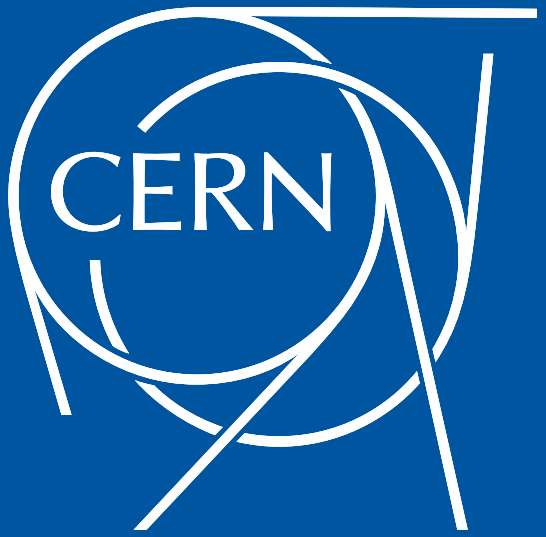

CERN

Status of the REX/HIE-ISOLDE post-accelerator: before and after CERN's long shutdown

Jose Alberto Rodriguez, CERN, BE-OP-ISO
on behalf of CERN's technical teams

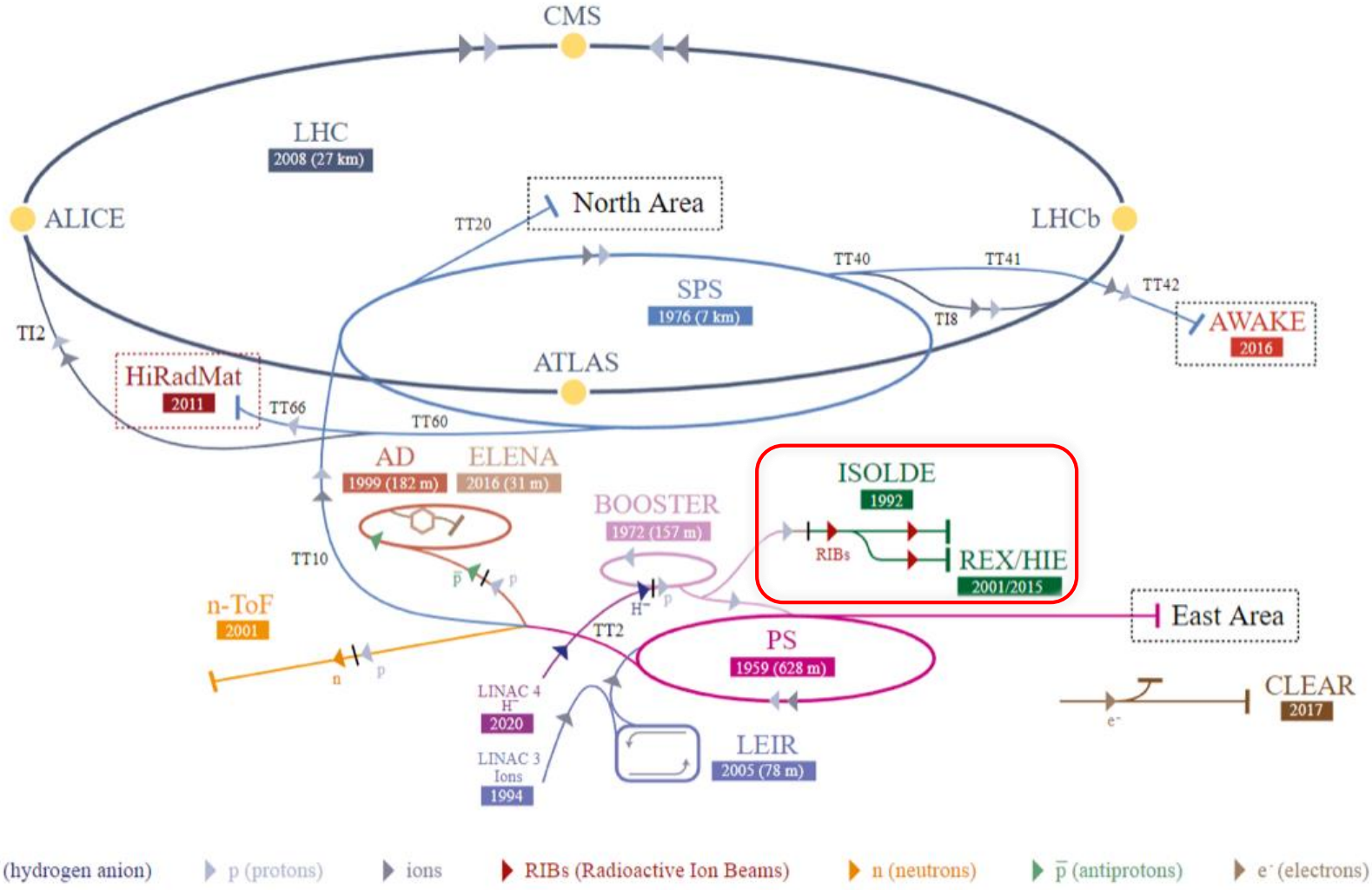
Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Summary

Introduction:

Major changes in the LHC injector chain during the Long Shutdown LS2 (2019-20). Among many others:

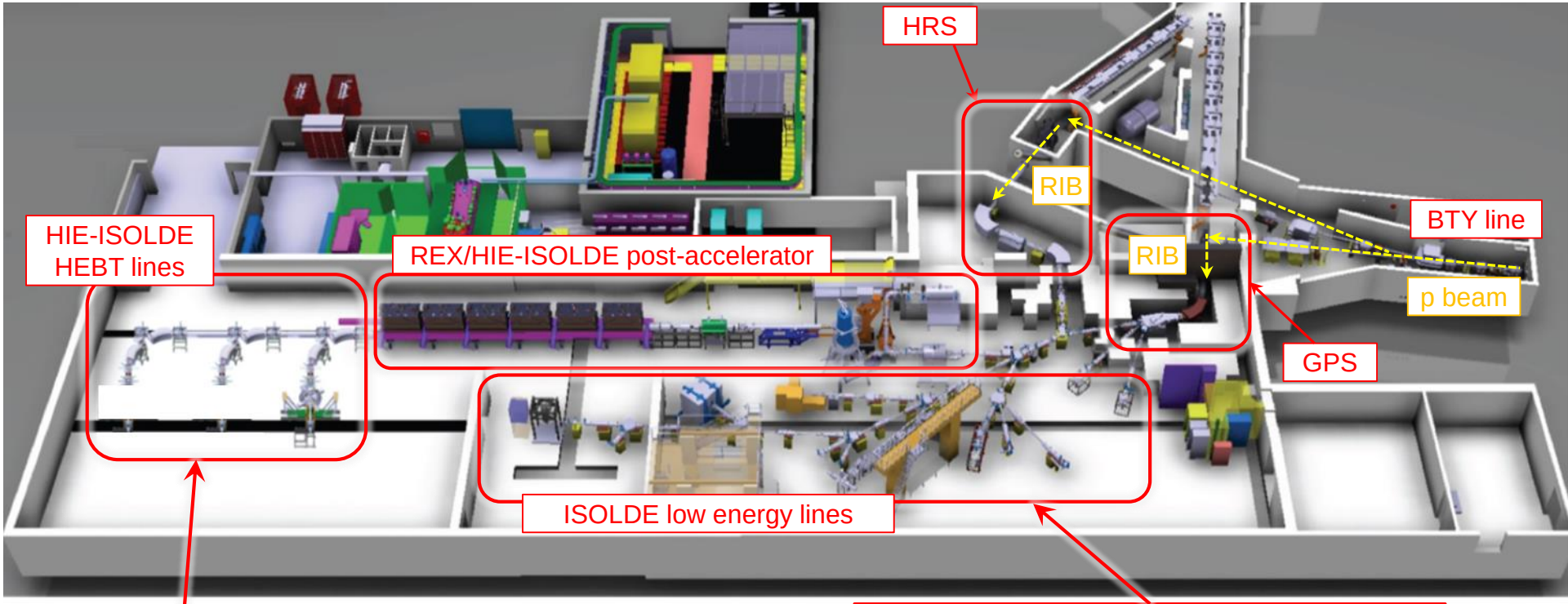
- Linac 2 will be replaced by Linac 4
- PSB output energy will increase to 2 GeV (unfortunately, the transfer line to ISOLDE will not be upgraded)



Introduction:

The low energy part of ISOLDE will also profit from the LS2 to upgrade many systems. Most notably:

- New target front-ends
- New tape station
- Renovation and upgrade of the beam instrumentation



High energy experimental stations:

- Miniball
- ISS
- Scattering Chamber

Low energy experimental stations:

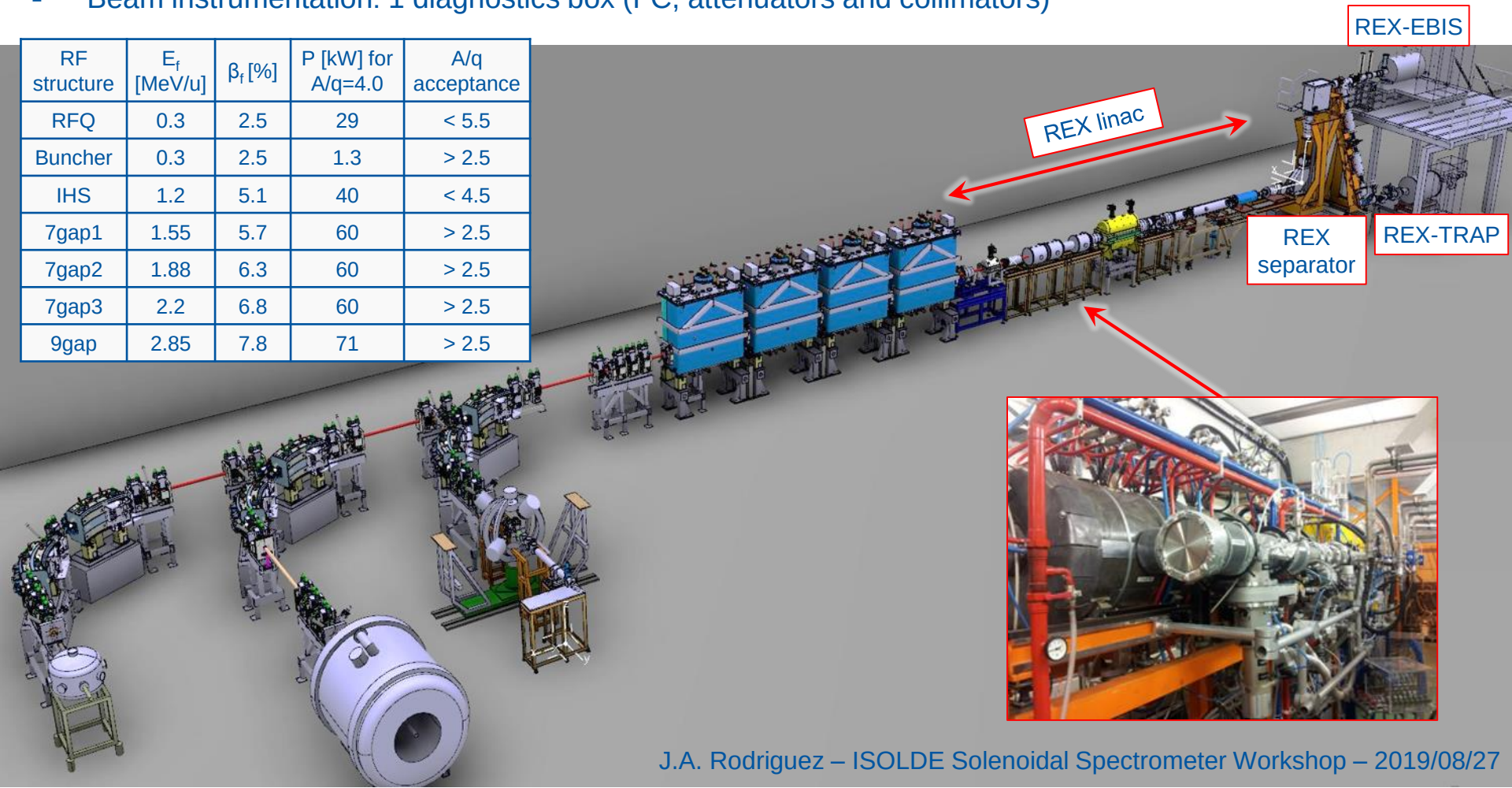
- IDS
- ISOLTRAP
- CRIS
- COLLAPS
- SSP stations
- VITO
- NICOLE
- WISARD

