

# Emittance Analysis for FACET-II



Facility for Advanced  
Accelerator Experimental Tests

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Under the Mentorship of Doug Storey

# What is FACET-II?



An advanced facility for testing new acceleration techniques!

# FACET-II is a user facility – scientists propose experiments

- Lots of experiments already planned for FACET-II (and more not included here!)

Proposal No.	Title	
E-300	Plasma wakefield acceleration	Plasma wakefield acceleration
E-301	Tailored plasma sources for plasma wakefield acceleration	
E-308	Extreme focusing with a passive thin plasma lens	
E-325	Automatic tuning for PWFA optimization	
E-304	Density down ramp injection in PWFA	
E-310	Trojan horse injection	
E-311	Plasma torch optical density down ramp injection	
E-338	Attosecond XUV/X-ray sources driven by PWFA	X-ray source application of PWFA
E-320	Strong field QED	Strong field quantum electrodynamics
E-332	Near field CTR based focusing of beams – laser-less SFQED	
E-305	Beam filamentation and bright gamma ray bursts	Strong field physics
E-336	Beam interactions with carbon nanotube materials	
E-315	Plasma afterglow attosecond metrology	Accelerator diagnostics
E-324	Optical visualization of plasma wakefield acceleration	
E-326	Non-intercepting beam diagnostics	
E-327	Virtual diagnostics for phase space prediction	
E-331	Neural network-based tuning	

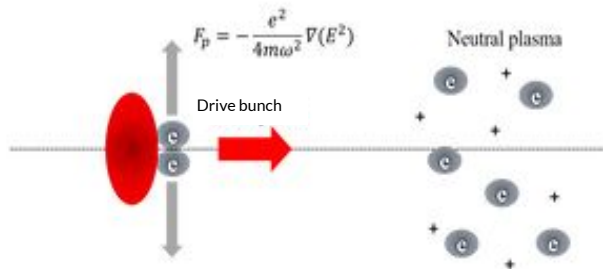
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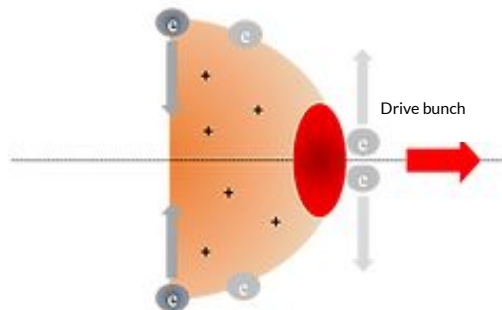
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# Plasma Wakefield Acceleration (PWFA)

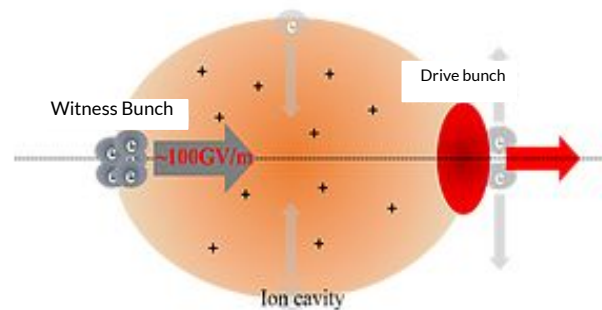
1. Plasma Electrons pushed away by Ponderomotive force



2. Electrons turn back by charge separation



3. Ion cavity formed and electrons are accelerated



Both beams travel to the right at about  $c$

$$\gamma_b \gg 1$$

The electron beams have strong, radial electric fields

In the wake of the drive bunch, electrons return to the axis, attracted by the ions

PWFA accelerates particles to high energies over orders of magnitude less distance than traditional accelerators

Plasma wakefield accelerator transfers energy from the drive beam to the witness.

