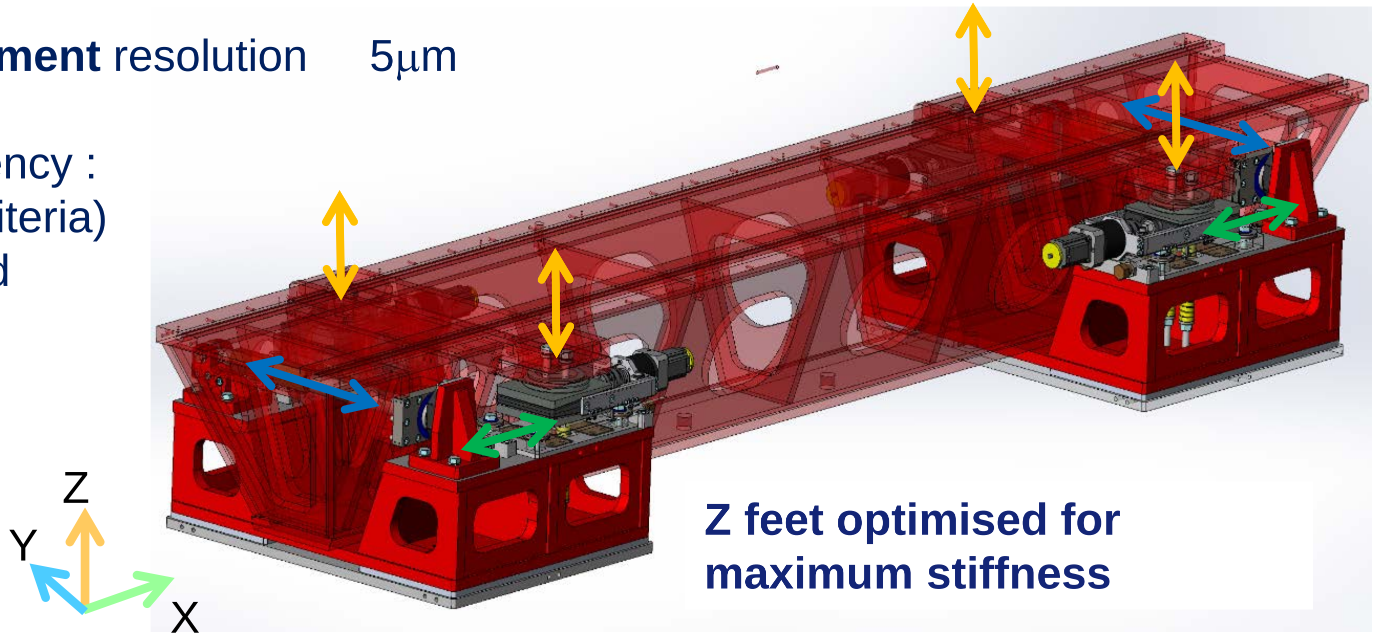
GIRDERS

- Girder supported by 4 adjustable Z feet made of motorised wedges
- Y adjustment by 2 manual jacks pushing the girder

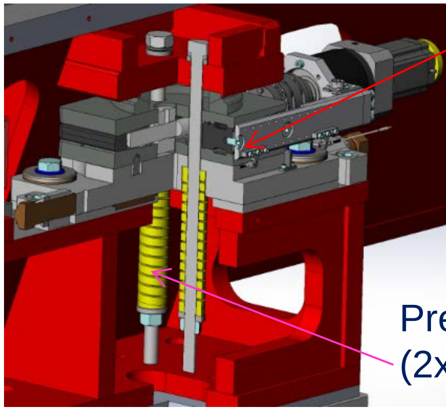
	HORIZONTAL (Y)	VERTICAL (Z)
Girder to girder	50 μm	50 μm

- **Motorized Z adjustment** resolution 5μm
- **Manual Y adjustment** resolution 5μm
- 1st natural frequency :
  - 50Hz (design criteria)
  - 49 Hz measured



GIRDERS [129+1]

- Vertical movement

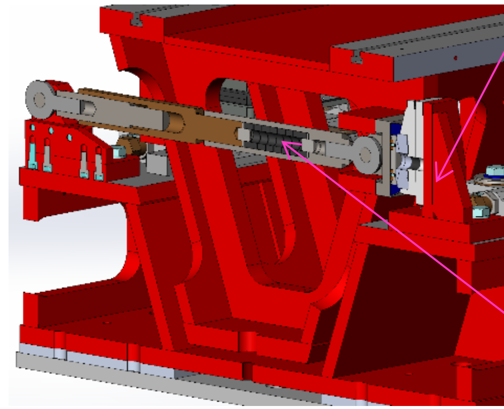


Motorised Wedge Airloc

Z movement:
- Accuracy: 10.8µm
- Repeatability: 3.3µm
- Increment: 0.3µm

Preload springs (2x0.7T)

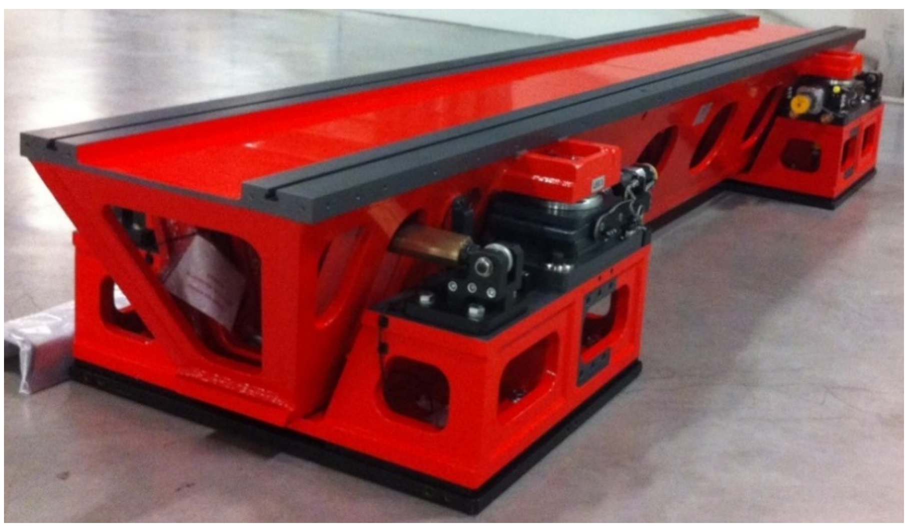
- Horizontal movement



Wedge Nivell DK2

Horizontal Jack functions:
- horizontal adjustment
- guiding the vertical movement
- improving the stiffness

«Pushing back» spring (3.5T)



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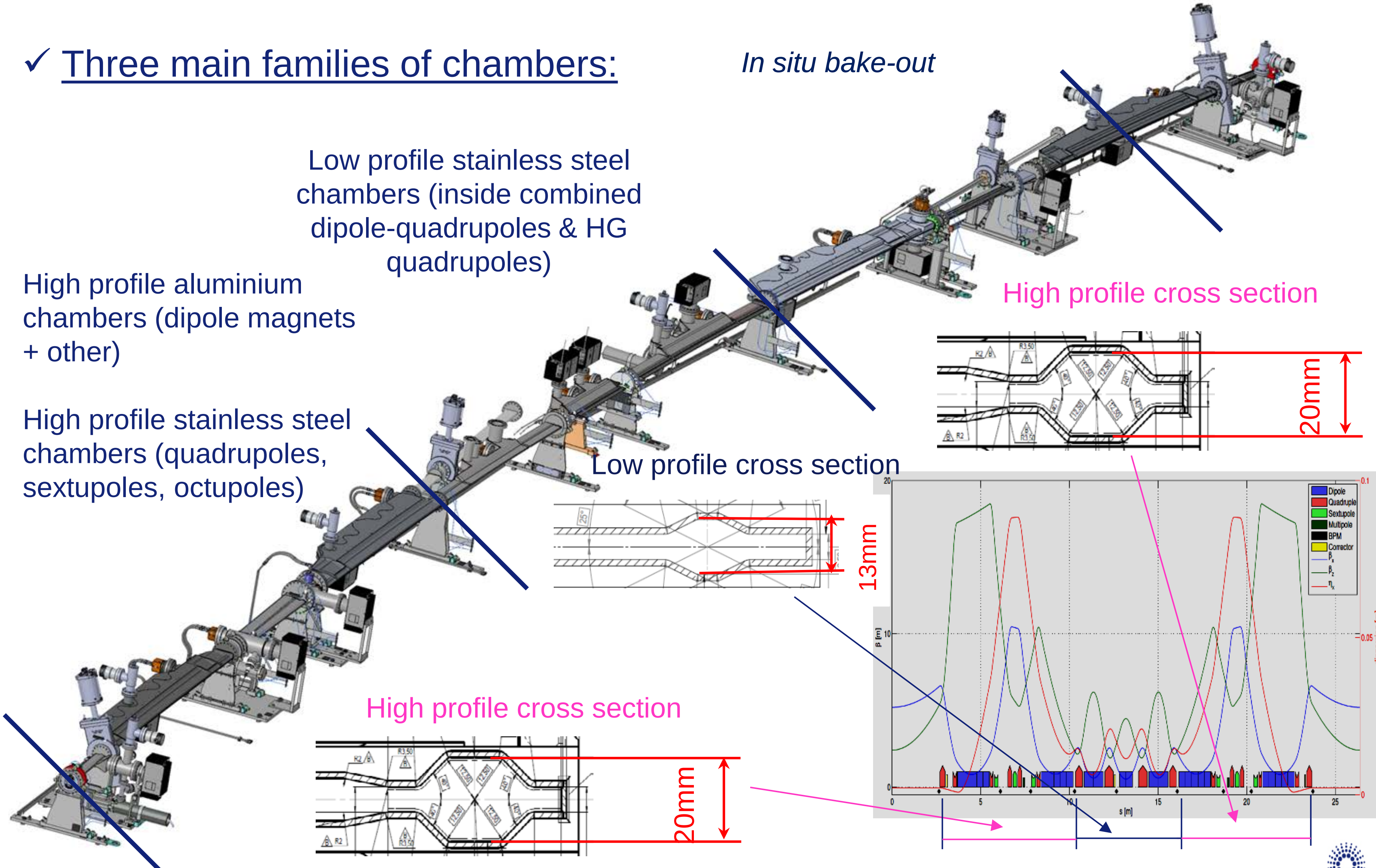
VACUUM CHAMBERS

✓ Three main families of chambers:



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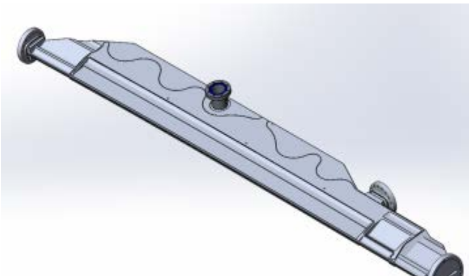
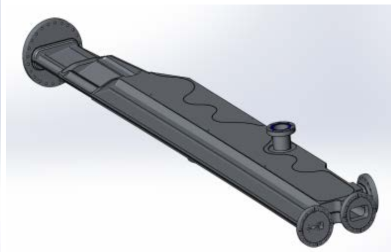
FAMILY 1: ALUMINIUM DIPOLE CHAMBERS

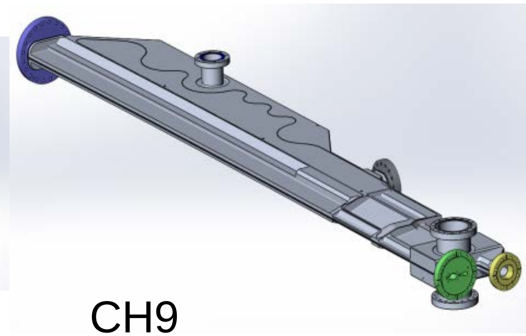
4 dipole chambers per cell made of Aluminum



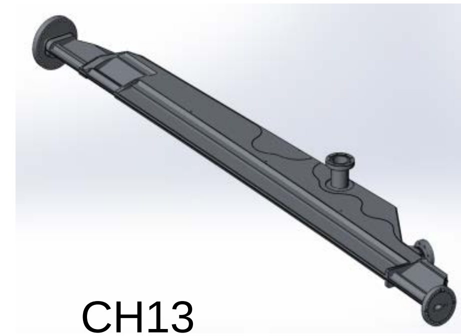
CH2



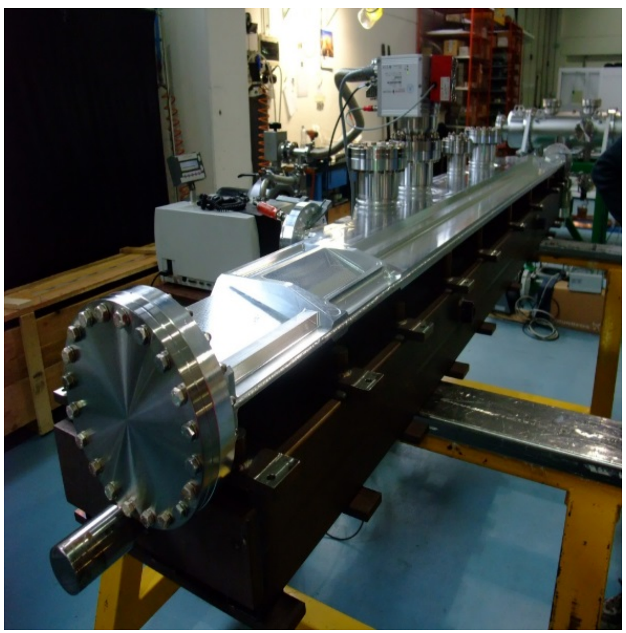
CH5



CH9



CH13



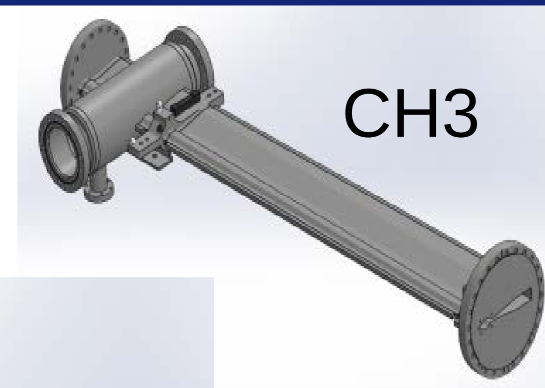
- Design completed
- Pre-series delivered
- Series Manufacturing in progress

