WG5: ERL Applications Summary

Deepa Angal-Kalinin (STFC Daresbury Laboratory & CI)
Oliver Bruning (CERN)
Nikolay Vinokurov (BINP)
Oleg Shevchenko (BINP)

15th - 20th September 2019, HZB, Berlin

Monday, 16th September 2019

14:00 **PERLE: A High Power Energy Recovery Facility at Orsay**
Walid Kaabi (IN2P3, France)

14:25 **A hard X-ray FEL and Nuclear Physics facility based on a Multi-pass re-circulating superconducting CW Linac with Energy Recovery**
Peter Williams (STFC, UK)

14:50 **Nuclear photonics with an ERL-based hard X-ray source**
Norbert Pietralla (TU Darmstadt, Germany)

15:15 **Electrodisintegration of 16O and the Rate Determination of the Radiative Alpha Capture on 12C at Stellar Energies**
Ivica Friscic (MIT, USA)

16:00 **The Use of ERLs to Cool High Energy Ions in Electron-Ion Colliders**
Stephen Benson (JLab, USA)

16:30 **Industrial Applications of cERL**
Hiroshi Sakai (KEK, Japan)

17:00 **Recent Advances in Terahertz Photonics and Spectroscopy at Novosibirsk Free Electron Laser**
Yulia Choporova (BINP, Russia)

17:30 **ERL as a versatile SRF test facility**
Erk Jensen (CERN, Switzerland)

Wednesday, 18th September 2019

16:00 **Asymmetric SRF dual axis cavity for ERLs: studies and design for ultimate performance and applications**
Yaroslav Shashkov (JAI, UK)

16:30 **ERL with Fixed Field Altrernating Gradient Linear Gradient Role in EIC**
Dejan Trbojevic (BNL, USA)

16:50 **High-Efficiency Broadband THz Emission via Diffraction-Radiation Cavity**
Miho Shimada (KEK, Japan)

Poster Session

THz User Operation With 200 pC CW Beam Generated by the ELBE SRF Gun II
Andre Arnold - Helmholtz-Zentrum Dresden-Rossendorf
X-Ray ICS Source Based on Modified Push-Pull ERLs.
Illya Drebot - Istituto Nazionale di Fisica Nucleare Sezione di Milano
A Hard X-ray Compact Compton Source at CBETA
Joe Crone - Cockcroft Institute The University of Manchester Physics and Astronomy Department
Design of an Energy Recovery Linac for Coherent Electron Cooling Experiment
Yichao Jing - Brookhaven National Laboratory Collider-Accelerator Department

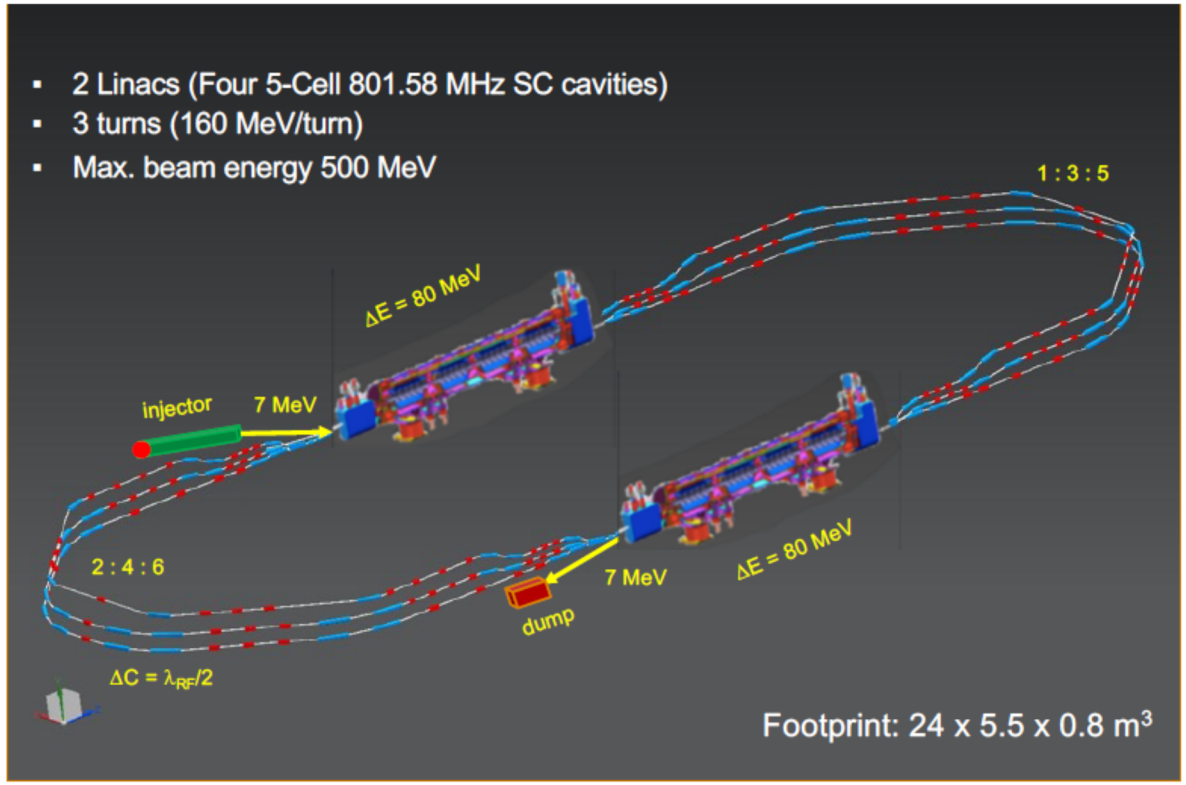
Wide range of applications of ERLs covered:

- Radiation sources
  - FELs: Far-IR, IR, EUV, hard X-rays,...
  - Intense THz (via coherent resonant diffraction radiation)
  - Gamma source (LCS, ICS)
  - ……..
- High resolution X-ray imaging
- Security and medical isotope manufacturing
- Particle Physics
  - LHeC & PERLE
- Nuclear Physics:
  - Cooler for high energy heavy ions in EIC (JELIC and eRHIC)
- Photonics (nuclear, surface plasmons,…)
- Spectroscopy (ultra-fast, pump-probe, ….)
- Nuclear astrophysics
- ……

