Tuning files for PyfiTQun

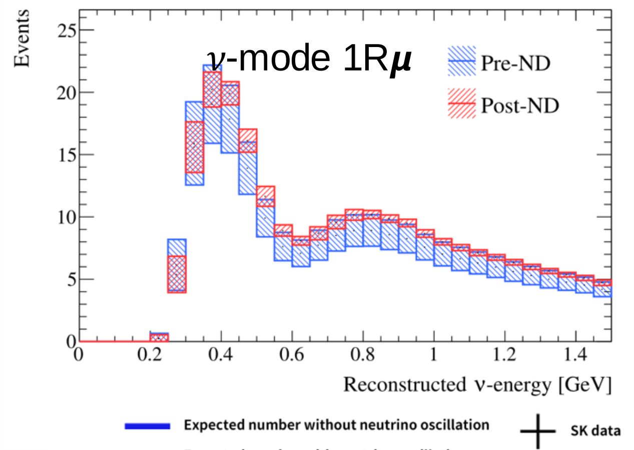
Lorenzo Restrepo Orrantia

Table of contents

Important quantities for the analysis

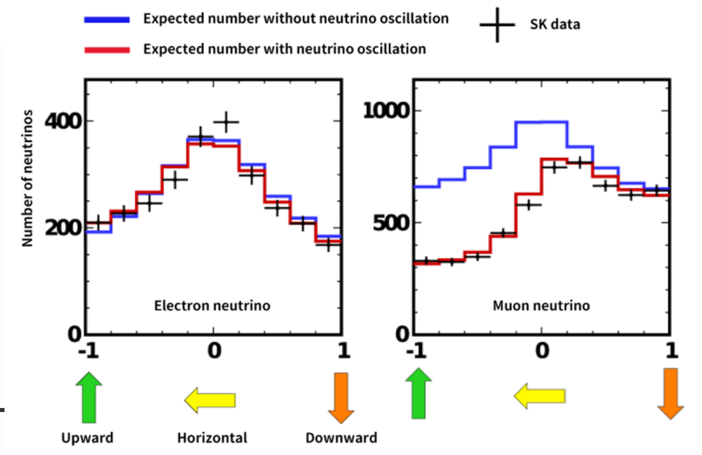
- Oscillation analysis (accelerator ν):

→ Neutrino energy (E) and type (e or mu)



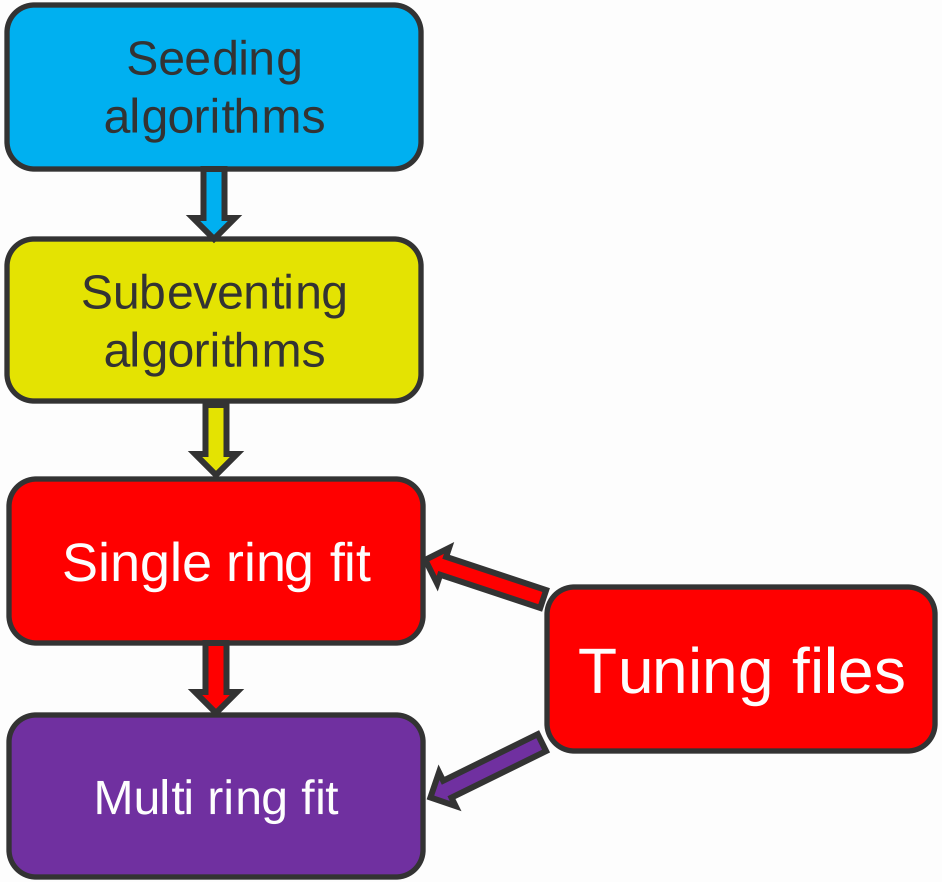
- Determination of the neutrino origin (beamline, atmospheric, Supernovae…)

