WbLS@FiTQun

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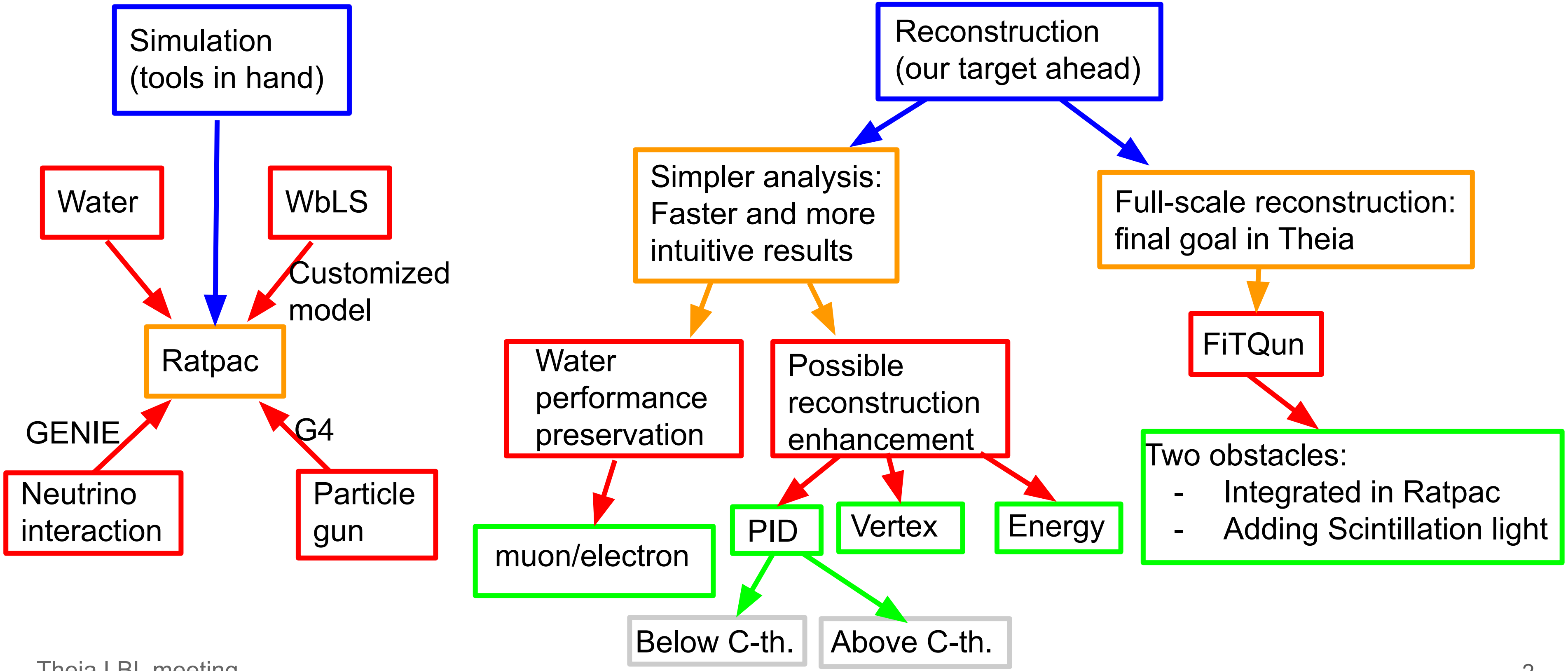
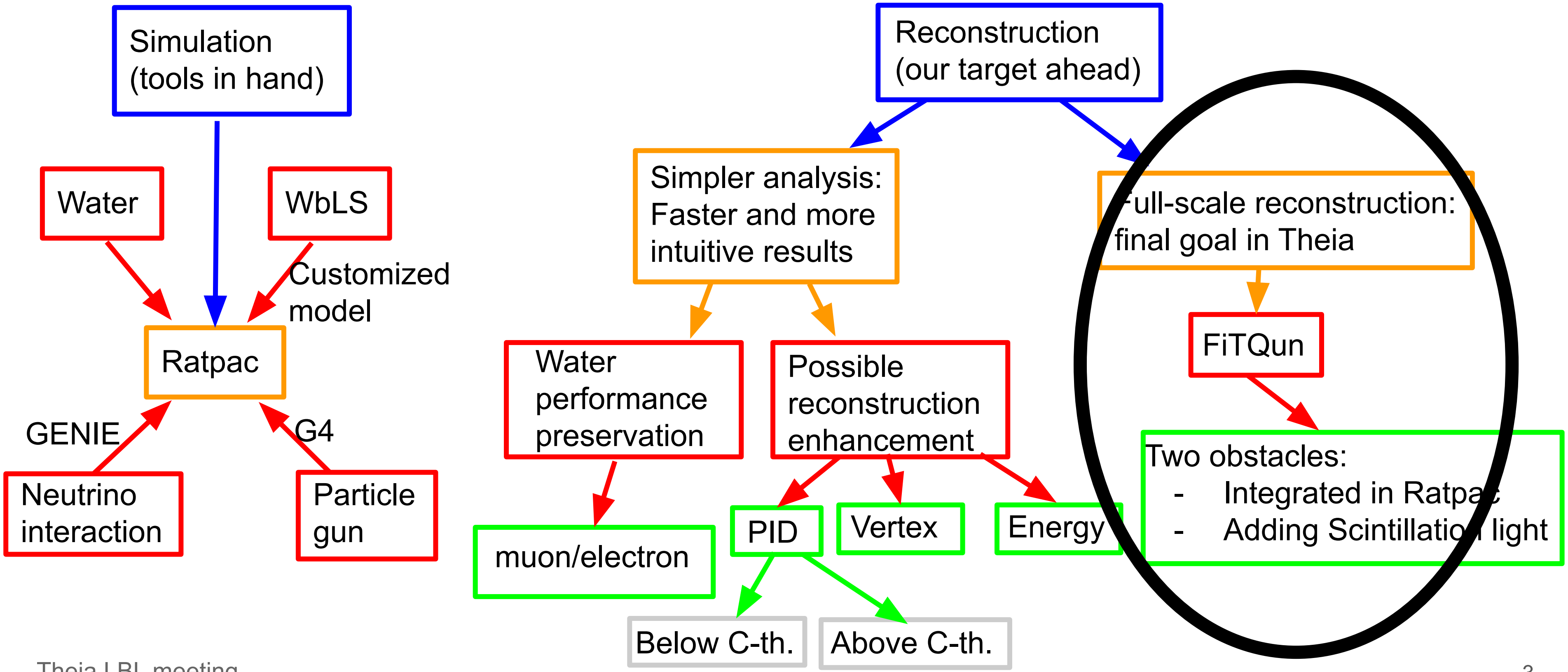
April 28 2023

