Commissioning of the Thomx SR

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on behalf of the commissioning group

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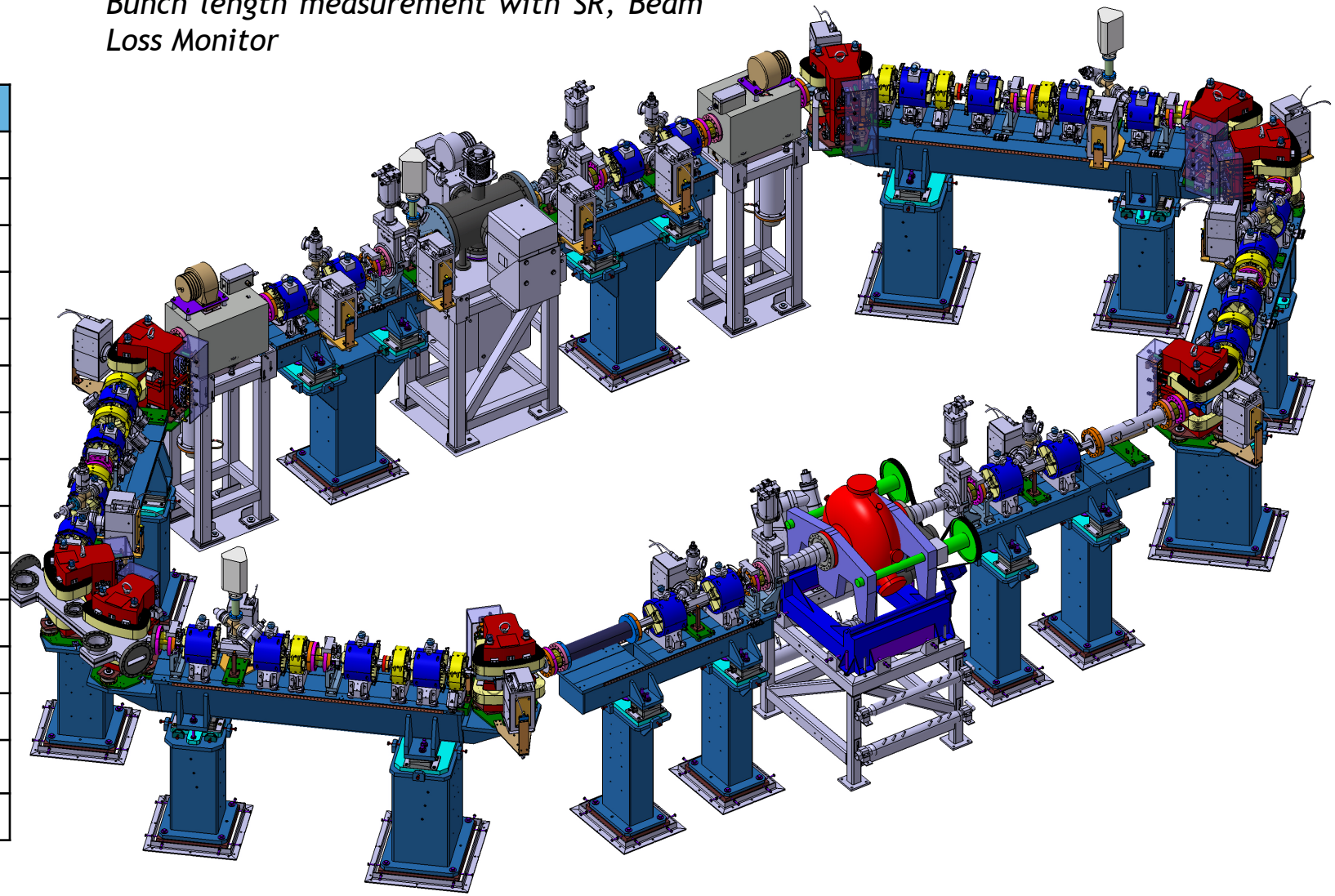
- 1 Septum
- 2 Kickers
- 1 RF cavity
- 12 BPM
- 8 Dipoles
- 24 Quadrupoles
- 12 Sextupoles
- 12 Correctors

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

<u>Diagnostics:</u> 12 BPMs, Moniteur de Rayonnement Synchrotron Visible (MRSV), Bunch length measurement with SR, Beam Loss Monitor

