PERLE@Orsay: A novel facility for ERL development and applications in multi-turn configuration and high-power regime

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In behalf of PERLE Collaboration

ARIEL TRIUMF Stony Brook University

Future projects with ERL. The project PERLE@Orsay

- **The development of ERLs has been recognized as one of the five main pillars of accelerators R&D in support of the European Strategy for Particle Physics (ESPP).**

- The ERL Roadmap Panel, chaired by Max Klein and Andrew Hutton, has done a tremendous job with broad and active participation. **The PERLE project was recognized as one of the "essential pillars of the ERL**," with milestones to be achieved by the next ESPP in 2026.

ESPP R&D Accelerator RoadMap
https://arxiv.org/ftp/arxiv/papers/2201/2201.07895.pdf

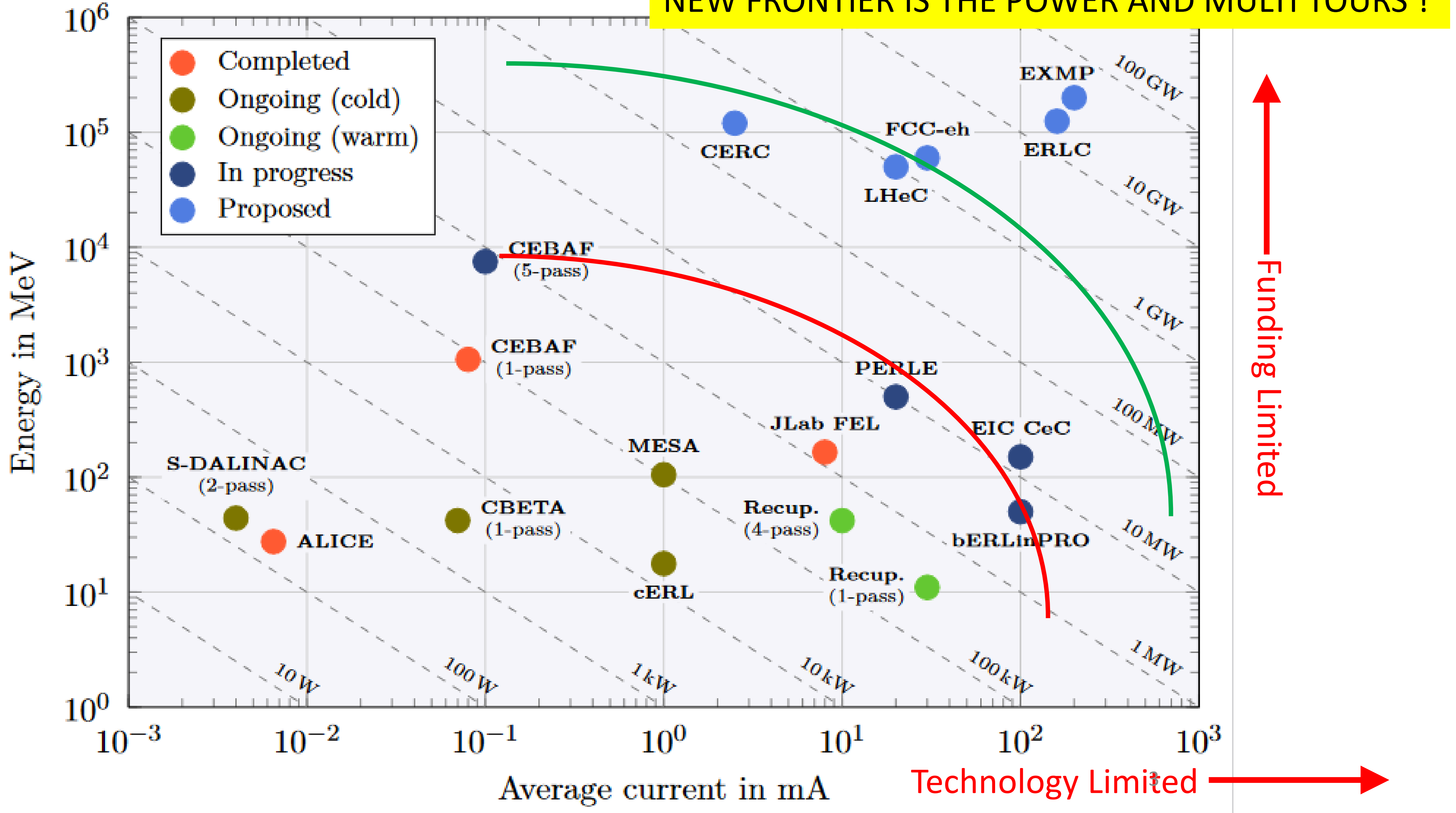
- Two other important points :
  - Upgrade bERLinPRO toward the First ERL Facility to operate 100mA in single turn with FRT control
  - Key Technology R&D Program – next generation ERLs

ERL machines « should allow » to reach
- high currents → high luminosity
- high energies and stay compact

Provided we can implement multi-turn, high power = high current x energy ERL machine

Many projects in the world : demonstrators, small machines, future projects…

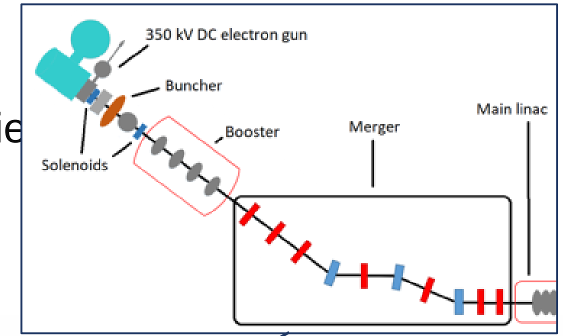
NEW FRONTIER IS THE POWER AND MULTI TOURS !

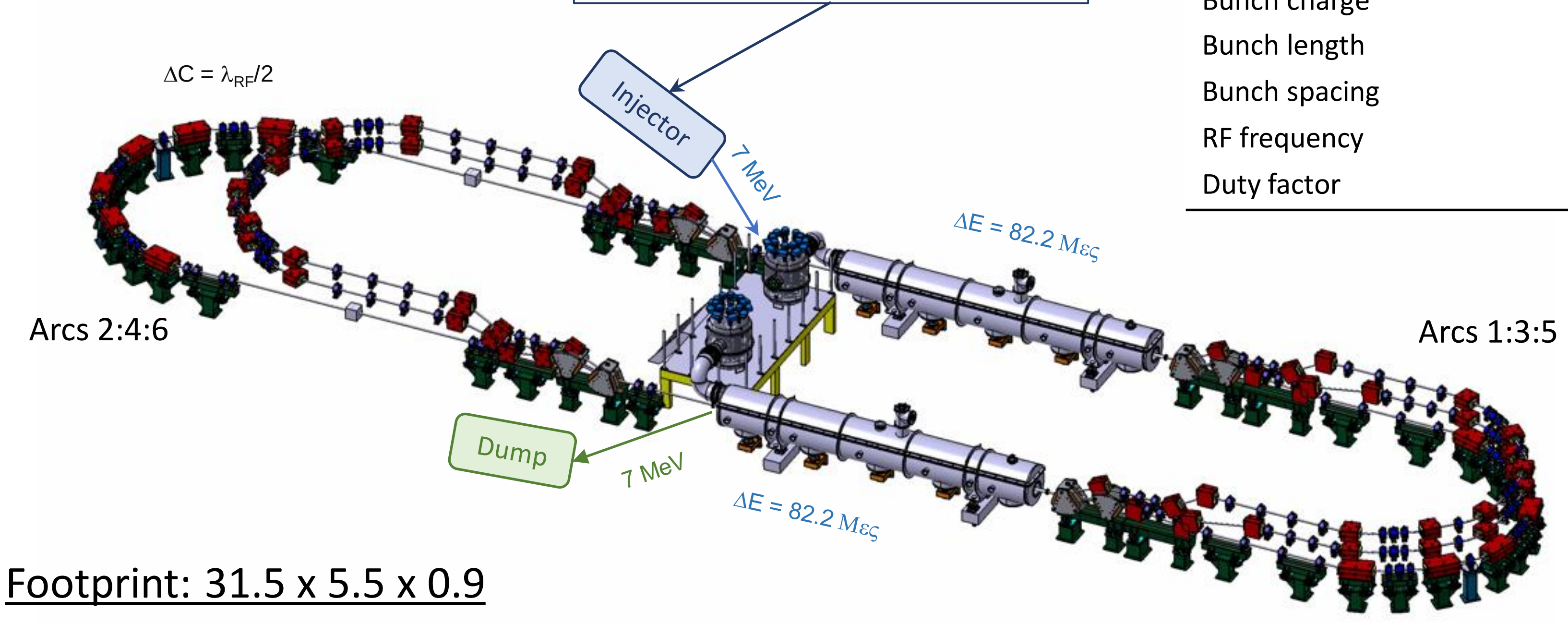


PERLE a key ERL project : Configuration and parameters

https://perle-web.ijclab.in2p3.fr/

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavitie
- 3 turns (164 MeV/turn)
- Max. beam energy 500 MeV





Footprint: 31.5 x 5.5 x 0.9

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

PERLE a key ERL project : HEP and Nuclear Physics communities

ERL machines open a new Frontier for the physics of "the electromagnetic probe"

(1) At low energy e Nuclei (PERLE and Destin@Orsay) 250-500 MeV
(2) At Higher Energy e p (e A) (LHeC and/or FCC-eh) 60 GeV

You need high luminosity → High current (from 10mA up to 100mA)
You need to increase the energy (remaining compact) → Multi turns

The (1) machine (PERLE@Orsay)

- will be the **first ERL dedicated to Nuclear Physics** for studying the eN interaction with radioactive nuclei.
- It's a **necessary demonstrator for the (2) -HEP machine (LHeC / FCC-eh)-** (same technological choices & beam parameters)

The key points : high power (current x energy) and complex machine in terms of beam dynamics (multi-turns)