Simulation and reconstruction highlight



Simulation and reconstruction highlight



FiTQun

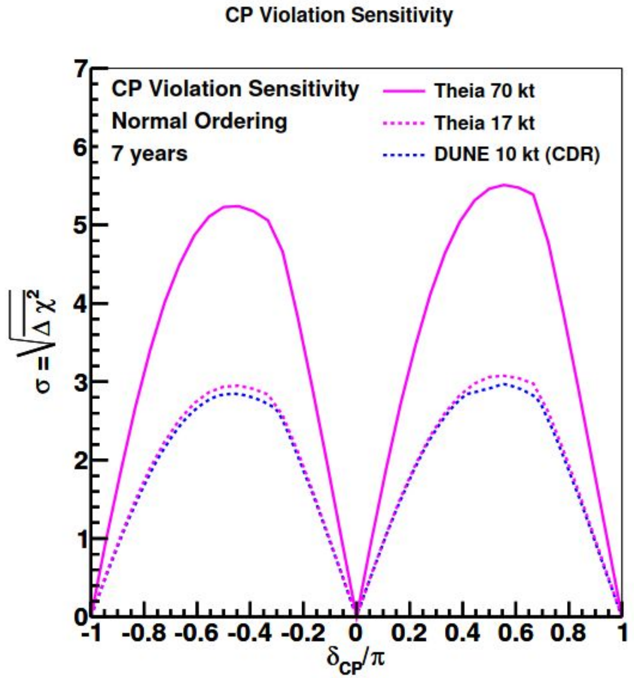
Being used in Super-K, T2K and WCSim

It has also been used in the Theia long-baseline result.

