Comparison of Diffusion and Transport in Human Head

Comparison of Monte Carlo and Finite Difference predictions of near-infrared light propagation in realistic adult head model

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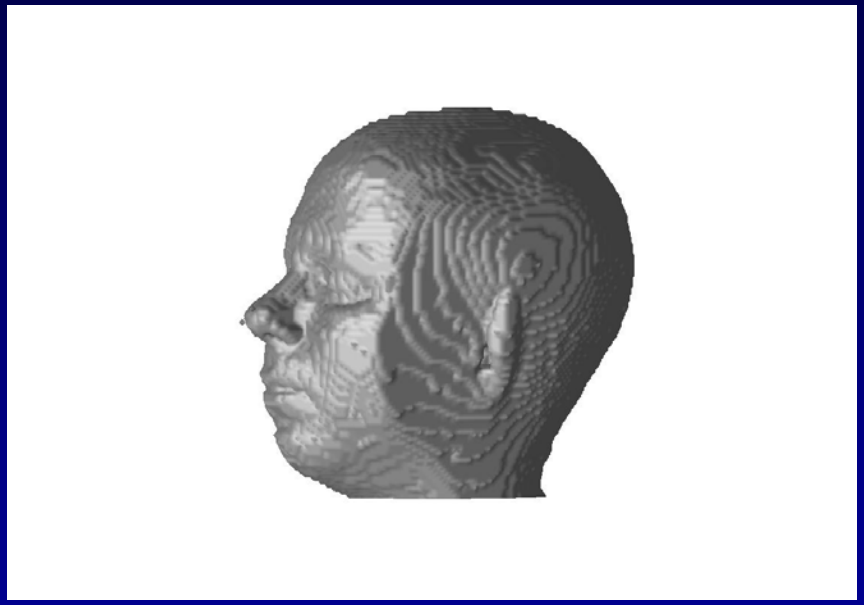
Outline

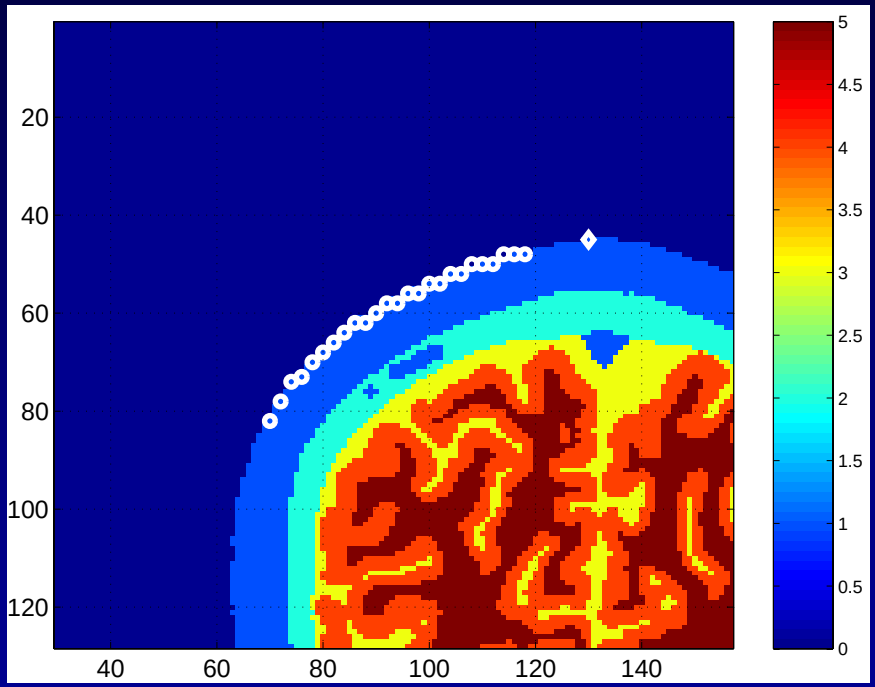
- Overview of the problem and framework
- Two (related) questions:
  - Monte Carlo (MC) or Finite Difference (FD)?
  - Cerebral Spinal Fluid (CSF) optical properties? CSF modelling?
- Our model:
  - Head geometry and probe
  - Tests and setup
  - Results
  - Starting the inverse problem…
- Conclusions
- Future work

Diffuse Optical Tomography (DOT)

- Biological tissue imaging: brain and breast
- Brain
  - Baseline
  - activation: why?
- Head geometry: MRI structural data…
  - Optical properties (5): absorption coefficient (μ_a) and scattering coefficient (μ_s)
  - Probe and opdotes structure

Adult head geometry





Monte Carlo (MC)

- Based on Transport equation
- Pro
  - accuracy
  - robustness
- Cons
  - Computational cost
  - Low Signal to Noise Ratio (SNR)

Finite Difference (FD)

- Based on Diffusion Approximation (DA)
- Cons: limited by
  - Boundary Conditions (BC)
  - rough surface
  - small scattering
- Pro
  - Computational cost
  - Good Signal to Noise Ratio (SNR)

Monte Carlo (MC) vs. Finite Difference (FD)

- When can we rely on the faster FD?
  [CSF]
- How much can we rely on FD?
  [qualitative-quantitative tests]
- How can we improve FD response?
  [finer lattice plus zero-padded head]
- How much does MC-FD discrepancy affect the optical properties restoration?
  [inverse problem exploration]

