Electron beam transport and performance in ERL for RHIC electron cooling

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RHIC e-Cooling Workshop May 24, 2006

Outline

- Layout of e-cooling facility
- High energy beam dynamics (emittances ≈ constant)
- Low energy beam dynamics
- Start to end tracking
- Summary

Part 1

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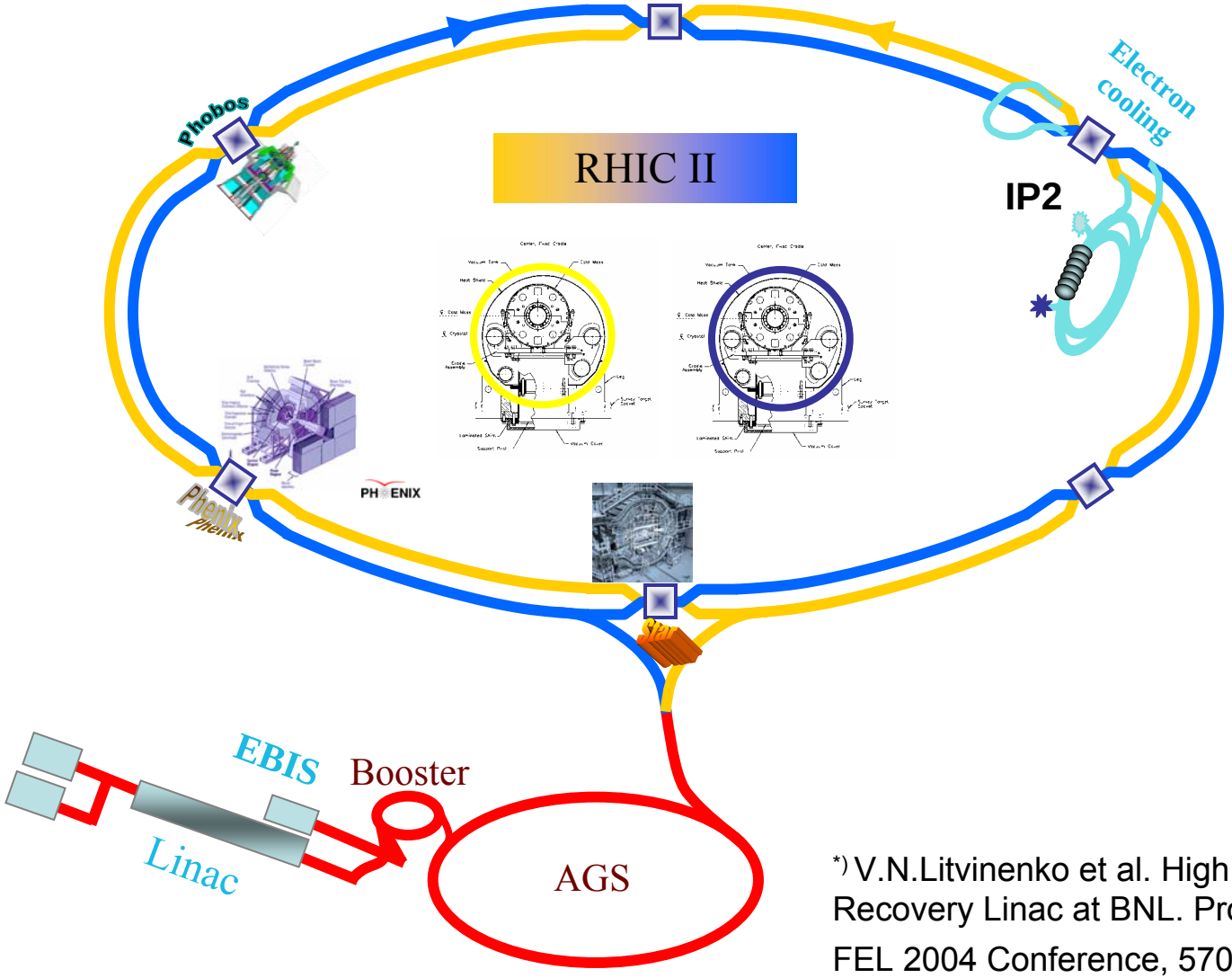
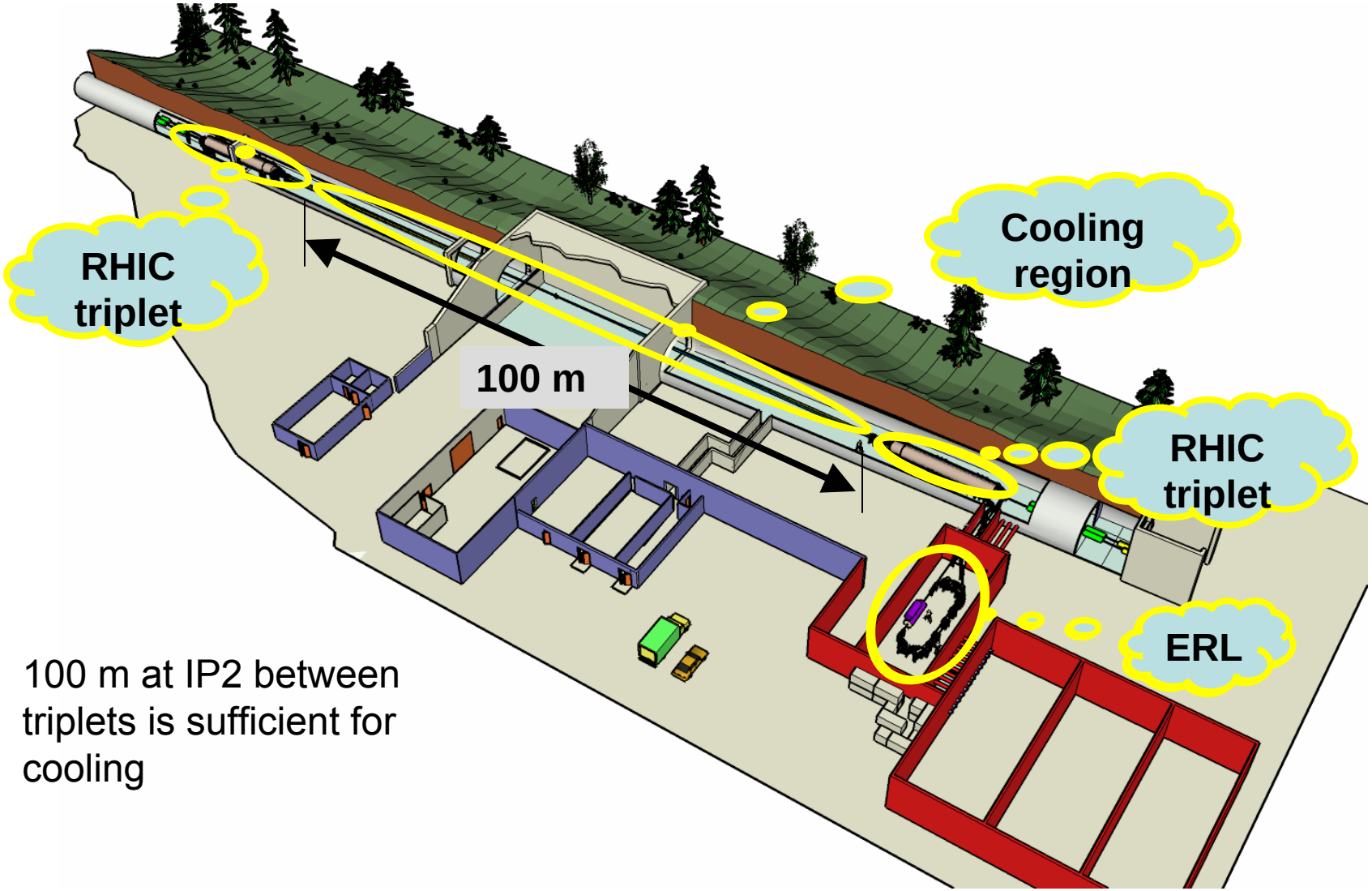
Layout of RHIC with electron cooler at IP2



