Proposal to study shielding of Coherent Synchrotron Radiation (CSR) at ATF/BNL

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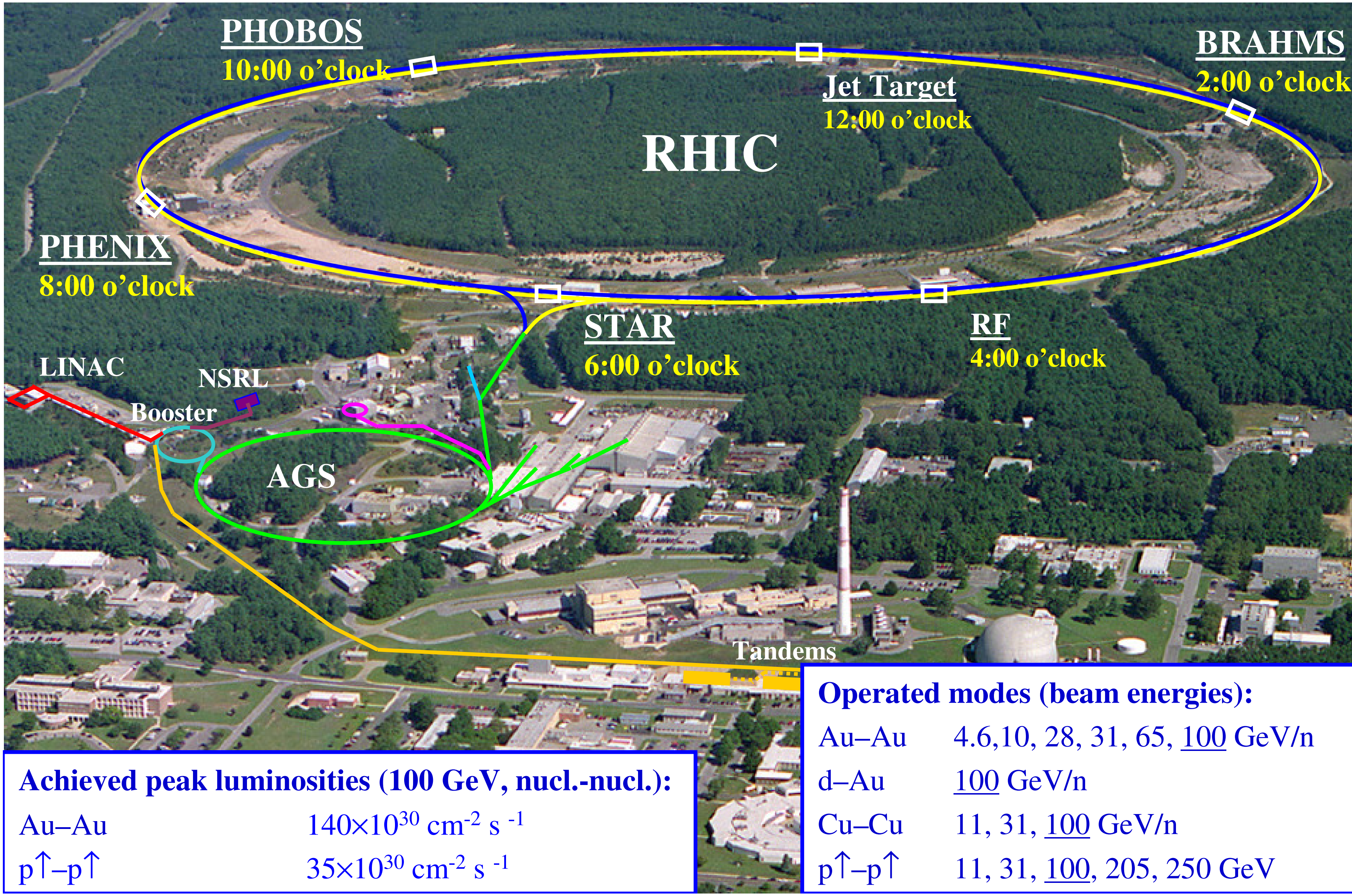
Outline

1. **Motivation for studies.**
2. **Very brief Review of analytic work on shielding and experimental data.**
3. **ATF Proposal.**

Motivation

1. **Important question for design of Electron Ion Collider at BNL (next few slides).**
2. **May benefit other ATF experiments which rely on short bunches with small energy spread.**

RHIC – a High Luminosity (Polarized) Hadron Collider



Achieved peak luminosities (100 GeV, nucl.-nucl.):

