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University of Wisconsin-Synchrotron Radiation Center TECHNICAL NOTE	File No. 220	Page 3
Subject: Modeling of the Initial Charge ‘Pancake’ at the Cathode for Production of ‘Blowout’ Mode Bunches	Author(s): Legg, R.	
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In order to model an electron gun which produces an ellipsoidal bunch using the “blow out” mode, an analogue of the initial “pancake” of charge produced at the cathode by a corresponding drive laser pulse must be simulated. This initial “pancake” of charge must have the correct “hemispherical” transverse density profile [1], Fig 1

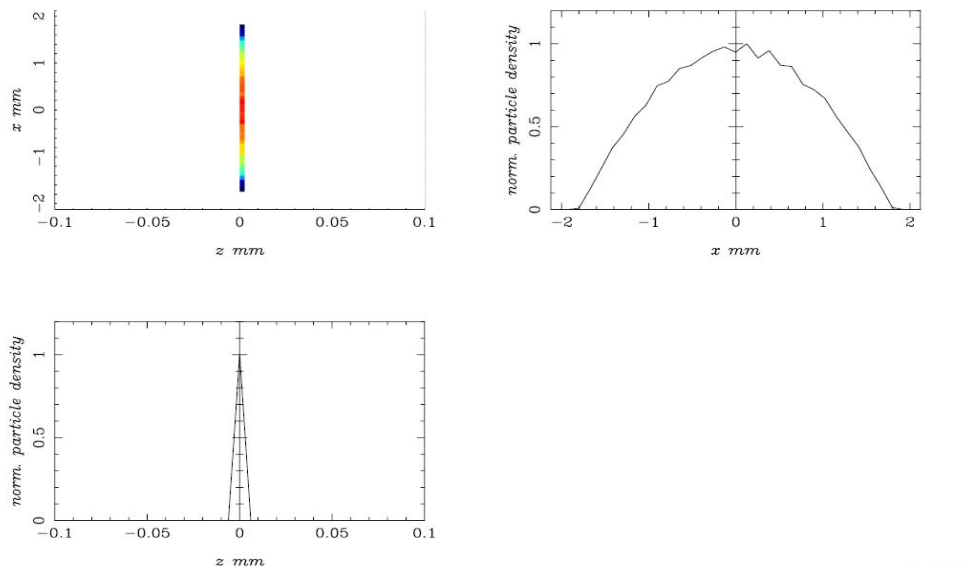


Figure 1

The particles in this distribution should also model the ‘thermal’ emittance, associated with the laser spot size and the particular cathode material. I’ve been using Cs2Te as a cathode material because of its relative high QE when compared to metal cathodes and prompt response when compared to Cs:GaAs. Cs2Te has a measured, projected, ‘thermal’ emittance of roughly 1 mm-mrad/mm RMS of laser spot size [2]. ASTRA [3] has a module called *Generator* which allows the user to choose a uniform ellipsoidal distribution which reproduces the hemispherical transverse distribution. Using this built-in distribution in *Generator*, the initial charge ‘pancake’ can be defined transversely using the built-in uniform ellipsoidal distribution, the initial RMS radius for the charge pancake, and the transverse emittance which is defined by that radius and the cathode material.

Longitudinally the model is even simpler. According to [4], so long as the laser pulse is short enough compared to the length of the inflated bunch, ~0.01 in this case, any particle distribution acts like an impulse function and will evolve to the desired ellipsoid with constant charge density under the effects of space charge forces. In my standard simulations, the longitudinal distribution is defined by the ‘uniform ellipsoid’ distribution and the RMS emission time is set by a variable to 30 fsec. The

longitudinal kinetic energy profile used models the electron energy distribution from a Cs2Te cathode; $\sim 0.6\text{eV}$ depending on the laser wavelength. The distribution should look like an almost mono-energetic spike when viewed in longitudinal profile.

The Generator input file looks like:

```
&INPUT
  FNAME = 'ellipsegun.ini'
  Add=.F.
  N_add=1
  IPart=10000
  Species='electrons'
  Probe=.True.
  Noise_reduc=.T.
  Cathode=.T.
  Q_total=0.20E0
  Ref_zpos=0.0E0
  Ref_clock=0.0E-5
  Ref_Ekin=0.0
  Dist_z='uniform ellipsoid',
  sig_clock=1.5E-5, sig_x=0.8E0, sig_y=0.8E0
  Nemit_x=0.74E0, Nemit_y=0.74E0
/
```

This produces a distribution file with columns of numbers representing x, y, z, px, py, pz, clock, charge, particle index and a particle status flag. For more details, see the documentation at http://www.desy.de/~mpyflo/Astra_dokumentation/. As a practical measure, ASTRA supplies another utility called *Postpro* which can display the distribution graphically. Because the initial distribution was generated in a temporal rather longitudinal coordinate, the initial distribution will not have a length, only an emission time. In using *Postpro* with an .ini file, only one of the two longitudinal displays, t or z, will have valid data in it, but this is still a very useful tool in order to check the initial cathode spot size and energy distribution. A typical distribution is shown in Figure 2. Note that the projection of the plot of x or y versus particle density will be a parabola for a hemispherical distribution, since the projection includes the density variation due to the bunch shape as well as the particle distribution.

