Beam Induced Fluorescence (BIF) Monitor for Transverse Profile Determination of 5 to 750 MeV/u Heavy Ion Beams

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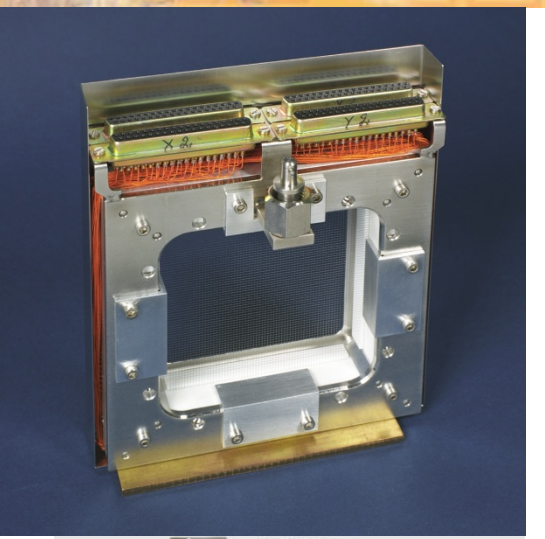
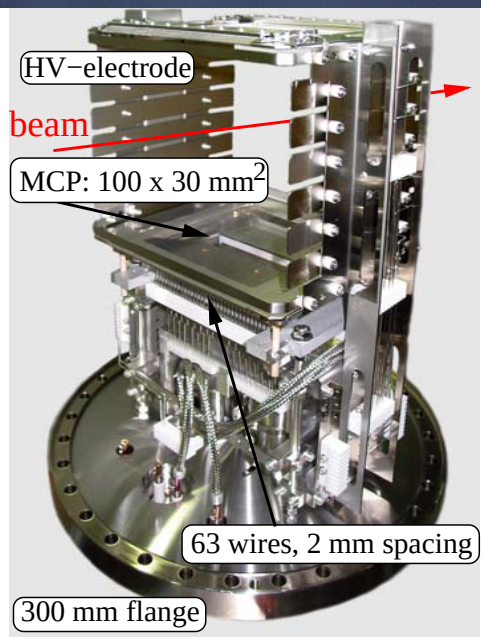
Outline

- Introduction
  - Detectors for high beam power
  - BIF-detection principle
- Experiment
  - Setup
  - Data Analysis
  - Results
- Conclusion

Comparison of Profile Monitors





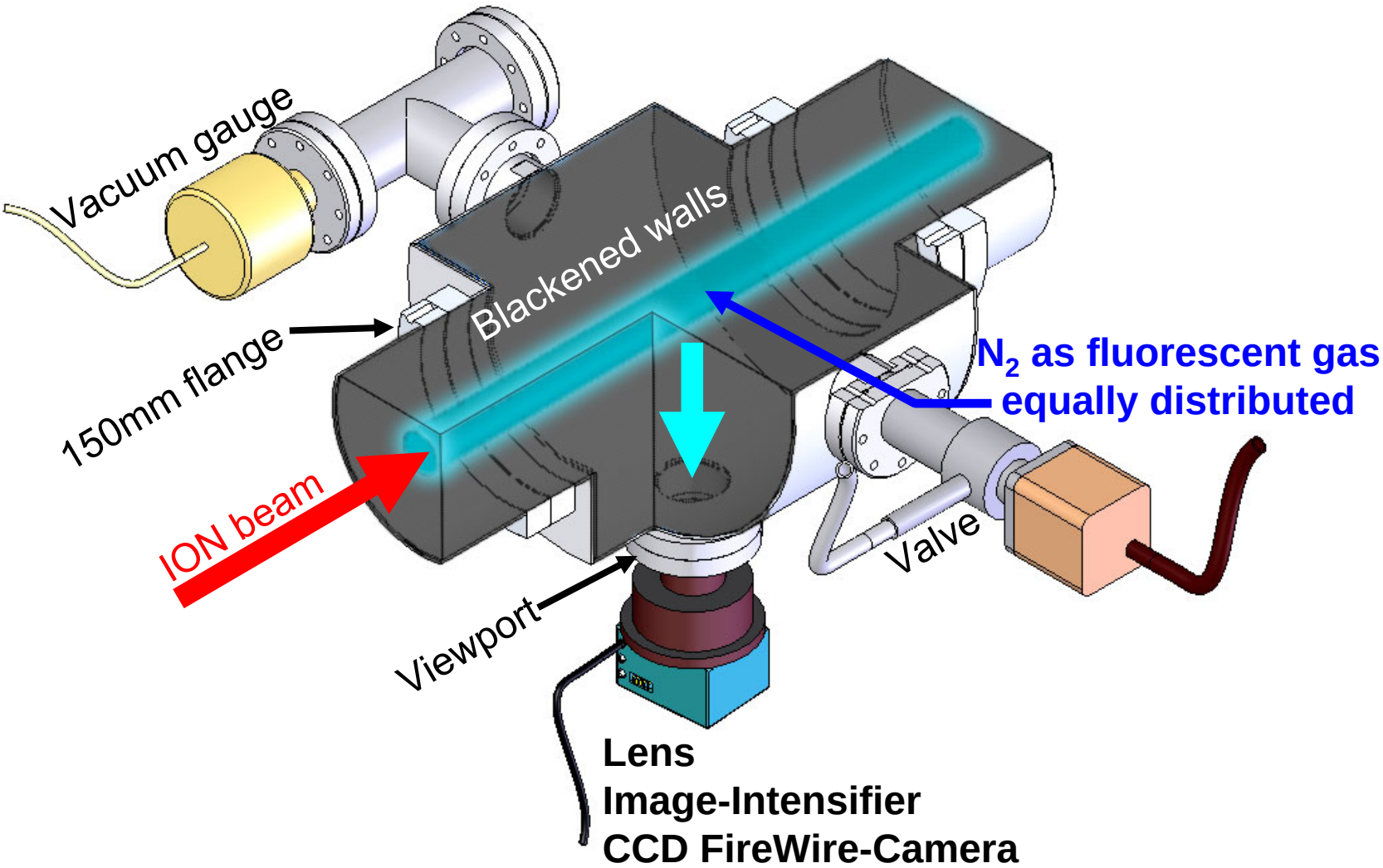
Secondary-Electron-Monitor (SEM) Grid

+ Standard tool, compact design
+ Low background level
- Limited spacial resolution (wire spacing)
-- Melts in high power beams!

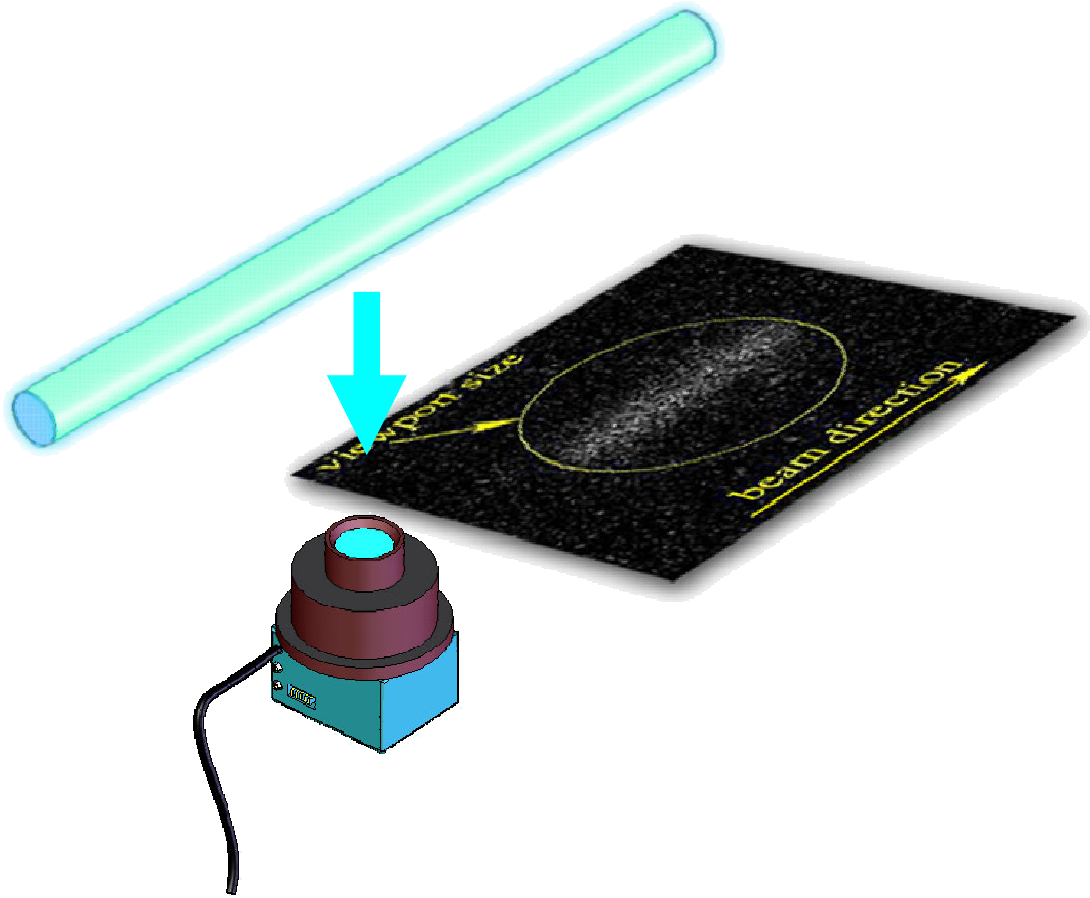
Residual Gas Monitor (RGM)

+ Non-intercepting monitoring
+ Measures even high power beams
+ Very sensitive ↦ used in synchrotrons
- Lot of mechanics inside vacuum

Beam Induced Fluorescence (BIF)



