ThomX commissioning

Iryna Chaikovska (LAL) on behalf of the commissioning group

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Commissioning team

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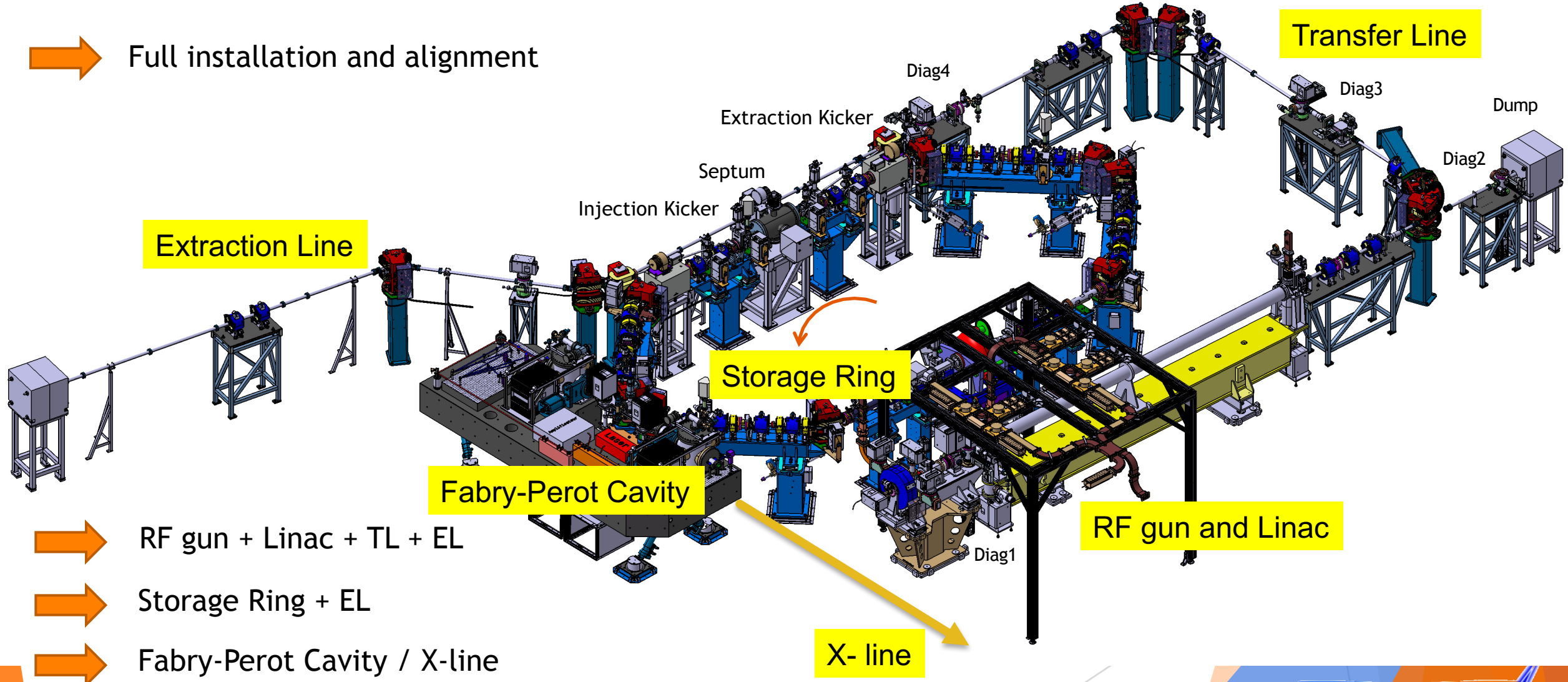
A. Loulergue (SOLEIL)

- RF gun + Linac + Transfer Line + Extraction Line => C. Bruni, S. Chance
- Storage Ring => I. Chaikovska, N. Delerue
- X-line => M. Jacquet, K. Dupraz

- Installation and alignment => D. Douillet
- RF Laser => V. Soskov
- Magnets => F. Marteau, C. Vallerand
- Pulsed Magnets => P. Alexandre, M. Omeich
- Linac RF => J-P Pollina, M. Omeich, M. El Khaldi
- Control system => P. Gauron
- SR RF and Feedback systems => M. El Khaldi, P. Marchand, R. Sreedharan
- Vacuum => B. Mercier
- Diagnostics => N. Hubert, N. Delerue
- Fabry-Perot cavity => R. Chiche, F. Zomer
- Synchronization => N. Delerue

Commissioning strategy

- Full installation and alignment



- RF gun + Linac + TL + EL
- Storage Ring + EL
- Fabry-Perot Cavity / X-line

Radiation protection aspects

- System of the Safety and Radioprotection (IRSD + IPNO): procedures started in **March 2017,** delivery/installation is expected **in Autumn 2017**.

- Authorization from **Autorité de Sûreté Nucléaire (**Nuclear Safety Authority) to operate the accelerator (a few years) but the agreement to start the commissioning should be obtained rapidly.

- Radiation protection system should ensure the commissioning with no special attention to the radiation levels.

Phase I of the commissioning

Phase I: The final assembly and the hardware testing (started/ongoing)

- Preparation of the hall for accelerator installation is ongoing: first girder (RF gun) is installed.
- To optimize the assembly => different components are preinstalled and prealigned in advance
  - The quadrupoles and sextupoles of the SR together with the vacuum chamber and the hardware will be mounted on 8 girders in Build. 208
- Testing of the different subsystems is ongoing.
- All the available equipment to be verified (including the magnet polarity, magnet cycling, power supplies, cabling, timing system, electronics etc.).
- The control system for most of the equipment is ready. To be integrated and validated on site. GUI to be developed and tested.
- The final tests for several subsystems will be performed with the beam.

Alignment works and accelerator installation have started in IGLEX in February 2017

Preinstallation and prealignment of the SR

8 girders of the SR are already preinstalled in Build. 208

Soon, the magnets will be mounted on the girders according to sorting procedure.

