eRHIC

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Inputs on Physics from BNL EIC task force and E.-C.Aschenauer, T. Ulrich A. Cadwell, A. Deshpande, R. Ent, W. Gurin, T. Horn, H. Kowalsky, M. Lamont, T.W. Ludlam, R. Milner, B. Surrow, S. Vigdor, R. Venugopalan, W. Vogelsang

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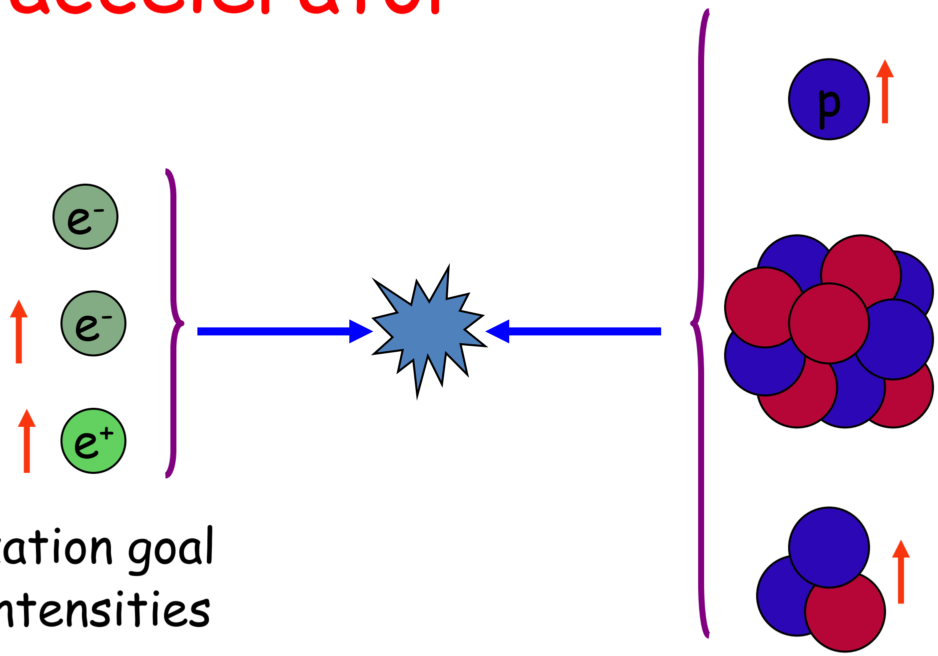
eRHIC Scope -QCD Factory

Electron accelerator

Unpolarized and polarized leptons
4-20 (30) GeV

70% beam polarization goal
Positrons at low intensities

RHIC



Polarized protons
50-250 (325) GeV

Light ions (d,Si,Cu)
Heavy ions (Au,U)
50-100 (130) GeV/u

Polarized light ions
(He^3) 215 GeV/u

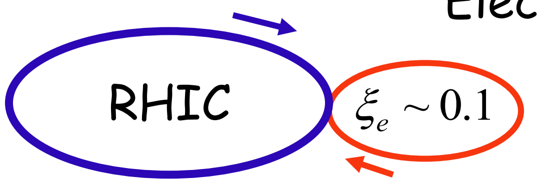
Center mass energy range: 15-200 GeV

2007 Choosing the focus: ERL or ring for electrons?

- Two main design options for eRHIC:
  - Ring-ring:

$$L = \left(\frac{4\pi \gamma_h \gamma_e}{r_h r_e} \right) (\xi_h \xi_e) (\sigma_h' \sigma_e') f$$

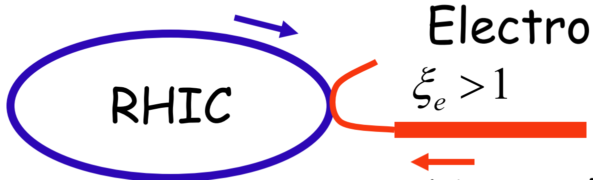
Electron storage ring



  - Linac-ring:

$$L = \gamma_h f N_h \frac{\xi_h Z_h}{\beta_h^* r_h}$$

Electron linear accelerator



Natural staging strategy

L x 10

Energy-recovery linac is required to accelerate high average electron current

2008: Staging of eRHIC

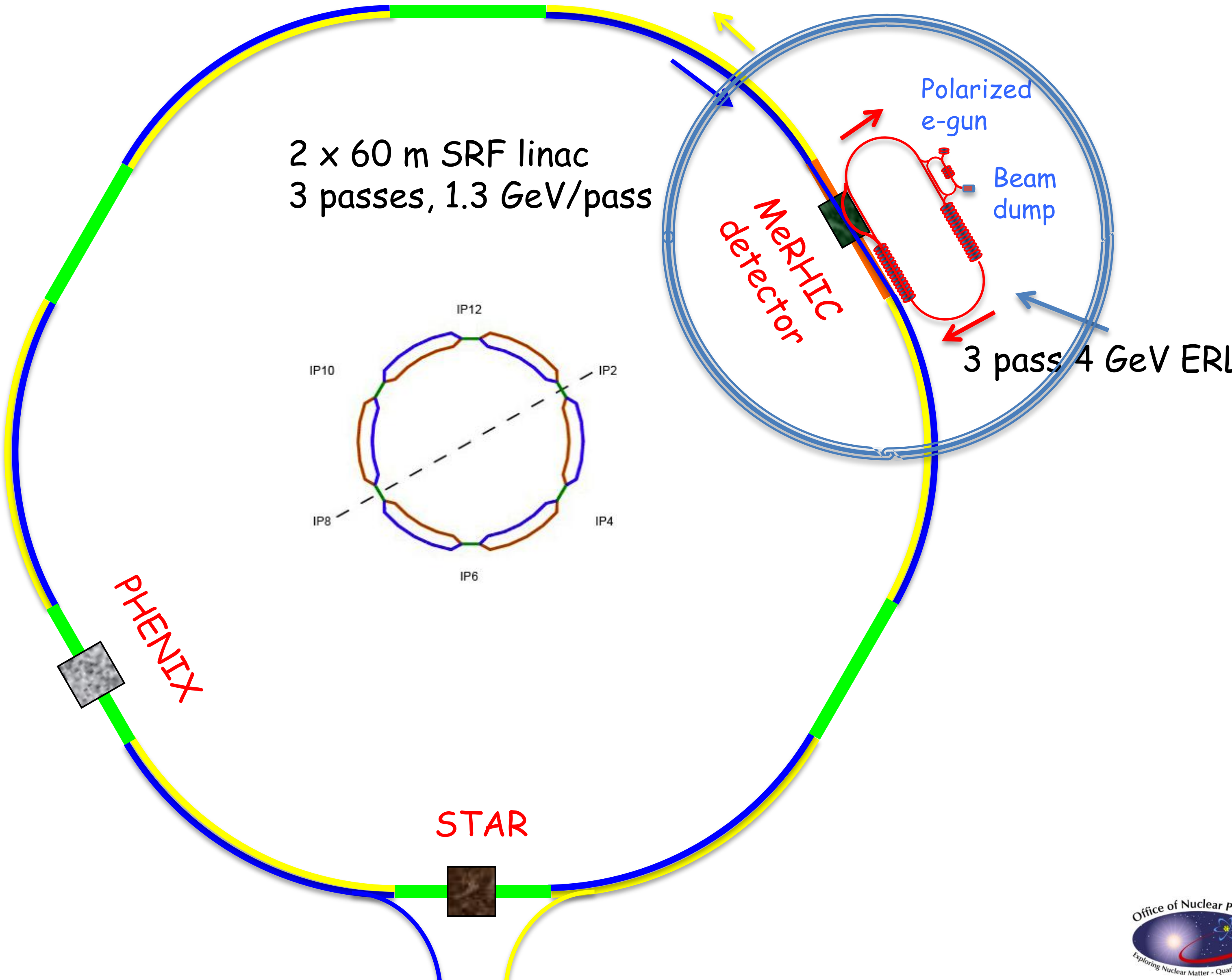
- **MeRHIC**: Medium Energy eRHIC
  - Both Accelerator and Detector are located at IP2 (or IP12) of RHIC
  - 4 GeV e^- x 250 GeV p (63 GeV c.m.), L ~ 10^{32}-10^{33} cm^{-2} sec^{-1}
  - 90% of hardware will be used for HE eRHIC
- **eRHIC, High energy and luminosity phase,** inside RHIC tunnel

  Full energy, nominal luminosity

  - Polarized 20 GeV e^- x 325 GeV p (160 GeV c.m), L ~ 10^{33}-10^{34} cm^{-2} sec^{-1}
  - 30 GeV e x 120 GeV/n Au (120 GeV c.m.), ~1/5 of full luminosity
  - and 20 GeV e x 120 GeV/n Au (120 GeV c.m.), full liminosity
- **eRHIC upgrades – if needed**
  - Higher luminosity
  - Higher hadron energy

MeRHIC is a single IP collider

4 GeV e x 250 GeV p - 100 GeV/u Au



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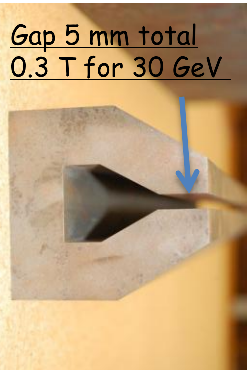
MeRHIC parameters for e-p collisions

