Summary of WG2: ERL Beam Dyn. & Instr.

Beam dynamics (layout, optics design, and particle dynamics)

- **Longitudinal phase space** dynamics in ERLs (S. Benson, **JLAB**)
- Beyond the limits of 1D coherent synchrotron radiation (P. Williams, **ASTEC**)
- CSR phase space dilution in ERLs (W. Lou, **Cornell**)
- Beam timing and cavity phasing (R. Koscica, Cornell)
- **Beam Halo** in Energy Recovery Linacs (O. Tanaka, **KEK**)
- The LHeC ERL – optics and performance optimizations (A. Bogacz, JLAB)
- Beam dynamics layout of the MESA ERL (F. Hug, **U-Mainz**)

Instrumentation (experienced during operation)

- **Essential instrumentation** for the characterization of ERL beams (N. Banerjee, Cornell)
- Design and commissioning experience MPS for LEReC accelerator (S. Seletskiy, BNL)
- Beam commissioning experience at the LEReC (D. Kayran, BNL)
- Electronic modulation of the FEL-oscillator power driven by ERL (O. Shevchenko, **BINP**)

Dynamics and Instrumentation consideration in operations preparation

- Adjusting bERLinPro optics to **commissioning needs** (B. Kuske, **HZB**)
- Beam dynamics simulations for the twofold ERL at S-DALINAC (F. Schließmann (**TU-Darmstadt**)
- Status of the control system for bERLinPro at HZB (T. Birke, HZB)

Conclusions on Longitudinal Phase Space Dynaimcs in ERLs

S. Benson (JLAB)

- ERL architecture is determined by the longitudinal design.
- **Transverse design follows the longitudinal** settings**.**
- For **FELs** one wants a **high peak current**:
- For small long wavelengths a parallel to point focus is optimal
- For short wavelengths a telescopic focus is better.
- **Nuclear Physics** applications do not need high peak current but need **small relative energy spread**.
- Can use either lattice or harmonic RF to get a good energy spread
- **Low charge, high repetition rate** is a better match to these applications.
- **Electron Cooling** applications need extremely **long bunches and extremely small energy spread**.
- **Harmonic RF** is almost required for such bunches.
- **Microbunching and CSR are now the big challenges**.

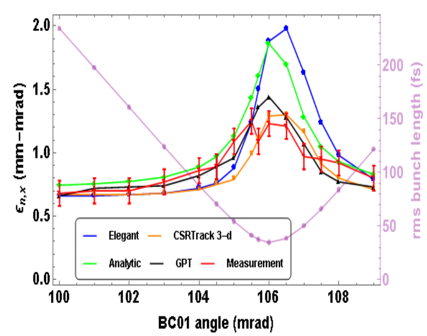
Beyond the limits of 1D coherent synchrotron radiation
Peter Williams (ASTEC)

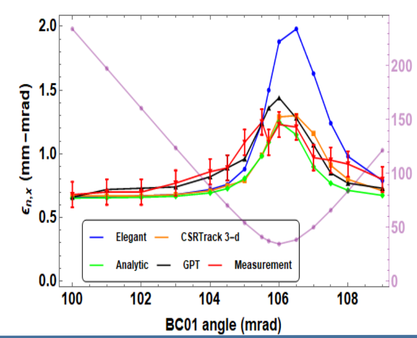
An extension to the 1D theory of CSR has been developed: Taking full account of the Lienard-Wiechert field demonstrates the interplay between Coulomb and radiation terms. Neglecting Coulomb term can underestimate CSR-induced emittance growth. Transients must take account of the Coulomb term to be accurate. (Particularly important for systems involving compressive arcs with many dipoles close!)

Measurements of the CSR-induced projected emittance growth have been made at FERMI: Brynes et al, New J Phys 20.073035 (2018)

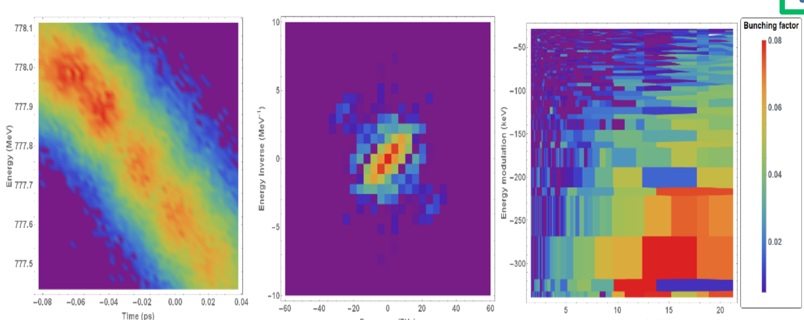
Comparisons with 3D simulation codes show good agreement over the full parameter range.

