AMICI

Bruxelles, 18th September 2019

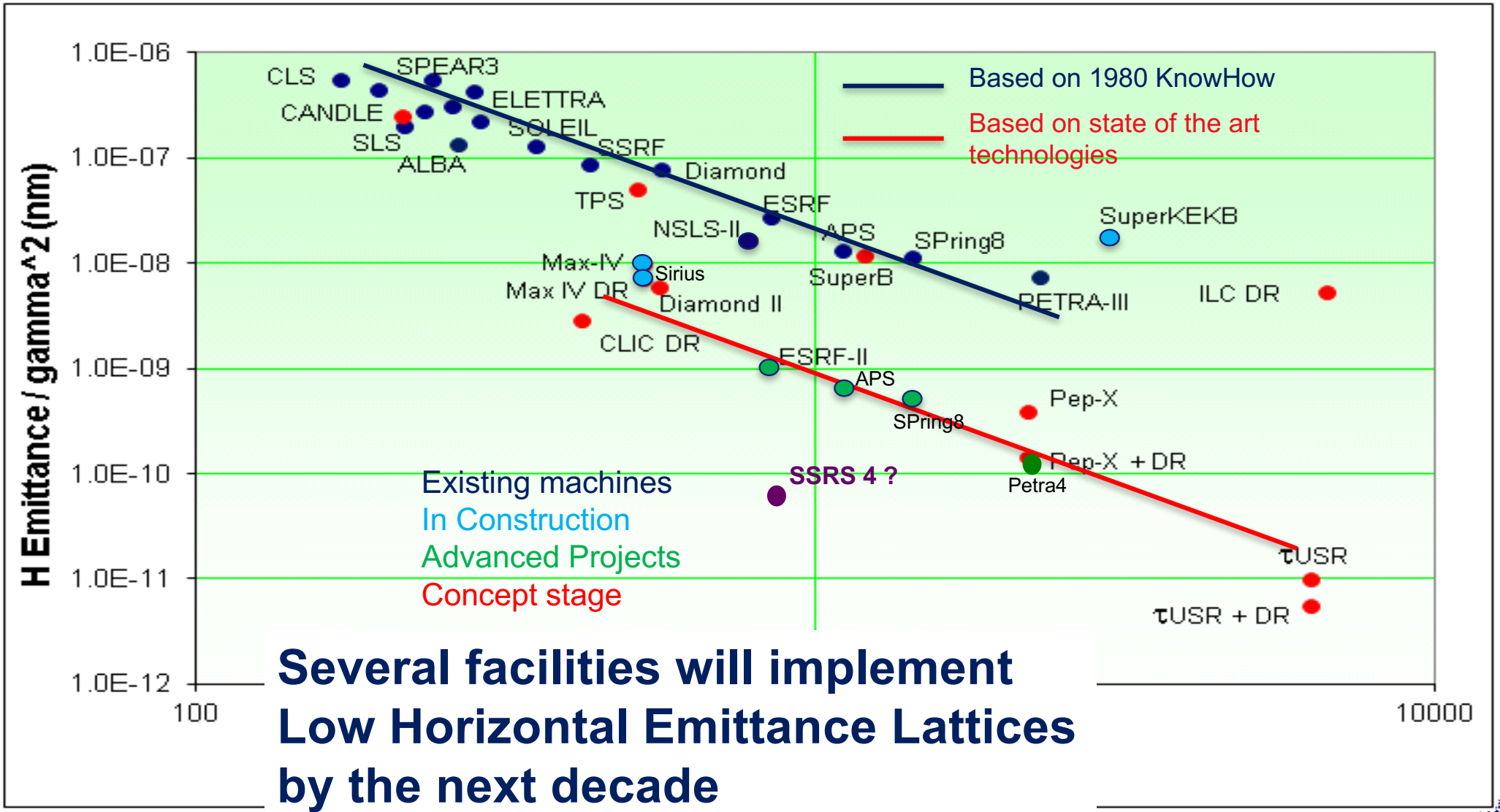
Light Sources next generation

P Raimondi

ESRF-EBS
Extremely Brilliant Source

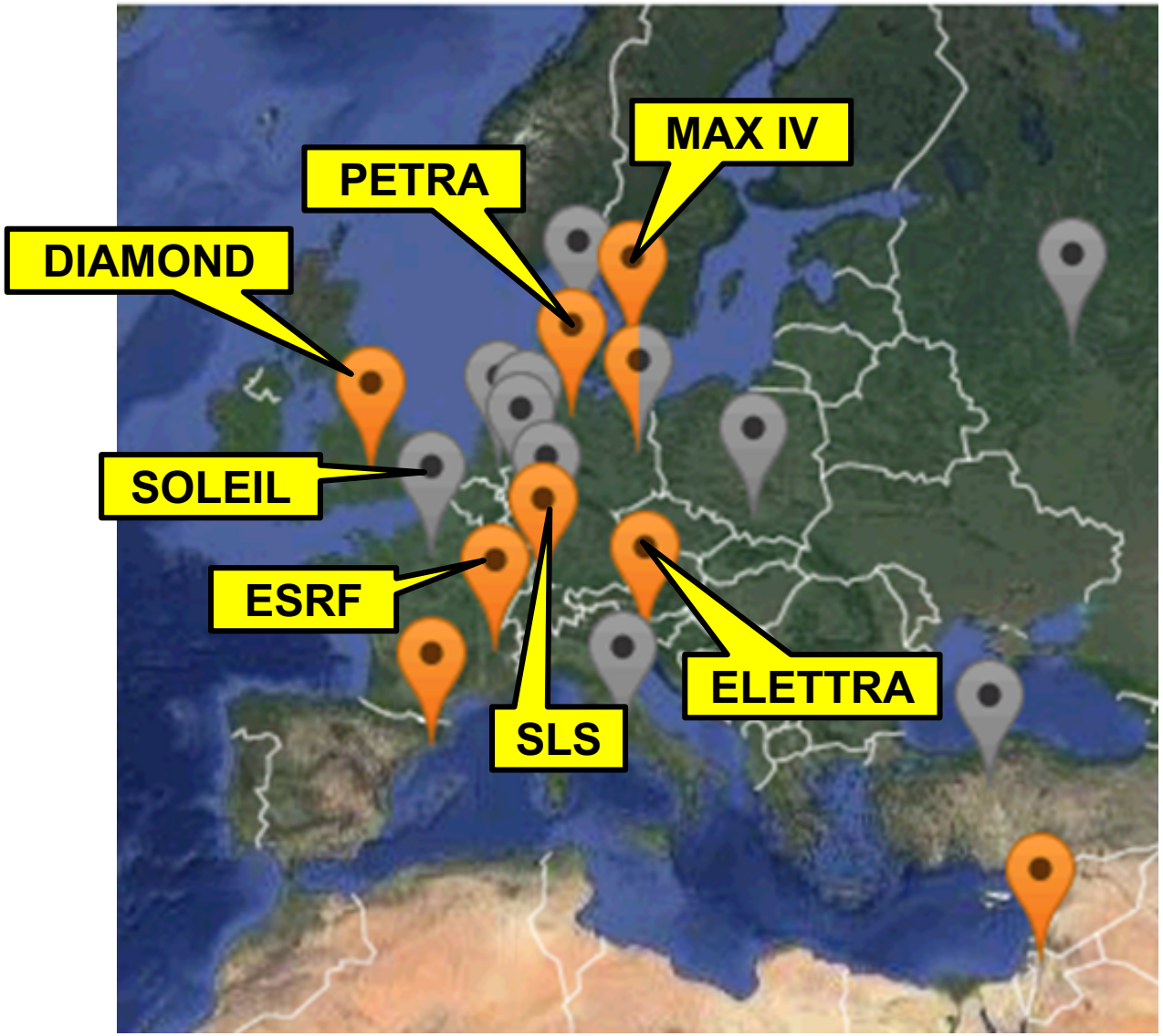
ESRF | The European Synchrotron

LOW EMITTANCE SYNCHROTRONS UPGRADES TREND

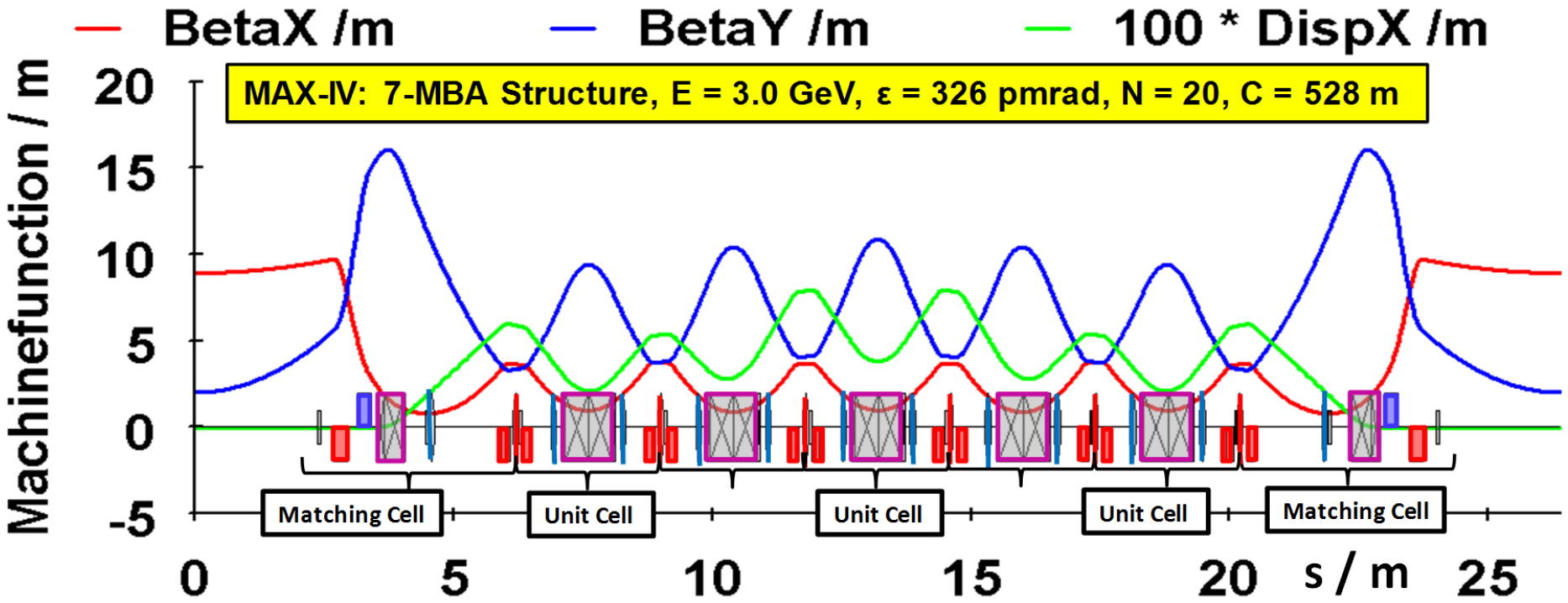


Several facilities will implement Low Horizontal Emittance Lattices by the next decade

UPGRADES IN EUROPE



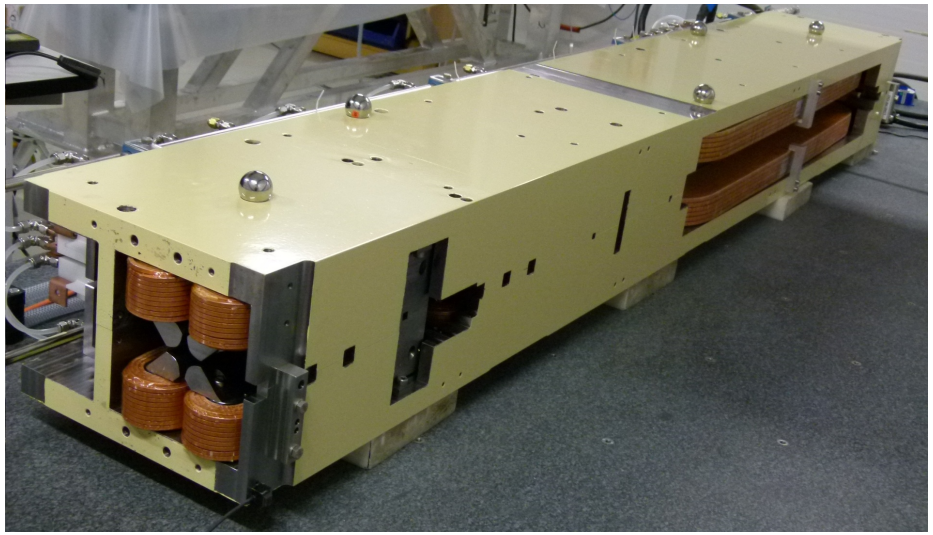
MAX IV 7-MBA-COMPLETED IN 2016

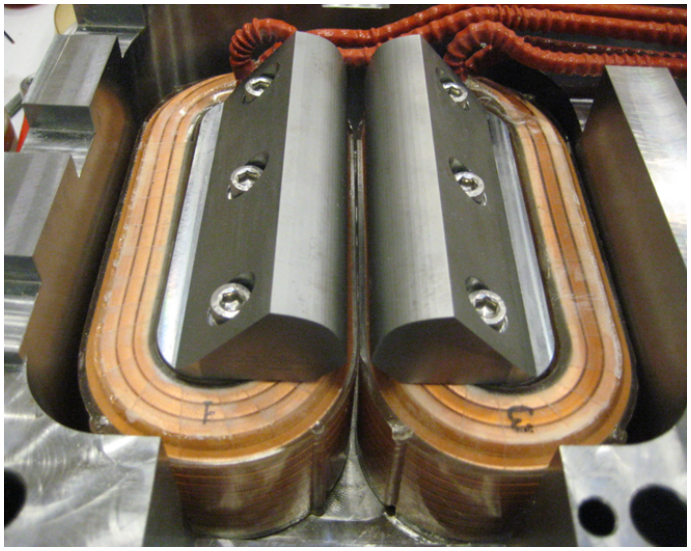


To achieve low emittance the following points should be considered:

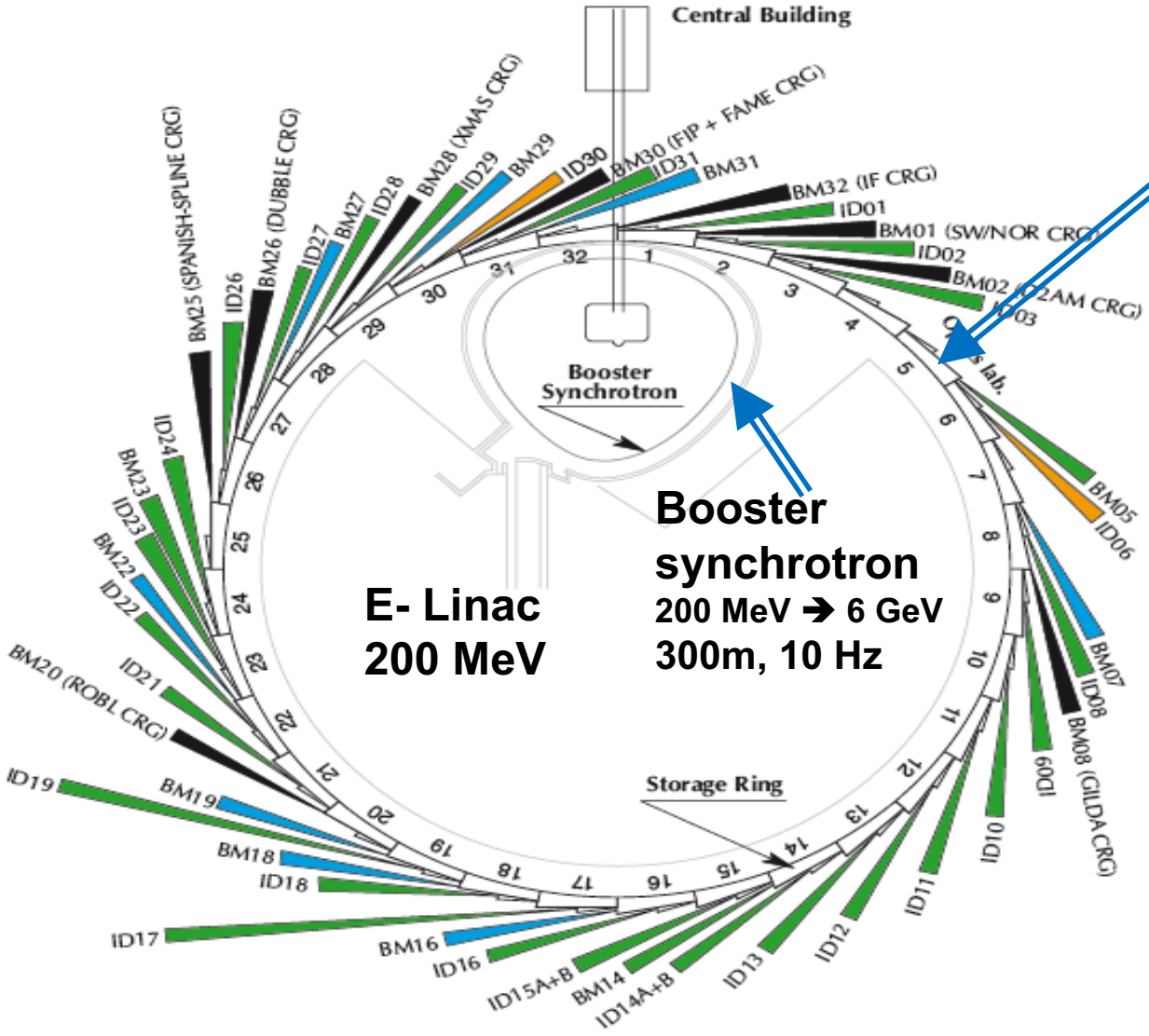
- The number of magnets has to be large, which means multi-bend achromat cells (MBA) with 5 or more bending magnets.
- The outer bending magnets must be shorter by roughly a factor 2
- The bending magnets should be combined-function construction with vertical focusing to increase or maximize J_x. Combined-function bending magnets also have the advantage of leading to a compact machine design.

