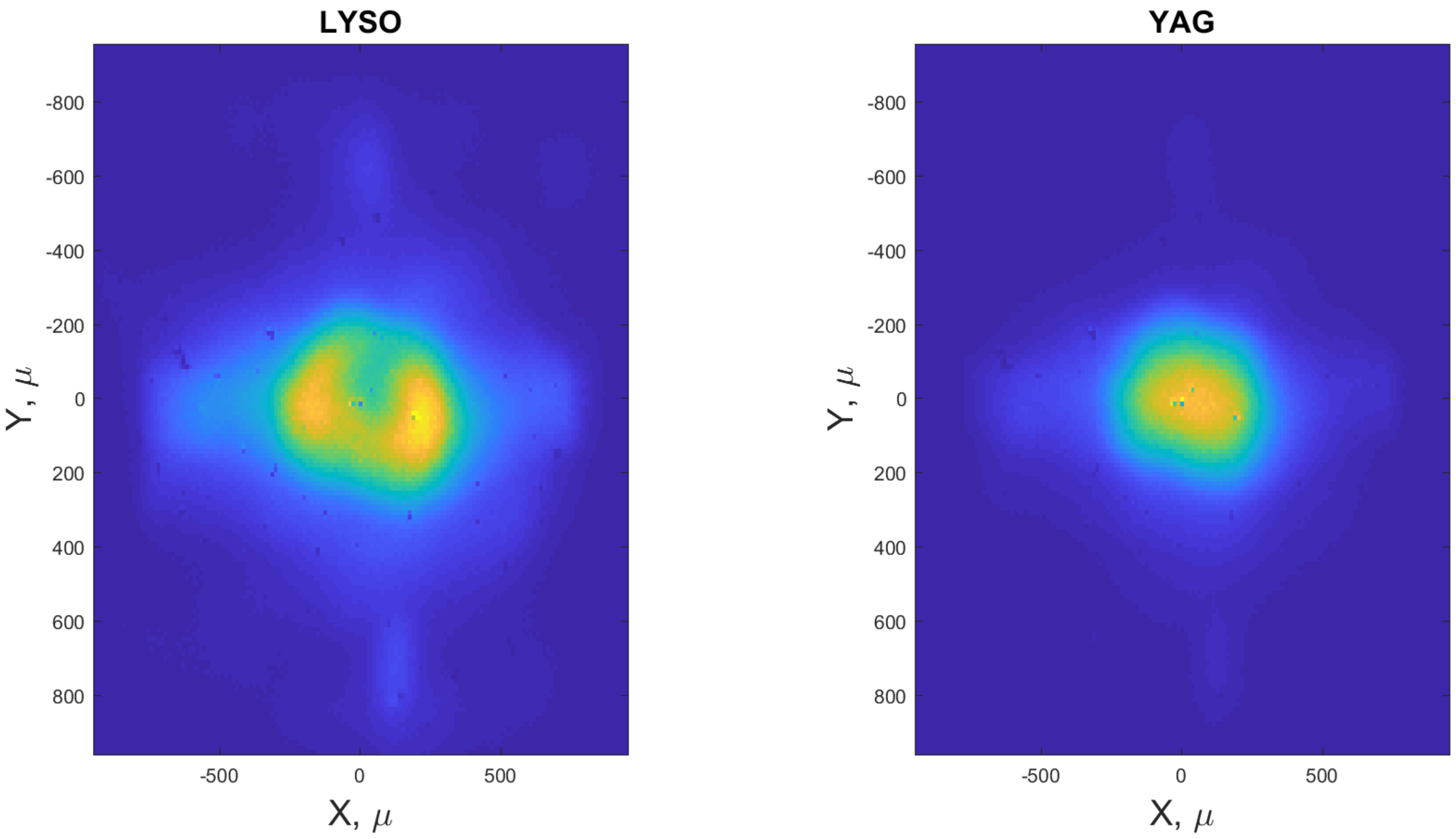
Studies of Scintillators Nonproportionality

Artem Novokshonov

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

Nonproportionality problem

- Example: LYSO vs YAG.
- The measurement has been done at the XFEL

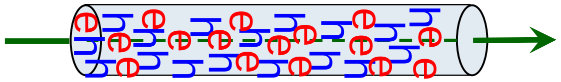


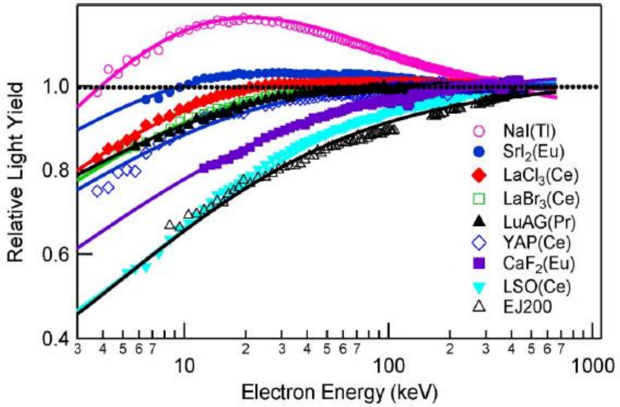
Nonproportionality problem

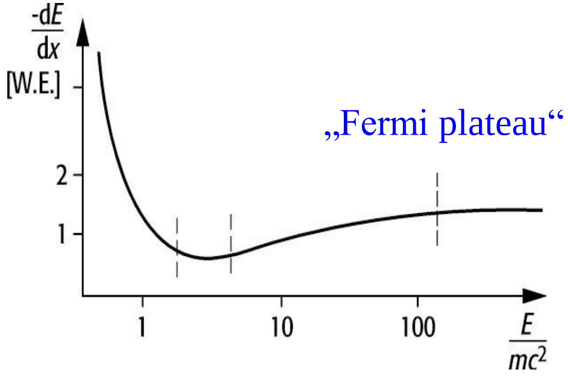
- The problem is well-known in High Energy Physics, but it affects energy measurement in the field.
- In beam diagnostics the effect the effect is reached by the electrons density.
- The effect depends on the scintillator material.
- The Total Light Output depends on the charge density.