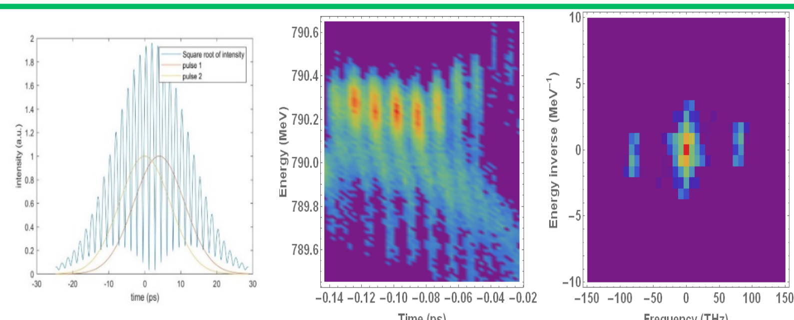
Stupakov correction to 1D analytic model also results in agreement for our case -> 1D is more robust than thought. Open question why Elegant simulations are outlier





Work in progress: Developed analytic model of microbunched beams to extract features of modulations in 2-d phase space via Fourier analysis – apply to both experimental data, simulations, analytic and semi-analytic Vlasov-based models for **natural** (left) and **beating induced** (right) microbunching

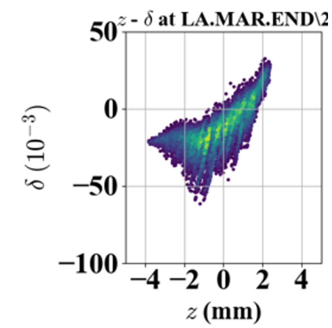




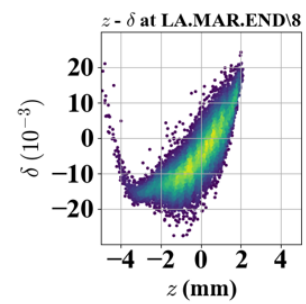
Summary on CSR in CBETA – William Lou (Cornell)

- CSR could deteriorate CBETA beam quality as bunch charge and number of FFA pass increase.

- For CBETA 1-pass, Q < 50pC is required for final max energy spread < ±5.0%
  (Beam stop can ideally take ±7.0%)

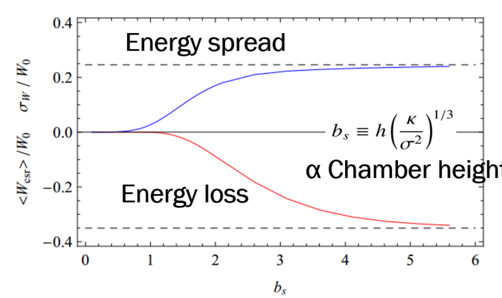


- For CBETA 4-pass, Q < 5pC is required for final max energy spread < ±5.0%, but for Q = 1pC 200/1M particles lost with the current lattice



Future Plan

- Investigate particle loss
- Test effect of shielding
- Test effect of increasing bunch length



ERL optimization goals

- Full energy recovery in each cavity (load → 0)
- Correct max energy

ERL symmetry reduces optimization system size.

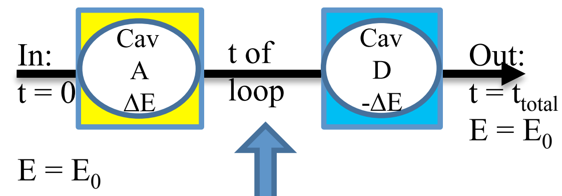
- Cavities are paired.
- Each pair has zero total load.

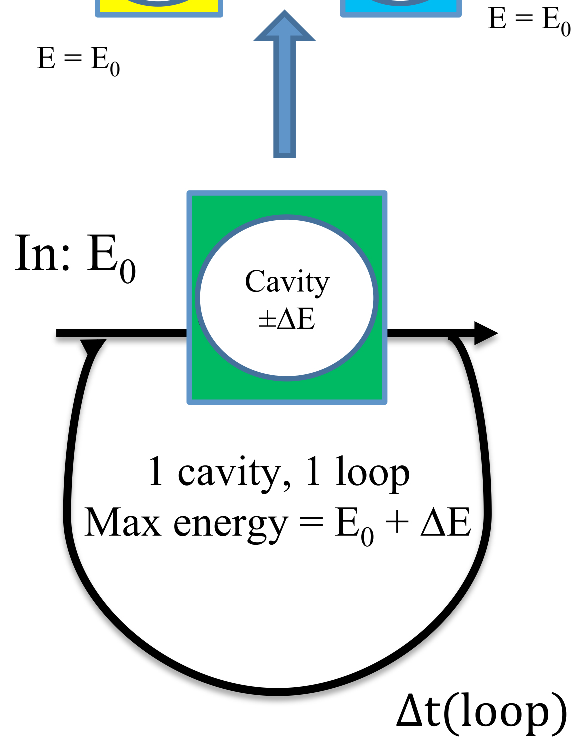
Set RF phases and central loop length to make system symmetric.

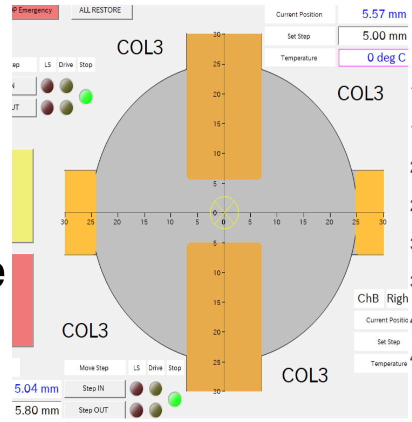
- m = pass # (of total M)
- n = cavity # (of total N)

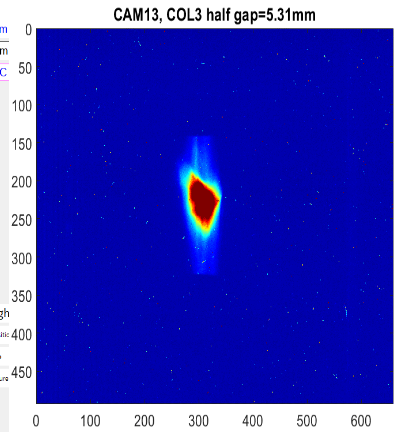
Conditions guarantee identical beam timing and energy steps in acc/dec.

