PERLE: A powerful Energy Recovery Linac at Orsay

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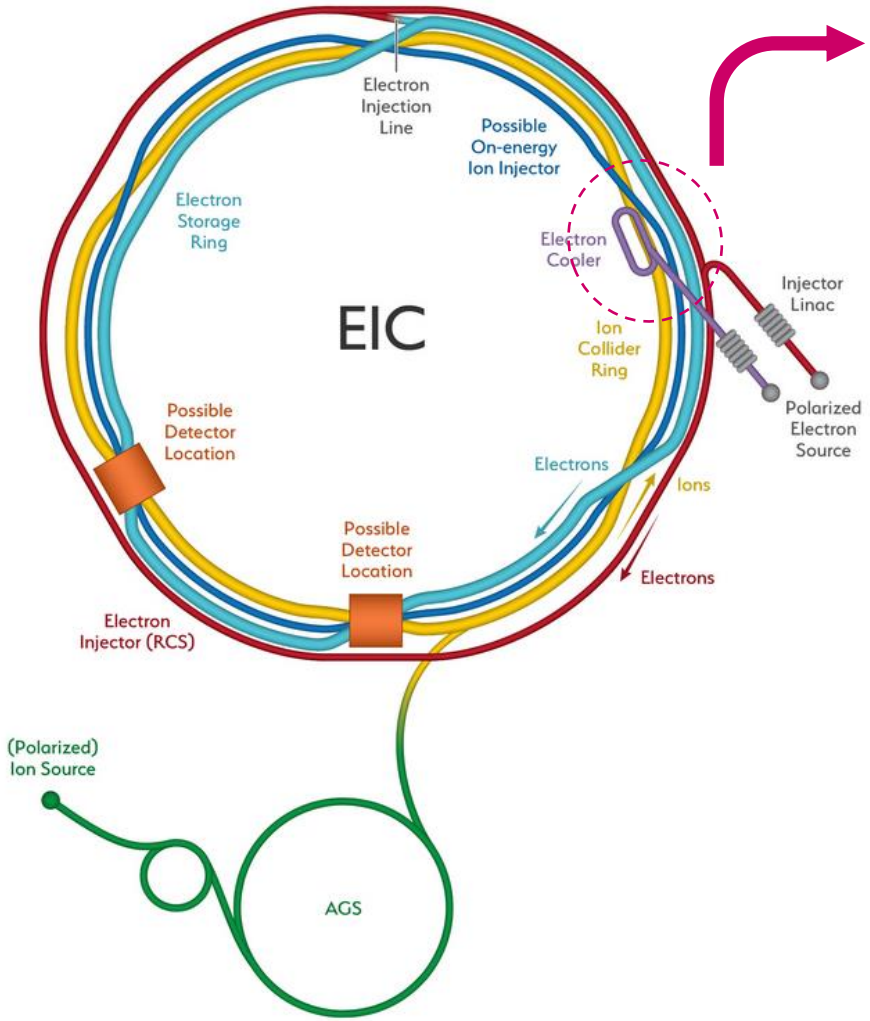
EIC Workshop, 7-9 October 2020

Introduction:



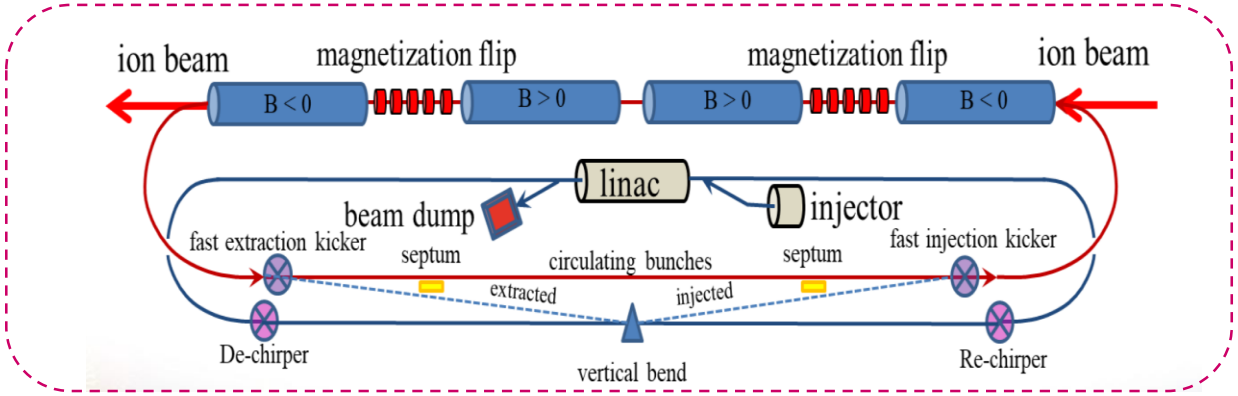
Electron Cooler: reduction and preservation of transverse and longitudinal emittance of ion beam in presence of mechanisms which cause emittance growth: the Intra Beam Scattering (**IBS**).

Challenge for EIC: Large proton energies up to 300 GeV
→ Electron currents required: **order of Ampere**!

- No electron source deliver CW electron currents in this range with the required beam brightness.
- Very high RF power needed to generate ampere beams of up to 150 MeV.

→ Superconducting Energy Recovery Linac techniques are need for accelerating the electrons.