- Birks-type weight coefficient
  J.B. Birks, Proc. Phys. Soc. A64 (1951) 874

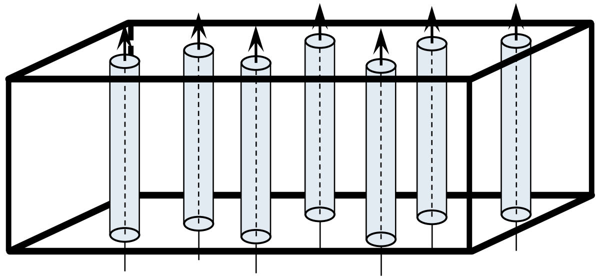
$$w = \frac{1}{1 + \alpha \frac{\mathrm{d}E}{\mathrm{d}x}} \quad \text{with} \quad \frac{\mathrm{d}E}{\mathrm{d}x} \propto (n_t)^3$$



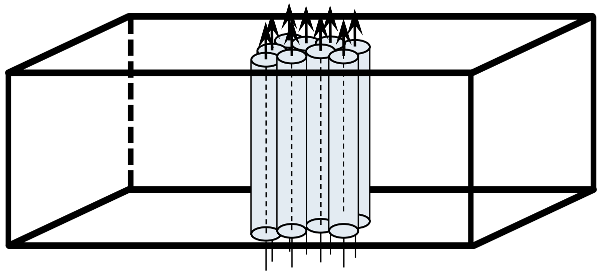


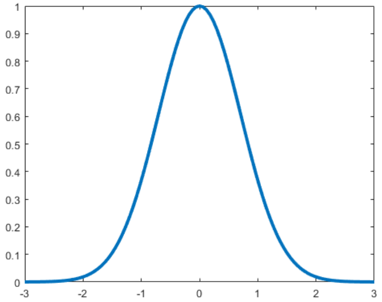


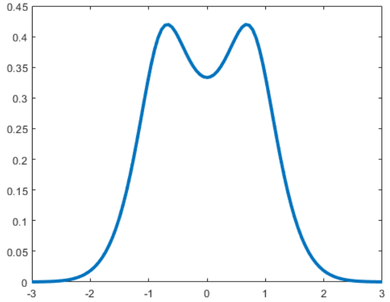
Low charge density



High charge density

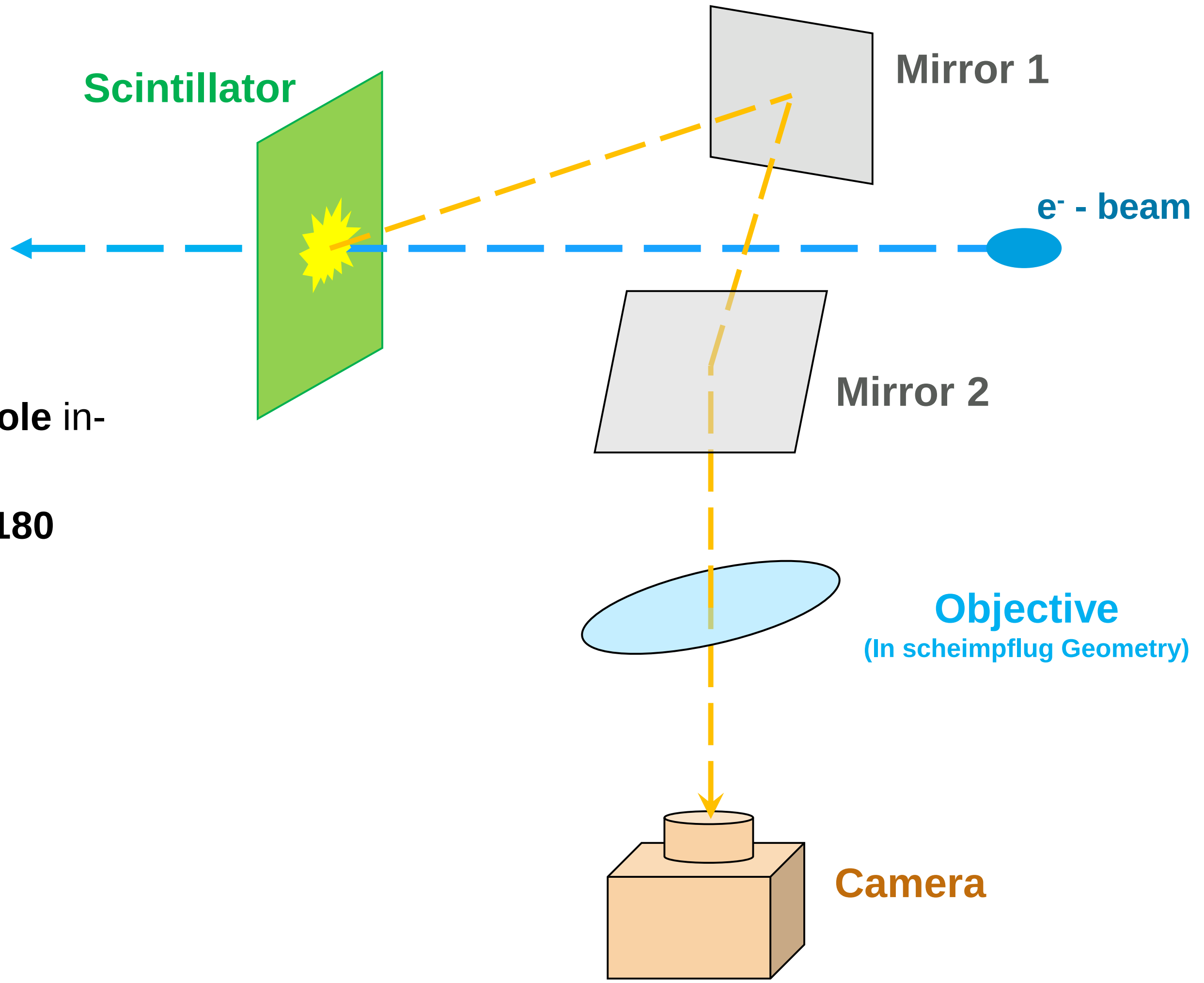






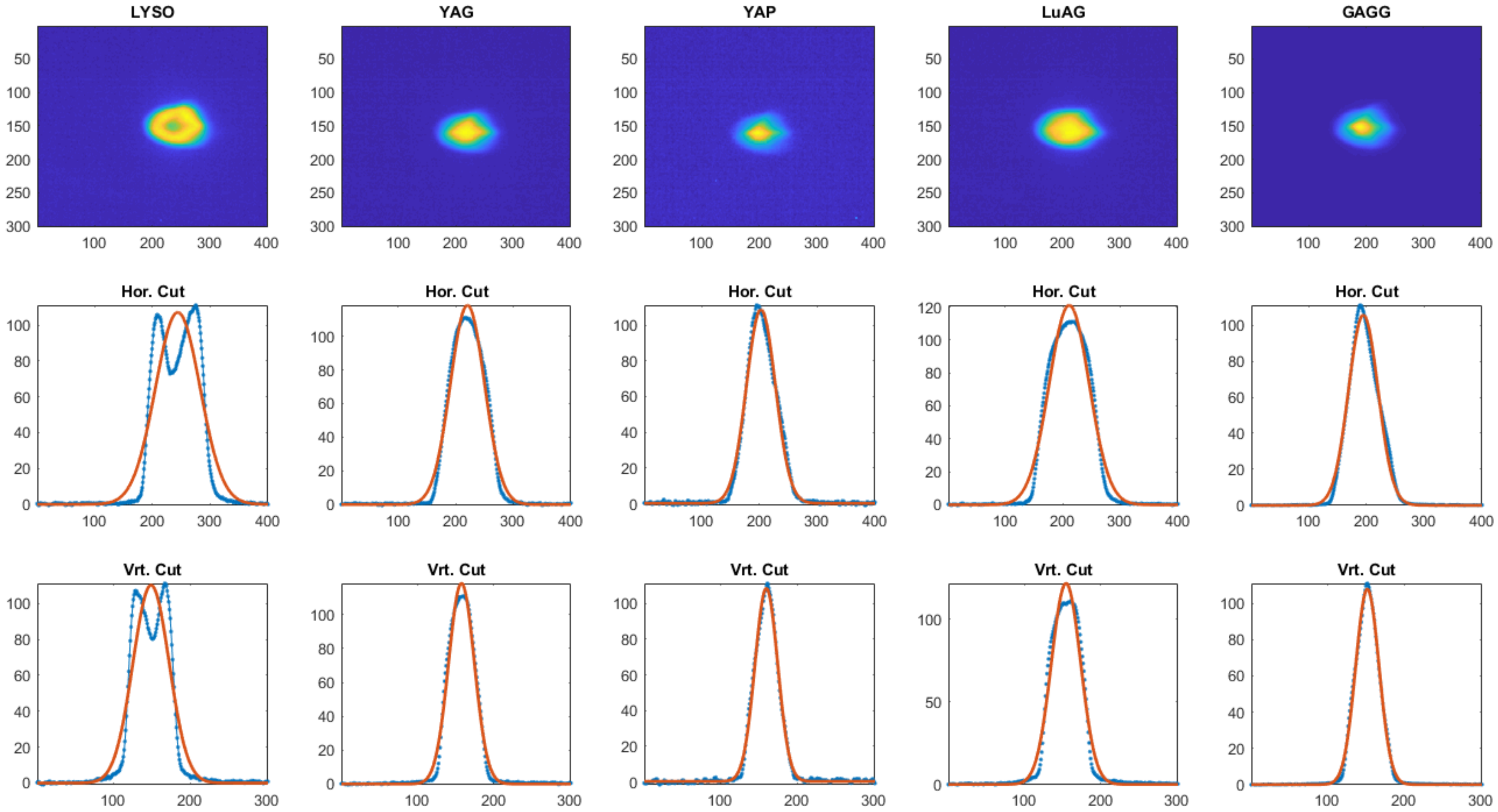
PITZ measurement setup

- The measurements have been carried out at the **High1.Scr5** station
- The were 5 different scintillator materials:
    1. *LYSO* ($Lu_2Y_2SiO_5$*:Ce*)
    2. *YAG* ($Y_3Al_5O_{12}$*:Ce*)
    3. *YAP* ($YAlO_3$*:Ce*)
    4. *LuAG* ($Lu_3Al_5O_{12}$*:Ce*)
