# ALGORITHM OF CHARGE RECONSTRUCTION FOR AMS–02 RICH

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- Introduction: RICH charge reconstruction capabilities
- Charge reconstruction algorithm
- Results
- Conclusions

# Capability of Z reconstruction of AMS RICH

The spectrum of Čerenkov photons radiated by a charged particle passing through the radiator is given by:

$$\frac{d^2N}{dxdE} \sim Z^2 sin^2\theta_c \quad (1)$$

$\rightarrow$ reconstructing the ring image and the Čerenkov angle ($\theta_c$) allows beta reconstruction with high precision
$\rightarrow$ counting the number of photons in the ring image ($N_{seen}$) and calculating the number of photons we expect ($N_{exp}$) for an equivalent particle of $Z = 1 \Rightarrow$ charge reconstruction

What we mean with *equivalent particle*: a particle with:

- same direction
- same position on top of radiator
- same beta

The relation between the number of photons radiated by a particle with charge $Z$ and an equivalent particle of unitary charge is:

$$N_\gamma^Z = Z^2 N_\gamma^{(Z=1)} \quad (2)$$

In our terminology: $N_\gamma^Z$ is the expected value of $N_{seen}$ and $N_\gamma^{(Z=1)} \equiv N_{exp}$

so Z is estimated as:

$$Z = \sqrt{\frac{N_{seen}}{N_{exp}}}$$

# Capability of Z reconstruction of AMS RICH (II)

$N_{seen}$ is measured experimentally, for each event:

$$N_{seen} = \Sigma_{i=1}^{NHITS} signal(i)$$

$N_{seen}$ is computed from the ADC signal given by the hits used in the reconstruction of the beta

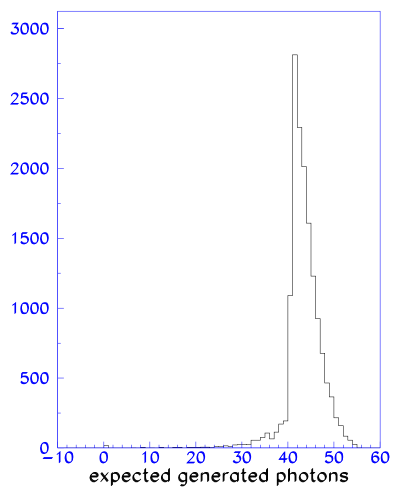
The reconstruction of the event has previously been made by the beta algorithm
$\Rightarrow$ all we need is a valuation of

$$N_{exp}$$

The main task of the charge reconstruction algorithm consists in calculating this number
The calculation of $N_{exp}$ is made individually for each event integrating the equation:

$$\frac{d^2N}{dx d\lambda} = 2\pi\alpha \frac{q(\lambda)}{\lambda^2} \sin^2\theta_c(n, \beta) \qquad (3)$$

where x has to be integrated on the particle path in the radiator and $\lambda$ on the range from 260 to 600 nm




Number of generated photons in aerogel of n=1.05 for a sample of beta=1

# The meaning of the number $N_{exp}$

Čerenkov light emission follows Poisson statistics. The probability of observing $n$ photons is:

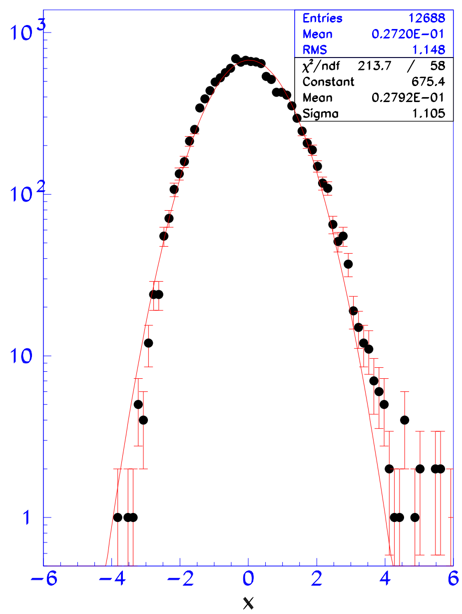
$$P_\mu(n) = e^{-\mu}\frac{\mu^n}{n!} \tag{4}$$

where $\mu$ is the mean value of the distribution
$N_{exp}$ is the number of photons we would expect if there were no smearing due to statistic fluctuations
Then the mean number of photons expected for a particle with charge Z is $\mu \equiv Z^2 N_{exp}$.
If $\mu$ is big enough (from z=2) the number of observed photons follows a gaussian distribution with:
mean $Z^2 N_{exp}$ and standard deviation $Z \times \sqrt{N_{exp}}$.