FAMILY 2: HIGH PROFILE STAINLESS STEEL CHAMBERS

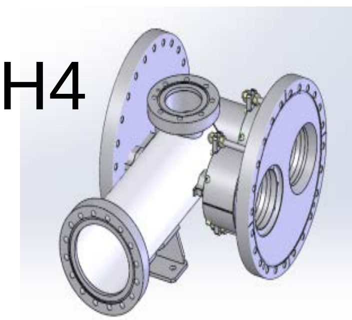
Straight Chambers

CH1

CH3

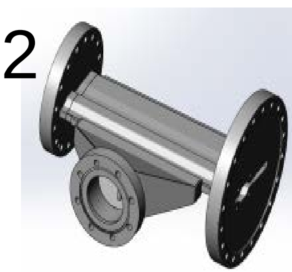


CH4



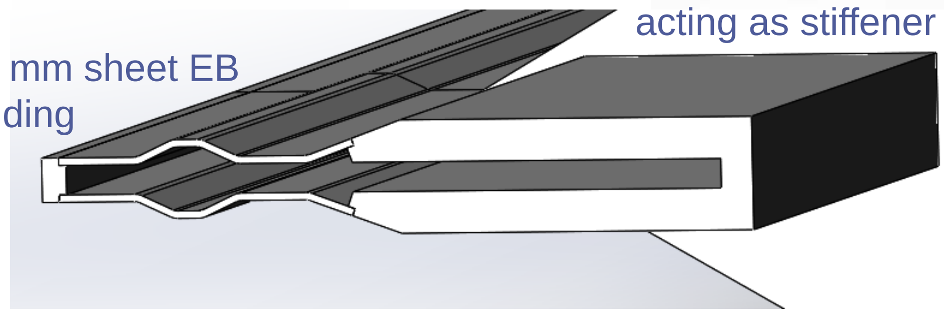
CH11

CH12

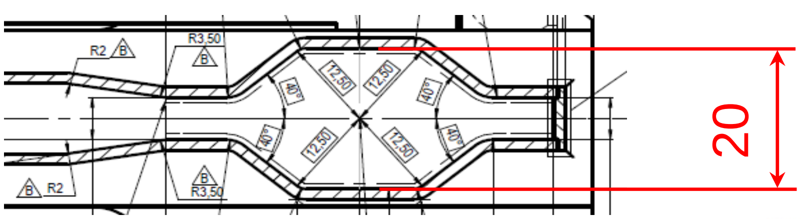


Thick ante-chamber acting as stiffener

1.5 mm sheet EB welding



High profile cross section



- Manufacturing in progress

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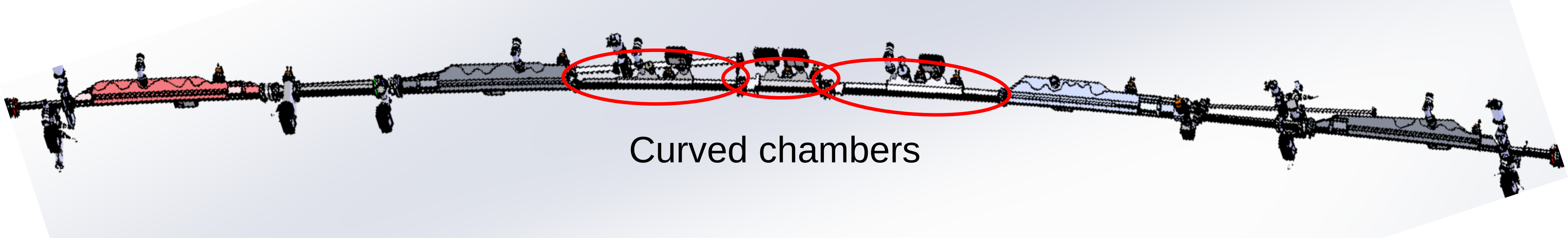
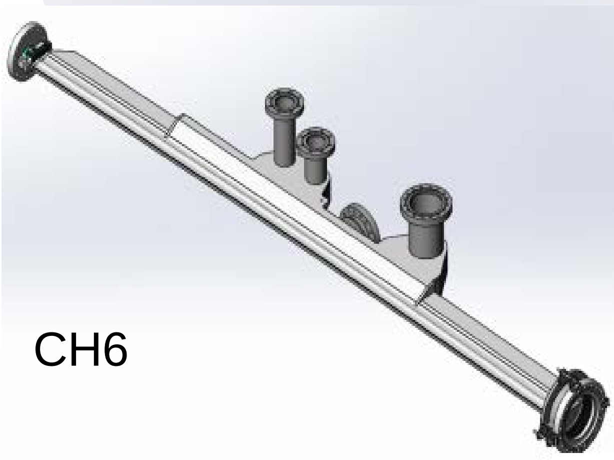
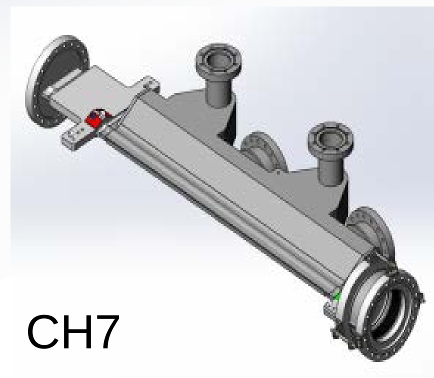
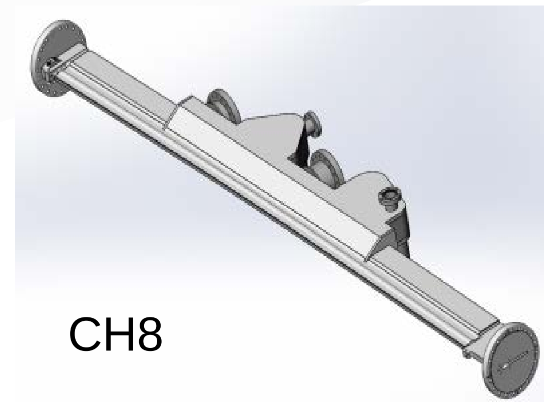
FAMILY 3: LOW PROFILE STAINLESS STEEL CHAMBERS



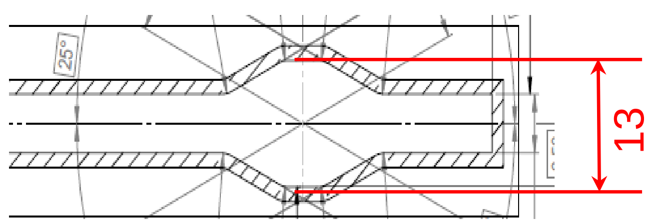


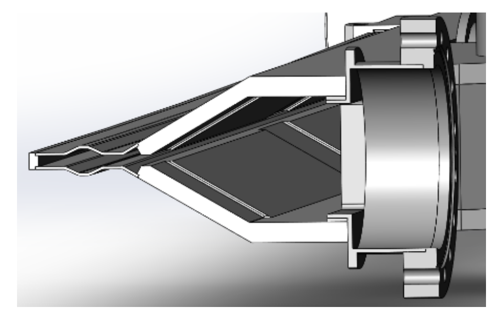




Low profile cross section (inside dipole-quadrupoles and HF quadrupoles)

- Manufacturing in progress





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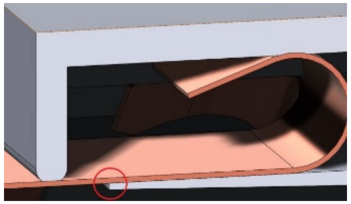
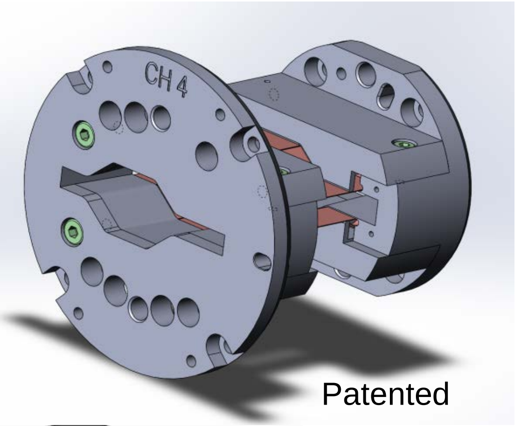
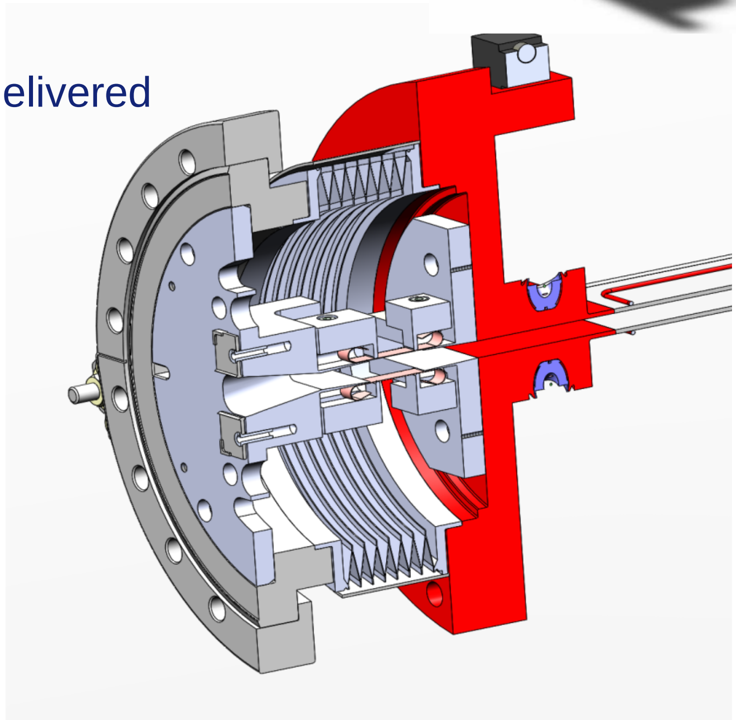
RF FINGERS

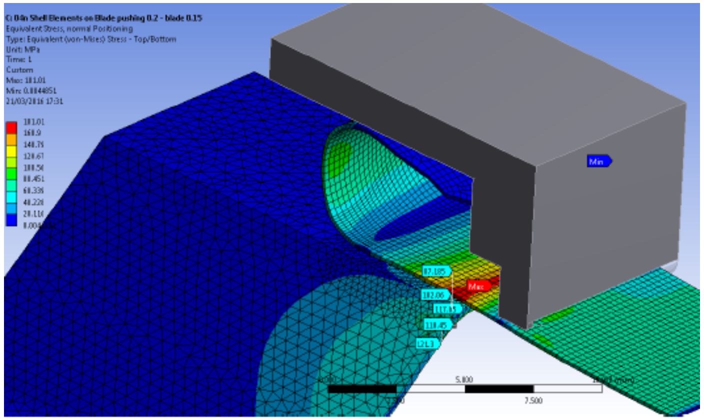
- 8 different bellows = 8 different RF Fingers.
- Close collaboration with the vacuum chamber designer.
- FEA model
- Design completed
- Prototype tested in the machine, Pre-series delivered
- Manufacturing in progress



Blade contact



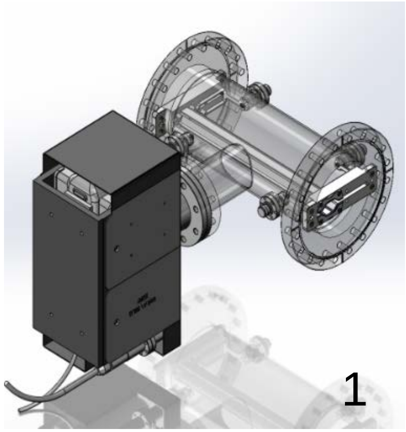




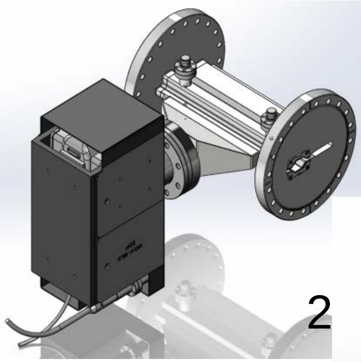
VACUUM CHAMBERS – CH12 DIAGNOSTICS

1. H stripline
2. V stripline
3. Shaker
4. Current transformer
5. Beam losses collimator

Procurement in progress



1



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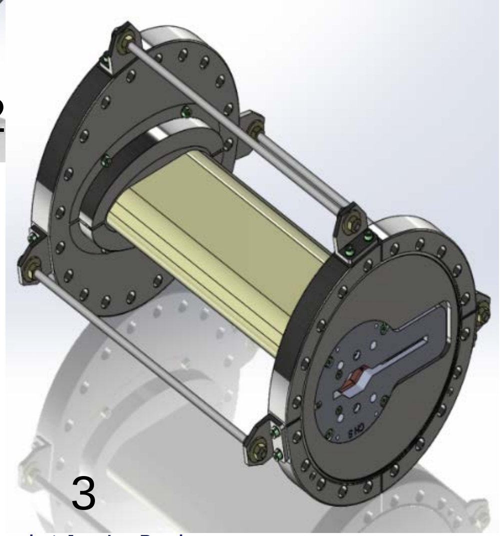

