WG2: Beam Dynamics, Optics and Instrumentation – Summary

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ERL Projects

Interesting projects being discussed

- ERL at KEK
- ALICE
- PERLE
- LHeC
- eRHIC
- CBETA
- ERL for MESA
- bERLinPro

Nice mixture of future, existing and past facilities

Summary: Operational Experience and Optimisation of ALICE Energy Recovery Linac

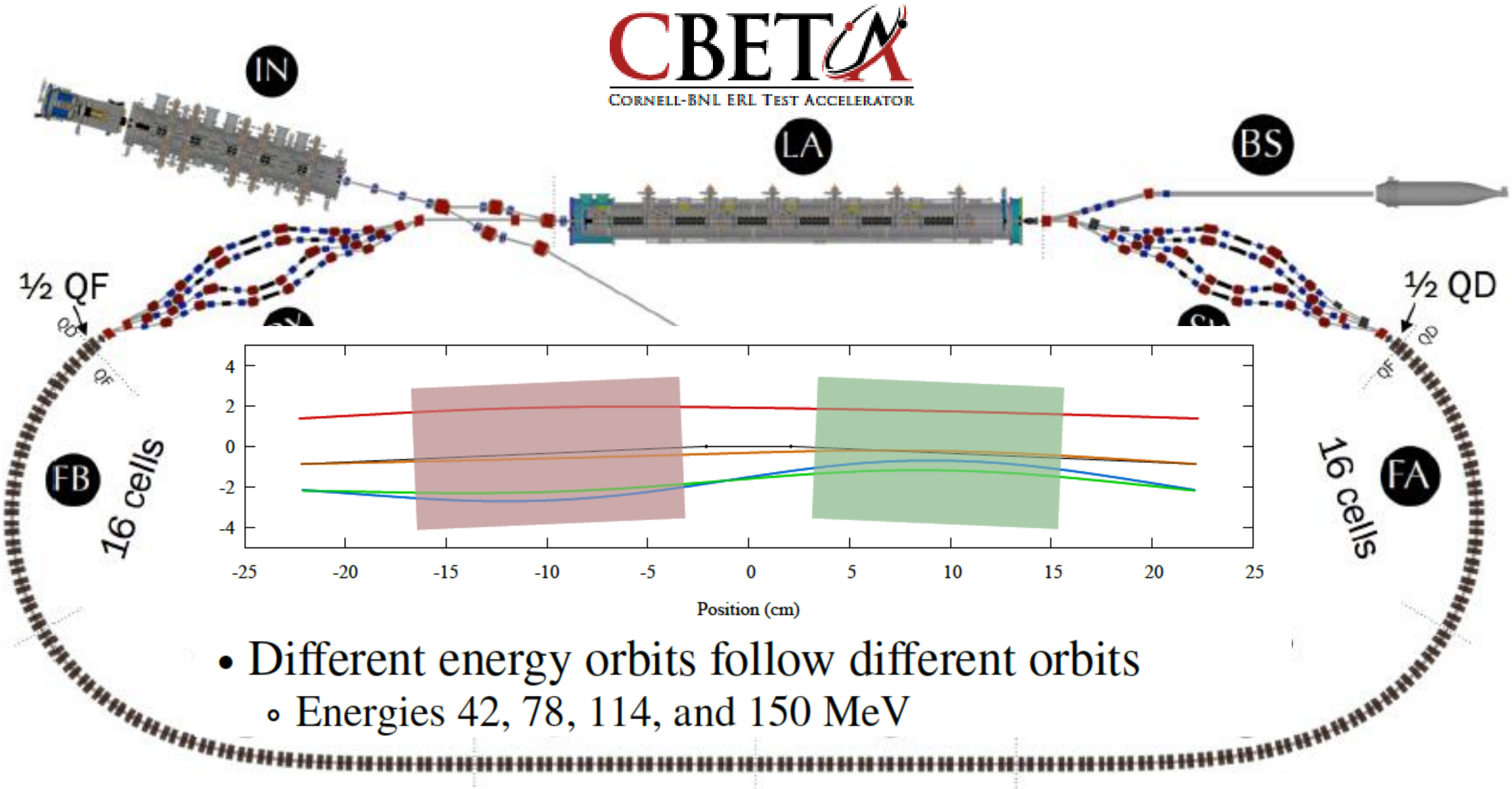
- Some advice for the developing ERL projects at this workshop
  - Do have well thought out **diagnostics for the LATTICE, and separately the BEAM** – both transversely and longitudinally in the first design stages of the project – how will your diagnostics **work together** to give you the information you need
  - In your simulations, **model the step-by-step procedures** you will use to establish the beam conditions and prove you have achieved the goals of your project
  - Never try to save money on **feedback systems**! Stability is key

