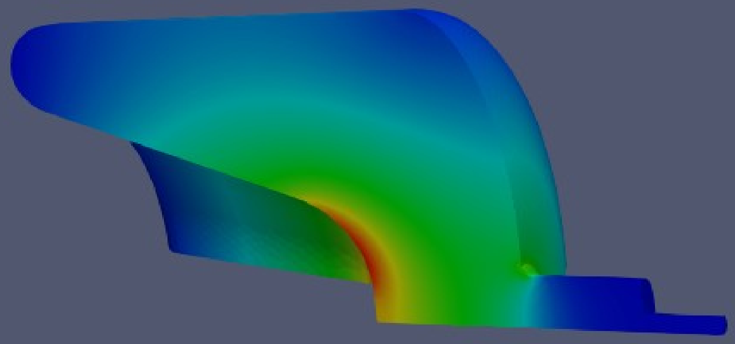
NORTHERN ILLINOIS CENTER FOR ACCELERATOR AND DETECTOR DEVELOPMENT

SRF ELECTRON SOURCE FOR MAGNETIZED ELECTRON COOLING



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Credits: with help from Tianzhe Xu (AWA) and Wei Hou Tan (APS) both graduate students at NIU and ANL. Benefited from discussions with Sasha Zholents and the SRF-gun team led by John Byrd at ANL.

U.S. DEPARTMENT OF ENERGY | Office of Science

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MOTIVATIONS

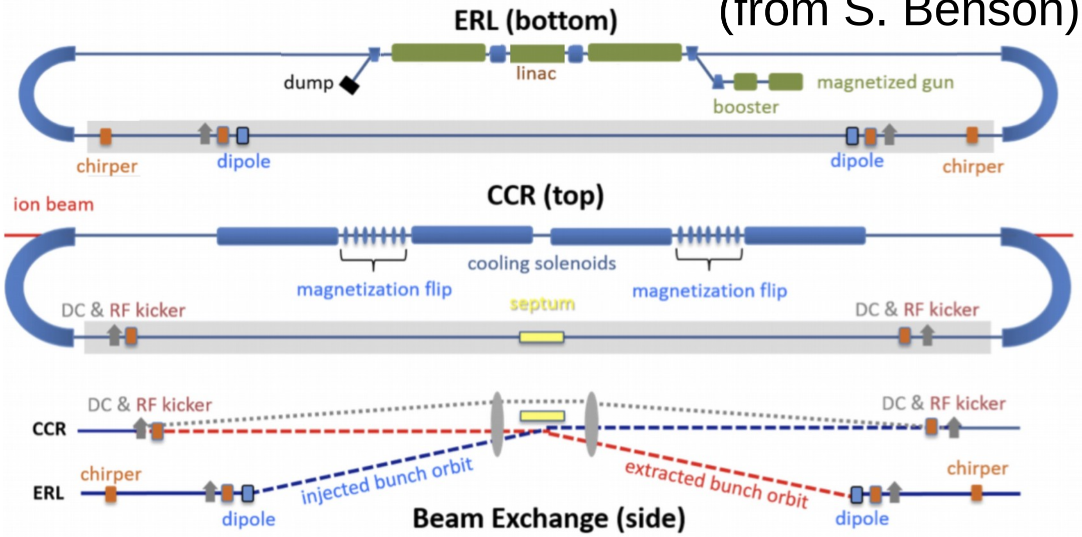
Electron beams for magnetized cooling with JLEIC specifications

- Typical requirements from injector:
  - beam current (~100 mA),
  - charge (up to 3.2 nC)
- relaxed emittance requirements (considering $\gamma \simeq 100$)
  - 4D transverse emittance

$$\varepsilon_{4d} \leq 26\ \mu\mathrm{m}$$

  - Longitudinal emittance
  - $\varepsilon_z \leq 5$ mm
- Total relative energy spread< $6\mathrm{x}10^{-4}$

(from S. Benson)



