Electron Spectrometer Measurements and Resolution

AWAKE Collaboration Meeting
11th – 13th March 2024

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MAX-PLANCK-INSTITUT
FÜR PHYSIK

Overview

The AWAKE Spectrometer

Summary of 2023 run

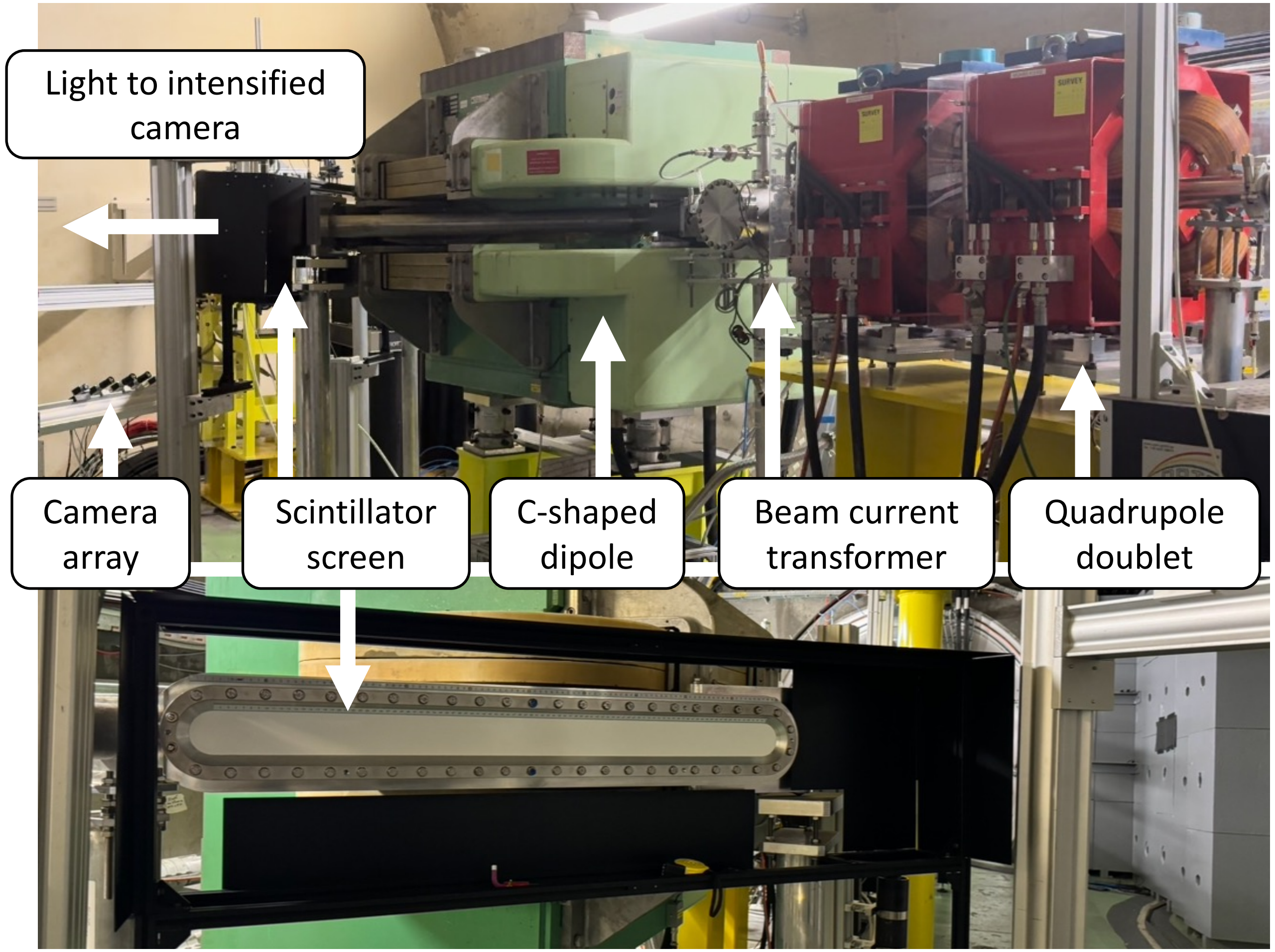
Preliminary resolution study at CLEAR

Preparing for 2024

The AWAKE Spectrometer

Design and goals

- Separate electrons from proton drive beam
- Introduce a transverse, energy-dependent spatial distribution to accelerated electrons
- Measure intensity of spatially distributed electrons
- Prevent significant beam loss of accelerated electrons prior to measurement
- Provide a sufficient dynamic range of measurable electron energies
- Measure, with sufficient resolution, the energy profile of electron bunch
- *Run 2a/b: Demonstrate the ability to measure the emittance of the accelerated electrons (David's talk)*



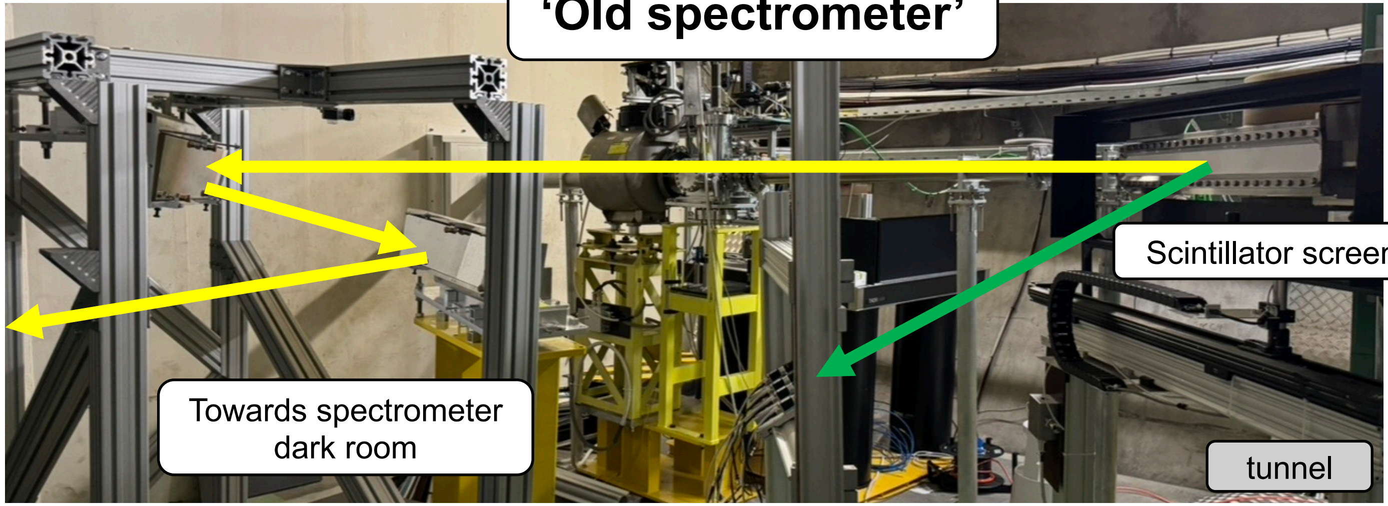
The AWAKE Spectrometer

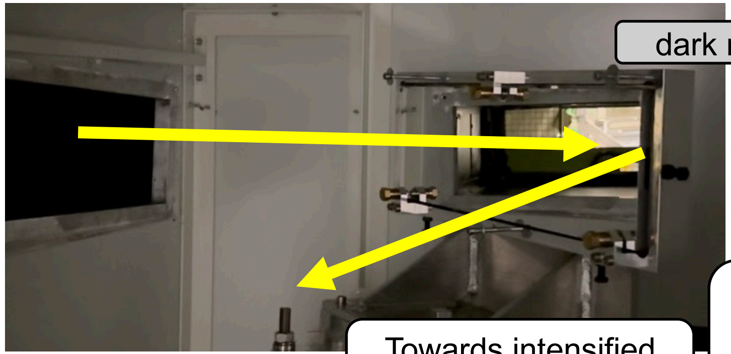
Optics

Run 1:

Intensified camera, 17m from screen, light transported through 3 mirrors.

'Old spectrometer'





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The AWAKE Spectrometer

Optics

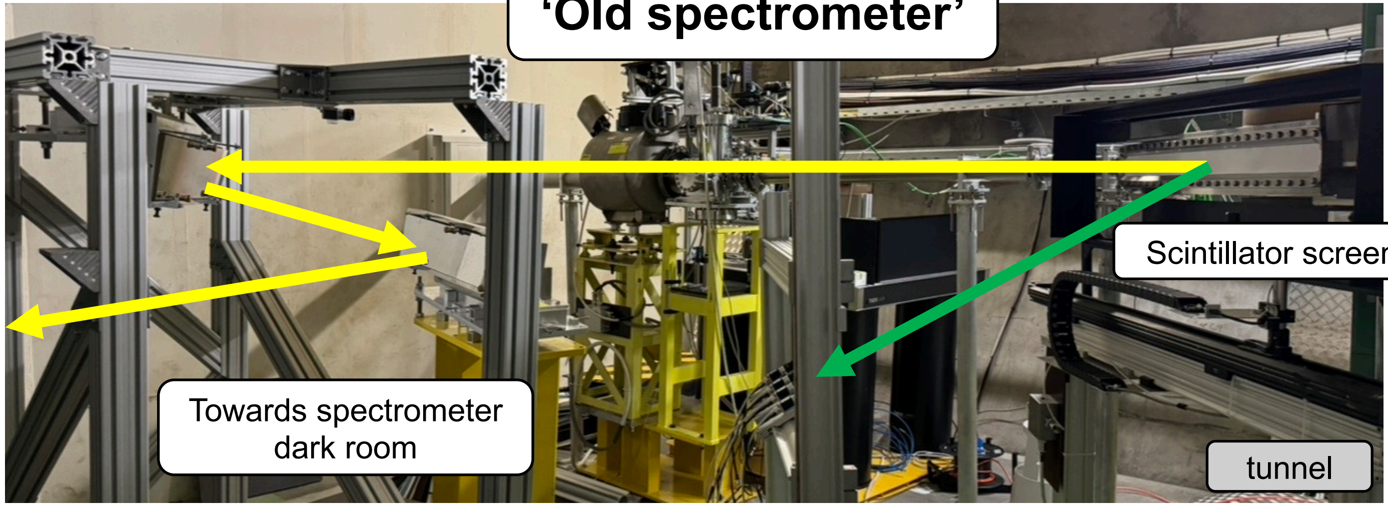
Run 1:

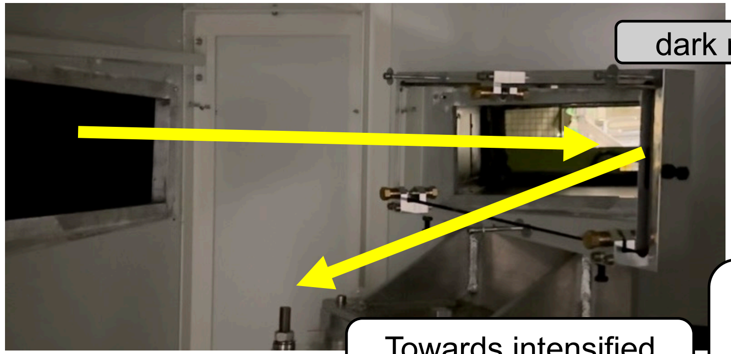
Intensified camera, 17m from screen, light transported through 3 mirrors.

