eRHIC accelerator design

V. Ptitsyn (for V. Litvinenko)

on behalf of BNL eRHIC Design team:

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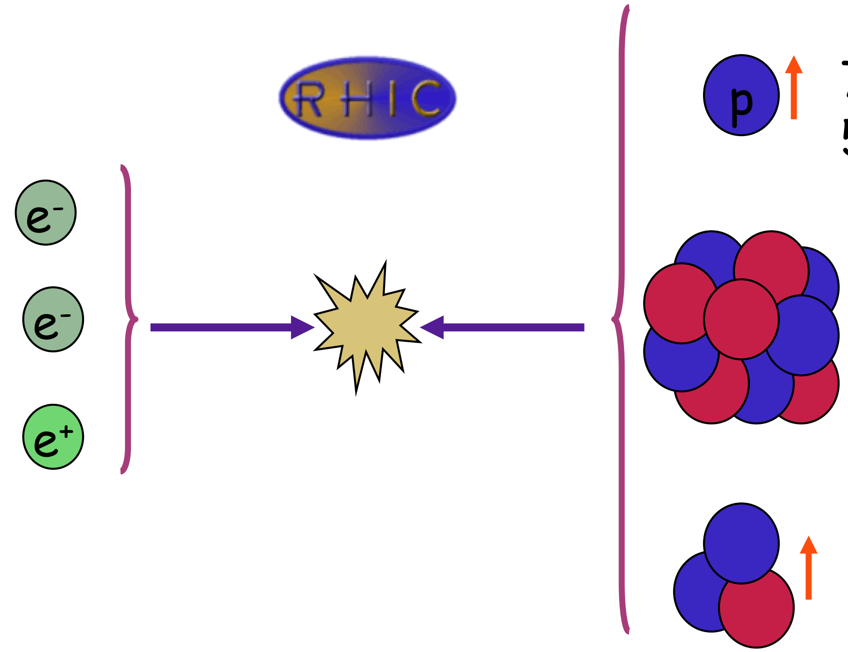
Content

- eRHIC general layout and luminosities
- Lattice and IR design
- R&D items
- Beam dynamics studies highlights
- Conclusions

eRHIC: QCD Factory at BNL

Add electron accelerator to the existing $2B RHIC

Unpolarized and
80% polarized
leptons, 2-30 GeV



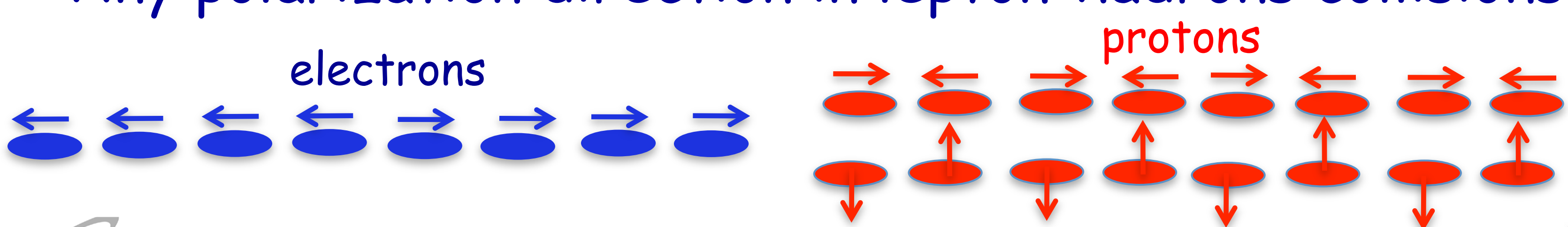
70% polarized protons
50-250 (325) GeV

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

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

Center of mass energy range: 20-200 GeV

Any polarization direction in lepton-hadrons collisions



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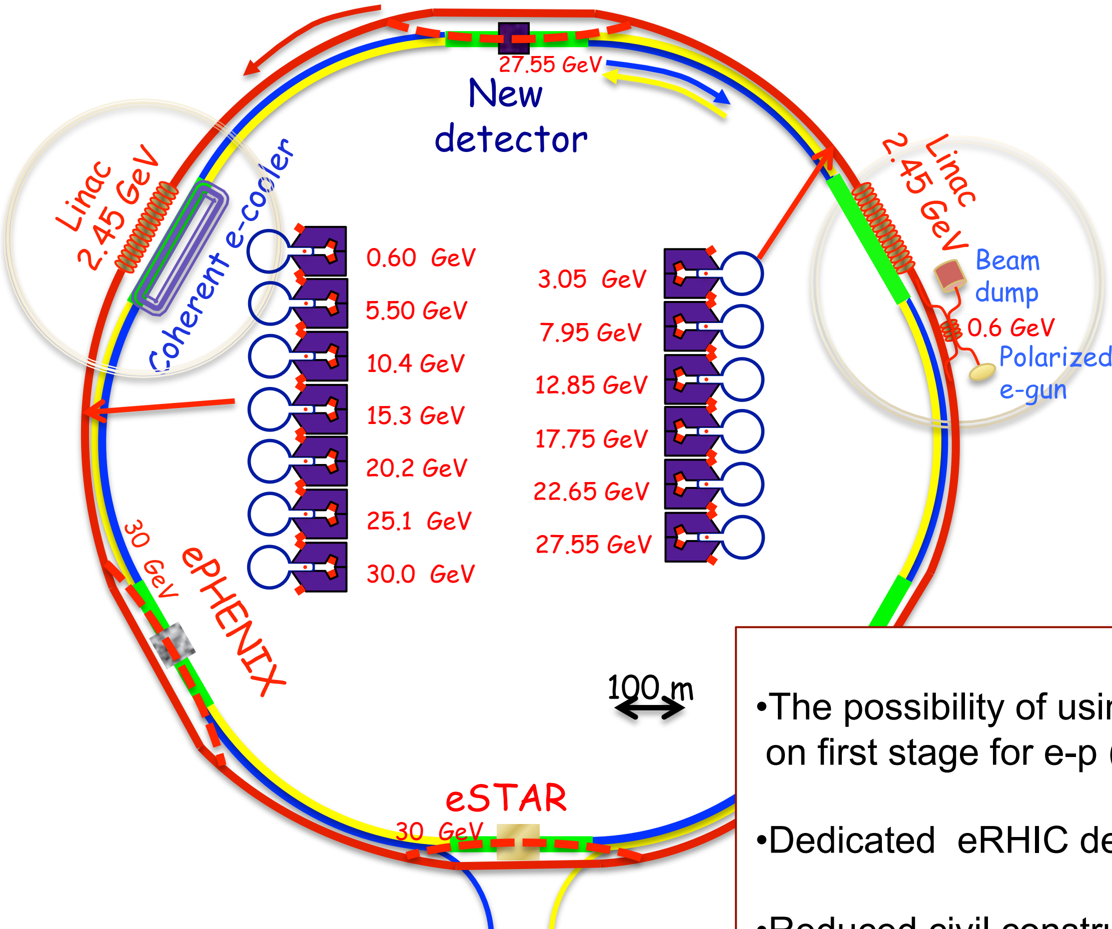
e-RHIC is a triple IP collider

5 to 30 GeV e^- x 325 GeV p - 130/u Au



✓All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.

✓Staging: the electron energy will be increased in stages, from 5 to 30 GeV, by increasing the linac lengths .

- The possibility of using upgraded STAR and PHENIX detectors on first stage for e-p (e-Au) collisions. (eSTAR and ePHENIX)
- Dedicated eRHIC detector can be added at IR12.
- Reduced civil construction cost

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Key ingredients:

- RHIC with all its species
- ERL technology
- 50 mA polarized electron gun
- Coherent electron cooling
- Crab-crossing
- High gradient SM magnets

Polarized e-p luminosities in 10^{33} cm^{-2} s^{-1} units

	Protons						
Electrons	E, GeV	**50**	**75**	**100**	**130**	**250**	**325**
	5	0.077	0.26	0.62	1.4	9.7	15
	10	0.077	0.26	0.62	1.4	9.7	15
	20	0.077	0.26	0.62	1.4	9.7	15
	30	0.015	0.05	0.12	0.28	1.9	3

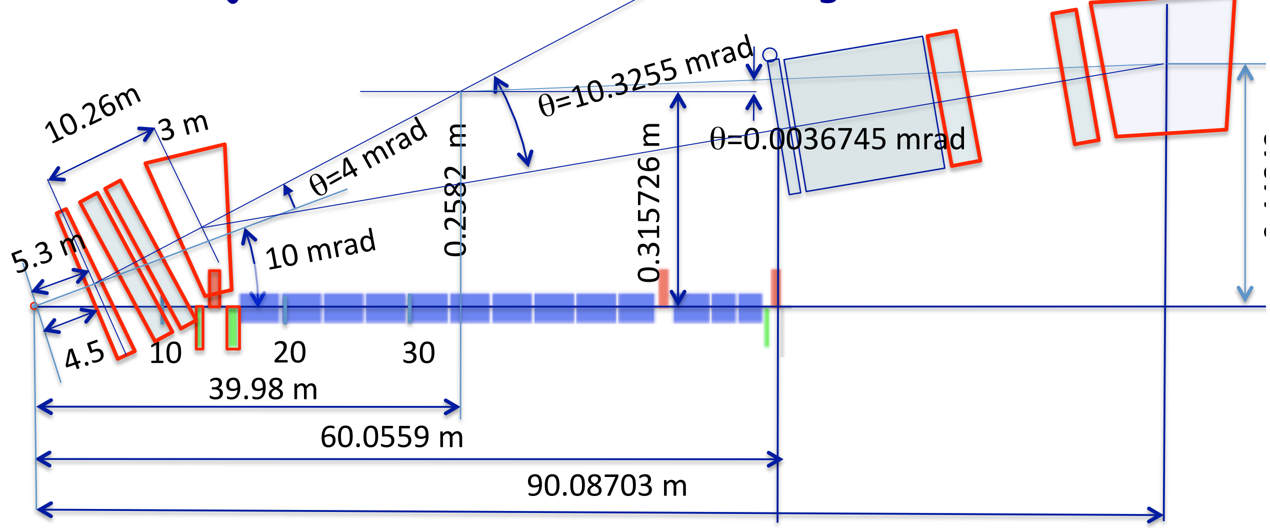
Assumed limits: I_e = 50 mA, ξ_p =0.015, ΔQ_{sp} = 0.035

Recent and continuing developments

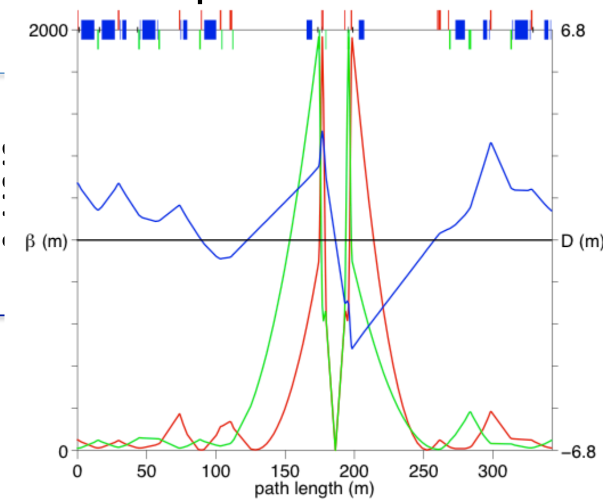
- Detailing layout and lattice of every straight section and arc, including linacs sections, splitters, combiners, passes around detectors…..
- New Interaction Region design integrates the detector requirements
- Developing clear models/prototypes for magnets, vacuum chambers
- Details of beam dynamics, timing, synchronization…
- Defining need for additional utilities, structures…
- Putting all parts together

The design of high-lumi IR with β*=5 cm and 10 mrad crossing angle

© D.Trbojevic, B.Parker, J. Beebe-Wang



proton lattice



•New interaction region design uses crab-crossing scheme with 10 mrad crossing angle and high gradient (200 T/m) Nb_3Sn focusing magnets.

•First magnet is 4.5m from the interaction point.

•The IR design allows effective separation and registration of low angle collision products.

•Careful bending of the electrons (with the weak field) to avoid SR impact

•The design is not compatible with parallel operation with p-p (ion-ion) collisions.

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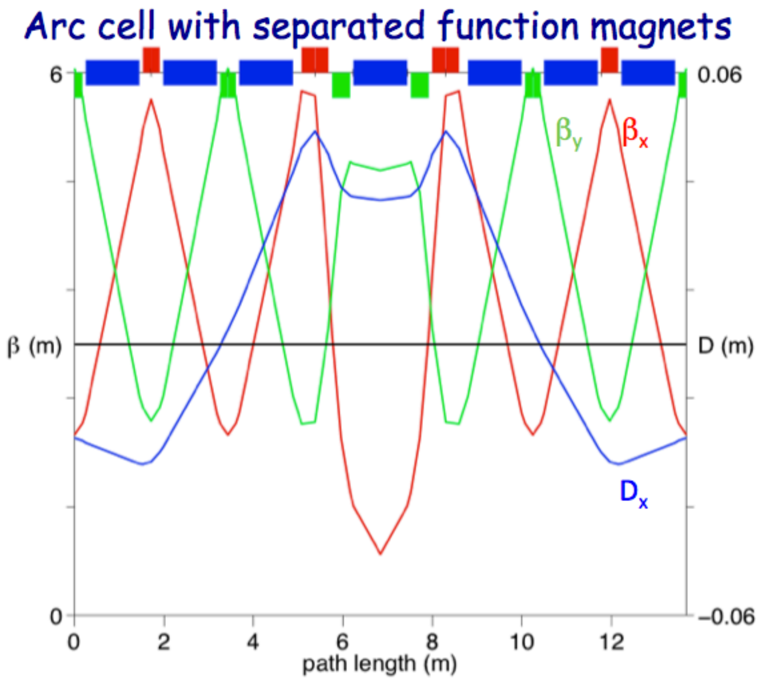
Recirculating arc lattice



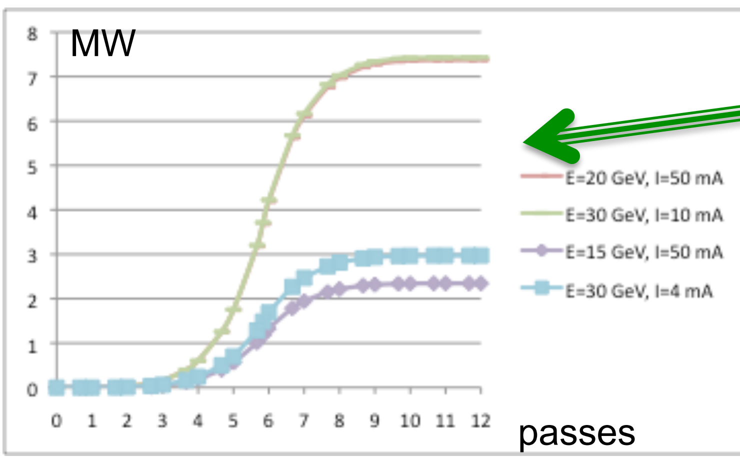
© D.Trbojevic

- Principle inherited from MeRHIC lattice
- M_{56} ~0 and can be varied

- Two variants has been developed:

-separated function magnets
-combined function magnets

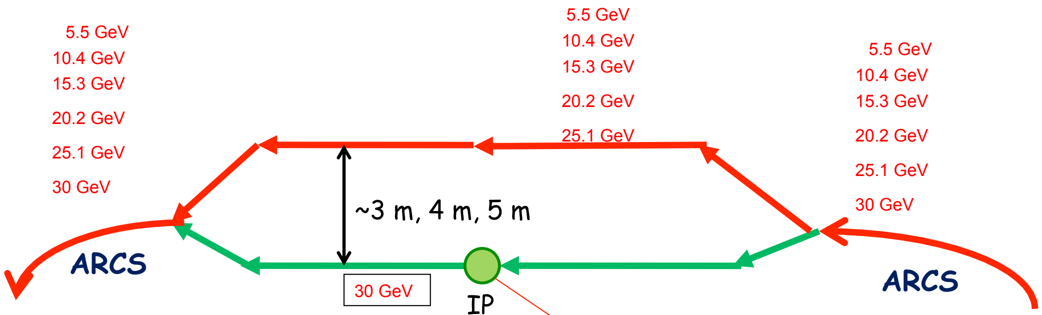
- Combined function magnets lattice has minimized effect of synchrotron radiation but the design of compact magnets may be problematic