Performance -> Atmospheric Neutrino Oscillation Analysis with Improved Event Reconstruction in Super-Kamiokande IV: arXiv. 1901.03230

Principle -> The extended-track reconstruction for MiniBooNE: arXiv. 0902.2222

Theia white paper



FiTQun

A full reconstruction providing information of neutrino interaction vertex, number of rings, and momentum and PID of each ring.

For a single ring, there are seven reconstructed quantities: location (3), momentum (1), direction (2), time (1), denoted as **x**.

$$\mathcal{L}(\mathbf{x}) = \prod_{\text{unhit}} (1 - P(i\ \text{hit}; \mathbf{x})) \times \prod_{\text{hit}} P(i\ \text{hit}; \mathbf{x})\ f_q(q_i; \mathbf{x})\ f_t(t_i; \mathbf{x})$$

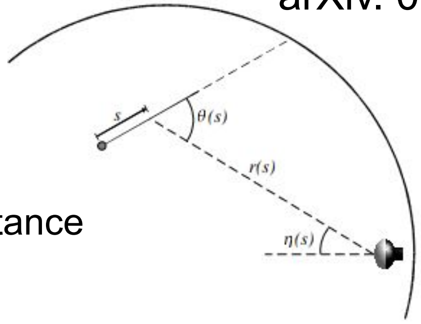
P is the likelihood the PMT got hit;
q,t are measured charged and time in pmts;
fq is the charge profile;
ft is the time profile;

$$F(\mathbf{x}) \equiv -\log \mathcal{L}(\mathbf{x}) \equiv F_q(\mathbf{x}) + F_t(\mathbf{x})$$

$$F_q(\mathbf{x}) \equiv -\sum_{\text{unhit}} \log(1 - P(i \text{ hit}; \mu_i)) - \sum_{\text{hit}} \log(P(i \text{ hit}; \mu_i) f_q(q_i; \mu_i))$$

The μ is the predicted mean charge.

arXiv. 0902.2222



Scintillation light

$$\mu_{\text{point,sci}} = \Phi_{\text{sci}} \Omega(r)\, T_{\text{sci}}(r)\, \epsilon(\eta)$$

LY Solid angle Transmission acceptance

$$\mu_{\text{sci}} = \Phi_{\text{sci}} \int_{-\infty}^{\infty} ds\ \rho_{\text{sci}}(s)\, \Omega(s)\, T_{\text{sci}}(s)\, \epsilon(s)\ .$$

Similarly,

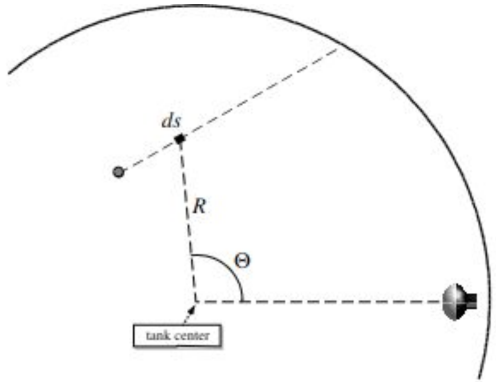
$$\mu_{\text{Ch}} = \Phi_{\text{Ch}} \int_{-\infty}^{\infty} ds \rho_{\text{Ch}}(s)\, \Omega(s)\, T_{\text{Ch}}(s)\, \epsilon(s)\, g(\cos\theta(s); s)$$

Cherenkov angular profile

Particle-independent input

Particle-dependent input

Indirect light



Scintillation

$$A_{\mathrm{sci}}(R, \cos\Theta) \equiv \frac{d\mu_{\mathrm{sci}}^{\mathrm{indirect}}}{d\mu_{\mathrm{sci}}^{\mathrm{direct}}} \,.$$

$$\mu_{\mathrm{sci}} = \Phi_{\mathrm{sci}} \int_{-\infty}^{\infty} ds\, \rho_{\mathrm{sci}}(s)\,\Omega(s) T_{\mathrm{sci}}(s)\epsilon(s)\left[1 + A_{\mathrm{sci}}\left(R(s), \cos\Theta(s)\right)\right]$$

