Hosing Analysis – Effects of Laser Alignment

Mathias Hüther MPP Munich

26.04.2019

Problems to retrieve the Alignment Data

- Checks to be done:

➢ compare BCT-timestamp to the timestamp of the laser data
  - if $\Delta t = 0$: alignment data are saved in the right file
  - if $0 < \Delta t < 40^{*}$ sec: alignment data of event i are saved in file of event $i + 1$ (about 40% of all data, normally in large blocks > 200 events)
  - if $\Delta t > 40$ sec: data is lost

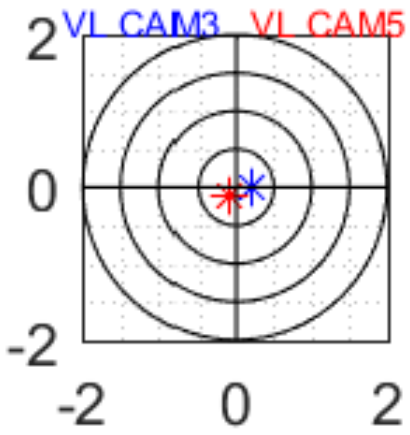
➢ compare VL-camera timestamps to BCT-timestamps
  - If PXI-BCT timestamp difference positive, virtual line images are saved correctly
  - If PXI-BCT timestamp difference negative, PXI-crate problem and data is lost

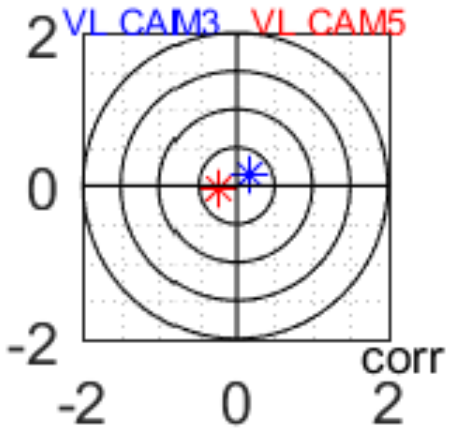
➢ (periodic) laser off events can be used as checks
  - If saved alignment data are NaN and above criteria are fulfilled: laser was off
  - about 95% of all data can be retrieved

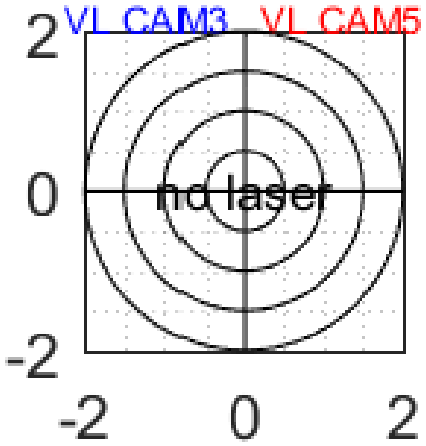
* has to be less than the minimal time between AWAKE extraction i and $i + 2$

Output of Program

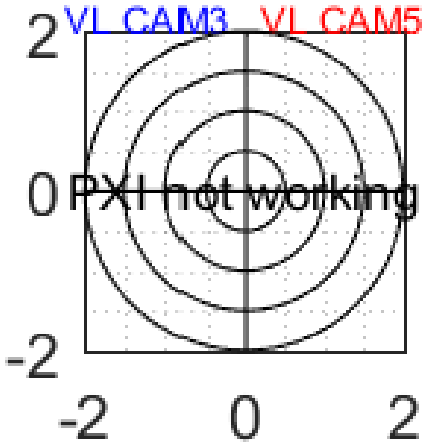
data retrieved:





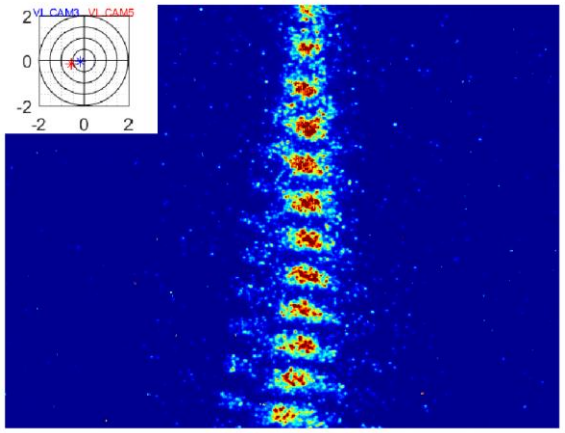
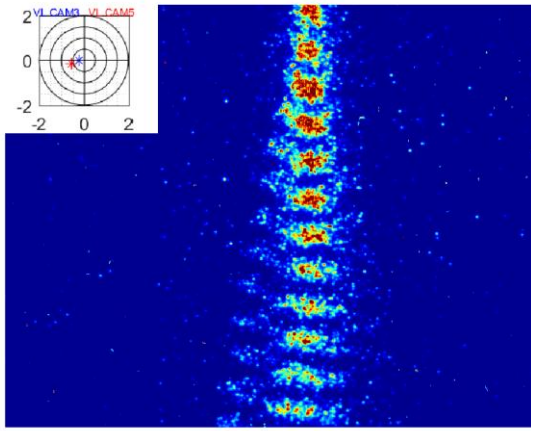
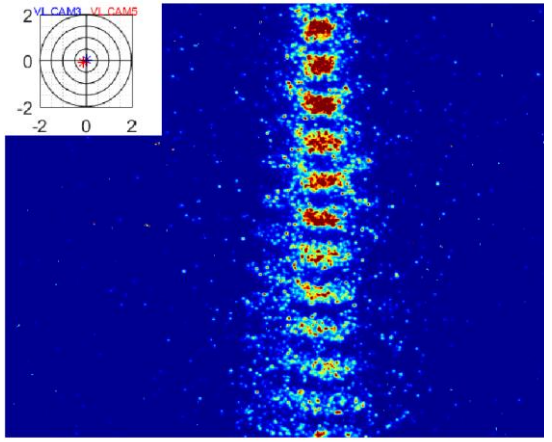
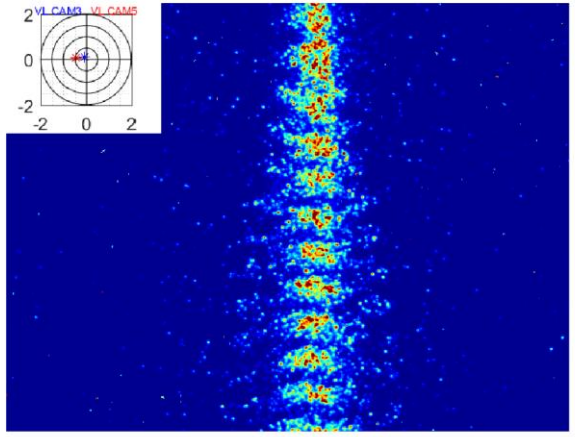
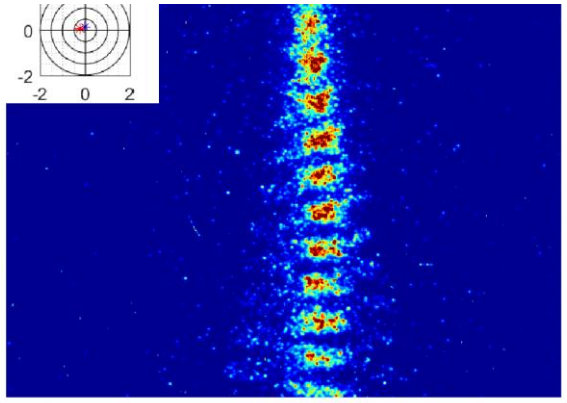
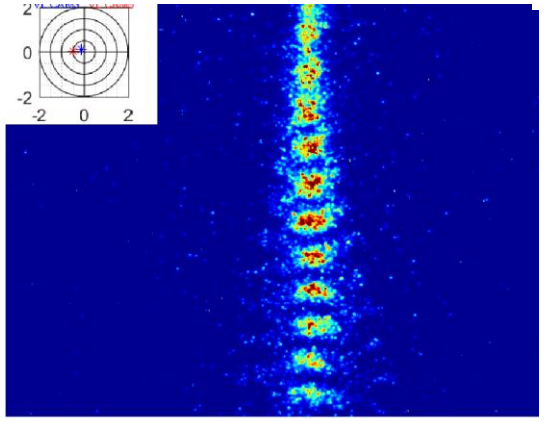
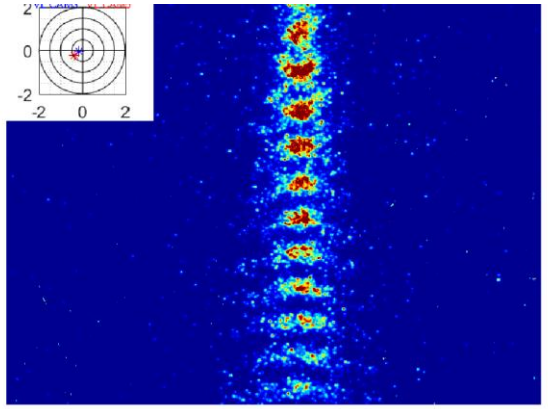
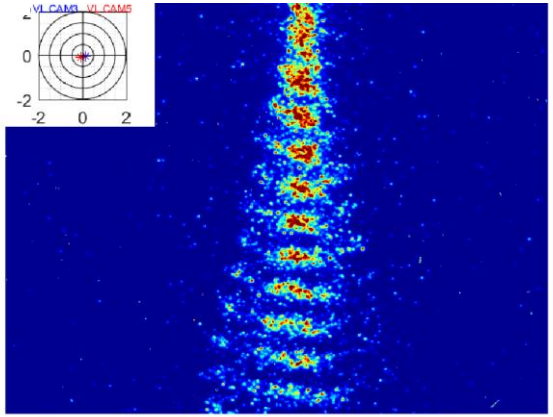


data lost:



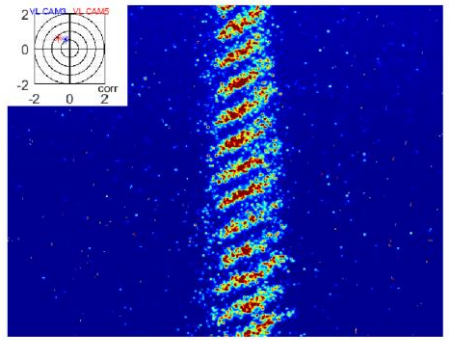
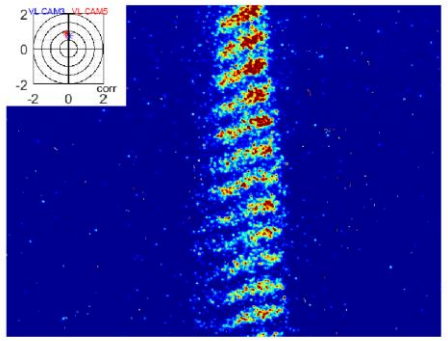
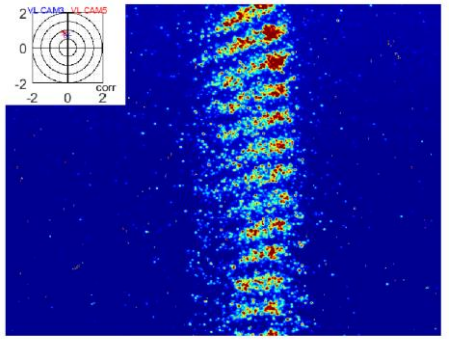
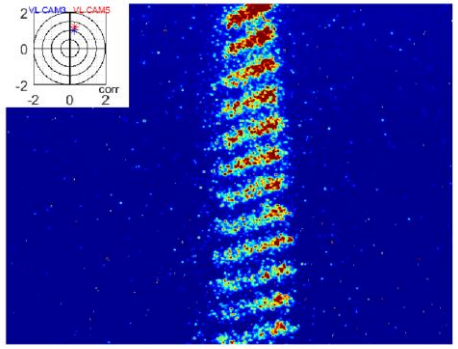
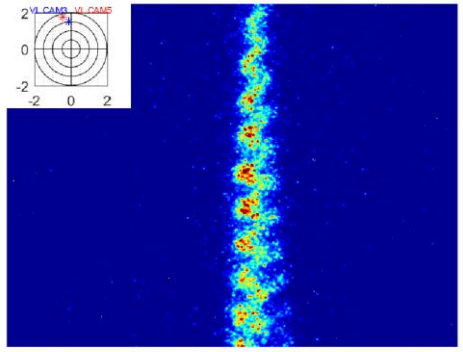
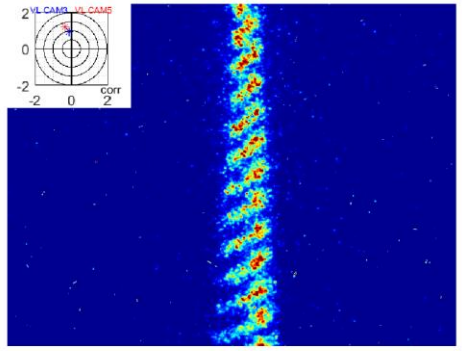
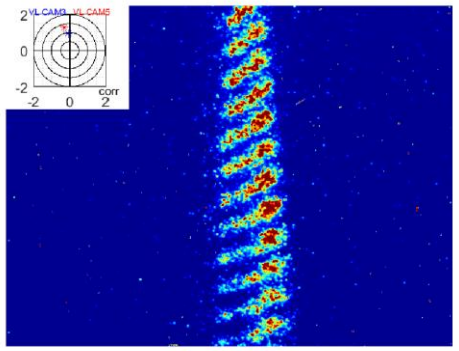
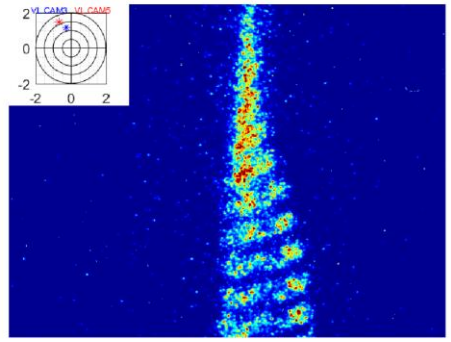
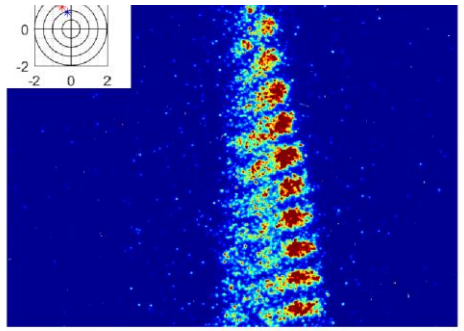
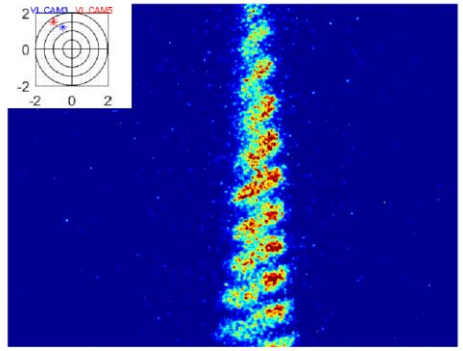
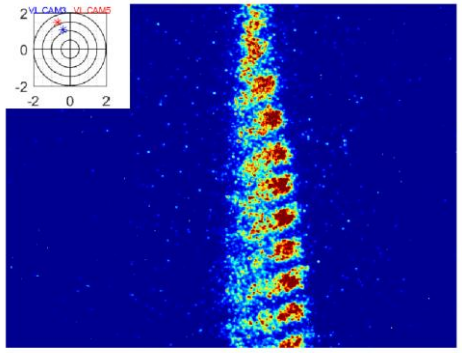
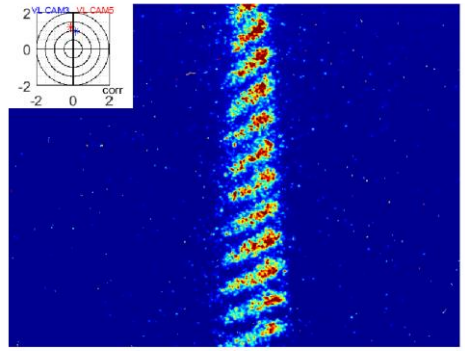
Delay 1000 ns

- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: 100mJ:
- Mostly symmetric events with self-modulation, no evident signs of hosing
- SSM still dominant, also for slight misalignment

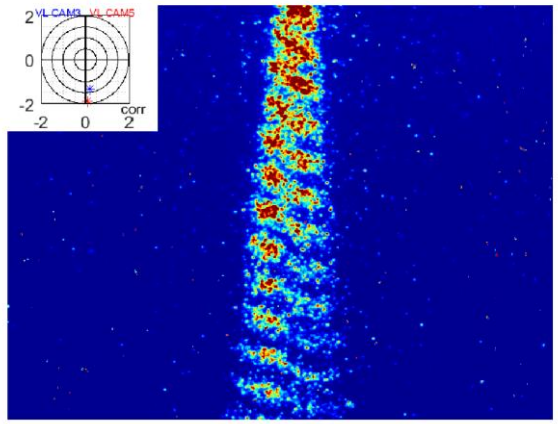
Delay 1000 ns

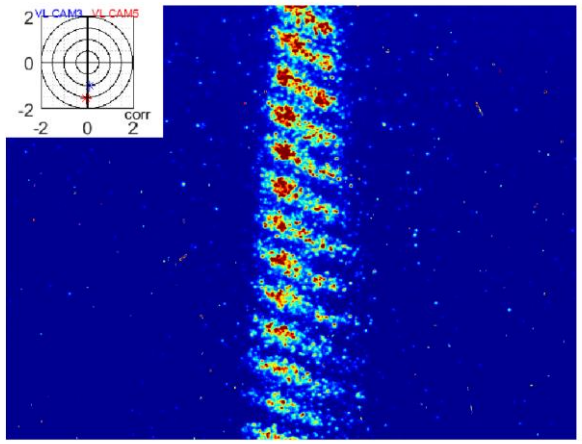
- Laser misaligned upwards, charge: 3e11 p^+/bunch, laser energy: 100mJ:
- Symmetric and asymmetric hosing, bunch tilts all upwards!

