# Rubicon IFEL

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On behalf of the RUBICON collaboration

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DEFENSE THREAT REDUCTION AGENCY
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# Outline

- Experiment overview
- Recent experimental progress report
- Outlook and project schedule

# Radiabeam-UCLA-BNL IFEL CollaboratiON (RUBICON)

Unites the two major groups active in IFEL

- Past experience: UCLA Neptune, BNL STELLA 2

Inverse Free Electron Laser accelerators suitable for mid to high energy range compact accelerators

- Control of longitudinal phase space (prebunching)
- Preservation of e-beam emittance
- Efficient energy transfer and high capture rate
- Far field acceleration => high gradient

Builds off UCLA Neptune experiment: helical geometry for higher gradient

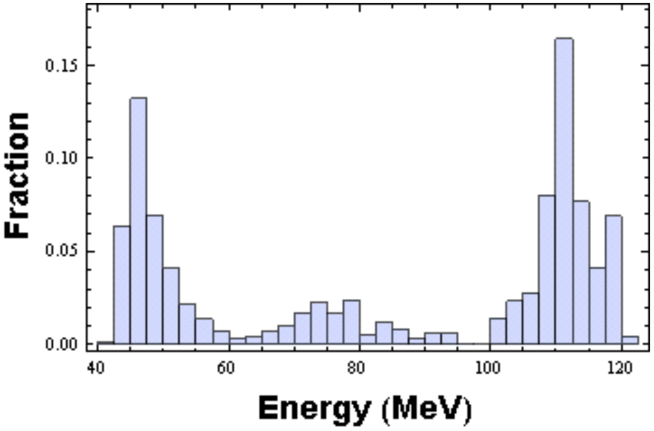
Collaboration paves the way for IFEL applications:

- Recirculation scheme
- ICS or FEL based light source driver.

# Experimental design

The primary goal of the experiment is to achieve energy gain and gradient significantly larger than what is possible with conventional RF accelerators.

Uses ATF's e-beam and high power CO2 laser system with a helical tapered undulator.

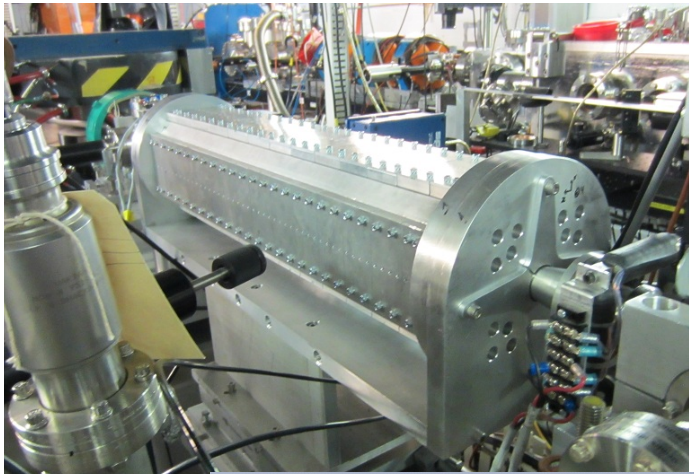


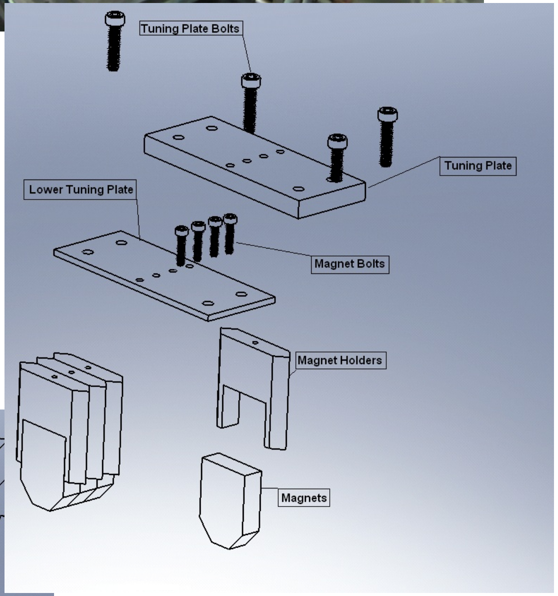
| Parameter | Value |
|---|---|
| Input e-beam energy | 50 Mev |
| Final beam energy | 117 MeV |
| Final beam energy spread | 4% |
| Average accelerating gradient | 124 MV/m |
| Laser wavelength | 10.3 μm |
| Laser power | 0.65 TW |
| Laser focal spot size (w) | 540 μm |
| Laser Rayleigh range | 9 cm |
| Undulator length | 60 cm |
| Undulator period | 4 – 6 cm |
| Magnetic field amplitude | 5.2 – 7.7 kG |

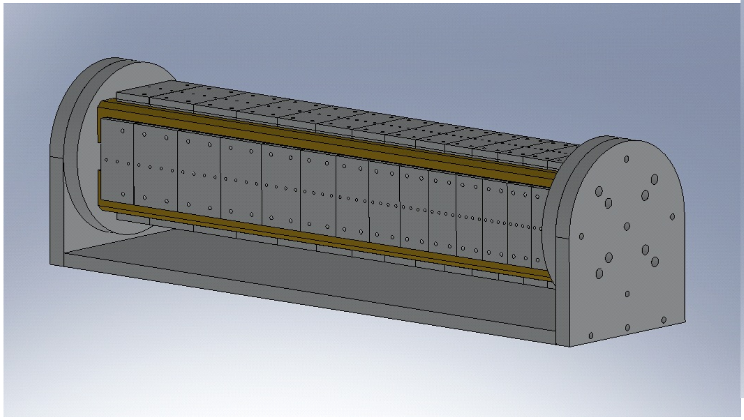
Table 1. Parameters for the RUBICON IFEL experiment

