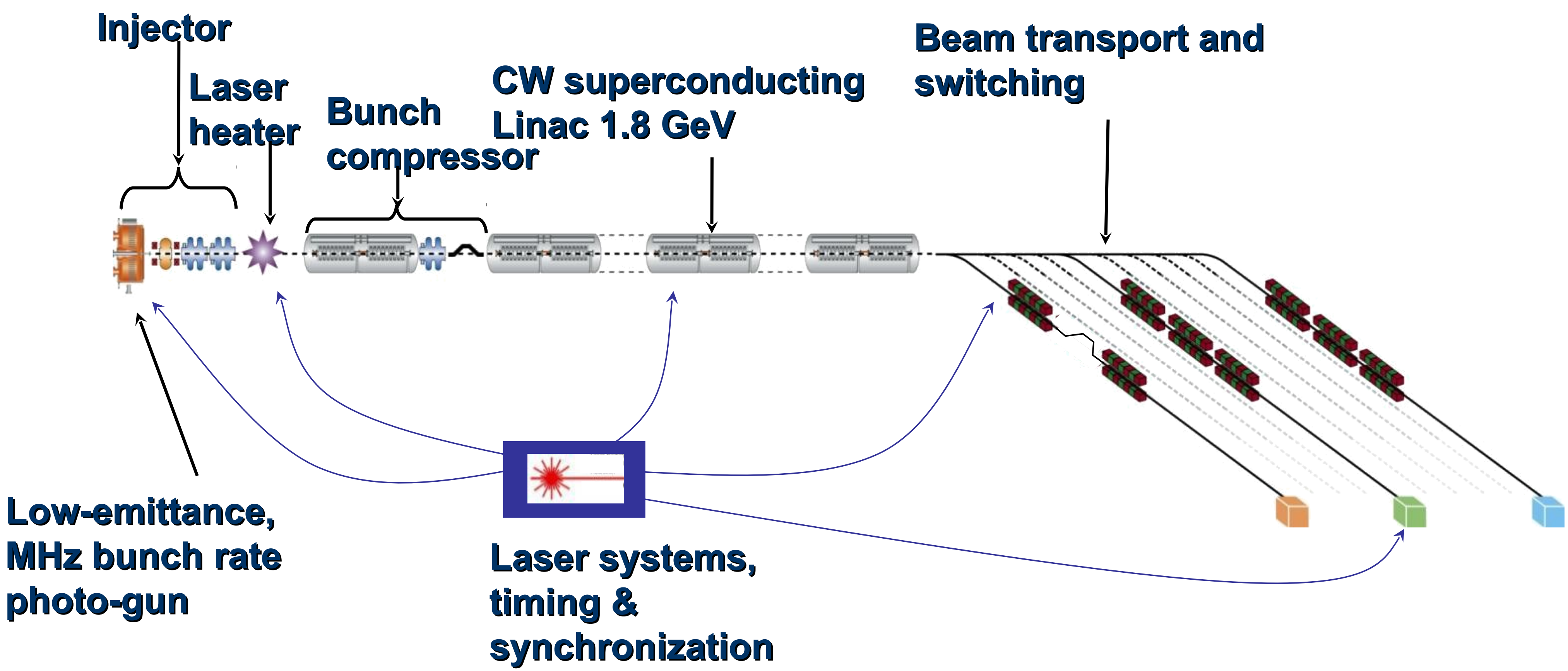
Injector Beam Dynamics for a Next Generation Light Source

