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Ideas for REX/HIE-ISOLDE Upgrade

Jose Alberto Rodriguez
on behalf of the ISOLDE Operations team

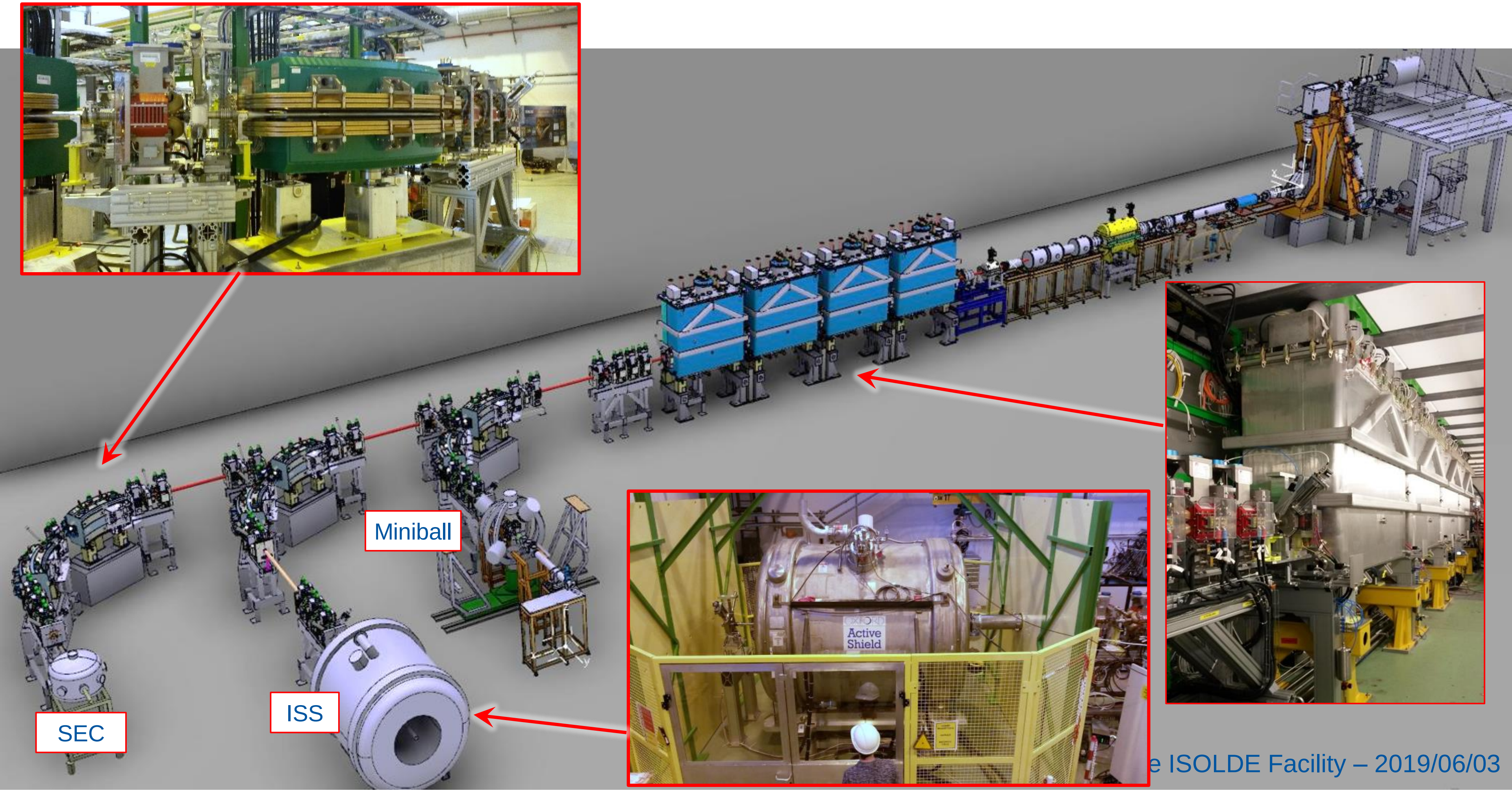
Outline:

- REX/HIE-ISOLDE before LS2
- REX/HIE-ISOLDE after LS2
- Ideas for long-term upgrades
- Summary

REX/HIE-ISOLDE before LS2

Phase 2B of HIE-ISOLDE completed and operational since 2018:

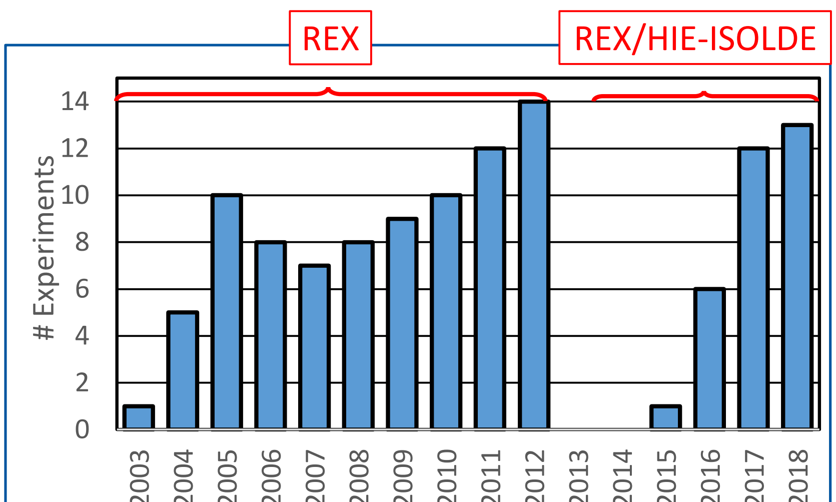
- Four cryomodules
- Three High Energy Transfer Beamlines (HEBT)
- ISS experimental station