Introduction:

The REX normal conducting linac:

- Beam from the charge breeder with 5 keV/u energy is accelerated to 2.8 MeV/u
- Charge state acceptance: 2.5 < A/q < 4.5
- Cavities: Seven RF structures: f = 101.28 MHz (except for 9gap at 202.56 MHz) up to 10% duty cycle
- Focusing: 6 triplets, 1 doublet Steering: 1 pair of horizontal/vertical steerers
- Beam instrumentation: 1 diagnostics box (FC, attenuators and collimators)

RF structure	E_f [MeV/u]	β_f [%]	P [kW] for A/q=4.0	A/q acceptance
RFQ	0.3	2.5	29	< 5.5
Buncher	0.3	2.5	1.3	> 2.5
IHS	1.2	5.1	40	< 4.5
7gap1	1.55	5.7	60	> 2.5
7gap2	1.88	6.3	60	> 2.5
7gap3	2.2	6.8	60	> 2.5
9gap	2.85	7.8	71	> 2.5



Introduction:

The HIE-ISOLDE superconducting linac:

- Cavities: Quarter Wave Resonators (QWR) made of a copper substrate with niobium sputtered
- Cryomodule: five QWR and one SC solenoid, common insulation and beam vacuum, top plate mounted
- Nominal energy: 9.2 MeV/u for A/q = 4.5, 14.2 MeV/u for A/q = 2.5
- Diagnostics: Scanning slits, collimators and FCs
- Focusing: SC solenoids, quadrupoles Steering: Vertical/horizontal very few meters
- Project staged (one cryomodule / year since 2015). Project completed in 2018

f [MHz]	101.28
Geometrical beta (β_g)	10.3
E_{acc} [MV/m]	6
Quality factor (Q_o) at E_{acc}	$5 \cdot 10^8$
Active length [m]	0.3
Beam aperture diameter [cm]	2
Max. Transit Time Factor (TTF)	0.9
E_{peak} / E_{acc}	5.6

Introduction:

The HIE-ISOLDE High Energy Beam Transfer (HEBT) lines :

- Three lines (XT01 – Miniball, XT02 – ISS and XT03 – Scattering Chamber / Travelling experiments)
- Focusing: quadrupoles Steering: Vertical/horizontal very few meters
- Beam instrumentation: Scanning slits, collimators, FCs and silicon detectors (3 units)
- Stripping foils to clean contaminants (specially useful for light beams)

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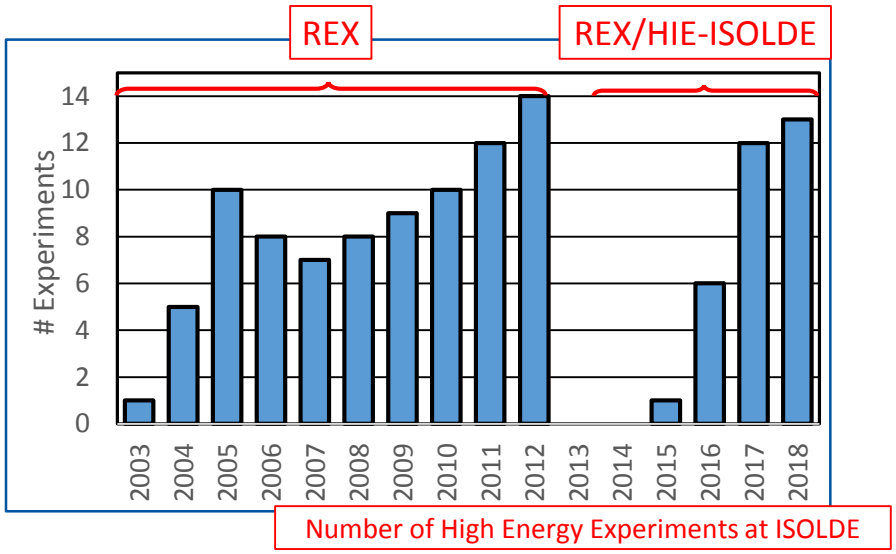
REX/HIE-ISOLDE before LS2:

Highlights 2018 Physics campaign (Jul. 11th – Nov. 21st):

