Streak camera installation at SIS-18

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1 Introduction

The streak camera allows to resolve the spacial and time structure of the bunches simultaneously with high resolution. Streak cameras have been used for accelerator applications for more than two decades, mostly to observe the synchrotron radiation at electron synchrotrons or storage rings [1]. In the late 90s, a streak Camera was installed at GSI facility to investigate the re-injection of cooled beam from ESR into SIS-18[2]. The transverse beam distribution was studied along the longitudinal profile during those studies [3].

A new installation of streak camera system was recently performed in the HHD beam line to observe the horizontal profile of the extracted beam. The plan is to optimize the SIS-18 operation primarily at injection and extraction using the streak camera. The observations of the bunch shape immediately after the extraction kick will determine whether the kicker deflects the beam at the right moment. Since the multi-turn injection happens in the horizontal plane, observations of the injection efficiency should also be possible with the present installation.

The next section of this report presents the details of streak camera, triggering hardware and the radiation concerns for the streak camera. After that, the choice of scintillators as well as design and construction of optics from the scintillator to the streak camera slit is described. Finally the commissioning and first experimental observations are discussed.

2 Streak camera details

May be we can make a system configuration figure here with streak camera and its triggering details.

2.1 Streak camera specifications

The installed streak camera is called the "Universal Streak Camera", model number C10910 (There are types 1,2,3 and 4 based on wavelength range, which one?) by the company Hamamatsu [4]. The camera is fully remote operational, it is also equipped with a remote controllable slit. The temporal resolution is

< 1 ps however the actual temporal resolution is given by the acquisition time and the spatial resolution of the readout CCD camera. **For an acquisition length of 1 us, it is ?(1 us/ number of pixels in the vertical direction of the camera**. The highest possible temporal resolution is limited by the scintillator response. The spacial resolution is given by the magnification of the optics, and is discussed in Section 3.

2.2 Triggering details

The streak camera is triggered by the fast extraction system of SIS-18. The kicker pulse is generated by the Rf-signal, such that the kicker kicks into the gap between the bunches. The kicker pulse is fed into a Stanford DG645 delay unit, which allows to adjust the exact time of recording for the streak camera. This delay accounts for the time-of-flight of the beam between extraction point and scintillation target.

2.3 Radiation concerns

Since the streak camera is installed near the Fragment seprator (FRS) and HHD beam dump, radiation was taken into account and FLUKA simulations were performed. The outcome of these simulations were.... Full details are given in presentations by S. Damjanovic [**?**].

3 Optics from beam pipe to streak camera input

Two scintillators (BaF2 and BC400) [5, 6] of size 50 x 50 mm^2 is mounted such that it is rotated by 45 degrees across the y-axis (see figure 1). The beam hits it such that the light emitted by the scintillator goes down towards the ground through a Borosilicate vacuum window [7, p.7-9]. The BC400 plastic scintillator emits light with wavelength $\lambda \approx 420$ nm with a decay time of 2.4 ns. The emitted light is modelled as a point source.

3.1 Design considerations

The light should be guided from the scintillator of 50 mm^2 to the streak camera with an input slit width of 10 mm.

The design of the optics system should fulfil the following requirements or constraints,

1. The magnification of the system should be $\leq 10/50 = 0.2$.
2. The horizontal axis of the beam should be coupled into the streak camera.
3. The distance between the scintillator and slit of the streak camera is 1.5 m i.e the optical system length should match this length.

4. An additional CCD camera should be installed to view two dimensional beam image and align the light into streak camera. A remote switch to select between the light path to either CCD camera or the streak camera.

5. Maximum light throughput while avoiding any vignetting.

3.2 Design and construction

The design was performed using simple ray optics matrices of thin lenses. The design was verified with thick lens model using the simulation tool Winlens®from Qi/Linos optics. A 2" diameter optics set-up was chosen to get maximum light throughput.

The optics design consists of the following components;

1. Scintillators: BC400 plastic scintillator was installed with a decay time 2.4 ns, the maximum emission is at 423 nm. The scintillators are mounted onto a stepper motor drive which allows to chose between the two mounted scintillators.

2. Lens L1, FL= 200 mm, Diameter = 2", the first lens towards the beam, lies on the vertical axis attached to the vertical support rod. It is positioned at 480 mm from the scintillator target.