REX/HIE-ISOLDE before LS2

Highlights 2018 Physics campaign:

- First radioactive ion beam (RIB) delivered on July 11th
- Campaign ended in Nov. 21st (pre-irradiated target)
- 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 ($^{8}B^{19}F_2$, $^{134}Sn^{34}S$)
- Multiple stable beams to the three experimental stations

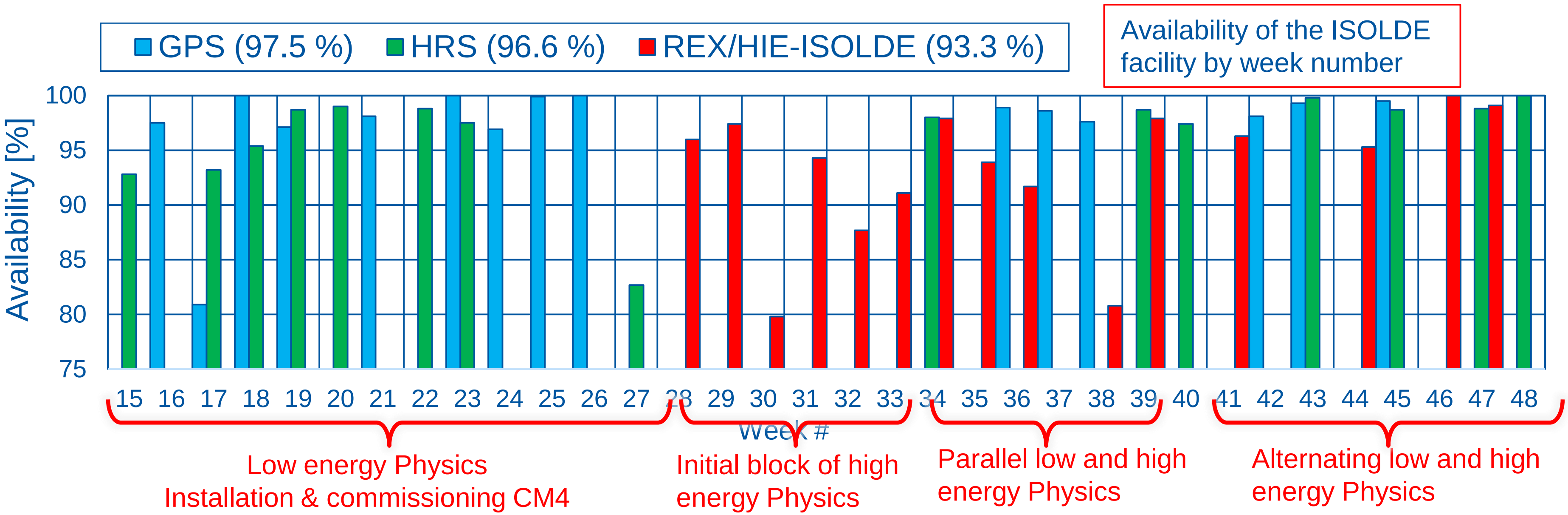


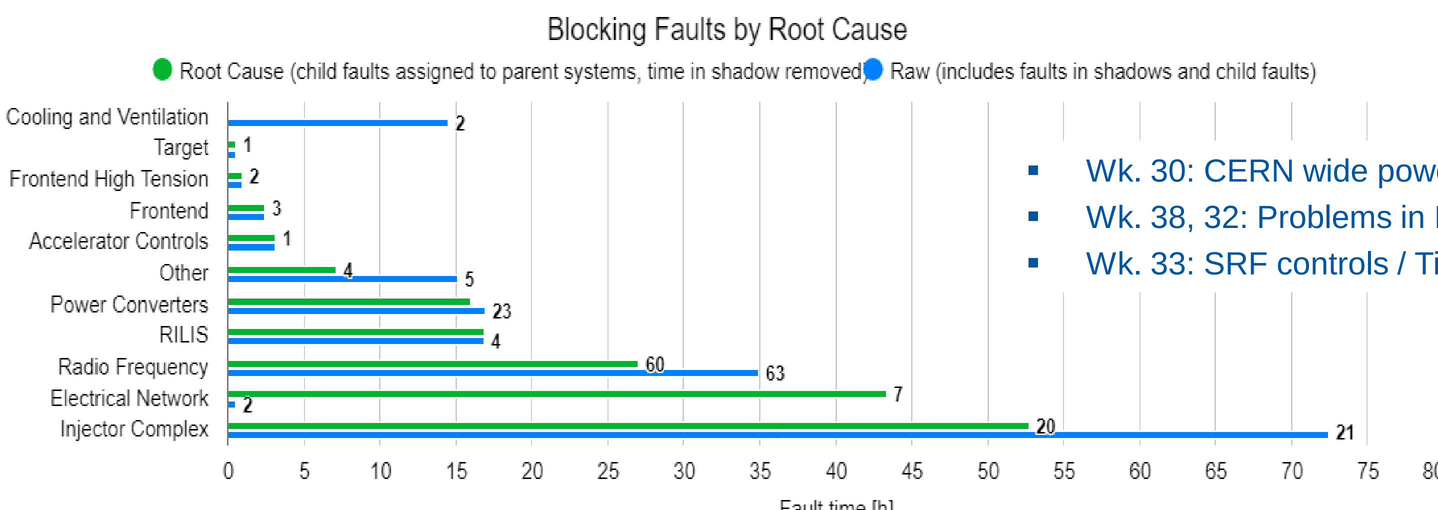
Number of High Energy Experiments at ISOLDE

