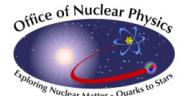


eRHIC Accelerator Design Status

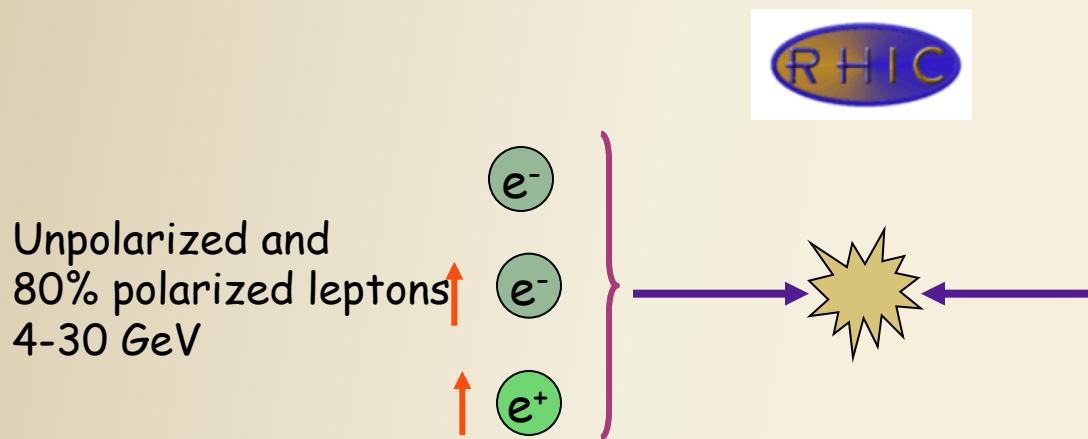
*J. Beebe-Wang, V. Ptitsyn, D. Trbojevic
on behalf of the eRHIC Design team*

**Workshop on electron-Nucleus Collider Physics
New York City , May 14, 2010**



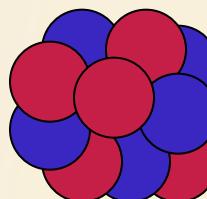
eRHIC: QCD Test Facility

Electron accelerator

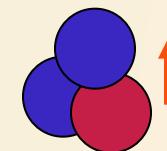


RHIC

p ↑ 70% Polarized protons
 $_{25} \downarrow$ 50-250 (325) GeV



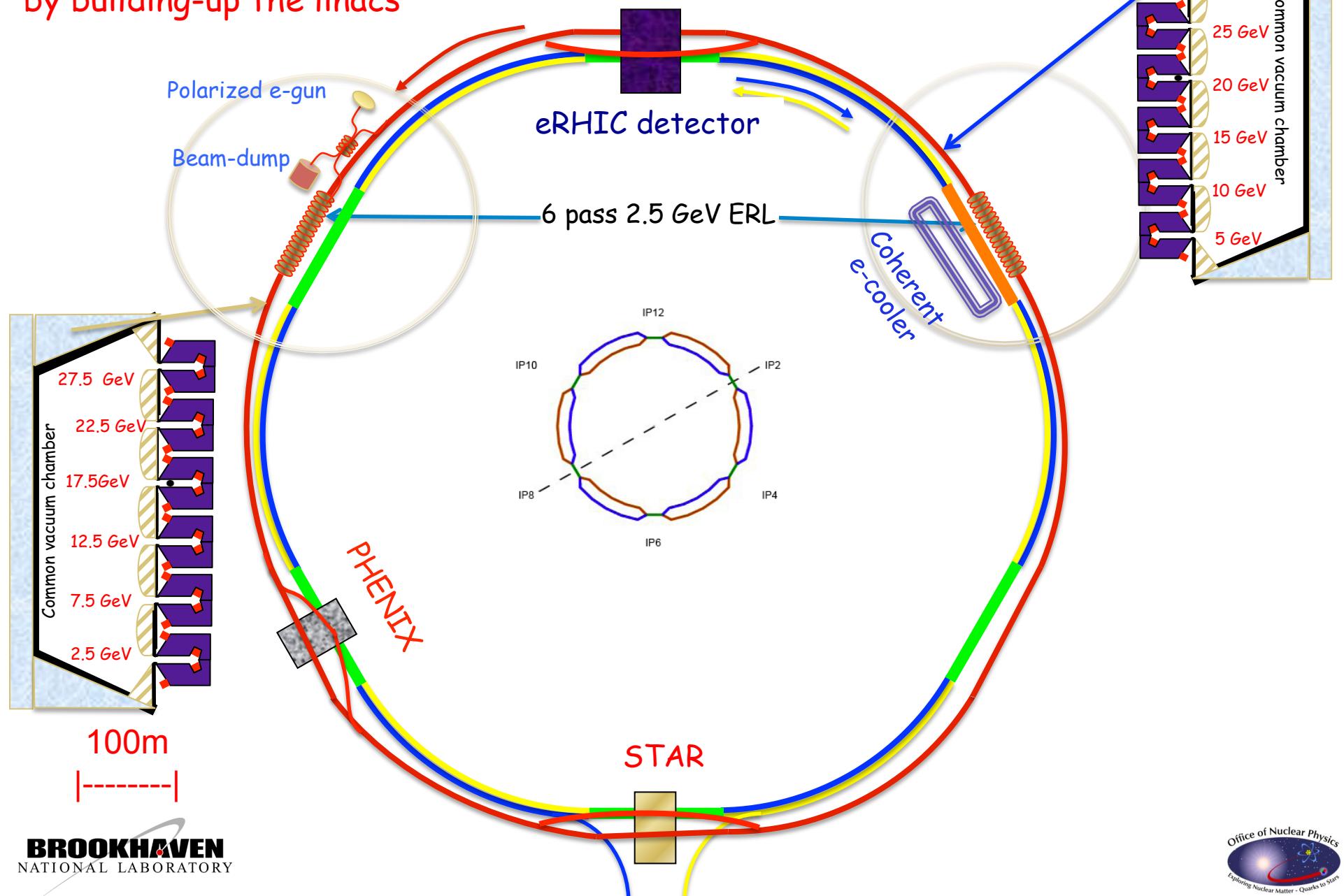
Light ions (d, Si, Cu)
Heavy ions (Au, U)
50-100 (130) GeV/u



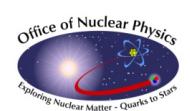
Polarized light ions
(He^3) 215 GeV/u

Center of mass energy range: 20-200 GeV
Any polarization direction in lepton-hadrons collisions

Staging all-in tunnel eRHIC:
energy of electron beam is increasing from 5 GeV to 30 GeV
by building-up the linacs



BROOKHAVEN
NATIONAL LABORATORY



Luminosity in eRHIC

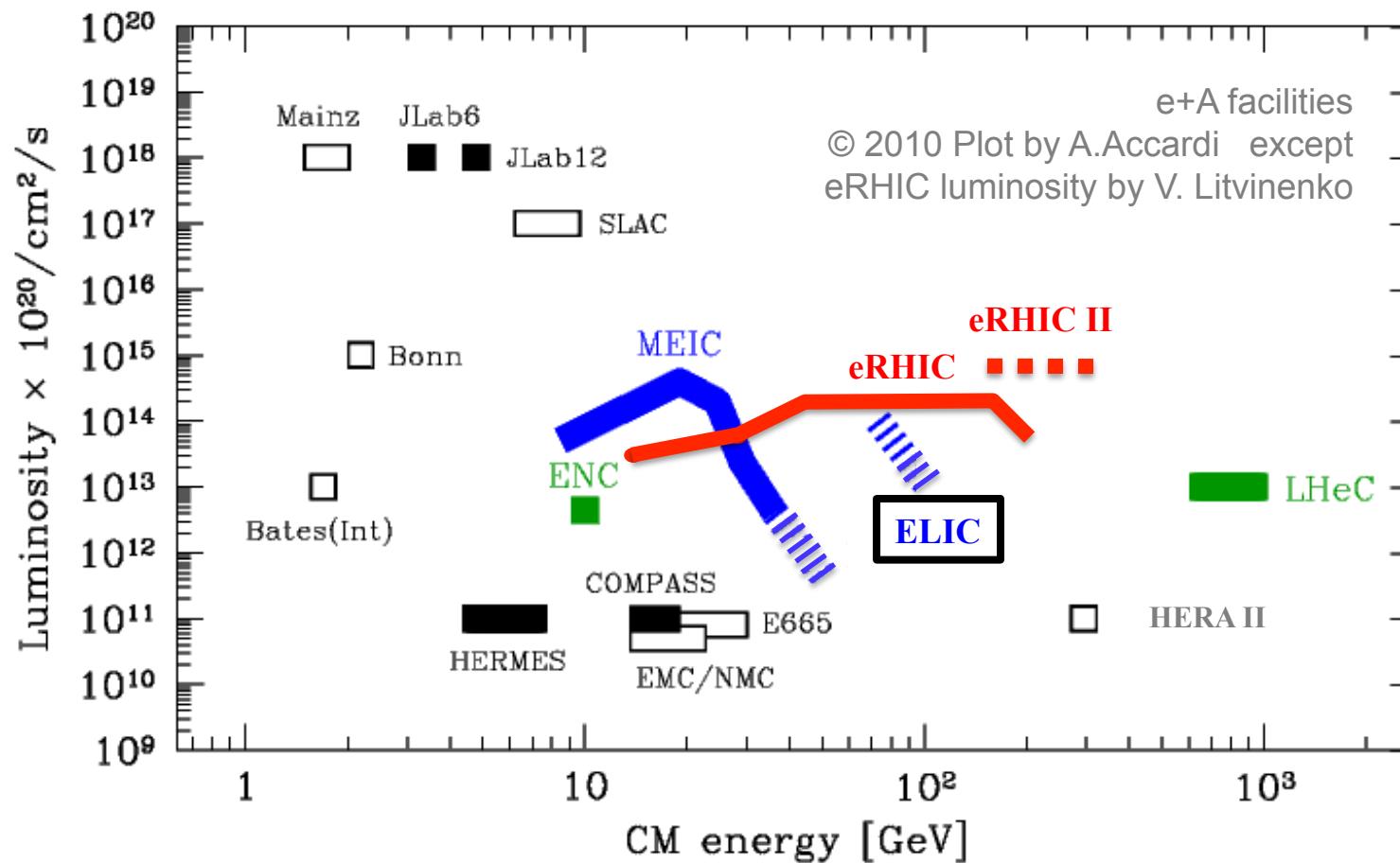
	eRHIC IR1	
	p / A	e
Energy (max), GeV	325/130	20
Number of bunches	166	74 nsec
Bunch intensity (u) , 10^{11}	2.0	0.24
Bunch charge, nC	32	4
Beam current, mA	420	50
Normalized emittance, $1e-6$ m, 95% for p / rms for e	1.2	25
Polarization, %	70	80
rms bunch length, cm	4.9	0.2
β^* , cm	5	5
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	1.46×10^{34} (including hour-glass effect h=0.851)	



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



Luminosities in electron-hadron collisions



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/cm² with good cathode lifetime.
- Energy recovery technology for high power beams
 - multicavity cryomodule development; high power beam ERL, BNL ERL test facility; loss protection; instabilities.
- 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:**