How a Profile is obtained



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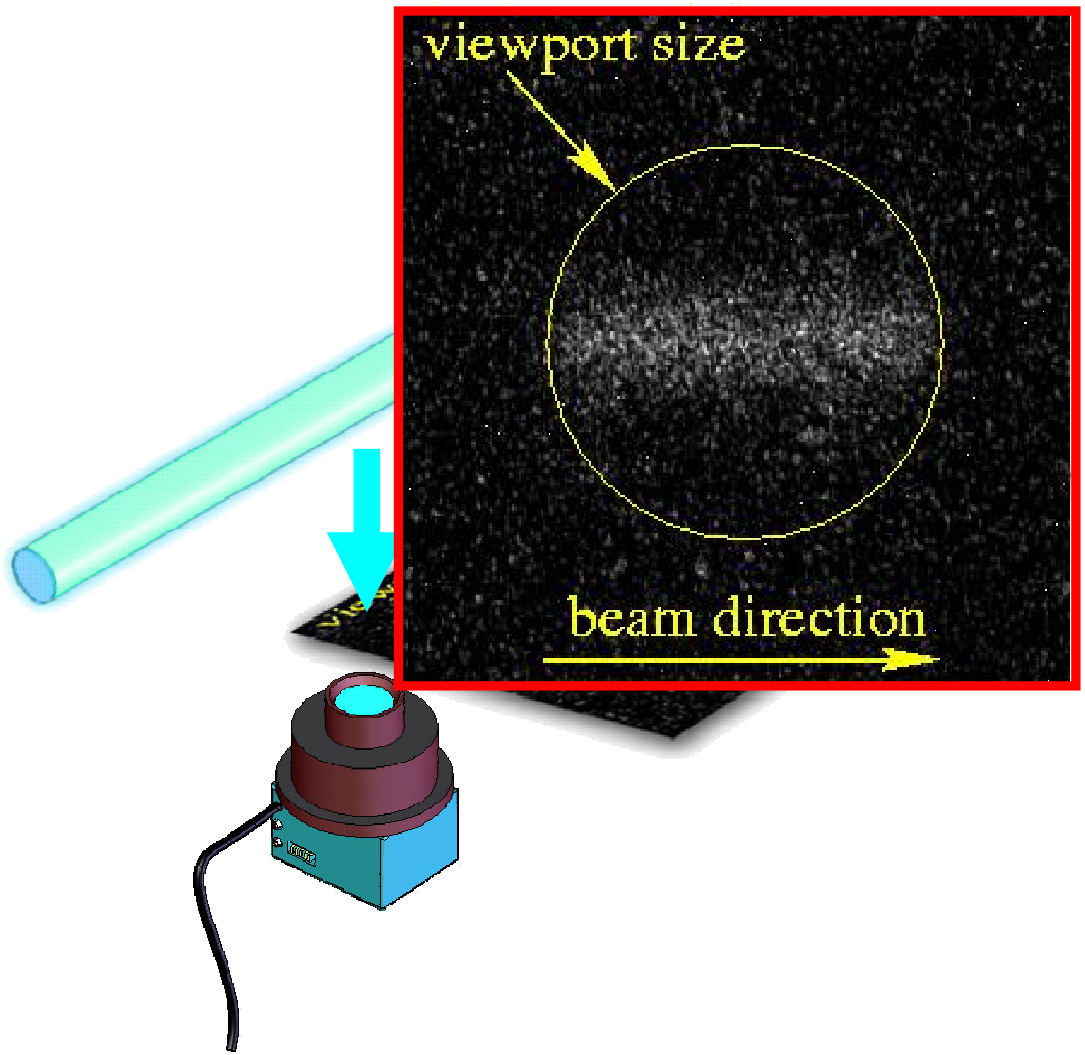

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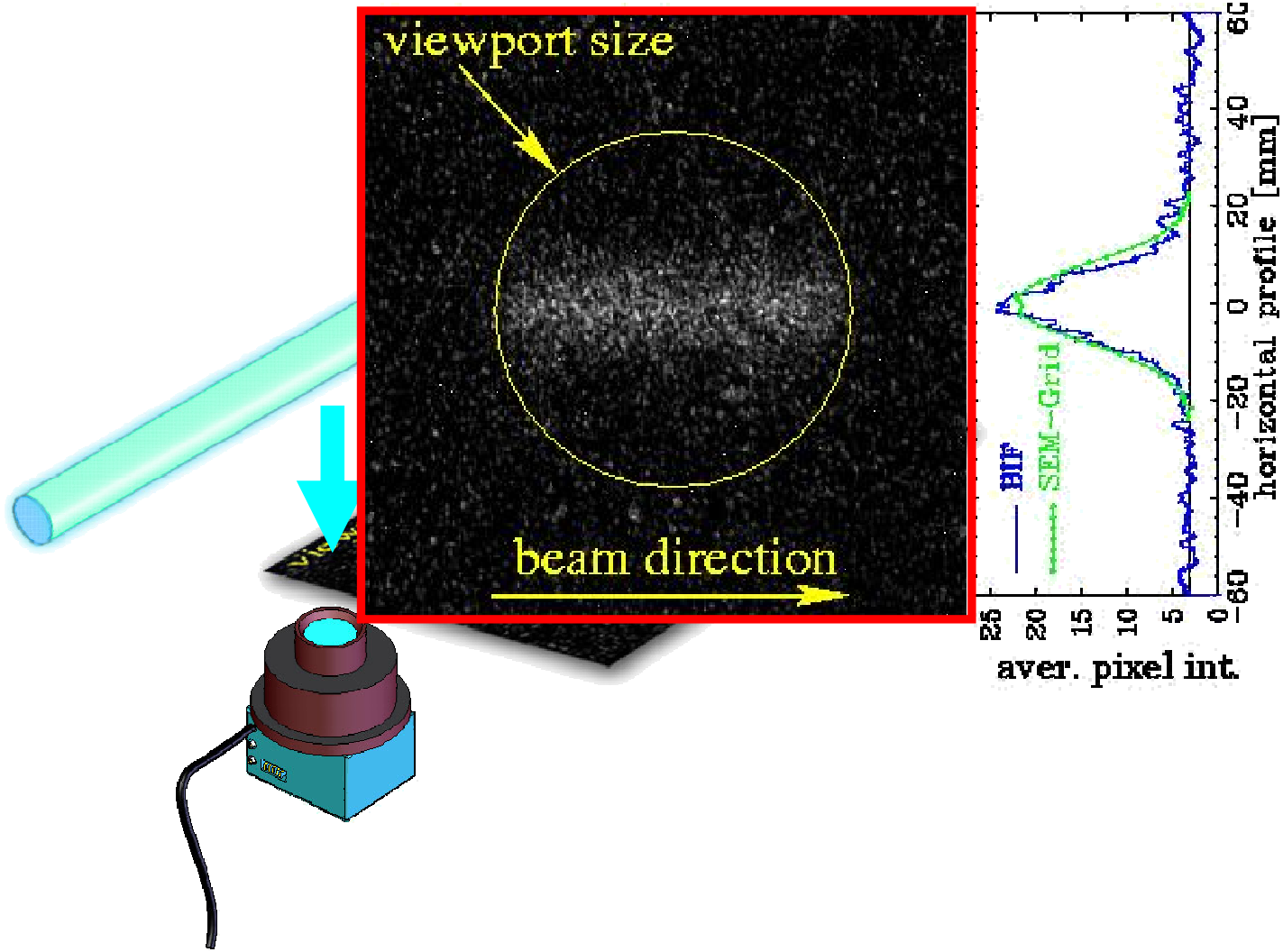
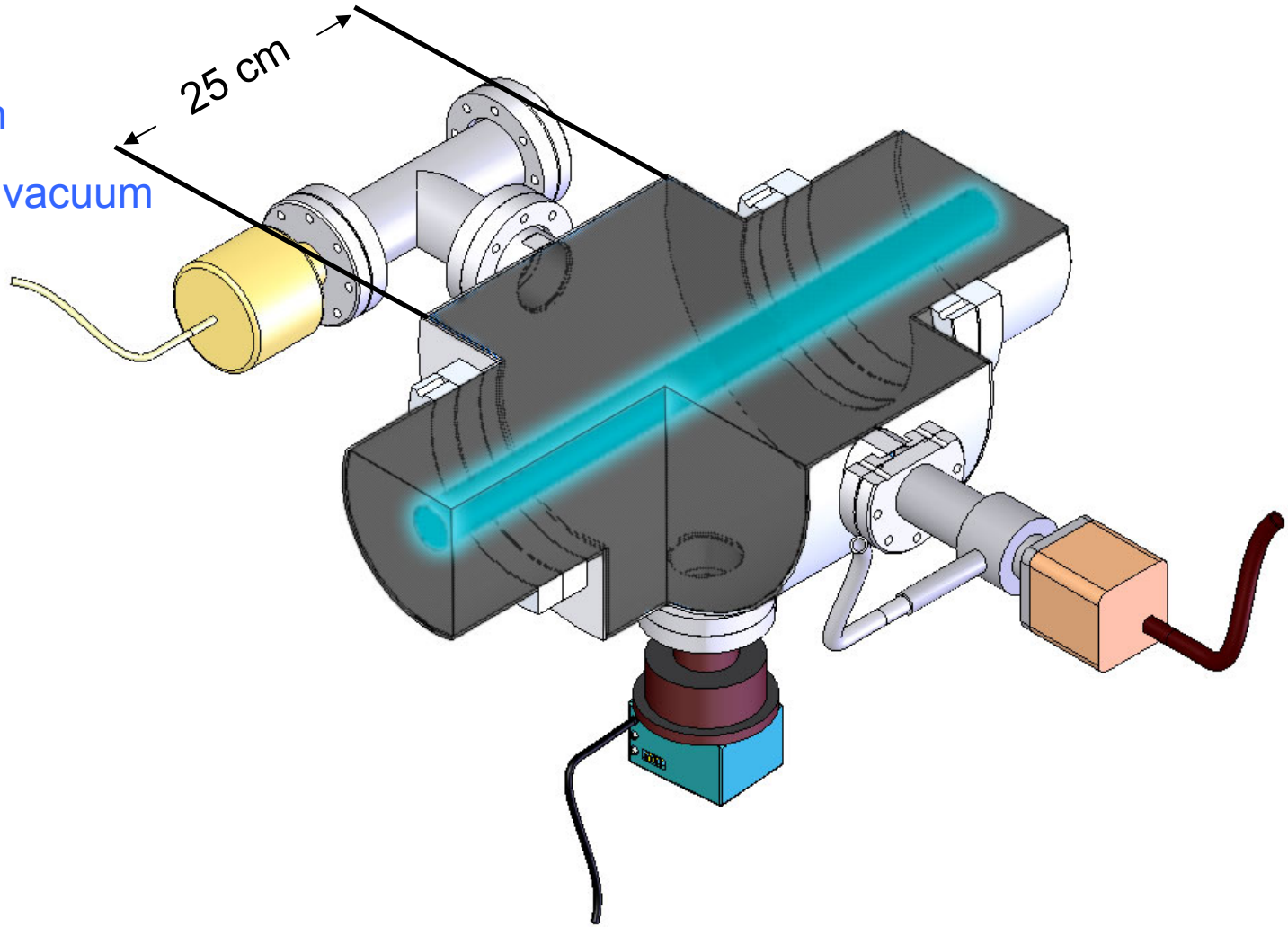