3. Lens L2, FL= 150 mm, Diameter = 2", the second lens towards the beam, lies on the vertical axis attached to the support rod. It is positioned at 360 mm from the lens L1.

4. Mirror M1, changes the light from vertical to horizontal plane. 45 degrees with respect to the x-y plane (see figure below), aligned along the x-axis (parallel to x-z plane). It is positioned at 180 mm from the lens L2.

5. Mirror M2, 45 degrees with respect to the x-z and y-z planes. It is positioned at 40 mm from the lens M1.

6. Mirror M3, 45 degrees with respect to the x-z and y-z planes. It is positioned at 105 mm from the lens M2.

7. Lens L3, FL= 100 mm, Diameter = 2", the third lens towards the beam (second towards the streak camera), lies on the horizontal axis. It is positioned at 40 mm from the lens M3.

8. Mirror M4, Mounted on a flipper motor which flips between two positions. Position 1 sends the light towards the CCD camera, and in position 2, it is removed from the axis, and the light goes towards the streak camera. It is positioned at 65 mm from the lens M3.

9. Lens L4, FL= 60 mm, Diameter = 2". It is positioned at 50 mm from the lens M3.

10. CCD, CCD chip size of 6.4 mm by 4.8 mm. It is positioned at 12 mm from the lens L4.

The components were aligned with a Laser(ref), while the slit of the streak camera was strictly kept closed to avoid any damage to the streak camera. A marked light foil was used to check the magnification. Figure 2 shows the image of the light foil on the CCD when the flipper mirror is in the position 1. The image of the ccd target is not sharp due to the mechanical limitations. It was not possible to get close enough to the last lens with the correct angle such that the ccd chip is on the exact image plane. However, the CCD camera is mainly installed to monitor the target image and the light intensity before directing it to the streak camera, and it serves the purpose quite well. Figure 3 shows the image on the streak camera when the flipper mirror is in position 2. The light foil imaged is of 33 mm width. Thus, all the images from stream camera has a width of 33 mm.

3.3 Characterization of the system

The presented design fulfilled the criterion mentioned above. The designed magnification of the system is 0.15 The light output is defined by the solid angle subtended by the area of first lens A (with radius 25.4 mm) with respect to the sphere of the point source at distance ($d = 480$ mm),

$$\Omega = A/4 * \pi * d^2 \tag{1}$$
$$= (\pi * 25.4 * 25.4)/(4 * \pi * 480 * 480) \approx 5 * 10^{-5} \tag{2}$$

Thus only 0.005 % of photons will be captured by the optics system.

The on-axis transmission of lenses is ≈ 0.6. The reflection by the mirrors is ≈ 99 % between $400 - 750$ nm.

The spacial resolution of the system is $10/1024 * 0.3 \approx 30$ μm.

4 Commissioning Observations

The streak camera was commissioned with a cooled 300 MeV/u Xe^{56+} beam with intensity $8 \cdot 10^8$ particles. The machine was operated in fast extraction mode and harmonic h= 1. Figure 4 shows the streak image with an "acquisition time" of 1 μs. The temporal profile looks similar to the profile obtained from the BPM installed in the extraction line. There seems to be a dip of ≈ 0.5 mm in the horizontal profile of the beam at the offset of ≈ 17.7 mm. It was caused by the spurious shadow of the CCD camera on the streak camera input. The light causing this shadow has since been blocked, and this systematic error is removed. Figure 5 shows the same image as Fig. 4 with twice the higher resolution by reducing the acquisition time to 500 ns. Figure-6 shows another image in the same beam time block with different cooler settings.

5 Experimental Observations

Observations with the streak camera under normal operations are discussed in this section.

5.1 Fast Extraction

Figures **??** and 9 show the comparison between the streak camera and extraction scope signals for a fast extracted 400 MeV/u N^{7+} beam. The agreement of longitudinal profile is evident.

In the extraction scope output, top curve shows the kicker pulse, the middle curves correspond to the pick-up signal from the synchrotron. The third curve is the output of extraction BPM. There is an anomaly in the scope output, the kicker pulses seem to arrive after the bunch extraction starts, but this is actually due to the delay caused by longer cables.