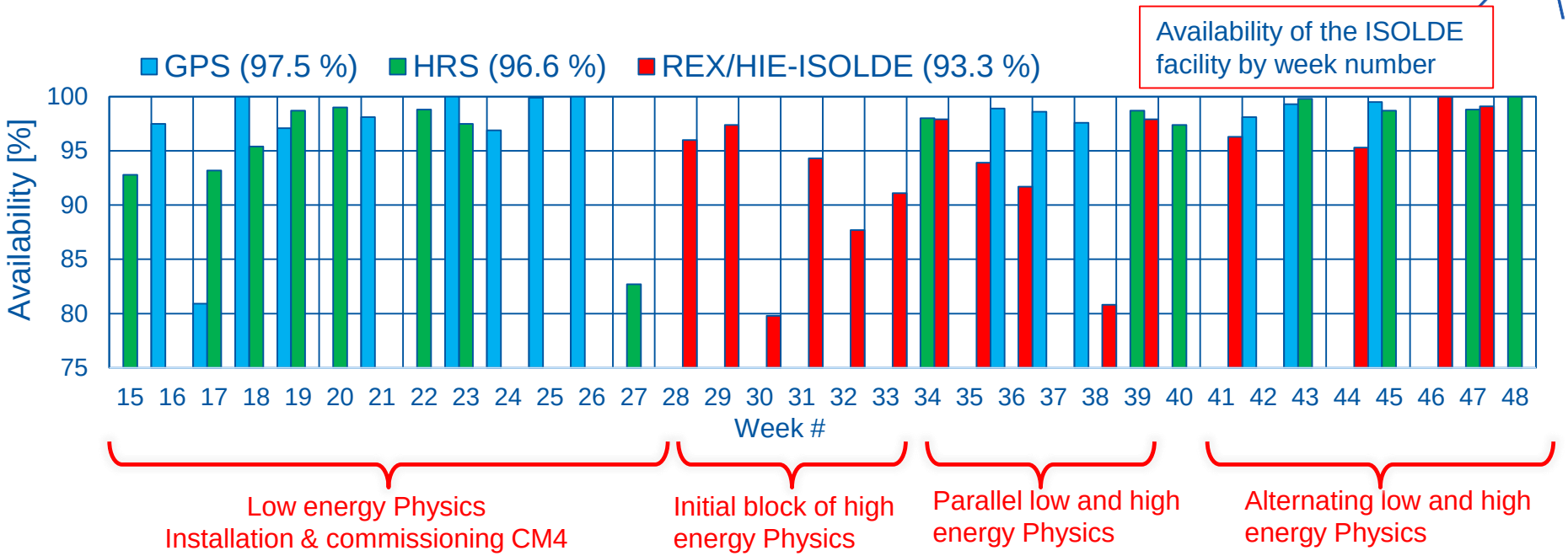
- Started after CM4 was installed and commissioned
- Thirteen experiments conducted:
  - First beams to the ISS (^{28}Mg and ^{206}Hg)
  - Light isotopes (^{7}Be, ^{8}B, ^{9}Li…)
  - Heavy isotopes (^{228}Ra, ^{226}Rn, ^{206}Hg…)
  - Slow extraction used during most of the experiments
  - Stripping foils to clean contaminants (^{9}Li, ^{7,11}Be , ^{8}B)
  - Molecular beams ($^{8}B^{19}F_2$, $^{134}Sn^{34}S$) ← Not very sucessful
  - Pre-irradiated target (^{7}Be)
- Multiple stable beams to the three experimental stations
- Around 1320 hrs of RIBs and 370 hrs of stable beams

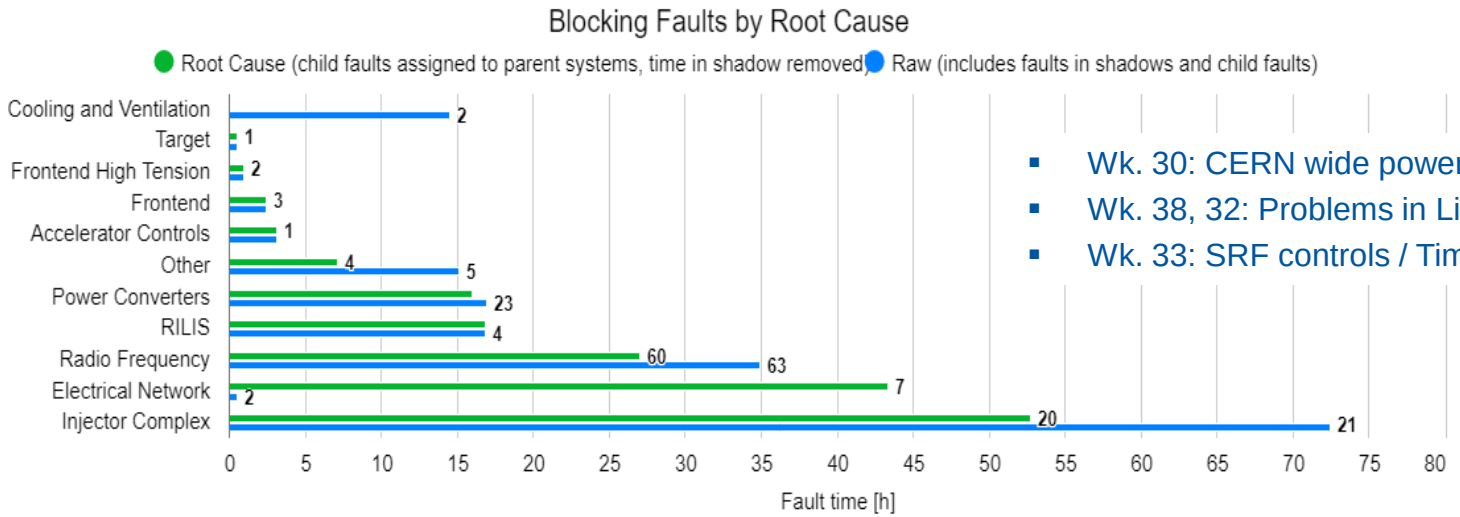


Experiment number	Isotope(s)	Energy [MeV/u]	Experimental station	Time [hours]
IS644	^{96}Kr	4.7, 5.3	Miniball	178.2
IS506	^{212}Rn	3.8, 4.4	Miniball	49.0
IS552	$^{222, 228}$Ra, $^{222, 224, 226}$Rn	4.3, 4.2, 5.1	Miniball	31.3, 82.9
IS553	^{142}Ba	4.2	Miniball	38.5
IS562	^{106}Sn	4.4	Miniball	91.4
IS616	^{8}B	4.9	SEC	97.2
IS655	^{11}Be	7.5	OTPC	117.5
IS654	$^{134, 132}$Sn	7.4, 7.2	Miniball	67.5
IS651	^{28}Mg	9.5	Miniball	116.0
IS621	^{28}Mg	9.5	ISS	116.8
IS631	^{206}Hg	7.4	ISS	98.0
IS561	^{9}Li	8.0	SEC	103.0
IS554	^{7}Be	5.0	SEC	135.0
			Total	**1322.3**

