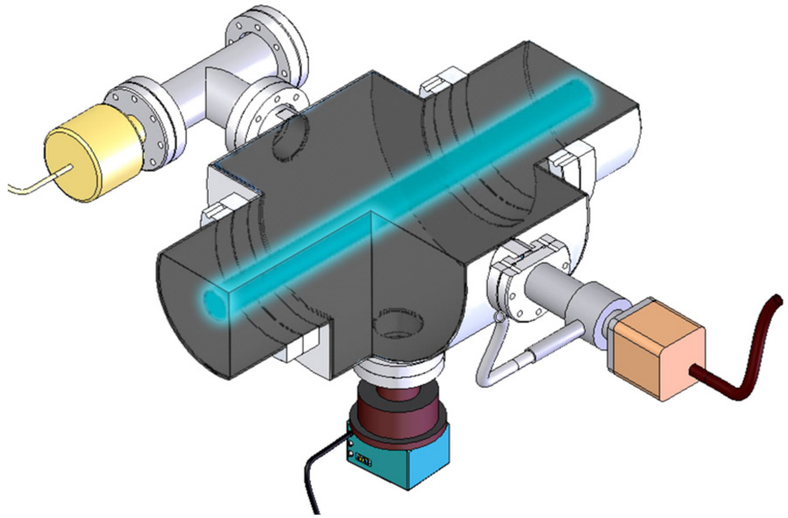
Beam Induced Fluorescence Monitors

BIF®, FPM®, BPL®, SPM®, OBPM®, VPM®, RGM®…



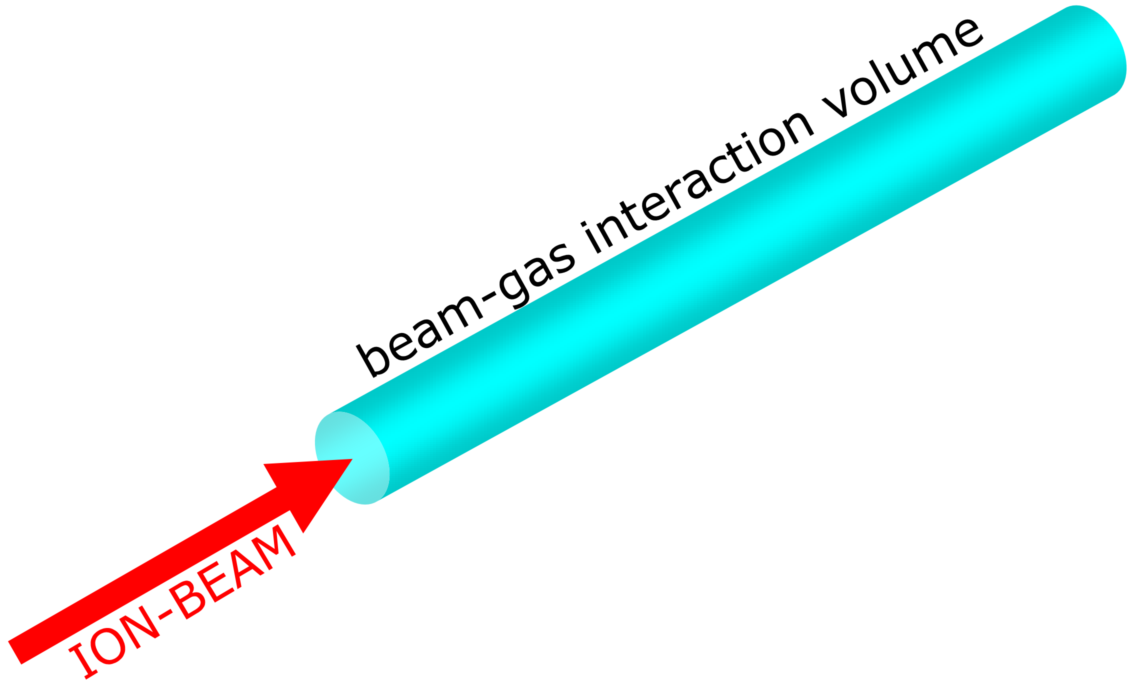
DIPAC2011 – May 18th

Frank Becker – GSI Beam Diagnostics

Outline

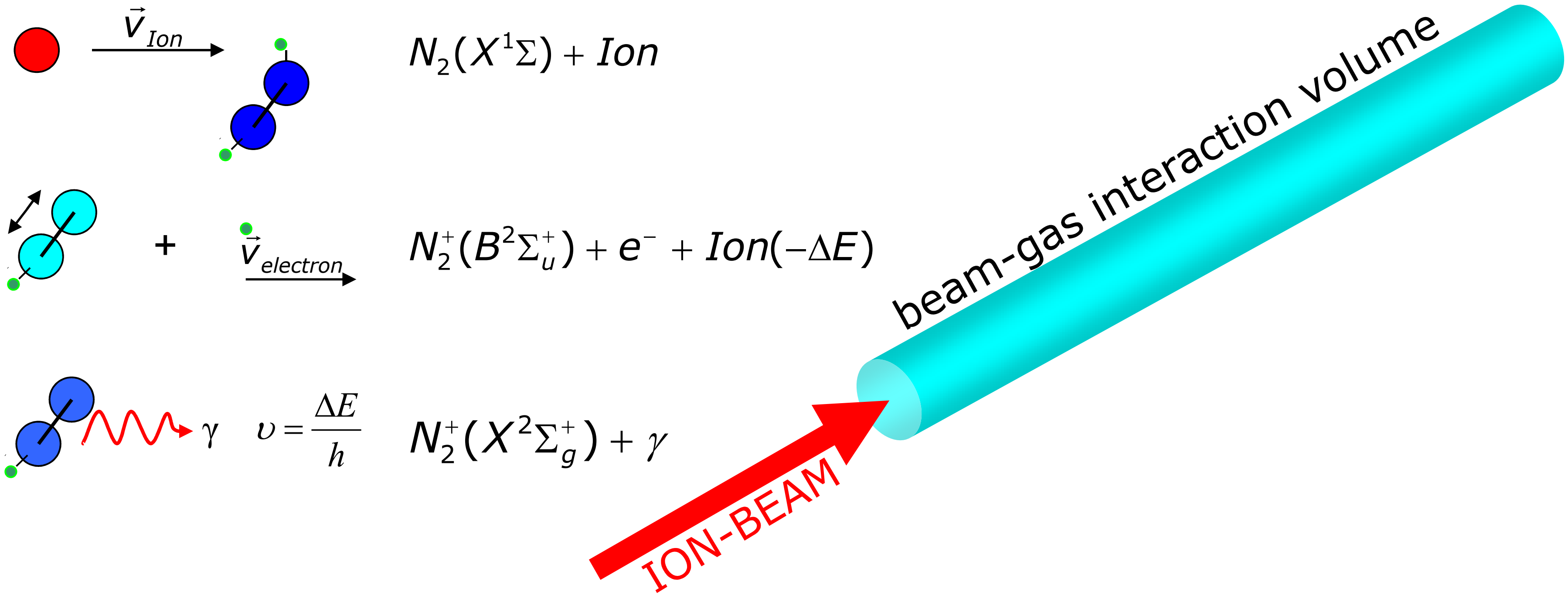
- Motivation & Introduction
  - Benefit of non-intercepting profile measurement
  - Detection priciple, components and functionality
- Physics – Results of Research
  - Estimation of the photon yield
  - Parameters to be optimized
  - Limiting factors (yield, radiation, displacement)
- Overview of Realizations
  - Transport & LINAC installations
  - Synchrotron installations
- Conclusion

Gas-Based Detectors



- N_2-dominated for p ≥ 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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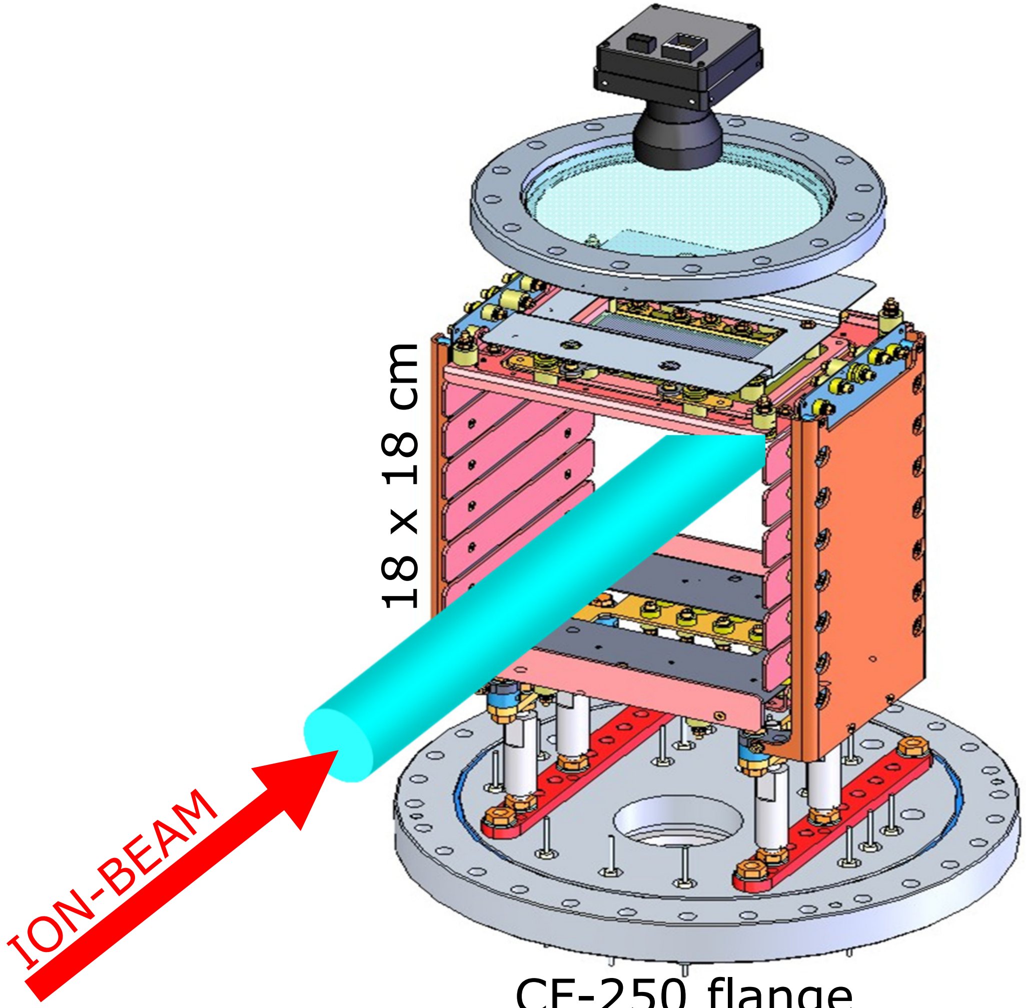
Ionization **P**rofile **M**onitor



- Gas-ions accelerated in homogeneous E-field vs. spatially resolving sensor

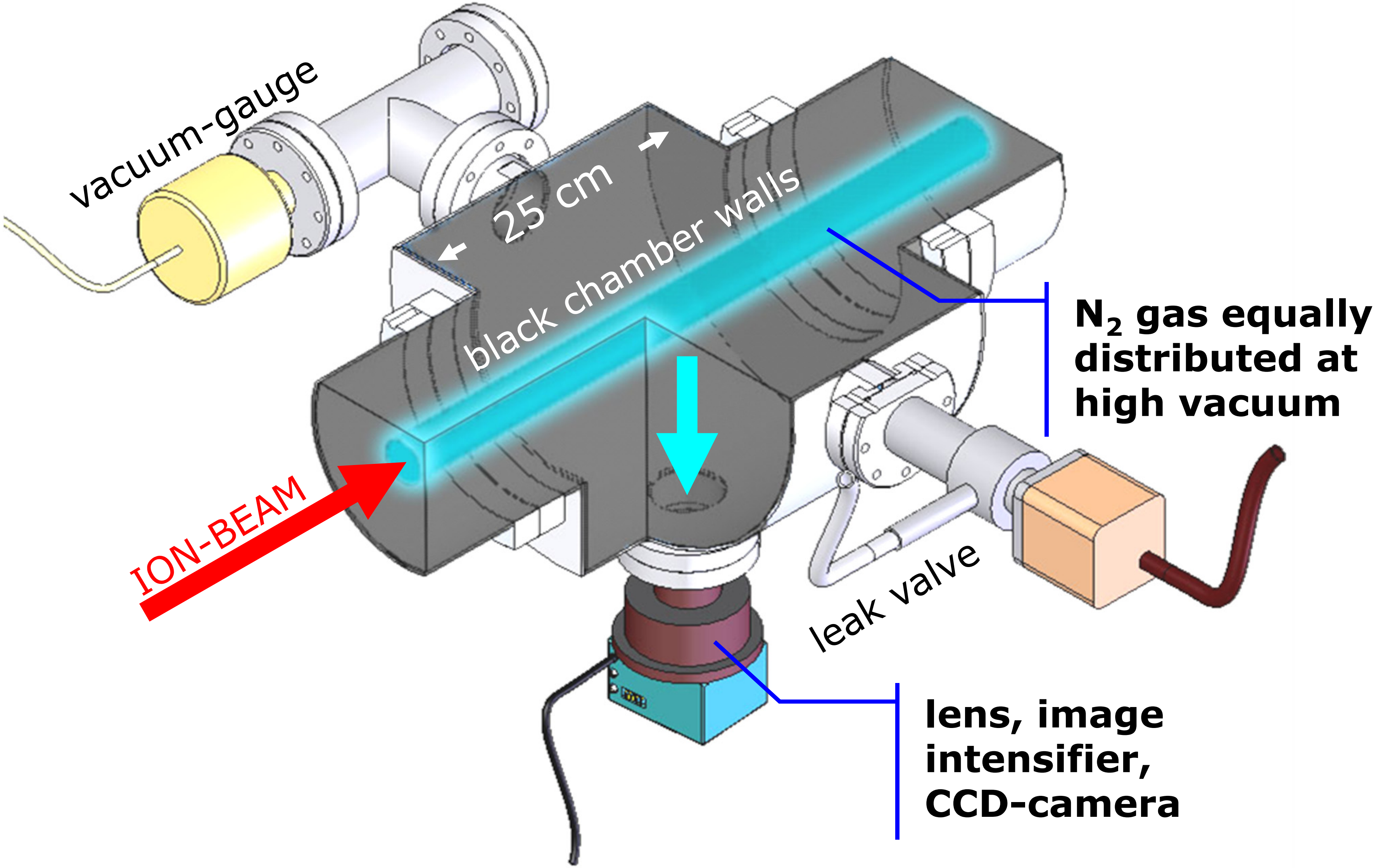
$\pm$6 kV accelerating voltage
$\rightarrow$ E = 70 kV/m

- TOF N_2^+ ions ~ 100 ns
- 4π-acceptance $\rightarrow$ all ions
- MCP-amplification ~10^6
- Stripline/optical readout

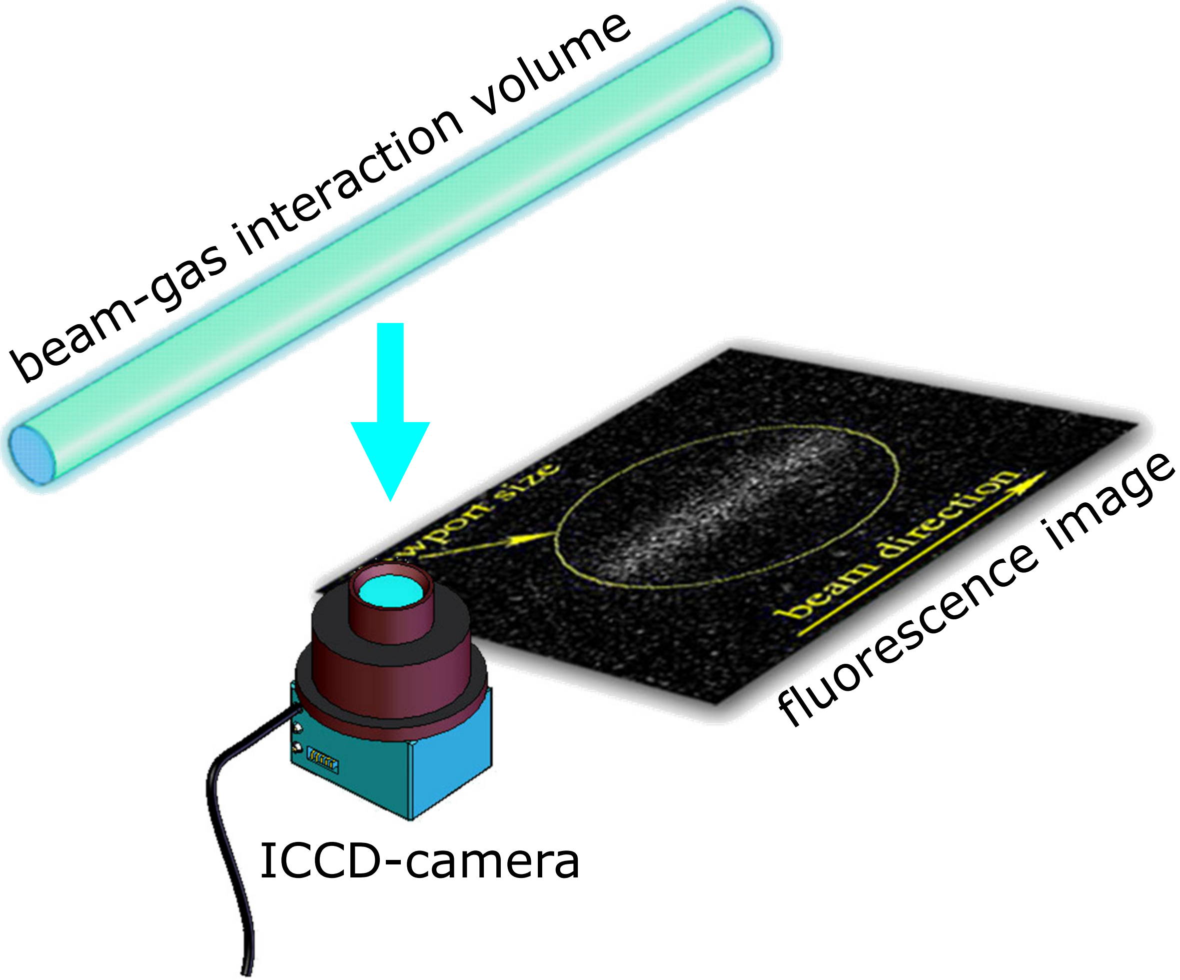
Sensitive profile monitor suitable for synchrotrons