# How strong are the fields?

- Size of the plasma wave scales as

$$\lambda_p = 2\pi c \sqrt{\frac{m_e \epsilon_0}{n_e e^2}}$$

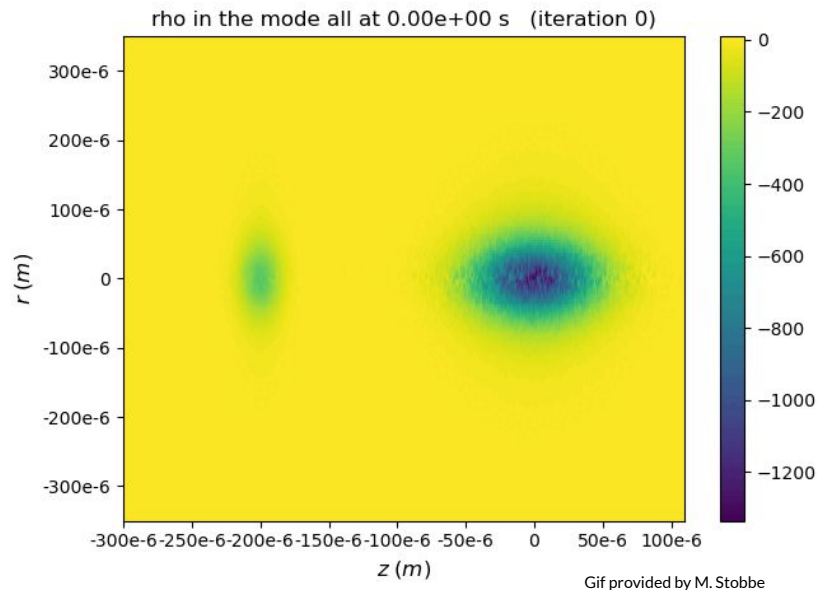
- Electric field scales as

$$E \approx 100 \sqrt{n [10^{18} \text{ cm}^{-3}]} [\text{GV/m}]$$

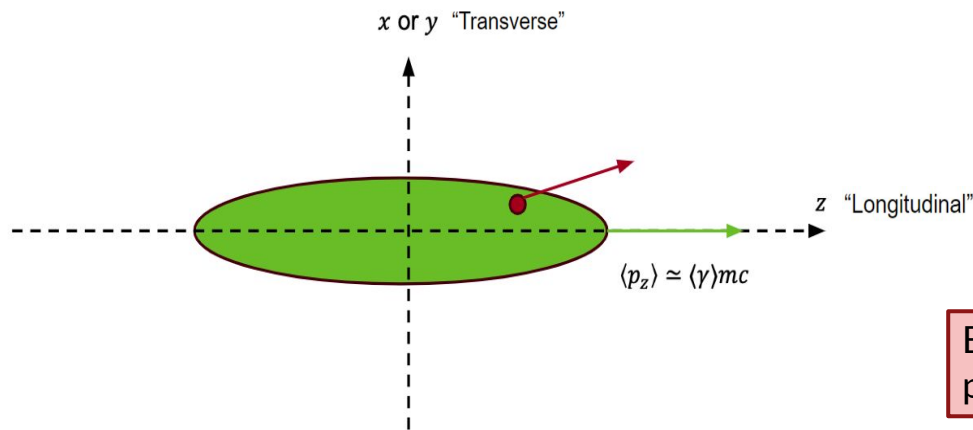
There is a GV/m in there!

Reminder: conventional linac is maybe 50 MV/m.

1m of PWFA can accelerate particles to energies that take current accelerator methods 1 km.



# Beam Dynamics and Emittance



$$\epsilon_x = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}$$

Emittance is the area of the phase space profile.

