WAVELENGTH-DEPENDENT SENSOR RESPONSE

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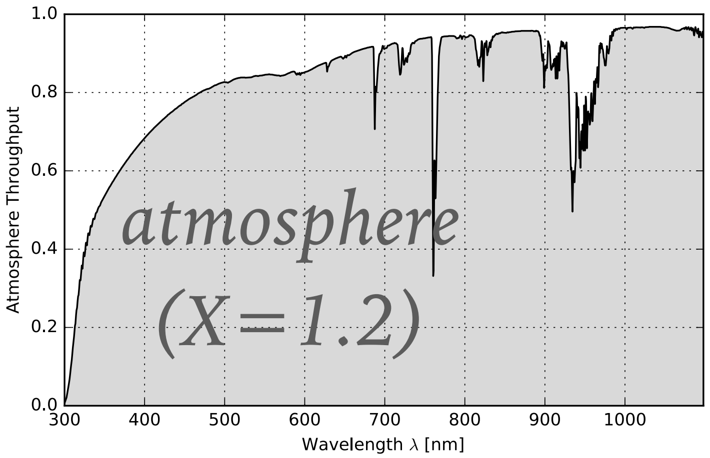
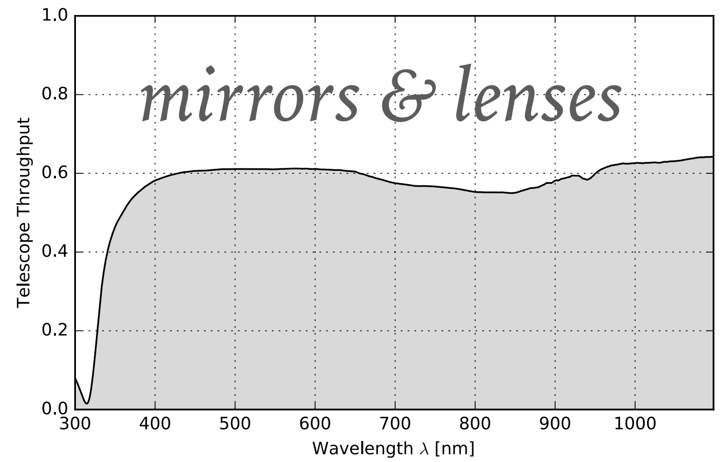
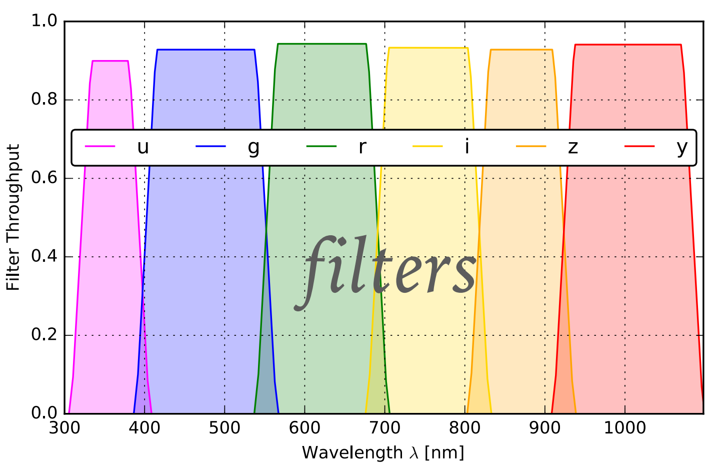
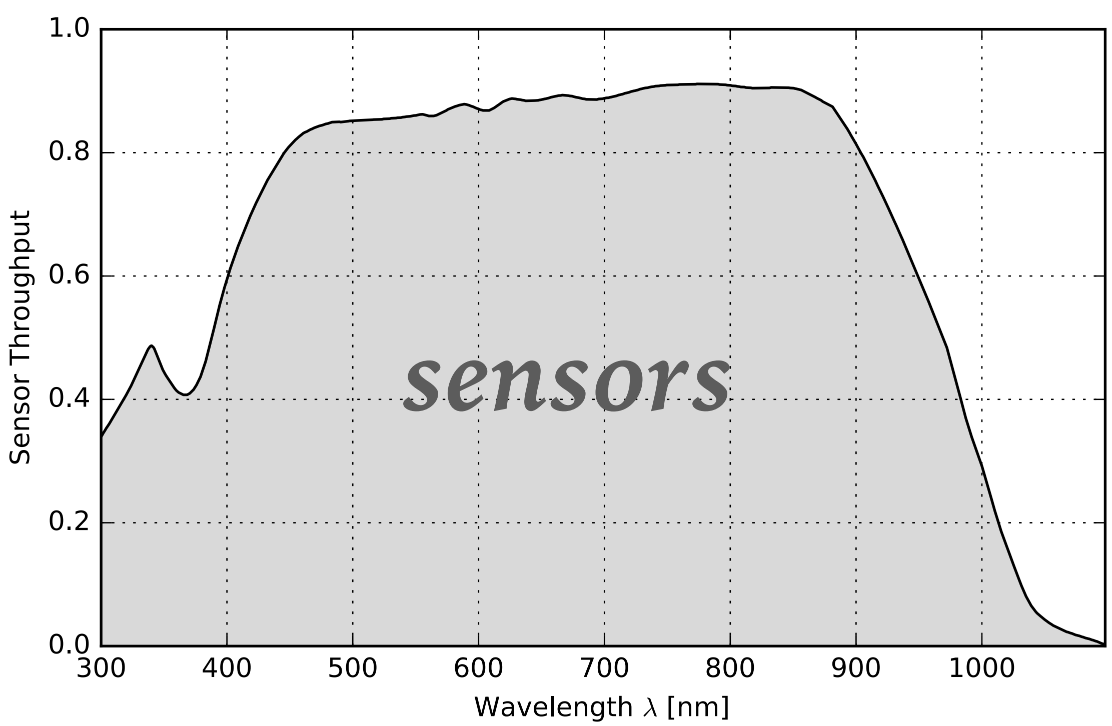
LSST DESC Collaboration Meeting, Oxford, July 2016.

