Velocity and Charge Reconstruction with the Rich Detector of the AMS Experiment

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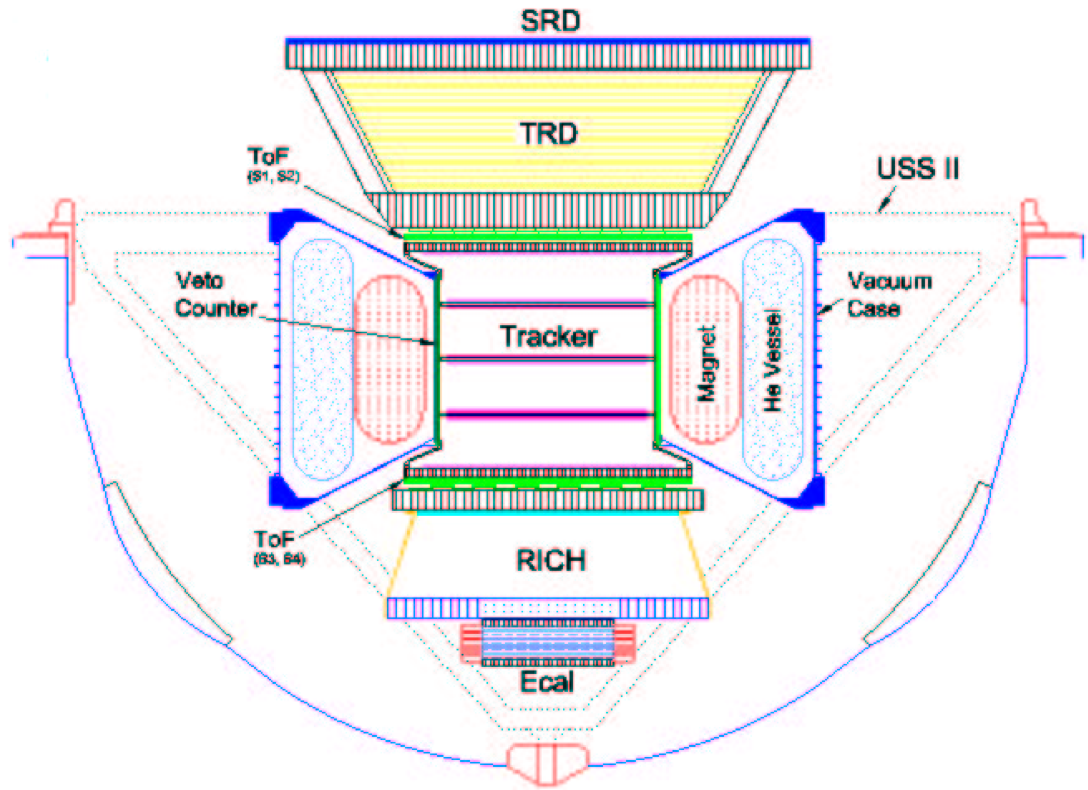
Outline

- ✔ AMS detector
- ✔ Rich Detector
- ✔ Photon pattern tracing
- ✔ Velocity reconstruction
- ✔ Charge reconstruction
- ✔ Conclusions

4th Workshop on RICH Detectors, NESTOR Institute-Pylos
June 5-10, 2002

AMS2: Spectrometer Capabilities

- particle bending
  Superconducting magnet
- particle direction of incidence
  Time-of-Flight and RICH
- Ridgidity (p/Z)
  Silicon Tracker
- Velocity (β)
  Time-of-Flight and RICH
- Charge (Q)
  Tracker, TOF and RICH
- e/p separation
  TRD and ECAL calorimeter
- photons
  ECAL calorimeter



Acceptance $\sim$ 0.5 $m^2.sr$

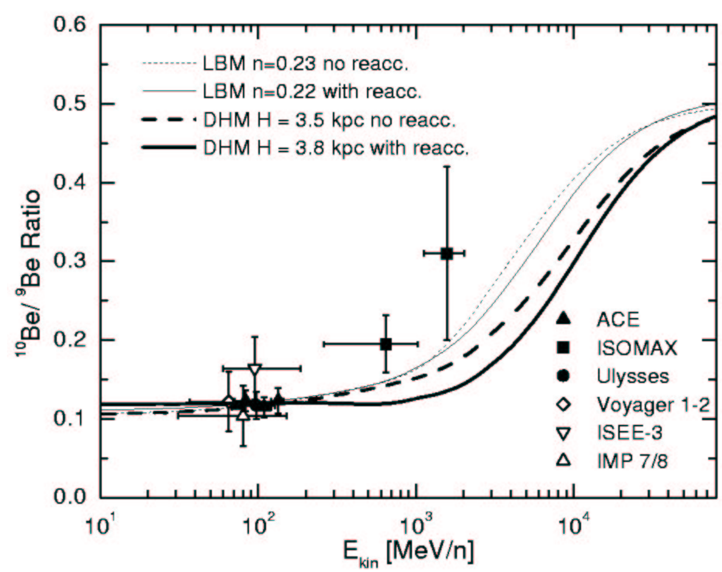
Physics motivations

- The study of secondary species such as Li, Be and B which result essentially from CNO spallation provides us information about propagation of cosmic-rays (CNO group) in galaxy (B/C)
  ($\boldsymbol{Z > 2}$ abondance only $\sim 1\%$)
- The propagation history of the Helium nuclei can be probed measuring the ratio $\boldsymbol{^3He/^4He}$
  $\boldsymbol{^3He}$ is essentially secondary and comes from the spallation of $\boldsymbol{^4He}$
- The measurement of the ratio $\boldsymbol{^{10}Be/^9Be}$ give us information about confinement of cosmic rays in the Galactic volume and is sensitive to different propagation models
  $\boldsymbol{(\,^{10}Be)\;\; t_{1/2} \sim 1.5 \times 10^6\; yrs}$

