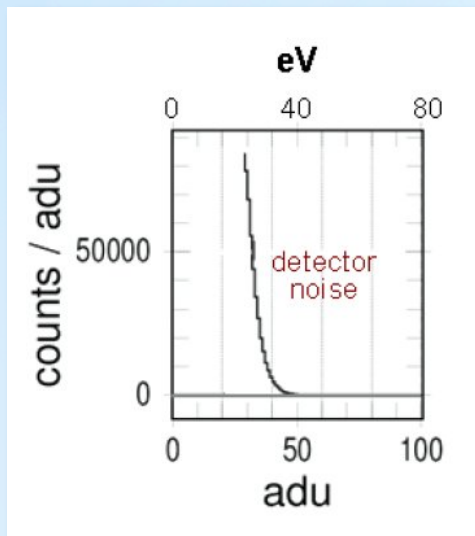




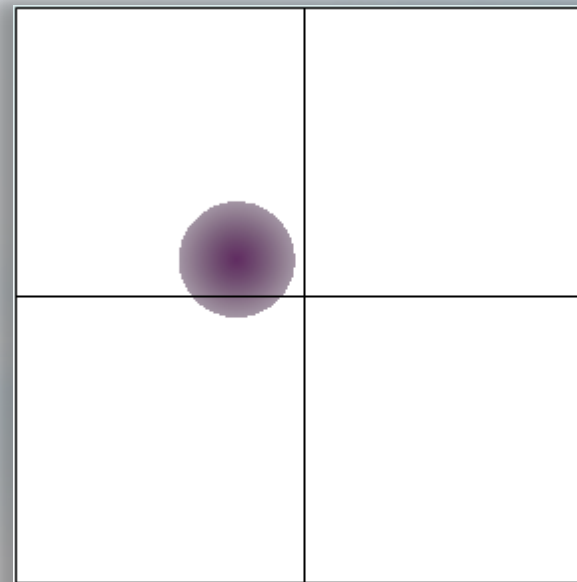
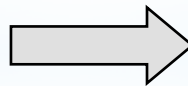
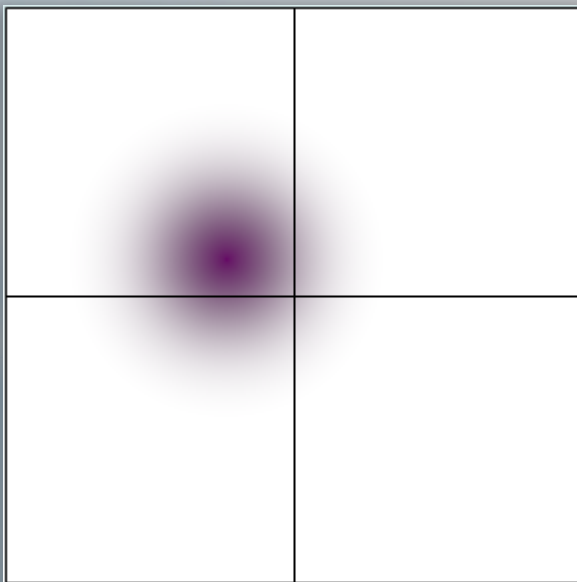
## Impact of the low energy threshold on the spatial resolution and spectral properties of X-ray CCDs

6<sup>th</sup> IACHEC Meeting, Villa Grazioli, Frascati, Italy

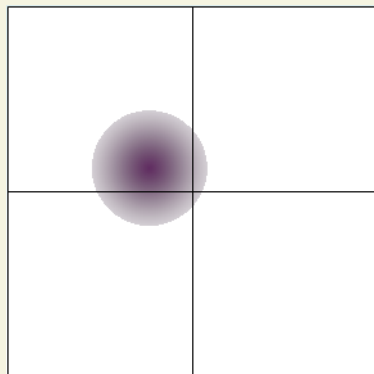
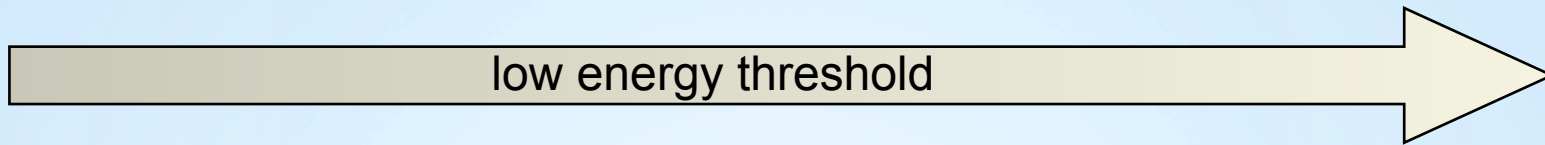
K. Dennerl, MPE



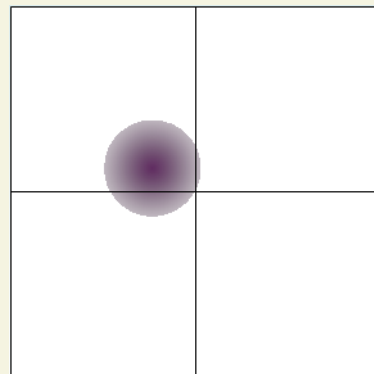
## The Low Energy Threshold ("Split Threshold")



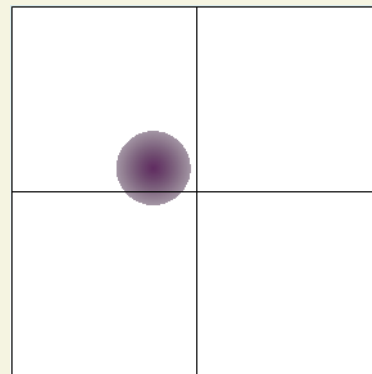




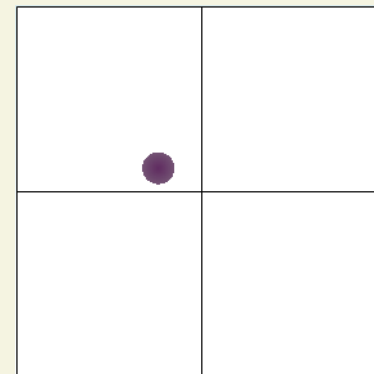
very low threshold



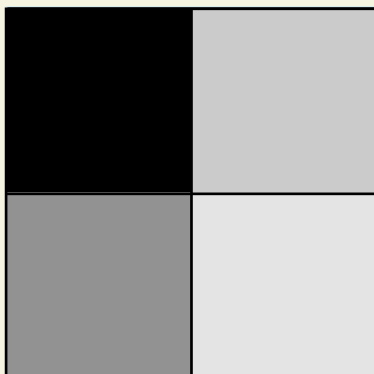
low threshold



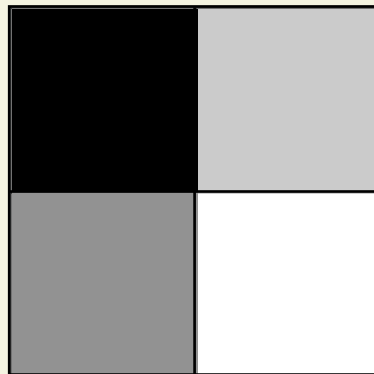
high threshold



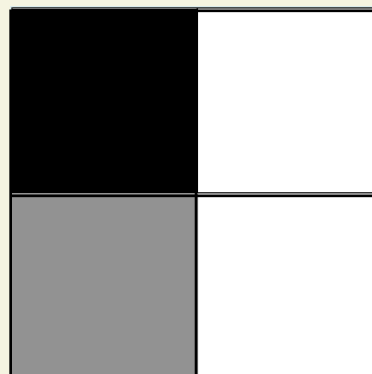
very high threshold



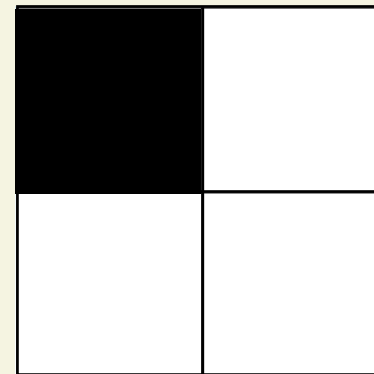
**quadruple**



**triple**

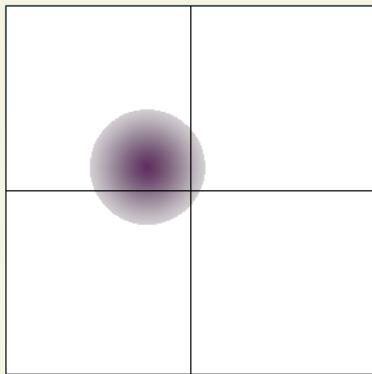
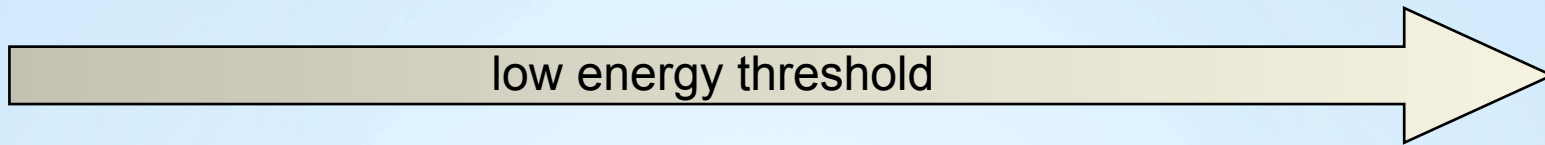


**double**

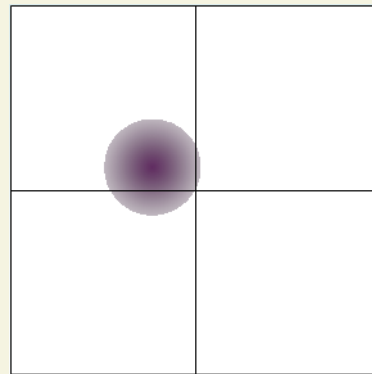


**single**

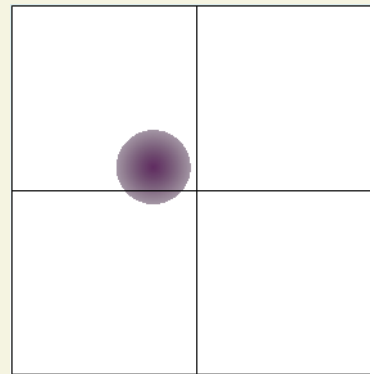
→ **observed pattern depends on the low energy threshold**



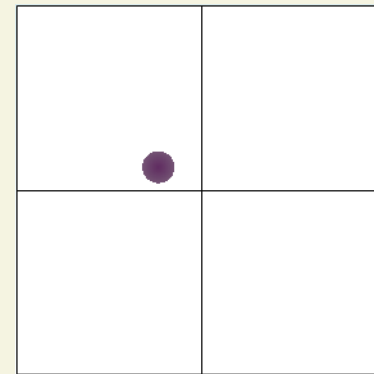
very low threshold



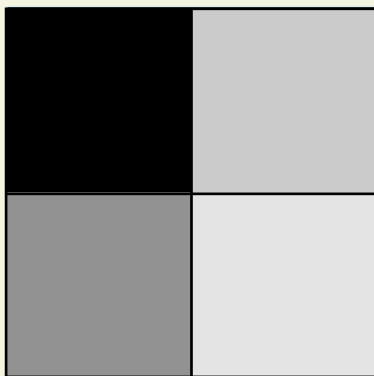
low threshold



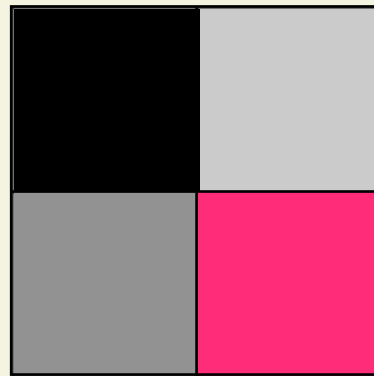
high threshold



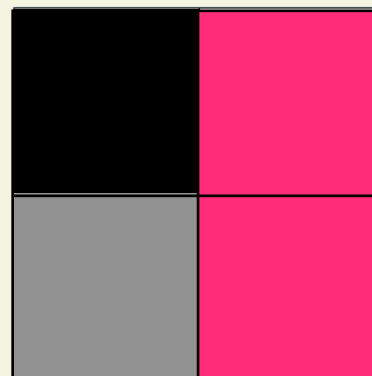
very high threshold



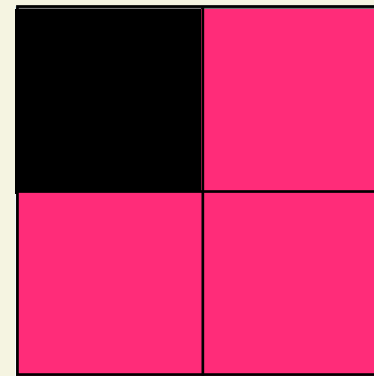
quadruple



triple



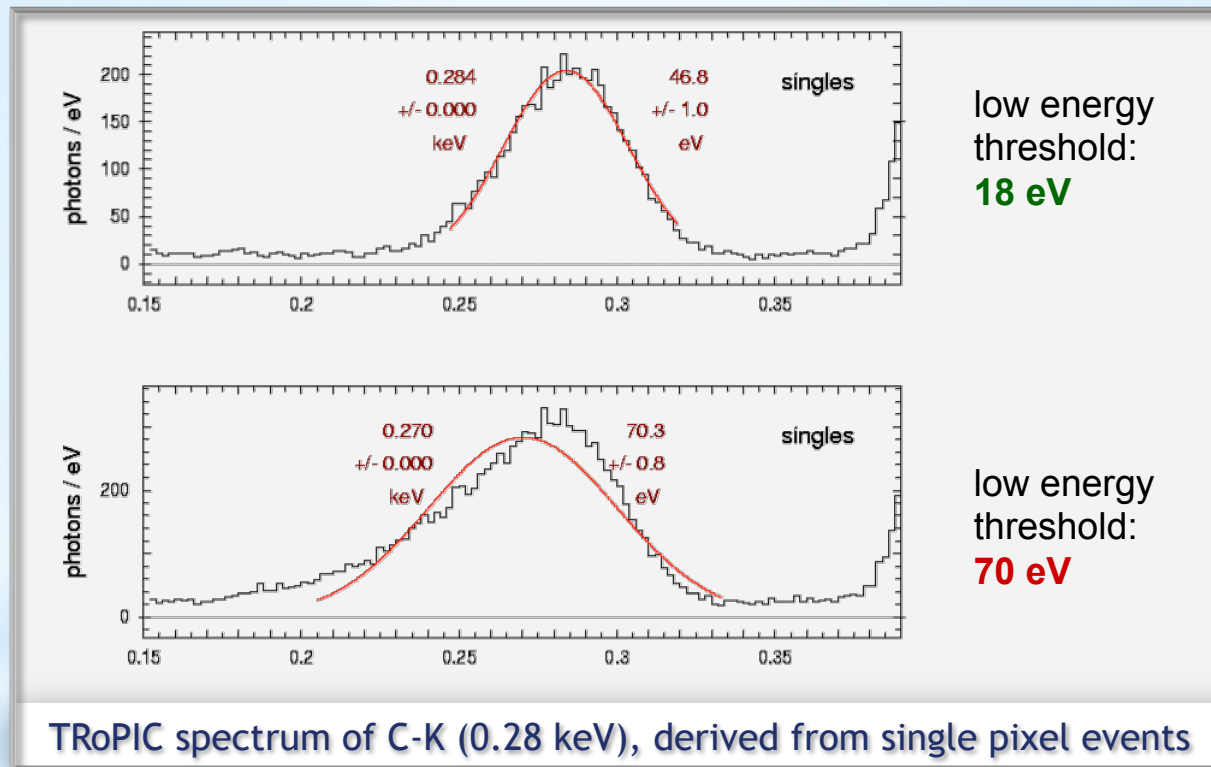
double



single

charge lost → degradation of the energy resolution

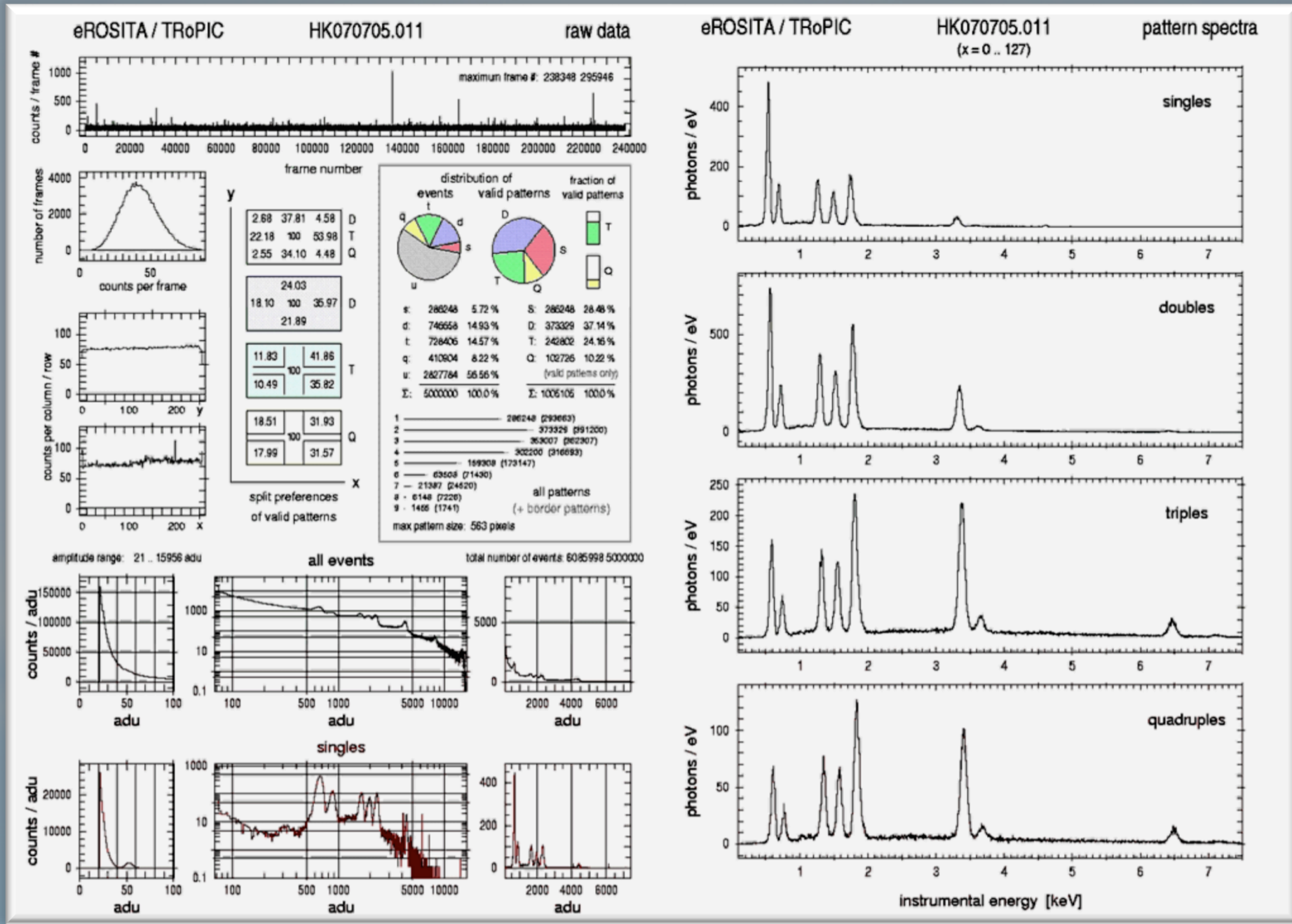
## Impact of the low energy threshold on the *spectral resolution*



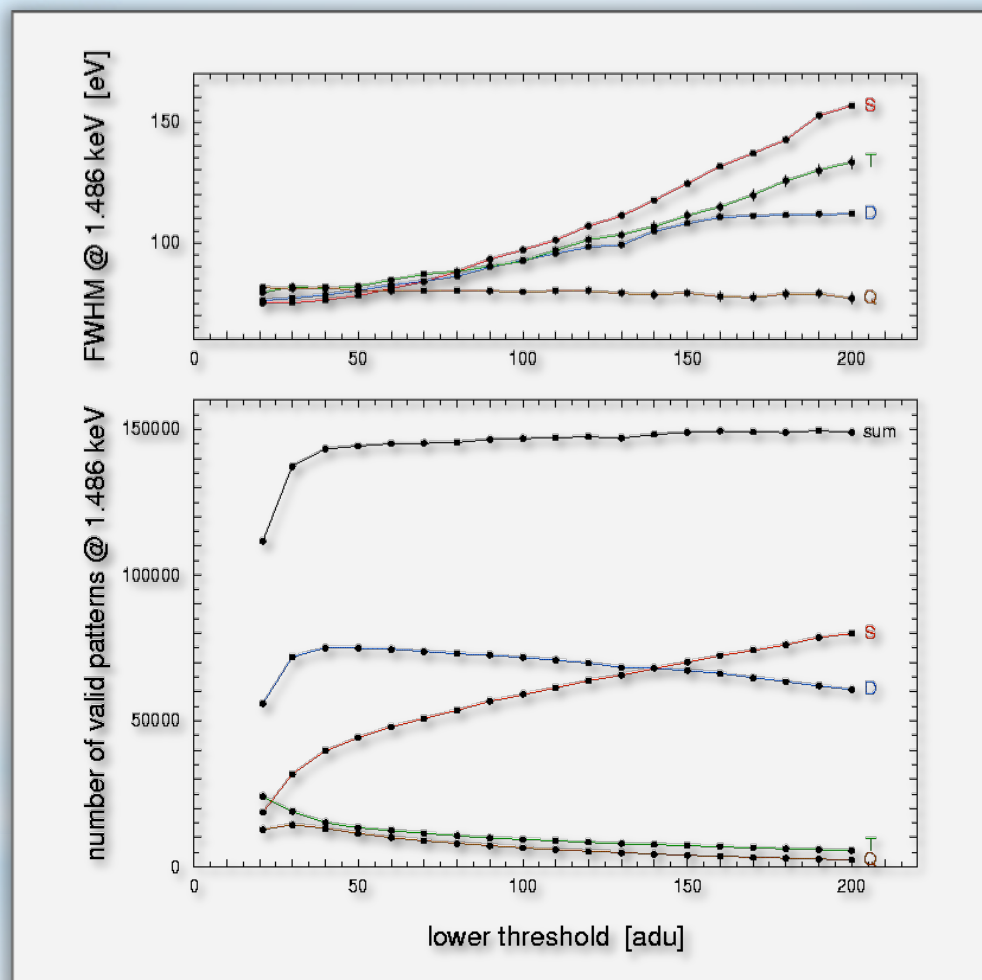
→ the spectral resolution depends on the low energy threshold