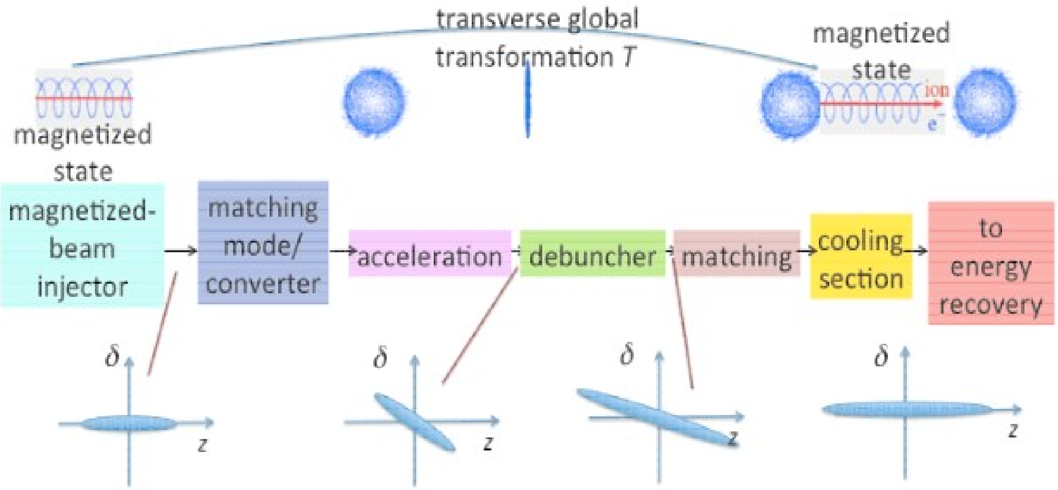
Strong Cooler Specifications (Electrons)

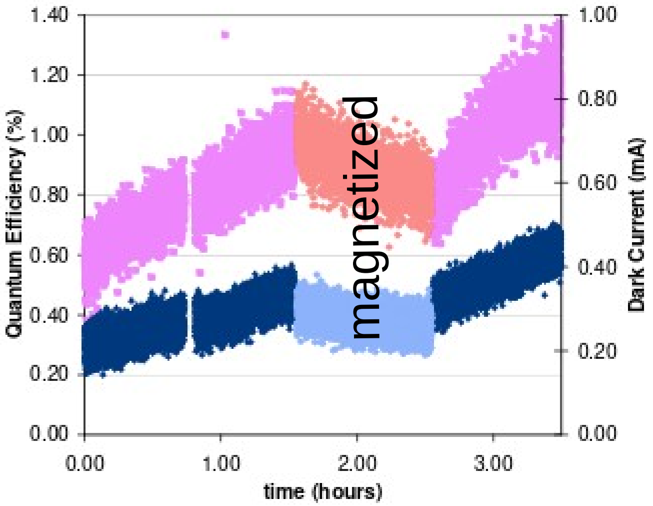
Energy	20–110 MeV
Charge	1.6 nC — used to be 3.2 nC
CCR pulse frequency	476.3 MHz
Gun frequency	43.3 MHz
Bunch length (tophat)	3-5 cm (17-29°)
Thermal (Larmor) emittance	<19 mm-mrad
Cathode spot radius	3.1 mm
Cathode field	0.05 T
Normalized hor. drift emittance	36 mm-mrad
rms Energy spread (uncorr.)	$3\mathrm{x}10^{-4}$
Energy spread (p-p corr.)	$<6\mathrm{x}10^{-4}$
Solenoid field	1–1.5 T
Electron beta in cooler	37.6 cm
Solenoid length	4x15 m
Bunch shape	beer can

SPECIFICATIONS

Magnetized beam

- Beam is "magnetized" at the cathode:
  - Accelerator needs to preserve the magnetization
  - beam eventually matched to the cooling section so that $B_{cath}\sigma^2_{cath} = B_{cool}\sigma^2_{cool}$
- Magnetization is produced by immersing cathode in a axial magnetic field
  - Affects photocathode performances (do not fully understand how but observed at several places)
  - Incompatible with SRF gun





R. Fliller, et al. (PAC95)

TRANSFORMATION OF MAGNETIZED BEAMS

Magnetized or flat beams?

