The fiTQun reconstruction algorithm

Cristóvão Vilela
For team fiTQun

NNN15 water detectors satellite meeting
October 27 2015

Introduction

- FiTQun is a reconstruction package initially developed for Super-K
  - Based on MiniBooNE reconstruction (NIM A 608, 206)
- Used for π^0 rejection in T2K ν_e appearance analysis (PRL 112, 061802)
- Systematics under study for fiTQun-only SK event selection
- Flexible algorithm structure
  - Runs on Super-K (SKDETSIM) and WCSim simulations
  - Easily adaptable to different detector geometries / characteristics
    - Currently supported detectors:
      - Super-K 1 – 4 (SKDETSIM)
      - Hyper-K (WCSim)
      - NuPRISM (WCSim)
  - Algorithm extensions possible
    - For example, addition of scintillation light would be straightforward

Likelihood-based reconstruction

FiTQun reconstruction is based on a likelihood maximisation

Use information from sensors both with and without registered hits in the event

$$L(\mathbf{x}) = \prod_{i_{unhit}} \mathrm{P}(i_{unhit}|\mathbf{x}) \prod_{i_{hit}} \mathrm{P}(i_{hit}|\mathbf{x}) f_q(q_i|\mathbf{x}) f_t(t_i|\mathbf{x})$$

Build likelihood function for event hypothesis **x**

For hit photosensors:

Compare observed charge to prediction and Compare hit time to prediction

Functions f_q and f_t incorporate the photosensor response (σ_t, σ_q, ...)

- Event hypotheses can be simple single-particle topologies, in which case:
  - **x** = (t_0, x, y, z, p, θ, φ)
- Or complex, multi-particle events, with an increased number of parameters
- Likelihood ratios are used to distinguish between hypotheses
  - i.e., PID – for single-particle hypotheses

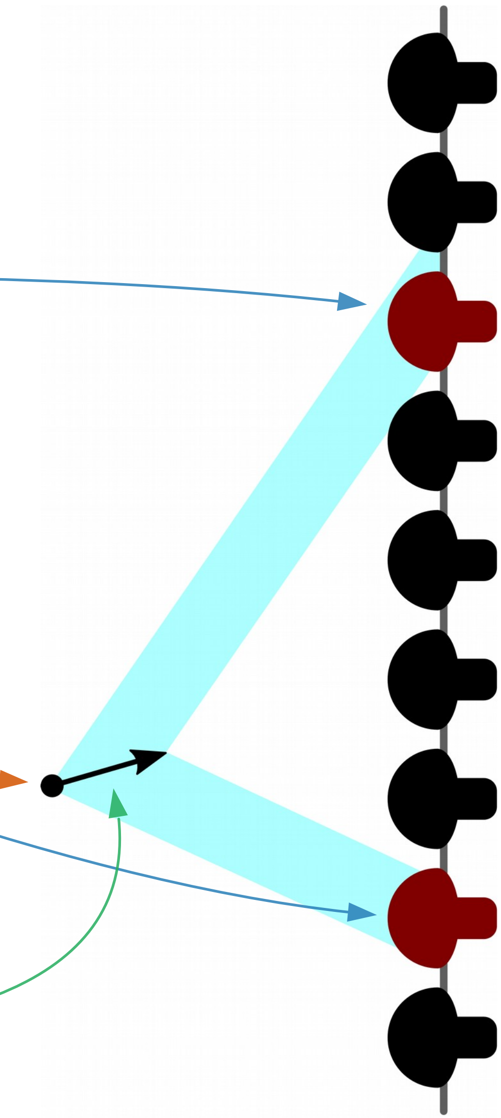
Direct light charge prediction

$$\mu^{dir} = \Phi(p) \int ds \, g(p, s, cos\theta) \; \Omega(R) \; T(R) \; \epsilon(\eta)$$

The direct light charge prediction μ is evaluated at each of the hit photosensors

The overall amount of light is governed by the function Φ, which depends on particle type and momentum

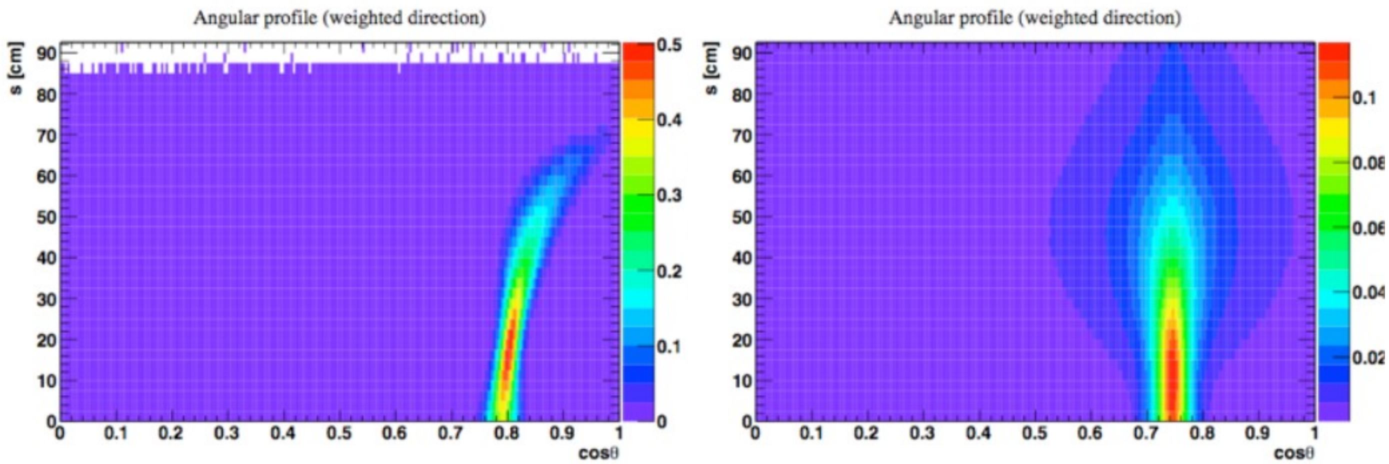
The factors g, Ω, T and ϵ are evaluated in an integral which is computed over the length of the track s