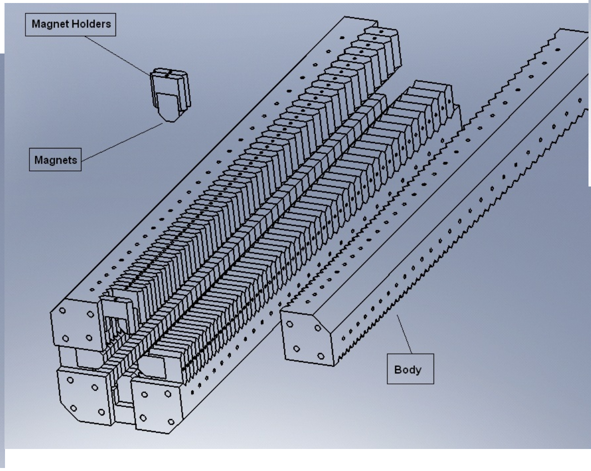
# Helical undulator design

- First strongly tapered high field helical undulator
- Helical geometry allows >2x higher gradient
- NdFeB magnets Br=1.22T
- Entrance/exit periods keep particle oscillation about axis
- Pipe of 14 mm diameter maintains high vacuum and low laser loses



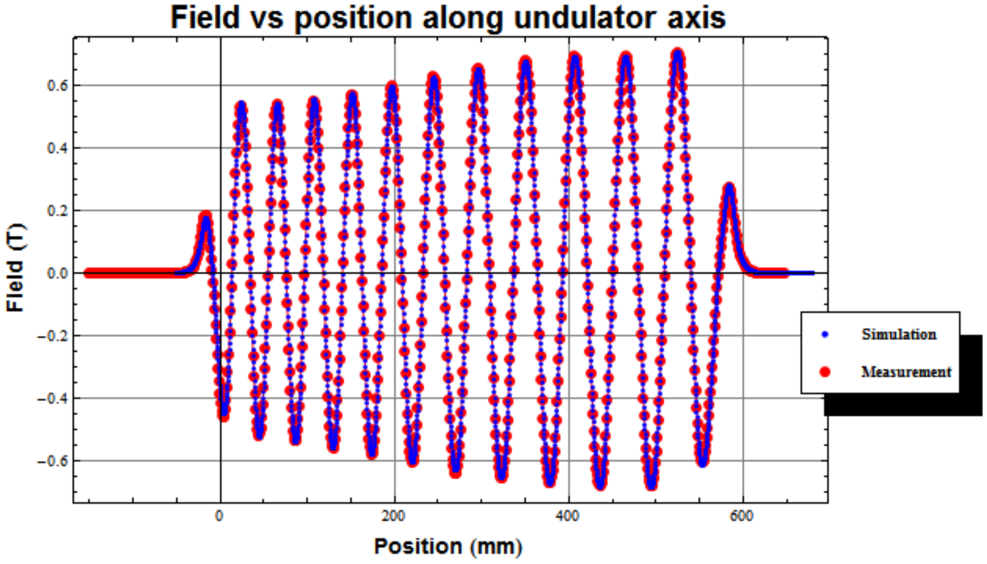


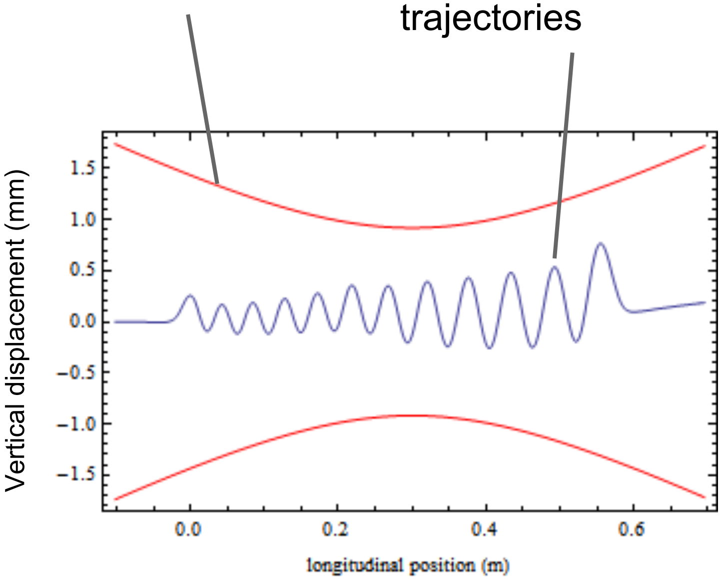




# Undulator integrals

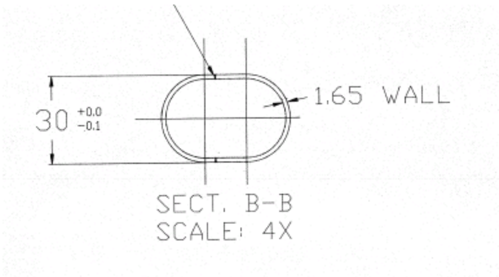
- Measured on axis fields with BH205 hall probe
- Good agreement with Radia calculation
- Second integral estimates particle trajectories
- Fields tuned to keep particle trajectories within laser waist for smooth gradient.



