Beam Induced Fluorescence

Profile Monitoring for Targets and Transport

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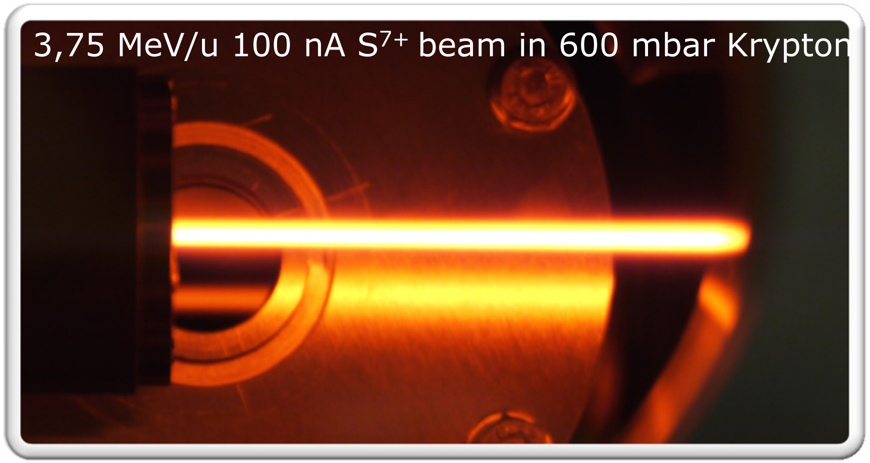
GSI BI Department



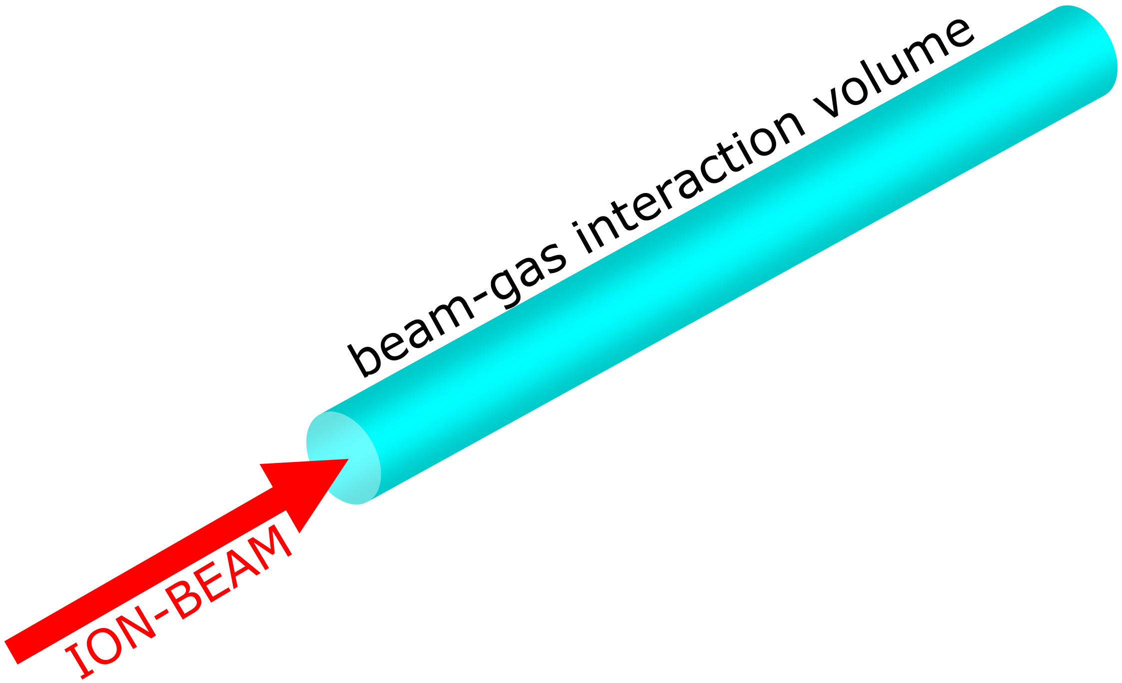
Outline

- Motivation & Introduction
  - Overview of common profile monitors
  - Benefit and principle of gas based profile measurement
- Physics – Results of Research
  - Comparison of BIF and IPM
  - Imaging spectroscopy in particular at high p
  - Issues for BIF imaging at high p
  - Reliable work around
- Summary - Outlook

Common Profile Monitors for FAIR?

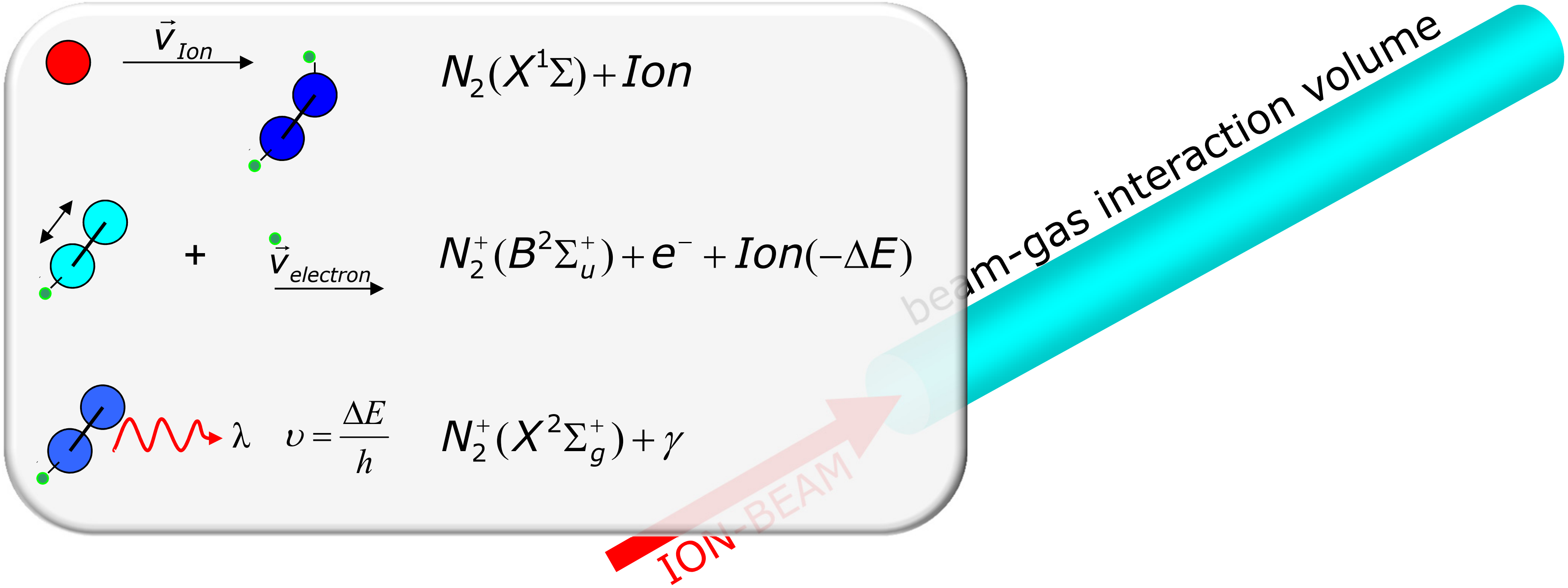
Device Name	PRO	CON
Scintillator Screen	2D image	Stability, accuracy, complex physics
OTR Screen	2D image	Scales with $q^2 \beta^2$
Wire Scanner	Sensitivity	Mechanical challenge, damage, thermionic e^-
SEM Grid	Sensitivity	Resolution, damage, thermionic e^-
Synchrotron Light	2D image	Needs magnetic field and relativistic particle
Laser Wire	2D image	Photon detachment works for H^- ions
Gas Based Systems	Work @ FAIR conditions	Scales with $\sim q^2/\beta^2$

Gas-Based Detectors



- N_2-dominated for $p \geq 10^{-8}$ mbar, H_2-dominated for lower p
- Atomic collisions drive -dE/dx → electronic stopping
- Processes to be observed: ionization and fluorescence…