**A particle in the beam is described by six coordinates:**

$$(x, y, \zeta = z - \langle z \rangle) \text{ and } (x', y', \Delta\gamma = \gamma - \langle \gamma \rangle)$$

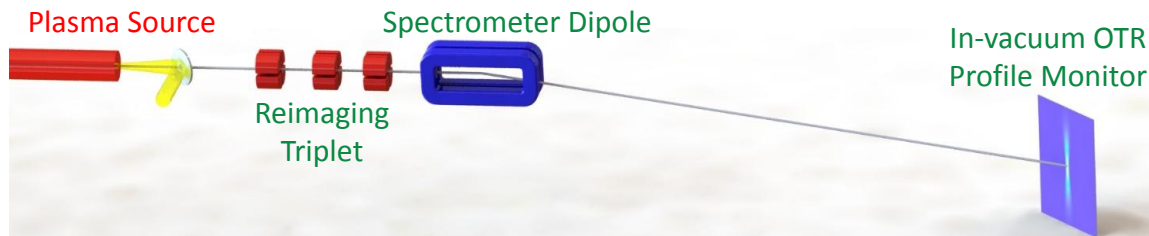
Position Coordinates

Momentum Coordinates

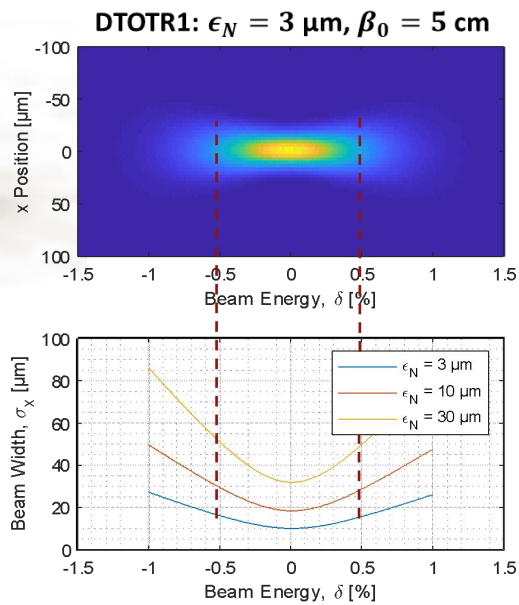
Emittance is a measure of the “quality” of the beam - having a low emittance is necessary for useful accelerator technologies such as FELs or Particle Colliders



# Analyzing the Beam Profile



Higher energies are more “rigid” meaning they are bent less by the dipole while lower energies are bent more - this gives a profile the transverse size of the beam as a function of the area



Using proper calibrations - can extract the size with energy of the beam from which a value for emittance can be determined.

Using the transport matrix - the beam size  $\sigma_x(E)$  on the screen is:

$$(\sigma_x(E))^2 = \frac{\epsilon_n}{\gamma_b(E)} \left[ M_{11}(E)^2 \beta_0 - 2M_{11}(E)M_{12}(E)\alpha_0 + M_{12}(E)^2 \left( \frac{1 + \alpha_0^2}{\beta_0} \right) \right]$$



# A Robust Tool for Analyzing Emittance

Select Data Set:

Experiment  dataSetID

DataSet Info

DAN log

Camera  dataSetIndex

Energy Calibration

Dipole Strength [GeV]

Nominal Dispersion [mm]

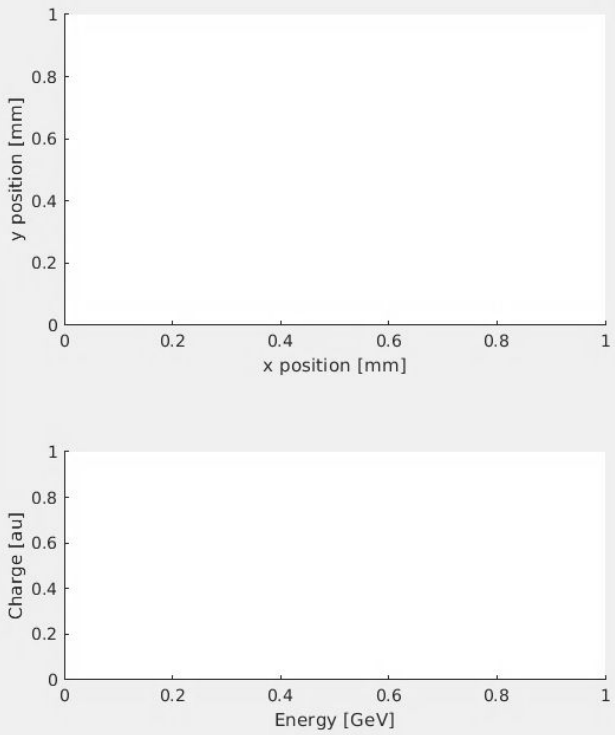
10 GeV Beam Position [mm]