Christos Papadopoulos
Erice 2011

Linear Accelerator for FEL



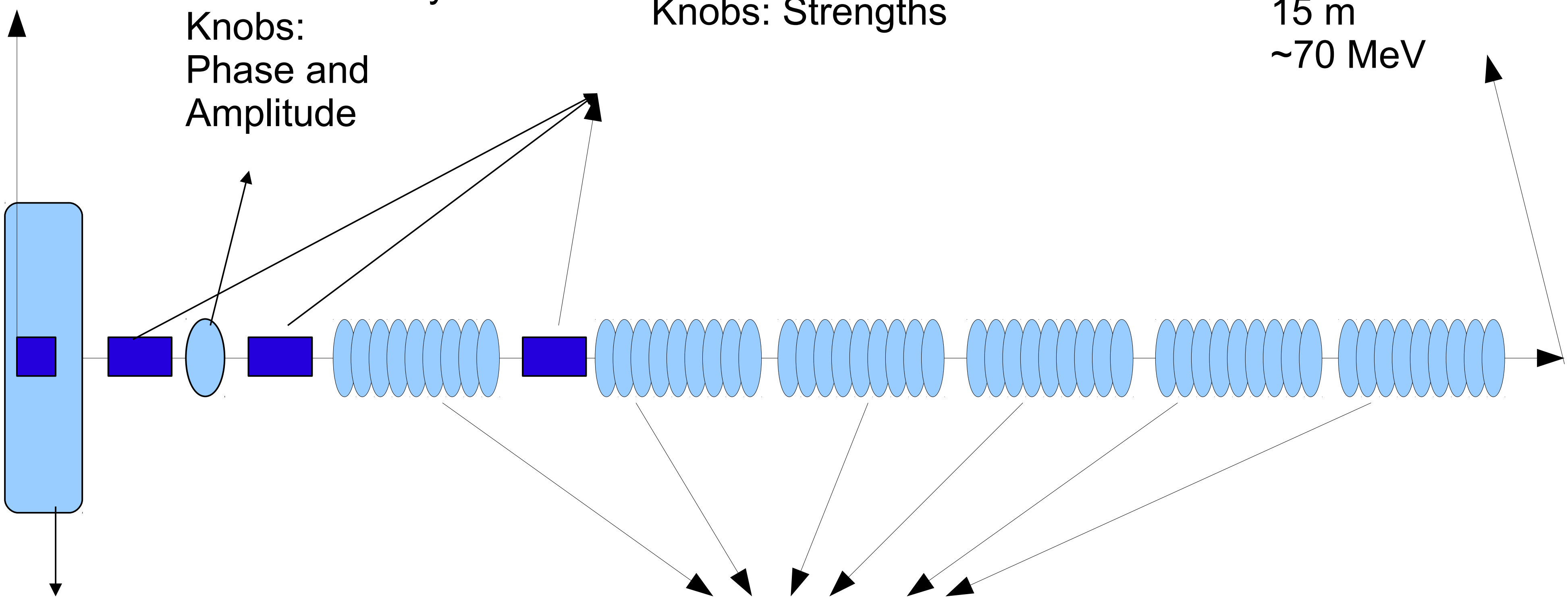
FEL Requirements

Parameter	Value at injector	Value at FEL
Energy	70 MeV	1.8 GeV
Peak Current	50 A	500 A
Slice normalized transverse emittance	<0.6 μm	0.6 μm
Slice energy spread	<5 keV	50 keV
Bunch Charge	300 pC	300 pC

Low emittance and energy spread: required by the FEL process
Relatively high charge: determined by bunch length, peak current and shot-to-shot jitter

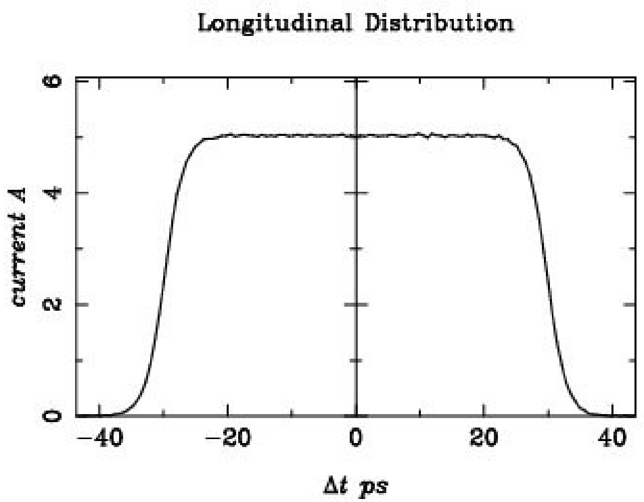
G. Penn
M. Venturini,
Ji Qiang
A. Zholents

