Potential use of eRHIC's ERL for *FELs and light sources*

ERL: Main-stream - 5-10 GeV e^-

Up-gradable to 20^+ GeV e^-

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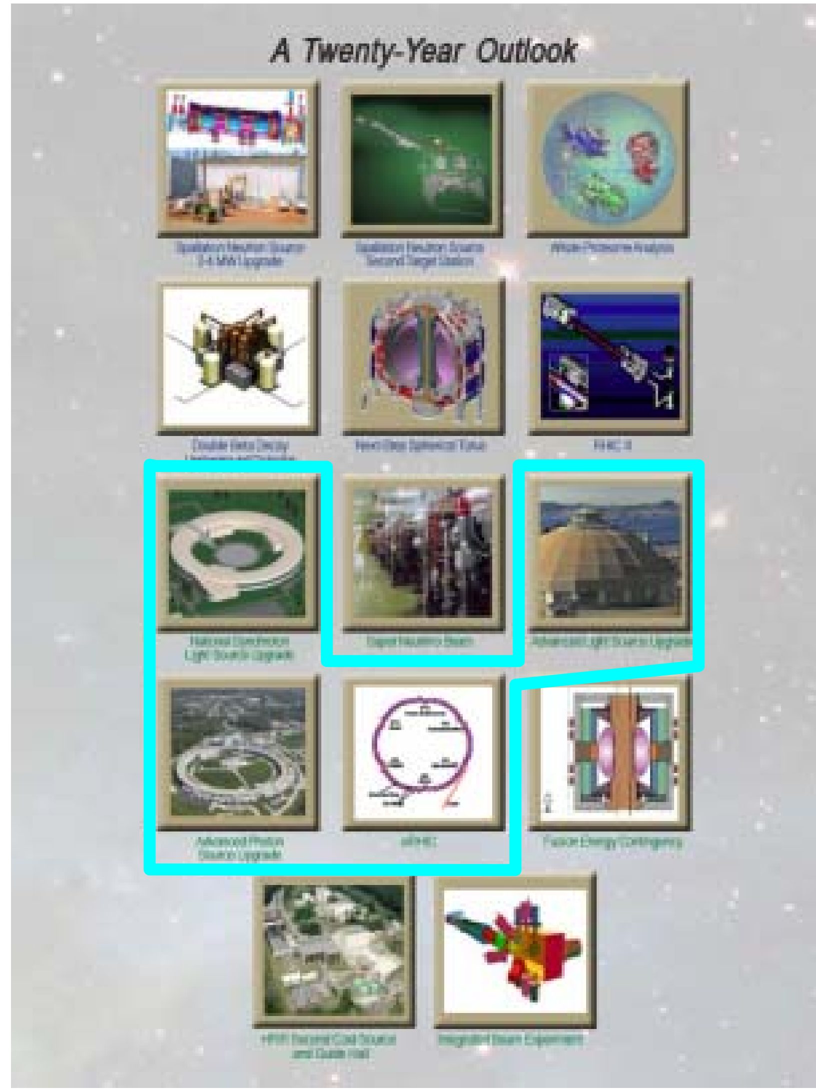
eRHIC - electron-ion colliders



Linac-ring eRHIC

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Appendix A of the eRHIC ZDR

Linac-Ring eRHIC.

