Accelerator R&D

Ralph W. Aßmann
Leading Scientist, DESY

23.07.2013

Acknowledge discussions with and/or material from:

1924: **Gustav Ising** (*19 February 1883 in Finja, Sweden, † 5 February 1960 in Danderyd, Sweden*), Prof. at the technical university Stockholm, publishes in 1924 idea how to realize multiple acceleration of an ion with a given high voltage: \( U_{\text{tot}} \gg U_{\text{HV}} \)

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**Thank you Sweden...**
Outline

> Acceleration in metallic RF structures
> Towards high luminosity
> Higgs collider concepts with leptons
> “New” ideas and concepts
> Conclusion
RF Acceleration in Metallic Structures

Isings scheme: Metallic structures are filled with oscillating, longit. e.m. fields.

Charged particles sit at the crest of the induced longitudinal voltage and are accelerated. One passage → linac. Many passages → storage ring.

Metallic walls can be super-conducting or room-temperature, RF fields can have different frequencies.

From Ising’s and Wideröe’s start to 21st century RF technology.
### Different RF Frequencies

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L band</td>
<td>1 to 2</td>
</tr>
<tr>
<td>S band</td>
<td>2 to 4</td>
</tr>
<tr>
<td>C band</td>
<td>4 to 8</td>
</tr>
<tr>
<td>X band</td>
<td>8 to 12</td>
</tr>
<tr>
<td>Ku band</td>
<td>12 to 18</td>
</tr>
<tr>
<td>K band</td>
<td>18 to 27</td>
</tr>
<tr>
<td>Ka band</td>
<td>27 to 40</td>
</tr>
<tr>
<td>V band</td>
<td>40 to 75</td>
</tr>
<tr>
<td>W band</td>
<td>75 to 110</td>
</tr>
</tbody>
</table>

IEEE Standard 521-1984  
http://www.microwaves101.com/
X-Band Technology (12 GHz): CLIC

P.K. Skowronski et al, IPAC2011
X-Band Technology (12 GHz): CLIC

\[ \approx 4 \times 10^{-3} \] breakdowns per 1 million

P.K. Skowronski et al, IPAC2011
If Accelerating Gradients Pushed too High (30 GHz)…

Major success for X-band: mastering of breakdown problem without damage.

Limitation for much higher gradients than 100 MeV/m!

Single feed power coupler
30 GHz, 16 ns,
66 MV/m local accelerating gradient

Location of damage

W. Wuensch 2002
Why the Trend towards Super-Conduting RF?

> There are a number of advantages from SC RF technology:

- Reduced wall dissipation by many orders of magnitude in super-conducting cavities over a copper cavity.
- This results in affordable higher CW and long pulse gradients → high power applications are feasible (SNS, ESS, ILC, ...).
- Long pulses → unique possibilities for X-ray light applications (FLASH, European XFEL as stroboscopic camera for fast processes).
- Better beam quality with larger cavity aperture (lower disturbing wakefields, intra-pulse feedbacks).

> R&D and technology for SC RF has achieved major advances, e.g. in accelerating gradients and production quality.

> There is no cost benefit in investments so far from going to higher frequencies and higher gradients (€ per GeV).
Production Yield and Even Higher Gradients: ILC

Production quality reaches demands of big projects:

- **Nb3Sn**: $T_c = 18 \text{ K}$, $H_{sh} = 3000 \text{ Oe}$ => $E_{\text{acc}} = 80 \text{ MV/m}$ (improved shape cavity)

- **MgB2**: $T_c = 38 \text{ K}$, $H_{sh} = 6200 \text{ Oe}$ => $E_{\text{acc}} = 172 \text{ MV/m}$ (improved shape cavity)

R&D towards much higher accelerating gradients (not achieved yet):

- $E_{\text{acc}}$ = 80 MV/m (improved shape cavity)
- $E_{\text{acc}}$ = 172 MV/m (improved shape cavity)

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Ralph Aßmann | EPS-HEP2013 | 23.07.2013 | Page 10
50 Yr-Growth of Installed Voltage for $v/c=1$ Accelerators