Run 2:

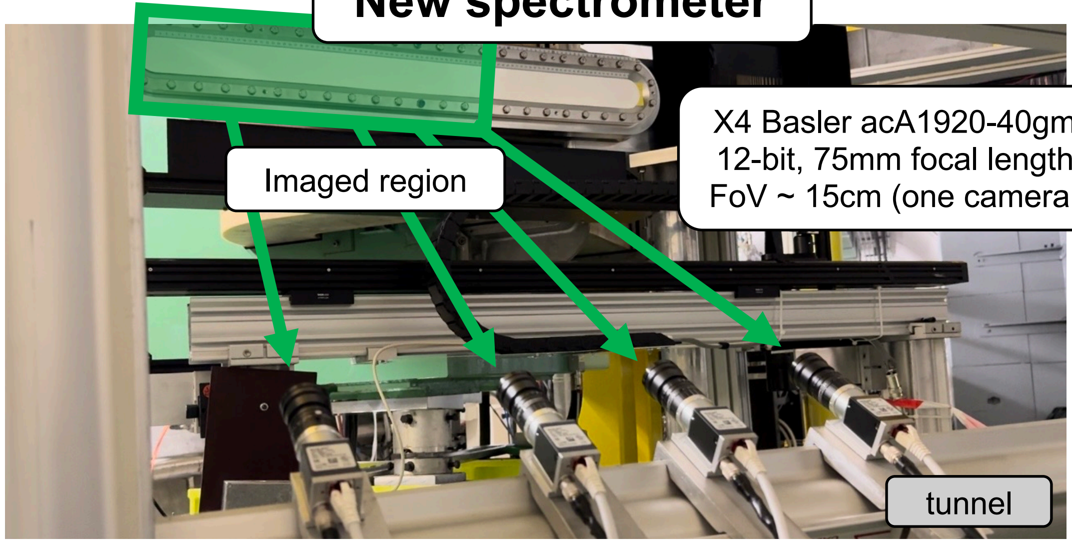
Addition of camera array for direct imaging. Angled -30º below horizontal to reduce radiation exposure.

'Old spectrometer'





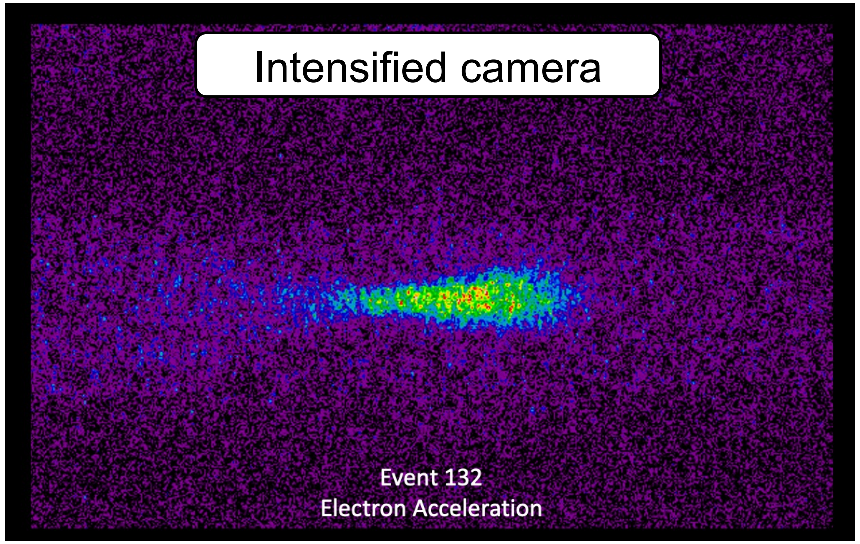
'New spectrometer'

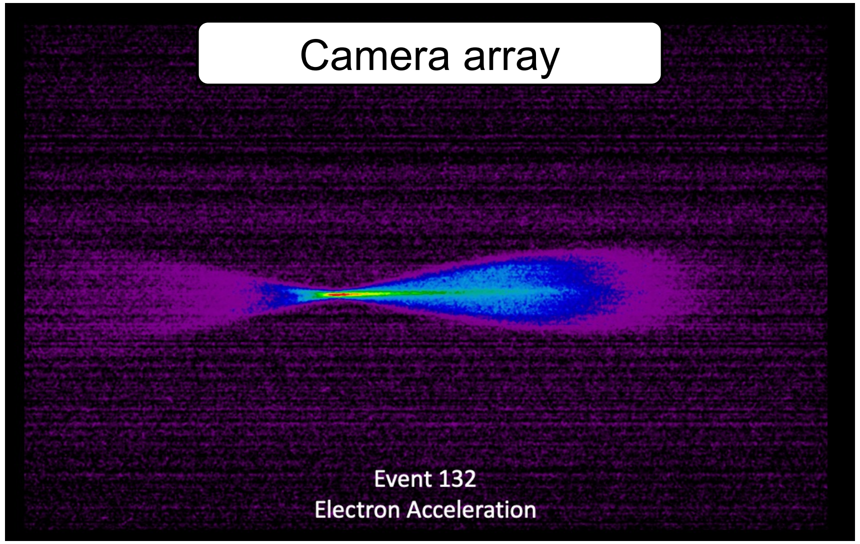


The AWAKE Spectrometer
Optics

Intensified camera is 16-bit, (relatively) low resolution.

- If a signal is there, we have a better chance of being able to extract it in post-run analysis.





The AWAKE Spectrometer

Optics

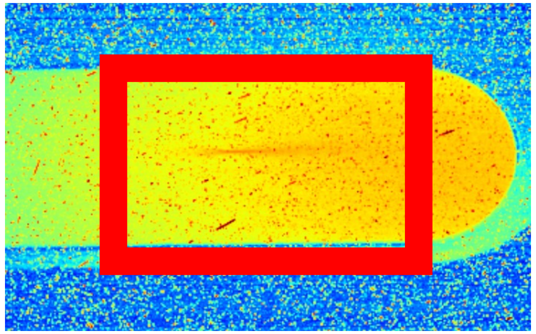
Intensified camera is 16-bit, (relatively) low resolution.

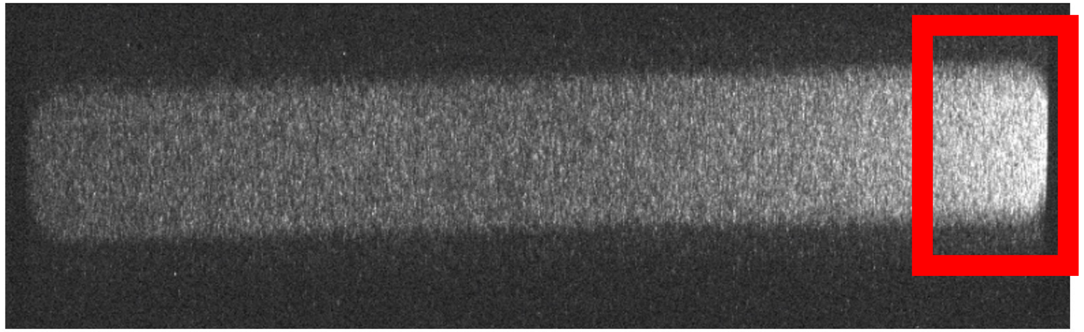
- If a signal is there, we have a better chance of being able to extract it in post-run analysis.

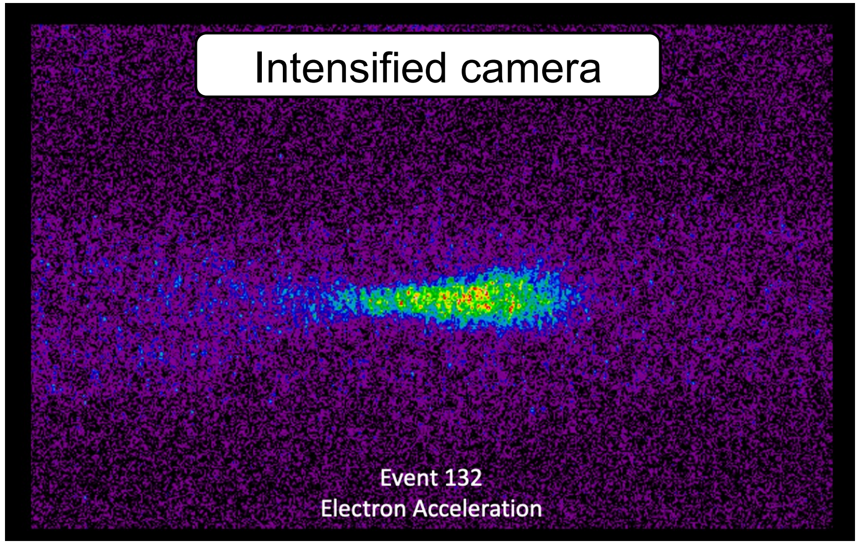
Camera array is 12-bit, high resolution.

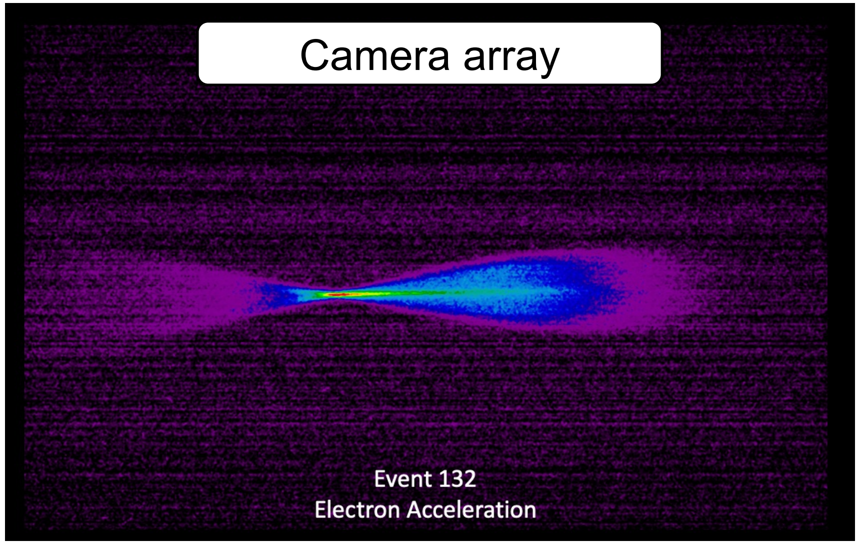
- During <u>live</u> data taking in the run, signals are identified that are not visible on the intensified camera.

When background is high, the camera array is our best chance during the run for locating position of signals.









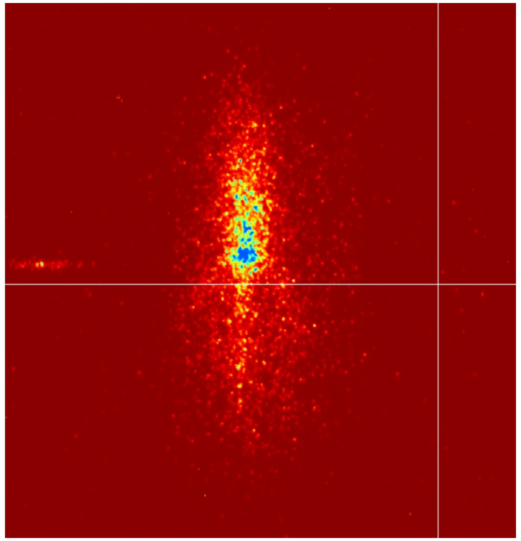
Summary of 2023 run activities

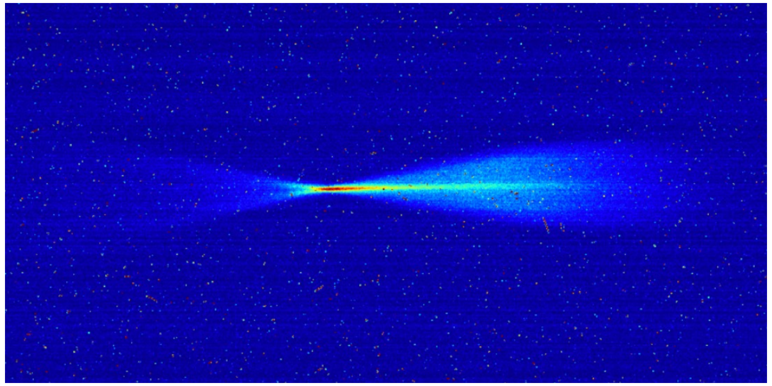
<u>The focus for 2023 was SM studies with plasma light.</u>

Final week of the October 2023 run (18th – 22nd), electron measurements were performed in parallel to proton + plasma program.