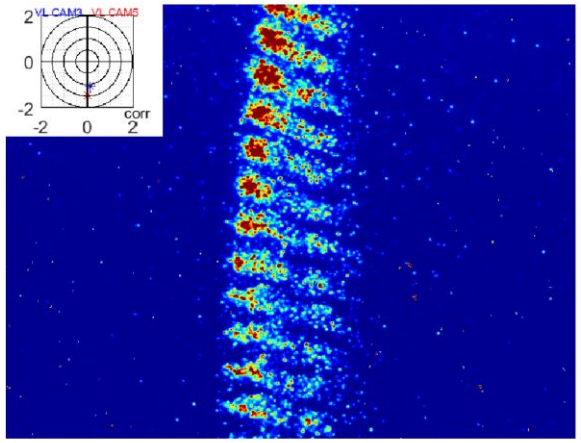













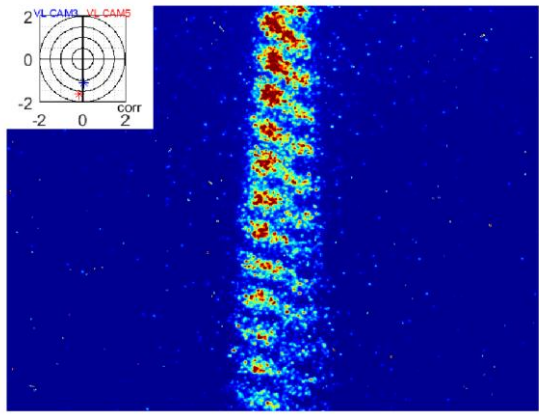
Delay 1000 ns

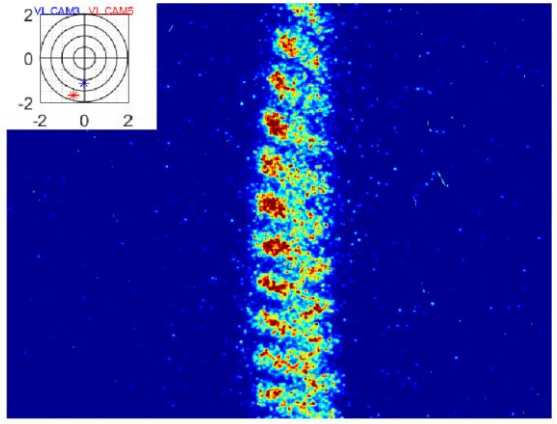
- Laser misaligned downwards, charge: 3e11 p+/bunch, laser energy: 100mJ:
- Symmetric and asymmetric hosing, bunch tilts all downwards!

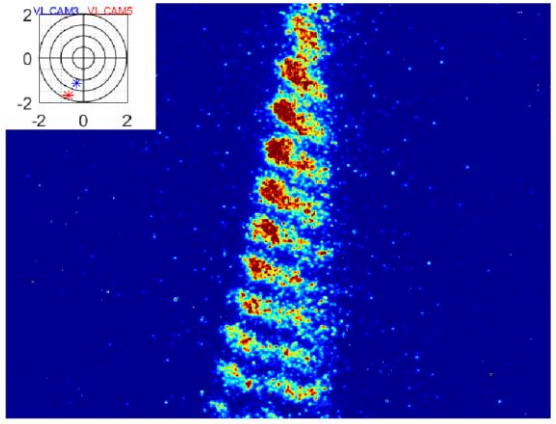


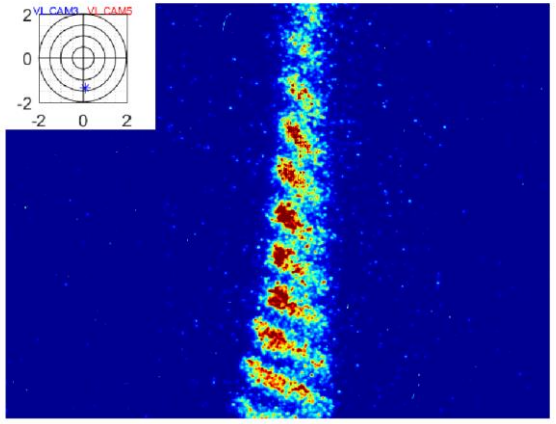






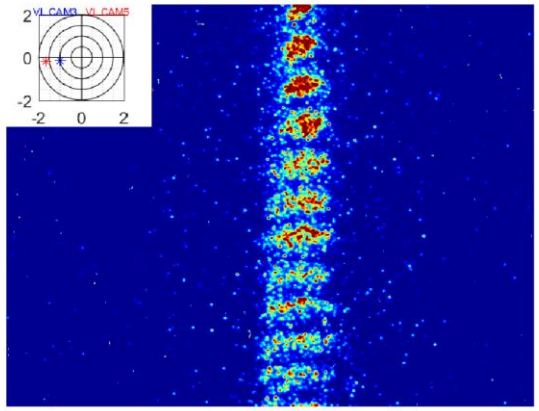
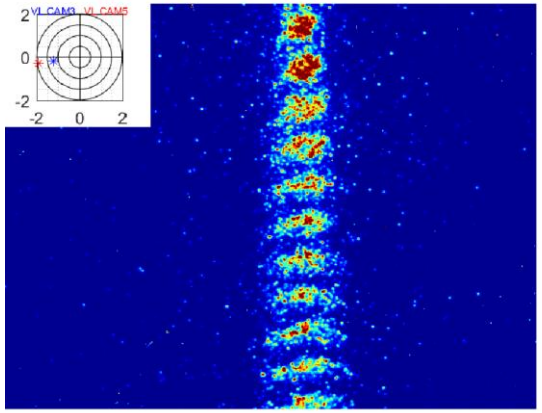
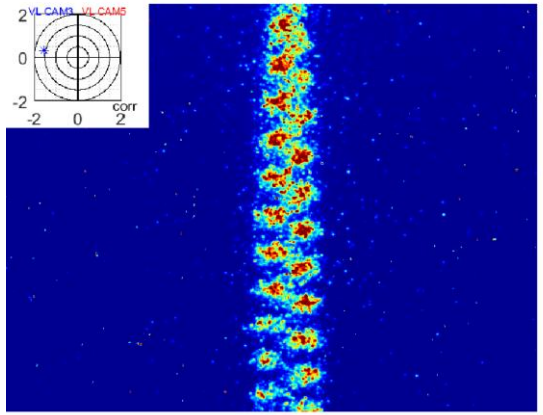
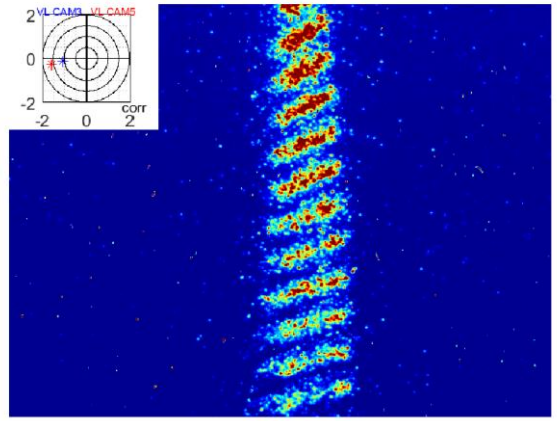
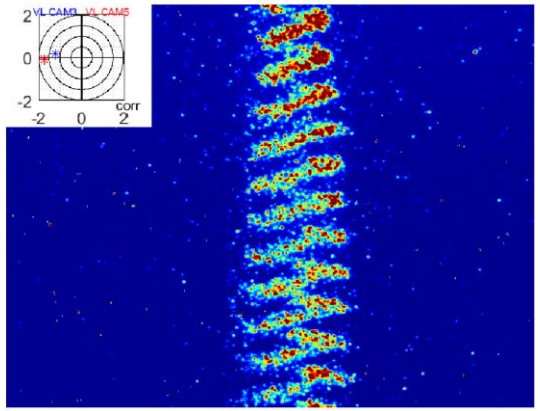
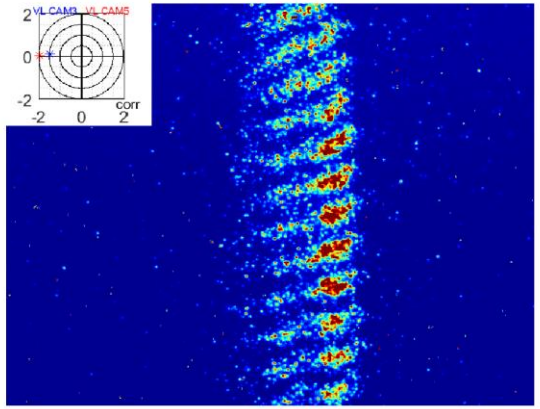
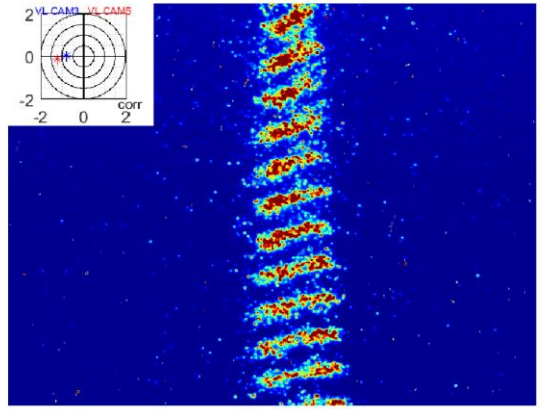
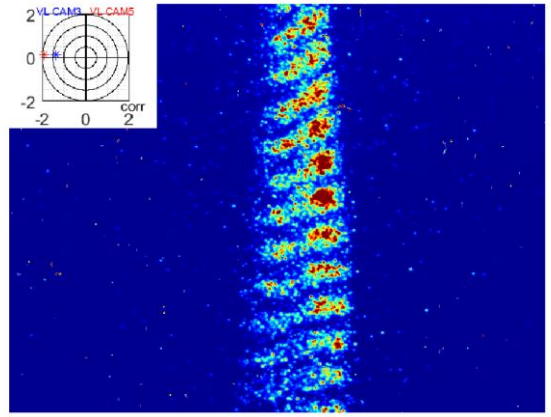