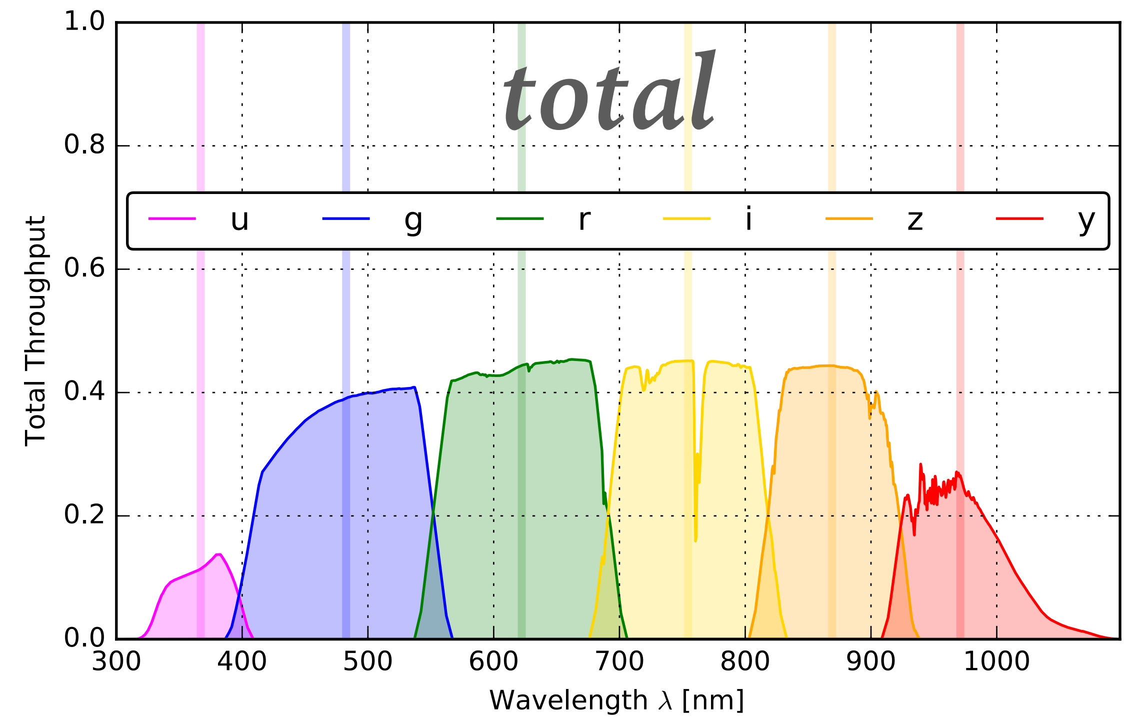
LSST WAVELENGTH RESPONSE



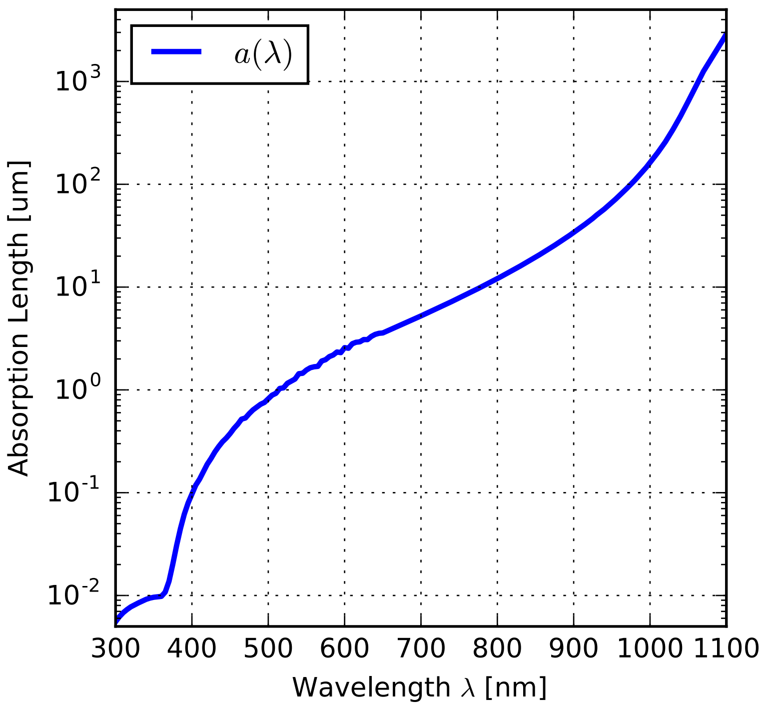


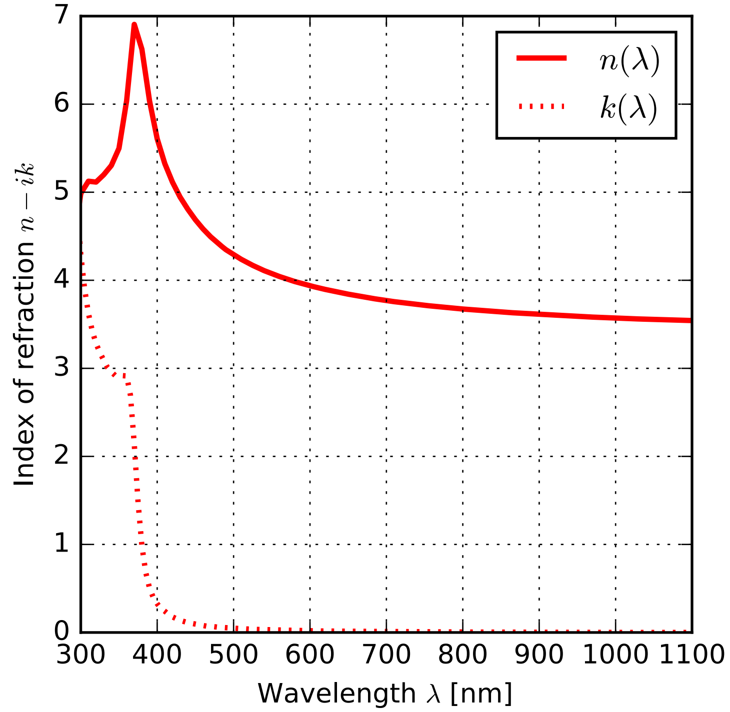






SILICON OPTICAL PROPERTIES



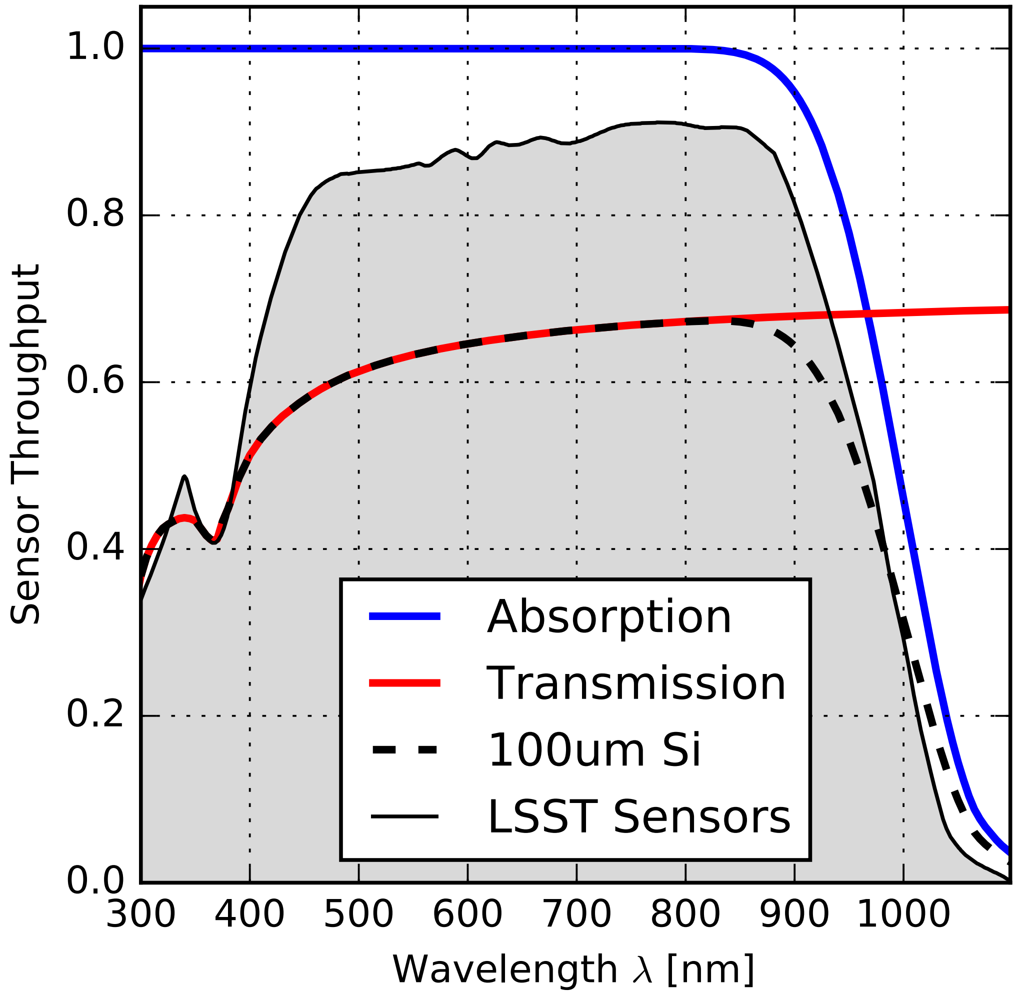


Absorption probability in Δz=100 μm:

$$A(\lambda, \Delta z) = 1 - \exp(-\Delta z / a(\lambda))$$

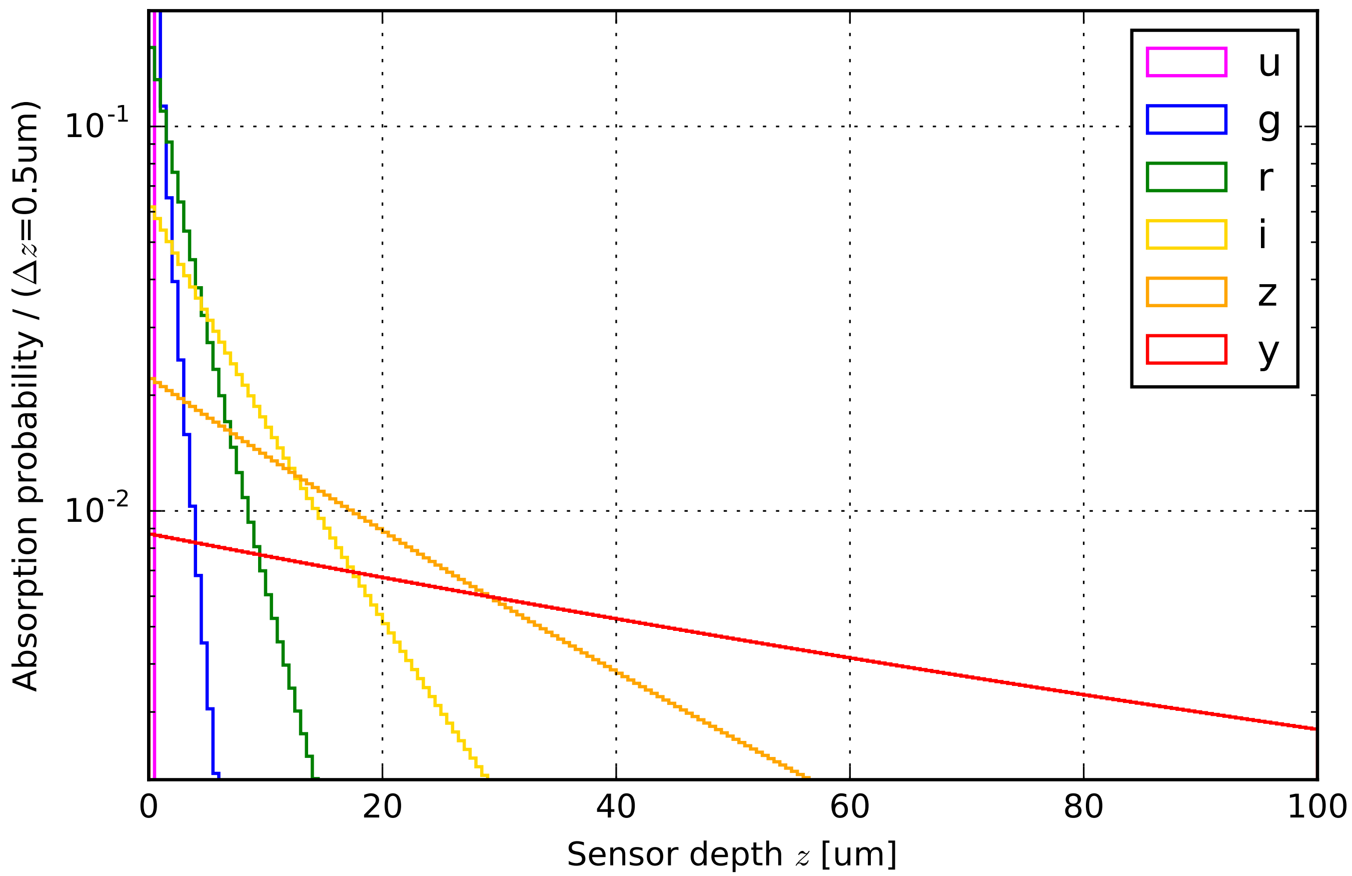
Transmission probability at 90° incidence:

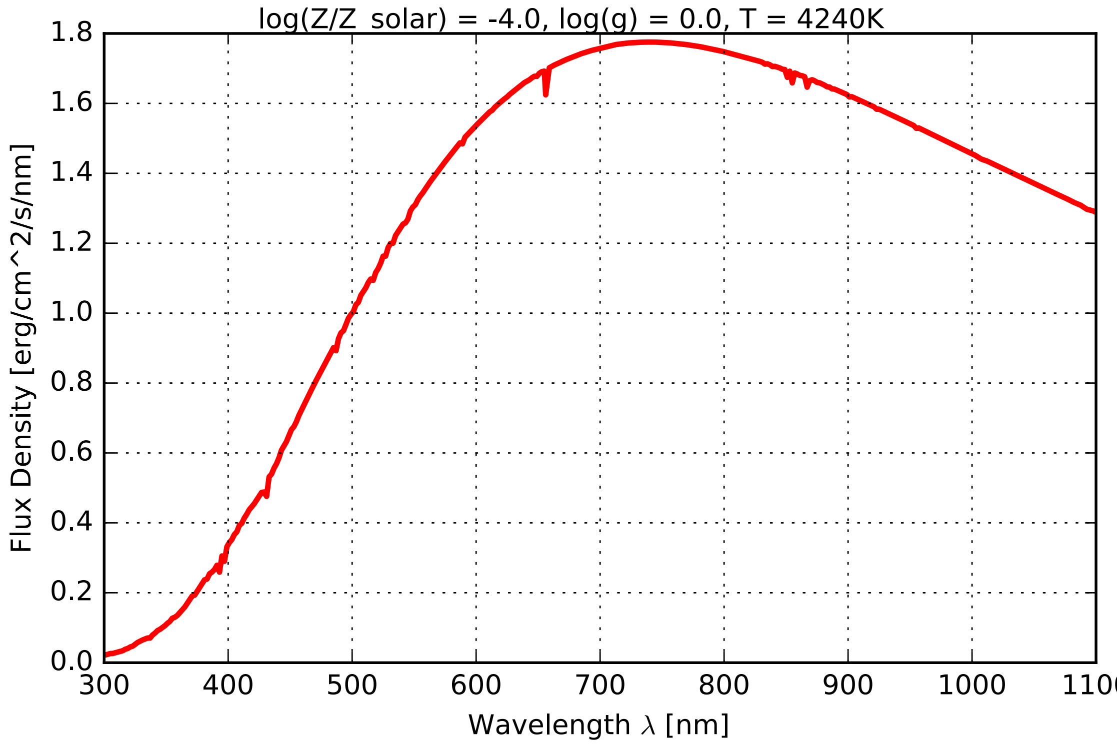
$$R(\lambda) = \frac{(n(\lambda) - n_0)^2 + (k(\lambda) - k_0)^2}{(n(\lambda) + n_0)^2 + (k(\lambda) + k_0)^2}$$

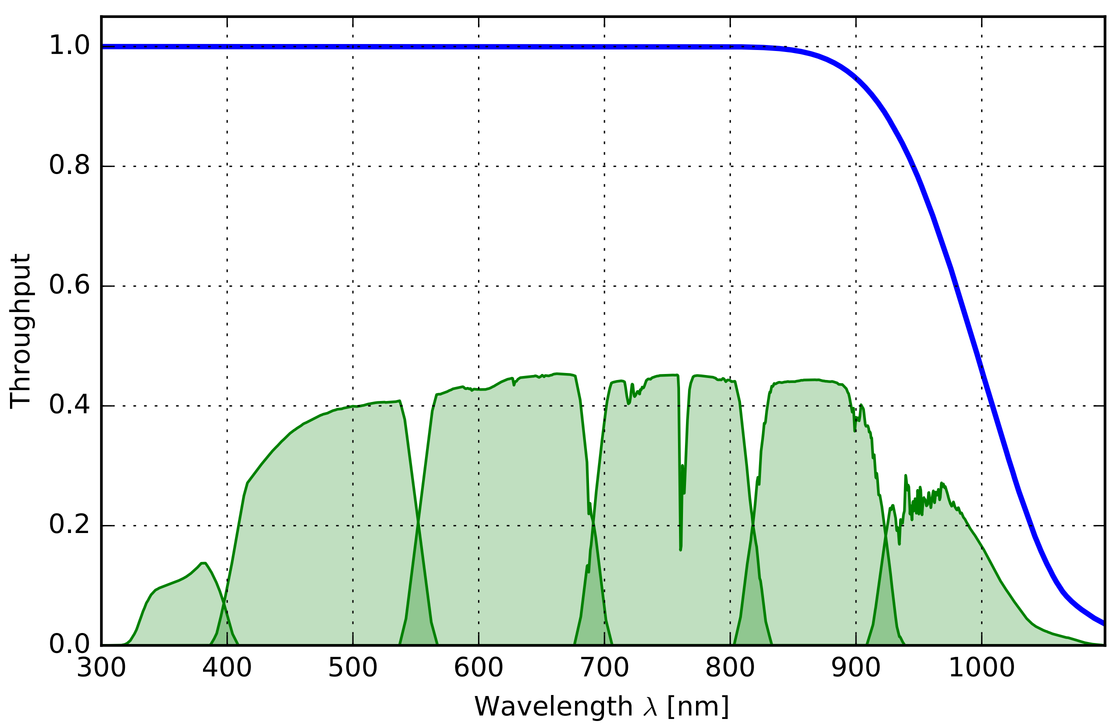


Depth profile of electrons due to a source viewed through a filter:

$$\frac{1}{N}\frac{dN}{dz} = \int s(\lambda) f(\lambda) \frac{e^{-z/a(\lambda)}}{A(\lambda, \Delta z)} \, d\lambda$$







How does "brighter-fatter" effect vary with the filter?