MAGNET BLOCKS OF MAX IV





ESRF TODAY



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

32 straight sections

DBA lattice

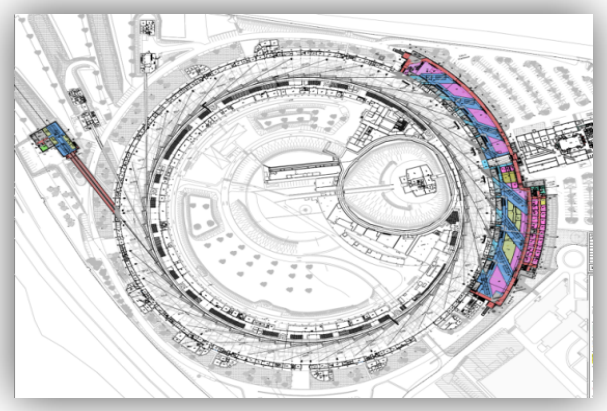
42 Beamlines

12 on dipoles

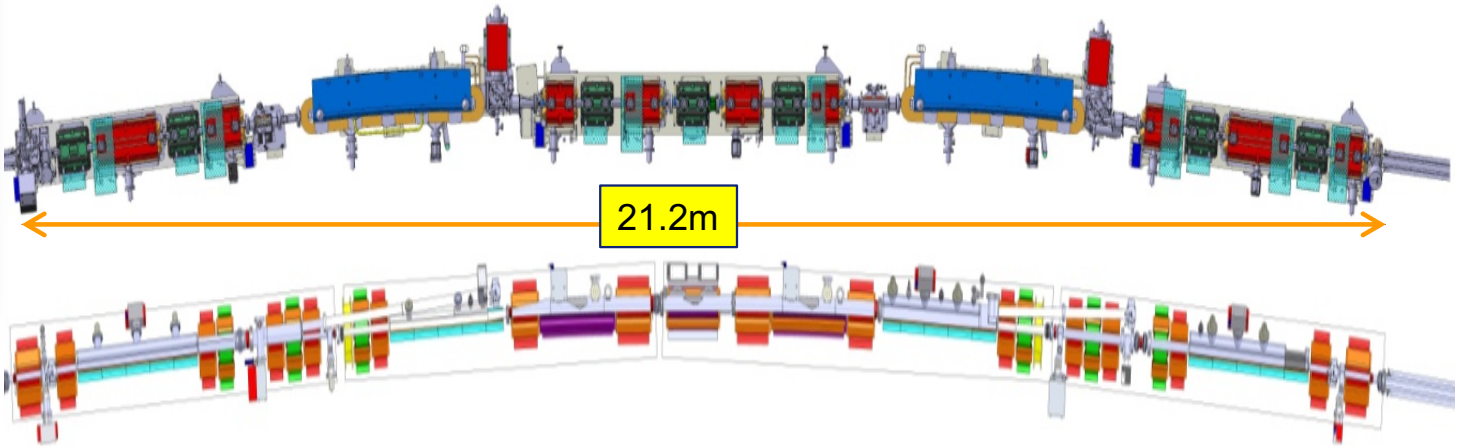
30 on insertion devices

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

ESRF Phase II Upgrade at the Bone



Present ESRF Arc Layout: Ex=4nm



New Low Emittance Layout: Ex=0.133nm

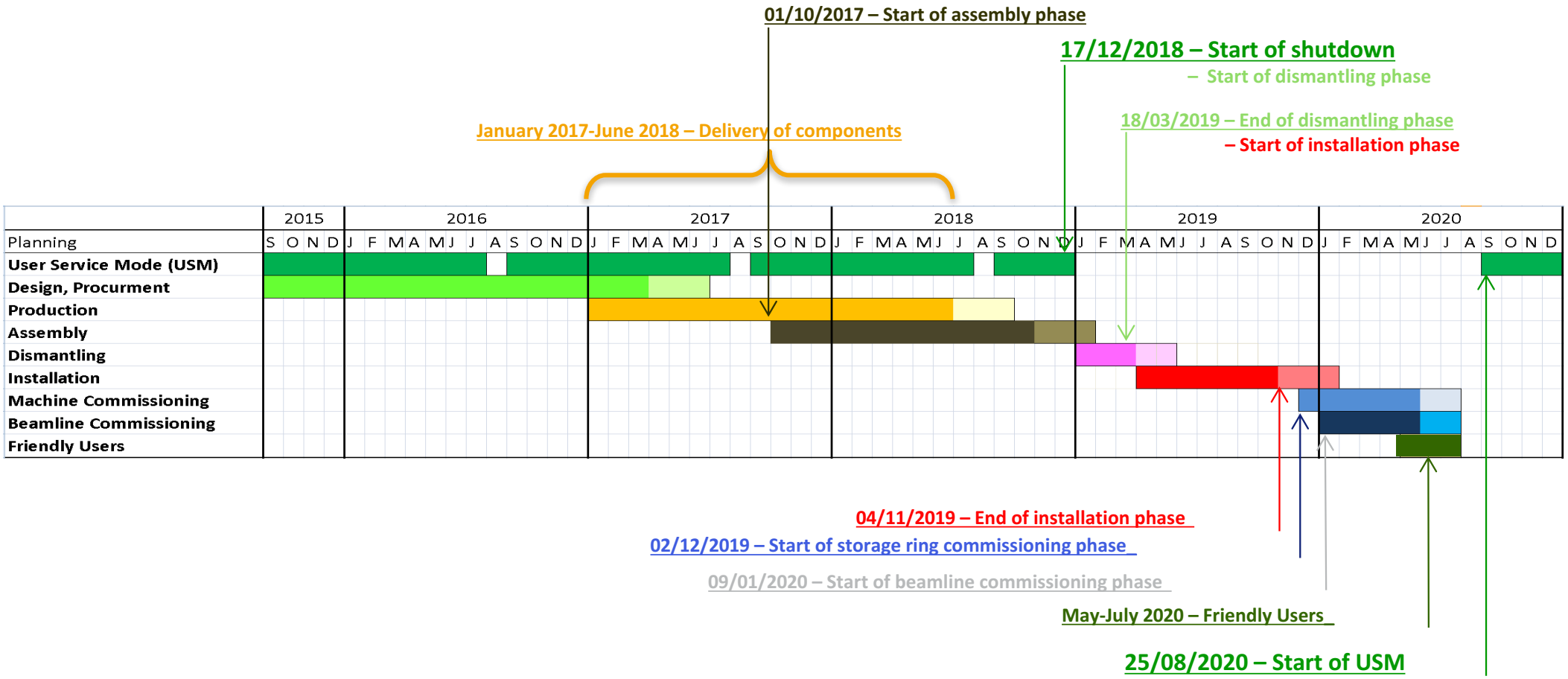
The 844m Accelerator ring consists of:
- 32 identical Arcs 21.2m long
- 32 straight sections 5.2m long equipped with undulators and RF

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.

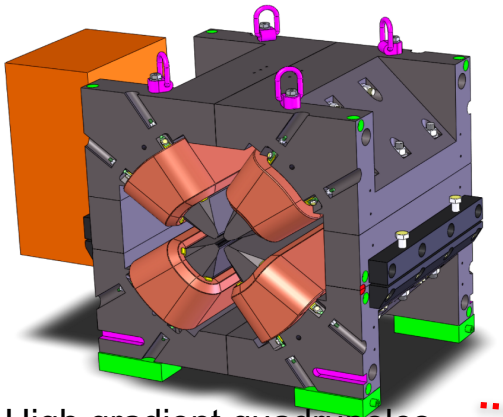
All the Arcs will be replaced by a completely new Layout

EBS MASTER PLAN (2015-2020) MADE IN 2014 (COUNCIL APPROVAL)

Master Plan and Major Milestones



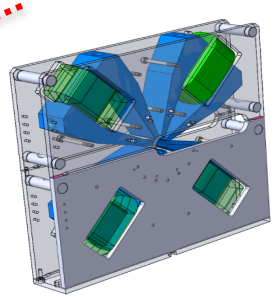
Design:Magnets System



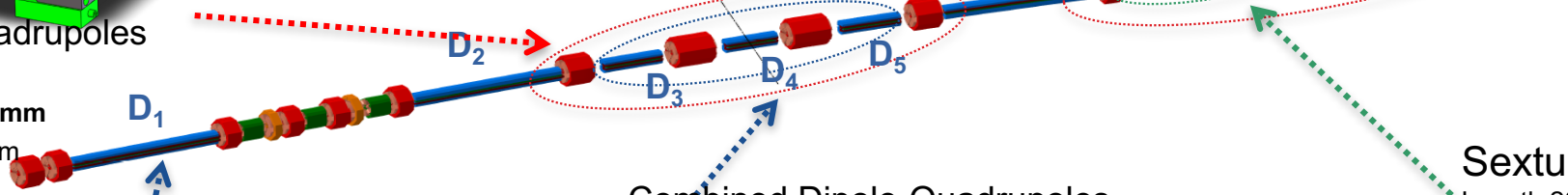
Mechanical design final drawing phase

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

Quadrupole
Around 52Tm^{-1}



Octupoles

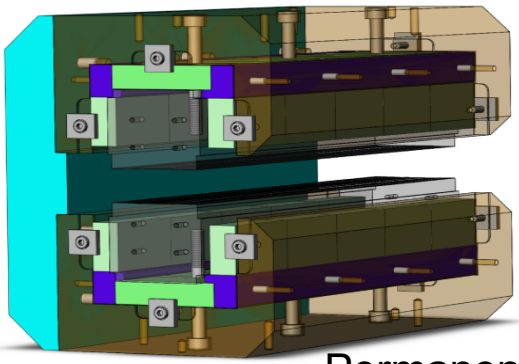


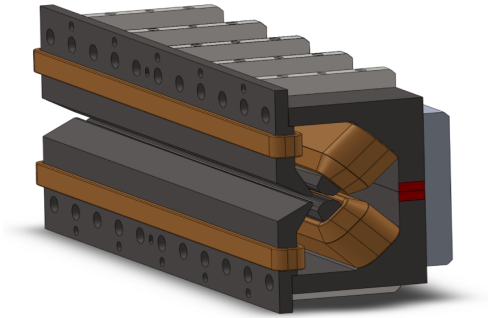
High gradient quadrupoles

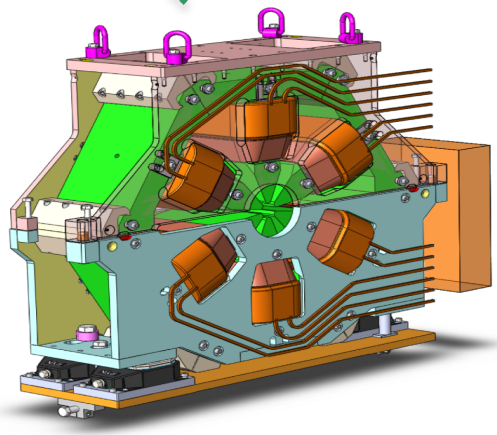
- Gradient: 90 T/m
- **Bore radius: 12.5 mm**
- Length: 390/490 mm
- Power: 1-2 kW

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

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



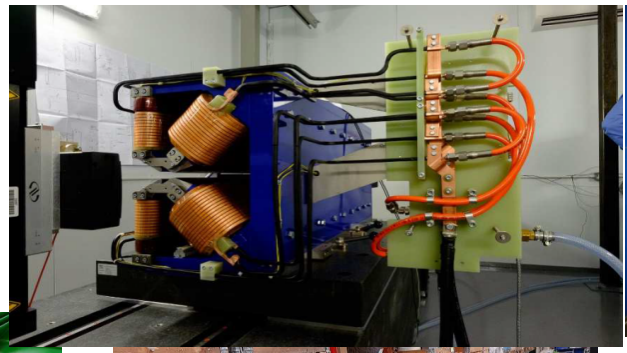




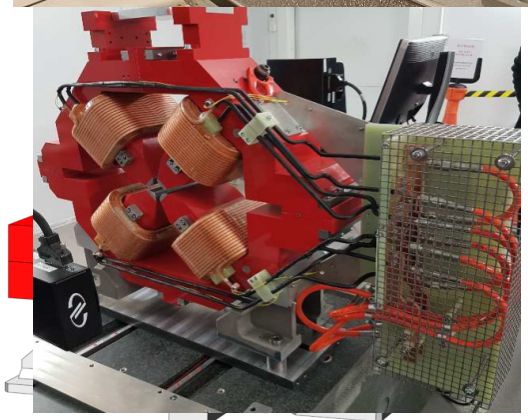
Permanent magnet (Sm_2Co_{17}) dipoles
longitudinal gradient 0.16 – 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

