Scintillating screens issues at the European XFEL

A. Novokshonov, G. Kube, M. Scholz, S. Liu, B. Beutner, S. Strokov

- **Quenching effects at the XFEL screen stations**
- **Charging effects at the of-axis XFEL screen stations**

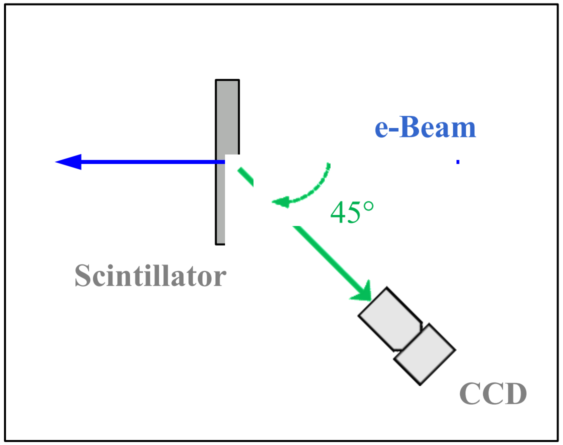
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

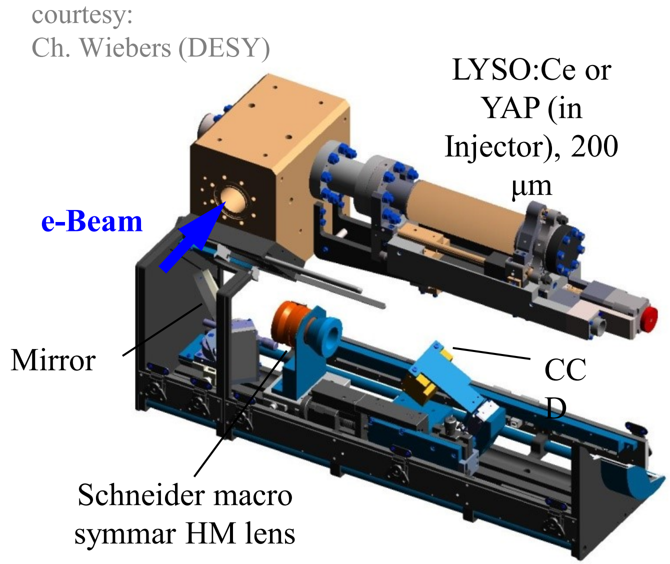
DESY.

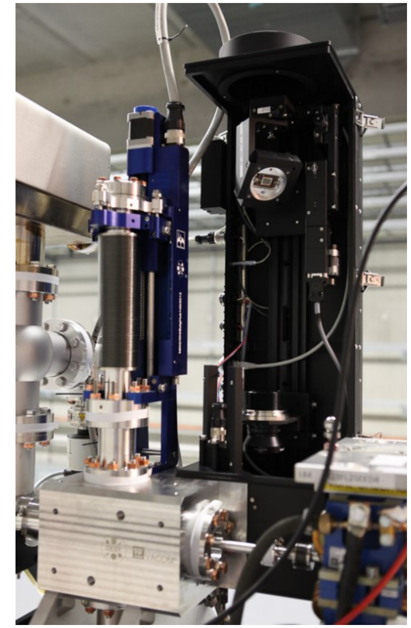
Quenching effects at XFEL

Scintillator based monitors at XFEL

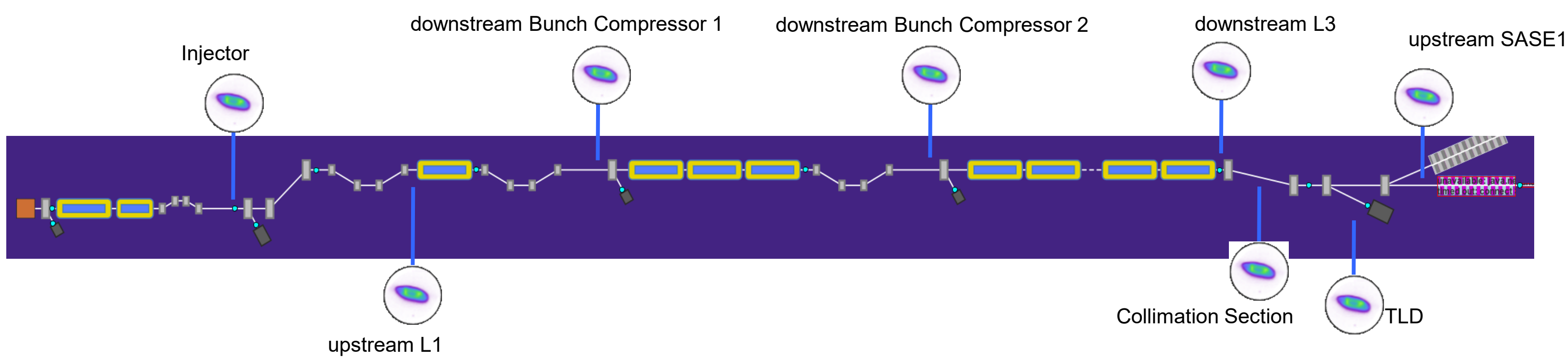
Geometry







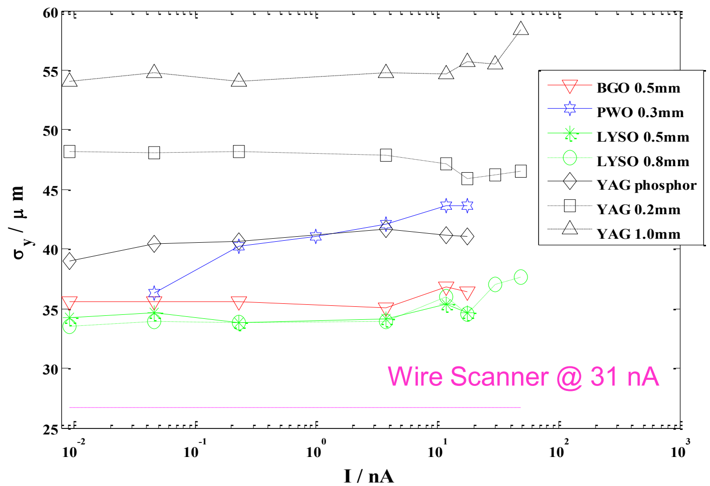
~ 70 monitors are used along the machine



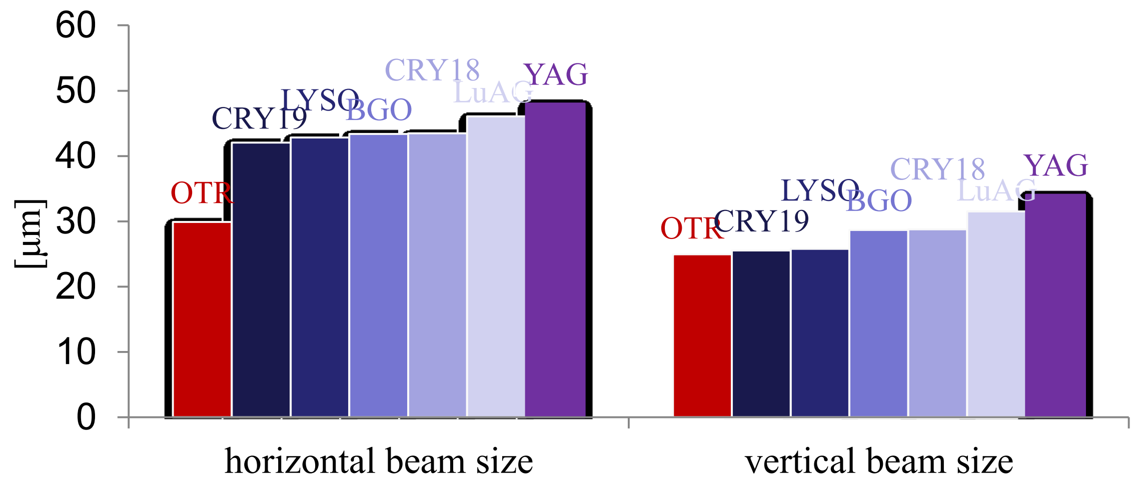
Scintillator based monitors at XFEL

Scintillating material

Measurements at Mainz Microtron MAMI

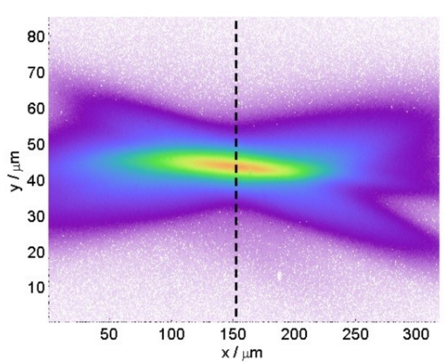


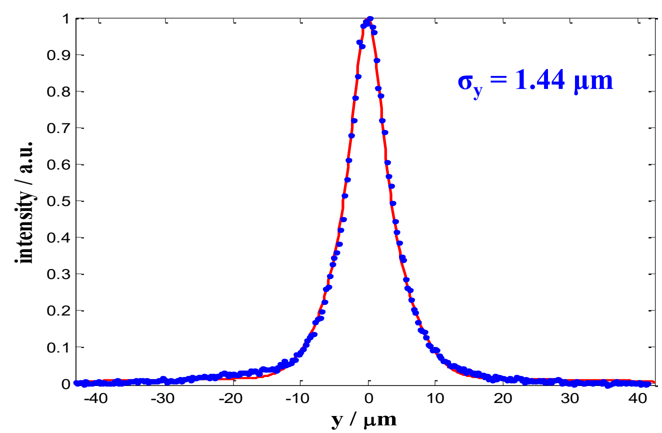
G. Kube et al., Proc. IPAC’10, Kyoto (Japan), 2010, p.906