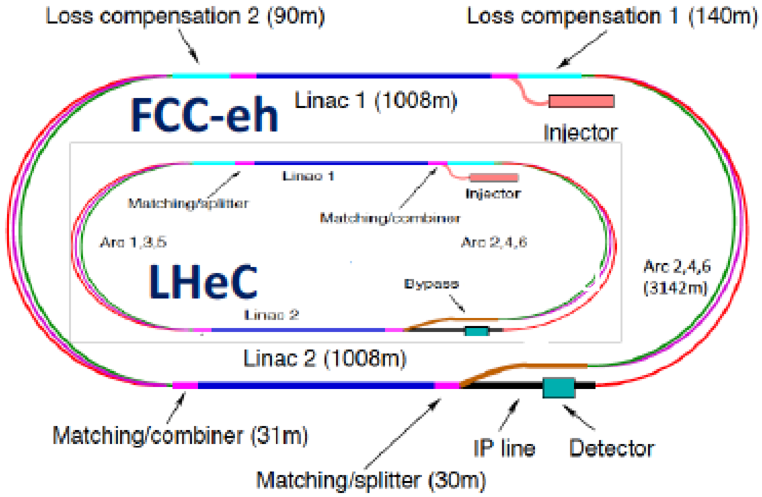
+ PERLE@Orsay (*not time today to discuss it)*

- is also a necessary demonstrator for other future machines and applications
- Elastic ep Scattering at PERLE (p Radius, Dark Photons, PV)
- Possibility of Nuclear Photonics (inverse Compton scattering γ's)

DIS (Deep Inelastic Scattering) ep Physics at High Energy in the next decades

Energy frontier DIS at HEP is necessary to explore SM and beyond

LHeC and **FCC-eh** are partners of LHC and FCC.



I(e) = 20mA

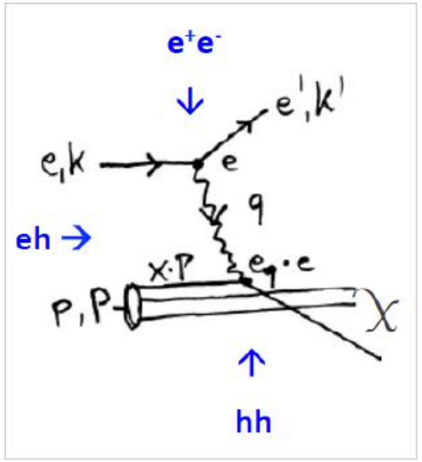
$\sqrt{s_{ep}}$ = 1-4 TeV

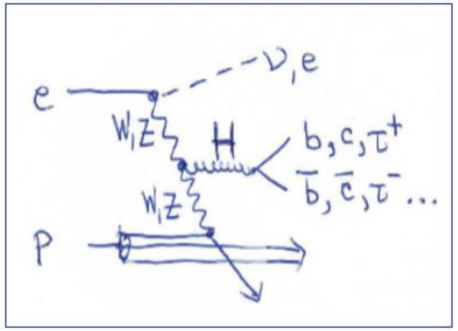
L(HERA) x 1000
(ERL and LHC)

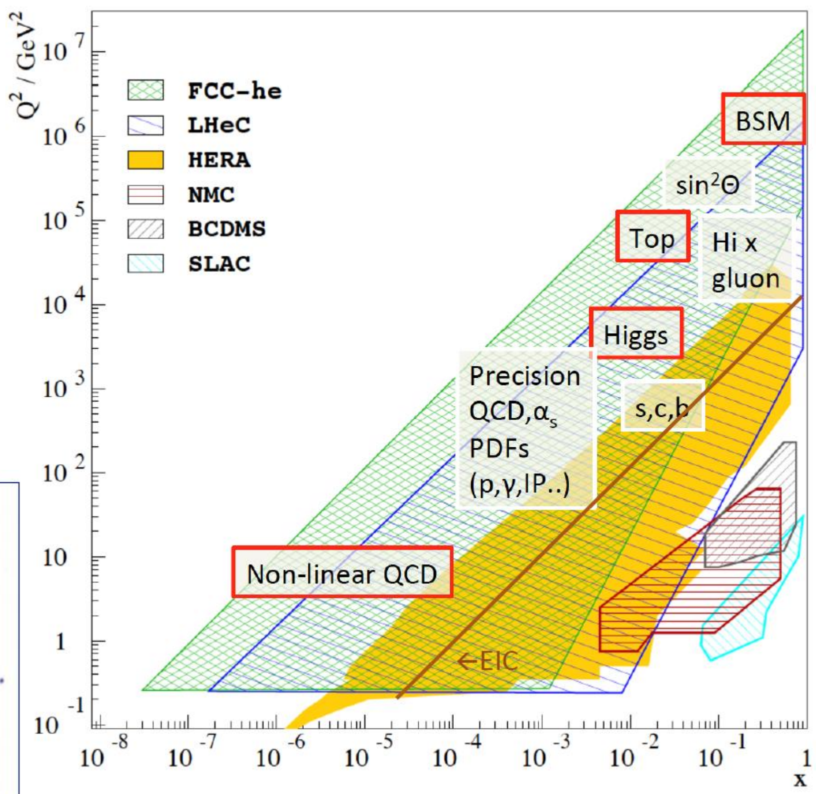
1206.2913, JPhysG
2007.14491, JPhysG

f=802Mz,
3+3 passes: 20mA x 6
20 MV/m, $Q_0 > 10^{10}$

Same parameters as the ones for PERLE@Orsay

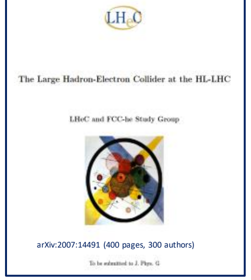






- Cleanest High Resolution Microscope: QCD Discovery
- Empowering the LHC/FCC Search Programme
- Transformation of LHC/FCChh into high precision Higgs facility
- Discovery (top, H, heavy ν's..) Beyond the Standard Model
- A Unique Nuclear Physics Facility

Published in 2020



Collection : from Max Klein

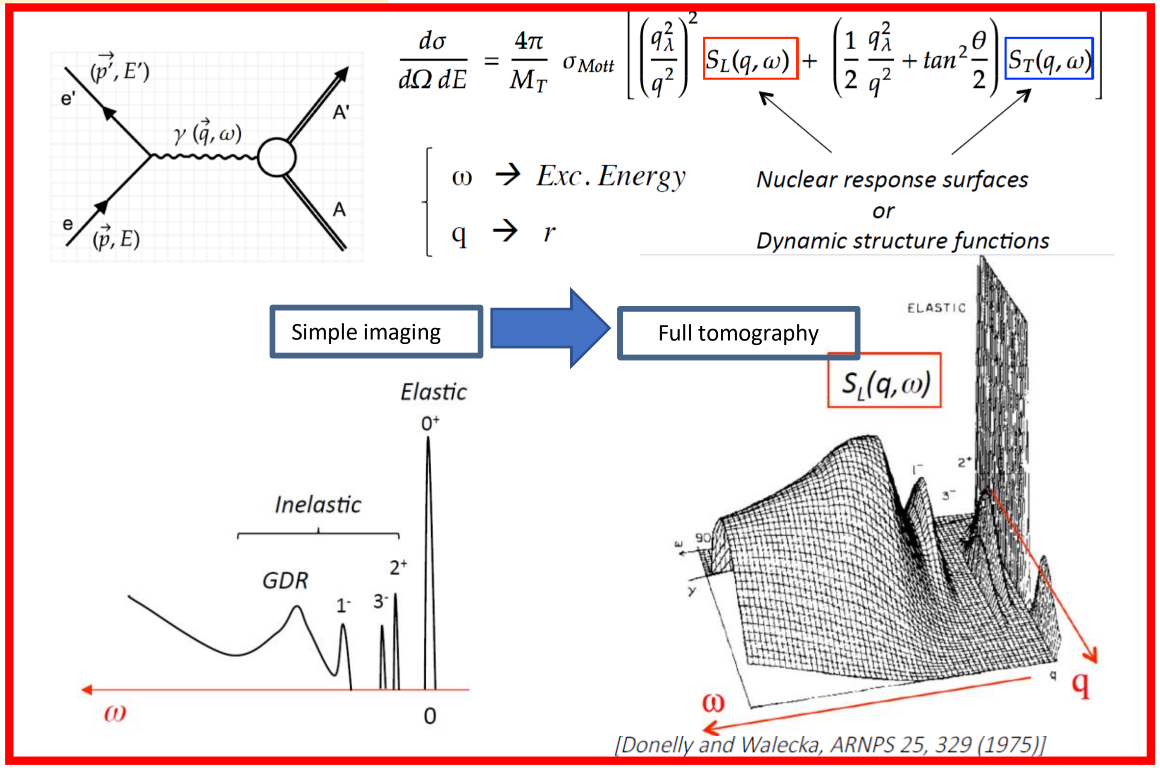
The New Frontier : e-RIB (Radioactive Nuclei Beam)scattering !

A completely new horizon, explore the interior of exotic nuclei :
charge radius, shape… New properties are emerging (halo, pairing..) !

