Some Comments on BIF Optics, Integration Times and Gas Curtain Thickness

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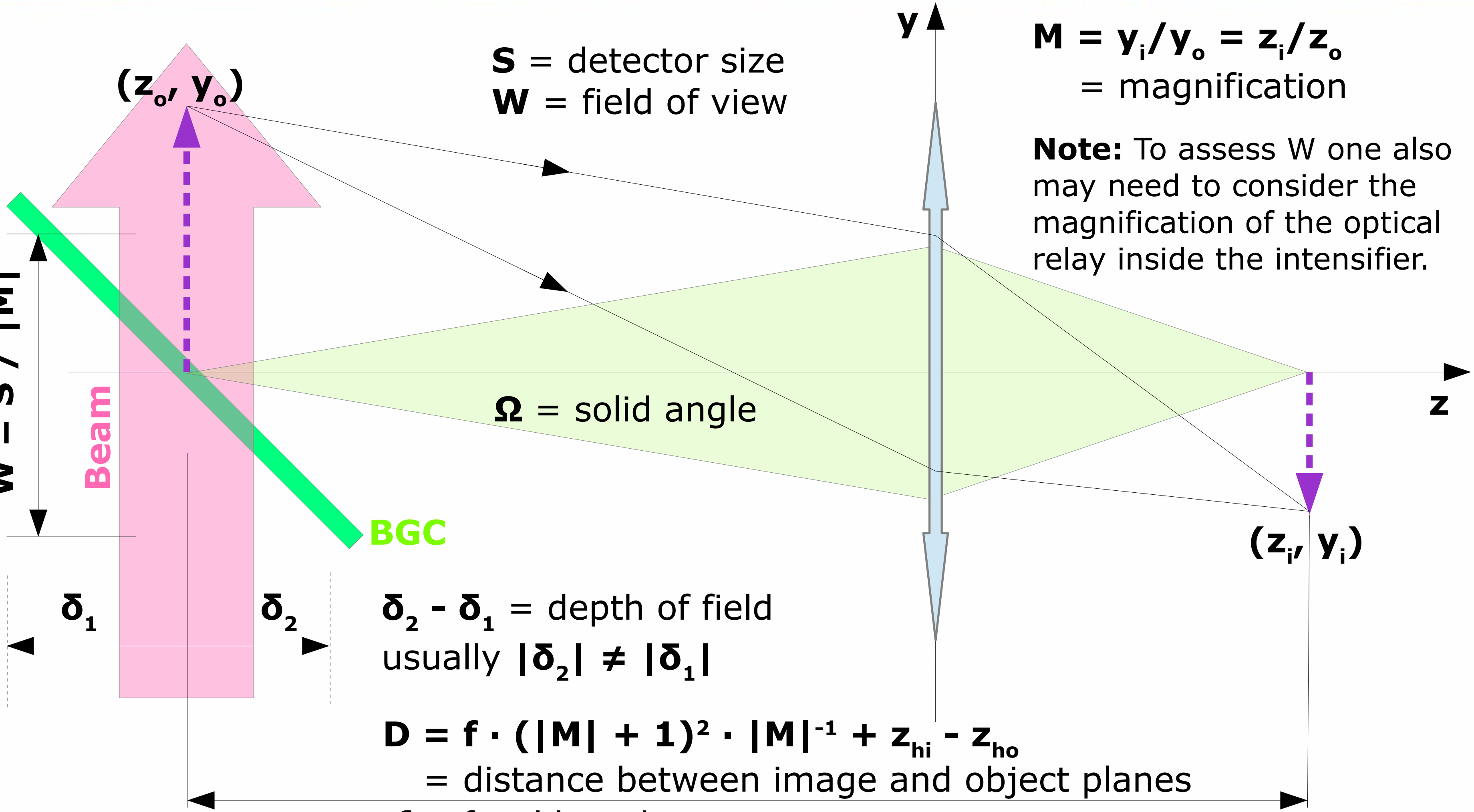
Optics, Simplified Overview



S = detector size
W = field of view

$M = y_i/y_o = z_i/z_o$
= magnification

Note: To assess W one also may need to consider the magnification of the optical relay inside the intensifier.

