Studies of an beam monitor for halo propagation mechanisms

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Abstract

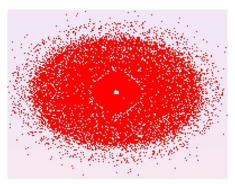
The beam halo is a key parameter to be improved for any high intensity accelerator. Therefore, experimental measurements of the halo distribution is very important to understand how to minimize the number of particles in the tail region of the beam distribution. The main idea of this study is to substantially improve a beam halo monitor to exceed a dynamic range of DR >10^6, to allow investigations into halo propagation and formation processes directly in an accelerator. The method developed to image beam halo is a new adaptive masking method, which uses the most advance high-definition digital micro-mirror-array device (HD DMD) that is capable of measuring transverse profiles with a dynamic range (DR) of better than, DR >10^5. The research will also involve the development of a new code which combines known halo formation processes into one single halo generator and use the resulting beam distribution for particle tracking through different facilities, such as the Jefferson Lab FEL Facility, SPEAR3 at SLAC, the CLIC test facility (CTF3) at CERN and the ALICE accelerator in the UK. With these new combination of optimizations into the optical imaging system, it will be capable of providing even higher frame rates and better spatial resolution, and be a tool in benchmarking the results with different laboratory studies or in experiments beams.

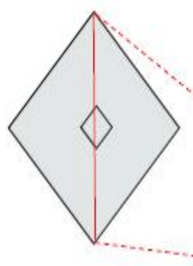
Introduction

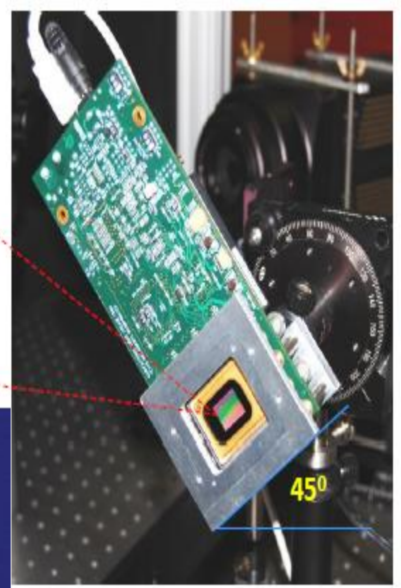
A rigorous *definition* of beam halo, is typically described as a low intensity distribution of particles observed at large radii from a more intense centralized portion of the beam, *i.e.* the "core".

The beam halo is a *intrinsic* property of the beam and is closely related to ε growth, which signifies a decreased beam quality and leads to undesirable effects *e.g.* :

- ***Nuclear Activation of Transport Channel***
- ***Damage to Beam-line Elements***
- ***Emission of Secondary Electrons***
- ***Increasing Noise in The Detectors***







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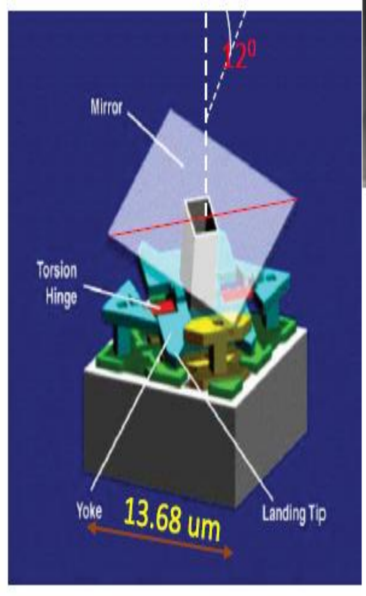
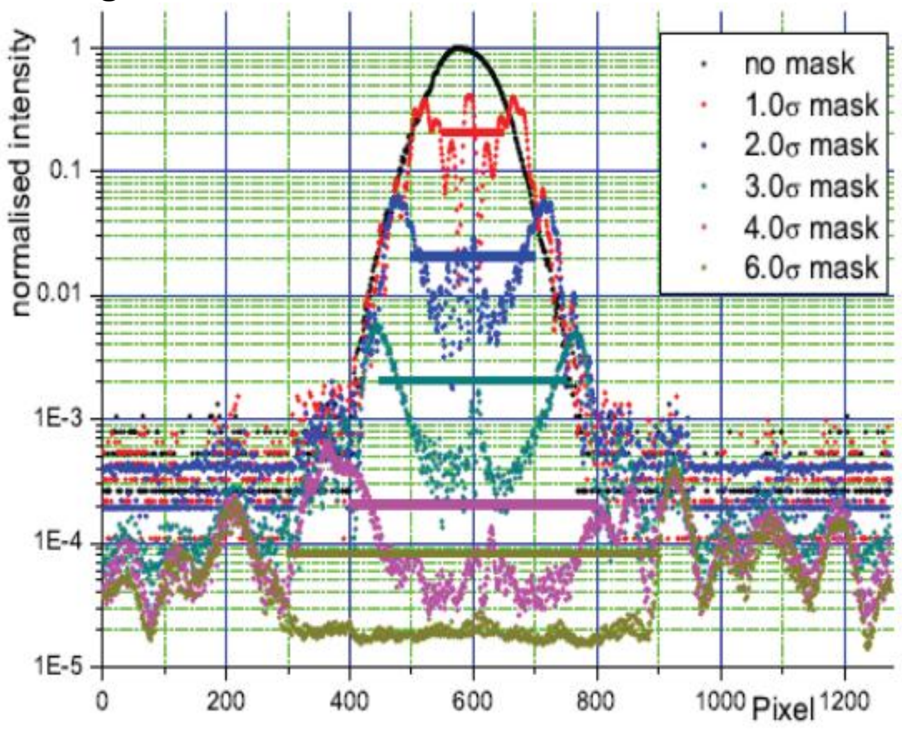
A novel diagnostic device is investigated using a adaptive masking method to image beam halo with high sensitivity as well as a high dynamic range, which can be exceeded by at least an order of magnitude, *i.e.* **DR** ~ 10^6.