Parameter	Value/Units
Beam energy	50-70 MeV
Bunch Charge	1 nC
Bunch length (rms)	30-40 ps
Circumference	18 m
Revolution frequency	16.7 MHz
Current	16.7 mA
RF frequency/Harmonics	500/30 MHz
Momentum compaction	0.0125 - 0.025
Betatron tunes	3.17/1.64
Natural chromaticity	-9/-13
Damping time trans./long.	1/0.5 s
Repetition frequency	50 Hz
Beam size at the IP	~70 μm
Nominal RF Voltage/cavity	300 kV (500 kV max)
Energy loss per turn	1.57 eV



ThomX commissioning stages

Stage	Objective	Beam Energy	Charge	Frep	Bunch Length	Energy Spread	Emittance	X-ray Energy	X-ray Flux
HC	**Hardware commissioning**								
TC	**Technical commissioning**								
	Beam commissioning (BC)								
A	**Injector commissioning**								
	RF gun + Linac	50 MeV	10→100 pC	0→10Hz	2-8 ps	0.2-0.4 %	~3 µm rad		
	RF gun + Linac + TL + EL	50 MeV	10→100 pC	0→10Hz	2-8 ps	0.2-0.4 %	~5 µm rad		
B	**Ring commissioning**								
	First turns + stored beam	50 MeV	10→100 pC	0→10Hz	2-8 ps (inj)	0.2-0.4 % (inj)	~5 µm rad (inj)		
C	**FPC commissioning + first X-rays**								
	Optimization of the IP	50 MeV	10→100 pC	0→10/50Hz	2-8 ps (inj)	0.2-0.4 % (inj)	~5 µm rad (inj)	45 keV max	10^{9}-10^{10} ph/s (@100kW)
D	**Commissioning at nominal charge** RF gun + Linac + TL + EL + SR	50 MeV	1 nC	0→50Hz	2-8 ps (inj		LI: 5 µm rad RI: 7-8 µm rad	45 keV max	10^{11}-10^{13} ph/s (@500kW)
E	**X-ray production towards nominal operation**								
	Increasing X-ray flux to nominal	50 MeV	1 nC	50Hz	2-8 ps (inj		7-8 µm rad	45 keV max	~10^{13} ph/s (@500kW)
F	**Commissioning and operation at 70 MeV**	70 MeV	1 nC	0→50Hz	2-8 ps (inj			90 keV max	~10^{13} ph/s (@500kW)

Ring commissioning strategy

Distinguish two forms of commissioning

- **Hardware Commissioning/ Technical Commissioning**
  - Acceptance tests of the equipment and functional checks (including control system)
  - Done during initial commissioning and as part of the 'machine checkout' after technical stops
- **Commissioning with Beam**
  - Inject, thread, store and extract
  - Commissioning of beam-dependent equipment

Hardware / Technical Commissioning (checklist)

Ongoing now

- Installation is completed, alignment checked shortly before commissioning
- 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 Ring beam diagnostics are installed and tested
- All functionality tests are completed
- Control system is fully implemented and tested
- …

Can start the Beam Commissioning

Ring commissioning with beam (phases)

Phase	Description
B.1	Injection and first turn: injection commissioning, threading, commissioning beam instrumentation
B.2	Establish circulating beam: closed orbit, orbit correction, tunes, chromaticity
B.3	Stored beam and extraction: precise measurements, BBA, feedback systems, beam diagnostics (SRM)
B.4	Machine physics: LOCO, beta beating, beta function and dispersion, diagnostics, beam dynamics studies