improve current Be isotopic measurements

☞ **done at relatively low energies**

☞ **based in poor event statistics**

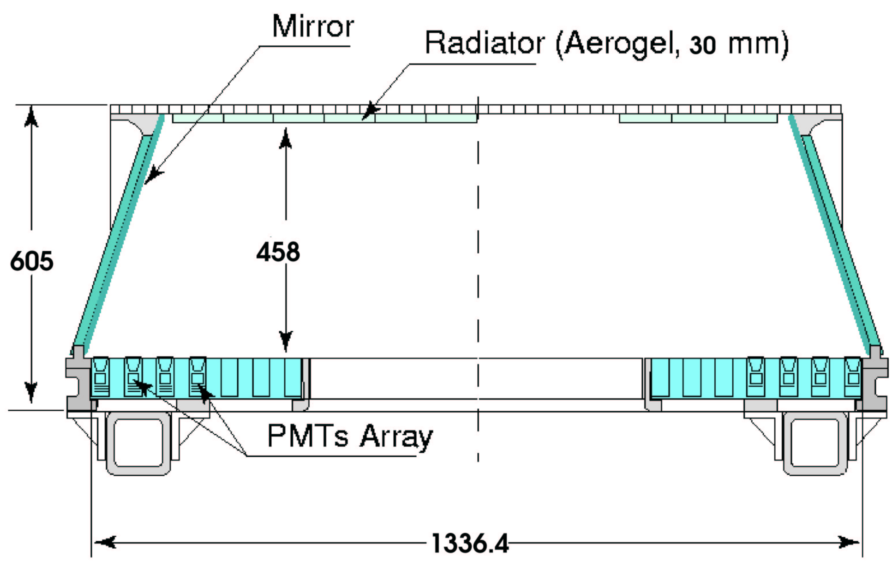


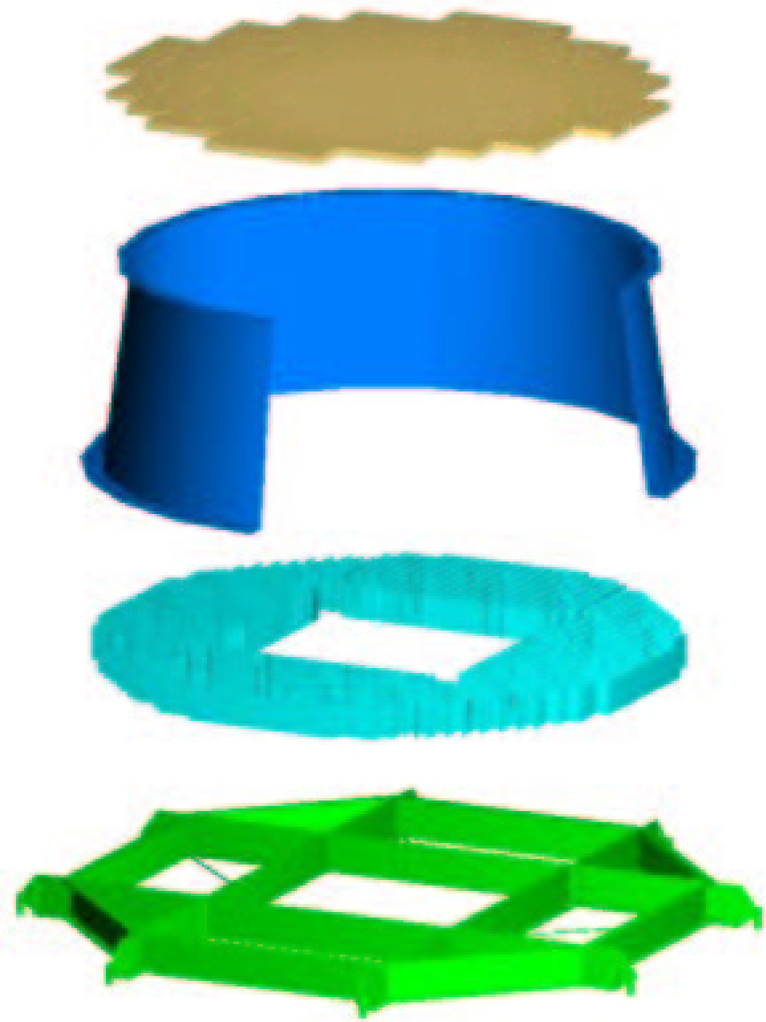
(A.Molnar, M.Simon ICRC2001)

RICH detector

The Ring Imaging Cerenkov of AMS is a proximity focusing detector with a low index radiator, a high reflectivity mirror and photomultiplier tubes.

- velocity measurement $\frac{\Delta\beta}{\beta} = 0.1\%$
- charge measurement $Z \sim 25$
- redundancy on albedo rejection $\overline{He}/He \sim 10^{-9}$
- e/p separation



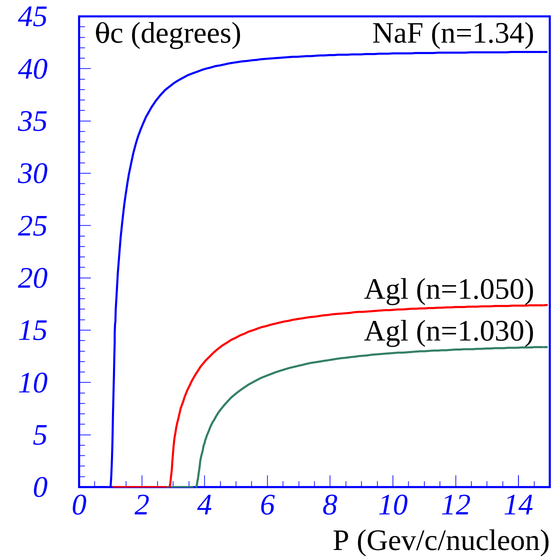


RICH Radiator

✔ Cerenkov radiation

a charged particle traveling in a medium with a velocity higher than the light speed radiates photons:

$$\cos\theta_c = \frac{1}{\beta n}$$



✔ Light Yield

the light yield increases with the radiator thickness (L), the charge (Z), the velocity (β) and refractive index (n):

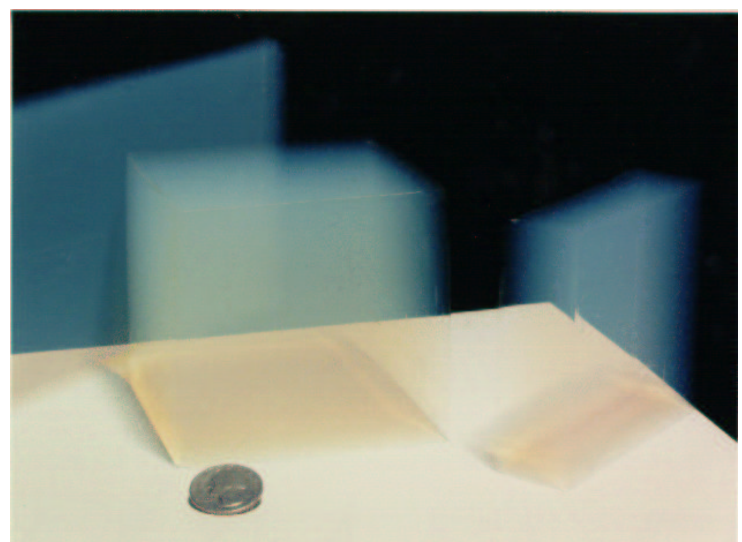
$$n_{p.e} \propto Z^2\, L \left(1 - \frac{1}{\beta^2 n^2}\right) \int \varepsilon dE$$

✔ radiator

Silica Aerogel (n=1.030/n=1.050) 2-3cm thick

aerogel tiles $11.5 \times 11.5 \times 1cm^3$

$N_\gamma \sim 50/cm$ (Z=1, $\beta \sim 1$)



