CeC for EIC

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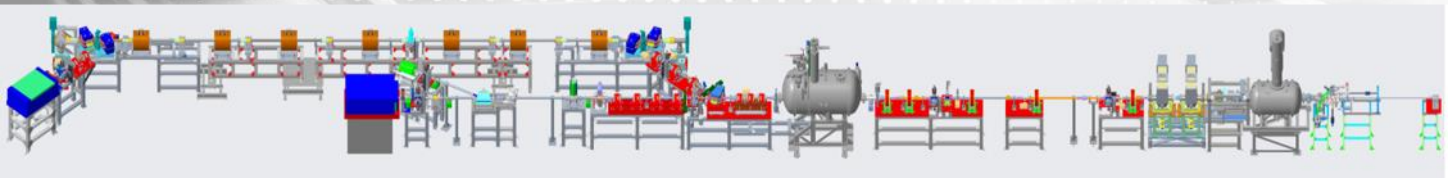


Important note

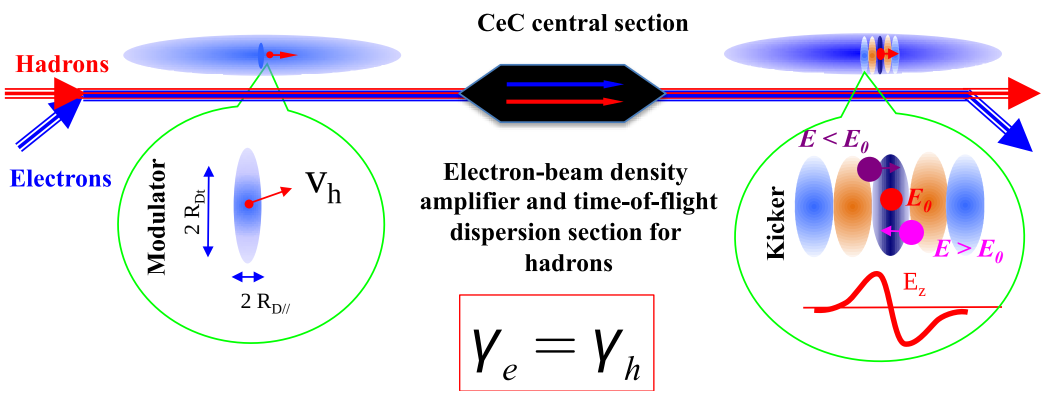
- CeC group was not encouraged to contribute to design of CeC for EIC
- We did minimal studies of CeC for EIC on our own initiative
- It was done in addition to our main task – designing, building, simulating, commissioning and operating real-world CeC cooler for 26.5 GeV/u hadron beam
- Up to the date we developed the following:
  - Unified 3D theory for all CeC amplifiers based on space-charge driven microbunching instability (both plasma-cascade (PC) and chicane-based (CB) systems)
  - 3D simulations for CeC all types of amplifiers
  - Full analytical treatment for type-2 plasma-cascade-amplifier (PCA)
  - Preliminary layout and beam for PCA-type 2-based EIC CeC
  - Estimation of cooling time for EIC CeC
  - 3D simulation for PCA-type 1-based EIC CeC

Plan

- Short Overview
- Gang Wang - Theory of Type-2 PCA amplifier and
- Jun Ma – Summary of 3D simulations
- Discussions

Coherent electron Cooling

- All CeC systems are based on the identical principles:
  - Hadrons create density modulation in co-propagating electron beam
  - Density modulation is amplified using broad-band (microbunching) instability
  - Time-of-flight dependence on the hadron's energy results in energy correction and in the longitudinal cooling. Transverse cooling is enforced by coupling to longitudinal degrees of freedom.



