Emittance Analysis for FACET-II

FACET-II

Facility for Advanced Accelerator Experimental Tests

Samuel Kresch

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
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
E-320	Strong field QED
E-332	Near field CTR based focusing of beams – laser-less SFQED
E-305	Beam filamentation and bright gamma ray bursts
E-336	Beam interactions with carbon nanotube materials
E-315	Plasma afterglow attosecond metrology
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

Plasma wakefield acceleration (E-300 to E-311)

X-ray source application of PWFA (E-338)

Strong field quantum electrodynamics (E-320, E-332)

Strong field physics (E-332 to E-336)

Accelerator diagnostics (E-315 to E-331)

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Plasma wakefield acceleration

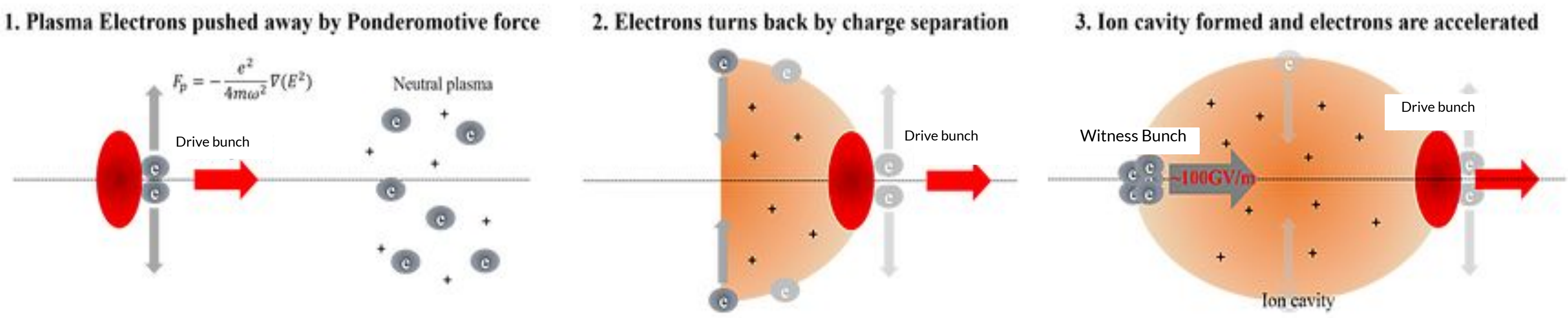
X-ray source application of PWFA

Strong field quantum electrodynamics

Strong field physics

Accelerator diagnostics

Plasma Wakefield Acceleration (PWFA)



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.

Image adapted from Department of Physics and Photon Science, GIST, Cheomdan-gwagiro 123, Buk-gu, Gwangju, 61005, Korea

How strong are the fields?

- Size of the plasma wave scales as

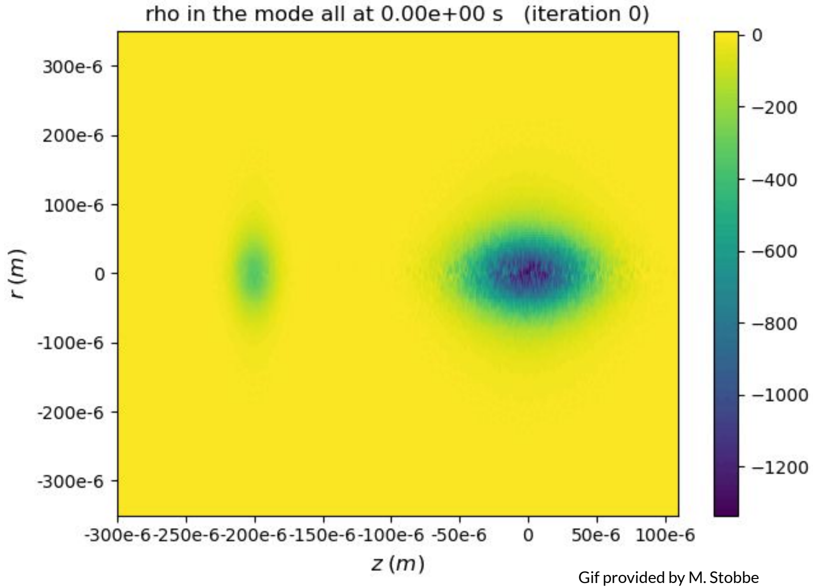
$$\lambda_p = 2\pi c \sqrt{\frac{m_e \epsilon_0}{n_e e^2}}$$

