# Fluorescence Profile Monitor for the CERN e-Lens

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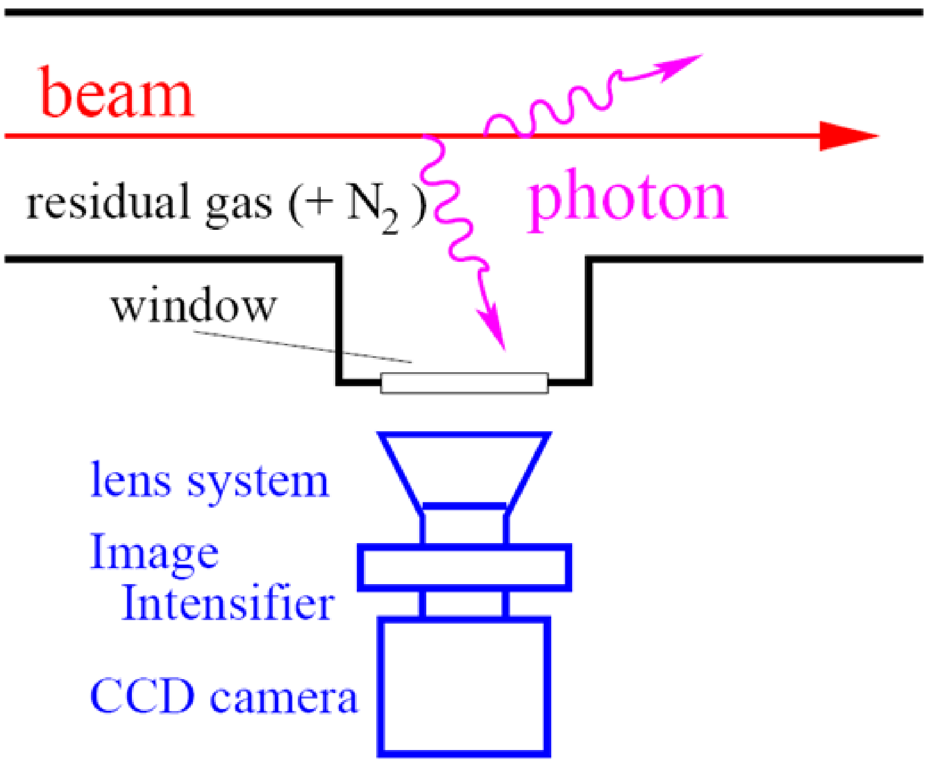
# Outline

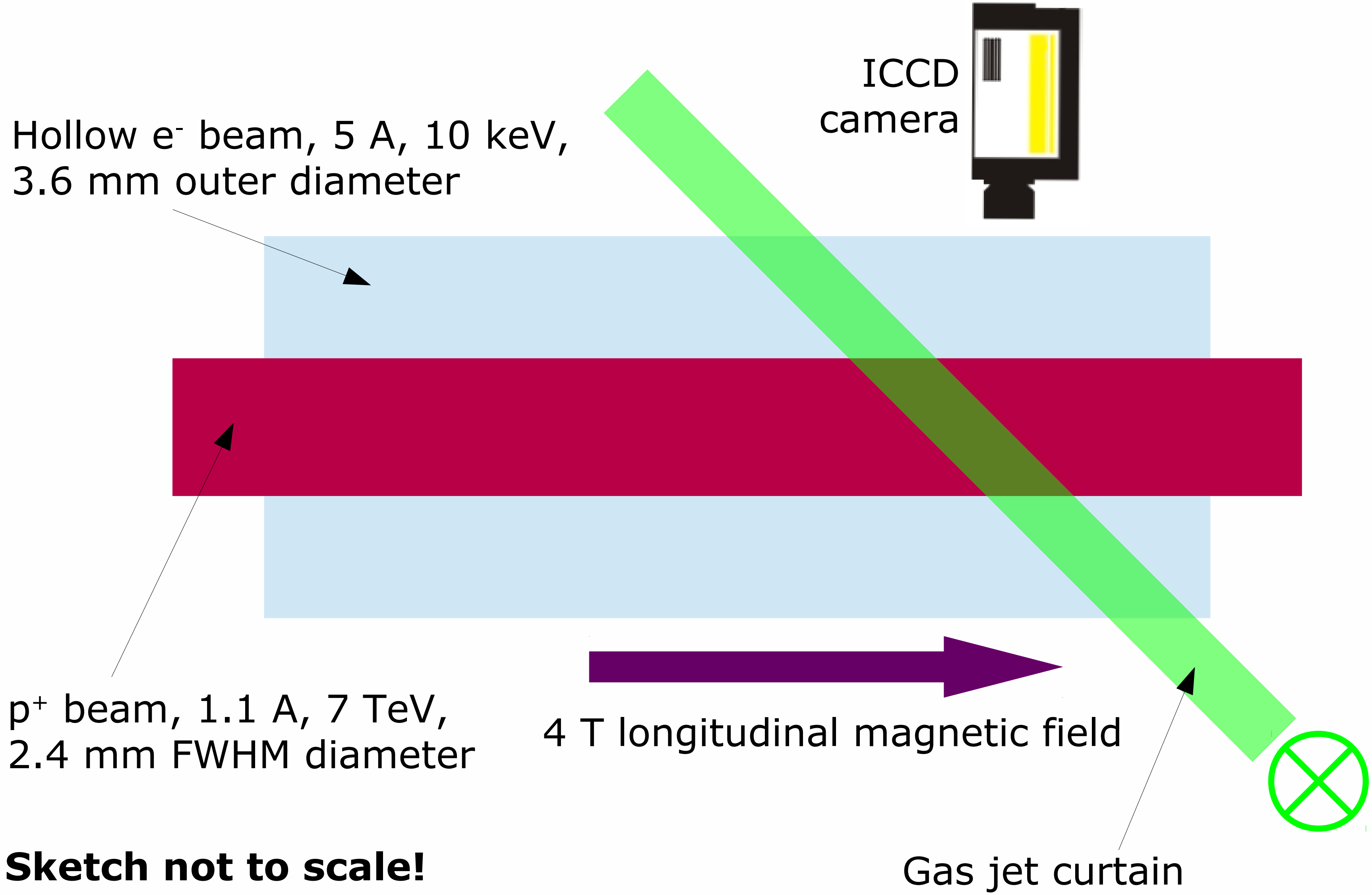
- Beam Induced Fluorescence (BIF) working principle and features
- Characteristics of the CERN e-lens setup
- $N_2$ and Ne as working gases
- Optics
- Image intensifier and camera
- Optomechanics
- Test setup and first results at the Cockcroft Institute
- Conclusions and outlook

# Beam Induced Fluorescence (BIF)

- Based upon the detection of photons emitted by residual or injected (low pressure) gas molecules
- Little influence on the beam
- Single pulse observation possible; e.g. ≈ 1 μs time resolution (depends on photon flux)
- Spatial resolution can be matched to application
- In case of low photon fluxes, commercial intensified cameras are available
- Compact installation, e.g. 25 cm for both planes

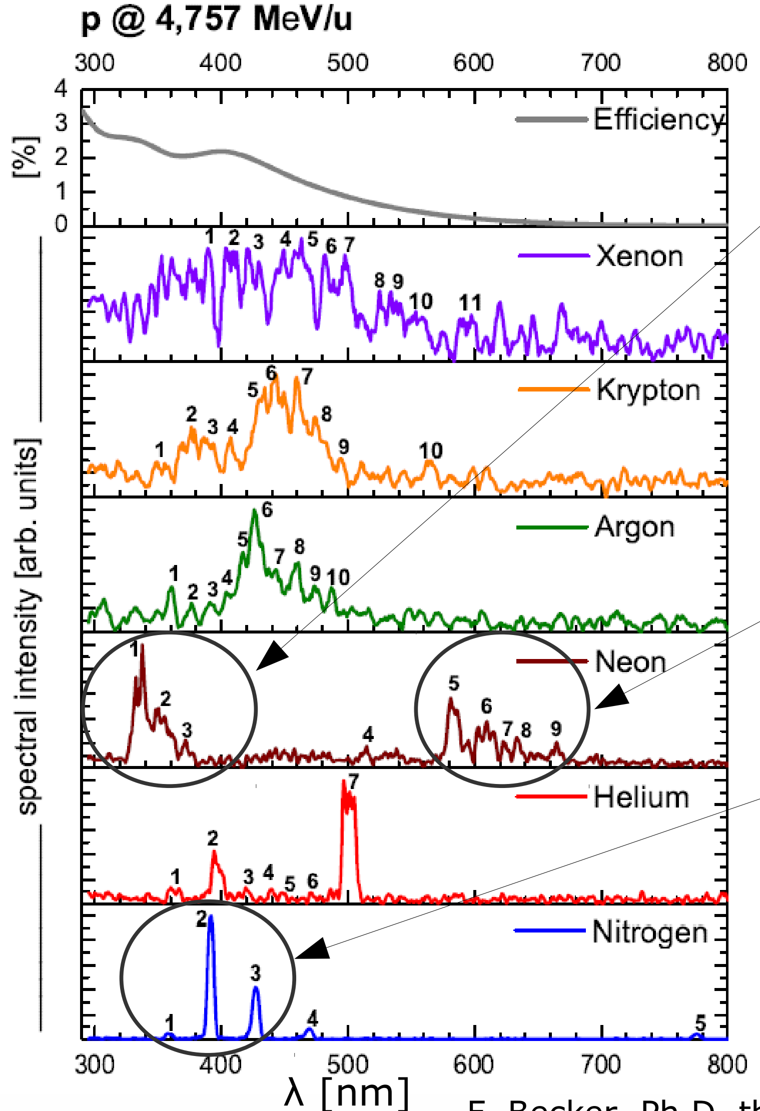


# E-Lens and BIF @ CERN




**Sketch not to scale!**

# Fluorescence of different gases




Several $Ne^+$ lines mainly corresponding to different $[2s^2 2p^4(^3P)]3p \rightarrow 3s$ transitions and with life times below 10 ns.