# Impact of the low energy threshold on the FWHM and sensitivity

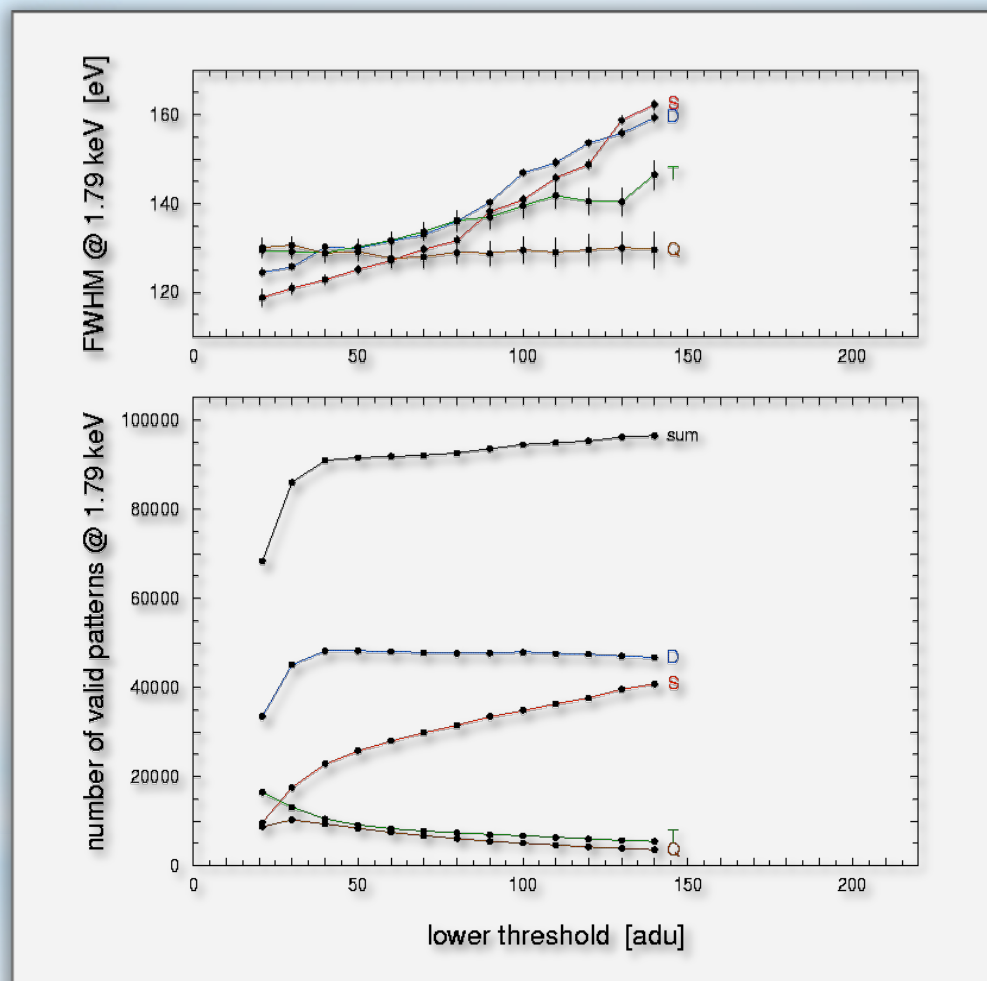


Al-K

1.486 keV

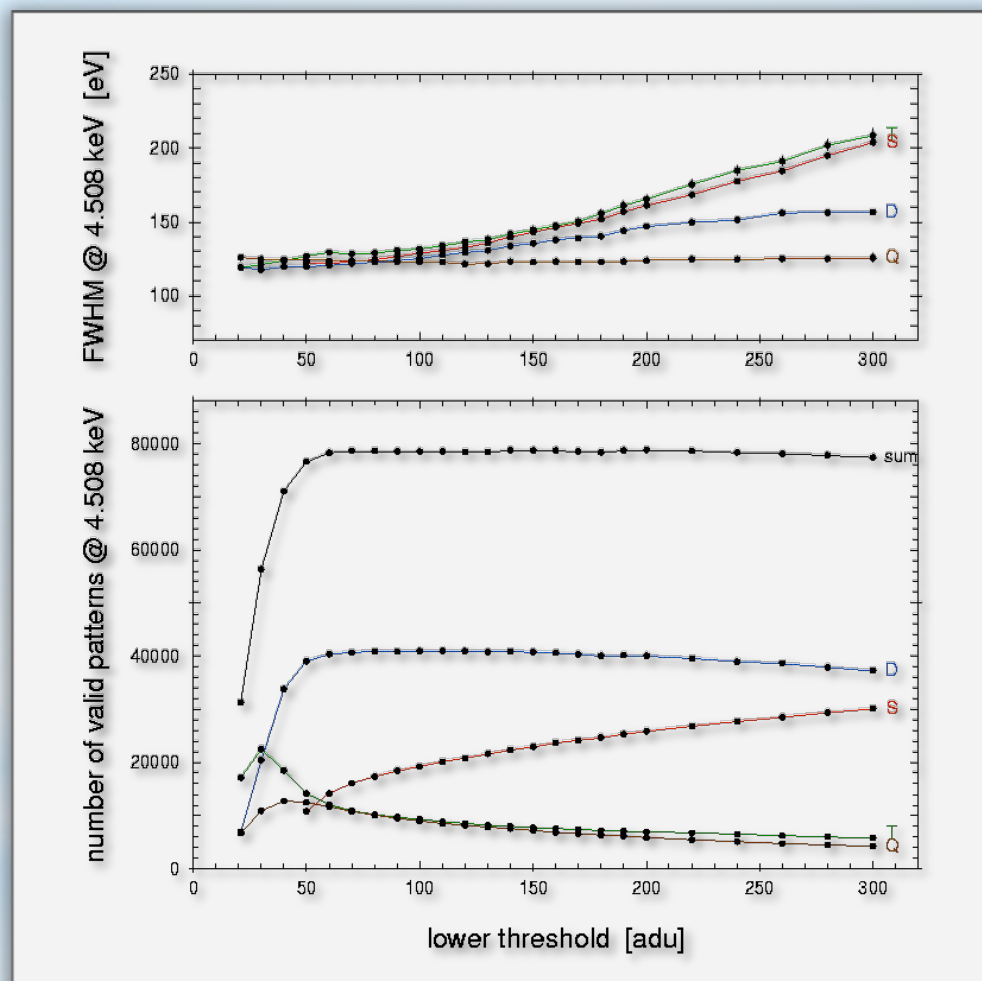


# Impact of the low energy threshold on the FWHM and sensitivity



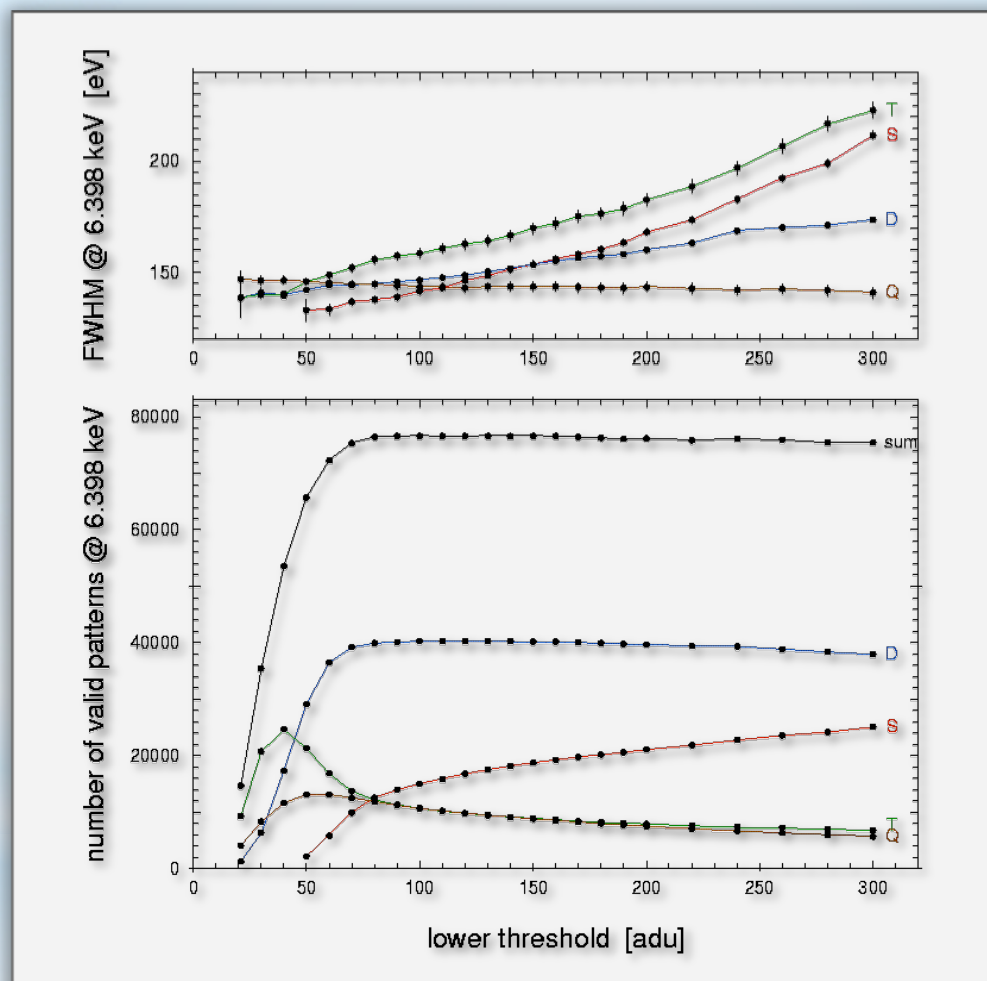
W-M  
1.79 keV

# Impact of the low energy threshold on the FWHM and sensitivity



Ti-K  
4.51 keV

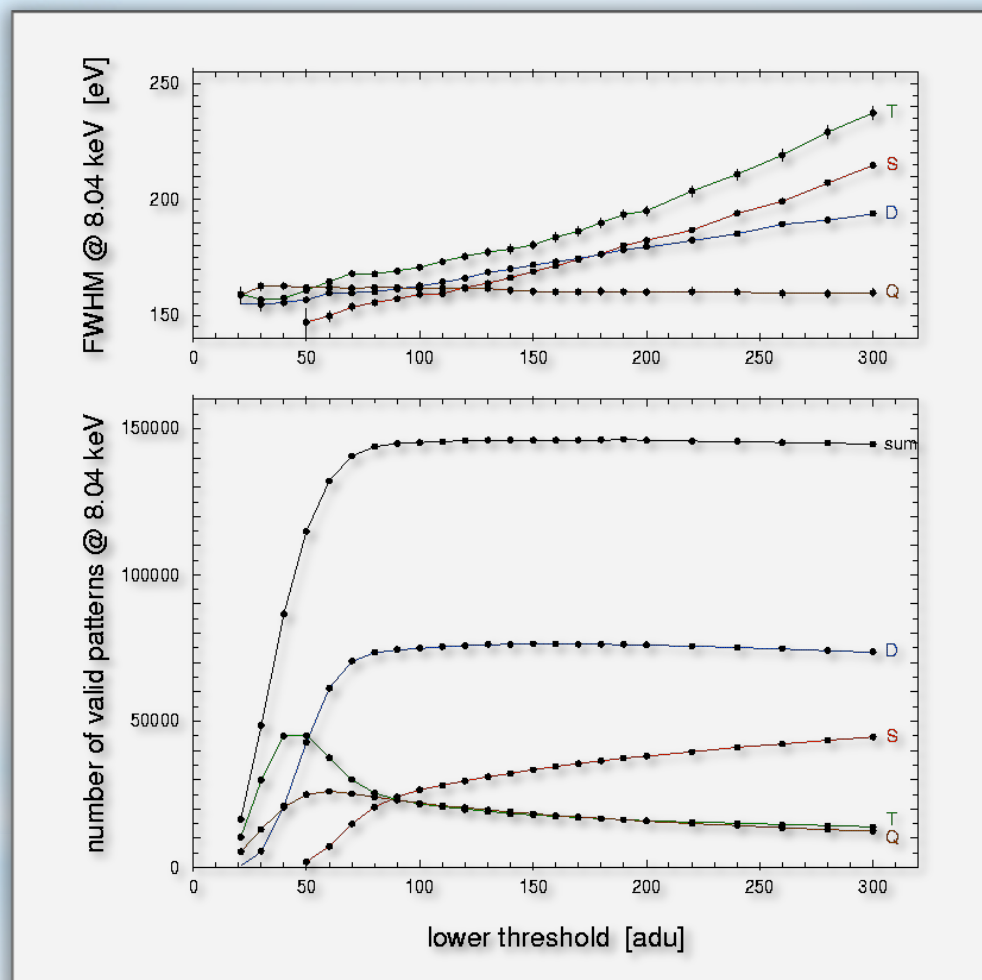
# Impact of the low energy threshold on the FWHM and sensitivity



Fe-K  
6.94 keV

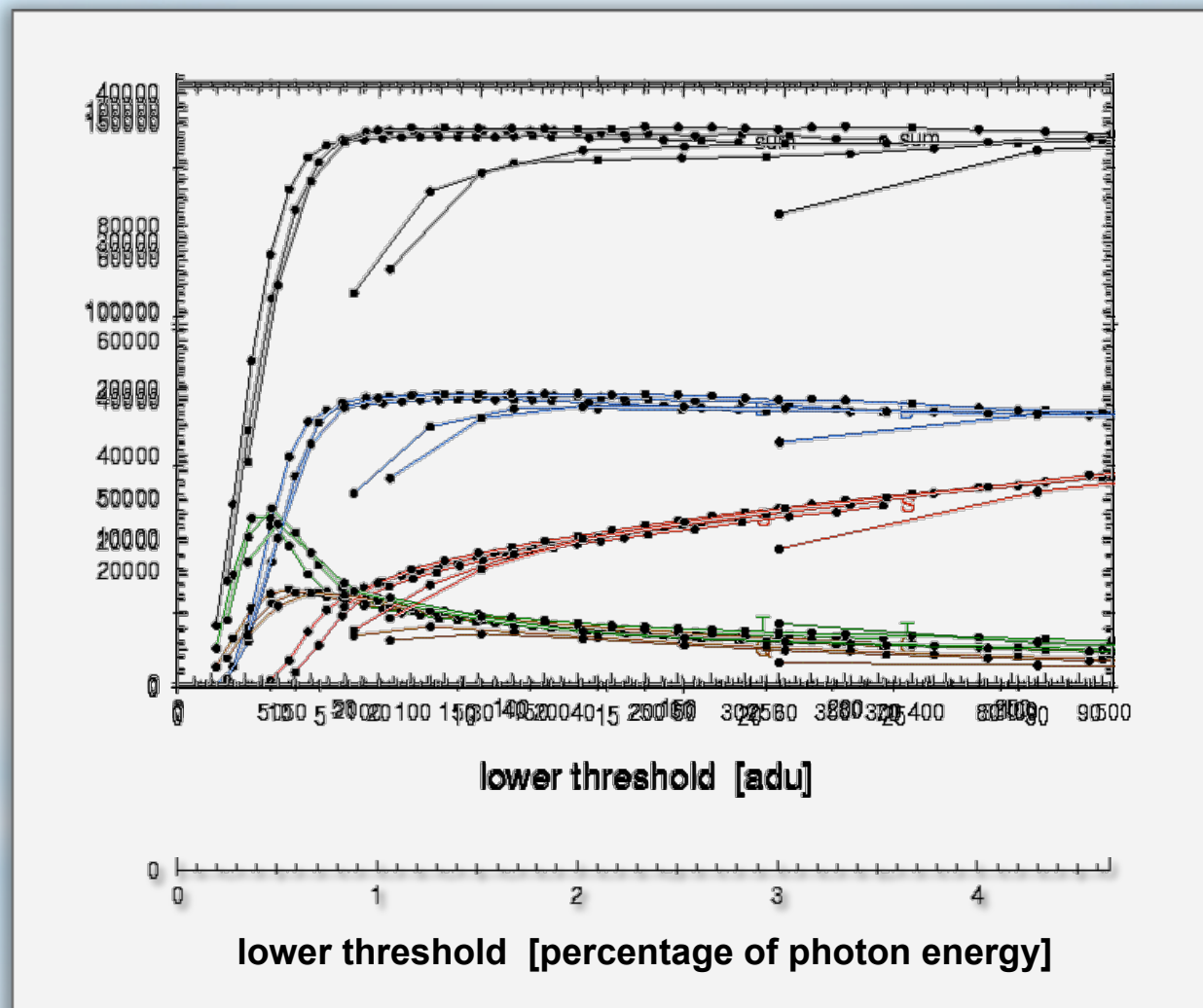


# Impact of the low energy threshold on the FWHM and sensitivity



Cu-K  
8.04 keV

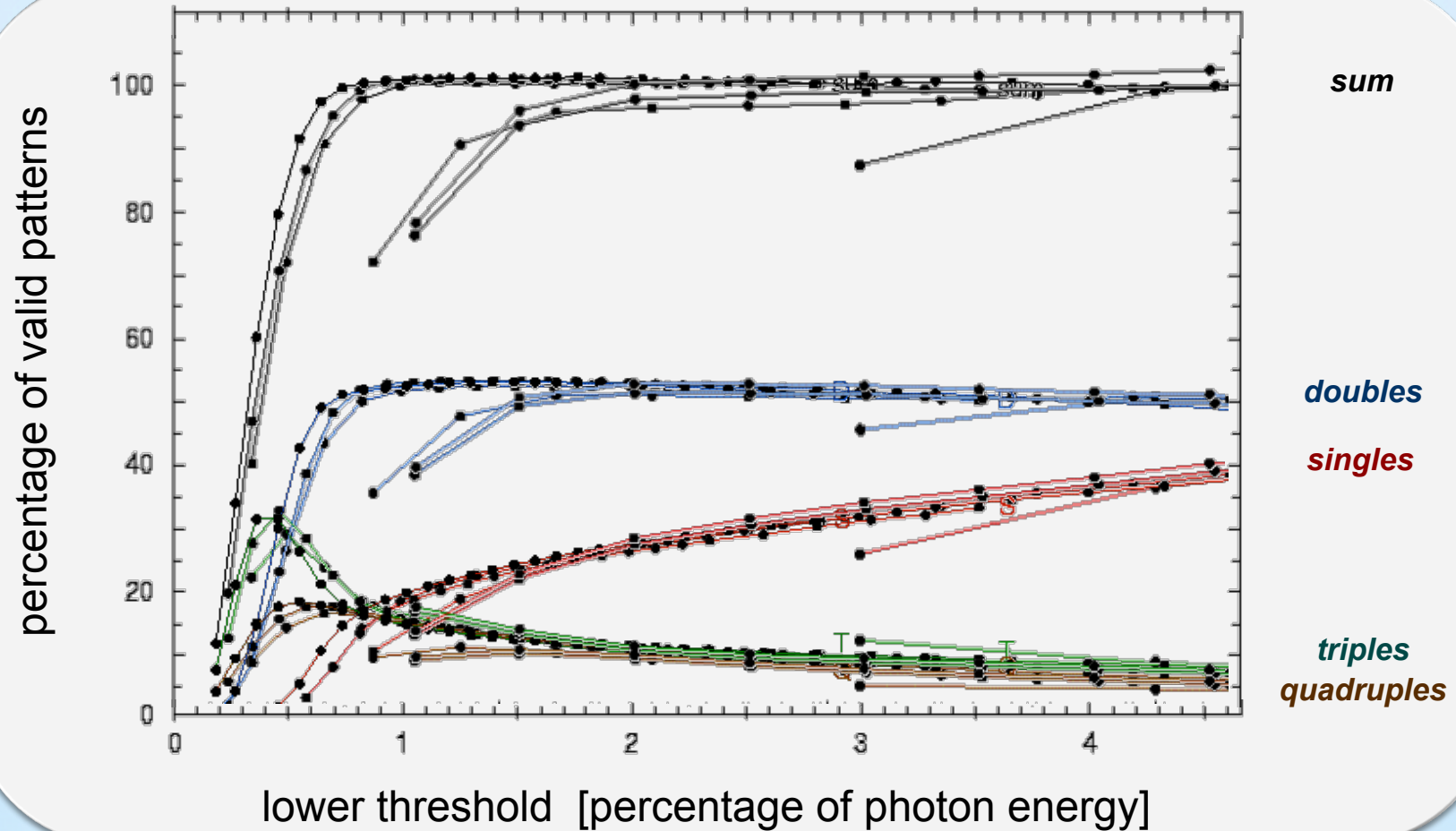
# Impact of the low energy threshold on the FWHM and sensitivity



C-K + Al-K + W-M + Ti-K + Fe-K + Cu-K

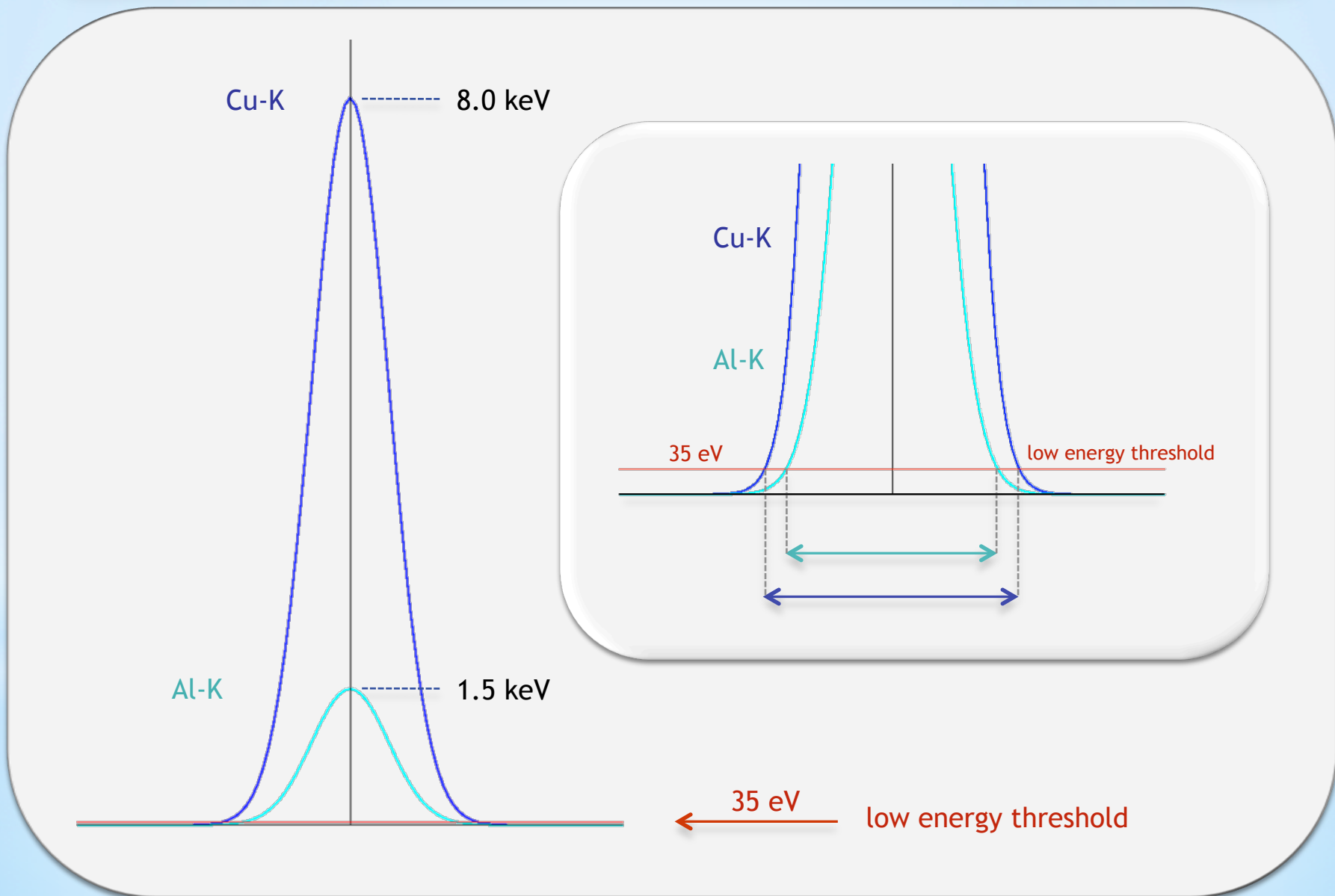
# Result: dependence of measured pattern fractions on energy and threshold

C-K + O-K + Al-K + W-M + Ti-K + Fe-K + Cu-K



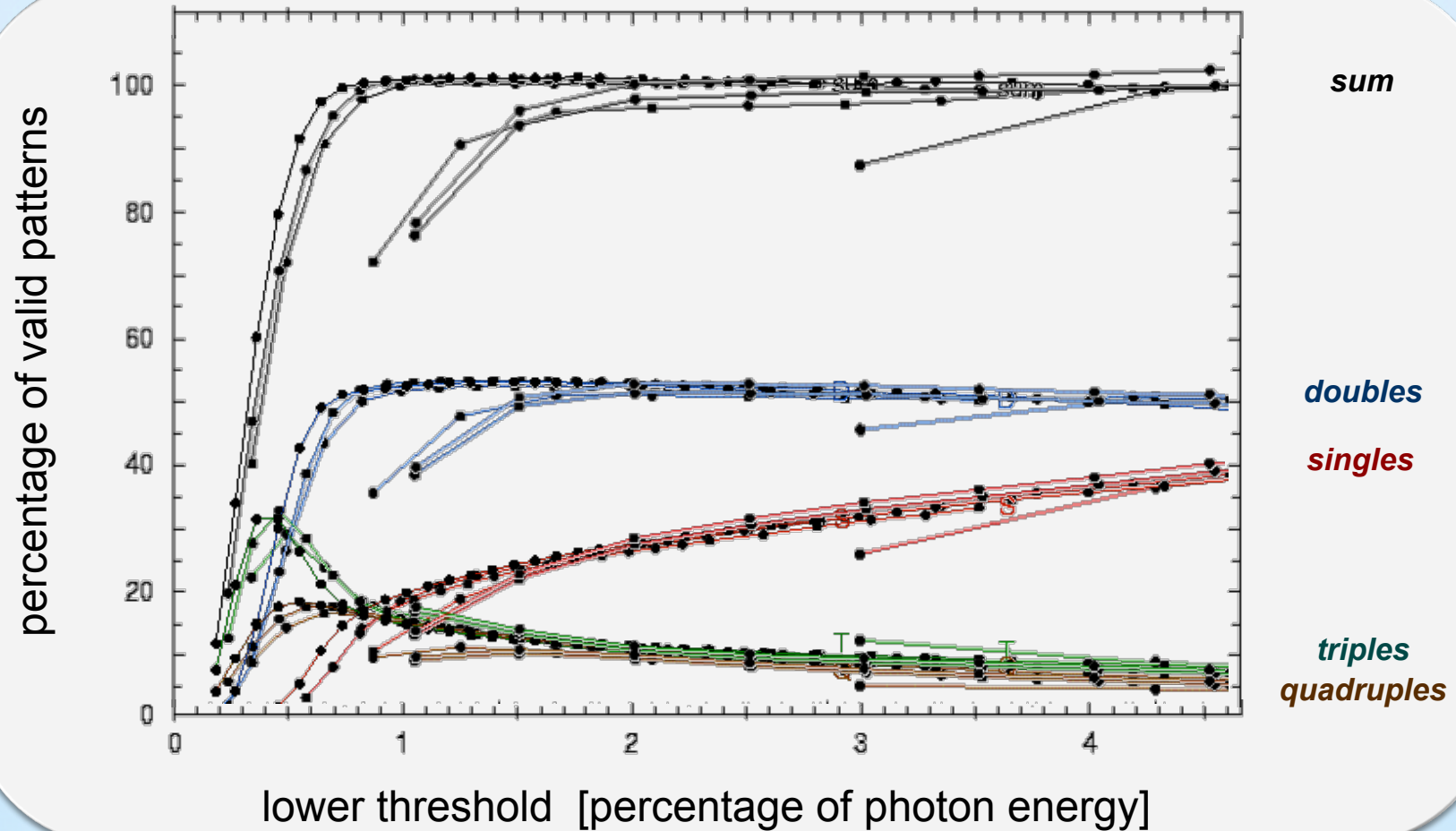


# Impact of the low energy threshold on the apparent pattern size

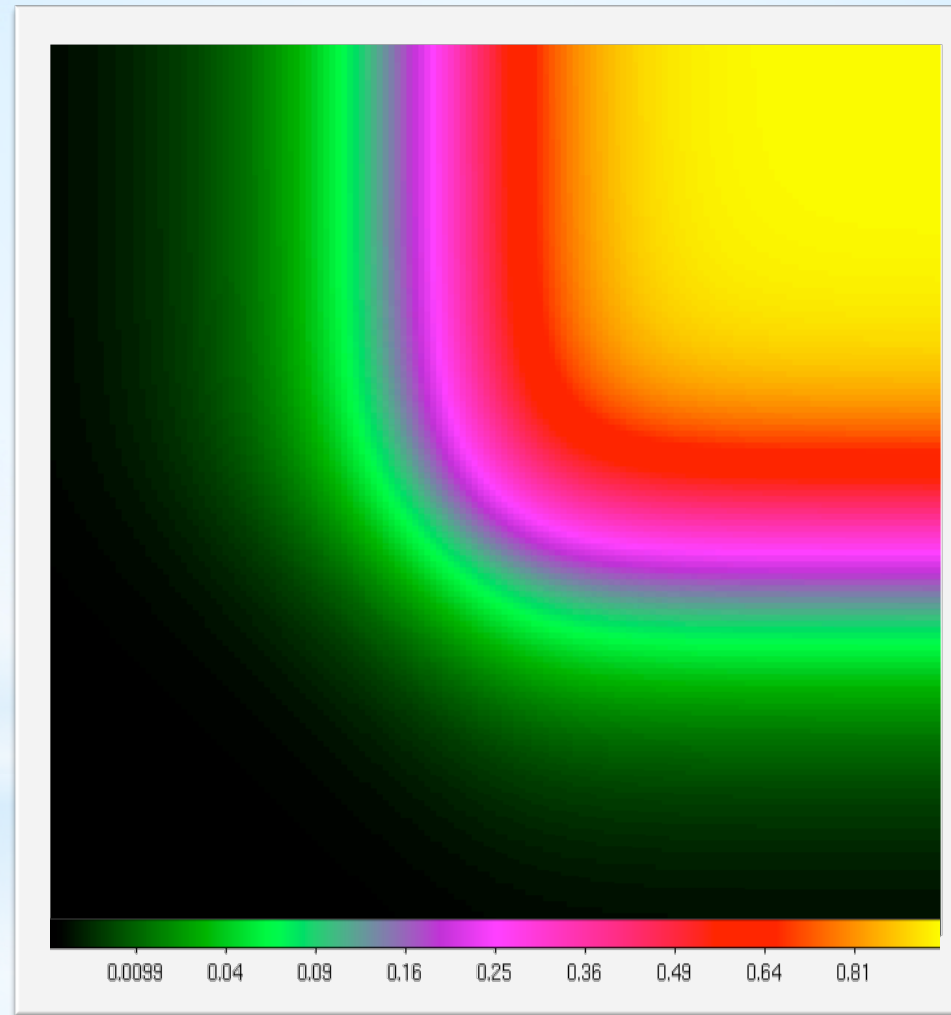


# Result: dependence of measured pattern fractions on energy and threshold

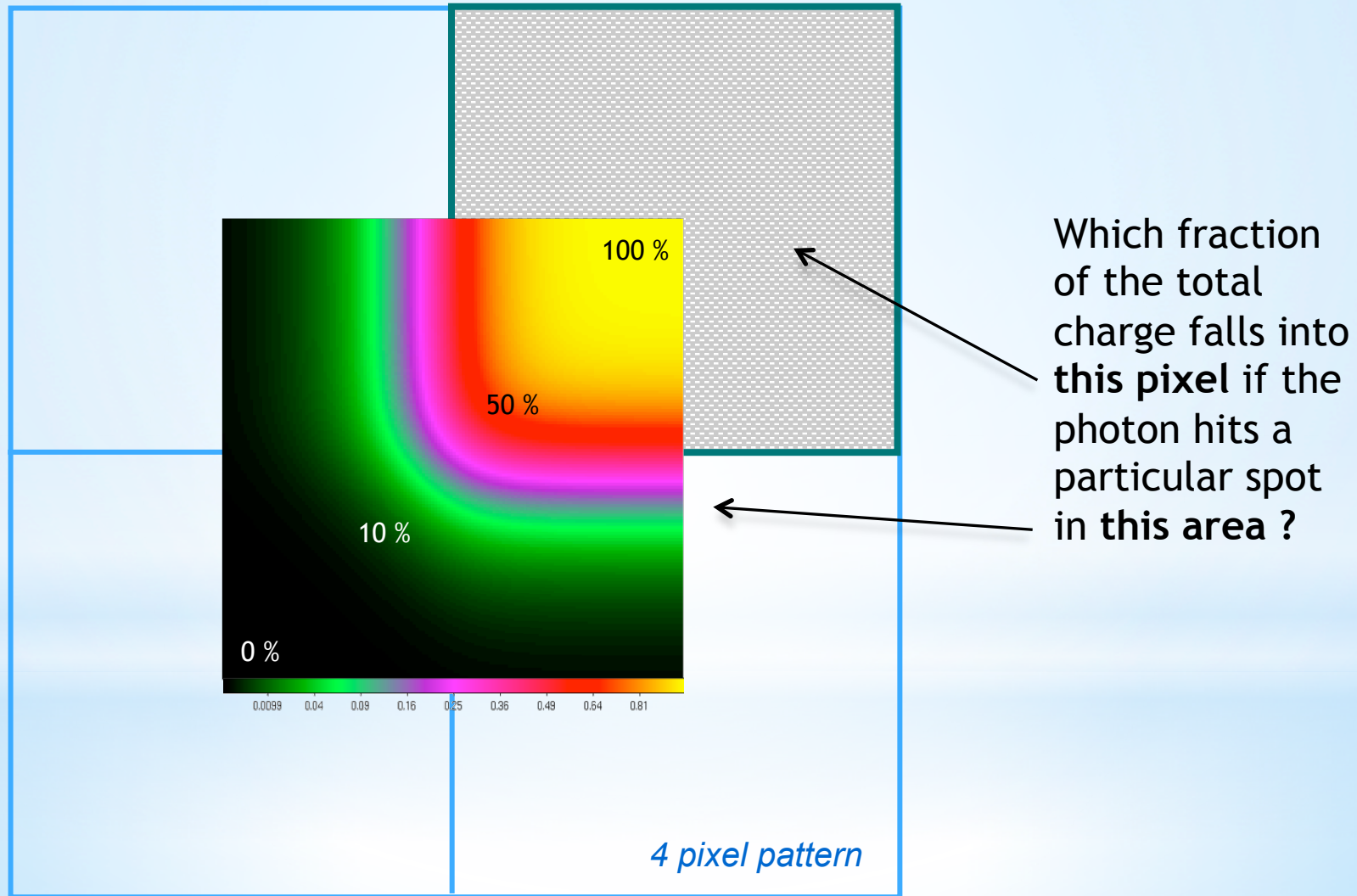
C-K + O-K + Al-K + W-M + Ti-K + Fe-K + Cu-K