Micro-mirror architecture

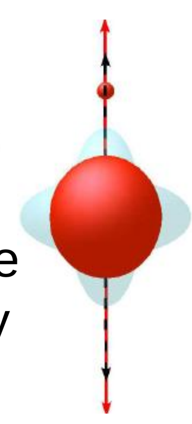


This beam halo monitor uses a HD digital micro-mirror-array device (**DMD**) to generate direct images of halos measured in a **CCD** camera from produced optical radiation, which is linearly proportional to the beam charge distribution for various experimental conditions.

The DMD masking technique generates a reflective mask *i.e.* to reject the intense light from the core with very high efficiency at a large angle away from the optical path before reaching the camera optics. Normalized scans of He-Ne laser images with various mask sizes shows how effective the DMD masking method is in profile thresholding.

Mechanisms for Halo Particles:

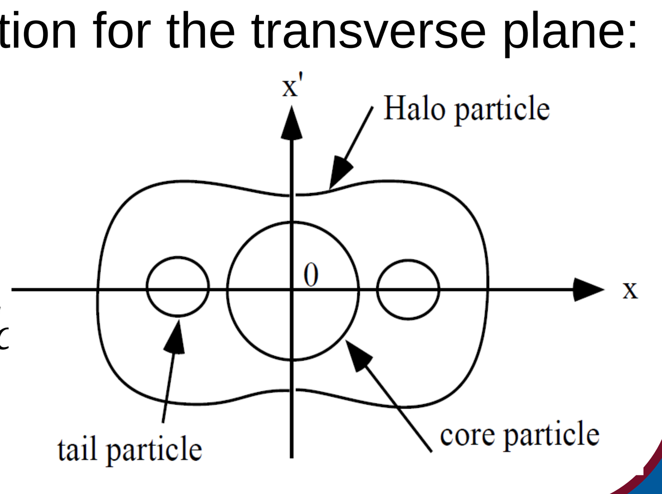
Beam halo formation is a complex process and has many factors for the **Formation,** such as interactions of the residual gas, the *space-charge effects* or effects of non-ideal *EM*-fields and if the tune of the machine falls onto a resonance, the beam will continuously grow, leading to halo particles and most likely a beam loss.



A simple way of studying the **mechanics of beam halo** is given by the formalism of the particle-core model, which describes how a single particle is driven to large amplitudes via a mismatched beam core oscillating twice as fast as the single particle. For a mismatched beam (*i.e.* $r_c \neq r_o$), the core radius starts oscillating with the eigen-frequency of the 1D eigen-mode, with the equation of motion for the transverse plane:

$$\frac{d^2 r_c}{dz^2} + k_o^2 r_c - \frac{\varepsilon^2}{r_c^3} - \frac{K}{r_c} = 0 \qquad (r_c \neq r_o)$$