A "Livingston Plot" for RF Superconductivity

Total Installation > 1000 m, > 20 GV

Year

Courtesy Padamse, Tigner
Outline

- Acceleration in metallic RF structures
- **Towards high luminosity**
- Higgs collider concepts with leptons
- “New” ideas and concepts
- Conclusion
Towards Very Small Beam Sizes in LC’s: ATF2 (Japan) as Test Bed for ILC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ATF2</th>
<th>ILC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy, GeV</td>
<td>1.3</td>
<td>250</td>
</tr>
<tr>
<td>L*, m</td>
<td>1</td>
<td>3.5-4.2</td>
</tr>
<tr>
<td>γs_xy, m*rad</td>
<td>3E-6 / 3E-8</td>
<td>1E-5 / 4E-8</td>
</tr>
<tr>
<td>IP β_xy, mm</td>
<td>4 / 0.1</td>
<td>21 / 0.4</td>
</tr>
<tr>
<td>IP η', rad</td>
<td>0.14</td>
<td>0.094</td>
</tr>
<tr>
<td>σ_F, %</td>
<td>~0.1</td>
<td>~0.1</td>
</tr>
<tr>
<td>Chromaticity</td>
<td>~1E4</td>
<td>~1E4</td>
</tr>
<tr>
<td>n_bunches</td>
<td>1-3 (goal A)</td>
<td>~3000</td>
</tr>
<tr>
<td>n_bunches</td>
<td>3-30 (goal B)</td>
<td>~3000</td>
</tr>
<tr>
<td>N_bunch</td>
<td>1-2E10</td>
<td>2E10</td>
</tr>
<tr>
<td>IP σ_p, nm</td>
<td>37</td>
<td>5</td>
</tr>
</tbody>
</table>

Tests a **new optics solution** (Raimondi/Seryi Final Focus optics) that reduces length of beam delivery by a factor 6!

*(local chromaticity correction)*

P. Raimondi, A. Seryi, PRL, 86, 3779 (2001)
Achieved Beam Sizes with New Optics Scheme in ATF2

Note:

**Adiabatic emittance damping** → means that physical emittance shrinks with 1/Energy → Beam size shrinks with 1/SQRT(Energy) → 64 nm corresponds to 5 nm at 250 GeV.

**Higher energy means less sensitivity to perturbations** like wakefields with higher currents!

Figure by A. Seryi et al

Previous HEP accelerator world record from 1994 with 46.6 GeV at SLAC

Note: Scanning Transmission Electron Microscopes achieve sub-nm spot size!
**SuperKEKB** (in construction for beam commissioning in 2015)

Table 1: Main Machine Parameters of SuperKEKB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LER(e⁺)</th>
<th>HER(e⁻)</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>4</td>
<td>7.007</td>
<td>GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>3016.315</td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>Crossing angle: full</td>
<td>83</td>
<td></td>
<td>mrad</td>
</tr>
<tr>
<td>Horizontal emittance</td>
<td>3.2</td>
<td>4.6</td>
<td>nm</td>
</tr>
<tr>
<td>Vertical emittance</td>
<td>8.64</td>
<td>11.5</td>
<td>pm</td>
</tr>
<tr>
<td>Coupling</td>
<td>0.27</td>
<td>0.28</td>
<td>%</td>
</tr>
<tr>
<td>$\beta_x / \beta_y$</td>
<td>32.0, 0.27</td>
<td>25 / 0.30</td>
<td>mm</td>
</tr>
<tr>
<td>Vert. beam size at IP</td>
<td>48</td>
<td>62</td>
<td>nm</td>
</tr>
<tr>
<td>Energy spread</td>
<td>8.10</td>
<td>6.37</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Beam current</td>
<td>3.60</td>
<td>2.60</td>
<td>A</td>
</tr>
<tr>
<td>Number of bunches</td>
<td></td>
<td></td>
<td>2500</td>
</tr>
<tr>
<td>Energy loss/turn</td>
<td>1.86</td>
<td>2.43</td>
<td>MeV</td>
</tr>
<tr>
<td>RF frequency</td>
<td>508.9</td>
<td></td>
<td>MHz</td>
</tr>
<tr>
<td>RF voltage</td>
<td>9.4</td>
<td>15.0</td>
<td>MV</td>
</tr>
<tr>
<td>Bunch length</td>
<td>6.0</td>
<td>5.0</td>
<td>mm</td>
</tr>
<tr>
<td>Vert. b-b param.</td>
<td>0.088</td>
<td>0.081</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>$8 \times 10^{35}$</td>
<td></td>
<td>cm⁻²s⁻¹</td>
</tr>
</tbody>
</table>

$$L = \frac{\gamma_s}{2\varepsilon_e} \left( 1 + \frac{\sigma_x}{\sigma_y} \frac{I_{\pm} \xi_{\pm}}{\beta_y} \frac{R_L}{R_y} \right)$$

Will break into new territory for **e+e- colliders**!

