Working Group 6: Sustainability

Stephen Benson and Norio Nakamura

Sustainability implications for high energy colliders

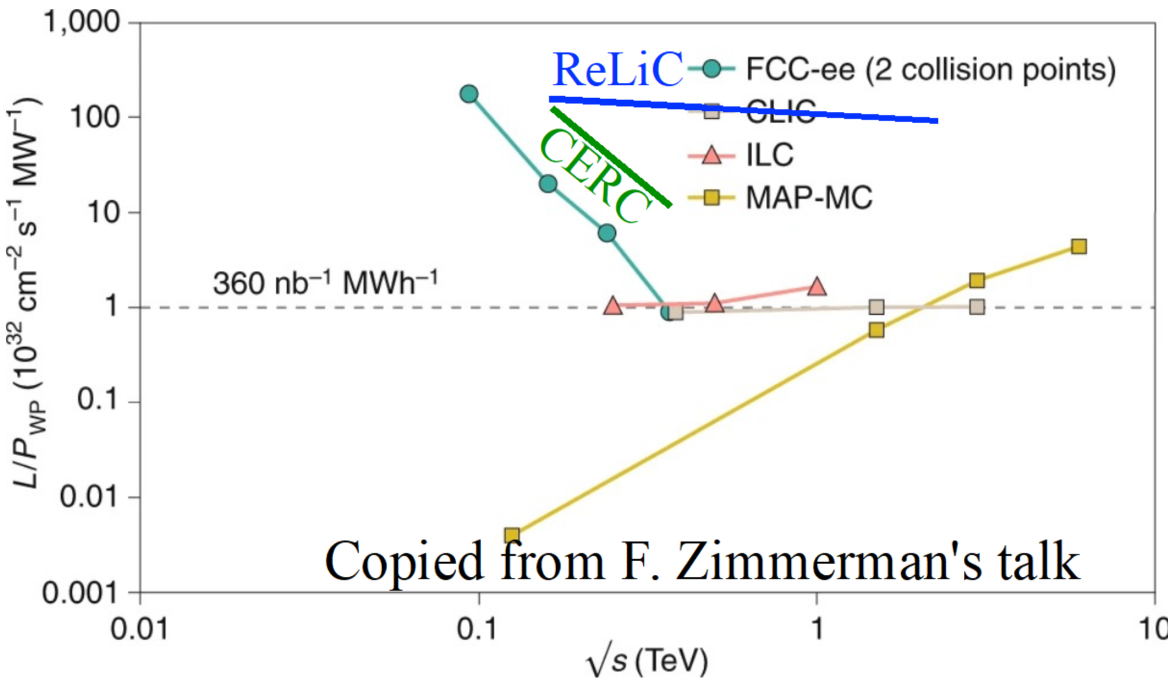
Vladimir N Litvinenko

There is empirical data which clearly indicates that our Earth and its climate are affected by global warming

There is sufficient evidence that we, humans, are responsible for significant part of this process

Accelerator facilities, especially large-scale colliders, do contribute to this problem

For us, as educated people, it is only natural to consider how we can reduce our contributions to these problems



Collider efficiency
: Luminosity/Power

ERLs are definitely wining in this parameter

Things specific to high-energy colliders

- List definitely includes
  - High energy consumption
    - Machinery of digging tunnels
    - Cryogenics
    - EM magnets
    - RF power
    - Driving from home to work, lighting, heat, etc.
  - Facilities that involves large volume of cement-based concrete
    - Stable foundation
    - Radiation shielding (use earth instead)
    - Offices and support buildings
  - Large volumes of cooling water
  - Radiation waist and pollution
  - Etc.

Areas of R&D to reduce energy consumption and carbon imprint

- Accelerator facilities need to produce high energy conditions. This means that energy efficiency often requires some form of recovery of the lost energy.

  - Energy efficient accelerator concepts (Storage rings, Energy Recovery Accelerators, …)
  - Recycling of used particles to reduce radiative waist
  - Build low loss accelerators to simplify shielding and construction cost
  - Traveling SRF system to effectively double accelerating voltage at fixed cryogenic losses
  - More efficient He refrigerators (presently 3 – 6 times worse than Carnot efficiency!)
  - Fast reactive tuners to reduce RF power need to fight microphonics
  - Use of energy efficient components (Superconducting technology, permanent magnets, HTS, …)
  - Etc.