Au–Au	140×10^{30} cm^{-2} s^{-1}
p↑–p↑	35×10^{30} cm^{-2} s^{-1}

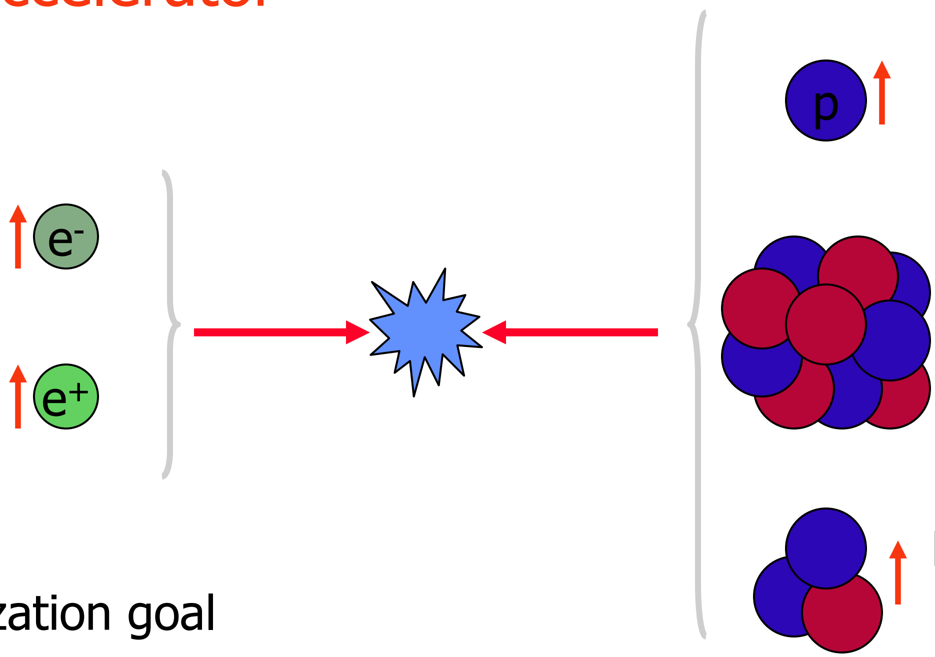
Operated modes (beam energies):

Au–Au	4.6,10, 28, 31, 65, <u>100</u> GeV/n
d–Au	<u>100</u> GeV/n
Cu–Cu	11, 31, <u>100</u> GeV/n
p↑–p↑	11, 31, <u>100</u>, 205, 250 GeV

Future RHIC upgrade: Electron-Ion collider (eRHIC)

