SUBLINEAR INTENSITY RESPONSE OF CERIUM-DOPED YTTRIUM ALUMINIUM GARNET SCREEN WITH CHARGE

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ABSTRACT

- APS-U swap-out injection necessitates ~17 nC electron bunches at 6 GeV.
- Diagnostic imaging screens are envisaged in the BTS.
- Important to determine whether the response of these screens to charge is linear.
- In the present work, we examine the effect of sublinear intensity quenching of a Cerium-doped Yttrium-Aluminium-Garnet scintillator screen.
- At 7 GeV, charge density $\rho \leq 10\ \mathrm{fC\ \mu m^{-2}}$, approximately 10 % reduction of the imaging intensity due to scintillator quenching.

MOTIVATION

- Saturation of scintillator screens has represented a challenge for beam imaging at many facilities – in particular linacs – e.g. recently at Euro-XFEL [1].
- At the APS, prior work on scintillator linearity included experiments using the electron linac [2, 3].
- With high-charge bunches through the BTS transport line for the Advanced Photon Source Upgrade (APS-U), will scintillator linearity with charge be a significant detrimental effect?

SCINTILLATOR QUENCHING

- Scintillator quenching occurs when charge density of incident beam depletes the vacancies in the crystal, and the crystal does not produce light output at a rate proportional to the input charge density [4–6].
- We consider limits to quenching of the scintillator along the theory of Birks [7].
- Results in approximate upper charge density limits of $16\ \mathrm{fC\ \mu m^{-2}}$ for LYSO scintillators [8], and $20\ \mathrm{fC\ \mu m^{-2}}$ for YAG:Ce scintillators [9].
- Quenching is possible in Chromox ($\mathrm{Al_2O_3{:}\,Cr}$), however contemporary applications of Chromox scintillators for imaging are typically proton rather than electron beams.
- Optical Transition Radiation (OTR) has no quenching limit: the limit is probably the damage threshold of the material surface. In practice, if an electron bunch is short (~tens of fs duration), the practical limit for OTR is probably the presence of Coherent Optical Transition Radiation.
- Even for bunches of ~ps duration, COTR will occur when there is microbunching, or if there is a narrow current spike.

METHOD

- In the present work, we use a 7 GeV electron beam coming from the booster, imaged using the fluorescent screen BTS:FS3 [10].
- Quenching of the scintillator reduces the light output of the scintillator at locations on the screen with highest charge density.
  - In effect, this results in fitting the 'tails' of the distribution, and essentially it appears that the image of the beam on a scintillator is larger than the rms electron beam size.
- We evaluate the electron beam size as a bivariate Gaussian distribution, in order to quantify the areal charge density.
  - The equation of a bivariate Gaussian distribution in coordinates x_i, with means μ_i, standard deviations σ_i and is given by \cite{do_2008}:

$$p = \frac{1}{2\pi\sigma_1\sigma_2}\left(-\frac{1}{2\sigma_1^2}(x_1-\mu_1)^2 - \frac{1}{2\sigma_2^2}(x_2-\mu_2)^2\right)$$

  - Hence an electron beam with a profile that is Gaussian in two dimensions with root mean square beam sizes σ_1, σ_2, we can describe the peak electron charge density ρ by:

$$\rho = \frac{q}{2\,\pi\sigma_1\sigma_2}$$

RESULTS – REGULAR BEAM

Figure 1: Images of the beam with charge. (a) 0.52 nC. (b) 1.06 nC. (c) 3.2 nC. (d) 4.6 nC.

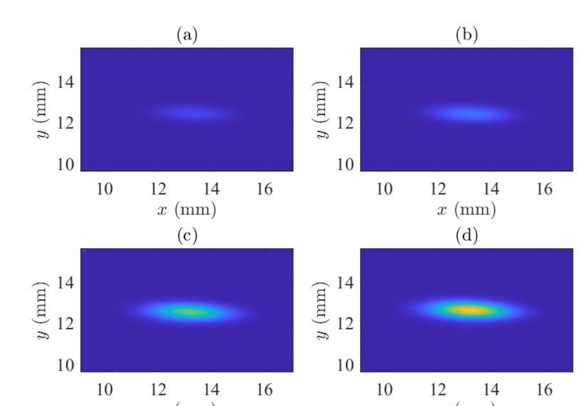


Figure 2: Fitted electron beam sizes as a function of electron beam charge.