[DIPAC: TUPD51, Giacomini]

Beam Induced Fluorescence

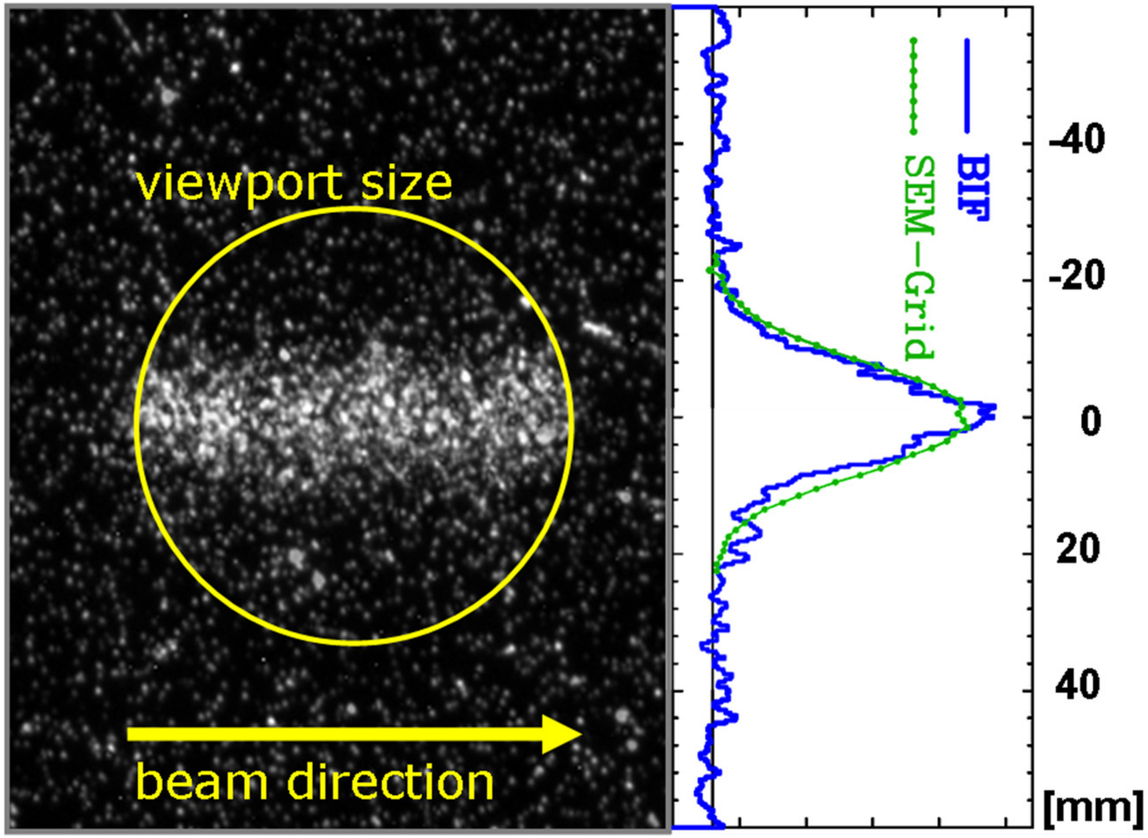


How a Beam Profile is Obtained



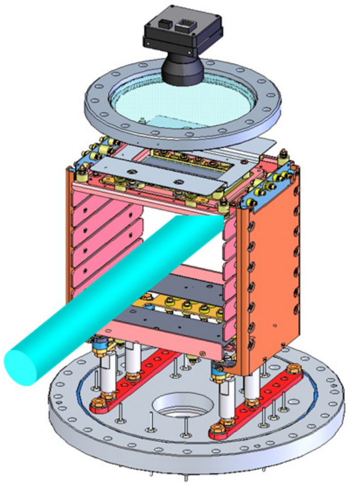
How a Beam Profile is Obtained

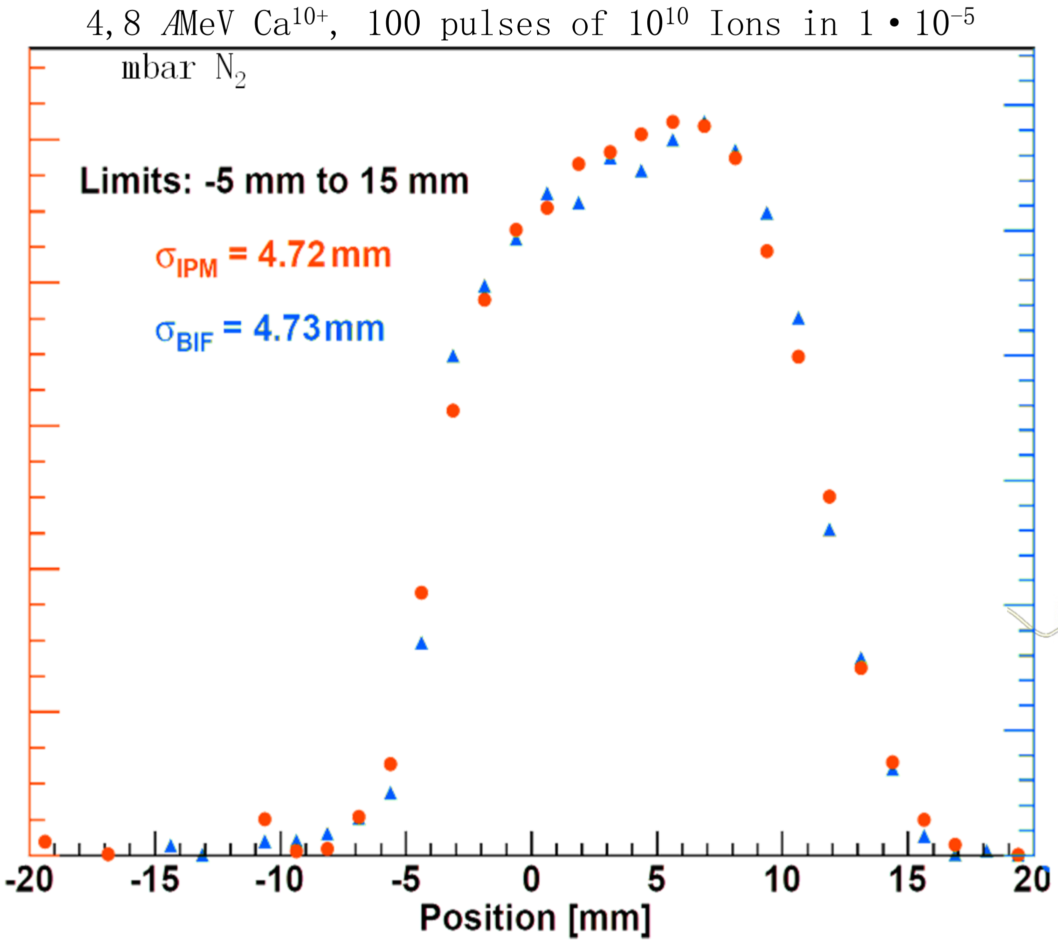
200 AMeV Xe^{48+}, 20 pulses of 10^9 Ions in $5 \cdot 10^{-4}$

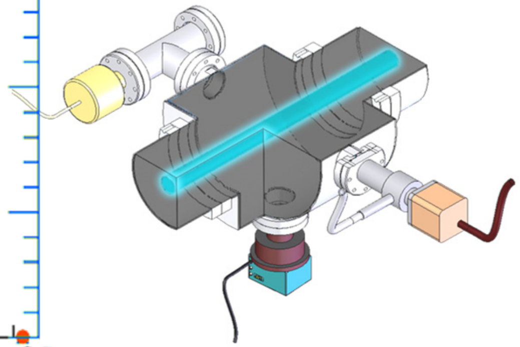


BIF- and SEM-profiles in accordance with each other, $\Delta\sigma/\sigma \leq 10\%$

Beam Profile Comparison



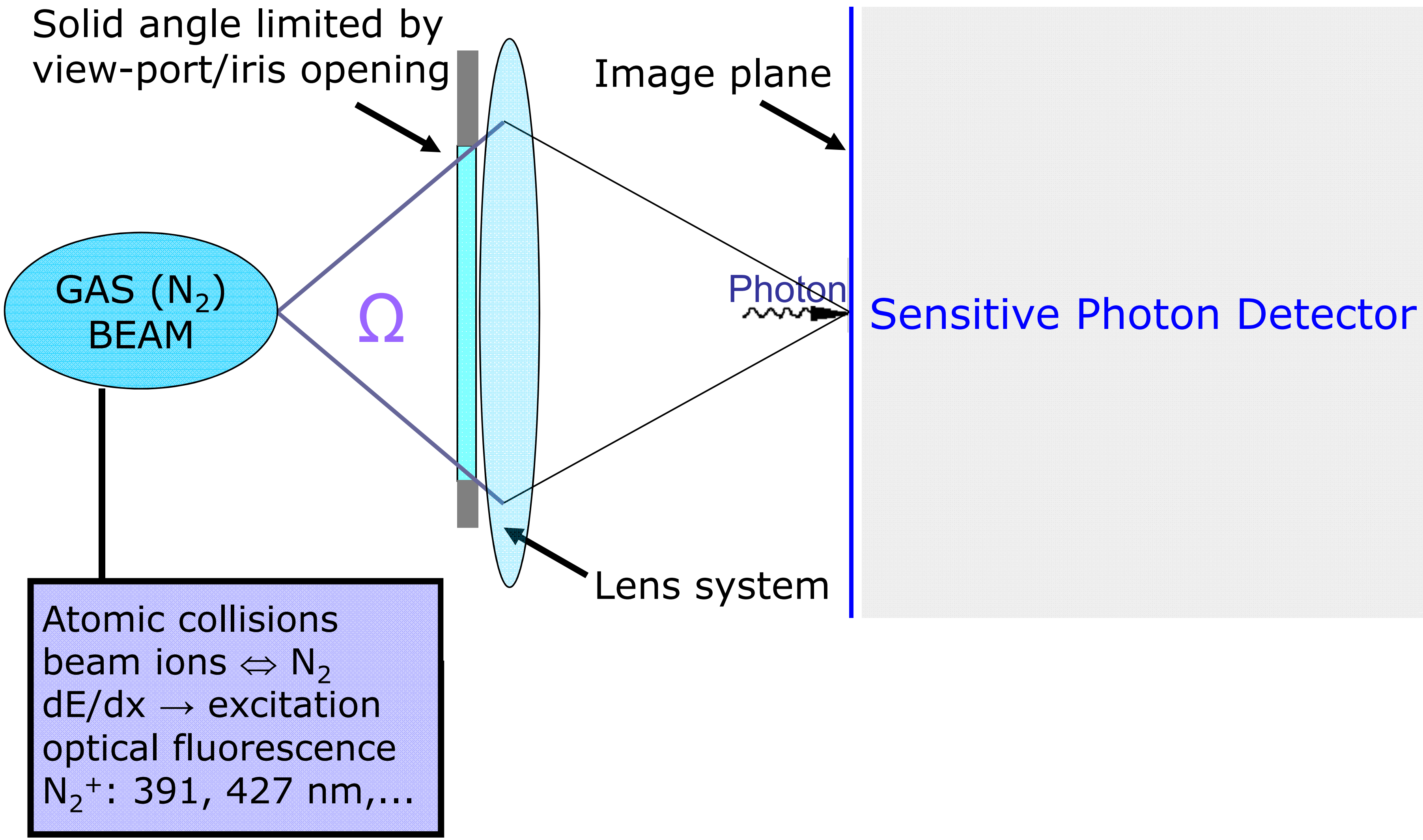




BIF- and SEM-profiles in accordance with each other, $\Delta\sigma/\sigma \leq 10\%$

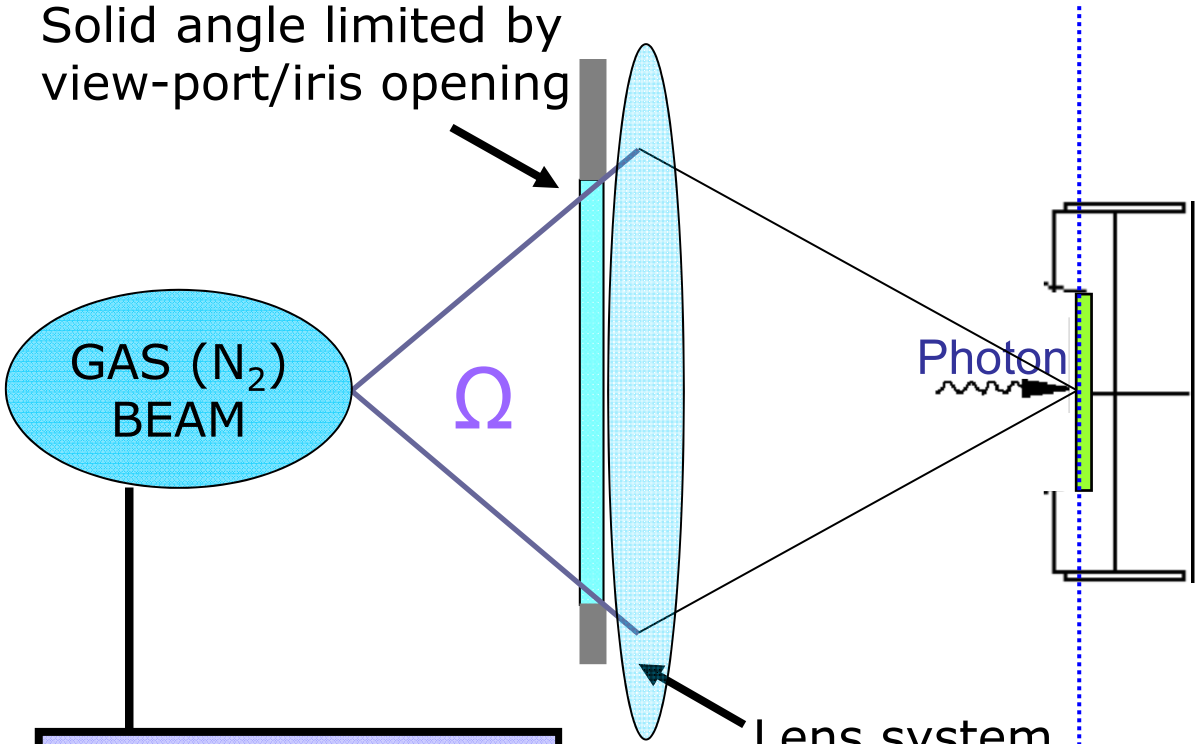
BIF- and IPM-profiles agree very well [DIPAC: WEOA03 Egberts]