Solve Poisson's equation in quasi-static limit:

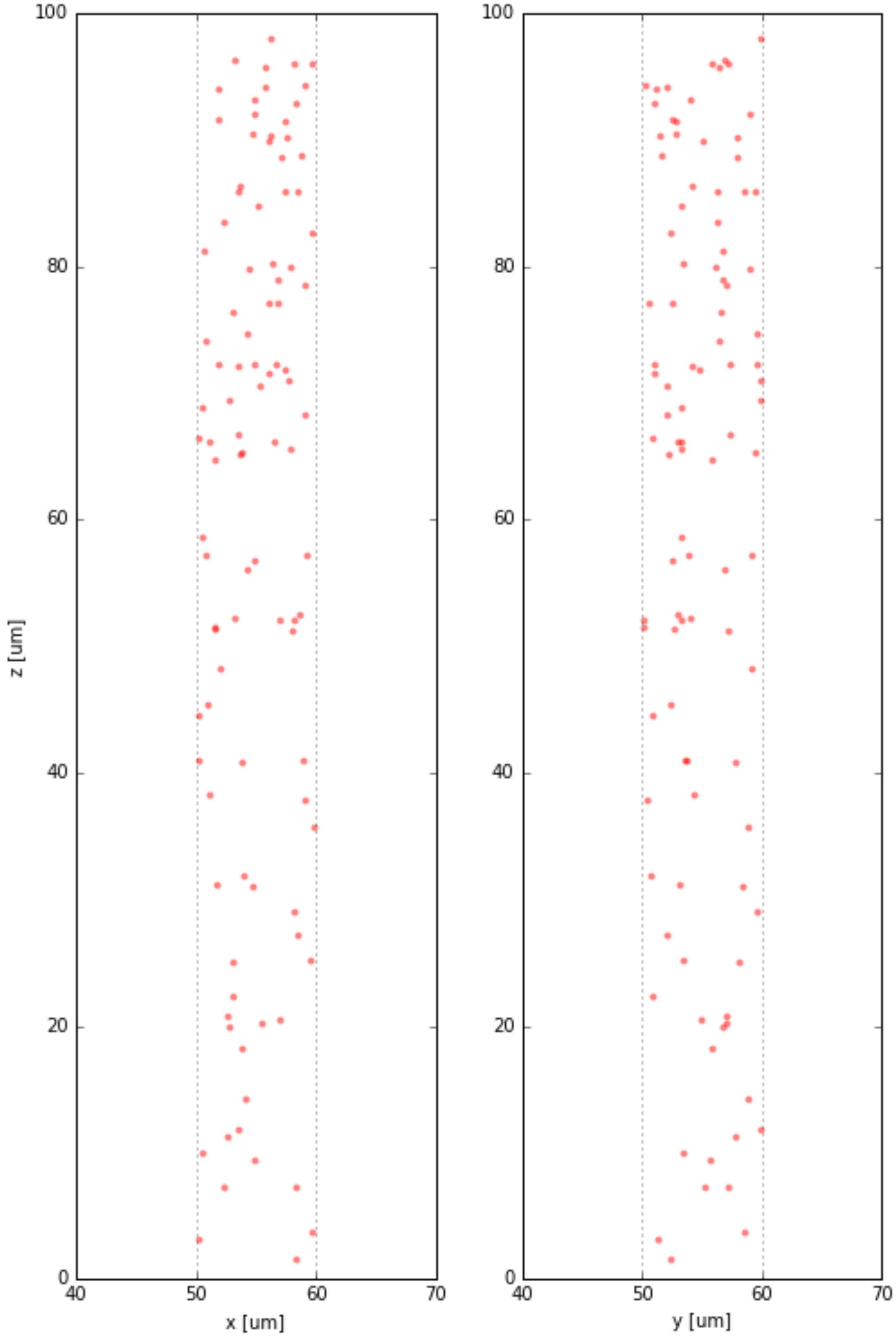
$$\nabla \cdot (\epsilon(x) \nabla \phi(x)) = \rho(x)$$

permittivity (geometry & materials)

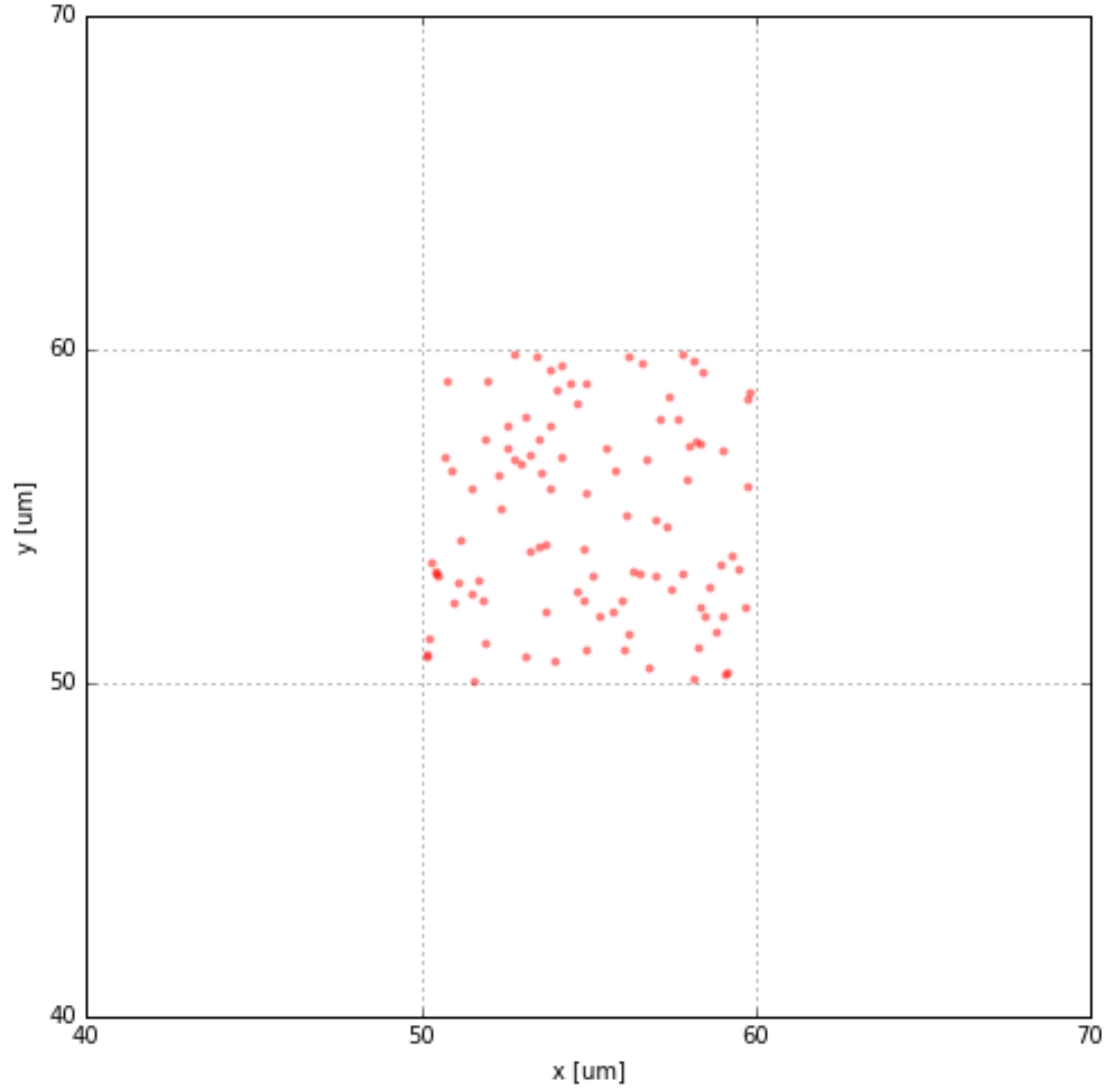
potential (bias & gate voltages)

charge density (static ions & mobile e + h)

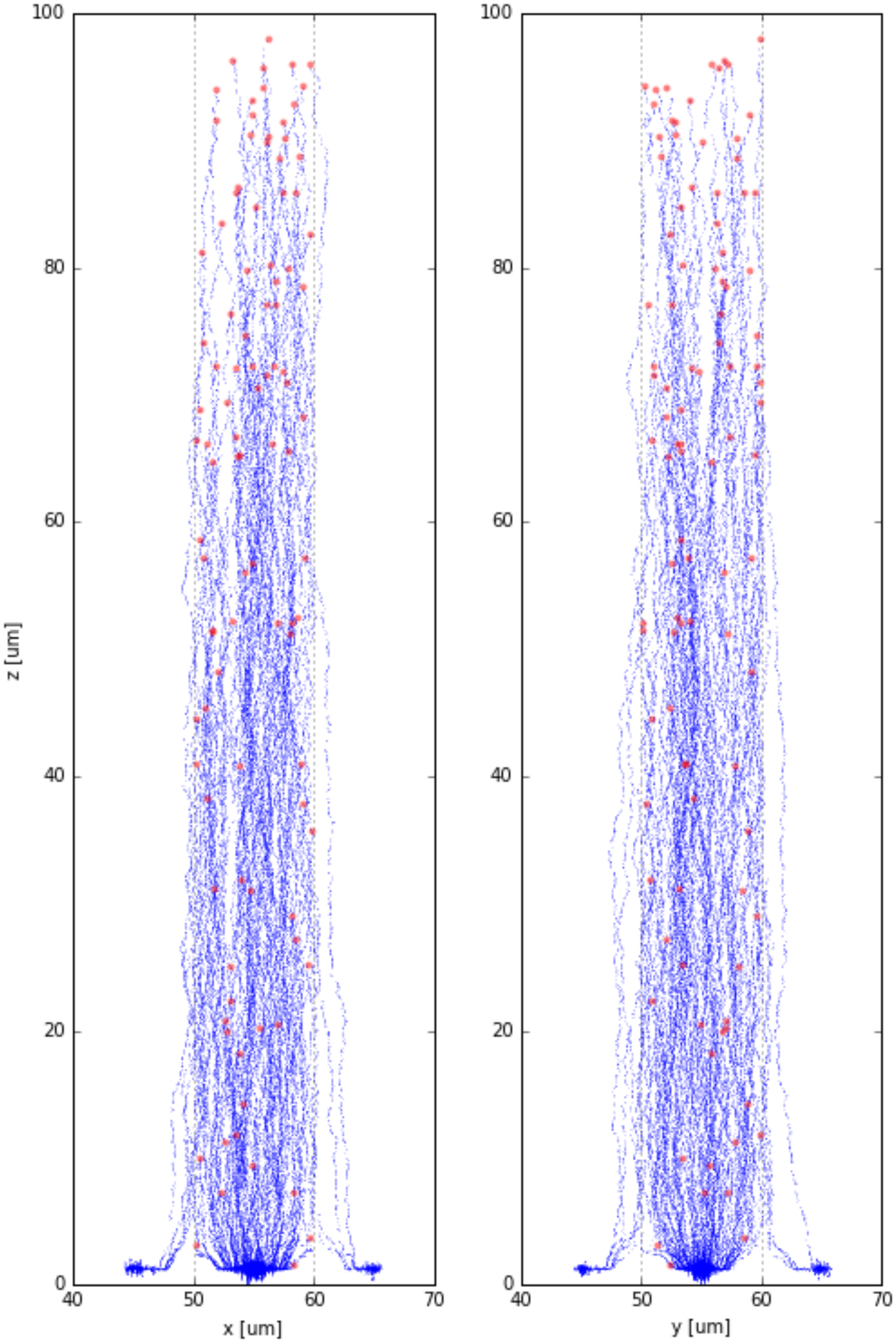
(Implemented in the wavelength_effects branch of Poisson_CCD22 repo.)