Cherenkov

$$A_{\mathrm{Ch}}(R, \cos\Theta, \cos\theta, \phi) \equiv \frac{d\mu_{\mathrm{Ch}}^{\mathrm{indirect}}}{d\mu_{\mathrm{Ch}}^{\mathrm{direct,iso}}}$$

$$\mu_{\mathrm{Ch}}^{\mathrm{indirect}} = \Phi_{\mathrm{Ch}} \int_{-\infty}^{\infty} ds\, \left[\rho_{\mathrm{Ch}}(s)\, \Omega(s)\, T_{\mathrm{Ch}}(s)\, \epsilon(s) \times A_{\mathrm{Ch}}\left(R(s), \cos\Theta(s), \cos\theta(s), \phi(s)\right)\right]$$

Particle-independent input

Particle-dependent input

Input for FiTQun

Charge profile

Angular response

Indirect light ratio table

Cherenkov profile

Time profile

— **Particle-independent input**

— **Particle-dependent input**

Need a "tuner" to provide all these information.
Currently FiTQun is compatible with two softwares:

- SuperK library -> too old, we might not want to use it.
- WCSim library -> pretty modern, taken as our target model. No scintillation light.

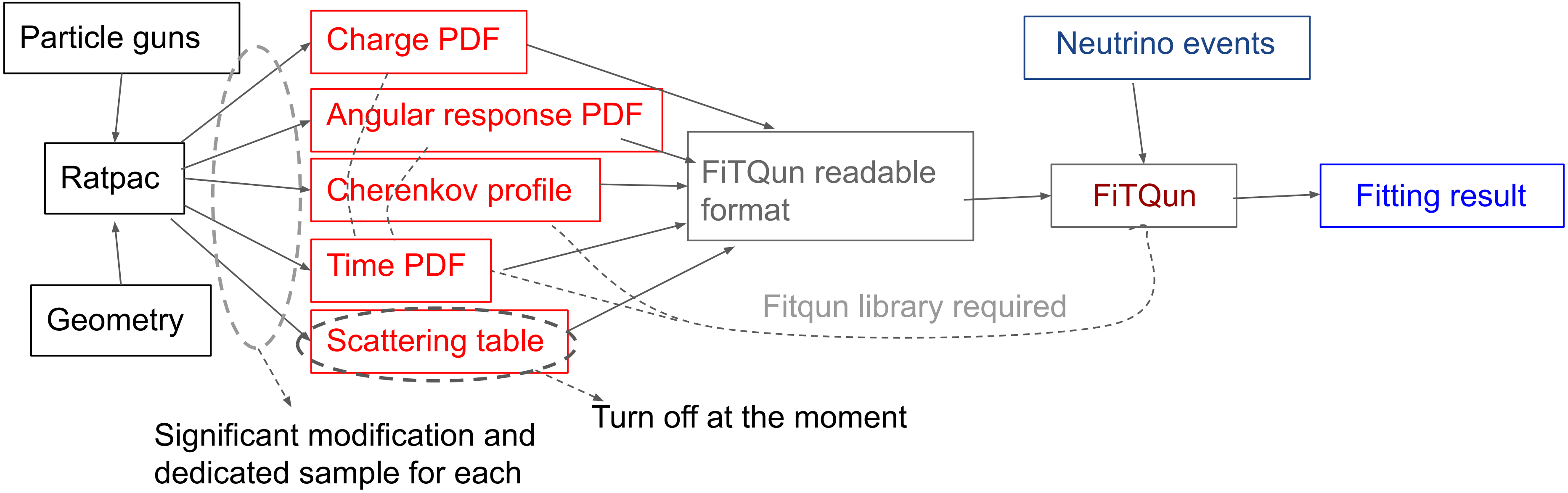
I am creating a Rat-pac tuner for FiTQun-> all these information should come from Ratpac including our best scintillation light modeling.

