

# Stochastic cooling in the EIC

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Electron-Ion Collider



# History

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Herr and Mohl reported cooling bunched beams in ICE (1978)

Chattopadhyay develops bunched beam cooling theory (1983)

$$\theta - \omega_0 t = \varphi(t) \approx a \sin[\omega_s(a)t + \psi_0]$$

Stochastic cooling considered for SPS, RHIC and Tevatron (80s).

Unexpected RF activity swamps the Schottky signal (~85).

Cooling rate scales as  $1/N$ ,  $Z=79$  for Au. Fast IBS, microwave technology.

Cooling of long bunches in FNAL recycler (2005).

Proton cooling experiment in RHIC (2006).

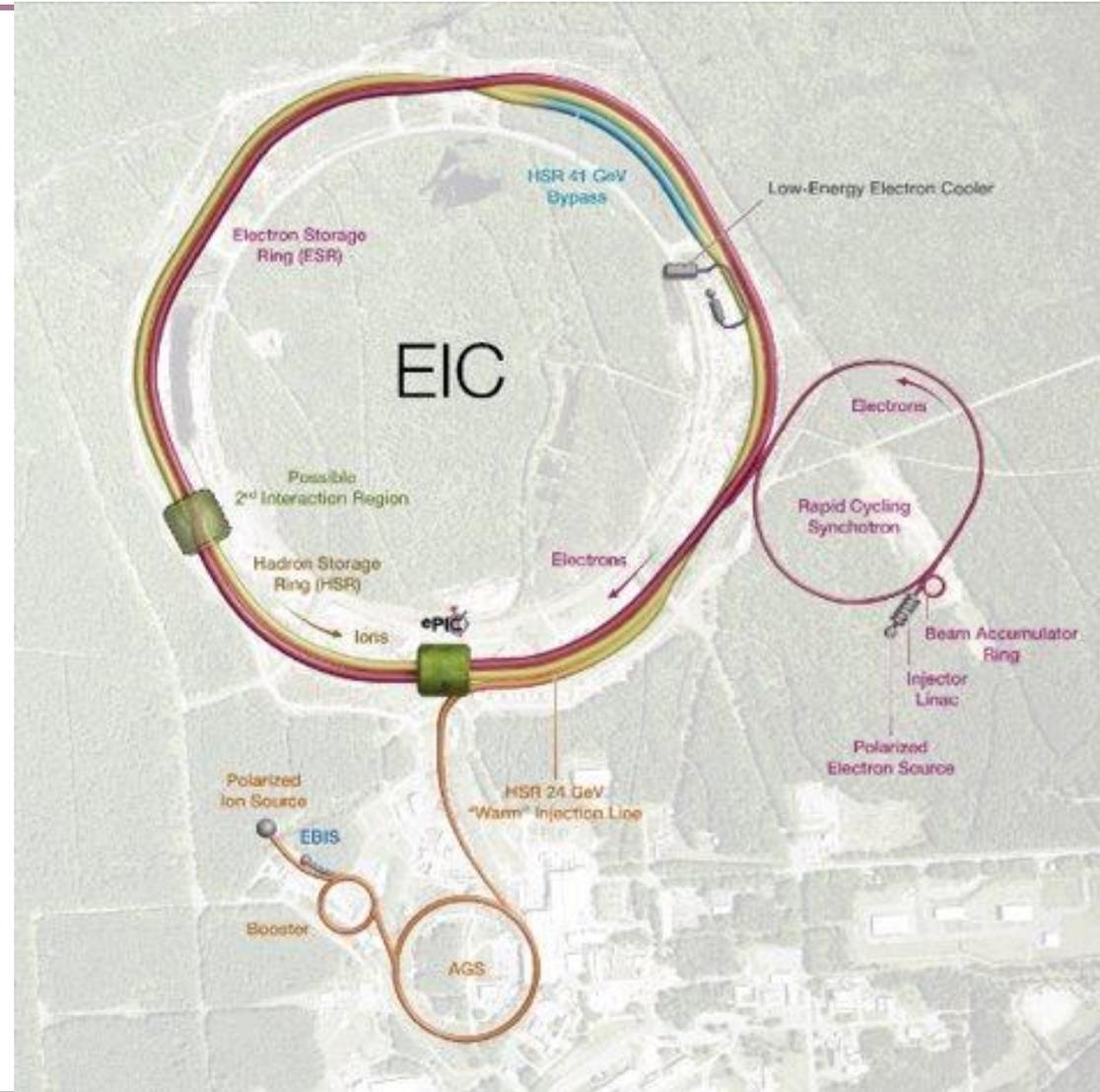
Operational longitudinal cooling of gold in RHIC (2007).

Transverse cooling in RHIC (2010).

