Proof-of-Principle Experiment for FEL-based Coherent Electron Cooling

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Collaboration of BNL, Jlab and Tech-X

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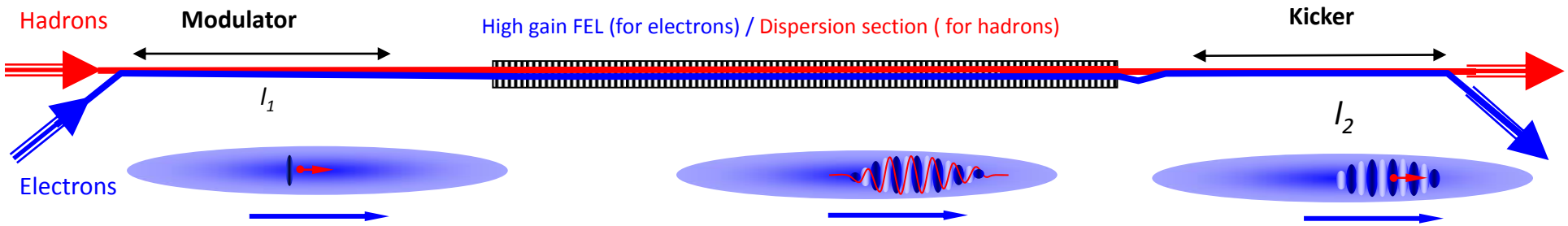
Outline

- Introduction to the concept of CeC
- Status of analytical and simulations studies
- Proof of Principal experiment
  - Motivation
  - Layout and parameters
  - Technical realization
    - Wiggler design
    - Electron accelerator
  - Preliminary electron beam dynamics simulation
  - Timeline
- Summary

Introduction to the Concept



Modulator:region 1 a quarter to a half of plasma oscillation

Amplifier of the e-beam modulation via High Gain FEL and Longitudinal dispersion for hadrons

Kicker: region 2

Electron density modulation is amplified in the FEL and made into a train with duration of $N_c \sim L_{gain}/\lambda_w$ alternating hills (high density) and valleys (low density) with period of FEL wavelength λ. Maximum gain for the electron density of HG FEL is ~ 10^3.

- Since the ion has to overlap with the wave-packet it induced and it is relatively easy to delay electrons, it is required that

$$v_{gr} \geq v_{ion} \quad \Rightarrow \quad a_w \leq \sqrt{\alpha/(1-\alpha)} \qquad \mathrm{v}_{gr} = \mathrm{v}_{ze} \cdot (1-\alpha) + \alpha \cdot c; \quad 0 < \alpha < 1$$

For our considered parameters, 3D simulation suggests $\alpha \in \{0.2, 0.25\} \Rightarrow a_{w,\max} \in \{0.5, 0.58\}$

Analytical Studies and Simulations

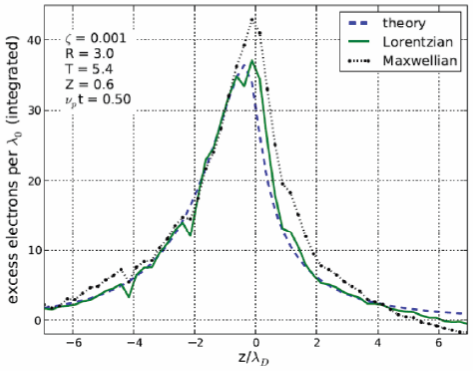
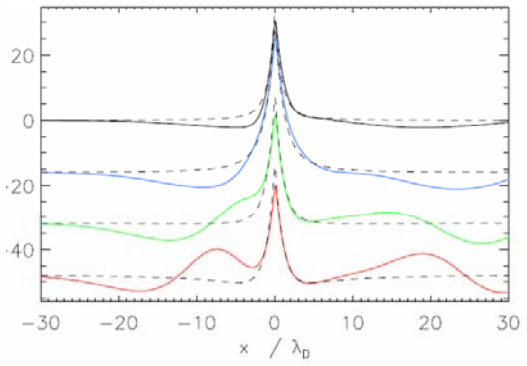
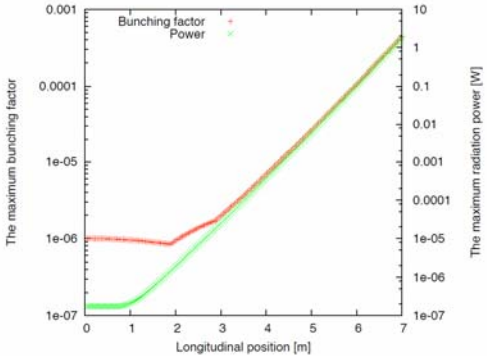


