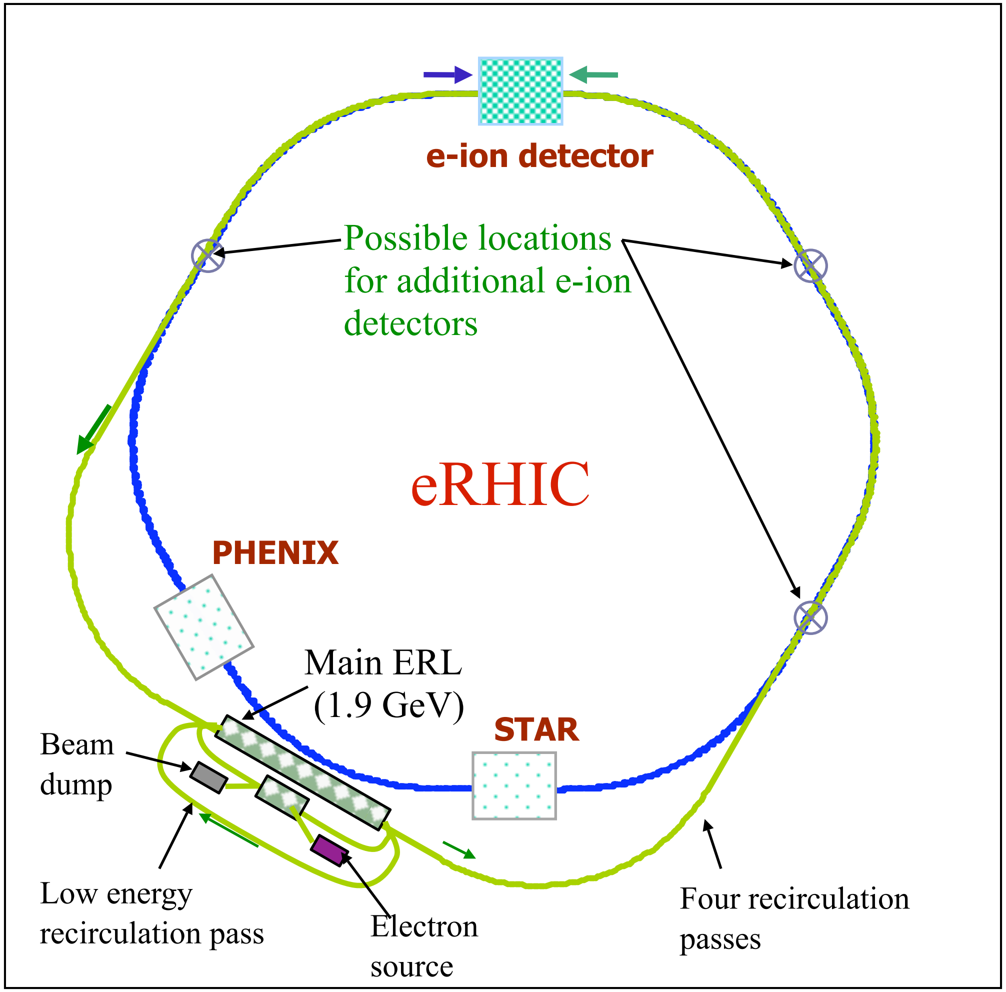
eRHIC and MEeIC parameters and layouts

V.Ptitsyn

eRHIC and MEeIC

- In both designs the ions (or protons) circulate in the existing RHIC ring.
  - eRHIC: 3-20 (30) GeV electron energy.
  - MEeIC, Medium Energy eIC: 2-4 GeV electron energy
- In both designs the ions (or protons) circulate in the existing RHIC ring.
  - eRHIC : completely new IR design (and magnets) even for ions
  - MEeIC: should be based on the present IR scheme (and magnets) for ions.
- MEeIC is considered as first stage for eRHIC. Major components have to be the same.

ERL-based eRHIC Design



- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring; compton backscattered; undulator-based. Though at lower luminosity.

Other design options

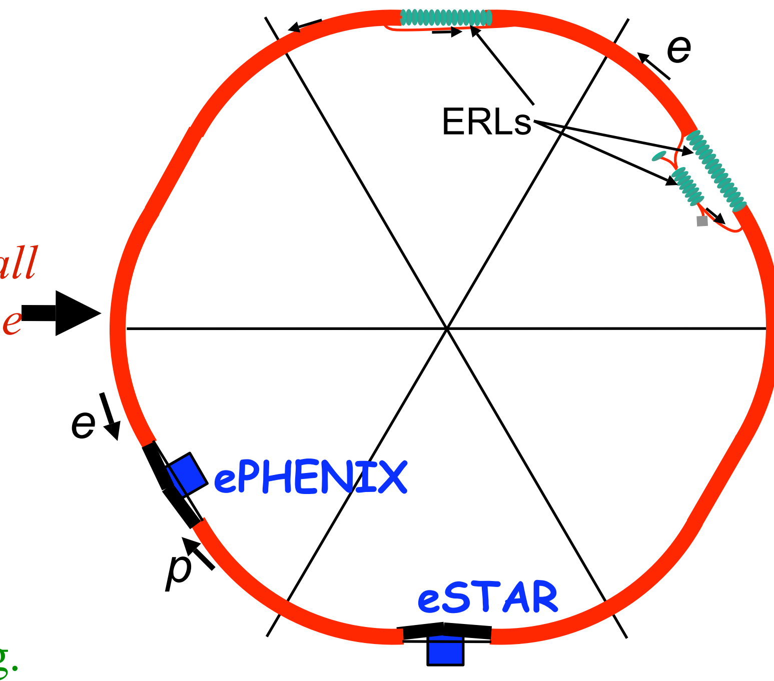
Under consideration also:

- *Medium Energy EIC at RHIC (MEeIC)*

  Electron energy up to 2-4 GeV. Acceleration done by an ERL linac placed in the RHIC tunnel. It can serve as first stage for following higher electron energy machine.
  Luminosity ~ 10^{32} cm^{-2}s^{-1} (without cooling)

- *High energy (up to 20-30 GeV) ERL-based design with all accelerating linacs and recirculation passes placed in the RHIC tunnel.*

  Considerable cost saving design solution.
  Luminosity exceeds 10^{33} cm^{-2}s^{-1}



- *Ring-ring design option.*

  Backup design solution which uses electron storage ring.
  See eRHIC ZDR for more details.
  The average luminosity is at 10^{32} cm^{-2}s^{-1} level limited by beam-beam effects.

