# Beam Gas Fluorescence and acquisition

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# Introduction

- Goal: find best experimental conditions for Beam Induced Fluorescence measurement: type of gas, optics, image processing.
- $\sigma$ measured for e- at 1-10 keV / p+ at MeV energies, extrapolated for GeV-TeV energy range (next slide…)
- Measurement in real experimental conditions (LHC): synchrotron radiation, losses,…

$$N_{ph} = N_e \sigma \rho_{Ne} \frac{\Omega}{4\pi}$$

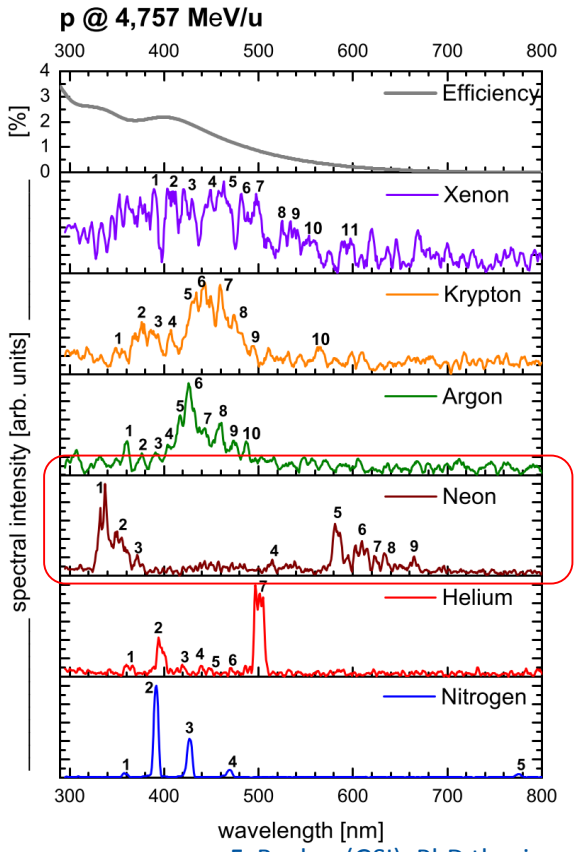
| | |
|---|---|
| $N_{ph}$ | photons per unit length & time |
| $N_e$ | number of charges (e-, p+) |
| $\sigma$ | fluorescence cross section [$cm^2$] |
| $\rho_{Ne}$ | gas number density [$cm^{-3}$] |
| $\Omega$ | optical acceptance [Sr] |

# Neon

- Data for Ne is scarce. Emission occurs between 300-400 nm ($Ne^+$) and 580-700 nm (neutral).
- Strongest (neutral) line 585.4 nm.
  Fluorescence by direct excitation (negligible cascading, no optical excitation), cross section based on $2p_1$ level excitation (Bretagne et al, J. Phys. D 1986, Puech & Mizzi, J. Phys. D 1991).
- Short life time: approx. 10 ns
- Data for electron impact up to 1 keV & protons up to 1 MeV. Extrapolated for 7 TeV protons

$$N_{ph} = N_p \sigma \rho_{Ne} \frac{\Omega}{4\pi} = 0.2 \text{ ph/bunch s cm}$$

**LOW LIGHT YIELD!**

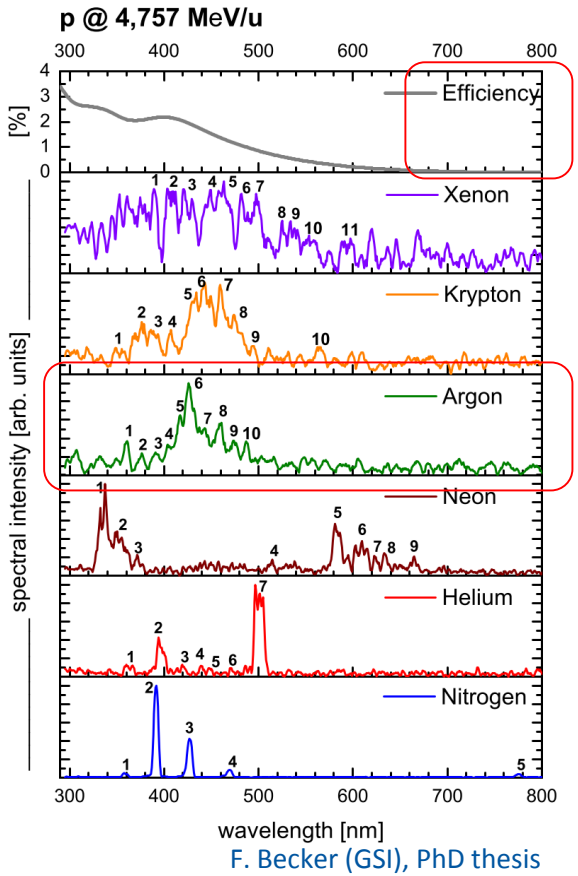


F. Becker (GSI), PhD thesis

| | |
|---|---|
| $N_{ph}$ | photons per unit length & time |
| $N_p$ | $10^{11}$ x 11400 (1 s int time) |
| $\sigma$ | **4.7 x $10^{-22}$ cm$^2$** |
| $\rho_{Ne}$ | 7.8 x $10^8$ cm$^{-3}$ @ 3x$10^{-8}$ mbar |
| $\Omega$ | 7 x $10^{-3}$ Sr (camera) |

# Argon

- Data for Ar available for electrons < 1keV. Main lines: 400-500 nm ($Ar^{+}$) and 700-800 nm (neutral). $Ar^{2+}$ negligible.
- Two neutral lines at 750.39-751.47 nm. No significant branching. Cascading present but with us life times => fluorescence cross section estimated from excitation to $2p_1$, $2p_5$ levels as Ne.
  - $\sigma_{Ar} = 5\sigma_{Ne}$ for 10 keV e-
  - $\sigma_{Ar} = 7\sigma_{Ne}$ for 7 TeV p+
- Strongest ionic line: 476.5 nm:
  - $\sigma_{Ar+} = 0.5\sigma_{Ne}$ for 10 keV e-
  - $\sigma_{Ar+} = 2\sigma_{Ne}$ for 7 TeV p+
- Detection efficiency higher at 476 than 750 nm
- Ar might prone to clustering

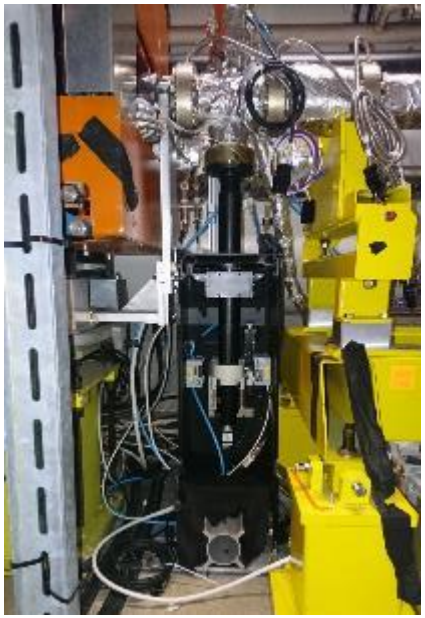


F. Becker (GSI), PhD thesis

**Ne still considered best compromise for BIF**

# LHC test

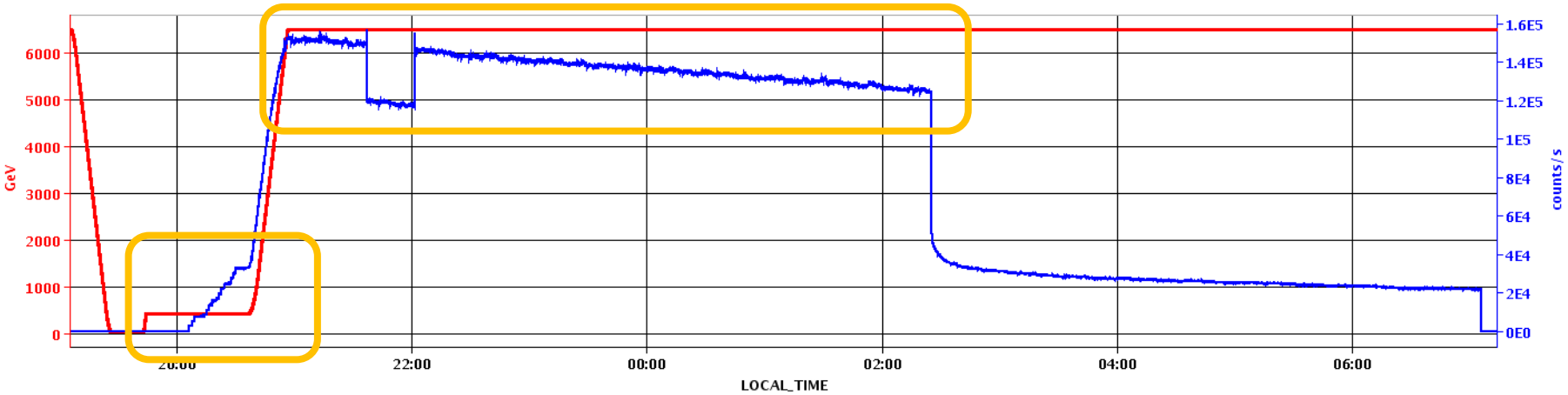
- MCP-PMT photon counting
- Time resolved measurement, 50 ps resolution over full LHC turn
- Goal: measurement of cross section and (exponential) time constant of fluorescence
- Installed YETS 17-18