Have cooled several species from 30 GeV/nucleon to 100 GeV/nucleon.

# Cooling Ions in the Electron Ion Collider

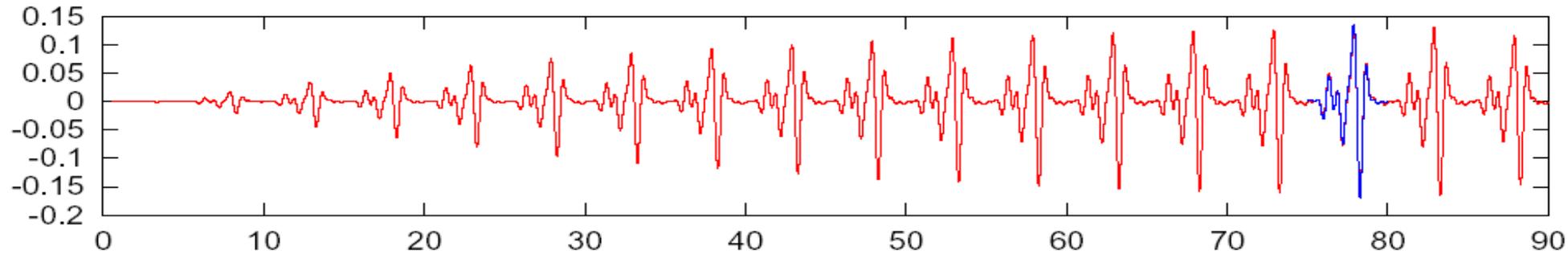
- 13 nC bunches of Au from 41 to 110 GeV/nucleon. Others Nb, Ag, Cu, U,...
- Can we adapt the RHIC system to the EIC?
- Existing system works with 80ns bunch spacing.
- Injection harmonic in Hadron Storage Ring is 315, 40ns bunch spacing. Double up kickers.
- Two bunch splits used to reduce the BB tune shift of the electrons, 10ns spacing.
- For 18 GeV the electron current is power limited. No bunch splitting is used.
- Initial RF in ESR  $\sim 1/4$  of final design and bunch splitting may be unnecessary.



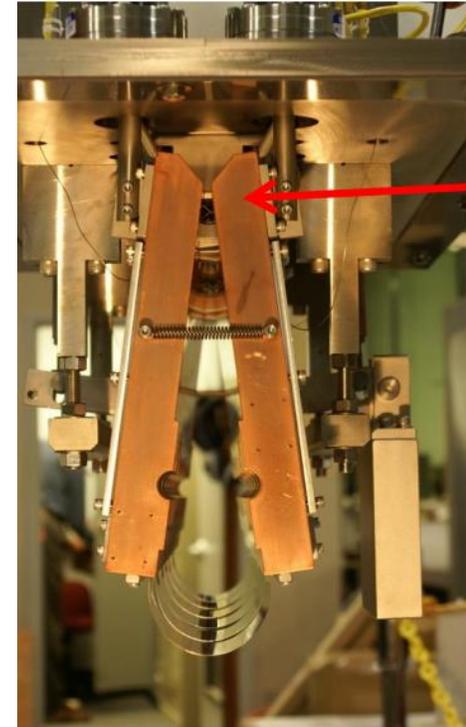
# Voltage Considerations

$$V(t) = \sum_n A_n \sin(2\pi n t / \tau_b + \theta_n)$$

- For the 6-9 GHz longitudinal system we need 5 kV rms for EIC.
- Bandwidth-Voltage product sets the cost scale.
- Bunches are  $\tau_b=5\text{ns}$  long spaced by 100 ns (40 ns for EIC  $h=315$ )
- The value of the kicker voltage matters only when the bunch is present. Drive signal is 80ns long traversal filter (5ns·4·2·2)