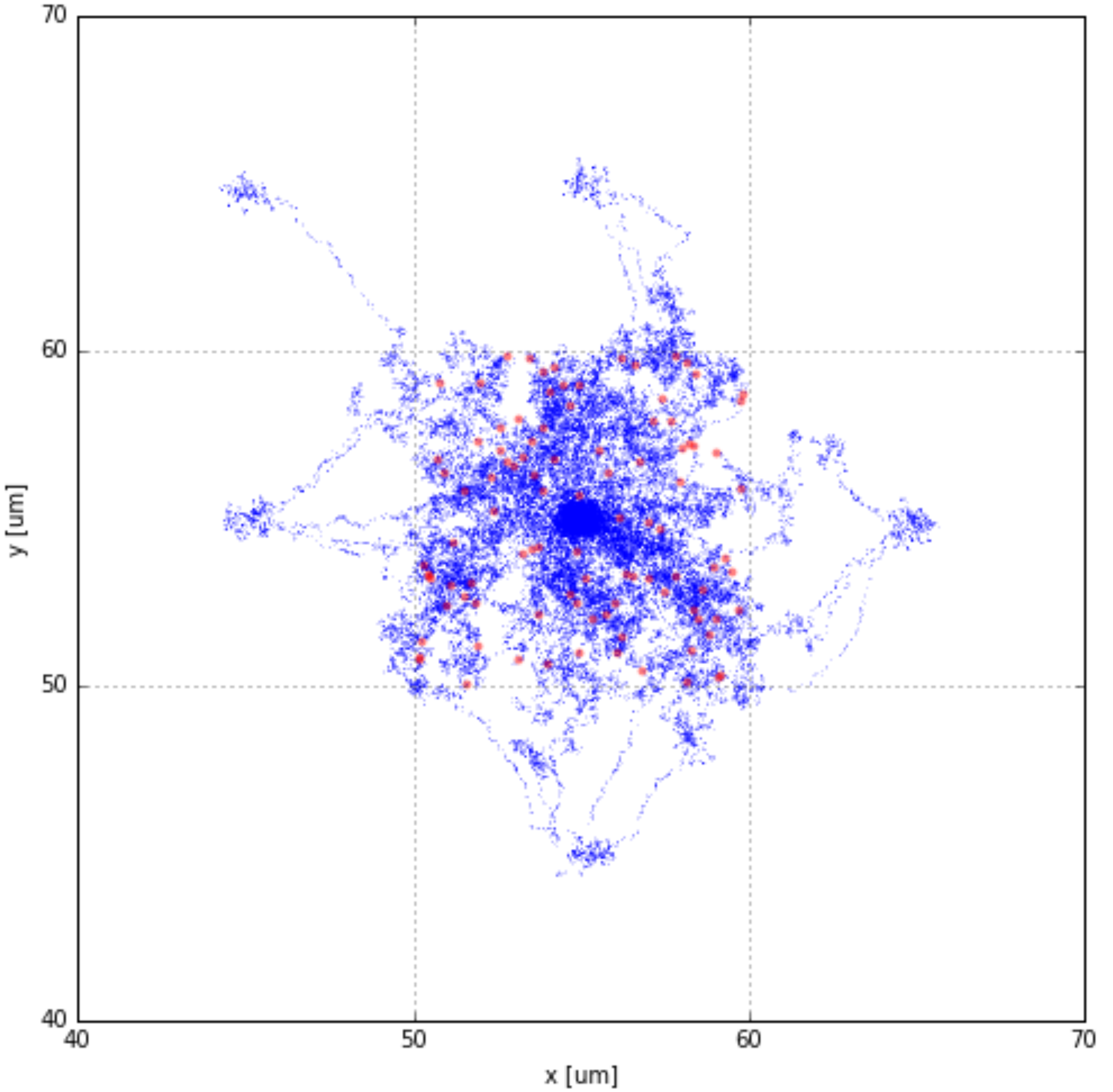
Y BAND
NO ACCUMULATED SIGNAL



Initial electron positions

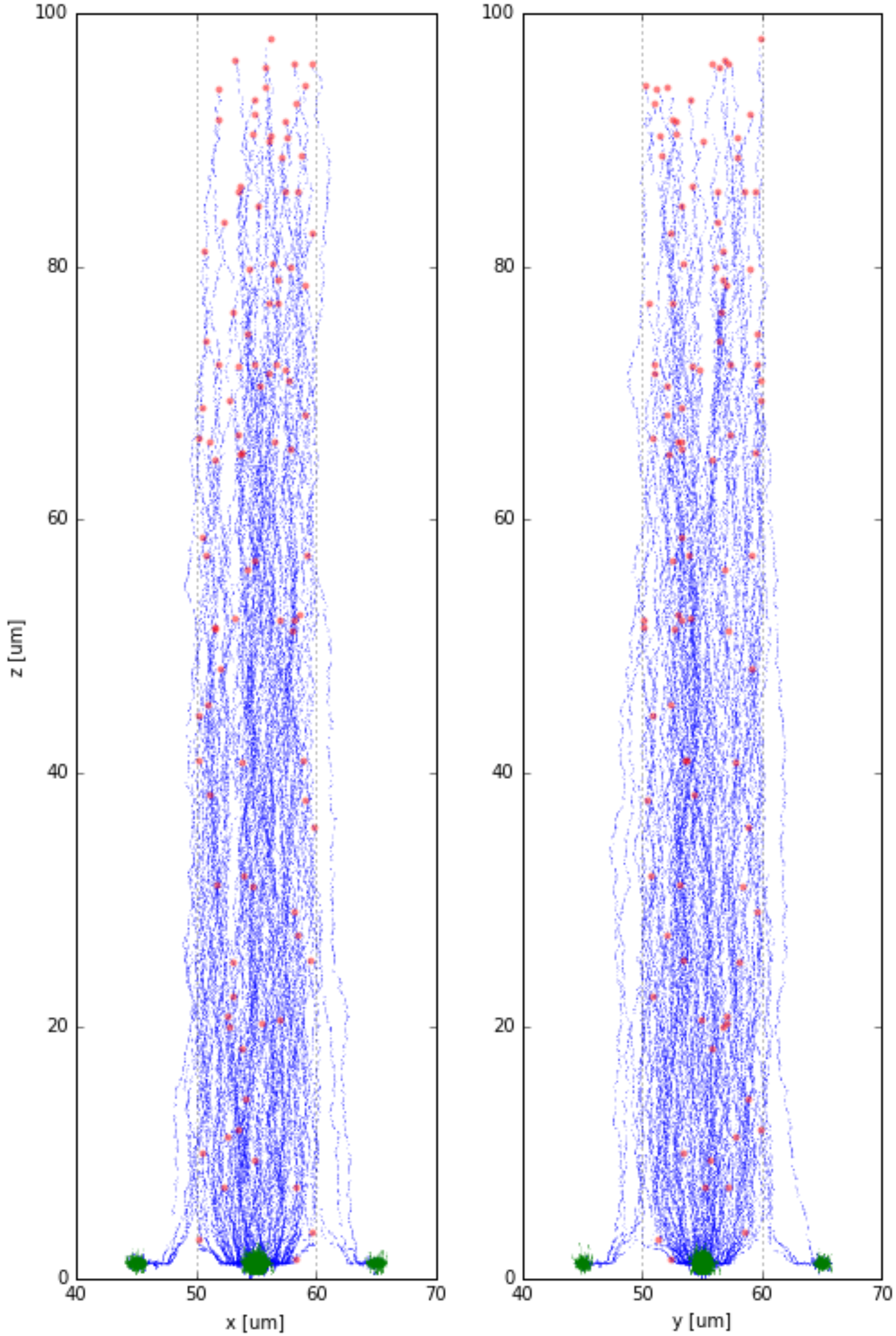


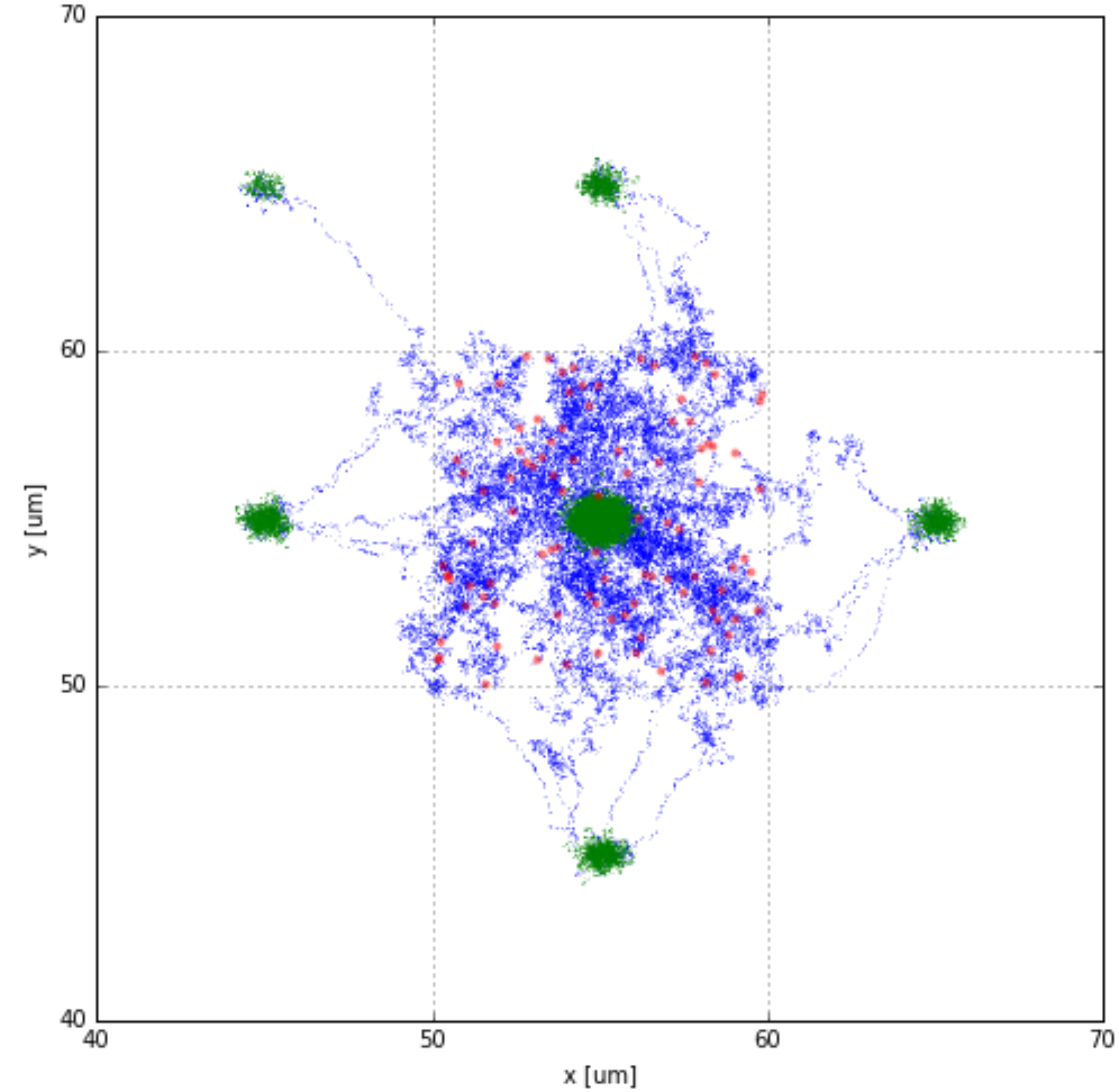
Y BAND
NO ACCUMULATED SIGNAL



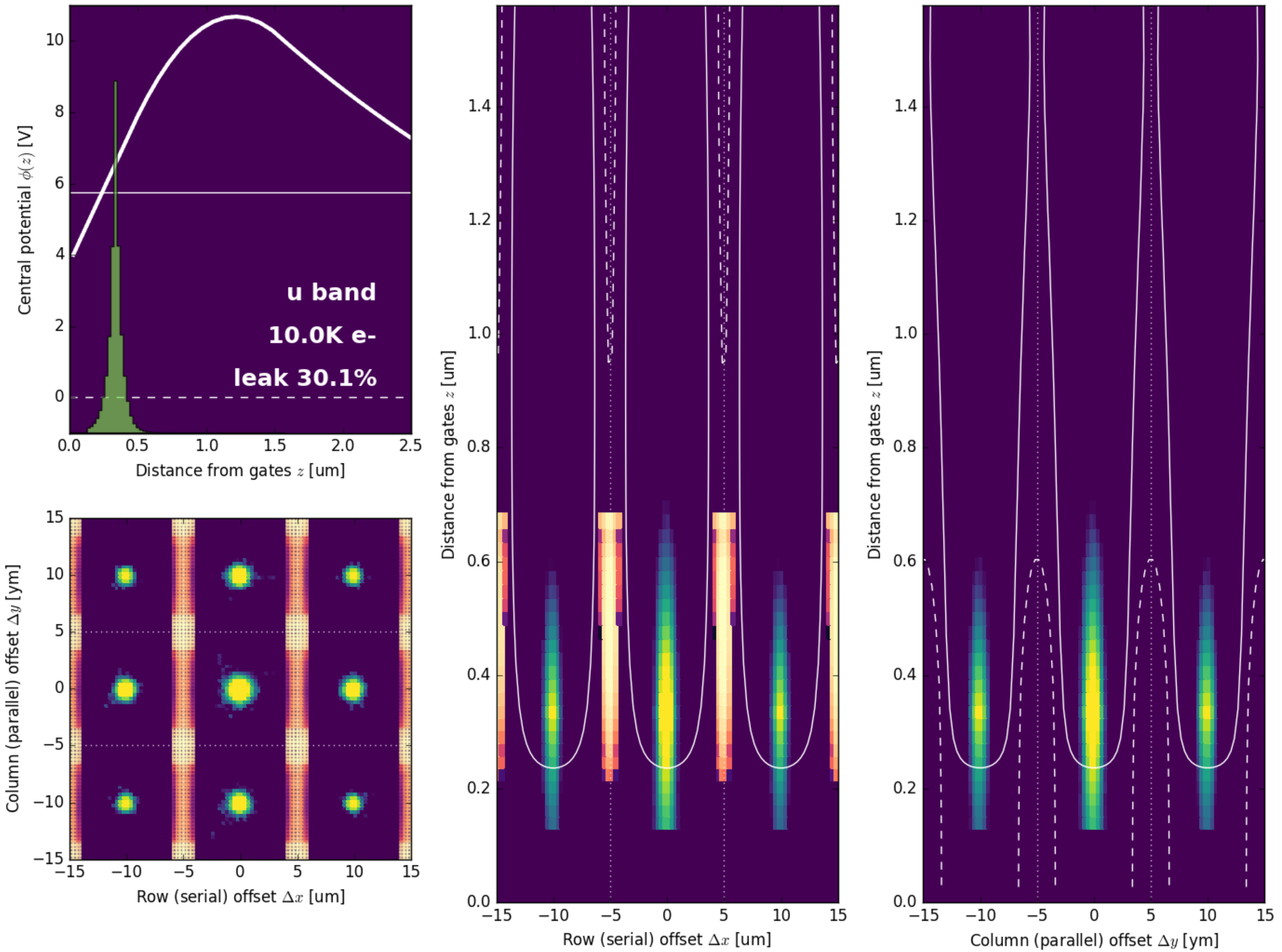
Electron tracks
(diffusion + E-field)