- Electric field scales as

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

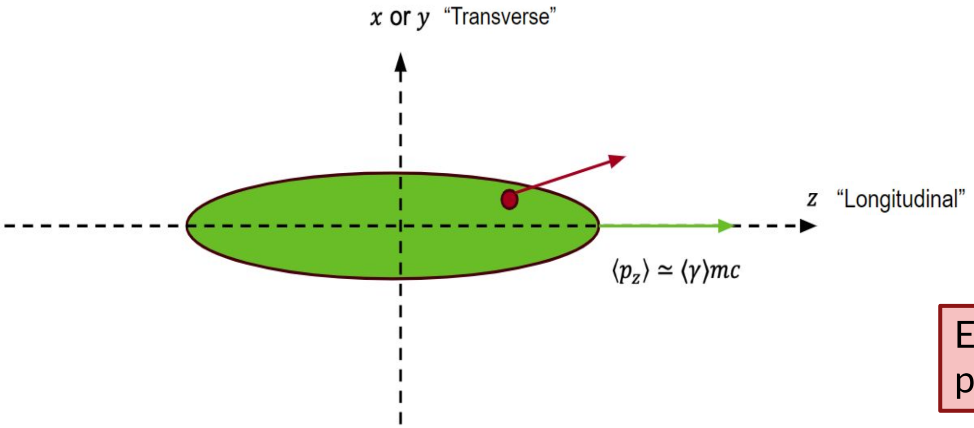
There is a GV/m in there!
Reminder: conventional linac is maybe 50 MV/m.

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



Gif provided by M. Stobbe

Beam Dynamics and Emittance



A particle in the beam is described by six coordinates:

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

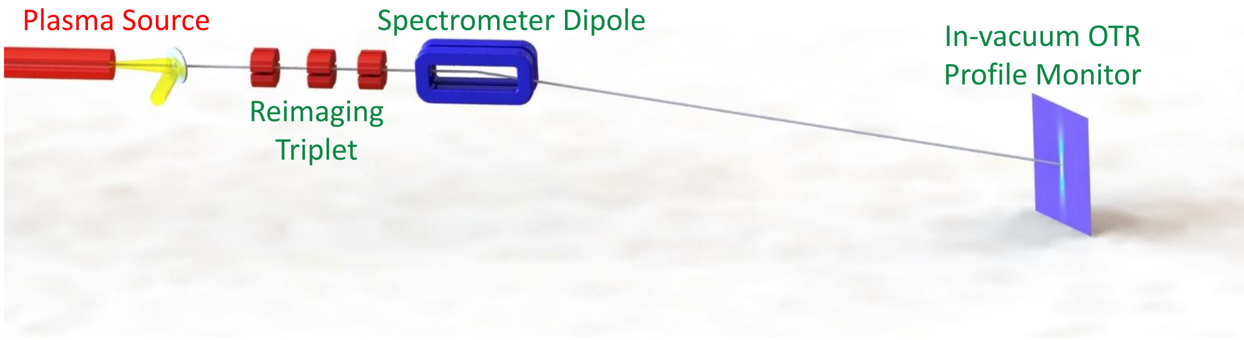
Position Coordinates — Momentum Coordinates

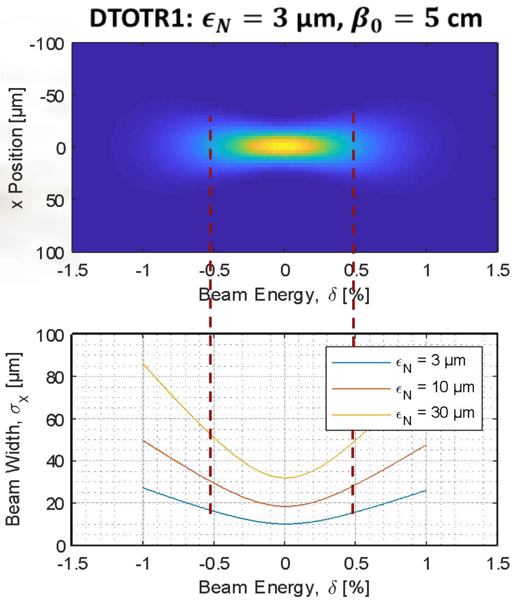
$$\epsilon_x = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

Emittance is the area of the phase space profile.