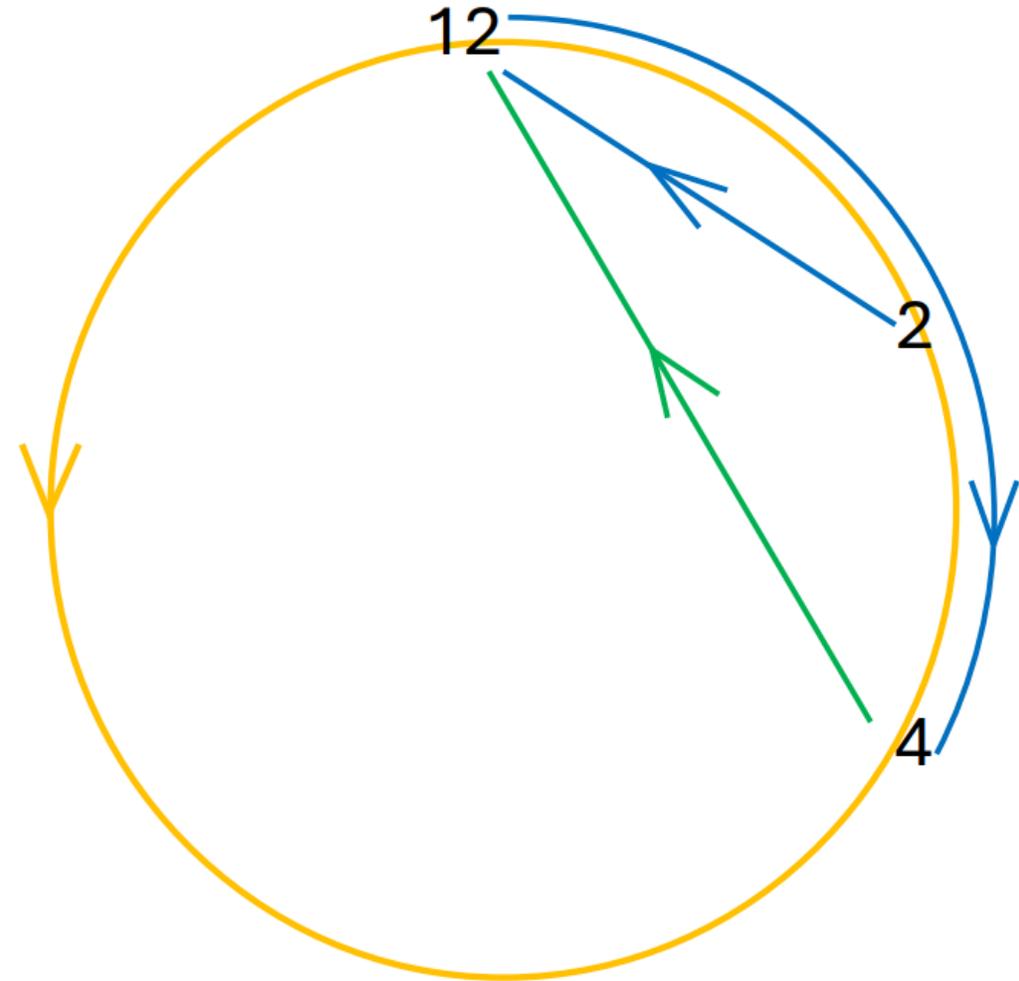
- Individual frequencies from different cavities.
- Transverse kicks from 5-8 GHz cavities.



Flexi-hinge allows smooth, repeatable closing.

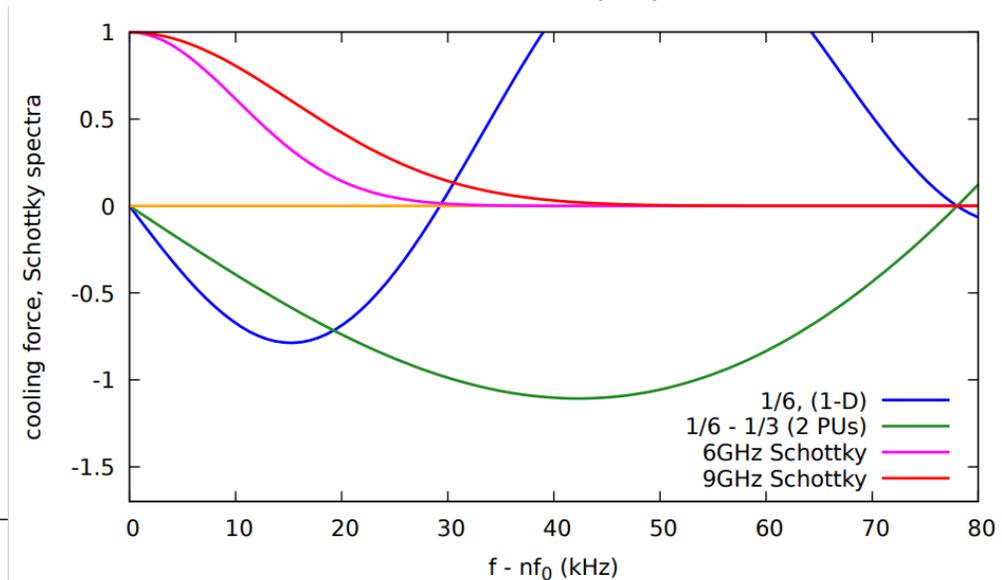
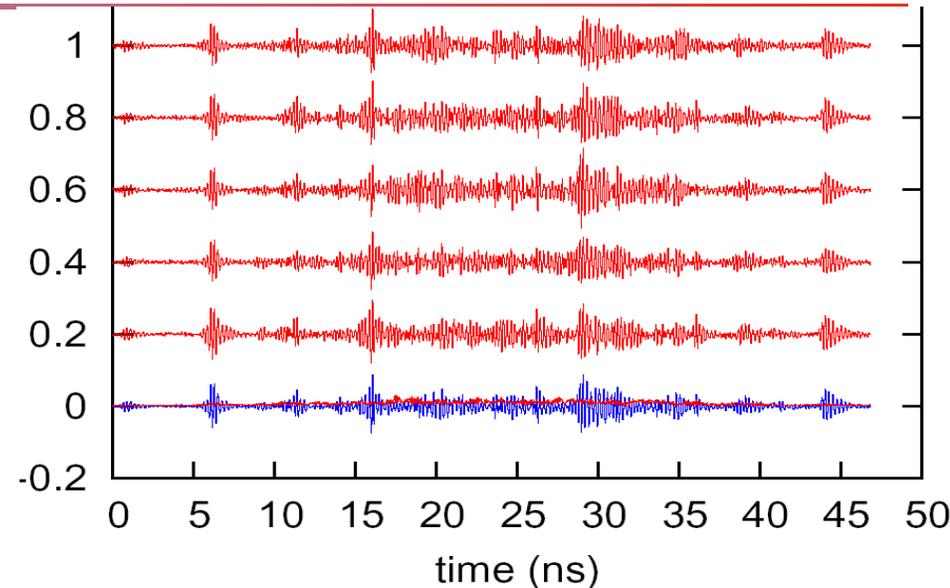
# System Layout for Yellow Ring