✔ Rayleigh scattering $\frac{d\sigma}{d\Omega} \propto \frac{(1+\cos^2\theta_c)}{\lambda^4}$

directionality of cerenkov photons lost

transparency decreases for UVs $\Lambda_{int} = \frac{\lambda^4}{C}$

C≡Clarity coeff. $0.0042\mu m^4/cm \ \ (n = 1.030)$

$0.0091\mu m^4/cm \ \ (n = 1.050)$

Detection Matrix

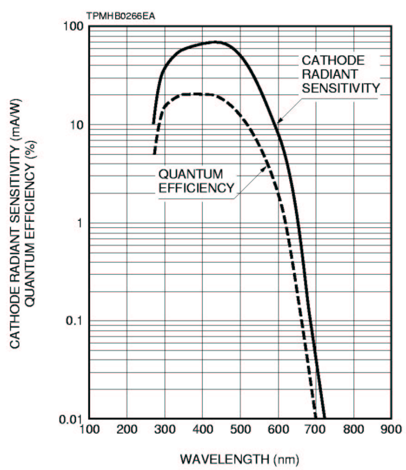
✔ Photomultipliers

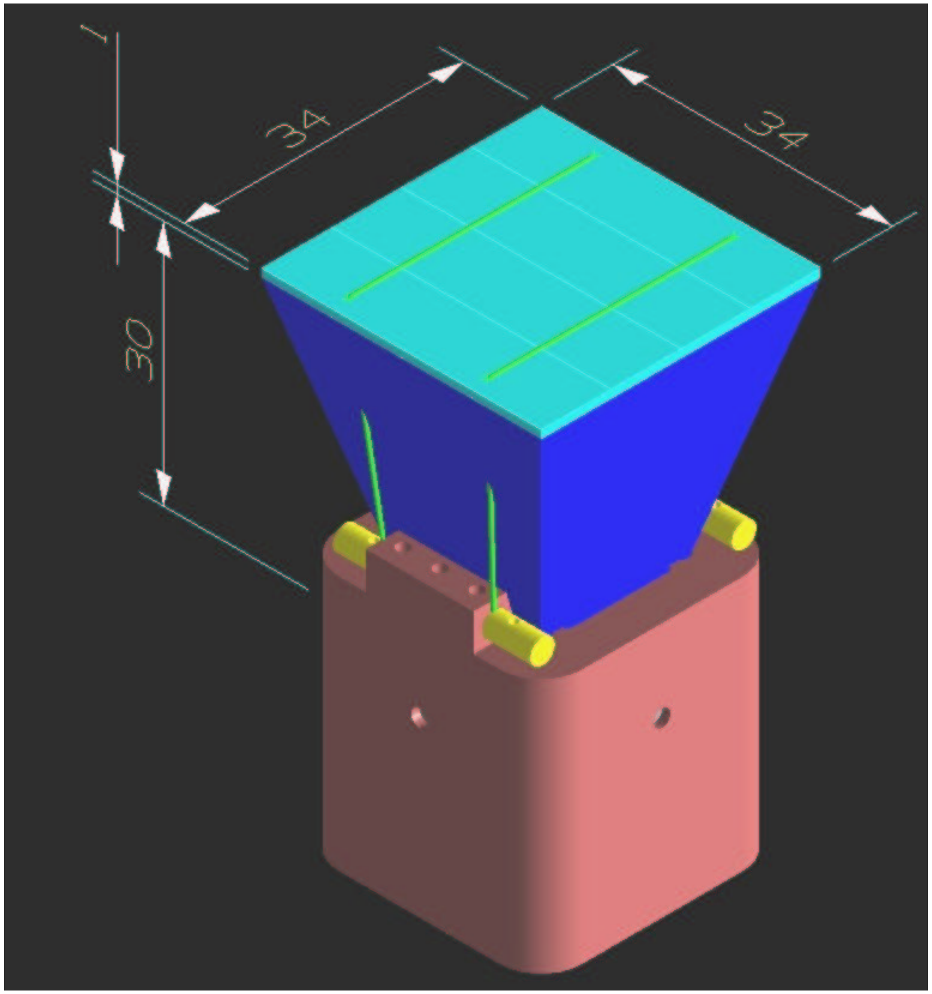
- ➡ matrix with around **700 PMT's**
- ➡ 4x4 multianode R7600-M16
  4.5 mm pitch
- ➡ borosilicate glass window
- ➡ spectral response 300-650 nm
  maximum at $\lambda = 420nm$

✔ Light Guides

Plexiglass (n=1.49) solid guides

Effective pixel size $\sim 8 - 8.5\ mm$





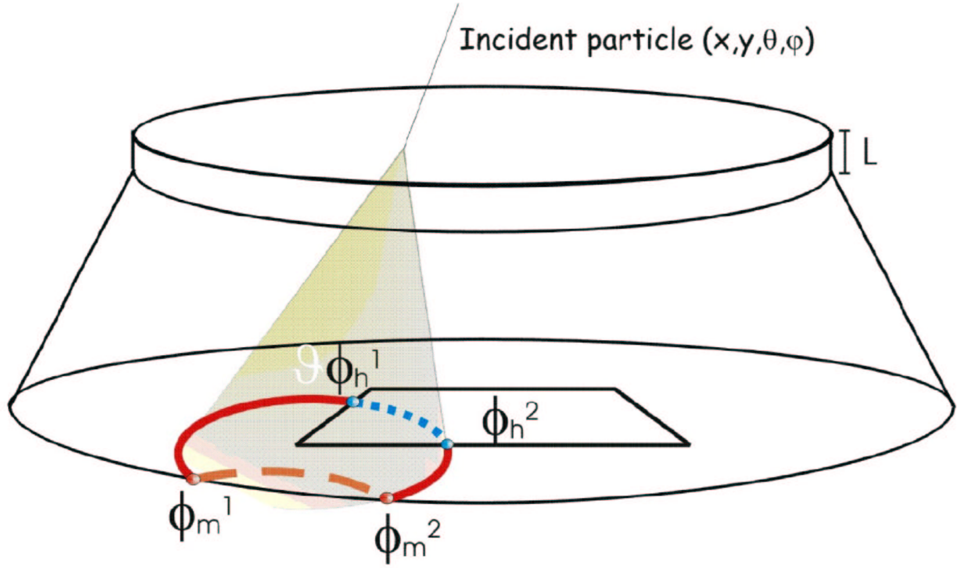
Photon pattern tracing

photon tracing includes

- ✔ emission at a reference point with an opening angle $\boldsymbol{\theta_c}$ and at a given azimuthal angle $\boldsymbol{\varphi}$