Several Ne lines mainly corresponding to different $[2s^2 2p^5(^2P)]3p \rightarrow 3s$ transitions and with life times of about 20 ns.

The strong lines correspond to the $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ electronic transition band of $N_2^+$, life times are of about 60 ns.

F. Becker, Ph.D. thesis, T.U. Darmstadt, Germany, 2009

# $N_2$ as working gas: excitation and emission

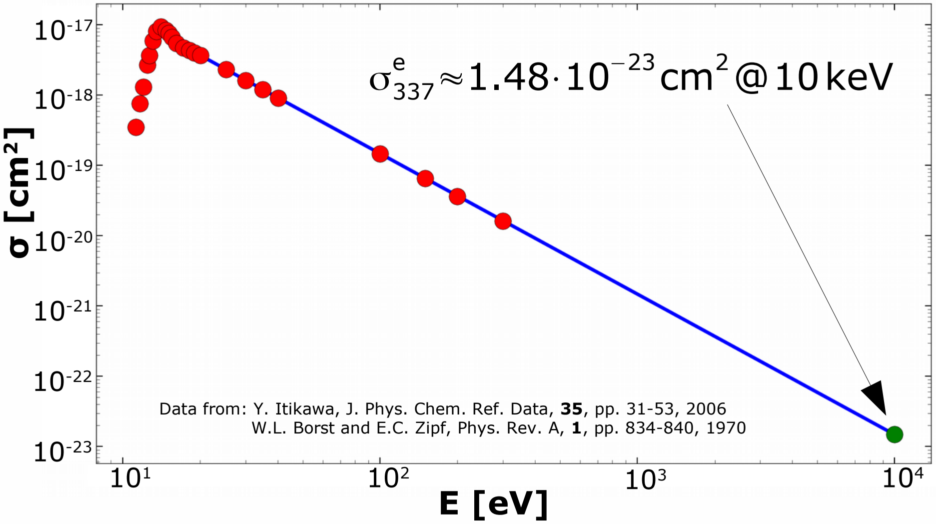
$N_2 + p/e^- \rightarrow (N_2^+)^* + e^- + p/e^- \rightarrow N_2^+ + \gamma + e^- + p/e^-$

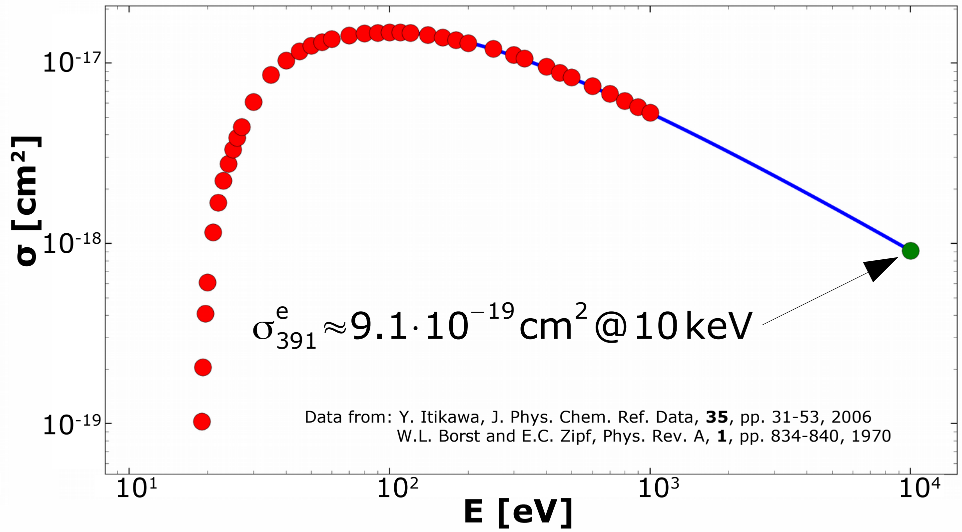
Leads to the electronic transition $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ of the molecular ion with wavelengths around 391 nm, depending upon involved vibrational and rotational states

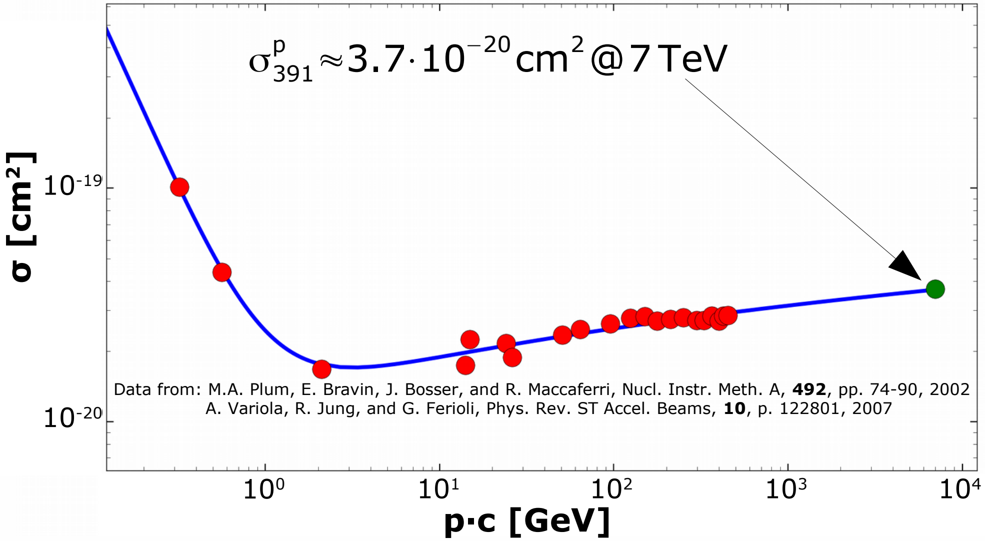
$N_2 + e^- \rightarrow (N_2)^* + e^- \rightarrow N_2 + \gamma + e^-$

Drives the electronic transition $C^3\Pi_u \rightarrow B^3\Pi_g$ of the neutral molecule with wavelengths around 337 nm. This process cannot be initiated directly by protons because it implies a spin flip mechanism: the upper $C^3\Pi_u$ state is a triplet one, while the ground state of $N_2$ is a singlet and total spin should stay preserved during excitation.