$\delta_2 - \delta_1$ = depth of field
usually $|\delta_2| \neq |\delta_1|$

$$D = f \cdot (|M| + 1)^2 \cdot |M|^{-1} + z_{hi} - z_{ho}$$

= distance between image and object planes

f = focal length

z_{hi}, z_{ho} = coordinates of the principal image and object planes*

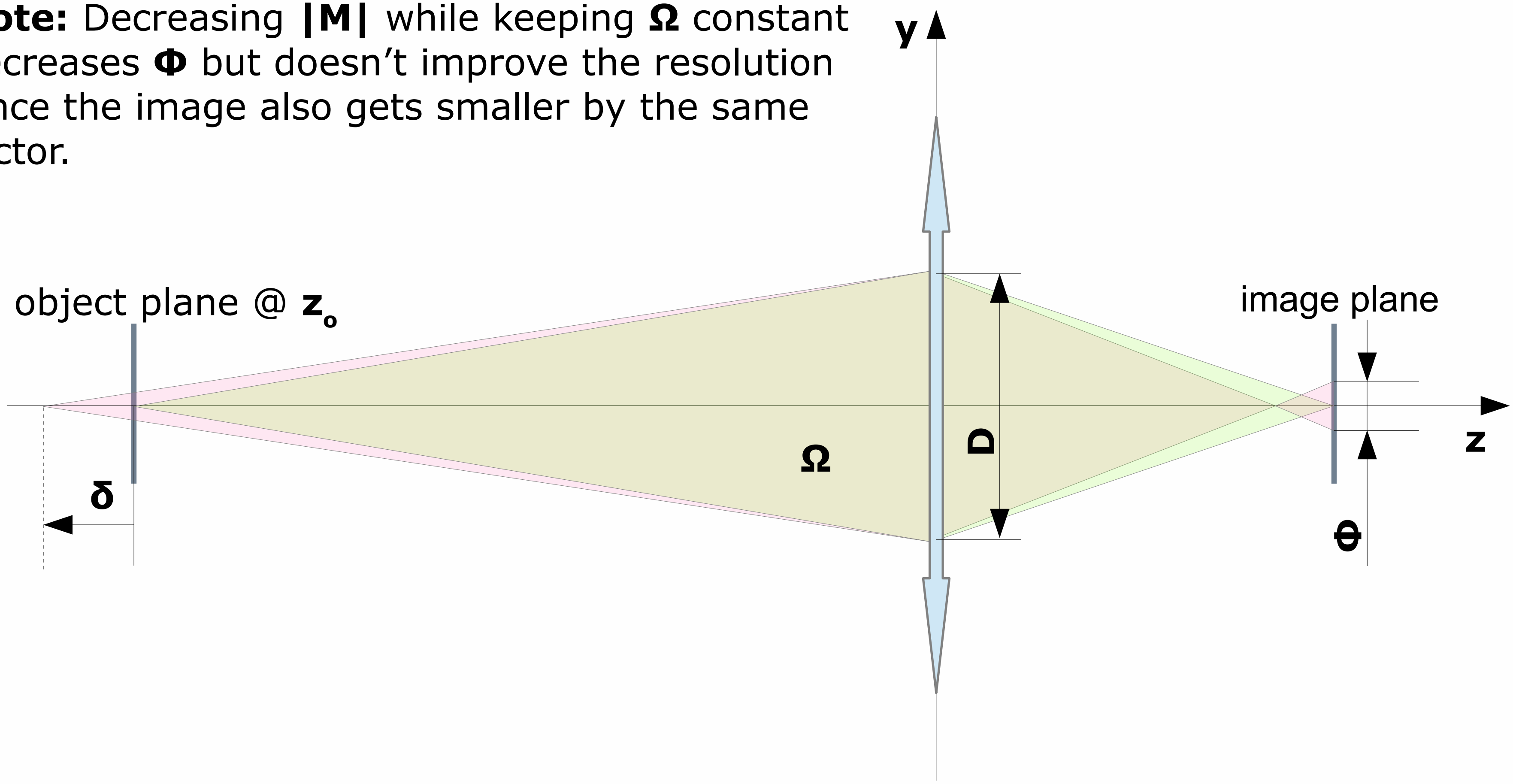
(*) Not shown here for simplicity.

