ESRF Operations and Machine Upgrade
BNL, April 26-28 2017
Pantaleo Raimondi
On behalf of the Accelerator Project Phase II Team
ESRF TODAY

Storage ring
6 GeV, 844 m

E-Linac
200 MeV

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

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
The Accelerator Upgrade Phase II aims to:

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

In the context of the R&D on “Ultimate Storage Ring”, the ESRF has developed a solution, based on the following requirements and constraints:

- Reduce the horizontal equilibrium emittance from 4 nm to less than 140 pm
- Maintain the existing ID straights beamlines
- Maintain the existing bending magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Keep the present injector complex
- Reuse, as much as possible, existing hardware
- Minimize the energy lost in synchrotron radiation
- Minimize operation costs, particularly wall-plug power
- Limit the downtime for installation and commissioning to less than 18 months.

Maintain standard User-Mode Operations until the day of shut-down for installation
# Machine Statistics for 2014-2017 at the ESRF

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

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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</thead>
<tbody>
<tr>
<td>Availability (%)</td>
<td>99.11</td>
<td>98.53</td>
<td>99.06</td>
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<tr>
<td>Mean Time Between Failures (hrs)</td>
<td>105.5</td>
<td>93.6</td>
<td>93.8</td>
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<tr>
<td>Mean duration of a failure (hrs)</td>
<td>0.94</td>
<td>1.37</td>
<td>0.88</td>
<td>0.87</td>
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(Until March 2017)
Several facilities will implement Low Horizontal Emittance Lattices by the next decade.
BRILLIANCE AND COHERENCE INCREASE

**Brilliance**

Source performances will improve by a factor 50 to 100

<table>
<thead>
<tr>
<th>Source performances will improve by a factor 50 to100</th>
<th>CPMU18, K=1.68</th>
<th>L=2m</th>
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<tr>
<td>Undulator</td>
<td>High Beta</td>
<td>Low Beta</td>
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<td>Coherence</td>
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<td>Vert. Emittance [pm]</td>
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<td>Energy spread [%]</td>
<td>0.1</td>
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<tr>
<td>$\beta_x [m]/\beta_z [m]$</td>
<td>37/3</td>
<td>6.9/2.6</td>
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</table>
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

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

**Double-Bend Achromat (DBA)**
- Many 3\textsuperscript{rd} gen. SR sources
- Local dispersion bump (originally closed) for chromaticity correction
THE HYBRID MULTI-BEND (HMB) LATTICE

ESRF existing (DBA) cell
- $Ex = 4$ nm$\cdot$rad
- tunes (36.44, 13.39)
- nat. chromaticity (-130, -58)

Proposed HMB cell
- $Ex = 140$ pm$\cdot$rad
- tunes (76.21, 27.34)
- nat. chromaticity (-99, -82)

- Multi-bend for lower emittance
- Dispersion bump for efficient chromaticity correction => “weak” sextupoles (<0.6kT/m)
- Fewer sextupoles than in DBA
- Longer and weaker dipoles => less SR
- No need of “large” dispersion on the inner dipoles => small $Hx$ and $Ex$
LIFETIME OF S28B

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

S28B
DA -10mm@S3
TLT ~ 21h

e_y=5pm  ESRF  Upgrade

<table>
<thead>
<tr>
<th></th>
<th>ESRF</th>
<th>Upgrade</th>
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<tr>
<td>Multibunch</td>
<td>64 h</td>
<td>21 h</td>
</tr>
<tr>
<td>16 bunch</td>
<td>6 h</td>
<td>2.1 h</td>
</tr>
<tr>
<td>4 bunch</td>
<td>4 h</td>
<td>1.4 h</td>
</tr>
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</table>
Technical challenge: Magnets System

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

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

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

Quadrupole
Around $52 Tm^{-1}$

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

Octupoles

Permanent magnet (Sm$_2$Co$_{17}$) dipoles
Longitudinal gradient 0.16 – 0.65 T, magnetic gap 25 mm
1.8 meters long, 5 modules

