

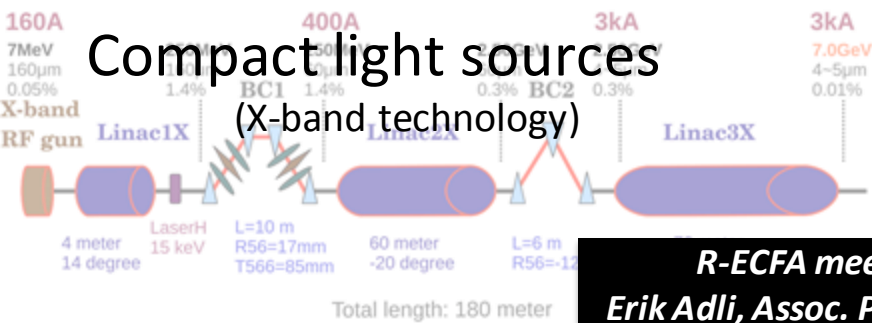
Particle Accelerator Physics

Compact Linear Collider
(Option for Multi-TeV electron positron collider)

European Spallation Source
(The world's most powerful proton driver)

Plasma wakefield acceleration
(Novel acceleration techniques)

Compact light sources
(X-band technology)



R-ECFA meeting, Oslo, October 2, 2015

Erik Adli, Assoc. Professor, Dep. Of Physics, U. Oslo

History, resources

- **Before 2006**, many Norwegian CERN technical students (BSc/MSc level) have worked on accelerator project, partly funded through the Norway-CERN instrumentation project, lead by Steinar Stapnes. Students from Trondheim, Oslo, Bergen, Gjøvik, Kristiansand ...
- **Since 2006**, seven Norwegian CERN-based PhD students have completed PhD work in accelerator physics. The Oslo-CERN instrumentation project has been vital to sustain Norwegian CERN students, on MSc and PhD level, by providing co-funding and travel support. **5/7 Norwegian accelerator PhDs are continuing in the field** (Oslo, Agder, CERN, ESS).
- **2009**: The Oslo High Energy Physics group got top rating (5/5) in the RCN evaluation of the Basic Physics Research in Norway in 2009. The evaluation specifically encouraged the group to expand activities in accelerator physics.
- **2011**: Through a national call for “Research institution-based strategic projects”, RCN granted funds for a 3-year accelerator physics project, which Oslo co-funded to create a permanent position; first in this field in Norway.
- **2013**: Oslo hired an **Associate Professor in accelerator physics**.

History, resources

2014: RCN accelerator grant for “Young Research Talents” (Fellesløftet) for accelerator R&D (emittance preservation in future colliders), in broad and tough national competition “FRINATTEK”

- One PostDoc, plus hardware and operational expenses
- Oslo MN Faculty sponsored another KD PhD
- CERN matched the PostDoc by providing funds for an additional PostDoc, on a “K-contract” for the CLIC project

Two out of three above personnel are **Oslo based**. An important step towards creating a sustainable **local environment in Oslo**.

ESS accelerator resources :