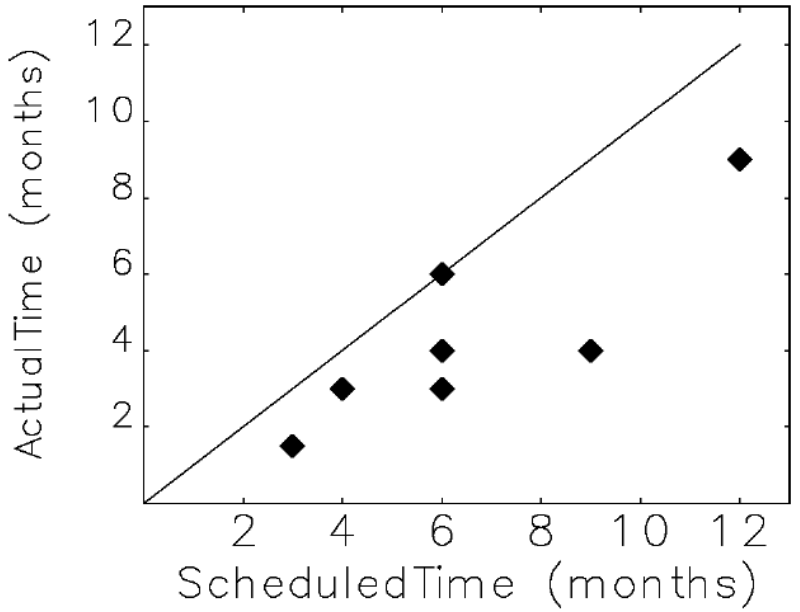
Phase	Description
C.1	Operation with FPC and IP optimization: position and phase scan
D.1	Ring commissioning at nominal charge: injection tuning and feedback test at the nominal charge, higher α_p optics
F.1	Ring commissioning at 70 MeV: repeat the necessary commissioning steps (phase B)

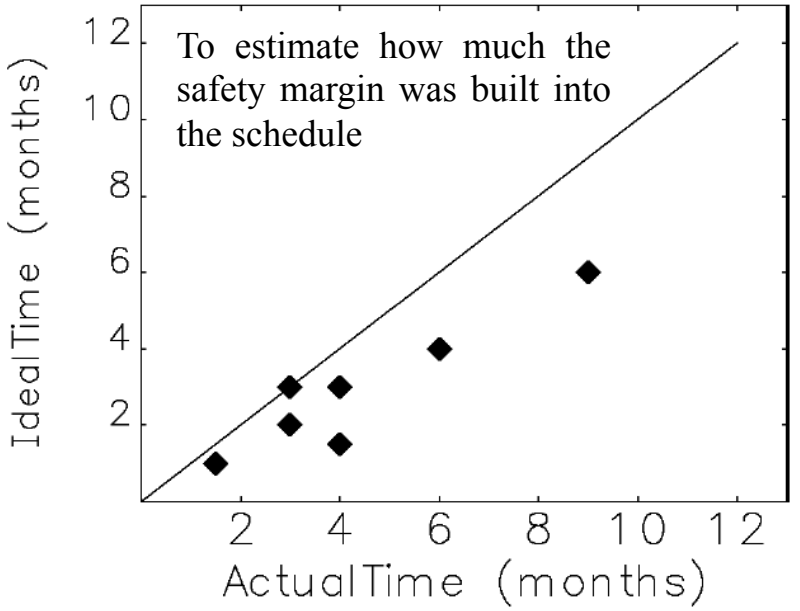
Duration of the SR commissioning

According to the survey
(ALBA, BESSY-II, DLS, PLS-II, SOLEIL, SSRF, SPEAR3)

M. Borland et al., Survey of Commissioning of Recent Storage Ring Light Sources, IPAC15

- Scheduled duration ranged between 4 and 12 months
- Five of seven responding facilities thought commissioning could be done in **3 months** or less
- Mostly 24/7, but with interruptions for repairs/installation in some cases





Duration of the SR commissioning =>ThomX

- Difficult to scale:
  - Operation from 8h45 to 17h45 (LAL opening hours) 4 days a week.
  - Operation will be carried out by blocks of 3 weeks followed by 1 week of scheduled maintenance.
  - Reduced manpower compared to other facilities.
- **ThomX SR commissioning duration => 60 weeks (240 days)**

Integrated to the planning presented by Hugues

- **Accelerator operation outside the LAL working hours? Shifts during the night ?**

Subsystems for the SR

Subsystem code	Subsystem	Person in charge
AE/PS	Magnetic Element/Power Supply	C. Vallerand, JN Cayla
AM	Alignement/Metrology Mécanique/integration	D. Douillet, R. Marie
CA	Control Acquisition	F. Wicek
CC	Control Command	P. Gauron, H. Guler
DG	Diagnostic	N. Delerue, I. Chaikovska
HFI	FH Igloo	M. El Khaldi, JN Cayla
CFP	FP cavity	R. Chiche, D. Nutarelli
PE	Pulsed Element	M. Omeich
RF	Radio Frequence 500 MHz	M. El Khaldi, JN Cayla
SY	Synchronisation	N. Delerue, V. Chaumat
VA	Vacuum	B. Mercier, F. Letellier
INS	Instrumentation	F. Wicek
INX	Interconnexion	M. Pichet
MPS	Machine protection	N. El Kamchi