# $N_2$ as working gas: cross sections



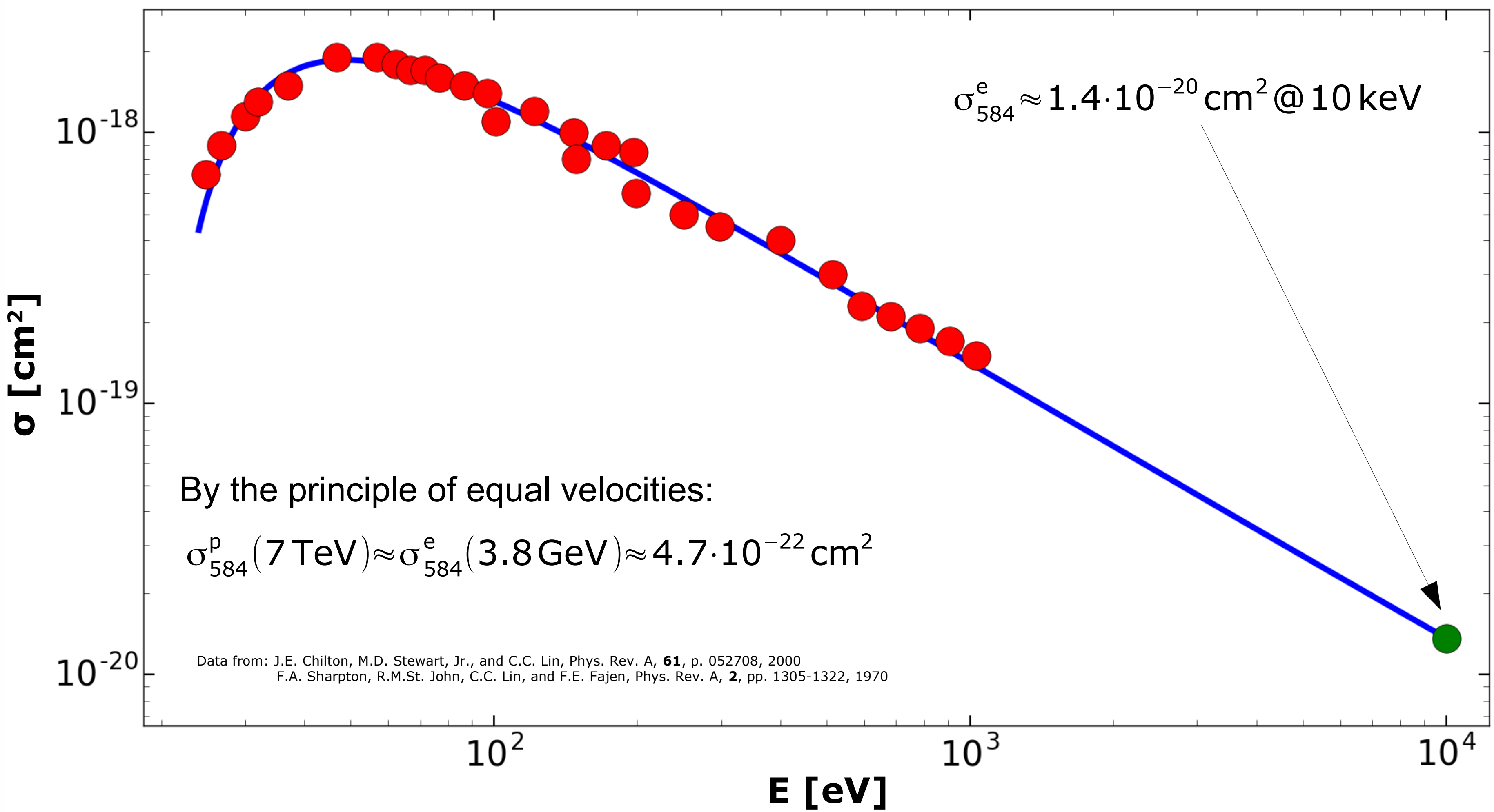



# Ne as working gas: some comments

- Strong fluorescence due to neutrals, but lower than $N_2$
- $Ne^+$ fluorescence from levels with short life times (< 10 ns)
- Mass comparable with that of $N_2$
- Emission by neutrals at long wavelengths ($\lambda$ > 580 nm); photo-cathodes with higher sensitivity in this region lead to a larger rate of dark counts
- Presently no known experimental data about fluorescence cross sections due to relativistic protons
- Presently known experimental data on cross sections for the interaction with electrons just for the neutral atom, no data regarding combined ionization and excitation

# Ne as working gas: cross sections



# Photon rate estimations

$$N_\gamma = \sigma \cdot \frac{I \cdot \Delta t}{e} \cdot n \cdot d \cdot \frac{\Omega}{4\pi} \cdot T \cdot T_f \cdot \eta_{pc} \cdot \eta_{MCP}$$

$n = 2.5 \cdot 10^{10}\ cm^{-3}$
$d = 5 \cdot 10^{-2}$ cm
$\Omega = 4\pi\ 10^{-4}$ sr
$T = 70\%$
$T_f = 30\%$
$\eta_{MCP} = 50\%$

$N_\gamma$ = average number of photons detected during time $\Delta t$
$\sigma$ = cross section of the photon generation process
$I$ = electron or proton current (electrical)
$e$ = elementary charge
$n$ = gas density
$d$ = distance traveled through gas (curtain thickness)
$\Omega$ = solid angle of the optics
$T$ = transmittance of the optical system
$T_f$ = transmittance of the optical filter
$\eta_{pc}$ = quatum efficiency of the photocathode
$\eta_{MCP}$ = detection efficiency of the MCP

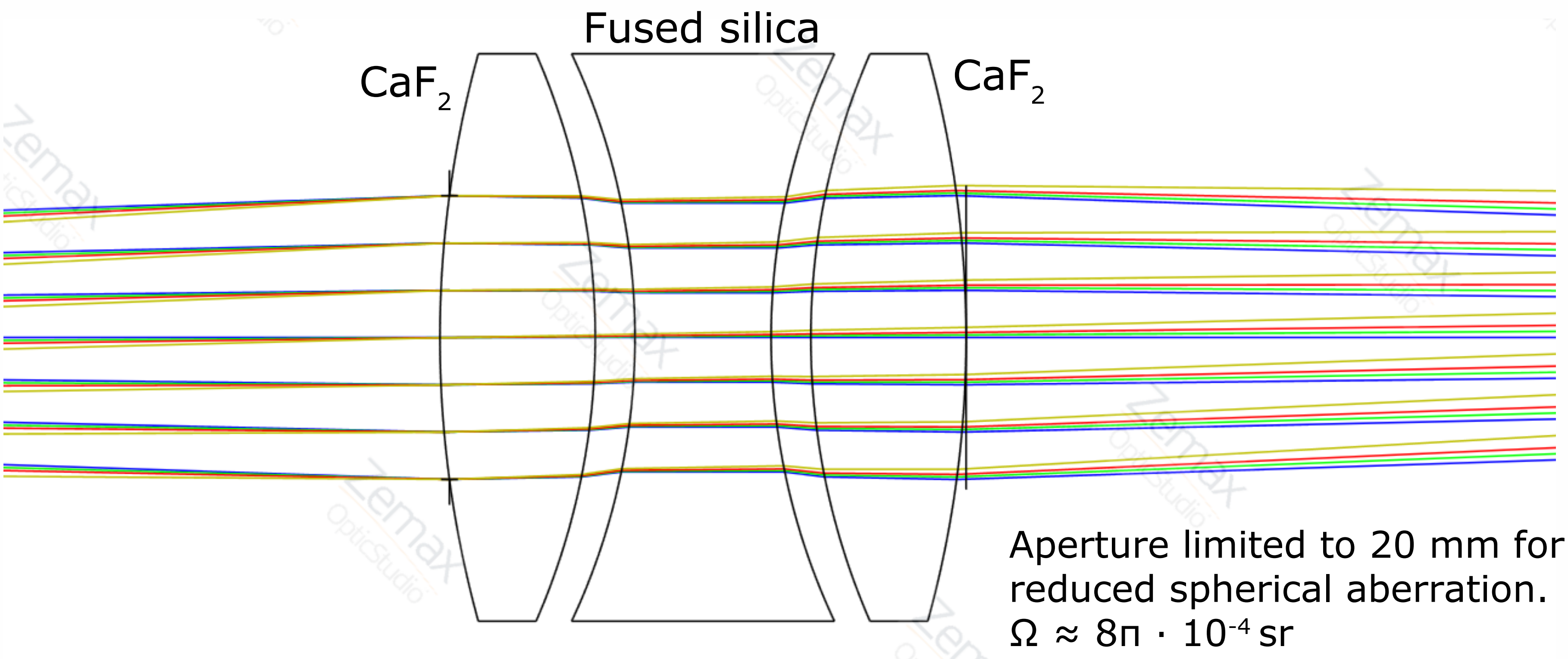
| Projectile | Gas | λ [nm] | σ [cm²] | I [A] | $\eta_{pc}$ | $N_\gamma$ [$s^{-1}$] | 1/$N_\gamma$ [s] |
|---|---|---|---|---|---|---|---|
| electron | $N_2$ | 337.1 | $1.5 \cdot 10^{-23}$ | 5 | 0.2 | 1.2 | 0.8 |
| electron | $N_2$ | 391.4 | $9.1 \cdot 10^{-19}$ | 5 | 0.2 | $7.5 \cdot 10^{4}$ | $1.3 \cdot 10^{-5}$ |
| proton | $N_2$ | 391.4 | $3.7 \cdot 10^{-20}$ | 1 | 0.2 | $6.1 \cdot 10^{2}$ | $1.6 \cdot 10^{-3}$ |
| electron | Ne | 585.4 | $1.4 \cdot 10^{-20}$ | 5 | 0.05 | $2.9 \cdot 10^{2}$ | $3.5 \cdot 10^{-3}$ |
| proton | Ne | 585.4 | $4.7 \cdot 10^{-22}$ | 1 | 0.05 | 1.9 | 0.5 |

# Optics: requirements

- Good transmission in the near UV, at least in the region 300 to 400 nm
- Good resolution, well corrected geometrical and chromatic aberrations
- A magnification of about 1 (absolute value) due to the relatively low resolution of the double MCP stack of at most 20 lp/mm
- Relatively large working distance to allow the placement of the detector system at d > 400 mm from the beam axis
- Large acceptance, a solid angle of about $4\pi \cdot 10^{-4}$ sr desirable
- Total depth of field (DOF) up to 15 mm with reasonable blur; can be relaxed if an appropriate setup geometry is used: camera looking perpendicular to the curtain plane or application of the Scheimpflug principle

