Electron-Hadron collisions at CERN

The **LHeC** is an accelerator study for a possible upgrade of the existing LHC

By adding a new electron accelerator, the LHeC would enable the investigation of electron-proton collisions at unprecedented high energies and rate.

The baseline design consists of a 3-pass ERL to provide a 60 GeV, high-current $e^-$ beam.

In parallel a design study for an **ERL test platform** is being pursued at CERN to test machine and operation issues before designing a large scale facility.
LHeC ERL Facility & SC RF

FUNDAMENTAL MOTIVATION:

- **Proof validity of fundamental design choices:**
  - Three-turns acceleration + three-turns deceleration
  - (other existing ERLs have only two passages)
  - Implications of high current operation (6 * 10mA > 60mA in the linacs!)

- **Build up expertise for a facility with a fundamentally new operation mode:**
  - ERLs are circular machines with tolerances and timing requirements similar to linear accelerators (no ‘automatic’ longitudinal phase stability, etc.)

- **Verify and test components and operation tolerances before building a large scale facility:**
  - Tolerances in terms of field quality of the arc magnets
  - Required RF phase stability (RF power) and LLRF requirements

Courtesy of O. Brüning
Goals of the ERL Facility

Dedicated Accelerator physics studies and R&D:
- Injector studies
- Beam diagnostics developments and testing with beam
- Could it be foreseen as the injector to LHeC ERL and to FCC?

Scientific and technical applications:
- Possible use for detector development
- Controlled quench and damage test for SC magnets
- Generation of gamma-ray beams via Compton backscattering

<table>
<thead>
<tr>
<th>TARGET PARAMETER*</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Energy [MeV]</td>
<td>5</td>
</tr>
<tr>
<td>Final Beam Energy [MeV]</td>
<td>900</td>
</tr>
<tr>
<td>Normalized emittance γε$_{x,y}$ [μm]</td>
<td>5</td>
</tr>
<tr>
<td>Delivered Beam Current [mA]</td>
<td>10</td>
</tr>
<tr>
<td>Bunch Spacing [ns]</td>
<td>25 (50)</td>
</tr>
<tr>
<td>Passes</td>
<td>3</td>
</tr>
</tbody>
</table>

*in few stages
Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN

3. SC RF

4. PLANNING AND TIMELINE
Planning for each stage

STEP 1
SC RF cavities, modules and e⁻ source tests
- Injection at 5 MeV
- 1 turn
- 75 MeV/linac
- Final energy 150 MeV

<table>
<thead>
<tr>
<th>ARC</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 1</td>
<td>80 MeV</td>
</tr>
<tr>
<td>ARC 2</td>
<td>155 MeV</td>
</tr>
</tbody>
</table>

Two cryomodules with 4 SRF 5-cell cavities at 801.58 MHz. Clear path already established in collaboration with JLab to obtain a prototype.
Planning for each stage

STEP 2
Test the machine in Energy Recovery Mode
- Injection at 5 MeV
- 3 turns
- 75 MeV/linac
- Final energy 450 MeV

<table>
<thead>
<tr>
<th>ARC</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 1</td>
<td>80 MeV</td>
</tr>
<tr>
<td>ARC 2</td>
<td>155 MeV</td>
</tr>
<tr>
<td>ARC 3</td>
<td>230 MeV</td>
</tr>
<tr>
<td>ARC 4</td>
<td>305 MeV</td>
</tr>
<tr>
<td>ARC 5</td>
<td>380 MeV</td>
</tr>
<tr>
<td>ARC 6</td>
<td>455 MeV</td>
</tr>
</tbody>
</table>

Recirculation realized with vertically stacked recirculation passes
Planning for each stage

STEP 3
Additional SC RF modules test
Full energy test in Energy Recovery Mode
- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 900 MeV