Electron accelerator

Polarized leptons
3-20 GeV



RHIC

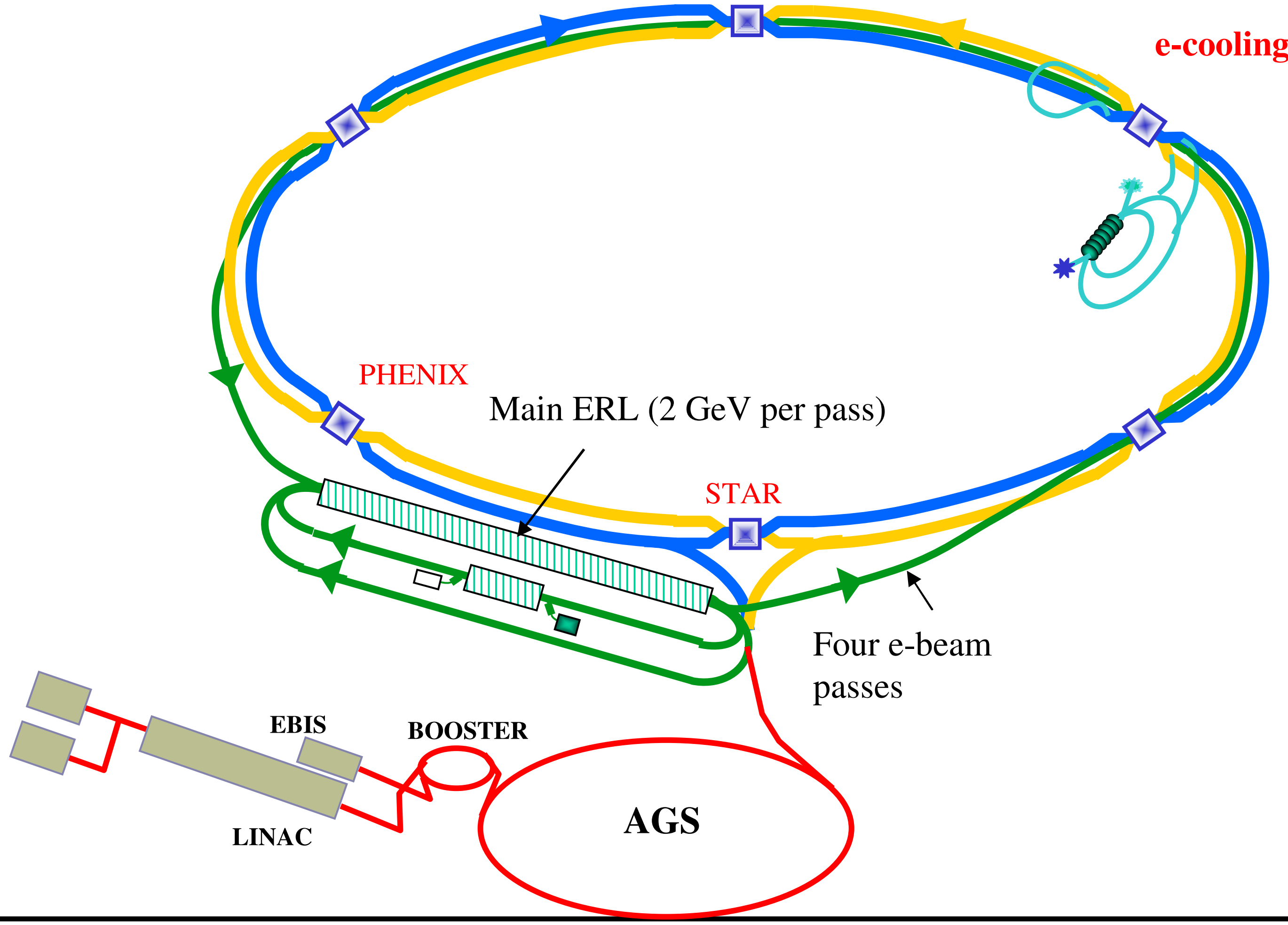
Polarized protons
50-250 GeV

Heavy ions (Au)
50-100 GeV/n

Polarized light ions (He^3)
167 GeV/n

70% beam polarization goal

eRHIC
(Linac-ring schematics)



MEeIC (V. Litvinenko et al., EIC Workshop, Dec. 2008)

Staging of eRHIC: Energy Reach and Luminosity

- **MEIC**: Medium Energy Electron-Ion Collider
  - Both Accelerator and Detector are located at IP2 of RHIC
  - 2 or 4 GeV e^- x 250 GeV p (45 or 63 GeV c.m.), L ~ 10^{32}-10^{33} cm^{-2} sec^{-1}
- **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, 10 GeV elevated luminosity phase,** inside RHIC tunnel

MEeIC design is presently under development at Collider-Accelerator Department at BNL

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-3	3.1	3.8e-3	7.7	0.015	15
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93		2.3		9.3	

CSR (without taking into account beam pipe shielding effect)

Gaussian longitudinal distribution:

- relative energy loss: $$< (p - p_0)/\, p_0 >= -0.35\, \frac{r_e N_e L_{eff}}{\gamma (R^2 \sigma_{es}{}^4)^{1/3}}$$

- increase in relative rms energy spread: $$\sigma_p = 0.22\, \frac{r_e N_e L_{eff}}{\gamma (R^2 \sigma_{es}{}^4)^{1/3}}$$

- Since it takes place in a dispersive region, the transverse phase-space distribution is also affected and beam emittance increases.

MEeIC - CSR effect after passing 10 arcs with local bending radius of 6.2m and 1 arc with 7.2m (100MeV arc is not included)

	rms bunch length σ_s=2mm (no shielding)	σ_s=4mm (no shielding)	σ_s=2mm (h=2cm)	σ_s=2mm (h=1cm)
Energy loss: -ΔE, MeV	8	3.2	2.1e-5	8e-18
-ΔE/E (relative energy loss, at 100MeV – our lowest energy arc)	0.08	0.03		
RMS nergy spread ΔE_{rms}, MeV	5.7	2.26		
$(\Delta E/E)_{rms}$ (relative energy spread, at 100MeV)	0.06	0.02		
Shielding suppression factor =P_{coh} (with shielding)/P_{coh}(without shielding)			2.6e-6	1e-18

Shielding of CSR

Since in present design of MEeIC we rely on a complete shielding of CSR due to beam-pipe walls, it is critical to answer the question:

How good is our understanding of CSR shielding?

