High Current & Non-Destructive Beam Diagnostics

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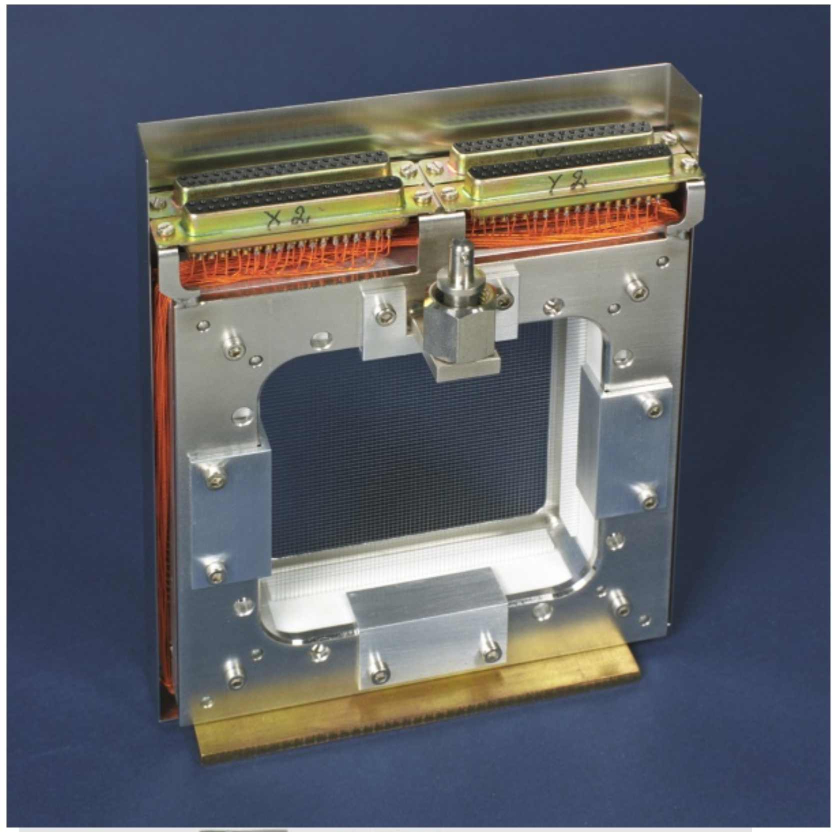
3) Universität Jena

Outline

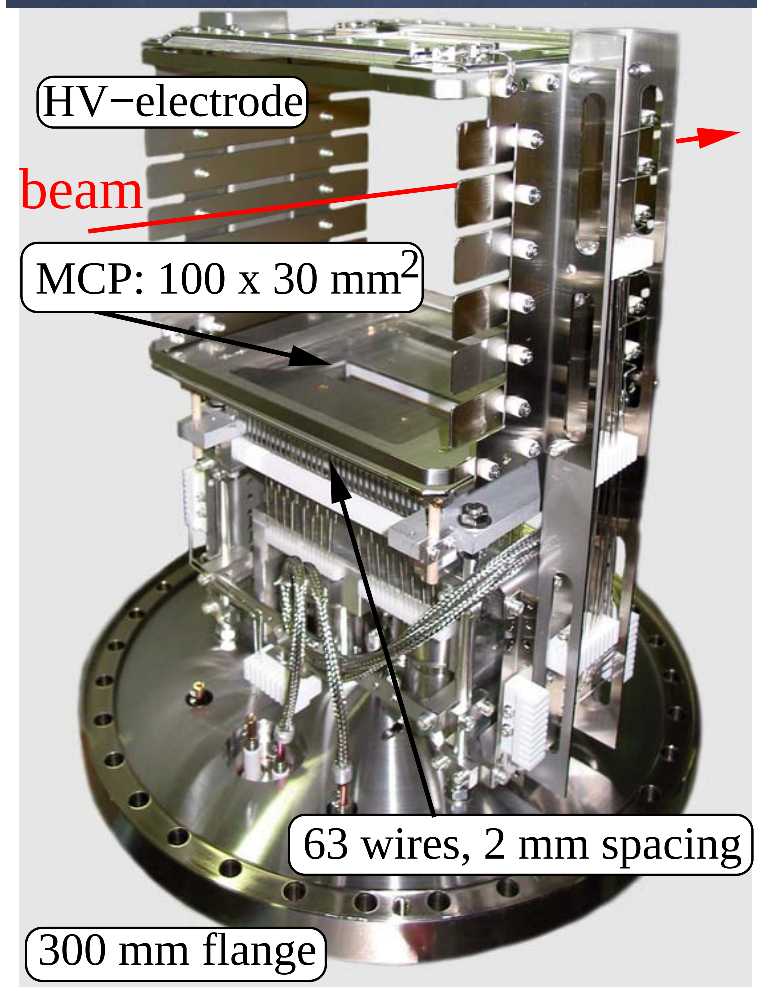
Part I   Beam Induced Fluorescence

Comparison of Profile Monitors



Secondary-Electron-Monitor (SEM) Grid & Multi Wire Proportional Chamber

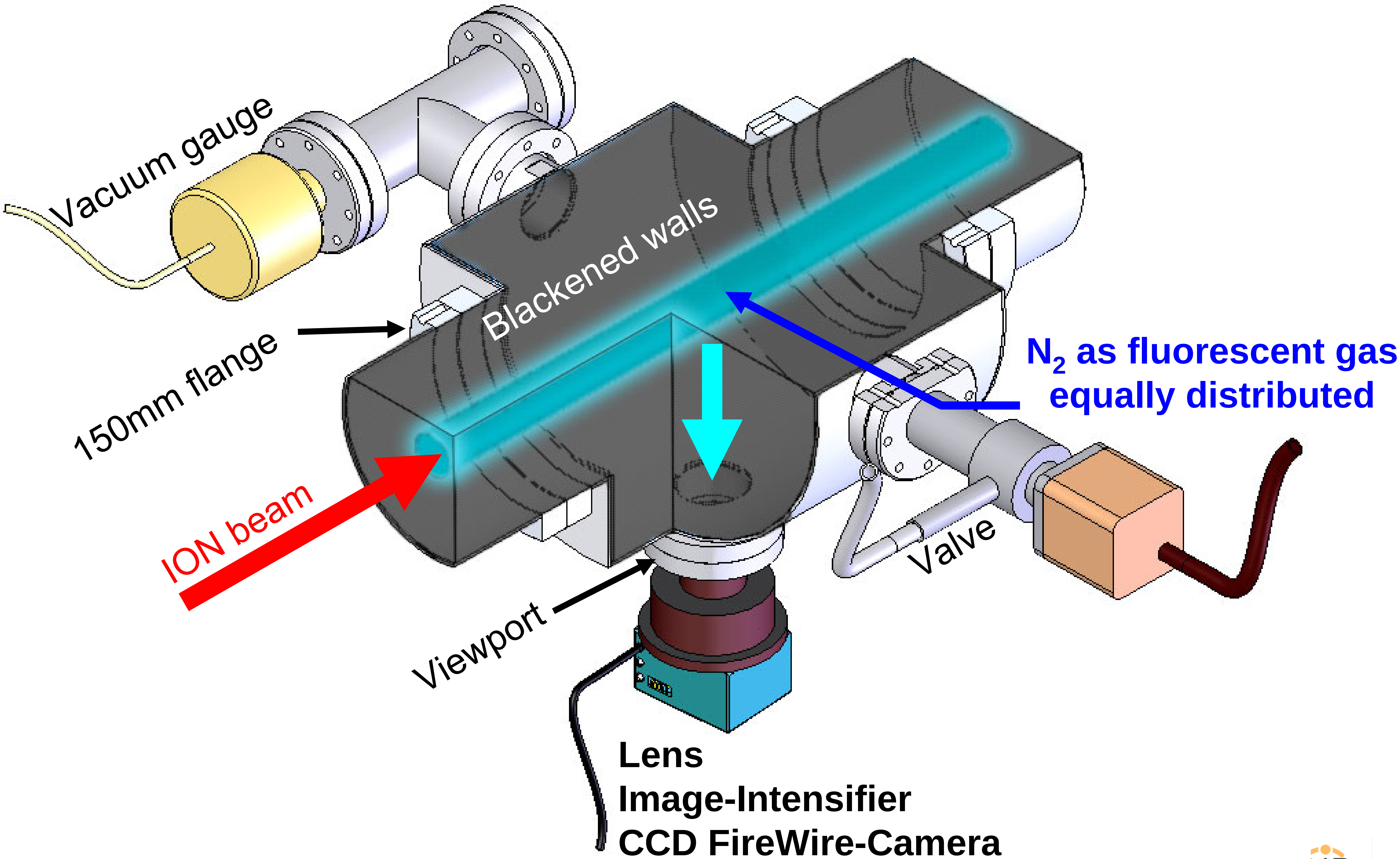
- \+ Standard tools, compact design
- \+ Low background level
- \- Limited spacial resolution (wire spacing)
- -- Melts in high power beams!



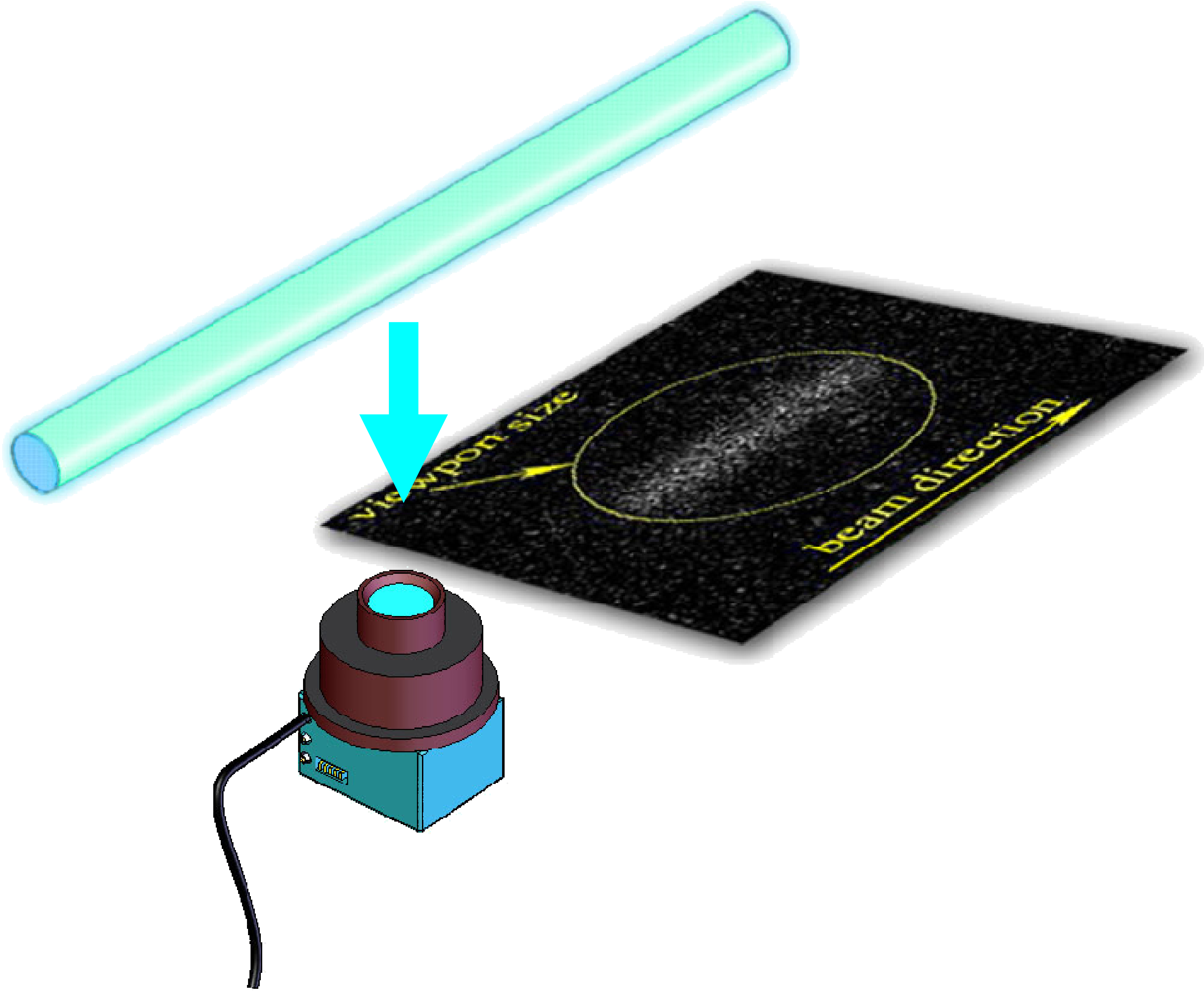
Ionization Profile Monitor (IPM)