Example of the lessons learned

P. Williams

What limits number of ERL passes?

- ERL with FFAG arcs – Can switchyard be configured with FFAG as well?



- Different energy orbits follow different orbits
  - Energies 42, 78, 114, and 150 MeV

G. Hoffstaetter | C. Mayes | S. Berg

Beam Dynamics Issues for Multi-pass ERLS

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Multi-turn ERLs

CBETA

ERLs provide: High currents for (a) either highly damaged beams or
(b) pristine beams (small e

Large range of beam dynamics issues

If the current is not high, use a linac!
If the beam is not pristine and not highly damaged, use a ring!

What are then the beam dynamics issues specific to ERLs?

1. High current effects
   a) space charge
   b) **halo dynamics**
   c) HOM heating
   d) Intra-Beam Scattering
   e) Touschek scattering
   f) Rest Gas scattering
   g) Ion accumulation
      i) optics changes
      ii) nonlinear dynamics
      iii) scattering
2. Beam quality
   a) Emittance matching
   b) **Time of flight control of energy spread**
   c) Wakefield interactions
   d) Micro bunching instability
   e) **Coherent Synchrotron Radiation**
3. Transport of damaged beam
   a) Phase space rotation for energy spread
   b) Large 6-D phase-space-aperture optics
4. Recovery topics
   a) Energy spread growth during deceleration.
   b) Halo transverse growth during deceleration.
   c) **Recirculative Beam Breakup instabilities.**
      i) **Transverse Dipole BBU**
      ii) **Longitudinal BBU**
      iii) **Quadrupole BBU**
   d) Ion instabilities
   e) **Simultaneous control of multiple beams**

What are the Beam Dynamic Issues for Multi-Turn ERLs?

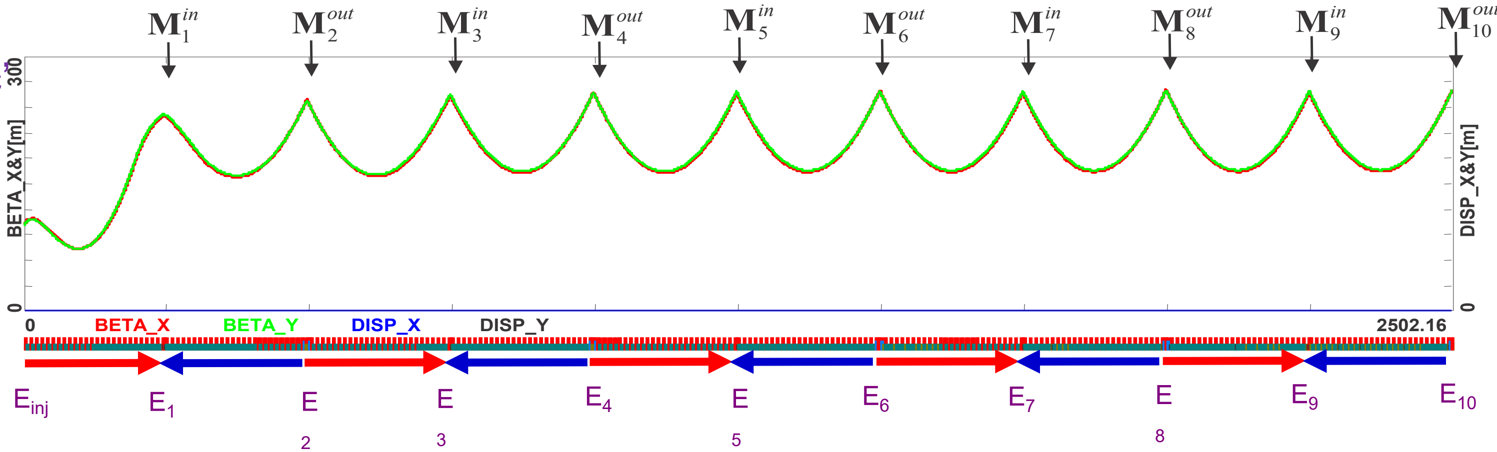
➔ All of the above, only worse!