PERLE: A High Power Energy Recovery Facility at Orsay

Walid Kaabi (IN2P3, France)

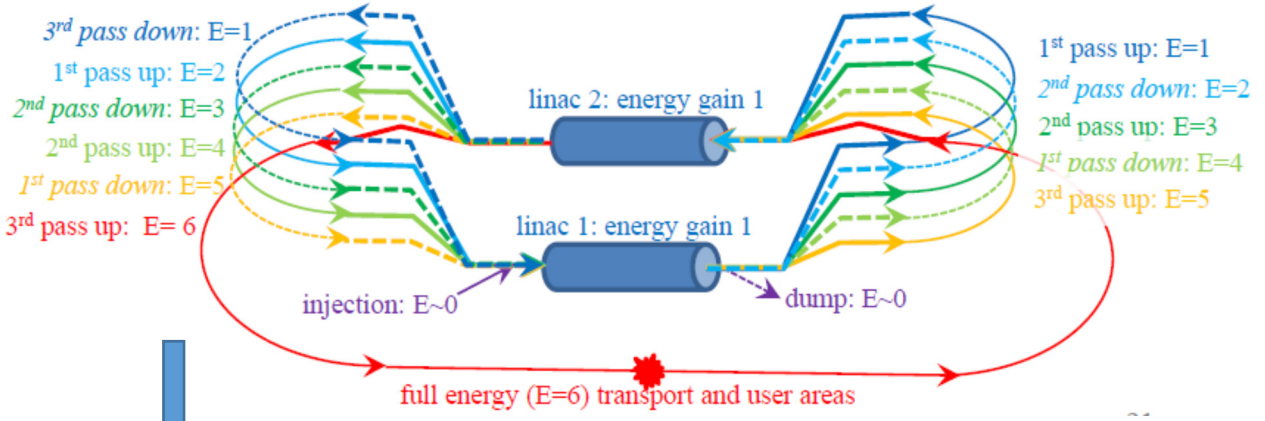
- A proposed 3 pass ERL based on SRF technology, to serve as testbed for studying, testing and validating a broad range of accelerator phenomena & technical choices for future projects.
- Particularly, design challenges and beam parameters are chosen to enable PERLE as the hub for technology development (especially on SRF) for the Large Hadron Electron Collider (LHeC).
- Project staging strategy and the status of international collaboration on design and technical developments.



Multi-Pass Recirculating Superconducting CW Linac

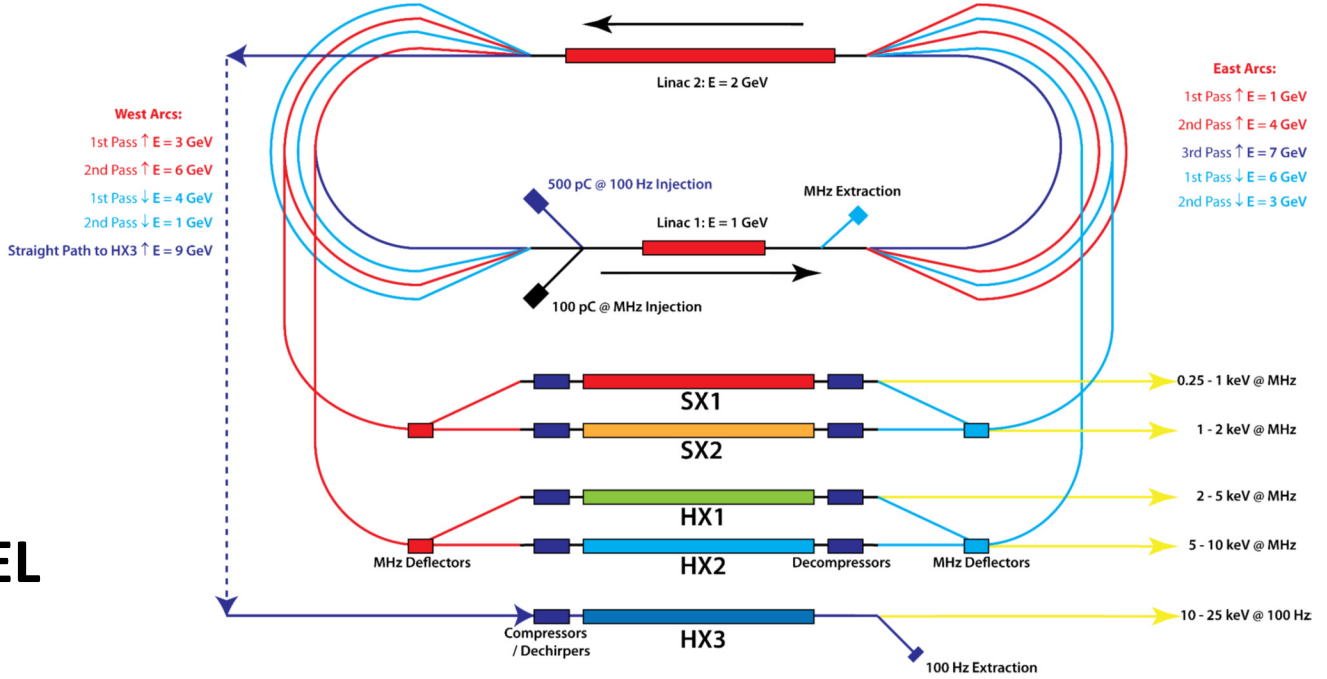
Peter Williams (STFC, UK)

- High beam powers (multi-MHz rep rates) enabled by SC technology is the unexplored frontier.
- A recirculating linac with energy recovery is the way to make this affordable and extend scientific reach into nuclear domain and high average power industrial FEL applications.