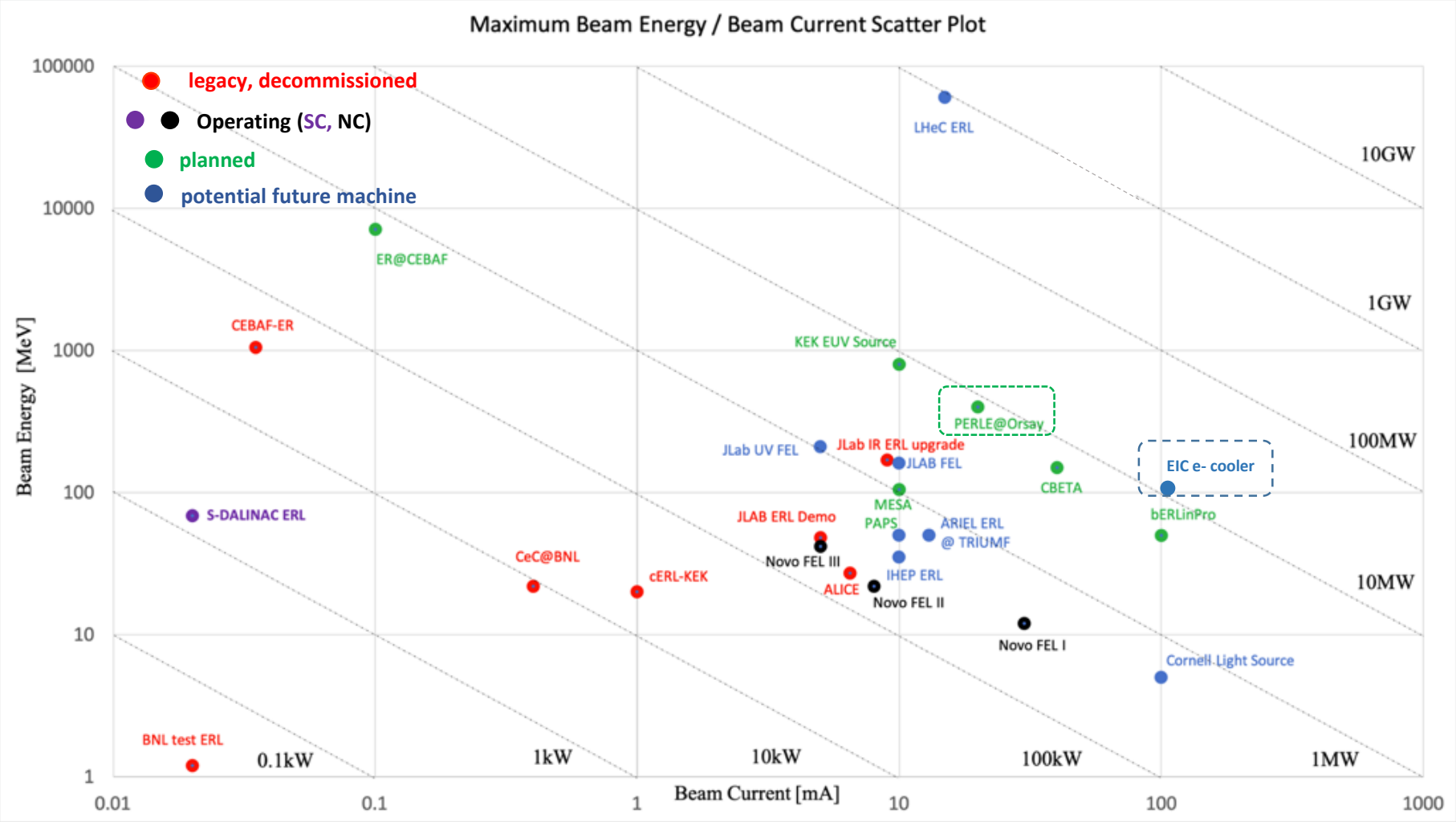
Introduction:



Typical beam parameters for such ERL:

- Energy: 150 MeV
- Charge per bunch: 1- 1.5 nC
- Peak current: 150 A
- Average current: 100 to 150 mA
- Normalized emittance: 1- 1.5 mm mrad
- RMS energy spread ~ 0.01%

Global ERL landscape



Introduction to PERLE

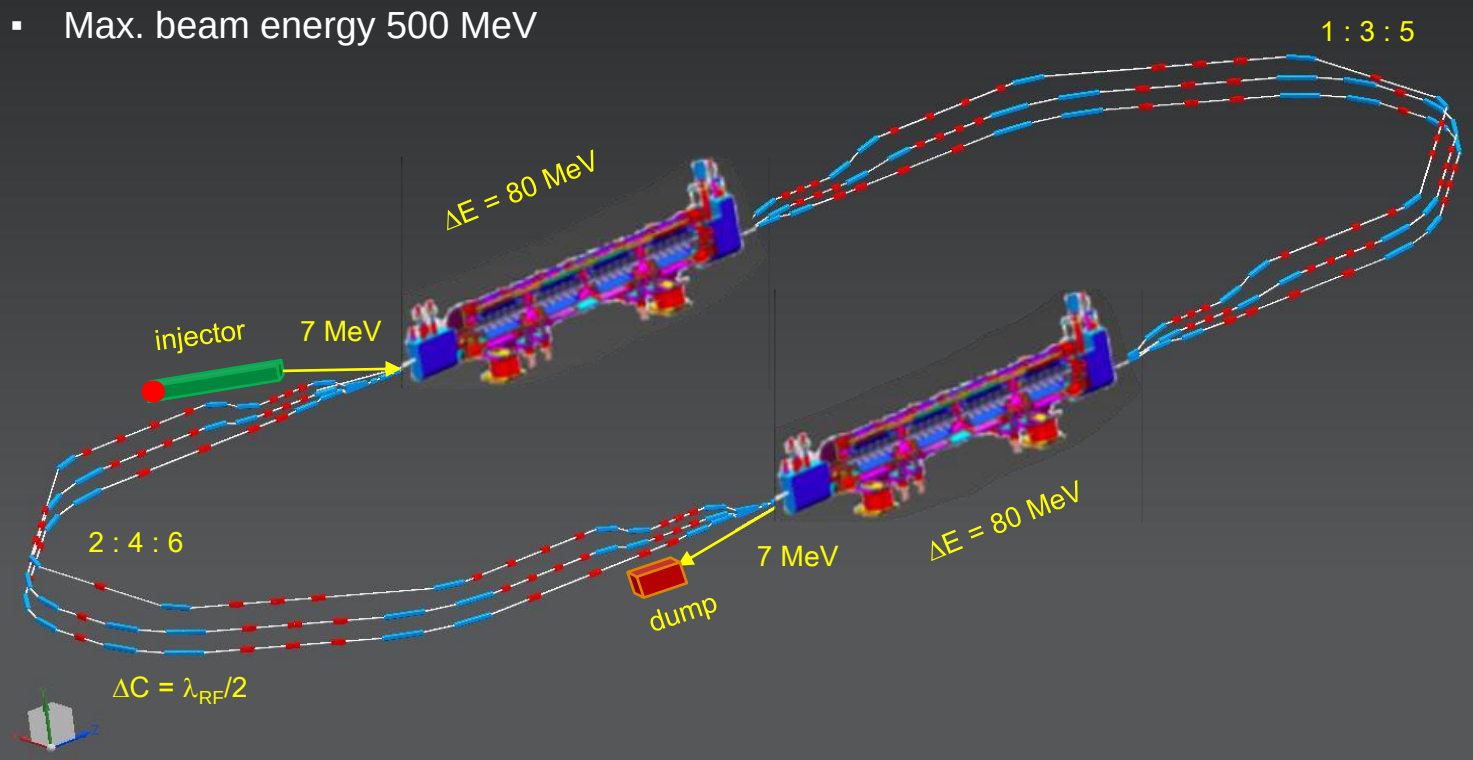
PERLE: A proposed 3 turns ERL, based on SRF technology, to serve as testbed for studying, testing and validating a broad range of accelerator phenomena & technical choices for future projects.