    5. *GAGG* ($Gd_3Al_2Ga_3O_{12}$*:Ce*)
- The charge density was varied either by one of the **Quadrupole** in-front of the screen or by the **Charge**
- The Objective - **Schneider Kreuznach Makro Symmar 5.6/180**
- The Camera - **Allied Vision Prosilica GT GC1350**



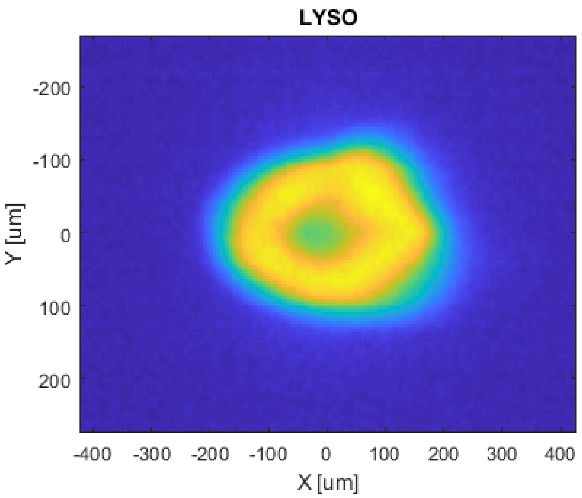
Comparison of Images and their Cuts

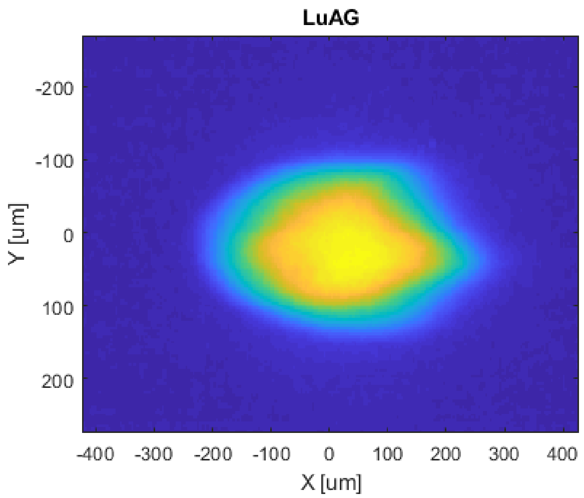
- Here is the comparison of the pictures and their fitted (gaussian) cuts for all 5 scintillators with the same beam conditions:
  - E = 20 MeV
  - Q = 2.2 nC
  - Exp. Time = 10 um
  - Gain = 0
  - Each image = average per 10 shots
  - 3 ND filters (1/120 transparency)
- One can see that LuAG is close to having the “smoke-ring” structure.
- YAP and GAGG fits look pretty well.