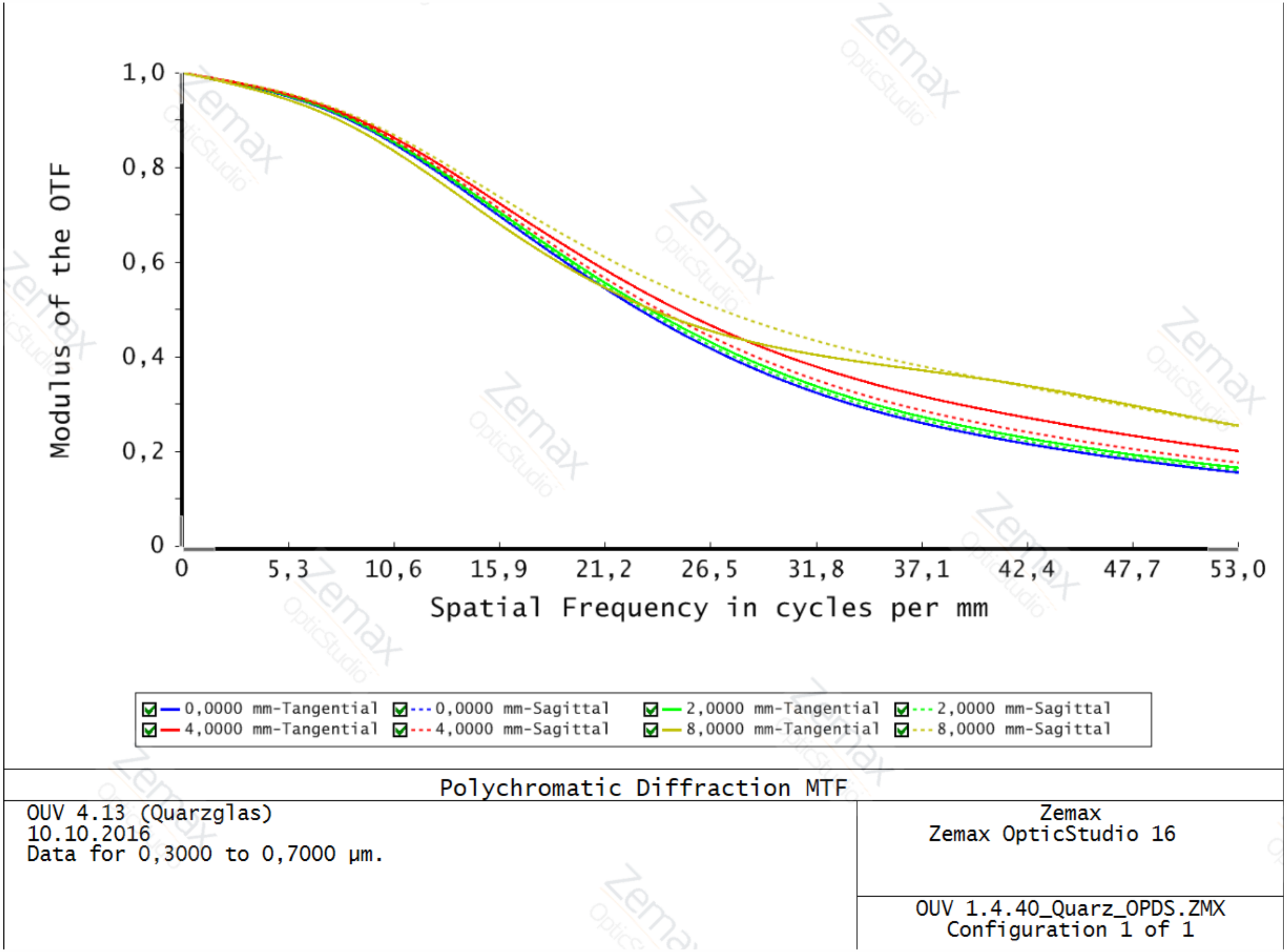
# Optics: commercially available lens (part 1)

Optimized for 1:-1 imaging
Focal length (EFL): 160 mm
Maximum aperture: 40 mm
Mount diameter: 50 mm
Mount length: 54 mm
Thread: M48x1

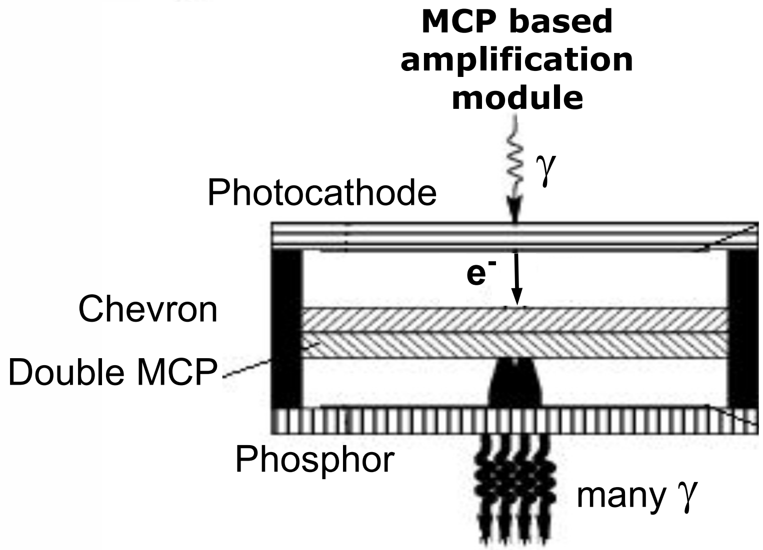



Aperture limited to 20 mm for reduced spherical aberration.
$\Omega \approx 8\pi \cdot 10^{-4}$ sr

# Optics: commercially available lens (part 2)

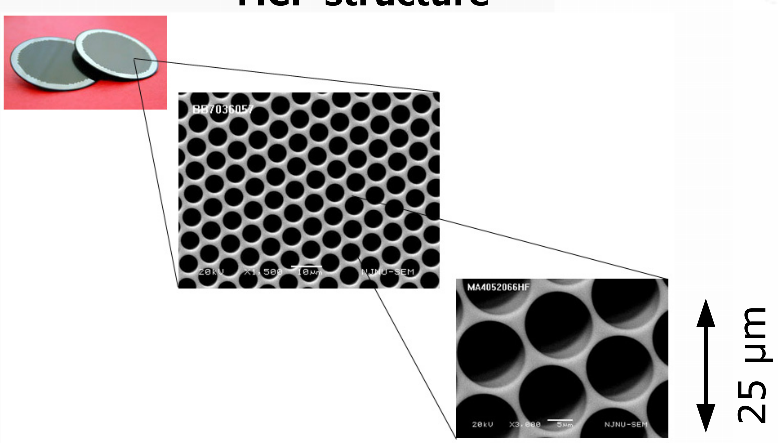


# Image intensifier working principle





MCP structure



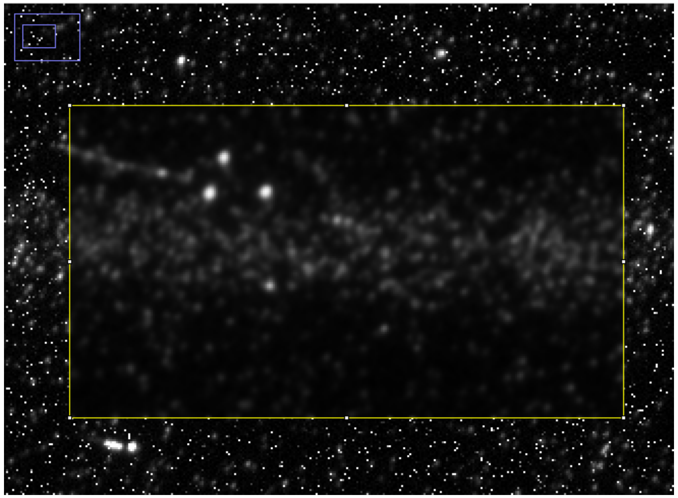
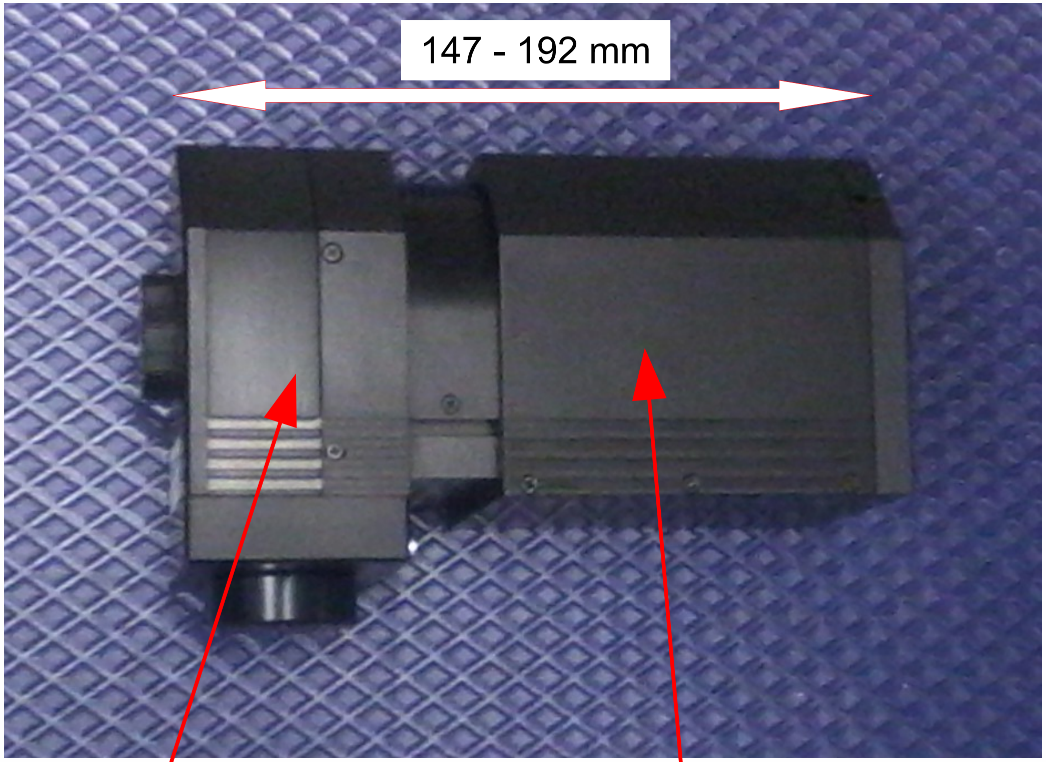



Image from $5\cdot10^{8}$, 300 MeV/u $^{238}U^{73+}$ ions in $N_2$, p= $5\cdot10^{-3}$ mbar.