Advantages of BIF

Short insertion length

No mechanics in the vacuum



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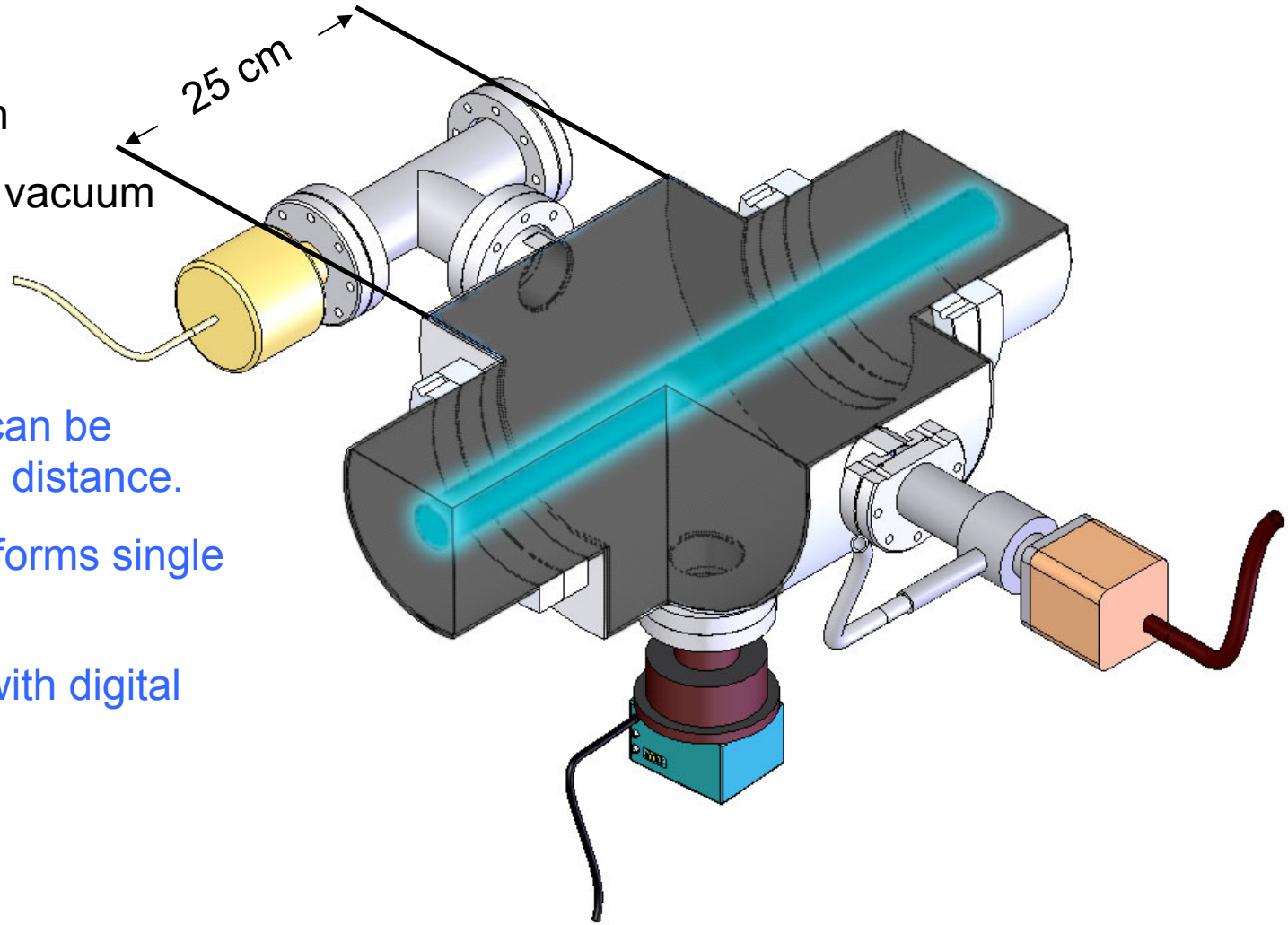

Reproduction scale can be matched by the focal distance.

Image intensifier performs single photon detection.

12-bit VGA camera with digital fire-wire interface.

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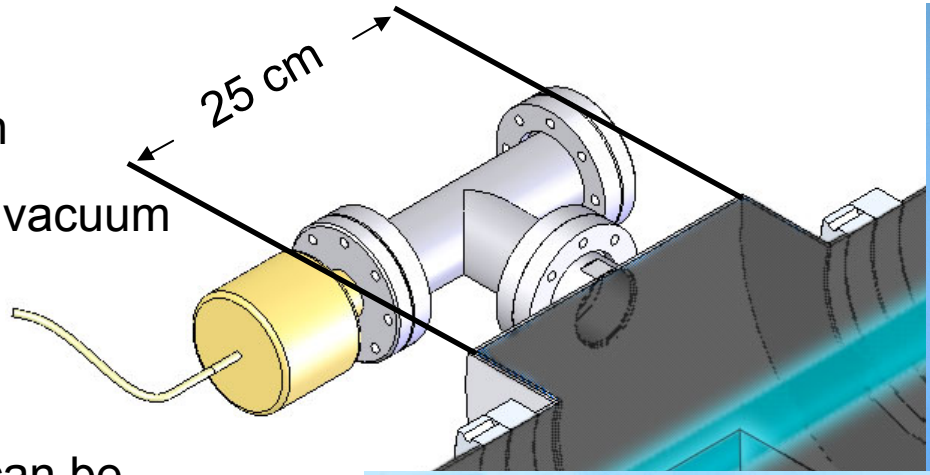

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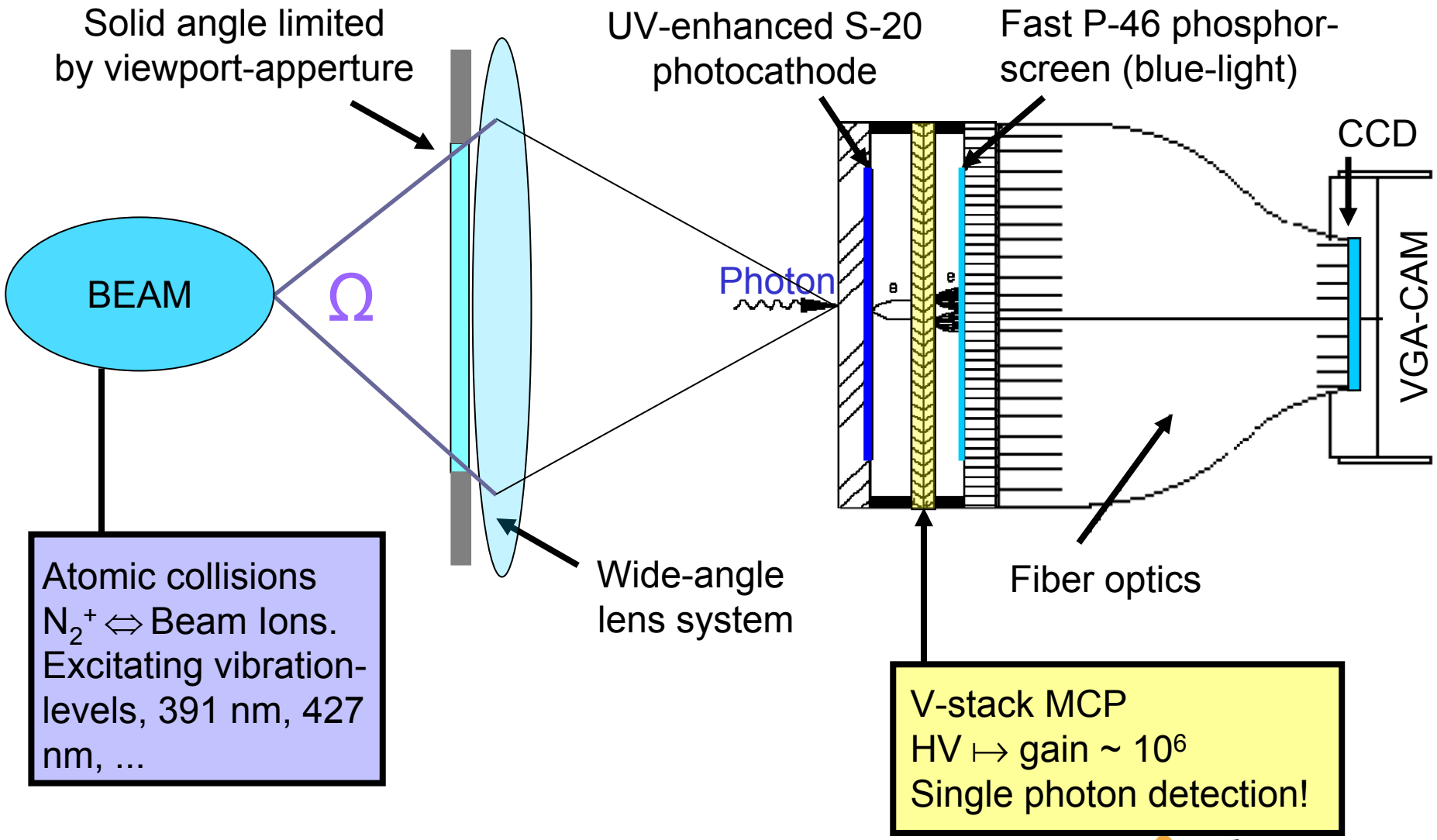
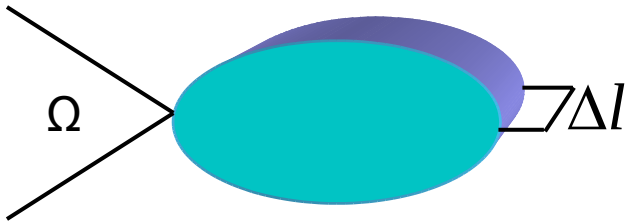
Commercial Components