To test the precision of the calculation we use the variable

$$x = \frac{N_{seen} - Z^2 N_{exp}}{Z\sqrt{N_{exp}}} \tag{5}$$

By construction x follows a gaussian distribution with:
mean value $\mu$ =0
standard deviation $\sigma$ =1
and adding the error due to the photomultiplier response (considering a single p.e. resolution of $50\,\%$): $\rightarrow \sigma$=1.12



# The calculation of $N_{exp}$

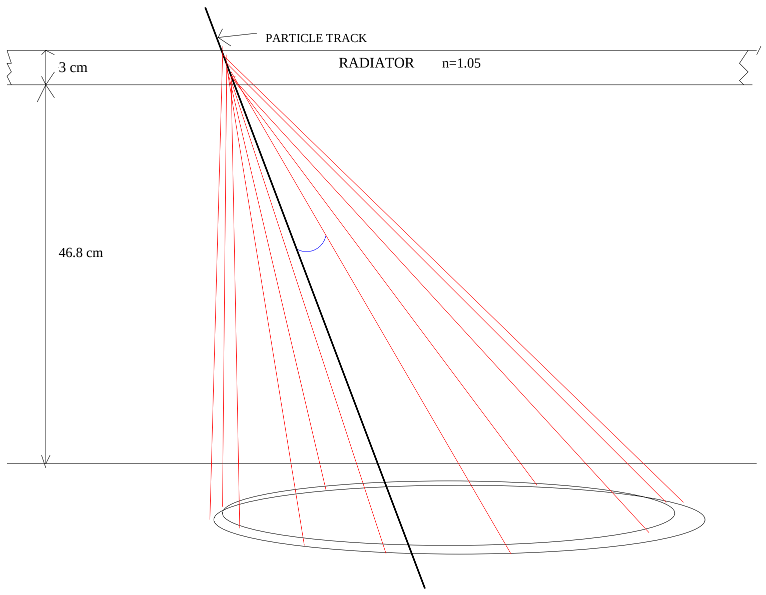
The calculation of $N_{exp}$ has to be made for each event that has been reconstructed. The algorithm takes in input:

- the reconstructed beta
- particle position on top of radiator
- particle direction

$$N_{exp} = \int d\lambda\, d\phi\, dx\, 2\pi\alpha \frac{q(\lambda)}{\lambda^2} \sin^2\theta_c(n,\beta) \times eff(position, direction)$$

$$\sim 2\pi\alpha \sum_{i=1}^{NL} \Delta\lambda_i \frac{q(\lambda_i)}{\lambda_i^2} \sin^2\theta_c(n,\beta) \sum_{i=1}^{NSTL} \Delta x \sum_{j=1}^{NSTP} \Delta\phi\, eff(\vec{r}_{i,j}, \vec{u}_{i,j})$$

to calculate this integral, the $\lambda$ dependent term can be separated from the geometrical efficiency and the integral is calculated making a double loop on the radiator length and on the azimuthal angle. For each interval of integration $\rightarrow$ one call to the routine of ray tracing




total number of rays traced:
$NSTEPS = NSTL \times NSTP$

# The calculation of $N_{exp}$, more in detail

The ray efficiency only depends on geometrical factors and can be calculated with no dependence on $\lambda$
The efficiency of the ray depends on:

- geometrical acceptance
- the light guide efficiency, tabulated as function of direction of the trace: $\theta$, $\phi$, and the light guide pipe
- Reflection on the mirror

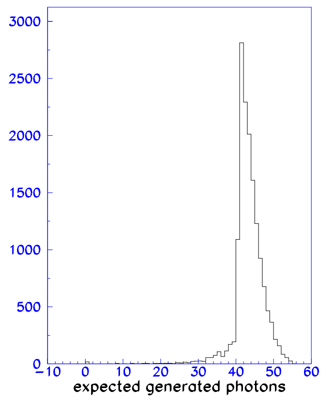
Furthermore, the routine of tracing gives as output:
Radiator material and light guide material crossed by the trace
These quantities are used by the routine which calculates the number of expected detected photons, integrating on $\lambda$

The number of detected photons depends on:

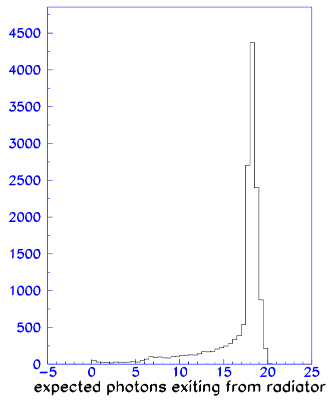
- photon absorption in the radiator, support foil and light guide material
- Rayleigh scattering in the radiator
- pmt quantum efficiency

Due to all these effects, the distribution of expected detected photons looks very different from the photons generated in the radiator
We made a comparison of the distribution of expected photons at four different levels in the RICH to see how the different factors included in the calculation affect the final distribution.

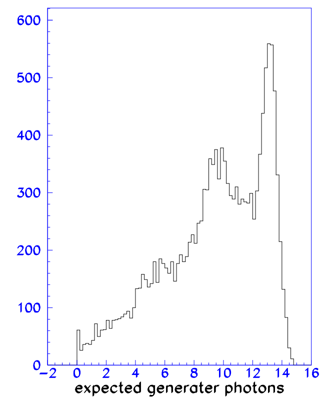
# The distributions of expected photons for a $\beta$=1 sample



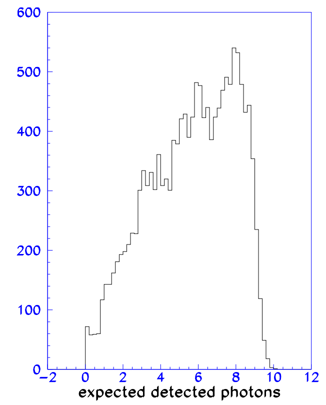

**A** Level of generated: only considers the Čerenkov spectrum. The plot shows a very sharp peak at $\sim$ 40 photons. The spread of the peak depends on the different path length in the radiator. The pmt quantum efficiency is already applied at the generation.




**B** Level of radiator: Rayleigh scattering shifts the peak at $\sim$ 18 photons, and photons losses due to the separation between tiles of aerogel cause a very large tail on the left.




**C** Level of the base: the peak moves slightly to the left at $\sim$ 13 photons (due to losses in the gaps between guides) and a very strong migration from the peak to the left is observed, due to photons lost in the E-CAL hole

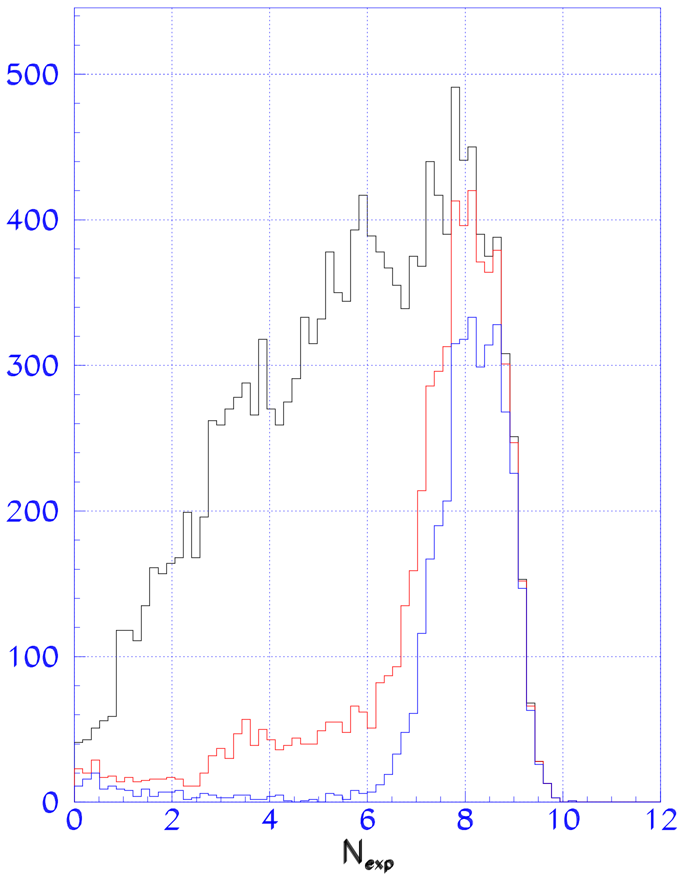



**D** Level of detected: all the effects are included. Due to the very inhomogeneous geometric acceptance, there is no peak in the distribution. Because of light guide efficiency the maximum moves to $\sim$ 8 photons