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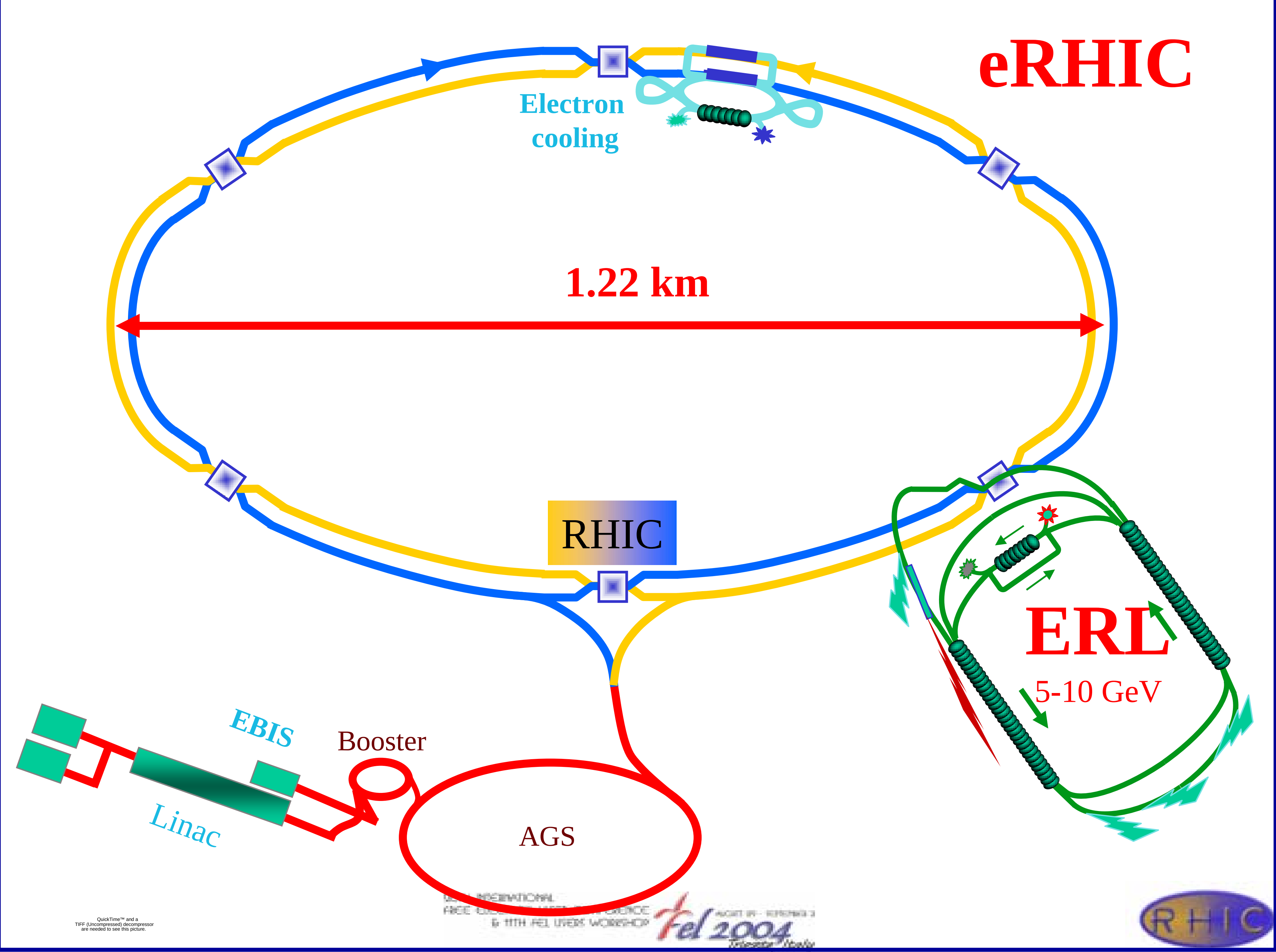
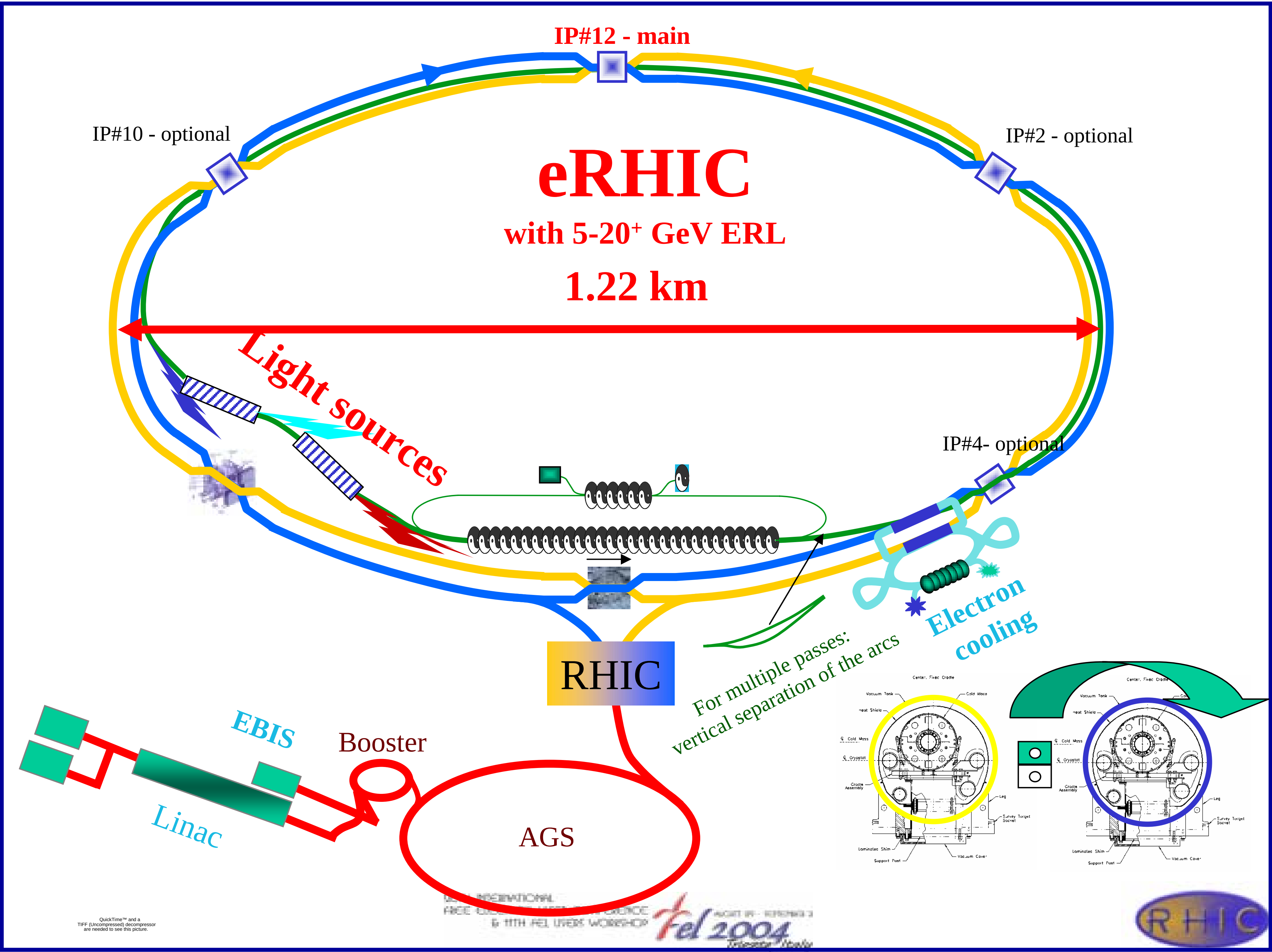
Content **page**

