# HINTS FOR THE AHEAD ANALYSIS

# Fitting the signal fadc traces

The fadc traces are fitted using a time dependent function for the amplitude (in volts).

$$V(t) = V_0 + V_{\max}\left(\frac{(t-t_0)e}{n\tau}\right)^n \exp\left(\frac{-(t-t_0)}{\tau}\right)$$

where $V_0$ is the baseline,
$n$ and $\tau$ are the parameters used to describe the single particle signal duration.

The signal charge is obtained by integrating $Q = \in (V(t) - V_0)dt$.

A charge calibration is obtained by triggering on single muons on the low gain channel of each detector but measuring the charge on the high-gain fadc trace. The minimum ionizing particle peak is fitted to obtain an averaged $< Q >$. This corresponds to bit more than what a vertical muon would release in the detector because of the average zenith angle distribution picked around $38°$. The $VEM$ value is thus deduced from the average charge by scaling it using a scaling factor obtained from a GEANT4 simulation.

$$Q_{VEM} = 0.8 < Q >$$

If the high gain channel is saturated, the low gain channel is fitted.

# Fitting the shower plane

Once the signals front-edge times are known in each detectors (from the previous fit), one can start reconstructing the shower plane, that is the shower direction angles $\theta$ and $\phi$. This is done by minimizing the following $\chi^2$ function:

$$\chi^2 = \sum_i \left( \frac{c(t_{0i} - T_0) - (u\ x_i + v\ y_i)}{\sigma_i} \right)^2$$

the shower direction angles are then obtained by:

$$\begin{aligned} \theta &= \arcsin \sqrt{u^2 + v^2} \\ \phi &= \arctan \sqrt{u/v} \end{aligned}$$

and the detector coordinates are $(x_i, y_i)$ (Northing,Easting).

The time resolution $\sigma_i$ is set its theoretical value (for fast rise time) of $\sigma_i = \tau_s/sqrt(12)$ with $tau_s$ the sampling time of the fadc. In the case of the old electronics (250MHz), this is $\tau_s = 4$ ns.

# Fitting the LDF

Whence the shower direction is known, one can proceed to the fit of the lateral density function. This will give us the shower size (that can be used to estimate the shower energy) and the core position.

The lateral distances to consider here are those projected into the shower plane. Hence, the distance from a detector to the shower axis is given by:

$$r = \sqrt{(x_i - x_0)^2(1 - u^2) + (y_i - y_0)^2(1 - v^2)}$$

where $u$ and $v$ are the parameters obtained from the previous fit, or $u = \sin(\theta)\sin(\phi)$ and $v = \sin(\theta)\cos(\phi)$ and $(x_i, y_i)$ are the detector coordinates (Northing, $-$Easting).