Gael Le Bec
Pole shape optimization

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

Low gradient pole profile

High gradient pole profile

Vacuum chamber and magnets sections
QUADRUPOLES

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

Moderate Gradient
- Up to 58 T/m gradient, 162–295 mm length
- 16.4 mm bore radius, 11 mm vertical gap
- 0.7 – 1.0 kW power consumption
Specifications

- 0.17 – 0.67 T field
- 5 modules of 357 mm each
- Larger gap for the low field module
- Allows the installation of an absorber

Measured field integral homogeneity (one module)

Longitudinal field distribution
DQ1 pole shape

DQ1 gradient homogeneity:

Integration of trajectory along an arc

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

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

DQs are machined in 7 solid iron plates

Poles curved longitudinally for maximum stay clear and good field region
**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
### Master Plan and Major Milestones

<table>
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<th>Event Description</th>
<th>Date</th>
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<tr>
<td>Start of assembly phase</td>
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<td>Start of shutdown</td>
<td>17/12/2018</td>
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<td>Start of dismantling phase</td>
<td>18/03/2019</td>
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<td>18/03/2019</td>
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<td>09/01/2020</td>
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<tr>
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<td>09/01/2020</td>
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<tr>
<td>Start of storage ring commissioning phase</td>
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<tr>
<td>Start of USM</td>
<td>25/08/2020</td>
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### Timeline Diagram

- **January 2017-June 2018**: Delivery of components
- **January 2017-June 2018**: User Service Mode (USM)
- **May-July 2020**: Friendly Users

### Table

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<tr>
<th>Year</th>
<th>2015</th>
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<th>2017</th>
<th>2018</th>
<th>2019</th>
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<td>O</td>
<td>N</td>
<td>D</td>
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<td>Friendly Users</td>
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</table>
Design of all the components nearly completed:

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

All elements have been fully integrated and are consistent with the overall specifications and requirements
PROGRESS STATUS: PROCUREMENT

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

Delivery of serial components has started will last about 2 years
All contracts in place, magnets in fabrication
FAT for HG-Quads, Sextupoles and correctors last week
All FAT should be completed by December
More than 1000 Magnets to be procured by the end of 2018

398 moderate gradient quadrupoles
130 high gradient quadrupoles
196 sextupoles
66 octupoles
100 correctors
PM Dipoles are being assembled by ESRF staff
More than 650 Magnets Modules for a total of about 130 5-Module dipoles
All contracts in place, chambers in fabrication
FAT for aluminium chambers in November
All FAT should be completed by December
More than 450 Vacuum Chambers to be procured by the end of 2018
FAMILY 3: LOW PROFILE STAINLESS STEEL CHAMBERS

Material: 316 LN

Curved Chambers

Pumping port

Absorber port

Straight part

Curved part following DQ Magnet curve

Straight part

Requested shape tolerance: 0.3mm!

Thick ante-chamber acting as stiffener

1,5mm sheet

EB Welding

Pumping block

Deformation at the Beam area 0.125mm

Joel Pasquaud
**BELLOWS RF FINGERS: ESRF DESIGN PATENTED**

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

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**Part pushing blade to contact**

**RF Finger**

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**Contract in place**

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**Blade contact**

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*Courtesy of P Brumund, L Eybert, L Goirand*
PRODUCTION – VACUUM CHAMBERS

STAINLESS STEEL

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

Pre-series still in progress

CH1 high profile pre series
CH4 high profile pre series
CH6 high profile pre series
CH11 high profile pre series
CH12 high profile pre series
CH3 & 11 high profile pre series

CH7 low profile pre series in progress

Courtesy of P Van Vaerenbergh, J Pasquaud, L Goirand
Aluminium Vacuum chambers pre-series: still in progress

January 2017
Factory acceptance for;

• Photon absorbers
Family Teeth (up to 110 W/mm²)

Family Frontal (up to 50 W/mm²)