# The distribution of expected detected photons.

The shape of the distribution is due to the very inhomogeneous geometric acceptance of the RICH. The acceptance depends very strongly on the trace (position and direction) of the particle $\Rightarrow$ it is necessary to calculate $N_{exp}$ for each event

$$N_{exp} = f\left(\vec{r}, \vec{u}, \beta\right)$$




Black histogram: all the events
Red histogram: events fully contained (no ray to the E-CAL hole)
Blue histogram: events with no photon lost in the aerogel blocks separation
In the simulation we consider radiator tiles of 11.4 cm side, separated by completely opaque surfaces

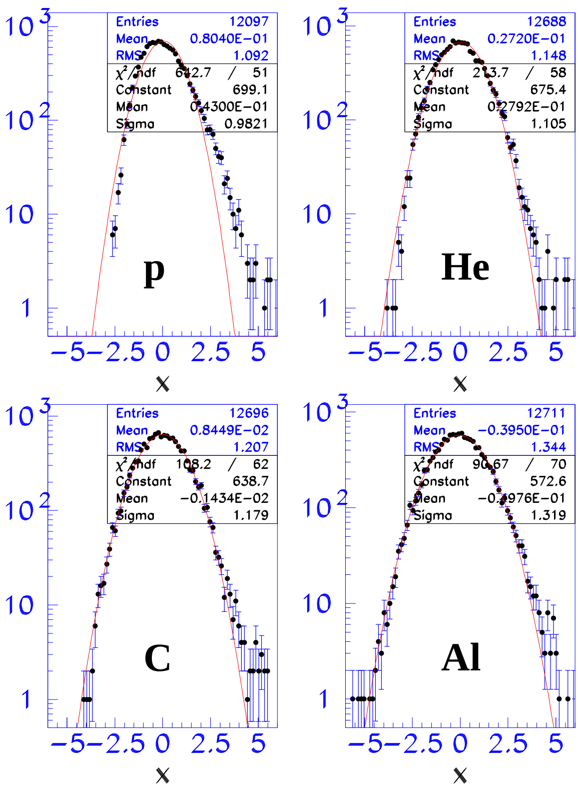
# The calculation of $N_{seen}$.

As a first approximation, $N_{seen}$ was calculated as the ADC signal associated to the hits used for the $\beta$ reconstruction.
Better results are obtained using the hits with a reconstructed beta within $\beta_{event} \pm n\sigma(\beta)$, where n is chosen in order to collect the maximum number of good hits and to minimize the presence of noise.

In summary:

- optimized criterion for good hit selection$\rightarrow N_{seen}$
- Calculation of the expected number of photons for an equivalent particle with same track and reconstructed beta $\rightarrow N_{exp}$

From these quantities we obtaine the following residual distributions. As a quantity representative of the precision of the calculation we consider the sigma of the distribution of the variable x (already defined):




| Z | $\sigma$ |
|---|---|
| 1 | 0.98 |
| 2 | 1.105 |
| 6 | 1.179 |
| 13 | 1.319 |

# Results: definition of the samples analyzed

The samples analyzed have been generated with:

- stand alone version of the simulation
- setup of 680 pmt
- light guide of 3.4 cm
- pitch of 3.7 cm
- 3 cm of radiator of aerogel of refractive index 1.05
- clarity of 0.0091 $\mu m^4 cm^{-1}$

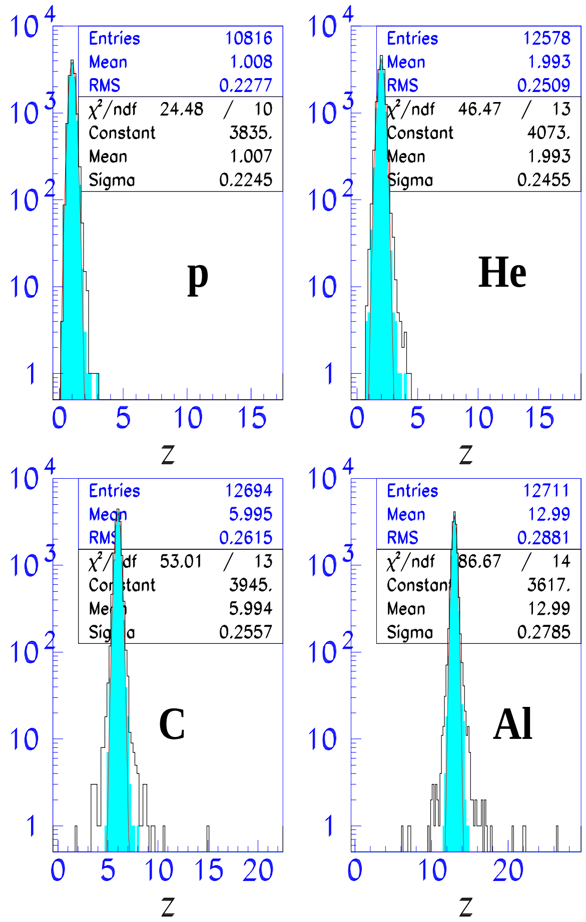
The particle track is taken from the generator
The beta is given by the reconstruction, selecting events with a beta resolution of $|\Delta\beta| < 0{,}2\,\%$