Brain activation overview

- Brain activity: BOLD, CBF, CBV, Hbr and HbO

$$(1+rCMRO_2)=(1+rCBF)(1+rCBV_{ven})^{-1}(1+rHbr_{ven})$$

- Measuring Hemodynamic: hemoglobin concentration

$$SO_2=\frac{[HbO_2]}{[HbO_2+Hbr]}$$

$$\begin{cases}\mu_{a,780}=c[Hbr]\cdot\varepsilon_{[Hbr],780}+c[HbO_2]\cdot\varepsilon_{[HbO_2],780}\\ \mu_{a,830}=c[Hbr]\cdot\varepsilon_{[Hbr],830}+c[HbO_2]\cdot\varepsilon_{[HbO_2],830}\end{cases}$$

Tests overview

- Frequency = 0
- Continuous Waves (CW) and Time Domain (TD)
- MC SNR: combination of 11 runs (x100 million photons)
- Linear probe (1 source, 25 detectors)
- Optical properties:

Tissue type	Absorption coefficient (mm^{-1})	Scattering coefficient (mm^{-1})
Scalp and Skull	0.019	0.86
CSF	0.004	1.0, 0.7, 0.1, 0.2, 0.3, 0.01, 0.001
Gray and White matter	0.01	1.11

Tests overview

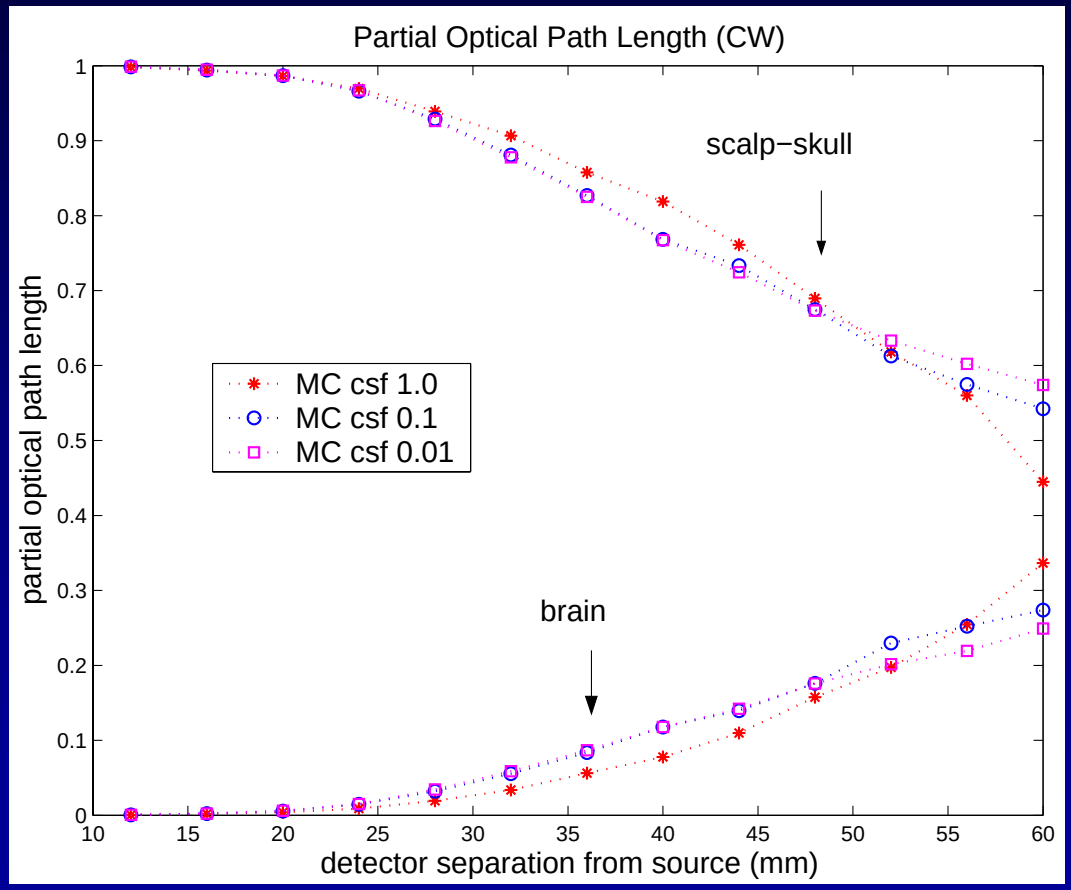
- TPSF: Temporal Point Spread Function
- PPF: Partial Optical Path Length Factor

$$\frac{\partial f(t)}{\partial \mu_{a_i}} = \frac{\left(f_{\mu_{a0}}(t) - f_{\mu_{ai}}(t)\right)}{\Delta \mu_a}$$