ERL-based eRHIC Parameters: e-p mode

	High energy setup		Low energy setup	
	p	e	p	e
Energy, GeV	250	10	50	3
Number of bunches	166		166	
Bunch spacing, ns	71	71	71	71
Bunch intensity, 10^{11}	2	1.2	2	1.2
Beam current, mA	420	260	420	260
Normalized 95% emittance, π mm.mrad	6	460	6	570
Rms emittance, nm	3.8	4	19	16.5
β*, x/y, cm	26	25	26	30
Beam-beam parameters, x/y	0.015	0.59	0.015	0.47
Rms bunch length, cm	20	1	20	1
Polarization, %	70	80	70	80
Peak Luminosity, 1.e33 $cm^{-2}s^{-1}$	2.6		0.53	
Aver.Luminosity, 1.e33 $cm^{-2}s^{-1}$	0.87		0.18	
Luminosity integral /week, pb^{-1}	530		105	

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If effective high energy transverse cooling becomes possible the proton emittance and electron beam current can be reduced simultaneously, keeping the same luminosity.

ERL-based eRHIC Parameters: e-Au mode

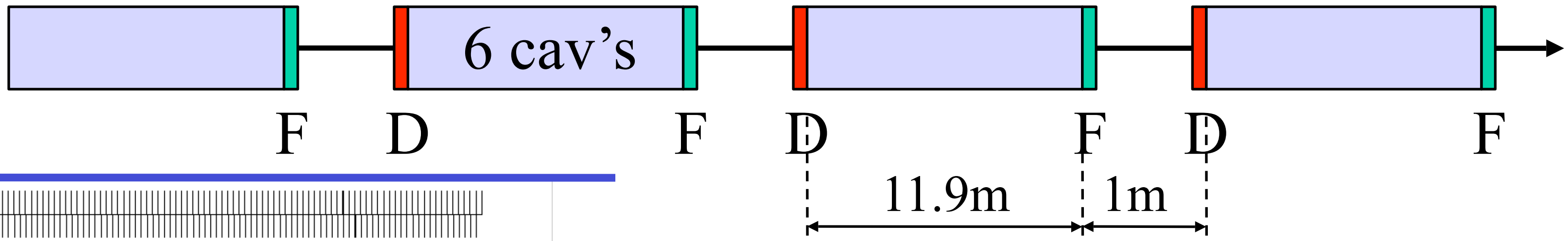
	High energy setup		Low energy setup	
	Au	e	Au	e
Energy, GeV	100	10	50	3
Number of bunches	166		166	
Bunch spacing, ns	71	71	71	71
Bunch intensity, 10^{11}	1.1	1.2	1.1	1.2
Beam current, mA	180	260	180	260
Normalized 95% emittance, π mm.mrad	2.4	460	2.4	270
Rms emittance, nm	3.7	3.8	7.5	7.8
β*, x/y, cm	26	25	26	25
Beam-beam parameters, x/y	0.015	0.26	0.015	0.43
Rms bunch length, cm	20	1	20	1
Polarization, %	0	0	0	0
Peak e-nucleon luminosity, 1.e33 $cm^{-2}s^{-1}$	2.9		1.5	
Average e-nucleon luminosity, 1.e33 $cm^{-2}s^{-1}$	1.0		0.5	
Luminosity integral /week, pb^{-1}	580		290	

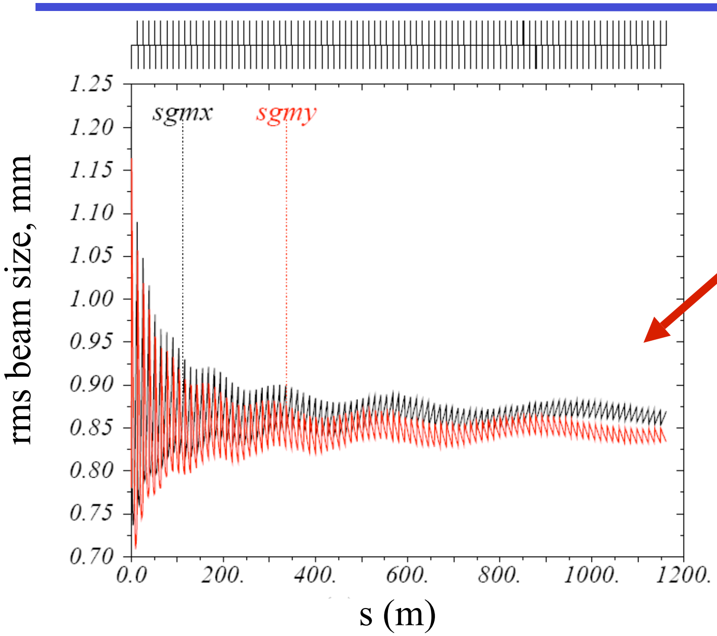
Main R&D Items

- Electron beam R&D for ERL-based design:
  - High intensity polarized electron source
    - Development of large cathode guns with existing current densities ~ 50 mA/cm^2 with good cathode lifetime.
  - Energy recovery technology for high power beams
    - multicavity cryomodule development; high power beam ERL, BNL ERL test facility; loss protection; instabilites.
  - Development of compact recirculation loop magnets
    - Design, build and test a prototype of a small gap magnet and its vacuum chamber.
  - Beam-beam effects: e-beam disruption
- Main R&D items for ion beam:
  - Beam-beam effects: electron pinch effect; the kink instability …
  - Polarized ^{3}He acceleration
  - 166 bunches
- General EIC R&D item:
  - Proof of principle of the coherent electron cooling