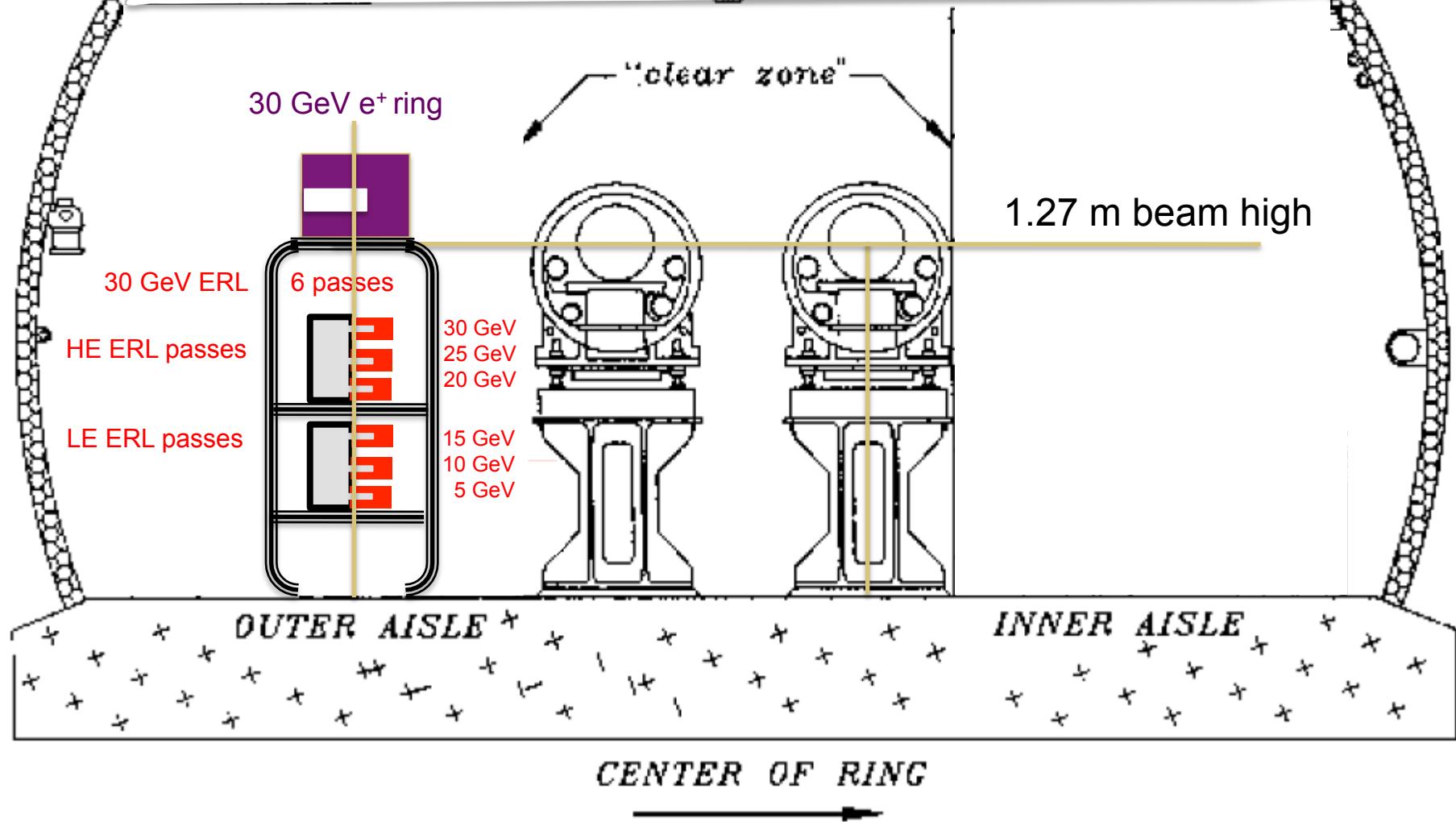
- Beam-beam effects: electron pinch effect; the kink instability ...
- Polarized ³He acceleration
- 166 bunches

- **General EIC R&D item:**

- Proof of principle of the coherent electron cooling

ARC's

Beam Optics of the ARC's
and
matching to Linac's is currently under study



eRHIC ARC magnets: LDRD R&D project

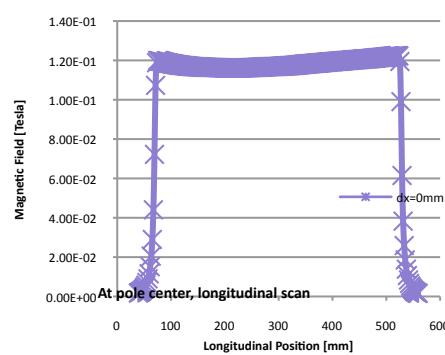
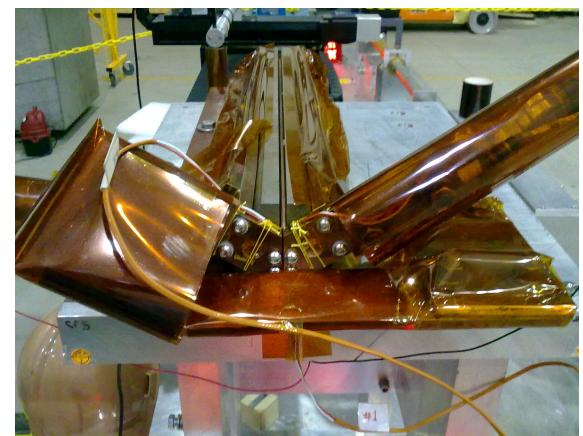
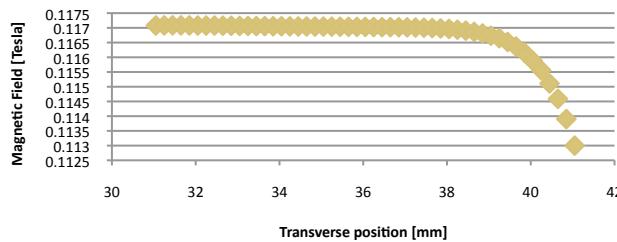
- Small gap provides for low current, low power consumption magnets
 - \rightarrow low cost eRHIC
 - Dipole prototype is under tests
 - Quad and vacuum chamber are in advanced stage

©, G. Mahler, W. Meng,
A. Jain, P. He, Y. Hao

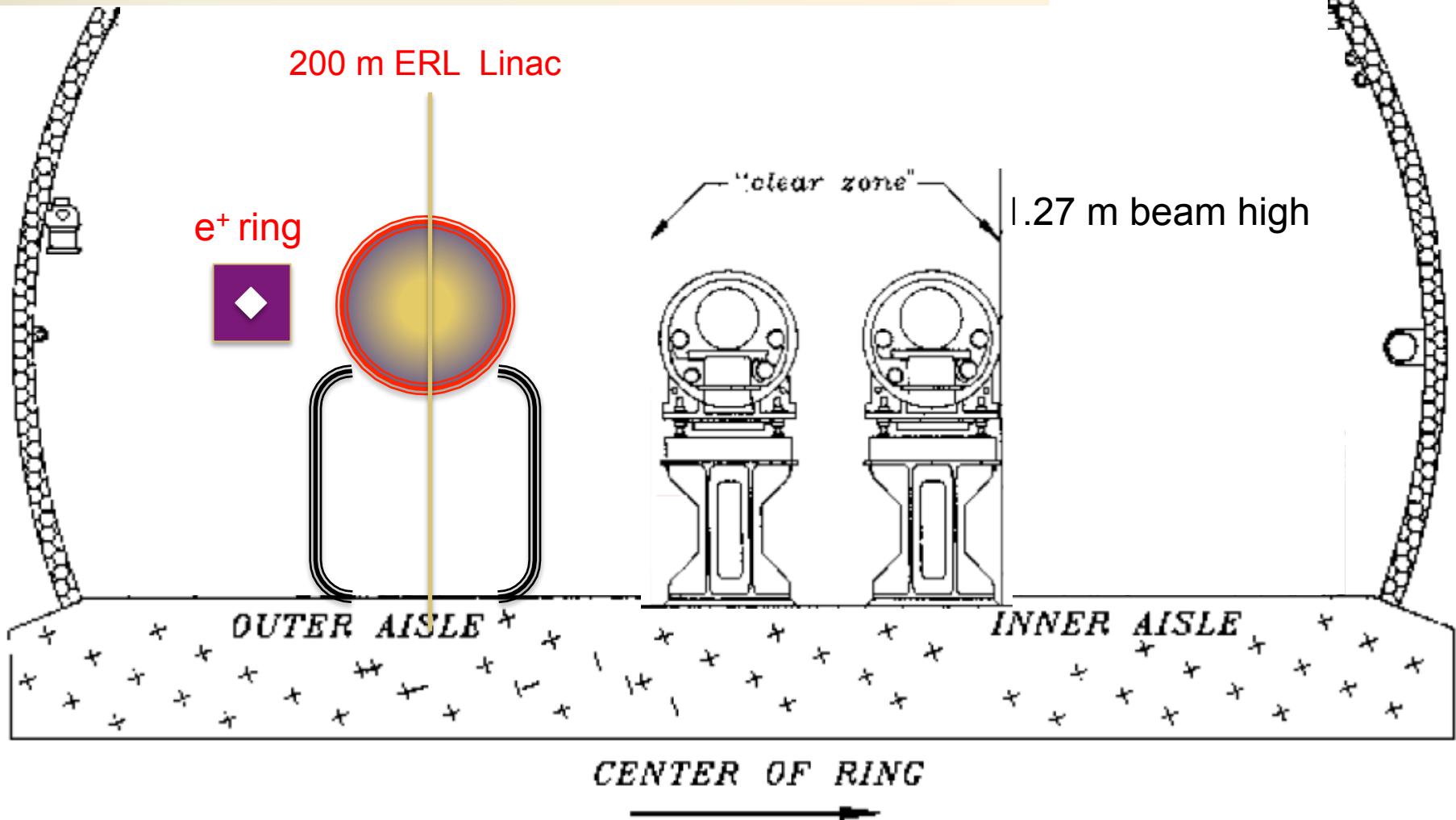
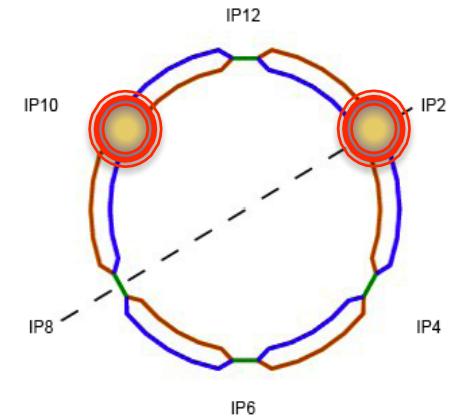
Gap 5 mm total
0.3 T for 30 GeV