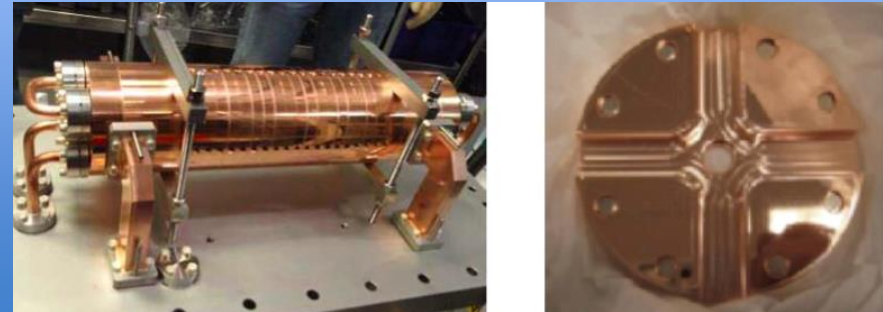
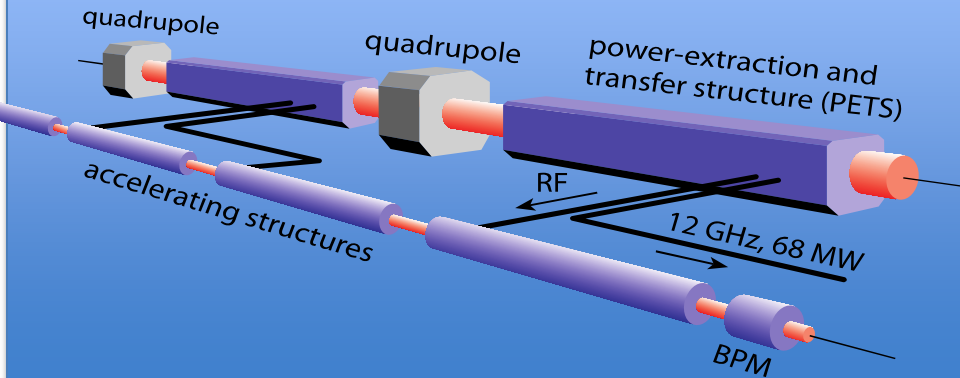
- **2013:** Joint RCN-ESS funded Oslo PhD student working on the ESS accelerator. Set up important link Oslo-ESS, facilitating probing of possibilities for future ESS cooperation
- **2015:** ESS in-kind money used to employ a PostDoc for 2 years at the **University of Agder** (in the South of Norway)

Linear Collider activities

The Compact Linear Collider, CLIC

Main linac technology: normal conducting Cu rf 12 GHz TW cavities, 100 MV/m

Nominal design for $E_{\text{CM}} = 3 \text{ TeV}$ (375 GeV to 3 TeV)



- Oslo is an official member of CLIC collaboration since 2006. Today a significant contributor, regulated through a MoU, until 2018 . We focus on methods and technologies to preserve beam quality (nanometer beam emittances), including lattice design, alignment algorithms, X-band wakefield monitor development, stabilization studies
- We do a **mix of simulation/theory** (can be done at Oslo) and **experimental activity** which are performed mainly at the CLIC Test Facility.
- Many of the activities and competences are relevant also for ILC, and also for high gradient / high beam quality electron accelerators in general

CLIC Test Facility activities

The Oslo group heavily involved in the experimental verification of the two-beam acceleration scheme. **The experiments have resulted in two Oslo PhD theses, and a number of publications.**

R. Lillestøl, S. Doebert, E. Adli and M. Olvegaard, *Phys. Rev. ST Accel. Beams* **17**, 031003 (2014)

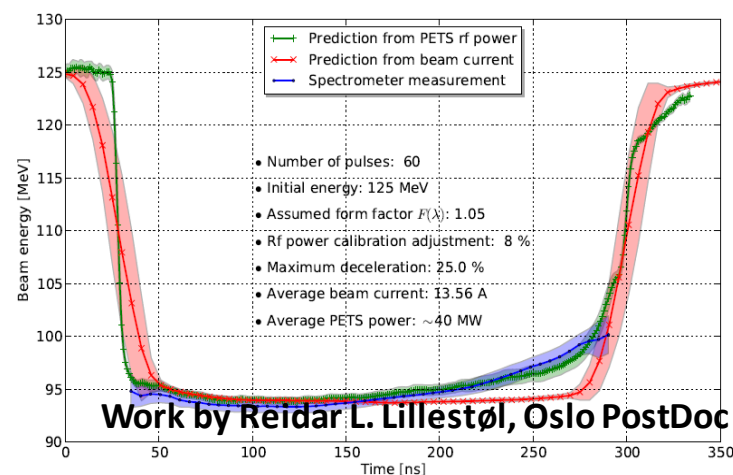
M. Olvegaard et al. *Phys. Rev. ST Accel. Beams* **16**, 082802 (2013)