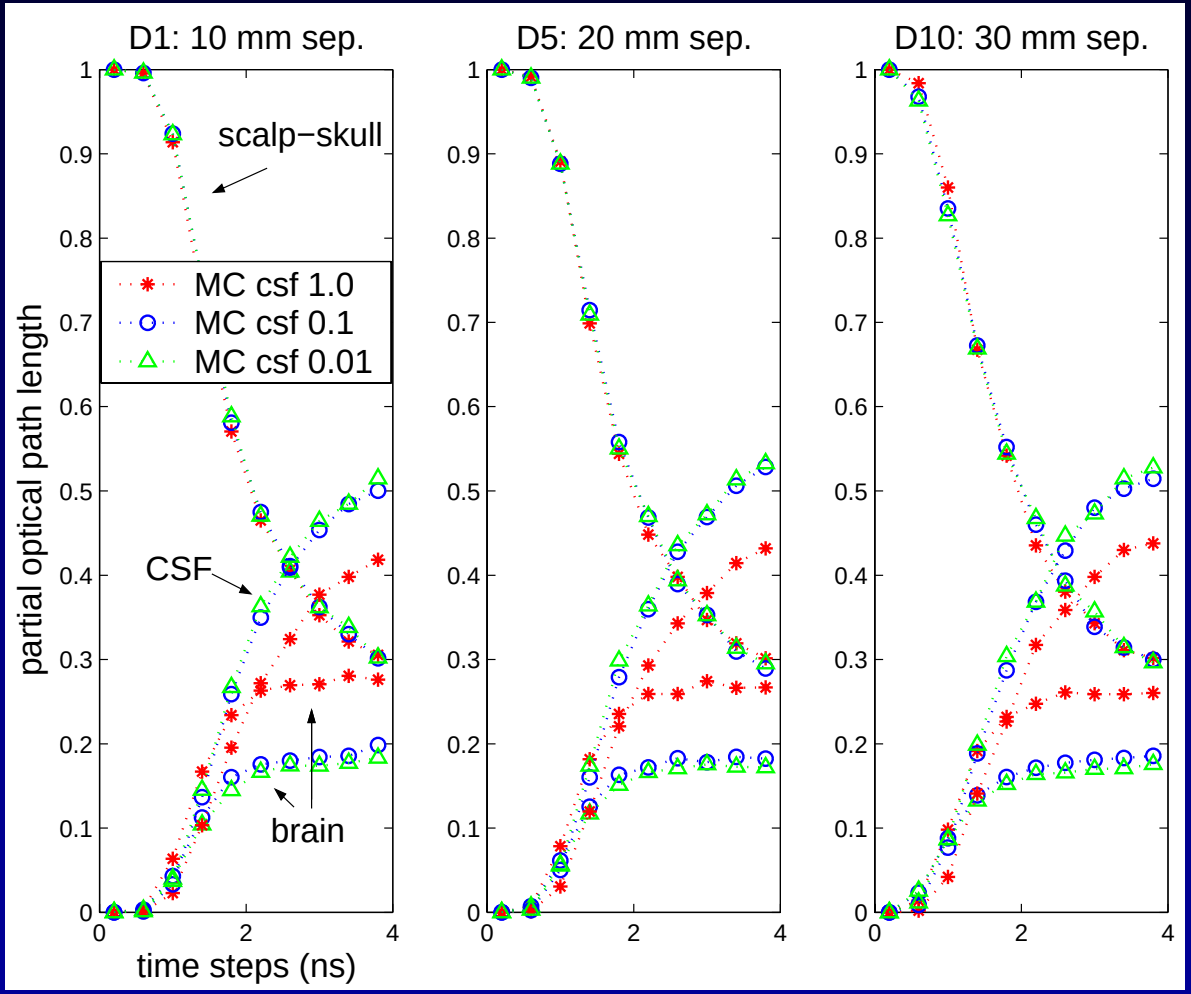
- CW: Continuous Wave (spatial sensitivity profile)
- Test structure
  - Pre-tests on MC
  - Pre-tests on FD finer lattice
  - Tests on MC v. FD

Pre-tests: CSF [CW]

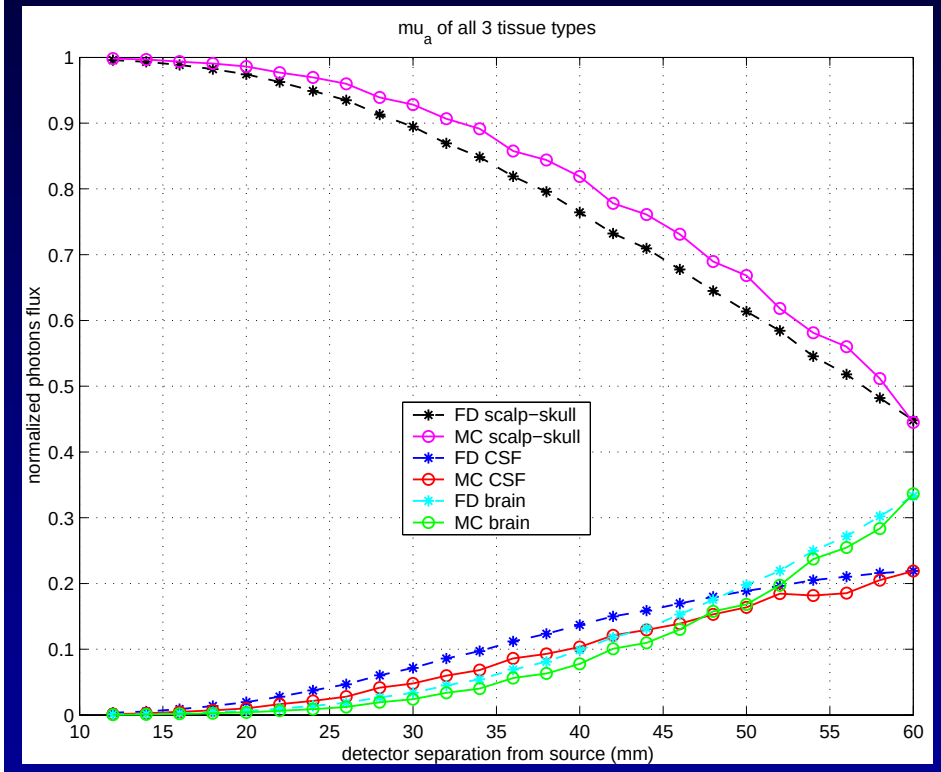
CSF scattering coefficient estimation (via MC CW and TD simulations)

