Simulation of light collection efficiency for the SpecTrap setup (results from D. Hampf's thesis)

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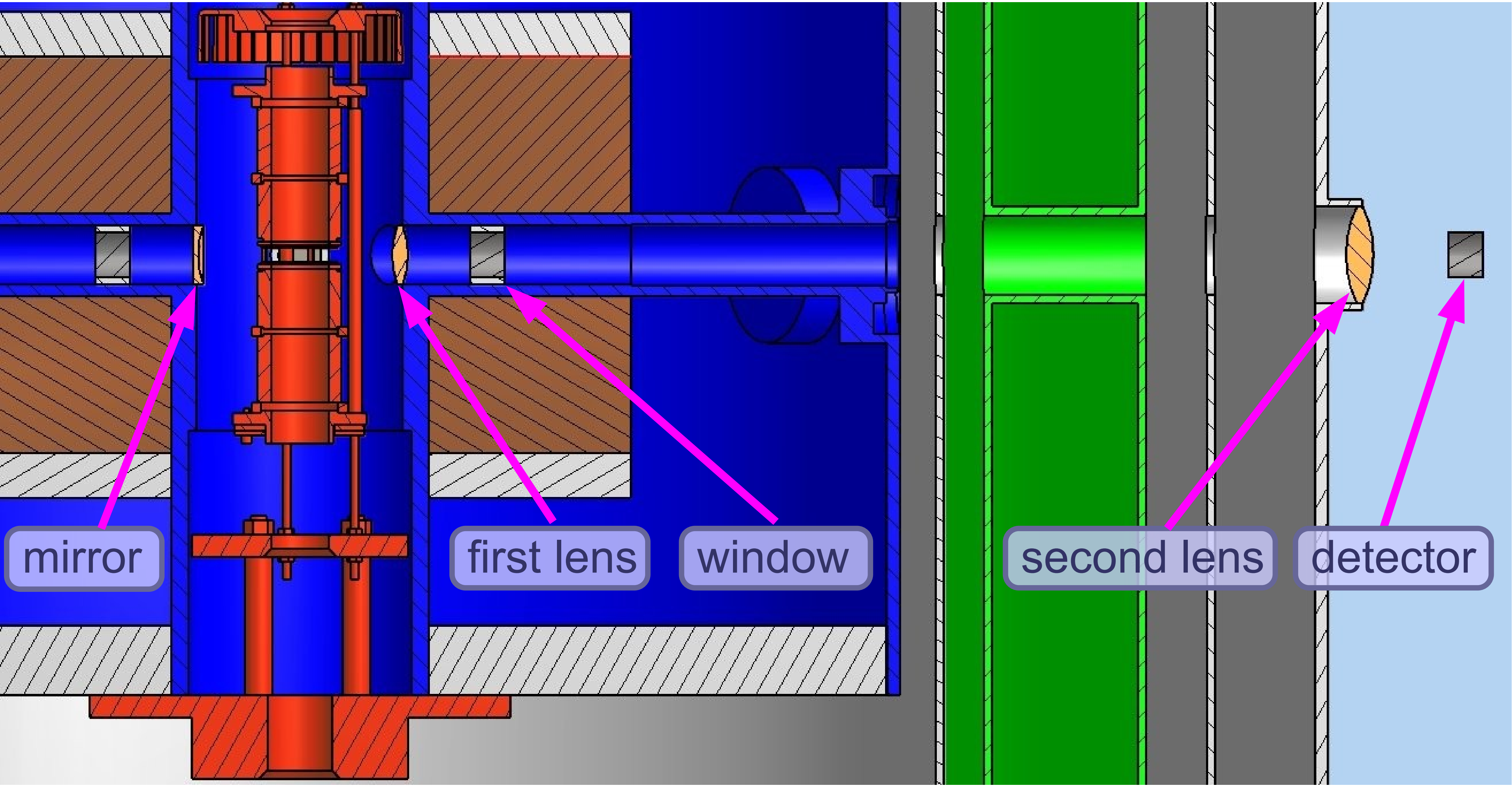
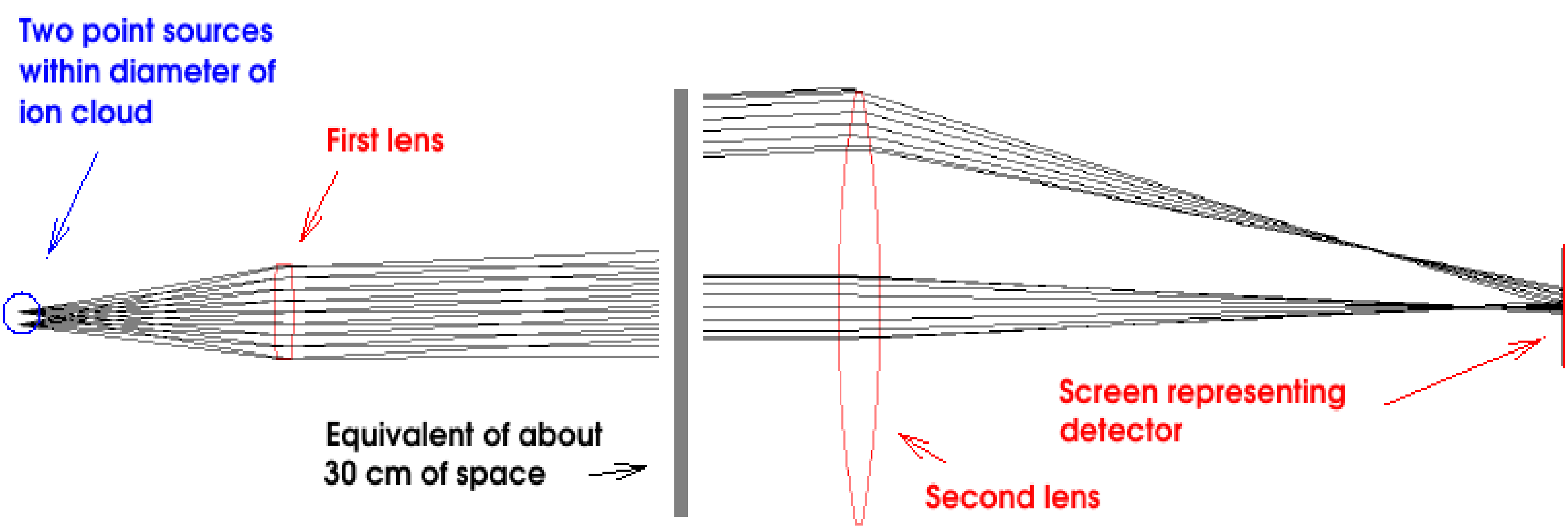
- Optical setup
- KOJAC Simulations
- Expected count rates
- Summary

