Project Sirius Overview and Sirius Magnets

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www.lnls.br
• Introduction
• Optics
• Building and high stability floor
• LINAC – Turn key 150 MeV from Shanghai (ready for installation)
• Girders
• Injection – Non Linear Kicker and Septum under simulations
• Alignment
• RF – same approach as the UVX machine.
• Vacuum
• BPMs
• Magnets and IDs
Introduction
City of Campinas (population: 1,100,000)

200 employees
80 students & trainees

UVX
- 1.37 GeV
- 100 nm.rad
- 18 beamlines
- Over 1200 users

40,000 students
Sirius building (29/08/2016)

Budget (2016)
- Accelerators 94 M €
- 13 beamlines 133 M €
- Building 200 M €
- Human Res 53 M €
- Total 480 M €

Schedule
- Jan.2015 start of building construction
- Sep.2017 start of machine installation
- Aug.2018 start of SR commissioning
- Jan.2019 phase 1 operation (20mA, NCC)
- Jul.2019 phase 2 operation (100mA, SCC)
## Sirius main parameter today

### Storage Ring
- **Beam energy**: 3.0 GeV
- **Circumference**: 518.4 m
- **Lattice**: 20 x 5BA
- **Hor. emittance (bare lattice)**: 250 pm.rad
- **Hor. emittance (with IDs)**: → 150 pm.rad
- **Betatron tunes (H/V)**: 48.10 / 13.17
- **Natural chromaticities (H/V)**: -124.4 / -79.9
- **rms energy spread**: $0.95 \times 10^{-3}$
- **Energy loss/turn (dipoles)**: 532 keV
- **Damping times (H/V/L) [ms]**: 15.5 / 19.5 / 11.2
- **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

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Documentation about Sirius available at [wiki-sirius.lnls.br](http://wiki-sirius.lnls.br)

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Courtesy Liu Lin
• 2012 - Sirius before Machine Advisory Committee

- Emittance: 1.7 nm.rad

2T permanent magnet superbend

3-Bend Achromat, 480m circumference

• 2012 - Sirius after MAC recommendation

- Emittance: 0.28 nm.rad

2T permanent magnet superbend

5-Bend Achromat, 518m circumference

Low field dipoles (0.58T) ⇒ lower energy dispersion ⇒ smaller beam size

• 2016 - Sirius today (version SI.V17.01-S05.01)

- Emittance: 0.25 nm.rad

3.2T peak field permanent magnet superbend

5-Bend Achromat, 518m circumference
Building and high stability floor
Sirius building (29/08/2016)

- 10 to 15 m deep piles
- 1500 piles for the high stability slab
Sirius building

- 6 long beamlines (up 150 m)
- 10 apertures for machine components and IDs installation
Sirius building
The main reason for the piles below the machine is the long term stability, specially considering the “cut and fill” operation on the site.
Girders
Welded girder
Cast iron girder
Girder optimization

Welded Steel
1st mode
511 Hz (measured)
515 Hz (calculated)
Damping ratio: 0.23%

Cast Iron
1st mode
287 Hz (measured)
281 Hz (calculated)
Damping ratio: 0.15%
Girder optimization
Girder optimization

Testing different suppliers for the levelling wedges

Precision levelling wedges
Vacuum System
Pro's (full NEG coated strategy):
- Simple chamber’s design
- More compact -> space saving
- Low PSD yield -> Fast vacuum conditioning

Con's (full NEG coated strategy):
- Limited number of activations (10 ...?...30)
- High temperature bake-out for NEG activation
- Many bellows to accommodate chamber’s expansion during bake-out

Pumping Station
(based on Petra III design)
- Crotch absorber
- Ion pump (20l/s)
- NEG cartridge
- Vacuum gauges

0.3 mm SS sector
For fast orbit correctors
Main characteristics
- Deposition of up to 3.2 m long chambers
- Magnetic field up to 600 Gauss
- Up to 6 straight chambers simultaneously
- Bake-out system integrated to the solenoids
- Automatic control of the deposition
- Individual control of each chamber
Main characteristics of the heaters:

- Developed along with a Brazilian company
- Thickness < 0.4 mm
- Voltage < 50V
- Max. tested temperature 220 °C
Impact of in-situ NEG activation on permanent magnets

\[ T_{\text{poles}} = 35.2 \, ^\circ\text{C} \]

\[ T_{\text{tube}} = 200 \, ^\circ\text{C} @ 24\text{h} \]

\[ T_{\text{ambient}} = 23 \, ^\circ\text{C} \]

\[ \text{max. } \Delta T_{\text{poles}} = 12.2 \, ^\circ\text{C} ; \text{max. } \Delta T_{\text{PM}} = 8.8 \, ^\circ\text{C} \]

Still need to check the radiation resistance of the heating tapes!
Brazed Al2O3 insulator, 1 mm thickness.

RP-SMA connector

Threads: thermal contact, RF shielding and fixation

Ti alloy (non-magnetic).