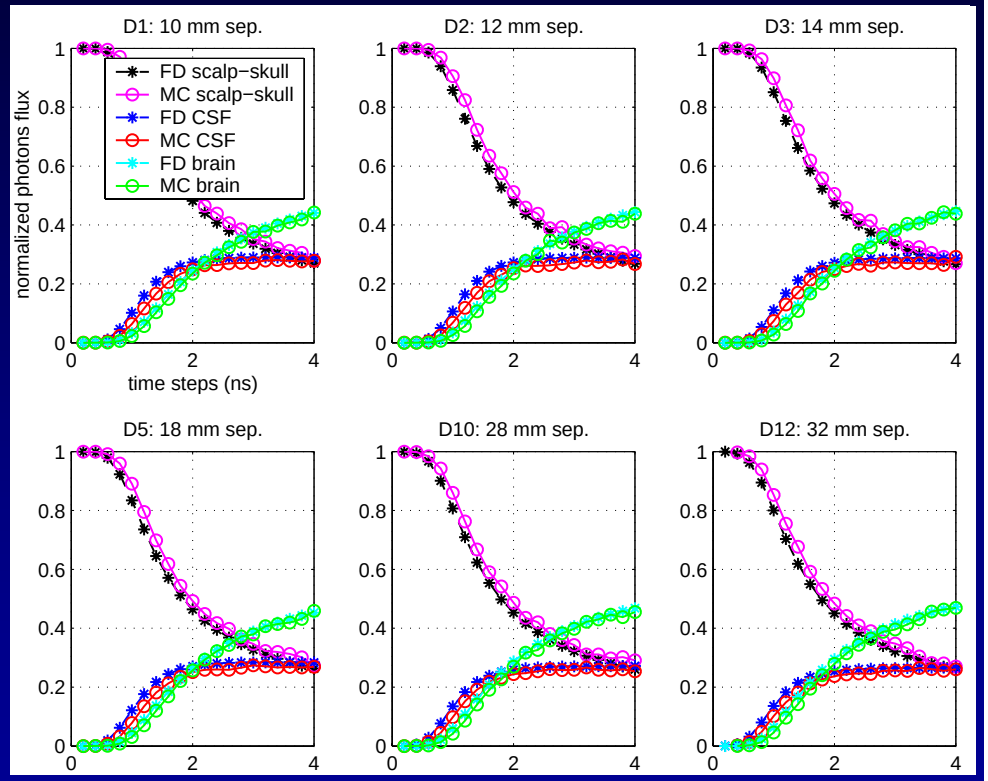


Pre-tests : CSF [TD] II



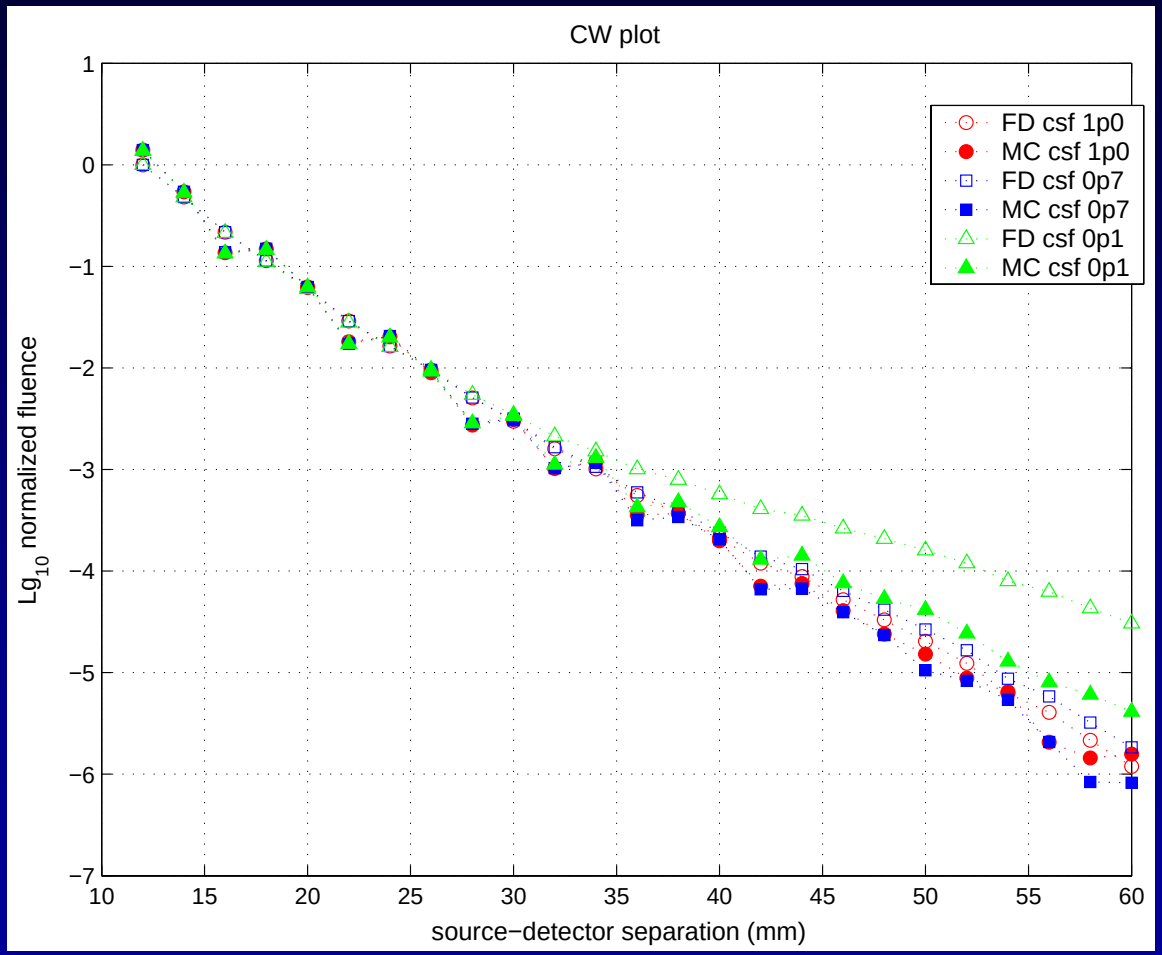
Pre-tests: finer lattice III



