

Measuring muon numbers with IceTop

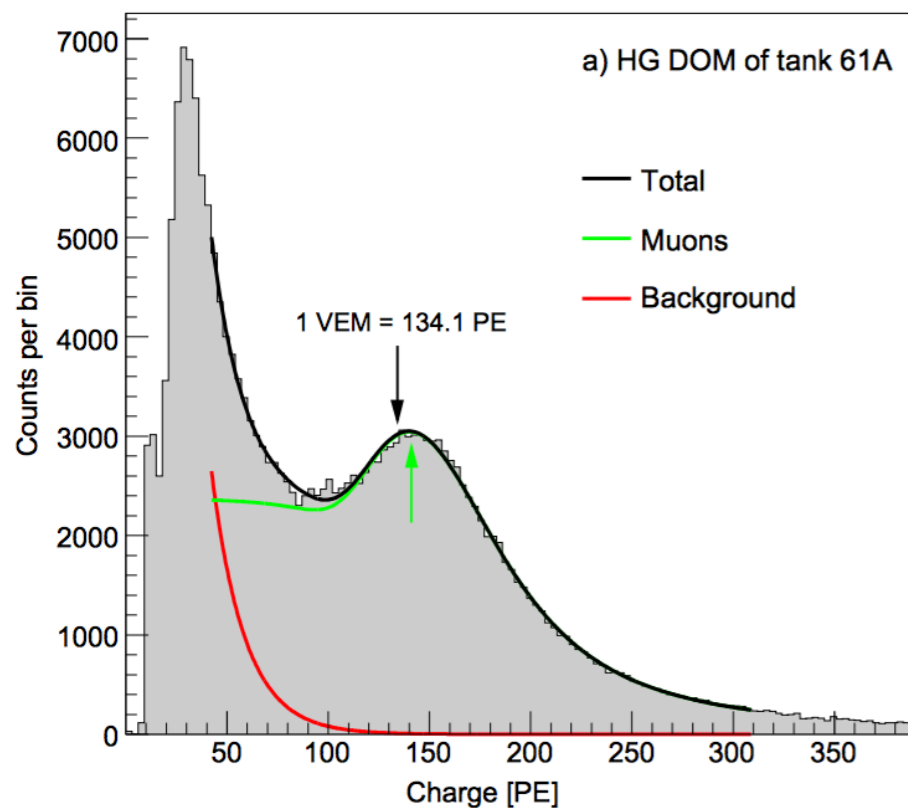
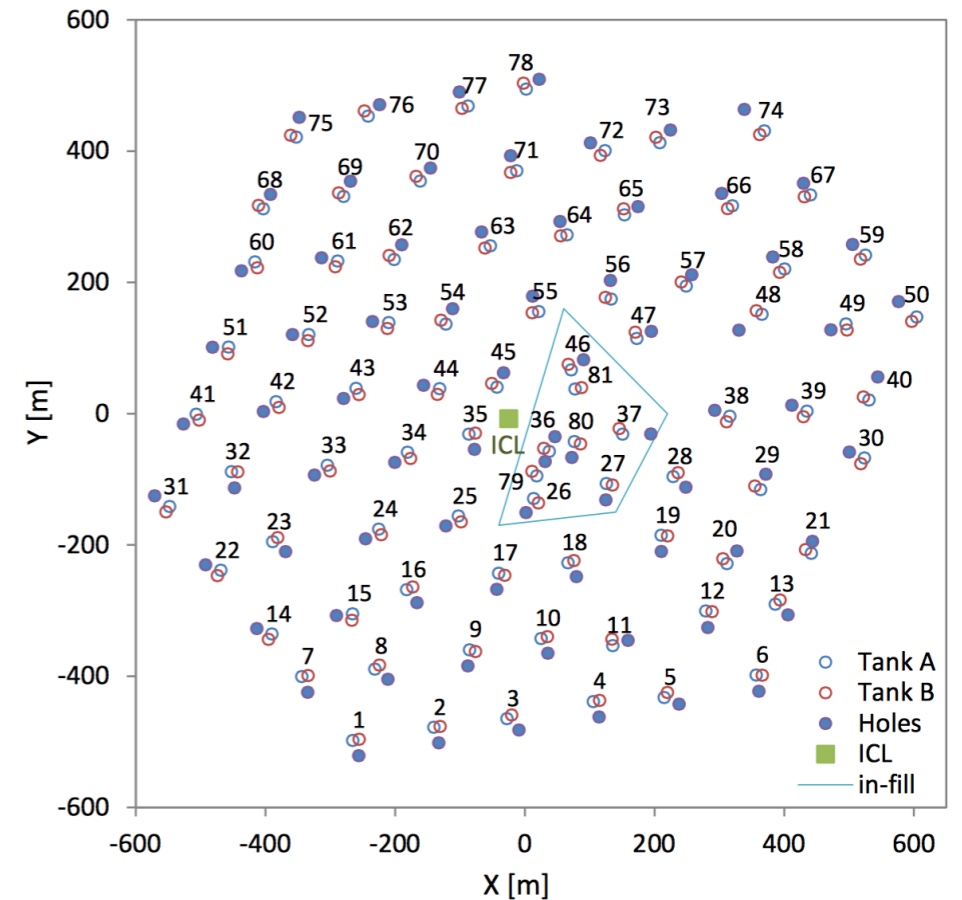
Daniel Bindig, University of Wuppertal, Germany

Muon workshop Madison,
2nd and 3rd of May 2015

Talk presented by Dennis Soldin

1. An issue i did not know about ...

- Are you working with IceTop?
- Are you using calibrated pulse charges for your analysis?
- Are you using ***I3ParamTankResponse*** as detector response (in detector simulation)?

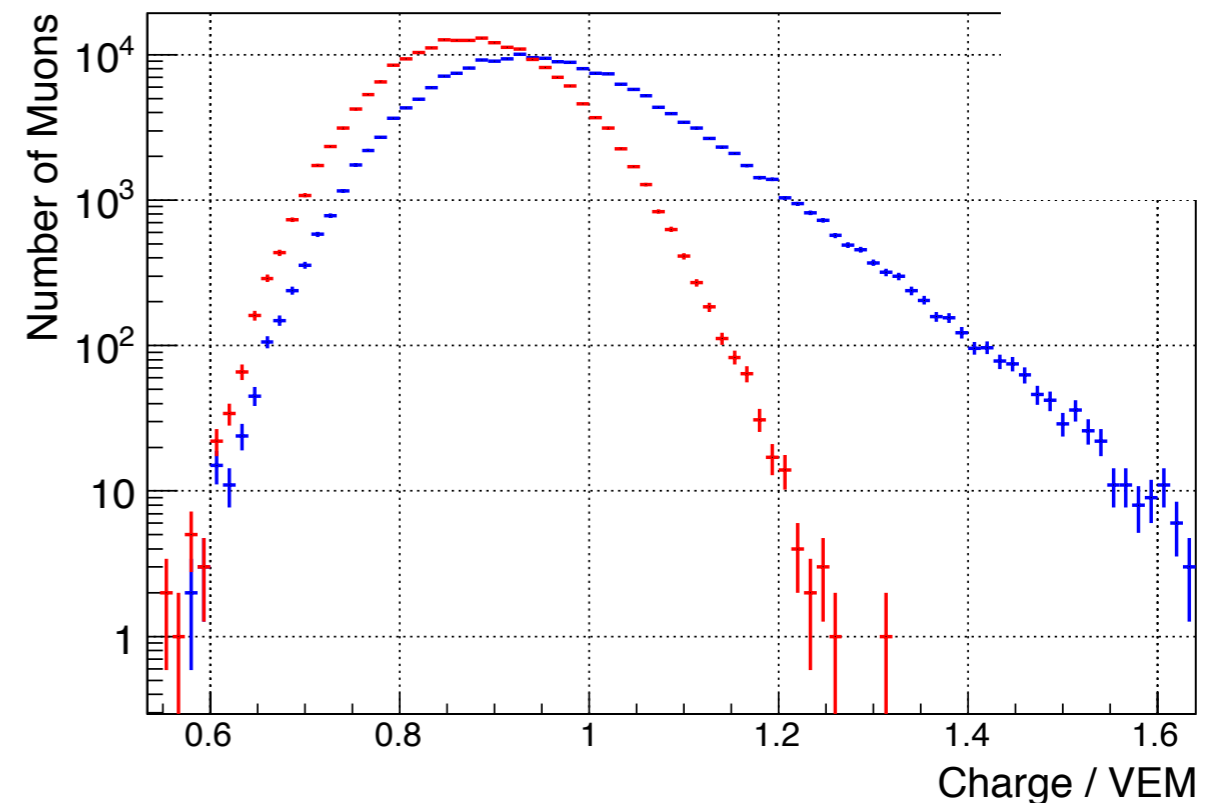
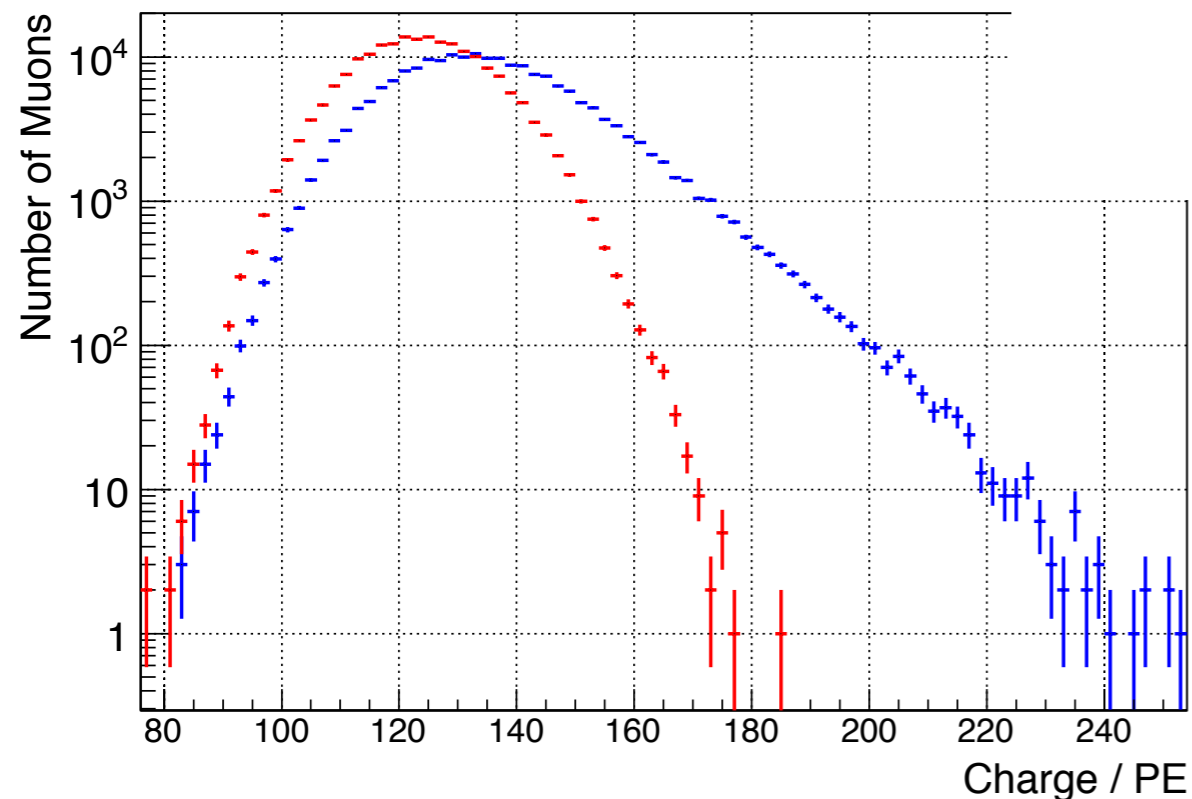