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

[2] J.L. Abelleira Fernandez et al, " A Large Hadron Electron Collider at CERN: Report on the Physics and Design Concepts for Machine and Detector ", J.Phys. G39 (2012) 075001, arXiv:1206.2913

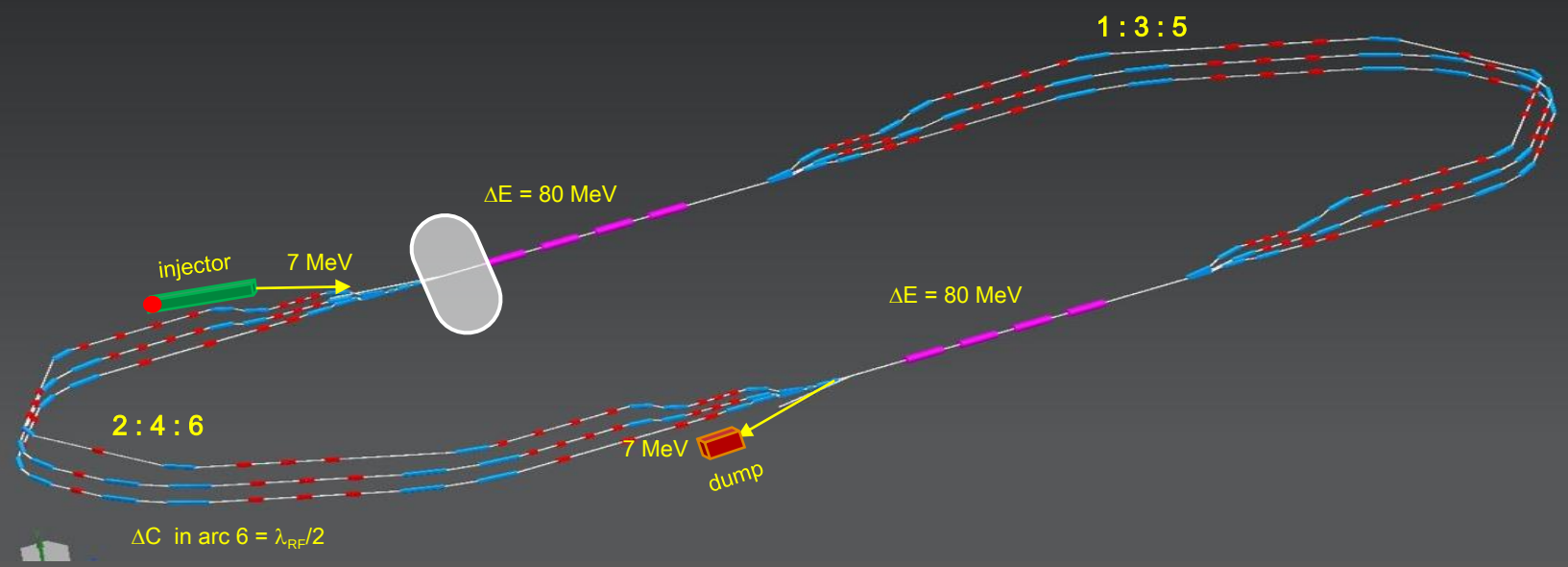
PERLE Configuration

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (160 MeV/turn)
- Max. beam energy 500 MeV



PERLE Configuration

Three passes ‘up’ to reach the maximum energy

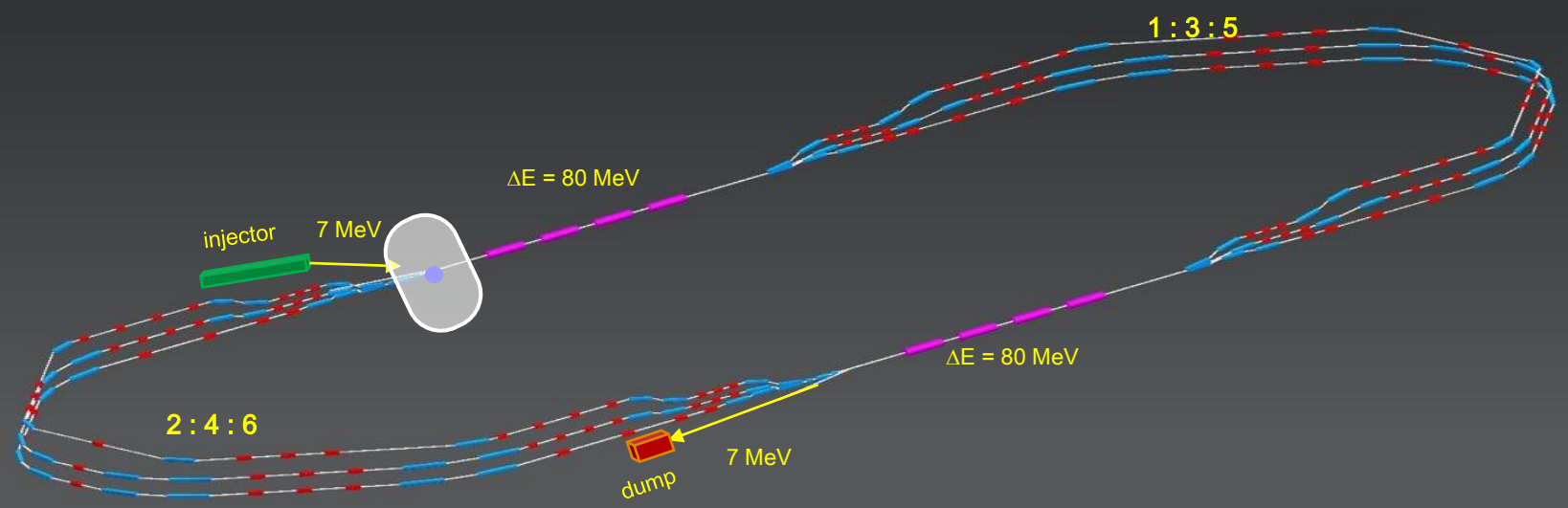


Electron beam at maximum energy could be used for:

- Elastic electron-proton scattering with polarised beam (Particle physics)
- Exploration of proton densities in exotic nuclei by electron scattering (Nuclear physics)
- Gamma ray production between 0.2 and 5 MeV (wide applications in Photo-nuclear physics),

PERLE Configuration

Three passes ‘down’ for energy recovery



Several benefits from this manipulation:

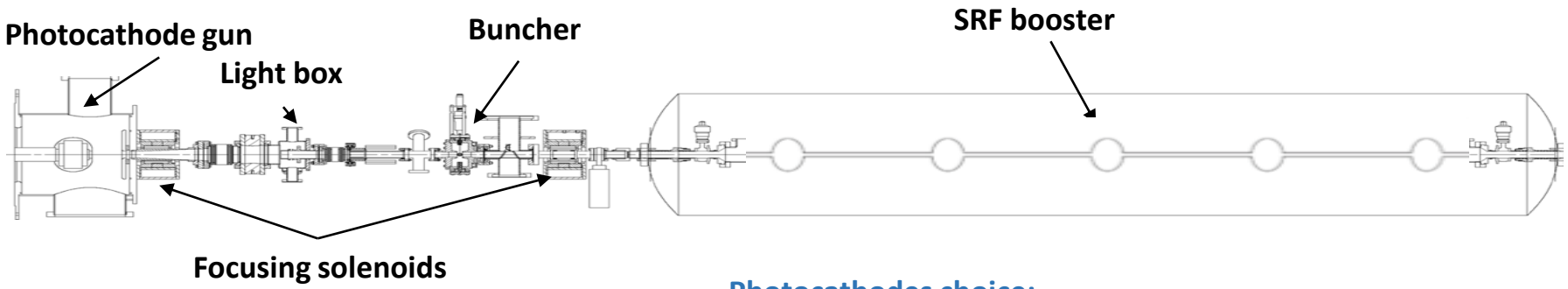
- The required RF power (and its capital cost and required electricity) is significantly reduced to that required to establish the cavity field and make up minor losses.
- The beam is constantly renewed: never reach equilibrium state --> provides flexibility to adapt beam properties for specific applications.
- The beam power that must be dissipated in the dump is reduced by a large factor.

PERLE injection line

Courtesy to B. Militsyn & B. Hounsell

It consist of:

- A DC photoemission electron gun (The ALICE DC gun to be upgraded).
- A bunching and focusing section: 401 MHz normal conducting buncher cavity placed between two solenoid.
- A superconducting booster with five 802 MHz cavities individually supplied and controlled on amplitudes and phases.
- Merger to transport the beam into the main LINAC,
- Beam diagnostics to be placed between components.



Photocathode laser choice:
Nd:YAG laser (532 nm) or Ti:Sapphire laser (400 nm).

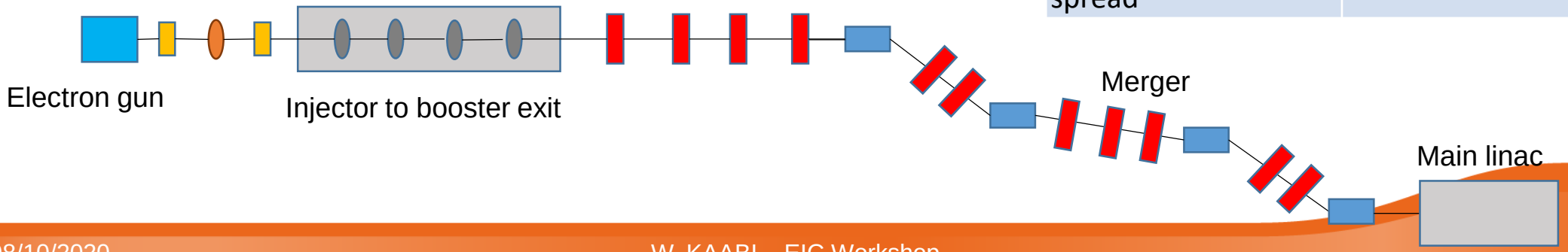
Photocathodes choice:

- **Sb-based photocathodes (unpolarized electrons) operated at 350 kV**
- **GaAs photocathodes (polarized electrons) operated at 220 kV**

PERLE injection line

- The PERLE injector must deliver a beam of sufficient quality and at high average current.
- The beam quality in an ERL is source limited which means that it is never better than it is at the cathode. The goal of the injector is to preserve this emittance as much as possible.
- The injector breaks down into three subcomponents
  - 350 kV DC electron gun
  - Injector (Gun to booster exit)
  - Merger

	PERLE Parameters
Injection energy	7 MeV
Bunch charge	500 pC
Bunch repetition rate	40.1 MHz
Unpolarised current	20 mA
RMS bunch length	3 mm
Emittance	< 6 π·mm·mrad
Uncorrelated energy spread	< 10 keV