Figures 10 and 11 are the observations from the Sm^{53+} beam for harmonic 4 and harmonic 1 operation for a cooled beam. Figure 10 shows the typical extracted bunch structure under typical h=4 operation. Figure 11 shows the image for Sm^{53+} at 400 MeV/u for the harmonic 1 operation. The transverse profile seems to be divided into several "islands". The reason for this structure is not fully determined yet. The first possibility that several stable isotopes of Samarium come from the ion source and pass through the whole accelerator chain. Since the streak camera is installed in a dispersive section, the isotopes separate into these islands. Another cause could be the charge stripping due to the passage of beam through a foil as it is extracted from SIS-18.

5.2 Slow Extraction

Images were also obtained with slow extraction and KO extraction, to study the micro and macro structure of the extracted beam. A 120 ms slowly extracted beam profile is shown in Fig. 12. Figures 13 and 14 show the initial and final part (of 120 ms each) of beam extracted by knock-out in 400 ms.

5.3 Destruction of the scintillator

In the last days of SIS-18 operation, high intensity beam with 10^9 Ur^{28+} ions were extracted and imaged on the streak camera. Figure. 15 shows the corresponding image, and one can see random blickering, which is understood to be due to excessive charging on the scintillator. **We have to find another figure to suggest this hypothesis.**

References

[1] K. Scheidt, "Review of streak cameras for accelerators : Features, Applications and results", Proceedings of EPAC 2000, Vienna, Austria.

[2] K. F. Johnson et al., "Streak Camera as a diagnostic for high intensity cooled beams", Proceedings of EPAC 1994, London, England.

[3] I. Hofmann, K. F. Johnson, P. Spiller, H. Eickhoff, G. Kalisch, W. Laux, and M. Steck, "Analysis of the Thermal Equilibrium State of Bunched Beams with a Streak Camera",Phys. Rev. Lett. 75, 3842 (1995) – Published 20 November 1995

[4] http://www.hamamatsu.com/resources/pdf/sys/e_streakh.pdf

[5] BaF2 Scintillator, http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/Barium%20Fluoride%20Data%20Sheet.pdf Retrieved : 30 September 2014

[6] BC400 plastic scintillator, http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/SGC%20BC400-404-408-412-416%20Data%20Sheet.pdf Retrieved : 30 September 2014

[7] Vacom catalogue, http://www.vacom.de/downloads/vacom-produktkatalog?download=7:vakuumoptik Retrieved : 30 September 2014