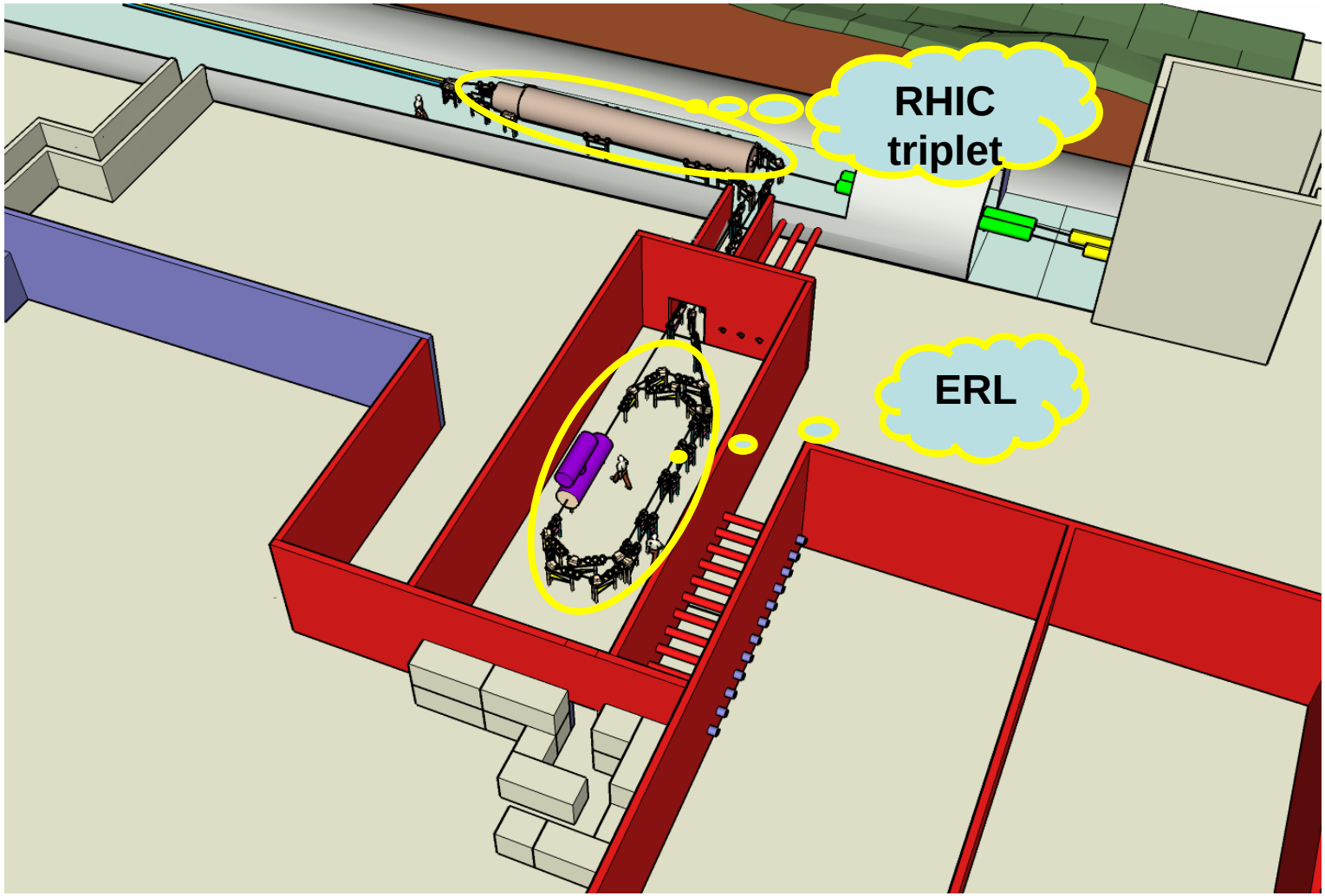
*) V.N.Litvinenko et al. High Current Energy Recovery Linac at BNL. Proceedings of the FEL 2004 Conference, 570-573.

A 3D site view of the RHIC electron cooler at IP2.

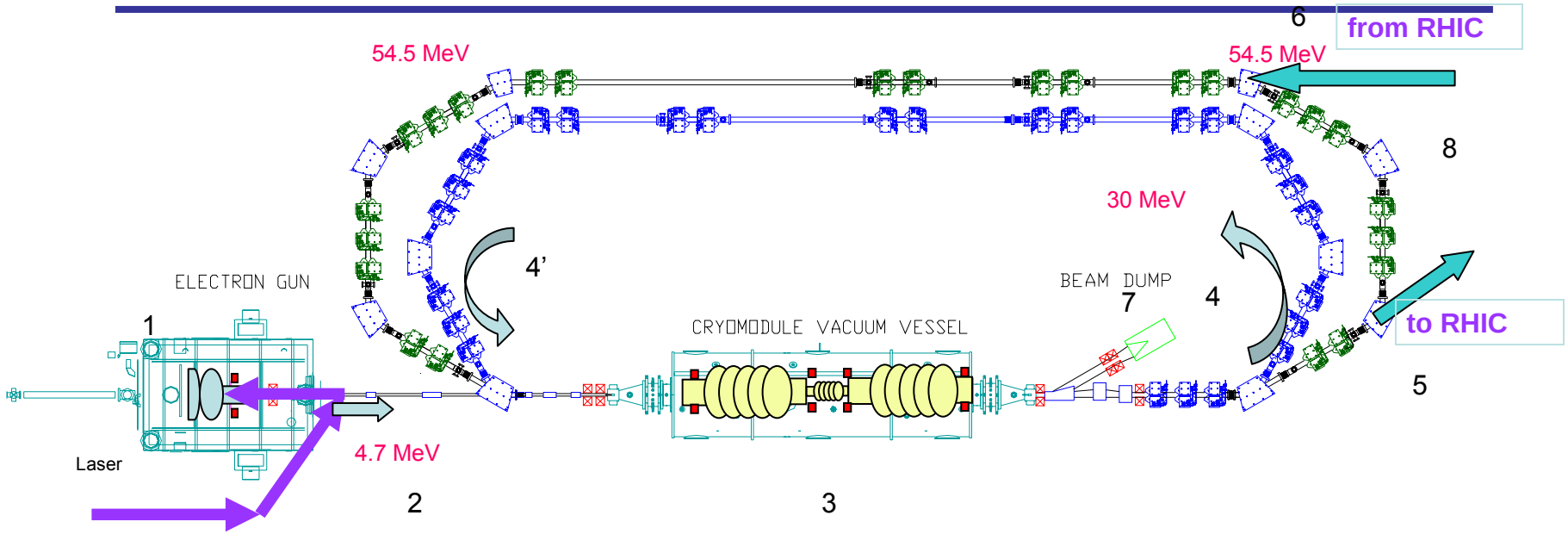


100 m at IP2 between triplets is sufficient for cooling

E-cooler ERL matched to RHIC



E-cooler: 2 passes ERL layout



1. SRF Gun,
2. Injection merger line
3. SRF Linac two 5-cell cavities and 3rd harmonic cavity

4, 4'. 180° achromatic turns

5, 6. Transport lines to and from RHIC,

7. Ejection line and beam dump
8. Short-cut for independent run of the ERL.

Part 2

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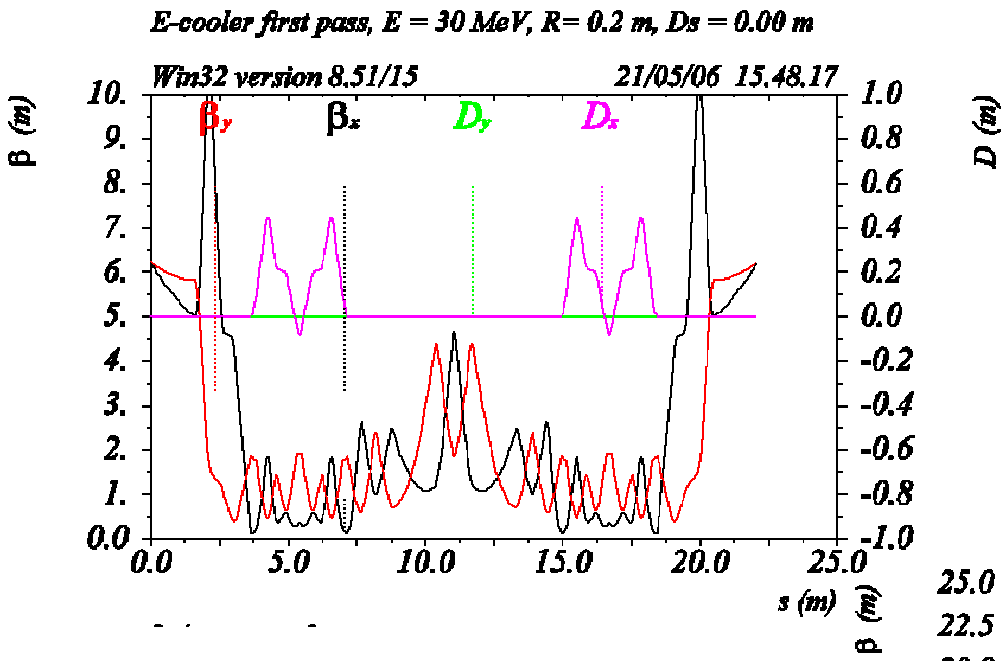
Loop lattice functions (MAD8 output)