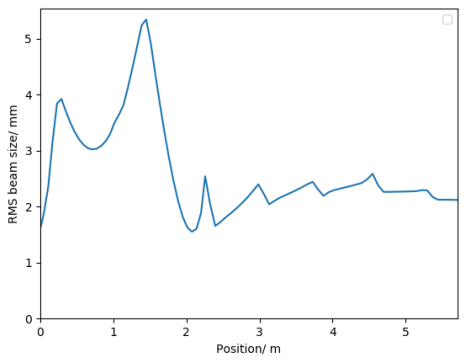


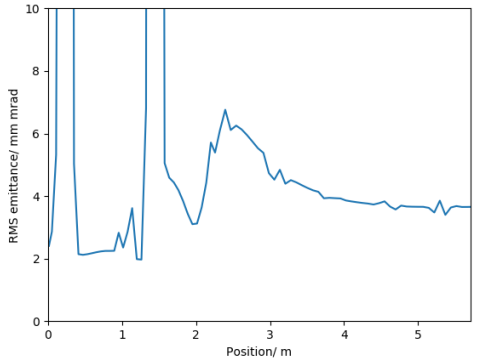
PERLE injection line

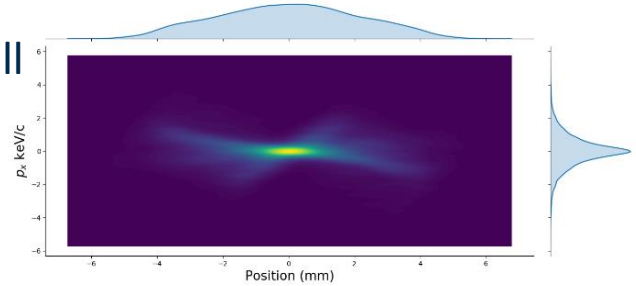
Electron source to booster exit optimisation:

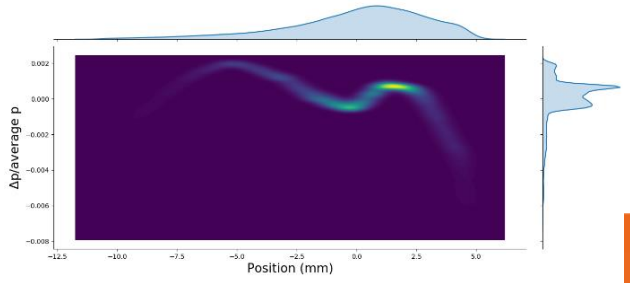
- The ALICE electron gun electrode geometry has been re-optimised for PERLE's new requirements.
- An optimisation was done with a 5 cavity booster linac from the cathode to the booster exit. The results can be seen on the right.
- The current optimisation meets the specification at this point.
- It is likely the booster design will be switched to a 4 cavity design.
- Both the gun and injector to booster exit will probably be iterated at least once more.

Achieved bunch parameters	
Transverse emittance	3.7 mm mrad
Bunch length	3.0 mm
Energy	7.0 mm





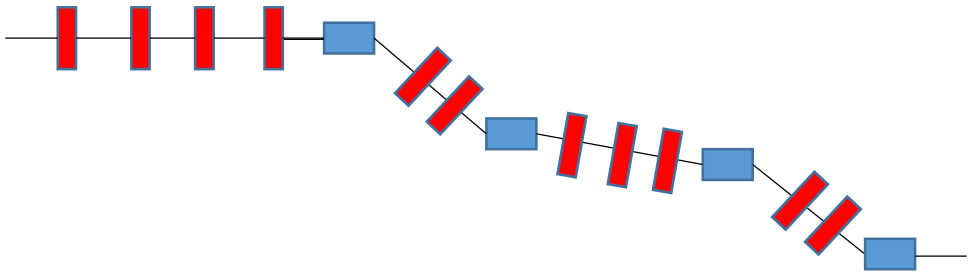


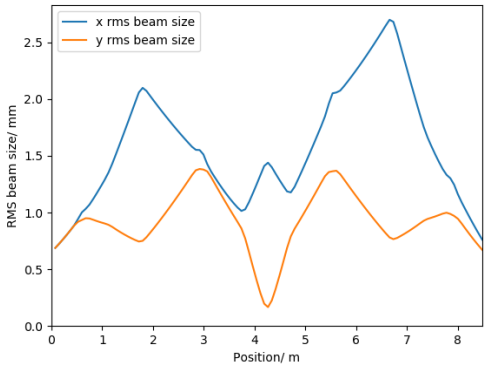


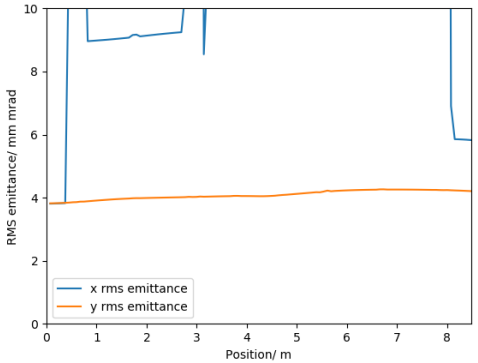
PERLE injection line

The merger study:

- The merger is the current area of development at the moment.
- It is the section which transports the 500 pC beam at 7 MeV to the main loop.
- Space charge is still significant and will need to be managed to prevent significant degradation to the emittance.
- 4 dipole schemes are currently being investigated as they have the potential to mitigate the effects of space charge on the dispersion and the consequent emittance growth.



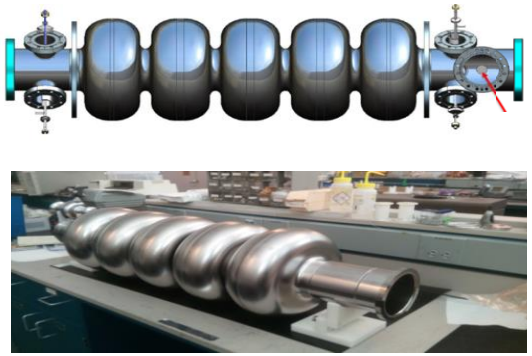


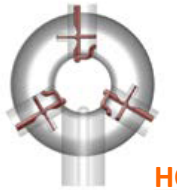


PERLE SRF System development

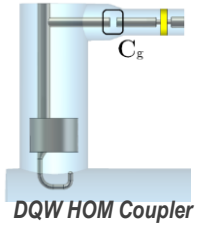
Courtesy to F. Marhauser

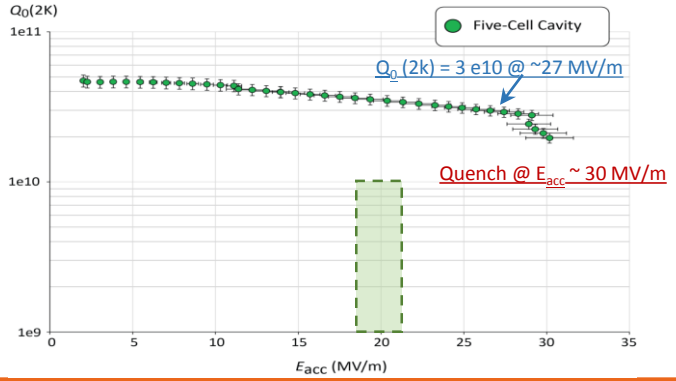
Design and prototyping of a **full dressed SRF cavity**: demonstration of level of SRF performance required in CW operation, high-average current environment, adequate damping of **HOM**.