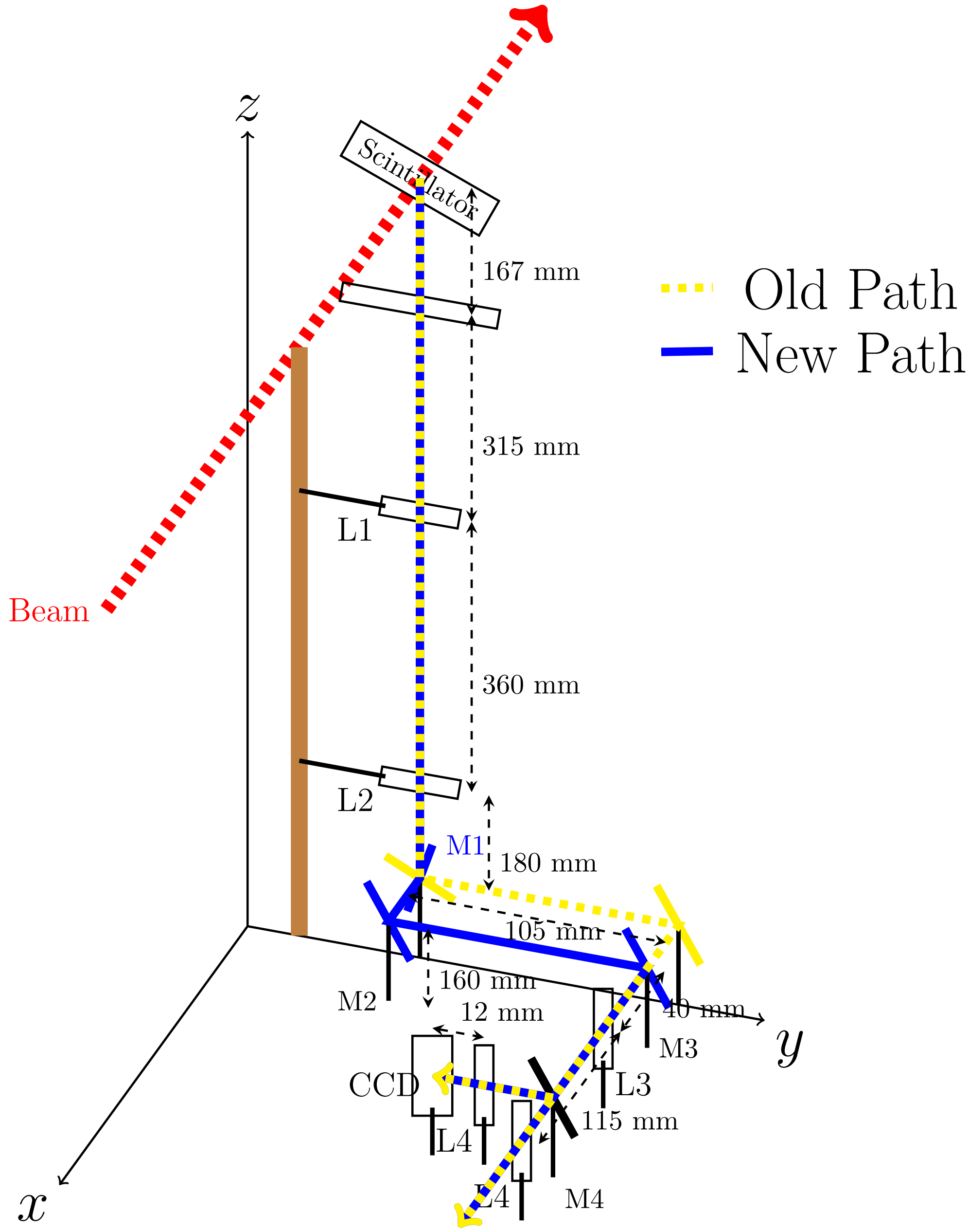

Figure 1: The optics layout from the scintillation target to the streak camera. The yellow dotted lines is the old optics path focused the beam vertical axis in the streak camera due to the inclination of mirror M1 parallel to y-z plane. The new optics path in blue maintains that the beam horizontal axis is focused into the streak camera by rotating M1 by 90 degrees such that it is parallel to plane x-z.

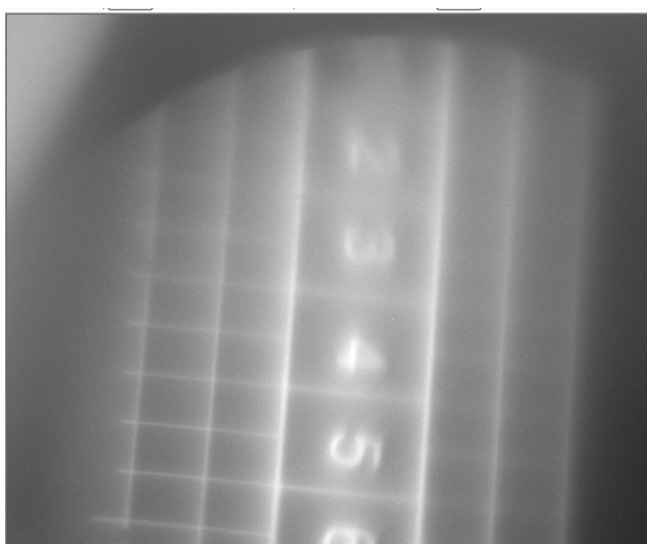

Figure 2: CCD image of the light foil target mounted on the actual target. The target area visible is 45x50 mm^2. The image of the ccd target is not sharp due to the mechanical limitations.

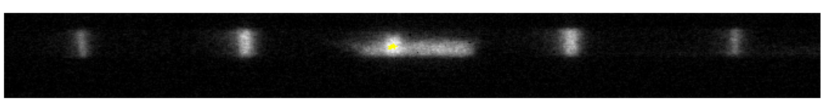

Figure 3: Image on the streak camera from the light foil mounted on the target. The total target width of 33mm in the horizontal plane is seen.