Direct light charge prediction

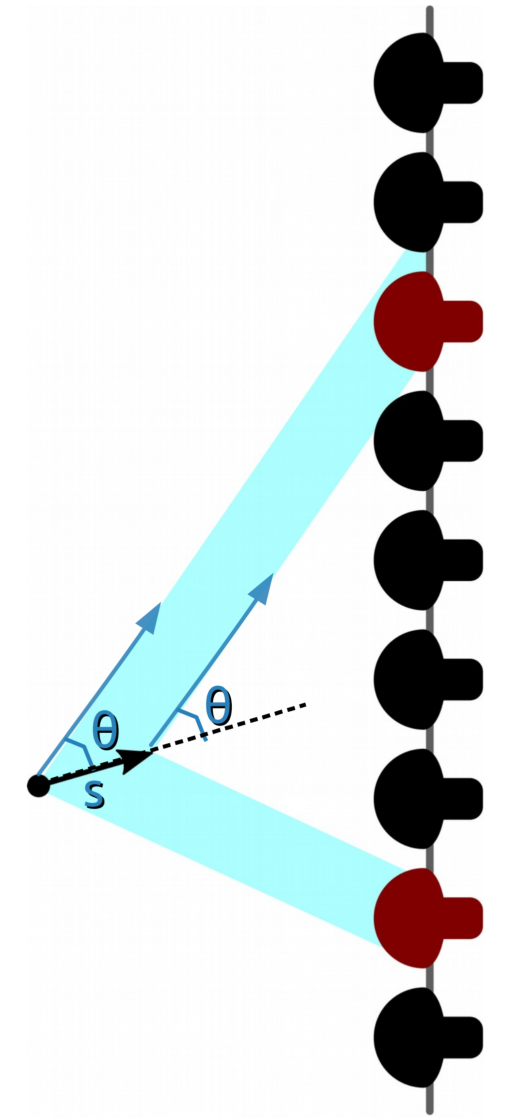
$$\mu^{dir} = \Phi(p) \int ds\, \boxed{g(p, s, cos\theta)}\, \Omega(R)\, T(R)\, \epsilon(\eta)$$

The function g encodes the Cherenkov emission profile



Electron (left) and muon (right) emission profiles at 300 MeV

- Cone collapse differs for particles of different mass
- This is all the information used for individual ring PID



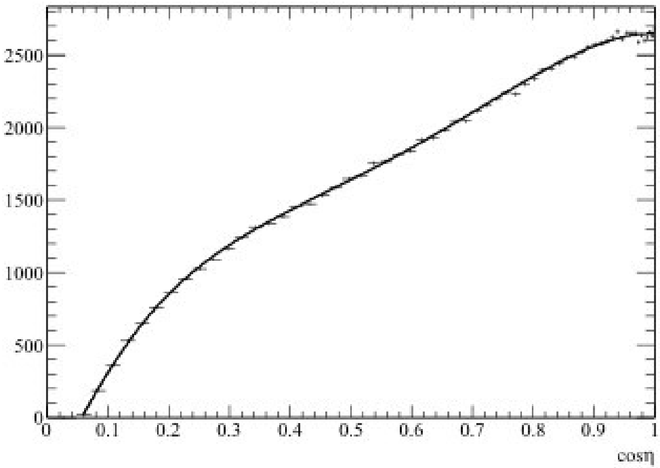
Direct light charge prediction

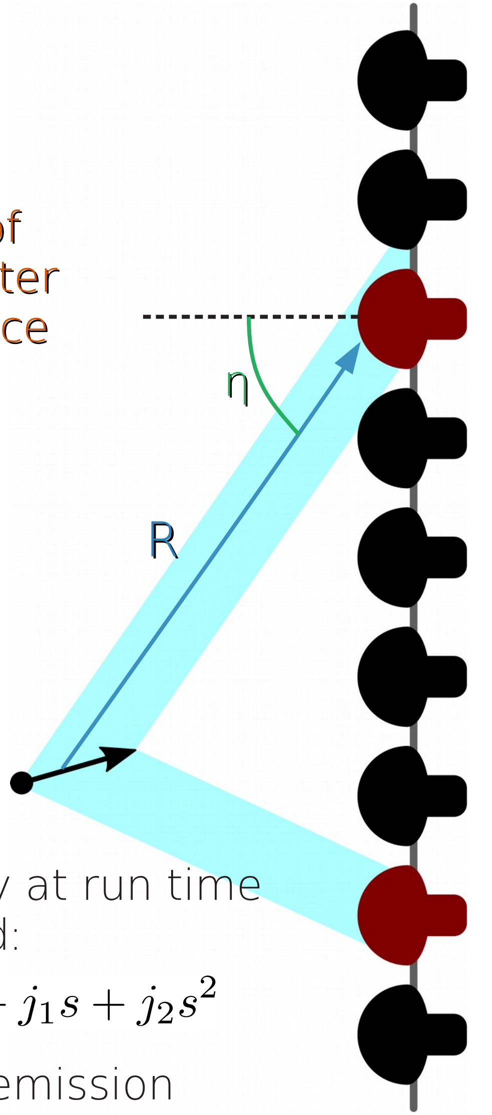
$$\mu^{dir} = \Phi(p) \int ds\, g(p, s, cos\theta)\, \Omega(R)\, T(R)\, \epsilon(\eta)$$