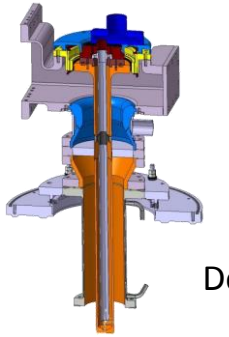


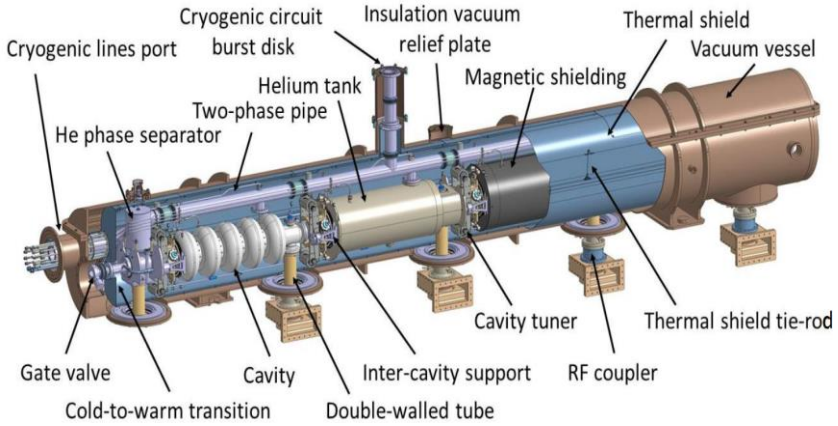


HOM coupler study







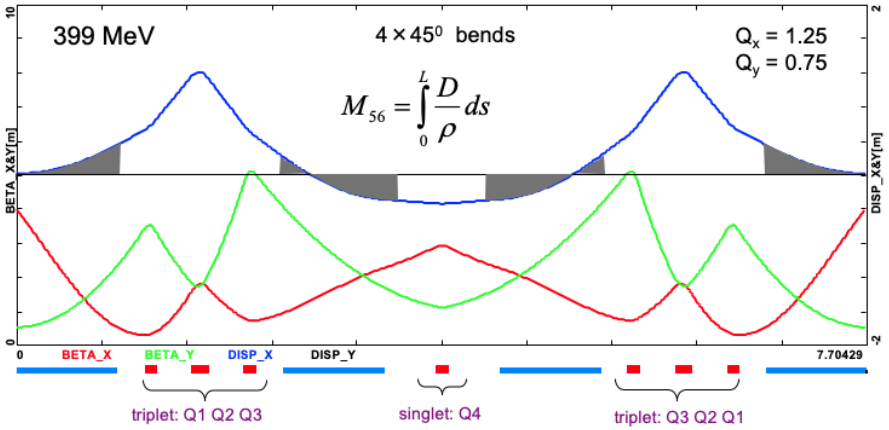


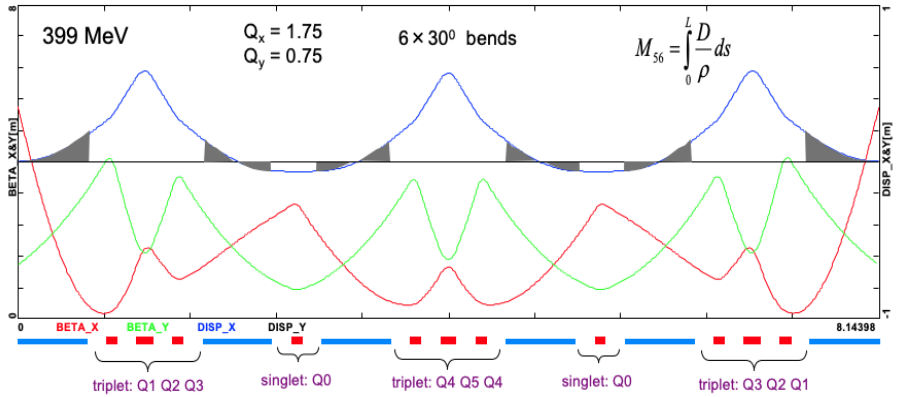
Linac cryomodule design: study the possibility of **SPL cryomodule adaptation** to PERLE need, **complete design of a cryomodule** for PERLE later.

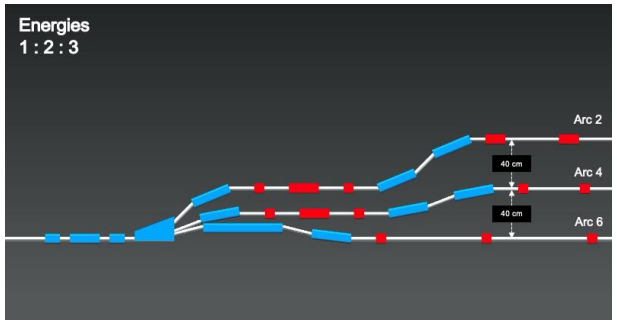
Design and prototyping of an **input power coupler**

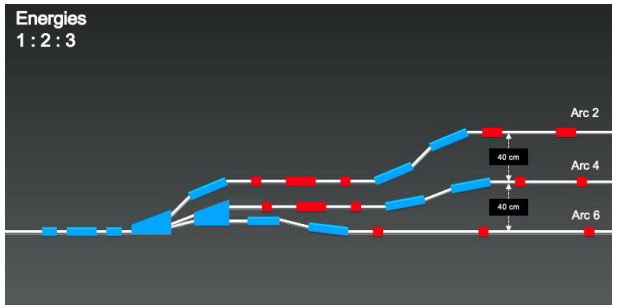
Lattice design optimisation of switchyards and circulating arcs