Compact linac design

Increased number of 700MHz cavities inside one cryostat to 6 cavities.
3rd harmonic cavities (2 per cryostat) for the momentum spread minimization.
Cavity gradient: 19.5 Mev/m;   Average acceleration rate: 8.2 MeV/m;
Total length of 1.9 GeV linac: 232m   (instead of ~360m in the previous design).





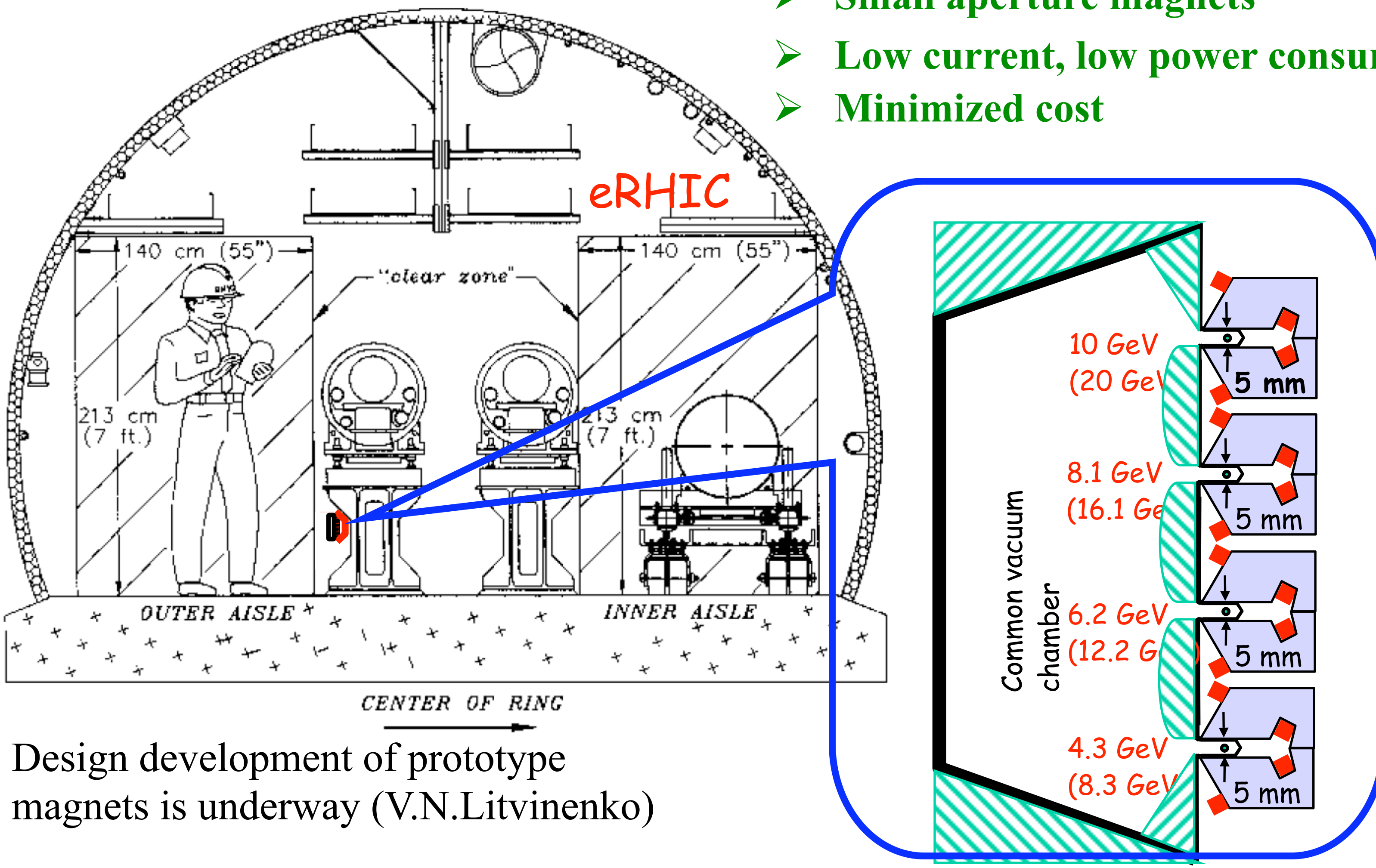
E.Pozdeyev

Evolution of rms beam sizes along the linac on all acceleration passes. Recirc.passes are presented by Unit matrix.
Doublet focusing (90º phase advance per cell)
Constant quadrupole gradient.