UM HE 91-28
August 7, 1991

COHERENT ELECTRON COOLING
1. Physics of the method in general

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Ann Arbor, Michigan 48109-1120 USA

ABSTRACT

A microwave instability of an electron beam can be used for a multiple increase in the collective response for the perturbation caused by a heavy particle, i.e. for enhancement of a friction effect in electron cooling method. The low-scale instabilities of a few kind can be

PRL 102, 114801 (2009) PHYSICAL REVIEW LETTERS

Coherent Electron Cooling

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Microbunched Electron Cooling for High-Energy Hadron Beams

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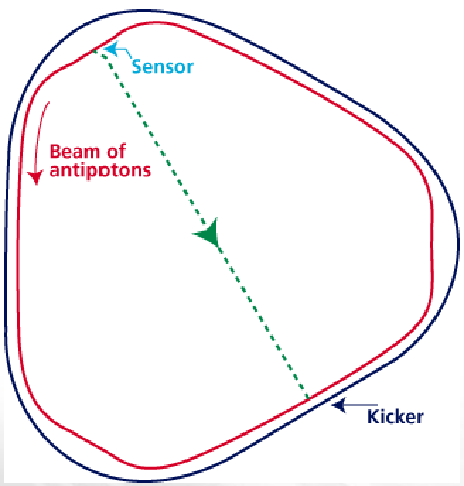
(Received 11 April 2013; published 20 August 2013)

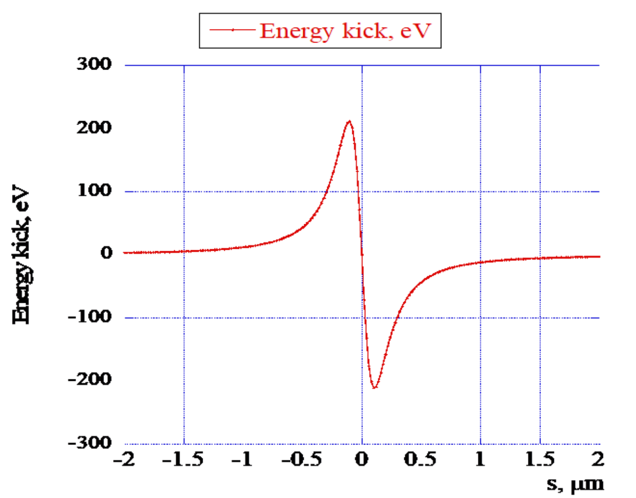
Coherent electron Cooling is Stochastic Cooling

$$\tau_c = -\left(f_{rev} \frac{1}{\varepsilon} \frac{d\varepsilon}{dn} \right)^{-1} = \frac{N_s}{f_{rev}} \propto \frac{I_{peak}}{Z} \cdot \frac{1}{\Delta f}$$

$$N_s = \frac{\dot{N}}{\Delta f} = \frac{I_{peak}}{Ze} \cdot \frac{1}{\Delta f}$$

- RF stochastic cooling is reaching its limits at ~ 10 GHz bandwidth
- PCA CeC for EIC has bandwidth ~ 500 GHz – x 50,000 that if RF systems





Requirements:

- ✓ **Linearity:** Amplifier must be linear (no saturation, gain limitations)
- ✓ **Overlapping:** Amplified signal induced by individual particle in the modulator (pick-up, sensor) must overlap with the particle in the kicker (beam separation?)
- ✓ **Bandwidth:** Cooling decrement per turn can not exceed $1/N_s$, where N_s is number of the particles fitting inside the response time of the system: $\tau \sim 1/\Delta f$
- ✓ **Noise:** diffusion induced by additional noise in the system should not exceed system cooling abilities

S. van der Meer, Rev. Mod.Phys. 57, (1985) p.689
S. van der Meer, 1972, Stochastic cooling of betatron oscillations is ISR, CERN/ISR-PO/72-31