<table>
<thead>
<tr>
<th>ARC</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 1</td>
<td>150 MeV</td>
</tr>
<tr>
<td>ARC 2</td>
<td>300 MeV</td>
</tr>
<tr>
<td>ARC 3</td>
<td>450 MeV</td>
</tr>
<tr>
<td>ARC 4</td>
<td>600 MeV</td>
</tr>
<tr>
<td>ARC 5</td>
<td>750 MeV</td>
</tr>
<tr>
<td>ARC 6</td>
<td>900 MeV</td>
</tr>
</tbody>
</table>
Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN: LAYOUT AND OPTICS
   MAGNET INVENTORY
   TRACKING SIMULATIONS

3. SC RF

4. PLANNING AND TIMELINE
Layout

5 MeV Extraction

5 MeV Injector

ARC 1 – 155 MeV
ARC 3 – 455 MeV
ARC 5 – 755 MeV
Linac 1 Multi-Pass Optics

A. Valloni, A. Bogacz
Linac 2 Multi-Pass Optics

![Graph showing Linac 2 Multi-Pass Optics with specified energies and optical elements such as $\beta_y$, $\beta_x$, and Disp$_x$.](image)
Arc 1 optics

155 MeV

Arc dipoles:
L_{dip} = 71.8 cm
B = 5.67 kGauss
\rho = 91.45 cm
Arc 3 optics

455 MeV

\[ \beta_x \quad \beta_y \quad \text{Disp}_x \quad \text{Disp}_y \]

Arc dipoles:
\[ L_{\text{dip}} = 90.58 \text{ cm} \]
\[ B = 6.58 \text{ kGauss} \]
\[ \rho = 230.66 \text{ cm} \]

9.8° bends
(1 rec. + 3 sec.)

2-step vert. Spreader

8×22.5° sector bends

2-step vert. Combiner

A. Valloni, A. Bogacz
Arc 5 optics

Arc dipoles:
- $L_{dip} = 90.58$ cm
- $B = 10.92$ kGauss
- $\rho = 230.66$ cm
Magnets inventory

155 MeV

455 MeV

755 MeV

305 MeV

605 MeV

905 MeV

A. Milanese
Summary of magnets inventory

A preliminary inventory of the magnets of the ERL Facility lists:

- 40 bending magnets (vertical field)
- 36 bending magnets (horizontal field) in the spreaders / combiners
- 114 quadrupole magnets
- a few magnets in the injection / extraction parts

Conventional iron-dominated resistive magnets can be used

<table>
<thead>
<tr>
<th>ARC</th>
<th>ENERGY</th>
<th>LENGTH</th>
<th># QUADS</th>
<th># DIPOLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC 1</td>
<td>150 MeV</td>
<td>35.98 m</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>ARC 2</td>
<td>300 MeV</td>
<td>35.74 m</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>ARC 3</td>
<td>450 MeV</td>
<td>35.61 m</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>ARC 4</td>
<td>600 MeV</td>
<td>35.74 m</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>ARC 5</td>
<td>750 MeV</td>
<td>35.98 m</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>ARC 6</td>
<td>900 MeV</td>
<td>34.43 m</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>297.9 m</td>
<td>114</td>
<td>76</td>
</tr>
</tbody>
</table>
Footprint

**ARCS**

Total length for Pass 1
99.86 m
267 x λrf = 20*n* λrf +7*λrf

Total length for Pass 2
99.48 m
266 x λrf = 20*n* λrf +6*λrf

Total length for Pass 3
98.55 m
263.5 x λrf = 20*n* λrf +3.5*λrf

**LINAC**

Linac length ~ 12.6 m
Chicane inj/extr length ~ 1.42 m
F= 801.58 MHz
λrf = 37.4 cm

Total length for 3 passes
297.9 m
Arc layout

14.22 m
13.66 m
42.46 m
13.66

98.5 cm
42.8 cm
6.8 cm
Start-to-end Optics with PLACET2*

Energy
\(\beta_x\)
\(\beta_y\)

\(s [m]\)

Betatron tune

Energy [MeV]

Beta [m]

\(0\)

\(50\)

\(100\)

\(150\)

\(200\)

\(250\)

\(300\)

\(350\)