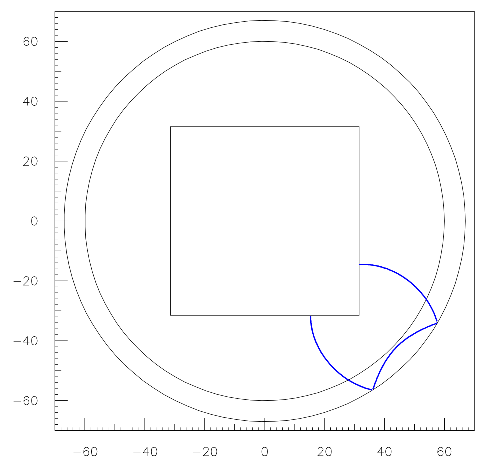
$$\vec{g}^{\,*}(\varphi;\theta_c) \xrightarrow{T(\theta;\phi)} \vec{g}(\varphi;\theta_c,\theta,\phi)$$

- ✔ escaping from radiator
- ✔ refracting at radiator boundary
- ✔ reflecting on mirror
- ✔ hitting detection plane

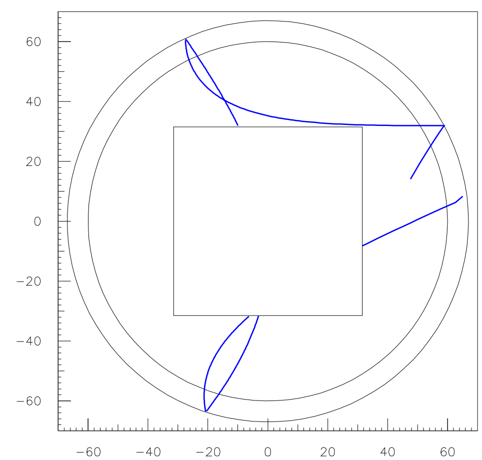


typical patterns for two radiators

- ✔ for aerogel (n=1.030)
- ✔ for NaF (n=1.34)



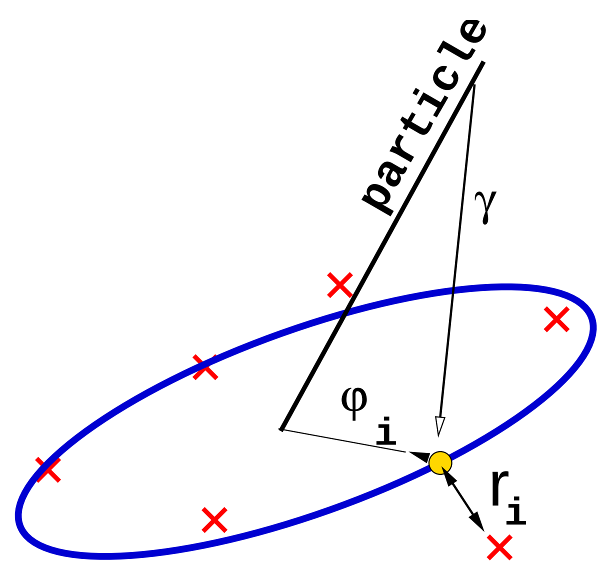
aerogel (n=1.030)



NaF

($\boldsymbol{\theta_c}$) reconstruction: A likelihood approach

- ✔ The AMS Tracker provides the **particle direction** $(\boldsymbol{\theta, \phi})$ and **impact point** at the RICH radiator
- ✔ The **photon pattern** at the PMT matrix plane is derived as a function of the cerenkov angle $(\boldsymbol{\theta_c})$
- ✔ The hits associated to the particle track are excluded
- ✔ The **maximization of a likelihood function** provides the **best** $\boldsymbol{\theta_c}$ **angle**



$$\boldsymbol{P(\theta_c) = \prod_{i=1}^{nhits} P_i\{r_i(\varphi_i;\theta_c)\}}$$

$\boldsymbol{r_i} \equiv$ *closest distance to photon pattern*

$\boldsymbol{P_i} \equiv$ *probability of a hit belonging to photon pattern*

θ_c reconstruction: probability function

- noisy hits distribution essentially flat

  PMT noise, scattering,...

$$P_{noise} = \frac{b}{R} \sim 10^{-3} \ /cm$$

$b \equiv$ photon background fraction per event

$R \equiv$ active matrix dimension

- pattern hits distribution essentially gaussian

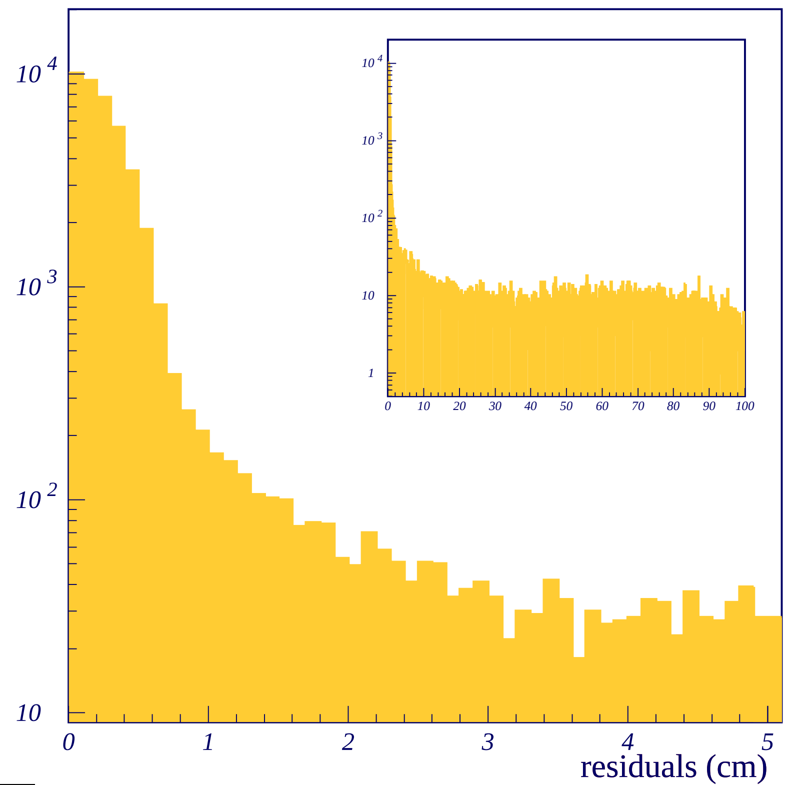
  pixel size, radiator thickness, chromaticity,...

$$P_{signal} = (1-b)\frac{1}{\sigma\sqrt{2\pi}}\exp^{-\frac{1}{2}\left(\frac{r_i}{\sigma}\right)^2} \quad (1)$$