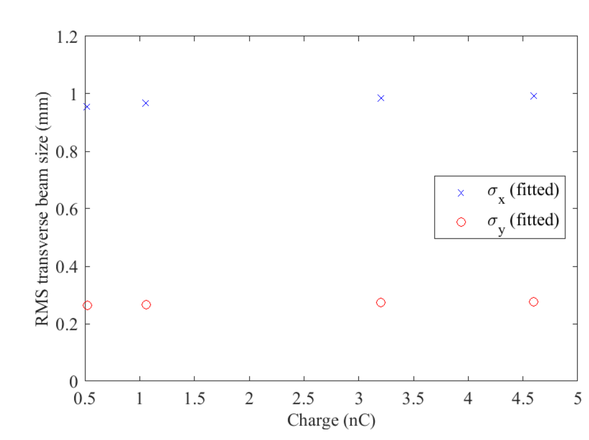


Figure 3: Fitted peak intensity as a function of electron beam charge.

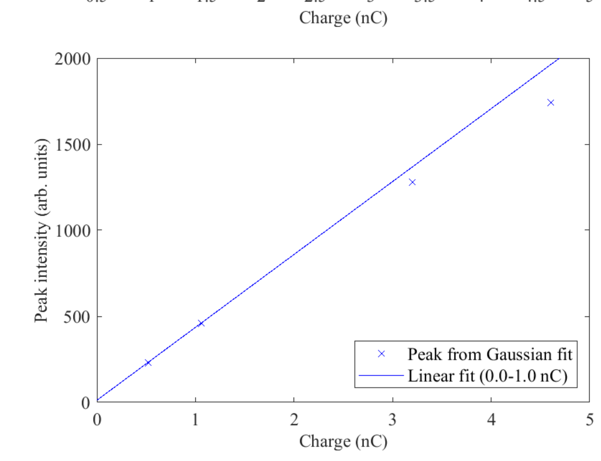
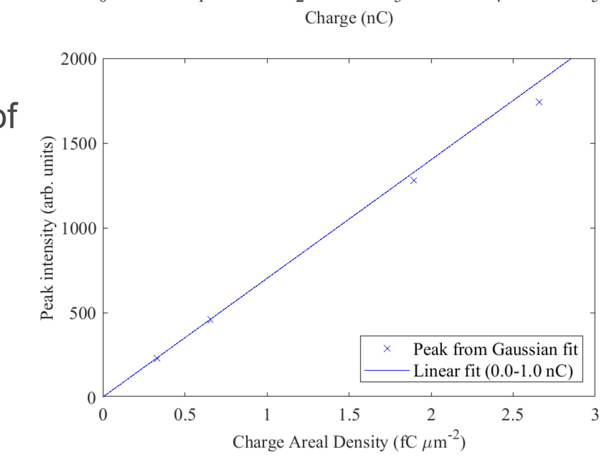


Figure 4: Intensity as a function of peak charge areal density.



RESULTS – FOCUSSED BEAM

Figure 5: Images of the beam as a function of charge. (a) 0.070 nC. (b) 0.15 nC. (c) 0.50 nC. (d) 1.0 nC. (e) 1.5 nC. (f) 2.0 nC.

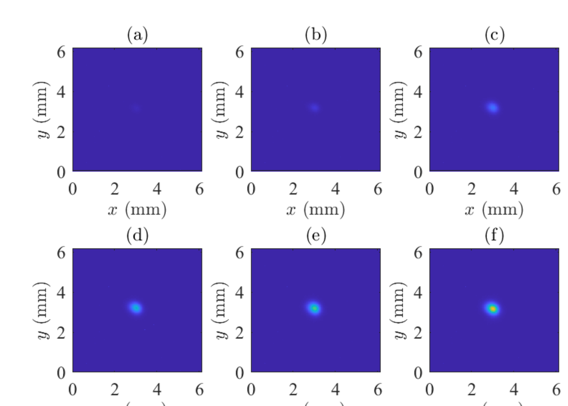


Figure 6: Fitted electron beam sizes as a function of electron beam charge.

