Computational Techniques for Photon Transport in Ice

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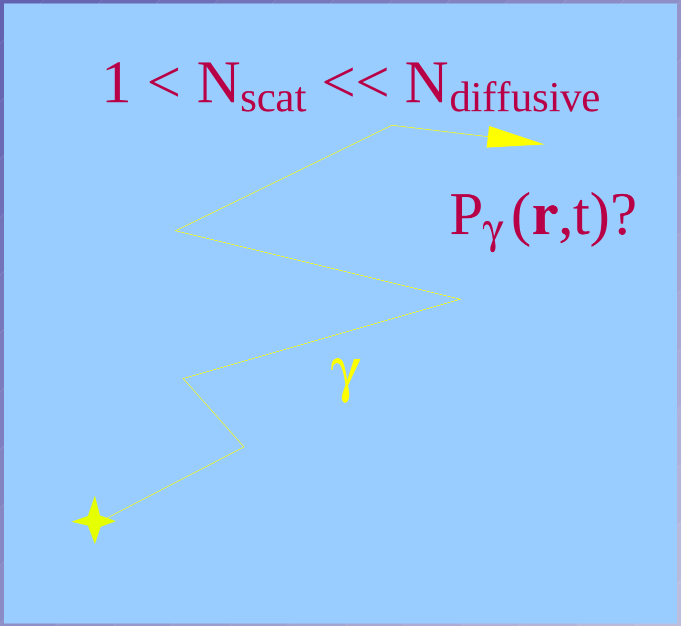
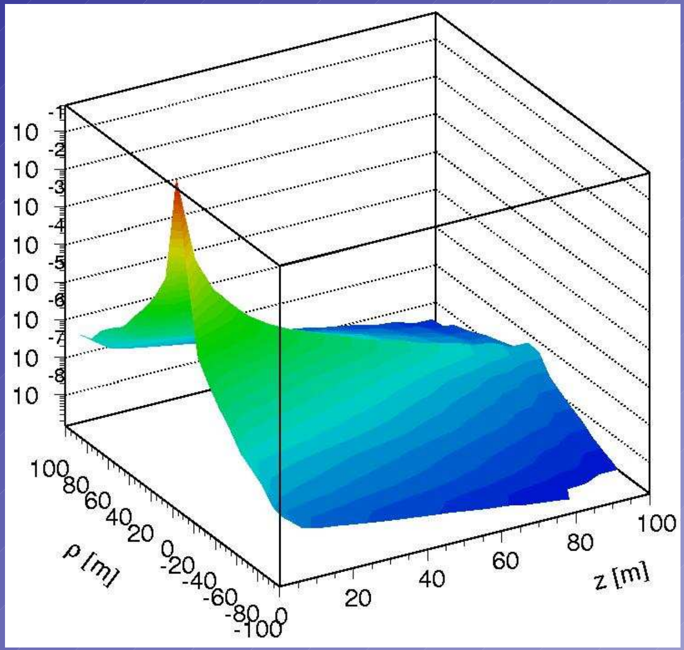
Motivation

- Photon transport can not be solved analytically in all cases
- Inhomogeneity of transport medium further complicates the problem

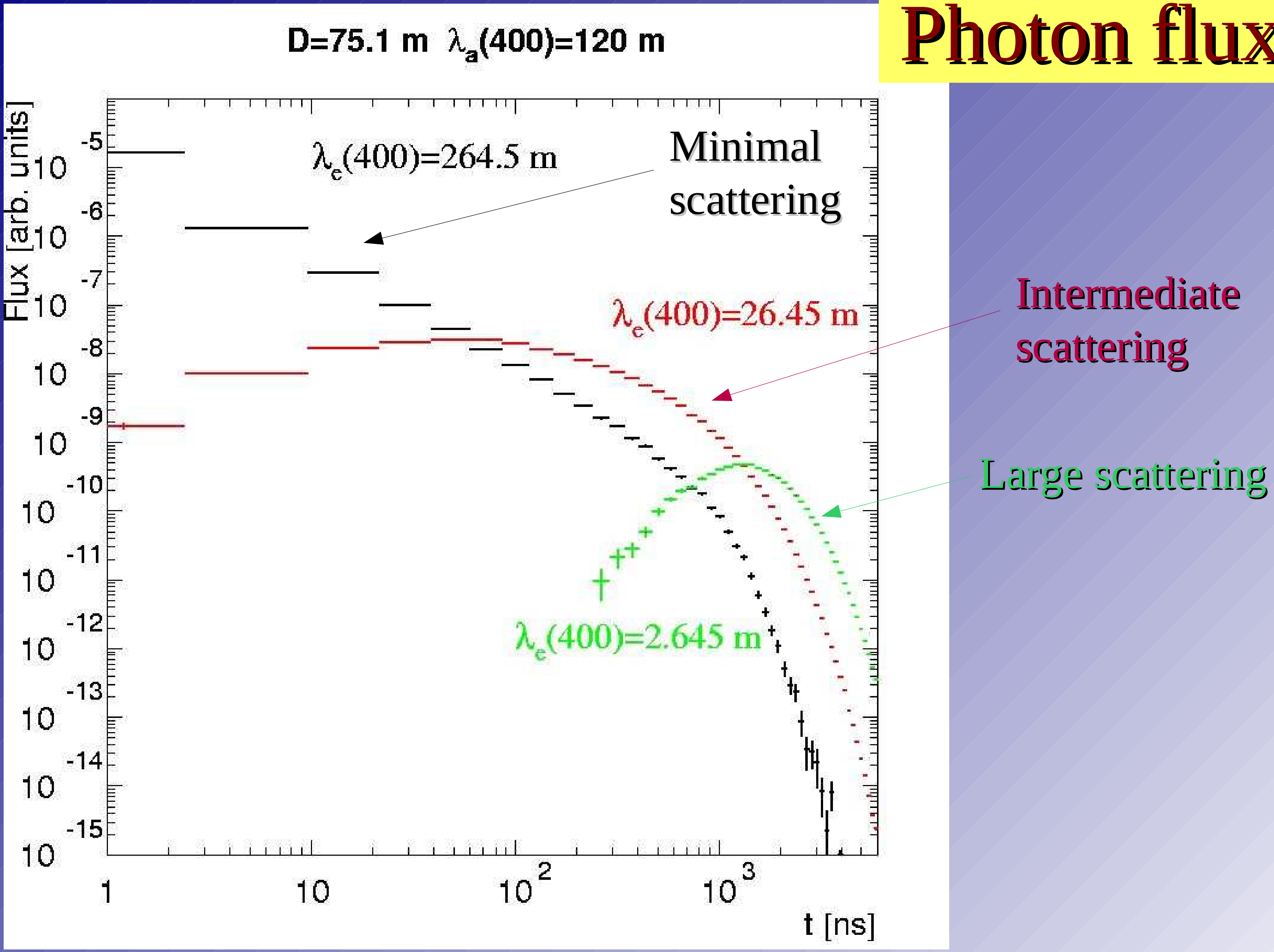




Implementation

- Monte Carlo generation of photon flux tables
- Table parametrization for simulation and reconstruction