- The magnetization $\mathcal{L} \equiv \kappa(B)\sigma_{cath}^2$ introduces full coupling between the two transverse degrees of freedom
- Which set two distinct “eigen emittance”

$$\varepsilon_+ \simeq 2\mathcal{L} \qquad \varepsilon_- \simeq \frac{\varepsilon_{4d,u}^2}{2\mathcal{L}}$$

- These eigen emittances can be recovered as conventional emittance using “vortex to flat” transformation
- Conversely (and originally) the flat-to-vortex transformation transforms an incoming beam with asymmetric emittances into a magnetized beam
- Can we start with a flat beam electron source?c

Adapting Optics for High Energy Electron Cooling

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February 19, 1998

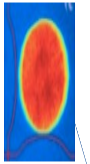
Abstract

A large value of beam horizontal emittance in ultrarelativistic electron synchrotrons is an obstacle to efficient introduction of electron cooling in hadron colliders. In this work, an adapting optics is proposed for the electron beam, in order to cancel the horizontal emittance's contribution to electron beam temperature in the cooling section. It involves a solenoid along the cooling section and special skew quadrupole blocks to match the solenoid and rest of electron ring, which has conventional optics. As result, the horizontal emittance becomes responsible only for the electron beam cross-section in the solenoid, while the transverse temperature in solenoid is determined by the outside vertical emittance, which is very small. This adaptation essentially raises the prospective efficiency of the high energy electron cooling.

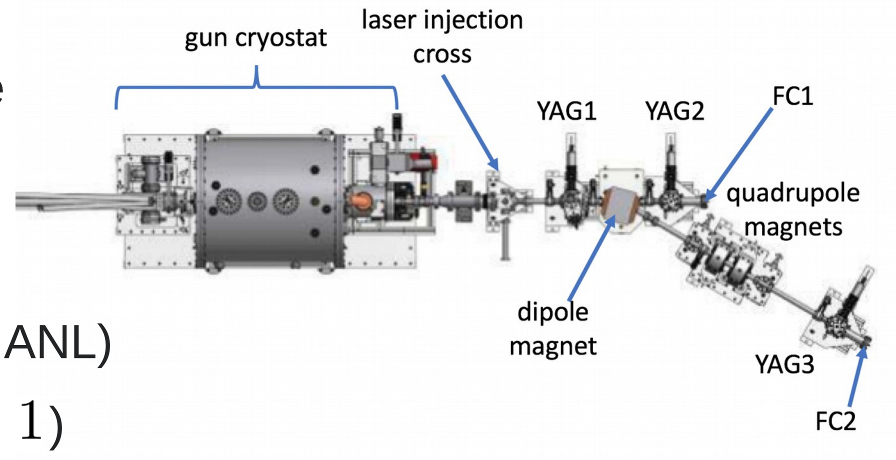
AB INITIO FLAT-BEAM ELECTRON SOURCES

Attempted by *many* for linear-colliders (LC) applications

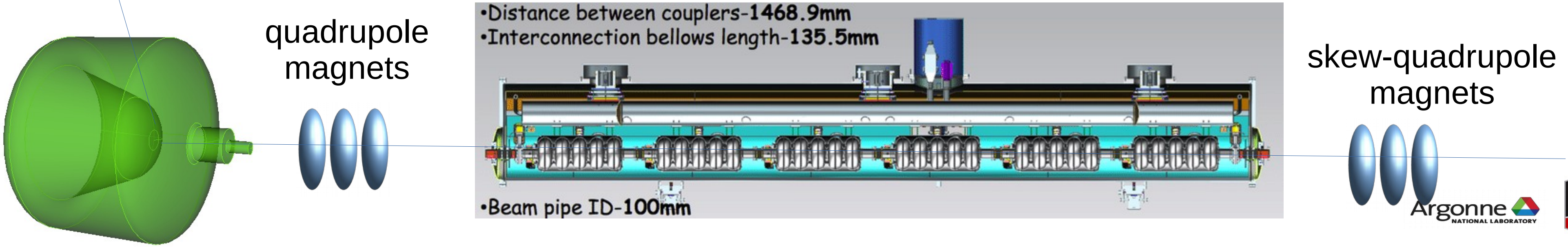
- **but** LC applications require very high transverse emittance ratio $\varrho \equiv \frac{\varepsilon_+}{\varepsilon_-} \sim 10^3$
- In the case of JLEIC the required transverse emittance ratio is very relaxed $\varrho \simeq \frac{36}{< 19} \geq 2$
- Practical implementation is straight forward