# The ProxiKit PKS 2581 TZ-V 25 µs

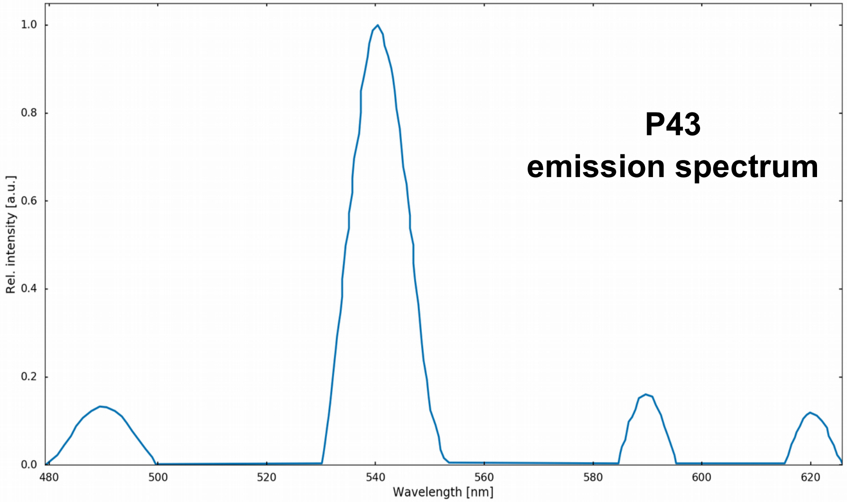



Double MCP based image intensifier and associated electronics modules

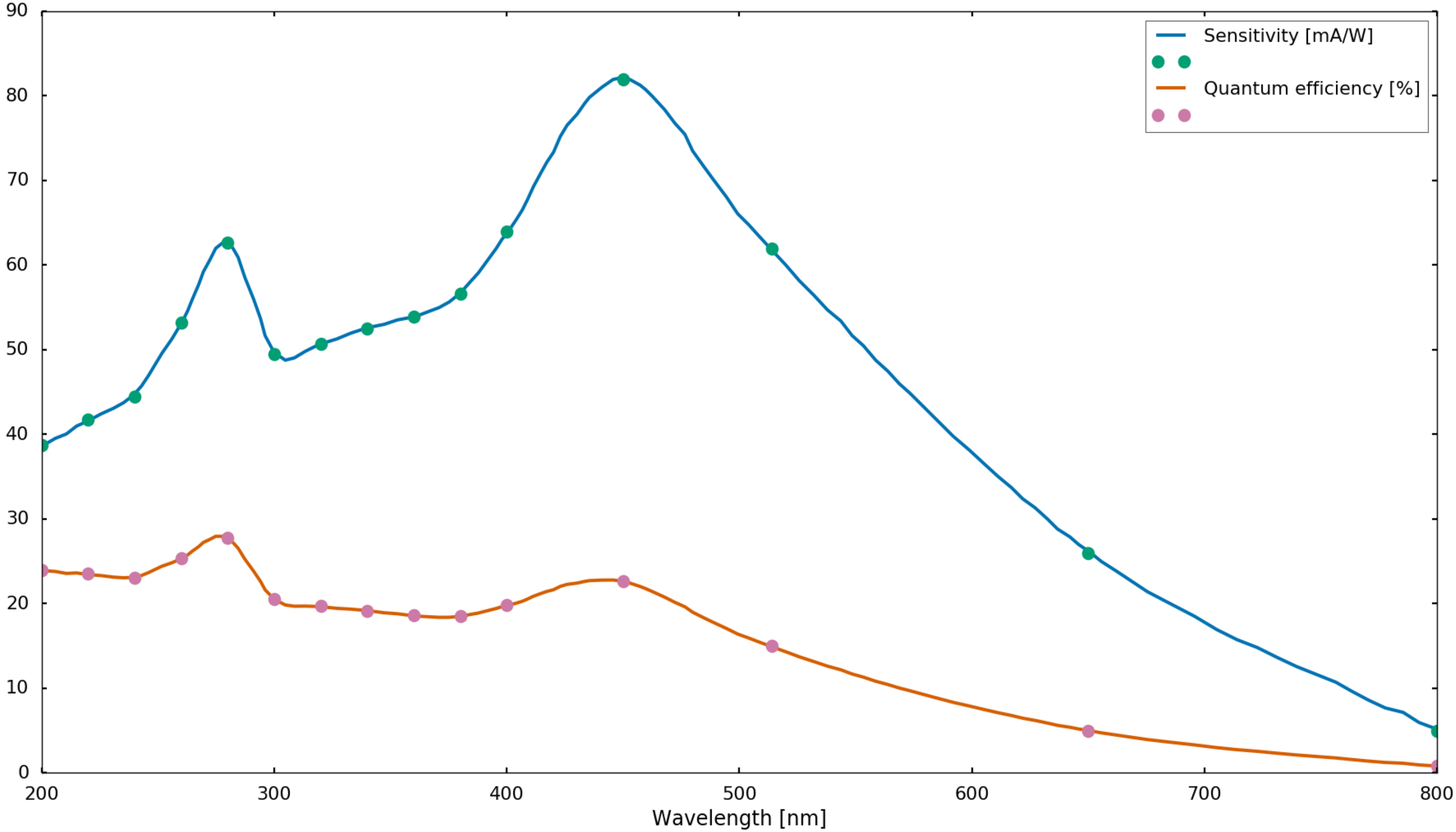
Relay optics module to image the phosphor screen onto the camera chip

**Features:**

– UV enhanced S20 photo-cathode
– P43 phosphor screen
– TTL gate: 25 µs to ∞, $f_{max}$ = 1 kHz
– Flexible, user serviceable relay optics based on a Schneider Componon 12 lens offering many image ratios, e.g. 18:11 & 25:11
– Any camera with C-mount mechanics or adaptable to it can be used, as long as the detector is sensitive in the visible wavelength range as emitted by the P43



