Accuracy and scalability in holographic content-addressable storage

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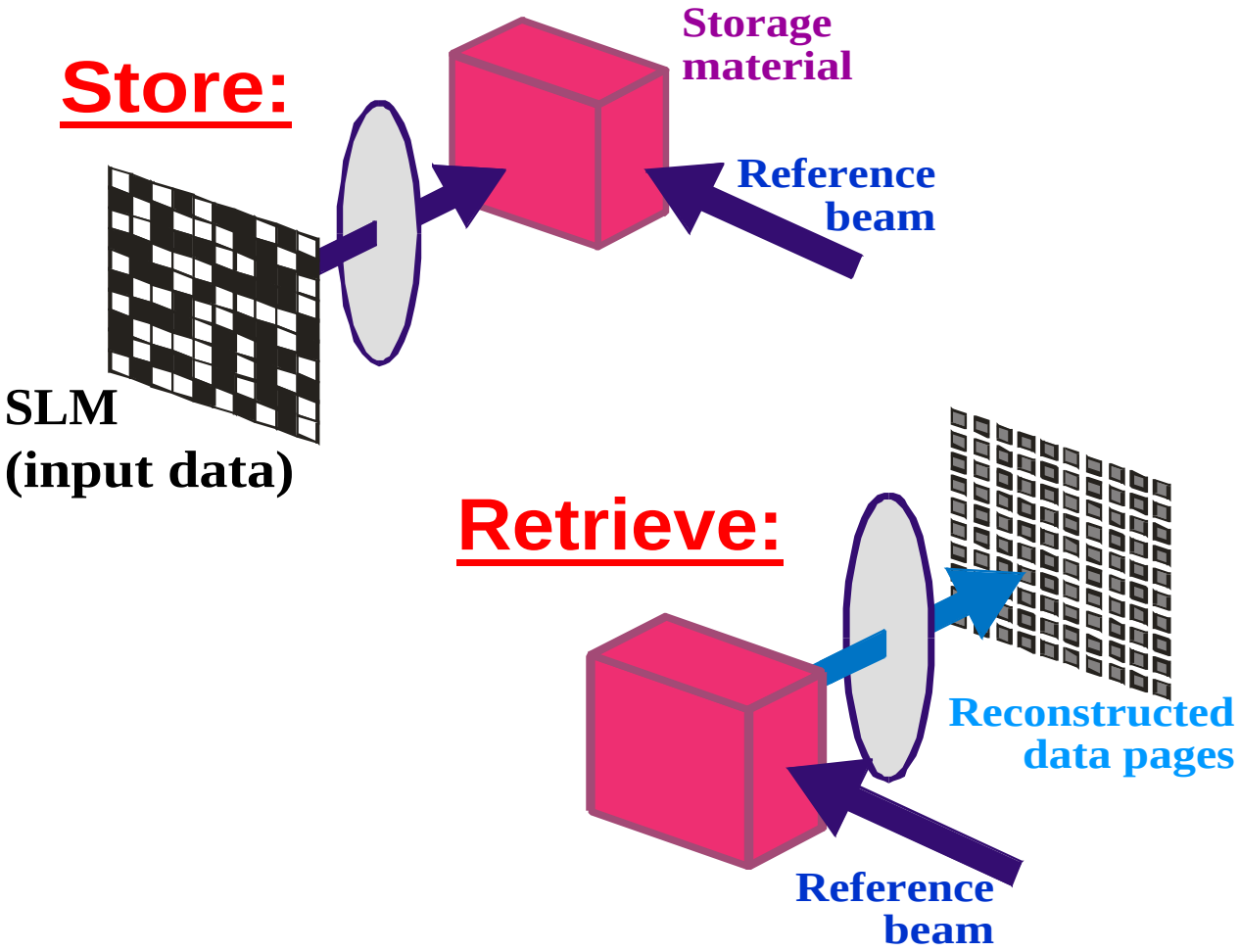
- **Introduction/motivation**
- **Review of our previous work**
  - **search through databases using optical 2-D inner-product**
    - **but this can be inaccurate**
- **New results**
  - **first experimental proof of solution to this inaccuracy**
  - **first pass at massive parallelism**
- **Outlook/Future work**

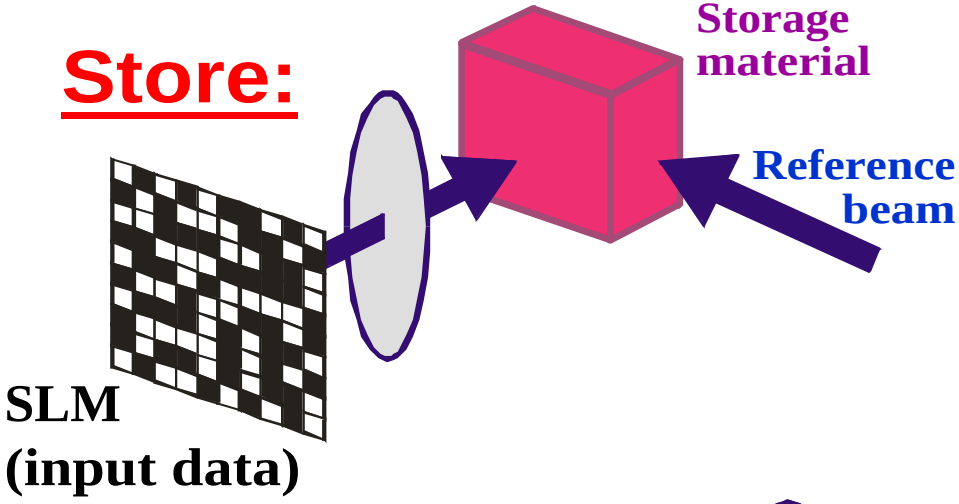
Holographic data storage



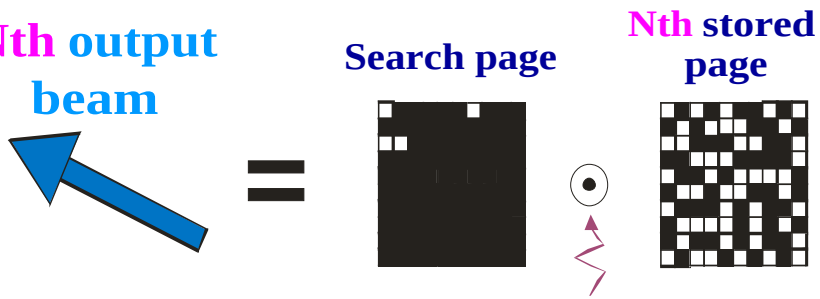
Associative retrieval

(holographic content-addressable memory or 'HCAM')