\(400\)

\(450\)

\(500\)

\(550\)
Transverse Phase space at 900 MeV
(PLACET2 – only optics)

Very well preserved phase space and transverse emittance at 900 MeV and down to the dump

Small impact of (coherent) synchrotron radiation verified with Elegant
Small impact of short-range wakefields expected (to be further investigated)
Bunch length preservation down to dump (very good isochronicity)
Some energy chirp at dump \(\rightarrow\) requires fine tuning of the arc lengths

With 6 mm long bunches, the RF curvature can be seen at high energy, still extremely small energy spread: 5 \(\%\) at injector \(\rightarrow\) 0.1 \(\%\) at 900 MeV

Possibility to introduce energy chirp and tune the arcs \(R_{56}\) to manipulate the phase space
Recombination Pattern

Multi-bunch effects are enhanced by the parameter:

\[ \int \frac{\beta}{E} ds \]

Almost the same for every passage in the linacs

Varies substantially

The bucket filling at subsequent turns can be controlled tuning the length of the arcs

\[ 20 \lambda \approx 25 \text{ ns} \]
Recombination Pattern

Multi-bunch effects are enhanced by the parameter:

\[ \int \frac{\beta}{E} ds \]

Almost the same for every passage in the linacs

Varies substantially

Maximum separation between lowest energy passages minimizes the bunch cross-talk
Long Range Wakefields Threshold Current

Multi-bunch tracking simulations with PLACET2 and optimal recombination pattern
26 dipole modes of the SPL cavity scaled to 802 MHz
100 particles per bunch – BBU triggered by statistical fluctuations of the centroid

Offending mode builds up in the vertical plane (coupling between a specific mode frequency, time of flight and the vertical betatron tune)

Threshold current >5 times higher than the nominal (2e9 particles per bunch)
Optics for steps 1 and 2

- Complete Step 2 and Step 1 configuration and optics layout
Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN

3. SC RF

4. PLANNING AND TIMELINE
CERN management has asked us to conduct a **Conceptual Design Study** for an Energy Recovery Linac Facility (ERLF).

Superconducting RF is a key area – this is where this planned facility comes in.

CERN needs to study and develop the technologies to prepare for a possible next energy-frontier machine (European Strategy for Particle Physics).

We have started this study and have started to establish collaborations.
At LEP II times, CERN had the largest SRF installation
SC RF Activities at CERN

...today (1/2)

Cavity reception & tuning

HIE-Isolde cavity preparation

HIE-Isolde cavity substrate

SM18 Upgraded and extended clean rooms with HP water rinsing and HP water station

HIE-Isolde cavity assembly

E. Jensen
SC RF Activities at CERN

...today (2/2)

SPL cryomodule
Frequency = 704 MHz
Novel cavity suspension by FPC cavities in bulk Nb

HL-LHC crab cavities,
Frequency = 400 MHz,
2-cavity prototype CM cavities in bulk Nb
(fabricated at Niowave)
SC RF Activities at CERN

The CERN SRF R&D has to cover many areas, accelerators, technologies. Where possible, choices were made to exploit synergies!

<table>
<thead>
<tr>
<th>PROGRAMME</th>
<th>FREQUENCY</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC, spare and more</td>
<td>400 MHz</td>
<td>Nb on Cu</td>
</tr>
<tr>
<td>LHC upgrade</td>
<td>800 MHz</td>
<td>Nb on Cu? Bulk?</td>
</tr>
<tr>
<td>HIE-ISOLDE</td>
<td>101 MHz</td>
<td>Nb on Cu</td>
</tr>
<tr>
<td>CRAB</td>
<td>400 MHz</td>
<td>Bulk Nb</td>
</tr>
<tr>
<td>SPL (ESS)</td>
<td>704 MHz</td>
<td>Bulk Nb</td>
</tr>
<tr>
<td>ERL-Facility, FCC-he</td>
<td>800 MHz</td>
<td>Bulk Nb</td>
</tr>
<tr>
<td>FCC-ee, FCC-hh</td>
<td>400 &amp; 800 MHz</td>
<td>Nb on Cu &amp; bulk</td>
</tr>
</tbody>
</table>
SCRF @ the ERL FACILITY