  - Asymmetric laser distribution on cathode
  - Quadrupole magnets for transport

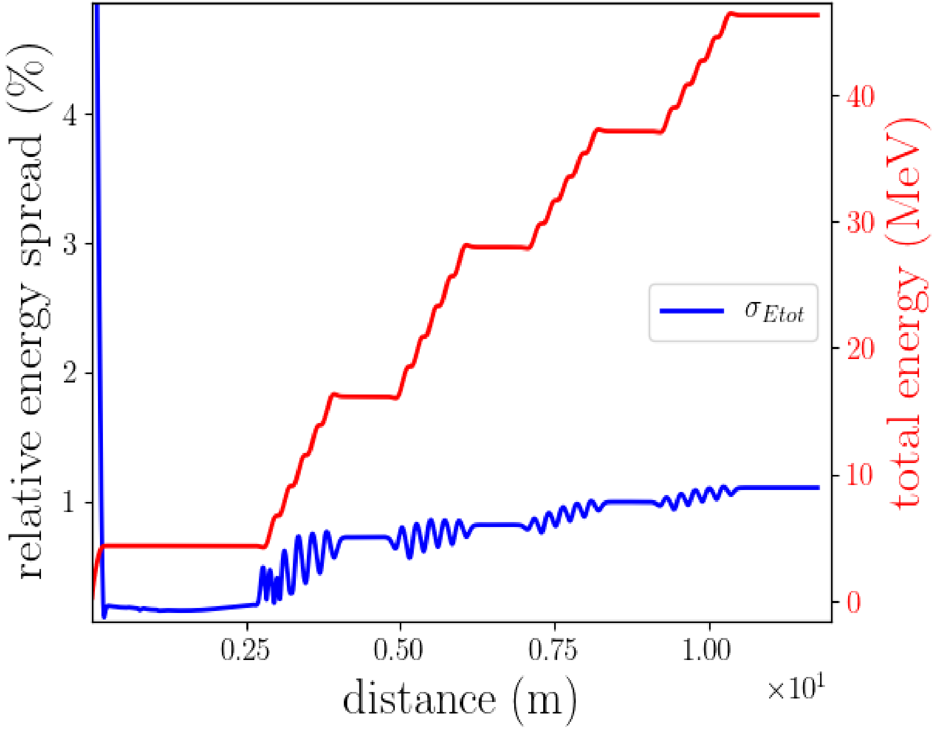


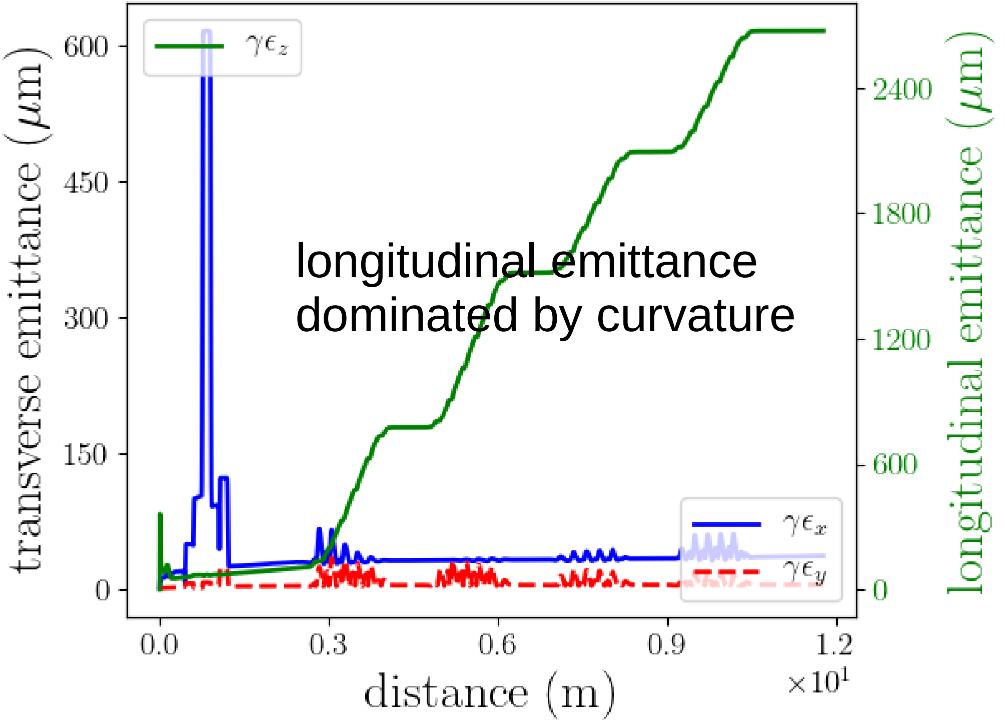
- Consider a 200+650 MHz:
  - 200 MHz WiFEL RF gun (to be tested at ANL)
  - 650 MHZ PIP-II cavity (modified for $\beta = 1$)