Photon flux

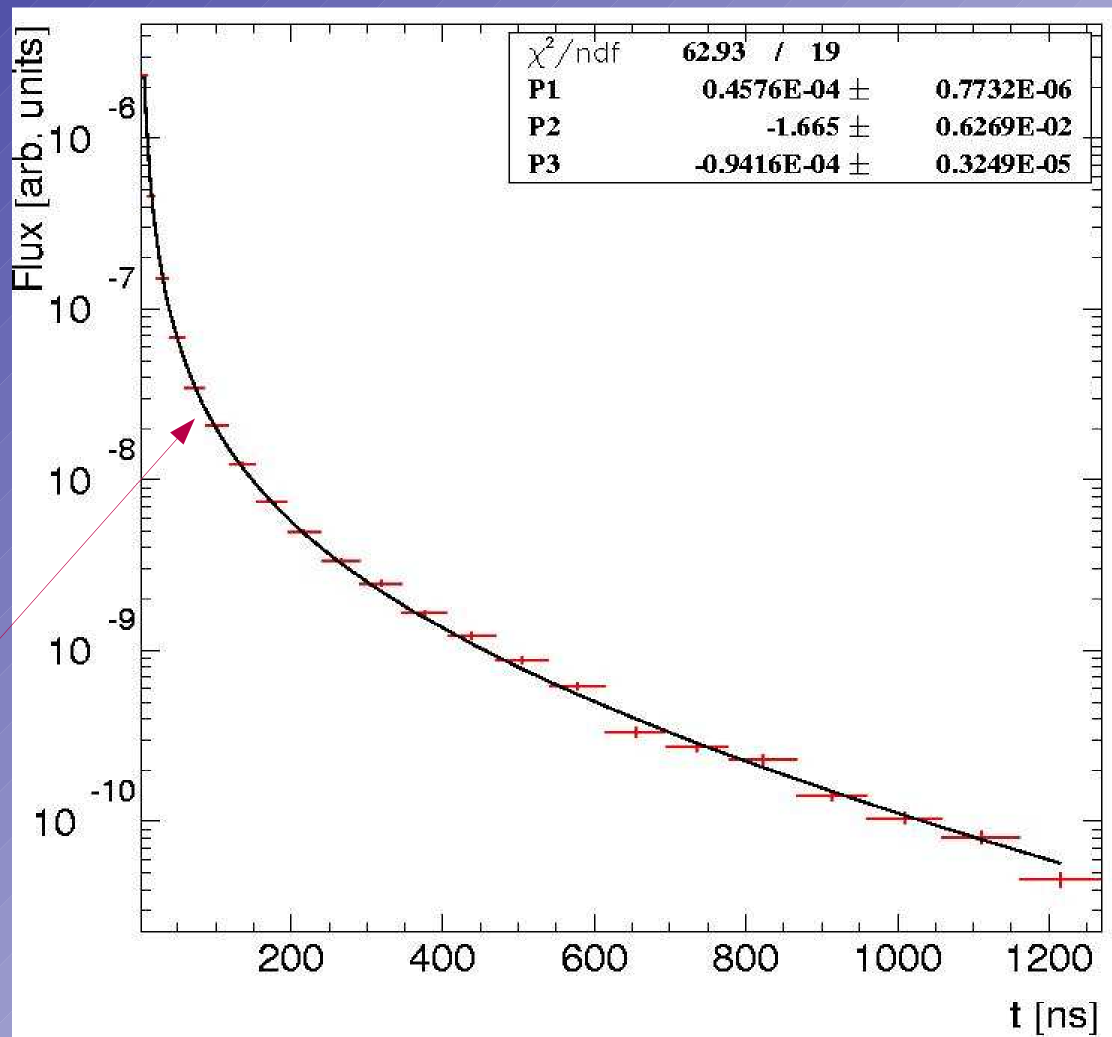


D=75.1 m $\lambda_a(400)$=120 m
Flux [arb. units]
t [ns]
$\lambda_e(400)$=264.5 m
$\lambda_e(400)$=26.45 m
$\lambda_e(400)$=2.645 m
Minimal scattering
Intermediate scattering
Large scattering

