Erk Jensen/CERN

O. Brüning, C. Bracco, R. Calaga, N. Catalan-Lasheras, B. Goddard, R. Torres-Sanchez, A. Valloni/CERN; M. Klein/CERN and U-Liverpool

Design Study of an LHeC ERL Test Facility at CERN

Many special thanks to
Outline

- Introduction: LHeC and FCC-he
- The ERL-TF: Goals and parameters
- Layout and Optics
- ERL Cavity/Cryomodule Development
- Summary
Introduction

LHeC and FCC-eh
LHeC Physics – complementary to pp and e+e-  

- BSM physics (leptoquarks, ...)
- PDFs for LHC/FCC-hh
- Higgs via vector boson fusion

New Physics

- pp
  - W, Z, top
  - Higgs, new symmetries?
  - new particles?
  - present status: LHC

- FCC-he
  - energy x4 (to 1.2 TeV) LHeC
  - energy x15 (to 4.5 TeV) FCC-he
  - luminosity x100 (to $10^{33} \text{ cm}^{-2} \text{s}^{-1}$)
  - or pushed even x1000 ($10^{34}$)

- ep
  - precision QCD
  - high density matter
  - Higgs, eq-Spectroscopy
  - present status: HERA

- e+e-
  - precision measurements
  - ttbar, Higgs spectroscopy?
  - present status: LEP

FCC-ee?

energy x2.4 (HE-LHC)
energy x7 (FCC-hh)
LHeC

- **Physics Goals:** Colliding LHC proton beam with e⁻ or e⁺ beam
  - Exploration of the energy frontier, complementing the LHC for BSM physics with high precision DIS measurements!
  - Investigation of a variety of fundamental questions in strong and electroweak interactions;
  - Electron-ion scattering in a \( (Q^2, 1/x) \) range extended by 4 orders of magnitude as compared to previous lepton-nucleus DIS experiments;
  - Novel investigations of neutron's and nuclear structure, initial conditions of Quark-Gluon Plasma formation and further QCD phenomena;
  - With \( \mathcal{L} = \mathcal{O}(10^{34}) \): Higgs factory via vector boson fusion

- **Constraints and challenges:**
  - Power consumption \( \leq 100 \text{ MW} \)!
  - \( \mathcal{O}(60 \text{ GeV}) \) ERL with two 10 GeV Linacs, 3 passes
  - Luminosity \( \mathcal{O}(100 \text{ fb}^{-1}) \) with \( 10^{33} \text{ cm}^{-2} \text{s}^{-1} \) (100 x HERA) (and possibly more!)
  - No interference with pp physics!
LHeC options: RR and LR

17 Juni 2014 IPAC '14, Dresden Erk Jensen: ERL Test Facility
LHeC options: RR and LR

Study team provided CDR:
Ring-ring option, feasible but impact LHC operation during installation
Study team provided CDR:
Ring-ring option, feasible but impact LHC operation during installation

**Linac-ring option**, the baseline

A solution exists, will now have to find the best solution

Already have a baseline and alternatives for some components
LHeC LR option (baseline)

Super Conducting Linac with Energy Recovery

Two 1 km long SC linacs in CW operation ($Q_0 > 10^{10}$)

- high current (> 6 mA)

- requires cryogenic system comparable to LHC system!

Relatively large return arcs

- ca. 9 km underground tunnel installation
- total of 19 km bending arcs
- same magnet design as for RR option: > 4500 magnets
LHeC LR option (baseline)

Super Conducting Linac with Energy Recovery & high current (> 6 mA)

- Two 1 km long SC linacs in CW operation
  \( \nu \sigma > 1 \\times 10^5 \)
  \( \Rightarrow \) requires cryogenic system comparable to LHC system!