Commissioning: RF gun/Linac/TL/EL

Main steps:

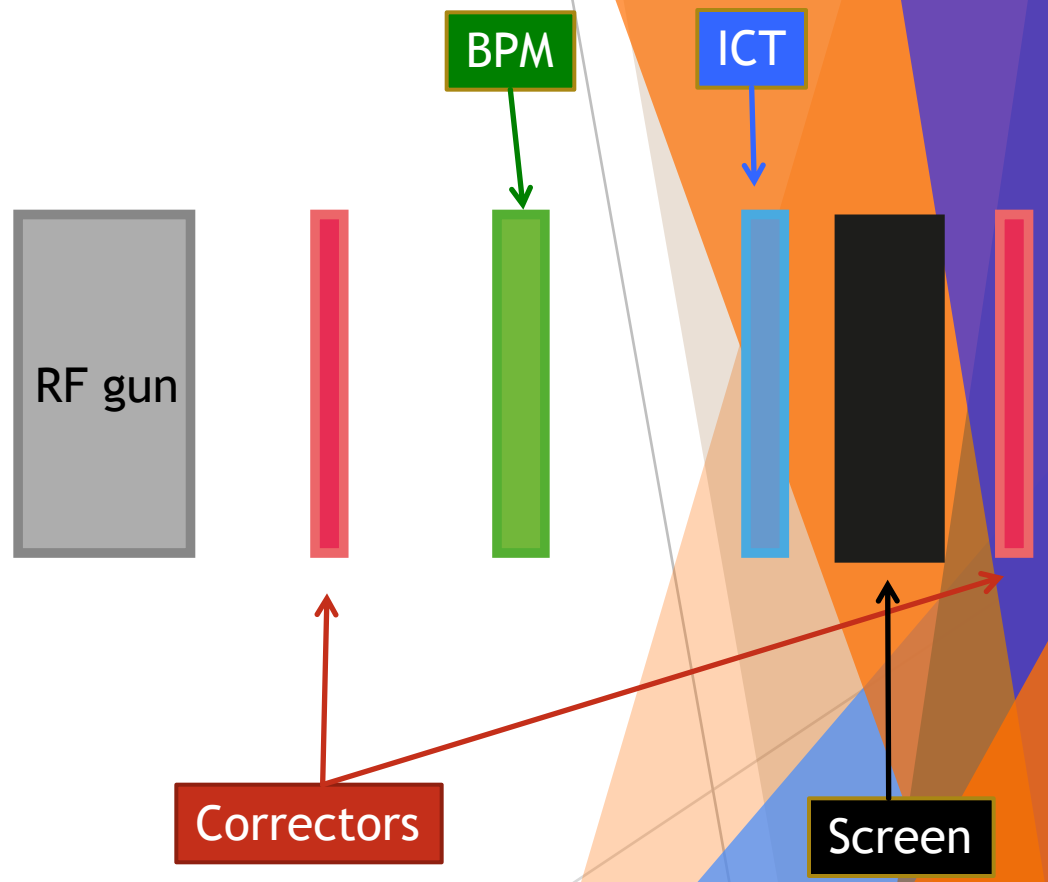
- Conditioning of the RF gun + Accelerating Section.
- Conditioning with the beam: Cu cathode (low repetition frequency 1-5 Hz)
  - Characterization of the cathode (charge measurements)
  - Characterization of the RF-gun (charge/phase, energy)
  - Characterization of the solenoids
  - Characterization of the LIL accelerating section + TL
- Nominal repetition frequency with the Cu cathode (~100 pC) => SR commissioning.
- Mg cathode (low repetition frequency): low charge/nominal charge.
- Nominal repetition frequency with the Mg cathode: low charge/nominal charge.

Expected to start in the beginning of 2018

Commissioning: RF gun/Linac/TL/EL

Characterization of the cathode, RF gun and solenoids:

