



REX/HIE ISOLDE post-accelerator: Capabilities after CERN's Long Shutdown 2

ISOLDE Workshop 5-6 December 2019, CERN

Erwin Siesling, on behalf of the CERN Technical and ISOLDE Operations teams

Courtesy: Jose Alberto Rodriguez for many of the slides

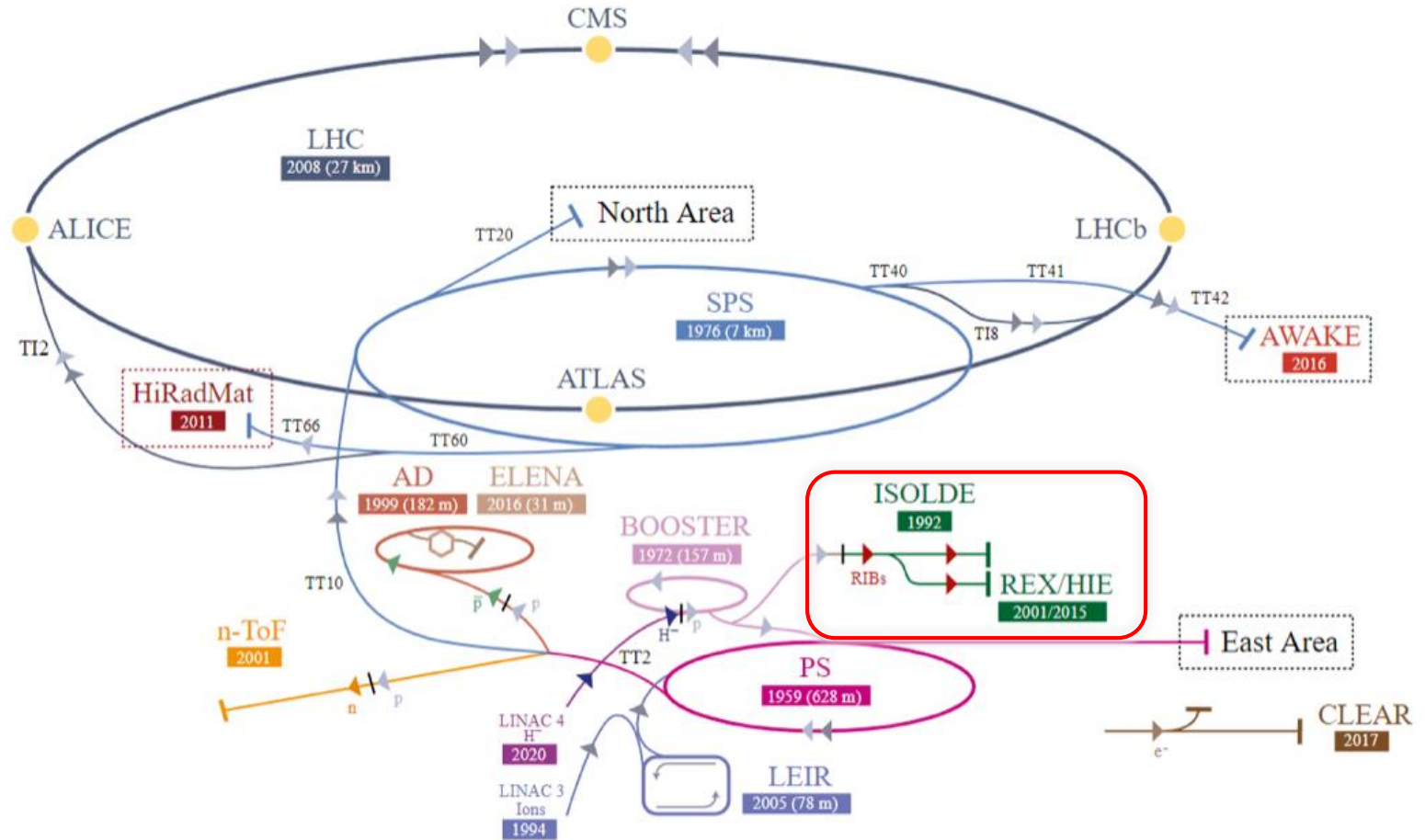
Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Beam Commissioning & Machine Studies 2020
- 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, yet..)

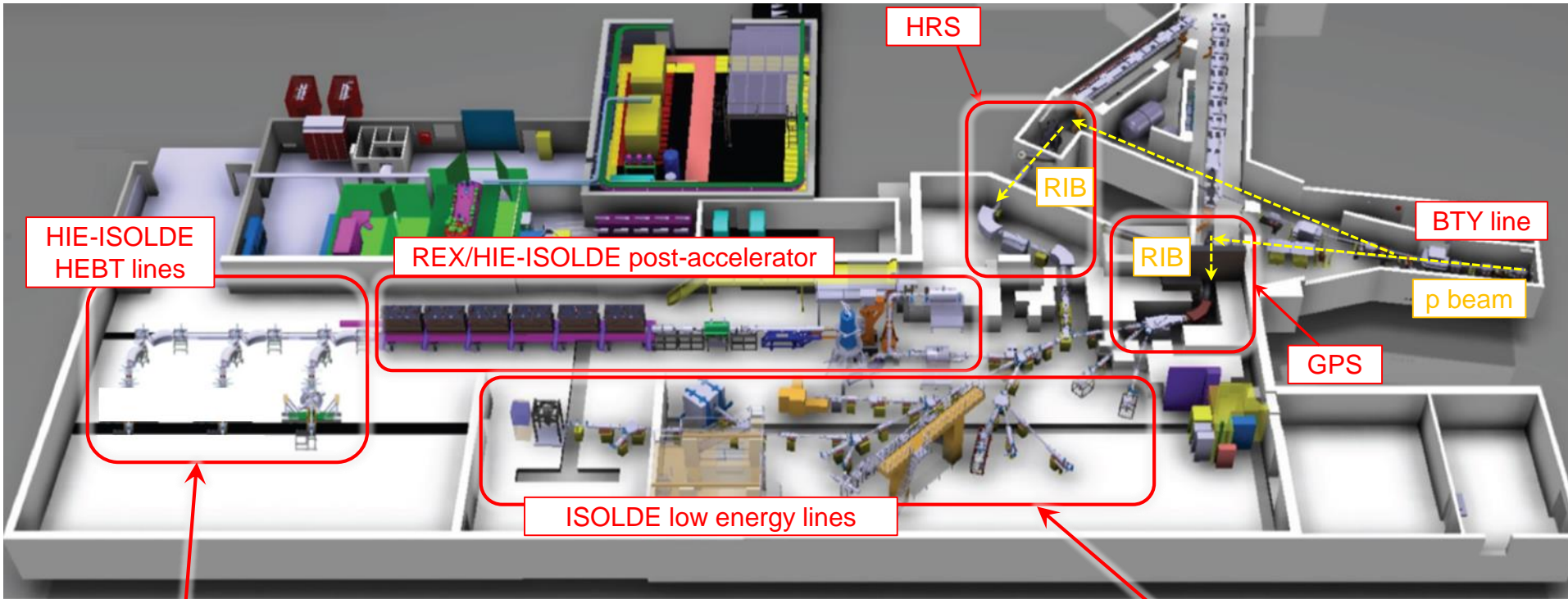


▶ H^- (hydrogen anion)
 ▶ p (protons)
 ▶ ions
 ▶ RIBs (Radioactive Ion Beams)
 ▶ n (neutrons)
 ▶ \bar{p} (antiprotons)
 ▶ e^- (electrons)