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency</td>
<td>801.58 MHz</td>
</tr>
<tr>
<td>Acc. Voltage/cavity</td>
<td>18.7</td>
</tr>
<tr>
<td># Cells/cavity</td>
<td>5</td>
</tr>
<tr>
<td>Cavity length</td>
<td>~ 1.2 m</td>
</tr>
<tr>
<td># Cavities/cryomodule</td>
<td>4</td>
</tr>
<tr>
<td>RF power/cryomodule</td>
<td>&lt; 50 MW</td>
</tr>
<tr>
<td># Cryomodules</td>
<td>4</td>
</tr>
<tr>
<td>Acceleration/pass</td>
<td>300 MeV</td>
</tr>
<tr>
<td>Bunch repetition</td>
<td>40 MHz</td>
</tr>
<tr>
<td>Duty factor</td>
<td>CW</td>
</tr>
</tbody>
</table>

Initial Cavity Design (SPL, JLAB and BNL experience)

Possibility to install and test cavities at other European frequencies (ESS, SPL,…), (LHC harmonic, SPS, LHeC, FCC,…) (XFEL, ILC) if:
- Photocathode pulsing at a sub-harmonic (12.16 MHz)
- Tunable arc length (10 cm) to match the phase

Cryomodule Design

JLAB had designed an 805 MHz cryomodule for SNS (concept for the 801.58 MHz baseline design)

Established collaboration with JLab taking advantage of their experience with CEBAF and the FEL in ERL mode:
- crucial contributions already obtained for the machine layout and lattice
- design and construct the 801.58 MHz cavities and cryomodules.
Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN

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ERL Facility at CERN for Applications

- Facility for testing quench and damage levels of SC wires and SC magnets
  - Intensities and repetition rates
  - Space, powering and other requirements

- Generation of high-energy monochromatic polarized photons via Compton backscattering of laser light from relativistic electrons for nuclear physics research
  - Investigate the maximum energy and flux of the gamma-beam generated
  - Define the laser requirements according to the electron beam parameters
Possible Site options

- Many site possibilities presented @ January 2014 LHeC Workshop

Three main options:

- **Point 2 @ ALICE** – apparently hosting power converters (tbc)
- **SM18** – existing cryogenic and powering infrastructure, but no available space
- **Prevesin site** – still under investigation

Site specific studies are foreseen for the ERL TF and auxiliary applications in preparation for the ERL TF CDR
Planning for the CDR

- Draft a preliminary version by the end of June 2015:

  To be presented at the next LHeC Workshop*
  CERN (24 June) and Chavannes-de-Bogis (25-26 June)

  **Organization committee:**
  S. Bertolucci, F. Bordry, O. Bruning, L. Hemery, M. Klein

- Complete CDR by the end of 2015

* https://indico.cern.ch/event/356714/
LHeC Workshop

International Advisory Committee:
Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Nicola Bianchi (INFN Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago and Fermilab)
Victor A. Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (EPF Lausanne)
Herwig Schopper (CERN) - Chair
Jürgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)

Working Group Convenors
Physics and Detector
Voica Radescu (Heidelberg)
Peter Kostka (Liverpool)

Accelerator and ERL Facility
Gianluigi Arduini (CERN)
Erk Jensen (CERN)
Summary

- An **ERL platform** is being pursued at CERN to validate the LHeC key design choices along with dedicated physical and technical applications.
- The concept of the ERL Facility is designed to allow for a **staged** construction with verifiable and useful stages for an ultimate beam energy in the order of 900 MeV.
- An **optics** design study of the ERLF has been completed and start-to-end analysis are ongoing.
- Design complementary to & synergetic with other proposals worldwide.
- Collaborations with other institutes have been started.
- Completion of **Conceptual design study** of an ERLF at CERN by 2015.