- RIF scans alongside energy gain
- The effects of density steps on energy gain
- First push for high energy

Served as an opportunity for commissioning and learning ahead of the 2024 program, where energy gain will become a key focus.



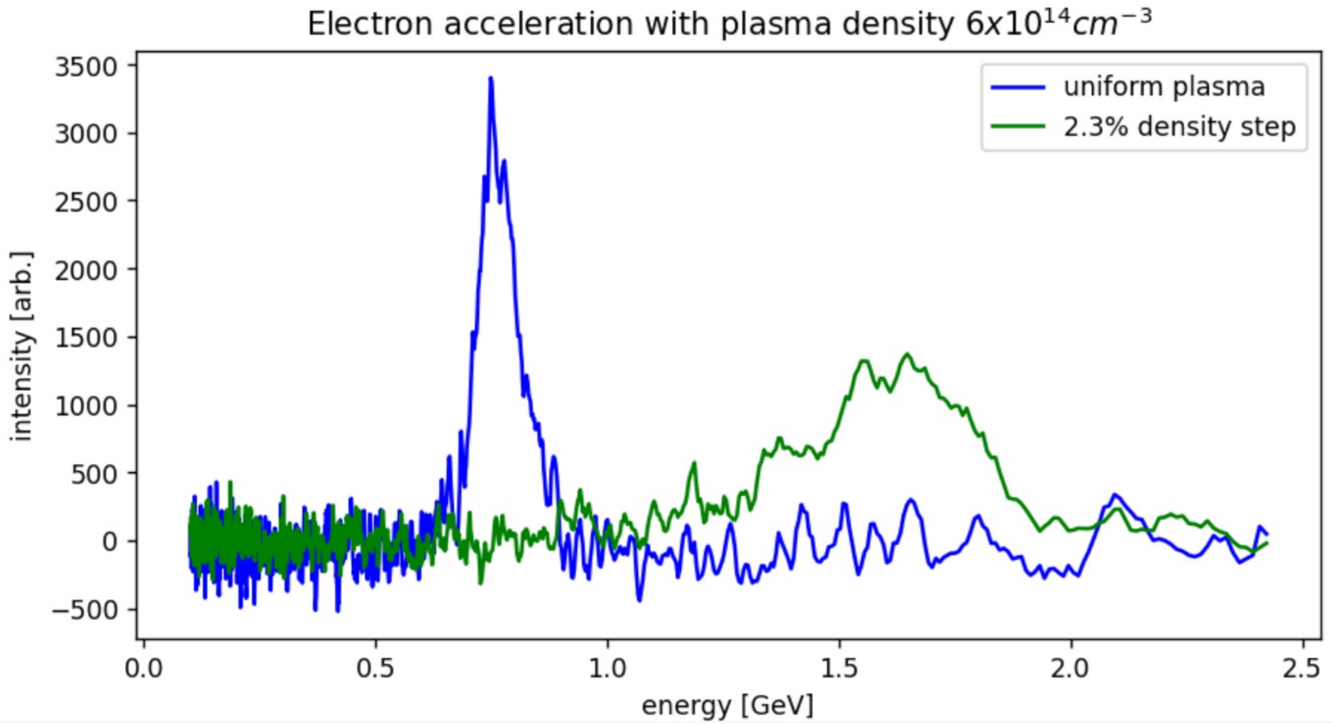


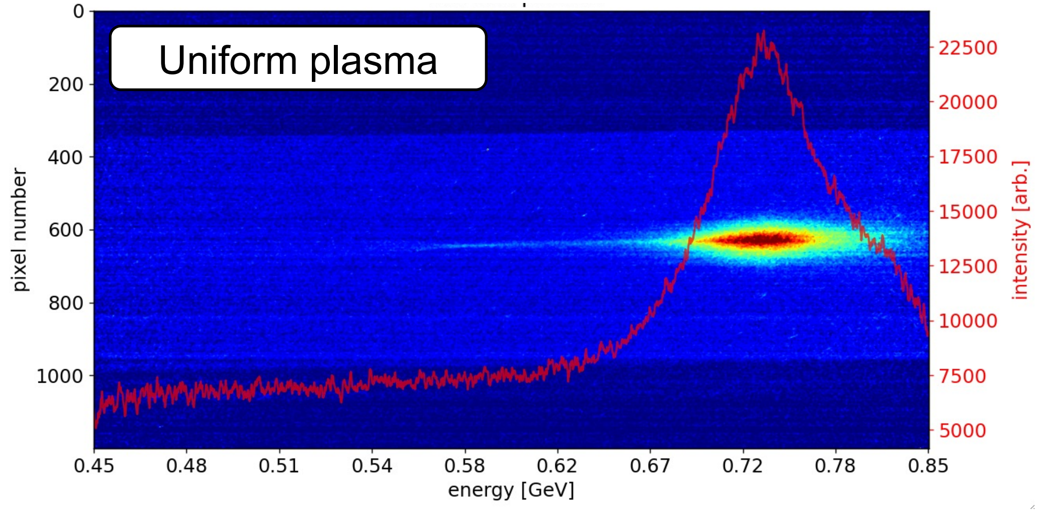
Summary of 2023 run activities: Density steps

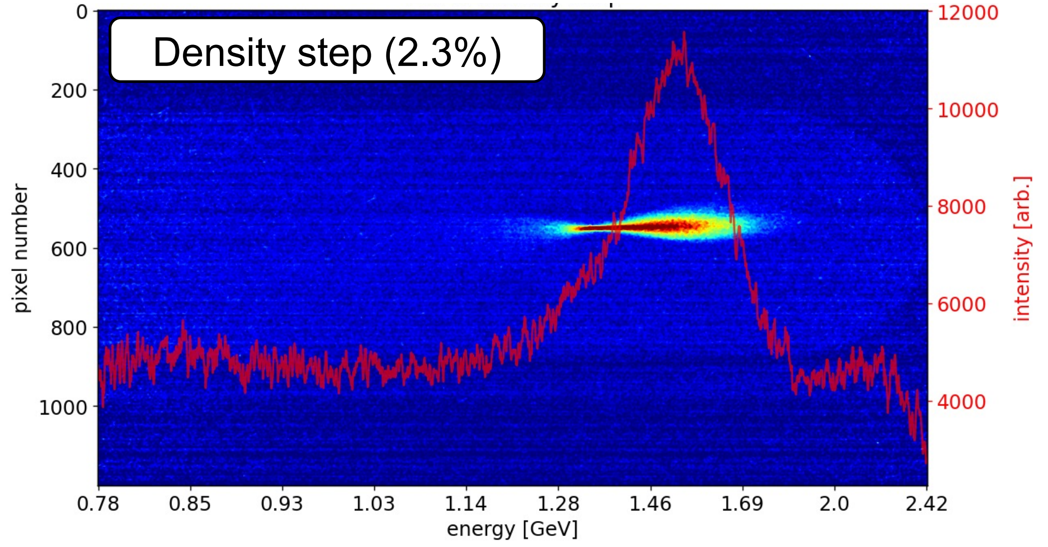
Plasma density: 6e14cm^{-3} (step 2.3% at 1.75m)

Proton bunch population: 3e11

RIF -100ps





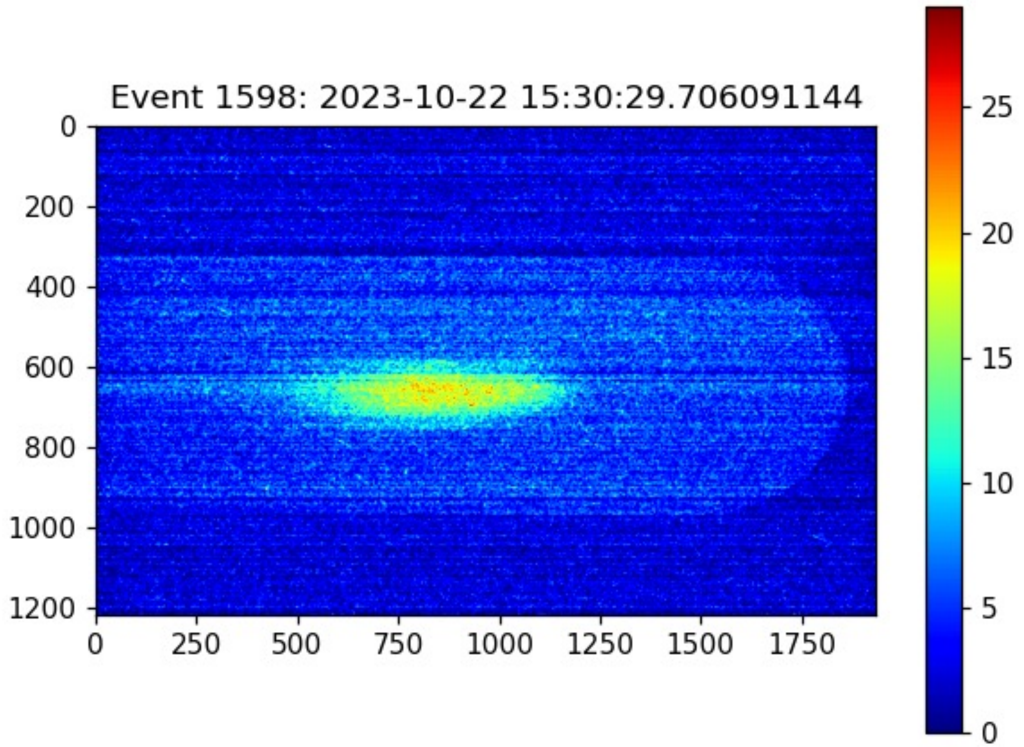


Summary of 2023 run activities: Energy gain

Plasma density: 9.9e14cm^{-3} (step 2.5% at 1.75m)

