Some thoughts and comments on Accelerator R&D Roadmap (2022)

(slides from ECFA + my comments)

Erik Adli, UiO, NORCC Strategy Kick-off March 11, 2022
B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs.

The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.

Lab Directory Group (LDG) has been Mandated to develop this roadmap (LDG: Directors of the Large Particle Physics Laboratories and CERN)

**Deliberation Document:**
“... This roadmap should be established as soon as possible in close coordination between the National Laboratories and CERN.”

<table>
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<th>LDG: European “Lab Directors Group” (10 labs)</th>
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<tr>
<td>o CERN, CIEMAT, DESY, IRFU, IJCLAB, NIKHEF, LNF, LNGS, PSI, STFC-RAL</td>
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<td>o lab-to-lab communications with a view to address together the ESPP</td>
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<td>o current chairperson: Dave Newbold (STFC-RAL)</td>
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Roadmap for Accelerator R&D (cont.)

• Provide an agreed structure for a coordinated and intensified programme of particle accelerator R&D, including new technologies, to be coordinated across national laboratories.

• Be based on the goals of the European Strategy, but defined in its implementation through consultation with the community and, where appropriate, through the work of Expert Panels.

• Take into account, and coordinate with, international activities and work being carried out in other related scientific fields, including development of new large-scale facilities.

• Specify a series of concrete deliverables, including demonstrators, over the next decade;

• Designed to inform, through its outcomes, subsequent updates to the European Strategy.

Accelerator R&D Roadmap planned to be released by end of 2021.
‘Chicken-and-egg’ problem

- Cannot define an R&D timeline without knowing the approximate dates of future facilities
- Cannot predict dates of future facilities without knowing R&D needs

Detector / accelerator roadmaps have used a common timeline

- Highly approximate, and not to be used out of context
- Dates represent the ‘earliest feasible date’, driven by both technical considerations and the processes of approval
- The goal on both sides is that R&D shall not be the rate-limiting step
The FCC integrated program
inspired by successful LEP – LHC programs at CERN

Comprehensive long-term program, maximizing physics opportunities

- **Stage 1**: FCC-ee (Z, W, H, t̄t) as Higgs factory, electroweak & and top factory at highest luminosities
- **Stage 2**: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options
- Complementary physics
- Common civil engineering and technical infrastructures
- Building on and reusing CERN’s existing infrastructure
- FCC integrated project allows seamless continuation of HEP after HL-LHC
increasing international collaboration as a prerequisite for success: links with science, research & development and high-tech industry will be essential to further advance with the FCC FS.
High-field Superconducting Magnets

- Key technology for future accelerators (hadron colliders, muon colliders, neutrino beams, …)

- To reach the required field strength of 16 – 20 T for FCC_hh, new technologies have to be established and brought into industrial production

Present candidates:  

- Nb$_3$Sn or High-Temperature Superconducting (HTS), …

- So far small magnets have been successfully built and operated, however, scale up to longer magnets is a challenge!  
  e.g. 11T Nb$_3$Sn magnets will not be installed in Run 3, but needed for HL-LHC

→ a long way to go!  
  Europe must intensify R&D (more resources (people, money,..), close cooperation with industry)

- HTS magnets interesting beyond HEP / industry  
  (NMR, fusion, power applications for motors and generators)
My comments: FCC/Magnet development

• Cannot contribute to main magnet R&D
• Possible to find other parts where to contribute to (design), in order to formally join the collaboration
  • Would be welcome by CERN/FCC (another country contributing)
  • Will take resources from existing, not only work resources, but formalities/meetings/boards/FCC weeks etc.
  • should only join if we
    • get new resources? (e.g. a dedicated PhD student)
    • profit scientifically?
    • and/or if concerted effort with national FCC physics/detectors?
• If likely that FCC will be approved: important to join, also in the accelerator studies
  • also for future industrial return
RF: Objectives