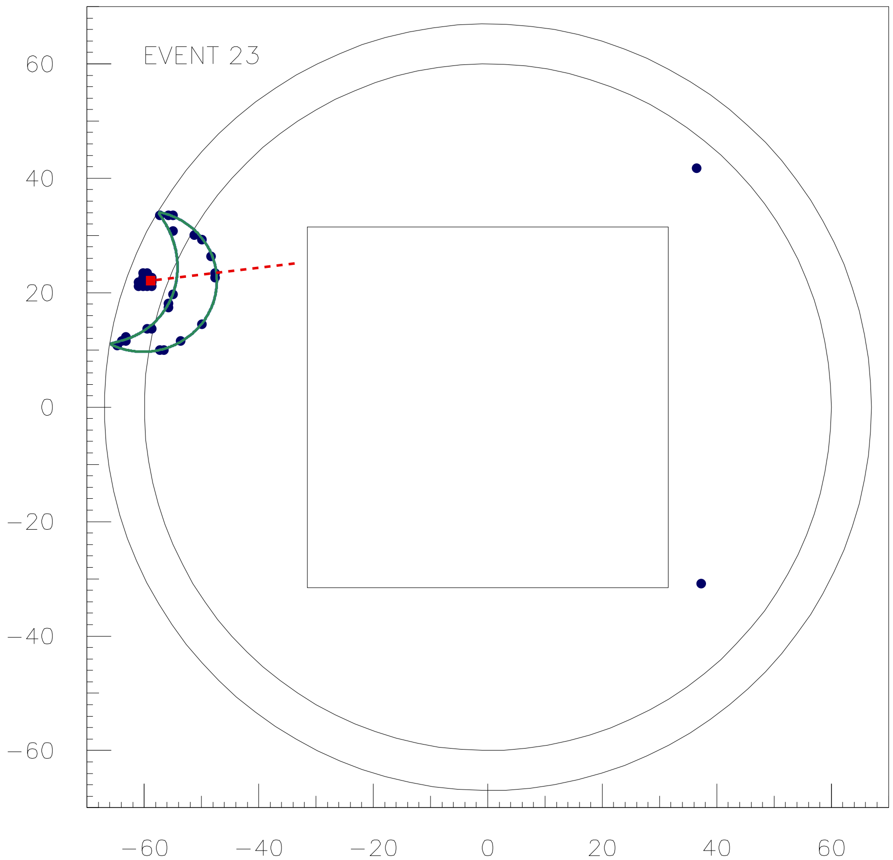
width: $\sigma \sim 0.5 \ cm$

- combined probability function

$$P_i = (1-b)g(r_i) + \frac{b}{R}$$

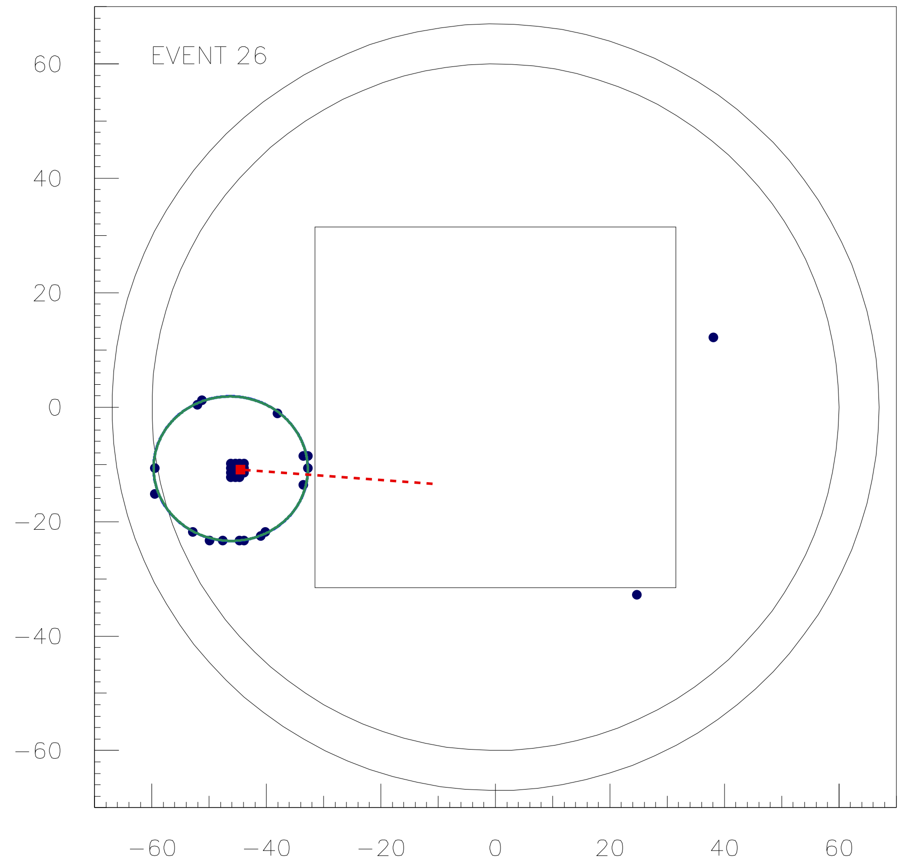


θ_c reconstruction: event displays



simulation event

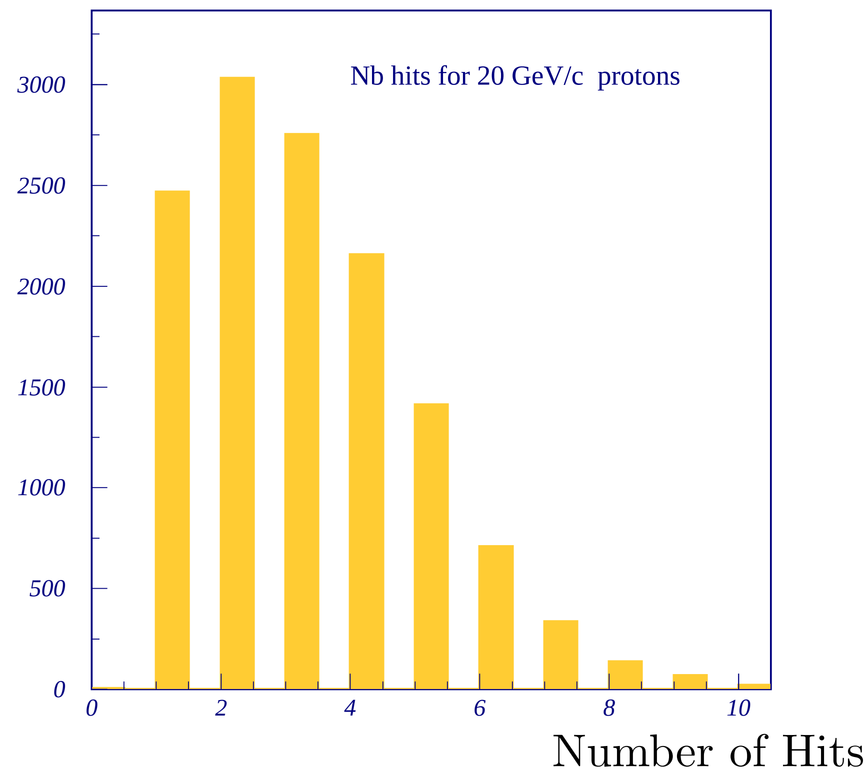
Helium (p=20 Gev/c/nucleon)