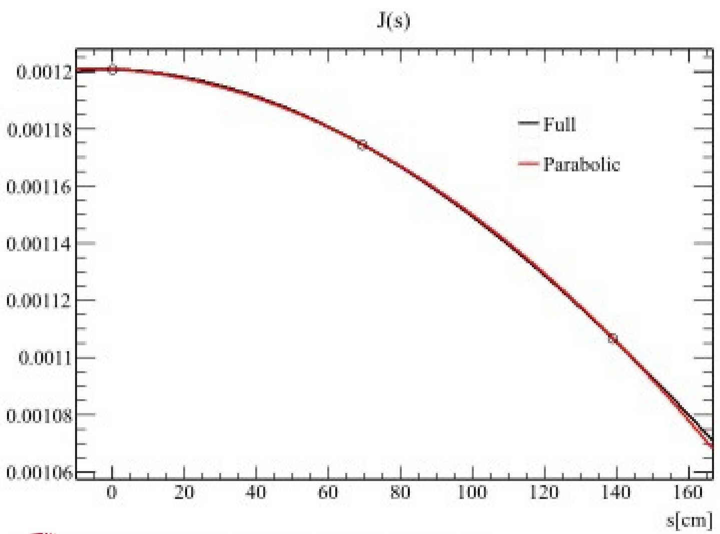
Ω reflects the change in apparent scale of the photosensor as a function of distance

T gives the amount of light attenuation in water as a function of distance

ϵ represents the angular response of the photsensor accounting for effects such as the shadowing due to adjacent PMTs and the shape of the photocathode







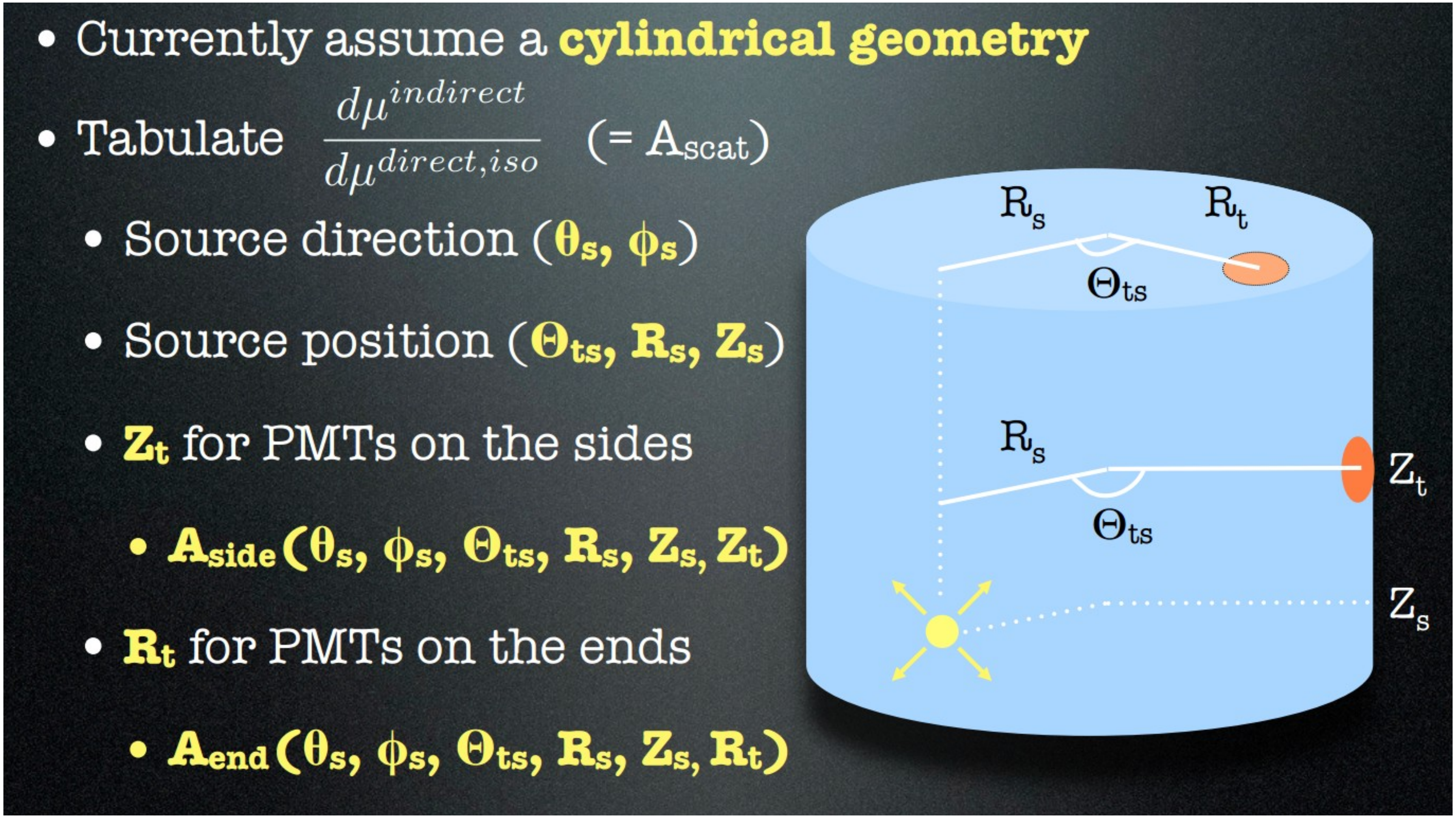
The integral is not computed explicitly at run time