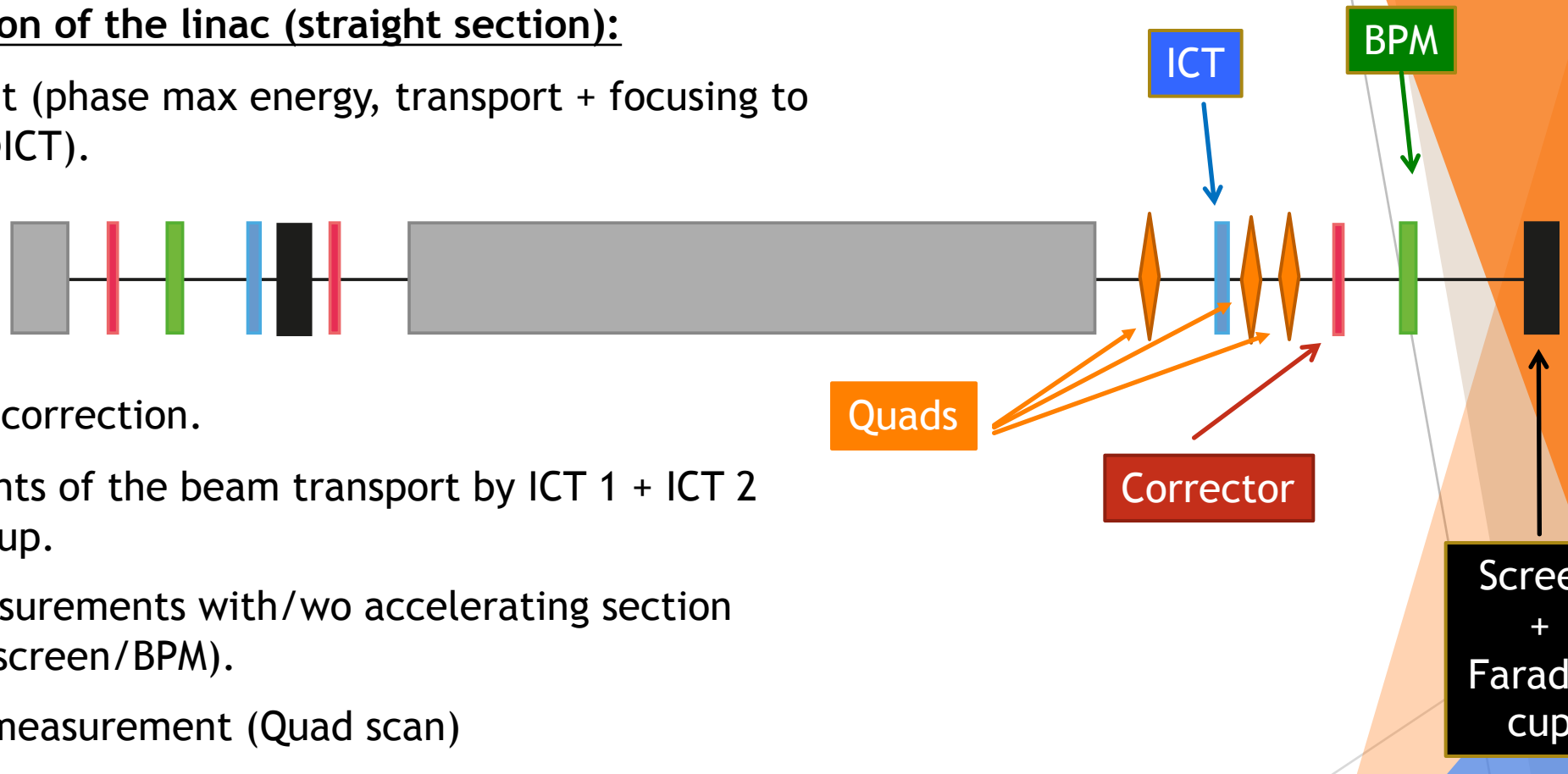
- Dark current measurements (ICT1).
- Laser beam measurements/laser alignment.
- Charge vs. phase measurements (ICT1).
- Beam energy measurements @RF gun exit (corrector, screen/BPM).
- Working point (phase max energy, charge ~30 pC, beam@screen) => solenoid alignment with the beam.
- Characterization of the solenoids (beam size measurements vs. solenoid field.



Commissioning: RF gun/Linac/TL/EL

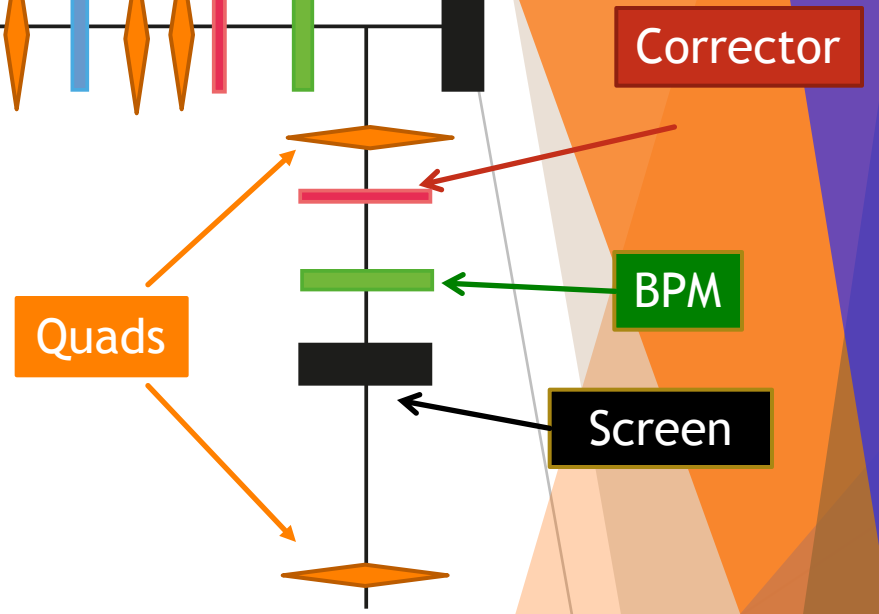
Characterization of the linac (straight section):

- Working point (phase max energy, transport + focusing to see the beam@ICT).



- Orbit/orbit correction.
- Measurements of the beam transport by ICT 1 + ICT 2 + Faraday cup.
- Energy measurements with/wo accelerating section (corrector, screen/BPM).
- Emittance measurement (Quad scan)
  - Optimization of the solenoid working point
  - Twiss parameters.

