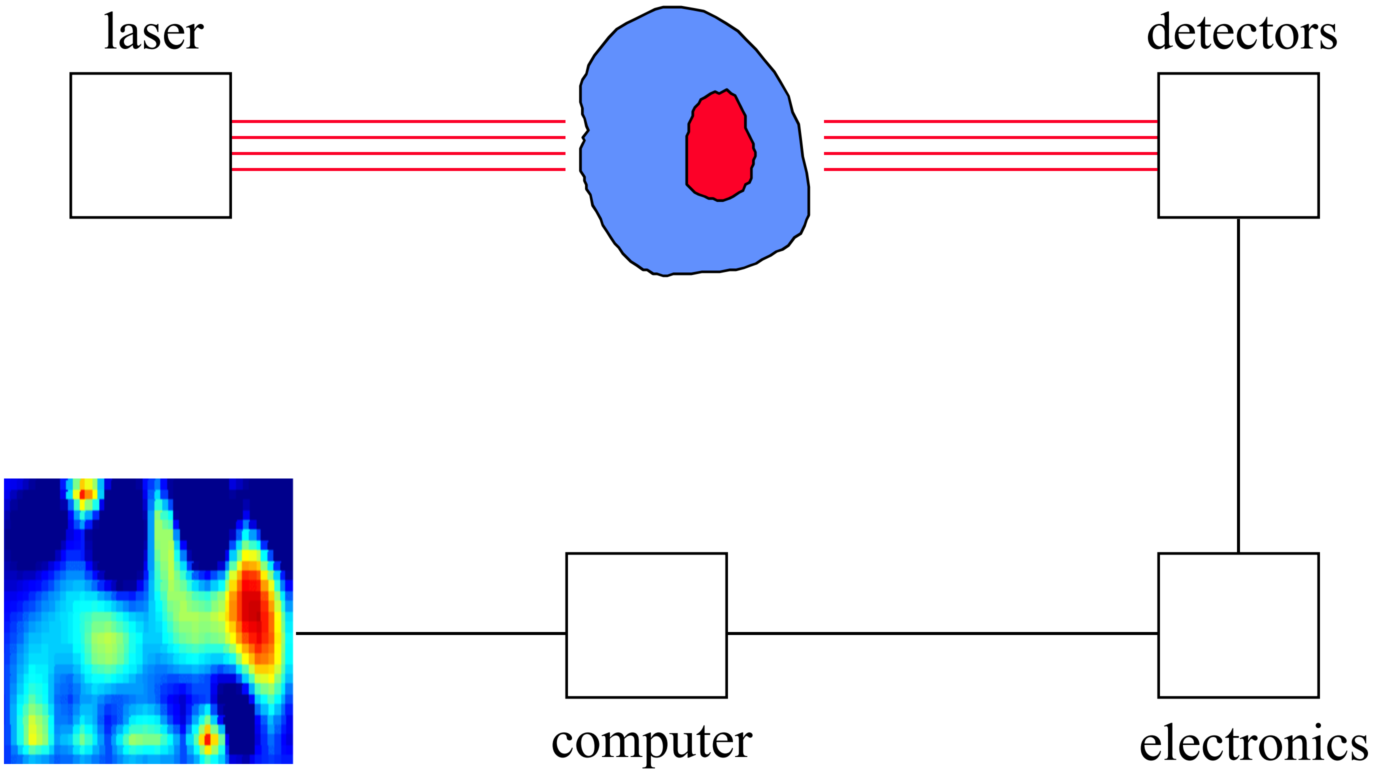
Image Reconstruction in Optical Tomography : Utilizing Large Data Sets

Vadim A. Markel, Ph.D.
Department of Radiology

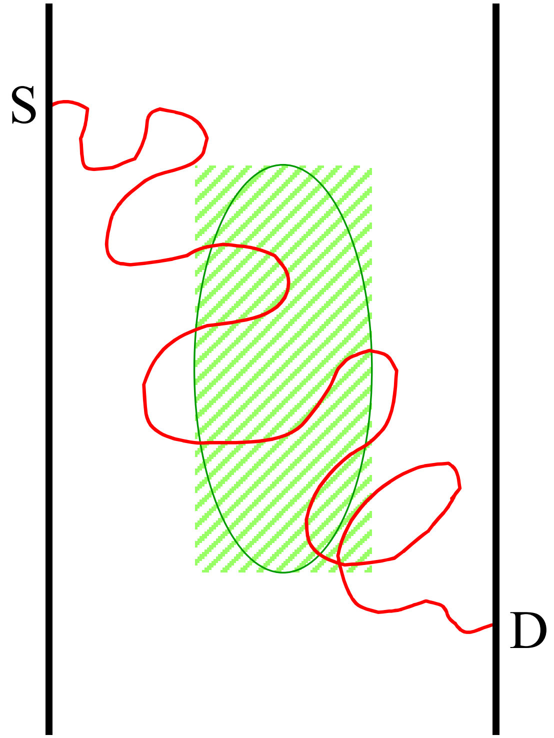
John C. Schotland, M.D., Ph.D.
Department of Bioengineering

http://whale.seas.upenn.edu

Optical tomography



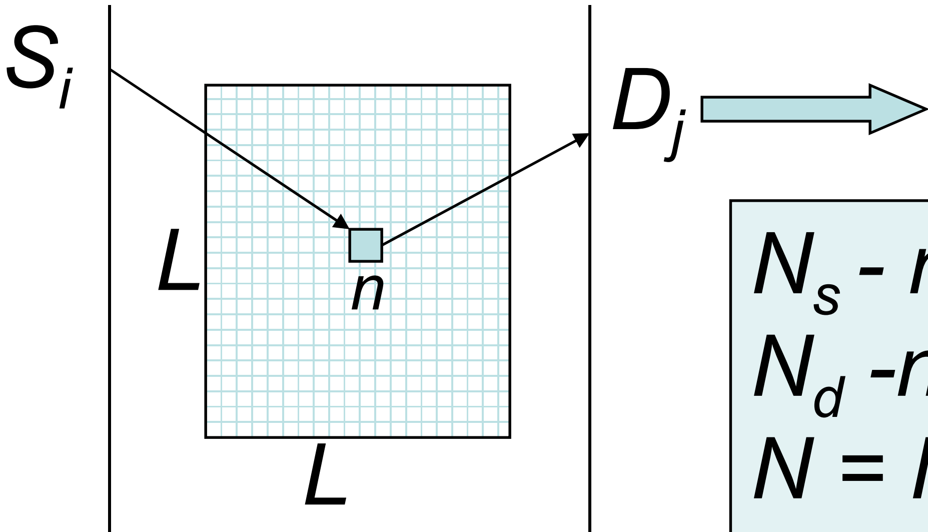
Inverse problem



- Ill-posed
- Nonlinear

Problem: Given measurements from multiple source-detector pairs, reconstruct the spatial distribution of the optical absorption and scattering coefficients.