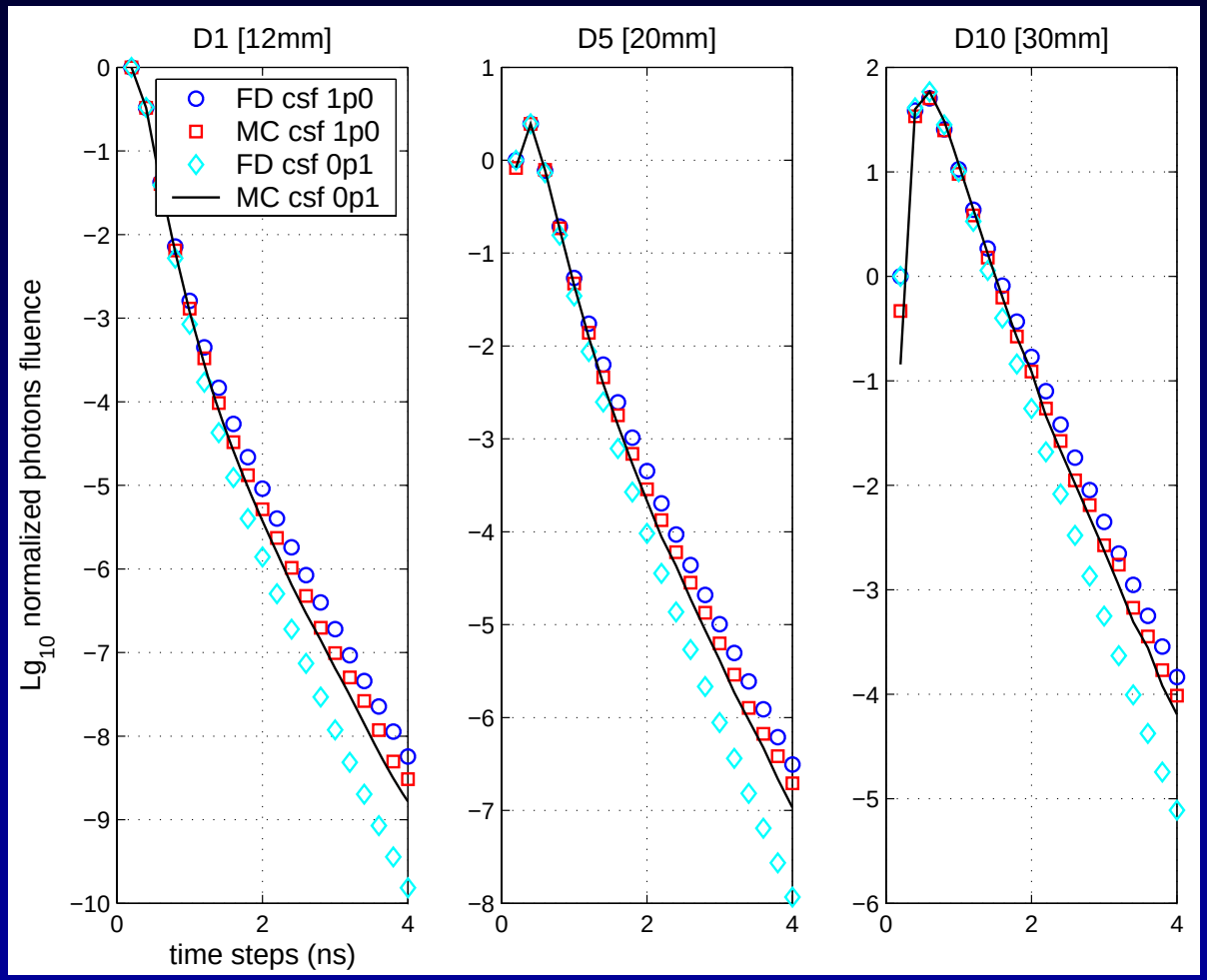


FD dx 1 mm; $\mu_{s,CSF}$ 1.0 mm^{-1}

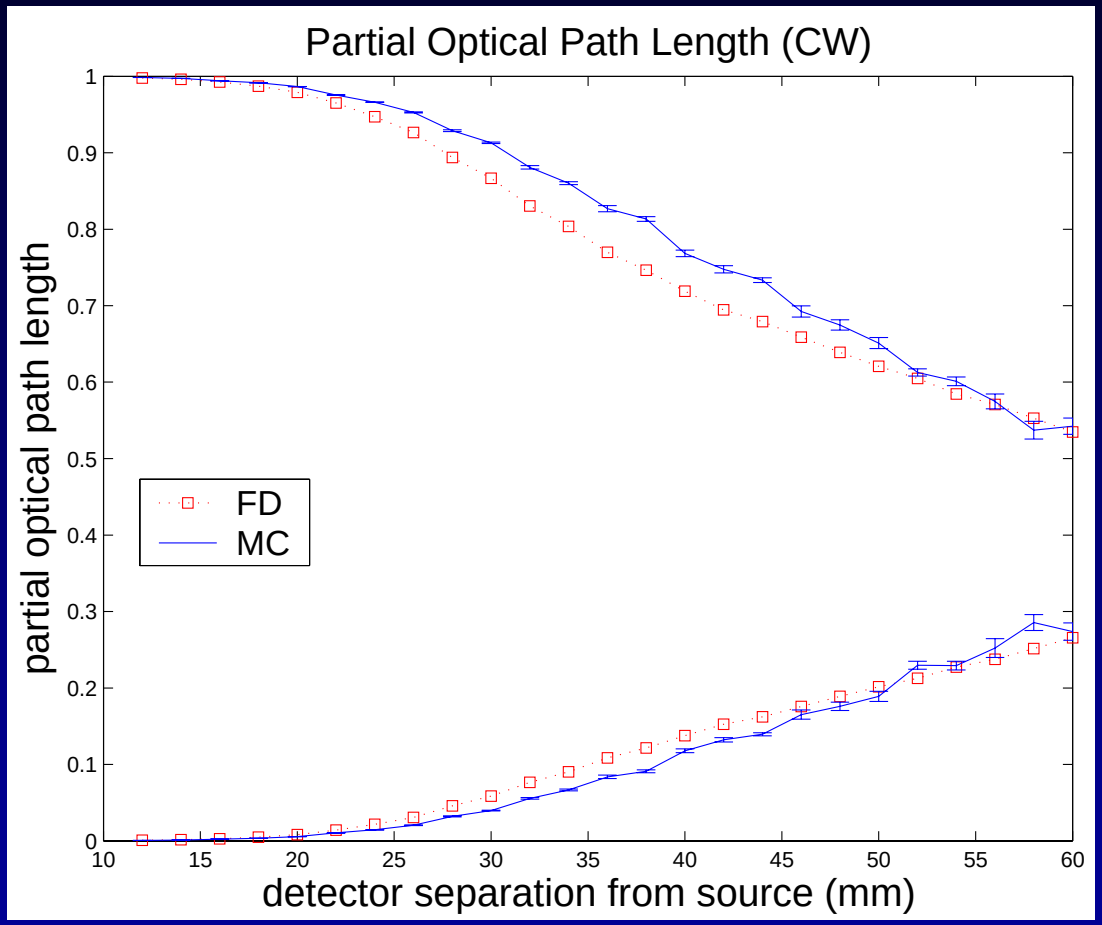
Results: Spatial Sensitivity Profile



Results: TPSF