Gael Le Bec
The European Synchrotron | ESRF

MAGNETS FABRICATION



66 octupoles



398 moderate gradient quadrupoles

130 high gradient quadrupoles

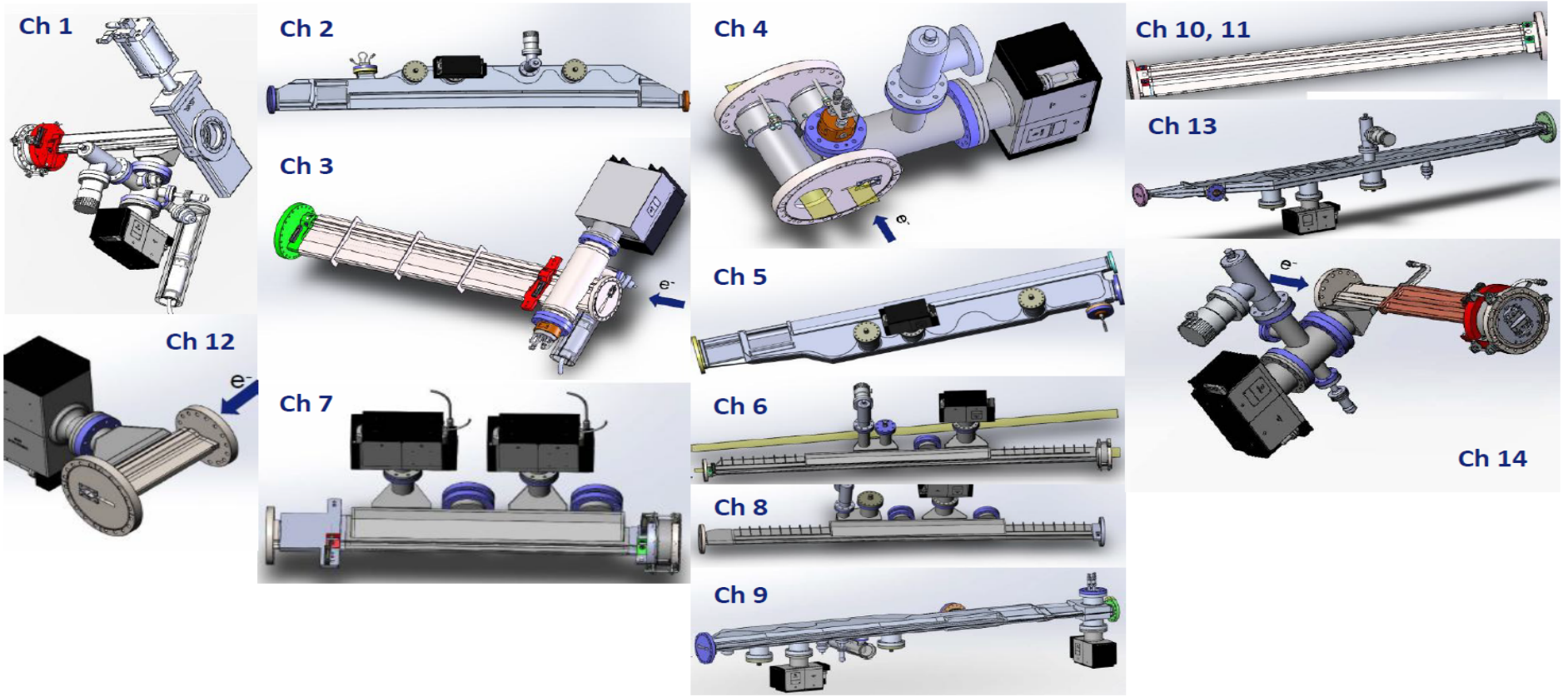
196 sextupoles

100 correctors

IMPLEMENTATION IN CHARTREUSE HALL

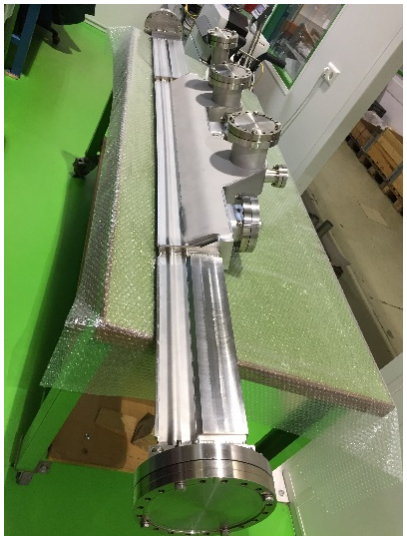
Dipole assembly area

VACUUM CHAMBERS FABRICATION

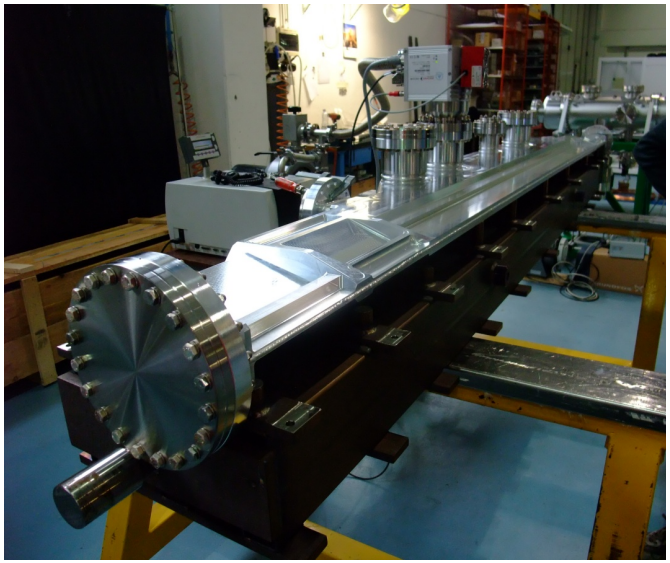


Courtesy of ASD-FE, ISDD-MEG & TID-VG

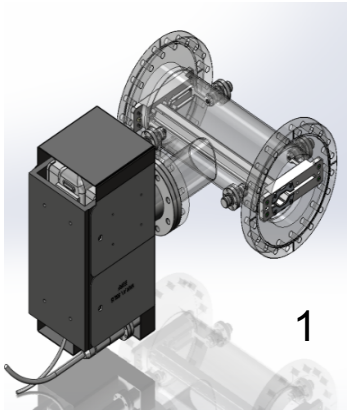
MAIN VACUUM CHAMBERS FOR THE ARCS



Production at FMB (up) and Cecom (down)

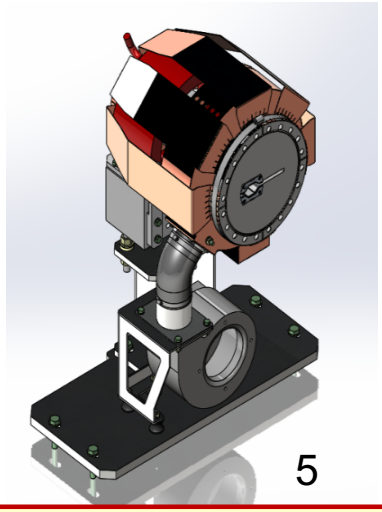


VACUUM CHAMBERS – DIAGNOSTICS

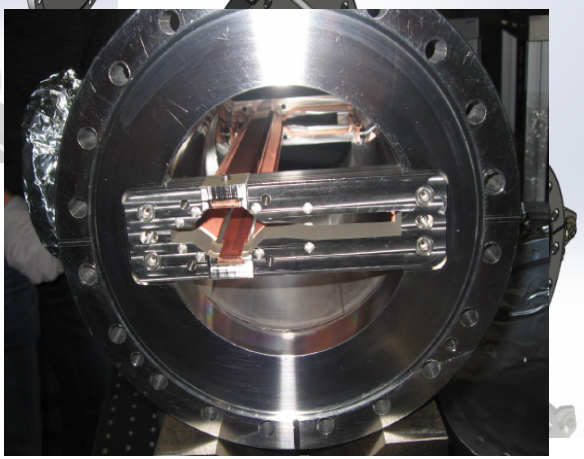


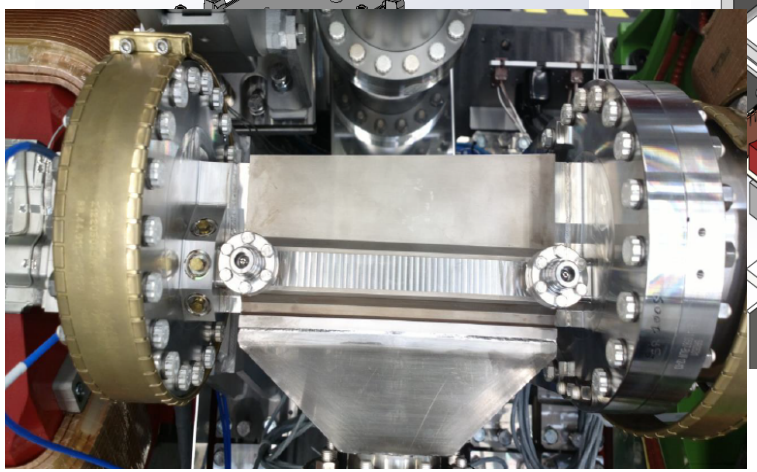
1. H stripline
2. V stripline
3. Shaker
4. Beam losses collimator
5. Current transformer

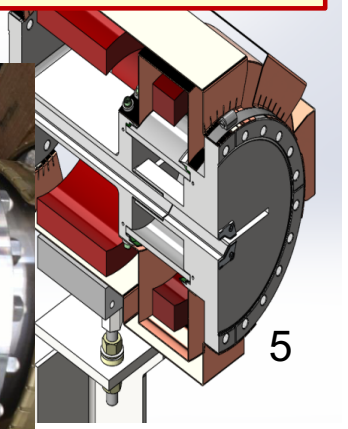
Procurement in progress



Single pieces components fabrication nearly finished







RF CAVITIES READY TO BE INSTALLED

ID14 – January 2018

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.

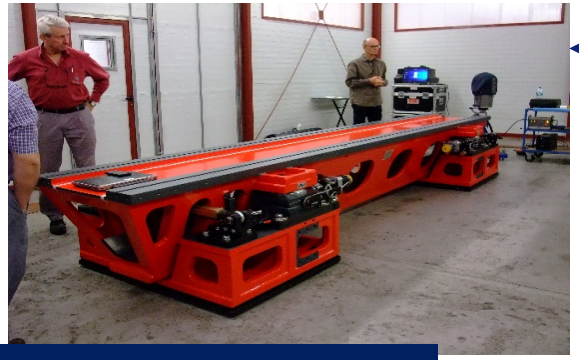
The integration in 32 cabinets will be designed with the Computer Services for redundancy and HOT-Swappability

COMECA PRODUCTION

Assembled racks (3 units each)

Cubicles (11 racks each)

GIRDERS PRODUCTION



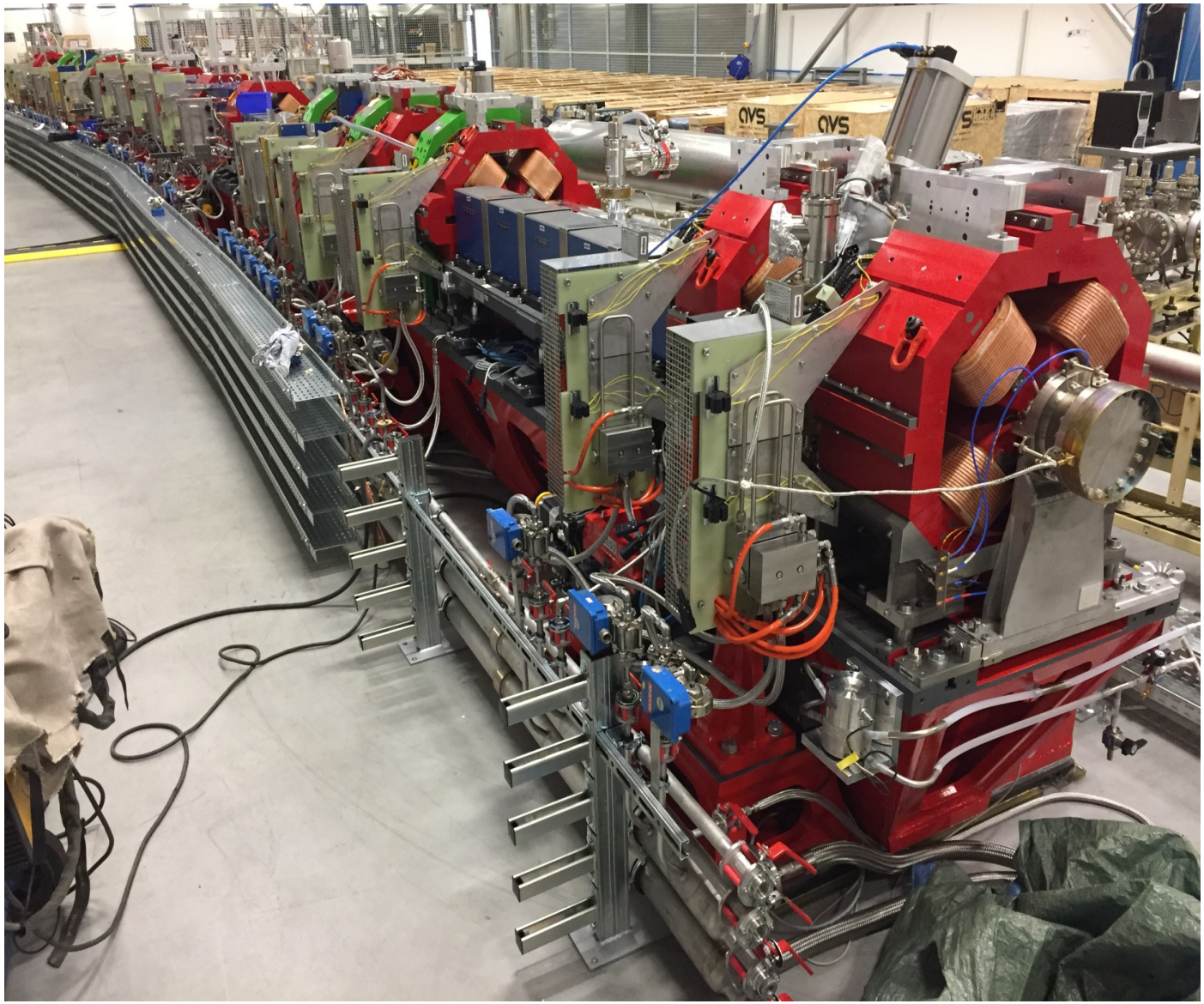
NORTEMECANICA (SP) 66

129 (+2 spares) Girders in total

AVS (SP) 65

Courtesy of T Brochard, F Cianciosi

MOCK-UP: AN ARC FULLY ASSEMBLED IN THE FINAL TUNNEL LAYOUT CONFIGURATION



Courtesy:
L. Eybert

GIRDER LIFTING BEAM

Delivery: end of July 2018

<u>Used to move assembled girders:</u>

- ✓ One at ESRF01 for lorry load / unload
- ✓ One at GLD for lorry load / unload

DISMANTLING: OLD SERVICES REMOVAL

Duration: 33H/cell. 3 cell in parallel

3 teams of 4 people:

Disconnect power cables

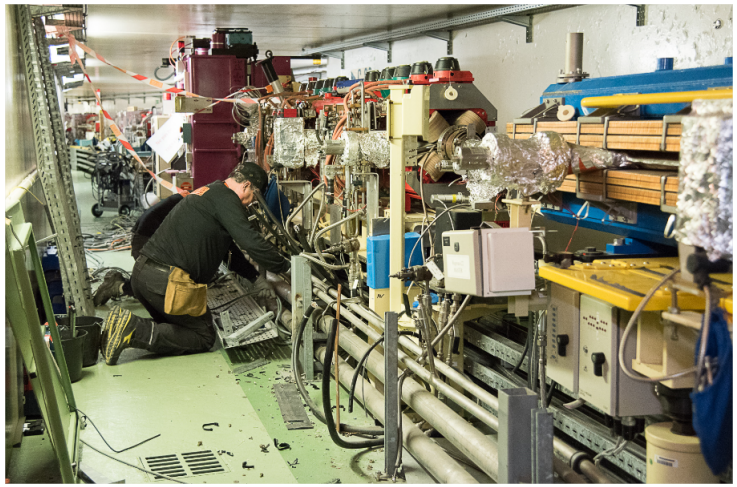
Remove

-Low current cables

-Electrical boxes

-Cable trays

-Pipes



Special cells: 32,1,2

ESRF11 FILLING UP

07/01/19

09/01/19

11/01/19

15/01/19

20/01/19

25/01/19

28/01/19

12/02/19

27/02/19

NON-ACTIVATION MEASUREMENTS: CABLE TRAYS

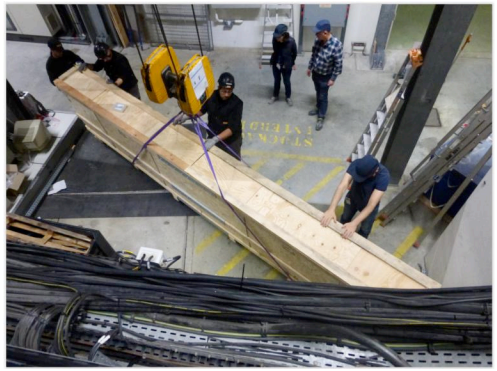
All cable trays measured by 5 March 2019
Total 123 measurements
No activation detected