→ Neutrino direction ($\boldsymbol{\theta}$, $\boldsymbol{\varphi}$)



fiTQun pipeline

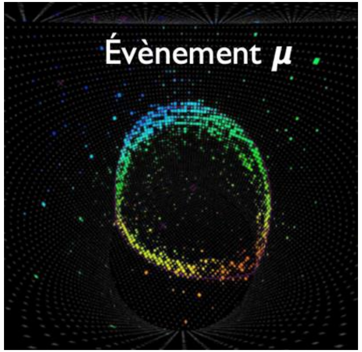
- SK reconstruction algorithm
- Divided into parts that perform different tasks
- Ring fit = heart of the algorithm
  → Determination of (x, $\boldsymbol{\theta}$, $\boldsymbol{\varphi}$, p)
  → PID



Single & multi ring fits

- Likelihood function ***L*** = probabilistic model

Probability of observing a set of hits (times and charges), knowing the particle parameters ***p*** = (x, ***θ***, ***φ***, E)



- Computed for different particle hypothesis

→ Single track hypothesis (e, mu…) = single ring fit

→ Multiple track hypothesis (pi0…) = multi-ring fit

- The set of parameters that maximise ln(***L***) are taken as particle parameters ***p***
- PID is done by applying cuts in ln(***L(H1)/L(H2)***) for each combination of particle hypothesis

The likelihood model

- Exclusively function of the track parameters ***x***

- Depends on the physics processes and the detector geometry

$$L(\mathbf{x}) = \prod_{j}^{\text{unhit}} P_j(\text{unhit}|\mu_j) \prod_{i}^{\text{hit}} \{1 - P_i(\text{unhit}|\mu_i)\} f_q(q_i|\mu_i) f_t(t_i|\mathbf{x})$$

- Complex model with some free parameters

- Tuning = fitting the free parameters

The likelihood model

Photoelectron production ~ Poissonian model

Charge PDF:
Probability of detecting charge qi knowing mui

$$L(\mathbf{x}) = \prod_{j}^{\text{unhit}} P_j(\text{unhit}|\mu_j) \prod_{i}^{\text{hit}} \{1 - P_i(\text{unhit}|\mu_i)\} f_q(q_i|\mu_i) f_t(t_i|\mathbf{x})$$

Predicted charge deposit in each PMT knowing ***X***

$$\mu_j \equiv \mu_j(\mathbf{x})$$

Time PDF:
Probability of measuring time ti knowing ***X***

PyfiTQun

- Our goal right now is to test the electron single-ring fit

- Initially, we will do it:

→ Without scattering

→ Without time pdf

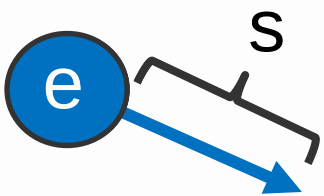
- For now, we only need:

→ Predicted charges (without scattering)