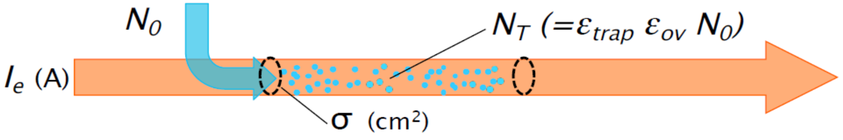
- all interesting phenomena occur at $q \gtrsim 2\text{fm}^{-1}$; the higher the q transferred the lower the cross section; consider previous achievements in this domain
  → **compromise starting at $E_e = 250 \dashrightarrow \simeq 500$ MeV (~0.5fm)**
- aimed luminosity should be 10^{29} $cm^{-2}s^{-1}$ but much can be already done at
  → **$\mathcal{L} \simeq 10^{27}$ ⁻ 10^{28} (with unstable nuclei EVERYTHING is new !)**

A long road ahead before reaching the full tomography of an exotic nucleus
The starting point is :

DESTIN [DEep STructure Investigation of (exotic) Nuclei]

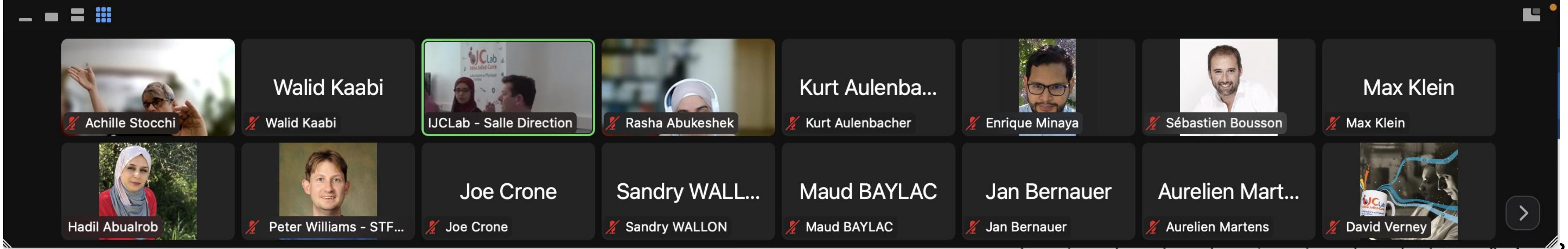


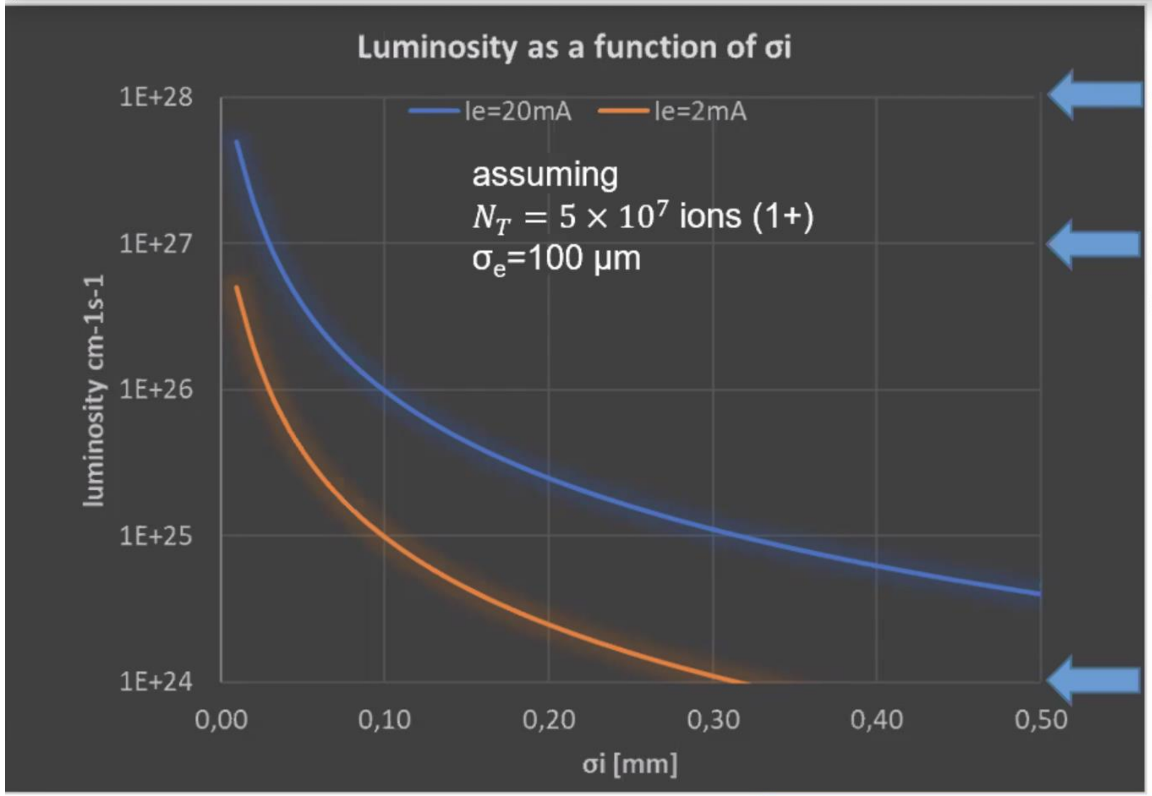
Very chanellenging
The beam will confine RIB in longitudinal plane e- with positive ions), and traps have to confined RIB in transversal plane (à la SCRIT at RIKEN)



$L \sim \frac{I_e/e \;\; N_T}{\sigma}$ /(cm²s)

Collection : from David Verney

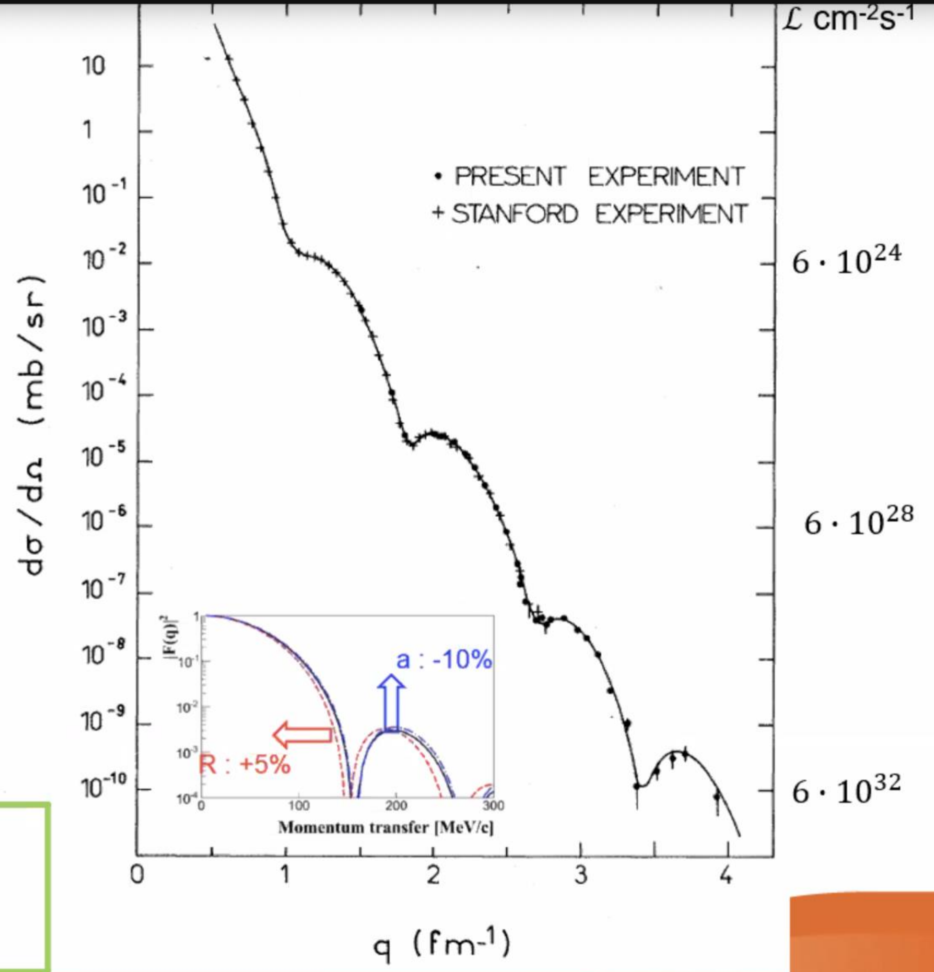




FAIR/ELISE targeted luminosity

SCRIT luminosity with stable nuclei

1953 Hofstadter's luminosity

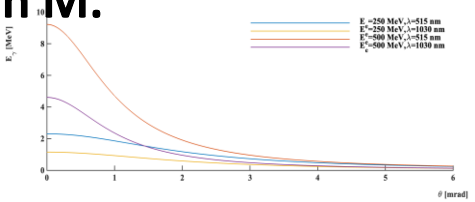


absolute radius
2-parameters charge distributions at reach

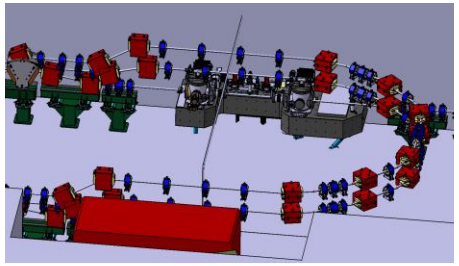
Talk: D. Verney

Physics Workshop –on 2022

ICS (Inverse Compton Scattering) Aurelien M.