Scope covers both SC and NC RF structures
  Not only cavities, but couplers, tuning elements, power sources, LLRF

Main objectives
  Efficiency and optimisation of the end-to-end system
  Efficient automation / industrialisation for assembly and tuning
  Diagnostics and rapid feedback mechanisms
  Development of sources, materials and structures for new wavebands (mm / THz)
Accelerating structure

Outside

Inside

6 mm diameter beam aperture

11.994 GHz X-band

Concept

beam propagation direction

LAL, 26 November 2015

Walter Wuensch, CERN
Well known effect, the WAKEFIELD

Ideal trajectory

Real trajectory

2x TD26s with Wakefield Monitors
My comments: RF

• Contributing today through CLIC/CLEAR MoU
  • Experts on RF design, instabilities, emittance preservation etc.
• MoU makes easy access to experiments at CLEAR and collaborations for application
  • important to sustain activity, despite the lesser focus on CLIC as an energy frontier machine in this period
• No competence on SC RF hardware, but on design/paper studies
  • in position to contribute to ILC
Novel accelerator concepts: **plasma acceleration**

**Principle:** drive a wave in plasma with particle or laser beams

**RF cavities:** limited by metal surface break down

**Alternative: high fields inside plasmas:**
- Plasmas of a large range of densities can easily be produced. Fields scale with density. **Very high fields can be generated.**
- Plasmas are already broken down. The plasma can **sustain the very high fields.**

**Plasma density** $\sim 10^{16-18}/\text{cm}^3$

**Field scale:** $10-100 \text{ GV/m}$

**Length scale:** $\lambda_p/2\pi = 10-100 \mu\text{m}$

**Great experimental progress recent years:**
50 GV/m accelerating fields, positron acceleration, AWAKE... **See UiO-thesis of Carl A. Lindstrøm**

**See parallel session talk by Ben Chen (UiO)**

**TW-PW laser technology**

**Plasma lenses for particle beams**

**See parallel session talk by Kyrre Sjøbæk (UiO)**
Goal is to complement large ‘external’ investment in plasmas
- Ensuring that the HEP-specific aspects are fully covered
- Drive for (essentially) plausible case for large-scale project at next ESPPU
  - Many ‘fundamental’ questions to be answered on paper, and demonstrated in a later phase
4. High-gradient Plasma and Laser Accelerators

### Task Table

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<td>Electron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)</td>
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<td>PLA.DLTA</td>
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<td>High-Efficiency, Electron-Driven Plasma Accelerator Module with High beam Quality</td>
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<td>PLA.SPIN</td>
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<td>2026</td>
<td>Scaling of DLA/THz Accelerators</td>
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### Diagram

#### Feasibility and pre-CDR on advanced accelerators

- Definition of particle physics case

#### Selection of technology base for a CDR

- CDR for an advanced collider
- TDR, prototyping and preparation phase
- Dedicated test facility: construction, operation

#### Decision on construction (in view of results and other collider projects)

- Construction of advanced collider

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*Image credit: EuPRAXIA Conceptual Design Report, A. Martinez*
### Table 4.4: Work packages and tasks in the minimal plan.