Courtesy to A. Bogacz and C. Vallerand

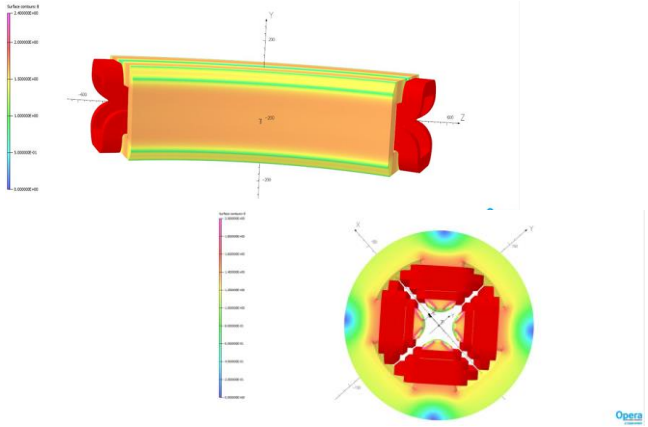








Design and prototyping of main magnets for arcs and switchyards



R&D toward PERLE TDR

- **Lattice design**: optimization of arcs and switchyards lattice, study of optics tolerances, magnets specifications, start to end simulation.
- **BBU study** in high average current environment: cavity design optimization for an efficient extraction of HOMs considering PERLE parameters: bench pattern recombination, current threshold, cryogenic efficiency…
- **Collective effects study**: effects of Coherent Synchrotron Radiation (CSR) and Longitudinal Space Charge (LSC) on beam quality, microbunching instability and ion cloud mitigation.
- **Particle tracking studies** of halo formation and control of beam loss.
- **LLRF and feedback system development**: RF control and stability under maximum practical Q_{Load}, development of multi-bunch BBU feedback systems.
- **Beam diagnostics development**

Plans toward PERLE realisation

Given the challenges imposed by PERLE design and technical choices, we plan to go through two main phases toward PERLE realisation :

- A design and prototyping phase that ends with the PERLE TDR:
  - Study the main phenomena imposed by the challenging design choices
  - Prototyping and test of the critical components (full dressed cavity, power coupler, dipoles…)
  - Design completion of the main sub-systems (booster, main cryomodule, DC gun upgrade…)
- Three staged construction, commissioning and exploitation phase, sketched in the following.

Plans toward PERLE realisation

PERLE configuration entails the possibility to built it in stages, we propose three main phases to attend the final configuration:

Phase 0: Installation of the injection line with a beam dump at its end

- Injection line includes: DC gun, load lock photocathode system, solenoids, buncher, booster, merger and required beam instrumentations to qualify the generated beam.
- Commissioning of the injection line will require the installation of cryogenics, Rf power source, power supplies for optics, photocathode laser, beam dump, control-command system, vacuum systems, site shielding, safety control system, fluids, etc.
- Many of these installations must be already sized according to the final configuration of PERLE.

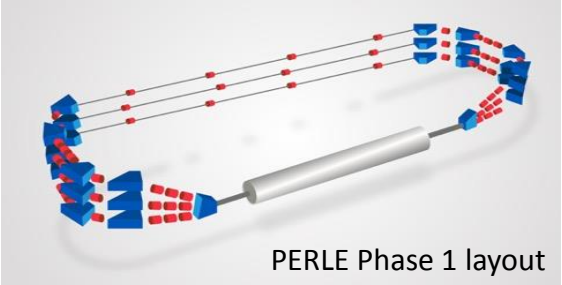
Plans toward PERLE realisation

Phase 1: 250 MeV version of PERLE

Installation of a single cryomodule in the first straight + beam pipes and complete return arcs. Both, the spreader and re-combiner with energy acceptance ratio 1:2:3. This version of the race track will be connected to the injection line built in phase 0, via the merger.

This particular staging is determined by the existence of SPL cryomodule. It will allow:

- Test the various SRF components with beam .
- Prove the multi-turn ERL operation.
- Gain essential operation experience.



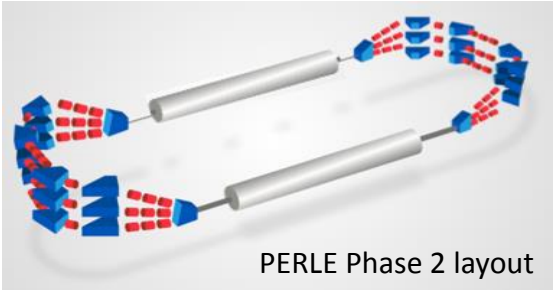
PERLE Phase 1 layout

Phase 2: PERLE at its design parameters as a 10MW machine

→ Upgrade of the e- gun to obtain the required nominal current.

→ Installation of the 2nd Spreader and re-combiner at the required energy acceptance ratio.