Compact linac design makes more realistic a design option with linac(s) placed inside the RHIC tunnel

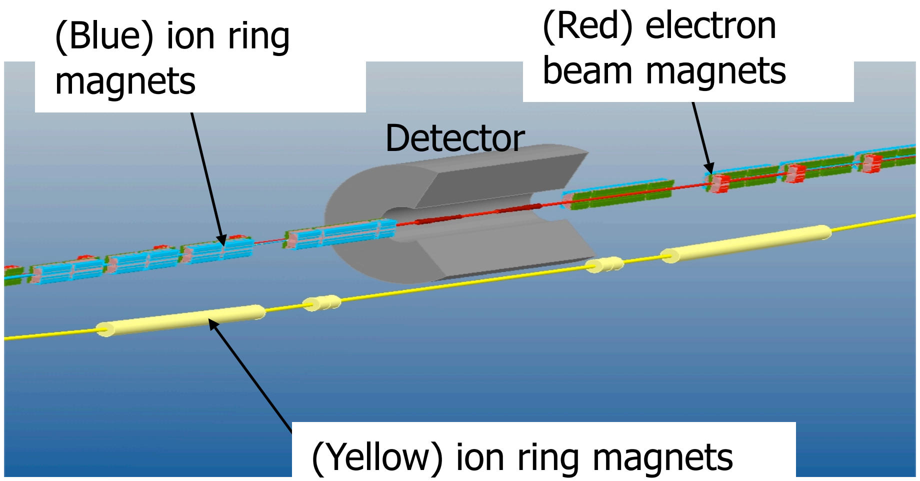
Recirculation passes

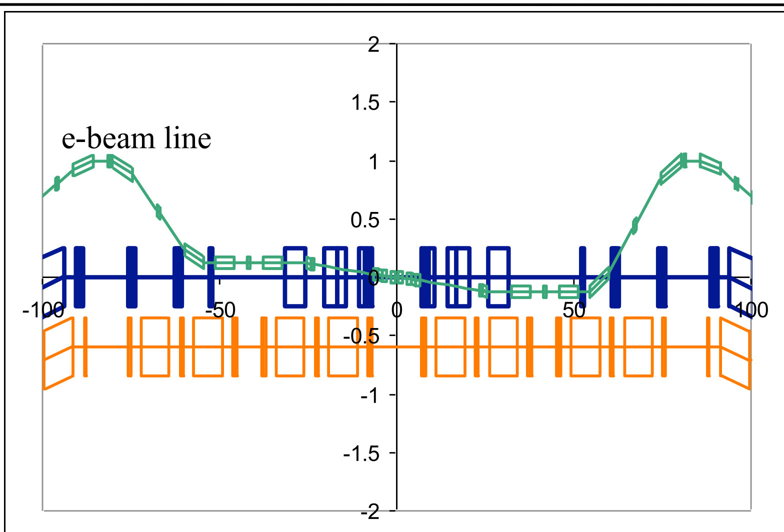
- Separate recirculation loops
- Small aperture magnets
- Low current, low power consumption
- Minimized cost



Design development of prototype magnets is underway (V.N.Litvinenko)

Interaction Region Design

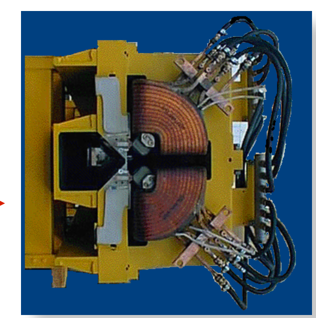




Present IR design features:

- No crossing angle at the IP
- Detector integrated dipole: dipole field superimposed on detector solenoid.
- No parasitic collisions.
- Round beam collision geometry with matched sizes of electron and ion beams.
- Synchrotron radiation emitted by electrons does not hit surfaces in the detector region.
- Blue ion ring and electron ring magnets are warm.
- First quadrupoles (electron beam) are at 3m from the IP
- Yellow ion ring makes 3m vertical excursion.

HERA type half quadrupole used for proton beam focusing

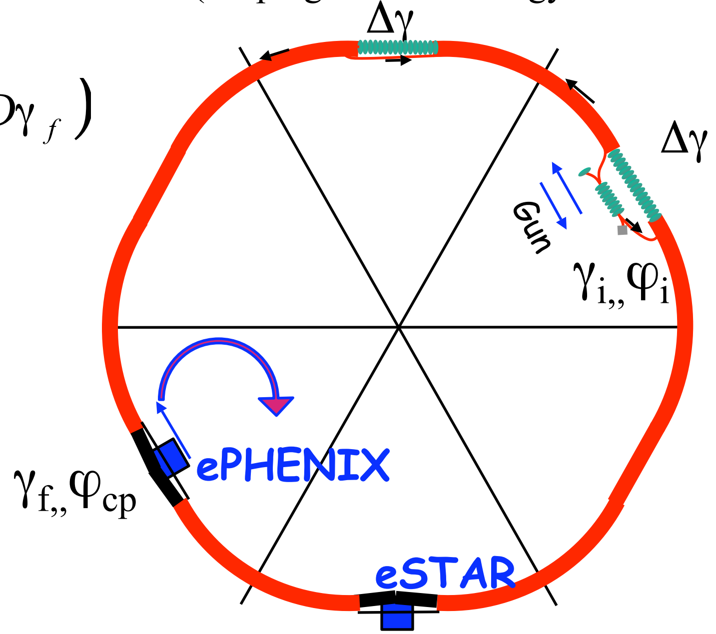


Electron polarization in ERL eRHIC

- No problem with depolarizing resonances
- Spin orientation control at the collision point:
  - Spin rotators after the electron source (Wien filter, solenoid)
  - Slight adjustment of energy gain in main and pre-accelerator linacs (keeping the final energy constant) *(V.N.Litvinenko)*

$$\varphi_{cp} + k\pi = \varphi_i + 2\pi a \times (A\gamma_i + B\Delta\gamma) = \varphi_i + 2\pi a \times (C\gamma_i + D\gamma_f)$$

a is anomalous magnetic moment
A,B,C,D are constants depending on general configuration: location of linacs and collision point, number of recirculation passes (n).



