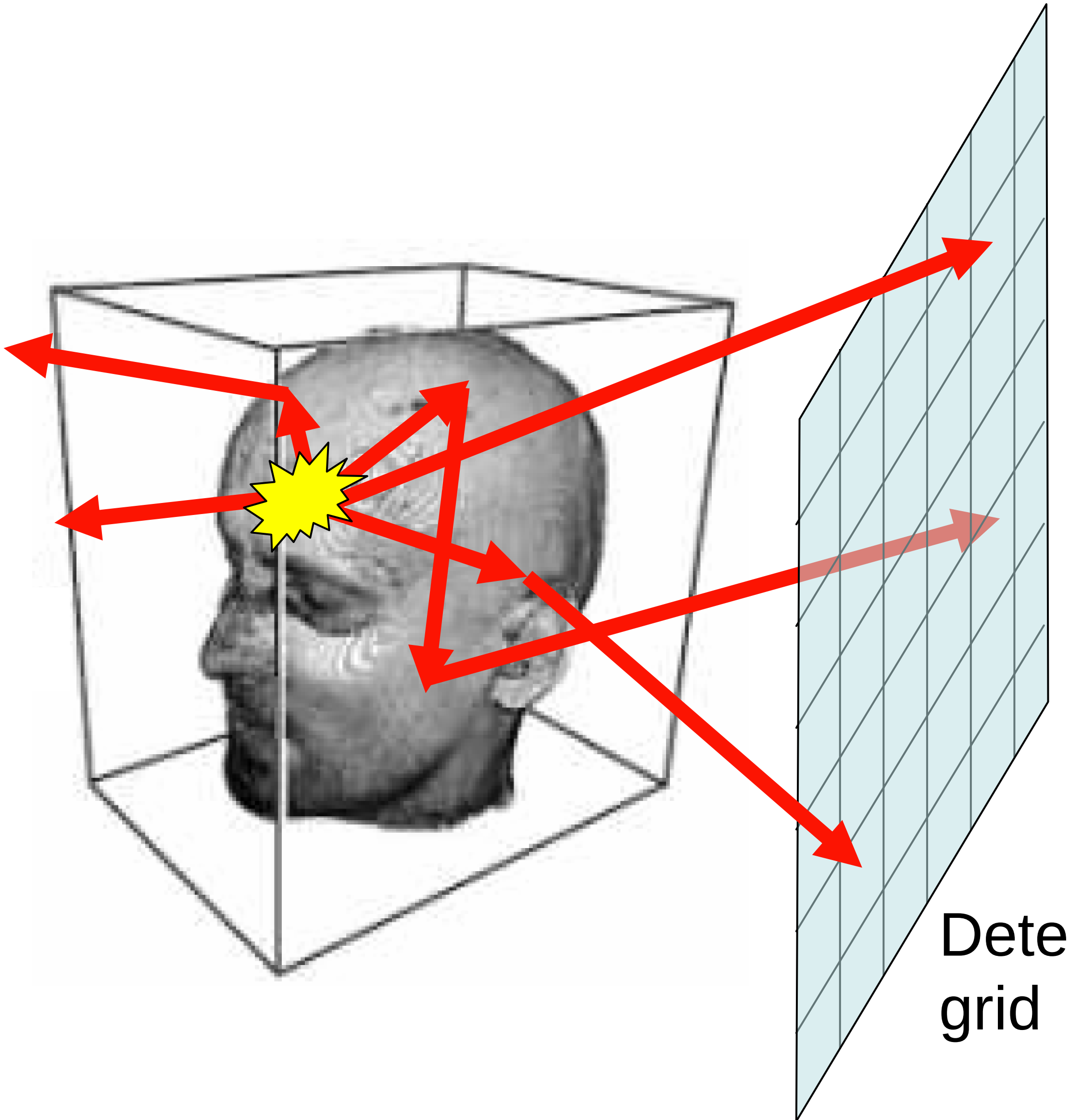
Gamma Photon Transport on the GPU for PET