Y BAND
NO ACCUMULATED SIGNAL

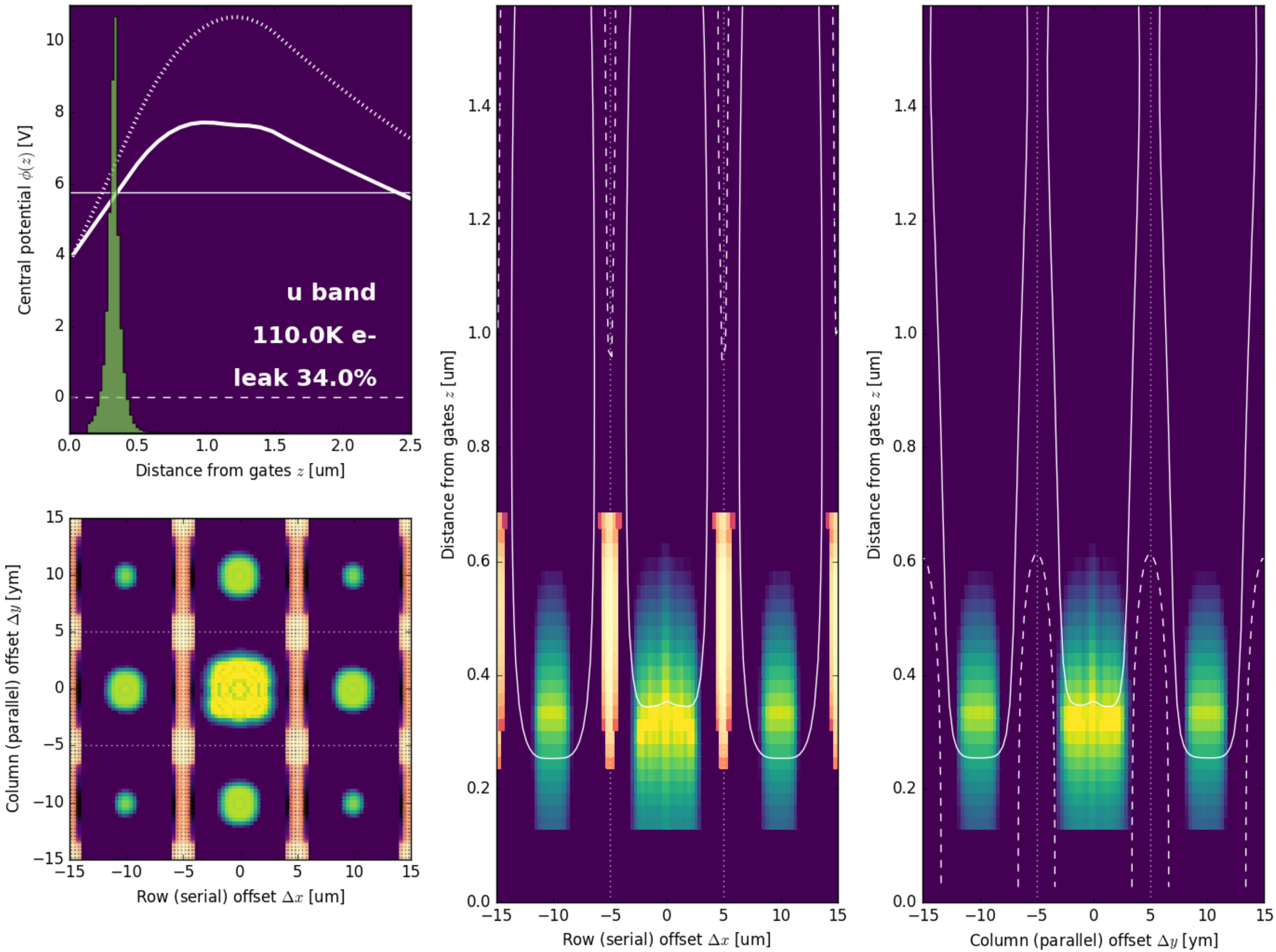




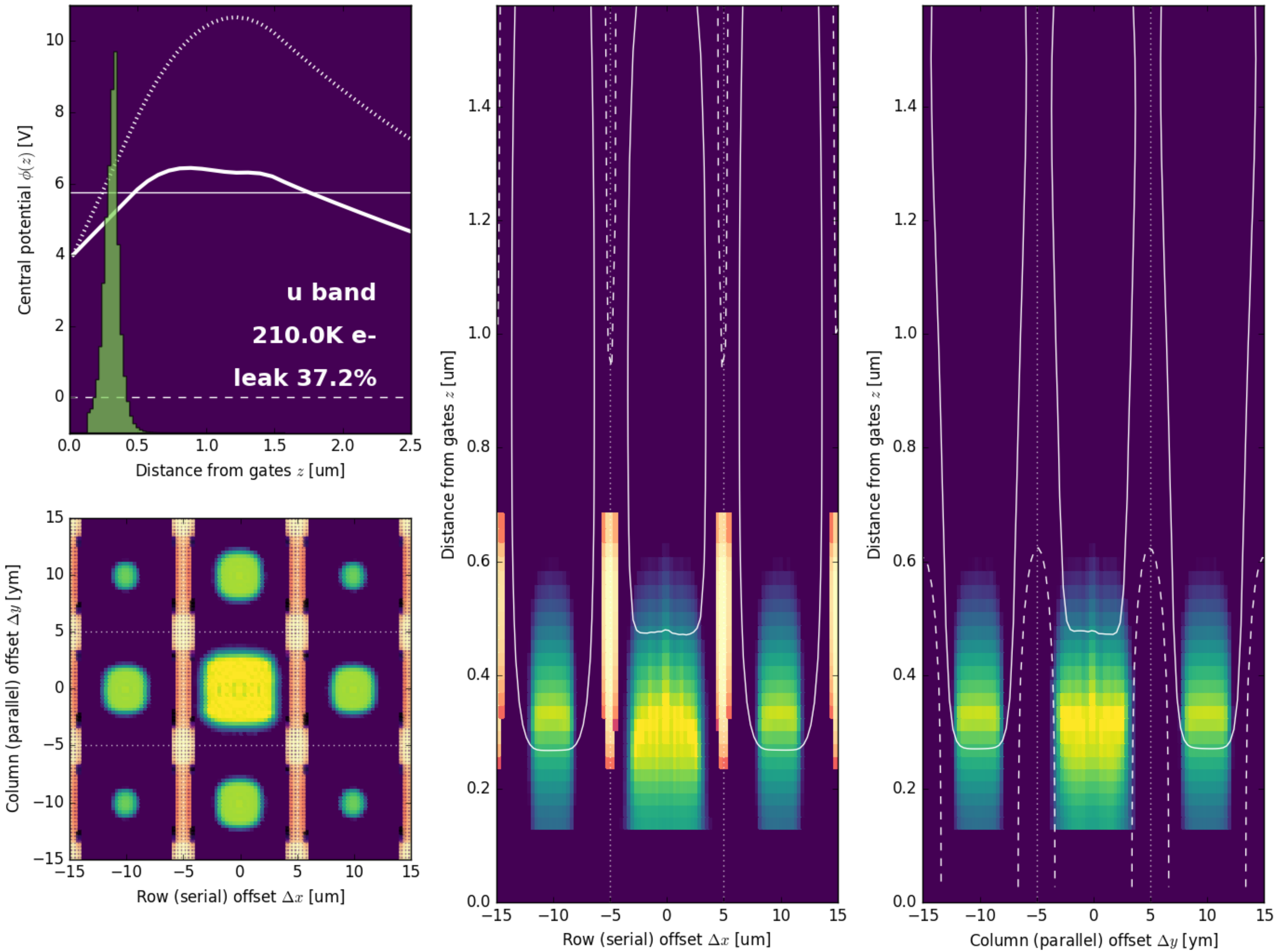
“Equilibrium” charge distribution



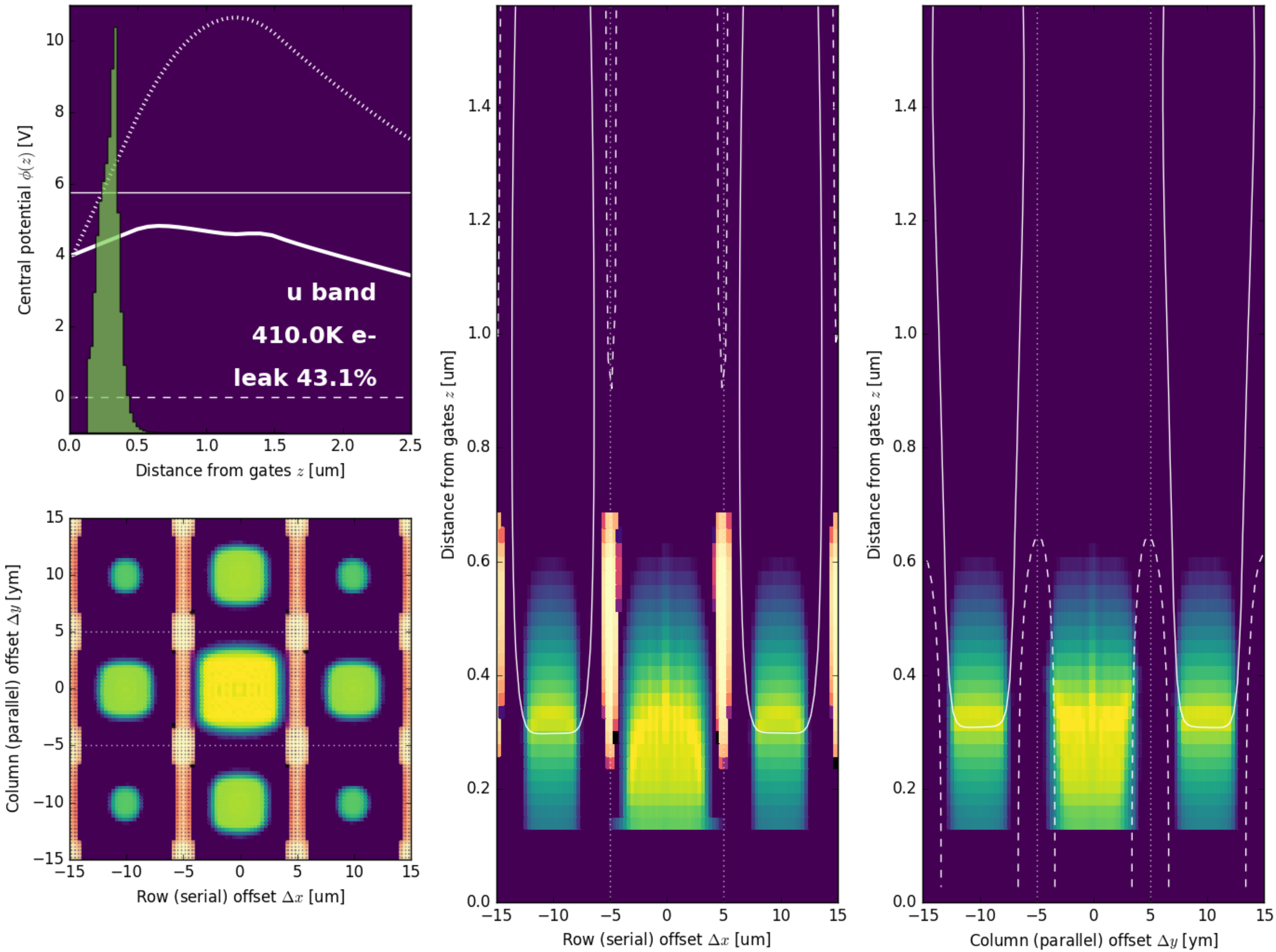
Central potential $\phi(z)$ [V]
Distance from gates z [um]
u band
10.0K e-
leak 30.1%