What limits number of ERL passes?

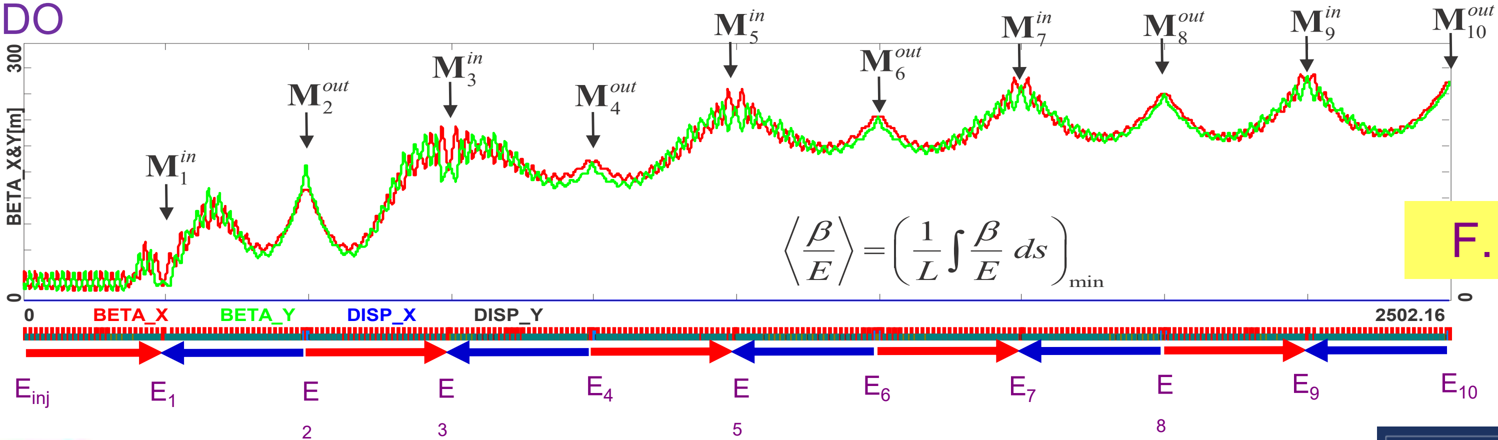
- Optimization of multi-pass linac Optics for ER operation

Acceleration/Deceleration

'Drift Linac'