→ Unhit probability

→ Charge pdf

Predicted charges



(Track length)

Angular response

Normalisation factor

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

Cherenkov profiles
= photon emission per track length and solid angle

Predicted charges: Normalisation factor

- $\Phi(p)$ should account for all the proportionality factors not accounted for in μ^{dir}

- In PyfiTQun, the normalisation factor is simply expressed as:

$$\Phi(p) = Q_{Eff} N_{\gamma}$$

Q_{Eff} → Quantum efficiency

N_{γ} → Number of photons

Predicted charges: Parabolic approximation

- The previous integral is not analytical, thus we introduce the parabolic approximation:

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

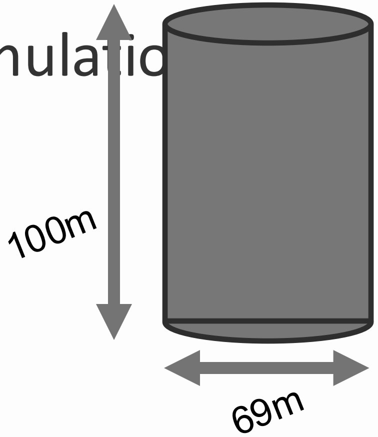
- The predicted charge becomes:

$$\mu^{\text{dir}} = \Phi(p) \int ds g(s) J(s) \approx \Phi(p)(I_0 j_0 + I_1 j_1 + I_2 j_2)$$