DIANA (1 GeV scale MHz ERL) will provide High **average power EUV-FEL** and **industrial ICS gamma source.**

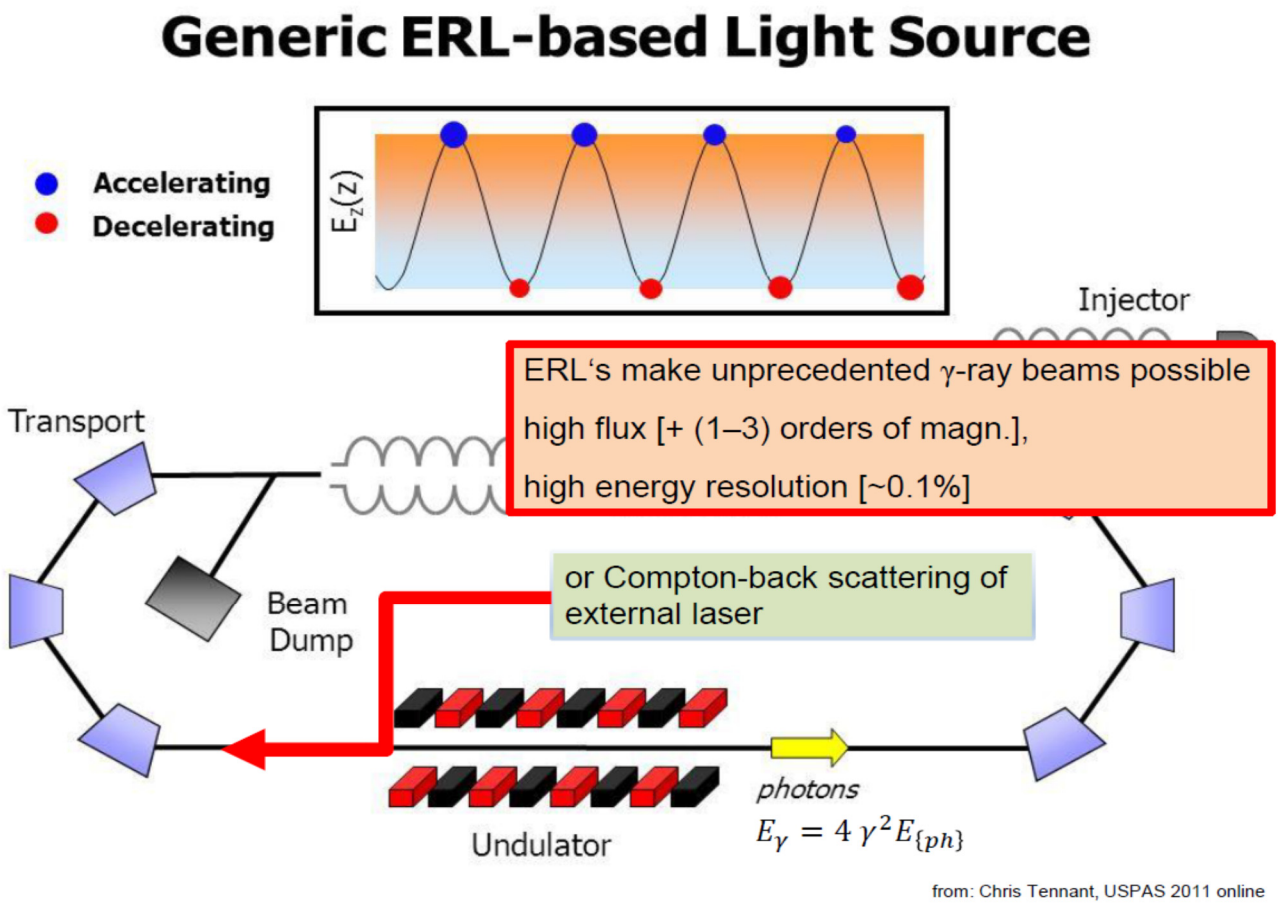
Will also serve as technology test bed for future proposed large scale facilities UK XFEL and potentially LHeC/FCC.



Research Opportunities in Nuclear photonics with an ERL-based hard X-ray source

Norbert Pietralla (TU Darmstadt, Germany)

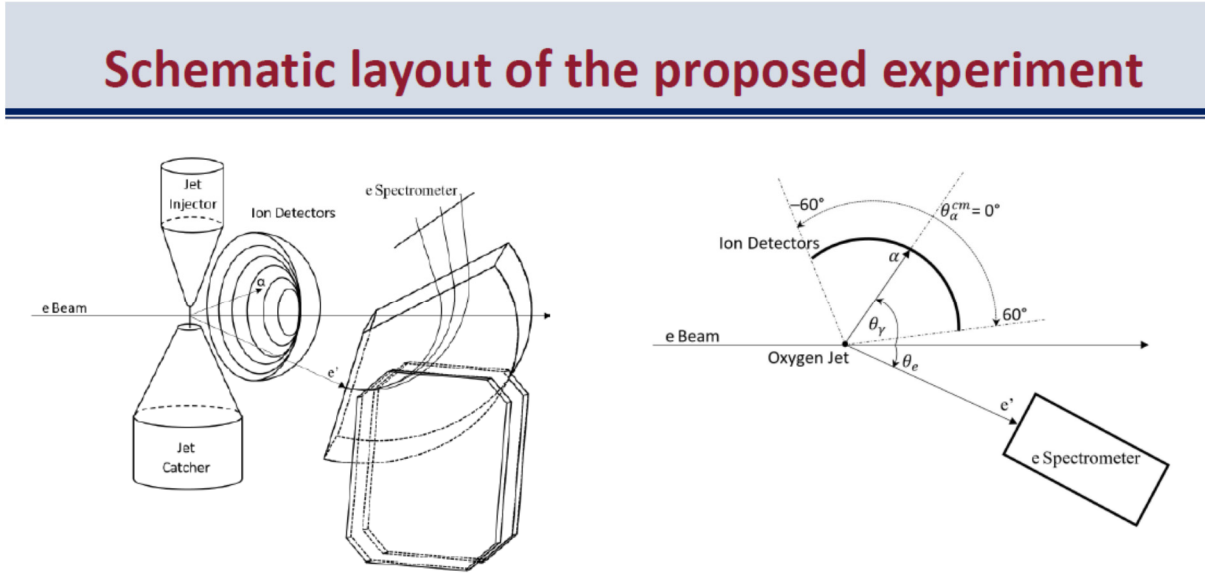
- Hard X-ray sources based on Compton scattering of laser beams on intense electron beams provide quasi-monochromatic, energy-tunable, fully polarized gamma-ray beams for photonuclear reactions.
- Examples for photonuclear reactions from S-DALINAC and from the High-Intensity gamma-ray Source (HIgS) at Duke University.
- Potential advantages of the ERL-based gamma sources is higher energy resolution (narrower radiation spectrum).