- CBETA symmetric model successfully optimized.



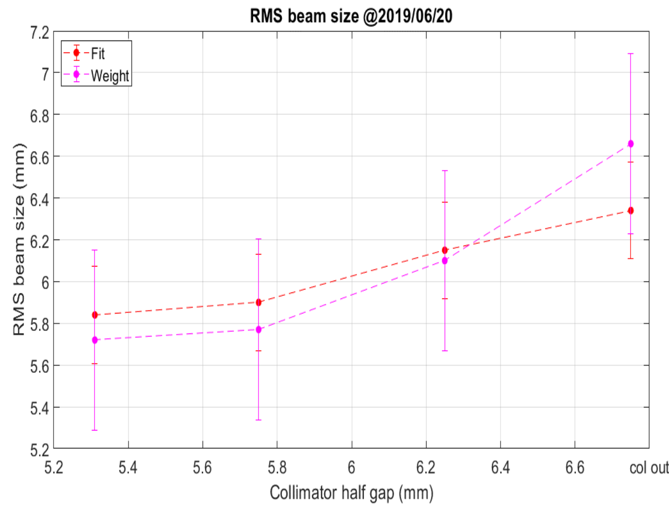






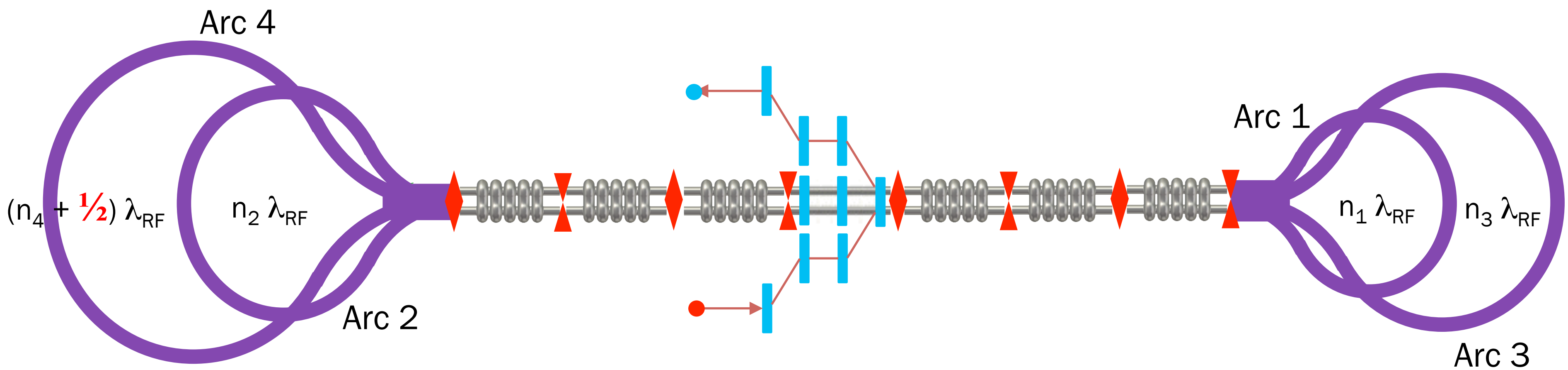
1. With the current beam parameters:
   1. Qtot = 60 pC burst mode.
   2. Bunch length = 4.5 ps.
   3. Normalized emittance at the ML entrance is ε_{nxy} = 2.89/1.99 πmm · mrad.
   4. Energy spread ~ 0.1%.
   5. Beam energy = 17.5 MeV (E_{inj} = 4 MeV).

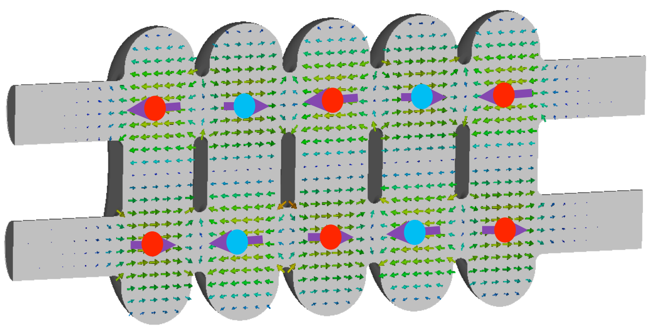
   Even if one closed the collimator's half gap up to **2 mm**, it will not affect the emittance and energy spread so much → **We have approved the usage of collimators.**
2. It was confirmed by measurement that the **horizontal beam size** and **energy spread was reduced** when the upper and lower halos were removed with a collimator.
3. For the CW mode operation the power loss is:
   1.3 GHz, power loss is **219.3 W**

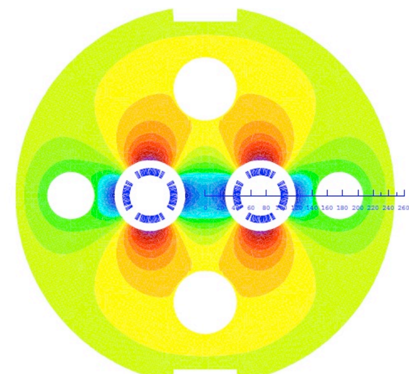


→ Need to revise the collimator's design (current assumed to be not sufficient).