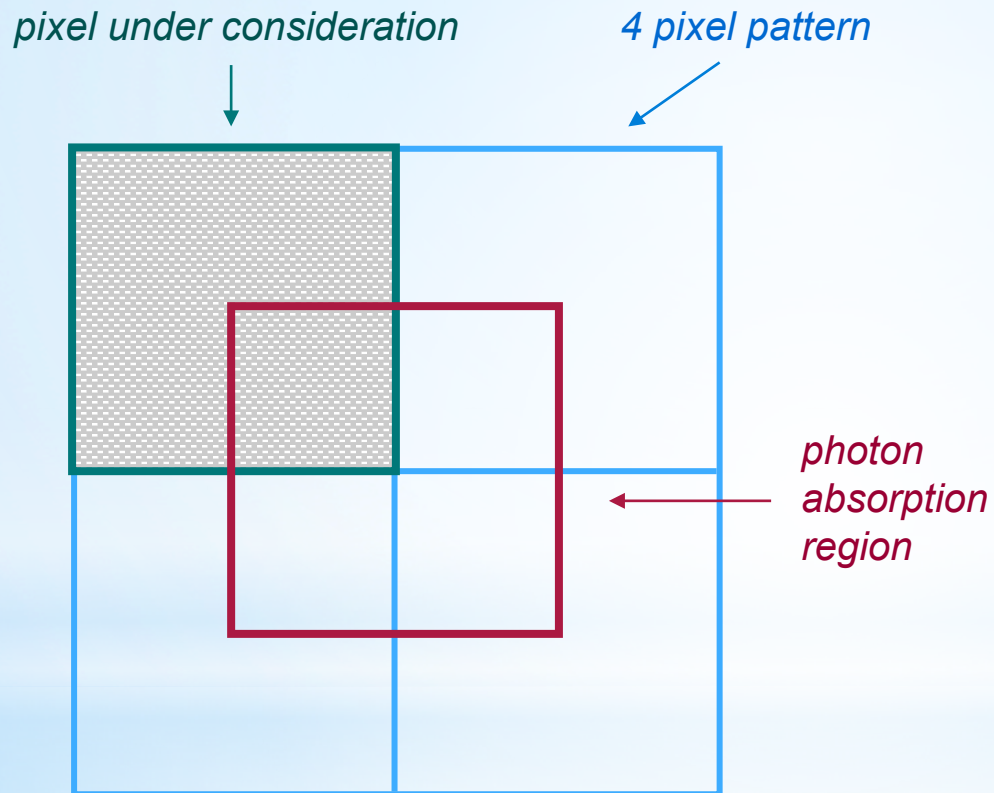
## Impact of the low energy threshold on the *spatial* resolution



## Computing threshold dependent charge fractions and constraining the subpixel position



## Computing threshold dependent charge fractions and constraining the subpixel position

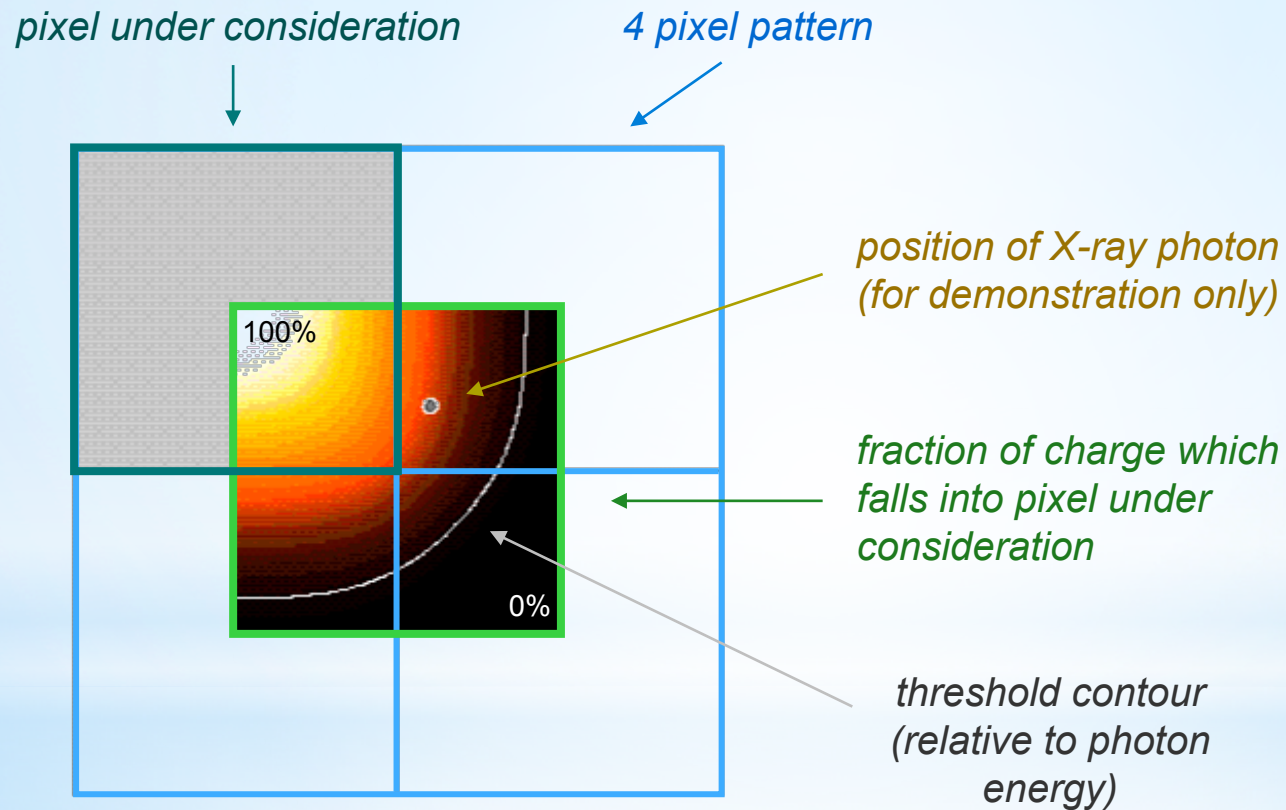


### Assumption:

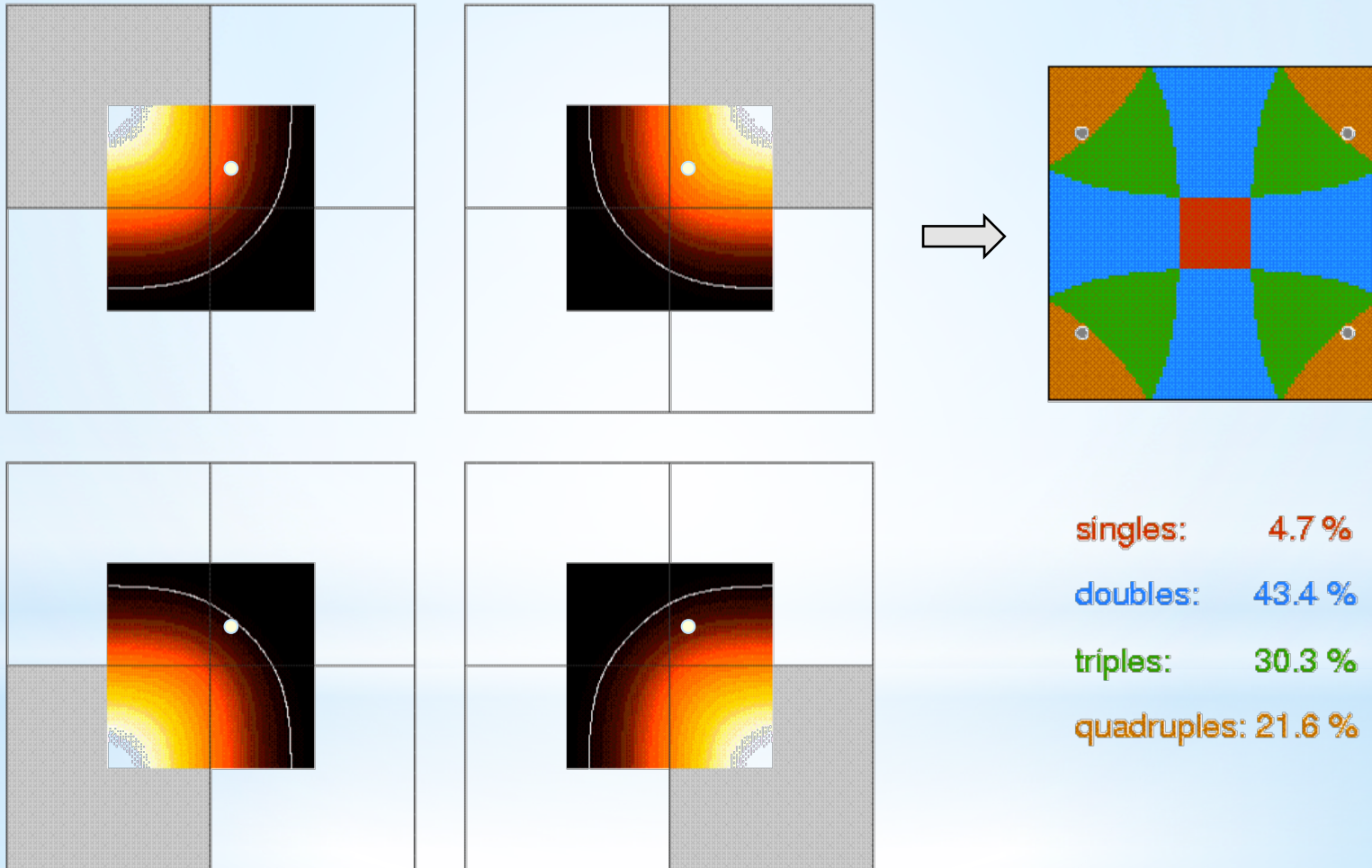
the fraction of the charge falling into the pixel under consideration is a unique function of the place of absorption, independent of the photon energy



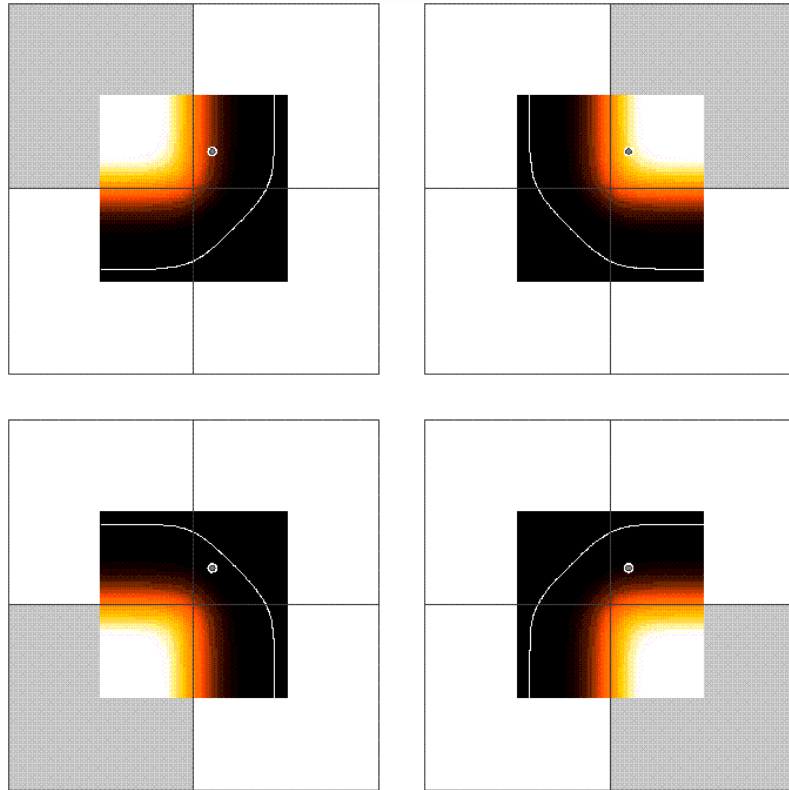
## Computing threshold dependent charge fractions and constraining the subpixel position



## Computing threshold dependent charge fractions and constraining the subpixel position

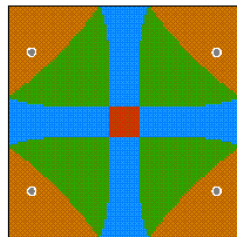
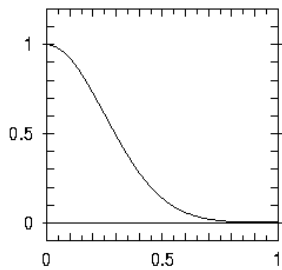


# Threshold dependent charge fractions and the subpixel position

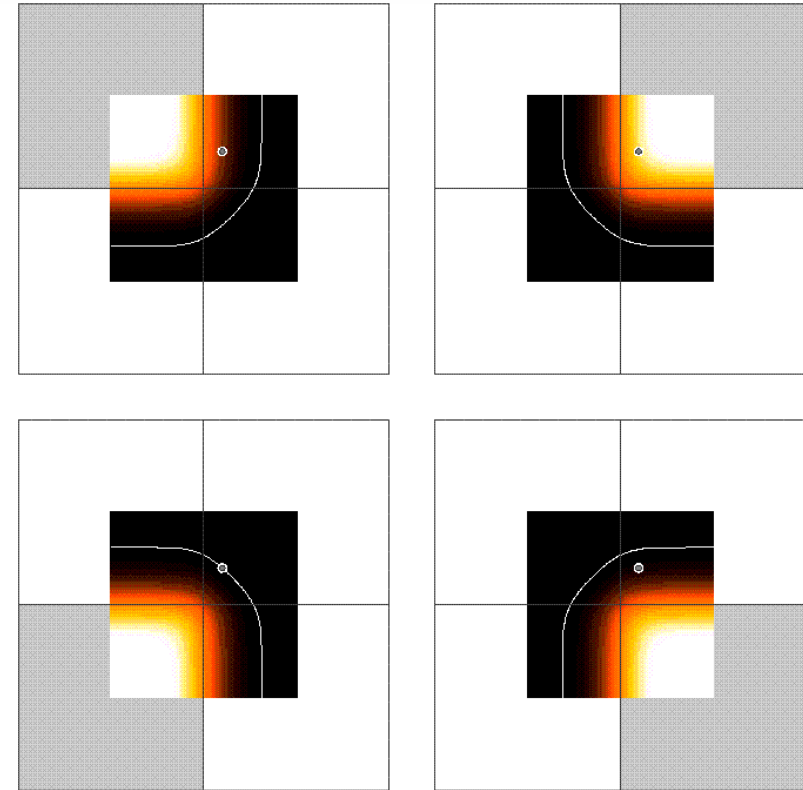


$$f(r) = e^{-(r/0.355)^2}$$

threshold: 0.001 (of total charge)

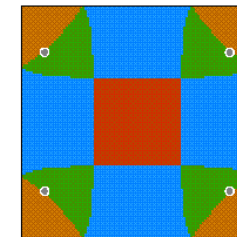
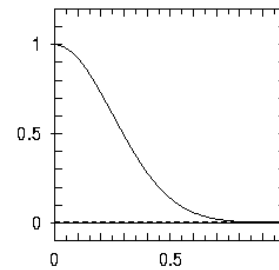


singles: 1.9 %  
 doubles: 26.2 %  
 triples: 37.2 %  
 quadruples: 34.7 %



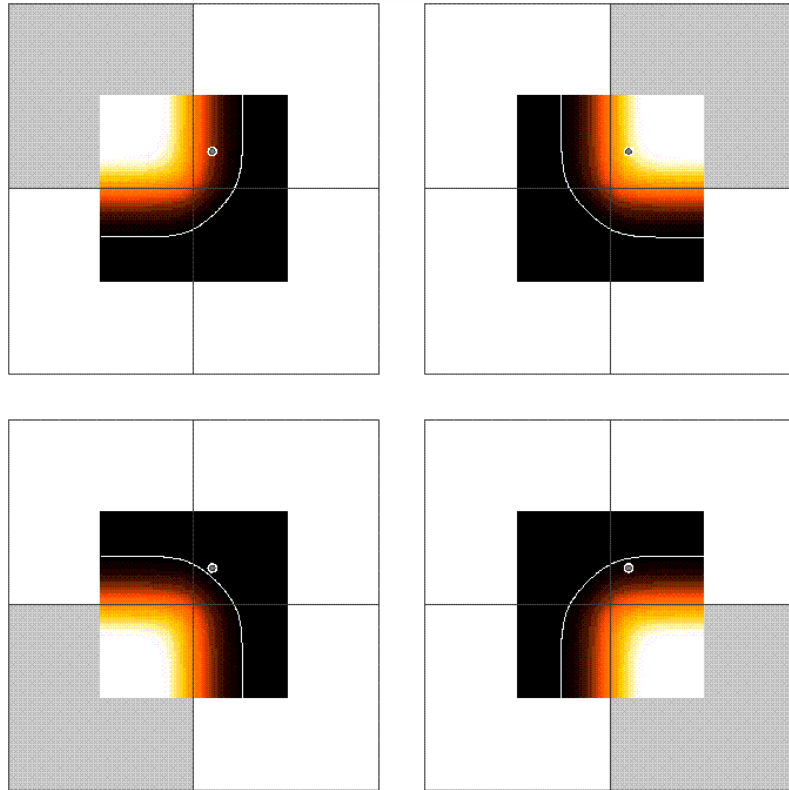
$$f(r) = e^{-(r/0.355)^2}$$

threshold: 0.007 (of total charge)



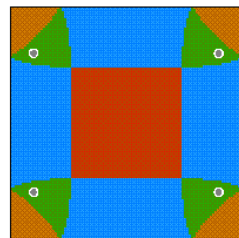
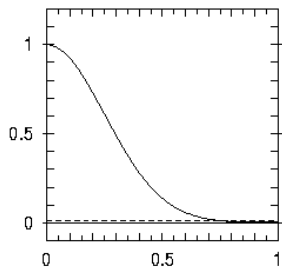
singles: 14.2 %  
 doubles: 50.0 %  
 triples: 19.1 %  
 quadruples: 16.7 %

# Threshold dependent charge fractions and the subpixel position

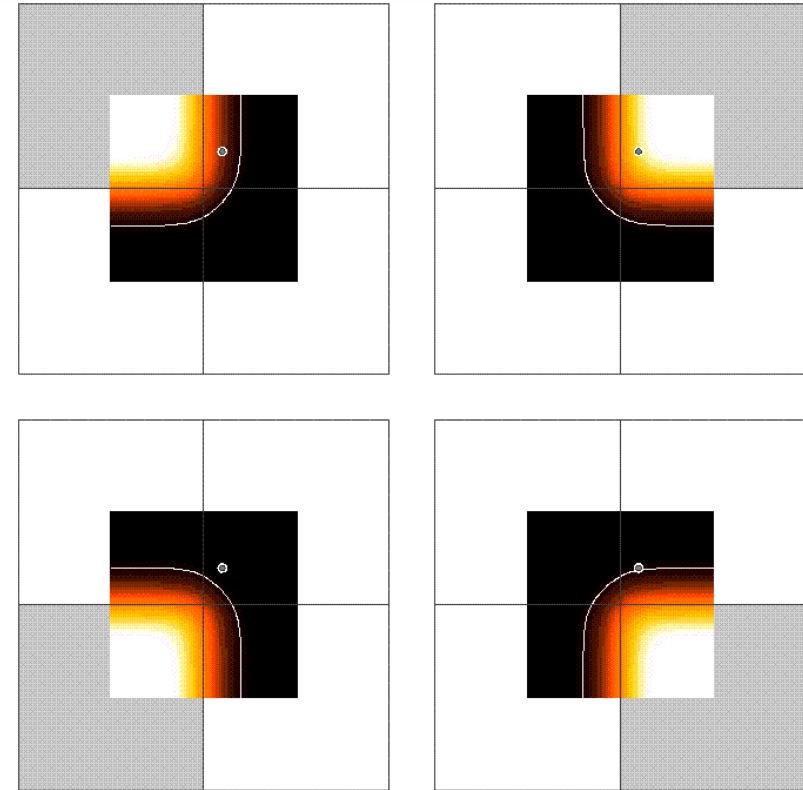


$$f(r) = e^{-(r/0.355)^2}$$

threshold: 0.015 (of total charge)

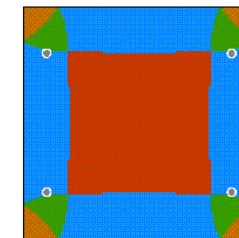
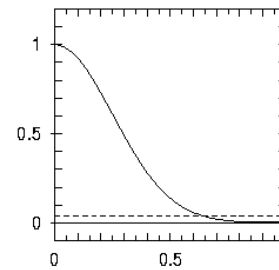


singles: 22.6 %  
 doubles: 52.7 %  
 triples: 13.6 %  
 quadruples: 11.1 %



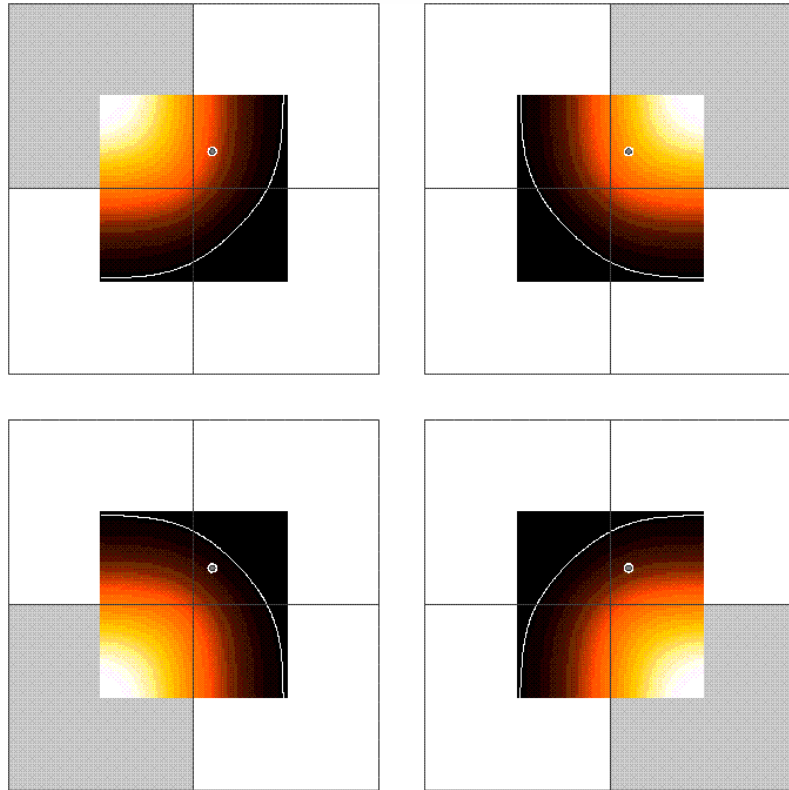
$$f(r) = e^{-(r/0.355)^2}$$

threshold: 0.040 (of total charge)



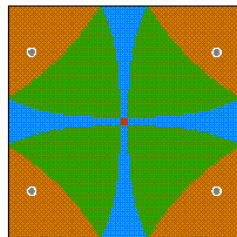
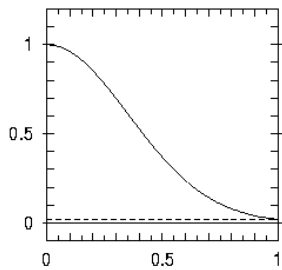
singles: 36.4 %  
 doubles: 50.5 %  
 triples: 7.6 %  
 quadruples: 5.5 %

# Threshold dependent charge fractions and the subpixel position

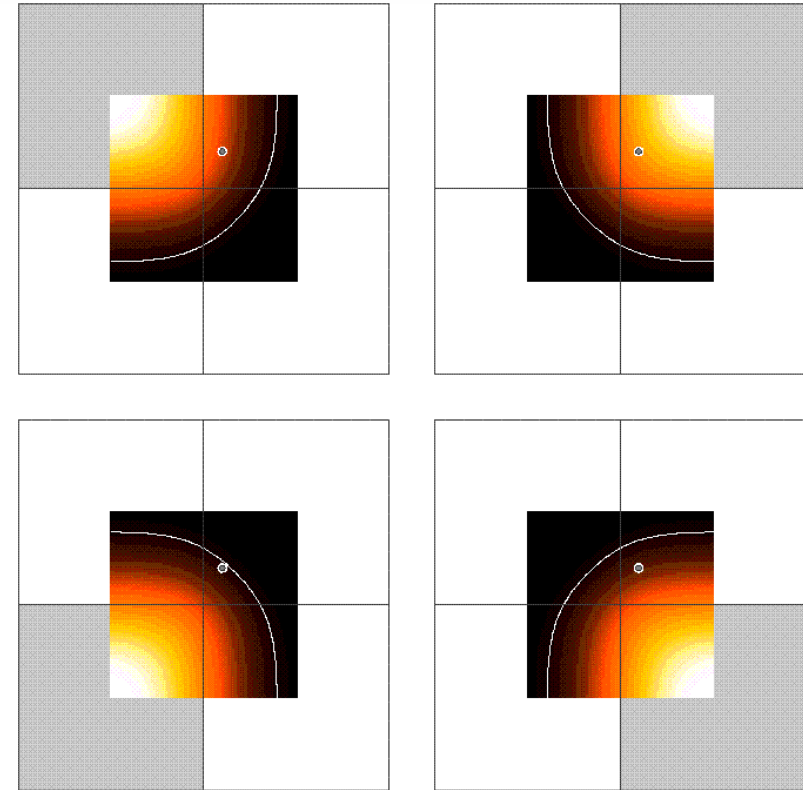


$$f(r) = e^{-(r/0.500)^2}$$

threshold: 0.020 (of total charge)

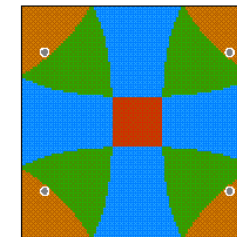
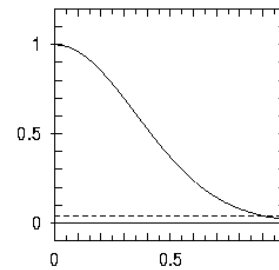


singles: 0.2 %  
 doubles: 16.9 %  
 triples: 46.2 %  
 quadruples: 36.8 %



$$f(r) = e^{-(r/0.500)^2}$$

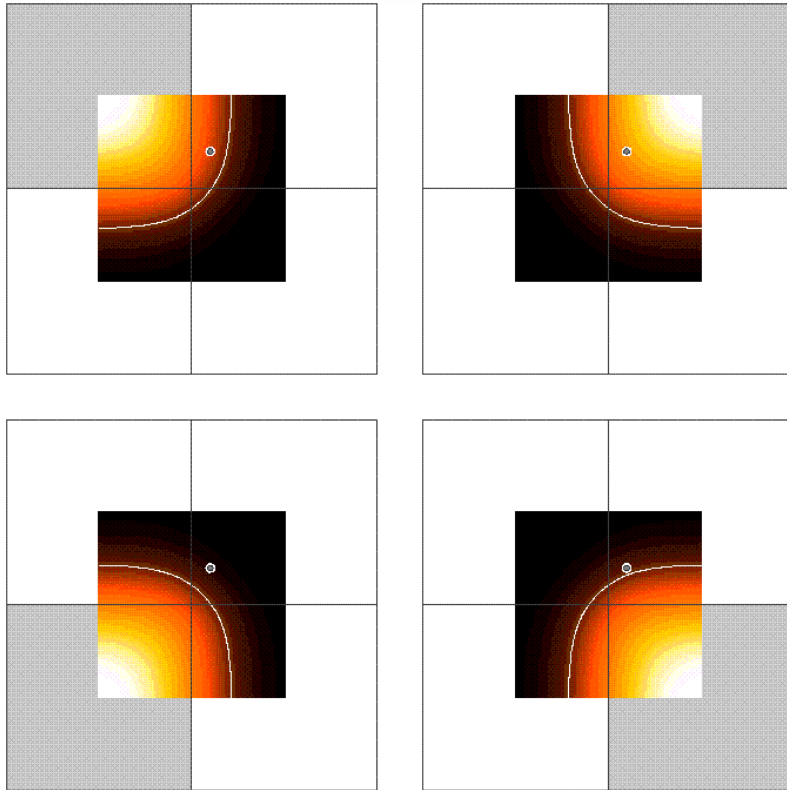
threshold: 0.040 (of total charge)



singles: 4.7 %  
 doubles: 43.4 %  
 triples: 30.3 %  
 quadruples: 21.6 %

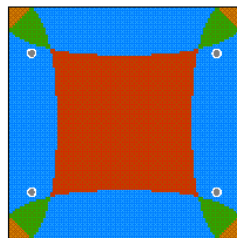
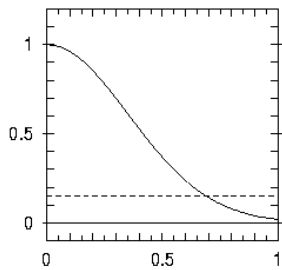


# Threshold dependent charge fractions and the subpixel position

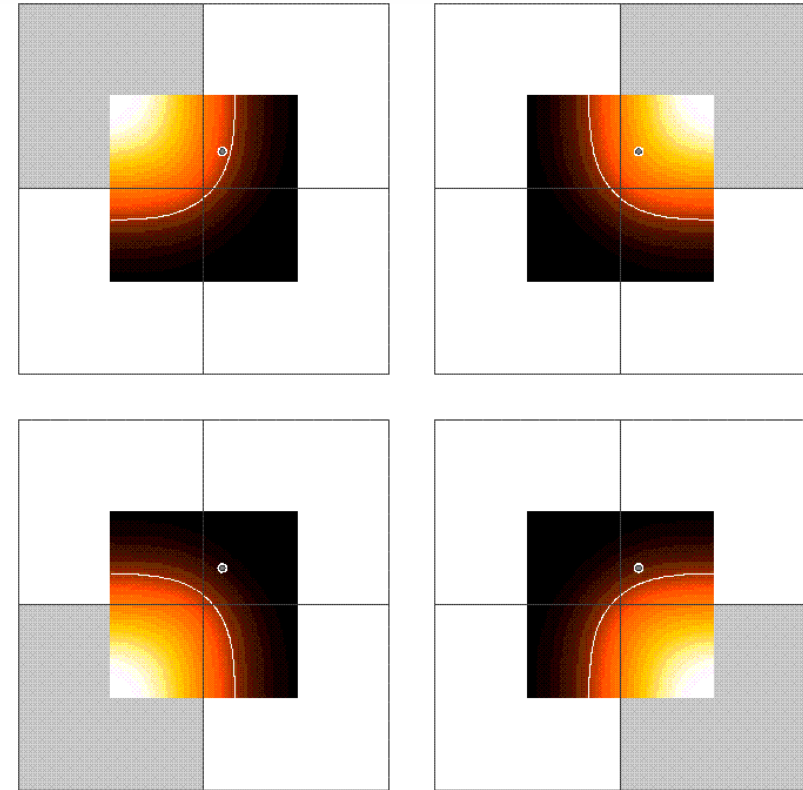


$$f(r) = e^{-(r/0.500)^2}$$

threshold: 0.150 (of total charge)