G. Kube et al., Proc. IPAC’12, New Orleans (USA), 2012, p.2119

LYSO:Ce best spatial resolution

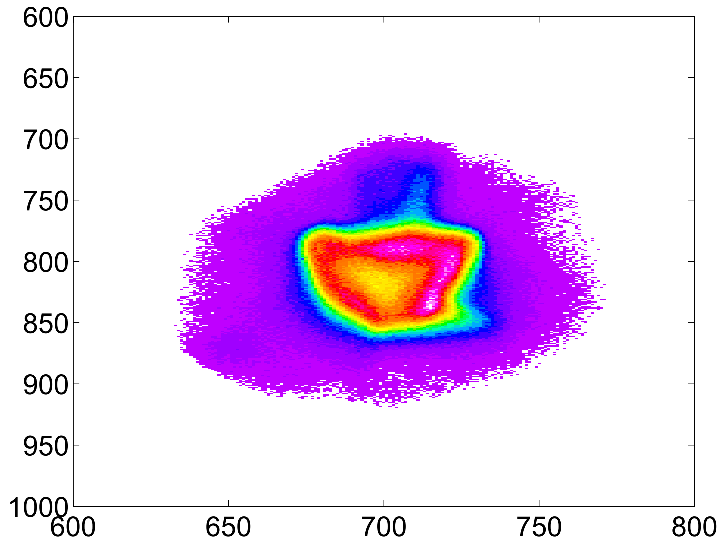


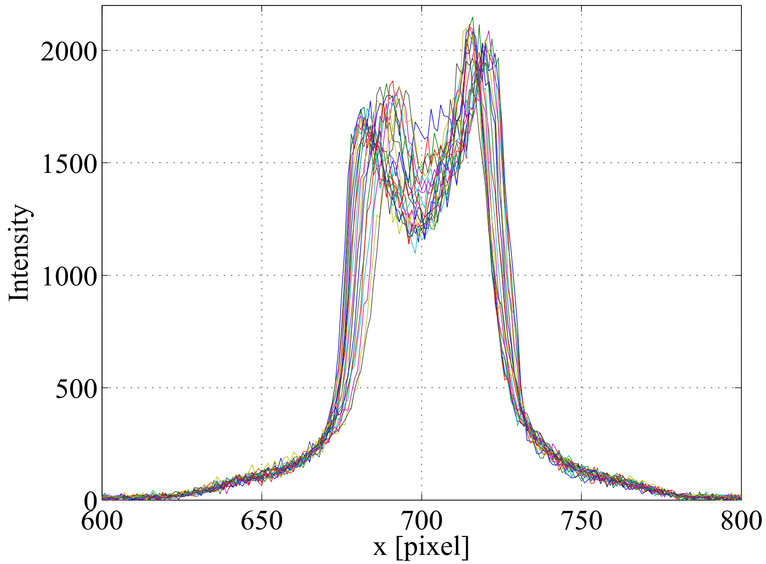


beam size in excellent agreement with independent OTR measurement

G. Kube et al., Proc. IBIC’15, Melbourne (Australia), 2015, p.330

"Smoke-ring" profile first observation





- The shape was observed along all the machine.
- The shape leads to higher emittances measured.

Excluded options:

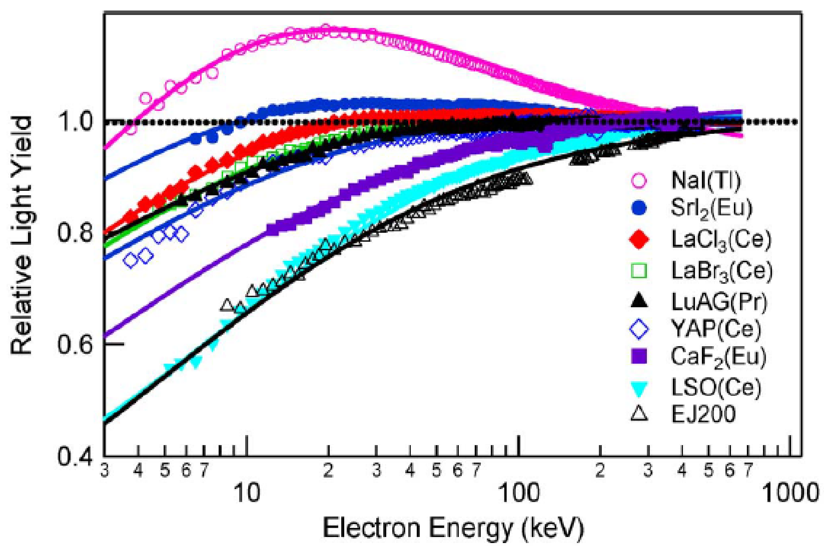
- COTR contribution
- Space charge effects from the gun
- CCD saturation

<u>Final suspicion is a scintillator effect</u>

HEP Scintillator experience

Calorimetry

S.A. Payne et al., IEEE Trans. Nucl. Sci. **58** (2011) 3392

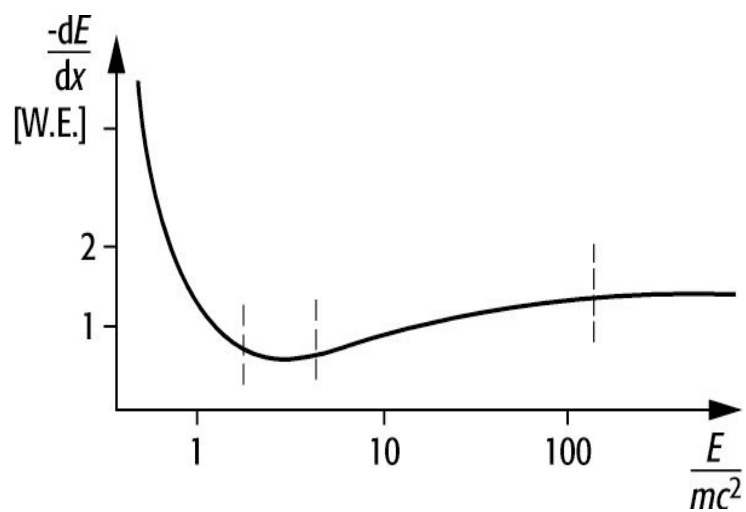


It is known from HEP experience:

- There is a non-linearity in energy resolution.
- An ionization track density is a critical parameter.

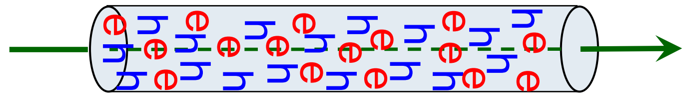
May we use the experience in the beam profile measurements field?

- In case of XFEL electrons have 130 MeV energy already at the very first screens. *So we are in so-called Fermi Plateau.*
- BUT! XFEL has high electron bunch population up to 10^{10} particles/bunch