Detection Principle



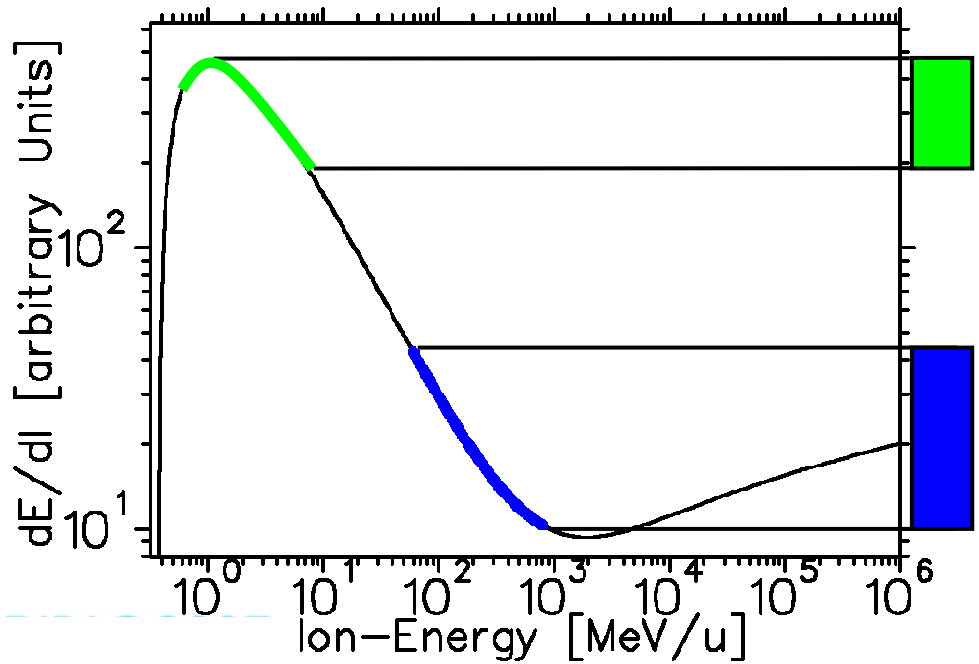
Expected Photon Yield



depends on setup geometry

~ integration time
~ number of particles per pulse

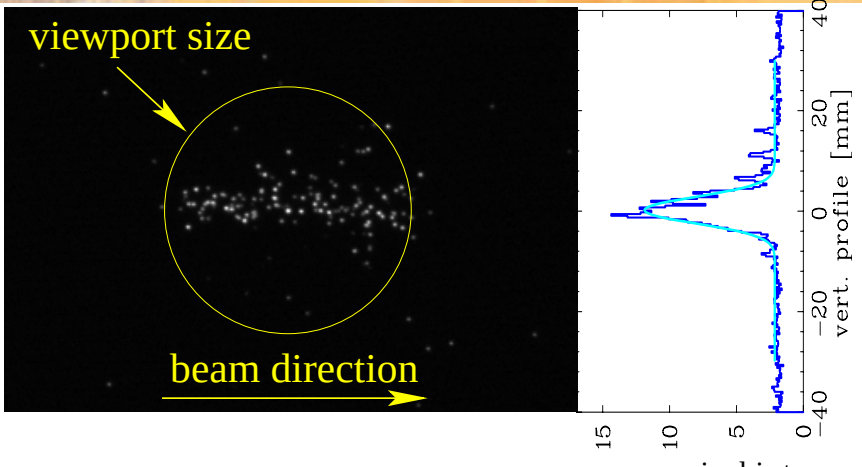
$$n_{photons} \propto \frac{dE(p,\beta,Z_{Ion}^2)}{dl}\,\Delta l\,\frac{\Omega}{4\pi}\,n_{projectiles}$$

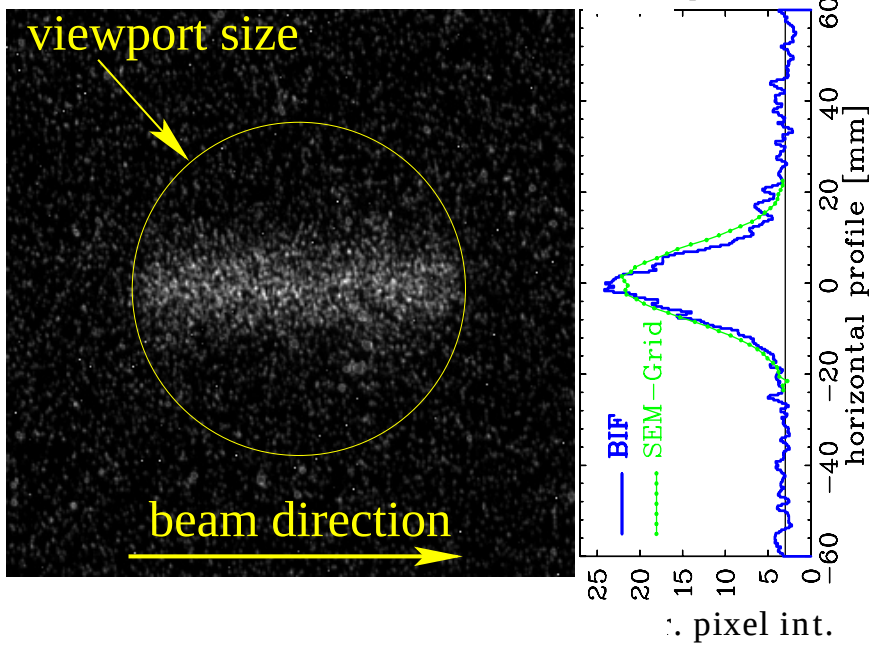


LINAC: High energy loss
typical: 5-11 MeV/u
2,5 mA ~ 10^{12} particles pp.

SYNC/ HEBT: Low energy loss
typical: 60-2000 MeV/u
10^{10} particles per cycle

Areas of Application





Detection-efficiency adjusted by pressure

LINAC:	2,5 mA ~ 10^{11} Ar^{10+} @4,4 MeV/u p=5 10^{-6} mbar single shot

SYNC-HEBT:	2,3 10^{9} Xe^{48+} @200 MeV/u p=10^{-3} mbar averaged over 20 shots

- Background is larger at HEBT energies

+ Application had been proven!

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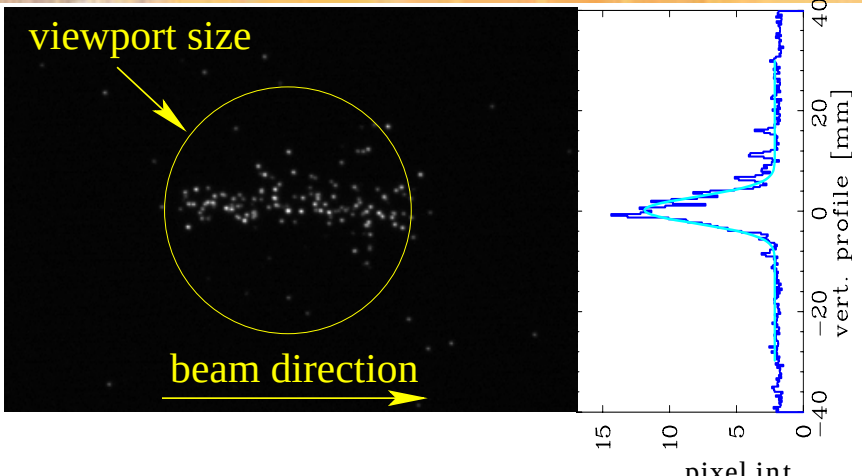