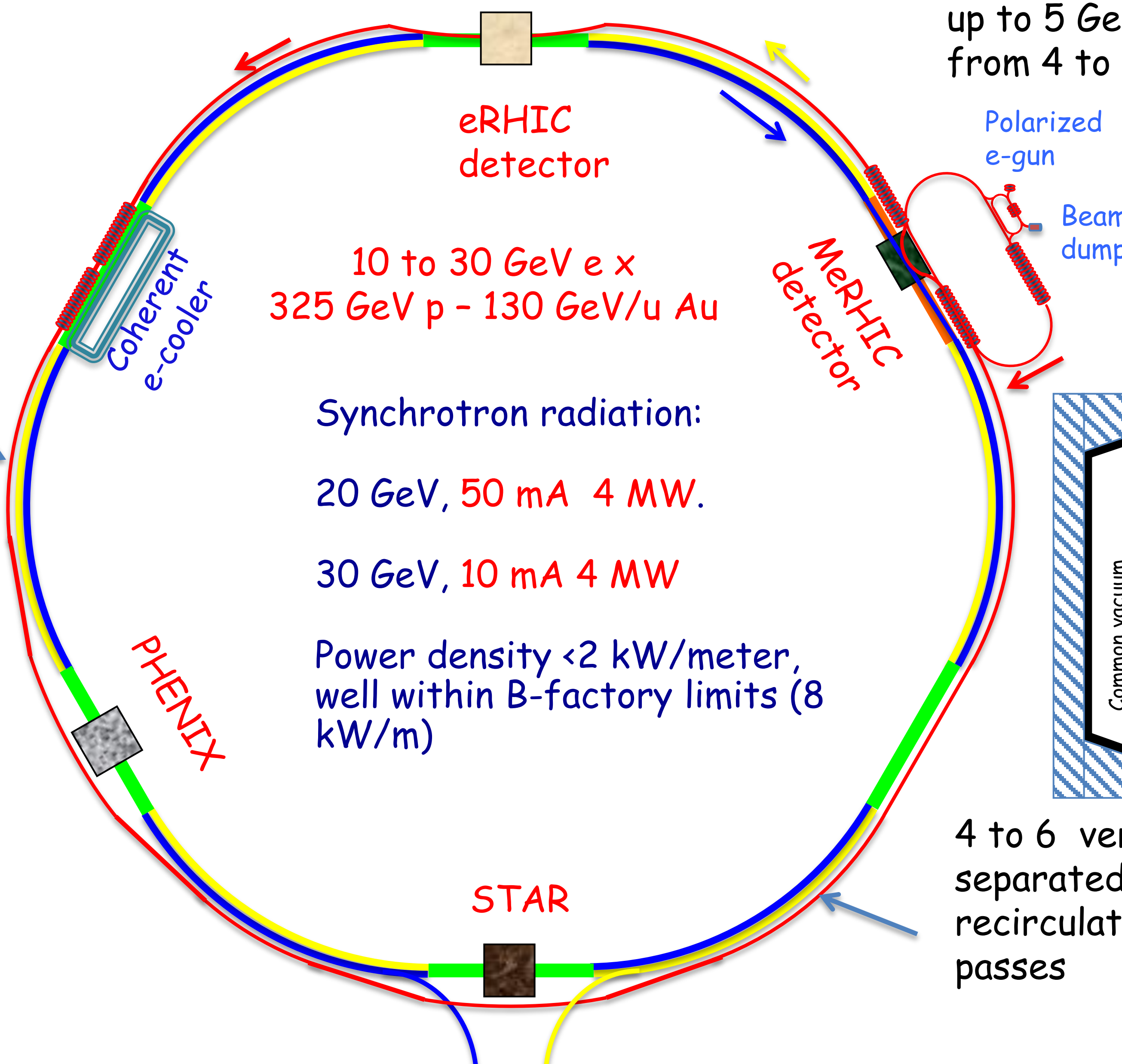
	not cooled		With cooling	
	p	e	p	e
Energy, GeV	250	4	250	4
Number of bunches	111		111	
Bunch intensity, 10^{11}	2.0	0.31	2.0	0.31
Bunch charge/current, nC/mA	32/320	5/**50**	32/320	5/**50**
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.5	7.3
rms emittance, nm	9.4	9.4	0.94	0.94
beta*, cm	50	50	50	50
rms bunch length, cm	20	0.2	5	0.2
beam-beam for p /disruption for e	1.5e-3	3.1	0.015	7.7
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	**0.93**		**9.3**	

Luminosity for light and heavy ions is the same as for e-p if measured per nucleon!

High energy stage of eRHIC: by adding additional linacs as well as recirculating passes in RHIC tunnel

2 x 200 m SRF linac
up to 5 GeV per pass
from 4 to 6 passes





10 to 30 GeV e x
325 GeV p – 130 GeV/u Au

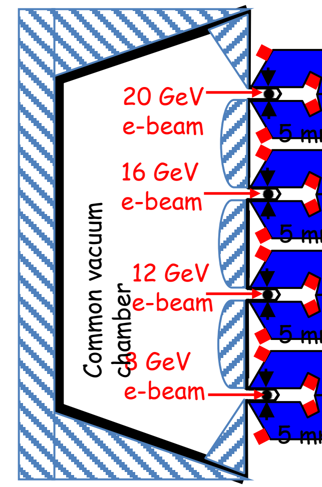
Synchrotron radiation:

20 GeV, 50 mA 4 MW.

30 GeV, 10 mA 4 MW

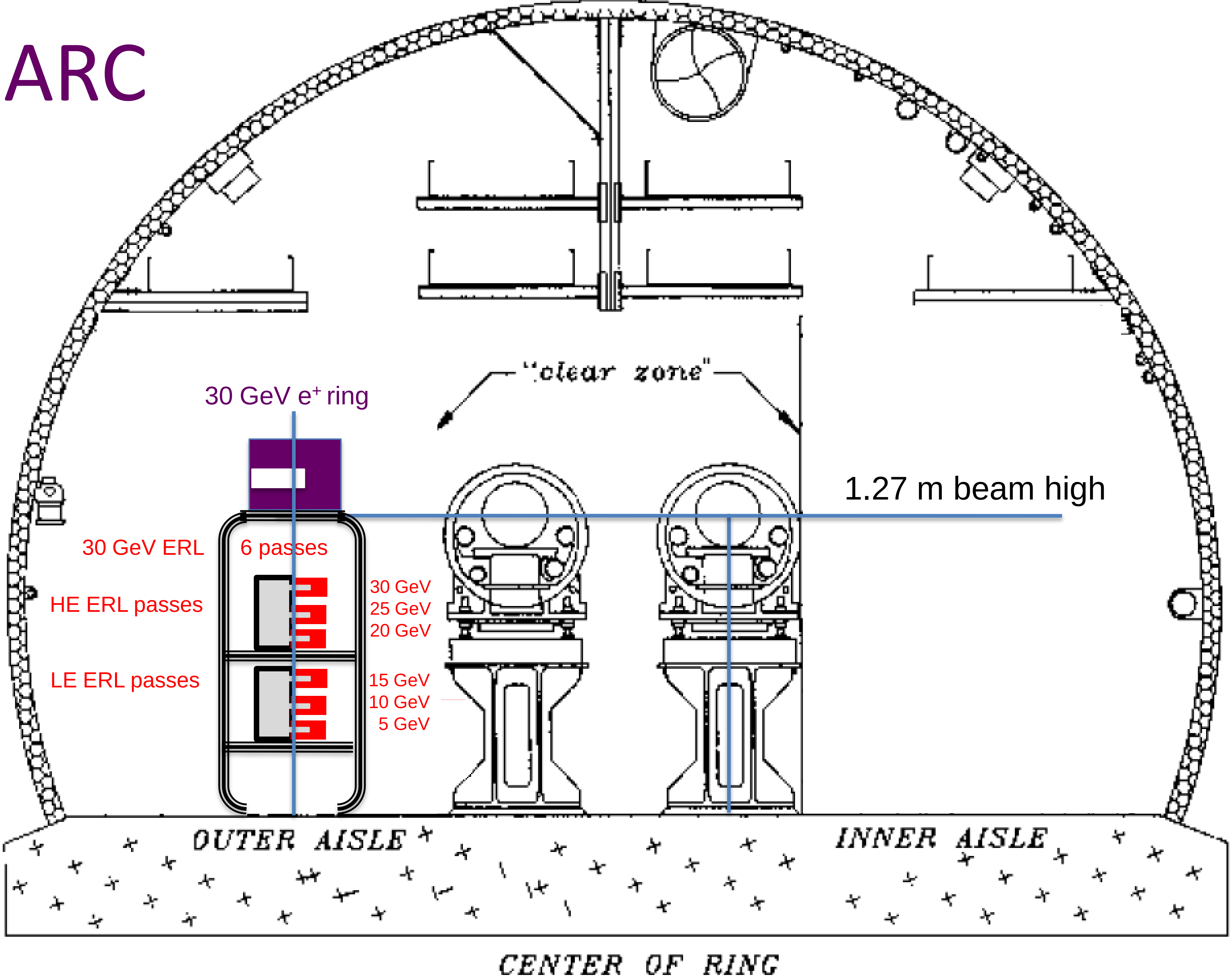
Power density <2 kW/meter, well within B-factory limits (8 kW/m)

Possibility of 30 GeV low current operation



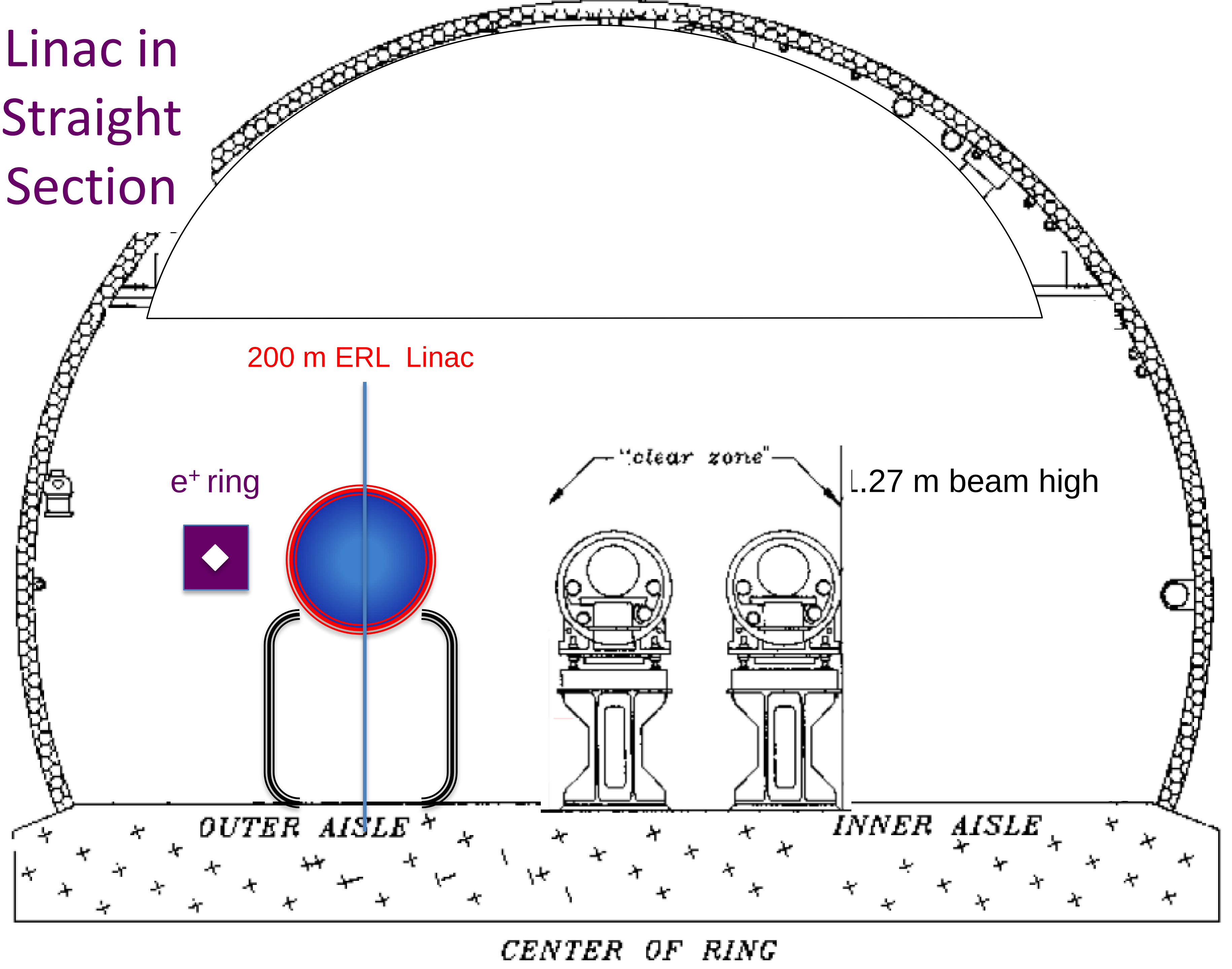
4 to 6 vertically separated recirculating passes

