SPIE Photonics West

# Model-based design of optical diagnostic instrumentation

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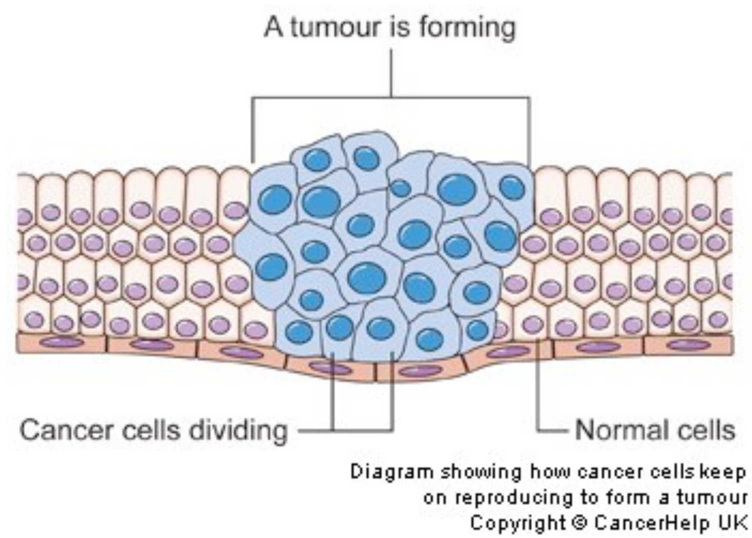
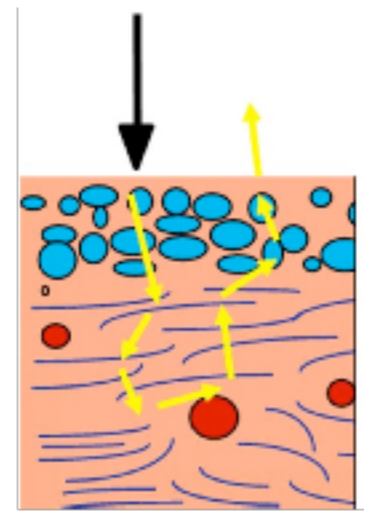
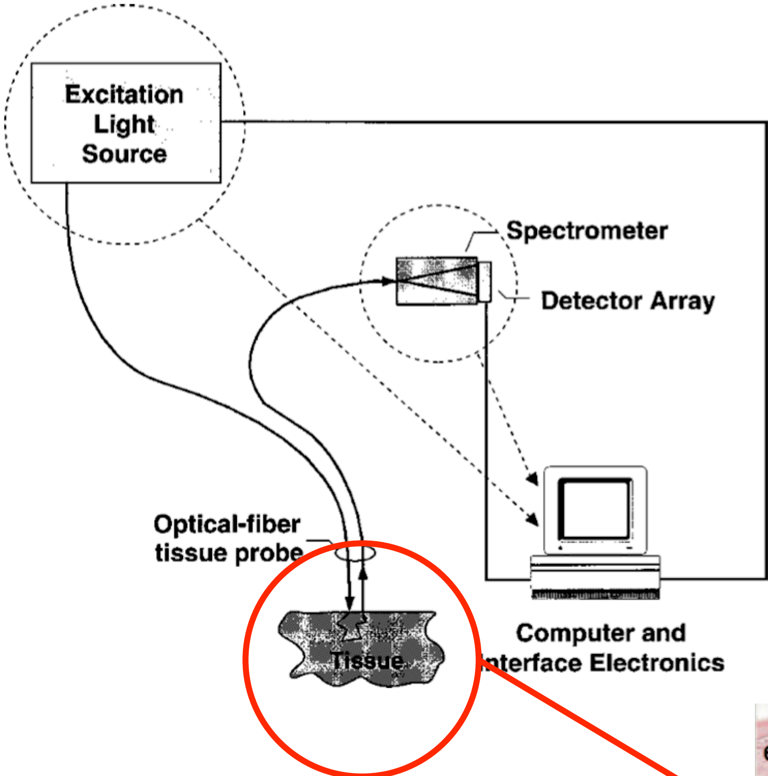
# How optical methods capture cancer information

