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 G^2-cm at I^2=1 A^2

II. Focal Length (1/mm): $\frac{1}{f} = \frac{c^2\ B2L\ I^2}{4\times10^{13}\beta^2\gamma^2 m_e^2}$

III. Parabola fit: $\sigma_x^2 = \sigma_y^2 = R_{12}^2\Sigma_{11} + 2R_{11}R_{12}\Sigma_{12} + R_{12}^2\Sigma_{22}$

IV. $R_{12} = d$ and $R_{11} = 1 - d\cdot\frac{1}{f}$

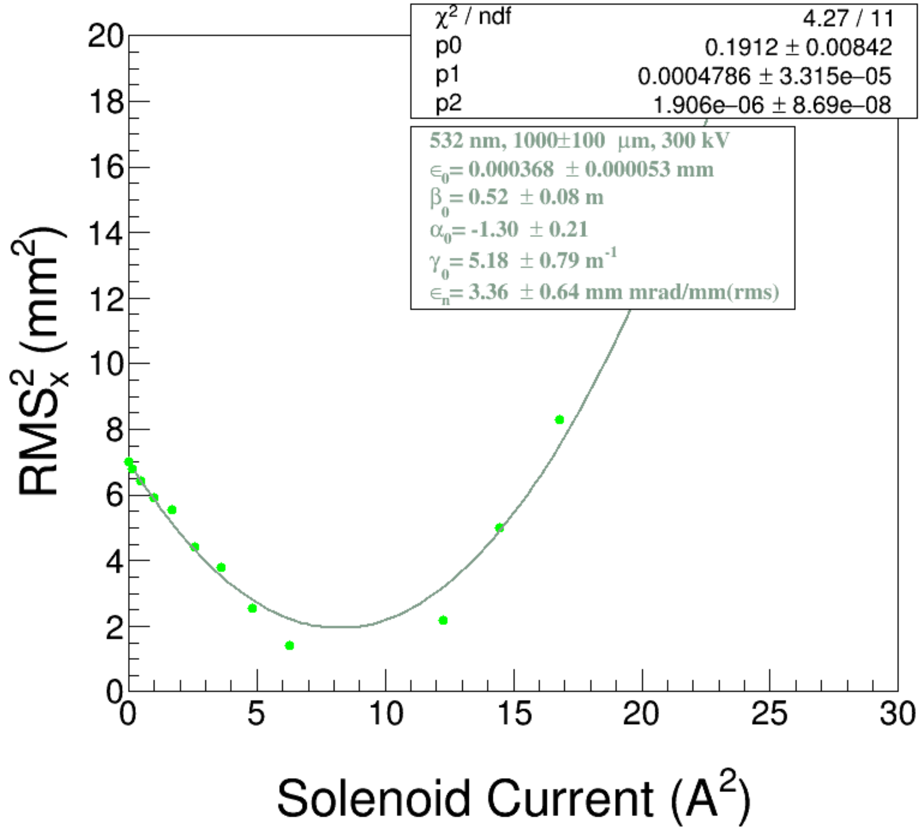
V. Geometric Emittance (mm mrad): $\varepsilon_y = 10^3\cdot\pi\sqrt{\Sigma\Sigma_{11}\Sigma_{22} - \Sigma_{12}^2}$

