Capacity estimation for multilayer holographic storage

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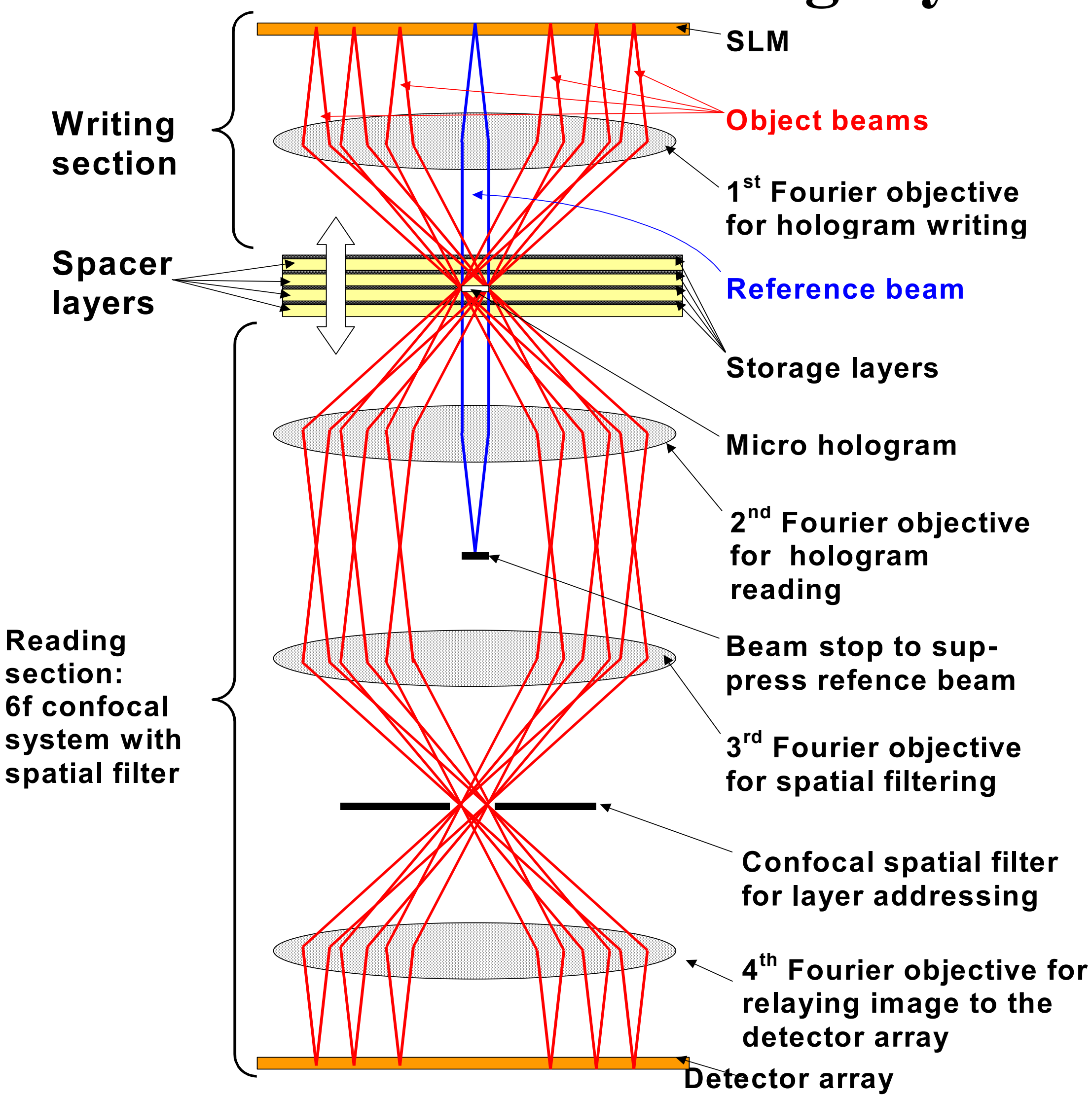
Background of holographic storage and targets

- Main target: storing 200-1000 Gigabytes in a single disk
- Current technologies store data in „two dimensions”
- MUX-ed holographic storage can theoretically realize volume storage
- No technologically feasible MUX-ed solution is known since
  - very high number (1000-10000) of MUX-ed holograms should be stored
  - shrinkage and M# of current storage materials are not good enough
  - very complicated optical system needed because of high number of MUX