- Super Conducting Linac with Energy Recovery
  & high current (> 6 mA)

- Relatively large return arcs
  \( \Rightarrow \) ca. 9 km underground tunnel installation
  \( \Rightarrow \) total of 19 km bending arcs

- Same magnet design as for RR option: > 4500 magnets

<table>
<thead>
<tr>
<th></th>
<th>PROTONS</th>
<th>ELECTRONS</th>
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<tbody>
<tr>
<td>Beam Energy [GeV]</td>
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<td>60</td>
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<td>Luminosity [10^{33} cm^{-2} s^{-1}]</td>
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<td>1</td>
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<td>Normalized emittance ( \gamma \varepsilon_{x,y} ) [\mu m]</td>
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<td>Beta Function ( \beta_{x,y}^* ) [m]</td>
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<td>7</td>
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<td>RMS Beam divergence ( \sigma'_{x,y} ) [\mu rad]</td>
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<tr>
<td>Beam Current [mA]</td>
<td>430 (860)</td>
<td>6.6</td>
</tr>
<tr>
<td>Bunch Spacing [ns]</td>
<td>25 (50)</td>
<td>25 (50)</td>
</tr>
<tr>
<td>Bunch Population</td>
<td>1.7\times10^{11}</td>
<td>(1\times10^9) 2\times10^9</td>
</tr>
<tr>
<td>Bunch charge [nC]</td>
<td>27</td>
<td>(0.16) 0.32</td>
</tr>
</tbody>
</table>
**LHeC LR option (baseline)**

**Super Conducting Linac with Energy Recovery**

& high current (> 6 mA)

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<table>
<thead>
<tr>
<th>PROTONS</th>
<th>ELECTRONS</th>
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</thead>
<tbody>
<tr>
<td><strong>10^{33} cm^{-2} s^{-1} Luminosity reach</strong></td>
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<td>Beam Energy [GeV]</td>
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<td>Beta Funtion $\beta^*_{x,y}$ [m]</td>
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<td>rms Beam size $\sigma^*_{x,y}$ [$\mu$m]</td>
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<td>rms Beam divergence $\sigma'_{x,y}$ [$\mu$rad]</td>
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<td>Bunch Population</td>
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<tr>
<td>Bunch charge [nC]</td>
<td>35</td>
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</tbody>
</table>

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Relatively large return arcs

→ ca. 9 km underground tunnel installation

→ total of 19 km bending arcs

→ same magnet design as for RR option. > 4500 magnets
LHC Conceptual Design Report

- Published in 2012 in Journal of Physics G:
  http://iopscience.iop.org/0954-3899/39/7/075001
- Introduction
- Physics
  - Precision QCD and Electroweak Physics
  - Physics at High Parton Densities
  - New Physics at High Energy
- Accelerator
  - Ring-Ring Collider
  - Linac-Ring Collider
  - System Design
  - Civil Engineering and Services
- Detector
  - Detector Requirements
  - Central Detector
  - Forward and Backward Detectors
- Conclusions
FCC-he

- 80-100 km tunnel infrastructure in Geneva area
- $pp$-collider ($FCC-hh$) defining the infrastructure requirements
- $e^+e^-$ collider ($FCC-ee$) as potential intermed. step
- $p$-$e$ ($FCC-he$) option
- international collaboration hosted by CERN

\[ \sim 16 \text{ T} \Rightarrow 100 \text{ TeV } pp \text{ in 100 km} \]
\[ \sim 20 \text{ T} \Rightarrow 100 \text{ TeV } pp \text{ in 80 km} \]
FCC-he

- 80-100 km tunnel infrastructure in Geneva area
- $pp$-collider ($FCC-hh$) defining the infrastructure requirements
- $e^+e^-$ collider ($FCC-ee$) as potential intermediate step
- $p$-$e$ ($FCC-he$) option
- international collaboration hosted by CERN

Two Options for FCC-he:
- Ring-Ring collider using $FCC-hh$ and $FCC-ee$
- Linac-Ring collider using ERL (LHeC) and $FCC-hh$

Both options offer performance reach of $\mathcal{L} = (10^{33} \div 10^{34}) \text{cm}^{-2}\text{s}^{-1}$ @ ca. 4.5 TeV CM

~16 T $\Rightarrow$ 100 TeV $pp$ in 100 km
~20 T $\Rightarrow$ 100 TeV $pp$ in 80 km
Goals and parameters

The ERL-TF
The Context

- In this decade, CERN is exploiting and upgrading the LHC – but not constructing “the next big machine”.
- CERN needs to study and develop the technologies to prepare for a possible next energy-frontier machine.
- This R&D focuses on high field magnets and high gradient acceleration. (European Strategy for Particle Physics)
- Superconducting RF is a key area – this is where this planned facility comes in.