Subsystem	Requested for start-up	Day 1	Phase B.1 (injection + 1st turn)	Status	Remains to be done
AM: Installation and Alignment	Survey of the SR with mechanical tolerances	Survey of the SR with mechanical tolerances as input for the simulations	idem	OK! Installation of the bellows, preliminary alignment is done	Installation Kicker/Septum, FPC, FBT, final alignement **Ready:** 2 weeks after the baking out of the vacuum chambers
AE/PS Magnets and Power Supplies	Magnets/PS and polarity are connected and checked. Control system is ready and checked.	Read/write the current SP. Magnet cycling.	idem	Under the test! Hydraulic connections, cooling of the dipoles.	Test of the power supplies, polarity tests, cycling for the magnets (dipoles and quadrupoles). **Ready:** February 2020
SY Synchronization	Trigger distributed to the pulsed elements and diagnostics, delay setting. Control for the RF cavity.	Trigger delays. Trigger on demand. Operation up to 10Hz.	idem	OK! System is deployed for whole machine, trigger board v2 is under the test, GUI under the test.	Jitter value ~ a few ns with trigger board v1 to be improved with trigger board v2 (~ 100 ps RMS) **Ready:** end of 2019
VA Vacuum system	Baked vacuum chambers. Vacuum level ~1e-9 mbar. Control of the valves, ion pumps, vacuum gauges	Valves open, gauges pressure reading.	idem	OK! SR chambers are ready. Baking out will be done after SR installation.	Vacuum data archiving (CC) **Ready:** 1.5 month after closing the ring.
DG Diagnostics	BPM configured (SP/TbT mode) and checked. BLM is set up and checked	Operational Ring BPM: sum signal and hor./vert. orbit in SP mode. Available BLM signals.	Operational Ring BPM and BLM (first estimation of the loss location.)	OK! Test of the BPM, development/tests of the GUI for the BLM, installation of the MRSV.	Diag DS for the Ring, install the BLM after the baking out of the vacuum chambers, optical transport line alignment for pulse length measurement . **Ready:** January/February 2020

Subsystem	Requested for start-up	Day 1	Phase B.1 (injection + 1st turn)	Status	Remains to be done
PE Pulsed magnets	Kickers and septum are tested. Control system is ready and checked.	Read/write the septum and injection kicker voltage and timing	idem	**Ongoing!** UHV cleaning of the septum elements	Assembly of the kicker pulser racks. Delivery of the kicker VC with additional layer of TiN: mi-December 2019 (after final magnetic measurements and UHV tests). Reassembling the magnet to a septum, UHV tests: mi-December 2019 to mi-January 2020. **Ready:** March 2020
HFI/RF RF cavity and power supply	RF cavity is conditioned and tested. Control system is ready and checked (control of the phase, frequency and voltage).	None. Needed for B.2 phase	None. Needed for B.2 phase	**OK!** Test of the cooling rack	Cavity tuning wrt to HOM, installation of the waveguide (amplifier-cavity) after septum installation, functional tests and debugging using RF PLC and Tango DS (under configuration now), GUI, RF conditioning of the cavity **Ready:** ASN + Septum installed + 2 months, FBT/electronics => summer 2020
CC Control System	Concerned DS are running, Tango operating smoothly	Concerned GUI/Apps tested on the machine	Concerned GUI/Apps tested on the machine	**OK!** Deployment of the DS for magnet cycling	DS configuration and validation tests for the RF system, pulsed magnets, main status window, RingDiagManager, TuneMeasurement, archiving.

Specific issues

- 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.
- **Operation of the Storage Rings => new expertise @ LAL, lost since a few decades => excellent investment in future!**
- **Strong interaction with the SOLEIL team during the commissioning.**

Summary

- **Up to now:** “Hardware / Technical Commissioning”: ring installation, testing of the different subsystems, functional tests, control system; high-level applications, GUI…

- **Critical steps:** authorization from ASN, additional delays by the PE, cooling of the dipoles.