‘Dogbone’ ERL with Elliptical Twin Axis Cavities - <u>Alex Bogacz (JLAB)</u>



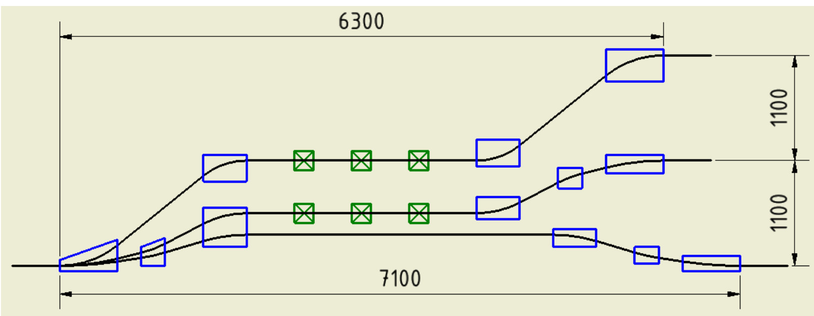


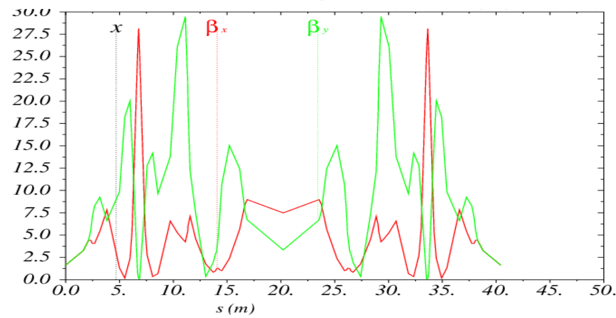


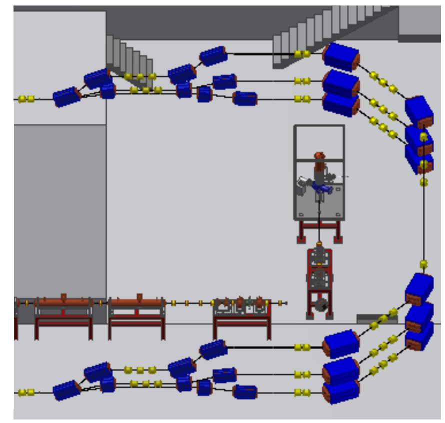
Elliptical Twin Axis Cavity capable of accelerating, or decelerating beams in **two separate beam pipes**

Double-aperture quad - single layer coil design (CERN)

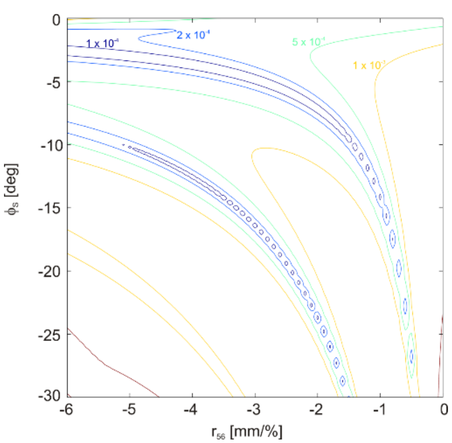
- Layout: double sided with vertical spreaders and vertically stacked return arcs. Path length adjustment important as accelerator will **run on different energies**

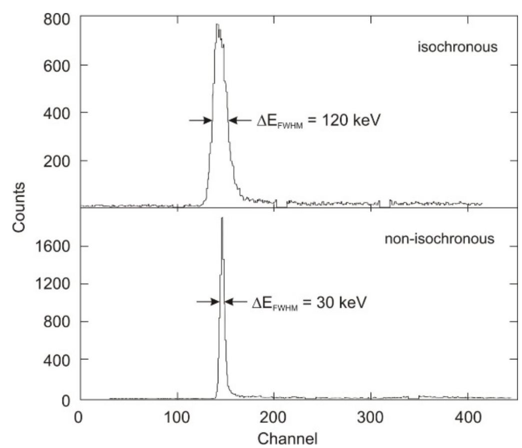


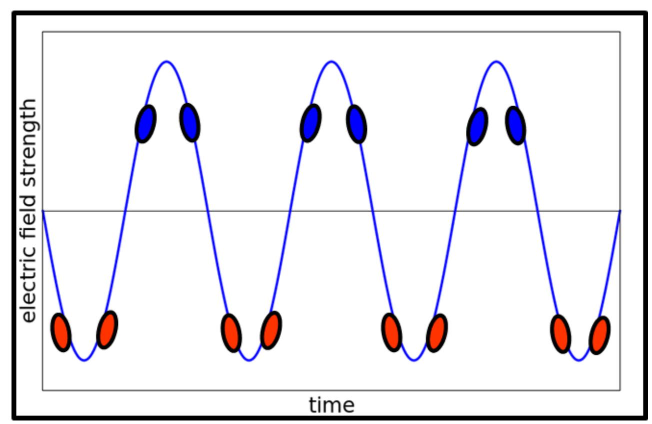




- we will use non-isochronous beam dynamics and off-crest acceleration in external mode and are going to test such a system in ERL mode as well. **Main goal: best energy spread and stability**

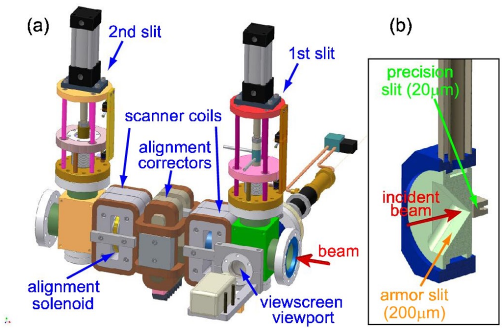




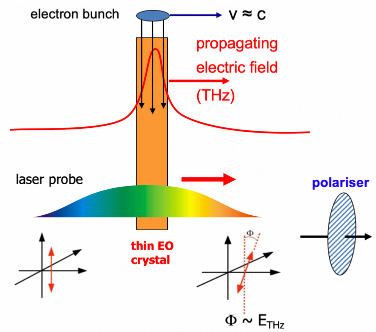


Besides orbit and time of flight measurements, **Bright High Power CW Beams** require an unique suite of diagnostics.