- Cancer causes morphological and biochemical changes in cells
- Morphological and biochemical changes perturb the interaction of light with tissue
- These interactions are monitored optically



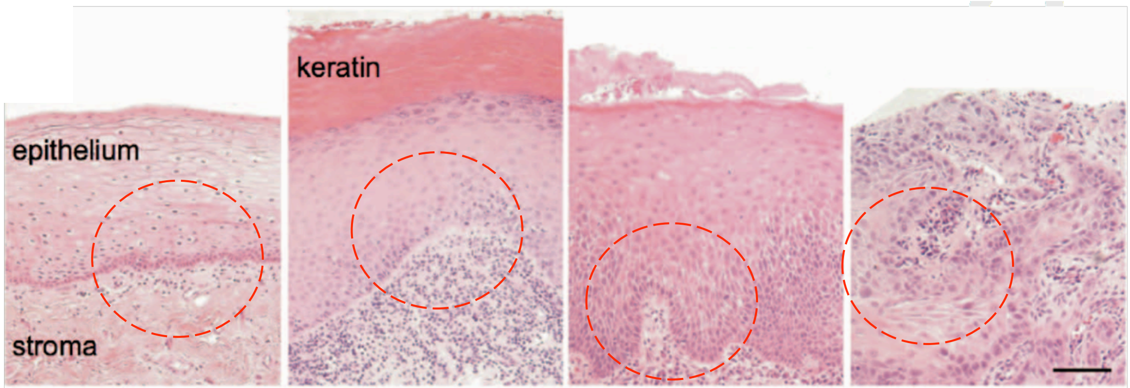



# Background and Targets for Optical Biopsy




Target signals…

- Contain cancer/precancer information
- Are what pathologists observe from tissue samples
- Are the goals for optical biopsy

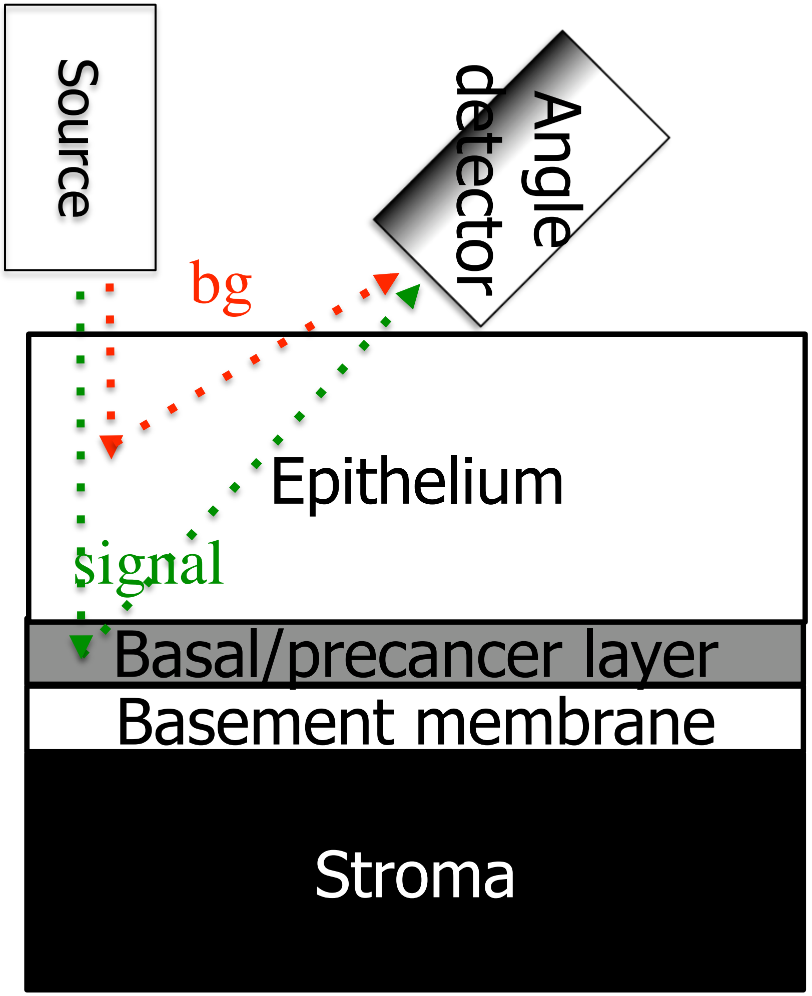



(a) Normal (b) Benign (c) MD (d) SD

- Sciubba, J. Oral cancer and its detection *The Journal of the American Dental Association, Am Dental Assoc,* **2001**

# Fundamental Questions

- How much detected light is from the layer that we "really" care about?
- In other words, what is the Target Signal Ratio (TSR)?