- **To be addressed (*essential for start-up*):** final tests of hardware control system, BPM calibration, magnet polarity, GUI, high-level applications, archiving.

Systèmes kickers :

- Aimants kickers reçus de SigmaPhi (fév. 2019).
- Ensembles aimants & pulsers définitifs (*alimentations pulsées*) testés avec succès aux valeurs nominales & maximales. Forme d'onde des impulsions de champ magnétique de déviation conforme aux spécifications et dimensionnements. Mesures magnétiques préliminaires conformes.
- Chambres à vide des kickers : 3 non-conformités :
  - Résistivité dépôt TiN trop élevée.
  - Longueur bride à bride trop grande.
  - Défaut de coplanarité des flasques.
  - Des solutions ont été mises en œuvre pour corriger ces défauts.
- Spécifications techniques du contrôle-commande à finaliser : interface baies EP & PLC de contrôle.

Système septum passif :

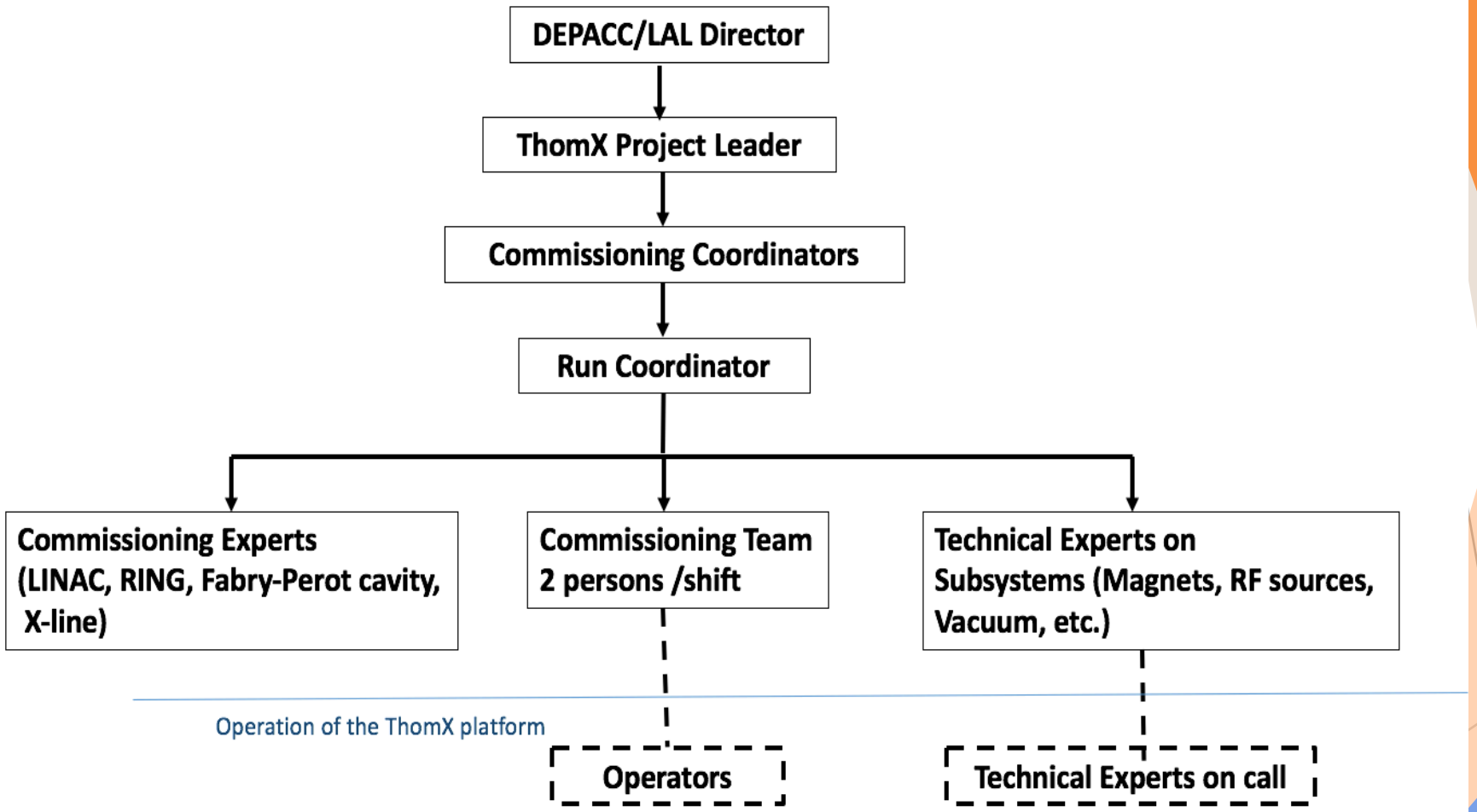
- Système complet (aimant sous ultravide + enceinte & châssis + pulser + câble) reçus de SigmaPhi fin juin 2019.
- Aimant & pulser validés (mesures magnétiques & électriques réalisées par SigmaPhi).
- Pollution ultravide de l'aimant & de l'enceinte:
  - Nuance de PEEK non conforme.
  - Propreté non conforme de certaines pièces.
  - Doute sur la nuance de cuivre sur une pièce.
  - Solutions mises en œuvre :
    - Etuvage haute température de l'enceinte.
    - Démontage de l'aimant et réexpédition à SigmaPhi pour nettoyage UHV.
    - Nettoyage de certaines à pièces à SOLEIL.