# UV enhanced S20 spectral response

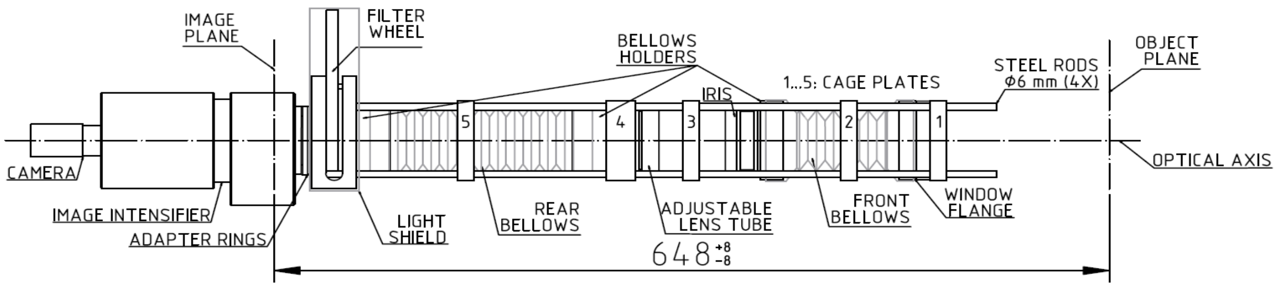


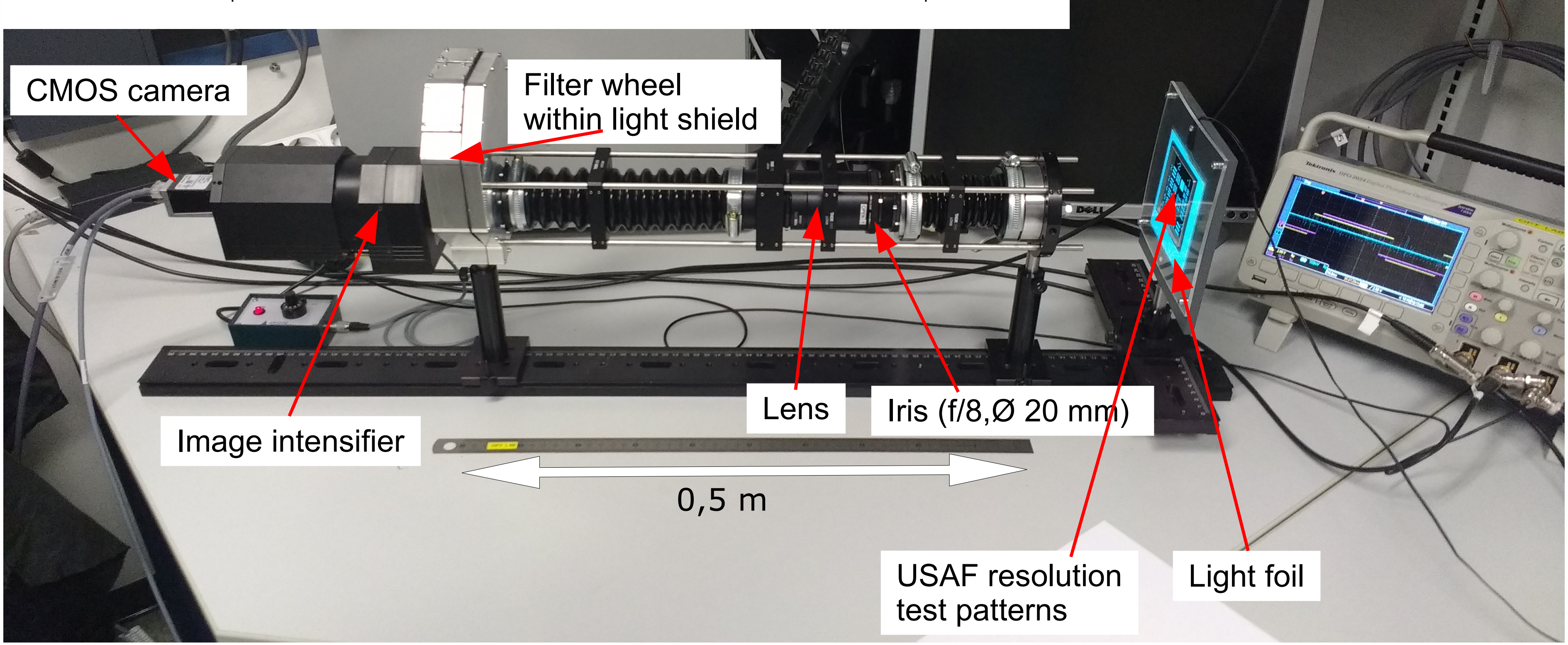

Based on data delivered by the manufacturer

# The acA1920-40gm CMOS camera

| Seller/ Manufacturer | Sensor | Resolution | Video Output | Exposure time | Trigger | I/O | Power (lowest voltage) |
|---|---|---|---|---|---|---|---|
| Rauscher/ Basler | Sony 1/1.2" IMX249, CMOS, 5,86x5,86 µm², Global Shutter | 1920x1200 | Mono 8bit, 12bit, 12bit packed | 34 µs @ 8bit/ 40 µs @ 12bit – 10 s or trigger width | *Hardware Trigger:* Pulse-Edge, Pulse-Width *Trigger Modes:* Trigger Width, Sequence | 1x ISO IN 1x ISO OUT 1x GP IN/OUT | PoE (36V)/ 12V DC via 6-Pin Hirose |