*Thank you for your attention*

...and thanks to the LHeC collaboration, in particular to A. Bogacz, O. Bruning, V. Chetvertkova, E. Jensen, M. Klein, D. Wollmann, F. Zomer.

http://lhec.web.cern.ch
# LHeC as an Higgs Factory: ultimate IP parameters

<table>
<thead>
<tr>
<th><strong>$10^{34}$ cm$^{-2}$ s$^{-1}$ Luminosity reach</strong></th>
<th>PROTONS</th>
<th>ELECTRONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy [GeV]</td>
<td>7000</td>
<td>60</td>
</tr>
<tr>
<td>Luminosity [$10^{33}$ cm$^{-2}$s$^{-1}$]</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Normalized emittance $\gamma \epsilon_{x,y} [\mu m]$</td>
<td>2.5</td>
<td>20</td>
</tr>
<tr>
<td>Beta Function $\beta^*_x,y [m]$</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>rms Beam size $\sigma^*_x,y [\mu m]$</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>rms Beam divergence $\sigma'_{x,y} [\mu rad]$</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Average Beam Current [mA]</td>
<td>1112</td>
<td>25 delivered 150 in linacs</td>
</tr>
<tr>
<td>Bunch Spacing [ns]</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Bunch Population</td>
<td>$2.2 \times 10^{11}$</td>
<td>$4 \times 10^9$</td>
</tr>
<tr>
<td>Bunch charge [nC]</td>
<td>35</td>
<td>0.64</td>
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</table>
Review of some ERL-based machines worldwide (planned/existing/operating)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Beam Energy</th>
<th>Beam Current</th>
<th>Bunch charge</th>
<th>RF frequency</th>
<th>Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>JLAB, FEL</td>
<td>88-165 MeV</td>
<td>10 mA</td>
<td>135 pC</td>
<td>1500 MHz</td>
<td>1</td>
</tr>
<tr>
<td>cERL facility, KEK</td>
<td>12-26 MeV</td>
<td>10 mA (100 mA)</td>
<td>40-60-200 pC</td>
<td>1300 MHz</td>
<td>1-2</td>
</tr>
<tr>
<td>ALICE, Daresbury</td>
<td>35-125-250 MeV</td>
<td>10 mA</td>
<td>7.7 pC-77 pC</td>
<td>1300 MHz</td>
<td>1-2</td>
</tr>
</tbody>
</table>
### Review of some ERL-based machines worldwide (planned/existing/operating)

<table>
<thead>
<tr>
<th>JLAB, FEL</th>
<th><strong>Beam Energy</strong></th>
<th>88-165 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Beam Current</strong></td>
<td>10 mA</td>
</tr>
<tr>
<td></td>
<td><strong>Bunch charge</strong></td>
<td>135 pC</td>
</tr>
<tr>
<td></td>
<td><strong>RF frequency</strong></td>
<td>1500 MHz</td>
</tr>
<tr>
<td></td>
<td><strong>Passes</strong></td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CORNELL ERL</th>
<th><strong>Beam Energy</strong></th>
<th>5 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Beam Current</strong></td>
<td>100 mA</td>
</tr>
<tr>
<td></td>
<td><strong>Bunch charge</strong></td>
<td>77 pC</td>
</tr>
<tr>
<td></td>
<td><strong>RF frequency</strong></td>
<td>1300 MHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Brookhaven ERL facility</th>
<th><strong>Beam Energy</strong></th>
<th>20 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Bunch charge</strong></td>
<td>0.5-5 nC</td>
</tr>
<tr>
<td></td>
<td><strong>Bunch current</strong></td>
<td>300 mA</td>
</tr>
<tr>
<td></td>
<td><strong>RF frequency</strong></td>
<td>704 MHz</td>
</tr>
<tr>
<td></td>
<td><strong>Passes</strong></td>
<td>1</td>
</tr>
</tbody>
</table>
Review of some ERL-based machines worldwide (planned/existing/operating)