Synchrotron radiation power for separated function magnet lattice

Emittance and momentum spread deterioration are acceptable

By-pass beam line around detectors for electrons



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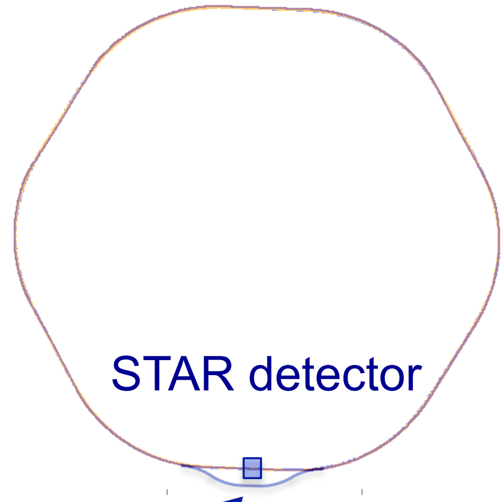
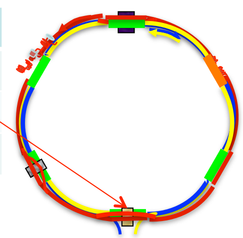
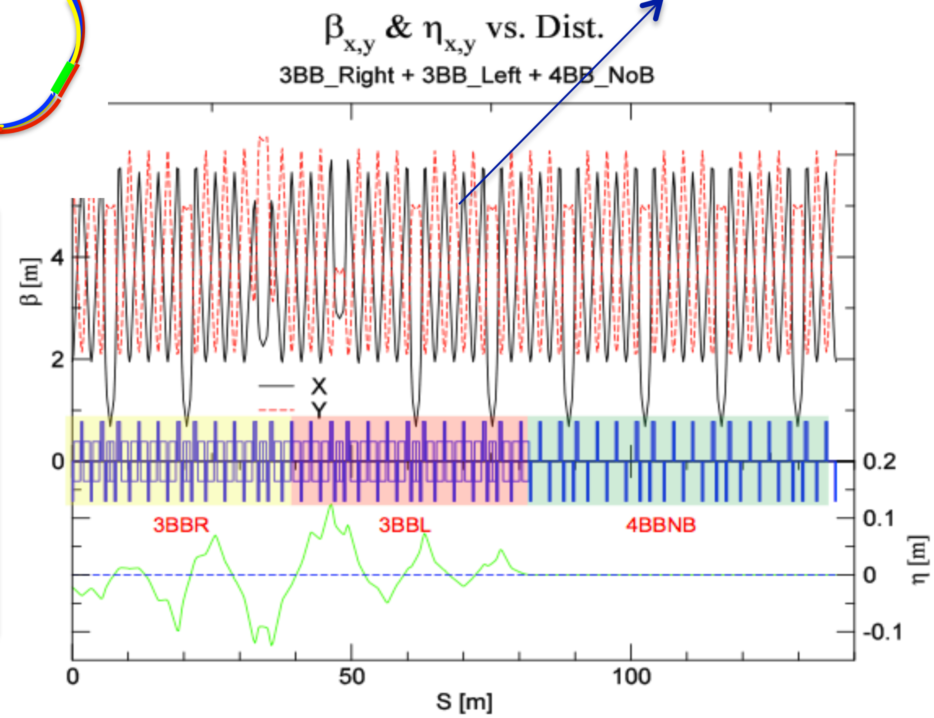


Line Displ.	Half-Line
5 m	3DBB_Right + 3DBB_Left + 4DBB_NoBend
4 m	2DBB_Right + 1DBB_NoBend + 2DBB_Left + 5DBB_NoBend
3 m	1DBB_Right + 2DBB_NoBend + 2DBB_Left + 5DBB_NoBend



DBB ≡ Dejan's BasicBlock



- Top energy line goes through the detector
- Other beam lines make excursion around the detector
- The variants of by-pass lines with 3, 4 and 5 m excursions have been developed

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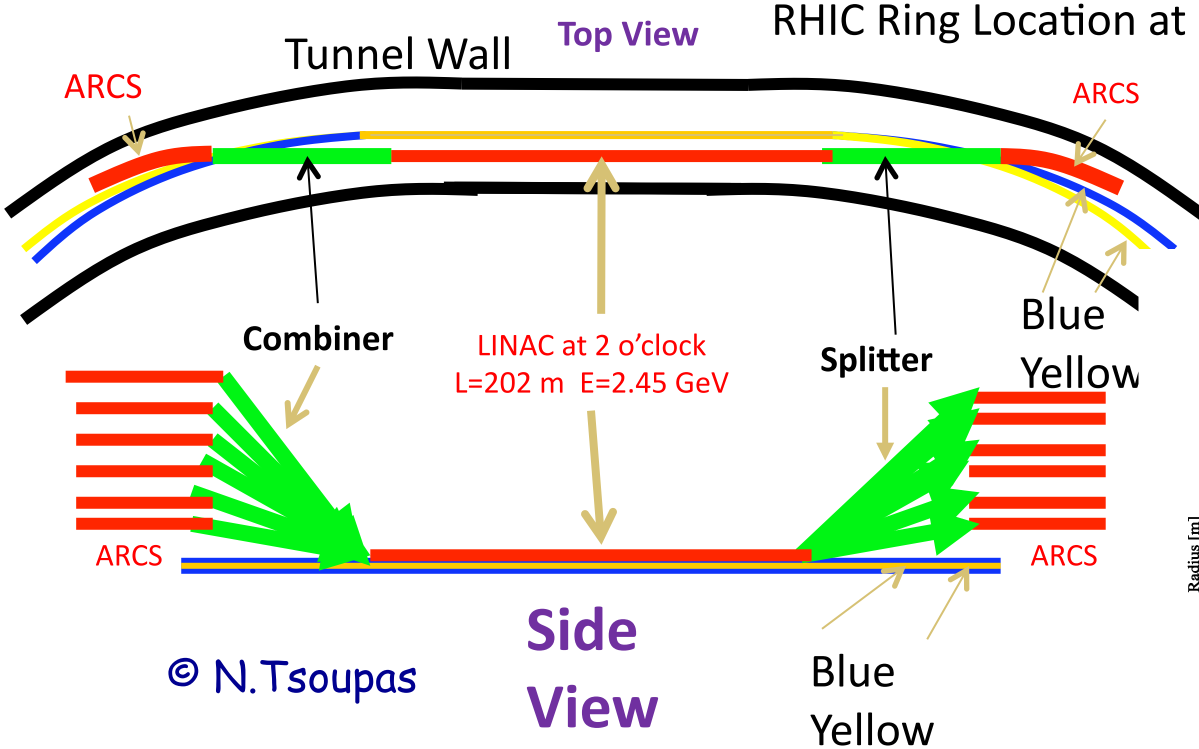
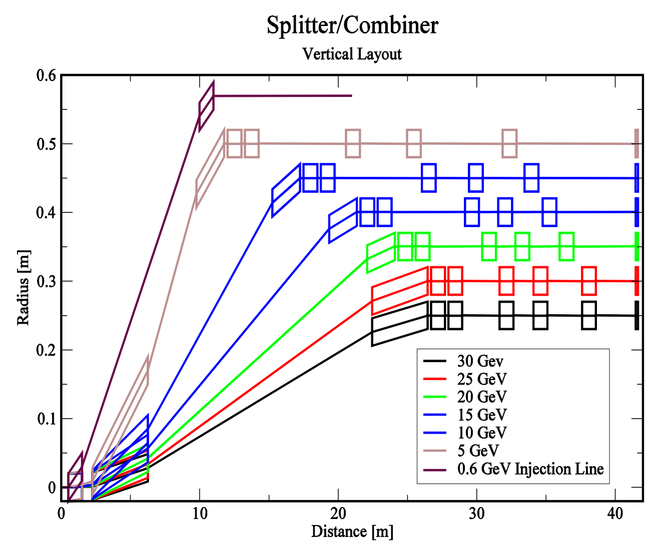
Splitter/Combiner in Relation to the RHIC Ring

RHIC Ring Location at 2 o'clock





- Makes the transitions between linacs and 6-pass lattice in the arcs
- Goes above the RHIC ion magnet lines
- Should provide reasonable bending and fit the tunnel

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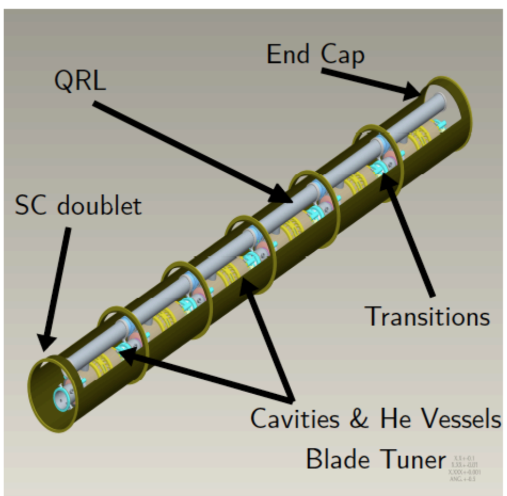
eRHIC Linac Design developments

- Energy of electron beam is increased in stages by increasing the length of the linacs, up to maximum length of 200m of each linac
- Acceleration gain per cavity: 18 MV for 26.5 Gev, 20.4 MV for 30 GeV

- Main variant of lattice does not include quadrupoles inside the linac. (Y. Hao)
- BBU simulations have defined tolerances on HOMs (J.Kewisch)

PRELIMINARY CRYOMODULE

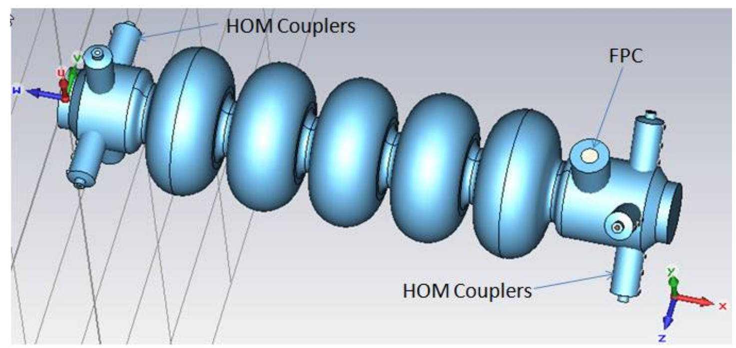
© I. Ben-Zvi, G.Mahler



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

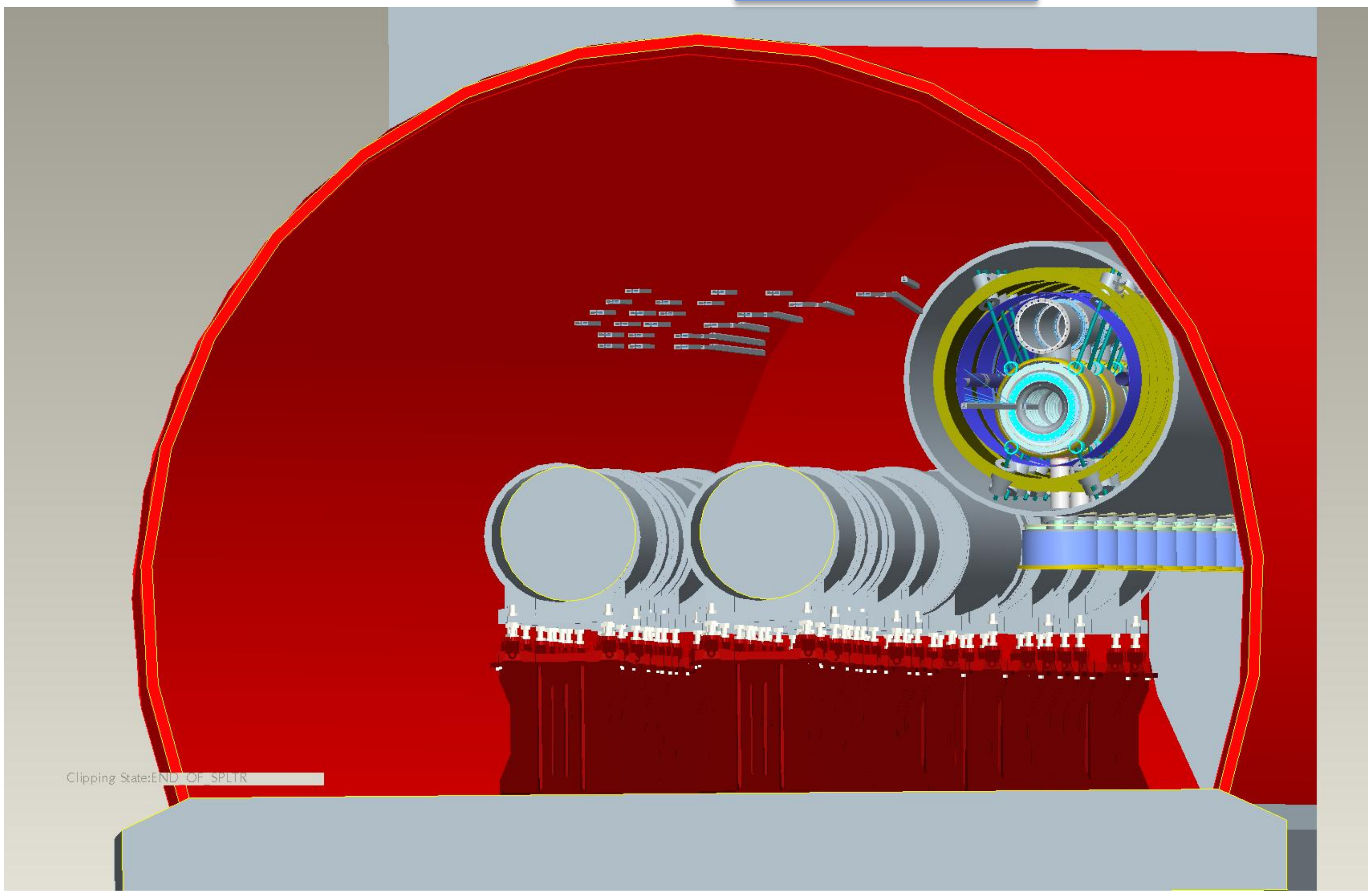


New design of 704 MHz cavity (BNL III):
-reduced peak surface magnet field
-reduced cryogenic load

Linac layout in the RHIC tunnel

© W.Jackson, H.Hahn, G.Mahler

In IR2 region



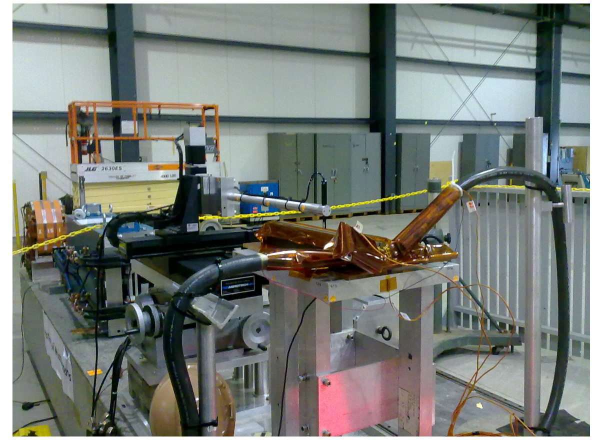
Main R&D Items

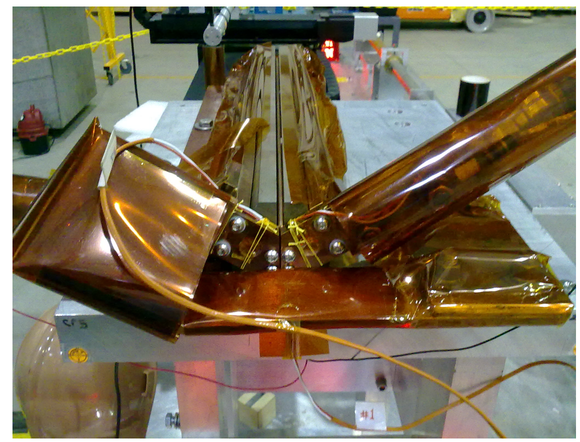
- Electron beam R&D for ERL-based design:
  - High intensity polarized electron source
    - Development of large cathode guns with existing current densities ~ 50 mA/cm^2 with good cathode lifetime.
  - Energy recovery technology for high power beams
    - multicavity cryomodule development; high power 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
  - Proof of principle of the coherent electron cooling.
  - Crab-crossing

Compact magnet development

- Small gap provides for low current, low power consumption magnets
  - Efficient and inexpensive-> **low cost eRHIC**
- **Dipole,cquadrupole and vaccuum chamber protitypes have been constructed (BNL LDRD)**
- **Magnetic measurements : dipole prototype meets specification**