Phase Space

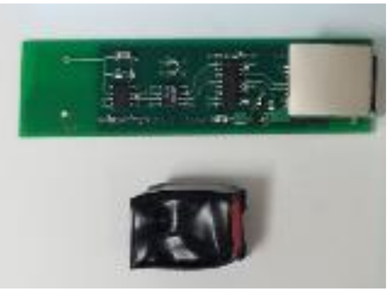


Double Slit for transverse phase space



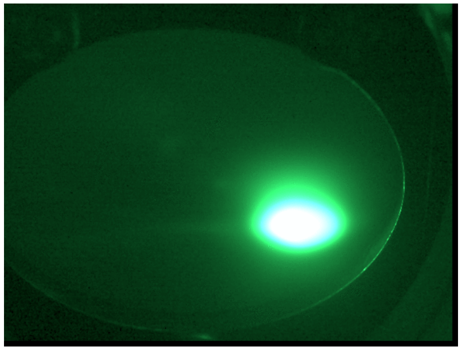
Electro-optic systems for non-destructive longitudinal profile measurements.

Beam Loss Monitors

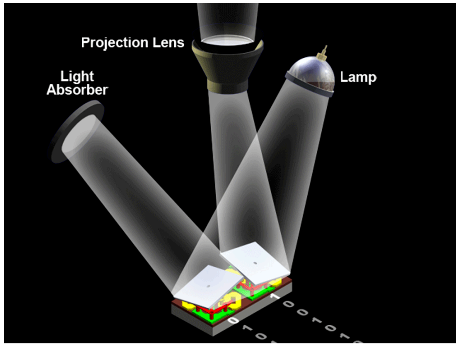


Scintillators for radiation detection.

Beam Halo

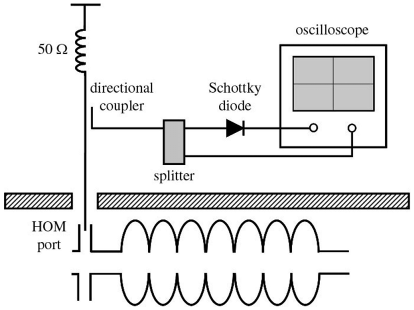


Boost dynamic range by adjusting exposure on normal viewscreens.



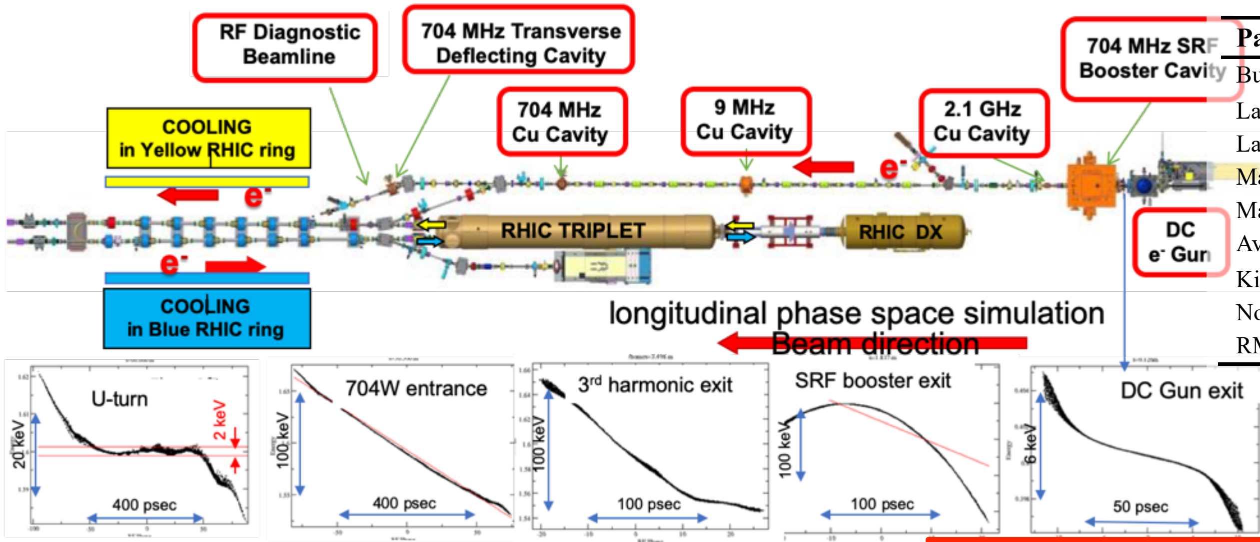
Micro Mirror Arrays for masking core.

Miscellaneous



Cavities for BBU detection.