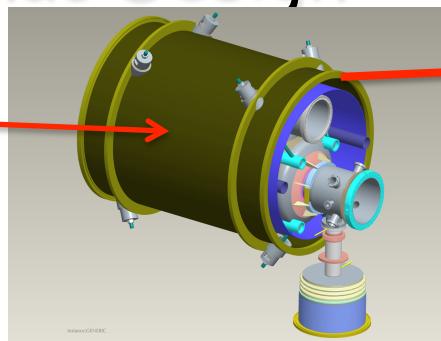
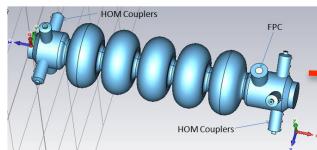
245Ampere, Transverse scan at center of the dipole



e⁻ Linac's Located
at 10 and 2 o'clock Straight Sections

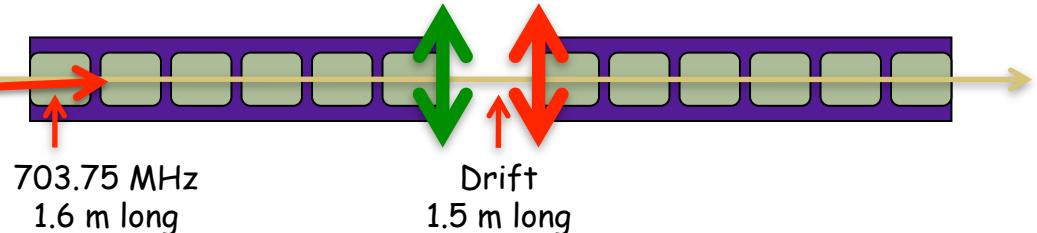


eRHIC Linac Design



Based on BNL SRF cavity with fully suppressed HOMs
Critical for high current multi-pass ERL

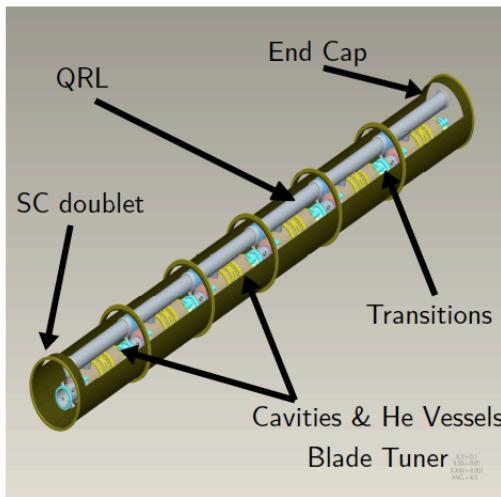
©I. Ben Zvi



Total linac length depend on energy
All cold: no warm-to-cold transition

PRELIMINARY CRYOMODULE

©George Mahler



String assembly of multiple cavities.
Heat shielding and top covers removed
for clarity.

Breakdown of the eRHIC Cryomodule

N cavities = 6 (but can 4-8)

Module length = 9.6 m

L period = 10.6 m

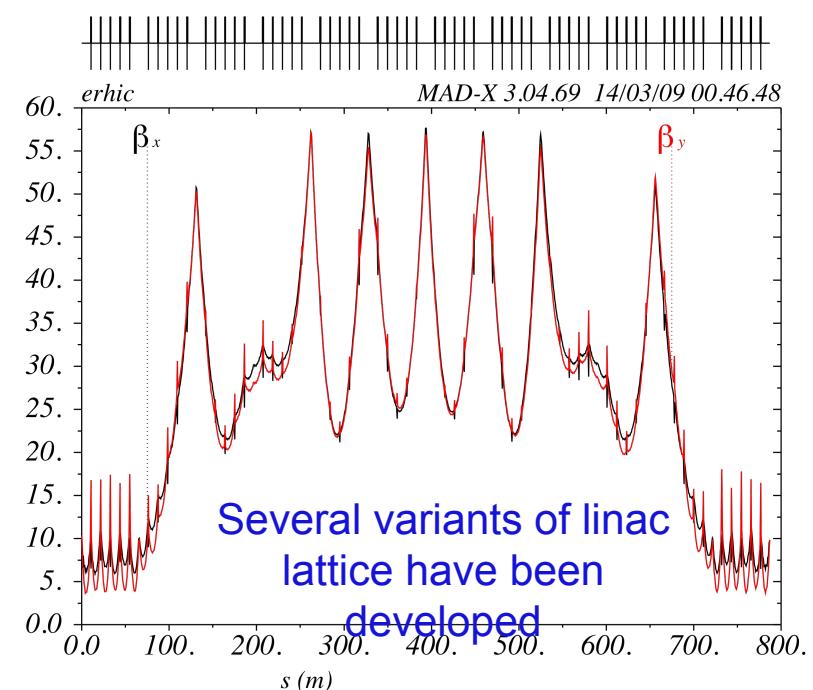
E_{acc} = 18.0 MV/m

dE/ds = 10.2 MeV/m

Injection

E_{max}

to Dump



Energy of electron beam is increased in stages by increasing the length of the linacs

Energy Recovery Linac (ERL) Test Facility Using the 5-cell SRF Cavity

- 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 μ m)
- 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.

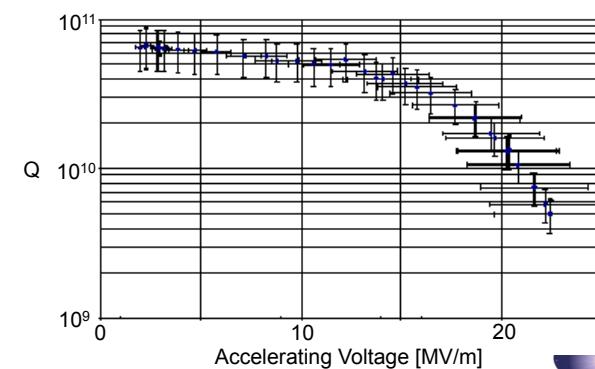
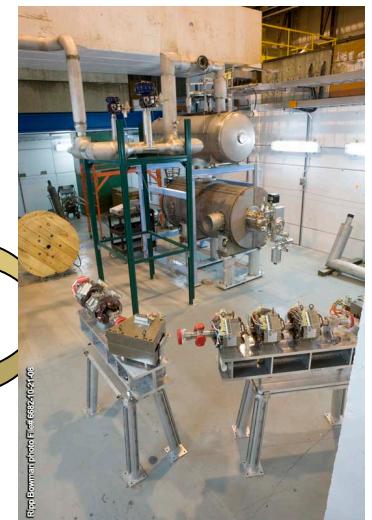
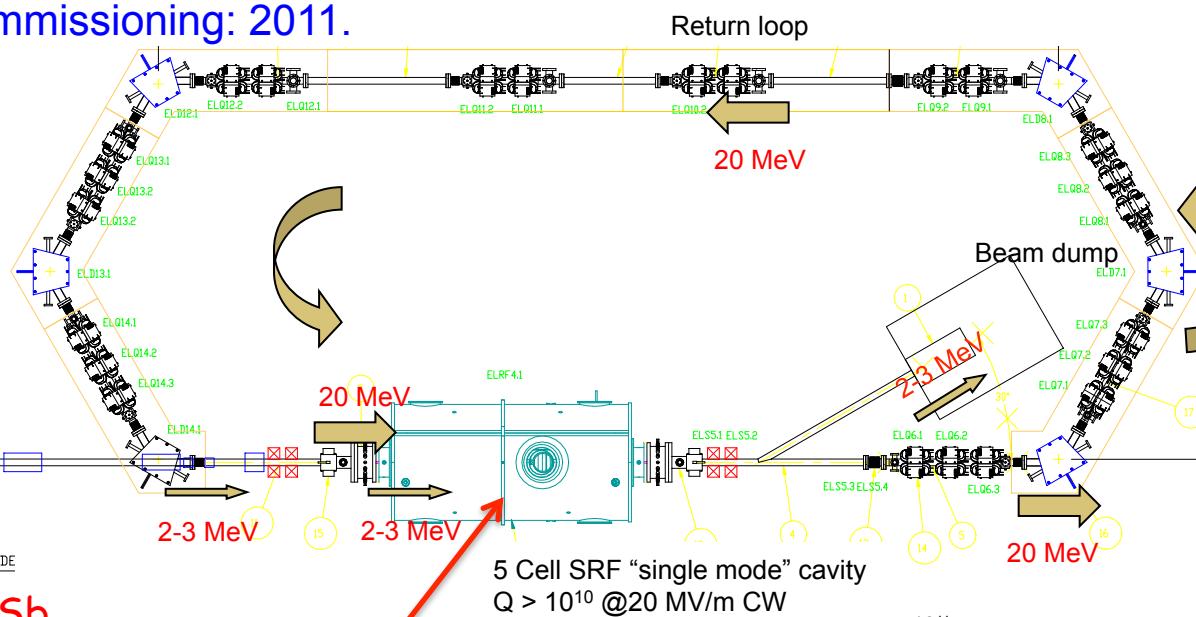


SRF Gun
2MV, 0.5A

CATHODE

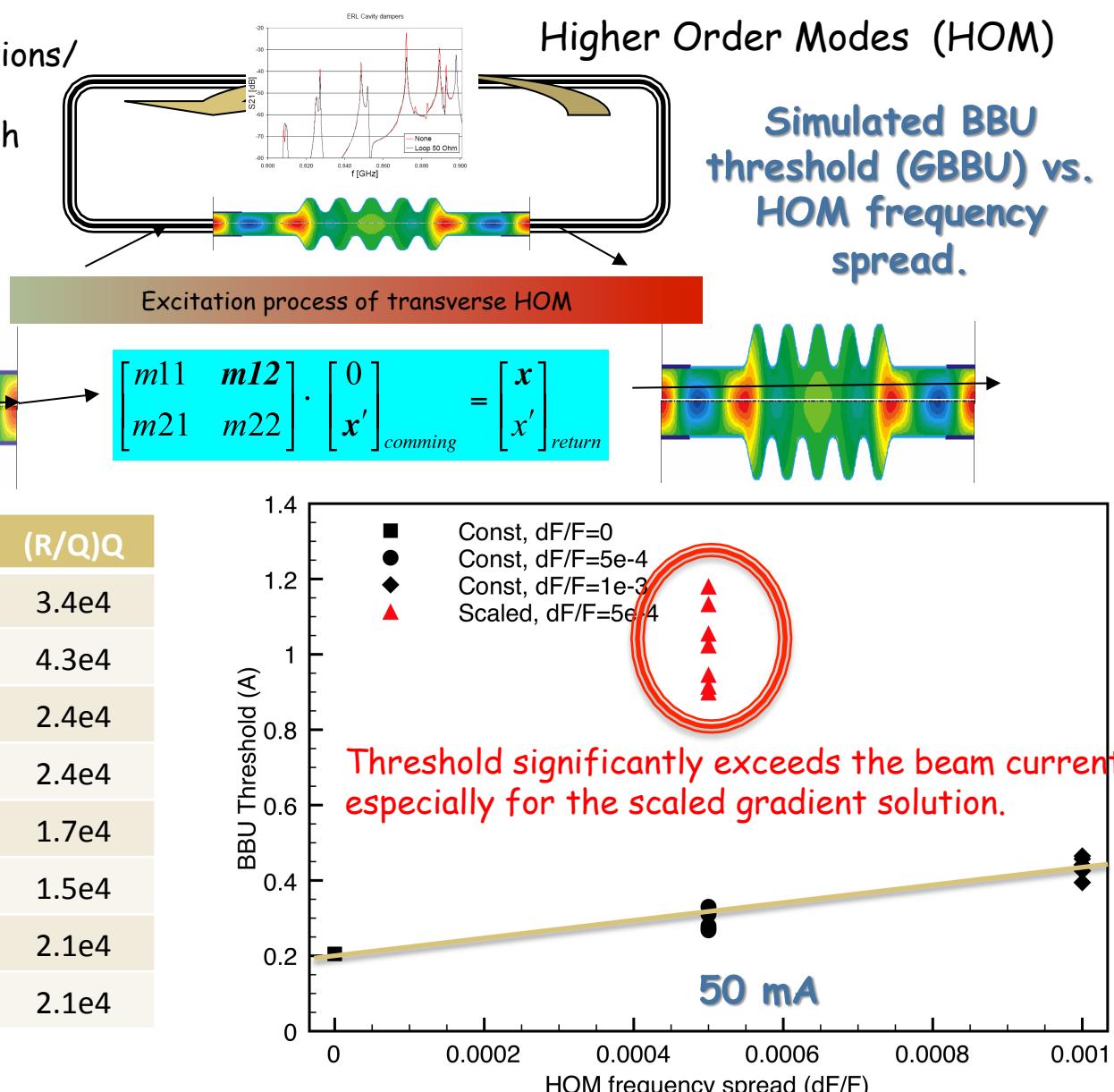
CsKsb

1 MW, 703.75 MHz CW Klystron



Transverse Beam BreakUp (TBBU) instability (©E. Pozdnyev)