CERN management has asked us to conduct a Conceptual Design Study for an Energy Recovery Linac Test Facility (ERL-TF).

We have started this study and have started to establish collaborations.
Goals of a CERN ERL-Test Facility

- Main goal: **Study real SRF Cavities with beam** – not interfering with HEP!
    - All problems will not be experienced until the complete subsystem is tested under realistic conditions. Be prepared to test, with full rf power systems and beam, all of the pre-production prototypes.

- In addition, it would allow to study **beam dynamics & operational aspects** of the advanced concept ERL (recovery of otherwise wasted beam energy)!

- Exploration of the ERL concept with multiple re-circulations and high beam current operation

- Additional goals:
  - Gun and injector studies
  - Test beams for detector R&D,
  - Beam induced quench test of SC magnets
  - ... later possibly user facility: $e^-$ test beams, CW FEL, Compton $\gamma$-ray source ...

- At the same time, it will be fostering international collaboration (JGU Mainz and TJNAF collaborations being formalized)
### Parameters of the ERL-TF

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>injection energy</td>
<td>5 MeV</td>
</tr>
<tr>
<td>$RF f$</td>
<td>801.59 MHz</td>
</tr>
<tr>
<td>acc. voltage per cavity</td>
<td>18.7 MV</td>
</tr>
<tr>
<td># cells per cavity</td>
<td>5</td>
</tr>
<tr>
<td>cavity length</td>
<td>$\approx 1.2 \text{ m}$</td>
</tr>
<tr>
<td># cavities per cryomodule</td>
<td>4</td>
</tr>
<tr>
<td>RF power per cryomodule</td>
<td>$\leq 50 \text{ kW}$</td>
</tr>
<tr>
<td># cryomodules</td>
<td>4 *)</td>
</tr>
<tr>
<td>acceleration per pass</td>
<td>299.4 MeV *)</td>
</tr>
<tr>
<td>bunch repetition $f$</td>
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<td>50 $\mu$m</td>
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<tr>
<td>injected beam current</td>
<td>$&lt; 13 \text{ mA}$</td>
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<tr>
<td>nominal bunch charge</td>
<td>$320 \text{ pC} = 2 \cdot 10^9 e$</td>
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<tr>
<td>number of passes *)</td>
<td>2</td>
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<tr>
<td>top energy *)</td>
<td>604 MeV</td>
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<tr>
<td>total circulating current *)</td>
<td>52 mA</td>
</tr>
<tr>
<td>duty factor</td>
<td>CW</td>
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</table>

*) in stages

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**Graph:**

- ARC 2 300 MeV
- ARC 4 600 MeV
- ARC 6 900 MeV
- ARC 1 150 MeV
- ARC 3 450 MeV
- ARC 5 750 MeV

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

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

A. Valloni, A. Bogacz
STEP 2
Test the machine in Energy Recovery Mode
- Injection at 5 MeV
- 3 passes
- 75 MeV/linac
- Final energy 450 MeV

Recirculation realized with vertically stacked recirculation passes

<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>
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<tr>
<td>ARC 4</td>
<td>305 MeV</td>
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<tr>
<td>ARC 5</td>
<td>380 MeV</td>
</tr>
<tr>
<td>ARC 6</td>
<td>455 MeV</td>
</tr>
</tbody>
</table>

A. Valloni, A. Bogacz
STEP 3
Additional SC RF modules test
Full energy test in Energy Recovery Mode
- Injection at 5 MeV
- 3 passes
- 150 MeV/(double length 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>
Linacs multi-pass optics

- **Linac 1**
  - **step 2:**
  - **step 3:**

- **Linac 2**
  - **step 2**
  - **step 3:**

A. Valloni, A. Bogacz
Arcs layout

- Isochronous
- Achromatic
- FMC optics
- Symmetric

FMC: Flexible Momentum Compaction

Total Arc length for Arc 1,3,5

\[ 34.5112 \text{ m} = 94 \times \lambda_{RF} \]

For all 6 arcs:

- 84 dipoles + 114 quadrupoles

A. Valloni, A. Bogacz
Arc 1 optics

155 MeV

2-step vert.
Spreader

4×45° sector bends

2-step vert.
Combiner

Arc dipoles:
L_{dip} = 71.8 cm
B = 5.67 kGauss
ρ = 91.45 cm

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Erk Jensen: ERL Test Facility

A. Valloni, A. Bogacz
Arc 3 optics

455 MeV

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

\( L_{\text{dip}} = 90.58 \text{ cm} \)
\( B = 6.58 \text{ kGauss} \)
\( \rho = 230.66 \text{ cm} \)

9.8° bends
(1 rec. + 3 sec.)