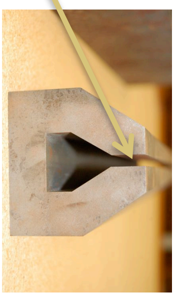
Y.Hao, G.Mahler, V.Litvinenko

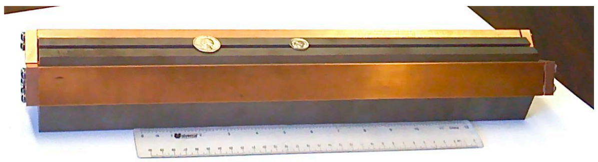


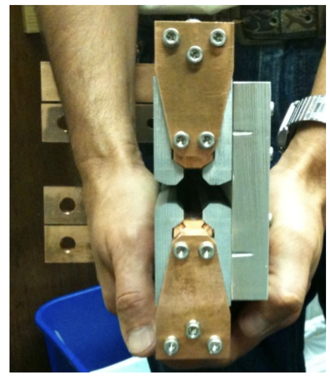


Gap 5 mm total

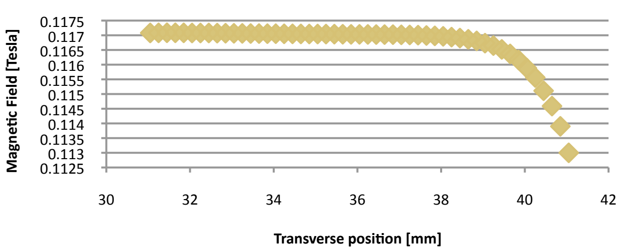
0.3 T for 30 GeV

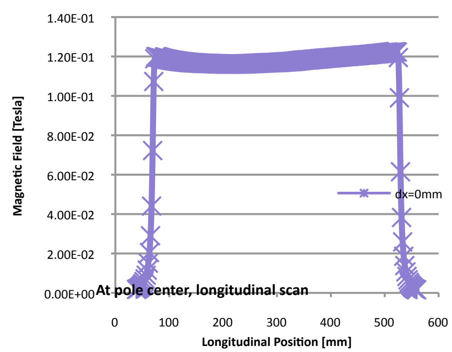






245Ampere, Transverse scan at center of the dipole





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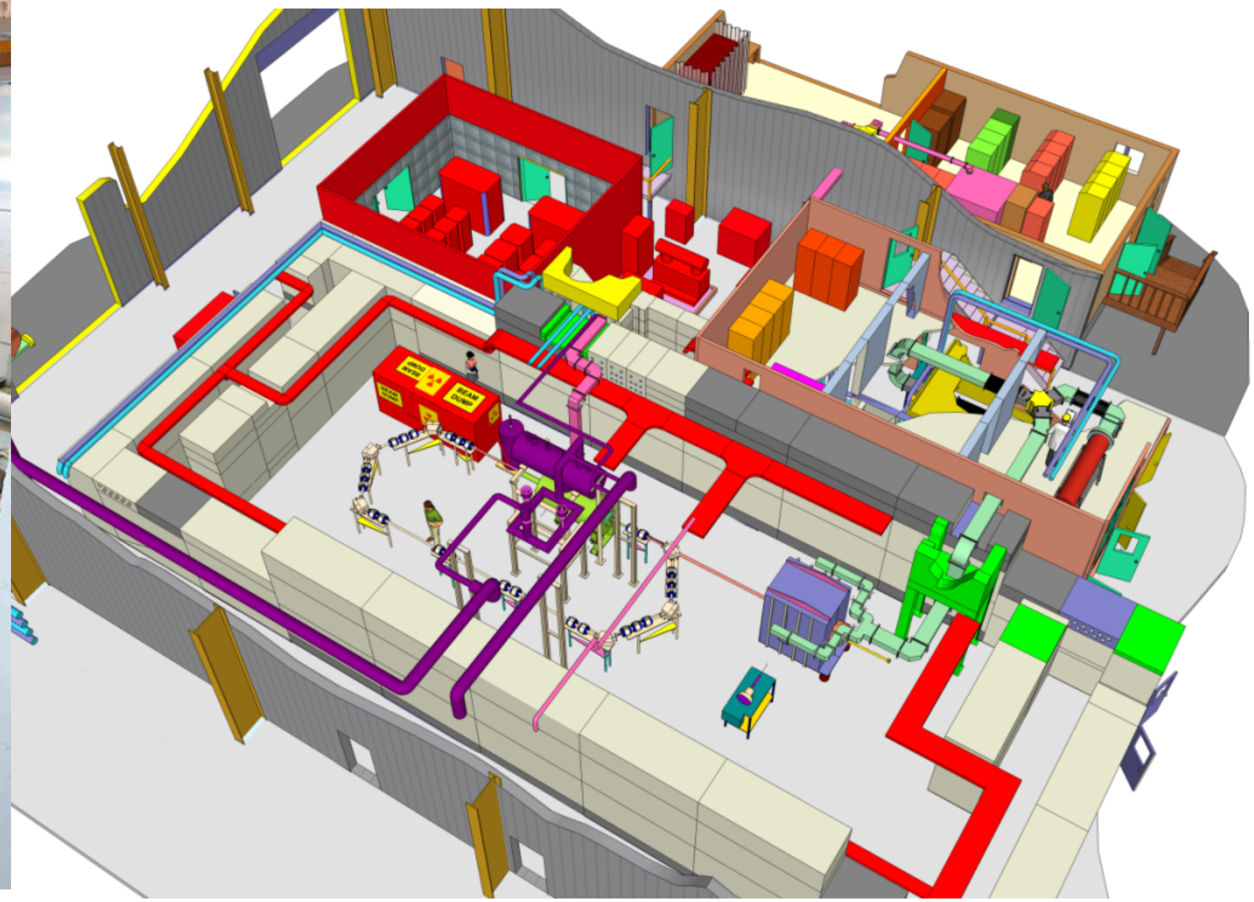
R&D ERL under construction.

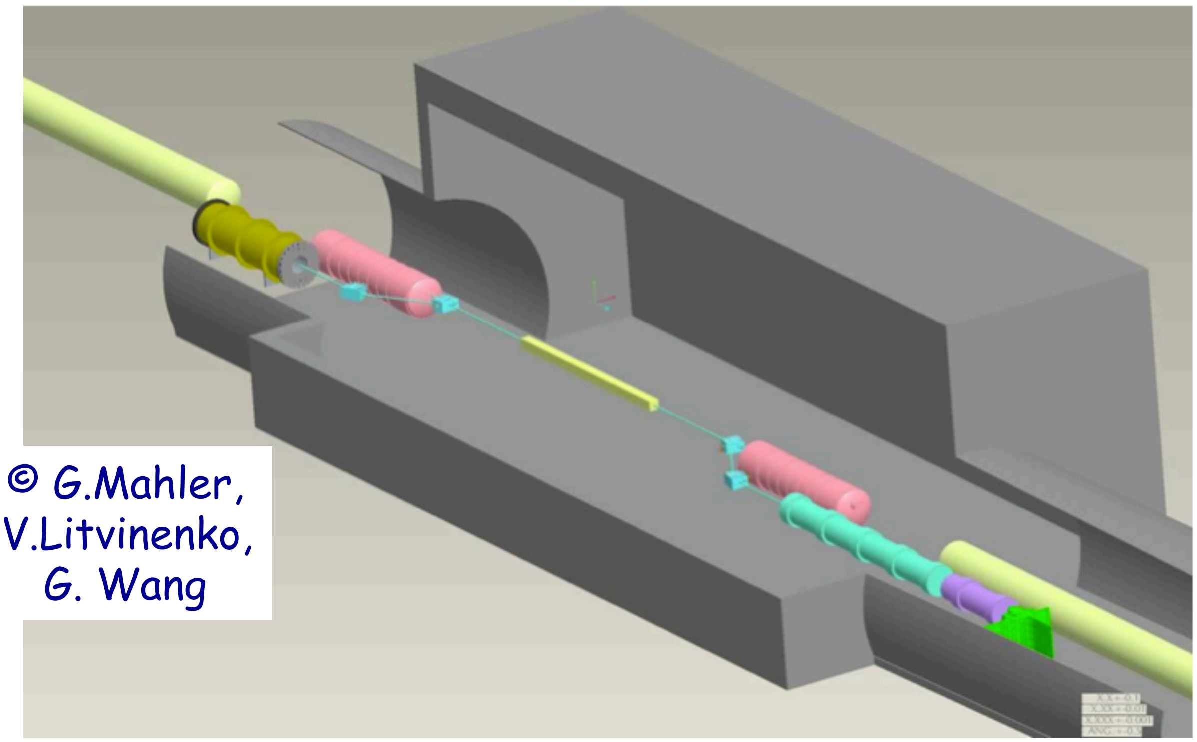
Aim: 0.5 amp CW

D. Kayran, G. McIntyre



Coherent Electron Cooling

NP DOE funding of proof-of-principle experiment at RHIC -> 5 years, $5.9M
Collaboration: BNL, Jefferson Lab, Tech-X Corporation
Projected dates: 2013-2014
Aim : to demonstrate cooling

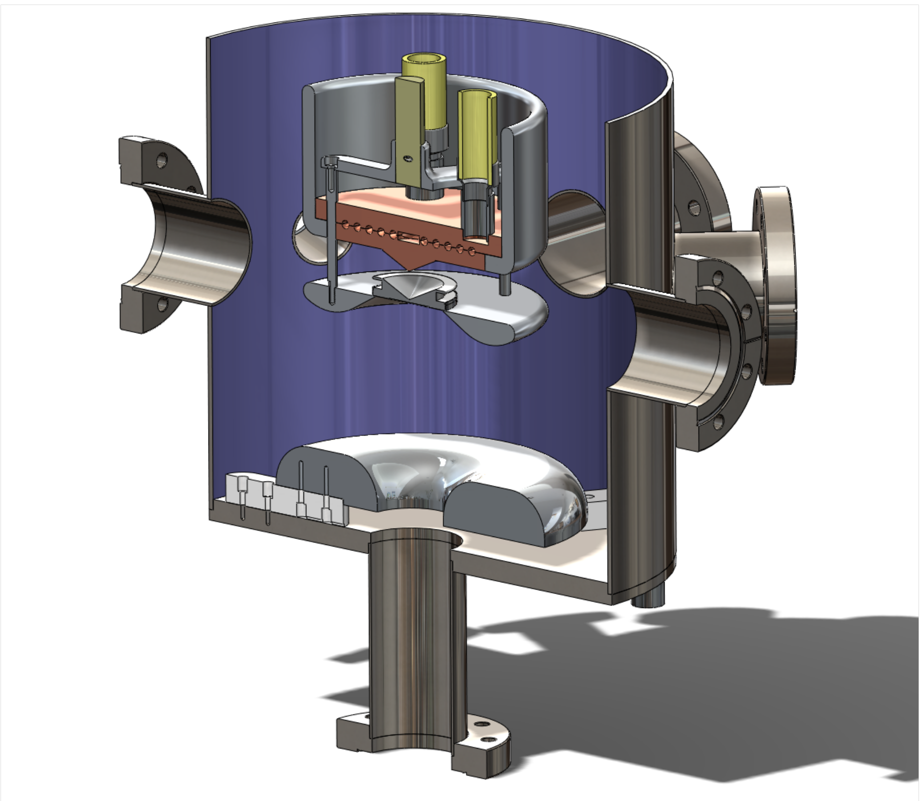


Layout of CEC proof-of-principle experiment in RHIC IR2

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

Developments under LDRD funding

Single large size cathode



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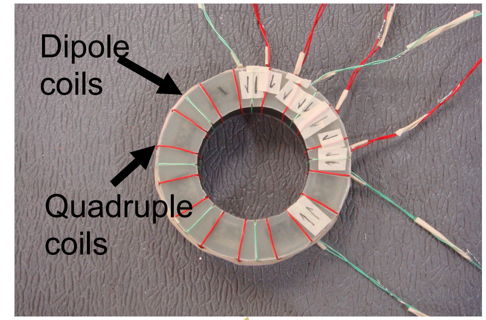
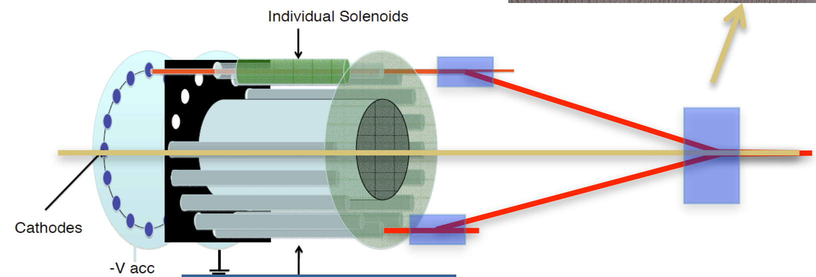
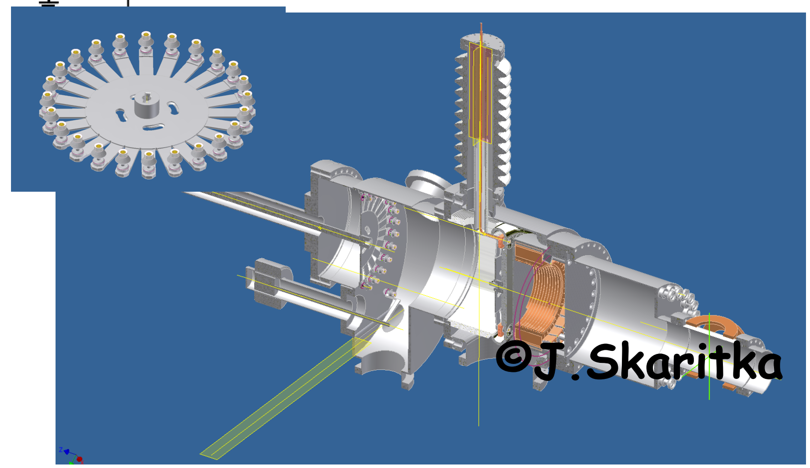
Gatling gun:







Mechanical design has been developed
Ready for prototype construction

X.Chang

Beam dynamics studies

Recent results on:
-electron beam energy losses and energy spread caused by the interaction with the beam environment (cavities, resistive walls, pipe roughness)
-incoherent and coherent synchrotron radiation related effects: energy losses, transverse and longitudinal emittance increase of the electron beam
-electron beam patterns; ion accumulation
-electron beam break-up, single beam and multi-pass
-electron beam-ion and intra-beam scattering effects
-electron beam disruption
-frequency matching

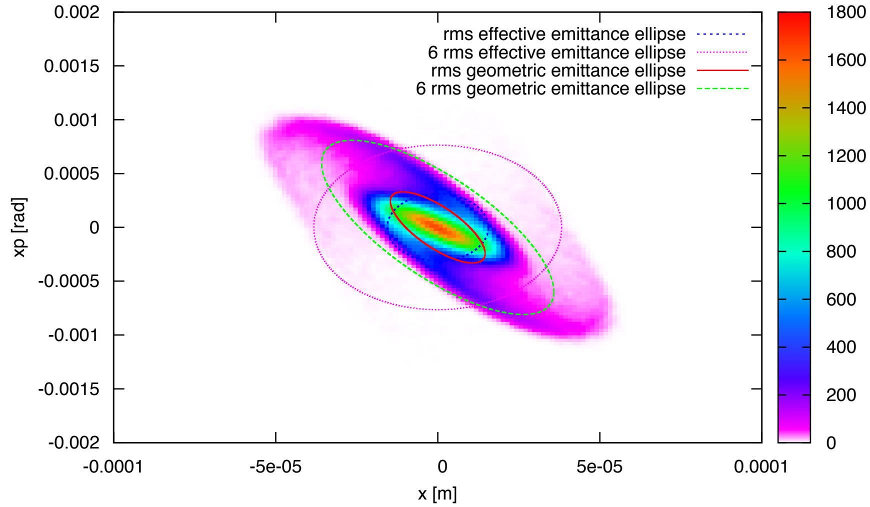
The issues presently under investigation:
- How small can be the electron beam pipe size?
- Compensation of the energy losses and the energy spread of the electron beam.
- How long should be the electron bunch?
- Crab cavities and their effect on beam dynamics