- Intensified camera
- Image of horizontal beam profile (integrated over vertical plane)
- 20um resolution (15 pix per sigma at 6.5 TeV)
- Goal: beam profile
- Installed TS2

- PMT data taken during fills 6612 (603b, 25/4), 6650 (2556b, 7/5), 6693 (1887b, 15/5), injection (lower statistics) and top energy
- Camera data: 6854 (1224b, 27/6), 6891 (1452b, 6/7), 6909 (2556b, 10/7), 7232 (2556b, 28/9) injection and top energy

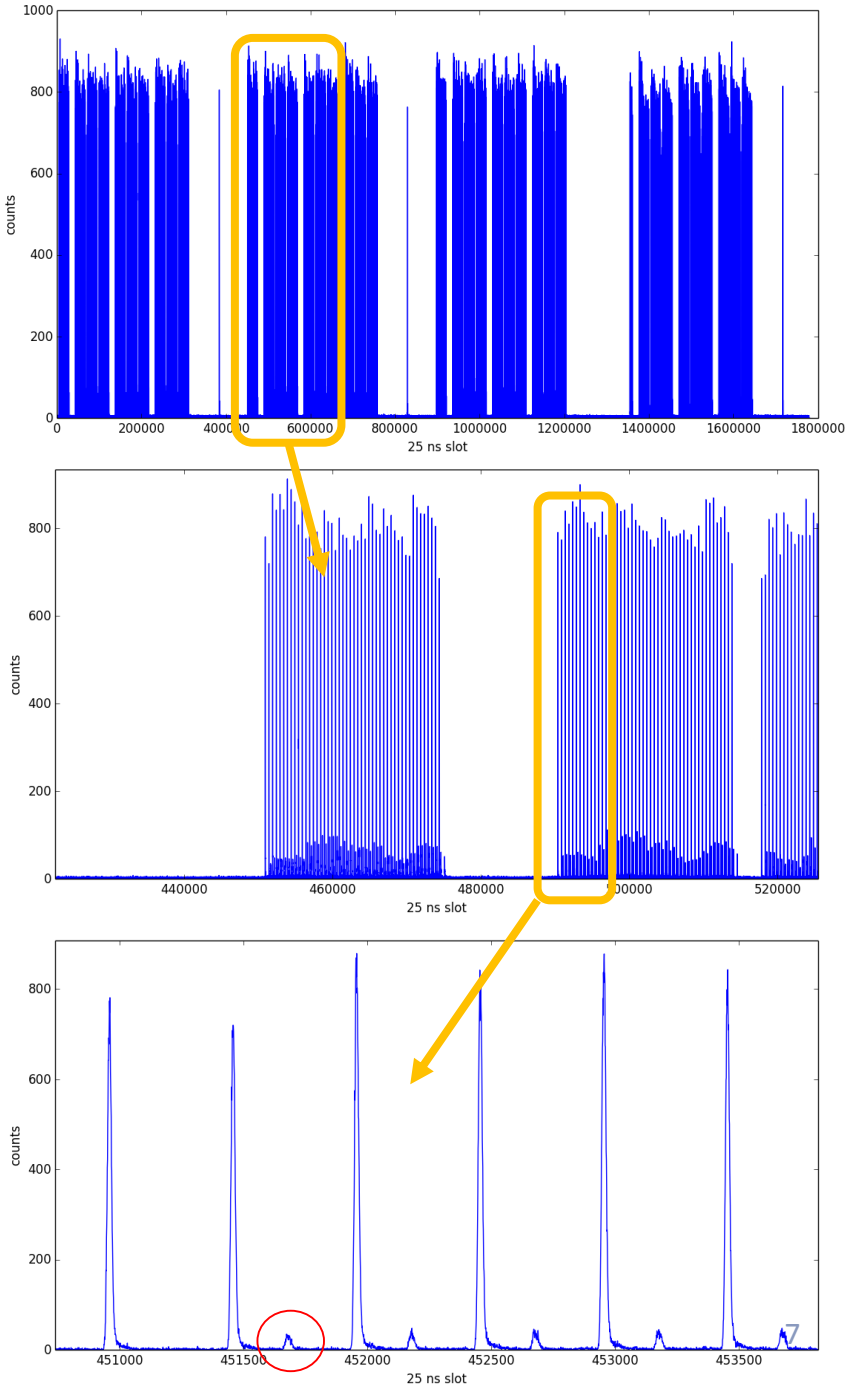
# PMT results




- 1887 bunches (physics), 2.05x$10^{14}$ protons (B1)
- Data acquired at injection energy: background (block filter) and signal (585 nm filter)
- Same at high energy (BG data around 22:00 hrs)
- At a glance:
  - Expected cps from fluorescence @ 585 nm: 5-10
  - BG (losses) cps: 1.2x$10^{5}$
  - Signal cps: 1.5x$10^{5}$

# PMT Data analysis

- Principle: use temporal data integrated over 300 s. Sum over 25 ns slots
- MCP-PMT has “negligible” afterpulsing, but enough to effect analysis > only “clean” slots used. This considerably reduces statistics (42 bunches used in a physics fill)



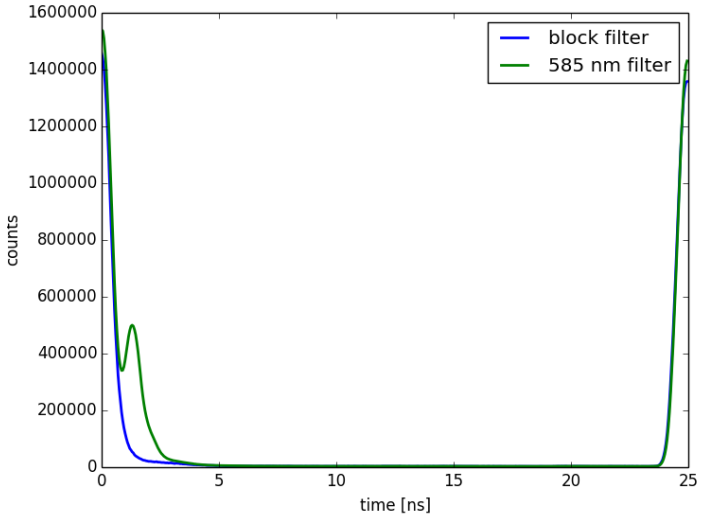

LDM SW (M. Palm, S. Bart)

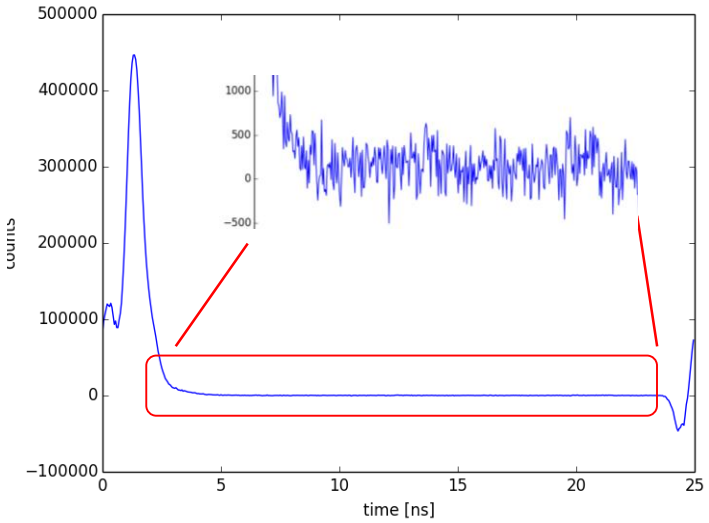
# PMT data analysis

- Overlap of 42 bunches, 300 s integration time.
- Expected fluorescence counts: 1500-1800 distributed over an exponential with tau = 10 ns
- Signal rms noise is however around 100 counts per 50 ps bin!