Optical setup



Kojac Simulations

- Simulation of photon transport from the ion cloud to the detector using the open source library **KOJAC** (3D raytracing utiliy):
- simulation of the ion cloud as 3D light source (approximated by 14 000 point sources scattered within volume of cloud)
- Optimise geometry of lensing system to produce parallel light rays and a small beam spot at the position of the detector



Transport efficiencies

- solid angle transported by first lens:

  $\Omega = 196\ \text{mm}^2 / (28.9\ \text{mm})^2 = 0.23\ \text{sr}$

  $\rightarrow \varepsilon_\Omega = 1.8\%$

- transmission losses due to exit mesh, and reflection at lenses and windows:

  $\rightarrow \varepsilon_{loss} = 51\%$ (visible and NIR)

  $\rightarrow \varepsilon_{loss} = 36\%$ (UV)

- geometrical losses between lenses:

  $\rightarrow \varepsilon_{lense} = 77\%$ (visible and NIR)

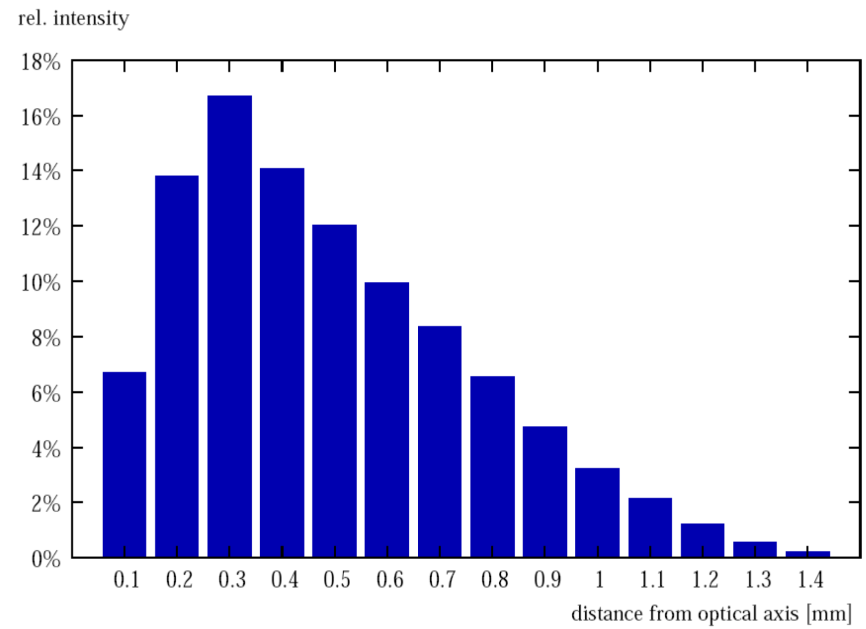
- resulting percentage of photons available for detection:

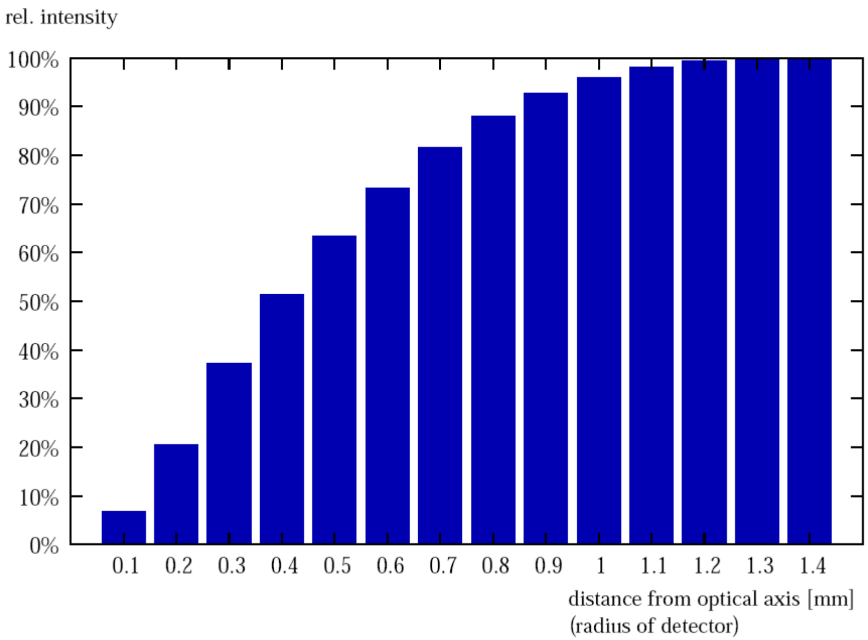
  $\rightarrow \varepsilon_{det} = \varepsilon_\Omega \cdot \varepsilon_{loss} \cdot \varepsilon_{lense} = 0.7\%$ (visible and NIR)

  $\rightarrow \varepsilon_{det} = \varepsilon_\Omega \cdot \varepsilon_{loss} \cdot \varepsilon_{lense} = 0.5\%$ (UV)

- ε_{det} does not include detector area and photon detection efficiency !

Effect of detector area





Relative intensity at given distance to optical axis

- largest percentage of photons is incident on the detector at intermidiate radii (solid angle effect)
- photon rate outside of 1.4 mm radius is neglectable

Integrated percentage of photons collected as a function of detector radius:

- detectors in the UV and visible region, where active areas have diameters of several millimeters collect all transmitted photons
- largest SPADs for NIR detection have diameters of 80 µm only → too small
- an NIR PMT with active diameter of 1mm would collect 65% of the photons