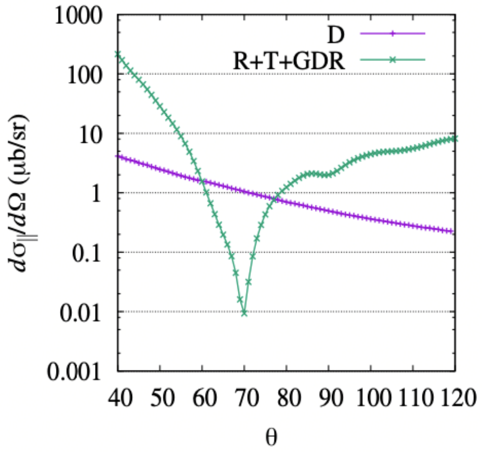


A high rate low energy gamma-ray source at 1.1MeV:
- ~>100x ELI-NP
- more at 500MeV e-beam energies, or with halved wavelength laser



A very nice driver for R&D on optical cavities :
- Very high average laser power in green (new AFAIK)

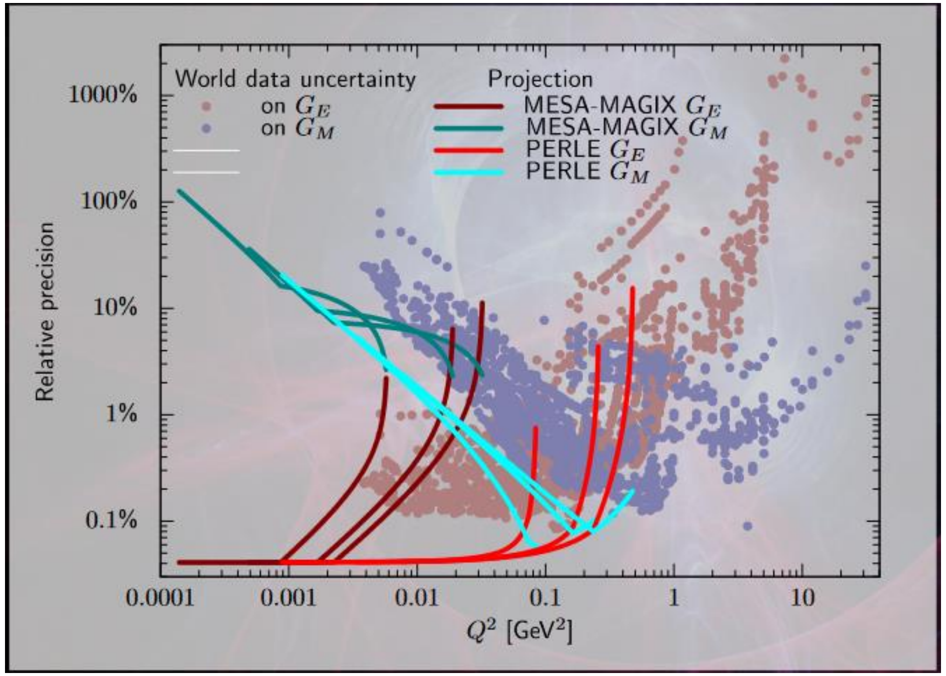
A place to demonstrate <0.1% bandwidth gamma source:
- NRF backgrounds…



A place to perform QED physics…
- Background free Delbrück scattering measurement in few days

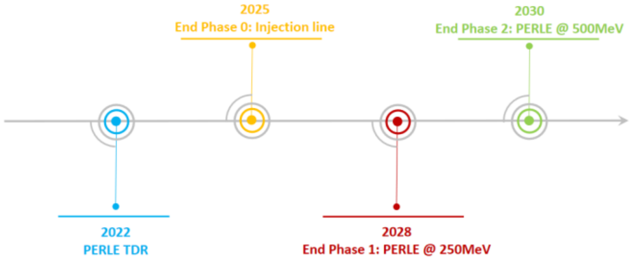
but also more conventional NRF research

Jan Bernauer – ep physics

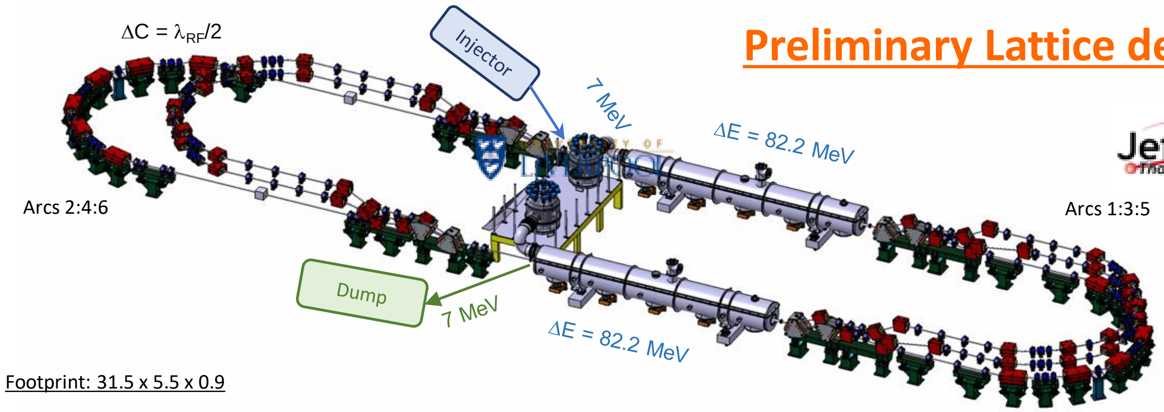


PERLE@Orsay is now a reality , it'a a project and an international collaboration

Opened to new members !

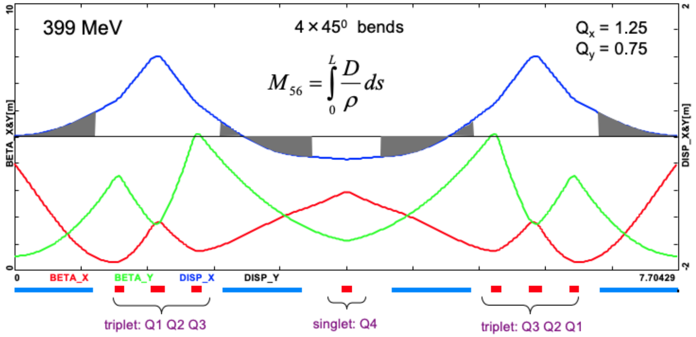


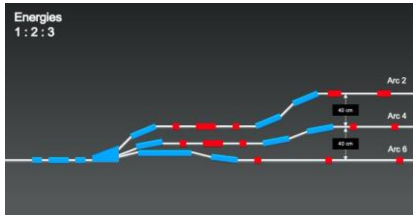
Already some nice acheivements on machine design, injection lines, SFR cavity…



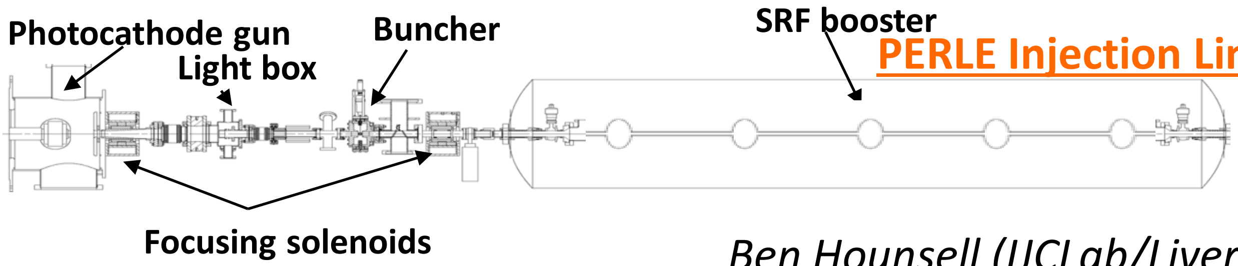
Preliminary Lattice design and footprint

Lattice design optimisation of switchyards and circulating arcs





PERLE : Some nice acheivements



PERLE Injection Line

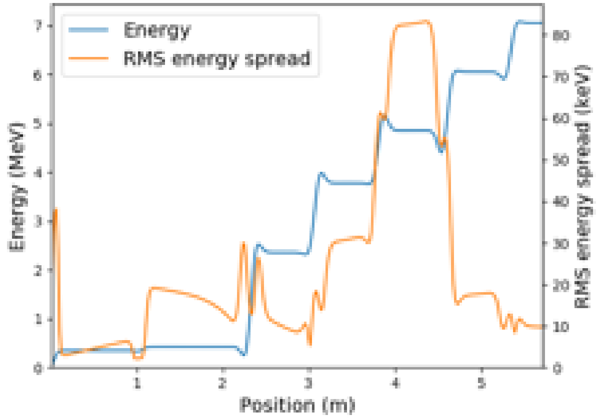
Ben Hounsell (IJCLab/Liverpool) PHD

Electron source to booster exit optimisation:

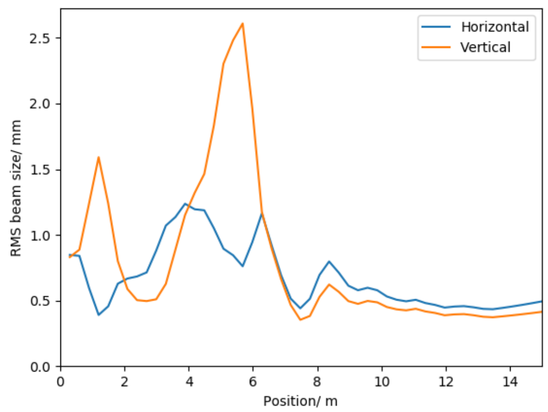
- The ALICE electron gun electrode geometry has been re-optimised for PERLE's new requirements.
- An optimisation with a 4 cavity booster linac, from the cathode to the booster exit, was done and meets the specification.