László Szirmay-Kalos, Balázs Tóth, Milán Magdics, Dávid Légrády, Anton Penzov

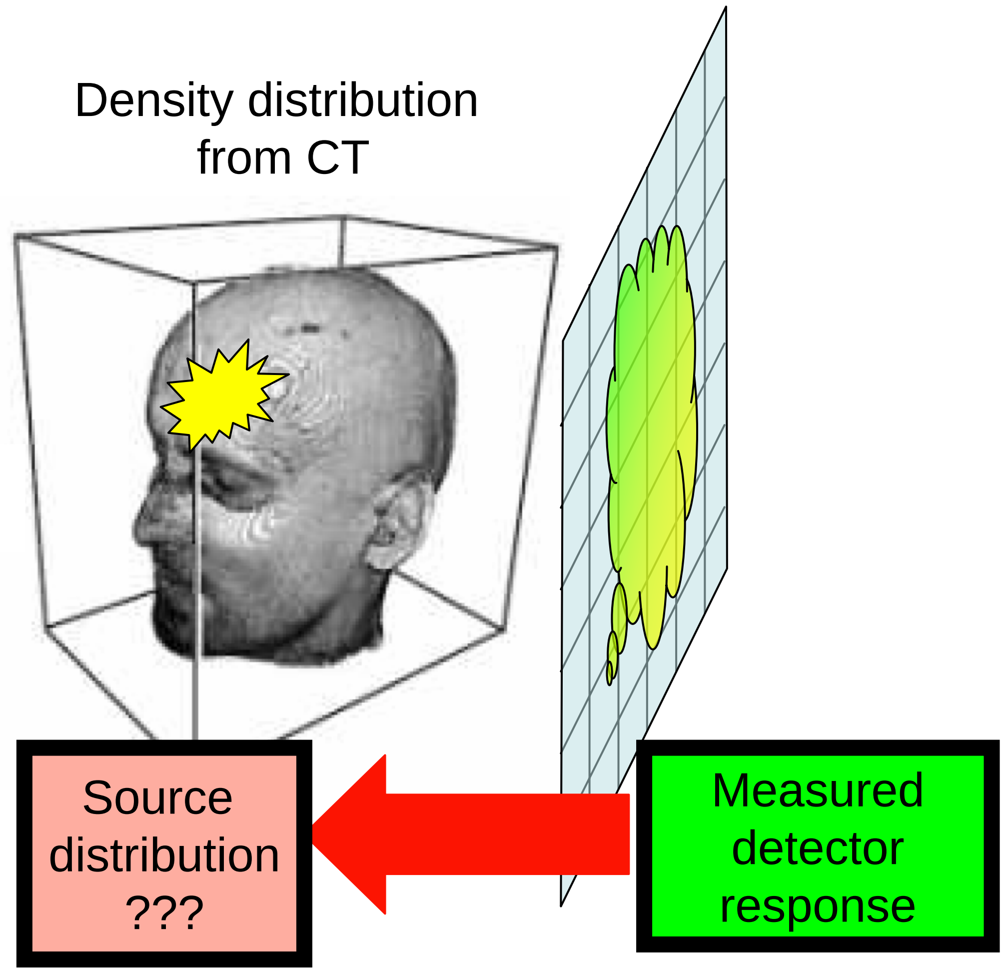
Budapest University of Technology

Gamma photon transport

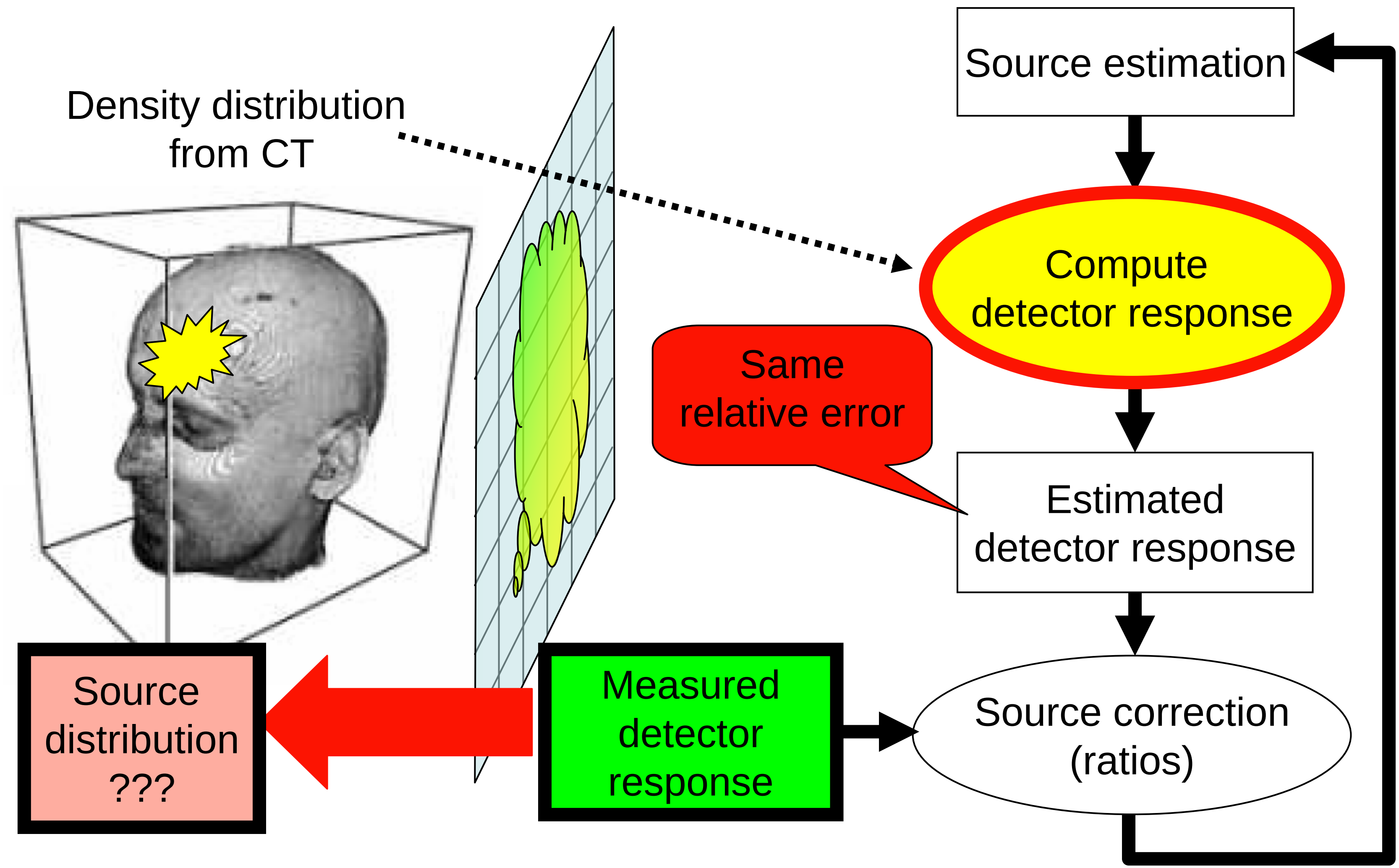


Compton scattering + Klein-Nishina formula = New
- Direction
- Energy (freq)

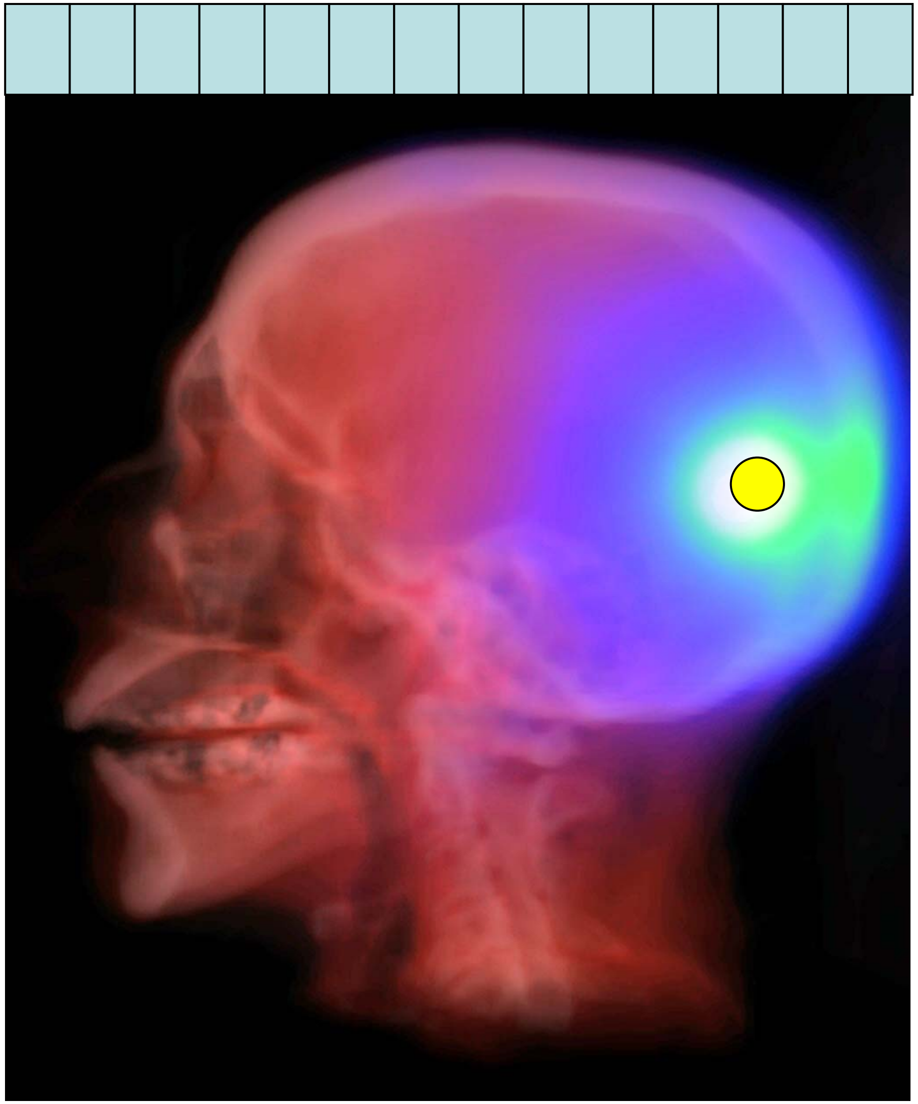
Why is it important?



