Accelerators: instruments for science and industry

Lenny Rivkin, EPFL & PSI
90 years of RF accelerators

Symposium on 6 September, 2017
at the Technical University Aachen
celebrating 1927 PhD thesis of Rolf Widerøe

https://90years-rf-accelerators.de/
World of Accelerators
High energy particle physics
Draft Schedule Considerations

- **Technical Design Phase**
- **Dipole short models**
- **Dipole long models**
- **16 T dipole industri. prototypes**
- **16 T dipoles preseries**
- **16 T series production**
- **Civil Engineering FCC-hh ring**
- **CE TL to LHC**
- **LHC Modification**
- **Installation + test FCC-hh**
- **CE FCC-ee ring + injector**
- **CE TL to LHC**
- **Installation + test FCC-ee**
- **Installation HE-LHC**
- **LHC Removal**
- **Strategy Update 2026 – assumed project decision**
Beam stability studies for the LHC, HL-LHC, HE-LHC and FCC

Flat vs round beams tune space

336
T. Pieloni

332
J. Barranco

334
L. Mether

452
C. Tambasco

447
P. Gonçalves
16 Tesla magnet R&D for FCC

Block coil

Canted Cosine Theta

Cos-theta

Common coils

B. Auchmann
High field magnets for HEP, medicine and light sources

SLS 2 Superbend (2015-2018)


Superconducting dipole for gantry (2015-2019)
ILC

- ILC TDR describes 500 GeV machine
- LCC Physics and Detector Group and JAHEP study: compelling physics case for 250 GeV ILC

- Starting with a 250 GeV Higgs factory + cavity R&D could allow for 40% lower cost than TDR
- The energy of a linear collider can be increased
- 250 GeV would be an important stepping stone for future development of the linear collider technology
CLIC

Accelerator collaboration with ~50 institutes
Detector collaboration with ~29 institutes

Under study is also klystron based machine for initial stage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>380 GeV</th>
<th>3 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre-of-mass energy</td>
<td>TeV</td>
<td>0.38</td>
<td>3</td>
</tr>
<tr>
<td>Total luminosity</td>
<td>$10^{34}$cm$^{-2}$s$^{-1}$</td>
<td>1.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Luminosity above 99% of $\sqrt{s}$</td>
<td>$10^{34}$cm$^{-2}$s$^{-1}$</td>
<td>0.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>Hz</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Number of bunches per train</td>
<td>ns</td>
<td>352</td>
<td>312</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>ns</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Acceleration gradient</td>
<td>MV/m</td>
<td>72</td>
<td>100</td>
</tr>
<tr>
<td>Site length</td>
<td>km</td>
<td>11</td>
<td>50</td>
</tr>
</tbody>
</table>

Legend: CERN existing LHC, Potential underground string: CLIC 1.5 TeV, CLIC 3 TeV, 4.4 km, 1.5 TeV, 5.9 TeV, 10 TeV, 0.9 TeV, 2.0 TeV, 50 Hz, 50 Hz, 352 bunches, 0.5 ns, 72 MV/m, 11 km
Intensity Frontier
PSI Ring Cyclotron in 1973 planned for 100 µA

590 MeV proton cyclotron was planned for **100 µA**

Today **2400 µA**

or

**1.4 MW** beam power
High intensity accelerators for research and industry

- Spallation neutron source
- Highest brightness muon beams
- Ultracold neutrons
- nEDM
- PIF
High intensity frontier: essential to have low beam losses

Frequency of operation at certain level of beam losses
+ reliability increases to over 90 %
Synchrotron Light Sources
Synchrotron Light Sources: about 50 storage ring based

60,000 users world-wide
Muscles and tracheal network during flight

R. Mokso et al., Scientific Reports 5 8727 (2015)
Ptychography applications

3D PXCT of unstained brain tissue
Shahmoradian et al. Submitted

Structure of disordered broadband scatterers
Wilts et al. In preparation

3D magnetic vector PXCT of vortex-antivortex interactions
Donnelly et al. Submitted

22-nm & 100-nm IC-imaging
Next generation of diffraction limited storage ring based sources

Two orders of magnitude increase in source brightness: needed for the flagship applications like Ptychography

Figure from P. Raimondi, LELD-1 WS, Barcelona, April 2015
SwissFEL – a new accelerator based Research Infrastructure