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

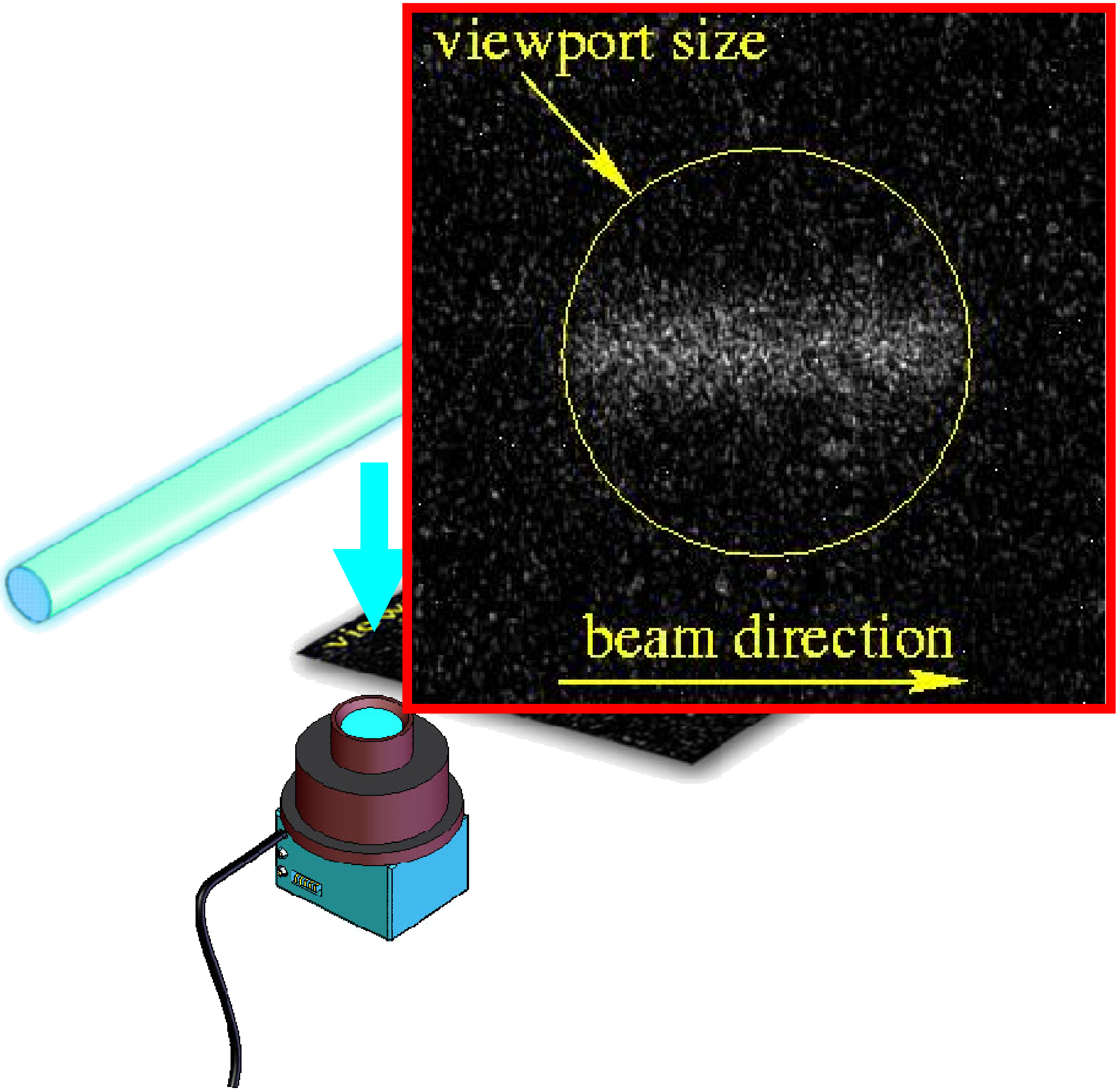
Beam Induced Fluorescence



How a Profile is obtained



How a Profile is obtained



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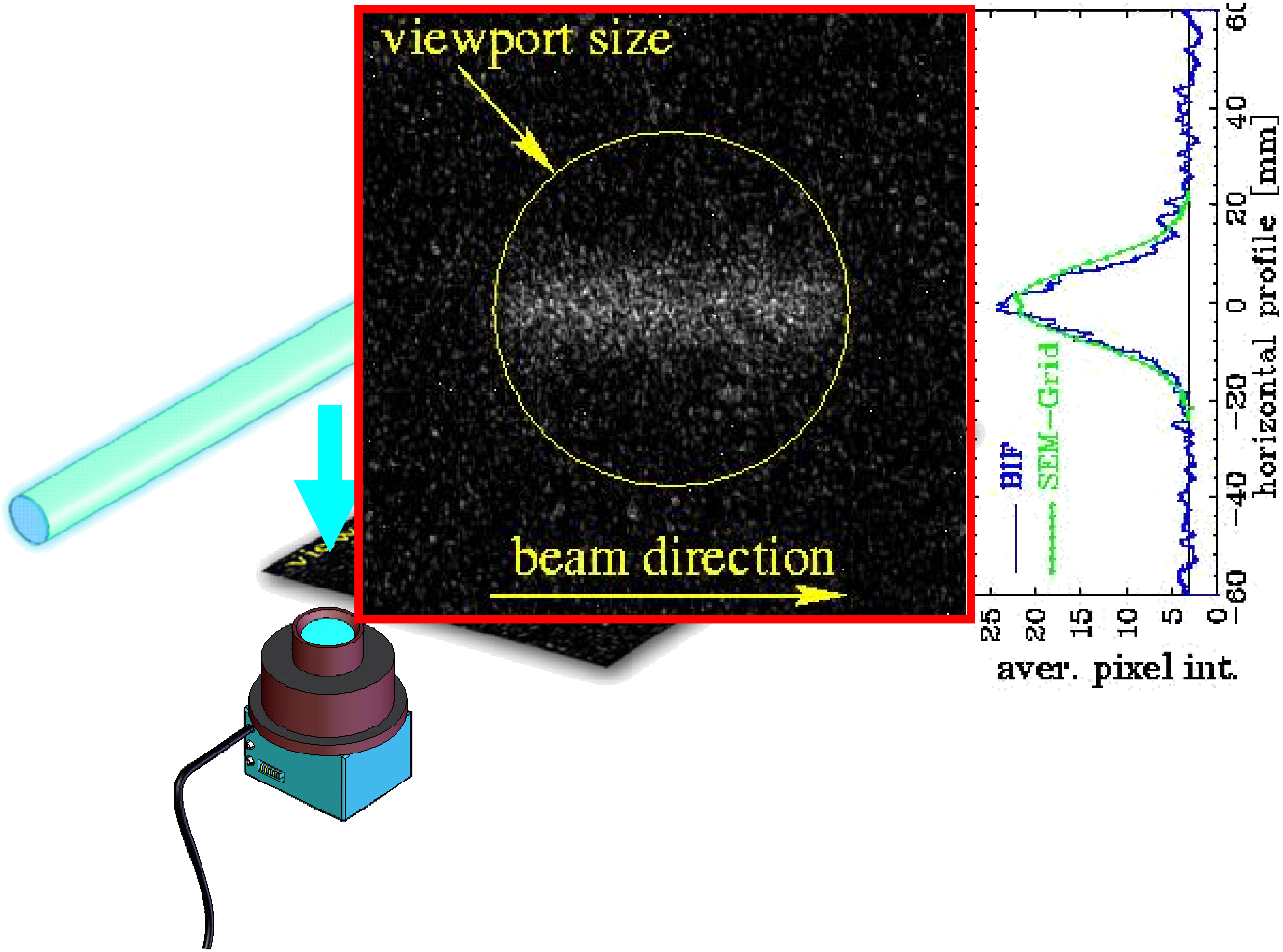
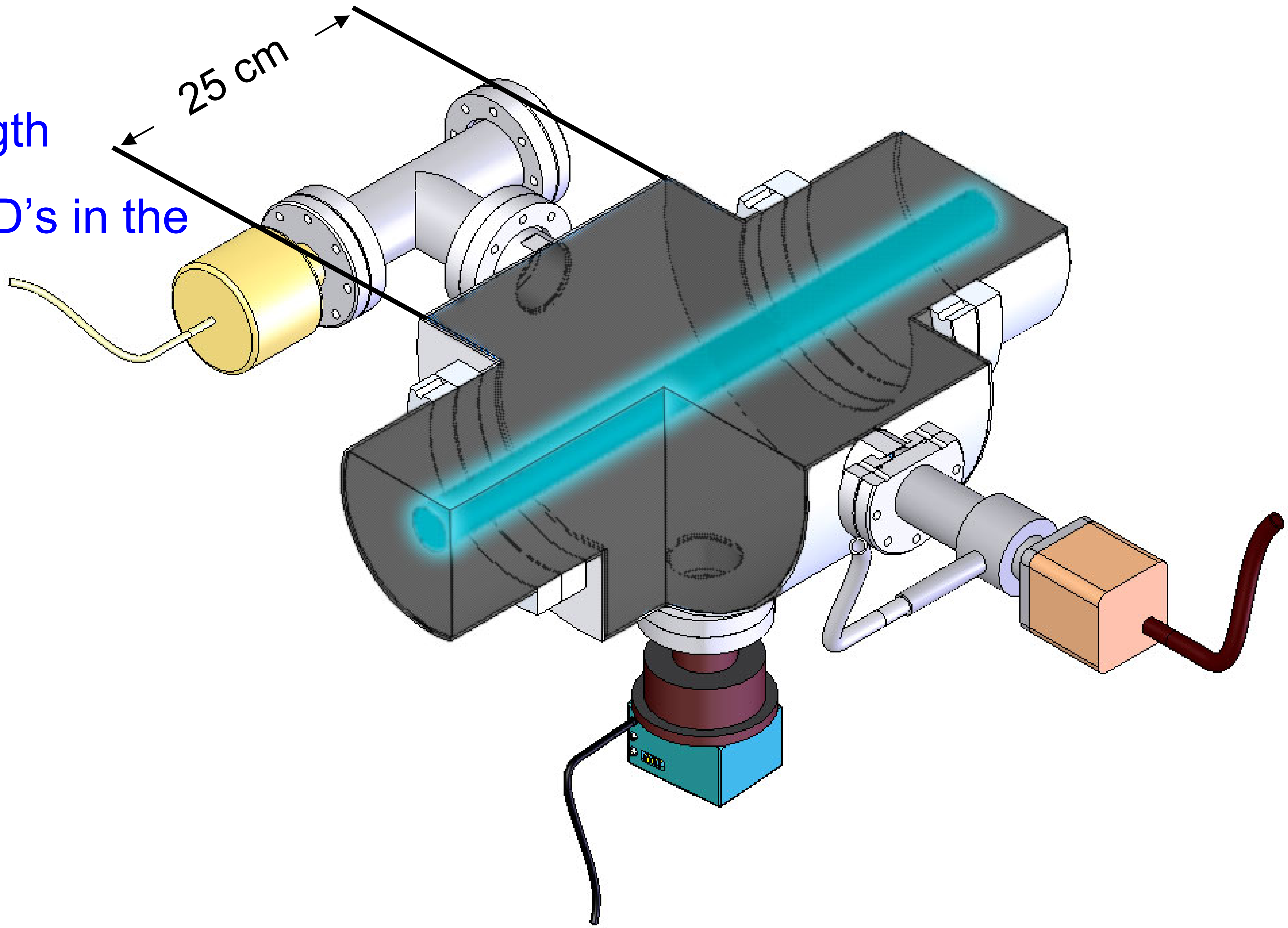


Advantages of BIF

Short insertion length

Just calibration LED's in the vacuum



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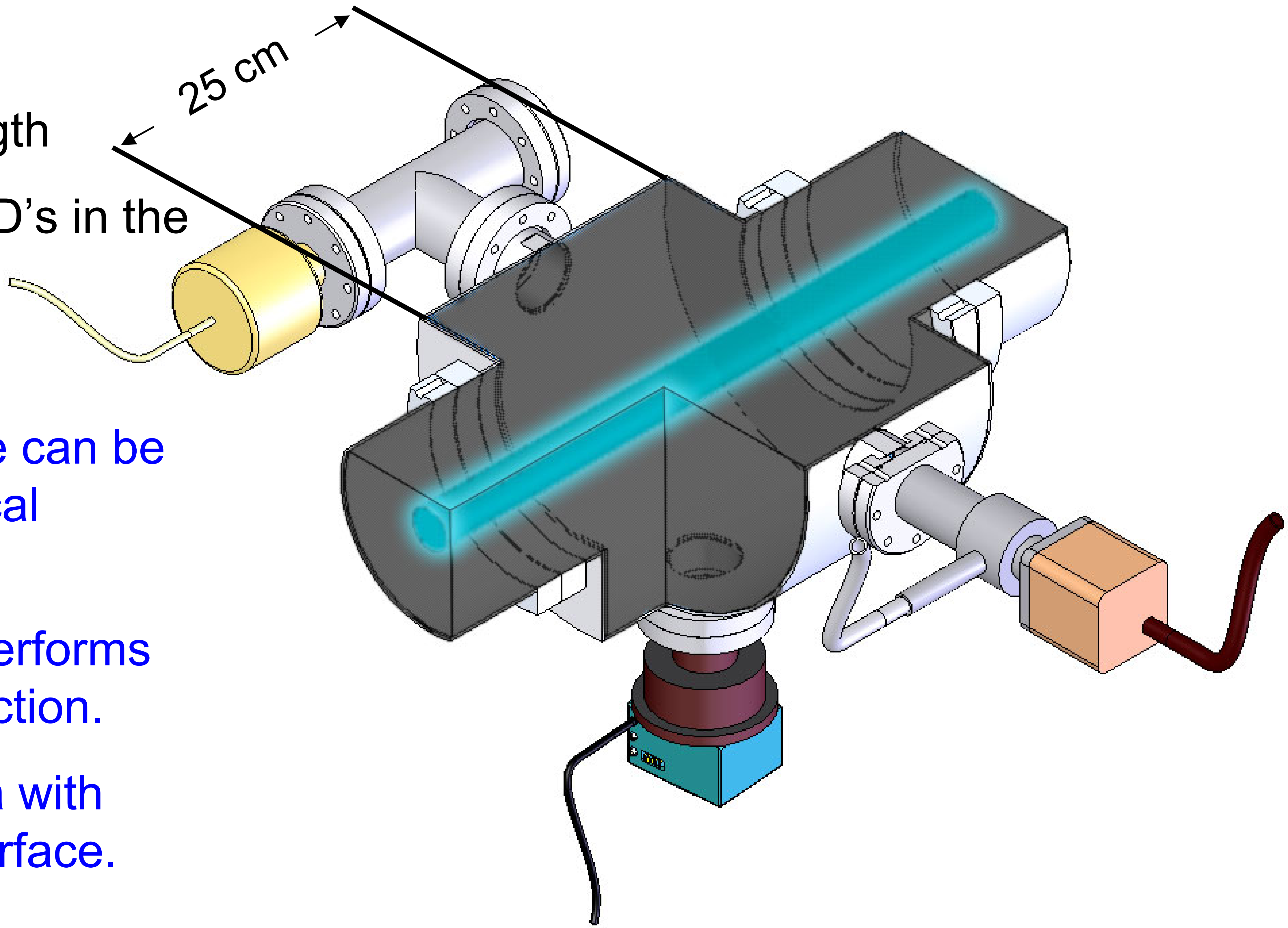

Reproduction scale can be matched by the focal distance.

Image intensifier performs single photon detection.

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

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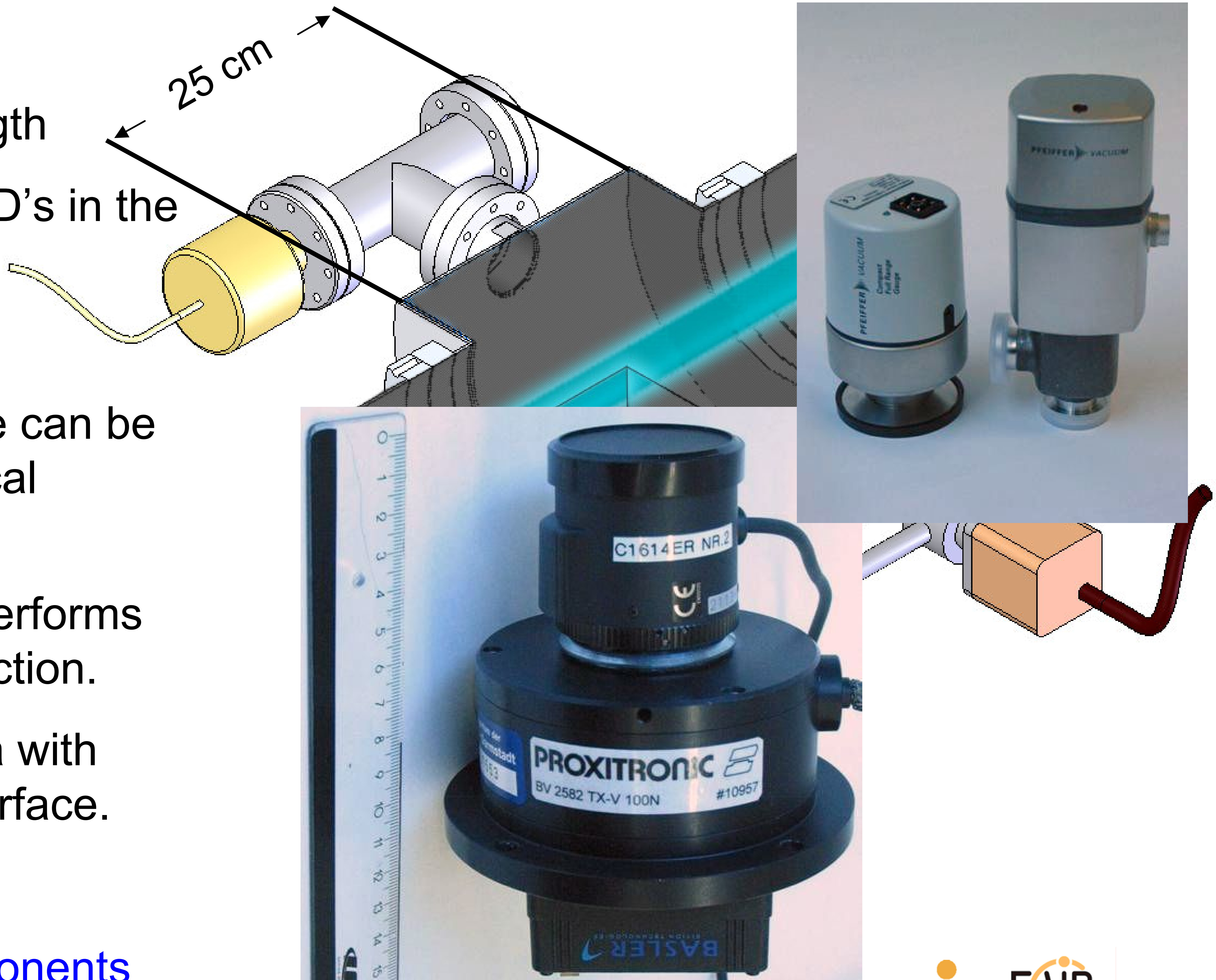
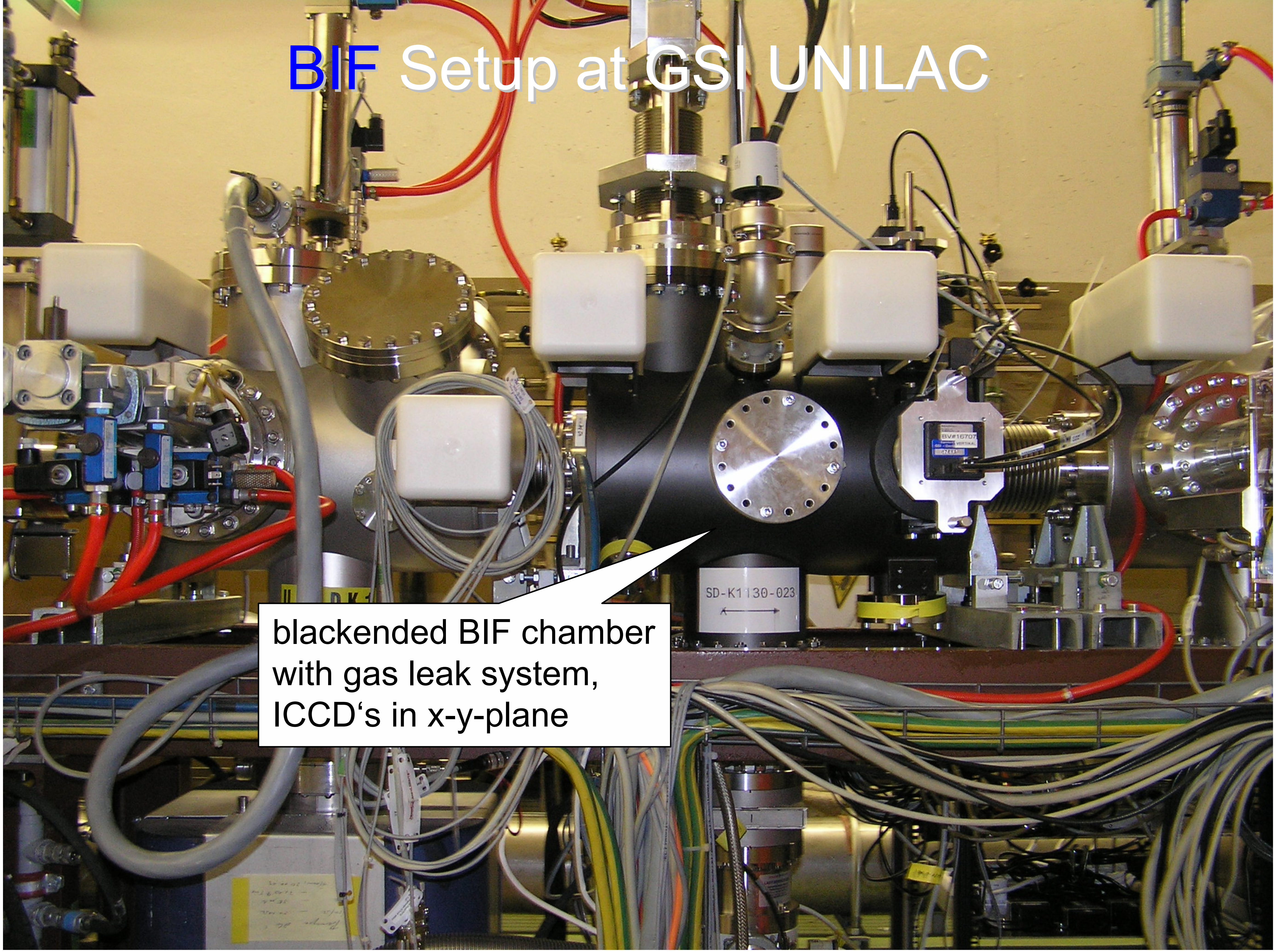