This cut reduces the samples as shown in the table:

| | beta 1 | uniform beta |
|---|---|---|
| p | 67 % 58 % | 46 % 42 % |
| He | 74 % 72 % | 64 % 62 % |
| C | 75 % 74 % | 70 % 68 % |
| Al | 76 % 74 % | 73 % 69 % |

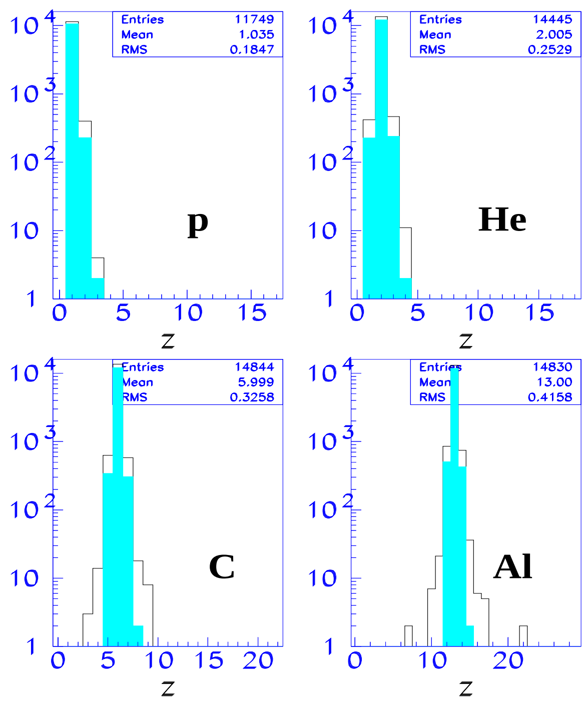
In the table: percentage of reconstructed events (in black), and percentage of reconstructed events with a $\beta$ resolution better than $0{,}2\,\%$ (in red). In the following I will show results relative to the latter sample.

# Results




No shadowed area: all the events of the sample
Shadowed area: events with $N_{exp} > 3$
continuous distribution of the charge