http://www.agsrhichome.bnl.gov/eRHIC/

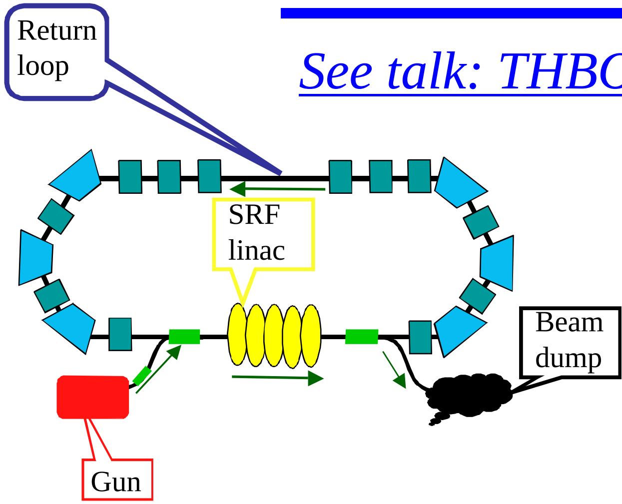

eRHIC
Electron
cooling
1.22 km
RHIC
ERL
5-10 GeV
EBIS
Booster
Linac
AGS
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



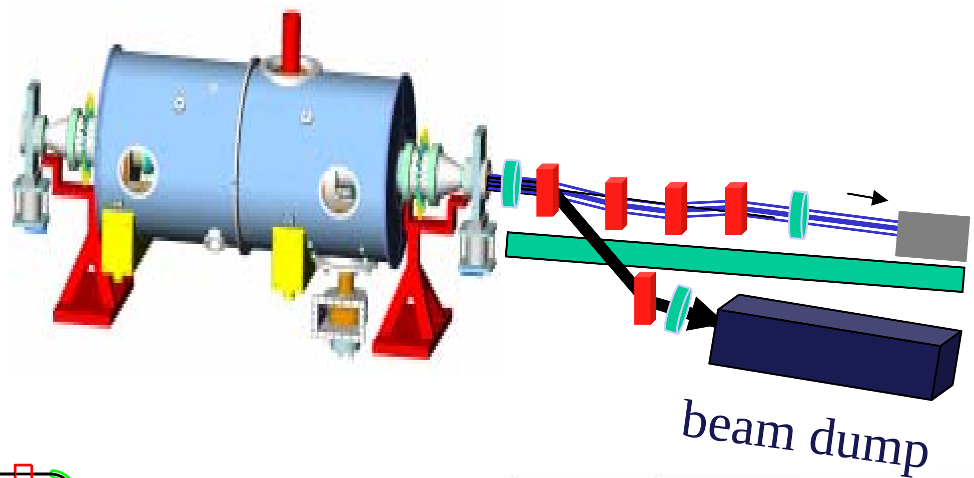
IP#12 - main
IP#10 - optional
IP#2 - optional
eRHIC
with 5-20+ GeV ERL
1.22 km
Light sources
IP#4- optional
Electron cooling
For multiple passes:
vertical separation of the arcs
RHIC
EBIS
Booster
Linac
AGS
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

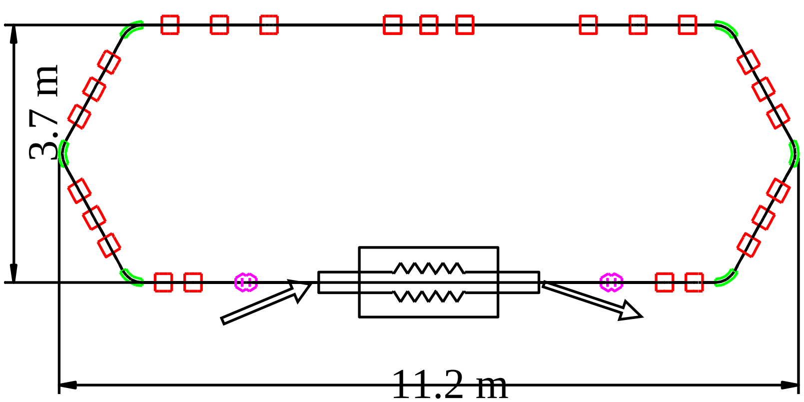
Main Components of ERL

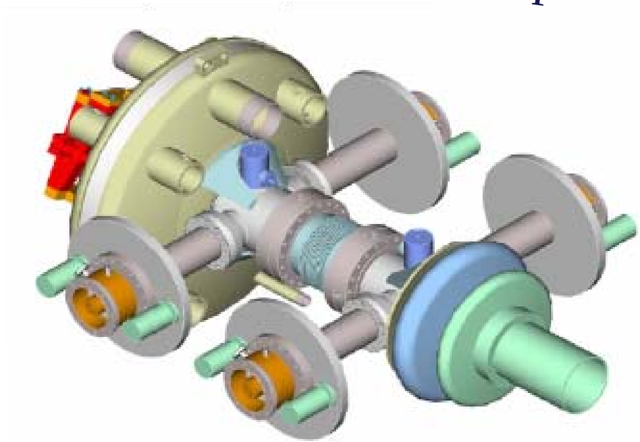
See talk: THBOC04 by I. Ben-Zvi, Thursday @ 12:00