Analytic work on shielding of CSR

Some (partial) history of some theoretical work on shielding:

1. J. Schwinger (1945), L. Schiff (1946); Nodvick and Saxon (1954).
2. R. Warnock (1990-91) – also for rectangular chamber
3. S. Heifets, A. Michailichenko (1991).
4. S. Kheifets and B. Zotter (1995) – overview of previous results and simple formulas for estimates.
5. Murphy, Krinsky, Gluckstern (1996) – using image-charges method.
6. R. Li, C. Bohn, J, Bisognano (1997) – review of Kheifets-Zotter/corrections and comparison with several more rigorous methods.

More recent work:

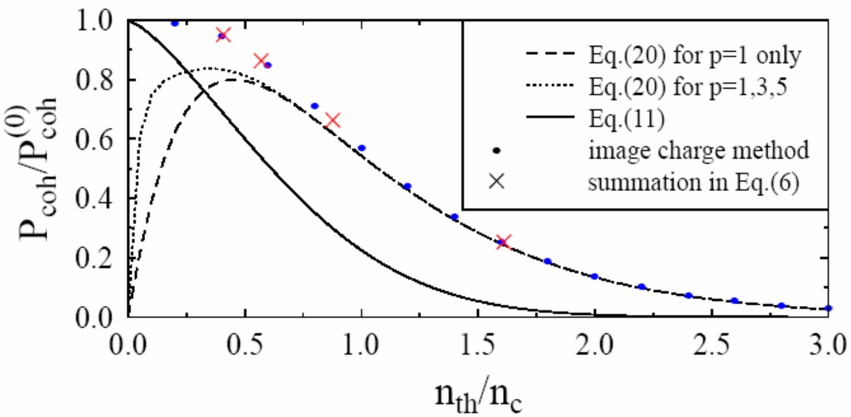
7. Stupakov et al. (2003)
8. Agoh, Yokoya (2004)
9. Sagan, Hoffstaetter (2008)
10. C. Mayes and G. Hoffstaetter (2009)

Correction to shielding factor (Li, Bohn, Bisognano, 1997)

Kheifets-Zotter:

$$P_{coh}/P_{coh}^{(0)} = F(x_{th})/\Gamma(2/3)$$

$$F(x_{th}) = \int_{x_{th}}^{x_c} dx x^{-1/3} e^{-x} \approx \Gamma(2/3, x_{th})$$



R. Li et al.:

$$P_{coh}/P_{coh}^{(0)} \simeq C_0 (n_{th}/n_c)^{5/6} \exp(-2n_{th}/n_c), \quad (n_{th} > n_c) \qquad (21)$$

with $C_0 = 4\sqrt{3\pi}/2^{2/3}[\Gamma(2/3)]^2 \simeq 4.2$. This modified

Corrected shielding factor was compared with exact treatment using method of images and direct summation over harmonics – perfect agreement for $n_{th} > n_c$ (or x_{th} $(=(n_{th}/n_c)^2)>1$)

R. Li (1999) – Transient effects with shielding

m, $\sigma_s = 1$ mm. Fig. 2 shows that the free-space power increases from zero and saturates to its steady-state value as the bunch moves into the bend. For $h = 2$ cm, the transient power oscillates and saturates to its steady-state value after $\theta = 30°$. For machine designs intending to reduce the CSR effect by using a narrow gap size, one should notice that in a certain bend region, the transient interaction with shielding has much bigger amplitude than its steady-state counterpart, as shown by the $h = 2$ cm curve in Fig. 2 around $\theta \sim 10°$.

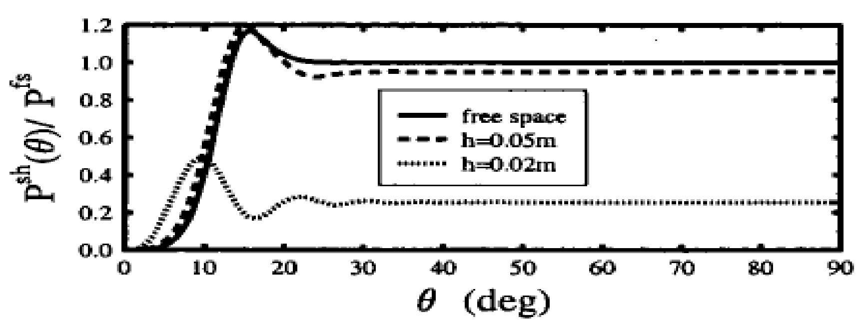


Figure 2: Transient power loss of an ultrarelativistic bunch, due to the curvature-induced self-interaction in the presence of two parallel plates, with $\rho = 1$ m, $\sigma_s = 1$ mm, and various plate spacing h. Here θ is the angle of the bunch center entering the bend.