**nano-beam scheme**

K. Oide et al
Developments towards High Luminosity

- A couple of impressive improvement paths were shown & discussed.
- In addition: we can see in the LHC how 21\textsuperscript{st} century colliders can work.
- Lot of the LHC success is due to improved instrumentation, modern digital feedbacks, efficient controls, design optimization with much improved simulation programs $\rightarrow$ 21\textsuperscript{st} century technology.
- No time to review this extremely important work in the available time for this talk, but some could be seen in Mike Lamont’s talk about LHC.
- Electron accelerators for photon science use similar tools with similar success as the LHC.
- All of this will be available for a future lepton collider and we can expect even further improvements with time (in CPU resources for online analysis, fs timing, fs synchronization, nm stabilization, feedbacks, simulation, …). See Saturday talk by P. Burrows.
- Luminosity promises are still critical but more realistic than in the past (simulate it realistically beforehand)!
Outline

- Acceleration in metallic RF structures
- Towards high luminosity
- Higgs collider concepts with leptons
- “New” ideas and concepts
- Conclusion
STATUS OF THE EXPLORATION OF AN ALTERNATIVE CLIC FIRST ENERGY STAGE BASED ON KLYSTRONS

D. Schulte, A. Grudiev, Ph. Lebrun, G. McMonagle, I. Syratchev, W. Tschupik, J. Westerwelle
CERN, Geneva, Switzerland

PRELIMINARY DESIGN OF A HIGGS FACTORY μ+μ− STORAGE RING∗

A.V. Zlobin*, Y.I. Alexahin, V.V. Kapm, V.V. Kashikhin, N.V. Mokhow, I.S. Tropin
FNAL, Batavia, IL 60510, U.S.A.

THE LHeC AS A HIGGS BOSON FACTORY

F. Zimmermann, O. Brüning, CERN, Geneva, Switzerland; M. Klein, DESY, Hamburg, Germany

TLEP: A HIGH-PERFORMANCE CIRCULAR e⁺e⁻ COLLIDER TO STUDY THE HIGGS BOSON

M. Koratzinos, A.P. Blondel, U. Geneva, Switzerland; R. Aleksan, CEA/Saclay, France; O. Brunner, A. Butterworth, P. Janot, E. Jensen, J. Osborne, F. Zimmermann, CERN, Geneva, Switzerland; J. R. Ellis, King’s College, London; M. Zanetti, MIT, Cambridge, USA

DESIGN OF A TeV BEAM DRIVEN PLASMA WAKEFIELD LINEAR COLLIDER∗

E. Adli†, University of Oslo, Norway
J.P. Delahaye, S.J. Gessner, M.I. Hogan, T. Raubenheimer, SLAC, Stanford, USA
W. An, W. Mori, C. Joshi, UCLA, Los Angeles, USA; P. Muggli, MPP, Munich, Germany

A MUON COLLIDER AS A HIGGS FACTORY∗

D. Neuffer*, M. Palmer, Y. Alexahin, Fermilab, Batavia IL 60510, USA, C. Ankenbrandt, Muons, Inc., Batavia IL 60510, USA, J. P. Delahaye, SLAC, Menlo Park, CA 94025 USA

OPTIMIZATION PARAMETER DESIGN OF A CIRCULAR e⁺e⁻ HIGGS FACTORY∗

D. Wang*, J. Gao, M. Xiao, H. Geng, S. Xu, Y. Guo, N. Wang, Y. An, Q. Qin, G. Xu, S. Wang
IHEP, Beijing, 100049, China

CONSIDERATIONS FOR A HIGGS FACILITY BASED ON LASER WAKEFIELD ACCELERATION

S. Hillenbrand, KIT, Karlsruhe, Germany and CERN, Geneva, Switzerland
A.-S. Müller, KIT, Karlsruhe, Germany
Assmann*, D. Schulte, CERN, Geneva, Switzerland