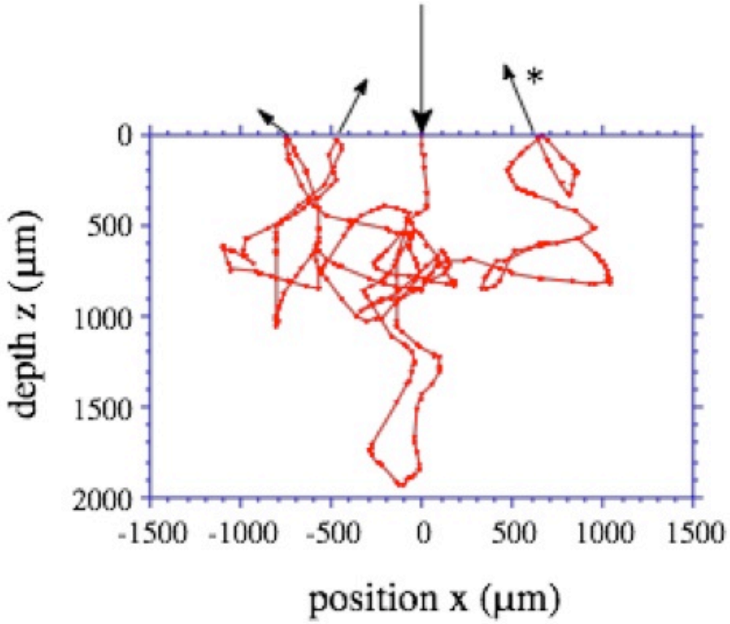


# What is Monte Carlo?

- Computational algorithms that rely on repeated **random sampling** to compute their results
- Invented by Stanislaw Ulam in 1946
- Name came from Monte Carlo Casino in Monaco
- Monte Carlo method is…
  - a statistical description of the whole system
  - flexible in tissue environment setting
- More accurate if more repetitions used

# A photon’s life (in simulation)

- Photon travels in straight line until an event happens:
  - Absorption
    - weight decreases
  - Scattering
    - weight remains
    - change travel direction
- Pol-MC*:
  - Stokes parameter S=(I, Q, U, V) defines polarization direction
  - Mueller matrix is the operator to modify polarization direction
  - Mueller matrix is calculated based on Mie theory (SCATMECH library)
  - Scattering angles: Jaillon sampling