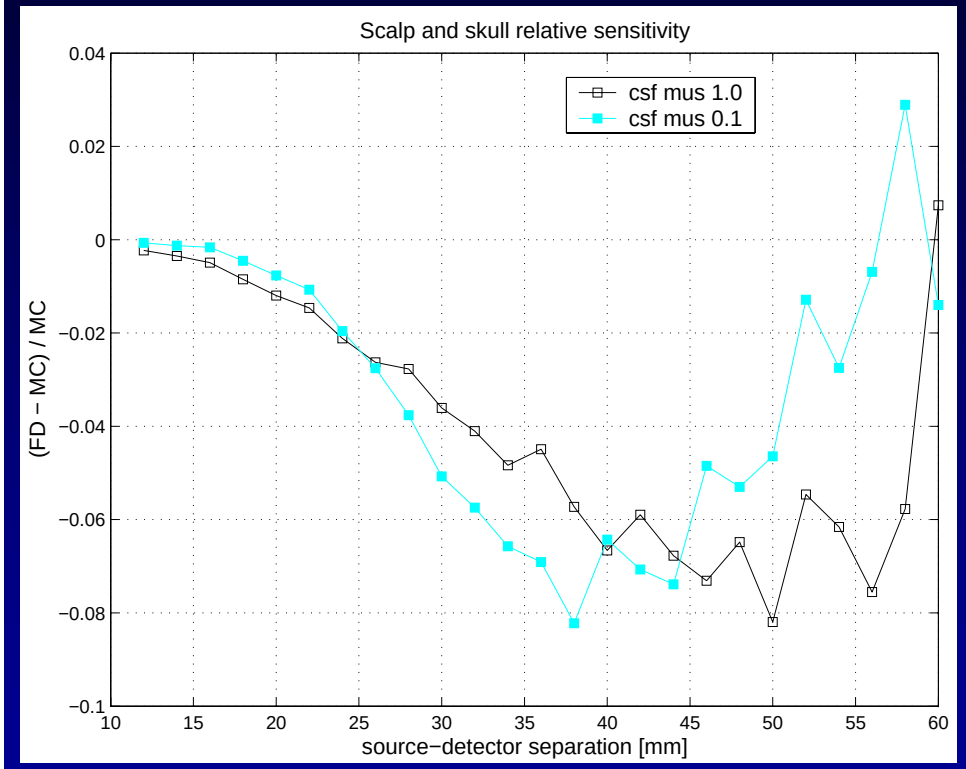


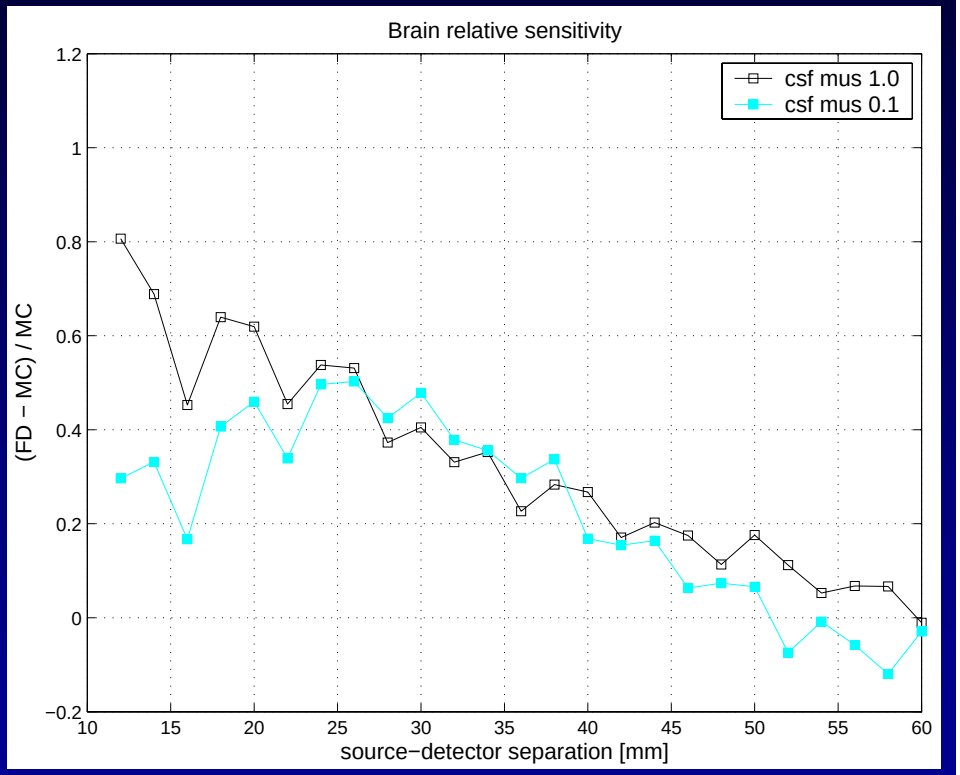
Results: Partial Optical Path-Length



PPF MC v. FD (dx 1 mm) [CW $\mu_{s,CSF}$ 0.1 mm^{-1}]