Codes

Many codes which treat CSR without shielding, including ELEGANT.

Some codes which can treat shielding:

1. TRAFIC4 (A. Kobel, M. Dohlus, T. Limberg) – older version of CSRtrack.
2. CSRtrack (M. Dohlus, T. Limberg)
3. GPT (Bazarov, Miyajima)
4. Bmad (Sagan, Hoffstaetter et al.)
5. Agoh-Yokoya code
6. R. Li's code

Dedicated experiments on CSR shielding

- H. Braun et al. (2001) – experiments at CLIC test facility CTF-II.
- Kato et al. (Phys. Rev. E, 1998).

Codes and Measurements (Beam experiments of CSR at Compact Linear Collider Test Facility, PAC'01)

the shielding chicane. In a first scan, a vacuum chamber with a height of 50 mm was used, which has no shielding effect for our bunch and chicane parameters. The energy loss due to CSR was deduced from the recorded energy spectra. Comparison with the energy loss calculated with ELEGANT showed an excellent agreement, while the TraFiC^4 simulations overestimated the measurements. In the following scans a flat chamber ($h_c = 15$ mm) was used.

The energy loss in a four-bend chicane is consistent with ELEGANT results for free space CSR. This agreement holds for measurements without shielding as well as for measurements where a significant shielding effect is expected. TraFiC^4 predicts for the free space case a considerable higher energy loss than ELEGANT. The simulations with shielding predict a reduction of the energy loss and underestimate the measurements. Further clarification is

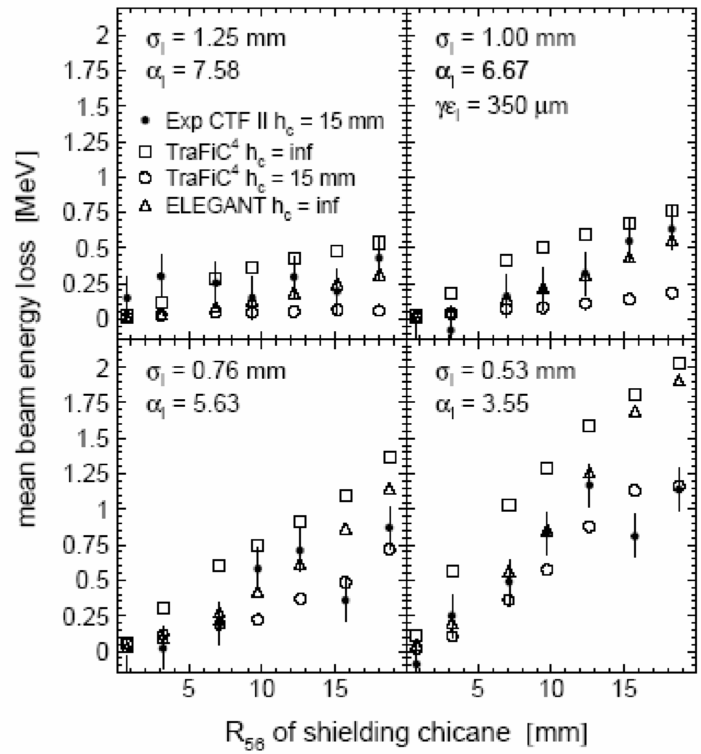


Figure 4: The measured energy loss in the shielding chicane as a function of R_{56} for four different initial bunch lengths and correlations. The chamber height was 15 mm.