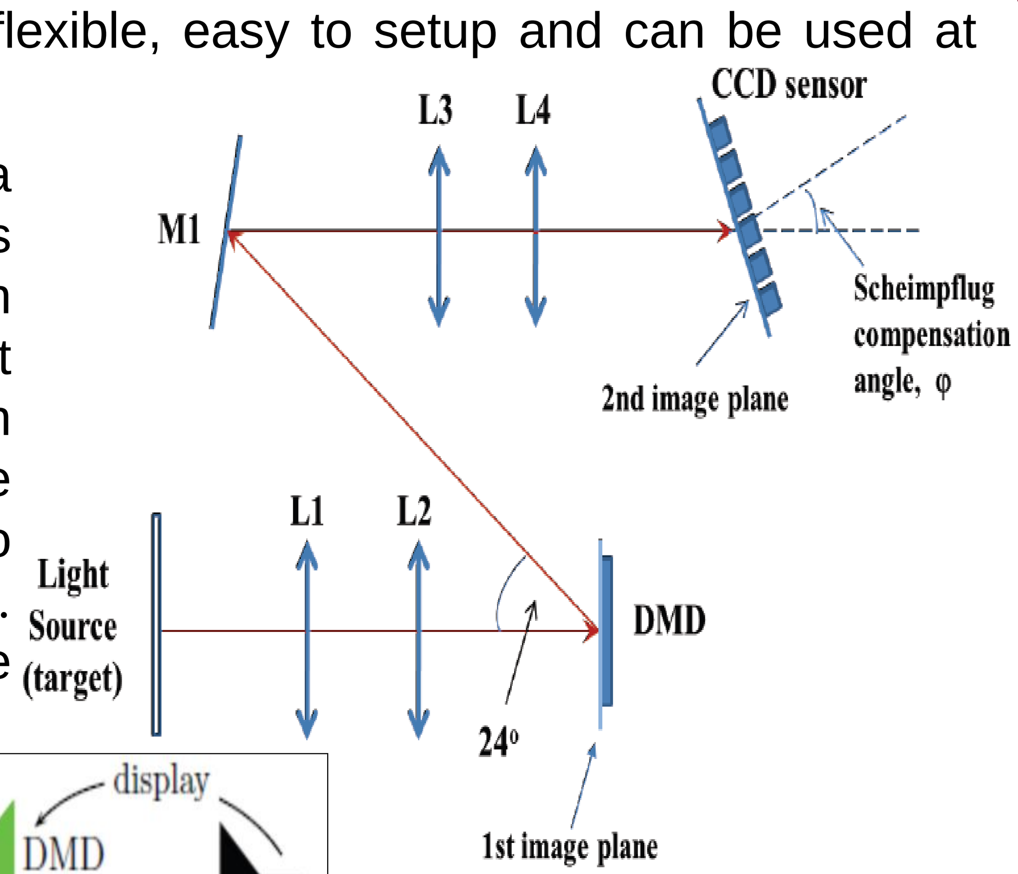
$$\frac{d^2 x}{dz^2} + k_o^2 x - F_{sc} = 0, \quad F_{sc} = \begin{cases} Kx/r_c^2 : |x| < r_c \\ K/x : |x| \geq r_c \end{cases}$$

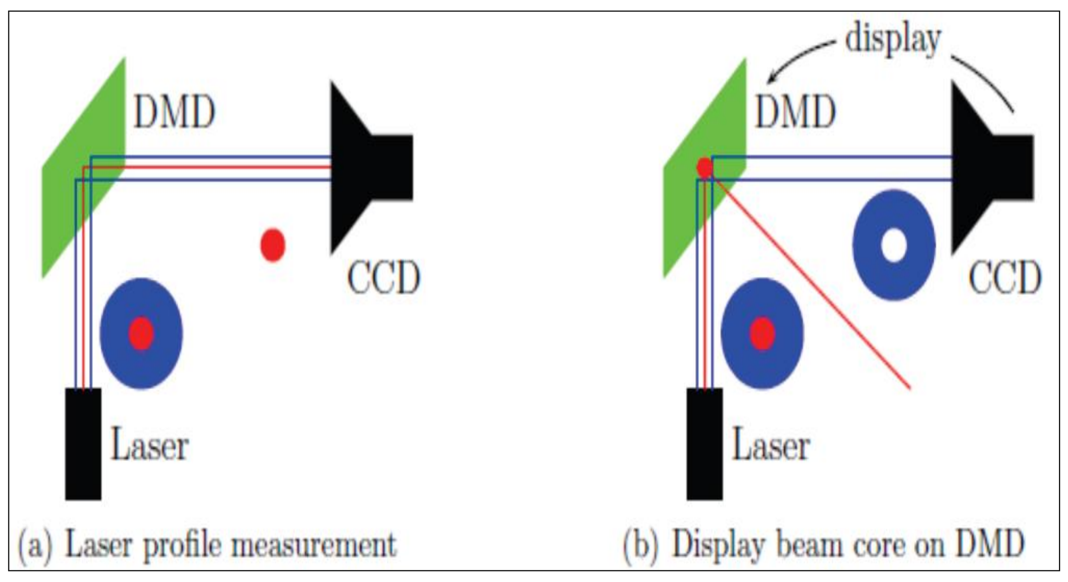


Optical Imaging System & Technique

The imaging method used is flexible, easy to setup and can be used at any accelerator or light source.