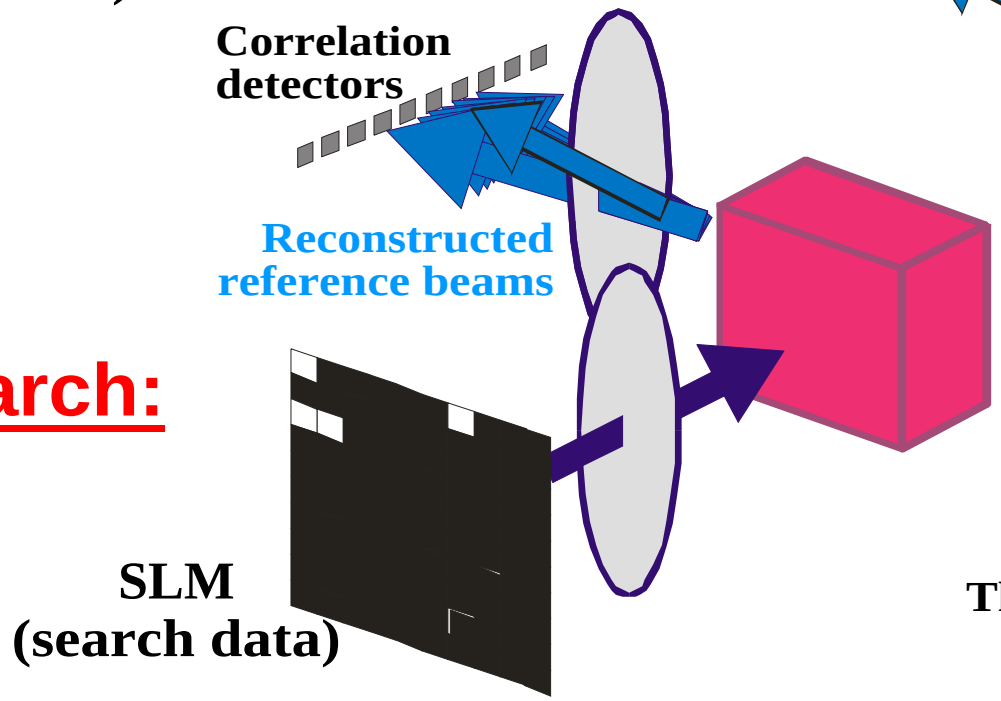
Store:



The intensity of the Nth output beam measures the similarity between the Nth stored page and the search page.



Search:



Good news:

All the holograms (*database records*) are searched in parallel!!

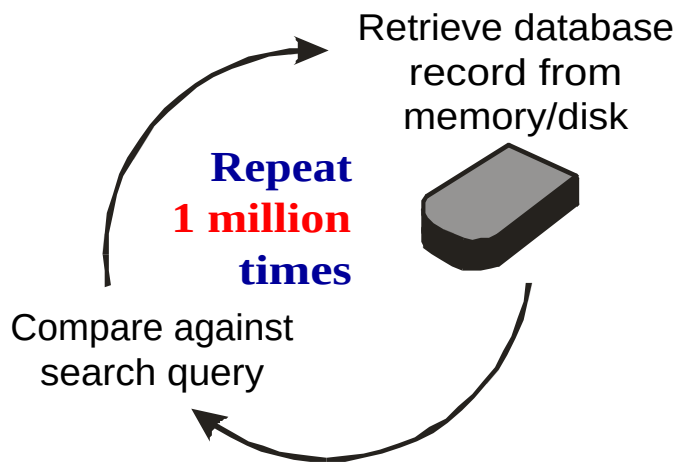
Bad news:

The measured correlation scores are analog and thus subject to noise.

Example: Searching a digital database of 1 million records for the best 10 matches

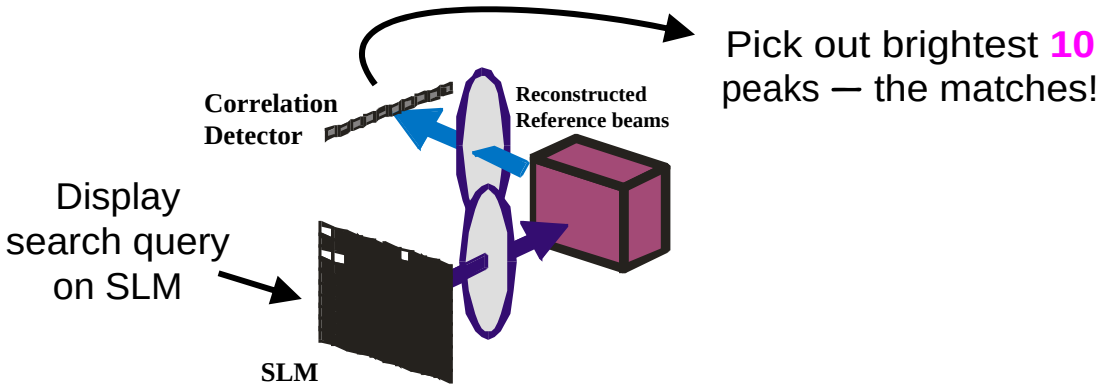
(Assumption: query is too complex for indexing)

Conventional search



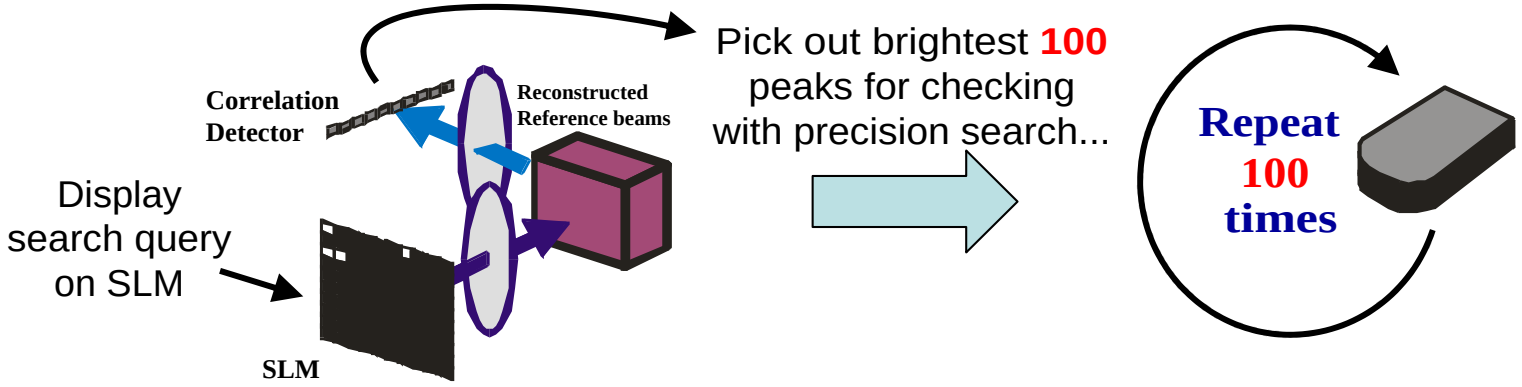
Digital & precise, but serial & slow

Content-addressable holographic data storage



Parallel & fast, but analog & noisy

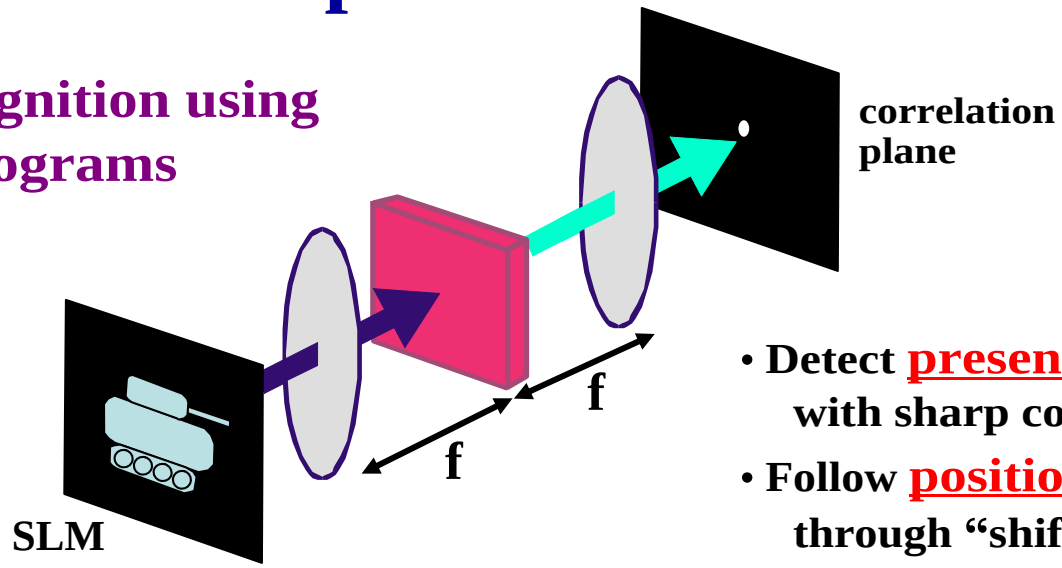
Content-addressable HDS as "front-end" database machine



Fast and accurate!