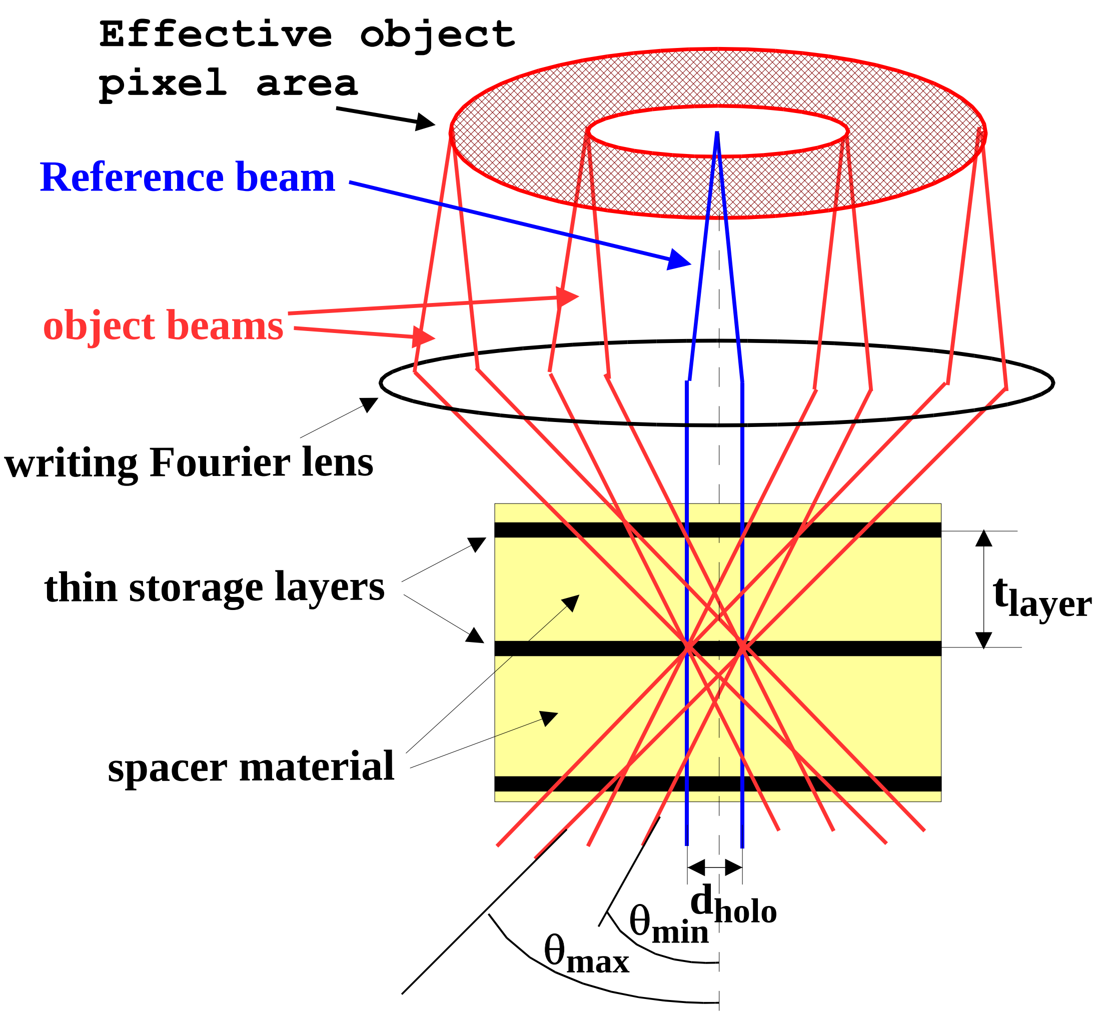
- Is there a technologically feasible solution with current storage materials and with a „simple” optical system?

Multilayer thin film holographic data storage system with confocal filter



- Axial reference beam
- Non axial object beams
- 2f optical system for hologram writing
- 6f optical system for hologram reading
- Confocal filter is a real image of the addressed hologram
- Thin film non Bragg selective storage material

Hologram writing and disk capacity



$$t_{layer} = \frac{d_{holo}}{\tan\left[\Theta_{min}\right]}$$

$$d\Omega_{pixel} = 2\pi \cdot \left(1 - \cos\left(1.22\,\frac{\lambda}{d_{holo}}\right)\right)$$

$$\Omega_{obj} = 2\pi \cdot \left(\cos\left(\theta_{min}\right) - \cos\left(\theta_{max}\right)\right)$$

$$Nbit_{holo} = \Omega_{obj} / d\Omega_{pixel}$$

$$N_{holo} = \frac{A_{disk}}{\left(d_{holo}/2\right)^2 \cdot \pi} \cdot \frac{t_{disk}}{t_{layer}}$$