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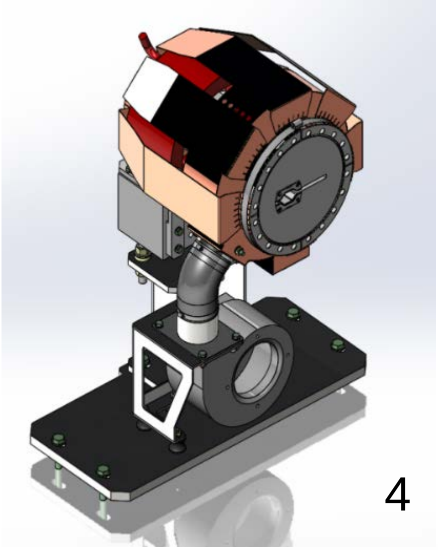

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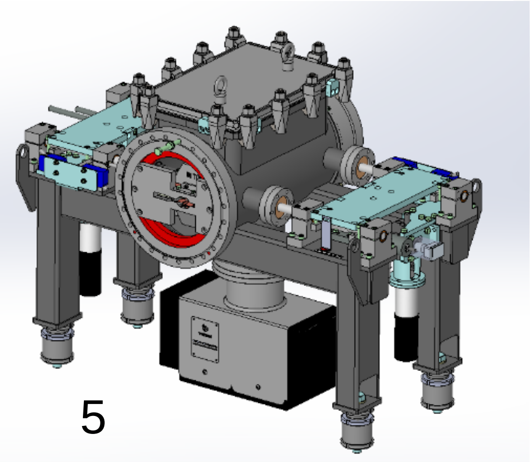

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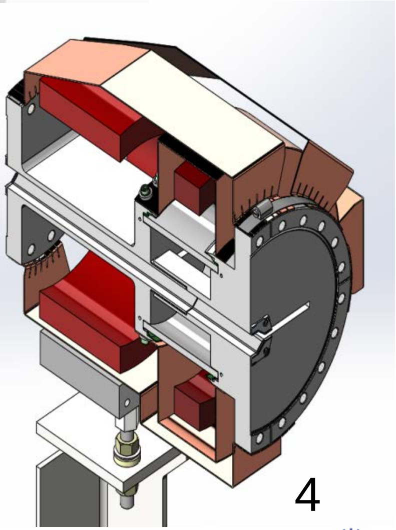

4

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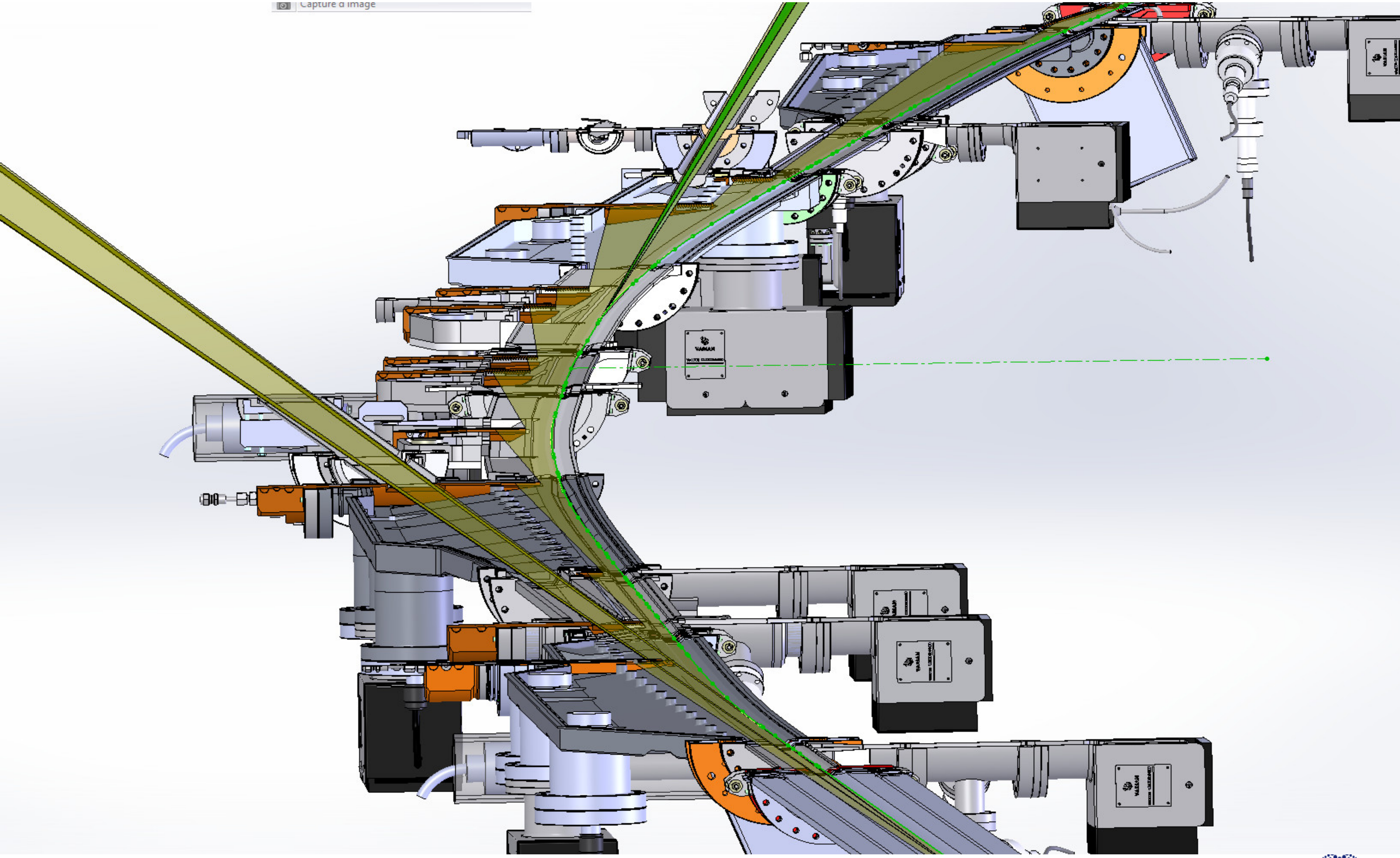
PHOTON ABSORBERS



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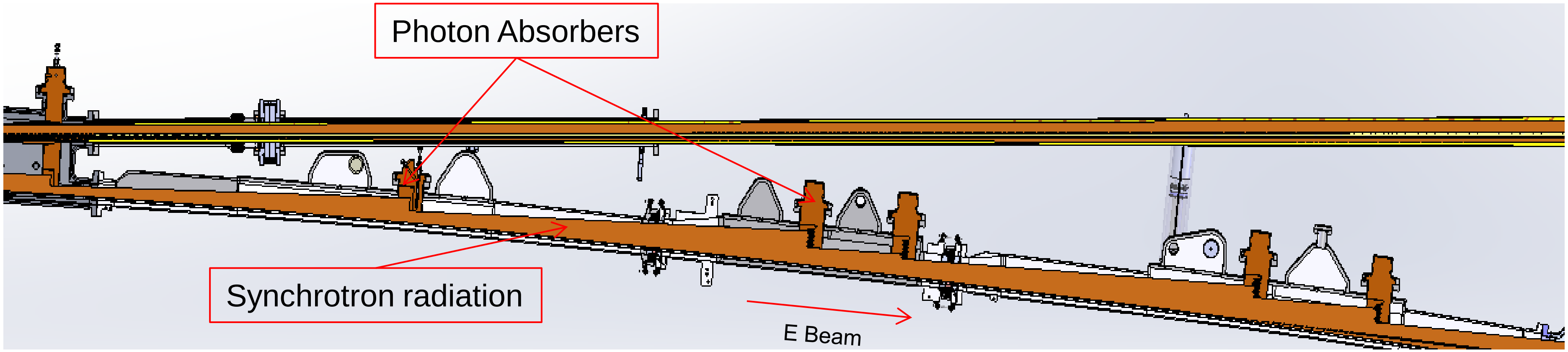
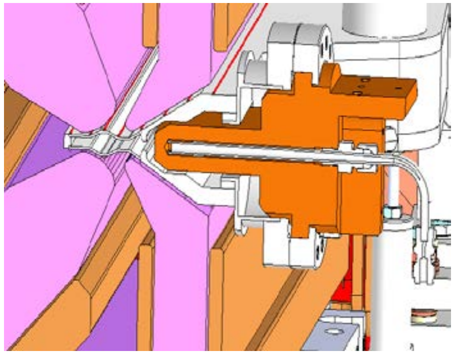
PHOTON ABSORBERS

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





Absorber flange mounted on the ante-chamber

Tight space constraints

-CuCr1Zr as an alternative to Glidcop

- Integrate the CF flange in the CuCr1Zr absorber body (Sharma Sushil idea)

Pre-series delivered, absorbers in series production

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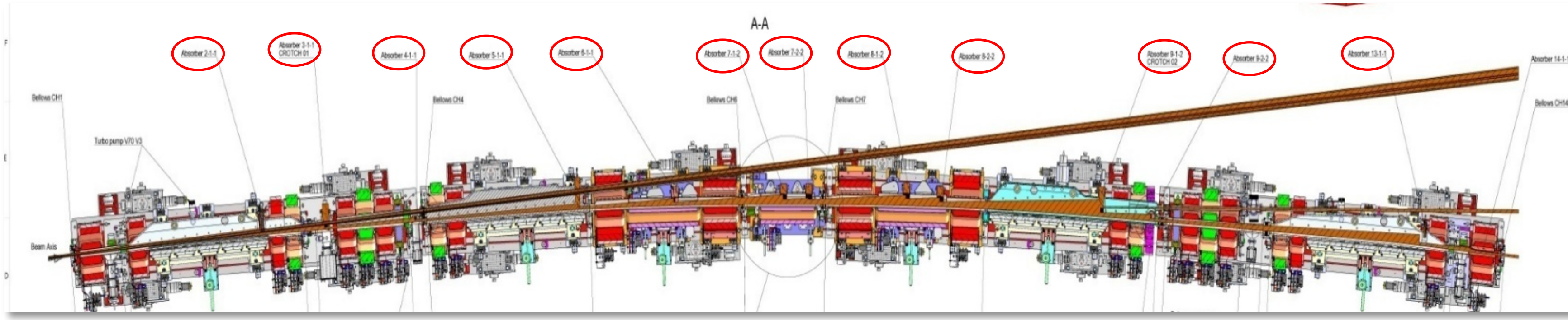
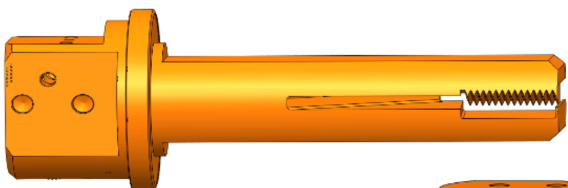
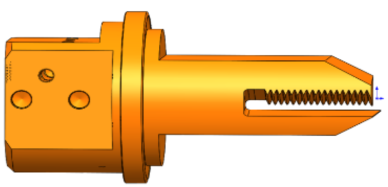
ABSORBERS DESIGN : TWO FAMILIES



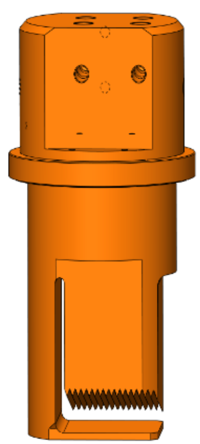
Family Toothed (up to 110 W/mm²)

Toothed geometry optimized to reduce thermal stresses over large area

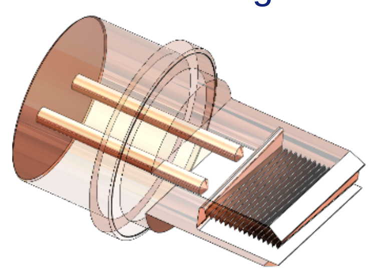


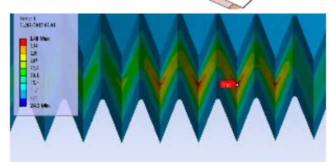


Crotch 1



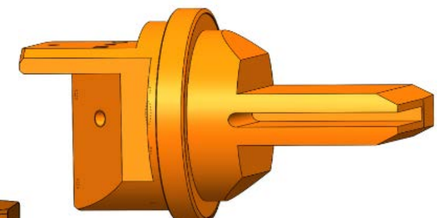
ABS CH9-1-29

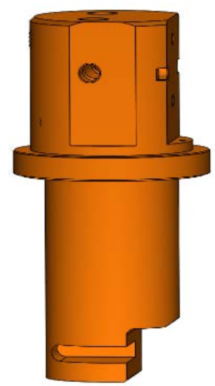




Temperature photon Toothed absorber

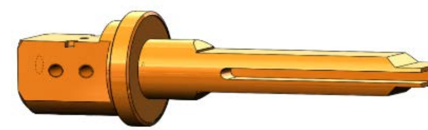
Family Frontal (up to 50 W/mm²)





