Optimizing Injection Into ERLs:

Space charge, CSR, and optimal energy

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Overview of Talk (and some caveats)

Based on our design efforts with LUX, I was asked to speak on the following topics for ERLs

Optimal Merger Energy **Space charge** **CSR**

This may still happen, but . . .

•The injector design process is part of the larger LUX machine study.

•LUX is a concept for high-brightness x-ray source, with very low average currents (10's μAmps).

•Some of our choices were driven by very different constraints.

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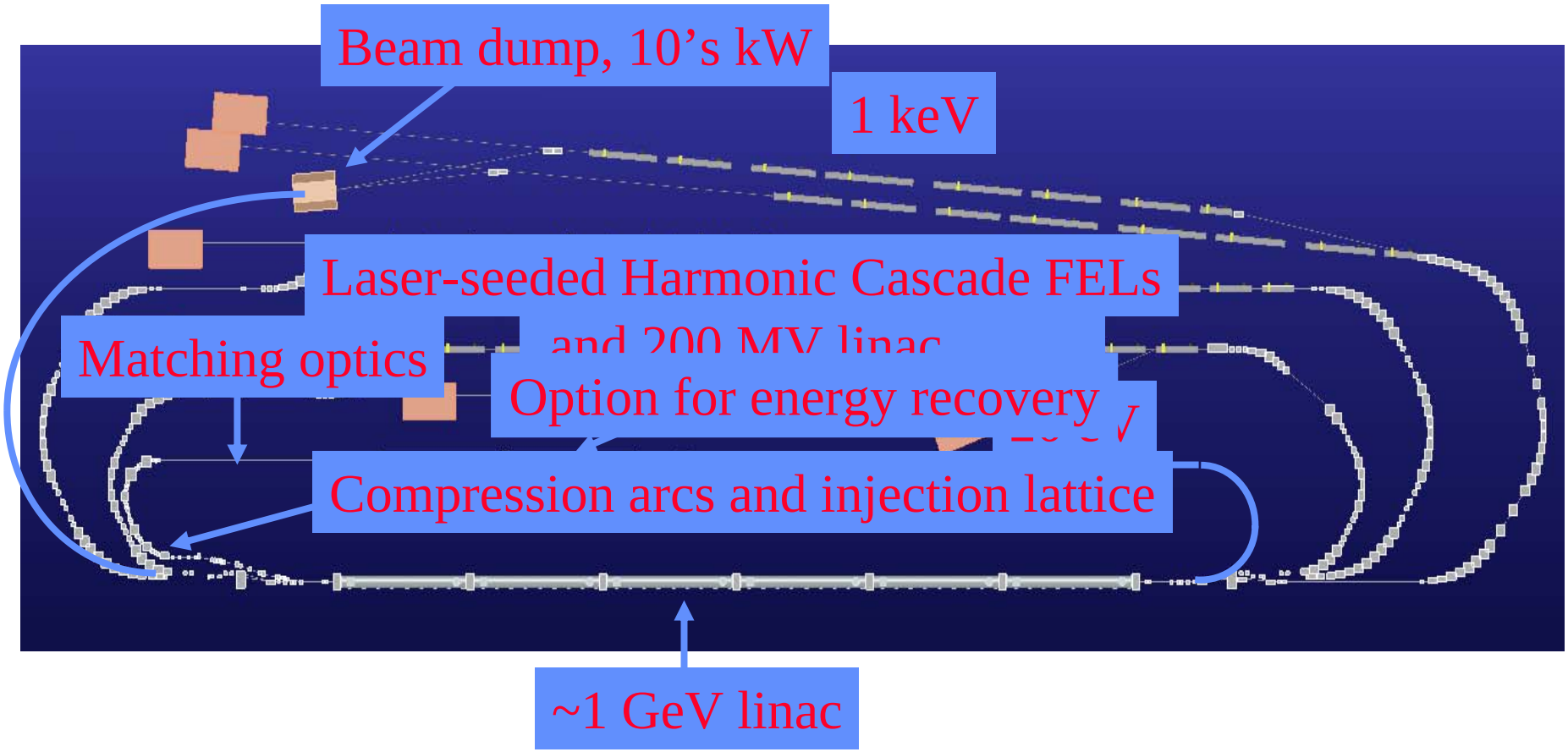
Overview of LUX Project



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Injector Requirements

Energy at rf gun exit	~ 10	MeV
Energy at compressor entrance	~ 185	MeV
Bunch charge	1-3	nC
Flat beam injector (1 nC):		
Horizontal emittance	~ 20	mm-mrad
Vertical emittance	< 0.4	mm-mrad
Total emittance	< 3	mm-mrad
Round beam injector (1 nC):		
Emittance	< 2	mm-mrad
Uncorrelated energy spread (rms)	± 3	keV
Correlated energy chirp	± 600	keV
Bunch length at compressor entrance	~ 35	ps
Bunch length at compressor exit	4	ps
Repetition rate	~ 10+	kHz

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Strategy for Matching into ERL

- **Optimize injector parameters and transport to first arc**
- **Optimize arc parameters for injection into linac**
- **Match beams at arc entrance**
- **Linac lattice symmetrized to allow for possible energy recovery**

CSR induced emittance growth is controlled in compressor and injection into linac:

$$H = \beta D'^2 + 2\alpha D'D + (1/\beta + \alpha)D^2$$

$$\Delta\varepsilon \sim H\,\delta E$$

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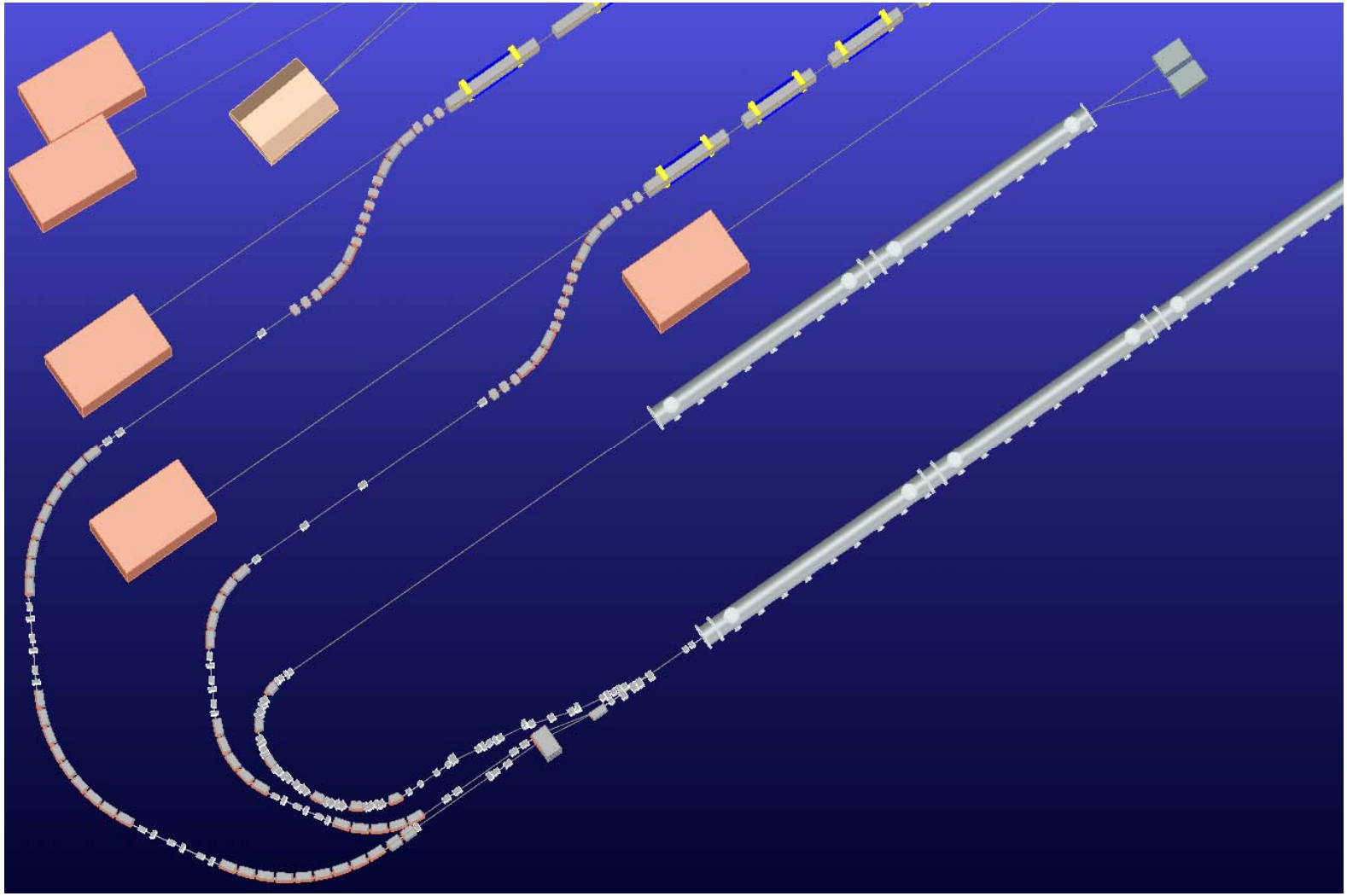
Optical Matching from Injector to Linac



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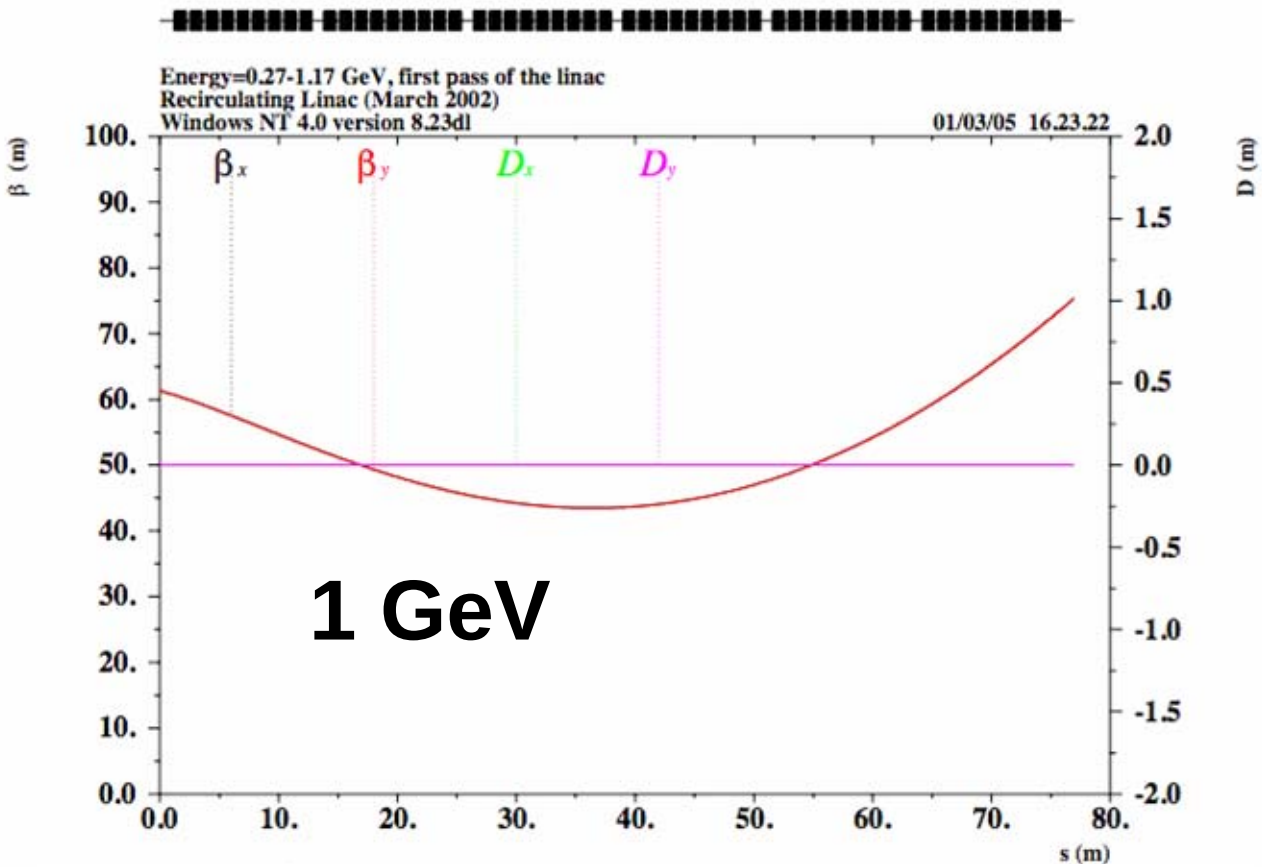
ERL Beta Functions