- The existing RHIC system has longitudinal kickers and transverse pickups in the 12 o'clock straight section.
- A microwave link is used to send the longitudinal pickup signal from 2 to 12, arrives before beam.  $1/6$  turn delay with previous turn subtracted.
- In 4 there are transverse kickers receiving their signal via fiber optic link. The signal arrives before the beam.  $2/3$  turn delay.
- For EIC an additional longitudinal pickup in 4 o'clock will send its signal to 12 via a microwave link, arriving before the beam. Take  $1/3$  turn minus  $1/6$  turn.



# Signal Processing

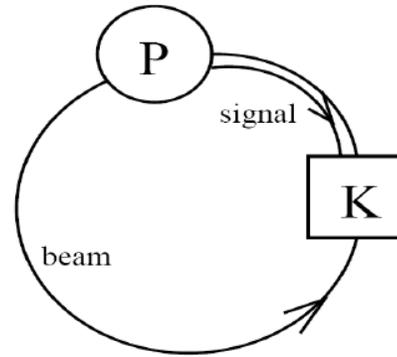
- The coherent lines at the bunching frequency must be filtered out or the system will saturate.
- Figure is 5 turns of data with 40 ns filter, blue is average, orange is standard deviation.
- For the existing longitudinal system the cooling range is in blue. Not OK for 9 GHz in EIC
- The two pickup EIC case is shown in green.
- The upper end of 9GHz Schottky spectrum is near the max of the cooling gain.



# Simulation Algorithm

- For longitudinal cooling we measure energy offsets and correct them with a kicker.
- The kick voltage scales as  $1/\sqrt{N_p}$  and the cooling time scales as  $N_p$ .
- The number of simulation macroparticles satisfies  $N_m \ll N_p$ .
- The number of turns needed to simulate the system is reduced by a factor  $N_m/N_p$ .
- By keeping the total beam charge the same fluid effects are unchanged.
- Allows for a scaling law.