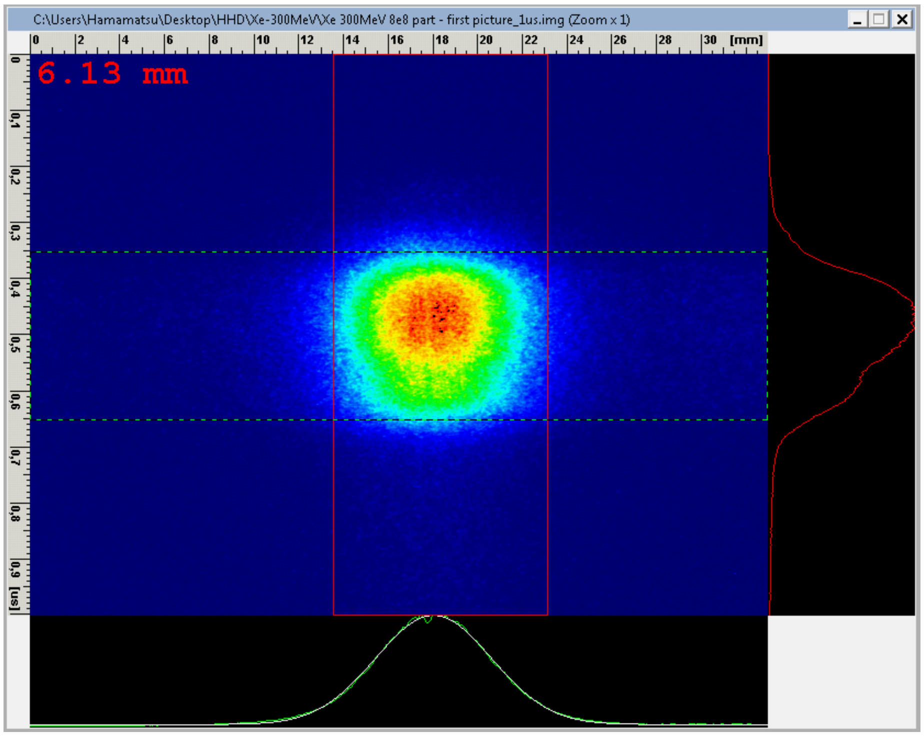

Figure 4: The image with an "acquisition time" of 1 μ s. The extent of horizontal scale is 33 mm, and directly corresponds to the beam profile. The temporal profile looks similar to the profile obtained from the BPM installed in the extraction line. There seems to be a dip of ≈ 0.5 mm in the horizontal profile of the beam at the offset of ≈ 17.7 mm. It was caused by the spurious shadow of the CCD camera on the streak camera input. The light causing this shadow has since been blocked, and this systematic error is removed.

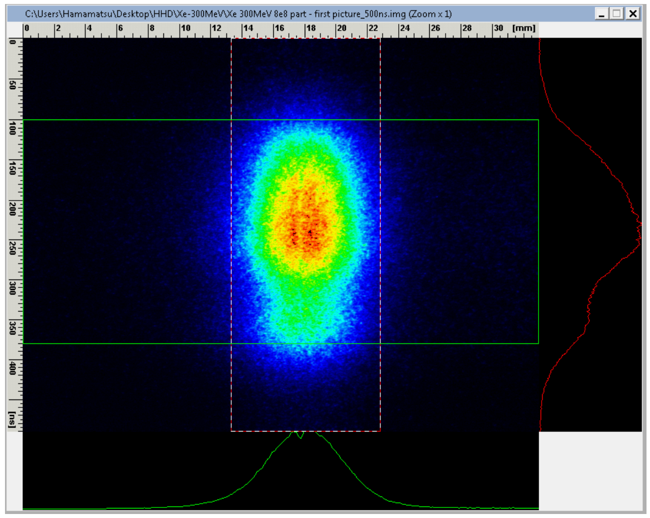

Figure 5: The image recorded with a acquisition time of 500 ns with the same beam as in Fig. 4.