Size of the Data Set and Complexity of the Problem



ϕ_{ij} (one data point)

N_s - *number of sources*
N_d -*number of detectors*
$N = N_s N_d$ – *total number of data points*
L^3 – *number of volume elements*

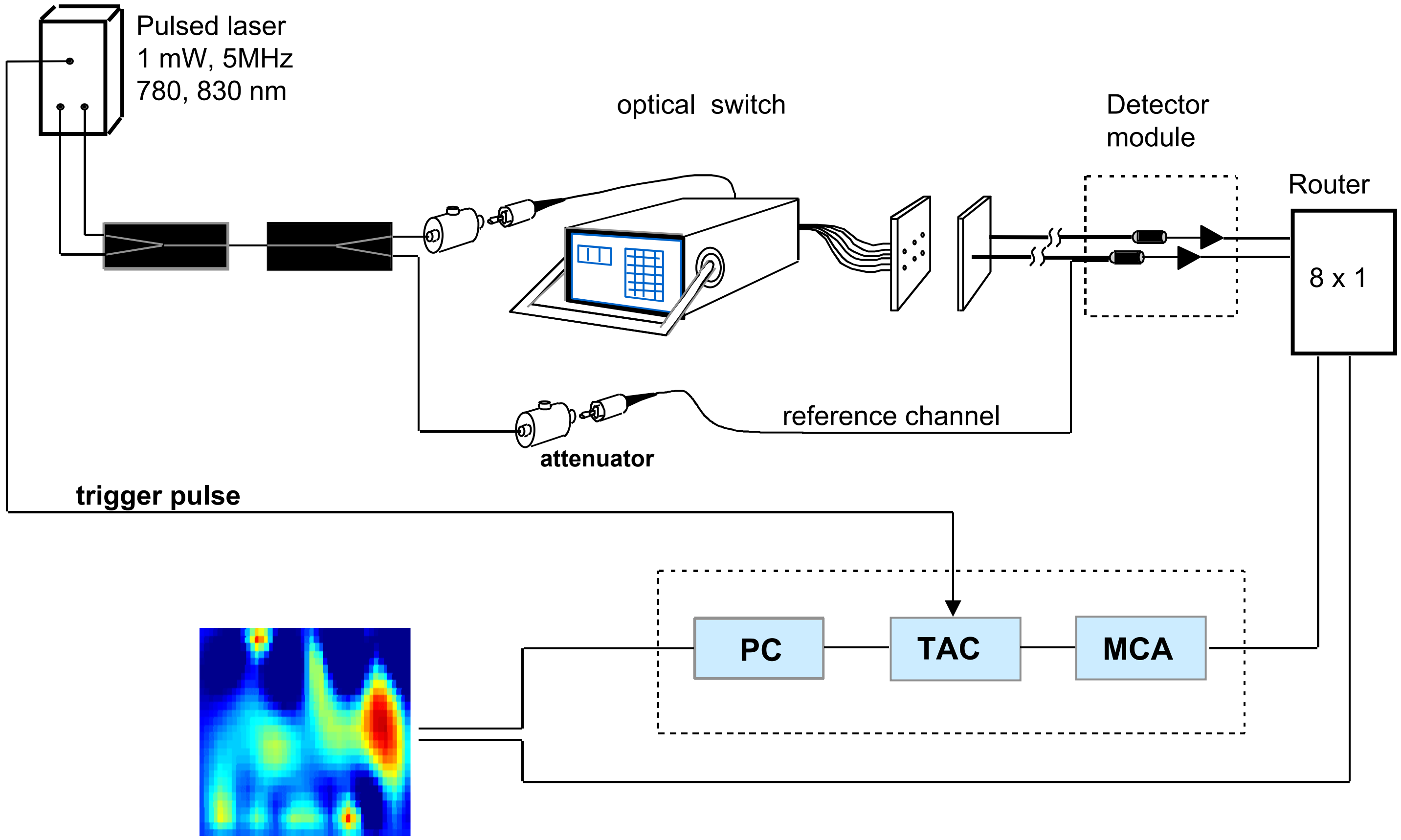
$$\phi_{ij} = \sum_j \Gamma_{ij,n} \delta\alpha_n$$