ARC



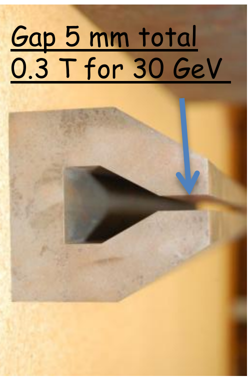
30 GeV e+ ring
"clear zone"
1.27 m beam high
30 GeV ERL
6 passes
HE ERL passes
30 GeV
25 GeV
20 GeV
LE ERL passes
15 GeV
10 GeV
5 GeV
OUTER AISLE
INNER AISLE
CENTER OF RING

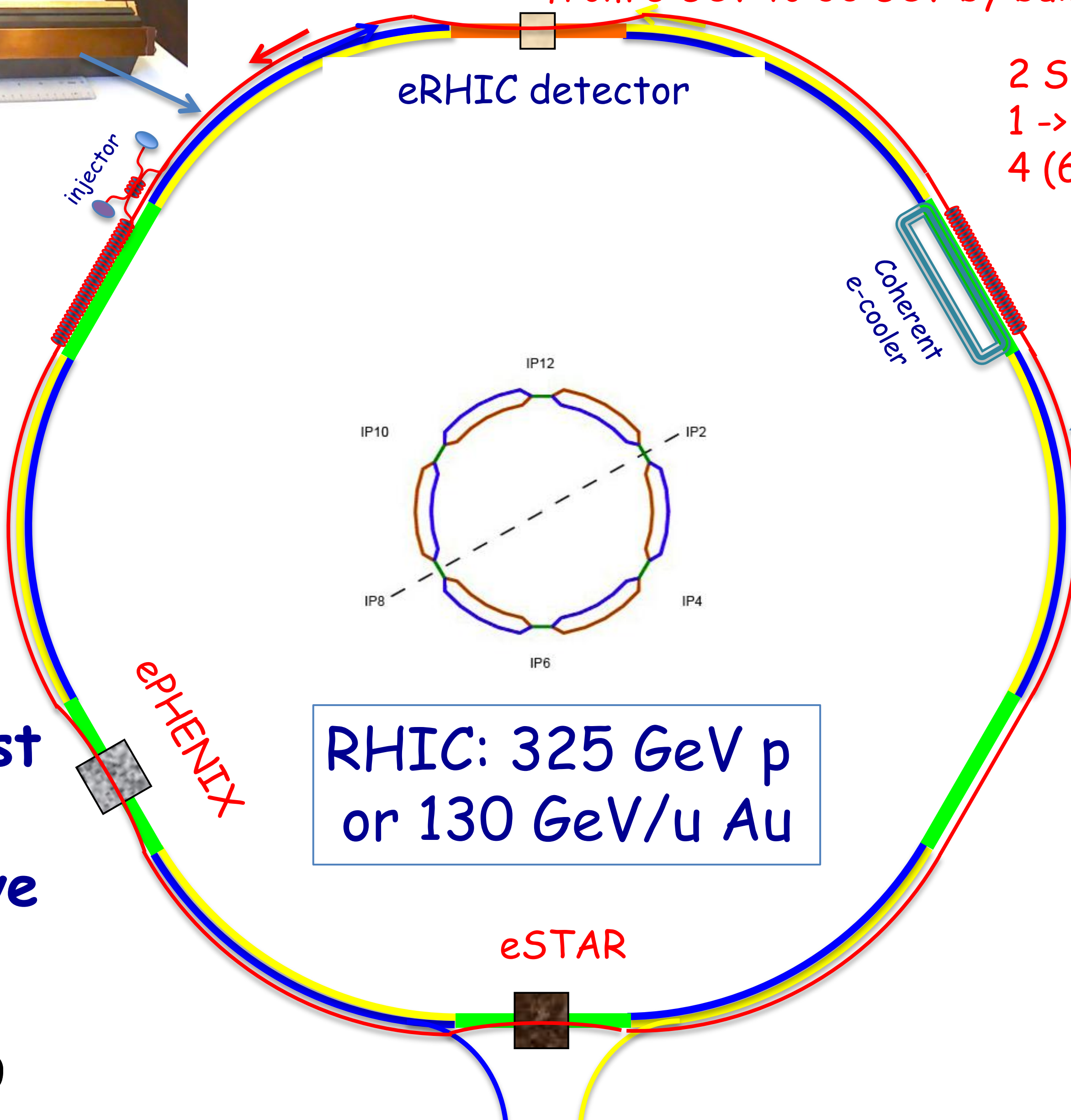
Linac in Straight Section



Staging approach under consideration presently: staging all-in tunnel eRHIC:

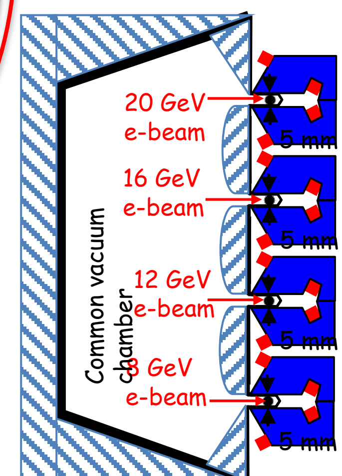
energy of electron beam is increasing from 5 GeV to 30 GeV by building-up the linacs





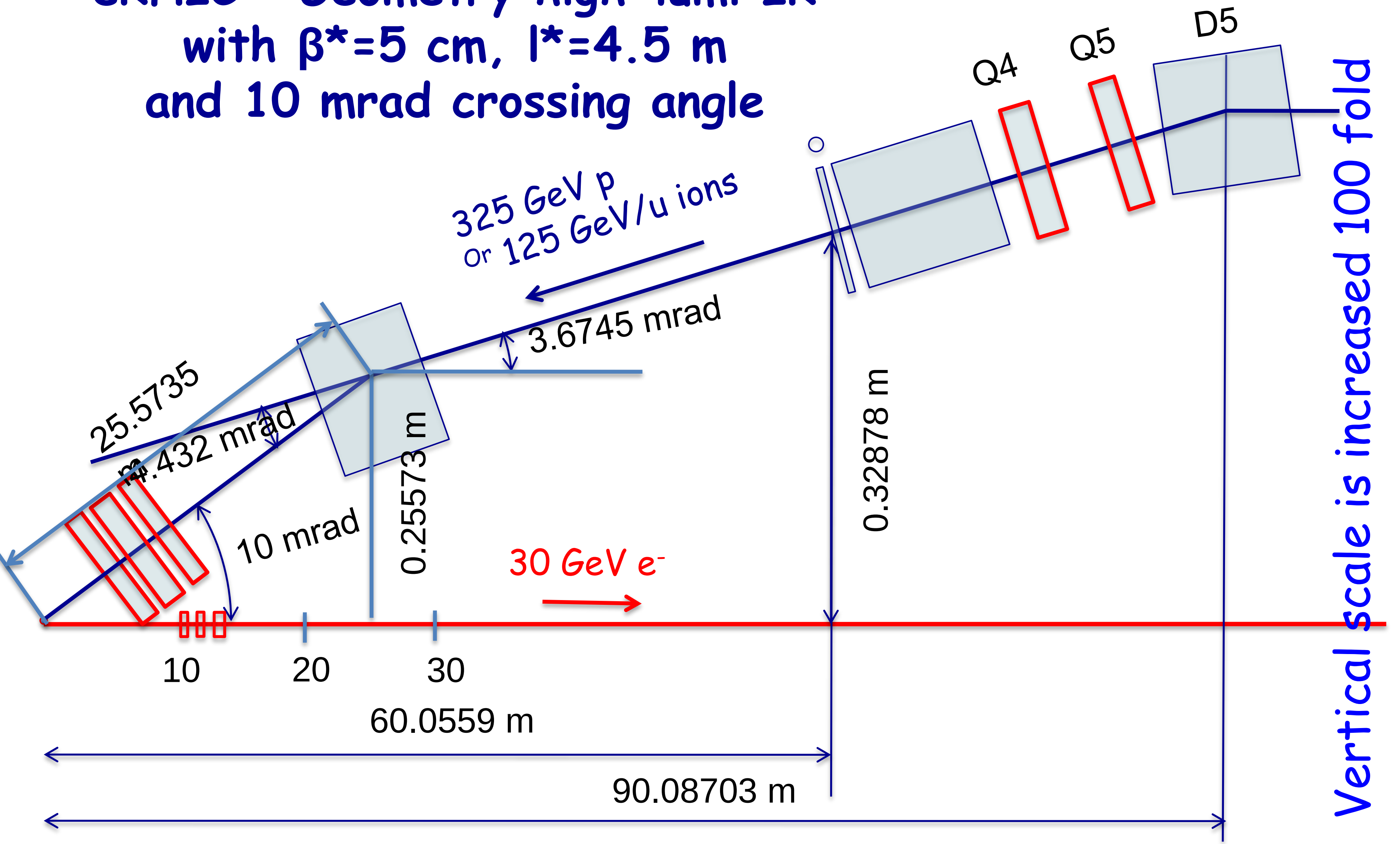
2 SRF linac
1 -> 5 GeV per pass
4 (6) passes

4 to 6 vertically separated recirculating passes.
# of passes will be chosen to optimize eRHIC cost



The most cost effective design

eRHIC – Geometry high-lumi IR with β*=5 cm, l*=4.5 m and 10 mrad crossing angle



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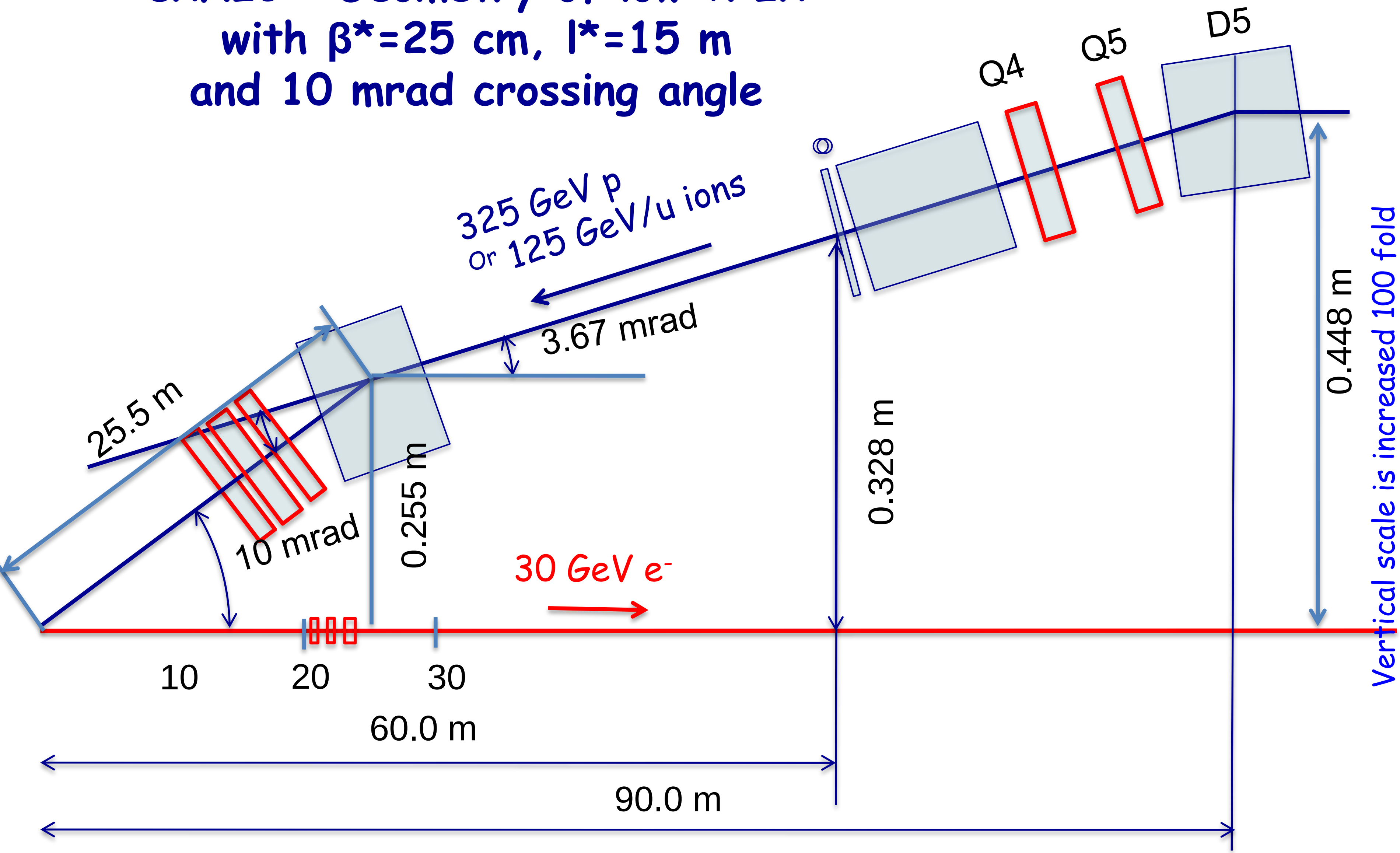
eRHIC – Geometry of low-x IR with β*=25 cm, l*=15 m and 10 mrad crossing angle