The DMD is used to generate a core blocking mask that is defined by establishing an intensity threshold, the light from the laser beam core can be reflected away from the optical path to the camera so that the rest of the profile, *i.e.* the wings or 'halo' of the distribution can be measured.



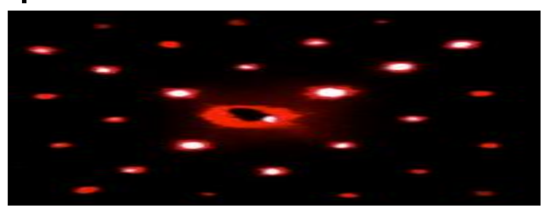


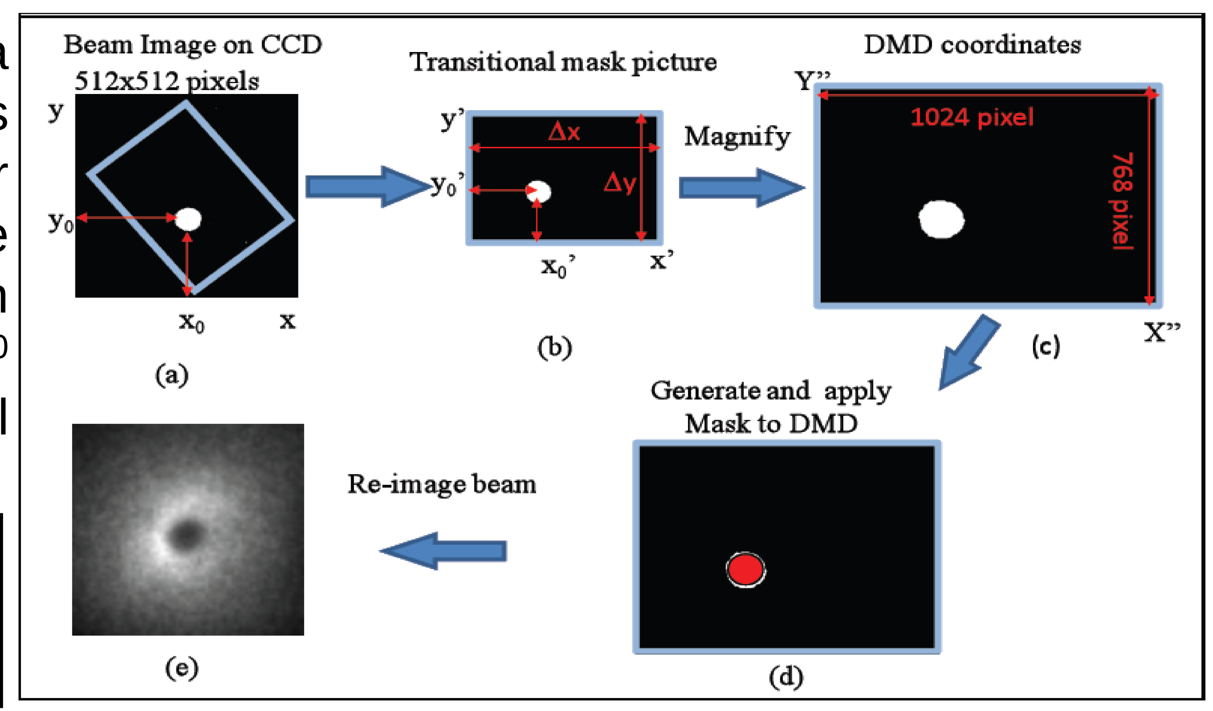
The setup uses two optical channels; the source, lenses L1, L2 and the DMD surface, which is perpendicular to the optical axis and is the first image plane. Thereafter, the DMD is a new source with lenses L3, L4 and the CCD sensor, which is the second image plane.

Halo Monitor Development:

The DMD forms the core of the setup and is used to generate a mask that is adapted to the shape of the beam for analysis. A algorithm to generate a mask for the beam core, is done using a coordinate transformation and rescaling, because of the 45° orientation of DMD and the different number of pixels in DMD and the 8-bit CCD sensor.

Using this technique, a 2D optical grating is obtained from a laser source forming a single wavelength diffraction pattern from a 45^0 rotated DMD with all pixels set at $+12^0$.





The monitor can only reach its full performance, if the optics to image the beam via the light it emits is chosen carefully. Due to the high dynamic range of this technique, it will allow for detailed investigations of the mechanisms of halo formation and its propagation and has excellent potential for being a very valuable tool for optimizing overall machine performance. In addition, there are strong indications from present results that the dynamic range of the technique, which is already very good, can be exceeded by at least an order of magnitude, *i.e.* DR > 10^6.

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