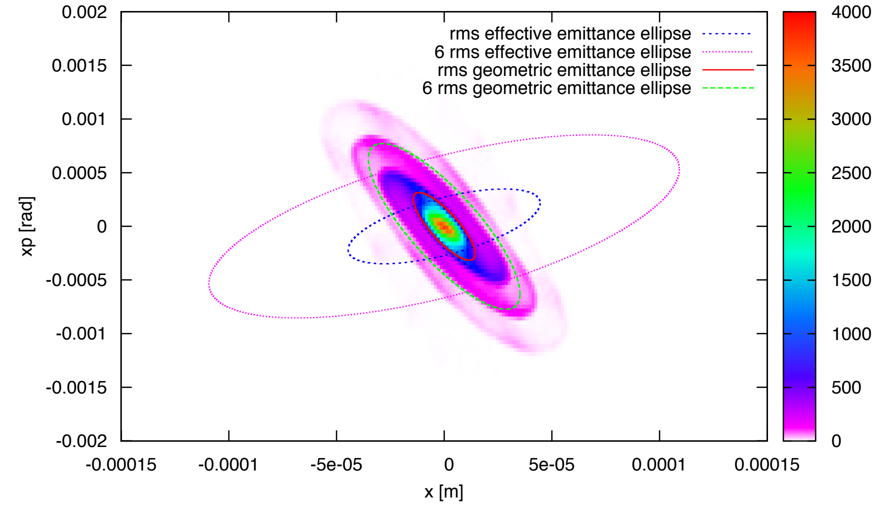
Electron beam disruption

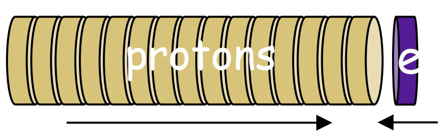
E=20 GeV, D=27

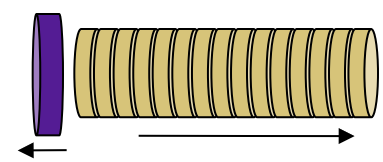
©Y. Hao

E=5 GeV, D=108



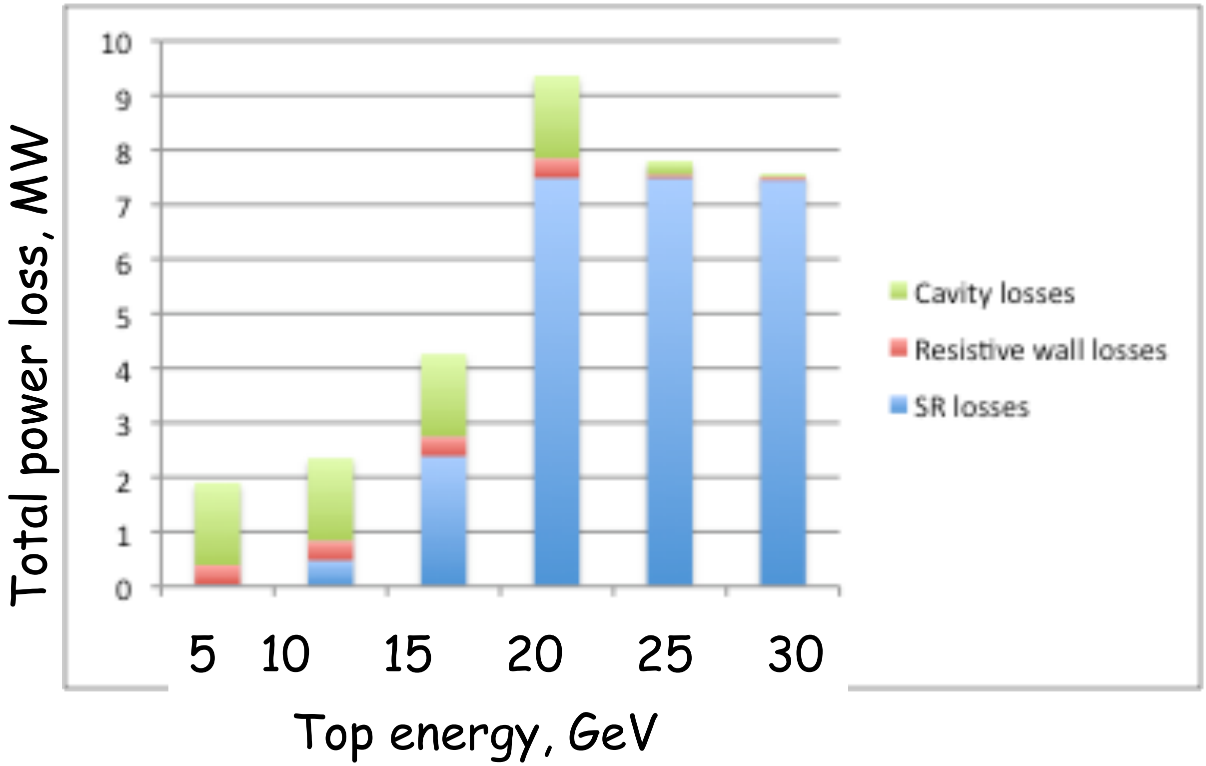






The electron beam after collision has to be still of a good quality to go lossless through the deceleration process

Electron beam energy loss budget for 6 pass scheme



How to decrease losses?:

-Combined function magnet lattice (SR losses -> 5 MW)

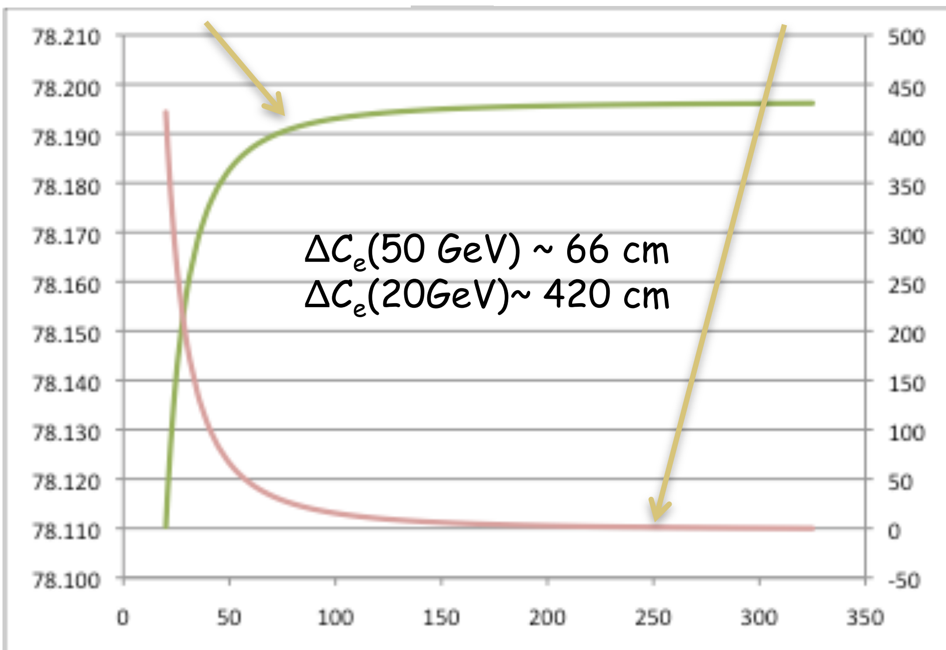
-Use 4 passes for acceleration up to 20 GeV (modification of splitter design)

-Longer bunch (2mm -> 4mm)

Electron-hadron frequency matching

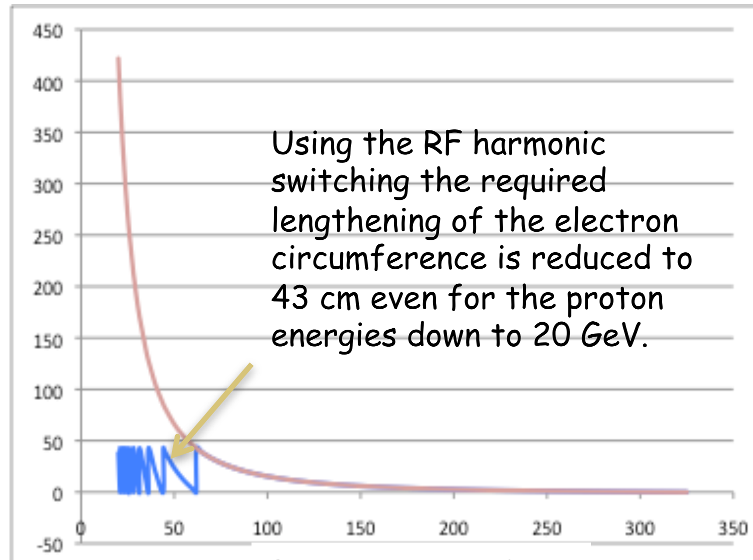
Proton revolution frequency, kHz

Electron pass circumference lengthening, cm



Hadron energy per nucleon, GeV

Electron pass circumference lengthening, cm



Proton energy, GeV

Electron bunch frequency should match the proton bunch frequency in wide energy range. Present eRHIC design: 50-325 GeV proton energy. Here we consider down to 20 GeV.

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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

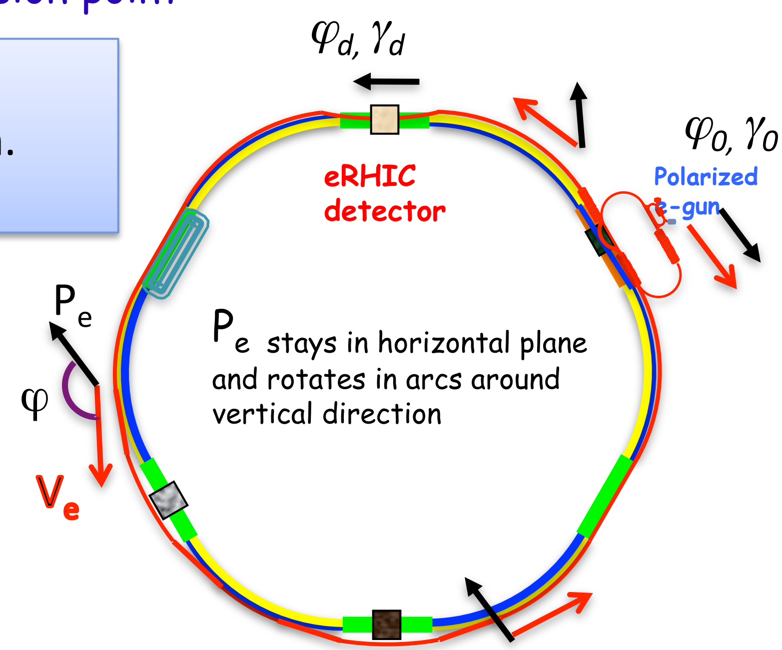
> The beam energy spread has to be kept under control to minimize spin decoherence during the acceleration.

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



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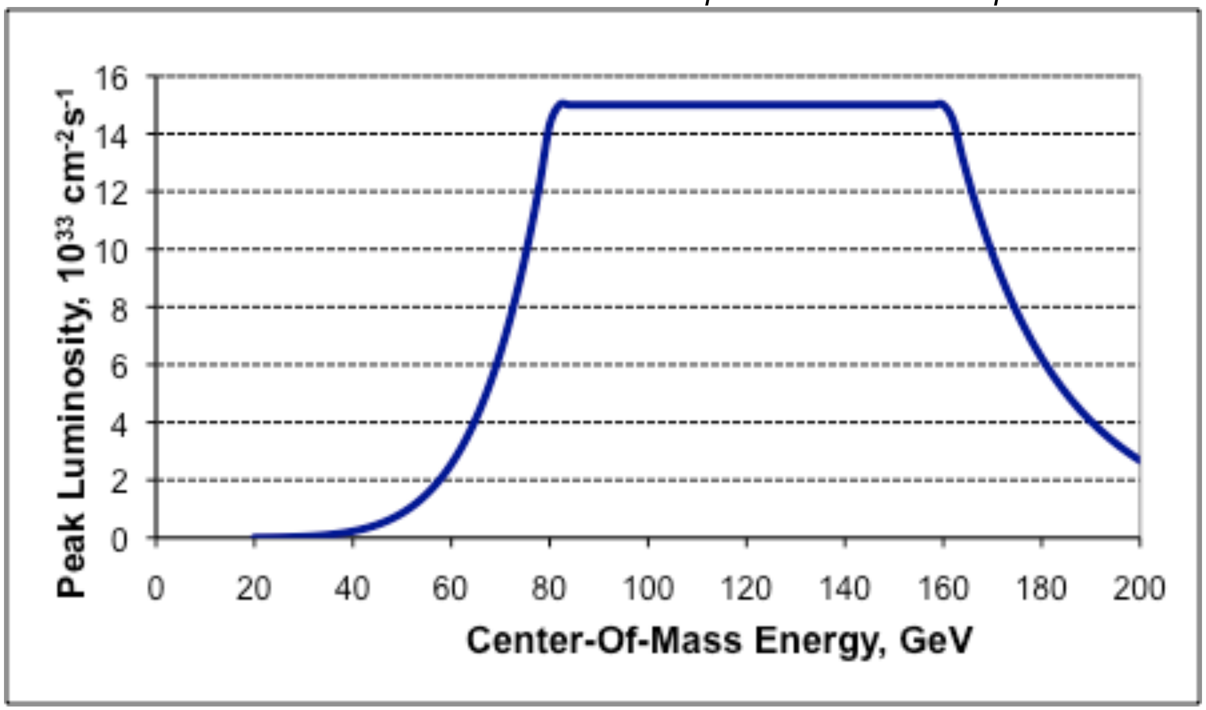
Summary

- Design of eRHIC is well advanced.
- The eRHIC luminosity is above 10^{34} cm^{-2} s^{-1}.
- Intensive development has been done for the electron beam lattice, IR design. Critical beam dynamic issues have been evaluated. And the work continues.
- Progress on critical R&D items: cavities and cryomodule; CEC; polarized source; compact magnets. Some supported by LDRD or SBIR funding.
- Our present plan is to complete conceptual design by the end of spring and to have detailed cost estimate before October.

Back-up slides

CME dependence of luminosity

Assumed limits: I_e = 50 mA, ξ_p =0.015, ΔQ_{sp} = 0.035



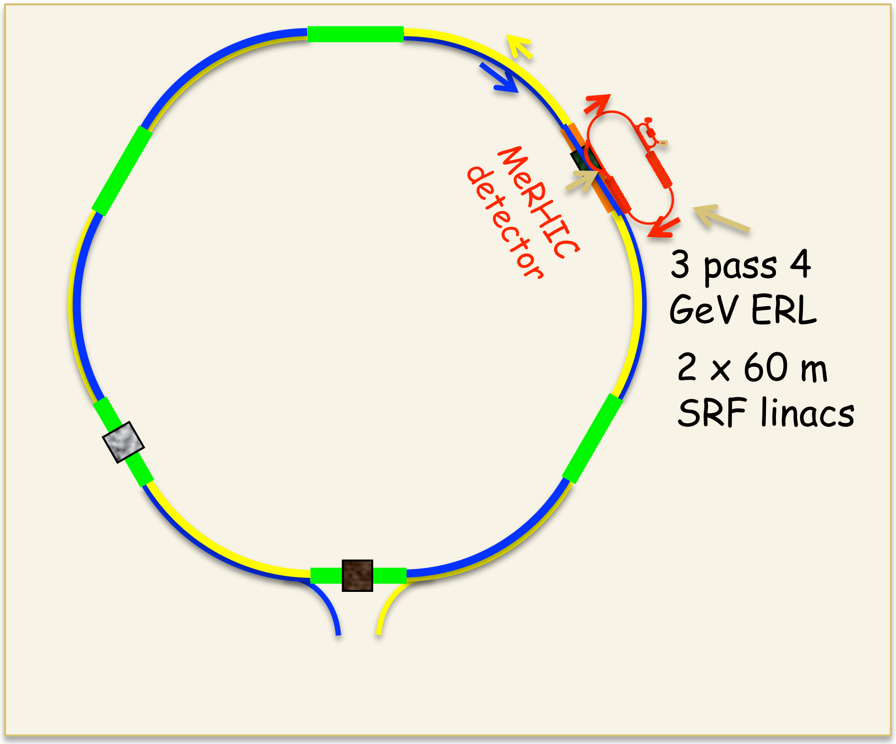
The value used in ELIC

What should be a design value for ΔQ_{sp} ?