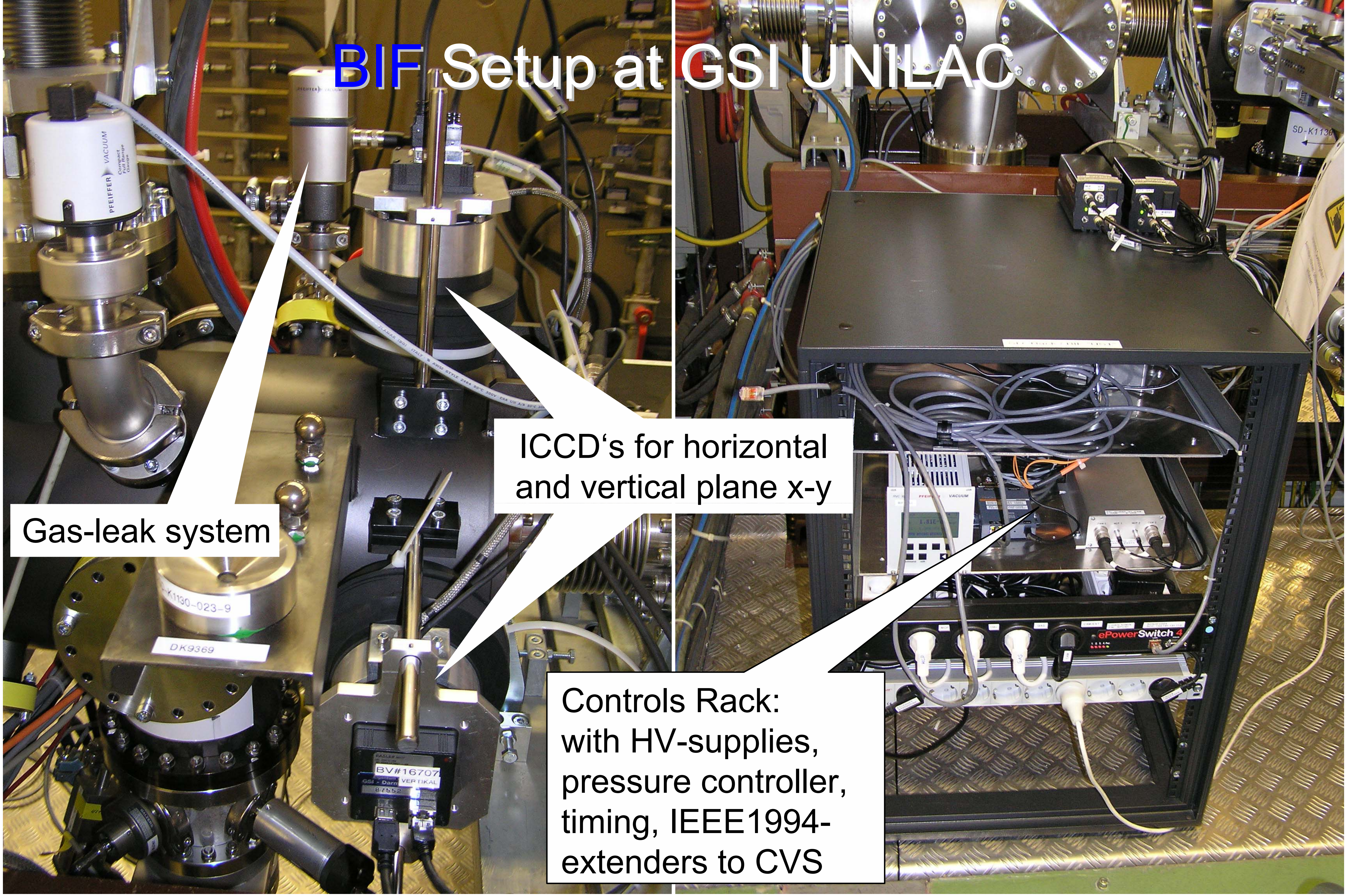
Commercial Components

BIF Setup at GSI UNILAC

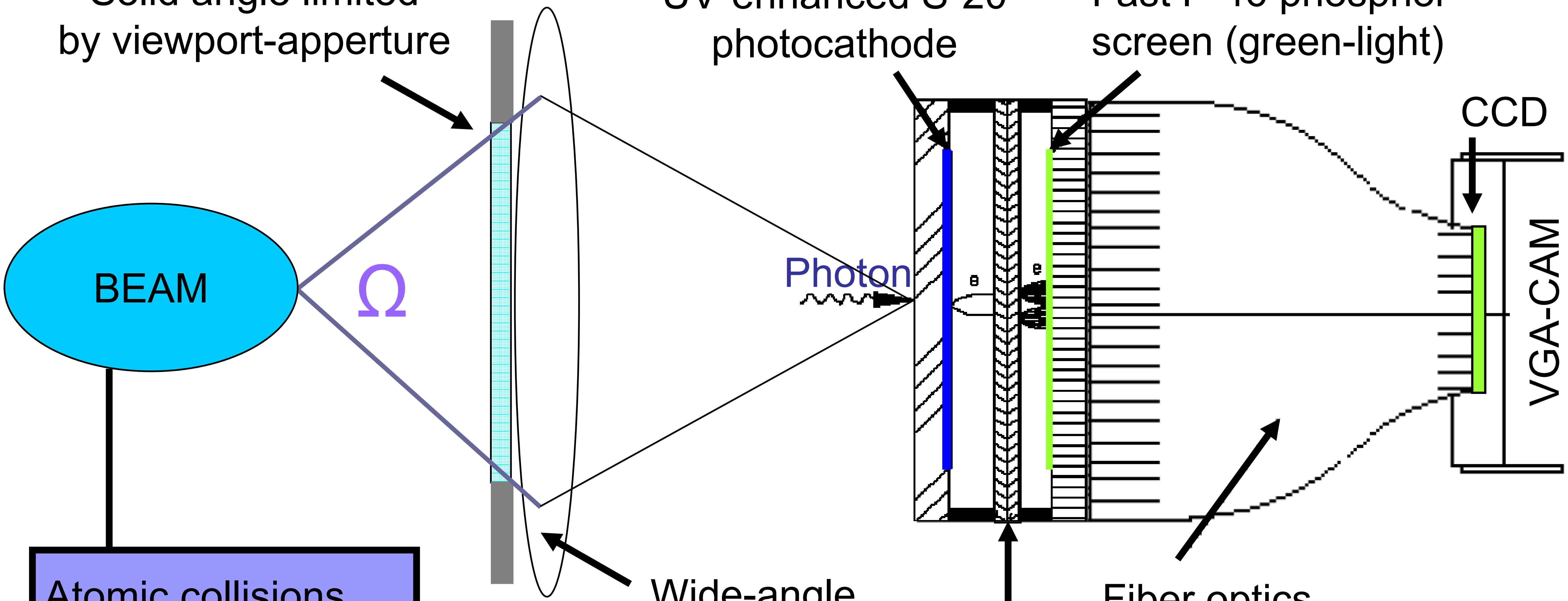


blackended BIF chamber
with gas leak system,
ICCD‘s in x-y-plane

BIF Setup at GSI UNILAC



ICCD Detection Principle

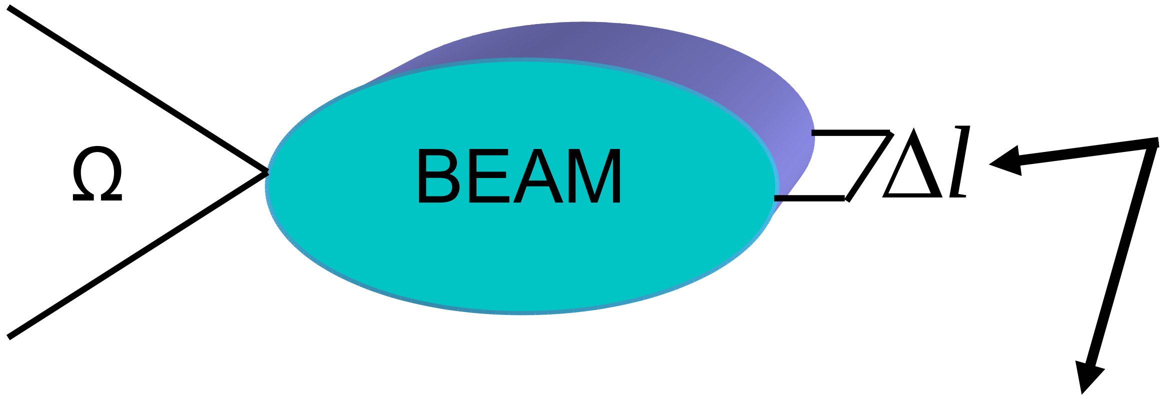


Atomic collisions
$N_2^+ \Leftrightarrow$ Beam Ions.
Excitating vibration-levels, 391 nm, 427 nm, ...

V-stack MCP
HV $\mapsto$ gain ~ 10^6
Single photon detection!

Also EMCCD cameras tested with comparable results…

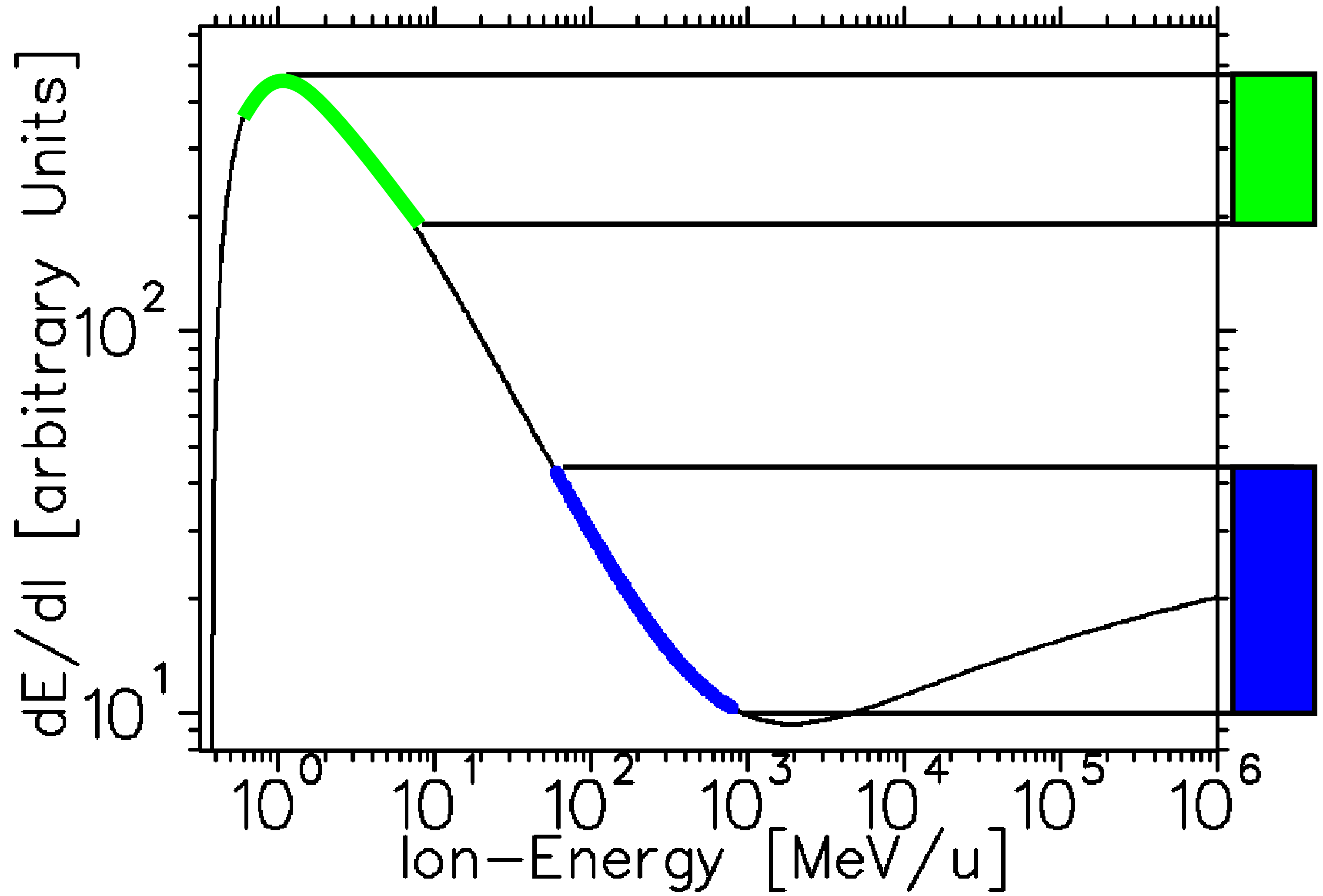
Expected Photon Yield



depends on setup geometry

~ integration time
~ number of particles per pulse

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



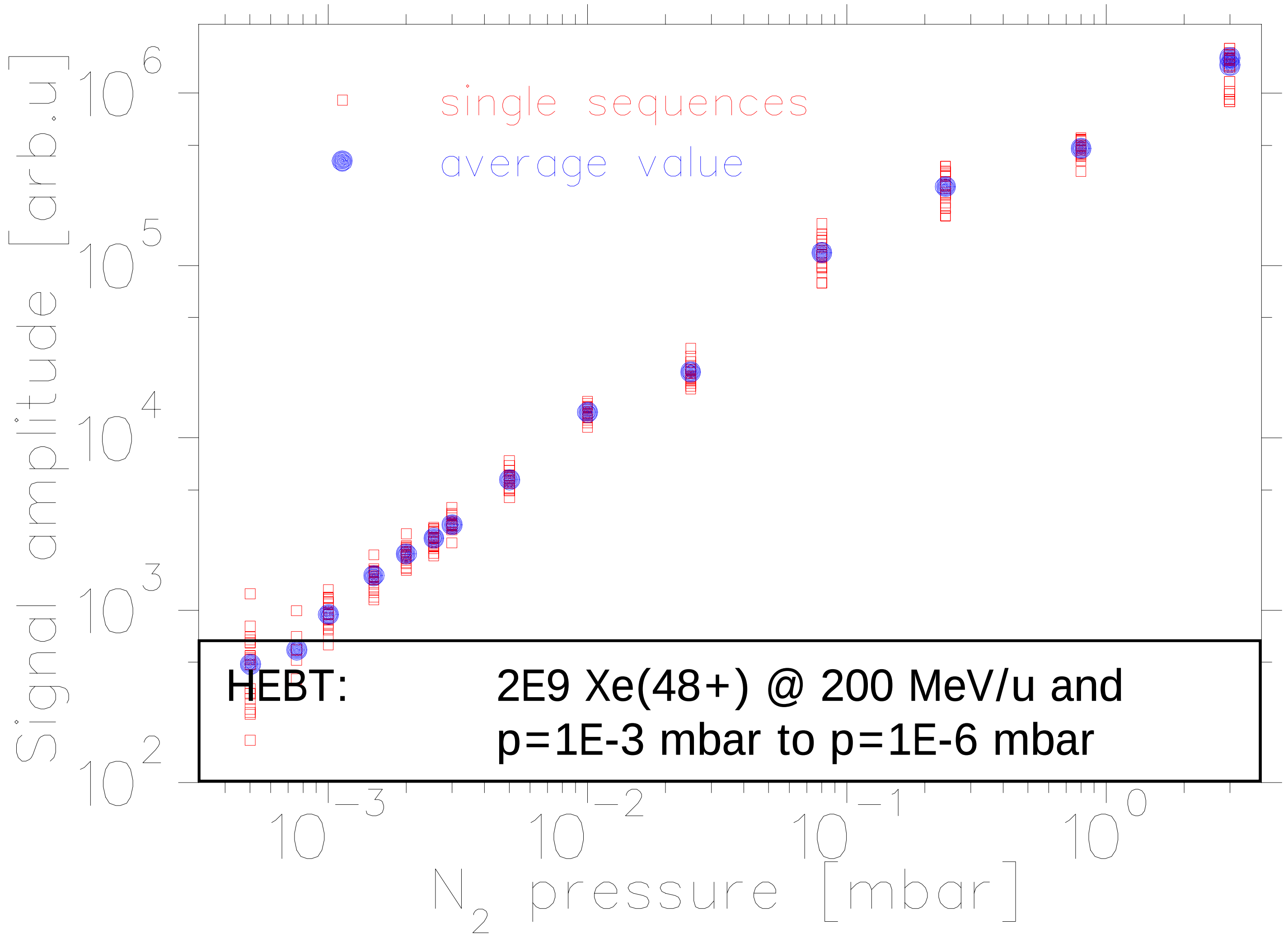
LINAC: High energy loss
typical: 5-11 MeV/u
2,5 mA ~ 10^{12} particles pp.

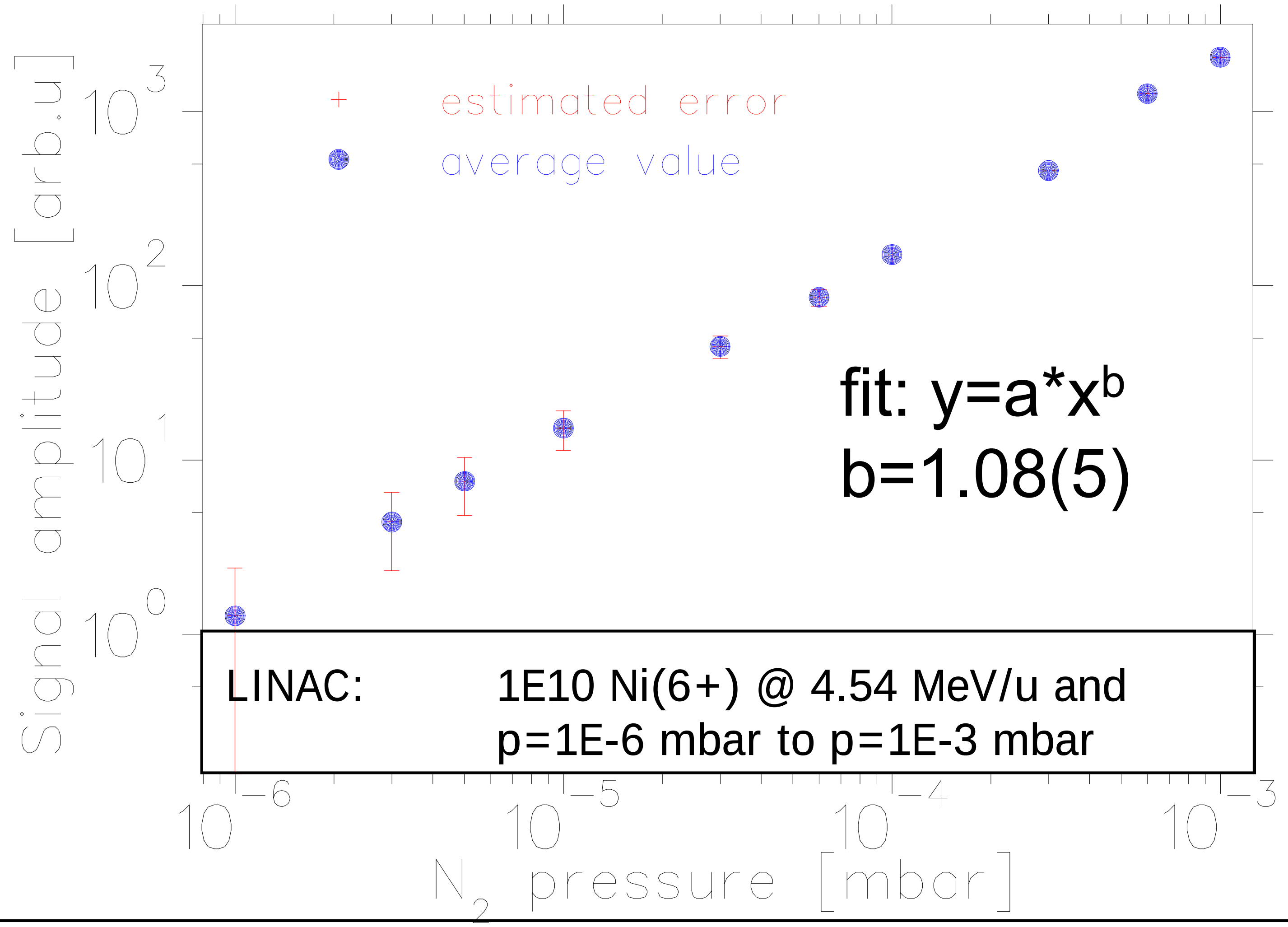
SYNC/ HEBT: Low energy loss
typical: 60-2000 MeV/u
10^{10} particles per cycle

HELMHOLTZ GEMEINSCHAFT GSI FAIR

Pressure Variation

p changed by **6** orders of magnitude





Signal amplitude increases proportional to p

For higher beam intensities lower pressures are sufficient!