VI. Normalized Emittance (mm mrad/mm (rms)):

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

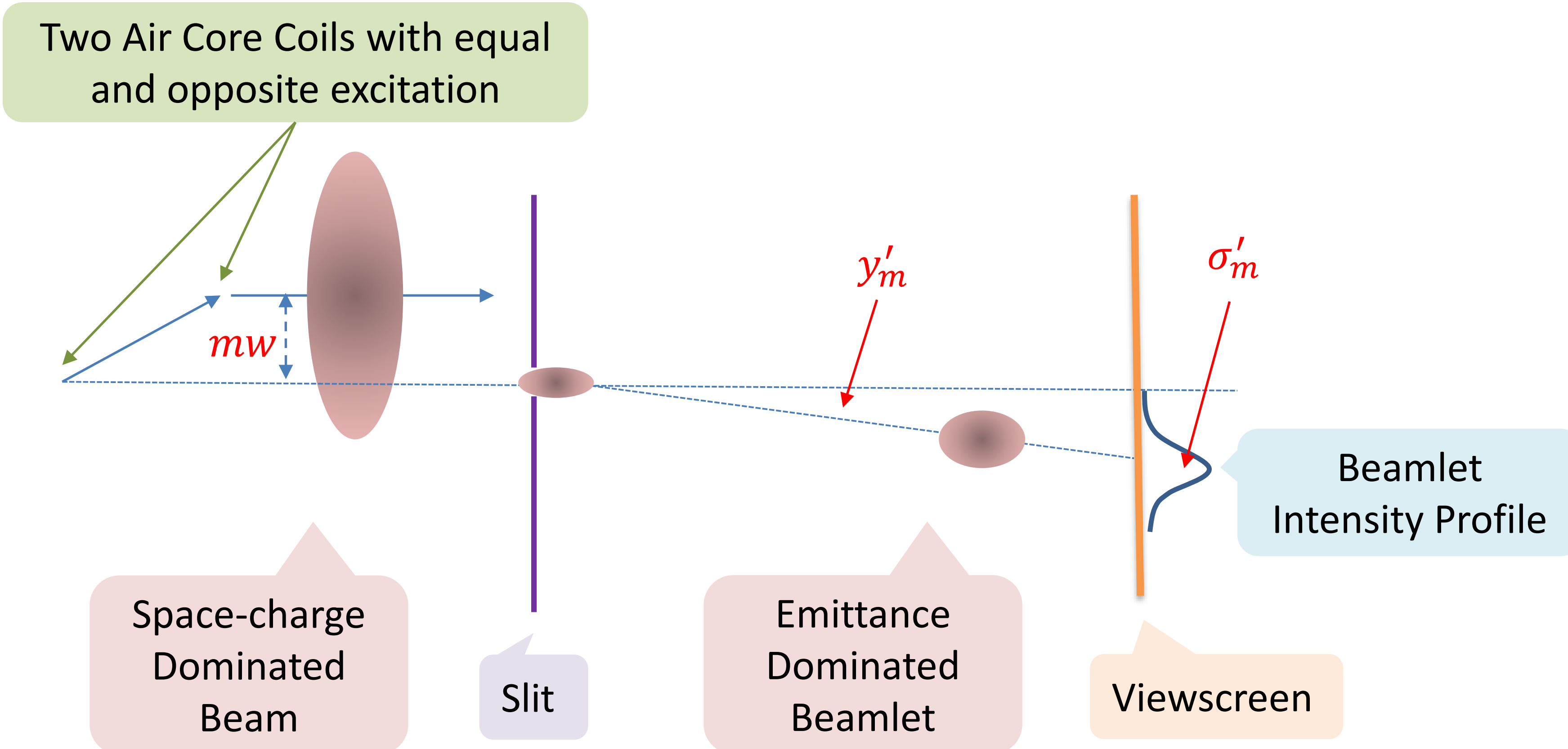
Measurement Details:

- Measure laser RMS (± error)
- Find camera pixel calibration (mm per pixel ± 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, …, N) with constant w step size
  (N ~ 20, w ~ 0.5 mm)