ΔQ_{sp} = 0.035:
L > 10^{33} s^{-1} cm^{-2}
CME > 51 GeV
E_p > 130 GeV

ΔQ_{sp} = 0.07:
L > 10^{33} s^{-1} cm^{-2}
CME > 46 GeV
E_p > 106 GeV

2009: MeRHIC as first stage



4 GeV electron accelerator placed locally near one of RHIC Interaction Regions
Dedicated MeRHIC detector.

-Well developed accelerator design
-Thorough cost estimate led to ~$350mln
(without the detector)

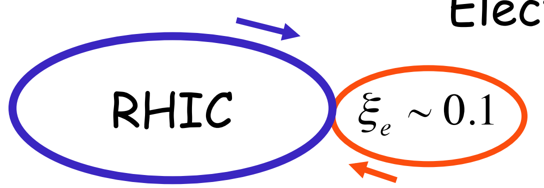
After that MeRHIC was replaced by a better all-in-tunnel staging approach to eRHIC is being pursued in 2010.

However, most of MeRHIC developments are used in new eRHIC design:
-linac cavities, cryomodules …
-recirculation pass optics (FMC cell approach)
-polarized source and low energy acceleration

2007 Choosing the focus: ERL or ring for electrons?

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

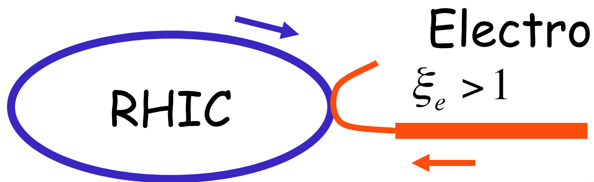
$$L = \left(\frac{4\pi\gamma_h\gamma_e}{r_h r_e}\right)(\xi_h\xi_e)(\sigma'_h\sigma'_e)f$$



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 50

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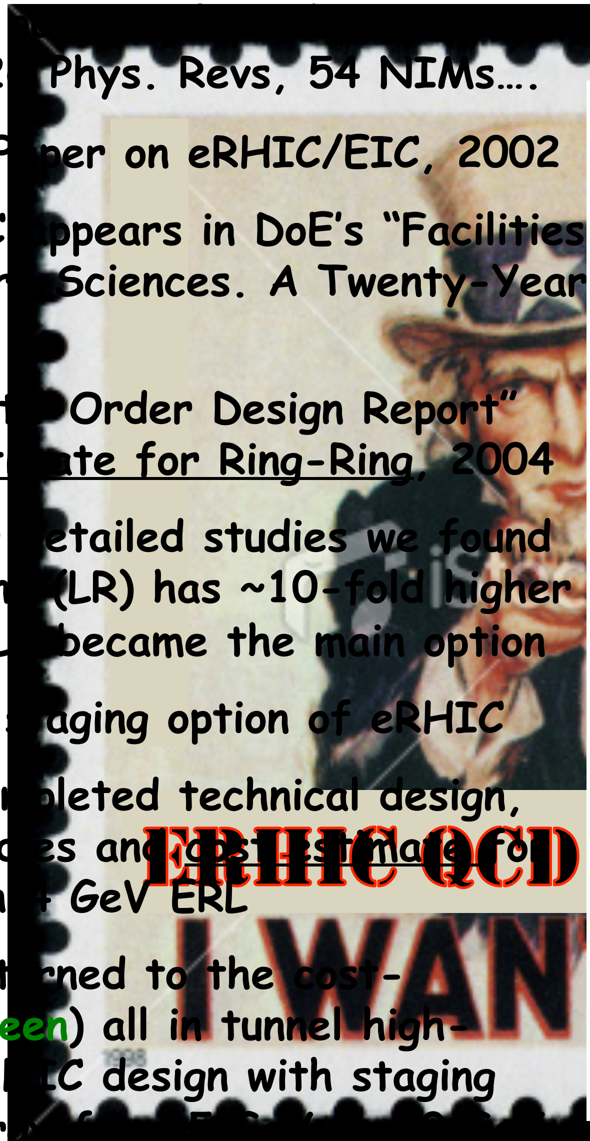
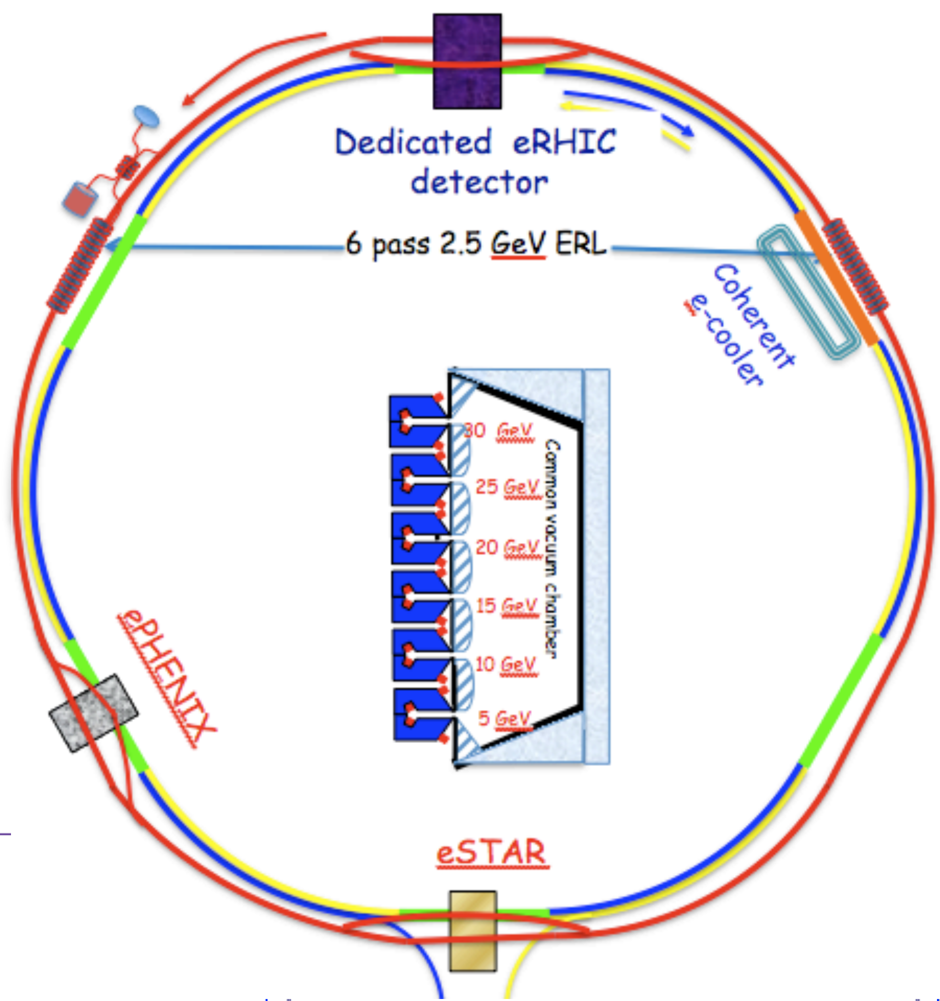
Achievements and plans in eRHIC lattice design

1. Lattices of the eRHIC electron passes are complete:
   - 1.1 eRHIC layout in the existing RHIC tunnel with a complete survey
   - 1.2 Beam optics with zero momentum compaction of required modules
   - 1.3 Interaction region lattice for 30 GeV electron beam:
     - 1.3.1 Without synchrotron radiation at interaction point
     - 1.3.2 Matched to the zero momentum compaction arcs
   - 1.4 Quadrupole free linac optics
   - 1.5 Linacs with splitters, combiners and arcs
   - 1.6 Straight passes through the interaction region of 30 GeV
   - 1.7 Bypasses of lower energy electron beams around detectors
2. RHIC proton and heavy ion lattice design
   - 2.1 Proton and heavy ion interaction region with β^*=5 cm
     - 2.1.1 Solid angle of 8 mrad for zero degree neutron calorimeter
     - 2.1.2 Detection of the partons with lower energies
     - 2.1.3 Deep virtual scattering for protons-electron collisions
3. Remaining work:
   - 3.1 Electron polarimeter and electron energy spectrum detection (in progress)
   - 3.2 Pipe size evaluations
   - 3.3 Engineering drawings of the layout with a cost estimate
   - 3.4 Dynamical aperture studies of both proton and electron designs
   - 3.5 Second and third order chromatic corrections studies
   - 3.6 Crab cavity placement and studies
   - 3.7 Complete the design of the interaction region quadrupoles

Brief history of eRHIC

- First eRHIC paper, 2000, I. Ben. Zvi et al., ~300 … @JACoW, 2… Phys. Revs, 54 NIMs….
- First White P… per on eRHIC/EIC, 2002
- 2003, eRHIC … ppears in DoE's "Facilities for the Futur… Sciences. A Twenty-Year Outlook"
- "eRHIC Zeroth… Order Design Report" with cost est… ate for Ring-Ring, 2004
- 2007 – after … etailed studies we found that linac-rin… (LR) has ~10-fold higher luminosity – L… became the main option
- 2008 – first … aging option of eRHIC
- In 2009 – co… pleted technical design, dynamics stu… es and cost estimate for MeRHIC with … GeV ERL
- Present - ret… rned to the cost-effective (green) all in tunnel high-luminosity eR… C design with staging electron ener…





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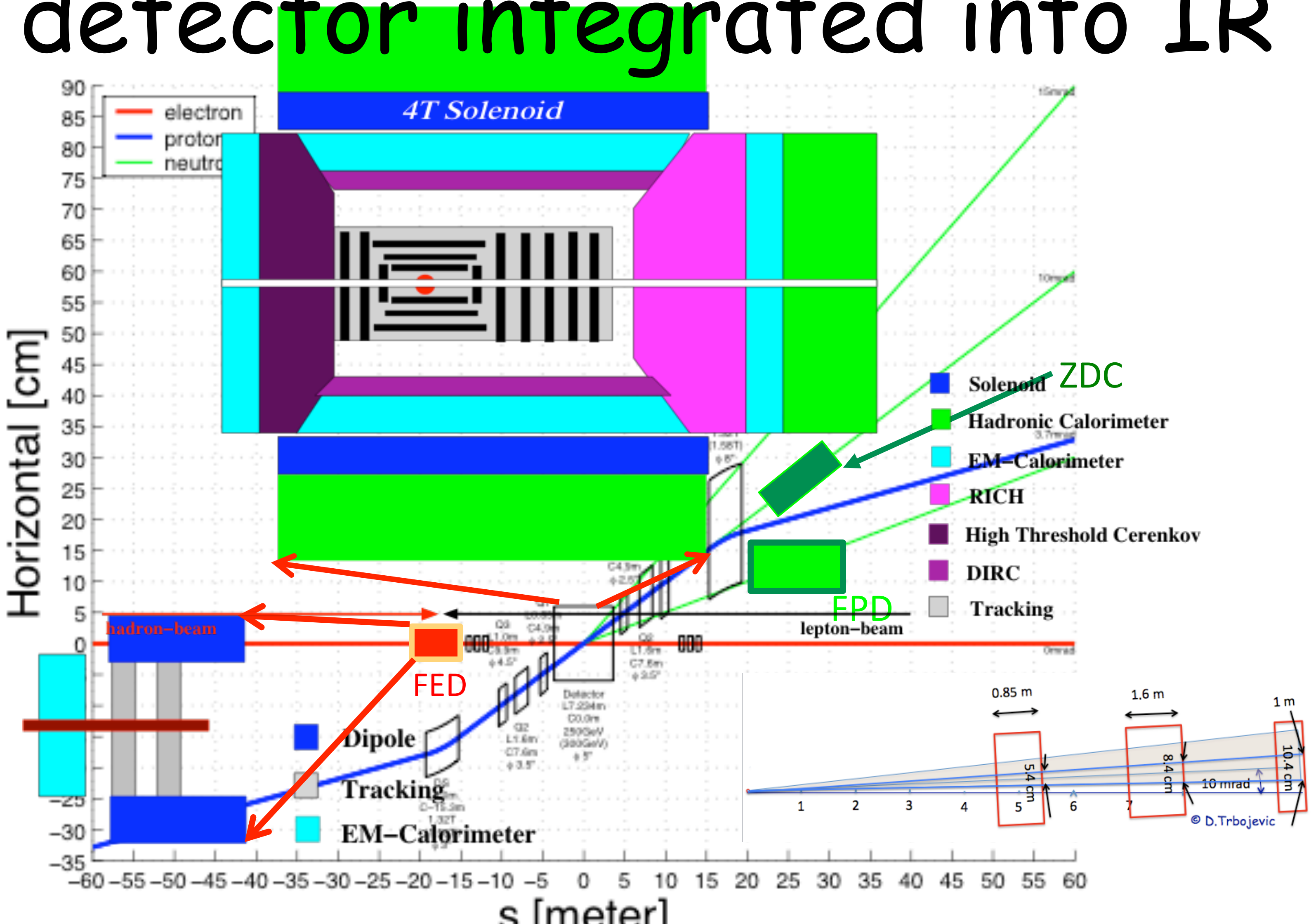
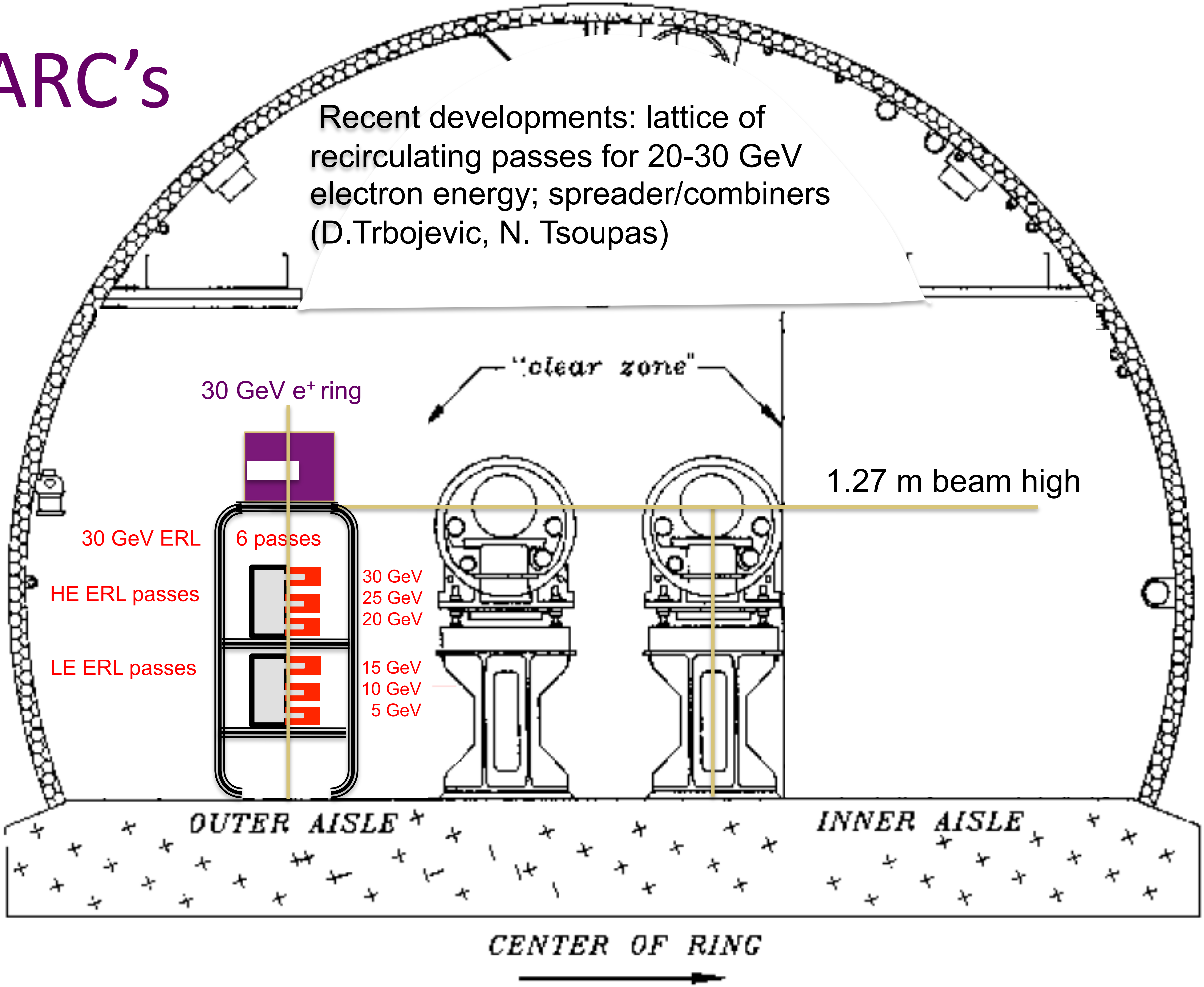
A detector integrated into IR



- ❑ Dipoles needed to have good forward momentum resolution
  - ➢ Solenoid no magnetic field @ r ~ 0
- ❑ DIRC, RICH hadron identification → π, K, p
- ❑ high-threshold Cerenkov → fast trigger for scattered lepton
- ❑ radiation length very critical → low lepton energies