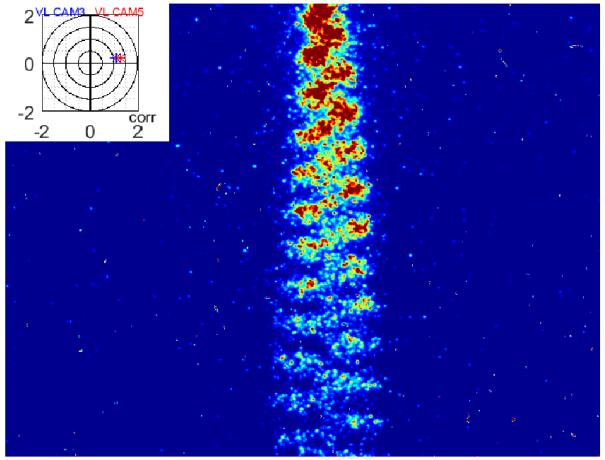
Delay 1000 ns

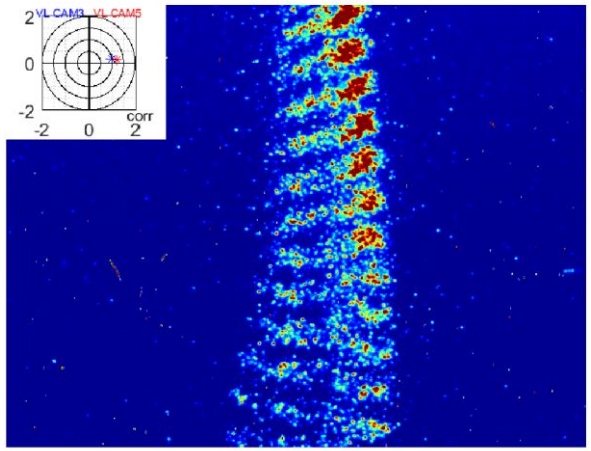
- Laser misaligned to the left, charge: 3e11 p^+/bunch, laser energy: 100mJ:
- Effects not so evident, sometimes (symmetric or asymmetric) hosing, “SSM-like” events!

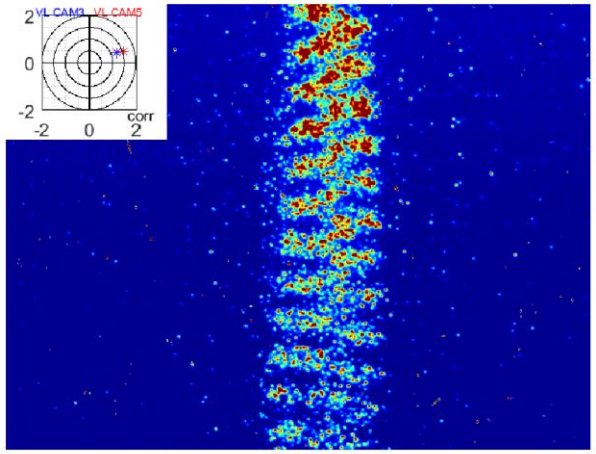









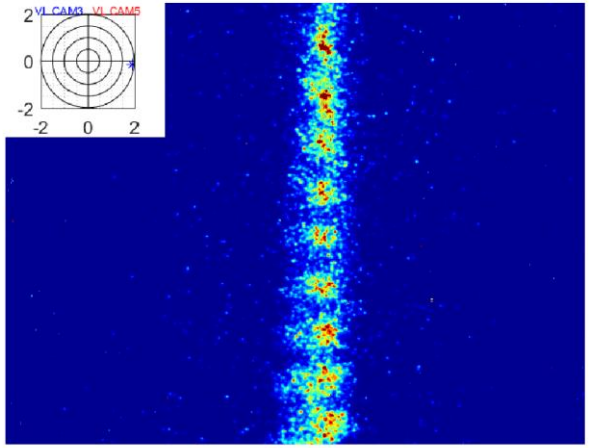
Delay 1000 ns

- Laser misaligned to the right, charge: 3e11 p^+/bunch, laser energy: 100mJ:
- Effects not so evident, sometimes (symmetric or asymmetric) hosing, sometimes “SSM-like” events!









Delay 1000 ns

- Conclusion:

➢ At a delay of 1000 ns misstearing the beam definitively seeds hosing, whereas for well aligned events self-modulation is still the dominant process

➢ Misstrearing horizontally leads to strong hosing and tilted beamlets. The direction of the tilts is determined by the direction of the misstearing*

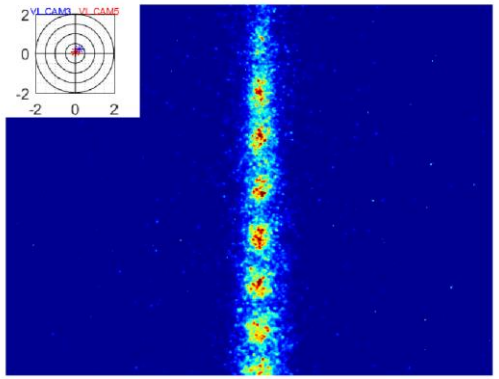
➢ The effect of vertical misstearing is less evident

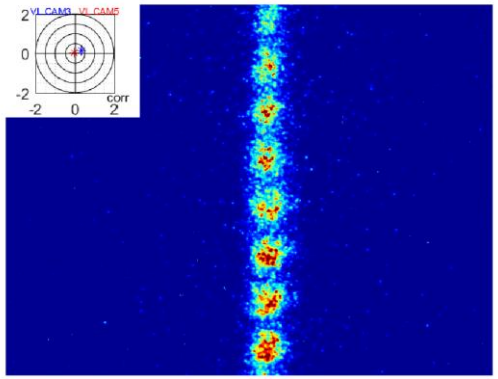
(axis perpendicular to silt?)

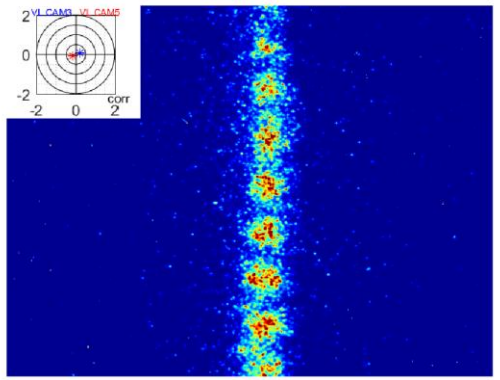
* did not find a single event out of ~ 70 where it would be different

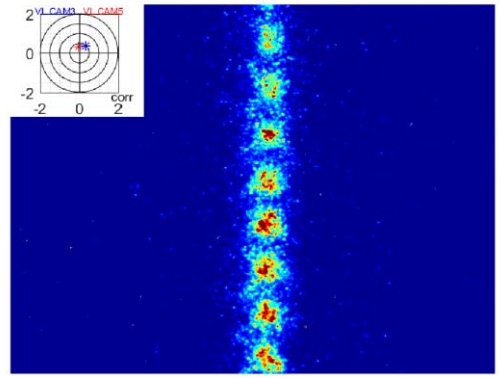
Delay 3000 ns

- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: ~100mJ:
- Mostly symmetric events with self-modulation, no evident signs of hosing