$$Nbit_{DISK} = Nbit_{holo} \cdot N_{holo}$$

$$\lambda \equiv 405\ nm$$

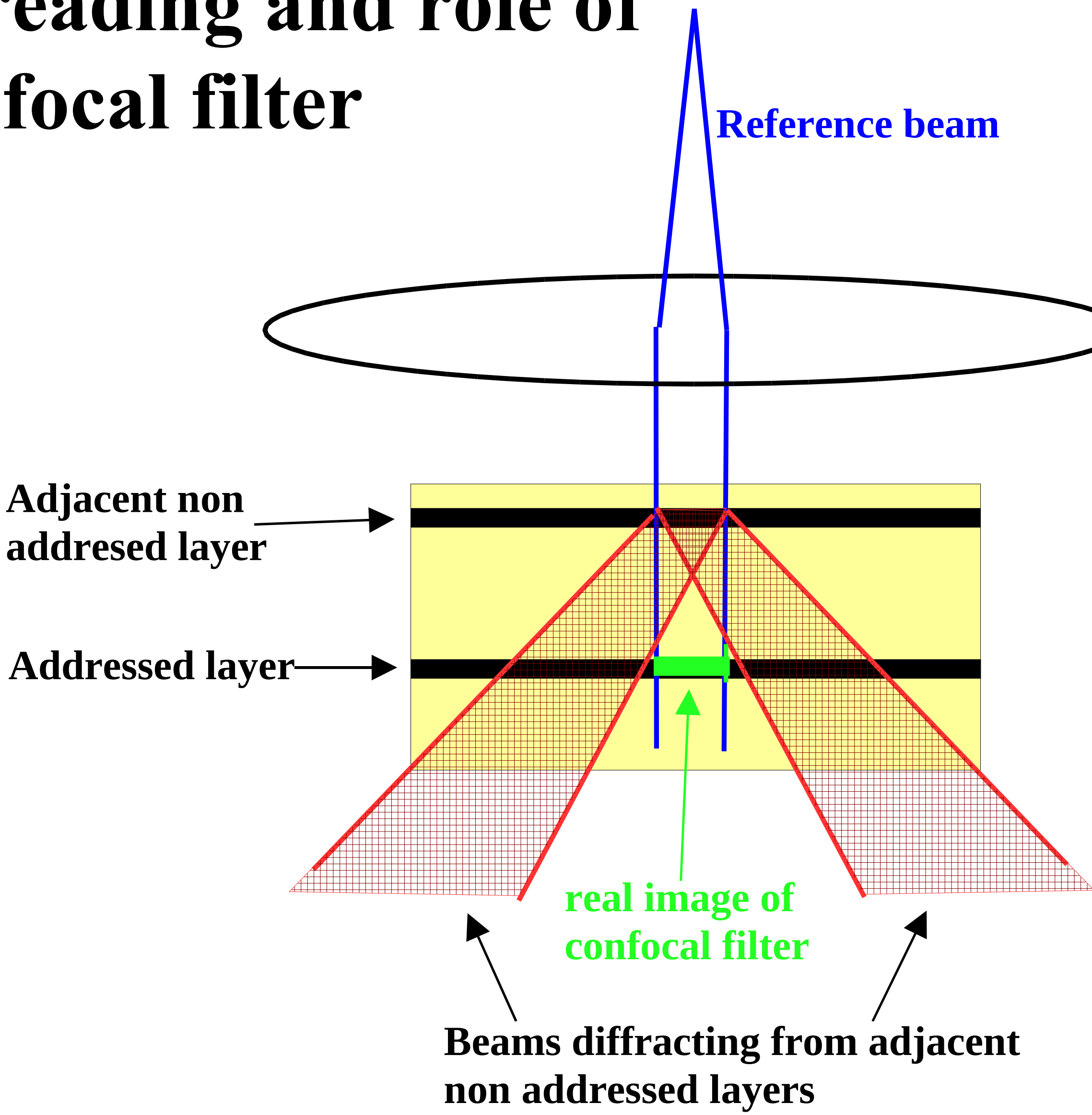
$$t_{disk} \equiv 1.2\ \mathrm{mm}$$