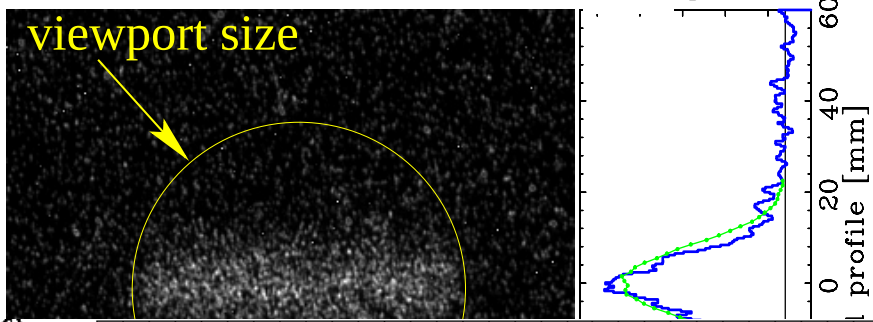

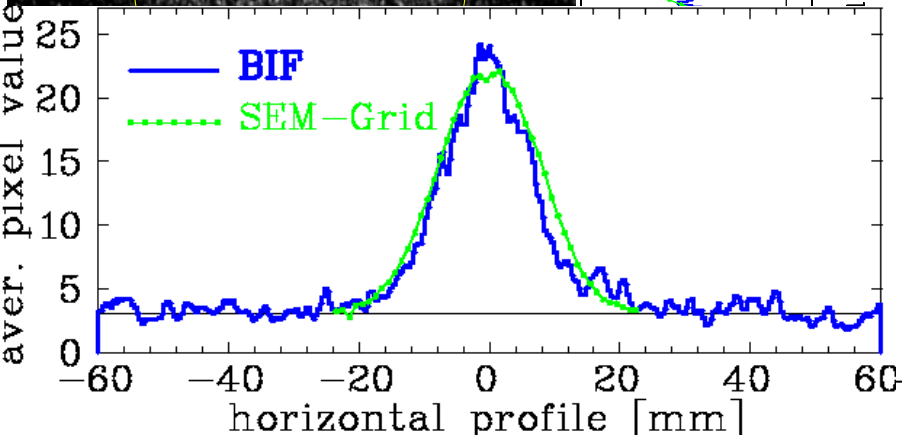

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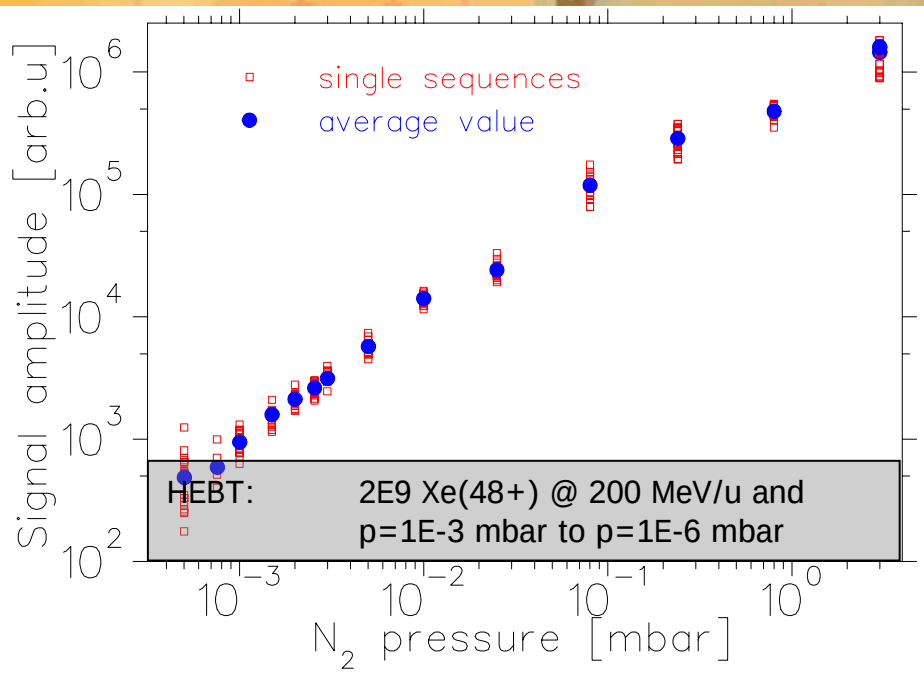
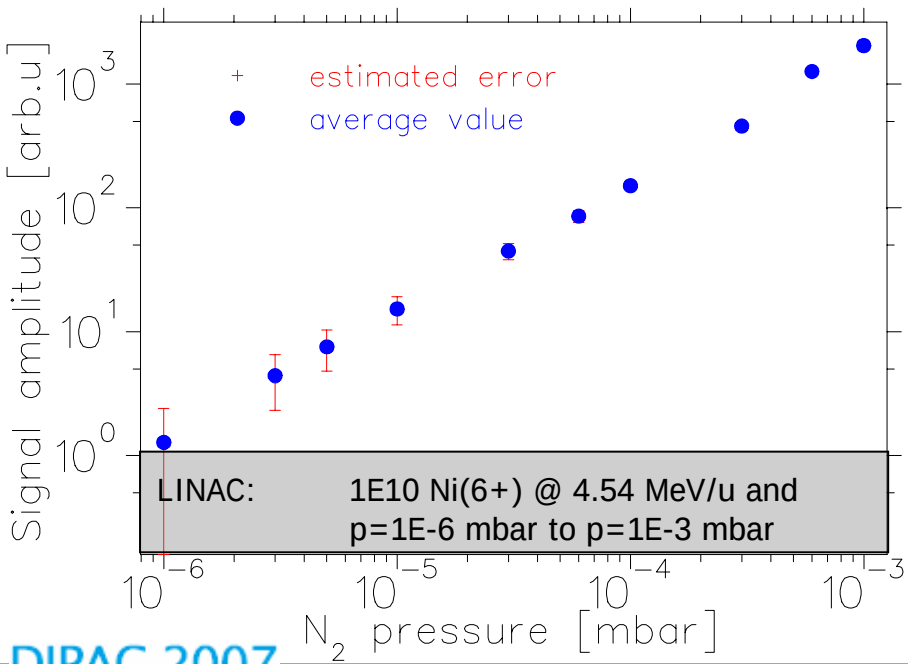
Pressure Variation

p changed by **6** orders of magnitude





Signal amplitude increases proportional to p

For higher beam intensities lower pressures should be sufficient!

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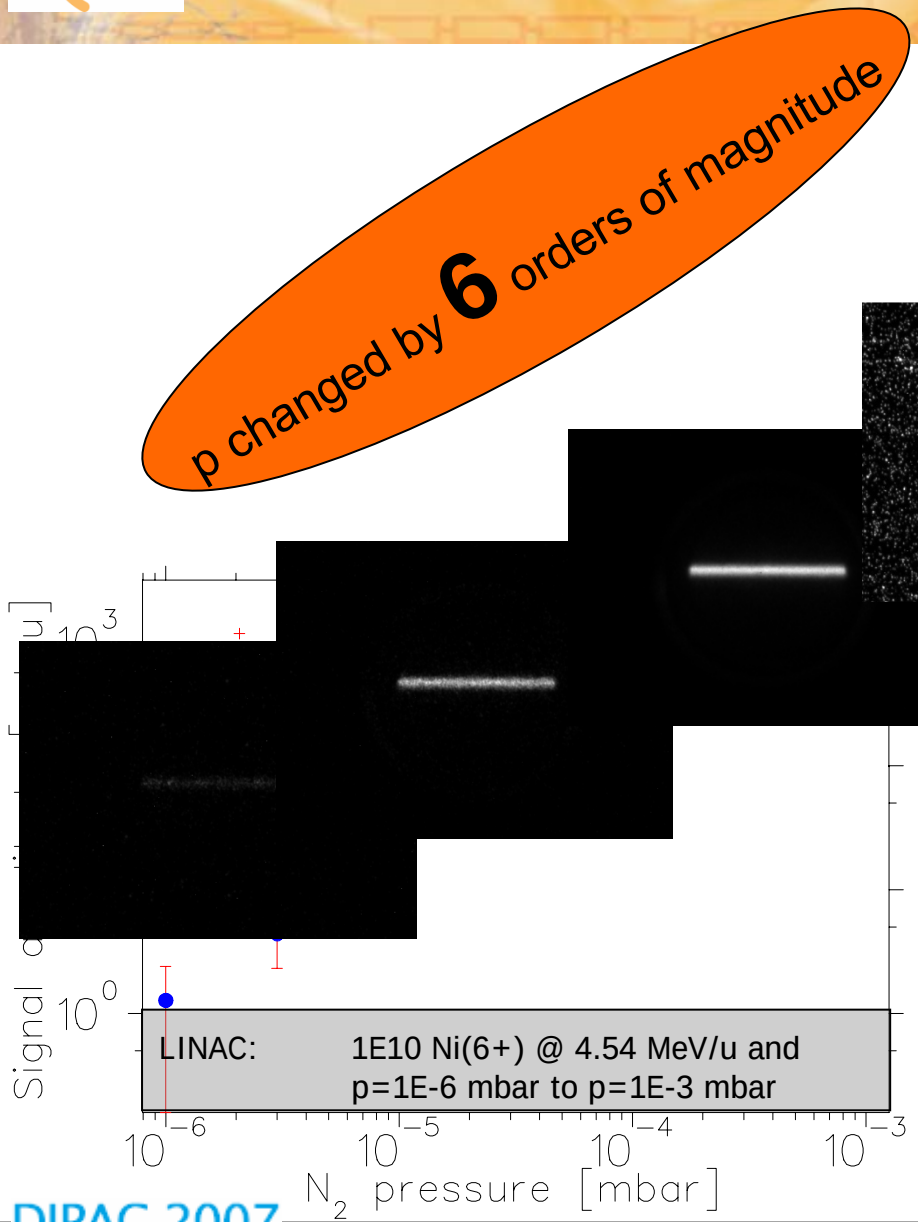

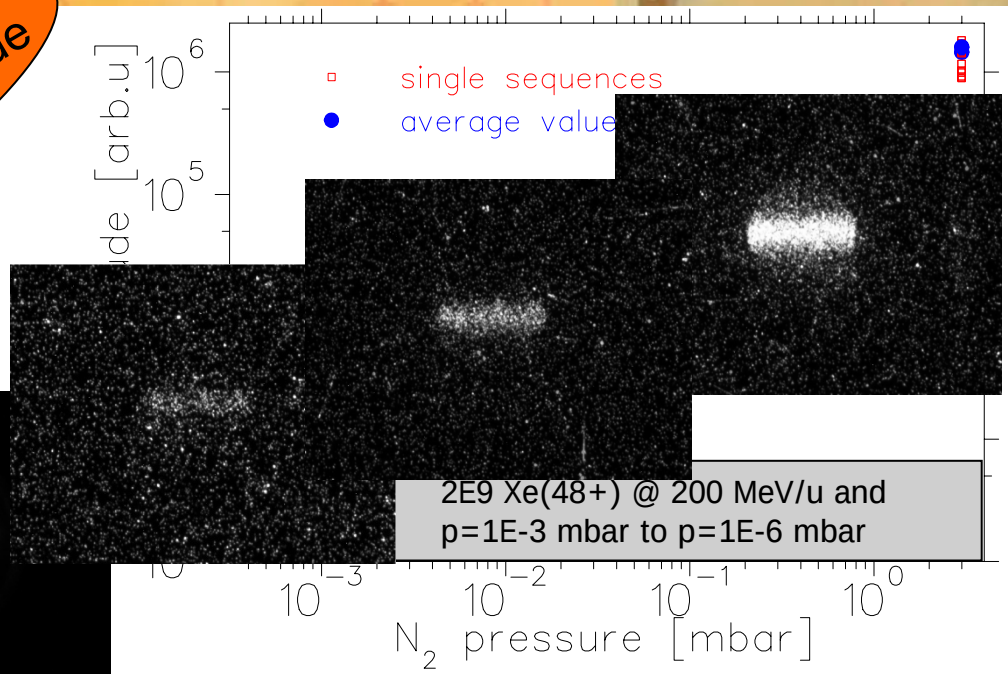

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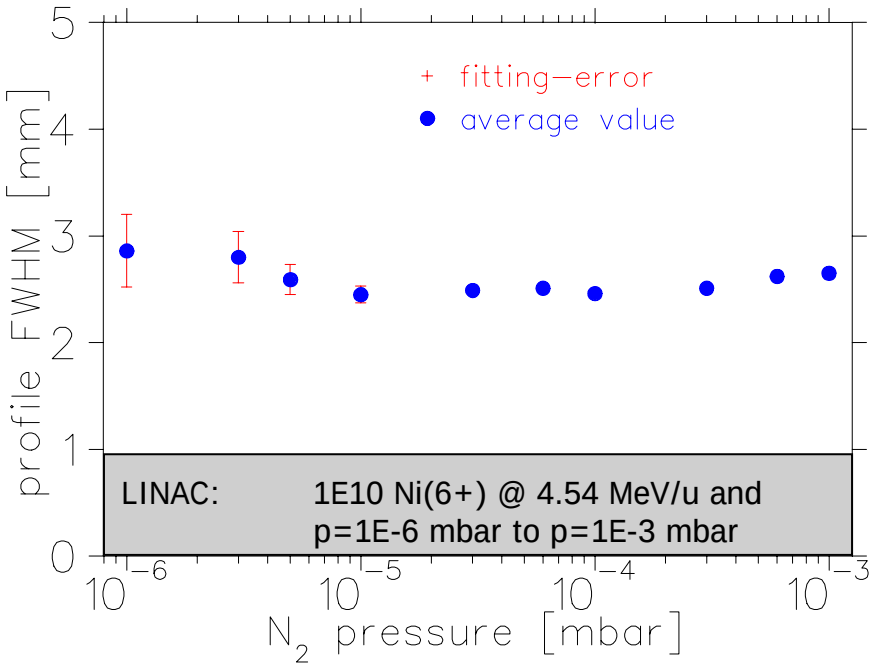
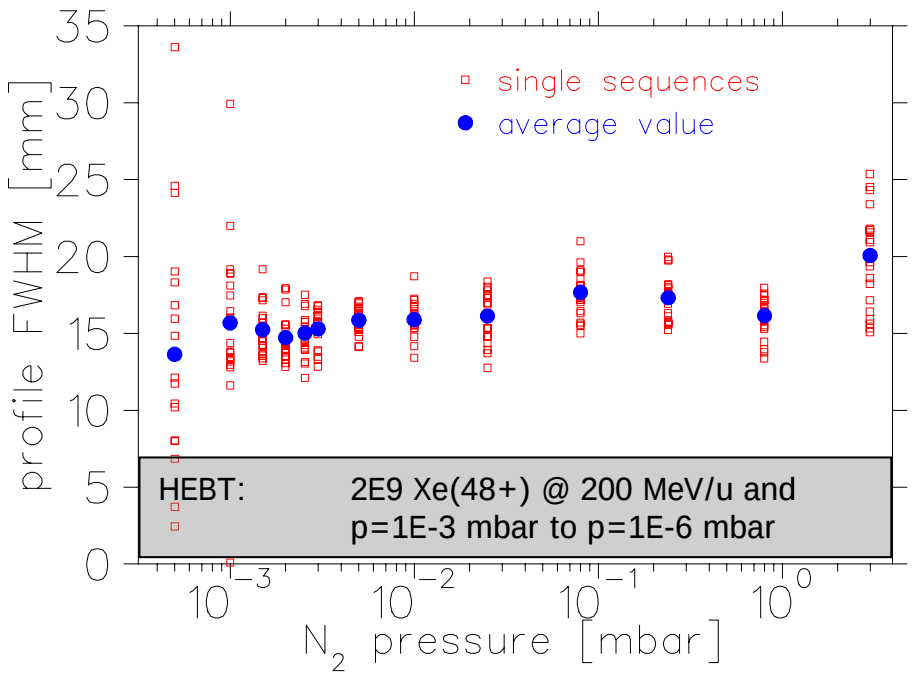