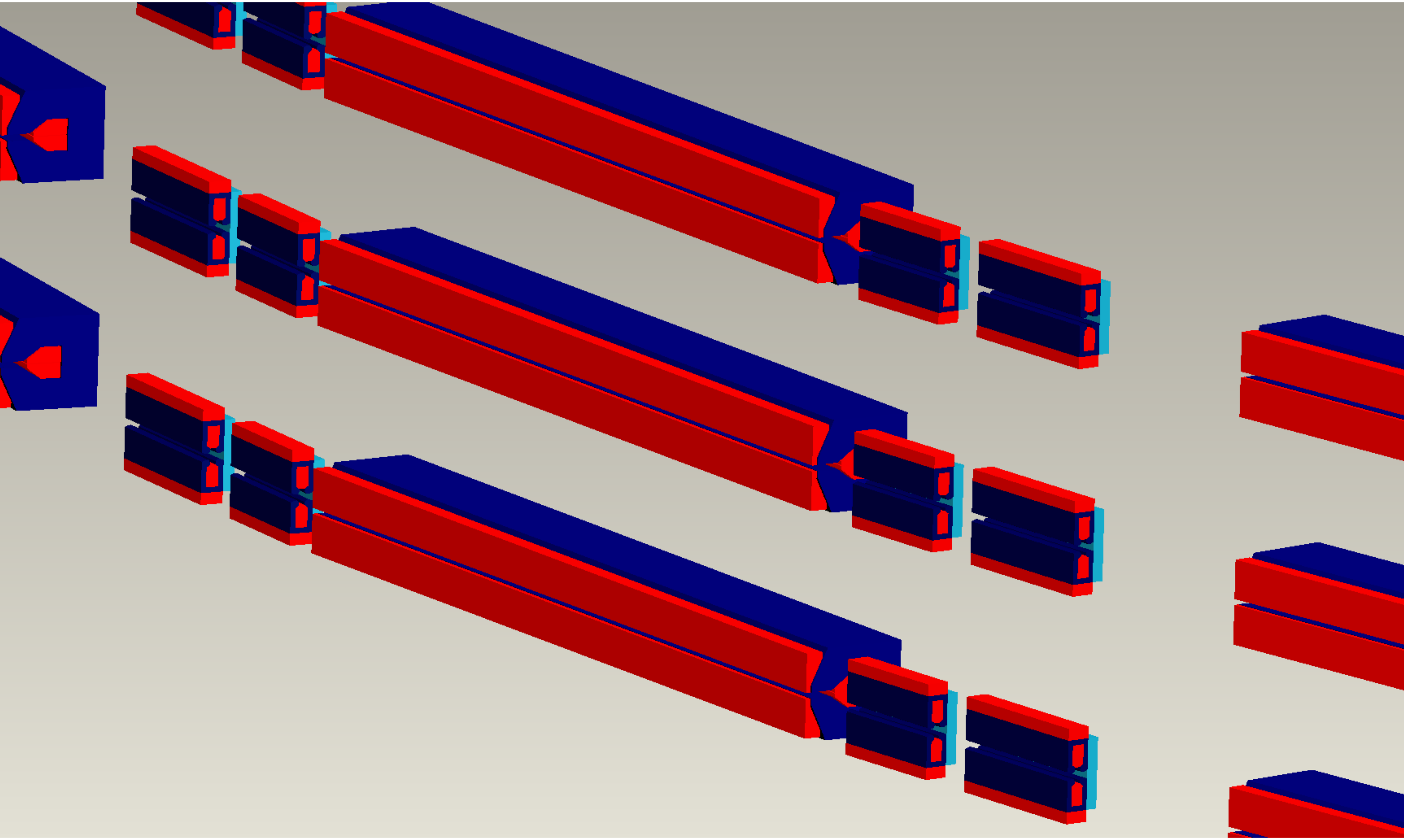
ARC's

Recent developments: lattice of recirculating passes for 20-30 GeV electron energy; spreader/combiners (D.Trbojevic, N. Tsoupas)

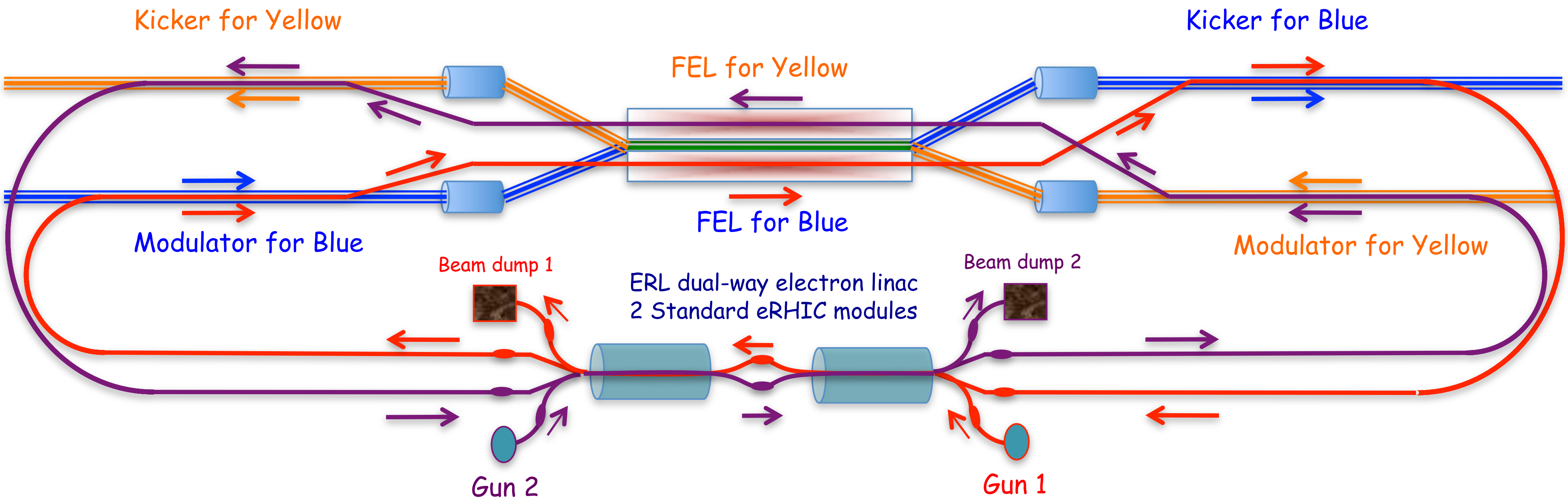


Recirculating arc lattice

© D.Trbojevic

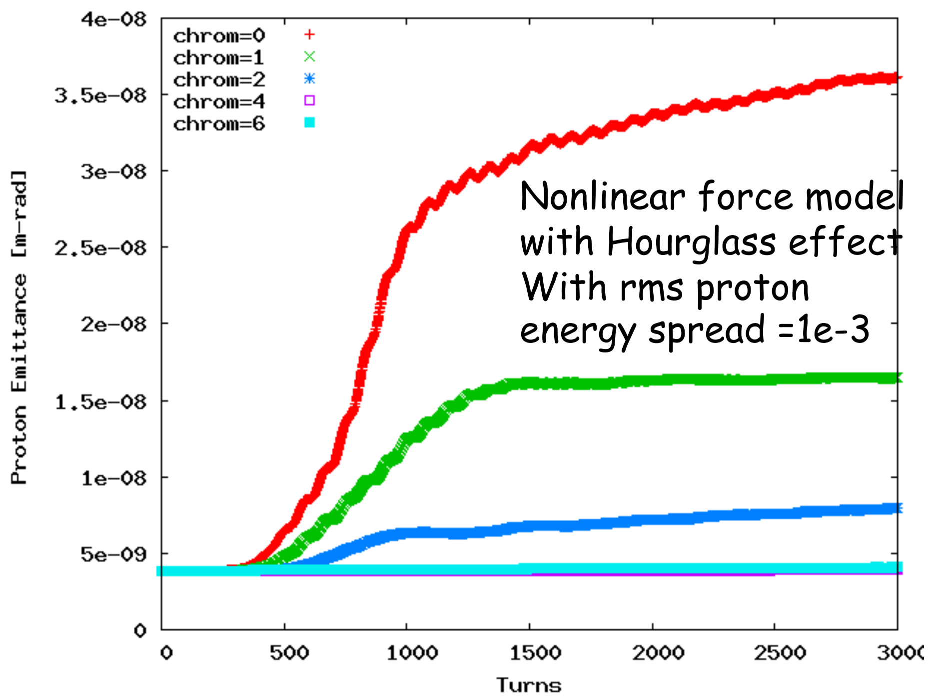


Possible layout in RHIC IP of CeC driven by a single linac for RHIC and eRHIC

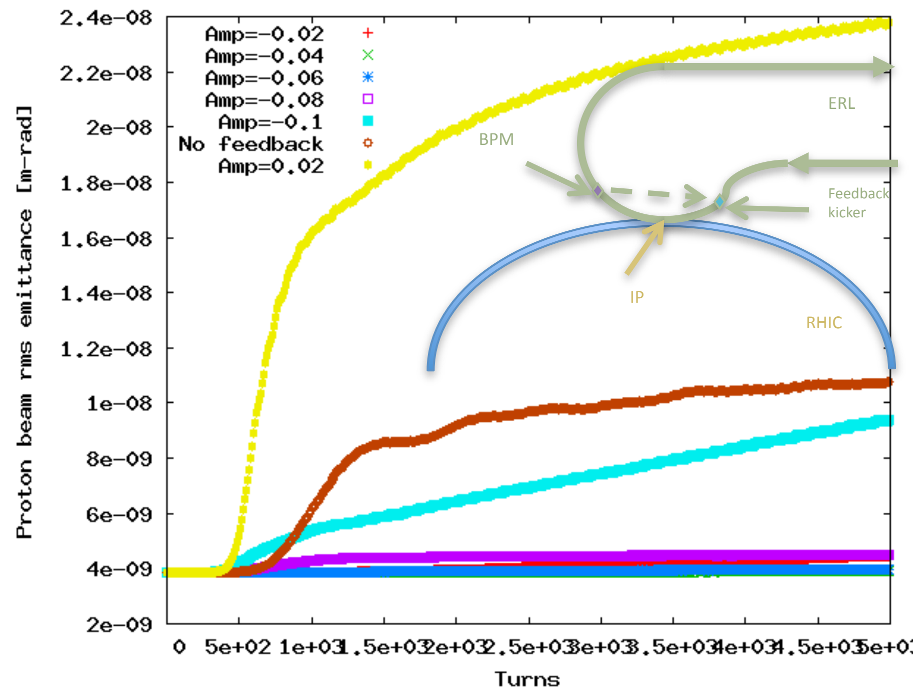


E_p, GeV	γ	E_e, MeV
100	106.58	54.46
250	**266.45**	**136.15**
325	346.38	177.00

Suppression of kink instability



By chromaticity: $\xi \sim +4$



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 eRHIC parameter ranges.

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Coherent Electron Cooling (CeC)

At a half of plasma oscillation

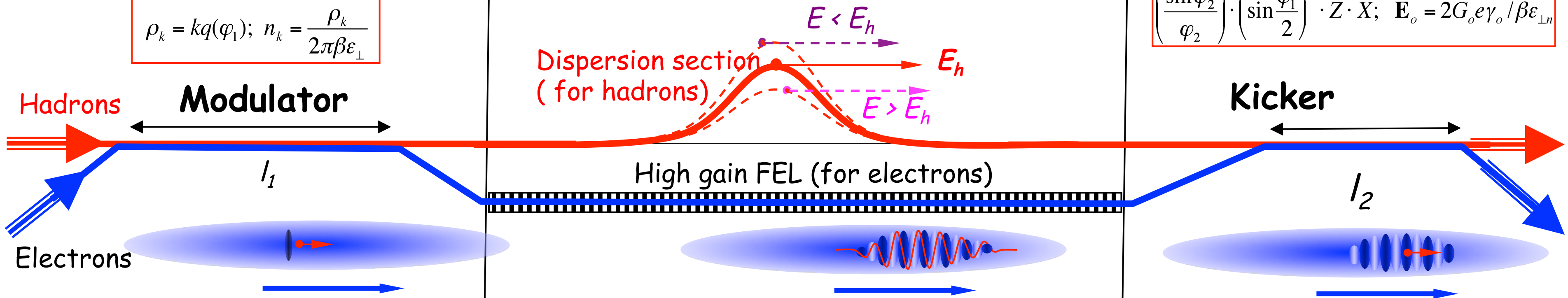
$$q_{\lambda_{FEL}} \approx \int_0^{\lambda_{FEL}} \rho(z)\cos(k_{FEL}z)\,dz$$

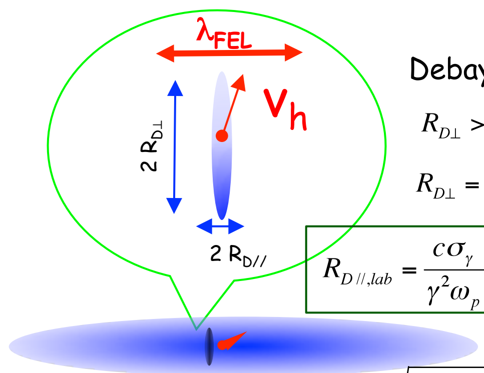
$$\rho_k = kq(\varphi_1);\ n_k = \frac{\rho_k}{2\pi\beta\varepsilon_\perp}$$

Dispersion

$$c\Delta t = -D\cdot\frac{\gamma-\gamma_o}{\gamma_o};\ D_{free} = \frac{L}{\gamma^2};\ \ D_{chicane} = l_{chicane}\cdot\theta^2 ....$$

$$\Delta E_h = -e\cdot \mathbf{E}_o \cdot l_2 \cdot \sin\left(k_{FEL} D \frac{E-E_o}{E_o}\right)\cdot \left(\frac{\sin\varphi_2}{\varphi_2}\right)\cdot\left(\sin\frac{\varphi_1}{2}\right)^2 \cdot Z\cdot X;\ \ \mathbf{E}_o = 2G_o e\gamma_o/\beta\varepsilon_{\perp n}$$





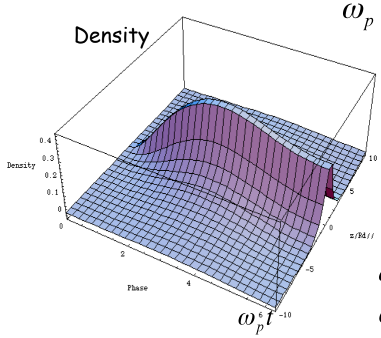
Debay radii

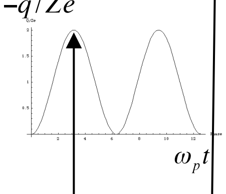
$$R_{D\perp} >> R_{D//}$$

$$R_{D\perp} = \frac{c\gamma\sigma_{\theta e}}{\omega_p}$$

$$R_{D//,lab} = \frac{c\sigma_\gamma}{\gamma^2\omega_p} << \lambda_{FEL}$$

$$\omega_p = \sqrt{4\pi n_e e^2/\gamma_o m_e}$$



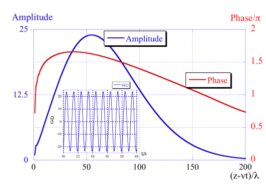


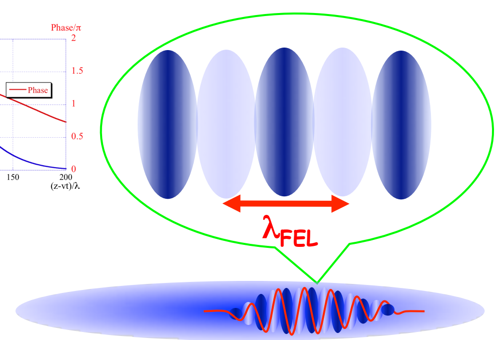
$$q = -Ze\cdot(1-\cos\varphi_1)$$

$$\varphi_1 = \omega_p l_1/c\gamma$$

$$q_{peak} = -2Ze$$

Amplifier of the e-beam modulation in an FEL with gain G_{FEL}~10^2-10^3





$$\lambda_{fel} = \lambda_w\left(1+\langle \vec a_w^2\rangle\right)/2\gamma_o^2$$

$$\vec a_w = e\vec A_w/mc^2$$

$$L_{Go} = \frac{\lambda_w}{4\pi\rho\sqrt{3}}$$

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Coherent Electron Cooling

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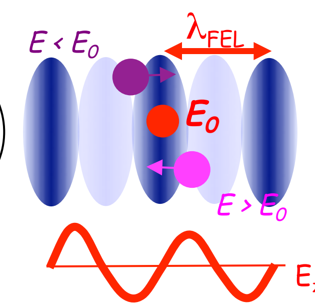
(Received 24 September 2008; published 16 March 2009)

$$A_\perp = 2\pi\beta_\perp\varepsilon_n/\gamma_o$$



$$k_{FEL} = 2\pi/\lambda_{FEL};\ k_{cm} = k_{FEL}/2\gamma_o$$

$$n_{amp} = G_o\cdot n_k\cos(k_{cm}z)$$

$$\Delta\varphi = 4\pi en \Rightarrow \varphi = -\varphi_0\cdot\cos(k_{cm}z)$$

$$\vec{\mathbf{E}} = -\vec\nabla\varphi = -\hat z\,\mathbf{E}_o\cdot X\sin(k_{cm}z)$$

$$\mathbf{E}_o = 2G_o\gamma_o\frac{e}{\beta\varepsilon_{\perp n}}$$

$$X = q/e \cong Z(1-\cos\varphi_1)\sim Z$$

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Major IEC Accelerator R&D in the US