Tig welding

Filler material
Sirius BPM Prototype

First prototype with welded buttons on Titanium body

Robotized welding

Initial concept for the BPM support
Analog performance (resolution, drifts, nonlinearity)

- Dominated by RF Front-End + ADC + clocking
- Switching frequency ~ 115 kHz

Signal Processing, Data Acquisition and Control Platform

- System maintainability
- High-end communication interfaces enable FOFB
- DSP algorithms flexibility

Open-source software and hardware facilitate collaboration
Analog performance (resolution, drifts, nonlinearity)

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Magnets
Multipole Magnet or Multipole Motor?
Partnership LNLS/WEG

**LNLS:** simulation, design & magnetic measurement

- 15,000 employes in this plant
- 50,000 electric motors/day

**WEG:** manufacturing, quality control, mechanical measurements and tests
Magnets manufacturing room at WEG
• Investment in software and hardware
• Same CMM machine at WEG and LNLS
• Same metrological procedures

Booster quadrupoles with typically ±30µm gap deviation and 20µm parallelism at reference surfaces
Superbend

To be assembled at LNLS

- NdFeB with 15 µm parallel surface
- Low carbon steel for the yoke and low field poles
- Vanadium-Permendur for high field poles.
- Aluminum for spacers

All magnets except the superbend

To be produced at WEG

Material: Silicon Steel 0.5mm

- Standard material for our magnet supplier
- Low hysteresis make combined magnets more linear

Technology: Laminated not glued

- Used before at LNLS 6 tons dipoles
- Compatible with our supplier know-how
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If you can not convince them using just mathematics...
FeSi Low Remanent Field

Sirius @ x=-18mm - Bmax[\text{G}] = 3330.0
UVX @ x=-42mm - Bmax[\text{G}] = 2430.0

At least 15 times less residual field
Magnet Simulations

Adaptive Time Stepping
Component Disabling
Transient-Transient link

Electro - Thermal
Complete 2D/3D Coupling

OptiNet
Automated Design Optimization

All storage ring, booster, pulsed magnets and IDs simulated in Infolytica Magnet.
Magnetic Measurements

Vibrating wire bench on a CMM

Kugler Measurement Bench

Rotating Coil
Booster, SR and IDs
Booster Magnets

- Horizontal and vertical correctors (same design)
- Booster and Storage Ring
### Booster Quadrupole Magnet

<table>
<thead>
<tr>
<th></th>
<th>QF</th>
<th>QD</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply type</td>
<td>monopolar</td>
<td>bipolar</td>
<td></td>
</tr>
<tr>
<td>Number of magnets</td>
<td>50</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Maximum integrated strength</td>
<td>0.425</td>
<td>-0.052</td>
<td>m⁻¹</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>0.227</td>
<td>0.101</td>
<td>m</td>
</tr>
<tr>
<td>Physical length</td>
<td>0.212</td>
<td>0.085</td>
<td>m</td>
</tr>
<tr>
<td>Maximum strength</td>
<td>1.873</td>
<td>-0.520</td>
<td>m⁻²</td>
</tr>
<tr>
<td>Bore diameter</td>
<td>40</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>Maximum integrated field gradient</td>
<td>-4.255</td>
<td>0.525</td>
<td>T</td>
</tr>
<tr>
<td>Maximum field gradient</td>
<td>-18.746</td>
<td>5.202</td>
<td>T⋅m⁻¹</td>
</tr>
<tr>
<td>Maximum field at pole tip</td>
<td>0.375</td>
<td>0.104</td>
<td>T</td>
</tr>
</tbody>
</table>
Booster Quadrupole Magnet
Booster Quadrupole Results

Booster QF quadrupole measurements for high current ($I=130$ A)

$|B^r ds| = (-4.826 \pm 0.004)$ T
rms excitation error = 0.08 %
peak-valley variation = 0.4 %
Booster Quadrupole Results

Booster QF quadrupole measurements for high current (I=130 A)

\[
\begin{align*}
\text{roll} &= (-0.46 \pm 0.10) \text{ mrad} \\
\text{peak-valley} &= 0.39 \text{ mrad}
\end{align*}
\]

\[
\begin{align*}
x_0 &= (9 \pm 17) \mu\text{m} \\
\text{peak-valley} &= 93 \mu\text{m}
\end{align*}
\]

\[
\begin{align*}
y_0 &= (-25 \pm 12) \mu\text{m} \\
\text{peak-valley} &= 48 \mu\text{m}
\end{align*}
\]
**Booster Sextupole Magnet**

Maximum Integrated Strength: \(-21.032 \pm 0.015\) T/m

Roll: \(0.12 \pm 0.3\) mrad

Magnetic Center Offset (Horizontal): \(17\mu m \pm 11\mu m\)

Magnetic Center Offset (Vertical): \(44\mu m \pm 6\mu m\)
Booster Sextupole Magnet