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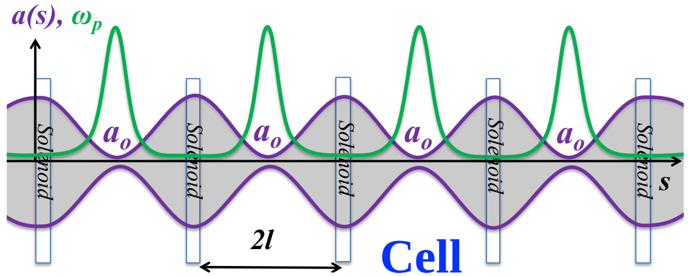
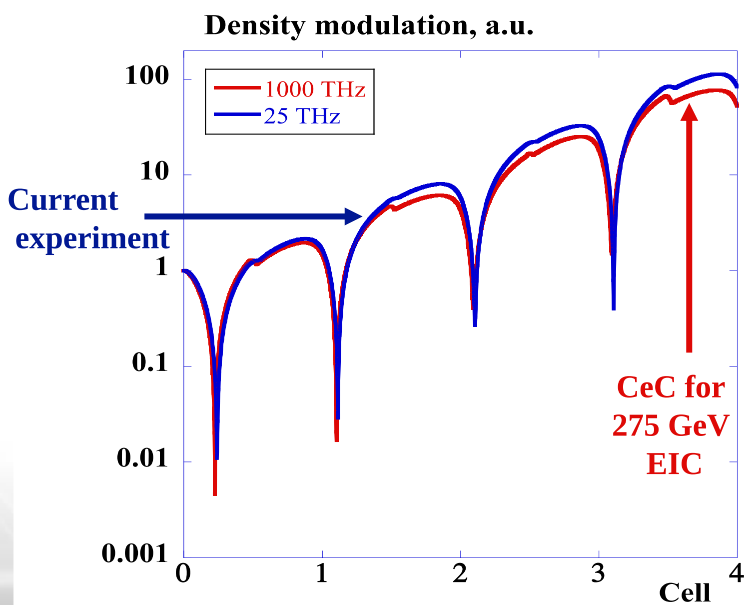
Current experiment and Cooling protons in the EIC

“Standard” 4-cell PCA

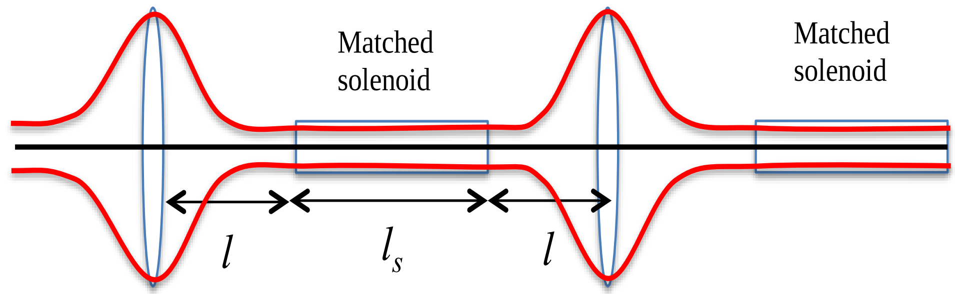


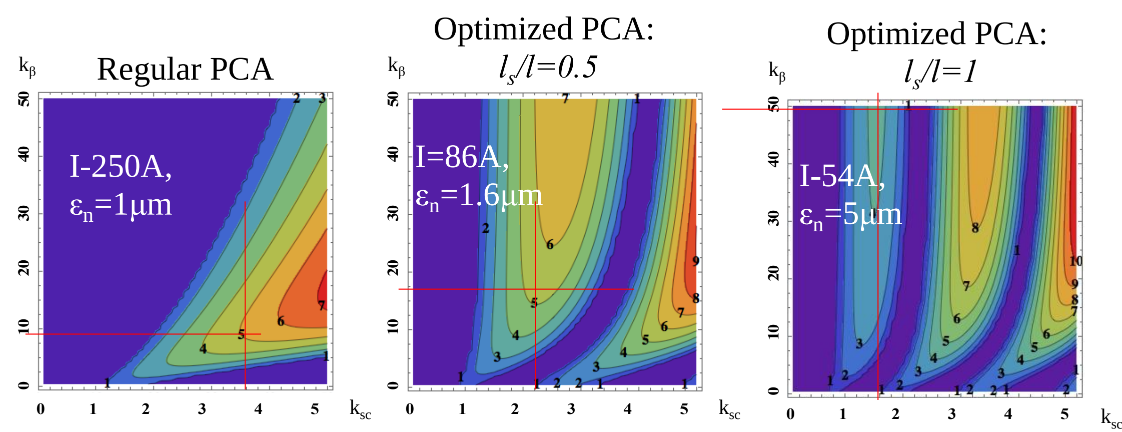
$$k_{sc} = \sqrt{\frac{2}{b_o^3 g_o^3} \frac{I_o}{I_A} \frac{l^2}{a_o^2}}; \quad k_b = \frac{el}{a_o^2}$$