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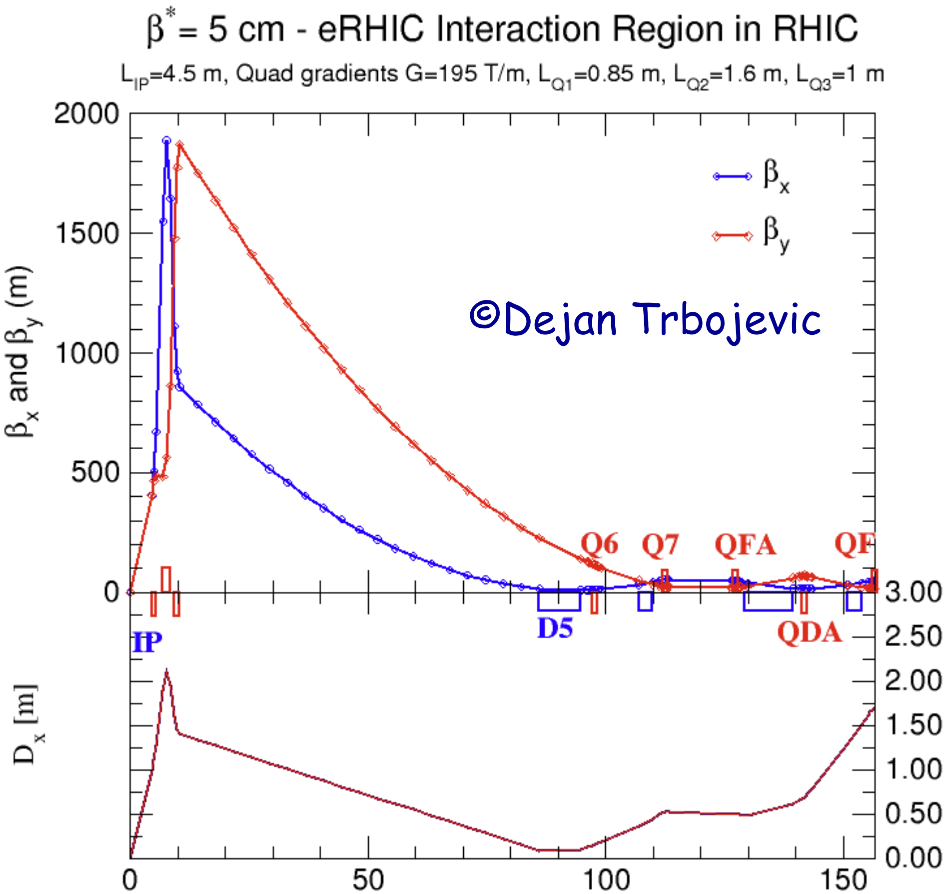
High luminosity IR design, β*=5cm

First quadrupole is 4.5 m from IP

L=1.4x10^34

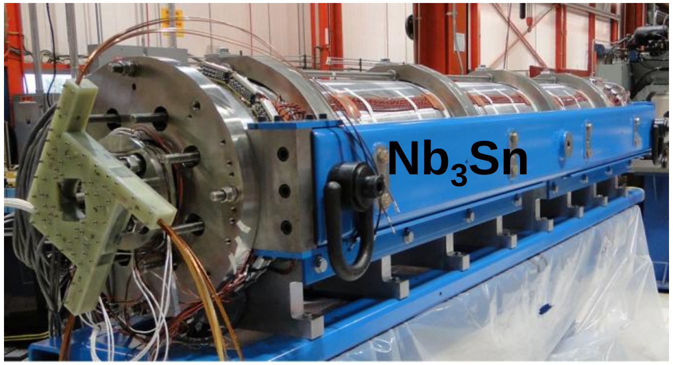


TRIPLET:

GDB1 = -197.05051 T/m

GFB2 = 199.49689 T/m

GDB3 = -192.97180 T/m



Plan to use newly commissioned LARP SC quads with 200 T/m gradient

Consideration of a design which includes crossing angle and crab cavities is presently under way. Simpler management of detector protection from synchrotron radiation

Luminosity in eRHIC

	eRHIC IR1		eRHIC IR2	
	p /A	e	p /A	e
Energy (max), GeV	325/130	20	325/130	20
Number of bunches	166	74 nsec	166	74 nsec
Bunch intensity (u) , 10^{11}	2.0	0.24	2.0	0.24
Bunch charge, nC	32	4	32	4
Beam current, mA	420	50	420	50
Normalized emittance, 1e-6 m, 95% for p / rms for e	1.2	25	1.2	25
Polarization, %	70	80	70	80
rms bunch length, cm	4.9	0.2	4.9	0.2
β*, cm	25	25	5	5
Luminosity, $cm^{-2}s^{-1}$	2.8×10^{33}		1.4×10^{34}	

Luminosity for 30 GeV e-beam operation will be at 20% level

From EICAC Report on Accelerator R&D Priorities

Highest priority:

- Design of JLab EIC
- High current (e.g. 50 mA) polarized electron gun
- Demonstration of high energy – high current recirculation ERL
- Beam-Beam simulations for EIC
- Polarized 3He production and acceleration
- Coherent electron cooling

High priority, but could wait until decision made:

- Compact loop magnets
- Electron cooling for JLab concepts
- Traveling focus scheme (it is not clear what the loss in performance would be if it doesn't work; it is not a show stopper if it doesn't)
- Development of eRHIC-type SRF cavities

Medium Priority:

- Crab cavities
- ERL technology development at JLAB

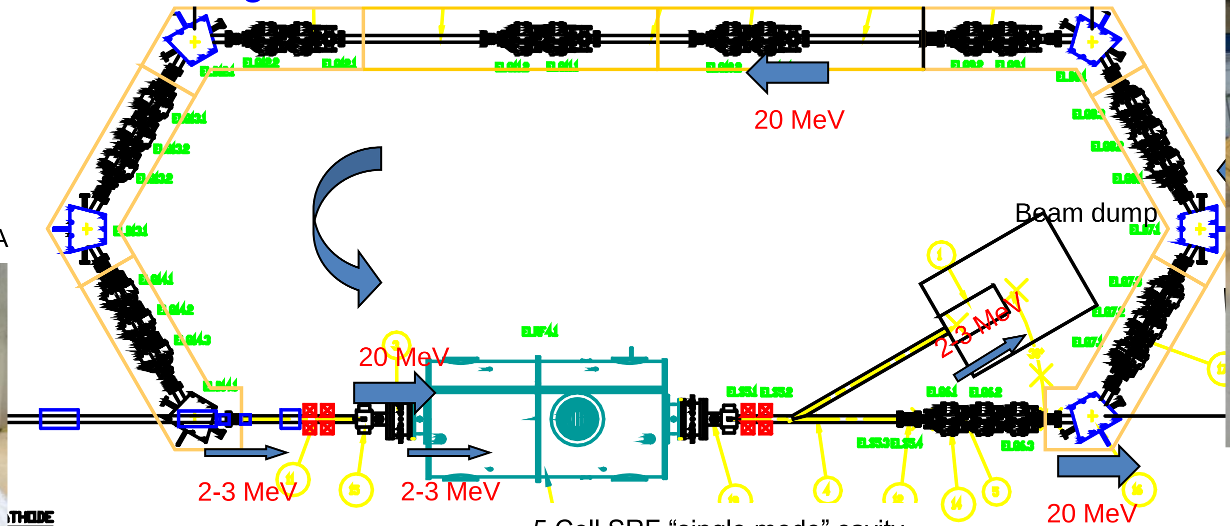
Main R&D Items

- 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

Energy Recovery Linac (ERL) Test Facility

- Test of high current (0.5 A), high brightness ERL operation
- Electron beam for RHIC (coherent) electron cooling (54 MeV, 10 MHz, 5 nC, 4 μm)
- Test for 10 – 20 GeV high intensity ERL for eRHIC
- Test of high current beam stability issues, highly flexible return loop lattice
- Allows for addition of a 2nd recirculation loop
- Start of commissioning: 2011.