8×22.5° sector bends

2-step vert. Combiner

A. Valloni, A. Bogacz

2-step vert. Spreader
Arc 5 optics

Arc dipoles:
Ldip = 90.58 cm
B = 10.92 kGauss
ρ = 230.66 cm

755 MeV

8×22.5° sector bends

Vertical chicane

A. Valloni, A. Bogacz
Arc optics option 2

Identical optics layout for all arcs (150 … 900) MeV

Arc dipoles:
8×22.5° bends
$L_{dip} = 1.006$ m
$\rho = 2.563$ mm

Arc quadrupoles
$L_{quads} = 0.3$ m

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>1GeV</th>
<th>750MeV</th>
<th>600MeV</th>
<th>450MeV</th>
<th>300MeV</th>
<th>150MeV</th>
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<tr>
<td>$B$</td>
<td>1.30 T</td>
<td>0.97 T</td>
<td>0.78 T</td>
<td>0.58 T</td>
<td>0.39 T</td>
<td>0.19 T</td>
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<tr>
<td>$Q_1$</td>
<td>-1.01</td>
<td>2.91</td>
<td>2.09</td>
<td>1.19</td>
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<tr>
<td>$Q_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_3$</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>$Q_4$</td>
<td></td>
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</table>

Attilio Milanese
Footprint

**Arcs**

Total length for Arc 1, 3, 5:
\[ 34.5112 \text{ m} = 94 \times \lambda_{RF} \]
(last cavity linac1 to first cavity linac 2)

Total length for Arc 2, 4:
\[ 34.2704 \text{ m} = 101 \times \lambda_{RF} \]
(last cavity linac2 to first cavity linac 1)

Total length for Arc 6:
\[ 34.4574 \text{ m} = 101.5 \times \lambda_{RF} \]
(last cavity linac 2 to first cavity linac 1)

**Linacs**

Total length ~ 13 m

**Injection/extraction chicane:**
Length ~ 1.75 m

**Total dimensions**
42 m x 13.7 m
We have started to look into possible existing buildings on site possibly suited to host the ERL test facility.

**Example shown here:**

**Building 2275, near LHC P2**
- Current use under investigation
- Power converters already in place
- Geographically perfect as injector for LHeC ERL

**Other options investigated:**
- SM18, extension to building 2173? Ideal for existing infrastructures!
- Building 973 (Prévessin), former QRL testing, partially existing cryo infrastructure.

N. Catalan Lasheras
We have started to look into possible existing buildings on site possibly suited to host the ERL test facility.

**Example shown here:**
Building 2275, near LHC P2

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N. Catalan Lasheras
ERL Cavity/Cryomodule Development

... only just starting
Post CDR frequency choice

LHeC Meeting at Daresbury Laboratory, January 2013

802 MHz buckets (harmonic 20 of 25 ns⁻¹)

Synergetic with CERN SPS, LHC, LHC upgrades, ...
JLAB-CERN-Mainz 801.58 MHz Cavity/cryomodule now under design
Post CDR frequency choice

LHeC Meeting at Daresbury Laboratory, January 2013

802 MHz buckets (harmonic 20 of $25 \text{ ns}^{-1}$)

Synergetic with CERN SPS, LHC, LHC upgrades, ...