RF focusing on first pass

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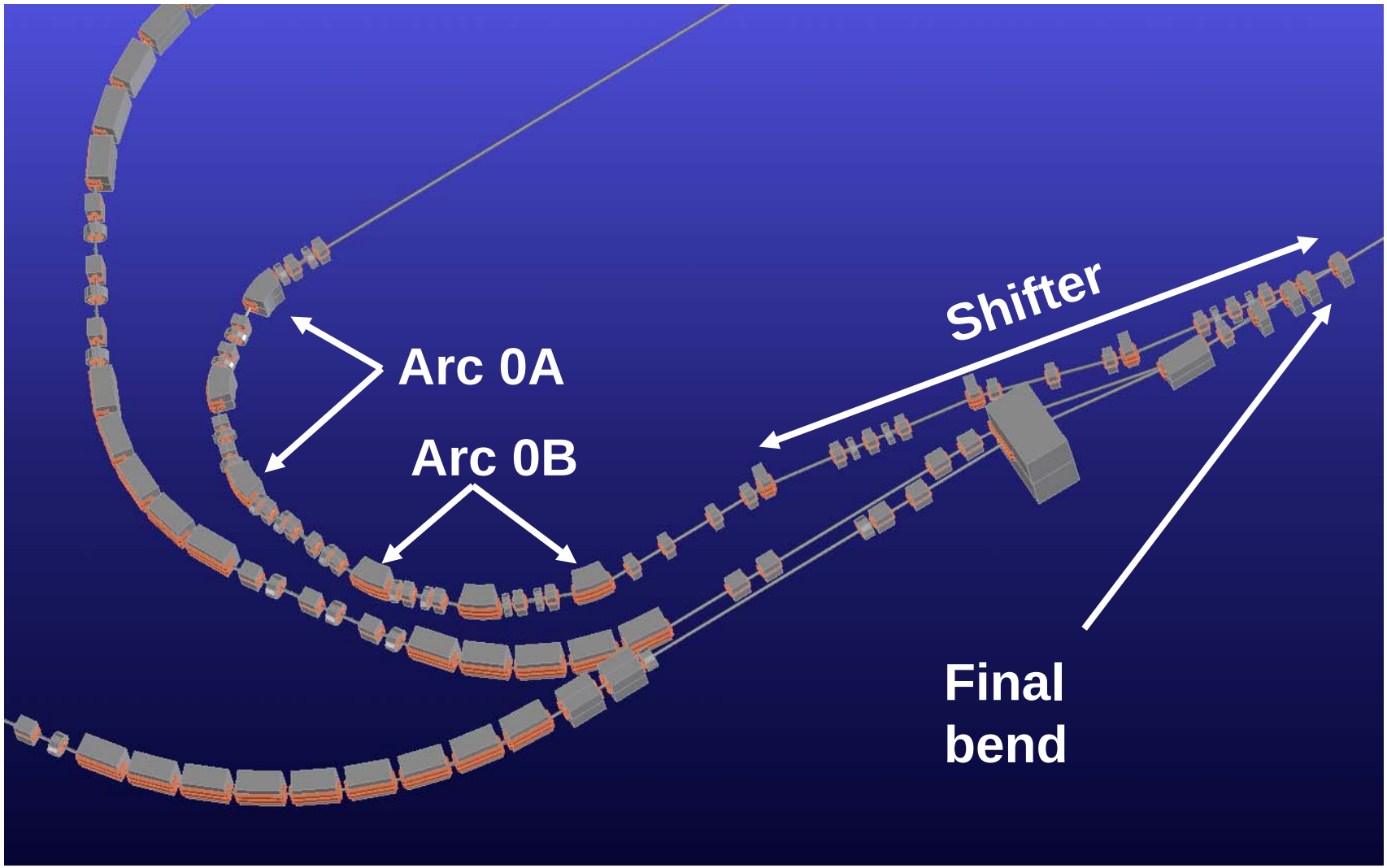
Magnet layout at ERL entrance



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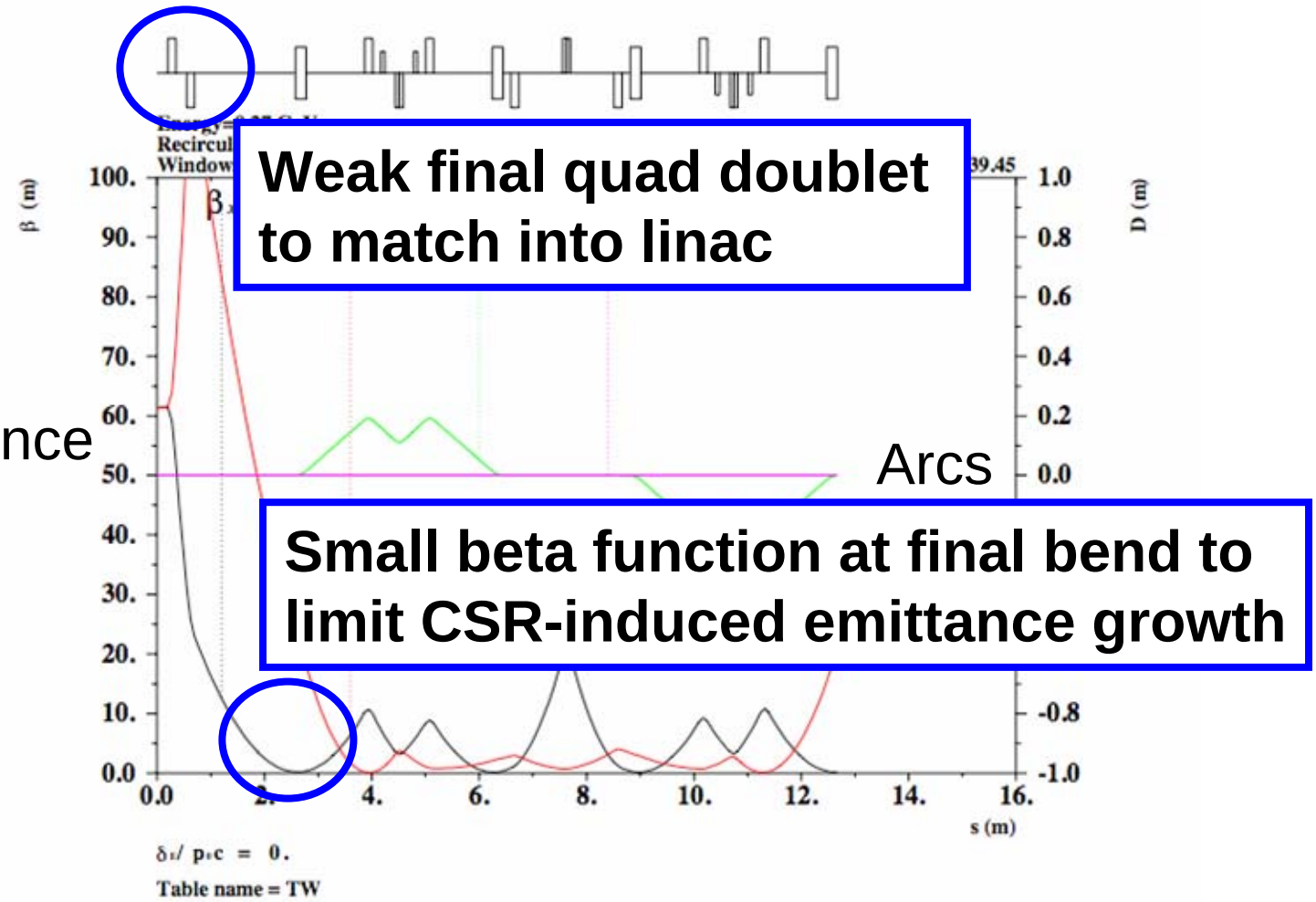
Matching into Shifter