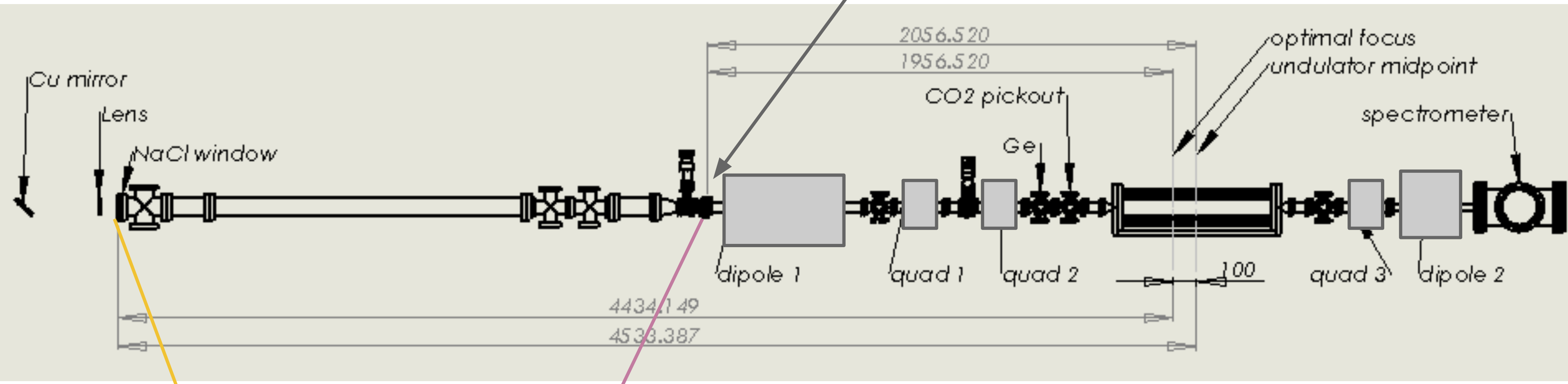

Laser waist

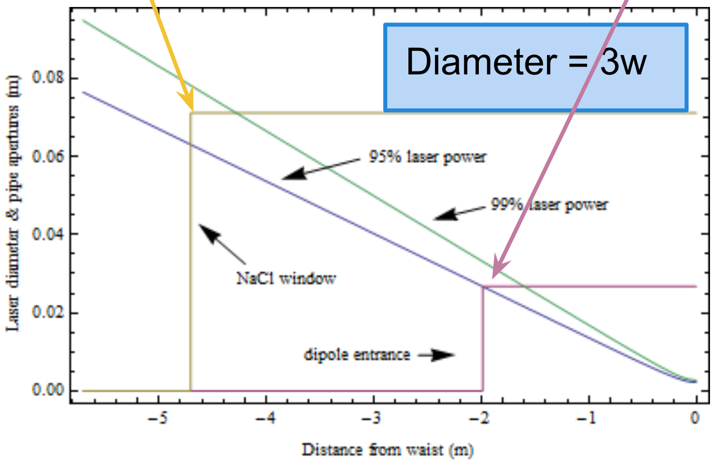
Estimated particle trajectories

# Choice of lens



Dipole aperture limits Rayleigh range





Minimize distance between undulator and dipole to reduce Rayleigh range

Cut slightly on dipole to further reduce Rayleigh range

9cm Rayleigh range -> 25cm

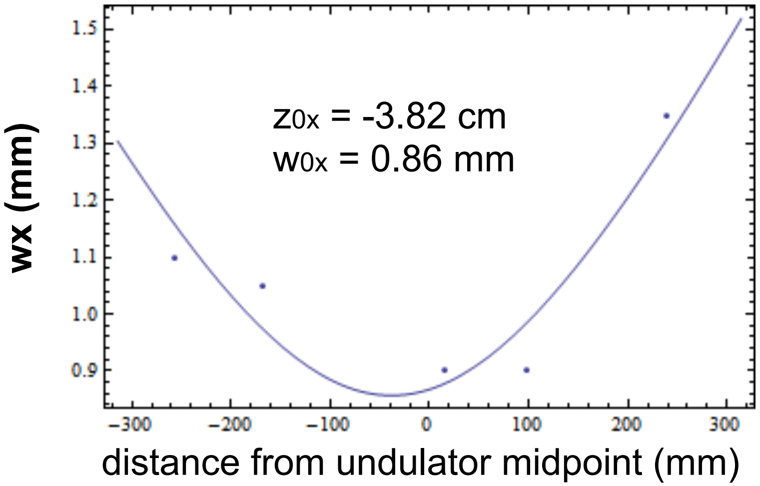
# Laser focal position

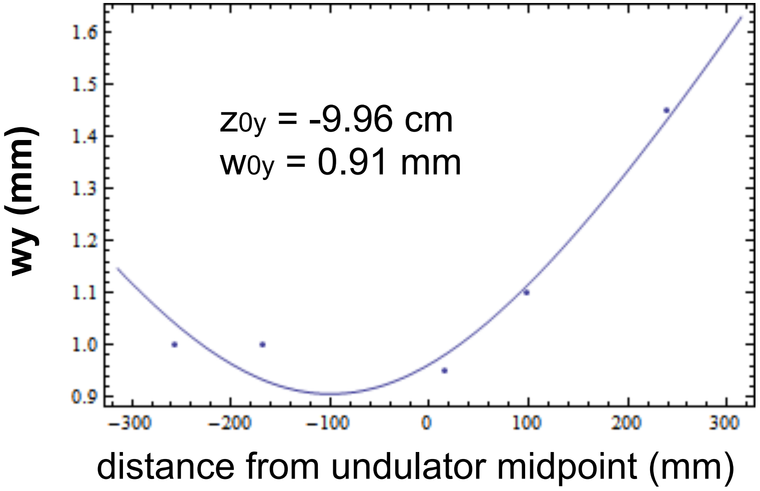
$$w(z) = w_0 \sqrt{1 + \left(\frac{z - z_0}{z_r}\right)^2}$$