Minimal scattering regime N_{scat}~1: treat delayed photons as a perturbation

- Majority of flux is "undelayed"
  $P(\mathbf{r},0) \propto \exp(-d/\lambda_a)$

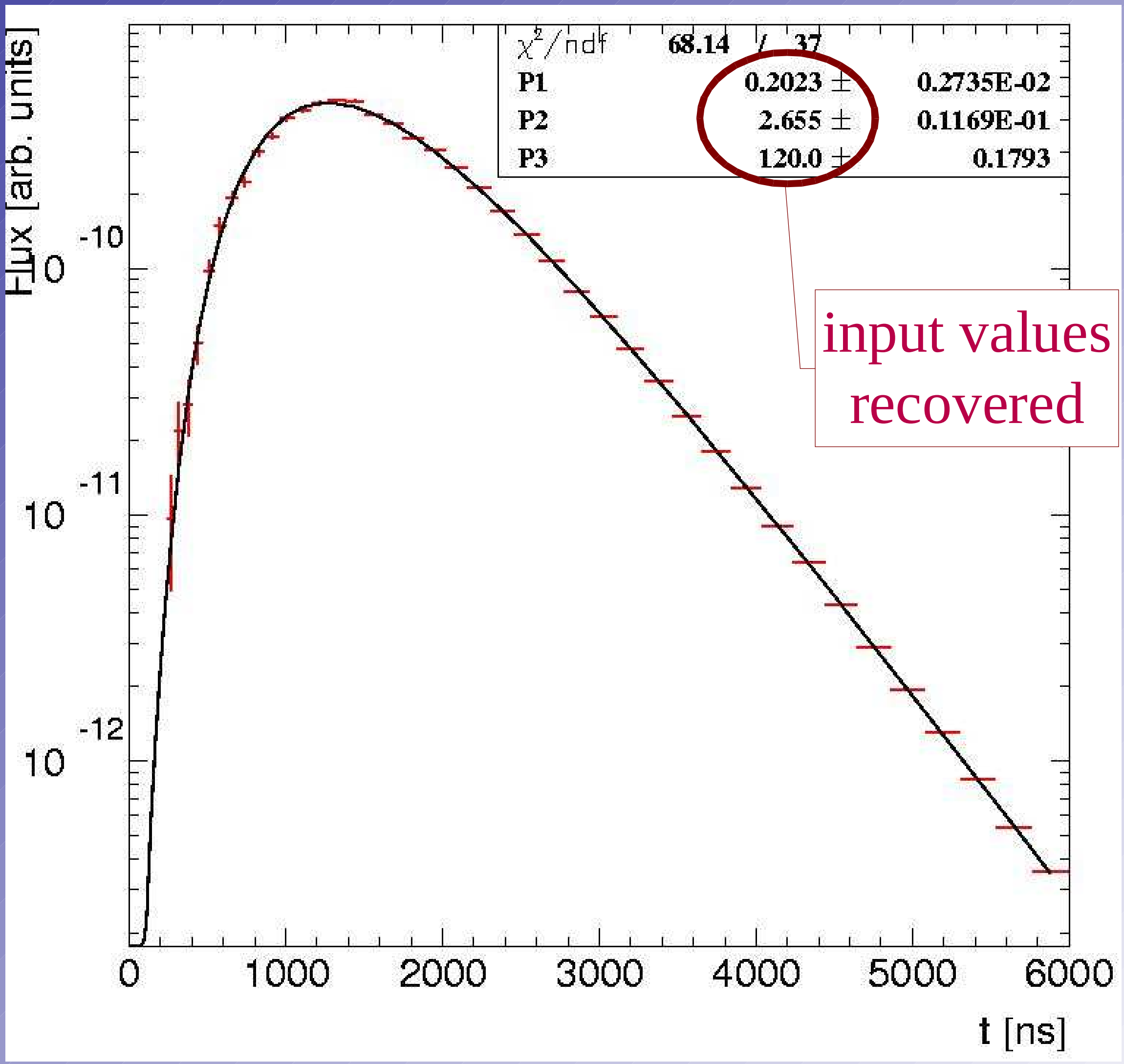
- Simple empirical power law-like fit to delayed flux
  $P(\mathbf{r},t) \propto P(\mathbf{r},0) \cdot t^{\alpha}$



Large scattering regime $N_{scat} \geq N_{diffusive}$: described by 3D random walk function*

Input parameters:

- $\lambda_e = 2.645$ m
- $\lambda_a = 120$ m



*B. Price and L. Bergström
Appl. Opt. **36**, 4181 (1997)

