

GTS Emittance Measurement

January 3, 2017

Emittance Measurement Techniques

I. Solenoid and Viewscreen

II. Single Slit and Viewscreen

III. Double-slit and Faraday Cup

We assume a round beam ($\varepsilon_x = \varepsilon_y$) –
measure vertical transverse phase space in
one dimension (y) with horizontal slit

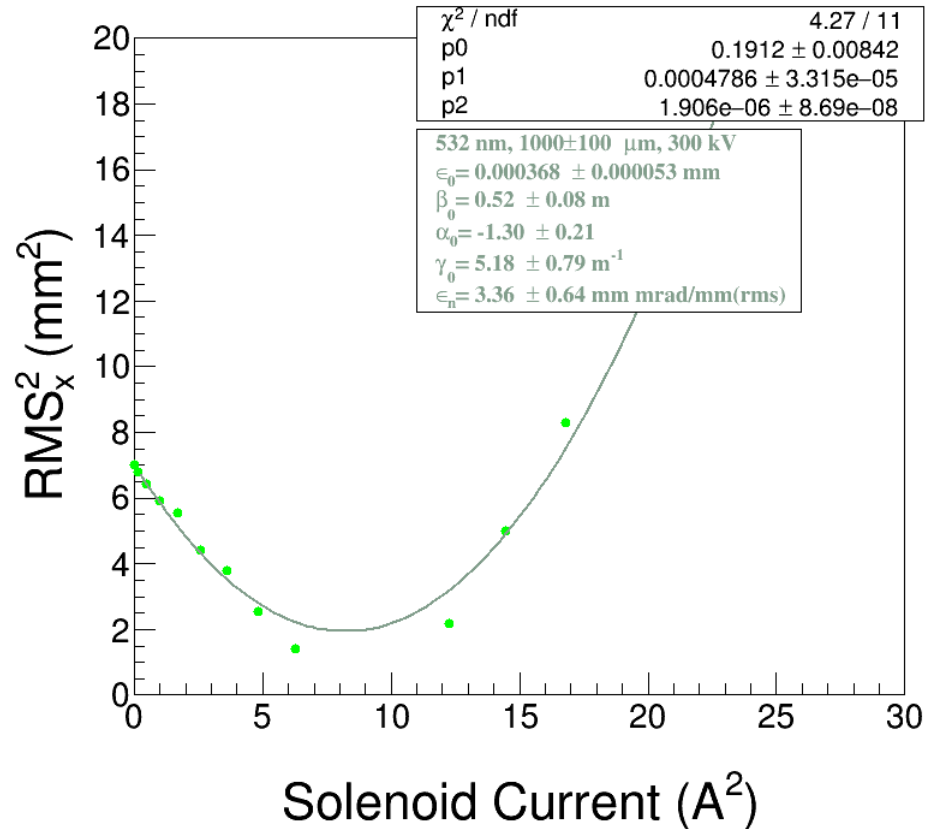
Solenoid and Viewscreen

- I. Distance between solenoid (MFGGT02) and viewscreen (ITVGT01A)
(d) = 900 mm. For MFGGT02, $B2L = 66940.02 \text{ G}^2\text{-cm}$ at $I^2=1 \text{ A}^2$
- II. Focal Length (1/mm): $\frac{1}{f} = \frac{c^2 B2L I^2}{4 \times 10^{13} \beta^2 \gamma^2 m_e^2}$
- III. Parabola fit: $\sigma_x^2 = \sigma_y^2 = R_{11}^2 \Sigma_{11} + 2R_{11}R_{12}\Sigma_{12} + R_{12}^2 \Sigma_{22}$
- IV. $R_{12} = d$ and $R_{11} = 1 - d \cdot \frac{1}{f}$
- V. Geometric Emittance (mm mrad): $\varepsilon_y = 10^3 \sqrt{\Sigma_{11}\Sigma_{22} - \Sigma_{12}^2}$
- VI. Normalized Emittance (mm mrad/mm (rms)):