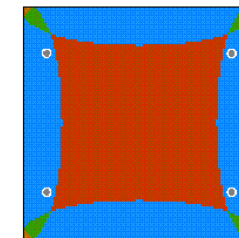
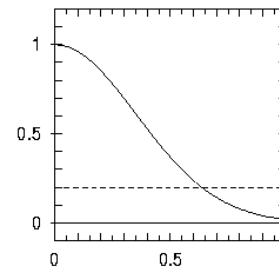


singles: 35.0 %  
 doubles: 56.2 %  
 triples: 6.4 %  
 quadruples: 2.5 %



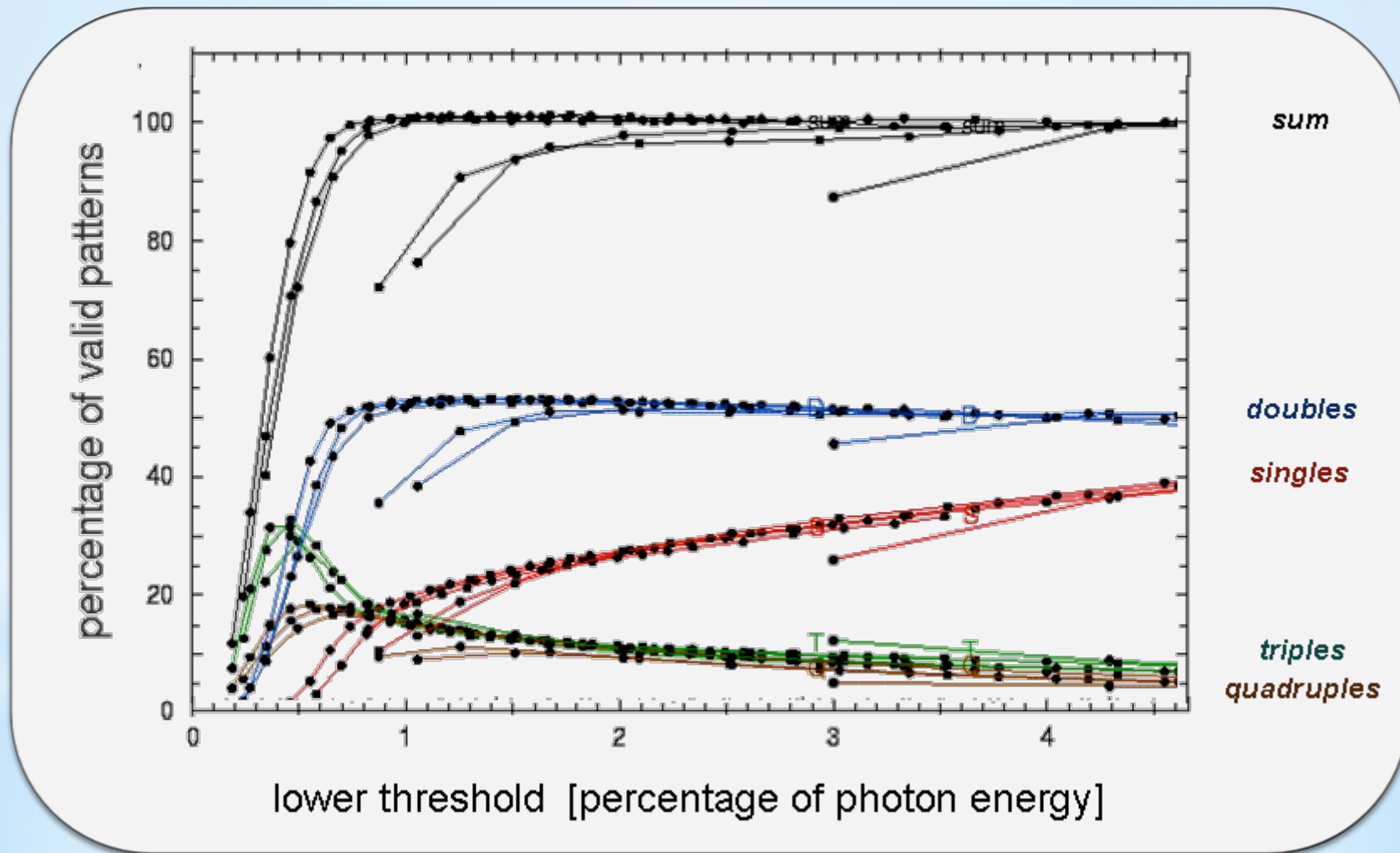
$$f(r) = e^{-(r/0.500)^2}$$

threshold: 0.200 (of total charge)

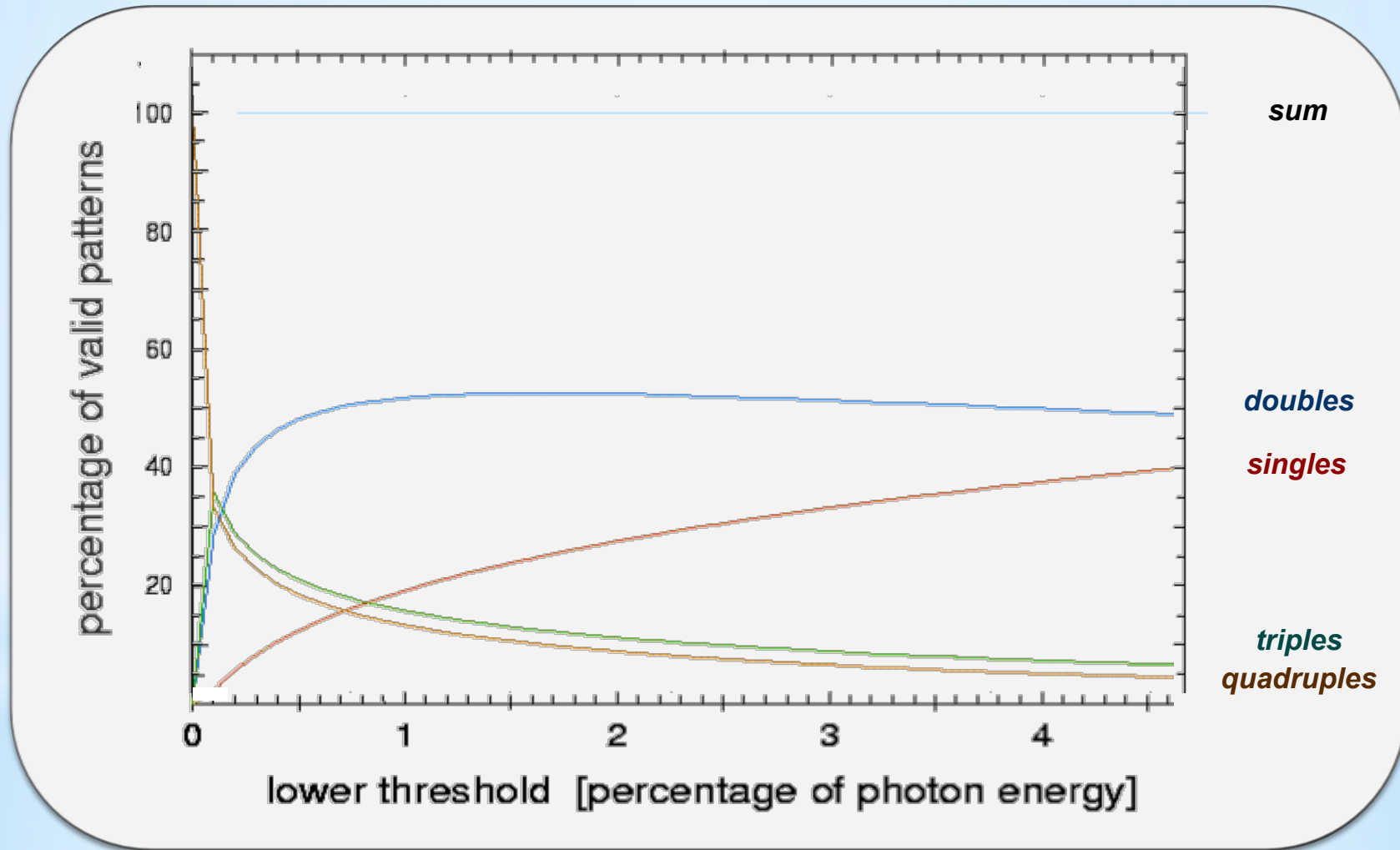


singles: 47.4 %  
 doubles: 49.7 %  
 triples: 2.3 %  
 quadruples: 0.6 %

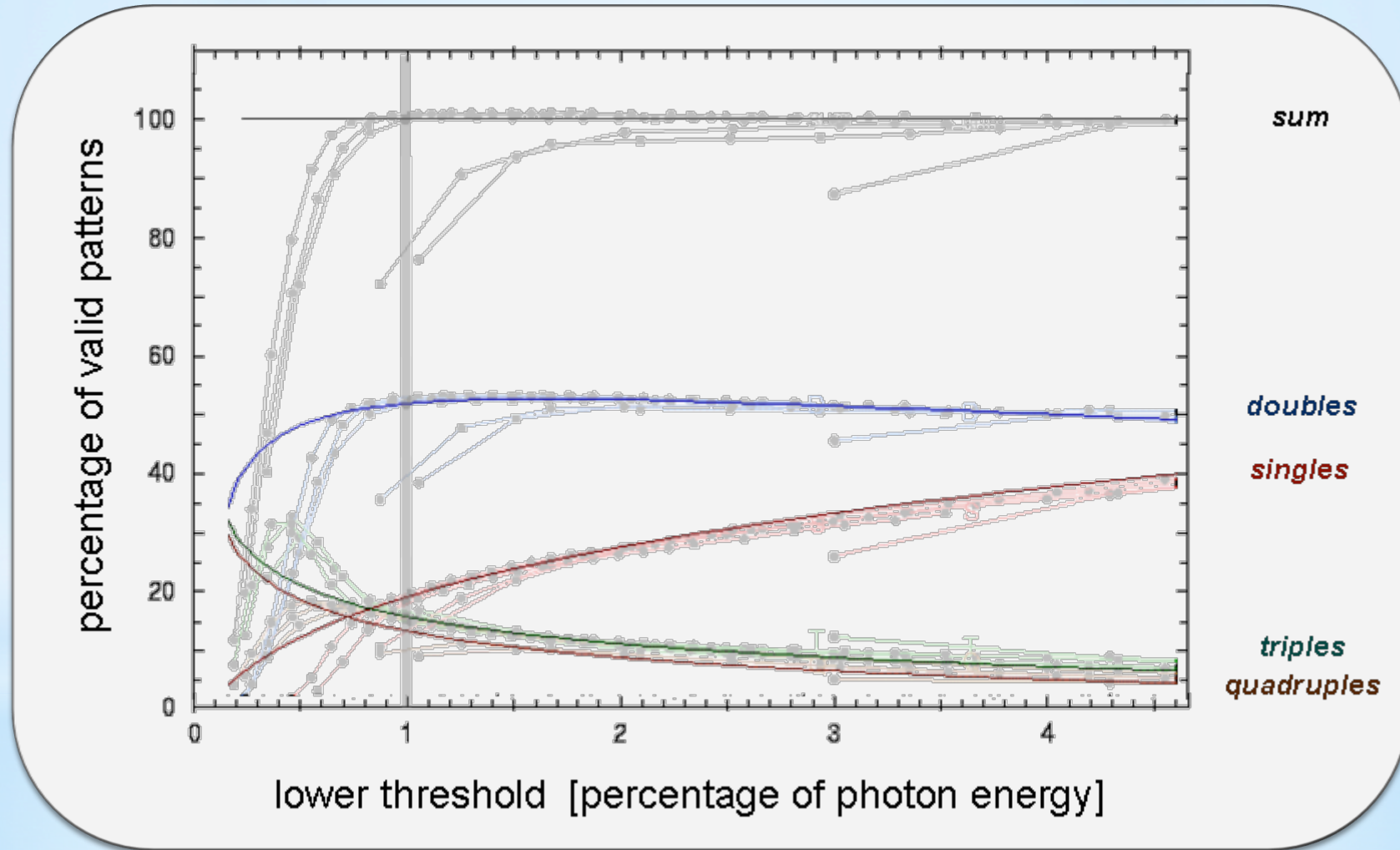
## Threshold dependent pattern fractions: Measurements



## Threshold dependent pattern fractions: Model Predictions

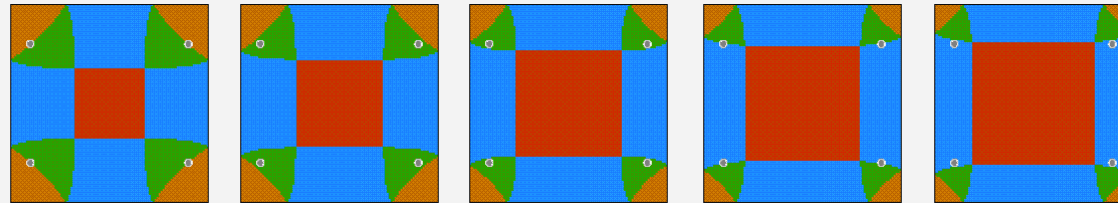


## Threshold dependent pattern fractions: Measurements and Model Predictions

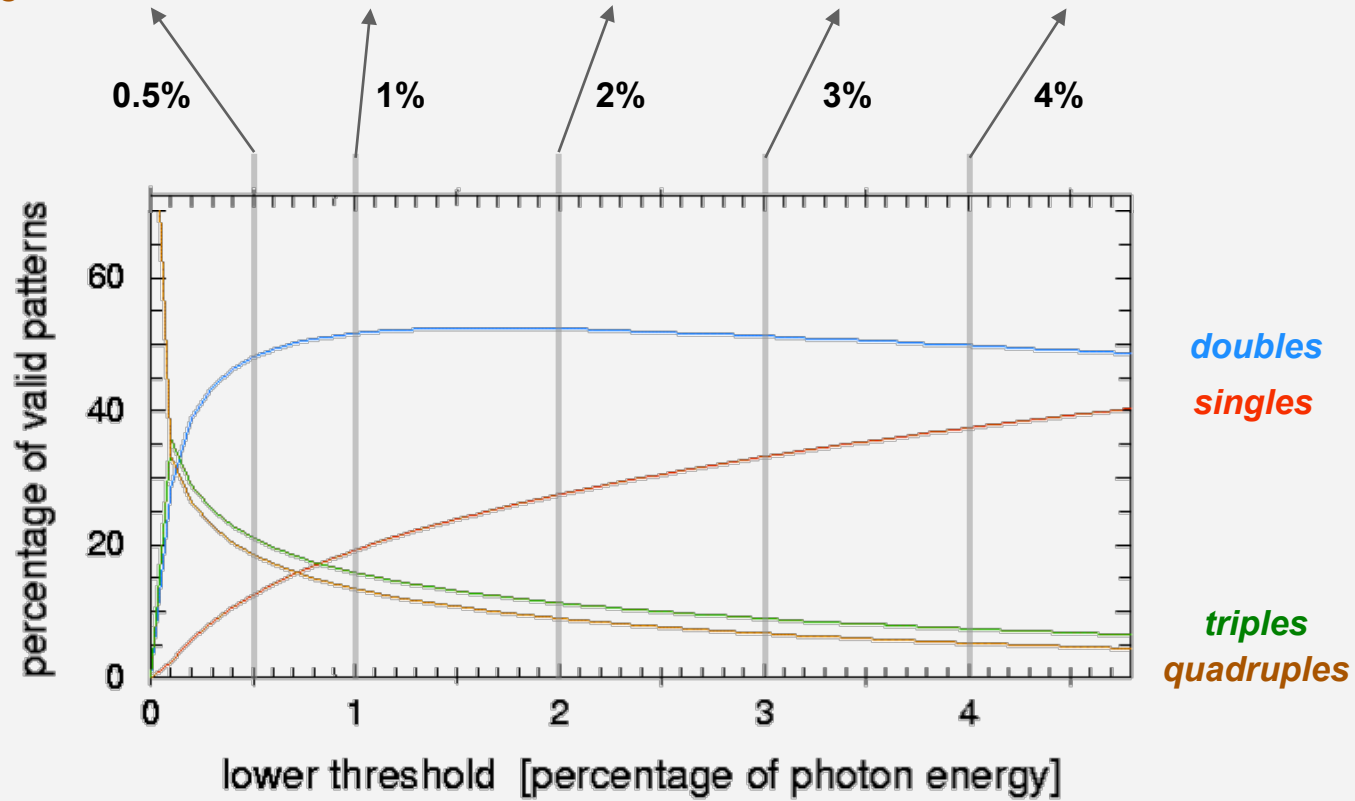


# Predicted subpixel regions

*singles*  
*doubles*  
*triples*  
*quadruples*



*only one parameter:  
 low energy threshold [%]*

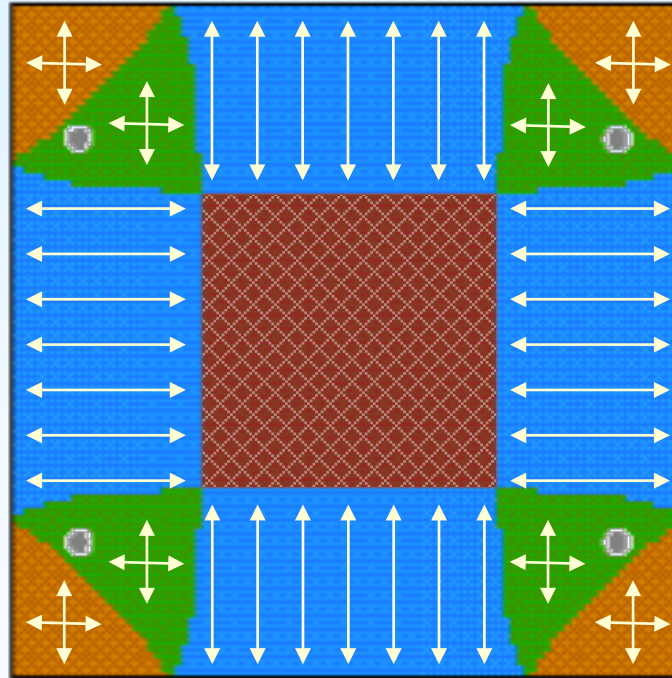




## Subpixel resolution properties

*singles: no spatial resolution*

*doubles: spatial resolution in one dimension*



*triples: spatial resolution in two dimensions*

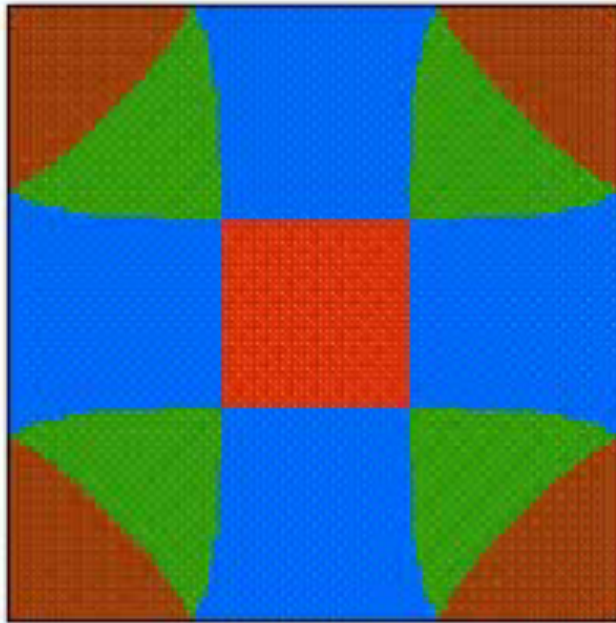
*quadruples: spatial resolution in two dimensions*

illustration for a low energy threshold of 1%

decreasing the low energy threshold

- decreases the number of ( 'false' ) singles
- increases the energy resolution
- increases the spatial resolution

# Subpixel regions



rel. threshold: 0.48 %

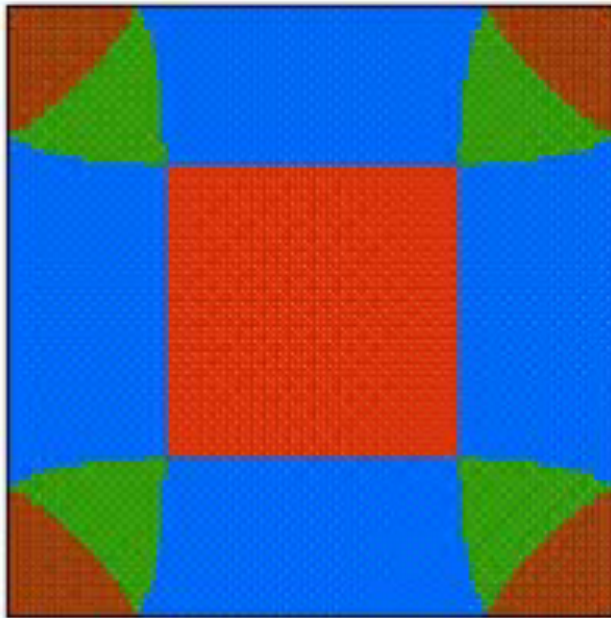
**singles:** 9.4 %

**doubles:** 45.8 %

**triples:** 23.4 %

**quadruples:** 21.3 %

# Subpixel regions



rel. threshold: 1.81 %

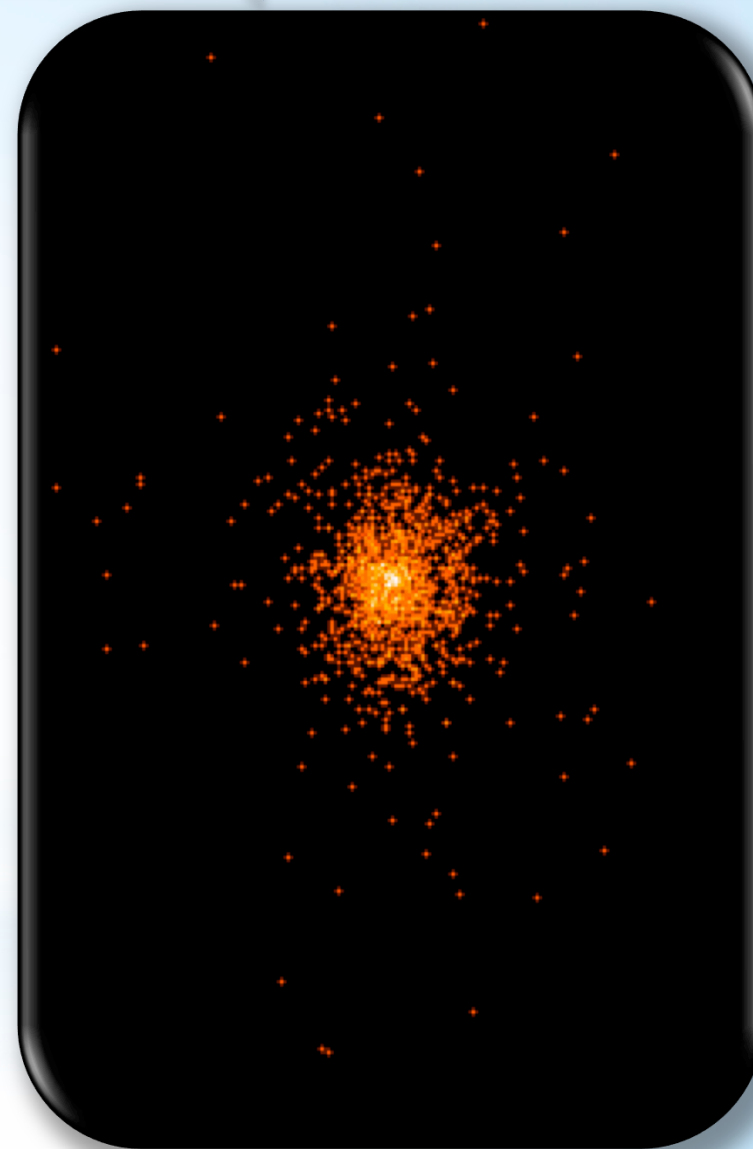
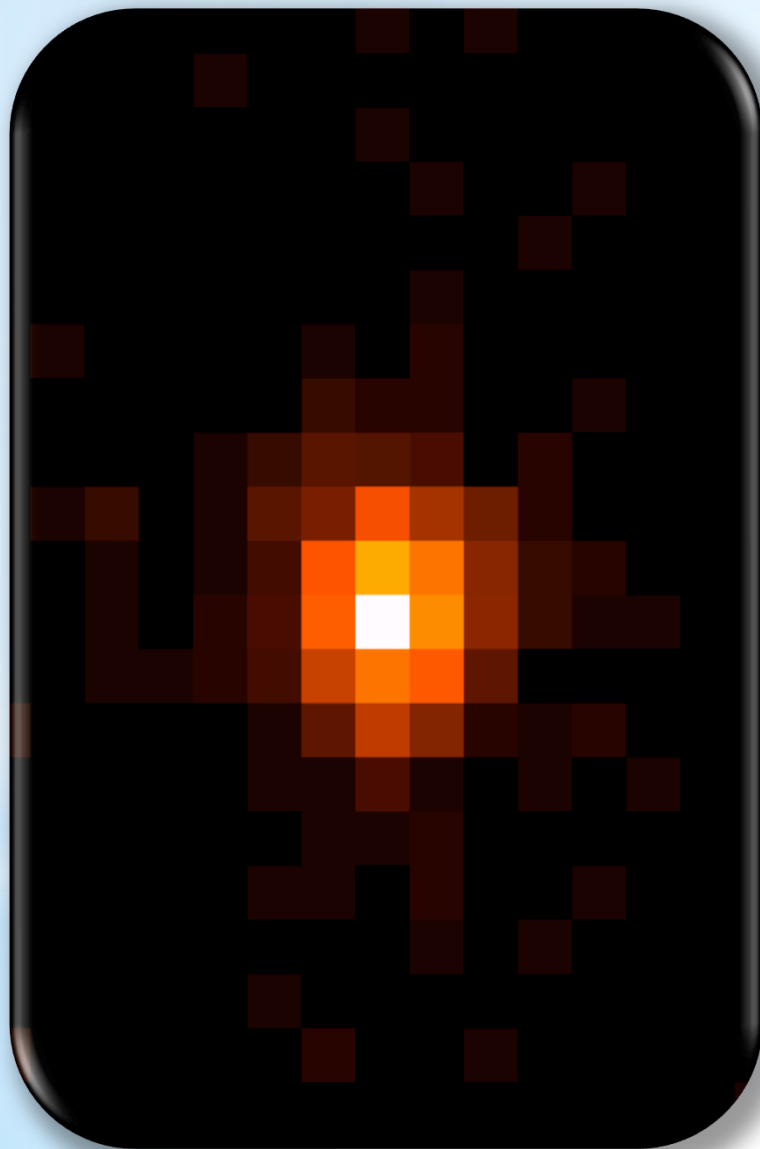
**singles:** 23.0 %