- A parabolic approximation is used:

$$J(s) = \Omega(R)\ T(R)\ \epsilon(\eta) \approx j_0 + j_1 s + j_2 s^2$$

- The integral over the Cherenkov emission profile is tabulated

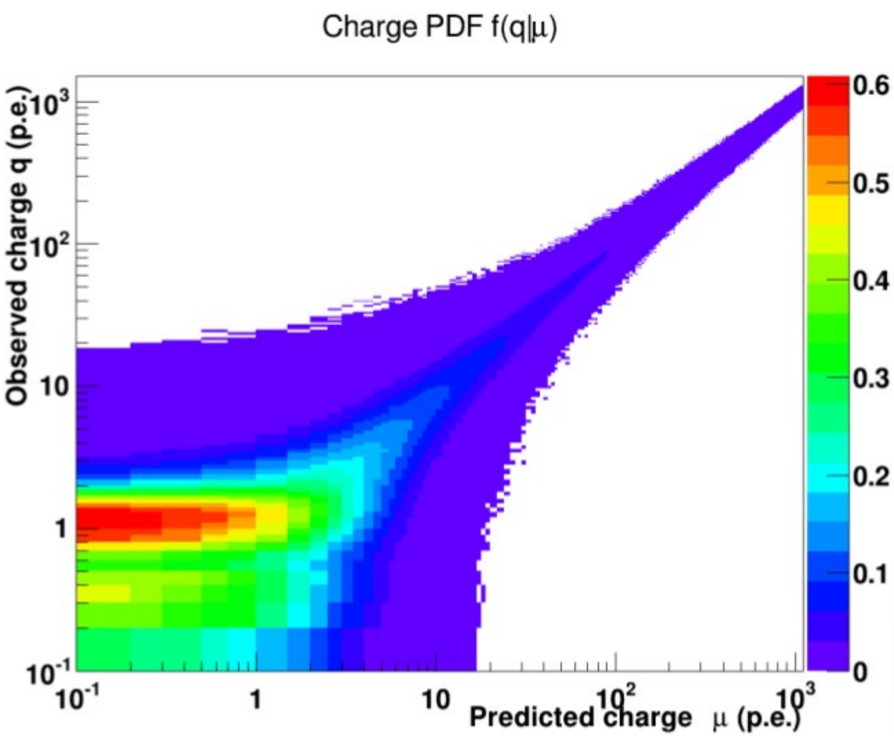
Indirect light charge prediction



Photosensor response

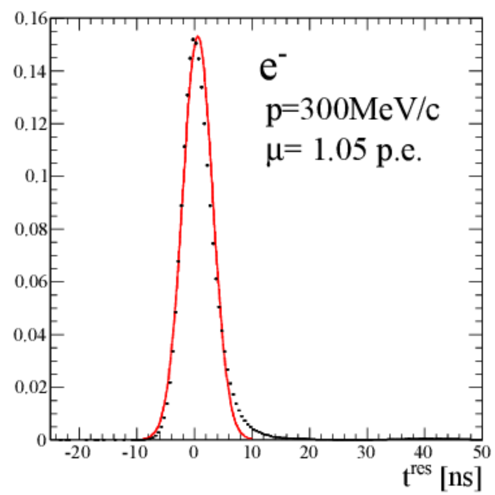
Charge

- PDFs of the observed charge for a given true mean obtained from Monte Carlo simulation
- Hit probability functions are extracted from these distributions

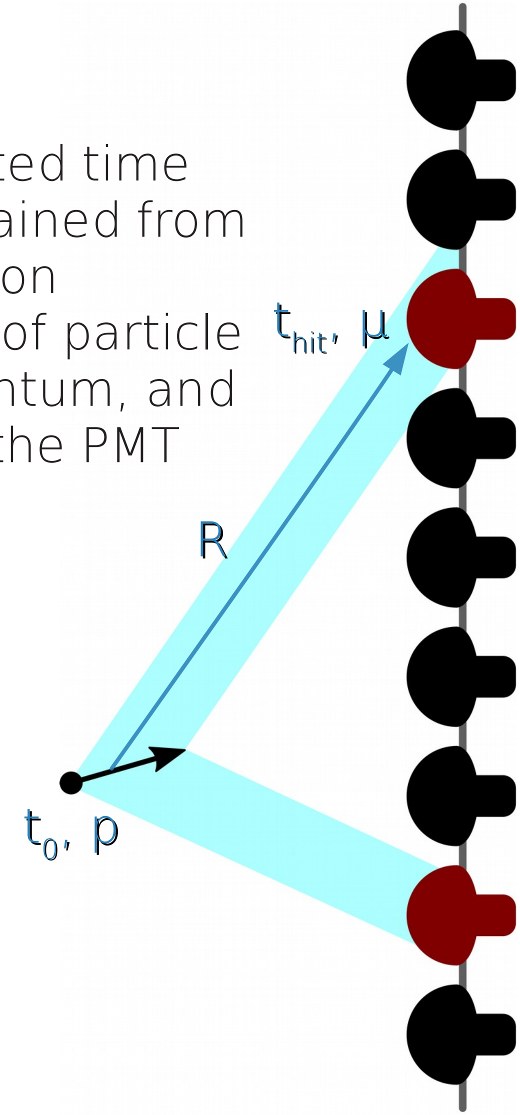


Time

- Time-of-flight corrected time distributions are obtained from Monte Carlo simulation
- Stored as a function of particle type, particle momentum, and predicted charge at the PMT