Basic idea

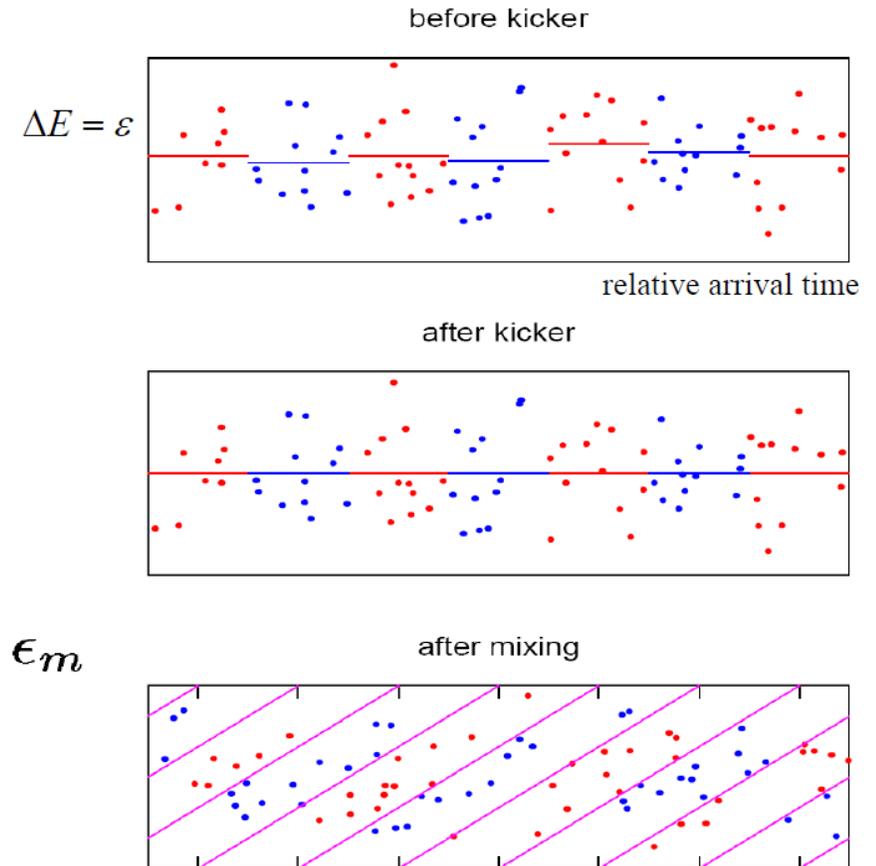


$$\bar{\epsilon}_k = \epsilon_k - \frac{g}{N_s} \sum_{m=1}^{N_s} \epsilon_m$$

$$\langle \epsilon_k \epsilon_m \rangle = \langle \epsilon^2 \rangle \delta_{k,m}$$

$$\langle \bar{\epsilon}^2 \rangle - \langle \epsilon^2 \rangle = (-2g + g^2) \langle \epsilon^2 \rangle / N_s$$

$$N_s \approx N_p / (4\Delta f \sigma_t)$$



# Algorithm Test

$$H_s(\epsilon, \tau) = \frac{T_0 \eta}{2\beta^2 E_0} \epsilon^2 - \int_0^\tau dt q V_{rf}(t)$$

- Check of scaling, simple RF, no IBS or longitudinal cooling.
- Strong effect of cooling rate on  $H_s$  first noted by Chattopadhyay (Thesis 1983)
- For RHIC and EIC longitudinal IBS leads to sufficient  $H_s$  diffusion to smooth out transverse cooling.
- Figure from Blaskiewicz and Brennan, COOL07, WEM2I05