Electrodisintegration of ^{16}O and the Rate Determination of the Radiative Alpha Capture on ^{12}C at Stellar Energies

Ivica Friscic (MIT, USA)

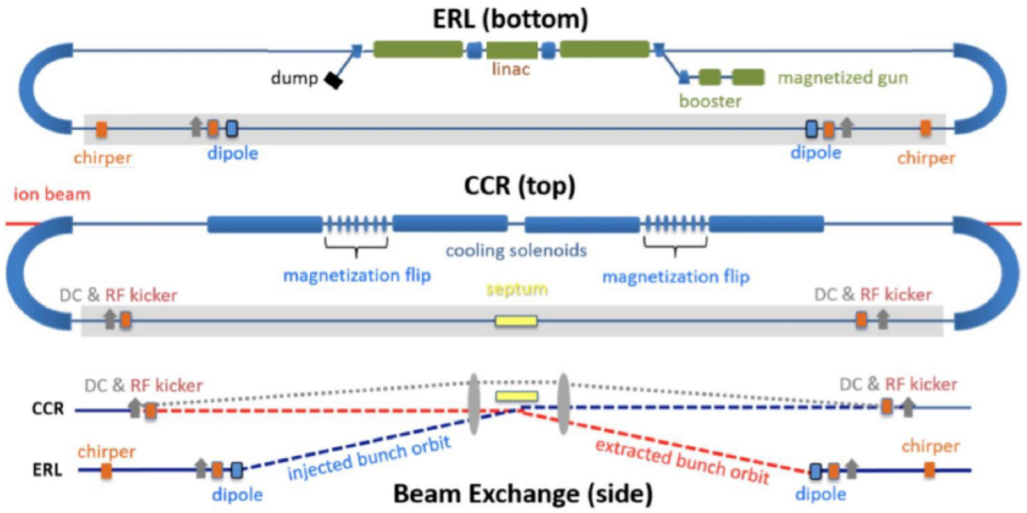
- Experimental nuclear astrophysics goal for past five decades has been to reduce the uncertainty of the S-factor of the radiative alpha capture on ^{12}C at stellar energies.
- Have developed a simple model in a high luminosity experiment using state-of-the-art gas target and an ERL, which will significantly improve the statistical uncertainty in the interesting astrophysical regime.
- If validated successfully experimentally, it will open up highly significant avenue of research spanning nuclear structure and astrophysics.



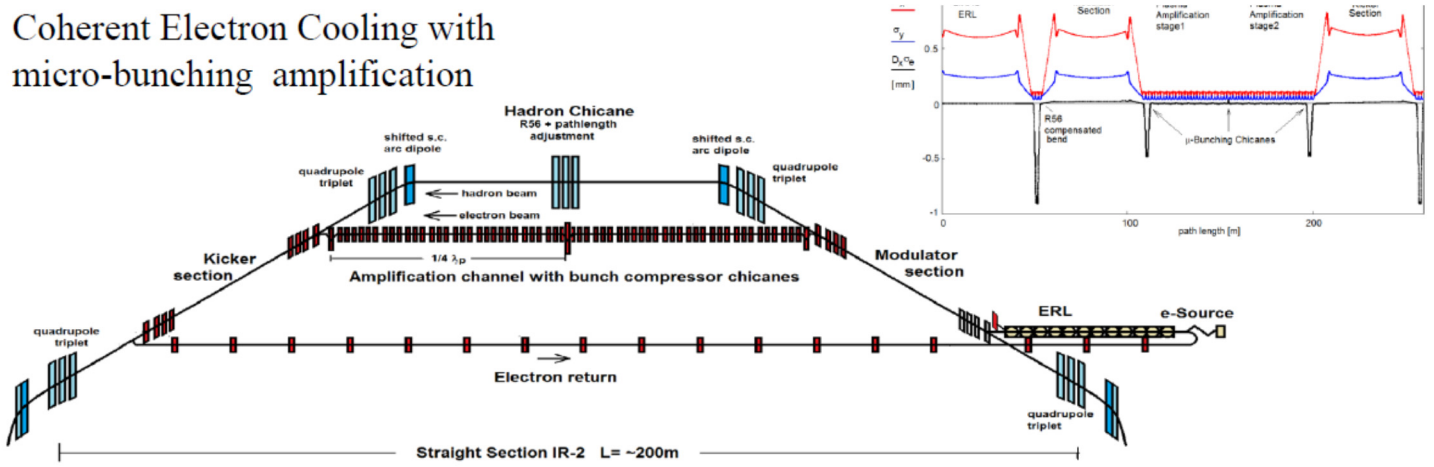
The Use of ERLs to Cool High Energy Ions in Electron-Ion Colliders

Steve Benson (JLAB, USA)

- Electron Ion Colliders are the highest construction priority in U.S. Nuclear Physics today.
- Two designs: JLEIC and eRHIC.
- The high luminosity (~10^{34} $cm^{-2}sec^{-1}$) demanded in both designs can be reached using strong hadron cooling.
- Multi-phase cooling required. At high energies, need bunched beam ERL cooler.
- Coherent electron cooling provides stochastic cooling at optical frequencies.
- Very stringent requirements for the electron beam.