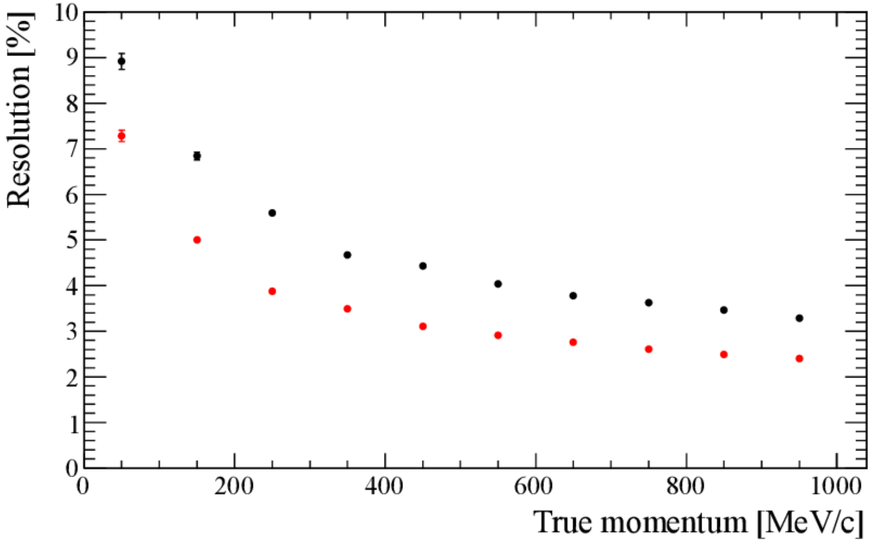


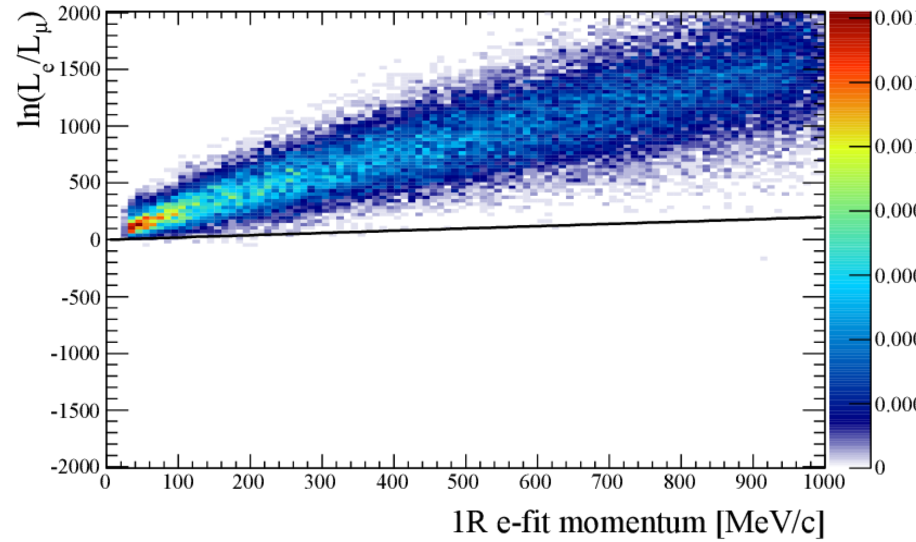
$$t_{corr} = t_0 - \left(t_{hit} - \frac{Rn}{c} - \frac{s}{2c} \right)$$