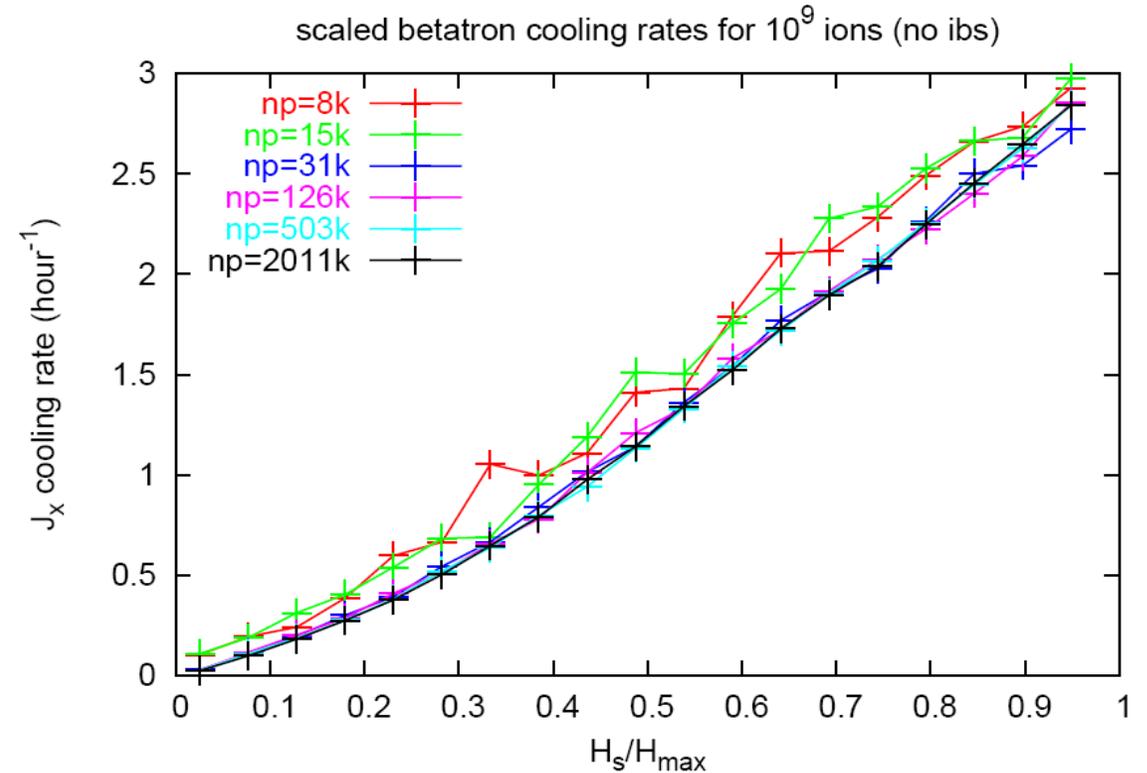
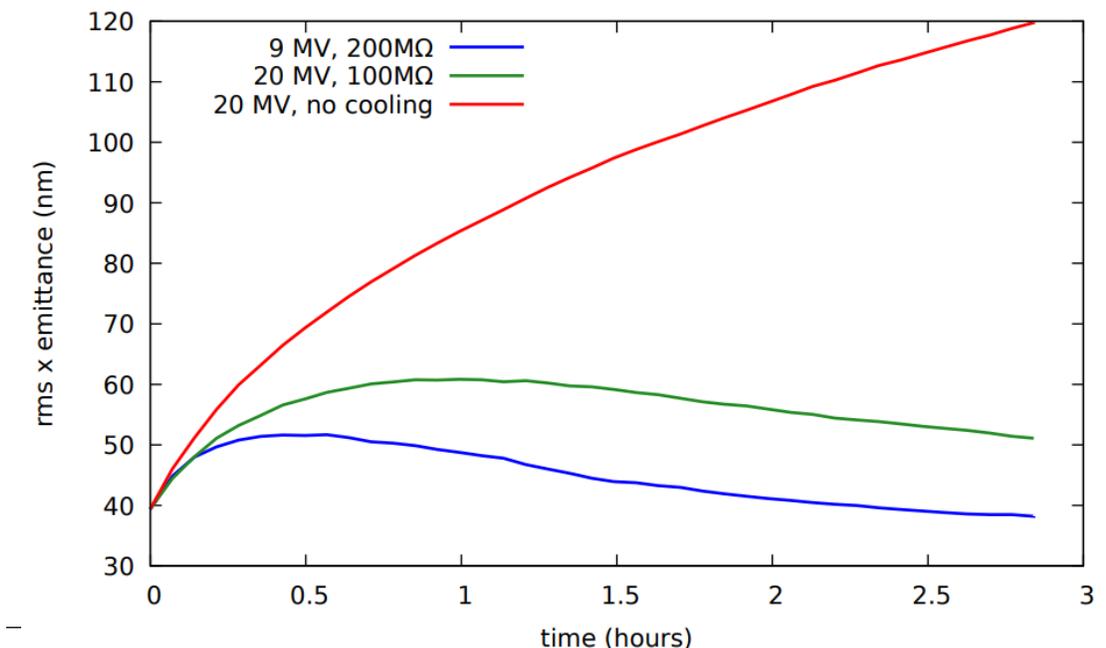