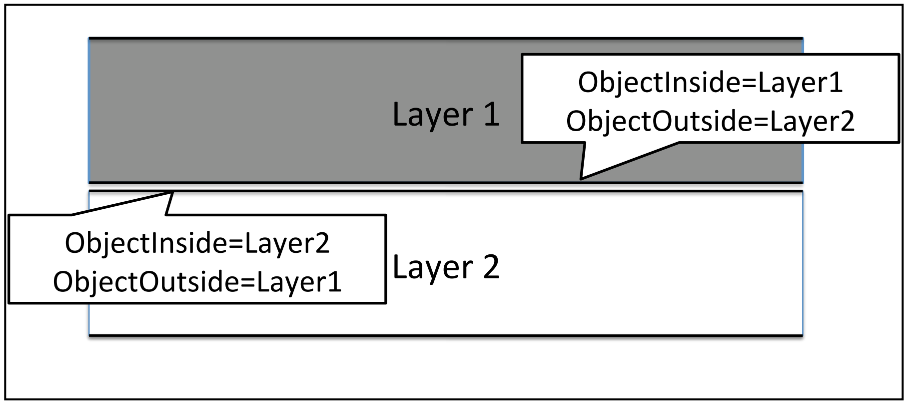


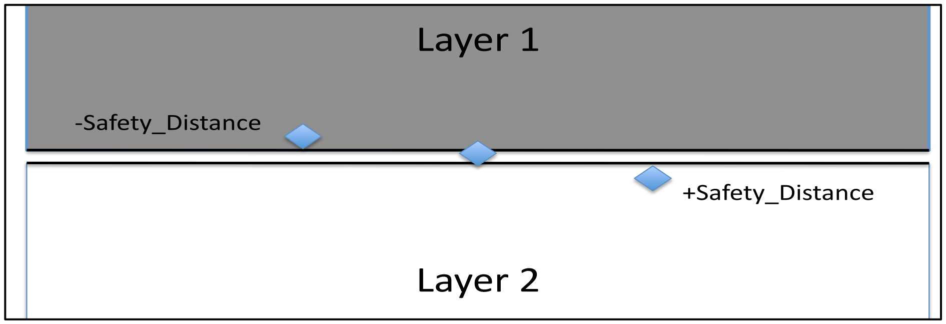

Jaillon, F. & Saint-Jalmes, H. “Description and Time Reduction of a Monte Carlo Code to Simulate Propagation of Polarized Light through Scattering Media
*Appl. Opt., OSA*, **2003**, *42*, 3290-3296

*Côté, D. & Vitkin, I. Robust concentration determination of optically active molecules in turbid media with validated three-dimensional polarization sensitive Monte Carlo calculations, *Optics Express, OSA,* **2005**