<table>
<thead>
<tr>
<th>Machine</th>
<th>Beam Energy (MeV)</th>
<th>Beam Current (mA)</th>
<th>Bunch charge (pC)</th>
<th>RF frequency (MHz)</th>
<th>Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERL-TF in IHEP, BEIJING</td>
<td>35</td>
<td>10</td>
<td>77</td>
<td>1300</td>
<td>1</td>
</tr>
<tr>
<td>BERLinPro, HZB</td>
<td>50</td>
<td>100</td>
<td>77</td>
<td>1300</td>
<td>1</td>
</tr>
<tr>
<td>MESA installation, Mainz</td>
<td>105</td>
<td>0.77</td>
<td>0.77</td>
<td>802/1300</td>
<td>2</td>
</tr>
</tbody>
</table>
Possible Site option: SM18

- Superconducting magnets and RF test facility.
  - Horizontal benches for SC magnets
  - Vertical cryostats for prototypes
  - RF powering and bunkers for RF SC cavities
- Cryogenics water power and other services already available.

- No space inside existing buildings.
- Adjacent positioning may interfere with SM18 activities.
- Parking space over the hill is not in use.
- South area less convenient as requires excavation
- All this possibilities are being discussed with the area managers
On the limit of the Prevessin site.

Constructed from shielding blocks, smaller than required but may be easily extended or rebuilt.

Some cryogenic infrastructure already available.
Controlled quench and damage tests

MOTIVATION
FACILITY FOR TESTING QUENCH AND DAMAGE LEVELS
OF SC WIRES AND SC MAGNETS

Question:
Are the intensities at extraction and repetition rates sufficient for the tests?

Requirements in terms of:

- Beam energy, intensity and pulse length (energy deposition)
- Space for the magnets installation (possible tests of cable samples and full cryo magnets)
- Cryo requirements
- Vacuum requirements
- Powering needs
Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Beam parameters

<table>
<thead>
<tr>
<th>Energy, MeV</th>
<th>Emittance, m</th>
<th>Sigma, cm</th>
<th>FWHM, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>1.70E-07</td>
<td>0.092</td>
<td>0.22</td>
</tr>
<tr>
<td>300</td>
<td>8.52E-08</td>
<td>0.065</td>
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<td>450</td>
<td>5.68E-08</td>
<td>0.053</td>
<td>0.13</td>
</tr>
<tr>
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<td>4.26E-08</td>
<td>0.046</td>
<td>0.11</td>
</tr>
<tr>
<td>750</td>
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<td>0.041</td>
<td>0.10</td>
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<tr>
<td>900</td>
<td>2.84E-08</td>
<td>0.038</td>
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</tr>
<tr>
<td>1000</td>
<td>2.55E-08</td>
<td>0.036</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Results are given for half of bulky target because of symmetry
Binning: 1 mm³ bins

Copper target
(no magnetic field)

Cylinder of copper
Radius = 50 cm
Length = 100 cm

Energy deposition, GeV/cm³/e⁻
Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Copper target (no magnetic field)
- Cylinder of copper
  - Radius = 50 cm
  - Length = 100 cm

Beam parameters

<table>
<thead>
<tr>
<th>Energy, MeV</th>
<th>Emittance, m</th>
<th>Sigma, cm</th>
<th>FWHM, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>1.70E-07</td>
<td>0.092</td>
<td>0.22</td>
</tr>
<tr>
<td>300</td>
<td>8.52E-08</td>
<td>0.065</td>
<td>0.15</td>
</tr>
<tr>
<td>450</td>
<td>5.68E-08</td>
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</tr>
</tbody>
</table>

Results are given for half of bulky target because of symmetry
- Binning: 1 mm³ bins

Energy deposition, GeV/cm³/e⁻

- Peak at z = 0.6 cm, r=0
  - Peak value = 0.2199 GeV/cm³

- Peak at z = 2.1 cm, r=0
  - Peak value = 1.0785 GeV/cm³

150 MeV

1 GeV
**Quench & Damage**

For quenching an LHC MB (main dipole magnet) a certain amount of energy should be deposited in $1\text{ mm}^3$

\[ \text{# electrons needed to quench the magnet} = \frac{\text{Quench threshold}}{\text{Maximum value for the energy deposition}} \]