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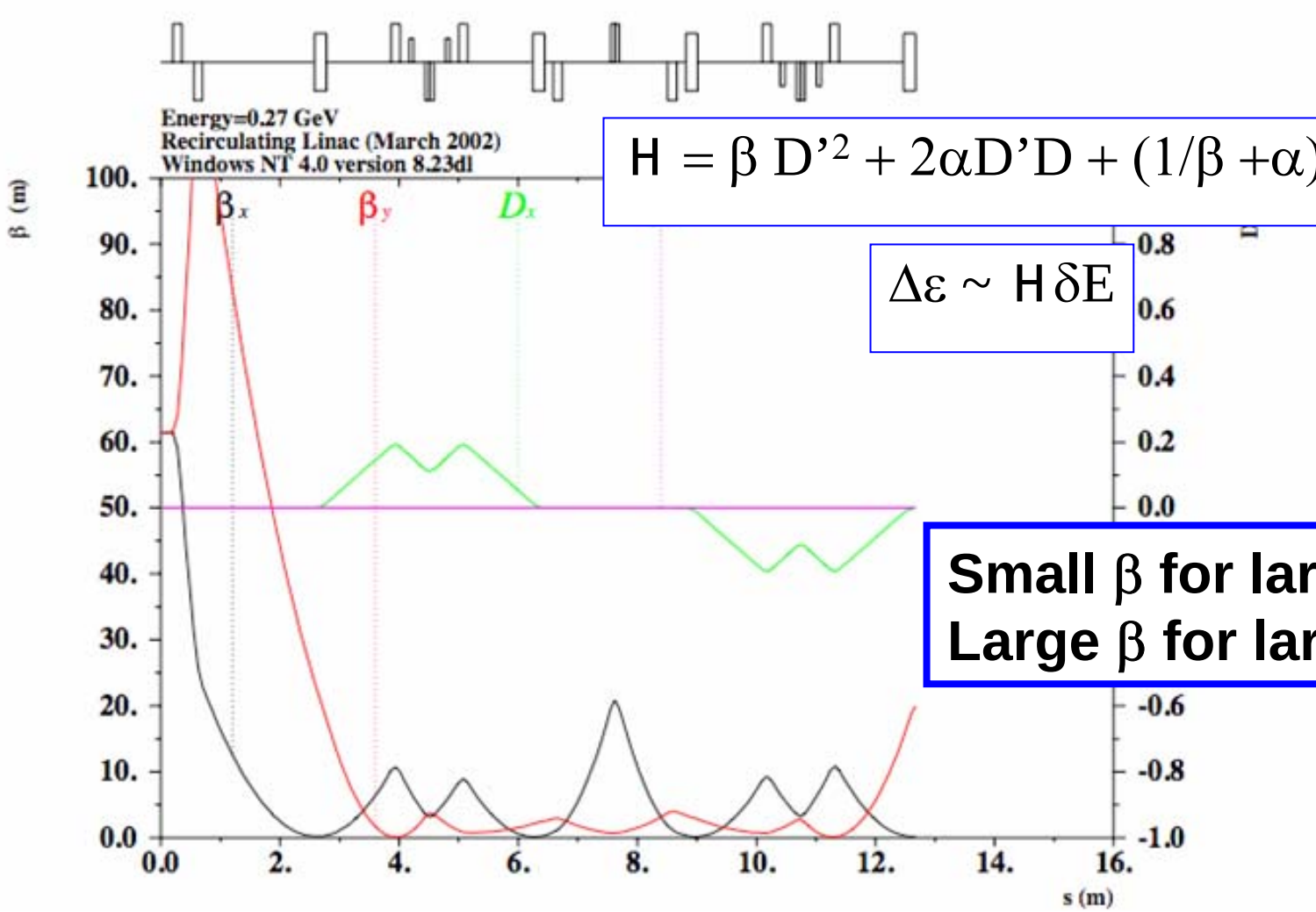
Limiting CSR emittance growth in Shifter



$$H = \beta D'^2 + 2\alpha D'D + (1/\beta + \alpha)D^2$$

$$\Delta\varepsilon \sim H\,\delta E$$

Small β for large D'
Large β for large D

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Optimization of Arcs

The design is largely affected by considerations to limit CSR-induced emittance growth:

- **–The bunch compressor is split into 2 parts linked by -I transform (approximately)**
- **–Use CSR kicks in downstream compressor to compensate for CSR kicks upstream**
- **–De-symmetrize the two compressor arcs**
  - **Stronger dipoles in 1st arc -> 108° turn**
    - **longer bunch -> weaker CSR**
  - **Weaker dipoles in 2nd arc-> 72° turn**
    - **shorter bunch -> stronger CSR**

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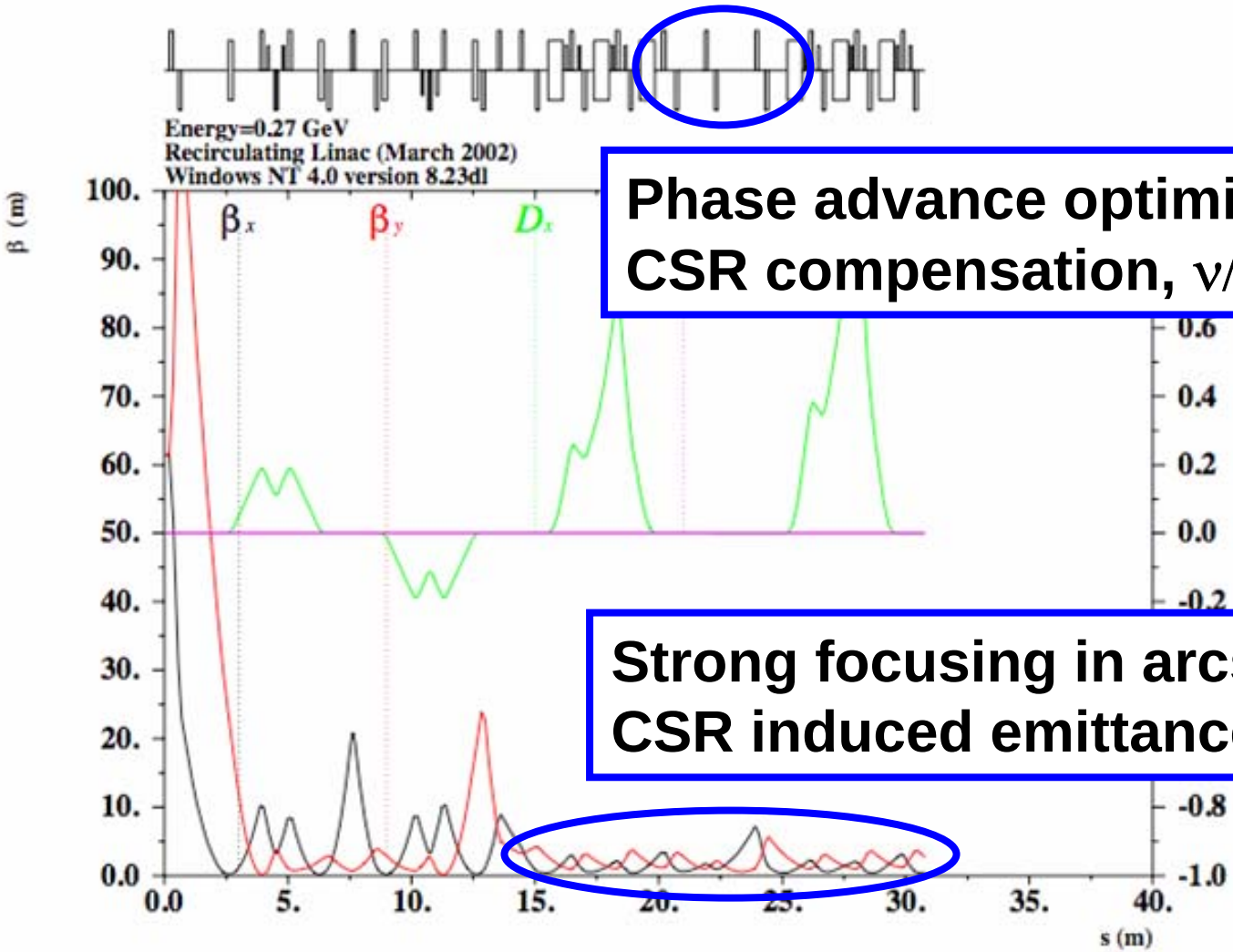
Entire Arc and Shifter Beamline