Proton bunch population: 3e11

RIF -100ps



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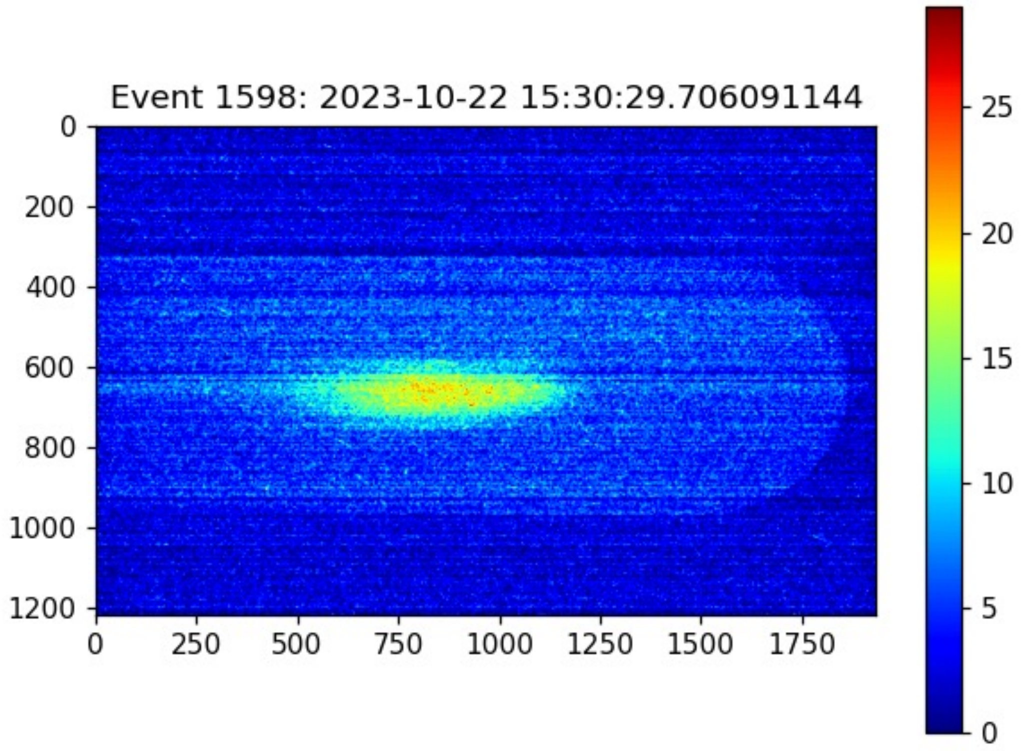
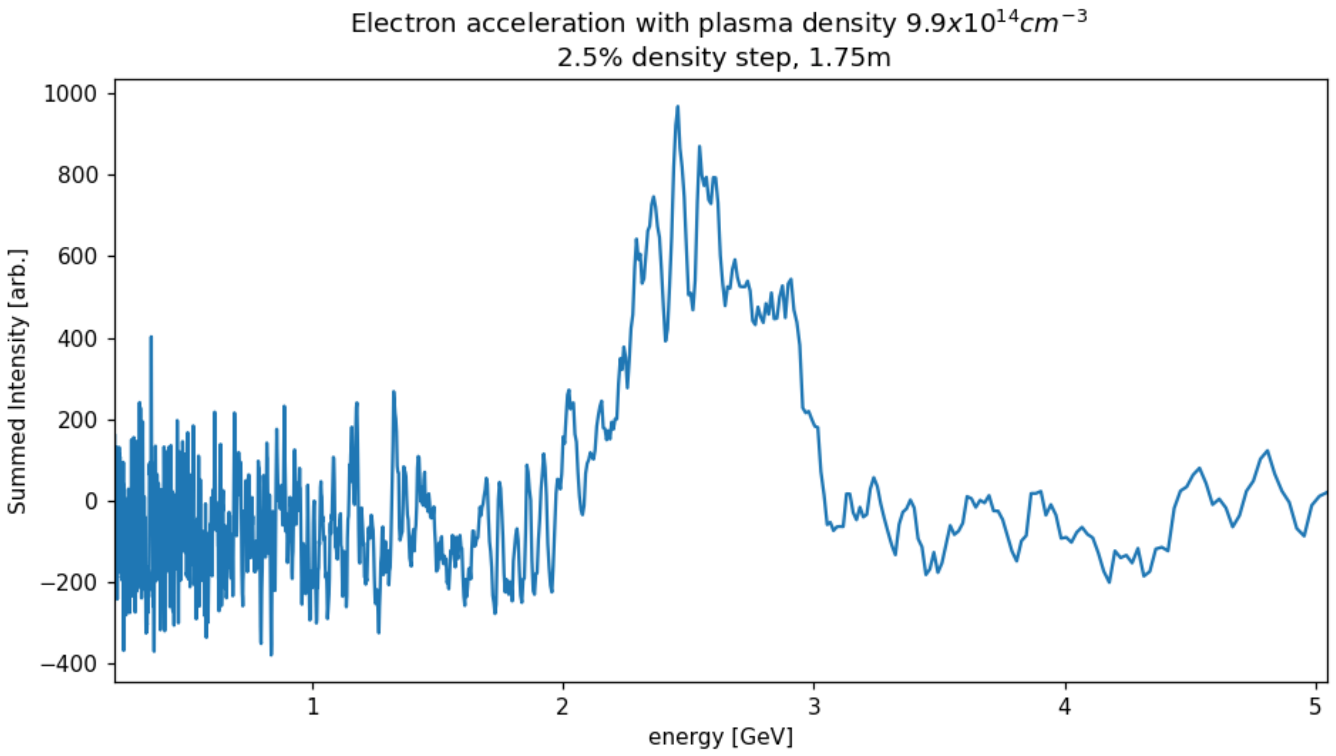




October 22nd 2023

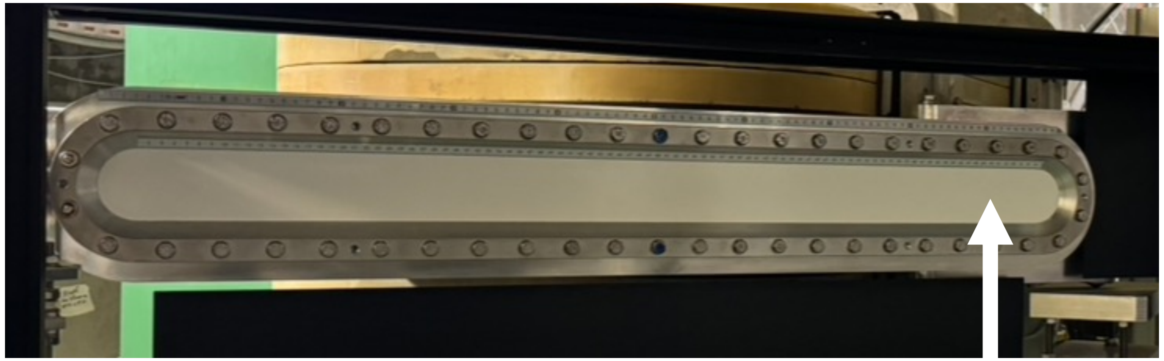
2.5 GeV measured on the spectrometer

Preliminary resolution study at CLEAR

Overall resolution of the spectrometer has contribution from the optics, and the scintillator screen

Cameras and lenses straightforward to assess resolution

Scintillator resolution requires electron beam tests



Mitsubishi Chemical, DRZ series
Lanex scintillator, $Gd_2O_2S:Tb$, 600us decay time

Current screen: DRZ-HIGH

Phosphor layer: 145 mg/cm2, relative brightness: 145%

New screen: DRZ-HR

Phosphor layer: 25 mg/cm2, relative brightness: 25%

Preliminary resolution study at CLEAR

Overall resolution of the spectrometer has contribution from the optics, and the scintillator screen

Cameras and lenses straightforward to assess resolution

Scintillator resolution requires electron beam tests

Point spread function (PSF):

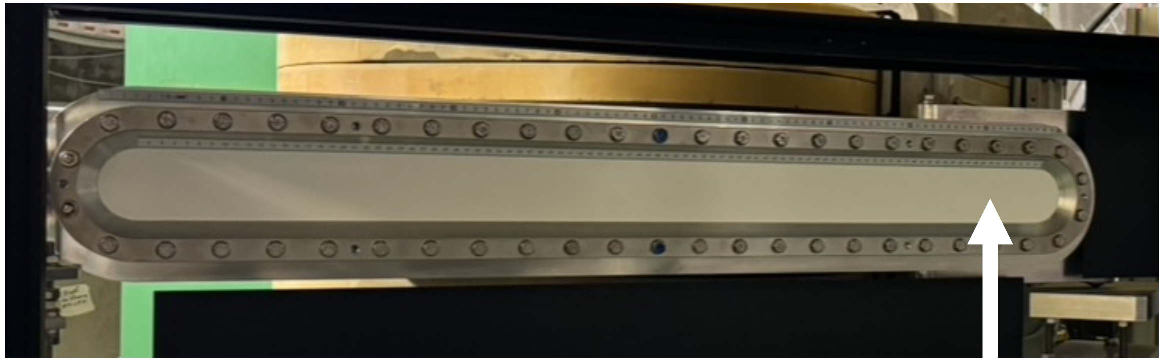
Requires 'point-like' beam (impractical…)

Resolution: Convolution of input distribution and measured size

Edge spread function (ESF):

Requires 'infinitely hard' edge (easier requirement?)

Resolution from spread of light across boundary



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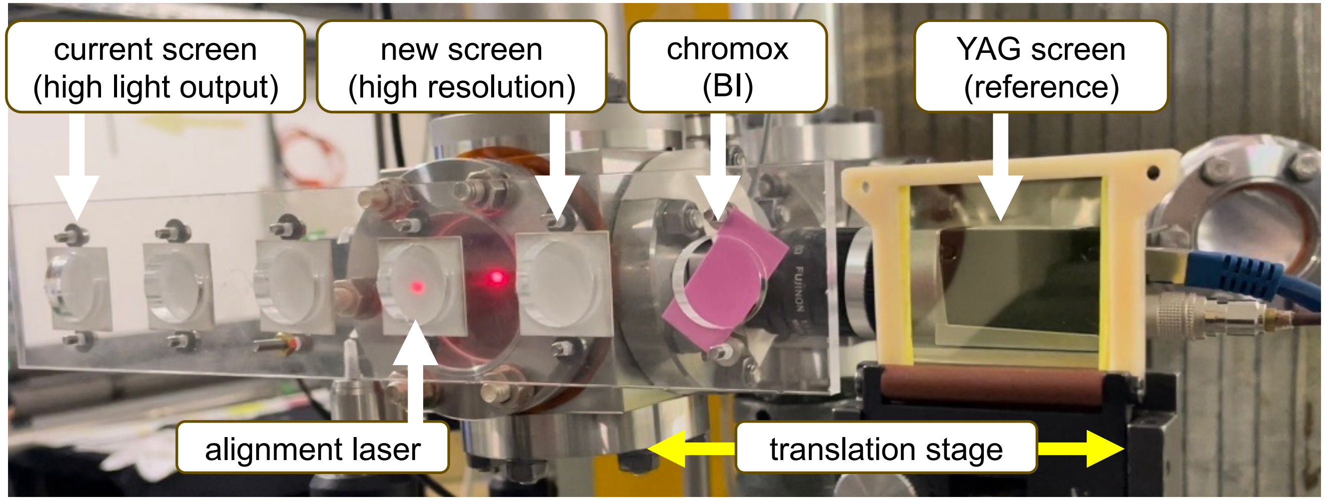
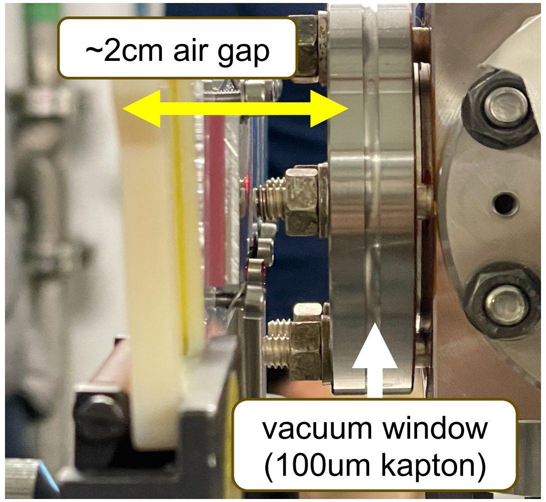
Investigate both methods in a (brief) preliminary study… see what we can learn!

