WORLD-WIDE REVIEW OF FORESEEN R&D AND TESTS PROGRAMS

Ralph W. Aßmann (DESY)
Coordinator European Network for Novel Accelerators

FACET-II
Science Opportunities Workshops
Plasma Acceleration Based Linear Colliders

12-16 October, 2015
SLAC, Menlo Park, CA

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453
Disclaimer

• I cannot and **will not present a world-wide review in a 20 minutes** presentation.
  – We can do this another time...
  – In 20 minutes and during a remote talk there would be great risk of omission and trouble caused by such an attempt.

• Instead: I focus on the **strategy that many of us adopt at present as the fastest route to success and to a plasma linear collider**.

• I will mention some of the new non-US projects that at the moment are emerging

• You know all about the pioneering US projects...
Recent Overview: EAAC2015 and AAC 2014

**EAAC2015:**

- **WG’s + Summaries:** 7
- **Invited Talks:** 30
- **Special Science Talk:** 1
- **WG Talks:** 138
- **Posters:** 76
- 258 registered participants. 45 sponsored students. Participants from 23 countries in 4 continents (incl. 11 EU member states)

*To come:*

- Proceedings
- Special Volume *NIM*
- Lead editor: *Ulrich Dorda*
Accelerator Radar Chart

- Better in all outside directions
- Larger area is better

- Performance, Beam Quality, 6D Emit.
- Beam Energy
- Collider Requirement
- Investment cost
- Size
- Positrons
- Polarization
- Operating Cost, Efficiency
- Photon Science Requirement
Better in all outside directions
Larger area is better

Performance, Beam Quality, 6D Emit.

Conventional RF accelerator

Positrons

Beam Energy

Investment cost

Size

Operating Cost, Efficiency

Polarization
Comments on Conventional RF Accelerator

• **Great success story of our field.**

• **Success raises the bar higher and higher → difficulties:**
  (1) investment cost (can we get the budget?)
  (2) operating cost (can we get the budget?)
  (3) size (does it fit the lab or local region?)

• The **limits encountered presently can change:**
  (1) new physics convinces science policy
  (2) new clever designs and projects raise the interest
  (3) change in political priorities

• Colleagues perform **excellent work on all fronts** but we must take into account practical limits in our means...
Plasma Accelerators

New kid on the block with quite a different footprint and level of maturity.

Very rapidly growing!
Accelerator Radar Chart

Better in all outside directions
Larger area is better

Positrons

Polarization

Beam Energy

Operating Cost, Efficiency

Size

Investment cost

Performance, Beam Quality, 6D Emit.

Novel plasma accelerator
Accelerator Radar Chart

Better in all outside directions
Larger area is better

Beam Energy

Investment cost

Novel plasma accelerator

Performance, Beam Quality, 6D Emit.

Positrons

Size

Operating Cost, Efficiency

Polarization
Investment cost, Beam Energy, Performance, Beam Quality, 6D Emit.

Better in all outside directions
Larger area is better

Size
Positrons
Polarization
Operating Cost, Efficiency
Novel plasma accelerator

Beams energy
投资额
性能、束质和6D发射

在所有方向上都更好
面积越大越好

尺寸
正电子
偏振
运行成本，效率
新型等离子加速器
Comments on Plasma Accelerator I

• Excellent progress achieved → exponential progress in several areas.
• Not competitive with conventional RF accelerators yet, but getting closer.
• Many projects (10 M€ - 50 M€) around the world are pushing forward...
• Next step beyond this (150-200 M€) is expensive and probably should be done in a multi-national collaboration.
Accelerator Radar Chart

Better in all outside directions
Larger area is better

Performance, Beam Quality, 6D Emit.

Beam Energy

Investment cost

Novel plasma accelerator

Size

Operating Cost, Efficiency

Positrons

Polarization

FACET2

BELLA

ELI

CILEX

BELLA-k

SPARC

AWAKE

ICAN

FLASH-F

Laser industry

all

PLUS...
**CILEX Project, Plateau de Saclay, France**
- The big French project.
- Laser: 5 PW laser and LWFA area.

**LUND Laser Center, Sweden**
- Well established lab, since 1992.
- Limil.
- High stability LWFA.

**SPARC LAB, Frascati, Italy**
- Electron beam: 150 MeV, multi-bunch, bunch length below 300 fs, 200 pC, 1 μm norm.
- FLAME laser: Ti:Sapphire, chirped pulse amplification (CPA), 200 TW, 25 fs long, 10 Hz repetition rate.
- SPA Incu plans expr of la.
- Comb project is unique: resonant beam driven plasma wakefields.

**X-5 Project at LOA, France**
- Salle Jaune Laser: 70 TW, repetition rate 10 Hz, pulse duration of 30 fs.
- Goals: Exploration of new laser plasma accelerator concepts, new laser plasma interactions, etc.
- LWFA for FEL.