Common R&D activities for eRHIC and ELIC

- Polarized 3He production and acceleration (BNL) [5 FTE-yrs; M&S: $ 1.0 M Total: $2M]
- Coherent Electron Cooling (BNL) [15 FTE-yrs; M&S: $ 5.0 M Total: $8M]
- Energy recovery technology for 100 MeV level electron beam. (JLab) [20 FTE-yrs; M&S: $4.5 M Total: $8.5M]
- Crab cavities [8 FTE-yrs; M&S: $1.2M Total: $2.8M]

R&D activities specific to eRHIC

- High current polarized electron source (MIT) [7.5 FTE-yrs; M&S: $ 2.0 M Total: $3.5M]
- Energy recovery technology for high energy and high current beams (BNL) [10 FTE-yrs; M&S: $ 3.0 M Total: $5M]
- Development of eRHIC-type SRF cavity (BNL) [10 FTE-yrs; M&S: $ 2.0 M Total: $4M]

R&D activities specific to ELIC

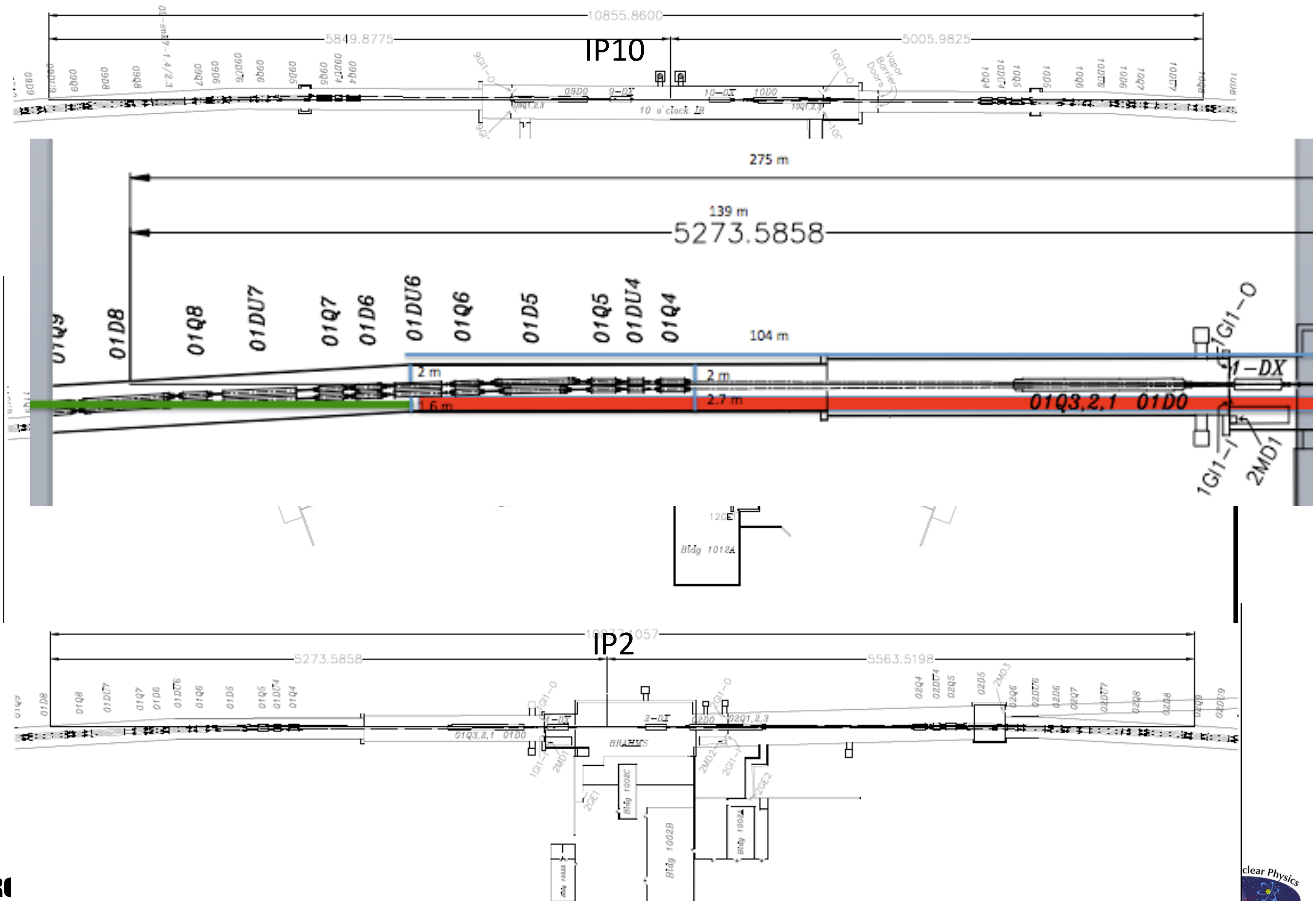
- Ion space charge sim. (JLab in collab. with SNS) [2 FTE-yrs; M&S: $0.5M Total: $0.9M]
- Spin track studies for ELIC (JLab) [8 FTE-yrs; Total: $1.6M]
- Studies traveling focus scheme (JLab) [3 FTE-yrs; Total: $0.6M]
- Simulation studies supporting ELIC project (JLab) [5 FTE-yrs; Total: $1.0M]

Main Accelerator Challenges

In red –increase/reduction beyond the state of the art

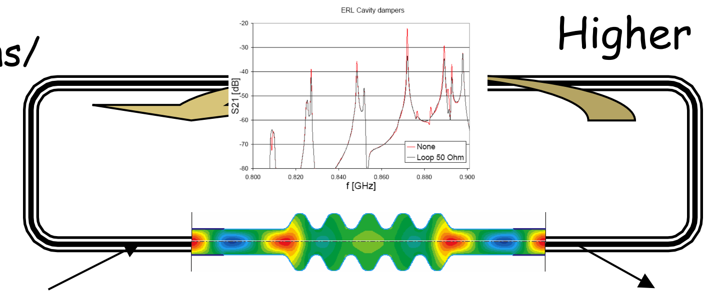
ENC at FAIR	ELIC at JLaB	eRHIC at BNL	LHeC at CERN Ring-Ring	LHeC at CERN Linac-Ring
	β*=0.5 cm 50x reduction	Polarized electron gun – 50x increase	Depolarization at the top energy	Polarized e^- source
8 MV, 3 A magnetized electrostatic (Voltage*2, Current*6)	HE Electron Cooling – 100x increase in the rate of cooling	Coherent Electron Cooling – New concept	Energy reach beyond 70 GeV for leptons	Potential 10x gains from cooling, but need special CeC
Investigation of large beam-beam tune shift in space charge dominated regimes	High current recirculating ring with ERL-injector New concept	Multi-pass SRF ERL 5x increase in current 30x increase in energy	Synchrotron radiation losses in the arcs	Multi-pass SRF ERL 5x increase in current 30x increase in energy 3-4x in # of passes
Crab crossing (compliance with acceptance of PANDA)	Crab crossing 5x the angle New for hadrons	Crab crossing New for hadrons	Crab crossing New for hadrons	Crab crossing New for hadrons
	Polarized ^{3}He production		By-passes	Totally new tunnel
Limited space for electron ring	Never explored beam-beam parameter range 3-4x in ξ	Understanding of beam-beam affects New type of collider	Complexity of the sharing tunnel with LHC	Very challenging to have e+ source
Polarization life time in electron ring (lattice considerations)	Dispersive crab crossing Traveling focus New concepts	β*=5 cm 5x reduction		Using crossing angle to avoid SR in IR
Space charge limits beam dynamics, Bunching (1→200)	Sub-nsec kicker with MHz rep-rate 50x shorter pulses	Multi-pass SRF ERL 3-4x in # of passes	Need new injector	
	Figure-8 ring spin dynamics New concept	Feedback for kink instability suppression Novel concept	Synchrotron radiation in the IR	

Layouts and engineering drawings: all 3.8 km of them…..



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

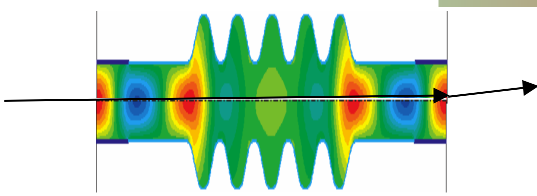
- HOMs based on R. Calaga's simulations/ measurements
- 70 dipole HOM's to 2.7 GHz in each cavity
- Polarization either 0 or 90°
- 6 different random seeds
- HOM Frequency spread 0-0.001



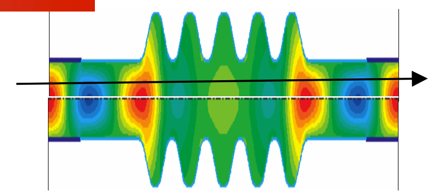
Higher Order Modes (HOM)

Simulated BBU threshold (GBBU) vs. HOM frequency spread.

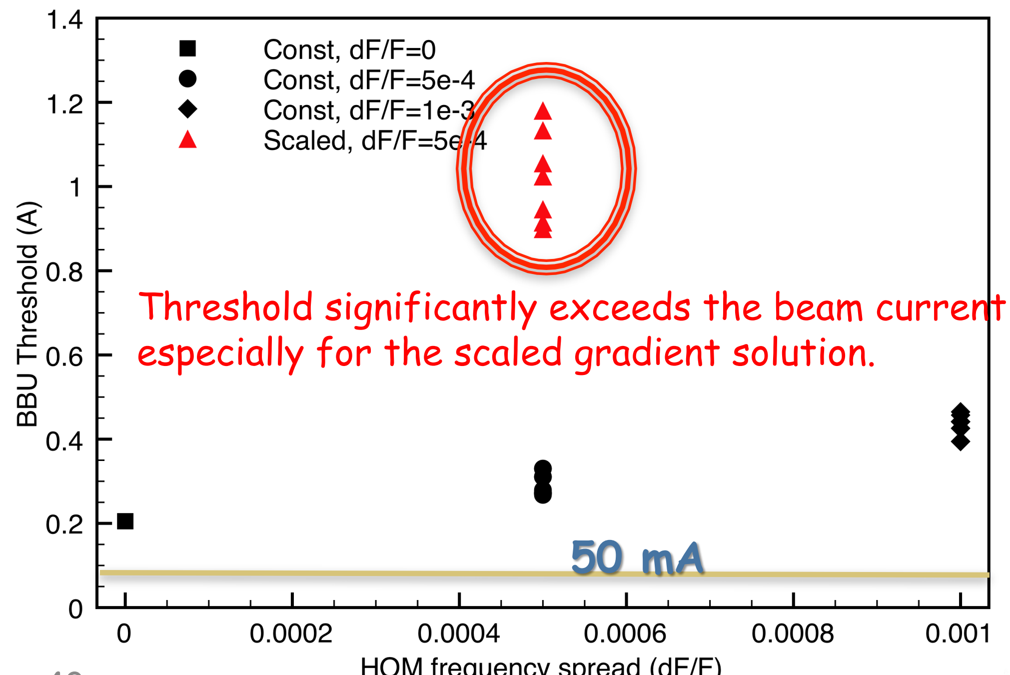
Excitation process of transverse HOM



$$\begin{bmatrix} m11 & \mathbf{m12} \\ m21 & m22 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \mathbf{x'} \end{bmatrix}_{comming} = \begin{bmatrix} \mathbf{x} \\ x' \end{bmatrix}_{return}$$



F (GHz)	R/Q (Ω)	Q	(R/Q)Q
0.8892	57.2	600	3.4e4
0.8916	57.2	750	4.3e4
1.7773	3.4	7084	2.4e4
1.7774	3.4	7167	2.4e4
1.7827	1.7	9899	1.7e4
1.7828	1.7	8967	1.5e4
1.7847	5.1	4200	2.1e4
1.7848	5.1	4200	2.1e4



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Gains from coherent e-cooling:

Coherent Electron Cooling vs. IBS

$$X = \frac{\varepsilon_x}{\varepsilon_{xo}};\; S = \left(\frac{\sigma_s}{\sigma_{so}}\right)^2 = \left(\frac{\sigma_E}{\sigma_{sE}}\right)^2;$$
$$\frac{dX}{dt} = \frac{1}{\tau_{IBS\perp}}\frac{1}{X^{3/2}S^{1/2}} - \frac{\xi_\perp}{\tau_{CeC}}\frac{1}{S};$$
$$\frac{dS}{dt} = \frac{1}{\tau_{IBS//}}\frac{1}{X^{3/2}Y} - \frac{1-2\xi_\perp}{\tau_{CeC}}\frac{1}{X};$$

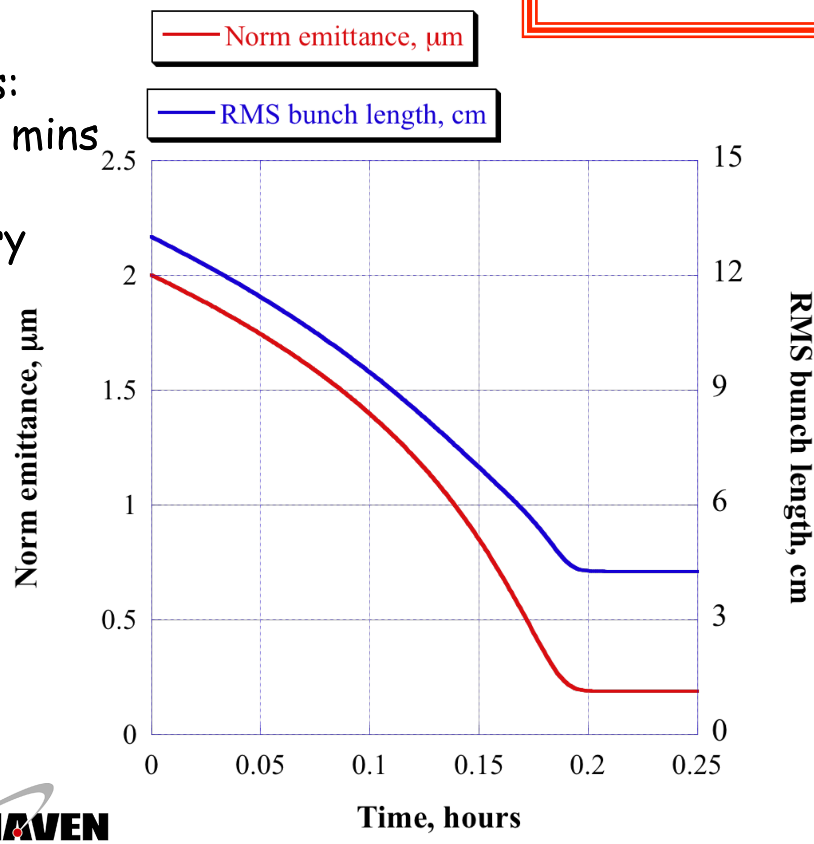
$$X = \frac{\tau_{CeC}}{\sqrt{\tau_{IBS//}\tau_{IBS\perp}}}\frac{1}{\sqrt{\xi_\perp(1-2\xi_\perp)}};\quad S = \frac{\tau_{CeC}}{\tau_{IBS//}}\cdot\sqrt{\frac{\tau_{IBS\perp}}{\tau_{IBS//}}}\cdot\sqrt{\frac{\xi_\perp}{(1-2\xi_\perp)^3}}$$