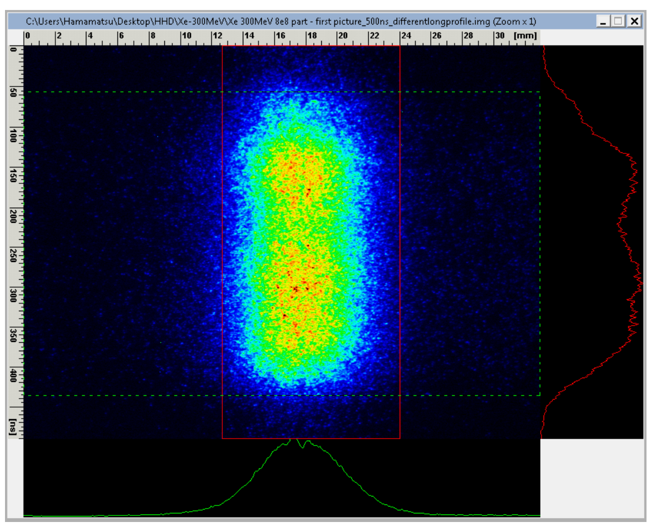

Figure 6: This image was acquired during the same commisioning beam time block. However the electron cooler settings were changed which resulted in a different temporal structure compared to Fig. 5. The acquisition time for this image was 500 ns.

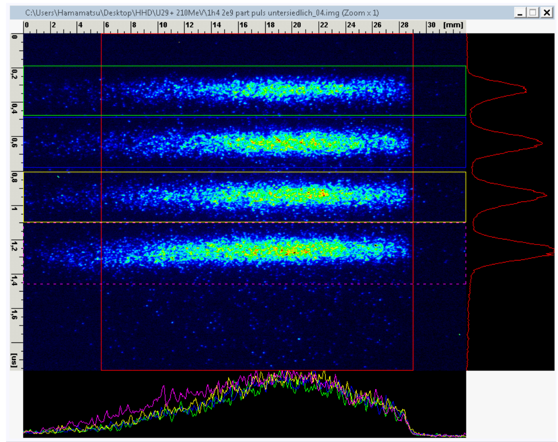

Figure 7: Streak camera image for U^{29+} at 210 MeV/u for the normal harmonic 4 operation is shown. The acquisition time of 1 μs is shown on the vertical axis.

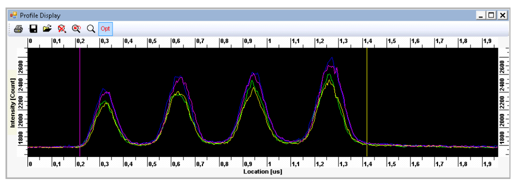

Figure 8: Time profiles of four different streak camera images. A normal harmonic 4 operation is shown with U^{29+} at 210 MeV/u. The acquisition time of 1 μs is shown on the horizontal axis. The interval between the vertical lines is 1.2 μs. The data from figure 7 are shown in the purple line.

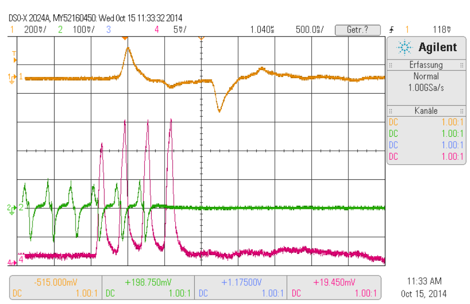

Figure 9: Extraction scope record for U^{29+} at 210 MeV/u for the normal harmonic 4 operation is shown. The top curve shows the kicker pulse, the middle curves correspond to the pick-up signal from the synchrotron. The third curve is the output of extraction BPM. The kicker pulse seem to arrive after the bunch extraction, but is actually the delay due to longer cables. The time scale division is 500 ns. The bunch length and height correspond to the ones obtained from streak camera image shown in Fig. 7.