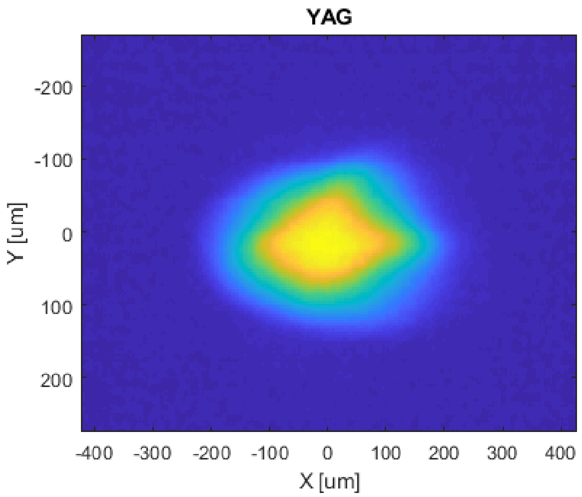


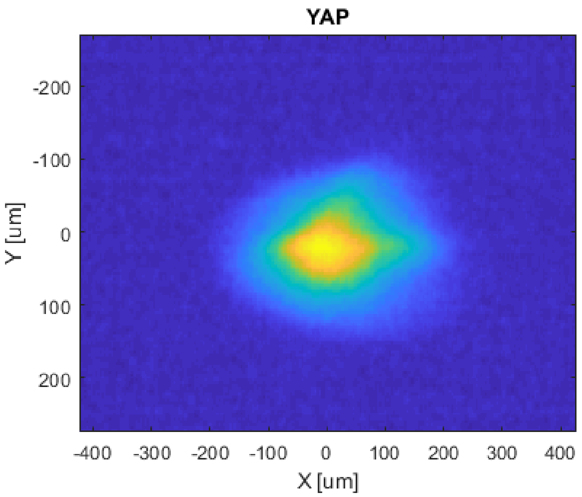
Comparison of Images

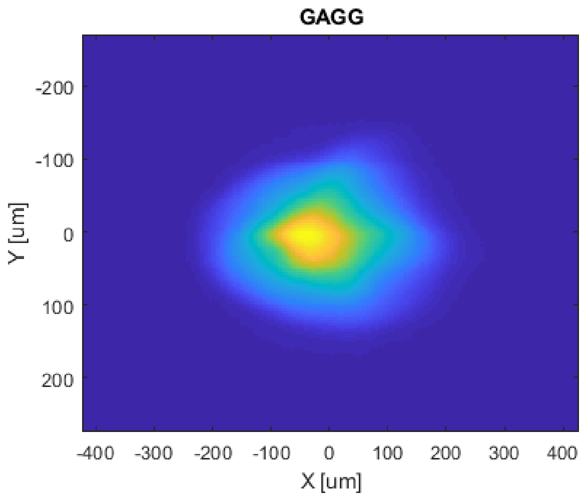
- Electron energy = 20 MeV.
- Charge is 2.2 nC
- The images are averaged per 10 shots.
- Exposure Time = 10 us, Gain = 0.
- 3 ND filters were used filter = 1/120 Transmittance