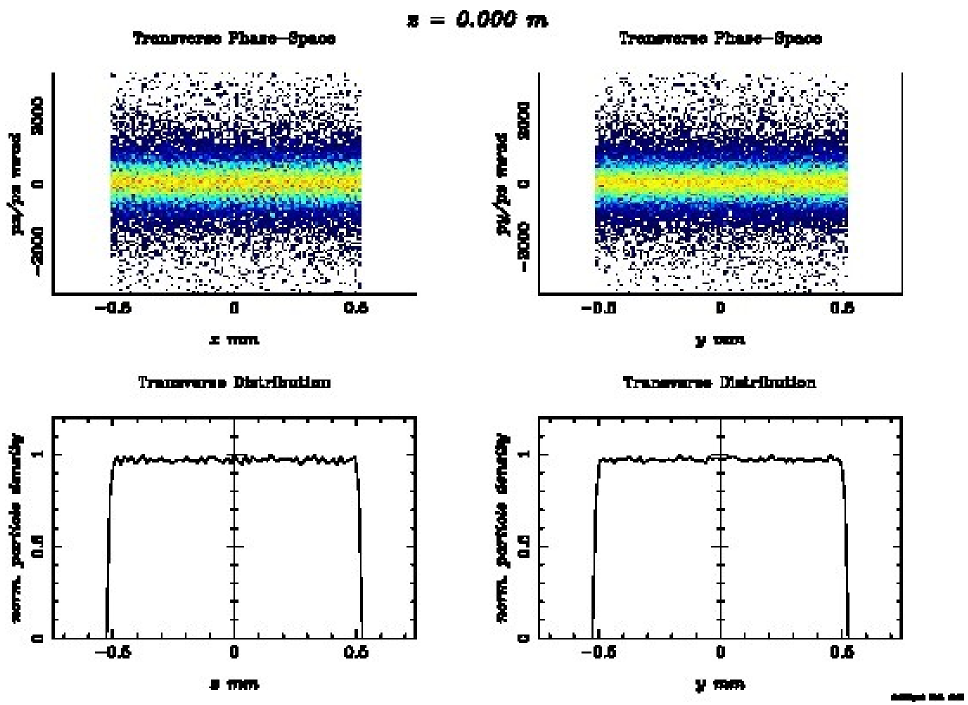
Injector Design



Knobs: Initial trans. and long. beam size

- Initial normalized emittance: 1 mrad*σ, from Cs2Te measurements (Miltchev et al, 2005)
- Peak field at the cathode is determined by the VHF Gun geometry (~19.5 MeV/m)
- Larger trans. size → larger emittance, lower space charge
- Larger long. size → longer pulse length, lower space charge