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





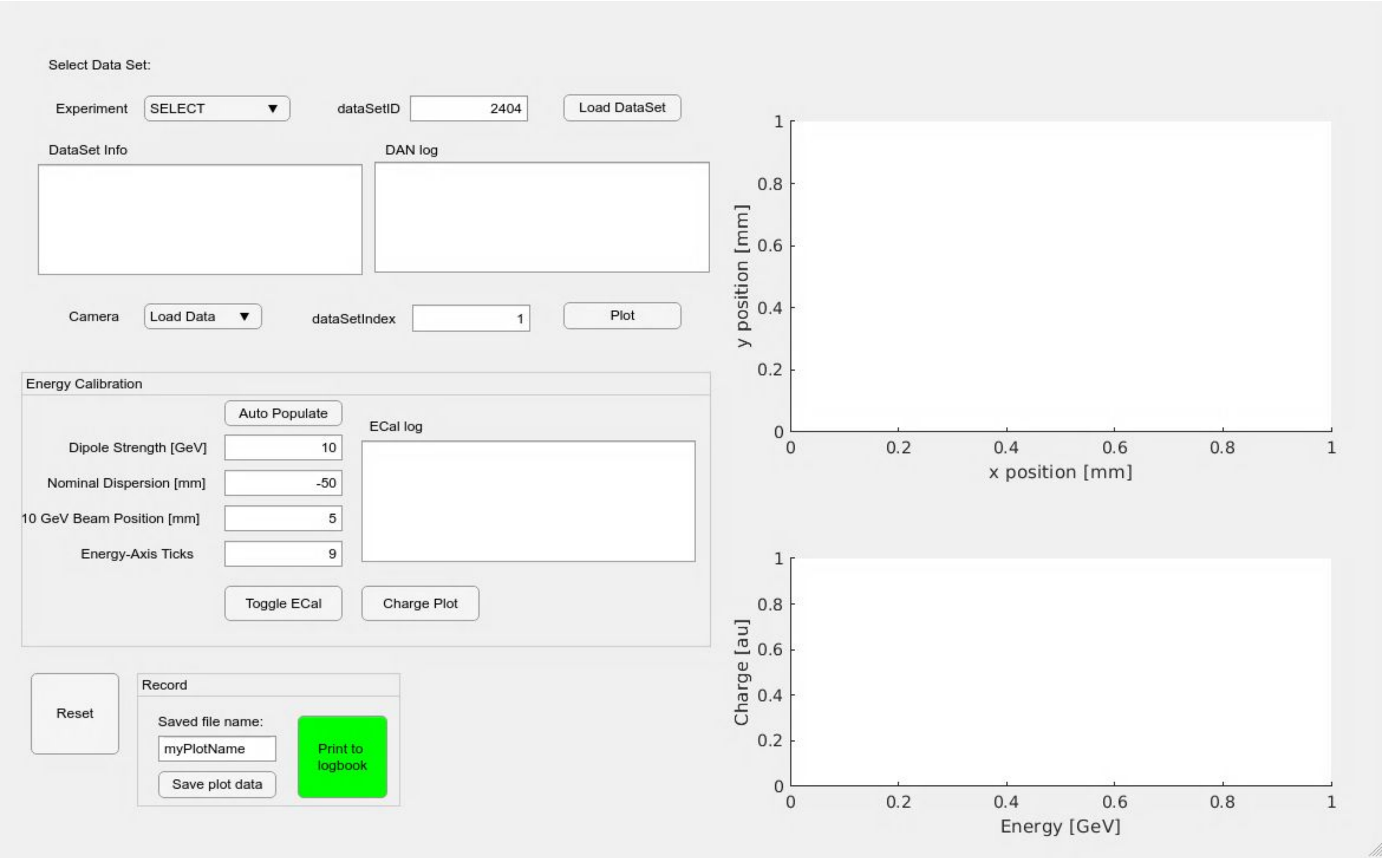
Higher energies are more "rigid" meaning they are bent less by the dipole while lower energies are bent more - this gives a profile the transverse size of the beam as a function of the area