Depth of Field

$\Phi \approx 2 \cdot |\delta| \cdot (\Omega/\pi)^{0.5} \cdot |M|$, $|\delta|/(|z_o| - f) << 1$ & $\Omega \leq 2.5 \cdot 10^{-2}$

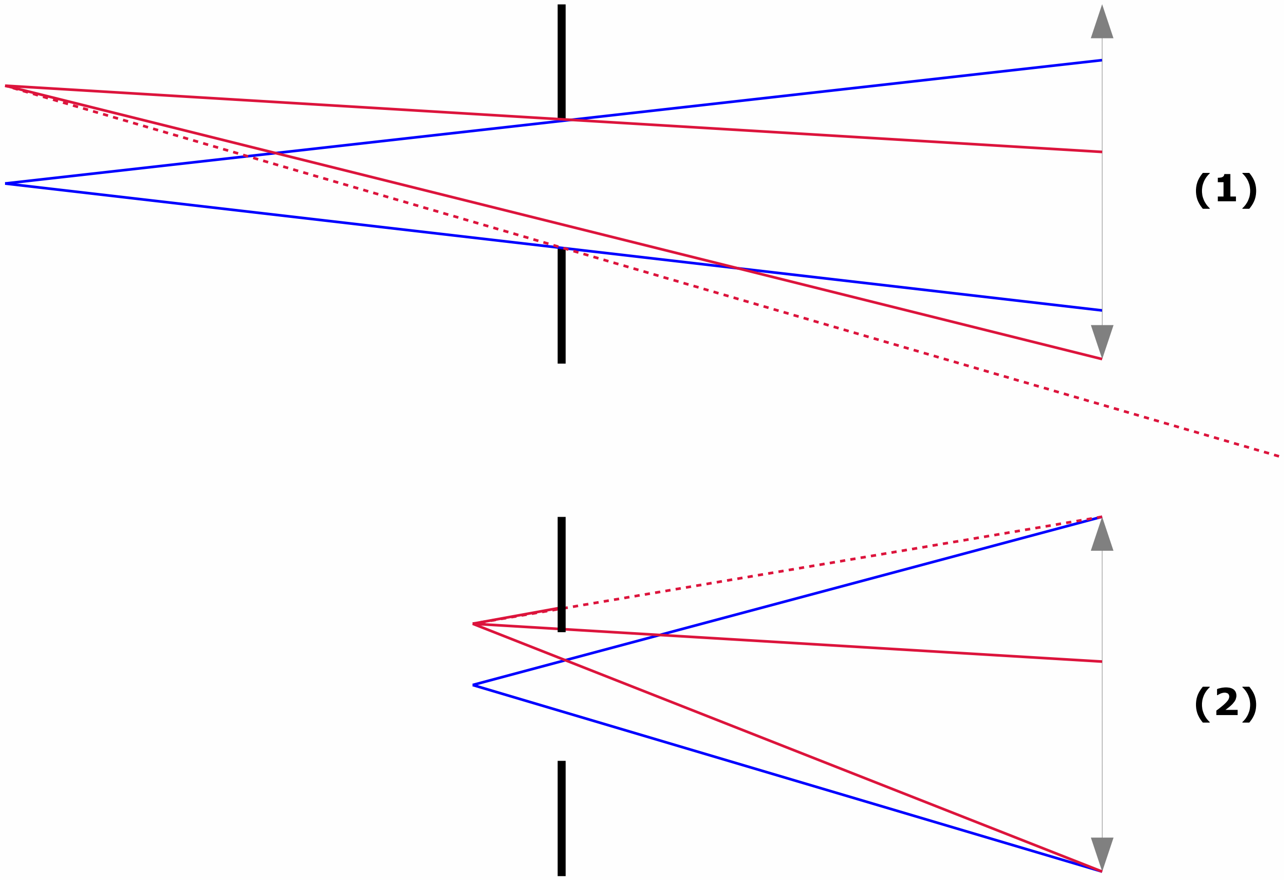
$(\Omega/\pi)^{0.5} \approx (D / 2f) \cdot |M| / (|M| + 1)$

Note: Decreasing **|M|** while keeping **Ω** constant decreases **Φ** but doesn't improve the resolution since the image also gets smaller by the same factor.



Solid Angle and Vignetting

The upper limit is imposed on the solid angle by the exit window. For (point) light sources off axis vignetting may appear at the lens (1) or at the window (2) and one has to consider these issues when trying to improve the signal by increasing the solid angle.