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

IBS in RHIC for eRHIC, 250 GeV, $N_p=2\cdot 10^{11}$
Beta-cool, ©A.Fedotov

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

Dynamics:
Takes 12 mins to reach stationary point



This allows

a) keep the luminosity as it is
b) reduce polarized beam current down to 50 mA
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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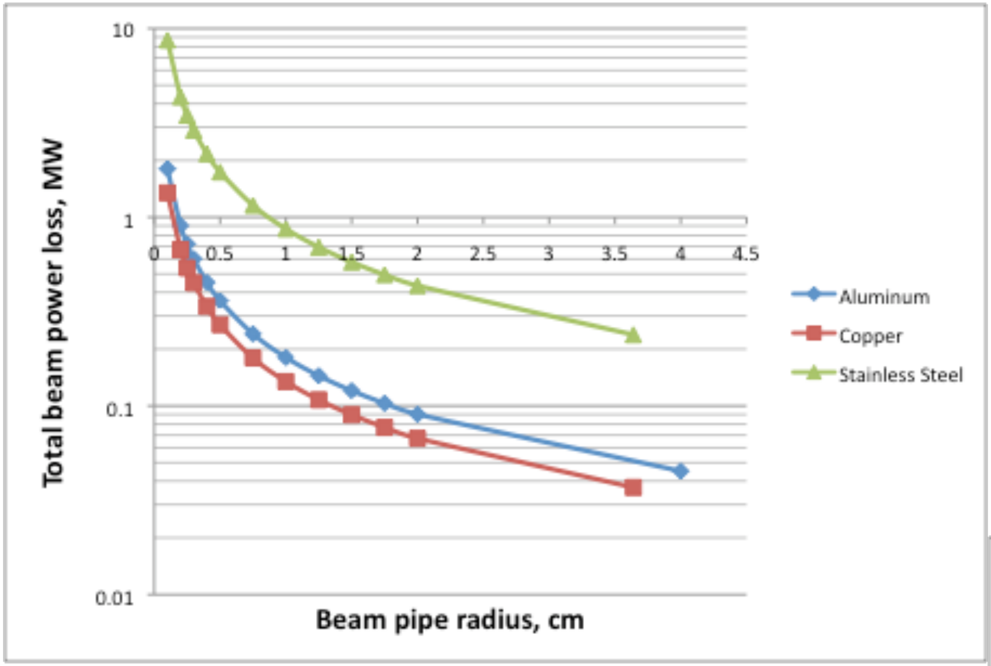
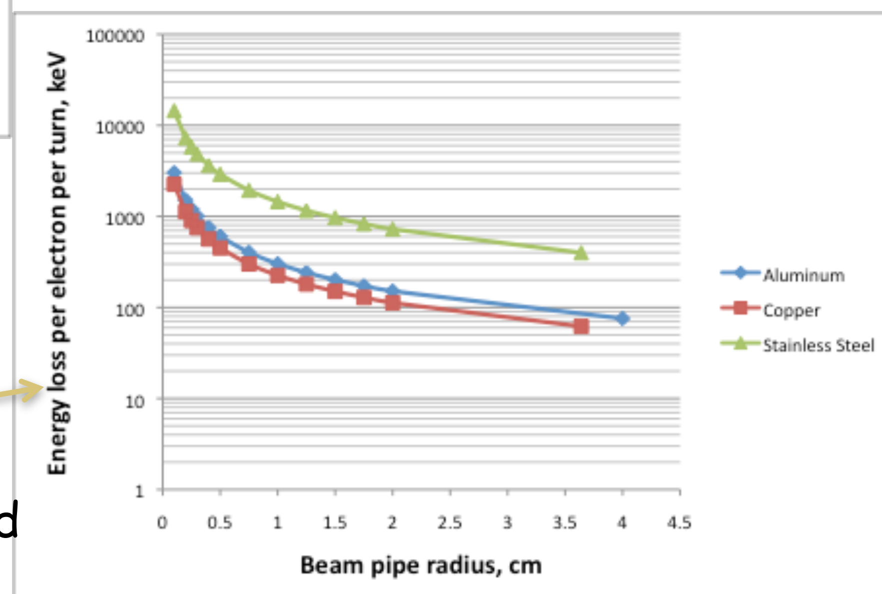
Resistive wall



6 pass scheme
One turn: 3440 m
Bunch length: 2 mm
Bunch charge: 3.54 nC
Beam current: 50 mA

Reasonable choice : Al or Cu pipe,
5 mm radius (or half-gap)

Characterizes also
resulting energy spread



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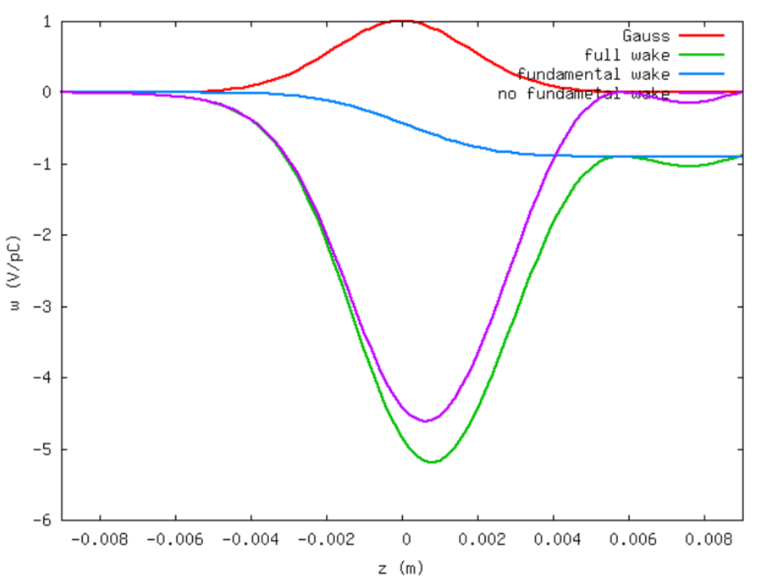
Cavity loss



Pozdeyev's calculation for MeRHIC σ=1.8 mm, Gauss

Bunch length: 2mm
K_{loss} = 3.5 V/pC
K_{loss_adj} = 3 V/pC

At eRHIC:
Bunch charge, nC = 3.54
Beam current = 50 mA
6 pass scheme

Using K_{loss_adj}:
Power loss per cavity per pass = 0.53 kW
Total power loss per cavity = 6.32 kW
Number of cavities = 120x 2 =240
Total power loss = 1.52 MW

© V.Ptitsyn

Resulting energy spread ~ 30 MeV !

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Harmonic relations

This condition is not required ERL !

One can change the relation between bunch frequencies using h_e

	RF harmonic	Bunch harmonic	RF to bunch harmonic
Protons:	$f_{rf\_p} = h_p f_{rev\_p}$	$f_{b\_p} = n_p f_{rev\_p}$ $n_p = 180$	$f_{rf\_p} = m_p f_{b\_p}$
Electrons:	$f_{rf\_e} = h_e f_{rev\_e}$ $h_e \sim 8980\text{-}9020$	$f_{b\_e} = f_{b\_p}$ ~~$f_{b\_e} = n_e f_{rev\_e}$~~	$f_{rf\_e} = m_e f_{b\_p}$ $m_e = 50$

Collision synchronization

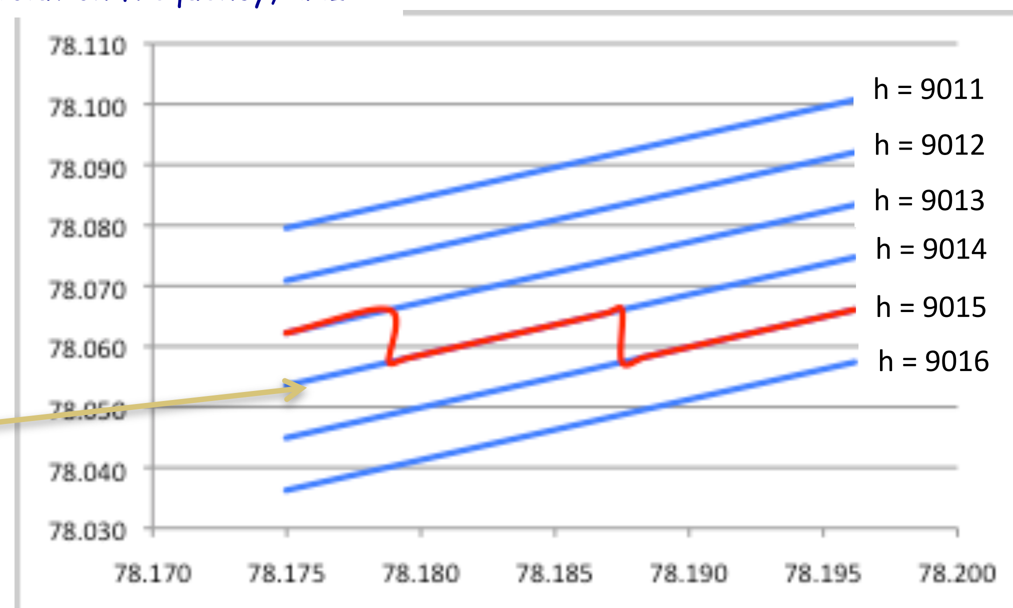
Depends on the design circumference length

From this:

$$f_{rev\_e} = \frac{m_e n_p}{h_e} f_{rev\_p} = \frac{9000}{h_e} f_{rev\_p}$$

Switching the RF harmonic number allows to reduce the variation of the electron revolution frequency

Electron effective revolution frequency, kHz



Proton revolution frequency, kHz

Shown only for 50-325 GeV proton energy range

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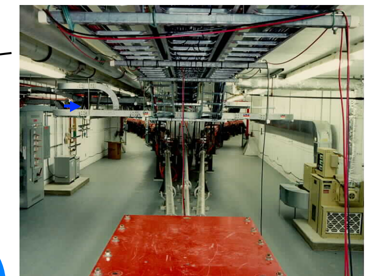
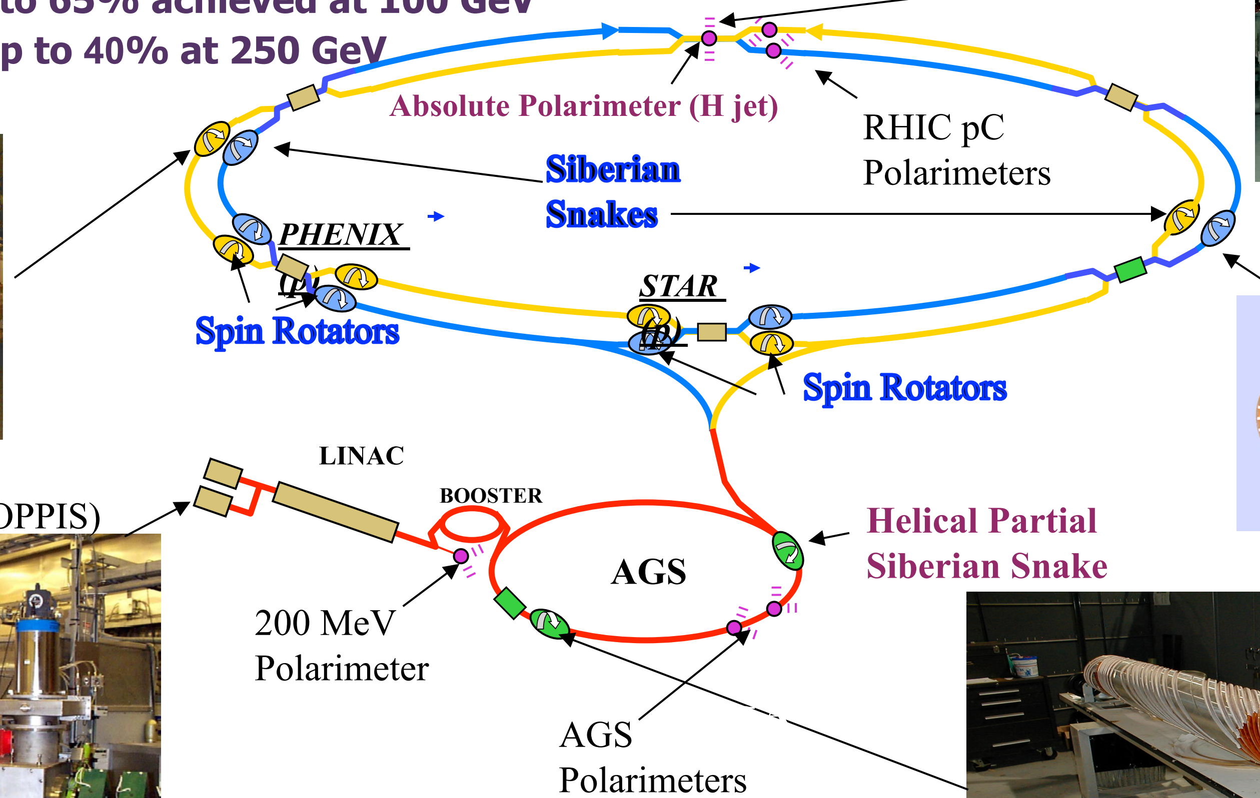
eRHIC: polarized protons already there

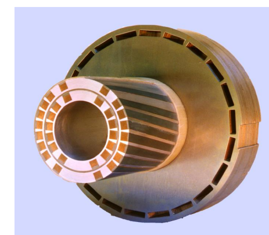
RHIC only polarized proton collider in the world

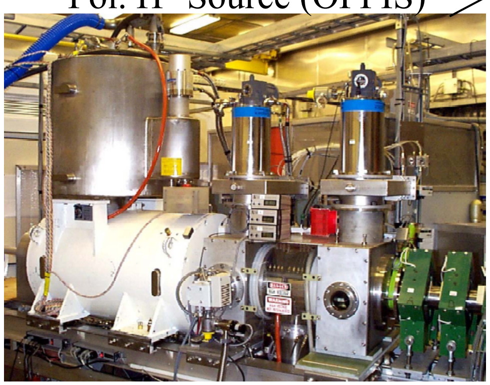
polarization: up to 65% achieved at 100 GeV

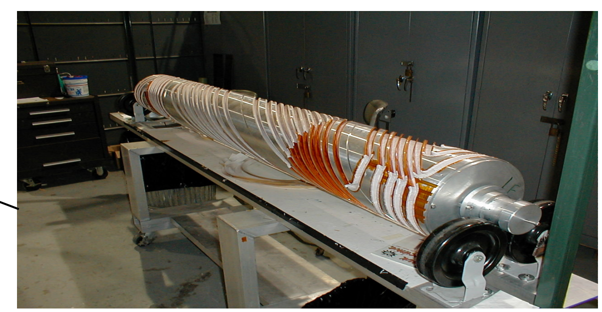
and presently up to 40% at 250 GeV





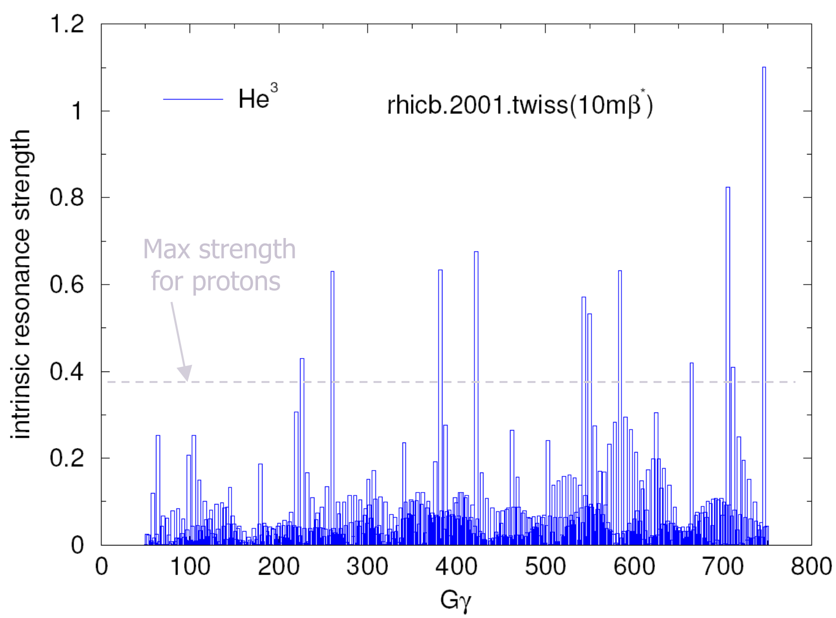






Polarized $^3He^{+2}$ for eRHIC

- 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. Stronger 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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