If you can answer yes to all questions, you are doing wrong!

I3ParamTankResponse does **not** provide the correct VEM calibration! Use ***I3G4TankResponse*** instead.

Elaborating the difference in detector response

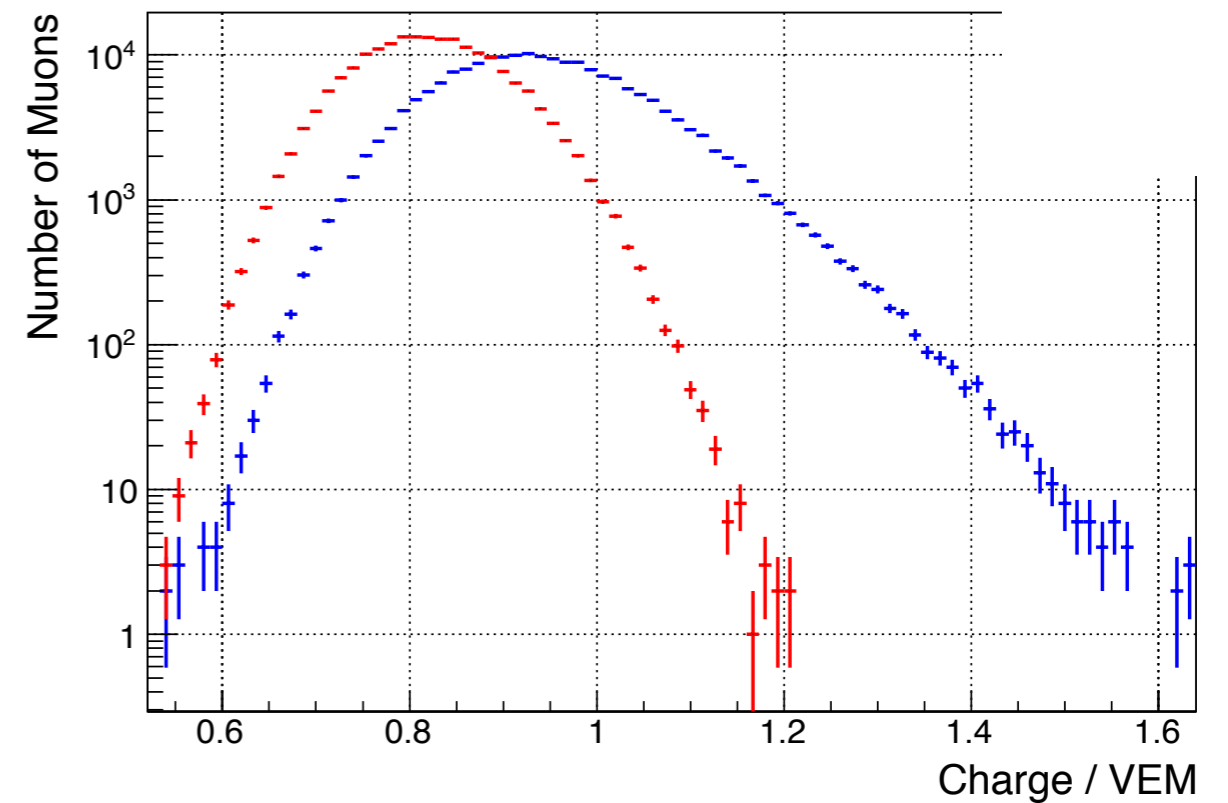
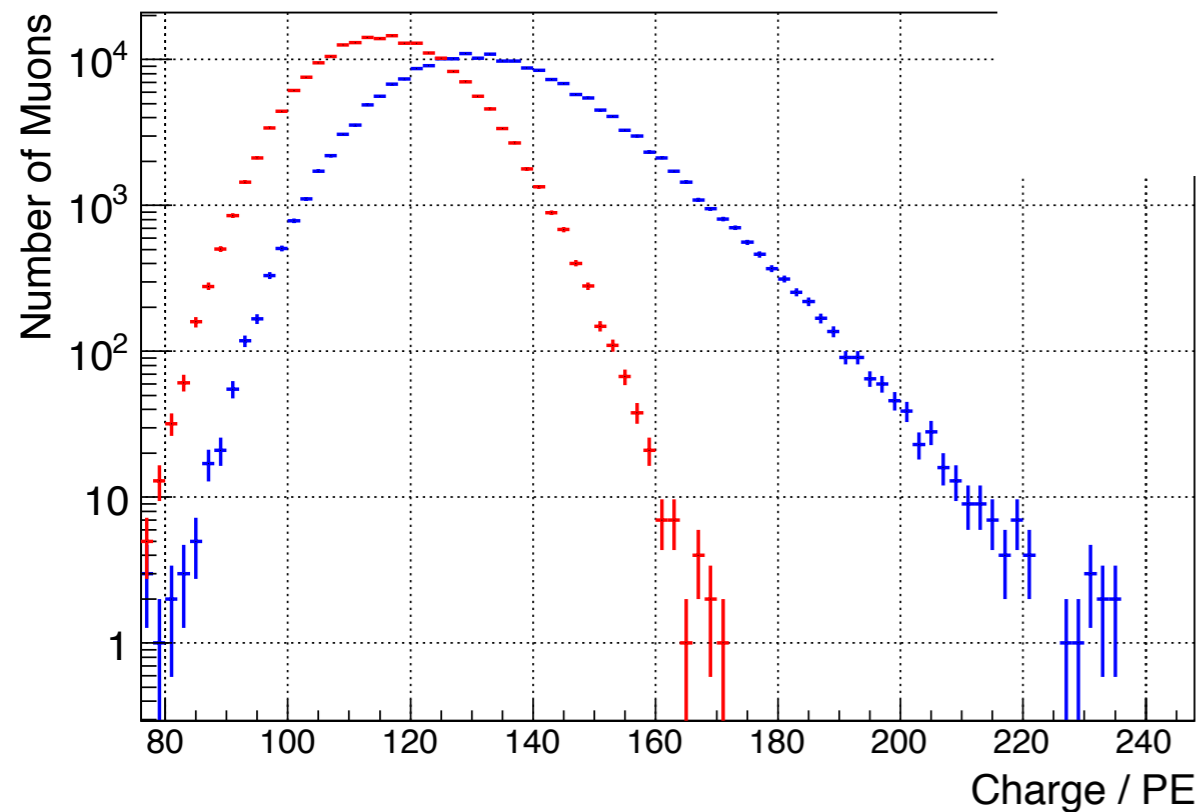
- Simulation of 200000 Muons for each of the detector responses modules
 - vertical muons (0°) of fixed energy (1 GeV)
 - Injection into 1 tank (56A) where **1 VEM \approx 141 PE**
 - no snow on tank





- I3ParamTankResponse
- I3G4TankResponse

Elaborating the difference in detector response

- same as before, but snow on tank included ($\approx 1,8\text{m}$)