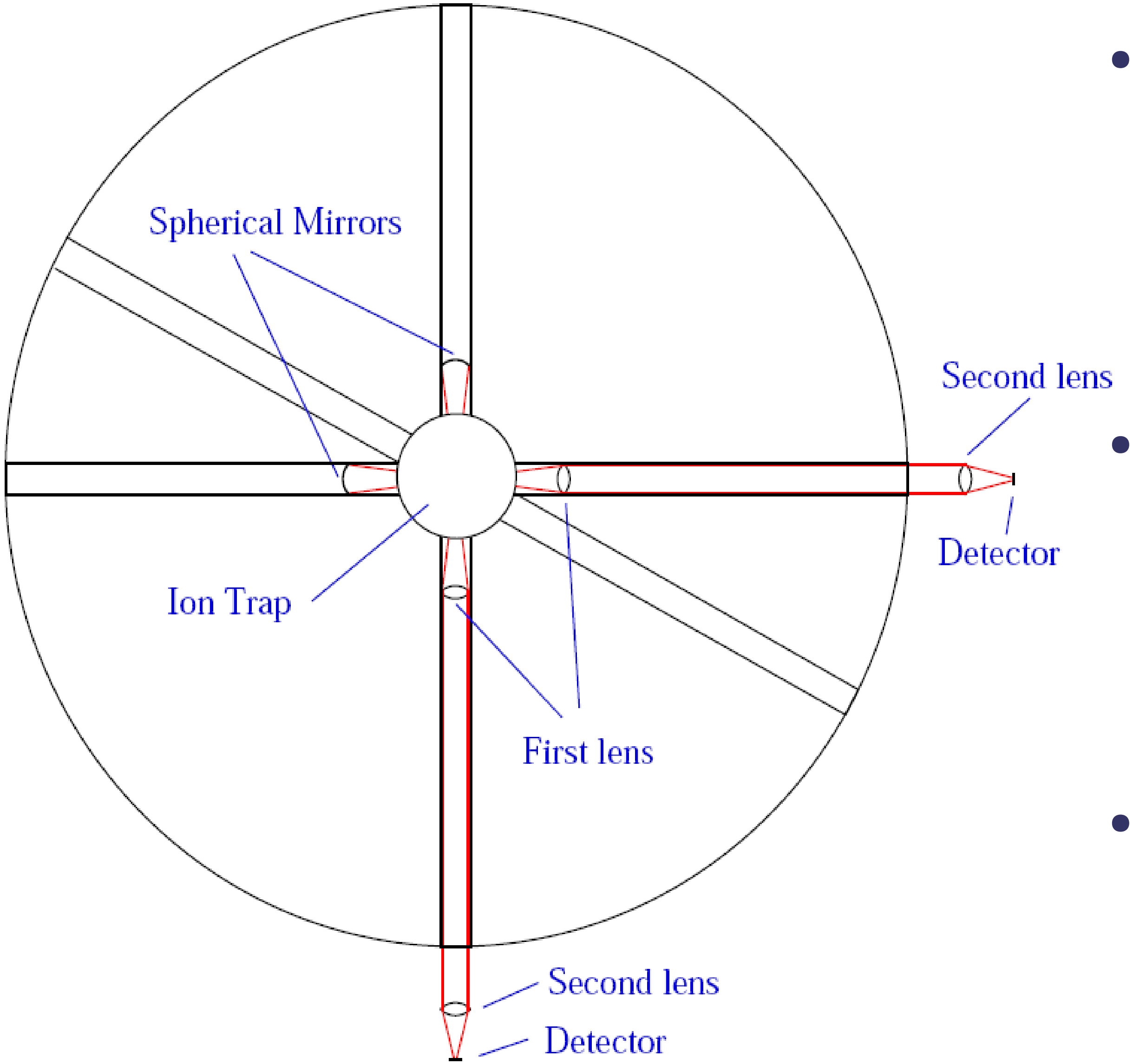
Resulting count rates

Count rate estimate based on the following numbers:

- Number of ions in the trap: **10^5**
- **50 %** of the ions in the upper hyperfine level
- **Large active areas** for UV and visible light detectors
- **1 mm** active diameter for NIR detector
- **20 %** photodetection efficiencies for all detector types

Isotop	Wellenlänge	Photonenrate	Möglicher Detektor	Zählrate
$^{209}Bi^{82+}$	244 nm	(625 ± 225) kHz	CPMs	(125 ± 45) kHz
$^{207}Pb^{81+}$	1020 nm	$(6,5 \pm 2,1)$ kHz	APDs	$(1,3 \pm 0,4)$ kHz
$^{209}Bi^{80+}$	1555 nm	$(3,4 \pm 1,0)$ kHz	Hybrid PMTs	(440 ± 130) Hz

Mirror system



- to increase the signal to noise ratio on an individual detector, mirrors might be placed on the opposite side of the given trap exit
- light that is reflected on the detector via this mirror has to pass the trap mesh twice
  → loss in intensity by **50 %**
- still we gain a factor **1.5** in photon count rate on the detector

Summary

- Efficiency with which photons are transported to the outside of SpecTrap:

  → $\varepsilon_{det} = \varepsilon_{\Omega} \cdot \varepsilon_{loss} \cdot \varepsilon_{lense} = 0.7\%$ (visible and NIR)

  → $\varepsilon_{det} = \varepsilon_{\Omega} \cdot \varepsilon_{loss} \cdot \varepsilon_{lense} = 0.5\%$ (UV)

- Visible and UV detectors are easily large enough to collect the transported photons
- NIR detectors should have an active diameter of **≥ 1 mm** (i.e. InGaAs APDs are ruled out at the moment)
- Further improvements in light collection system should be considered, e.g. a mirror system might make more sense than additional detectors on all SpecTrap exits