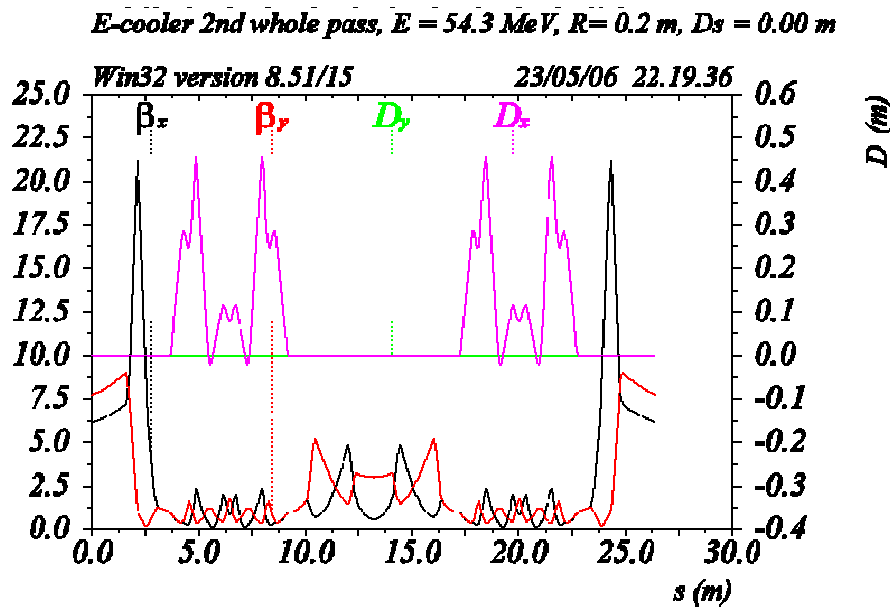


First pass

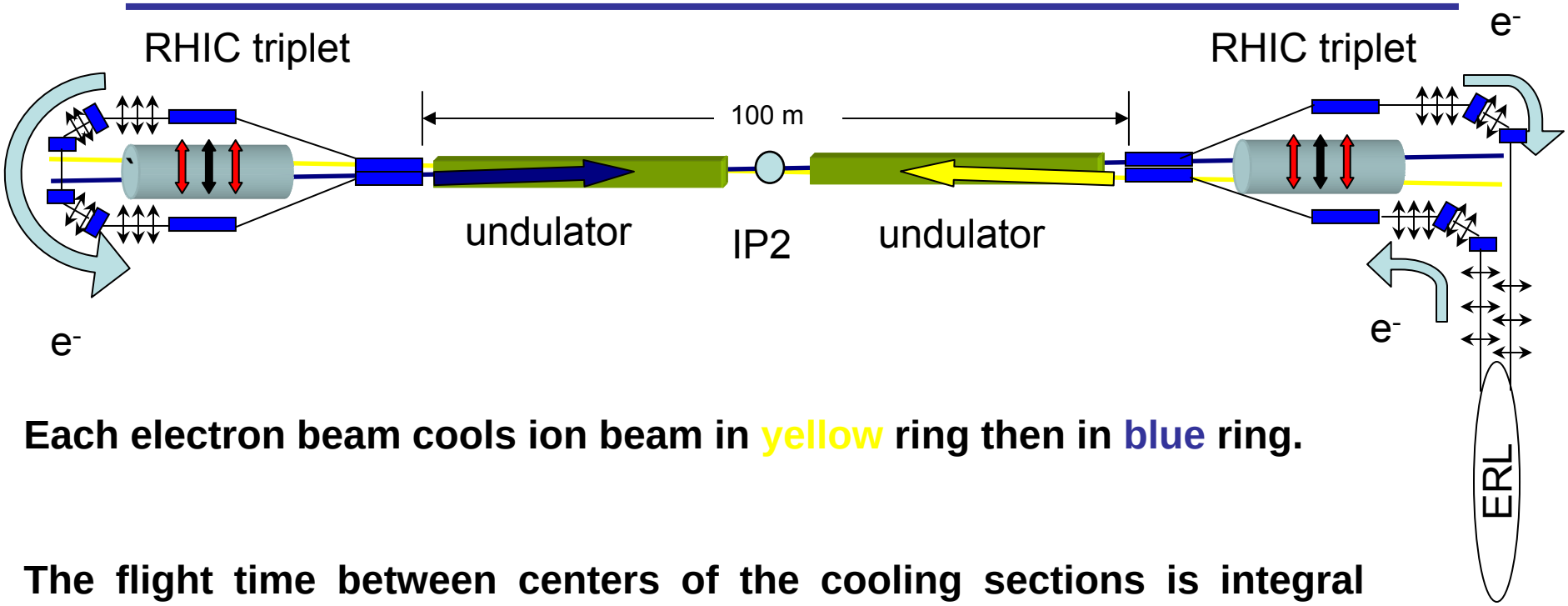
KEnergy=30MeV

Second pass

KEnergy=54.3 MeV



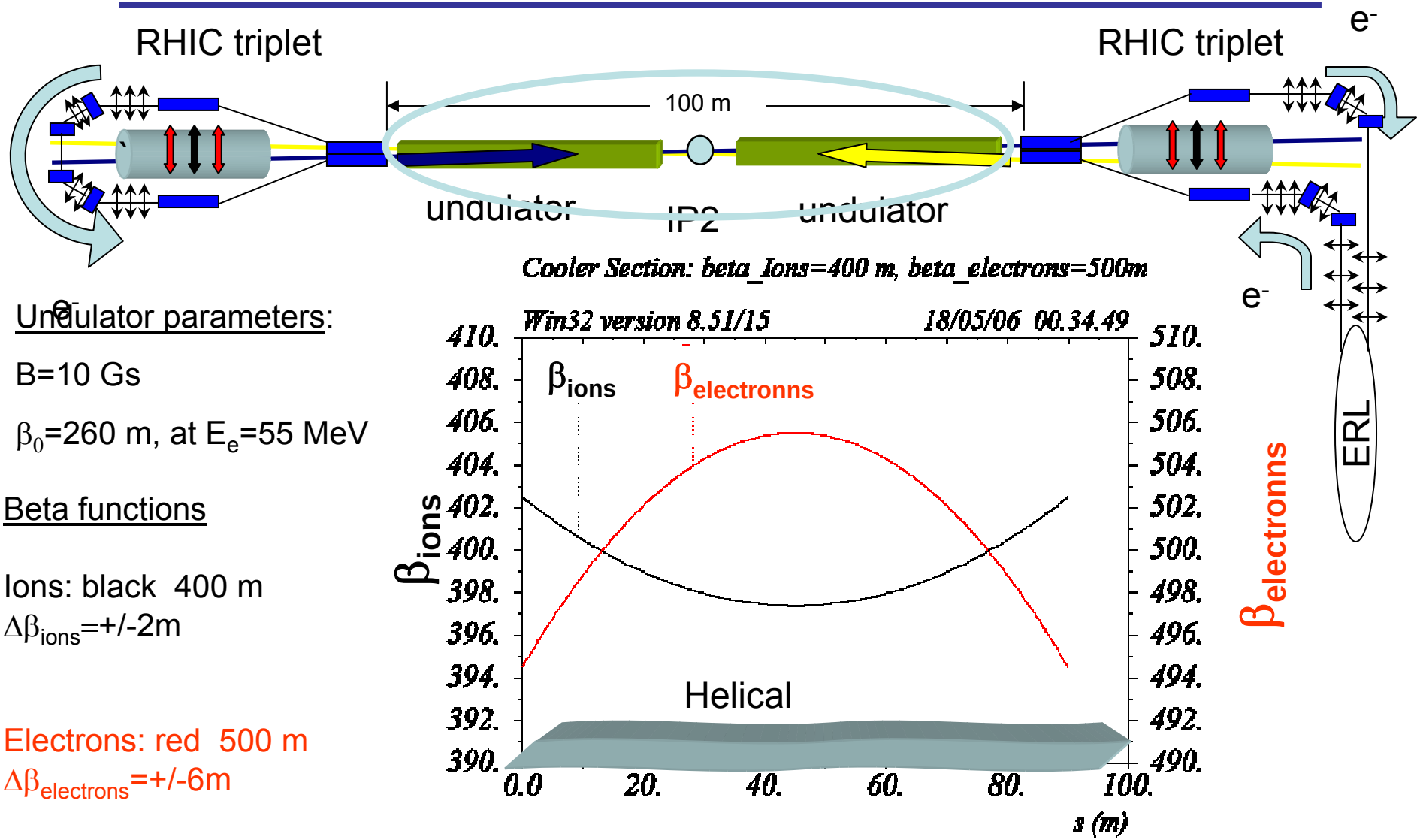
E-cooling ERL attached to the RHIC at 2 o'clock IP



Each electron beam cools ion beam in yellow ring then in blue ring.

The flight time between centers of the cooling sections is integral number of ion beam time sequence (1/9.383MHz=106.6 nsec)

Cooling region: undulator is needed to suppress effects of recombination .