EXAMPLE OF RESULTS AT 3.2 NC

RMS longitudinal beam parameters

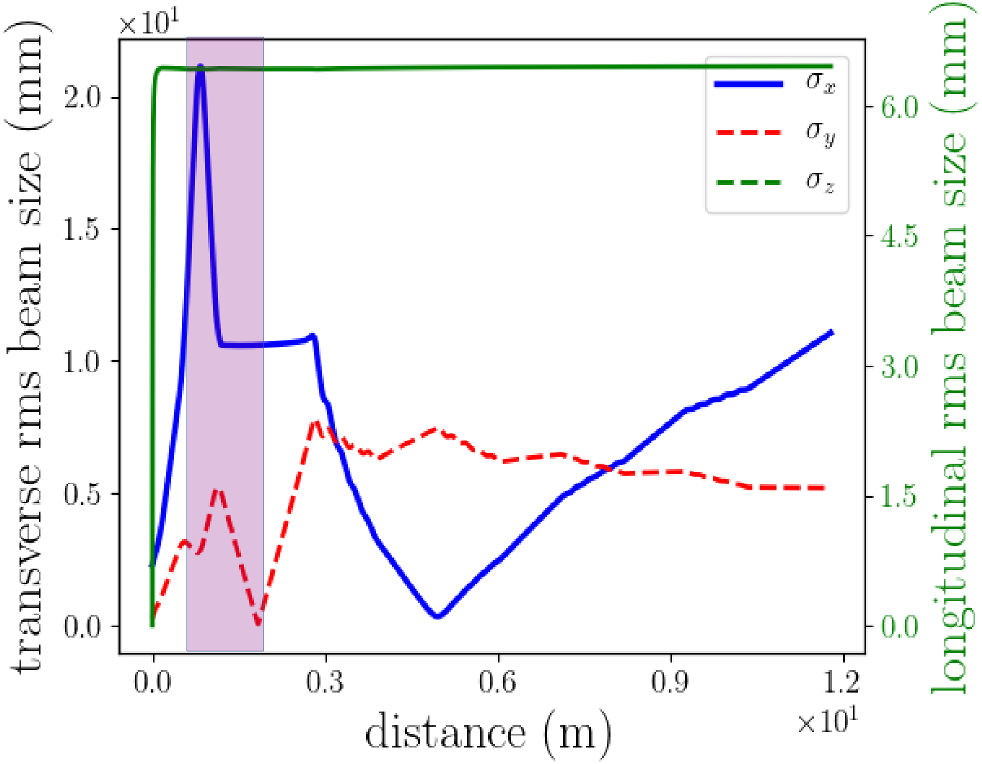


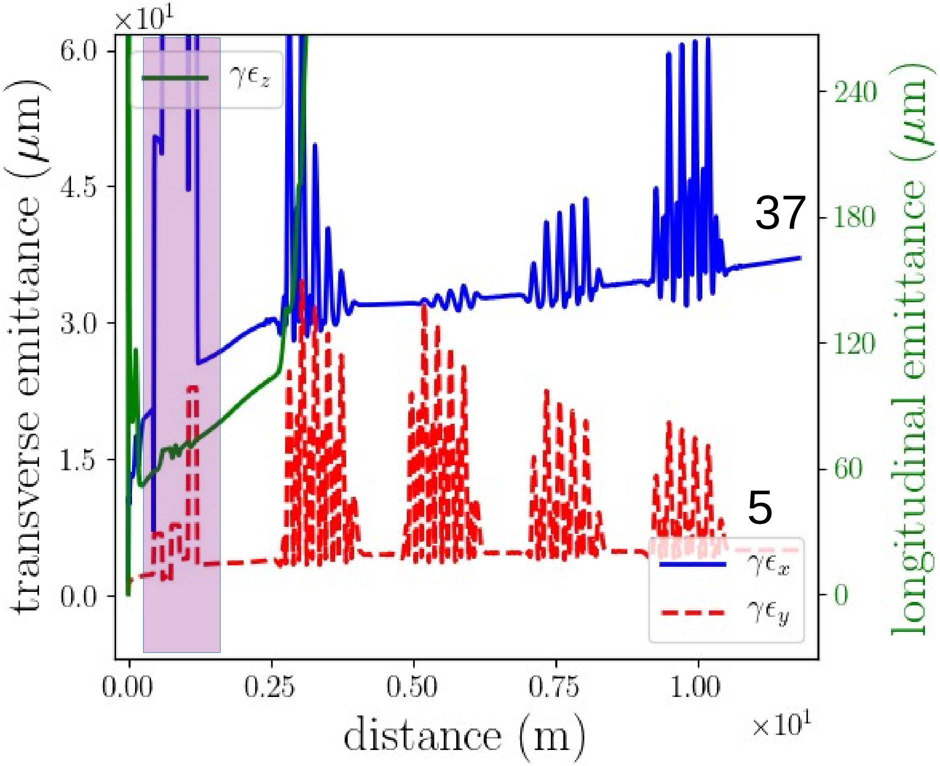