Commissioning: RF gun/Linac/TL/EL



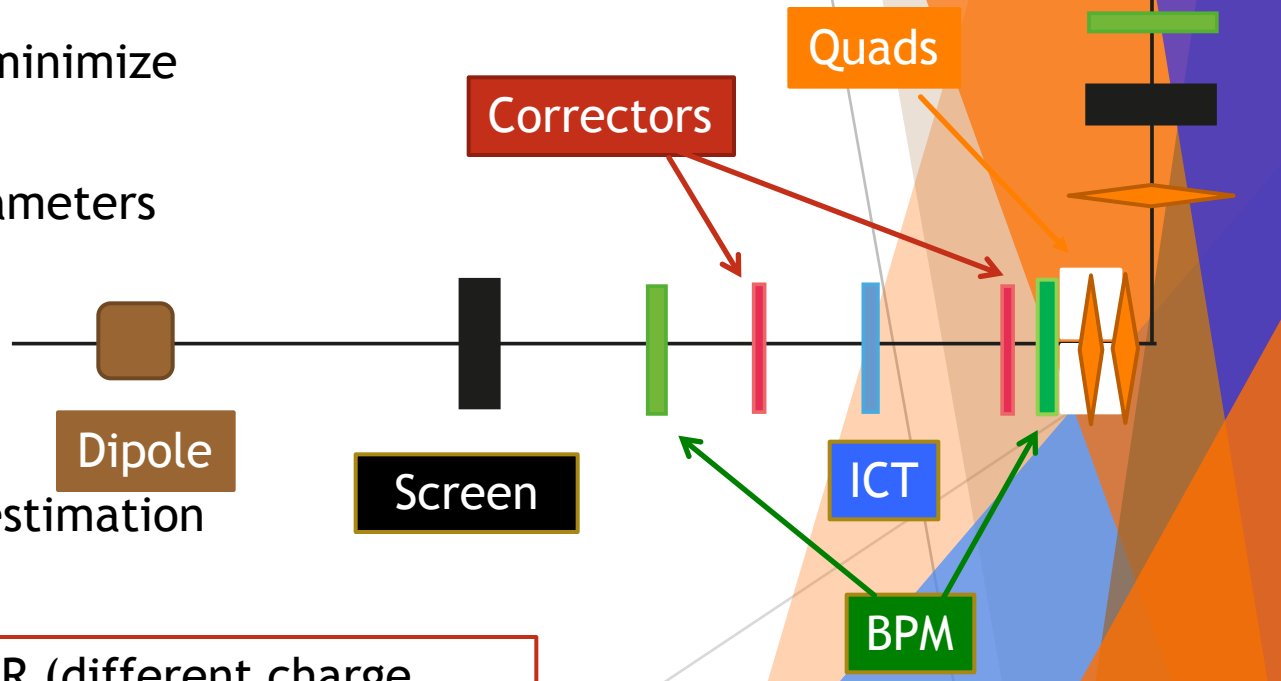
Characterization of the linac (bend section 1):

- Working point (phase max energy, solenoid field to minimize the emittance, beam@screen).
- Tune the beam transport according to the Twiss parameters found before to focus the beam @Dipole entrance.
- Measurement of the beam energy and energy spread.
- Estimation of the bunch length with the 3 phase method.
- Measurement of the dispersion function (LIL section with the BPM).

Commissioning: RF gun/Linac/TL/EL

Characterization of the linac (bend section 2):

- Working point (phase max energy, solenoid field to minimize the emittance)
- Tune the beam transport according to the Twiss parameters found before to inject into the SR
- Orbit/orbit correction
- Measurements of the beam transport along TL (ICT)
- Emittance and Twiss parameters measurements => estimation of the emittance degradation.

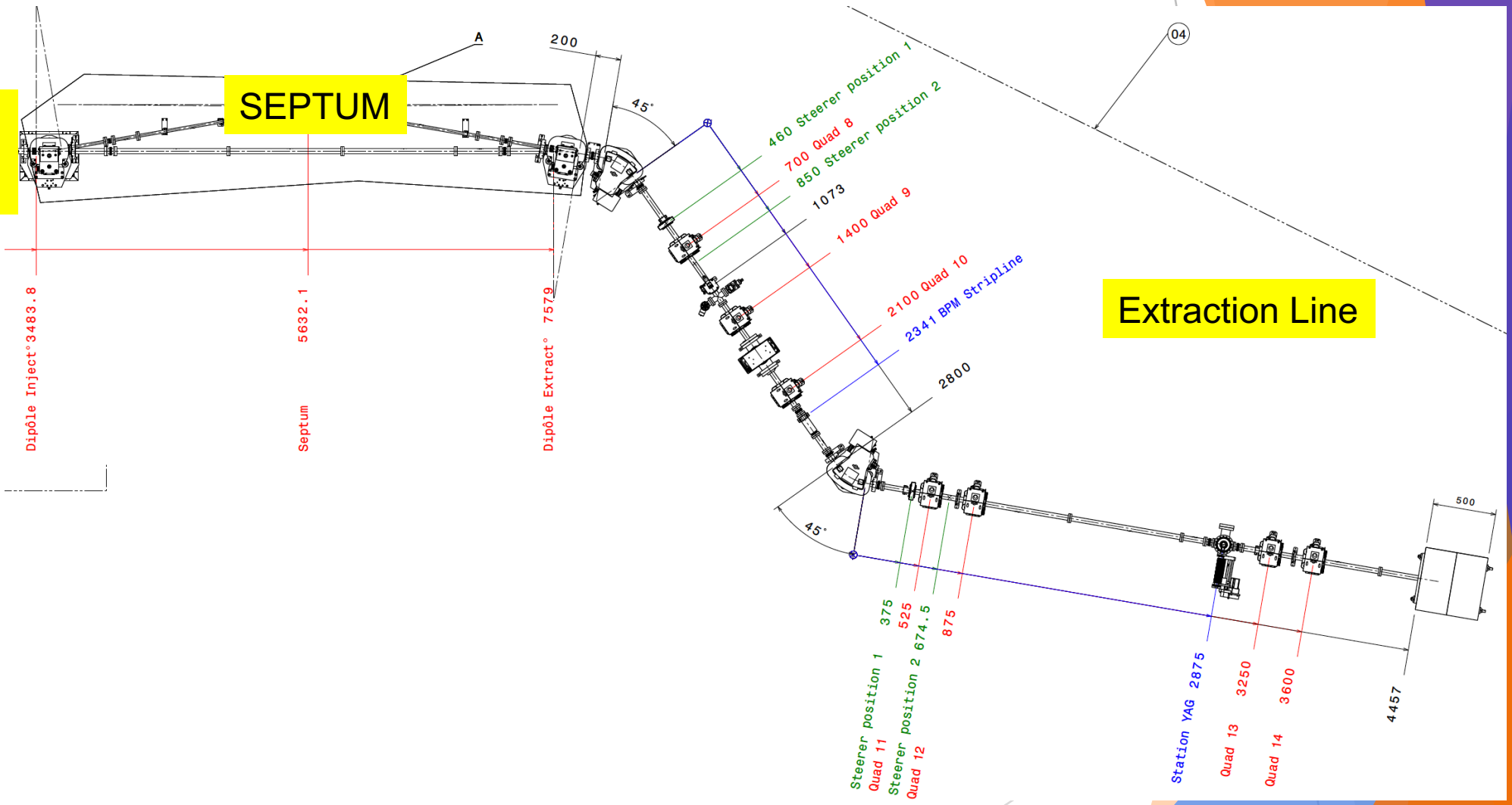


Preparation of the different working points for the SR (different charge, energy, energy spread, emittance) => commissioning of the SR can start.