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



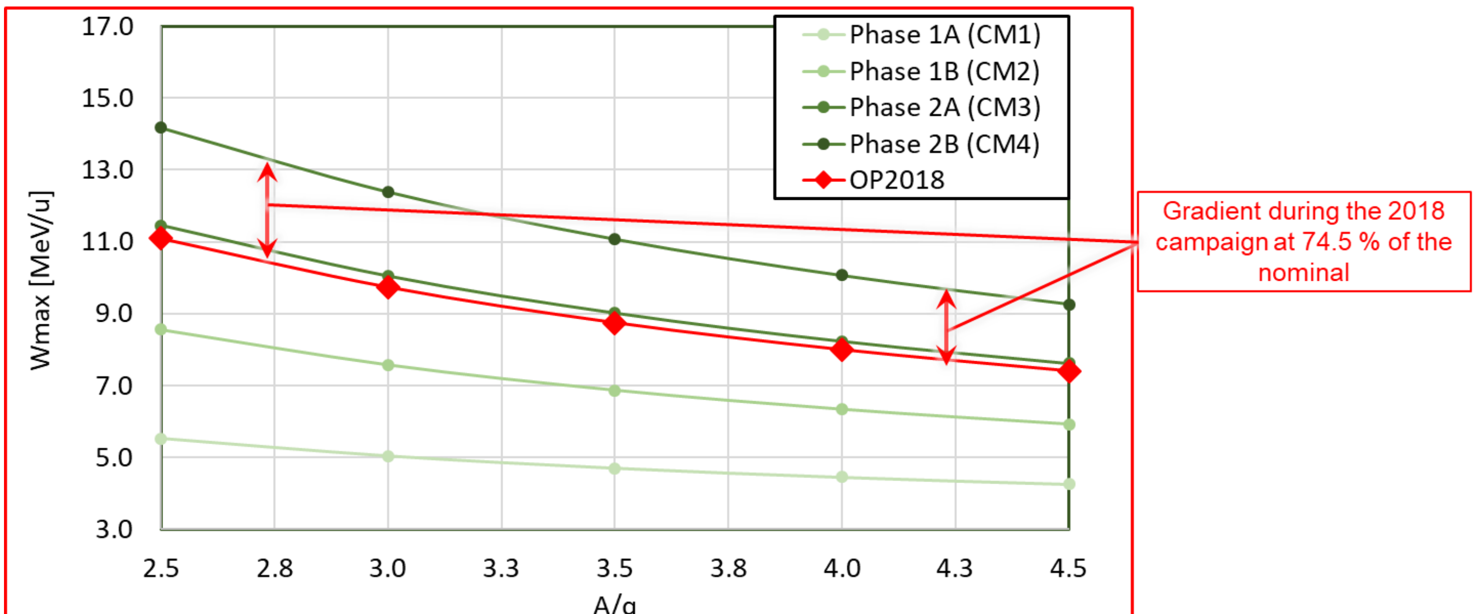


- Wk. 30: CERN wide power cut
- Wk. 38, 32: Problems in Linac2
- Wk. 33: SRF controls / Timing problem with request

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
- Around 15-20 % not understood beam losses
  - 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



Reachable energies for beams with different A/q

Outline:

- REX/HIE-ISOLDE before LS2
- REX/HIE-ISOLDE after LS2
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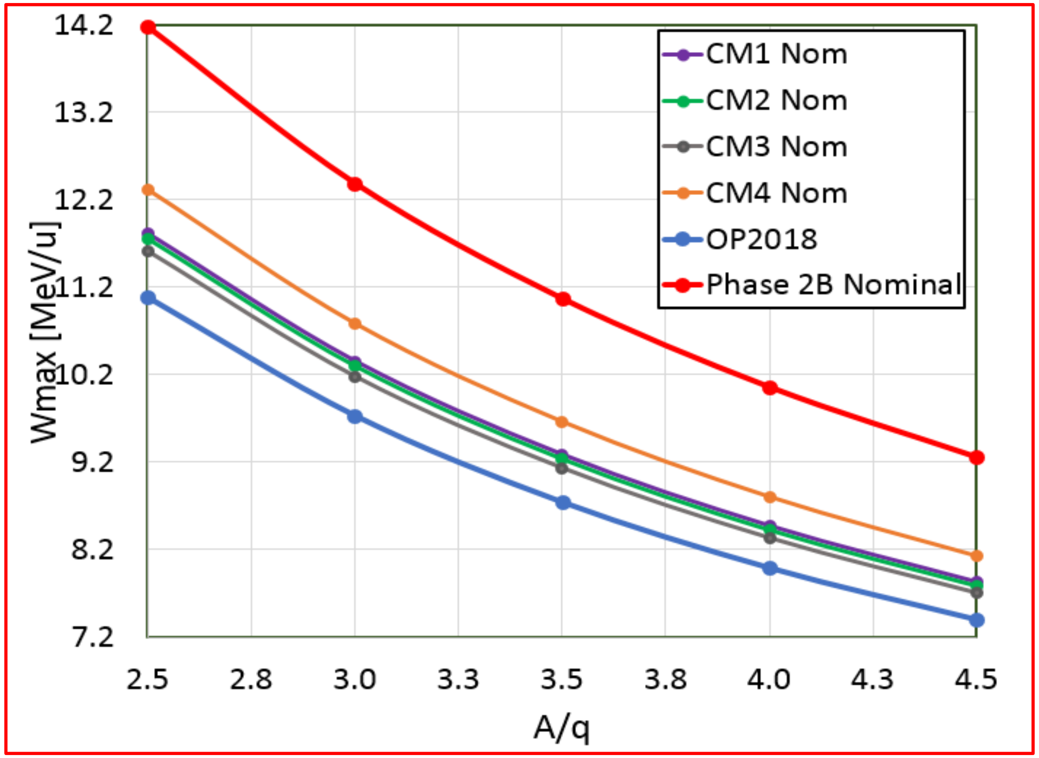
REX/HIE-ISOLDE after LS2

Main issues/worries:

- SRF cavities operating at 74.5 % of nominal gradient
  - CM4 uninstalled and sent back to SM18 (E. Siesling) → Done
  - Cavity SRF18 repair (W. Venturini) → Done
  - Replacement of the two worse performing cavities by the best two spares (W. Venturini) → Decided not to exchange
  - Testing in bunker of SM18 (W. Venturini) → Waiting for bunker to be available
  - Transport back to ISOLDE and installation (E. Siesling) → Scheduled for Jan. 2020



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

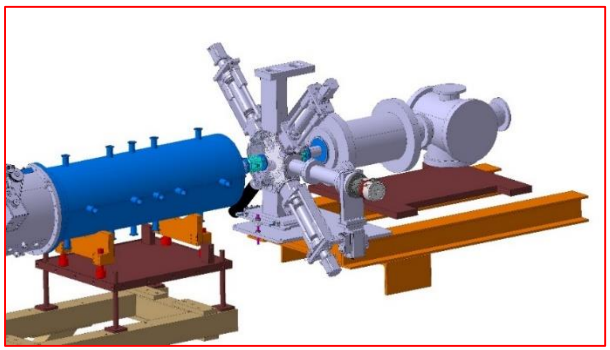
	CM1	CM2	CM3	CM4
CAV. 1	5.0	4.0	5.5	4.2
CAV. 2	5.0	4.5	5.5	4.2
CAV. 3	5.0	5.5	5.5	0.0
CAV. 4	5.0	4.0	5.5	4.5
CAV. 5	2.0	5.0	5.5	4.0
Average	4.4	4.6	5.5	3.4

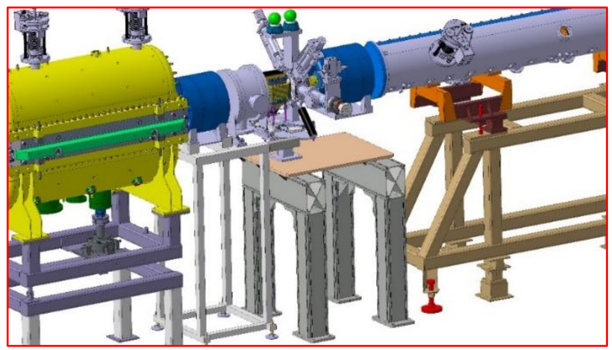
After LS2 (with SRF18 and the rest of the couplers in CM4 repaired and with additional conditioning of some of the other cavities), we hope we will be able to reach 7.8 MeV/u for beams with A/q = 4.5 or 10.4 MeV/u for A/q = 3.0 (~ 80 % nominal gradient)

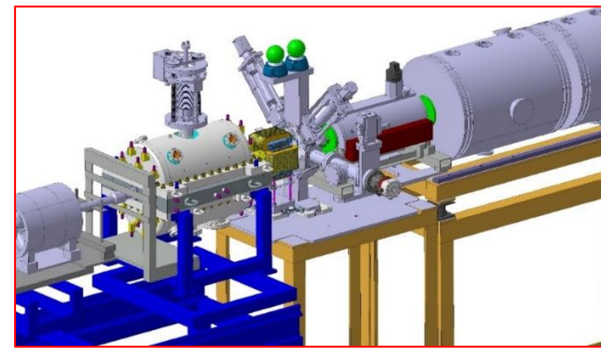
REX/HIE-ISOLDE after LS2

Main issues/worries:

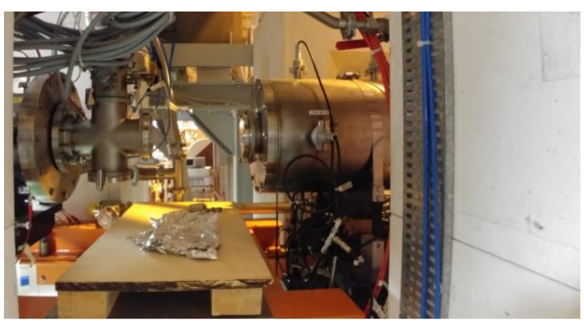
- Around 15-20 % not understood beam losses
  - Aperture check between REX separator and CM1 (E. Siesling) → Done
  - Additional diagnostics and steerers in the REX linac (S. Mataguez) → Scheduled for the beginning of 2020
  - Additional beam commissioning time 2020 requested (E. Siesling) → Waiting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

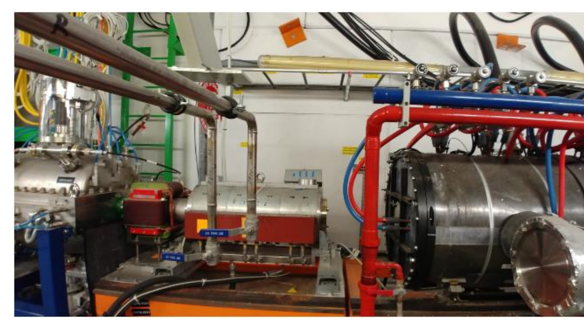






Mechanical drawings courtesy of C. Capelli EN-MME





REX/HIE-ISOLDE after LS2

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Request for schedule change made to the LS2 committee (E. Siesling)

REX/HIE-ISOLDE after LS2

Main issues/worries:

- REX-EBIS electron gun cathode degradation faster than anticipated

  Three approaches being pursued in parallel to address this problem (F. Wenander):

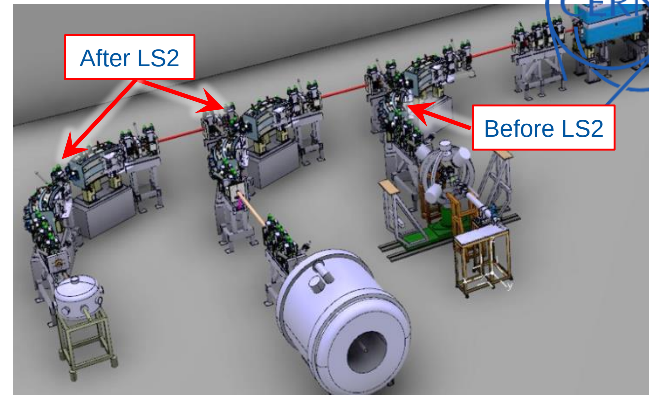
  - Understanding and solving or mitigating the problem with the present cathode
    - Less risky option since there would be no major design changes
    - Spare cathodes available. Cathode replacement could potentially be scheduled
    - Discussions with the manufacturer on-going
  - New immersed gun 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

REX/HIE-ISOLDE after LS2

Main issues/worries:

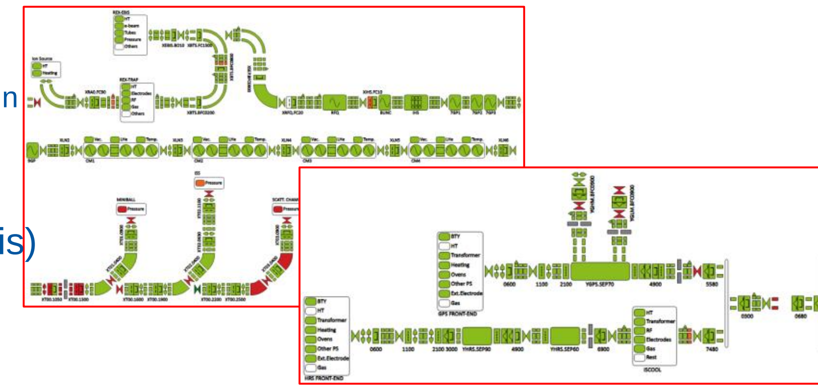
- Trips of SRF cavities after instability of the cryo system
  - Maintenance of the cryo-plant on-going (O. Pirotte) → Scheduled to be completed before end of 2019
  - Setup of automatic controls for transient modes on-going → Scheduled to be completed before end of 2019
  - Additional time for restart 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

REX/HIE-ISOLDE after LS2



Additional planned improvements:

- 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
- Semi-automatic phasing of SRF cavities (E. Piselli)
  - Additional reference set-ups at the beginning of the Physics campaign
  - Less set-up time needed if problems with one SRF cavity appear
- Improvements in beam diagnostics applications (E. Piselli)
- New version of the Fast Beam Investigation (FBI) (E. Fadakis)
  - Full integration of C2MON and Grafana
  - More functionalities and additional views will be available
- X-ray monitors for each of the cryomodules
  - Better diagnostics on the field emission of the SRF cavities
  - Potential gains in cavity gradients
- Major refurbishment of REX RF amplifiers (C. Gagliardi, L. Timeo)
  - Remote and automatic re-start after trip on-going
  - Several sources of problems identified and fixed
  - Better power and gradient calibrations
  - Higher peak powers available (90 kW)
  - New cooling for the IH structure
  - Potential more reliable operations and less down time
- Validation of beam optics models (J.A. Rodriguez, N. Bidault)
  - Important time investment during the recommissioning in 2020



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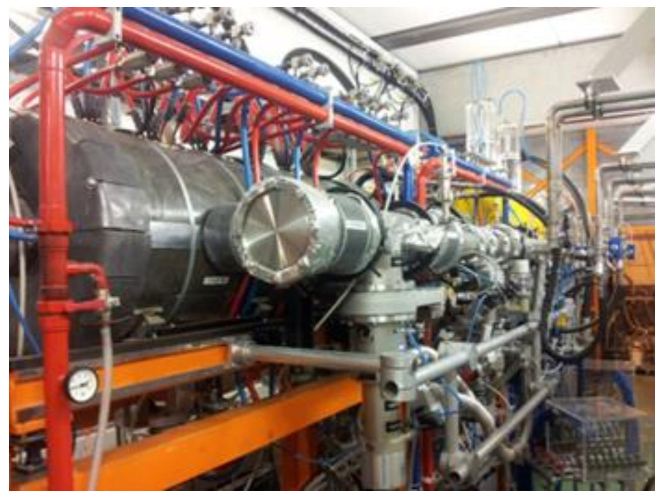
REX linac

The REX normal conducting linac:

- Beam from the charge breeder with 5 keV/u energy is accelerated to 2.85 MeV/u
- Seven RF structures: f = 101.28 MHz (except for 9gap at 202.56 MHz) up to 10% duty cycle
- Charge state dynamic acceptance: 2.5 < A/q < 4.5

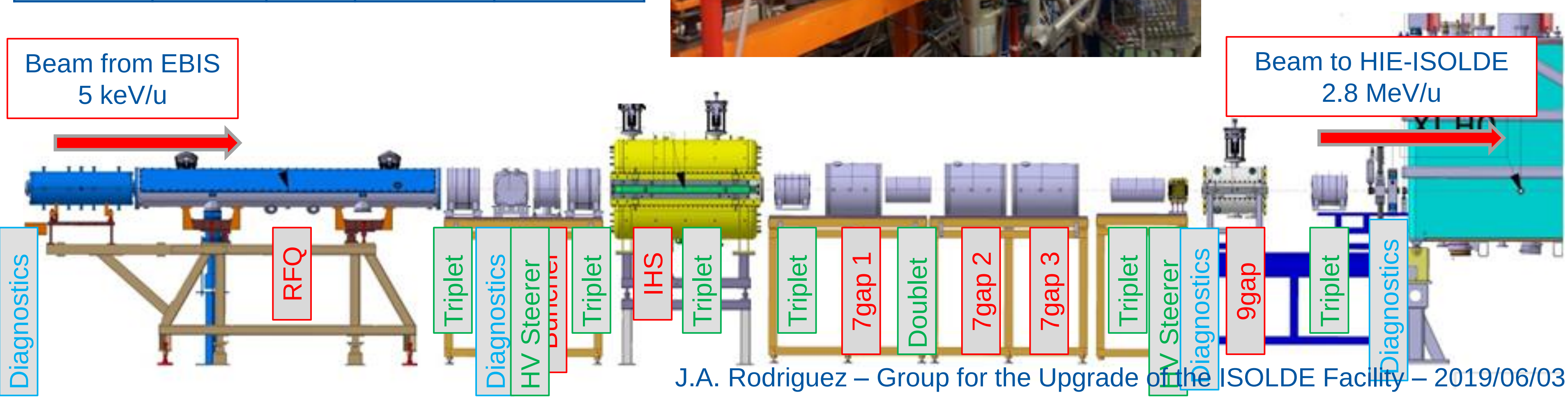
RF Systems:

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



Magnets:

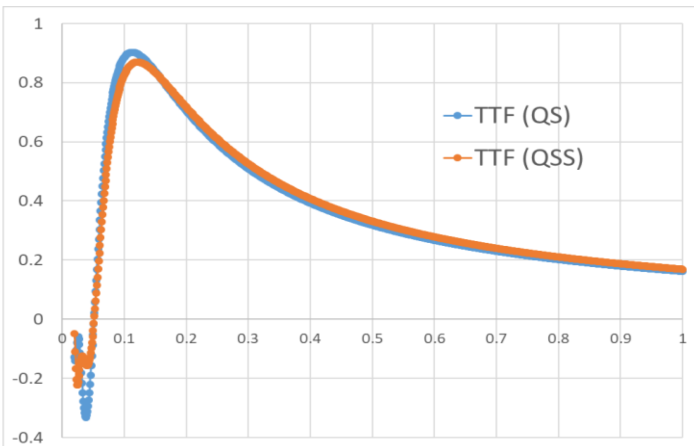
Triplets	6
Doublets	1
Steerers	2H, 2V



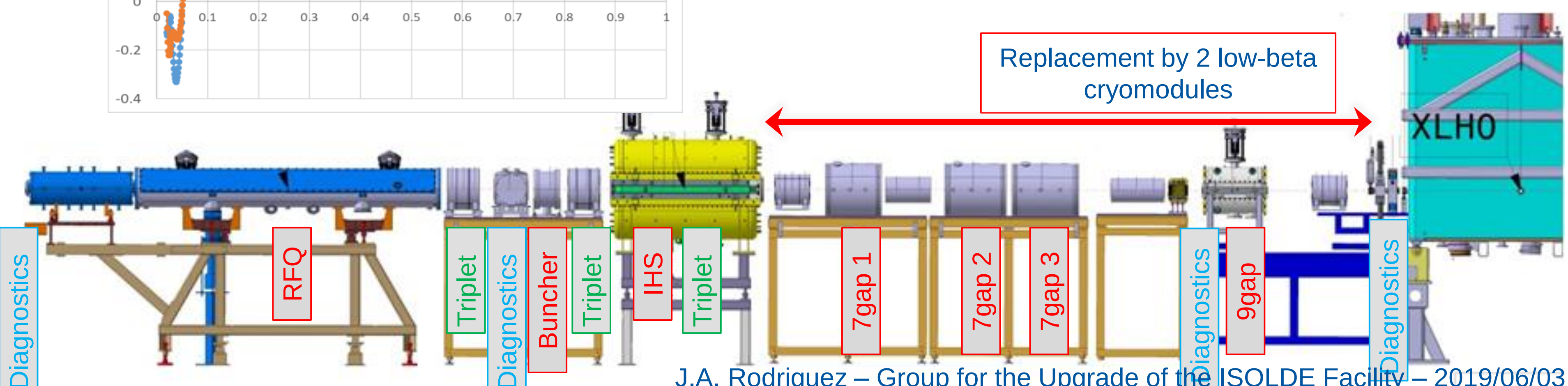
HIE Phase 3

- Replacement of the 9gap and the 3x7gap structures by two low-beta cryomodules
- First high-beta cryomodule moved to the end of the tunnel
- Energy: 10 MeV/u for A/q = 4.5, 16.5 MeV/u for A/q = 2.5
- Possible pre-buncher and chopper to increase bunch spacing

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

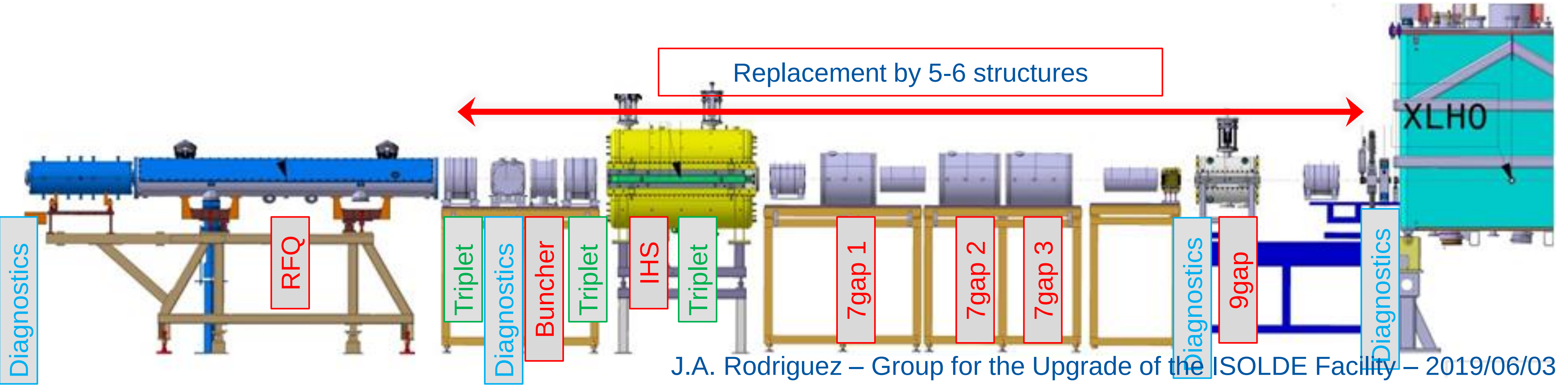


	Phase 1-2	Phase 3
# of cavities	20	12
# of solenoids	4	4
f [MHz]	101.28	101.28
Geometrical beta (β_g)	10.3	6.3
E_{acc} [MV/m]	6.0	6.0
Quality factor (Q_o)	$> 5 \cdot 10^8$	$> 3.2 \cdot 10^8$
P [W] at 4.2 K for E_{acc}	< 10	< 7
Length [m]	0.3	0.195
Beam aperture diameter [cm]	2.0	2.0
Maximum Transit Time Factor (TTF)	0.9	0.85
E_{peak} / E_{acc}	5.6	5.4