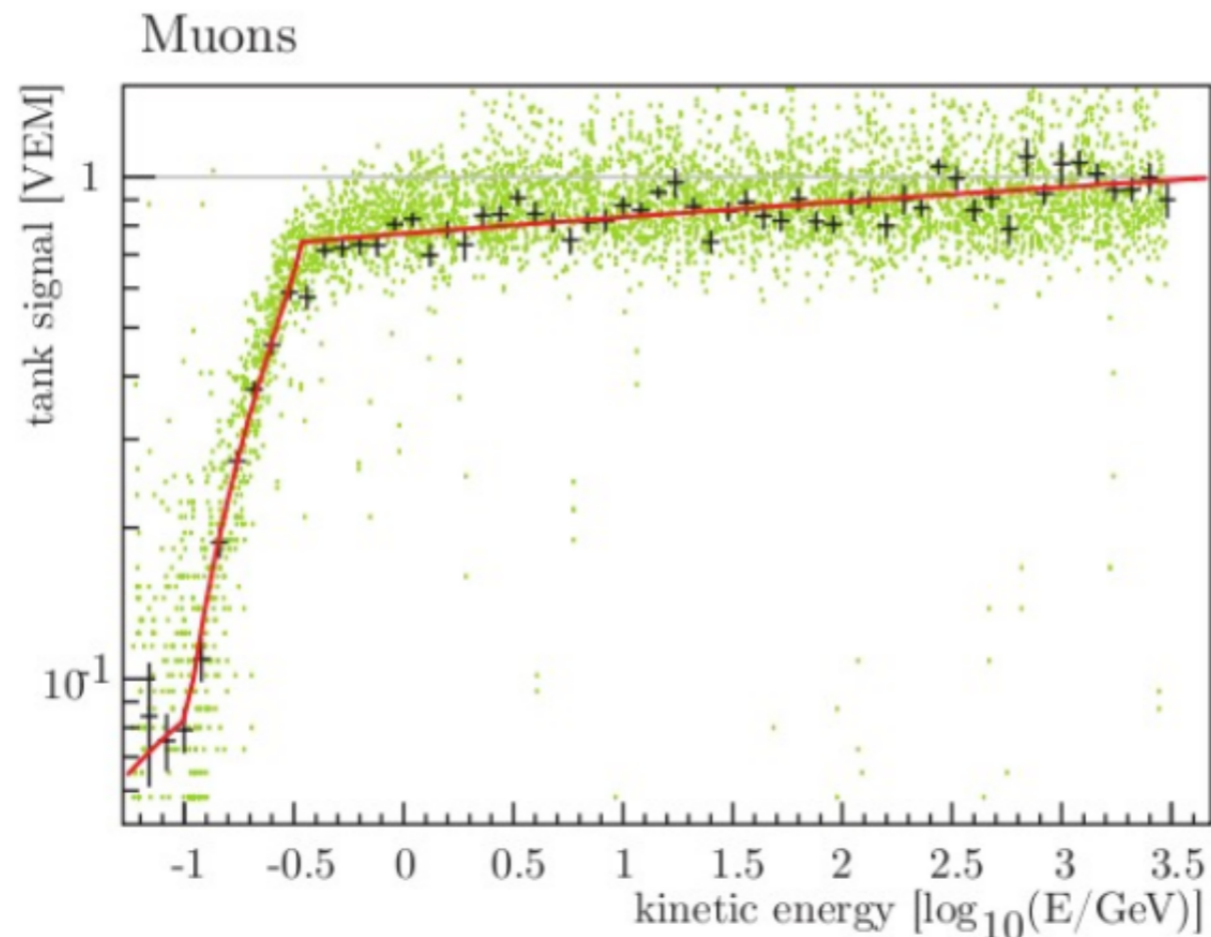


 I3ParamTankResponse
 I3G4TankResponse

I3G4TankResponse performs the VEM calibration on the fly.

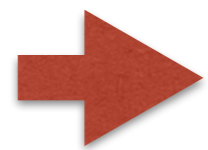
2. About my analysis

Goal: Count number of muons in the ***shower periphery***
(region far away from reconstructed core with less particles)



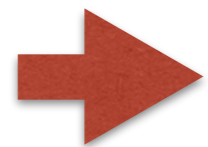
Muon light yield at ~ 1 VEM for all muon energies!

This is not expected for the electromagnetic shower part.



In the shower periphery we calculate an **average charge per tank with signal.**

This dominates in case of muons producing signals.



Use this issue to reduce elm. background.

Detector simulation

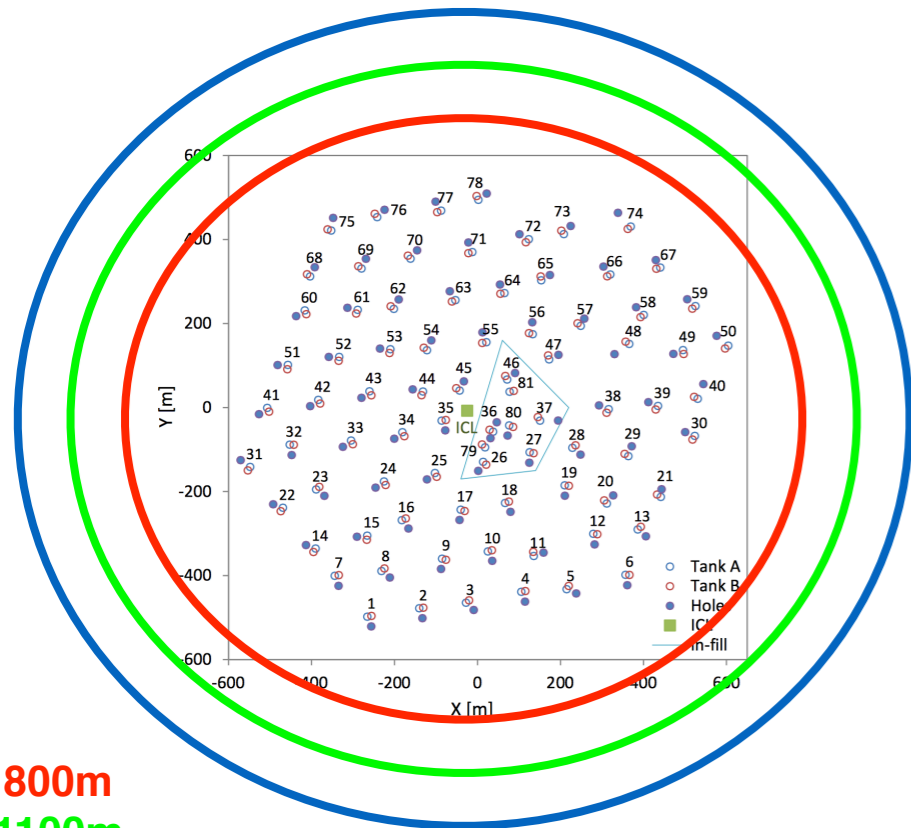
Use CORSIKA datasets 9112 and 9138 as input for detector simulations:

p and **Fe** showers based on **SYBILL2.1** interaction model,

$0 \leq \theta \leq 65^\circ$; $0.1 \text{ PeV} \leq E \leq 100 \text{ PeV}$; 30 bins of $\log(E) = 0.1$, 2000 showers per bin in E

CORSIKA shower

Modified I3TopSimulator



800m
1100m
1700m

Shower cores distributed in energy dependent radii around detector center;
Resampling rate = 50

All
Particles

Elm.
Particles

Muons

Non-elm.
no muon

Detector simulation includes

- ... simulation of snow heights
- ... noise simulation (vuvuzela)
- ... PMT response simulation
- ... simulation of the DOM electronics
- ... Simulation of the SMTTrigger
- ... evaluation of the waveforms