SIMULATED BEAM-BEAM LIMIT FOR CIRCULAR HIGGS FACTORIES

K. Ohmi, KEK-ACCL, 1-1 Oho, Tsukuba, 305-0801, Japan
F. Zimmermann, CERN-ABP, Geneva, CH-1211, Switzerland

Known Higgs Boson Energy → e⁺e⁻ Higgs Factory Design...
Lepton collider options beyond LHC
Lepton collider options beyond LHC

ILC (phase 1 to full, up to 1 TeV c.m.)

CLIC (similar footprint for up to 3 TeV c.m.)

SPS

LEP/LHC

km

-25 -20 -15 -10 -5 0 5 10 15 20 25

TDR's published
Lepton collider options beyond LHC

ILC (phase 1 to full, up to 1 TeV c.m.)

CLIC (similar footprint for up to 3 TeV c.m.)

TDR's published

SPS

LEP/LHC

LHeC (e-p, ERL)
Lepton collider options beyond LHC

- **ILC** (phase 1 to full, up to 1 TeV c.m.)
- **CLIC** (similar footprint for up to 3 TeV c.m.)
- **LEP/LHC** (injector to TLEP?)
- **LHeC** (e-p, ERL)
- **SPS** (injector to TLEP?)
- **TLEP** (up to 0.35 TeV c.m.)
- **VHE-LHC** (100 km version)

TDR's published

TDR to be worked out
Lepton collider options beyond LHC

- **ILC** (phase 1 to full, up to 1 TeV c.m.)
  - CLIC (similar footprint for up to 3 TeV c.m.)

**New compact accelerators**

- **μ⁺μ⁻ collider**
- **Plasma Linear Collider**
  - R&D on feasibility ongoing

**TLEP** (up to 0.35 TeV c.m.)

**VHE-LHC** (100 km version)

**TDR's published**

**TDR to be worked out**
The Large Hadron Electron Collider (LHeC) → Mike L.

- LHeC would be a 9 km addition to the LHC ring.
- TDR is published.
- Electrons from LHeC energy recovery linac (ERL) collide with protons from the LHC.
- ERL’s see rapid development, as they drastically increase efficiency by recovering stored energy from beam. Several photon science projects plan to use ERL’s!
- Can be extended into a γγ collider (SAPHiRE).

Table 3: LHeC Higgs factory comparison (where 1 year is taken to be $10^7$ s at design luminosity).

<table>
<thead>
<tr>
<th></th>
<th>LHeC</th>
<th>LHeC-HF</th>
<th>SAPPHiRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>luminosity</td>
<td>0.1</td>
<td>2</td>
<td>0.06</td>
</tr>
<tr>
<td>$[10^{34} \text{cm}^{-2}\text{s}^{-1}]$</td>
<td>(ep)</td>
<td>(ep)</td>
<td>($\gamma\gamma &gt; 125 \text{GeV}$)</td>
</tr>
<tr>
<td>cross section</td>
<td>~200 fb</td>
<td>~200 fb</td>
<td>&gt;1.7 pb</td>
</tr>
<tr>
<td>no. Higgs/yr</td>
<td>2k</td>
<td>40k</td>
<td>&gt;10k</td>
</tr>
</tbody>
</table>
e+e-: Linear Collider Baseline and the Circular Version

![Graph showing luminosity vs. cm energy](image)

- TLEP
- ILC
- CLIC

Figure F. Zimmermann & K. Oide
**e+e-: Linear Collider and the Circular Version**

**TLEP** is 1.15 times LEP2 (1998 – 2001) in terms of energy
Tunnel length is 3-4 times LEP/LHC tunnel → luminosity
Requires ring injector infrastructure, as existing at CERN
Low Higgs mass regenerated interest as Higgs factory
**e+e- circular collider** is strong at lower energies
Luminosity drops sharply with energy
4 simultaneous experiments are possible
Strong synchrotron radiation damping
Beam property fixed by equilibrium (stable but inflexible)
Can be superseded by pp collider but not be upgradeable in E