Preliminary resolution study at CLEAR

Point spread function experiment





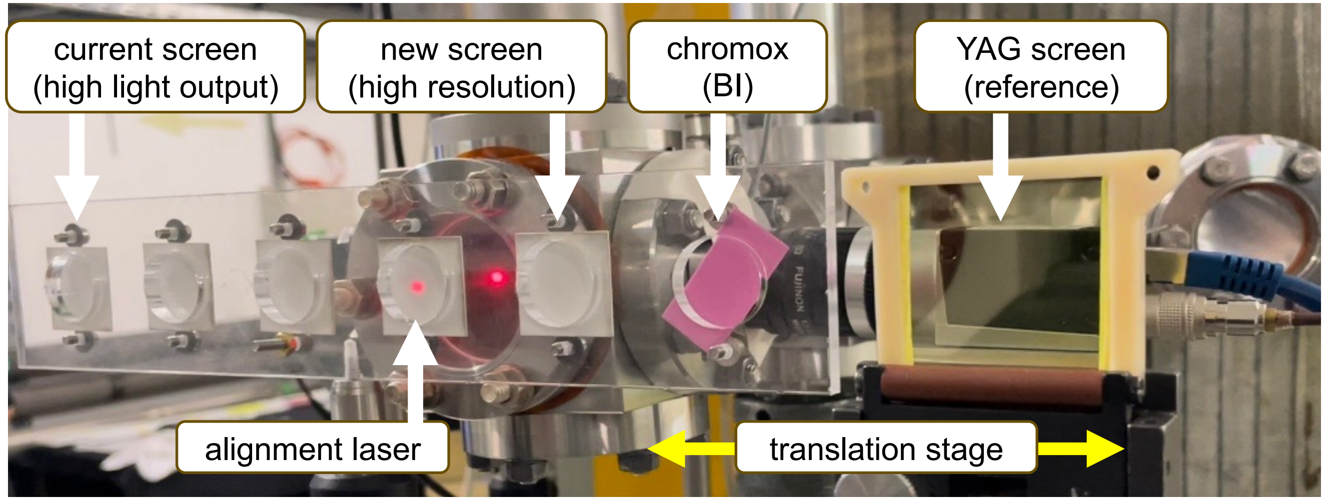
Achieving 'micro' beams:

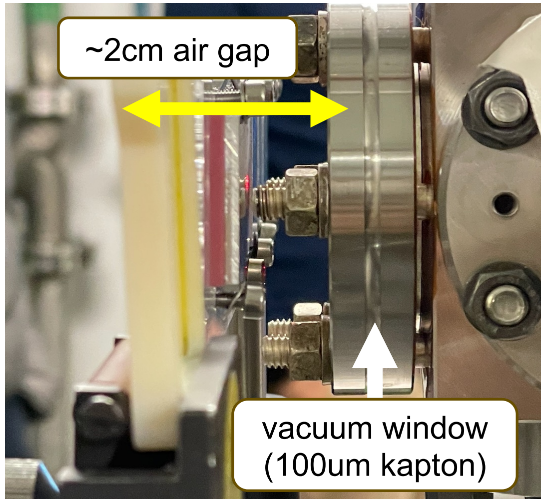
Experiment at the end of the CLEAR line.

Defocusing in the quadrupole triplet allows for stronger focusing in the final quadrupole doublet.

Preliminary resolution study at CLEAR

Point spread function experiment





Achieving ‘micro’ beams:

Experiment at the end of the CLEAR line.

Defocusing in the quadrupole triplet allows for stronger focusing in the final quadrupole doublet.

YAG, as the highest resolution screen available, was used as the reference measurement

Smallest obtained beam size was 50um (in air, measured on YAG)

Camera imaging from slight horizontal offset

- Clear of beam path and minimal perspective distortion
- High resolution lens contribution to spread from optics negligible ($\sigma < 10um$ in the lab at minimum working dist.)

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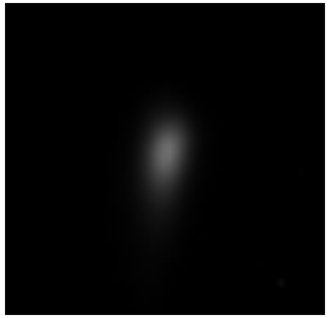
Preliminary resolution study at CLEAR

Point spread function experiment

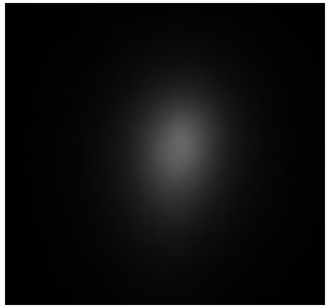
100 images acquired for each, size fluctuation minimal, position jitter non-negligible → fit sizes individually

Assuming Gaussian for now, as deconvolution is more straight-forward



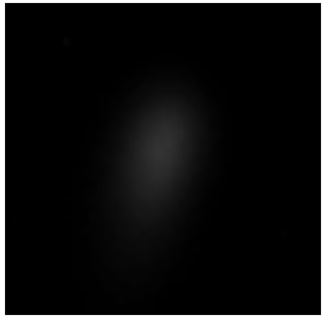
YAG

49.5 um



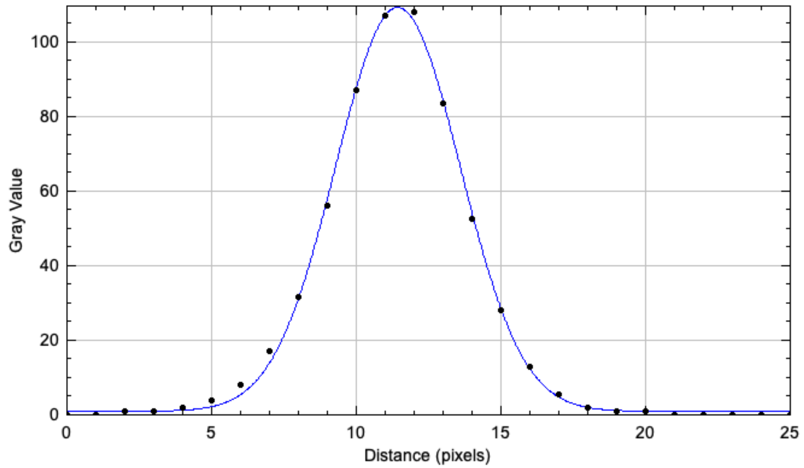
DRZ-HIGH
(current screen)

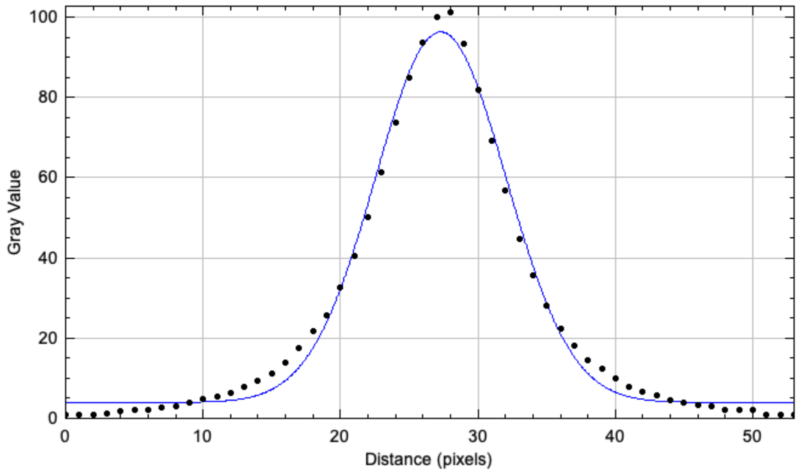
112.5 um

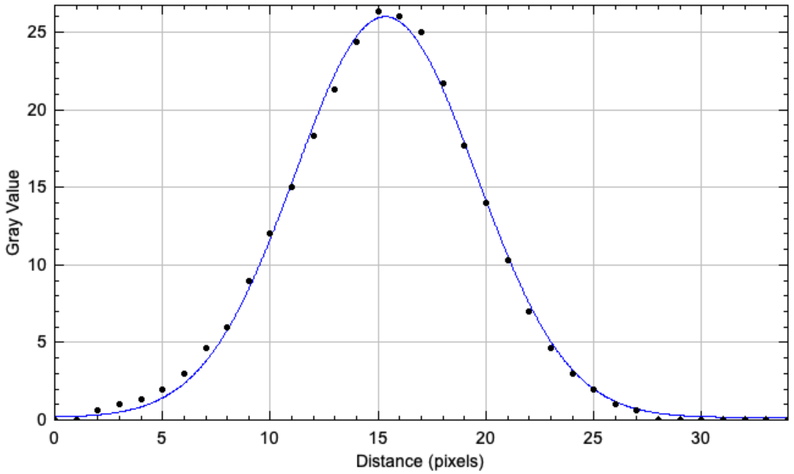


DRZ-HR
(new screen)

96.6 um







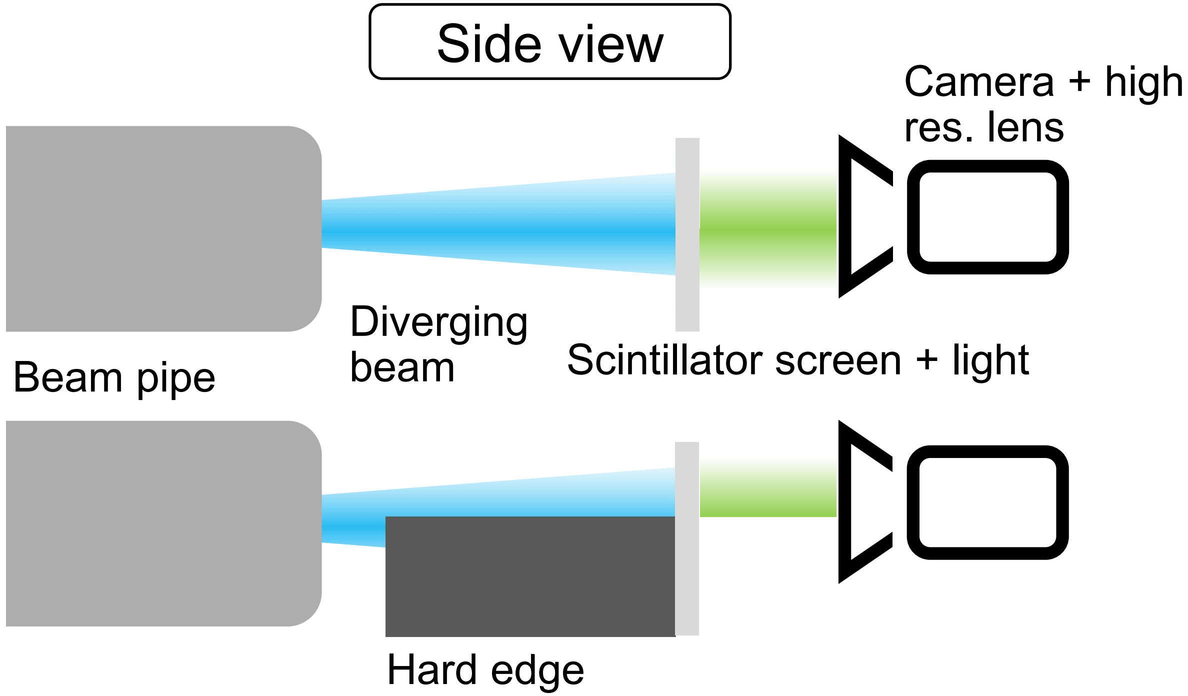
Preliminary resolution study at CLEAR

Edge spread function experiment

Attempt to create a ‘step’ by blocking out a portion of the beam

Diverging beam → limit the portion of the phase space entering the block / crossing the boundary

Beam size limitation removed, but possibility for other contributions to spread → investigate