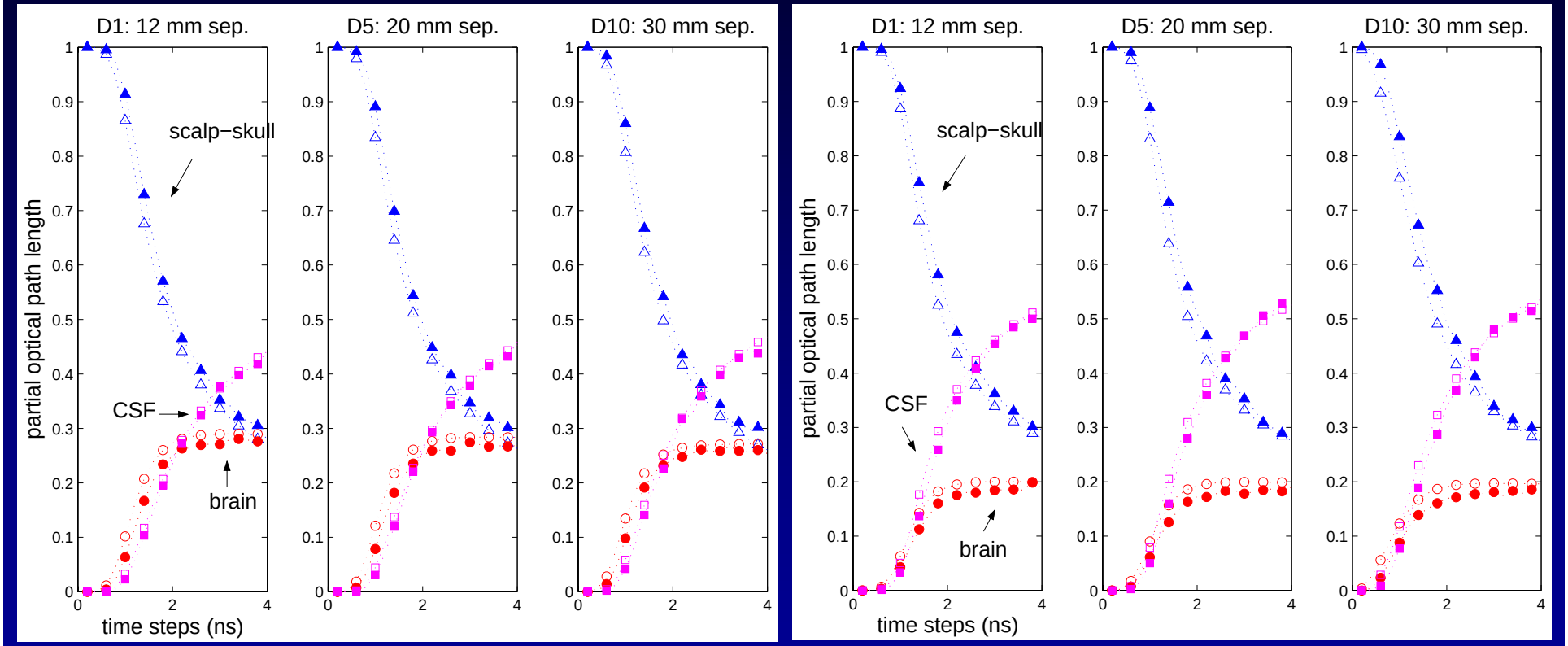
Results: Partial Optical Path-Length





PPF MC and FD relative discrepancy [CW]
[w.r.t. MC]