POOR S/N

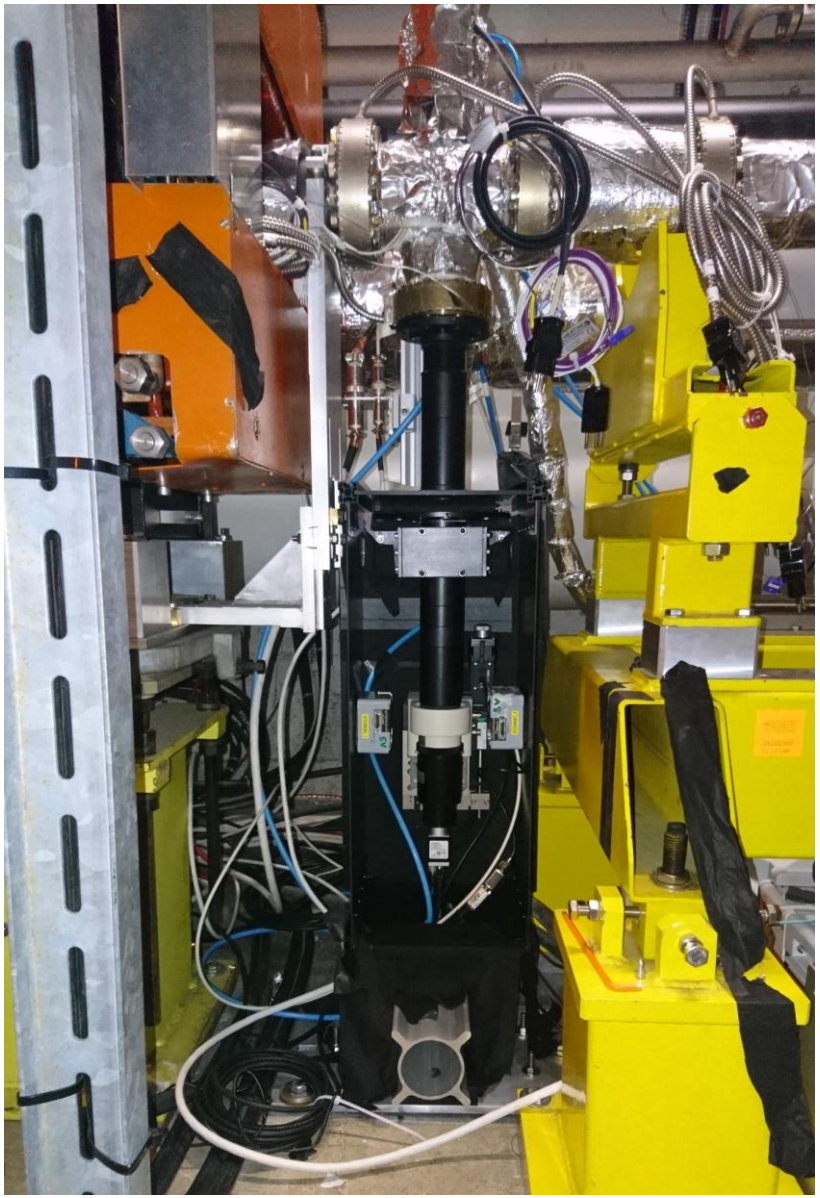
TRY IMAGING



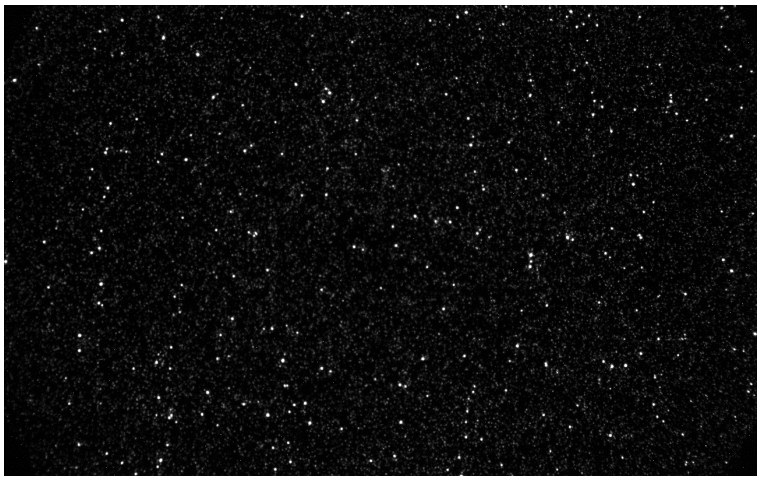



# Camera setup

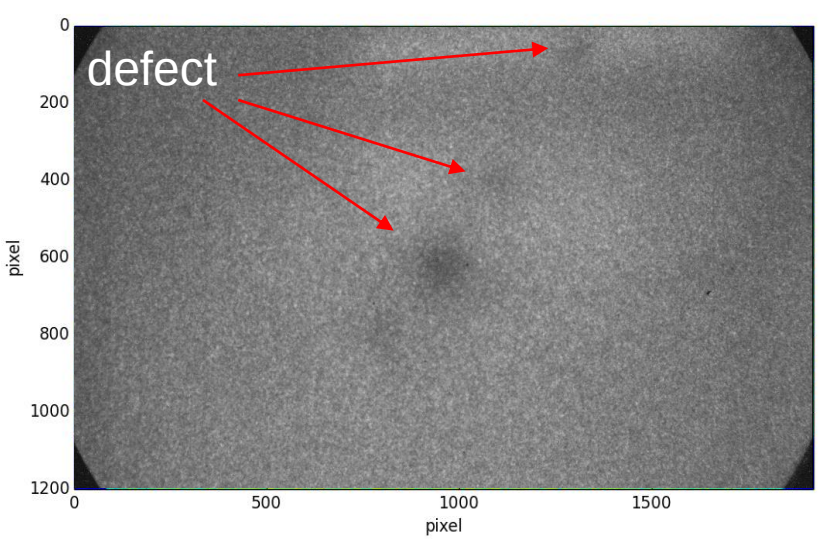
- First installation during TS1. Camera failure on 11/7 (under investigation)
- Re-installation during TS2. New camera (bialikali photocathode) mounted on 50 mm translation stage
- Optics: image formed with pair of achro doublets, f = 300 mm, 2” dia. Field depth around 5 mm, final magnification 0.3. Large optical acceptance (7 x $10^{-3}$ Sr)
- Batmon installed during TS2.

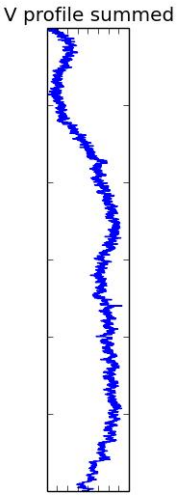


# BIF Images



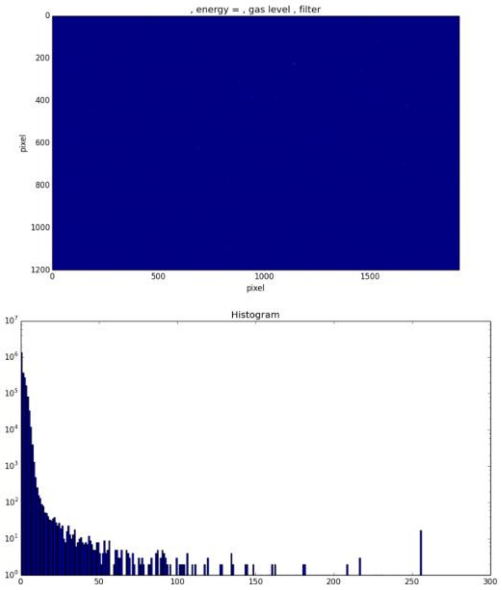
Ne at $3 \times 10^{-8}$ mbar, 2555b, 450 GeV, 400 ms exp. Time, 585 ± 20 nm filter