# Optomechanics

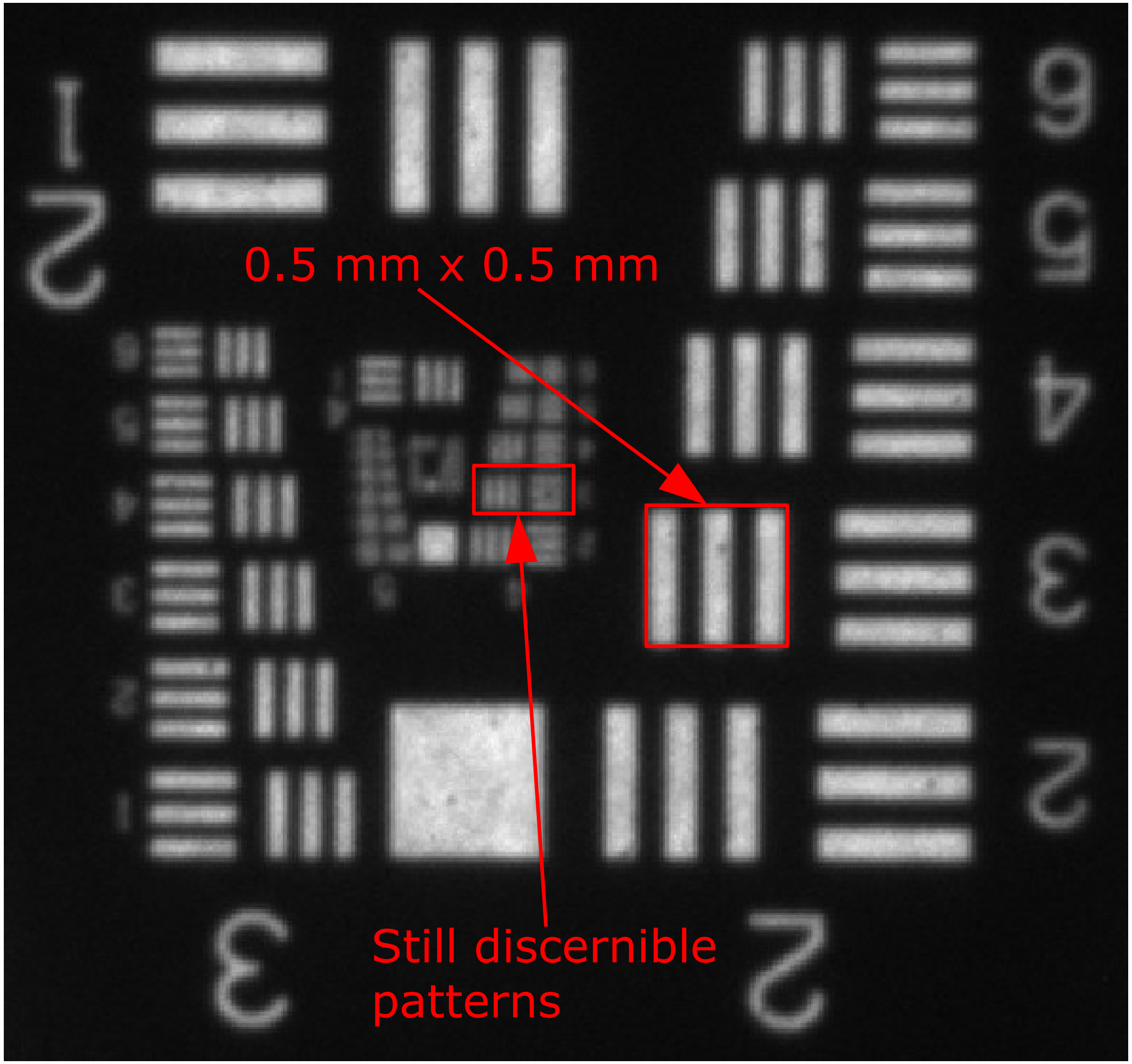



*NOTE: Not all parts are yet available.*

*Acknowledgements: C. Andre for her help during setup preparation.*

# Test image (central part)



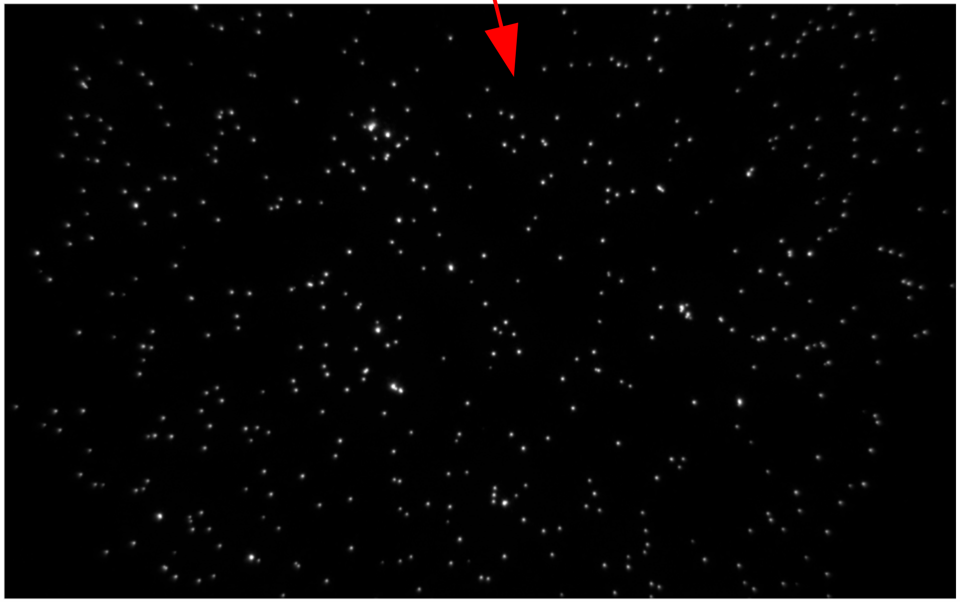

Results:
– Resolution up to 20 lp/mm
– Magnification @ MCP: 0.93 ± 0.1

**Note:** The DOF has been estimated to be 4.5 ± 0.5 mm

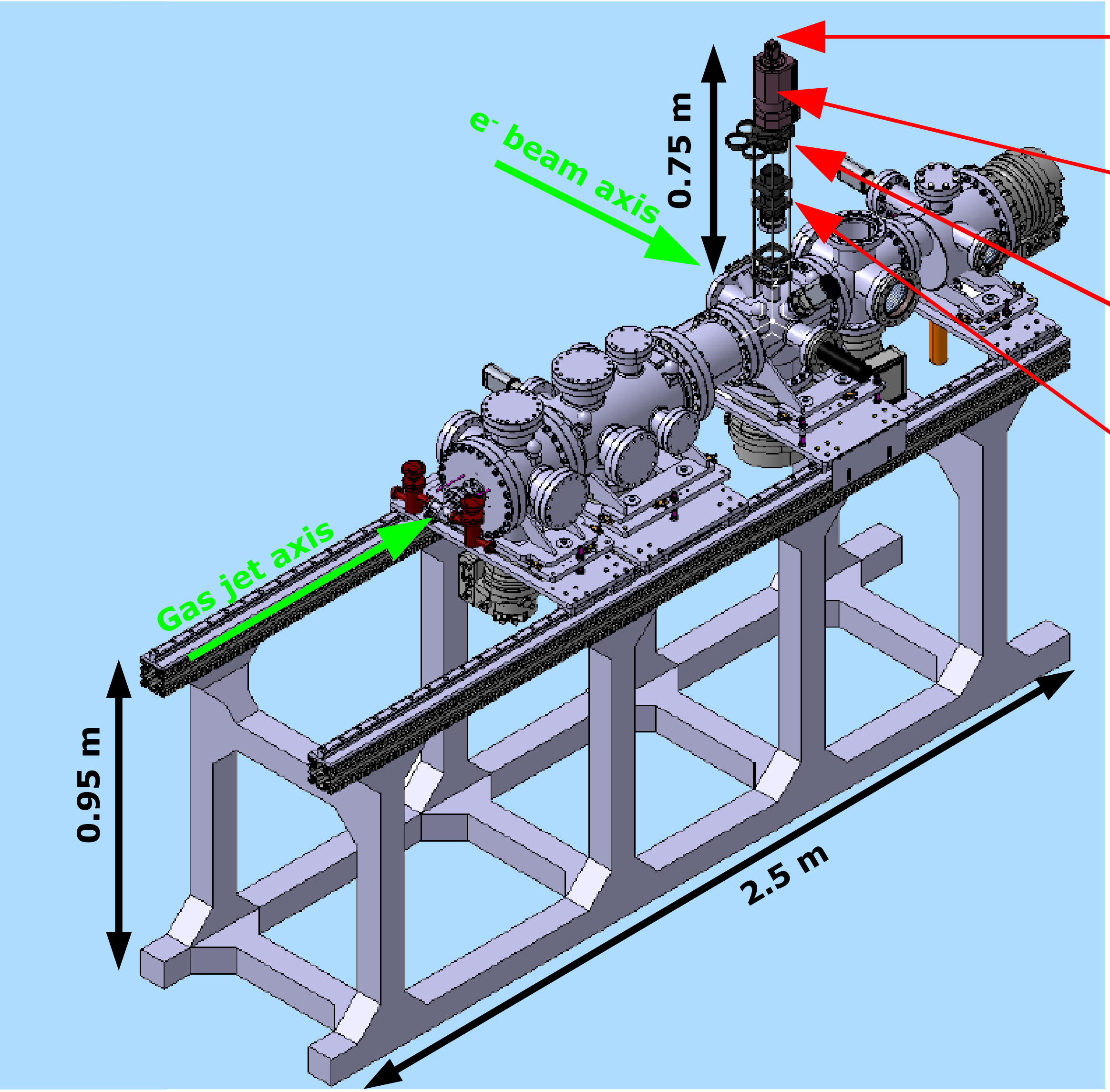
# Effectivity of light shielding

Image obtained with the image intensifier at maximum amplification attached to the new setup and with the input window covered. The room was lit as usual.

Image obtained with the protective cap mounted at the input of the image intensifier and at maximum amplification. The room was lit as usual.