$$\Theta_{min} \equiv 20\ ^\circ$$

$$\Theta_{max} \equiv 35\ ^\circ$$

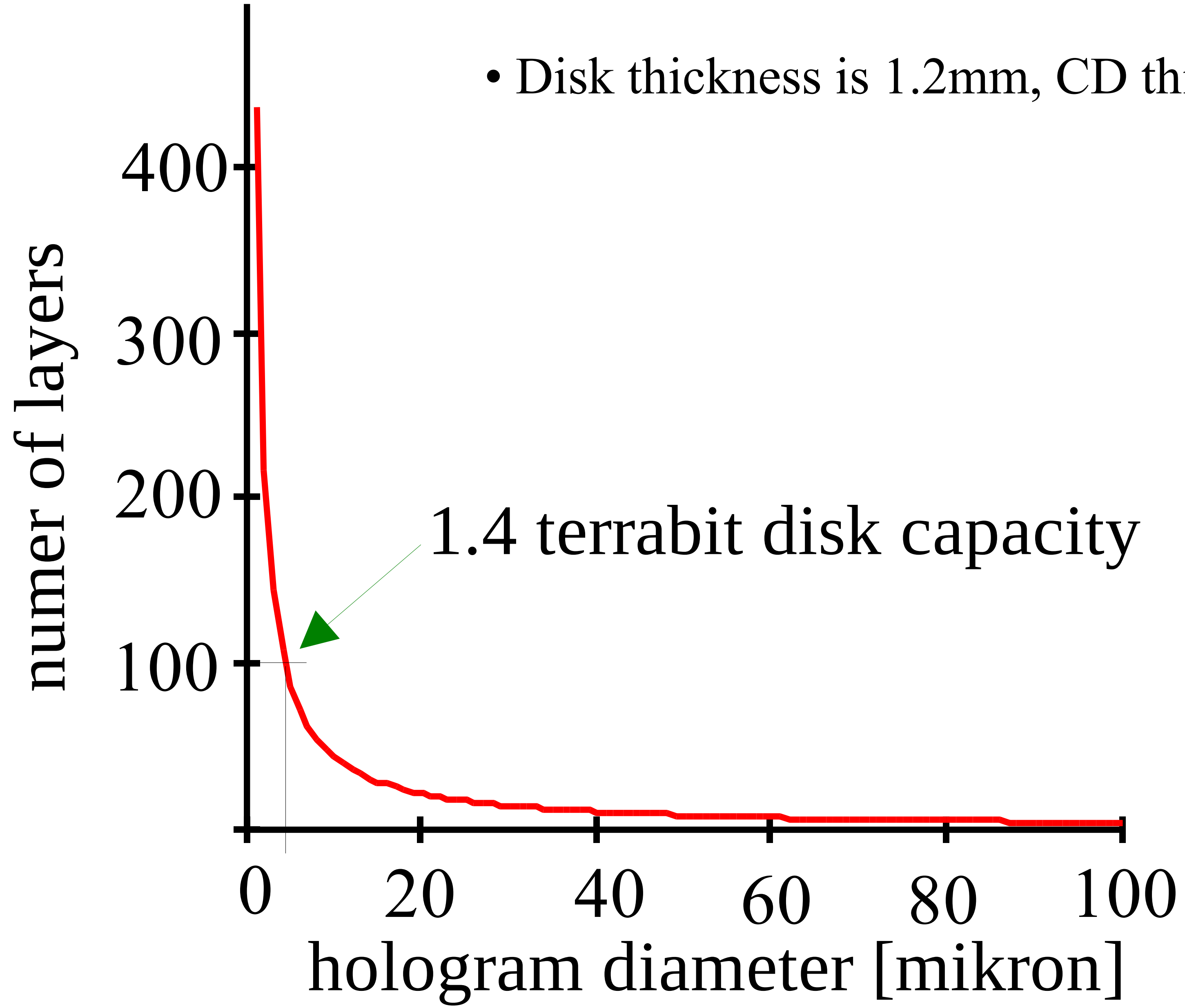
$$A_{disk} \equiv 10000\ \mathrm{mm}^2$$