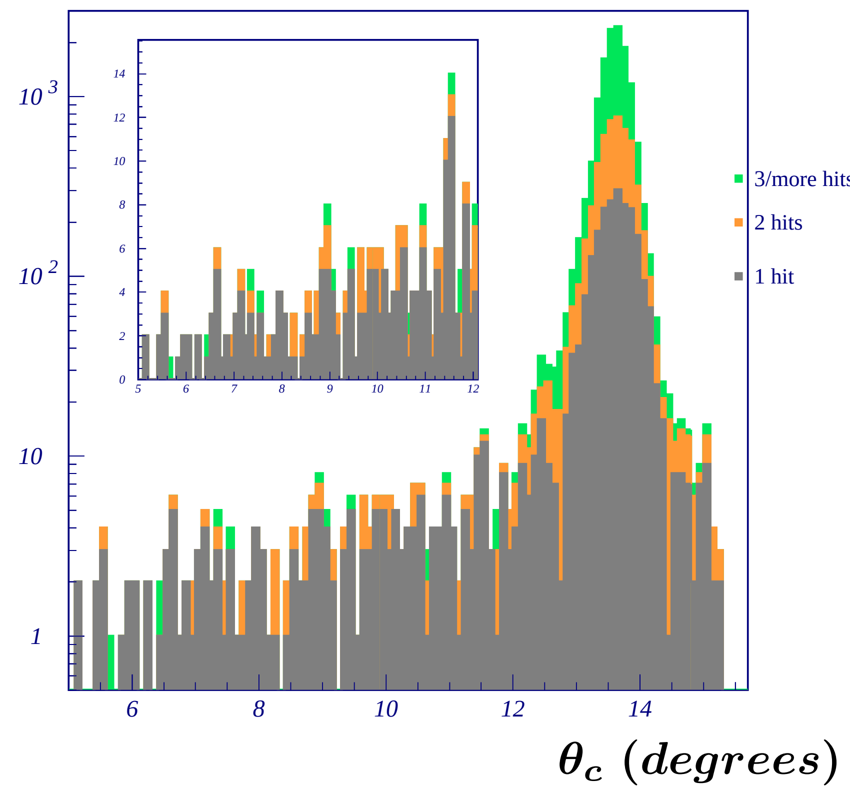


simulation event

Helium (p=20 Gev/c/nucleon)

Results: the Number of hits





☞ radiator: aerogel (n=1.030) 2cm thickness

☞ large tails for events with $\leq$ **3** hits

$\sim$ **40% of protons with less than 3 hits**

a radiator thickness of 3 cm envisaged

Cerenkov angle resolution

☞ The cerenkov angle:

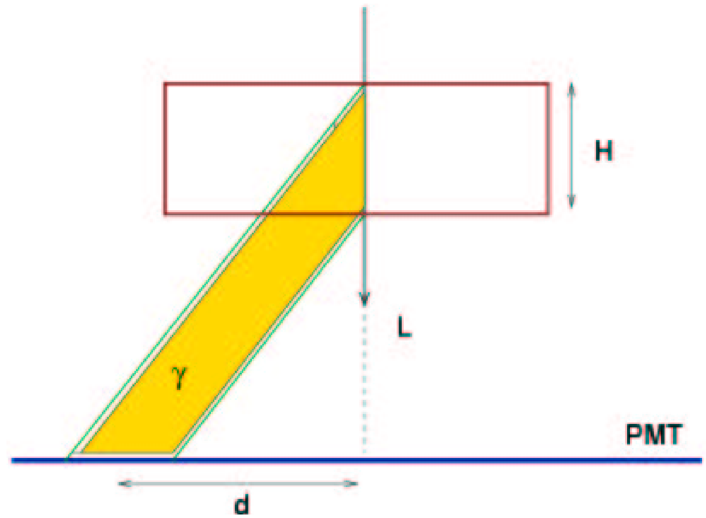
$$\cos\theta_c = \frac{1}{\beta\, n}$$

☞ The particle velocity uncertainty (per hit):

$$\frac{\Delta\beta}{\beta} = \tan\theta_c\, \Delta\theta_c$$

☞ The cerenkov angle uncertainty:

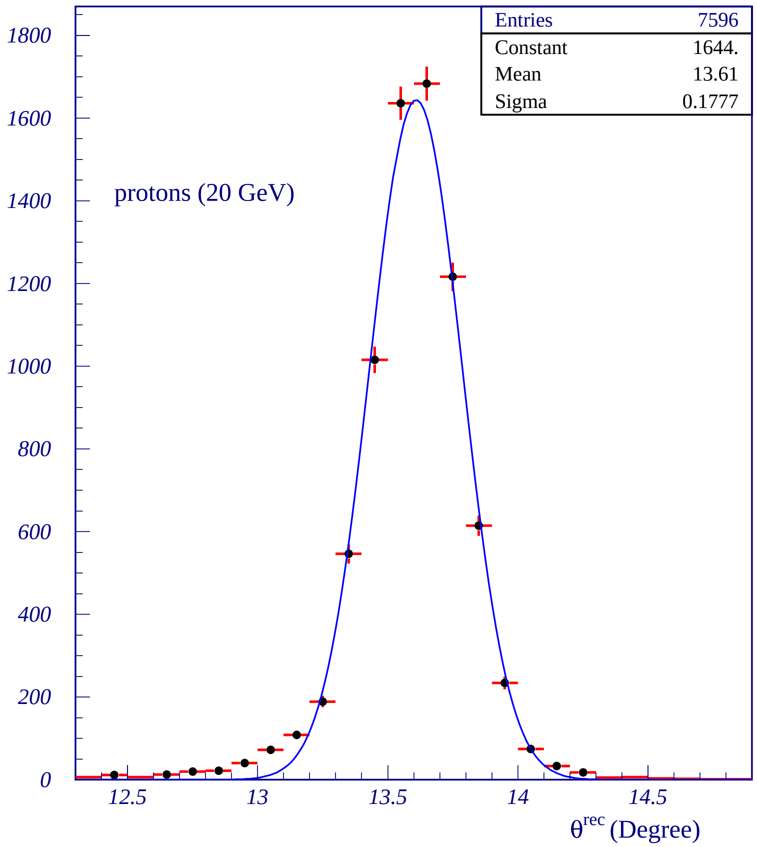
$$\Delta\theta_c \sim \cos^2\theta_c \frac{\Delta d}{L}$$