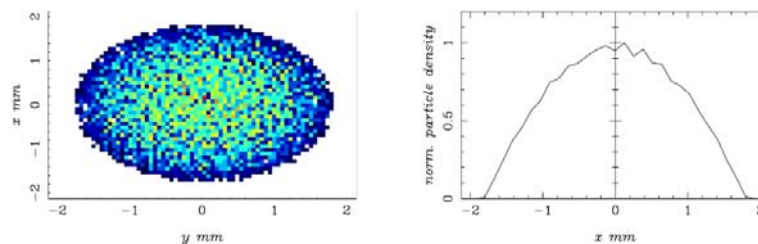


Figure 2

The one problem with using this method to generate an initial distribution is that the longitudinal distribution profile cannot be controlled; it's always ellipsoidal. If a non-ellipsoidal distribution is desired, then there is a second approach to generating an initial distribution with a hemispherical transverse distribution. The approach uses *Generator*'s ability to add multiple distributions together. The transverse distribution is divided into a set of charge 'pancakes' of different diameters with uniform charge distribution. The diameters of the 'pancakes' are chosen such that when added together – 'stacked' – the correct transverse distribution is produced. Since each charge 'pancake' is specified individually, any longitudinal distribution profile can be selected. The particle density distribution produced will have edges where each 'pancake' is added to the 'stack', but if a sufficient number of individual distributions are added together initially, the edges become small overall much like a Newton's approximation of a function going toward the limit.

To produce 'pancakes' which have the correct amount of charge for a given diameter, it is necessary to solve the integral for a sphere in x and then use the formula below to calculate the volume in a slice whose thickness is a fraction of the radius of the sphere and then normalizing to the total bunch charge, . This method lends itself to spreadsheet solutions, and for convenience

I use 10 slices per hemisphere to generate my distributions. The transverse distribution, with projections, for this initial distribution is shown in Figure 3. For most runs the simpler uniform ellipsoidal distribution is used for its smoother, more uniform distribution.

$$\text{Charge in slice} = \pi \left[r^2 x - \frac{x^3}{3} \right]_{x_1}^{x_2} \times Q_{Total} / \frac{2\pi r^3}{3}$$

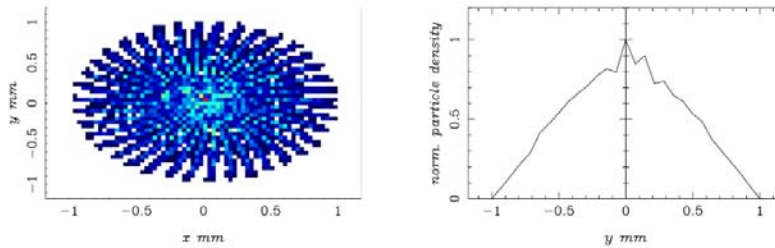


Figure 3

DETAILS: In order to model non-uniformities in the photocathode's emission, it is possible to add additional bunches created using generator to the "perfect" initial distribution. These additional distributions can be made using smaller, off-axis spots which simulate emission hot spots on the cathode. This allows the user to create emission sites on the cathode which are transversely off axis from the bulk of the emitted beam or that have significantly different emittance properties from the bulk of the beam, for example a field emitter on a photocathode. An example distribution is shown in Figure 4. By running simulations using initial distributions with imperfections, their effect on the final bunch profiles, emittance and energy distributions can be estimated.

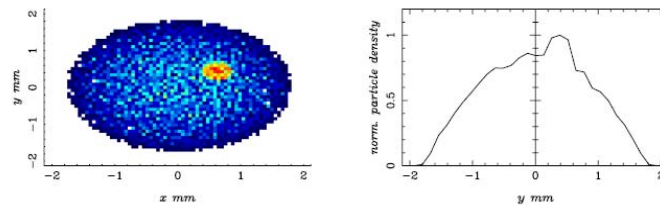


Figure 4

Bibliography:

1. O.J. Luiten, S.B.van der Geer, et al. Phys Rev Lett. **93**, 094802 (2004)
2. V. Miltchev, *Investigations on the transverse phase space at a photo injector for minimized emittance*, Dissertation, University of Berlin, Feb 3, 2006
3. K. Flottmann, <http://www.desy.de/~mpyflo/>
4. C. Limborg-Deprey, P. Bolton, *NIM-A*, **557** (2006) 106-116