Detection Principle



Detection Principle – Digital Camera

Solid angle limited by view-port/iris opening



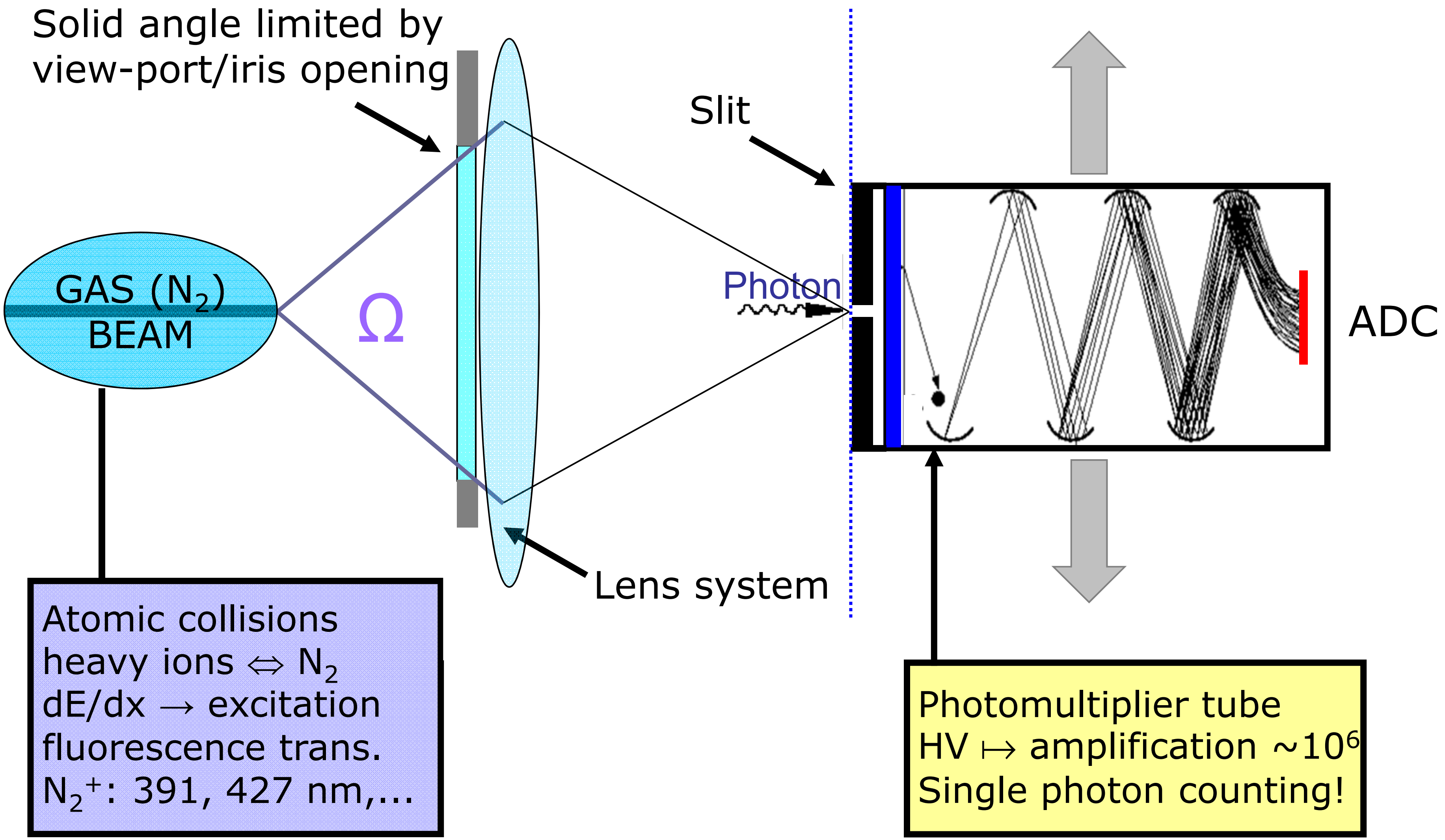
Lens system

Low noise CCD/CMOS sensors with active cooling.

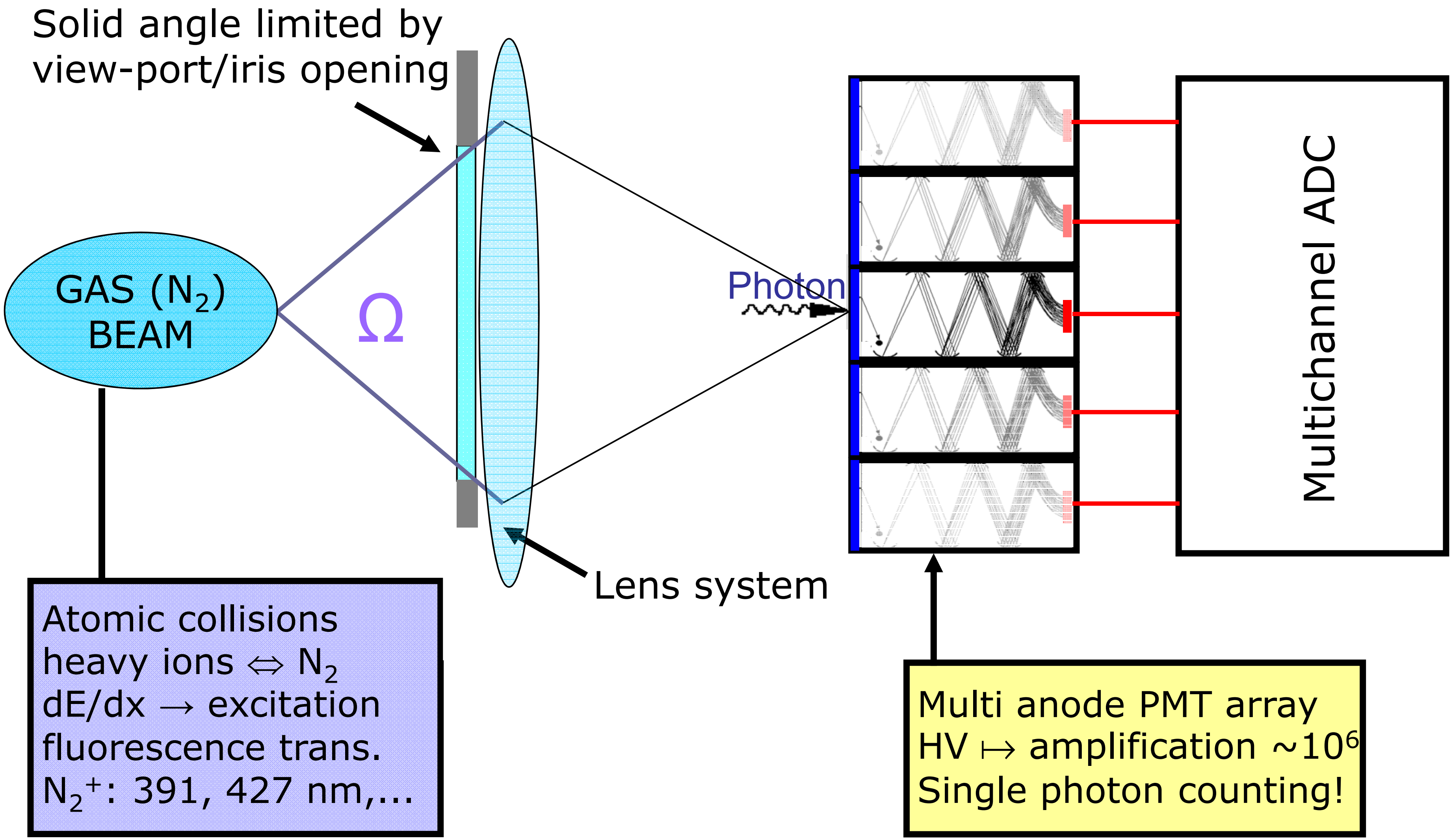
State of the art ADCs and digital interfaces GigE, FireWire, …

Atomic collisions
heavy ions $\Leftrightarrow$ N_2
dE/dx $\rightarrow$ excitation
fluorescence trans.
N_2^+: 391, 427 nm,...

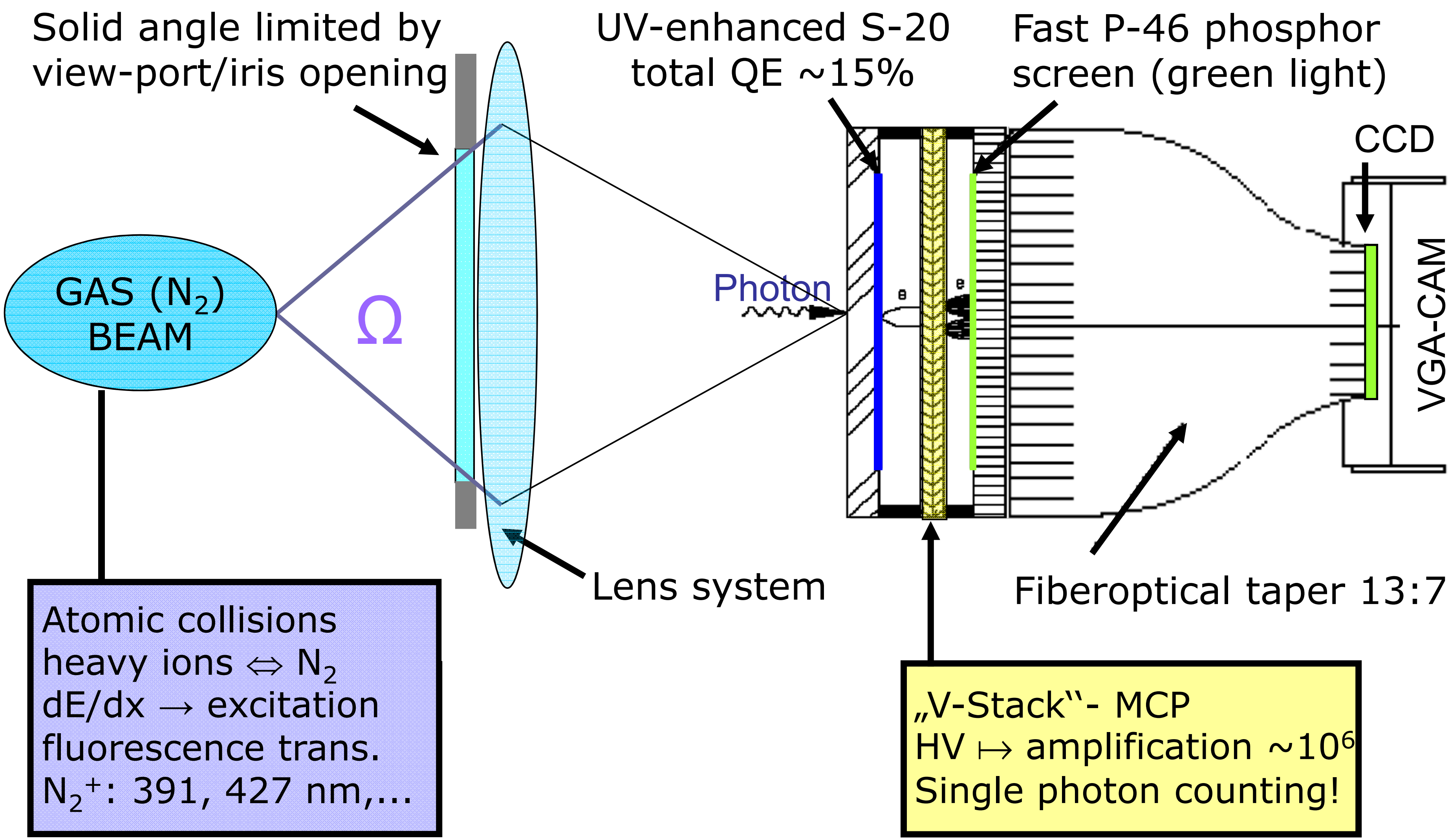
Detection Principle – Slit with PMT



Detection Principle – PMT Array

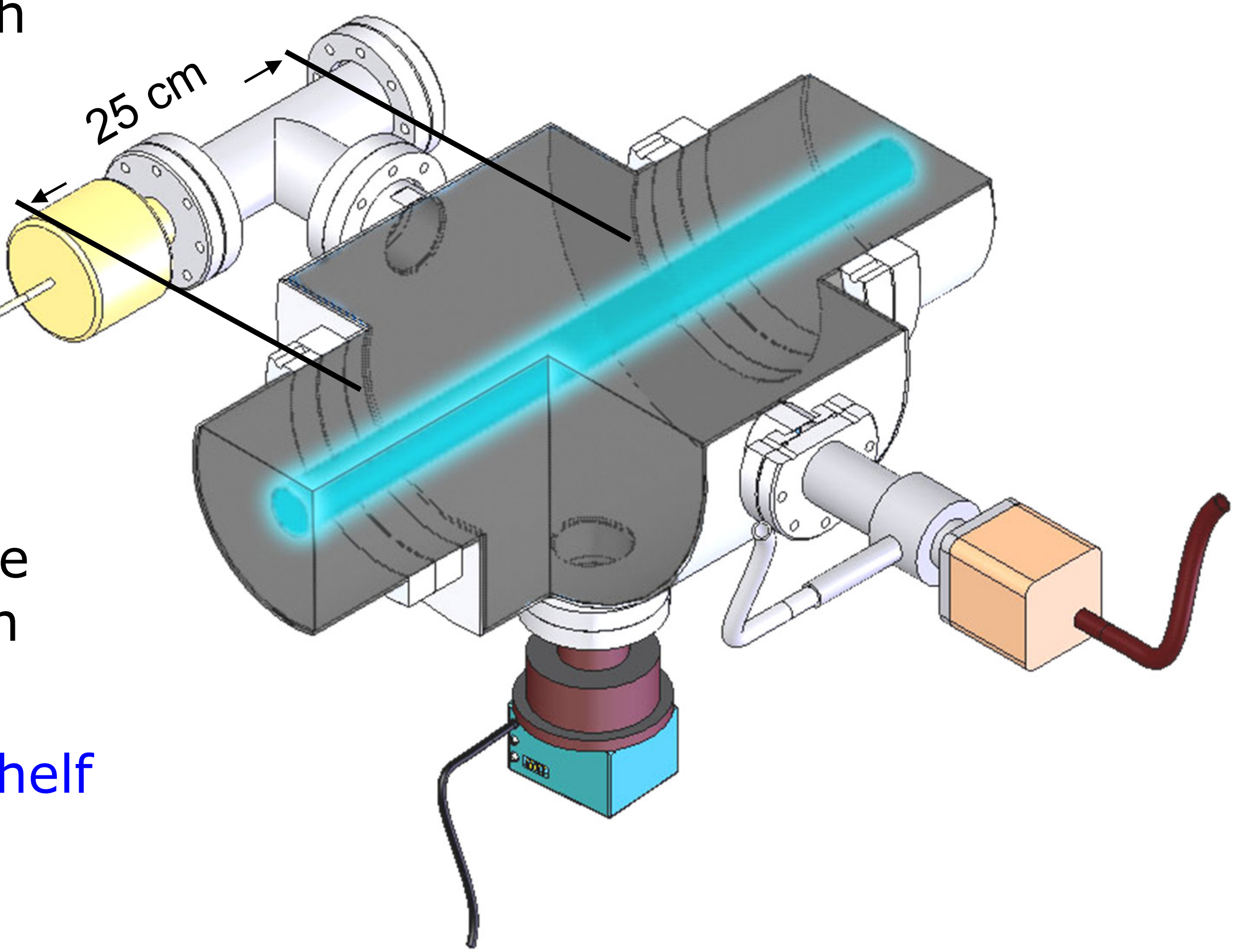


Detection Principle – 2 Dimensional



Benefit of the BIF-monitor

- Short insertion-length
- No mechanical parts inside the vacuum
- Gas pressure adjusts signal strength
- Optical system can be tailored to application
- Components of the shelf
  - Lens with motorized iris
  - V-stack image intesifier
    single photon counting
  - Digital 12-bit VGA-cam
    with FireWire-interface



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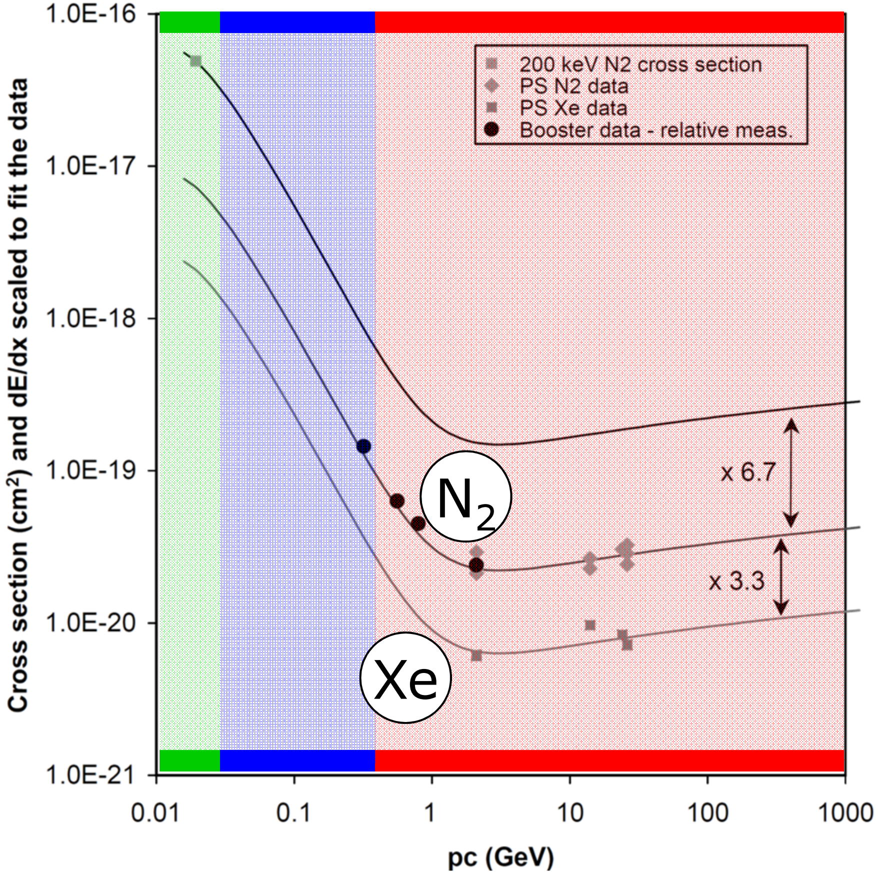
  - Examples – synchrotron installations
- Conclusion