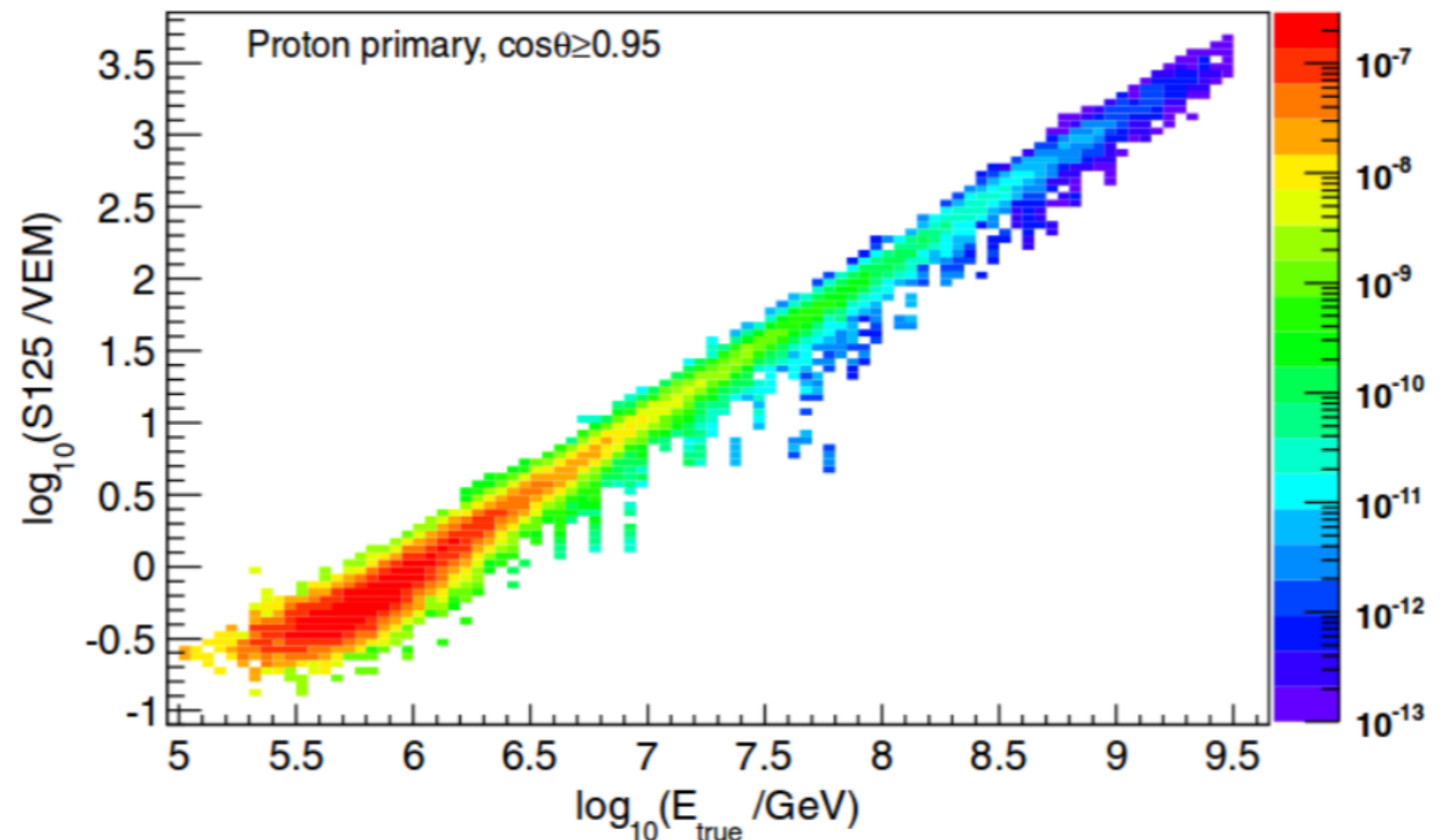
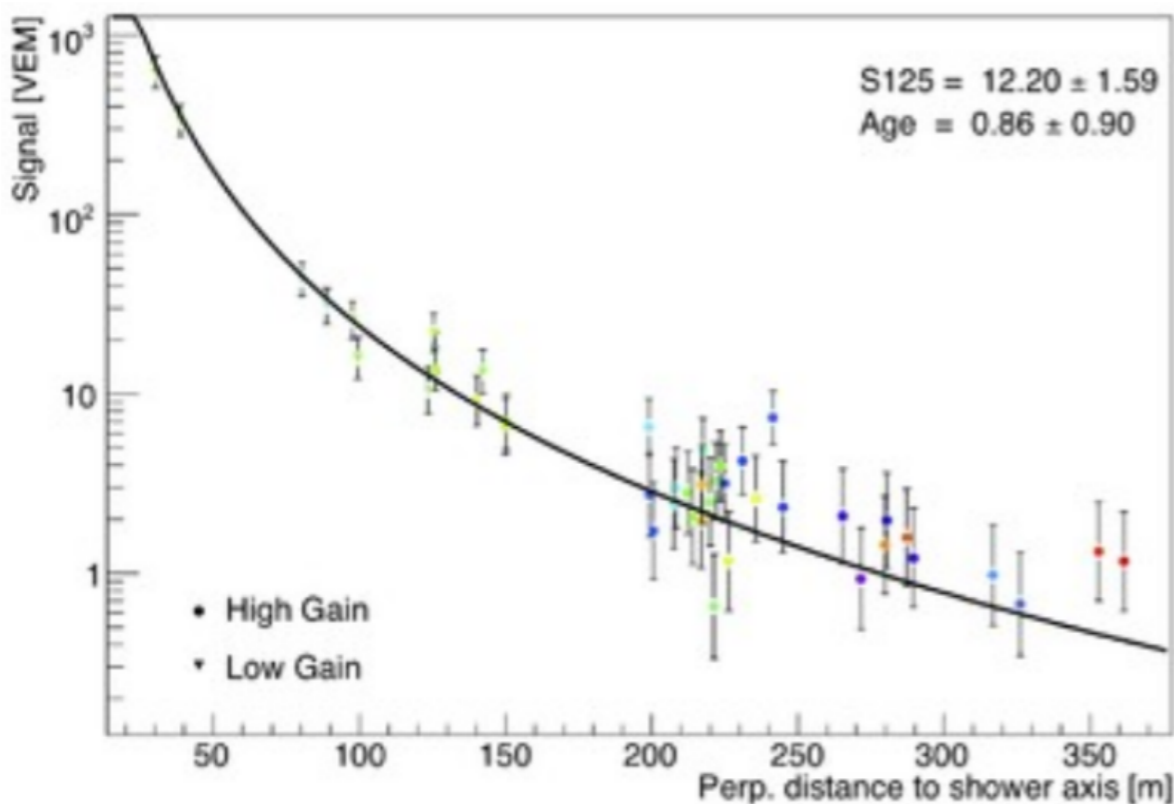
The response of single particle types is kept if full shower triggers the SMT.

Air shower reconstruction in IceTop

LDF:
$$S(R) = S_{125} \left(\frac{R}{125m} \right)^{-\beta - \kappa \log_{10} \left(\frac{R}{125m} \right)}$$

DLP:
$$\log_{10}(S(R)) = \log_{10}(S_{125}) - \beta \log_{10} \left(\frac{R}{125m} \right) - \kappa \log_{10} \left(\frac{R}{125m} \right)^2$$

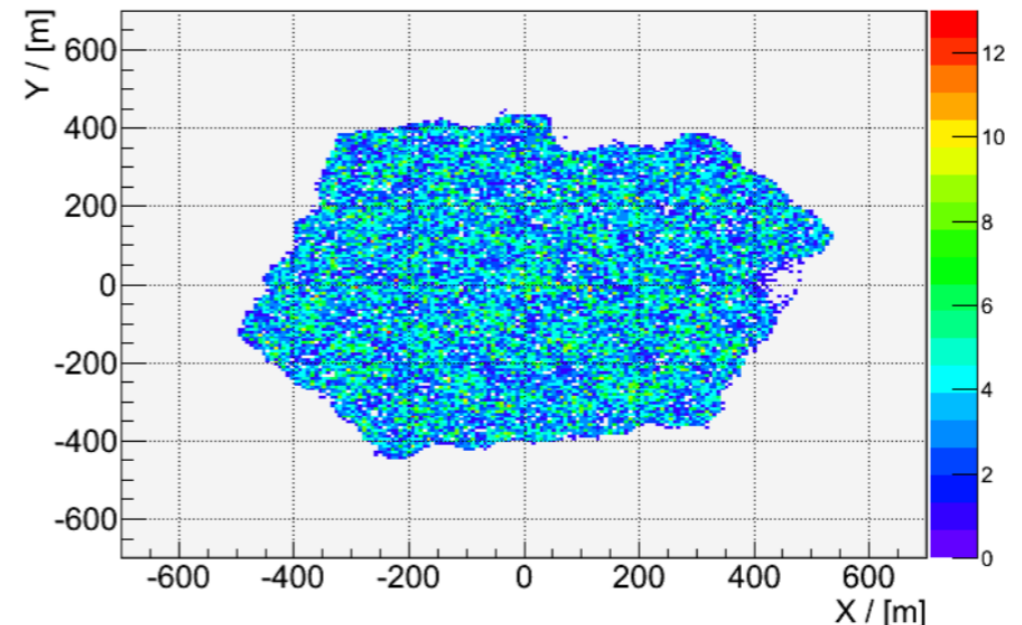
Snow correction:
$$S_i^{corr} = S_i \exp \left(- \frac{h_s^i}{\lambda_s \cos \theta} \right)$$