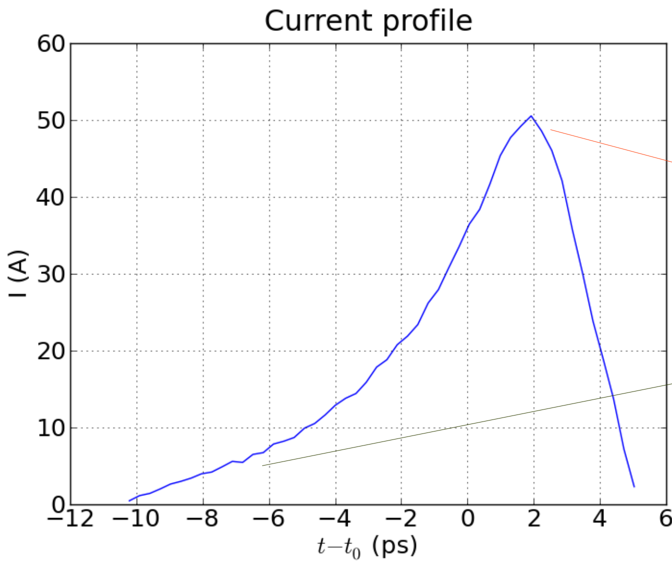


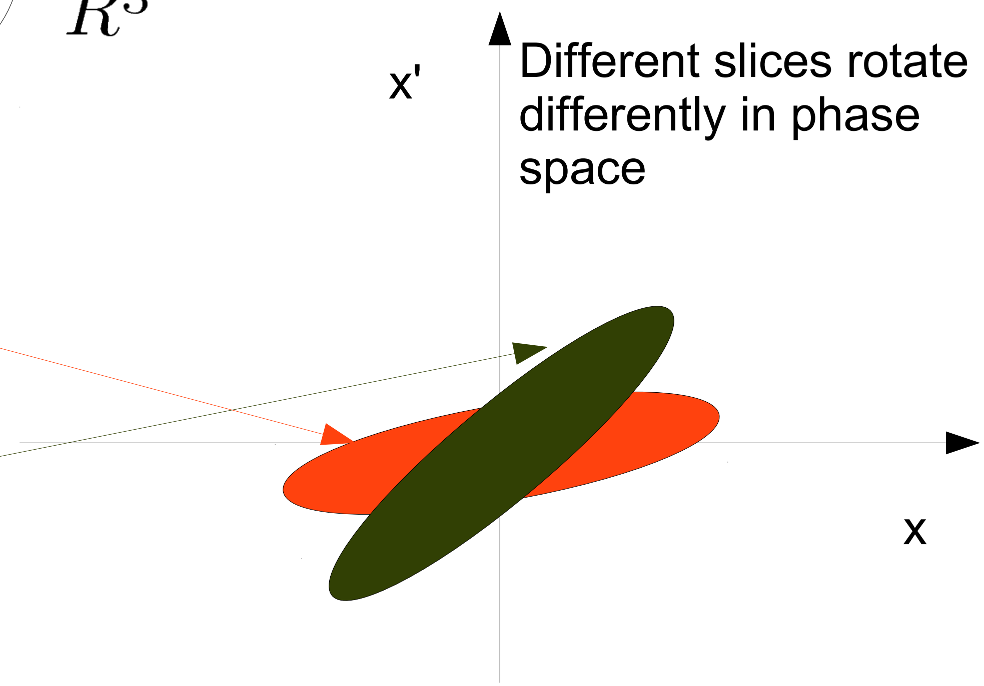
Knobs: Solenoids for emittance compensation

Sol. focusing

Space charge defocusing

$$R'' + k_0^2 R - \frac{2I}{I_0(\beta\gamma)^3}\frac{1}{R} - \frac{\epsilon^2}{R^3} = 0$$



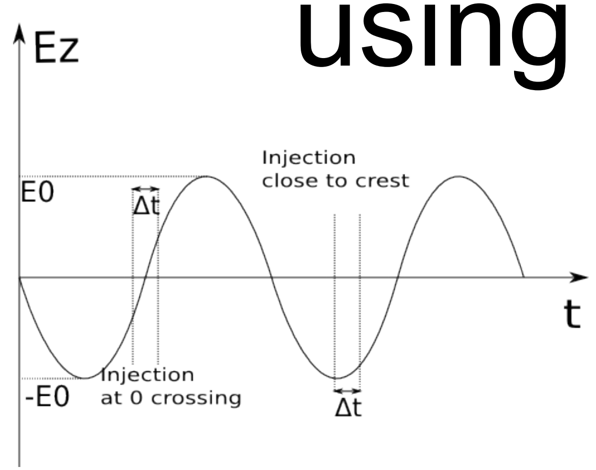


Different slices rotate differently in phase space

The trick is to align the ellipses, then accelerate as fast as possible

Carlsten 1996
Serafini, Rosenzweig 1997

Knobs: Bunch compression using velocity bunching



Increase the energy of the tail relatively to the head → velocity differential will lead to compression
Efficient only at low energies: $\Delta\beta \sim \Delta\gamma/\gamma^3$

Using a single cell cavity at 0 crossing:

- Symmetric
- No acceleration

Dephasing an accelerating cavity:

- Asymmetric (long tails)
- Accelerates at the same time

Ferrario et al 2010

ASTRA Simulations

- Particle-in-Cell code, includes trans. and long. space charge, widely used for photoinjector simulations
- Typical run numbers:
  - 300 pC charge
  - 10k-50k particles
  - Variable step size
  - Variable grid
  - Not enough to resolve microbunching, CSR
  - Good enough for core properties, emittance growth
  - FAST (10 mins-1hr for a single run)

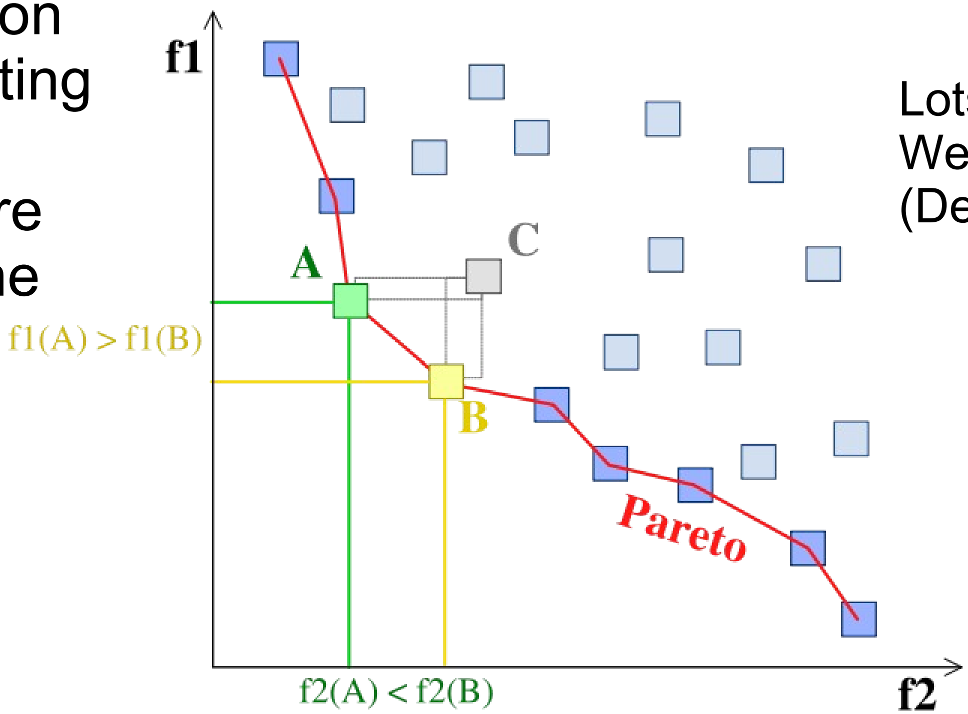
http://www.desy.de/~mpyflo/

Multiobjective Genetic Optimization

The problem:
Find global optimum(s) for a problem with multiple, non-linearly coupled knobs
The solution:
Multi-Objective Genetic Algorithms

Vilfredo Pareto
1848-1923

The result is not a single solution, but a population of solutions approximating a "Pareto front".
 Their relative merits are then evaluated, and one of them is chosen.