- HOMs based on R. Calaga's simulations/measurements
- 70 dipole HOM's to 2.7 GHz in each cavity
- Polarization either 0 or 90°
- 6 different random seeds
- HOM Frequency spread 0-0.001

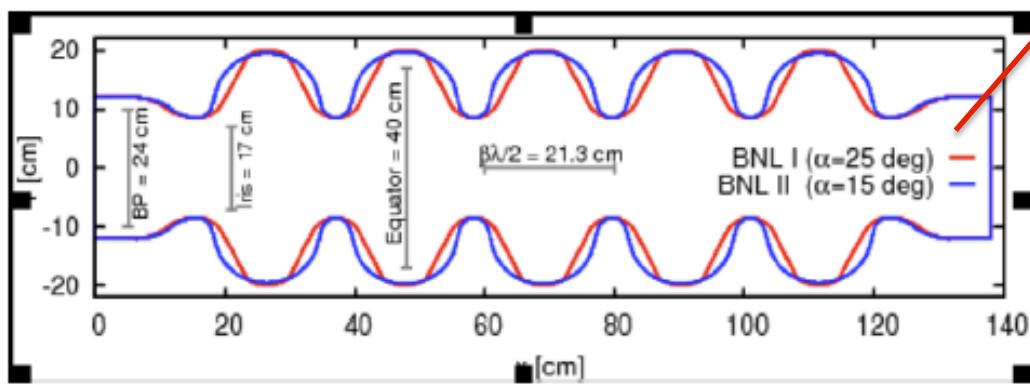
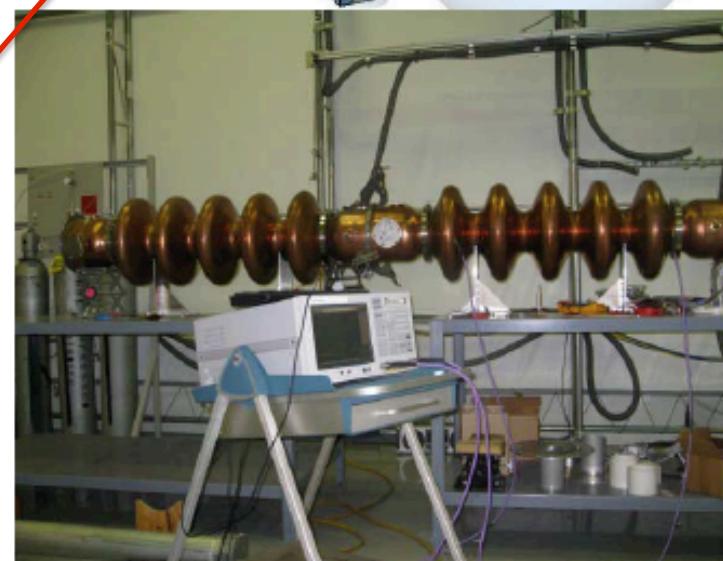
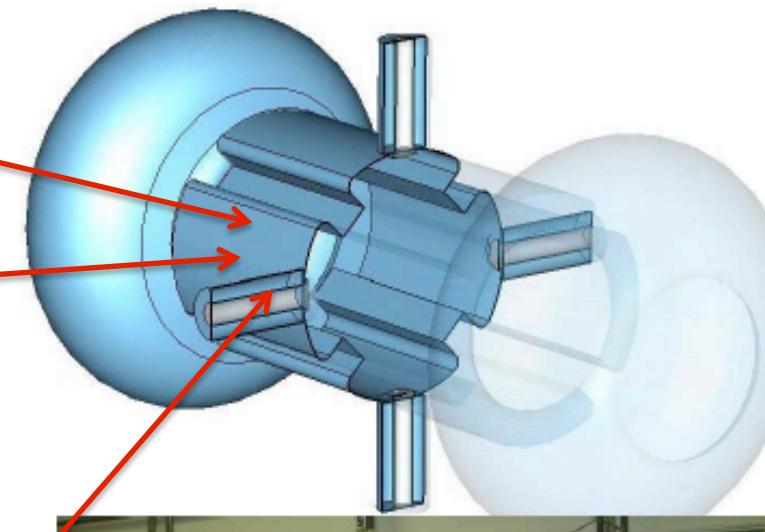


eRHIC New Cavity Design

f=703.75

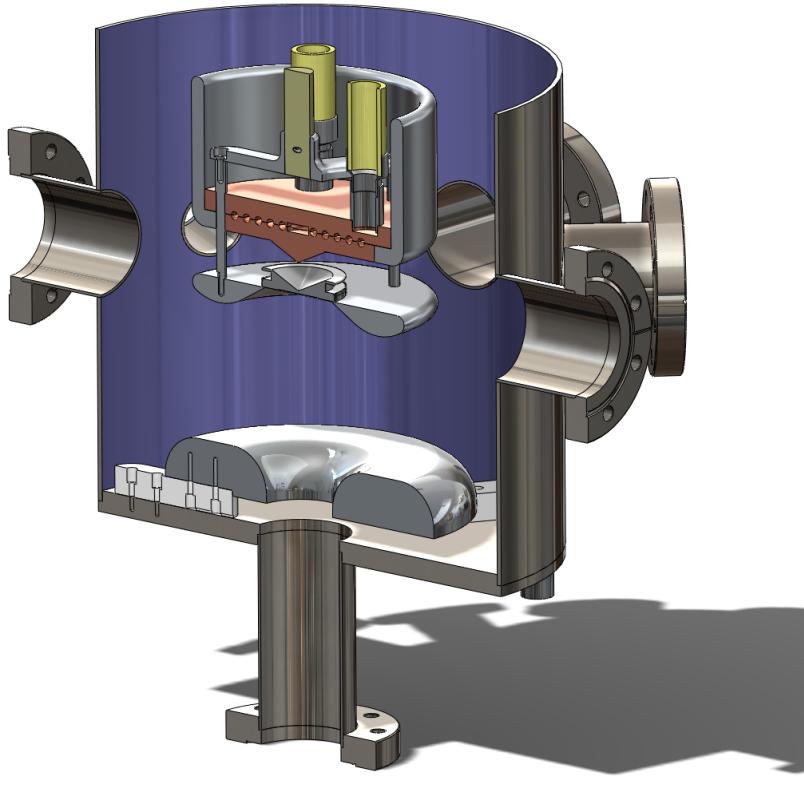
New cavity design f
eRHIC

- Reduce peak magnetic field.
- Reduce stiffness.
- Apply new ideas in HOM damping.
- Reduce fundamental at HOM
couplers
- Increase real-estate gradient
- Development / measurement
program

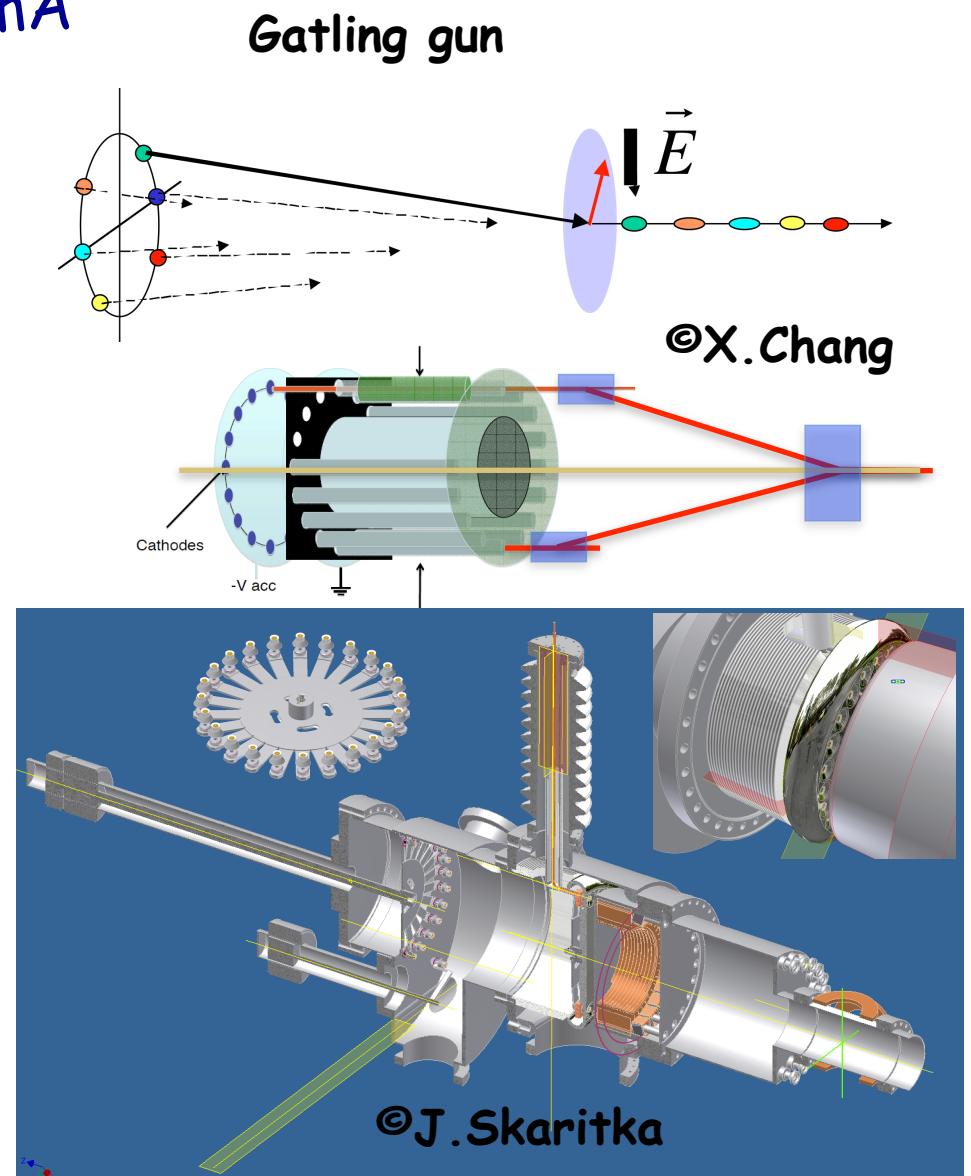


Main technical challenge is 50 mA
CW polarized e^- gun:
we are building two versions