- With: $I_n \equiv \int ds g(s) s^n$ → ***= Cherenkov integrals***

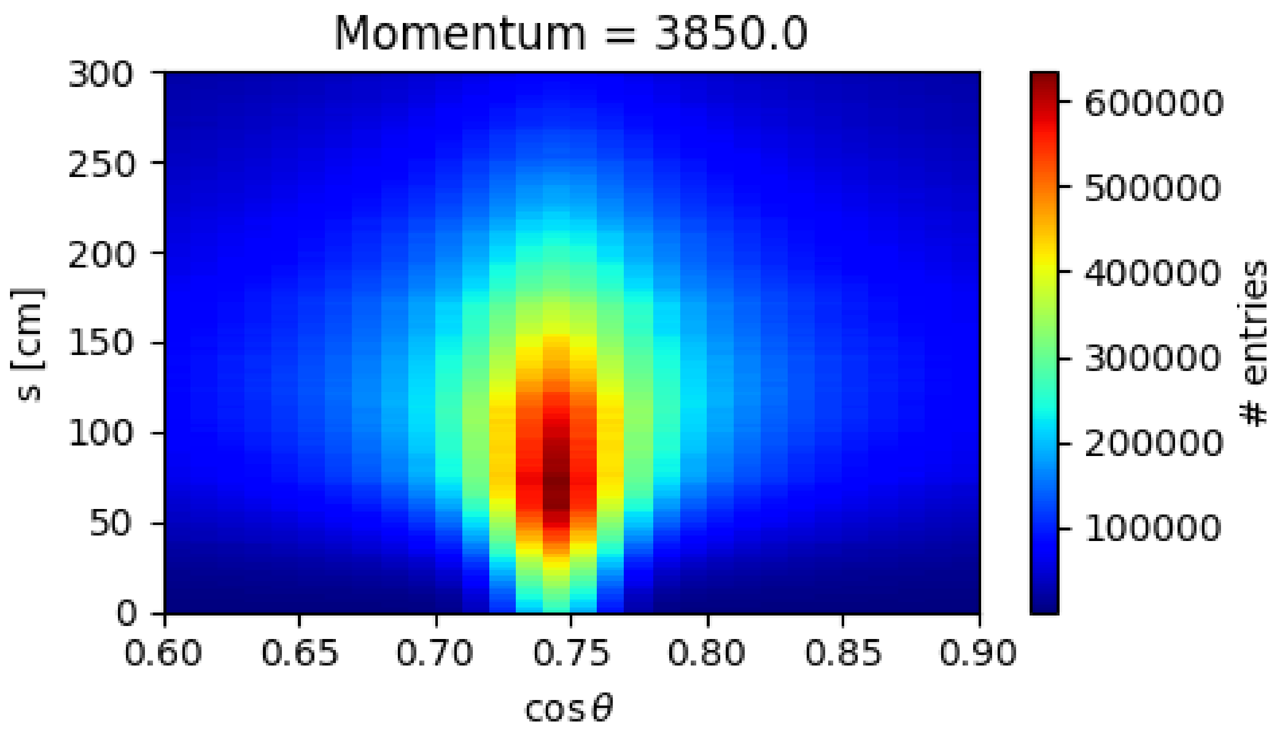
Predicted charges: Cherenkov profiles

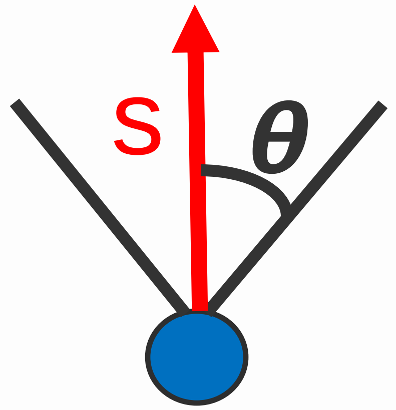
- The Cherenkov profiles are generated through simulatio in a precise geometry



- Simulated energy range: 50MeV - 4GeV
- 1000 events/energy

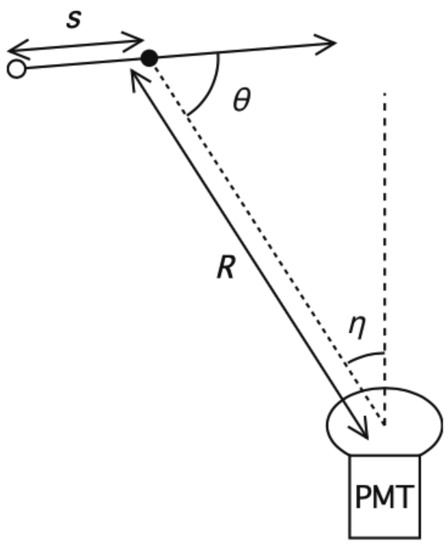
Predicted charges: Cherenkov profiles





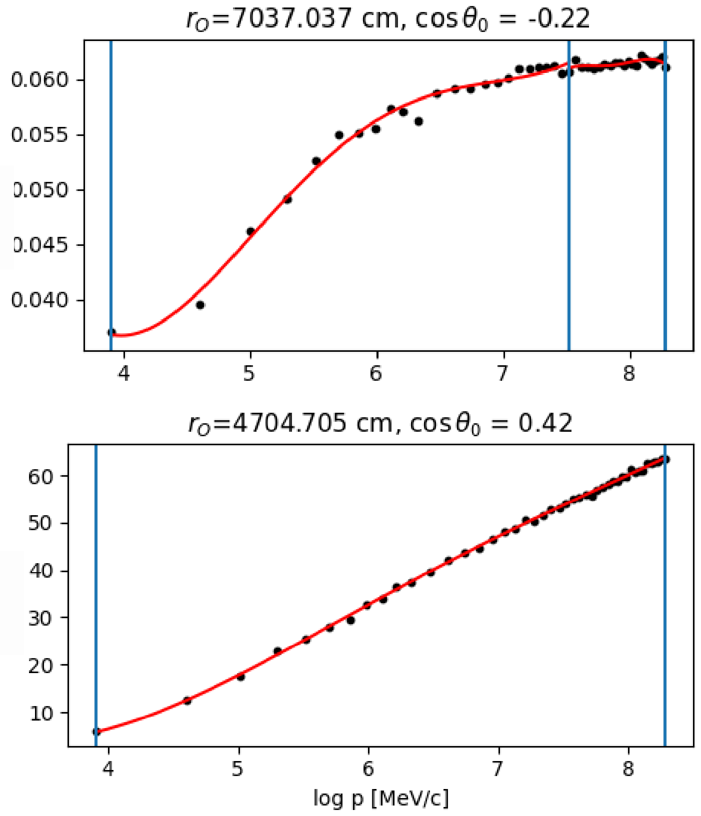
Predicted charges: Cherenkov profiles

- The Cherenkov integrals are fitted as a function of E for each (R_0, $\boldsymbol{\theta}_0$)