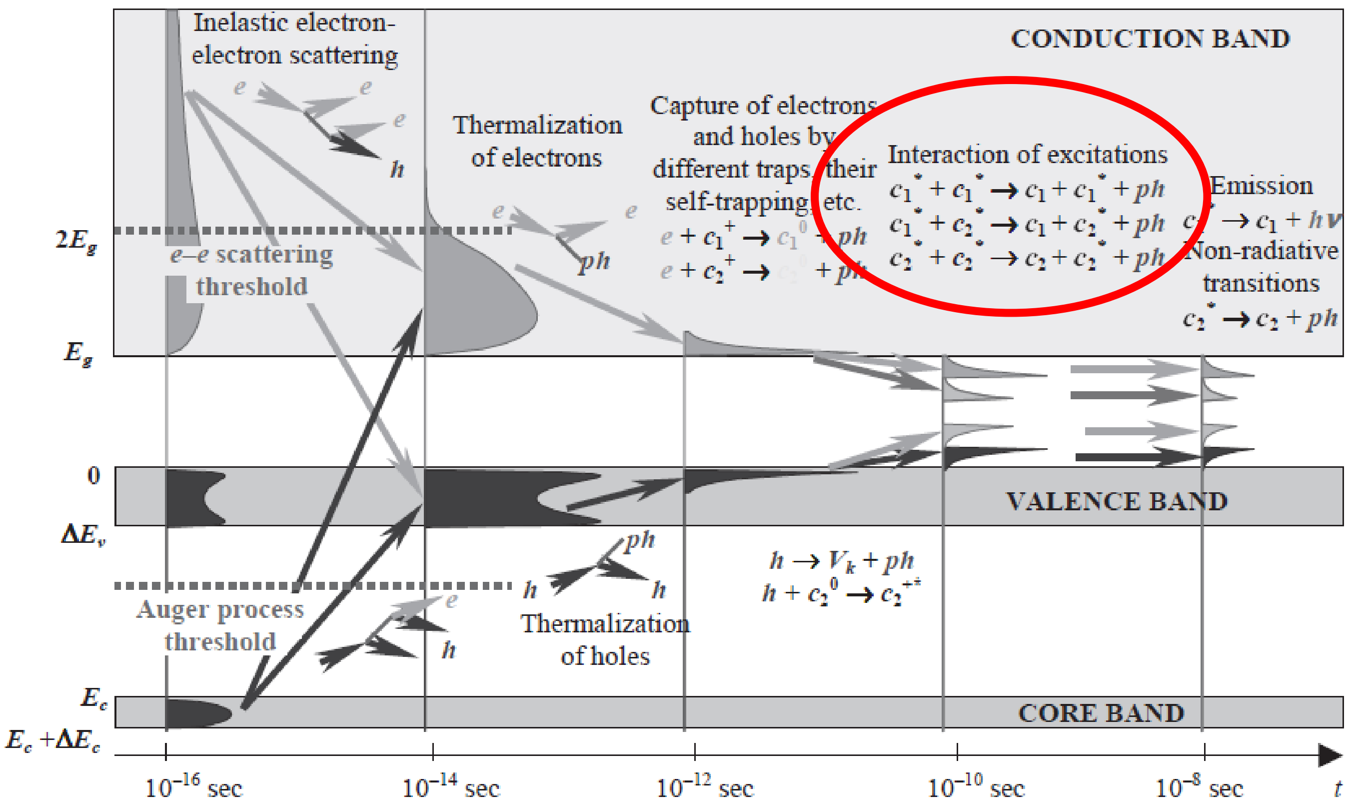
Scintillating process in details

- When a particle goes through a scintillator material it creates plenty of *e-h pairs* in small area around its track (radius of the area is about 3-5 nm).



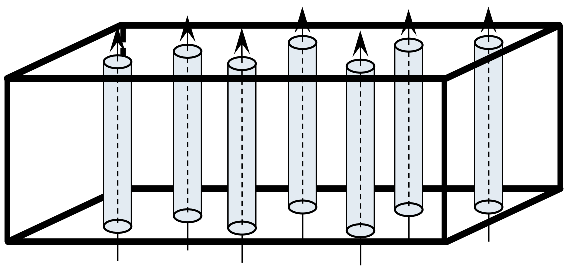
- Then the *e-h pairs* should pass several stages to be converted into light we detect later

A.N. Vasil‘ev, Proc. SCINT’99, Moscow (Russia), 1999, p.43



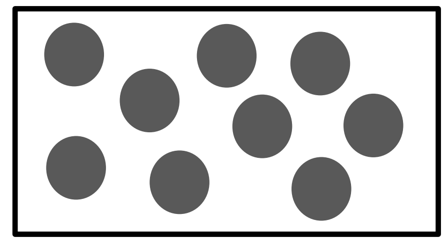
Ionization density at XFEL

low charge density beam

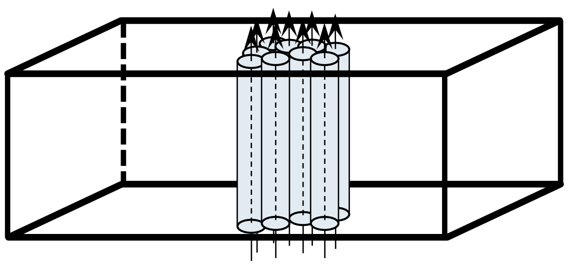


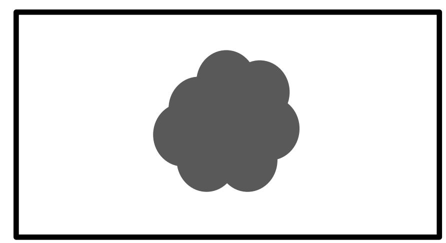
static homogeneous ionization tubes:

2D representation sufficient



high charge density beam

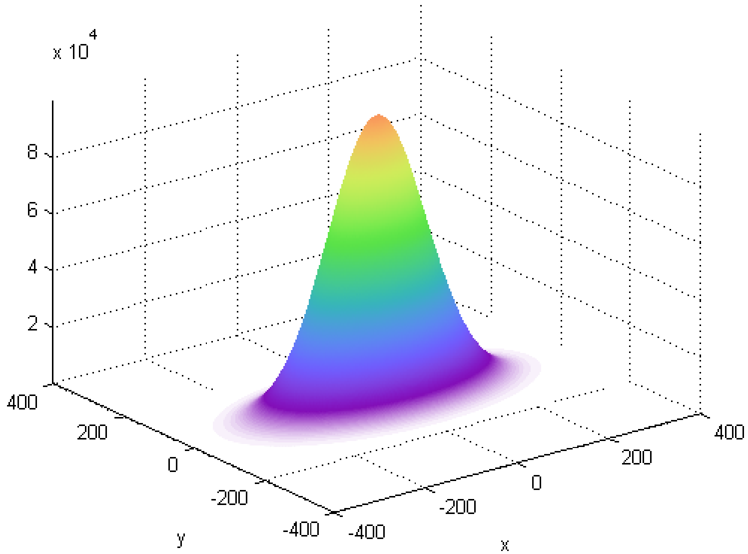




Instead of having high track ionization density caused by the primary particle high losses, we get the density by having the tracks of the primary particles overlapped.

Quenching model for beam profiles

Gaussian beam

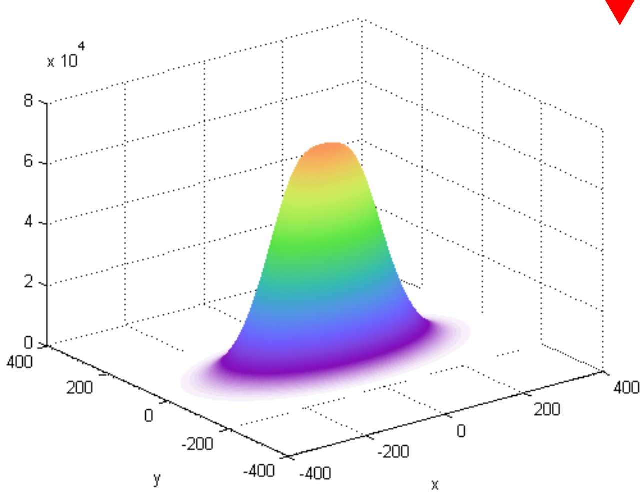


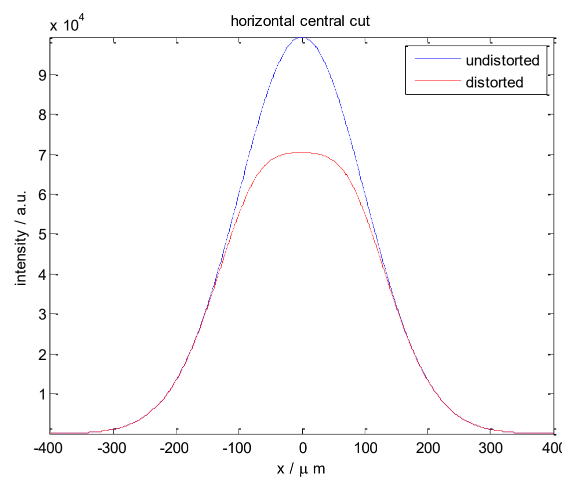
Birks-type weight factor for scintillator non-linearity