Super conducting RF photo-gun
And high current 5-cell SC RF Cavity







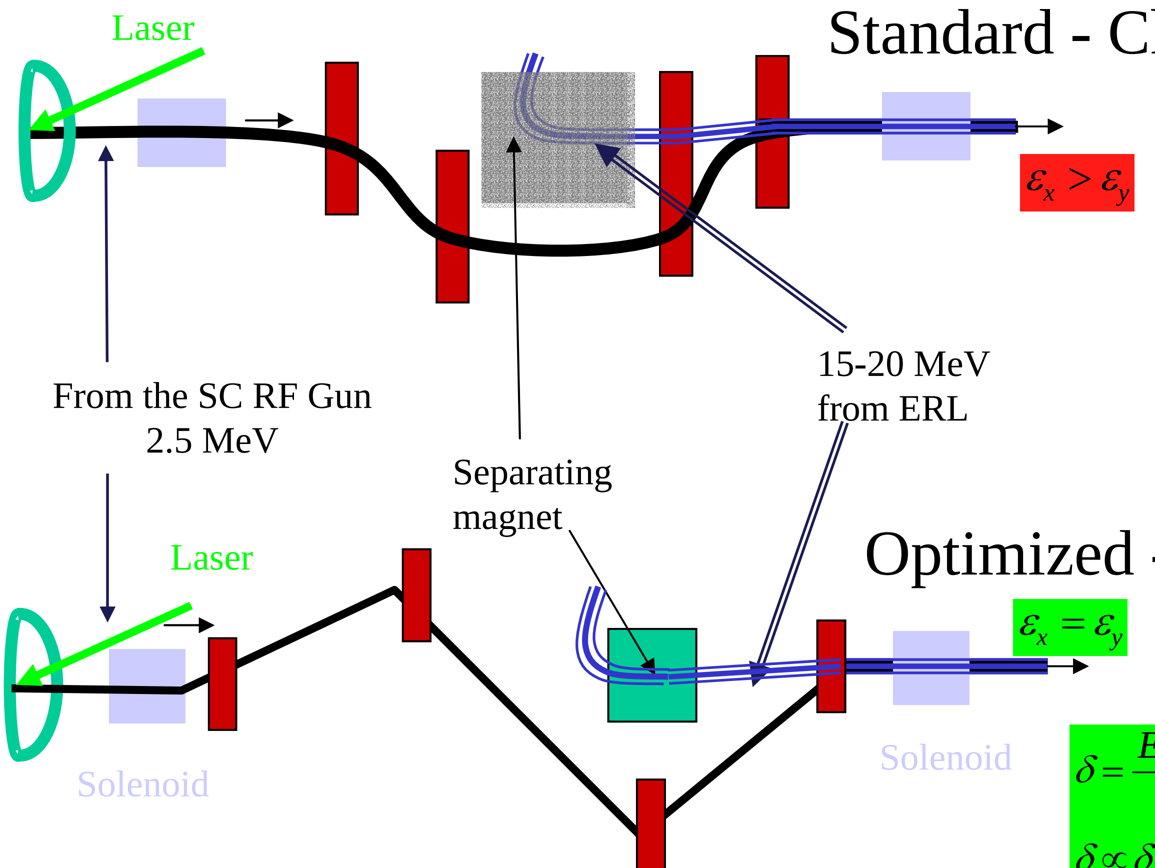
Beam parameters

RHIC	eRHIC	*Light source option*
Ring circumference [m]	3834	
Number of bunches	360	
Beam rep-rate [MHz]	28.15	
Protons: number of bunches	360	
Beam energy [GeV]	26 - 250	
Protons per bunch (max)	$2.0 \cdot 10^{11}$	
Normalized 96% emittance [μm]	14.5	
RMS Bunch length [m]	0.2	
Gold ions: number of bunches	360	
Beam energy [GeV/u]	50 - 100	
Ions per bunch (max)	$2.0 \cdot 10^{9}$	
Normalized 96% emittance [μm]	6	
Electrons:		
Beam rep-rate [MHz]	28.15	*703.75*
Beam energy [GeV]	2 – 20	
γ, Relativistic factor	**$3.9\ 10^{3}$ - $3.9\ 10^{4}$**	
RMS normalized emittance [μm]	5- 50	*0.9*
Beam emittance @ 20 GeV [Å]	***1.25-12.5***	***0.18***
Full transverse coherence λ[Å]		*1.13*
photon energy [keV]		*11*
RMS Bunch length [psec]	30	*0.03 - 3*
Electrons per bunch	$0.1 - 1.0 \cdot 10^{11}$	
Charge per bunch [nC]	1.6 -16	*0.7*
Average e-beam current [A]	0.45	*0.5*

Presently, RHIC operates for ~ 28 weeks/year
The rest of the year the RHIC ion rings do not work ➔
Time for dedicated LS run