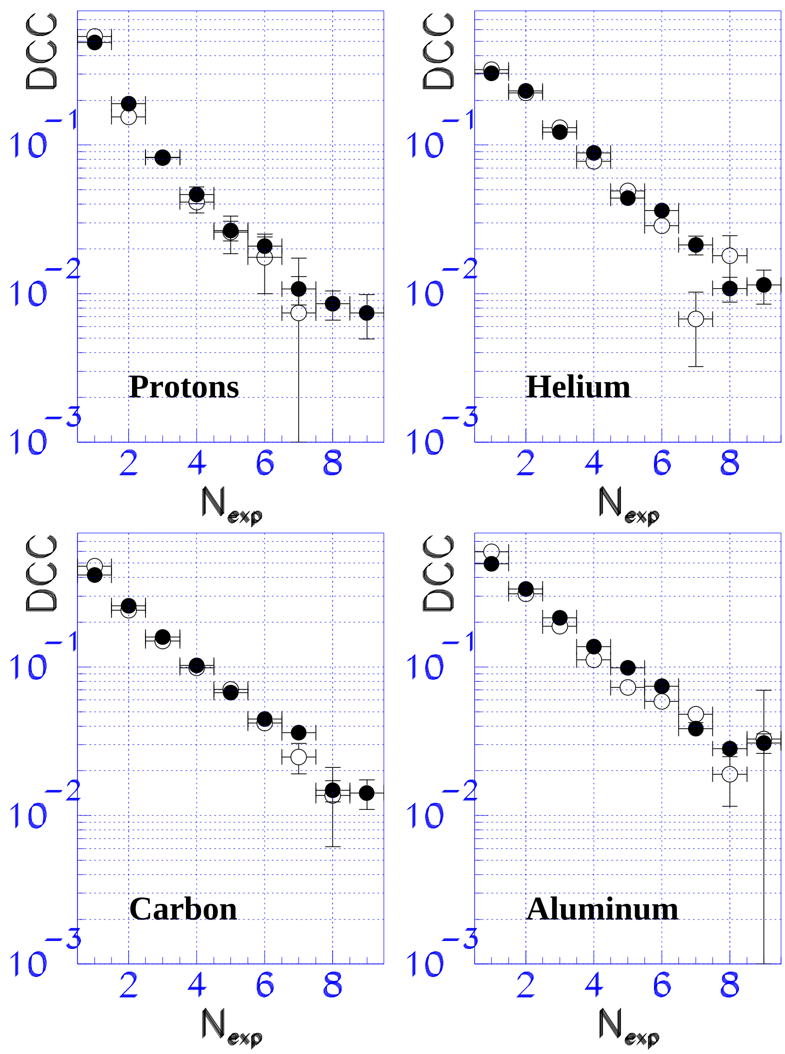
$$Z = \sqrt{\frac{N_{seen}}{N_{exp}}}$$




reconstructed charge obtained applying a maximum likelihood method: Three possible values of Z are calculated and their probabilities.
The reconstructed charge is value of Z that maximizes the probability $P_{\mu}(N_{seen})$, where $\mu = Z^2 \times N_{exp}$

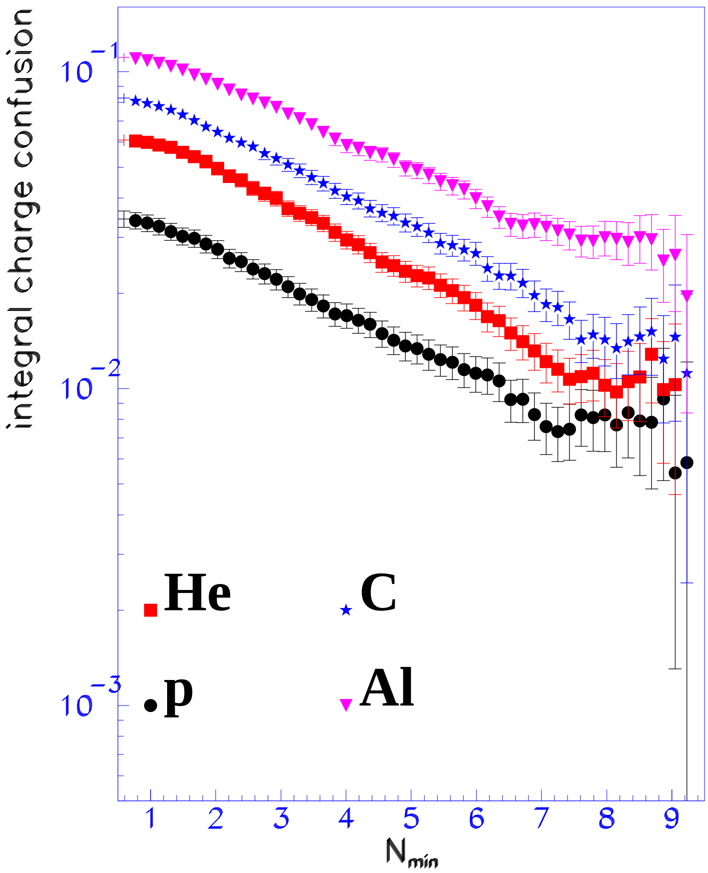
# Differential charge confusion vs $N_{exp}$

The charge confusion only depends on the number of expected photons associated to an event. Values of charge confusion for the two samples of beta 1 and uniform beta are very similar.