<table>
<thead>
<tr>
<th>3rd gen. synchrotron</th>
<th>optical lasers</th>
</tr>
</thead>
<tbody>
<tr>
<td>fine, slow</td>
<td>fast, coarse</td>
</tr>
</tbody>
</table>

SwissFEL fine and fast at extreme high intensity

new direct insights into chemical, physical, biological mechanisms governing our daily-life

2017 -- 701 -- 718 SwissFEL
X-Ray Free Electron Lasers

PAL XFEL 2016

SACLA 2011
8.5 GeV, 60 Hz NC

SwissFEL 2017

European XFEL 2016
DESY, Hamburg

LCLS I, II 2009, 2019
Compact light sources based on Compton scattering
The Problem: EUV Lithography needs mask inspection

- Chip production using Extreme UV radiation (EUV, $\lambda=13.5$nm) for lithography to follow Moore’s law.
- EUV lithography: Planned for HVM production in 2019
- All reflective optics and mask, plasma source
- Conventional photomask inspection does not work for EUV masks
- Finding the elusive defects on the mask is a big problem
RESCAN project
Lensless EUV mask inspection tool for semiconductor industry

Required is:

1. Experience in EUV coherent scattering microscopy

2. Fast, sensitive detectors

3. Know-how in accelerator physics & design

All available at PSI!

Y. Ekinci, PSI
Diffraction limited rings technology: a much brighter compact source
Brightness vs photon energy of various sources

COSAMI - type Compact Sources based on PSI Technology

Compton Sources

Source: AAT/Axilon

Udo Klein, AAT
Brightness vs photon energy of various sources

COSAMI - type Compact Sources based on PSI Technology

Compton Sources

Source: AAT/Axilon

Advanced Accelerator Technologies

Udo Klein, AAT
Accelerators for medicine
X-Ray radiotherapy

Varian brothers start at Stanford

50,000,000

patients treated with photons

1947, 2 MeV/m
One meter long
250 MeV proton cyclotron (ACCEL / Varian)

100,000 patients treated with hadrons

- Closed He system
  4 x 1.5 W @4K
- Proton source
- Superconducting coils
  => 2.4 - 3.8 T
- 4 RF-cavities
  ≈100 kV on 4 Dees
BRAGG PEAK: SPOT SCANNING

ENERGY

POSITION
Hadron therapy: method of choice for pediatric cancers
Gantries for hadron therapy
Gantry for carbon therapy (Heidelberg)
PSI Superconducting gantry designs

EXPECTED IMPROVEMENTS: NOT much smaller, but:

- Weight: 200 tons → 50 tons
- Field size: 12 \times 20 \text{ cm}^2 \rightarrow 20 \times 20 \text{ cm}^2
- Energy acceptance: 1.5\% \rightarrow 20\%
High field magnets for HEP, medicine and light sources

SLS 2 Superbend
(2015-2018)

16 T Dipole magnet for the Future Circular Collider
(2016-2019)

Superconducting dipole for gantry
(2015-2019)
Compact accelerators: sources of photons, neutrons, electrons etc.
Compact is relative…

Quest for high gradient acceleration

e.g. compact sources for electron diffraction
Laser-Based Accelerators

Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

Shimoda
RF Acceleration: scaling with frequency

- 50 MHz Ring Cyclotron
- 12 GHz CLIC
- Laser THz?
Peak gradient as a function of Laser Field

Peralta et al.,
Nature 503, 91 (2013)
Switzerland: host to two world leading accelerator centres

Swiss Accelerator Research and Technology CHART Collaboration supports the future accelerator projects at CERN and the development of accelerator concepts beyond the existing technology for synchrotron light sources and medical applications. An extraordinary grant has been released by SERI as initial funding for these activities.
CHART: Swiss Accelerator Research and Technology

16 Tesla

1 GeV/m
Beam Dynamics and Technologies for Future Colliders, 21 February – 6 March 2018, Zürich
“Le véritable voyage de découverte ne consiste pas à chercher de nouveaux paysages, mais à avoir de nouveaux yeux”

Marcel Proust
Summary

In the past 90 years accelerators have become an essential tool for research and numerous applications, able to address society’s essential needs.

Future poses formidable challenges for the accelerator R&D, not the least of them is educating the new generation of specialists.

CERN and PSI provide a very strong local advantage in Switzerland, for both academia and industry.