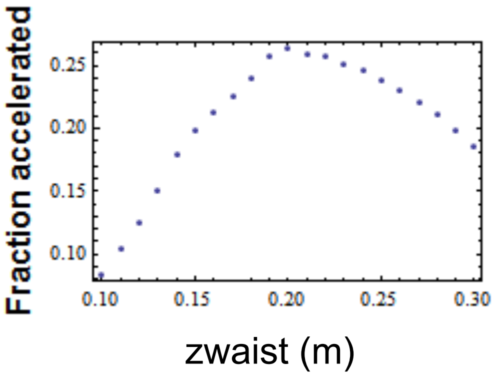
Measured waist with Pyrocam images of the CO2 oscillator pulse for different positions near the undulator's midpoint.

Optimal focal position z0 is 10 cm upstream of undulator center.

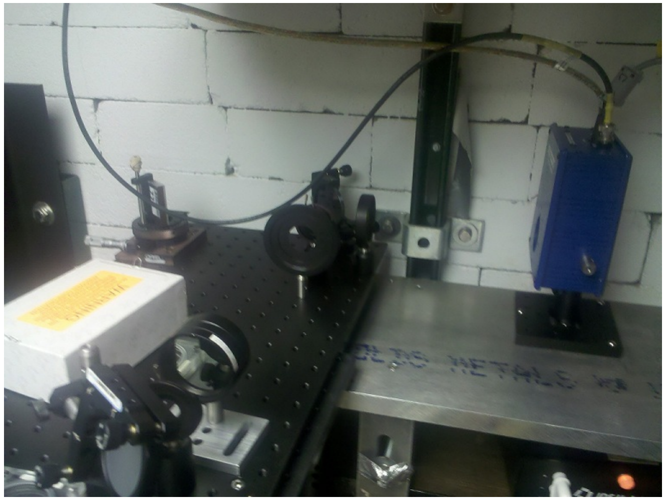
Measured Rayleigh range and spot size is reasonable.

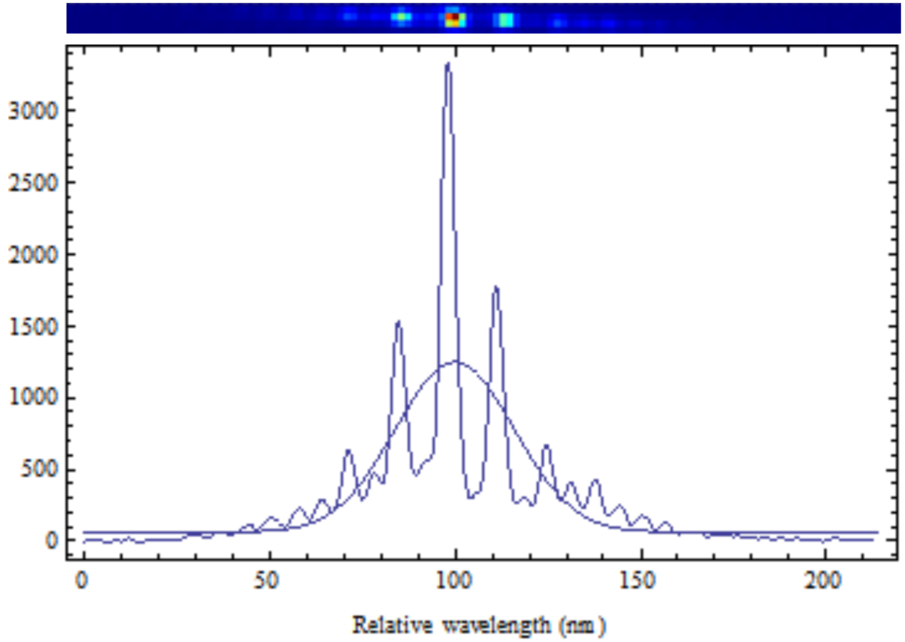




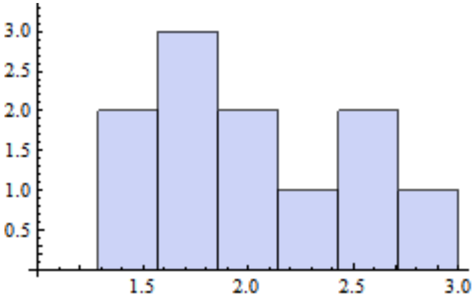


# Laser performance



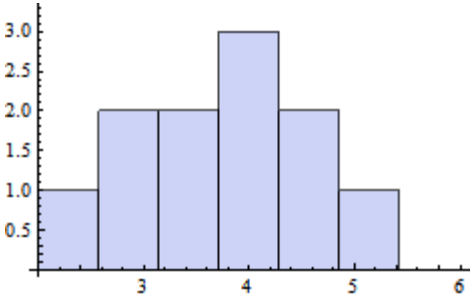


Spectral width: 37.7 nm
Pulse length: 4.14 ps
Output energy: 2.9 J
Average power: 0.700 TW



Pulse energy (J)