(3rd degree polynomial fit with multiple fit zones)

I_0



I_1

Predicted charges: Angular acceptance

Solid angle: $\Omega(R) = \frac{a^2}{2(R^2 + a^2)}$

(Implemented)

$$J(s) \equiv \Omega(R)T(R)\epsilon(\eta)$$

PMT angular acceptance: needs to be tuned with simulations!

(Implemented)

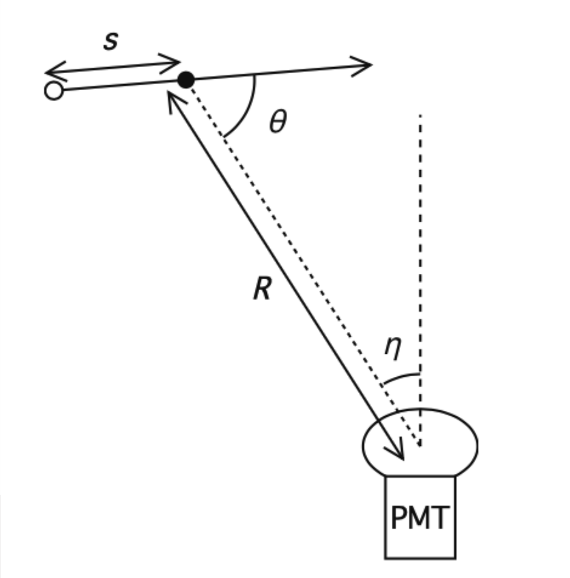
Transmission: $T(R) = \exp(-R/L^{\mathrm{att}})$

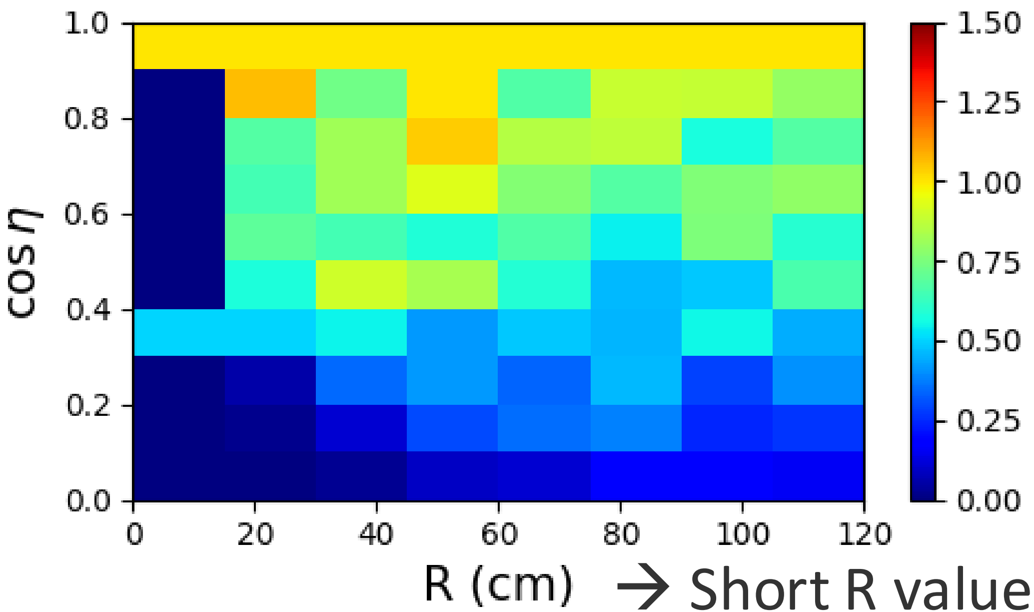
Predicted charges: Angular acceptance

- The simulations consist of “electron bombs“ (~3MeV)
  → Supposed to be point-like Cherenkov sources
- Used for the angular acceptance AND the Scattering Table
- 10 million events in HK geometry