$$i = 1, \ldots, N_s$$

$$j = 1, \ldots, N_d$$

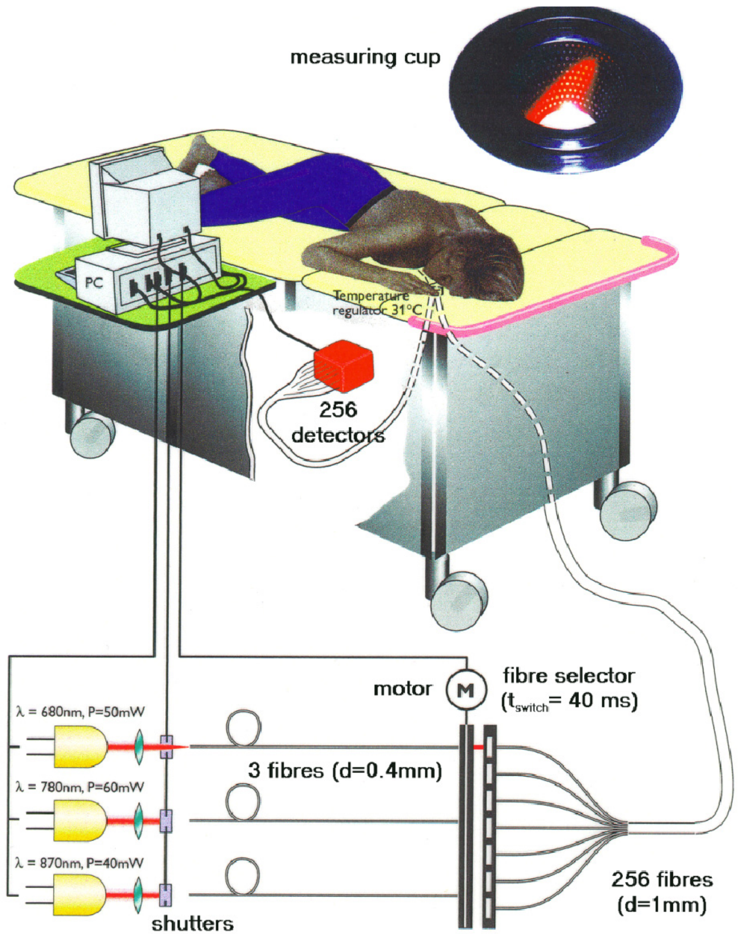
$$n = 1, \ldots, L^3$$

First generation Penn Scanner (~1995)



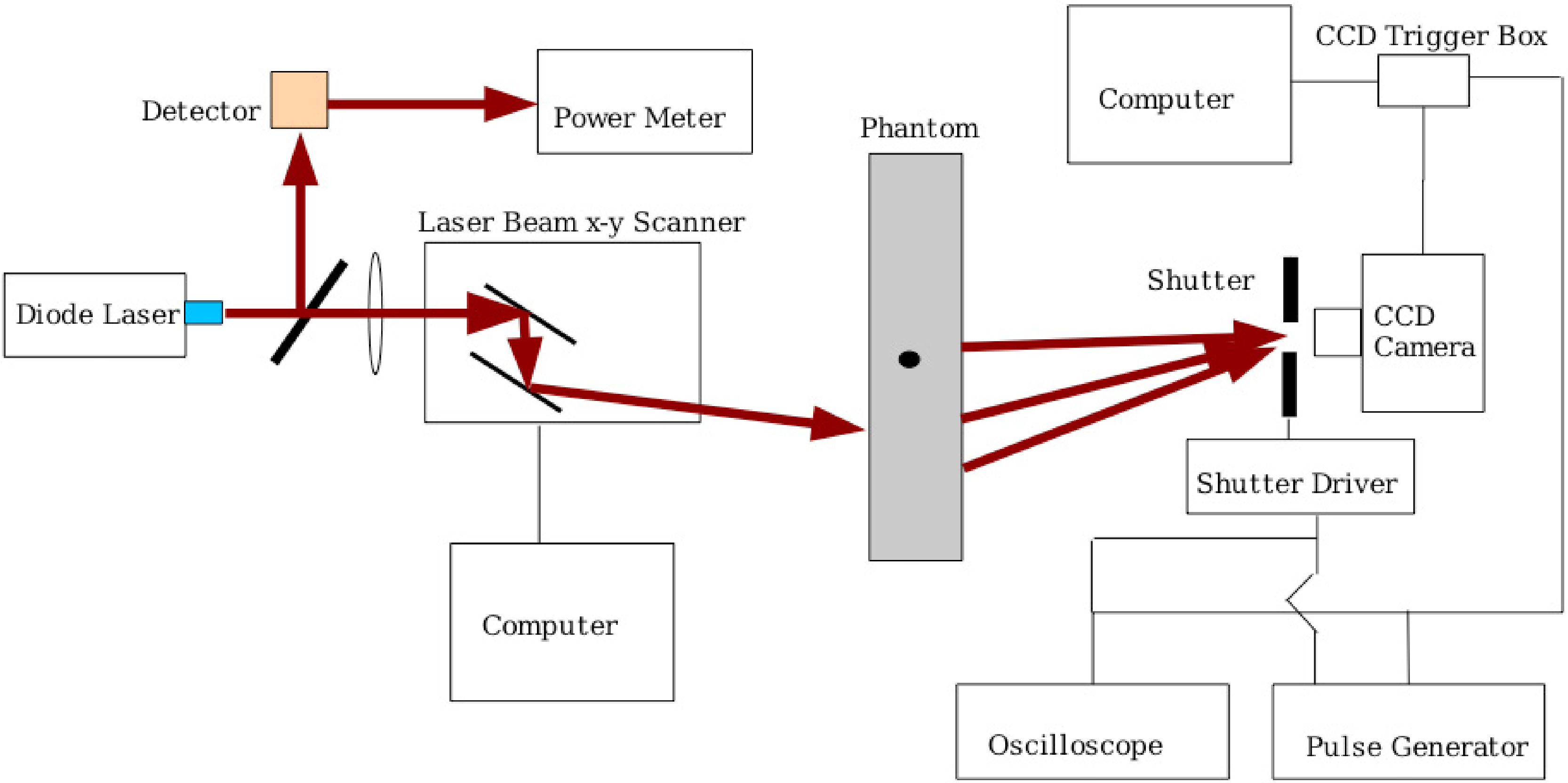
~100 source-detector pairs

Philips Scanner (~1998)



~10^5 source-detector pairs

Noncontact imager (2005)



10^8 - 10^{10} source detector pairs

Scaling to Large Data Sets

QUESTIONS:

- Is it possible to practically use data sets significantly larger than 10^5 points ?
- Is more data better ?
- How does the size of data set affect image resolution ?
- How does the size of data set influence noise tolerance and image artifacts ?