JLAB-CERN-Mainz 801.58 MHz Cavity/cryomodule now under design
R&D goal: large $Q_0$ – recent progress

Sam Posen et al. (Cornell): “Theoretical Field Limits for Multi-Layer Superconductors”, SRF 2013

Anna Grasselino et al. (FNAL): “New Insights on the Physics of RF Surface Resistance and a Cure for the Medium Field Q-Slope”, SRF 2013

Andrew Hutton (JLAB), private communication 2014: recent results with large-grain Nb in low-loss shape (CEBAF upgrade end cell)
802 MHz cavity: Some first choices

<table>
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<th>Value</th>
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<td>$n_{cell}$</td>
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</tr>
<tr>
<td>$V_{acc}$</td>
<td>18 MV</td>
</tr>
<tr>
<td>$f_0$</td>
<td>801.58 MHz</td>
</tr>
<tr>
<td>$W$</td>
<td>131 J</td>
</tr>
<tr>
<td>aperture $\varnothing$</td>
<td>75 mm</td>
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<tr>
<td>equator $\varnothing$</td>
<td>347 mm</td>
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<tr>
<td>$R/Q$</td>
<td>462 $\Omega$</td>
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<tr>
<td>$G$</td>
<td>276 $\Omega$</td>
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<tr>
<td>$E_{peak}$</td>
<td>41 MV/m</td>
</tr>
<tr>
<td>$B_{peak}$</td>
<td>86 mT</td>
</tr>
<tr>
<td>$P_{diss}</td>
<td>_{2K}$</td>
</tr>
</tbody>
</table>

R. Calaga
Impedance spectra

801.58 MHz Cavity, Short range wake, s=10cm, $\sigma_z=2$mm

R. Calaga
HOM power estimate (short bunches)

$P_{HOMs} \approx 200 \text{ W} \left(40 \text{ mA}, k_{||} = 2.35 \frac{V}{\text{pC}}\right)$

Longitudinal Loss Factor ($\sigma_z = 2\text{ mm}$)

Note: with 13 mA injected, the total current for HOM excitation can be 80 mA!
JLAB proposal: SNS style Cryomodule

- Based on SNS CM
  - 5-cell low-loss shape
  - coaxial FPC
  - Single RF Window
  - DESY Style HOM coupler
  - Cold tuner drive
- Overall length: 7.524 m
- Beamline length 6.705 m
- End Cans include integral heat exchanger for improved efficiency at 2K operations

Scaled for $\beta = 1$
JLAB CM Design Maturity

- **Design maturity**
  - Cryostat design is complete, SNS cryostat and cryogenic connection is a “drop in” design
  - Jefferson Lab has existing 750 MHz and 800 MHz cavity designs
    - Needs HOM coupling design, detail SNS style coupler for this application
    - Can use SNS coupler with minimal changes for CW operations (lower average power in this case, makes the design simpler)

- **Production**
  - Cryostat and power coupler costs from SNS production (2002) available
    - Costs need to be corrected for small quantity production and escalation
  - Jefferson Lab in-house cavity assembly to control schedule
CERN experience: SPL Short Cryomodule

- Cryogenic circuit burst disk
- Vacuum vessel relief plate
- Thermal shield
- Cryogenic lines port
- Helium tank
- Magnetic shielding
- Vacuum vessel
- Phase separator
- Bi-phase pipe
- Cavity tuner
- Gate valve
- Inter-cavity support
- Cavity
- Thermal shield tie-rod
- Cold-to-warm transition
- Double walled tube
- RF coupler

O. Capatina, V. Parma, R. Bonomi, S. Rousselot
Recent SPL progress in pictures
### RF Power Couplers (FPCs)

<table>
<thead>
<tr>
<th>Machine</th>
<th>Design</th>
<th>Construction</th>
<th>Operation</th>
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<td>SPS 200</td>
<td>✓</td>
<td>✓</td>
<td>2001</td>
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<tr>
<td>LHC 400</td>
<td>✓</td>
<td>✓</td>
<td>2006</td>
</tr>
<tr>
<td>SPL cylindrical</td>
<td>✓</td>
<td>✓</td>
<td>1 MW TW 550 kW SW</td>
</tr>
<tr>
<td>SPL disk</td>
<td>✓</td>
<td>✓</td>
<td>1 MW TW 1 MW SW</td>
</tr>
<tr>
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<td>✓</td>
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<td>300 kW CW</td>
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<tr>
<td>ANL-APS</td>
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<td>100 kW CW</td>
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<tr>
<td>Linac 4</td>
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<td>✓</td>
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</tr>
<tr>
<td>HIE-Isolde</td>
<td>To be improved</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIU-SPS 200</td>
<td>To come</td>
<td></td>
<td></td>
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<tr>
<td>SPS 800</td>
<td>To come</td>
<td></td>
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</tr>
<tr>
<td>SOLEIL</td>
<td>To come</td>
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<td>Crab Cav x 3</td>
<td>To come</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Some good results this year:**
  - ESRF
  - APS (tests still on-going)
  - SPL coaxial disk
- **Some still to be improved:**
  - SPL cylindrical
  - HIE-Isolde
- **Some still operating without troubles:**
  - SPS 200
  - LHC 400
- **Some additional to come**
The planned collaboration:

- We are now finalizing collaboration agreements with JG|U Mainz and JLAB to build prototype 802 MHz cavities/CMs together!
  - JG|U to provide infrastructure (MESA and HIM) manpower and resources
  - CERN to design/engineer cavities, HOM dampers, FPCs, tuners, He vessel, ancillaries...
  - JLAB to design/engineer the CM (based on SNS 805 MHz concept)
- 1st prototype cavities can serve in MESA.
Summary

- The concept of the ERL-TF is designed to allow for a staged construction with verifiable and useful stages for an ultimate beam energy in the order of 1 GeV.
- A key part of the design study is the development of superconducting RF cavities and CM’s.
- This study has started in collaboration with JLAB and JG|U Mainz.
- There is strong synergy with the JG|U Mainz project “MESA” – the cavities/cryomodules could be identical.
- CERN is in the process of re-establishing know-how and upgrading its facilities for SRF R&D.
- Ongoing work in SRF at CERN also includes LHC, SPL, HIE-ISOLDE, crab cavities HL-LHC; planned future work will include the study of a large circular collider (FCC).

Thank you for your attention!
Spare slides
Controlled quench tests of SC magnets

Study beam induced quenches (quench thresholds, quenchino thresholds) at different time scales for:

- SC cables and cable stacks in an adjustable external magnetic field
- Short sample magnets
- Full length LHC type SC magnets
- Vital program for the development of high field magnets for FCC-hh and HE-LHC

MB quench limit @ 3.5 TeV

Number of particles

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>MB quench limit @ 3.5 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>20 mJ/cm³, 10 μs</td>
</tr>
<tr>
<td>200</td>
<td>25 mJ/cm³, 100 μs</td>
</tr>
<tr>
<td>300</td>
<td>50 mJ/cm³, 1 ms</td>
</tr>
<tr>
<td>400</td>
<td>75 mJ/cm³, 10 ms</td>
</tr>
<tr>
<td>500</td>
<td>250 mJ/cm³, 0.1 s</td>
</tr>
<tr>
<td>600</td>
<td>750 mJ/cm³, 1 s</td>
</tr>
<tr>
<td>700</td>
<td>3000 mJ/cm³, 10 s</td>
</tr>
<tr>
<td>800</td>
<td>20000 mJ/cm³, 100 s</td>
</tr>
</tbody>
</table>

$1 \text{ GeV} = 1.602 \times 10^{-7} \text{ mJ}$

MB quench limit 450 GeV is 140 mJ/cm³ in 10 ms:
$\approx 2.2 \times 10^9 e^- @ 1 \text{GeV necessary}$

MB quench limit 7 TeV is 16 mJ/cm³ in 10 ms:
$\approx 0.3 \times 10^9 e^- @ 1 \text{GeV necessary}$

These numbers are well in reach (bunch charge $2 \times 10^9 e^-$).
possible later applications

ELI-NP is the M€ 293 pillar for nuclear physics of the European Extreme Light Infrastructure presently under construction at Magurele, near Bucharest, Romania.

It is a major laser facility, including a 700 MeV electron linac for production of intense, energy-tuneable, quasi-monochromatic, polarized gamma-ray beams.

http://www.eli-np.ro/

Interest formulated by Norbert Pietralla, IKP Darmstadt

With a ERL TF @ CERN, one could produce significantly (2 orders of magnitude) larger gamma-flux in very narrow bandwidth (CW operation)
Overview SRF Activities at CERN

- At the times of LEP II (1990s), CERN was at the forefront of SRF Technology
  - Key technology: Nb sputtered on Cu!
- Then came TESLA/ILC and technology progressed tremendously – CERN lagging behind … (see previous page)

- Recently, CERN is involved in the following SRF projects/studies:
  - LHC operational, 16 cavities in 4 CMs, 2 MV/cavity, Nb/Cu
  - HIE-ISOLDE construction (20 + 12) QWR cavities, Nb/Cu
  - HL-LHC Crab Cavities CERN coordinating; 3 different designs, bulk Nb
  - SPL study, with CEA, IPNO and ESS, 4 cavity CM, bulk Nb
  - LHeC design study, ERL, ERL-TF
  - FCC design study – about starting now.