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

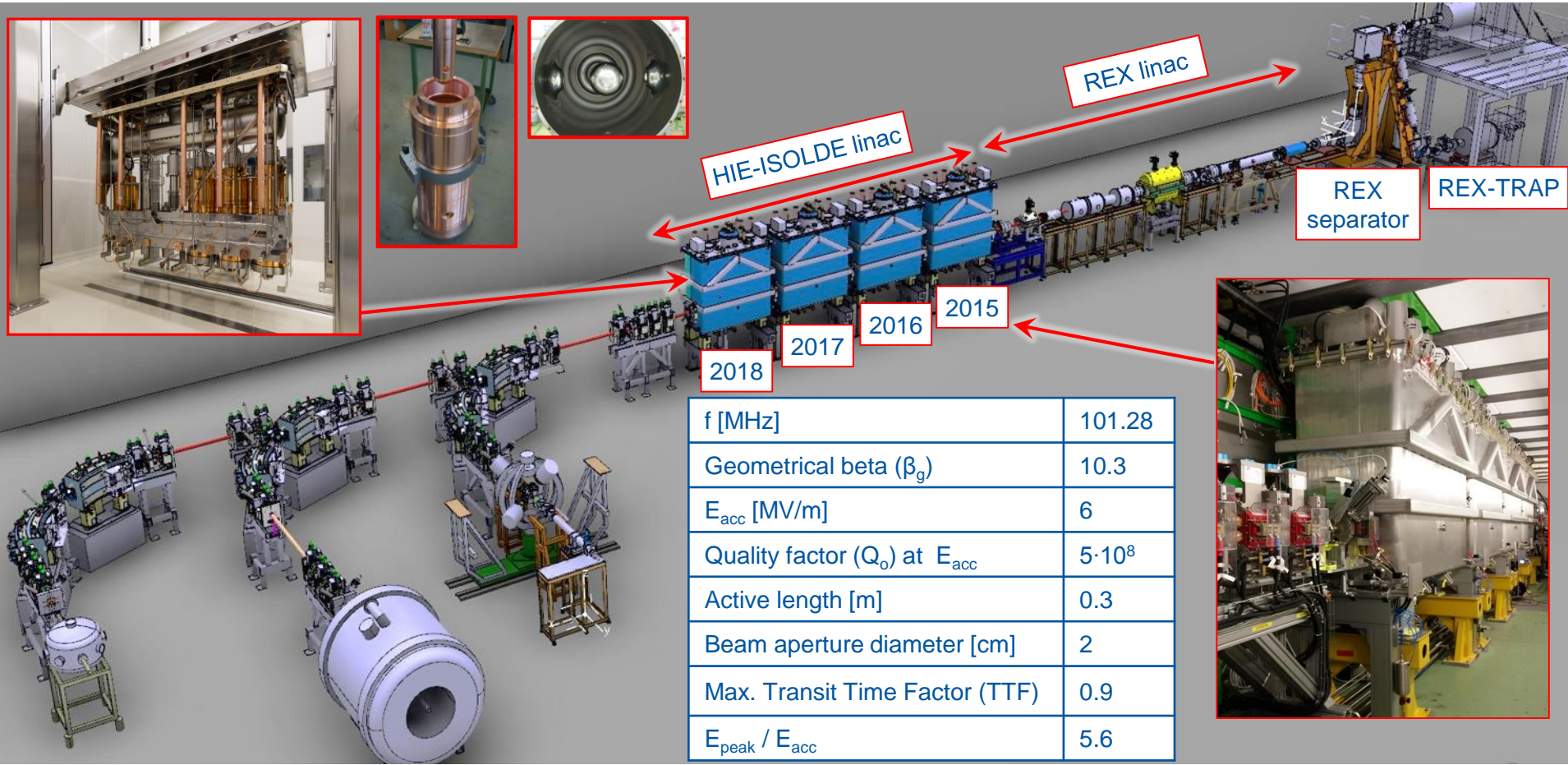
Low energy experimental stations:

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

Introduction:

The HIE-ISOLDE superconducting linac:

- Cavities: Quarter Wave Resonators (QWR) made of a copper substrate with niobium sputtered
- Cryomodules: 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 every few meters
- Project staged (one cryomodule / year since 2015). Project completed in 2018