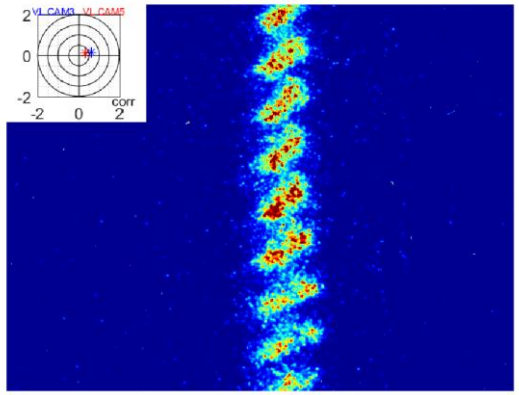






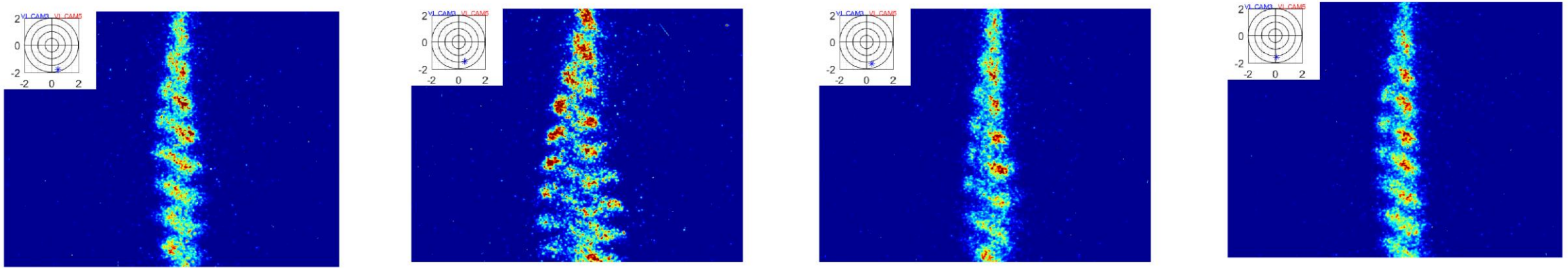


Introducing small misalignment (~ 0.5 mm):

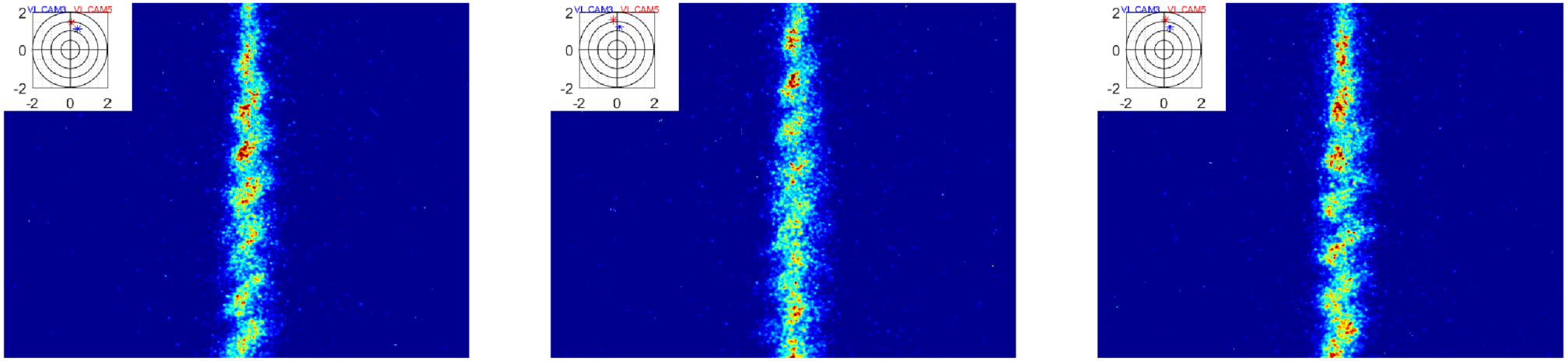


Delay 3000 ns

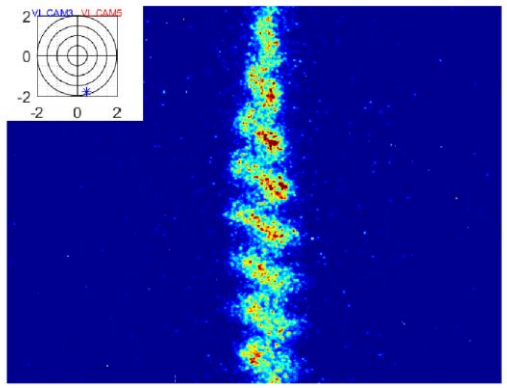
- Laser misaligned downwards, charge: 3e11 p+/bunch, laser energy: 100mJ:

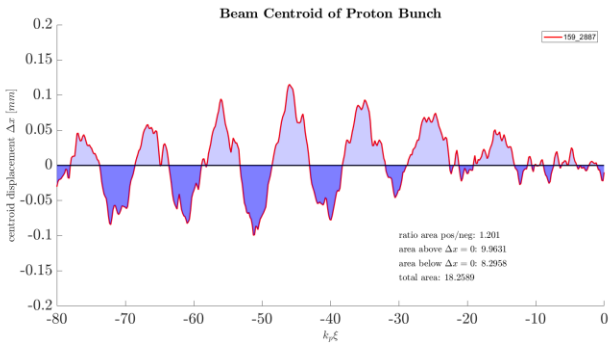


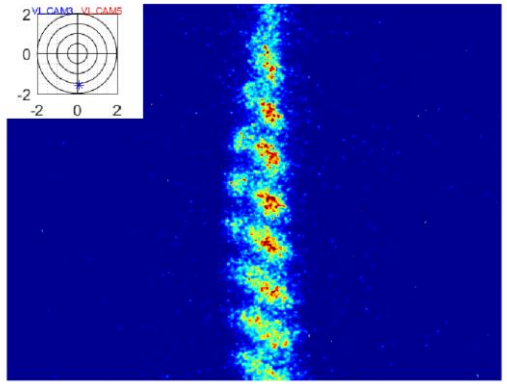
- Laser misaligned upwards, charge: 3e11 p+/bunch, laser energy: 100mJ:

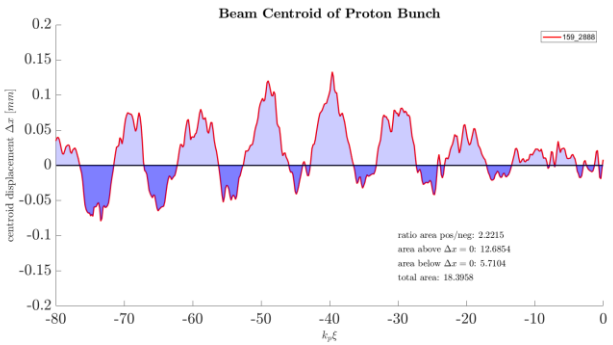


Delay 3000 ns - Symmetry

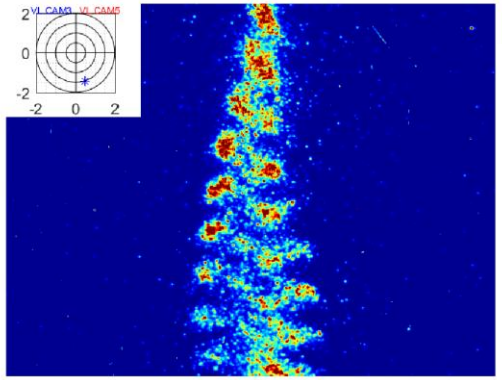


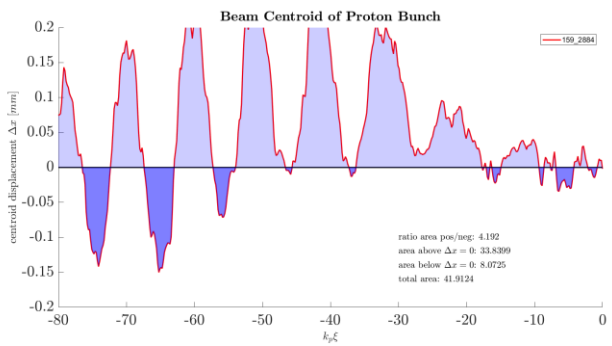


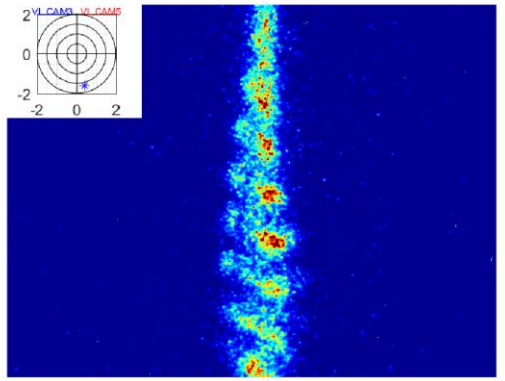


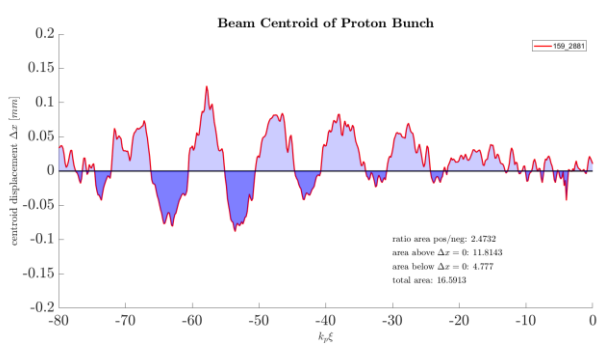


Central axis defined by position average of central axis of 10 events without plasma