2.1 ± 0.53 J



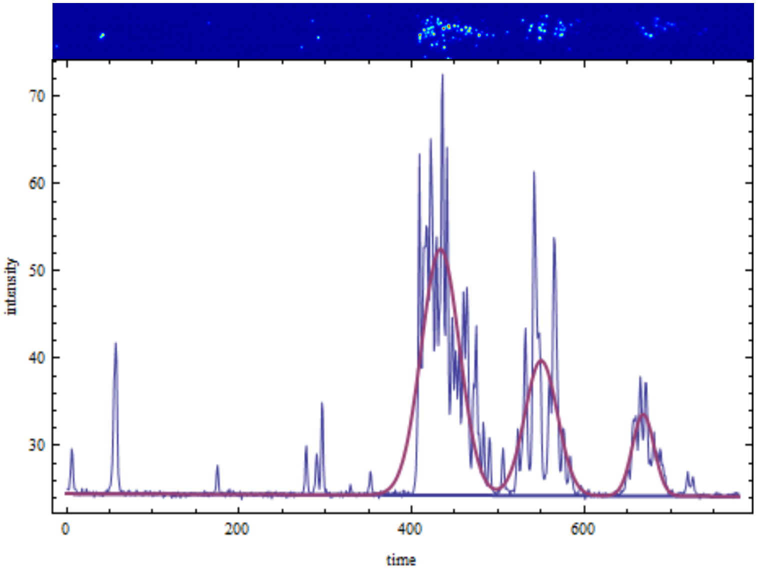
Pulse length (ps)

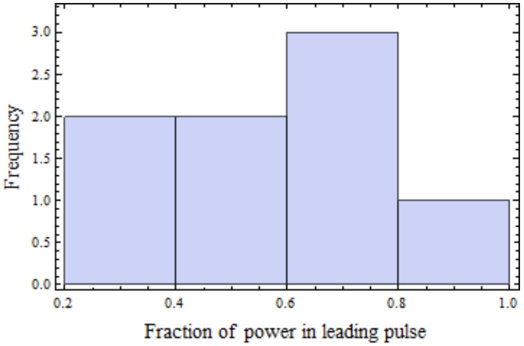
3.8 ± 0.82 J

# Laser pulse structure

The laser pulse energy is spread out over several pulses.

The average fraction of available energy in the first pulse for 8 shots was 58%.





# Available laser power

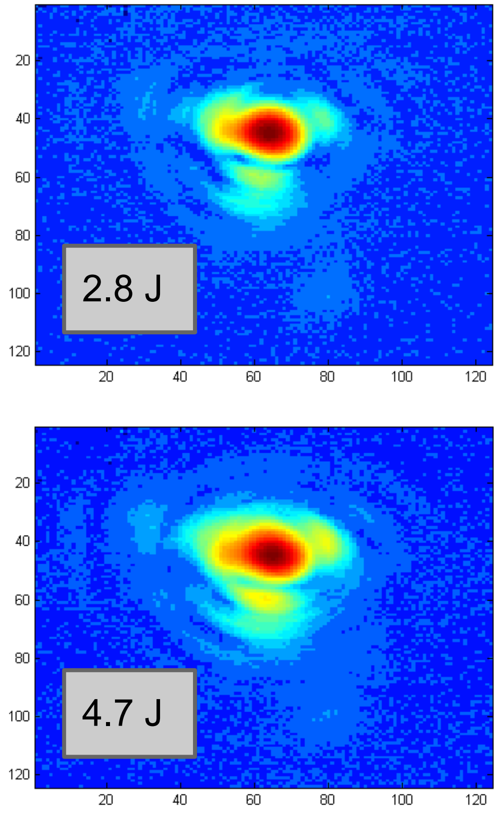
- Reflections at each window reduce available laser power by ~8%.
    - One window and one lens implies losses of up to 15%.
    - Should measure in the future.

- About 12% of power is lost to higher order transverse modes.

- Total power available for acceleration:

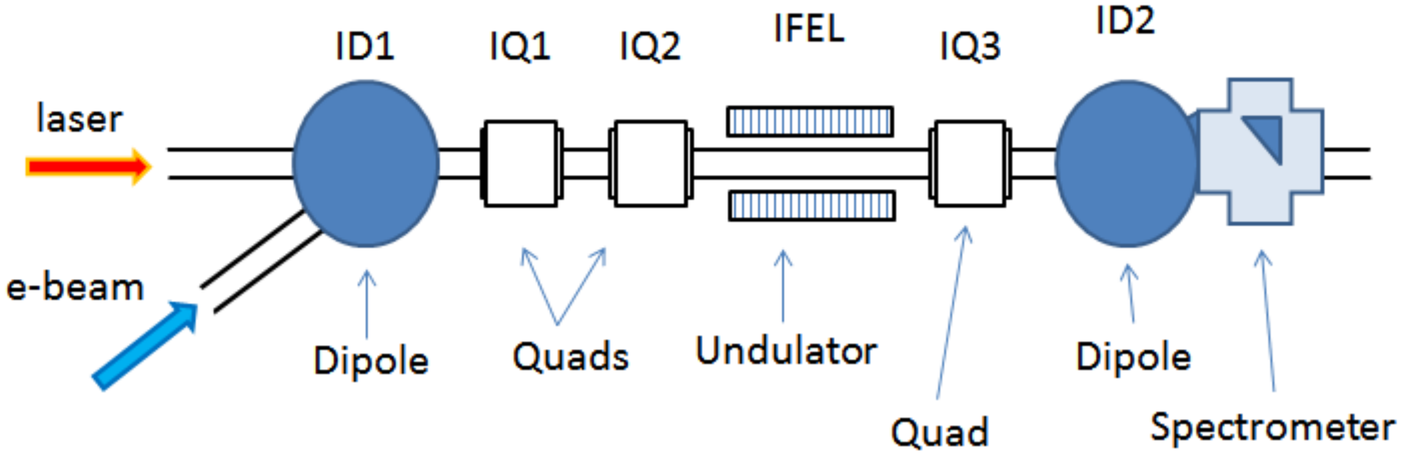
$$P = \frac{2.1\ \mathrm{J}}{3.8\ \mathrm{ps}} \times 0.58 \times 0.85 \times 0.88 = 240\ \mathrm{TW}$$