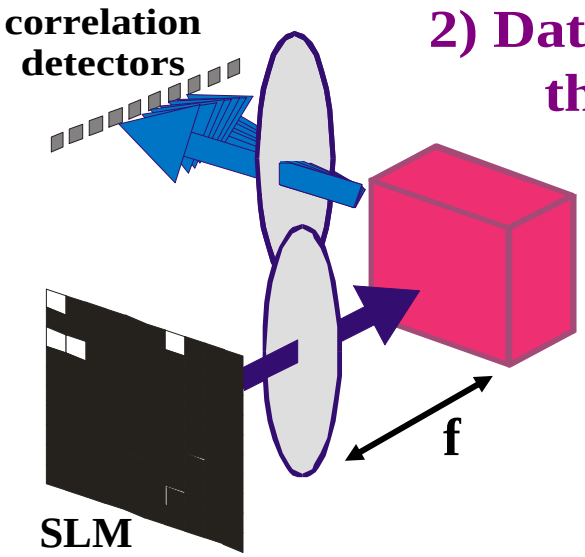
Applications of Optical Correlation

1) Target recognition using thin holograms



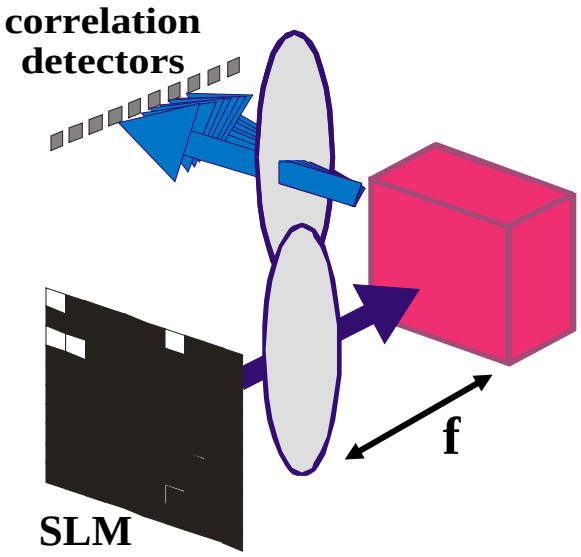
- Detect **presence** of target image with sharp correlation peak
- Follow **position** of target image through "shift invariance"

2) Database search using thick holograms



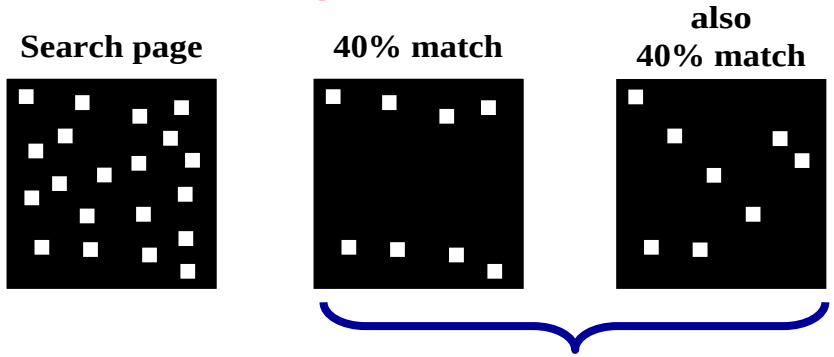
- Sacrifice horizontal shift-invariance in exchange for multiple correlations
- But optical power in correlation peak ***must*** accurately measure **2-D inner product** between stored template and search page

The "defocused" correlator



Defocus leads to a loss of vertical shift invariance [1] ...

...and also causes problems in measuring the inner product [2]...



These two pages *should* have the same inner-product...

...but the defocussed correlator will *not* rank them the same!

The simplest abstraction of this effect is as follows:

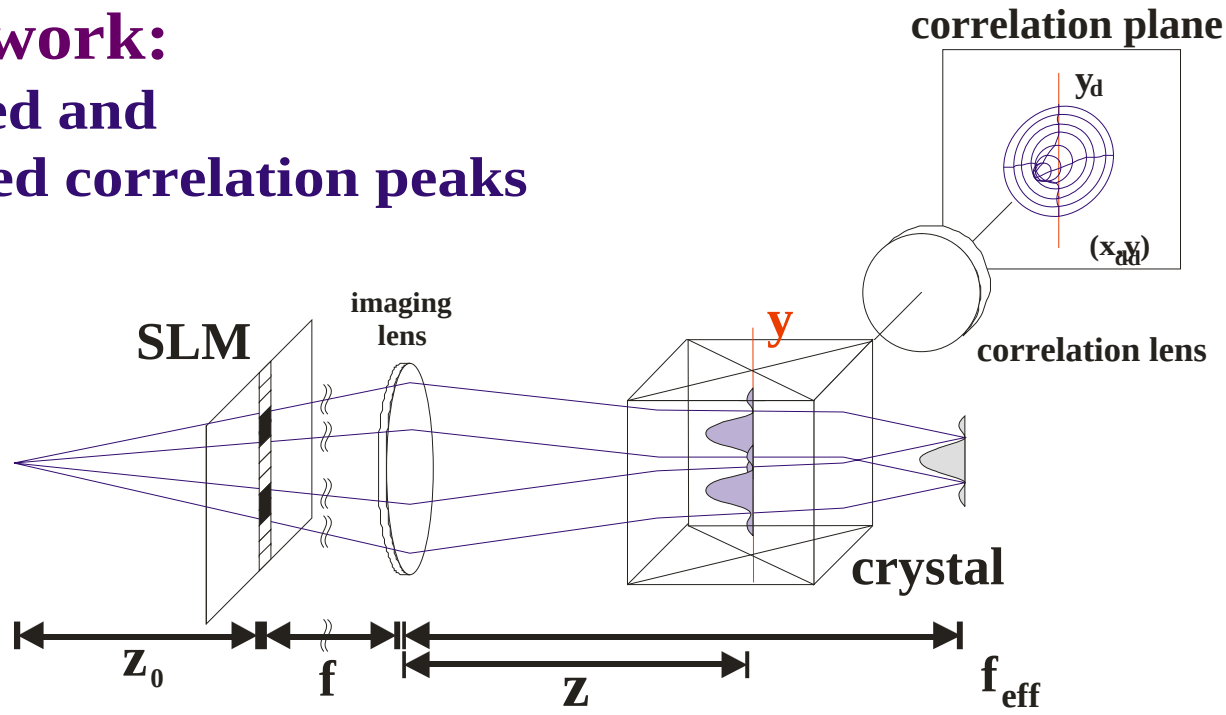
...no matter where the second block is placed!

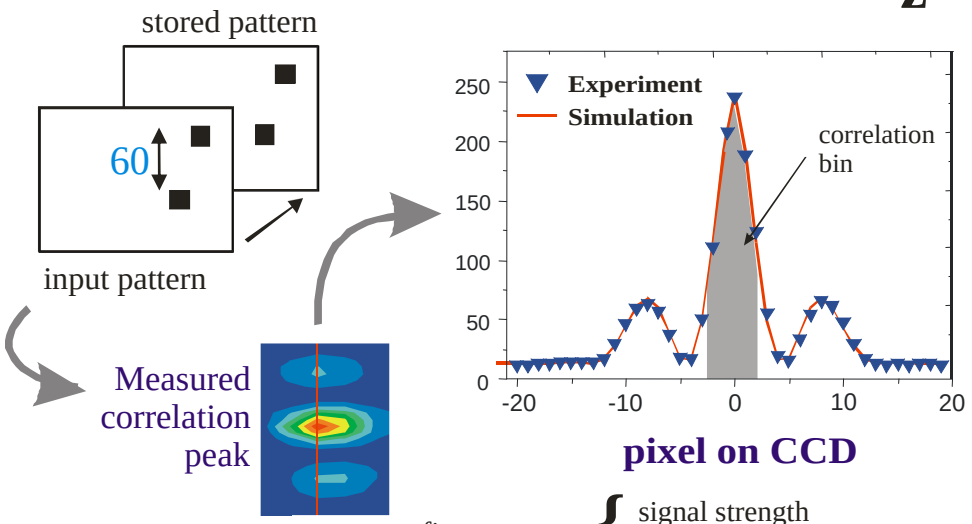
[1] M. Levene, G. J. Steckman, and D. Psaltis, Applied Optics, **38**(2), 394 (1999).