**CALA Project, Munich, Germany**
- Builds on expertise at MPQ and LMU.
- High stability LWFA for science (FEL, ...).

**ELI Beamlines, Czech Republic**
- Laser: 10-15 fs duration, up to 10 PW, End stage: a few kW in 15 fs (~200 PW) with low repetition rate (minute based).
- Might be new fs display tools for testing.
- Laser for use in diamond precision 100 GeV for high quality cancer therapy.

**COXINEL Project at SOLEIL, France**
- COXINEL: Coherent X-ray source inferred from electrons accelerated by laser.
- Leader: Marie-Emmanuelle Couprie, SOLEIL.
- Goals: FEL R&D for LWFA.

**ICAN Project**
- ICAN for high efficiency.

**AWAKE Experiment, CERN**
- International collaboration with approved experiment at CERN beam.
- Driver: 450 GeV proton bunch, 1ef1, 3.5 μm emittance, bunch length << plasma wavelength.
- Mode: 1) Protons at focusing regions survive.
- 2) Protons at defocusing regions get lost.
- Surviving microbunches induce wakefields.
- Accelerate injected electrons from several 10 MeV to GeV.
Plasma Acceleration at Hamburg: LAOLA

LWFA FEL
- competition rate towards FEL
- beam-driven for efficient development

Beams:
- Beam-driven plasma wakefields
- Beam-driven plasma wakefields with shaped beams and innovative injection methods.

PWFA modulation

The LiGHT test-stand at GSI: coupling of laser-accelerated ions into conventional accelerators

- Principle: manipulation of laser-accelerated ions
  - Laser-driven ion acceleration
    - Beam conditioning (optimization)
    - Initial current
    - Target area
  - Optimization process

- ARD test facility
  - Extension of the target area
  - Study for an improvement of PWFA accelerator
  - Relevant laser developments (repetition rate and temporal contrast)

Helmholtz-Institute Jena

LWFA low density, external inj.
atto-s radiation sources

plasma wakefield imaging

ELBE center for high power radiation sources

Two 1 PW laser, ion/p plasma acc., radiation therapy R&D

Jülich Short-Pulse Particle and Radiation Centre

LWFA, polarized particles

STFC – CLF and John Adams Institute in UK

LWFA, medical imaging, training

Material research

Cockcroft Institute and CLARA Project

FEL, industrial applications, PWFA

STFC = Scottish Centre for the Application of Plasma-based Accelerators
- LWFA for generation of particle beams, i.e. electrons, protons...
- ELBE for R&D
- Dedicated to the Production and Application of Ultra-short Electron Bunches and Radiation Pulses.
Better in all outside directions
Larger area is better

Performance, Beam Quality, 6D Emit.

Investment cost
Size
Operating Cost, Efficiency

Very exciting: Low power photon science applications almost there → Address quality!

Usability will attract resources and push faster towards plasma LC!
Investment cost, Performance, Beam Quality, 6D Emit.

Beam Energy

Better in all outside directions
Larger area is better

Investment cost

Novel plasma accelerator

Size

Polarization

Operating Cost, Efficiency

Positrons

Performance, Beam Quality, 6D Emit.

EUPRAXIA
ATHENA
BELLA
LOA
LUX
FACET2
ImPACT

European Network for Novel Accelerators
The Most Serious Challenge: Quality

• Issues: **Beam quality, 6D emittance, shot-to-shot stability, tolerances**

• Many projects gear up to attack this by various means:
  – Low plasma density → relaxed tolerances
  – Improved lasers, stabilized optical paths, ...
  – Cutting-edge timing technology
  – Working points optimized for quality instead of max. energy

• If quality improved, then potential for photon science user application as **first usage at “lower” energy**
  – **Draws in additional resources and interest**
  – **Will accelerate progress, also towards plasma LC**
... Quality costs a lot of money and manpower ...

See experience with conventional accelerators!
Moving towards a European Plasma Acc. in the 2020’s

European design study for a "European Plasma Research Accelerator with eXcellence In Applications"

Approved with full funding → Excellent signal from European Commission – Research and Innovation
• Two design studies approved in the accelerator area.

Big success for accelerator field!

Amazing success for novel accelerators!