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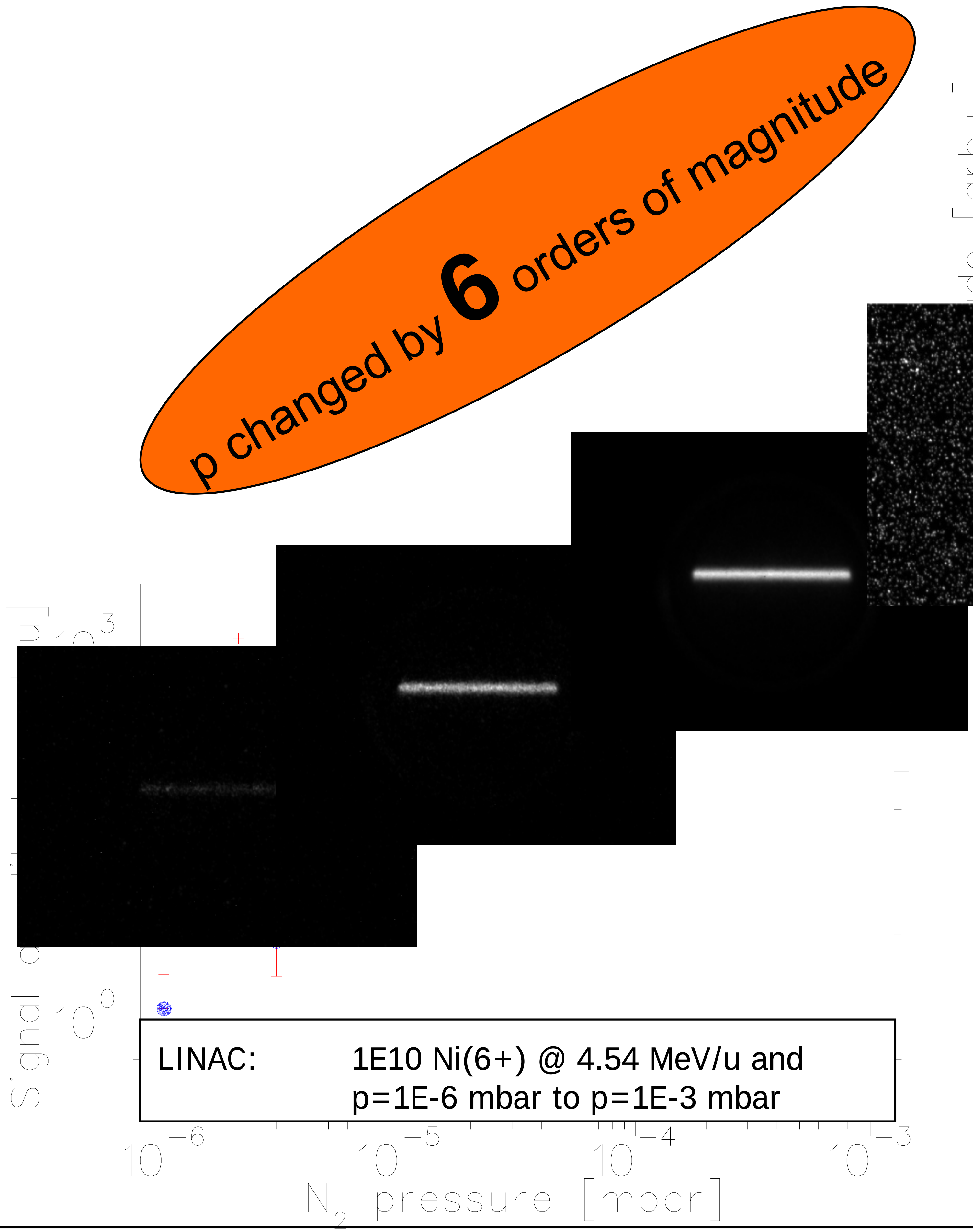

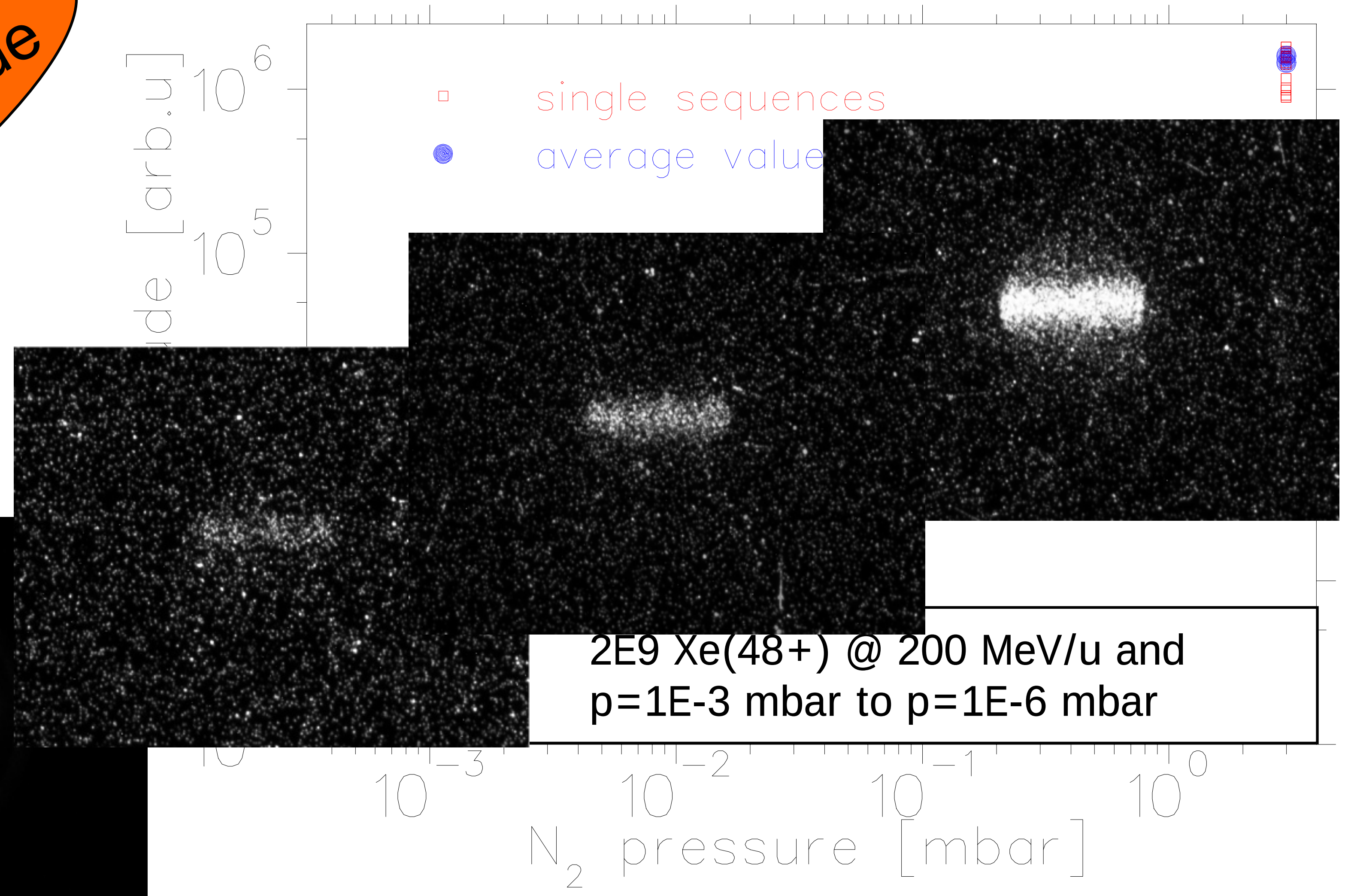

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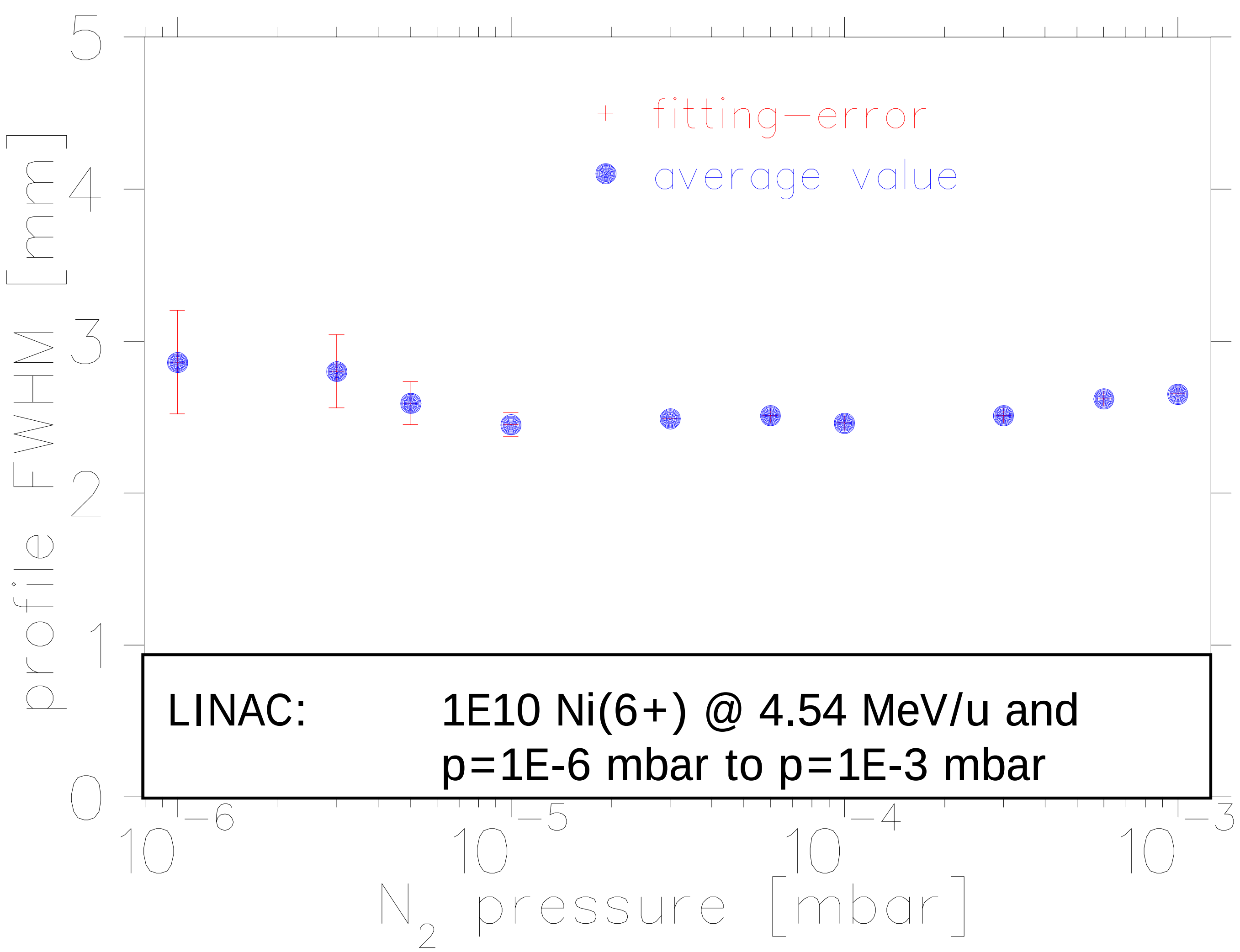
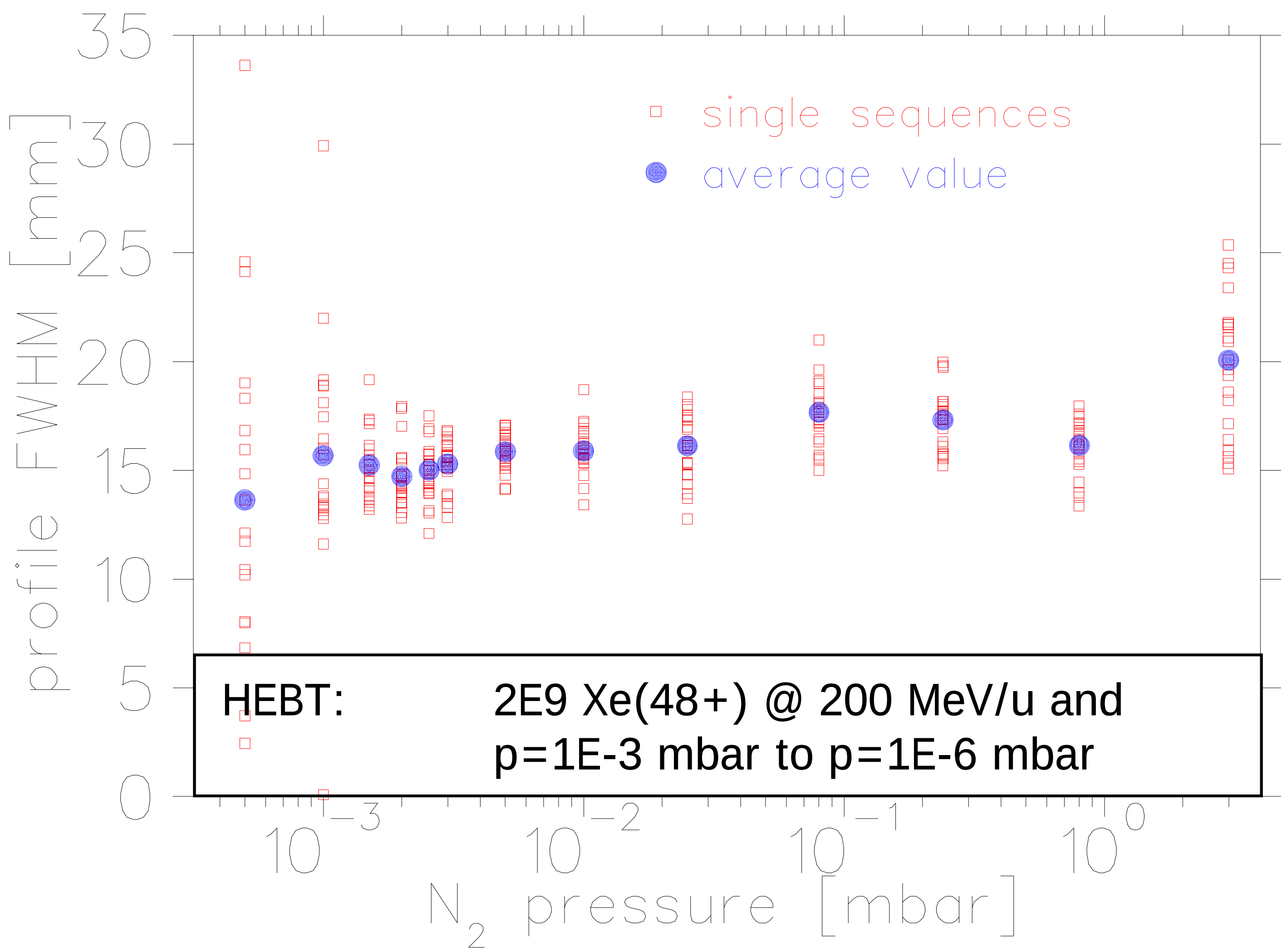




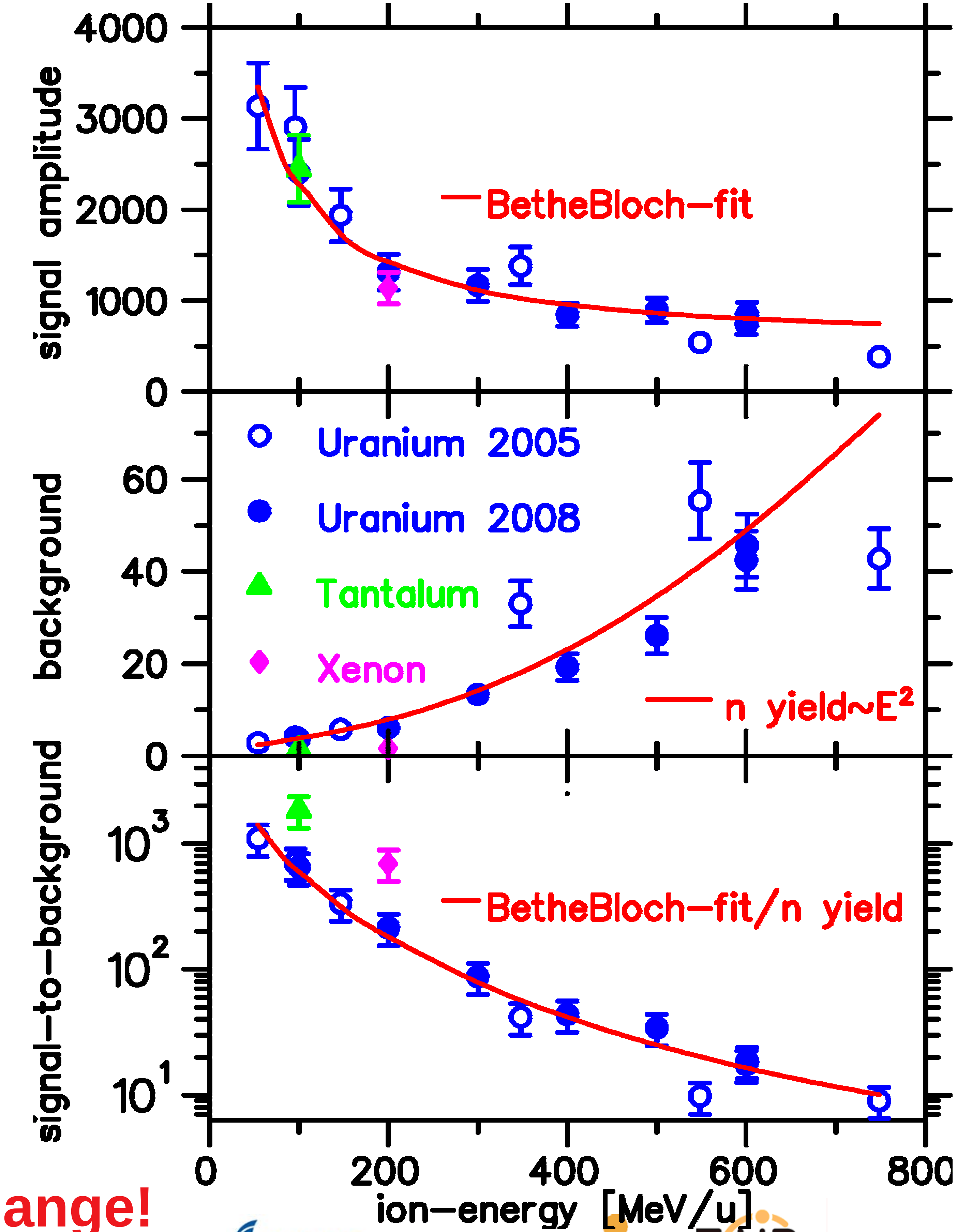
Profile width remains constant → p is suitable parameter to match signal strength!