Undulator parameters:

B=10 Gs

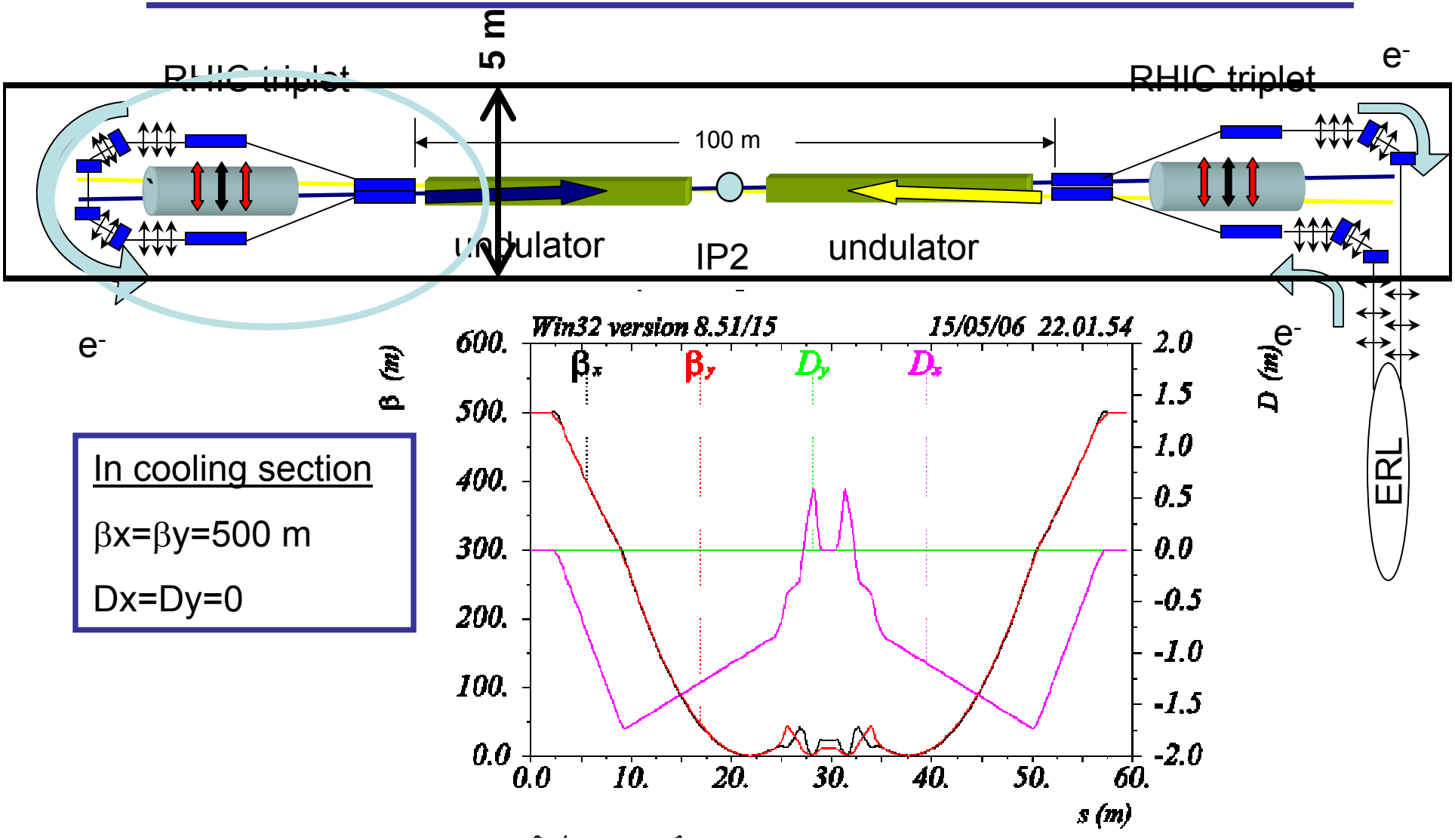
β_0=260 m, at E_e=55 MeV

Beta functions

Ions: black 400 m
$\Delta\beta_{ions}$=+/-2m

Electrons: red 500 m
$\Delta\beta_{electrons}$=+/-6m

Matching two rings



In cooling section

βx=βy=500 m

Dx=Dy=0

Part 3

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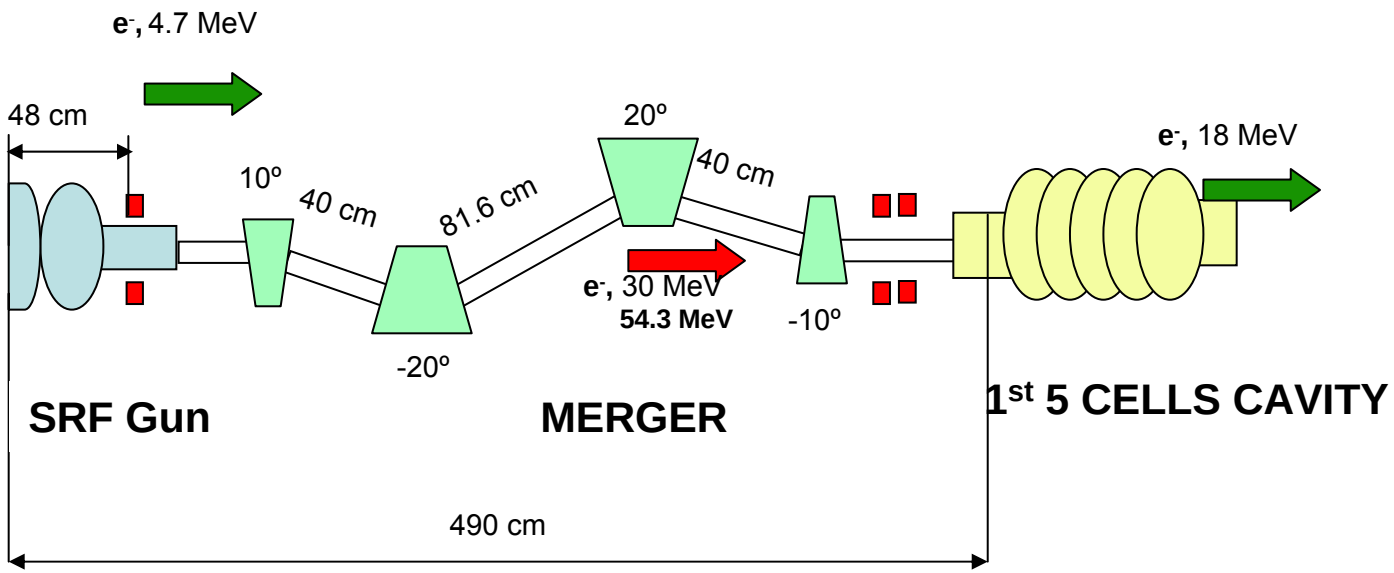
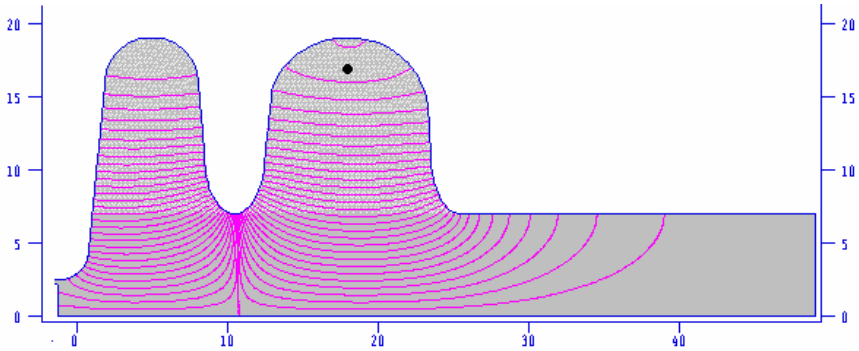
Vertical injector layout



SRF Gun

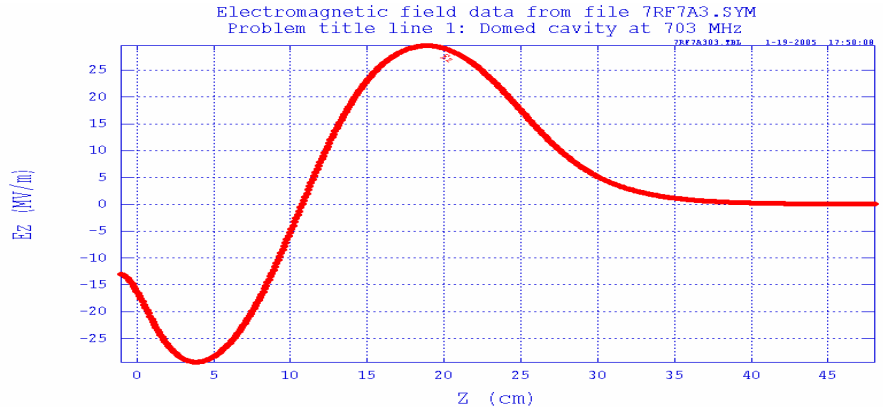
R (cm)