Gas-Based Detectors



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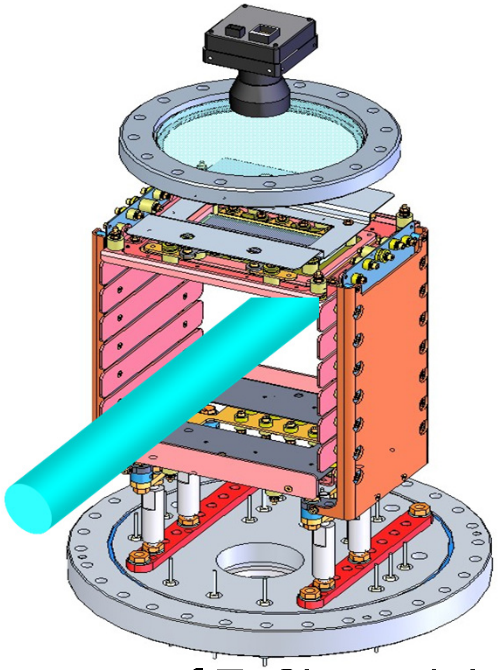
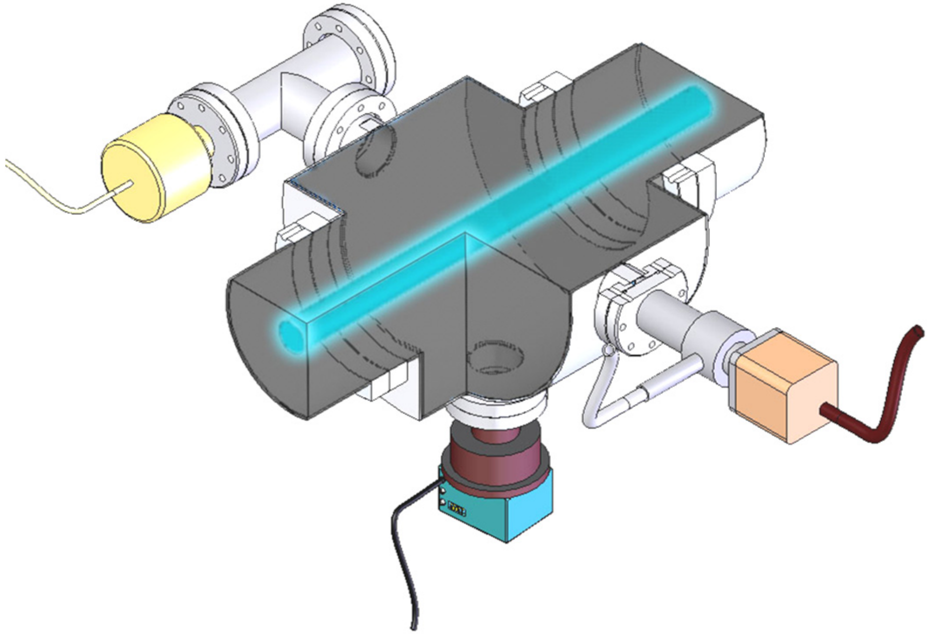
IPM and BIF Monitor

Ionization **P**rofile **M**onitor



[courtesy of T. Giacomini (GSI)]

Beam **I**nduced **F**lorescence

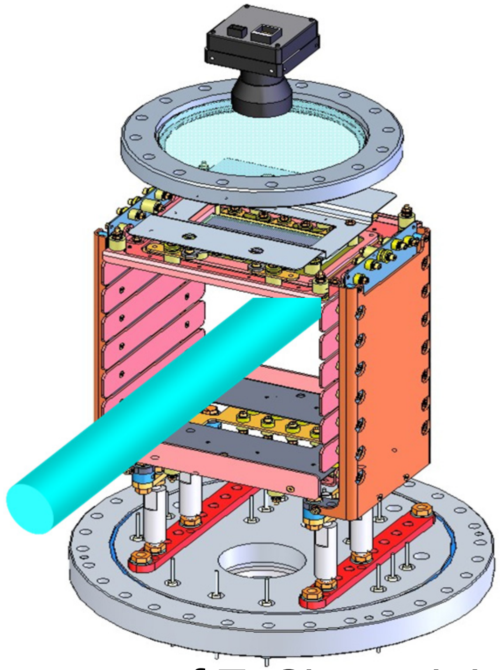


$$Y_{ionize} = \sigma_{ionize}(E,\bar{q})\, N_{Ion}\, \Delta s\, P_{Det}\, \rho$$

$$Y_{photon} = \sigma_{photon}(E,\bar{q})\, N_{Ion}\, \Delta s\, \Omega\, P_{Det}\, \rho$$

IPM and BIF Monitor

Ionization **P**rofile **M**onitor



[courtesy of T. Giacomini (GSI)]

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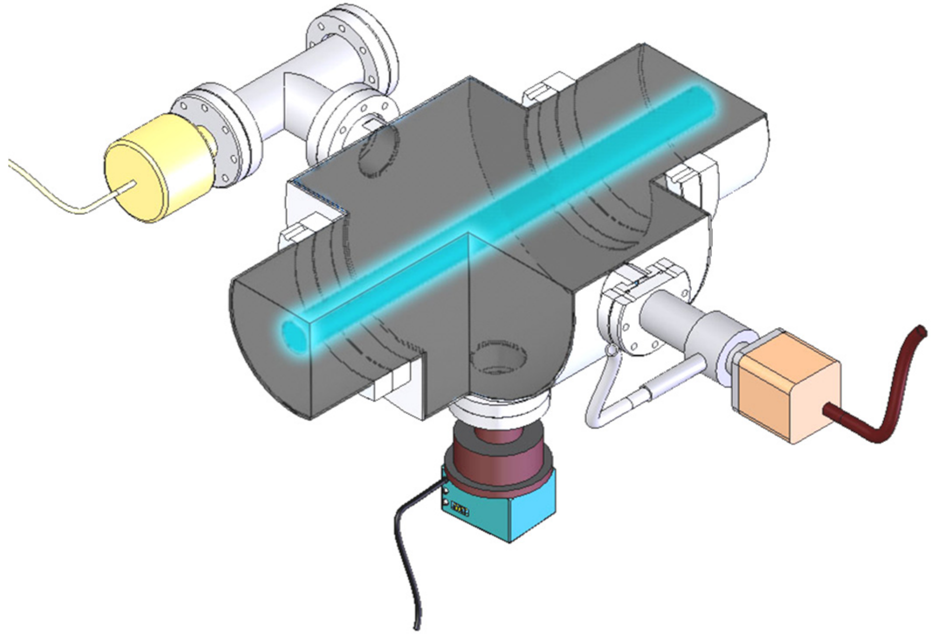

$$Y_{ionize} = \sigma_{ionize}(E \ldots P_{Det}\,\rho$$

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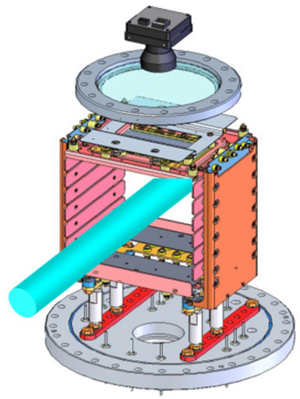
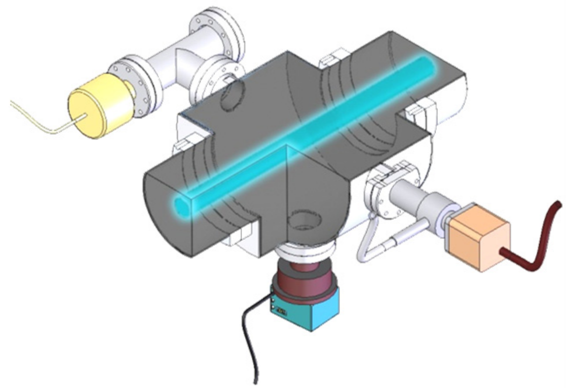
-7 OM