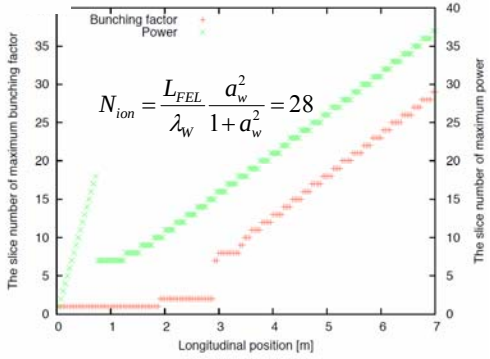
Figure 3: Longitudinal charge density perturbation of a plasma in the vicinity of a moving Au^{+79} ion.

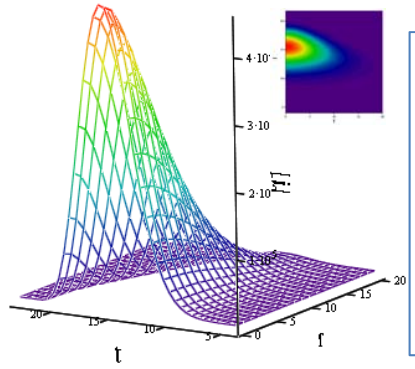


➢ Modulator: VORPAL simulation has been validated by analytical model and progresses have been made recently towards simulations with more realistic beam profile.

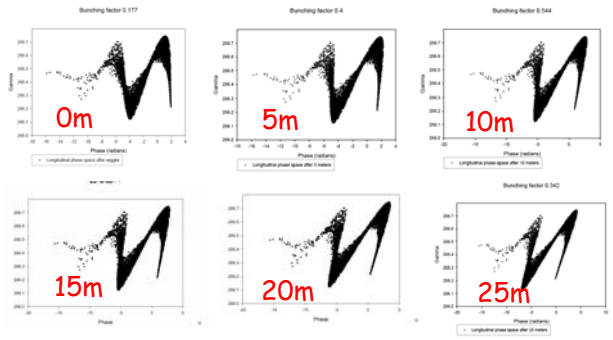
➢FEL amplifier: we use Genesis to simulate the evolution of electron density modulation. Efforts have been made to correctly taken into account shot noises. We are also developing analytical tool to better understand underlying physics and scaling law.

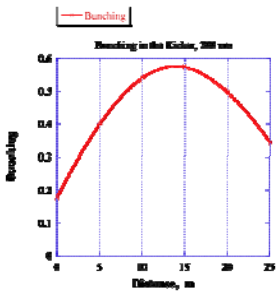


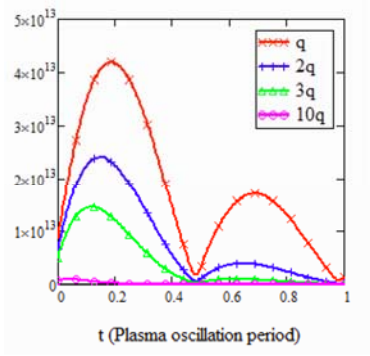




• Relevant Poster sessions: MOP073, MOP066, MOP067, MOP069, MOP073, MOP074, THP149