Single large size cathode

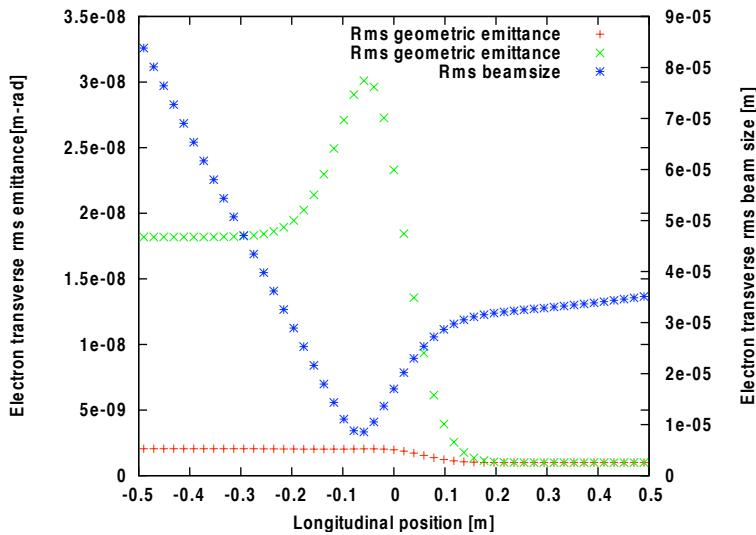


© E.Tsentalovich, MIT

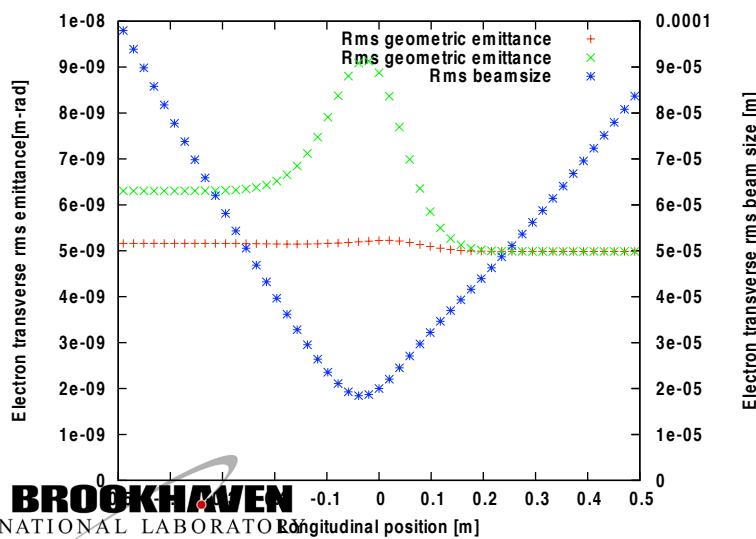


Electron beam disruption for eRHIC. Optimization of beam parameters

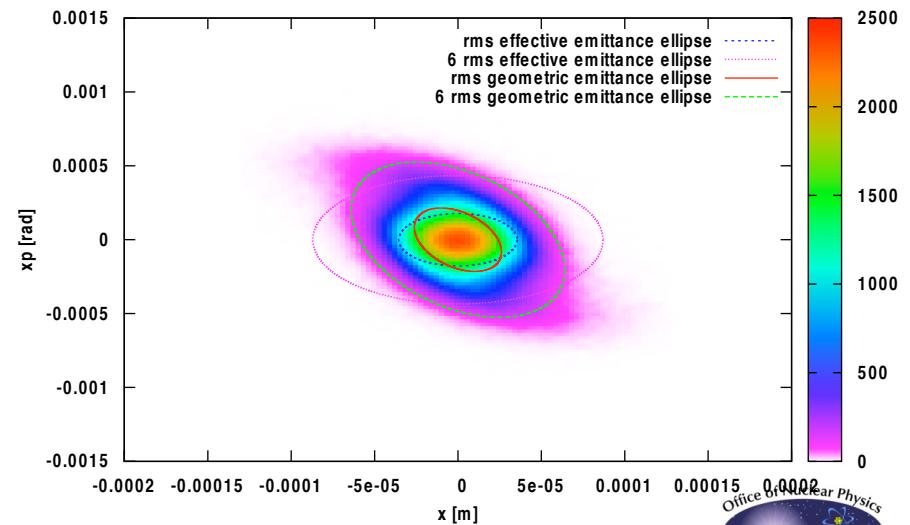
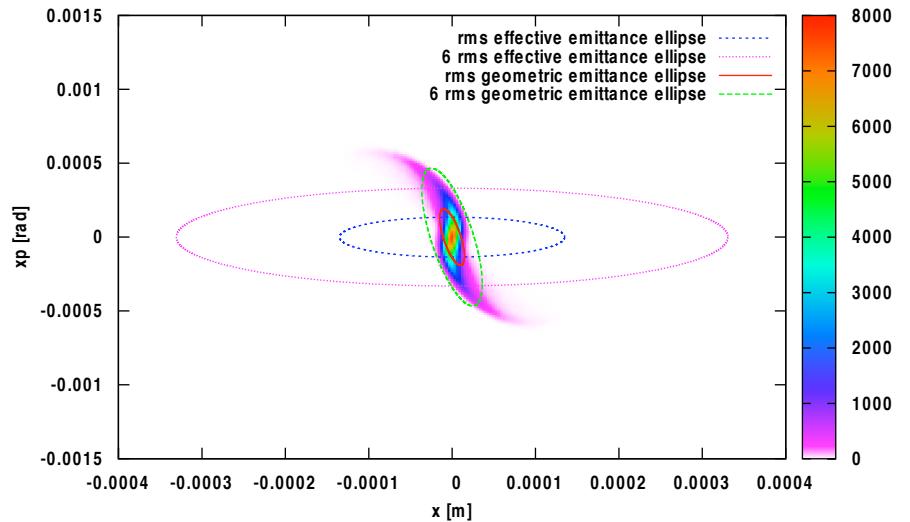
Y.Hao



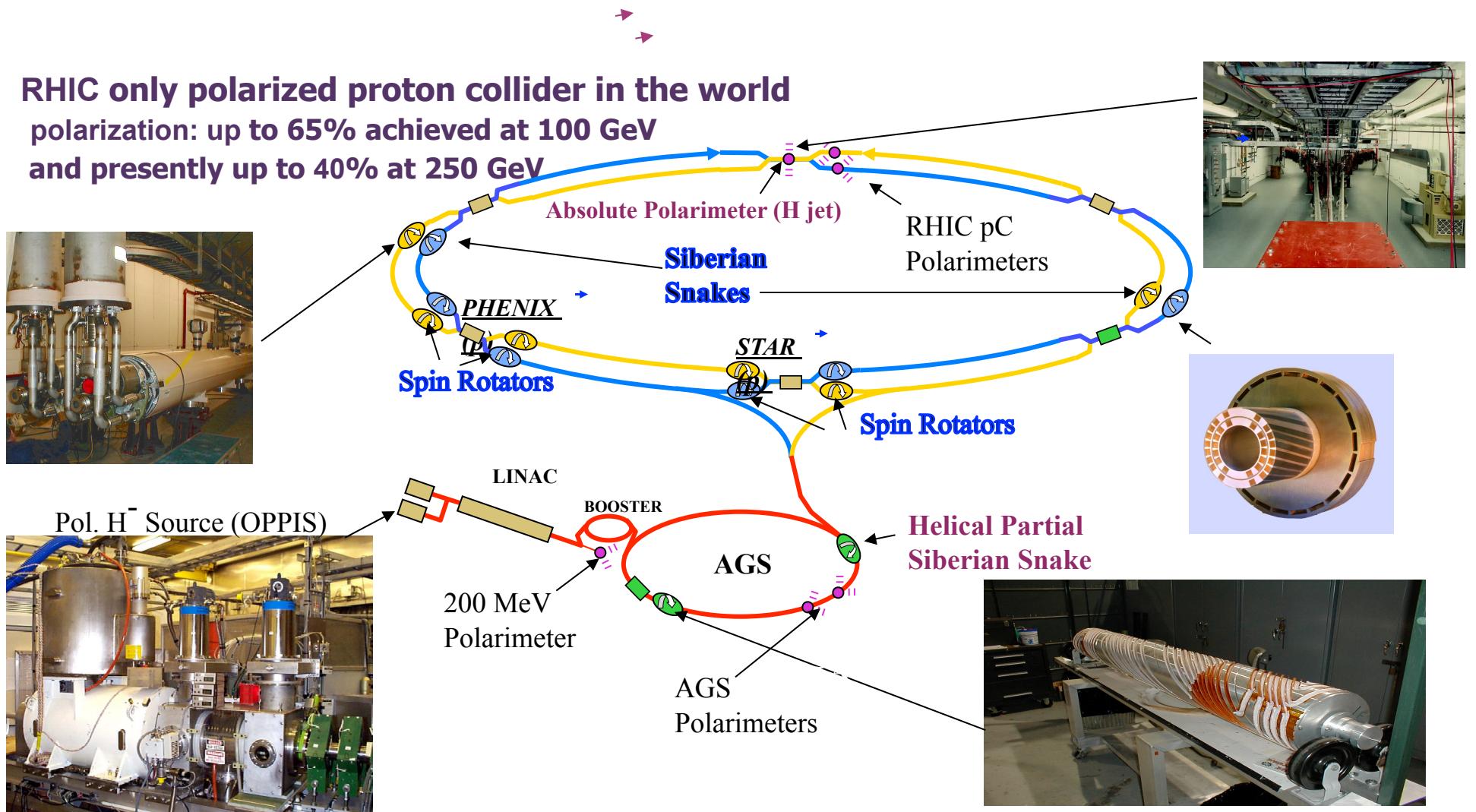
$\beta^* = 1\text{m}$
Emittance:
 1nm-rad



Parameters
with minimal
disruption:
 $\beta^* = 0.2\text{m}$
Emittance:
 5nm-rad

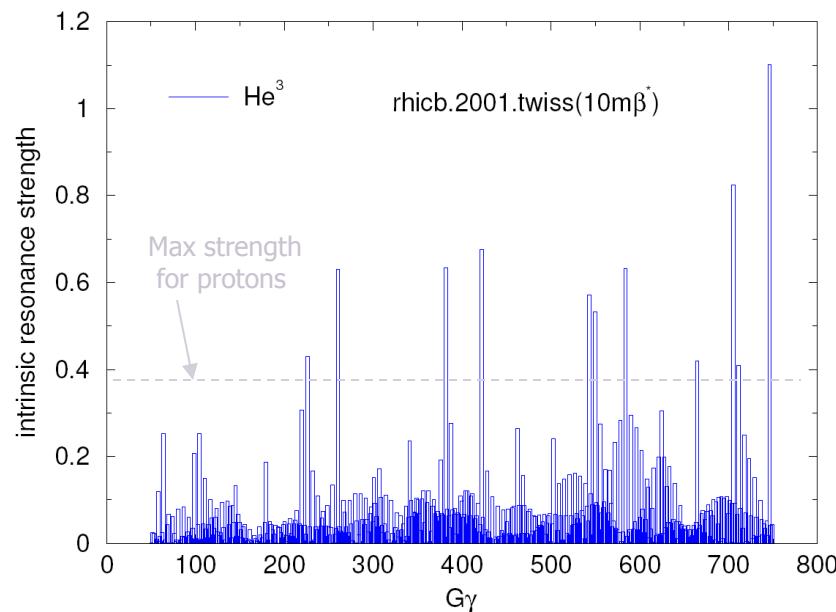


eRHIC: polarized protons



Polarized ${}^3\text{He}^{+2}$ 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. Stronger resonance strength.
- Spin dynamics at the acceleration in the injector chain and in RHIC has to be studied.