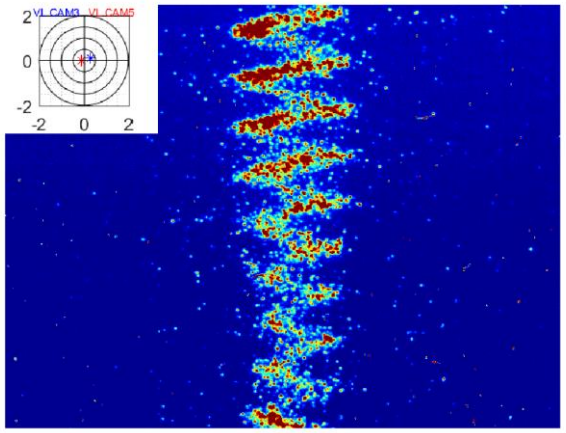
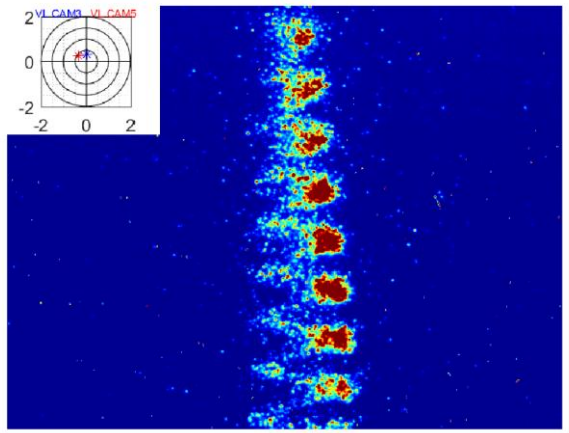
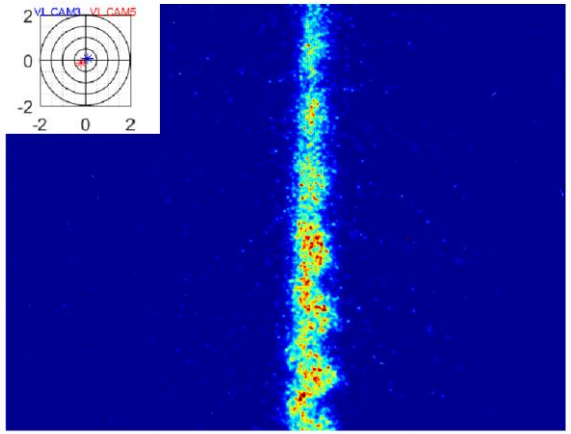
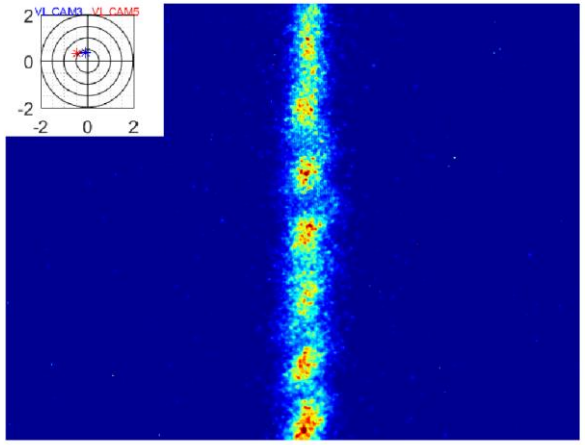
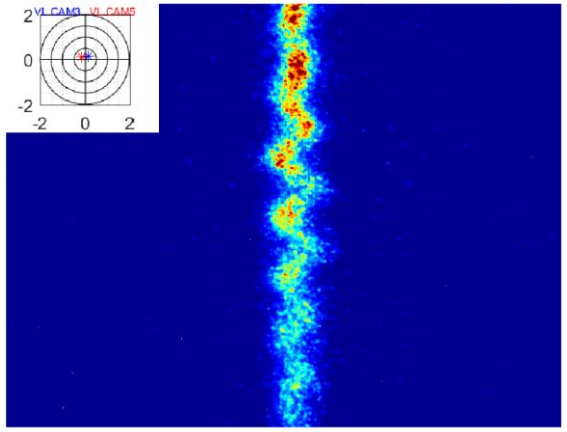
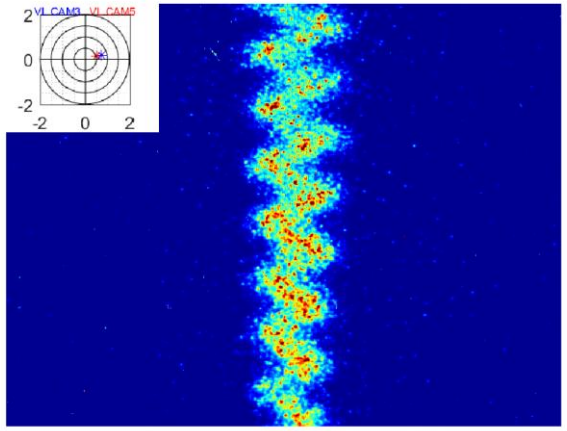






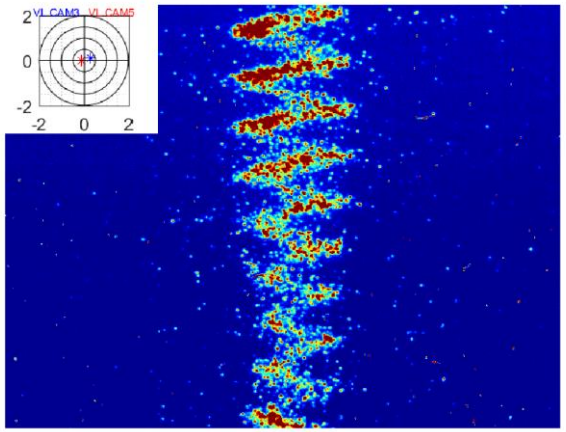
Delay 4000 ns

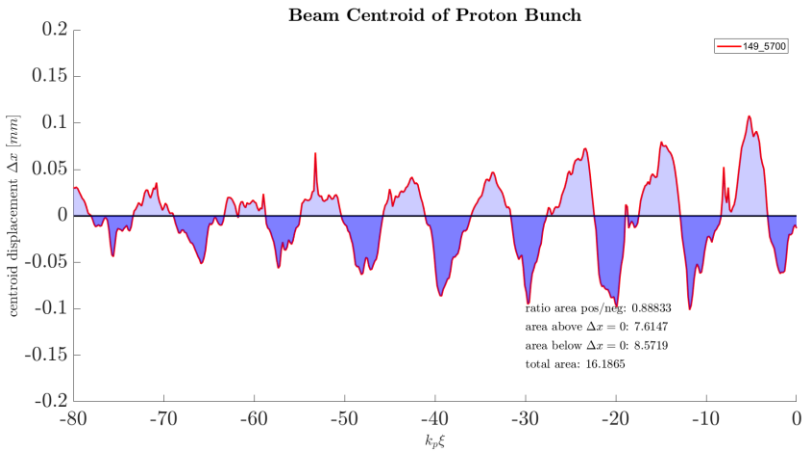
- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: ~100mJ:
- Almost all events with hosing, but symmetric and asymmetric regardless of alignment

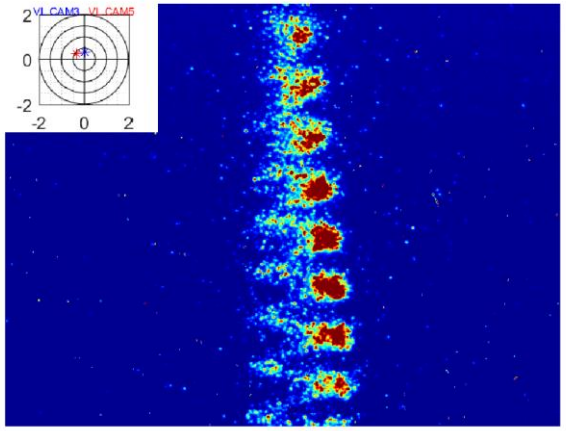







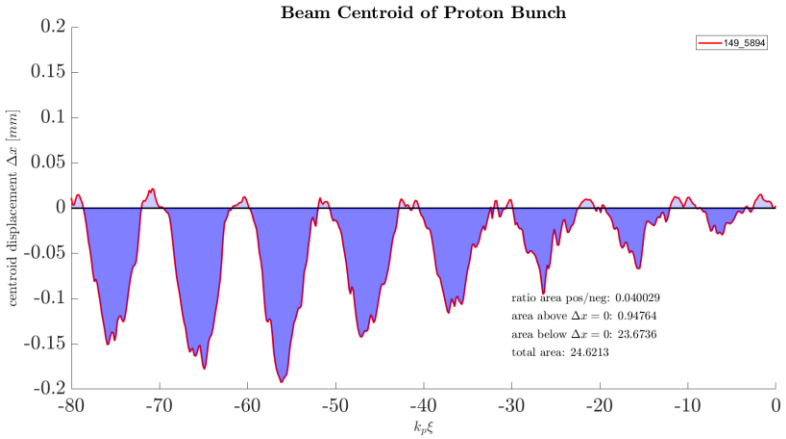
Delay 4000 ns - Symmetry

- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: ~100mJ:
- Almost all events with hosing, but symmetric and asymmetric regardless of alignment