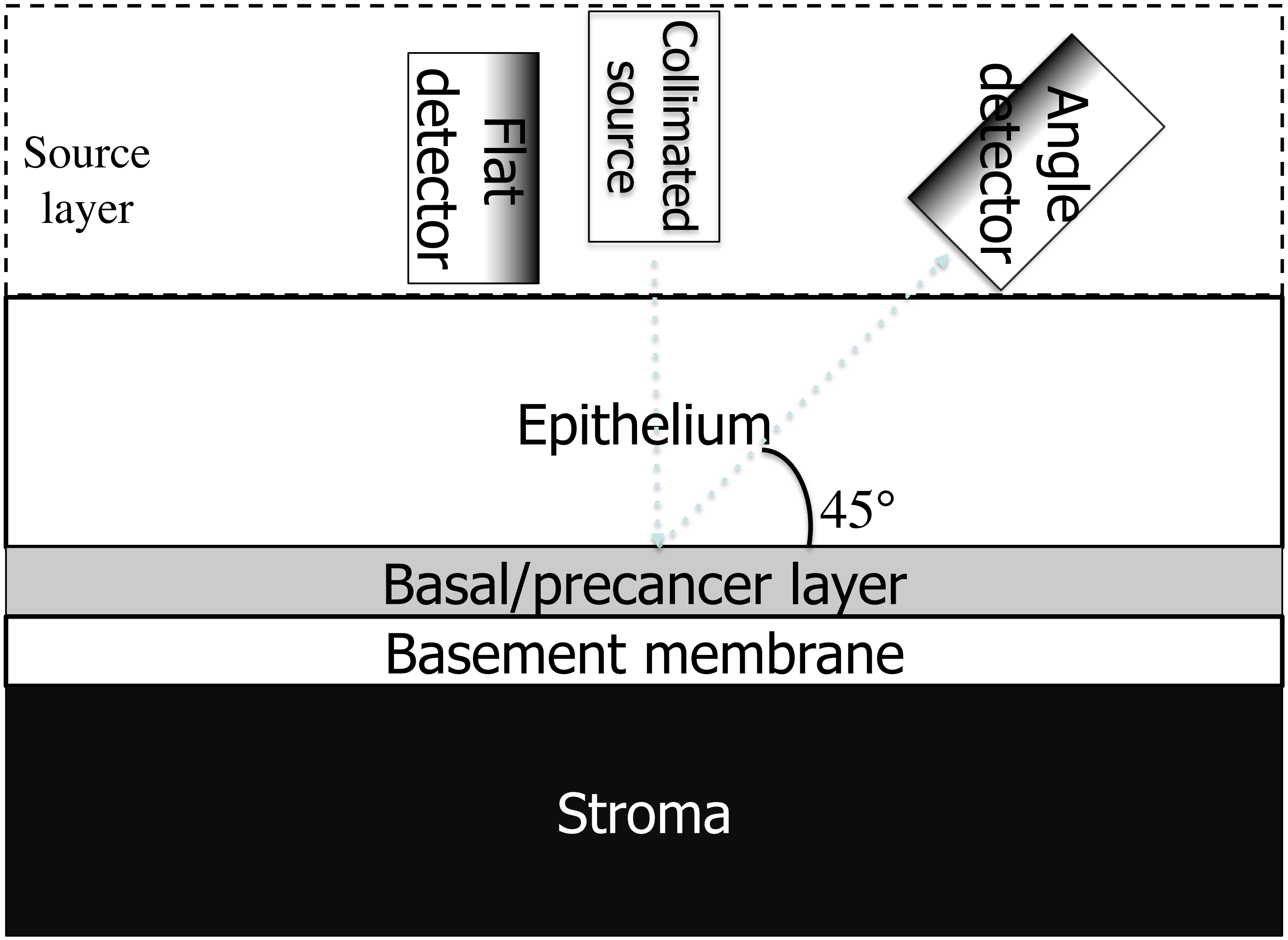
# Contributions to Pol-MC

- Multiple layers implementation
- More advanced geometry checks
- Parallel computing
- Features for “Inside-the-box” simulation



# Simulation geometry setting



# Simulation tissue parameters

| | thickness ($\mu m$) | scattering | g | index(media) | index(scatterer) | $\mu_a$ | $\mu_s$ | scatterer radius($\mu m$) |
|---|---|---|---|---|---|---|---|---|
| Source layer | 10000 | HG** | 0.5 | 1.335 | — | 0.1 | 1 | — |
| Epithelium | varies | Jaillon | — | 1.369 | 1.41 | 1 | 100 | 6 |
| Basal layer | varies | Jaillon | — | 1.369 | 1.41 | 1 | 120 | varies |
| Stromal membrane | 30 | HG** | 0.5 | 1.41 | — | 1 | 0 | — |
| Stroma | 1000 | Jaillon | — | 1.369 | 1.41 | 1 | 150 | 6 |

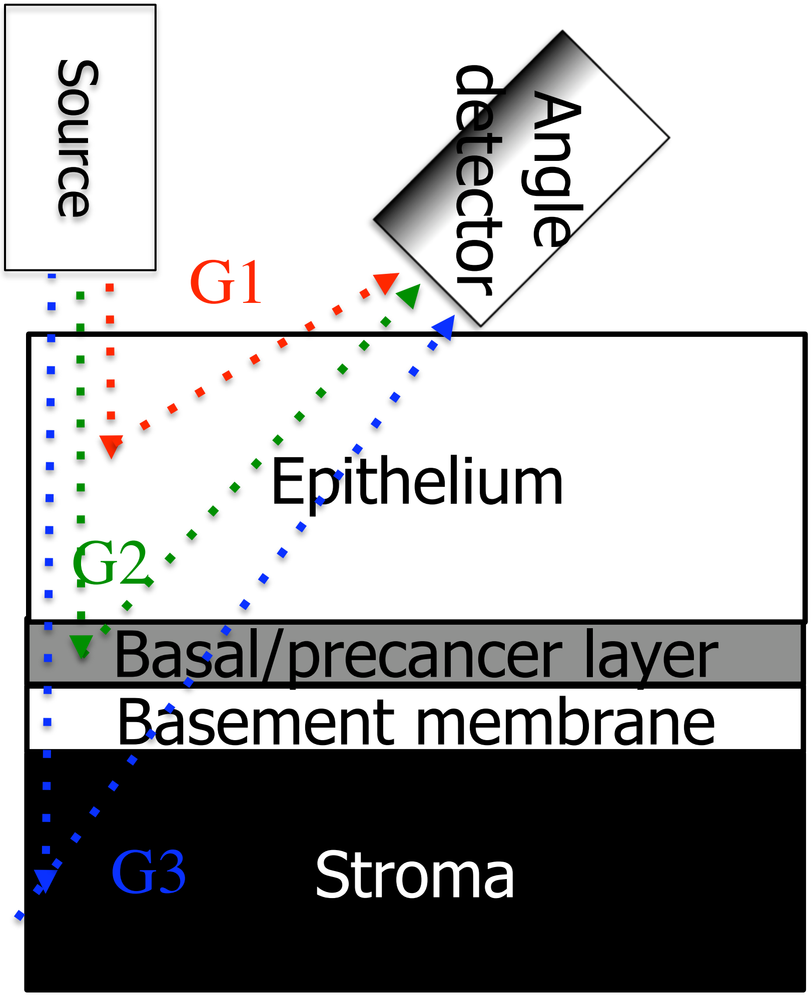
| thickness and radius ($\mu m$) | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Source layer | 10000 | 10000 | 10000 | 10000 |
| Epithelium | 250 | 250 | 230 | 190 |
| Basal layer | 20 | 20 | 40 | 80 |
| Stromal membrane | 30 | 30 | 30 | 30 |
| Stroma | 1000 | 1000 | 1000 | 1000 |
| Basal layer scatterer radius | 6 (normal) | 8 (abnormal) | 8 (abnormal) | 8 (abnormal) |