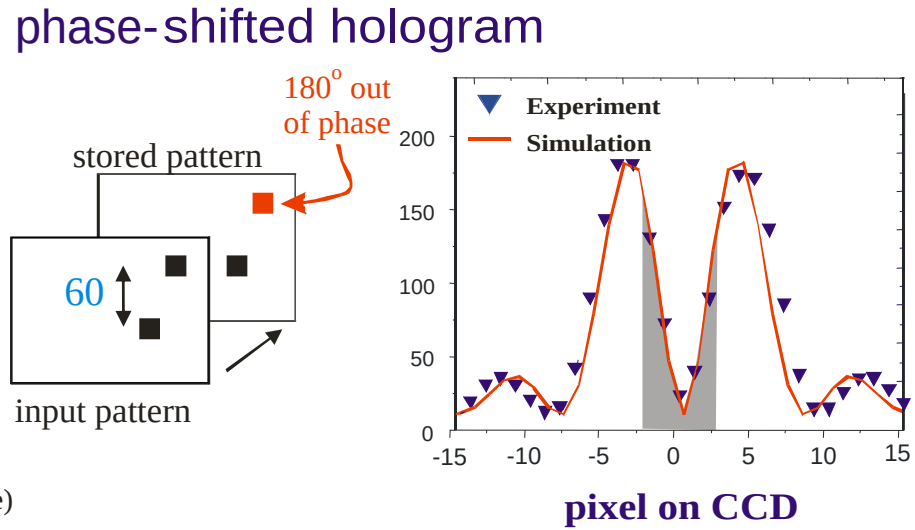
[2] S. Kobras, G. W. Burr, H. Coufal, and G. Abstreiter, CLEO 1998.

Previous work:

Measured and Simulated correlation peaks





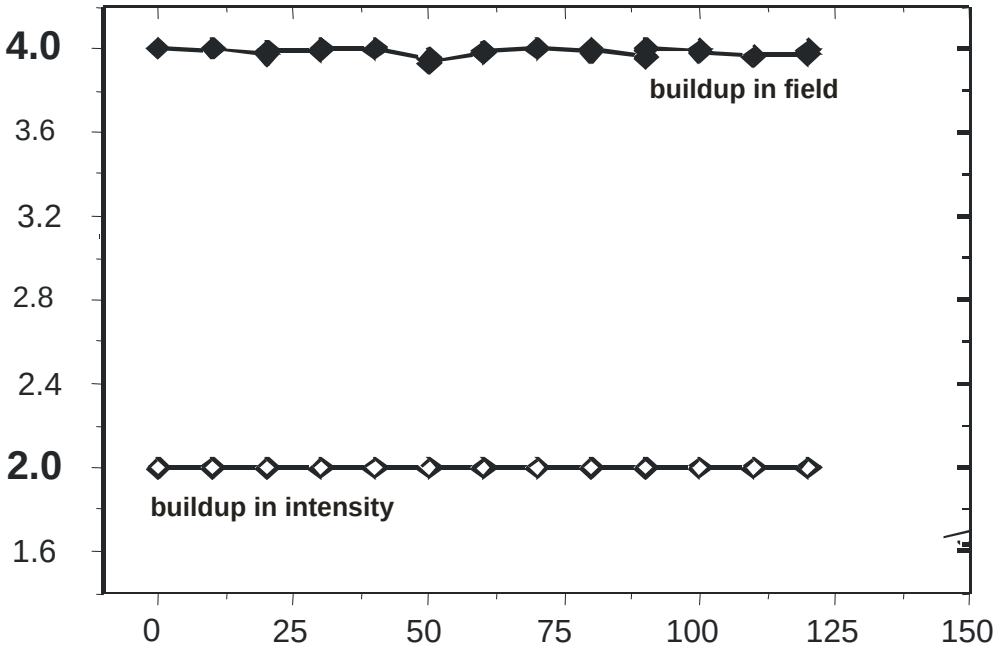


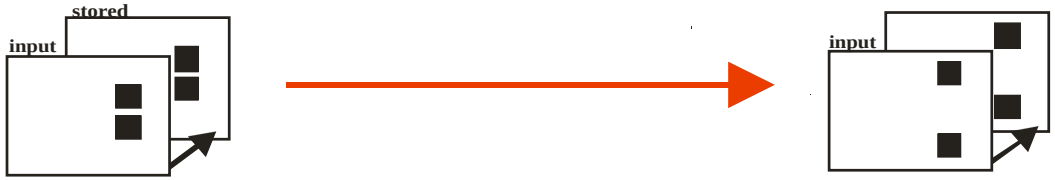
[1] S. Kobras, Diplomarbeit, 1998.

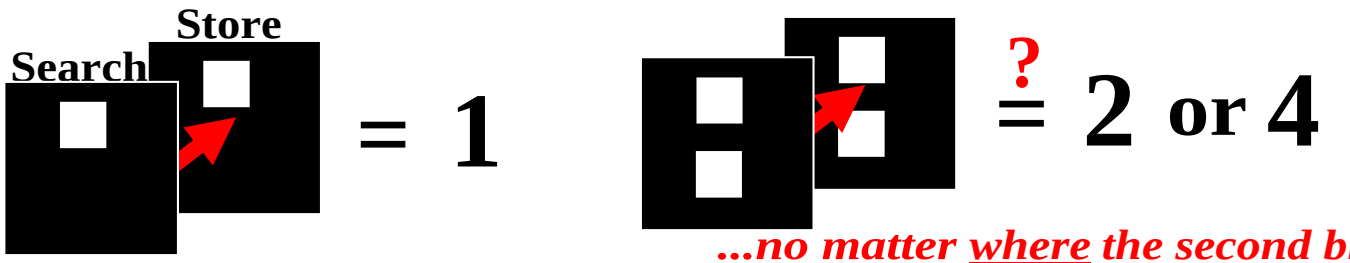
[2] S. Kobras, G. W. Burr, H. Coufal, and G. Abstreiter, CLEO 1998.

Results we were expecting

Correlation signal [a.u.]