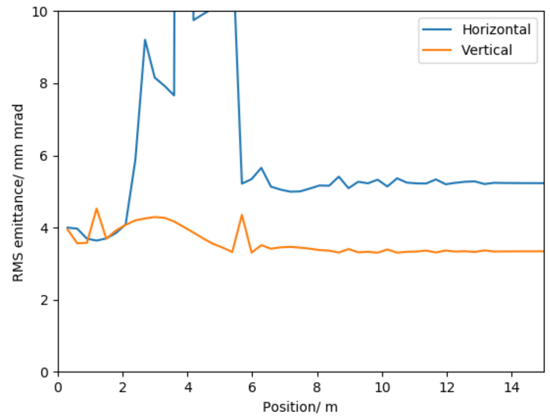
	Achieved values	Specification
Horizontal emittance	5.23 mm mrad	< 6 mm mrad
Vertical emittance	3.34 mm mrad	< 6 mm mrad
Bunch length	3.22	3 mm
Kinetic energy	86.1 MeV	88.6 MeV
Horizontal beta function	7.89 (mismatch 8.3 %)	8.6
Horizontal alpha function	-0.74 (mismatch 11.6 %)	-0.66
Vertical beta function	8.76 (mismatch 1.8 %)	8.6
Vertical alpha function	-0.67 (mismatch 1.5 %)	-0.66

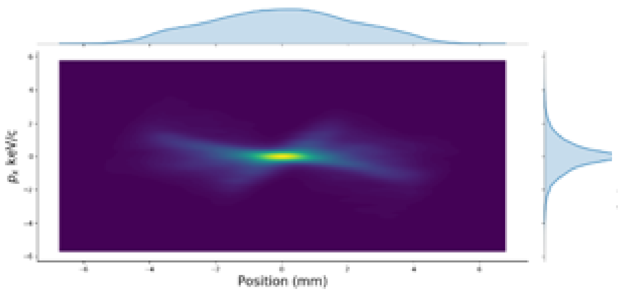
Energy spread

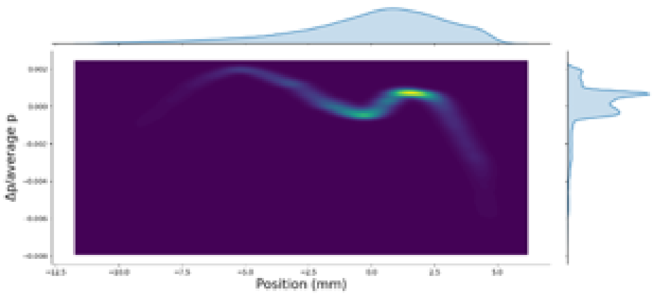


Transverse beam size and emittance

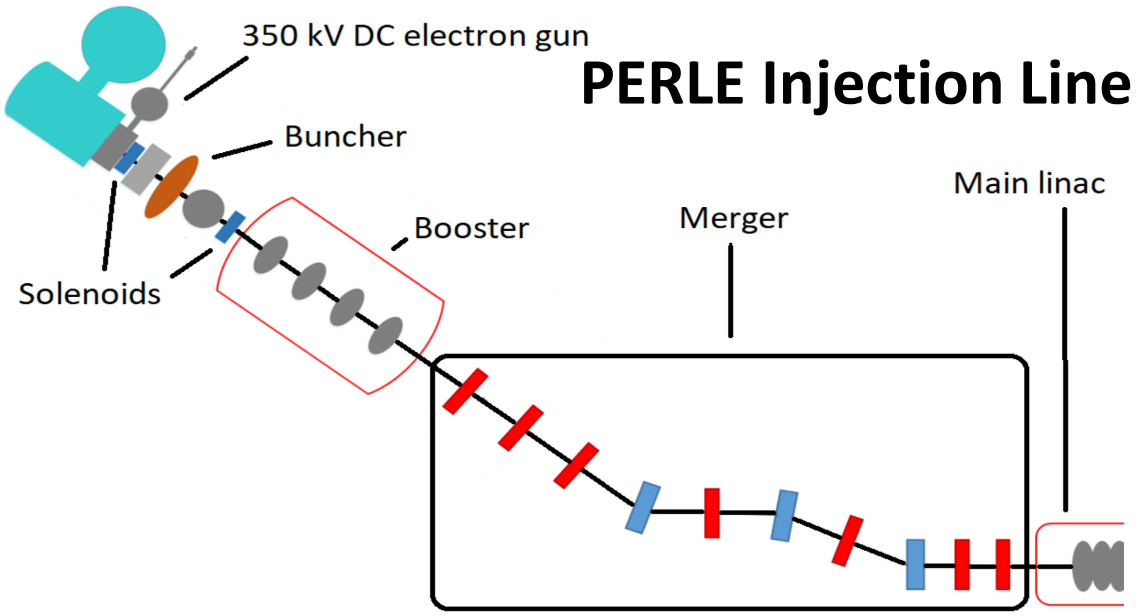








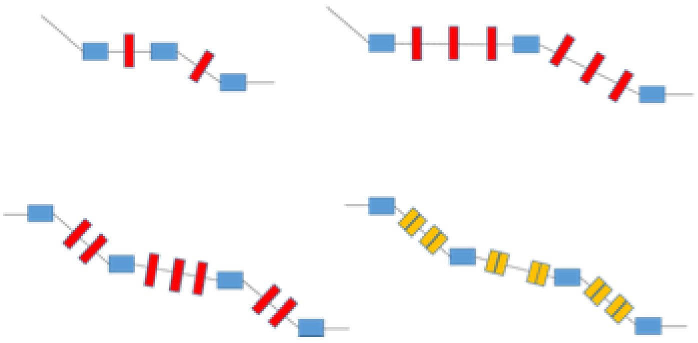
PERLE : Some nice acheivements

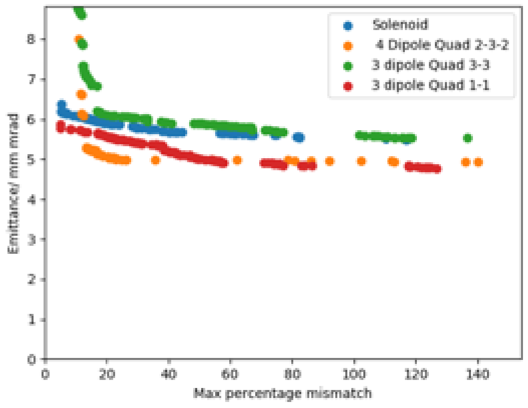


The PERLE Merger design:

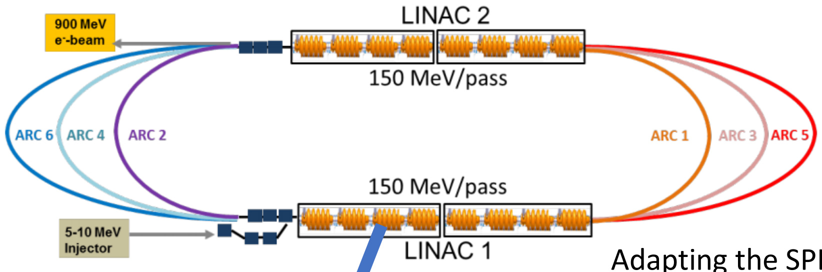
- The merger is the beamline which transports the beam into the main ERL loop.
- The merger presents significant opportunity for emittance growth:
  - Longitudinal space charge force induced shift in the dispersion
  - Potentially asymmetric emittance compensation.
- There are a wide range of possible designs and several were studied.
- Generally shorter and smaller bending angles is better
- 4 dipole schemes were investigated as they have the potential to mitigate the effects of space charge on the dispersion and the consequent emittance growth.

Merger schemes investigated:

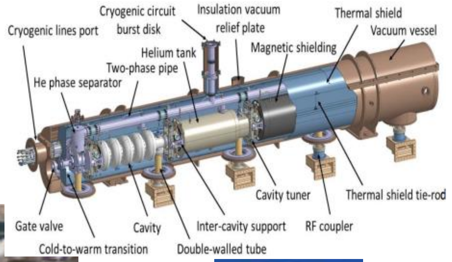




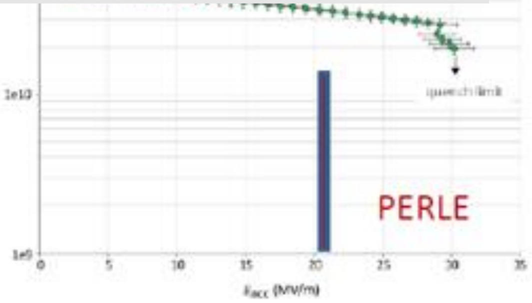
PERLE : Some nice acheivements



Adapting the SPL Module (IJCLab/CERN)

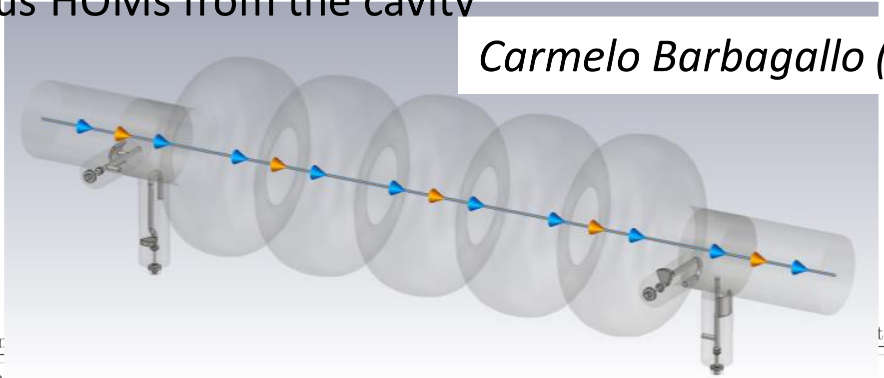


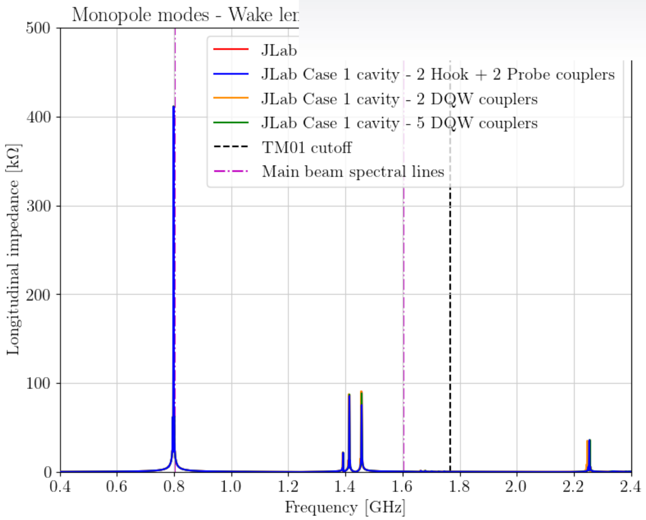
The first Nb 801.58MHz 5-cell elliptical cavity fabricated at JLab.