ABS CH4-1-1

ABS CH5-1-1



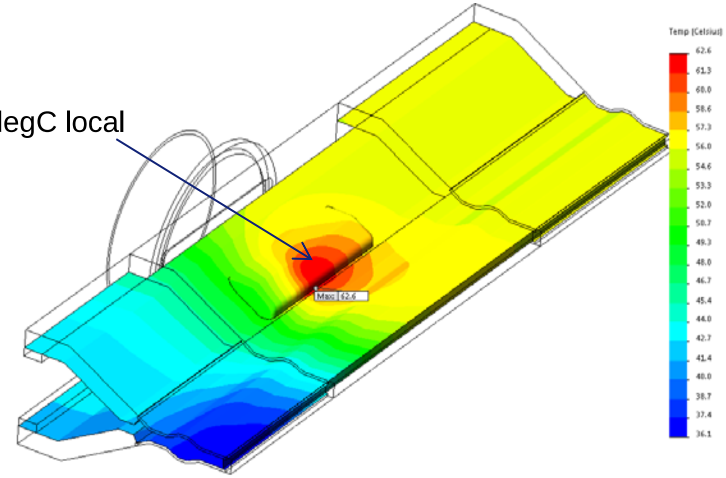
ABS CH13-1-13

No weld, no braze

ABSORBERS OPTIMIZED TO BLOCK SCATTERED RADIATION

- ❑ No water cooling on chambers

60degC local

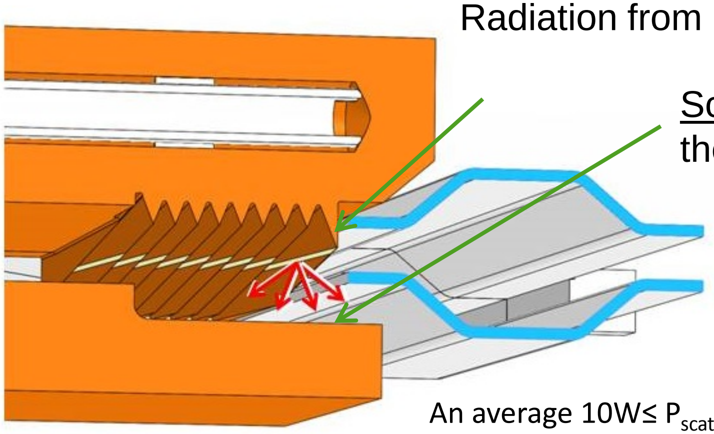


Teeth Absorbers intercept the Radiation at grazing angle

⇒Scattered fraction is high (5-10%)

Long End Tooth blocking the Scattered Radiation from reaching the Chamber

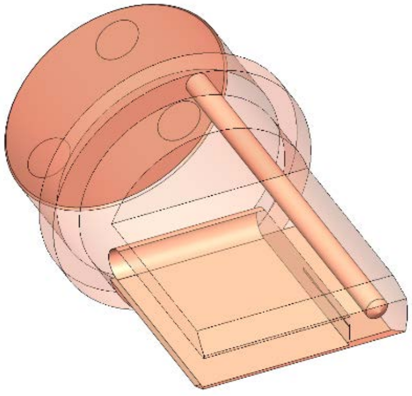
Screen blocking most of the scattered radiation



An average 10W≤ P_{scatt} ≤30W irradiated on vessels

Efficiency ~ 85% (Screen + Long Tooth)

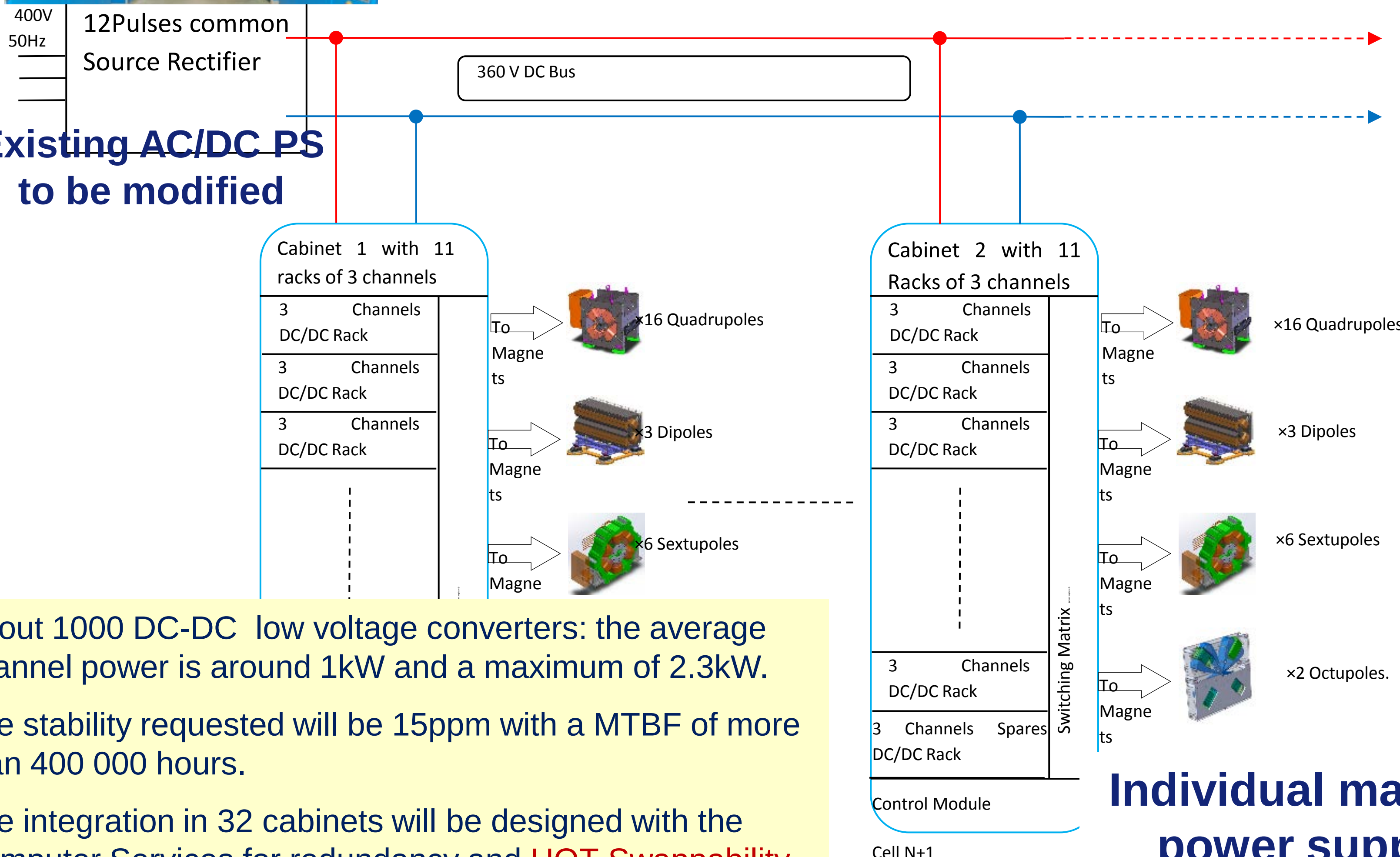
Frontal Absorbers intercept Radiation close to Normal Incidence
=> Scattered Fraction is low (<3%)



POWER SUPPLIES

360 V dc distribution network

Existing AC/DC PS to be modified



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

Individual magnet power supply

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1000 LARGE POWER SUPPLIES AND 1000 SMALL POWER SUPPLIES

DC-DC converters *[371 racks of 3 channels]*:

- Prototypes validated
- Contract signed, design in progress

DC-DC Corrector Power Supplies *[100 crates of 9 channels]*

- Prototypes validated
- Contract signed, design in progress

Hot swap manager:

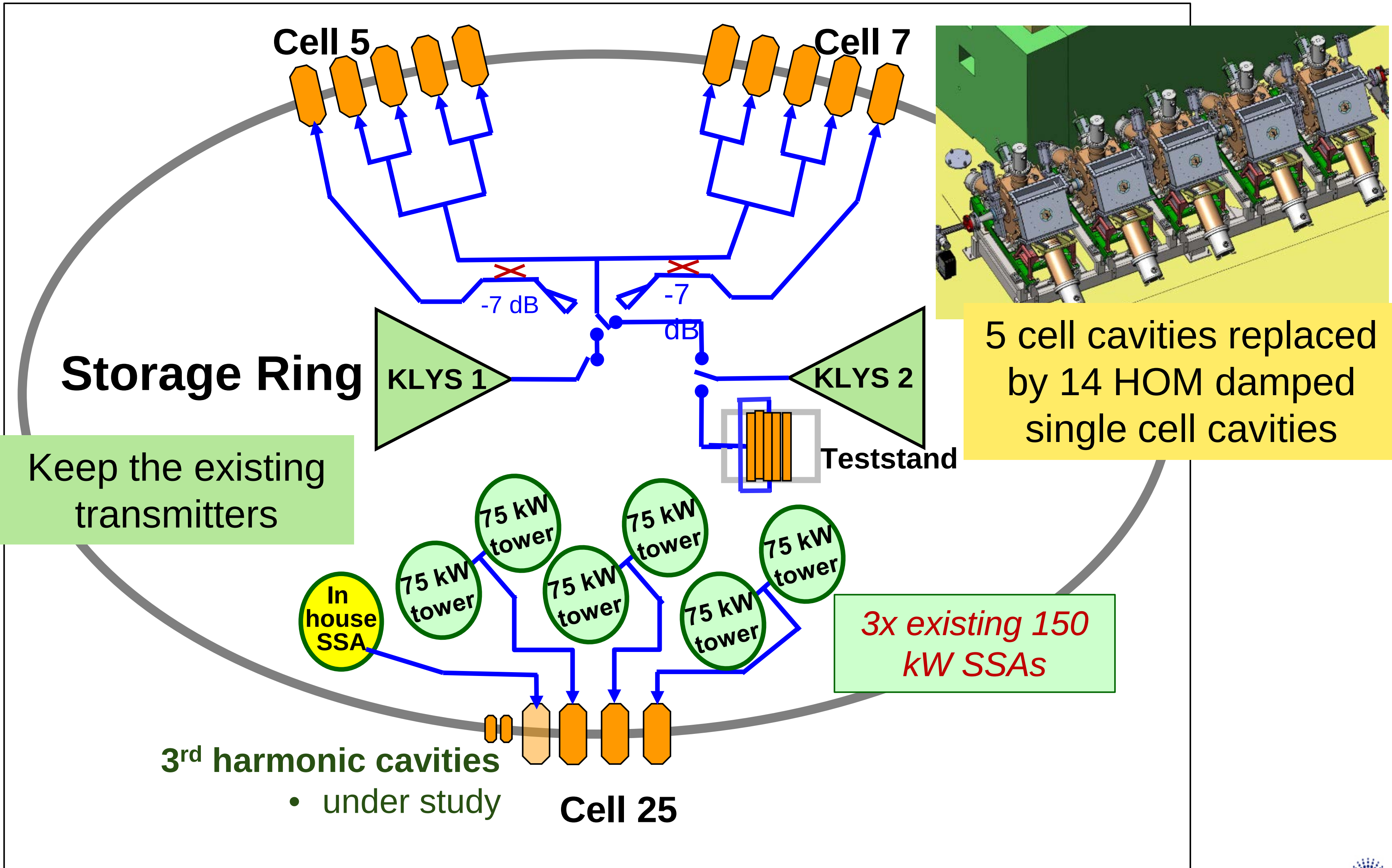
- Patent process finalized, Specification done
- Produced by ESRF/ISDD

Hot swap cubicles *[34]*

- RFQ for prototype cubicle delivered
  CFT by second half 2017

DC-DC Proto 2 (2 channels)

RF LAYOUT



5 cell cavities replaced by 14 HOM damped single cell cavities

RF CAVITIES

Three operational prototypes in house
Fabrication of 12 HOM damped cavities by RI