J.B. Birks, Proc. Phys. Soc. **A64** (1951) 874

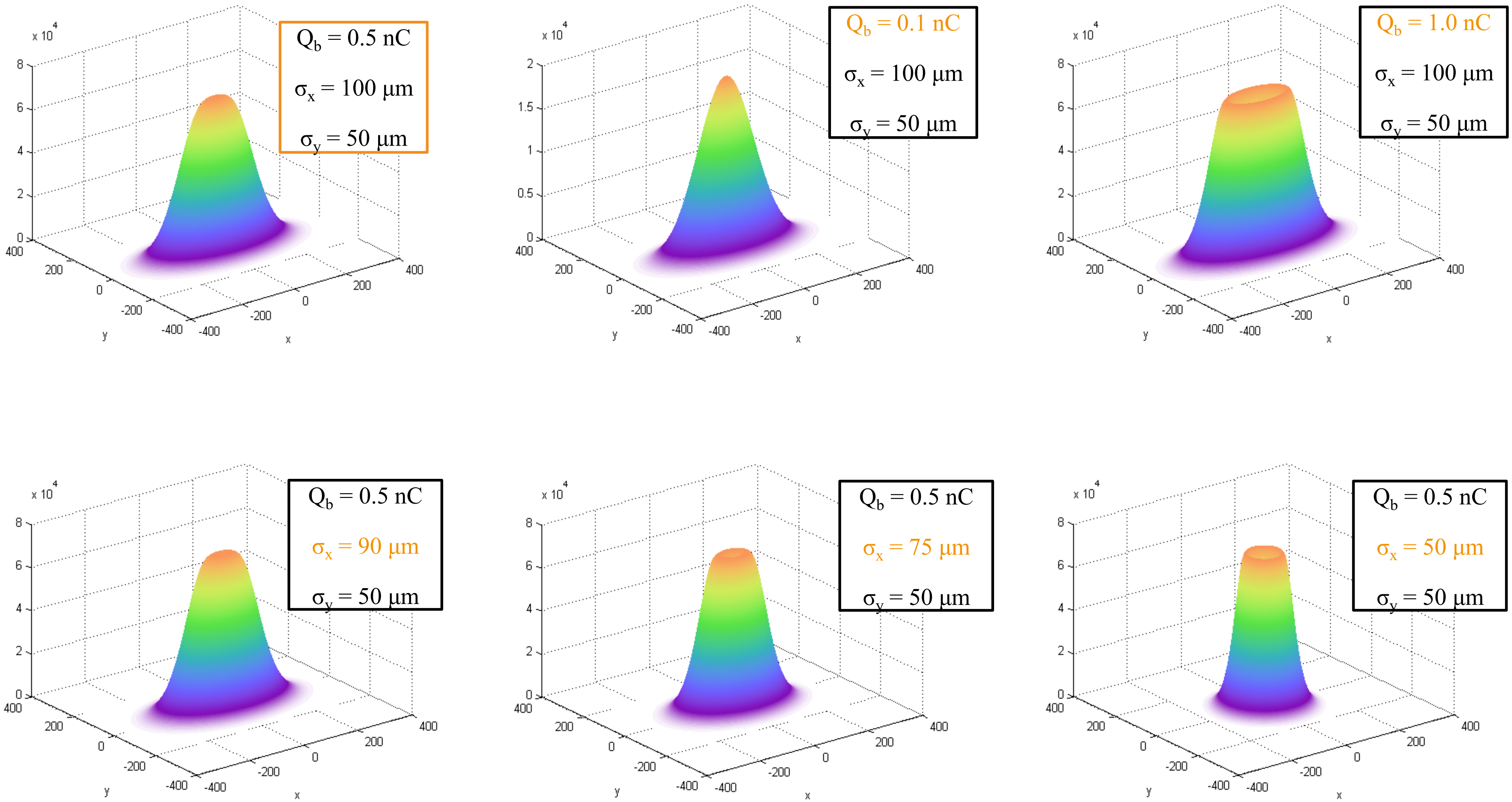
$$w = \frac{1}{1 + \alpha \frac{\mathrm{d}E}{\mathrm{d}x}} \quad \text{with} \quad \frac{\mathrm{d}E}{\mathrm{d}x} \propto (n_t)^3$$

α is a free adjustable parameter





Model calculation

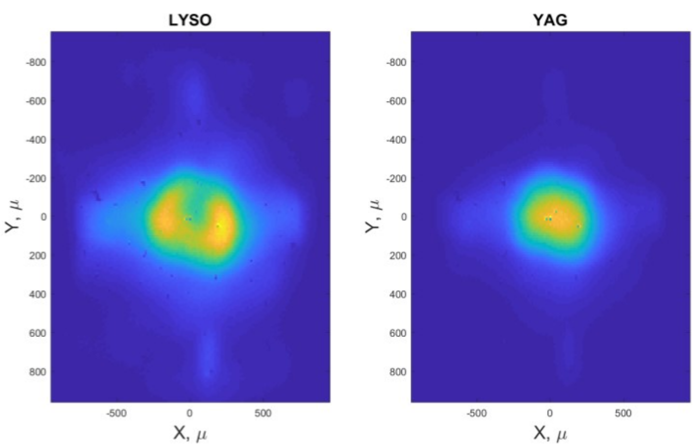


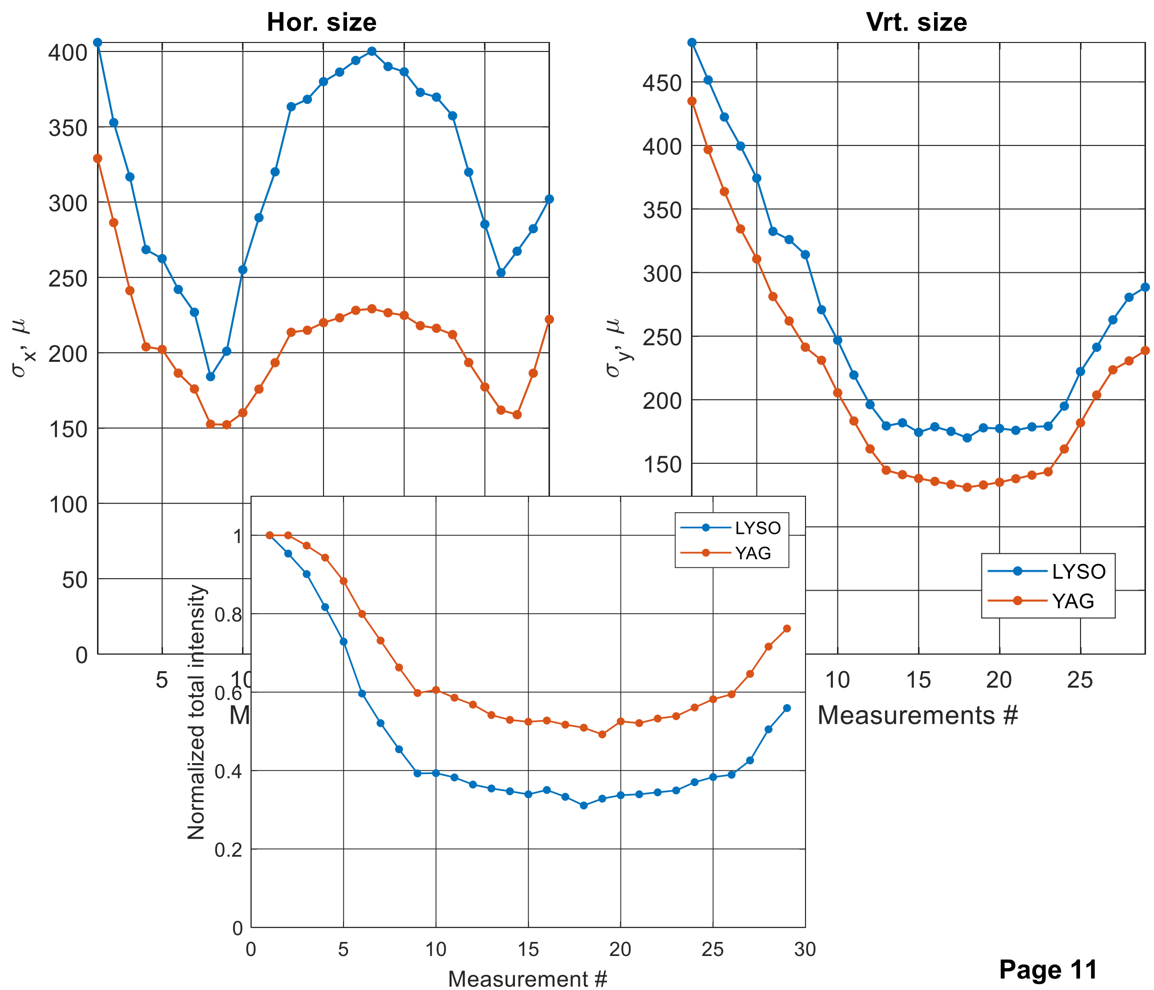
Measurements at XFEL

- To compare materials several stations were equipped with two materials - LYSO with additional one. The additional ones were: *YAG, YAP, GAGG, LuAG*.
- To test the materials a quad scan was performed.