Can easily quench with a single bunch at 150 MeV

Bunch charge $2e^9 > \text{quench threshold } 1e^9$

- **Damage limit** in present studies is defined as a number of electrons needed for melting $1\text{ mm}^3$ of Cu

- Number of electrons for melting Cu should be delivered to the target within several hundreds ms in order to avoid heat transfer

<table>
<thead>
<tr>
<th>Cu melt.</th>
<th>1358 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\text{kJ/cm}^3]$</td>
<td>5.07</td>
</tr>
</tbody>
</table>

2e$11$ electrons required over $0.1$ s to melt $1\text{ mm}^3$

8e$15$ electrons accelerated over $0.1$ s (can extract few bunches with a fast kicker)
Gamma beams at the ERL Facility

GOAL: Generation of high-energy monochromatic polarized photons via **Compton backscattering** of laser light from relativistic electrons for nuclear physics research.

- **Incident electron beam** $E_e$
- **Incident laser beam** $E_L$
- **Scattered laser beam** $E_\gamma$
- **Theta** $\theta_L$, $\theta_\gamma$
Gamma beams at the ERL Facility: input parameters

**ELECTRON BEAM PARAMETERS**
- Energy: 900 MeV
- Charge: 320 pC
- Bunch Spacing: 25 ns
- Spot size: 30 um
- Norm. Trans. Emittance: 5 um
- Energy Spread: 0.1%

**LASER BEAM PARAMETERS**
- Wavelength: 515 nm - 1030 nm
- Average Power: 300 kW - 600 kW
- Pulse length: 3 ps
- Pulse energy: 7.5 mJ - 15 mJ
- Spot size: 30 um
- Bandwidth: 0.02 %
- Repetition Rate: 40 MHz
Gamma beam properties at the ERL facility

Maximun Gamma Energy ≈ 30 MeV

<table>
<thead>
<tr>
<th>GAMMA BEAM PARAMETERS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>30 MeV</td>
</tr>
<tr>
<td>Spectral density</td>
<td>$9 \times 10^4$ ph/s/eV</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Flux within FWHM bdw</td>
<td>$7 \times 10^{10}$ ph/s</td>
</tr>
<tr>
<td>ph/e⁻ within FWHM bdw</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Peak Brilliance</td>
<td>$3 \times 10^{21}$ ph/s<em>mm²</em>mrad² 0.1%bdw</td>
</tr>
</tbody>
</table>
Input laser beam

Mode locked laser beam: electric field

Four mirror cavity resonator: Each tooth of the comb locked to a cavity mode

\[ P_{\text{circ}} = G \times P_{\text{in}} \]

State of the art (average power/\ ~10 ps pulses):
- \( P_{\text{circ}} \approx 670\text{kW} \) for \( P_{\text{in}} = 315\text{W} \) (250MHz; table top; Garching, OL39(2014)2595)
- \( P_{\text{circ}} \approx 50\text{kW} \) for \( P_{\text{in}} \approx <10\text{W} \) (178.5MHz; gamma-ray exp. at ATF/KEK, CELIA/KEK/Hiroshima/LAL/LMA)
Configuration for LHec ERL gamma source:
~same as ThomX project (CELIA, LAL)
R&D going on at LAL and CELIA Labs.

- ps master Oscillator
- Stretcher
- Fiber amplifiers
- Compressor
  - Frequency doubling

Gain ~10000
Fabry Perot Cavity

- 150 W 10 ps 1030 nm
- 70 W 7 ps 515nm

E. Cormier (CELIA)
Configuration 2 for LHec ERL gamma source

- ps master Oscillator
- Stretcher
- Fiber amplifiers
- Coherent combiner
- Compressor
- Fabric Perot Cavity
- Frequency doubling

Gain ≈ 10000

E. Cormier (CELIA)