Results of 3D simulations with code SPACE

Optimized PCA cell

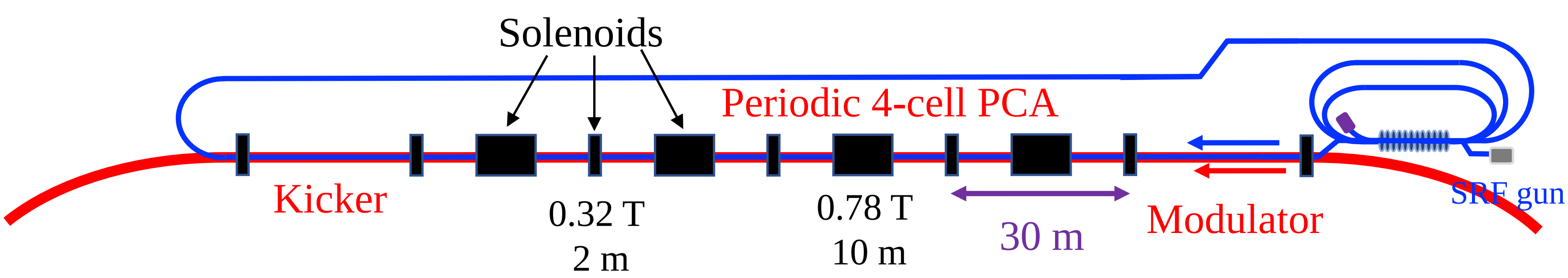




Simulations of Coherent Electron Cooling with Two Types of Amplifiers, Jun Ma, Gang Wang, Vladimir Litvinenko, International Journal of Modern Physics A (IJMPA), Vol. 34 (2019) 1942029 (

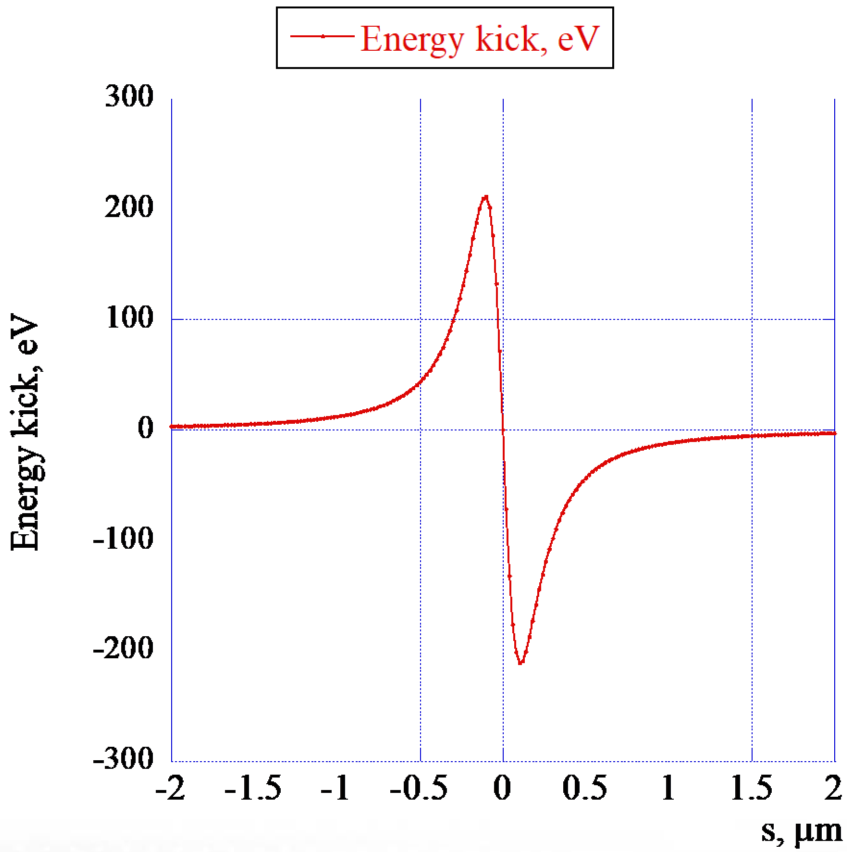
Plasma-Cascade micro-bunching Amplifier and Coherent electron Cooling of a Hadron Beams, V.N. Litvinenko, G. Wang, D. Kayran, Y. Jing, J. Ma, I. Pinayev, arXiv preprint arXiv:1802.08677, 2018