LYSO/YAG comparison

- E = 14 GeV
- Q = 1 nC

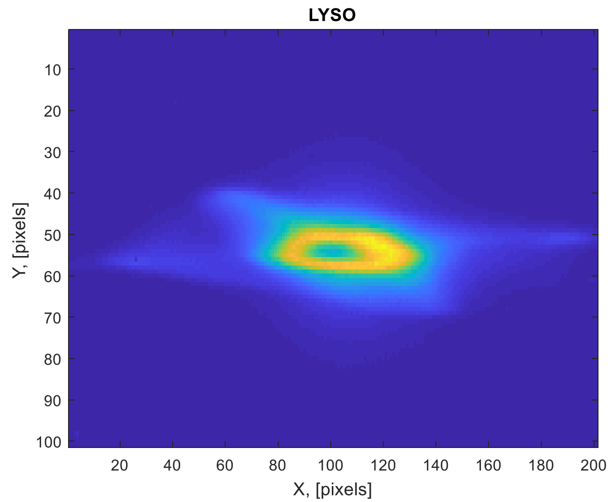


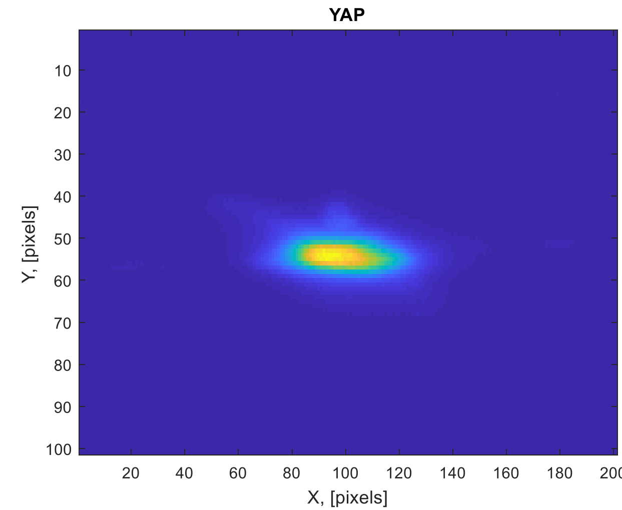


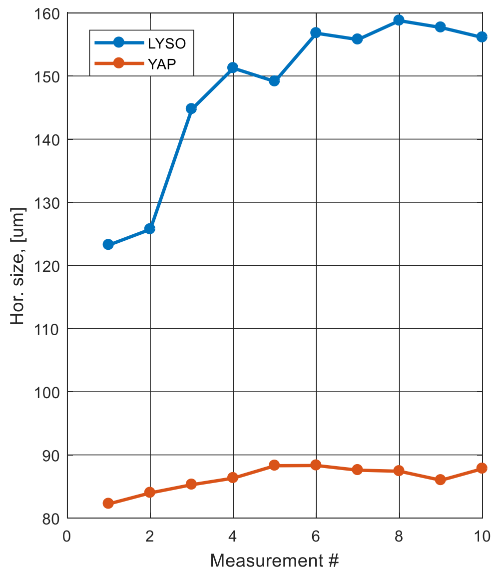
Measurements at XFEL

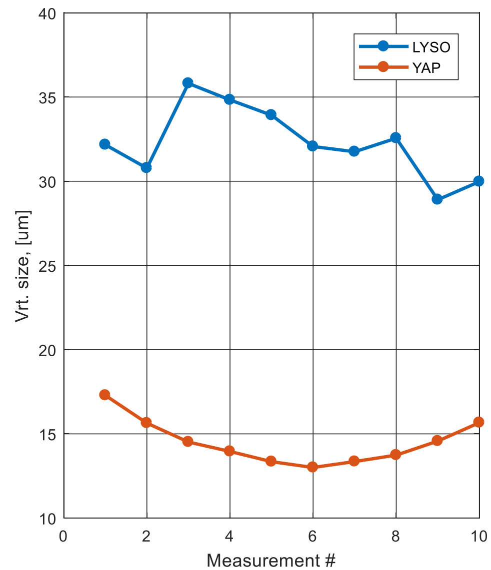
LYSO/YAP comparison

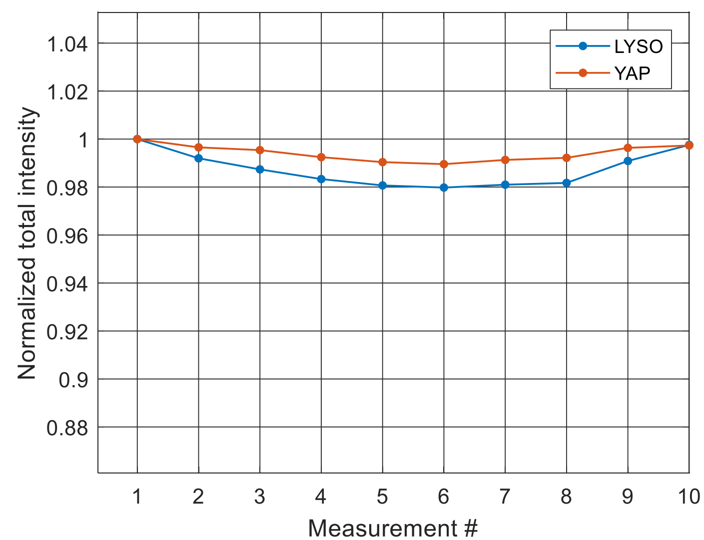
- E = 14 GeV
- Q = 0.45 nC







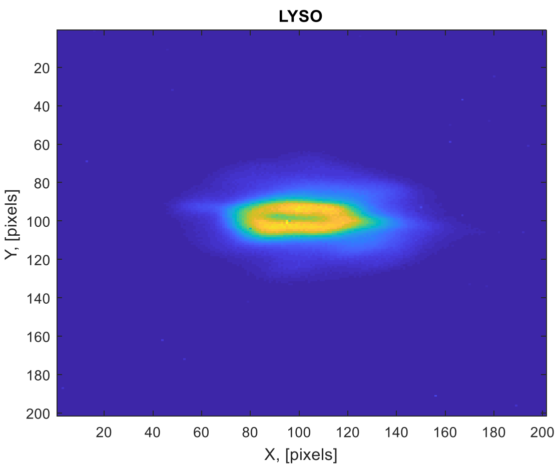


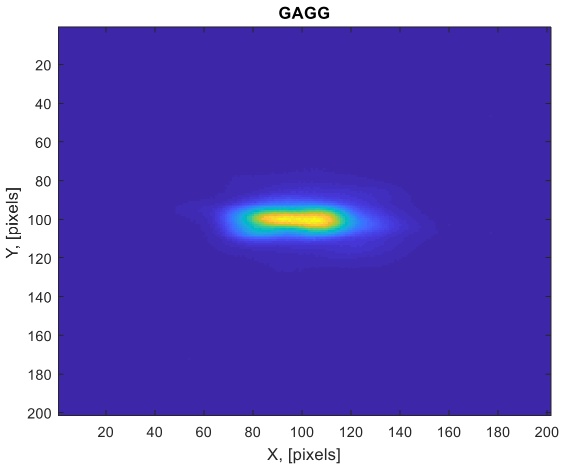


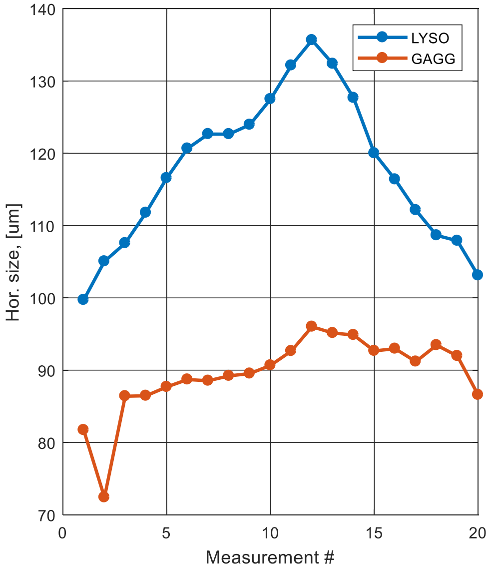
Measurements at XFEL

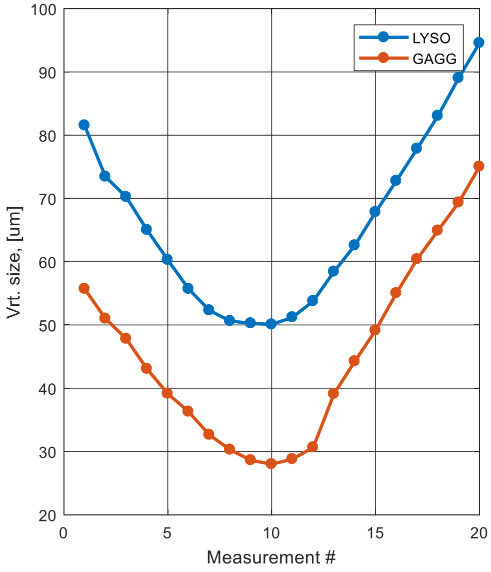
LYSO/GAGG comparison

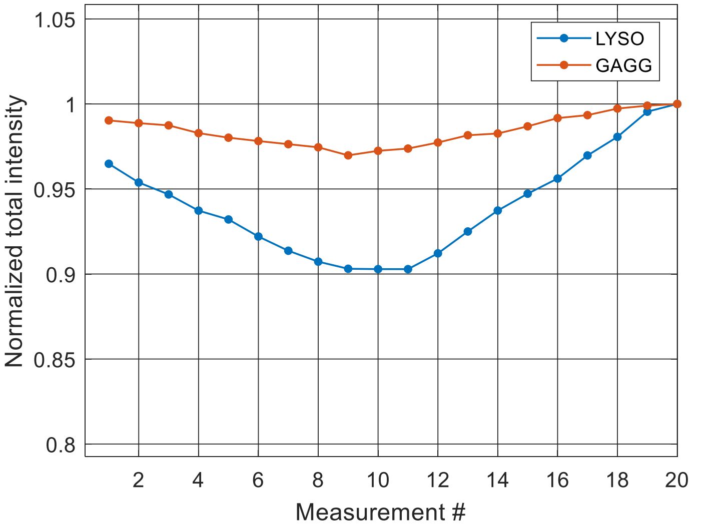