Frequancy: 703.75 MHz

Maximum field on axis: 29.5 MV/m

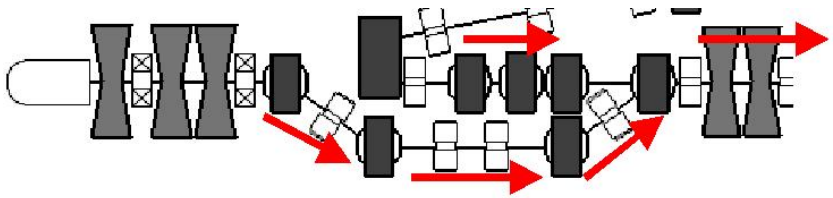
Maximum field on surface: 49.3(MV/m)



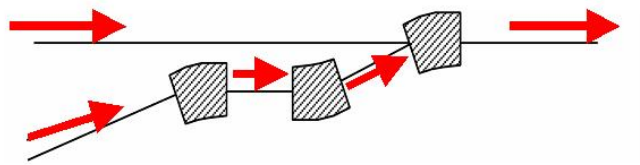
Electric field profile: results of SUPERISH simulation

Z (cm)

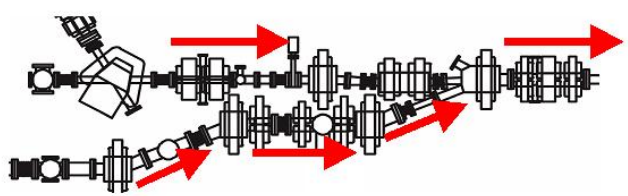
Mergers used in operational ERLs



Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia



Tomas Jefferson National Accelerator Facility (TJNAF) Newport News, VA, USA



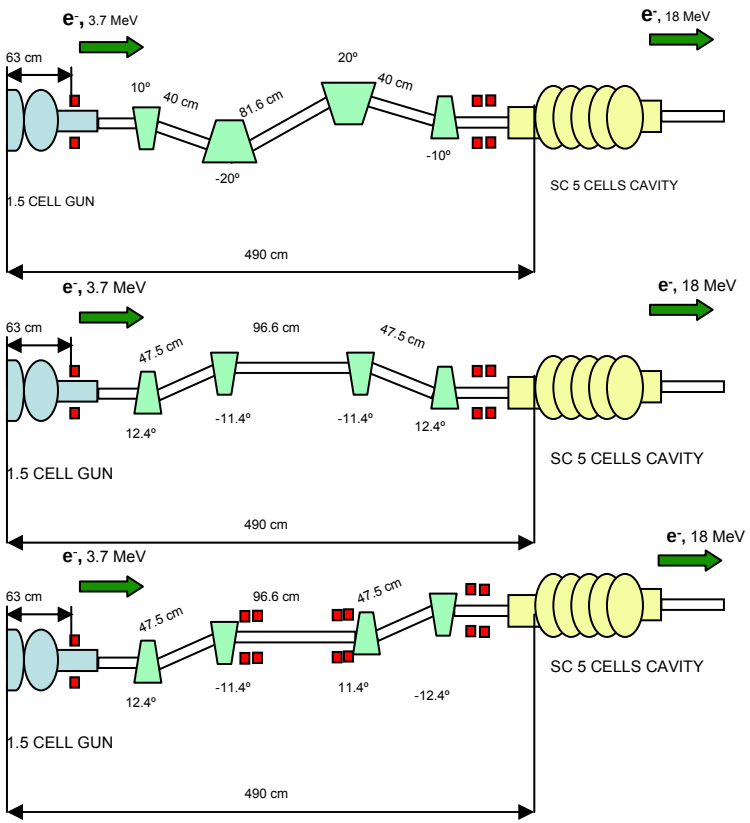
Japan Atomic Energy Research Institute (JAERI), Tokai-mura, Ibaraki, Japan

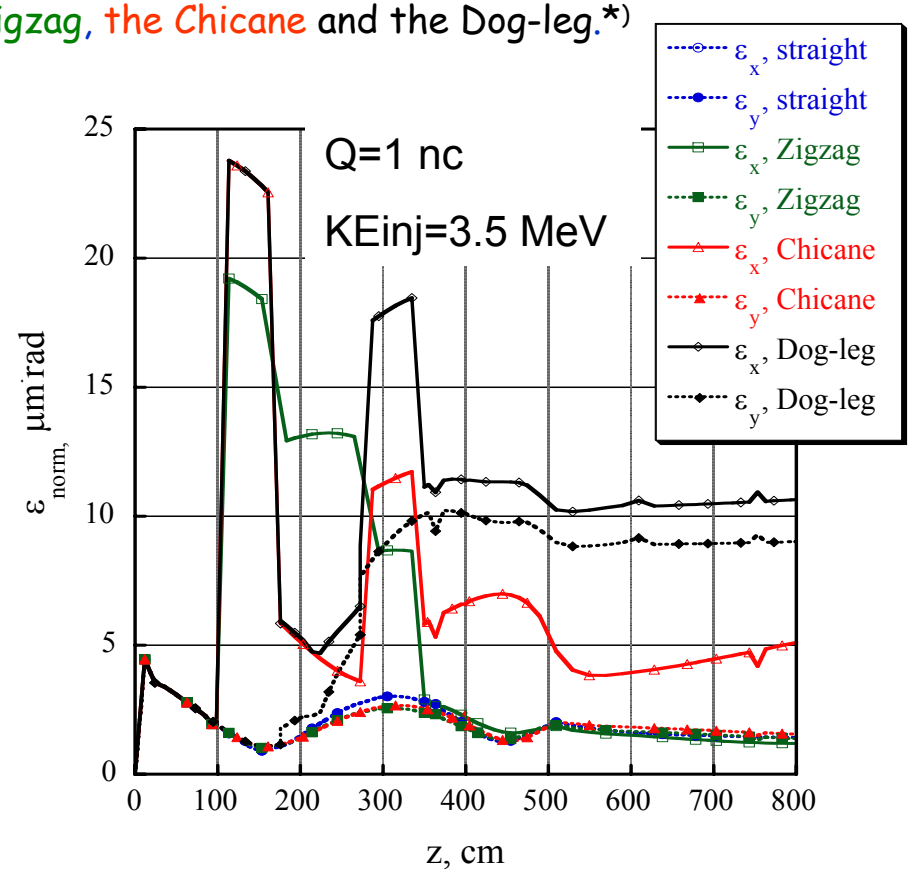
	BINP	TJNAF	JAERI
Gun type	Thermionic	Photocathode	Thermionic
Inj.energy	2 MeV	9.1 MeV	2.5 MeV
Q_{bunch}	1.5 nC	0.135 nC	0.5 nC
ΔT_{bunch},	150 psec	2 psec	9.4 psec
Merger type	Chicane with quad sstrong focusing	Three dipole strong focusing	Dog-leg, with quads strong focusing
$\varepsilon_{N_x}/\varepsilon_{N_x}$	30/30 μ	10/10 μ	35/26 μ

Beam parameters after the mergers in operation ERLs

Compare of different merger systems

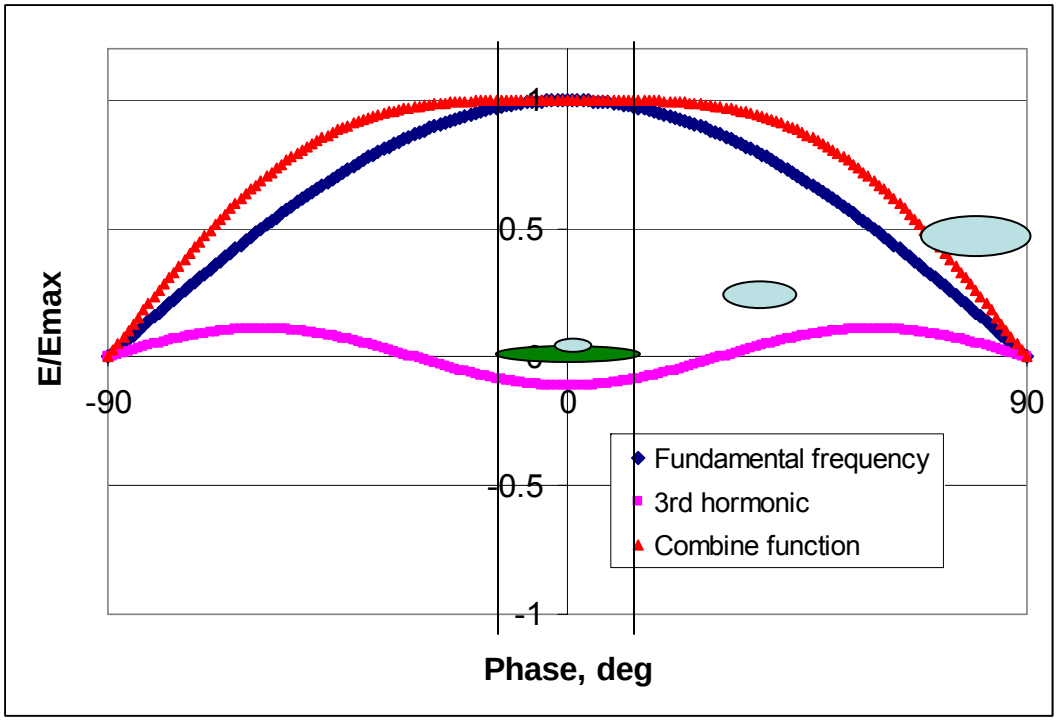
Evolution of horizontal and vertical normalized emittances in the four systems: the axially symmetric system (straight line), the Zigzag, the Chicane and the Dog-leg.*)





*) Vladimir N. Litvinenko, Ryoichi Hajima, Dmitry Kayran. Merger design for ERLs. Nuclear Instruments and Methods in Physics Research A 557 (2006), pp. 165 - 175.