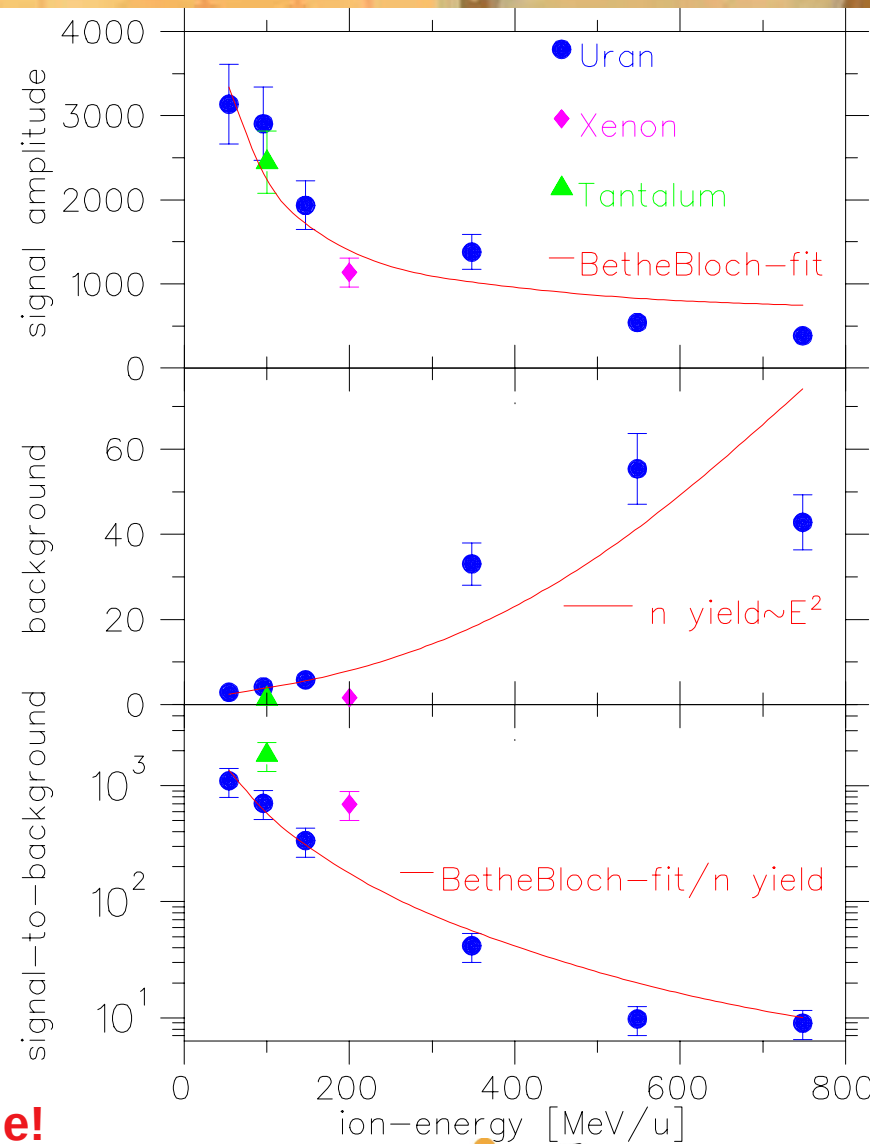
Profile width remains constant → p is suitable parameter to match signal strength!

Energy Variation

Integrated signal amplitude scales with Bethe-Bloch function.
Good accordance for all ions normalized by their charge and mass with respect to U^{73+}

Background level encreases with approximately E^2.
It is generated by thermal NEUTRONS hitting the photo-cathode.

Signal to background ratio decreases two oders of magnitude.
Short gating during fast extraction improves the ratio by a factor 4, for Xe and Ta.



↦ **Background reduction is major challange!**

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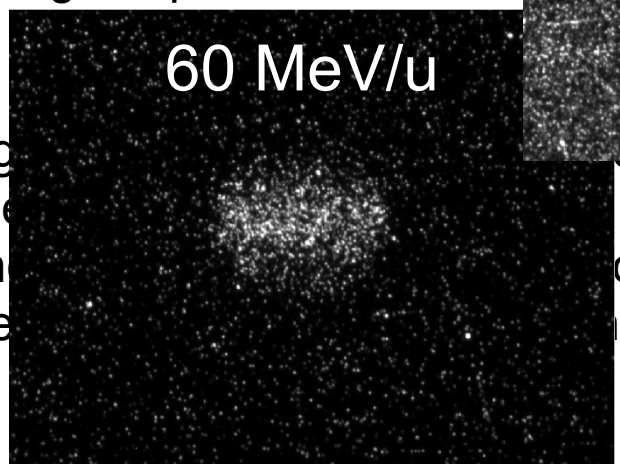

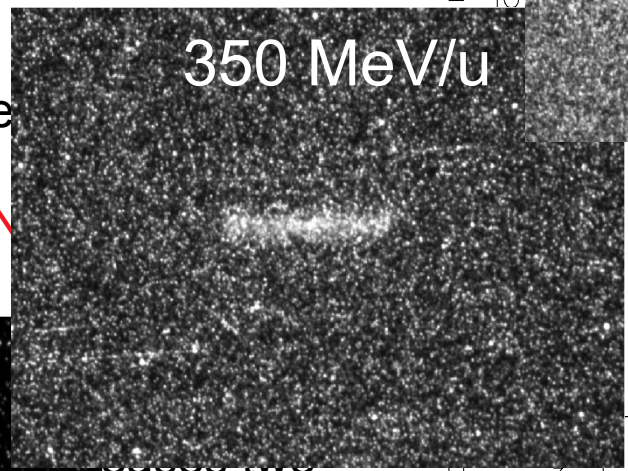

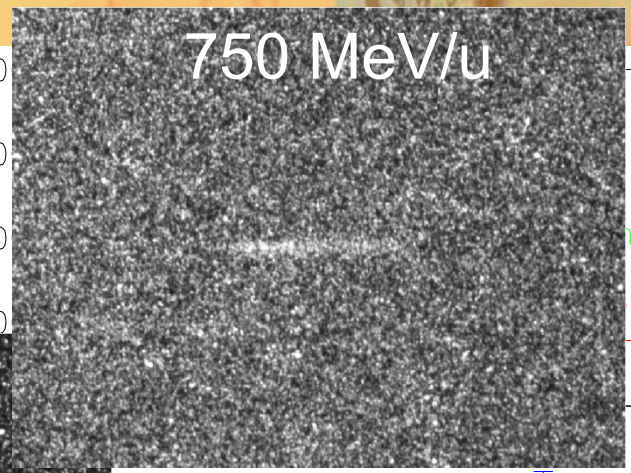

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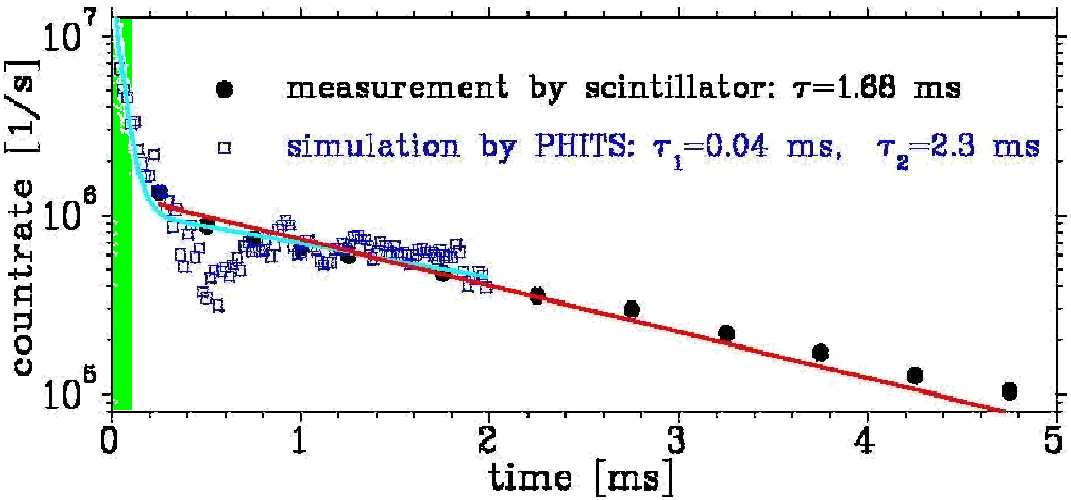
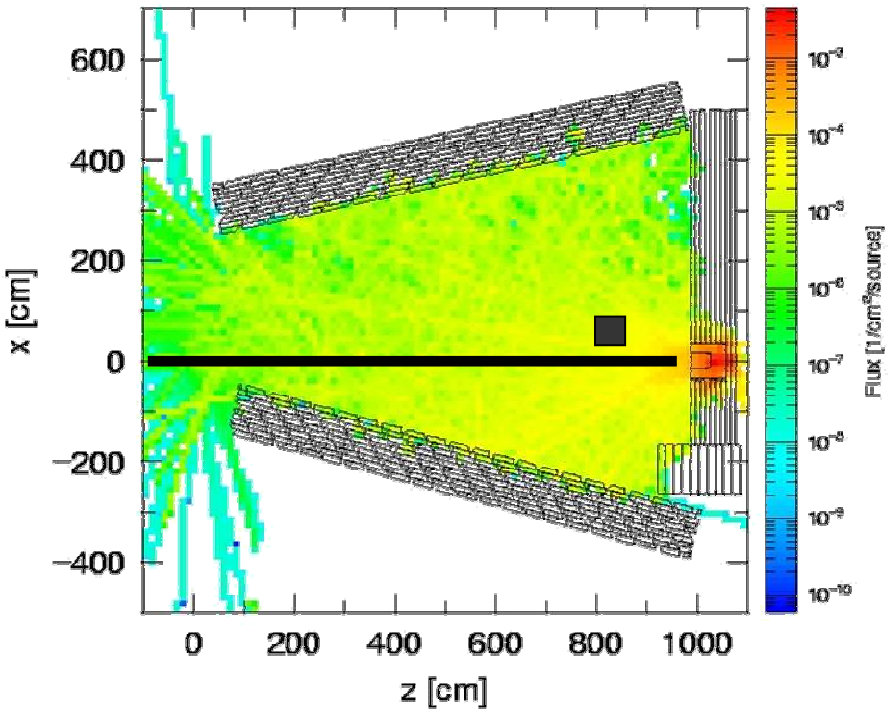
Background Distribution