**doubles:** 53.0 %

**triples:** 13.0 %

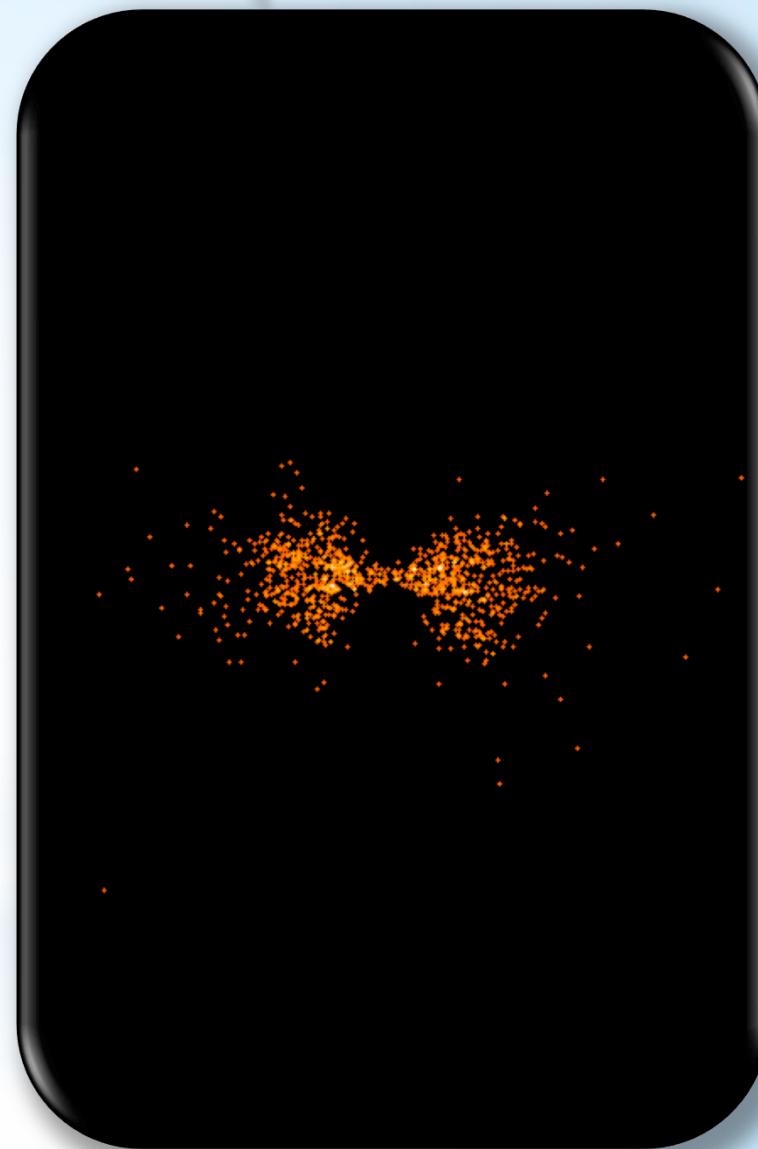
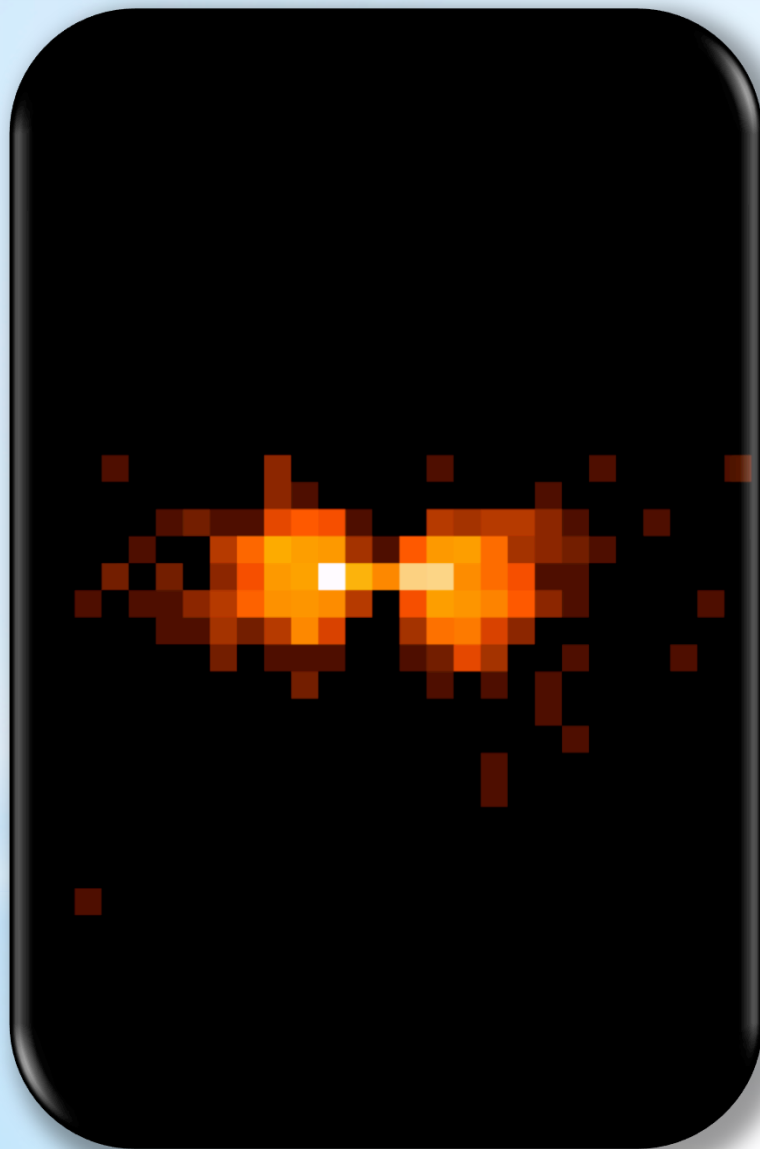
**quadruples:** 11.0 %

## Comparison of X-ray CCD images without and with subpixel resolution



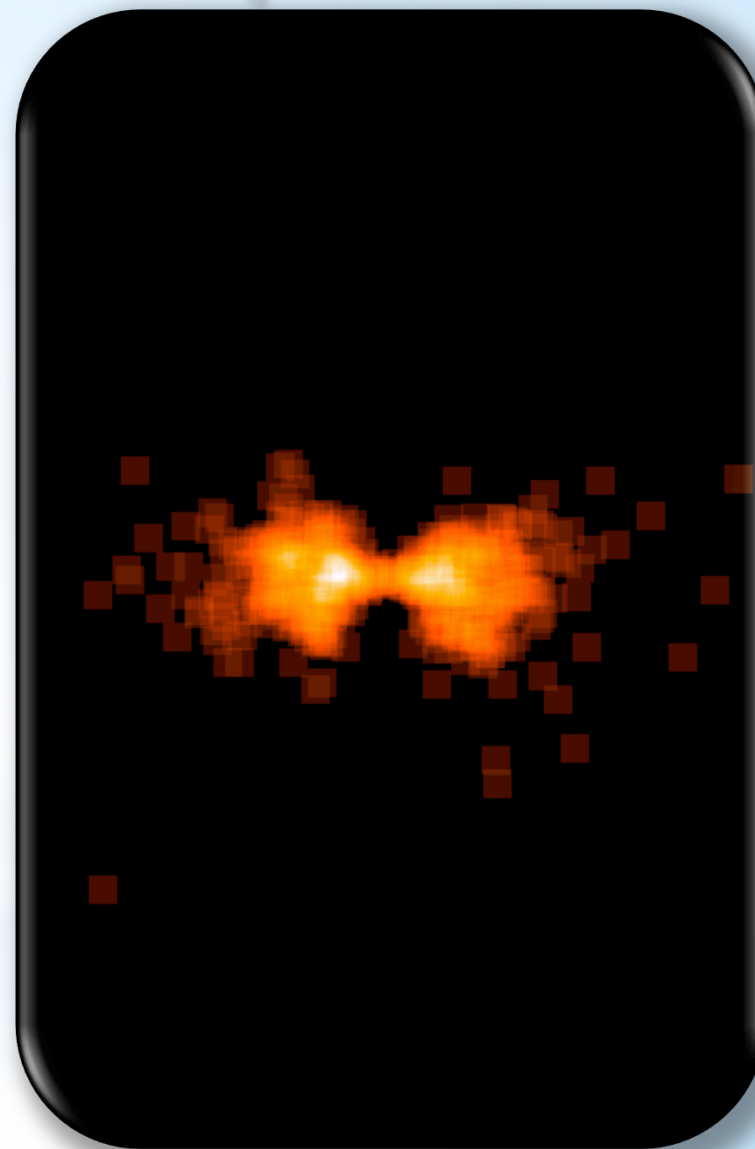
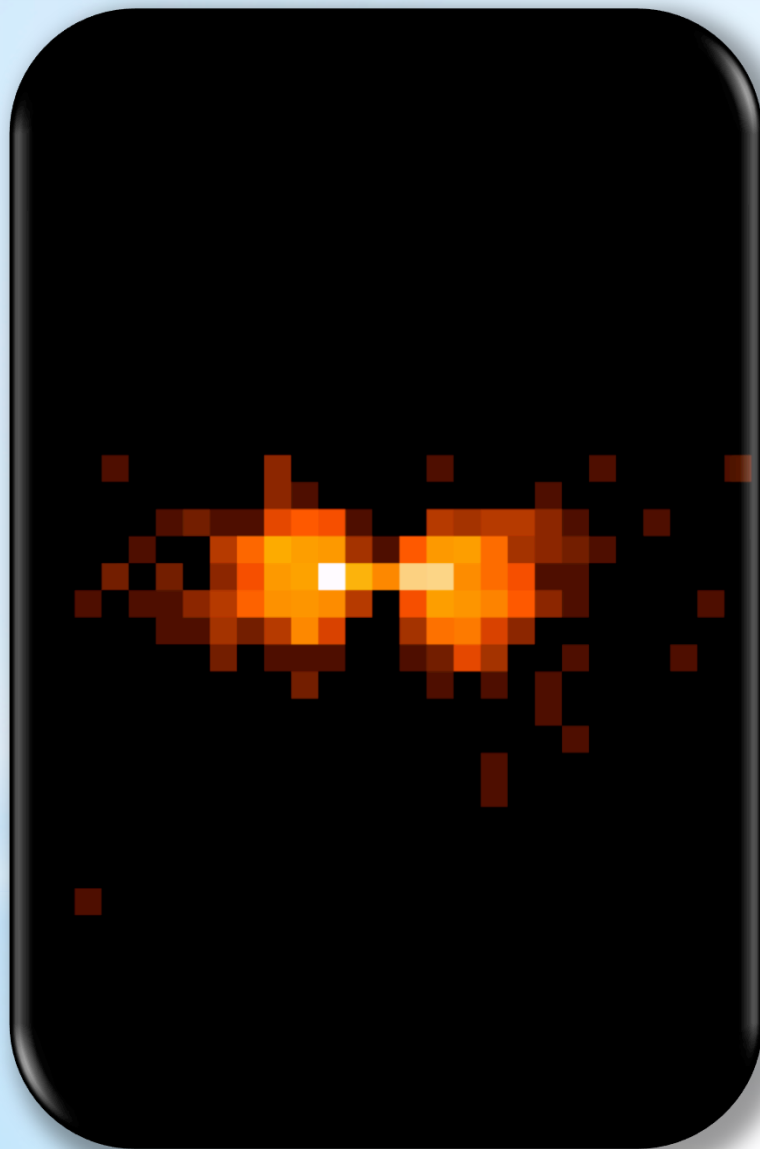


## Comparison of X-ray CCD images without and with subpixel resolution

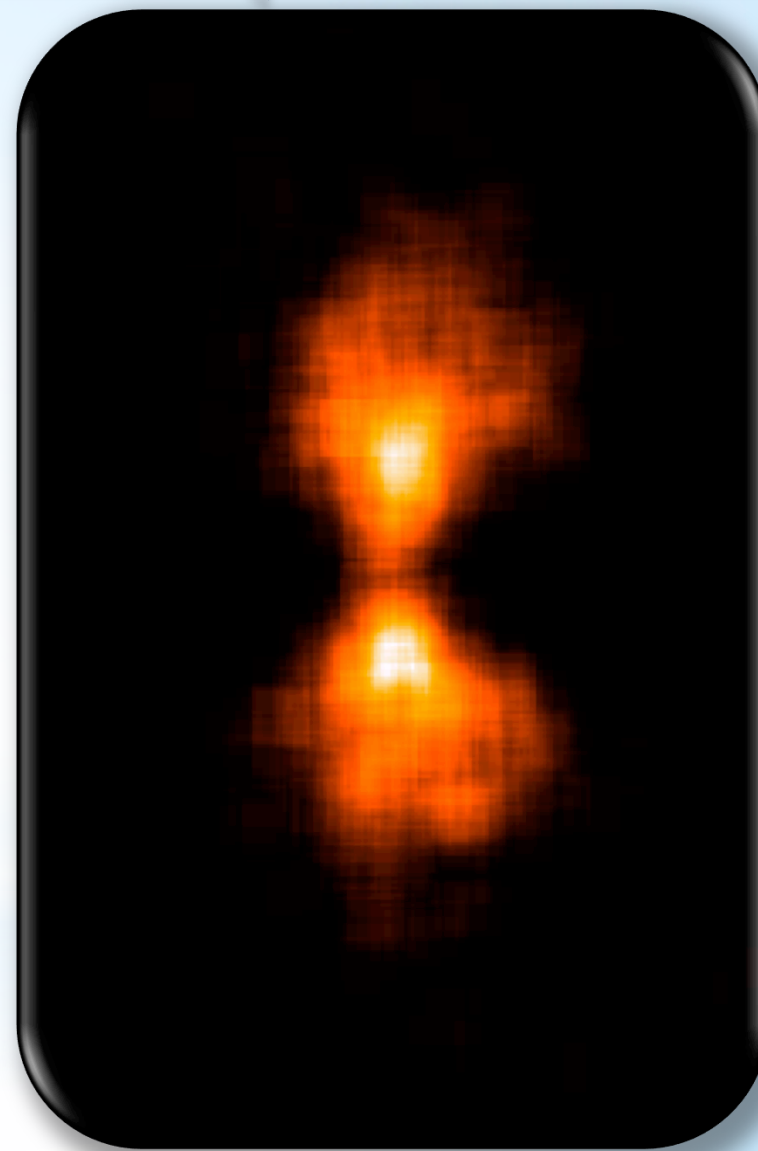




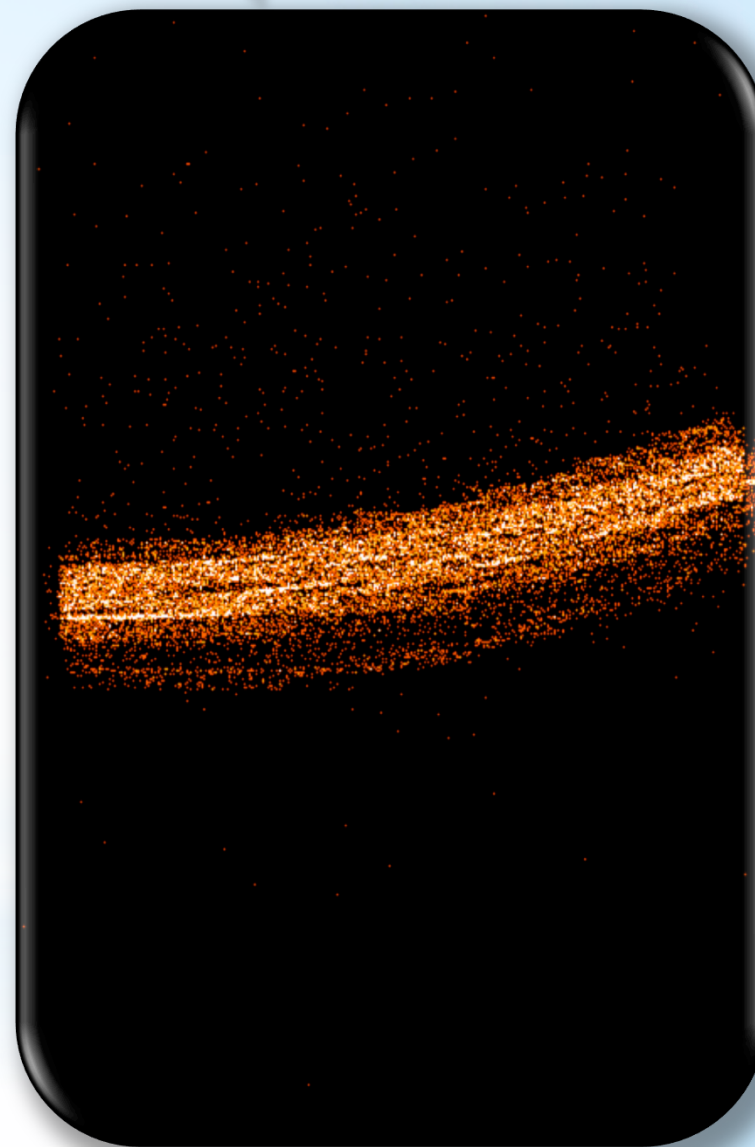
## Comparison of X-ray CCD images without and with subpixel resolution



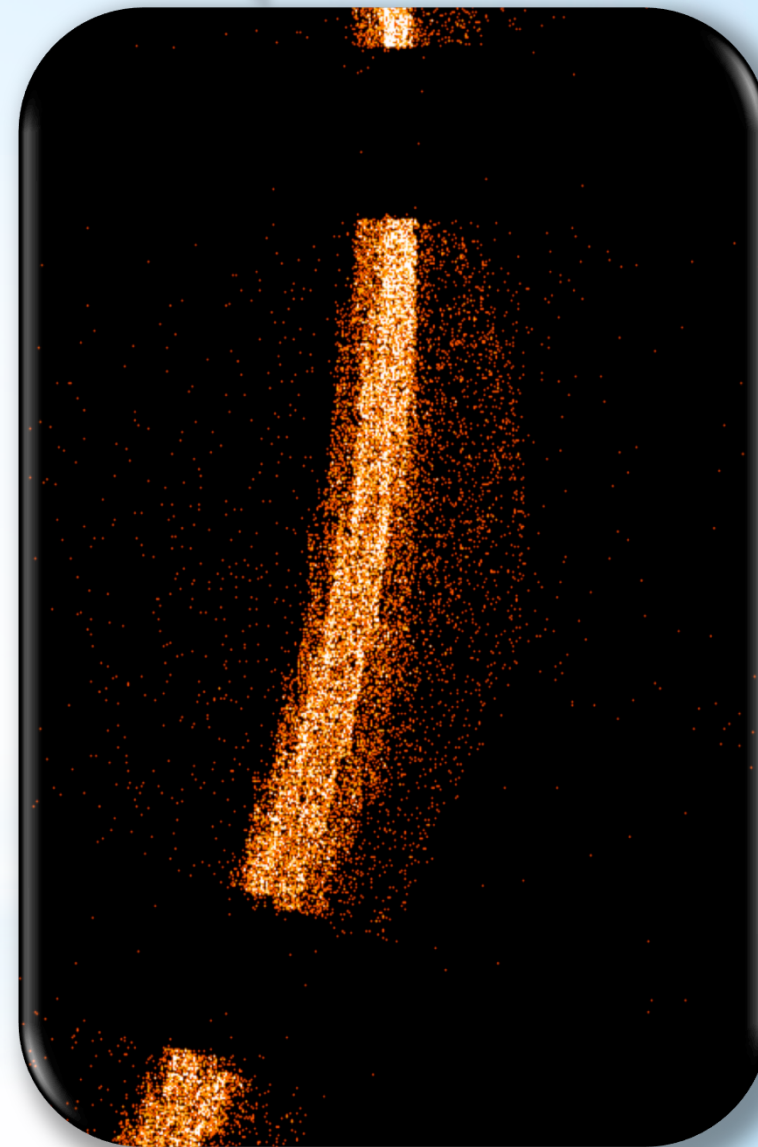
## Comparison of X-ray CCD images without and with subpixel resolution



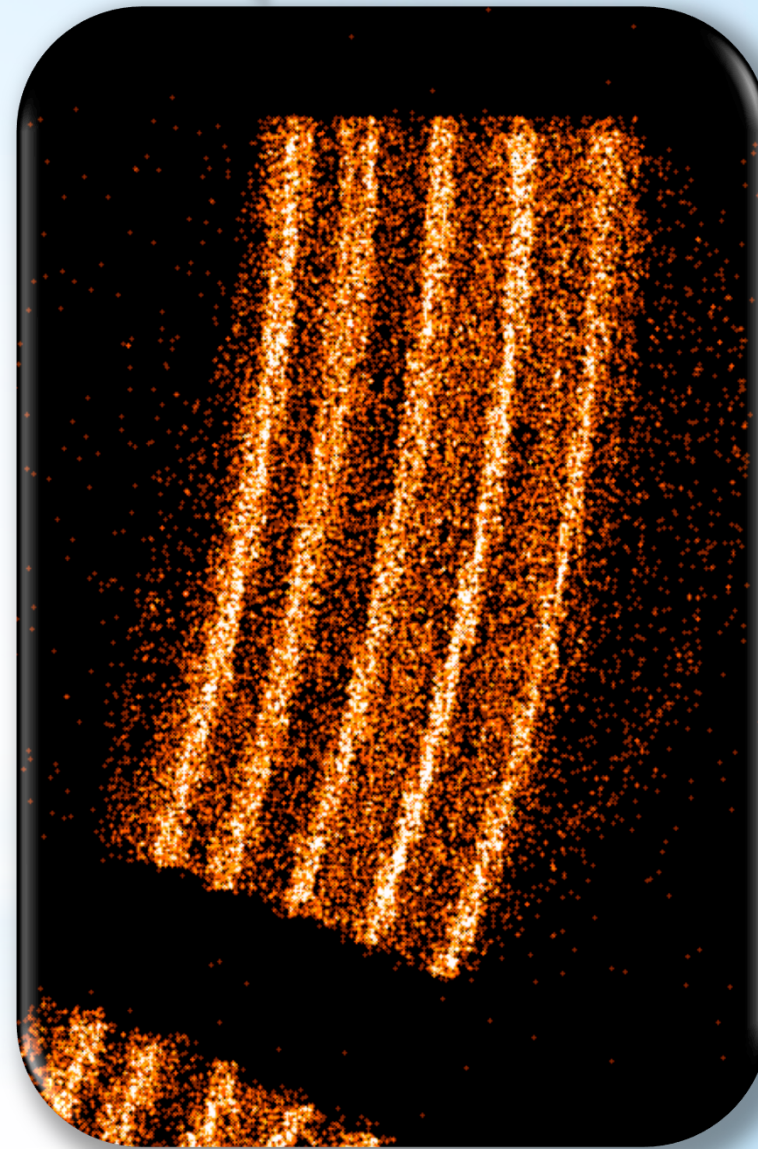
## Comparison of X-ray CCD images without and with subpixel resolution



## Comparison of X-ray CCD images without and with subpixel resolution

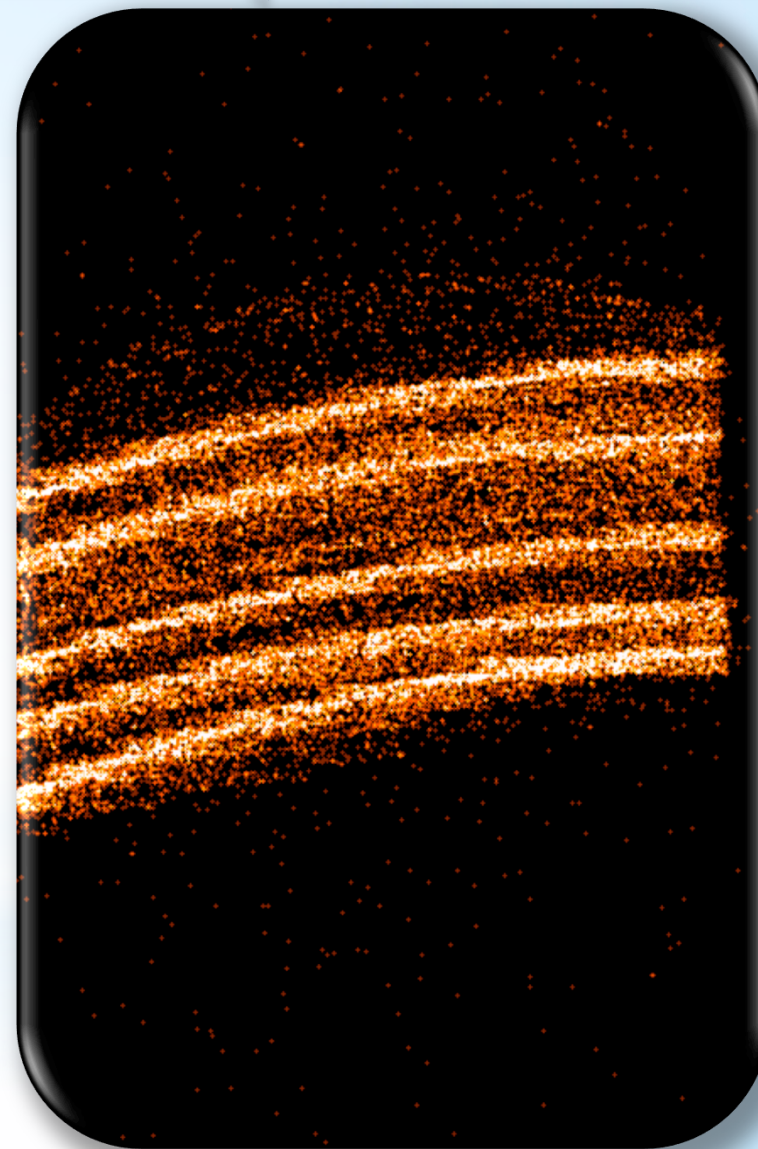
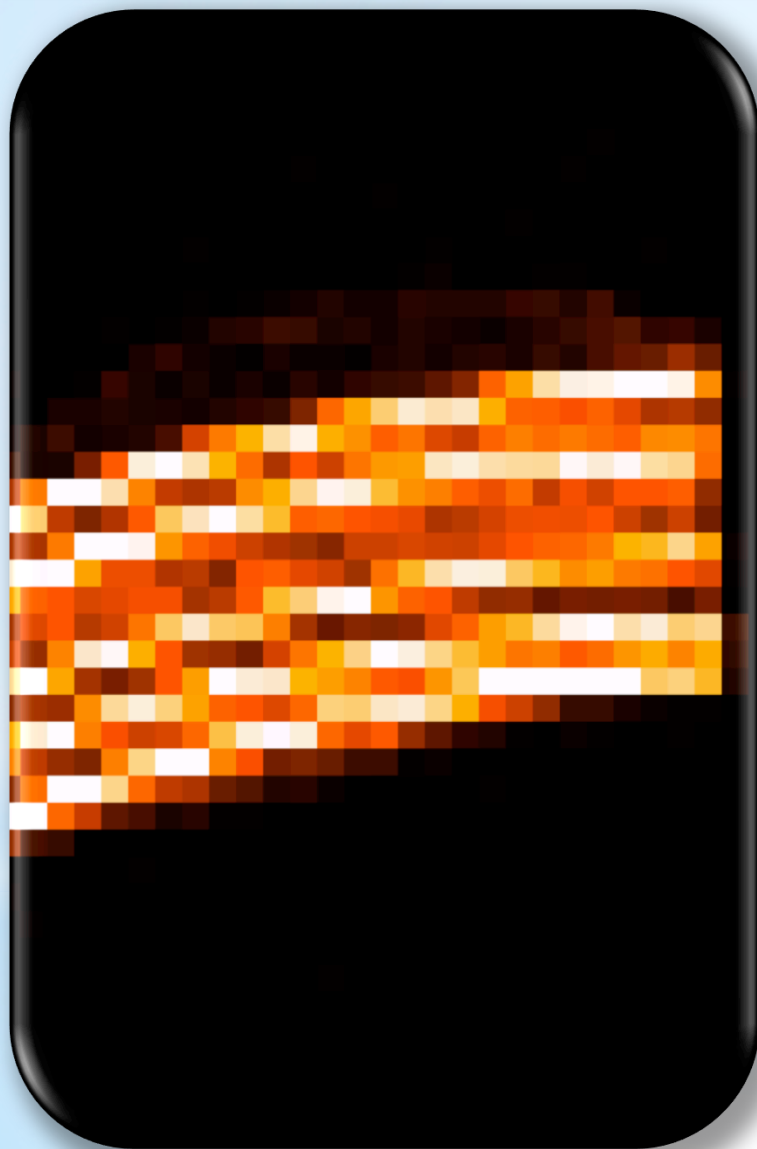