All cavities delivered
HOM absorbers to be delivered Oct17-May18

6 cavities conditioned to 750 kV within 2 weeks each

Cavity assembly area

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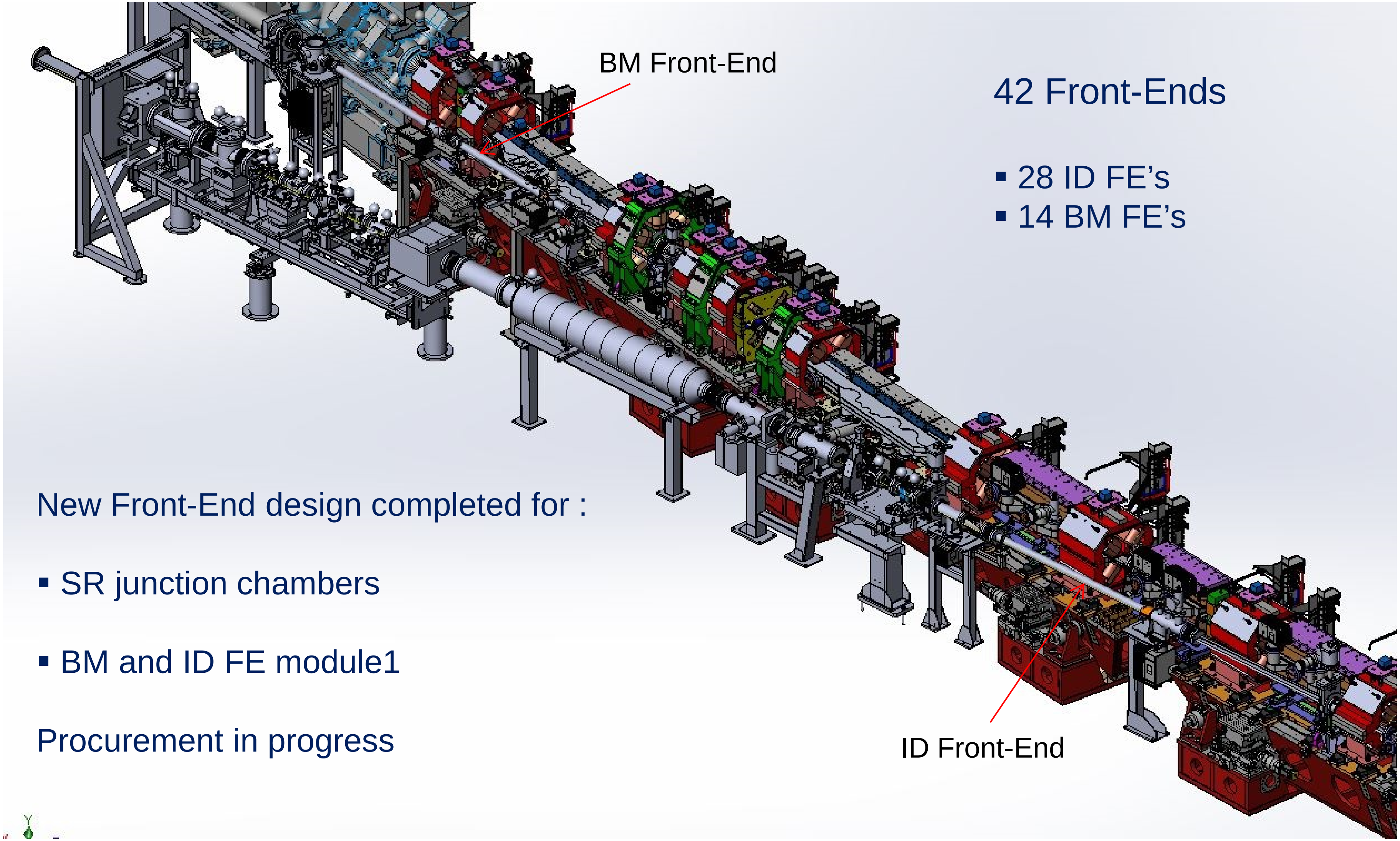
FRONT-ENDS



42 Front-Ends

- 28 ID FE's
- 14 BM FE's

New Front-End design completed for :

- SR junction chambers
- BM and ID FE module1

Procurement in progress

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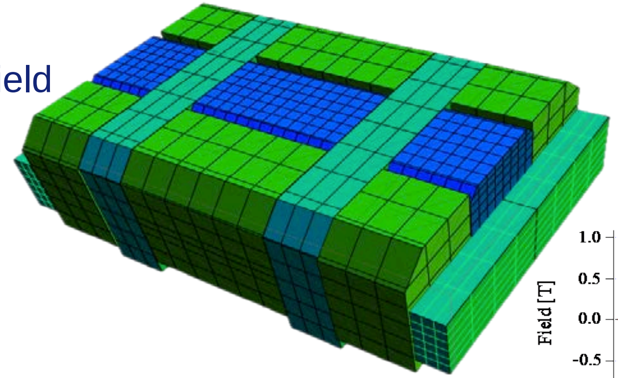
BENDING MAGNETS SOURCE: 1- POLE BM, 2-POLE & 3-POLE WIGGLERS

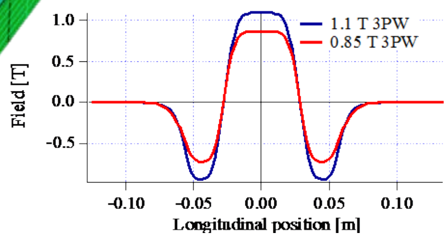
All new projects of diffraction limited storage rings have to deal with:



Half assembly

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

Conflict with hard X-ray demand from BM beamlines

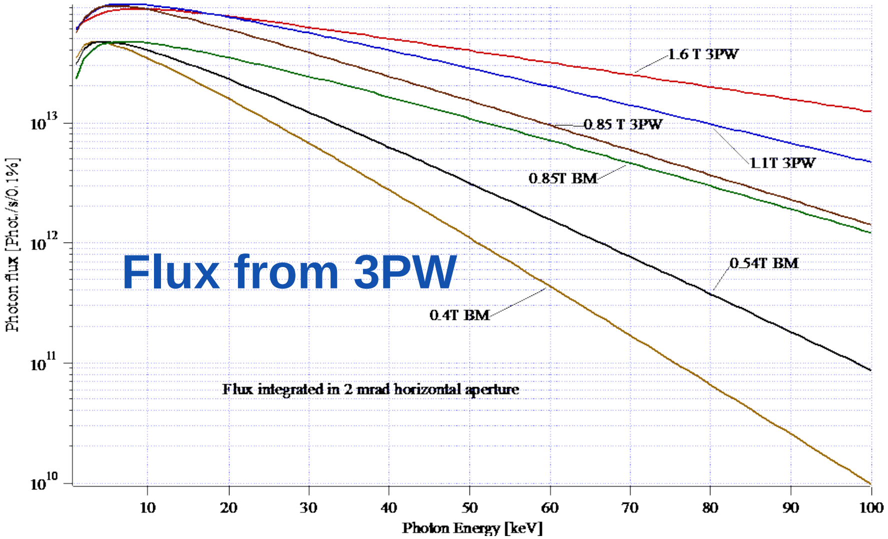


ESRF will go from 0.85 T BM to 0.54 T BM

The BM Sources will be replaced by dedicated 1-Pole short super bend, 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



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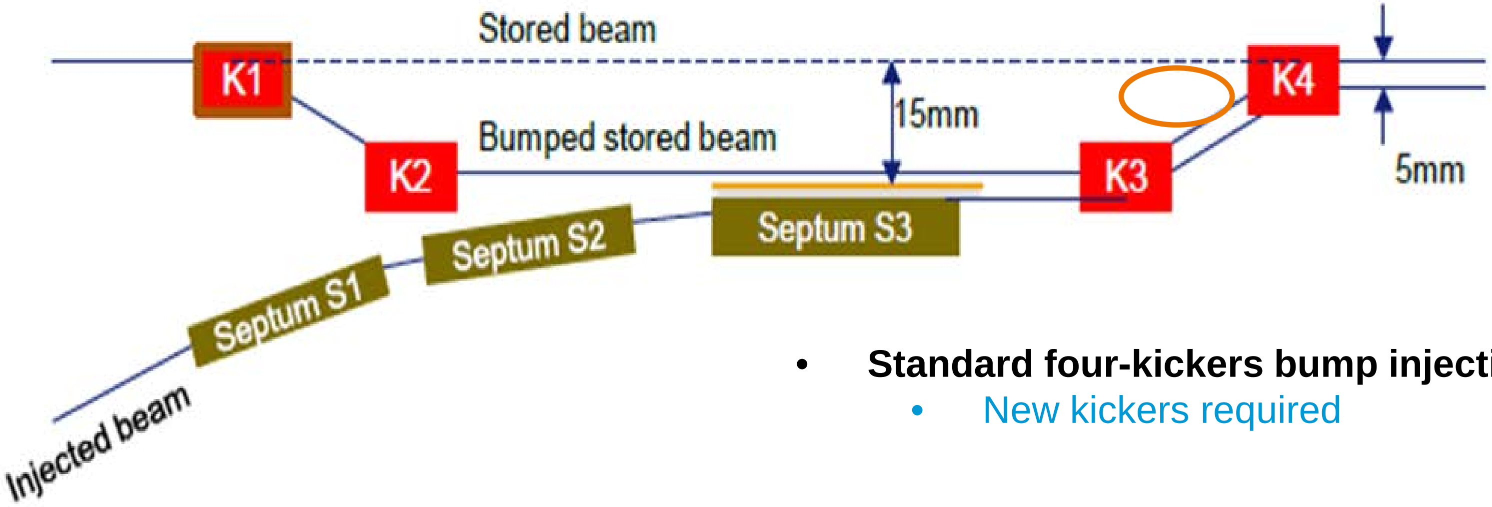
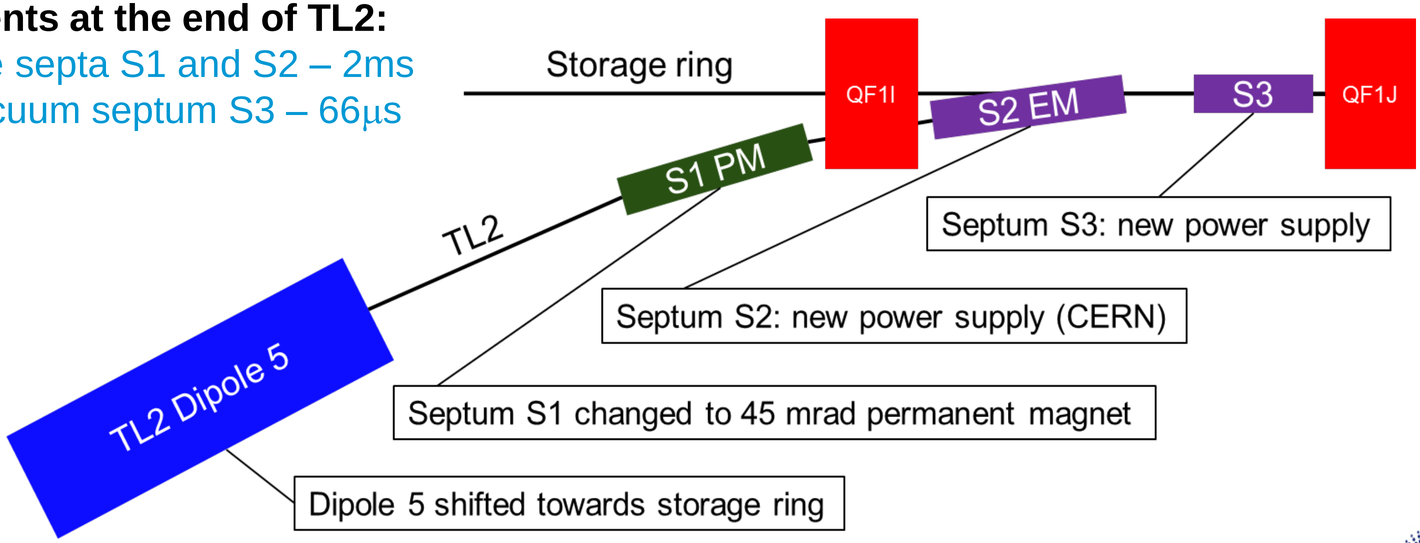
INJECTION IN THE STORAGE RING

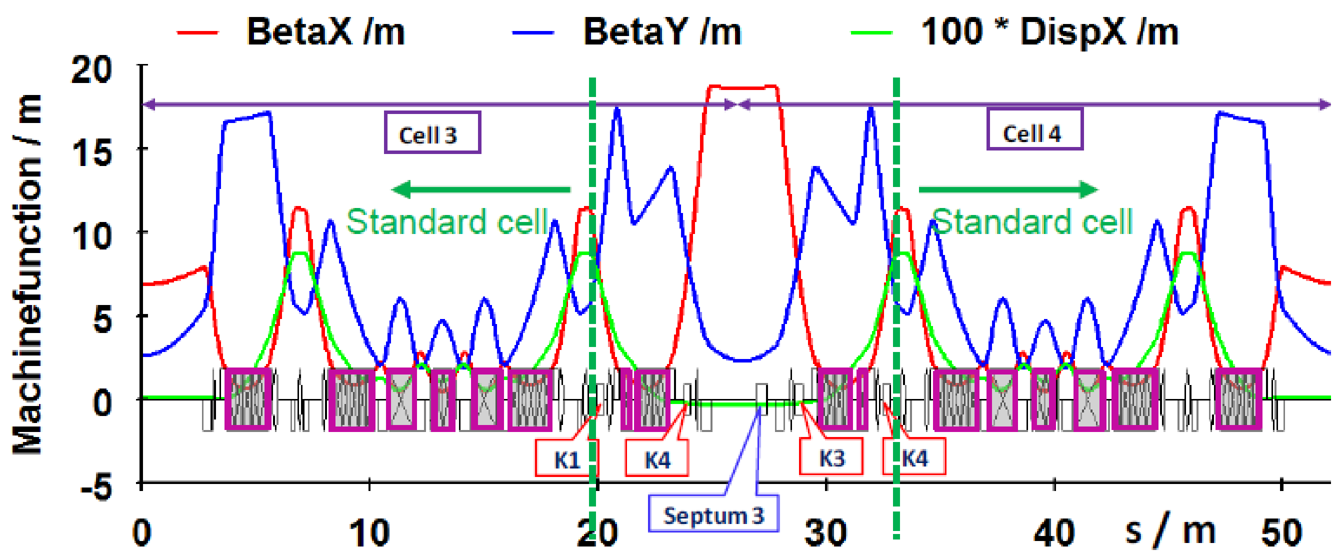


- **Standard four-kickers bump injection (3µs):**
  - New kickers required

- **Pulsed elements at the end of TL2:**
  - 2 active septa S1 and S2 – 2ms
  - 1 in-vacuum septum S3 – 66µs