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

Electron polarization in eRHIC

The polarization benefits greatly from the linac acceleration geometry

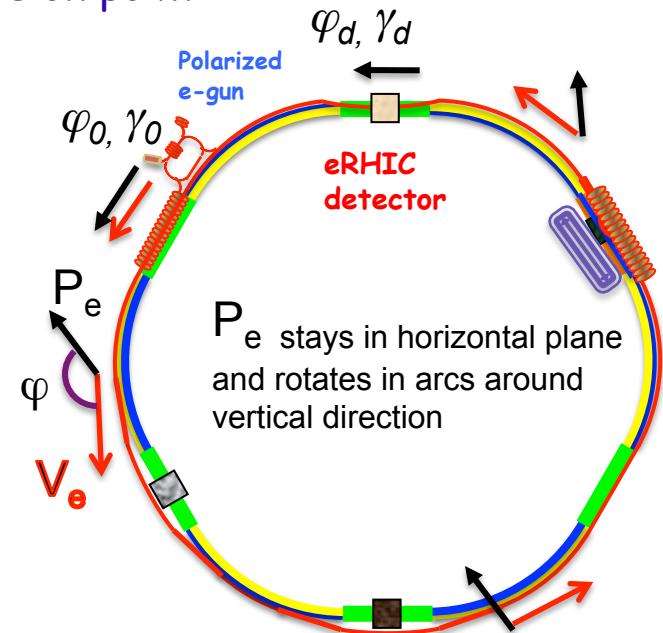
- No coherent buildup of small depolarizing errors -> No problem with depolarizing resonances
- No depolarization due to synchrotron radiation
- Simple control of spin orientation at the collision point

The polarization orientation at the eRHIC detector:

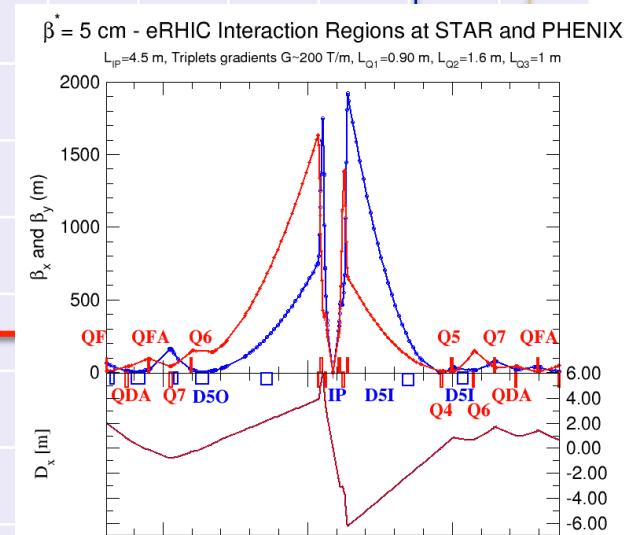
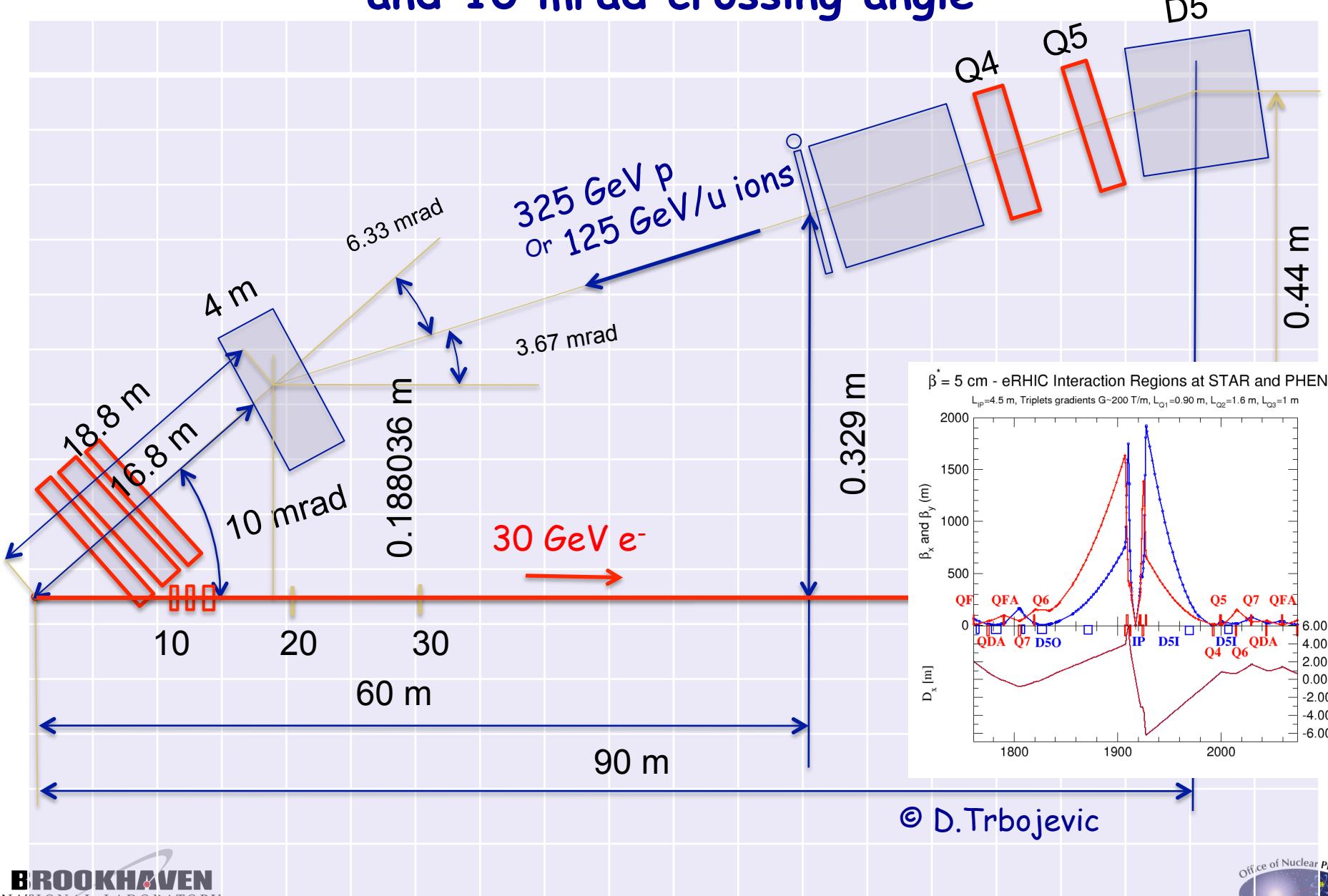
$$\varphi_d = \varphi_0 + G \int_0^{\theta_d} \gamma(\theta) d\theta$$

Adjusted by Wien filter rotator after the source

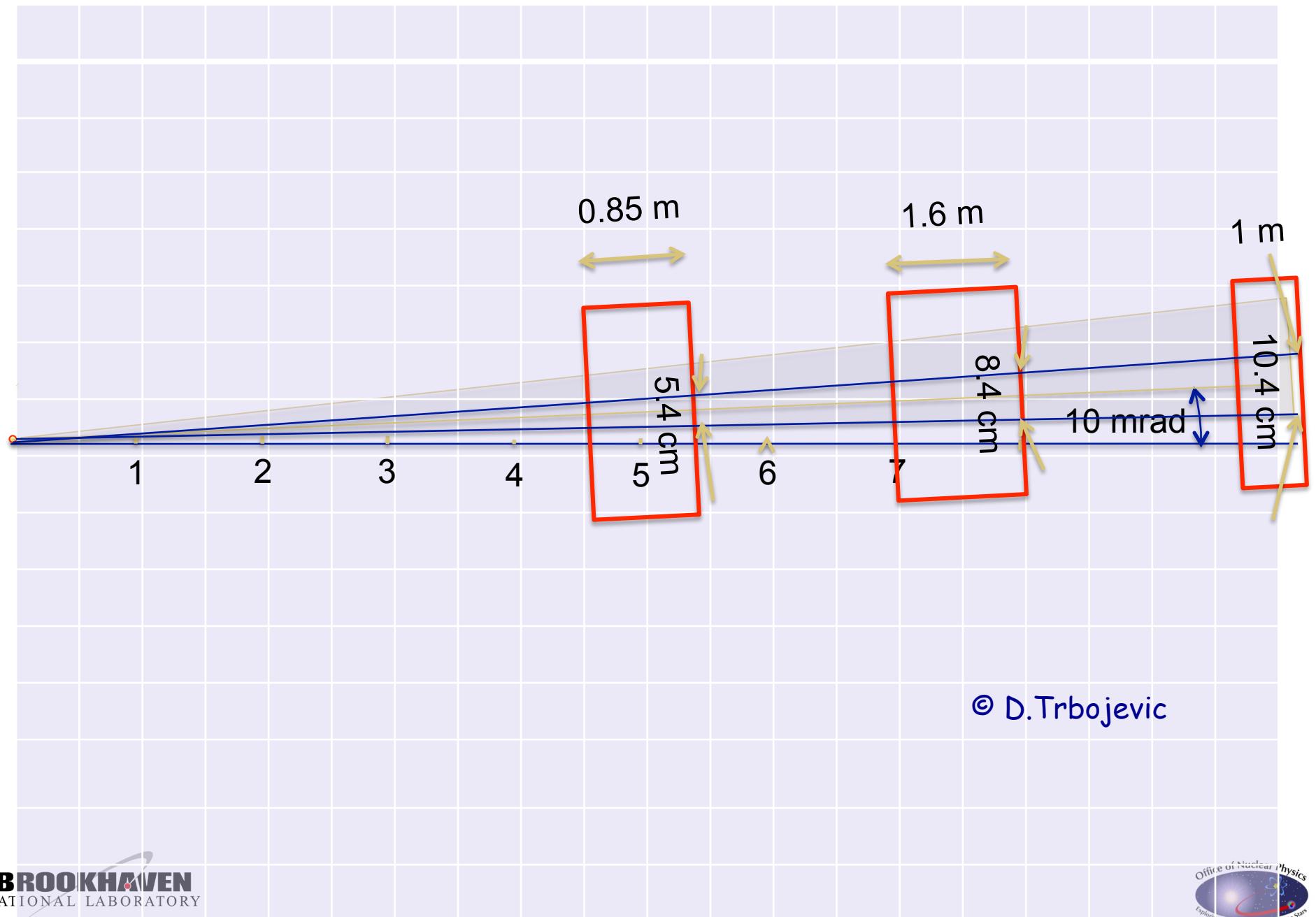
Adjusted by modifications of energy gains in the linacs