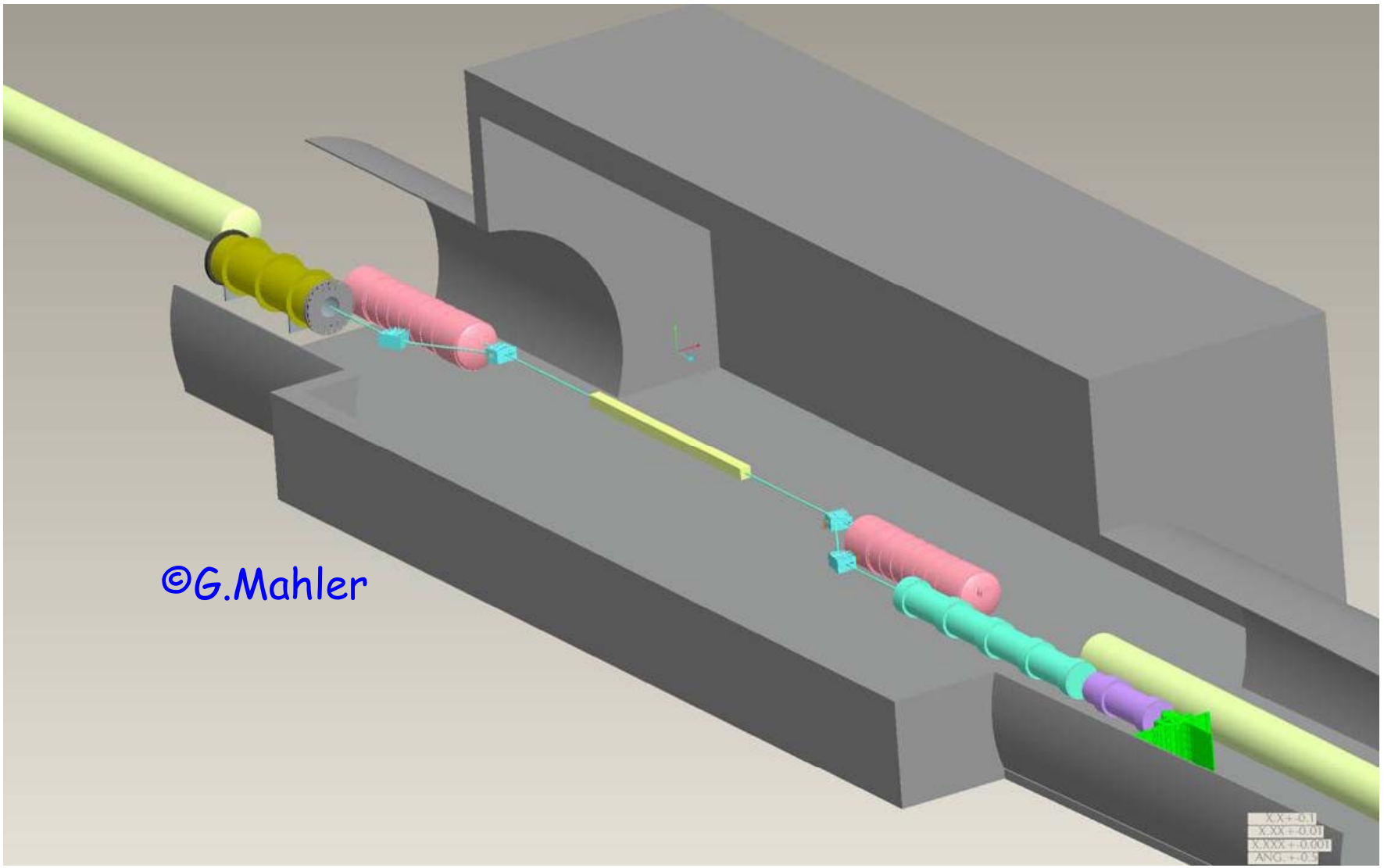






➢Kicker: analytical model has been developed. Preliminary simulation qualitatively agrees with analytical model. VORPAL simulation is under way with space charge effect and Landau damping taken into account.