Iterative reconstruction

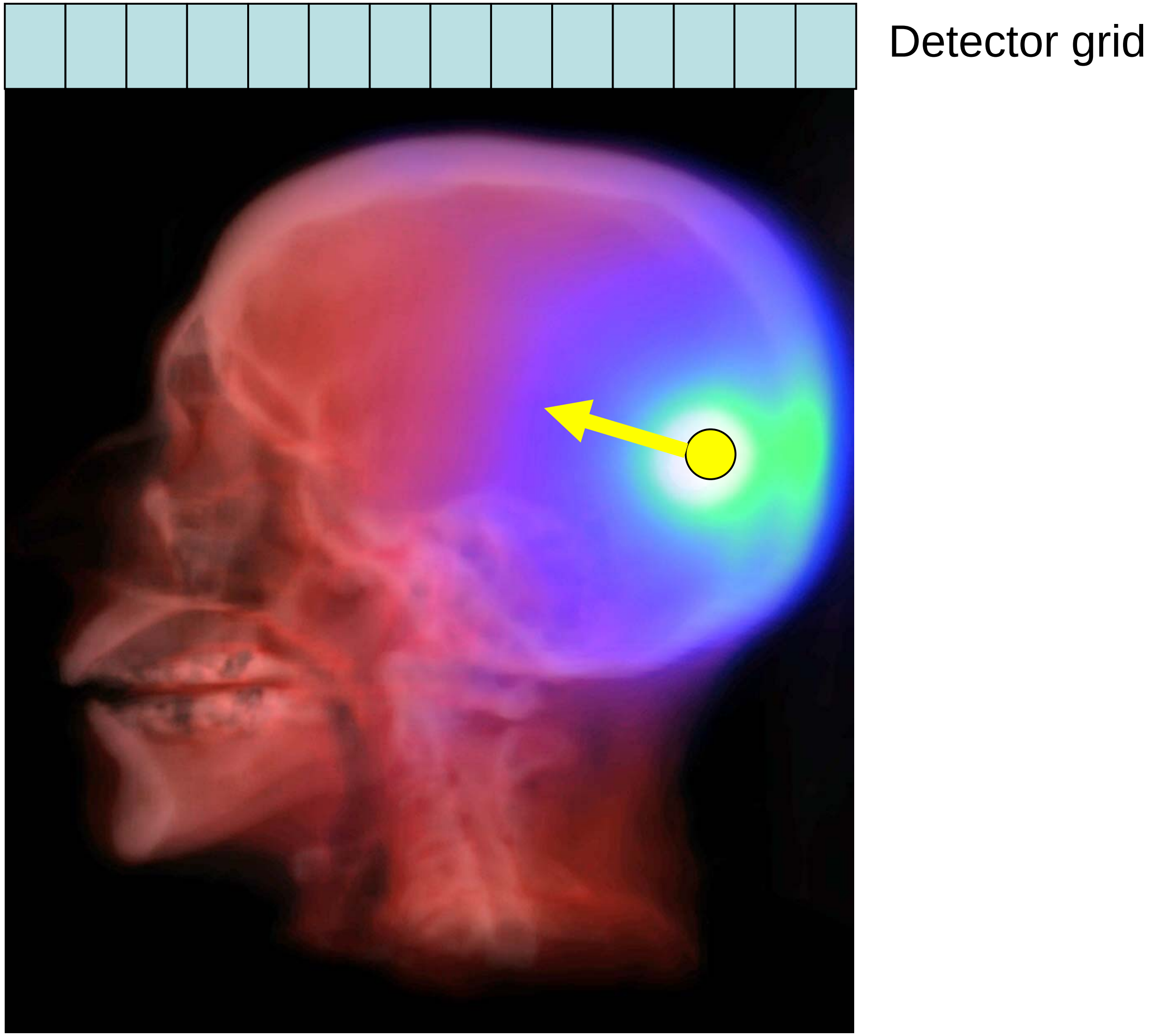


Physicists' approach

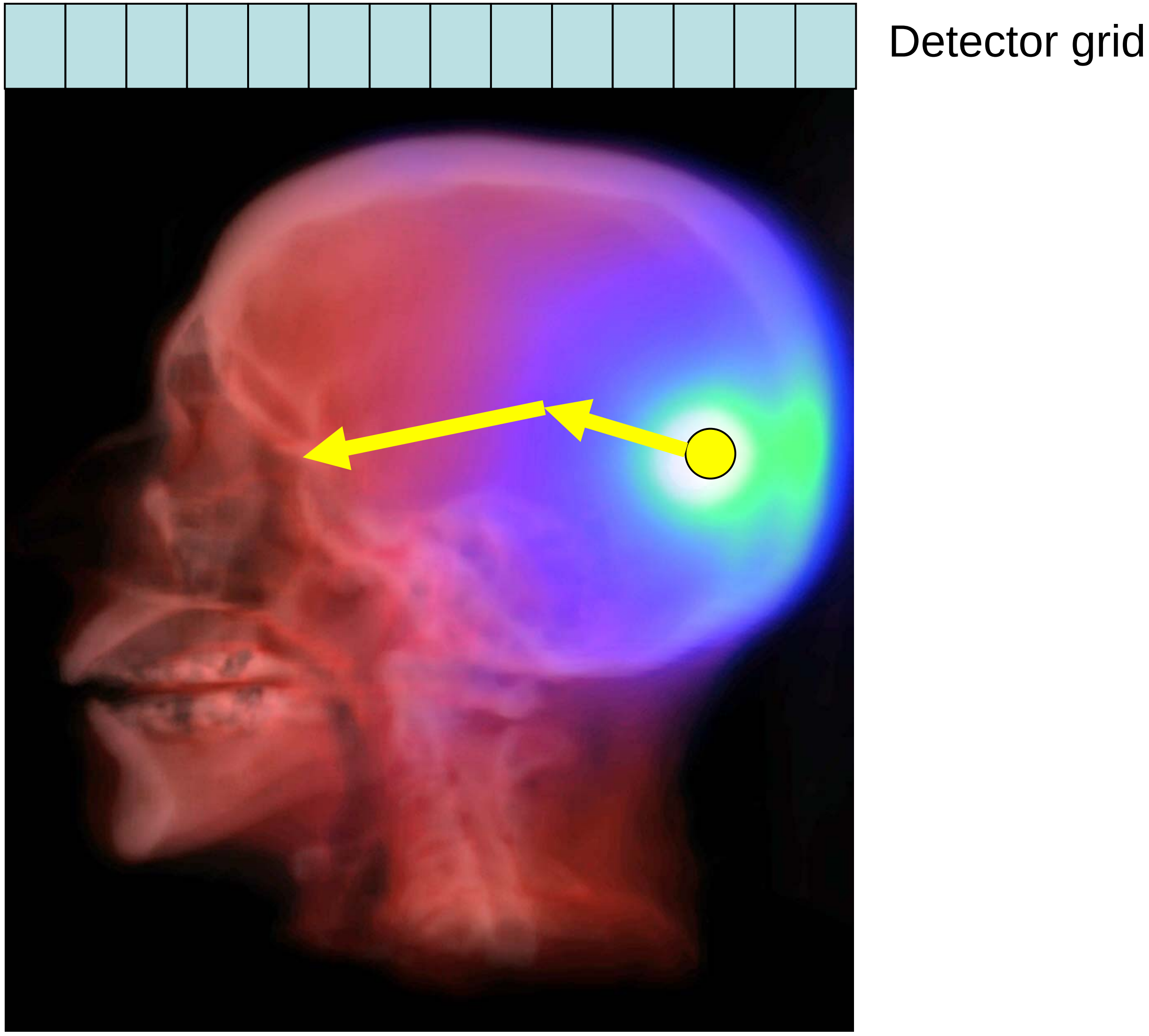


Detector grid

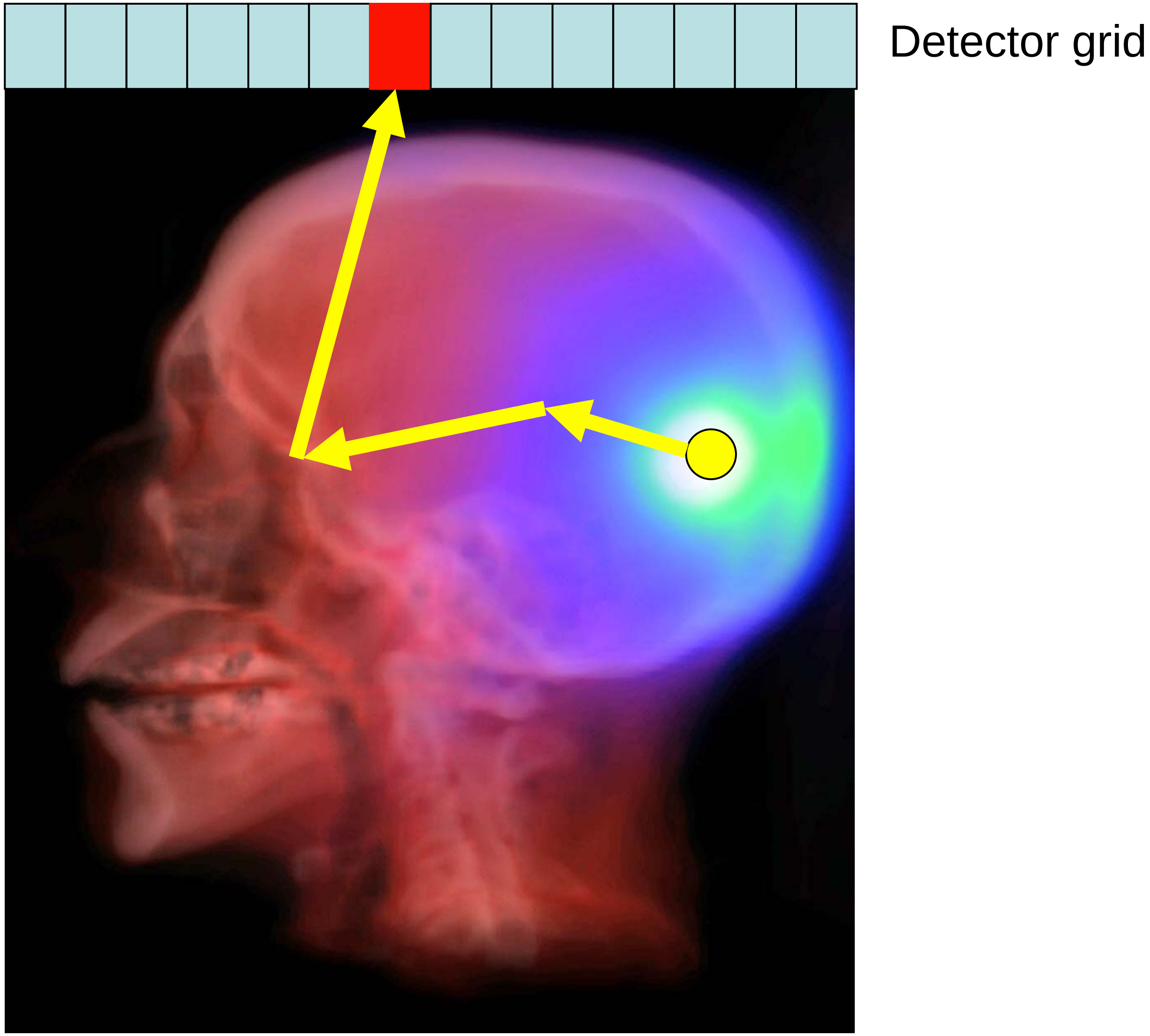
Physicists’ approach



Physicists' approach



Physicists’ approach

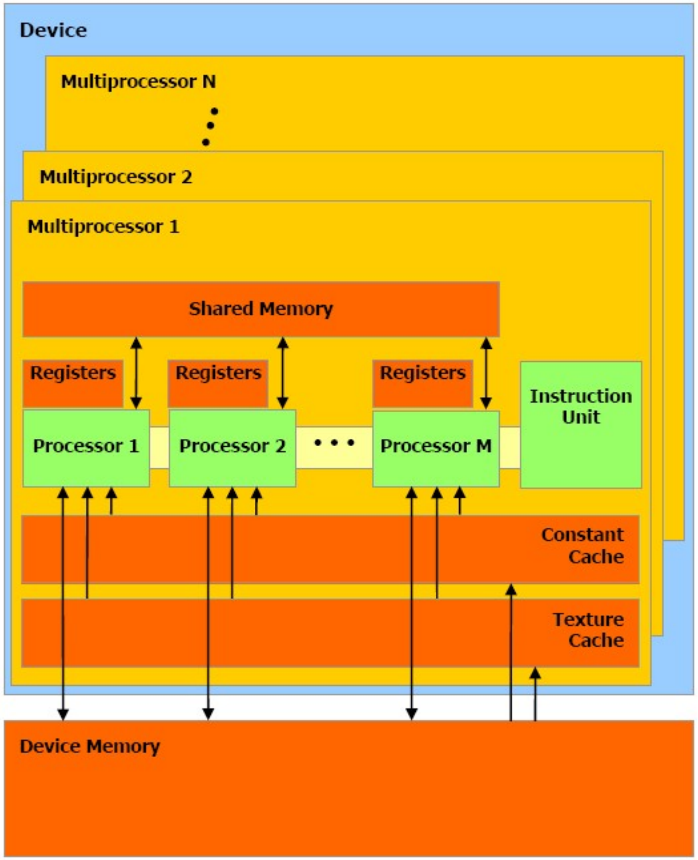


Physicists' approach