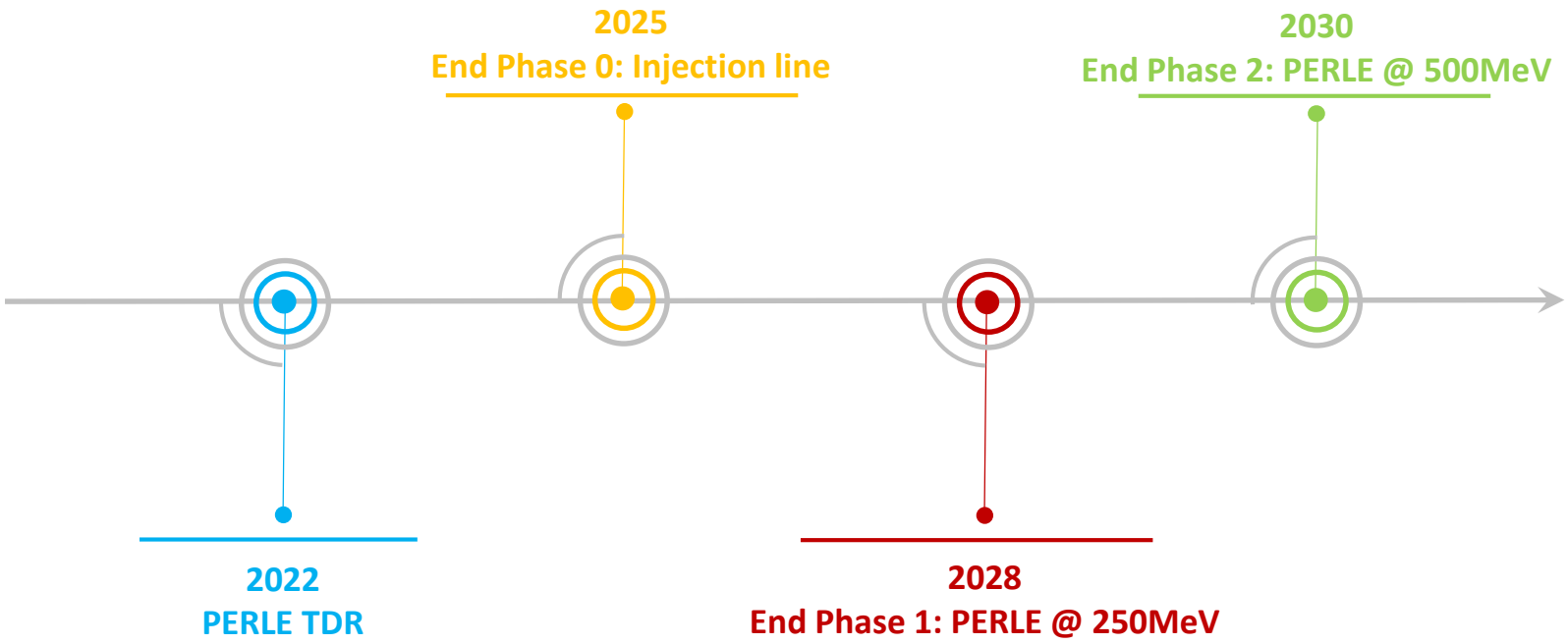
→ Installation of the second cryomodule in the second straight.



PERLE Phase 2 layout

PERLE Timeline

The Collaboration is currently developing a detailed time schedule. Currently it is foreseen to complete the TDR by 2022, Phase 0 by 2025, Phase 1 by 2028 and Phase 2 by 2030. A scheme of milestones will be worked out and agreed upon with emphasis on the accelerator but including a timeline for future experiments.



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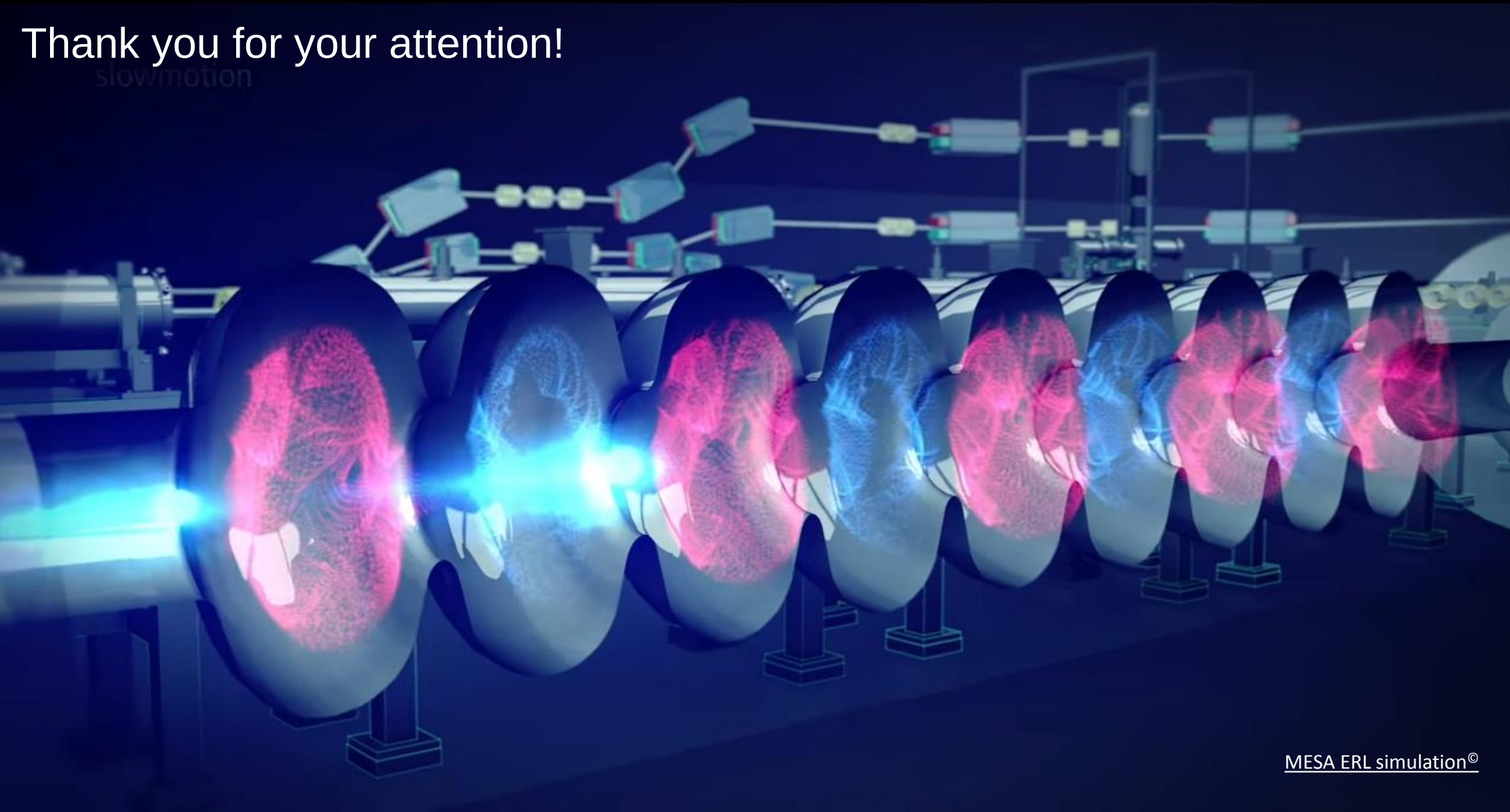

MESA ERL simulation©