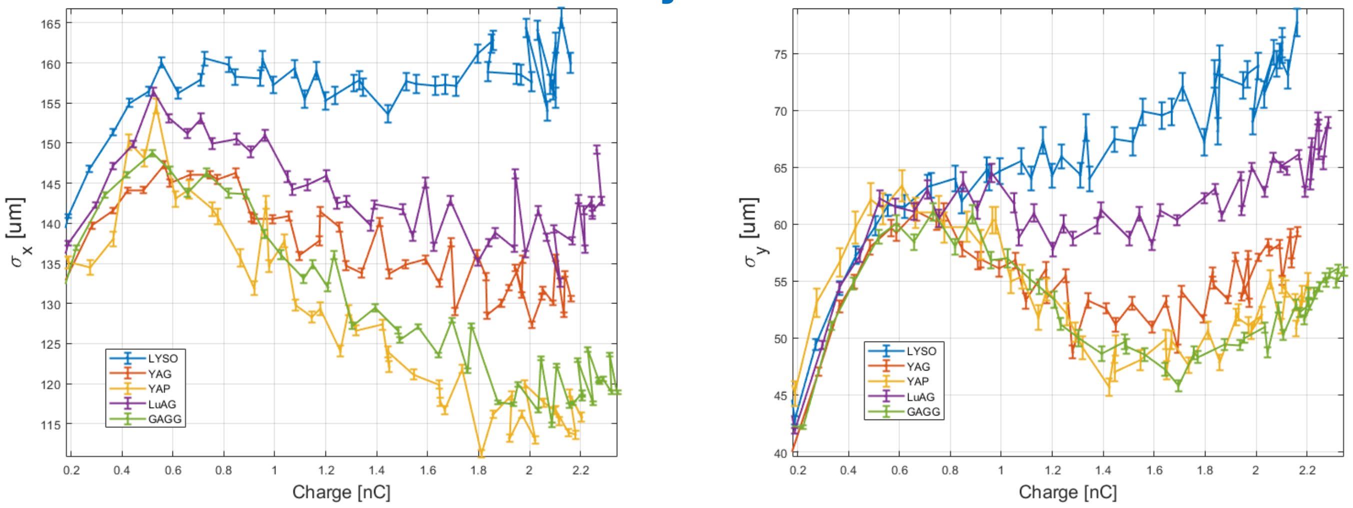
Beam Sizes Comparison

- Here the fit results of the central cuts and the projections are compared

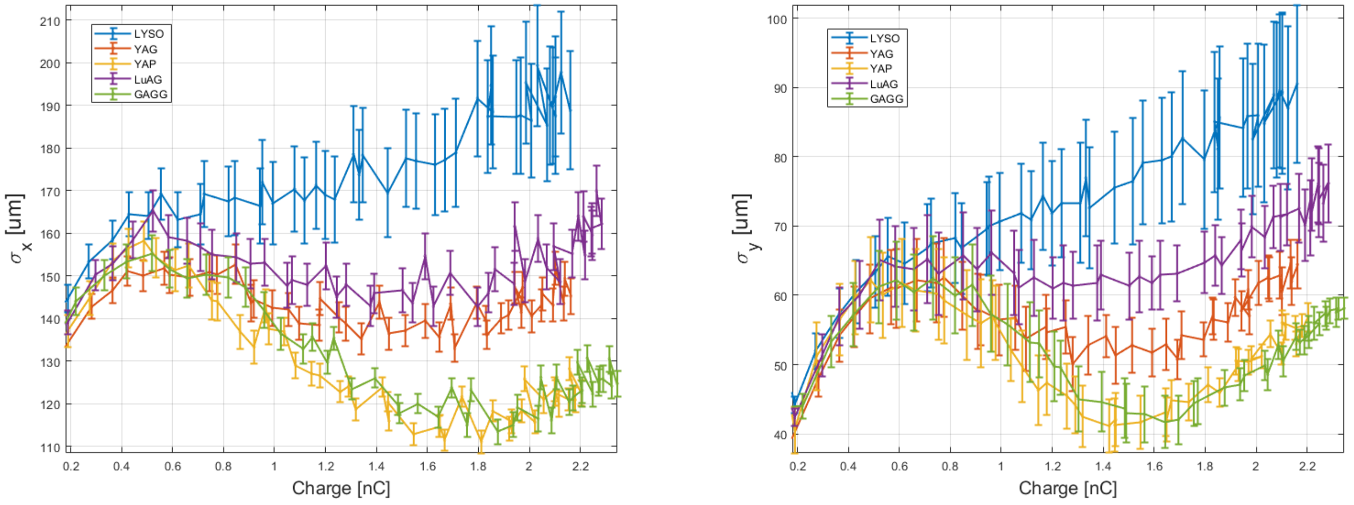
- The central cuts have 5 pixels width

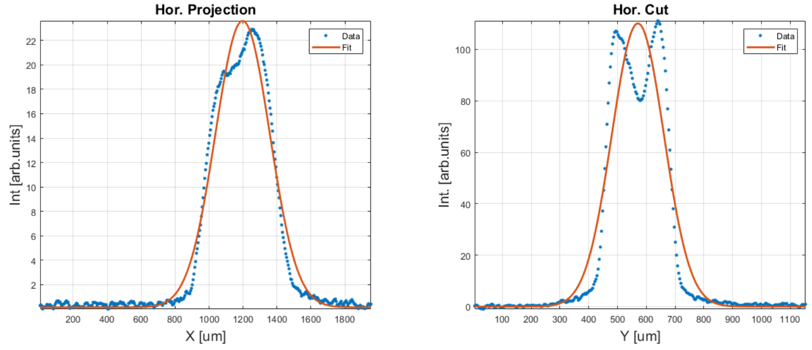
- The projections give smaller beam sizes and errors because the nonlinearity is smeared out in that case (picture below)