## Comparison of X-ray CCD images without and with subpixel resolution

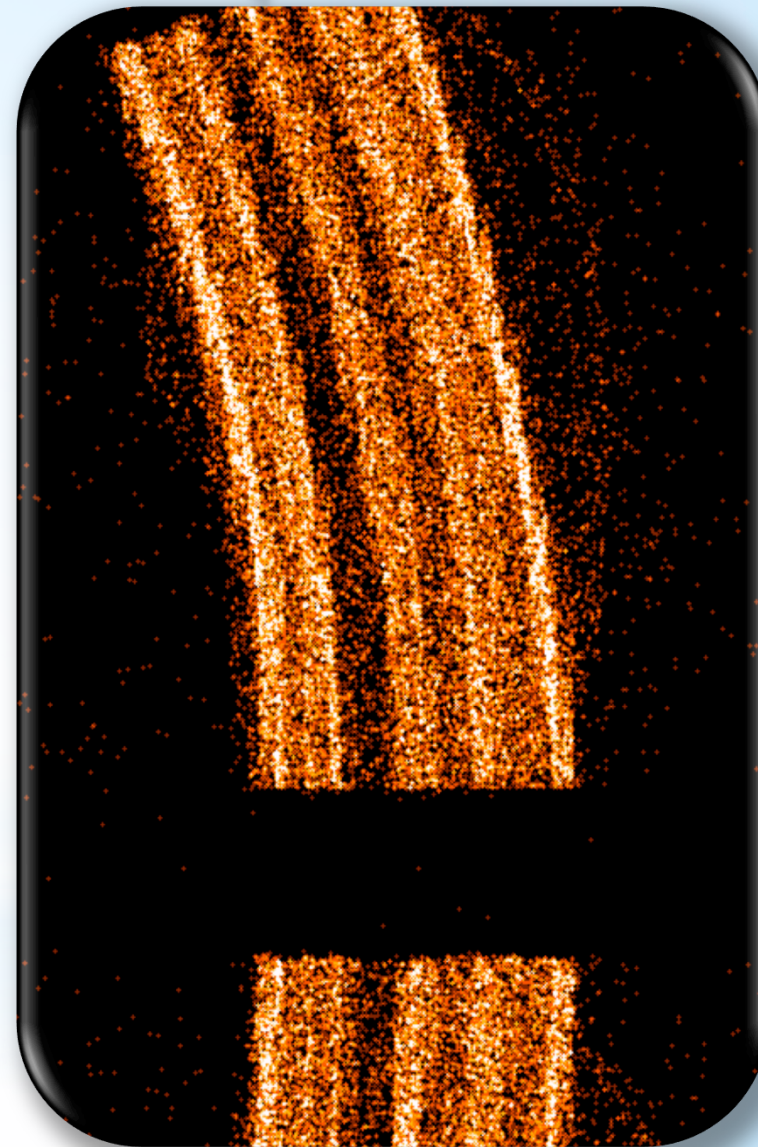




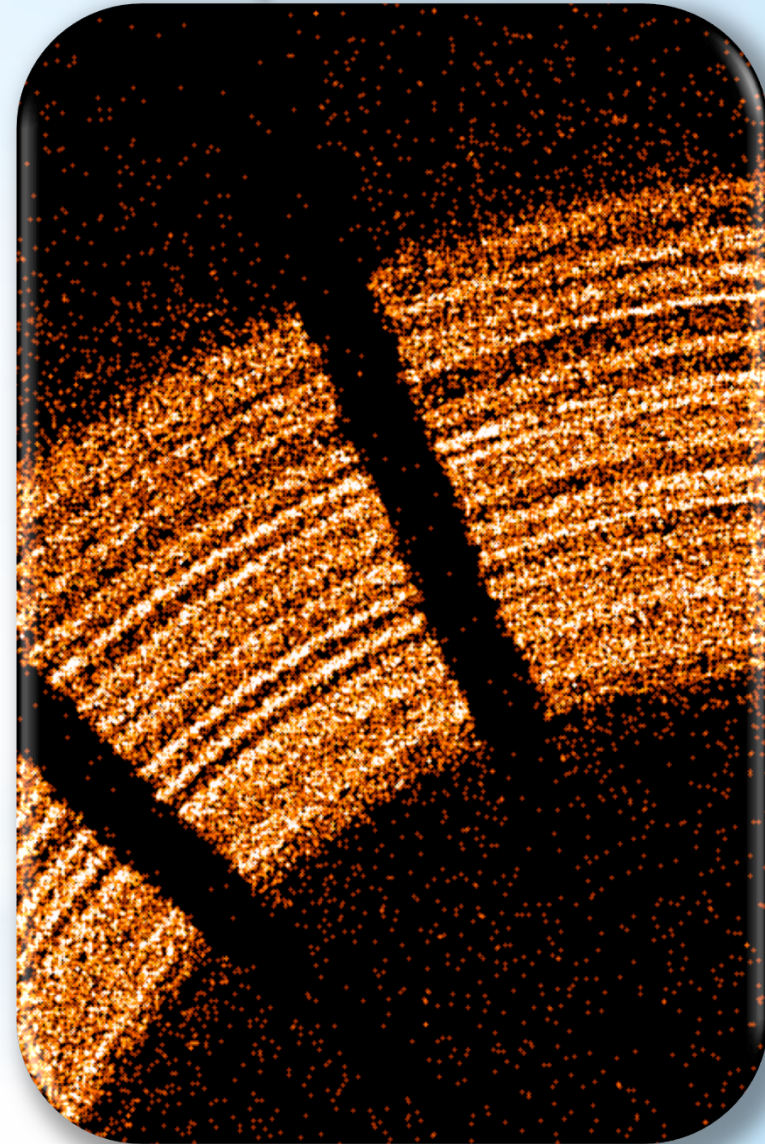
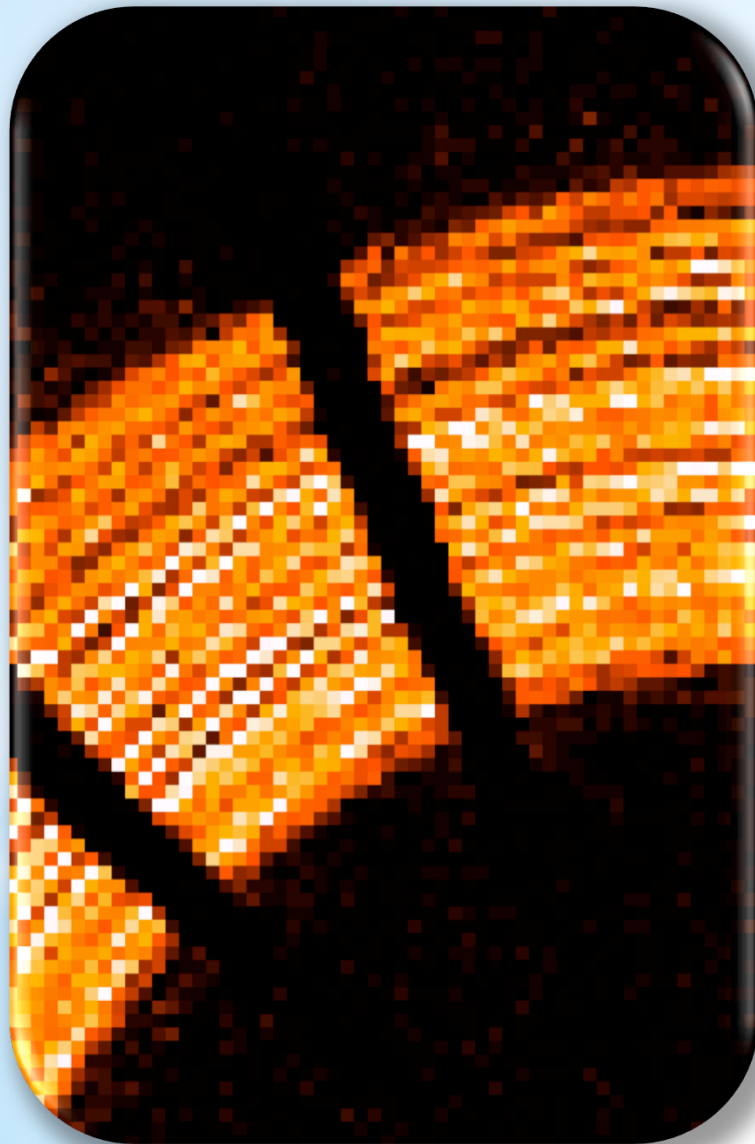
## Comparison of X-ray CCD images without and with subpixel resolution



## Comparison of X-ray CCD images without and with subpixel resolution

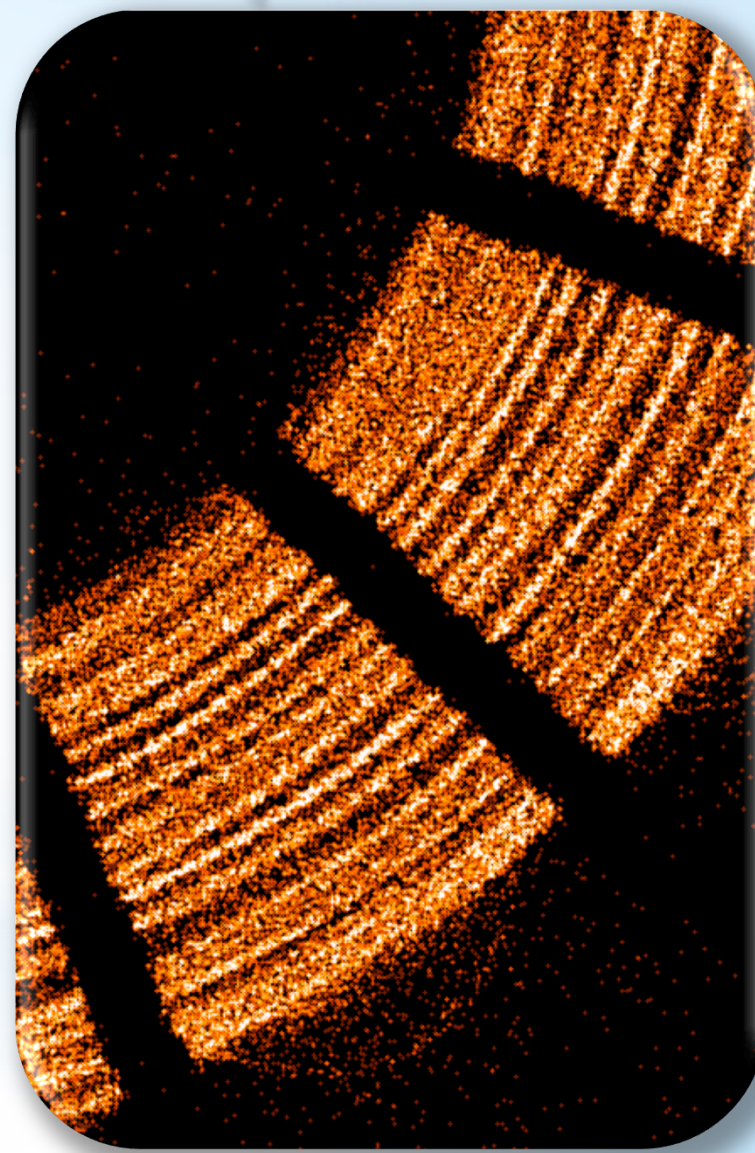


## Comparison of X-ray CCD images without and with subpixel resolution

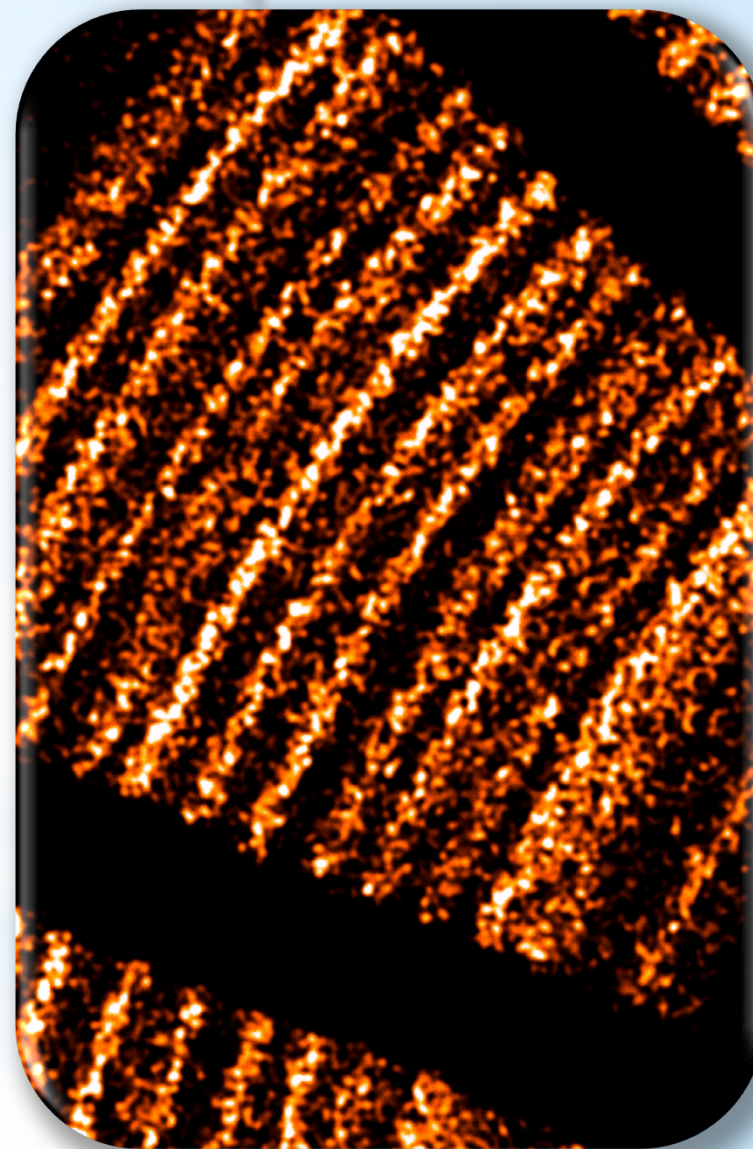




## Comparison of X-ray CCD images without and with subpixel resolution

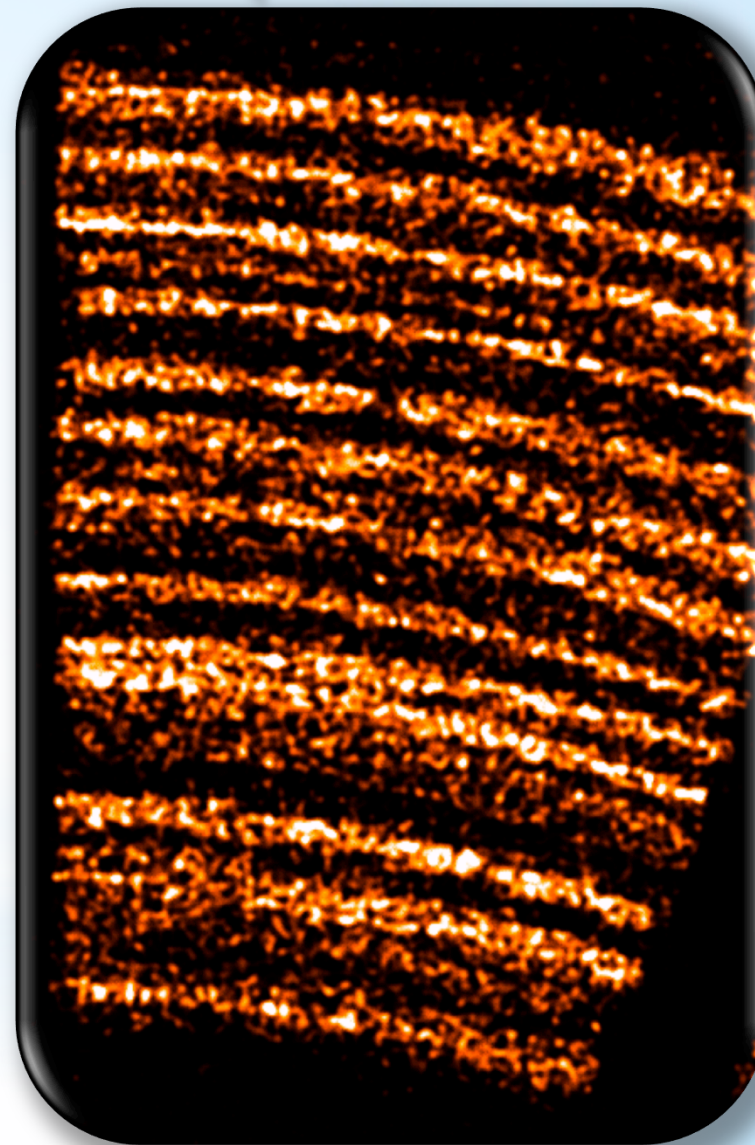
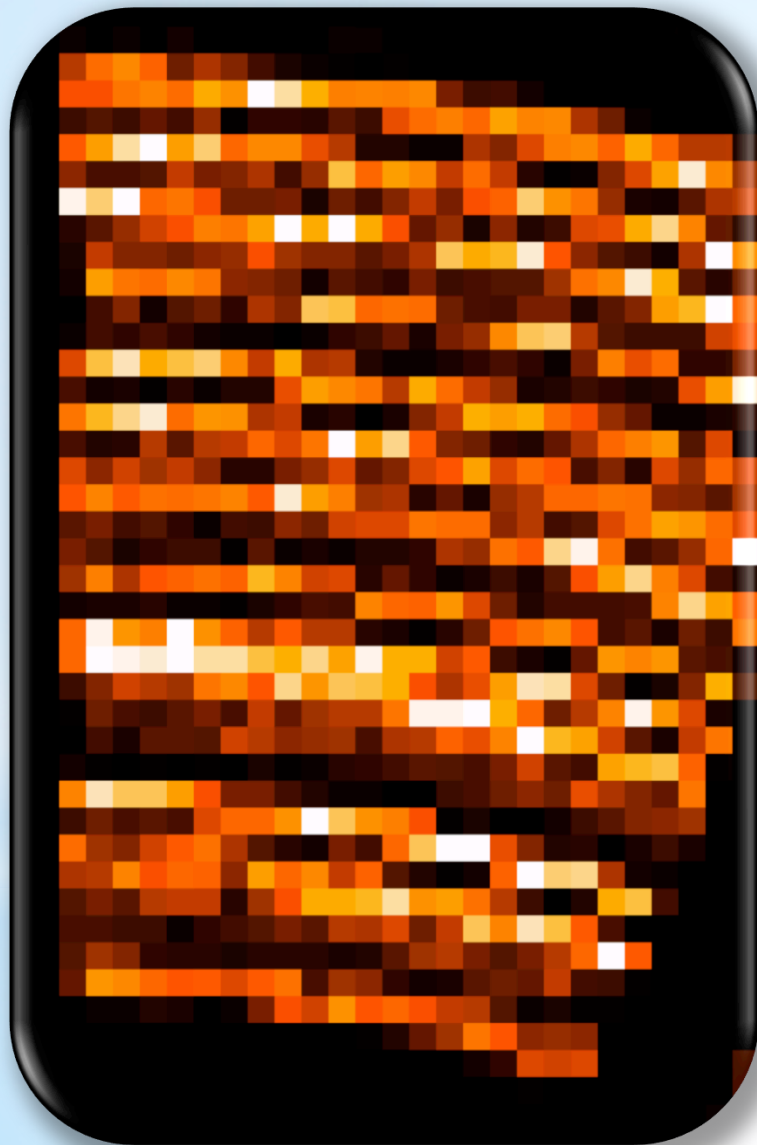


## Comparison of X-ray CCD images without and with subpixel resolution

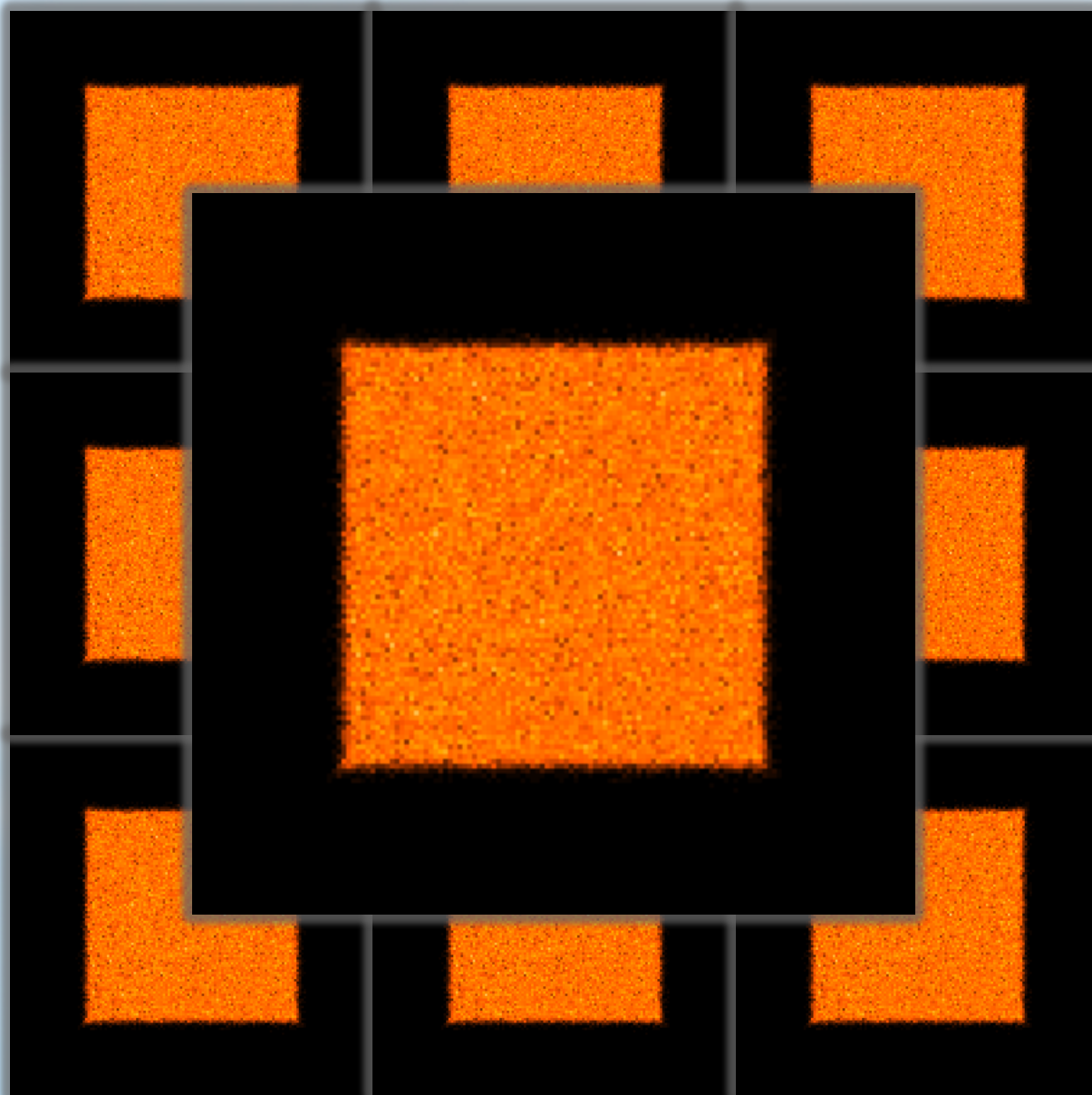




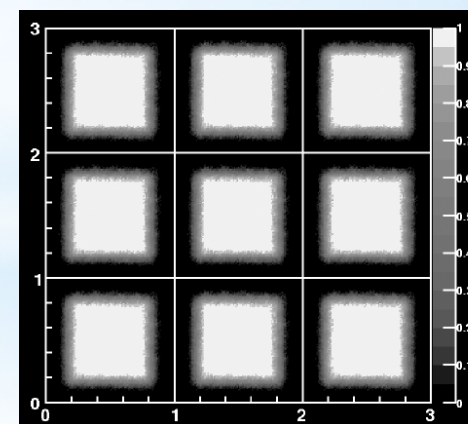
## Comparison of X-ray CCD images without and with subpixel resolution