# Fitting the LDF

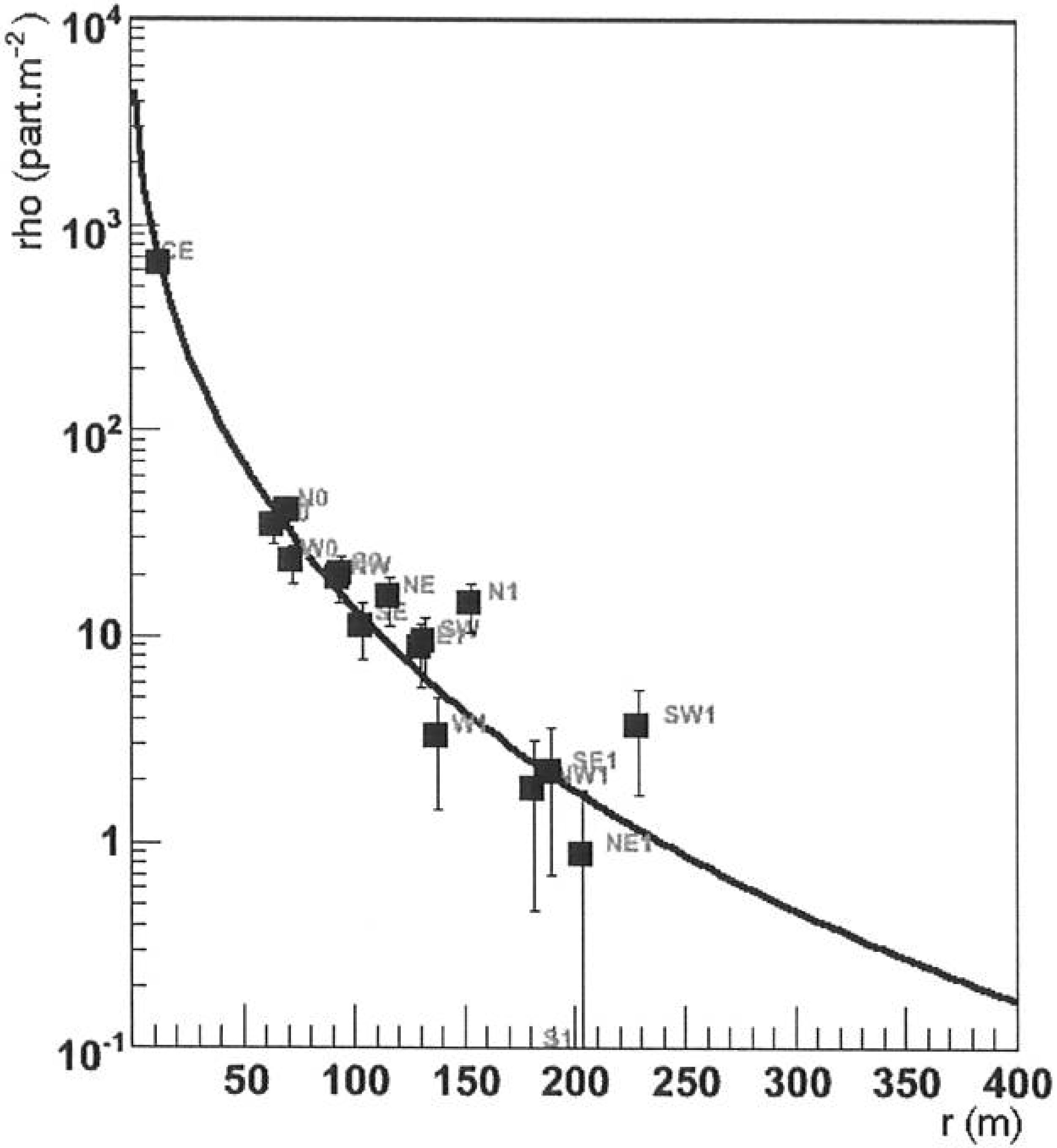
A Nishimura, Kamata, Greisen (NKG) function is fitted to the particle densities (measured signal charge / $Q_{VEM}$):

$$
\begin{aligned}
\rho_{NKG} &= N_e \frac{C_s}{r_m^2} \left(\frac{r}{r_m}\right)^{s-2} \left(1 + \frac{r}{r_m}\right)^{s-4.5} \\
\text{with } C_s &= 0.366\ s^2\ (2.07 - s)^{1.25} \\
r_m &= 80 \text{ m, the Moliere radius} \\
s & \quad \text{is the shower age. It is fixed to } s = 1.2.
\end{aligned}
$$

The fitted parameters are $N_e$, the shower size, and $(x_0, y_0)$ the core position.

NB: given the rather small size of the array, this fit will have a tendency to diverge unless the shower foot (core position) is contained with the geomertical limits of the peripheral detectors. We will hence restrict ourselves to fit the energy of events selected to have a measured charge in the central detector larger than that measure by the peripheral detectors.

# Fitting the LDF



# Estimating the energy

There one should do a full study using similated showers to calibrate the convertion function from $N_e$ to a true energy in PeV. One should also take into account the shower attenuation in the atmosphere which depends on the zenith angle.