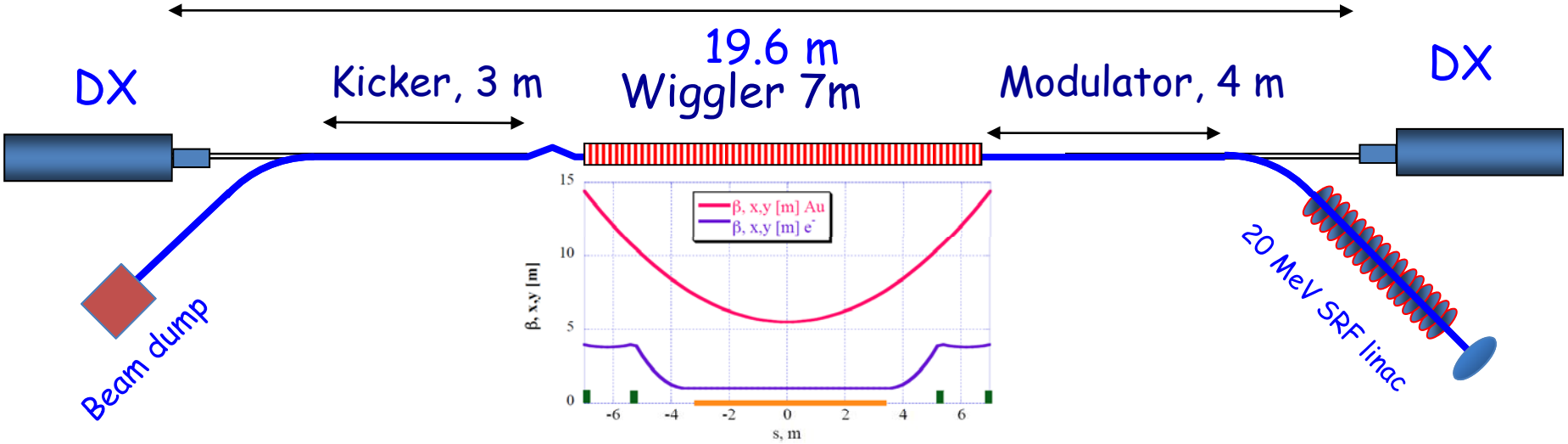
Proof of principal experiment



Motivation

- To demonstrate experimentally Coherent Electron Cooling (CeC)
- To develop the necessary numerical- and analytical-tools for accurately predicting CeC performance
- To predict the exact performance of an as-built CeC system at RHIC
- To measure the performance of this CeC
- To compare the measured performance with the predicted one to evaluate adequacy of the codes
- To develop experimental experience with CeC system

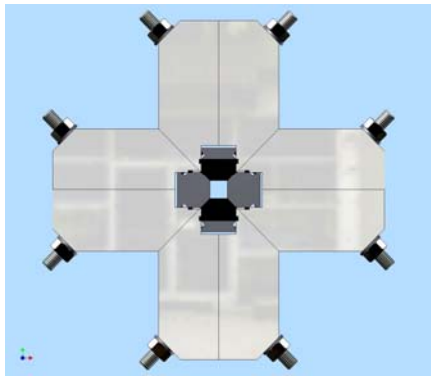
Parameters



Electron beam and FEL parameters		Au in RHIC parameters	
Energy (MeV)	21.8	Energy (GeV / u)	40
RMS Energy Spread	1×10^{-3}	RMS Energy Spread	3.5×10^{-4}
Bunch Charge (nC)	0.5-1	Bunch Intensity	1×10^{-9}
Norm. Emittance (μm)	5	RMS Norm. Emit. (μm)	2
Peak Current (A)	60-100	Long. Emittance (eV-s)	0.5
Bunch Charge (nC)	0.5-1	RMS Bunch Length (ns)	1.5
Undulator length (m)	7	β* (m)	5.5
Undulator Period (m)	0.04	S* (m)	0
Undulator Strength	0.437		
FEL wavelength (μm)	10		