Hologram reading and role of confocal filter

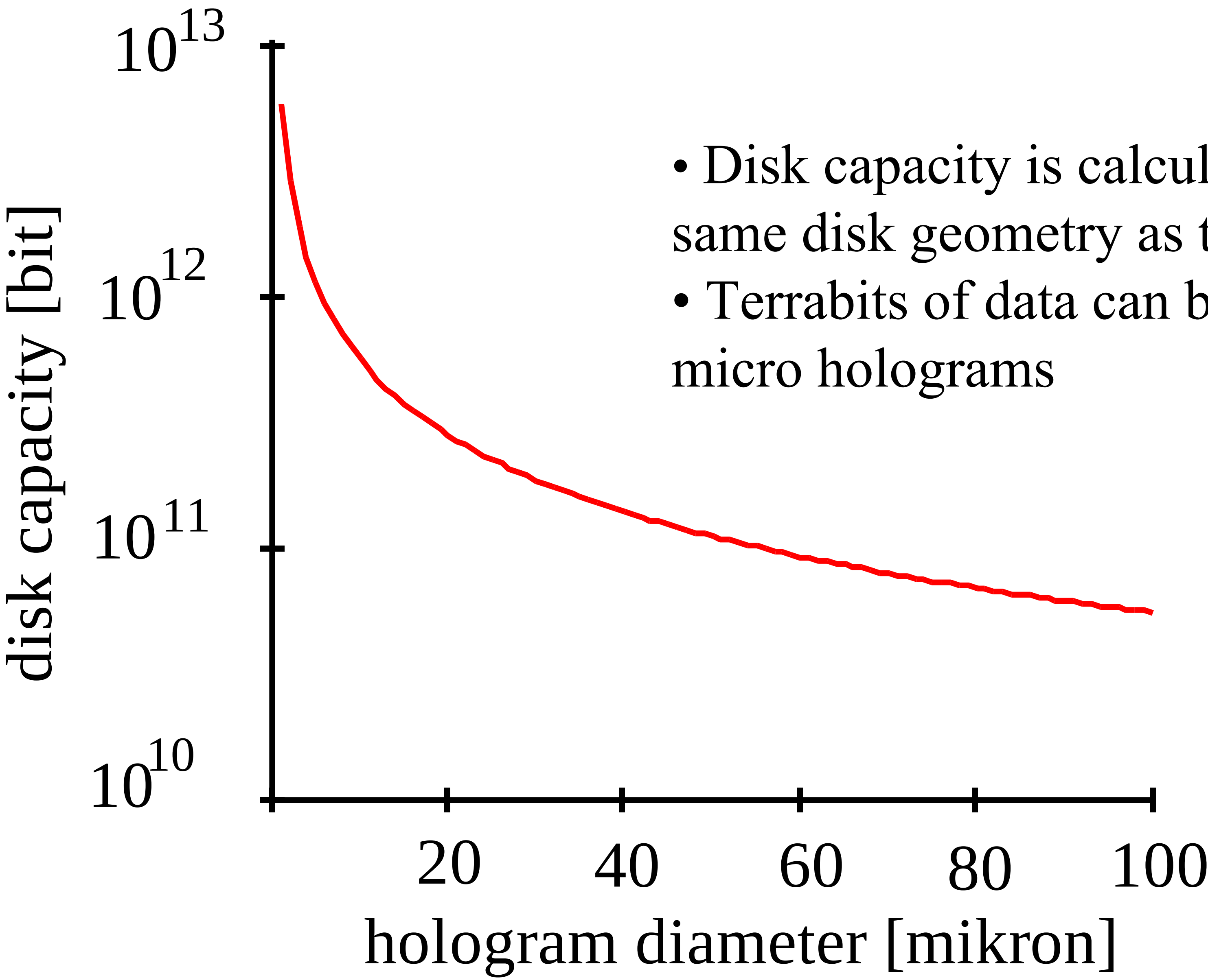


Beams diffracting from non addressed layers do not propagate through the confocal filter! Large number of layers can be used!

Number of layers vs. hologram diameter

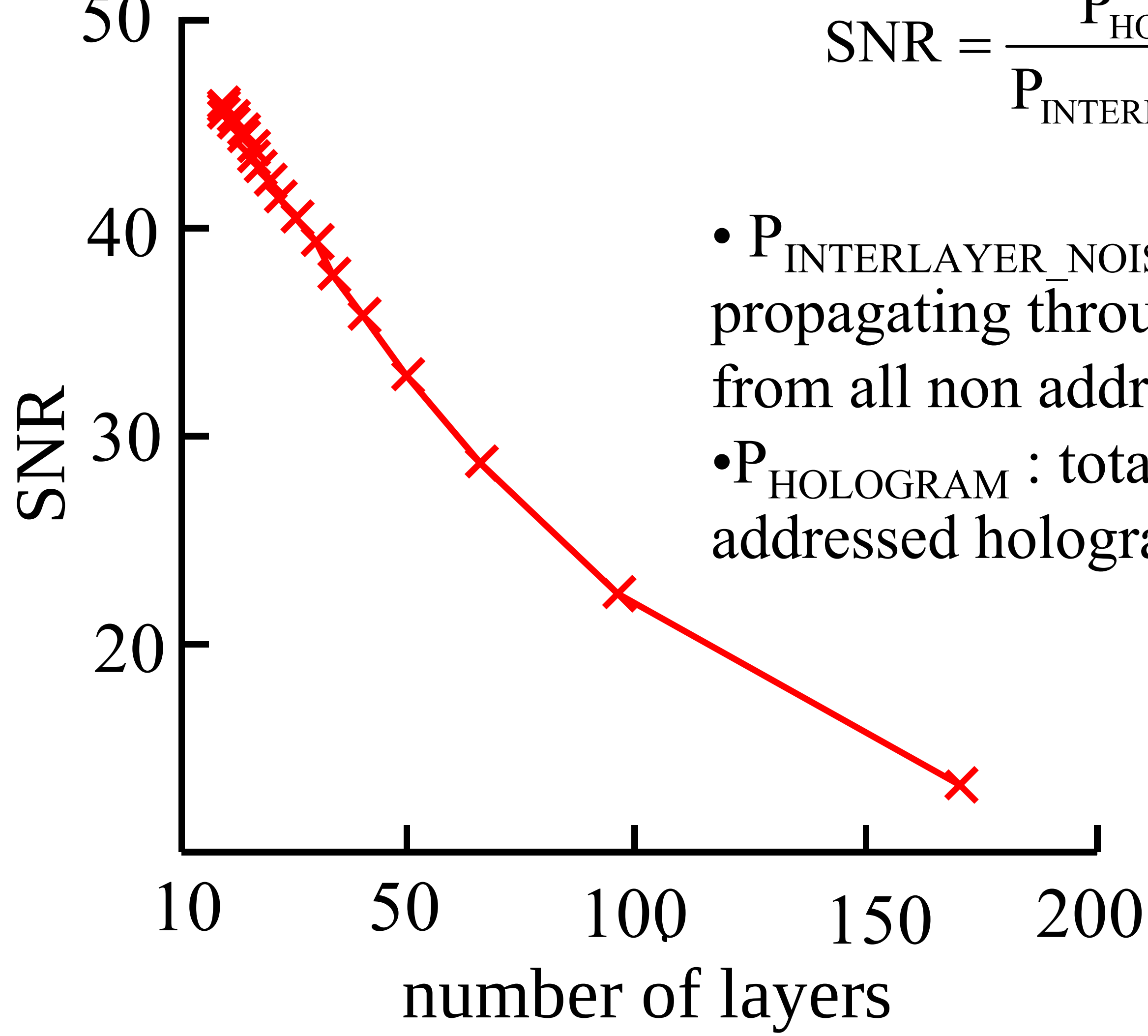


Disk capacity vs. hologram diameter



- Disk capacity is calculated for the same disk geometry as the CD
- Terrabits of data can be stored with micro holograms