Commissioning: RF gun/Linac/TL/EL

End of the Transfer Line

SEPTUM



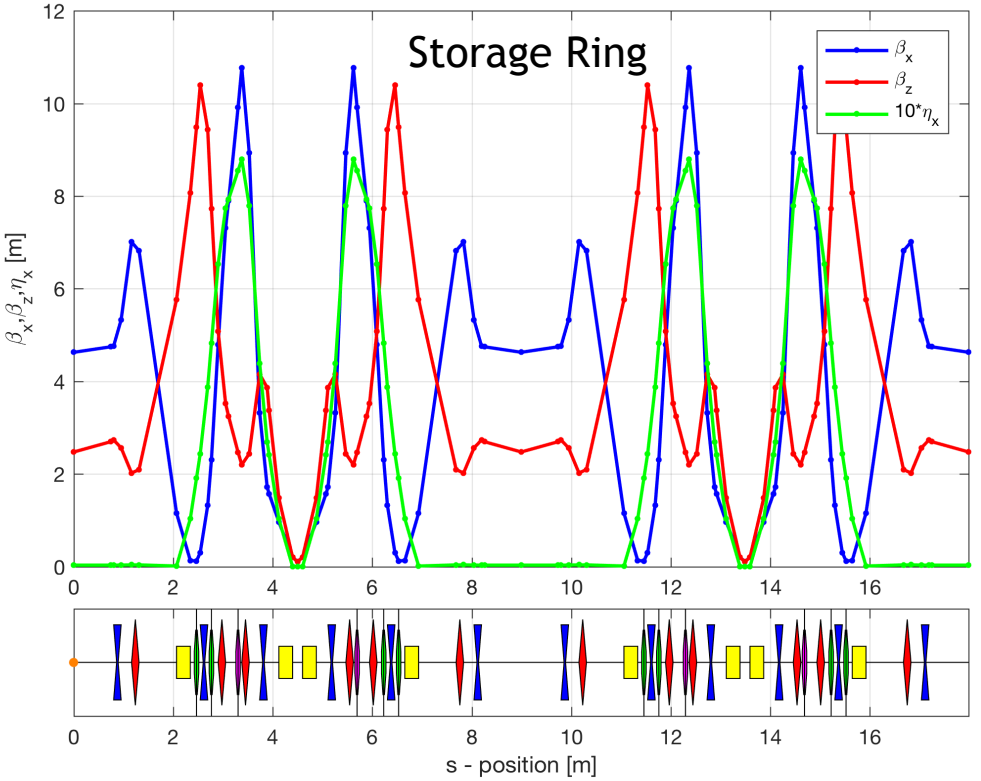
Extraction Line

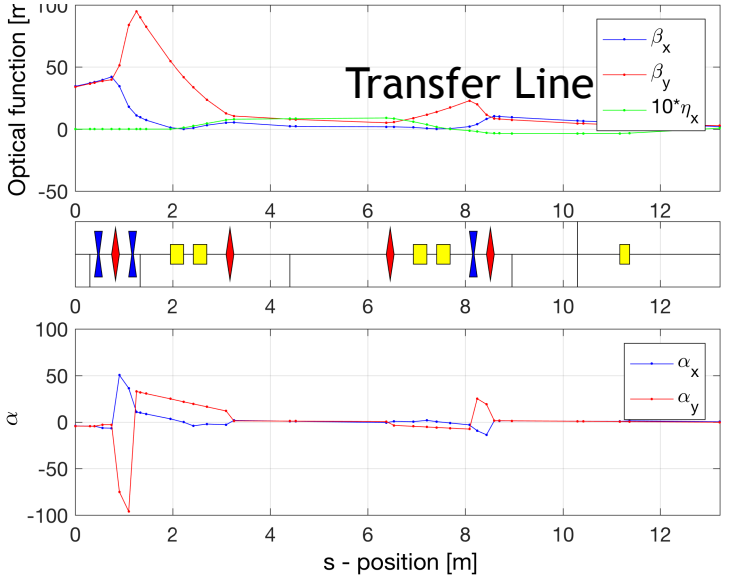
Commissioning: Storage Ring

ThomX SR: L = 18 m, T = 60 ns, Frep = 16.7 MHz

- 8 Dipoles
- 24 Quadrupoles
- 12 Sextupoles
- 2 Kickers
- 1 Septum
- 1 RF cavity
- 12 BPM
- 12 Correctors

Parameter	Value/Units
Beam energy	50-70 MeV
Bunch Charge	1 nC
Bunch length (rms)	20-30 ps
Circumference	18 m
Revolution frequency	16.7 MHz
Current	16.7 mA
RF frequency/Harmonics	500 MHz /30
Momentum compaction	0.0125 - 0.025
Betatron tunes	3.17/1.64
Natural chromaticity	-2.6/-5.7
Damping time trans./long.	4/1.8 s
Repetition frequency	50 Hz
Beam size at the IP	70 µm
RF Voltage/cavity	300 kV (500 kV max)
Energy loss per turn	1.57 eV (synchro)





Commissioning strategy: Storage Ring

ThomX SR operation: low energy, high bunch charge, collective effects/instabilities, absence of the synchrotron damping, short lifetime => commissioning is a challenge.