Integration Times

Projectile	Emitter	λ [nm]	σ [cm²]	I [A]	η_{pc}	η_{CCD}	$\langle t_i \rangle_{MCP}$	$\langle t_i \rangle_{emCCD}$
electron	N_2	337.1	$1.5\cdot10^{-23}$	5	0.19	0.30	$1.8^{6582}_{0.32}\cdot10^{-2}$	$8.4^{20320}_{1.8}\cdot10^{-3}$
electron	N_2^+	391.4	$9.1\cdot10^{-19}$	5	0.19	0.70	$2.9^{10608}_{0.51}\cdot10^{-7}$	$5.9^{14272}_{1.3}\cdot10^{-8}$
proton	N_2	337.1	0.0	1	0.19	0.30	∞	∞
proton	N_2^+	391.4	$3.7\cdot10^{-20}$	1	0.19	0.70	$3.6^{14330}_{0.59}\cdot10^{-5}$	$7.3^{19228}_{1.4}\cdot10^{-6}$
electron	Ne	585.4	$1.4\cdot10^{-20}$	5	0.09	0.93	$4.0^{23475}_{0.71}\cdot10^{-5}$	$2.9^{6989}_{0.65}\cdot10^{-6}$
proton	Ne	585.4	$4.7\cdot10^{-22}$	1	0.09	0.93	$5.9^{37760}_{0.97}\cdot10^{-3}$	$4.3^{11283}_{0.90}\cdot10^{-4}$
electron	Ar	750.4	$5.6\cdot10^{-20}$	5	0.02	0.85	$4.5^{29392}_{0.59}\cdot10^{-5}$	$7.9^{19237}_{1.7}\cdot10^{-7}$
electron	Ar	751.5	$1.8\cdot10^{-20}$	5	0.02	0.85	$1.4^{9142}_{0.18}\cdot10^{-4}$	$2.5^{6088}_{0.53}\cdot10^{-6}$
electron	Ar	750 & 751	$7.4\cdot10^{-20}$	5	0.02	0.85	$3.4^{22205}_{0.44}\cdot10^{-5}$	$6.0^{14610}_{1.3}\cdot10^{-7}$
electron	Ar^+	454.5	$4.2\cdot10^{-21}$	5	0.22	0.82	$5.4^{19389}_{0.97}\cdot10^{-5}$	$1.1^{2653}_{0.24}\cdot10^{-5}$
electron	Ar^+	476.5	$5.7\cdot10^{-21}$	5	0.19	0.85	$4.6^{16826}_{0.82}\cdot10^{-5}$	$7.8^{18993}_{1.7}\cdot10^{-6}$
electron	Ar^+	454 & 476	$9.9\cdot10^{-21}$	5	0.20	0.84	$2.5^{9072}_{0.45}\cdot10^{-5}$	$4.5^{10926}_{0.96}\cdot10^{-6}$
proton	Ar	750.4	$2.3\cdot10^{-21}$	1	0.02	0.85	$5.5^{39107}_{0.67}\cdot10^{-3}$	$9.6^{25450}_{1.9}\cdot10^{-5}$
proton	Ar	751.5	$9.6\cdot10^{-22}$	1	0.02	0.85	$1.3^{9245}_{0.16}\cdot10^{-2}$	$2.3^{6097}_{0.45}\cdot10^{-4}$
proton	Ar	750 & 751	$3.3\cdot10^{-21}$	1	0.02	0.85	$3.8^{27021}_{0.46}\cdot10^{-3}$	$6.7^{17762}_{1.3}\cdot10^{-5}$
proton	Ar^+	454.5	$7.3\cdot10^{-22}$	1	0.22	0.82	$1.6^{6256}_{0.27}\cdot10^{-3}$	$3.1^{8141}_{0.62}\cdot10^{-4}$
proton	Ar^+	476.5	$9.9\cdot10^{-22}$	1	0.19	0.85	$1.3^{5174}_{0.21}\cdot10^{-3}$	$2.2^{5832}_{0.43}\cdot10^{-4}$
proton	Ar^+	454 & 476	$1.7\cdot10^{-21}$	1	0.20	0.84	$7.4^{29315}_{1.2}\cdot10^{-4}$	$1.3^{3433}_{0.26}\cdot10^{-4}$

$$N_\gamma = \sigma \cdot \frac{I \cdot \Delta t}{e} \cdot n \cdot d \cdot \frac{\Omega}{4\pi} \cdot T \cdot T_f \cdot \eta_{pc} \cdot \eta_{MCP}$$