Intermediate scattering regime

$1 < N_{scat} << N_{diffusive}$

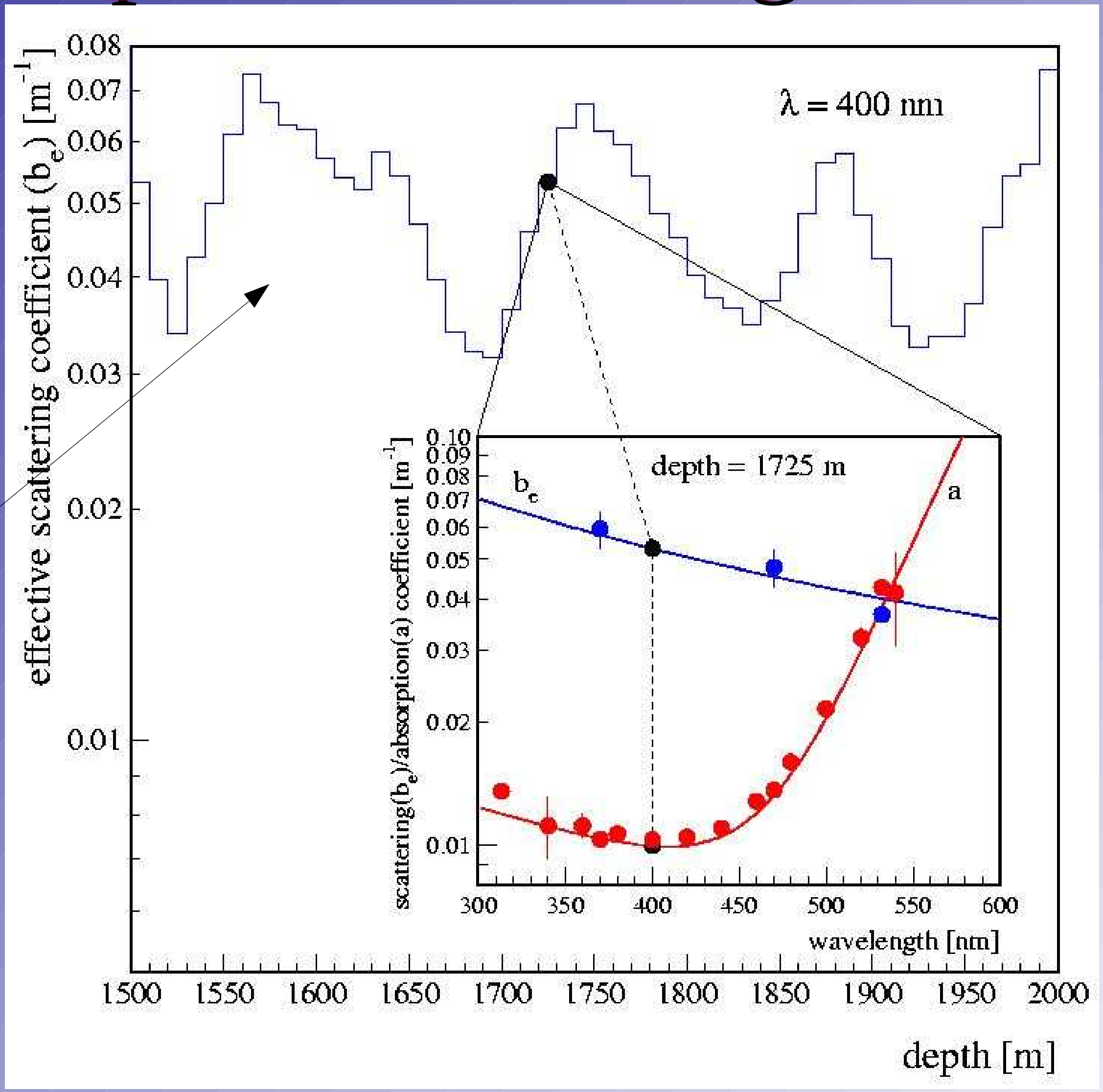
no closed form solution

$\Rightarrow$ calculate fluxes numerically*

*see A. Karle, in proceeding of Simulation and Analysis Methods for Large Neutrino Telescopes workshop, July 1998, Zeuthen, Germany, p. 174

Optical properties between photon source and detection point can change!

Variation in ice transparency in AMANDA



Photonics software package

numerical solution to flux calculation problem

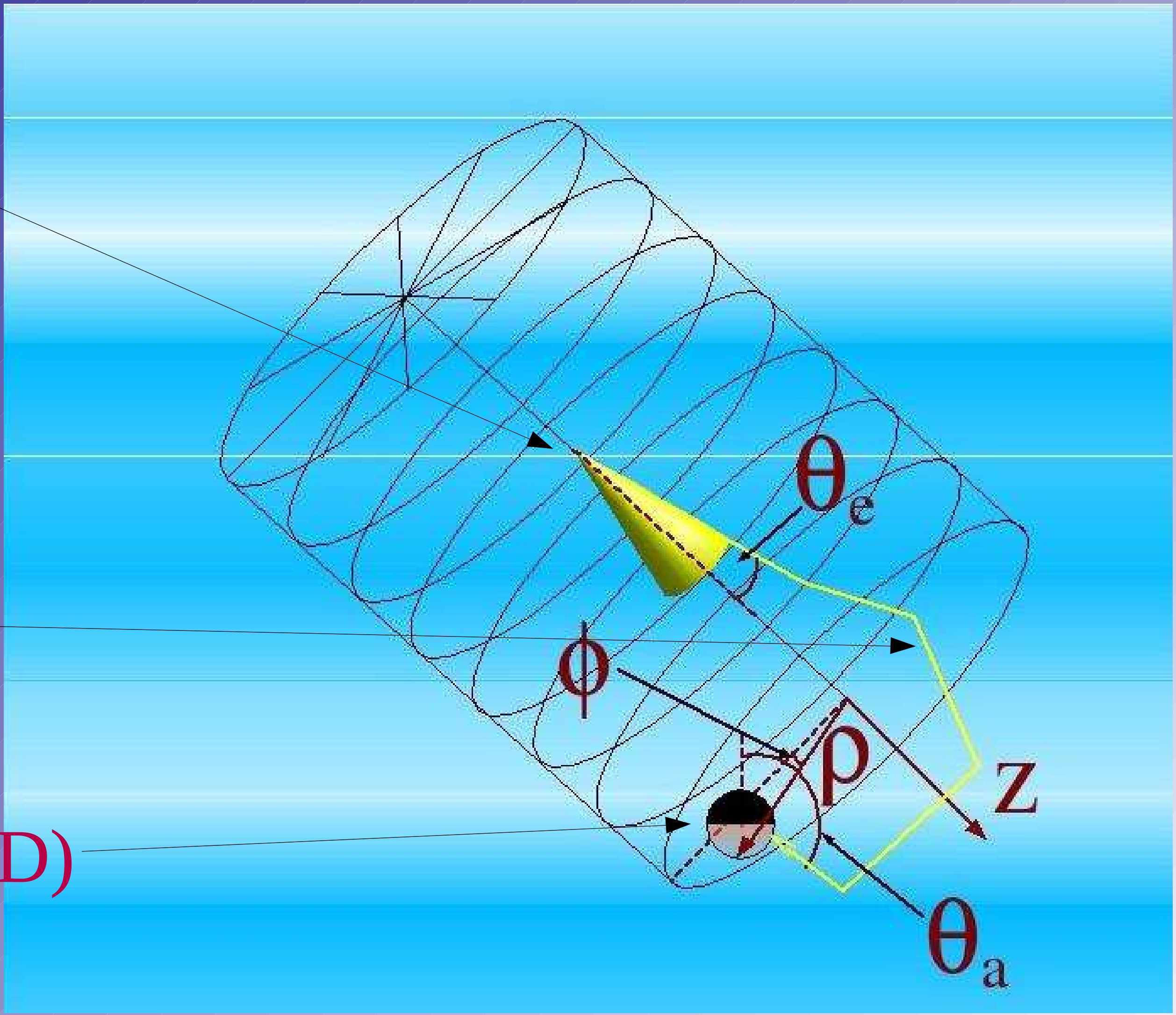
- ray-tracing approach to photon transport
- handles varying optical properties
- highly flexible geometry and runtime configuration
- very fast
- easily extendable

Multidimensional tables used to keep results

source location
& orientation (2D)

photon orientation
& travel time (3D)