JLEIC Circulating Cooler Ring fed by ERL



Strong Coherent Hadron Cooling for eRHIC

Industrial Applications of cERL

Hiroshi Sakai (KEK, Japan)

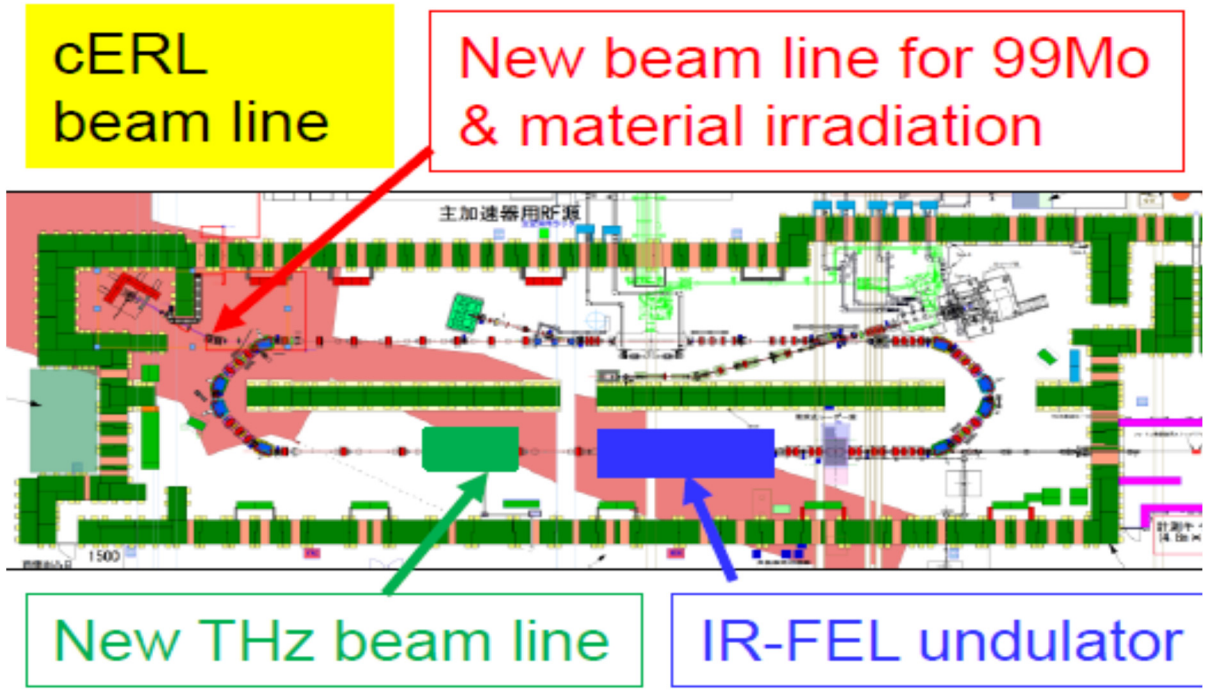
Several important industrial High current (~10mA) applications.

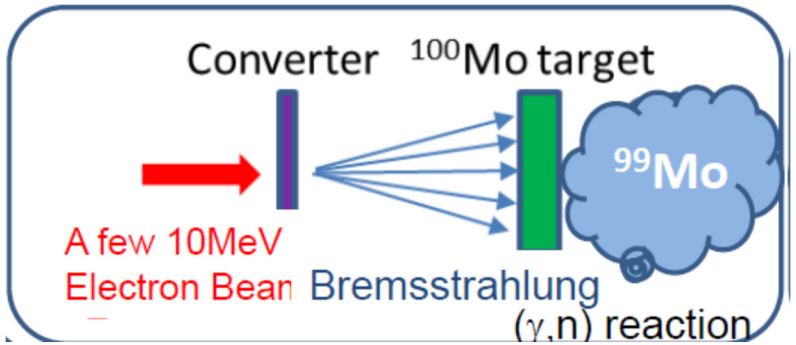
(Already achieved using LCS)

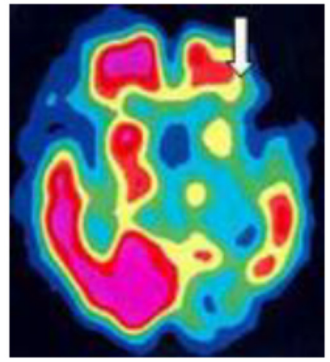
- High resolution X-ray imaging device for medical use
- Nuclear security system(gamma-ray by LCS)

(Near Future)

- RI manufacturing facility for nuclear medical examination
- Intense THz light generation
- Design concept for high repetition rate high current EUV-FEL for Future Lithography for industrial application –operational experience with high current is studies in cERL