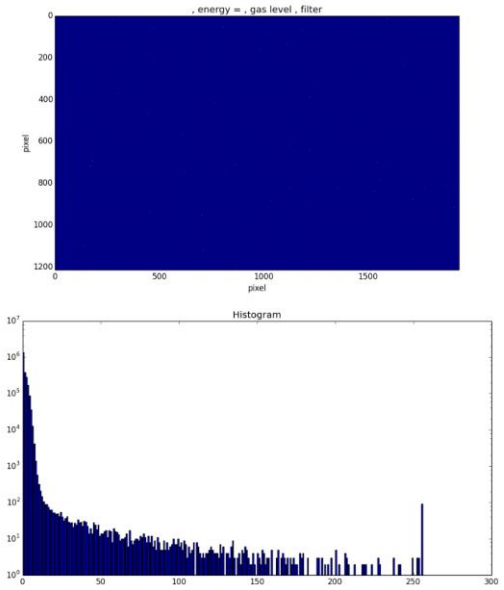




Sum of 324 images (130 s exp.time). No evidence of fluorescence

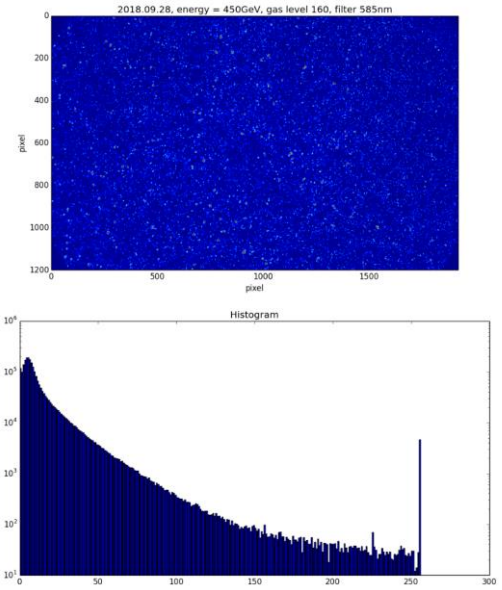
# BIF Images: threshold




intensifier off, 10 ms exp. time

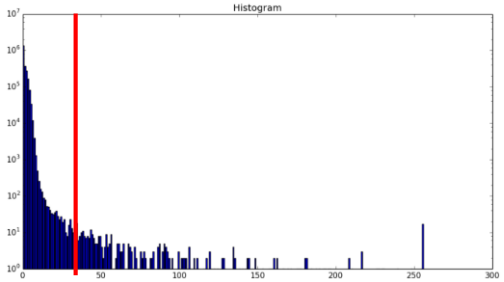


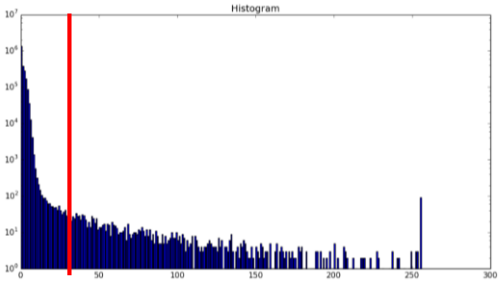

No beam, 10 ms exp. time,

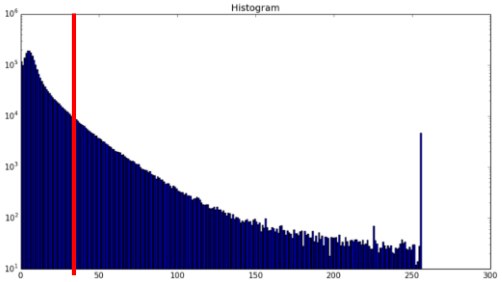



Ne at 3x10-8 mbar, 2555b, 450 GeV, 400 ms exp. time, 585 ± 20 nm filter

# BIF Images: threshold

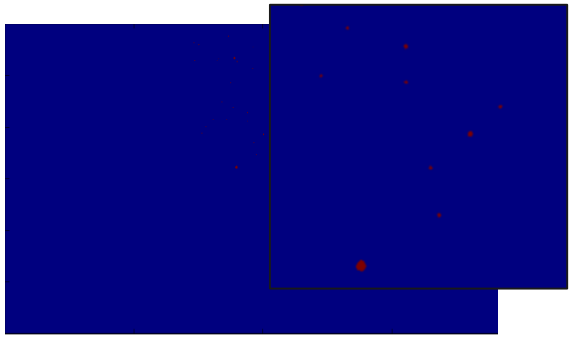


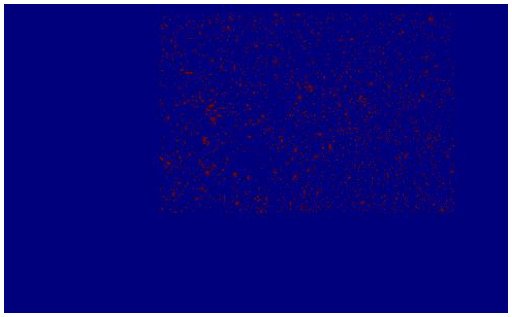




Apply threshold (35 graylevel). Count clusters with size > 5 pixels

0 clusters

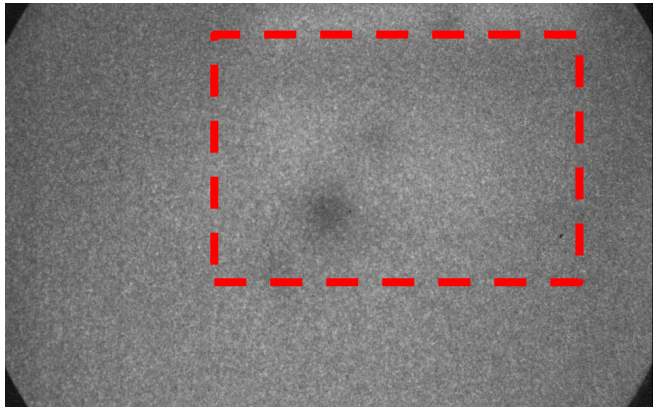


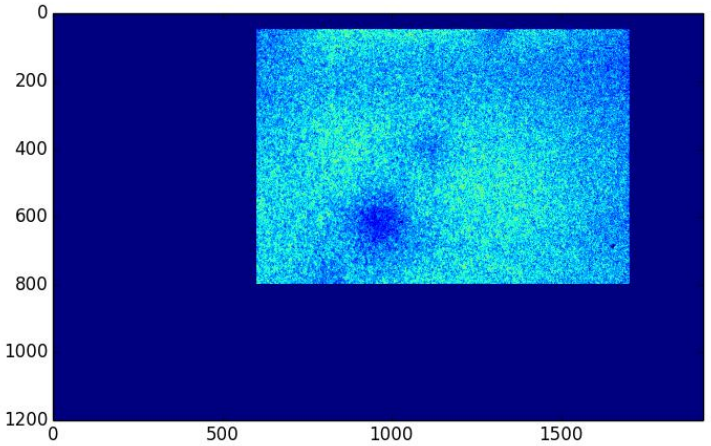
≈ 5 clusters



≈ 3000 clusters

# BIF images: threshold






Ne at $3 \times 10^{-8}$ mbar, 2555b, 450 GeV, 400 ms exp. Time, 585 ± 20 nm filter

Photons per second: approx. 8000

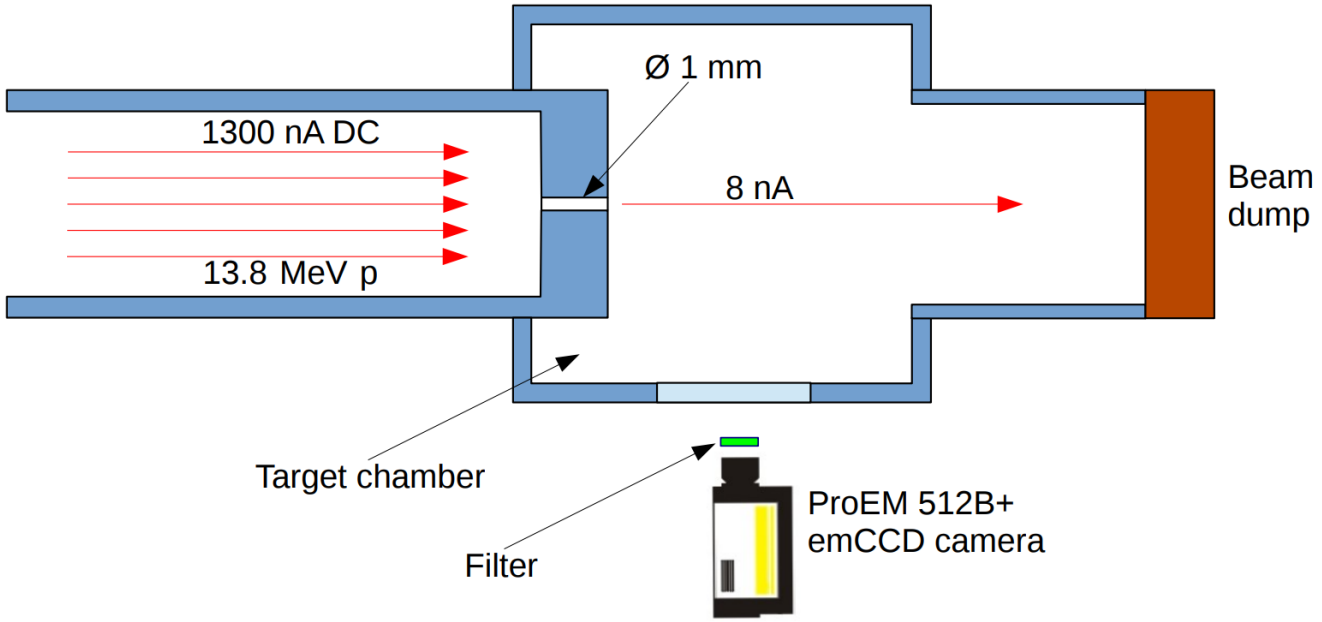
Expected fluo cps:

- 1000 ph on the MCP
- 80 ph detected (qi 8%)

Still no trace of fluo signal

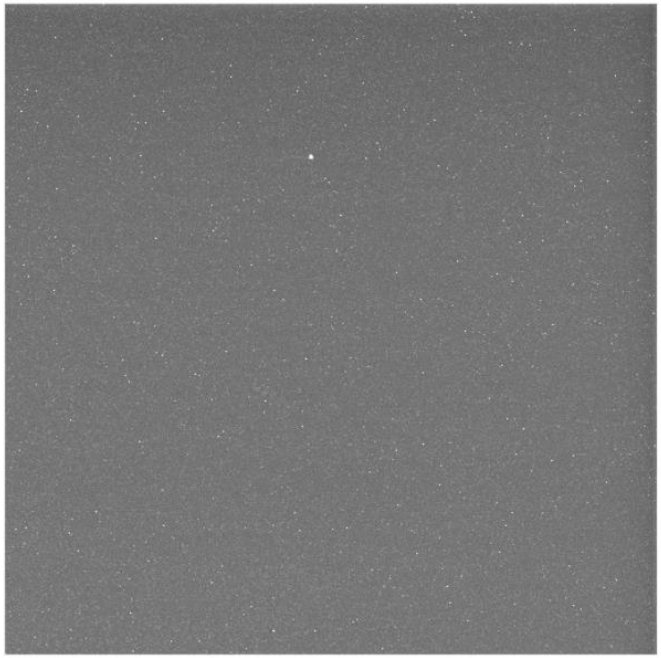
Way forward: higher gas pressure ($10^{-6}$ mbar?), Pb ions (x20 light yield)

# BIF tests at TU Munich

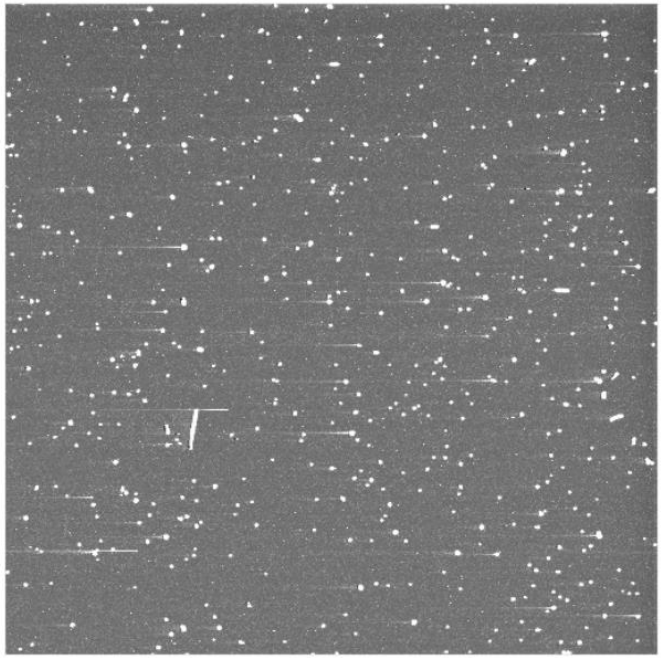



Measurements have been performed for $N_2$, Ne and Ar at pressures between $2 \cdot 10^{-4}$ and 0.3 mbar. Depending on gas different filters have been used.

# Raw data



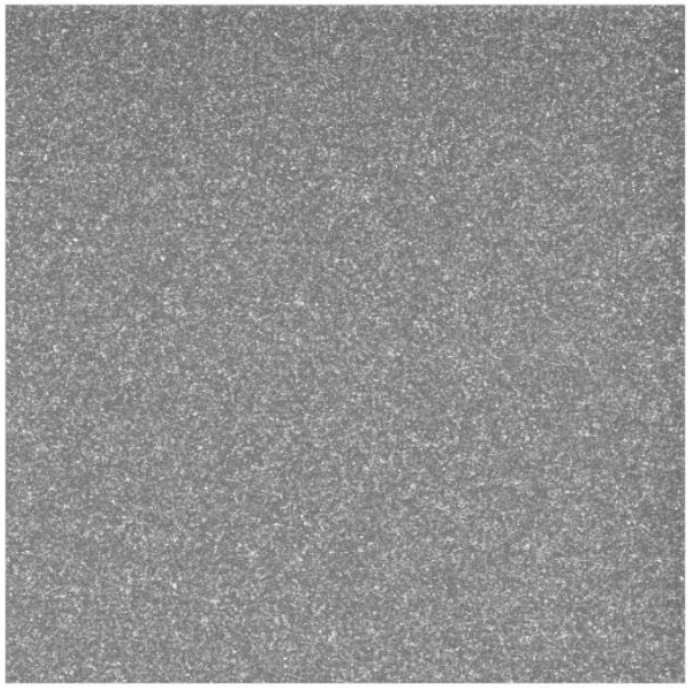
Typical background single shot image, 10 s exposure



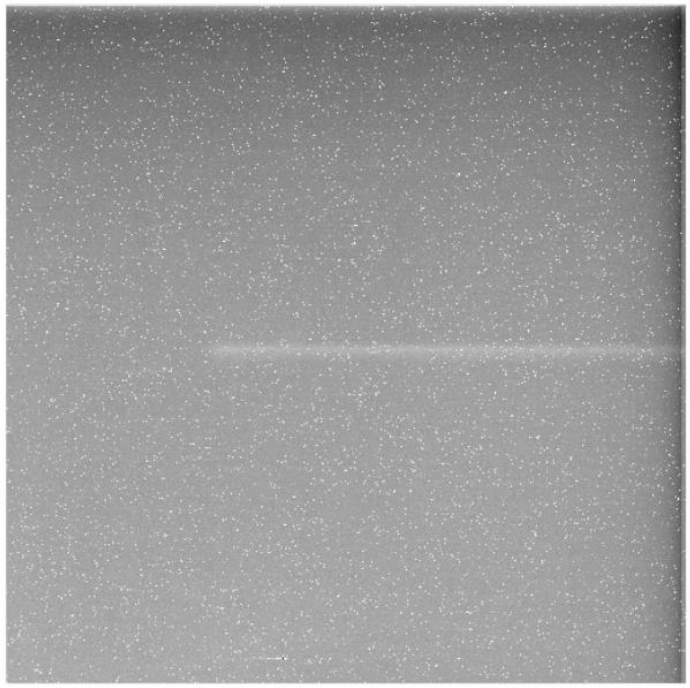
Typical single shot image with beam on, 10 s exposure

**Note:** Strongly exposed spots of several pixels due to secondary particles; stripes starting at such spots most likely due to smearing.