All contracts in place
400 Absorbers in fabrication

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

No weld, no braze
ABSORBERS WITH TEETH OPTIMIZED TO REDUCE THERMAL STRESSES

Teeth distribute the heat over a larger area

Teeth geometry optimized to reduce thermal stresses

A: temperature is max Stress is min

B: temperature is min Stress is max

Expansion possible

Expansion blocked

Temperature plot on Teethed absorber

Principal stress plot on Teethed absorber

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

Stress criteria < Yield strength
80% of the losses are relocated on the scrapers for 4% lifetime reduction:

ID entrance 30 %

Scrapers 1+2 80 %

Two scrapers in DR_37 of cells 13 and 24

Scraper 1 47 %

Scraper 2 33 %

No scrapers
Collimator design nearly completed CFT by Dec 2016
CURRENT TRANSFORMER & STRIPLINES

all in Ch.#12

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

all detailed designs ready
CFTs by December 2016
All supports in Production phase

Vacuum Chambers supports KURSTERS & BOSCH (NL)

Dipole supports KINKELE (D)

Magnets supports CASTELLINI (IT)

Courtesy of L EYBERT
BEAM LOSS MONITORS: COMPACT, CHEAP, PERFORMING

BLD with its Alu housing
190x25x25mm

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

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

4 pick-up inputs  Trigger input  4x RJ-25  Dip switch panel
# 1000 LARGE POWER SUPPLIES AND 1000 SMALL POWER SUPPLIES

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>quantity per cell</th>
<th>NOMINAL FIELD VALUES</th>
<th>Electrical design</th>
<th>PS O(V)design factor</th>
<th>nom Watts</th>
<th>max Watts</th>
<th>total P</th>
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<tbody>
<tr>
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<td>Length [m]</td>
<td>[kW] Voltage [V]</td>
<td>Current [(A)]</td>
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<td>Quadrupole, mod. gradient</td>
<td>QF1</td>
<td>2</td>
<td>0.349 53.7</td>
<td>1.06 12.1</td>
<td>87.5 1.2</td>
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<td>0.36 95.2</td>
<td>1.42 15.7</td>
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**Contracts in place by December 2016**

| Total PS power for one cell for main electromagnets | 30.3 | 41.1 |

**Total number of coils/cell**

<table>
<thead>
<tr>
<th>magnet coils type</th>
<th>51</th>
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<tr>
<td>corrector AC+DC (5 independent coils)</td>
<td>3 5  AC+DC</td>
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<tr>
<td>Sextupole, short correctors</td>
<td>6 6  DC</td>
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</table>

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.
All girders will be fully assembled before starting the shutdown for installation.
Pre-series girders delivered

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

NORTEMECANICA (SP) 65

AVS (SP) 65

Courtesy of T Brochard, F Cianciosi
1.) Movement of 12 pallets with magnets from B2 to B1.
2.) Movement of 4 pallets with DL-bendings from Chartreuse
3.) Movement of DL-supports

Movement of components during assembling

4.) Movement of 4 girders "out"
5.) Movement of 4 girders "in"
6.) Movement of vacuum chambers and components.

Moving of magnets on the girders
SEQUENCE OF MAGNET INSTALLATION
SEQUENCE OF VACUUM ASSEMBLY

1.) Sector Valve

3.) Chamber

6.) Gauges and RGA

9.) Prepumping valves

1.) Sector Valve

3.) Chamber

6.) Gauges and RGA

9.) Prepumping valves
STATUS - VACUUM ASSEMBLY – GIRDER 1

1ST Assembly + alignment = 4 hours
“Standard cells”
Design in progress

“Specific cells”
C5 – C7 – C25 (RF)

“Specific cells”
C13 - C24 (Collimator)

Injection zone TL2

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

And then drawings:
For the piping
For the cable trays
Main steps since the last MAC (4):
- Metallic structure
- Facade
- Overhead crane
- Ground preparation - Asphalt
- Concrete slab
- Facilities
Dismantling – INSTALLATION – PLANNING OVERVIEW

Dismantling

Girder Moving

Installation
CONCLUSION

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

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