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

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

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

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

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

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

where I_m is measured integrated intensity in mth beamlet

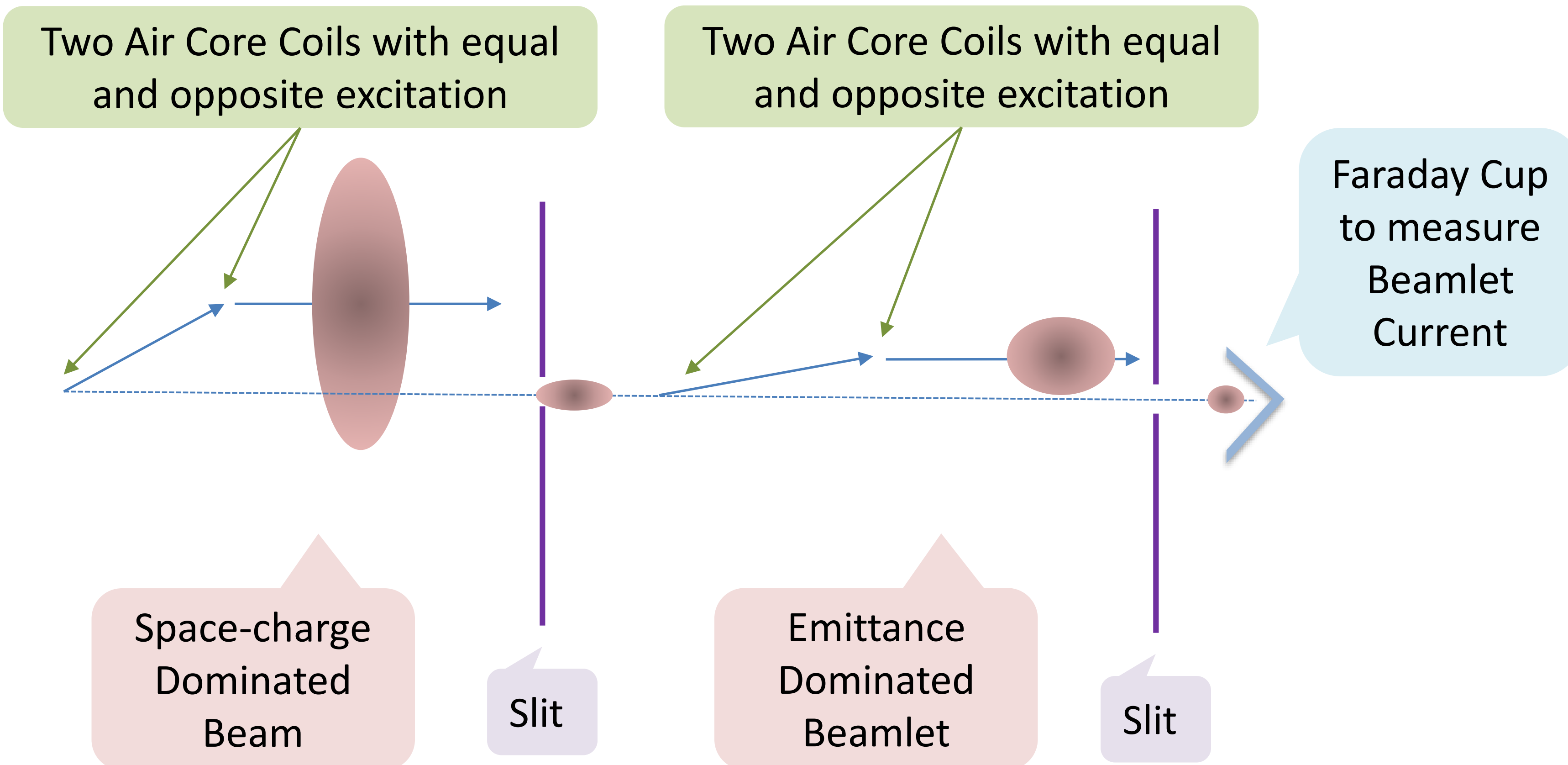
$$\varepsilon_y = \pi \sqrt{\langle y^2 \rangle \langle y'^2 \rangle - \langle yy' \rangle^2}$$

Measurement Details:

- Measure laser RMS (± error)
- Find camera pixel calibration (mm per pixel ± error)
- Record Gun HV
- Power limit of 10 W (30 μA, 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 × 100 at 200 Hz (1 minute each measurement)

Measurement Details:

- Measure laser RMS (± error)
- Find camera pixel calibration (mm per pixel ± error)
- Record Gun HV
- Power limit of 10 W (30 µA, 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