- **Single particle beam dynamics: <u>lower charge</u>**
  - Linear dynamics (optical functions, working point, closed orbit…)
  - Nonlinear dynamics (chromaticities, tune shift with amplitude/momentum deviation, dynamic aperture, momentum acceptance…).

- **Multi particle beam dynamics (collective effects): <u>nominal charge</u>**
  - Coherent Synchrotron Radiation (CSR)
  - IntraBeam Scattering (IBS)
  - Ion instabilities
  - …

Commissioning: Storage Ring

- Phase I The final assembly and the hardware testing (started/ongoing).
- Phase II Goal: obtain stored beam of sufficient quality.
- Phase III Goal: reach the SR design parameters.
- Phase IV Goal: operate with the Fabry-Perot cavity and test the X-ray production
  - Optimization of the Interaction Point => X-ray production.

When phases I - IV are finished the beam commissioning is over

Subsequent work on the SR will be focused on the further optimization, beam dynamics studies and optimization of the X-ray production.

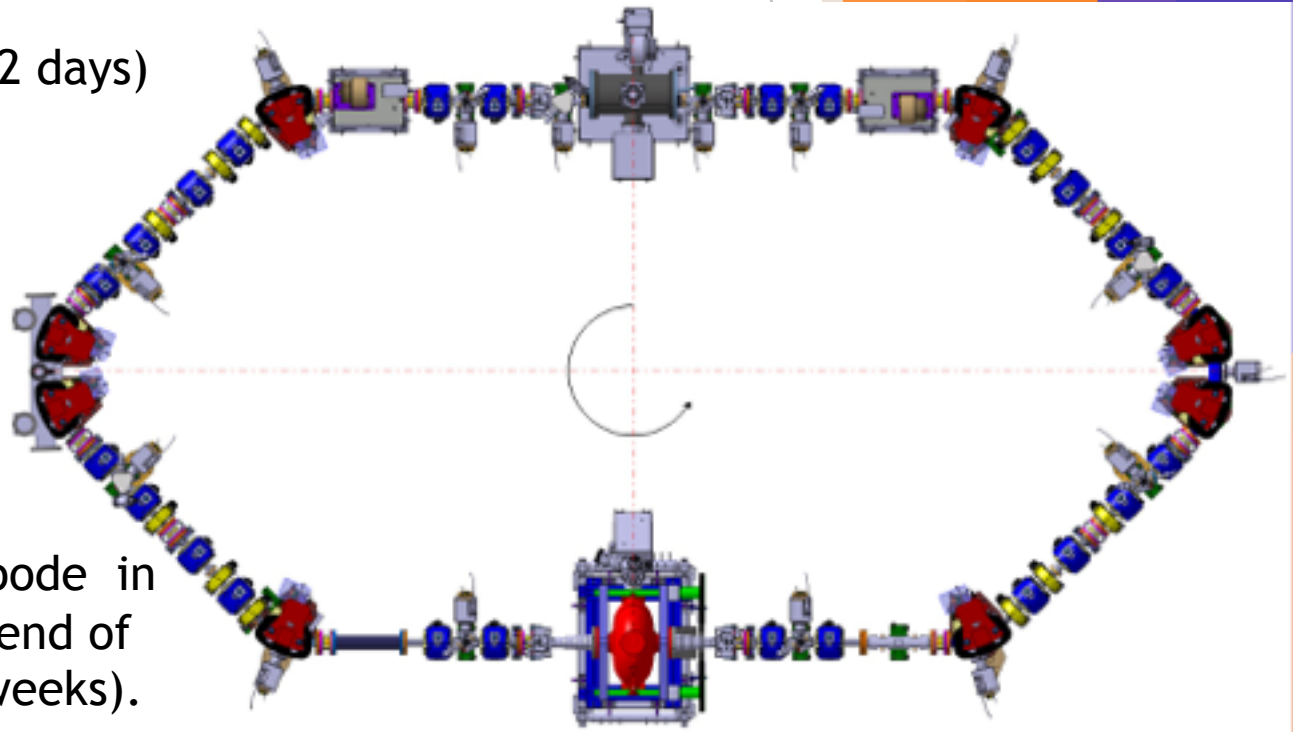
SR commissioning: subsystem status

- Installation is completed, alignment checked shortly before commissioning
- Injector (linac + TL + EL) is commissioned
- Injection/extraction system (septum + kickers) is tested
- Synchronization system is implemented and tested
- Radiation protection and safety systems are fully implemented
- Magnets are installed and checked (PS control, polarity…)
- Technical interlocks are tested
- Vacuum ideally 10^{-10} mbar
- RF cavity is conditioned
- Feedback systems are installed and tested
- All beam diagnostics are installed and tested
- All functionality tests are completed
- Control system is fully implemented and tested
- All applications are developed for the commissioning.

SR commissioning: subsystem status

After the first survey concerning the different subsystems of the SR, estimate for the time needed to make the subsystem work after its installation:

- Diagnostics: BPM (~4 days), MRSV (~2 days), BLM (~2 days)
- Vacuum: 2 months
- Magnets: ~2 days
- Pulsed Magnets: in progress
- Synchronization: 3 days
- RF + Feedback: 3 weeks
- Fabry-Perot Cavity: whole installation on the hexapode in the laser room => moving the whole system at the end of Phase II or Phase III to the accelerator hall (a few weeks).
- X- line can be commissioned w/o beam at the same time as FPC.

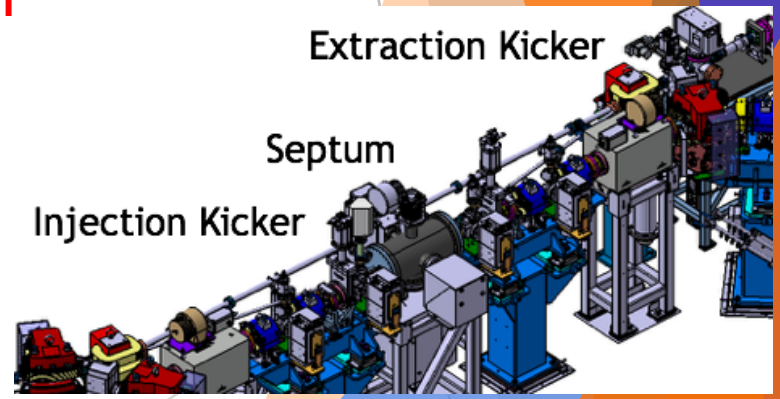


Phase II: expected to start in the beginning of 2018 (spring ?)