  - Compact accelerators, such as Muon collider and Wakefield Accelerators to reduce size of colliders but there is big ?? about their energy efficiency..
  - Replacing concrete with natural materials (soil, sand) and use advanced materials for accelerator tunnel structures (fiberglass? advanced plastics?...)
  - ……

Advancements and Challenges in Large-scale Cryogenics for Accelerator Facilities – Nusair Hasan

- For long term sustainable and stable operation, it is important to develop and deploy a cryogenic system that is operated with the actual heat load (instead of a combination of actual and artificial load to match the design load)
  - Stable and efficient (~ 250 W/W at 4.5 K) long-term operation with the Floating Pressure process cycle has been demonstrated at multiple US-DOE particle accelerator facilities
  - Further improvements on this efficiency requires improvement on the warm compressor performance. Approx. 2/3rds of the overall cryogenic system losses are emanated from this component
- Efficient system operation is a major challenge for the facilities requiring cryogenic system with 2.0 K capacities of few hundred watts or less (e.g. lot of users in ERL community)
  - Present ‘turn-key’ technology uses direct vacuum pumping system – in which the inverse COP is approx. 3200 W/W or worse. Typically, the cooling from the boil-off gas is not recovered
  - It has been identified that the efficiency of these systems can be improved significantly. A scalable design integrating refrigeration recovery and subsequent purification of the sub-atmospheric stream is required
- It is prudent to not only invest in cryogenic equipment / system R&D, but also in workforce development for a sustainable progress in this field
  - There is no incentive, nor is it effective for industry to pursue R&D in cryogenic equipment and systems needed for accelerators

Challenges and breakthroughs in recent RF Solid State PA design by Radial Combiner design with Initiatives for SDGs - Reichiro Kobana

- 16 years ago, R&K started designing and producing some hundreds kW RF SSA for accelerator applications as alternatives to Klystron / tube.

- The measure characteristics of SSA allows one to design a source in a very wide frequency range available from a few MHz to 14 GHz, and these sources are upgradable in max-power from a few kW to few MW design even after system completed.

- Recently, SSA is being recognized the significant advantages over vacuum tubes in terms of size, low power consumption, higher efficiency, low cost, and adaptive power design. In addition to these, we have learnt that SSA has very low phase noise and low envelope noise that cannot be achieved with vacuum tubes.

- Note that SSAs do not required as much investment in spares and offer the possibility of hot spares as well. Efficiency is already 72% and might reach 90%.

- All these advantages are transforming SSAs into the first-chosen RF power source even for particle accelerators. There is no doubt that all these improved performances of SSA will minimize overall resource utilization, and well match with sustainable industry and society.

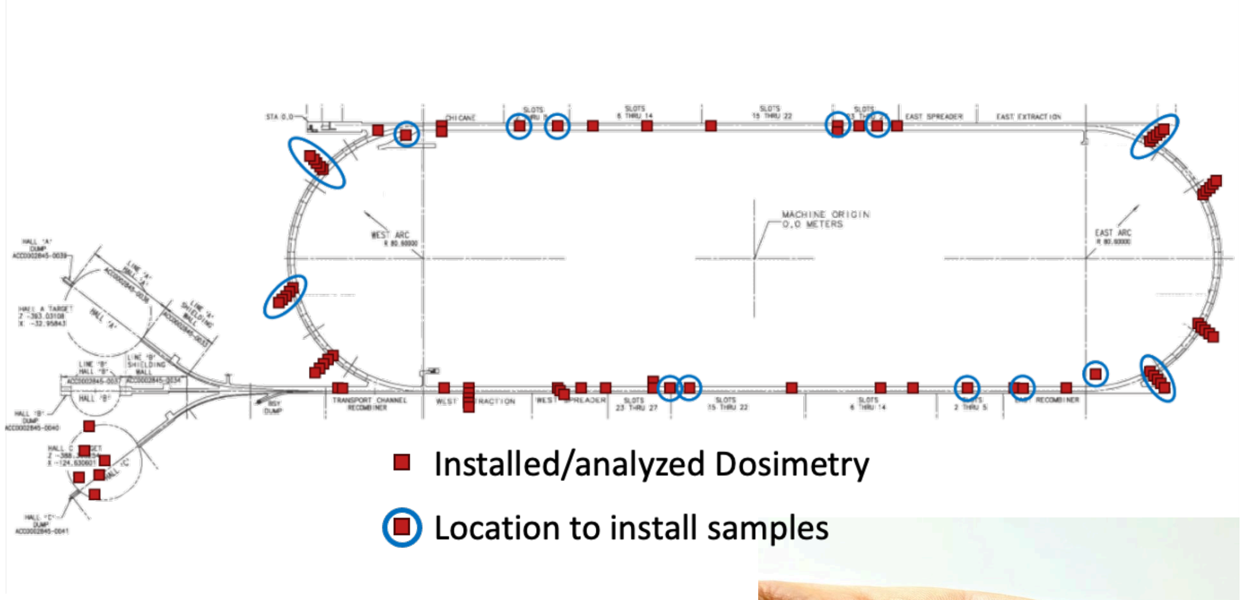
Investigating Permanent Magnet Resiliency to Radiation: A Study at Jefferson Lab's CEBAF – Ryan Bodenstein