Structure of our work

FiTQun with Ratpac in water — ***Still Here***

FiTQun with Ratpac in WbLS

FiTQun with Ratpac in water



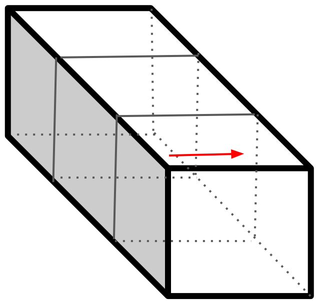
Geometry

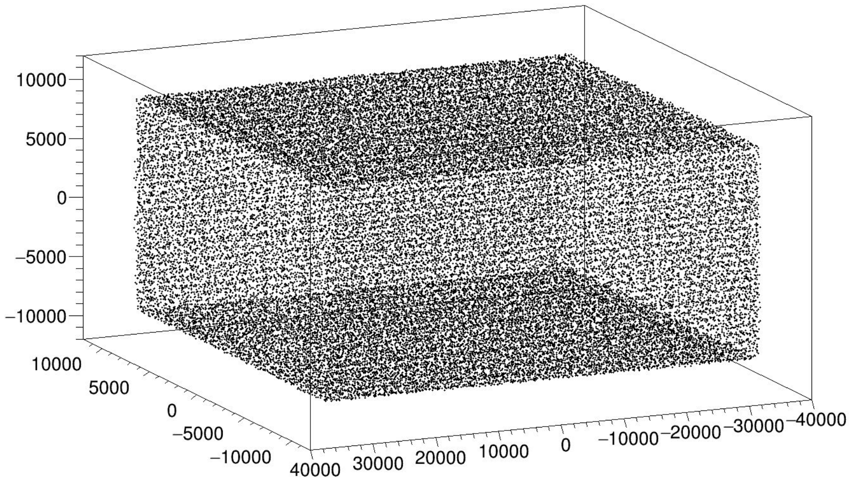
Theia 25 kt letter box inside DUNE cavern: 20 m x 18 m x 69 m

To speed up the process, 14 sensitive pads were used.

Currently, test the framework with the 14 “giant PMTs”.

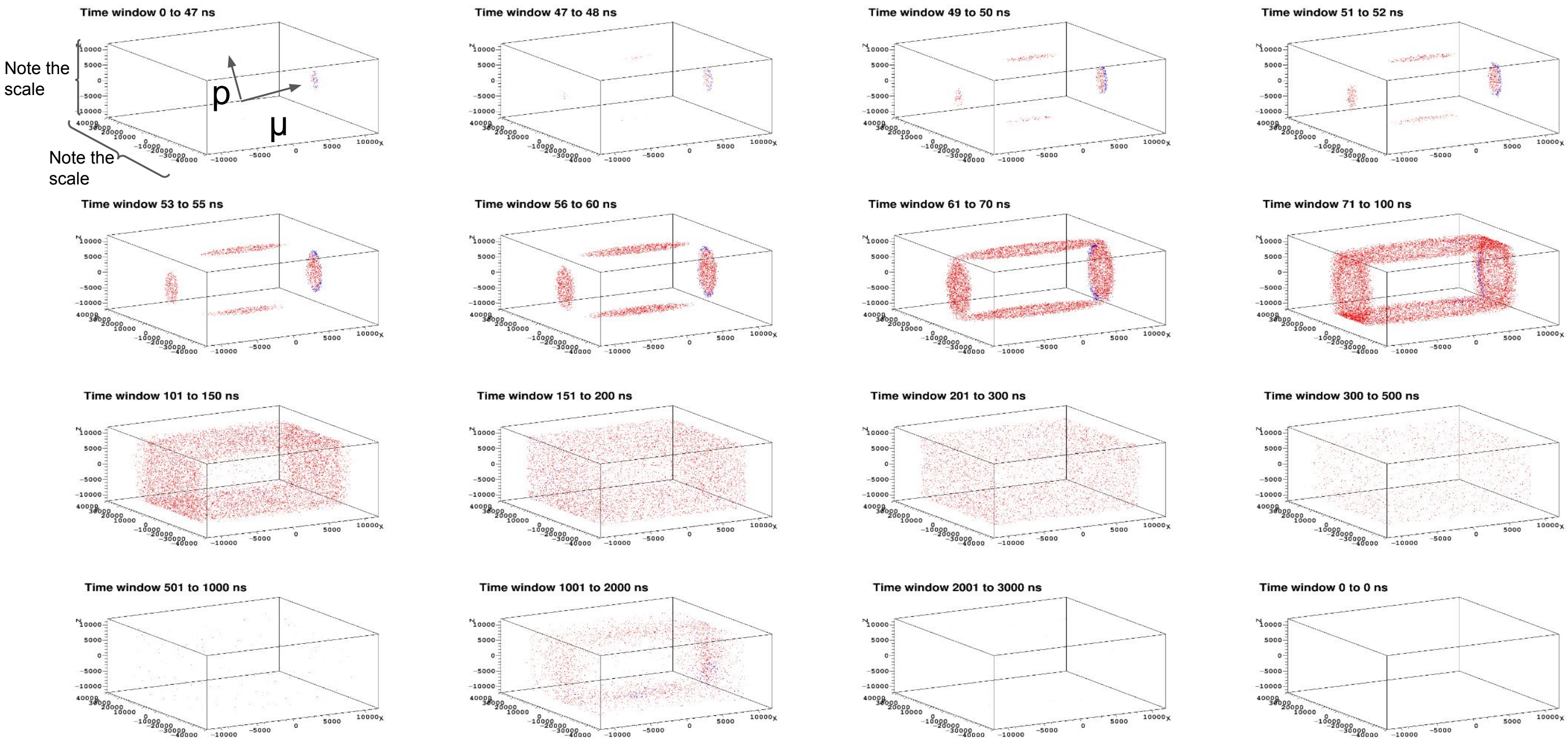
Any specific region selection is possible such as uniform 40% coverage.