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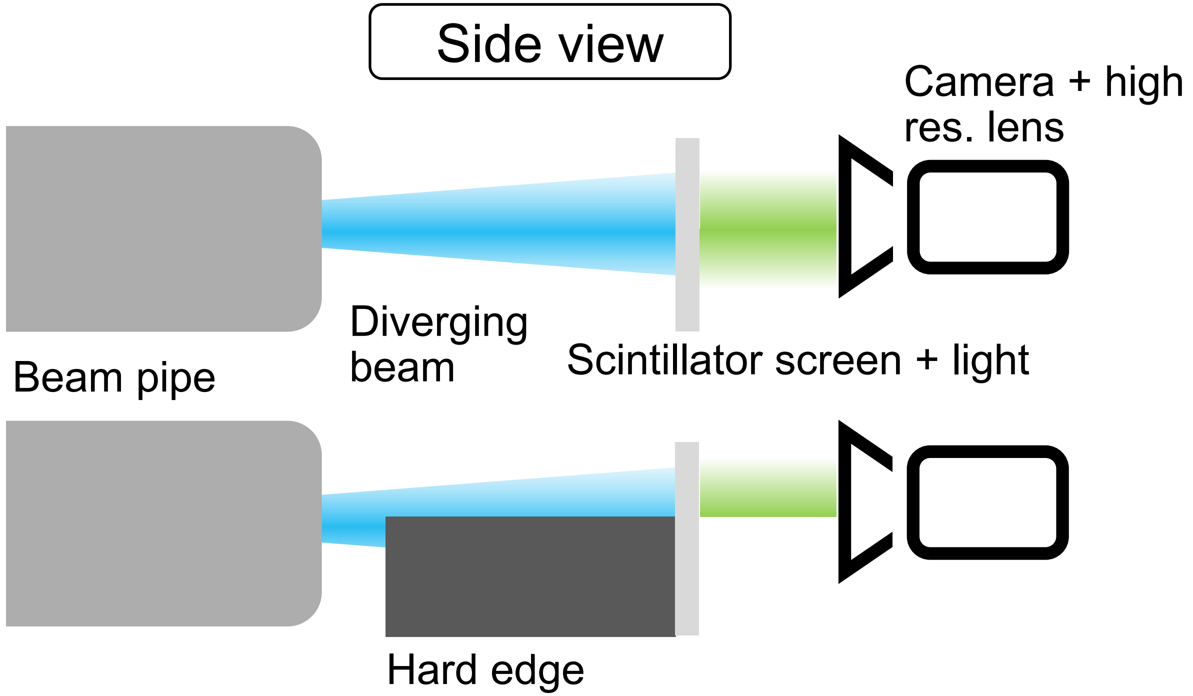

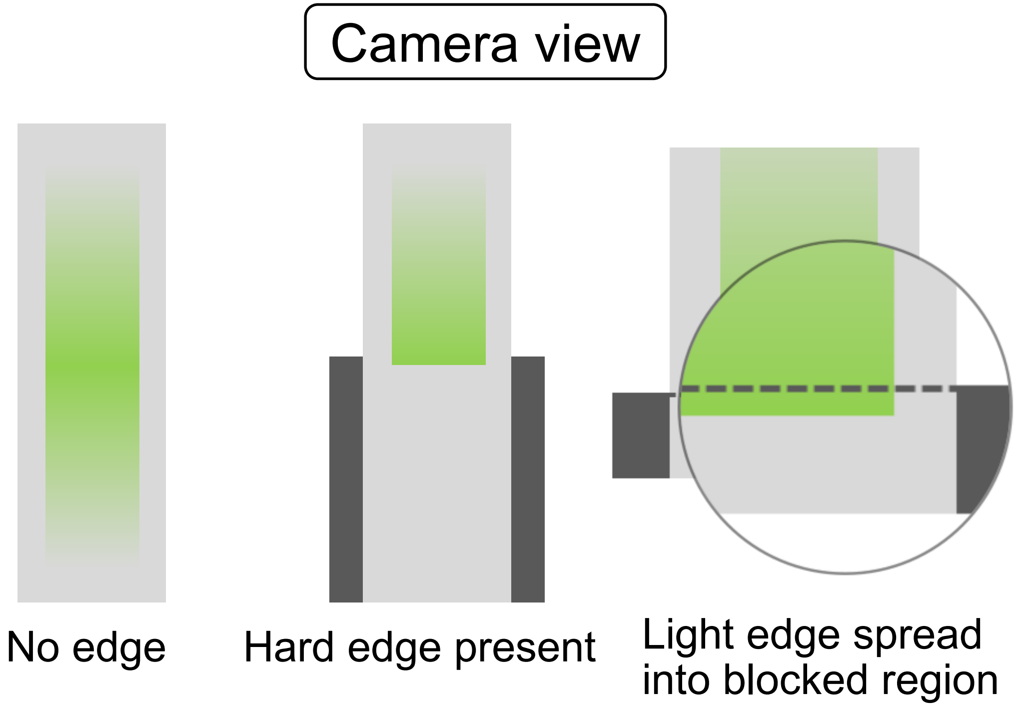

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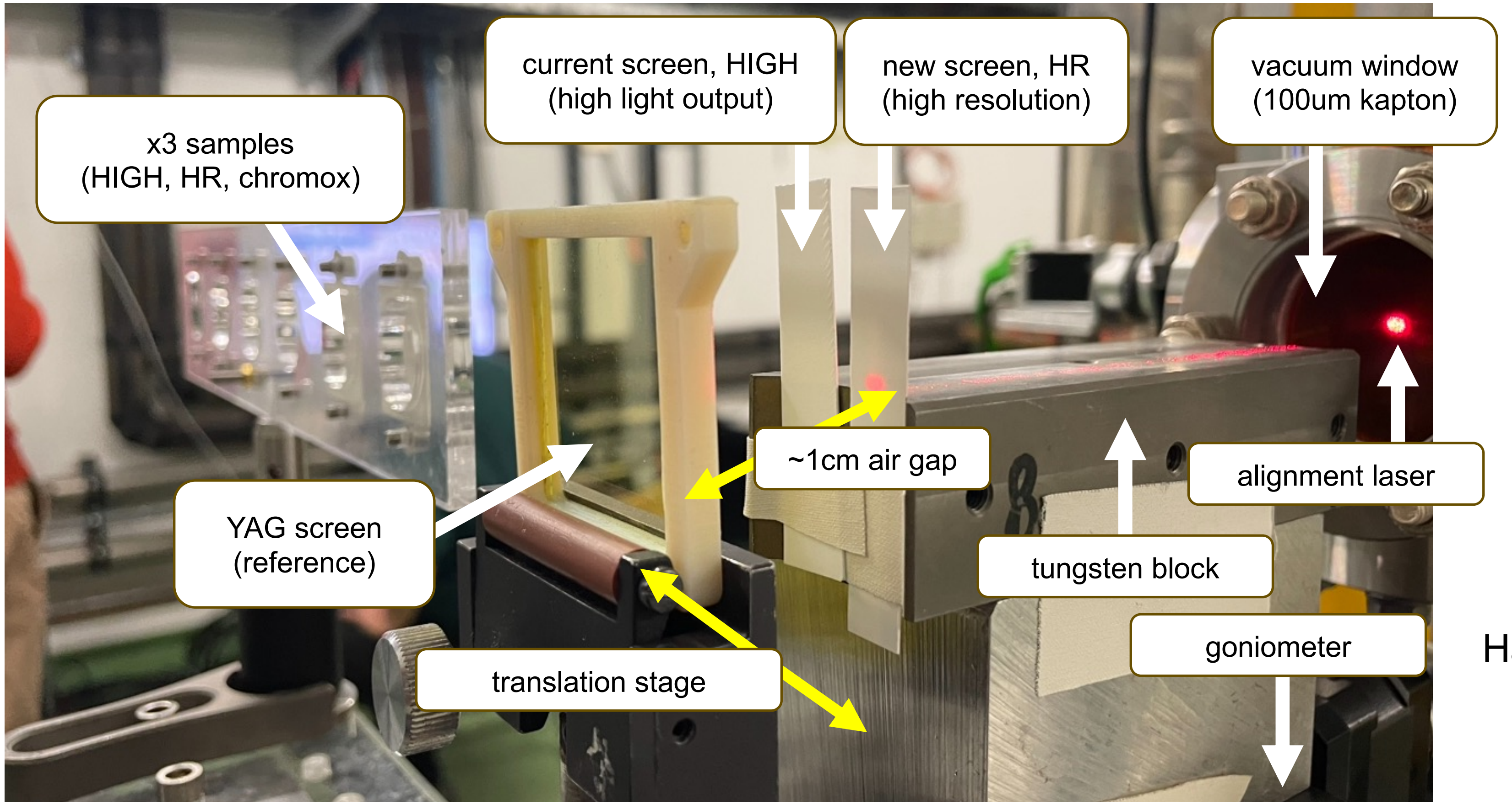
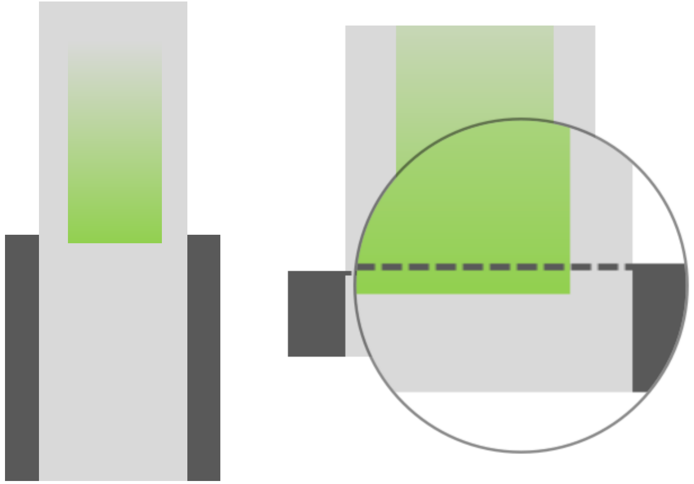