$$\varepsilon_{n,y} = \beta \gamma \varepsilon_y / Laser_{RMS}$$

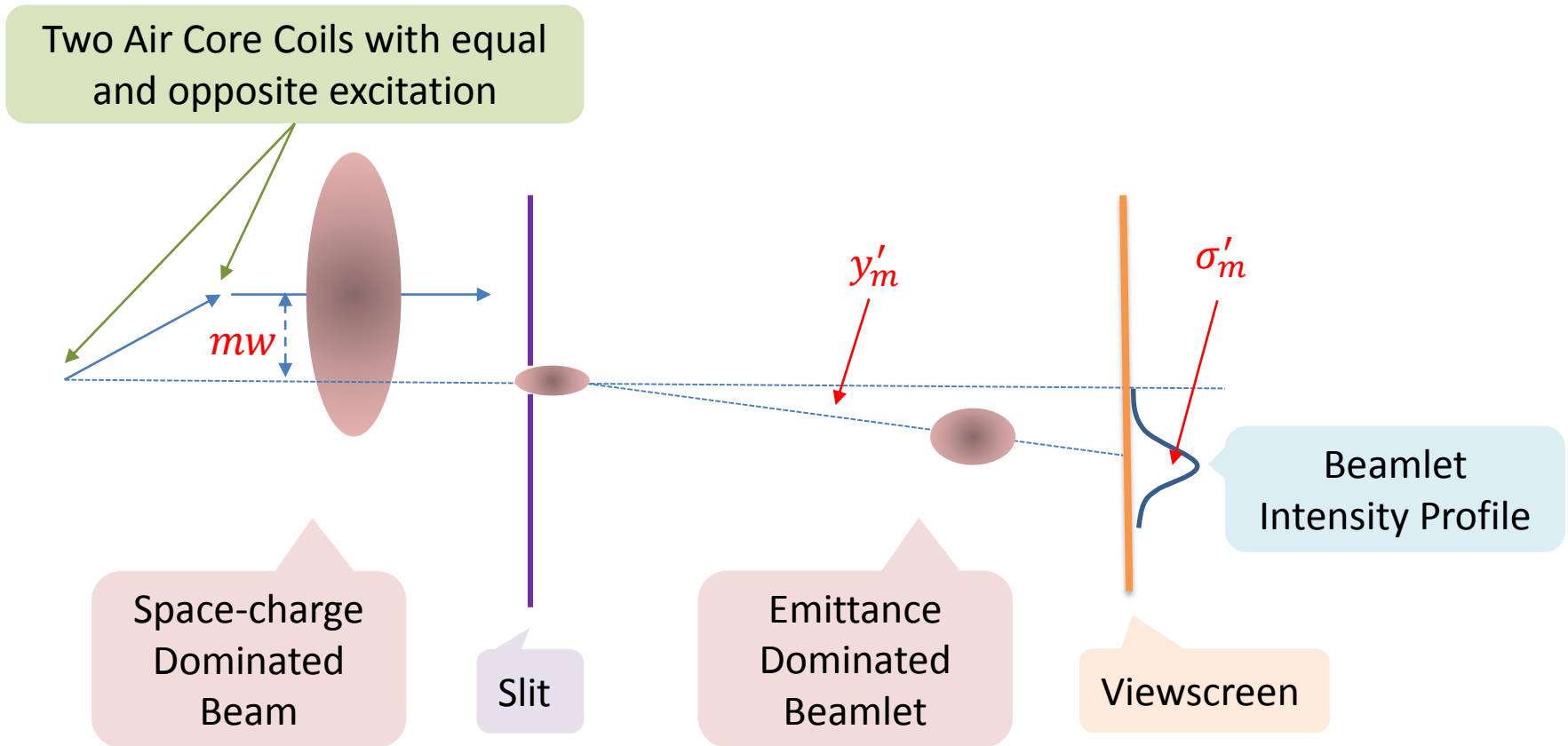
Measurement Details:

- Measure laser RMS (\pm error)
- Find camera pixel calibration (mm per pixel \pm error)
- Record Gun HV
- Use low beam current (<50 nA DC, 0.001 pC CW)
- (σ^2, I^2) plot has to be symmetric about minimum – unreliable emittance calculation if not



There is a **root** macro to calculate emittance for Solenoid and Viewscreen technique

Single Slit and Viewscreen



- Slit Gap (s) = 40 μm
- Distance between slit and viewscreen (d) = 500 mm
- Measurement steps ($m = 1, \dots, N$) with constant w step size ($N \sim 20, w \sim 0.5 \text{ mm}$)

$$y'_m = \frac{\langle y_m - mw \rangle}{d}$$

$$y'_{m,c} = y'_m - \frac{\sum_{m=1}^N I_m y'_m}{\sum_{m=1}^N I_m}$$

$$y_{m,c} = mw - \frac{\sum_{m=1}^N I_m mw}{\sum_{m=1}^N I_m}$$

$$\langle y^2 \rangle = \frac{\sum_{m=1}^N I_m y_{m,c}^2}{\sum_{m=1}^N I_m}$$

$$\langle y'^2 \rangle = \frac{\sum_{m=1}^N I_m (y_{m,c}'^2 + \sigma_m'^2)}{\sum_{m=1}^N I_m}$$

$$\langle yy' \rangle = \frac{\sum_{m=1}^N I_m y_{m,c} y'_{m,c}}{\sum_{m=1}^N I_m}$$

where I_m is measured
integrated intensity in
 m th beamlet

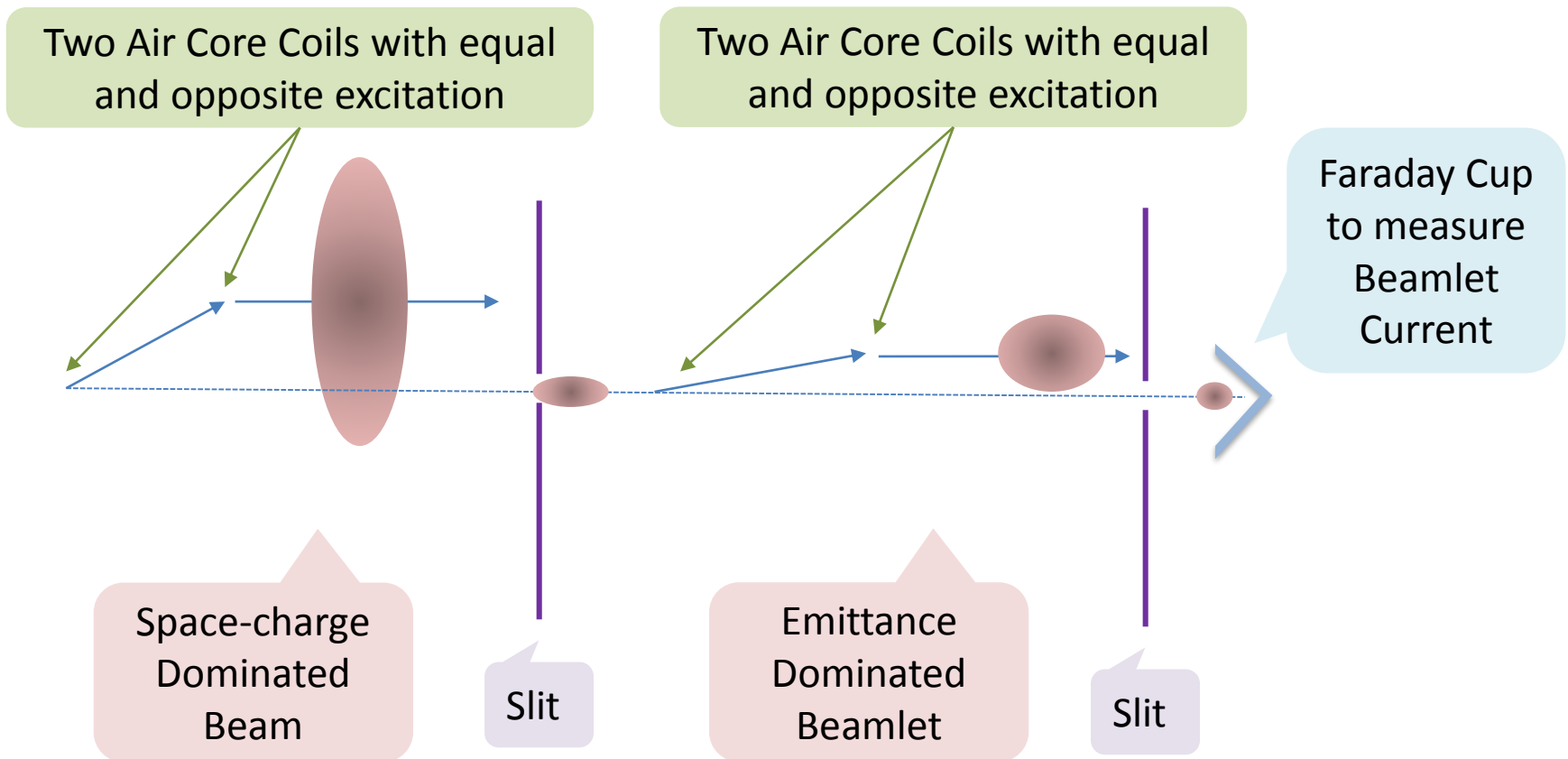
$$\varepsilon_y = \sqrt{\langle y^2 \rangle \langle y'^2 \rangle - \langle yy' \rangle^2}$$