**ILC** is the baseline complementary approach to LHC
**e+e- linear collider** without competition at higher energies
Luminosity increases with energy
Can operate efficiently beyond the Higgs energy
Long. polarization available in collision
1 simultaneous experiment, 2nd experiment with push-pull
High flexibility pulse by pulse
Initial Higgs-only stage can be implemented (reduced cost)
Upgradeable in \( E_{\text{max}} \) with higher gradient RF (afterburner)
Required Accelerator R&D for ILC, TLEP, …

> The ILC linear e+e- collider project:

- Reviews, tests, successful SC projects → feasibility OK. Can start, once budget and manpower are available. **Mature design for a complementary e+e- collider to LHC.**
- There is some R&D, in most cases optimization (D) work, to be done (see published TDR review recommendations 2/2013): IP spot size, power coupler, Marx modulator opt., Klystron Cluster Scheme (KCS) opt., LLRF system opt., effects of faults, coaxial tap-offs adjustments in operation, cavity tuner design opt., positron source R&D, new overall tolerance study.

> An 80-100 km circular e+e- collider (TLEP) as pre-cursor to VHE-LHC:

- A detailed Technical Design Report (TDR) must be prepared. See presentation by F. Bordry from CERN on Saturday and VHE-LHC plus TLEP project plan at CERN. No technical show-stopper to be expected (1.15 times LEP2 in energy, studied similar proposal in 2001: VLEP in VLHC) but cost must be analyzed in detail.
- There is R&D to be done (list needs more detail and thought): RF couplers, instabilities at injection, effect of ground motion and tolerances, beam-beam effects, required upgrades to CERN’s beam generation chain, polarization, synchrotron radiation power handling, …
## 500 GeV Parameters

**Physics**

- **Max. \( E_{cm} \)**: 500 GeV
- **Luminosity**: \( 1.8 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1} \)
- **Polarisation (e-/e+)**: 80% / 30%
- \( \delta_{BS} \): 4.5%

**Beam (Interaction point)**

- \( \sigma_x / \sigma_y \)
- \( \sigma_z \)
- \( \gamma \varepsilon_x / \gamma \varepsilon_y \)
- \( \beta_x / \beta_y \)
- **Bunch charge**: \( 2 \times 10^{10} \)
- **Number of bunches / pulse**: 1312
- **Bunch spacing**: 554 ns
- **Pulse current**: 5.8 mA
- **Beam pulse length**: 727 \( \mu \text{s} \)
- **Pulse repetition rate**: 5 Hz
- **Average beam power**: 10.5 MW (total)
- **Total AC power**: 163 MW
  - (linacs AC power: 107 MW)

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N. Walker (DESY) – ILC Worldwide Event – CERN – 12 June 2013
The completion of the Technical Design Report on the ILC and the low Higgs mass have triggered strong interest to host and provide host state funding for ILC in Japan.

N. Walker: “Looking towards East…”
Outline

> Acceleration in metallic RF structures
> Towards high luminosity
> Higgs collider concepts with leptons
> “New” ideas and concepts
> Conclusion
R&D on Lower Cost Alternatives for the Long Term...

➢ What if we do not get the xx B€ required for the big e+e- collider projects like ILC? Can we still build a collider? → We hope so after some serious R&D...

➢ Accelerator R&D on higher gradient (and less expensive) acceleration or other lepton types (μ) required!

➢ Feasibility (and lower cost) of colliders based on these concepts is not yet shown.

➢ R&D is ongoing, today only commenting on plasma acceleration progress (μ–collider see ECFA talk by L. Rivkin, Saturday).
Reminder: Plasma-Acceleration (Internal Injection)

Laser Pulse (200 TW, ~30 fs, $E_{\text{transv}} \sim \text{TV/m}$)

Plasma electrons
(plasma cell, $\sim 10^{19} \text{ cm}^{-3}$)
Reminder: Plasma-Acceleration (Internal Injection)

Bubble

Laser Pulse \( (E_{\text{transv}} \sim \text{TV/m}) \)

Plasma electrons
(plasma cell, \( \sim 10^{19} \text{ cm}^{-3} \))
Reminder: Plasma-Acceleration (Internal Injection)

- Trapped electron beam
- Bubble \( (E_{\text{long}} \sim 100 \text{ GV/m}) \)
- Laser Pulse \( (E_{\text{transv}} \sim \text{TV/m}) \)
- Plasma electrons (plasma cell, \( \sim 10^{19} \text{ cm}^{-3} \))
Reminder: Plasma-Acceleration (Internal Injection)

This accelerator fits into a human hair!
And Plasma Acceleration (trapping) Works...