Projections

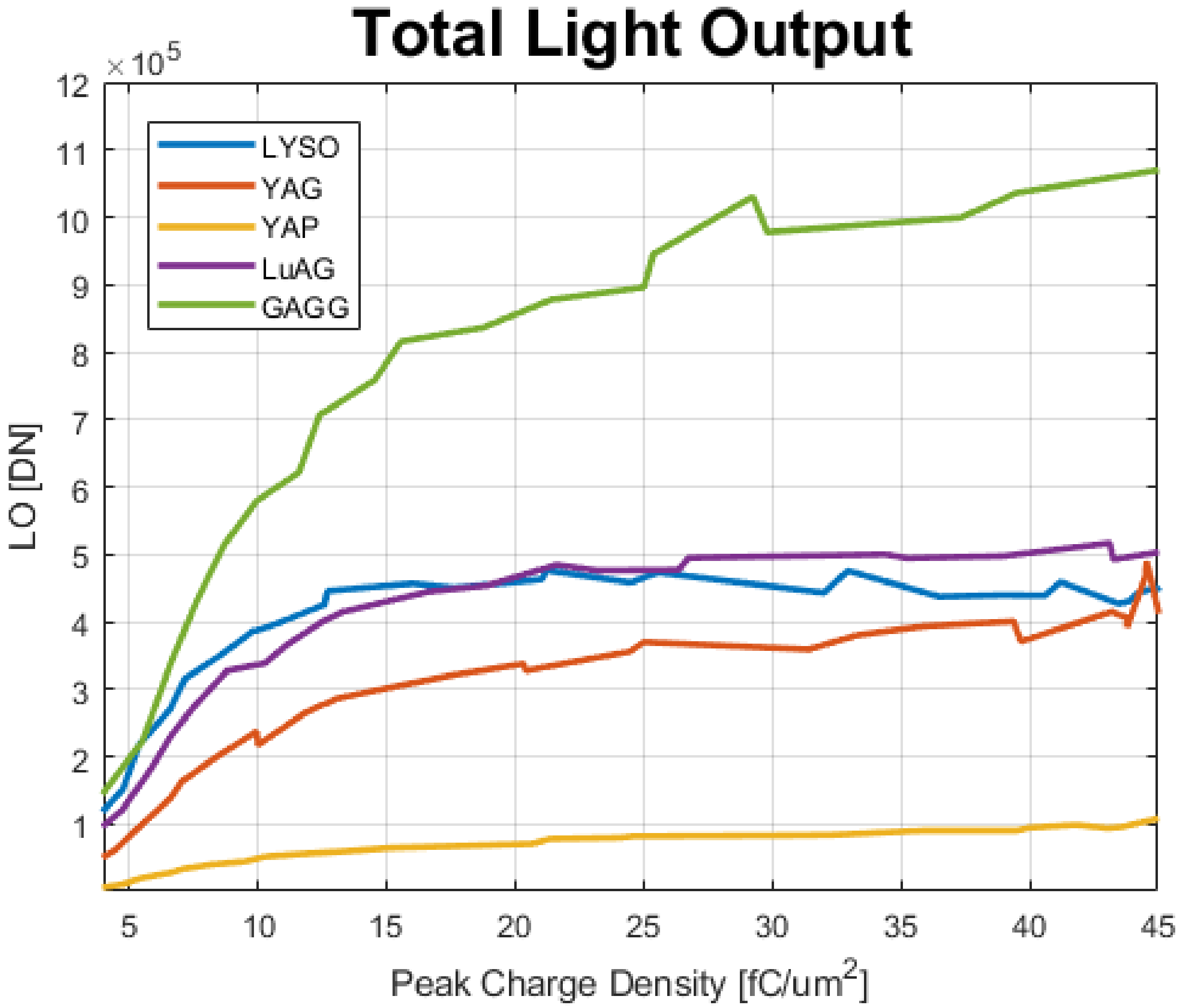


Central Cuts



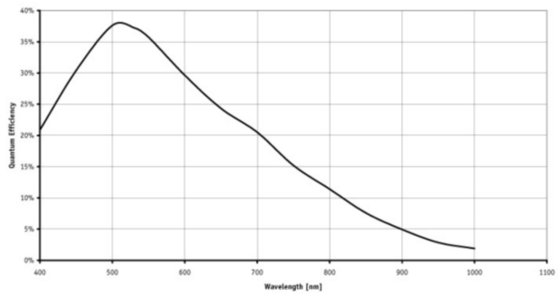


Light Output on the Charge Density

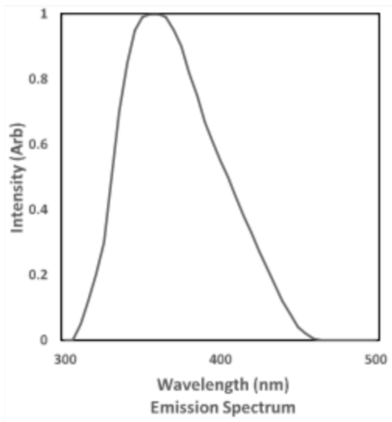


- All the materials show nonlinear behavior, but only LYSO has even a drop in intensity after ~20 fC/um^2
- GAGG material is the brightest one
- YAP should be comparable with YAG, LuAG and LYSO, but its spectrum is out of the camera sensitive region