# Improving S/N



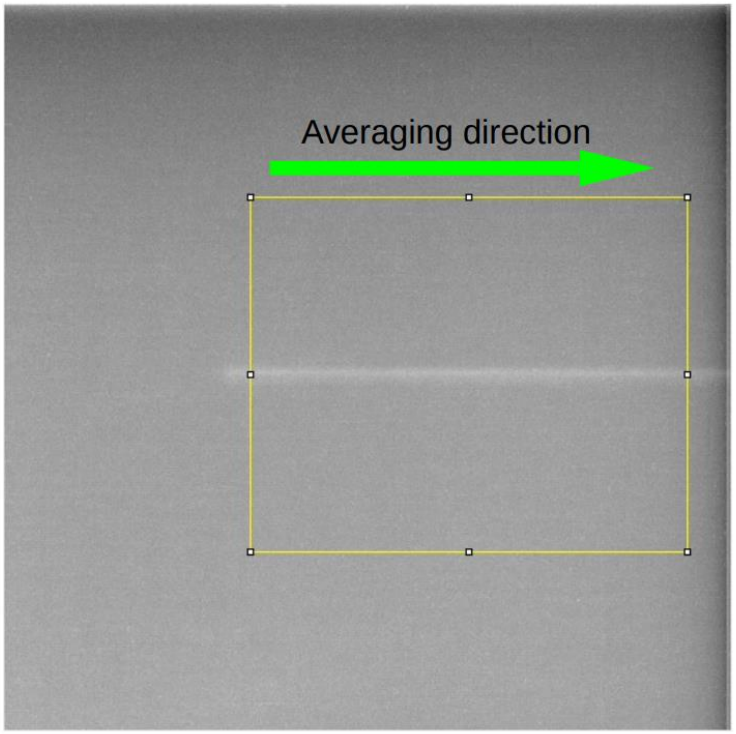
Averaging over a few 100 images doesn't help



Computing the median of the same images works

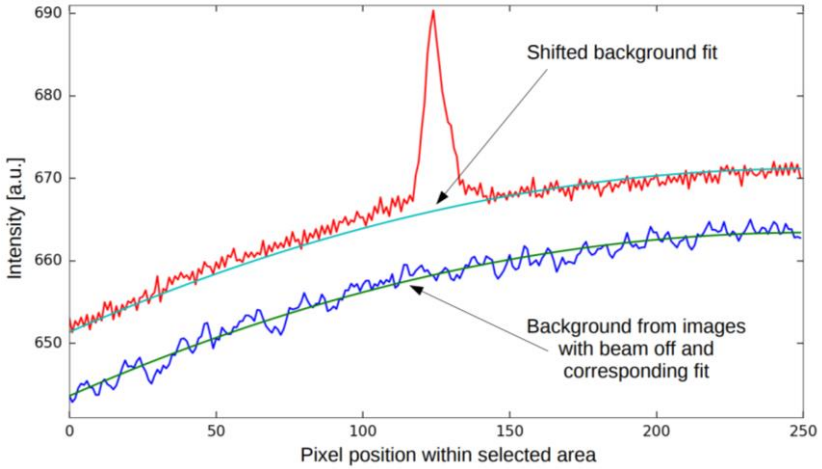
**Note:** The hot spots in the median image can be removed by a thresholded median filter applied to it (called "Remove Outliers" in ImageJ). See ~~last~~ backup slide for a short explanation of median and median filter.

# Extracting the profile

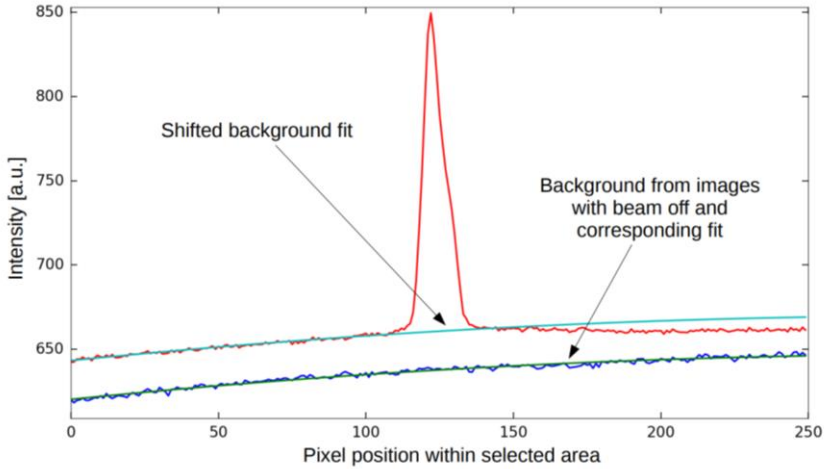



The average pixel value is computed for each row within the selected area. This is done separately for images obtained with beam on and off.

# Beam profiles

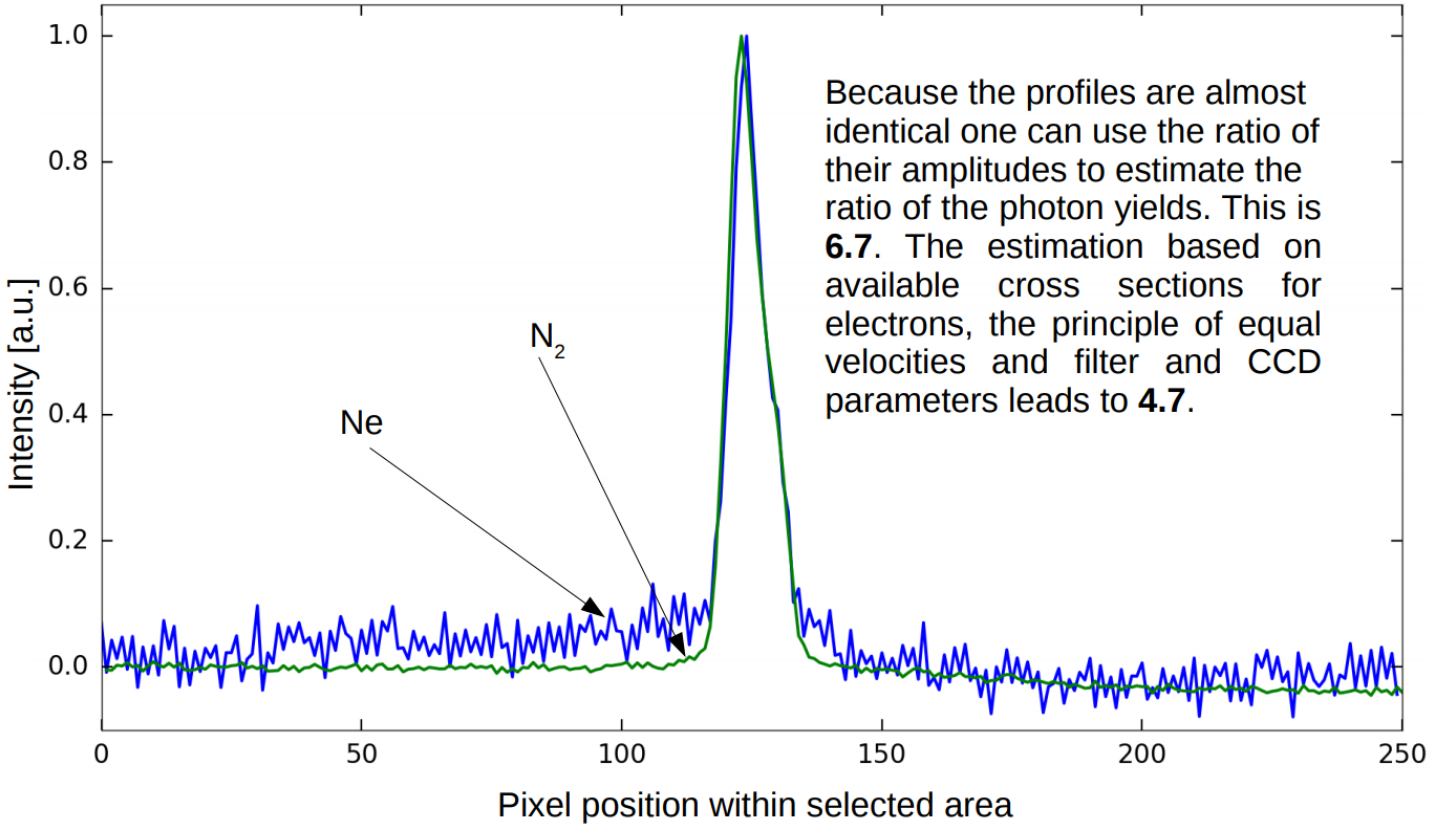



Ne at 0.03 mbar, 585.4 nm line




$N_2$ at 0.03 mbar, 391.4 nm line

# Beam profiles




**Note:** The Ne profile shows some week wings which need further investigations. Former measurements with He also showed wings which got stronger with pressure (He finally proved to be rather unsuited for profile measurements).