European design study for a "European Plasma Research Accelerator with eXcellence In Applications"
EuPRAXIA Strategy

<table>
<thead>
<tr>
<th>Today</th>
<th>2020’s</th>
<th>2030’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEP collider, e.g. 27 km LHC</td>
<td>Conventional FEL’s towards CW operation, ultra-fast science, …</td>
<td>HEP collider, e.g. ILC, FCC, Higgs factory, 50 – 100 km</td>
</tr>
<tr>
<td>Conventional 5 GeV FEL: 500 – 1000 m</td>
<td>EuPRAXIA Research Infrastructure 5 GeV FEL &amp; HEP 250 m</td>
<td>HEP Plasma Linear Collider 3 – 5 km</td>
</tr>
<tr>
<td>Multi GeV e-bunches in plasma acc. (30 m)</td>
<td></td>
<td>Ultra-Compact FEL 10 – 100 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ultra-Compact e-medical accelerator</td>
</tr>
</tbody>
</table>
H2020 Project

Today

- HEP collider, e.g. 27 km LHC
- Conventional 5 GeV FEL: 500 – 1000 m
- Multi GeV e-bunches in plasma acc. (30 m)

Future

- Conventional FEL’s towards CW operation, ultra-fast science, ...
- HEP Plasma Linear Collider 3 – 5 km
- EuPRAXIA Research Infrastructure 5 GeV FEL & HEP 250 m
- Ultra-Compact FEL 10 – 100 m
- Ultra-Compact e-medical accelerator
EuCARD²

Today

- HEP collider, e.g. 27 km LHC
- Conventional 5 GeV
  FEL: 500 – 1000 m
- Multi GeV e- bunches
  in plasma acc. (30 m)

EuPRAXIA Research
Infrastructure
5 GeV FEL & HEP
250 m

FCC H2020 Project

- HEP collider, e.g. FCC, Higgs factory,
  50 – 100 km

H2020 Project

INNOVATION

European design study for a "European Plasma Research
Accelerator with eXcellence In Applications"

H2020 Project
EuPRAXIA – Connected Labs and Institutes

<table>
<thead>
<tr>
<th>Participant no.</th>
<th>Participant organisation name</th>
<th>Short name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Coordinator)</td>
<td>Stiftung Deutsches Elektronen Synchrotron</td>
<td>DESY</td>
<td>Germany</td>
</tr>
<tr>
<td>2</td>
<td>Istituto Nazionale di Fisica Nucleare</td>
<td>INFN</td>
<td>Italy</td>
</tr>
<tr>
<td>3</td>
<td>Consiglio Nazionale delle Ricerche</td>
<td>CNR</td>
<td>Italy</td>
</tr>
<tr>
<td>4</td>
<td>Centre National de la Recherche Scientifique</td>
<td>CNRS</td>
<td>France</td>
</tr>
<tr>
<td>5</td>
<td>University of Strathclyde</td>
<td>USTRAH</td>
<td>UK</td>
</tr>
<tr>
<td>6</td>
<td>Instituto Superior Técnico</td>
<td>IST</td>
<td>Portugal</td>
</tr>
<tr>
<td>7</td>
<td>Science &amp; Technology Facilities Council</td>
<td>STFC</td>
<td>UK</td>
</tr>
<tr>
<td>8</td>
<td>Synchrotron SOLEIL – French National Synchrotron</td>
<td>SOLEIL</td>
<td>France</td>
</tr>
<tr>
<td>9</td>
<td>University of Manchester</td>
<td>UMAN</td>
<td>UK</td>
</tr>
<tr>
<td>10</td>
<td>University of Liverpool</td>
<td>ULIV</td>
<td>UK</td>
</tr>
<tr>
<td>11</td>
<td>Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile</td>
<td>ENEA</td>
<td>Italy</td>
</tr>
<tr>
<td>12</td>
<td>Commissariat à l'Energie Atomique et aux energies alternatives</td>
<td>CEA</td>
<td>France</td>
</tr>
<tr>
<td>13</td>
<td>Sapienza Universita di Roma</td>
<td>UROM</td>
<td>Italy</td>
</tr>
<tr>
<td>14</td>
<td>Universität Hansestadt Hamburg</td>
<td>UHH</td>
<td>Germany</td>
</tr>
<tr>
<td>15</td>
<td>University of Oxford</td>
<td>UO XF</td>
<td>UK</td>
</tr>
<tr>
<td>16</td>
<td>Imperial College London</td>
<td>ICL</td>
<td>UK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Associated partner organisation name</th>
<th>Short name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jiaotong-Universität Shanghai</td>
<td>JUS</td>
<td>China</td>
</tr>
<tr>
<td>Tsingua University Beijing</td>
<td>TUB</td>
<td>China</td>
</tr>
<tr>
<td>Extreme Light Infrastructures - Beams</td>
<td>ELI-B</td>
<td>Czech Rep.</td>
</tr>
<tr>
<td>Lille University</td>
<td>PHLAM</td>
<td>France</td>
</tr>
<tr>
<td>Helmholtz Institute Jena</td>
<td>HIJ</td>
<td>Germany</td>
</tr>
<tr>
<td>Helmholtz-Zentrum Dresden-Rossendorf</td>
<td>HZDR</td>
<td>Germany</td>
</tr>
<tr>
<td>Ludwig-Maximilians-Universität München</td>
<td>LMU</td>
<td>Germany</td>
</tr>
<tr>
<td>Wigner Research Center of the Hungarian Academy of Science</td>
<td>WIGNER</td>
<td>Hungary</td>
</tr>
<tr>
<td>European Organization for Nuclear Research</td>
<td>CERN</td>
<td>IEIO</td>
</tr>
<tr>
<td>High Energy Accelerator Research Organization</td>
<td>KEK</td>
<td>Japan</td>
</tr>
<tr>
<td>Kansai Photon Science Institute, Japan Atomic Energy Agency</td>
<td>KPSI-JAEE</td>
<td>Japan</td>
</tr>
<tr>
<td>Osaka University</td>
<td>OU</td>
<td>Japan</td>
</tr>
<tr>
<td>RIKEN SPring-B Center</td>
<td>RSC</td>
<td>Japan</td>
</tr>
<tr>
<td>Lund University</td>
<td>LU</td>
<td>Sweden</td>
</tr>
<tr>
<td>Center for Accelerator Science and Education at Stony Brook U &amp; BNL</td>
<td>CASE</td>
<td>USA</td>
</tr>
<tr>
<td>Lawrence Berkeley National Laboratory</td>
<td>LBNL</td>
<td>USA</td>
</tr>
<tr>
<td>SLAC National Accelerator Laboratory</td>
<td>SLAC</td>
<td>USA</td>
</tr>
<tr>
<td>University of California, Los Angeles</td>
<td>UCLA</td>
<td>USA</td>
</tr>
</tbody>
</table>