-3 OM

-4 OM

IPM and BIF Monitor

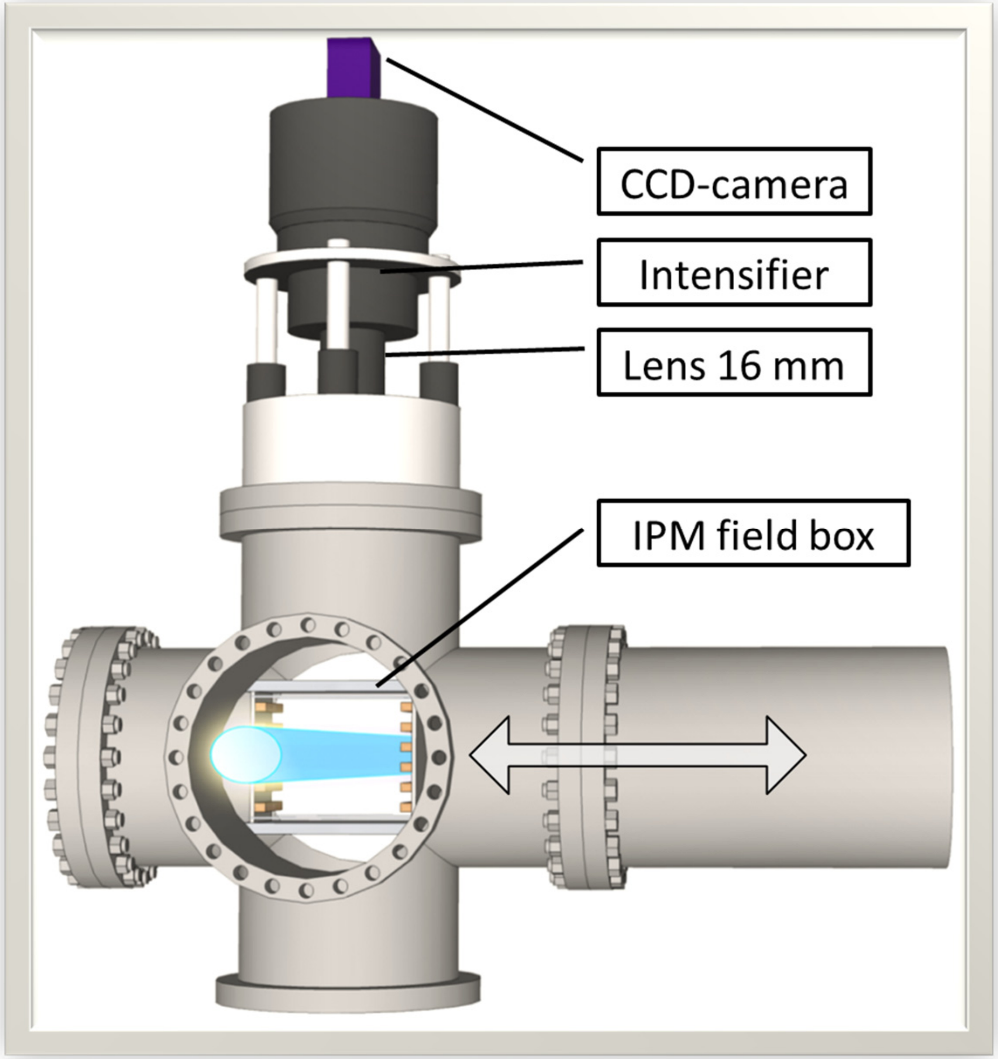




Parameter	Evaluation IPM	Evaluation BIF
$p_{acc}=10^{-12}$ to 10^{-9} mbar	🟢	🔴 gas jet @ RHIC BNL
$p_{tp}=10^{-9}$ to 10^{-6} mbar	🟢	🟢
$p_{tgt}=10^{-3}$ to 1000 mbar	🔴 HV breakdown	🟡 **?**
high charge density	🟡 magnet system req.	🟡 only short lifetimes
spatial/temporal res.	≥ 30 µm/ ≥ 10 ns	≥ 30 µm/ ≥ 100 ns
limited insertion length	🔴 500 to ~3000 mm	🟢 200 mm
system complexity	🟡	🟢

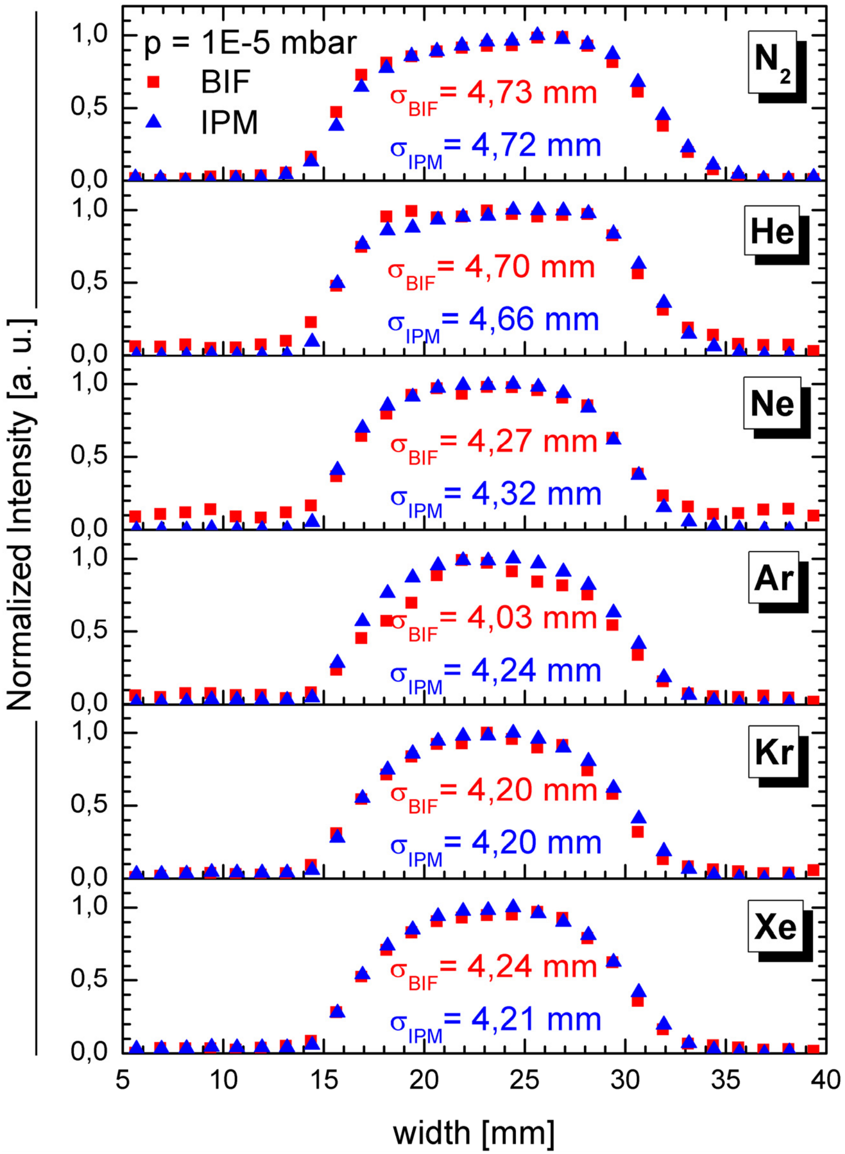
BIF-IPM Comparison

- BIF and IPM mounted to observer the same plane
- BIF monitor as ICCD setup
- IPM with electrical readout on remote motor drive
- Chamber was blackened and connected to a gas dosing system
- Nitrogen and rare gases (high purity) were applied against constant pump flow



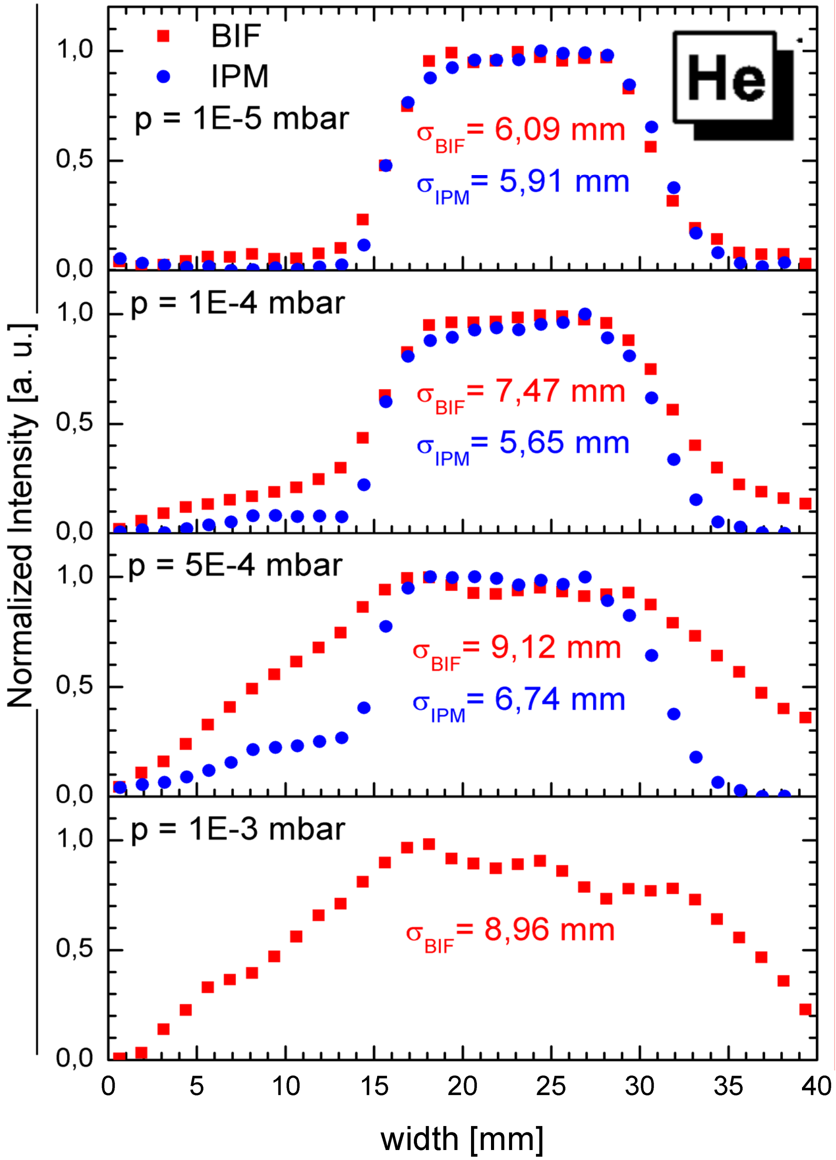
[courtesy of J. Egberts (CEA-Saclay)]