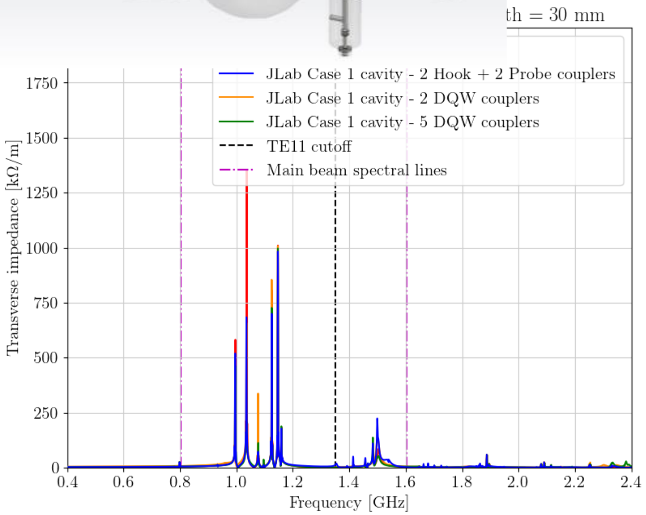


HOM-damping studies : **Objective**:extract the energy of the dangerous HOMs from the cavity

Carmelo Barbagallo (IJCLab) PHD



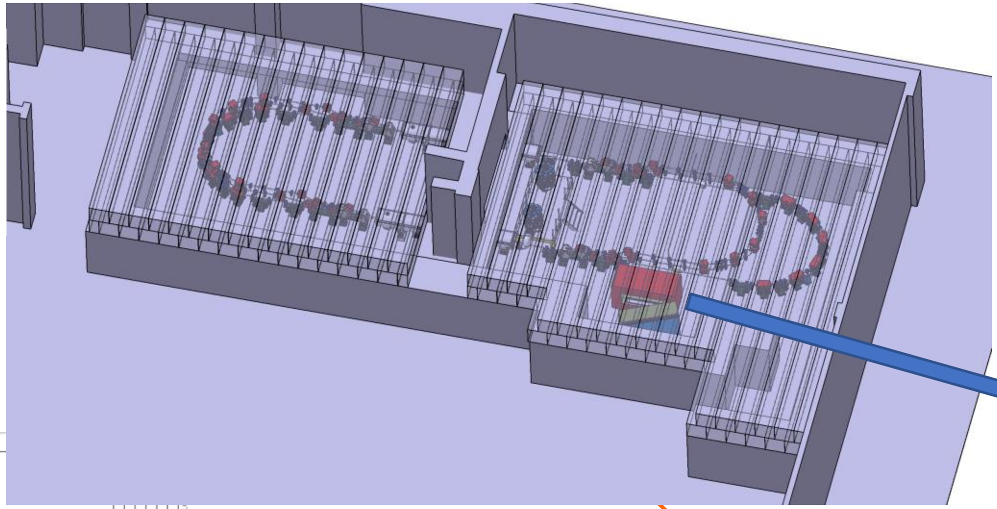




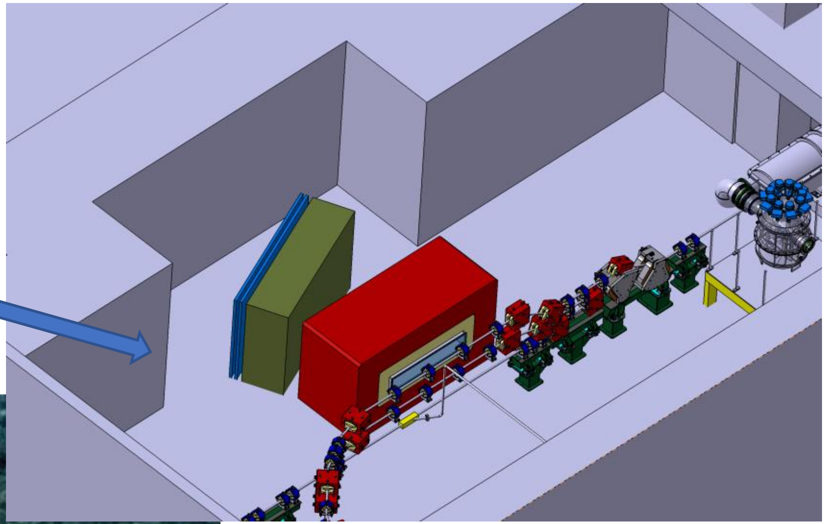
Preliminary results:

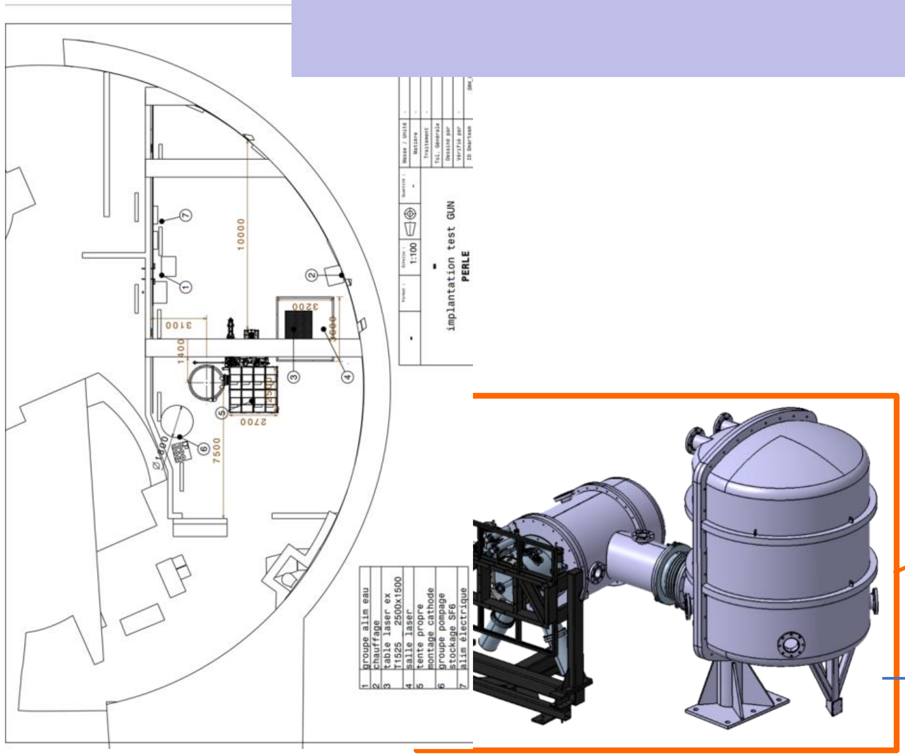
- 2Hook+2Probe couplers configuration seems to provide better damping than the DQW couplers configurations. However,couplers have still to be optimized!
- Beam-stability impedance thresholds needed to determine the maximum allowed impedance.

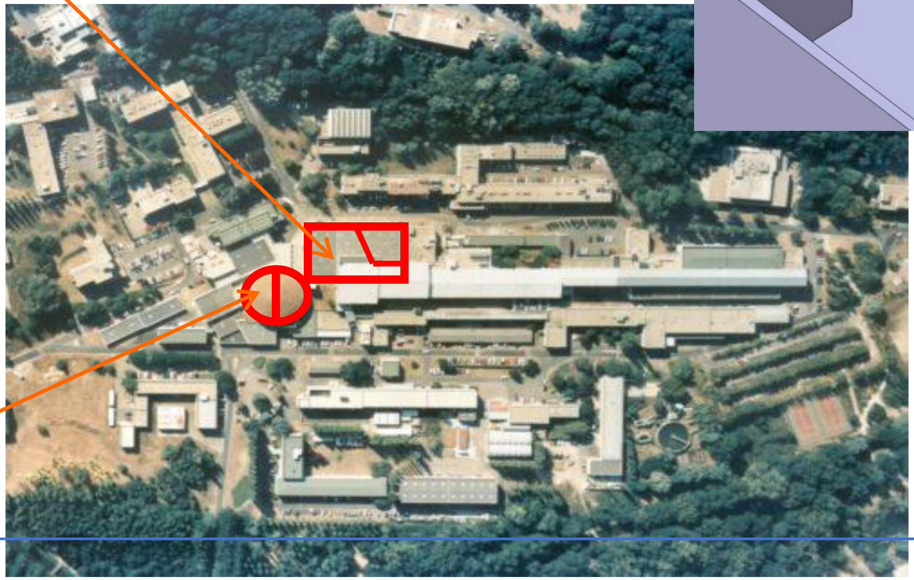
Proposed implantation @ IJCLab-Orsay. Infrastructure study work started



The possible footprint fo the nuclear eN experiment







Start of the installation of the DC gun – see next slide

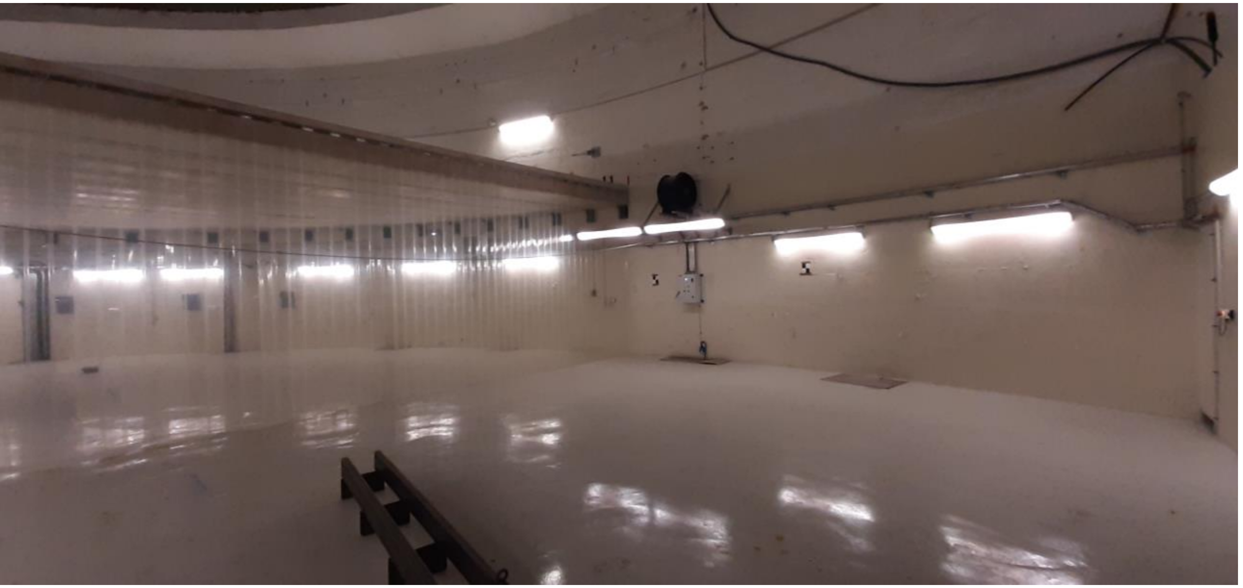
Daresbury DC-Gun for PERLE in the IGLOO Area : work started !