16 beneficiaries from 5 EU member states plus 18 associated partners
5 GeV and two user areas for pilot users
# EuPRAXIA Research Infrastructure

## Goal Parameters

<table>
<thead>
<tr>
<th>Beam Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle type</td>
<td>-</td>
<td>Electrons</td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>1 – 5</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>pC</td>
<td>1 – 50</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>Hz</td>
<td>10</td>
</tr>
<tr>
<td>Bunch duration</td>
<td>fs</td>
<td>0.01 - 10</td>
</tr>
<tr>
<td>Peak current</td>
<td>kA</td>
<td>1 – 100</td>
</tr>
<tr>
<td>Energy spread</td>
<td>%</td>
<td>0.1 – 5</td>
</tr>
<tr>
<td>Norm. emittance</td>
<td>mm</td>
<td>0.01 – 1</td>
</tr>
</tbody>
</table>
• **Goal is to** design one operational facility at one location.
• **Resources will be distributed** to all partners:
  – Model of big particle physics detector: Many institutes team up to build one detector at one place, each contributing a part.
• **Site study** with the goal to propose the best site:
  – Existing infrastructure, host lab support, scientific user community, support from funding agency, ...
• Facility will be **devoted to provide for pilot users:**
  – Ultra-compact X-ray FEL
  – Ultra-compact GeV electron source for HEP detector development
• **EuPRAXIA must prove the potential of plasma accelerators.**
• Needed step before building a linear collider or operational plasma FEL.
ImPACT project (FY2014-2018)

ImPACT=Impulsing Paradigm Change through disruptive Technologies Program

“Ubiquitous Power Laser for Achieving a Safe, Secure and Longevity Society” (PM: Dr. Sano)

- Overview
  Ubiquitous quantum beam technologies and devices will be developed through power laser ultraminiaturization and integration with plasma and accelerator technologies, which will have applications in equipment diagnosis, security, advanced medicine and other fields, and will help to achieve a safe, secure and longevity society.

- Impact on Industry and Society in the Event of Achievement
  - Enabling the use of XFEL* (a National Critical Technology), which currently exists in only two locations in the world, at each institution.
  - Industrial innovation through analysis on the atomic level, ubiquitous equipment diagnosis and repair, biological imaging, quantum beam radiotherapy and so on, anytime, anywhere

Disruptive technology=laser acceleration!, Hi-risk, Hi-return

Japan

SLIDE
M. Kando
Conclusion

• Novel accelerators should give us **more science for the money (cost and size) or open new parameters.** Price to pay: Technical complexity and difficulty.

• **FACET-2, ATF2 and BELLA/iBELLA/BELLA-k** keep pushing the technology in the US. Excellent for the community and science.

• **New big projects** outside US, trying to establish intermediate steps with users before we can attack a plasma LC for HEP:
  
  – **EuPRA**XIA for plasma acceleration of electrons for photon science and HEP has been fully funded.
  
  – **ImpACT project in Japan** for a plasma FEL with significant funds!
  
  – **ATHENA project in Germany** for user-readiness of electron and hadron beams from plasma accelerators.
Towards useable, novel accelerators with reduced size, better cost efficiency, excellent science and multiple applications for HEP, photon science, medicine and others...
Thank you for your attention