M. Olvegaard et al., *NIM A683* 19-39 (2012)

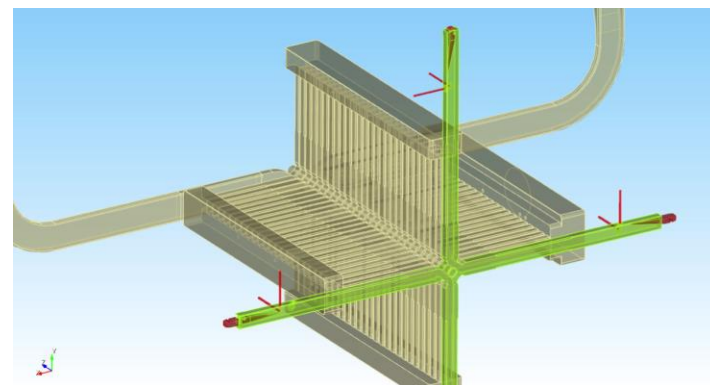
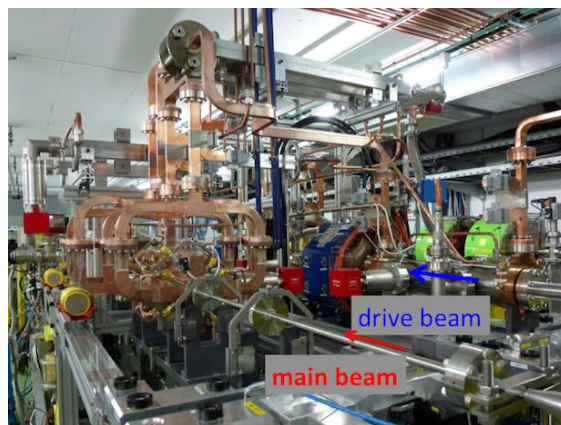
E. Adli et al., *Phys. Rev. ST Accel. Beams* **14**, 081001 (2011)

...

Today: continuing beam based experiments, with focus on emittance preservation methods and hardware. **1.5 PostDoc, 1 CERN PhD student on linear collider activities.**



Drive Beam Deceleration Test Beam Line



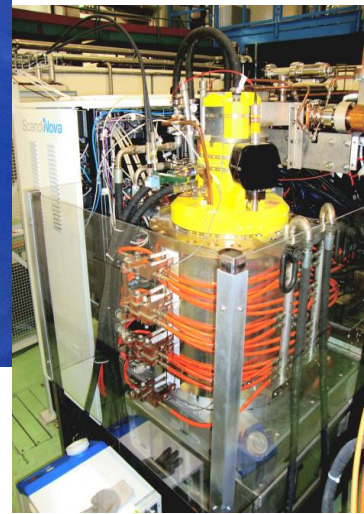
CLIC Two Beam Module with wakefield monitors, at CTF3

The CLIC test facility, CTF3/CALIFES, has been and is very important for the Oslo group as training and research facility for PhD students.

CLIC X-band for compact FEL

XbFEL collaboration: promote the use of CLIC X-band technology for FEL based photon sources. Leverage existing CERN expertise and test-facilities to aid smaller countries to work towards an accelerator based photon source.

<http://xbandfel.web.cern.ch/>



X-band based linacs are more compact and energy efficient than lower frequencies.