(Quality) Cuts

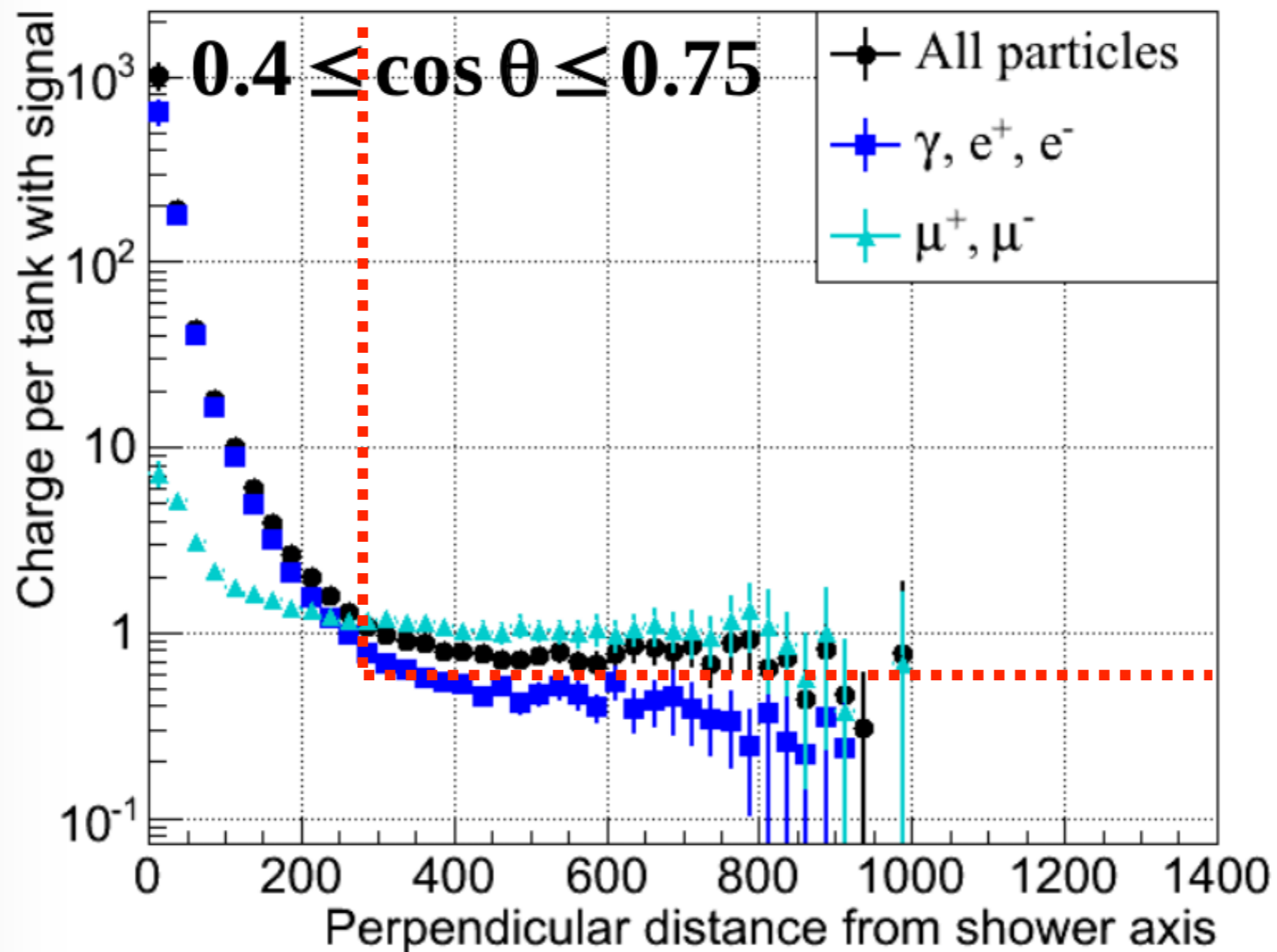
- 1) IceTopSTA5 filter (before reco)
- 2) FitStatus = OK
- 3) $\log_{10}(S125) \geq 0$
- 4) $\theta \leq 65^\circ$
- 5) $2 \leq \beta \leq 4.5$
- 6) Reject showers where loudest station is on edge of array or its charge is larger than 6 VEM

- 7) Containment cut: $\text{icetop_scale} \leq 0.9$



- 8) Cleaning of SLCs
 - Recalibrate SLCs
 - Skip afterpulses
 - Skip offtime HLC and SLC pulses:
At DOM position, calculate difference of measured pulse time and arrival time of shower front;
keep pulses where time difference is within specific time interval

A few results (Example)

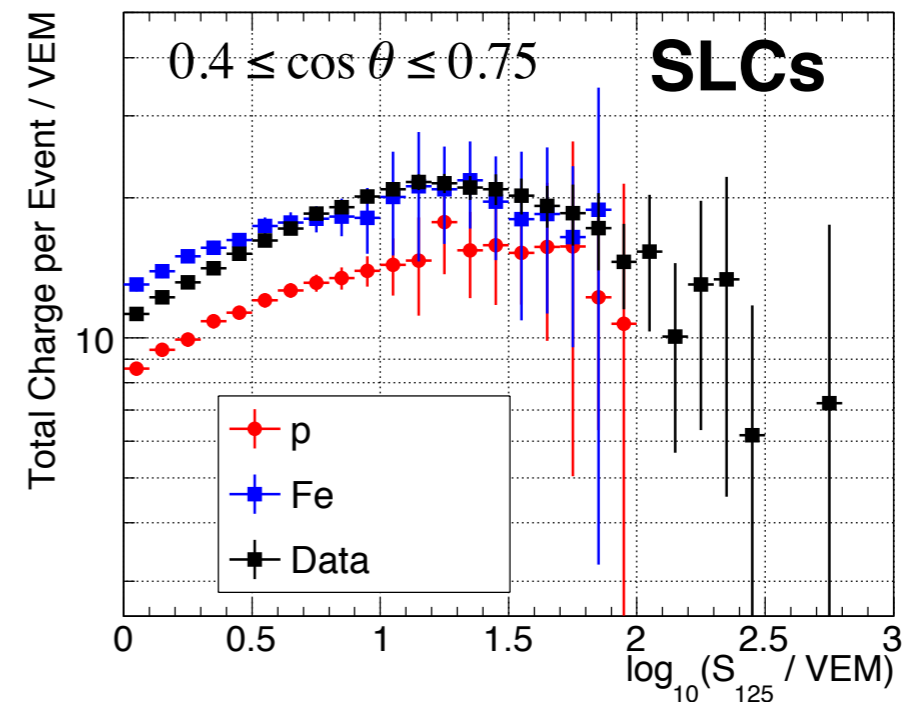
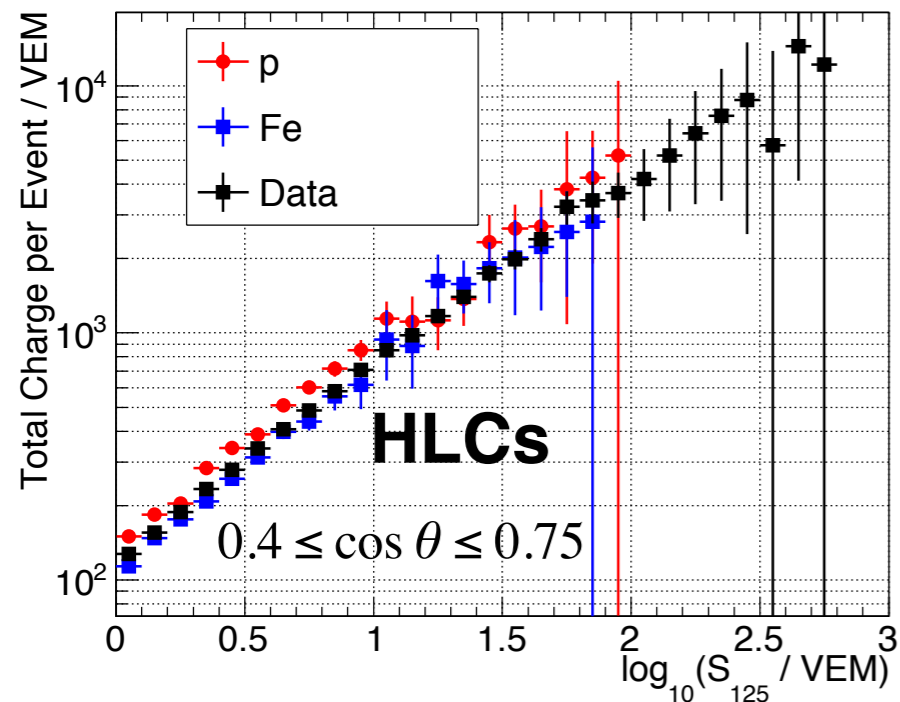
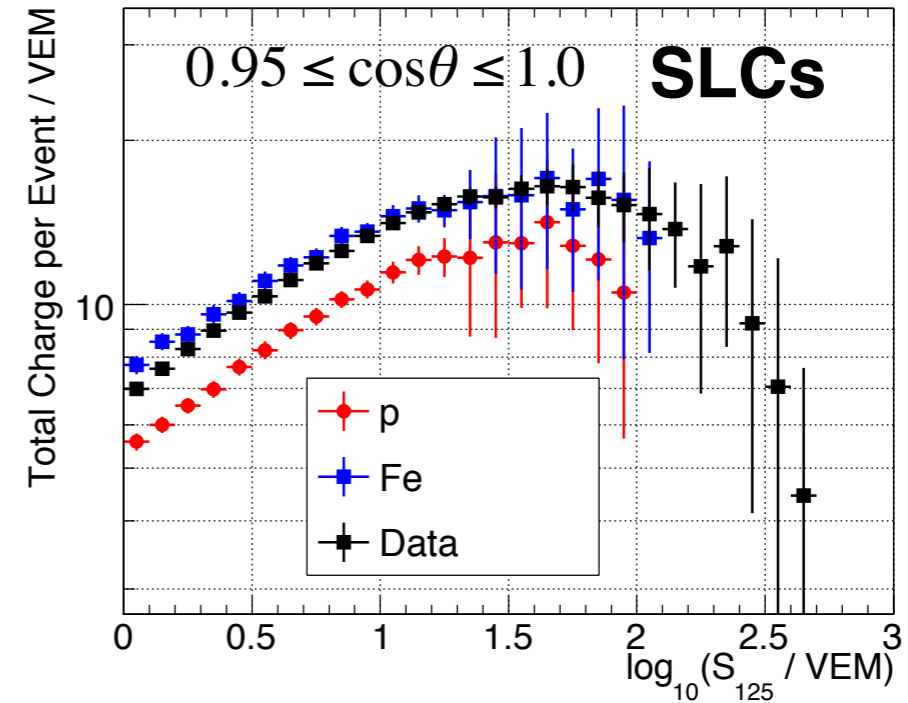
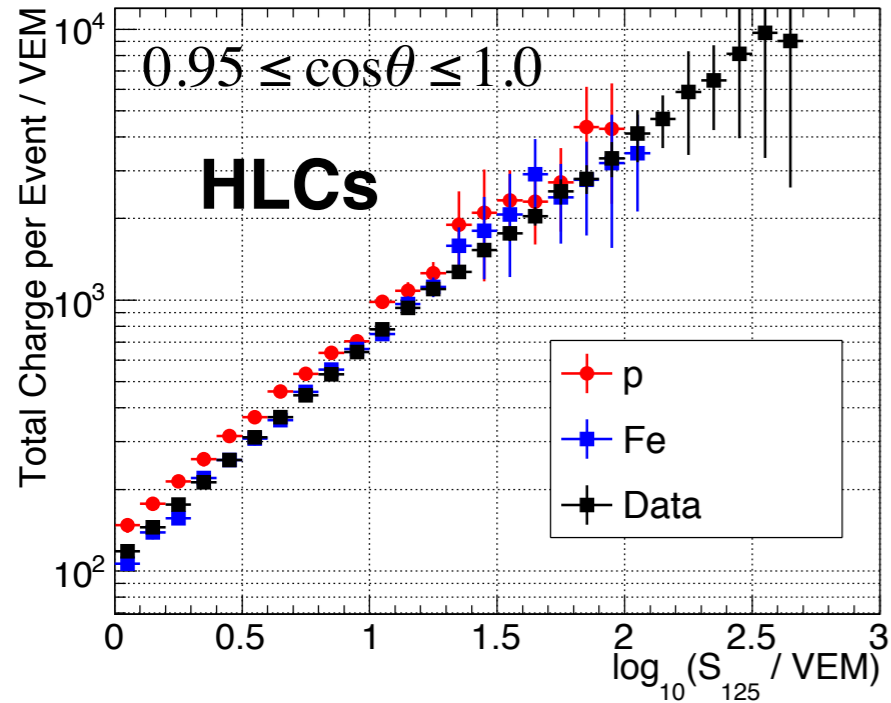