Suppression and enhancement of coherent synchrotron radiation in the presence of two parallel conducting plates

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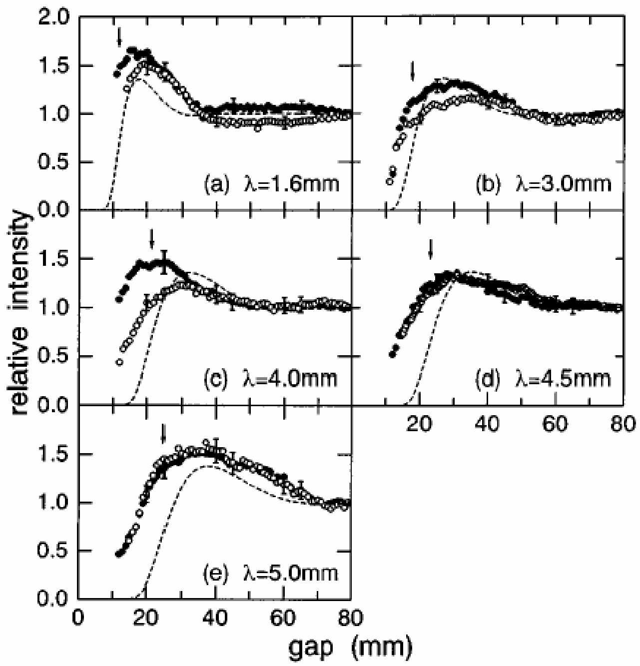

FIG. 8. Relative intensities of coherent synchrotron radiation as a function of the gap between the metallic plates for wavelengths from 1.6 to 5.0 mm. The intensities are normalized with the intensity at the gap of 80 mm for each wavelength. The solid circles denote intensities measured with the slit for cutting stray light and the open circles without it. The dashed lines are calculated values.

The emission of coherent synchrotron radiation was studied in the presence of conducting boundaries. The suppression effect of coherent radiation due to the metallic plates was observed. They not only suppressed the emission of coherent synchrotron radiation but also enhanced it. The intensity became 1.3–1.5 times higher in a certain region of the gap between the plates.

theory, on the other hand, could not account for the intensity reduction in the region of wavelengths longer than 2 mm, which indicates the possibility of another or other suppressing effects.

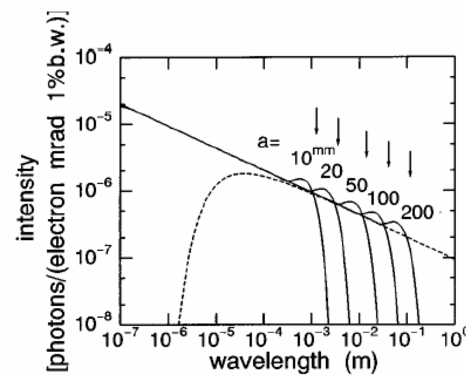

FIG. 2. Spectra of synchrotron radiation in the presence of the infinitely wide parallel conducting plates calculated with the theory

Some Issues

1. **One experiment did not show expected theoretical reduction (with shielding) in energy loss due to CSR.**
2. **Another experiment studied synchrotron radiation rather than effects on the beam – also some issue were reported, like disagreement with theory for small gap sizes, etc.**
3. **While there seems to be is a clear picture about suppression of CSR power loss with shielding, effect of shielding on energy spread is less transparent.**
4. **Transient effects.**

Simple, well-controlled experiment is desired to address these issues. ATF@BNL is ideally suited for such an experiment.

ATF proposal

Team:

A. Fedotov, D. Kayran (C-AD, BNL), P. Muggli (USC),

V. Yakimenko (ATF, BNL), others

Experimental goal:

To have a quantitative study of CSR suppression with shielding due to vacuum chamber. Measurements will be compared with detailed simulations of CSR which will including shielding and transient effects.

Experiment description

- **Construct and install a system of two vertical plates with controllable gap between the plates to be placed inside the vacuum chamber of bending magnet.**
- **Beam parameters will be chosen to enhance CSR effect without shielding.**
- **Energy loss and energy spread will be measured for various values of the gap between the plates.**
- **Measurements will be done both for Gaussian and square-shape longitudinal beam profiles.**
- **Measurements will be compared with detailed simulations.**

Resources

- All the diagnostics needed for the experiments is already available at ATF.
- Approximately 1 week of installation and 1-2 weeks divided over multiple runs of data taking are expected.
- ATF is expected to provide help with installation and operations.
- Plates will be installed inside first dipole of the beam line 2.
- Setup will have adjustable gap and will have minimal effect on the clear aperture when plates are retracted.
- Financial part of the experiment is expected to be covered either from BNL LDRD or C-AD eRHIC R&D funds.

Summary

- Understanding of CSR shielding due to vacuum chamber is an important topic for present design of Electron Ion Collider at BNL's Collider-Accelerator Department.
- ATF at BNL is ideally suited for dedicated experiment on CSR shielding.
- Other experiments at ATF which rely on micro bunch beam with small energy spread might benefit from this setup as well.