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

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

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

A Robust Tool for Analyzing Emittance



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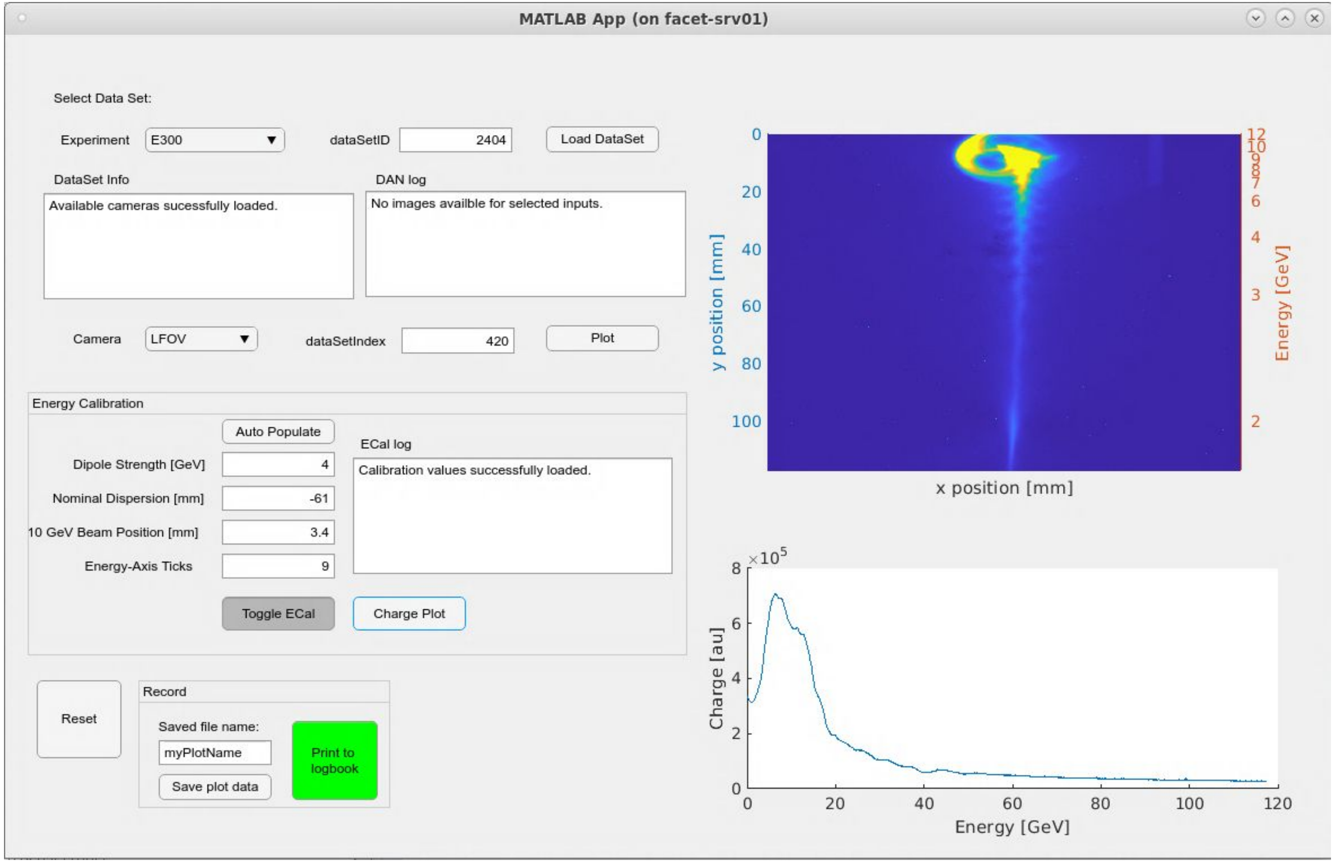

What’s Left

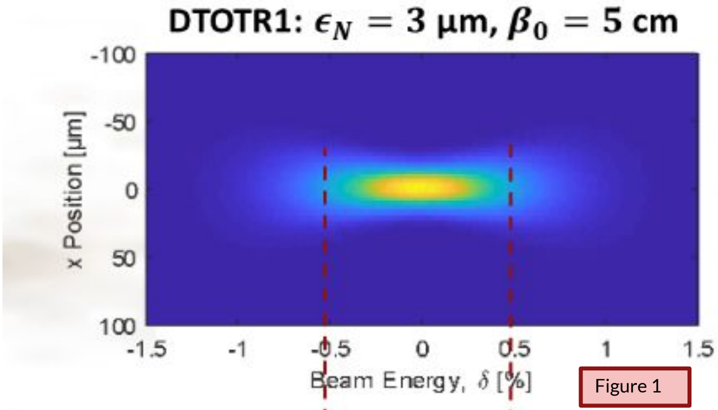

Figure 1

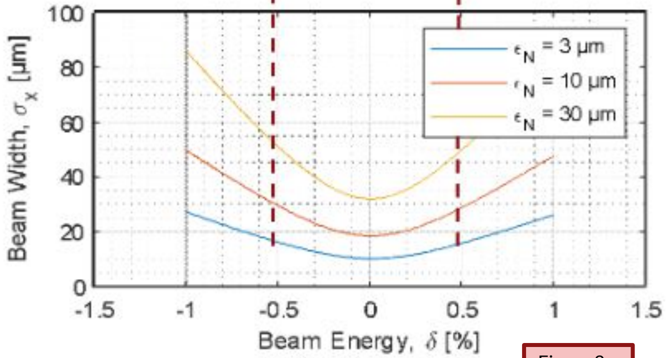

Figure 2

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

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

ϵ_n, β_0, and α_0 are emittance and Twiss parameters at the plasma exit

γ_b is the Lorenz factor

Fit this function to the beam size to extract: ϵ_n, β_0, and α_0

Extracting a numerical value for emittance for any loaded dataset

Complete: Figure 1
Incomplete: Figure 2

Acknowledgments

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