Acceleration gain for different passing linac phase with and without 3-rd harmonic cavity.



Our beam is sitting here length: +/- 10 degrees

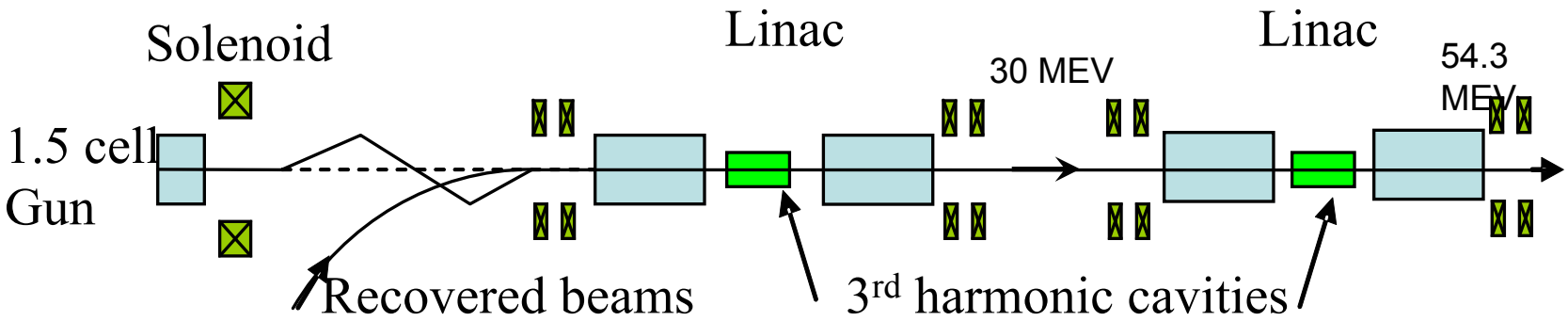
Without 3rd harmonic

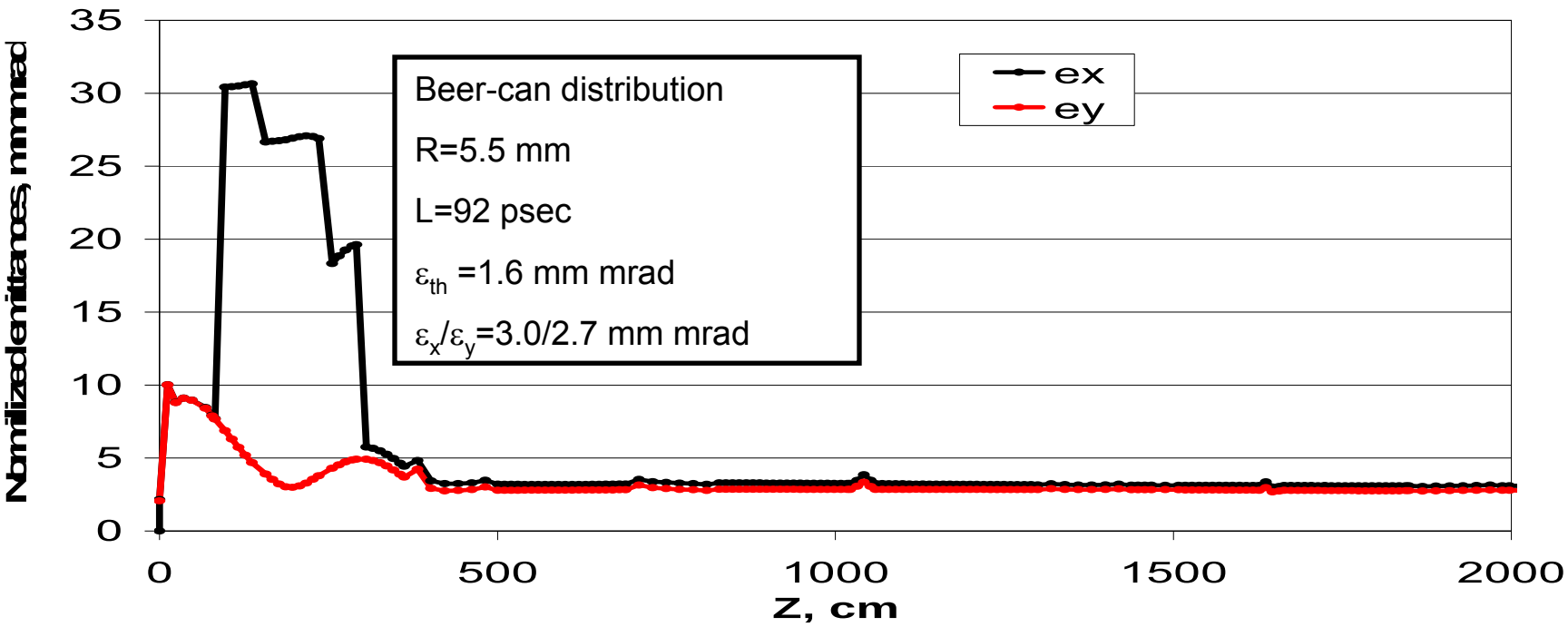
$\Delta E/E \approx 1.7 \times 10^{-3}$

Requirement is 3×10^{-4}

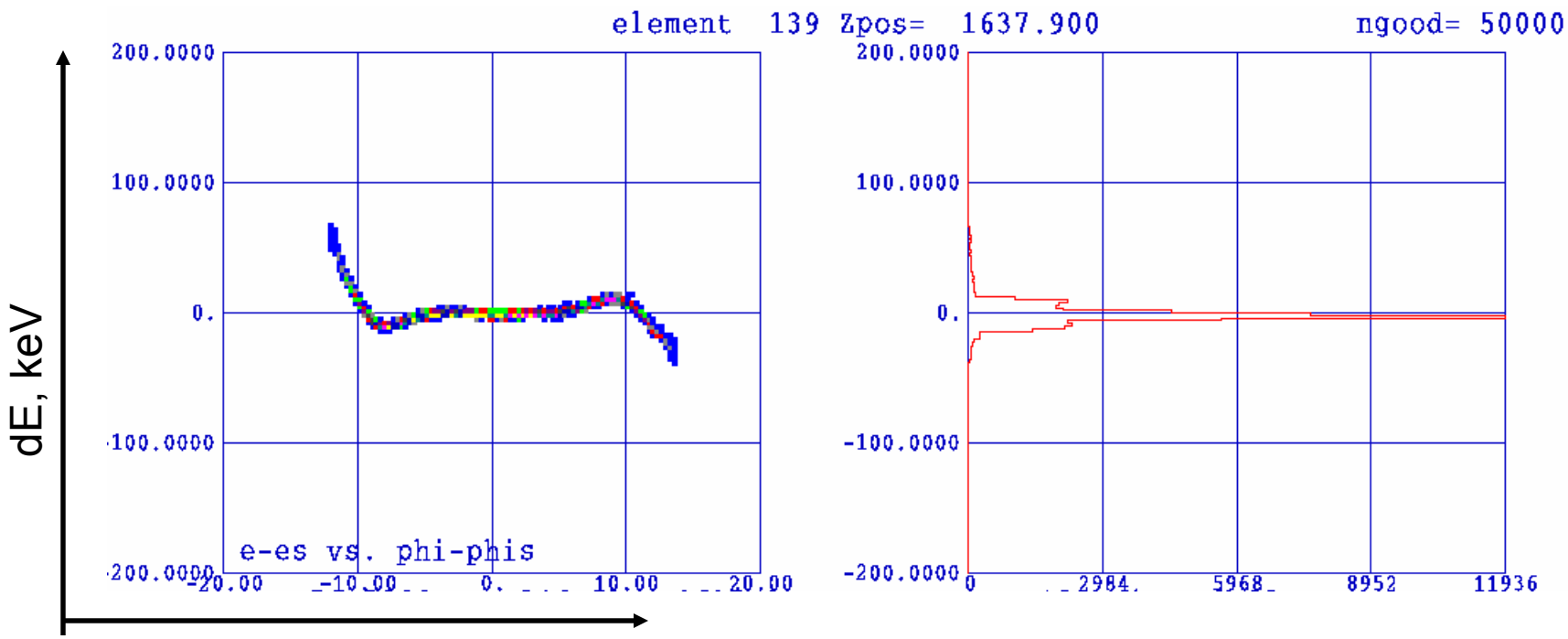
3rd harmonic cavity is needed!