Number of Detected Photons

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

The Given Parameters

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

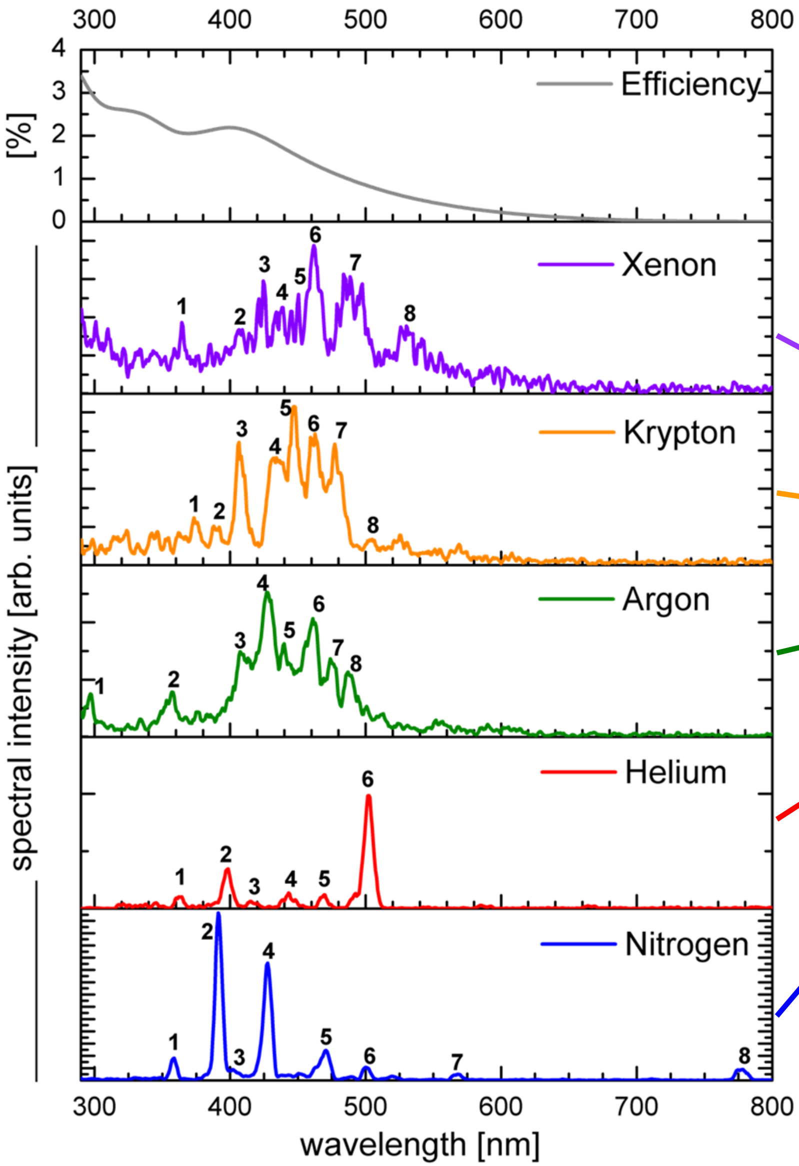


[M.A. Plum et al. NIM A 2002]

- Cross sections experimentally determined at PS-Booster/PS:
- dE/dx energy ependency but more data points required…
- Source, LINAC/Cycl., Synchr.
- Yield scales with $\bar{q}^{\,2}$
- Gas species determines light yield and energy loss

We like to have the maximum number of photons per dE/dx

Results Spectroscopy – Photon Yield



S^{6+} Ions @ 5 *A*MeV in 10^{-3} mbar gas:

- Fluorescence for rare gases and N_2: near UV to green
- Intensive lines and highest Y for N_2

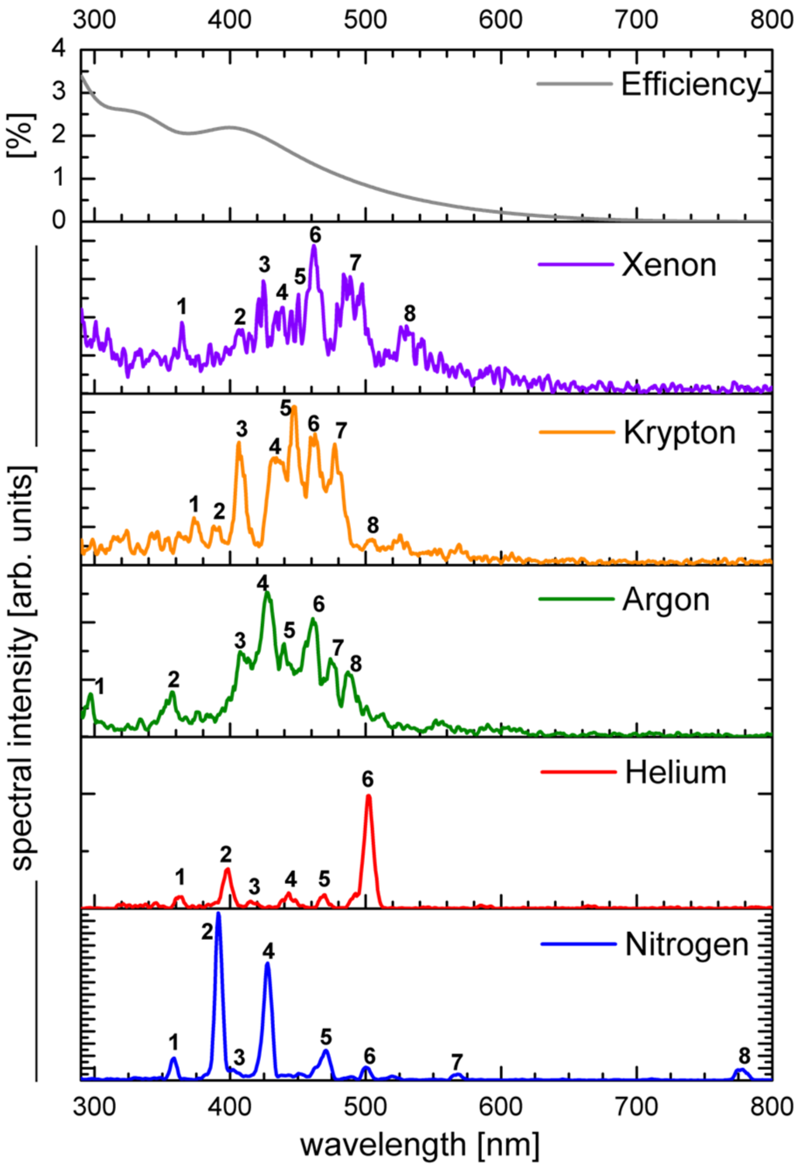
Gas	*Y* to *p*	*Y* to p/n_e
Xe	86 %	22 %
Kr	63 %	25 %
Ar	38 %	30 %
He	4 %	26 %
N_2	100 %	100 %

- Gas electron density $n_e \propto dE/dx$

N_2^+ and Xe^+ are recommended!

[F. Becker et al. BIW 2010]

Results Spectroscopy – Profile Reading



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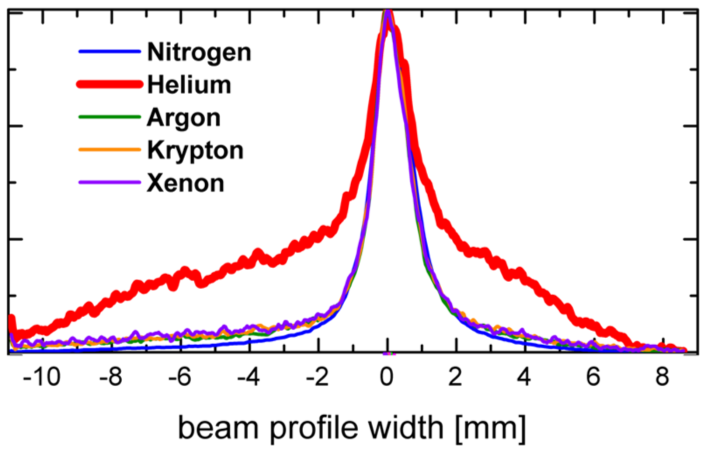


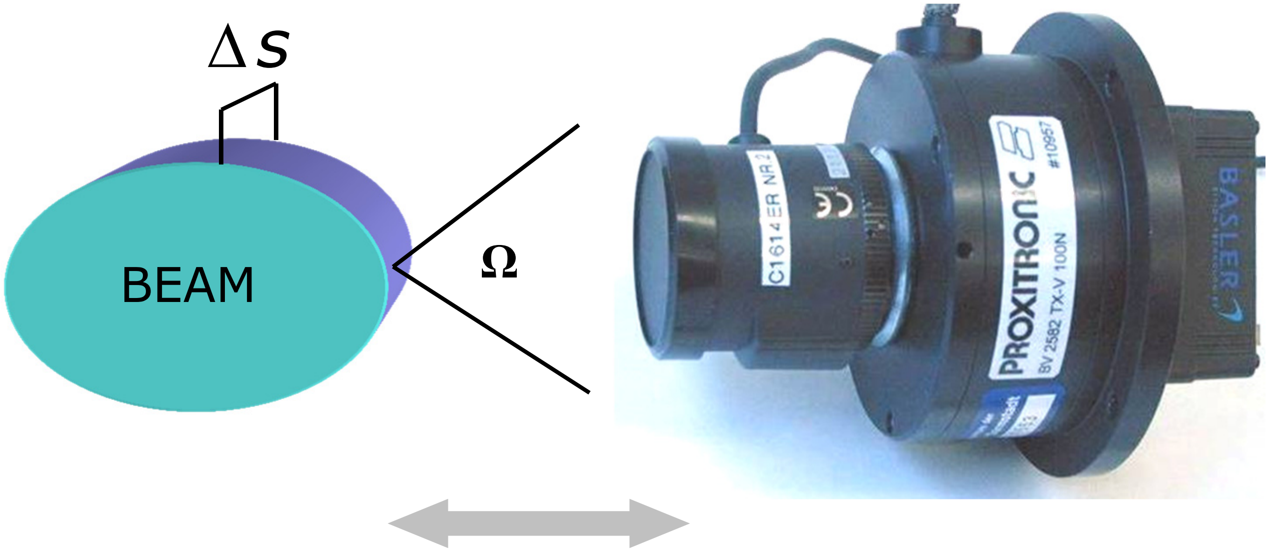
- Profile reading is equal for all gases except for He

N_2^+ and Xe^+ are recommended!

[F. Becker et al. BIW 2010]

Parameters to be Optimized

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



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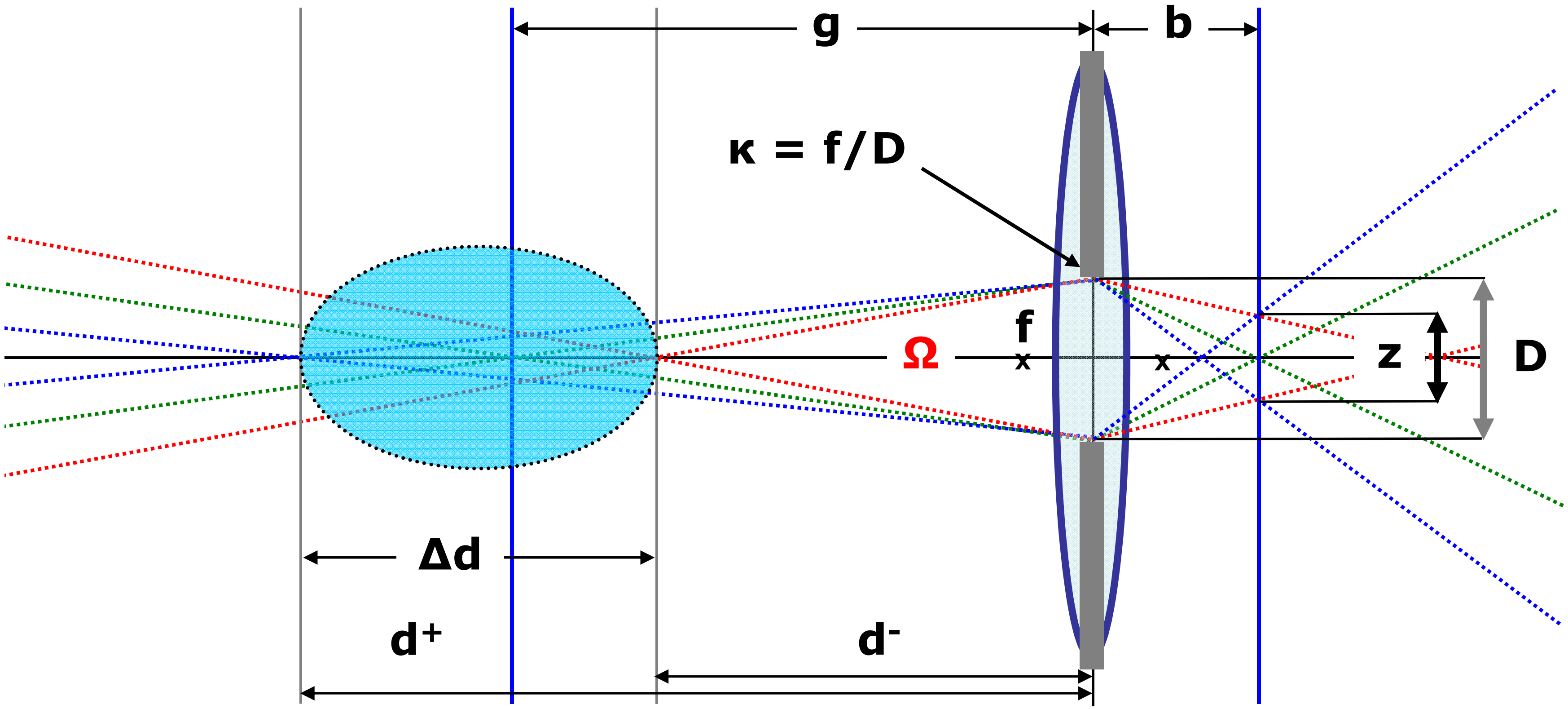
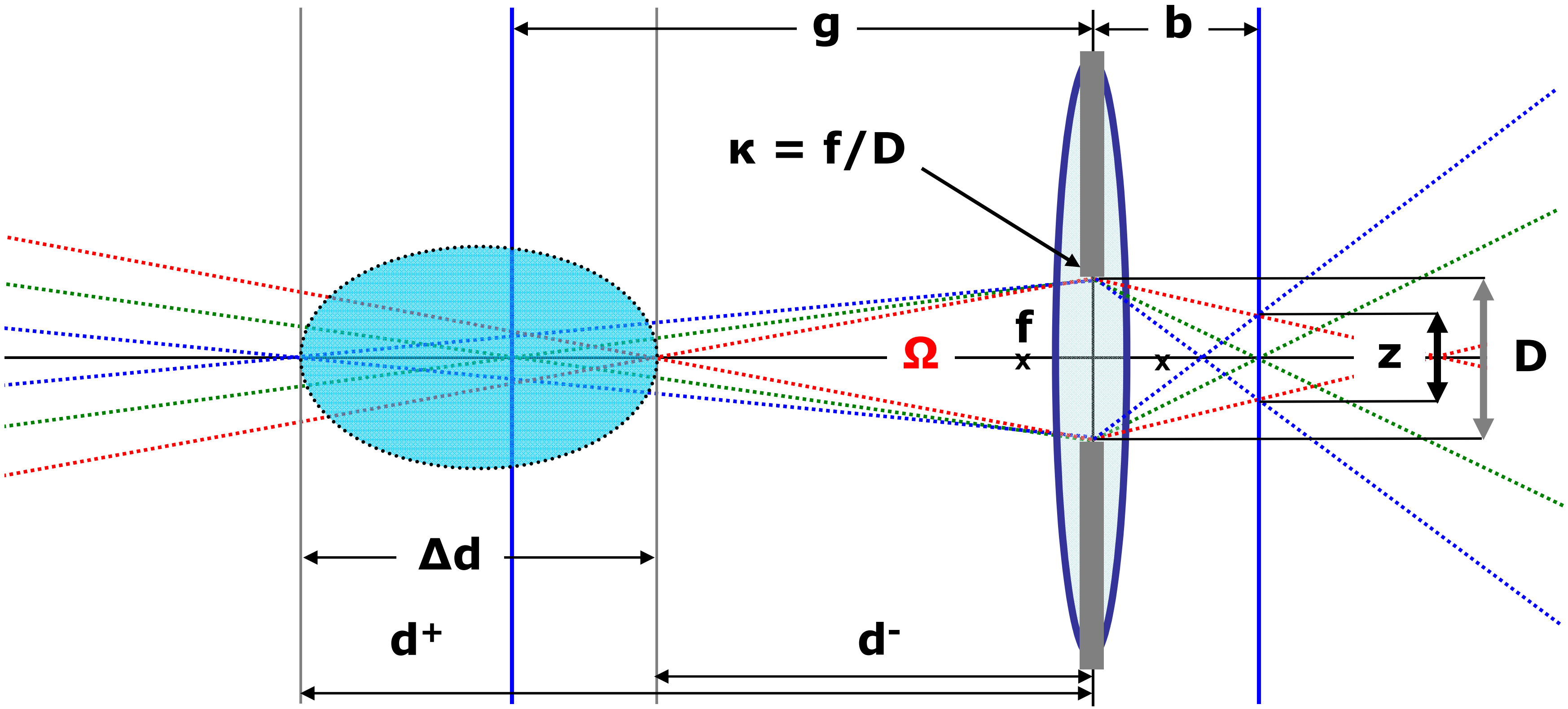