Prosilica AVT GC1300 Quantum Efficiency

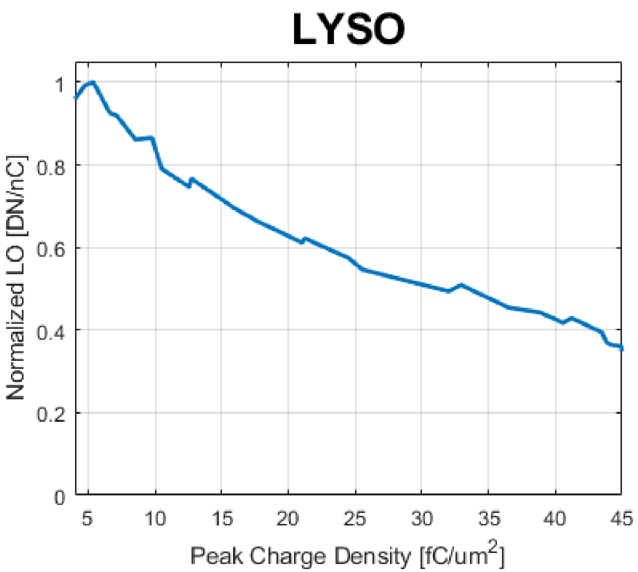


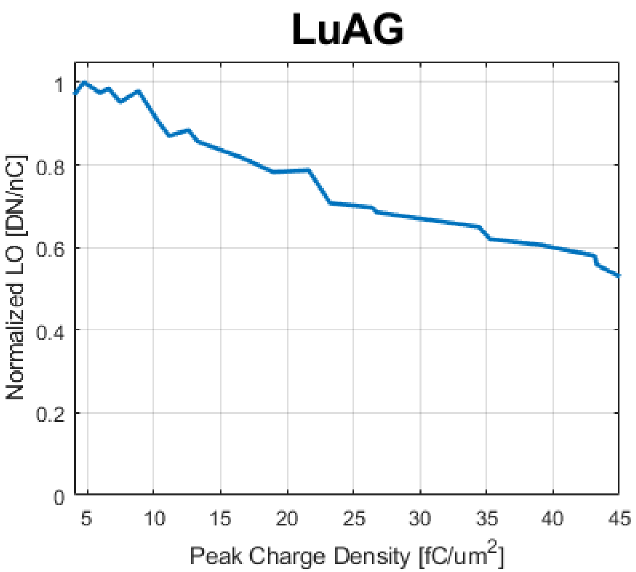
YAP emission spectrum

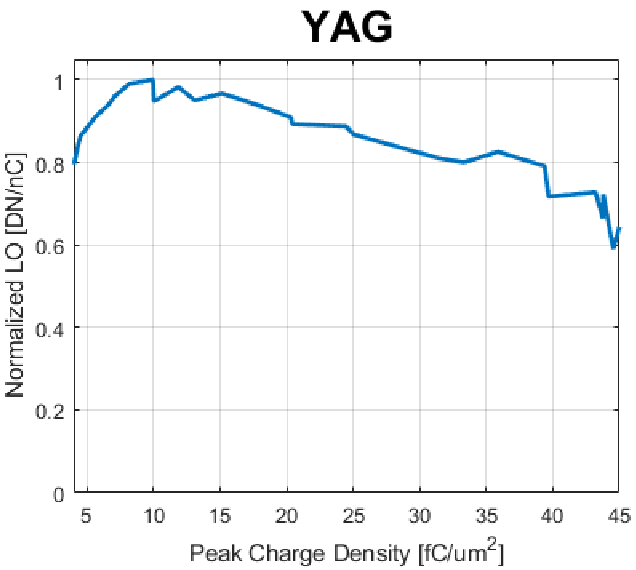


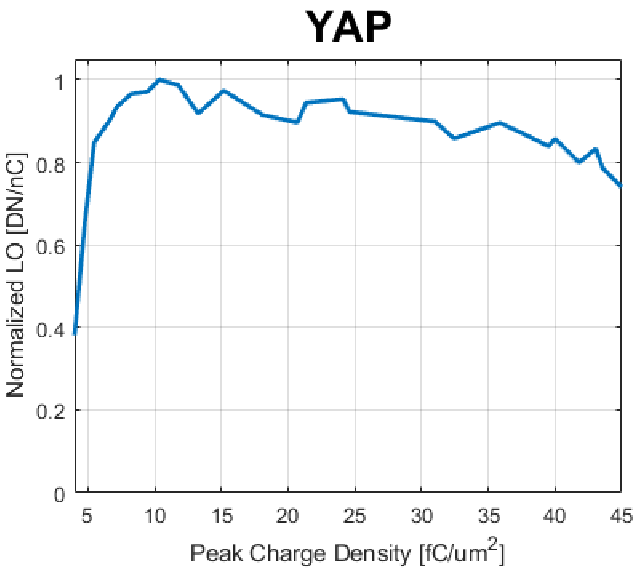
Light Output on Charge Density

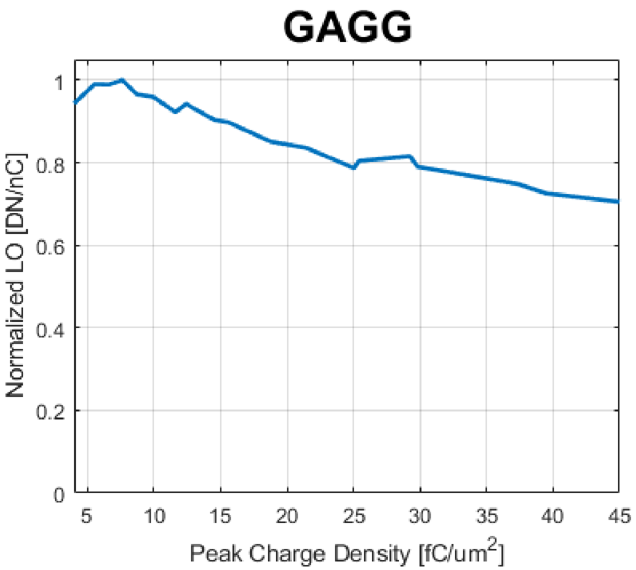
- Here is the comparison of the Light Output per nC
- All the scintillators reveal the intensity drop
- However LYSO has the largest drop ~ 60 %
- *One cannot take GAGG as reference to derive the Birks factor of the other materials…*











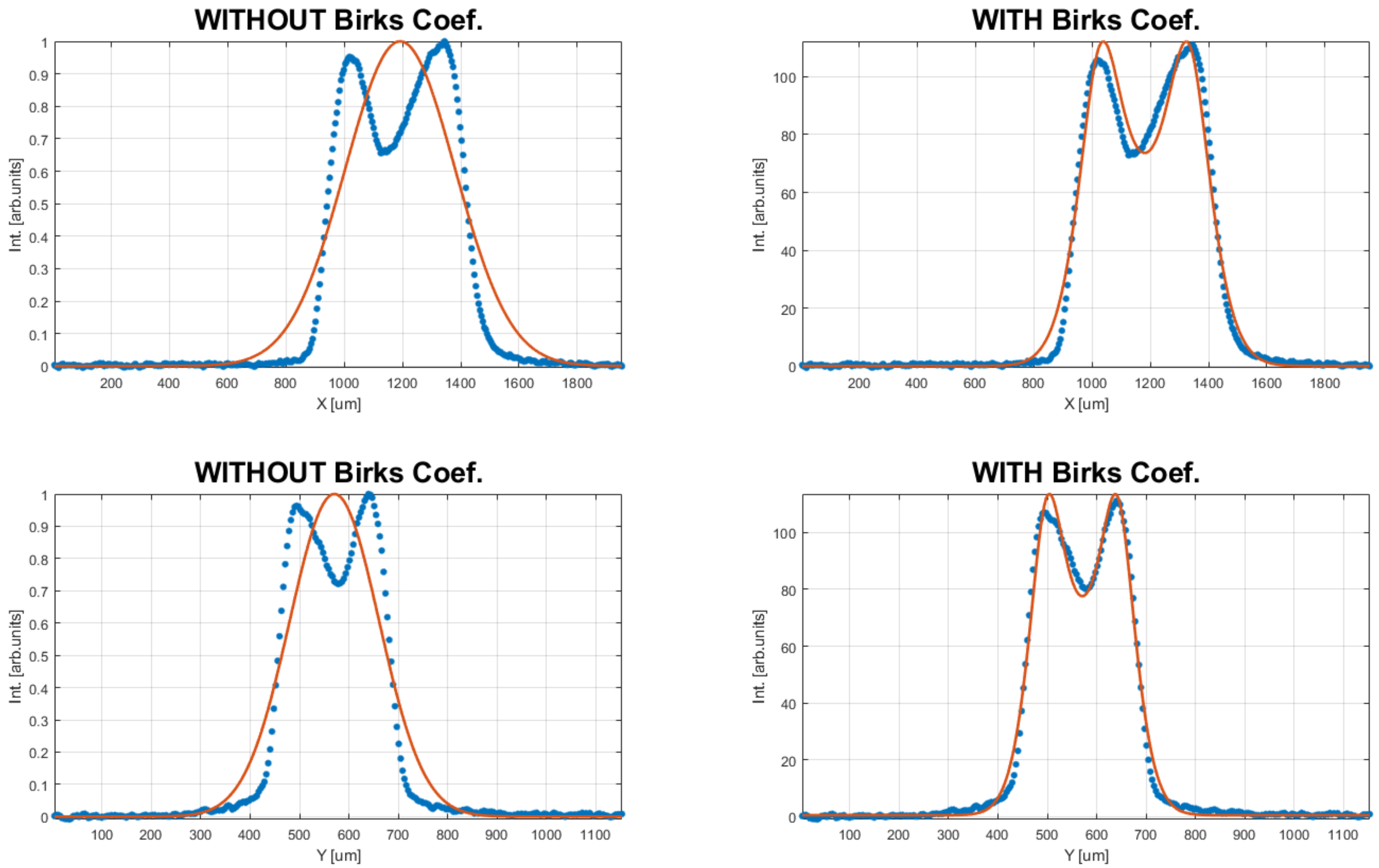
Implementation of the Birks Coefficient

- If one supposes that the GAGG sizes are the real ones, one can derive the “relative” Birks coefficient for the other materials
- Implementation of the coefficient leads, obviously, to the better fits

$$w = \frac{1}{1 + \alpha \frac{\mathrm{d}E}{\mathrm{d}x}} \quad \text{with} \quad \frac{\mathrm{d}E}{\mathrm{d}x} \propto (n_t)^3$$