Normal conducting upgrade

- Replacement of the 9gap, the 3x7gap and the IH structures by 5-6 new normal conducting structures
- Possible pre-buncher and chopper to increase bunch spacing
- This is only a possibility worth studying. At this point, only qualitative analysis. Full study is needed



HIE-ISOLDE Phase 3 vs. Normal Conducting

Beam intensity and time structure considerations:

HIE-ISOLDE Phase 3:

- Improved beam dynamics resulting in lower beam losses
- Maximum A/q still at 4.5 (limited by the IH structure)

Normal conducting upgrade:

- Improved beam dynamics resulting in lower beam losses
- Maximum A/q could be pushed to 5.5 (limited by the RFQ and REX-EBIS high tension)
  - Lower charge states could be accelerated.
    For example: $^{206}Hg^{38+}$ (A/q = 5.421) instead of $^{206}Hg^{46+}$ (A/q = 4.478)
  - Very significant increase in beam intensity (i.e. higher REX-EBIS efficiency)
  - Higher repetition rates and better time structure (i.e. reduction in the optimum breeding time)

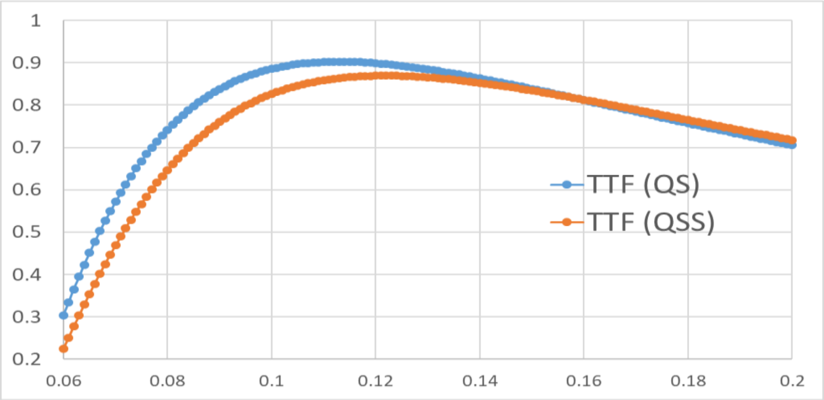
HIE-ISOLDE Phase 3 vs. Normal Conducting

Beam energy considerations:

HIE-ISOLDE Phase 3:

- Continuous energy changes above 1.2 MeV/u
- Possible beam deceleration down to ~ 0.6 MeV/u

	E_o [MeV/u]	β_o [%]	E_f [MeV/u]	β_f [%]
Nominal – A/q = 4.5	3.5	8.6	10.0	14.3
Nominal – A/q = 2.5	5.4	10.7	16.5	18.6
80% nominal – A/q = 4.5	3.0	8.1	8.2	13.0
80% nominal – A/q = 2.5	4.8	10.1	13.7	16.7



Normal conducting upgrade:

- These estimates are based on a rough initial analysis
- Final number depend on the design and the number of cavities as well as on the amplifiers peak powers
- Only discrete energy steps between 0.3 and 3.5 MeV/u

	E_o [MeV/u]	β_o [%]	E_f [MeV/u]	β_f [%]
Nominal – A/q = 5.5	3.5	8.6	8.6	13.2
Nominal – A/q = 4.5	3.5	8.6	10.0	14.3
Nominal – A/q = 2.5	3.5	8.6	14.6	17.0
80% nominal – A/q = 5.5	3.5	8.6	7.5	12.5
80% nominal – A/q = 4.5	3.5	8.6	8.5	13.0
80% nominal – A/q = 2.5	3.5	8.6	12.5	16.0

HIE-ISOLDE Phase 3 vs. Normal Conducting

Cost and other considerations:

HIE-ISOLDE Phase 3:

- Upgrade of the cryoplant necessary
- R&D for new low-beta cavity required
- Low beta cryomodule design needed
- Cryoline and other ancillary equipment already in place
- Longer set-up times than for the normal conducting option (i.e. higher operational cost)
- Possibly less AC power consumption (i.e. lower operational cost)
- In-vacuum triplet in the IH structure will remain a very weak point

Normal conducting upgrade:

- Possible spreading of the cost over a longer period of time
    - RF cavities and 2-3 amplifiers initially
    - Four REX amplifiers could be used for a few years and replaced later
- Shorter set-up times than for the superconducting option (i.e. lower operational cost)
- Possibly more AC power consumption (i.e. higher operational cost)
- Possibly lower maintenance cost

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Summary:

- Main improvements after LS2:
  - CM4 partially repaired
  - Additional beam diagnostics and steerers in REX
  - Additional time to restart and recommission the cryoplant and the SRF systems
  - Thorough beam commissioning. Validation of beam optics models
  - Semi-automatic phasing application
  - Improved controls for the beam diagnostics

- Long-term upgrade of REX:
  - Normal conducting option should be evaluated. Potentially:
    - Lower cost
    - A/q as high as 5.5 (i.e. higher beam intensities specially for heavier beams)
  - Both normal conducting and superconducting upgrades will require years. In my opinion, we should start working on them very soon

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