Δd should cover the beam width → Ω is limited due to κ_{min}

Parameter free to Choose

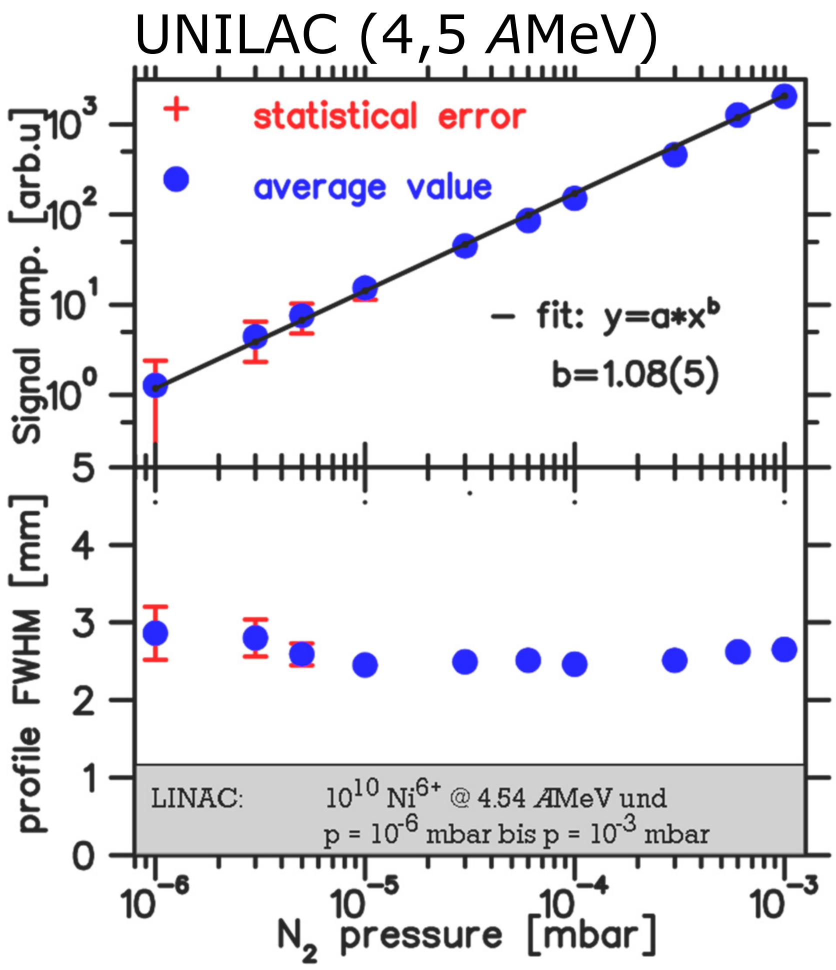
$$Y_{photon} = \sigma_{photon}(E, \bar{q})\, N_{Ion}\, \Delta s\, \Omega\, P_{Det}\, \boxed{\rho}$$

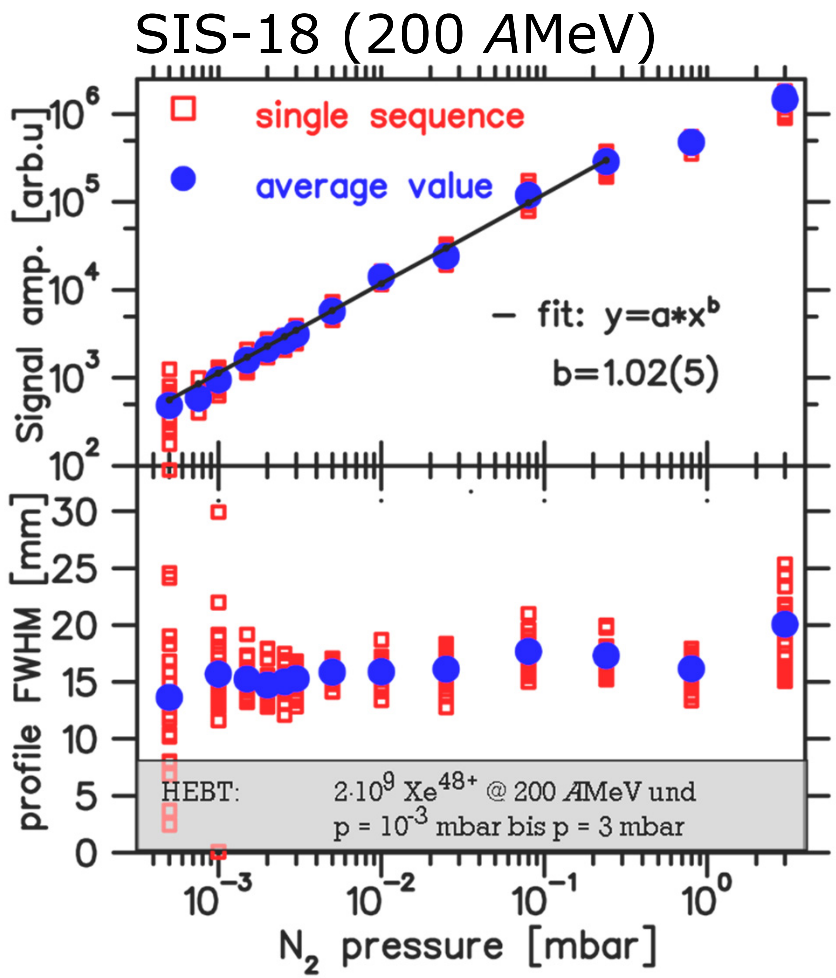


Δd should cover the beam width → Ω is limited due to κ_{min}

Pressure-Variation

[DIPAC´07, F. Becker et al.]



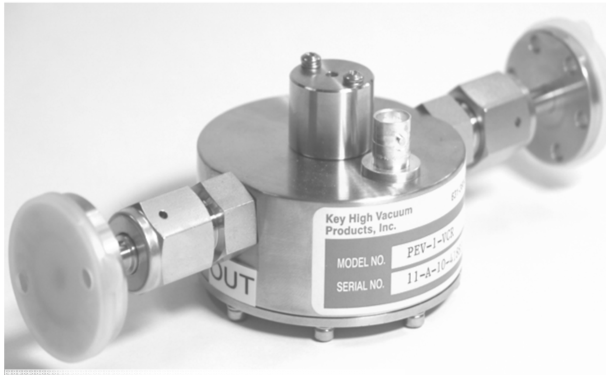


Light yield ~ p and σ = constant → p is a free parameter

Gas Dosing Systems

Wide range gauge and
motorized needle valve

+
controller



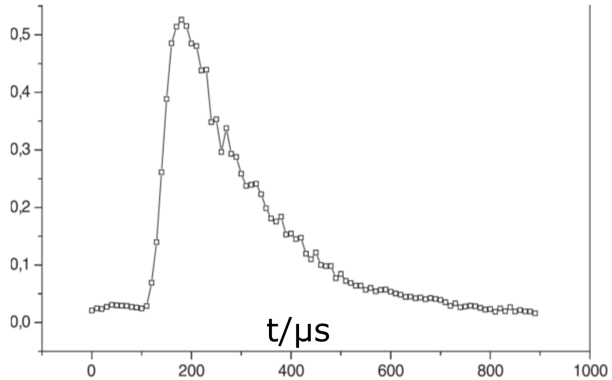
Bending element

Linear stack

controller +

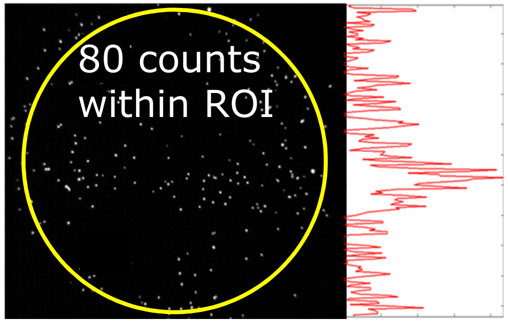
HV-pulse supply

Time scale: minutes ⟺ ms pulses

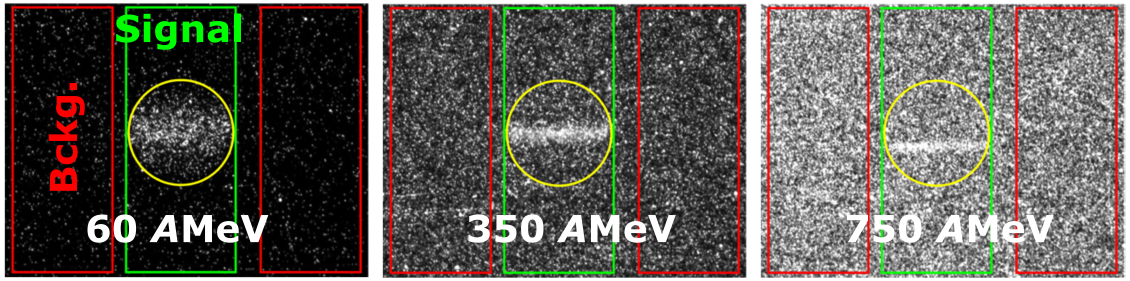


Limiting Factors

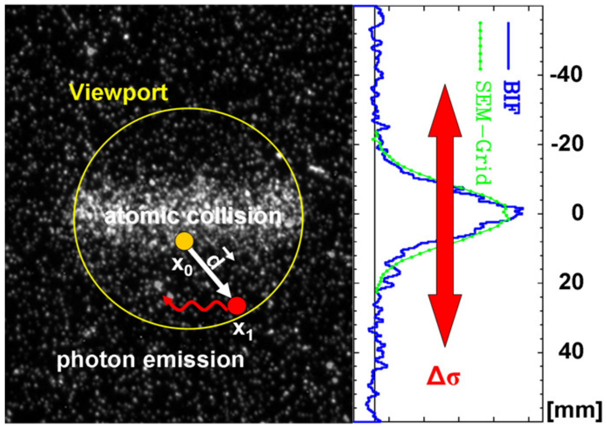
- Photon Yield
  shotnoise, statistics



- Radiation induced
  noise & damage



- Displacement
  process, lifetime,
  particle mass…



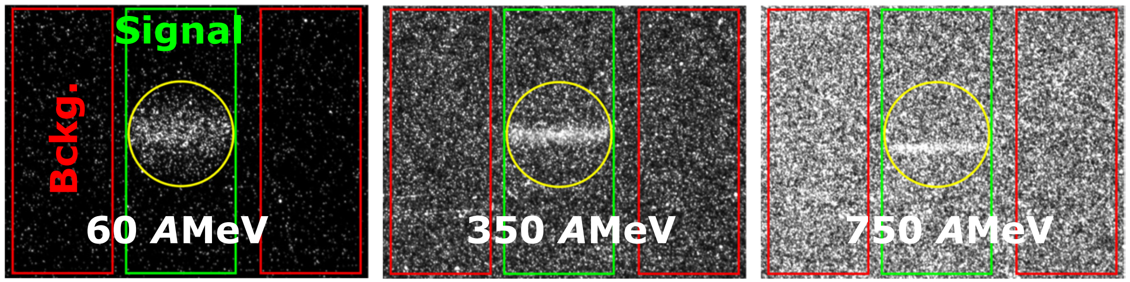
Limiting Factors → Improvements

- Photon Yield
  shotnoise, statistics

→

- Optimized Geometry + Optics
  and single photon counting

- Radiation induced
  noise & damage



- Displacement
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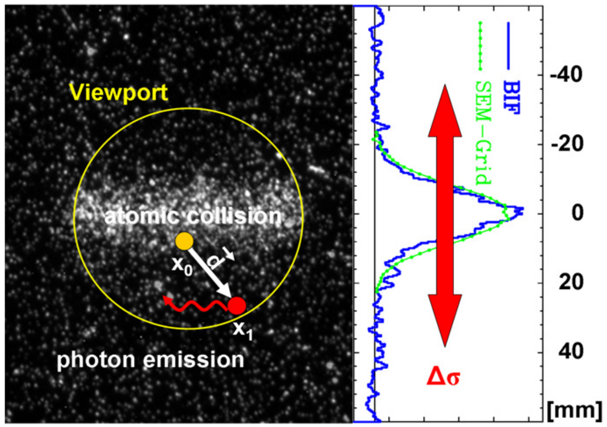

Limiting Factors → Improvements

- Photon Yield
  shotnoise, statistics

→

- Optimized Geometry + Optics
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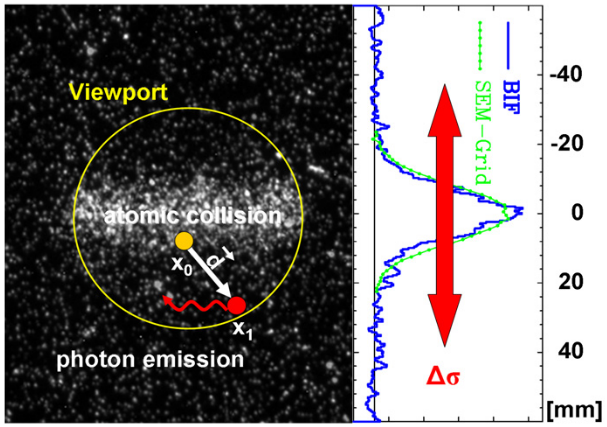
- Radiation induced
  noise & damage

→

- Radiation tolerant components
  and sufficient shielding

- Displacement
  process, lifetime,
  particle mass…



Limiting Factors → Improvements

Limiting Factors		Improvements
▪ Photon Yield shotnoise, statistics	→	▪ Optimized Geometry + Optics and single photon counting
▪ Radiation induced noise & damage	→	▪ Radiation tolerant components and sufficient shielding
▪ Displacement process, lifetime, particle mass…	→	▪ Ionized gas particles reduce excitation by electrons, heavy species with short lifetime, e.g. Xe^{+}

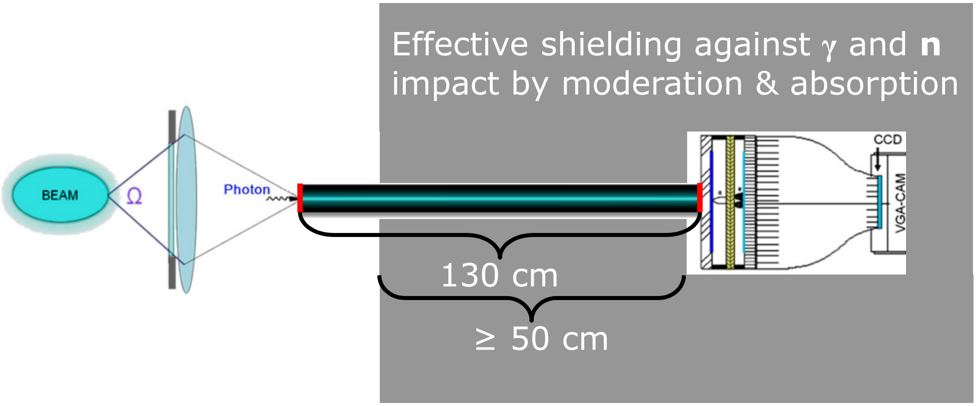
Shielding-Concept with Image-Guide

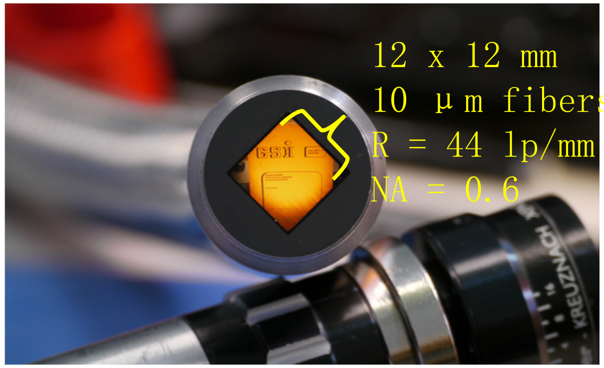
- Shielding walls or blocks
  1m³ → ≥90% reduction