Beam(s)	Energy [MeV/u]	Experimental station	Time [hours]
$^{22}Ne^{7+}$	6.2, 4.6, 9.5	Miniball	110.5
$^{22}Ne^{7+}$	9.5	ISS	126.8
$^{129}Xe^{31+}$	4.8	Miniball	4.0
$^{12}C^{4+}$	2.8, 4.9, 8.0	SEC	89.8
$^{132}Xe^{31+}$	7.2	Miniball	21.0
$^{130}Xe^{29+}$	7.4	ISS	14.5
$^{181}Ta^{42+}$	7.4	Miniball	2.0
		Total	**368.6**

REX/HIE-ISOLDE before LS2:



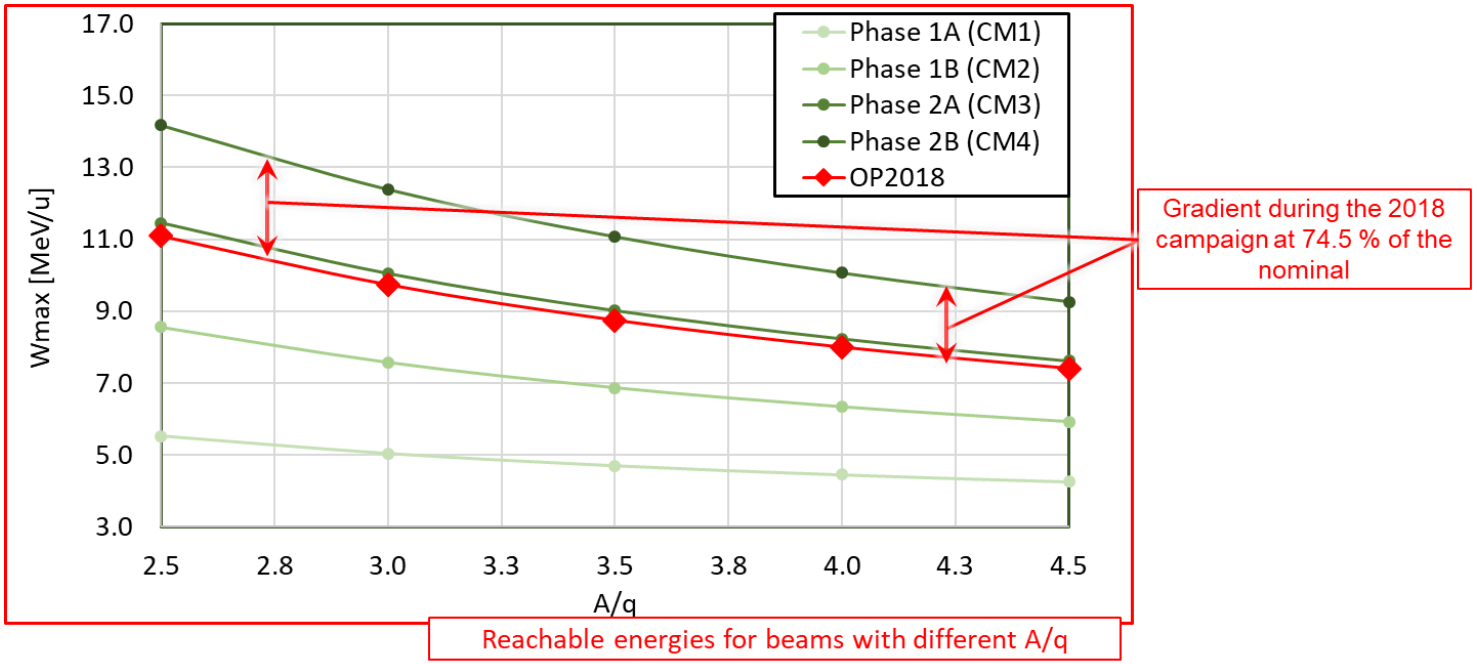


- Wk. 30: CERN wide power cut
- Wk. 38, 32: Problems in Linac2
- Wk. 33: SRF controls / Timing problem with request

REX/HIE-ISOLDE before LS2:

Main issues/worries:

- SRF cavities operating at 74.5 % of nominal gradient
  - Three of the 13 experiments conducted last year would have benefited from higher energies
- Not understood beam losses (15-20 %)
  - Linac transmission better during the REX years. Not explained by beam dynamics simulations
- REX-EBIS electron gun cathode degradation faster than anticipated
  - No impact on the Physics in 2018. However, it had to be replaced once during the campaign and the second one also degraded towards the end of the year
- Trips of SRF cavities after instability of the cryo system
  - Main source of downtime in the post-accelerator. Additional set-up time required to re-phase the linac