- Neutron ´afterglow´ longer than µs beam delivery

- Simulation and experiment agree well!

⇒ Reduction by short gating (improvement: factor 4)

Simulation by PHITS:

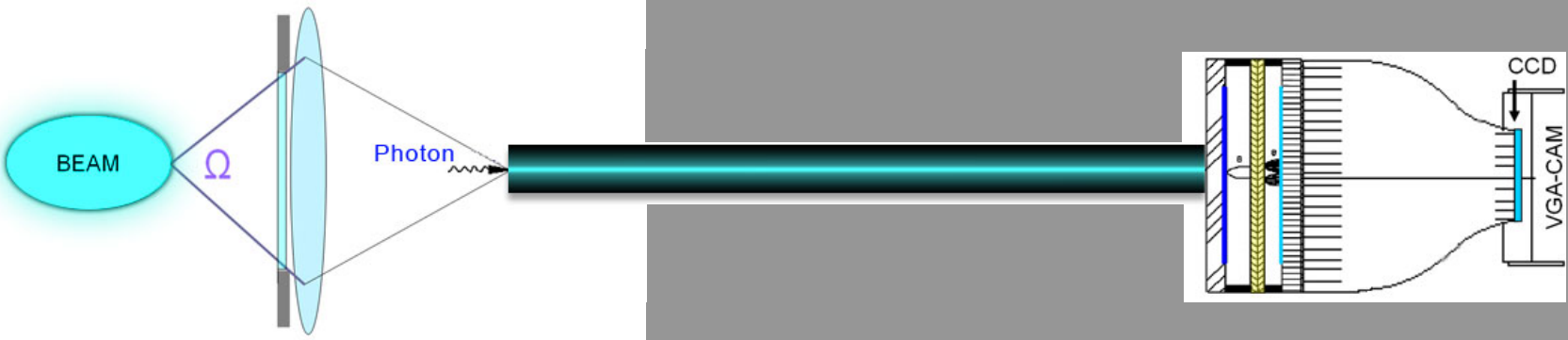
- Neutrons are backscattered from walls

- Neutron flux in whole cave

⇒ Reduction by moderation and absorbtion in shielding

Shielding Concept

Effective neutron SHIELDING:
Moderation and Absorbtion



Distance extension by ~1 million fiberoptics boundle
without loosing solid angle!

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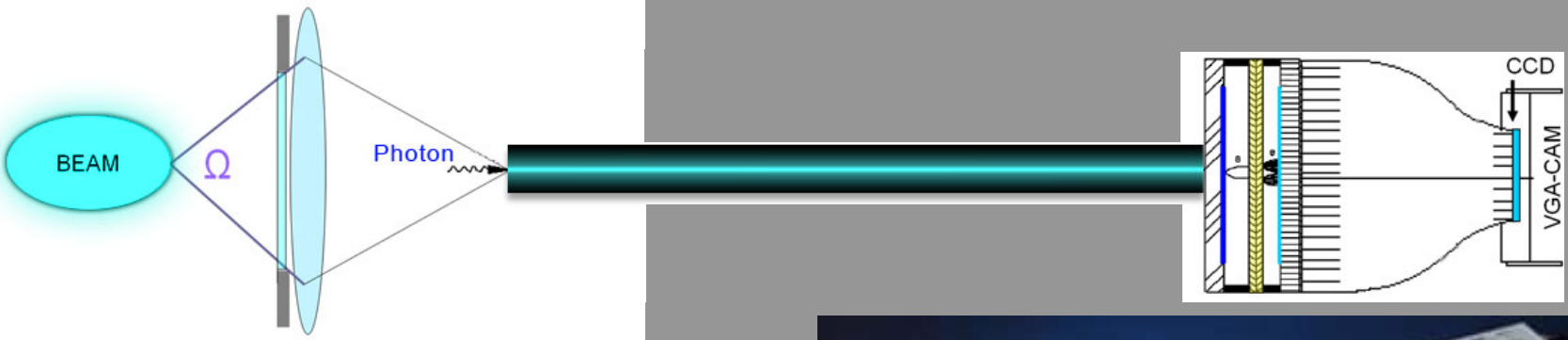

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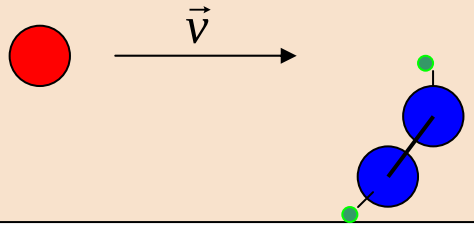
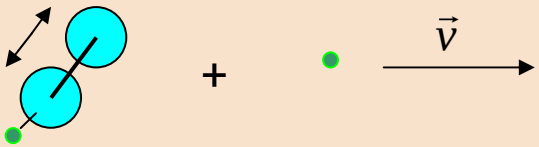
Commercial Systems →

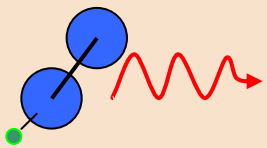
How Excitation affects Profiles



$$N_2(X^1\Sigma) + Ion$$



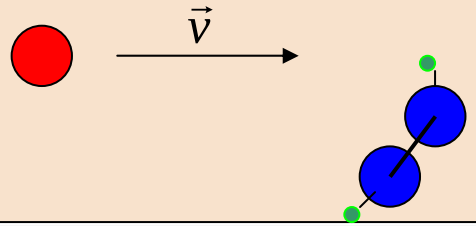
$$N_2^+(B^2\Sigma_u^+) + e^- + Ion$$



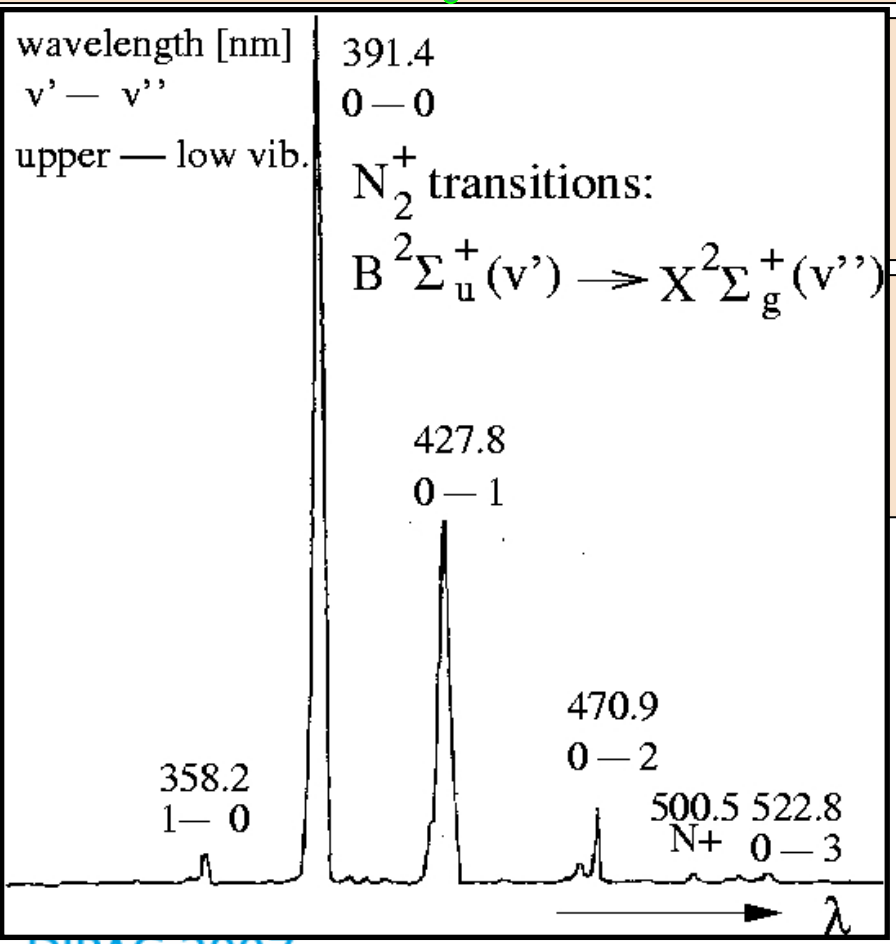
photon $\upsilon = \frac{\Delta E}{h}$

$$N_2^+(X^2\Sigma_g^+) + \gamma(390 \le \lambda \le 471nm)$$

How Excitation affects Profiles



$$N_2(X^1\Sigma) + Ion$$

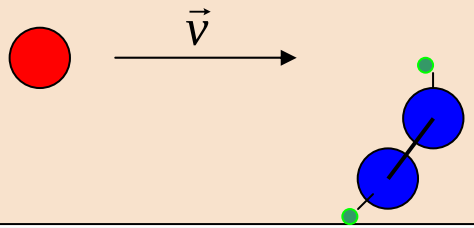


$$N_2^+(B^2\Sigma_u^+) + e^- + Ion$$

$$N_2^+(X^2\Sigma_g^+) + \gamma(390 \le \lambda \le 471nm)$$

Vibrational spectrum [Huges, Philpot 1961] for 100 keV protons.
Strongest lines at 391,4 nm and 427,8 nm.
Optical glasses + photocathode have to be UV-enhanced. ~60 ns lifetime.