| WP   | Task                                                                                     | Short Description                                                                 | Invest Personnel |
|------|---------------------------------------------------------------------------------------------------------------------------------------------|------------------|
|      | **COOR**                                                                                   | Coordination Plasma and Laser Accelerators for Particle Physics                  | —                |
|      | **FEAS**                                                                                   | Feasibility and pre-CDR Study on Plasma and Laser Accelerators for Particle Physics | 300 kCHF 75 FTEy |
| FEAS.1| Coordination                                                                                  |                               |                  |
| FEAS.2| Plasma Theory and Numerical Tools                                                            |                               |                  |
| FEAS.3| Accelerator Design, Layout and Costing                                                      |                               |                  |
| FEAS.4| Electron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)          |                               |                  |
| FEAS.5| Positron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)          |                               |                  |
| FEAS.6| Spin Polarization Reach with Advanced Accelerators                                            |                               |                  |
| FEAS.7| Collider Interaction Point Issues and Opportunities with Advanced Accelerators             |                               |                  |
| FEAS.8| Reach in Yearly Integrated Luminosity with Advanced Accelerators                           |                               |                  |
| FEAS.9| Intermediate steps, early particle physics experiments and test facilities                  |                               |                  |
| FEAS.10| Study WG: Particle Physics with Advanced Accelerators                                       |                               |                  |
|      | **HRRP**                                                                                   | Experimental demonstration: High-Repetition Rate Plasma Accelerator Module        | 1200 kCHF 30 FTEy |
|      | **HEFP**                                                                                   | Experimental demonstration: High-Efficiency, Electron-Driven Plasma Accelerator Module with High beam Quality | 800 kCHF 10 FTEy |
|      | **DLTA**                                                                                   | Experimental demonstration: Scaling of DLA/THz Accelerators                      | 500 kCHF 16 FTEy |
|      | **SPIN**                                                                                   | Experimental demonstration: Spin-Polarised Beams in Plasma Accelerators          | 350 kCHF 16 FTEy |
|      | **LIAI**                                                                                   | Liaison to Ongoing Advanced Accelerator Projects, Facilities, Other Science Fields | —                |
Conclusion

To move towards PLC: a collider parameter “paper” study (not necessary at a CDR level), leading to a consistent global parameters set, and key performance metrics

- needed to understand the promise of a plasma collider, and key parameters
- needed to guide future feasibility demonstrations
- Main input to paper study: performance can be based on theory/simulation, rather than present (non-ideal) experiments. Represents a “a best case”.

Experiment:
Few MeV energy gain, far from pump depletion.

Example (FlashFoward)

Simulation:
Energy doubling at 25 GV/m and pump depletion

Resources for design: a significant number of man-years. Still small compared to cost of ongoing and proposed experiments and facilities. Some technology choices should be made.
My comments: laser/plasma

• Contributing today, mainly through other NFR projects
  • plasmas: we have expertise, “sexy” subject for students
  • Possibility to do high impact research
• Path towards a plasma collider unclear
  • Needs a concerted effort, with clear leadership/ownership (muon collider)
  • Collider design: not necessarily high impact research, harder to get funding
  • Contributions to colliders studies: depends on funding schemes
Novel accelerator concepts: muon collider

Novel concepts: boost accelerator performance with **radical change in technology**

Very promising and interesting research, many hurdles to overcome before use in a collider.

**Muon collider pros and cons**

- Negligible synchrotron radiation

Main challenge: $\tau_\mu = 2.2$ $\mu$s

- Produce sufficiently dense muon beams
- Rapid acceleration
- Mitigate radiation hazards

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Protons on target hadronic showers, Pions decay into muons

Muons are captured, bunched and then cooled.

Rapid acceleration to collision energy

Collision

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Precision, plus discovery potential!

- **3 TeV ~ LHC**
- **14 TeV ~ FCC-hh**
- **30 TeV ~ “amazing”**

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**Diagram:**

- Proton Driver
- Front End
- Cooling
- Acceleration
- Collider Ring

- E_{coM}: Higgs Factory to ~10 TeV

- Accelerators: Linacs, RLA or FFAG, RCS

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**Graph:**

- lepton vs protons

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**Graph:**

- $\sqrt{s_{\mu}}$ [TeV] vs $\sqrt{s_p}$ [TeV]
Muons: Objectives

- Objectives are again focused on the ‘plausibility case’
  - Examine the key technical barriers and cost drivers before next EPSSU
  - Planning towards a muon beam demonstrator an optional element

- Key topics
  - Machine parameters; muon cooling cell; siting considerations; neutrino radiation; magnets & RF
Muons: Plan