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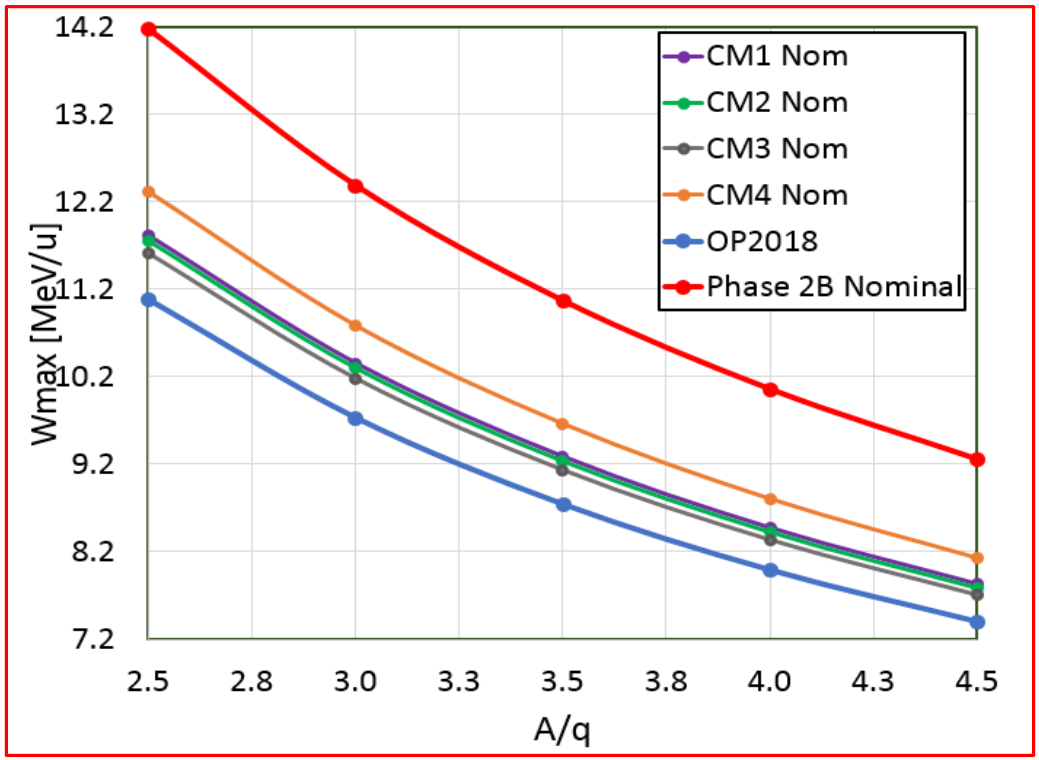
Improvements after LS2: Repair of CM4

- SRF cavities operating at 74.5 % of nominal gradient
  - CM4 uninstalled and sent back to SM18 → Done
  - Cavity SRF18 repair → Done
  - Replacement of the two worse performing cavities by the best two spares → Decided not to exchange (Niobium residue found on water)
  - Testing in bunker of SM18 → Preparation of the bunker infrastructure on-going
  - Transport back to ISOLDE and installation → Scheduled for Jan. 2020



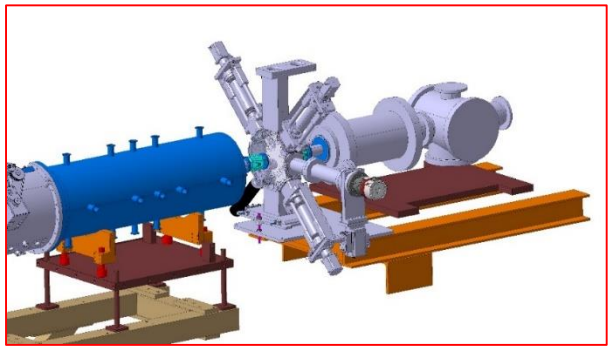
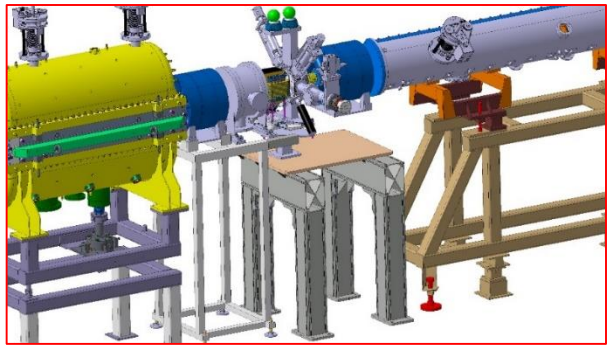
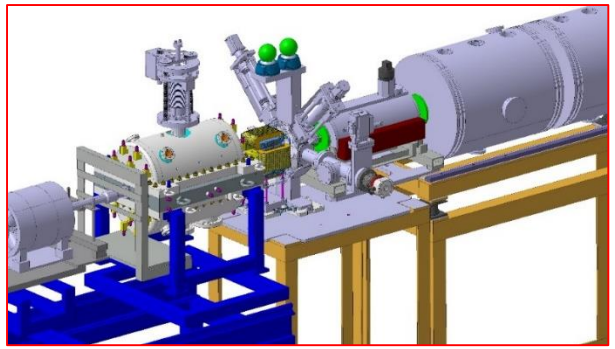
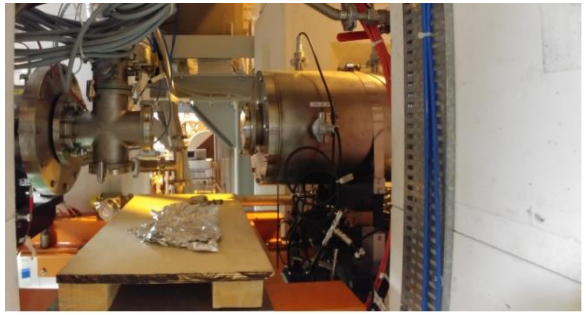
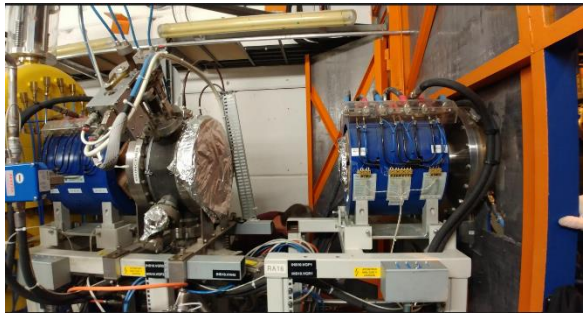
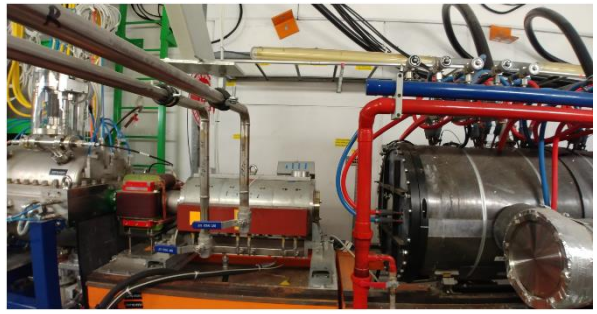
Operational gradient for each SRF cavity during the 2018 campaign [MV/m]