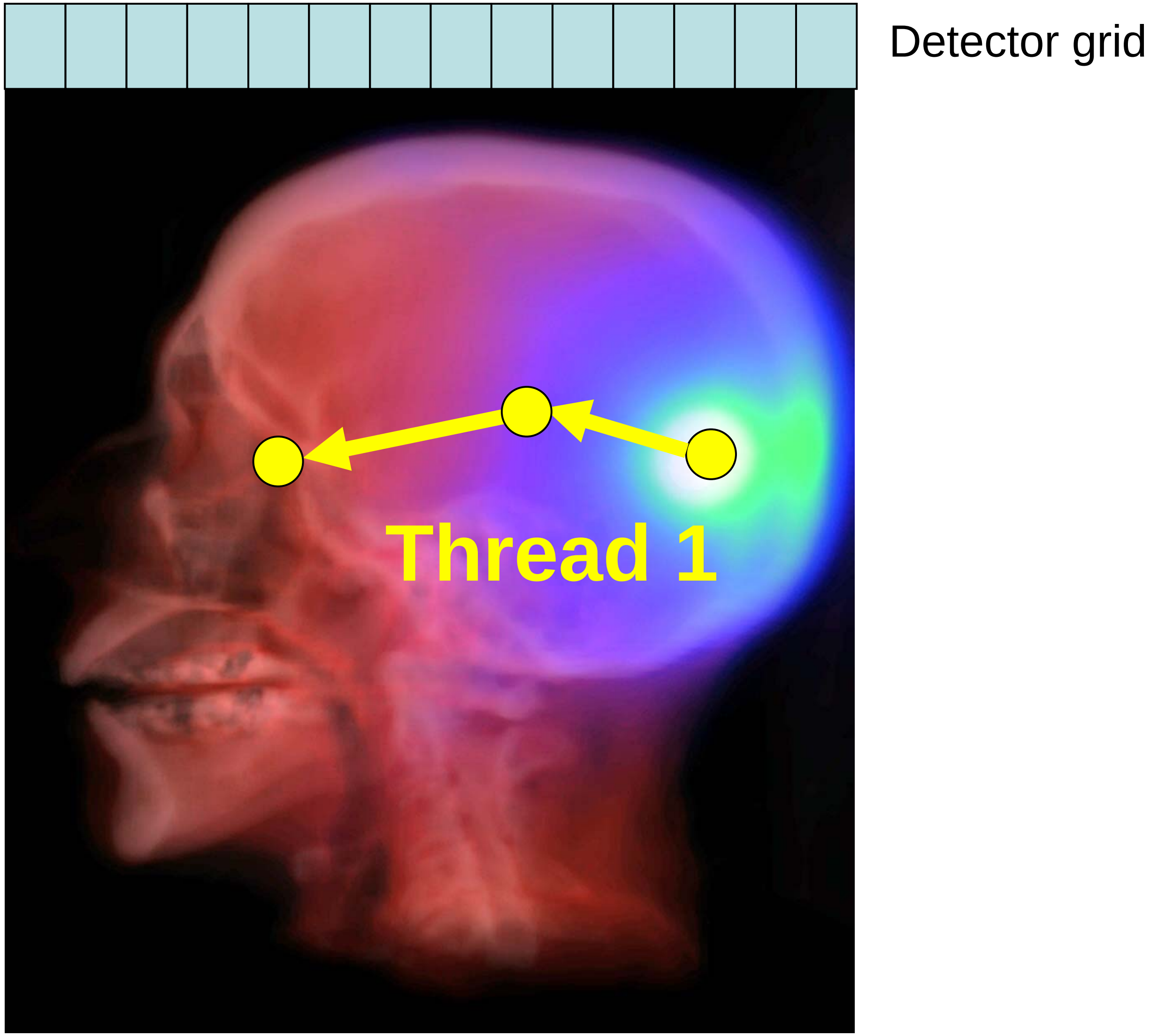
- Pros
  - Direct simulation of nature
  - Rejection sampling can mimic the Klein-Nishina phase function
  - Paths are computed independently, so it scales well on MIMD (multi-CPU = slow and expensive)
- Cons
  - Bad on SIMD (GPU = fast and cheap)
  - Similar absolute error in detectors