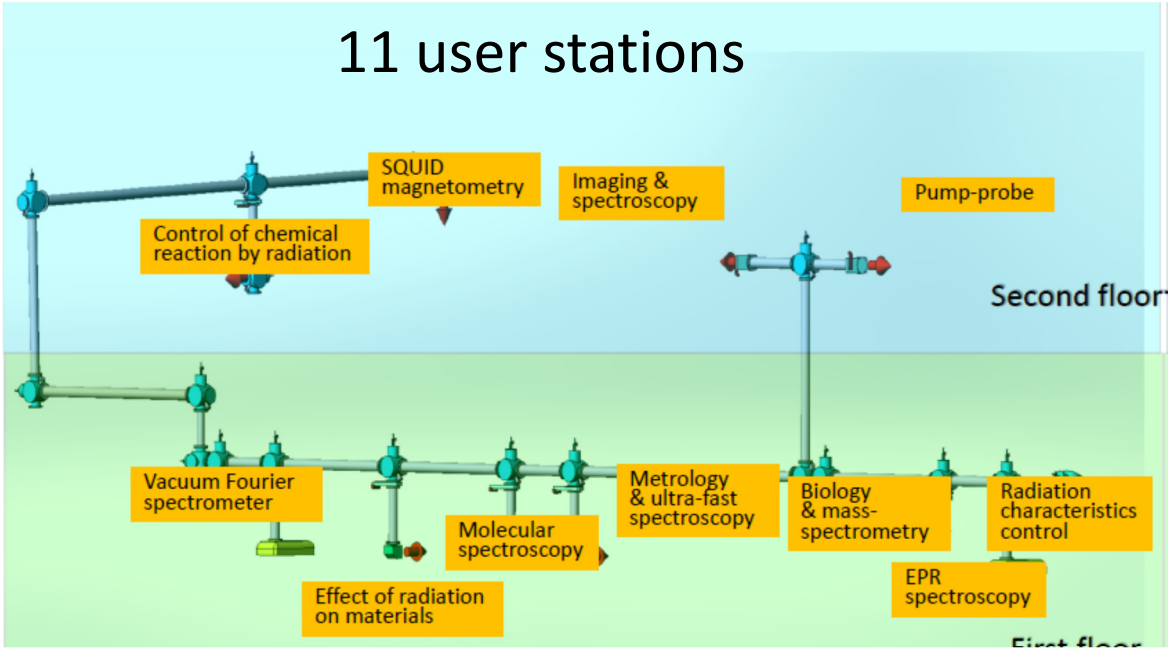


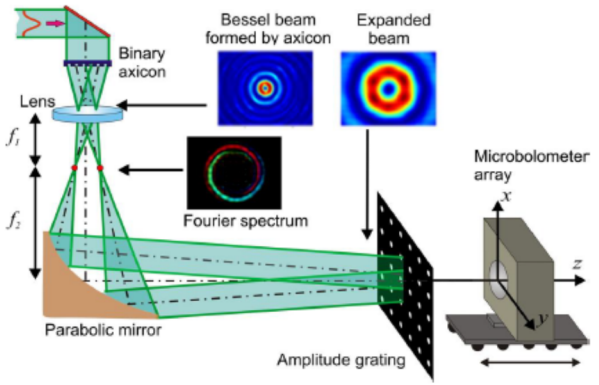
A state of brain blood flow revealed by nuclear medicine diagnosis by 99 mTc

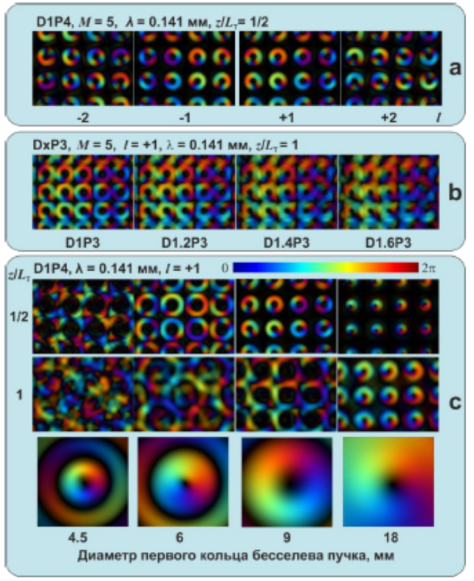
Recent Advances in Terahertz Photonics and Spectroscopy at NovoFEL

Yulia Choporova (BINP, Russia)

- NOVOFEL operates three FELs covering wavelengths ~5-240 μm Provides high power, narrow linewidth and frequency tunability enabling a wide variety of experiments.
- Selected experiments in photonics performed at the facility and the transformation of FEL radiation into modes different than Gaussian were presented.
- Use of Diffractive Optical Elements for beam manipulation.







ERL as a versatile SRF test facility

Erk Jensen (CERN, Switzerland)

- What do you need for an SRF test facility?
  - examples of SRF cavities @CERN
- Tests with beam to fully validate the system
  - beam parameters?

Do not necessarily need an ERL!

"What characteristics should an ERL have for SRF tests?"

- examples of 2 versions of PERLE, S-DANILAC, bERLinPro, CBETA and MESA
- operation in different acceleration configurations in phases
- return arcs, spreader/combiners and path length adjustments
- operation at different RF frequencies
- choice of bunch repetition rate with a suitable subharmonic

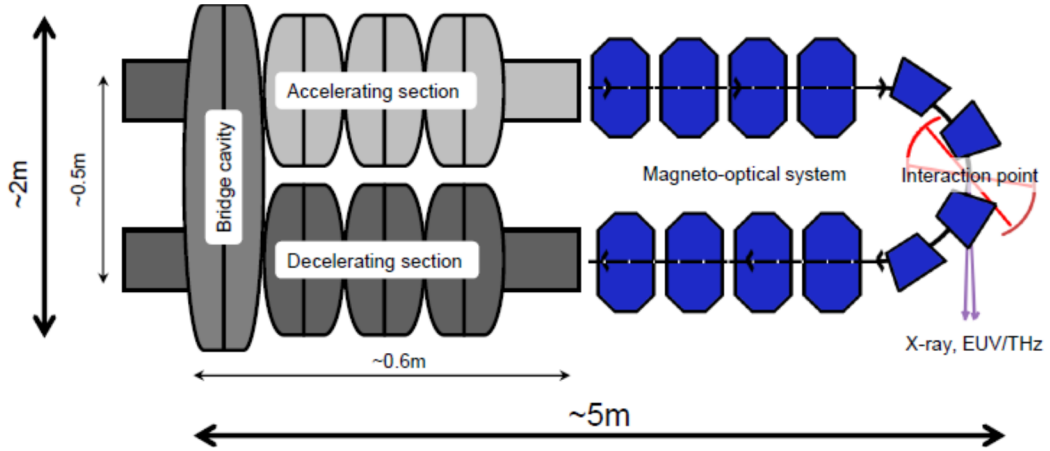
Conclusion

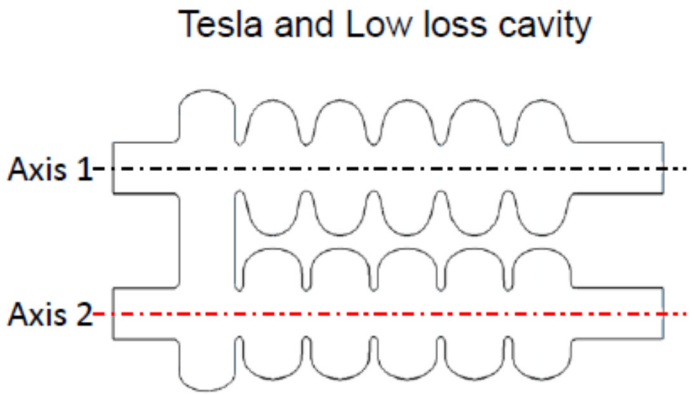
You don't need an ERL if you need a versatile SRF beam test facility, but if you want to use your ERL as SRF facility – the required pre-requisites need to be considered.