	CM1	CM2	CM3	CM4
CAV. 1	5.0	4.0	5.5	4.2
CAV. 2	5.0	4.5	5.5	4.2
CAV. 3	5.0	5.5	5.5	0.0
CAV. 4	5.0	4.0	5.5	4.5
CAV. 5	2.0	5.0	5.5	4.0
Average	4.4	4.6	5.5	3.4

After LS2 (with SRF18 and the rest of the couplers in CM4 repaired and with additional conditioning of some of the other cavities), we hope we will be able to reach ~ 7.8 MeV/u for beams with A/q = 4.5 or ~10.4 MeV/u for A/q = 3.0 (~ 80 % nominal gradient)

Improvements after LS2: Additional diagnostics

- Not understood beam losses (15-20 %)
  - Aperture check between REX separator and CM1 → Done
  - Additional diagnostics and steerers in the REX linac → Scheduled for the beginning of 2020
  - Additional (automatic) machine checkout tests → Prototype software under development
  - Additional beam commissioning time 2020 requested → Waiting for formal approval by LS2 committee
  - Automatic beam optimizer → Software ready

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  - Additional beam commissioning time 2020 requested → Waiting for formal approval by LS2 committee
  - Automatic beam optimizer → Software ready

Request for schedule change made to the LS2 committee

Improvements after LS2: REX-EBIS electron gun

- REX-EBIS electron gun cathode degradation faster than anticipated

  Three approaches being pursued in parallel to address this problem:

  - Understanding and solving or mitigating the problem with the present cathode
    - Less risky option since there would be no major design changes
    - Spare cathodes available. Cathode replacement could potentially be scheduled
    - Discussions with the manufacturer on-going
  - New immersed gun solution
    - New cathode provider identified
    - Electron beam gun simulations on-going
    - Technical design will follow and it take 2-3 months
    - Manufacturing of the pieces will need to be outsourced (CERN main workshop busy with LS2) and will take several months
  - New MEDeGUN Brillouin gun solution
    - Currently being tested at the TwinEBIS
    - Working well but very complex design and no long-term performance data available (most risky option)
    - Current design will need to be adapted for REX-EBIS
    - Discussions with the manufacturer on-going

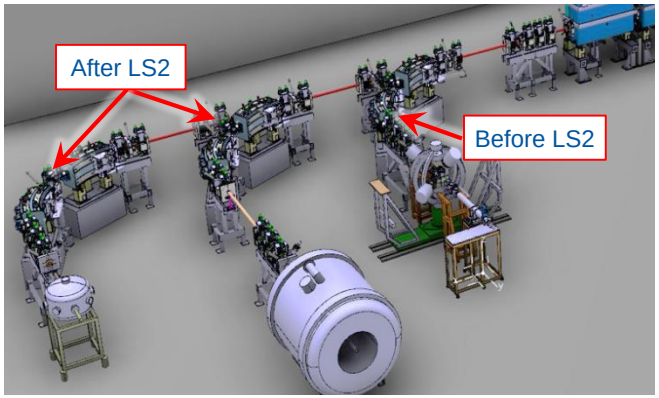
Improvements after LS2: Cryo system and SRF cavities

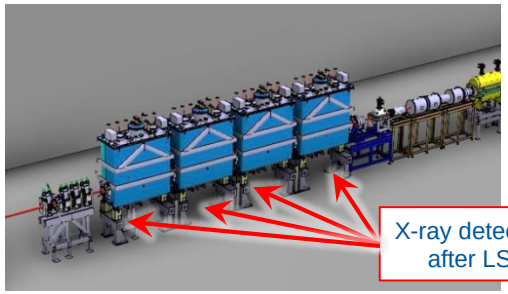
- Trips of SRF cavities after instability of the cryo system
  - Maintenance of the cryo-plant on-going → Will be completed by Dec. 2019
  - Setup of automatic controls for transient modes on-going → Will be completed by Dec. 2019
  - Additional time for restart and recommissioning of cryo available (cost of early restart ~ 15 kCHF/month) → Waiting for formal approval by LS2 committee
  - Additional time for recommissioning of SRF systems available → Waiting for formal approval by LS2 committee

Improvements after LS2: Hardware and beam optics



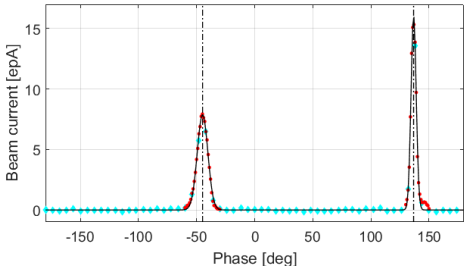
- Major refurbishment of REX RF amplifiers
  - Several sources of problems identified and fixed
  - Better power and gradient calibrations
  - Higher peak powers available (90 kW)
  - New cooling for the IH structure
  - Potentially more reliable operations and less down time
- New silicon detectors will be installed between the two dipoles in XT02 and XT03
  - Beam energy measurements possible in the three HEBT lines
  - Reduction in set-up time for beams to ISS and Scattering Chamber
  - Energy loss measurements after stripping foils possible
  - Redundancy in case one of them fails
- X-ray monitors for each of the cryomodules
  - Better diagnostics on the field emission of the SRF cavities
  - Potential gains in cavity gradients
- Validation of beam optics models
  - Important time investment during the recommissioning in 2020