How Excitation affects Profiles



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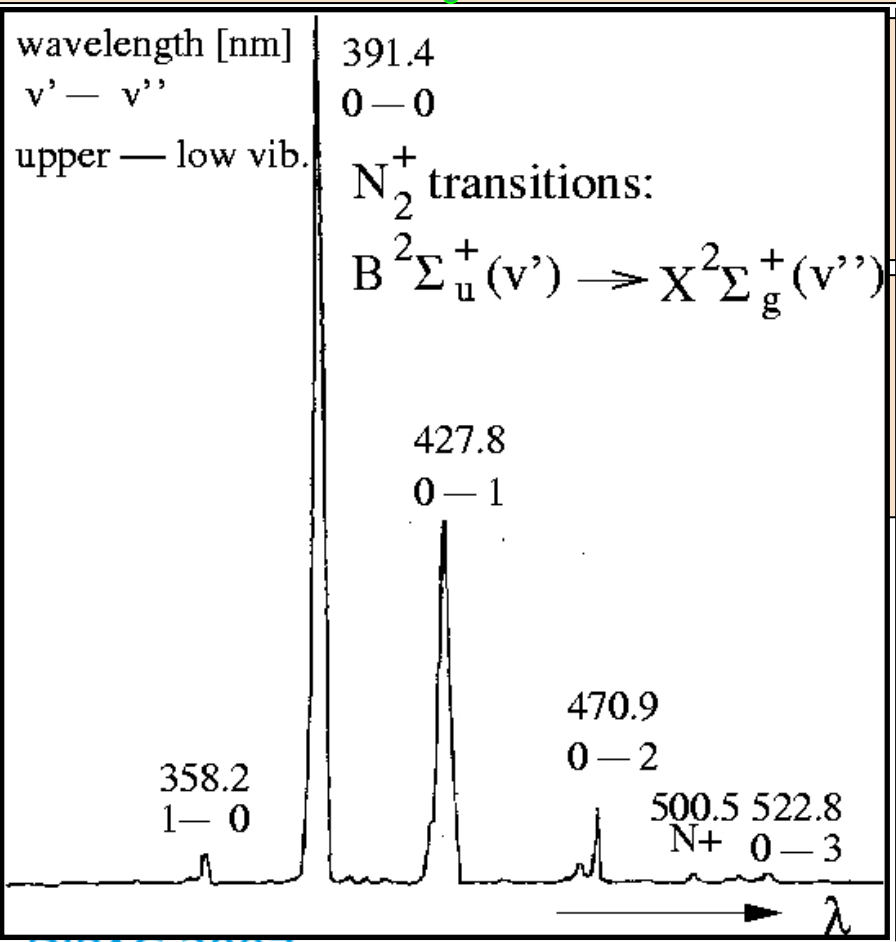
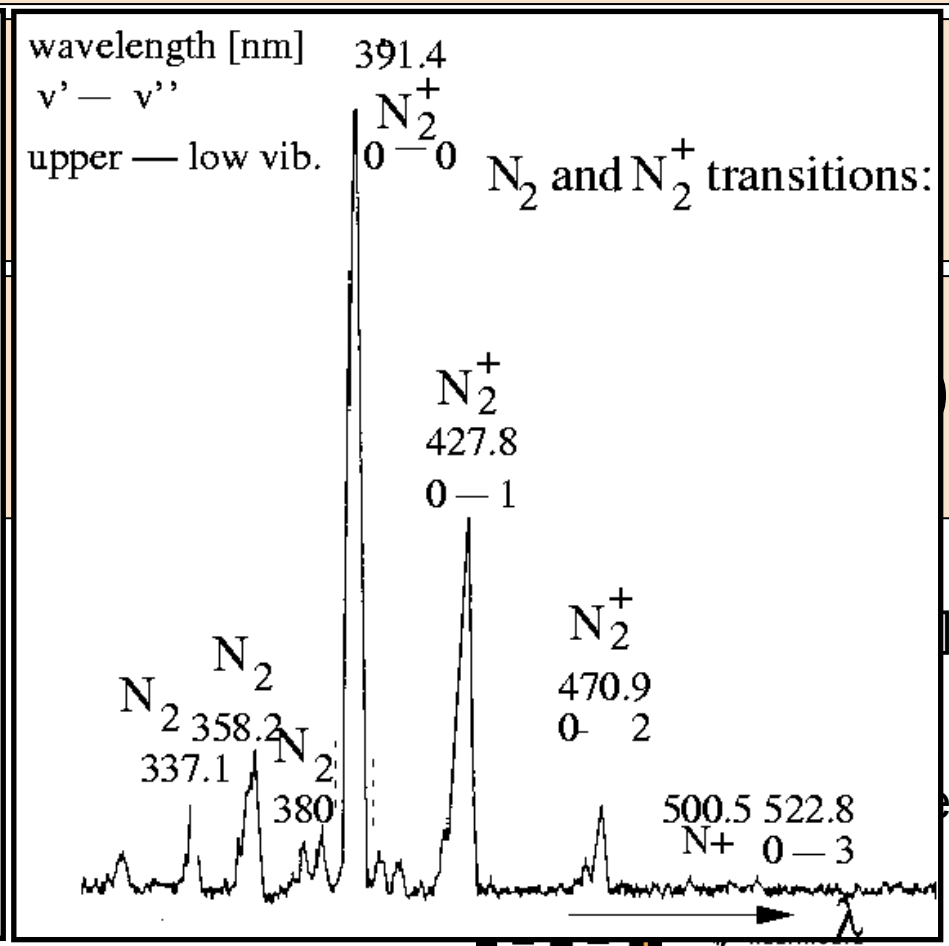
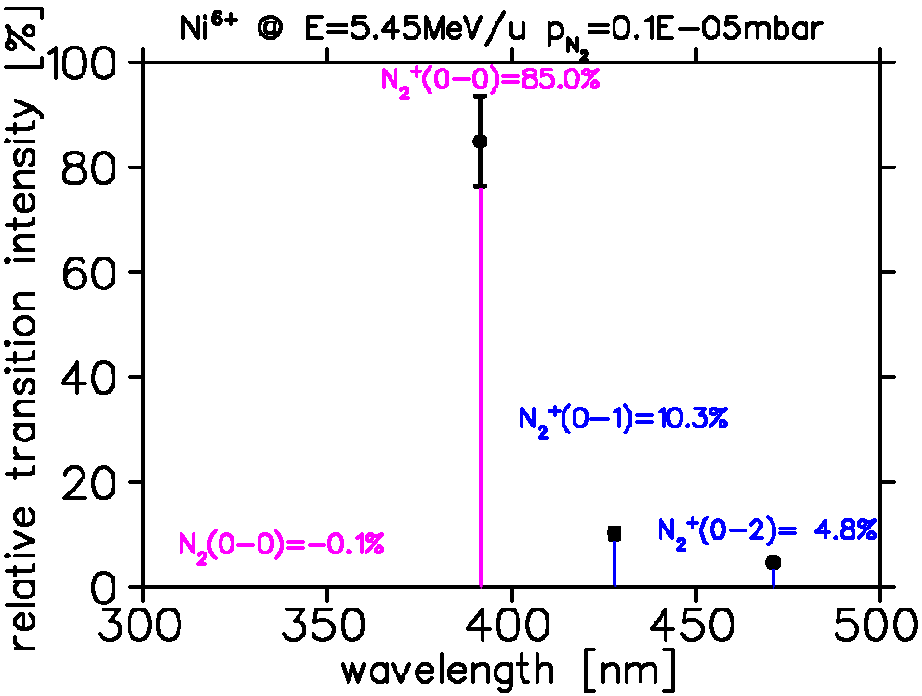
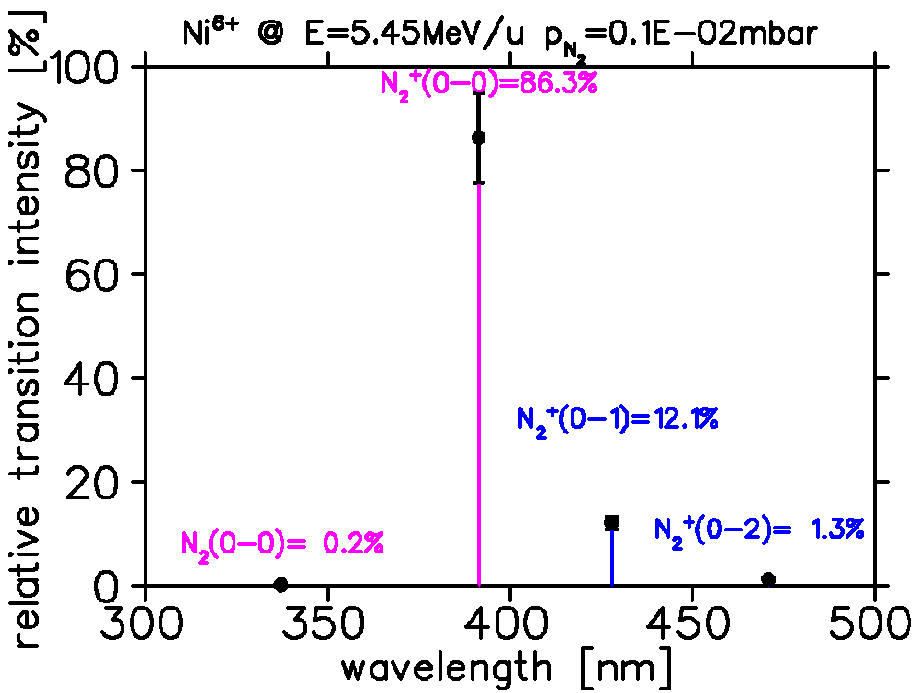




Fluorescence Levels





Contribution of fluorescence levels remains constant up to p=10^{-3} mbar

Contribution by 2-step excitation can be neglected!

Conclusion

- General functionality of BIF had been proven!
  - Profile determination in SINGLE PASS MODE!
- Careful investigation concerning:
  - Signal strength → linear with p, Bethe-Bl. with E
  - Profile width → constant with p
  - Background contribution → ~E^2, neutron shielding
  - Fluorescence levels → even for high p no distortion
- Future Improvements:
  - Optimizing geometry, lens, intensifier and camera
  - Development of shielding using fiberoptics bundle
  - Further investigation to establish BIF as standard tool!

Thank You ☺