Commissioning: SR (Injection)

To ensure the SR commissioning the injector must deliver the beam with the sufficient quality (**energy, charge**, emittance, energy spread).

- To start => lower bunch charge (< 200 pC) and lower injection frequency (~1 Hz) => beam lifetime ⬆ and the impact of the collective effects ⬇.
- The injection will be done using the standard septum and one fast kicker set-up => single-turn on-axis injection.
- **Conditions:** quadrupoles + sextupoles + RF system are OFF. Extraction kicker is OFF. Dipoles are ON.
- The dipoles will be cycled to the same current as the TL dipoles.
- Scan of the septum and injection kicker voltage and timing.
- Diagnostics: BPM signal (sum of all electrodes) and orbit, BLM.
- **Result:** the beam is injected on-axis.



Commissioning: SR (First Turns)

- **Conditions:** sextupoles + RF system are OFF. Extraction kicker is OFF. Quadrupoles and dipoles are ON (cycled to a good energy).
- Turn-by-turn analysis on ~100 turns
  - Measurement of the integer part of the tune
  - First measurements of the tune and first orbit and orbit correction
  - By tuning the septum/kicker try to steer the beam and so decrease the betatron oscillations (BPM signal).
- Without RF system => bunch lengthening => the BPM signal becomes weaker (BPM signal sum goes to 0 after ~500 turns).
- Sextupoles are ON and set to fraction of the nominal fields (10% …100%)
  - Checking the injection with the sextupoles ON
  - First chromaticity measurements by varying the linac energy only.
- **Result:** the tune, orbit and chromaticity are measured on the first turns.

Commissioning: SR (Stored Beam, Extraction)

- **Conditions:** quadrupoles + sextupoles + RF system are ON. Extraction kicker is OFF.
- Optimization of the RF frequency, voltage and phase to store the beam circulated for larger number of turns (1000 and more).
- Good response of the BPM.
  - More precise measurements of the beam tune, orbit, chromaticity
  - Chromaticity and ORM measurements => test of the SR model.
- Scan of the tune/chromaticity vs. storage performance (number of turns).
- Test of the extraction system (septum + extraction kicker ON)=> beam sent to the dump.
- Test of the higher injection frequency.
- **Result:** beam storage. Tune, orbit, chromaticity are well defined. Full injection@50 Hz.

Beam based hardware and software checkouts, optimization and debugging of the high level control applications.

Commissioning: SR (Machine Physics/IP optimization)

- **With beam stored in the SR**
  - ORM measurements => LOCO (beam optics, SR model/real machine calibration)
  - Test of the RF voltage up to 300 kV
  - Measurements of the beta function and dispersion
  - Measurements of the bunch length (streak camera) + beam size/emittance (SRM)
  - Beam dynamics studies, BBA...
- Test of the higher charge ~ 1 nC. Possibility to employ different optics (higher momentum compaction) => the impact of the collective effects ⬇.
- Tuning the injection + test of the feedback systems with the nominal charge.
- **Conditions:** Fabry-Perot cavity is commissioned and the laser is ON, the repetition frequency is set to 50 Hz, bunch charge 1 nC.
  - Position and phase scan => optimization of the Interaction Point.
- **Result:** Full injection at 50 Hz, 1 nC of beam charge, IP is optimized. X-ray production.

Phase IV of the commissioning is finished!

Control system

- The ThomX control system is based on Tango.
- Different Tango Device Servers essential for the commissioning (e.g. BPM, magnets PS) are currently under the test.
- Control applications for commissioning and operation to be developed (control windows for different subsystems, status windows…).
- High level application to perform the physics measurements are under development by using the Matlab Middle Layer (MML) adapted from SOLEIL.
- An electronic logbook will be set up to record commissioning results (shift staff, shift agenda, operation details and summary). The prototype of the e-logbook is under the test now.

Example of the Applications

>> gev2bend(0.05) = 159.2996 A

>> bend2gev(300) = 0.077 GeV

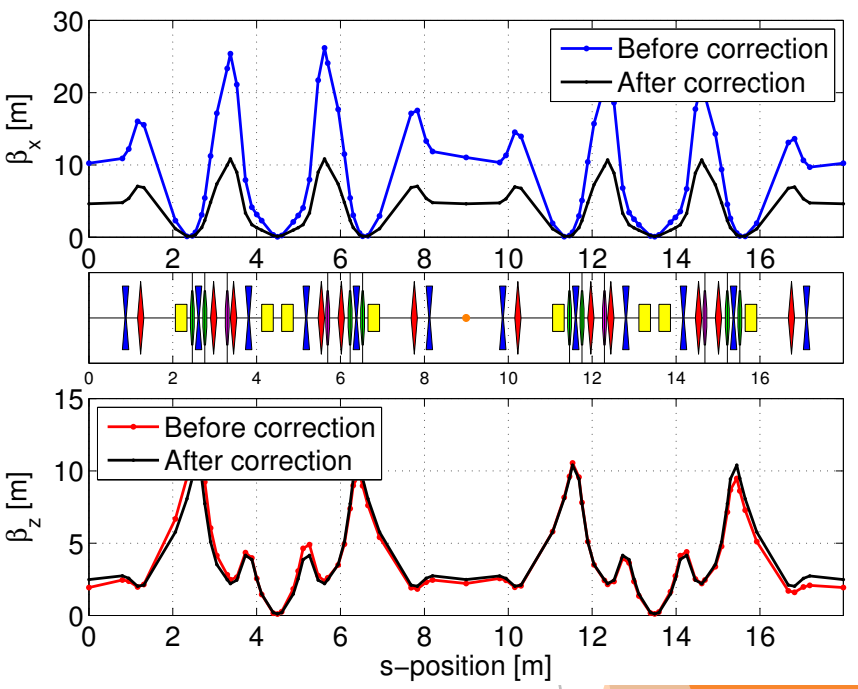
>> k2amp('QP2','Monitor', 9.9755,[1 2], 0.05) = 3.2596 A