The method usally used for that purpose is the CIC (constant intensity cut method) that use the fact that CR flux is istotropical and frequency of the events above a given size threshold should be intependant from $\theta$.

See the specific file giving the detailed method for the CIC correction.

On top of that correction, we will restrict ourselves to moderate zenith angles ($< 50°$) and use the following ampirical formula (trained on simulated showers):

$$E^{(p)} = 2.138 \times 10^{10} < N_e(0) >^{0.9} \text{ [eV]}$$

# AHEAD root tree

- ******************************************************************************
- *Tree :MyTree : shower *
- *Entries : 23737 : Total = 789028159 bytes File Size = 151000003 *
- * : : Tree compression factor = 5.22 *
- ******************************************************************************
- *Br 0 :d0 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 723024 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.53 *
- *.....................................................................................*
- *Br 1 :d1 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 737244 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.51 *
- *.....................................................................................*
- *Br 2 :d2 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 715686 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.55 *
- *.....................................................................................*
- *Br 3 :d3 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 718253 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.54 *
- *.....................................................................................*
- *Br 4 :d4 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 730282 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.52 *
- *.....................................................................................*
- *Br 5 :d5 : am:bl0:sbl0:af:bl:rt:tm:tf:ts:tdfc:tot:qf *
- *Entries : 23737 : Total Size= 1363564 bytes File Size = 731015 *
- *Baskets : 11 : Basket Size= 15776493 bytes Compression= 1.52 *
- *.....................................................................................*

# AHEAD root tree (cont)

- *Br 6 :tt : ev/I:run:year:month:day:hour:min:sec *
- *Entries : 23737 : Total Size= 761409 bytes File Size = 150131 *
- *Baskets : 9 : Basket Size= 15776493 bytes Compression= 4.93 *
- *…………………………………………………………………………*
- *Br 7 :dtt : jd/D:djd/D *
- *Entries : 23737 : Total Size= 381039 bytes File Size = 197704 *
- *Baskets : 7 : Basket Size= 311808 bytes Compression= 1.87 *
- *…………………………………………………………………………*
- *Br 8 :traces : fadc0[1024]/F:fadc1[1024]:fadc2[1024]:fadc3[1024]: *
- * | fadc4[1024]:fadc5[1024]:fadc6[1024]:fadc7[1024] *
- *Entries : 23737 : Total Size= 778276572 bytes File Size = 144336132 *
- *Baskets : 4661 : Basket Size= 15776493 bytes Compression= 5.36 *
- *…………………………………………………………………………*
- *Br 9 :reca : tinf:toutf:pinf:poutf:toutm:poutm:stoutm:spoutm:alphaf:*
- * | tinm:pinm:alpham:alpha0:tzero:ki2n *
- *Entries : 23737 : Total Size= 1427054 bytes File Size = 822871 *
- *Baskets : 13 : Basket Size= 15776493 bytes Compression= 1.69 *
- *…………………………………………………………………………*

# AHEAD root tree (cont)

```
d0 and d5 central det channels,
d1 to d4 are the peripheral detectors.
        Easting, Northing, Altitude
AHEADC  277633.00 5113127.00  511.9
AHEAD1  277645.27 5113099.08  512.0
AHEAD2  277660.99 5113139.12  512.0
AHEAD3  277621.29 5113155.16  512.0
AHEAD4  277604.67 5113115.71  512.0
dx branches: (x from 0 to 5)
     am: amplitude peak value (raw),
     bl0: baseline estimate (raw)
     sbl0: sigma baseline estimate (raw)
     af: amplitude from fit
     bl: baseline from fit
     rt: risetime from fit
     tm: time for amplitude peak
     tf: fitted start time
     ts: time fist threshold crossing
     tdfc: start time from constant fraction method
     tot: time over threshold
     qf: charge from fit (fitted function integrated – fitted baseline)
tt branch: event time and date info
dtt branch: event julian date info
traces: fadcx[1024]/F (x from 0 to 5)
reca branch: reconstructed shower plane info (ask me).
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