EXAMPLE OF RESULTS AT 3.2 NC

RMS transverse beam parameters

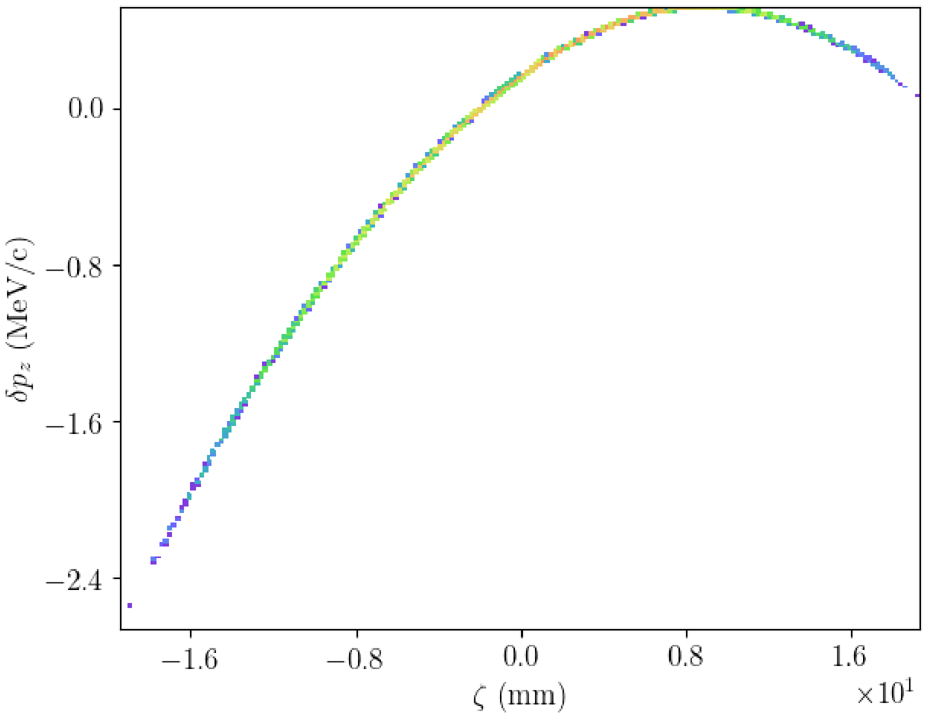
$$\varrho \equiv \frac{\varepsilon_+}{\varepsilon_-} > 7$$