How does a 1 GeV neutrino event looks like

375 KE u- and
493 KE Proton



Go through the inputs

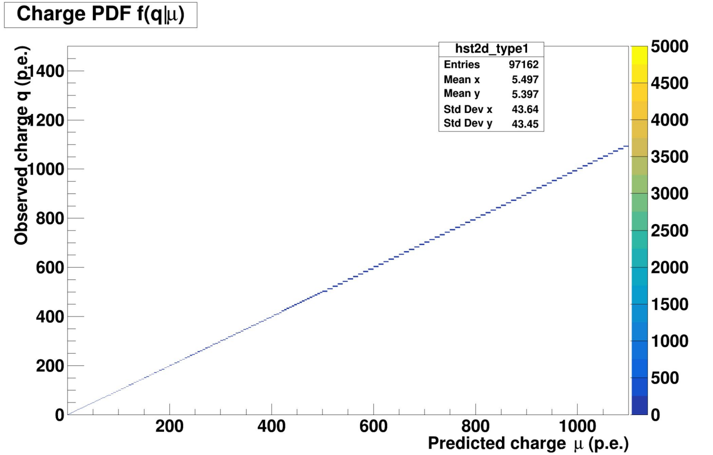
Charge and angular PDF

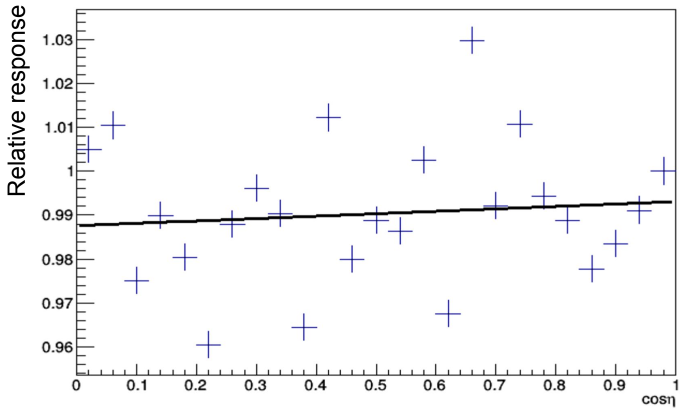
Charge: PMT response to 1,2,3… Photons

- Sample: individual number of PEs in front of the PMT
- Fast solution: assuming perfect response

Angular: PMT response to photons entering from different angles

- Sample: low-energy electron bombs with different angles to the PMT
- Fast solution: uniform response to all entering angles