# Target Signal Ratio calculation and photon categories

Categories of photons: G1,G2,G3

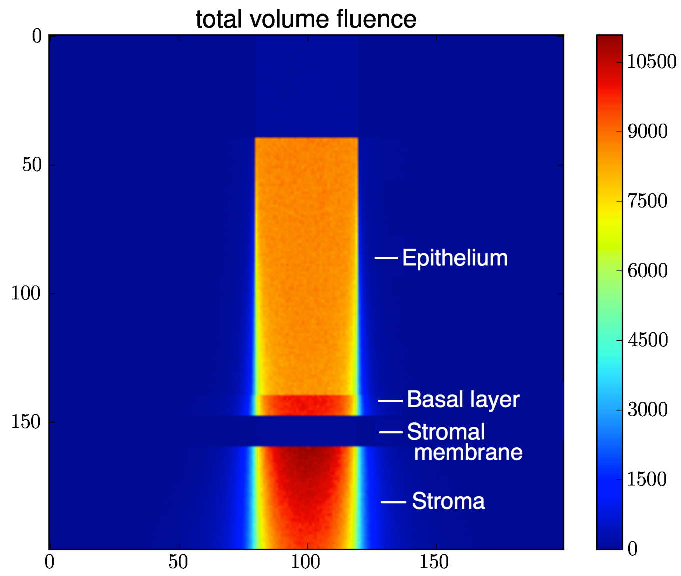
Definition of TSR:

$$TSR = \frac{\sum w_{G2}}{\sum w_{G1} + \sum w_{G3}}$$

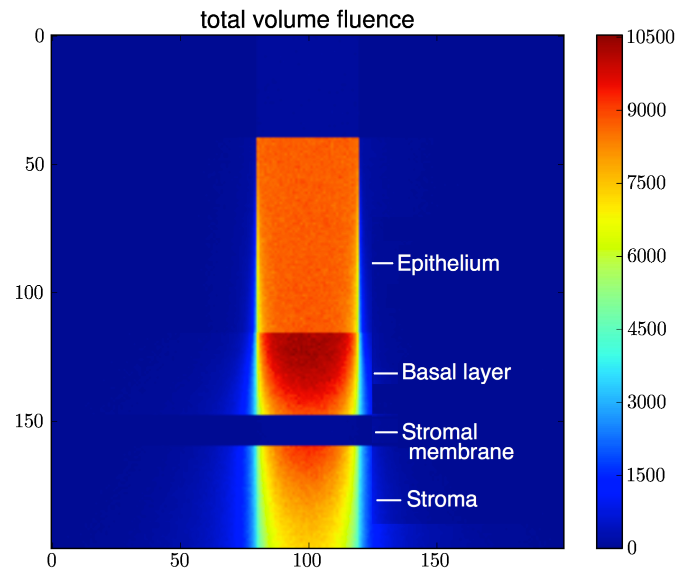


# Results: Fluence plots

Model 2
Basal thickness=20

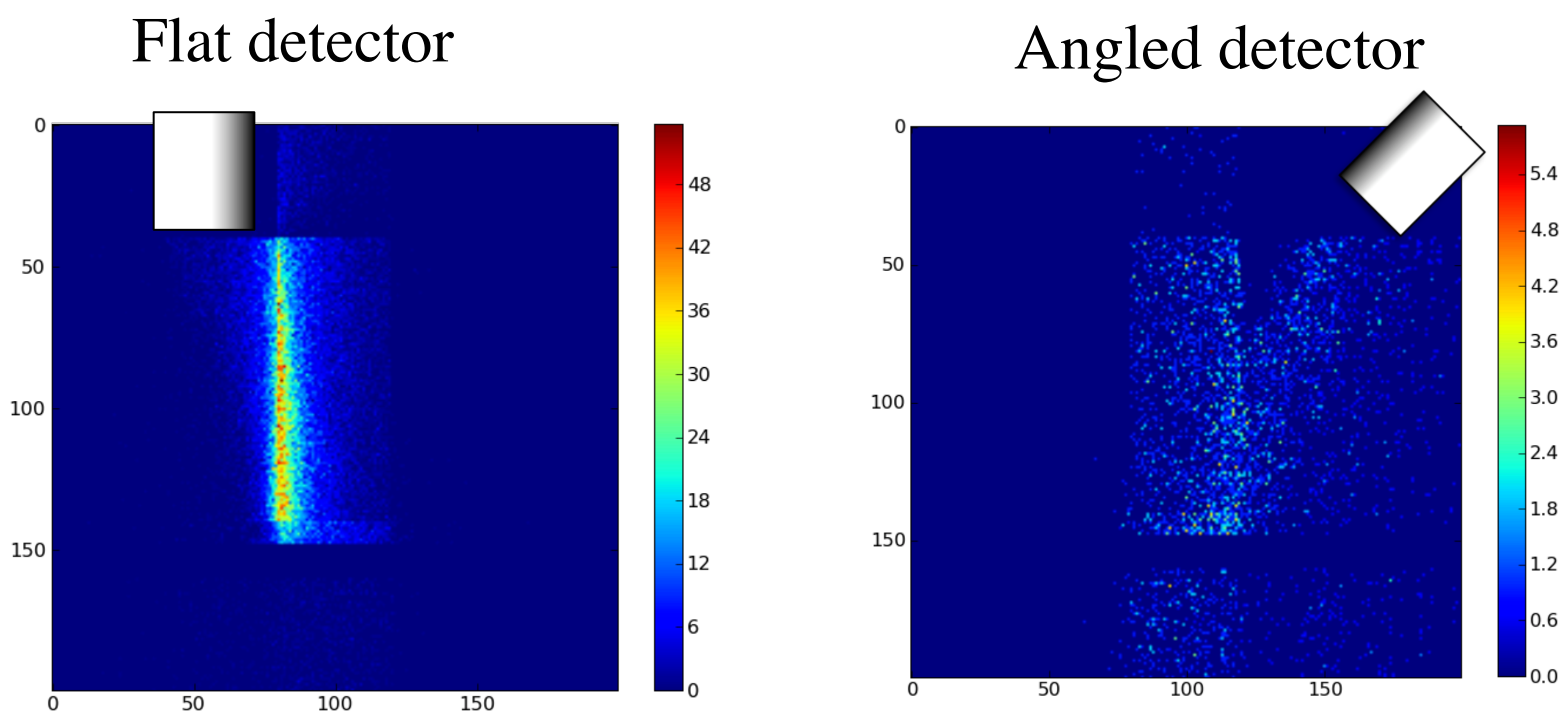



Model 4
Basal thickness=80



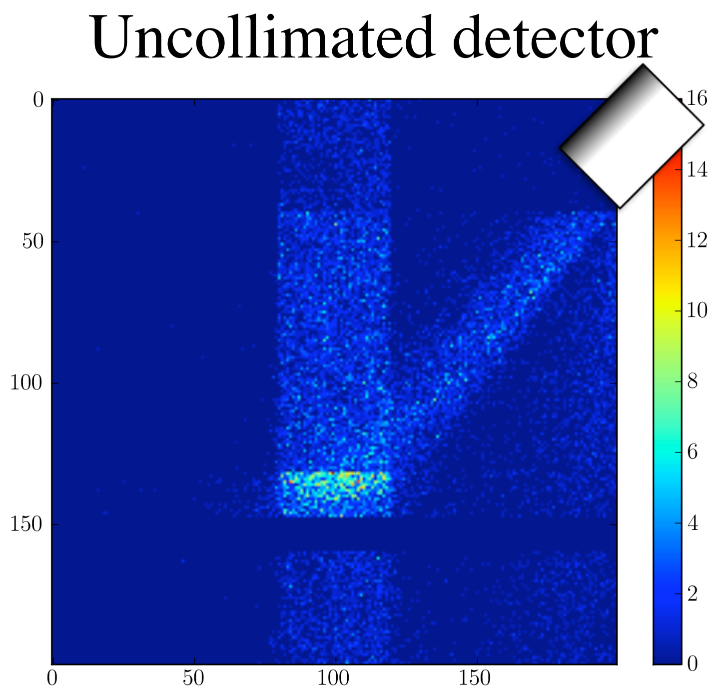

10^9 photon run takes 300 core-hours

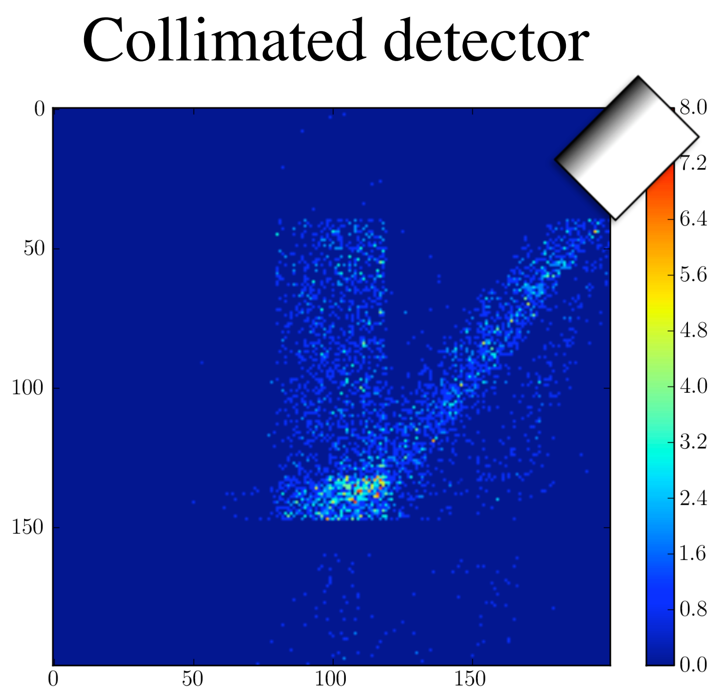
# Flat vs. angled detectors




The ability to separate signals for different detectors

# Uncollimated vs. Collimated




Collimation equals to NA of 0.35

# Results: Target Signal Ratio

TSR for an angle detector: collimated

| | Epithelium | Basal/ precancer | Stroma | TSR |
|---|---|---|---|---|
| Model 1 | 8986 | 33157 | 1746 | 3.09 |
| Model 2 | 636 | 7006 | 1191 | 3.83 |
| Model 3 | 558 | 13458 | 1156 | 7.85 |
| Model 4 | 385 | 23491 | 1003 | 16.92 |

TSR for an angle detector: uncollimated

| | Epithelium | Basal/ precancer | Stroma | TSR |
|---|---|---|---|---|
| Model 1 | 163053 | 51621 | 43415 | 0.25 |
| Model 2 | 111216 | 21342 | 25489 | 0.16 |
| Model 3 | 110726 | 42718 | 23006 | 0.32 |
| Model 4 | 108527 | 87430 | 19167 | 0.68 |

# Conclusions: “Virtual probe design”

- Contributions:
  - Multi-layer Monte Carlo that uses Mie theory
  - Definition of theoretical target signal ratio
  - Proof-of-concept: “Virtual probe design”
- Challenges:
  - Extremely computationally intensive
  - Polarized Monte Carlo is difficult to implement

**C. W. Kan**, K. Travis, D. C. Cote, K. Sokolov, M. K. Markey, “Virtual probe design”: Monte Carlo simulation in the design of diagnostic instrumentation (in preparation)

# Thank you!

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