BIF-IPM Comparison 10^{-5} mbar



- Profile data recorded for same spatial regions and matched statistical increments
- 2nd statistical moment was obtained in presented range
- Very good agreement of all beam profiles @ 10^{-5} mbar and the applied gases

BIF-IPM Comparison for rising p



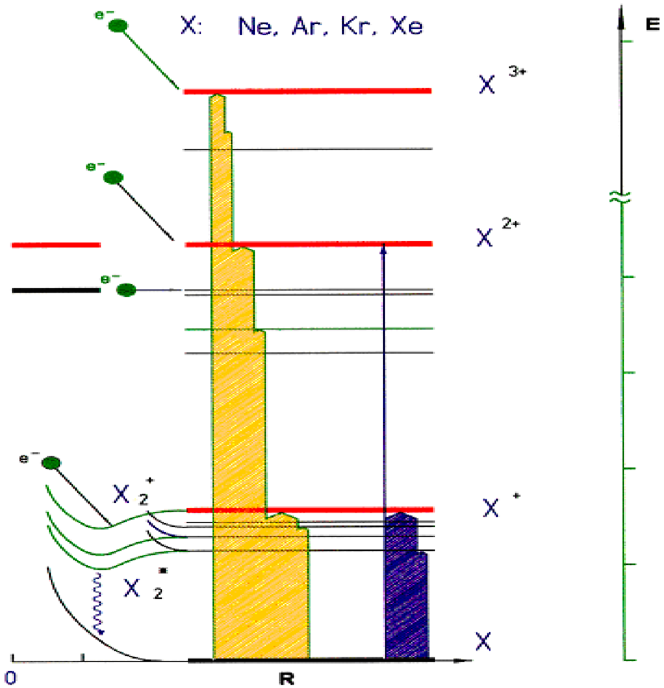
- Profile data recorded for same spatial regions and matched statistical increments
- 2nd statistical moment was obtained in presented range
- Very good agreement of all beam profiles @ 10^{-5} mbar and the applied gases
- Drastic discrepancy for rising pressure in He and other gases

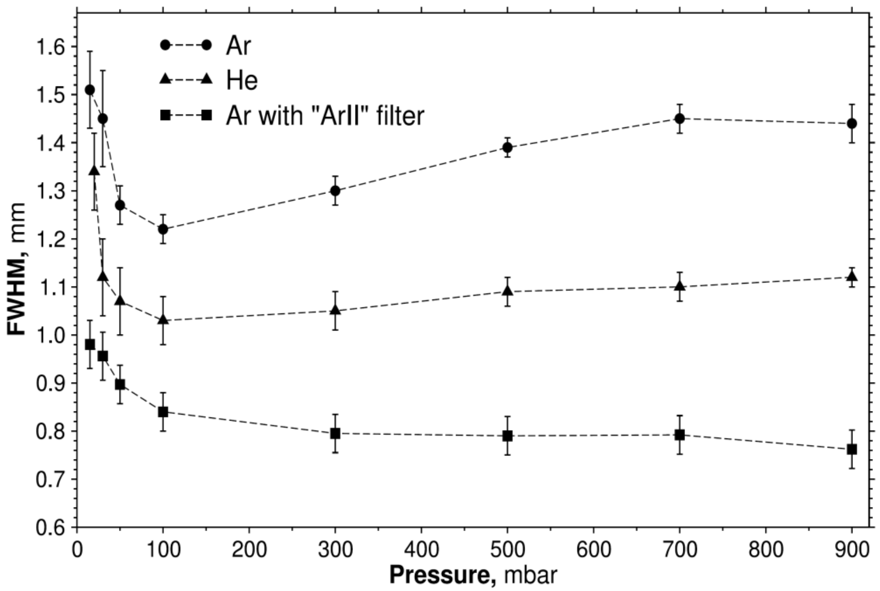
For high pressure application a systematic study was mandatory

Studies in Atmospheric Pressure

[A. Ulrich - habilitation 1998]

- cross section ratio e⁻/HI-excitation decreases with degree of ionization
- Therefore profile reading in ionized gases should have higher accuracy

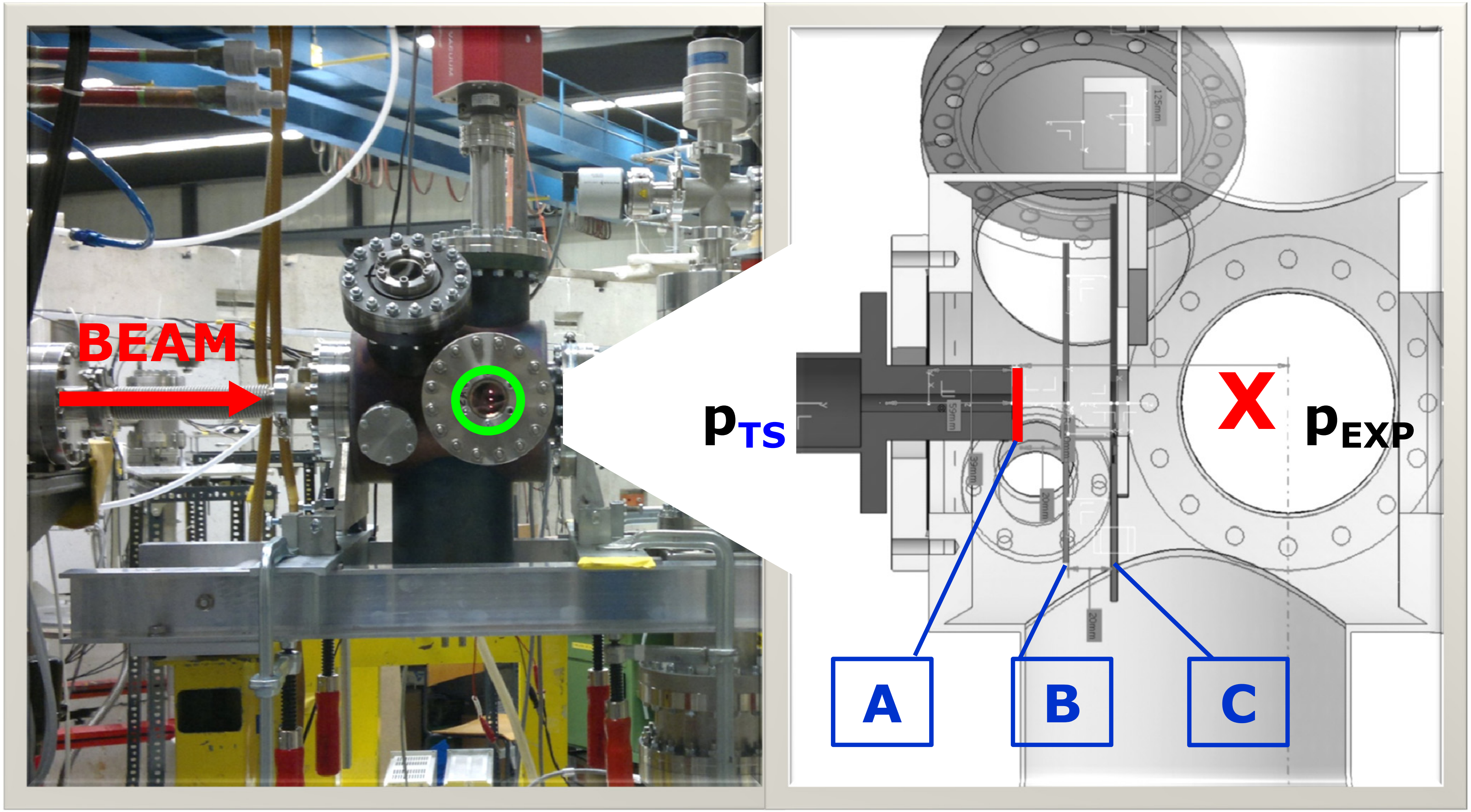




[D. Varentsov et al. CPP-J 2008]