NON-ACTIVATION MEASUREMENTS

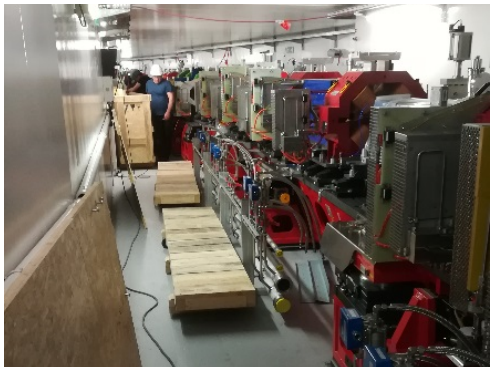
ESRF11 on 16 March 2019

ESRF11 today
(23 April 2019)

INSTALLATION PHASES – PIPING INSTALLATION

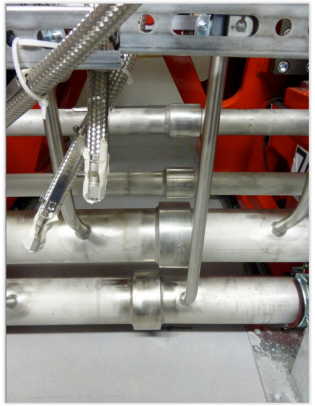

Supply in drop zone

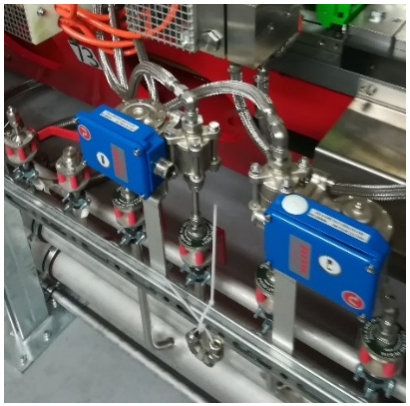

Insert in SRTU


Opening of wooden boxes


Piping inserted in SRTU


Fittings and flanges to install


24 welds


Connection to equipment

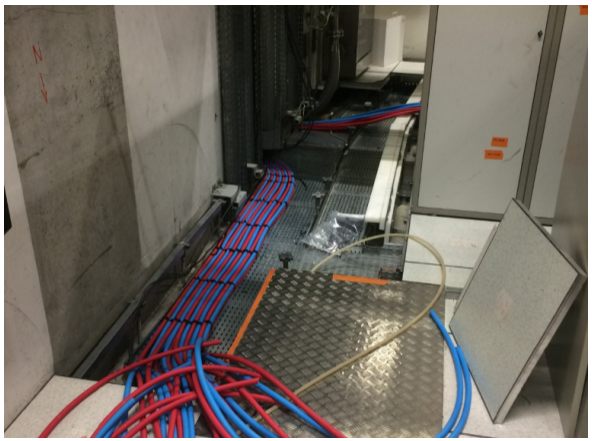

Connection to network

Courtesy: F. Favier

INSTALLATION PHASES – CABLING

SRTU CABLING WORKS

Supply in drop zone



Pushing cables from
TZ to SRTU

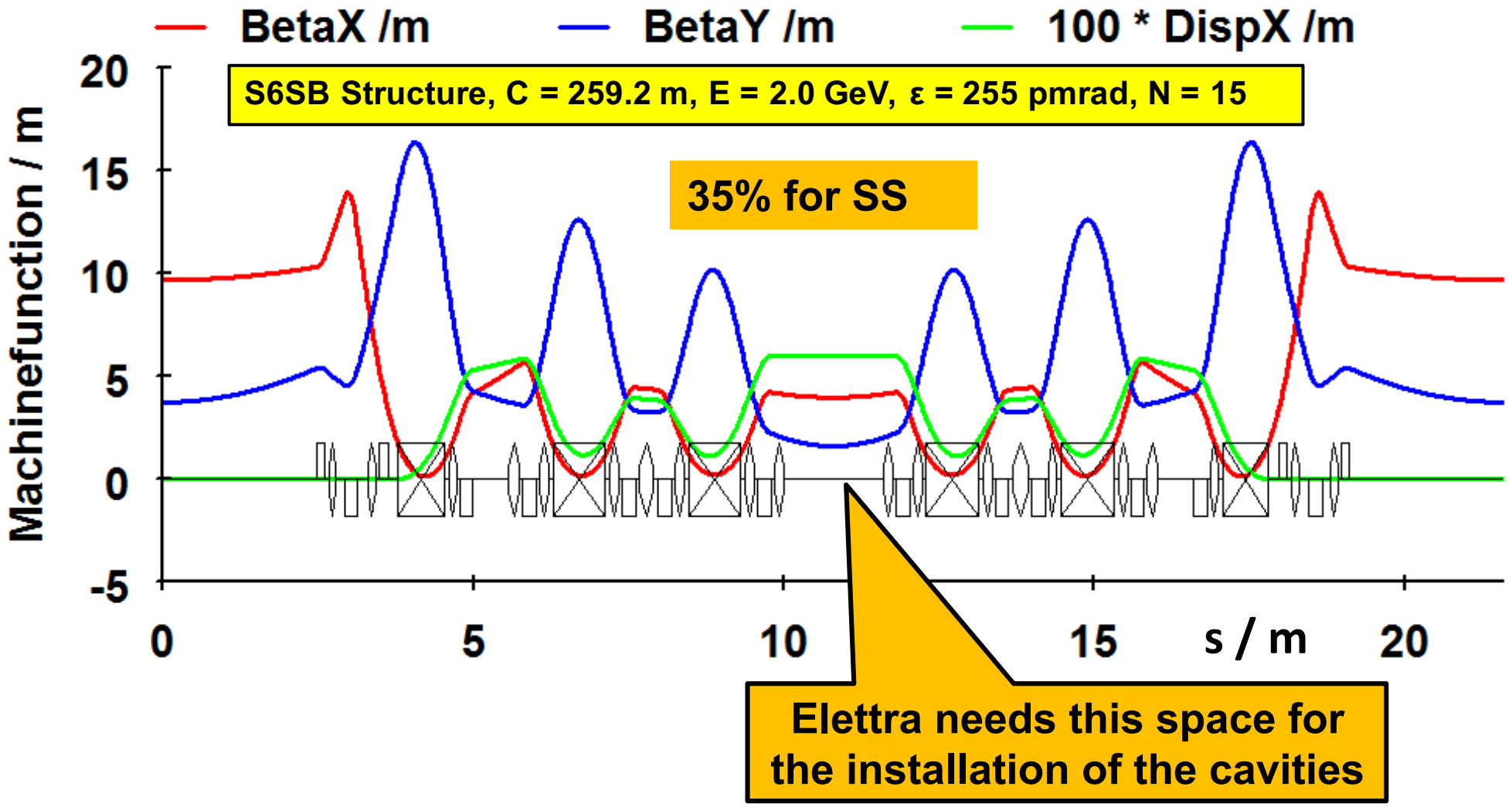
Cables installation in SRTU

Cabling work started on cell 04 on 29th April

ZONE	START of Work	ZONE	START of Work
SRTU 2	10th May 2019	SRTU 7	11th July 2019
SRTU 8	28th May 2019	SRTU 3	12th July 2019
SRTU 5	05th June 2019	SRTU 1	18th July 2019
SRTU 6	26th June 2019	SRTU 4	06th August 2019

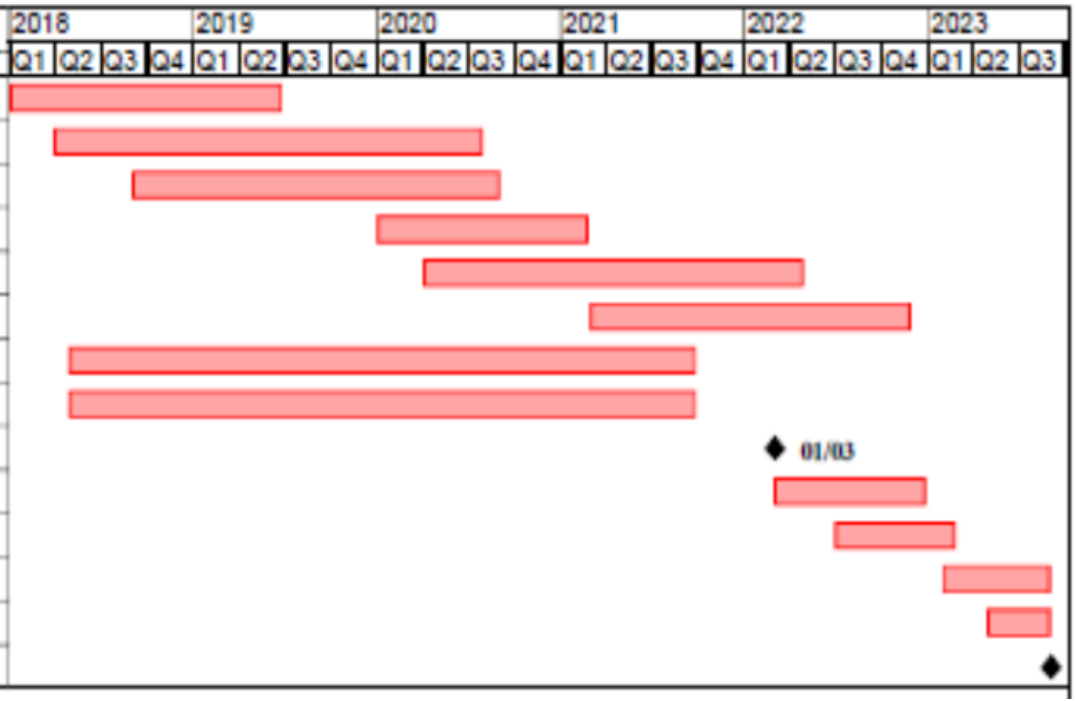
Courtesy: Y. Gouez
The European Synchrotron | ESRF

PROPOSAL FOR THE ELETTRA 2.0 LATTICE



ELETTRA II UPGRADE SCHEDULE

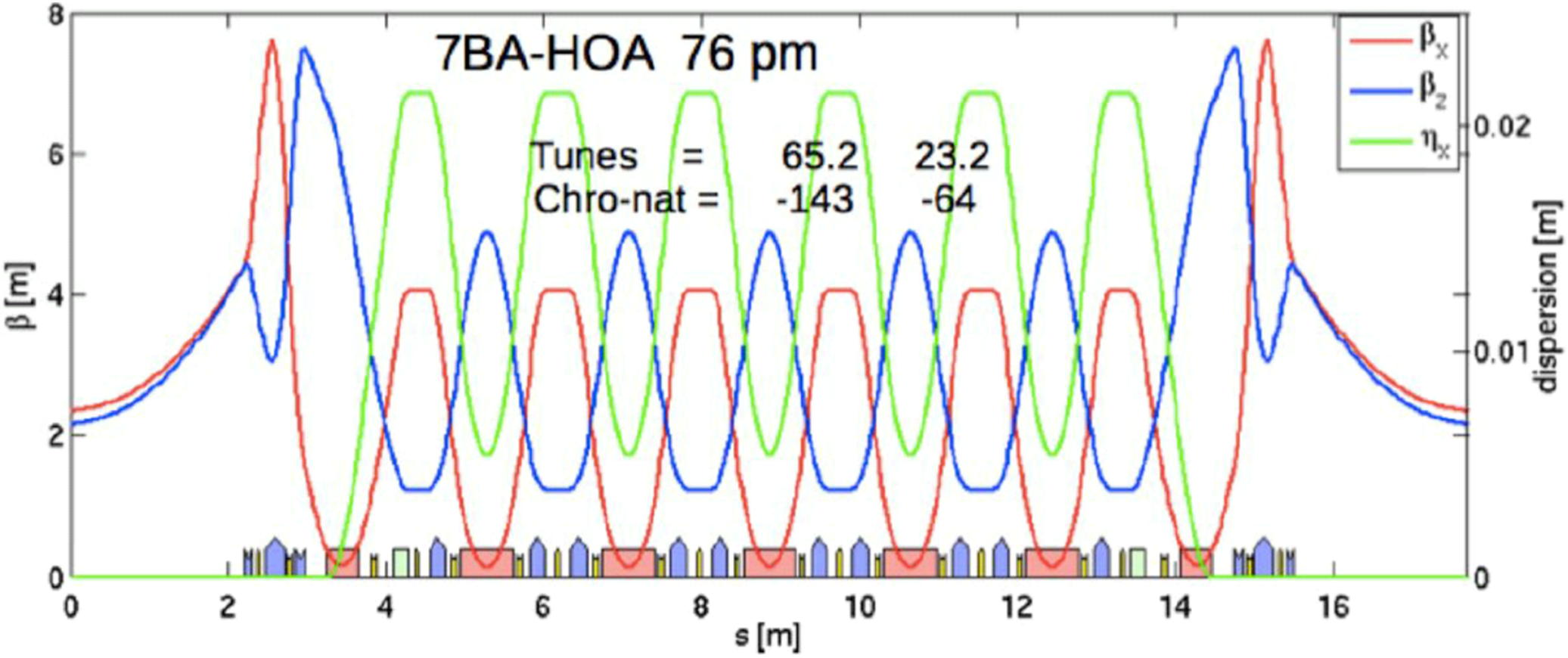
	Name	Durati...	Start	Finish	P...	R...
1	Technical design study	390 ...	01/01/18...	28/06/19...		
2	Engineering Design	610 ...	02/04/18...	31/07/20...		
3	Prototyping	524 ...	01/09/18...	03/09/20...		
4	Calls for tender	303 ...	01/01/20...	26/02/21...		
5	Manufactoring construction and t...	542 ...	02/04/20...	29/04/22...		
6	Preparation and assembly	458 ...	01/03/21...	30/11/22...		
7	Infrastructures upgrade	892 ...	01/05/18...	29/09/21...		
8	Beam Lines upgrade	892 ...	01/05/18...	29/09/21...		
9	End user mode	1 day?	01/03/22...	01/03/22...		
10	decommissioning	219 ...	01/03/22...	30/12/22...		
11	Installation	173 ...	01/07/22...	28/02/23...		
12	Accelerator tests/ commissioning	153 ...	01/02/23...	01/09/23...		
13	Beam line commissioning	90 d...	01/05/23...	01/09/23...		
14	Start Elettra2.0 user mode	1 day?	04/09/23...	04/09/23...		



Dark period is estimated to 18 months. Users don't like it asked if it can be avoided? How?