- Interesting for Norway to participate, since compact and cost-effective light sources may be an option for national infrastructure (on the medium term)
- Oslo participates through design studies of the high gradient linac, and study of the undulator photon production (**~50% of a PostDoc**)
- This participation provides Norway valuable **competences in FELs and light sources**

Plasma wakefield activities

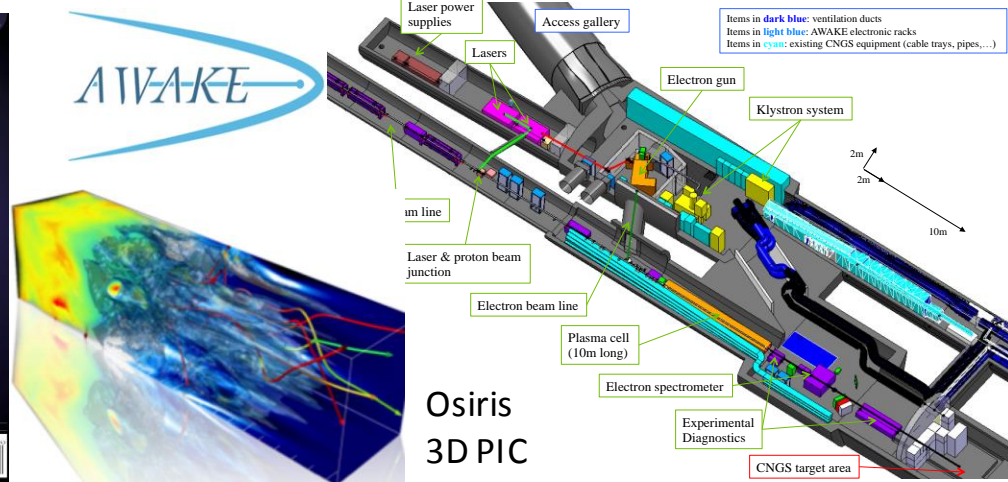
- Beam-driven plasma wakefield experiments have **recently shown significant experimental progress**. Although technology is far from mature, results indicate that there may be potential for HEP applications in the future.
- The Oslo group is **full member** of the plasma wakefield experiments at both SLAC (FACET) and CERN (AWAKE), as result of PostDoc experience of the group leader. This is very interesting physics and high impact research. A privilege, and fruitful academically, to be a member of these collaborations, which perform **world class research**.
- Oslo group: **two Oslo-funded PhDs (“KD”)** + significant fraction of time of group leader.

FACET: recent demonstration of acceleration of a witness beam with high efficiency ($\sim 30\%$ wake to beam), high gradient (5 GV/m) and low energy spread ($\sim 1\%$) at FACET.

AWAKE: proton-driven plasma wakefield experiments at CERN. Commissioning 2016. Oslo participation regulated through a MoU. **HPC 3D PIC simulations** + experiment commissioning.

Recent FACET publications:

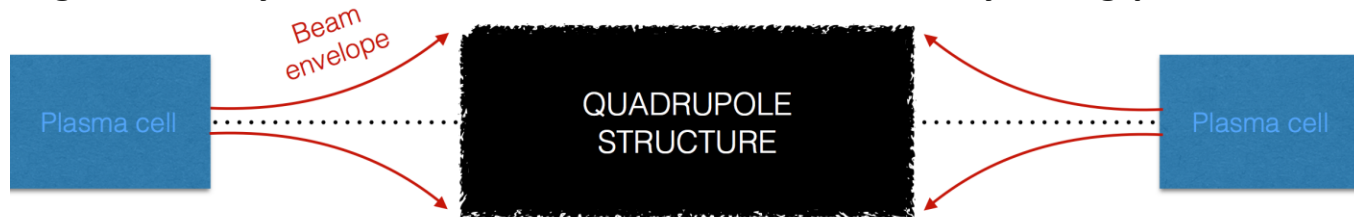
S. Corde et al, *Nature* **524**, 442–445
 E. Adli et al. *NIM A* (2015),
[dx.doi.org/10.1016/j.nima.2015.02.003](https://doi.org/10.1016/j.nima.2015.02.003)
 M. Litos et al., *Nature* **515**, 92–95
 S. Li et al., *Plasma Phys. Control. Fusion*
 56, 084011 (2014)
 N. Vafaei et al., *Phys. Rev. Lett.* 112,
 025001 (2014)
 W. An et al., *Phys. Rev. ST Accel. Beams*
 16, 101301 (2013)
 ...