Test-bed system





Longitudinal phase space at working energy 54.3 MeV



dPhi, deg

rms($\Delta E/E$)<2 10^{-4}

Summary for test-bed studies

The parameters of the electron beams for different initial distribution at the exit of the test-bed system at required kinetic energy 54.3 MeV

	Required for cooling	Parmela simulation results*)		
		Gaussian	Beer-can	Elliptical
Charge per bunch, nC	5	5	5	5
Energy, MeV	54.3	54.3	54.3	54.3
Transverse emittances, $\varepsilon_x/\varepsilon_y$ mm*mrad	<4	5.3/4.9	3.0/2.7	2.5/2.0
RMS Energy spread, $\delta E/E$	3×10^{-4}	2.9×10^{-4}	2.5×10^{-4}	1.8×10^{-4}

***) More details of test-bed studies will be discussed by Xiangyun Chang tomorrow.**

Part 4

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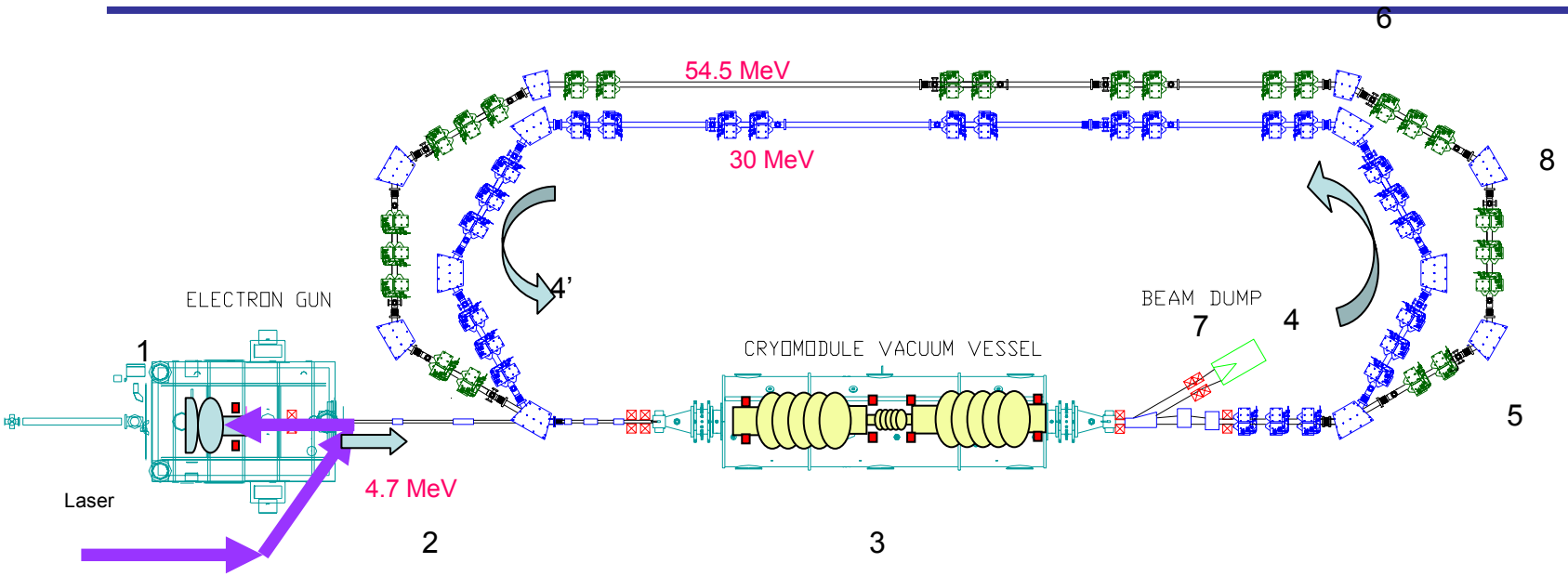
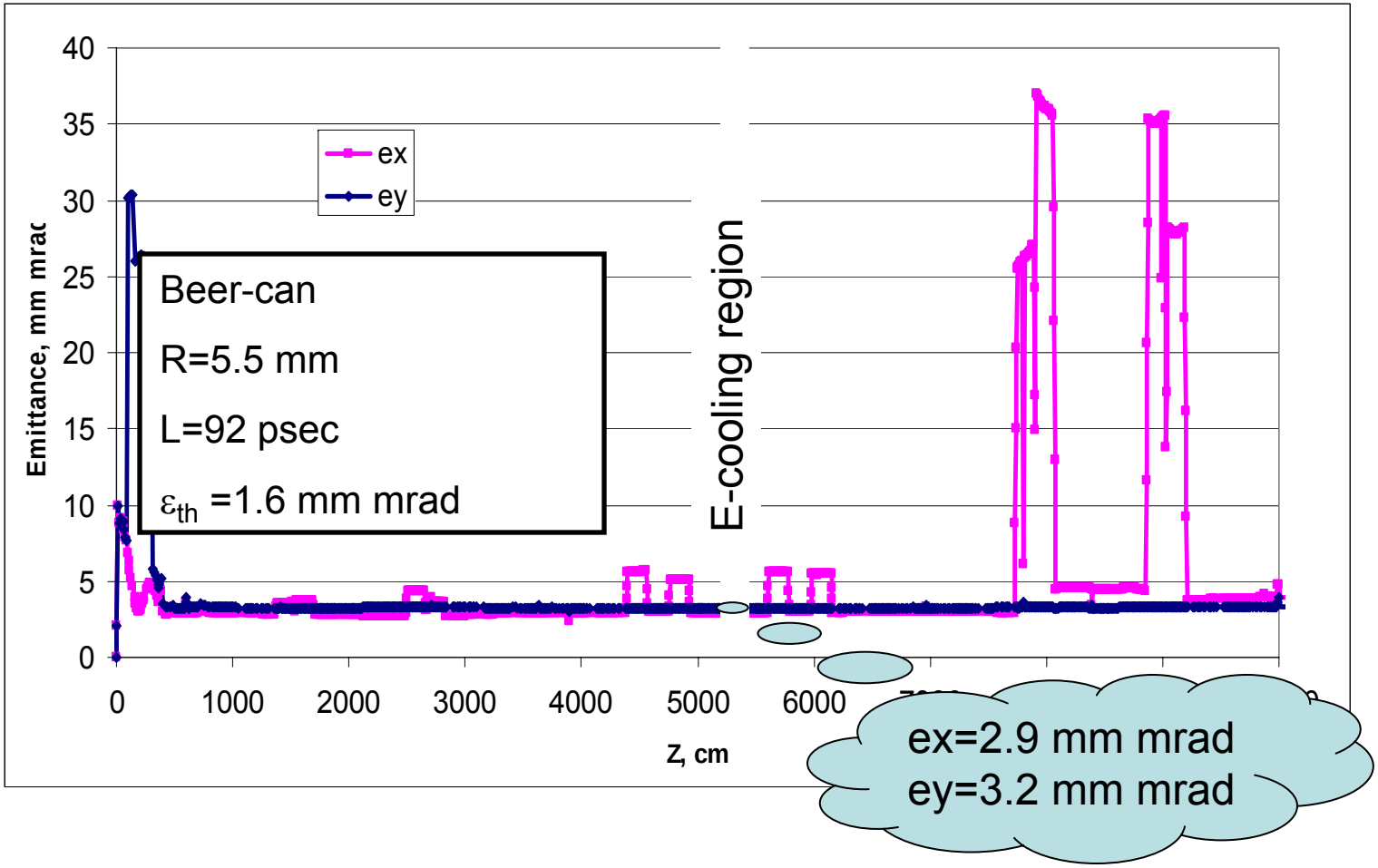
Layout of system for start-to-end tracking