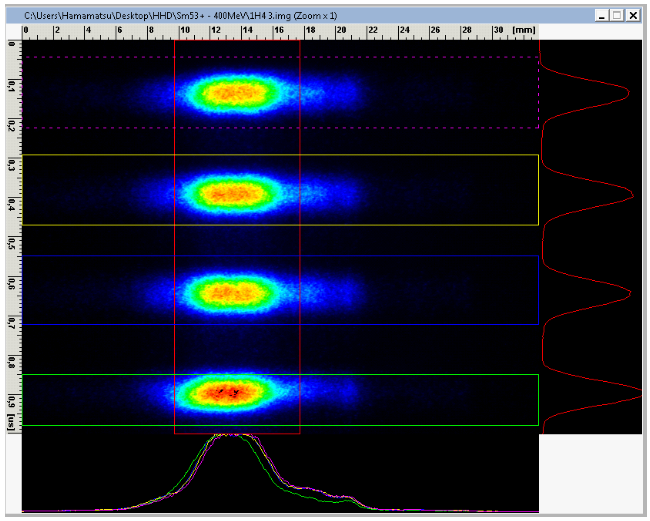

Figure 10: Streak camera image for Sm^{53+} at 400 MeV/u for the normal harmonic 4 operation is shown. The acquisition time of 1 μs is shown on the vertical axis.

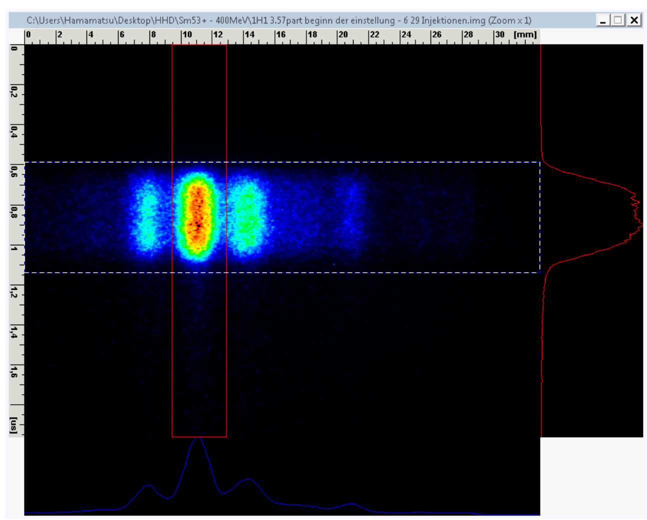

Figure 11: Streak camera image for Sm^{53+} at 400 MeV/u for the harmonic 1 operation is shown. The transverse profile seems to be divided into several "islands". The reason for this structure is being studied (see text). The acquisition time of 2 μs is shown on the vertical axis.

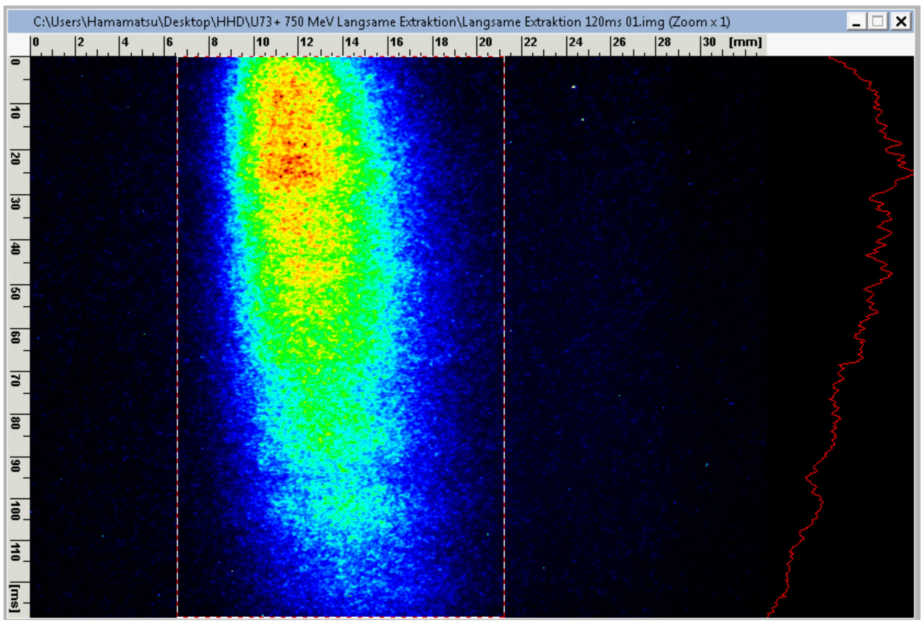

Figure 12: Streak camera image Ur^{73+} at 750 MeV/u which is extracted with slow extraction process with a length of 120 ms. The acquisition time is kept at 120 ms to capture the whole extraction process. One has to keep in mind, that the temporal resolution is reduced for longer acquisition time.