Energy-Axis Ticks

ECal log

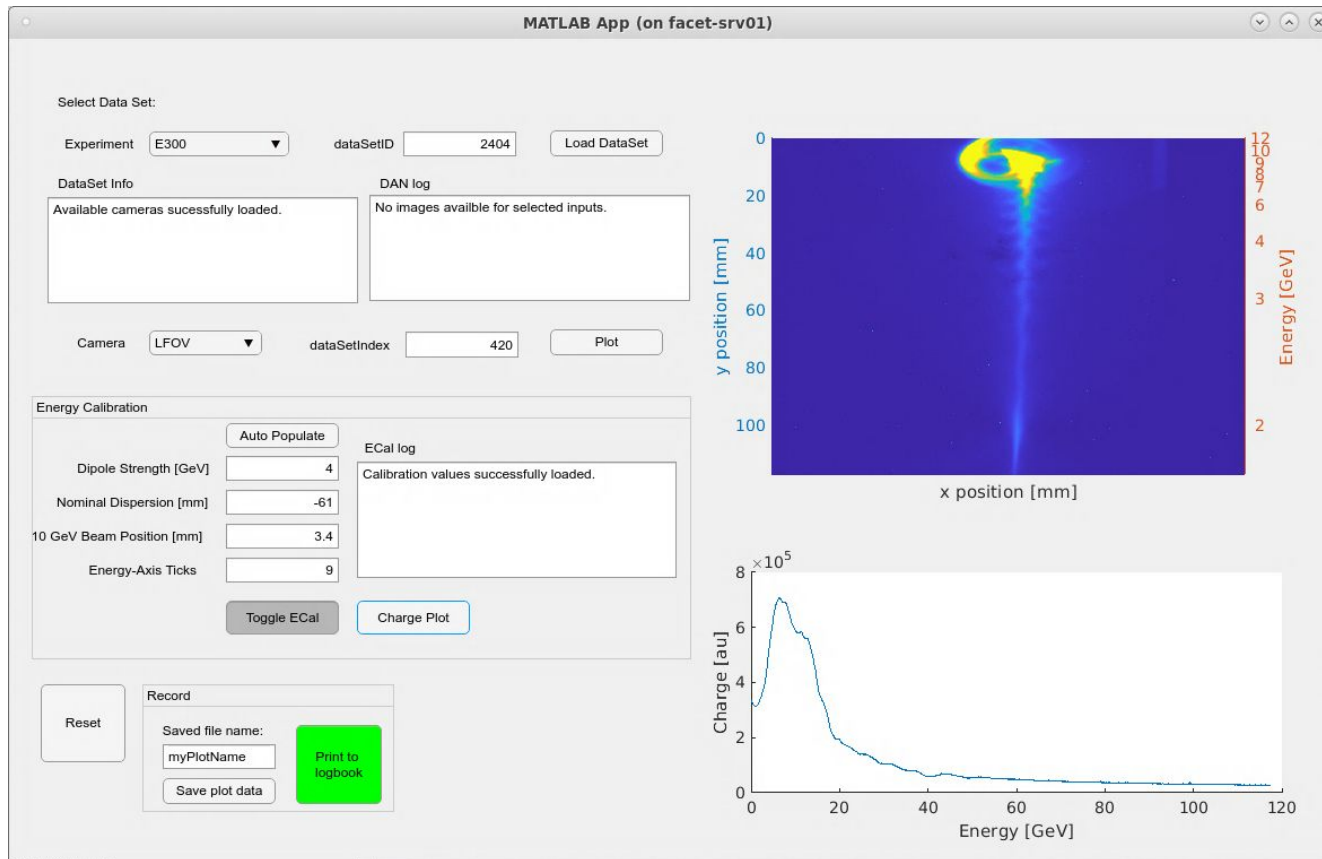
Record

Saved file name:

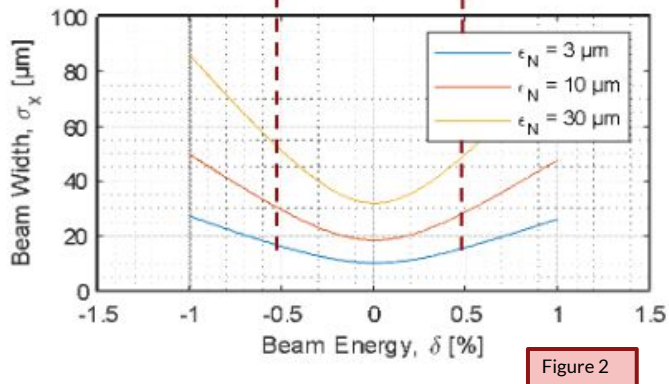
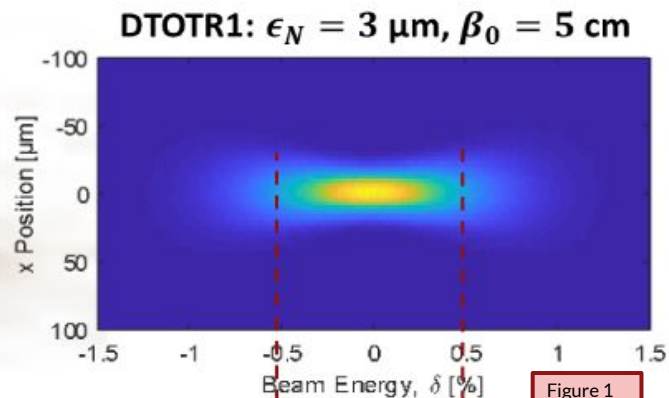


The image displays a software interface for analyzing emittance. It features a control panel on the left with various input fields and buttons. The top section allows selecting a data set by experiment and ID, with a 'Load DataSet' button. Below this, there are text areas for 'DataSet Info' and 'DAN log'. A 'Camera' section includes a 'Load Data' dropdown and a 'dataSetIndex' field with a 'Plot' button. The 'Energy Calibration' section contains several numerical input fields: Dipole Strength (10 GeV), Nominal Dispersion (-50 mm), 10 GeV Beam Position (5 mm), and Energy-Axis Ticks (9). It also has an 'Auto Populate' button, an 'ECal log' text area, and 'Toggle ECal' and 'Charge Plot' buttons. At the bottom left, there is a 'Reset' button and a 'Record' section with a 'Saved file name' field (containing 'myPlotName'), a 'Print to logbook' button, and a 'Save plot data' button. On the right side, there are two empty plots. The top plot is a 2D plot of y position [mm] versus x position [mm], both axes ranging from 0 to 1. The bottom plot is a 2D plot of Charge [au] versus Energy [GeV], both axes ranging from 0 to 1.

# A Robust Tool for Analyzing Emittance



# What's Left



Take the energy-calibrated beam profile and fit each “energy slice” to a gaussian to get a beam width:

$$(\sigma_x(E))^2 = \frac{\epsilon_n}{\gamma_b(E)} \left[ M_{11}(E)^2 \beta_0 - 2M_{11}(E)M_{12}(E)\alpha_0 + M_{12}(E)^2 \left( \frac{1 + \alpha_0^2}{\beta_0} \right) \right]$$

$\epsilon_n$ ,  $\beta_0$ , and  $\alpha_0$  are emittance and Twiss parameters at the plasma exit  
 $\gamma_b$  is the Lorentz factor

Fit this function to the beam size to extract:  $\epsilon_n$ ,  $\beta_0$ , and  $\alpha_0$

Extracting a numerical value for emittance for any loaded dataset

Complete: Figure 1  
Incomplete: Figure 2

# Acknowledgments

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- Doug Storey
- Spencer Gessner
- Mark Hogan
- Sharon Perez
- Hillary Freeman
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