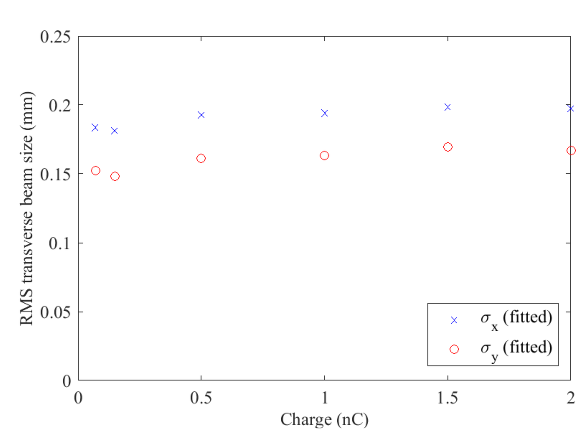


Figure 7: Fitted peak intensity as a function of electron beam charge.

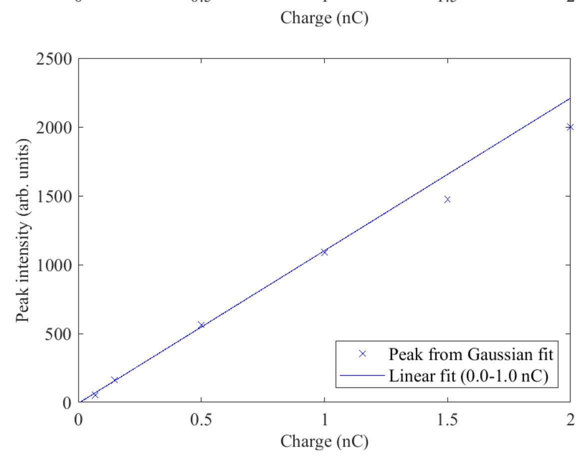
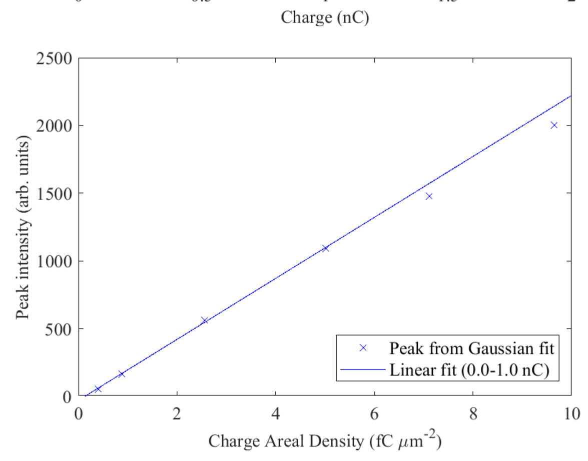


Figure 8: Intensity as a function of peak charge areal density.



DISCUSSION

- At the charge densities investigated ($\rho \leq 10\ \mathrm{fC\ \mu m^{-2}}$), even though we start to observe nonlinear behaviour of the scintillator, Figs. 2, 6 show negligible change to the measured beam sizes.
- However, at charge areal densities $\rho \geq 10\ \mathrm{fC\ \mu m^{-2}}$, one should anticipate that the size of the electron beam determined from the scintillation profile would become increasingly unreliable.

SUMMARY

- In conclusion, measurements of the electron beam on the BTS:FS3 screen were made.
- At 7 GeV beam energy leaving the booster, over the charge densities investigated ($\rho \leq 10\ \mathrm{fC\ \mu m^{-2}}$), an approximately 10 % reduction of the imaging intensity due to quenching of the scintillator was observed.

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