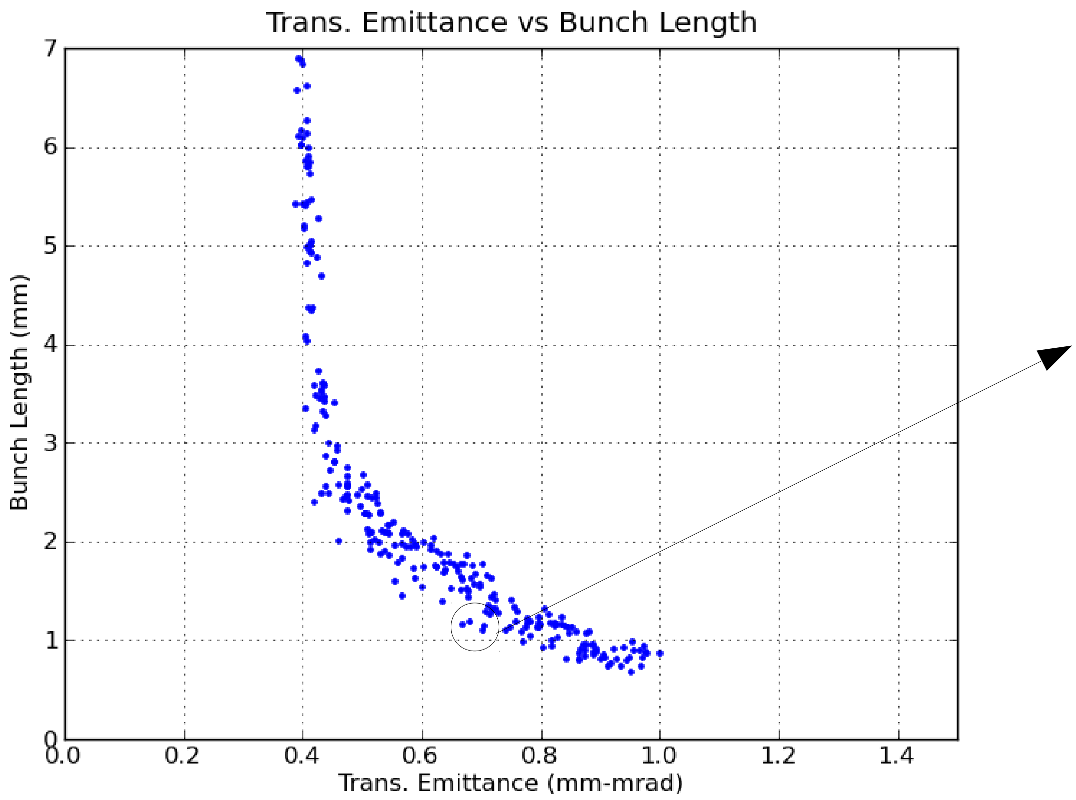


Lots of algorithms.
We use NSGA2
(Deb 2002, Bazarov 2005)