# Summary & outlook

- $2s_1$ Ne line at 585 nm still considered the best option: neutral, short time constant (10 ns), good sensitivity
- No BIF signal in LHC tests due to high noise level (secondaries, SR). Plan: higher gas pressure, ion runs (more light), 2 stage MCP camera
- Several learnt lessons for Beam Gas Curtain project:
  - Reduction of SR through blackening / SR stops
  - Optics (two achro doublets (LHC) or triplet (cockroft)) is OK for BIF: good resolution, high optical acceptance
  - Noise from secondary particles must be minimized: residual gas as low as possible, long optical line
- Tests at TU Munich with 13.8 MeV p+ positive: Ne /$N^+$ cross section in fair agreement with expectations

# Thanks to the BGC collaboration:

M.Ady, N.Chritin, J.Glutting, T.Marriott-Dodington, R.Jones, R.Kersevan, S.Mazzoni, A.Rossi, G.Schneider (CERN)
P.Forck, S.Udrea (GSI Darmstadt)
A. Salehilashkajani C.Welsch, H.Zhang (Cockcroft Institute and University of Liverpool)
P. Smakulski (Wroclaw University of Science and Technology)



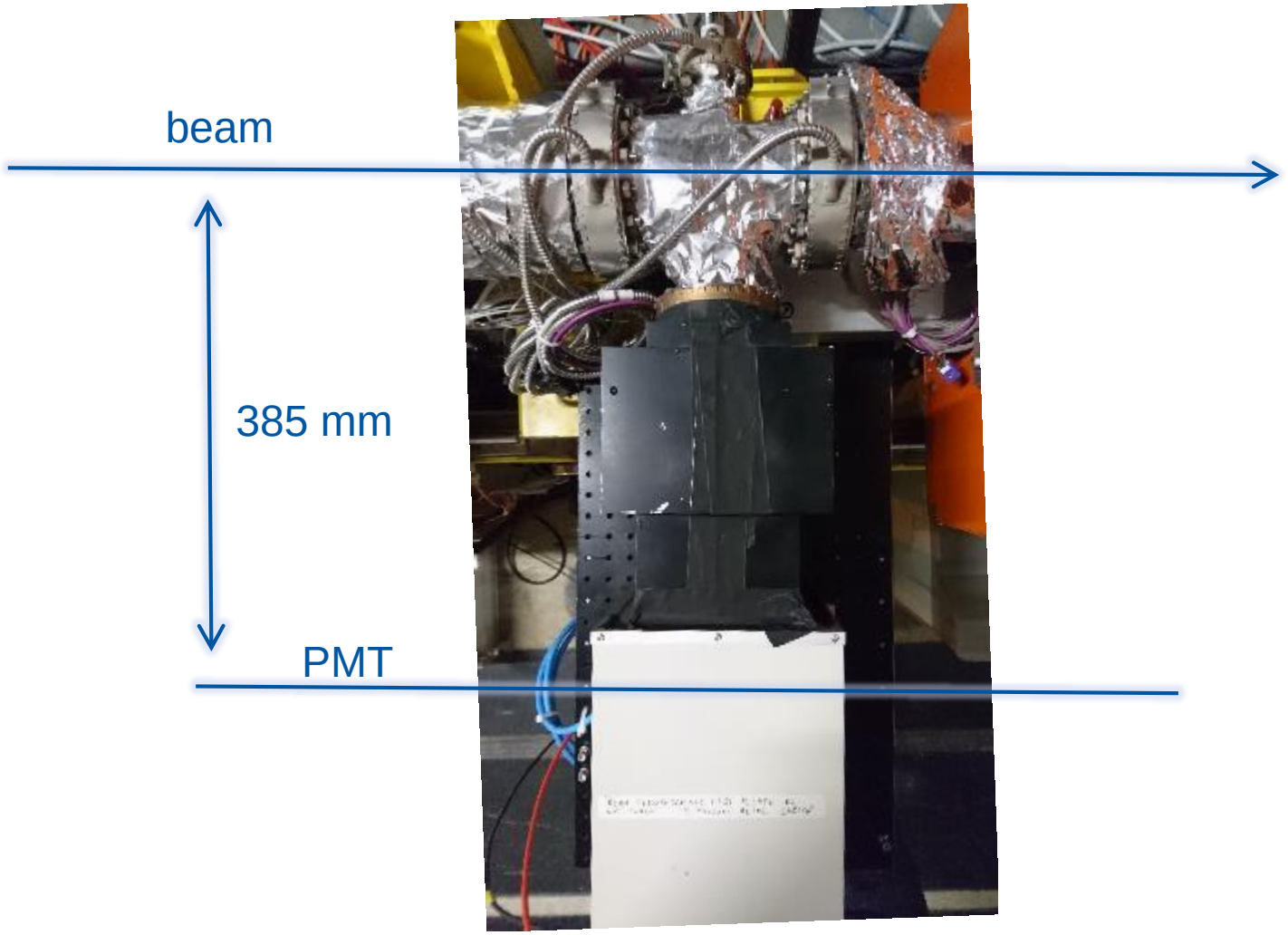



# Thanks to the team at TU Munich:

A. Ulrich, J. Wieser, R. Hampf and the team at the Tandem accelerator

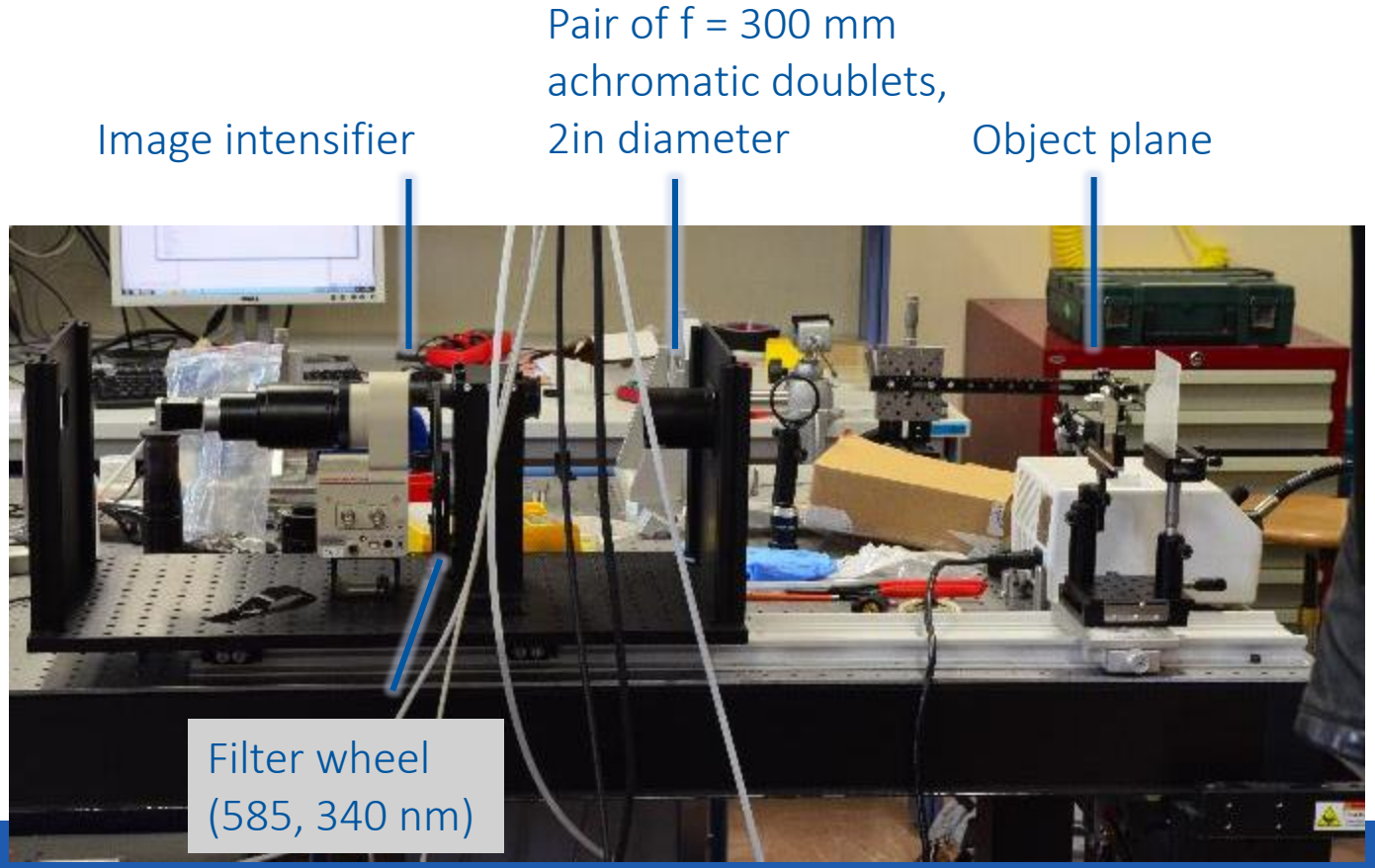

CERN

# backup slides


beam
385 mm
PMT

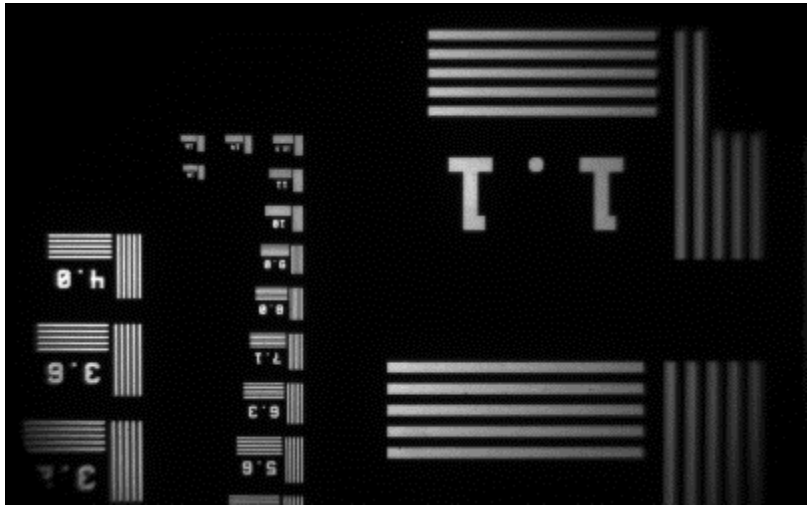
# BIF camera installation

- Camera installed in the LHC during 1st Technical Stop (18-21 June 2018)
- Optical setup (picture from final lab test)