- Today CERN is trying to re-establish know-how and upgrade its facilities to be able to perform relevant R&D and help prepare SRF technology for the future.
- In the centre of attention (but not exclusively) are again the thin-film techniques
State of the art in magnetron sputtered Nb/Cu films

$Q_0 = 1 \cdot 10^{10}$ @ 15 MV/m is a value that would make film cavities a competitive option in several future projects. Current R&D is focused on improving the “slope”, applying films to new geometries, new materials.
Possible origin of Q-slope: film defects

Crystallographic defects can be at the origin of reduced $H_{c1}$ compared to bulk Nb

\[ \frac{1}{l_{\text{total}}} = \frac{1}{l_{\text{intra-grain}}} + \frac{1}{D} \]

RRR of films: $10 \div 30$
⇒
mfp of films $(30 \div 100)$ nm

Grain size of films $> 100$ nm
⇒
RRR limited by intra-grain defects in most cases

The goal is to make films as bulk-like as possible in terms of microstructure. The grain size does not seem to be a major issue
HiPIMS: a way to produce Nb ions for coating

With HiPIMS at this early stage we are currently at the level of the best performing magnetron sputtering coatings, for an equivalent surface preparation (SUBU vs EP)
Superconducting Proton Linac - SPL

- $\beta = 0.65$ cavities developed by IPN Orsay, tested at CEA Saclay
- $\beta = 1$ cavities developed and tested by CEA Saclay and (short CM) by CERN.
- Strong Synergy and collaboration established with the European Spallation Source

SPL Short Cryomodule

New supporting system (by double-walled tube) could minimize heat load to 2 K bath

O. Capatina, V. Parma, R. Bonomi, S. Rousselot

Vacuum vessel
Double tube of the power coupler
Inter-cavity support
Interface with vacuum vessel
Helium tank

O. Capatina, V. Parma, R. Bonomi, S. Rousselot
Cryolab Activities

New Coating Technologies: HIPIMS on 1.3 GHz cavities

Collaboration with S. Calatroni and G. Terenziani

Fundamental SRF studies using the Quadrupole Resonator

PhD Thesis S. Aull (Univ. Siegen)
Supervisor: S. Doebert

Cavity Diagnostic Developments with OSTs

Master Thesis B. Peters (Univ. Karlsruhe)
Co-Supervisor T. Koettig
New Electron-Beam Welding Machine

O. Capatina
Electro-polishing

High pressure rinsing

O. Capatina, L. Marques, K. Schirm
2 K Cryo-upgrade in SM18

RF Test facility area

Horizontal test stands
M7 and M9 for cryomodules

Vertical test stands
V3 to V6 for cavities

New helium transfer line

He supply from 25 m³ liquid tank

17 Juni 2014
2 K Cryo-upgrade in SM18

RF Test facility area

New helium transfer line

Vertical test stands V3 to V6 for cavities

Horizontal test stands M7 and M9 for cryomodules

T. Koettig, O. Pirotte, K. Schirm
Cavity and module test area SM18

Service module in horizontal bunker

Helium tank

Cavity RF Test Area
SM18: Clean room & Preparation Zone Upgrade

Existing clean room upgrade and extension

New clean room facility – HIE-ISOLDE

Clean room layout

RF Control Room

High-pressure rinsing

Ultra-pure water station
New cavity reception area
Cavity diagnostics

Optical Inspection Bench

Quench localization via second sound on SPL cavities

Fundamental research

J. Chambrillon, K. Liao, B. Peters, K. Schirm
Cavity ancillaries

Bead-pull measurement setup for field mapping

Cell-by-cell tuning system

F. Pillon, S. Mikulas, K. Schirm