# Overview of future setup




CMOS camera

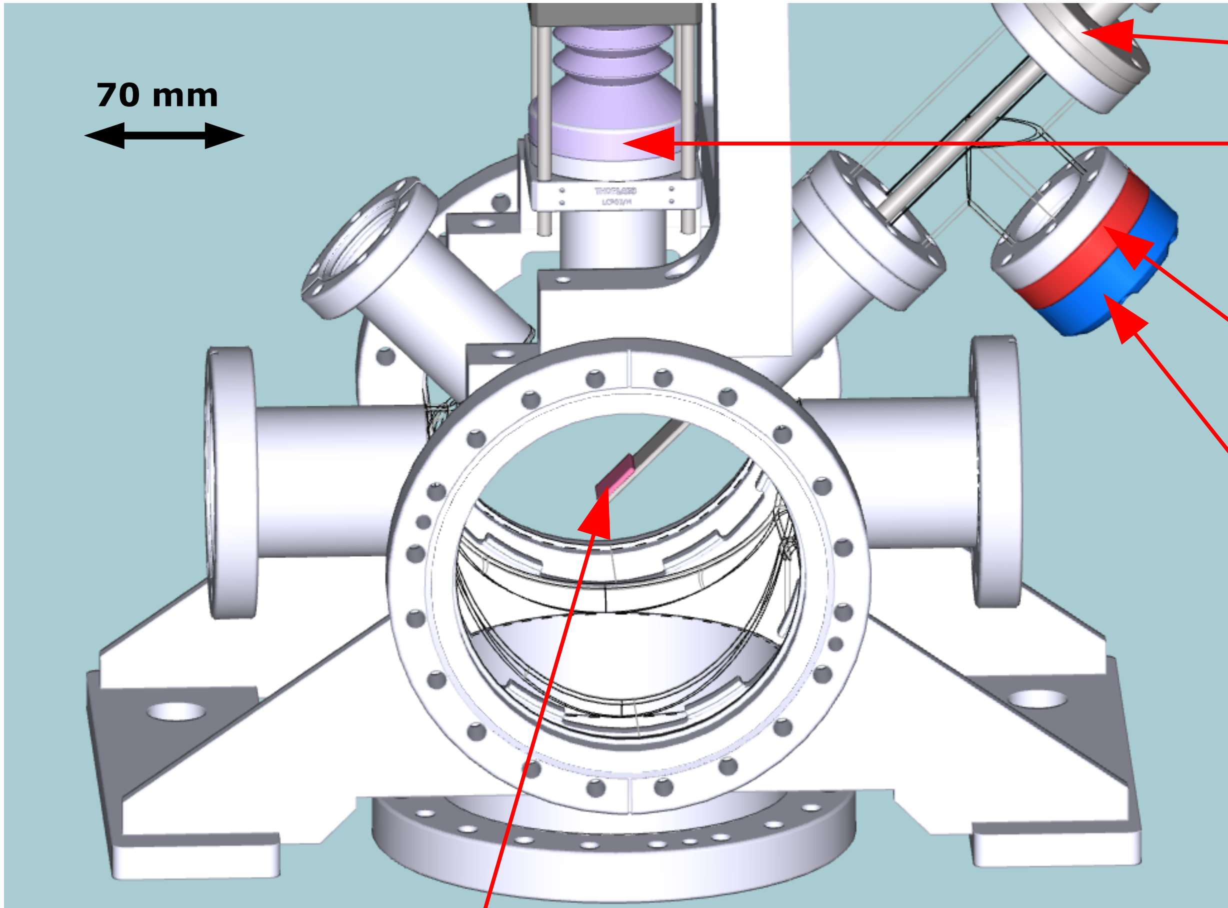
Image intensifier with relay optics

Filter wheel

Apochromat triplet optimized for 1:1 imaging, f=160 mm

**Note:** For a more detailed and up-to-date CAD model see the presentation of Elena Barrios Diaz

# Adjustment target




Mechanical feed-through

BIF setup

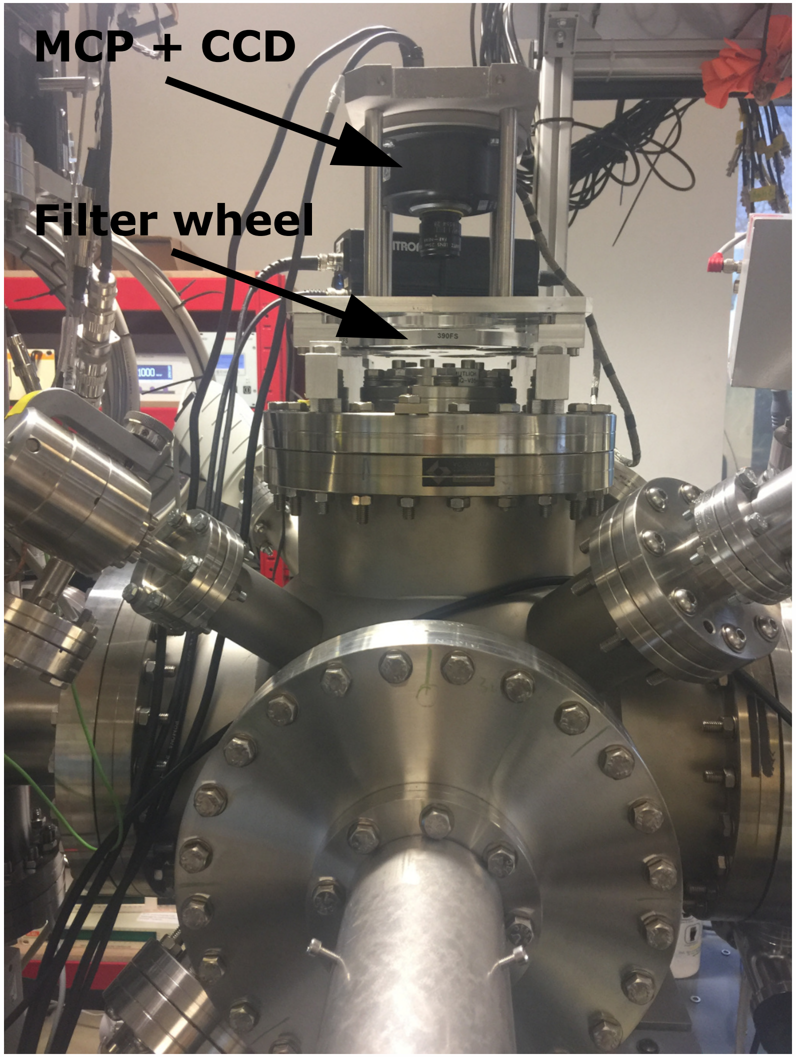
Vacuum window

LED holder add-on

$Al_2O_3$ plate with calibration pattern

**Note:** A solution based on LEDs placed in vacuum, as used successfully at GSI, is not possible because of the much stricter vacuum conditions.

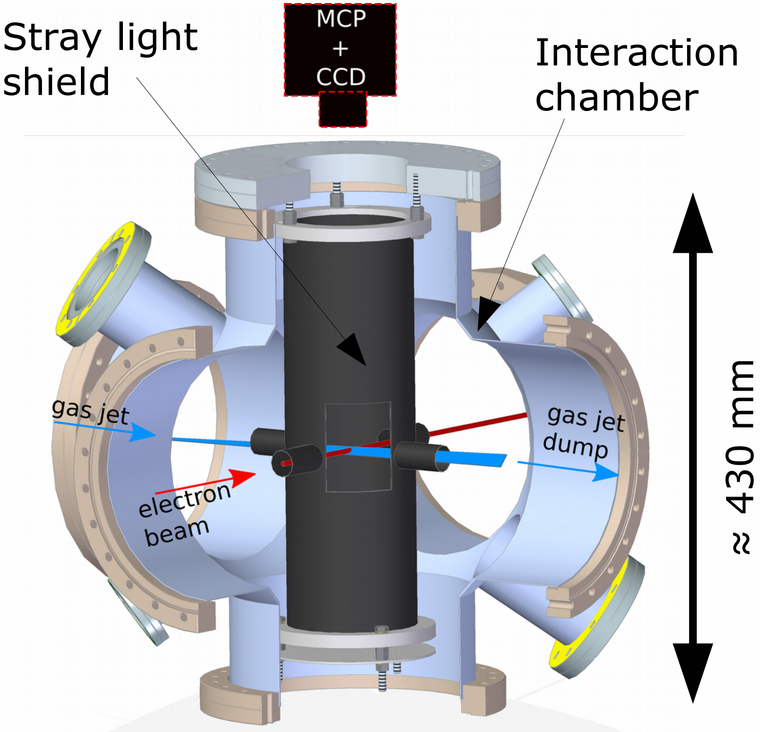
# Preliminary test setup at Cockcroft



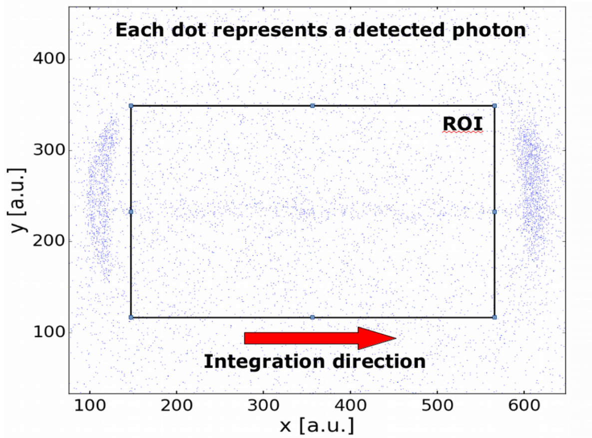

BIF setup:
- Proxivision image intensifier with chevron double MCP
- Basler A311f CCD camera
- Pentax B2528-UV objective, f=25 mm, F#=2.8-16, transmission band 230–800 nm
- Filter wheel with 10 nm bandwidth filters at 337, 390, 430 & 470 nm

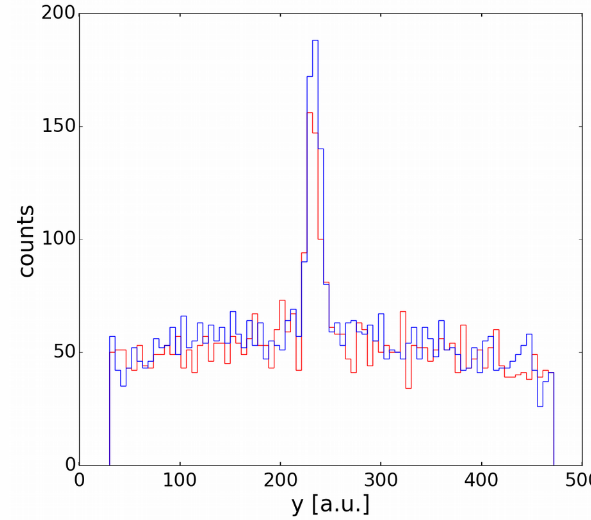
Gas jet:
- $N_2$
- Density ≈ $2.5 \cdot 10^{10}$ $cm^{-3}$
- Thickness ≈ 0.4 mm
- Width ≈ 4 mm

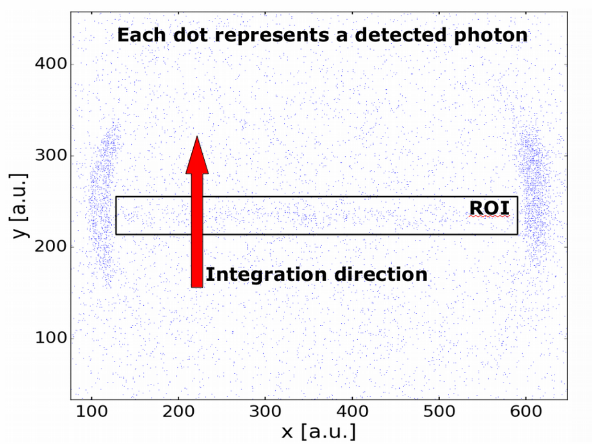
Electron beam:
- E < 5 keV
- I < 20 μA
- Φ ≈ 1 mm

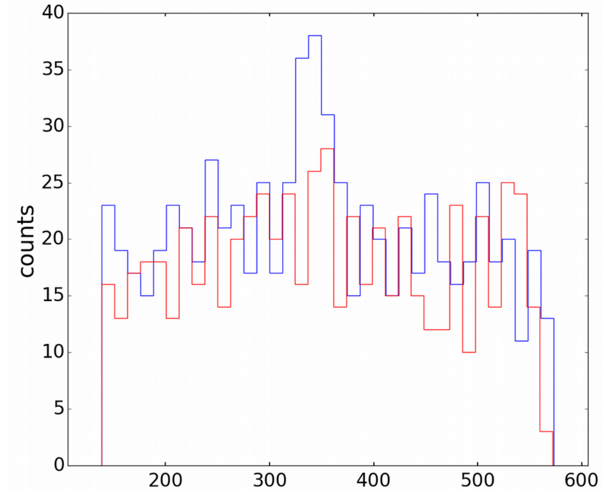


# First signals at Cockcroft




Images to the left have been obtained by centroiding, $t_{int}$ ≈ 1000 s. **Red histograms:** measurement without gas jet. **Blue histograms:** first successful measurement with gas jet. Because of the low number of photons, the histogram representing the longitudinal profile uses a lower number of bins.

# Conclusions and outlook

- The new MCP based BIF setup has been realized and successfully tested offline
- Present not-optimised BIF setup at Cockcroft delivered promising signals
- Commissioning of and measurements with the new BIF setup on the present gas curtain installation at Cockcroft to follow **as soon as possible**
- New adjustment target still under development
- Some questions still open: influence of gas jet curtain thickness and particle dynamics on image quality, comparison between Neon and Nitrogen