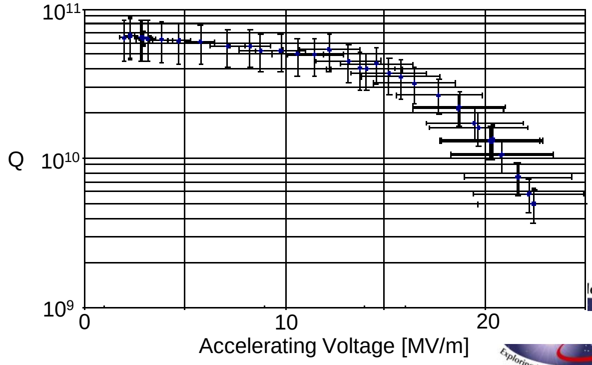
Return loop



SRF Gun
2MV, 0.5A

1 MW, 703.75 MHz CW Klystron

5 Cell SRF “single mode” cavity
Q > 10^{10} @20 MV/m CW



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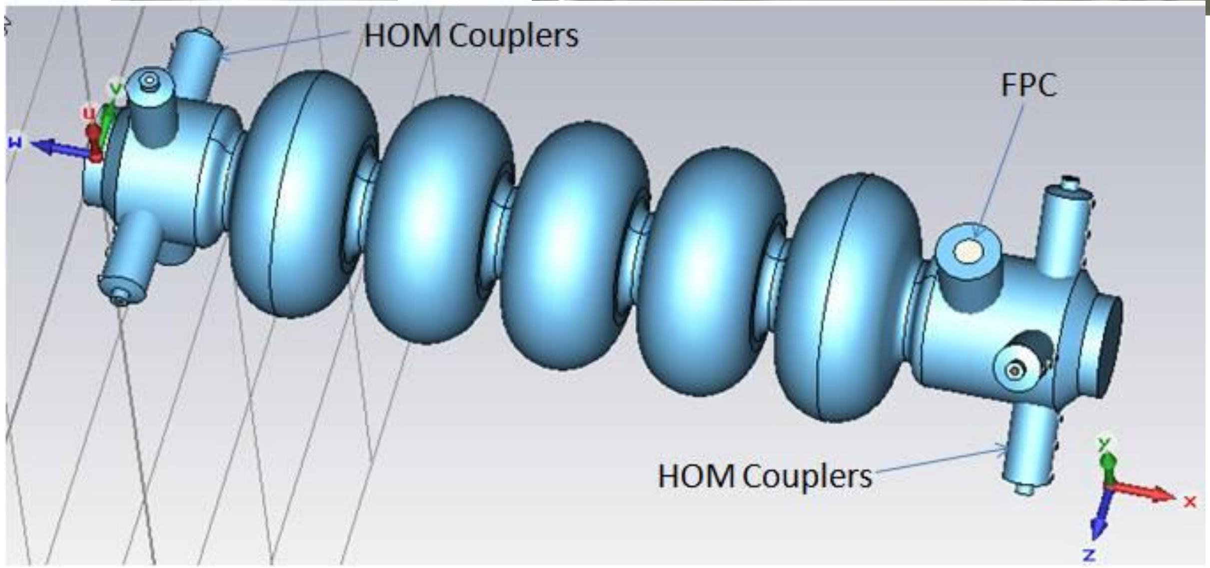
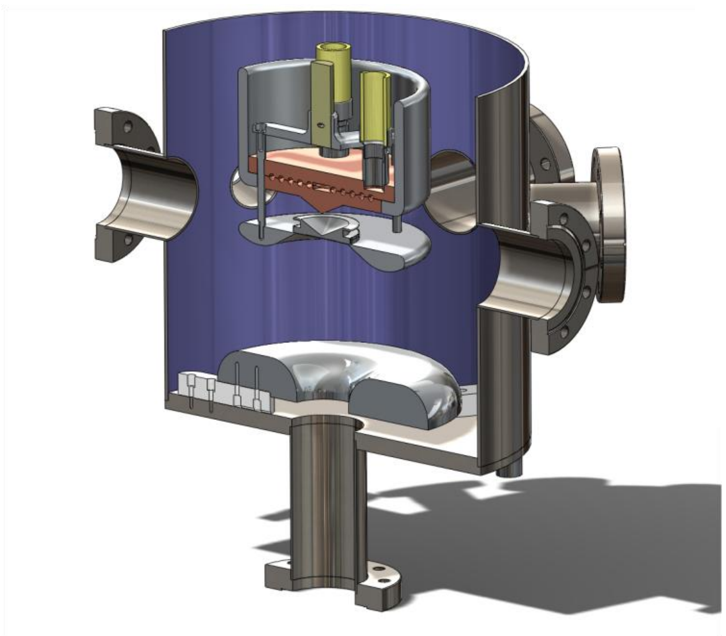
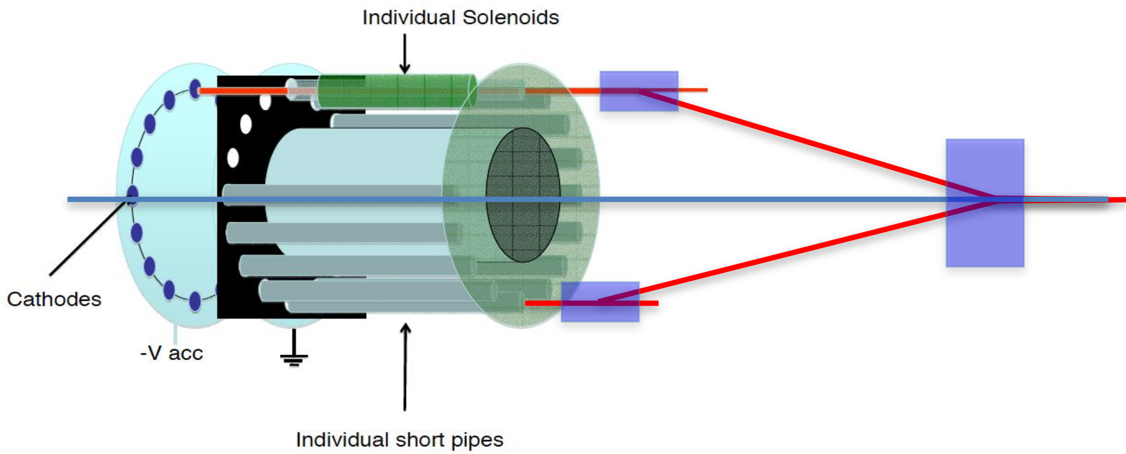
High-current cavity R&D

- Based on the success of our BNL I cavity, with experience gained we are designing our next generation cavity for eRHIC.



Main technical challenge is 50 mA CW polarized gun: we are investigating two versions





Funneling ("Gatling") gun

Parameter	Value
Laser longitudinal distribution	Gaussian
Bunch length at cathode	1 nS [FWHM
Laser transverse distribution	Uniform
Laser spot diameter	8mm
Bunch charge	5nC
Accelerating voltage	200kV
Cathode-anode gap	3cm
Integrated solenoid field	2.1kG-cm