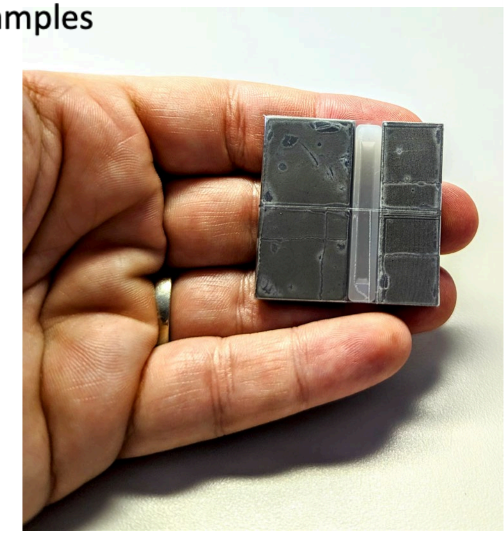
- **Use of permanent magnets may help reduce power needs and provide greener alternatives in some cases**

- ***Human Rights concerns must be addressed!***

- The radiation hardness has been studied in other regimes, and we are continuing these studies with studies in CEBAF's accelerator enclosure
    - Taking in-situ magnet and dosimetry measurements periodically during CEBAF operations
    - Setup is ongoing, studies to begin when CEBAF returns to operation in January of 2025

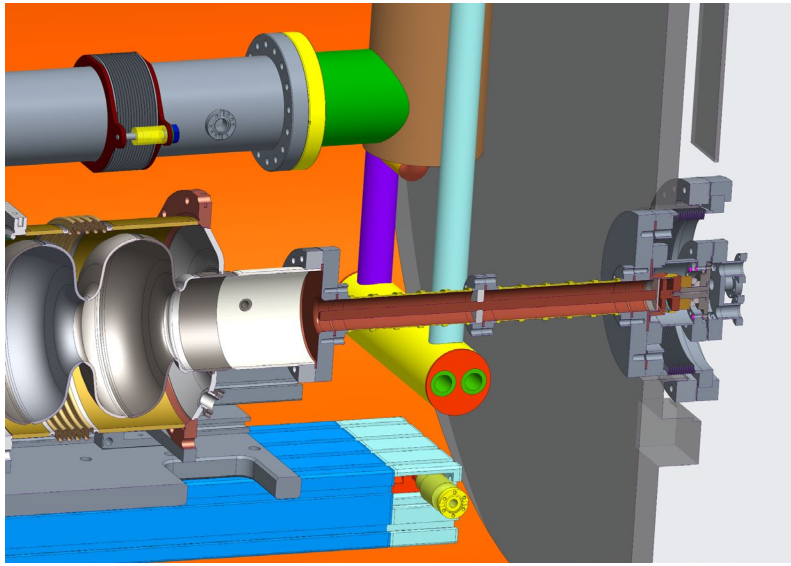
- **Looking forward to contributing to the community as we gather our results!**