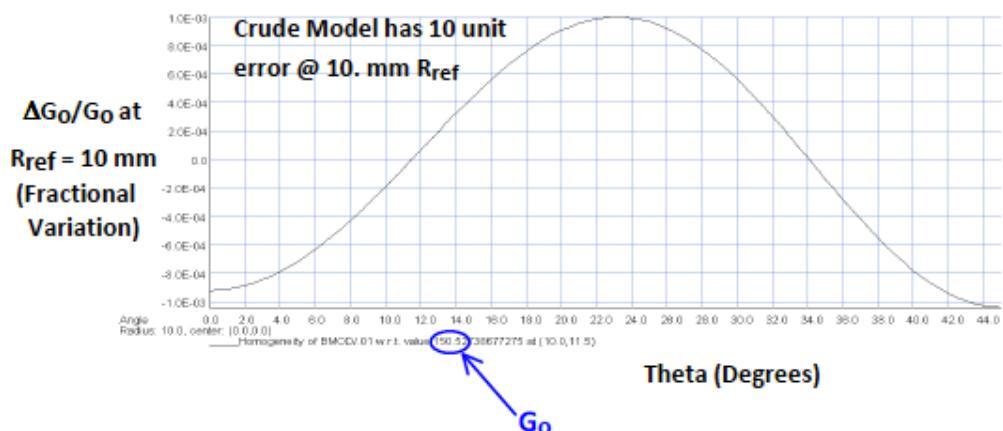
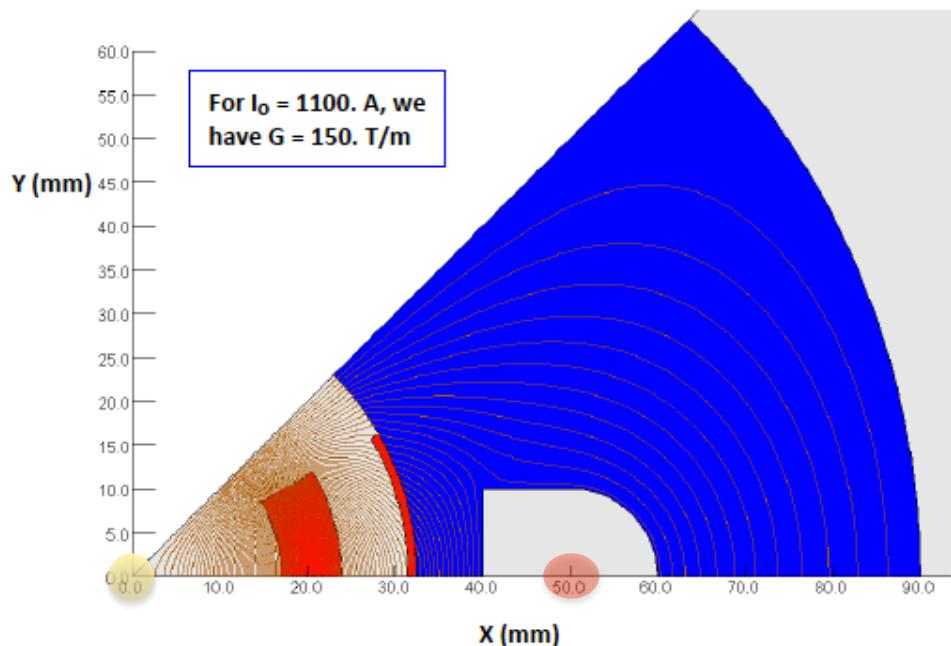
eRHIC - Geometry high-lumi IR with $\beta^*=5$ cm, $l^*=4.5$ m and 10 mrad crossing angle



RHIC - Geometry high-lumi IR

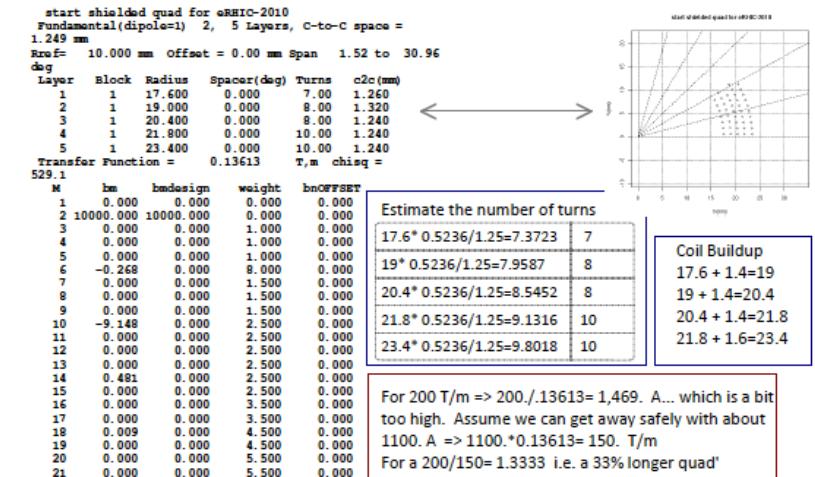


Quads for $\beta^*=5$ cm



Note: this is a crude model that has not yet been optimized but it gives a "proof of principle." If you allow more field in the cutout region, then the gradient can be increased slightly (or both can be reduced).

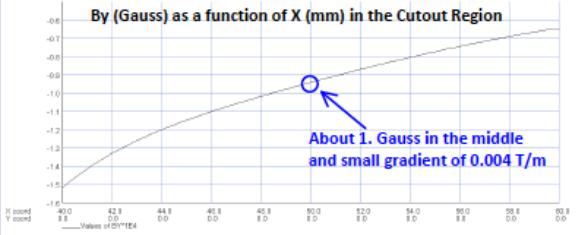
Dejan wants about 200 T/m but for 15 mm radius aperture. Now we might get away with a 2 mm thick coil support tube and maybe just 5 conductor layers (i.e. planar pattern first and then two Serpentine coil sets). $15+2+6=17.6$ mm with the rest



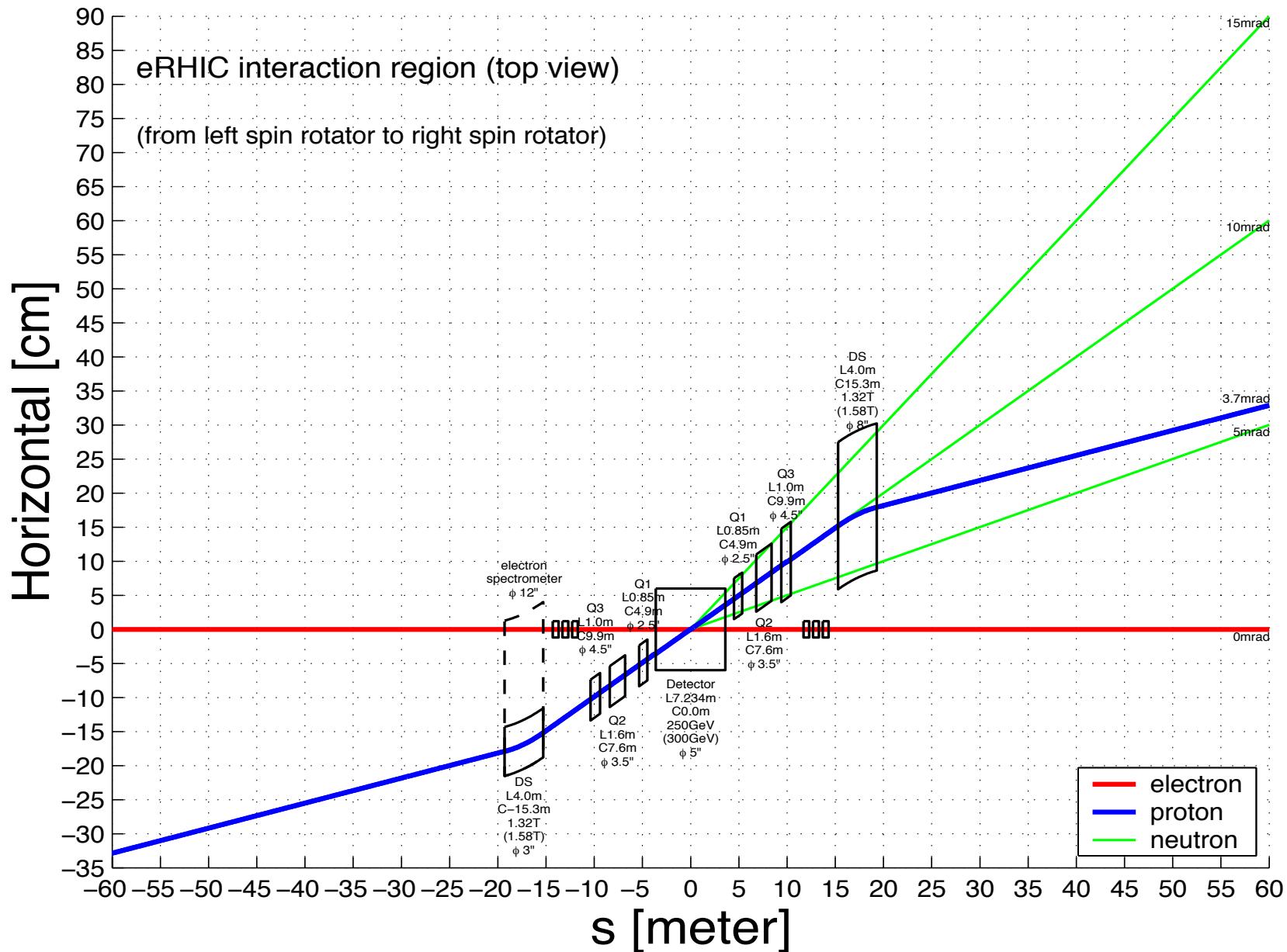
Average radius = $(17.6+19+20.4+21.8+23.4)/5 = 20.44$ mm then block goes from $R_{in} = 17$ mm to $2 * 20.44 - 17 = 23.88$ mm for R_{out}
Total Turns = $7+8+8+10+10 = 43$ Turns/pole for $N_I = 1100 * 43 = 47300.$ Total Amp Turns