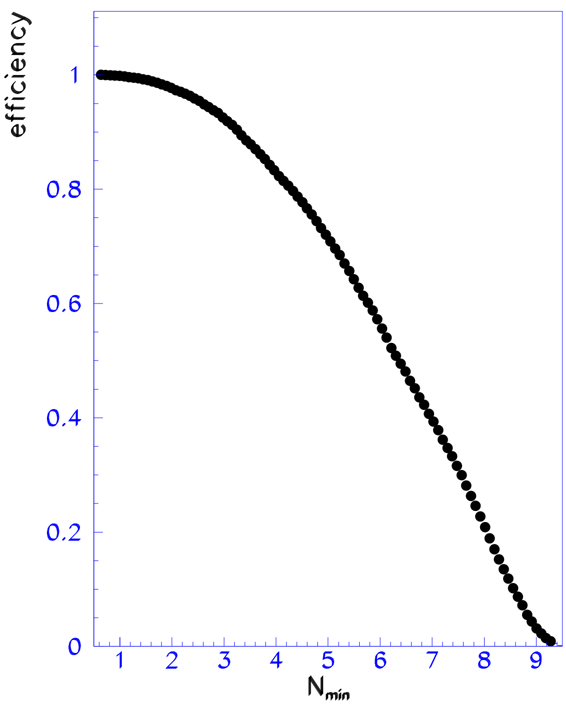

Full marks: differential charge confusion for samples of $\beta$=1
Empty marks: same plots for samples of uniform beta $1/n < \beta < 1$

# Results: integral charge confusion vs $N_{exp}$



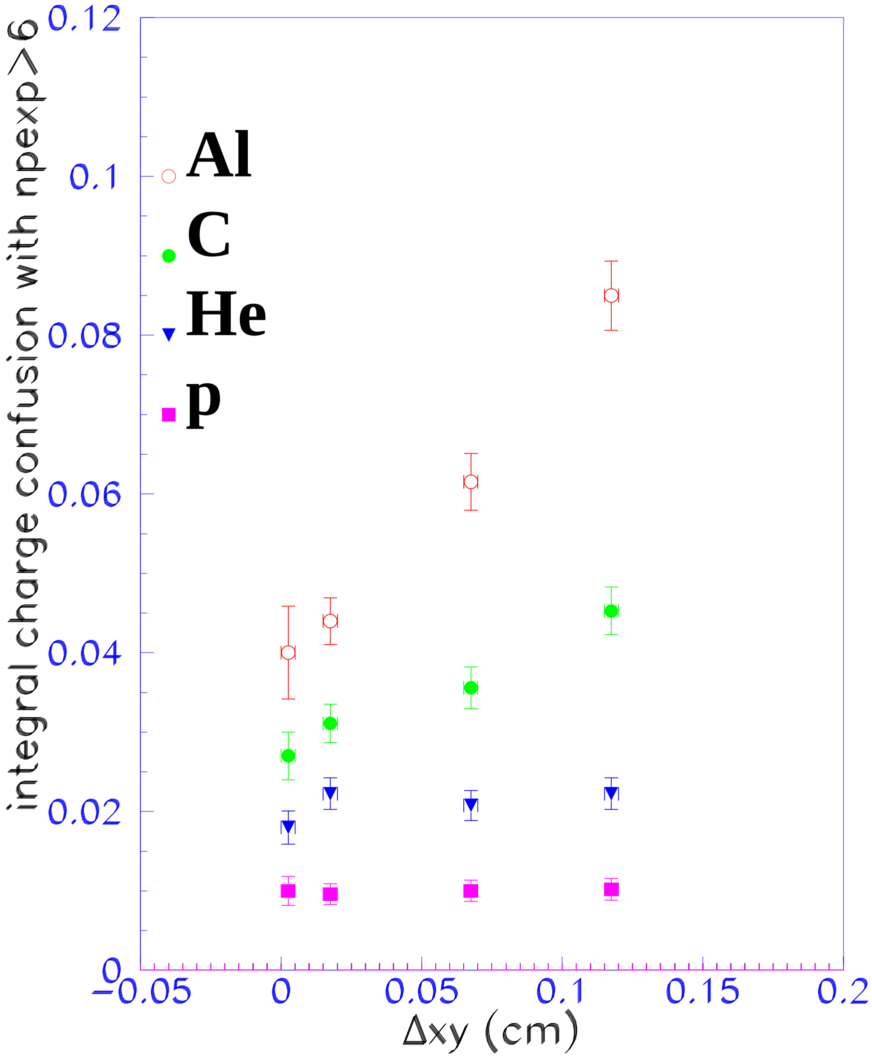

A cut $N_{exp} > 6$ reduces the sample to the $\sim 50\,\%$ and gives a percentage of events with bad identified charge as shown in the table:

| Z | cc |
|---|---|
| 1 | 1 % |
| 2 | 1.8 % |
| 6 | 2.7 % |
| 13 | 4 % |




Efficiency of the cut $N_{exp} > N_{min}$ for a sample of beta = 1

# Charge dependence on the reconstructed track




The plot shows the charge confusion computed applying a smearing to the position of the particle. The smearing is simulated with a gaussian distribution with different values of spread up to 0.12 cm