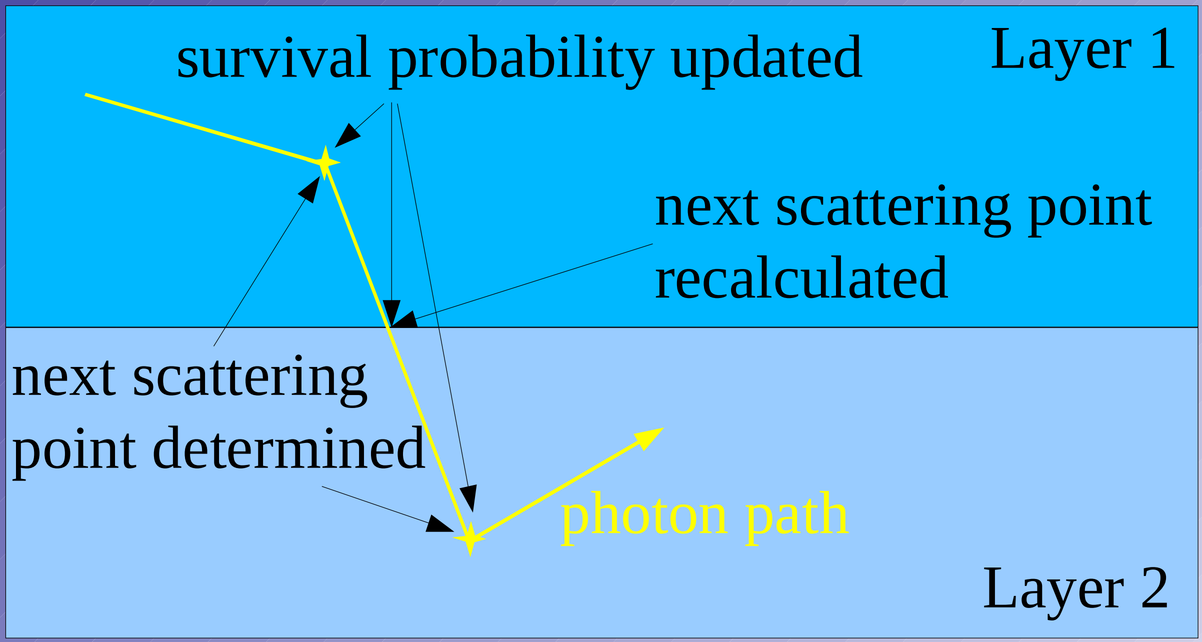
receiver location (3D)



Absorption treated as photon survival probability

- speeds up table evaluation
- allows treatement of varying optical properties

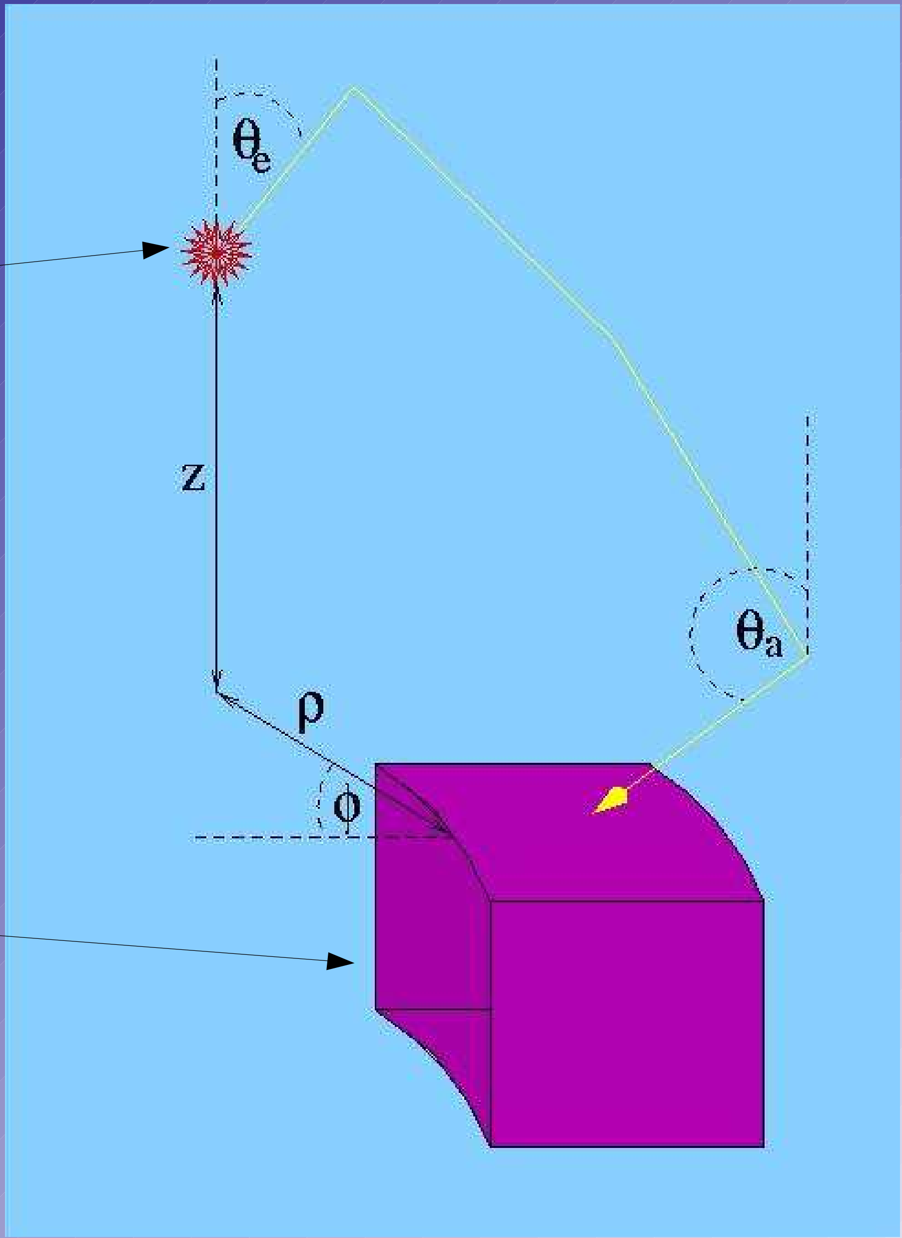
Scattering treated by Henyey-Greenstein approximation to Mie scattering theory