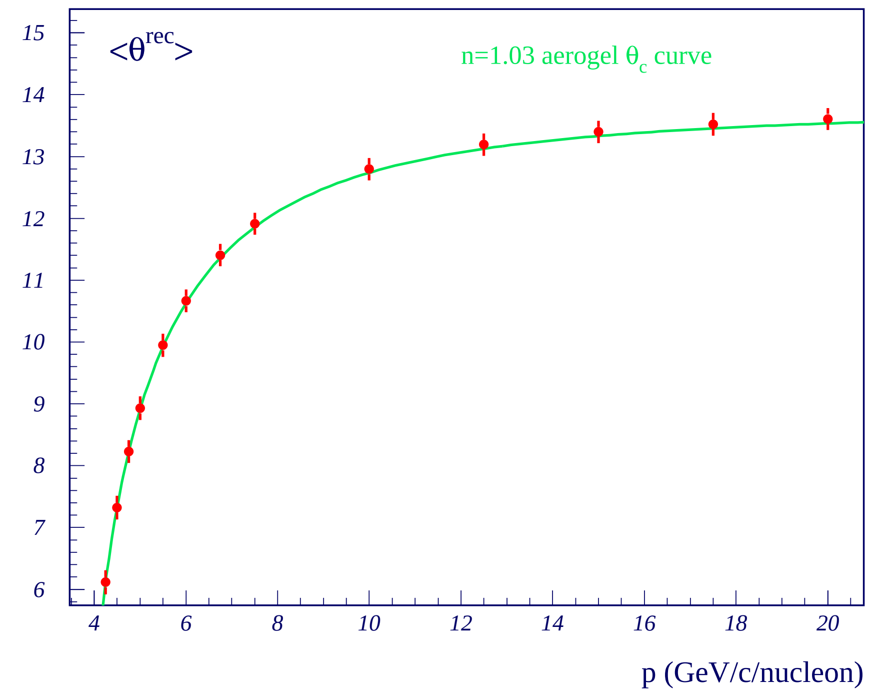


☞ the θ_c uncertainty deals with

❏ pixel size (granularity) $\sim 8.5mm$	$\Delta d \sim \frac{pixel}{\sqrt{12}}$	$\Rightarrow \Delta\theta_c \sim 5\ mrad$
❏ radiator thickness $2-3cm$	$\Delta d \sim \frac{H\ \tan\theta_c}{\sqrt{12}}$	$\Rightarrow \Delta\theta_c < 5\ mrad$
❏ chromaticity	$\Delta\theta_c \sim \frac{\Delta\ n}{\sqrt{2(n-1)}}$	$\Rightarrow \Delta\theta_c < 5\ mrad$

Cerenkov angle reconstrucion

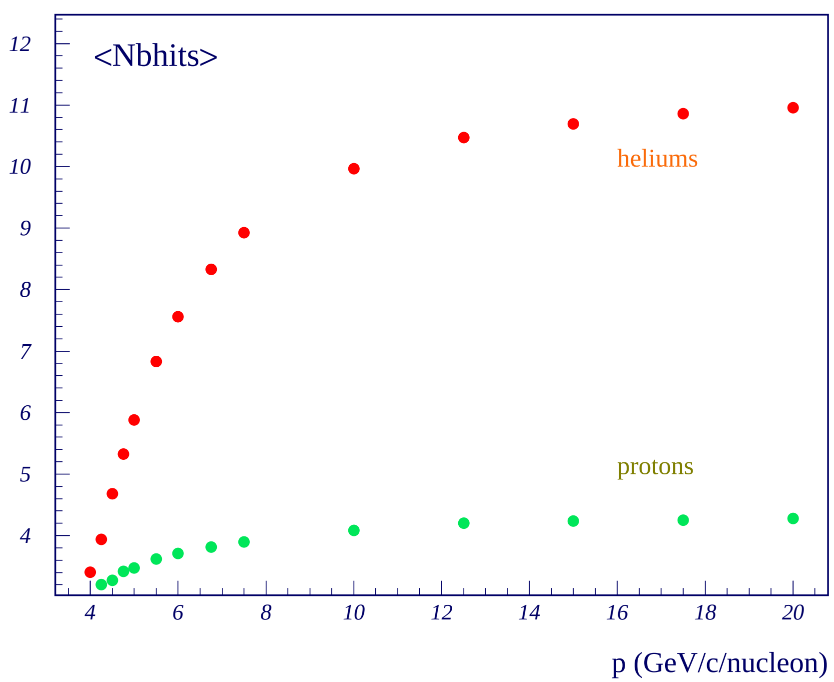


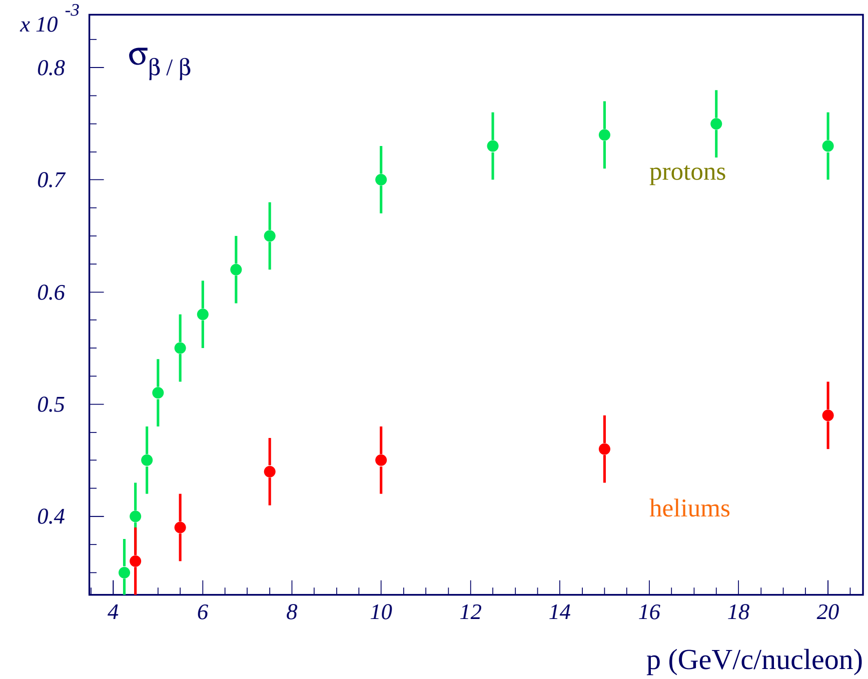


☞ Cerenkov angle reconstruction for events with at least 3 hits

☞ The reconstructed Cerenkov angle follows the expected law $\boldsymbol{cos\theta_c = \frac{1}{\beta n}}$ at all energies