Photos: wikipedia

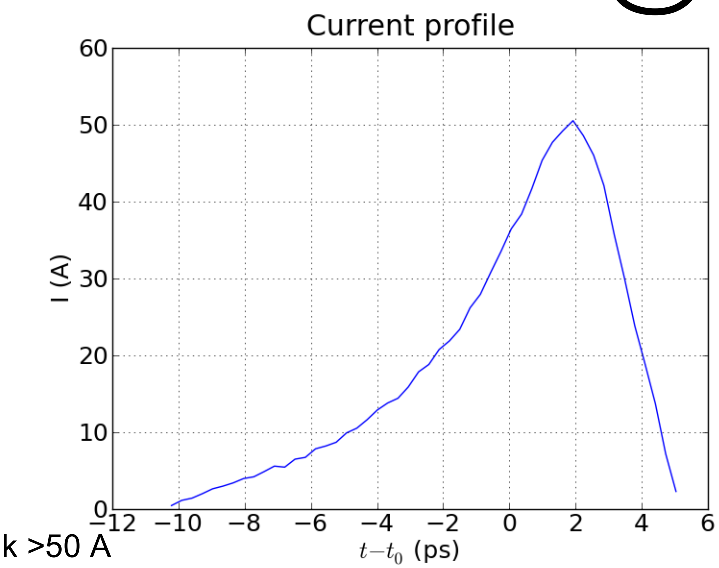
Pareto optimum for εn and σz

Solution Population: 256
After 100s of generations
and days at lawrencium

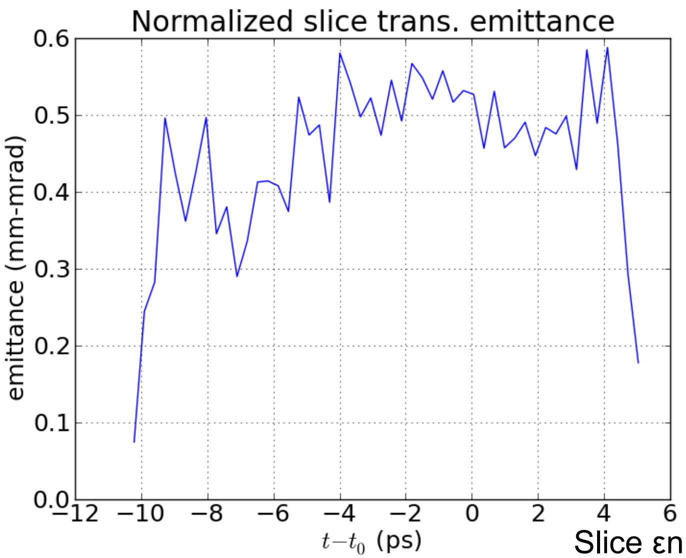


Our chosen solution at the end of the injector (~70 MeV)