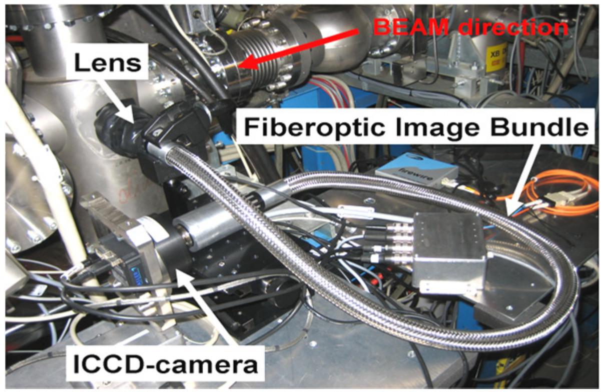
- Image transport with relay
  optics or image guide

- Radiation hard components
  and optics are recommended:
  ICID, CMOS, quartz fibers…

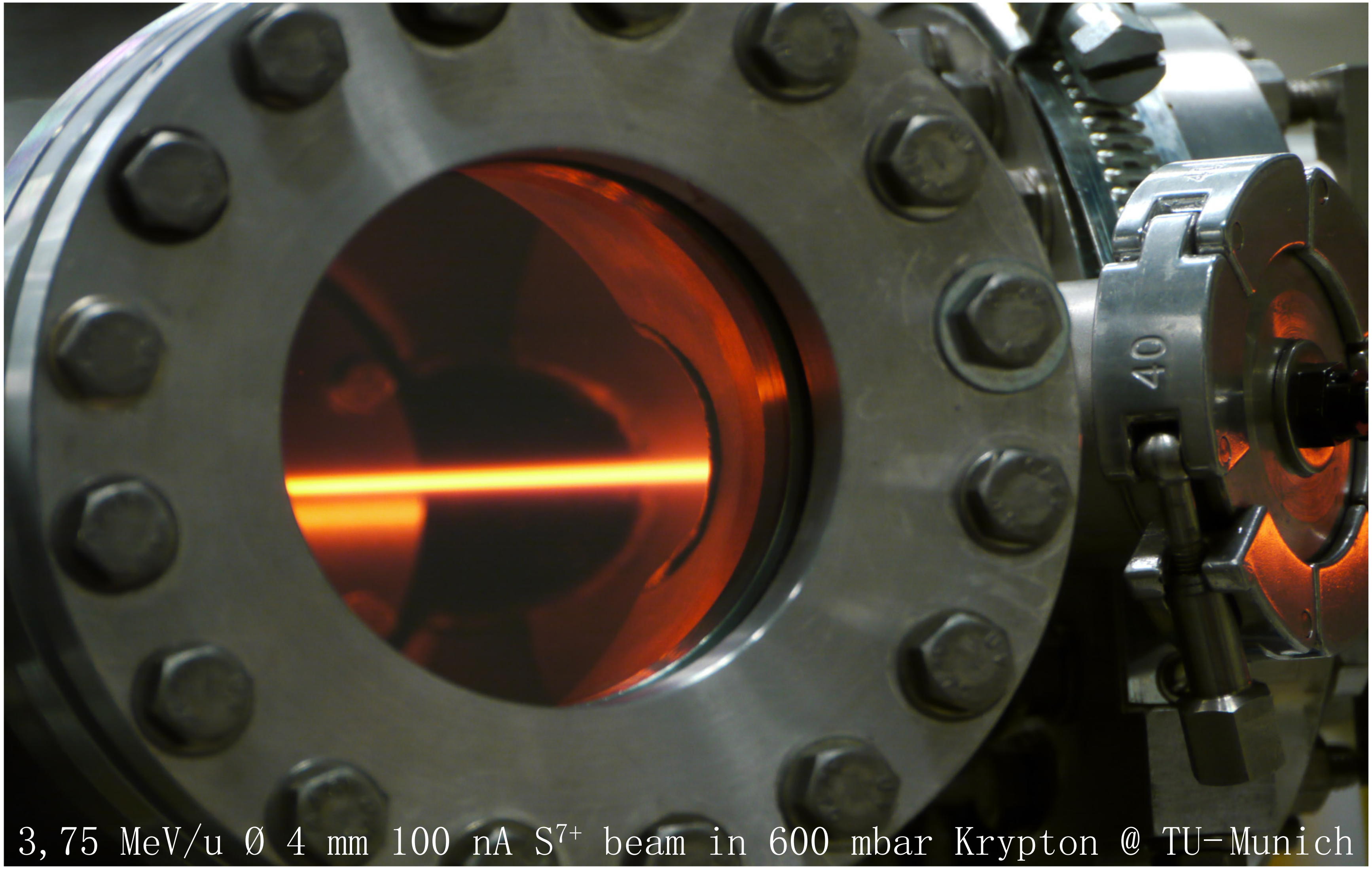
[C. Zamantzas, DIPAC]
[F. Senée, DIPAC-09]
[F. Becker, BIW-08]







Diagnostics with the Eye :-)



3,75 MeV/u Ø 4 mm 100 nA S^{7+} beam in 600 mbar Krypton @ TU-Munich

[A. Ulrich et al., Tandem accelerator, TUM]

Decreasing Kr-Pressure 1000 – 1 mbar

3,75 MeV/u Ø 4 mm 100 nA S^{7+} beam in 1000 - 1 mbar Krypton @ TU-Munich

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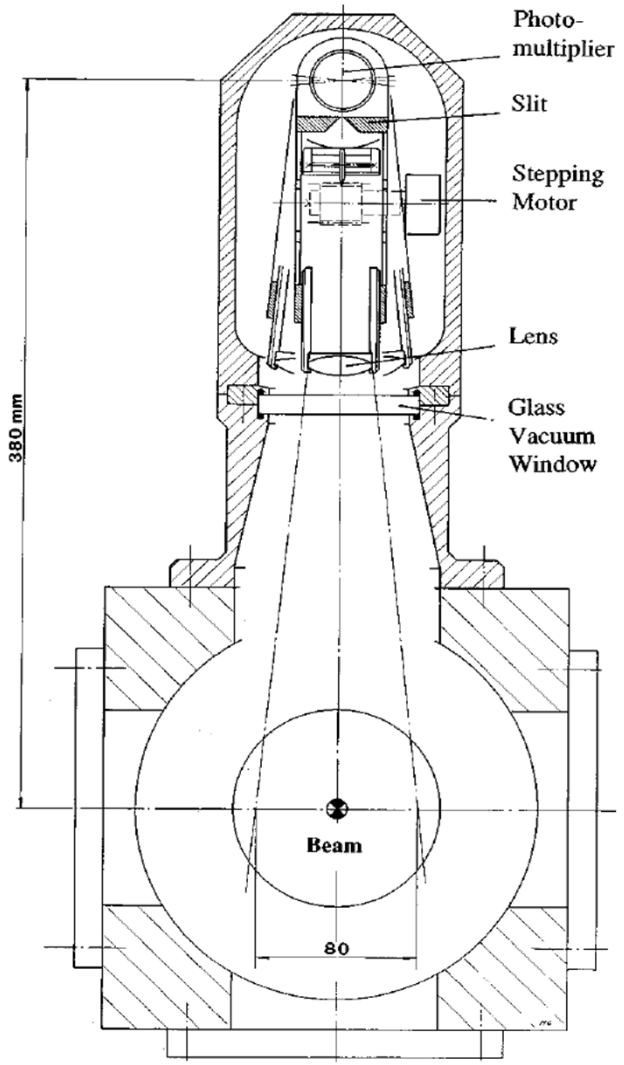
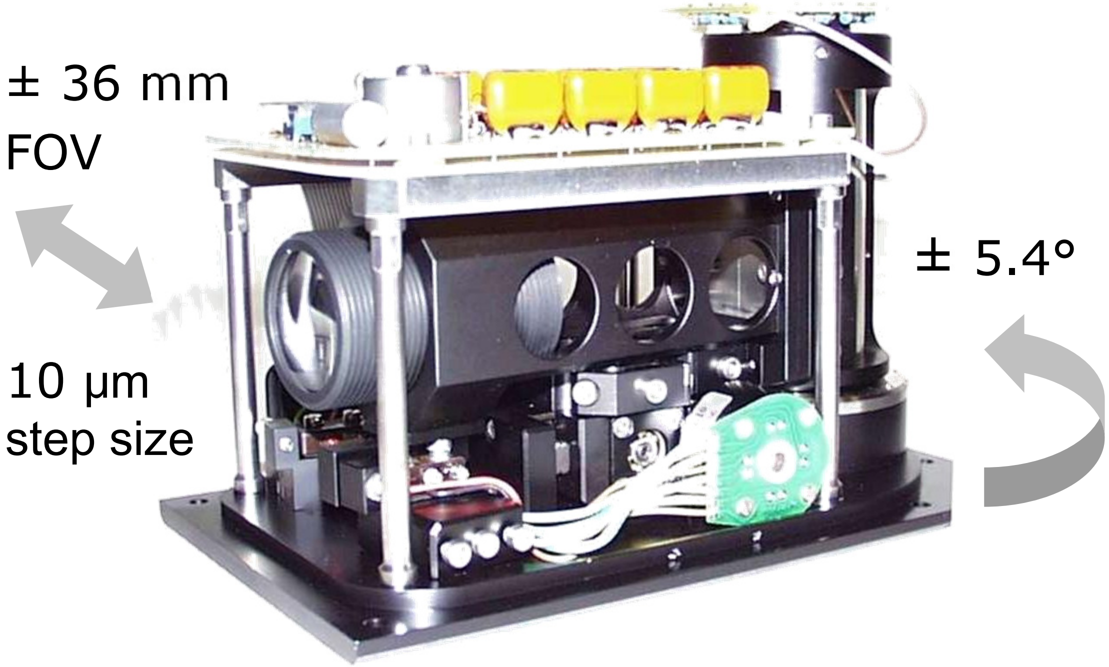
PSI Cyclotron and LEBT

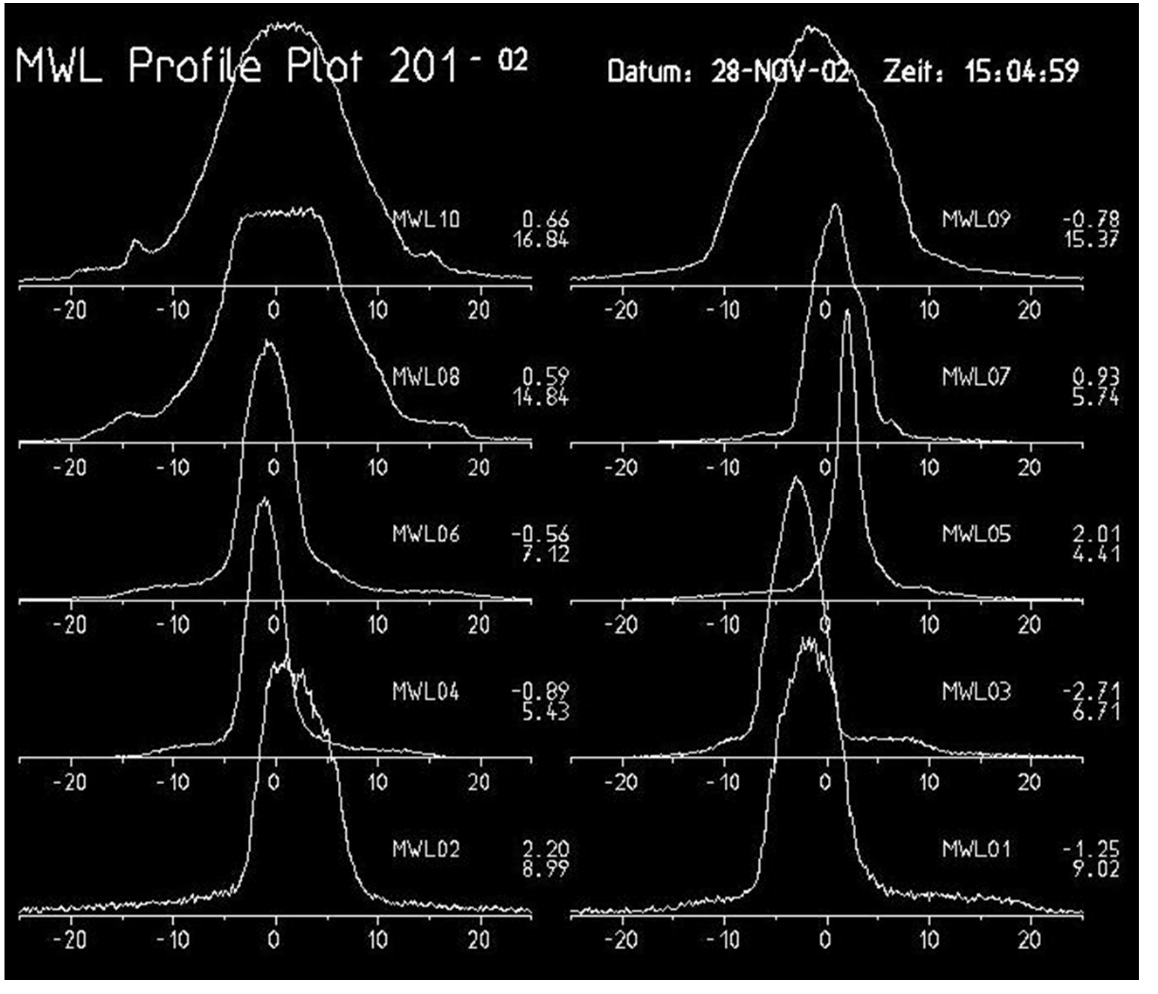




- Monitor commissioned 1987 @ PSI
- 9-14 mA protons at 870 keV in 10^{-6} – 10^{-5} mbar H_2 and N_2 gas
- 720 steps with 2-32 ms int. time each
- Successfully operated at 10 LEBT locations since installation :-)

[CYC-1987 L. Rezzonico, PSI] [Courtesy of R. Doelling, PSI]

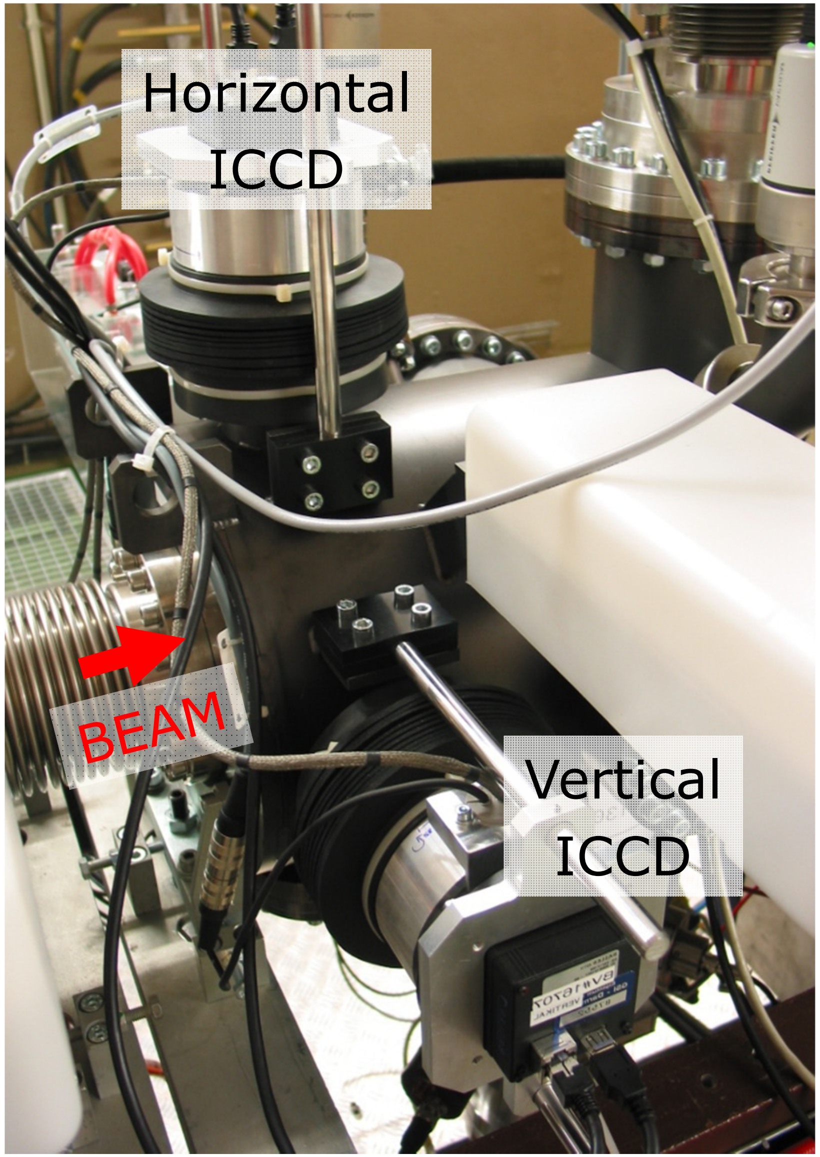
PSI Cyclotron and LEBT

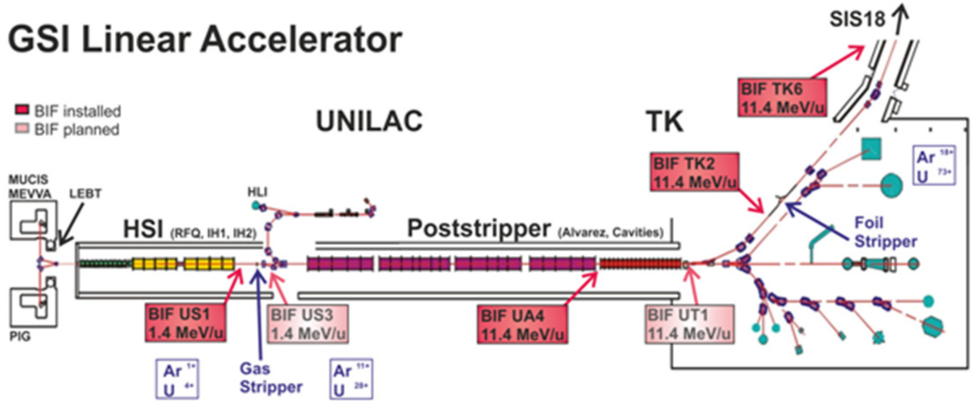


Measurement of 10 luminescent profile monitors along the transport section. 870 keV, 13 mA DC proton beam in ≤ 10^{-5} mbar residual gas.