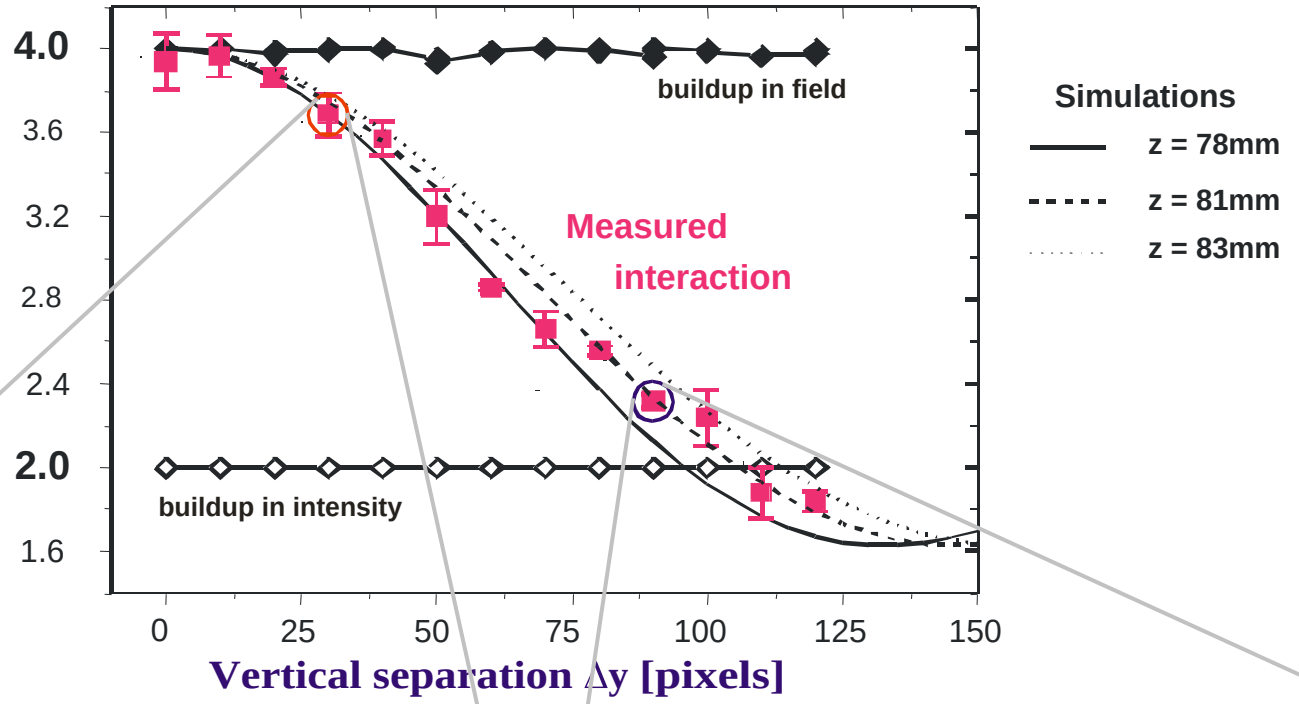


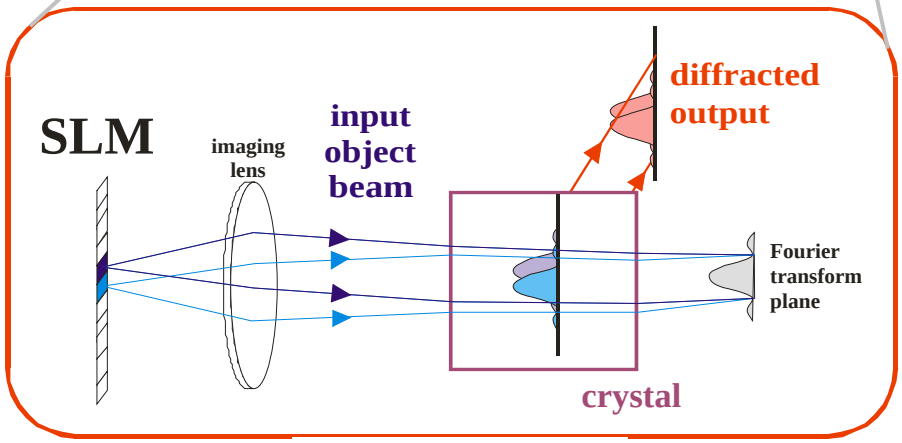




...no matter <u>where</u> the second block is placed!