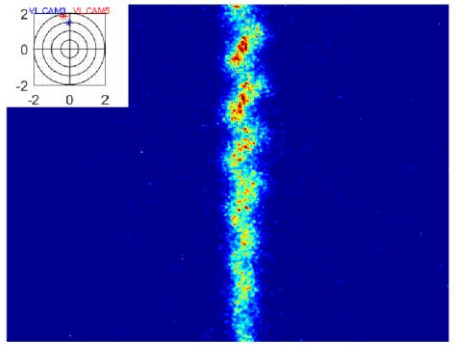


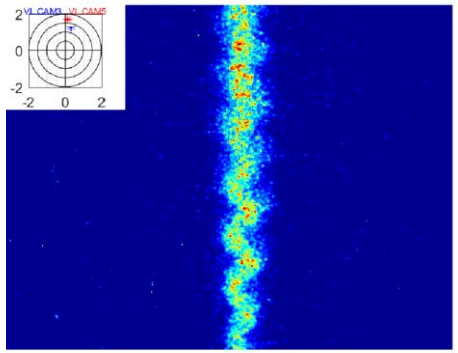
Events from same run -> reference trajectory identical

Central axis defined by average of position of central axis of 10 nearby laser off events

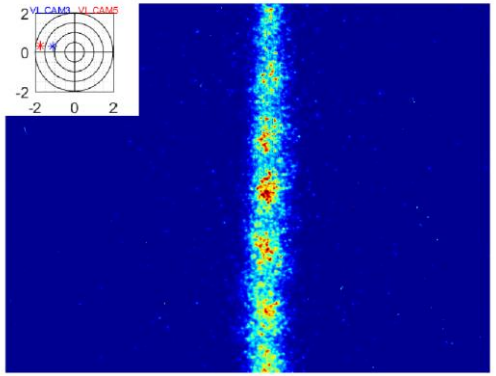
Delay 4000 ns – misaligned events

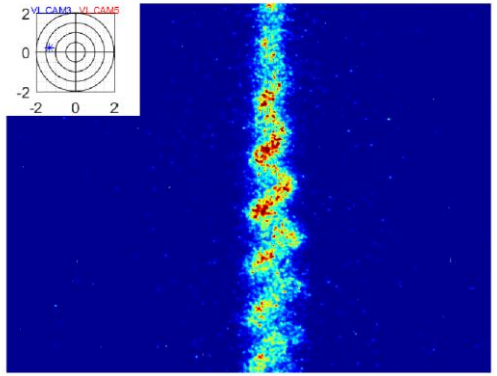
Laser up

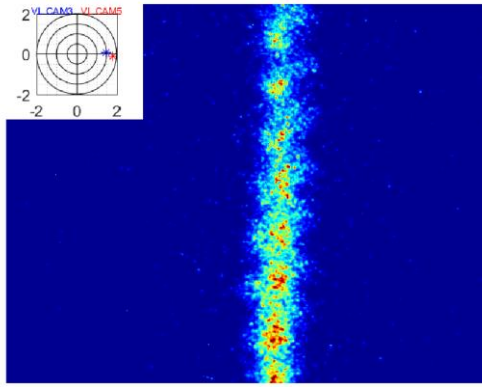


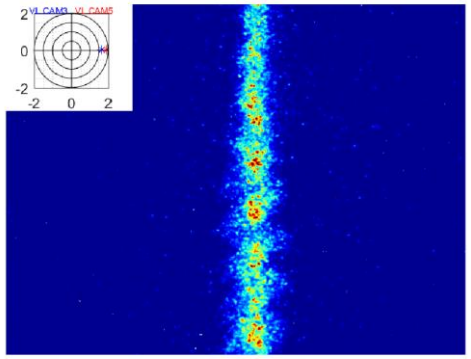


Laser left

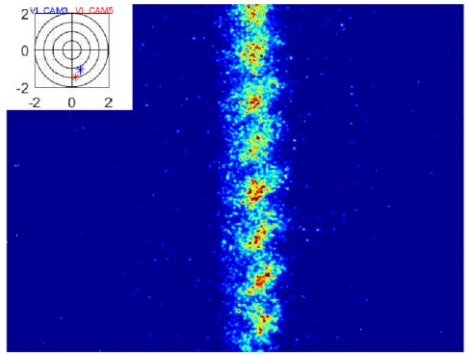


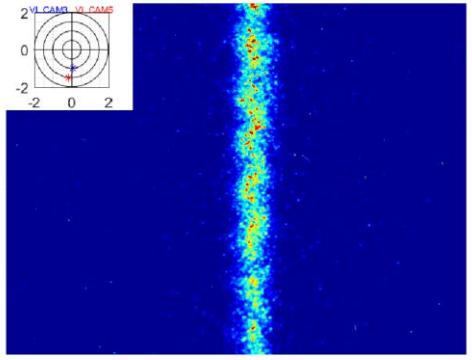






Laser right

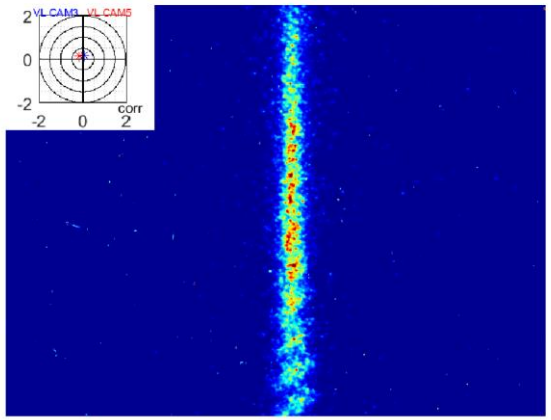


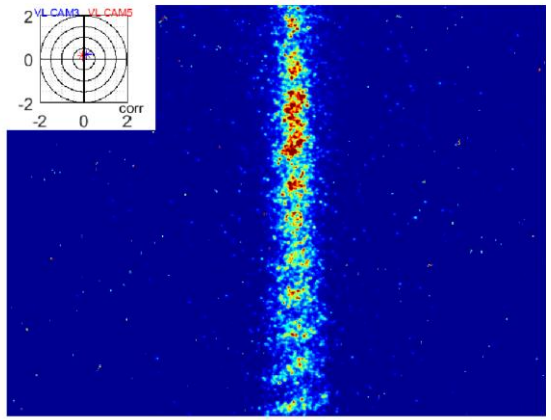


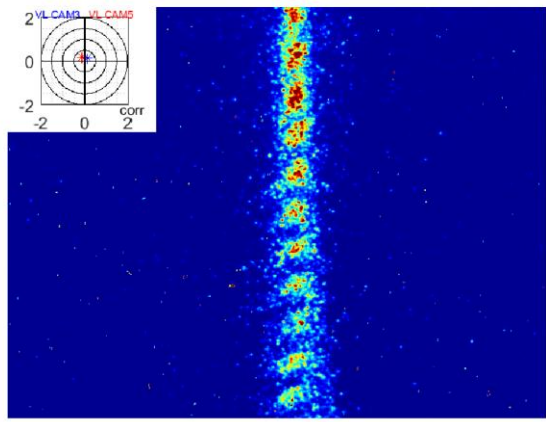
Laser down

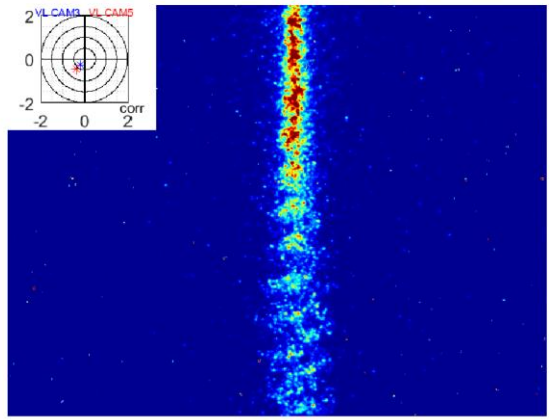
Comparison with lower laser energy events – Delay 1000 ns

- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: 25 mJ:
- Self-modulation less distinct