INJECTION CELLS

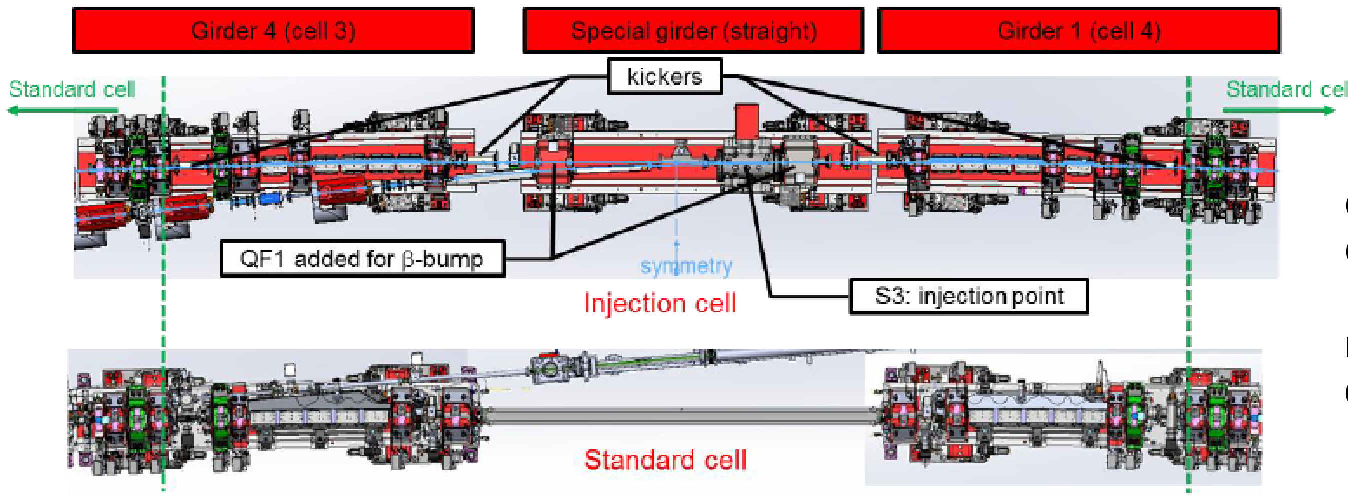


Dedicated injection cells:

Standard cell optics up to QF4

β_x at the injection point increased

Minimize symmetry breaking



Girder 4 of Cell 3 and Girder 1 of Cell 4 are

non standard with a dedicated layout

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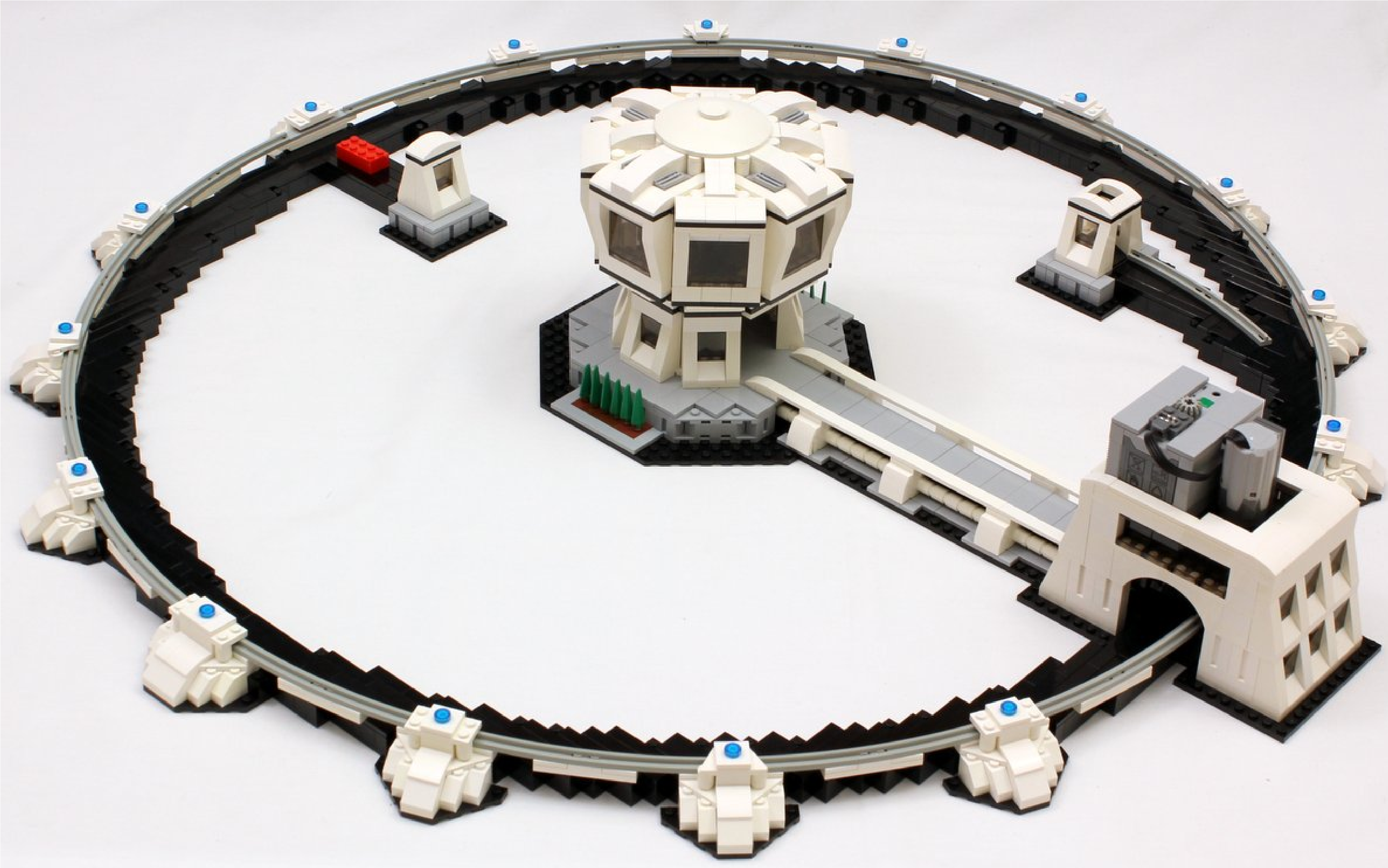
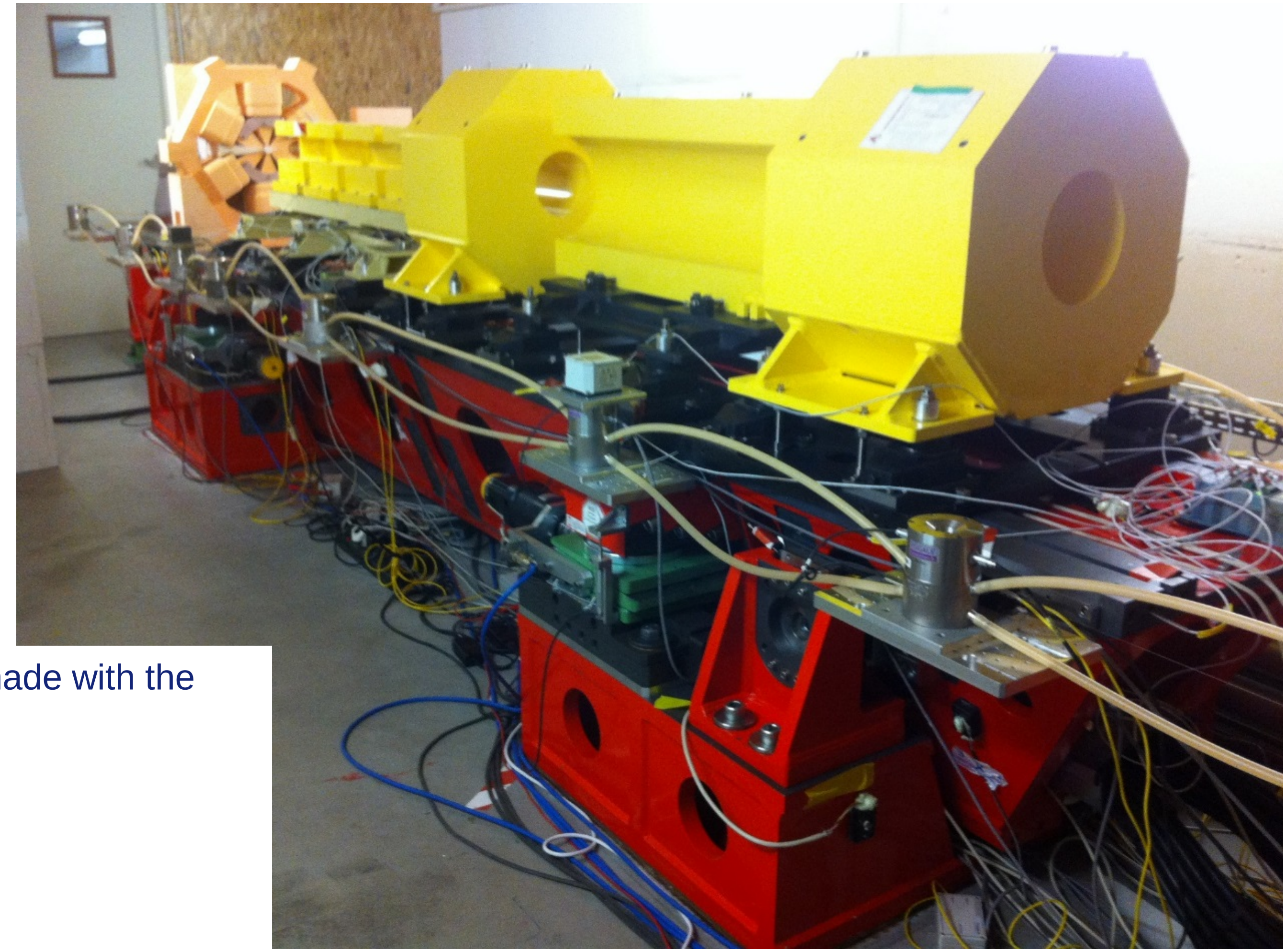
ASSEMBLY AND INSTALLATION OF THE NEW ACCELERATOR

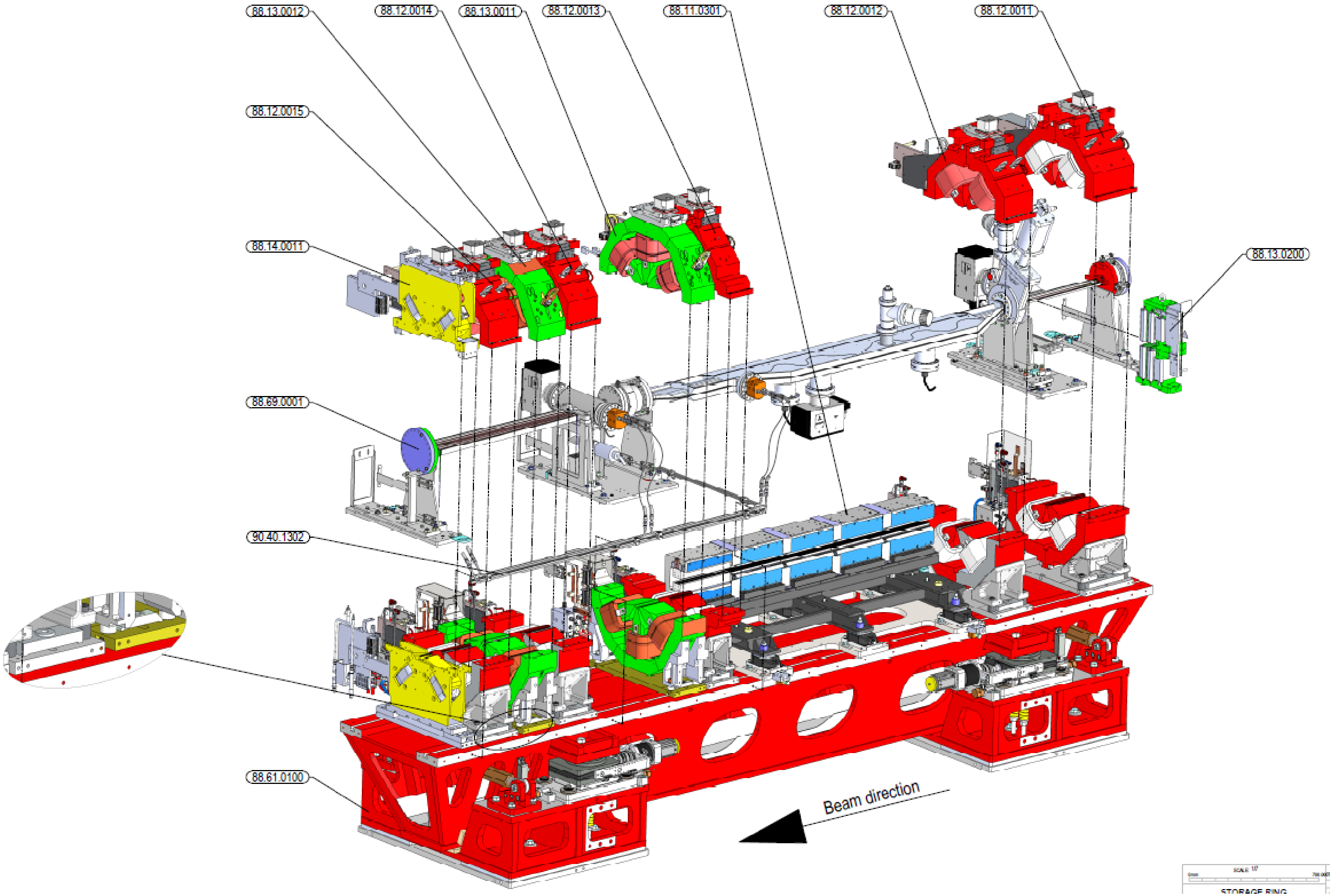


INITIAL PROTOTYPE MOCKUP

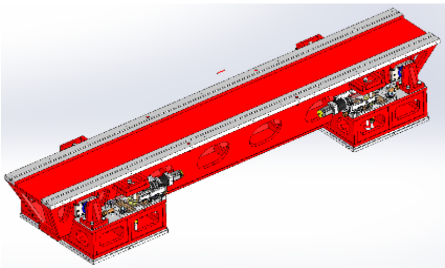


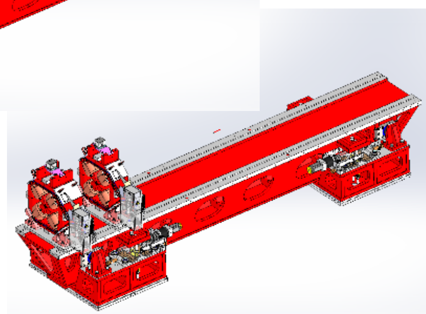
Many tests have been made with the prototype mockup:
• Girder performances
• Girder handling
• Survey
• Thermal issues
• Compatibility checks
• Services and cabling optimization