Measurement Details:

- Measure laser RMS (\pm error)
- Find camera pixel calibration (mm per pixel \pm error)
- Record Gun HV
- Power limit of 10 W (30 μ A, 350 kV) on first slit (not water-cooled) – otherwise may deform gap
- One vertical magnetic beam scanner before first slit – has two pairs of identical air core coils with equal and opposite excitation in each coil – Radiabeam coils with steel core should be fine
- Use first viewscreen to calibrate magnetic beam scanner excitations ($N \sim 20$, $w \sim 0.5$ mm)
- Calibrate beamlet position on second viewscreen
- Measure (y, y') phase space

Need to develop scripts for calibrations and to calculate emittance

Double-slit and Faraday Cup



- Slit Gap (s) = 40 μm
- Distance between two slits (d) = 500 mm
- Measurement steps: 100 \times 100 at 200 Hz (1 minute each measurement)

Measurement Details:

- Measure laser RMS (\pm error)
- Find camera pixel calibration (mm per pixel \pm error)
- Record Gun HV
- Power limit of 10 W (30 μ A, 350 kV) on first slit (not water-cooled) – otherwise may deform gap
- Two vertical magnetic beam scanners: one before first slit and one between two slits – each has two pairs of identical air core coils with equal and opposite excitation in each coil
- Measurement steps: 100×100 at 200 Hz (1 minute each measurement) – Radiabeam coils with steel core are too slow
- Need four air core coils and Faraday cup with fast controls and readout

Need to develop hardware, firmware and scripts
for calibrations and to calculate emittance

Slits Survey and Alignment

- I. To ensure symmetric transverse phase space distributions:
 - I. Beam axis from center of photocathode (electrostatic center of gun) through solenoids and slits to better than 0.1 mm (?)

Summary

- I. Solenoid and Viewscreen technique is ready, Single Slit and Viewscreen needs software development while Double-slit and Faraday Cup technique requires new hardware and software.
- II. Measure laser distribution for each emittance measurement – must account for laser being not at normal incidence.
- III. Calibrate beam size on each viewscreen using its frame
- IV. For space-charge dominated beam, solenoid scan suffers from systematic errors – beam envelope is under the influence of both space-charge and emittance effects. $(\sigma^2, 1/f)$ plot has to be symmetric about minimum – unreliable emittance if not.
- V. Calculate thermal emittance by tracing back to photocathode measured emittance at solenoid or first slit