- Linear polarization reduces available gradient by more than a factor of 2



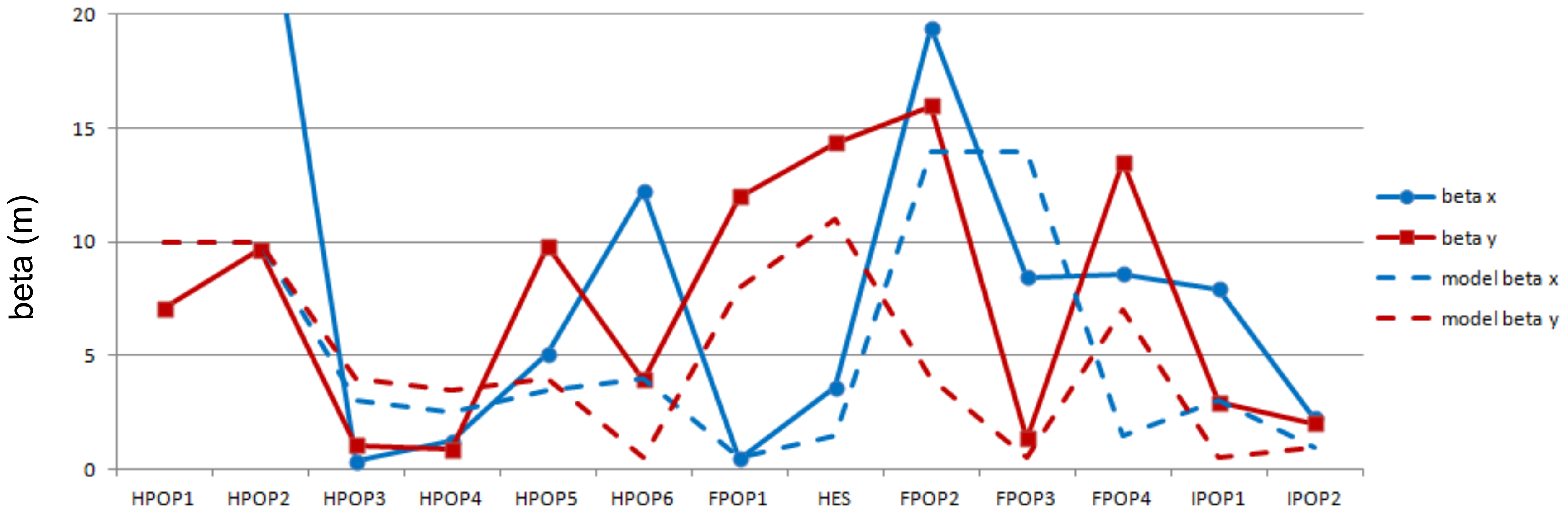
Pyrocam images of amplified laser transverse profiles (logarithmic scale). The central distributions contain 88% (above) and 83% (below) of the total power.

# Lattice



Measured beamline tuning agrees with simulation.

Two upstream quads allow good beta function for matching into the undulator.