EIC CeC with PCA



Name	Current experiment	CeC cooler for EIC
PCA Lattice	Periodic, 4 cells, regular	Periodic, 4 cells, optimized
γ	28.5	293
Hadrons	Au ions	Protons
E_h, GeV	26.5	275
E_e, MeV	14.56	150
l, m	2x1	2x15
a_0, mm	0.2	0.15
Q, nC	1.5	1.5
I_0, A	75	150
ε_{norm}, m	$5\ 10^{-6}$	$5\ 10^{-6}$
Frequency, THz	25	500
PCA gain	100	400
Lattice	regular	1:2
3D emittance Cooling time, min	15-20	<5

Some key parameters for EIC CeC with PCA



Protons		
Np	6.90E+10	
γ	293.1	
β	0.99999418	
$\beta\gamma$	293.0982941	
Energy	2.750075E+11	eV
Ep	275.0	GeV
f_rev	7.83E+04	Hz
σ_z	6	cm
σ_t	2.0E-10	sec
$\sigma\gamma/\gamma$	1.00E-04	
σx	0.67	mm
σy	0.20	mm
Electrons		
Energy	149.8	MeV
Bro	499.60	kGs cm
Kicker length	40	m
Ip	150	A
Q	1.5	nC
Ne	9.36E+09	
FWHM τ	3.99E-12	sec
FWHM s	1.2E-01	cm
σx	0.70	mm
σy	0.20	mm

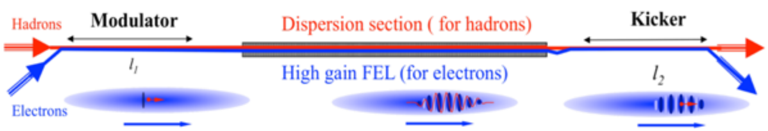
Short summary

- PCA amplifier promises bandwidth ~ 500 THz, which is significantly larger than that for Chicane-Based Amplifier (CBA)
- We plan perfume 3D simulation of EIC CeC with type-2 PCA amplifier in few weeks
  - We understand that there will be factors 2, 3, 4, reductions in cooling efficiencies caused by reality
  - If cooling time is shorter that required for the EIC, we plan optimizing distribution of the CeC cooling by switching from bunch to bunch in addition to ”swiping”
- After that we plan to run 3D simulation for EIC CBA presented by Erdong Wang

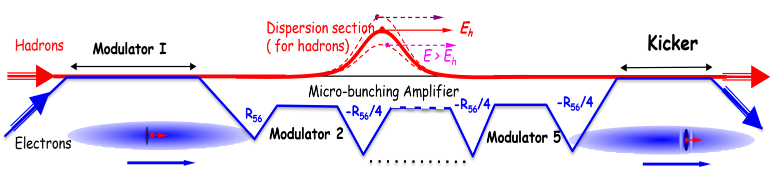
Back-up

What can be tested experimentally?

Litvinenko, Derbenev, PRL 2008

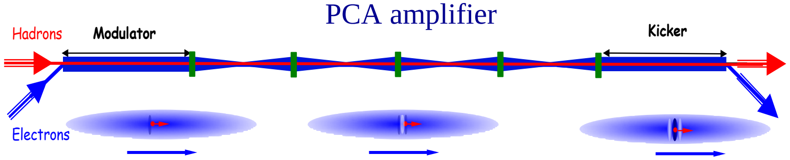


Ratner, PRL 2013

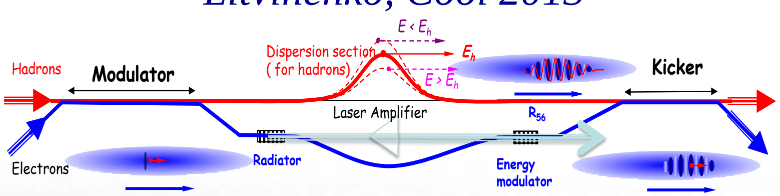


Litvinenko, Wang, Kayran, Jing, Ma, 2017

PCA amplifier



Litvinenko, Cool 2013



RHIC Run 18

High gain FEL amplifier with low-a_w wigglers

Cooling test would require significant modification of the RHIC lattice & superconducting magnets quadrupling the cost

RHIC Runs 20-22

Plasma-Cascade Amplifier

Cooling test would require significant modification of the RHIC lattice & superconducting magnets quadrupling the cost

Derbenev is suggesting to explore CSR as and CeC amplifier