- E = 14 GeV
- Q = 0.45 nC











Conclusion on Quenching Effect

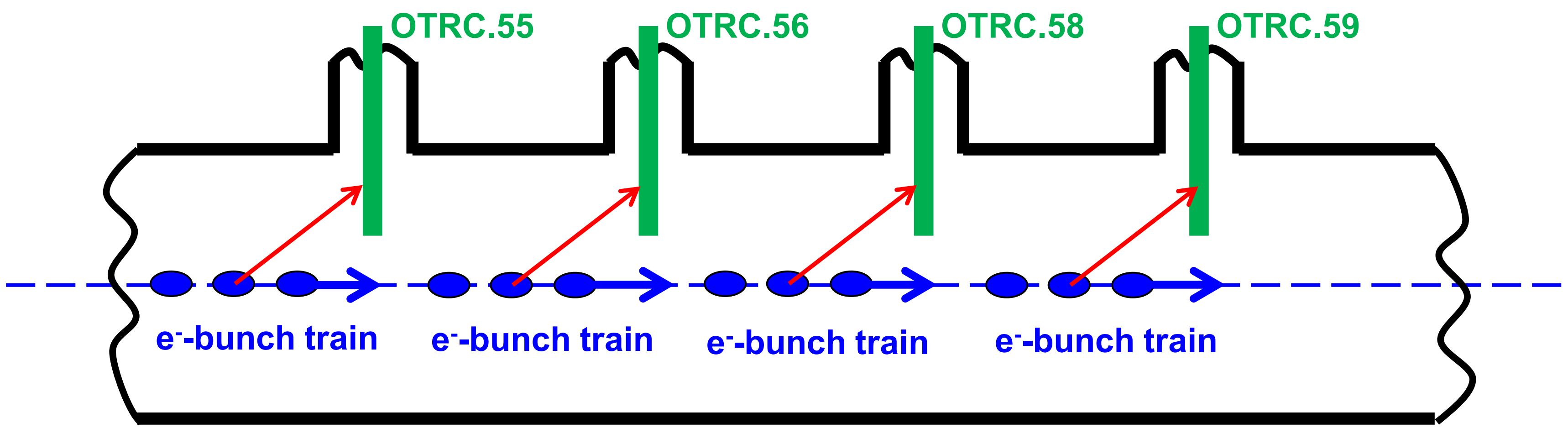
- Measured beam sizes are larger than expected.
- Quest for suitable scintillator material.
- Development of the quenching model and further experimental investigations.

Charging effects at XFEL

Of-axis screens at XFEL

Geometry

Scheme of the off-axis screen monitors

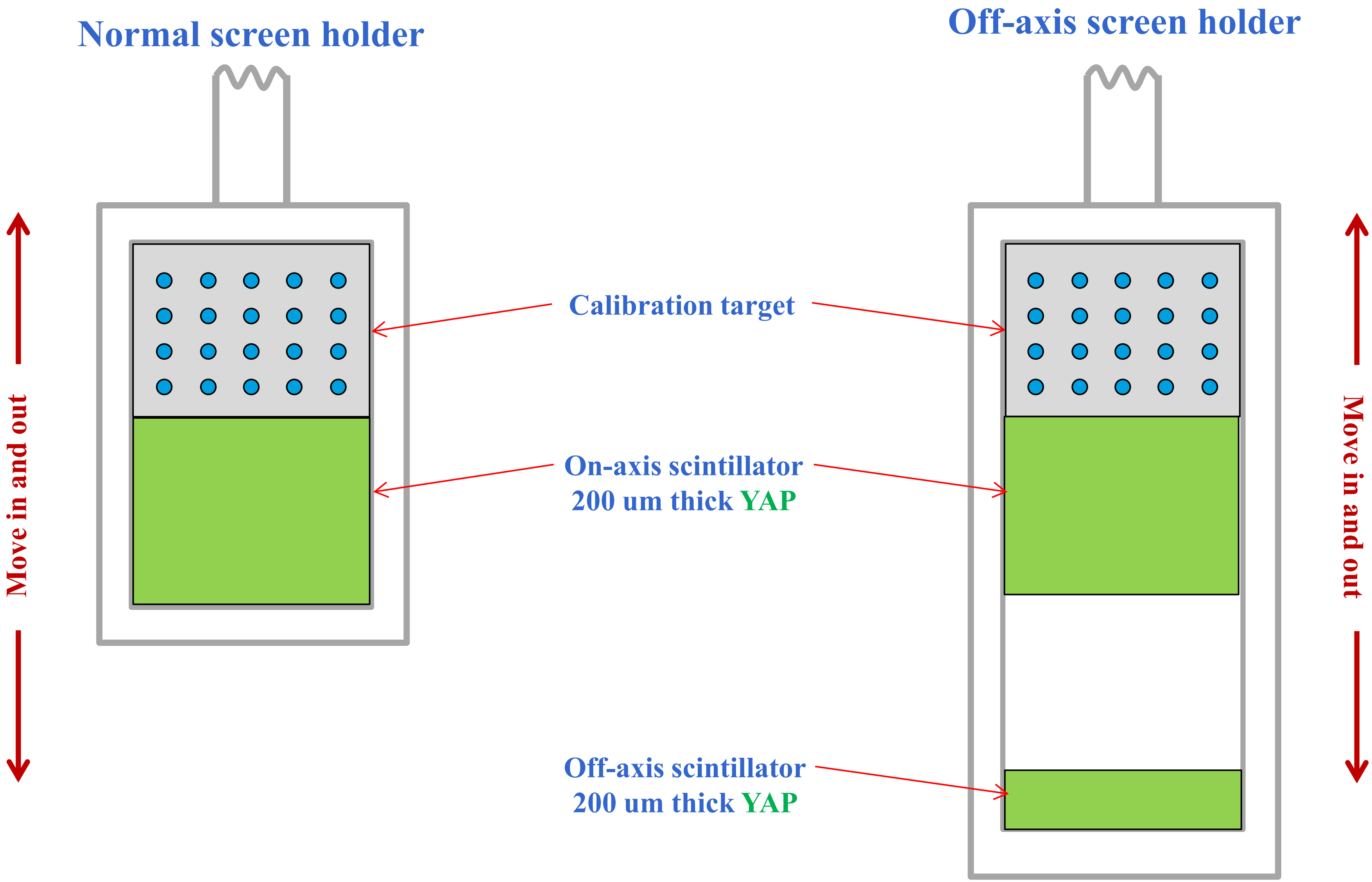


Vacuum chamber

Allow to measure beam profiles in online mode by kicking a single bunch out fo the whole bunch-train onto the screens.