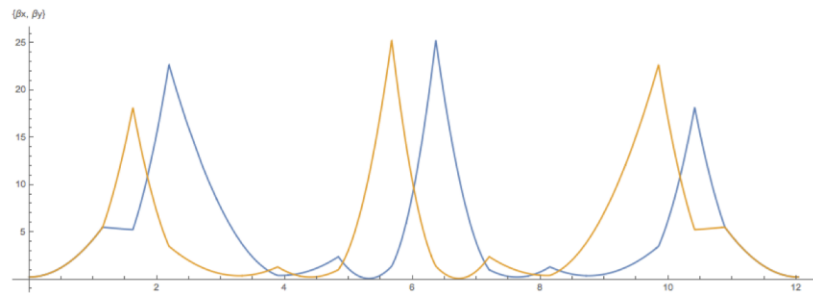
Synergy collider and plasma work

- Oslo is in good position to contribute to future HEP-studies by combining our linear collider experience and our plasma experience
- **Example:** we develop plasma interstage beam line design. Such interstages are required for a plasma based HEP-collider
- Outcome of this work: novel optics design methods, that may benefit BOTH the plasma community and the linear collider community

Plasma interstage : basically a double final focus, because of the very strong plasmas focusing

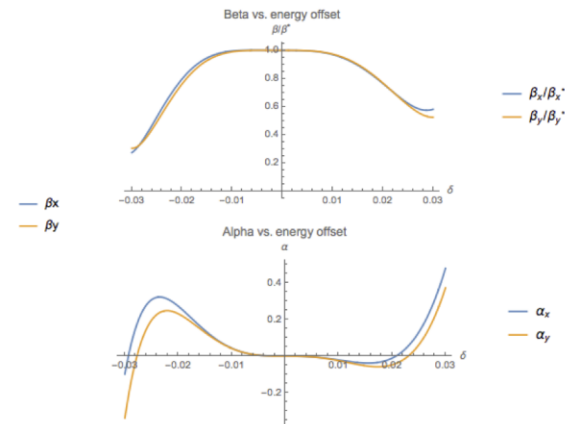


12 quads: cancel chromaticity to 2nd order.

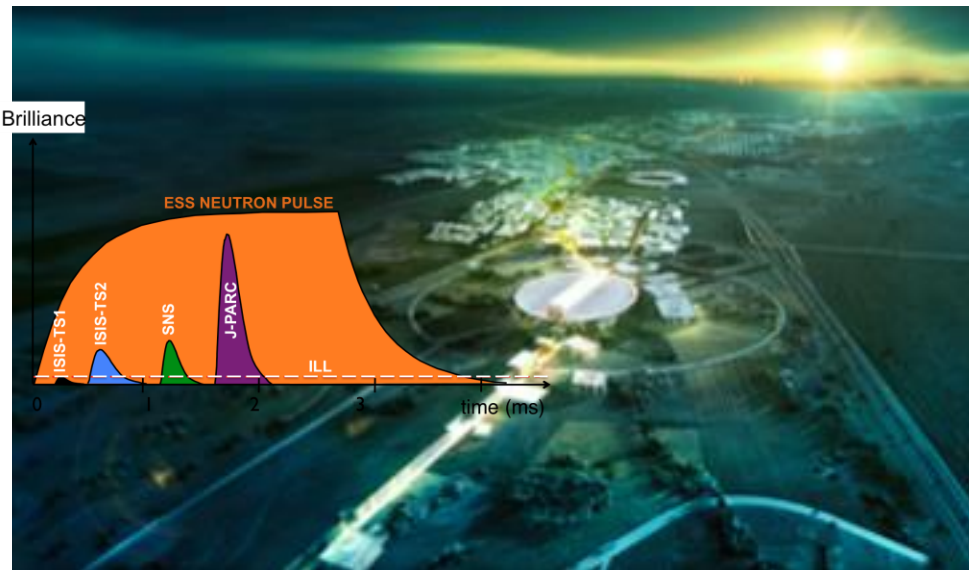


For 0.5% energy spread: $(\Delta E_x/E_x, \Delta E_y/E_y) = (0.000186, 0.000186)$