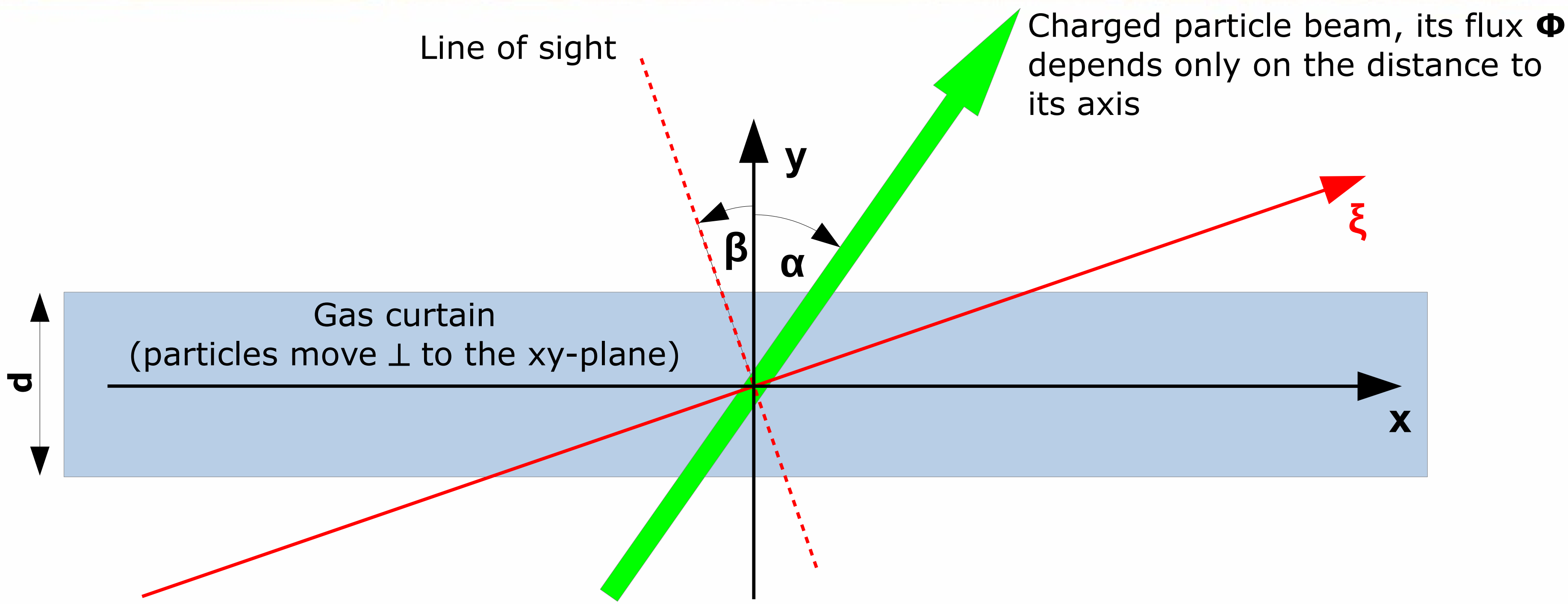
Parameter	Old value	New value	Worst value	Best value
n	$2.5\cdot10^{10}$ cm^{-3}	$2.5\cdot10^{10}$ cm^{-3}	$2.5\cdot10^{9}$ cm^{-3}	$5\cdot10^{10}$ cm^{-3}
d	0.5 mm	0.5 mm	0.3 mm	0.7 mm
T	0.7	0.85	0.7	0.9
T_f	0.3	0.8	0.3	0.9
Ω	$4\pi\cdot10^{-4}$ sr	$40\pi\cdot10^{-4}$ sr	$\pi\cdot10^{-4}$ sr	$50\pi\cdot10^{-4}$ sr
η_{pc}	λ-dependent	λ-dependent	λ-dependent	λ-dependent
η_{MCP}	0.5	0.75	0.5	0.9
η_{CCD}	–	λ-dependent	λ-dependent	λ-dependent
I_p	1 A	1 A	0.9 A	1.1 A
I_e	5 A	5 A	4.9 A	5.1 A

λ [nm]	337	391	454	476	585	750
η_{pc}	$0.19^{0.21}_{0.17}$	$0.19^{0.21}_{0.17}$	$0.22^{0.24}_{0.20}$	$0.19^{0.21}_{0.17}$	$0.09^{0.1}_{0.05}$	$0.02^{0.03}_{0.01}$
η_{CCD}	$0.3^{0.33}_{0.27}$	$0.7^{0.77}_{0.63}$	$0.82^{0.90}_{0.74}$	$0.85^{0.94}_{0.76}$	$0.93^{0.97}_{0.84}$	$0.85^{0.94}_{0.76}$

Note: $\langle t_i \rangle$ are the mean single photon integration times

Table usage example: $\langle t_i \rangle = 1.4^{9142}_{0.18}\cdot10^{-4}$ s means that the value of $1.4\cdot10^{-4}$ s should be achievable according to present estimations, while the worst case value is estimated to $9142\cdot10^{-4}$ s ≈ 0.91 s and the best case one to $0.18\cdot10^{-4}$ s = $1.8\cdot10^{-5}$ s.