Of-axis screens at XFEL

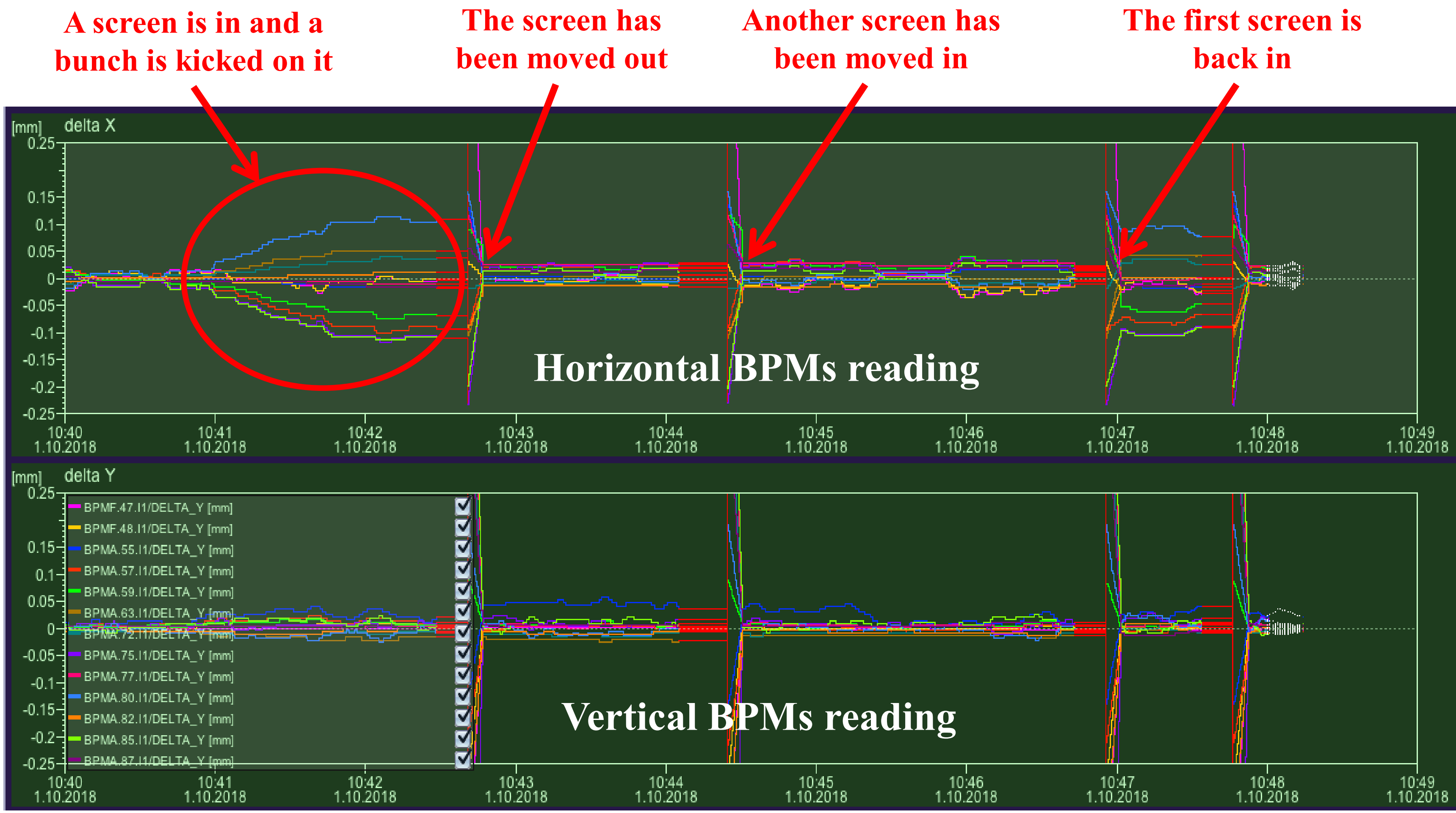
Scintillator holder



Charging effect first observation

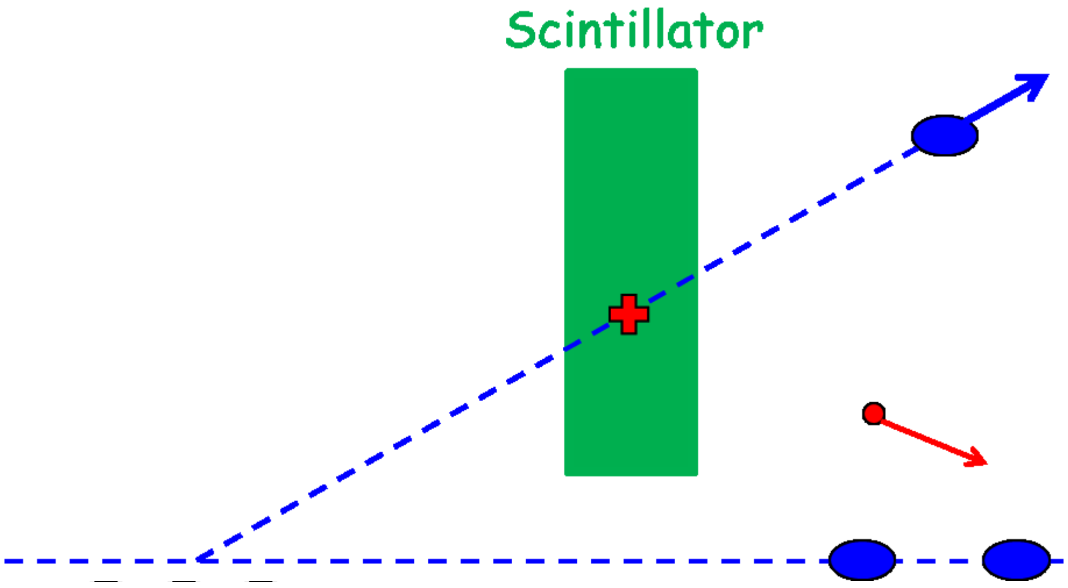
During emittance measurements with the off-axis screens the SASE level drops in time:

- First guess was that the kickers somehow cause the effect.
- Downstream BPMs reveal changes in the orbit



Physics behind the effect

- The kicked electron bunch causes ionization.
- Every bunch can leave up to 3% of its charge in the scintillator (Simulated in GEANT4).
- The scintillator material is an insulator → discharging goes slowly.
- Every next bunch passing by the scintillator feels the Coulomb force.

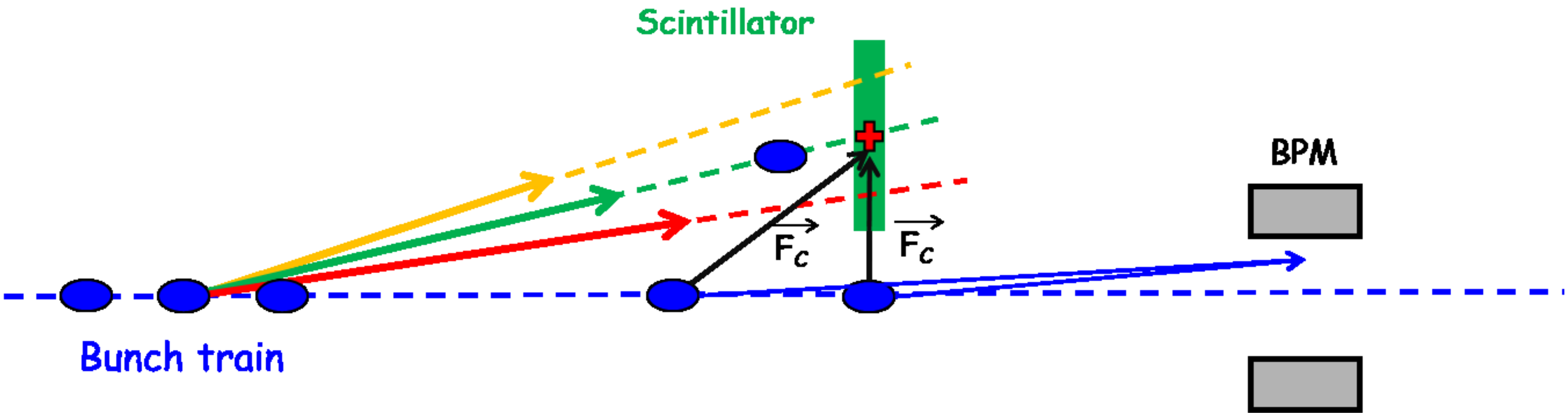


Nevertheless charging competes with discharging. Thus the behavior of charging in time should be described by the equation:

$$\frac{dN}{dt} = -\lambda_1 N + \lambda_2 (N_0 - N) \longrightarrow N_q = A_1 - A_2 \exp\left[-A_3 \, t\right]$$

Measurements scheme

To measure the effect we had one of four off-axis screen inserted, kicked one bunch of a bunch train on it continuously and measured a BPM reading downstream. We consider then the charge on he screen is local.



Since we have Coulomb force → the deviation downstream depends on the distance between the screen charge and the bunch train.

Every position has been measured **300 seconds = 3000 bunches** passed through the scintillator.

Bunch charge was **250 pC**, electron energy - **130 MeV.**

To measure the position of the passing by bunches the normal screen was inserted after the measurements and the picture taken.

Measurement #1

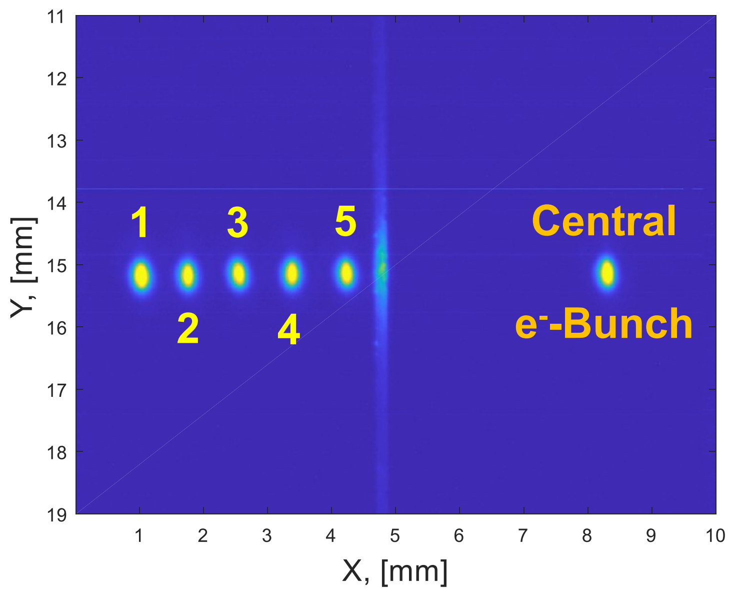
The bunch train consisted of **2 bunches**

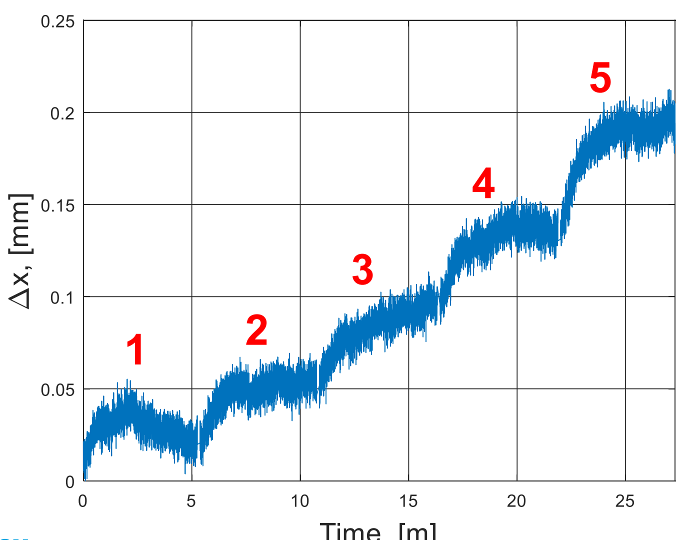
Number of “on screen” bunch positions was **5**

Distances between on-screen bunches and the central bunch one:

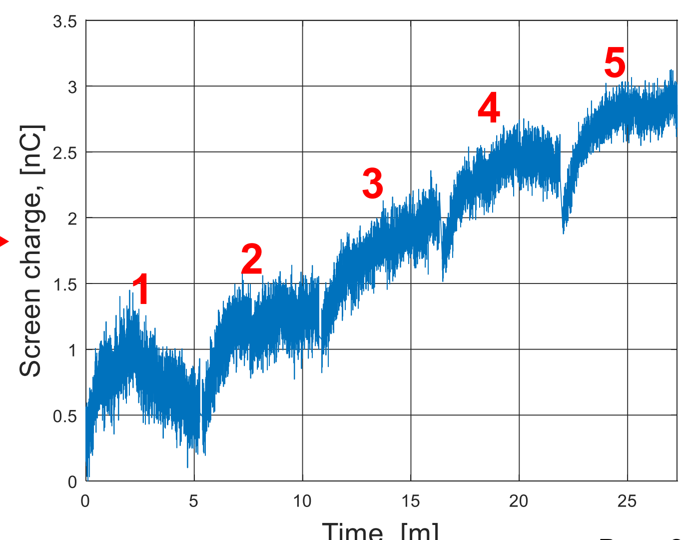
- *1 =7.3 mm*
- *2 = 6.6 mm*
- *3 = 5.8 mm*
- *4 = 4.9 mm*
- *5 = 4.1 mm*

Distance between the screen and BPM was **4 m**





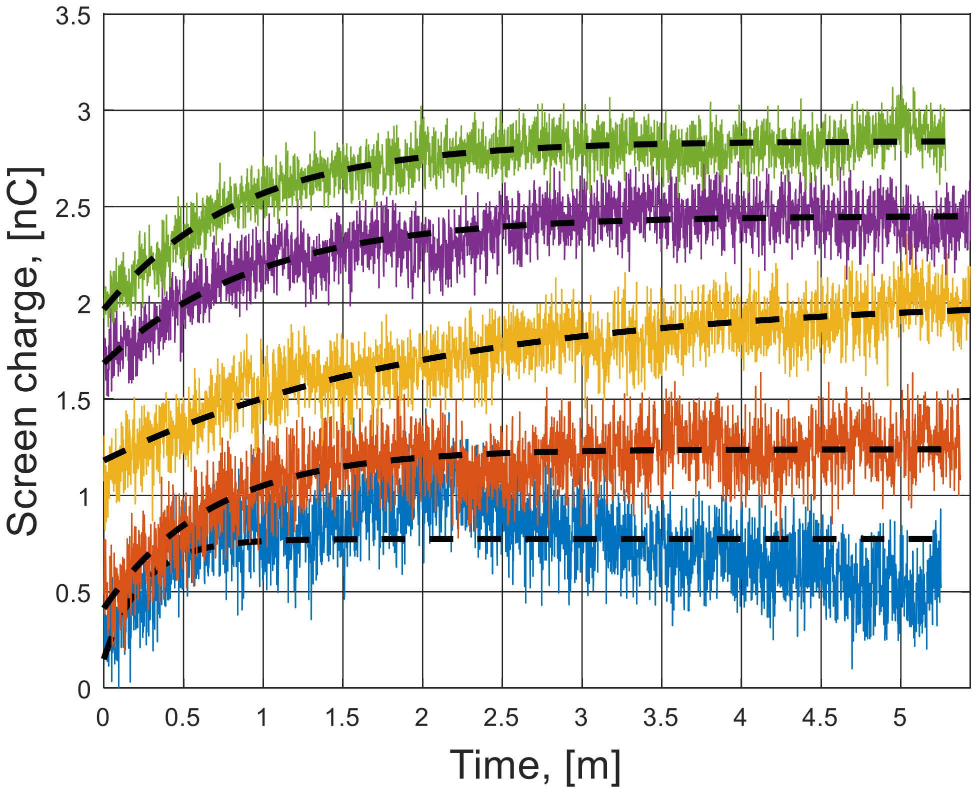
Recalculation into charge



Measurement #1

Fitting formula:

$$N_q = A_1 - A_2 \exp\left[-A_3\, t\right]$$



This was used for comparison with GEANT simulation.

The result of the simulation was that **3 %** of a bunch charge should be created in the scintillator after it has passed. Also the losses doesn't depend on the electron energy in the region of XFEL electrons (around 130 MeV)

From the data we have around **6 %**

Measurement #2

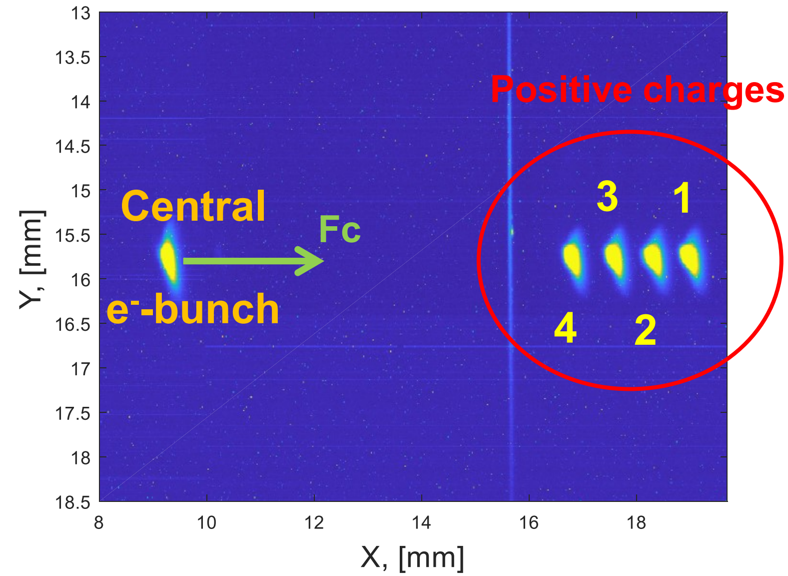
The bunch train consisted of **158 bunches**

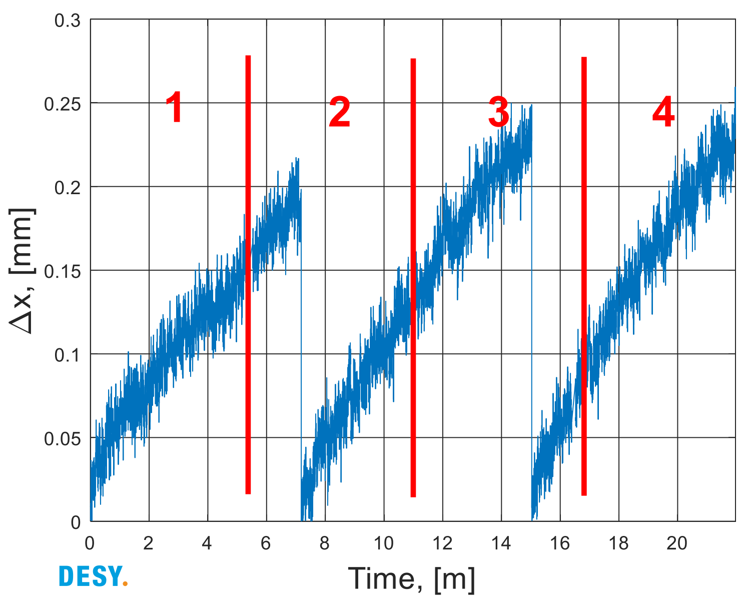
Number of on screen bunch positions was **4**

Distances between on-screen bunches and the central bunch one:

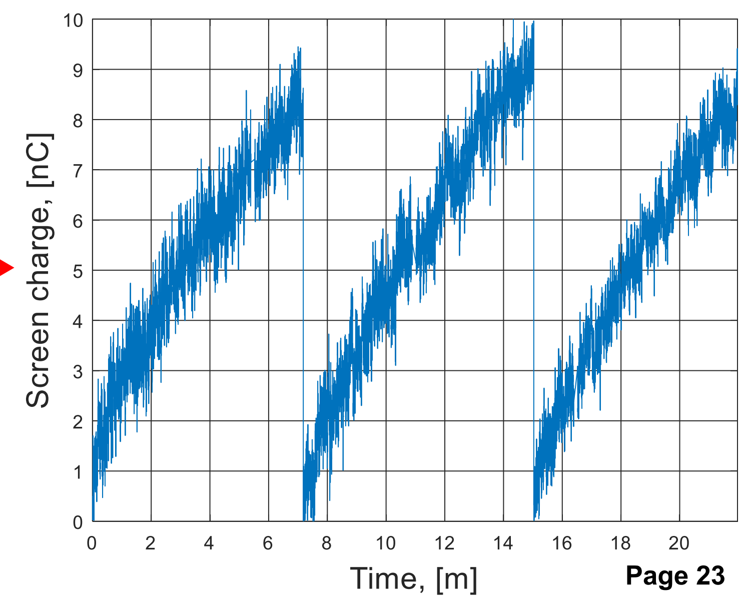
- *1 =9.7 mm*
- *2 = 9.0 mm*
- *3 = 8.3 mm*
- *4 = 7.5 mm*

Distance between the screen and BPM was **2 m**





Recalculation into charge



Conclusion on Charging Effect

- The beam orbit and the SASE level as a consequence are affected by the charging of the scintillators.
- Further systematic studies are planned at XFEL and at our laboratory stand with an electron gun and a scintillator in front of it.
- The fast discharging issue still has unknown nature.
- Might be useful to cover a scintillator by a conductive layer to discharge it as fast as possible.

Thank you