LETTERS

GeV electron beams from a centimetre-scale accelerator

W. P. LEEMANS1**, B. NAGLER1, A. J. GONSALVES2, Cs. TÓTH1, K. NAKAMURA1,3, C. G. R. GEDDES1, E. ESAREY1**, C. B. SCHROEDER1 AND S. M. HOOKER2

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2 University of Oxford, Clarendon Laboratory, Parks Road, Oxford OX1 3PU, UK
3 Nuclear Professional School, University of Tokyo, 2-2 Shinane-shirakata, Takai, Naka, Ibaraki 319-1188, Japan

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**e-mail: WPLee mans@lbl.gov

2-3 orders of magnitude higher acceleration voltages than conventionally demonstrated

Smaller and less expensive accelerators are possible.

Higher energies → Discovery potential.

Compact → new applications (medicine, industry, ...) for society.
1% relative energy spread

Stability in plasma accelerators still insufficient. At the same time no fundamental limit on stability is known.

**Modular Ansatz:**
- A known e-beam is injected → external injection.
- Hybrid: DESY „Best in Class“ accelerator + laser + plasma.
- Reduced complexity!
- Allows placing several accelerating plasma structures behind each other (“Staging”).

> Not shown so far!
EuroNNAC
European Network for Novel Accelerators

- University of Oxford
- University of Strathclyde
- Manchester University
- Lancaster University
- Cockcroft Institute
- STFC Daresbury Laboratory
- John Adams Institute
- ASTeC
- STFC Central Laser Facility
- Liverpool University
- University College London
- Imperial College
- Instituto Superior Tecnico de Lisboa
- LULI Soleil
- LPGP
- LOA
- IRAMIS/CEA
- Laboratoire Leprince-Ringuet (Ecole polytechnique - CNRS/IN2P3)
- LAL
- European Organization for Nuclear Research (CERN)
- PSI
- University of Rome LA SAPIENZA
- INFN-LNF
- Pisa University and INFN
- Consiglio Nazionale Delle Ricerche, INO
- Inst. of Physics, Chinese Academy of Sciences
- Tsinghua University, Beijing
- Shanghai Jiao Tong University
- Fermilab
- SLAC
- UCLA
- LBNL
- BNL
- KEK
- ICFA
- ICUIL
- EINDHOVEN University of Technology
- University Düsseldorf
- LMU University Munich
- DESY
- GSI
- Max-Planck-Institute for Quantum Optics
- Max-Planck-Institute for Physics
- Helmholtz Institute Jena
- Helmholtz-Zentrum Dresden-Rossendorf
- University Hamburg
- Lund University
- Budker INP
- Institute of Applied Physics RAS
- Extreme Light Infrastructures (ELI)

Pointing out some European efforts...

> **CERN**: Approval of AWAKE project: proton-driven plasma acc.

> **Extreme Light Infrastructure (ELI) project (1 B€)**: Several highest power lasers to come (e.g. in Budapest) with plasma acc. program.

> **France**: Constructing CILEX project around APOLLON laser – electron beams driven by 5 PW laser pulses.

> **EU Projects**: ICAN for high laser efficiency (G. Mourou et al).

> **Germany**: Helmholtz-ARD program with 1 out of 4 program topics on plasma acceleration (6 Helmholtz centers). Coordinated by R. Brinkmann.
  - DESY Hamburg & Zeuthen: LAOLA collaboration (DESY + Uni Hamburg), 3 experiments (200 TW laser- and beam-driven). DORIS storage ring into accelerator test facility?
  - Activities in GSI, Uni Düsseldorf, Max-Planck Institute for Quantum optics Munich, Jena.

> **Italy**: Running SPARC project with plasma acc. program.