In order to separate the elm. background, apply cuts on distance and charge.

Based on reconstructed zenith angle and energy, choose these cuts wisely!

It already has been shown that after these cuts, the remaining total charge and number of tanks are good muon number estimators.

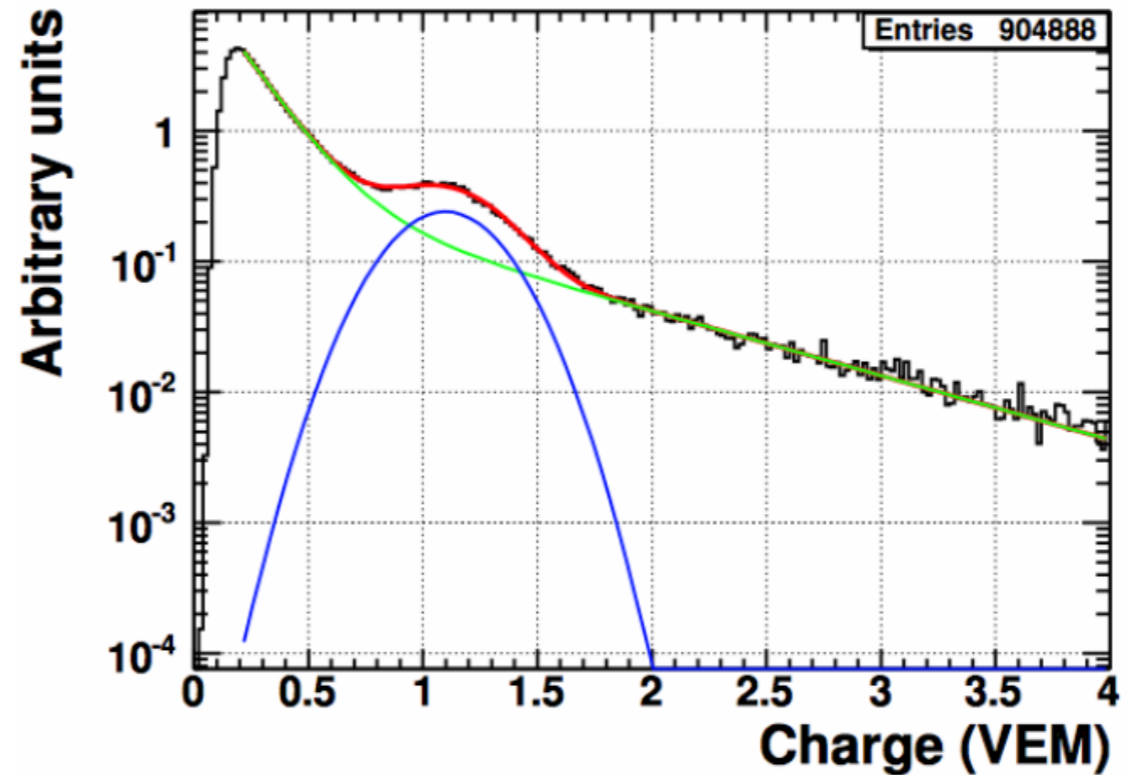
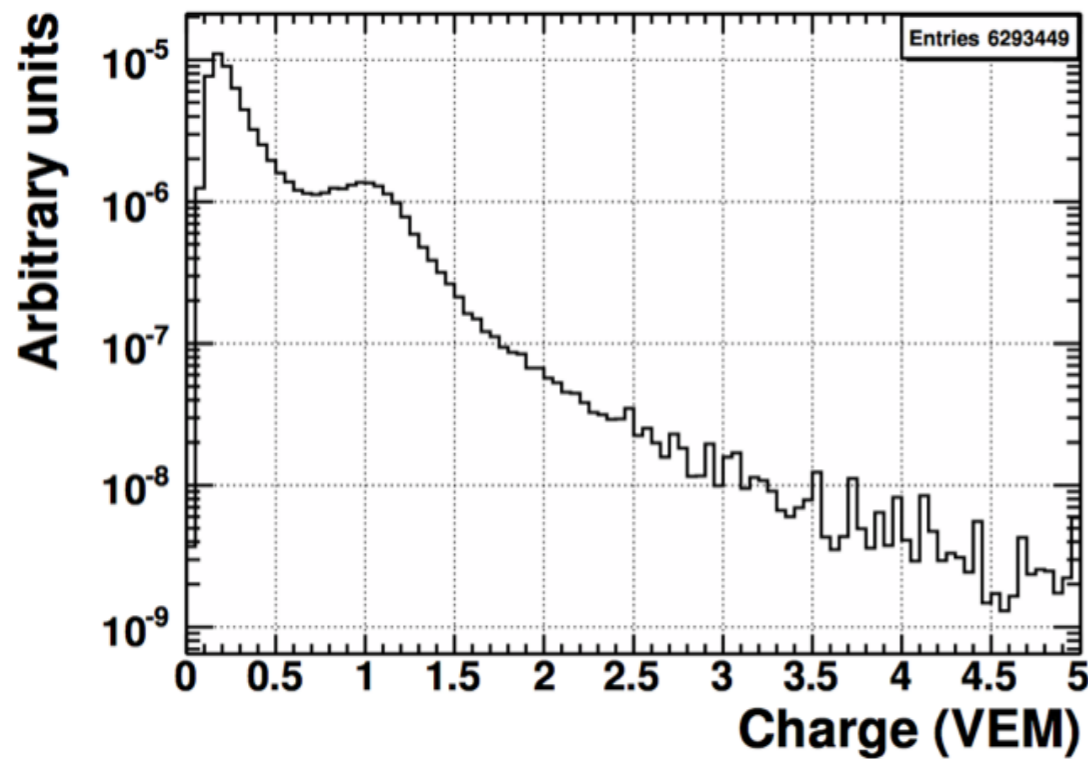
Data / MC comparisons before cuts on charge & distance



Good agreement for HLCs. Agreement for SLCs vanishes with increasing energy. Plots with higher statistics at high energies and other interaction models are on the way.