Helical Wiggler: prototyping at BINP

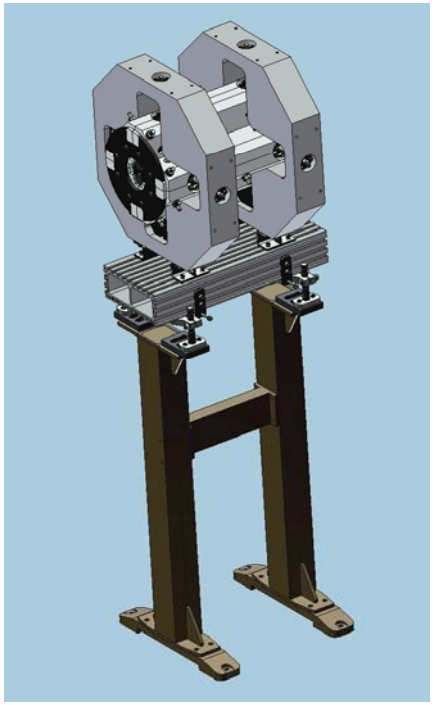
Courtesy to P.Vobly and M.Kholopov

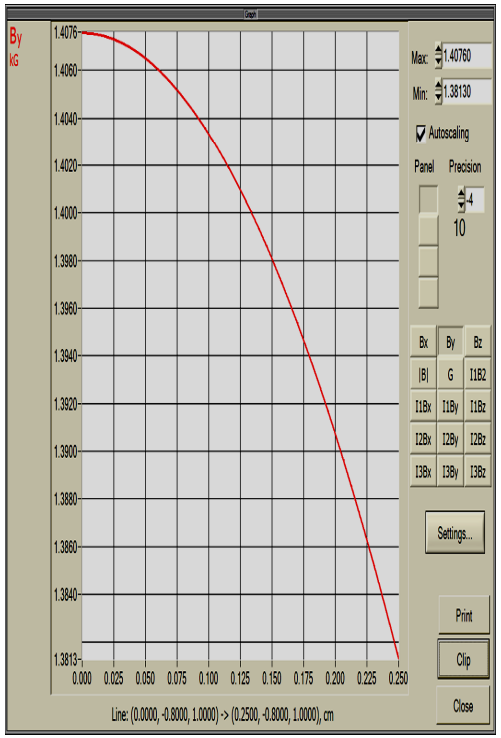


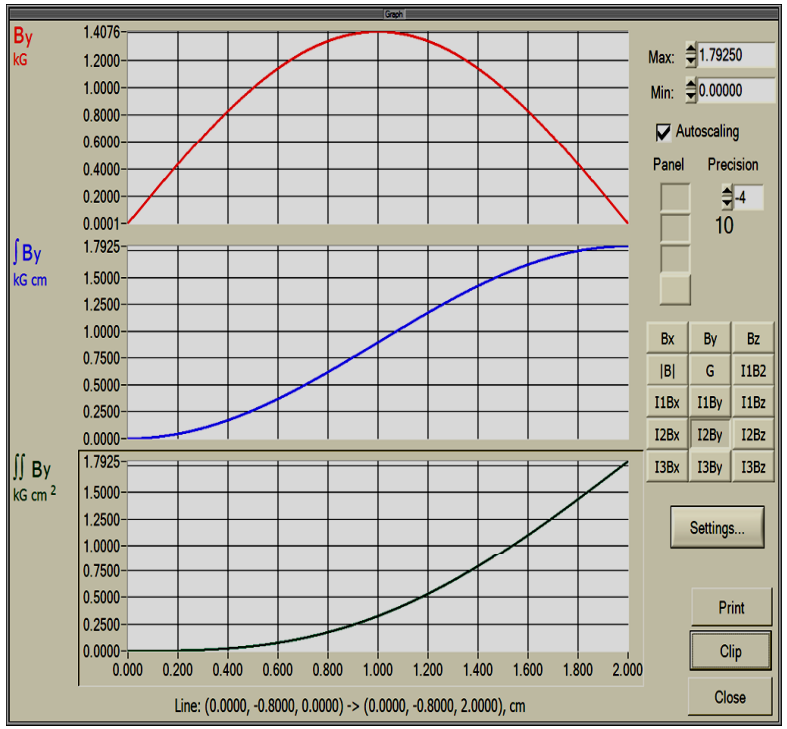
At present next stages of work has been done:

1.Magnetic and force calculation
2.Design of helical undulator prototype
3.Preliminary undulator drawings

After BNL approval of helical undulator design it's necessary to order permanent magnets and start detailed designing.