METHODS:

- We have developed image reconstruction algorithms that are capable of utilizing extremely large data sets
- We have built an experimental imager which can acquire $\sim 10^8$ data points

Simulations: Relation Between Sampling and Resolution

- Slab geometry with absorbing boundaries (mammography)
- Sampling on square lattice with spacing h
- Measurements in window of size W
- Assumptions

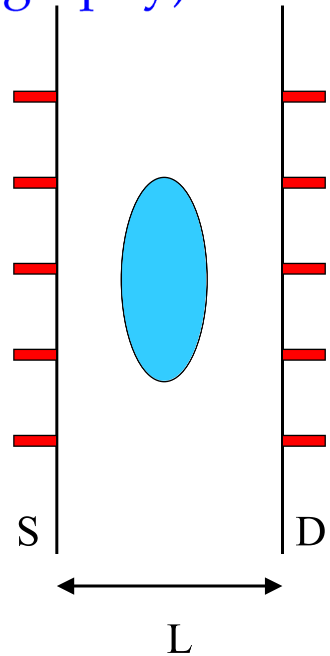
  — DC

  — physiologic values of background α, D

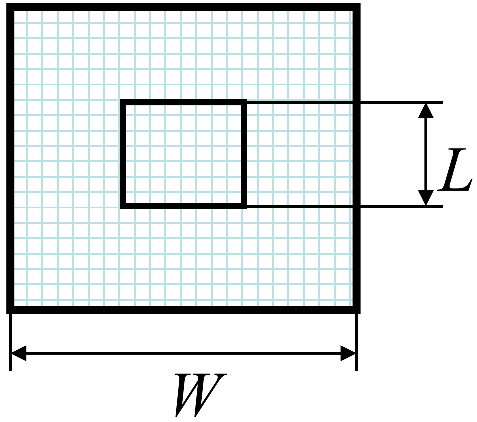
  — point absorbers

  — $L = 6$ cm

  — FOV= 6 cm $\times$ 6 cm

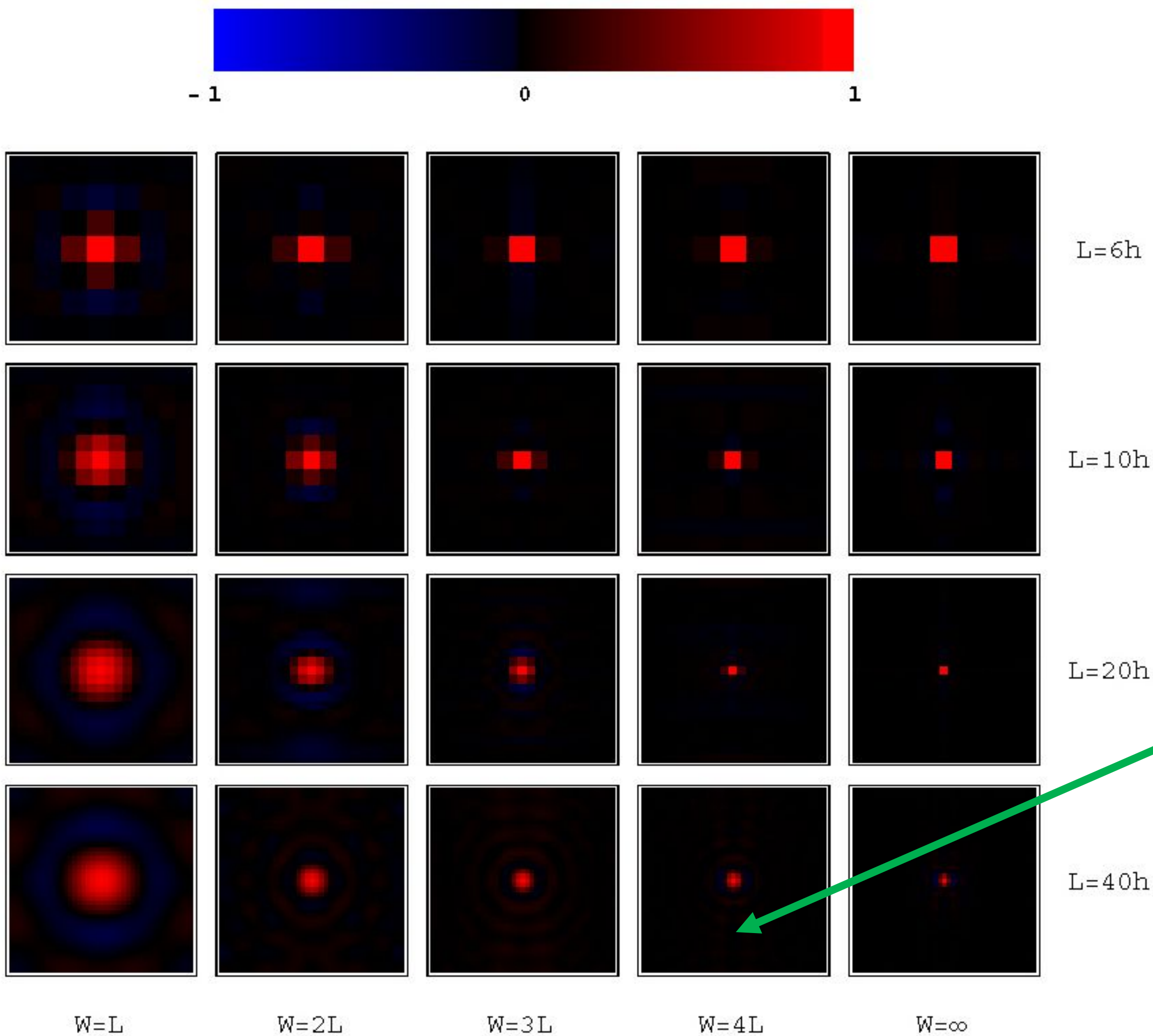


Resolution



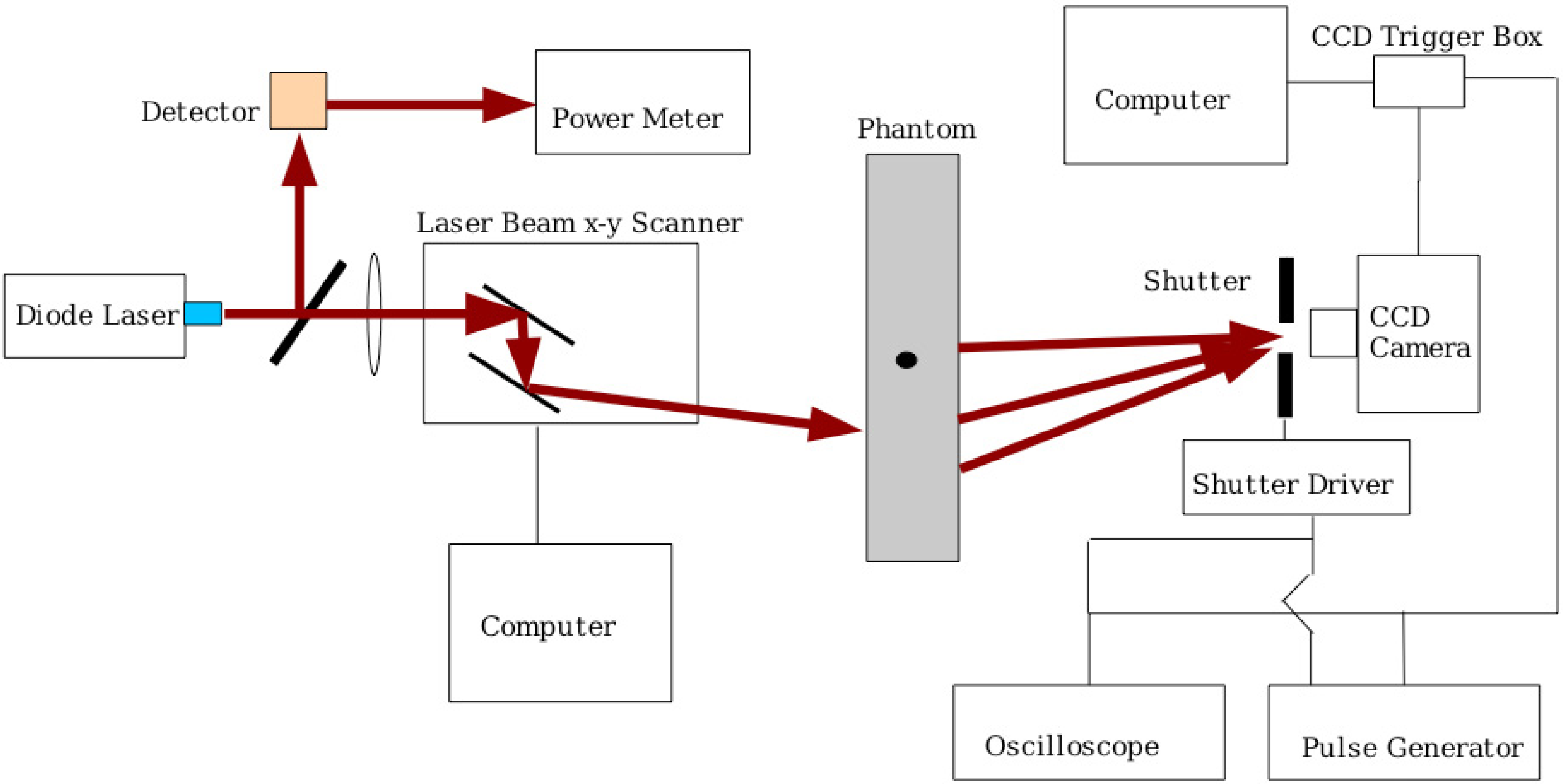
- Fundamental limit of transverse resolution is h
- Depth resolution determined by numerical precision

Sampling and limited data



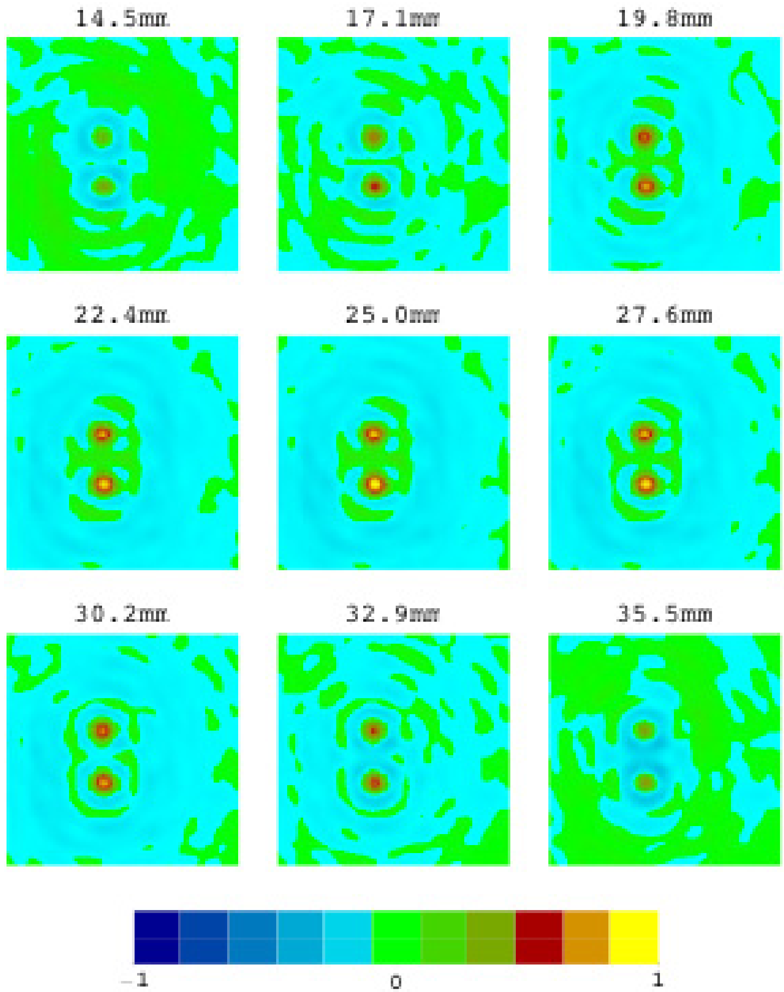
Data set size approximately corresponding to our current experimental set up