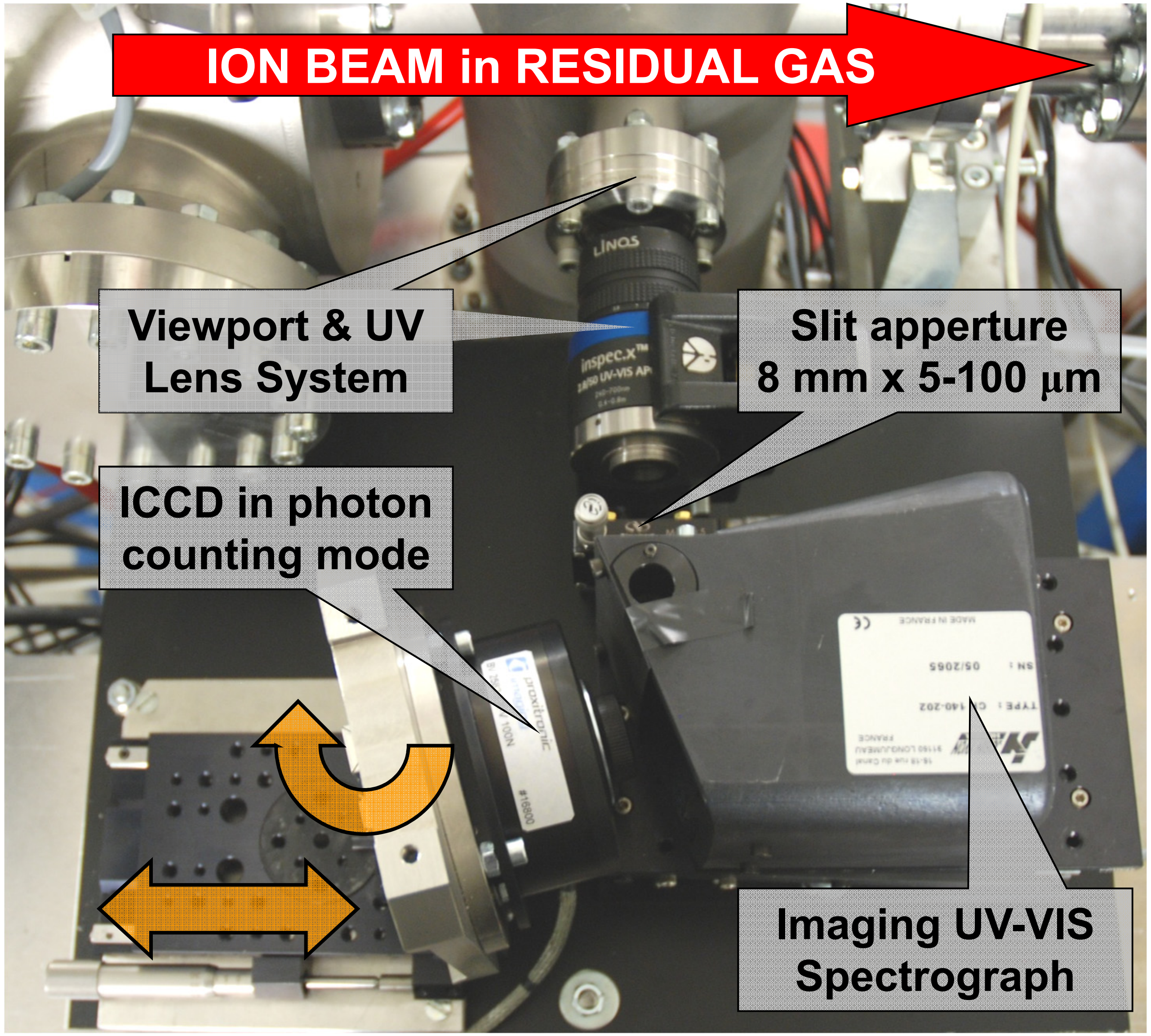
- BIF works for p ≥ 50 mbar
- Only ArII lines @ 458 nm provide correct profile reading

Experimental Setup MLL Garching

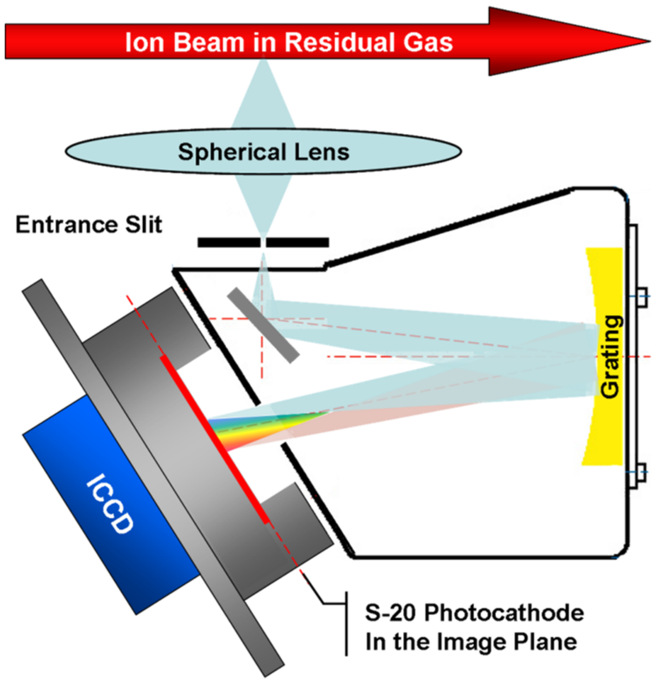


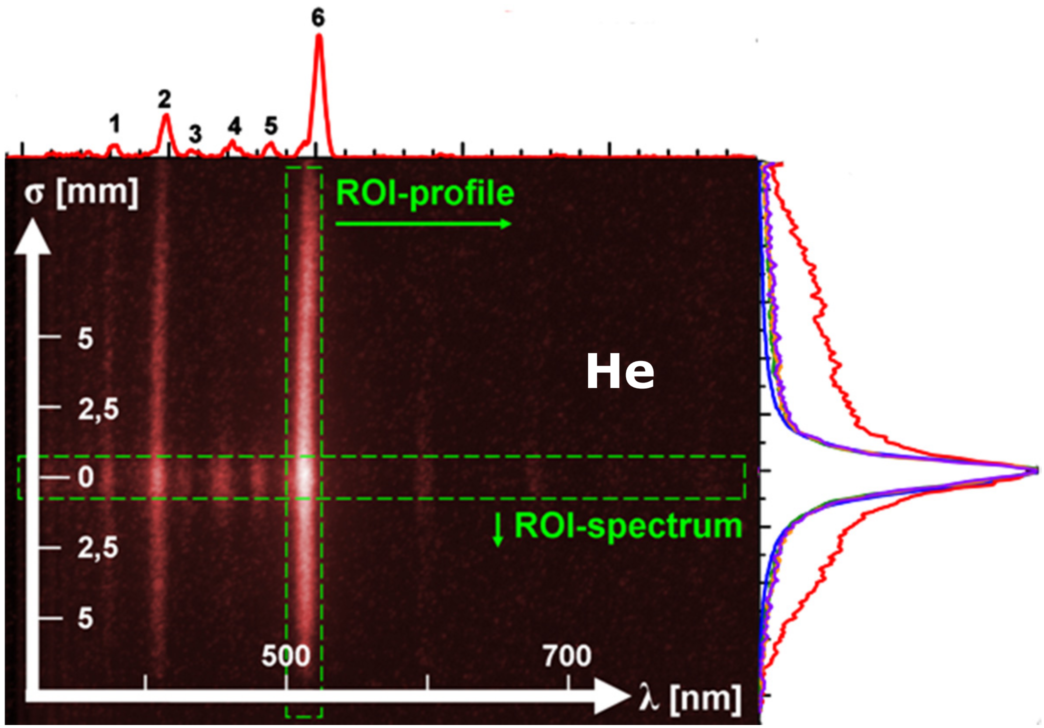
A: Ti-window 1.1 mg/cm² | B,C: repeller plates | X: optical center