[Courtesy of R. Doelling, PSI]

BIF Setup at GSI-UNILAC

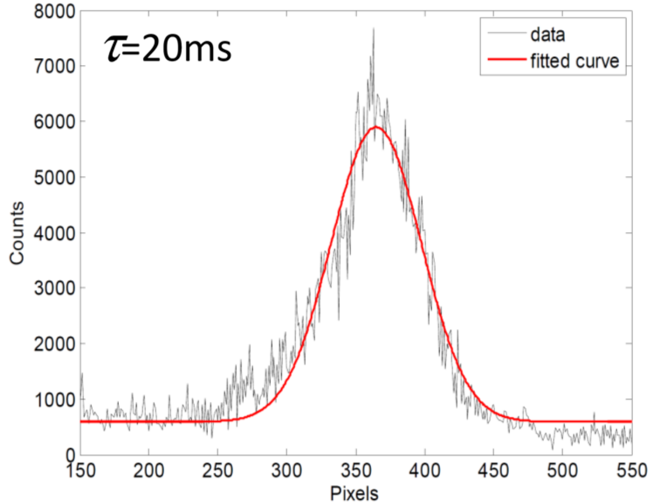


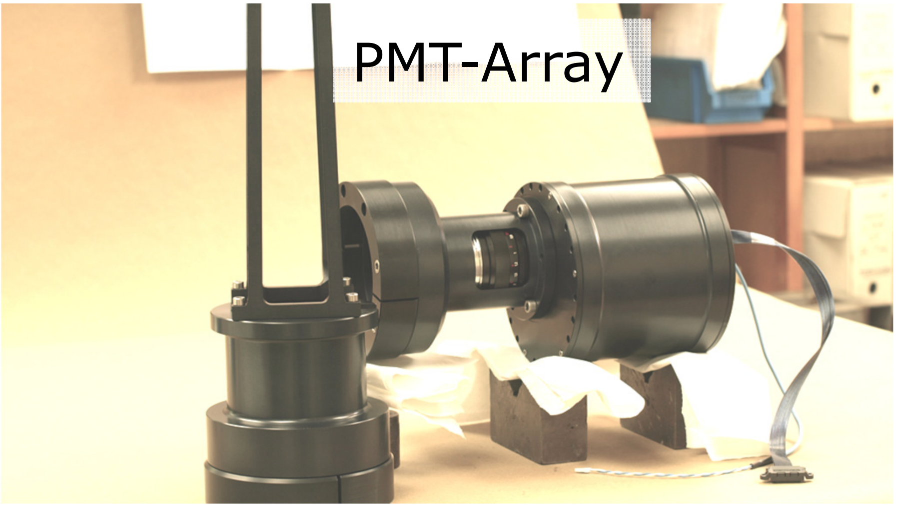


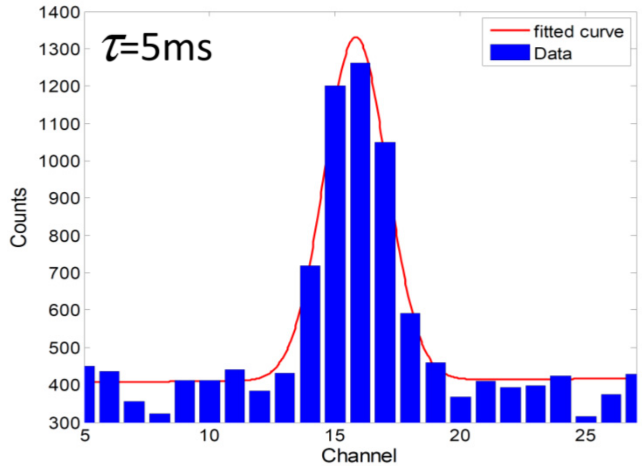
- Single pulse operation
- Typical gating times µs-ms
- 4 systems in operation
- 2 Systems in preparation
- Profile-View software for online monitoring in the controls room [DIPAC 2009 R. Haseitl]

[DIPAC: MOPD60 C. Andre]

IFMIF EVEDA – Prototype Testing



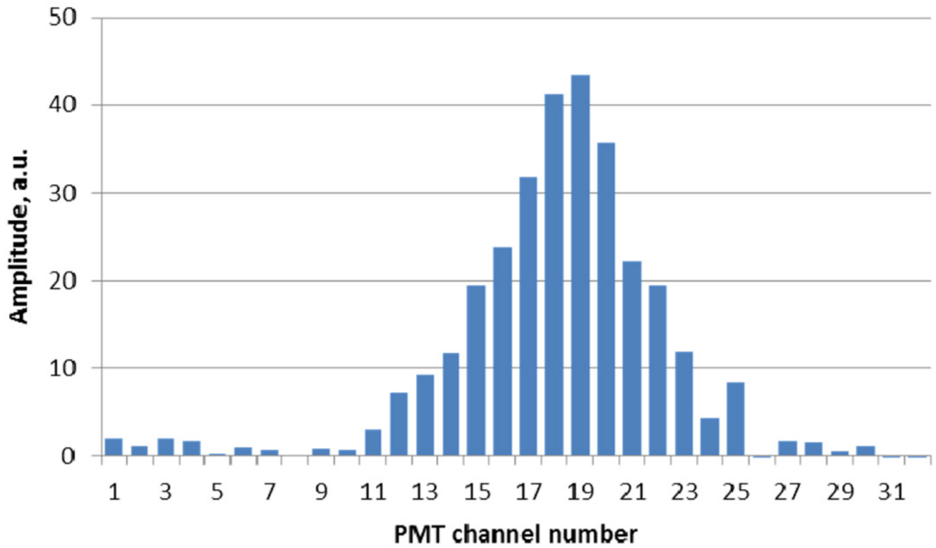




15 μA D^+ beam at 9 MeV/u in $7 \cdot 10^4$ mbar N_2 gas (125 mA is intended)

[Courtesy of J.M. Carmona]

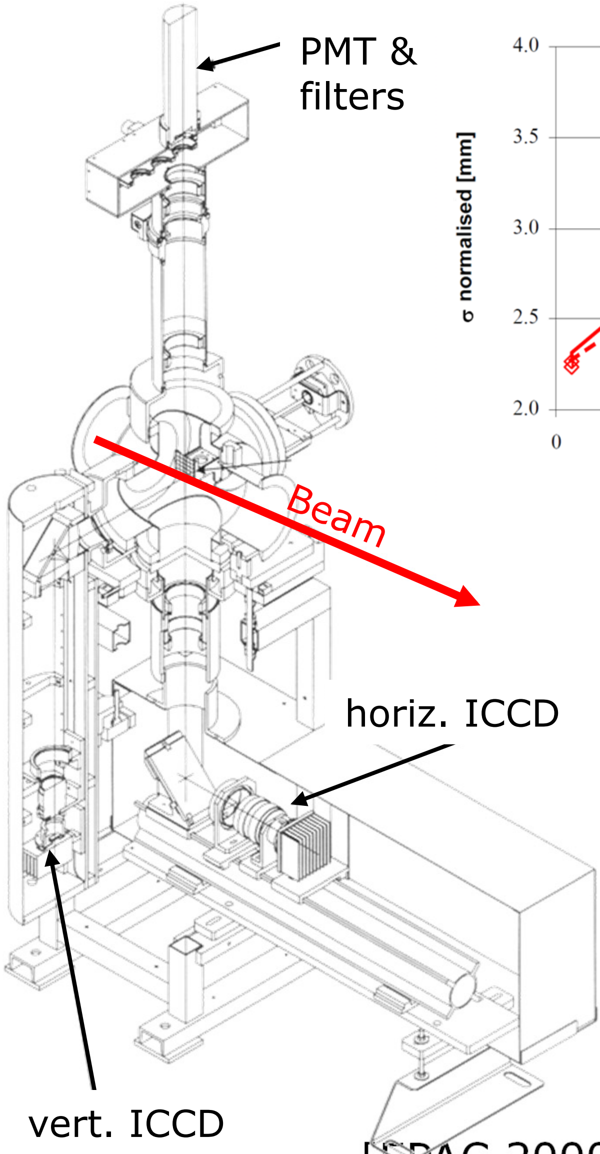
FZ-Jülich COSY

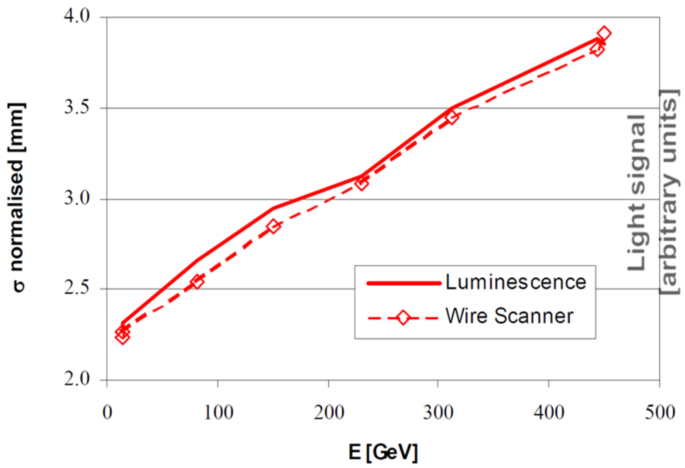


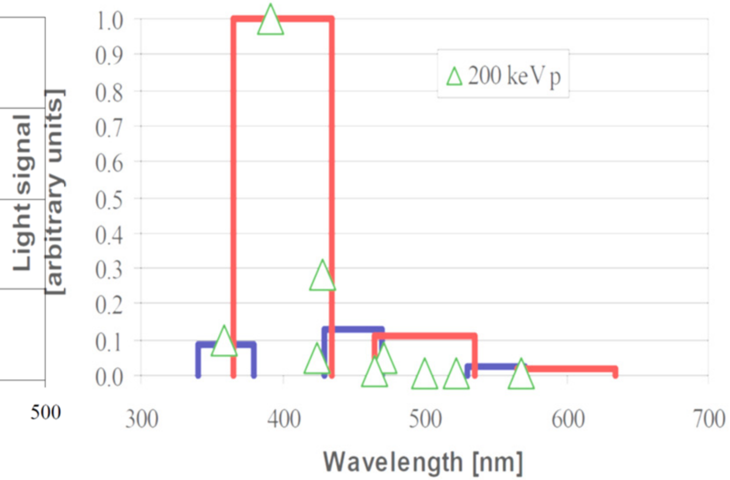
- $1.5 \cdot 10^{10}$ protons at 2.6 GeV/c cooler storage synchrotron, low p
- Pulsed piezo leak valve to minimize gas load (t_{min} ~1 ms)
- $p_{base} \sim 2 \cdot 10^{-9}$, $p_{measure} \sim 4 \cdot 10^{-8}$ mbar
- Integration time counteracts low p

[DIPAC: MOPD51 V. Kamerdzhiev]

CERN – SPS



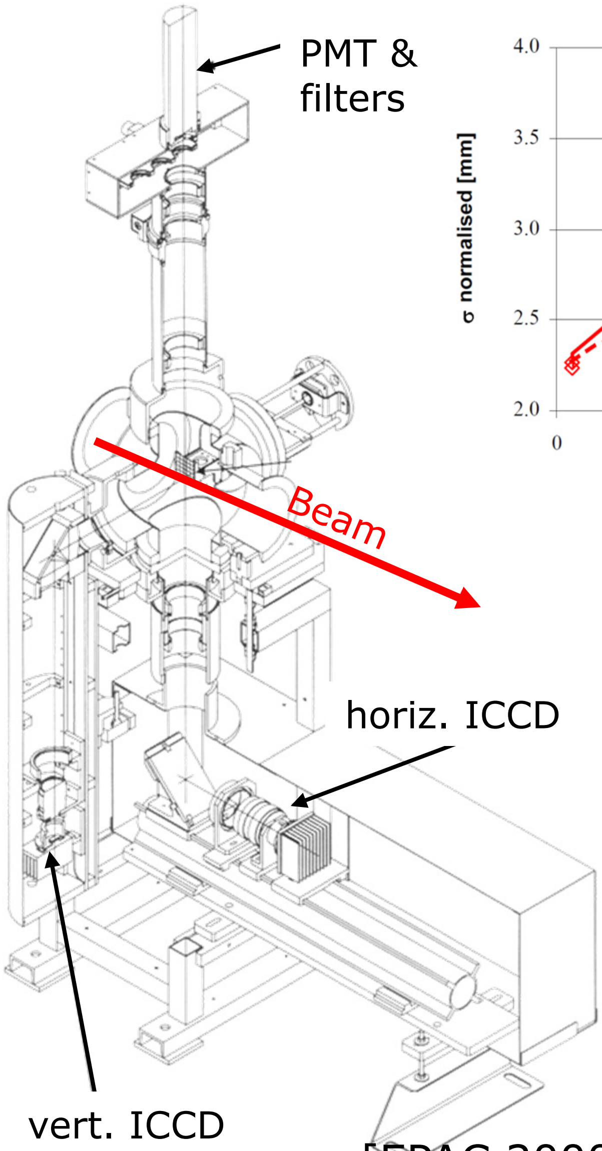


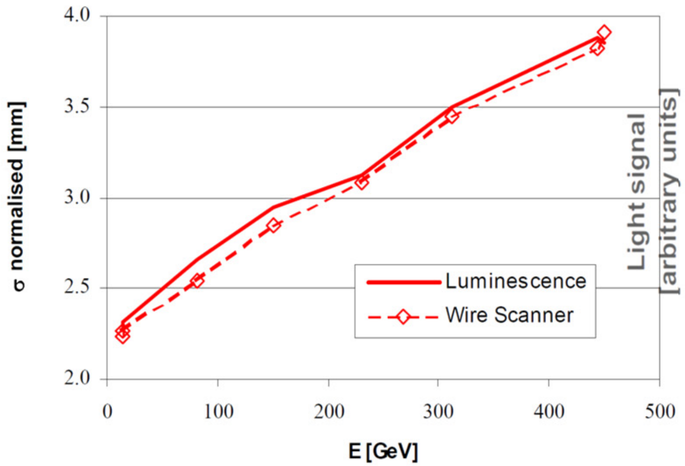


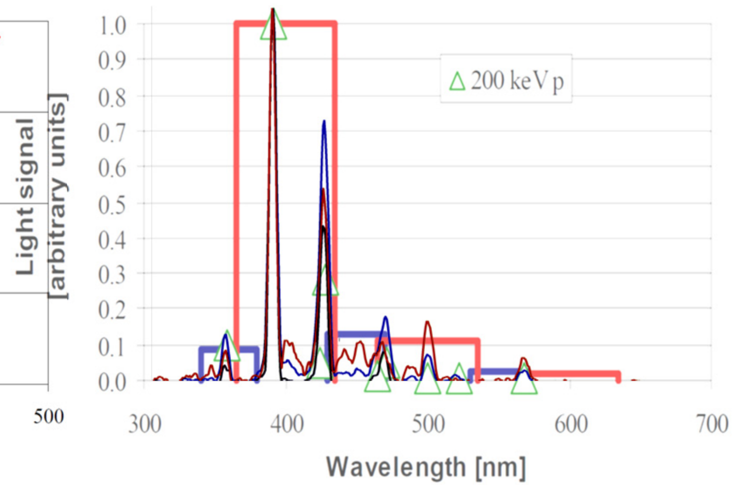
- 450 GeV SPS proton beam
- In 10^{-7} – 10^{-5} mbar N_2 gas
- Beam size monitoring during ramp in agreement with wire scanner
- Fluorescence CS from 14-450 GeV
- Spectral mapping agrees with 200 keV