Chicane and Zigzag merging systems

Standard - Chicane



$$\delta = \frac{E - E_o}{E_o};$$

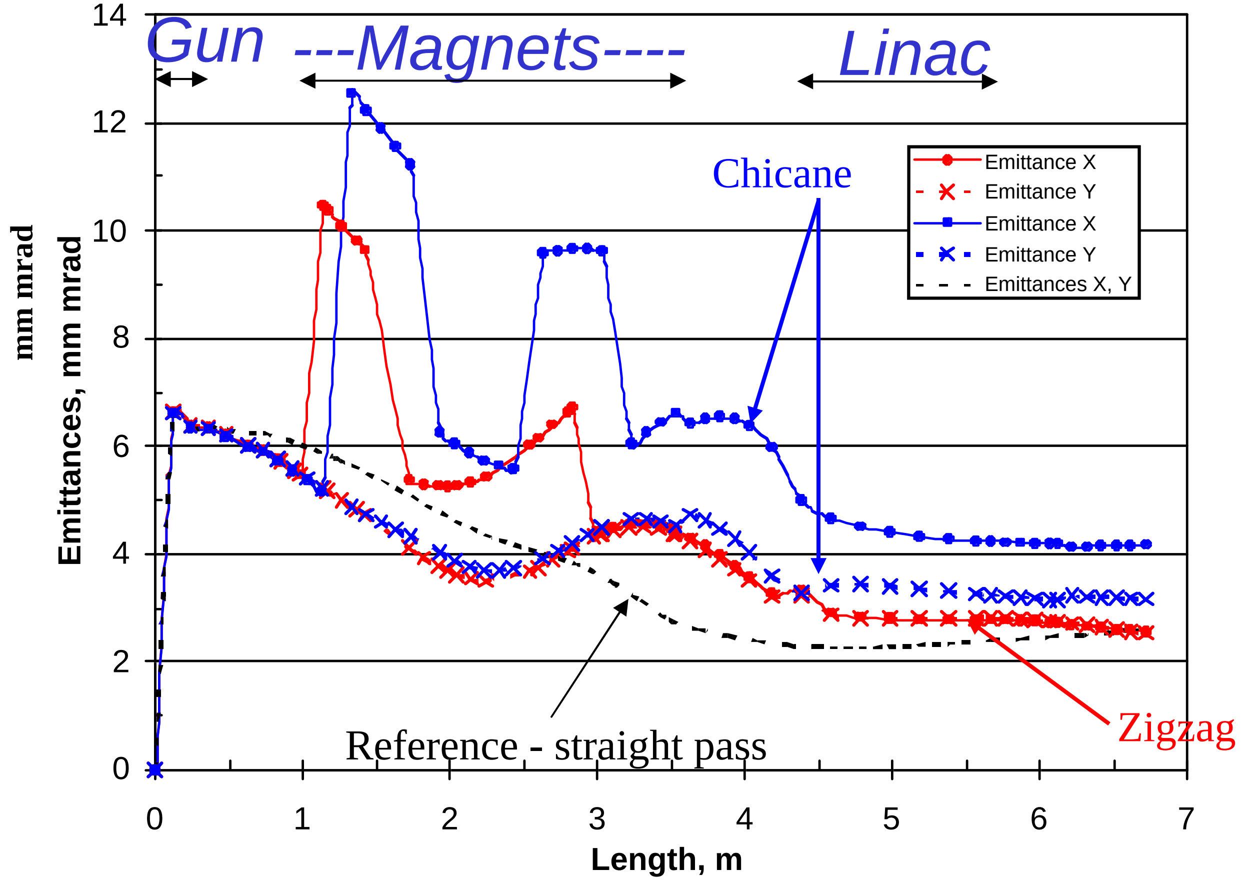
$$\delta \propto const \quad + \quad \text{no focusing} \quad \Rightarrow \sum_i \theta_i = 0; \sum_i z_i \theta_i = 0$$

Optimized - Z-system

$$\delta = \frac{E - E_o}{E_o};$$

$$\delta \propto \delta_o + \kappa \cdot z \cdot f(\varsigma)$$

$$\text{(no focusing)} \quad \Rightarrow \sum_i \theta_i = 0; \sum_i z_i \theta_i = 0; \sum_i z_i^2 \theta_i = 0$$



Results of Parmela simulation for 1 nC e-bunch from the cathode to the end of the linac: black dashed curve is for a round beam passing without bends; blue curves are for a compensated chicane, red curves are for Zigzag merging system.

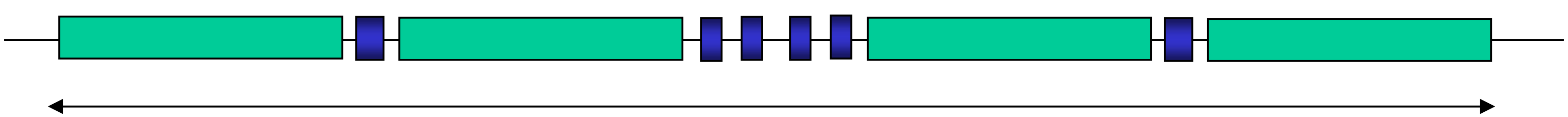
In contrast with <u>traditional chicane</u> where horizontal emittance suffers some growth as result of the bending trajectory, the <u>Z-system</u> (zigzag) the emittances are equal to each other and are very close to that attainable for the straight pass.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

RHIC

Beam parameters

Energy	**20**	GeV		Energy	10	GeV	
γ	3.91E+04			γ	1.96E+04		
Circumference	**3834**	m		Circumference	*3834.00*	m	
R, average	610.20	m		R, average	*610.20*	m	
% fill	65.55%			% fill	*65.55%*		
R magnets	400.00	m		R magnets	*400.00*	m	
B	1.67	kGs		B	0.83	kGs	
N TBA cells	**150.00**			N cells	*150.00*		
ε_{norm}	9.50E-07	m rad		ε norm	*9.50E-07*	m rad	
ε	**0.243**	**Å rad**		ε	**0.485**	**Å**	
Bunchlength	**from 0.1 to 2**	**psec**		Bunchlength	**from 0.1 to 2**	**psec**	
Damping time	1.45E-02	sec		Damping time	1.16E-01	sec	
Revolution time	1.28E-05	sec		Revolution time	1.28E-05	sec	
Δε (TBA)	***0.016***	***Å rad***	***6.70%***	***Δε (TBA)***	***0.001***	***Å***	***0.10%***
ε	**0.259**	**Å rad**		ε	**0.486**	**Å**	
RMS energy spread	2.54E-05			RMS energy spread	4.49E-06		



25 meters TBA cell

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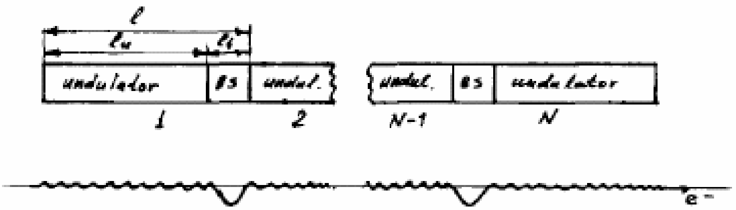
Nuclear Instruments and Methods in Physics Research A304 (1991) 463–464