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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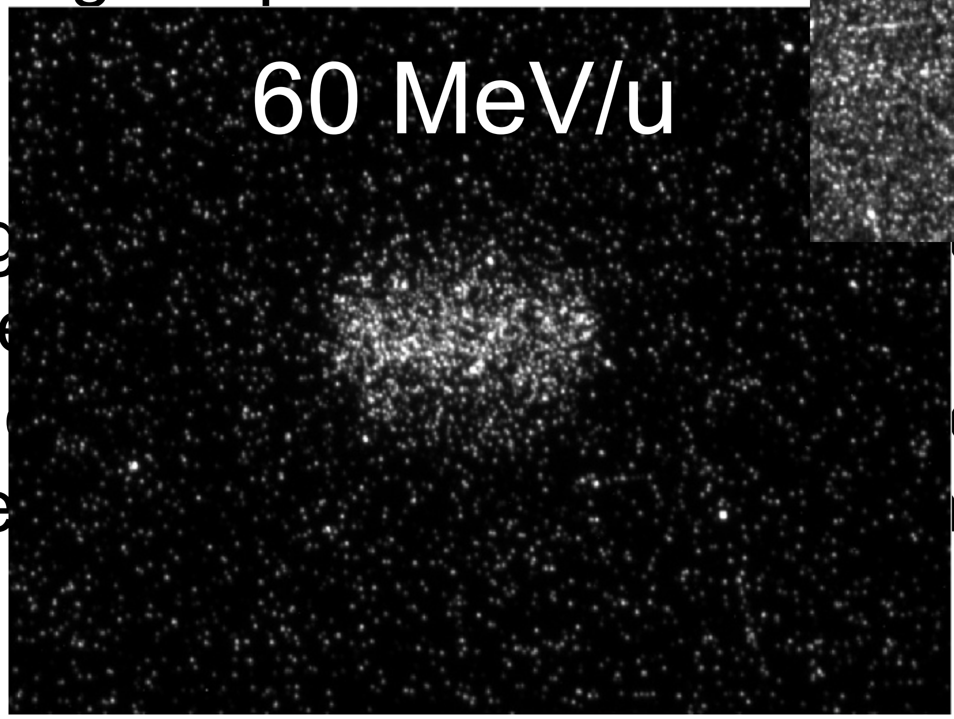
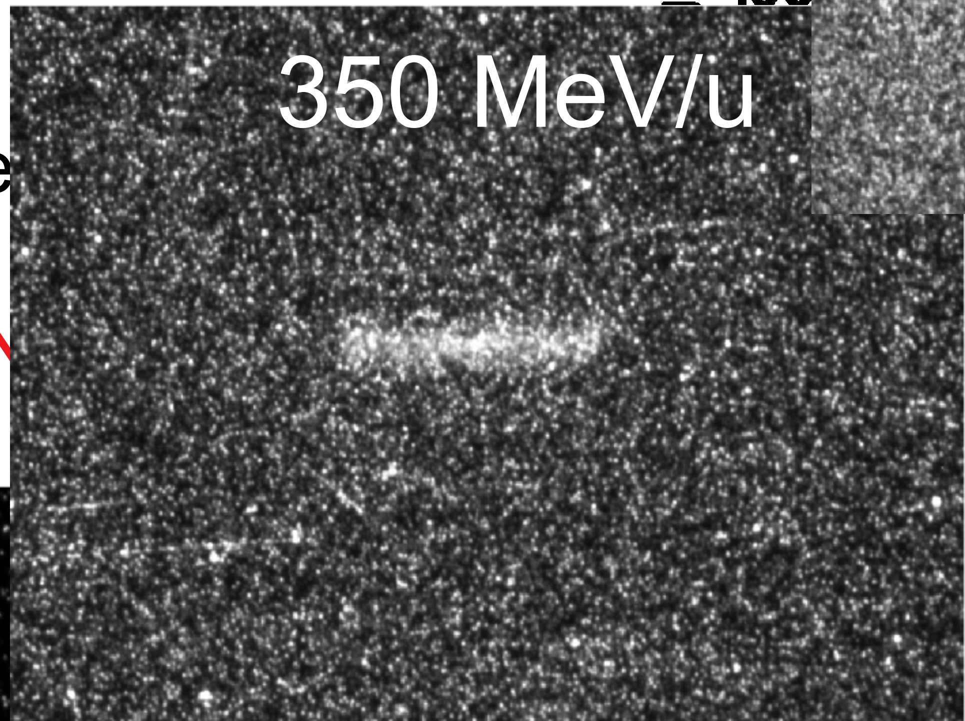
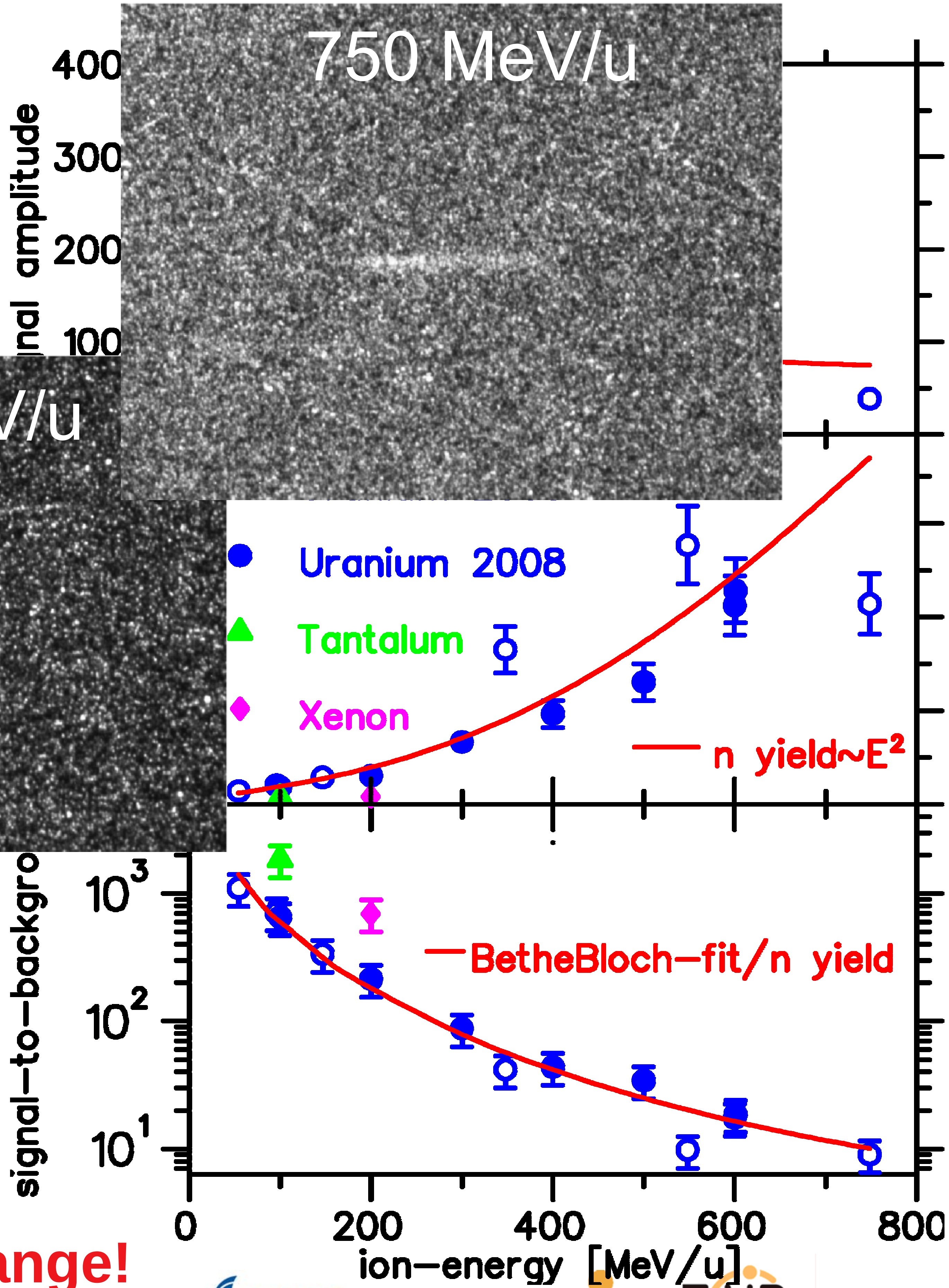
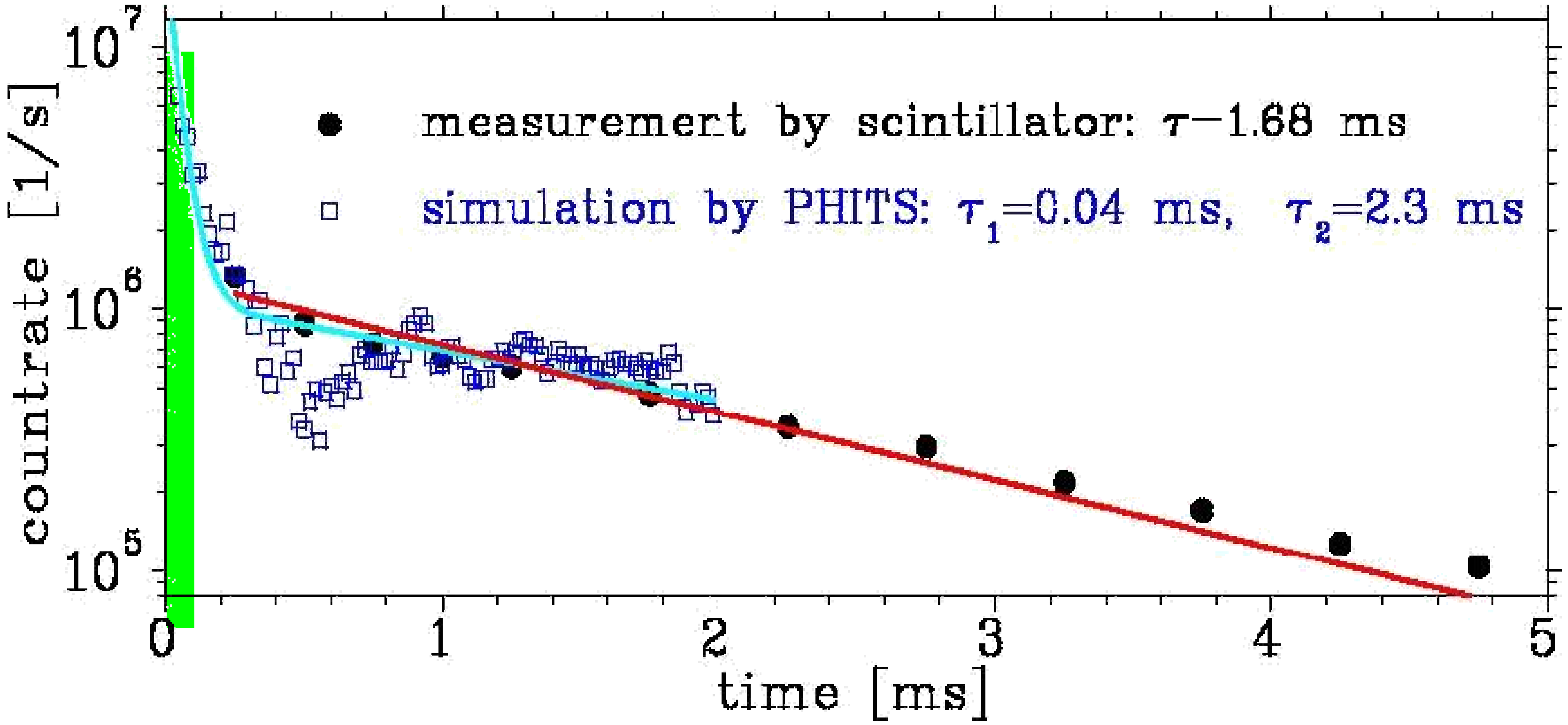






↦ Background reduction is major challange!

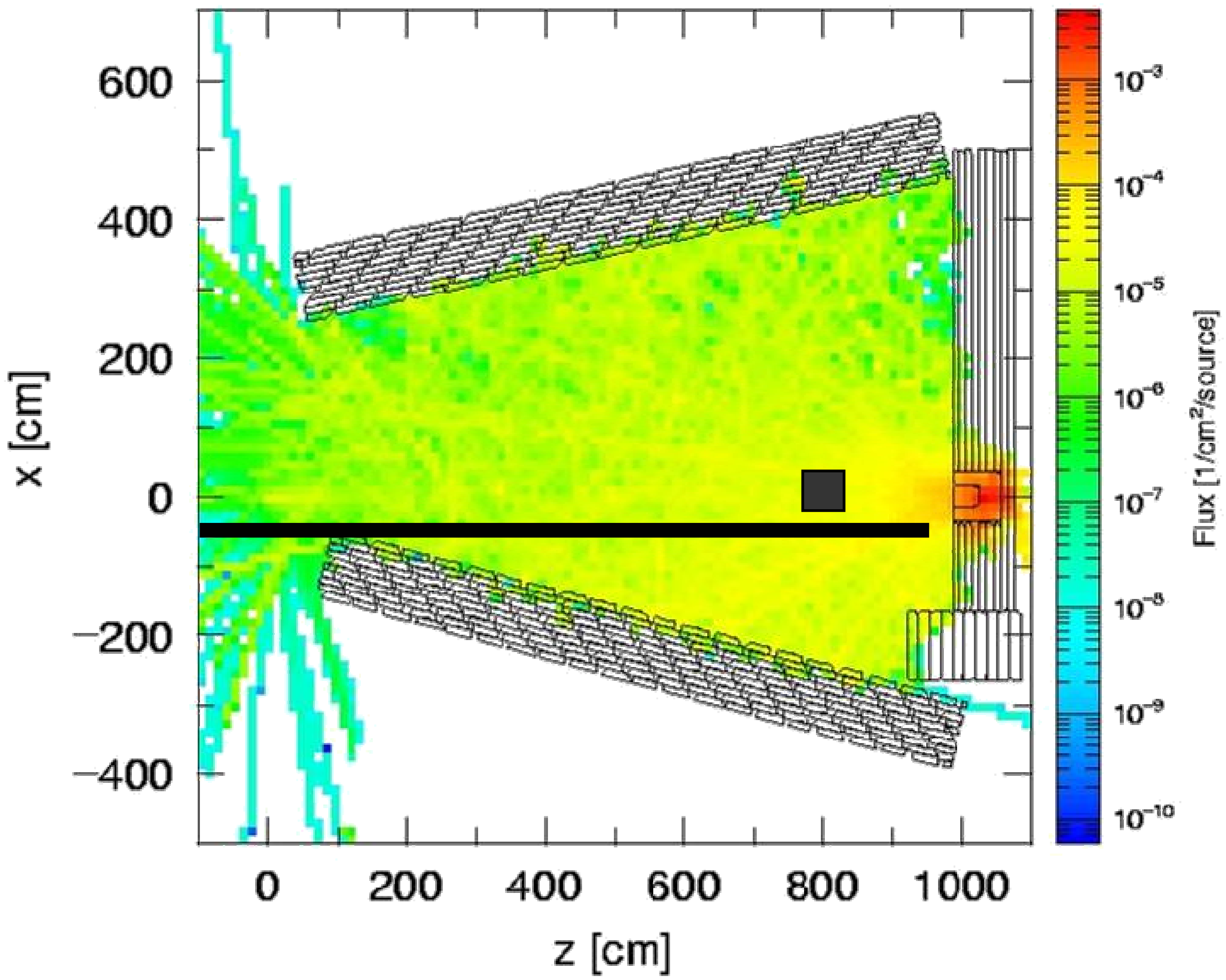
Background Distribution



- 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

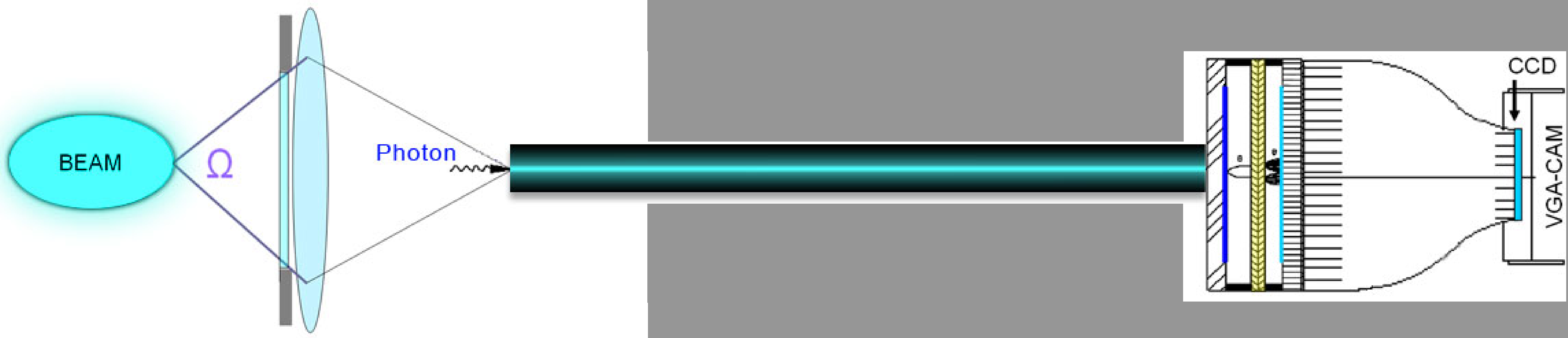
- Neutron flux in whole cave

⇒ Reduction by moderation and absorbtion in shielding

Shielding Concept

Fiber-optic image bundle with about 1 million sorted fibers:

Effective neutron SHIELDING:
Moderation and Absorbtion



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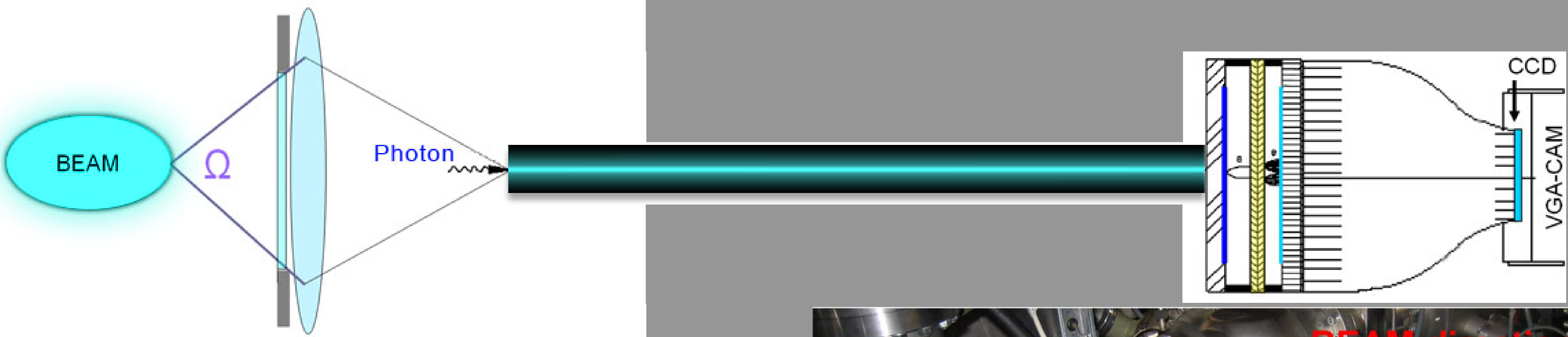
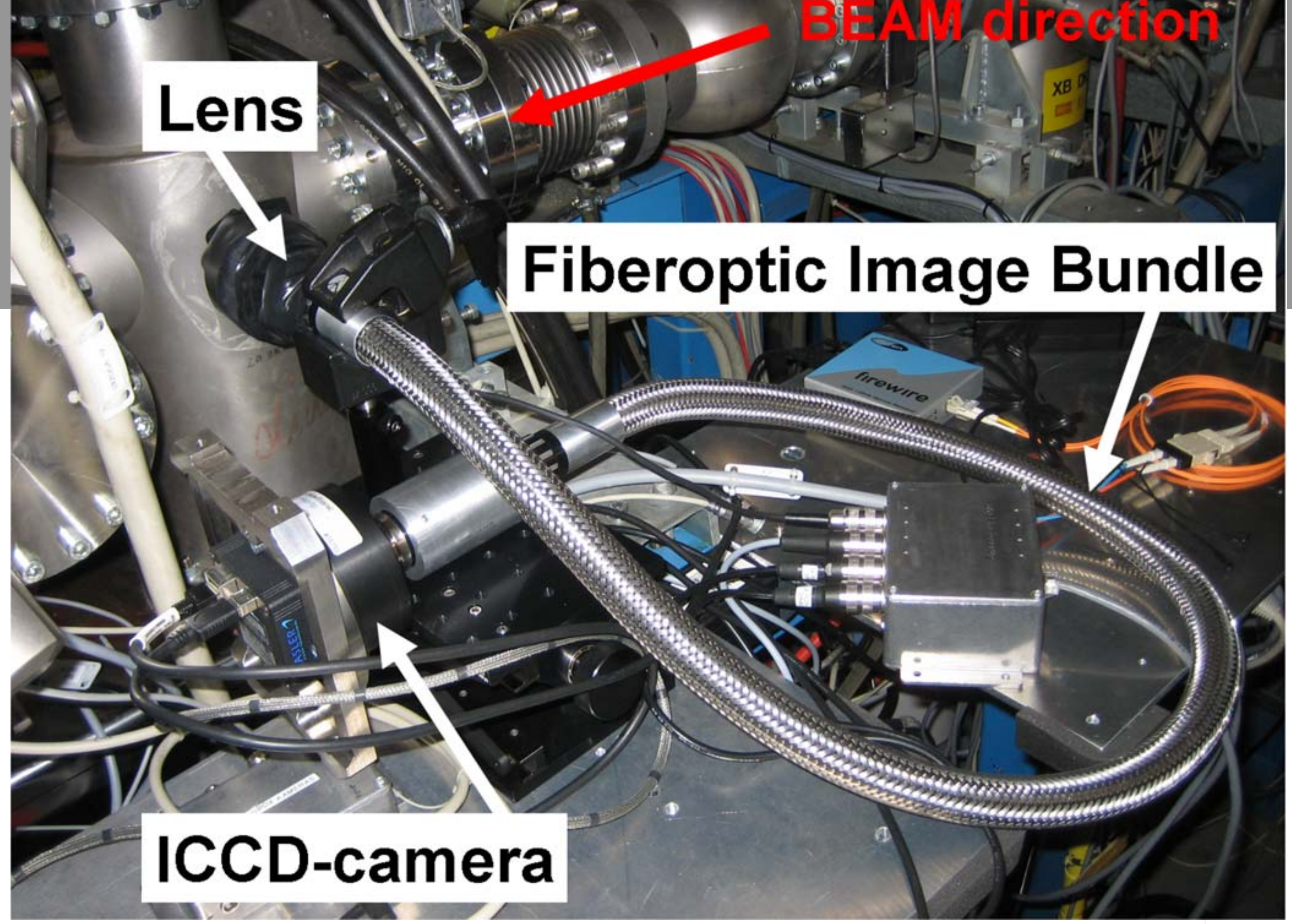


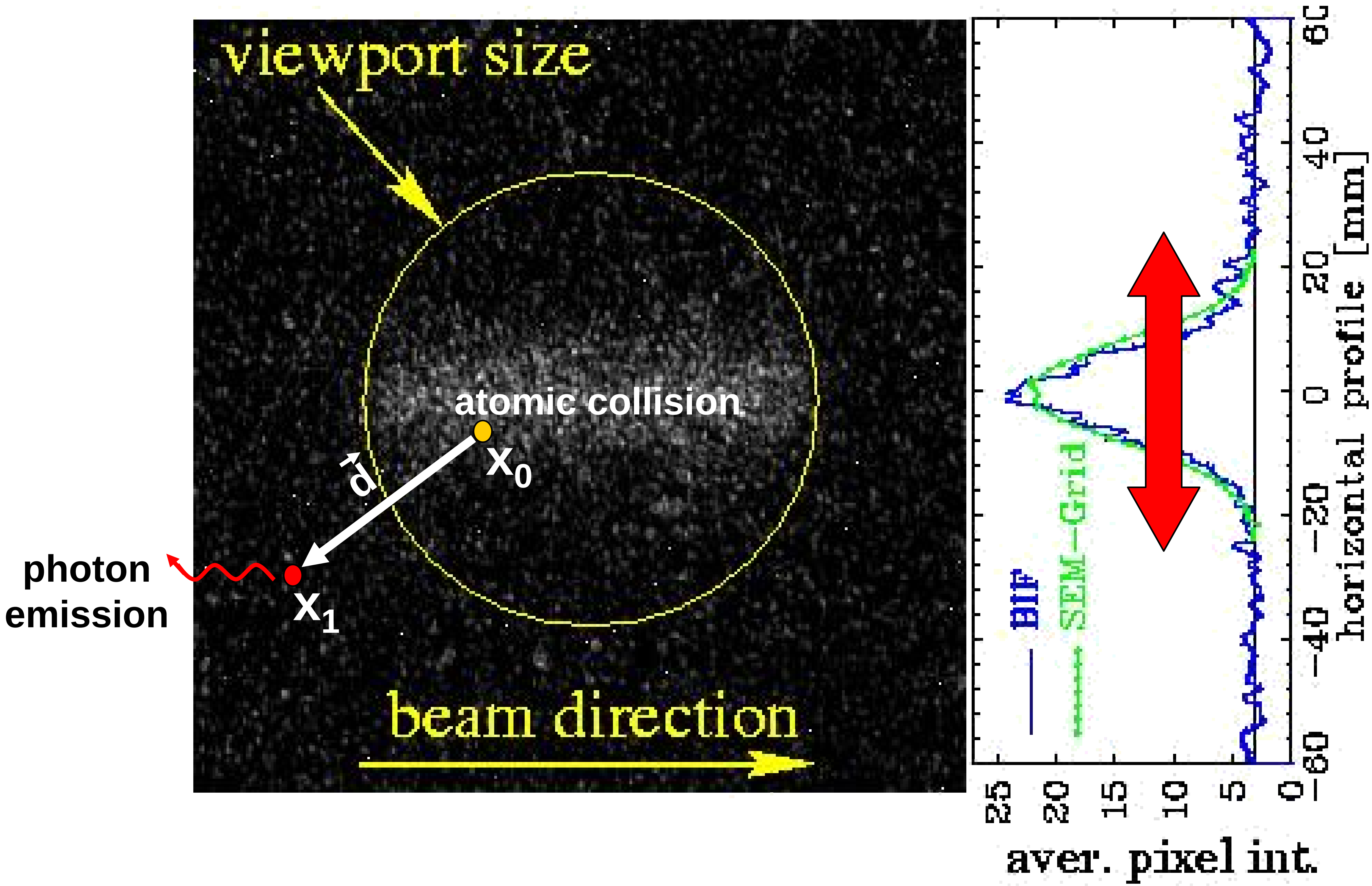


- Commercially available device to reduce background & CCD damage
- Image Intensifier & CCD in shielded area maintaining the solid angle

First Results:

- No significant image distortion
- Low scintillation by neutrons and gammas inside bundle
- un-shielded: ≈30 % background increase

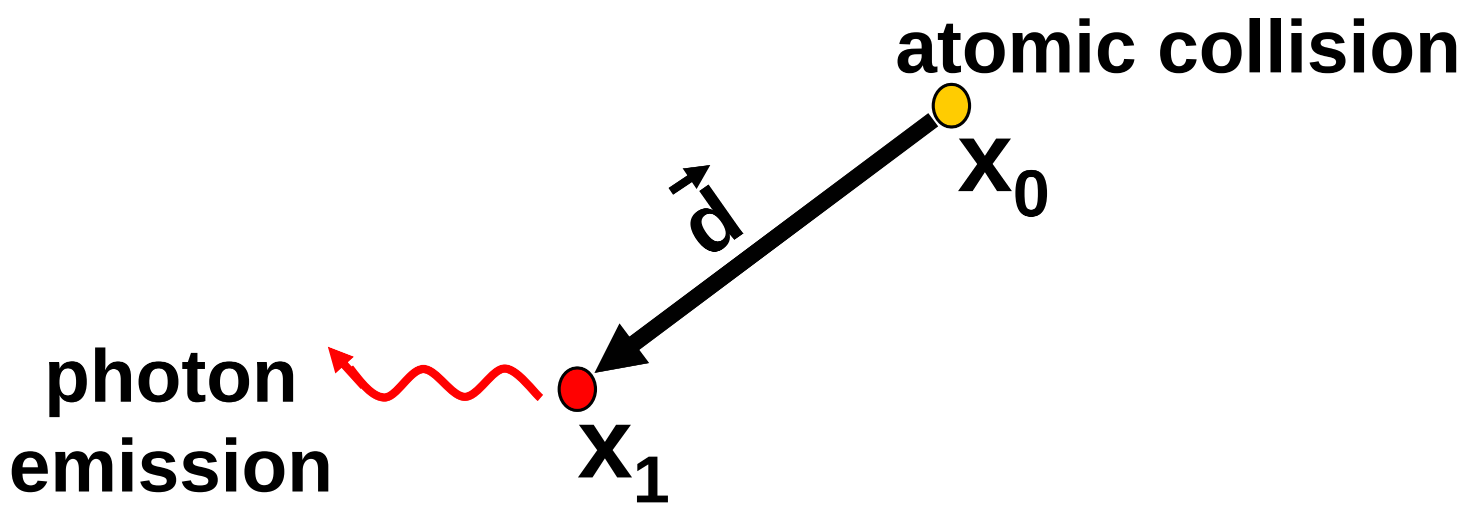
Systematic Profile Distortion



Systematic Profile Distortion

$$d(\tau) = \tau\left(v_{thermal} + v_{collision}\right) + \min(\tau,t)\int_0^{\tau,t}\left(v_{E-field}\right) + \ldots$$

$$v_{thermal} = \sqrt{\frac{2k_B T}{M}} \qquad v_{collision} = \sqrt{2\frac{0.014eV}{M}} \qquad v_{E-field} = \frac{Eq\tau}{M}$$

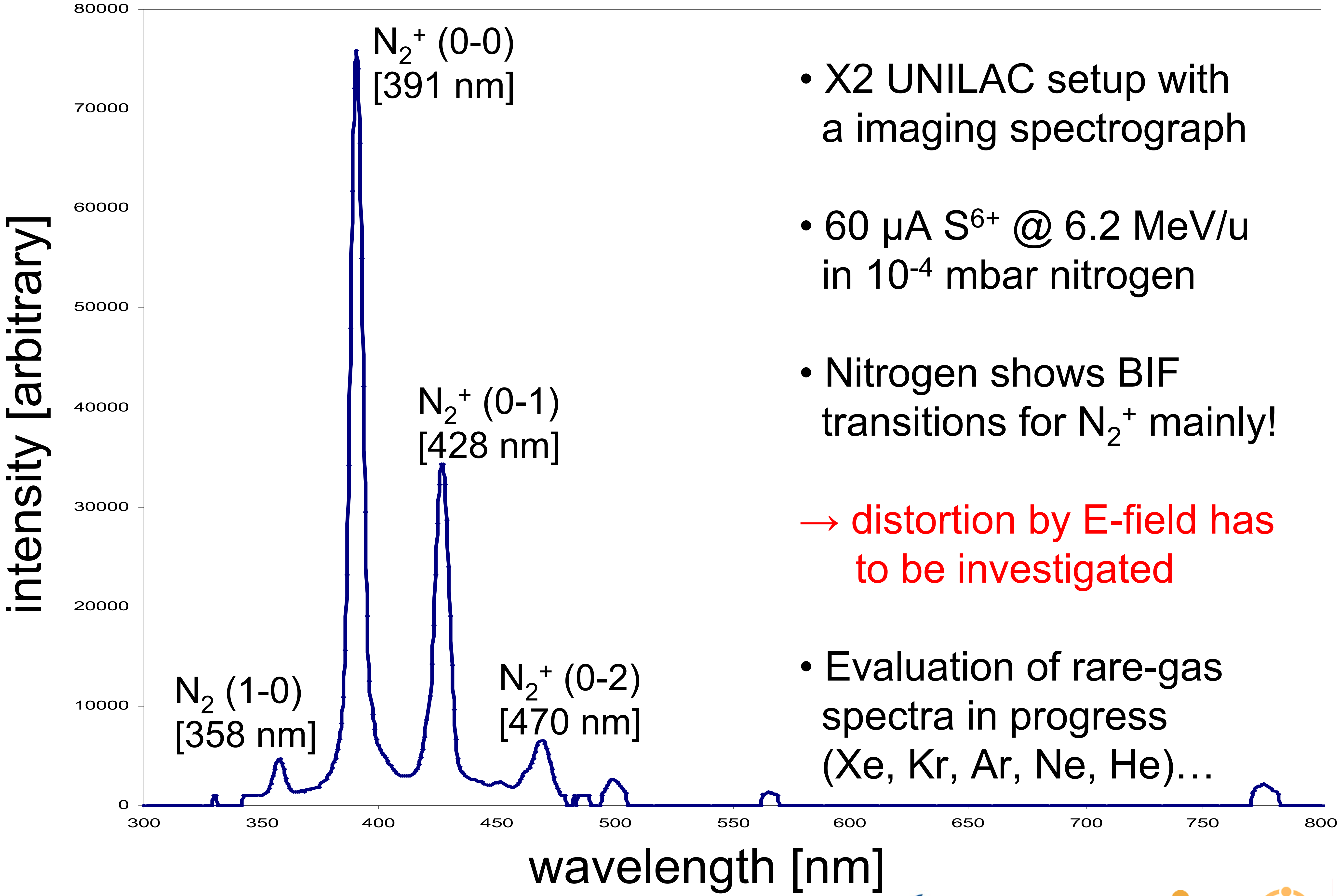


[M.A. Plum, NIM A (2002)]
[W.H. DeLuca, NuSc. (1969)]

parameters to choose: ***τ, M, q***

$$d(\tau,M,q) = \tau\left(\sqrt{\frac{2k_B T}{M}} + \sqrt{2\frac{0.014eV}{M}}\right) + \tau^2\frac{Eq}{2M} + \ldots$$

BIF Spectrum of Nitrogen



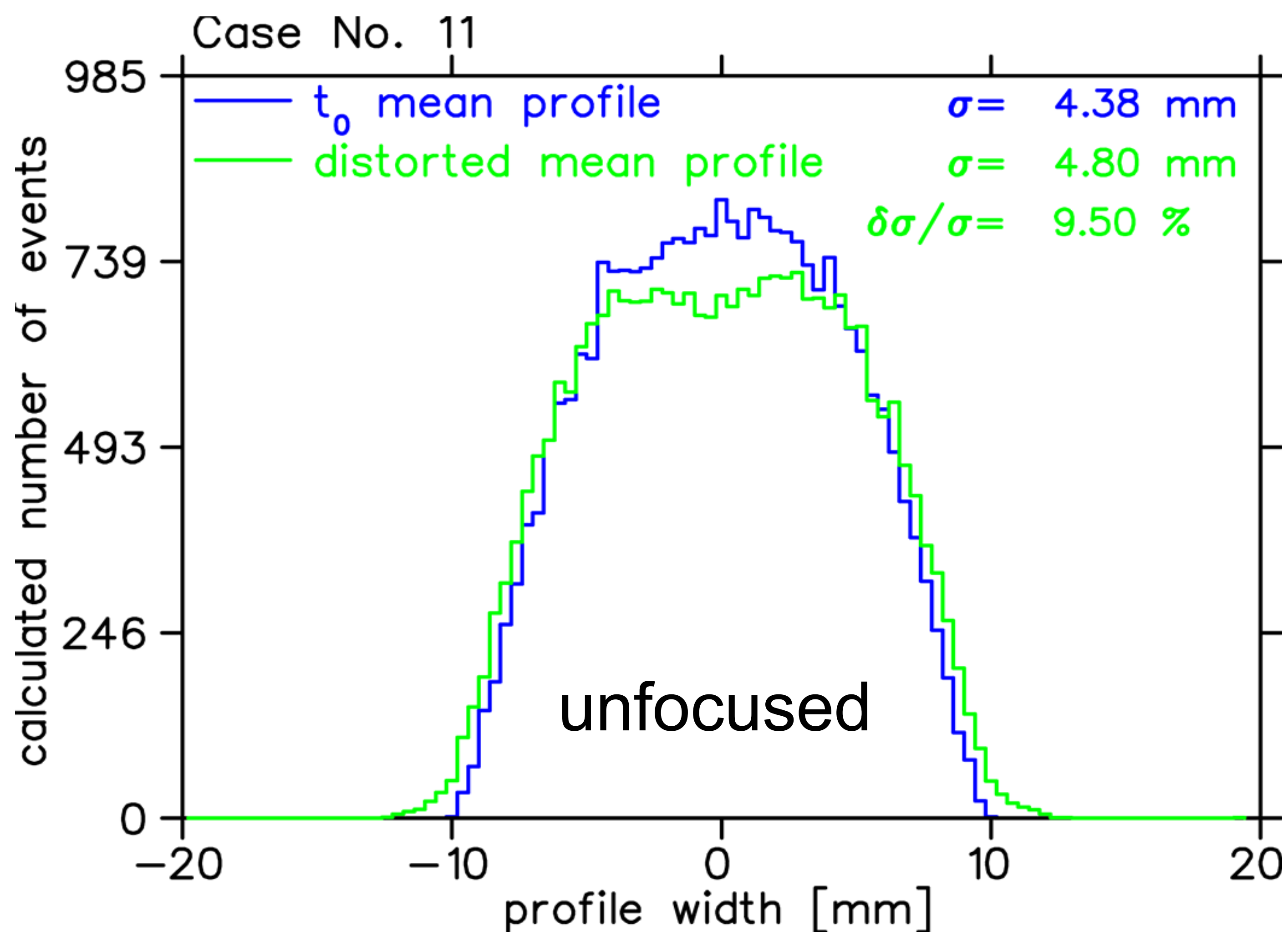
- X2 UNILAC setup with a imaging spectrograph
- 60 µA S^{6+} @ 6.2 MeV/u in 10^{-4} mbar nitrogen
- Nitrogen shows BIF transitions for N_2^+ mainly!