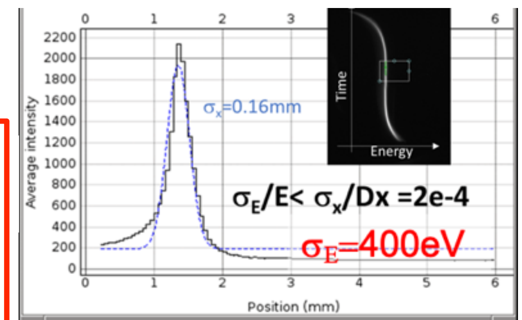
Beam Commissioning Experience at Low Energy RHIC electron Cooler: D. Kayran, BNL



Required Beam quality is achieved

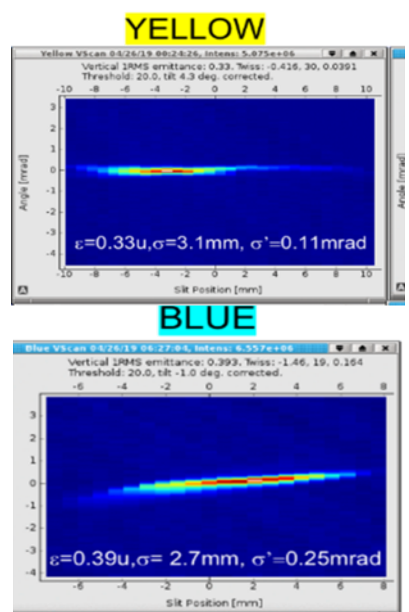
Parameter	Required	Achieved*
Bunch charge, pC	130-200	10-200
Laser pulse duration, psec	40	40
Laser average power, Watts	10	10
Macro-bunch charge, nC	4-6	1-6
Macro-bunch rep. rate, MHz	9.3	9.3
Average Current, mA	36-55	14-30
Kinetic Energy, MeV	1.6 -2.6	1.6, 2.0
Normalized emittance, μm	<2.5	1.6
RMS energy spread, $x10^{-4}$	<5	<2

Measured long. phase space MB_Charge=3nC

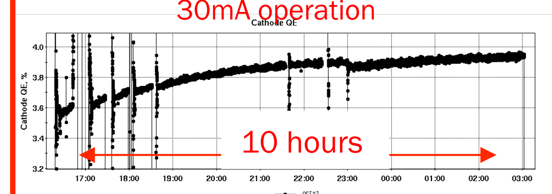


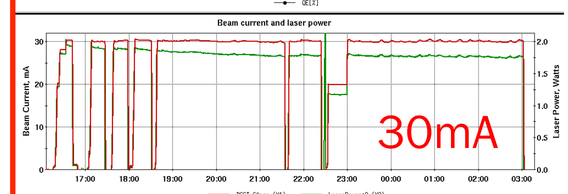
- LEReC is electron accelerator based on HV dc photogun and RF acceleration
- LEReC demonstrated beam parameters required for cooling of ions using RF acceleration and longitudinal phase space gymnastic
- Beam quality suitable for cooling is preserved through acceleration and 100 m of beam line in pulsed and CW modes of operation
- It allowed to cool Ion bunches in both RHIC rings simultaneously using the same LEReC beam at two different energies (gamma 4 and 5)
- **Plan for the next year**: cooling efficiency optimization to maximized RHIC collision rate

Measured emittance and transversal phase space



No cathode life time degradation at 30mA operation

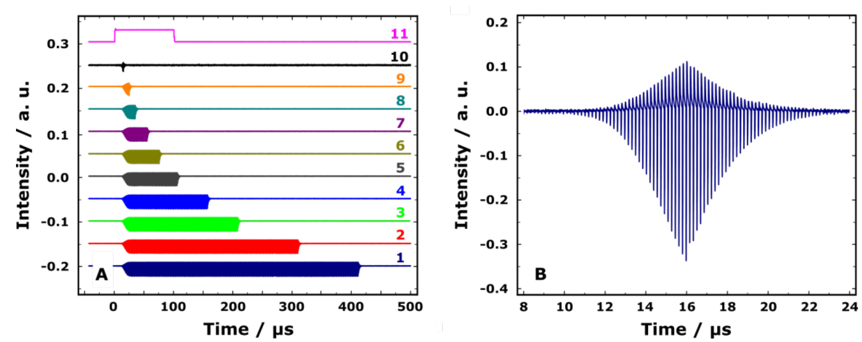


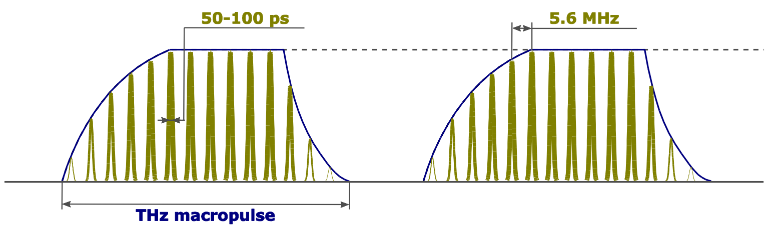


Modulation of the FEL-oscillator radiation power driven by ERL

O. Shevchenko (BINP)

Approach to the creation of THz macropulses at any repetition rate and almost any individual pulse length was developed and implemented at NovoFEL.