3. Another approach

Matthias Vraeghe's master thesis: Fit the muon peak in sim and data (SLCs only)



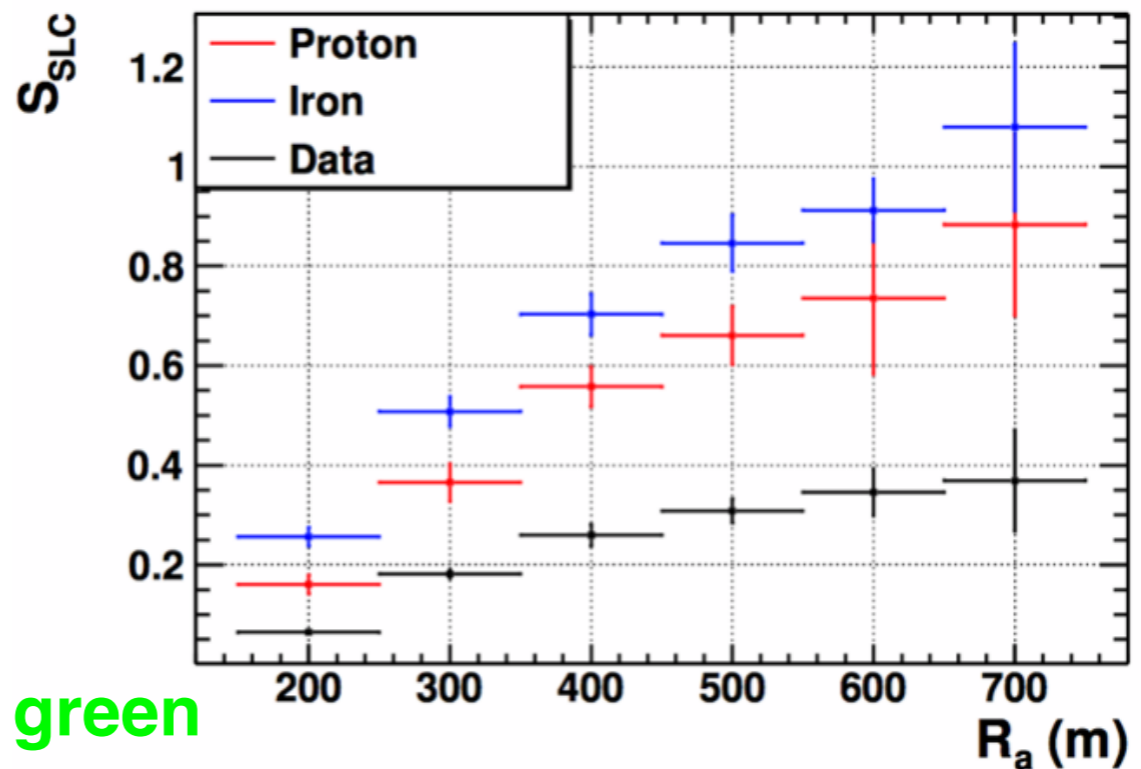
$$e^{p_0+p_1 \cdot x} + e^{p_2+p_3 \cdot x} + \frac{p_4}{p_6 \sqrt{2\pi}} e^{-(x-p_5)^2 / (2 \cdot p_6^2)}$$

Fit two exponentials to the elm part (green)

Fit a gaussian to the the muon part (blue)

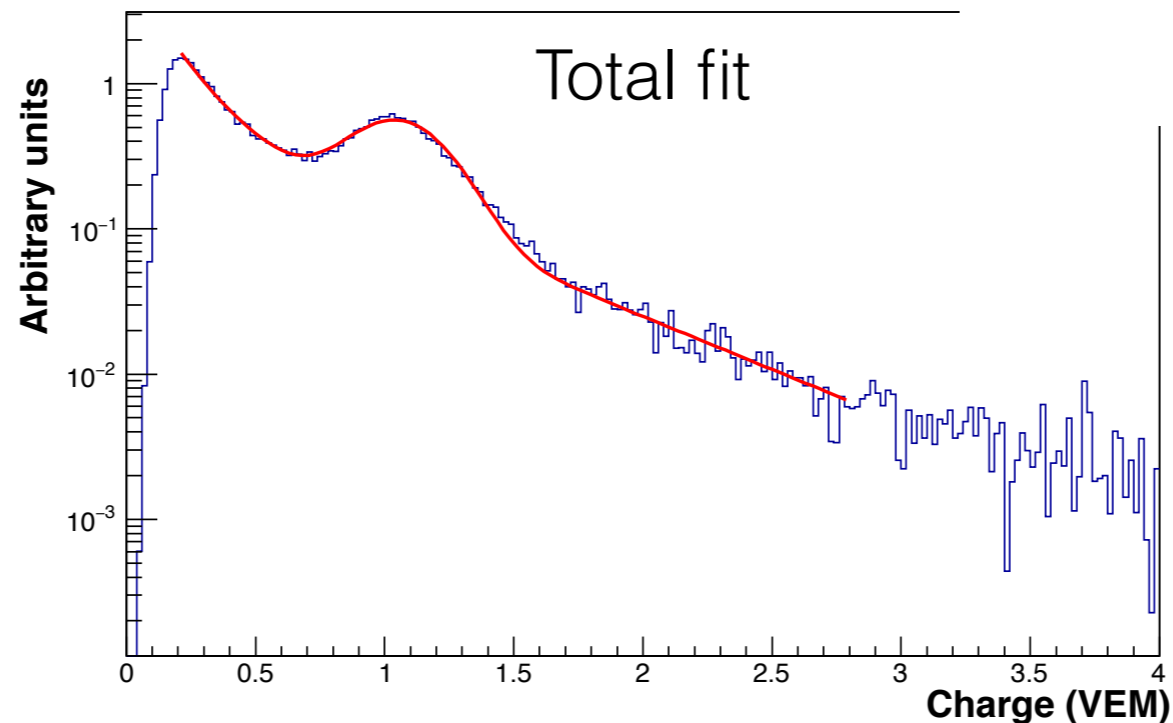
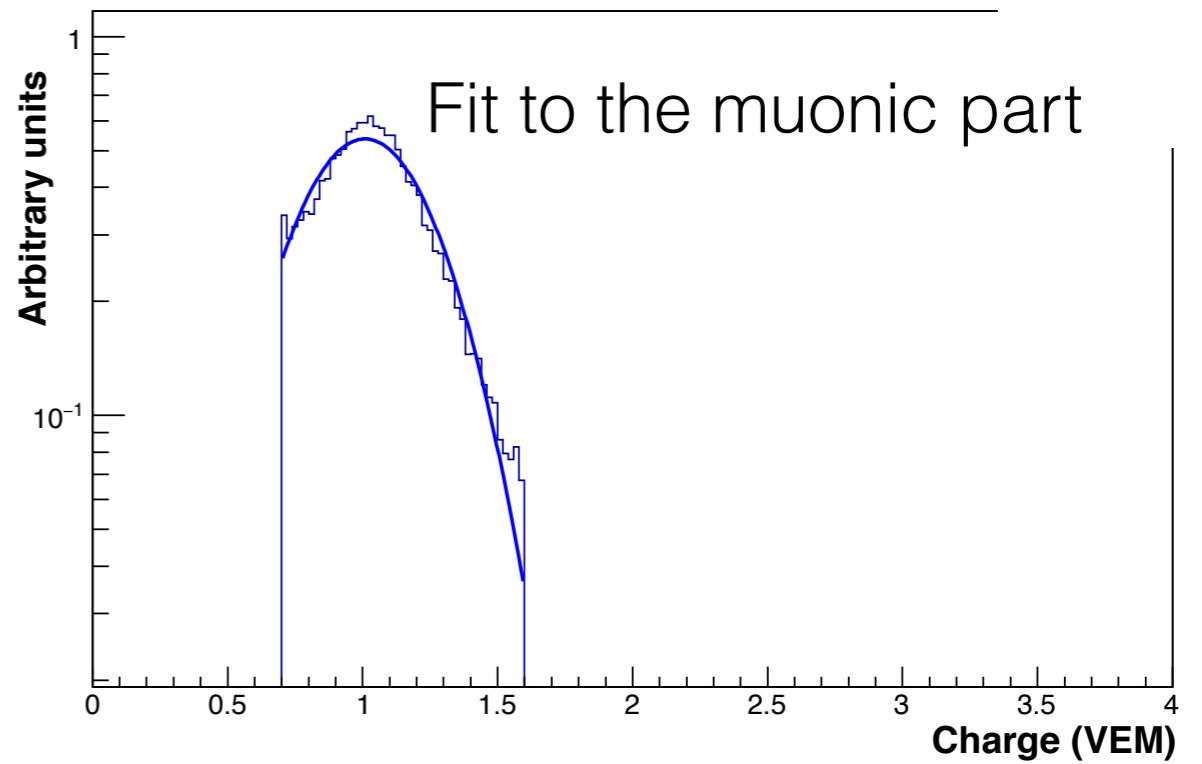
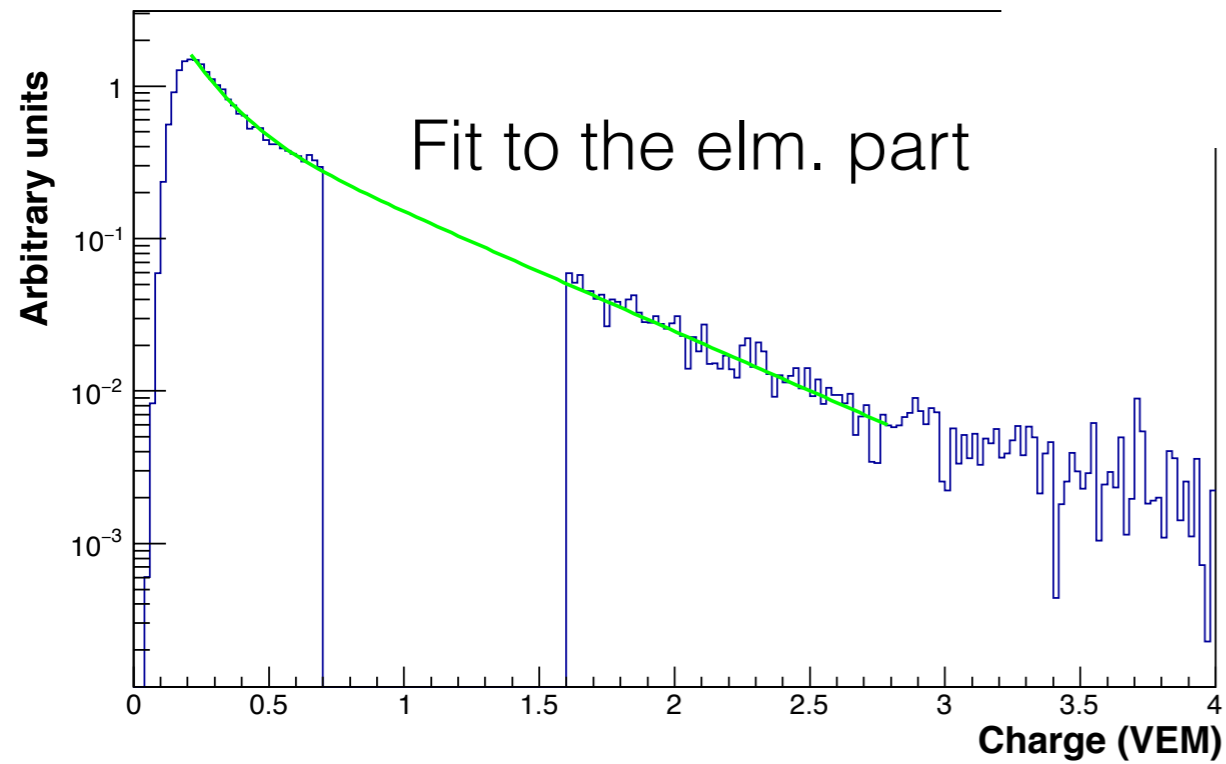
Total fit given in red