Variation of pre-accelerator linac energy:

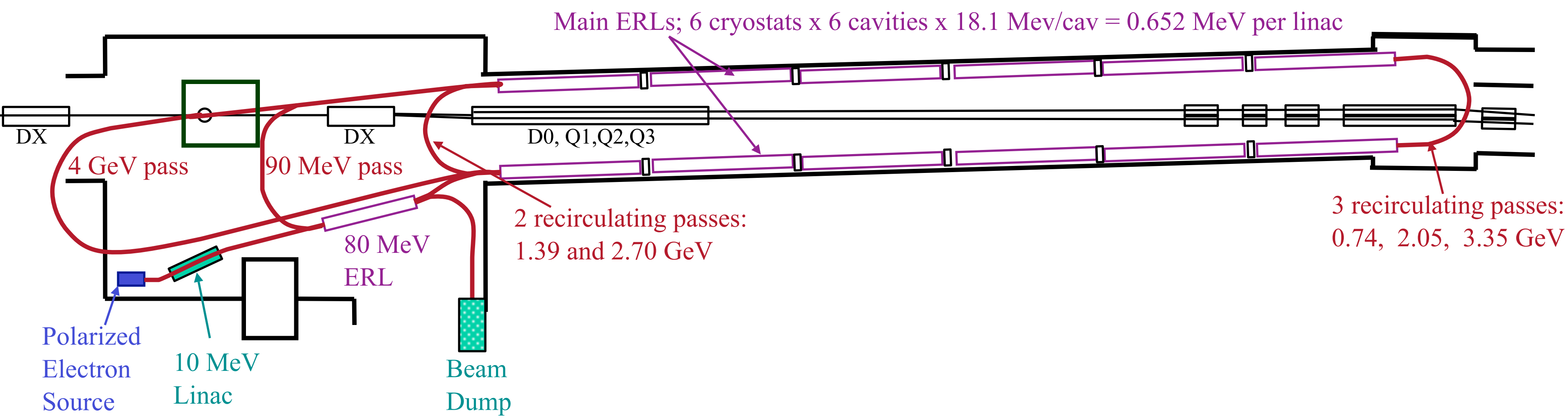
$$\boxed{\delta E_{i\,\max} = \pm 37 \quad MeV \quad \vee\; n = 5}$$

MEeIC design development

- Goal: detailed technical design report before the next EIC Collaboration meeting (April-May 2009)
- Design developments so far:
  - General layout and parameters
  - Recirculating pass optics
  - Bunch length and peak current issues: cavity wakes, CSR
  - Longitudinal dynamics
  - Beam-beam effects (Y.Hao’s presentation)
  - IR design issues (J.Beebe-Wang’s and C.Montag’s presentations)

MEeIC Layout

Recirculating pass energies are shown for 4 GeV top energy



MEEIC parameters for e-p collisions

	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	**250**	**4**	**250**	**4**	**250**	**4**
Number of bunches	**111**		**111**		**111**	
Bunch intensity, 10^{11}	**2.0**	**0.31**	**2.0**	**0.31**	**2.0**	**0.31**
Bunch charge, nC	**32**	**5**	**32**	**5**	**32**	**5**
Normalized emittance, 1e-6 m, 95% for p / rms for e	**15**	**73**	**6**	**29**	**1.5**	**7.3**
rms emittance, nm	**9.4**	**9.4**	**3.8**	**3.8**	**0.94**	**0.94**
beta*, cm	**50**	**50**	**50**	**50**	**50**	**50**
rms bunch length, cm	**20**	**0.2**	**20**	**0.2**	**5**	**0.2**
beam-beam for p /disruption for e	**1.5E-03**	**3.1**	**3.8E-03**	**7.7**	**0.015**	**7.7**
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	**0.93**		**2.3**		**9.3**	

MEEIC parameters for e-p collisions

	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	**250**	**2**	**250**	**2**	**250**	**2**
Number of bunches	**111**		**111**		**111**	
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beta*, cm	**50**	**50**	**50**	**50**	**50**	**50**
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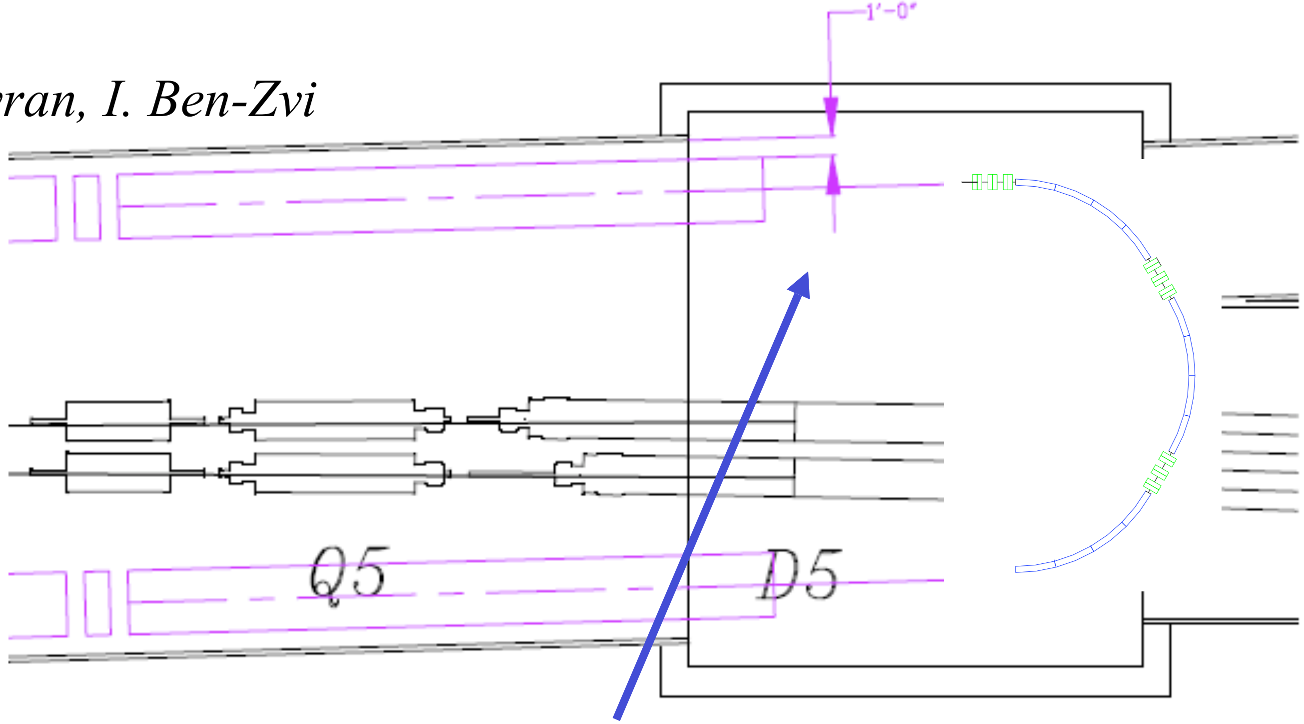
beam-beam for p /disruption for e	**1.5E-03**	**6**	**3.8E-03**	**15**	**0.015**	**15**
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	**0.93**		**2.3**		**9.3**	