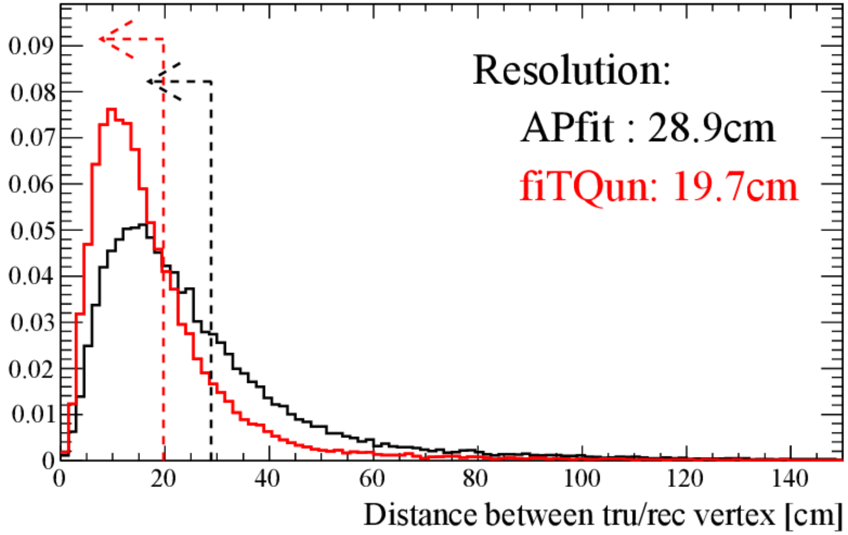


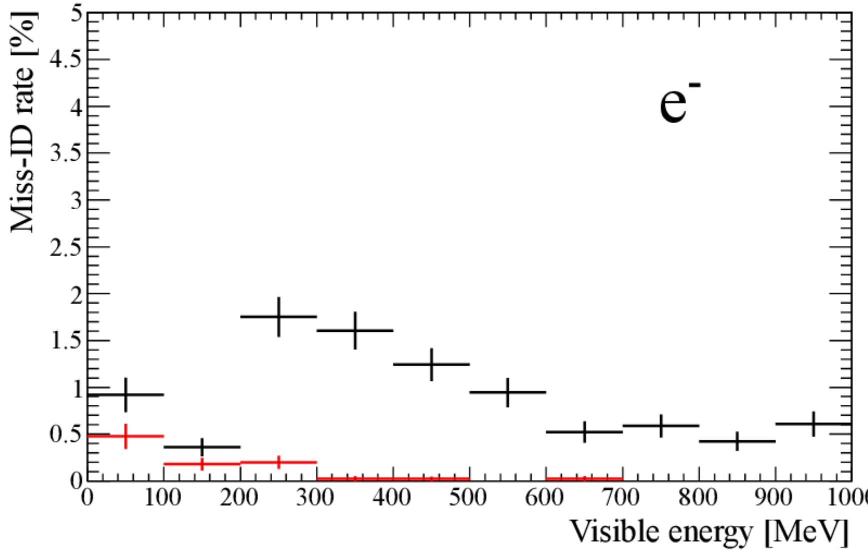
Single-ring fitters: e

Super-K particle gun performance

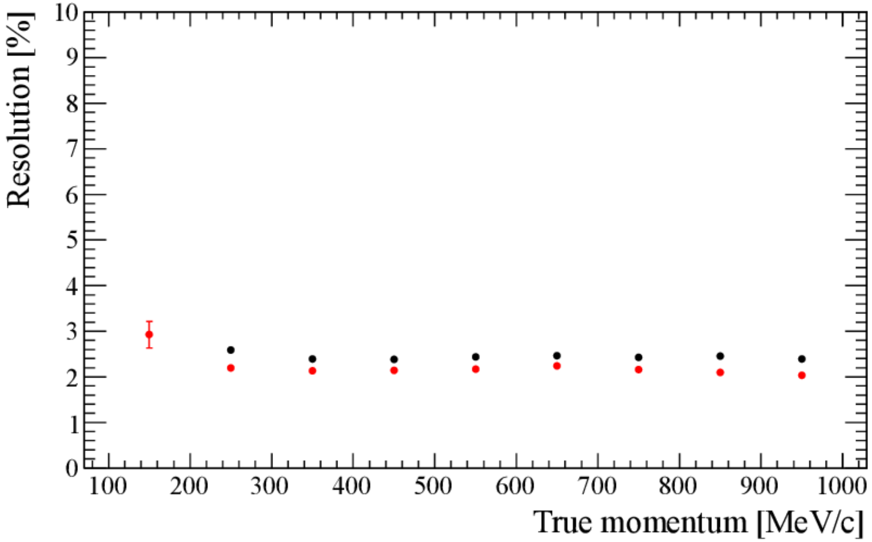


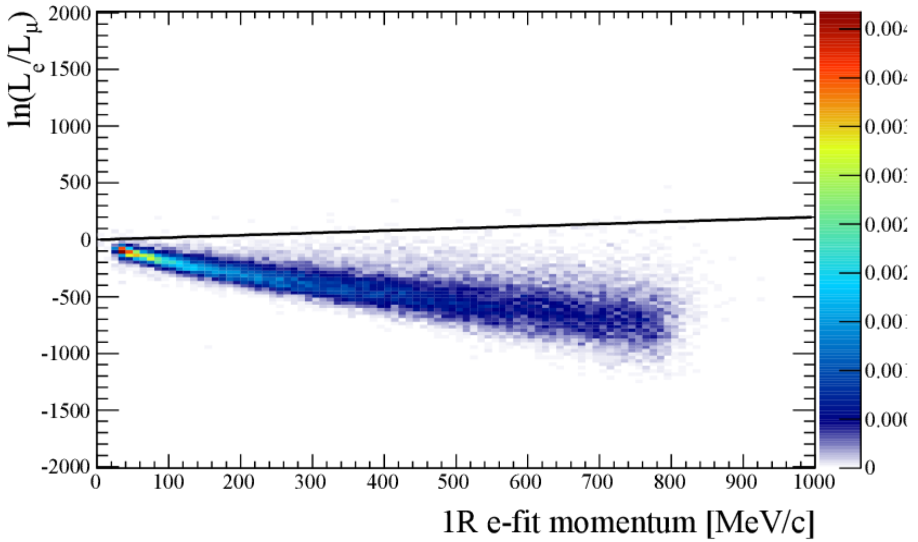


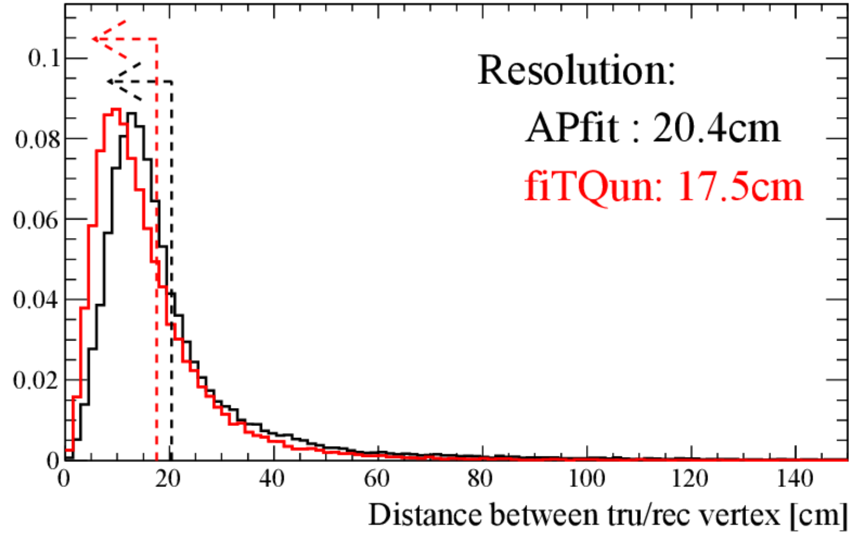


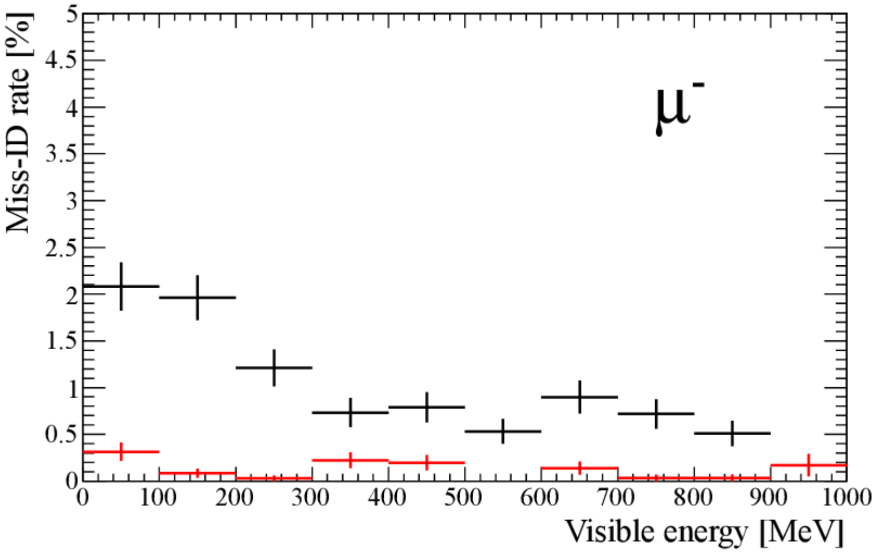


Single-ring fitters: μ
Super-K particle gun performance





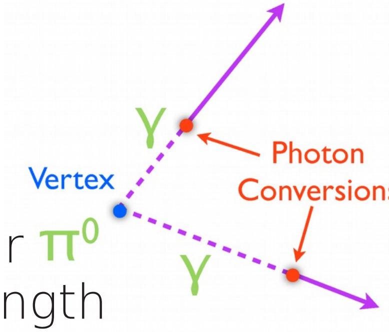




