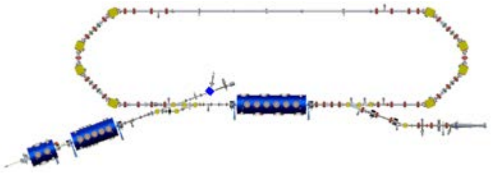
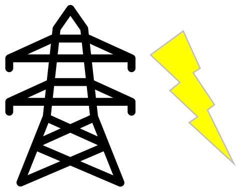
How sustainable is accelerator-based science?

An ERL is per definition efficient regarding beam power → How to improve the remaining power consumption → A possible program at SEALab



- Recovery beam power



From grid to accelerator experiment:

- RF power consumption
- Cryo-plant power consumption (Carnot)
- Power supplies, cooling water, air conditioning

- RF power ~ $\Delta\omega^2$ detuning and beam-loading transients
  → control microphonics
  → operate at high Q_L

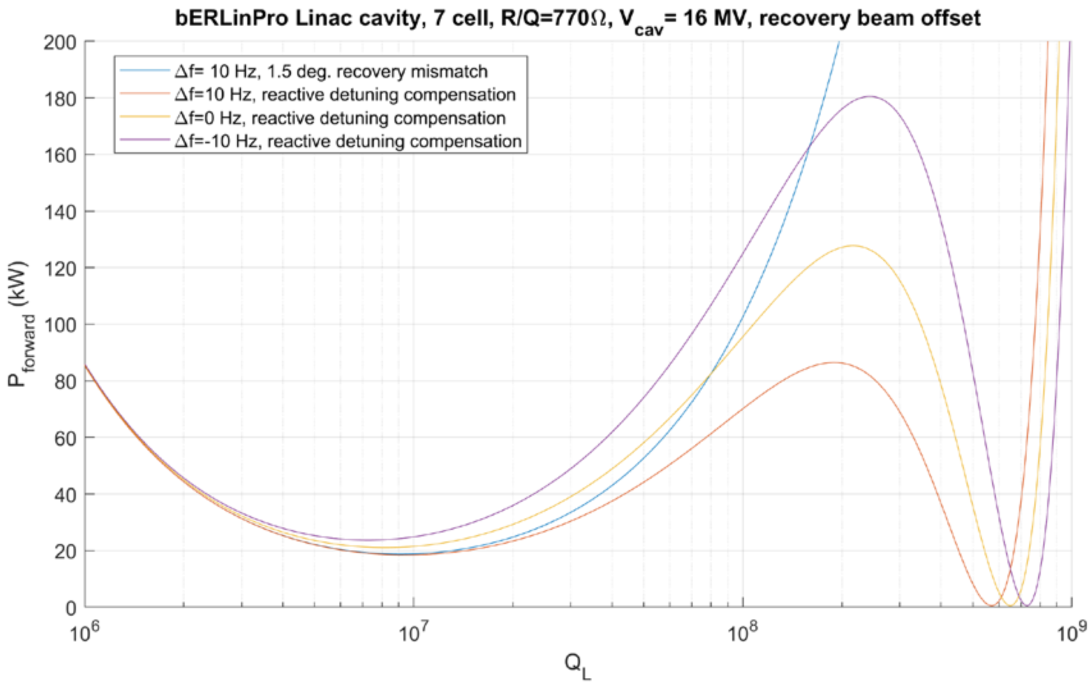
- Cryogenic wall plug power ~ $(300K - T)/T$ and ~$1/Q_0$ by dissipated heat
  → operate at higher T and improved SRF surface resistance:
  e.g. Nb_3Sn ... ess cooling power

G. Ciovati, JLab

- Detuning compensation by ferro-electric fast reactive tuner
- Optimal cavity field control by AI/ML methods → jitter control
- Allow a test location with beam for higher T_C material coated cavity
- Potential partners: CERN, IJCLab, DESY, MESA, STFC, JLab(ext), MINERVA (MYRRHA), ESS, Lancaster