MEeIC: recirculation inside the tunnel

D. Kayran, I. Ben-Zvi



The distance between the linacs axis is 6.3 m

80% fill factor gives the radius 2.5 m showed

Current work:

- Lattice development
- Evaluation of superconducting magnet design

MEeIC: ERL some parameters

eBeam energy in the last right arc: E_{max}-$\Delta E_{perpass}/2$ *D.Kayran*

Energy losses per full turn [KeV]=88.5 E[GeV]^4 /R[m]

Highest energy pass

R (0.8 filling factor), m	2.5	2.5	2.5	**5**
Current, mA	50	50	50	**50**
Number of passes	3	3	3	**3**
E_{max}/E_{arc}, GeV	2/1.67	3/2.5	4/3.33	**4/4**
Dipole magnetic field, T	2.2	3.3	4.4	**2.7**
Energy losses per arc (half turn), MeV	0.05	0.7	2.2	**2.3**
Power losses per arc, kW per m kW/m	2.5 0.32	35.2 4.5	110.7 14.1	**115.2** **7.33**

Energy loss to Cavity Wakes

E.Pozdeyev

qb (pC)	5000	I(A)	0.05
fb (Hz)	1.00E+07	ncav	360

sig(mm)	kii (V/pC)	kii_adj (V/pC)	Vloss (MV)	Ploss (kW)	dVtot (MV)
1.500	-4.336	-3.817	-6.8706	-343.530	-9.288
1.800	-3.797	-3.281	-5.9058	-295.290	-8.136
2.000	-3.504	-2.990	-5.382	-269.100	-7.47
2.500	-2.951	-2.437	-4.3866	-219.330	-6.138
5.000	-1.744	-1.232	-2.2176	-110.880	-3.186
7.500	-1.304	-0.796	-1.4328	-71.640	-1.872
10.000	-1.071	-0.567	-1.0206	-51.030	-1.548

Related issues:

-Compensation of average energy loss (Vloss), to eliminate energy difference in the same pass for accelerating and decelerating beam. (Second harmonic cavities?)

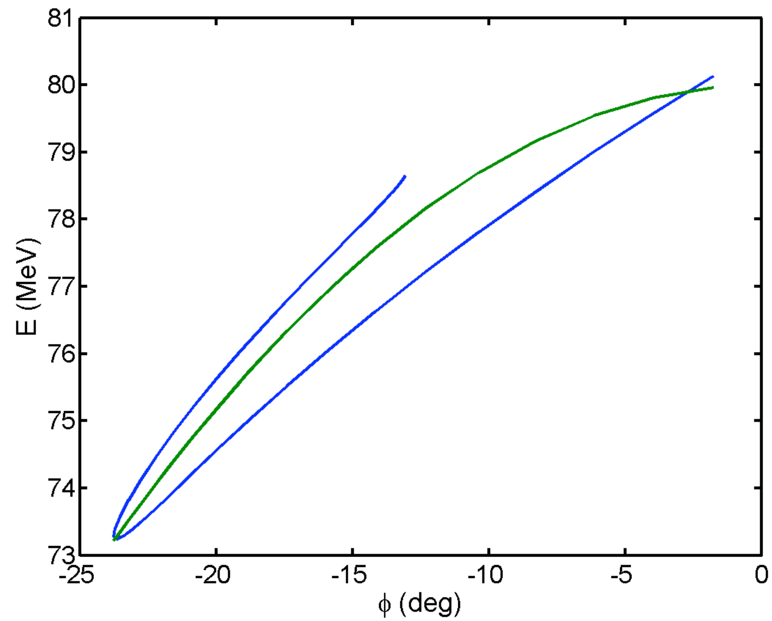
-Managing HOM power output.

-Reduction of the energy spread (dVtot) for lower energy (10 MeV) transfer

Energy spread compensation

E.Pozdeyev

Partial compensation can be done by proper choice of R56 and T566 parameters in 90 MeV arc together with proper deceleration RF phase in 80 MeV linac



σ=1.8 mm, Gauss

in deg   in cm

V (MV)	R56	R56	T566	phi_{guess}	de_{guess}	de	phi_{min}	de_{opt}
50	85	-10	435	31	1.5	4.5	29	1.3
80	135	-16	735	24.4	1.9	6.0	23	1.6
100	155	-18	1035	21	2.2	6.8	22	1.92

(MeV)

Limit on minimum bunch length for CSR to be suppressed by shielding:

$$\sigma_{th,\min} = \sqrt{\frac{6h^3}{\pi R}}$$

A.Fedotov

h - beam pipe aperture
R – magnet bending radius

We take the smallest number of R=2m for estimate:

For R=2m (for turn around inside the tunnel): σ_{min}=5mm, for h=3cm

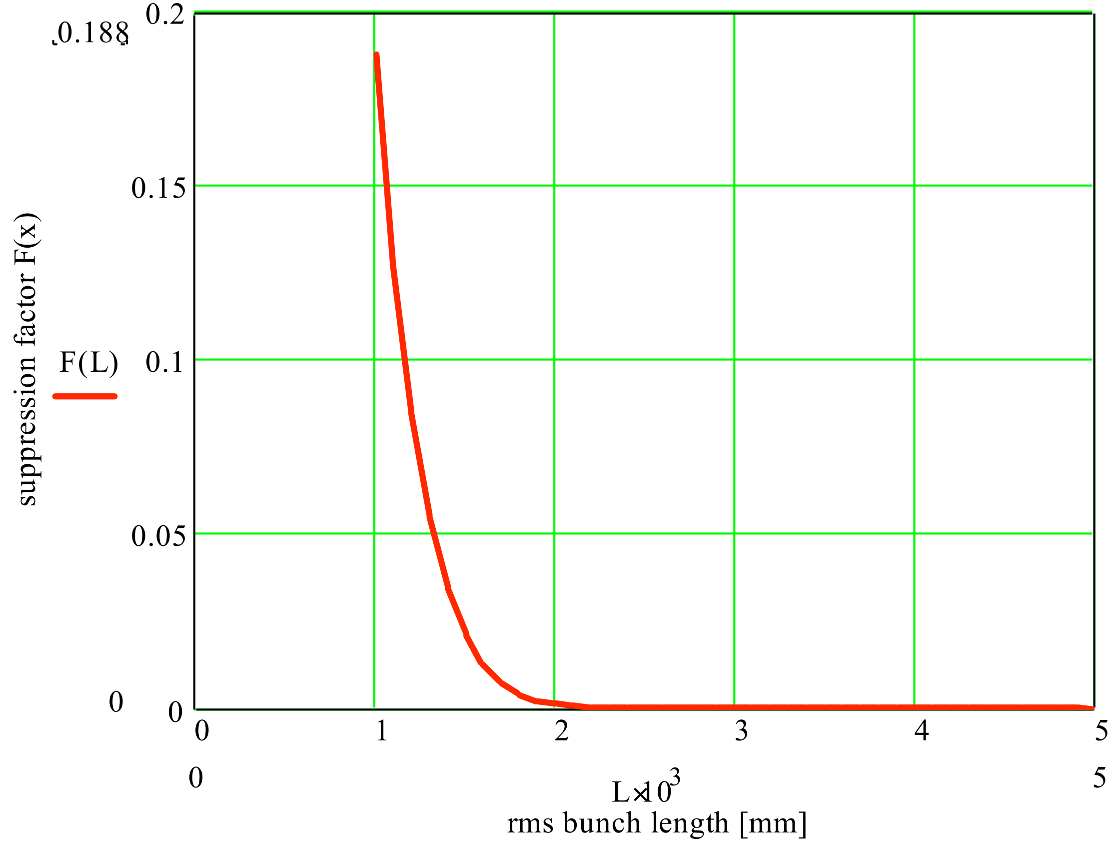
σ_{min}=1mm, for h=1cm

- If h=1cm then CSR will be completely shielded for bunch length 1mm rms (full length 4.8mm) or larger.

- If h=3cm will be completely shielded for 5mm (full length 2.6cm) or larger. But even for 2mm rms – reduction factor is F=0.001.

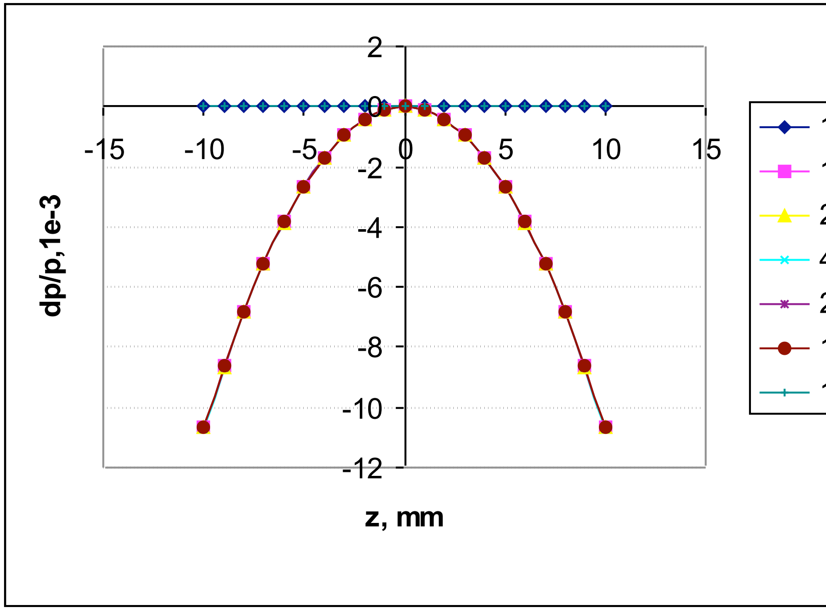
Shielding suppression factor F(x) as a function of rms bunch length L – for bending radius R=2m and vacuum chamber full height h=3cm