❖ ***Project approved by the Italian Government!!!***

SOLEIL: UPGRADE SITUATION 2018/2019

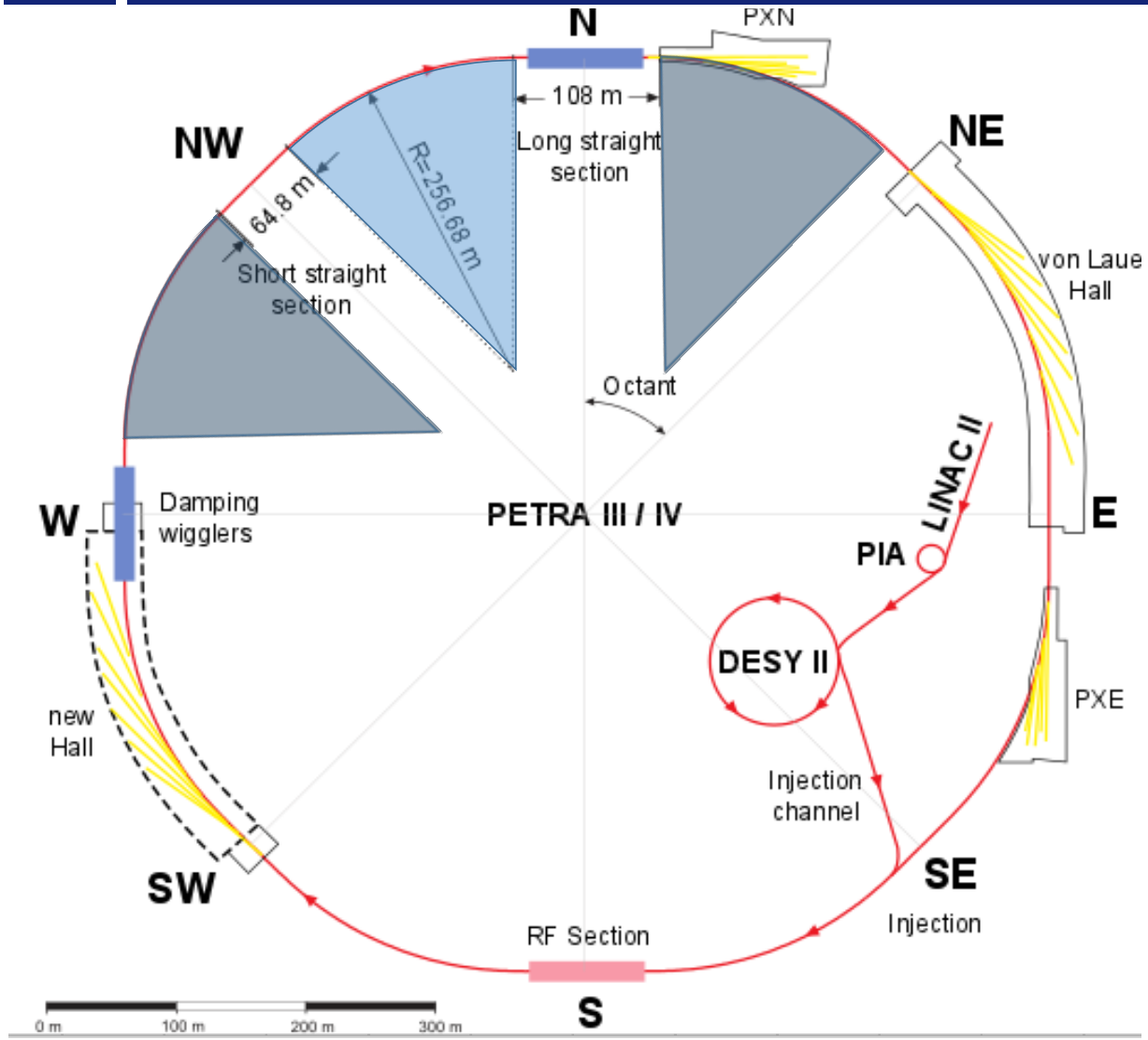


Status of SOLEIL and Upgrade Plan, XXVI ESLS, Krakov, 2018

SOLEIL UPGRADE: TIME SCHEDULE

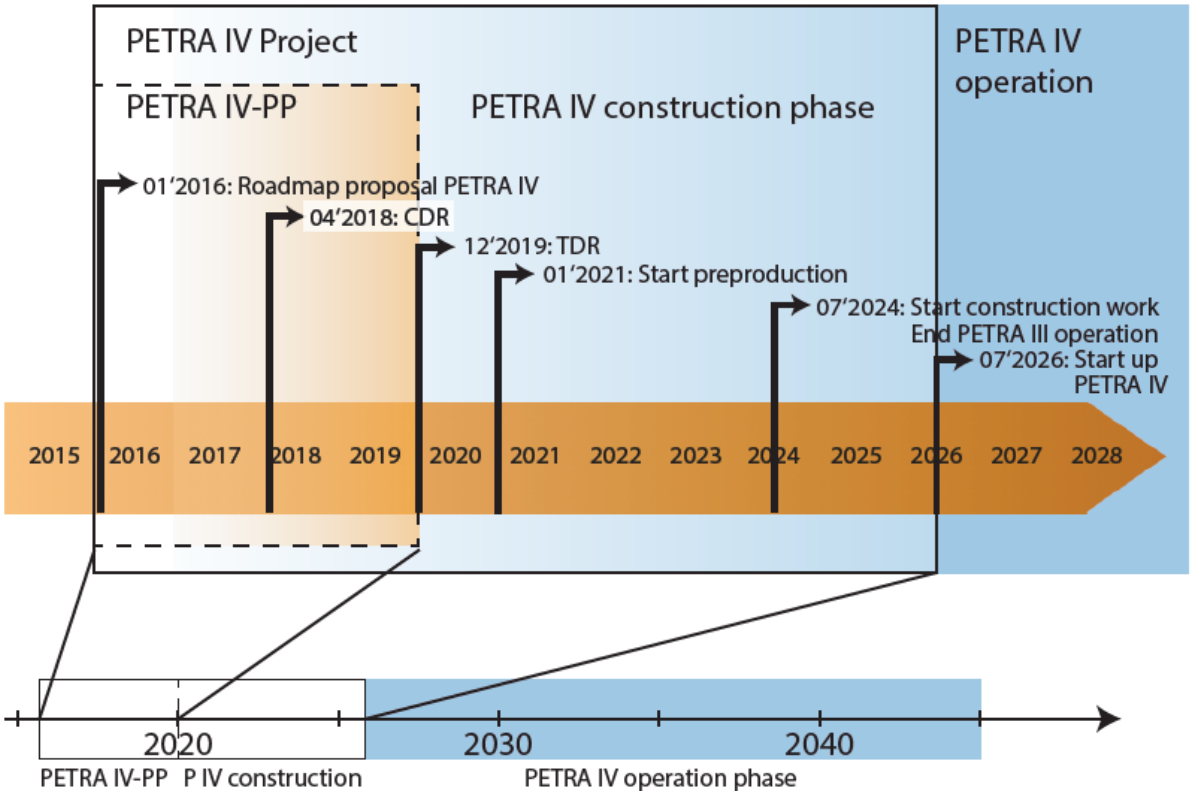
Date	Phase
Dec. 2016	Council meeting, presentation of the first proposal for an upgrade.
2017 - 2019	Discussions regarding the definition of the project (beamlines and storage ring); definition of objectives. Baseline Lattice defined.
2018 - 2019	Continuation of discussions and prototyping to assess feasibility of key options.
2019	**Decision to launch a Conceptual Design Report (CDR).**
2019-2020	CDR based on preliminary studies and prototyping.
2020	**Decision to launch a Technical Design Report (TDR).**
2020-2022	Technical Design Report.
2022	**Decision to start the project.**
2022-2025	Reconstruction of storage ring and beamlines.
2026	Restart of user operation.

UPGRADE OF PETRA III TO PETRA IV



Parameter	Value
Energy	6 GeV
Current	100 mA, Top-Up
Hor. Emittance	1.2 nm·rad
Ver. Emittance	12 pm·rad
Bunches	40, 960
Circumference	2304 m
Harmonic number	3840
RF Voltage	20 MV
Energy loss/Turn	6.1 MeV

TIME SCHEDULE OF PETRA IV PROJECT

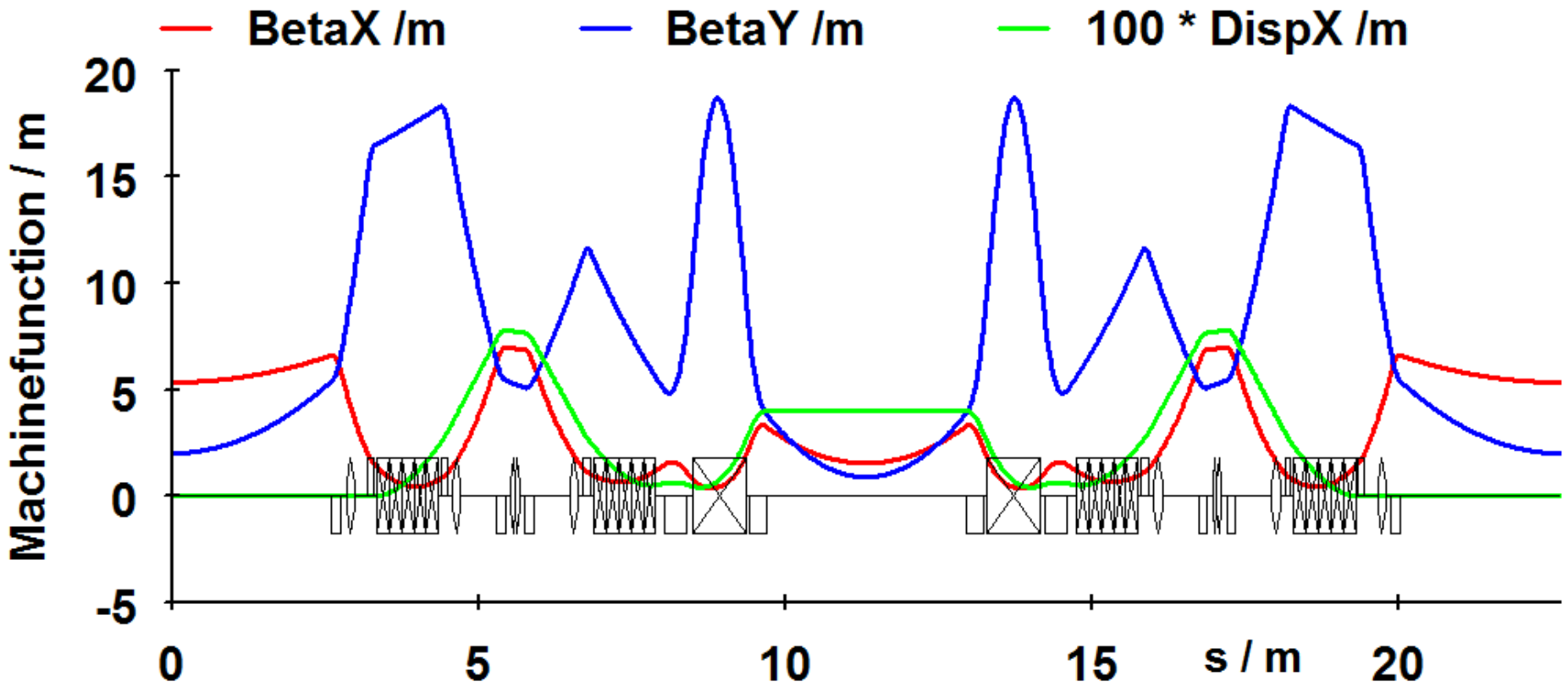


Tight time schedule:

- Project preparation phase 1/16 – 12/19
- Conceptual Design Report 4/2018
- Technical Design Report 12/2019

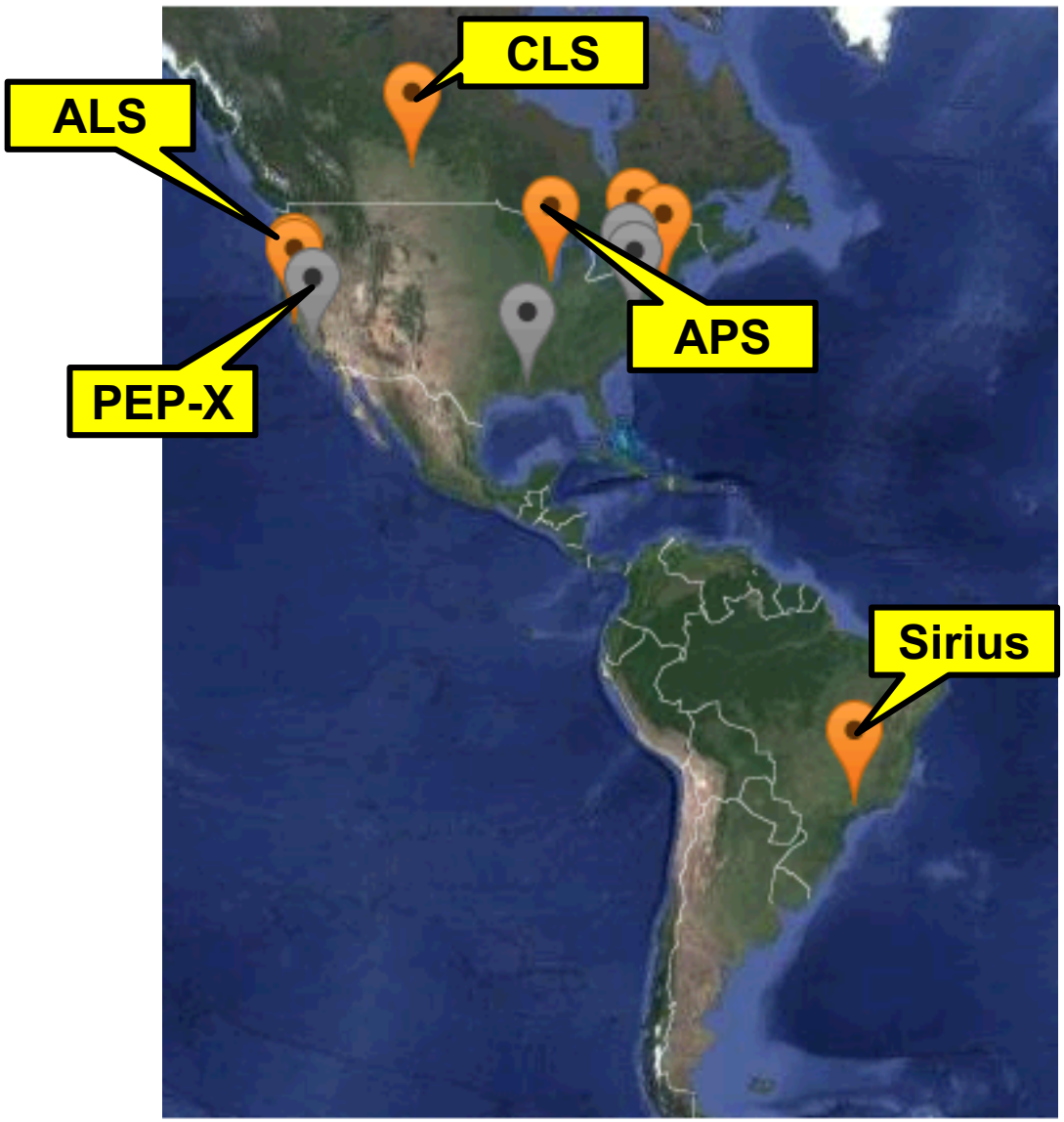
DIAMOND UPGRADE 2018-2023

DIAMOND II: DTBA Structure, C = 561 m, E = 3.0 GeV, ε = 101 pmrad, N=24

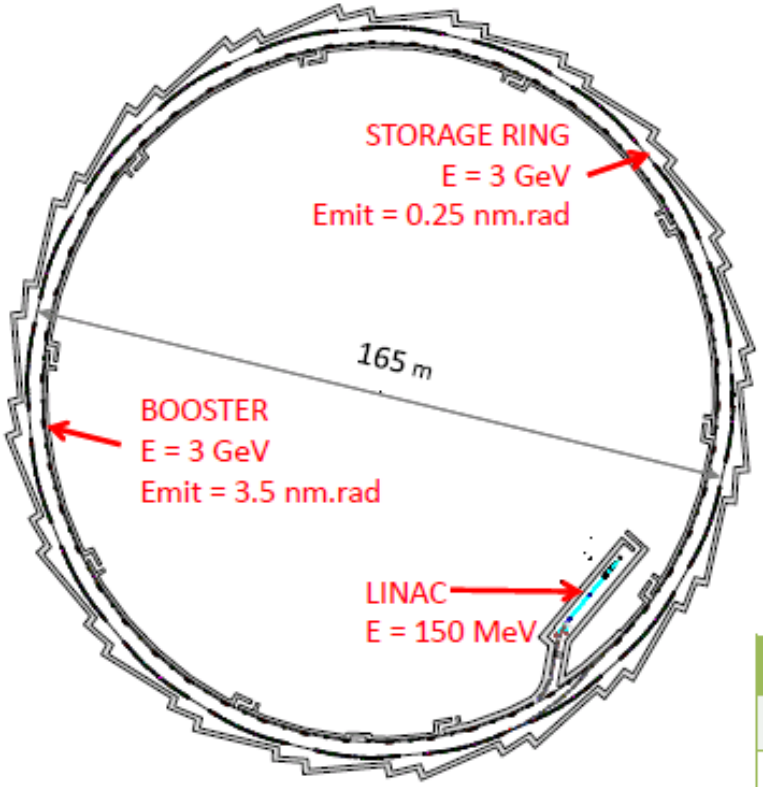


37 % of the circumfence are devoted to straight lines

UPGRADES IN AMERICA



LAYOUT OF SIRIUS

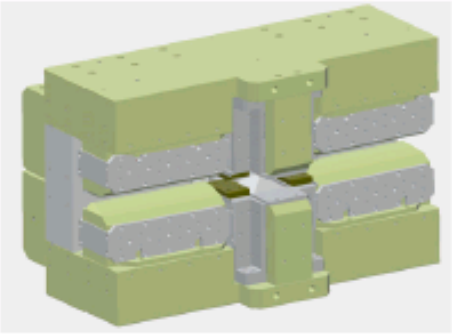


Storage Ring	
Beam energy	3.0 GeV
Circumference	518.4 m
Lattice	20 x 5BA
Hor. emittance (bare lat.)	0.25 nm.rad
Hor. emittance (with IDs)	→ 0.15 nm.rad
Betatron tunes (H/V)	49.11 / 14.17
Natural chrom. (H/V)	-119.0 / -81.2
rms energy spread	0.85 x 10^{-3}
Energy loss/turn (dipoles)	473 keV
Dam. times (H/V/L) [ms]	16.9 / 22.0 / 12.9
Nominal current, top up	350 mA