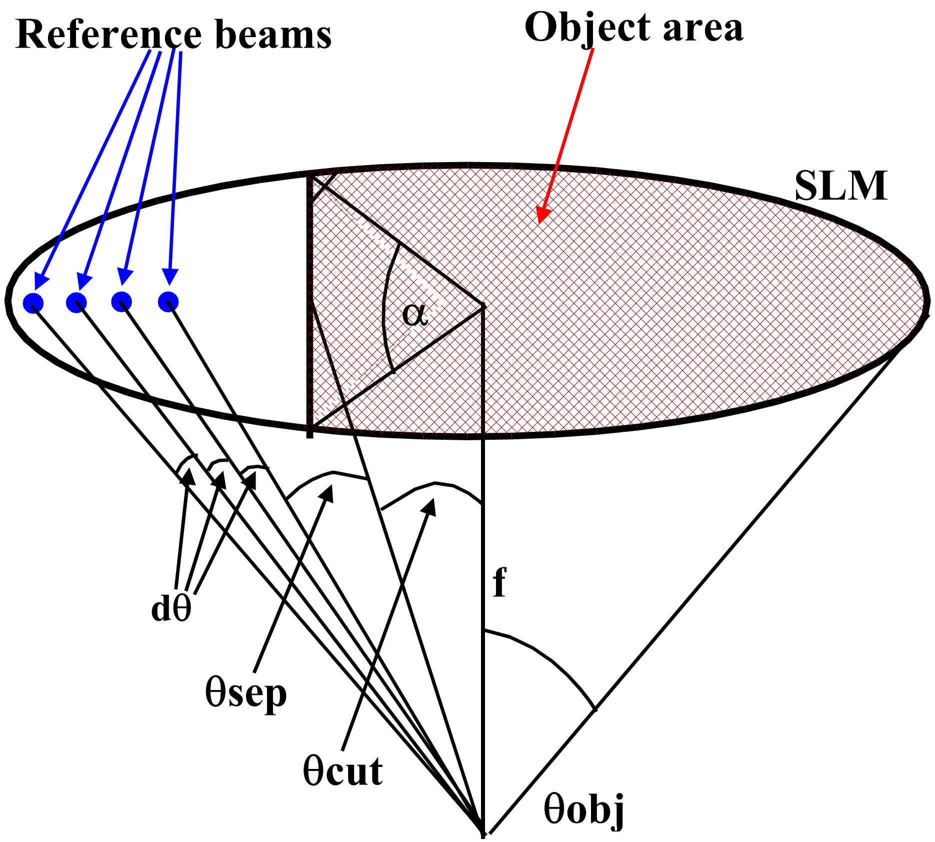
SNR calculation for interlayer crosstalk



$$SNR = \frac{P_{HOLOGRAM}}{P_{INTERLAYER\_NOISE}}$$

- $P_{INTERLAYER\_NOISE}$: total noise power propagating through the confocal filter from all non addressed layers.
- $P_{HOLOGRAM}$: total power from an addressed hologram

Multilayer phase coded or angular multiplexing setup



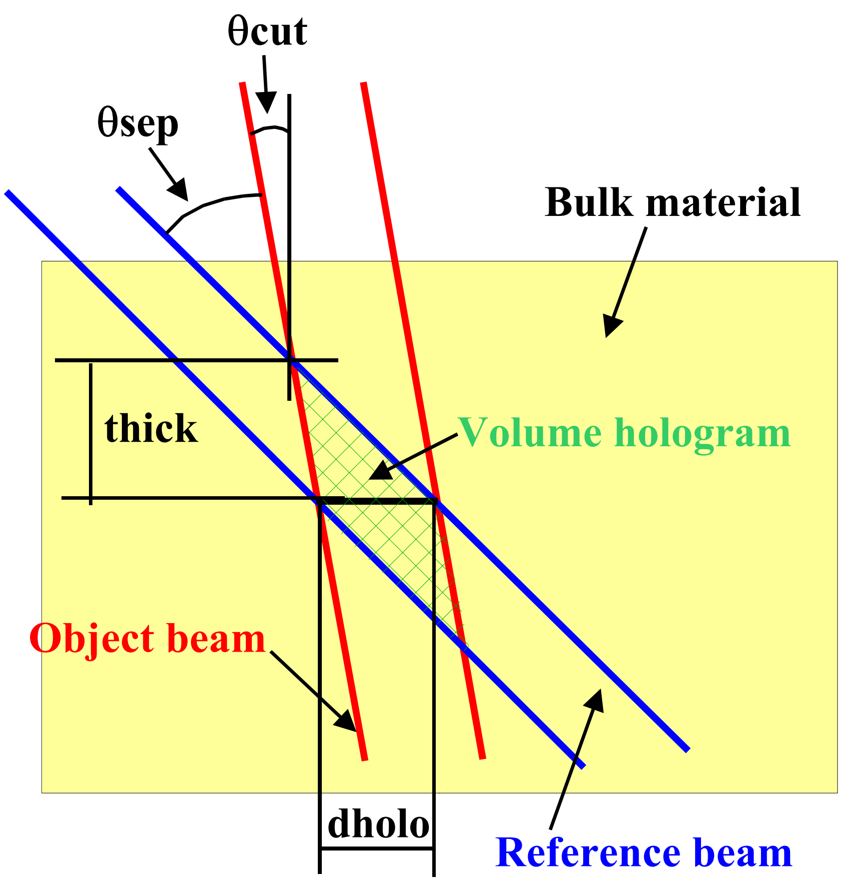
$$\alpha = 2 \cdot a\cos(\theta cut / \theta obj)$$