Noncontact imager



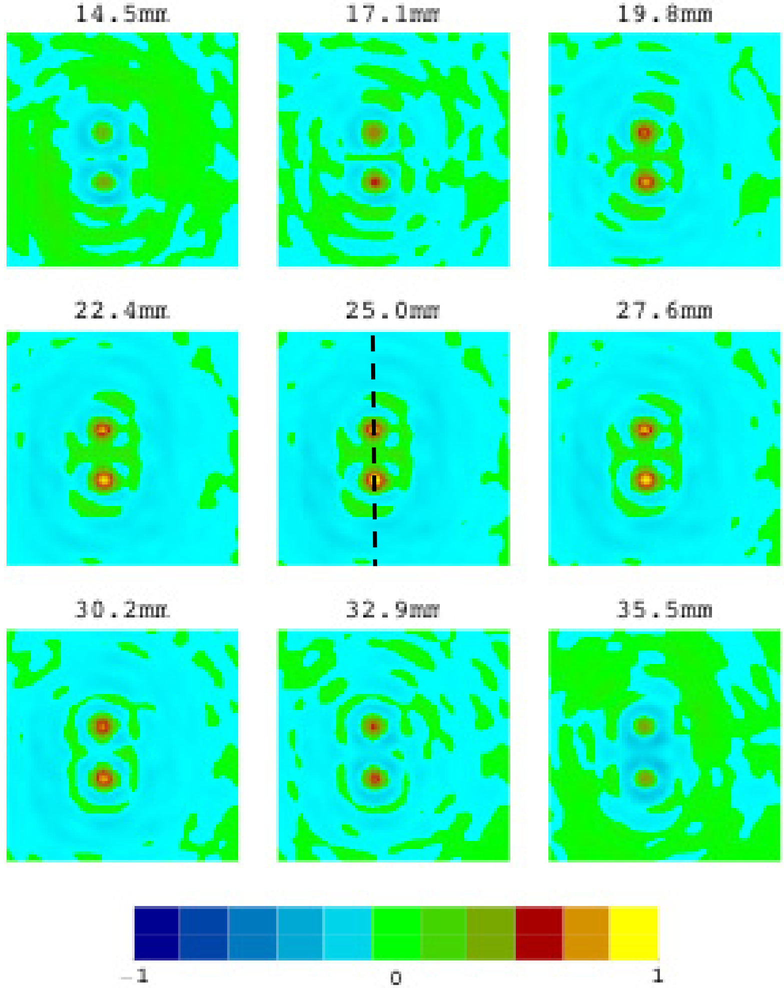
10^8 - 10^{10} source detector pairs

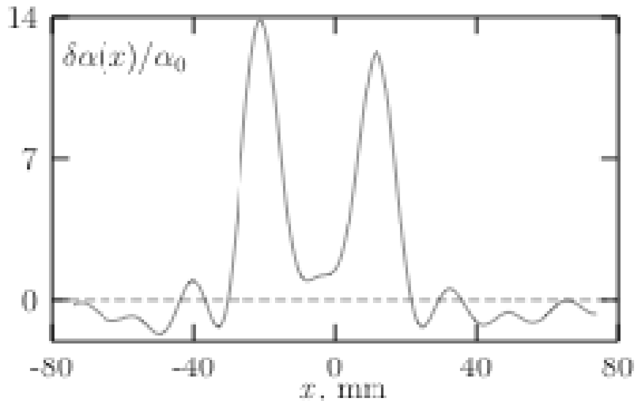
Reconstructions from experimental data



- 10^8 source-detector pairs
- 10^3 sources and 10^5 detectors
- 8 mm diameter black balls in 1% Intralipid
- Balls in midplane of sample
- 50 mm slab thickness
- 2.6 mm slice separation
- 15 cm x 15 cm FOV