Booster	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Lattice	50 Bend
Cycling frequency	2 Hz

SIRIUS PROGRESS

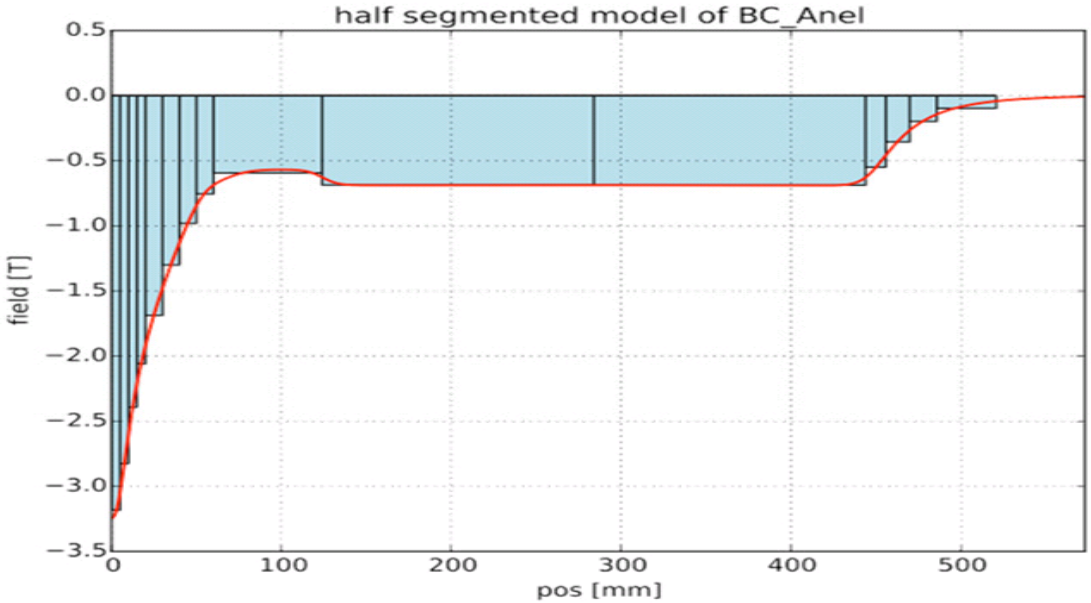
MAGNET AND TIME SCHEDULE OF SIRIUS



Permanent magnet (NdFeB)

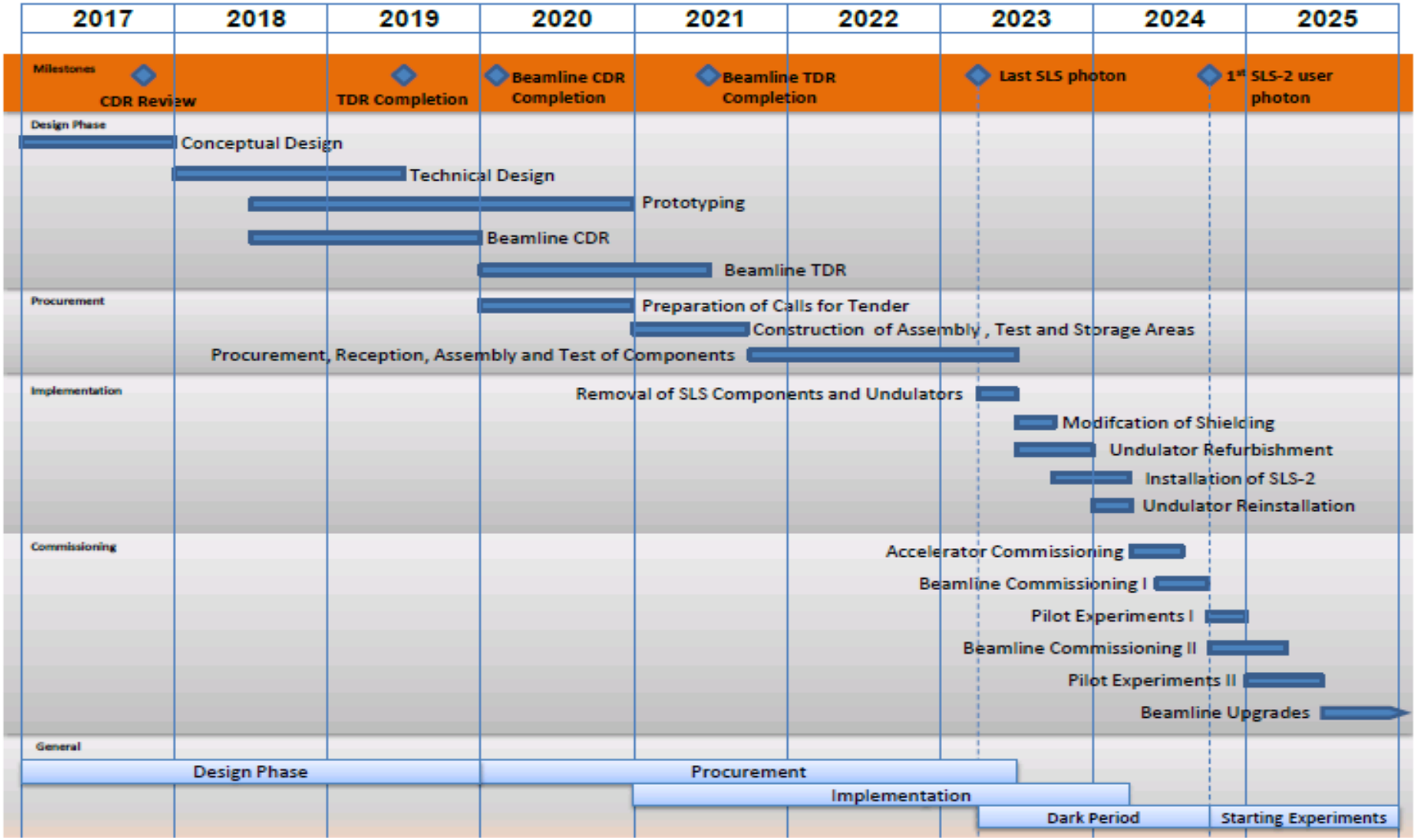
High field insert (3.2 T) superbend

- 19 keV critical energy at peak
- Hard X-rays produced only at beamline exit
- Total energy loss/turn from dipoles = 473 keV



The schedule is the following:
February 19th : start of the supports installations in the storage ring
March 5th : Start of the Linac installation
May 5th: Linac commissioning completed
July 31st: Machine installation completed
Second semester 2018: commissioning with normal conducting cavity (up to 100 mA)

TIME SCHEDULE FOR SLS-2

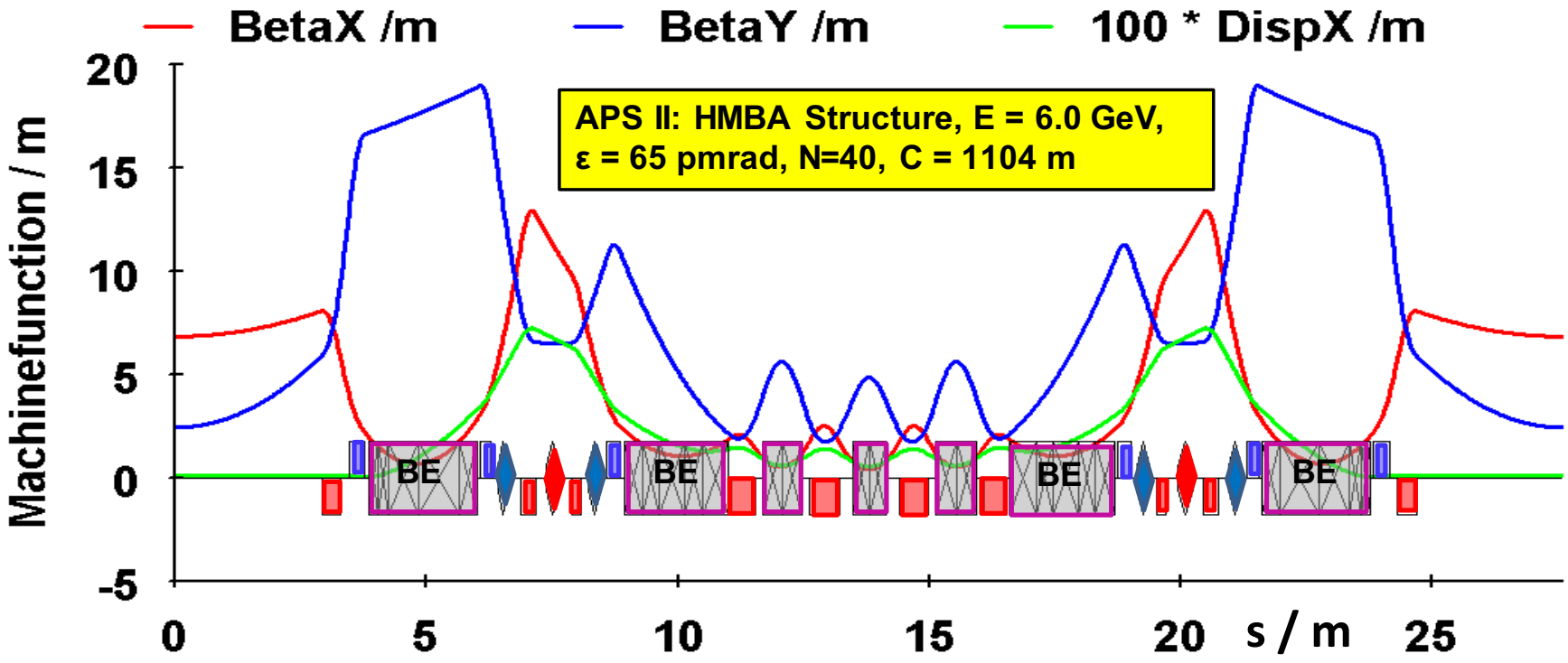


APS UPGRADE BASED ON LATTICE 7-HMBA ACHROMAT

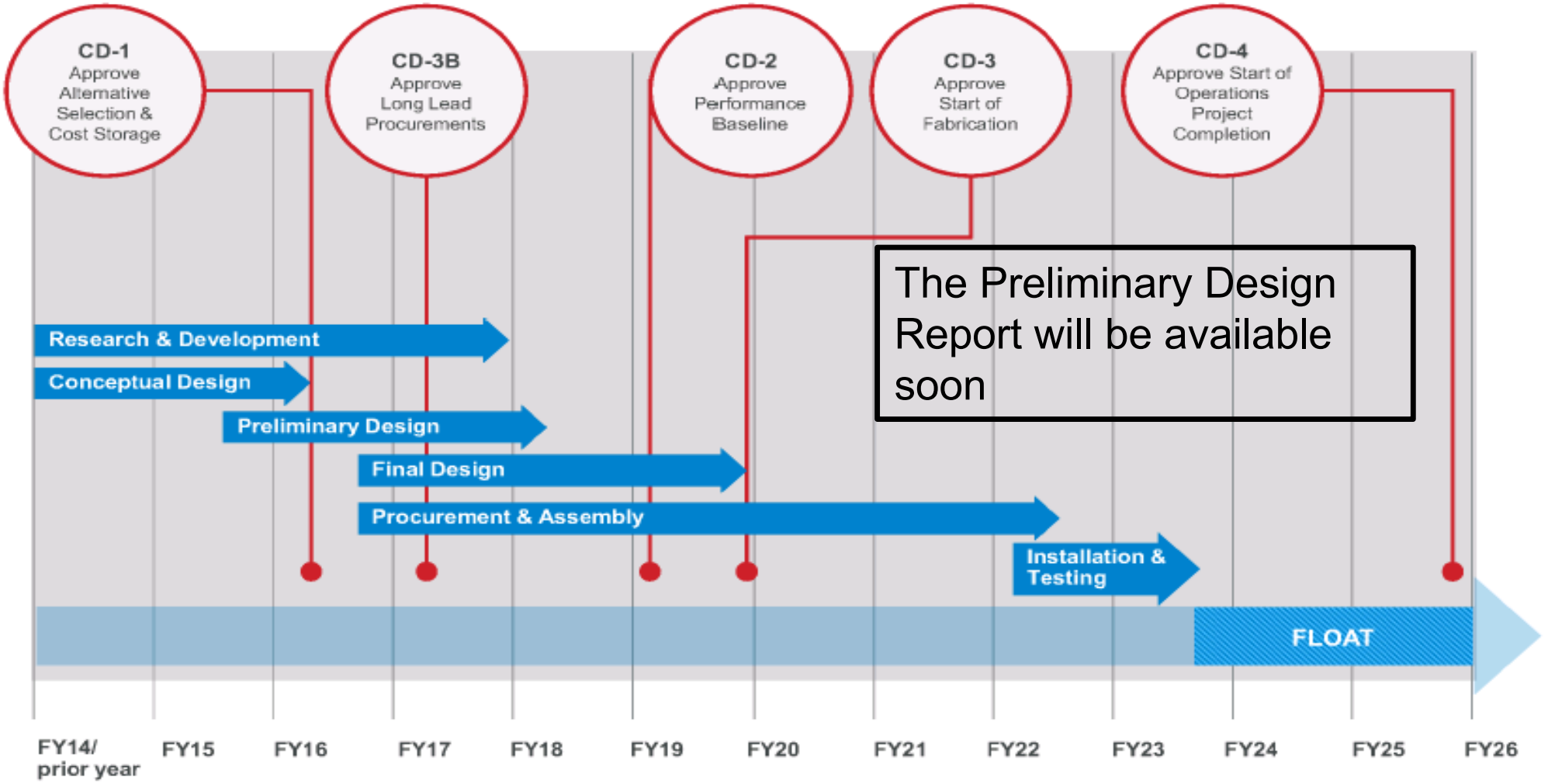
After extensive study, chosen hybrid 7-bend achromat with 4 longitudinal gradient dipoles, 3 transverse-gradient and 6 reversed dipoles

- **It provides for two locations with larger dispersion that can be used for chromatic corrections**
- **Phase separation between sextupole triplets is ≈ 3π in X and ≈ π in Y**

Introduction of reverse bends allowed us to further reduce emittance.