Phase advance optimized for CSR compensation, $\nu/2\pi$ =-0.8

Strong focusing in arcs to limit CSR induced emittance growth

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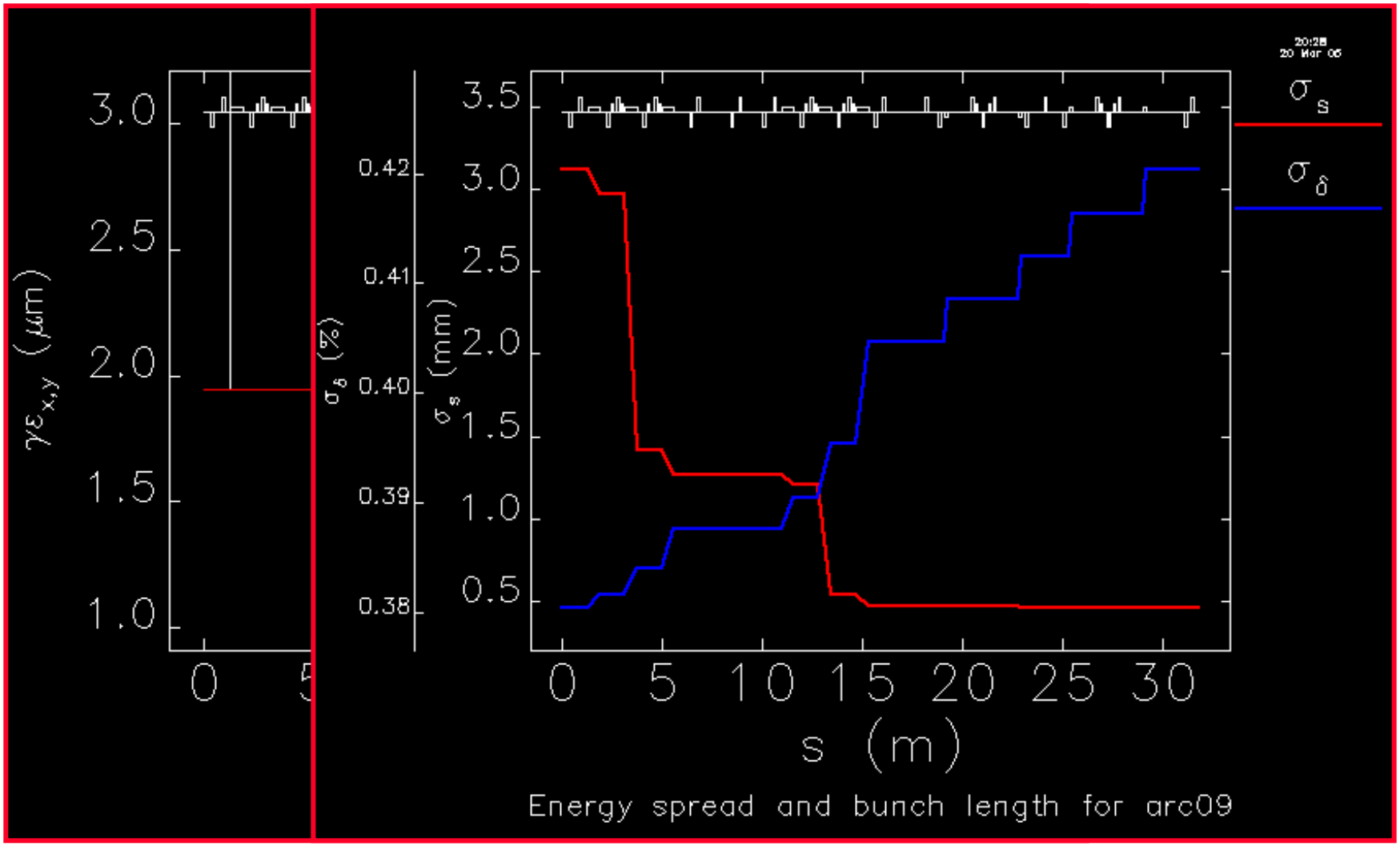
Emittance and Energy Spread



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Optimization of Injector Linac and Optics

- **Space charge forces reduced by extending pulse length to 35ps**
- **Accelerate to ~200 MeV to remove space charge effects before compression**
- **Linearize longitudinal phase space before compression**
- **Provide skew quad lattice to create flat beam from magnetized cathode, while limiting asymmetry in beam from unmagnetized cathode**
- **Provide normal quad lattice to match to arc Twiss parameters**
  - **Some quads are pulsed to switch between round and flat beams**