  - Paths are computed independently, so it cannot exploit coherence
  - Random writes

Our approach

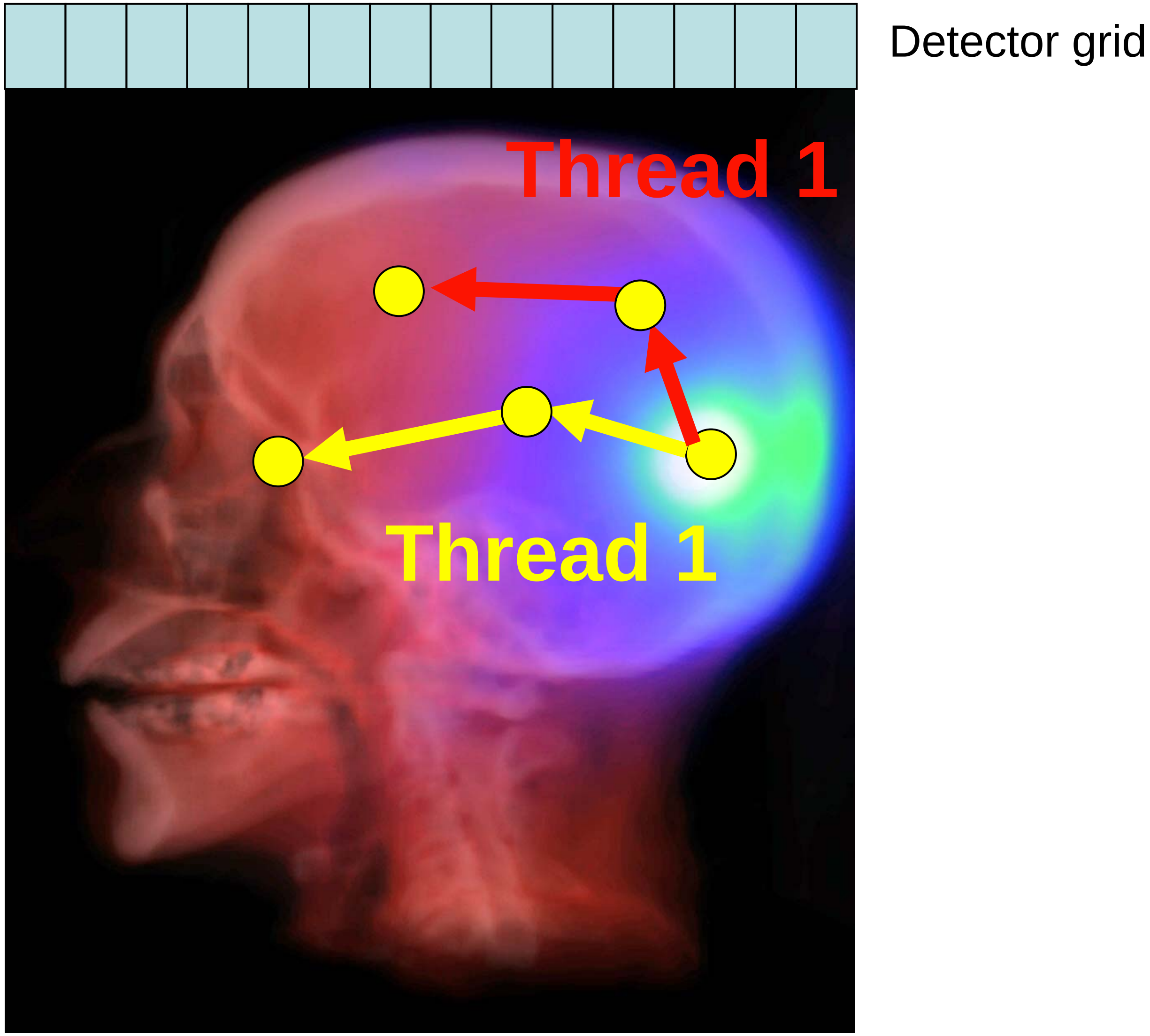
- SIMD-like algorithm (GPU)
  - Same algorithm for all samples (no conditionals + table driven sampling)
  - No random writes
- Reuses paths
- Same relative error in all detectors