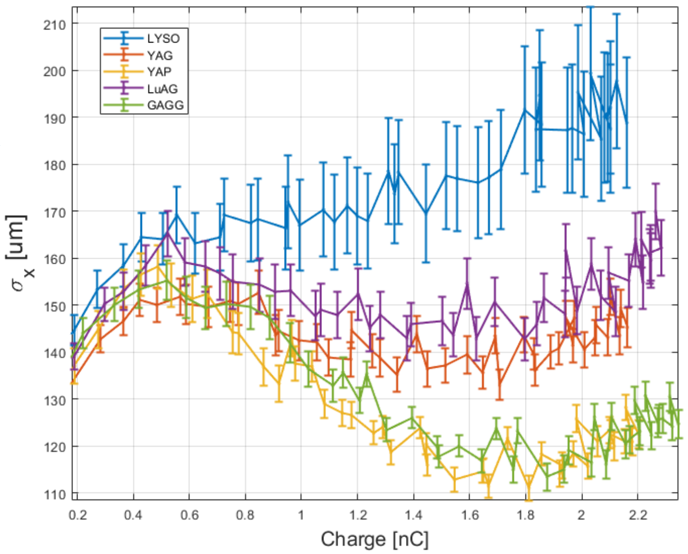
Horizontal Cuts

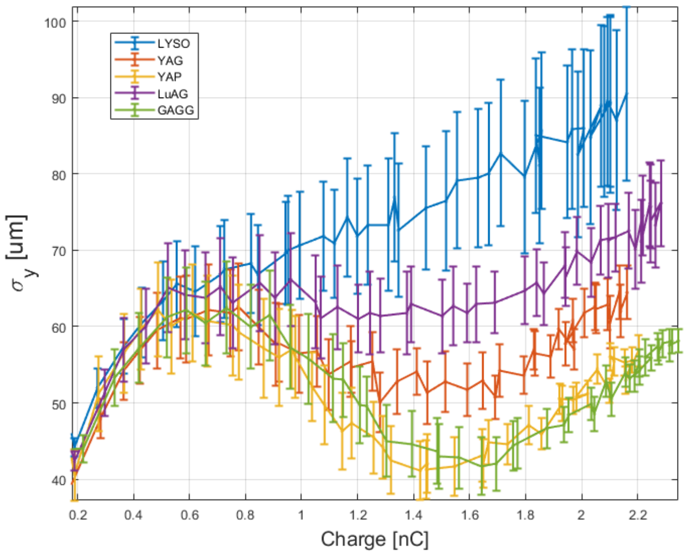
Vertical Cuts



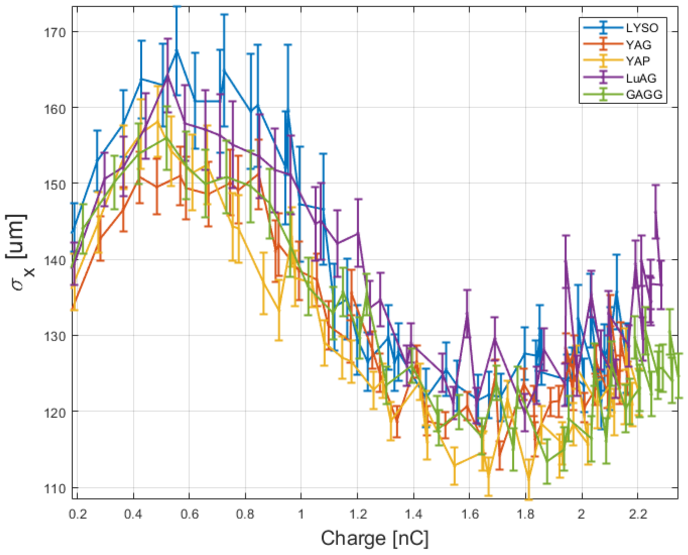
Comparison of Sizes WITH and WITHOUT Birks Coef.

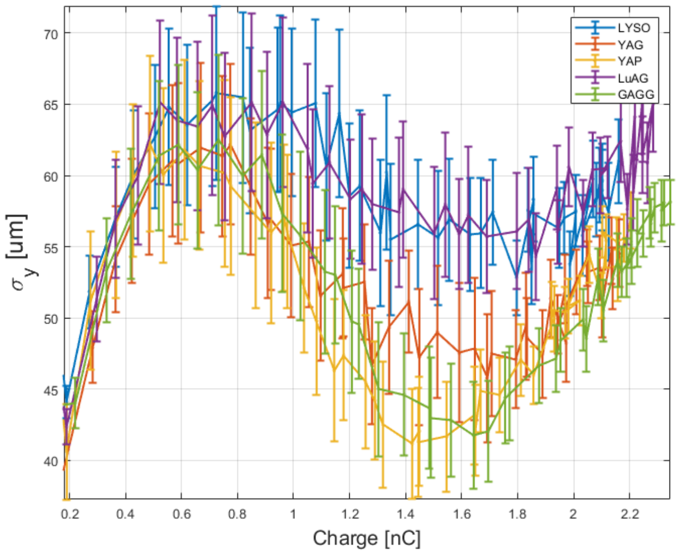
WITHOUT Birks Coefficient





WITH Birks Coefficient





The ones with the coefficient implemented have:

- less discrepancy with the GAGG sizes
- smaller error bars.

Conclusion

1. In the measurement *LYSO* clearly has shown the “smoke-ring” structure.
2. The second candidate to reveal the structure is *LuAG.*
3. The GAGG material is the best candidate to be used in the diagnostics.
4. There would be good to have such measurement with a system not affected by any nonlinearity.