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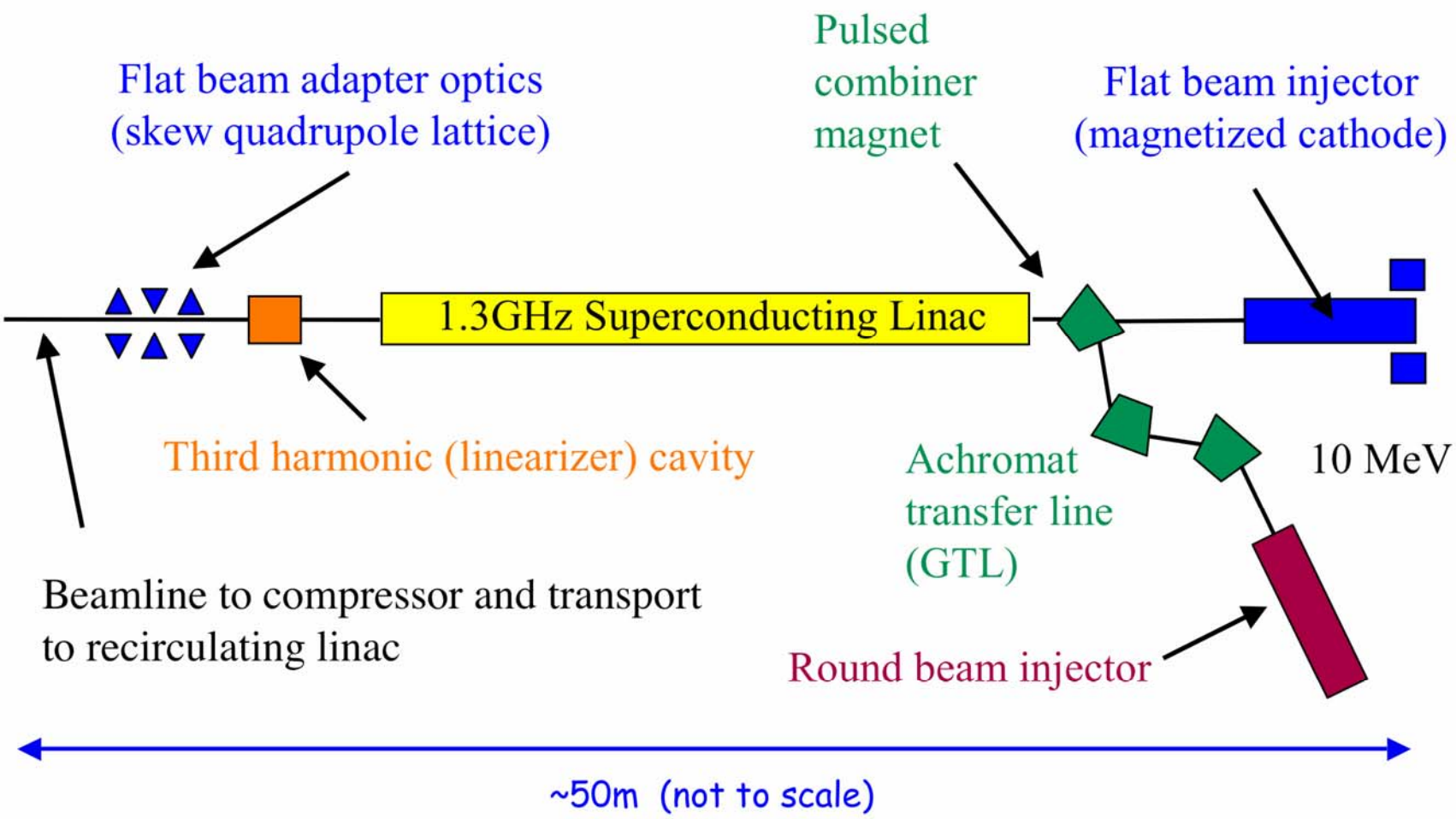
Injector Overview



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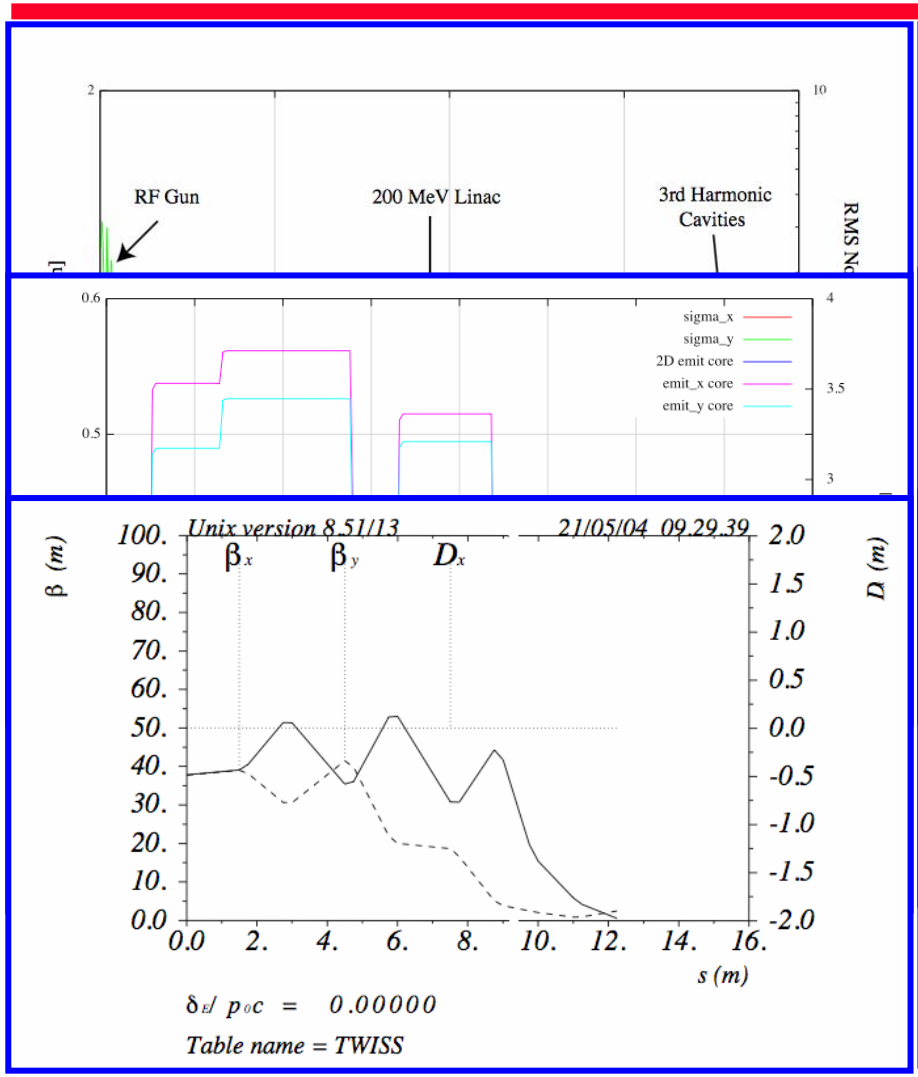
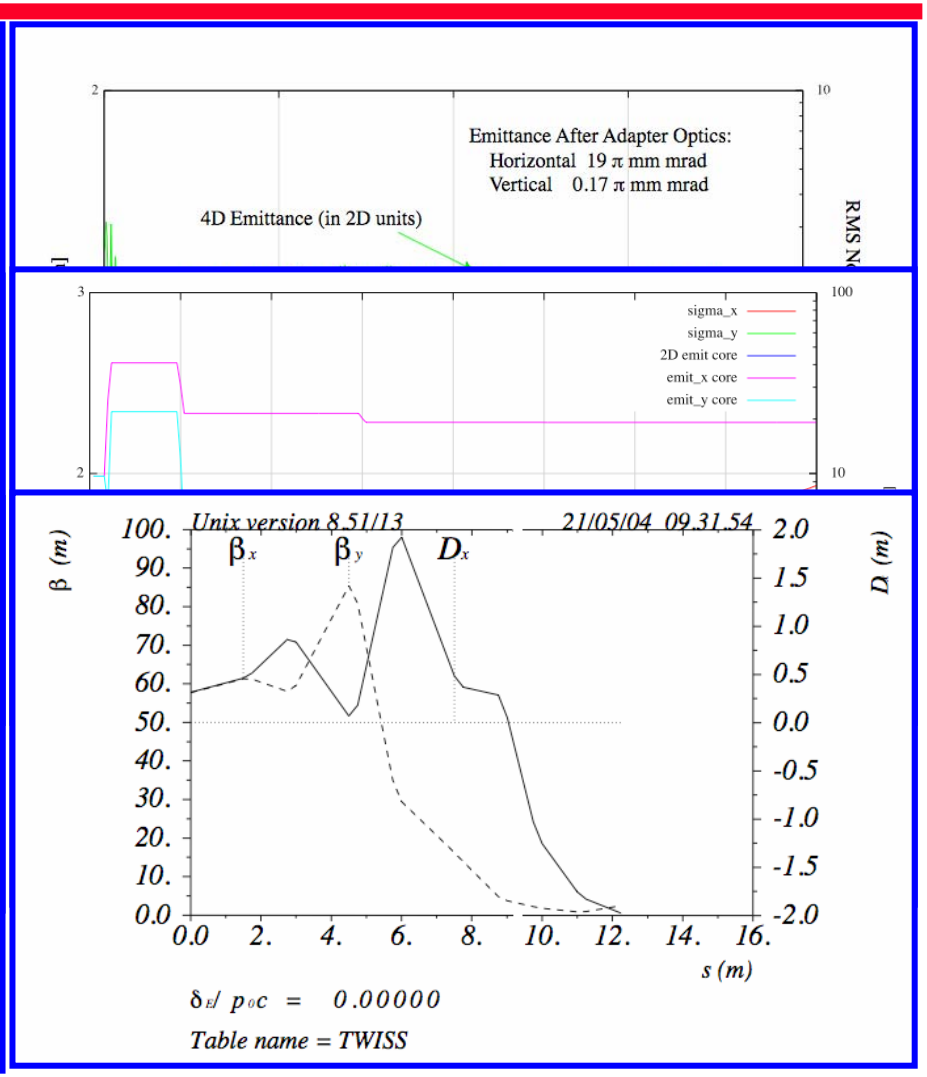
Injector Transverse Beam Dynamics