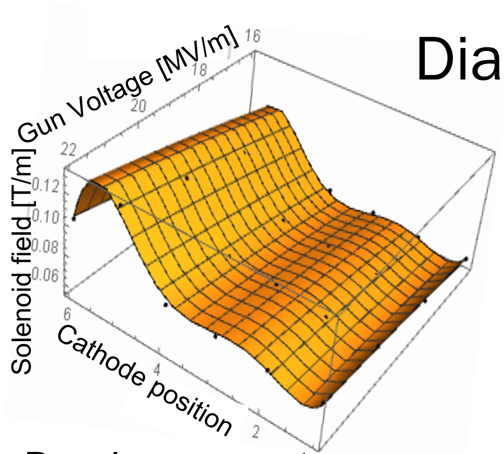
Series of macropulses with different durations from 10 to 400 μs were measured at all three FELs of the NovoFEL facility.

Possible applications include:

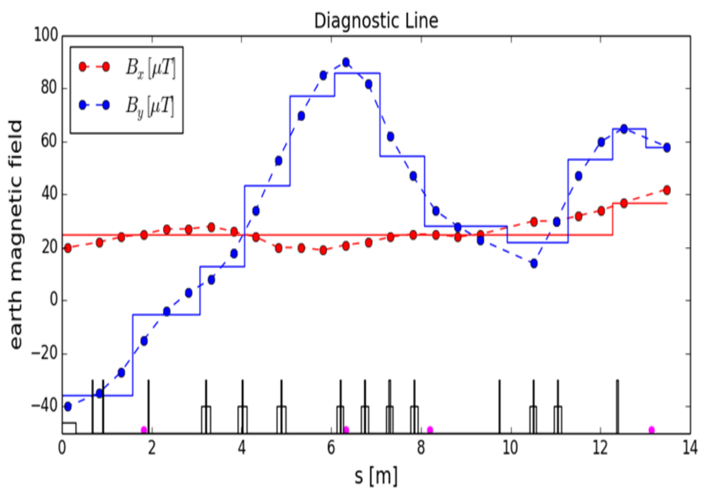
- *Control of the average THz power in CW regime*
- *Formation of short high-power THz macropulses*
- *Lock-in detection*
- *FEL physics experiments*
- *Note: impact to Bar Camp about bERLinPro applications*

Bettina Kuske, Michael Abo-Bakr, Meghan McAteer, HZB

Diagnostics line

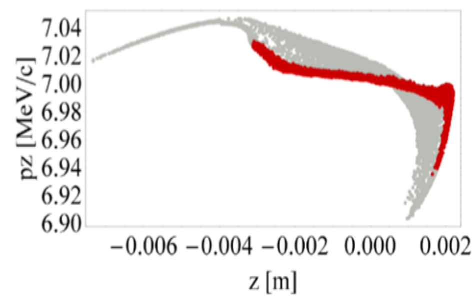


Develop parameter dependencies to reduce independent parameters in commissioning

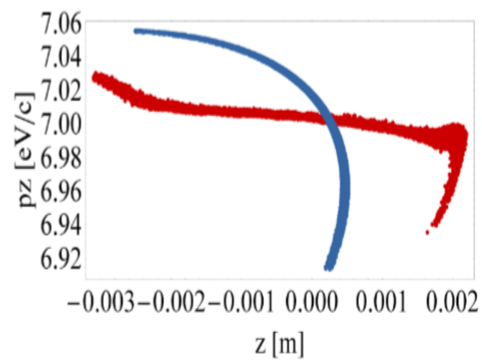


Effect of magn. field in hall much larger than conventional errors

Banana

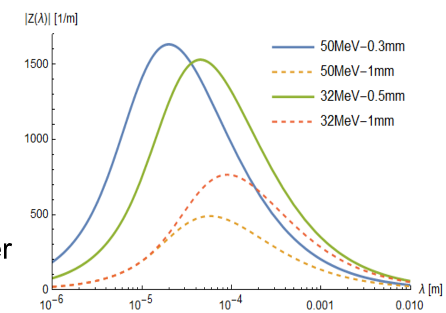


Longitudinal phase space behind merger
Gray: halo, Red: main bunch

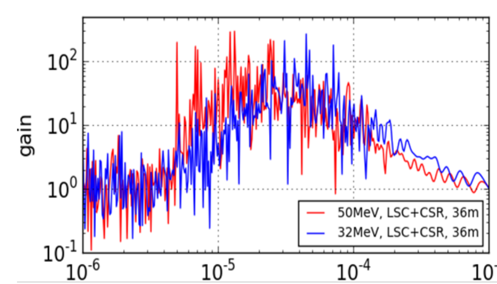


Longitudinal phase space behind Merger Gray: halo, Red: main bunch

Recirculator



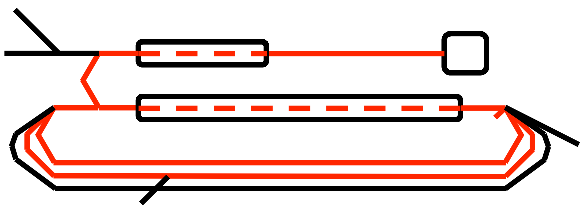
Longitudinal space charge impedance model for
two energies and different radii.