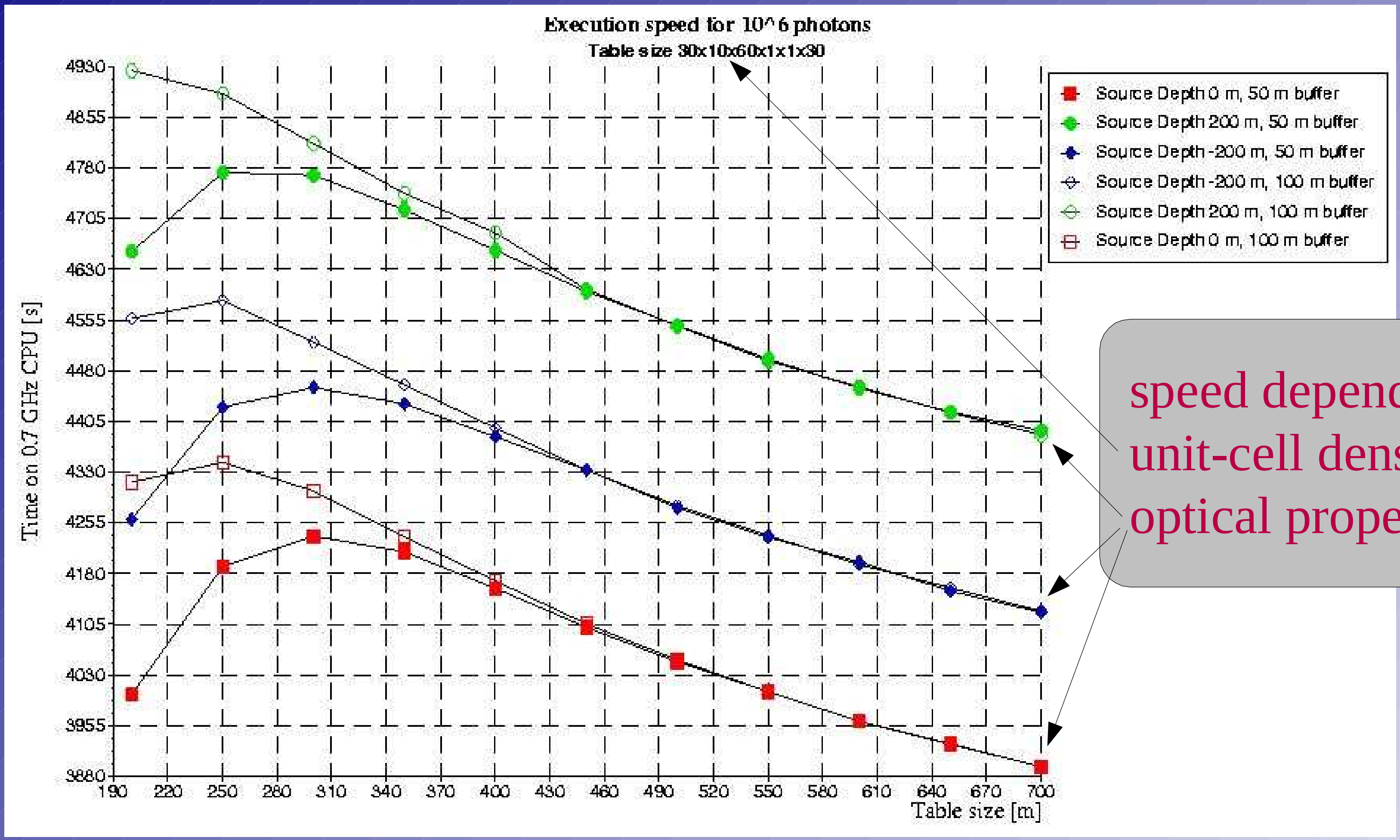
light source

flux calculated in
volume unit-cells

$\Phi_\gamma \propto P_{surv}(\gamma)/A_\perp(\text{cell})$



execution speed ~ 10^6 γ / hour / GHz



speed dependent on unit-cell density & optical properties

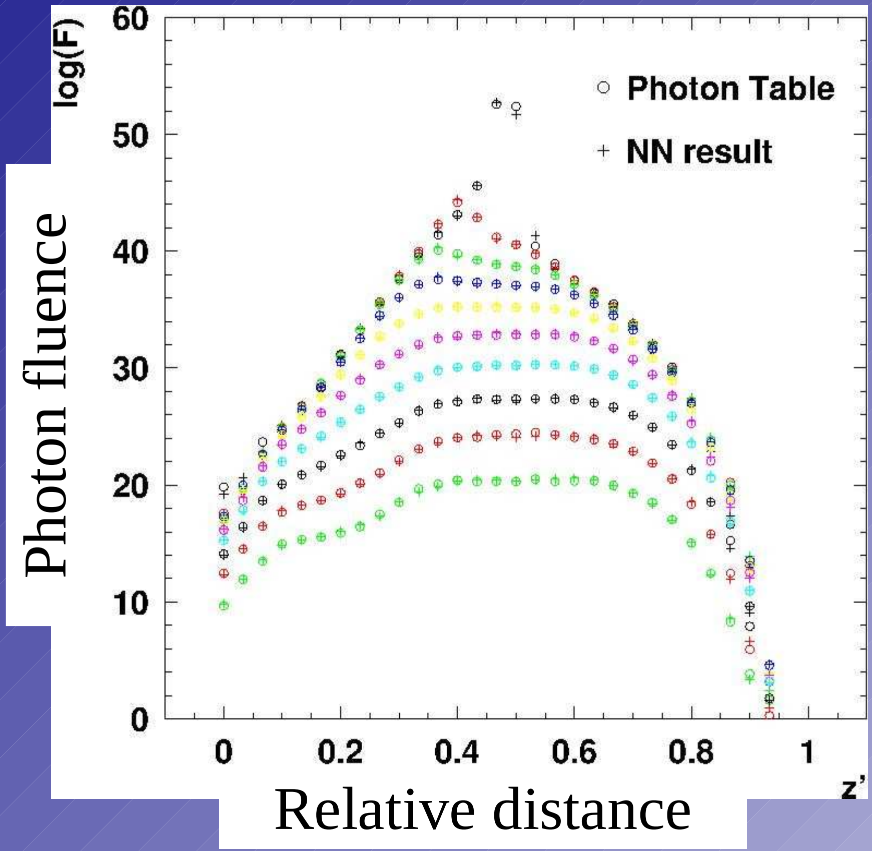
But....