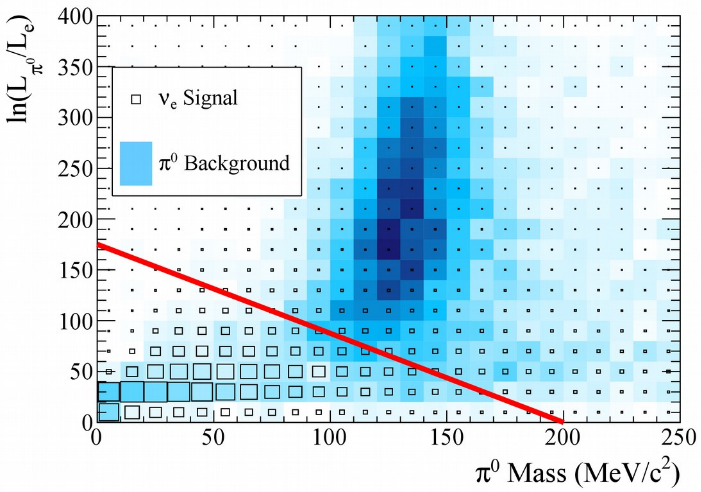
Complex single-particle hypotheses

π^0

- Fit two electron-like tracks with common vertex, accounting for π^0 photon conversion length

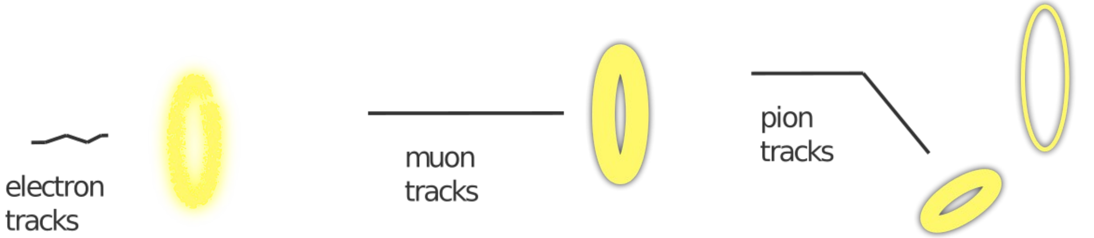


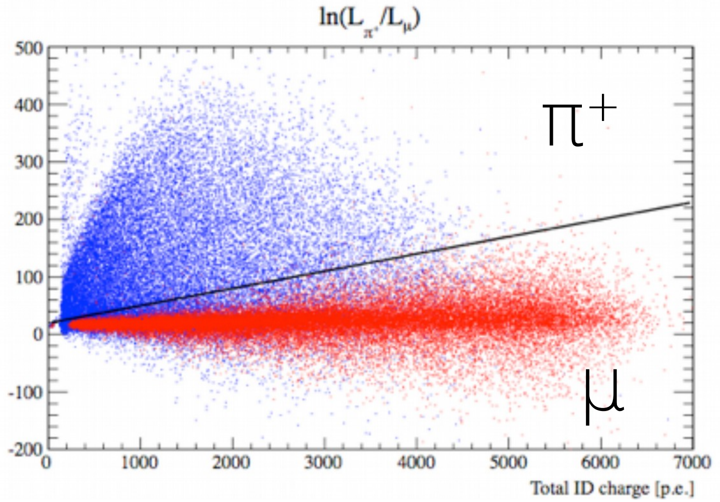
- 12 parameter fit, seeded with single-ring fit result
- FiTQun's sensitivity to low energy rings gives good selection (rejection) efficiency



π^+ (kinked track)