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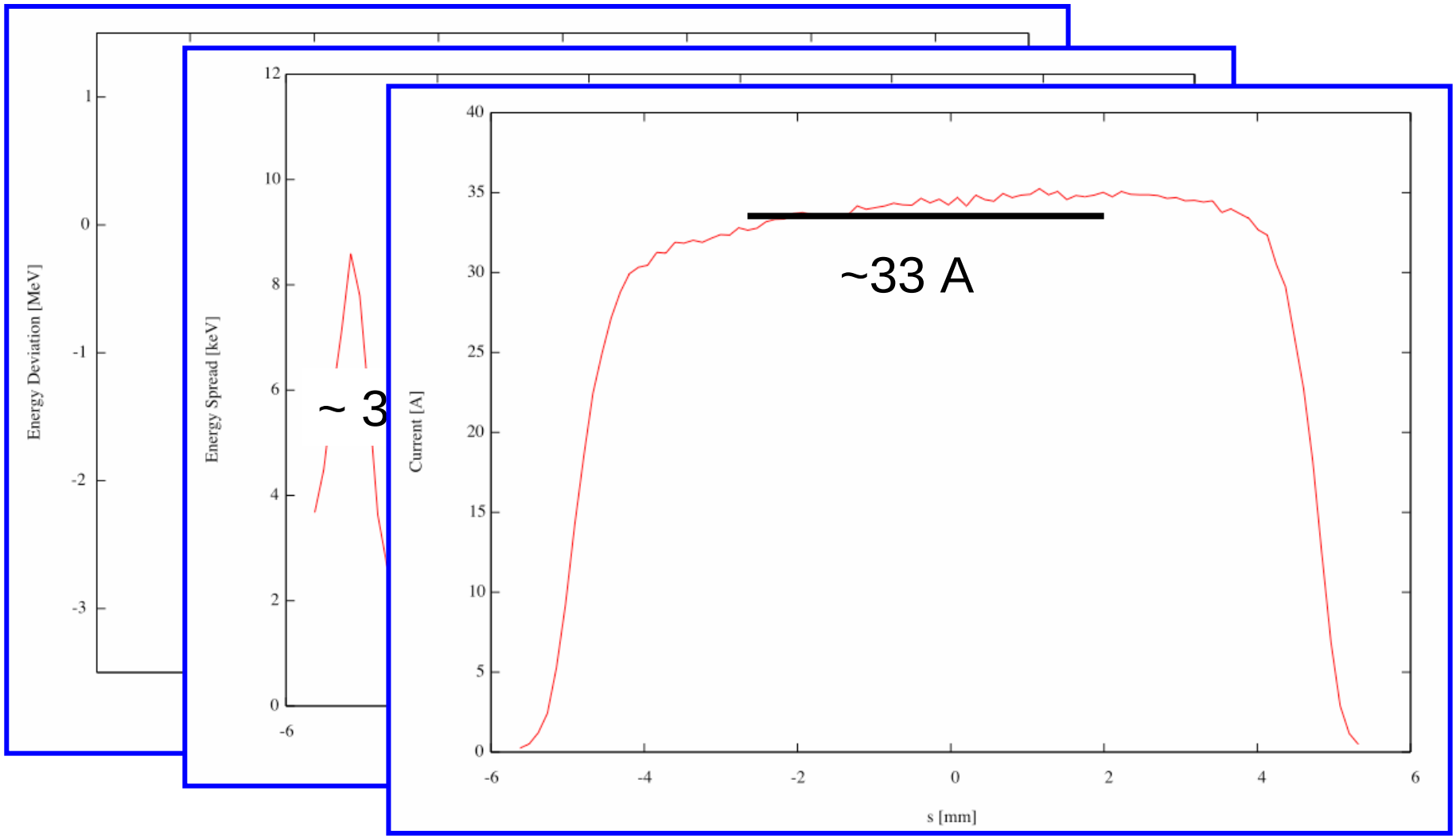
Injector Longitudinal Beam Dynamics