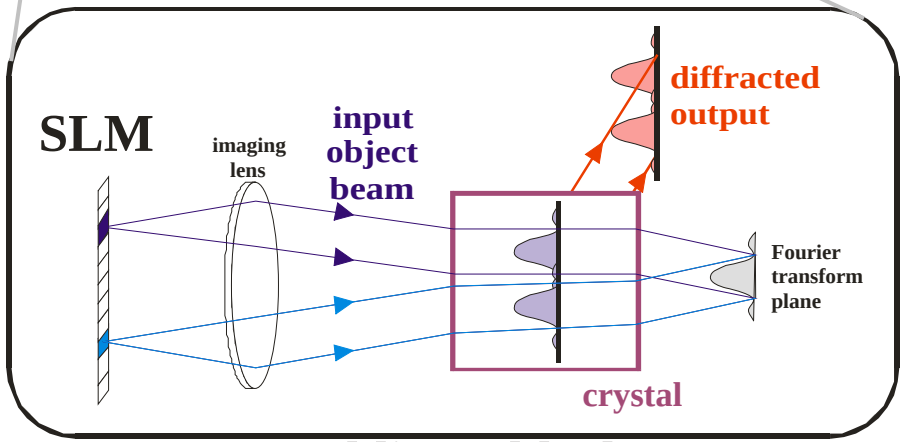
Actual experimental results





Adding a block doubles **amplitude**

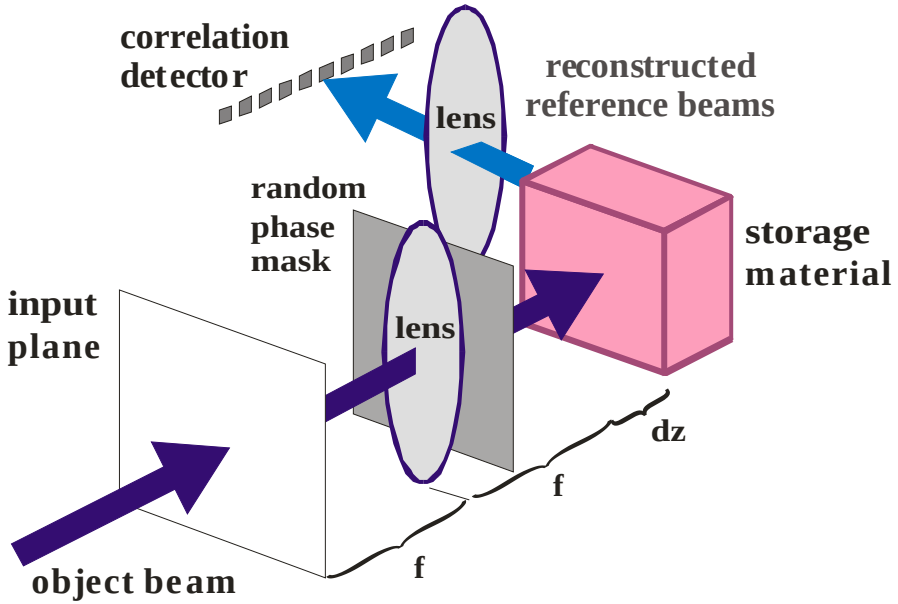
➡ **4x** Intensity



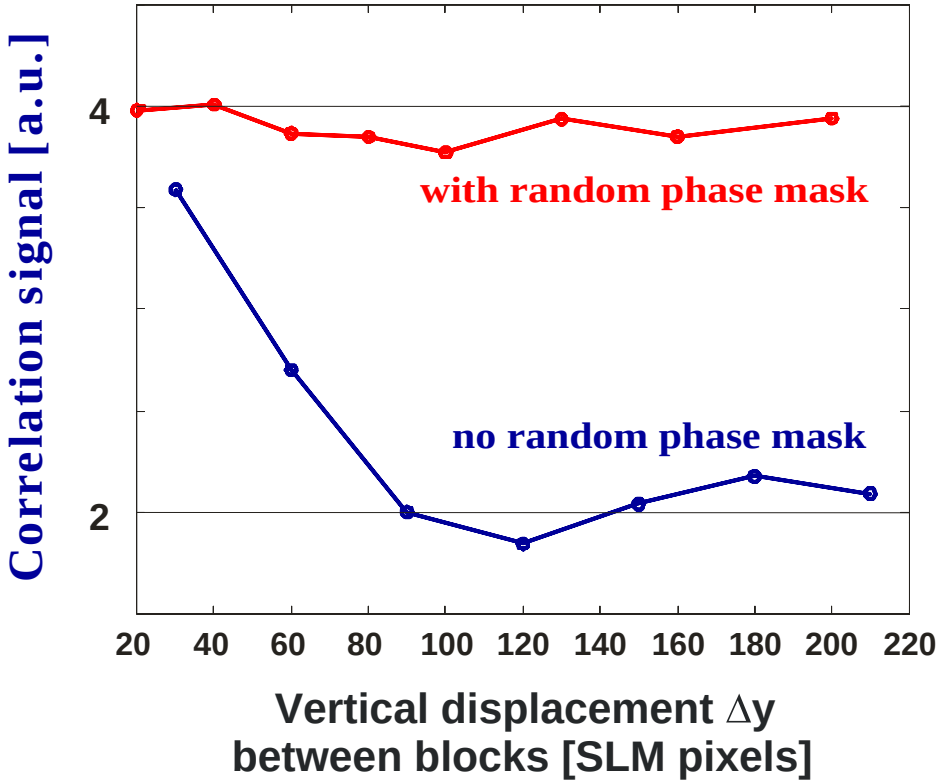
Adding a block doubles **beam height**

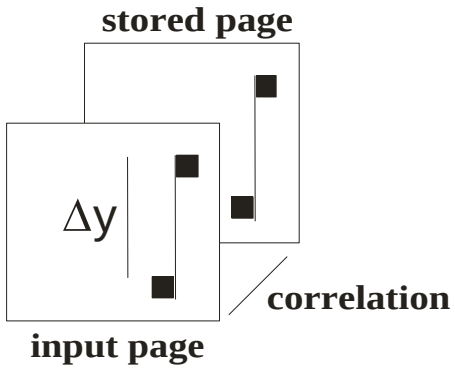
➡ **2x** Intensity

Solution: introduce a *random phase mask…*



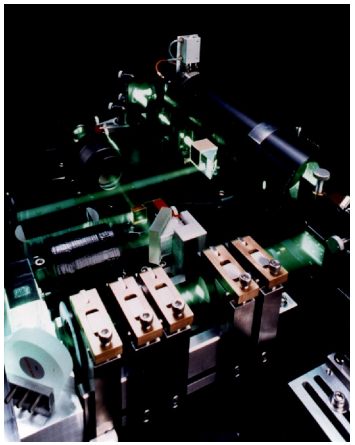
Simulation results

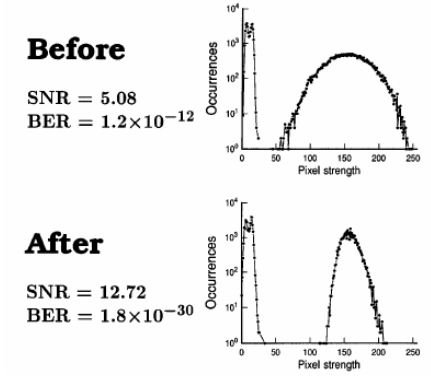


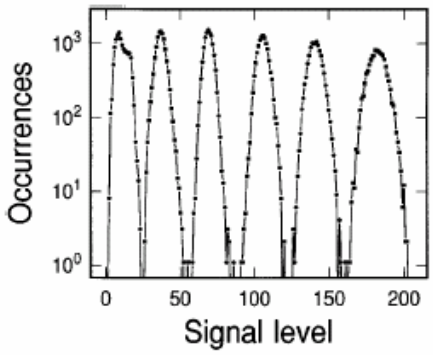


[1] F. Grawert, G. W. Burr, S. Kobras, H. Hanssen, M. Riedel, C. M. Jefferson, M. Jurich, and H. Coufal, Proceedings of the SPIE, Vol **4109,** pg. 177 (2000).

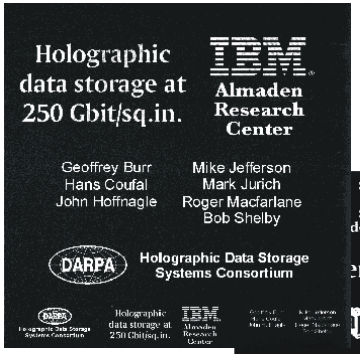
DEMON 1
(1996-2000)

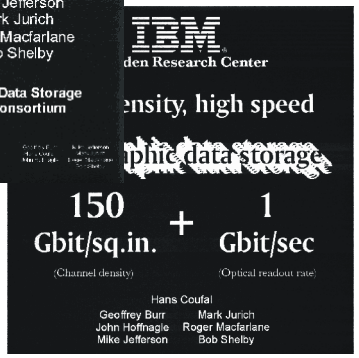


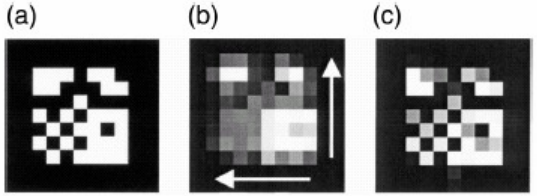




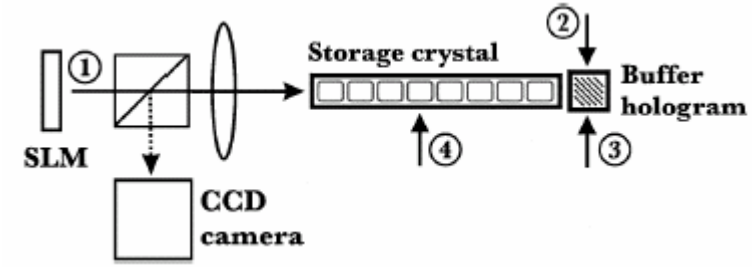
DEMON 2
(1999-2001)