Predicted charges: Angular acceptance

- First the overall angular acceptance is computed:





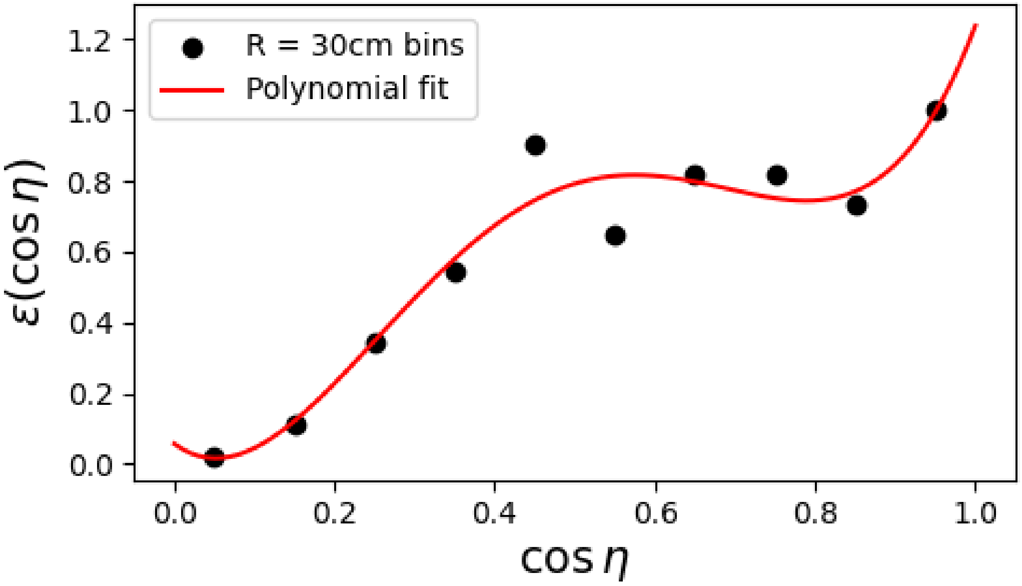
→ Short R values

Predicted charges: Angular acceptance

- Second, knowing that $J(R=0,\eta) = \Omega(0)T(0)\epsilon(\eta) \sim \epsilon(\eta)$

We can fit an estimation of $\epsilon(\eta)$

(4th degree polynomial fit)



Unhit probability

- For a PMT the photoelectron production can be modelled as a ***Poisson law*** with mean : μ $$p(\mu, k) = \frac{\mu^k}{k!} e^{-\mu}$$
- Thus, the unhit probability: $$P(unhit|\mu_i) = p(\mu, k=0) = e^{-\mu}$$

Taking into account the PMT threshold, a correction is applied:

$$P(\text{unhit}|\mu) \approx (1 + a_1\mu + a_2\mu^2 + a_3\mu^3)e^{-\mu}$$

Unhit probability

- The simulations use the TRUE deposited charges
- From 0.1C to 50C
- 5000 events per charge value
- Also used for ***the charge pdf***