Imaging Spectrograph - Setup



Imaging Spectrograph with ICCD

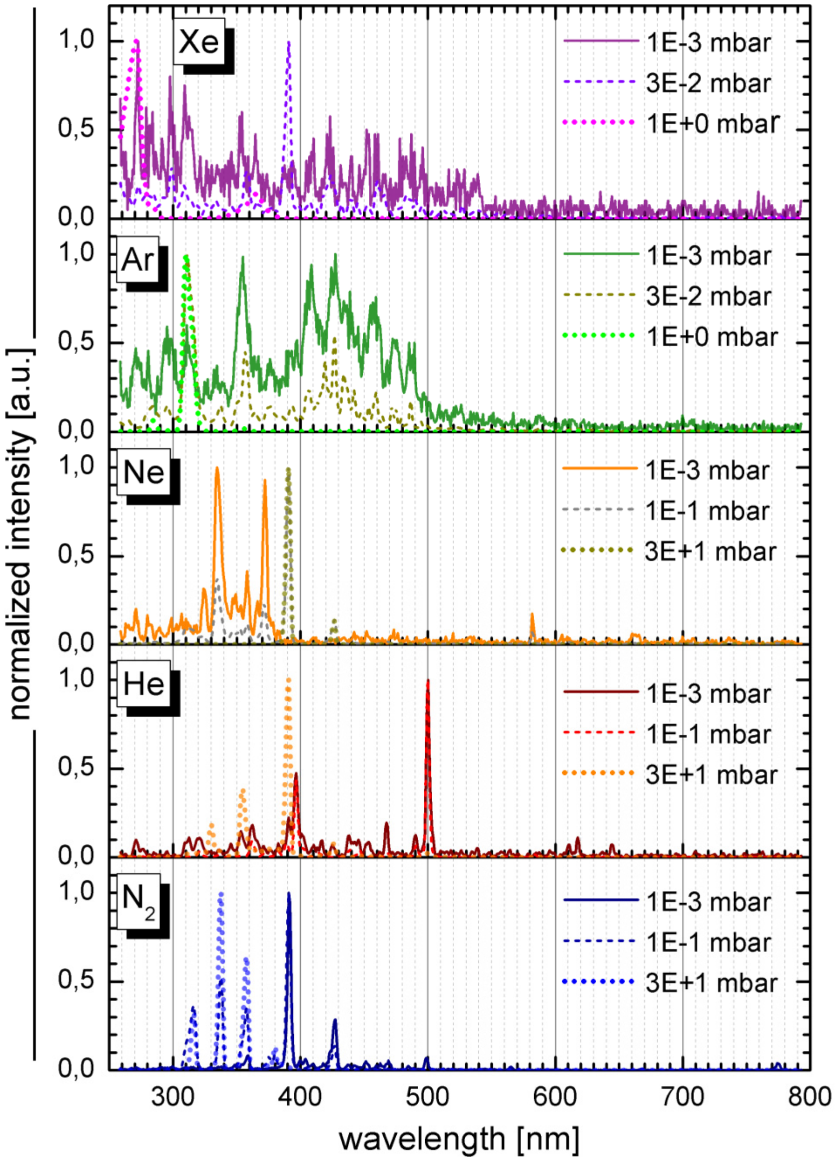


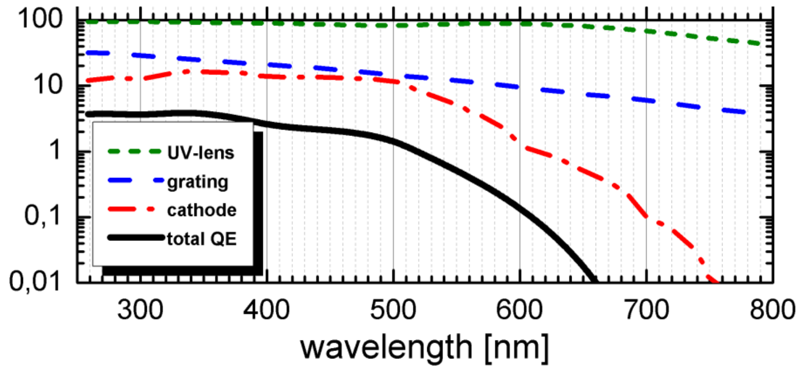


- Technique allows to record fluorescence-images with spectral and spatial information (profiles and spectra)
- Chromatically corrected quartz-optics (300 – 800 nm)

Intensity **&** spectral position of transitions → profile-width

Fluorescence Spectra in Various Gases

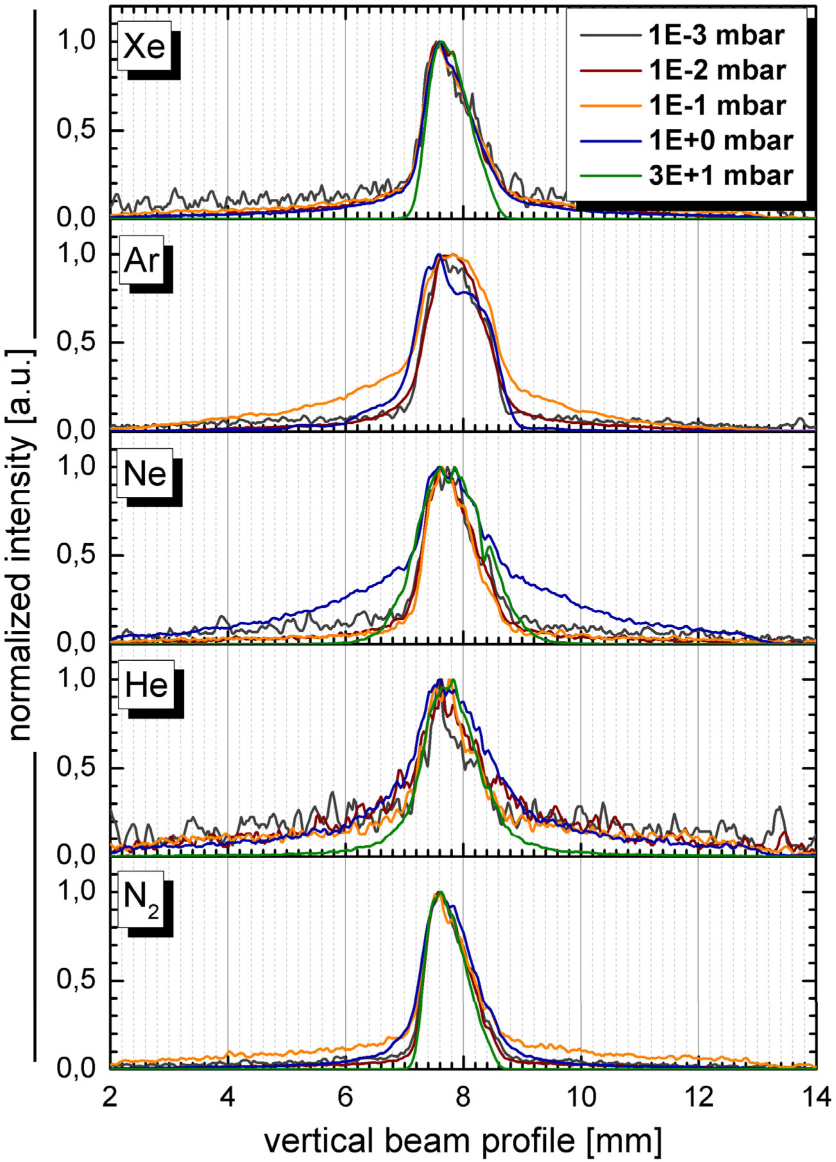




- Spectral response (semi-log)
- Observed spectra for minimal and maximal pressures
- Drastic change in all spectra
- Nitrogen impurities observable in all rare gas species
- Hydroxide (OH*) in Argon
- Nitrogen changes from ionic N_2^+ to neutral transitions N_2