## Distribution of reconstructed photon positions

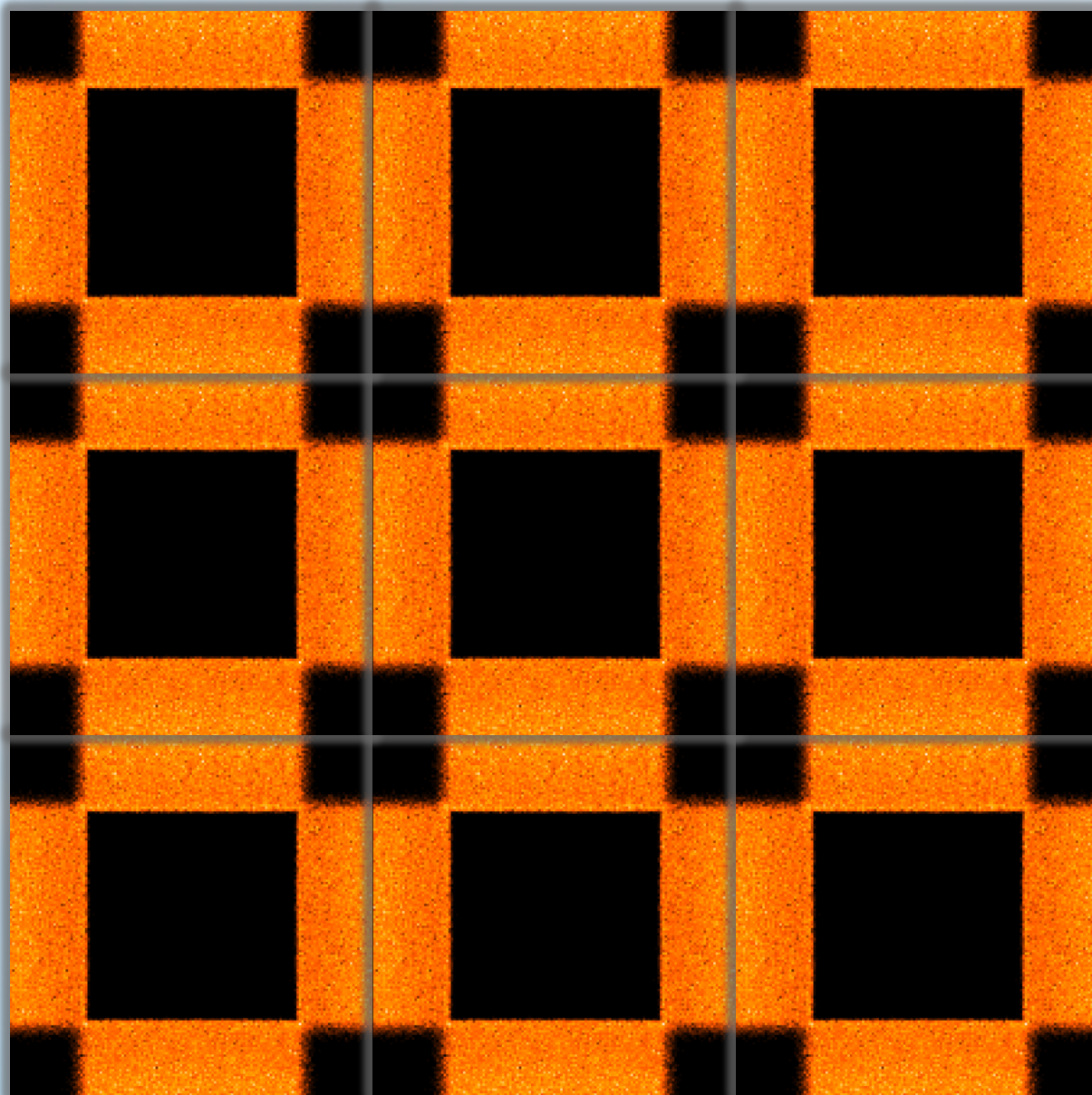


single pixel events

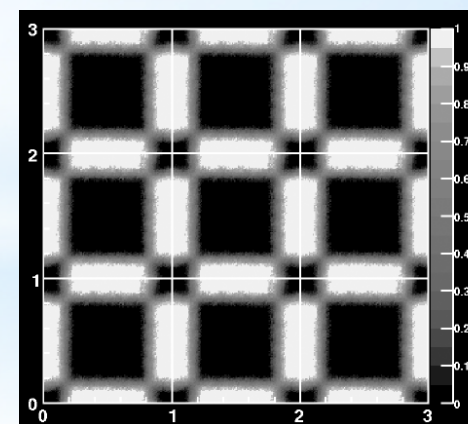


Kimmel et al., SPIE 6276, 2006

## Distribution of reconstructed photon positions

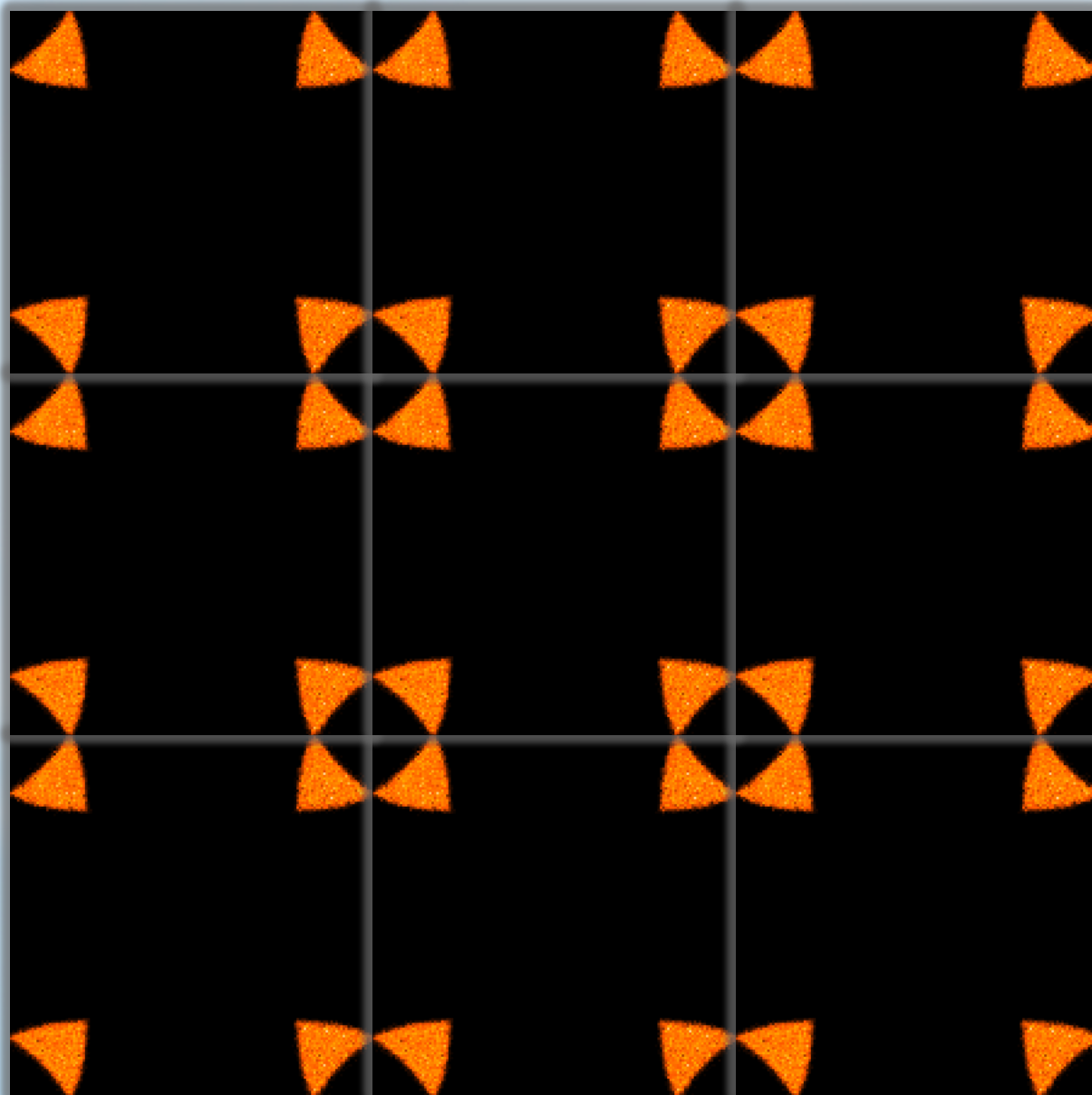


double events

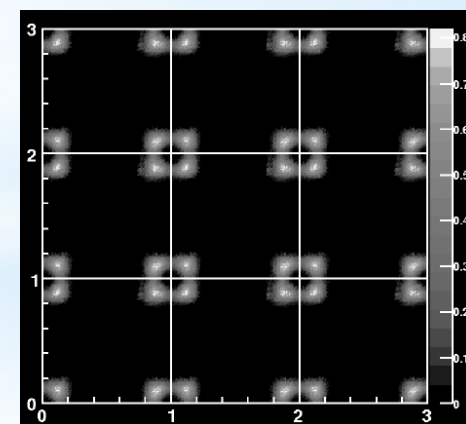


Kimmel et al., SPIE 6276, 2006

## Distribution of reconstructed photon positions

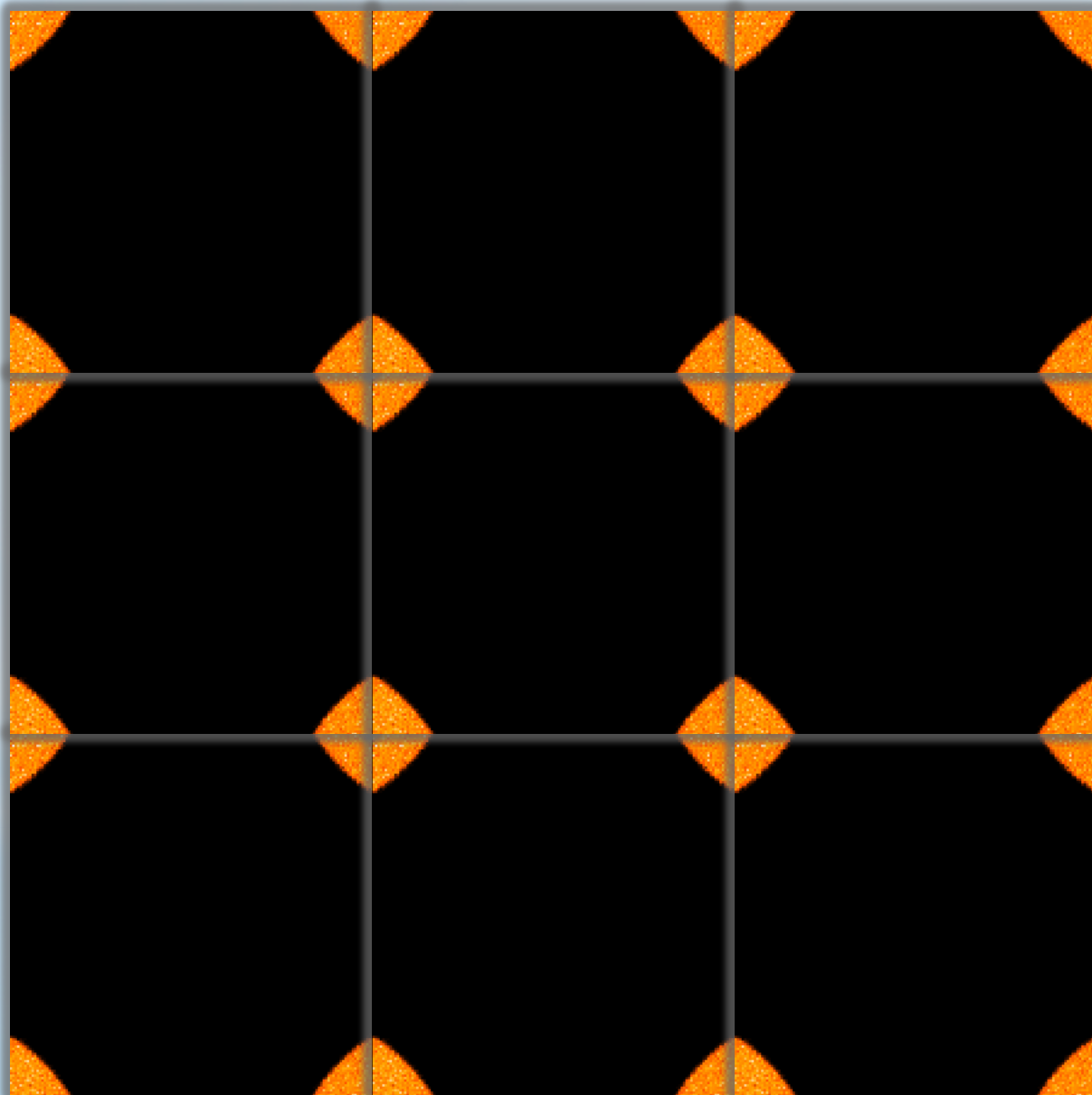


triple events

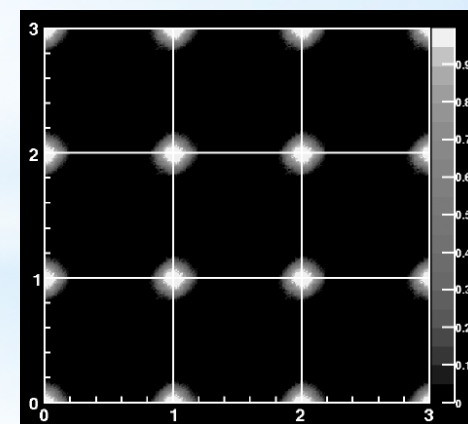


Kimmel et al., SPIE 6276, 2006

## Distribution of reconstructed photon positions



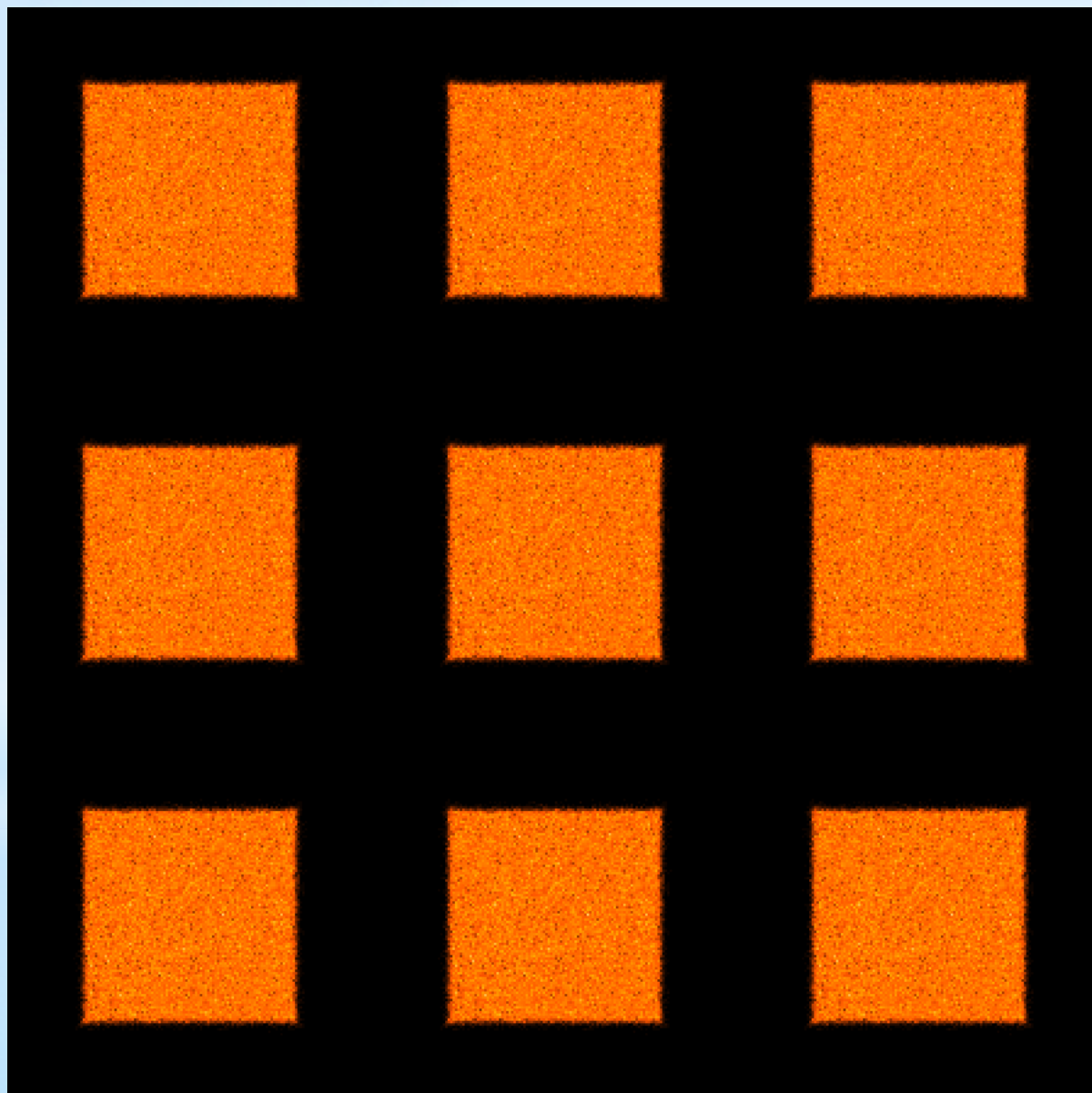
quadruple events



Kimmel et al., SPIE 6276, 2006

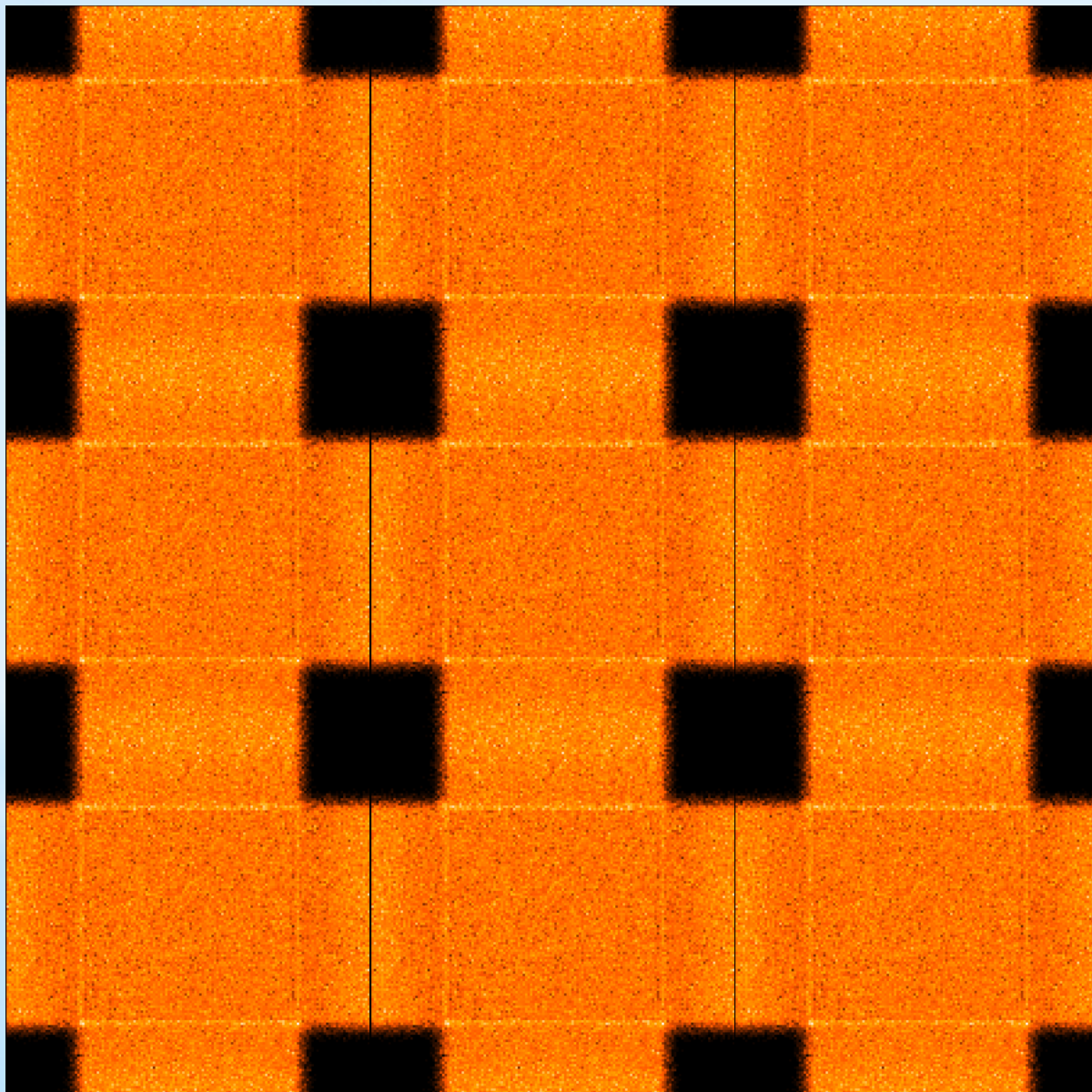


## Distribution of reconstructed photon positions



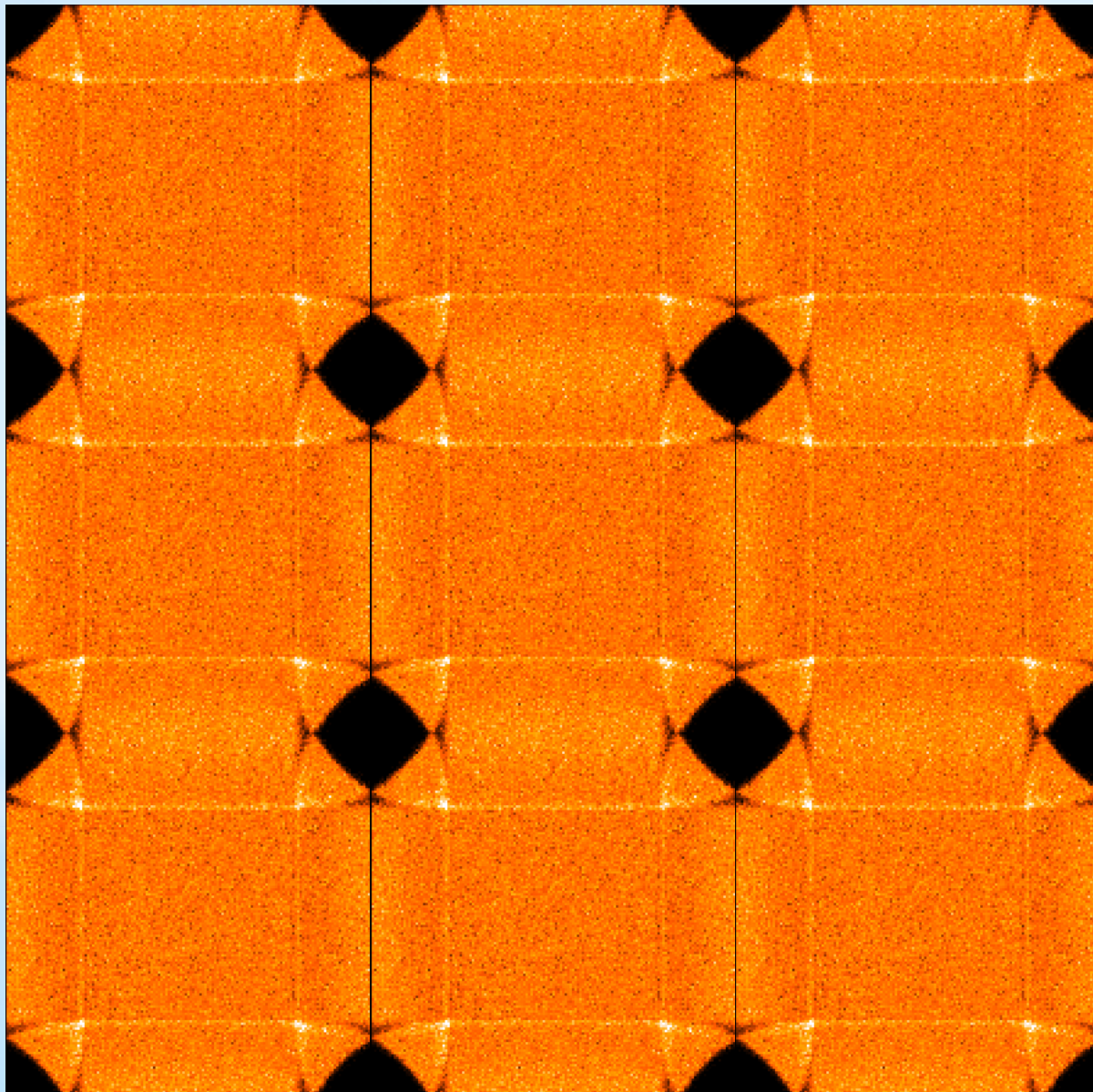
single pixel events

## Distribution of reconstructed photon positions



single pixel events  
+  
double events

## Distribution of reconstructed photon positions



single pixel events

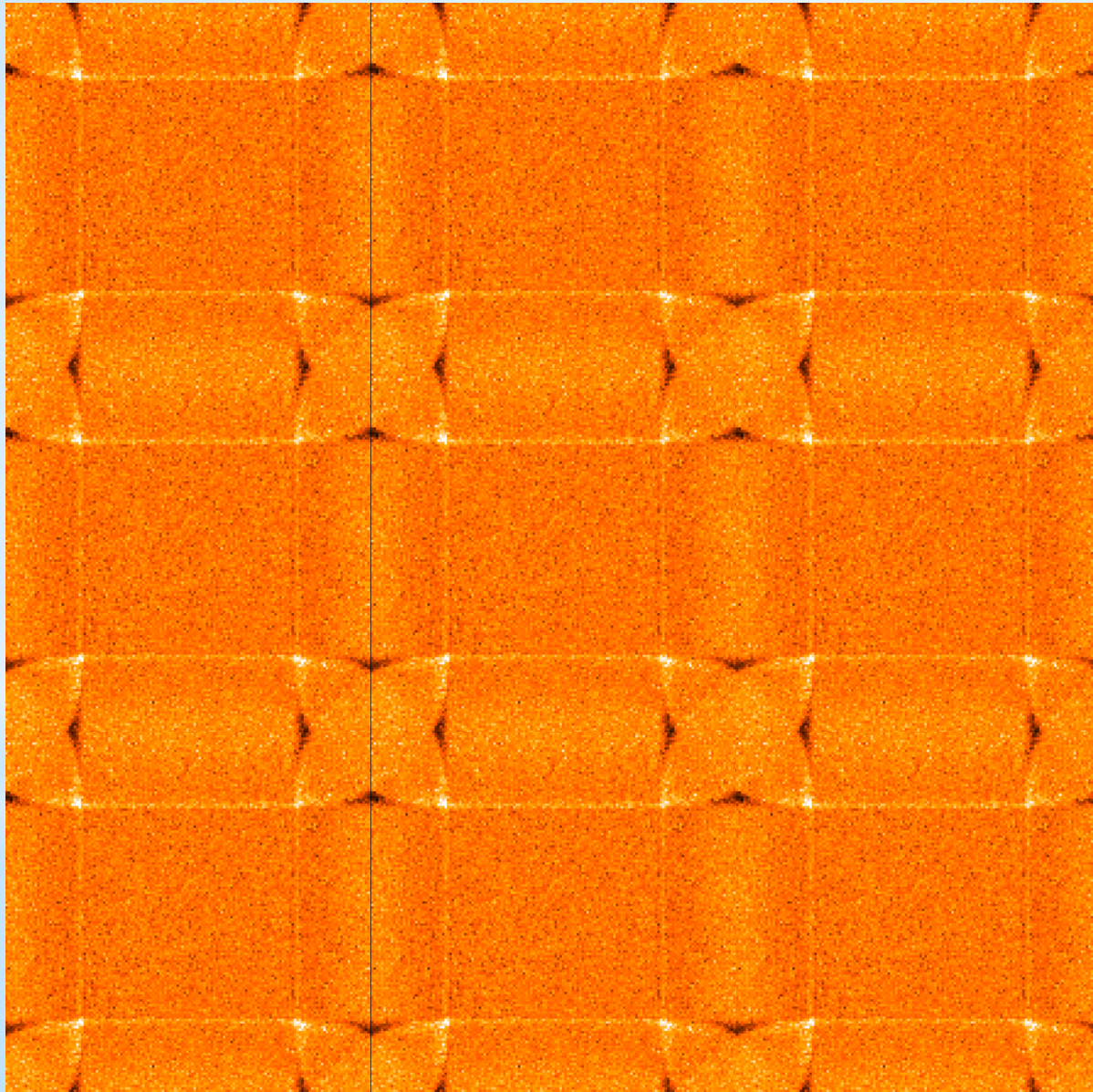
+

double events

+

triple events

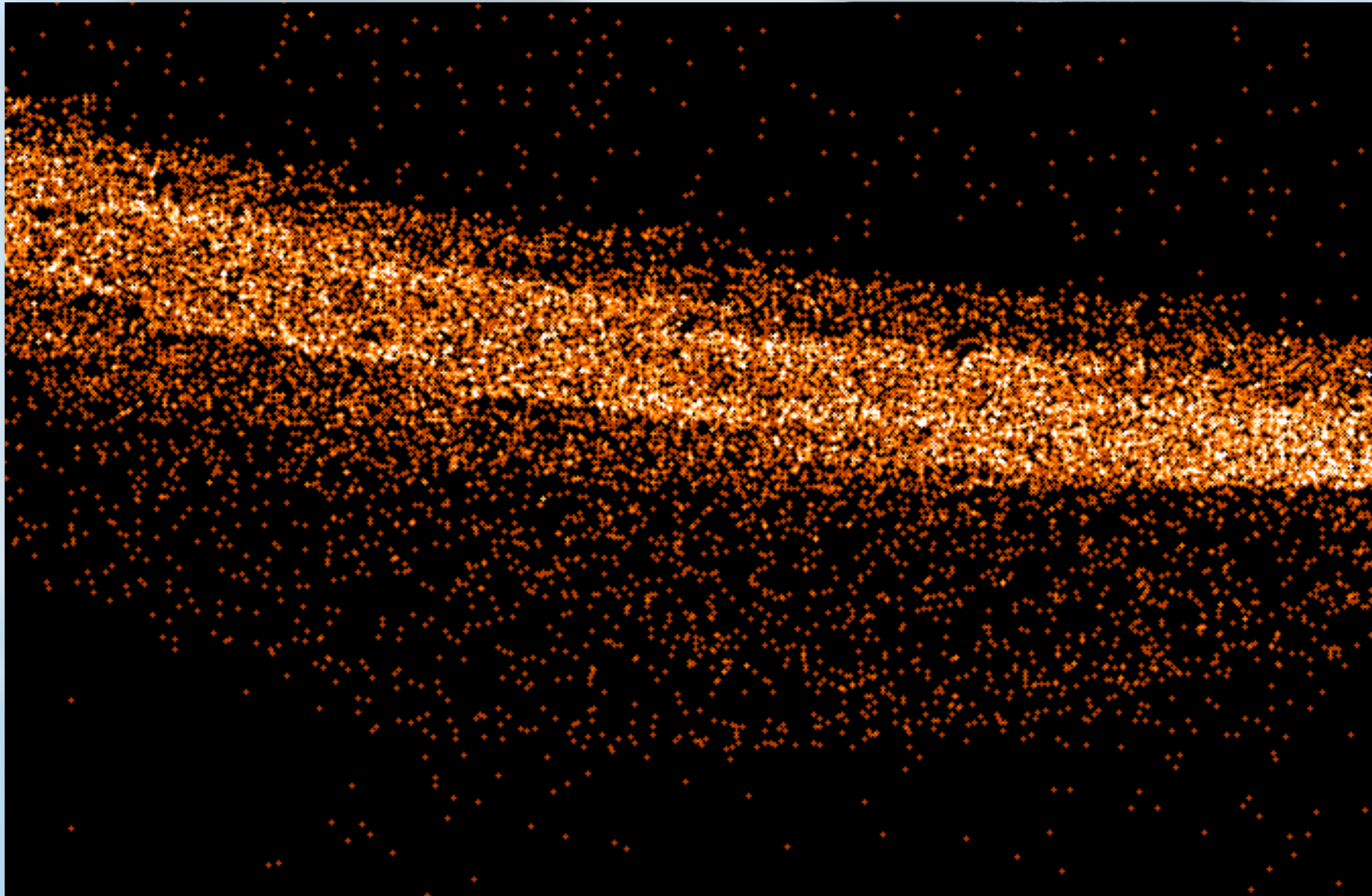
## Distribution of reconstructed photon positions



single pixel events  
+  
double events  
+  
triple events  
+  
quadruple events