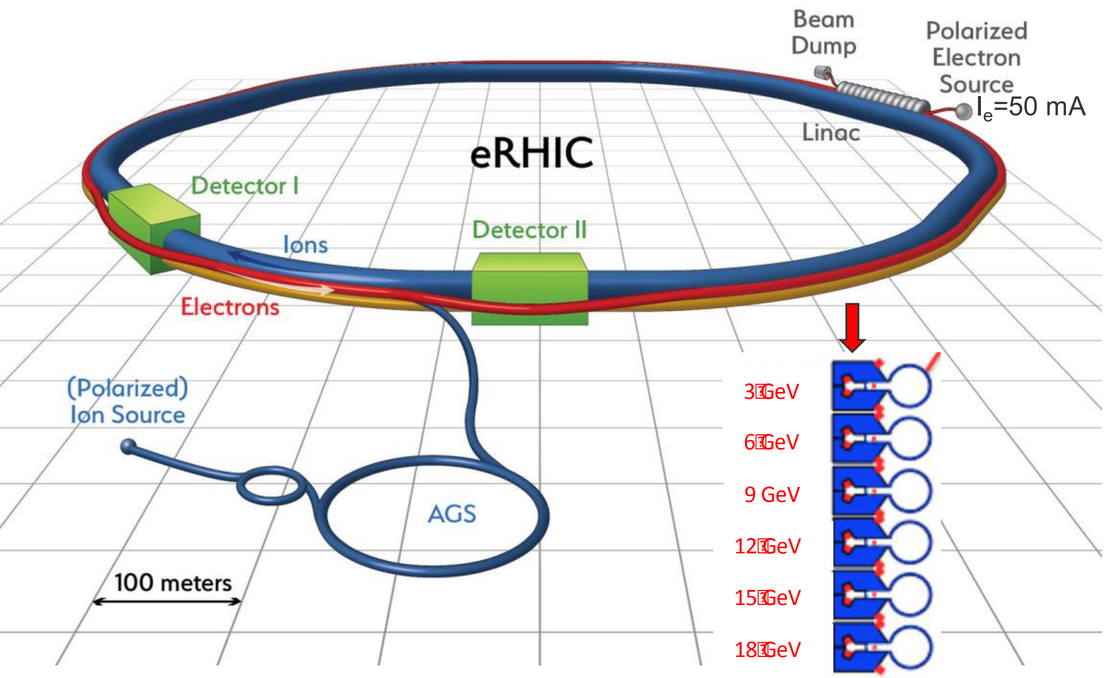
60^0 FODO



F. Meot

What limits number of ERL passes?

- Optimization of multi-pass linac Optics for ER operation



Maximum electron energy: 18 GeV

50 mA polarized electron source employing merging electron current produced by multiple electron guns

Main ERL SRF linac(s): 647 MHz cavities, 3 GeV/turn

Six individual re-circulation beamlines based on electromagnets

For very high luminosity (~10^{34} cm^{-2} s^{-1}) with hadron cooling system (CeC)

V. Ptitsyn

eRHIC

- Not the main focus of the work
  - Ring-ring option is in the focus
  - But still efforts on ERL
- Important challenges
  - Beam break-up
    - Addressed by cavity design with strong damping
  - Beam losses
    - An important concern for many projects
    - Technical means: Apertures, collimation, diagnostics
    - But also understanding of sources and choice of beam current
- CBETA will provide important input, an example of the synergy in the field

Limits on longituinal acceptance in high energy ERLs

- LHeC 60 GeV ERL – Beam Dynamics Issues

Single-particle/single-bunch effects:

- *Synchrotron Radiation:*
  - Almost 2 GeV lost around the racetrack, 750 MeV in Arc 6.
  - Induced energy spread and emittance blowup limiting the deceleration.
- *Beam-Beam effect:*
  - Disruption of the electron beam (still need to be decelerated).
  - Stability of the proton beam (impact on the other LHC experiments).
- *Short range wakefields and impedances:*
  - energy spread and emittance growth.
- *Lattice imperfections:*
  - Misalignments and field errors, RF stability.

Multi-bunch effects:

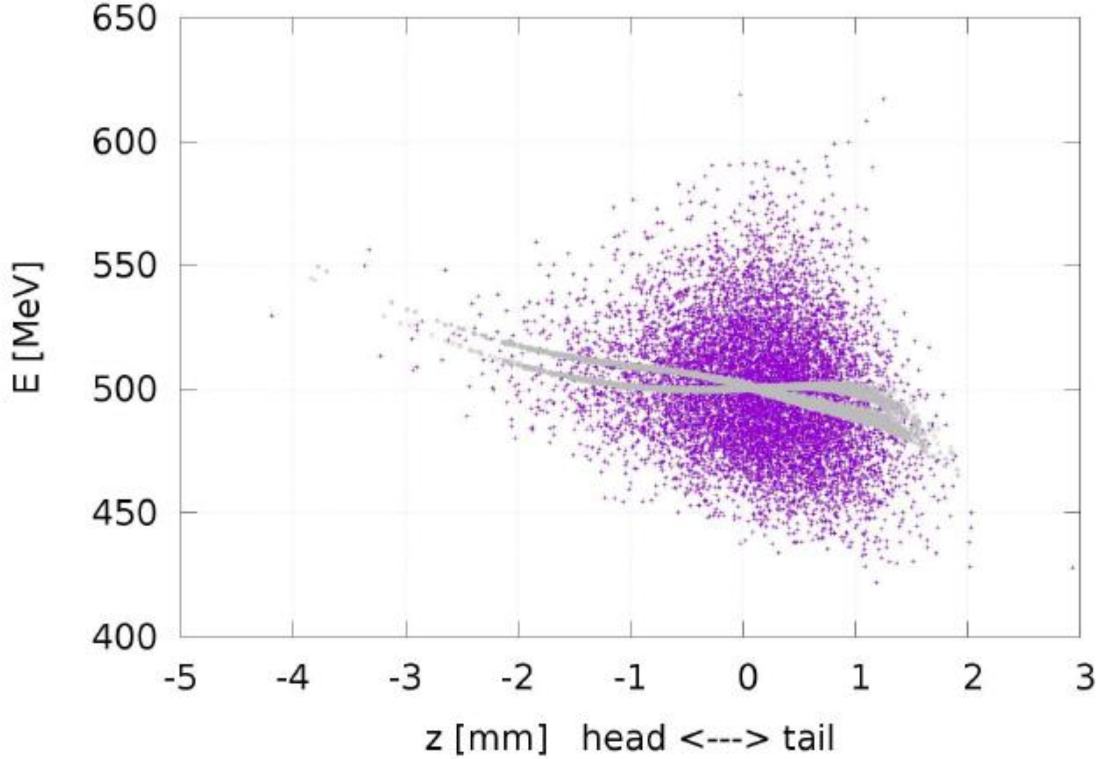
- *Long range wakefields* (excitation of higher order modes in the cavities).
- Ion cloud build up (preliminary estimations in the CDR, seems ok but needs to be reviewed).

Limits on longituinal acceptance in high energy ERLs

Longitudinal Phase Space at Dump

Short Range Wake Fields + Synchrotron Radiation:

LHeC 60 GeV ERL



Big energy spread from quantum excitation, optics and sr wake effect masked!

D. Pellegrini

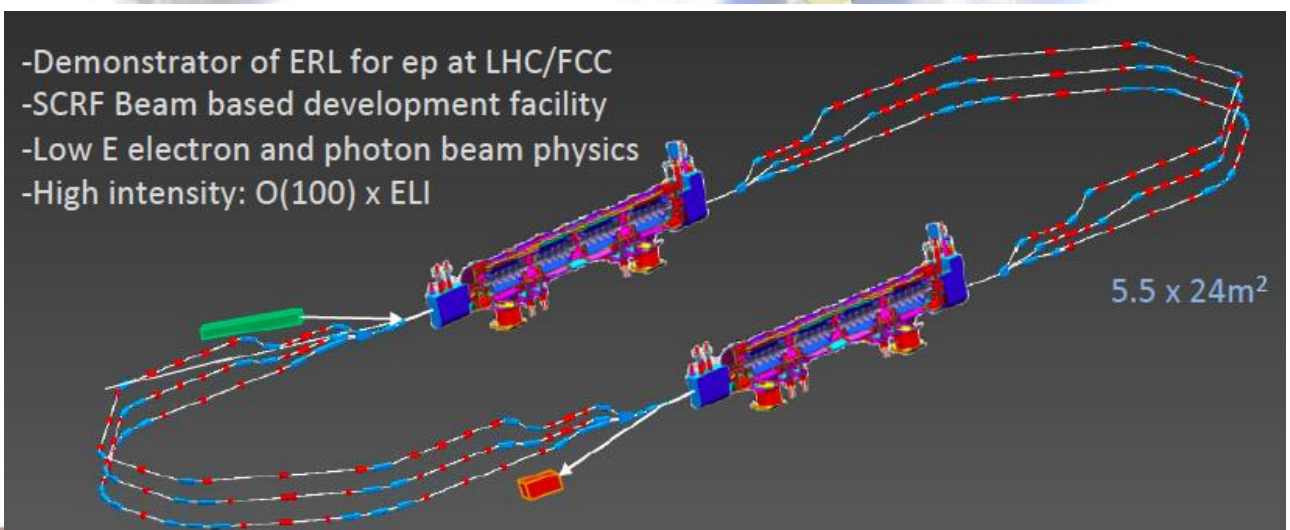
Limits on virtual power vs RF power in high energy ERLs