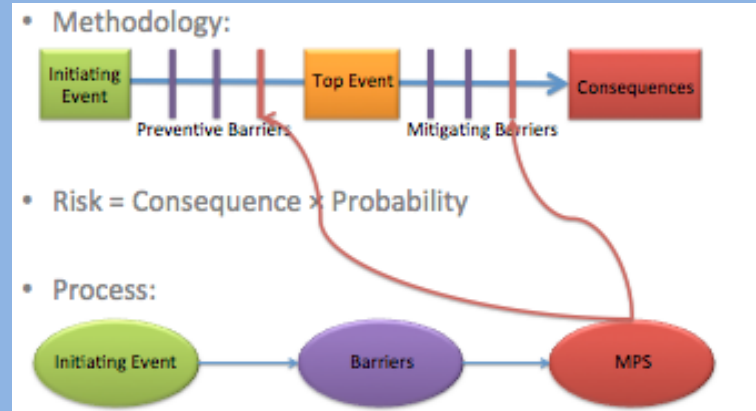
For 1.% energy spread: $(\Delta E_x/E_x, \Delta E_y/E_y) = (0.0119, 0.0119)$



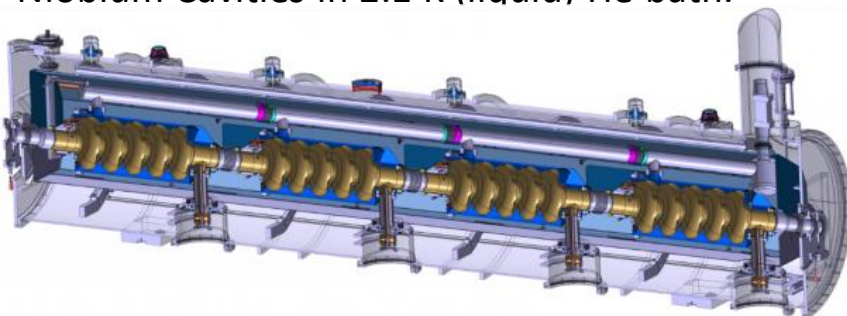
European Spallation Source (ESS)



Oslo: currently involved in the development of a novel and robust Machine Protection System with **one PhD student**.



The accelerator will be the world's most powerful **proton driver**. Superconducting part: 310 m of Niobium Cavities in 2.1 K (liquid) He bath.



Proton-driver: same technology as needed in an Accelerator Driven Nuclear Power Plant

Norway plan to contribute “In-Kind” about 150 MNOK (18 MEUR)

- **Univ. of Agder:** first Norwegian in-kind contribution (200 kEUR) : 2 man-years at the Univ. of Agder: **expert on ion sources**
- **Oslo:** in discussions for a 2-3 MEUR accelerator in-kind project on **target beam diagnostics**

Related accelerator activities in Norway

- The **Oslo Cyclotron Laboratory** (OCL) houses the only accelerator in Norway for basic research, a MC-35 Cyclotron (p, d, ^3He , ^4He , up to 35 MeV p). The laboratory serves as an experimental center for various fields of research and applications. No accelerator physics research activities. Potentially a value resource as test-beam for beam instrumentation.



Modernized control room



MC-35 Scanditronix Cyclotron



Beam delivery, gamma detector

- **Particle therapy** : in 2013, the Norwegian State started a process to establish the particle therapy centers in Norway. Funding has been allocated to the different region to prepare such centers. In Bergen, several research activities related to biological effects of ion treatments, and detector research. Currently there is no accelerator physics research related to the Norwegian process towards a particle therapy center.
- A note related to accelerator R&D : in Norway there **is no high power/high intensity laser activities**. This is a field that may be important for future generation of high-energy particle accelerators.