[EPAC 2000 G. Burtin et al.] [A. Variola et al. PhysRevSTAB 2007]

CERN – SPS



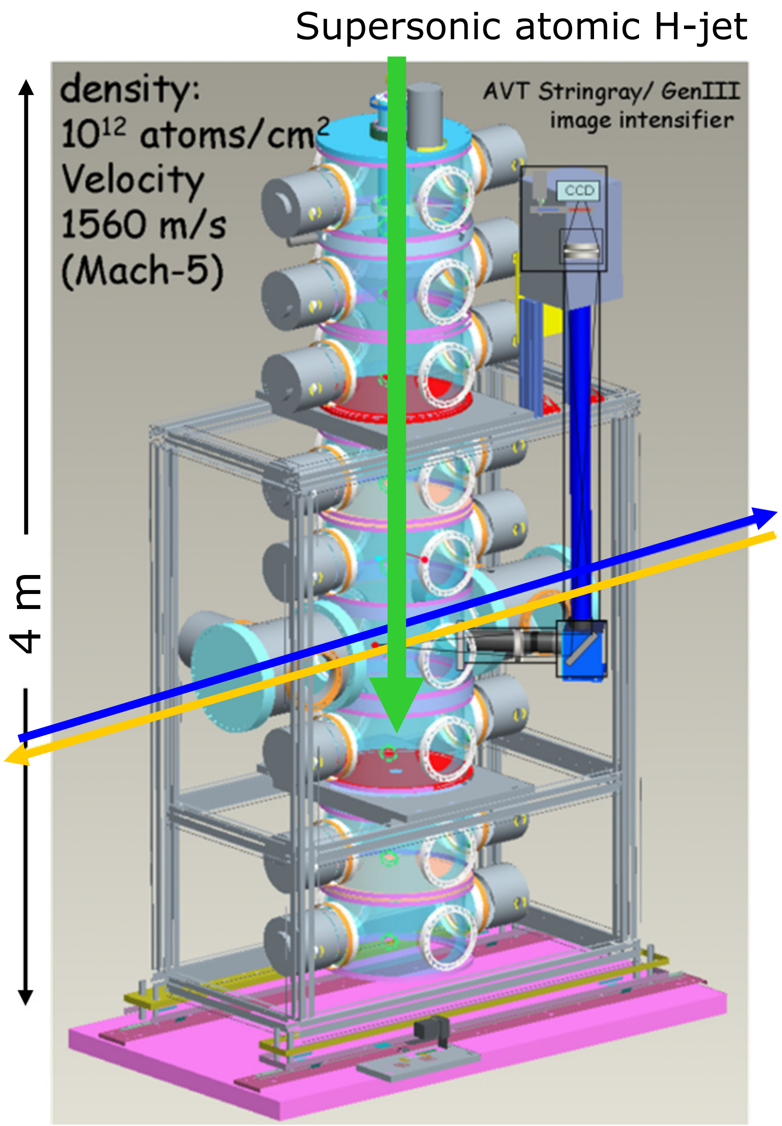


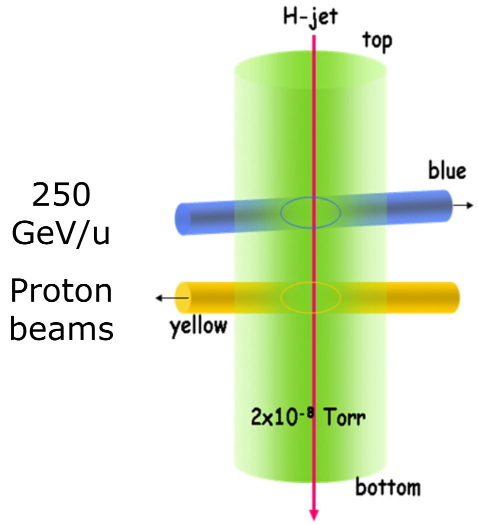


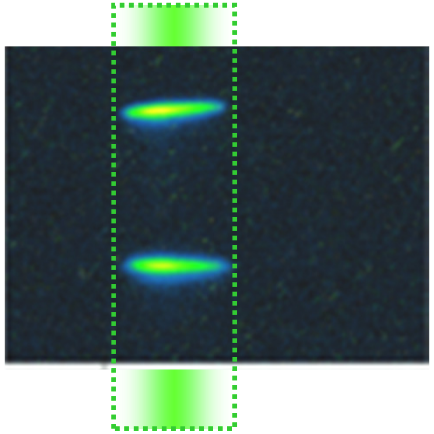
- 450 GeV SPS proton beam
- In 10^{-7} – 10^{-5} mbar N_2 gas
- Beam size monitoring during ramp in agreement with wire scanner
- Fluorescence CS from 14-450 GeV
- Spectral mapping agrees with 200 keV and 5 MeV data (GSI)

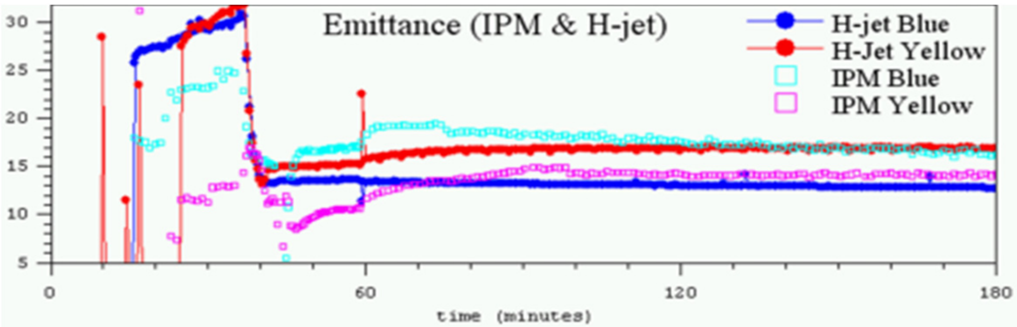
[EPAC 2000 G. Burtin et al.] [A. Variola et al. PhysRevSTAB 2007]

BNL – RHIC Injected Gas Jet





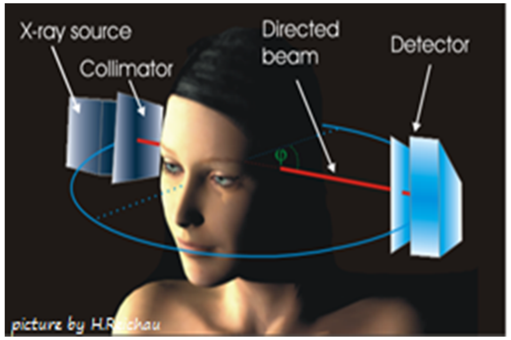


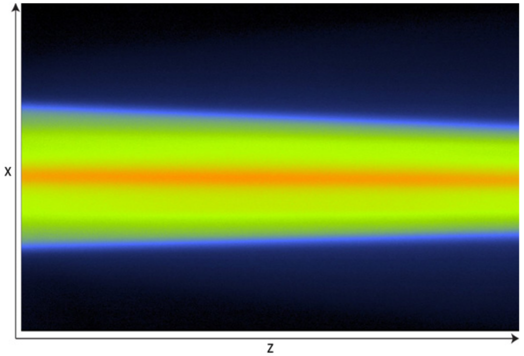


- Directed jet provides $p \leq 10^{-3}$ mbar
- Integration ~10^{19} 100 GeV protons
- Online emittance measurement

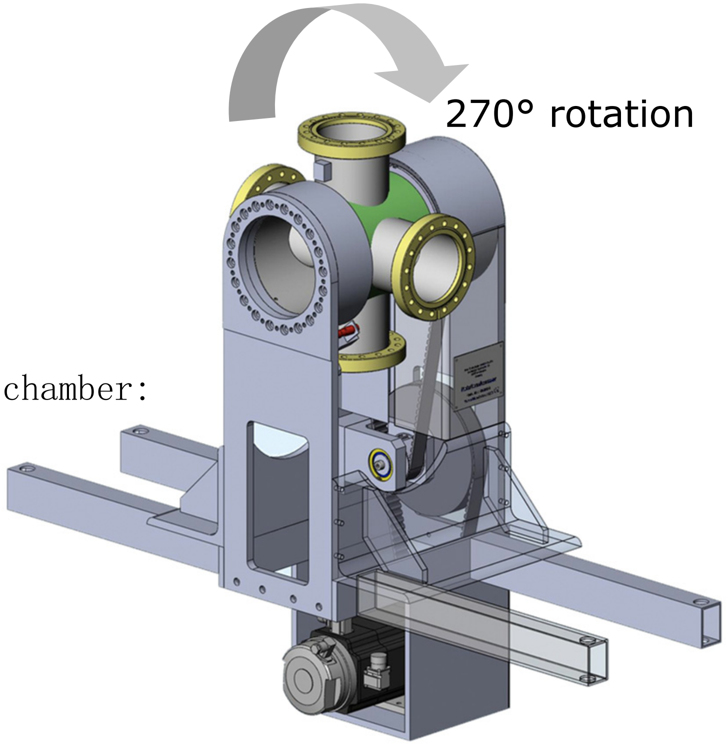
[PAC'11: paper MOP210 T. Tsang]

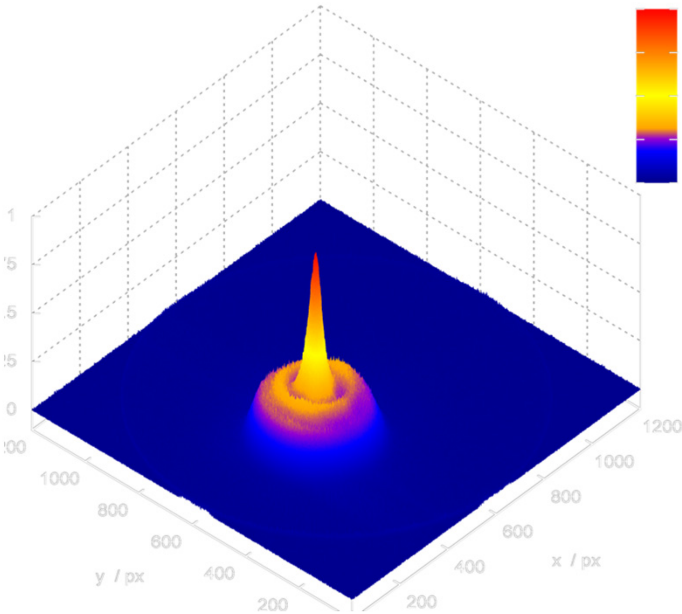
IAP Frankfurt – Tomography





Tomography: 181 profile projection measured with rotating chamber:



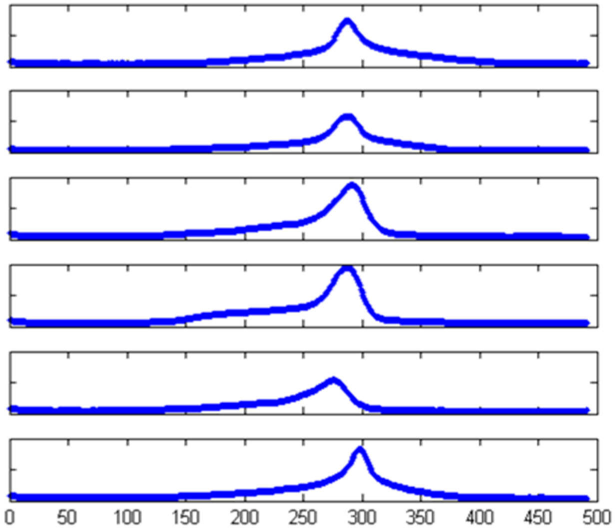


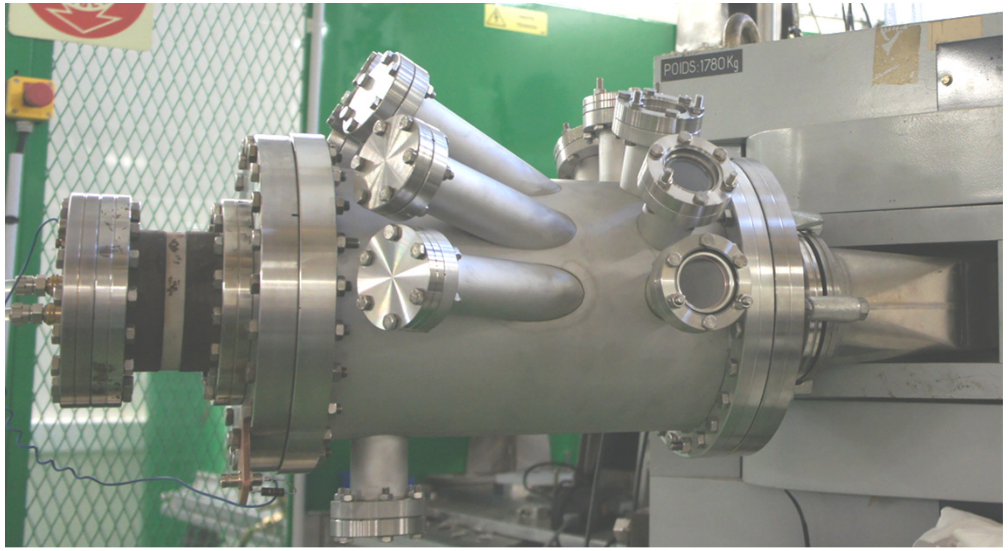
Reconstructed density distribution

- 2-dimensional density distributions
- High res. scanning, radon transform
- Non-invasive emittance determin.
- 120 keV, 200 mA H^+, $5 \cdot 10^{-5}$ mbar N_2

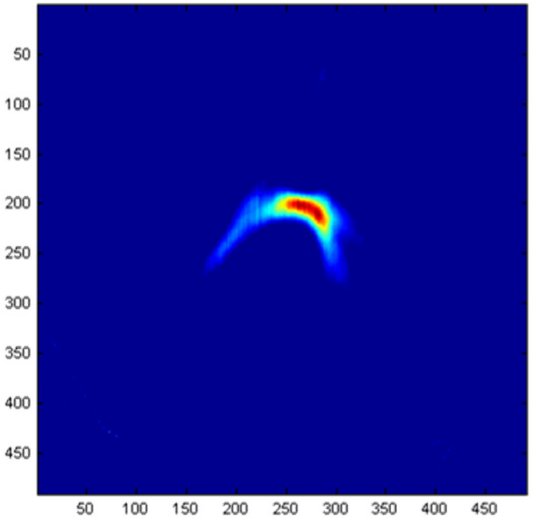
[DIPAC: TUBD60 & TUPD52 H. Reichau/C. Wagner]

CEA Saclay – Tomography





Projections and reconstruction (bottom) Diagnostic chamber with 6 equally spaced viewports for CCDs



- 2-dimensional density distributions
- Iterative Algebraic reconstruction technique (ART)
- Installed at BETSI source test bench
- 50 keV, 5 mA H^+ beam, $5\cdot10^{-5}$ mbar H_2

[DIPAC: TUPD58 C.M. Mateo]

Conclusion

- Remarkable developments for:
  - Synchrotrons & transport to characterize intensive ion beams
- Results of research:
  - Signal-amplitude $\rightarrow$ linear with p, dE/ds with E $\rightarrow$ f = const.
  - Profile-width $\rightarrow$ does not depend on p $\rightarrow$ p free parameter
  - Radiation-induced background $\rightarrow$ $\sim E^2$ $\rightarrow$ shielding is mandatory
  - Rare gases (Kr, Xe) can replace N_2 $\rightarrow$ reduced profile errors
  - N_2 has highest fluorescence-efficiency per energy loss
- Successful implementation of BIF-monitors:
  - In the energy-range of 7,5 *A*keV – 450 *A*GeV
  - In transport sections and synchrotrons
  - Many innovative installations are in operation
  - The story goes on…

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Thank you for your attention! ☺