$$S = M/B = \int \text{blue} / \int \text{green}$$



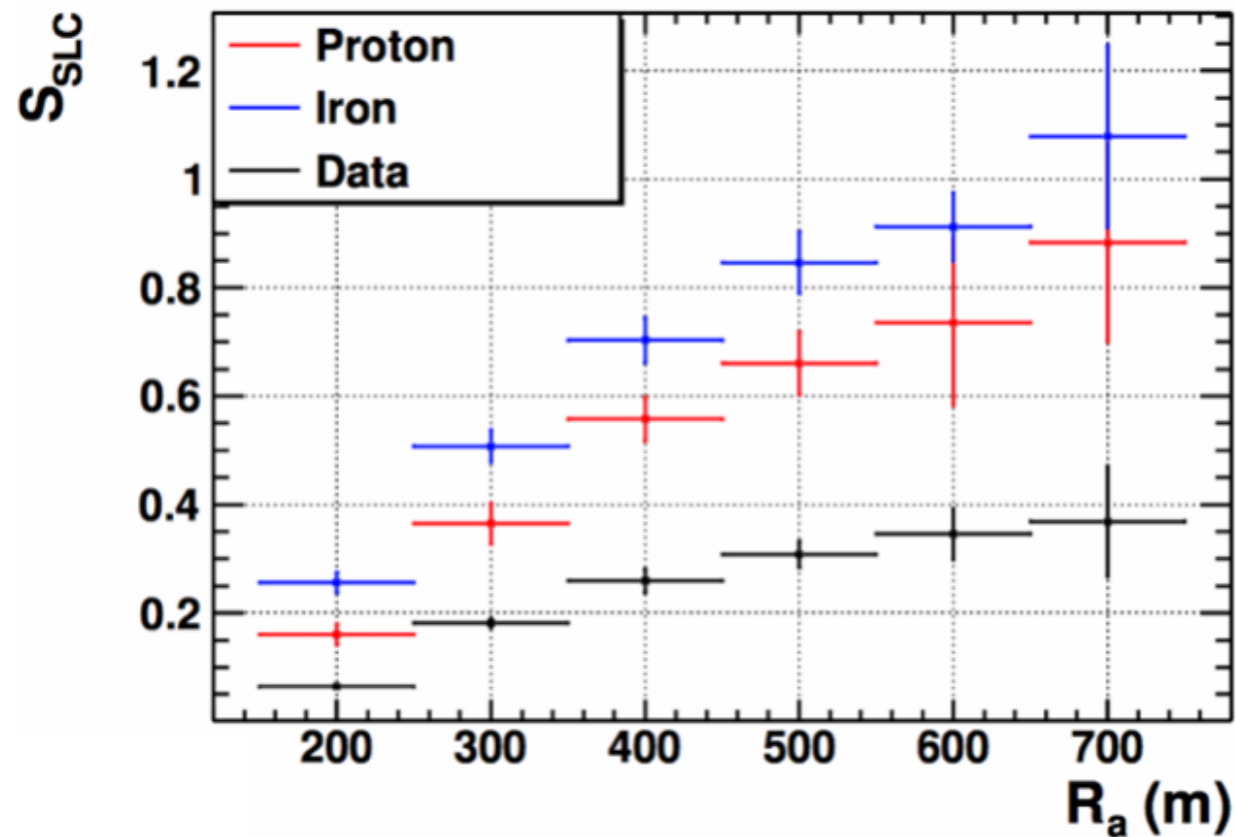
In my case...

During fit procedure the charge distribution is splitted

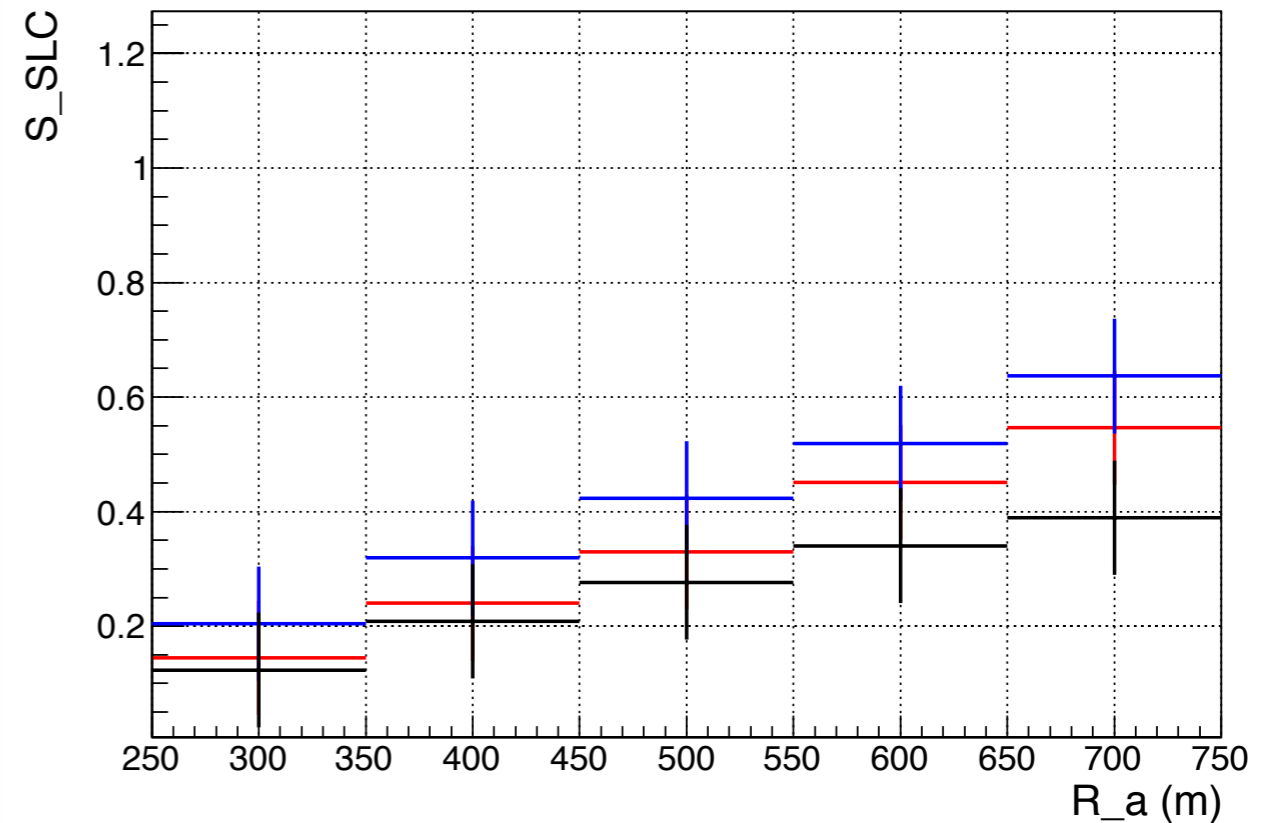


Comparison of the results

Matthias work

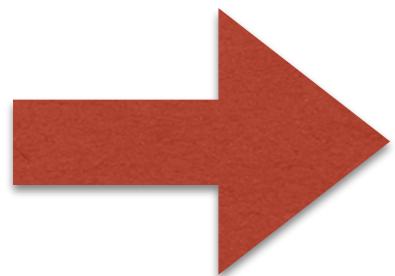


My work



For whatever reason, my plot looks better.

I will also try with other interaction models (QGSJetII04, EPOS_LHC)



There are a lot of open issues regarding (surface) muons!