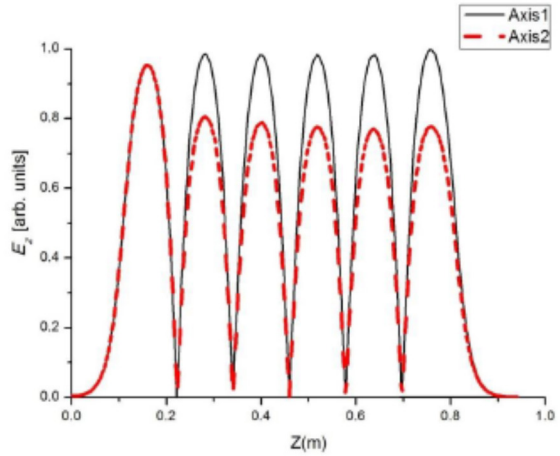
Asymmetric SRF dual axis cavity for ERLs: studies and design for ultimate performance and applications

Yaroslav Shashkov (MEPhl, Russia)

- Design aims to surpass any existing designs of ERLs in the electron beam handling capabilities and footprint to provide high current ERL for Compton light source and FEL.
- Well suited for THz and EUV applications.
- Proof of concept and optimisation of 7-cells aluminium and 11-cells copper dual axis asymmetric cavities with preliminary studies of HOMs carried out.



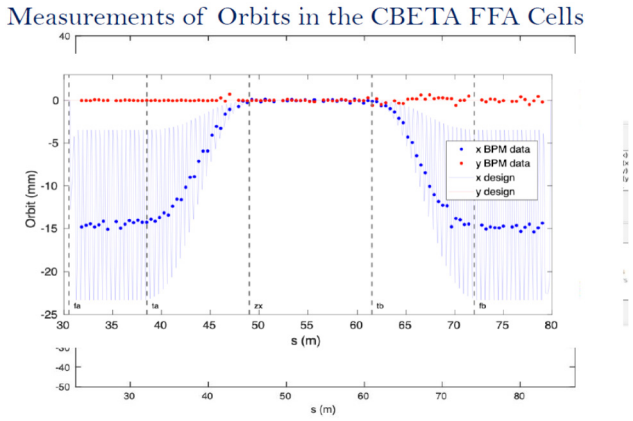




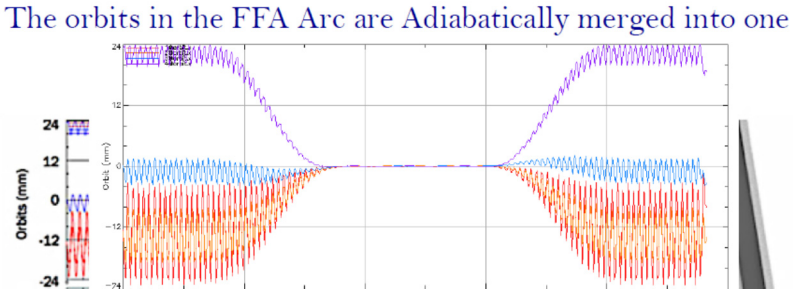
ERL with Fixed Field Alternating Gradient Linear Gradient Role in EIC

Dejan Trbojevic (BNL, USA)

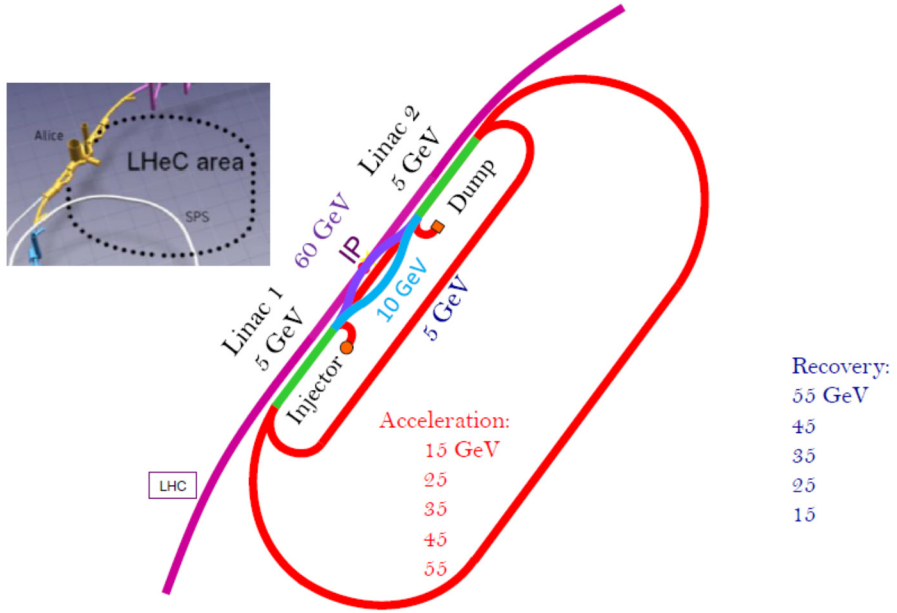
- The new concept of the ERL with a single fixed-field alternating linear gradient (FFA-LG) return lines.
- Lower energy ERLs with a single FFA-LG (e.g. eliminates four spreaders and combiners in present CBETA design).
- High energy ERLs require fixed field triplet quadrupoles inside the SC linacs. Electrons from linac pass through adiabatic transition beamline and the arc section.
- Proposed examples of using this concept in PERLE, eRHIC, LHeC ….



Several experimental confirmations that the Fixed Field Alternating gradient concept is real.



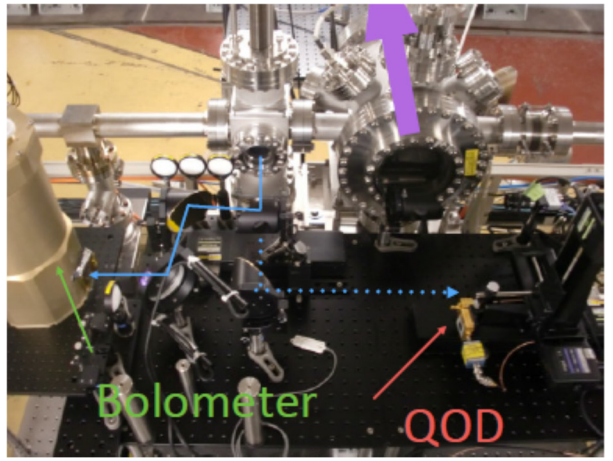
Fixed Field LHeC Recirculator with ER

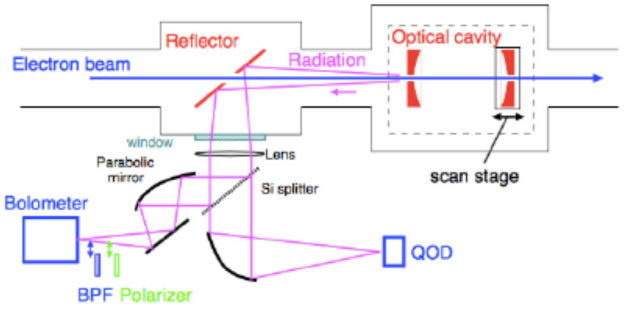


High-Efficiency Broadband THz Emission via Diffraction-Radiation Cavity

Miho Shimada (KEK, Japan)

Experiment showing Stimulated Coherent Diffraction Radiation in Optical Cavity performed at cERL.