From the simulation the position resolution for AMS will be 0.02 cm

# Reconstruction time: $t_Z/t_\beta$ vs Z

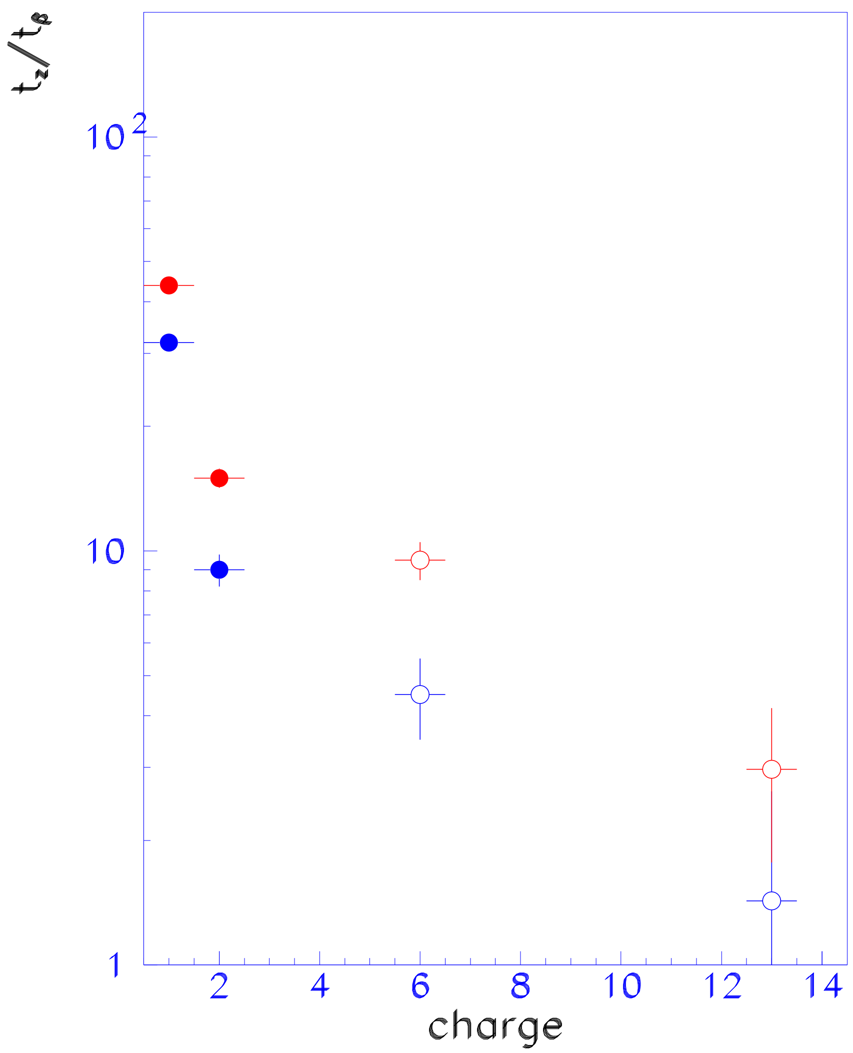
Charge reconstruction time only depends on the number of calls to the tracing routine: NSTEPS

For low Z event (Protons and Helium) about 1000 steps give enough precision

For higher Z events statistical fluctuations become smaller and a more precise calculation is needed → NSTP = 6400

$$t_\beta \propto Z^4$$

$$t_Z \propto \text{number of loops}$$




Red marks: uniform beta samples

Blue marks: beta=1 samples

Full marks: NSTEPS=1050

Empty marks: NSTEPS=6400

# Conclusions

- The algorithm is actually implemented in the stand alone version of CIEMAT. Next step will be the implementation in AMS simulation
- It has been tested for the setup of 680 pmt's and aerogel of n=1.05, simulating different kinds of particles, with different velocity spectra
- For events with good reconstructed beta, the charge identification is given with a resolution of 0.22e for protons and increasing to 0.28e for Aluminum
- The algorithm will be implemented to reconstruct prototype data