Teaching

- At Oslo: building up **accelerator curriculum**. Currently a good fraction of the Experimental HEP course. Enough material for a pure accelerator course, however, currently not large enough student base to create a new course.
- **Nordic Particle Accelerator School**. Received **Erasmus+ EU funding** for teaching and for Norwegian students. Will participate in accelerator MOOC development.



Nordic Particle Accelerator School 2015
Lund University, Sweden
August 17-23, 2015

Registration online by May 30, 2015:
<http://www.eit.lth.se/index.php?cluid=922&t=1>
Contact: christine.darve@esss.se

Topics:
A one week introductory course on the physics of particle accelerators, aimed at Bachelor and Master students in Physics and Electrical Engineering. Students will receive an introduction to accelerator based science and learn how modern particle accelerators work.

Preparation team:
Lund University: Anders Karlsson, Sverker Werin
MAX IV Laboratory: Pedro Fernandes Tavares, Simon Leemann
European Spallation Source: Christine Darve
Uppsala University: Maja Olvegard, Roger Ruber
Aarhus University: Søren Pape Møller
University of Oslo: Erik Adli
University of Jyväskylä: Pauli Heikkinen
CERN: Rüdiger Schmidt

The First Nordic Particle Accelerator School was organized August 2015; success, with 40 students at BSc and MSc level. The schools aims to be at lower level than existing schools, and to attract new students to the field.

- We also encourage accelerator students to go to CAS, USPAS.
- Oslo invited by Director of JUAS to become a member University of JUAS (answer: no candidates to participate for the moment).

Summary of current Norwegian resources

Linear colliders for HEP, CLIC

Reidar Lillestøl

Lukas Malina - CERN

Plasma wakefield acceleration –
FACET@SLAC and AWAKE@CERN

Veronica K.B.Olsen

Carl A. Lindstrøm

Jurgen Pfingstner

Medical accelerators

Compact accelerators
for particle therapy
(based on CLIC
technology)

Free electron lasers

Compact FELs (based on
CLIC technology).
Opportunity for Norway?

Summary:

1 Assoc. professor

2+1 Post.Docs.

2 Ph.D. students

+ 2 Ph.D. students funded
mostly by ESS or CERN

Italic: CERN or ESS employed.

ESS and proton-drivers

Riccard Andersson - ESS

Acc. in-kind contributions

Unv. of Agder : **Øystein Midttun**

Oslo contributions: **TBC**

Other CERN-related projects (*Lukas Malina*, LHC operations)

Teaching in accelerator physics: Oslo course plus international schools (CAS, Nordic PAS)

E. Adli: Oslo project leader. **S. Stapnes**: CERN linear collider study leader

Future challenges

Oslo group is **involved in a number of different project**. Very interesting, however, diversification is a challenge given small resources (energy frontier, linear colliders and plasma, vs. hardware development vs. ESS). **Not easy to exclude activities :**

- CERN and linear collider activities: our main activity is to **contribute to future HEP-projects**
- Heritage involvement AWAKE/SLAC: world leading groups, **increased interest in PWFA in Europe**
- ESS: **in-kind money is available**, however, accelerator development not strongly linked to HEP activities. A significant ESS activity requires adding experienced personnel to the group
- Concrete invitation to join efforts for future European plasma wakefield accelerators at DESY, Lund, Cockcroft, Stratchclyde ... Currently must say no to all of these invitations.

The mid-term future for large HEP projects is uncertain :

- future global linear collider activities depends on LHC results and possibly on other external factors (ILC@Japan)
- Future Circular Collider: design study on-going until 2018
- CERN may update priorities with regards to CLIC and FCC by 2018-2019
- Plasma accelerator technologies are currently “hot” in Europe. However, on the mid-term field must progress fast in order to become a viable alternative to conventional technology

Important for group to keep the be involved in several activities until future is clearer.