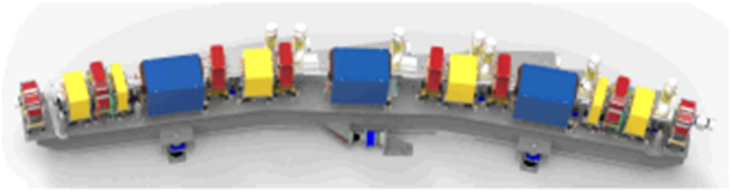


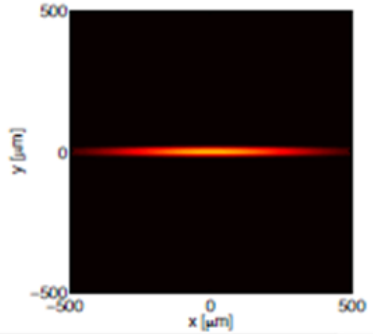
APS UPGRADE PROJECT SCHEDULE

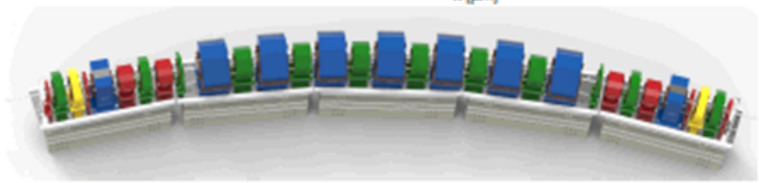


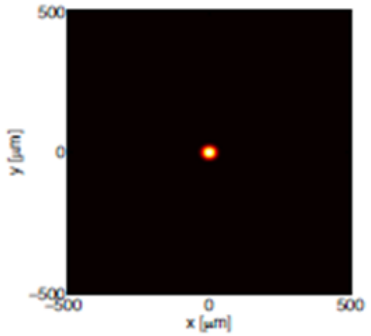
Robert Hettel - DOE Review of the APS Upgrade Project – December 12-13, 2017

ALS-UPGRADE PARAMETERS









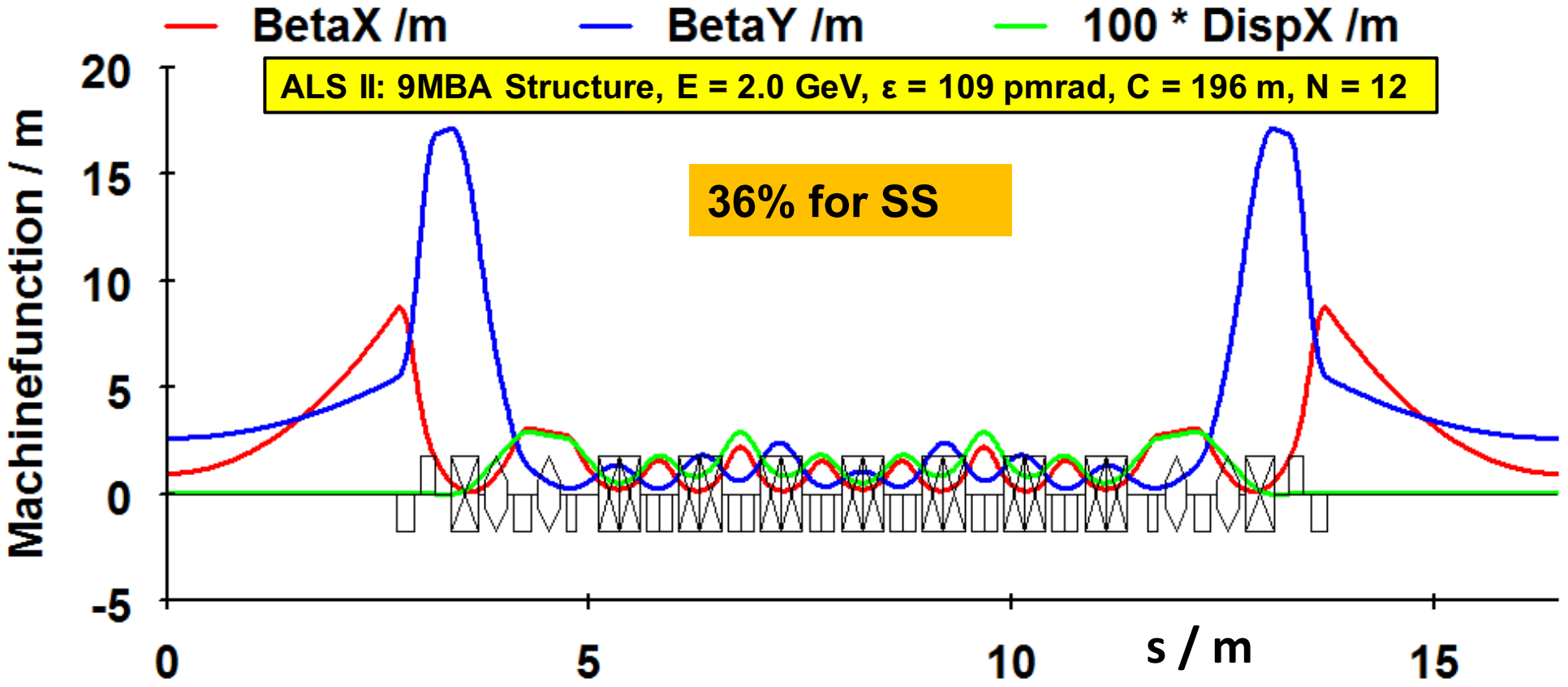
Parameter	Units	ALS	ALS-U
Electron energy	GeV	1.9	2.0
Horiz. emittance	pm	2000	~50
Vert. emittance	pm	30	~50
Beamsize @ ID center (σ_x/σ_y)	mm	251 / 9	<10 / <10
Beamsize @ bend (σ_x/σ_y)	mm	40 / 7	<5 / <7
bunch length (FWHM)	ps	60-70 (harmonic cavity)	120-200 (harmonic cavity)
RF frequency	MHz	500	500
Circumference	m	196.8	~196.5

BERKELEY LAB

ALS-U

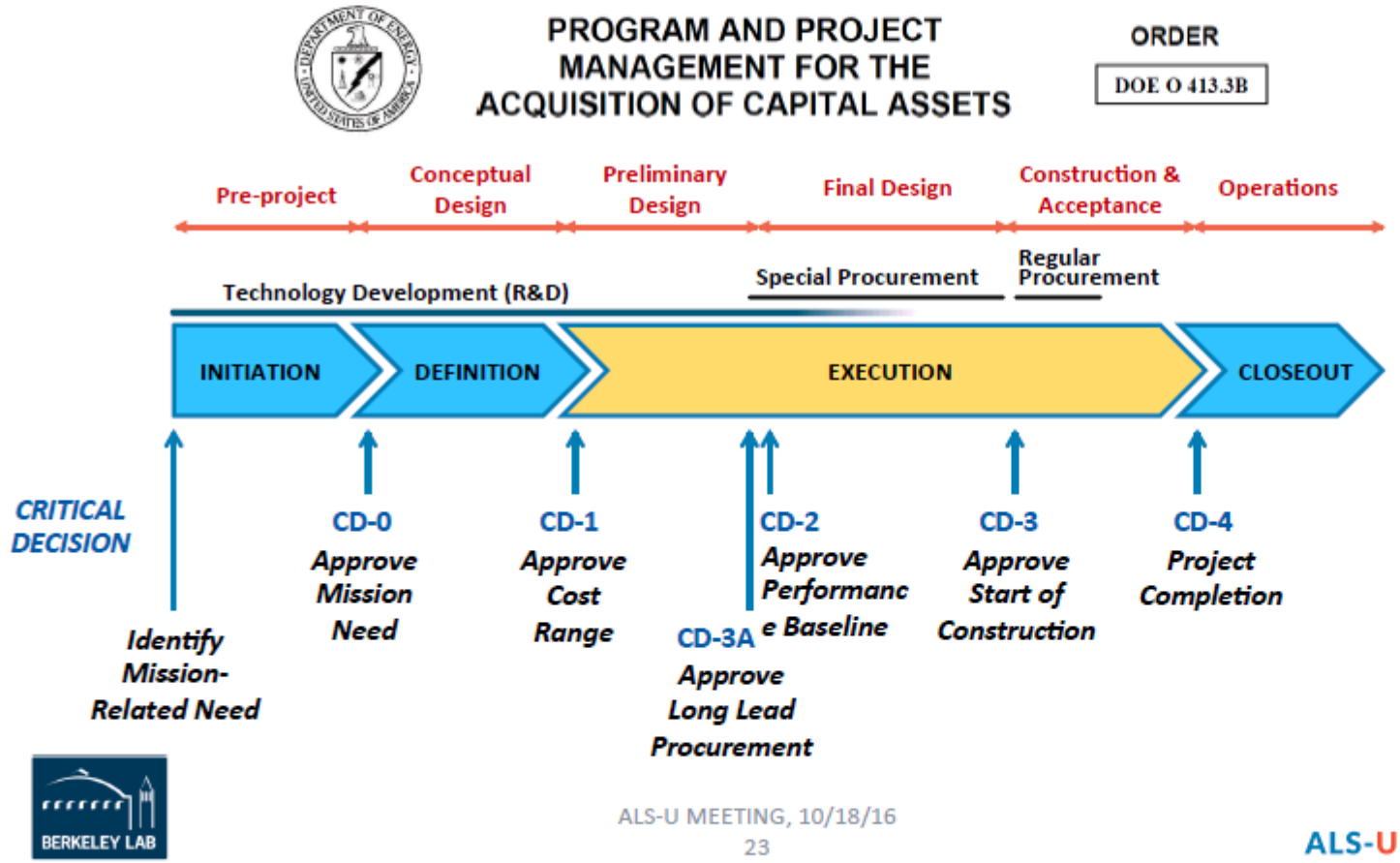
The European Synchrotron | ESRF

ALS-UPGRADE

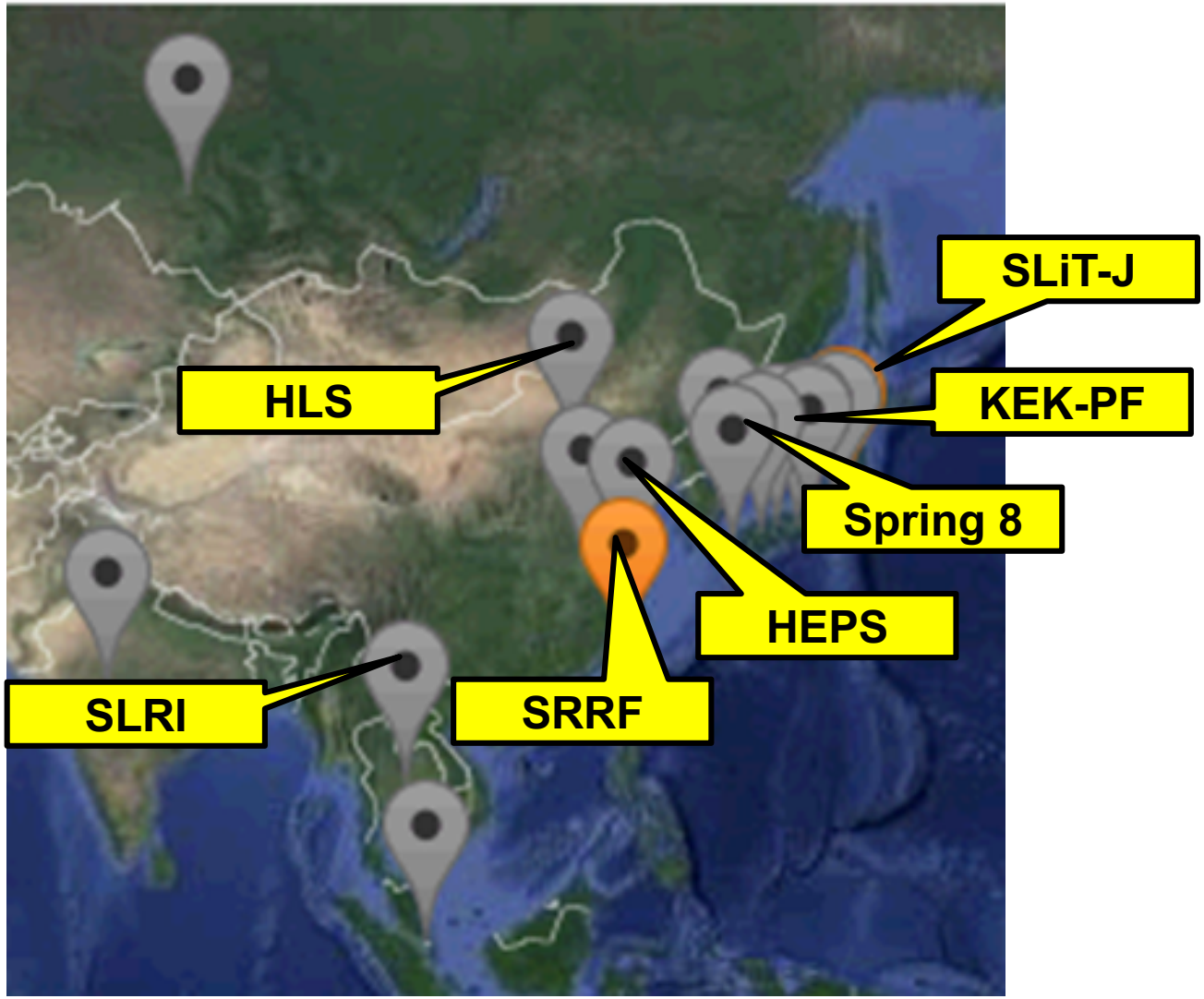

BetaX /m
BetaY /m
100 * DispX /m
ALS II: 9MBA Structure, E = 2.0 GeV, ε = 109 pmrad, C = 196 m, N = 12
36% for SS
Machinefunction / m
20
15
10
5
0
-5
0
5
10
15
s / m

ALS TIME SCHEDULE

CD-0 means the project has started!



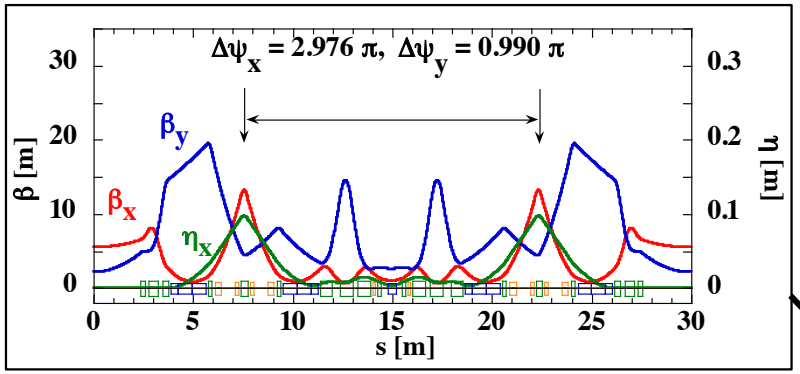
UPGRADES IN ASIA



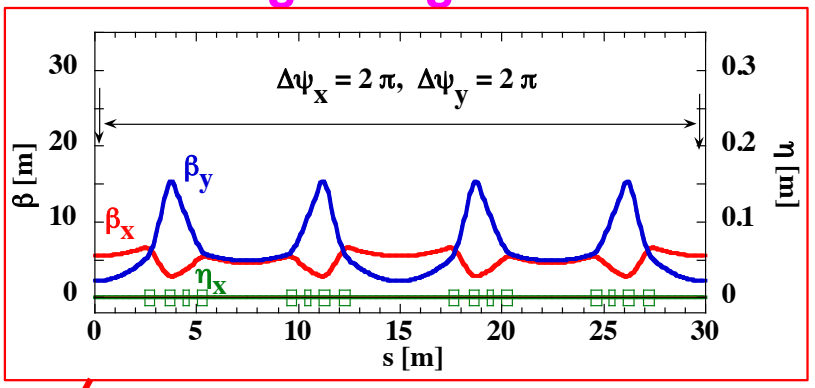
SPRING 8 UPGRADE : RING CONFIGURATION

The ring has four long straight sections (LSS) of about 30m and an injection section having high horizontal beta of β_x = 20m. In both sections phase matching condition is imposed and these sections are transparent for on-momentum electrons.