Random first pass

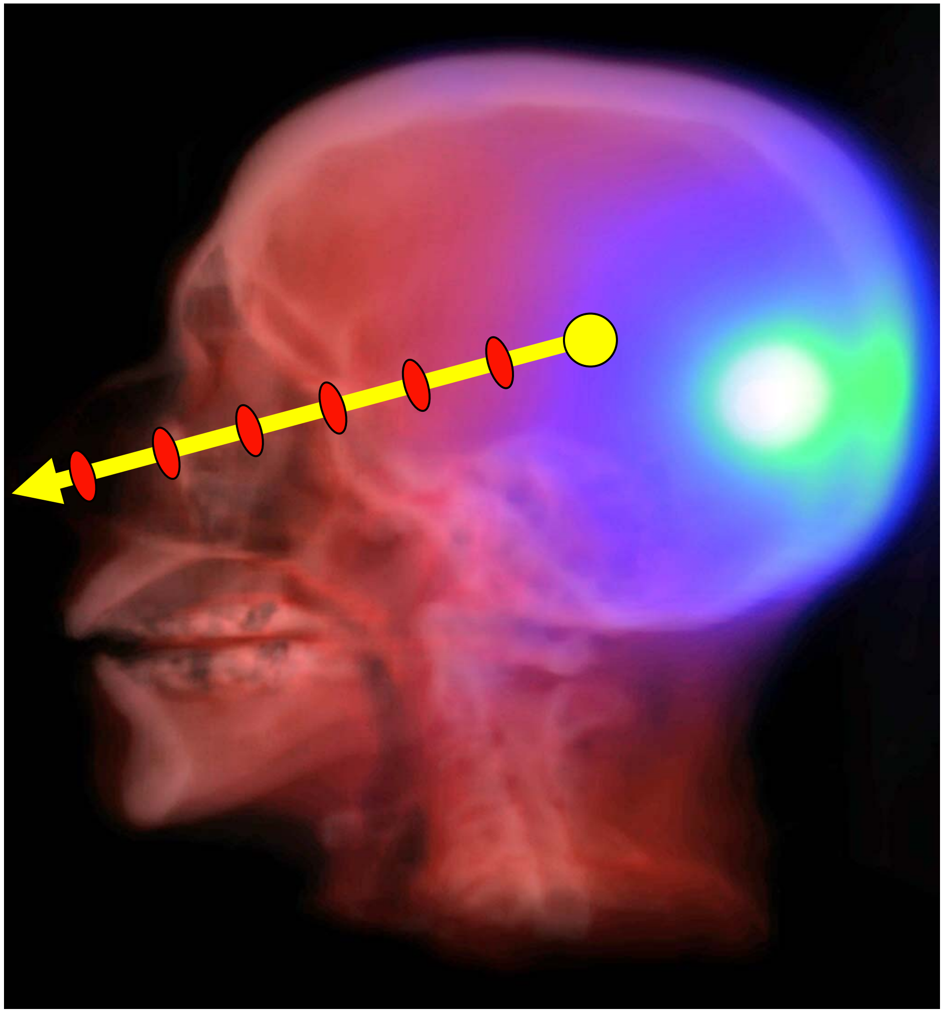


Random first pass



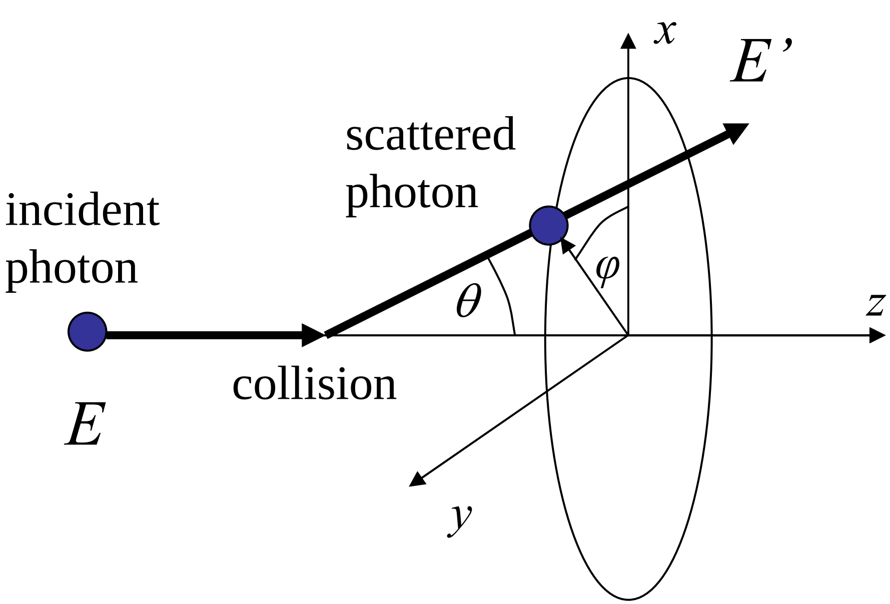
SIMD free path sampling

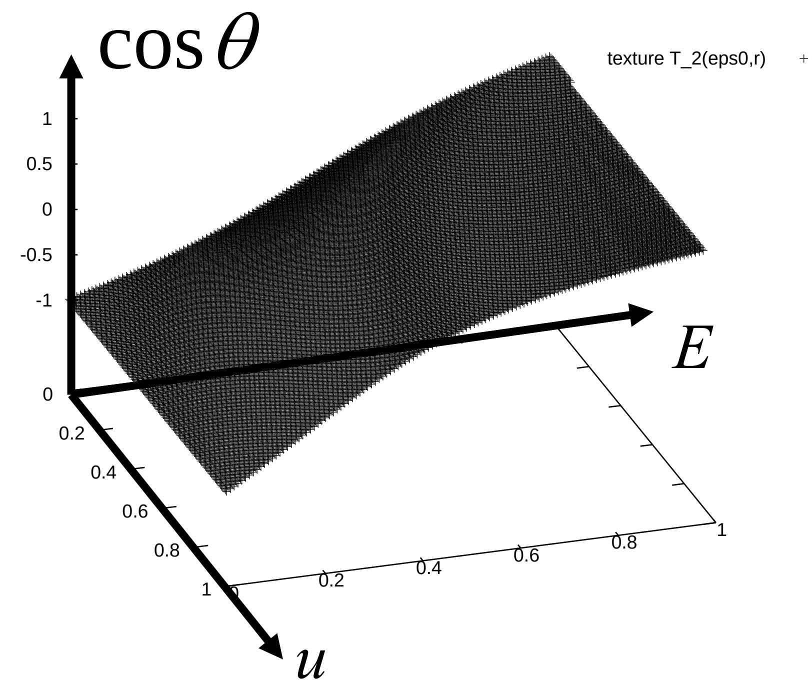
$$r = CDF(S) = 1 - \exp(-\int_0^S \sigma_t(s, E)\mathrm{d}s)$$



- Deterministic marching (no Woodcock tracking)
- Tri-linear interpolation from the voxels
- Table driven handling of the energy dependency
- Sorting multi-dimensional samples to increase coherence