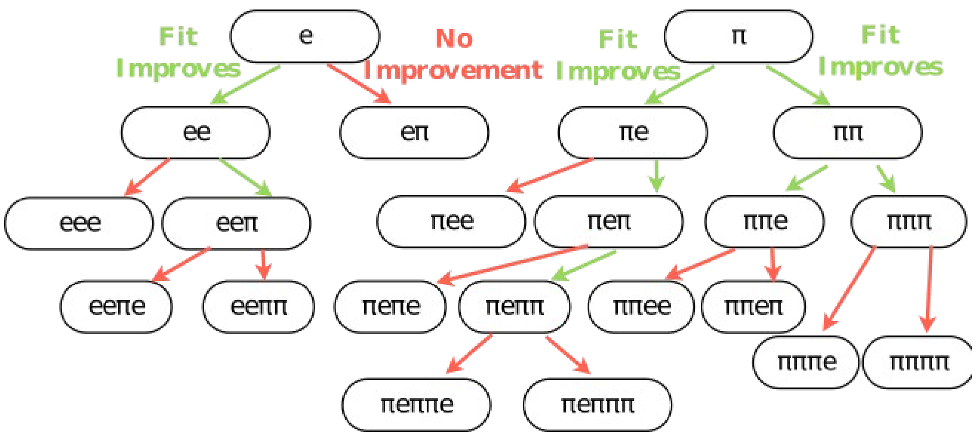
- Single-ring π^+ difficult to distinguish from μ
- However π^+ is more likely to hard-scatter
- Look for kinked π^+ track with two rings

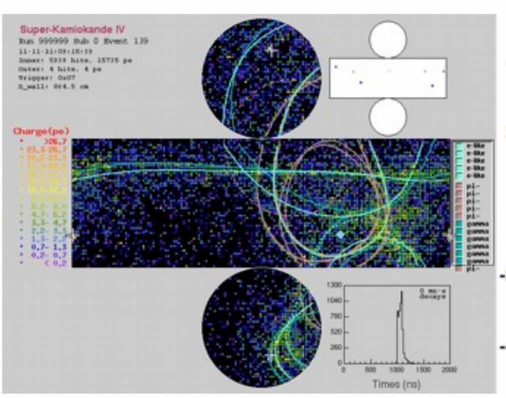


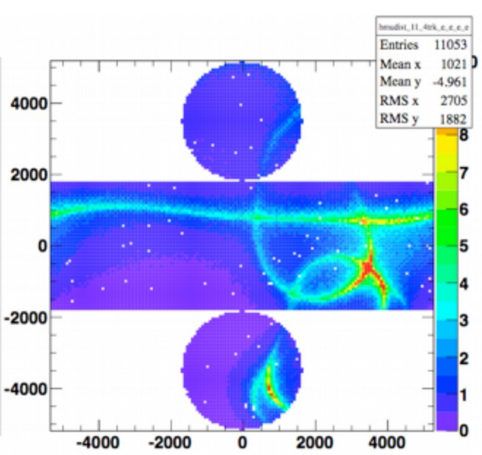


Other complex hypotheses

Generic multi-ring



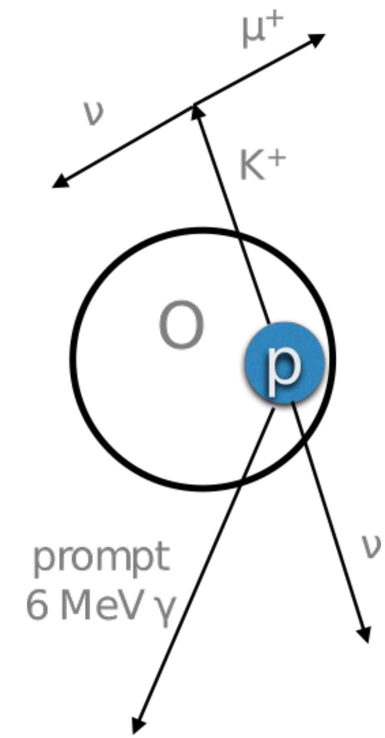




Proton decay

$p \rightarrow K^+ \nu$

- Fit for prompt low energy γ followed by a μ from K decay
- Preliminary studies show separation from muon-only hypothesis is achievable



$p \rightarrow e^+ \pi^0$

- Fit for 3 e-like rings
- Initial studies show improved selection with fiTQun, with better background suppression

FiTQun on multiple detector geometries

- FiTQun was written for Super-K, with tunes for its four eras
  - Different coverage fractions, electronics, photosensors (acrylic covers)
  - Tuning procedure based on SKDETSIM
- FiTQun has been adapted to run on WCSim Monte Carlo
  - WCSimWrapper class allows for fiTQun to be compiled independently of SK software libraries, linked only to WCSim (and ROOT)
  - WCSim is open-source, we are now looking to open the WCSim-based fiTQun code
  - Tuning procedure has been "translated" into WCSim
  - ~First generations of WCSim tunes are now being produced
    - Hyper-K
    - NuPRISM
  - The plan is to produce and maintain tunes for all geometries available on WCSim
    - Procedure is being streamlined so that it can be easily performed (by non-experts)

Summary

- FiTQun reconstruction has shown excellent performance on Super-K
  - Used for π^0 rejection in T2K ν_e appearance results
  - Systematics under study for roll-out of fiTQun-based event selection
- Fitting algorithm is flexible
  - Additional, complex, event hypotheses under continuous development
  - Straight-forward extension of likelihood function (e.g.: scintillation light)
- "Core" components are well separated
  - Compiles separately against two very different libraries (WCSim / SKDETSIM)
  - Running on the several available detector tunes is straightforward
- Code is currently hosted in private Github repository
  - Ongoing efforts to "open up" fiTQun linked to WCSim (but not SKDETSIM)
  - https://github.com/fiTQun/fiTQun