AP processes change completely

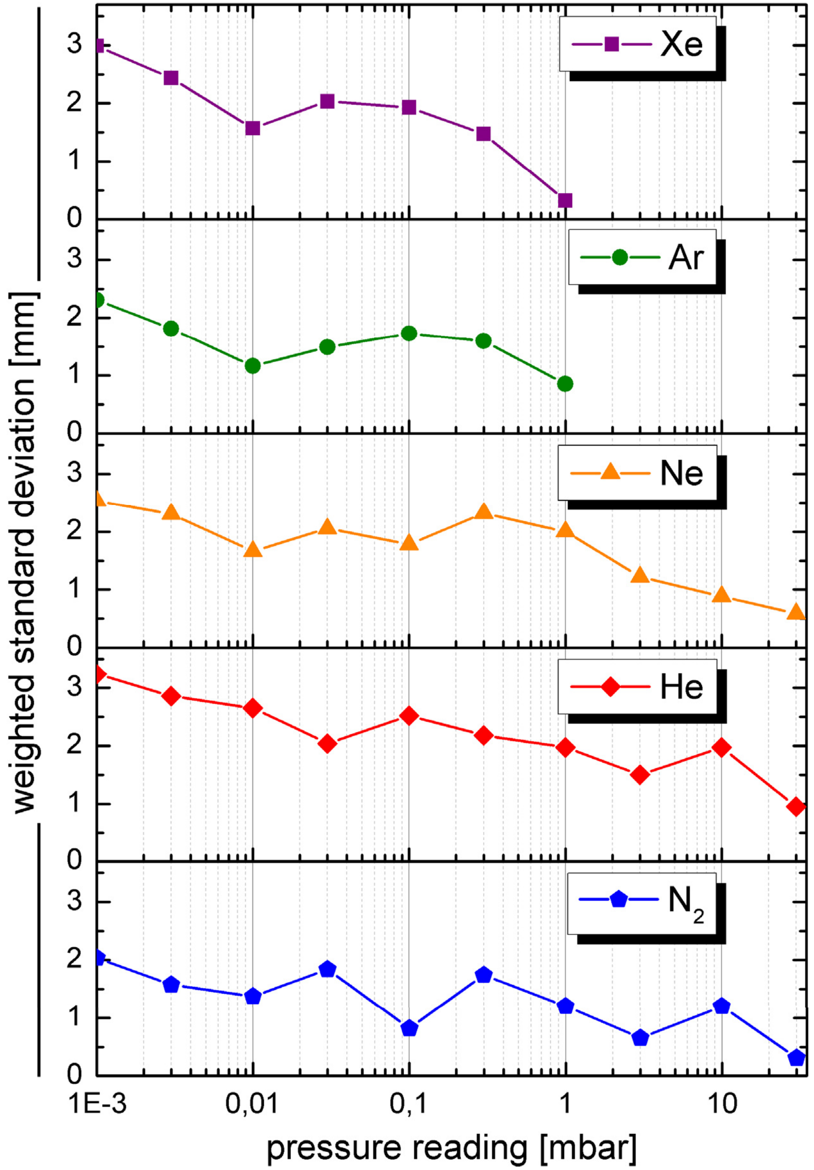
Beam Profiles in Various Gases



- Beam profiles for full p-sweep without spectral line selection

- Nitrogen looks most stable, but all gases falsify profiles
- Core region is less affected, shoulders appear ≥10^{-3} mbar
- Smallest profiles were observed for the highest pressure setting

Beam Profiles in Various Gases

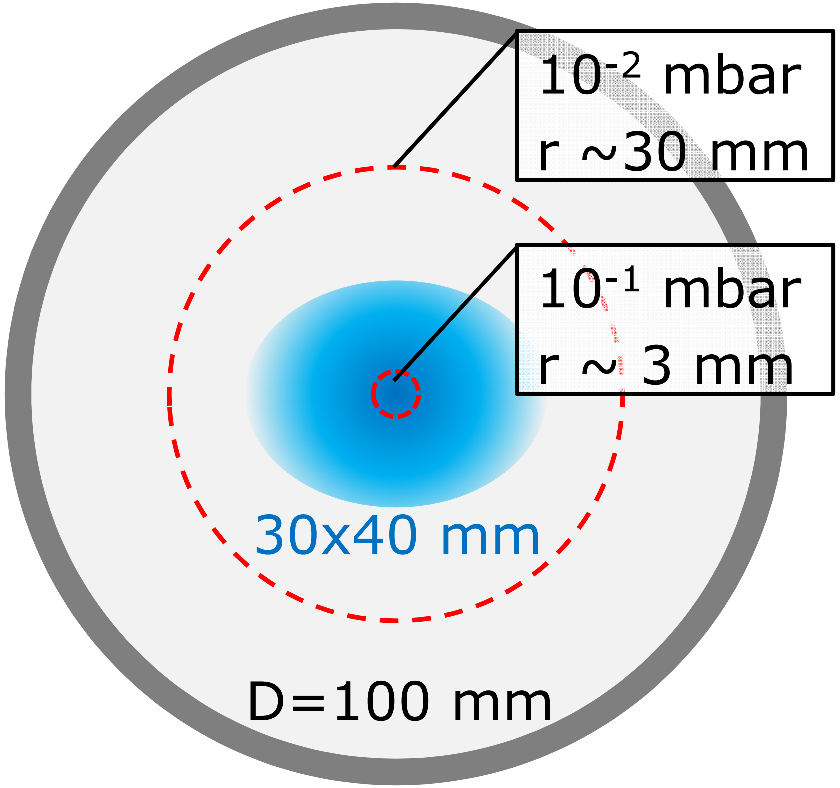


- Beam profiles for full p-sweep without spectral line selection

- Nitrogen looks most stable, but all gases falsify profiles
- Core region is less affected, shoulders appear ≥10^{-3} mbar
- Smallest profiles were observed for the highest pressure setting
- 2nd statistical moments show profile hump for intermediate p

How can unwanted excitation mechanisms be excluded?

Mean Free Path – Spectral Selection



- For small MFP spontaneous de-excitation replaced by collisional
- Secondary electron halo excites transitions with different CS

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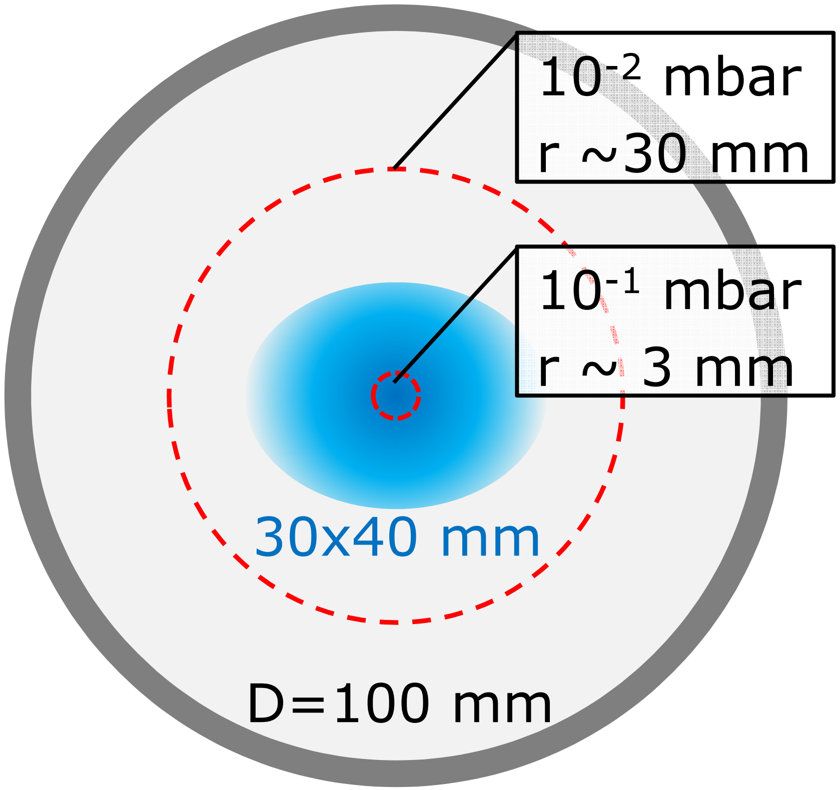
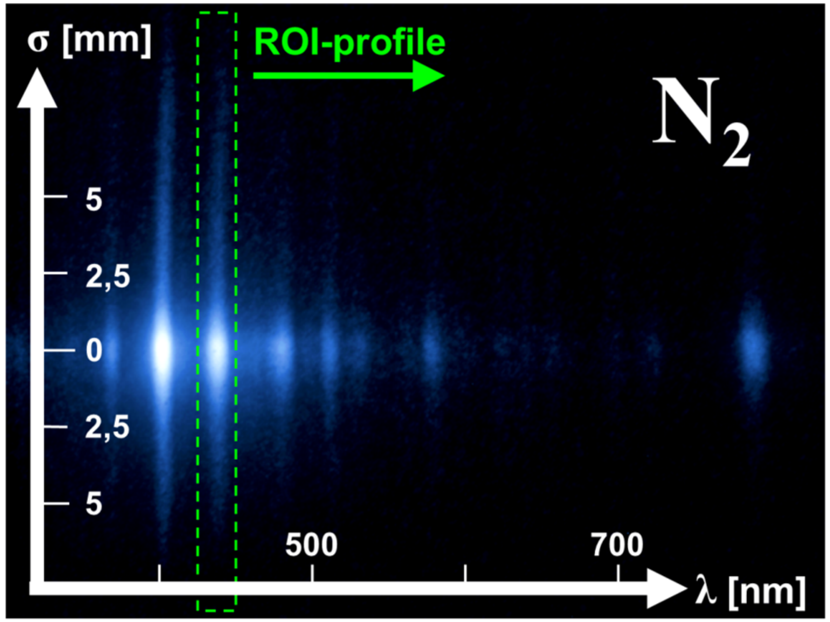