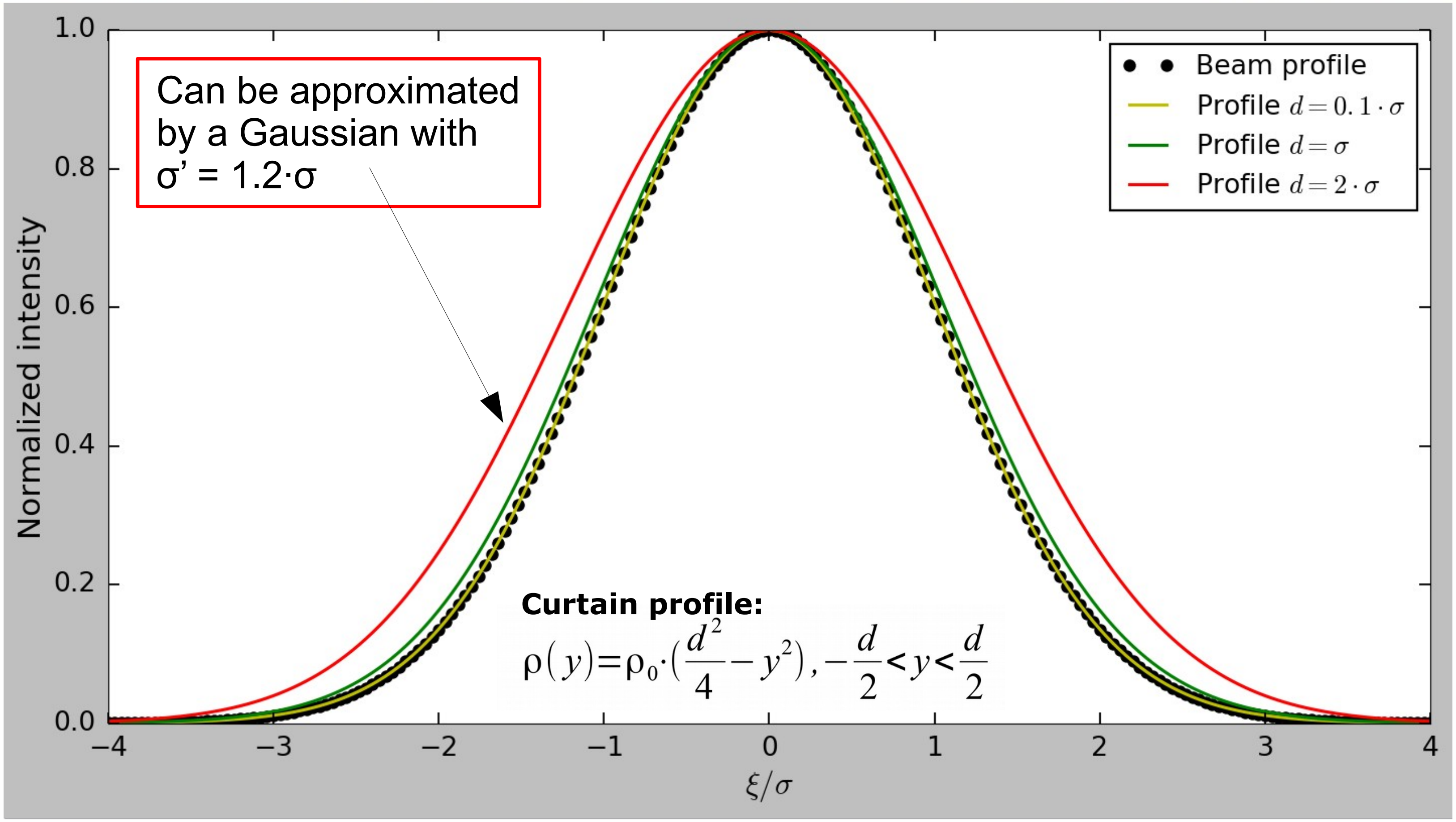
Influence of Curtain Thickness: 1D-Model