SIMD Scattering with Texture Mapping



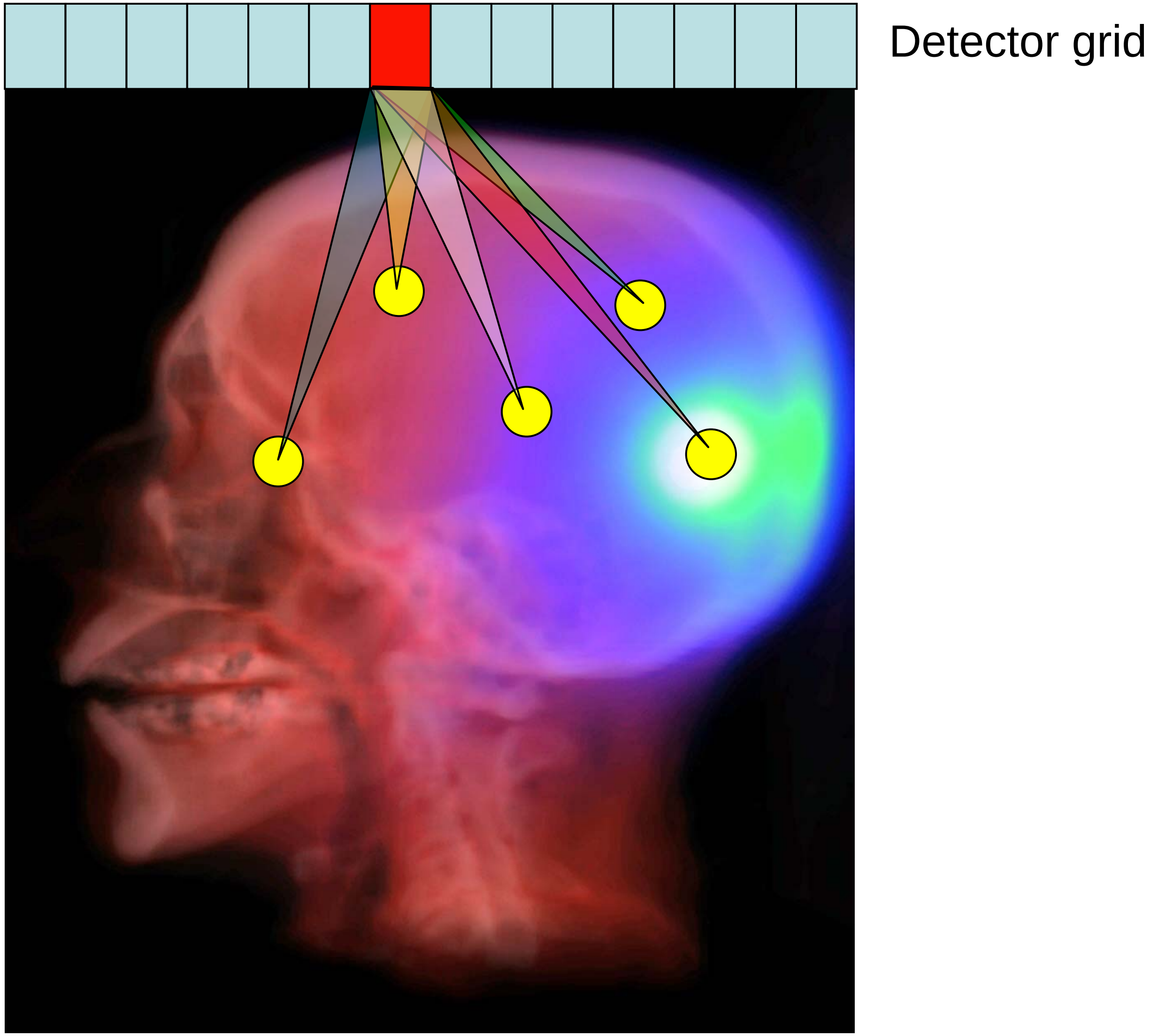


$$CDF(\cos\theta, E) = u \quad \Rightarrow \quad \cos\theta = T(u, E)$$

SIMD termination

- Deterministic (No Russian-roulette)
  - N paths of length 1
  - p^2N paths of length 2
  - p^3N paths of length 3
  - …
- p=probability of
  - absorption and
  - leaving the volume

Deterministic second pass

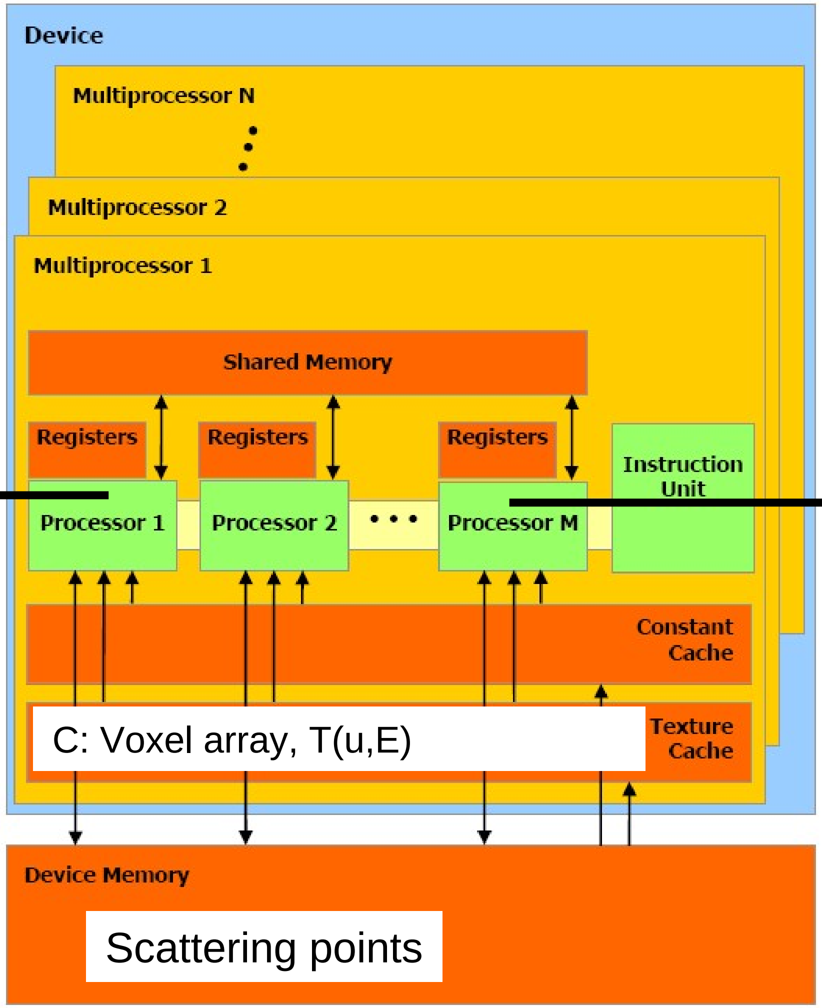


Mapping onto the GPU

First pass
Path building phase

Simulates
a photon path
of fixed length

Reads voxels.
Writes scattering points
of a path.