$$Ccut = \frac{\sin(\alpha) + 2\pi - \alpha}{2\pi}$$

$$d\theta_{Bragg} = \frac{\lambda / n}{2 \cdot thick \cdot \sin(\theta sep)}$$

$$M = \frac{\theta obj - \theta cut - \theta sep}{d\theta_{Bragg}}$$

Multilayer MUX-ed data capacity calculation



$$thick = dholo / \theta sep$$

$$d\Omega_{pixel} = 2\pi \cdot \left(1 - \cos\left(1.22\frac{\lambda}{d_{holo}}\right)\right)$$

$$\Omega_{obj} = 2\pi \cdot (1 - \cos(\theta_{obj})) \cdot Ccut$$

$$Nbit_{holo} = \Omega_{obj} / d\Omega_{pixel}$$

$$N_{holo} = M \cdot \frac{A_{disk}}{\left(d_{holo}/2\right)^2 \cdot \pi} \cdot \frac{t_{disk}}{thick}$$

$$Nbit_{DISK} = Nbit_{holo} \cdot N_{holo}$$

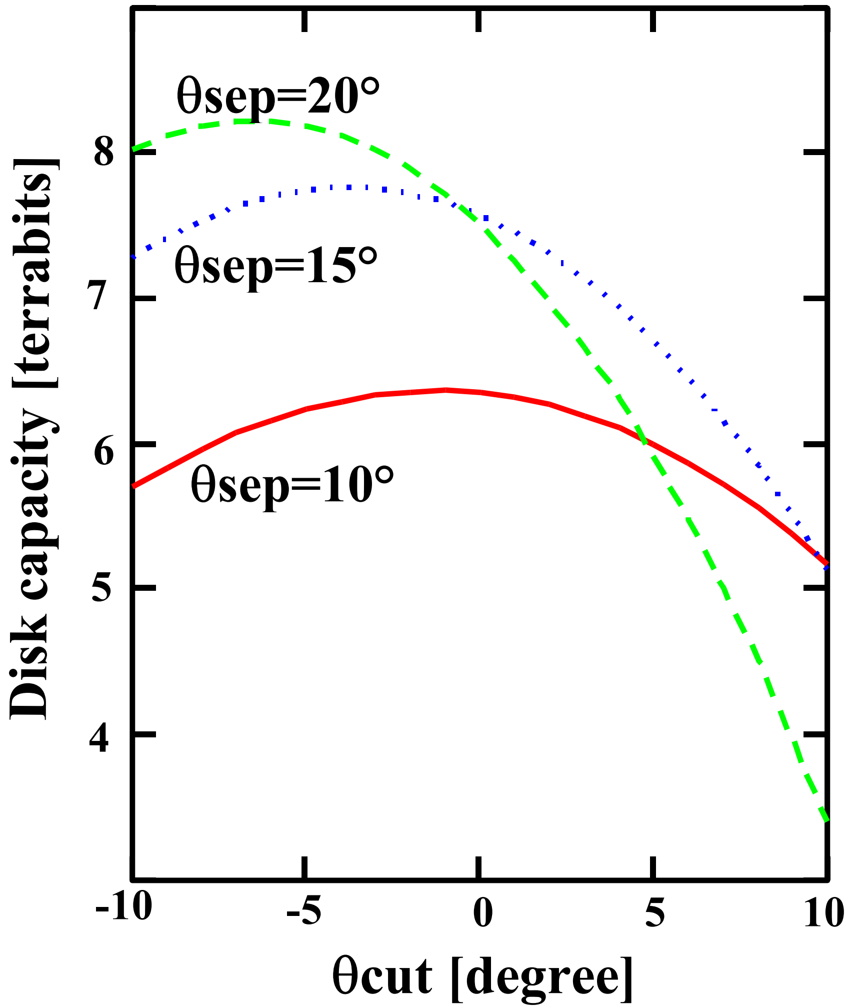
$$\lambda \equiv 405\ nm$$

$$t_{disk} \equiv 1.2\ mm$$

$$\Theta_{obj} \equiv 35\ °$$

$$A_{disk} \equiv 10000\ mm^2$$

Optimizing θsep and θcut

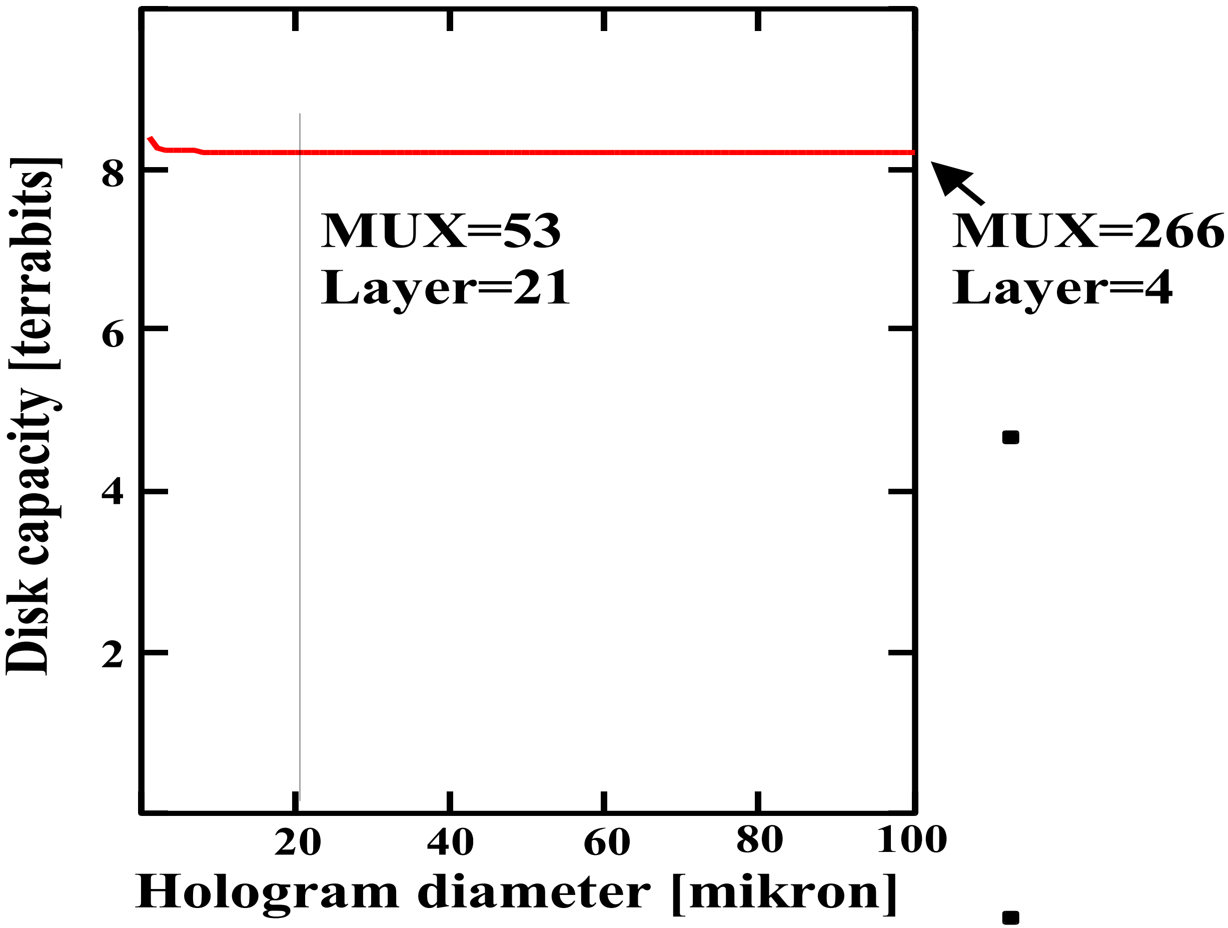


Approximate optima:

Θsep=20°

Θcut=-6°

Disk capacity vs. hologram diameter



Θsep=20°

Θcut=-6°

- Total disk capacity does not strongly depend on hologram diameter.
- Total capacity is determined by NA of objective, storage material thickness

Requirements for a technologically feasible system

- **moderate M# storage material**
- **moderate shrinkage requirements**
- **moderate number of MUX**
- **moderate number of storage layers**
- **minimal number of moving element**
- **moderate servo requirements**

Conclusion: optimal trade-offs among system parameters should be found.

Comparison of concepts

Systems	**Material**	**Disadv.**	**Servo**
Multilayer digital	✓	High noise	<0.1 μm
Volume holographic	Shrinkage ??	Compli-cated opt. System	<0.1 μm <0.005°
Thin film multilayer holographic	✓	Very high number of layers	0.5 μm
MUX-ed multilayer holographic	✓	?	1 μm