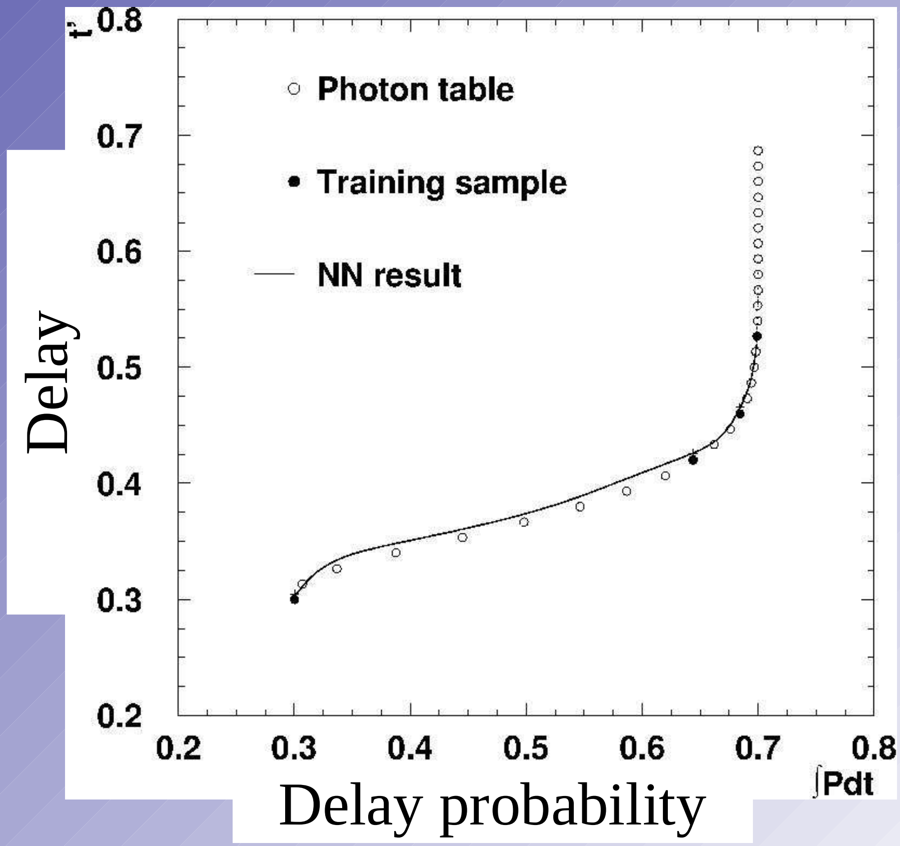
Full production table set size is $\geq$ 1 GB

$\Rightarrow$ need to parametrize the tables

Attractive properties of Neural Networks

- model free fitter
  → superposition of weighted sigmod functions
- interpolation ability

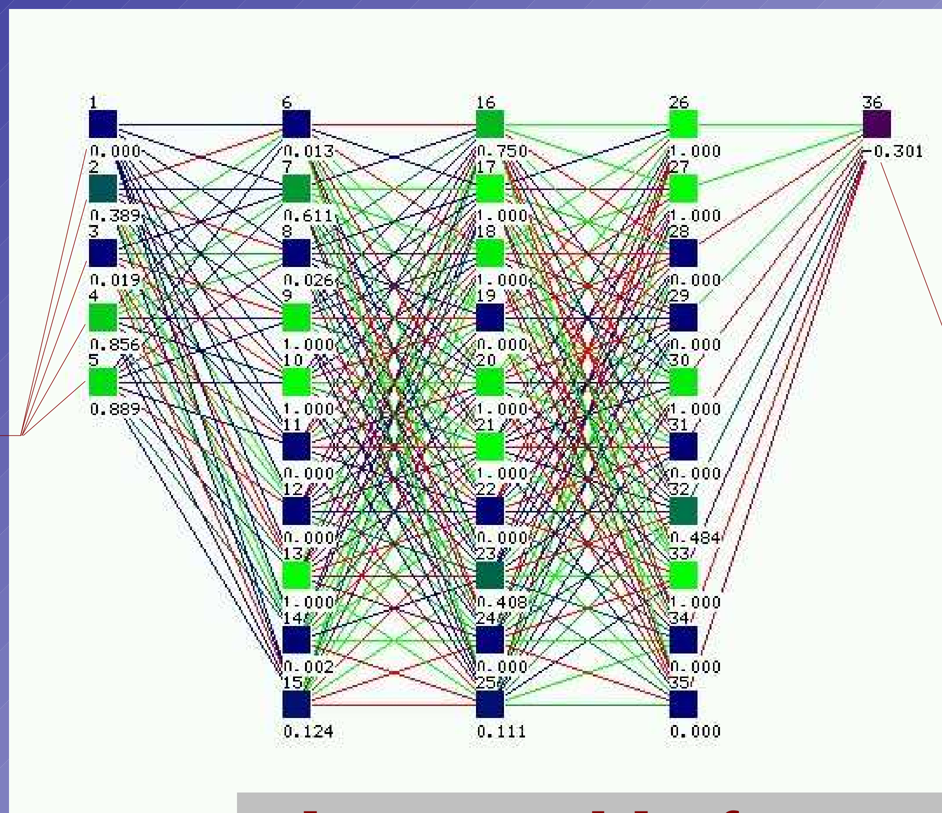




NN configuration:

- Fully connected Multilayer Perceptron Network
- timing delay tables 6x10x10x10x1
- fluence tables 5x60x60x1 or 5x10x10x10x1