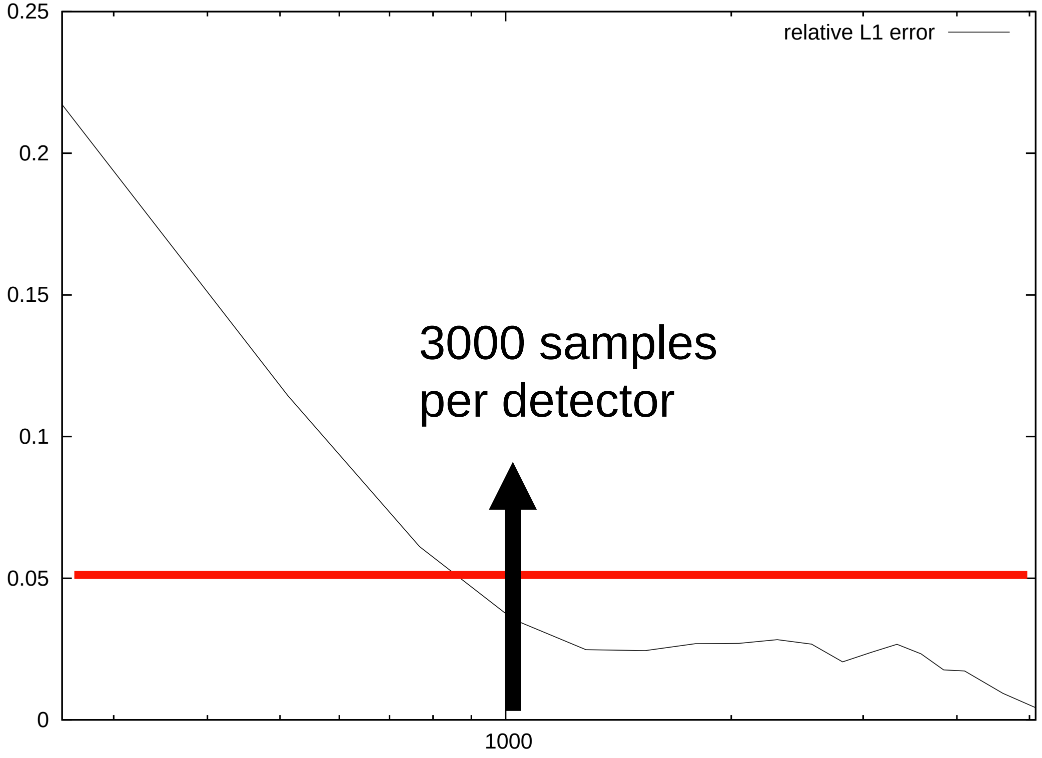
Second pass
Connection phase

Connect all
Scattering points
to a detector

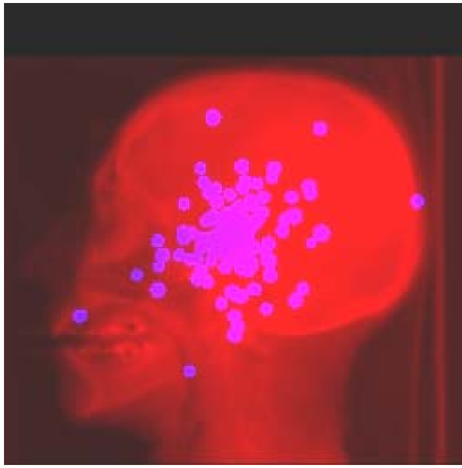
Reads voxels and
scattering points

Writes a detector

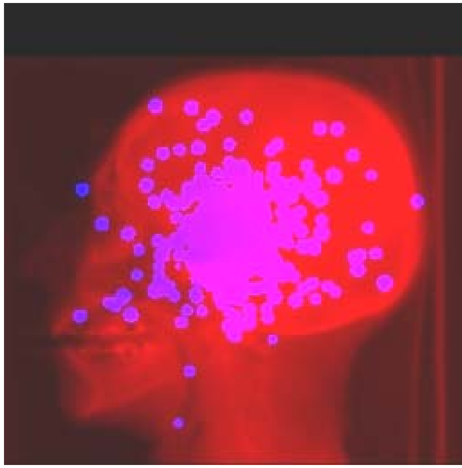
Results



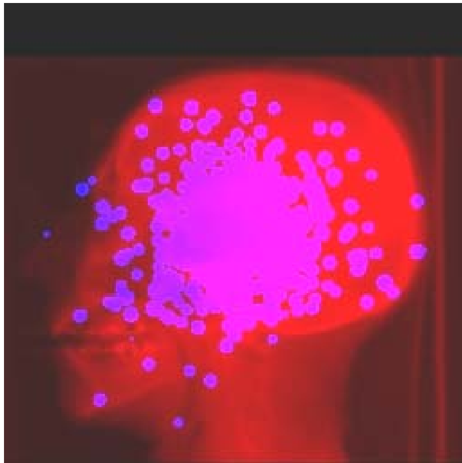
128 paths
1.4 sec



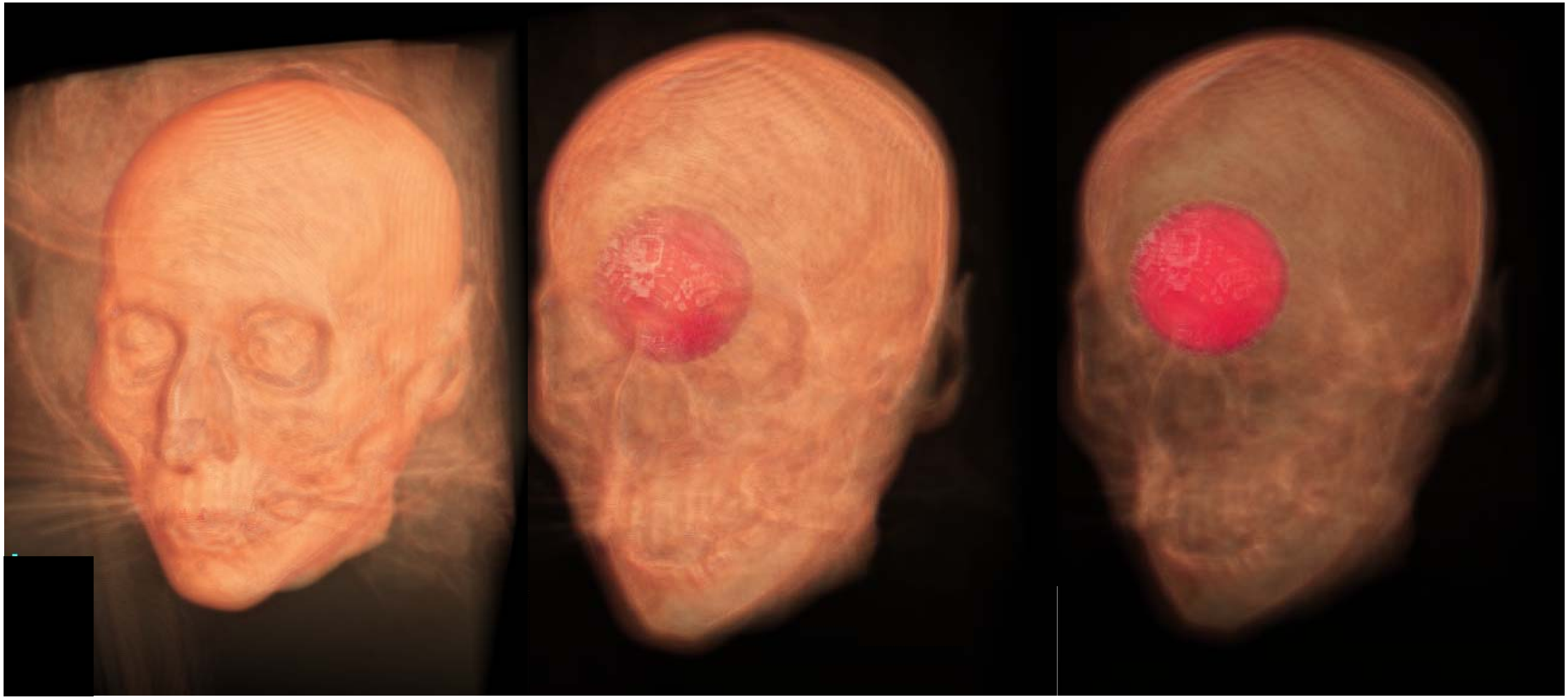
512 paths
2.3 sec



1024 paths
3.6 sec



Reconstruction results



Conclusions

- Instead of physics analogy develop algorithms preferred by the hardware
  - SIMD - GPU
- GPUs are appropriate for solving particle transport interactively.