- Gas curtain's density **ρ** depends only on **y**
- Gas curtain's refractive index is 1
- Gas curtain extends from **y** = -d/2 to **y** = d/2
- 1D detector parallel to the **ξ** axis
- Ideal optics placed practically at infinity
- Practically infinite depth of field
- 0 ≤ **β** < 90° **(presently 45°)**
- -90° < **α** < 90° **(presently 45°)**

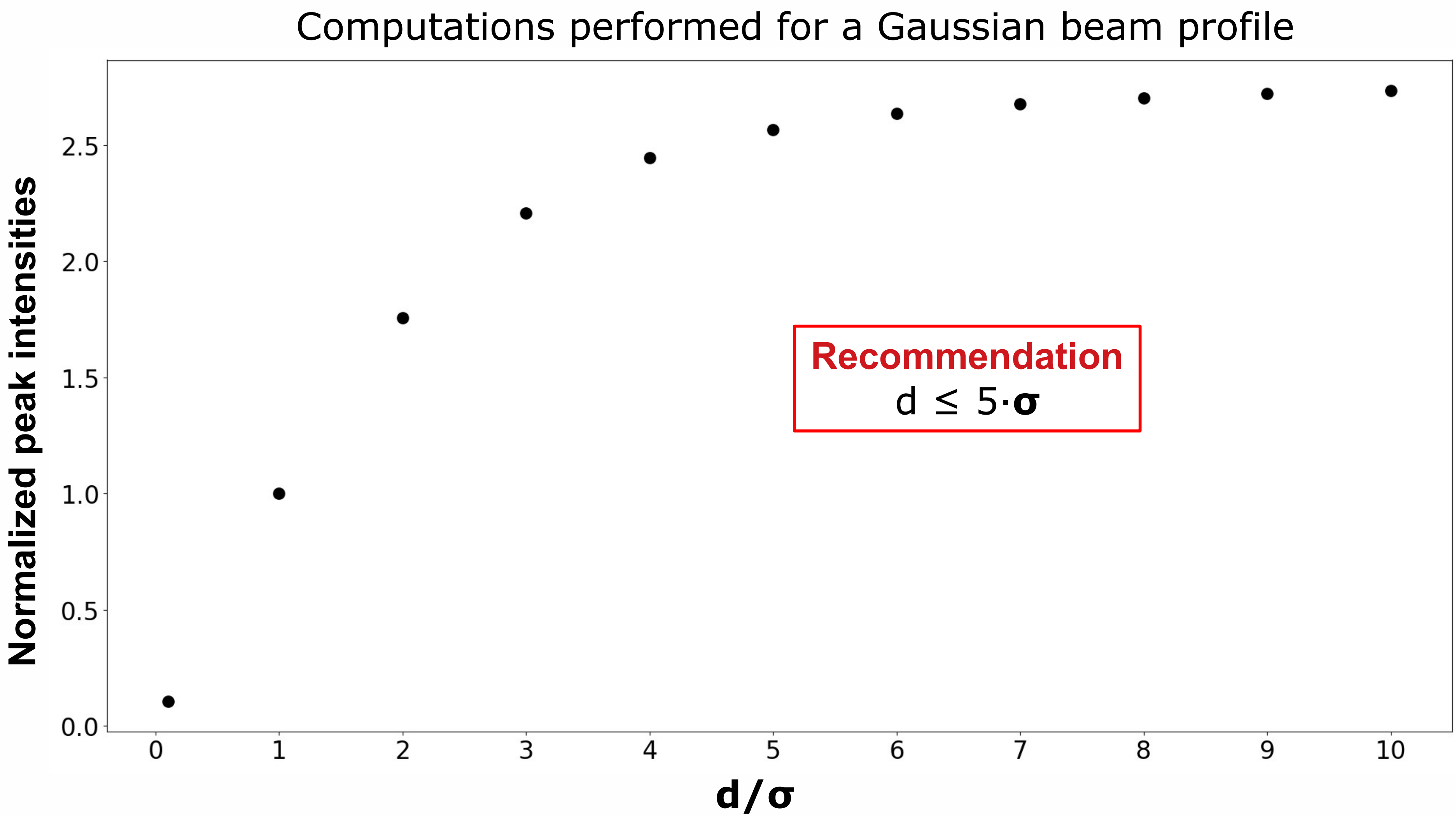
$$I(\xi) \propto \int_{-d/2}^{d/2} \rho(y) \cdot \phi\left(\xi \cdot \frac{\cos(\alpha)}{\cos(\beta)} - \frac{\sin(\alpha+\beta)}{\cos(\beta)} \cdot y\right) dy$$