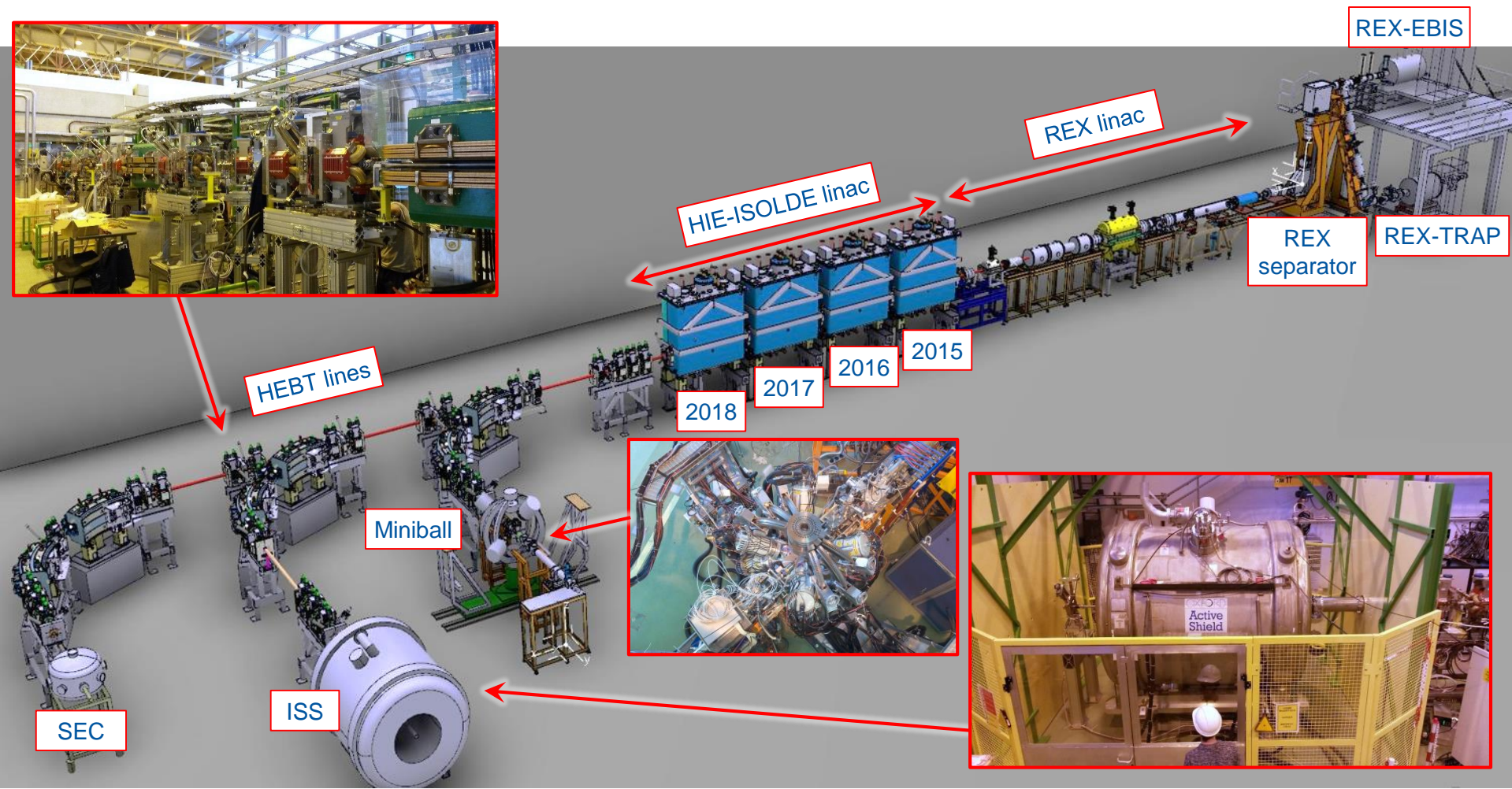


f [MHz]	101.28
Geometrical beta (β_g)	10.3
E_{acc} [MV/m]	6
Quality factor (Q_0) at E_{acc}	$5 \cdot 10^8$
Active length [m]	0.3
Beam aperture diameter [cm]	2
Max. Transit Time Factor (TTF)	0.9
E_{peak} / E_{acc}	5.6

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 every few meters
- Beam instrumentation: Scanning slits, collimators, FCs and silicon detectors (3 units)
- Stripping foils to clean contaminants (specially useful for light beams)



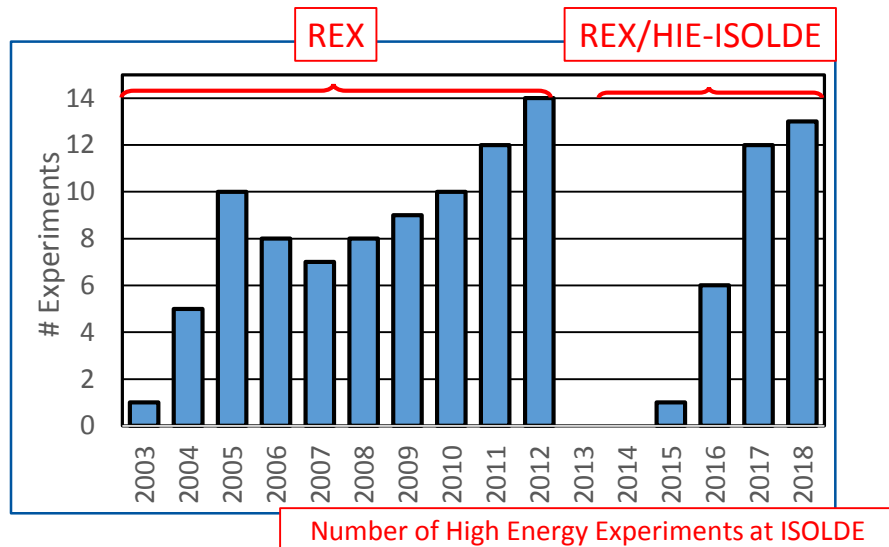
Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Beam Commissioning & Machine Studies 2020
- Summary

REX/HIE-ISOLDE before LS2:

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

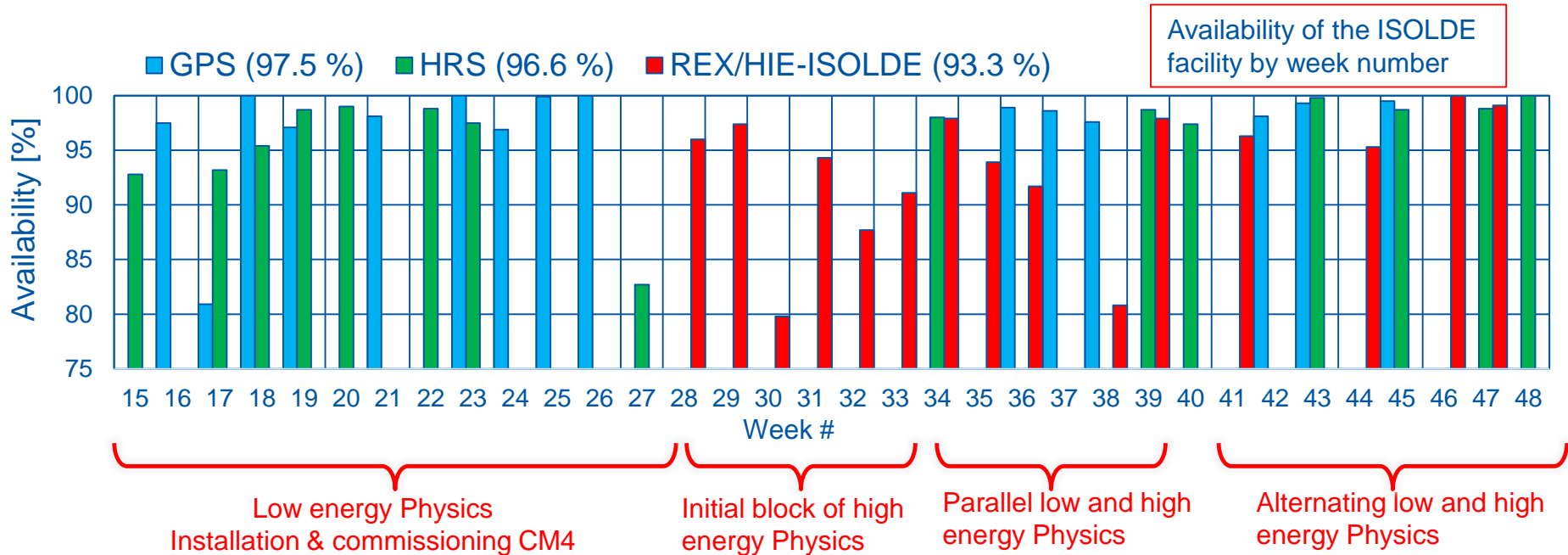
- Started after CM4 was installed and commissioned
- Thirteen experiments conducted:
 - First beams to the ISS (^{28}Mg and ^{206}Hg)
 - Light isotopes (^7Be , ^8B , ^9Li ...)
 - Heavy isotopes (^{228}Ra , ^{226}Rn , ^{206}Hg ...)
 - Slow extraction used during most of the experiments
 - Stripping foils to clean contaminants (^9Li , $^{7,11}\text{Be}$, ^8B)
 - Molecular beams ($^8\text{B}^{19}\text{F}_2$, $^{134}\text{Sn}^{34}\text{S}$) ← Not very successful
 - Pre-irradiated target (^7Be)
- 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	$^{222, 228}\text{Ra}$, $^{222, 224, 226}\text{Rn}$	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	^8B	4.9	SEC	97.2
IS655	^{11}Be	7.5	OTPC	117.5
IS654	$^{134, 132}\text{Sn}$	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	^9Li	8.0	SEC	103.0
IS554	^7Be	5.0	SEC	135.0
			Total	1322.3