Production will be delivered September 26th
Booster Dipole Magnet

- Booster dipole (with quadrupole and sextupole components)
- 28 mm gap and 1200 mm length
- Dipole hardedge field: 1.09 T
- Quadrupole gradient at extraction: 2.14 T/m
- Sextupole gradient at extraction: 22.3 T/m²
- 50 units
Almost there!
We asked for 0.150 mm
Booster Dipole Magnet

Pre-Series in September 26th
Production (55 units) will be delivered in December 2016 to finish all Booster Magnets.
Storage Ring quadrupole single plate measurement at CMM
Storage Ring quadrupole endplate measurement at CMM
Storage Ring quadrupole (single pole) measurement at CMM
SR Magnets
Quadrupoles
SR Magnets
Quadrupoles
• Prototype delivered (one of each size).

• Pre-Series in November 2016.

• Production starts in December 2016 to Mach 2017.
SR Magnets Sextupole

- Storage ring sextupole
- Multifunctional: sextupole, H or V slow corrector and skew quadrupole
- 28 mm bore diameter
- 2402 T/m² maximum gradient
- 280 units (15 cm each)

Prototype in October 2016.

It’s ugly, but compatible with the girder.
SR Magnets
Low Field Dipole

Reviewing Dipole Simulations

Modulated Dipoles (400 mm)

<table>
<thead>
<tr>
<th></th>
<th>B1</th>
<th>B2</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excitation</td>
<td>monopolar power supply</td>
<td>monopolar power supply</td>
<td></td>
</tr>
<tr>
<td>Number of magnets</td>
<td>40</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Deflection angle</td>
<td>2.7553</td>
<td>4.0964</td>
<td>°</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>0.828</td>
<td>1.231</td>
<td>m</td>
</tr>
<tr>
<td>Physical length</td>
<td>0.807</td>
<td>1.21239</td>
<td>m</td>
</tr>
<tr>
<td>Integrated quadrupole strength</td>
<td>-0.6458</td>
<td>-0.9602</td>
<td>m⁻¹</td>
</tr>
<tr>
<td>Integrated sextupole strength</td>
<td>0.0</td>
<td>0.0</td>
<td>m⁻²</td>
</tr>
<tr>
<td>Full central gap</td>
<td>24.0</td>
<td>24.0</td>
<td>mm</td>
</tr>
<tr>
<td>Hardedge bending radius</td>
<td>17.2181</td>
<td>17.2178</td>
<td>m</td>
</tr>
<tr>
<td>Hardedge quadrupole strength</td>
<td>-0.7800</td>
<td>-0.7800</td>
<td>m⁻²</td>
</tr>
<tr>
<td>Hardedge sextupole strength</td>
<td>0.0</td>
<td>0.0</td>
<td>m⁻³</td>
</tr>
<tr>
<td>Hardedge sagitta</td>
<td>4.977</td>
<td>11.000</td>
<td>mm</td>
</tr>
<tr>
<td>Integrated field¹</td>
<td>-0.48</td>
<td>-0.72</td>
<td>T·m</td>
</tr>
<tr>
<td>Integrated quadrupole gradient¹</td>
<td>6.4629</td>
<td>9.6084</td>
<td>T</td>
</tr>
<tr>
<td>Integrated sextupole gradient¹</td>
<td>0.0</td>
<td>0.0</td>
<td>T·m⁻¹</td>
</tr>
<tr>
<td>Hardedge field</td>
<td>-0.5812</td>
<td>-0.5812</td>
<td>T</td>
</tr>
<tr>
<td>Hardedge quadrupole gradient</td>
<td>7.8054</td>
<td>7.8054</td>
<td>T·m⁻¹</td>
</tr>
<tr>
<td>Hardedge sextupole gradient</td>
<td>0.0</td>
<td>0.0</td>
<td>T·m⁻²</td>
</tr>
</tbody>
</table>

Prototype and Production in 2017
SR Magnets
Low Field Dipole

B1 (800 mm)
2 Modules

B2 (1200 mm)
3 Modules
SR Magnets BC

Prototype in October 2016. In house production
Superbend as x-ray source

- 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 = 532 keV

Flux density (ph/s/0.1%bw/mm²) of 19 keV photons at 10 m from the source, calculated with SRW.

Roughly 10% emittance reduction due to superbends.

B_y segmented model for BC (half)
Delta type undulator

- 1.3 T maximum magnetic field
- 1200 mm length
- 7 mm gap (diagonal)
- 20 mm period
Delta Type Undulator under Analysis

- Smoother K changes through phase
- Horizontal, Vertical and Circular x-ray polarizations on the same energy range
- e-beam focusing independent of K
Conclusion

• We don’t know if we will get all the money we need.

• We spend 3 years to produce around 200 magnets and now we have 1 year to procure 800 (challenging but possible).

• Build BPMs electronics at WEG as well.

• We are running as fast as possible to have a very competitive machine in the 1 to 7 KeV range.
Thank you