Reconstructions from experimental data



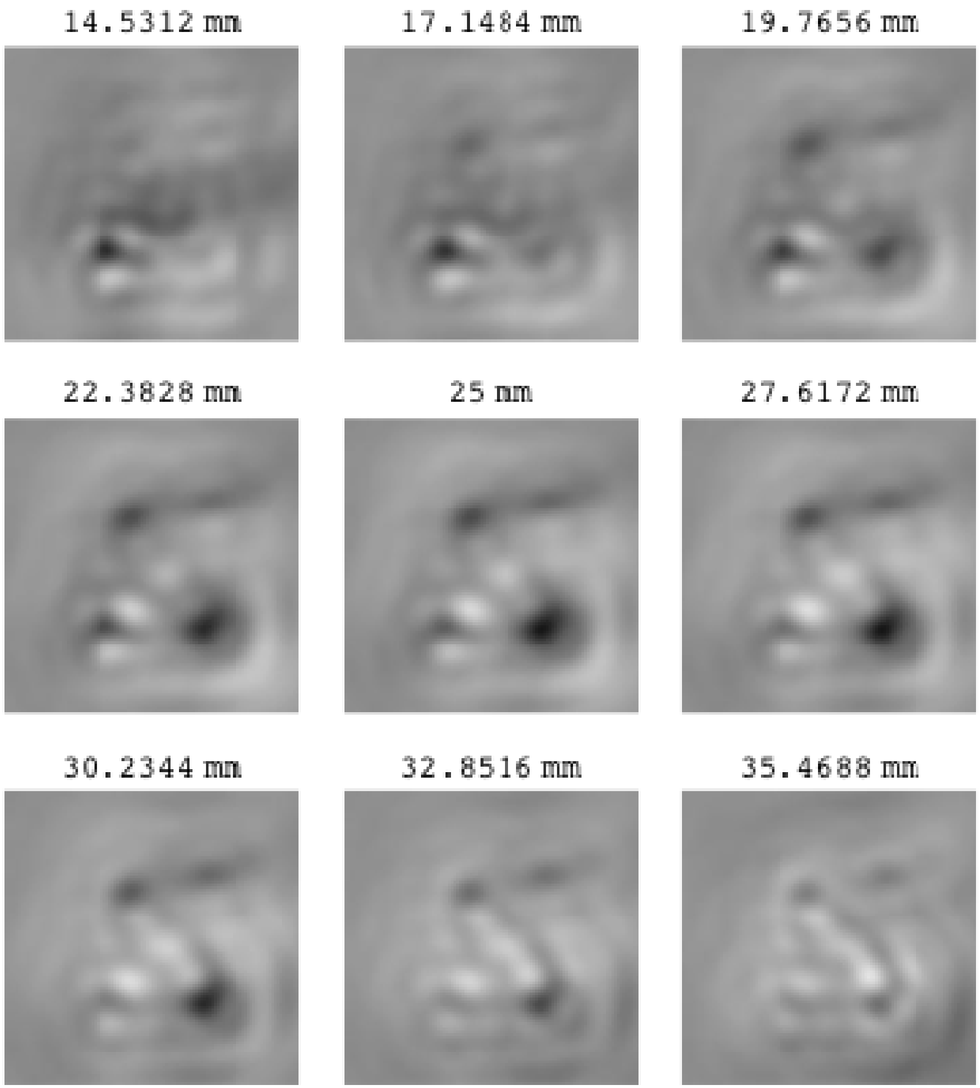


FWHMxy=11 mm

FWHMz=1.5 cm

Separation=3.3 cm

Reconstruction of a chicken wing



- 10^8 source-detector pairs
- 10^3 sources and 10^5 detectors
- 2.6 mm slice separation
- 15 cm x 15 cm FOV

CONCLUSIONS

- We can reconstruct images from large experimental data sets (currently ~10^8 data points)
- Theory and experiment are in agreement at this stage
- Although it is difficult to quantify, image quality seems to be better than in other optical tomography experiments with similar parameters

FUTURE DIRECTIONS

Three known factors that impact image quality in our experiments:

1) Noise
2) Mechanical design and precision
3) Number of sources

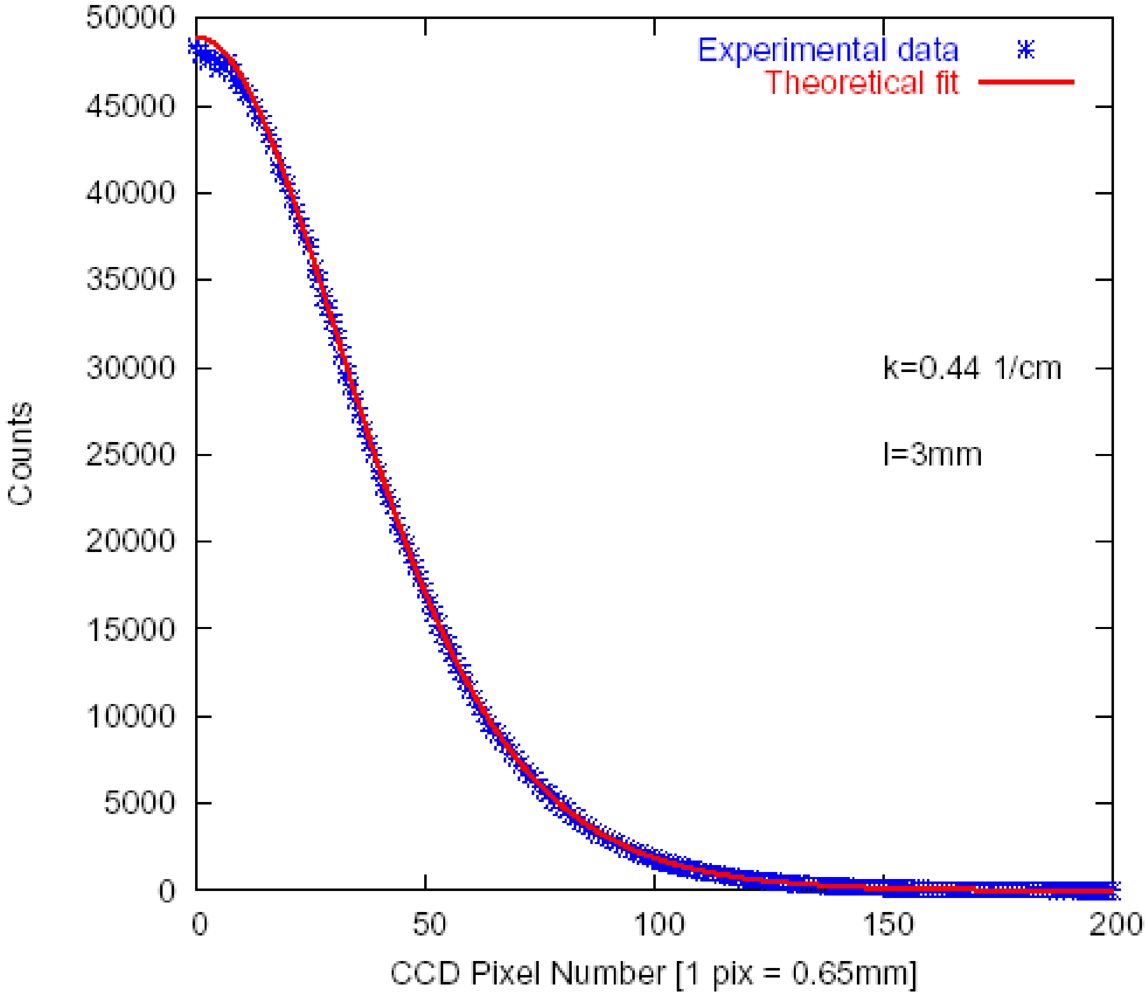
Solutions:

1) Higher laser power, overexposing the tails of transmission function (but not enough is known about the nature of noise at this time …)