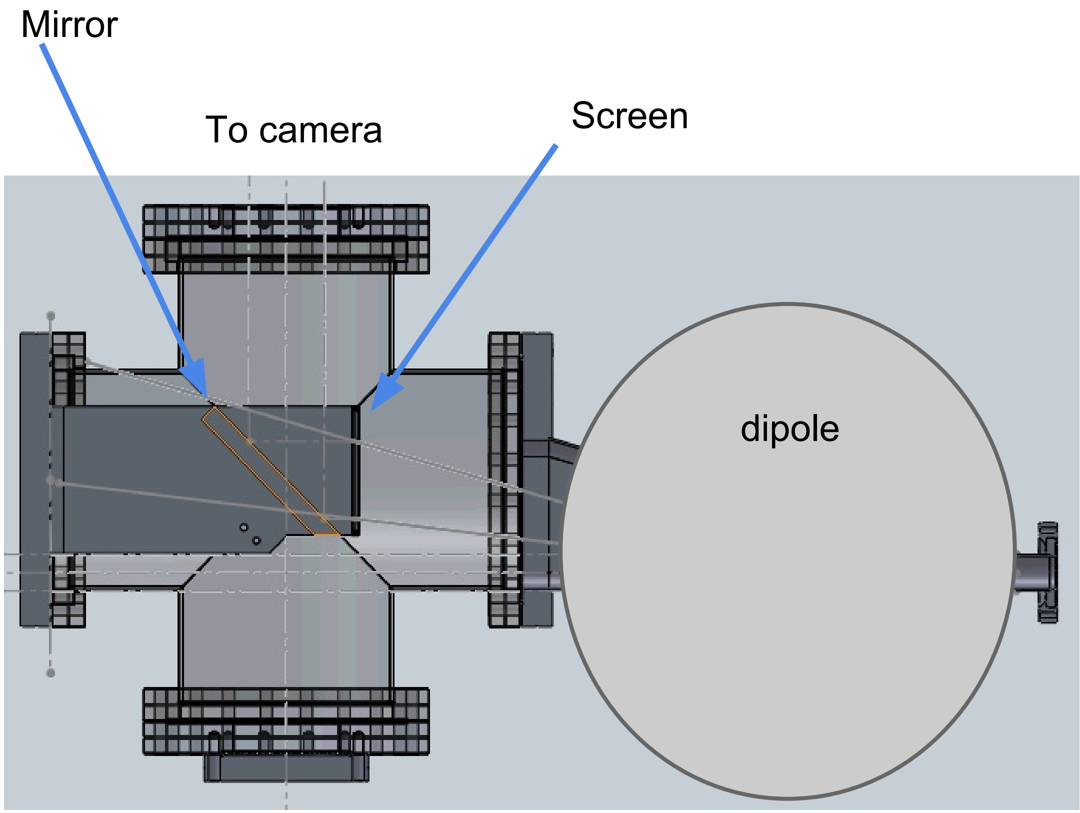


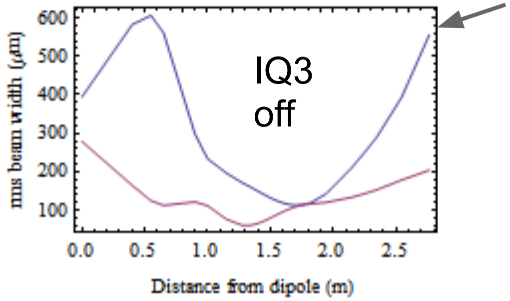
# Spectrometer

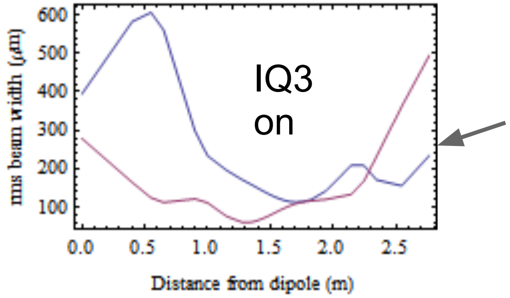
Accepts 50MeV to 115MeV

Energy resolution limited by beam size on screen

Adding quad between undulator and spectrometer reduces rms beam size from 560um to 230um