Plans

HEP accelerator activities: important to **be present in both conventional and novel accelerator developments the coming years**. In order to have a diverse activity following several activities, with a limited group size, it is important to use **CERN as a focal point** for HEP accelerator activities. Also non-HEP accelerator cooperation with **Lund/ESS**.

Current funding ends 2017-2018. In order to keep the momentum and keep current commitments : apply for funding in 2016 (ERC grants, national funding) + continue to use CERN PhD students to support Oslo accelerator projects.

Oslo plans to keep **strong collaboration** and network with European acceleration partners :

- Participation in CLIC and AWAKE
- Activities towards ESS
- Participation in TIARA
- Co-organizer of the Nordic Particle Accelerator School
- Potential participation with EuCARD3

Medium-term goal: establish a **small research accelerator in Norway**, as a national base for accelerator activities. For Norway: perhaps the most realistic would be a light source based on inverse Compton scattering, or a compact soft FEL (X-band? All optical?). The exact nature of a future local facility is to be studied.

Summary

- The CERN students programme + Norway-CERN instrumentation project (MSc, PhD level) have been crucial for recruitment of personnel to Norwegian accelerator activities. For future recruitment, it is important to sustain a current level of 4-5 CERN PhD student over a 4 year period
- **CERN is a focal point** for Norwegian accelerator research and education. The possibility to use CERN electron accelerators as “local laboratory” is important for the building up of Norwegian accelerator competences
- **Must secure funding for the next period** (Europe and/or National)
Focus on accelerator R&D towards the energy frontier
- **A new Norwegian university** (Agder) is starting accelerator R&D activities, focusing on ESS
- **Future:** define need, feasibility and funding for a national research accelerator (most likely a light source) – would be local hub of Norwegian accelerator competence

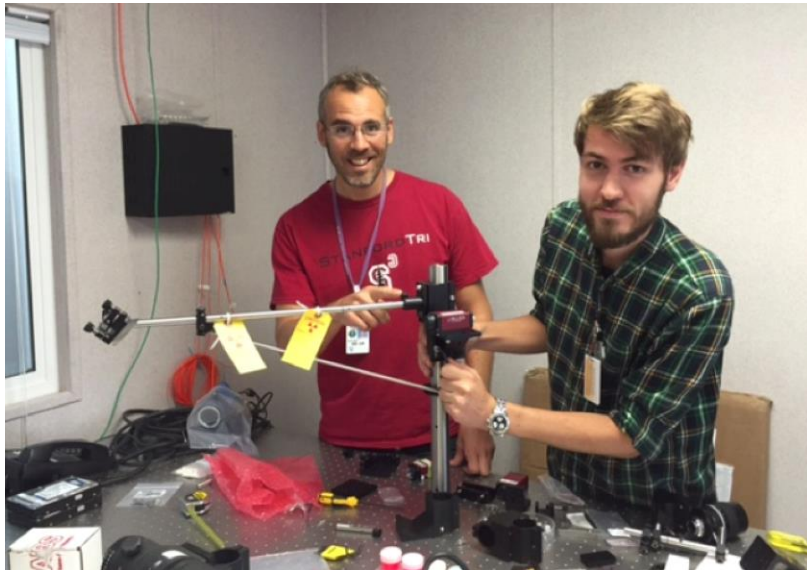
Thank you for your attention!



Veronica K. B. Olsen discussing self-modulation physics at an AWAKE collaboration meeting



Reidar L. Lillestøl, Jurgen Pfungstner and Lukas Malina performing CLIC wake field monitor experiments at the CERN CALIFES electron beamline



Carl A. Lindstrøm preparing a plasma filament imaging set-up at SLAC



Riccard Andersson with PLCs for ESS machine protection