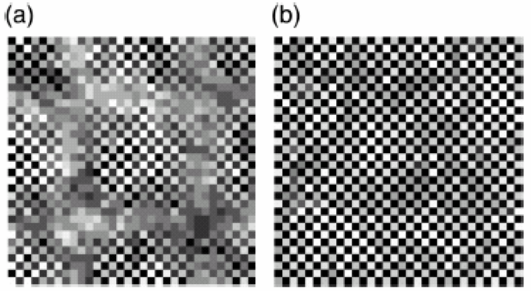






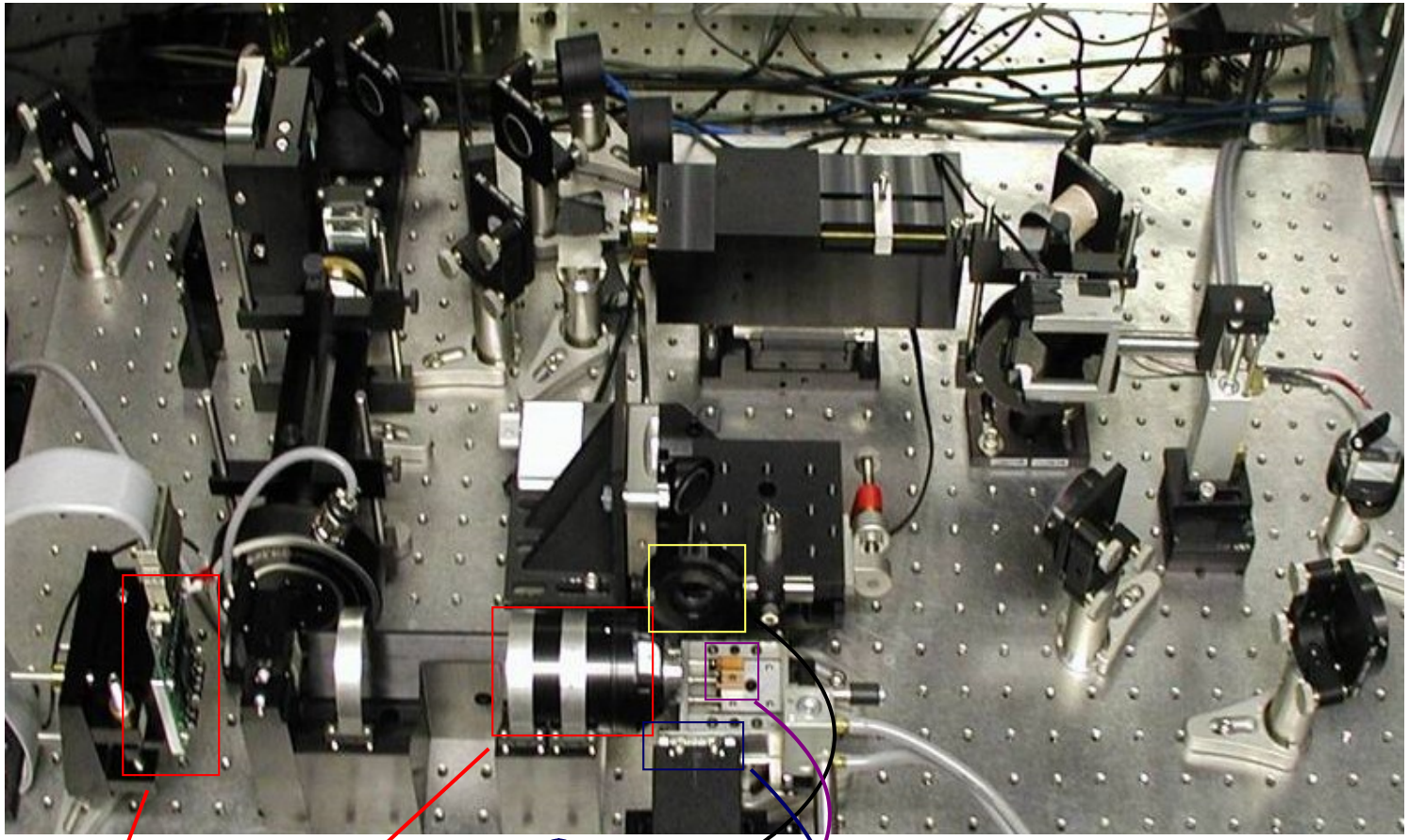
DEMON 3
(2000-)

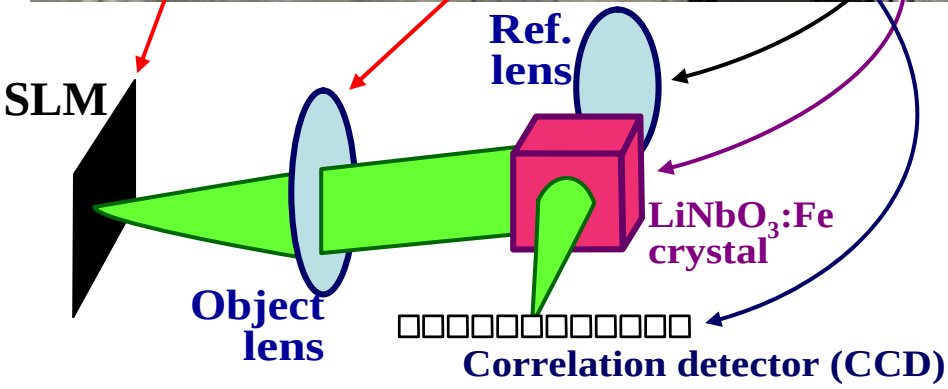




DEMON 4
(2003-)