Camera view

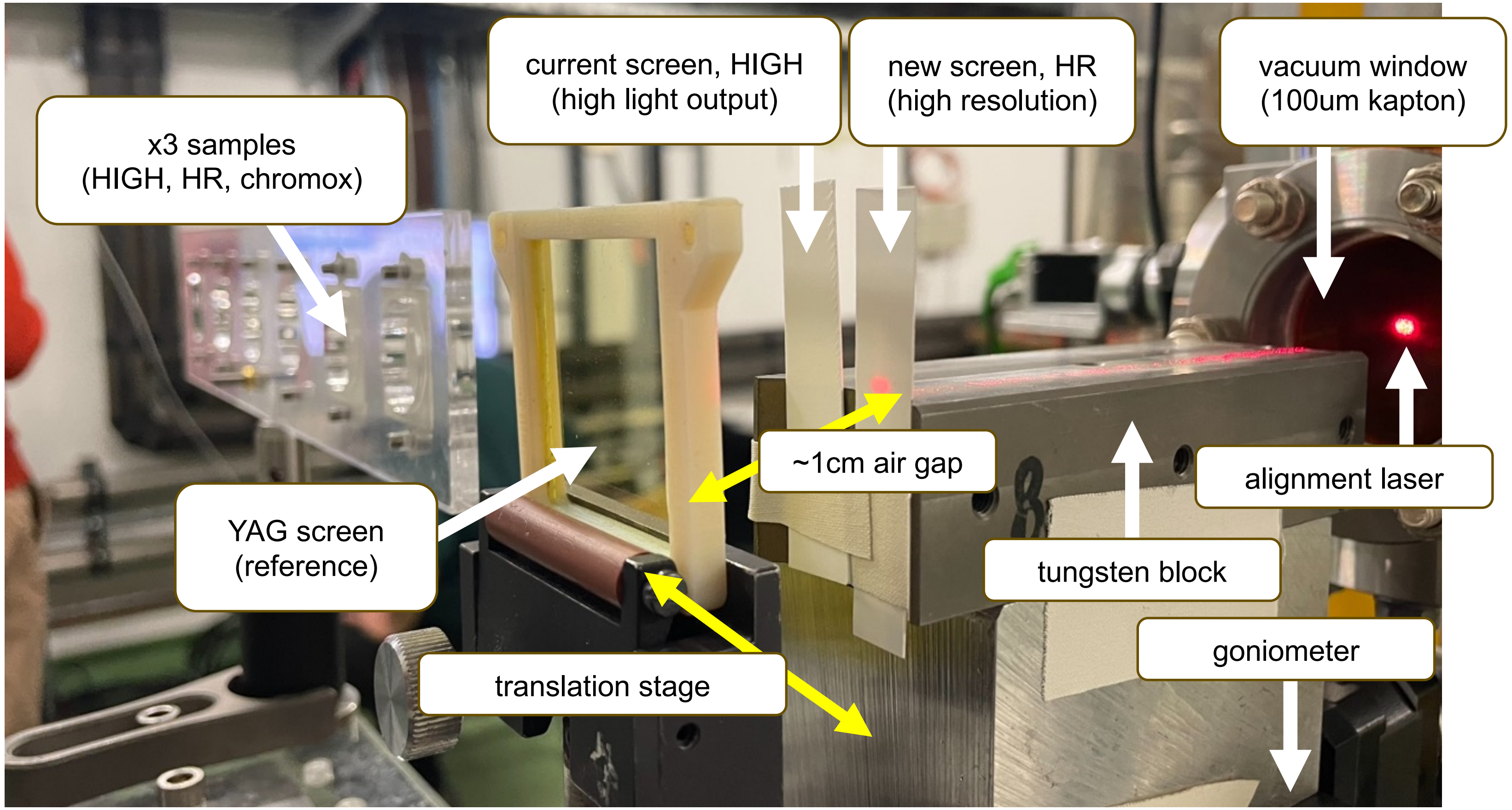


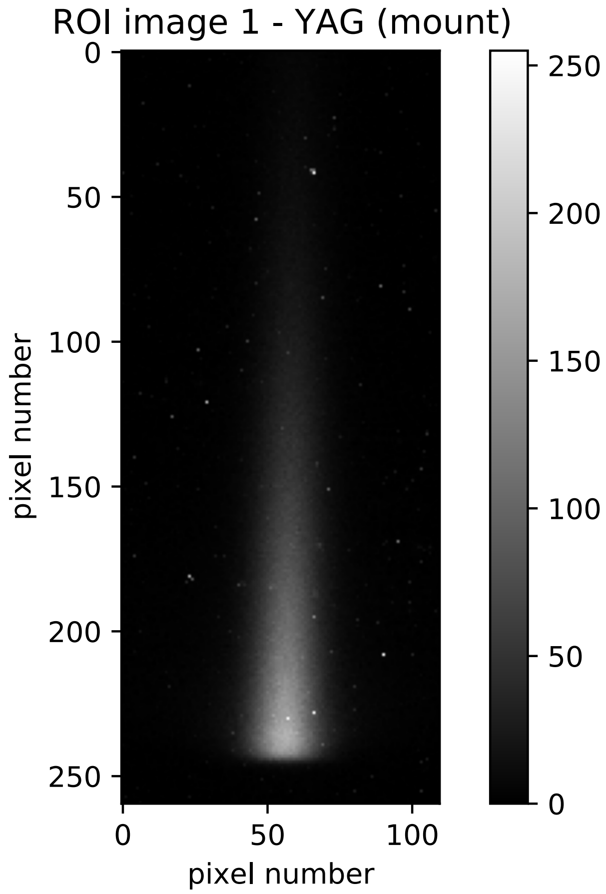
Hard edge present

Light edge spread into blocked region

Preliminary resolution study at CLEAR

Edge spread function experiment





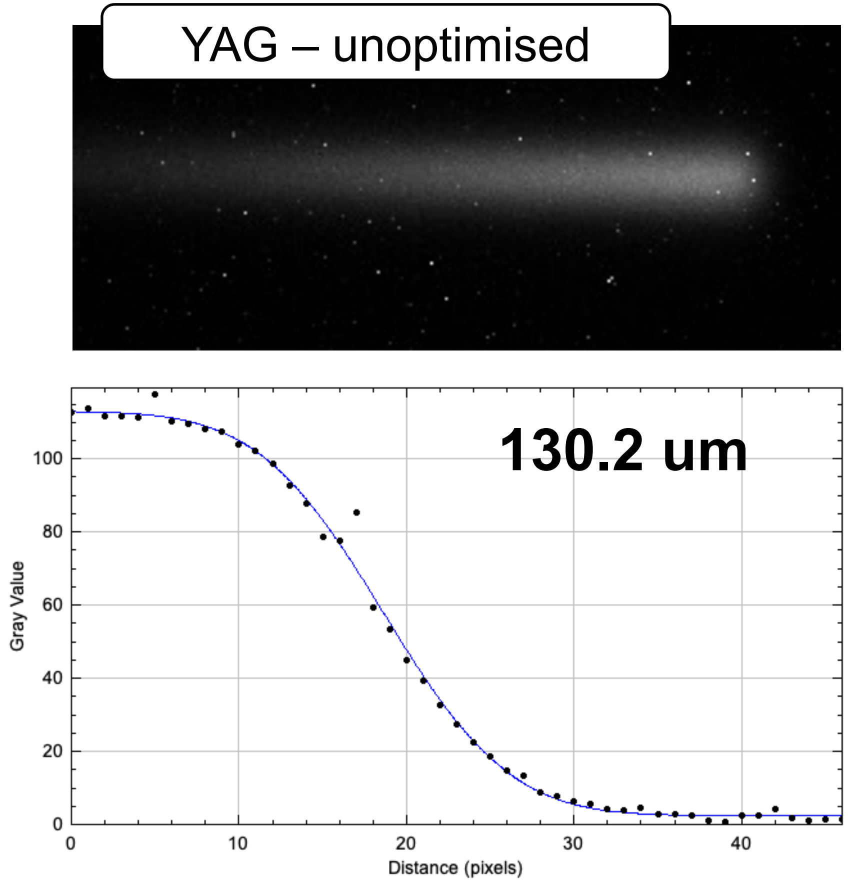
Preliminary resolution study at CLEAR

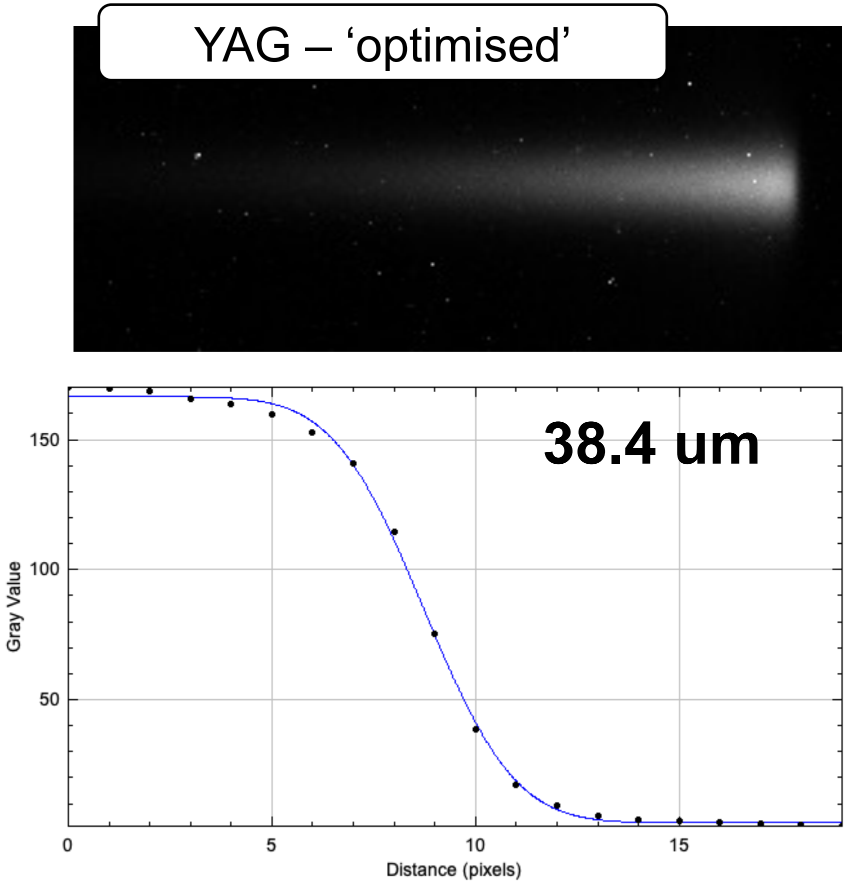
Edge spread function experiment

Important that we align the electron trajectory parallel to the block.

Otherwise we introduce additional spread across the boundary into the blocked region.