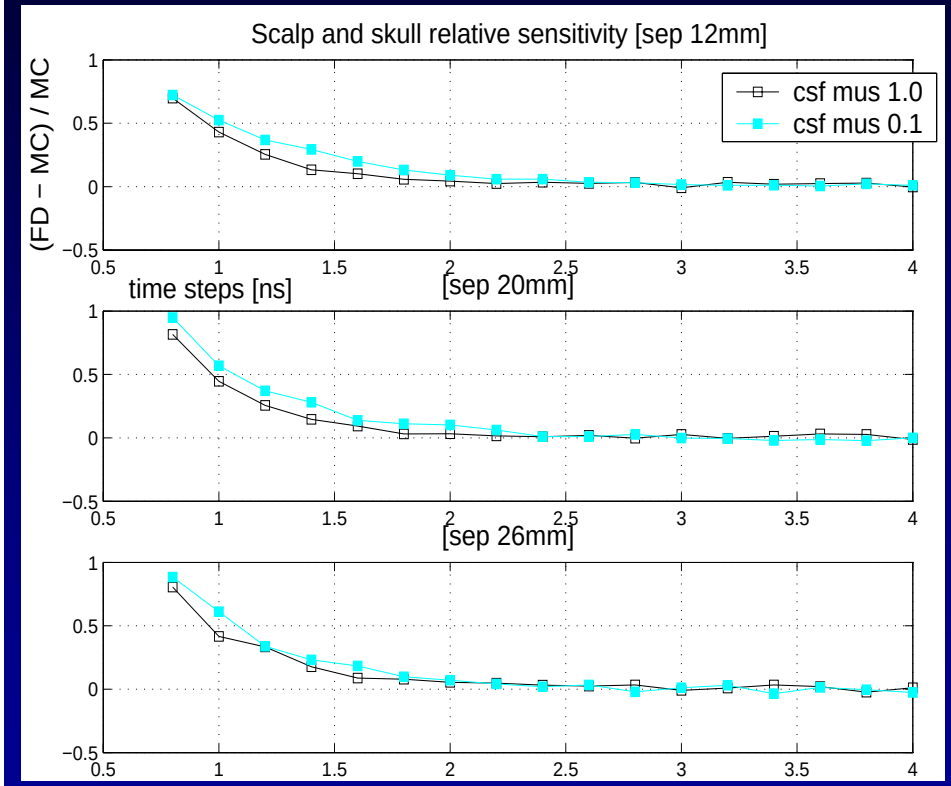
Results: Partial Optical Path-Length

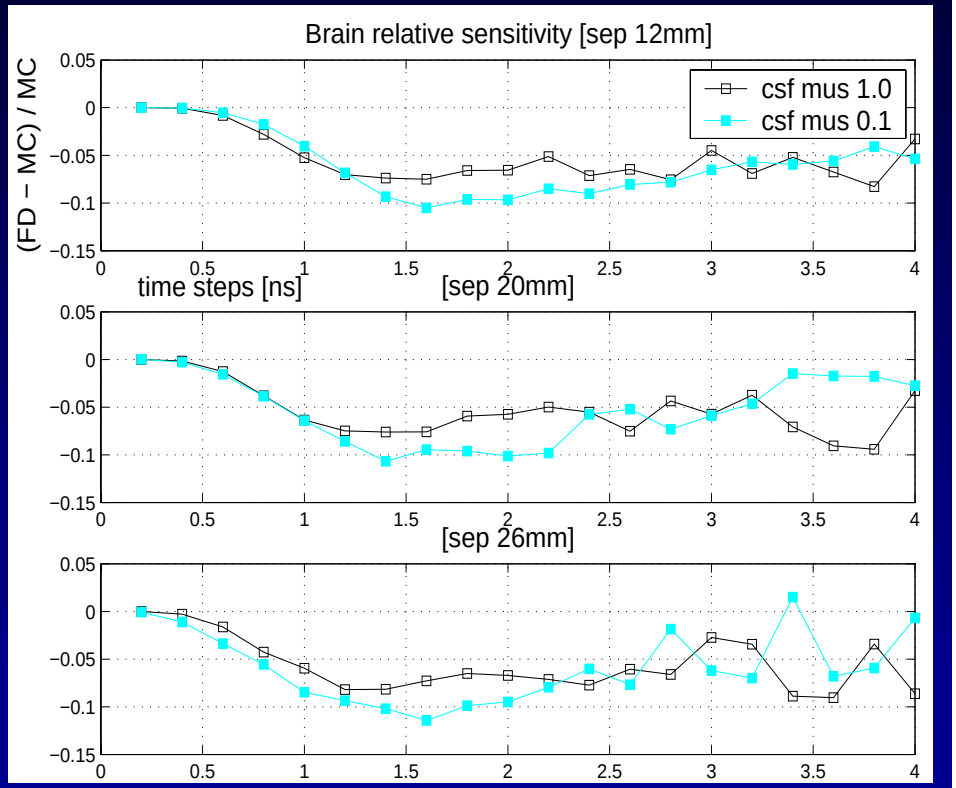


PPF MC v. FD (dx 1 mm) [TD]

[right μs,CSF 1.0 mm^{-1}; left $\mu_{s,CSF}$ 0.1 mm^{-1}](full MC, empty FD)

Results: Partial Optical Path-Length





PPF MC and FD relative discrepancy [TD]
[w.r.t. MC]

Conclusions

- FD reliable for “reasonable” optical properties:
  - CSF: good characterization
  - Accurate head model
  - Finer lattice improves FD reliability but increases run time (zero-padding)

Future work

- Forward model:
  - BC for FD
  - Finer lattice (smoother edges)
  - Use all 5 tissue types
  - Combine multiple sources
  - Use multiple wavelengths
- Inverse model:
  - Tune optimal parameters and stopping criteria
  - Regularization parameters
  - Linear and Non-linear approaches
  - Comparing various inverse techniques

Thank you!

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...Questions?

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