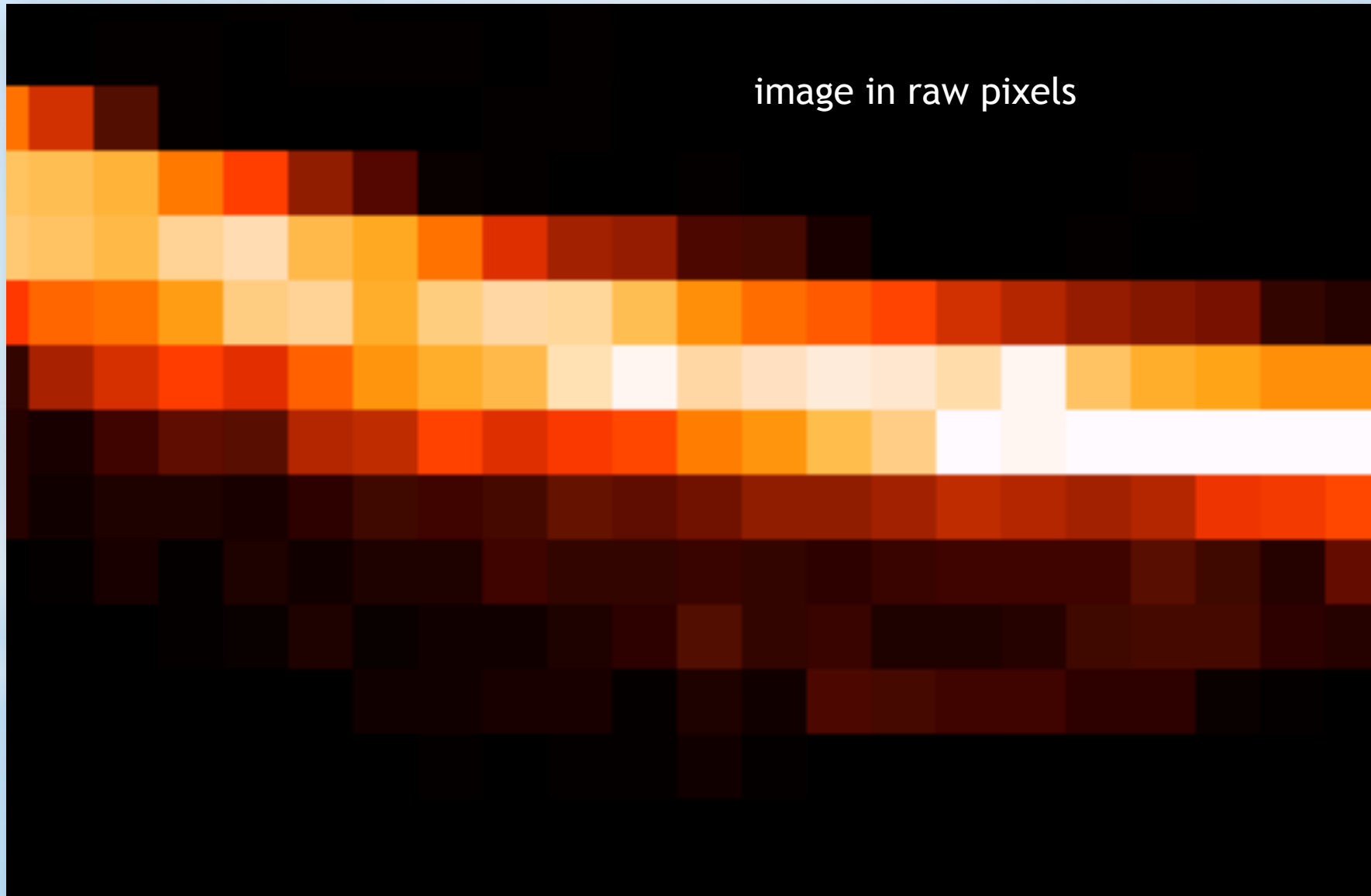


## Pattern resolved subpixel anatomy of an X-ray CCD image

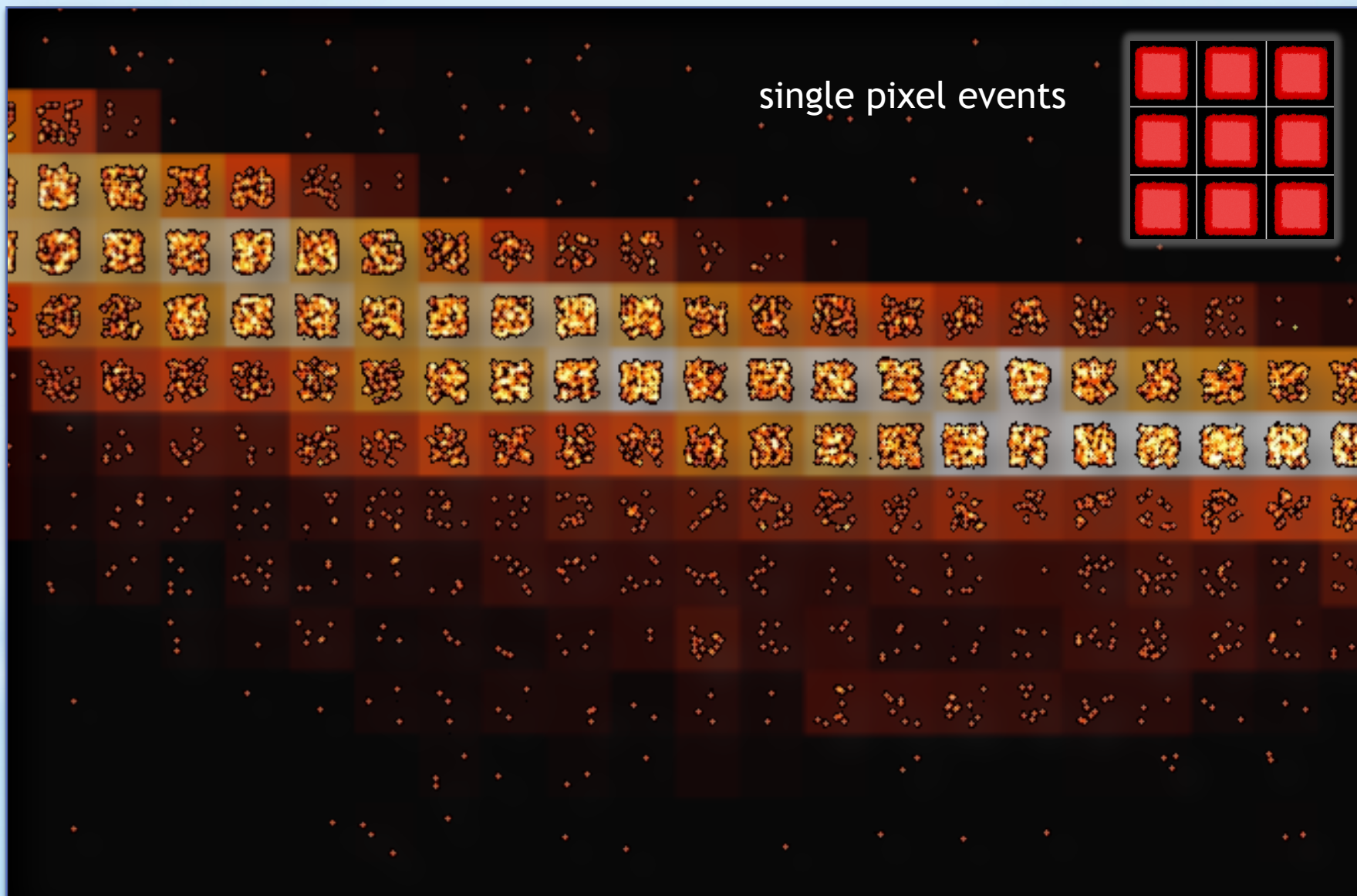




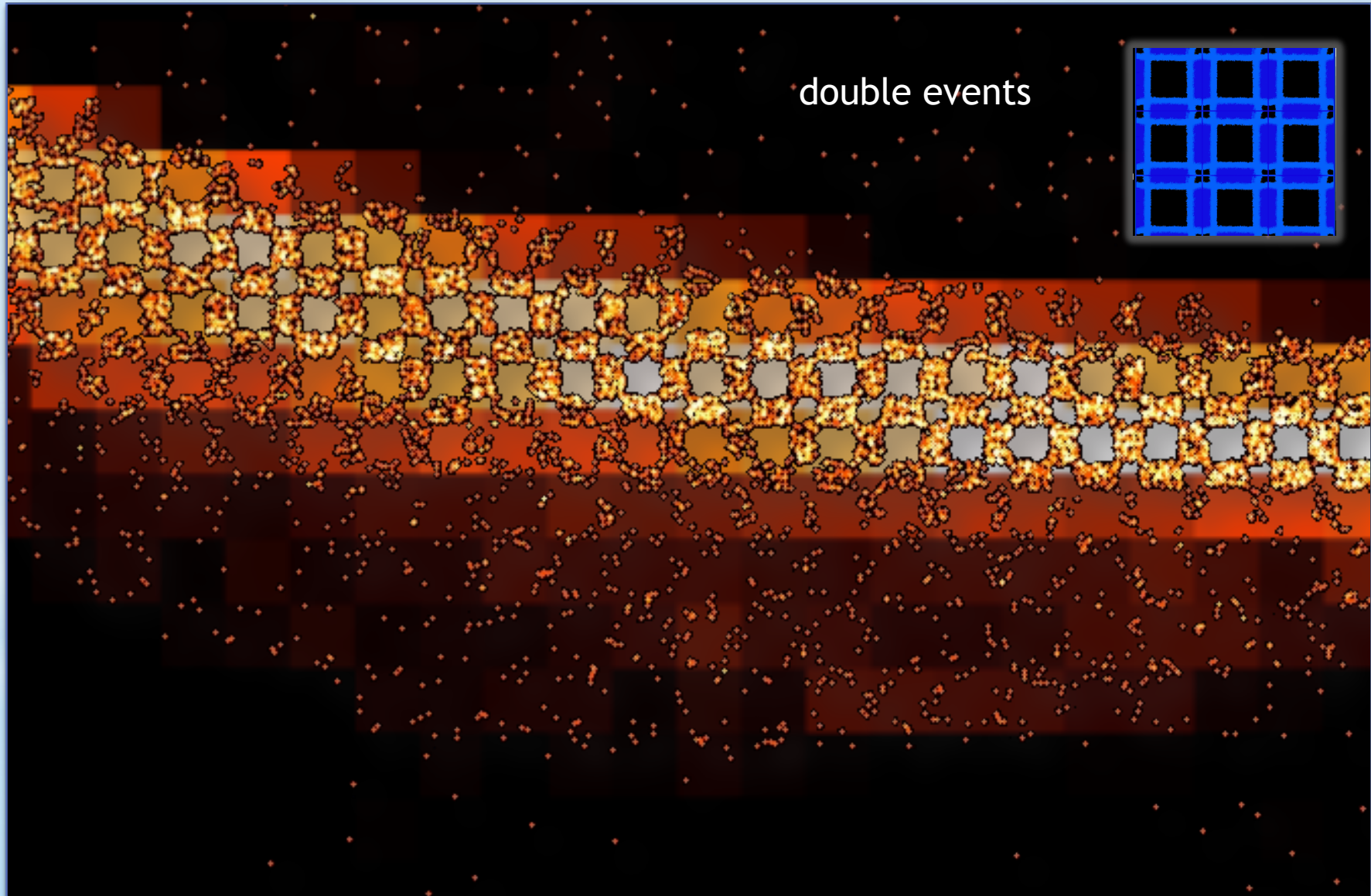
## Pattern resolved subpixel anatomy of an X-ray CCD image



# Pattern resolved subpixel anatomy of an X-ray CCD image

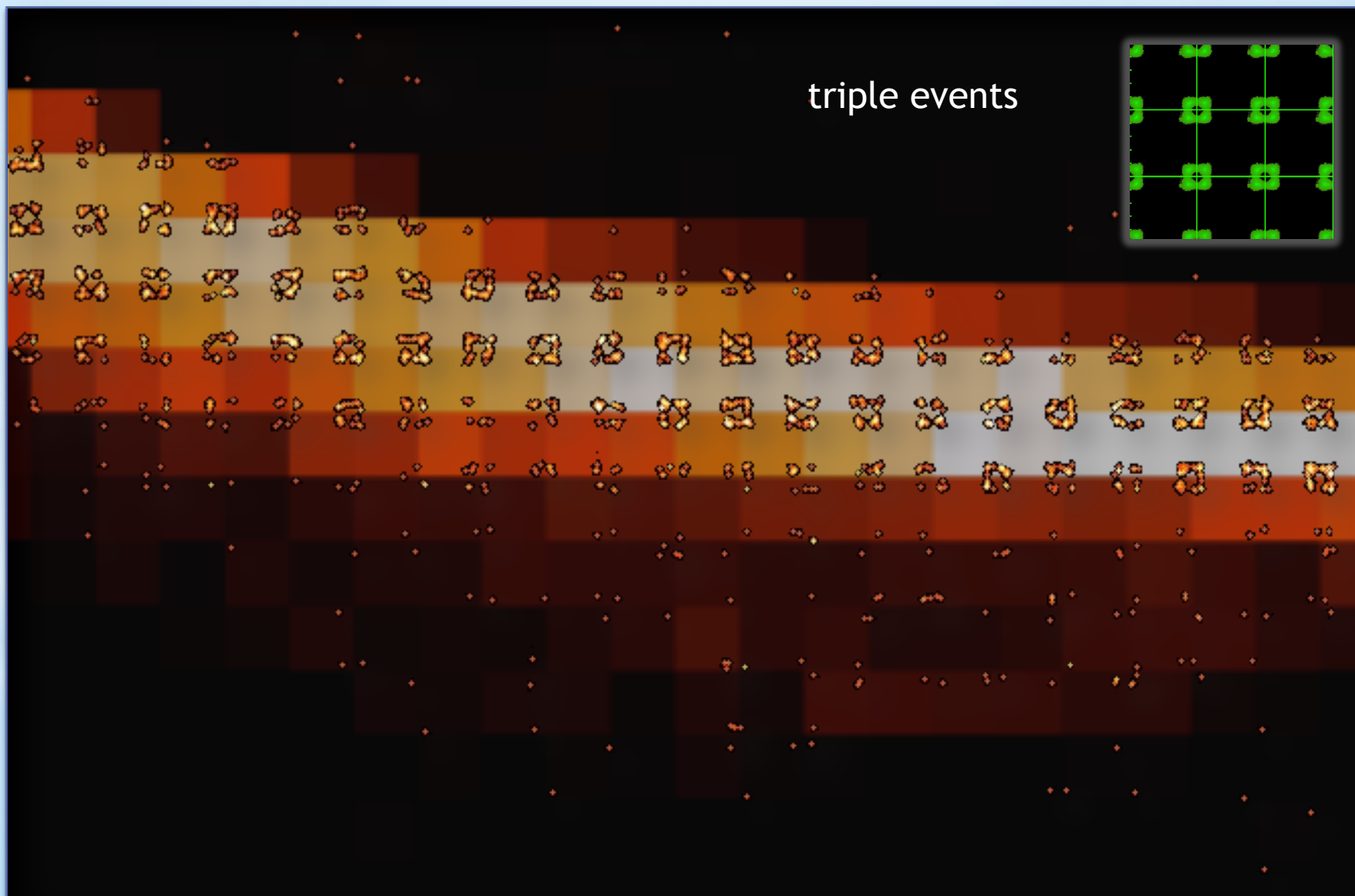


# Pattern resolved subpixel anatomy of an X-ray CCD image

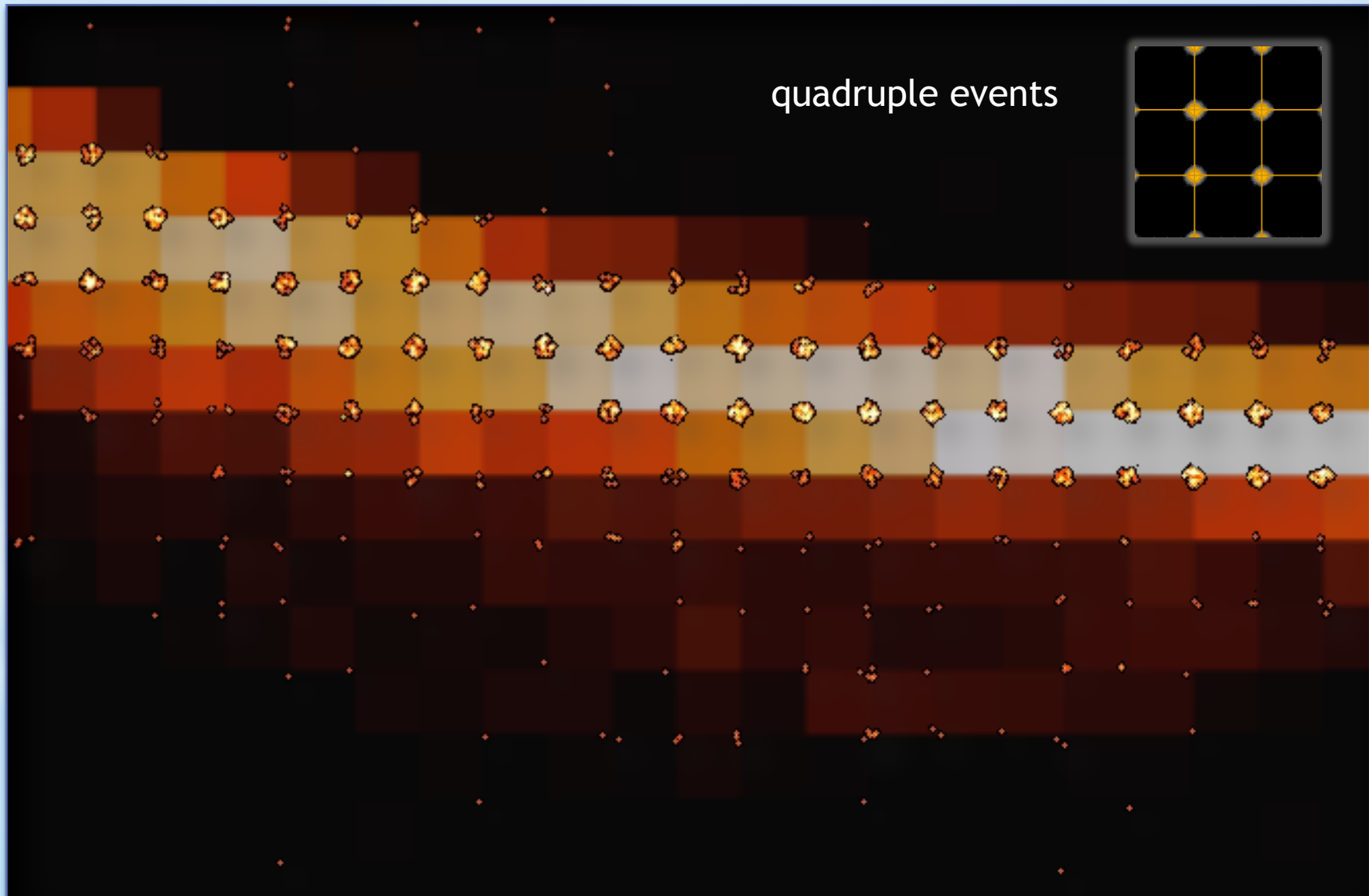




# Pattern resolved subpixel anatomy of an X-ray CCD image

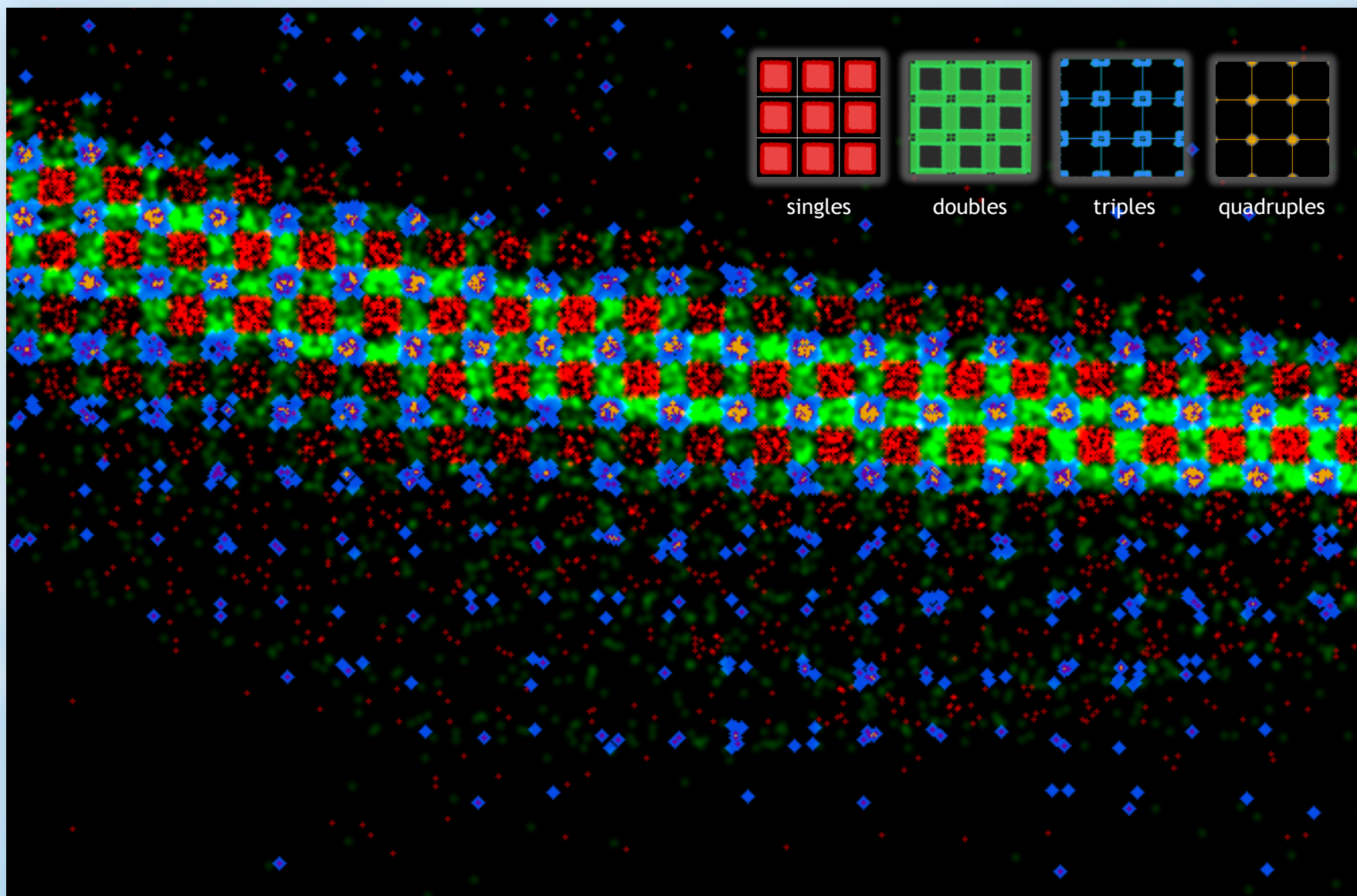


## Pattern resolved subpixel anatomy of an X-ray CCD image

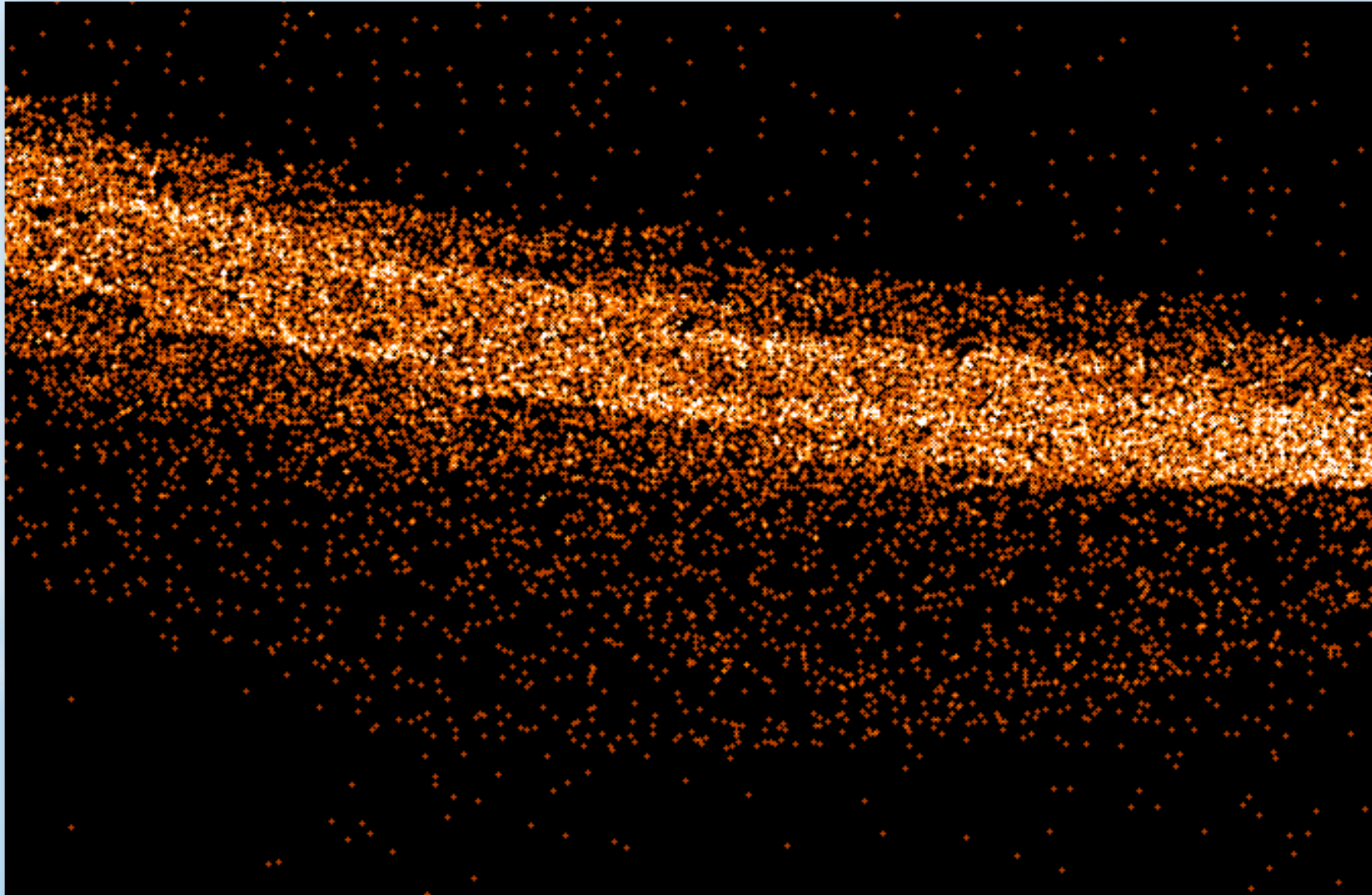




# Pattern resolved subpixel anatomy of an X-ray CCD image

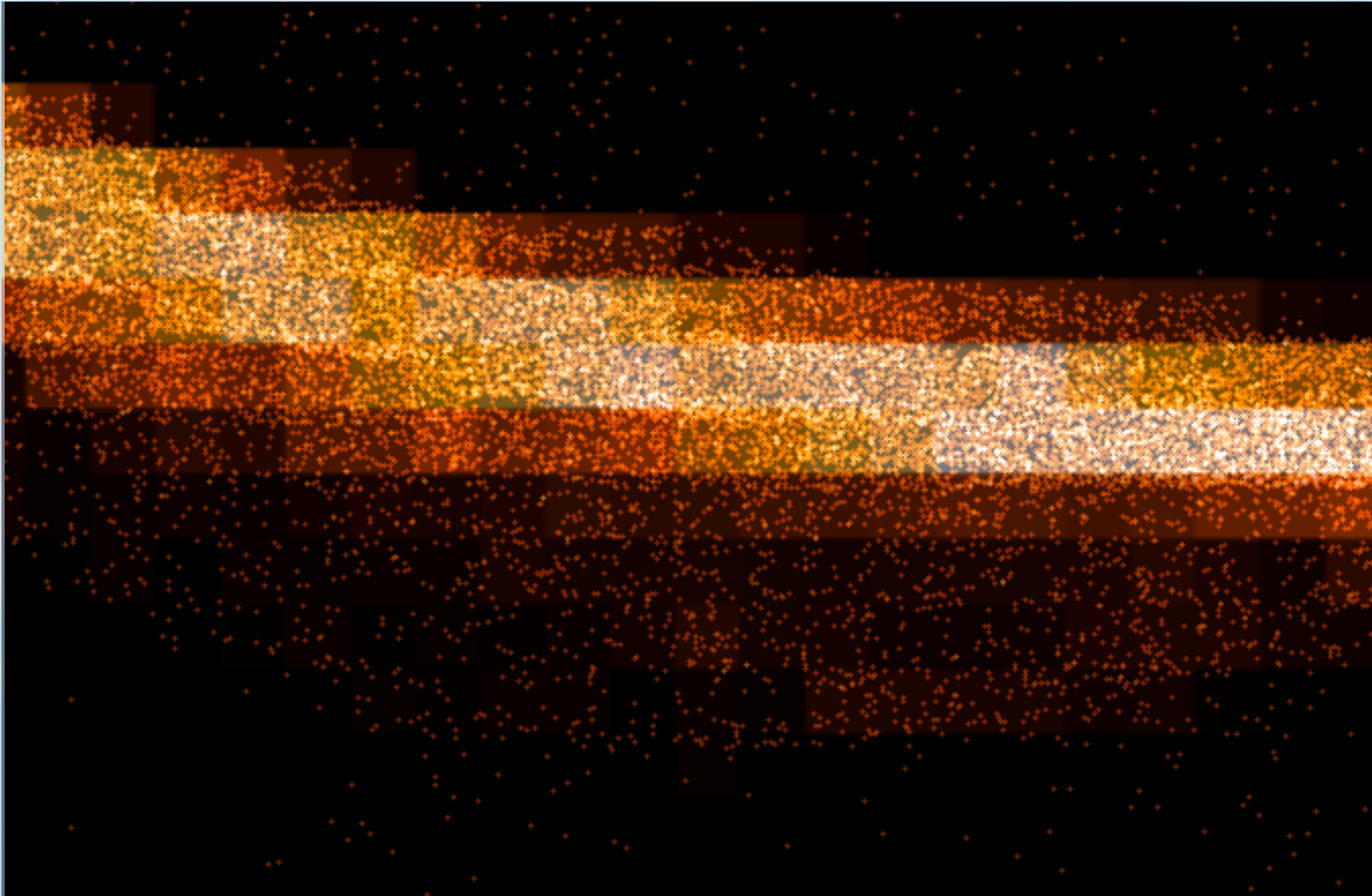


## Pattern resolved subpixel anatomy of an X-ray CCD image

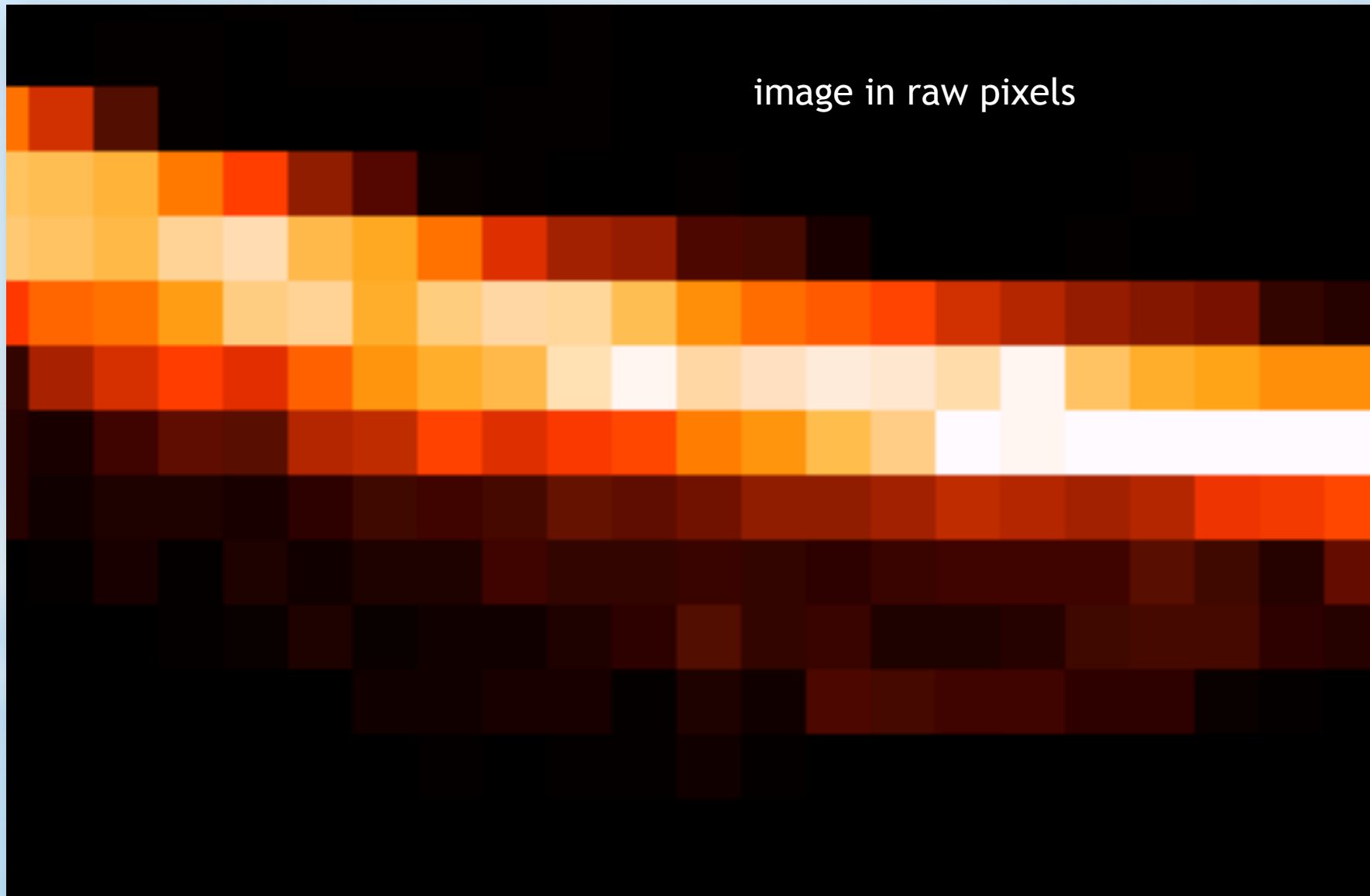




## Pattern resolved subpixel anatomy of an X-ray CCD image



## Pattern resolved subpixel anatomy of an X-ray CCD image



## Summary

The low energy threshold is an important quantity which has a considerable impact on the

- spectral resolution
- spectral sensitivity
- spatial resolution