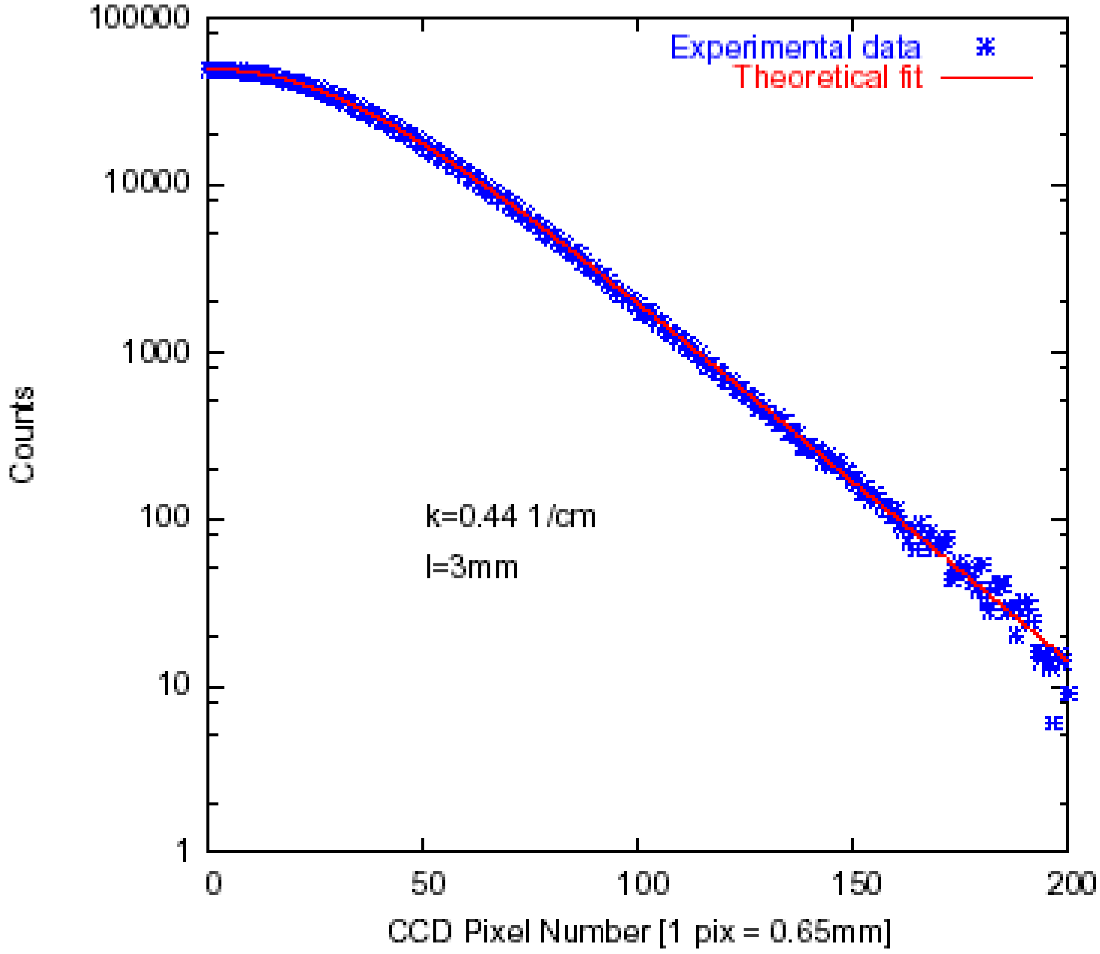
2) Better mechanical precision

3) Using a faster CCD camera (video-rate) will allow us to increase the number of sources by about the factor of 100.

Transmission Through a Slab: Experimental Data vs Theoretical Fit



Transmission Through a Slab: Experimental Data vs Theoretical Fit (LIN –LOG Scale)



ACKNOWLEDGEMENTS

- **COLLABORATORS:** Vivek Mital (Grad. Student), George Panasyuk, Zhengmin Wang, Vitaliy Pustovit (Research Associates), Joseph Sullivan (WashU, EE)
- **FUNDING:** NIH (P41RR0205, R21EB004524)

- **RECENT PUBLICATIONS** (see http://whale.seas.upenn.edu):

2005

G.Y.Panasyuk, J.C.Schotland, and V.A.Markel, "Radiative transport equation in rotated reference frames, " submitted to J.Phys.A. (2005).

Z.Wang, G.Y.Panasyuk, V.A.Markel, and J.C.Schotland, "Experimental demonstration of an analytic method for image reconstruction in optical tomography with large data sets," submitted to Opt. Lett. (2005).

G.Y.Panasyuk, V.A.Markel, and J.C.Schotland, "Superresolution and corrections to the diffusion approximation in optical tomography," submitted to Appl. Phys. Lett. (2005).

V.A.Markel, J.C.Schotland, "Multiple projection optical diffusion tomography with plane wave illumination," Physics in Medicine and Biology, 50(10), 2351 (2005).

2004

V.A.Markel, J.C.Schotland, "Symmetries, inversion formulas and image reconstruction for optical tomography," Phys. Rev. E 70(5), 056616 (2004).

V.A.Markel, J.C.Schotland, "Dual-projection optical diffusion tomography," Opt. Lett. 29(17), 2019 (2004).

V.A.Markel, "Modified spherical harmonics method for solving the radiative transport equation," Waves in Riandom Media 14(1), L13 (2004).

V.N.Pustovit, V.A.Markel, "Propagation of diffuse light in a turbid medium with multiple spherical inhomogeneities," Appl. Opt. 43(1), 104 (2004).

2003

V.A.Markel, J.A.O'Sullivan, J.C.Schotland, "Inverse problem in optical diffusion tomography. IV. Nonlinear inversion formulas," JOSA A 20(5), 903 (2003).

V.A.Markel, V.Mital, J.C.Schotland, "Inverse problem in optical diffusion tomography. III. Inversion formulas and singular value decomposition," JOSA A 20(5), 890 (2003).

2002

V.A.Markel, J.C.Schotland, "Effects of sampling and limited data in optical tomography," Appl. Phys. Lett. 81(7), 1180 (2002).

V.A.Markel, J.C.Schotland, "Scanning paraxial optical tomography," Opt. Lett. 27(13), 1123 (2002).

V.A.Markel, J.C.Schotland, "The inverse problem in optical diffusion tomography. II. Inversion with boundary conditions," JOSAmerica A 19(3), 558 (2002).

2001

V.A.Markel, J.C.Schotland, "Inverse scattering for the diffusion equation with general boundary conditions," Phys. Rev. E 64(3), R035601 (2001).

J.C.Schotland, V.A.Markel, "Inverse scattering with diffusing waves," JOSA A 18(11), 2767 (2001).

V.A.Markel, J.C.Schotland, "The inverse problem in optical diffusion tomography. I. Fourier-Laplace inversion formulas," JOSA A 18(6), 1336 (2001).