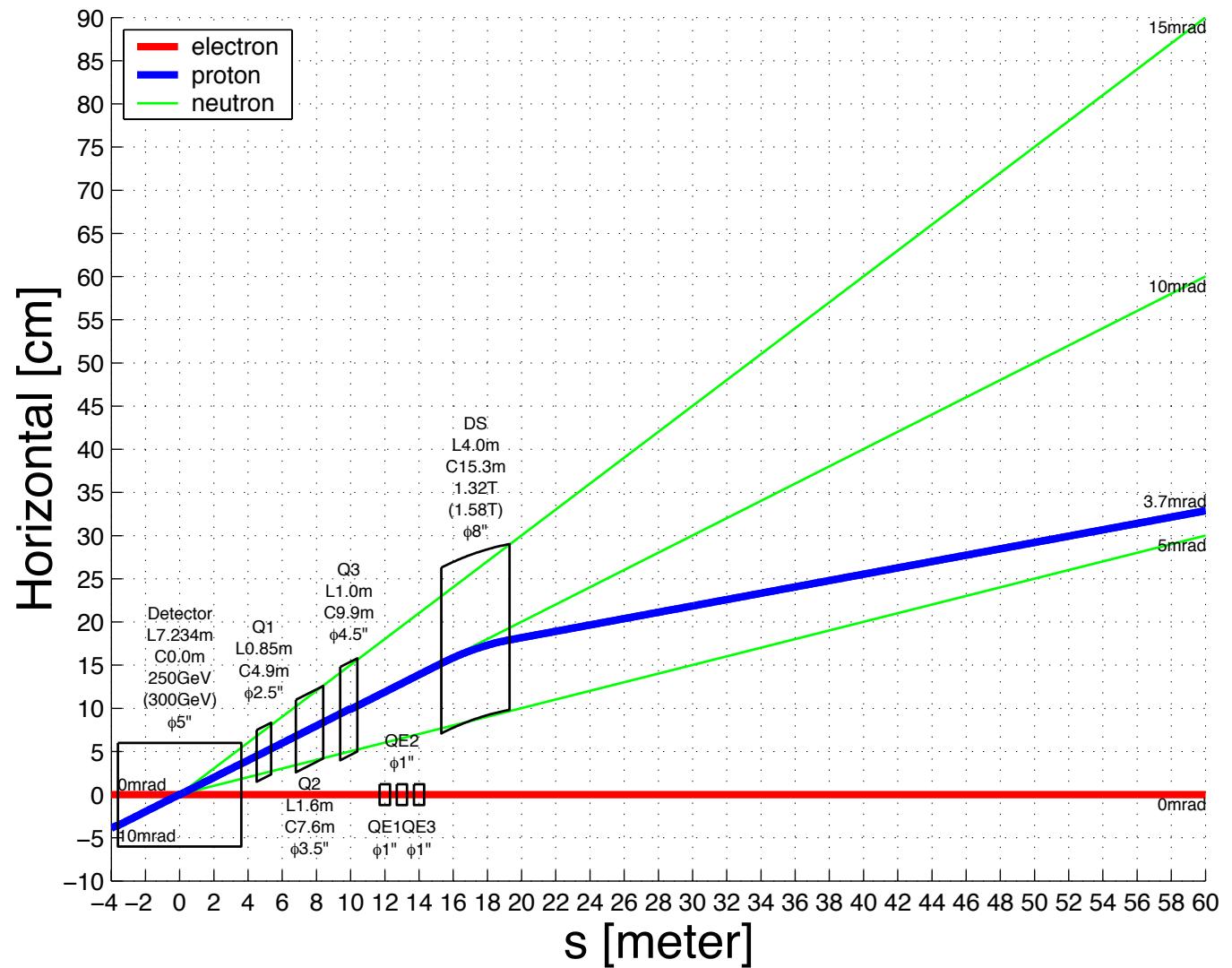
For compensation coil $(23.88/32)^4 = 0.31$ gives about the same percentage drop as before, so we have $R_{in_comp} = 31.5$ mm & $R_{out_comp} = 32.5$ mm
Look for partial compensation (just to reduce flux in septum region) with $1100 * 9 = 9900.$ Amp Turns

```
Opera-2d> POINT
METHOD=CARTESIAN XP=51 YP=0
COMPONENT=by HOMOGENEITY=NO
At [51,0,0] BY
=-9.05621499991756E-05
OK
Opera-2d> POINT
METHOD=CARTESIAN XP=49 YP=0
COMPONENT=by HOMOGENEITY=NO
At [49,0,0] BY
=-9.79337100016302E-05
G = (9.79-9.06)*1e-5/2e-3=
0.0036 T/m Gradient in
the cutout region
```

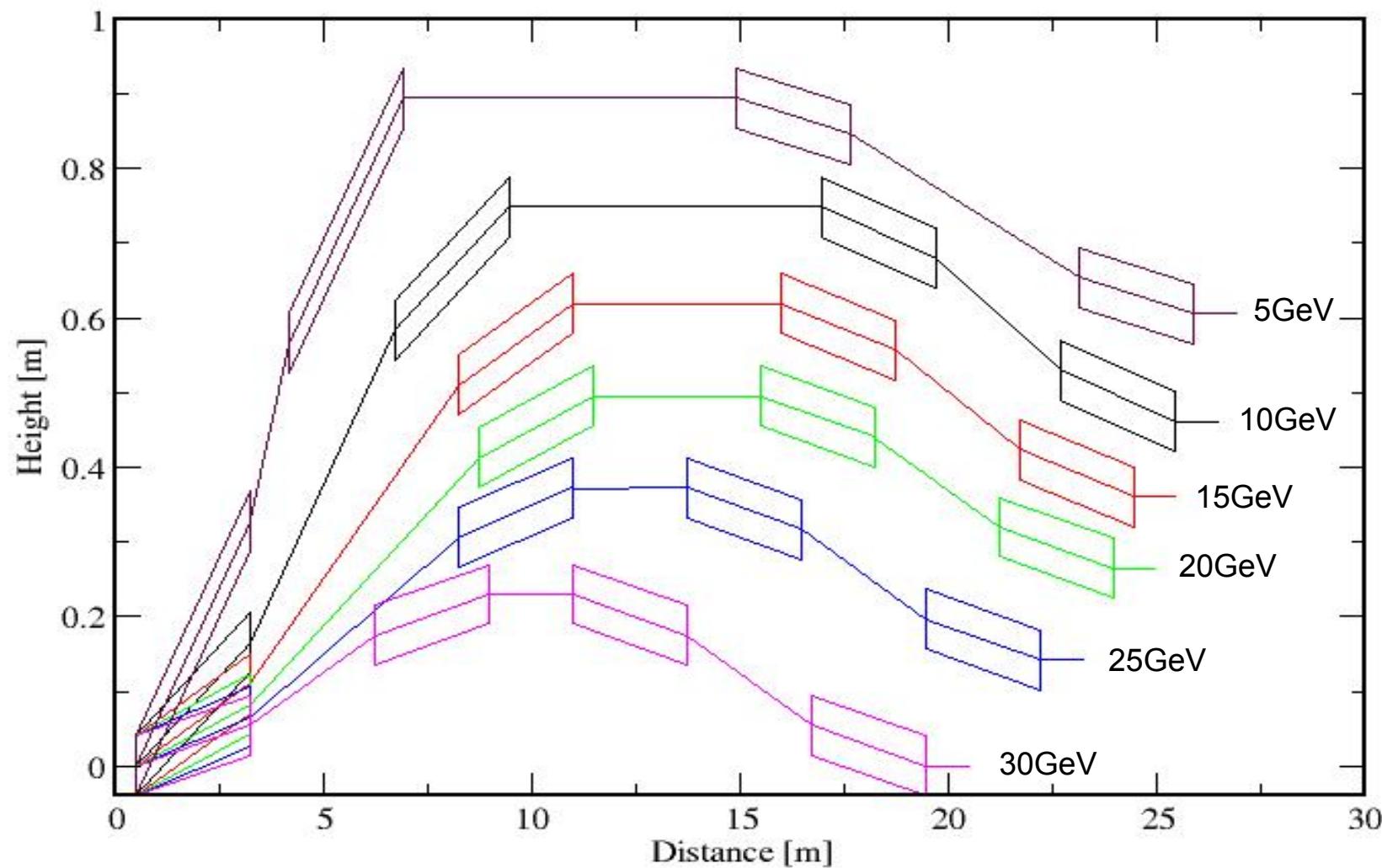


© B.Parker



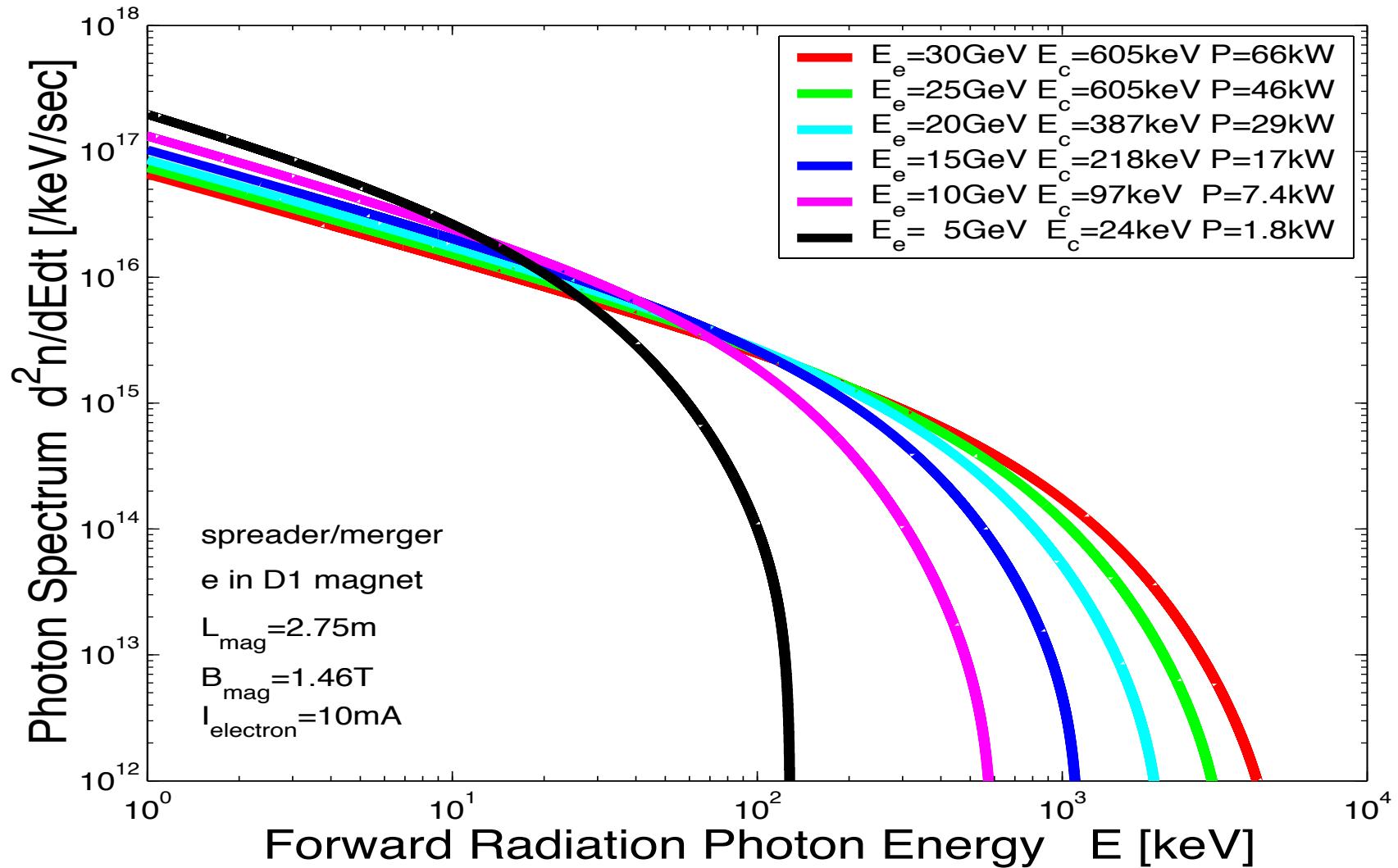


Electron Spreader / Merger



Direct Synchrotron Radiation from Hard Bend

(direct radiation will be masked from detector, but they generate secondary radiation)



Direct Synchrotron Radiation from Soft Bend

(this part of direct radiation + some indirect radiation will get into eRHIC detector)