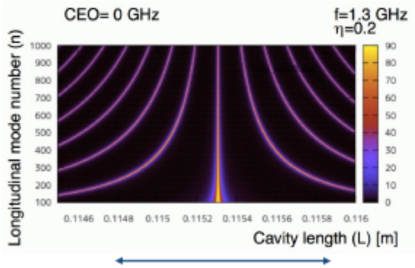


Experimental Results

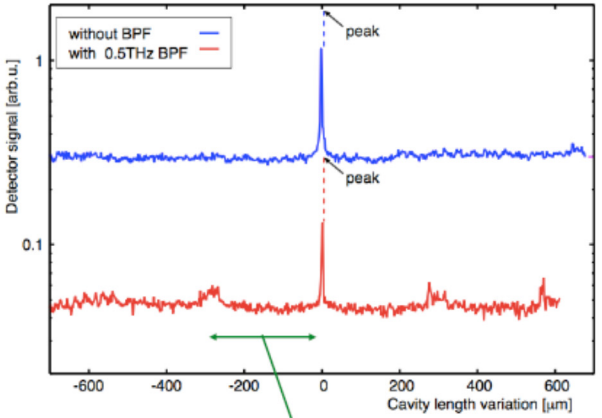
- Observed sharp resonance peak, showing broadband excitation.
- Time domain measurement shows time constant characteristics.
- Observed beam deceleration simultaneously with THz radiation.

Wide-band

Narrow-band
(with 0.5THz BPF)



Scan in this range



λ/2 of 0.5THz (λ=600um)

- Confirms zero-CEP design

Future plans

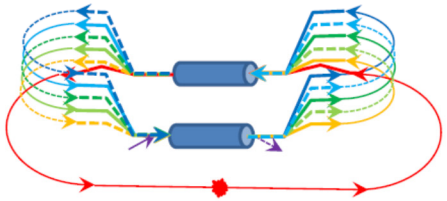
CSR inverse Compton scattering – to demonstrate high-intensity X-ray and gamma-ray source.

ERL applications continue to be realised ……

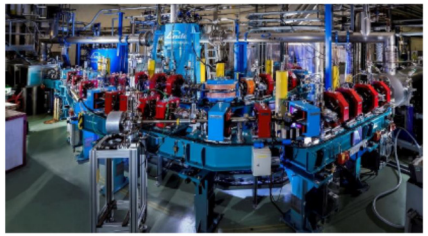
Still many challenges to overcome……..

Science & Technology Facilities Council
Daresbury Laboratory

Evolution of ERLs at Daresbury / Cockcroft



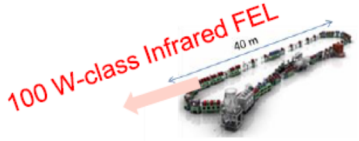
… To Industrial Applications



From Accelerator Research …

Staging to realize the EUV-FEL light source

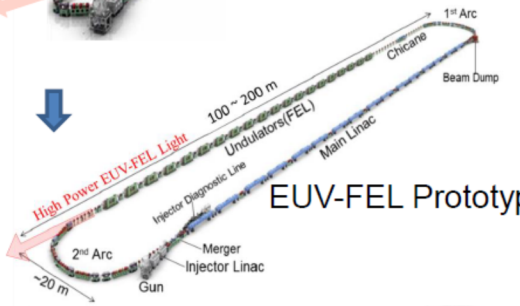
1st stage:
Development of the feasible technologies



cERL

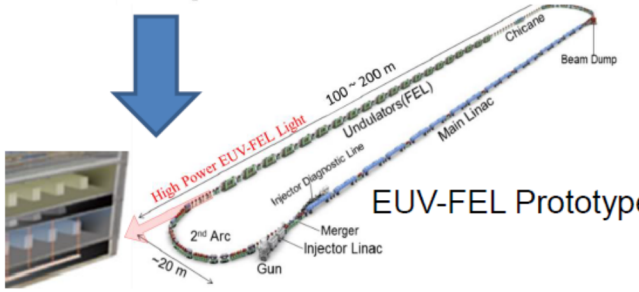
CASA Center for Applied Superconducting Accelerator 応用超伝導加速器センター

2nd stage Phase 1:
Establishment of the EUV-FEL Lithography system



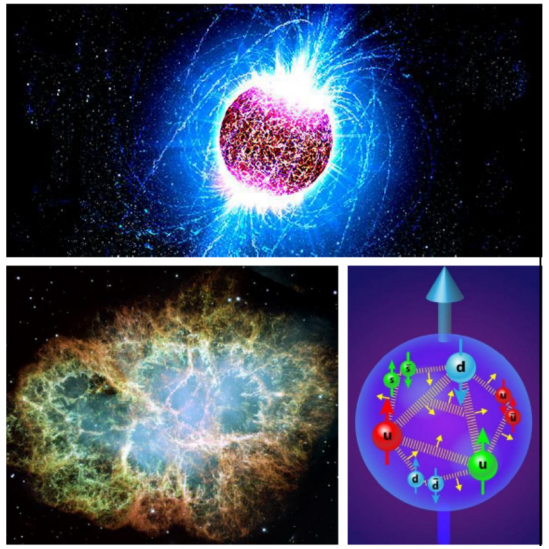
EUV-FEL Prototype

2nd stage Phase 2:
International Development Center on the processing of EUV-FEL lithography



EUV-FEL Prototype

Clean room with EUV exposure system



Thanks to all the WG5 presenters and for your attention

bERLin 2019