→ distortion by E-field has to be investigated

- Evaluation of rare-gas spectra in progress (Xe, Kr, Ar, Ne, He)…

N_2^+ Profile Distortions by E-field - Simulation

- Gas ion trajectories are calculated with a Monte Carlo code
- $\cos^2$ start-distribution is projected (blue profile)
- Discretised convolution of trajectories with the decay rate (green profile)
- Relativistic field transformations included ($\gamma_{SFRS} = 2$)



NDCX Diagnositic chamber:
$5 \cdot 10^{11}$ K+ @ 7,69 keV/u in 3µs
σ=4.4 mm, no sc-compensation

→ For relativistic beams and small foci distortions by E-fields are an issue!

Alternative Residual Gases - VIS

Gas	Lifetime	Spectrum	+ / -
^{20}Ne	$1/A_{ik}$(Ne II)~7 ns	UV to blue	+ high photon yield predicted; - small mass
^{40}Ar	$1/A_{ik}$(Ar II)~13 ns	blue	+ high photon yield predicted; - narrow band spectrum
^{84}Kr	$1/A_{ik}$(Kr II)~12 ns	blue	+ heavy
^{131}Xe	$1/A_{ik}$(Xe II)~14ns	blue to green	+ heaviest rare gas; - wide band spectrum; - small photon yield predicted

Outline

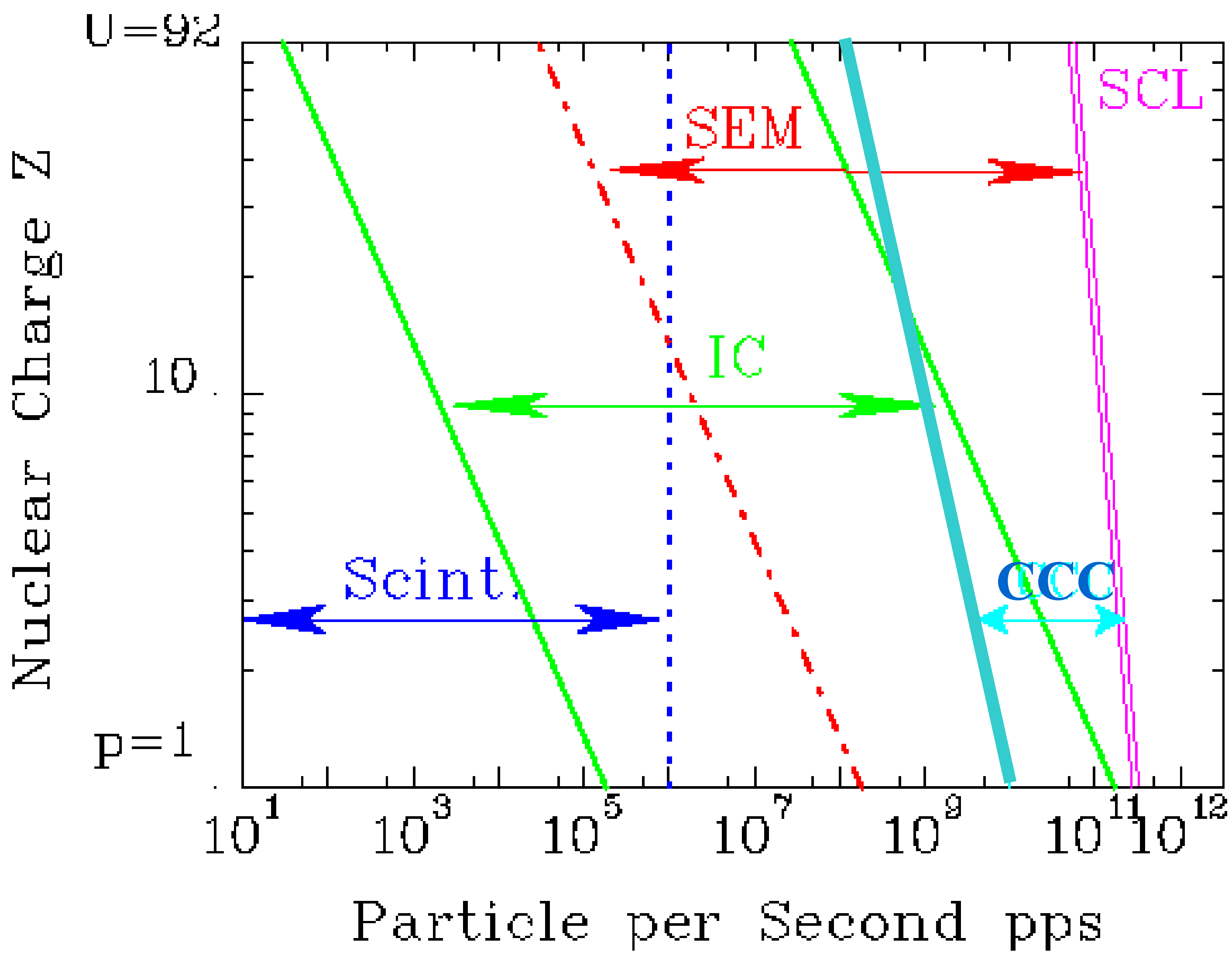
Part II Cryogenic Current Comparator

Current Measurement for slow Extraction

Slow extraction current measurement → particle detector as standard

- **Scintillator:**
  particle counting r<10^6 ppp
- **Ionization Chamber:**
  lower limit I_{sec}= 1 pA
  upper limit I_{sec}= 1 µA
  due to recombination
- **Secondary Electron Monitor**
  lower limit I_{sec}= 1 pA
  (requires calibration,
  radiation damage)
- **Cryogenic Current Comparator**
  SQUID based B-field measure
  lower limit I_{beam}=10 nA
  due to noise contribution

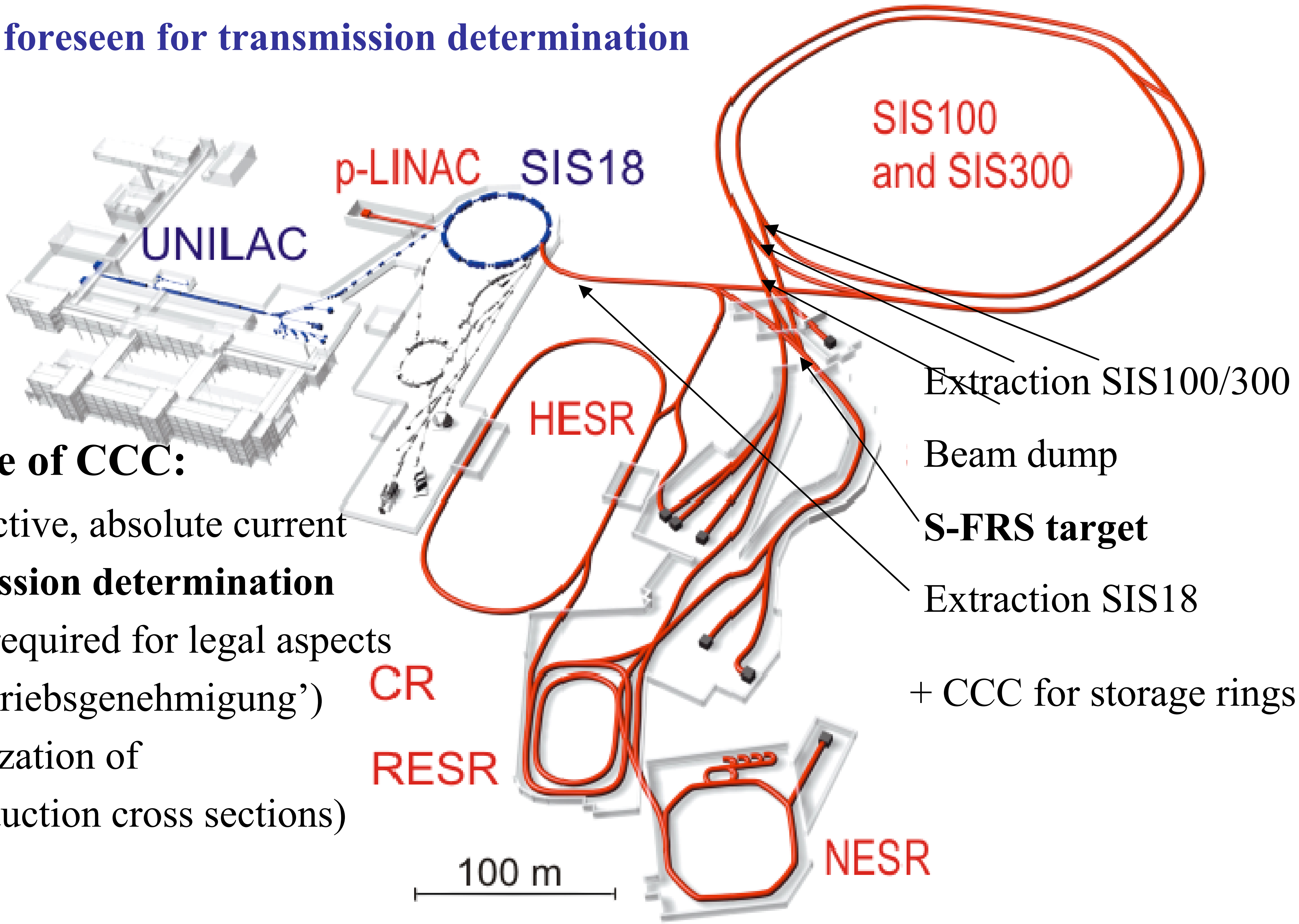
Detector ranges for E_{kin}= 1 GeV/u and A=1 cm²:



CCC: *non-destructive and absolute* current reading due to calibration with current source!

FAIR-HEBT: Foreseen Installation of CCC

6 CCC are foreseen for transmission determination



Advantage of CCC:

Non-destructive, absolute current

⇒ **Transmission determination**

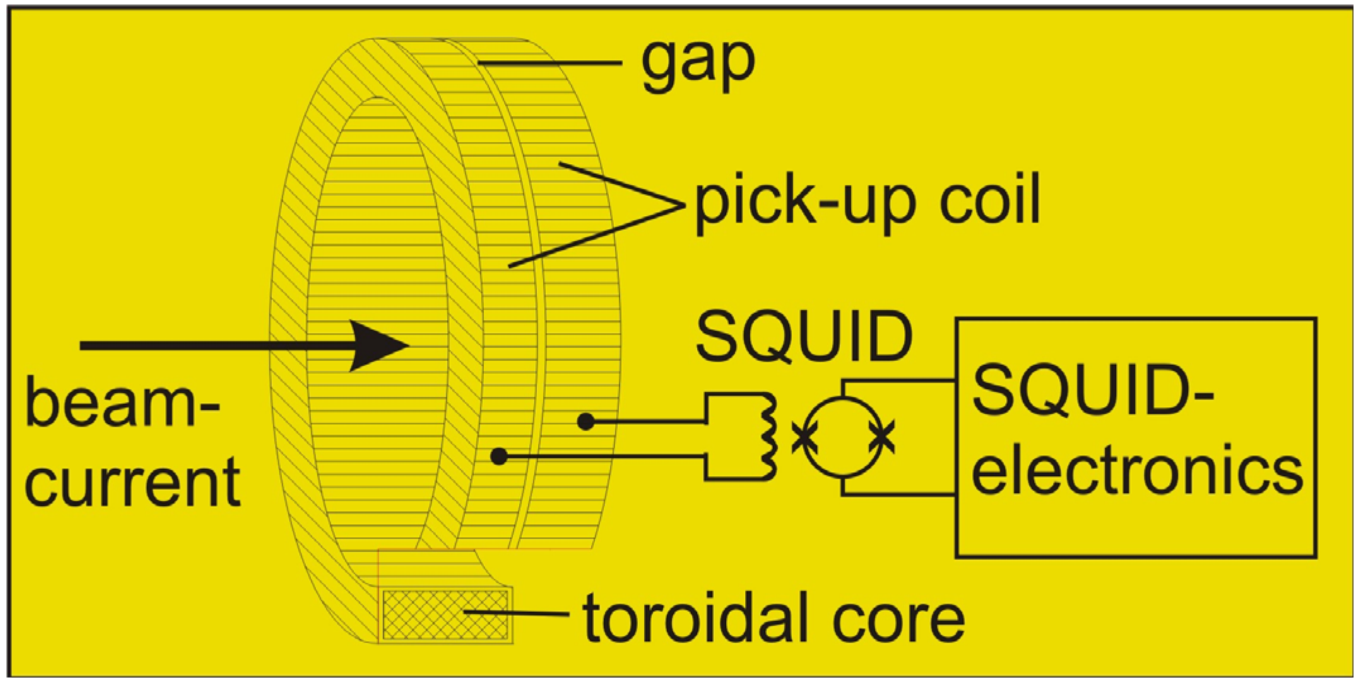
⇒ (Device required for legal aspects like ‘Betriebsgenehmigung’)

⇒ (Normalization of RIB production cross sections)

Current Determination with *nA* Resolution

- **HEBT:** slow extraction → online transmission control
- **Rings:** low stored current e.g. RIB.

Cryogenic Current Comparators:



Torus within cryostat at University Jena:

- Prototype tested at GSI in the 90ies
- Improvement:

  Nb instead Pb for the flux transducer with less temperature drift
- reached 0.25 nA/√Hz ⇒ **8 nA @ 1 kHz**
- ***R&D:*** GSI, DESY and Uni-Jena.

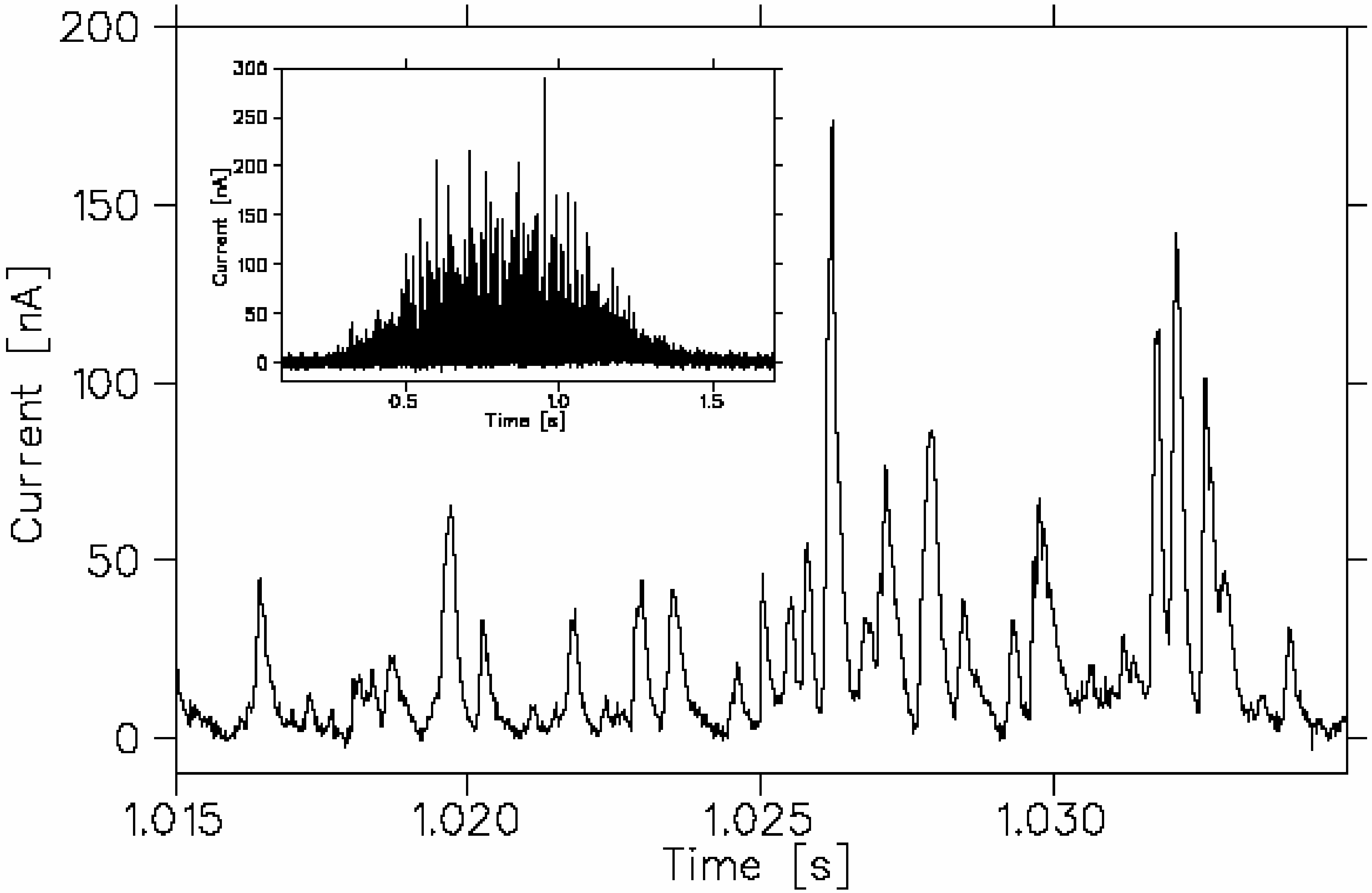
Achievements 1993 to 1999 at HEBT at GSI