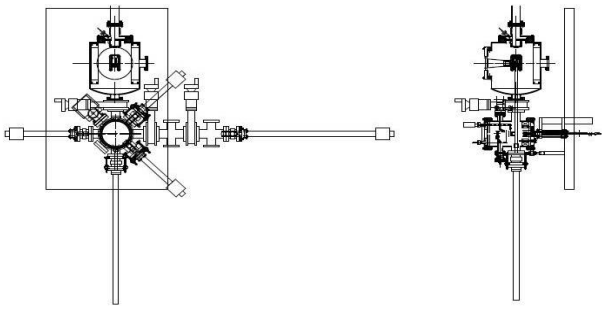


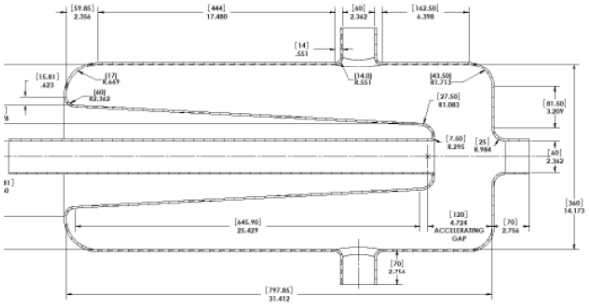




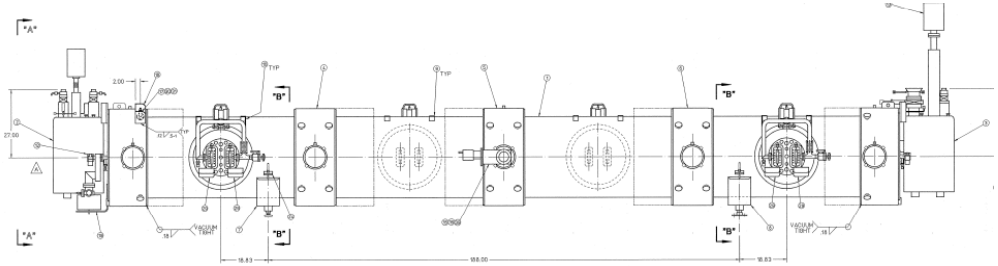
Electron Accelerator System

- Guns: DC (Jlab) or BNL's 112 MHz?

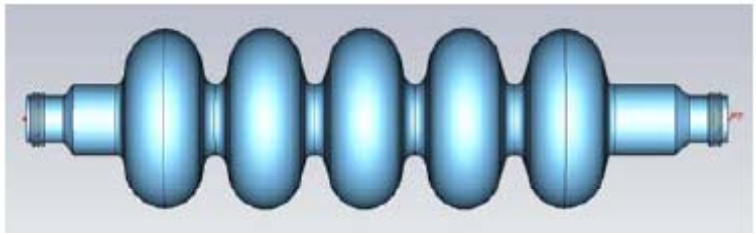




- SRF: CEBAF 1.5 GHz or BNL3 703 MHz?