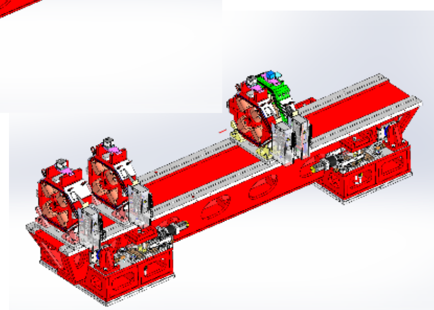
COMPLETE GIRDER DISASSEMBLED VIEW

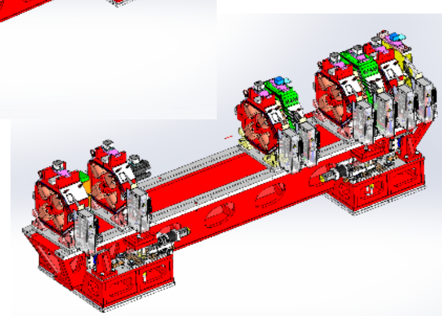


ASSEMBLY PHASE



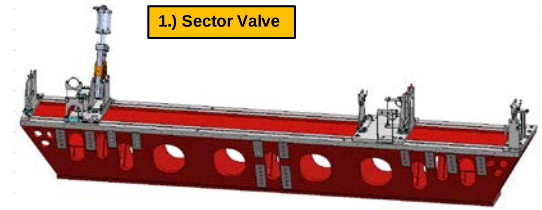


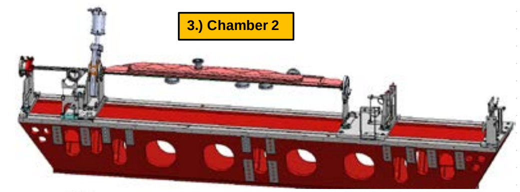


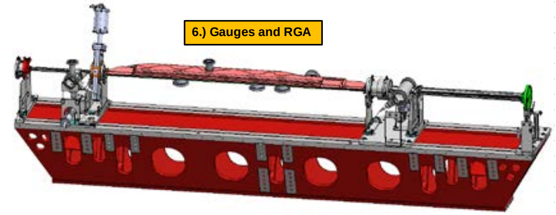


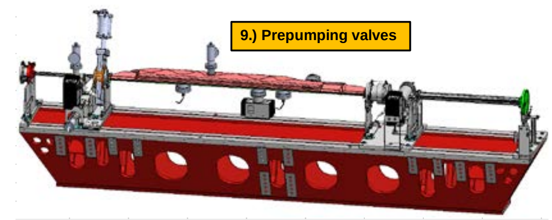
Assembling of magnets on the girders

Assembling of vacuum chambers on dedicated tables









Then opening of magnets and add the whole vacuum section,… alignment,…..

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FULL CELL MOCKUP

Four girders for a complete cell preparation

A full cell mockup began to be assembled in January 2017:

• 4 fully assembled girders to be used to test and optimise the assembly and installation sequences

Four tables for the vacuum chamber preparation area

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FULL CELL MOCKUP

FULL CELL MOCKUP

vacuum chambers assembly handling tool

vacuum chambers handling tool

vacuum chambers assembly table

Handling tools and logistics preparation

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FULL CELL MOCKUP

The four girders are now assembled with the pre-series components:

- No major problems encountered with the different components; everything fits together
- Minor modifications required to the suppliers for the series production

- The overall assembly procedure has been validated
- Detailed and optimised procedures are under preparation

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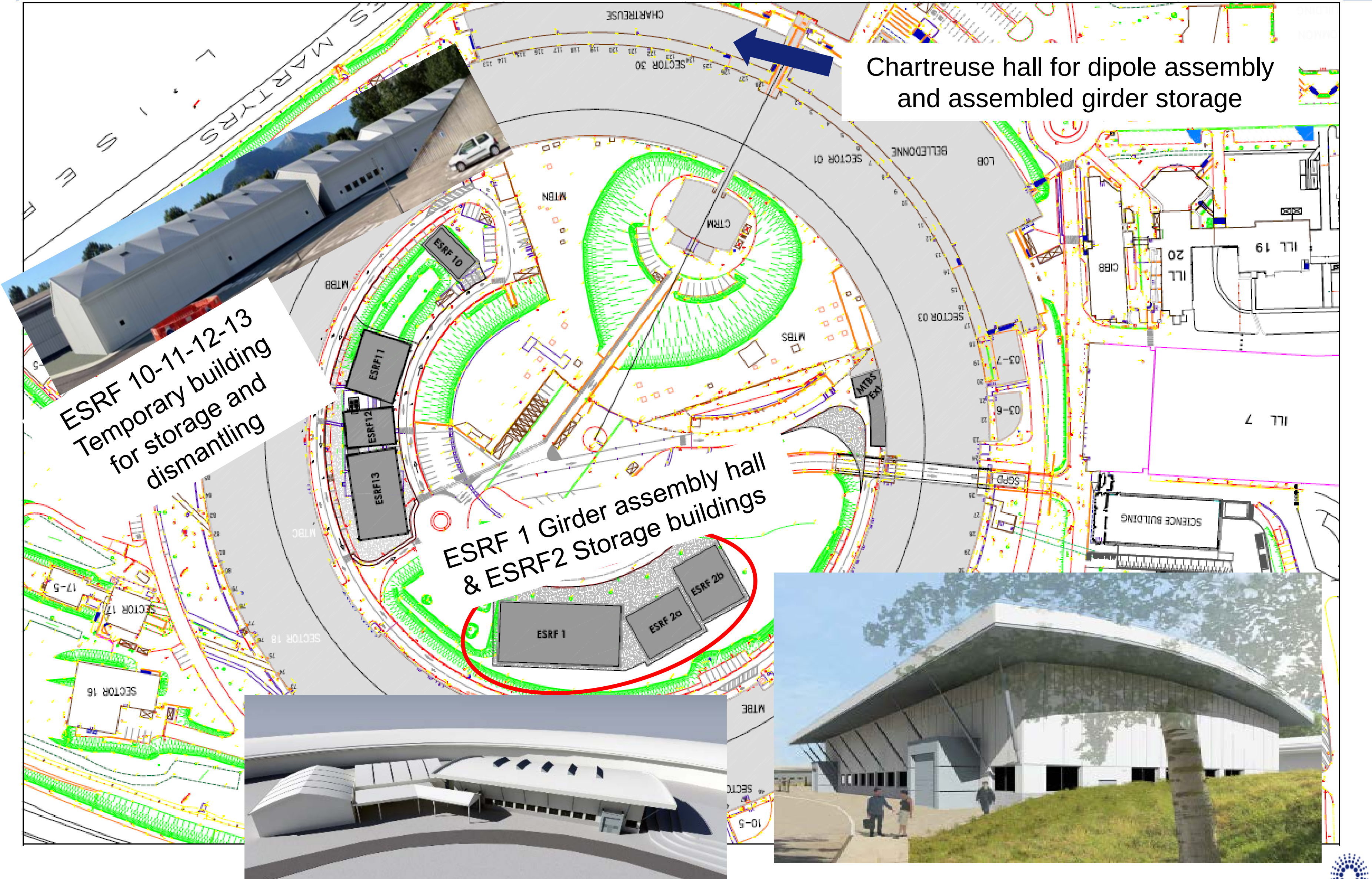
BUILDINGS FOR THE ASSEMBLY AND INSTALLATION PHASE



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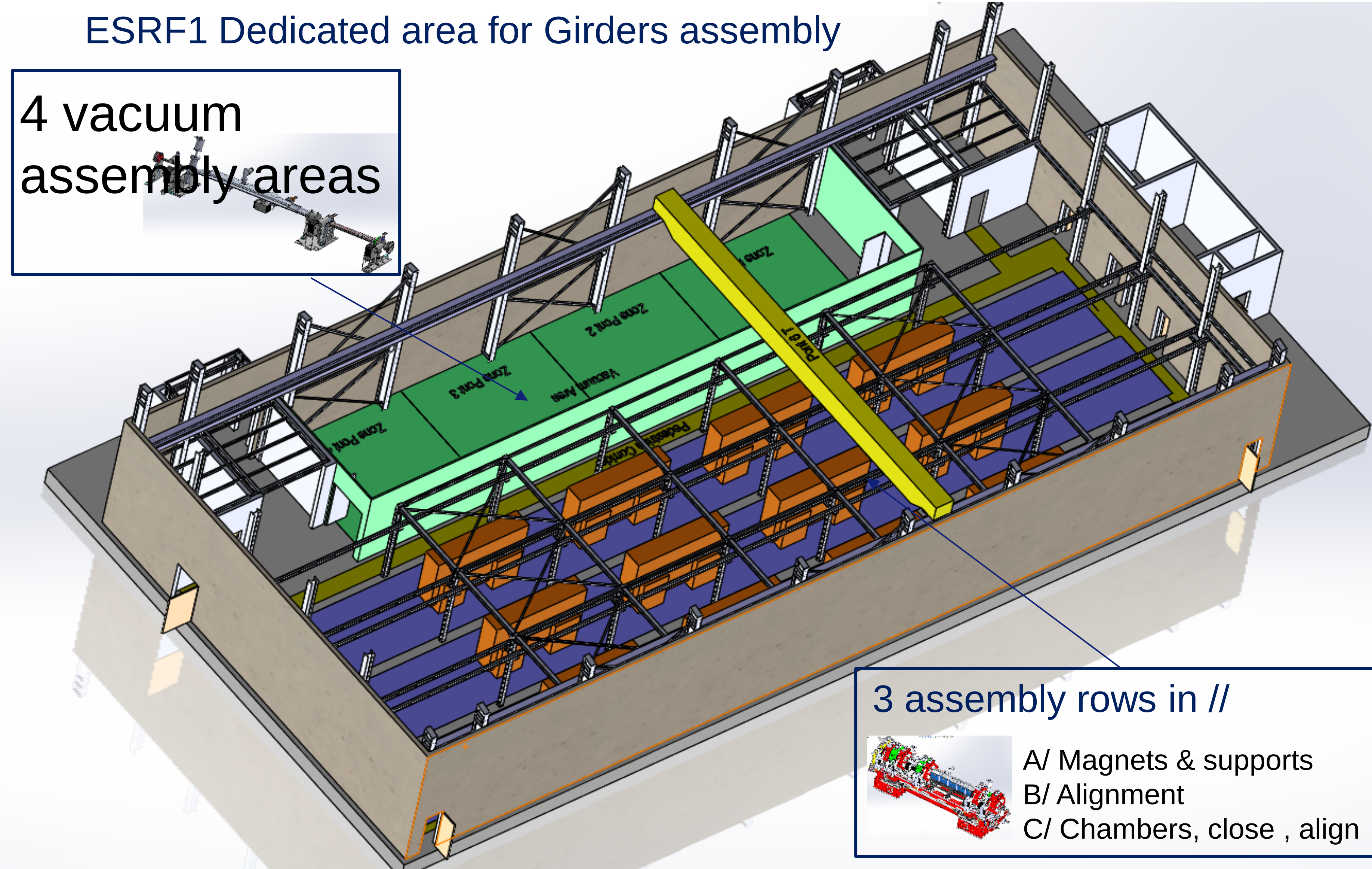
BUILDINGS FOR THE ASSEMBLY AND INSTALLATION PHASE