Planning :

- Fin d'assemblage des 2 baies de pulser des kickers : mi-décembre 2019 (avec alimentations HT reçues).
- Réception chambres à vides kickers avec dépôt TiN supplémentaire : mi-décembre 2019 (puis mesures magnétiques définitives & tests UHV).
- Remontage aimant à septum passif puis tests UHV : mi-décembre 2019 à mi-janvier 2020.
- Installation sur ThomX : mi-janvier 2020 au plus tôt.
  - Installation des aimants en parallèle de l'installation & câblage des baies de pulsers.
  - Métrologie préalable des chambres et châssis.
  - Etuvage in situ.
- Tests de mise en service : février 2020.

P. Alexandre

Commissioning chart/manpower



The commissioning will require the involvement of accelerator physicists, the experts on the technical components (subsystems) and technical support.

Phase B.1 short example (Injection and first turn)

Short description of what should be achieved

The injection will be done using the standard septum and one fast kicker set-up => single-turn on-axis injection. Once, the beam is injected, by tuning the correctors try to thread the beam and close the first turn.

Entry and Exit conditions

Entry: Injector delivers the beam with the sufficient quality (energy, charge, emittance, energy spread) + Injection matching

Exit: the beam is injected on-axis. The beam is steered through the whole ring for first turn.

Machine setup

Quadrupoles, sextupoles, RF system, extraction kicker are OFF. Dipoles are ON.

The dipoles are cycled to the same current as the TL dipoles.

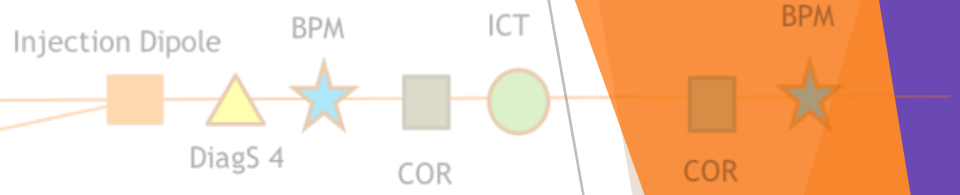
Diagnostics: BPM (sum signal and orbit), BLM.

Procedure

Scan of the septum and injection kicker voltage and timing. Observe the first signal on BPM.

Perform the beam steering through the ring/beam threading.

Phase B.1 short example (Injection and first turn)



List of possible problems and first-order solutions

- Cannot thread the beam / beam lost somewhere
  - Causes: physical aperture, misalignment, wrong magnet settings, polarity errors…
  - Diagnostic tools: BLM, BPM sum signal…
  - Solutions: local steering, realignment, element replacement…
- BPM errors make threading impossible
  - Causes: Polarity errors, calibration errors, cable inversions, electronic faults
  - Diagnostic tools: detailed analysis of the data, systematic polarity/calibration scans
  - Solutions : update the configuration, disable affected BPM, replace faulty equipment.