> **Sweden**: Lund laboratory with plasma acc. program.

> **UK**: Finalizing SCAPA (Scotland) for plasma acceleration work. Proposal of CLARA project in Daresbury with a plasma acc. program.
Ongoing Required Work: Lasers with 30% Efficiency

Figure 1 | Principle of a coherent amplifier network. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of >10 J at a repetition rate of ~10 kHz (7).

The future is fibre accelerators

Gerard Mourou, Bill Brocklesby, Toshiki Tajima and Jens Limpert

Could massive arrays of thousands of fibre lasers be the driving force behind next-generation particle accelerators? The International Coherent Amplification Network project believes so and is currently performing a feasibility study.
HEP lab: Plasma Acceleration R&D at CERN ➔ AWAKE

> **Protons** store much more energy than photons or electrons: **very efficient drivers** for HEP applications of plasma acc.

> **SPS proton bunch** driven into a several m long plasma, where bunch self-modulates and excites acc. wakefields.

> **Electrons are inj. & accelerated up to 1 GeV** and later more.

> Plan: Start beam operation **end 2015**.

Figures: A. Caldwell et al
HEP and photon science lab: DESY Accelerator R&D

Accelerator Research at DESY

**SC Processes**
(sFLASH, FLASH2 seeding, ongoing)

**FEL Seeding**
(beam-driven plasma acceleration, 2016+)

**SINBAD** (ultra-short bunches, LAOLA, prototype table-top FEL, 2017+)

**AXSIS** (atto-second bunches, ICS, 2014+)

**LAOLA at REGAE**
(laser-driven plasma acceleration, 2013-2016)

**SC Technology**
(R&D on CW, cryo module test bench, ongoing)

**Surface Technology**
(cavity surfaces, CRISP, ongoing)

**Goal:** Table-top GeV e-accelerator module with high beam quality!

Zeuthen Campus

Photo-Injector
(ongoing)

LAOLA at PITZ
(bunch modulation in plasma, 2013+)
DESY: DORIS into Accelerator R&D Facility?

ERC Grant Proposal Kärtner, Aßmann, Chap- man, Fromme: **THz injector for atto-s bunches**

ARD collaboration on **very short bunches** (DESY, Uni HH, KIT, …)

LAOLA-ARD experiments (DESY, Uni HH, …) on **staged, ultra-high gradient plasma acceleration**

Room for additional experiments: the PIER Voss-Wideröe Center will be a forum to call for proposals
Conclusions I

> **Short overview was given on accelerator research** activities performed around the globe by many colleagues:
  - Apologies that not all important topics could be covered in the available time.

> **New ideas, technologies, concepts, talents are developing and maturing**, even if it sometimes takes half a century from idea to large scale implementation, sometimes only a decade.

> **Several acceleration technologies** (SC, C-band, X-band) are ready to be used in a next HEP project.

> **SC RF technology is at the moment the technique of choice for many high power applications** (SNS, XFEL, ESS, ILC, …). Together with the energy recovery linac concept, efficiency is much improved.

> The **discovery of the Higgs boson has removed uncertainty about the target energy for a future HEP project** → exciting time for the accelerator field with new ideas and concepts entering discussion.
Conclusions II

> Several concepts for a **next big HEP project**, including precision Higgs factories, are under study, covering a range of different technologies, time-scales, costs, luminosities, readiness, …

  - The linear collider: **ILC** or CLIC → TDR for ILC. The most mature option and project ready for decision.
  - The (really last) e+e- circular collider: **TLEP** → TDR to be prepared as part of VHE-LHC project at CERN (see presentation F. Bordry on Saturday).
  - A new e-p collider: **LHeC** → TDR is published.
  - A first **muon collider** → feasibility to be shown.
  - A **compact Higgs collider with new acceleration methods**: feasibility to be shown.

> **Accelerator R&D work ongoing towards really compact (and maybe less expensive) accelerators** (plasma acc., lasers, dielectric struct., …). The big labs in Europe are joining in and help with conventional accelerator expertise: need conceptual progress.

> The Higgs discovery inspires accelerator R&D → we are looking forward to the next big news from HEP…
Towards the table-top, really compact accelerator…
… for high power physicists

Thank you for your attention!