100 mAmp
50 MeV

A. Jankowiak

M. Abo-Bakr

PERLE



15 mAmp
400 MeV

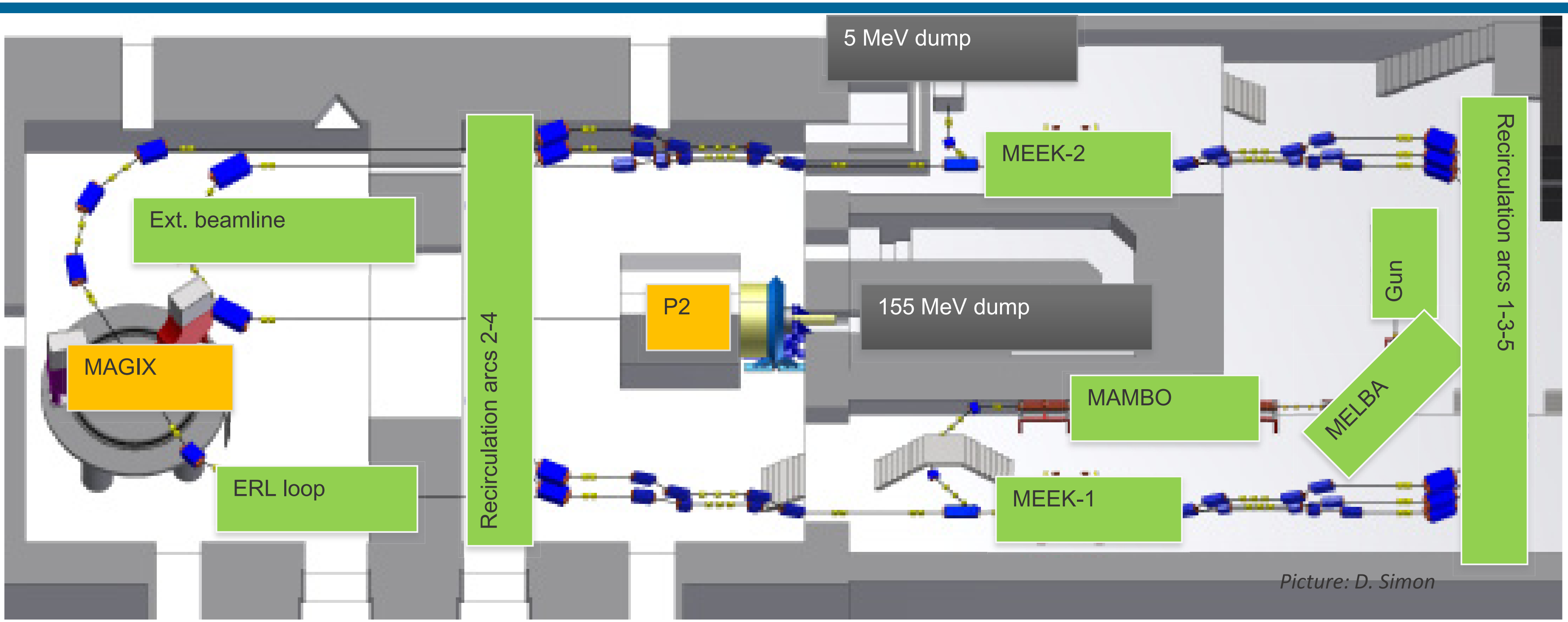
W. Kaabi

A. Bogacz

PERLE R&D Program - TDR

- Liner lattice optimization Initial magnet specs ★
- Momentum acceptance and longitudinal match ★
- End-to-End simulation with synchrotron radiation, CSR micro-bunching (ELEGANT)
- Correction of nonlinear aberrations (geometric & chromatic) with multipole magnets (sext. octu.?)
- RF cavity design, HOM content BBU studies (TDBBU)
- Injection line/chicane design Space-charge studies at injection
- Diagnostics & Instrumentation
- Multi-particle tracking studies of halo formation
- Final magnet specs
- Engineering design