Input coordinates

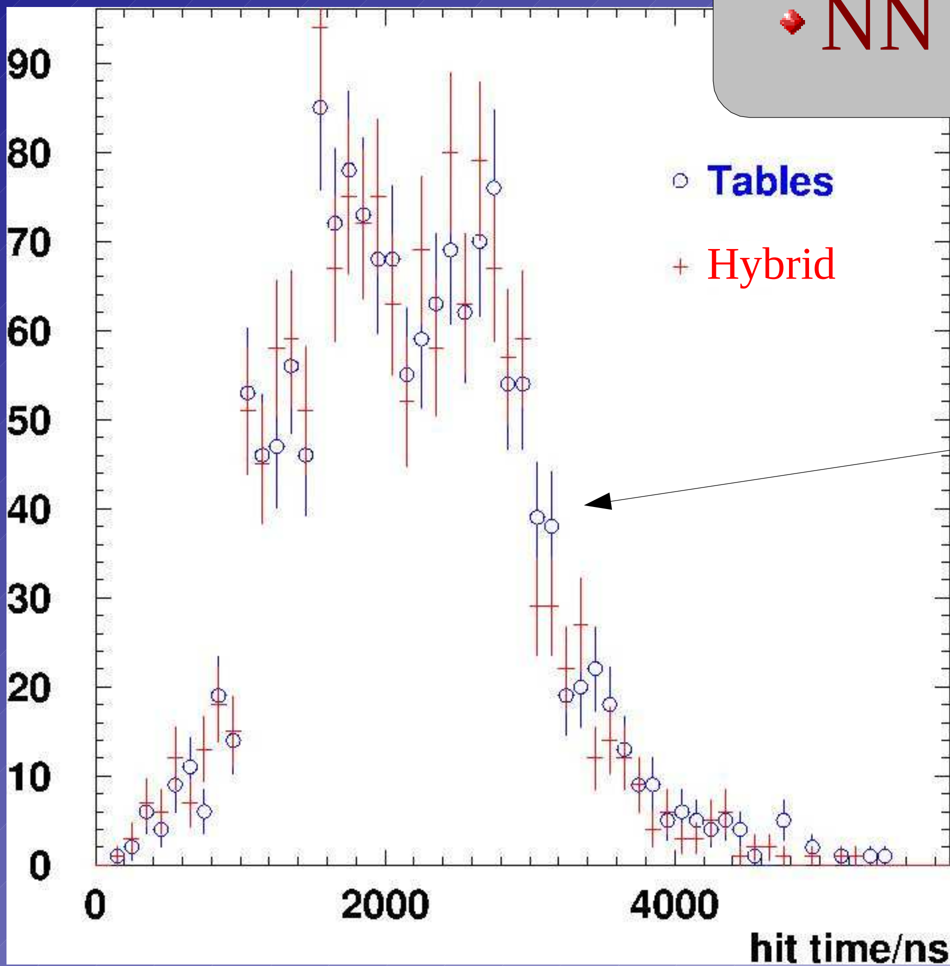


Output flux

Fluence table fitting not finalized

"hybrid" model for initial evaluation

- table lookup for fluence
- NN fit to timing delay tables



simulated hit-time distribution agree

NN performance in detector simulation

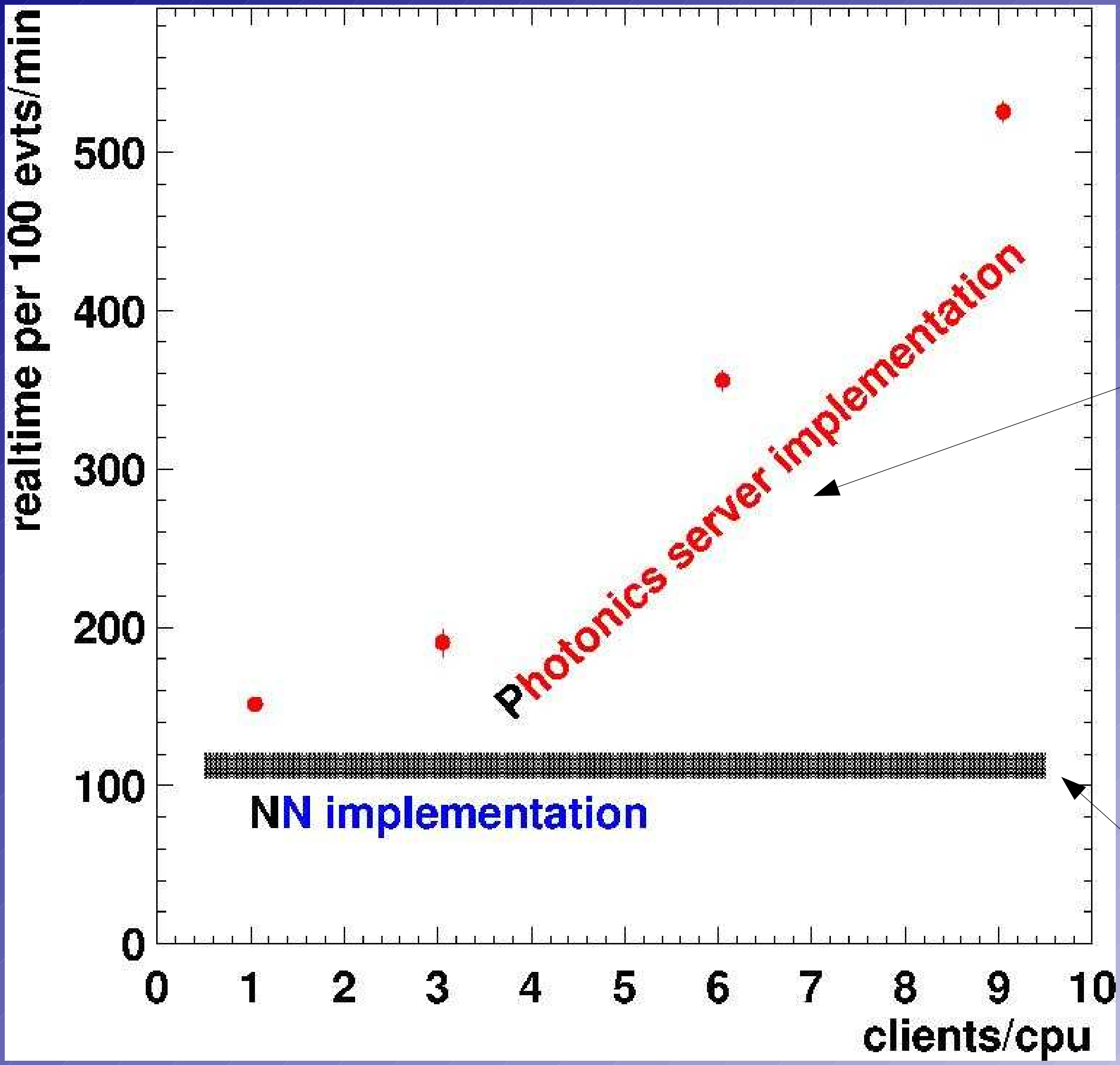


Table lookup on centralized server incurs large system overhead

decentralized NN evaluation

Summary & Outlook

- MC table generation tested and running well
- NN parametrization of flux timing tables is adequate
- Fine tune parametrization of fluence tables
- proceed with full scale implementation into AMANDA simulation chain