High gain distributed optical klystron

V.N. Litvinenko

$1/4\pi\chi\rho > \sigma\gamma/\gamma,$

$$\mathrm{d}X/\mathrm{d}\tau = -\mathrm{i}Y\kappa,$$
$$\mathrm{d}Y/\mathrm{d}\tau = Z(1+B)\kappa,$$
$$\mathrm{d}Z/\mathrm{d}\tau = -X\kappa,$$

κ- filling factor

$$\mu_{DOK} \cong \mu_{SASE} \cdot \kappa \cdot \sqrt[3]{1+B} \cdot e^{-\frac{(1+B)^2\left(\frac{4\pi\sigma_\gamma L_G}{\gamma\lambda_w}\right)^2}{6}}$$

$$L_{G\ DOK} \cong L_G \cdot \left\{ e^{\frac{1}{4}} \cdot \sqrt[2]{\frac{4\pi L_G}{\lambda_w}\frac{\sigma_\gamma}{\gamma}} / \kappa^{3/2} \right\}$$

R. Bonifacio, L. Narducci and C. Pellegrini, Opt. Commun 50 (1984) 373;

$\eta = (\gamma - \gamma_0)/\gamma_0,$

X	laser field,
$Y = \langle e^{-i\psi_0}\vartheta\rangle$	bunching function,
$Z = 1/\rho\langle e^{-i\psi_0}\eta\rangle$	energy deviation,

$$\mathrm{d}X/\mathrm{d}\tau = \mathrm{i}\delta X - \mathrm{i}Y,$$
$$\mathrm{d}Y/\mathrm{d}\tau = Z,$$
$$\mathrm{d}Z/\mathrm{d}\tau = -X,$$

$$\mu^3 - \delta\mu + 1 = 0$$

$\delta = 0$ $\qquad \mu_{fel} = \frac{1 - \mathrm{i}\sqrt{3}}{2}$

DOK reduces the gain length **2.2 fold** at 20 GeV
and **5 fold** at 10 GeV for eRHIC 0.5- 1 Å FELs

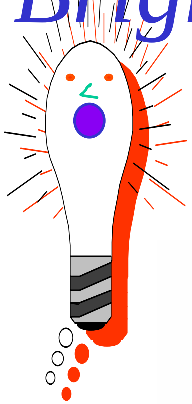
Single pass Ångstrom-class FELs at eRHIC

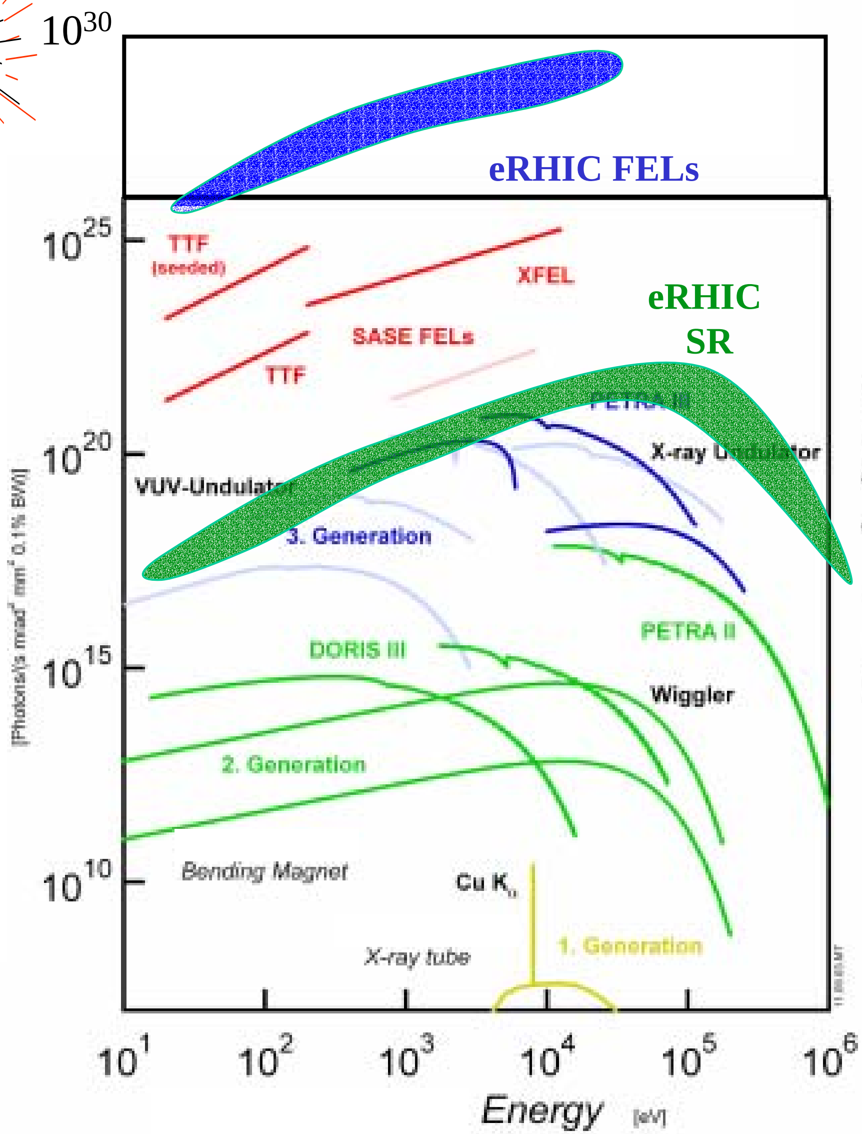
Average lasing power is a problem!