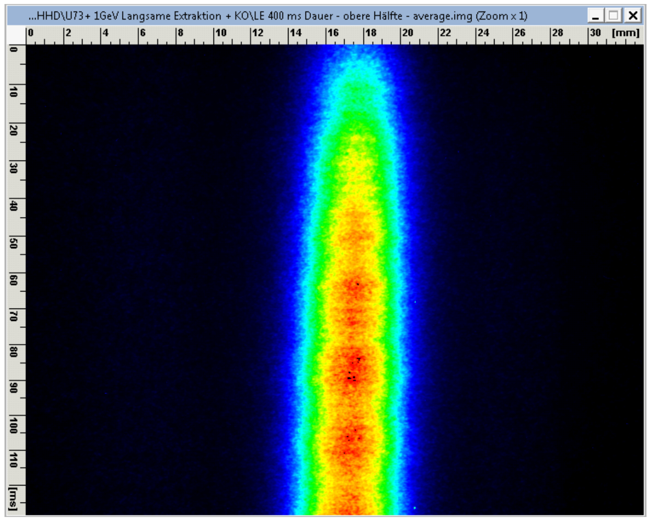

Figure 13: Streak camera image Ur^{73+} at 750 MeV/u which is extracted with knock out extraction process with an extraction length of 400 ms. This image shows the initial part of the extracted beam. The acquisition time of 120 ms is shown on the vertical axis.

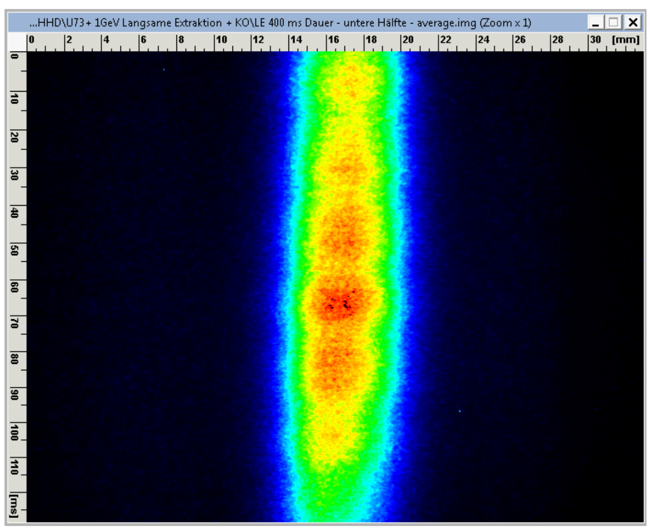

Figure 14: Streak camera image Ur^{73+} at 750 MeV/u which is extracted with knock out extraction process with an extraction length of 400 ms. This image shows the final part of the extracted beam. The acquisition time of 120 ms is shown on the vertical axis.

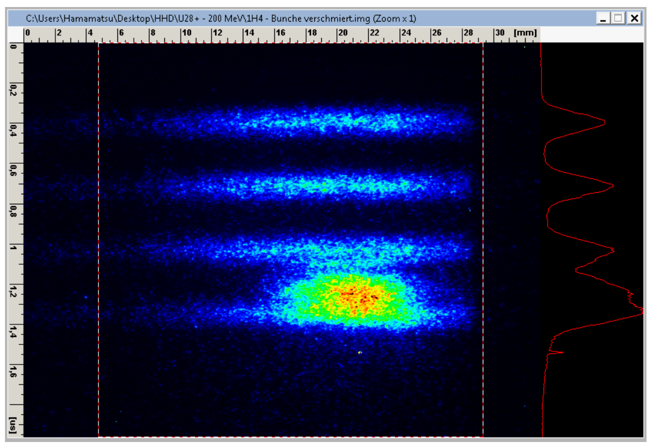

Figure 15: Streak camera image Ur^{28+} at 200 MeV/u for $\approx 10^9$ particles. The scintillator seems to be charged, and is blickering and random locations.