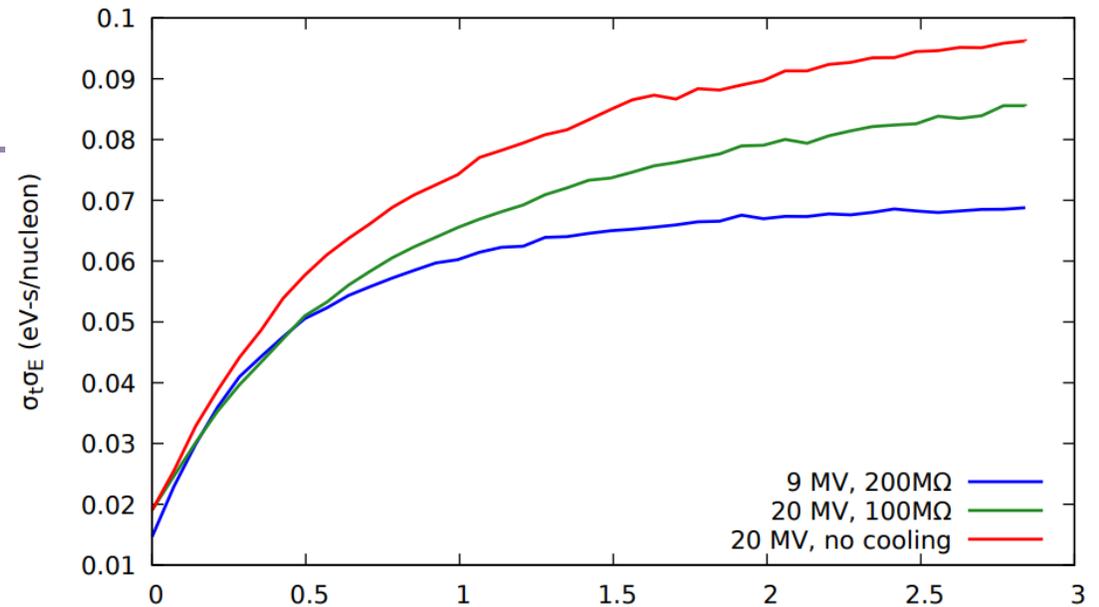
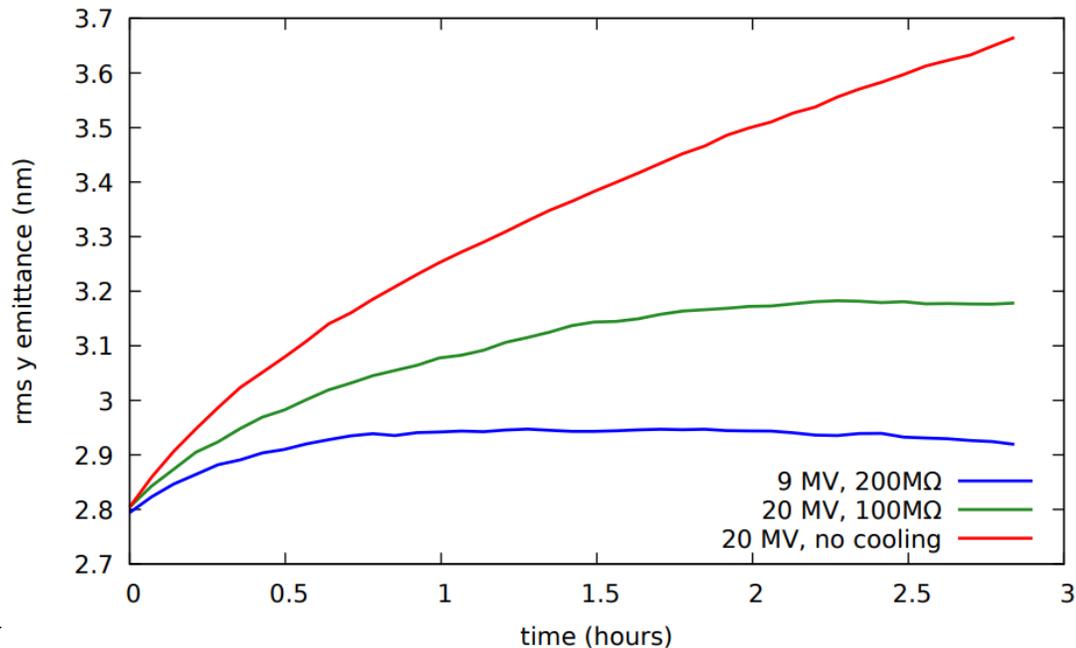