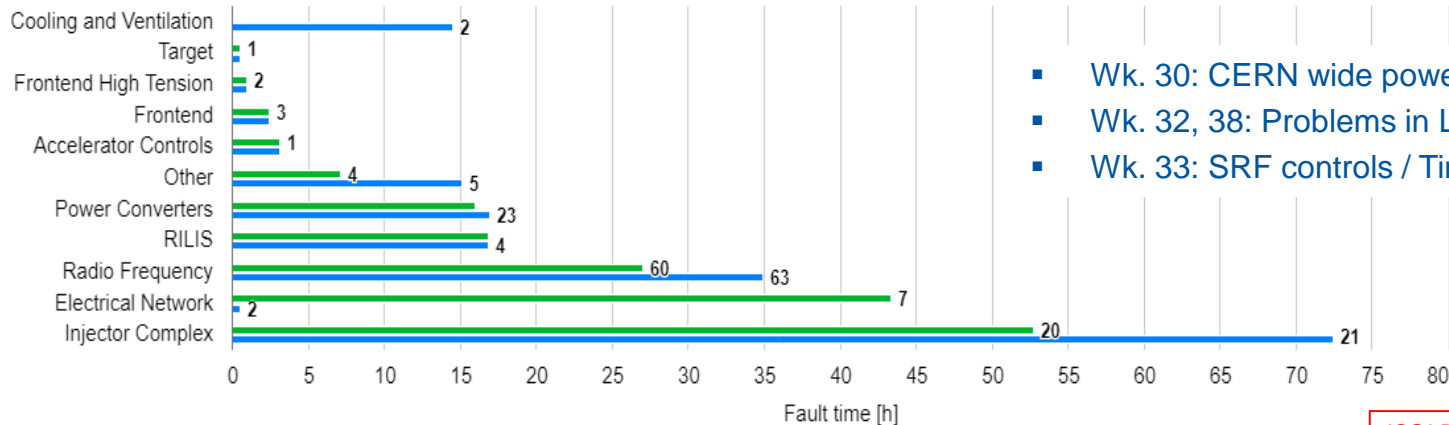
Beam(s)	Energy [MeV/u]	Experimental station	Time [hours]
$^{22}\text{Ne}^{7+}$	6.2, 4.6, 9.5	Miniball	110.5
$^{22}\text{Ne}^{7+}$	9.5	ISS	126.8
$^{129}\text{Xe}^{31+}$	4.8	Miniball	4.0
$^{12}\text{C}^{4+}$	2.8, 4.9, 8.0	SEC	89.8
$^{132}\text{Xe}^{31+}$	7.2	Miniball	21.0
$^{130}\text{Xe}^{29+}$	7.4	ISS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

REX/HIE-ISOLDE before LS2:



Blocking Faults by Root Cause

● Root Cause (child faults assigned to parent systems, time in shadow removed) ● Raw (includes faults in shadows and child faults)

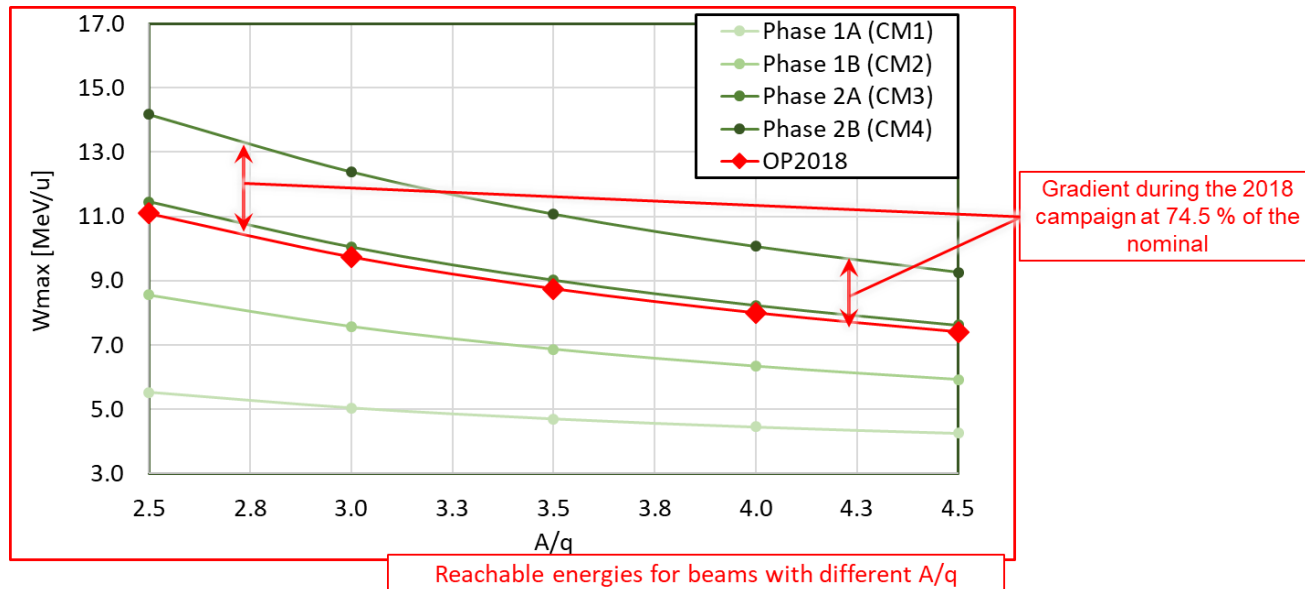


- Wk. 30: CERN wide power cut
- Wk. 32, 38: Problems in Linac2
- Wk. 33: SRF controls / Timing problem with request

REX/HIE-ISOLDE before LS2:

Main issues/worries:

- SRF cavities operating at 75 % of nominal (6 MV/m) gradient
 - Achieved energy: 7.4 MeV/u for $A/q = 4.5$, 11.2 MeV/u for $A/q = 2.5$
(Nominal energy: 9.2 MeV/u for $A/q = 4.5$, 14.2 MeV/u for $A/q = 2.5$ at nominal gradient 6MV/m)
 - Three of the 13 experiments conducted last year would have benefited from higher energies



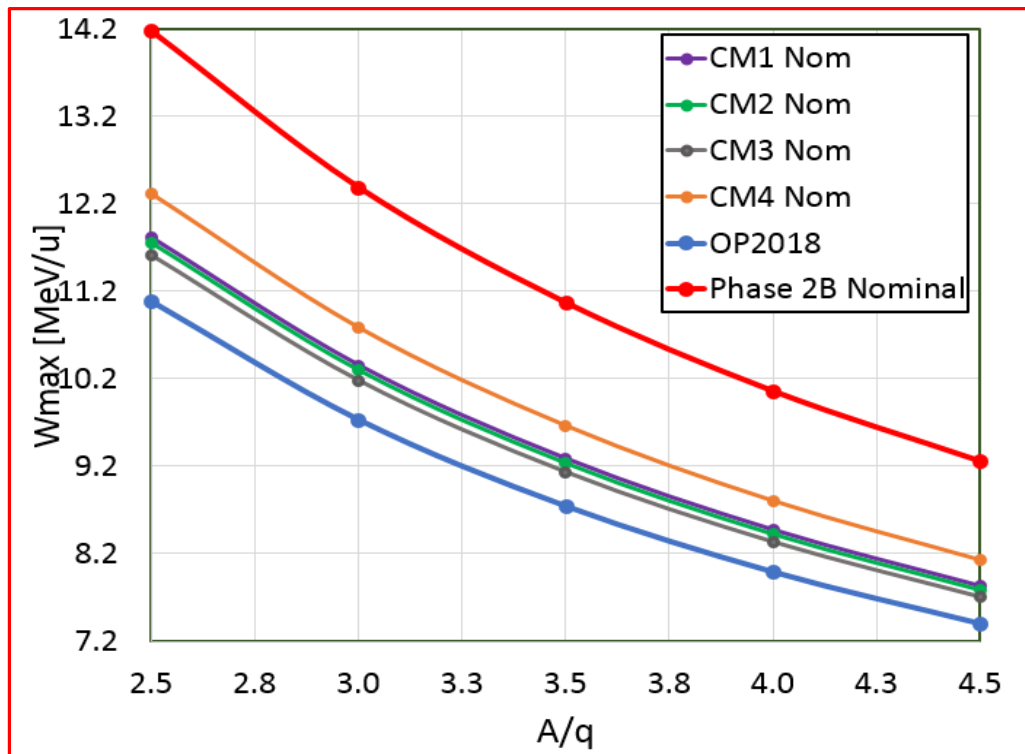
- Not understood REX linac beam losses (15-20 %)
 - Linac transmission better during the REX years. Not explained by beam dynamics simulations
- REX-EBIS electron gun cathode degradation faster than anticipated
 - No impact on the Physics in 2018. However, it had to be replaced once during the campaign 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

Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Beam Commissioning & Machine Studies 2020
- Summary

Improvements after LS2: Repair of CM4

- SRF cavities operating at 75 % of nominal (6 MV/m) 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 in water after rinsing)
 - Testing in bunker of SM18 → Tests finishing. 1 week delay due to power cut
 - 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

With the possibility to have one CM refurbished during LS2, CM4 was chosen which will have the largest effect on improving the overall performance of the HIE Linac in terms of energy increase.

Improvements after LS2: Repair of CM4

➤ Expected energy reach after CM4 refurbishment

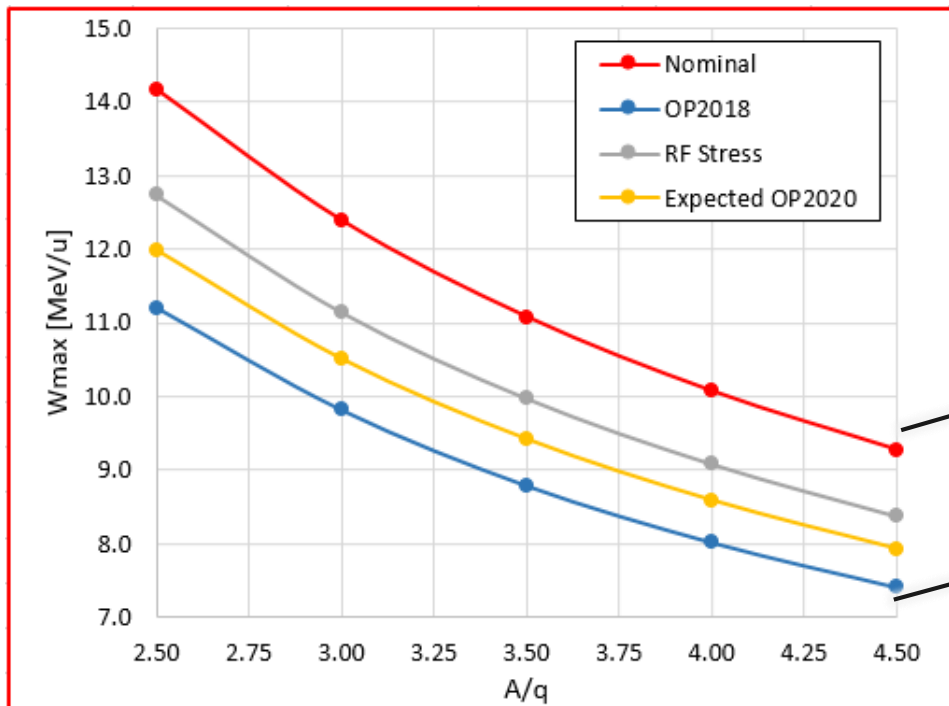
- Best case:

The RF group estimates for beams with $A/q=4.5$ an increase in energy to 8.4 MeV/u with CM4 cavity SRF18 running at 5MV/m and others assumed to run at the higher gradients found during the RF stress tests at the end of the run 2018. (~87% of the nominal gradient)

- Operational stability:

Operations require a stability of the cavities with max 1 trip / day therefor, taking 5MV/m for SRF18 in account and additional conditioning of some of the other cavities, we hope we will be able to reach ~ 7.9 MeV/u for beams with $A/q = 4.5$ or ~10.5 MeV/u for $A/q = 3.0$. (~ 80 % nominal gradient)

- Operational gradients and stabilities are to be tested and validated during the test & development run in 2020 with stable beams

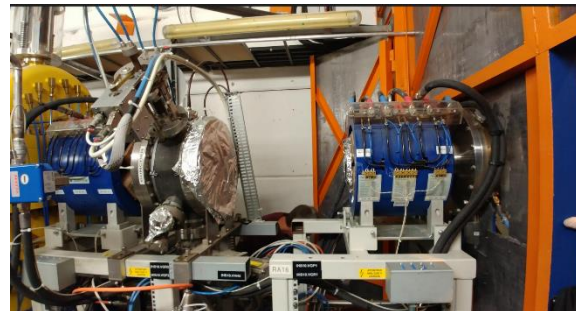
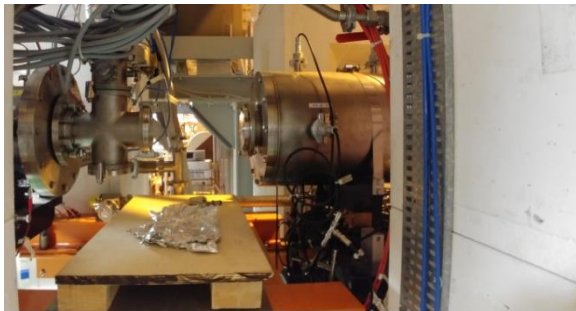
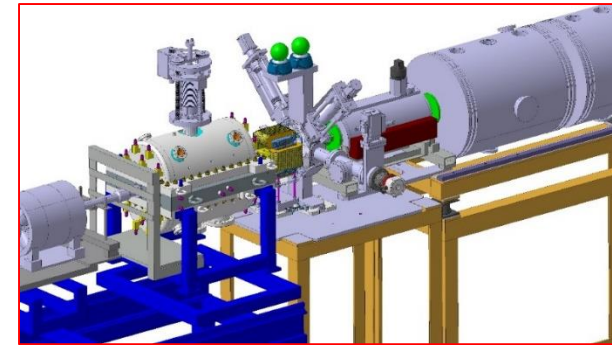
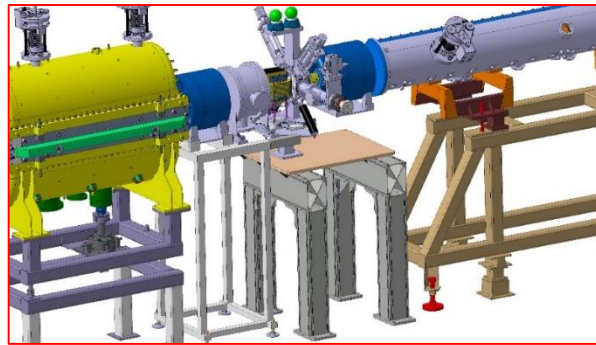
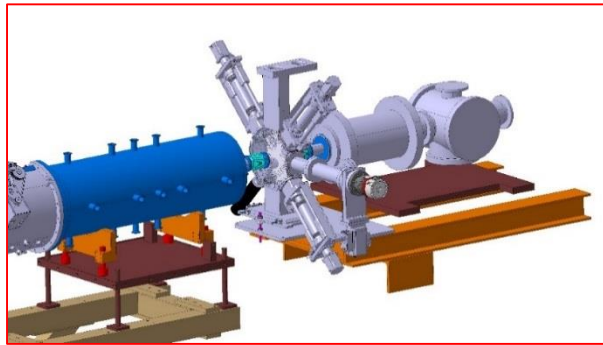