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]



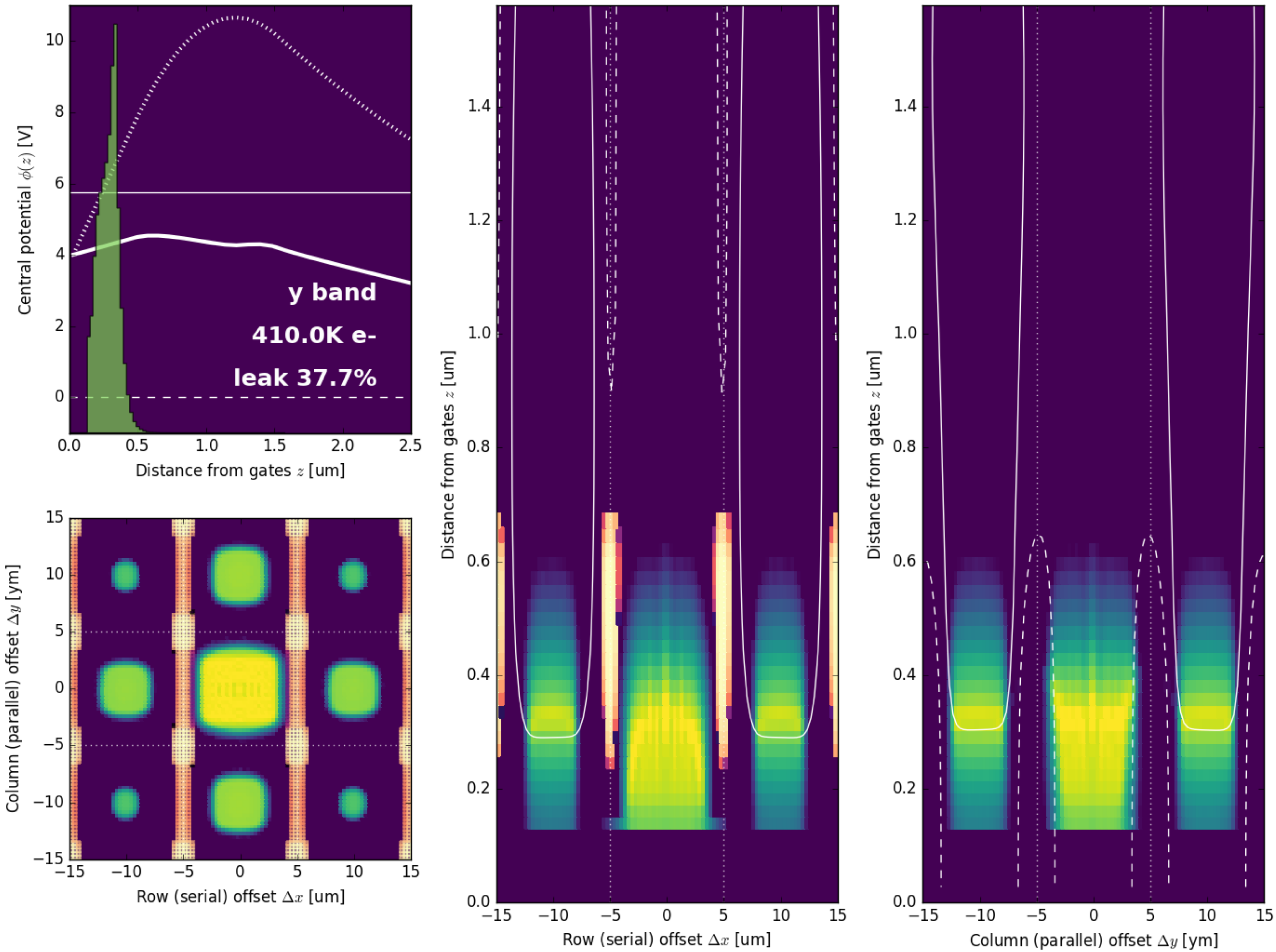
u band
110.0K e-
leak 34.0%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]



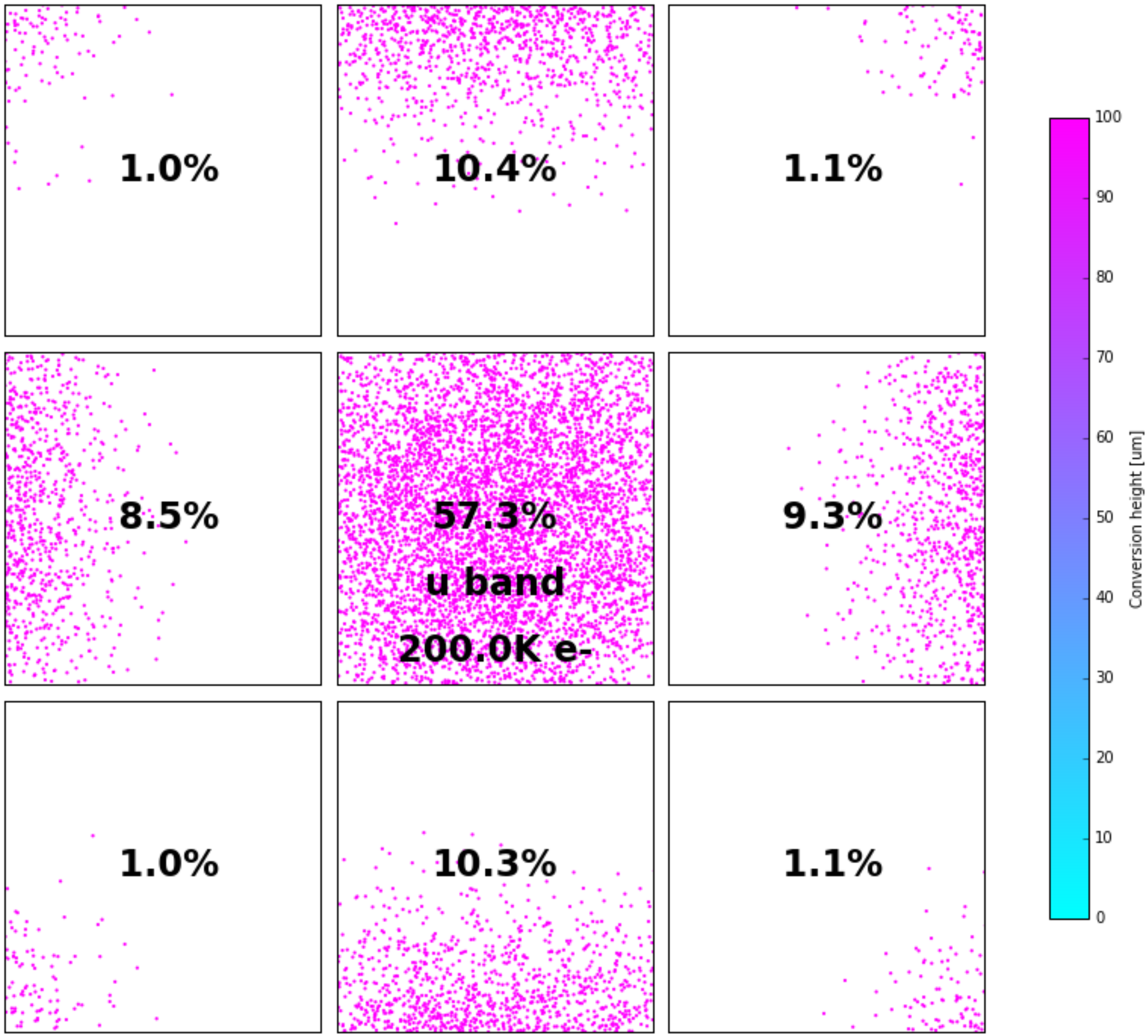
u band
210.0K e-
leak 37.2%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]