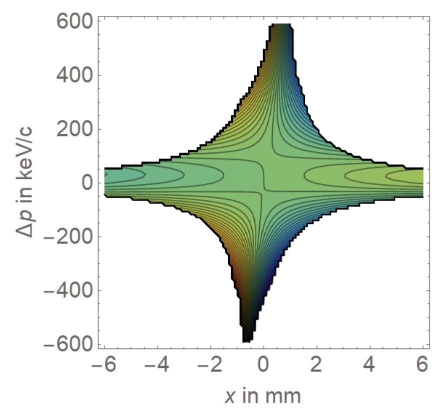
Wave length [m]

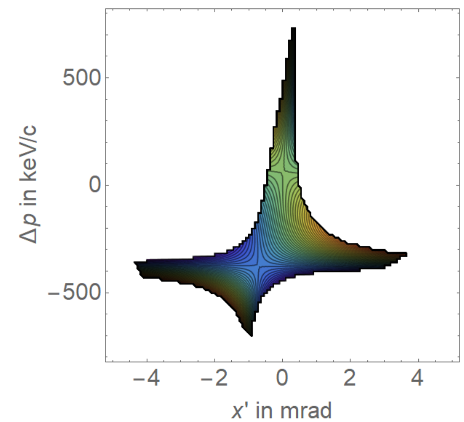
Gain in 1. arc @ 50MeV shifted to lower wave length, gain comparable as higher energy is compensated by larger beam size.

Beam Dynamics Simulations for the Twofold ERL Mode at the S-DALINAC – Felix Schließmann (TU-Darmstadt)

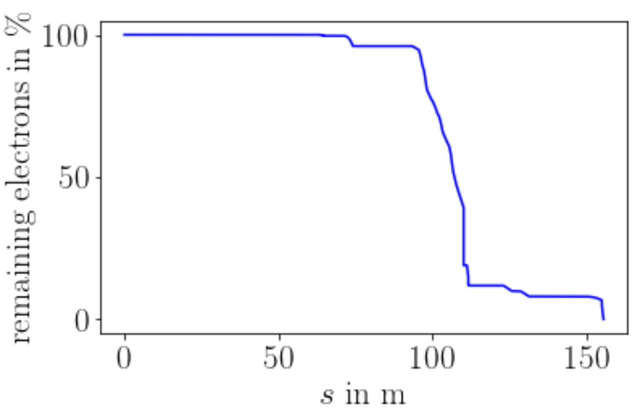


1.) Acceptance study
for the last part of the beamline

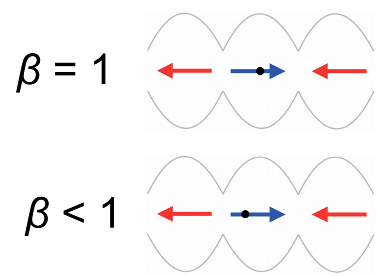




2.) Acceptance study for the entire accelerator



3.) Phase slippage
problem and
ASTRA to solve it

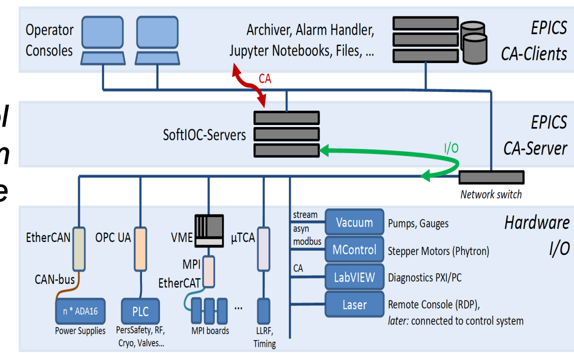


$$q \int_0^s \hat{E}(\bar{s}, t) d\bar{s} = -q \int_0^s (-\tilde{\hat{E}}(\bar{s}, t)) d\bar{s}$$

Status of the bERLinPro Control System – Thomas Birke (HZB)

- Control System Infrastructure basically a copy of BESSY & MLS controls
  - Installation and setup follows installation of components
  - Development of dedicated/specialized software on demand
  - Cooperations with DESY (LLRF) and MBI (Laser)

Control System Structure



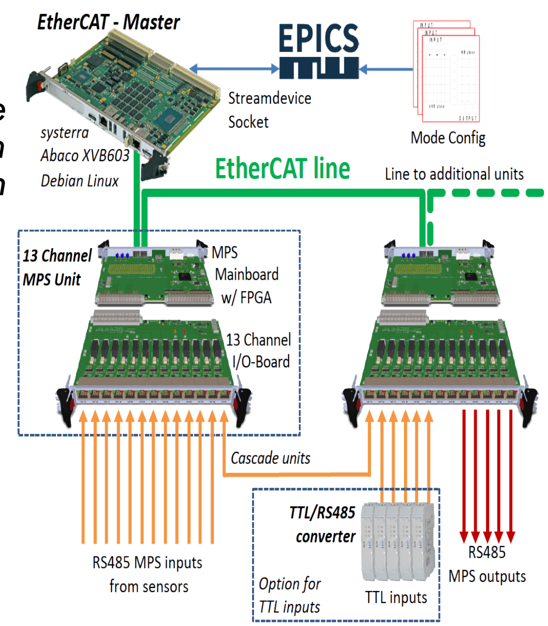
- **Reusing software and some hardware**
  + a few new developments
  - Novel requirements and the need to reduce costs and get things done with available workforce
- **Evaluate and introduce novel tools and core software**
  - Control System Studio CSS/phoebus, EPICS 7, pyDm, …

„The EPICS Software Framework Moves from Controls to Physics"

EPICS Core Developers Group – IPAC'19 – TUZZPLM3

- **Integration of 3rd party systems is in the works**

Machine Protection System



Thanks for the fruitful exchange

Continue exchange of CSR and micro-bunching exchange

Stimulate exchange of EPICs implementations

Exchange simulations and components for Halo control

….

Continue the good work - together