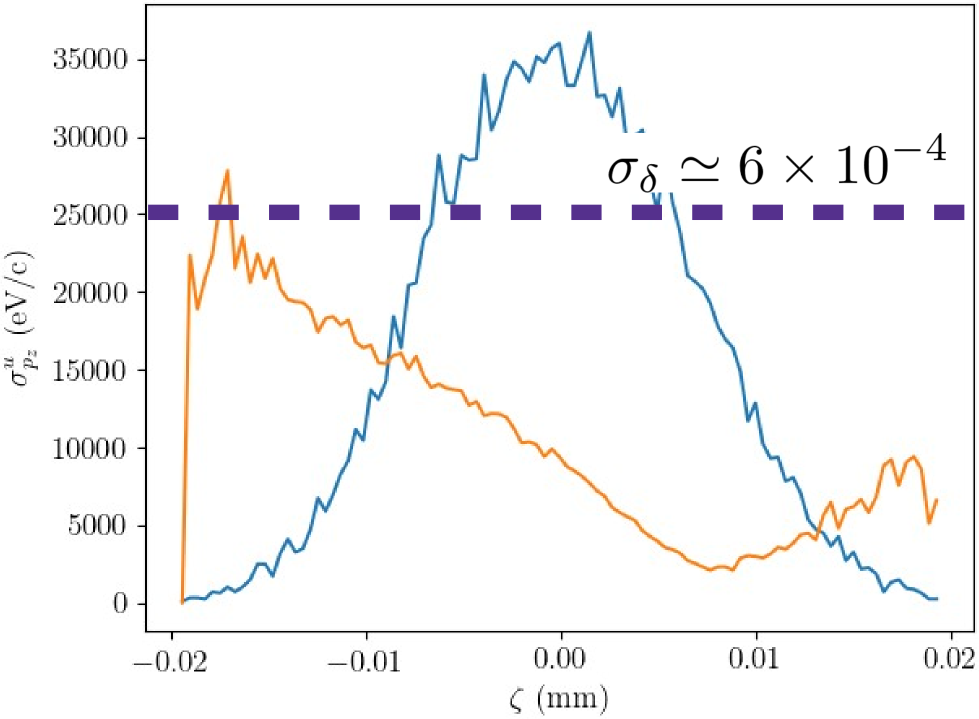




EXAMPLE OF RESULTS AT 3.2 NC

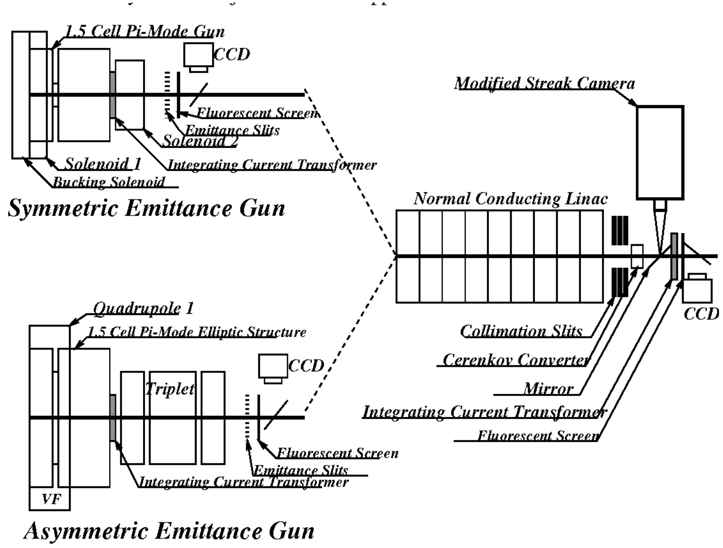
LPS and slice energy spread





COMMENTS & FUTURE WORK

- These simulations are encouraging: required eigen-emittance ratio for the JLEIC electron cooler is easily satisfied
- Results should be taken with a grain of salt: assumed SRF gun performances (E=40 MV/m on cathode) have not been demonstrated in a low-frequency SRF gun (a related program has recently been initiated at ANL with support from BES)
- Still some work:
  - Implement the flat to round converter (so far issue with large correlated energy spread),
  - Longitudinal-phase-space linearizer
  - The inline injector modeled so far is not realistic (need a merger with bending magnets…)
- Possible using an asymmetric cavity
- Nevertheless results obtained so far are encouraging...



E. Colby, et al. AIP Conference Proceedings 335, 708 (1995);

QUESTION?