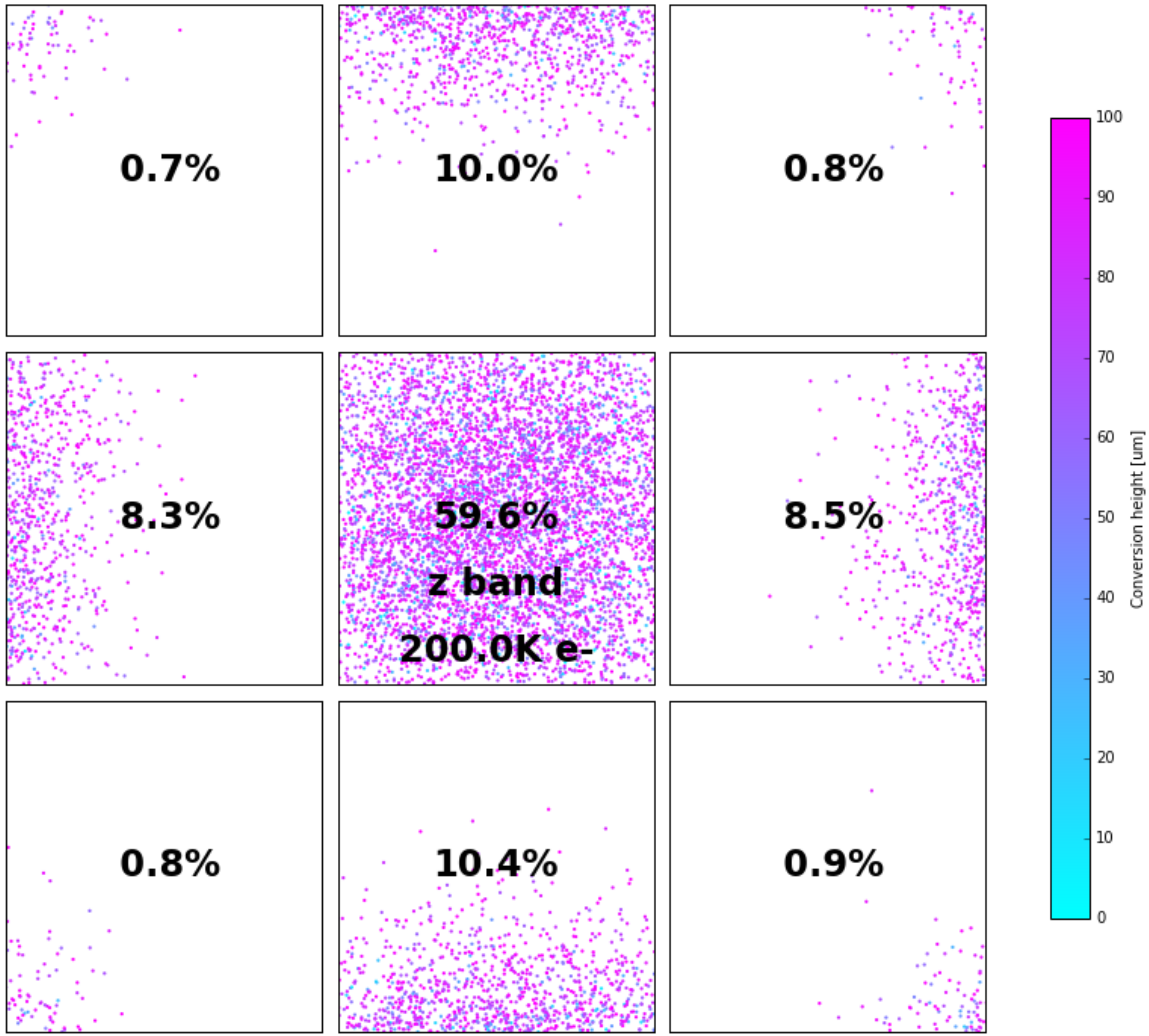


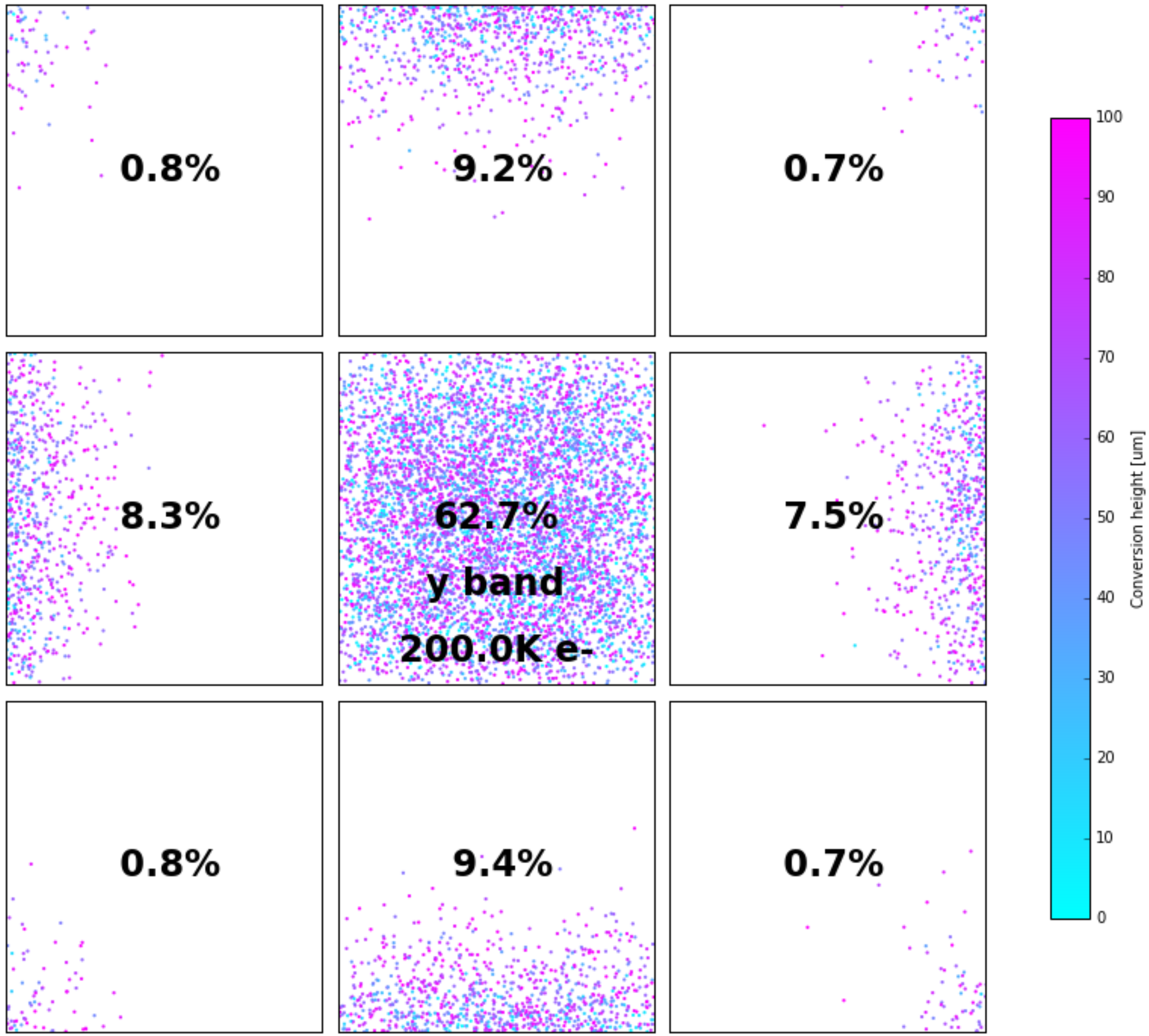
u band
410.0K e-
leak 43.1%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]



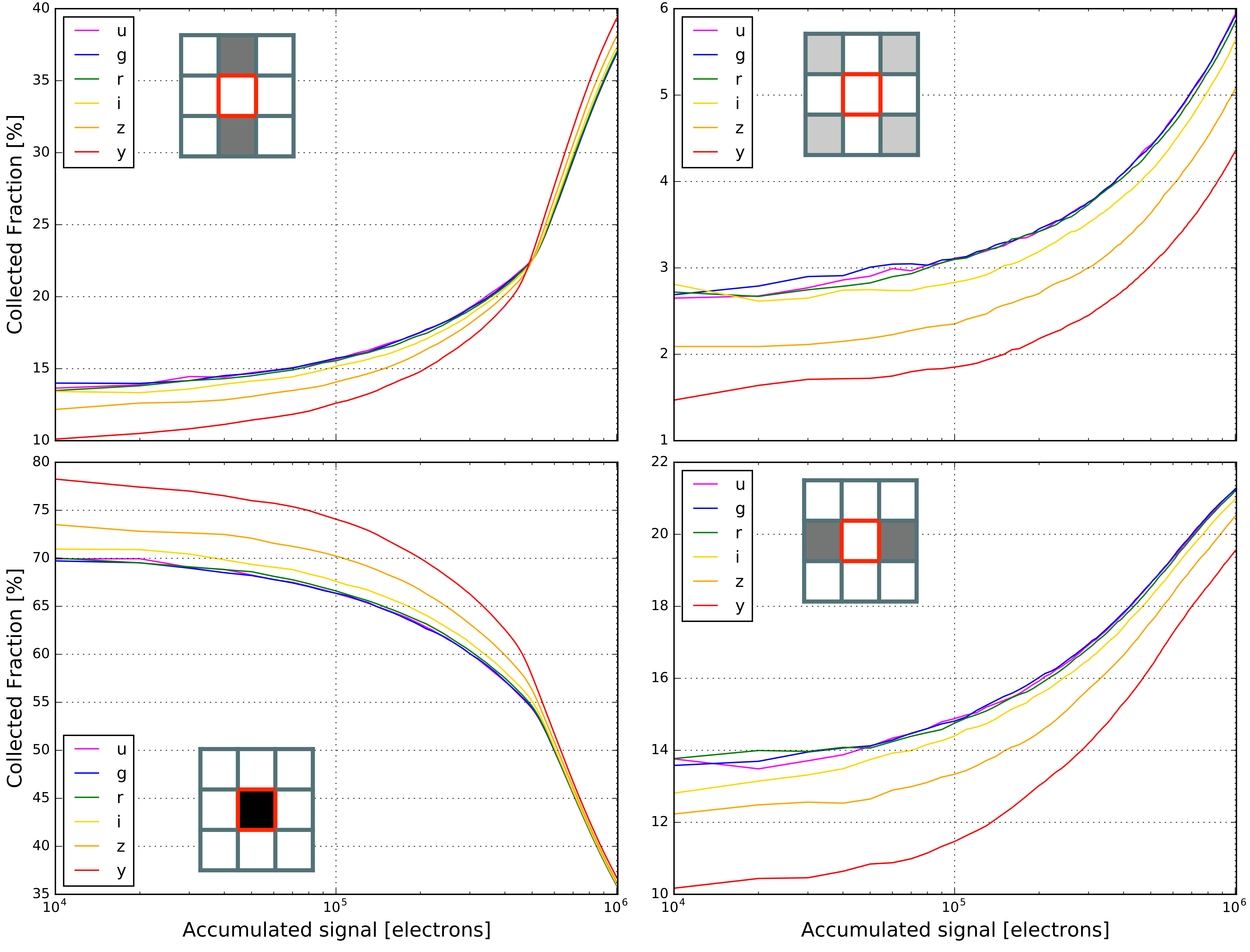
y band
410.0K e-
leak 37.7%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]


1.0%
10.4%
1.1%
8.5%
57.3%
u band
200.0K e-
9.3%
1.0%
10.3%
1.1%
100
90
80
70
60
50
40
30
20
10
0
Conversion height [um]


0.7%
10.0%
0.8%
8.3%
59.6%
z band
200.0K e-
8.5%
0.8%
10.4%
0.9%
Conversion height [um]
0
10
20
30
40
50
60
70
80
90
100



0.8%
9.2%
0.7%
8.3%
62.7%
y band
200.0K e-
7.5%
0.8%
9.4%
0.7%
100
90
80
70
60
50
40
30
20
10
0
Conversion height [um]



Collected Fraction [%]
Accumulated signal [electrons]
u
g
r
i
z
y

NEXT STEPS

- Compare with test bench data using tungsten lamp + filters and Fe-55 X-rays.
- Revisit how BF effect is modeled in GalSim?
  - Pixel effective area less well defined because of interplay of depth distribution with diffusion.
- Include effects of non-normal photon incidence and depth of focus.
  - Effects now depend on focal-plane position and break up/down & left/right symmetries.
  - Red sensor PSF is now bigger than blue!