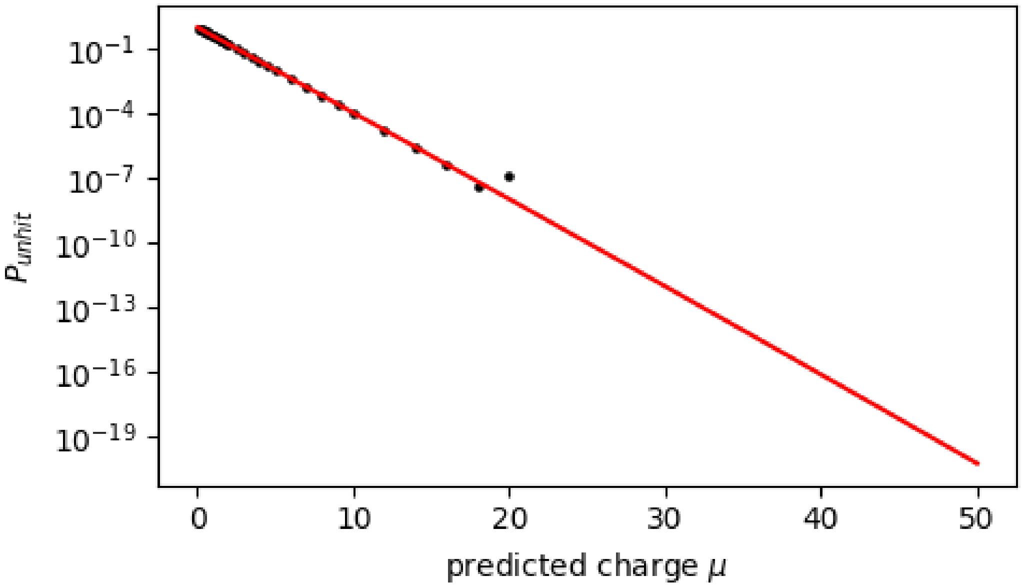
$$f_q(q_i|\mu_i)$$

Unhit probability

$$P(\text{unhit}|\mu) \approx (1 + a_1\mu + a_2\mu^2 + a_3\mu^3)e^{-\mu}$$

- Unhit probability fit =
  fit of a1, a2 and a3

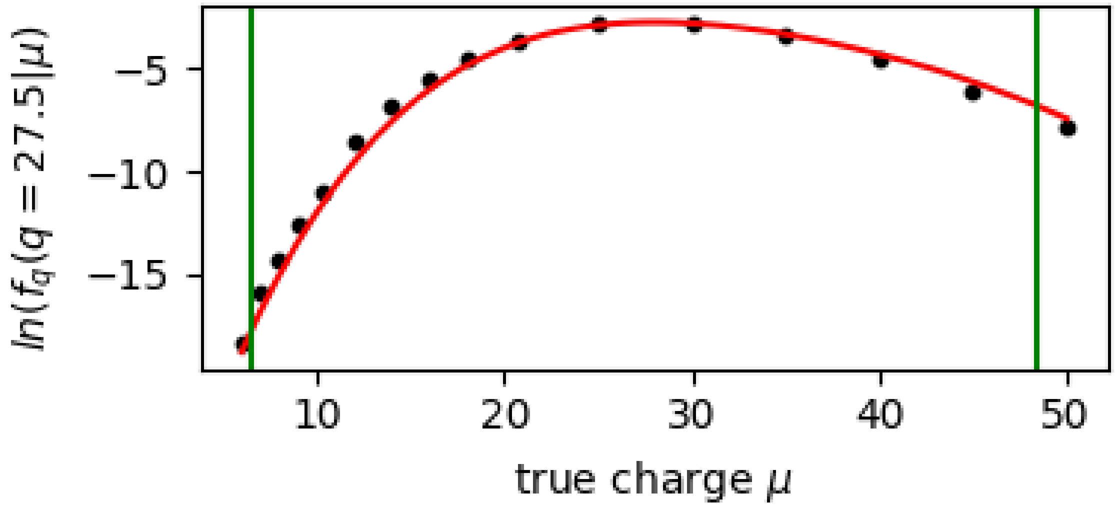
$$P(unhit|\mu_i)$$



Charge pdf $f_q(q_i|\mu_i)$

- Charge pdf = probability of detecting the charge $\mathbf{q_j}$, knowing the true charge μ_j

(6th degree polynomial fit)



Conclusion

- Preliminary performance study of the electron single ring, using PyfiTQun with HK geometry

- Starting point: same models as fiTQun (for now)

Done

- Cherenkov profiles
- Unhit probability
- Charge pdf

TODO

- Angular acceptance
- Scattering tables
- Time pdf

Thank you

Backup

Cherenkov profiles: potential issue in I0

- There is a weird behaviour for cos($\boldsymbol{\theta}$) ~ 0.5 integrals at low energies (first bin)

- Ongoing investigation…