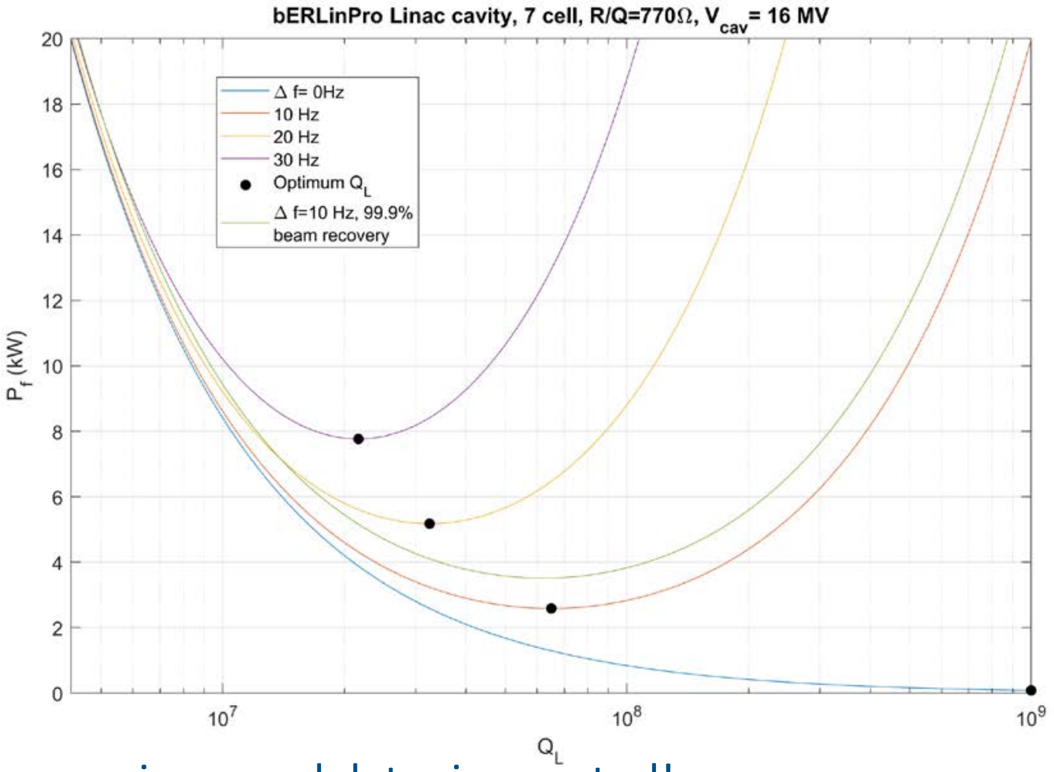
The problem and cure

Single pass ERL case, recovery variations mismatch (1.5 deg.)



Single pass Linac case, ERL 100% recovery, 99.9% recovery 100 mA

RF budget



<u>The higher the loaded Q, the lower the power consumption given an improved detuning control!</u>

In ERLs, there is also an uncertainty by variations of the recovered beam

→ Control tuning, beam current, arrival time, field level and loaded Q!

SRF cavities at high QL become a complex system in interplay with beam → AI/ML assistance helpful, machine protection becomes an issue at high currents!

TA#1: Energy savings from RF power→LLRF(+SSA)

	Task 1 High loaded Q CW operation					
Total	Achievement	Personnel 1.25/1.25	Invest 60/40	Min	Nom	Amb
Year 1	Assessment of existing field controllers in CW	0.75		x	x	x
Year 2	Review+develop new techniques to characterize microphonics	0.5		x	x	x
Year 3	Long pulse with high E_{acc}, high Q_L, Long pulse with optimum tuning	0.75			x	x
Year 4	High loaded Q CW with piezo+FRT	0.5				x

Understand+Improve CW/long pulse LLRF control

	Task 2 Mechanical tuner + piezo based detuning control					
Total	Achievement	Personnel 0.75/0.75	Invest 60/40	Min	Nom	Amb
Year 1	Assessment of existing resonance controller in CW	0.5		x	X	x
Year 2	Develop Improved resonance controller	0.5			x	x
Year 3	Test improved detuning controller schemes	0.25			x	x
Year 4	Test improved controller with beam	0.25			x	x

Improve classic mech. tuning control

A. Neumann for TA#1

TA#1: Energy savings from RF power→LLRF(+SSA)

	Task 3 FE Fast Reactive tuner based detuning control (+beam transient)					
Total	Achievement	Personnel 0.75/0.75	Invest 40/40	Min	Nom	Amb
Year 1	FRT integration studies	0.5		x	x	x
Year 2	Firm+software integration, first single cell test	0.5		x	x	x
Year 3	Improve controller scheme, firmware development	0.4			x	x
Year 4	Full horizontal multi-cell test	0.1			x	x

FE-FRT LLRF control

	Task 4 Integrate into ML/AI/digital twin environment					
Total	Achievement	Personnel 1.5/1.5	Invest 50/100	Min	Nom	Amb
Year 1	Assessment of ML/AI techniques for LLRF, ML based methods for diagnostics in LLRF (Quench...)	1		x	x	x
Year 2	Cavity simulator based on digital twin	1			x	x
Year 3	Test in HTS	0.75			x	x
Year 4	Test with beam (e.g. SEALab injector)	0.25				x

AI/ML methods to improve performance

The sum

- TA#1 LLRF requires more personnel than actual invest as cavity physics, control theory, AI/ML expertise, firmware and software programming need to be tackled
- The laboratories can provide matching by part-time involved personnel: RF + LLRF eng./scientists, personnel to run cavity/beam tests, support programming
- The laboratories can also provide matching funds by providing existing LLRF equipment of the state of the art level
- TA#1 has a strong commitment towards the FE-FRT part of this TA, but also needs to demonstrate the operation with FRT and classic tuner methods at high Q_L

In total we estimate: 8.5 FTEy for this part, from which half is matching by the corresponding institutes (here we already underestimate some testing effort)
3.75 would be an absolute minimum program, 7.75 nominal, 8.5 ambitious
→ 425 k€ for ambitious version in personnel

For the invest from Horizon, we ask about 250 k€, where 180 k€ are matching funds. If real operation cost are assumed, the matching funds are much higher. Here, only the minimum program would ask for zero invest from Horizon.

Labs involved: DESY, HZB, CERN (FRT), IJCLab, MYRRHA, Lancaster, ESS (tbc)

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