Single large size cathode

E.Tsentalovich, MIT

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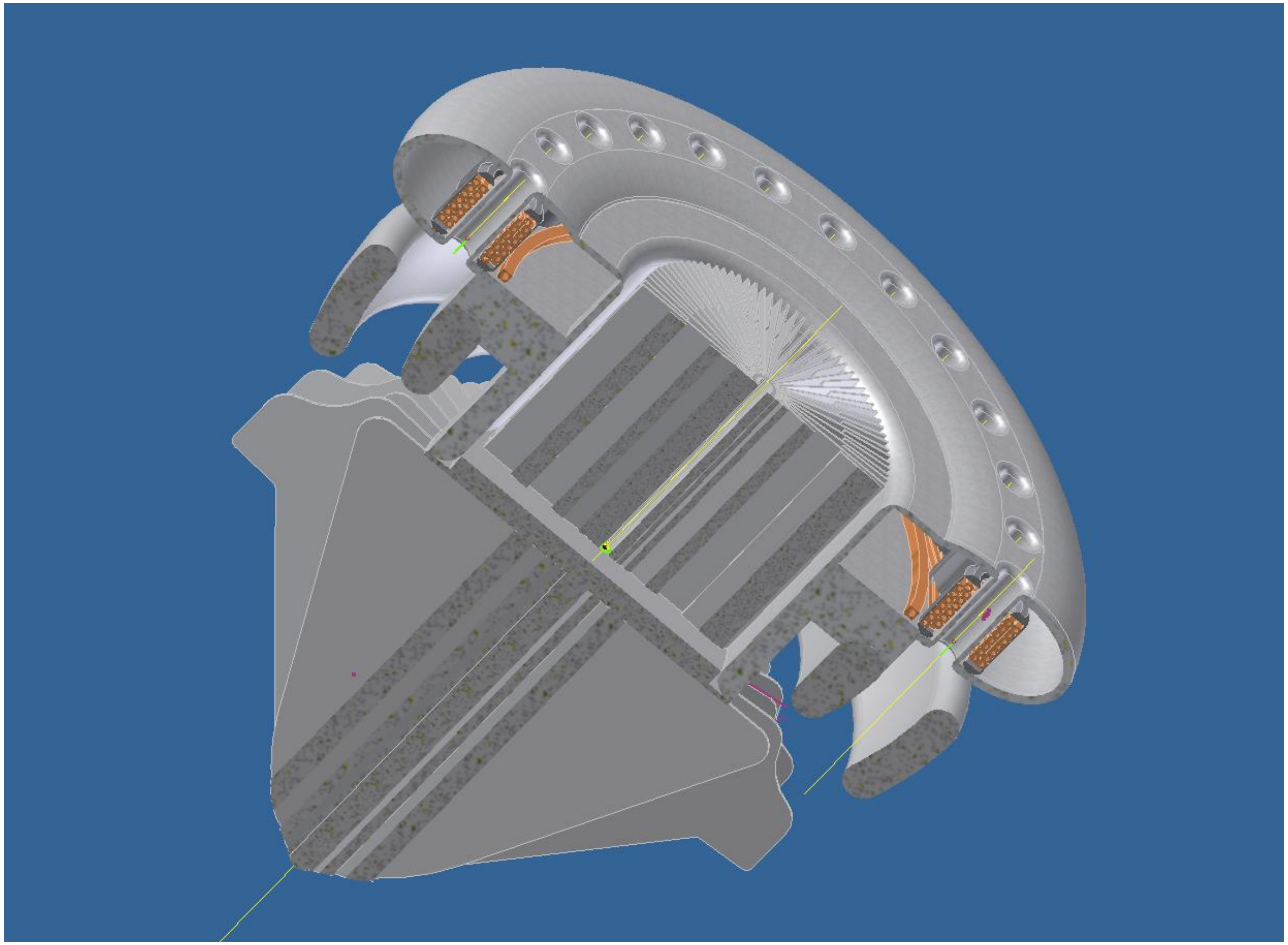
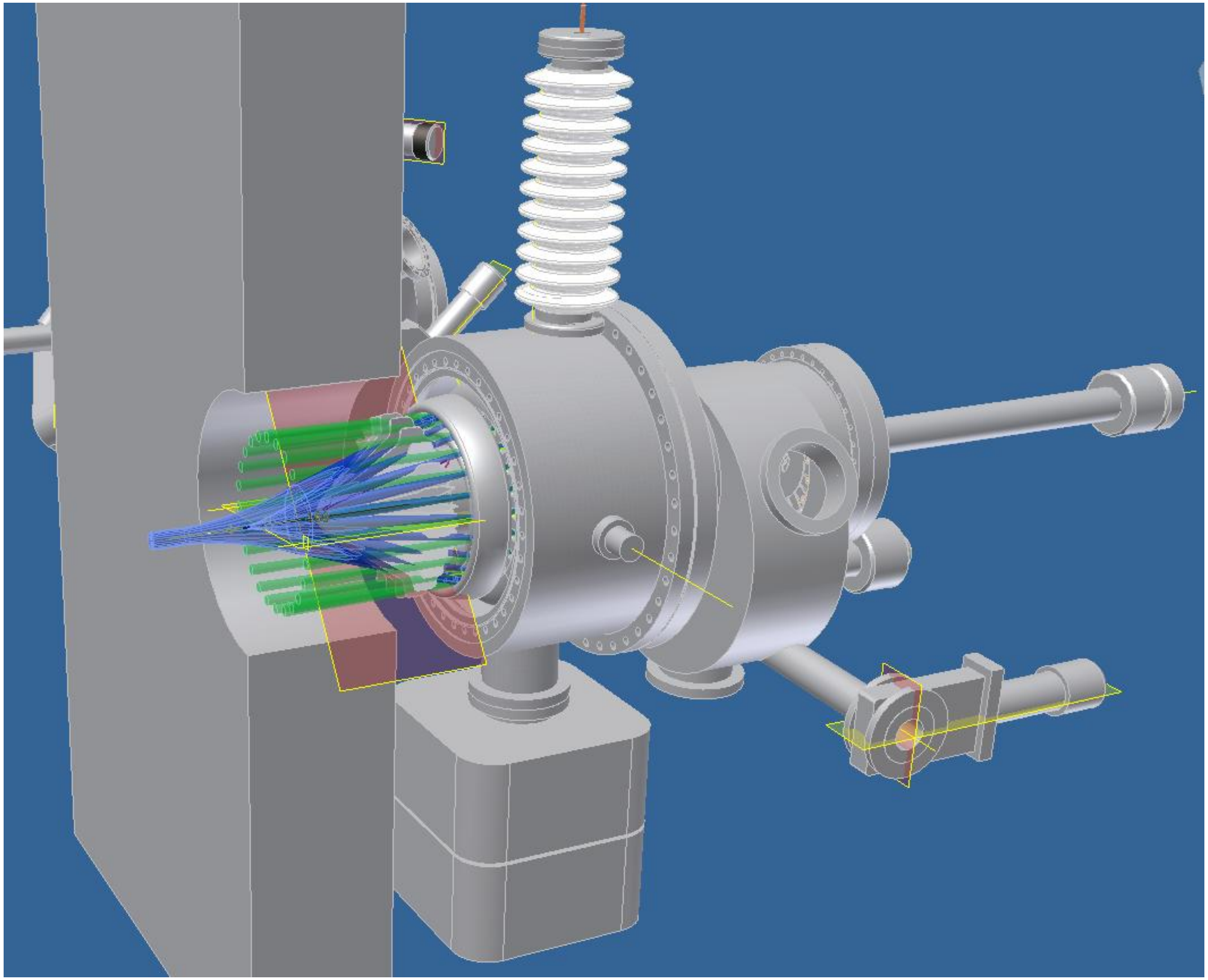
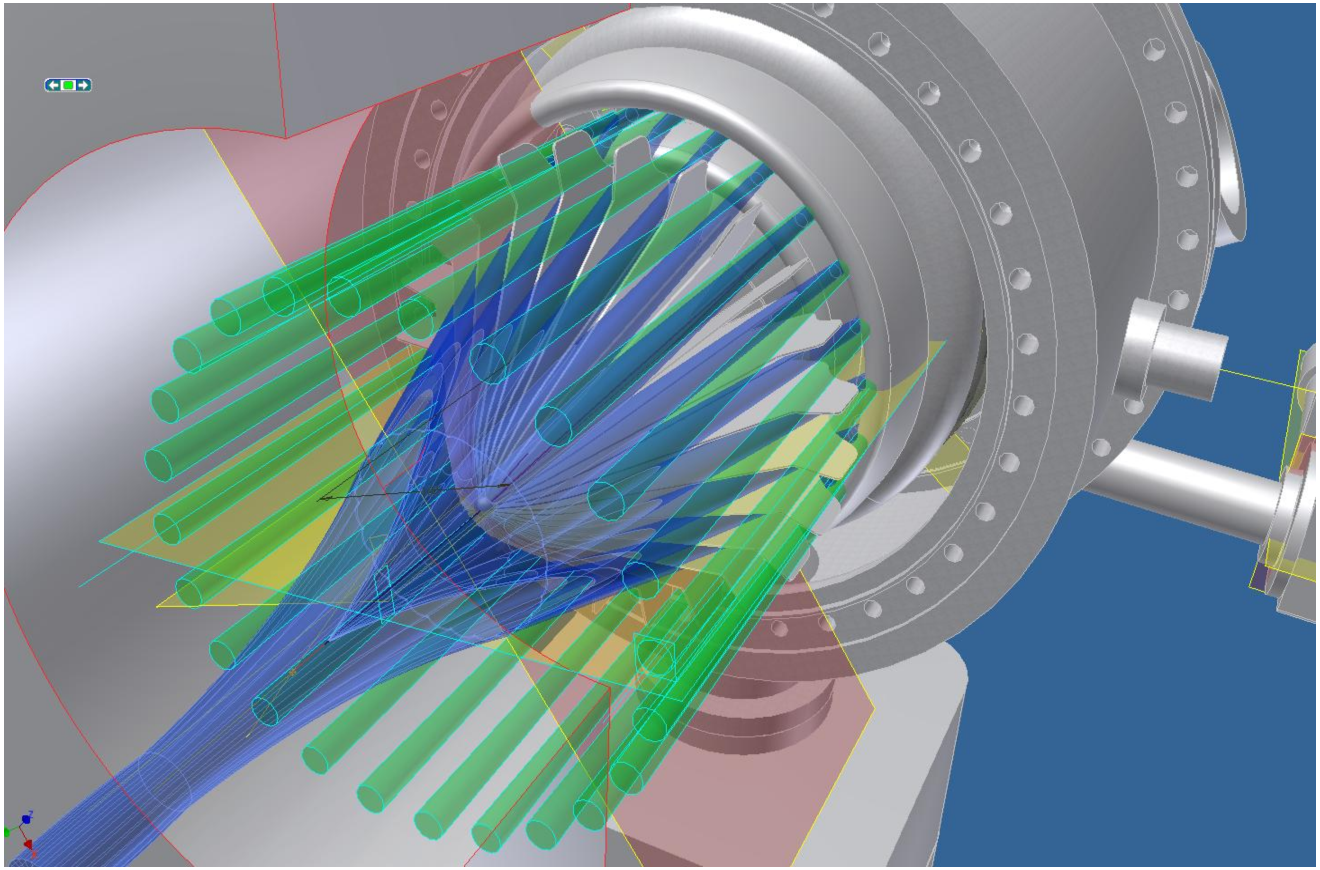
Sectioned view of Anode assembly depicting the solenoids electrostatic steerer and NEG pump arrays