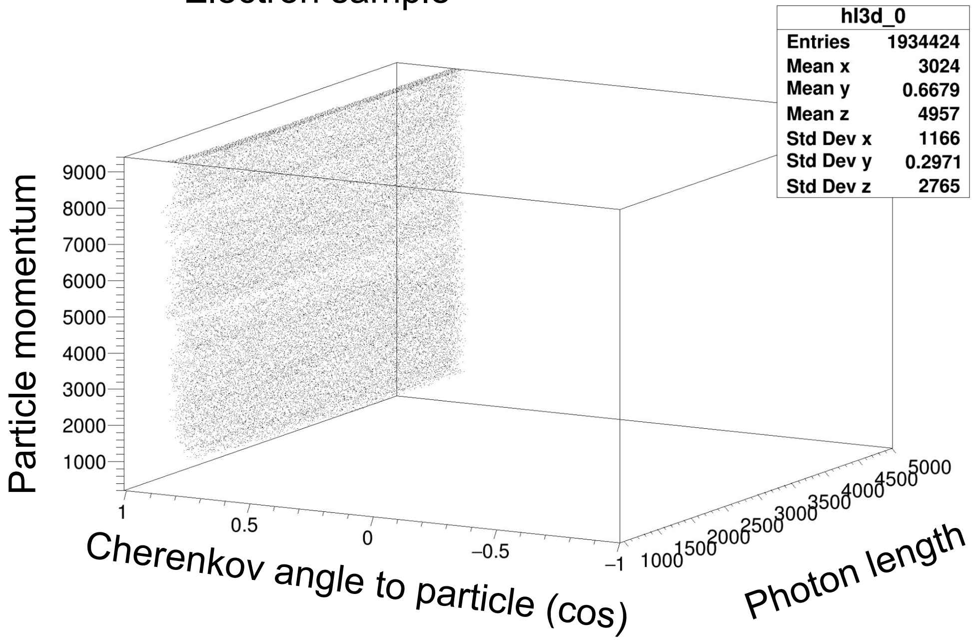
Cherenkov profile

Cherenkov light emission direction as functions of particle momentum and track length

- Sample: each particle type with each momentum generated uniformly in the detector
- Not using fast solution

Highly parameterized later serving as FiTQun input

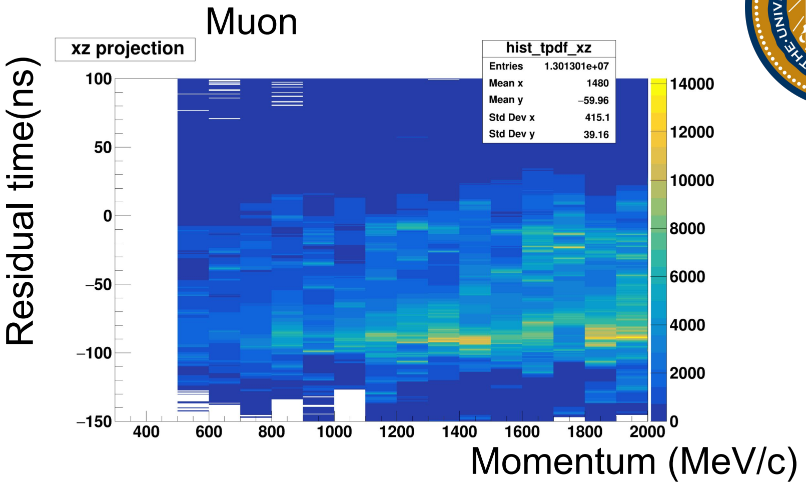
Electron sample

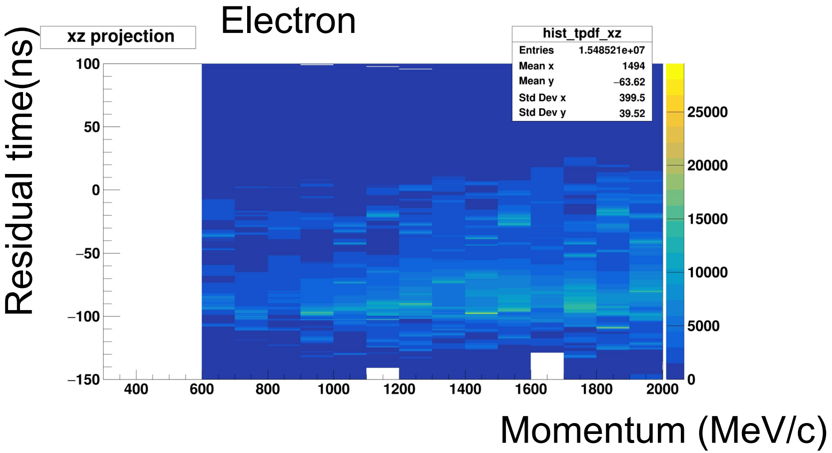


Time PDF

Time profile as functions of charge for each particle

- Time corrected for the light travel path
- Particle track mean location is considered as the particle vertex
- Sample: different types of particles with each momentum generated at the center of the detector
- Not fast solution
- More samples needed





Current status

The ratpac-tuner for fitqun input should be ready. However, more samples covering full phase space are needed. Then start the fitqun water fit with ratpac -> more problems expected.

Moving to WbLS needs longer time.