PERLE: The development of a multi-turn, high current ERL

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In behalf of PERLE Collaboration
• Introduction.
  o The ERL concept
  o 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


- 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.
**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

- 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

- 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

- 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 average beam power in compact machine, excellent beam parameters with high flexibility
The recuperation of the energy can become quickly a limiting factor.

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.

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

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

\( \rightarrow P_{cavity} \sim 200kW ! \)

ERL machines « should allow » to reach

- high currents \( \rightarrow \) high luminosity
- high energies (no problem with synchrotron radiation)

Provided we can implement multi-turn, high power = high current \( \times \) energy ERL machine
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.

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

ESPP R&D Accelerator RoadMap
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 cavities)
- 3 turns (164 MeV/turn)
- Max. beam energy 500 MeV

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

Footprint: 31.5 x 5.5 x 0.9
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 \(\rightarrow\) **High current** (from 10mA up to 100mA)
You need to increase the energy (remaining compact) \(\rightarrow\) **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 y’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.

\[ I(e) = 20\text{mA} \]

\[ \sqrt{s_{ep}} = 1-4\text{ TeV} \]

\[ L(\text{HERA}) \times 1000 \]

(ERL and LHC)

1206.2913, JPhysG
2007.14491, JPhysG

\[ f = 802\text{Mz}, \]

3+3 passes: 20mA x 6
20 MV/m, \[ Q_0 > 10^{10} \]

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

Collection: from Max Klein

Published in 2020

The Range Extension Limits at the MEGII
LHeC and FCC-erh at the future LHC

05/05/2022 PERLE: The development of a multi-turn, high current ERL DIS 2022 - Santiago de Compostela
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
  $\Rightarrow$ compromise starting at $E_e = 250 \rightarrow \approx 500 \text{ MeV (~0.5fm)}$

- aimed luminosity should be $10^{29} \text{ cm}^{-2}\text{s}^{-1}$ but much can be already done at
  $\Rightarrow \mathcal{L} \approx 10^{27} - 10^{28}$ (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 channelling
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)

Collection : from David Verney
PERLE@Orsay is now a reality, it’s a project and an international collaboration opened to new members!

Already some nice achievements on machine design, injection lines, SFR cavity...

Lattice design optimization of switchyards and circulating arcs

Preliminary lattice design and footprint

Footprint: 31.5 x 5.5 x 0.9
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Achieved values</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Horizontal emittance</td>
<td>5.23 mm mrad</td>
<td>&lt; 6 mm mrad</td>
</tr>
<tr>
<td>Vertical emittance</td>
<td>3.34 mm mrad</td>
<td>&lt; 6 mm mrad</td>
</tr>
<tr>
<td>Bunch length</td>
<td>3.22</td>
<td>3 mm</td>
</tr>
<tr>
<td>Kinetic energy</td>
<td>86.1 MeV</td>
<td>88.6 MeV</td>
</tr>
<tr>
<td>Horizontal beta function</td>
<td>7.89 (mismatch 8.3 %)</td>
<td>8.6</td>
</tr>
<tr>
<td>Horizontal alpha function</td>
<td>-0.74 (mismatch 11.6 %)</td>
<td>-0.66</td>
</tr>
<tr>
<td>Vertical beta function</td>
<td>8.76 (mismatch 1.8 %)</td>
<td>8.6</td>
</tr>
<tr>
<td>Vertical alpha function</td>
<td>-0.67 (mismatch 1.5 %)</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

Energy spread

Transverse beam size and emittance

Ben Hounsell (IJCLab/Liverpool) PHD

PERLE: Some nice achievements
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.
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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.

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

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

Adapting the SPL Module (IJCLab/CERN)

Carmelo Barbagallo (IJCLab) PHD
Proposed implantation @ IJCLab-Orsay. Infrastructure study work started

The possible footprint for the nuclear eN experiment

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

05/05/2022
Daresbury DC-Gun for PERLE in the IGLOO Area: work started!

DC GUN in the IGLOO AREA – March 2022
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