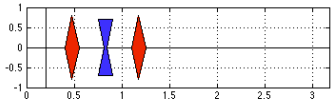
>> amp2k('QP2','Monitor',12,[1 2], 0.05)=35.2716 1/m^2

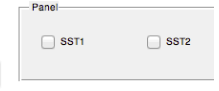
Example of the Applications

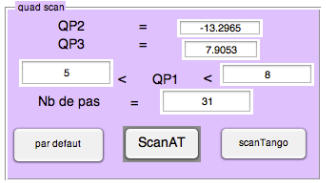
- Save/Restore the machine configuration
- First turns applications
- BPM test programs
- Orbit correction
- Optical functions measurement
- Tune display and control
- ORM measurements
- Chromaticity measurement
- Injection matching
- Magnet cycling
- Lattice symmetry restoration (LOCO)
- Emittance measurement
- BBA

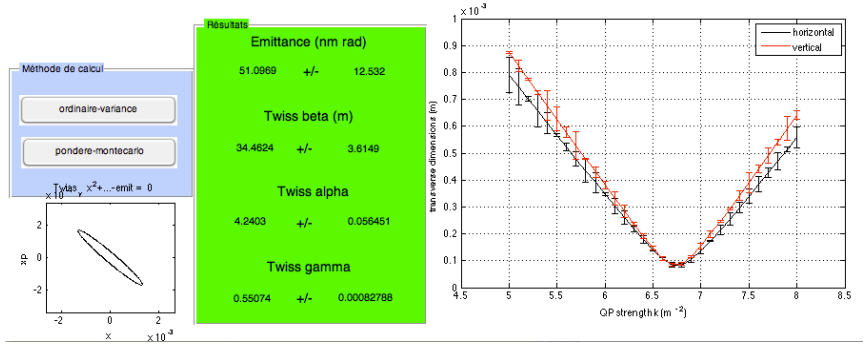
- Closed orbit bumps
- Analysis of nonlinearities
- Analysis of the collective effects
- …

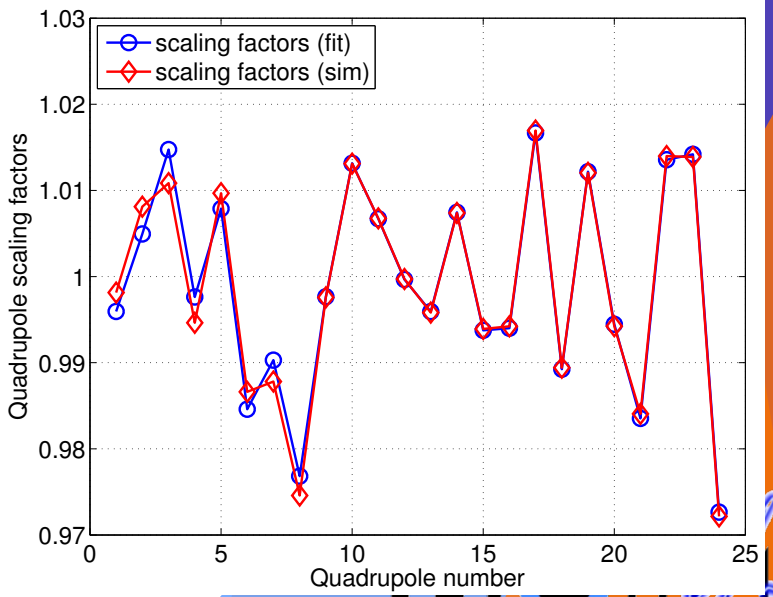












Specific issues

- Injector commissioning (RF gun + Linac + TL + EL): a good knowledge of the photoinjectors (PHIL) @LAL together with the SOLEIL expertize on the Linac commissioning (LIL section).
- Some components are common to both TL and SR => benefit from the experience gained during the TL commissioning.
- The SR commissioning will face with many challenges
  - high particle density and low energy
  - mismatched beam injection and absence of the synchrotron damping
  - nonlinear beam dynamics + collective effects
  - limited beam storage
  - need for the precision and stability in the Interaction Region.
- Strong interaction with the SOLEIL team.

Time plan and organization

- The commissioning with beam => **start in the beginning of 2018 (end of 2017 ?)**.
- While waiting for the authorization (Safety and Radioprotection) => **Phase I of the commissioning** (full installation, alignment and the hardware testing phase)
  - Several tests of the control system
  - Setting and testing of the MML configuration/control of the devices
  - Testing of the different hardware on-site with its control system
  - Test of the applications/GUI for commissioning.
- Organization of the commissioning:
  - The shift schedules (only the working hours are foreseen at the moment)
  - The shift team composition
  - Intervention team
  - Communication and meeting organization (daily/weekly meetings).

Perspectives

- The commissioning preparation work will continue in close collaboration with the control system team (**Phase I of the commissioning**).
- Meetings: continue the monthly **meetings (Commissioning)** + twice a month **(Technical Commissioning)**.
- The documentation for the commissioning (**commissioning plan** + **beam dynamics measurements with procedures** + **beam dynamics in the SR**) under the preparation.
- **End of the ANR EQUIPEX** program in **December 2019** => according to the current planning/timing, the **commissioning of the ThomX** should be **finished by then**.