GIRDERS ASSEMBLY IN ESRF01 TO BE STARTED IN OCTOBER 2017

ESRF1 Dedicated area for Girders assembly



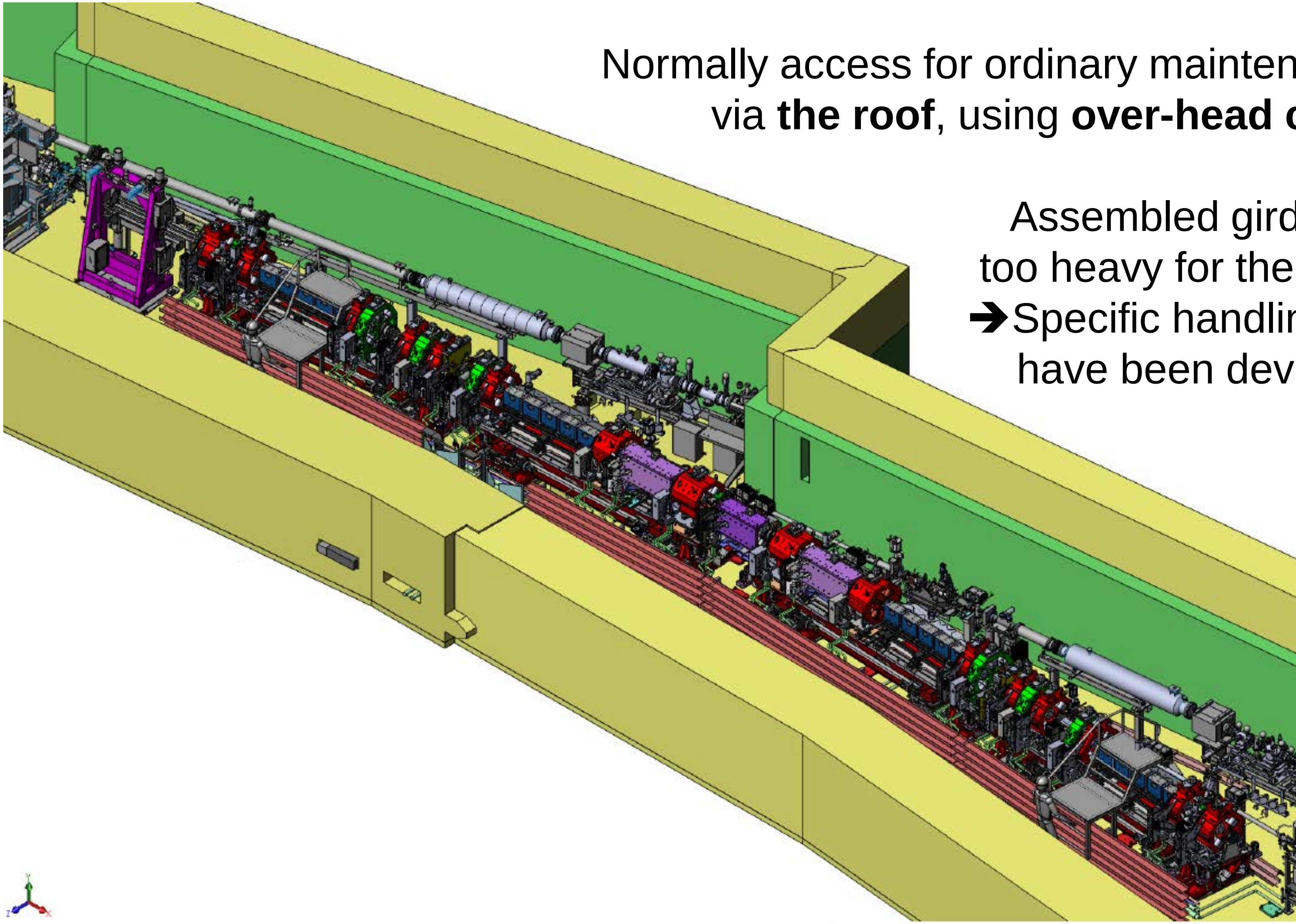
4 vacuum assembly areas

3 assembly rows in //

A/ Magnets & supports
B/ Alignment
C/ Chambers, close , align

DISMANTLING AND INFRASTRUCTURE PREPARATION

- The tunnel must be cleaned up prior to the installation of the new machine.
- Some work/upgrades will be anticipated prior the long shutdown
- The existing machine will be dismounted using cranes
- Each component of the present storage ring must be fully dismounted, radiation measured, traced and stored following French safety regulations.
- Some civil work needed prior to rolling the new girders.



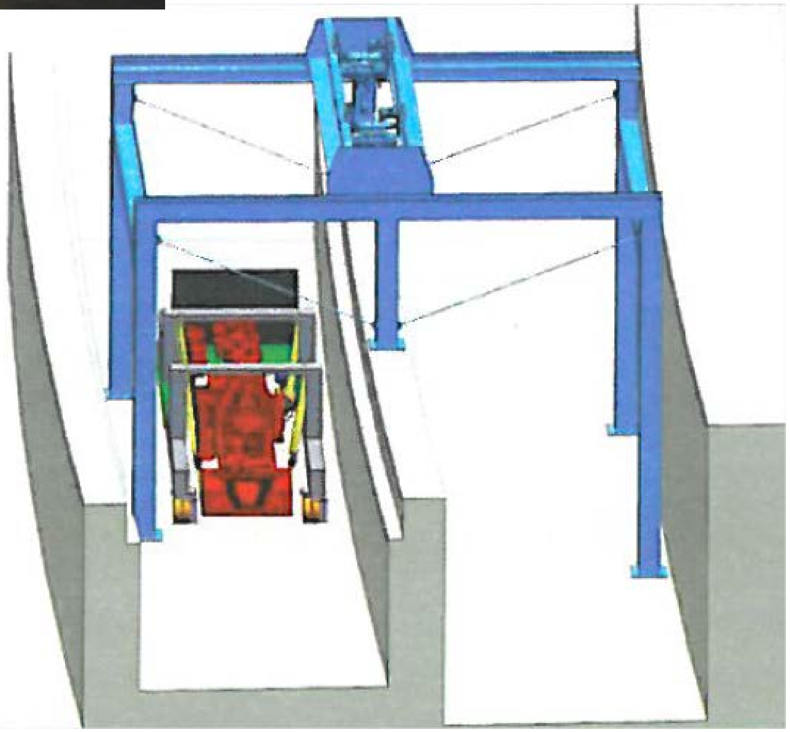
Normally access for ordinary maintenance is via **the roof**, using **over-head cranes,** but ….

Assembled girders are too heavy for the cranes

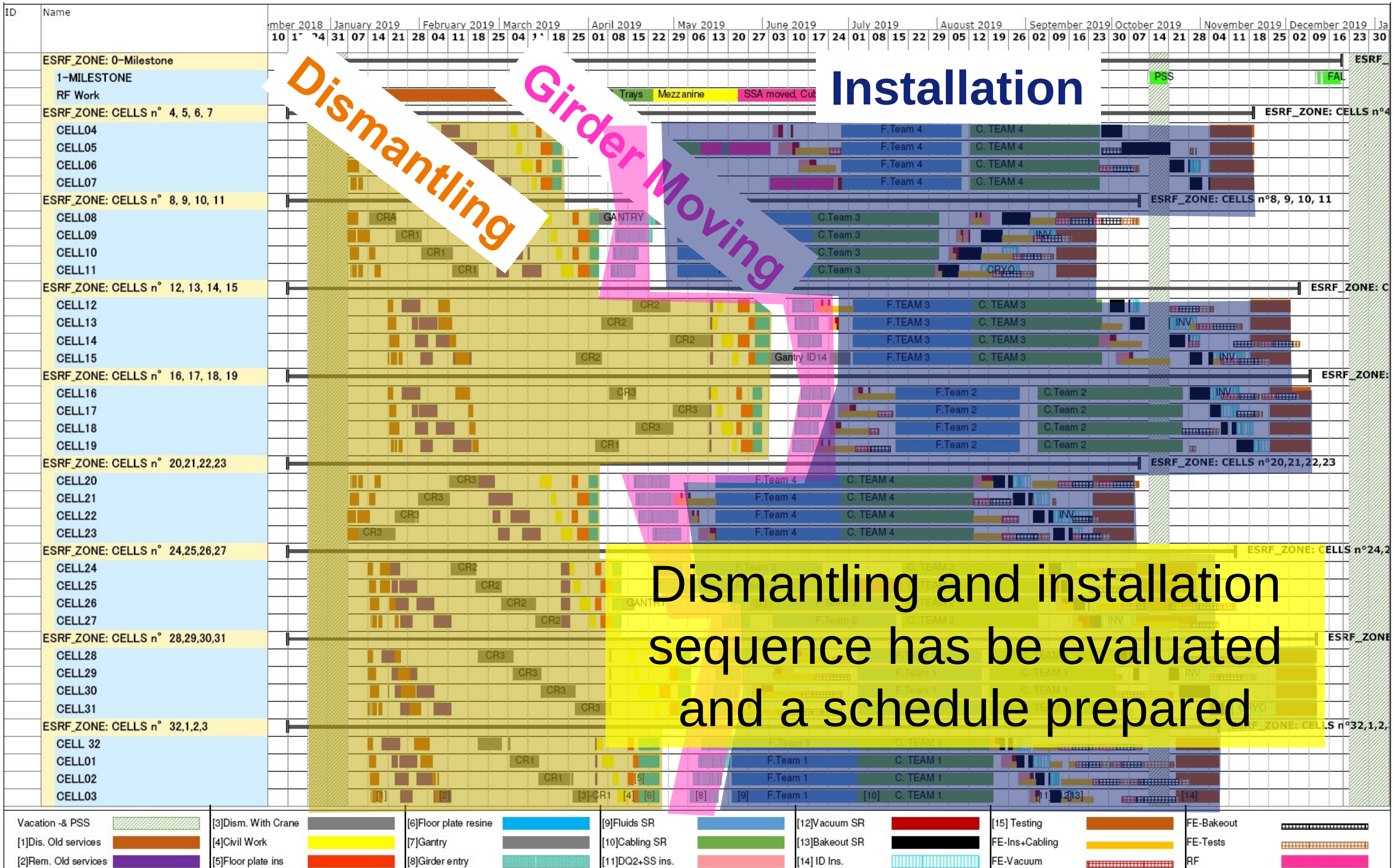
➔Specific handling tools have been developed.

INSTALLATION

- Dedicated transport module has been developed
- Dedicated gantry will be installed to pass over the tunnel wall



DISMANTLING & INSTALLATION PLANNING



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CONCLUSION

<u>EBS</u> project running in parallel with ESRF operation

- No impact on user operation
- Continuation of the development (injector, top-up, cryo undulators,…)

Project execution progression:

- Engineering Design virtually completed
- Procurement in full swing
- Delivery of all pre-series components almost completed

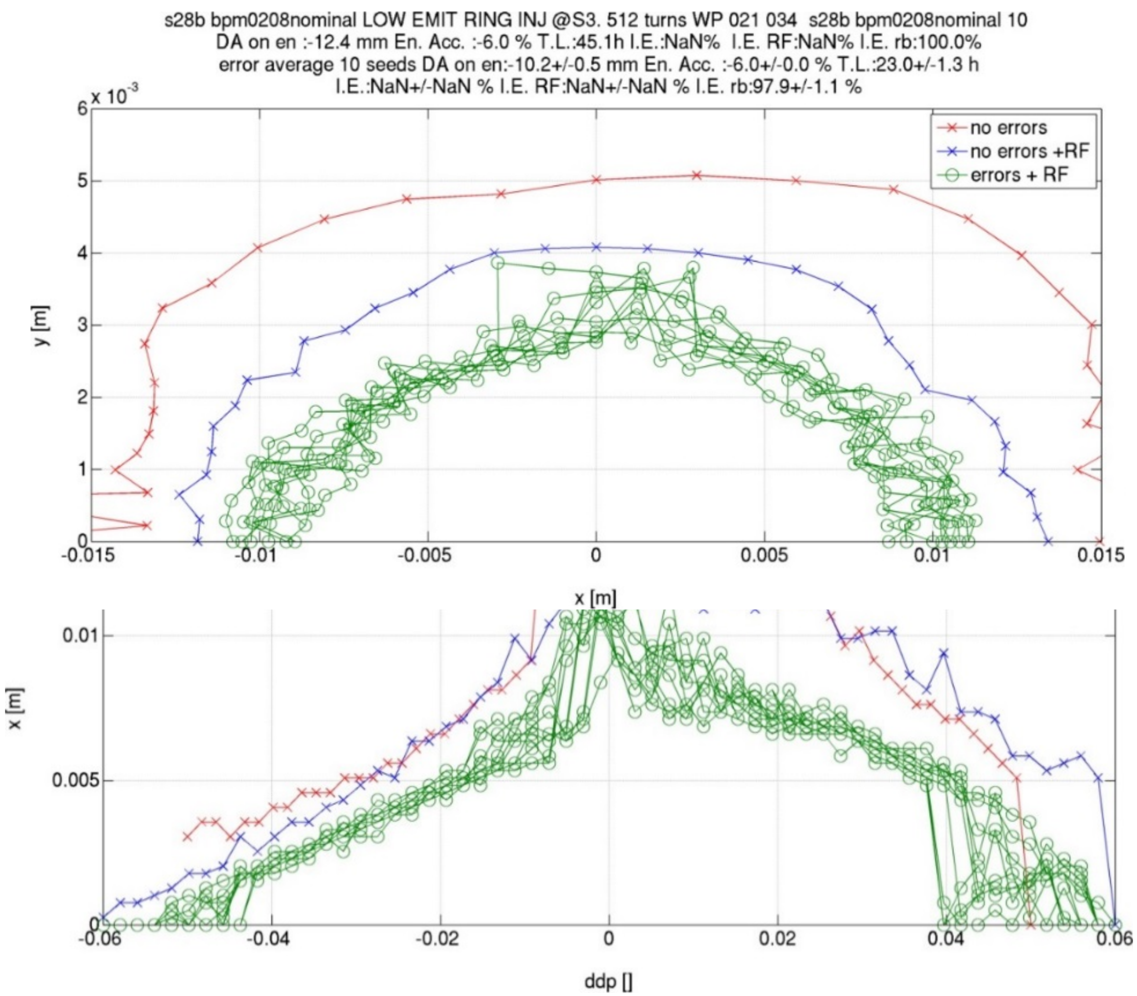
➔ Schedule now heavily linked to external manufacturers

- Mock-up cell almost completed
- Assembly to be started in less than 3 months (mock spring 2017)
- Dismantling/installation/commissioning in preparation

At this stage, no major show stopper identified.

MANY THANKS FOR YOUR ATTENTION

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

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