Figure 5: Transverse cooling rate versus the value of the longitudinal hamiltonian. Similar results are shown in [6, 7]

# Performance for Ag

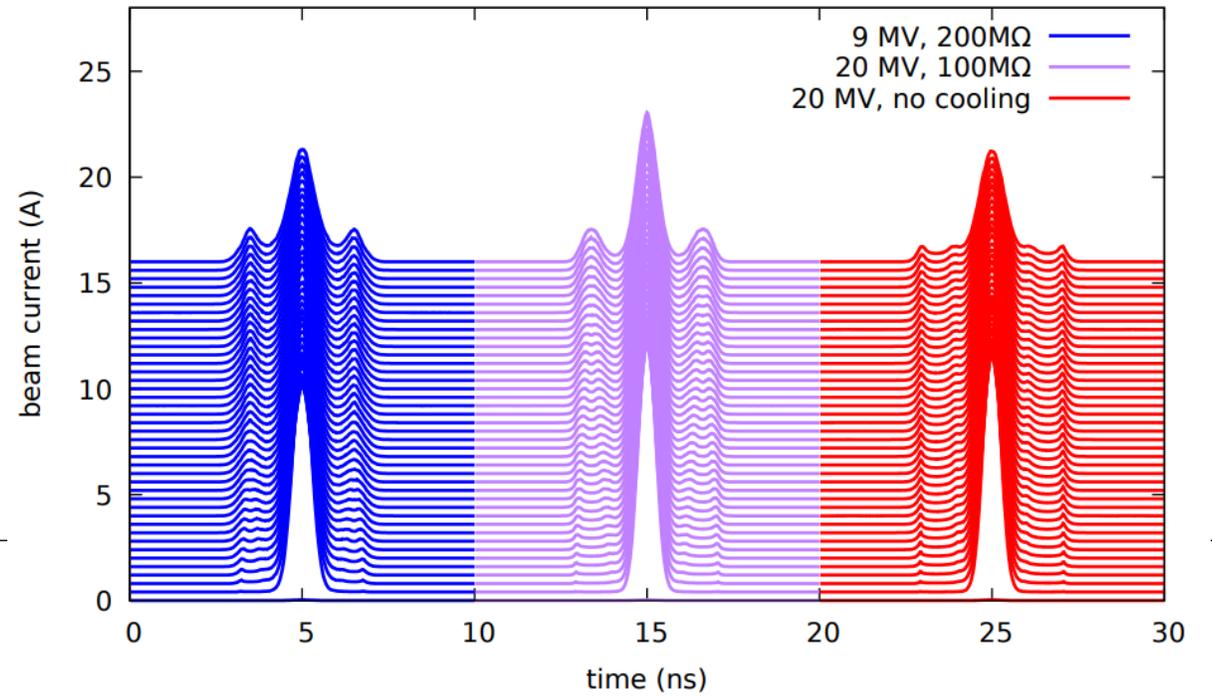
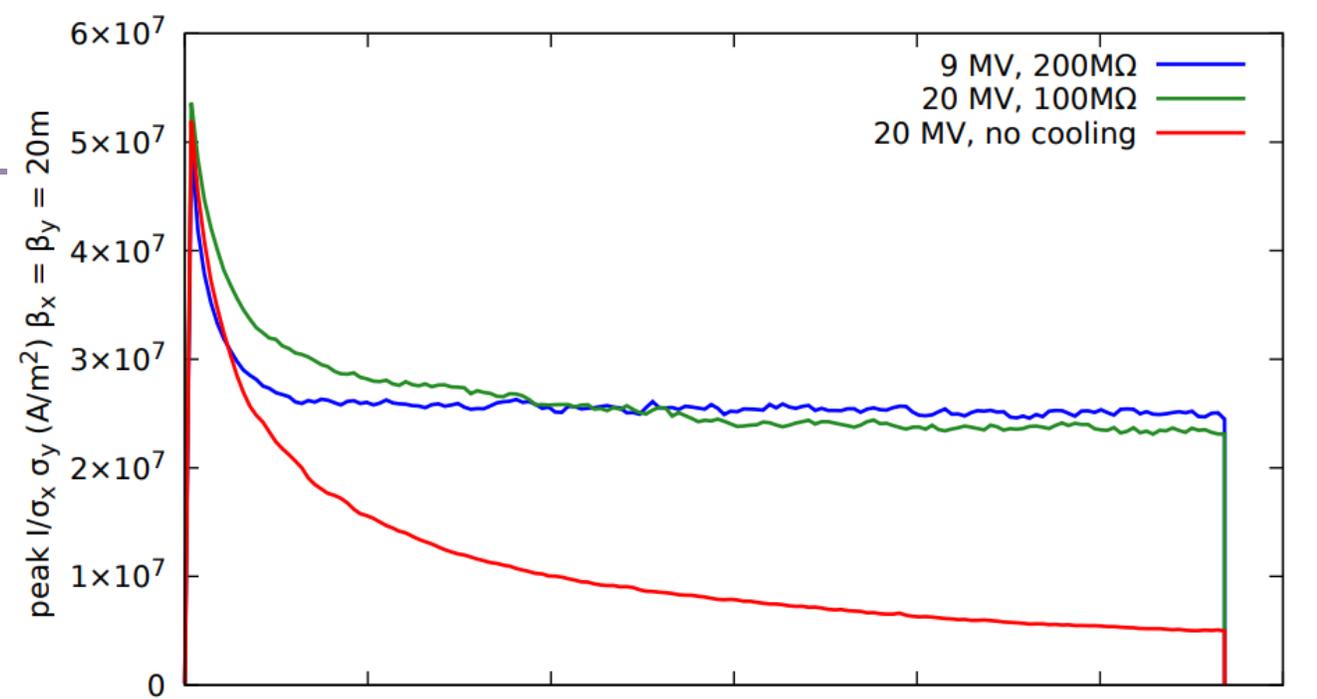
- Did some simulations using code developed for RHIC but adapted to the two pickup scheme.
- Simulation parameterized by voltage on 591 MHz system and effective impedance of longitudinal cooling.



# Performance for Ag

- The central density of the beam is good for both cooling scenarios.
- The improvement in luminosity is significant for these parameters.

$\gamma=127$ ,  $\sigma_t=340\text{ps}$ ,  $N=10^9$ ,  $A=108$ ,  
 $N=47$ ,  $Z_x=1400\text{M}\Omega/\text{m}$ ,  $Z_y=100\text{M}\Omega/\text{m}$



# Summary

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- Stochastic cooling is feasible for the EIC.
- The existing system is close to what we need.
- Significant luminosity gains are possible.
- The system will always be useful when working with 18 GeV electrons.