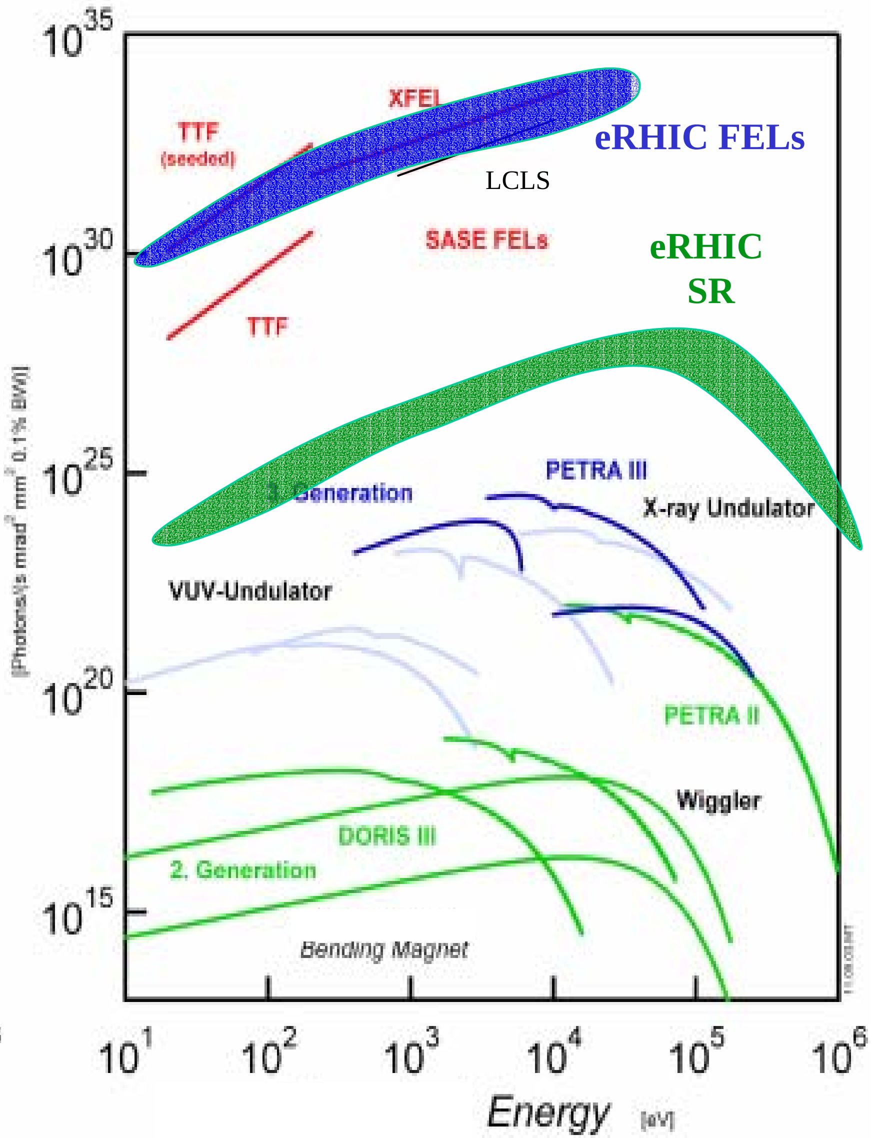
@ 1Å (12 keV) It is from 0.6 MW to 1.3 MW

Energy, GeV	20		15		10	
Wavelength, Å	**0.5**	**1**	**0.87**	**1.8**	**2**	**4**
Bunch length, psec	0.2	0.2	0.27	0.27	0.4	0.4
Peak Current, kA	5	5	3.75	3.75	2.5	2.5
Wiggler period, cm	**2.5**	**3**	**2.5**	**3**	**2.5**	**3**
SASE gain length, m	**7.5**	**4.3**	**5.5**	**3.3**	**3.7**	**2.4**
SASE Saturation length, m	100	60	76	47	51	34
Saturation power, GW	**7.7**	**19**	**6.4**	**14**	**4.5**	**9**
DOK, gain length, m	3.5	1.4	1.5	.65	.51	.25
DOK, saturation length, m	47	19	21	9	7	3.5

Brightness **Average** & **Peak**







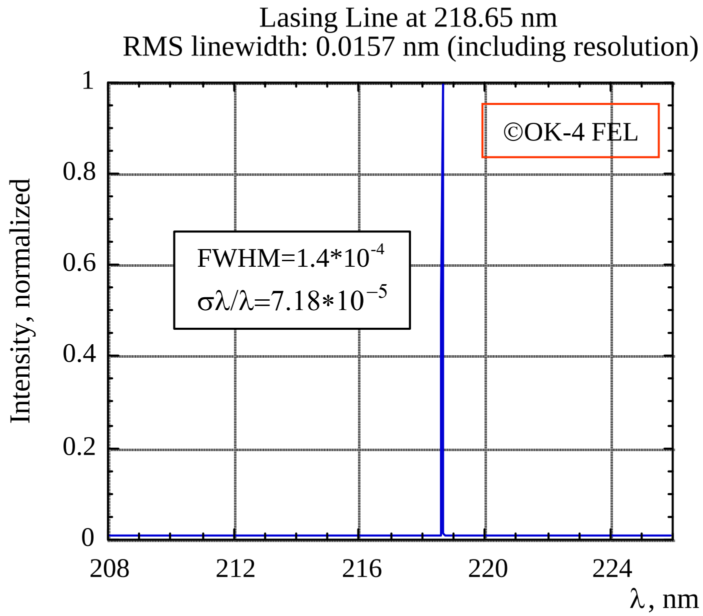
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Oscillators and HGHG vs. SASE FELs