Improvements after LS2: Software and controls

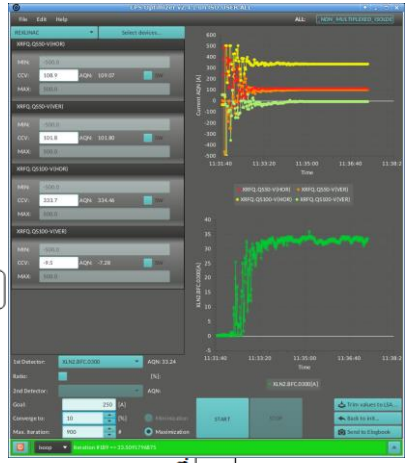
- Semi-automatic phasing of SRF cavities
  - Additional reference set-ups at the beginning of the Physics campaign
  - Less set-up time needed if problems with one SRF cavity appear

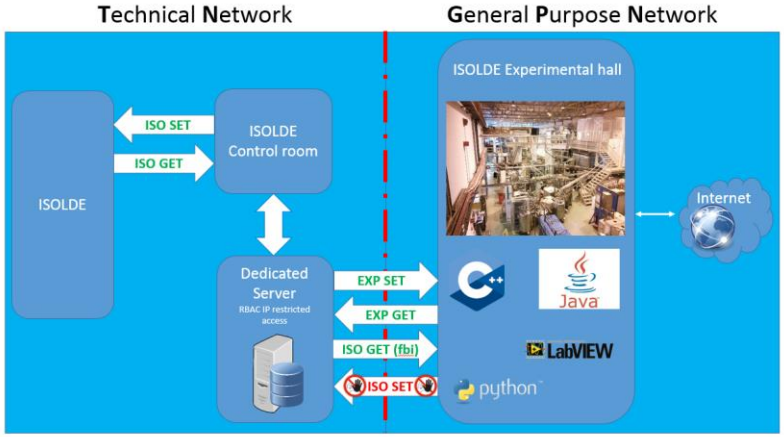


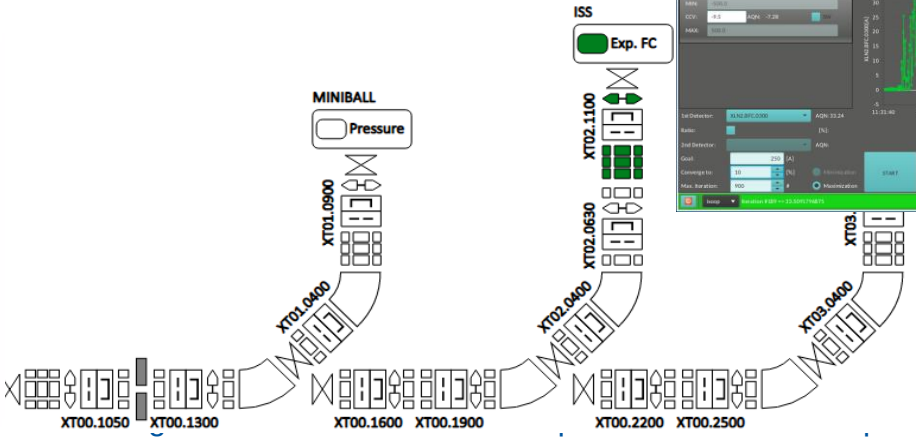
- New version of the Fast Beam Investigation (FBI)
  - Full integration of C2MON and Grafana
  - More functionalities and additional views will be available

- Beam optimizer to improve the injection into the experimental stations
  - Automatic scans of optic elements to maximize beam current at the FCs

- New dedicated server to pass information between technical and general networks (not approved yet)
  - FBI views of the experimental stations
  - Beam optimizer will be able to use the detectors and devices of the experimental stations







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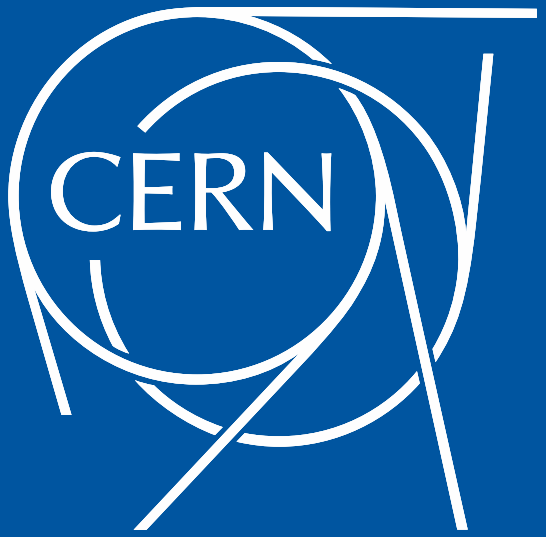
Summary:

- Phase 2B of the HIE-ISOLDE project (the last one funded) completed in 2018
- Reasonably successful high energy Physics campaigns in 2016, 2017 and 2018
- Main issues during these years:
  - Problems with the production of molecular beams
  - SRF cavities operating at 75 % of nominal gradient and not always stable
  - Not understood beam losses (15-20 %)
  - Degradation of the cathode of the electron gun REX-EBIS
- Main activities during LS2:
  - CM4 has been partially repaired
  - Additional time will be allocated for the re-commissioning of the cryoplant and the SRF systems
  - Additional beam diagnostic boxes and a steerer will be install in REX
  - Additional time will be allocated for the beam commissioning and validation of beam optics models
  - REX RF amplifiers have been refurbished
  - Additional hardware will be installed and new software will be developed
- Hopefully, these investments will result in better quality beams for experiments at ISS

On behalf of all the CERN's technical teams working at REX/HIE-ISOLDE, thank you for your support during these years!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