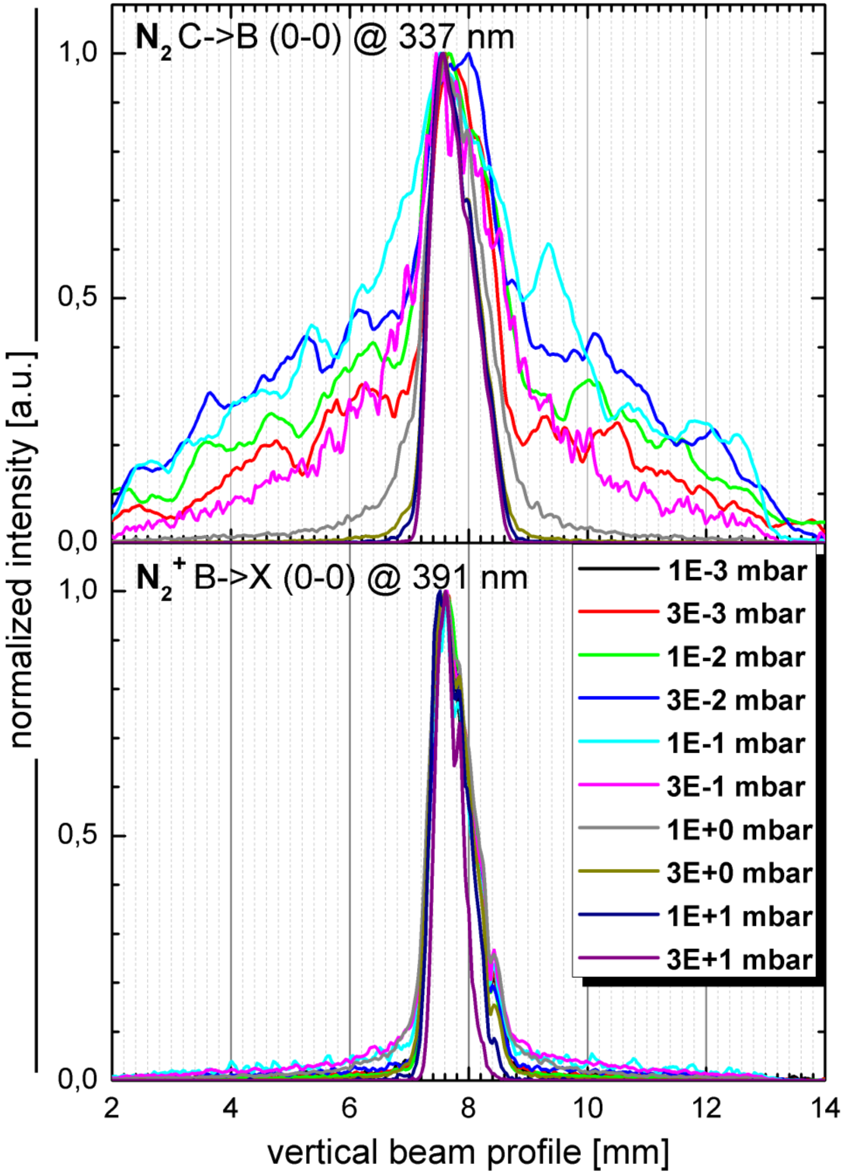


- For small MFP spontaneous de-excitation replaced by collisional
- Secondary electron halo excites transitions with different CS

- Region of interest to observe profiles of single transitions (8nm spectral acceptance)

Transition Selective Profile Analysis N_2

- Spectral acceptance (ROI) 8 nm to select transitions separately
- Profiles of neutral transition N_2 show in- and decreasing halo (one tick is 200 µm)
- Profiles of ionic transition N_2^+ unchanged from 10^{-3} to 30 mbar
- Fluorescence light in rare gases distributed among several lines but similar tendency is observed



N_2^+ B→X (0-0) should be selected

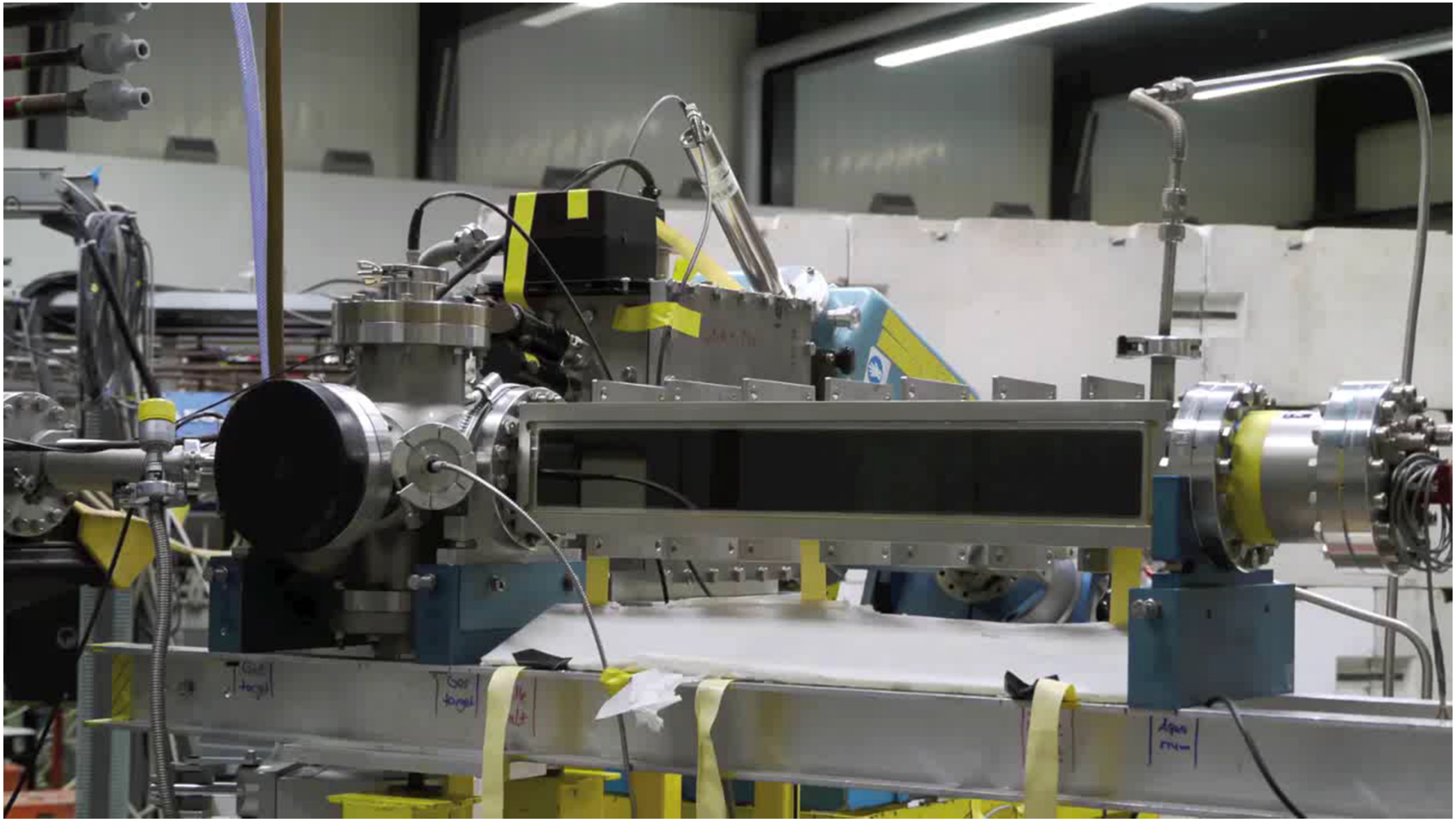
Conclusion

- Online profile instrumentation at FAIR:
  - will be gas based detectors like IPM and BIF monitor

- Results of research:
  - BIF and IPM profiles agree very well for $p \leq 10^{-4}$ mbar
  - BIF spectra and profiles change drastically for increasing p
  - Observed profile hump shows the full image acc. former studies
  - 2^{nd} electron halo explains profile halo in neutral transitions
  - Spectral selection of ionic transitions avoids distortions

- Successful implementation of BIF-monitors:
  - In the energy-range of 7,5 *A*keV – 450 *A*GeV (former studies)
  - Now we showed application for mbar pressures and beyond
  - BIF monitors and IPMs cover FAIR requirements

Decreasing Kr-Pressure 1000 – 1 mbar



Acknowledgements

Thank you for your attention! ☺