CCC designed and tested in collaboration with Uni Jena (W. Vodel)

⇒ functionality proven (due to low space not installed permanently)

Installation at HTP:

7x10^9 Ar^{11+} at 300 MeV/u within 1.2 s, readout 20 µs:

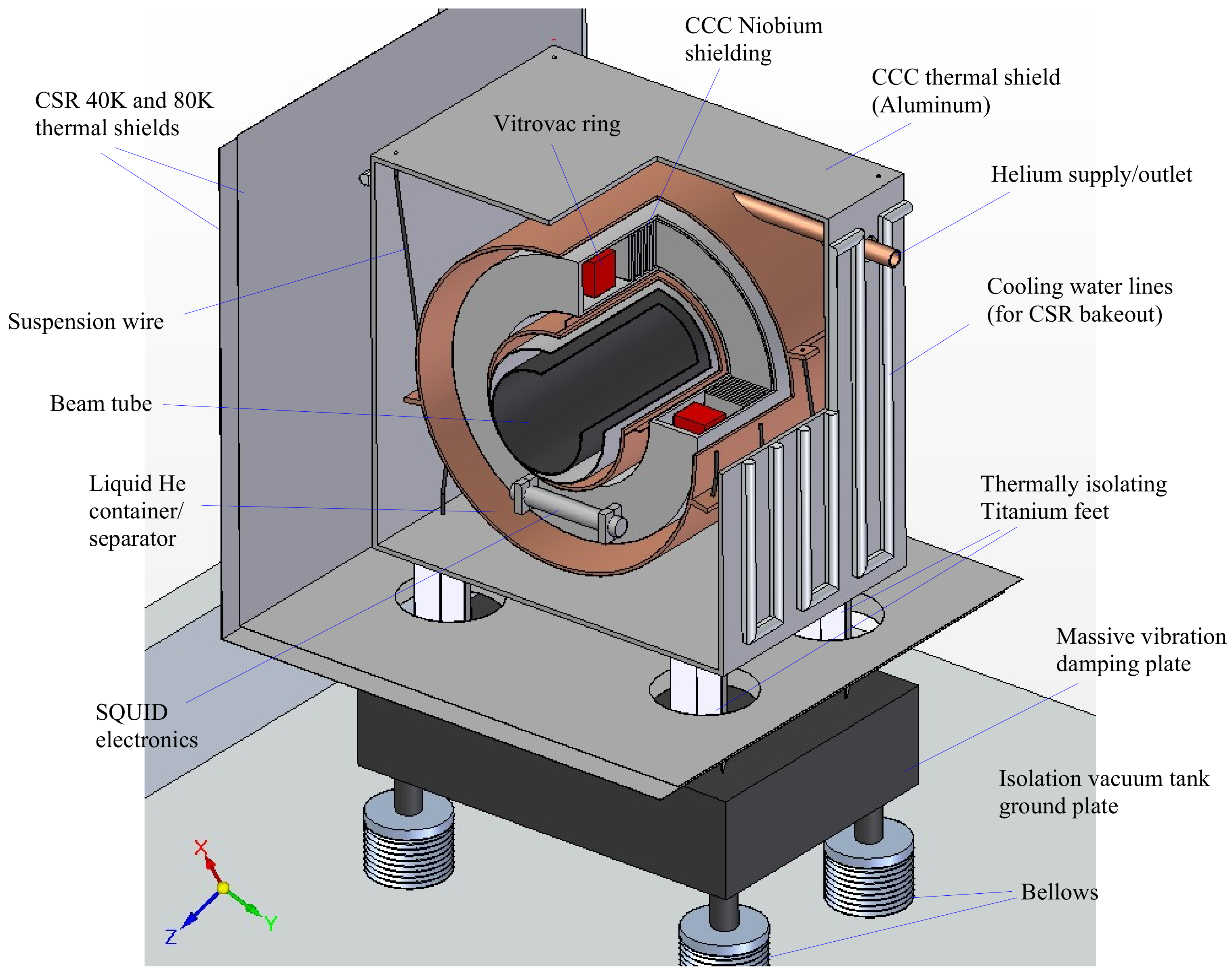


⇒ large slew rate required for electronics…….

Recent Developments: Uni Jena, MPI-K, DESY, GSI

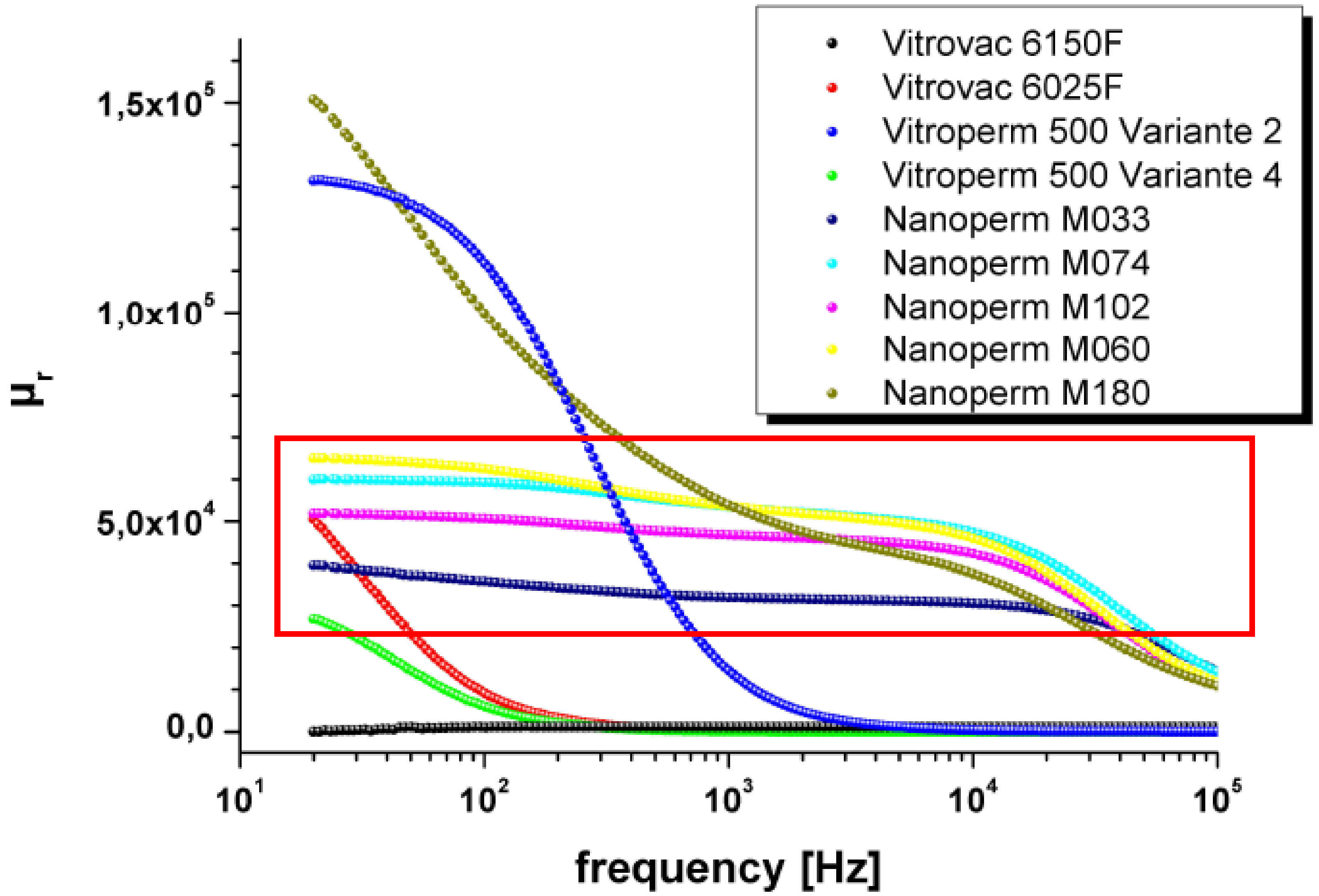
Collaboration for material research and installation within a storage ring

Idea for CSR low energy storage ring at MPI-K, Heidelberg:



Investigations:

- Materials for low thermal drifts and low magneto-striction
- Optimization of geometry for low pick-up
- Compact installation close to warm section
- Construction of prototype at MPI-K
- Open PhD position at GSI for HEBT design



Conclusion

BIF: Non-destructive method for profile measurement:

- Compact installation with high resolution (simpler mechanics as IPM)
- Same device for fast and slow extraction (in total 18 locations foreseen FAIR)
- Sufficient experiences for mechanical design, data acquisition and analysis
- Investigation of different gases in progress
- Ideas for background suppression using an fiber image bundle

  → more investigations for background suppression required

CCC: Only non-destructive method for absolute current measurement:

- Absolute transmission determination and delivery to target
- Achieved 10 nA@1kHz
- Projected 3 nA@1kHz by matched materials and careful design for stable operation

Some Backup-Slides…

Systematic Profile Distortion

$$d(\tau) = \tau\left(v_{thermal} + v_{collision}\right) + \min(\tau,t)\int_0^{\tau,t}\left(v_{E-field}\right) + \ldots$$

$$v_{thermal} = \sqrt{\frac{2k_BT}{M}} \qquad v_{collision} = \sqrt{2\frac{0.014eV}{M}} \qquad v_{E-field} = \frac{Eq\tau}{M}$$

Parameters for N_2^+:
(N I trans. not suitable!)

τ	=	60 ns
$v_{thermal}$	=	$4.2\cdot10^{-4}$ mm/ns
$v_{collision}$	=	$3.1\cdot10^{-4}$ mm/ns
$E_{max\ NDCX}$	>	$2\cdot10^{5}$ V/m
$M_{Nitrogen}$	=	28 amu
q	=	+1

[M.A. Plum, NIM A (2002)]
[W.H. DeLuca, NuSc. (1969)]

parameters to choose: ***τ, M, q***

$$d(\tau,M,q) = \tau\left(\sqrt{\frac{2k_BT}{M}} + \sqrt{2\frac{0.014eV}{M}}\right) + \tau^2\frac{Eq}{2M} + \ldots$$

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→

Actual displacement for N_2^+ (absolute numbers):

$d_{thermal}$	=	25.2 µm
$d_{collision}$	=	18.6 µm
	→	43.8 µm

$$d(\tau, M, q) \quad = \quad \tau\left(\sqrt{\frac{2k_B T}{M}} + \sqrt{2\frac{0.014eV}{M}}\right) + \tau^2\frac{Eq}{2M} + \ldots$$

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Parameters for Xe^+:

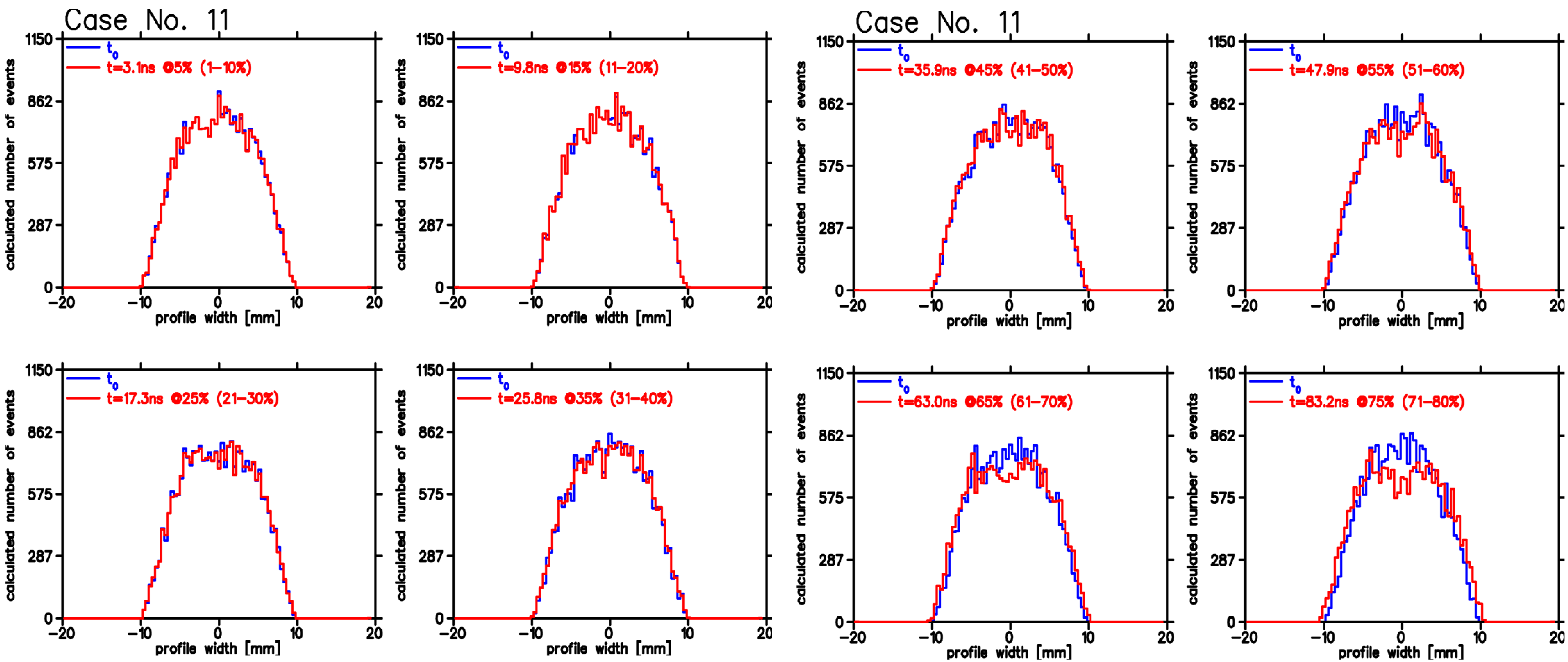
τ	≤	10 ns
$v_{thermal}$	=	$1.9 \cdot 10^{-5}$ mm/ns
$v_{collision}$	=	$1.4 \cdot 10^{-5}$ mm/ns
$E_{max\ NDCX}$	>	$2 \cdot 10^{5}$ V/m
M_{Xenon}	=	133 amu
q	=	+1

Actual displacement for Xe^+ (absolute numbers):

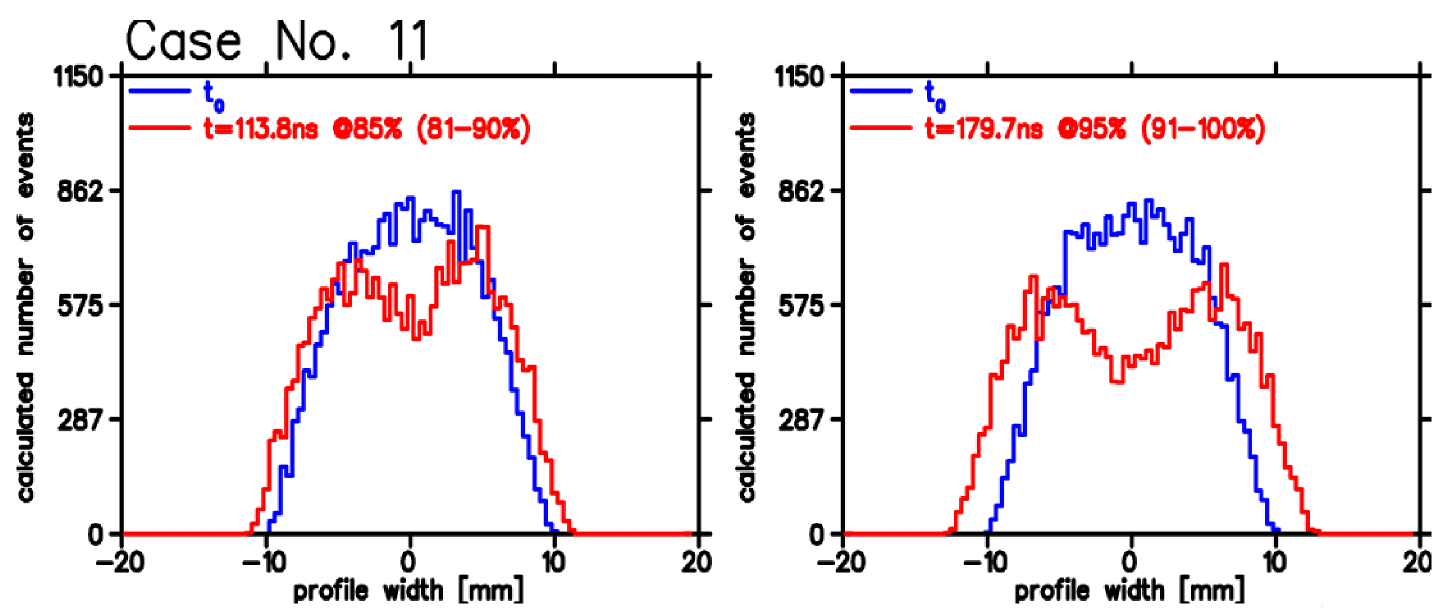
$d_{thermal}$	=	1.9 µm
$d_{collision}$	=	1.4 µm
	→	3.3 µm

$$d(\tau, M, q) \quad = \quad \tau\left(\sqrt{\frac{2k_B T}{M}} + \sqrt{2\frac{0.014eV}{M}}\right) + \tau^2\frac{Eq}{2M} + \ldots$$

N2+ Profile Distortions by E-field - Simulation



NDCX Diagnositic chamber:



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Alternative Residual Gases - VIS

Gas	Lifetime / wavelengths	+ / -
^{20}Ne	$1/A_{ik}$(Ne II)~7 ns 332.4, 337.8, 339.3 nm	• high photon yield (+) • small mass (-)
^{40}Ar *)	$1/A_{ik}$(Ar II)~13 ns 434.8, 476.5, 488.0 nm	• high photon yield (+) • narrow band spectrum (-)
^{84}Kr	$1/A_{ik}$(Kr II)~12 ns 435.5, 473.9, 465.9 nm	• heavy (+)
^{131}Xe * *)	$1/A_{ik}$(Xe II)~14ns 484.4, 541.9, 699.0 nm	• heavy (+) • wide band spectrum (-) • small photon yield predicted (-)

*) [A. Ulrich, J. Wieser, G. Ribitzki (1992/93)] * *) [M.A. Plum, NIM A (2002)]