5.7.2 Scope of the Full Scenario

The full scenario contains theoretical studies of the accelerator design and the technologies in order to define key functional specifications of the collider complex and components that allow achievement of the performance goals and that are realistic targets for the technology developments. This effort will be supported by a limited experimental programme to improve the reliability of the estimates:

5.7.1.2 R&D plan

The R&D plan will describe the R&D path toward the collider, in particular during the CDR phase. Key steps in this programme are:

- 6D solenoid models and the RF cavity tests provide input to the design choice for the prototype module.
- An evaluation of whether this facility can be installed at CERN or another site.
- An integrated concept of a muon cooling cell that will allow construction and testing of this key novel component.
- A description of other R&D efforts required during the CDR phase including other demonstrators.
- Timeline for the technology R&D part of the programme. The solenoid model testing aims to provide a design load for the prototype module.

5.7.1.3 Interim Report

This R&D plan will allow the community to understand the technically limited timeline for the muon collider development after the next ESPPU. It will also provide an opportunity for additional feedback to the collaboration.

The Interim Report at the end of 2023 will allow the community to gauge the progress of the concept well in advance of the next ESPPU.
My comments: muon collider

• Norway can contribute to interesting topics (design, application of novel technology)
  • Would be welcome by CERN/MC (another country contributing)
  • Will take resources from existing, not only work resources, but formalities/meetings/boards/workshop weeks etc.
  • from the accelerator point of view: possibly greater scientific interest in MC than in joining the FCC design
• should only join if we
  • get new resources? (e.g. a dedicated PhD student)
Energy Recovery Linacs – The idea

- high average („virtual“) beam power (up to A, many GeV)
- many user stations
- beam parameter defined by equilibrium
- typical long bunches (20 ps – 200 ps)
- outstanding beam parameter
- single pass experiments
- high flexibility
- low number of user stations
- limited average beam power (<<mA)

• high average beam power (multi GeV @ some 100 mA) for single pass experiments, excellent beam parameters, high flexibility, multi user facility

e.g. ESRF: 6 GeV, 200 mA
1.2 GW
virtual power, stored energy only 3380 J

e.g. XFEL: 17.5 GeV, 33 μA
“only” ~ 600 kW, but real power

\[ \varepsilon \sim \frac{1}{\gamma} \cdot \varepsilon_{\text{source}} \]

intrinsic short bunches, high current
ERL: Objectives

- **Three-part programme**
  - Support and exploit ongoing facility programmes (worldwide)
  - Focused technical R&D into key technologies
  - Development or upgrade of European facilities for the mid-2020s

- Relevant to both absolute performance and sustainability of future machines
My comments: ERL

- Norway, no particular experience with / interest for ERL
How can we maintain the future of our field?

• Accelerators are large, cost-expensive, funding situation becomes more difficult

• Young generation feels large uncertainty!!

No concrete future project yet, beyond (HL)-LHC

• We must do all possible to decide soon (latest at the next strategy) on the next project to inject new energy (or keep the momentum) in our field

→ FCC feasibility study essential and must get full support of CERN + ECFA countries!

Do we only consider an integrated FCC_ee + FCC_hh programme, or are we open as well for an ILC + FCC_hh solution?

(Load on CERN would be reduced, better distributed world-wide, in Europe more resources could be focussed on key fcc_hh issues, i.e. high-field magnet development; will this be enough to develop magnets in a reasonable timescale?
In addition, more time to accumulate funding for FCC?
If ILC decision would be taken soon, e^+e^- machine could be realised earlier!! )
Summary

• We already contribute to Accelerator R&D Roadmap (RF, plasma), through the CERN centre and other NFR project
• With flat budget must cut existing (successful) collaborations/efforts to join new ones – should not spread out too thin
• Design contributions for future machine: hard to sell as high impact research to funding agencies
• If resources are enabled by the R&D roadmap (implementation unclear as of now), we could increase activities towards muon collider, FCC – this will put us in a position to ramp up if e.g. FCC is approved
  • FCC: more interesting to join accelerator, if Norway also joins detector/physics