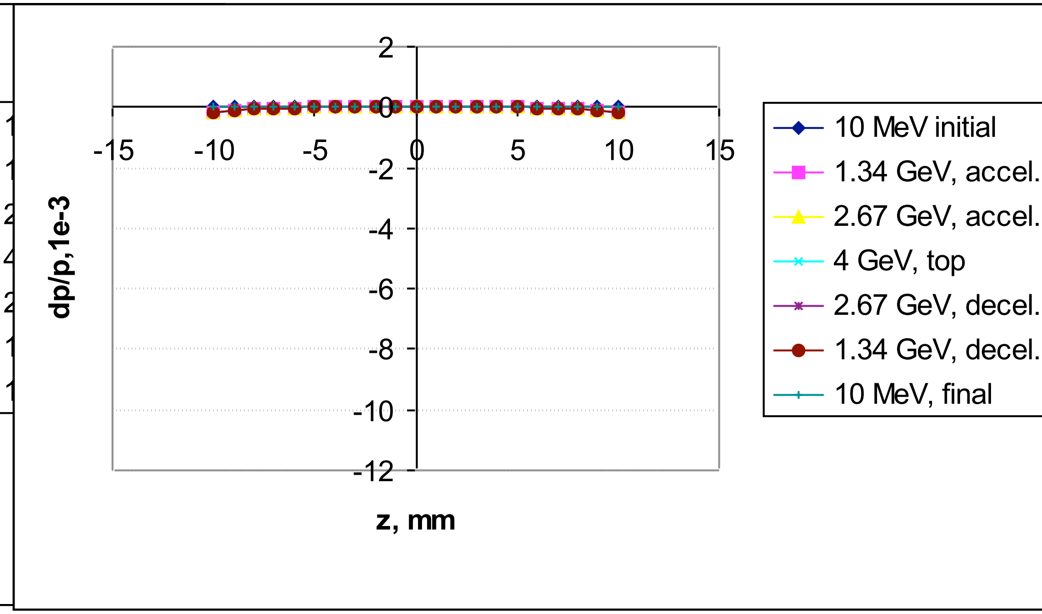
A.Fedotov



No CSR starting rms length L=5mm, but CSR already strongly suppressed for rms bunch length L=2mm -> F=0.001.

Momentum spread versus longitudinal coordinate during acceleration and deceleration



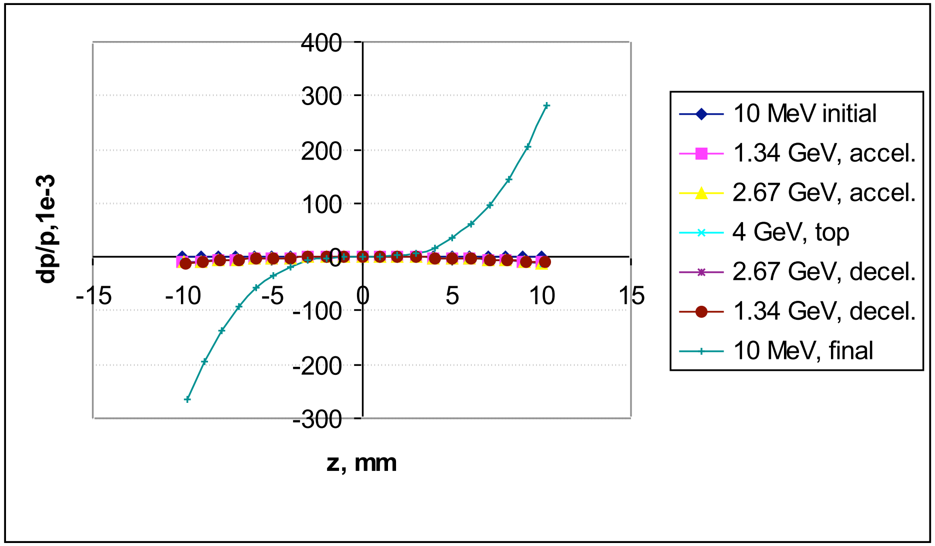


R_56 = 0, no 3rd harmonic RF

R_56 = 0, with 3rd harmonic RF

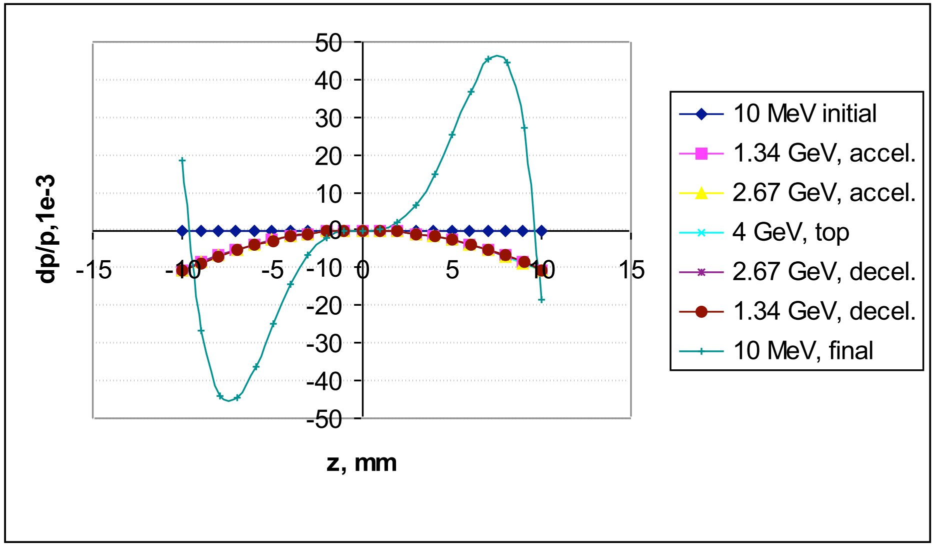
For +- 5mm bunch, the momentum spread is acceptable even without 3rd harmonic RF

Remaining momentum spread after energy recovery



R_56 = 10 mm, T_566=0 mm, no 3rd harmonic RF

Conclusion: no 3rd harmonic cavity required.



R_56 = 10 mm, T_566=1000 mm, no 3rd harmonic RF