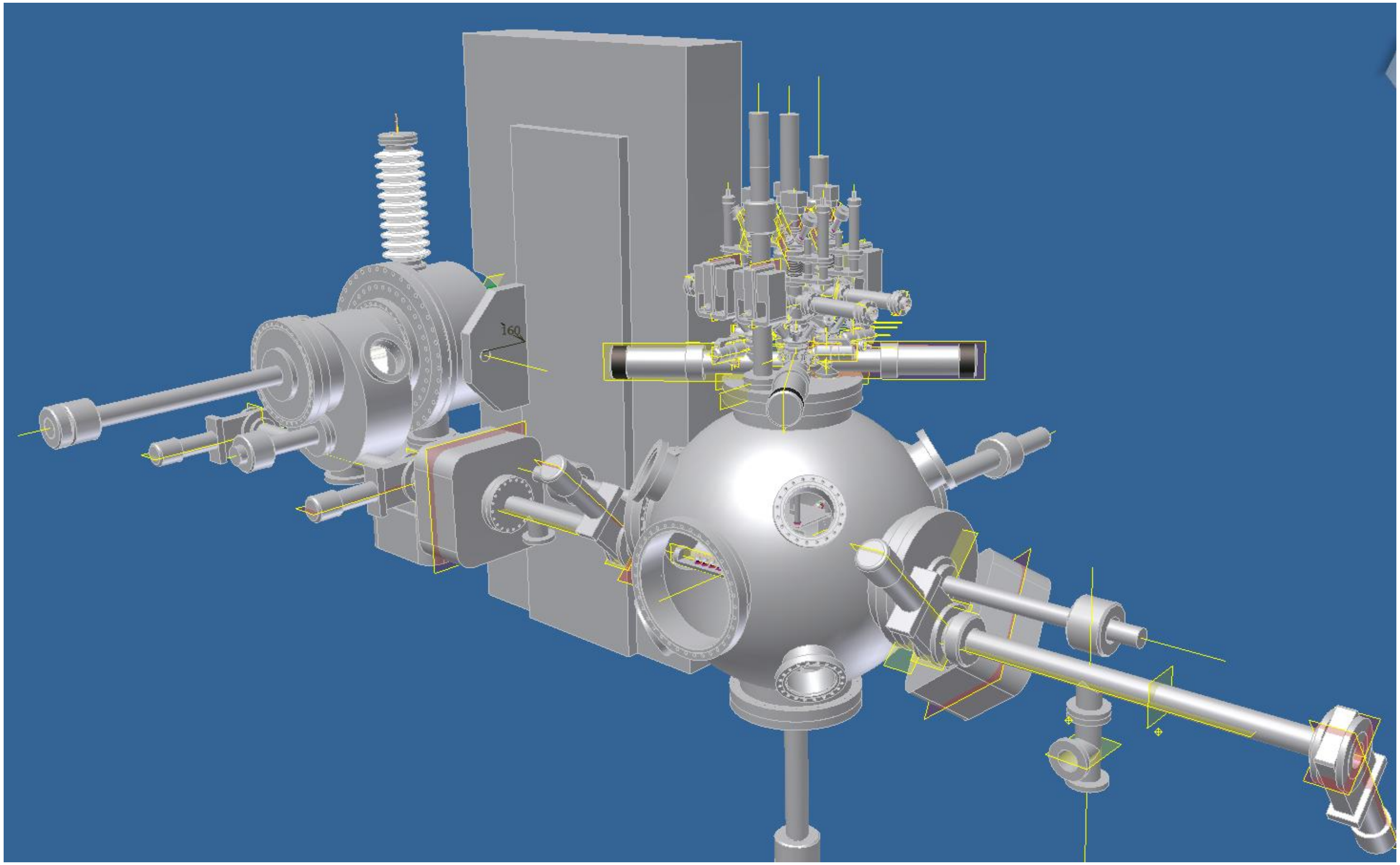
View of Gun Assembly



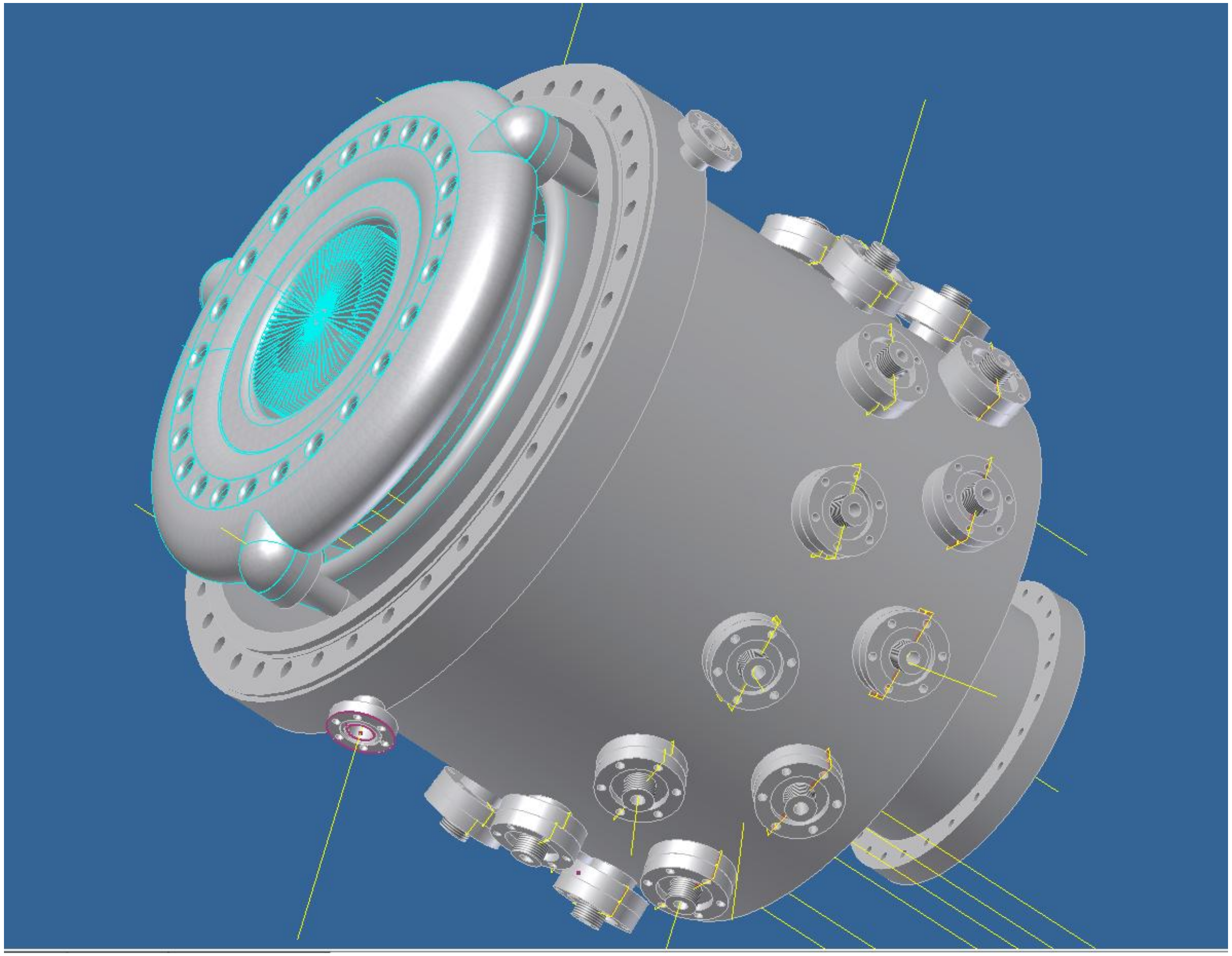
View of 24 incident LASERs (green) and the paths of the resultant electron beams (blue)



View of gun and cathode preporation chambers



Anode and Solenoid with electrostatic feedthrough assembly



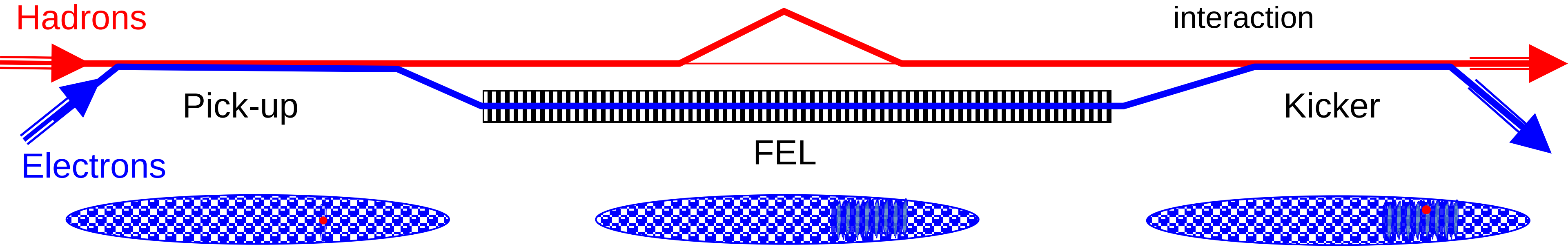
Coherent Electron Cooling

- Idea proposed by Y. Derbenev in 1980, novel scheme with full evaluation developed by V. Litvinenko. Draws on advantages of electron cooling AND stochastic cooling.
- Fast cooling of high energy hadron beams, independent of beam energy.
- Made possible by high brightness electron beams and FEL technology
- ~ 20 minutes cooling time for 250 GeV protons at much reduced electron current, higher eRHIC luminosity
- Proof-of-principle demonstration possible in RHIC using test ERL.

Pick-up: electrostatic imprint of hadron charge distribution onto co-moving electron beam

Amplifier: Free Electron Laser (FEL) with gain of 100 -1000 amplifies density variations of electron beam, energy dependent delay of hadron beam

Kicker: electron beam corrects energy error of co-moving hadron beam through electrostatic interaction



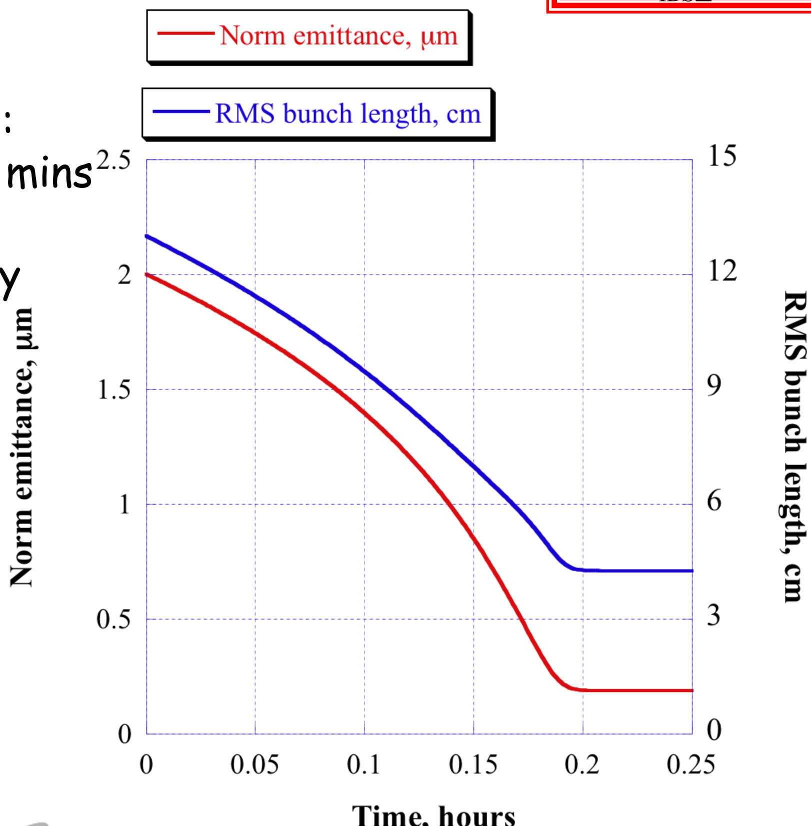
Gains from coherent e-cooling:

Coherent Electron Cooling vs. IBS

$$\varepsilon_{xn0} = 2\,\mu m;\ \sigma_{s0} = 13\,cm;\ \sigma_{\delta 0} = 4\cdot 10^{-4}$$
$$\tau_{IBS\perp} = 4.6\ \ hrs;\ \tau_{IBS//} = 1.6\ \ hrs;$$

IBS in RHIC for eRHIC, 250 GeV, N_p=2·10[11]
Beta-cool, A.Fedotov

Dynamics:
Takes 12 mins to reach stationary point



$$\varepsilon_{xn} = 0.2\,\mu m;\ \sigma_s = 4.9\ \ \text{cm}$$

This allows

a) keep the luminosity as it is
b) have polarized beam current down to 50 mA (10 mA for e-I)
c) increase electron beam energy to 20 GeV (30 GeV for e-I)
d) increase luminosity by reducing β* from 25 cm down to 5 cm

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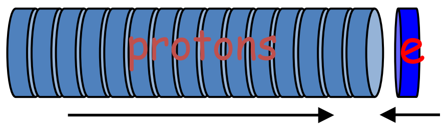
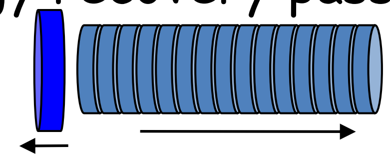
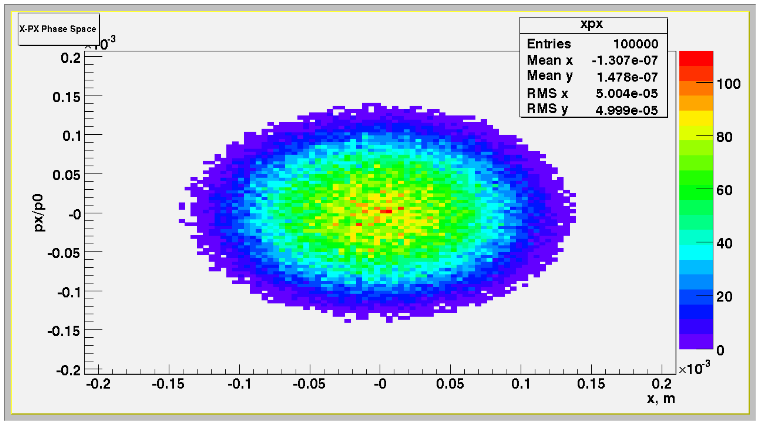
e-Beam Disruption by collisions – disrupted bunches have to be decelerated in energy recovery passes