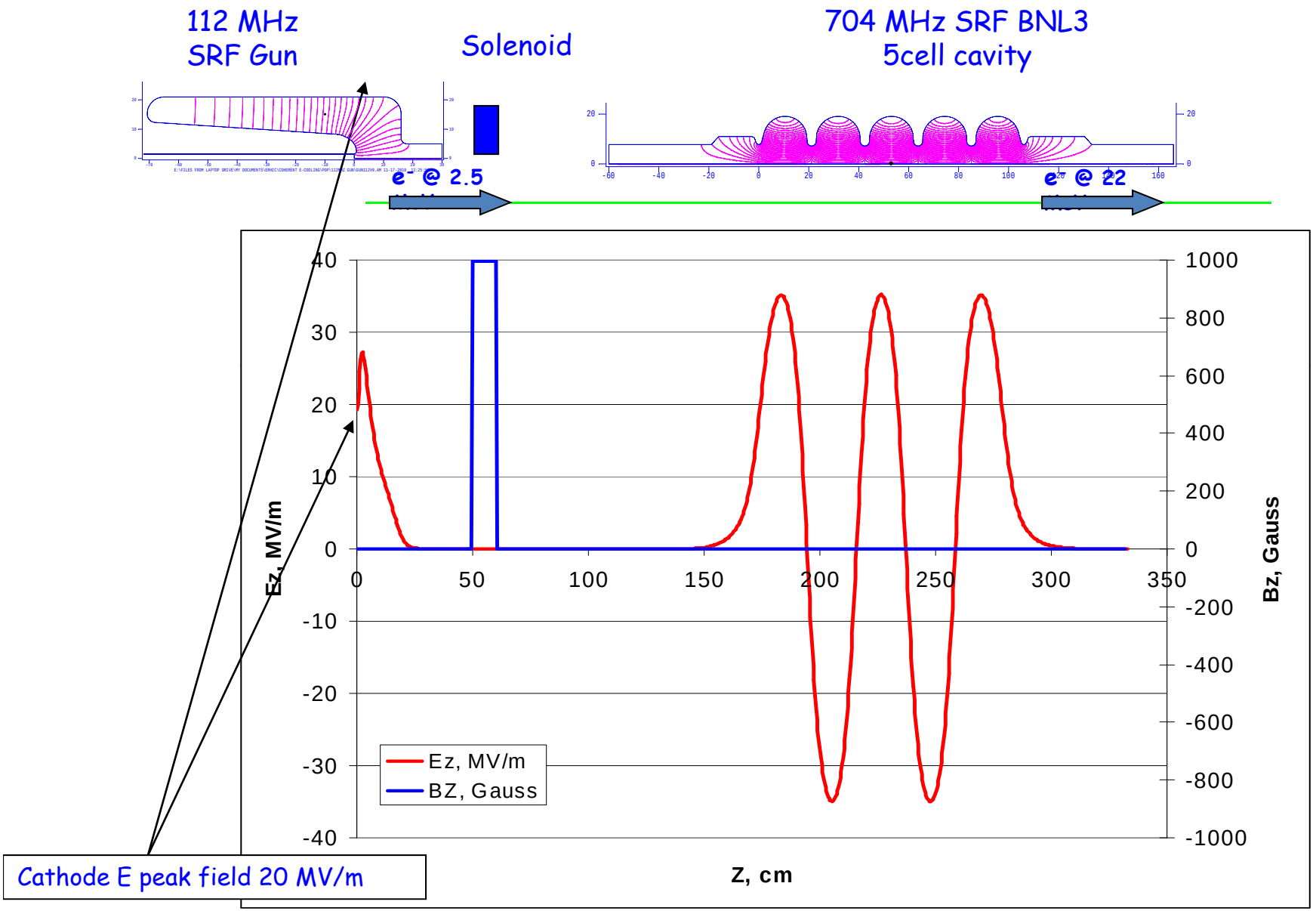


Existing, operational but long and needs eight 1.5 GHz klystrons



Cavity is manufacturing but need to design and built its cryostat

Electron Beam Dynamics Simulation: Schematic layout

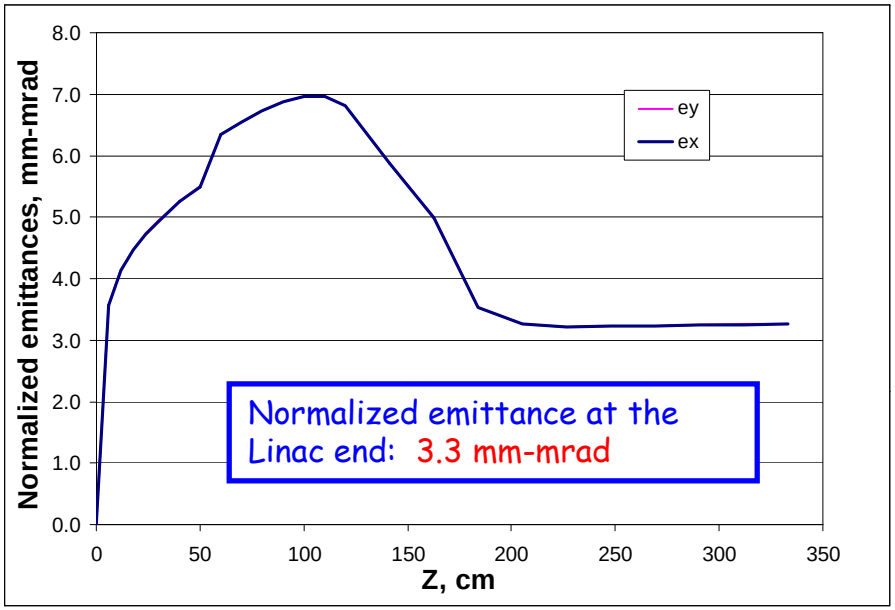


Courtesy to D. Kayran

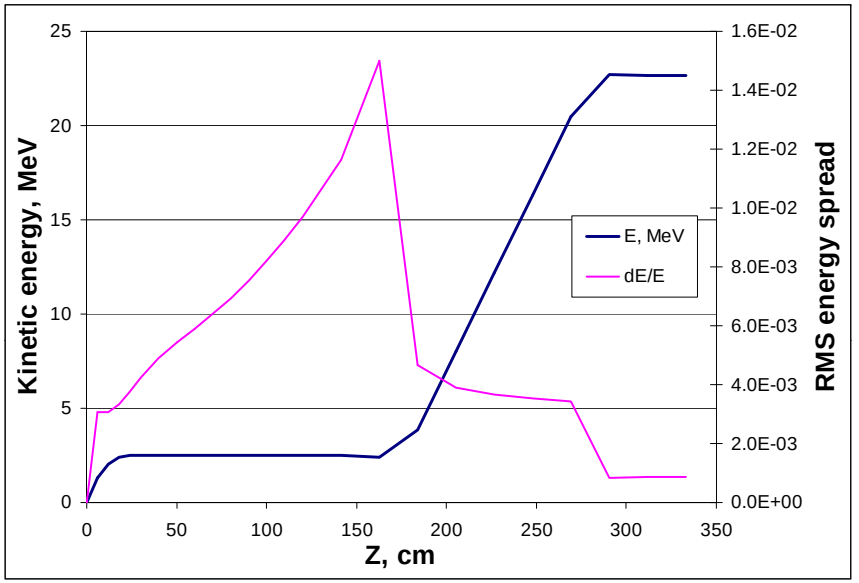
Electron Beam Dynamics Simulation: Results

Courtesy to D. Kayran

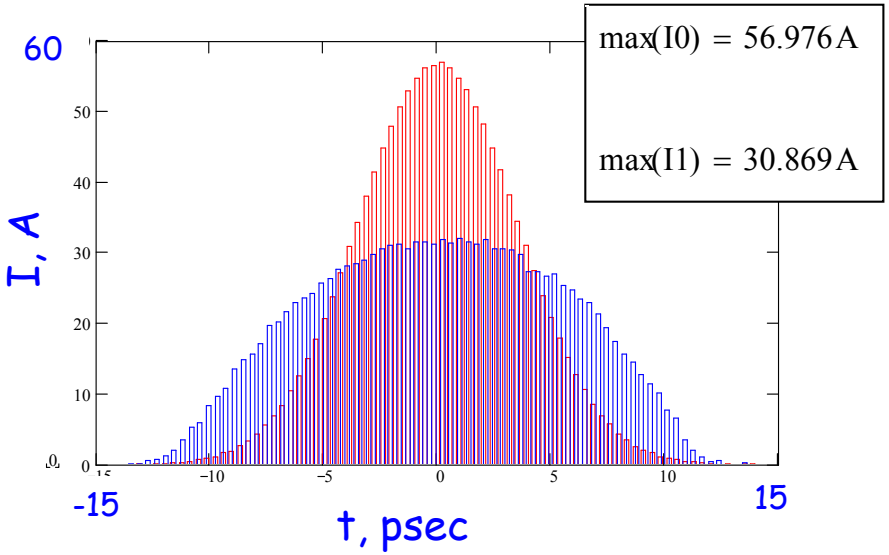
Trans. beam dynamics from the cathode to the Linac end

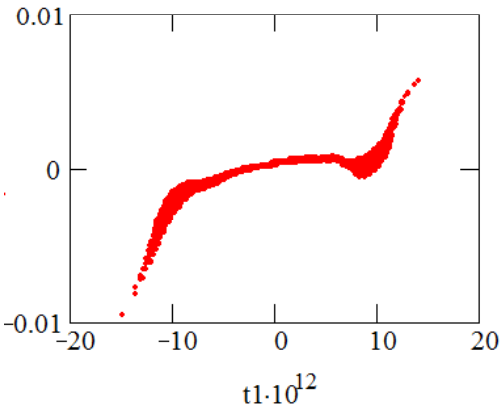


Longi. beam dynamics from the cathode to the Linac end



RMS energy spread at the Linac end: 9×10^{-4}





$$Q := 0.5\cdot10^{-9}$$

Timeline

- **FY11**
  - Design the system, prototype the wiggler, start Cryo-system
  - Choose the accelerator system
- **FY12**
  - Installing equipment in and around IP2 area
- **FY13**
  - Install the CeC into IP2 with straight pass
  - Commission the system during Run 13
- **FY14**
  - Move the CeC system to the IR2 (between the Dxes)
  - Commission the system and start cooling, Run 14
- **FY15, Run 15**
  - Complete the experiment

Summary

- A proof of principal experiment will be conducted in RHIC at IP2 and completed in five years (2011-2015).
- We are developing simulation and analytical tools for FEL-based CeC, which will be used to predict the results of the PoP experiment.
- Preliminary beam dynamic simulation of 112MHz SRF cavity based electron accelerator has been done and the results look very encouraging.