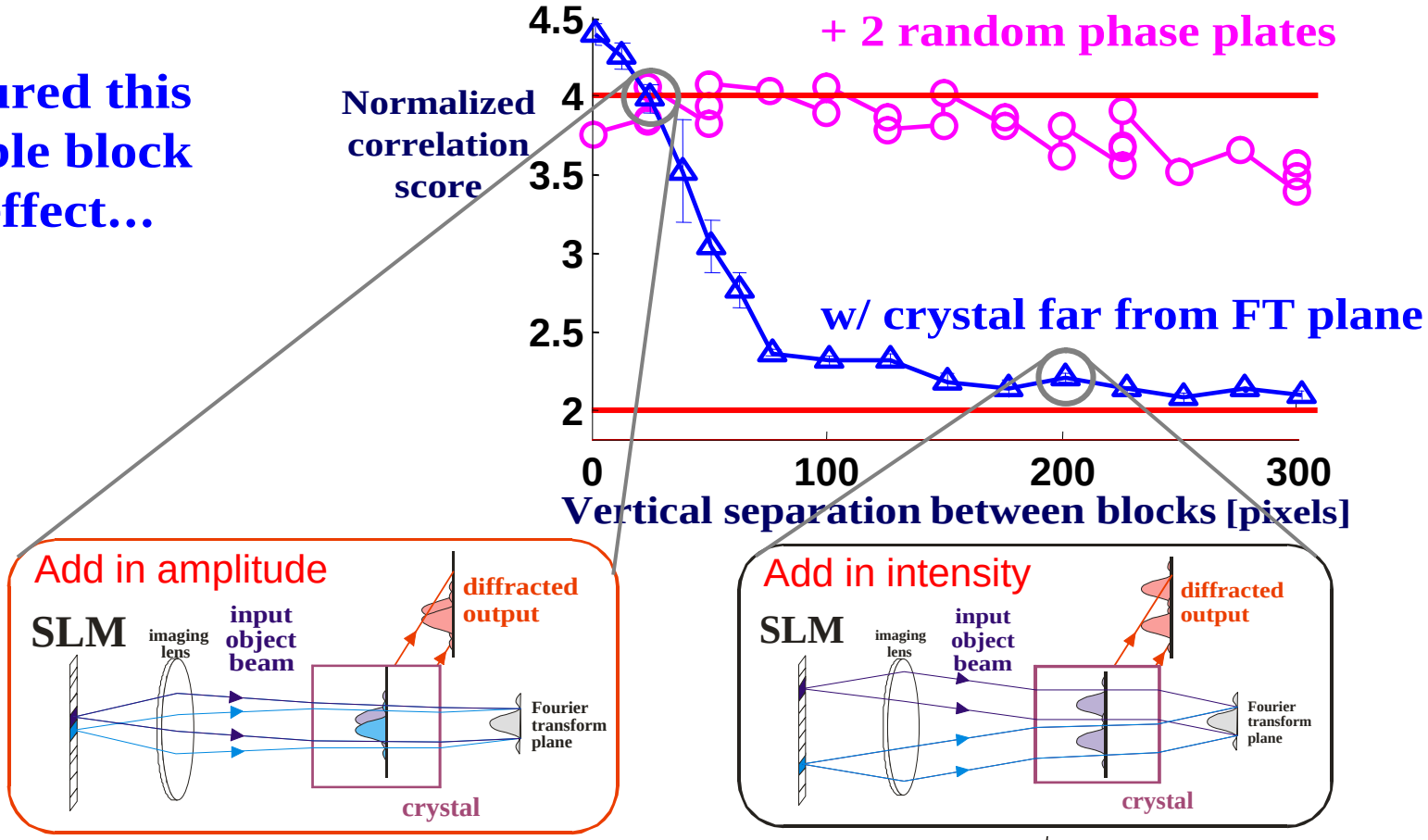
Associative retrieval platform





DEMON 4: first experimental results

We re-measured this undesirable block position effect…

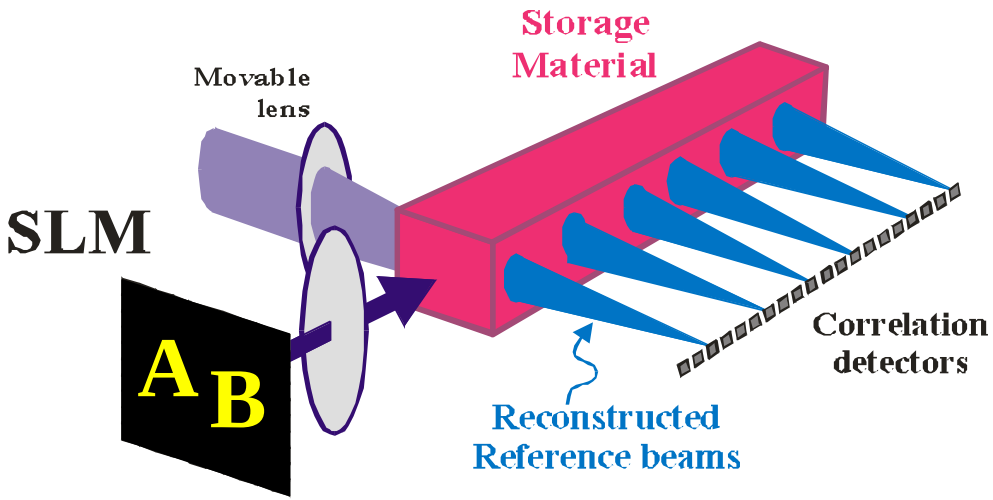


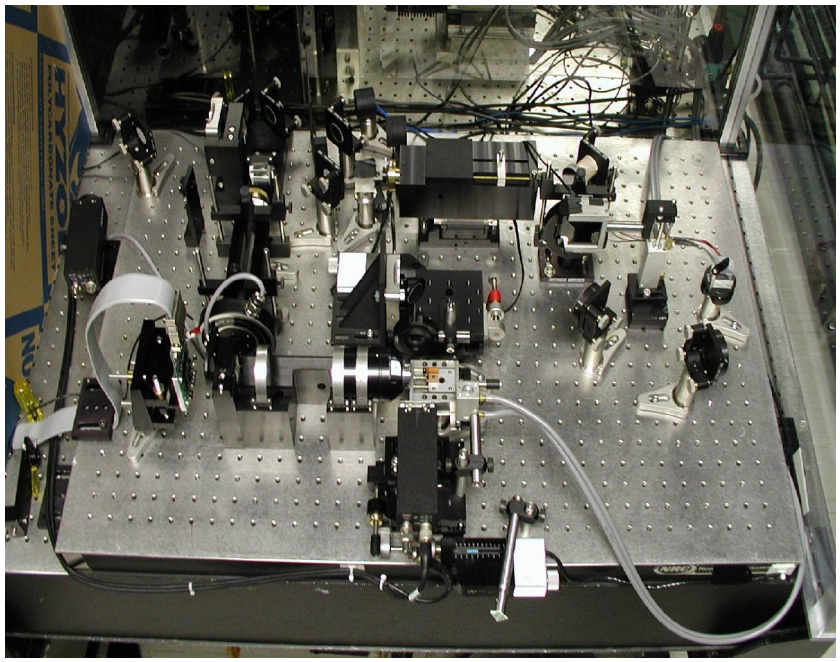
Then, we obtained our first experimental proof that our proposed solution (random phase mask) to this problem would work…

E. Kalman et. al.

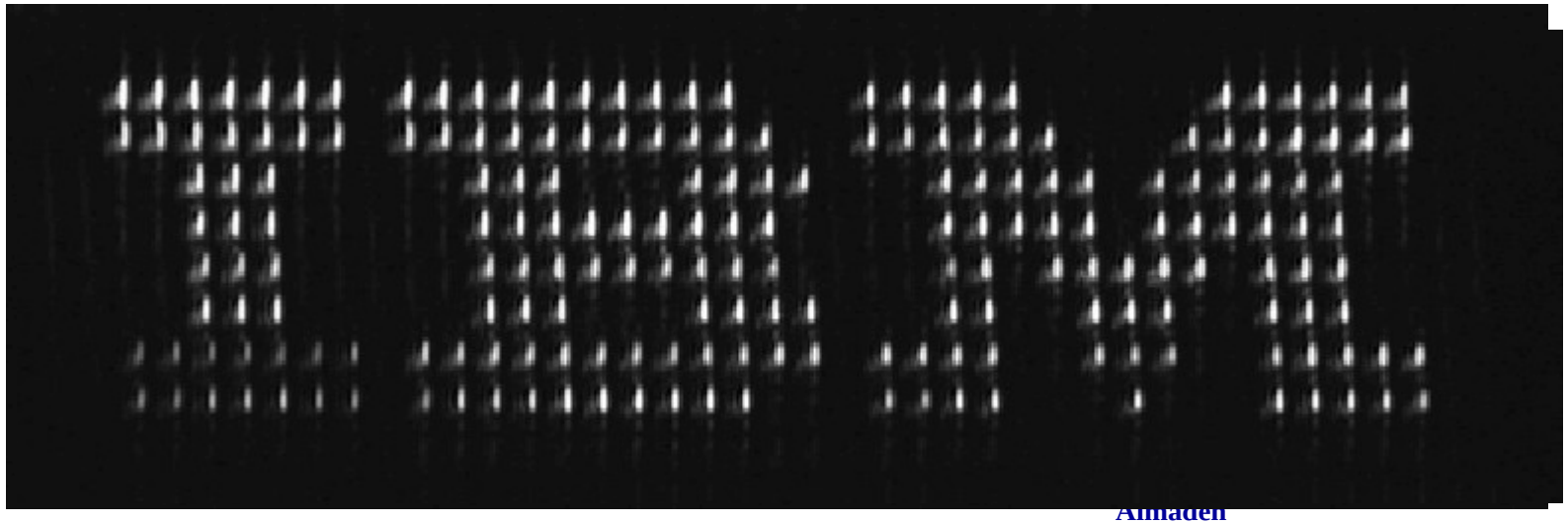
Associative retrieval

- **Demonstrate massive parallelism**





- **Sample correlation plane**



Conclusions

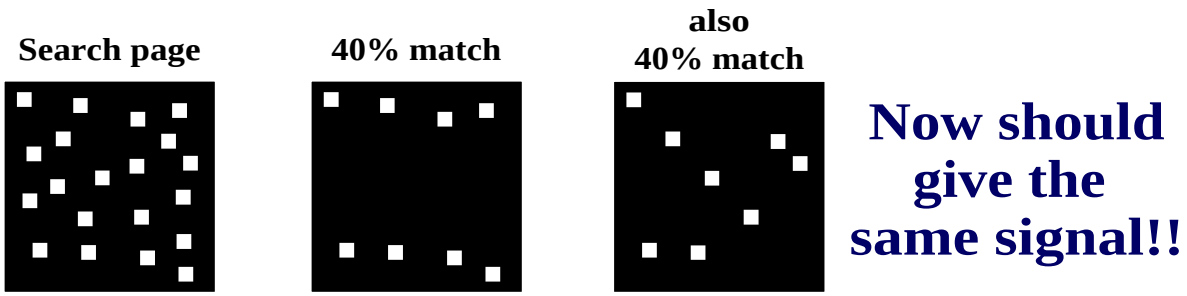
- **Content-addressable holographic storage could search vast databases in parallel**
  - **best used as a front-end filter to a conventional digital search**
  - **capable of arbitrarily low error and significant speed advantages**

- **An accurate 2-D inner product between search page and stored template...**

  ...is critical for high-fidelity search

  ...is lost in the defocussed correlator (used to get massive parallelism)

  ...can be recovered by the use of a random phase-mask



Now should give the same signal!!

- **First experiments towards massive parallelism**

Acknowledgement: IBM/NSF/SJSU summer research program (C. Wade, D. Miller)