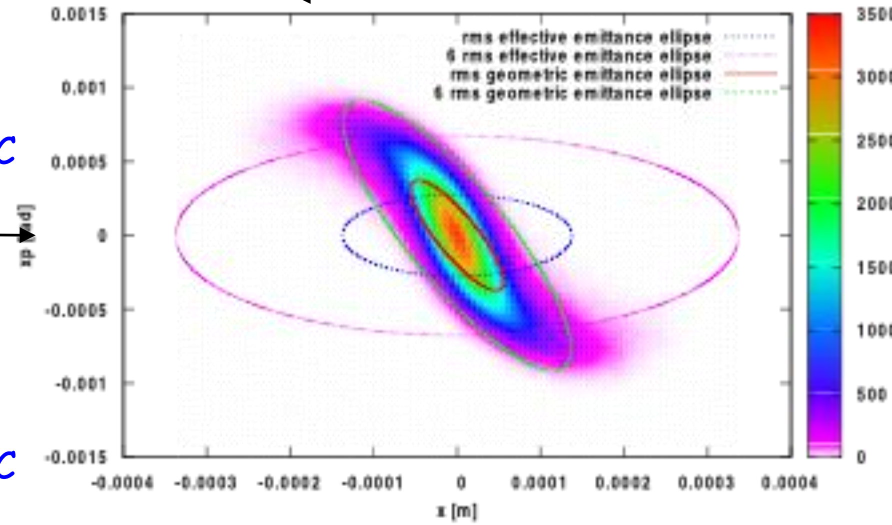


Y. Hao

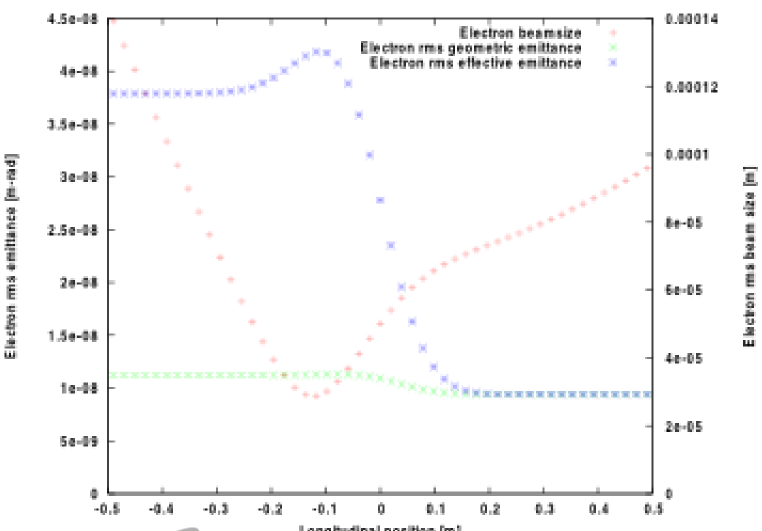


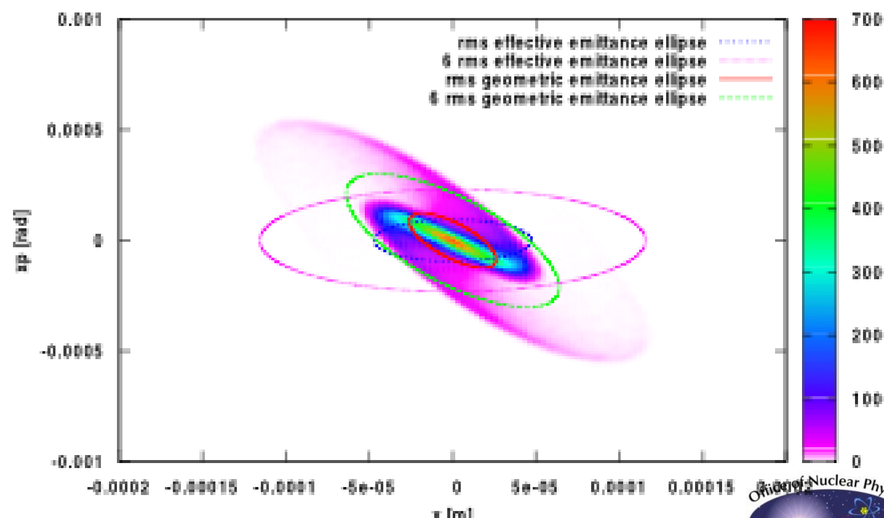


MeRHIC



eRHIC





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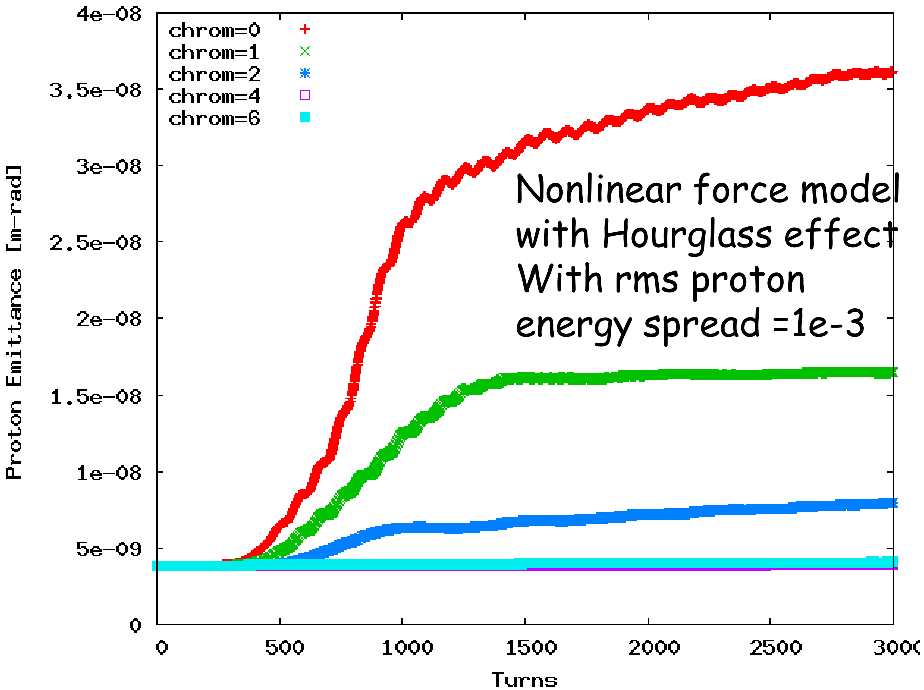
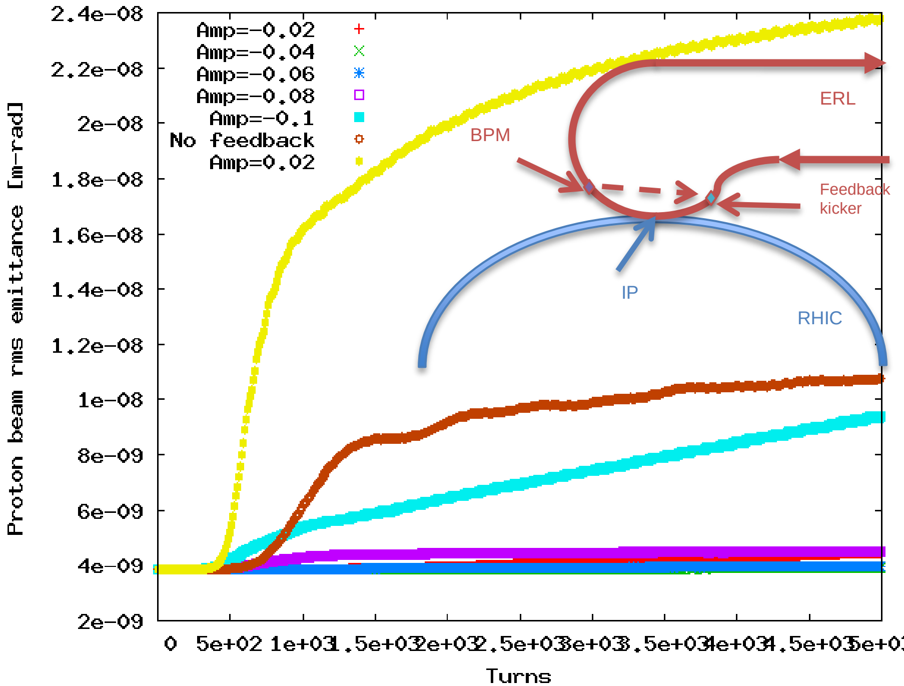
Suppression of kink instability

Y. Hao





By chromaticity: ~ +4

By feedback

Kink instability – a possible instability of the proton beam caused by its interaction with the electrons. Specific for linac-ring scheme.

Simple feed-back on electron beam suppress kink instability completely for all MeRHIC/eRHIC parameter ranges.

Electron polarization in eRHIC

The polarization benefits greatly from the linac acceleration geometry

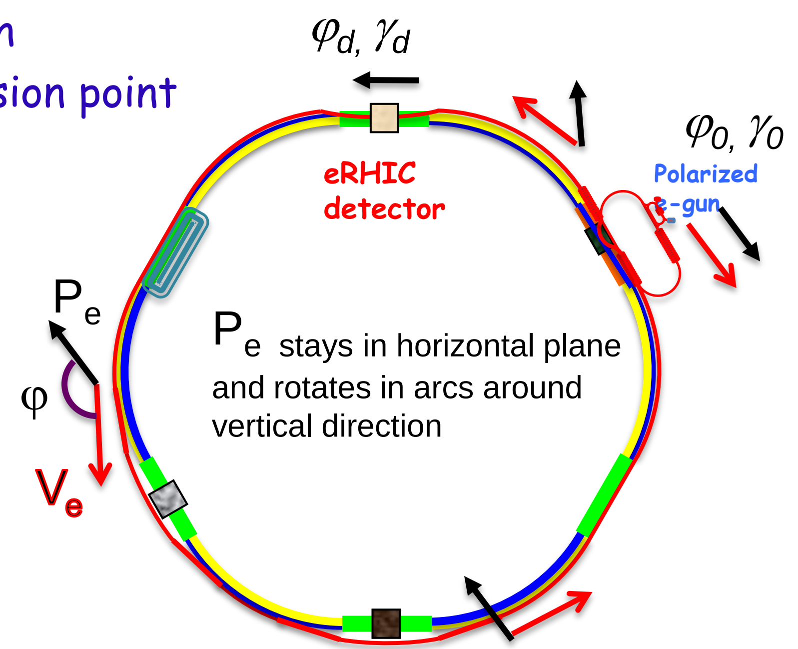
- No coherent buildup of small depolarizing errors -> No problem with depolarizing resonances
- No depolarization due to synchrotron radiation
- Simple control of spin orientation at the collision point

The polarization orientation at the eRHIC detector:

$$\varphi_d = \varphi_0 + G\int_0^{\theta_d} \gamma(\theta)\,d\theta$$

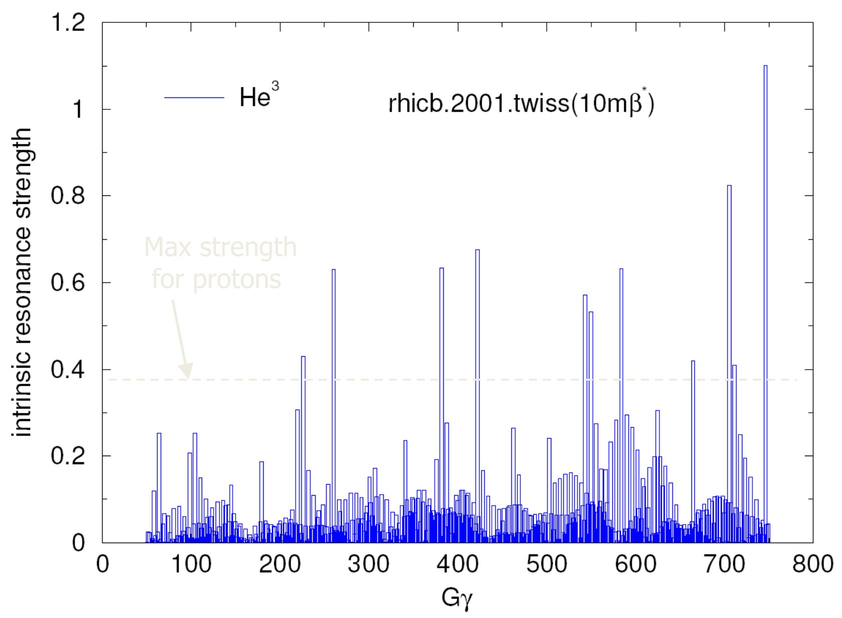
Adjusted by Wien filter rotator after the source

Adjusted by modifications of energy gains in the linacs



Polarized $^3He^{+2}$ for eRHIC

- Larger G factor than for protons
- RHIC Siberian snakes and spin rotators can be used for the spin control, with less orbit excursions than with protons.
- More spin resonances. Larger resonance strength.
- Spin dynamics at the acceleration in the injector chain and in RHIC has to be studied.



	$^3He^{+2}$	p
m, GeV	2.808	0.938
G	-4.18	1.79
E/n, GeV	16.2-166.7	24.3-250
γ	17.3-177	25.9-266
$\lvert G\gamma \rvert$	72.5-744.9	46.5-477.7

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