Science & Technology Facilities Council

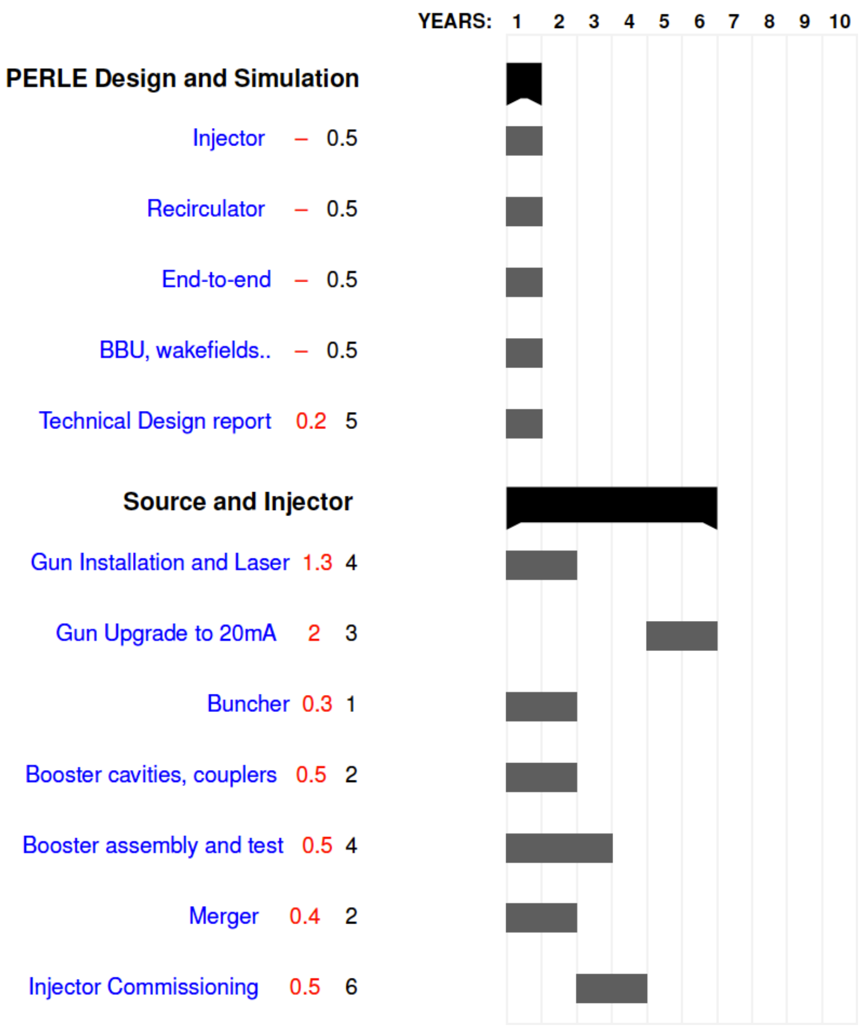
DC GUN in the IGLOO AREA – March 2022

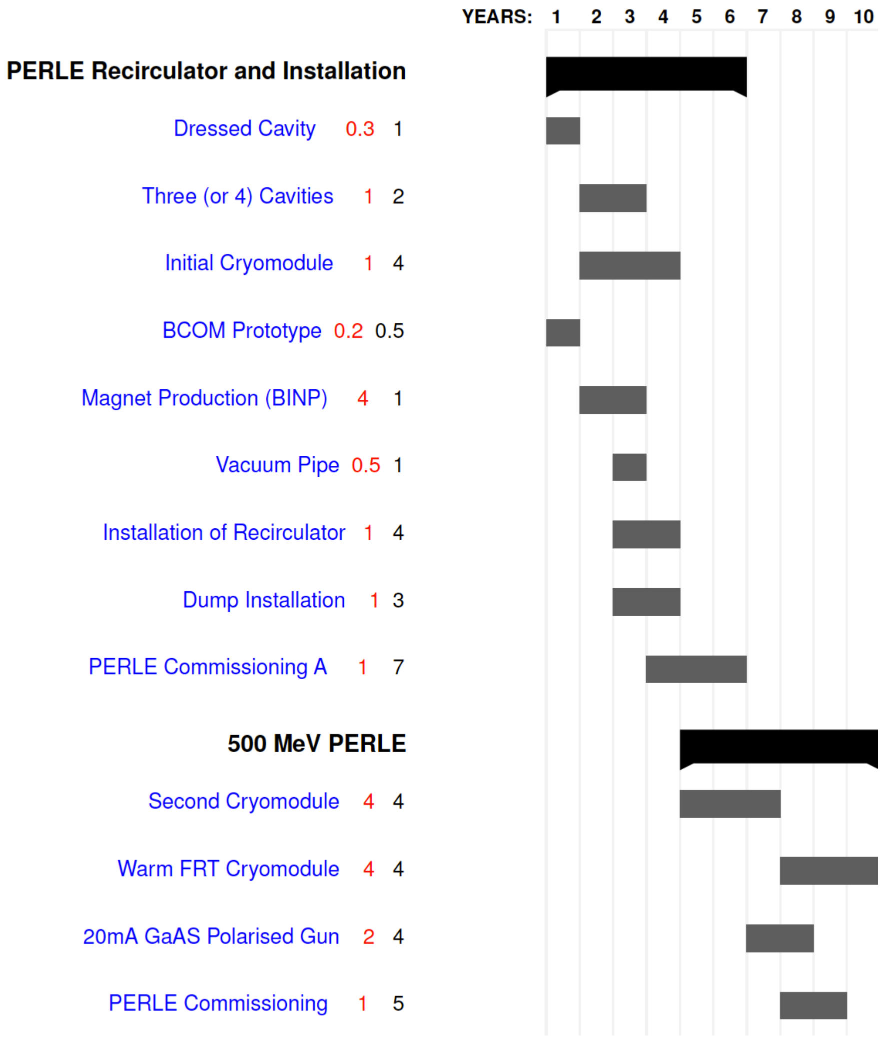
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

LPSC GRENOBLE | MODANE



Some preliminary planning : 6 years for PERLE 250 MeV





Conclusions

I hope to have shown you that the ERL technique worth exploring at the 10MW level and opens beautiful scientific and technical perspectives !

and of course

I hope I convinced you that is just the right time to work on ERL !

and **at PERLE@Orsay**

Looking forward to discuss with you and meeting you next time.

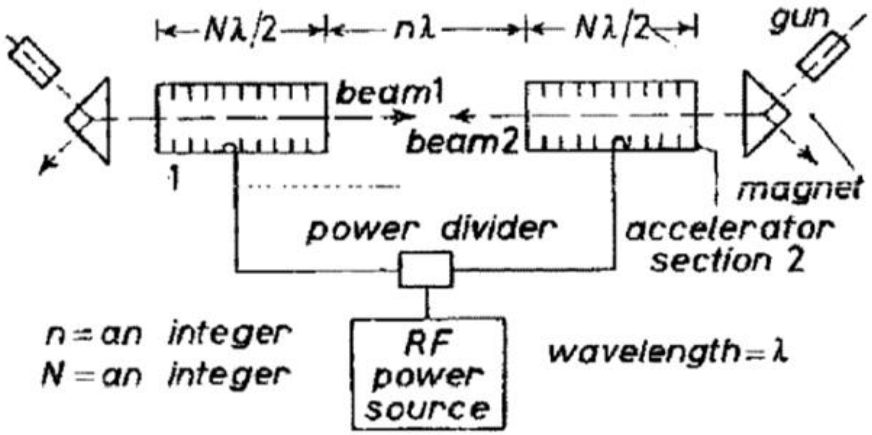
Backup

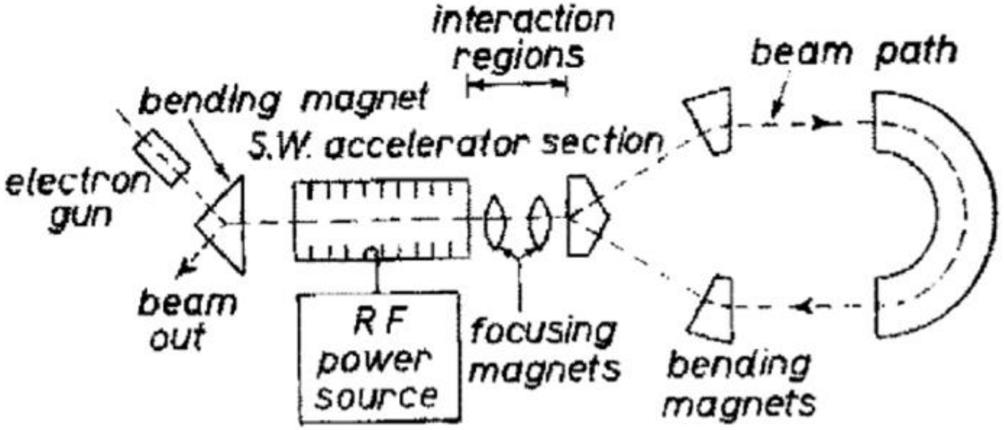
- Introduction.
  - The ERL concept
  - How an ERL works. Why an ERL today

5’ to introduce the subject !