BACKUP

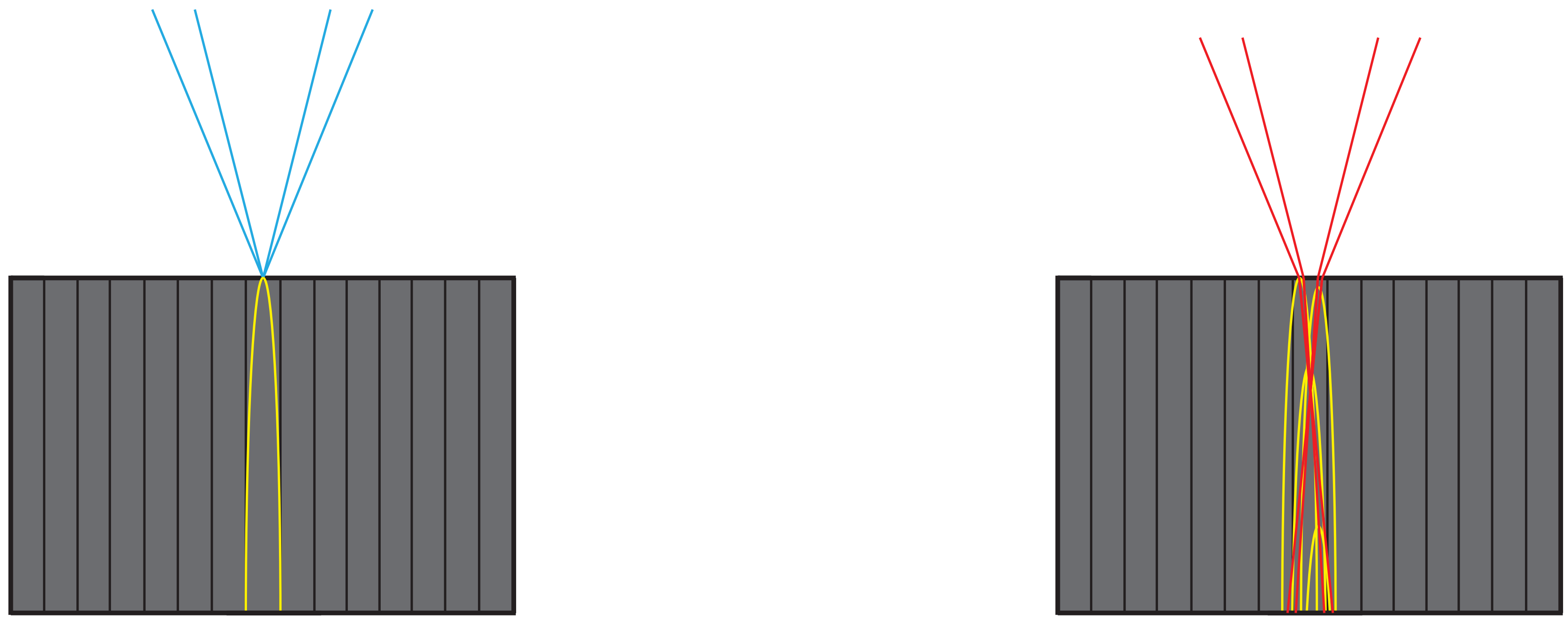
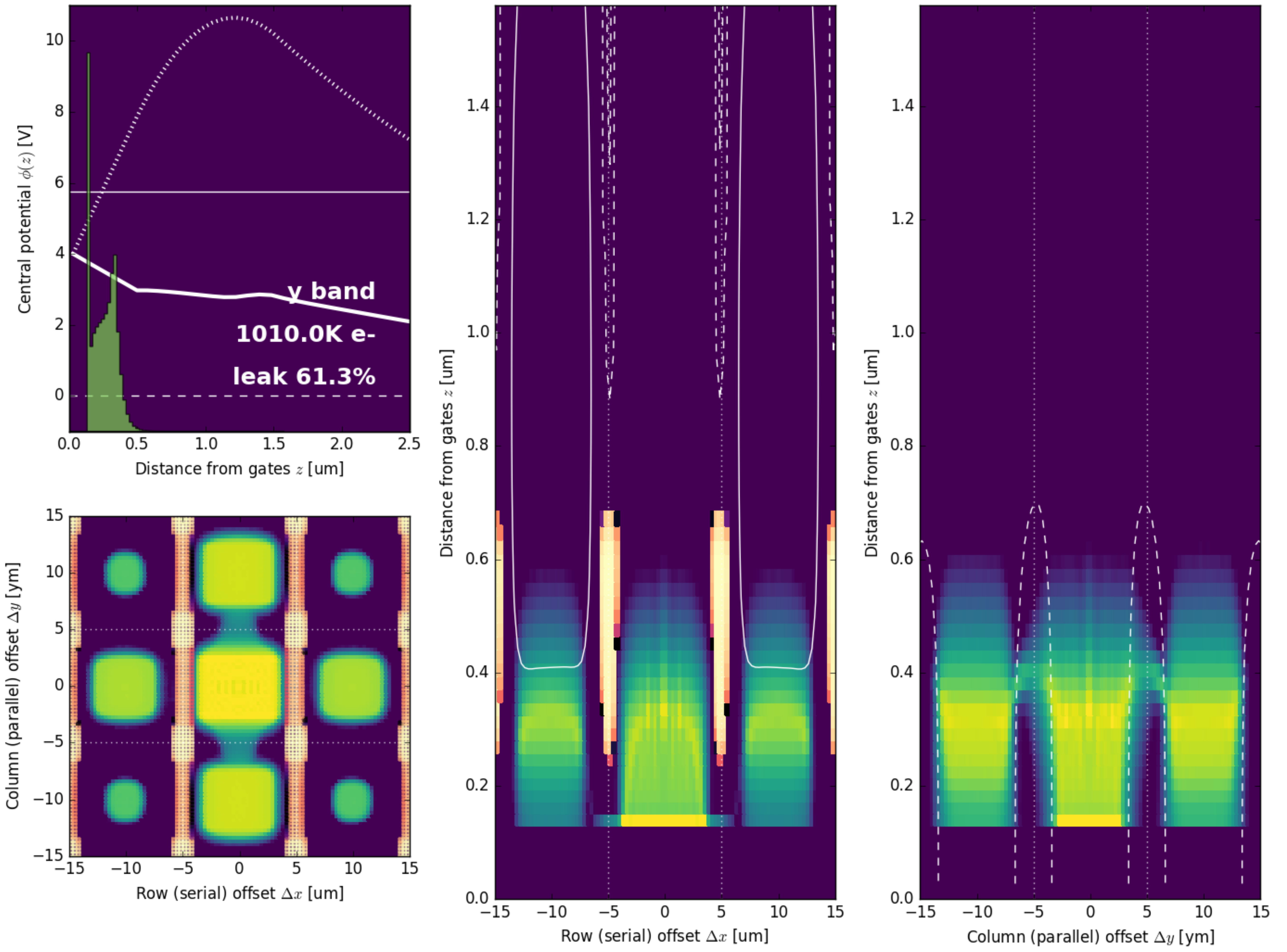
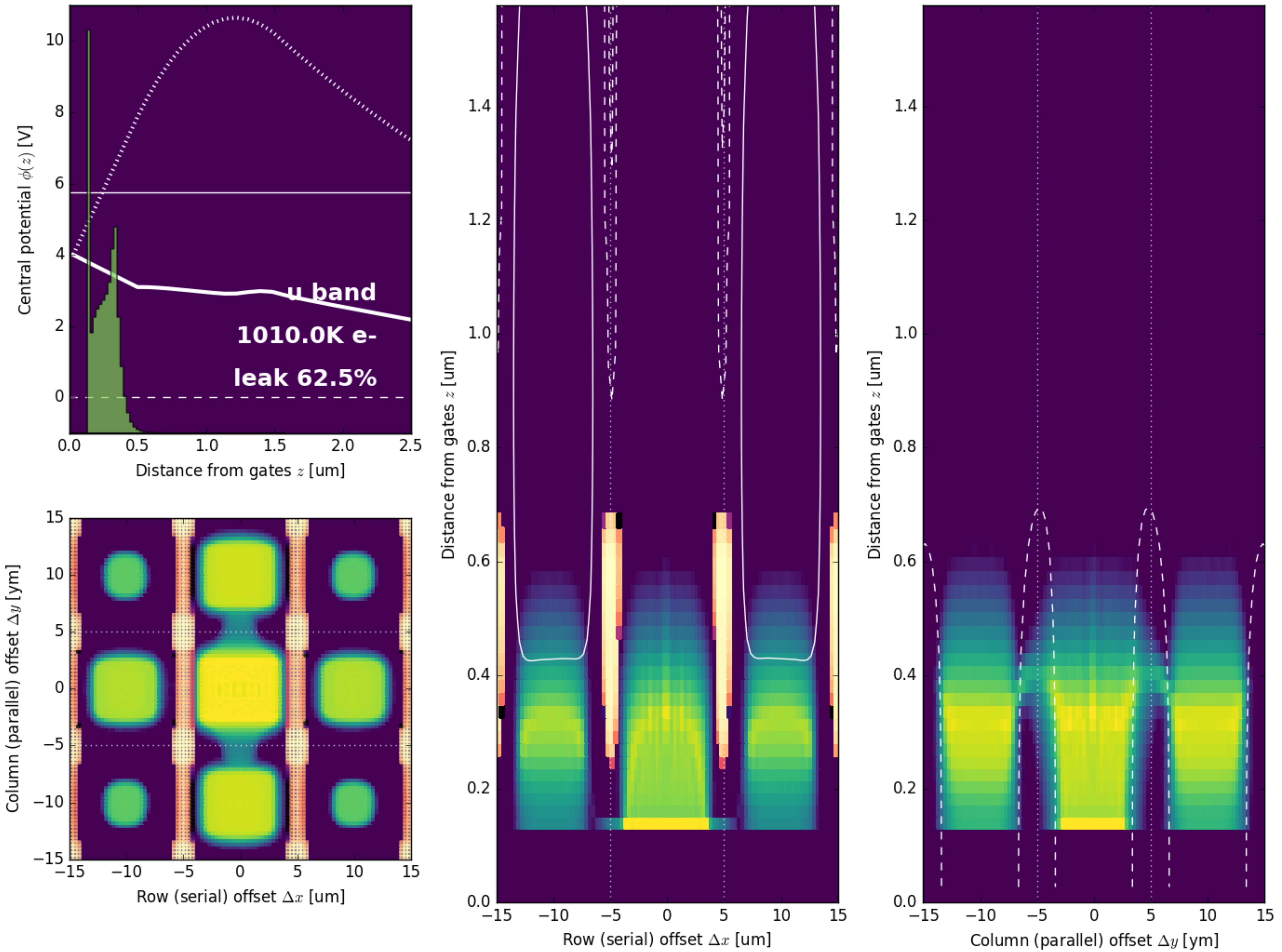


Figure 5. Cartoon figure of LSST beam and CCD geometry. Fifteen 10-micron wide and 100-micron deep pixels are shown in each cartoon. The f/1.2 beam is shown approaching the CCD from above for bluer filters (left) and redder filters (right). Blue photons convert into electron-hole pairs almost immediately, and the photo-electrons diffuse the entire depth of the CCD (shown in yellow). Red photons may penetrate deeper into the CCD bulk before converting. Combined with the diverging beam, which is still f/4.5 inside the silicon, the longer absorption length of redder photons leads to a larger PSF. Note that the position of best focus is a competition between beam divergence and charge diffusion. For bluer filters, the best focus is at the CCD surface, while for redder filters it is inside the bulk of the CCD [4].

Meyers & Burchat 2015 "Chromatic CCD effects on weak lensing measurements for LSST", arxiv.org/abs/1505.02307



y band
1010.0K e-
leak 61.3%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]



u band
1010.0K e-
leak 62.5%
Central potential $\phi(z)$ [V]
Distance from gates z [um]
Column (parallel) offset Δy [ym]
Row (serial) offset Δx [um]
Distance from gates z [um]
Row (serial) offset Δx [um]
Distance from gates z [um]
Column (parallel) offset Δy [ym]