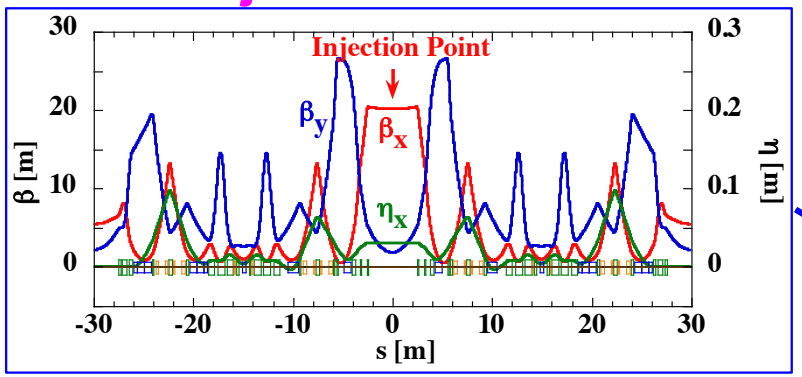
Unit Cell

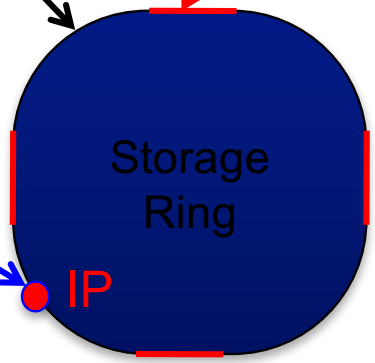


Long Straight Cell



Injection Cells

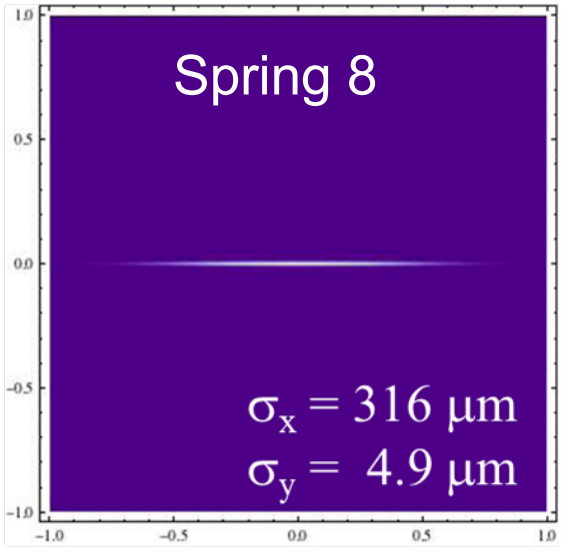


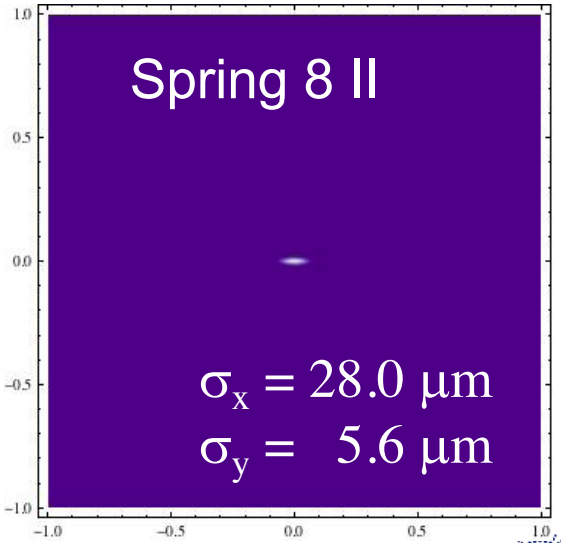


42 Unit Cells
+ 2 Injection Cells
+ 4 Long Straight Cells

MAIN PARAMETERS OF SPRING-8-2

	SPring-8-II	SPring-8 (Present)
E [GeV]	6	8
I [mA]	100	100
C [m]	1435.45	1435.95
Lattice	5BA (w/ Long. Var.)	DB
e [nmrad]	0.157 ~0.10 w/ und.	2.4
(b_x, b_y) [m] @ ID	(5.5, 2.2)	(31.2, 5.0)
h_x [m] @ ID	0.0	0.146
(n_x, n_y)	(108.10, 44.58)	(41.14, 19.35)
$(x_x, x_y)_{natural}$	(-143, -147)	(-117, -47)
a	3.24e-5	1.60e-4
$s_{Dp/p}$ [%]	0.093	0.109
k [%]	10	0.2
h	2436	2436
f_{RF} [Hz]	508.76	508.58





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HEPS: LATTICE LAYOUT

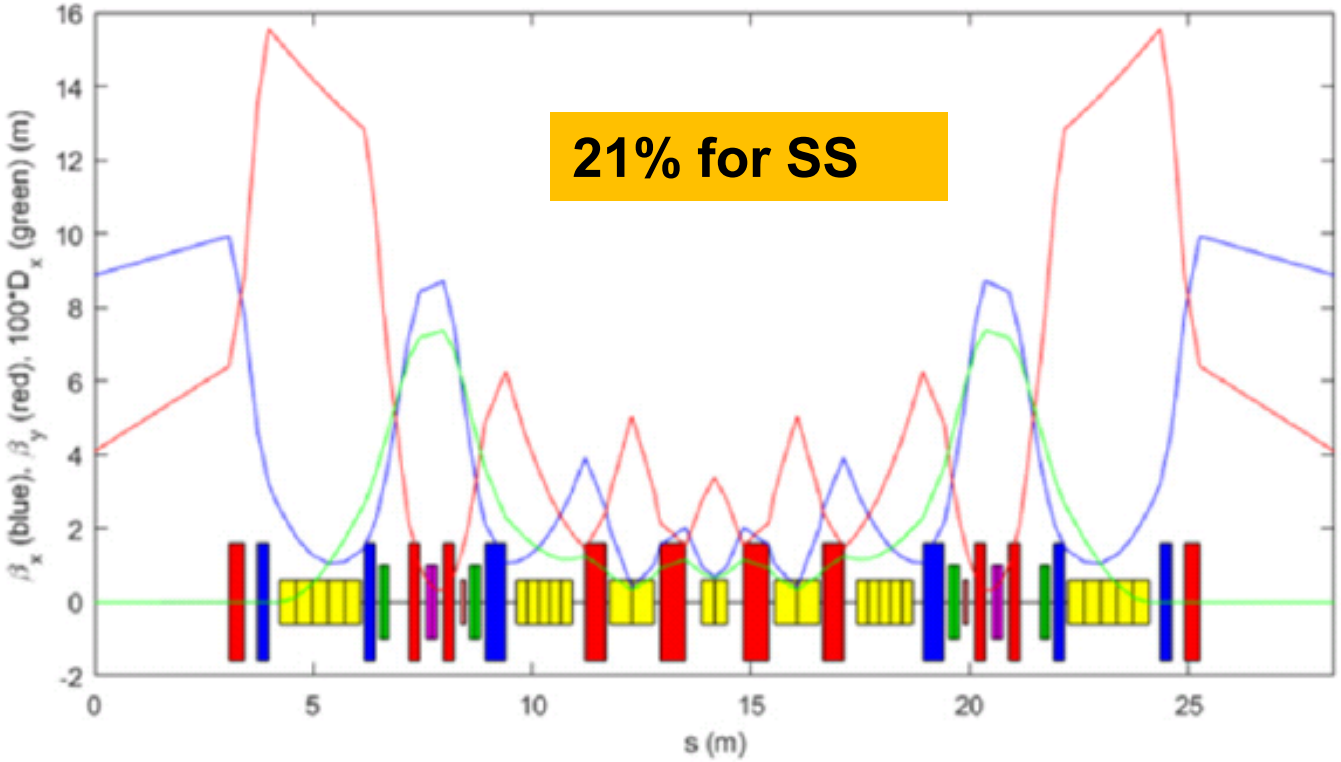


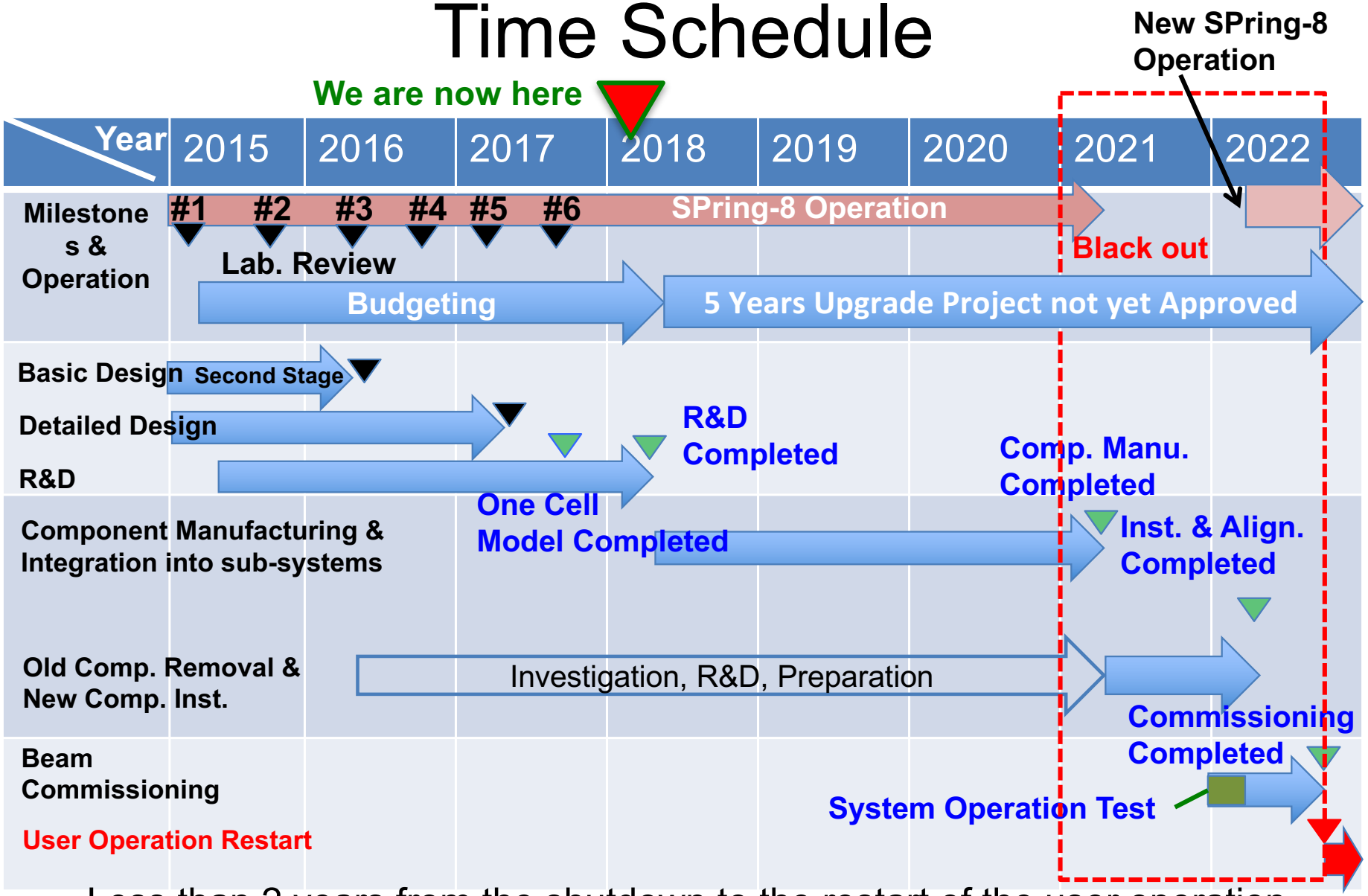
Table 1: Ring Parameters of Present HEPS Lattice

Parameters	Values
Energy E_0	6 GeV
Beam current I_0	200 mA
Circumference	1360.4 m
Natural emittance ε_{x0}	58.4 pm.rad
Working point υ_x/υ_y	107.37/82.43
Natural chromaticities (H/V)	-214/-133
No. of superperiods	48
ID section length L_{ID}	6.15 m
Beta functions at ID sect. (H/V)	8.9/4.1 m
Energy loss per turn	1.959 MeV
Rms energy spread	8.20×10^{-4}
Momentum compaction	3.43×10^{-5}

HEPS will be the next storage ring light source with high energy and low emittance in China, and the HEPS test facility has been started. Lattice design and physics studies are going smoothly.

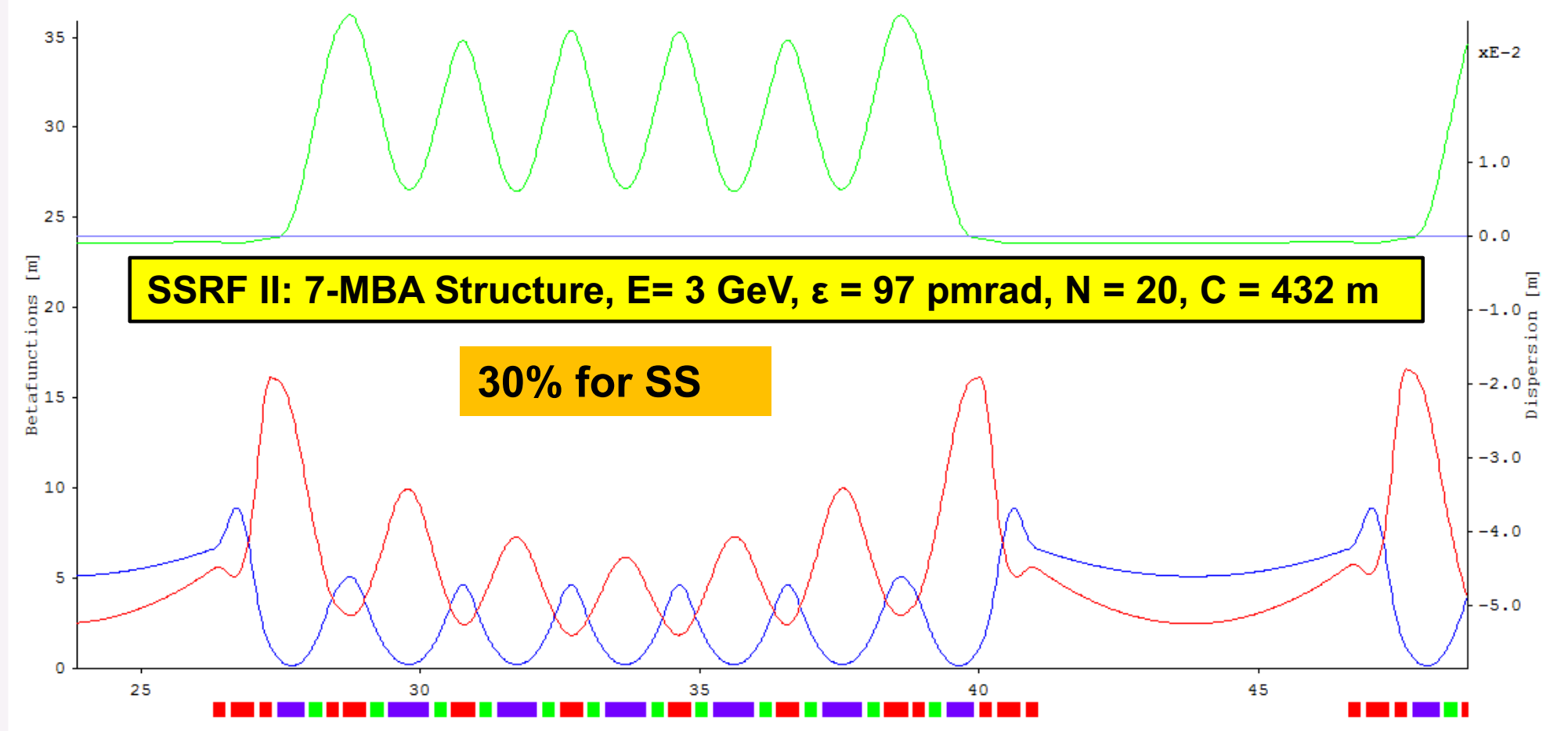
Now ESRF-EBS, APS-U, HEPS, ALS-II, etc. adopts hybrid-MBA lattice.

Time Schedule



Less than 2 years from the shutdown to the restart of the user operation

SHANGHAI LIGHT SOURCE (SSRF) UPGRADE PROPOSAL



CONCLUSIONS

- **ESRF has pioneered the SR light sources upgrade by replacing its synchrotron with a complete new ring**
- **At least 10 facilities will do very similar upgrades in the next 5-10 years**
- **Some green-field facilities will be also be built worldwide with similar concepts and technologies**
- **Upgrades involve the realization of hundreds of:**

  high quality magnets

  vacuum chambers

  power supplies

Upgrades are great opportunities for high-tech industries

- **Upgrades involve heavy logistics activities**
- **Upgrades budget envelopes range between 100ME to 400ME**

THANK YOU FOR YOUR ATTENTION