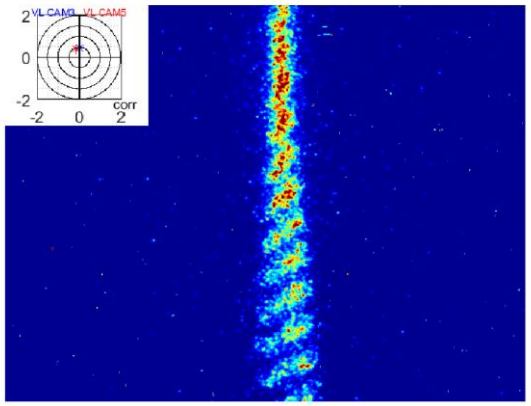


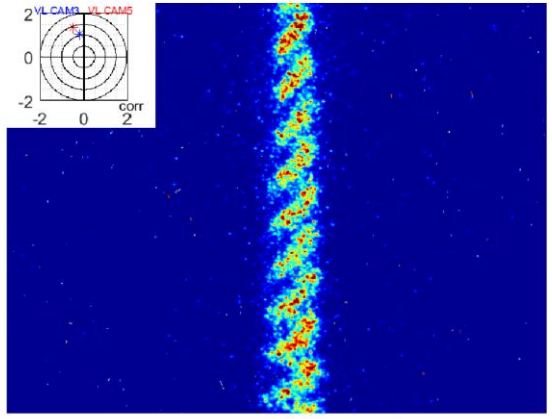


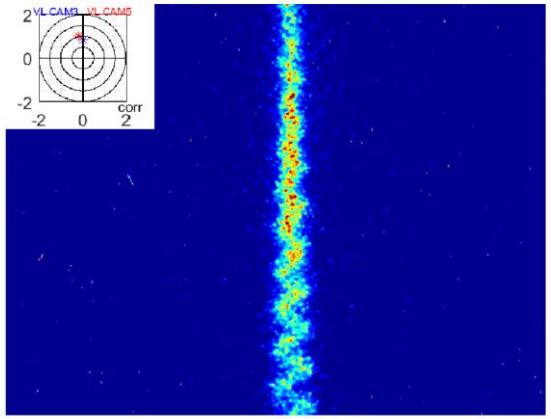


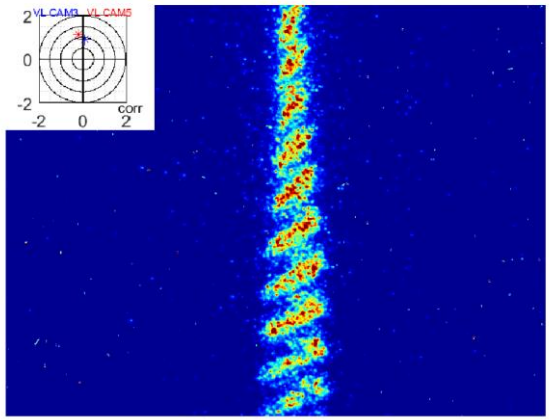


- Laser misaligned upwards, charge: 3e11 p^+/bunch, laser energy: 25 mJ:
- Hosing similar to higher laser energy, already small misalignment leads to Hosing (see first event)



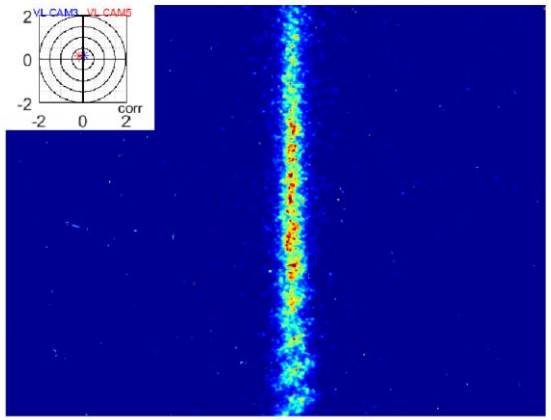


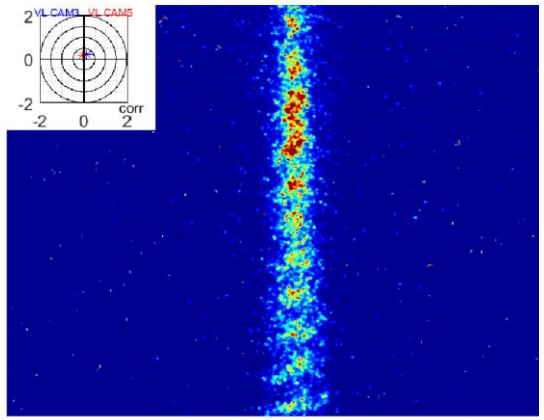


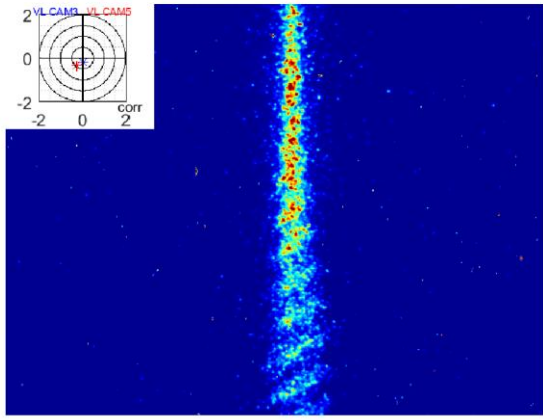


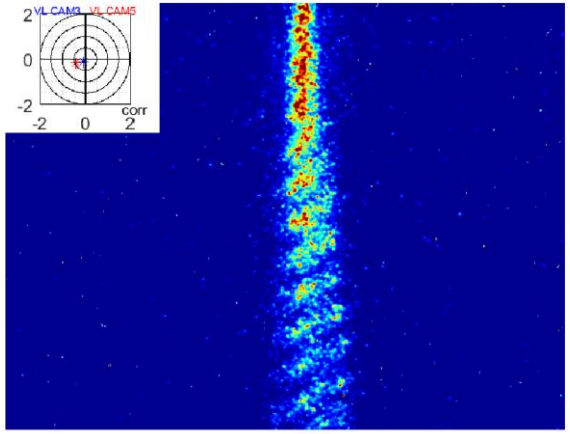
Comparison with lower laser energy events – Delay 1000 ns

- Laser centered (within 0.5 mm around ideal position), charge: 3e11 p^+/bunch, laser energy: 25 mJ:
- More events with Hosing than at full laser energy

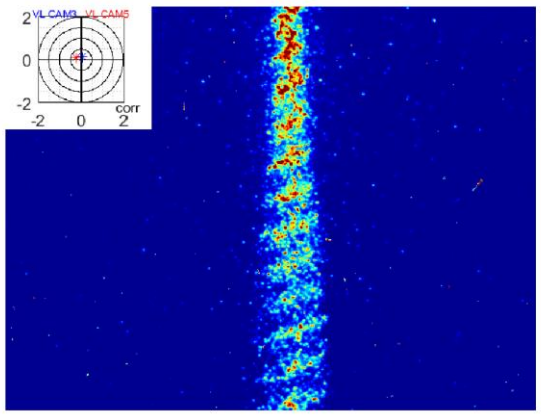


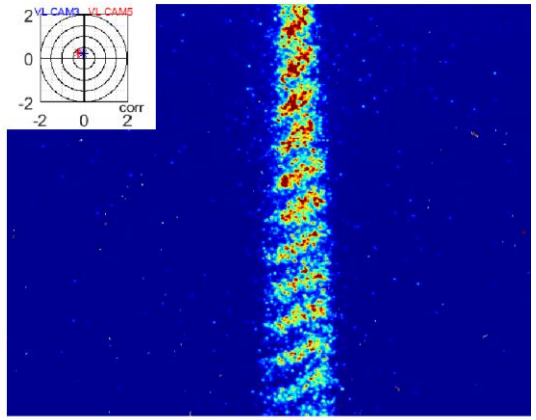


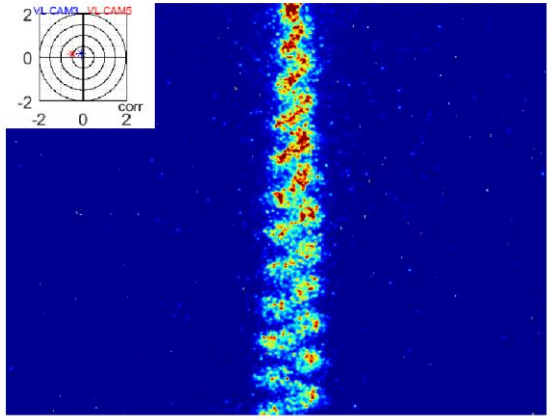


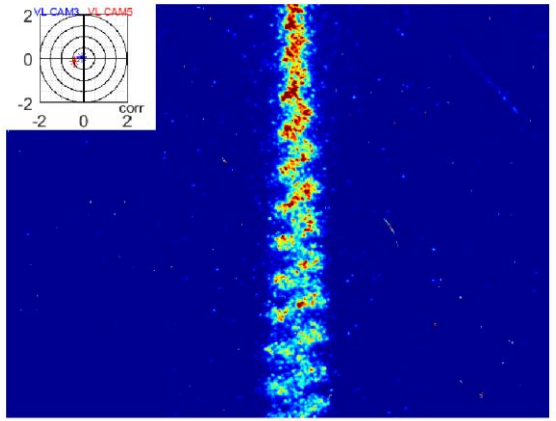


- Laser centered (within 0.5 mm around ideal position), charge: 2e11 p^+/bunch, laser energy: 25 mJ (maybe better data):
- Hosing already growing for small misalignment









“Story to tell”

- For laser/proton delays around 1000 ns, Hosing is a result of a misaligned laser and seeded by the interaction of the proton bunch with the rather rigid plasma boundary. For a well aligned laser, the bunch is self-modulating, while for a large misalignment the bunch starts to hose. There is a clear correlation between the hosing axis and the direction of the laser misalignment.

- For increasing the delays, the plasma density becomes smaller due to expansion and recombination. The plasma boundary is less rigid and the overall density distribution is less uniform than at lower delays. The main reason for the hosing seed are (random) initial plasma uniformities.

- At 3000 ns delay, very well aligned events are still mainly self-modulated, but already a small misalignment leads to hosing. The part of the plasma channel with almost full ionization has become smaller.
- At 4000 ns delay, the growth of hosing seems to be independent of the alignment. The plasma is uniform enough that hosing is always growing from some plasma uniformity.

- For lower laser energies, the plasma column was initially smaller. Therefore, already at shorter laser/proton delays (i.e. 1000 ns), the effects described above appear.