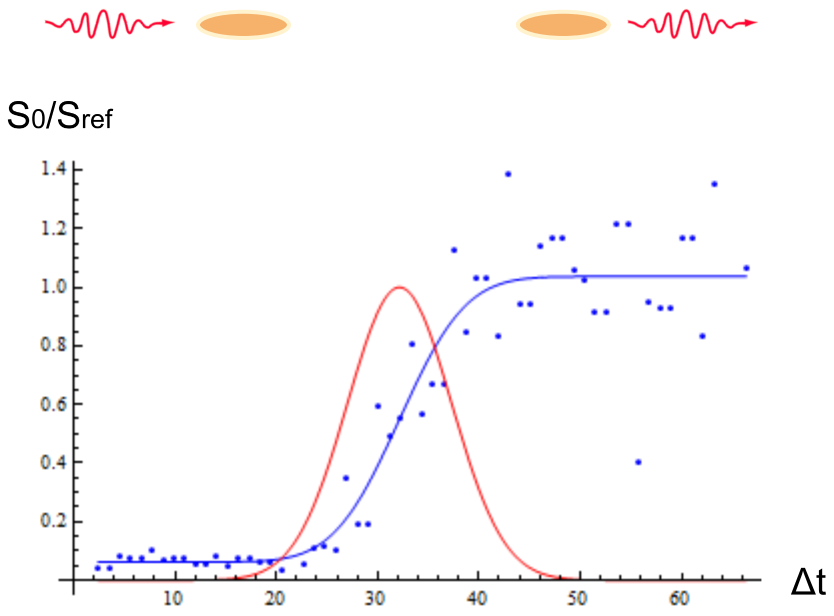


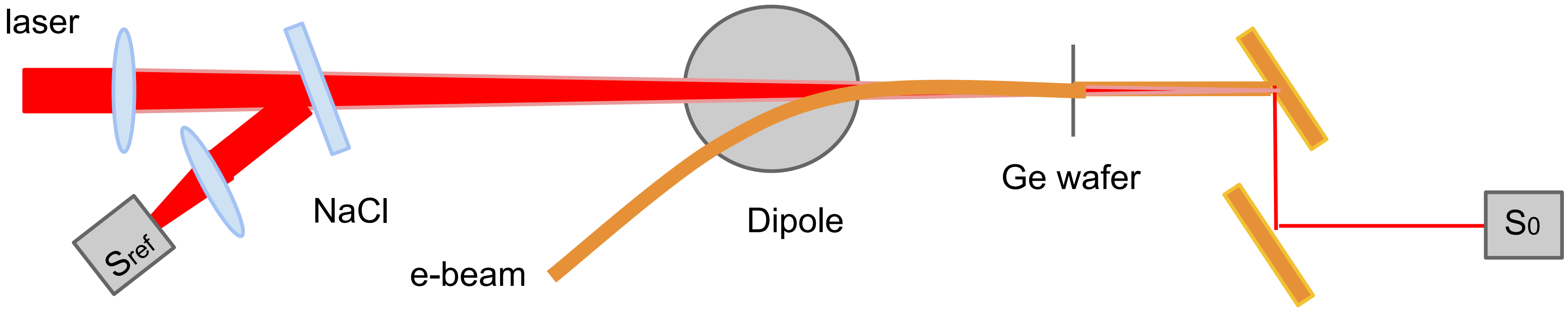
# Timing

Laser delay variable with delay stage

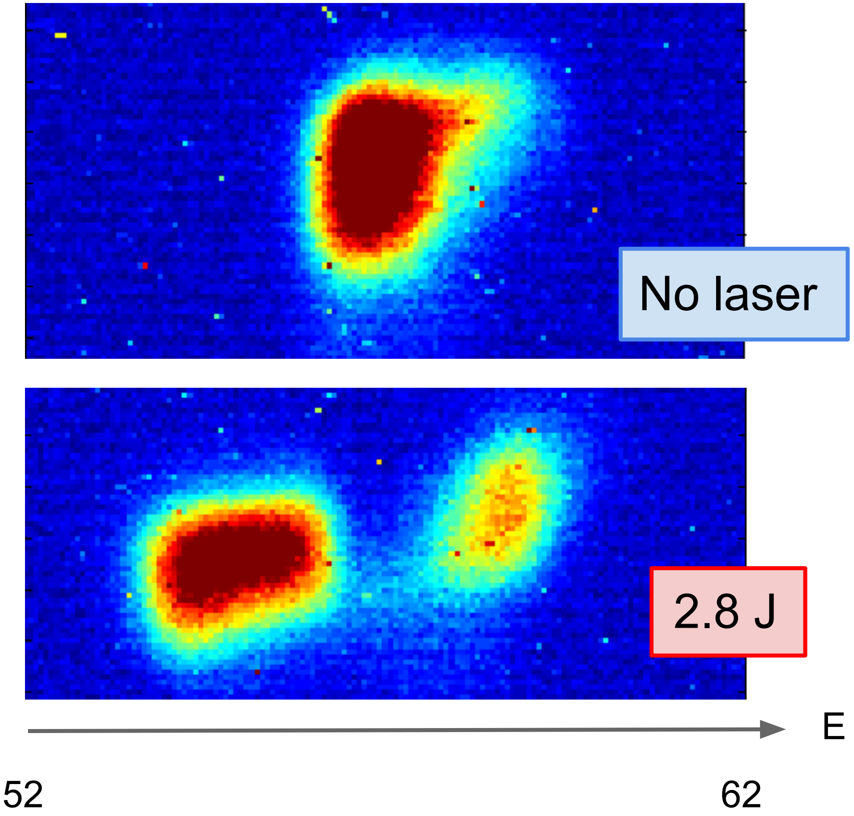
Coarse alignment with stripline coincidence

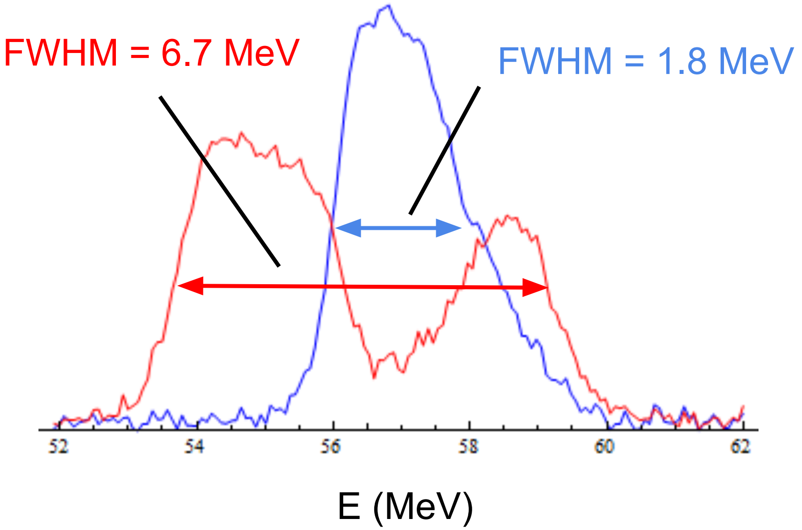
Germanium used for fine tuning



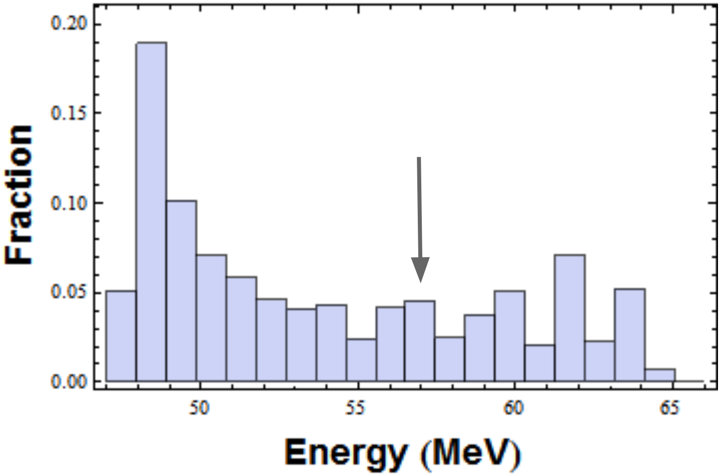


# IFEL induced energy spread





# Compare to simulation



3D simulation with measured experimental parameters and estimated available laser power shows similar structure.

# Where do we go from here?

- Insert quarter waveplate
- Measure power losses in laser transport
- Align beamline elements w/o undulator
- Align undulator
- Optimize timing