ERL. The original Idea.

- ERL concept was proposed first in 1965 by Maury Tigner [1]



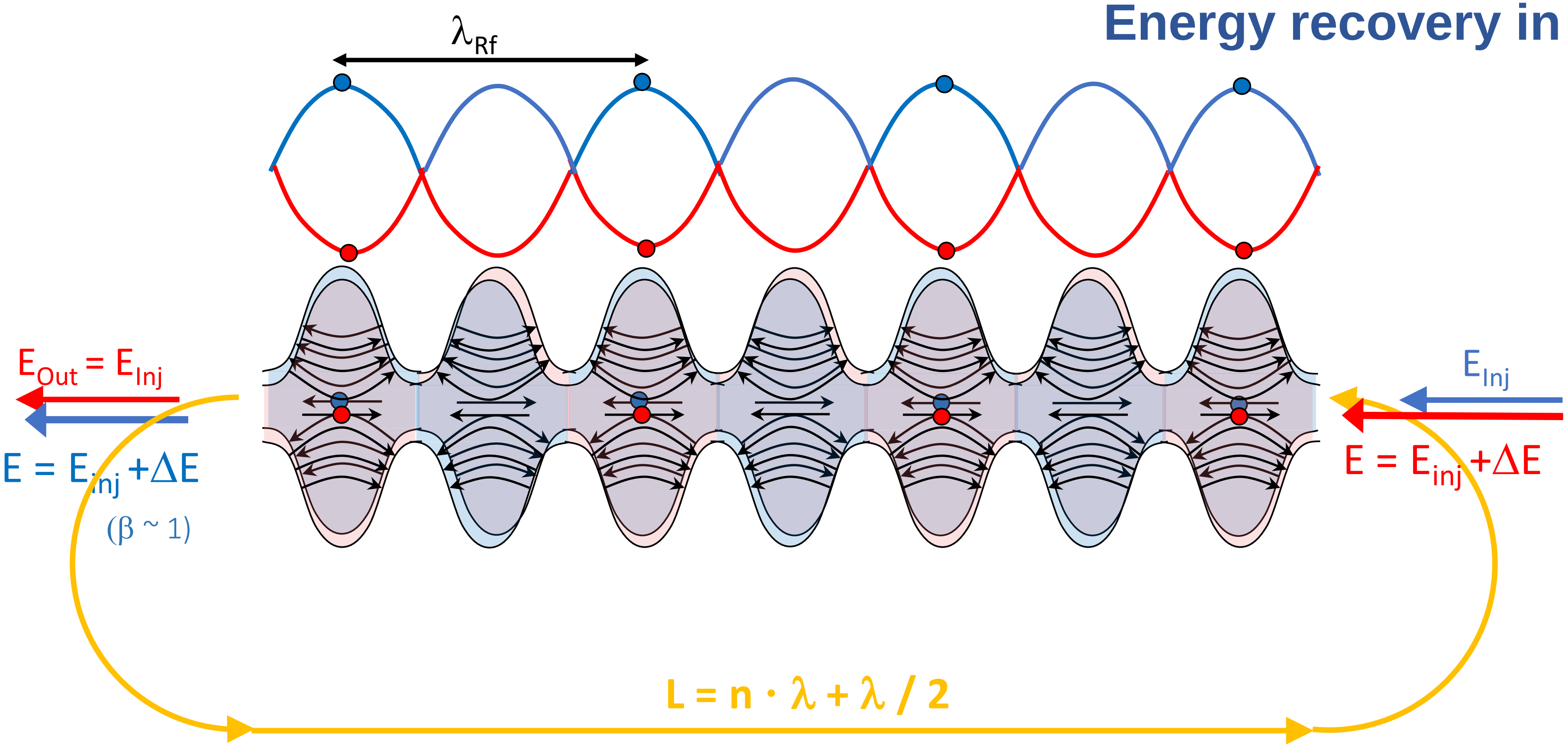


[1] M. Tigner: “A Possible Apparatus for Electron Clashing-Beam Experiments”, Il Nuovo Cimento Series 10, Vol. 37, issue 3, pp 1228-1231,1 Giugno 1965

- First test was done at Stanford in 1986 (interesting concept for FELs, Compton light sources and high current electron cooler)
- Concept become only viable with recent advances in SRF technology.

ERL how it works

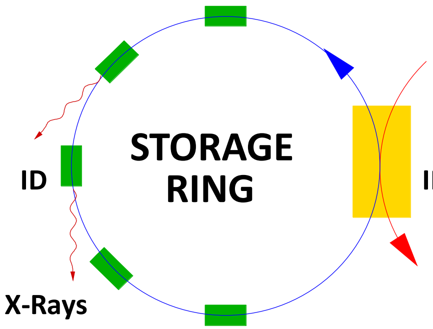
Energy recovery in RF fields:



- Energy supply → acceleration
- Deceleration = "loss free" energy storage (in the beam) → Energy recovery

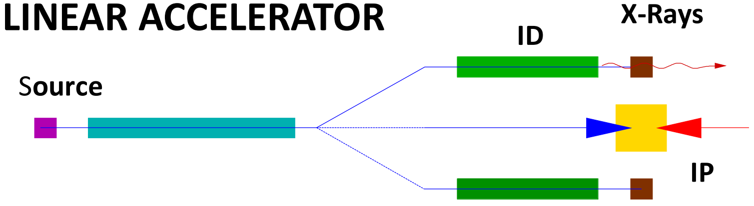
ERL WHY ? : The Best of Two Worlds

Limitation : syncrotron radiation



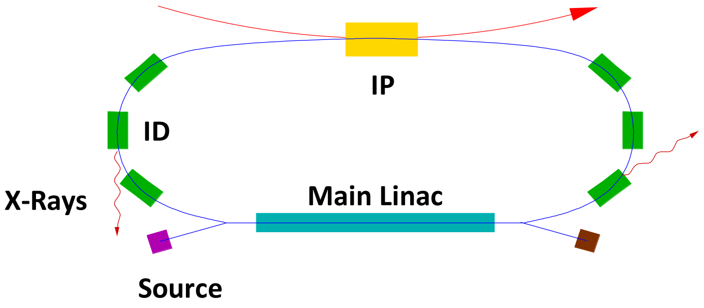
- Beam parameters defined by equilibrium
- Limited flexibility – multi-pass
- High average beam power (A, multi GeV)
- Typically long bunches (20 ps – 200 ps)
- Many user stations

LINEAR ACCELERATOR



- Beam parameters defined by the source
- High flexibility – single pass
- Limited average beam power (<< mA)
- Possible short bunches (sub psec)
- Low number of user stations

ENERGY RECOVERY LINAC



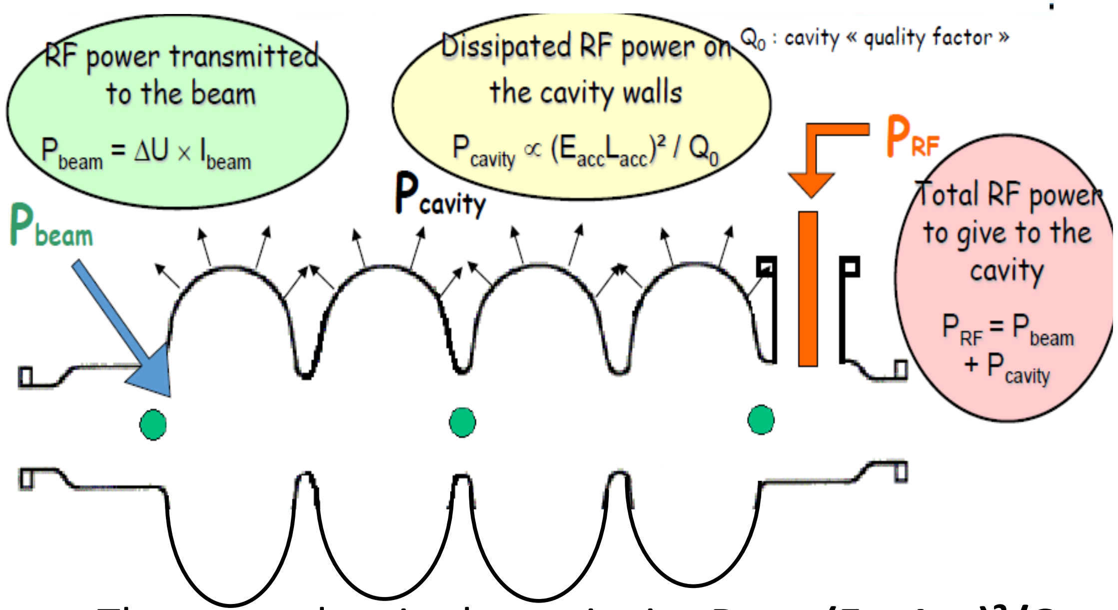
- **Linac-like beam quality**
- Easy to upgrade (add linac section or recirculation passes)
- Tolerate more “damage” to the beam from collisions with another beam (the beam is dumped soon after)

- **High beam current possible (RF power limit removed)**
- **Reduced power bill (RF power recovered)**
- Reduced cost of RF amplifiers (smaller RF power amplifiers)
- Reduced beam power and energy in beam dump (less shielding / activation issues)

High average beam power in compact machine, excellent beam parameters with high flexibility

ERL next to come

The **recuperation of the energy** can become quickly a limiting factor.



The power lost in the cavity is : $\mathbf{P_{cavity}\ (E_{acc}\ L_{acc})^2/Q_0}$

Ex : elliptical cavity, 10MV/m, Proton beam = 10mA, L~1m, with Q_0~10^9

→ P_{cavity} ~ 200kW !

In addition to be able **to go to higher energy** and to stay compact (length of the linac sections) you need to introduce and mastering the **multi turn scheme**

<u>ERL machines « should allow » to reach</u>

- high currents → high luminosity
- high energies and stay compact

Provided we can implement multi-turn, high power = high current x energy ERL machine