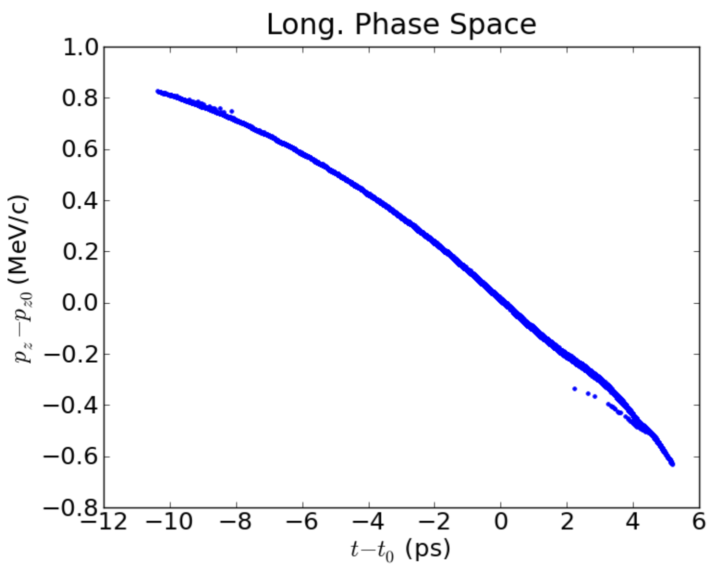
Slice properties of beam @ ~70 MeV

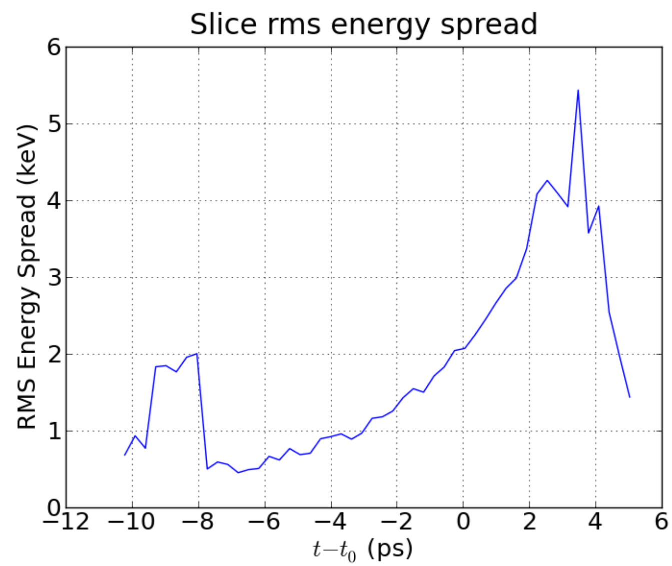


Ipeak >50 A



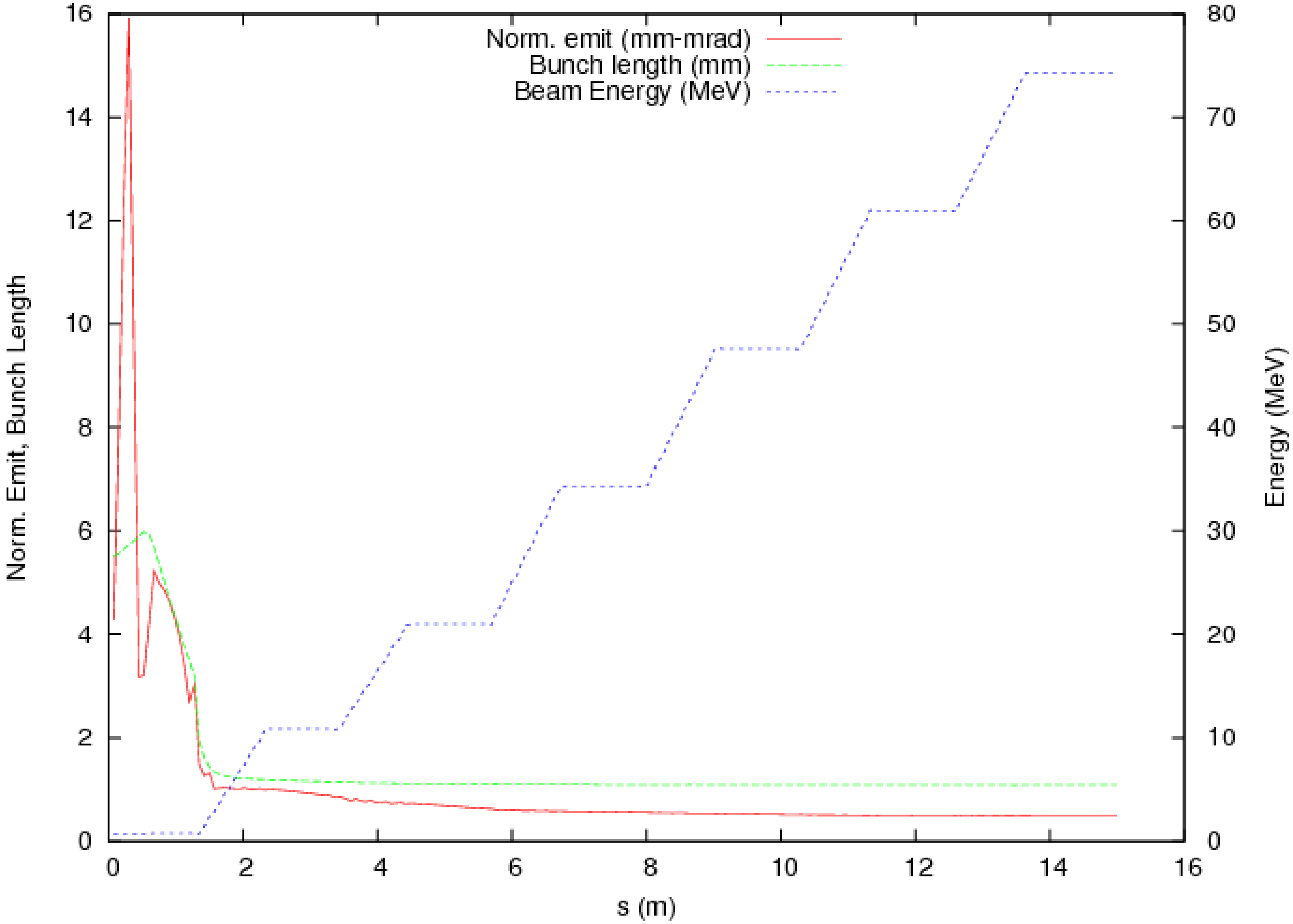
Slice εn < 0.6 μm





ΔE < 4 keV

Beam paremeter evolution



Bunch compression:
Flat

Emit. Compensation:
Still in progress,
but not by much

Conclusions

- Simulations show the low emittance and moderate compression required for the NGLS injector
- The linear and nonlinear space charge forces are significant but under control
- A genetic optimizer is used to find a population of solutions, and choose the optimum one

Challenges

- Higher order correlations/instabilities seem to be under control, but is always a challenge
- Investigate different bunch charges, esp. low charge regime
- Start-to-end simulation of the FEL
- Halo/tail management