Parabolic Gas Curtain Profile and Gaussian Beam

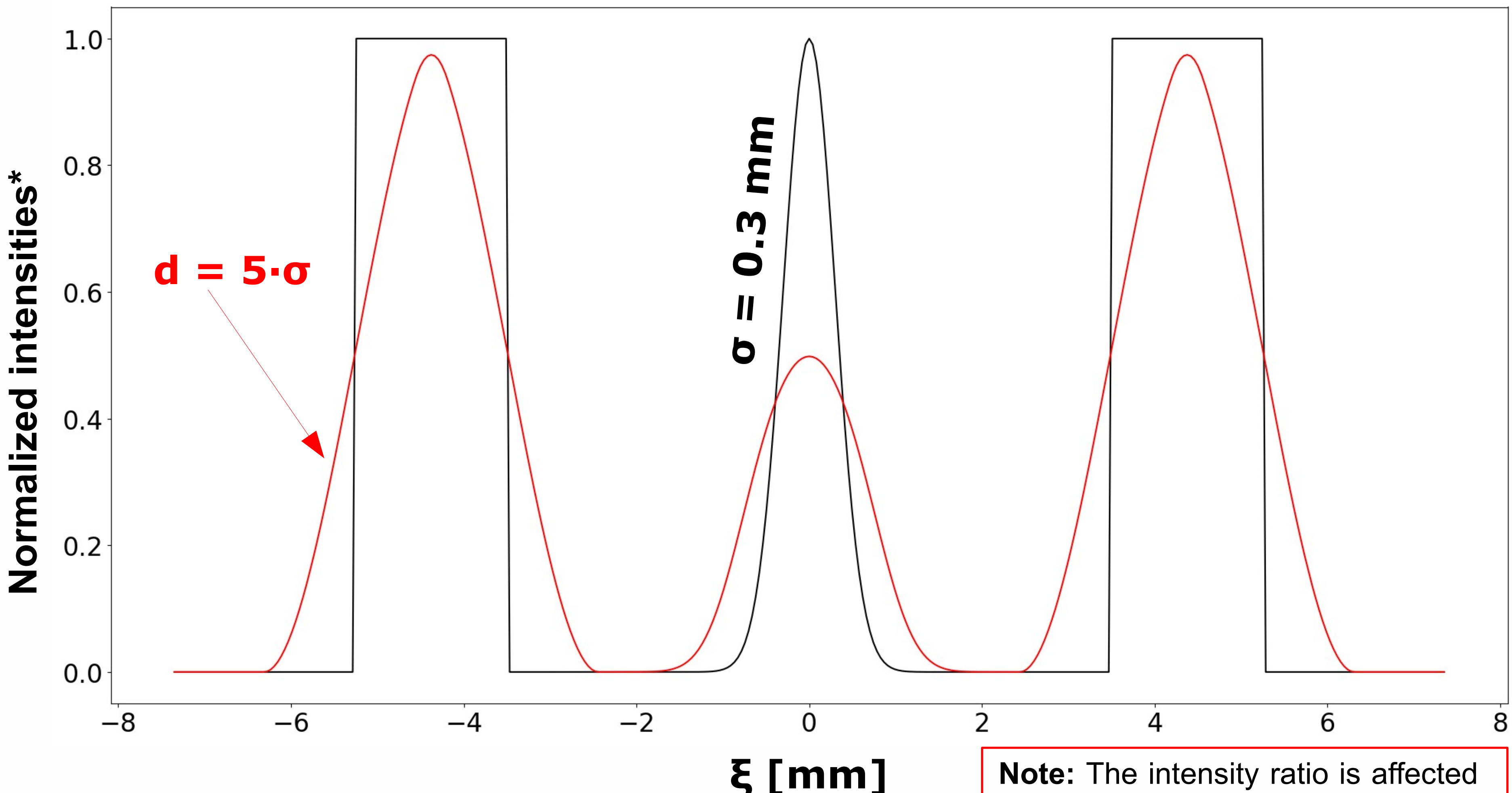


Line of sight and beam axis are perpendicular to each other, moreover α = β = 45°
The charged particle beam has a Gaussian profile with standard deviation **σ**, three gas curtain thicknesses **d** are considered: 0.1·**σ**, **σ** and 2·**σ**.

Peak Intensities and Curtain Thickness



Curtain Thickness 5·σ



(*) Integrals are equal

Note: The intensity ratio is affected in favor of the electron beam signal!