Strict time limitation → optimised by eye, can be improved with angle scans



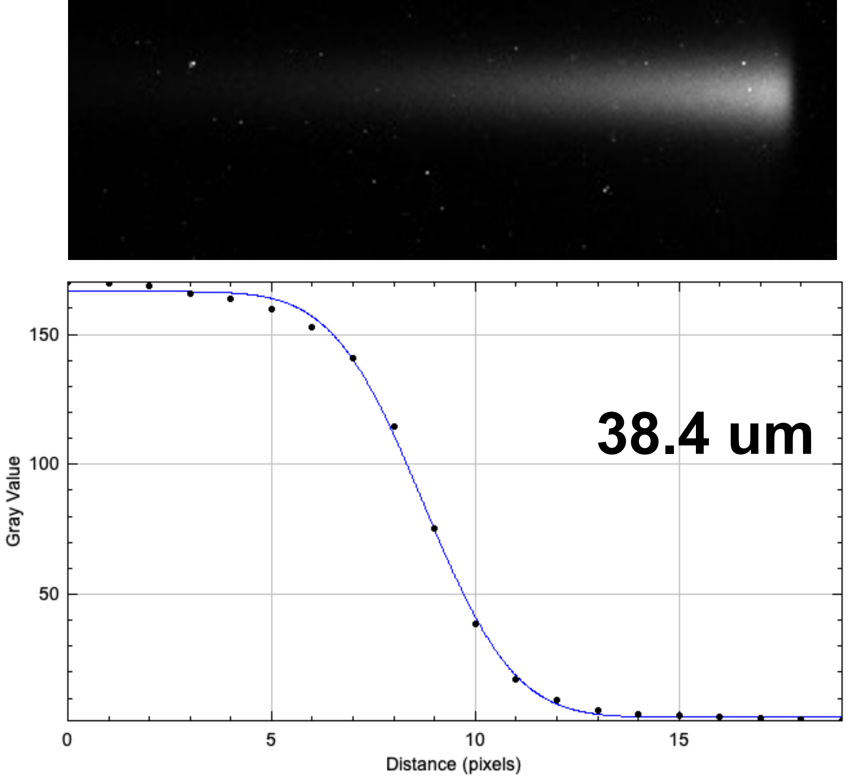


Preliminary resolution study at CLEAR

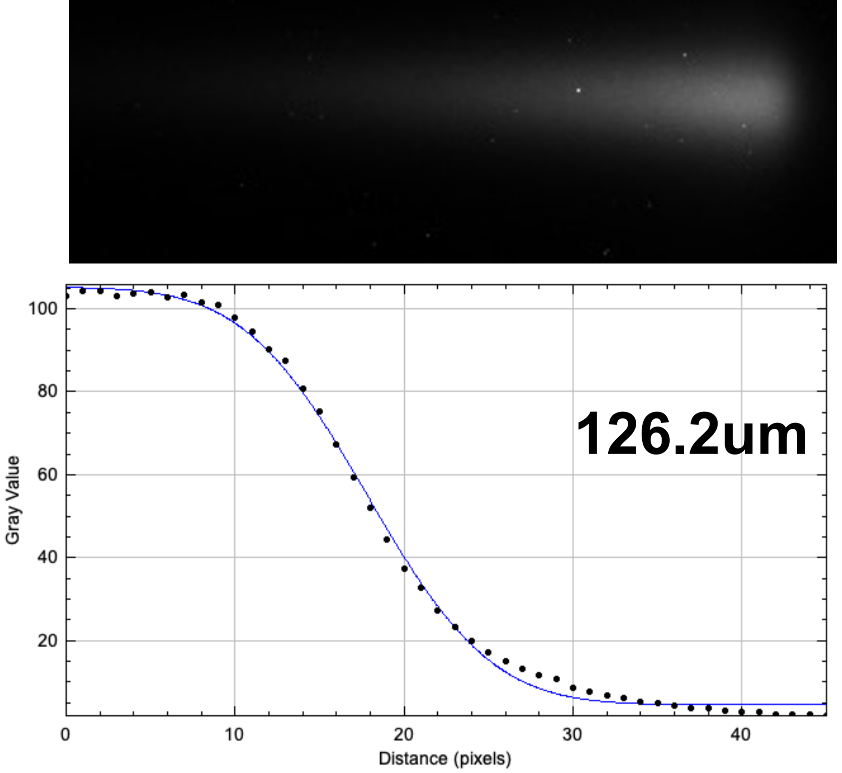
December 2023

Edge spread function experiment

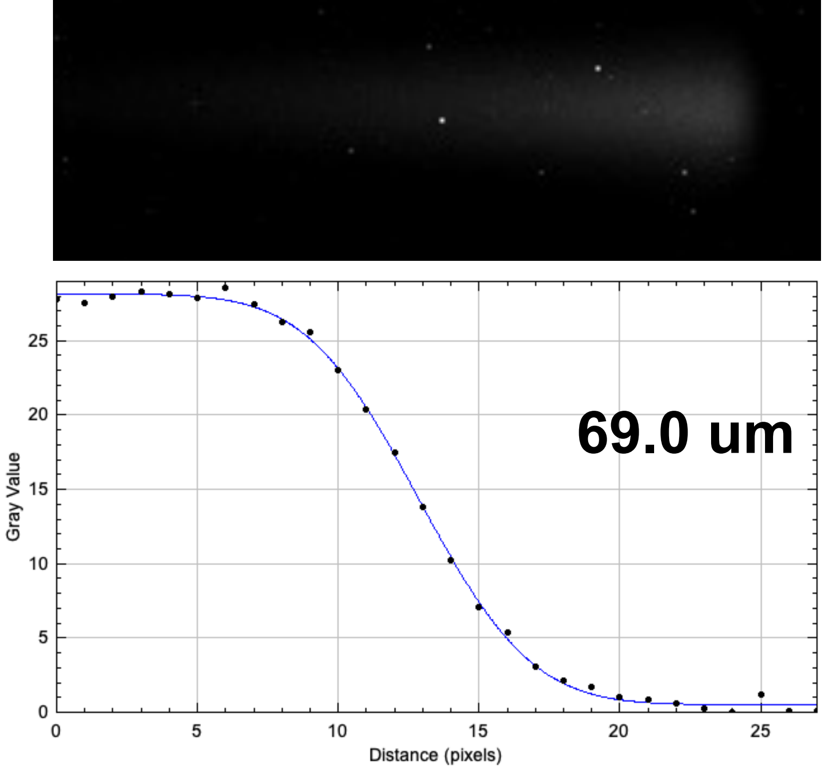
YAG



DRZ-HIGH (current screen)



DRZ-HR (new screen)



Preliminary resolution study at CLEAR

The edge spread method, under certain assumptions, is a direct measurement of the resolution. Additional spread can come from:

- Angle misalignments between the electrons and the tungsten block
- Halo from scattering with the tungsten
- Portion of the beam phase space crossing the boundary

Simulation and detailed investigation can evaluate these components

- Simulations underway
- Returning to CLEAR for a one week, detailed experiment, this year

These will make the resolution worse, we can think of the edge spread results as 'upper bounds' on the screen resolutions (current screen ~130um, new screen ~70um)

We can cross-check with the PSF results after the upcoming study

Preparing for 2024

Instrumentation upgrades

Expanding the camera array from 4 to 7

- Allows us to see the whole screen
- If we aren't sure of the energy, cover ourselves!

Installation of high-res translation camera

- Reusing the old spectrometer calibration lamp track
- Mount the camera from above → do not obscure camera array
- If we're limited by pixel size, this camera can recover us.

Preparing for 2024

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Simulations and background

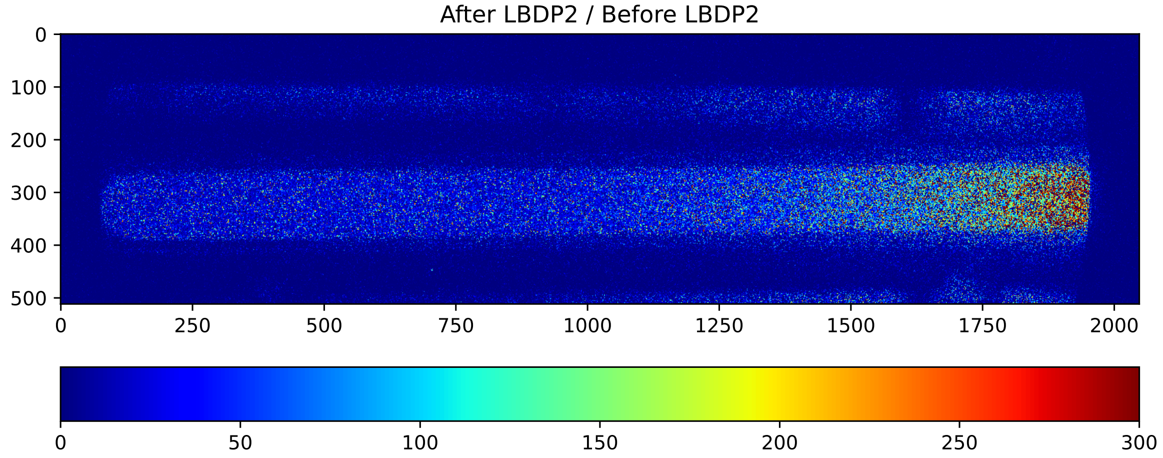
Changing the plasma length with laser foils

- 400GeV protons through the foils → background increases
- Quick test with LBDP2 in October confirms this (x ~100)
- Modelling (and removing) background difficulty, but needed

Electrons through the foils

- Understanding electron scattering through the foils
- Decisions on where to place them along the vapour source

The increased background from protons
The scattering of electrons through the foils



Thanks!

Backup

Preliminary resolution study at CLEAR

$$measured\ size^{\,2} = true\ size^2 + resolution^2$$

PSF ↓ ESF ↓

YAG: $49.5^2 = true\ size^2 + 38.4^2$ → True beam size calculated as 31um

HR: $96.6^2 = true\ size^2 + 69.0^2$ → True beam size calculated as 67.6um

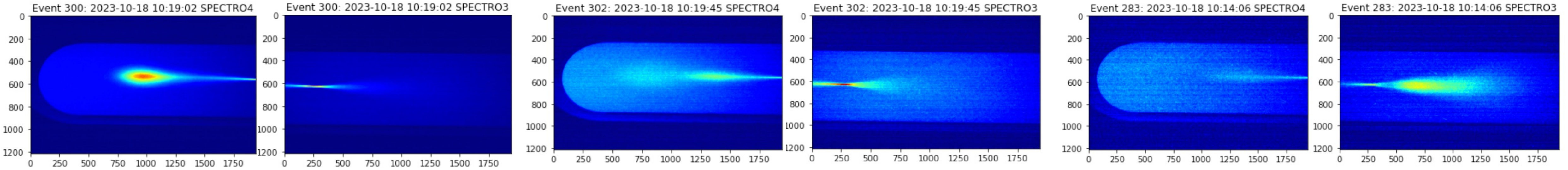
HIGH: $112.5^2 = true\ size^2 + 126.2^2$ → Calculation fails

It looks like we aren’t working with Gaussian beams.

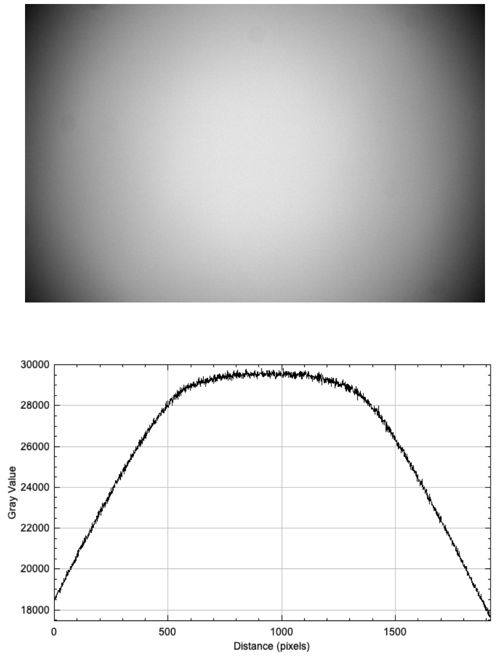
Now looking into new convolutions.

Image stitching with the new camera array

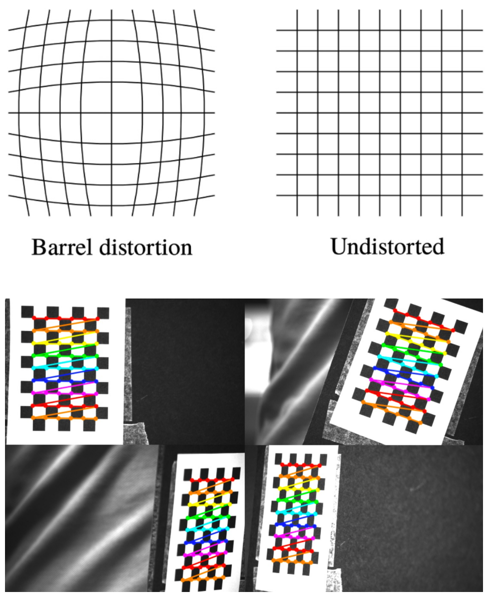
Proceedings paper written for IBIC2023 https://ibic2023.vrws.de/papers/tup023.pdf



Vignetting correction



Lens distortion



Perspective correction

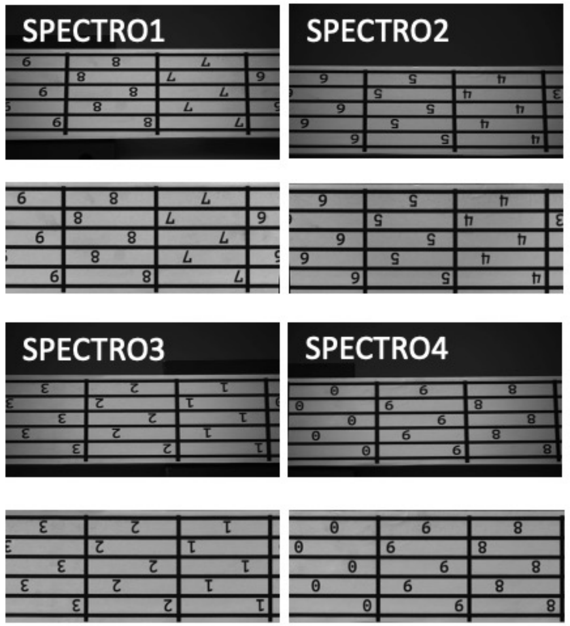


Image overlaying