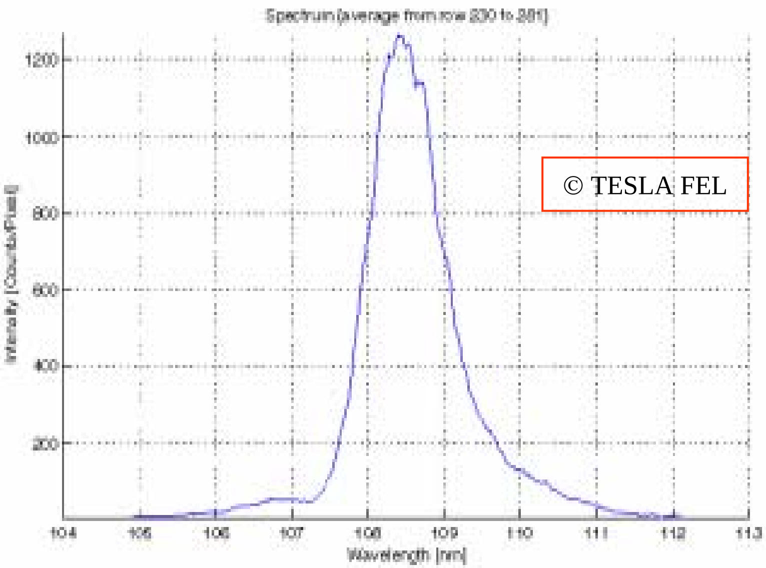
Precision vs. *Crude* Power

$\Delta\lambda/\lambda = 10^{-6} \rightarrow @1Å \;\; t_{coh} = 0.3\ psec$

OK-4 - $7 \cdot 10^{-5}$ RMS;
- 0.015 nm @ 218 nm

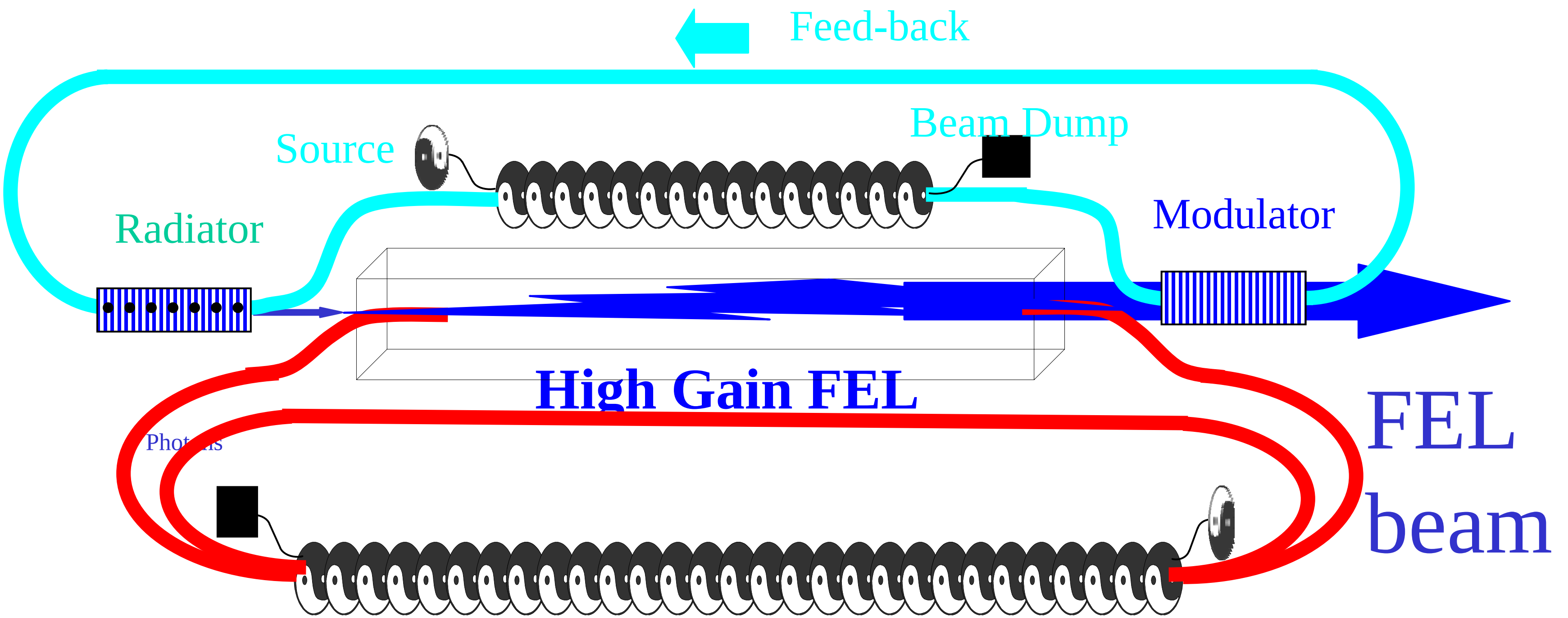


TESLA - $5 \cdot 10^{-3}$ RMS
- 0.55 nm @ 108 nm



Optics-Free FEL Oscillator

- Use lower energy low current e-beam with low emittance and low energy spread for the feed-back
- The feed-back-beam is modulated and carries-on the modulation to the entrance of the FEL
- Fully tunable! Line-width of oscillator



Conclusions

- High current 10-20 GeV ERL considered as a possible electron accelerator for eRHIC electron-hadron collider
- 10-20 GeV ERL will be very bright and powerful light source both in parasitic and dedicated modes of operation
- Sub-angstrom FEL can be successfully driven by the ERL in SASE or HGHG modes (L~100m), DOK or OFFO mode (~50m)

Work is supported by DoE