Energies [MeV/u] for different SRF cavity gradients: W. Venturini, D. Valuch, J.A. Rodriguez

A/q	Exp 2020	RF Stress	OP2018	Nominal
2.5	12.0	12.7	11.2	14.2
3.0	10.5	11.1	9.8	12.4
3.5	9.4	10.0	8.8	11.1
4.0	8.6	9.1	8.0	10.1
4.5	7.9	8.4	7.4	9.3

Improvements after LS2: Additional diagnostics

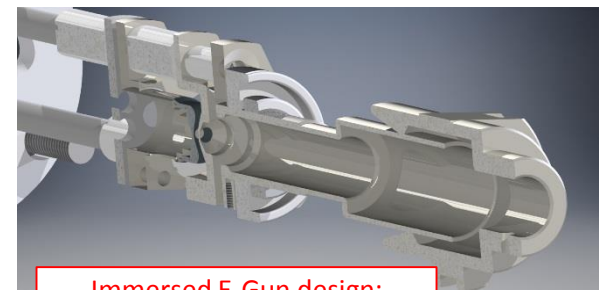
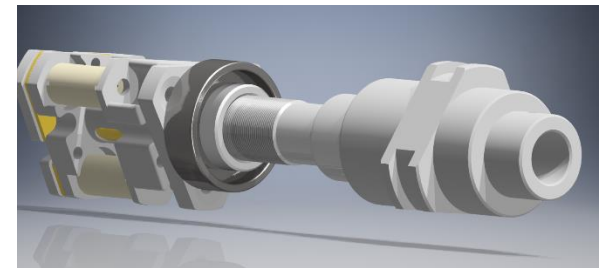
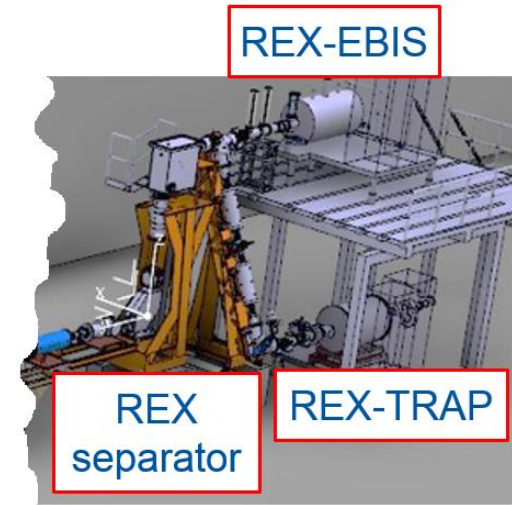
- Not understood REX beam losses (15-20 %)
 - Aperture check between REX separator and CM1 → Done
 - Additional diagnostics and steerers in the REX linac → Scheduled for the beginning of 2020
 - Additional (automatic) machine checkout tests → Prototype software under development
 - Automatic beam optimizer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



Three new Diagnostic Boxes in the REX Linac:
S. Mataguez, J.A. Rodriguez, BE/BI, EN/MME

Improvements after LS2: REX-EBIS electron gun

- REX-EBIS electron gun cathode degradation faster than anticipated LS2 activities and beyond for improvement:
 - New immersed gun solution as of 2020
 - New cathode provider identified
 - Electron beam gun simulations done
 - Technical design done
 - Manufacturing of the pieces outsourced:
 - Reception of the pieces end of the year
 - Assembly foreseen January
 - Earliest installation February
 - Tests & Commissioning end of April – the real work starts..
 - Understanding and solving or mitigating the problem with the present cathode
 - In case the new design does not perform as expected the existing configuration could be used as a fall-back solution
 - Spare cathodes available. Cathode replacement could potentially be scheduled
 - Discussions with the manufacturer on-going
 - Test & development: 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



Immersed E-Gun design:
M. Lozano Benito, F. Wenander

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
 - Setup of automatic controls for transient modes on-going
 - Additional time for restart and recommissioning of cryo available but at certain costs for operations and electricity
 - Additional time for recommissioning of SRF systems available
- Will be completed for 2020
- Will be completed for 2020
- Waiting for formal approval by Research Board
- Waiting for approval by Research Board

Approved 4th Dec



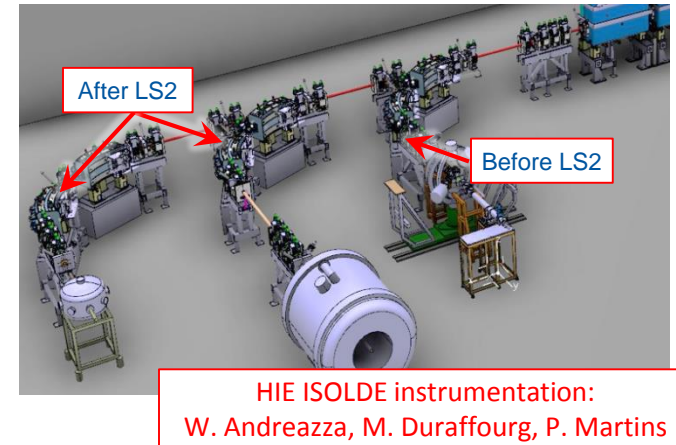
HIE ISOLDE Cryo Systems:
O. Pirotte, N. Guillotin

Improvements after LS2: Hardware and beam optics

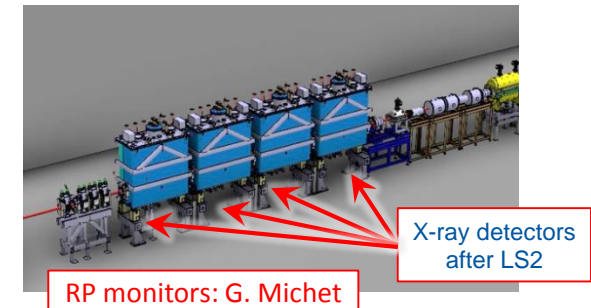
- Major refurbishment of REX RF amplifiers
 - Several sources of problems identified and fixed
 - Better power and gradient calibrations
 - Higher peak powers available (90 kW)
 - New cooling for the IH structure
 - Potentially more reliable operations and less down time