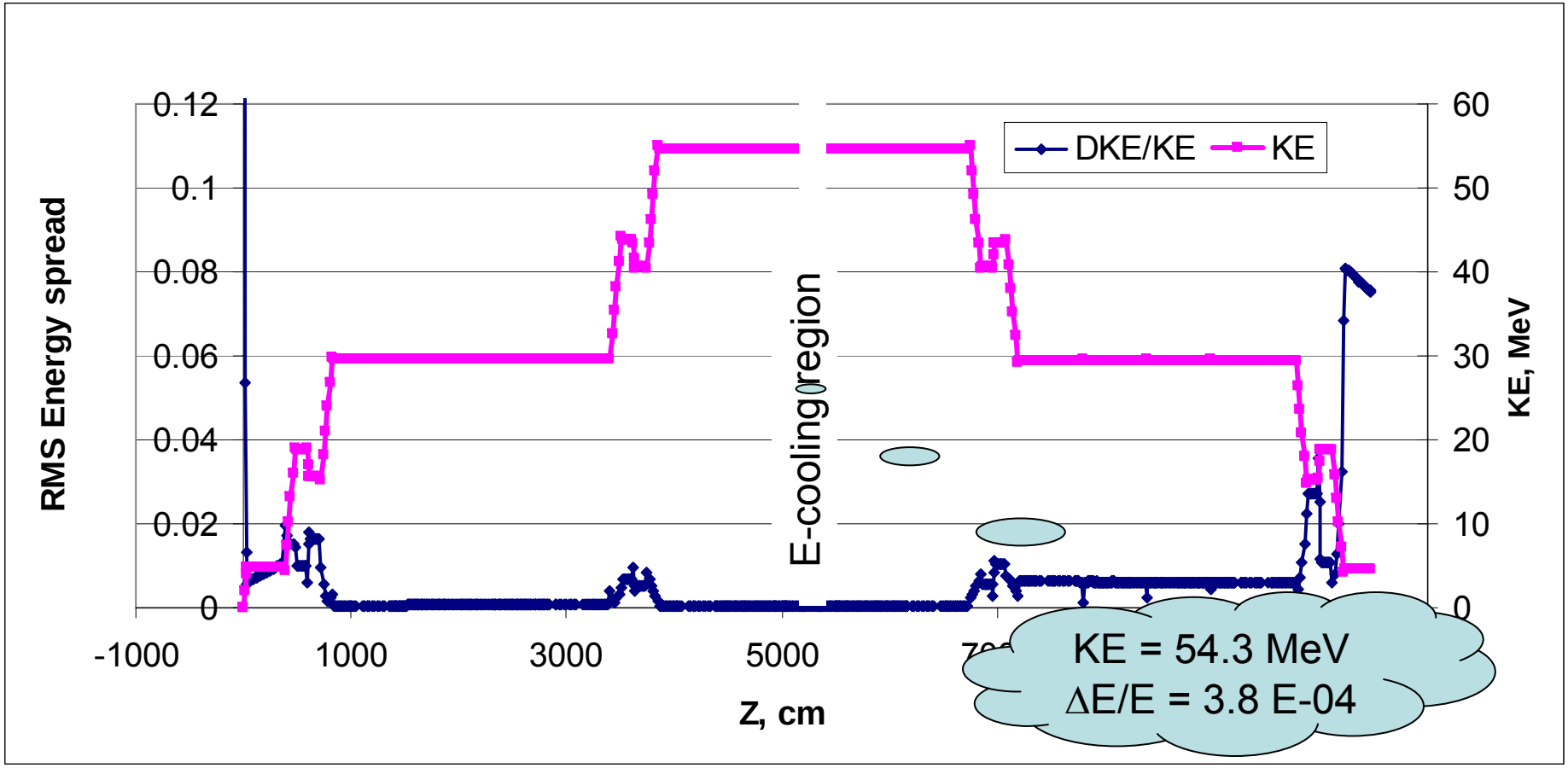
Result of start-to-end tracking

Transverse normalized emittances evolution from cathode to the dump



Result of start-to-end tracking (cont.)

Energy spread and avrage energy evaluation



Transverse Beam Break Up studies of two loops ERL

From Eduard Pozdeyev (Jefferson Lab) studies of the two loops ERL with two 5 Cell cavities :

The threshold average current is always more than **1.5 A**.

Which is sufficiently for e-cooling operation: average current **0.05 A**.

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The parameters of the electron beams for different initial distribution at the exit of the test-bed system at required kinetic energy 54.3 MeV

	Required for cooling	Parmela simulation results*)		
				Beer-can (T_{eff}=0.4eV)
Charge per bunch, nC	5			5
Energy, MeV	54.3			54.3
Threshold average current, mA	>50			1500
Transverse emittances, $\varepsilon_x/\varepsilon_y$ mm*mrad	<4			3.2/2.7
RMS Energy spread, $\delta E/E$	3×10^{-4}			3.8×10^{-4}
RMS Bunch length, cm	>1			0.78

✓The results of the beam dynamics studies according of start-to-end PARMELA simulation are very promising and provide the needed parameters for RHIC e-cooling project.

Things to do

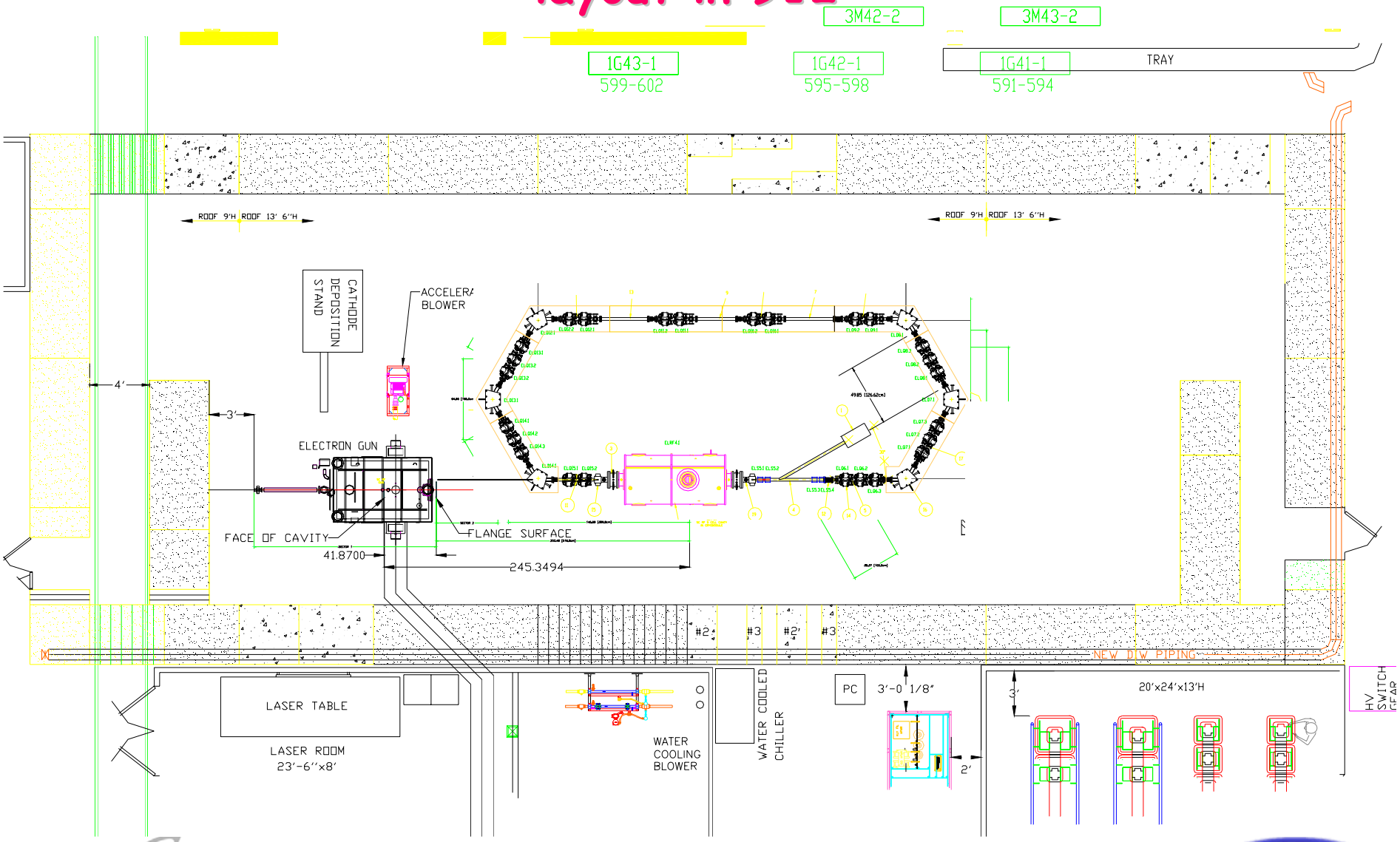
- ✓ Start to End simulation has to be done using magnets (solenoids, dipoles, quads) with real edges in real boundary conditions
- ✓ Wake field effects has to be well understood.
- ✓ Start to end simulation should include ions-electrons interaction impact
- ✓ Longitudinal instability

- ✓ Many R&D should be done

- ✓ A List of R&D items should be developed by this workshop

Thank you!

20 MeV High Current High Brightness R&D ERL : layout in 912



R&D ERL and E-Cooler beam parameters

	R&D prototype ERL		Required for cooling
	High average current	High charge per bunch	
Charge per bunch, nC	1.4	5	5
Numbers of passes	1	1	2
Energy maximum/injection, MeV	20/2.5	20/3.0	54.3/5.2
Average current, mA	500	50	50
Injected/ejected beam power, MW	1.0	0.15	0.26
Transverse emittances, mm*mrad	<5	<10	<5
Energy spread, $\delta E/E$	3×10^{-3}	5×10^{-3}	10^{-3}

- The prototype ERL will demonstrate the main parameters of the e-beam required for e-cooling
- The prototype will also serve as a test bed for studying issues relevant for very high current ERLs