MESA Project, Research Facility



F. Hug

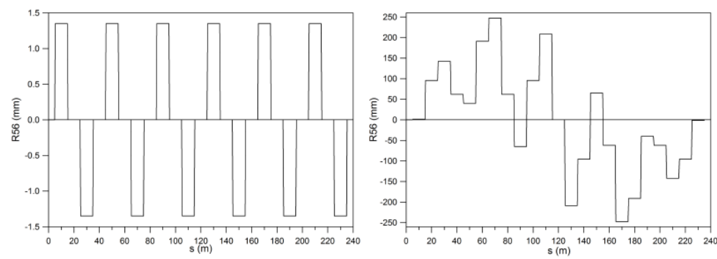
- Normalconducting injector and superconducting main linacs
- Double sided recirculation design with vertically stacked return loops
- Two modes of operation:

- EB-operation (P2/BDX experiment): polarized beam, up to 150 μA @ 155 MeV
- ERL-operation (MAGIX experiment): (un)polarized beam, up to 1 (10) mA @ 105 MeV

Mitigation scheme for CSR/microbunching

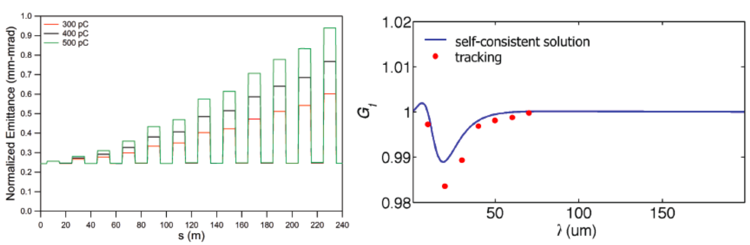
Isochronous Arc Study

	Example A	Example B
Energy (GeV)	1.3	1.3
$\varepsilon_{x,y}$ (mm-mrad)	0.25	0.25
$\sigma_{\delta E/E}$	9×10^{-6}	9×10^{-6}
σ_t (ps)	3.0	3.0
Structure	Periodically isochronous & achromatic	Globally isochronous & achromatic

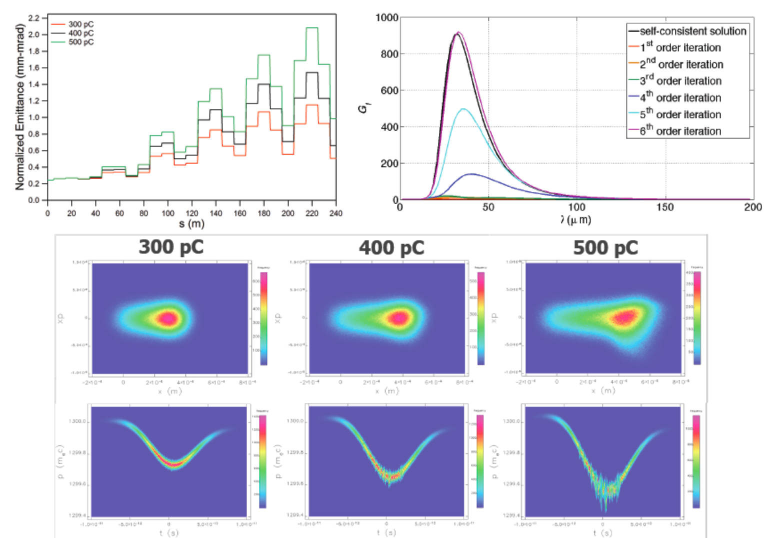


Arc: Example A

- effective suppression of CSR-induce emittance growth
  - ✓ an initial CSR kick is cancelled by a second kick a half-betatron wavelength away
- design manifests *no evidence* of microbunching gain



Arc: Example B



C. Tennant

Outlook

- Number of existing and future ERL's
- Various beam dynamics issues being addressed by several ERLs
  - Maximizing number of passes
  - Maximizing virtual beam power
  - Mitigation of limiting factors: BBU, CSR/microbunching
  - Diagnostics & Instrumentation for multiple beams (10?)
  - Multi-particle tracking studies of halo formation
- Importance of lessons learned from past ERLs