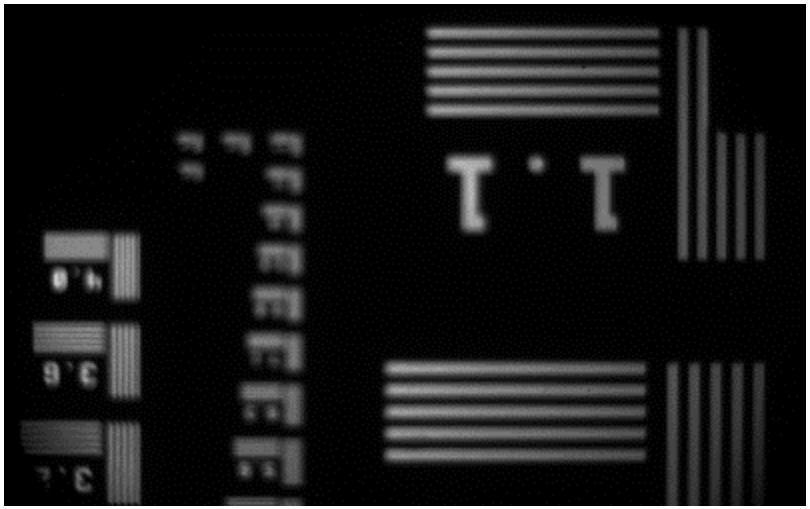


# BIF lab setup

- Overall magnification: 0.3 (0.6 at I.I. plane, then 0.5x relay lend to CMOS camera ). Equivalent pixel: approx. 20 um. => 15 pixel /sigma
- Images recorded with 585 nm filter at reference +/- 5 mm with 1 mm step for evaluating out-of-focus response



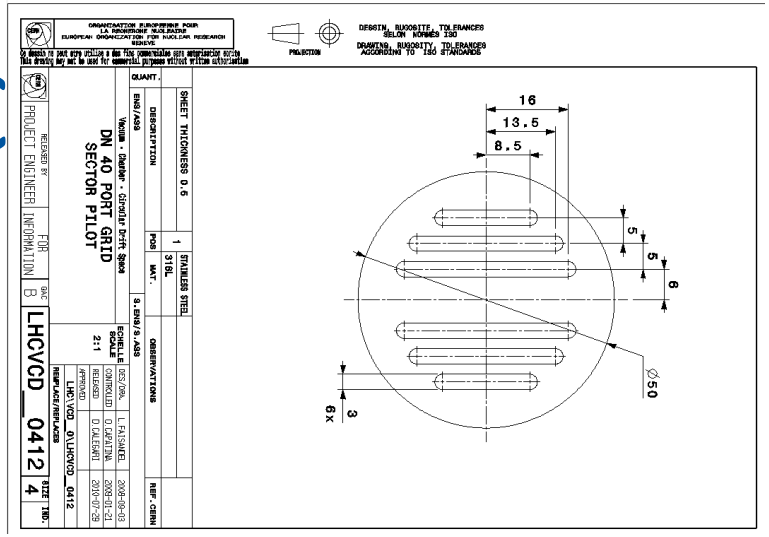
Reference plane

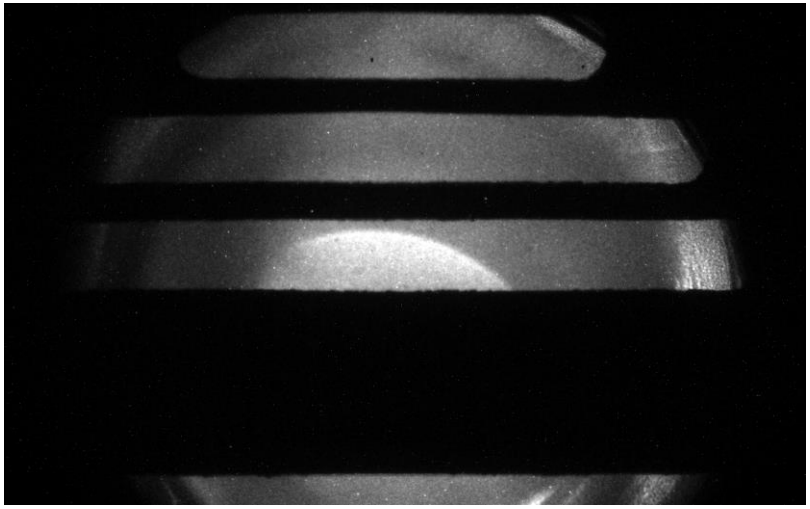


Target + 5 mm wrt reference

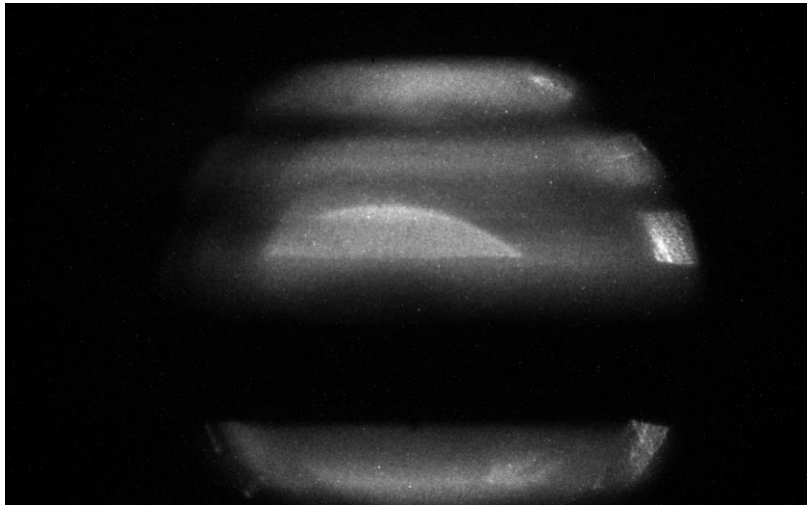
# Alignment in the LHC

- Method: found image plane using the grid in front of the hot filament gauge.
- Then whole system move downwards of 40 mm (position of beampipe centre)
- End magnification: 0.34



Hot filament grid
(BPC+40 mm)



Beam pipe centre

# Median and median filter

1, 3, 3, **6**, 7, 8, 9

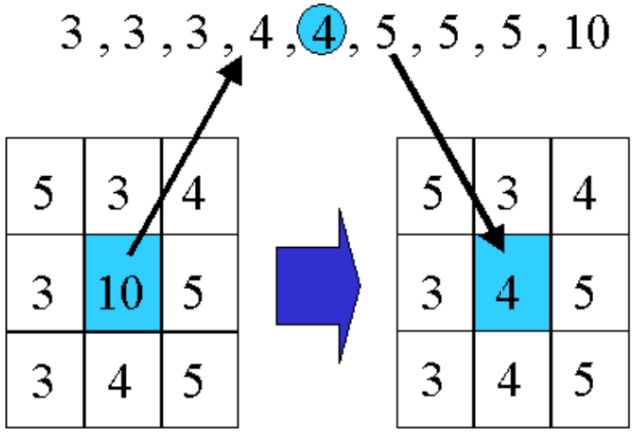
Median = **6**

1, 2, 3, **4**, **5**, 6, 8, 9

Median = (4 + 5) ÷ 2

= **4.5**

Computing the median of a series of numbers.




Applying a median filter to a set of pixels in an image. When removing outliers a threshold is set and the central pixel's value is changed just if it differs by more than the threshold from the median.