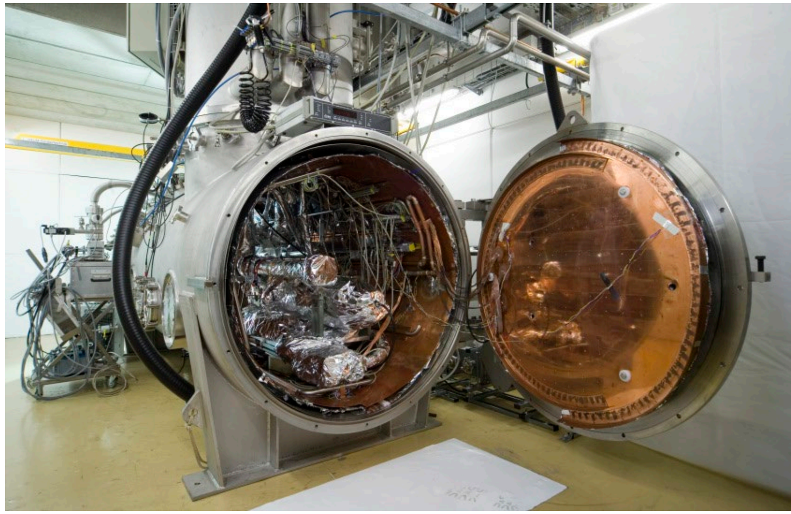


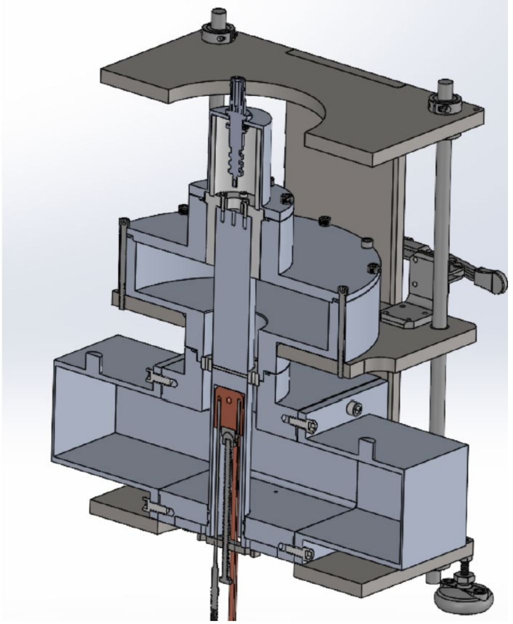


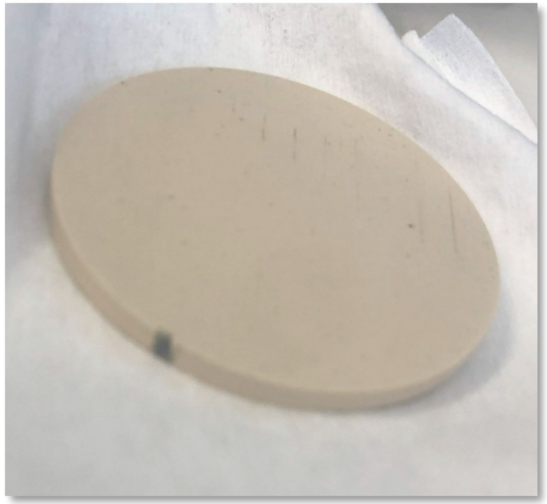
FE-FRT Research at HZB
Nicholas Shipman

- FE-FRTs are exceptionally fast non mechanical cavity tuners
- Excellent tool for microphonics suppression
  - Can reduce RF power requirements by > order of magnitude
  - Increased sustainability and affordability for e.g. ERLs
- Current Objective: Build FRT and compensate microphonics in 1.3GHz cavities
  - Preliminary FE-FRT RF design complete
  - Mechanical design and integration at advanced stage
  - Sample characterisation at 1.3GHz ongoing (FERMAT)
- Estimate FRTs would reduce RF power for bPRo main LINAC cavities to:
  - <200W (from 3.4kW avg. and 6.8kW peak)









Clockwise from top:
FRT and booster cavity in HoBiCaT; HoBiCaT; FERMAT (FERro-electric MAterial Teststand); ferro-electric sample.

Advancing Nb_3Sn High Q Cavities by Mechanical Polishing – Eric Viklund

Operation at 4.5 °K can reduce cryogenic loads and simplify the system.

- Key findings:
  - Mechanical polishing used to produce extremely smooth Nb_3Sn films.
  - Mechanical polishing in combination with a recoating increases the maximum accelerating gradient.
  - Recoating found to recover performance of degraded cavities by healing strain induced cracks.