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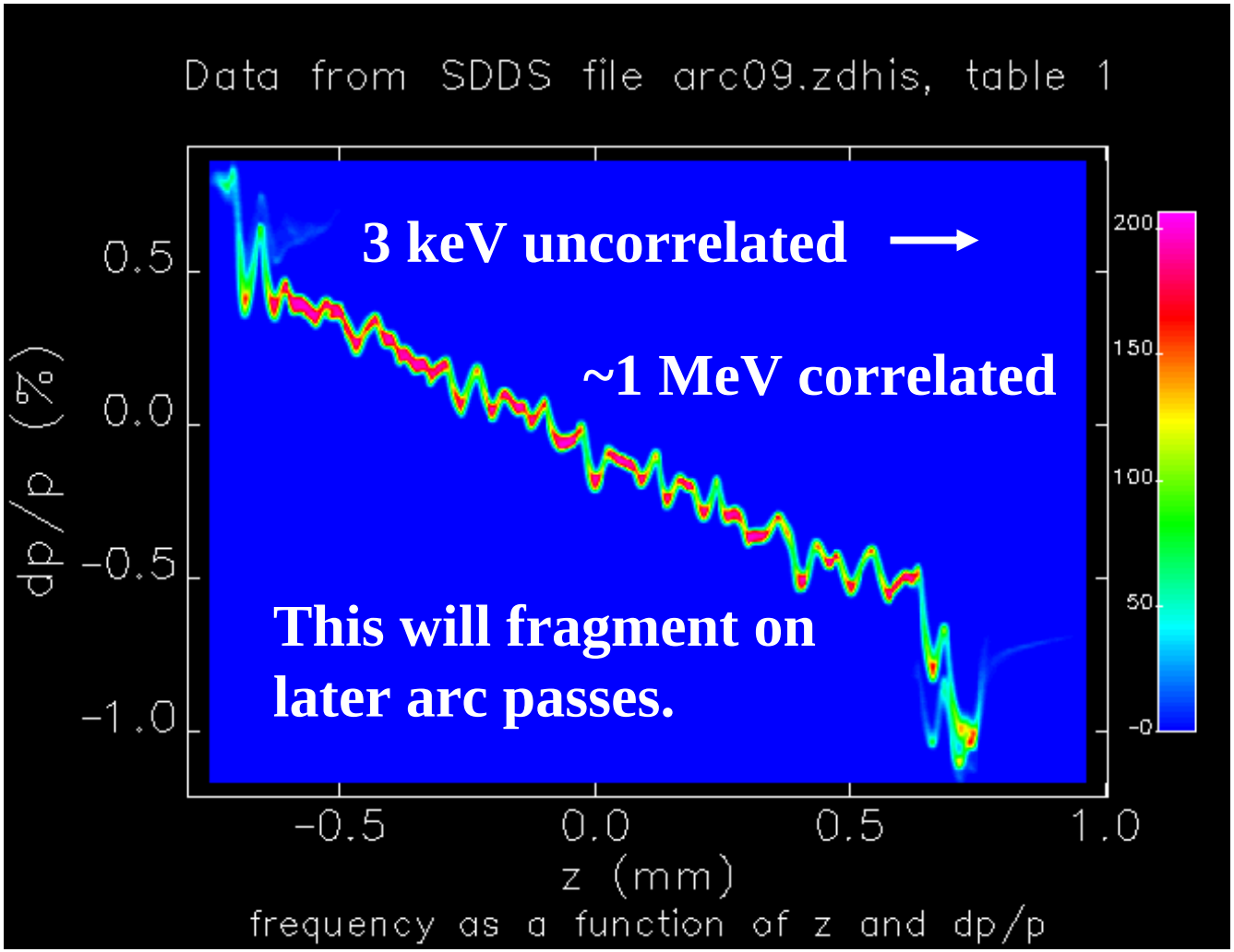
Transport of low energy spread beam in arcs



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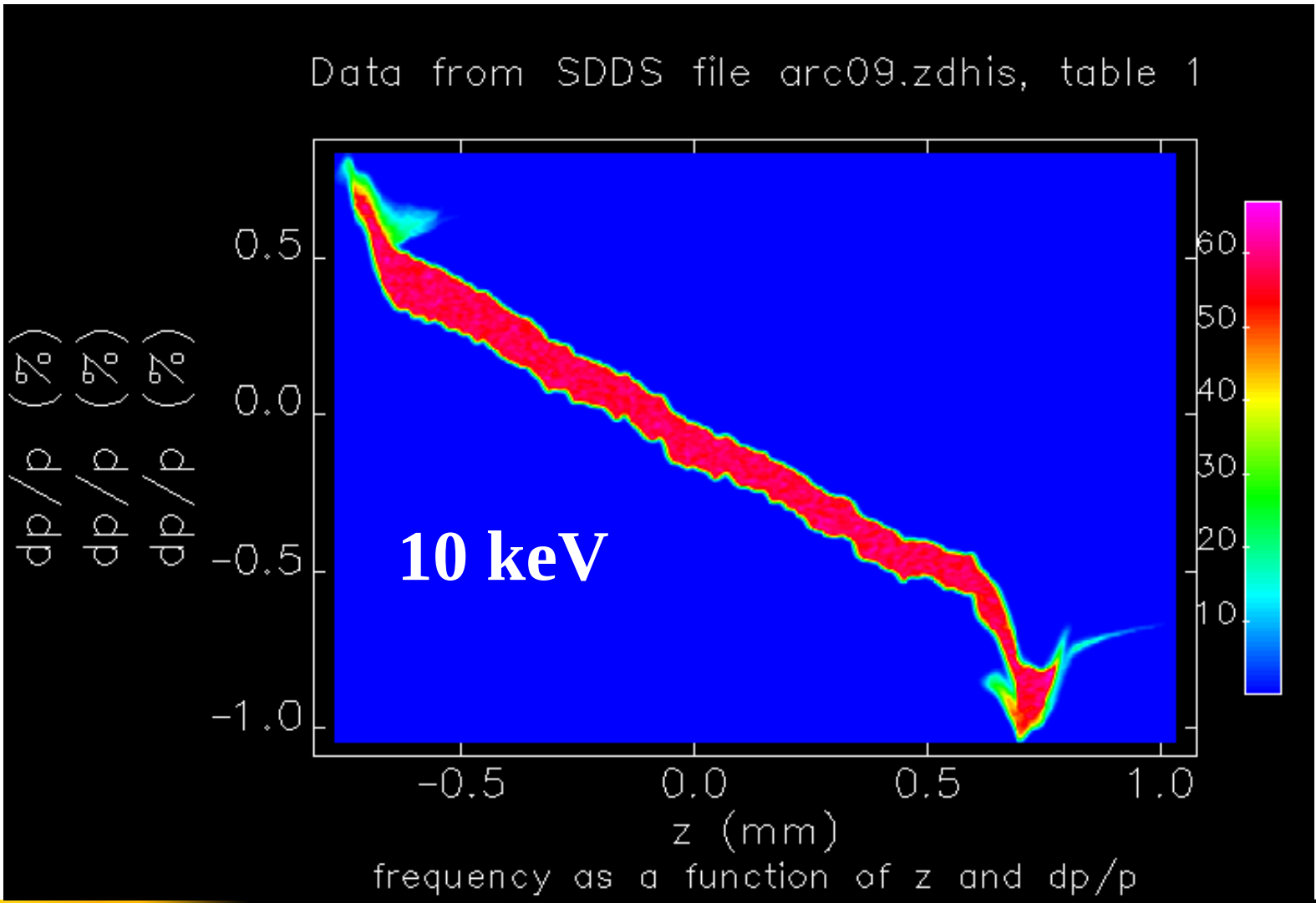
Transport of heated beam in arcs



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Conclusions

- **Optimal energy is linked to reducing space charge effects in the compressor**
- **CSR induced emittance growth and longitudinal instabilities considerations dominate the design of the arcs and injection lattice**
- **Slice energy spread from the photoinjector beam is too small to prevent longitudinal instability growth**
- **Laser 'heating' techniques are useful to introduce a correlated energy spread at high frequency that acts as an uncorrelated spread at frequencies with large gain in the longitudinal CSR instability.**

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