- Additional 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



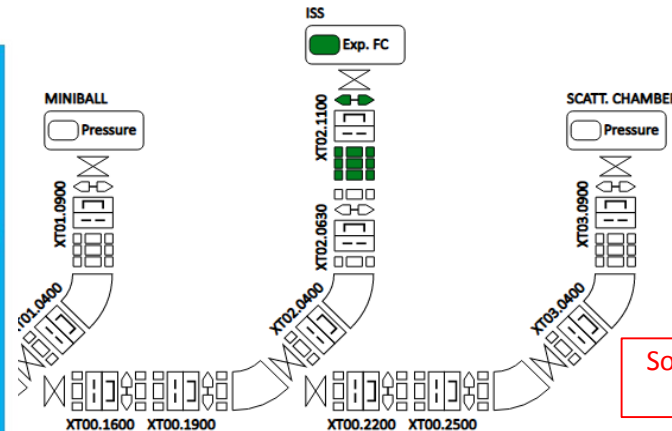
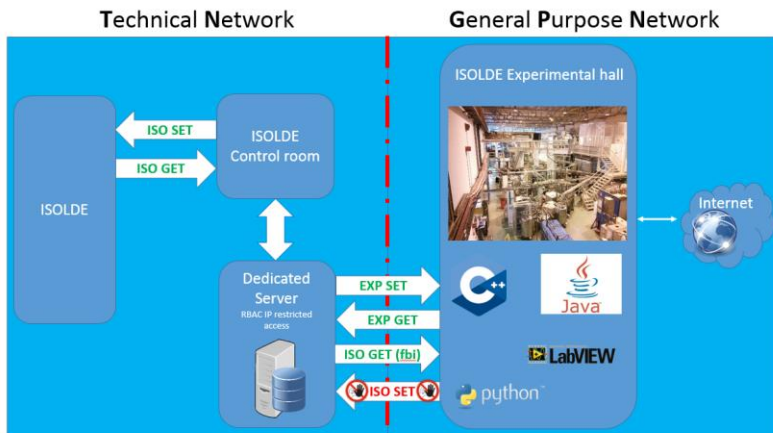
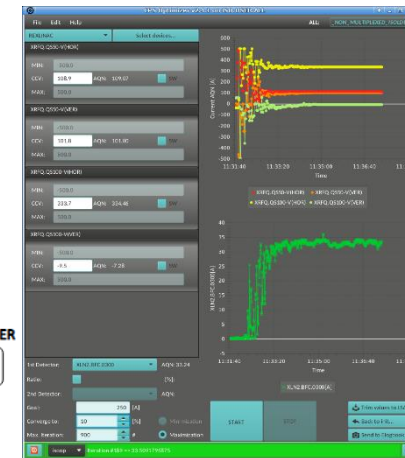
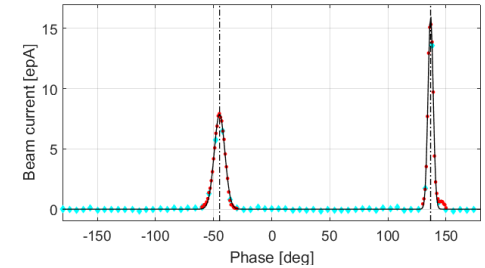
- X-ray monitors for each of the cryomodules
 - Better diagnostics on the field emission of the SRF cavities
 - Potential gains in cavity gradients



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



Software & Controls development:
E. Fadakis, E. Piselli

Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Beam Commissioning & Machine Studies 2020
- Summary

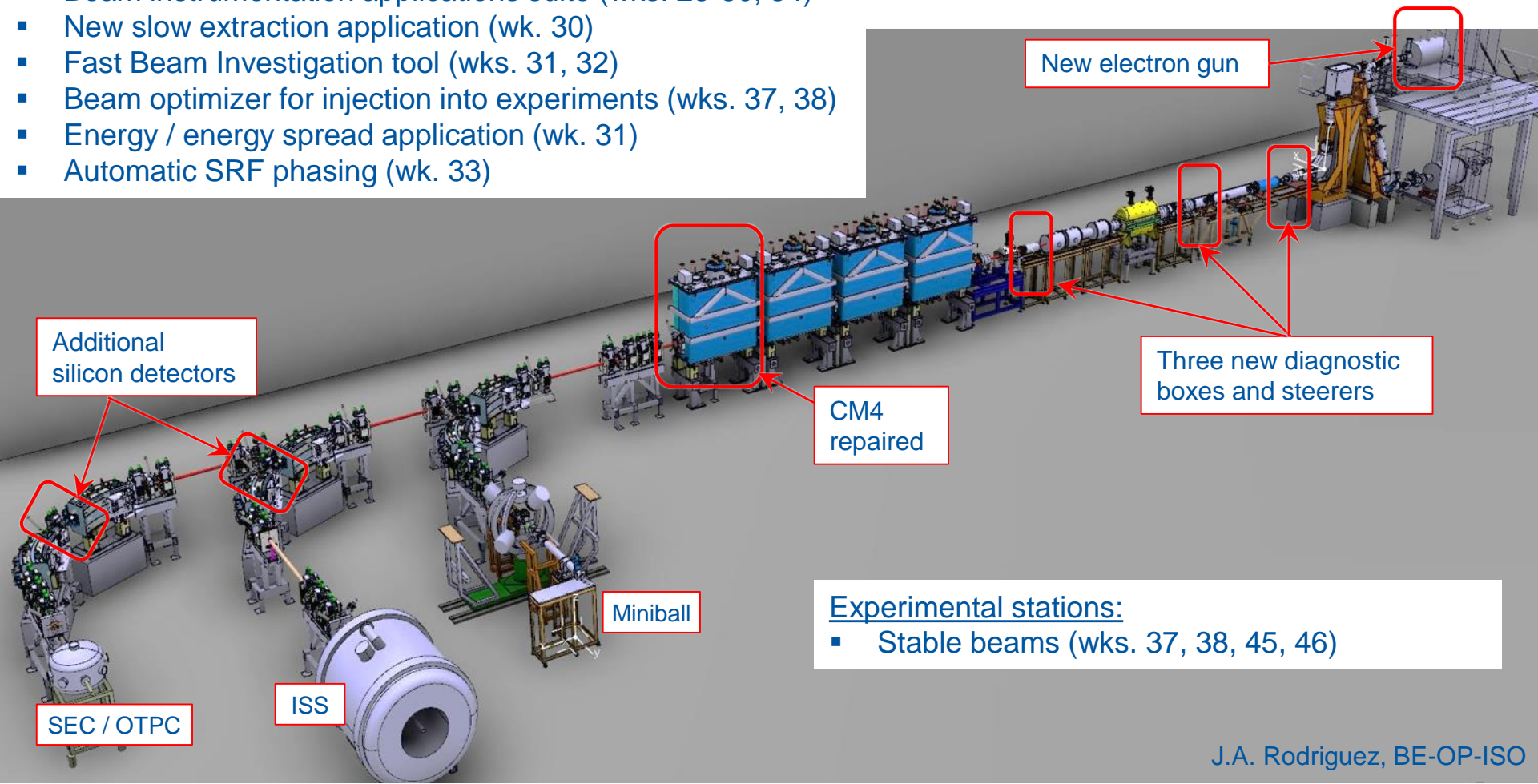
Beam Commissioning 2020:

New or heavily refurbished hardware:

- New steerers and diagnostic boxes: FCs, slits, attenuators, collimators and silicon detectors (wks. 28, 29, 30)
- New electron gun in the REX-EBIS charge breeder (contaminant characterization: wks. 29, 31)
- REX RF amplifiers (wks. 30-32)
- Phasing of refurbished cryomodule 4 (CM4) (wk. 33)
- Two additional silicon detectors (wk. 34)

New software or major application upgrades:

- Beam instrumentation applications suite (wks. 28-30, 34)
- New slow extraction application (wk. 30)
- Fast Beam Investigation tool (wks. 31, 32)
- Beam optimizer for injection into experiments (wks. 37, 38)
- Energy / energy spread application (wk. 31)
- Automatic SRF phasing (wk. 33)



Experimental stations:

- Stable beams (wks. 37, 38, 45, 46)

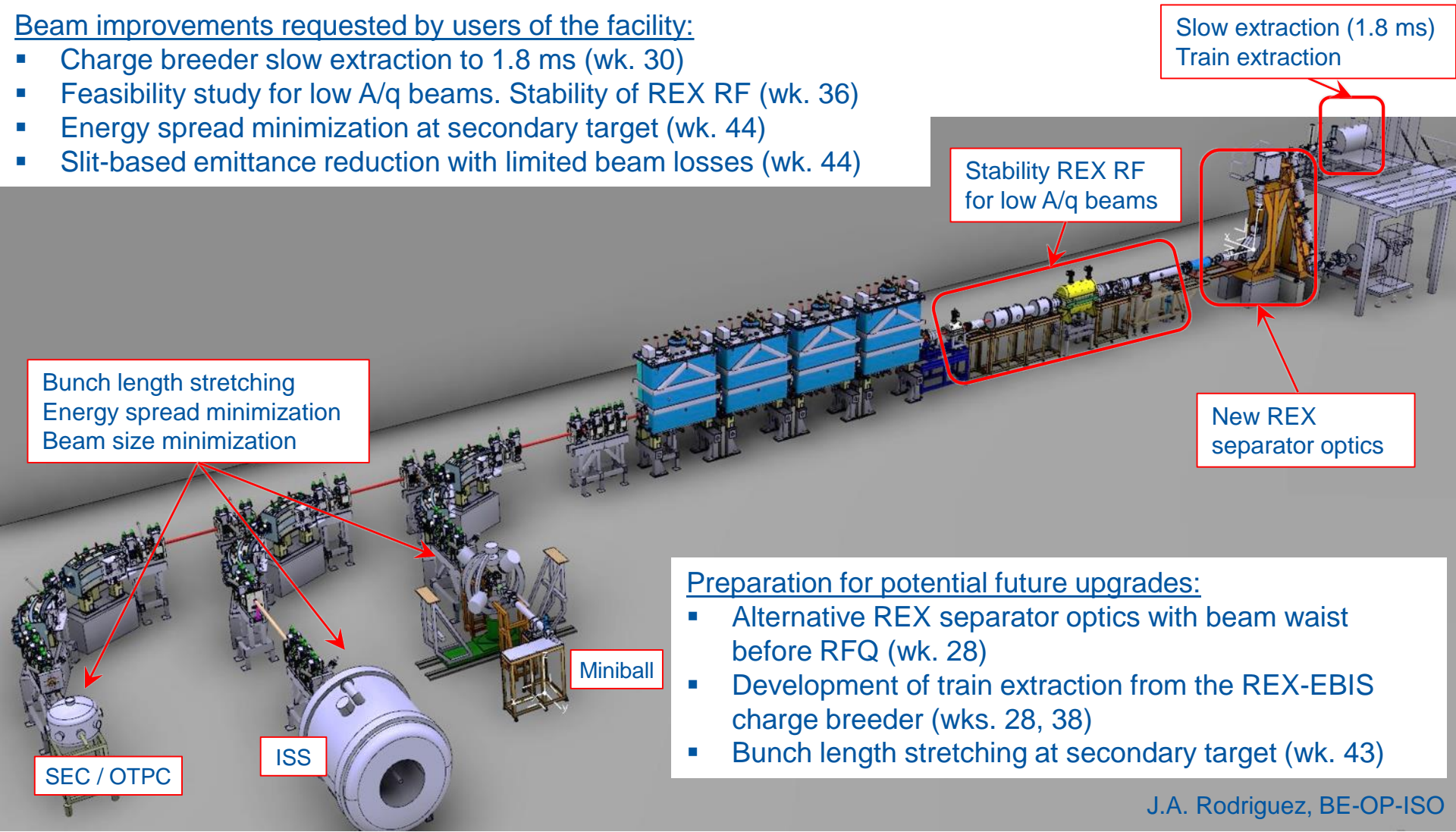
Machine Studies 2020:

Machine development:

- Energy and energy spread measurement in three HEBT lines (wk. 34)
- Transverse and longitudinal phase space characterization and validation of optics models (wks. 35, 43)
- Machine A/q scalability studies (wk. 41)
- Development of beam-based energy gain measurement (wk. 42)

Beam improvements requested by users of the facility:

- Charge breeder slow extraction to 1.8 ms (wk. 30)
- Feasibility study for low A/q beams. Stability of REX RF (wk. 36)
- Energy spread minimization at secondary target (wk. 44)
- Slit-based emittance reduction with limited beam losses (wk. 44)



Preparation for potential future upgrades:

- Alternative REX separator optics with beam waist before RFQ (wk. 28)
- Development of train extraction from the REX-EBIS charge breeder (wks. 28, 38)
- Bunch length stretching at secondary target (wk. 43)

Outline:

- Introduction
- REX/HIE-ISOLDE before LS2
- Improvements after LS2
- Beam Commissioning & Machine Studies 2020
- Summary

Summary:



- The HIE-ISOLDE project (phase 2b) was completed in 2018
Successful high energy Physics campaigns in 2016, 2017 and 2018

- Main issues during these years:
 - 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 and capabilities after:
 - Repair of CM4 - Expected operational values 7.9MeV/u for $A/q=4.5$, 12MeV/u for $A/q=2.5$ (average ~80% of the nominal gradient for the SRF cavities)
 - Additional time will be allocated for the re-commissioning of the cryoplant and the SRF systems – higher stability of the cryo and SRF systems resulting in higher stability of the SRF cavities
 - Additional beam diagnostic boxes and steerers will be installed in REX – address the losses in the Linac
 - REX RF amplifiers have been refurbished – higher reliability
 - Additional and new software will be developed – decrease set-up time and improve operational aspects
 - Additional time will be allocated for the beam commissioning, machine studies and validation of beam optics models in 2020 (early start-up has been approved by the Research Board)

- These investments will result in higher availability and better quality beams at higher energies for experiments at ISOLDE's post-accelerator REX/HIE ISOLDE



**Thank you for your
attention and
Enjoy the Fondue!**





Stress test after physics run on 7 December 2018: cavities locked for a few hours to higher fields

cavity	proposal [MV/m]	Achieved [MV/m]	Stress test [MV/m]
XLL2.1	5	5	6
XLL2.2	5	5	5
XLL2.3	5	5	5.5
XLL2.4	5	5	5
XLL2.5	2	2	2.5
XLH1.1	5.5	4	5.5
XLH1.2	5.5	4.5	6
XLH1.3	5.5	5.5	6
XLH1.4	5.5	4	6
XLH1.5	5.5	5	5
XLH2.1	5	5.5	5
XLH2.2	4	5.5	6
XLH2.3	5	5.5	5.5
XLH2.4	5	5.5	6
XLH2.5	5	5.5	5
XLH3.1	5	4.2	4.5
XLH3.2	5	4.2	4.5
XLH3.3	0	0	0
XLH3.4	5	4.5	5.2
XLH3.5	5	4	5.2