Results : β resolution scaling





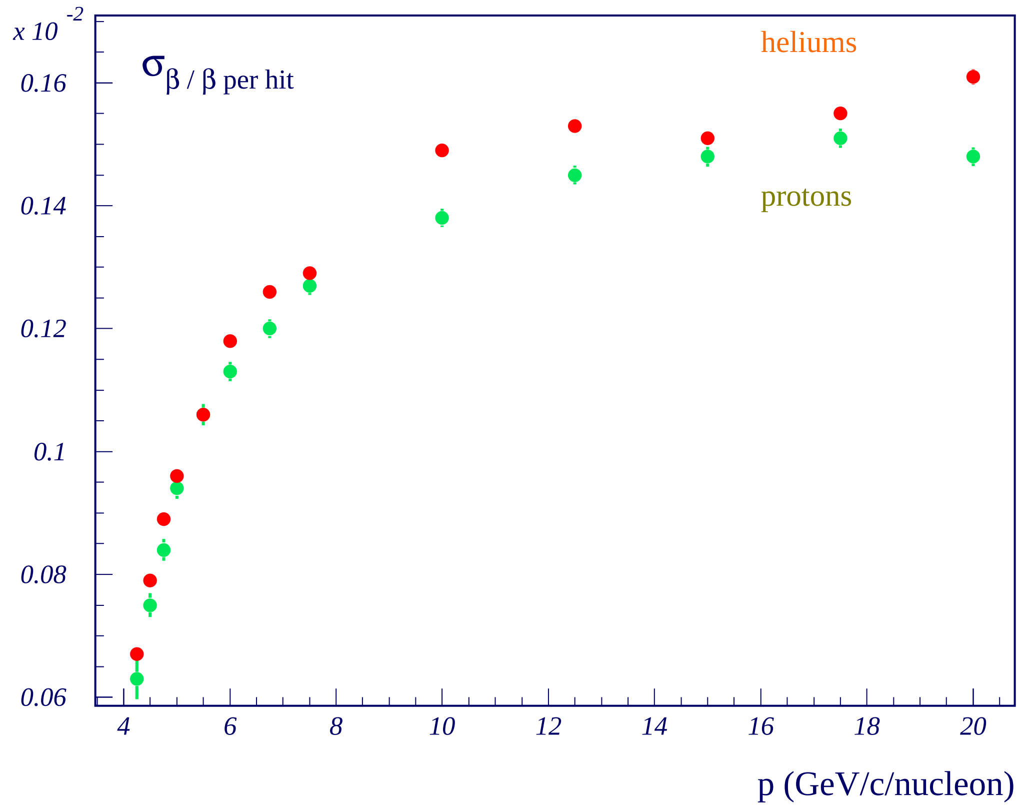
☞ the relative uncertainty on the velocity determination scales down with the number of hits

$$\frac{\Delta_\beta}{\beta} = \tan\theta_c \frac{\Delta_\theta}{\sqrt{N_{hits}}}$$

$\Delta\beta/\beta$: Resolution per hit

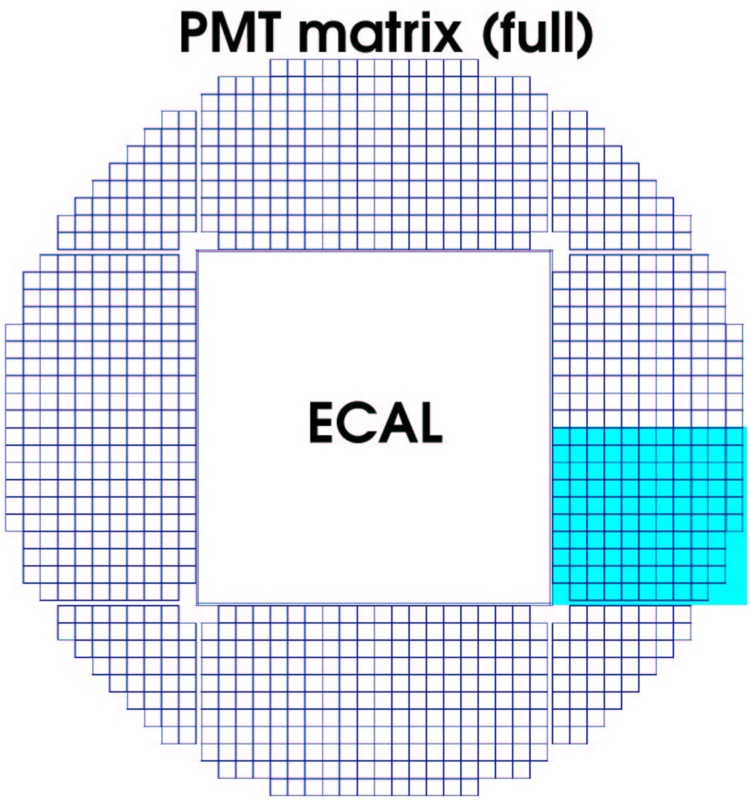
✔ It is possible to estimate the velocity resolution independently of the number of hits of every event

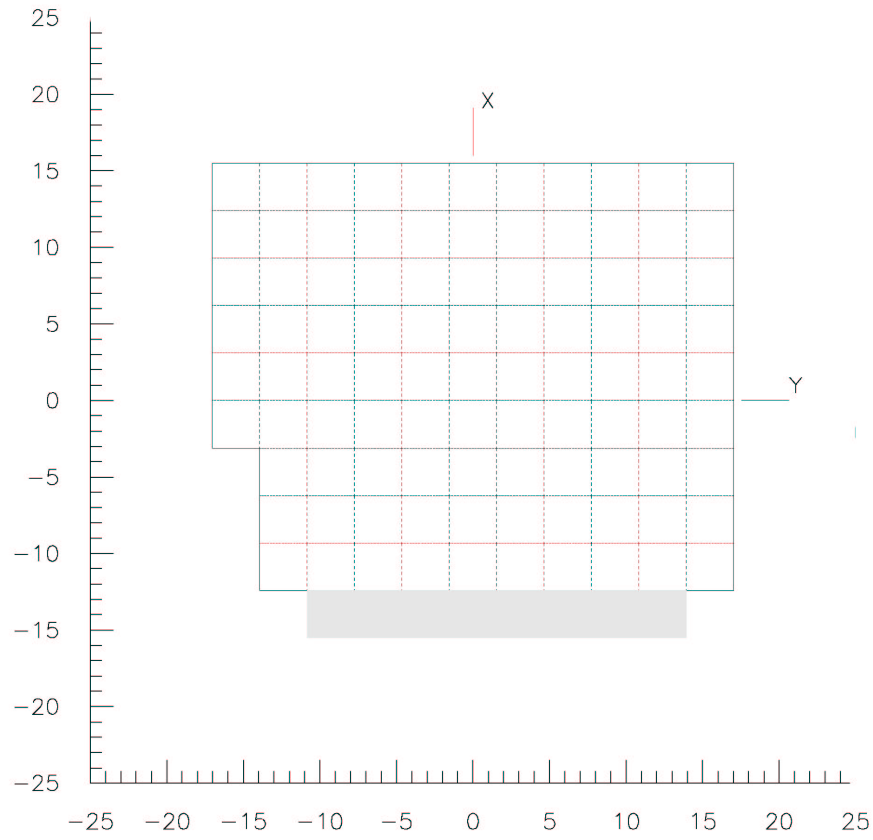
$$\left(\frac{\Delta\beta}{\beta}\right)_{hit} = \frac{\Delta\beta}{\beta} \times \sqrt{N_{hits}}$$



RICH Prototype

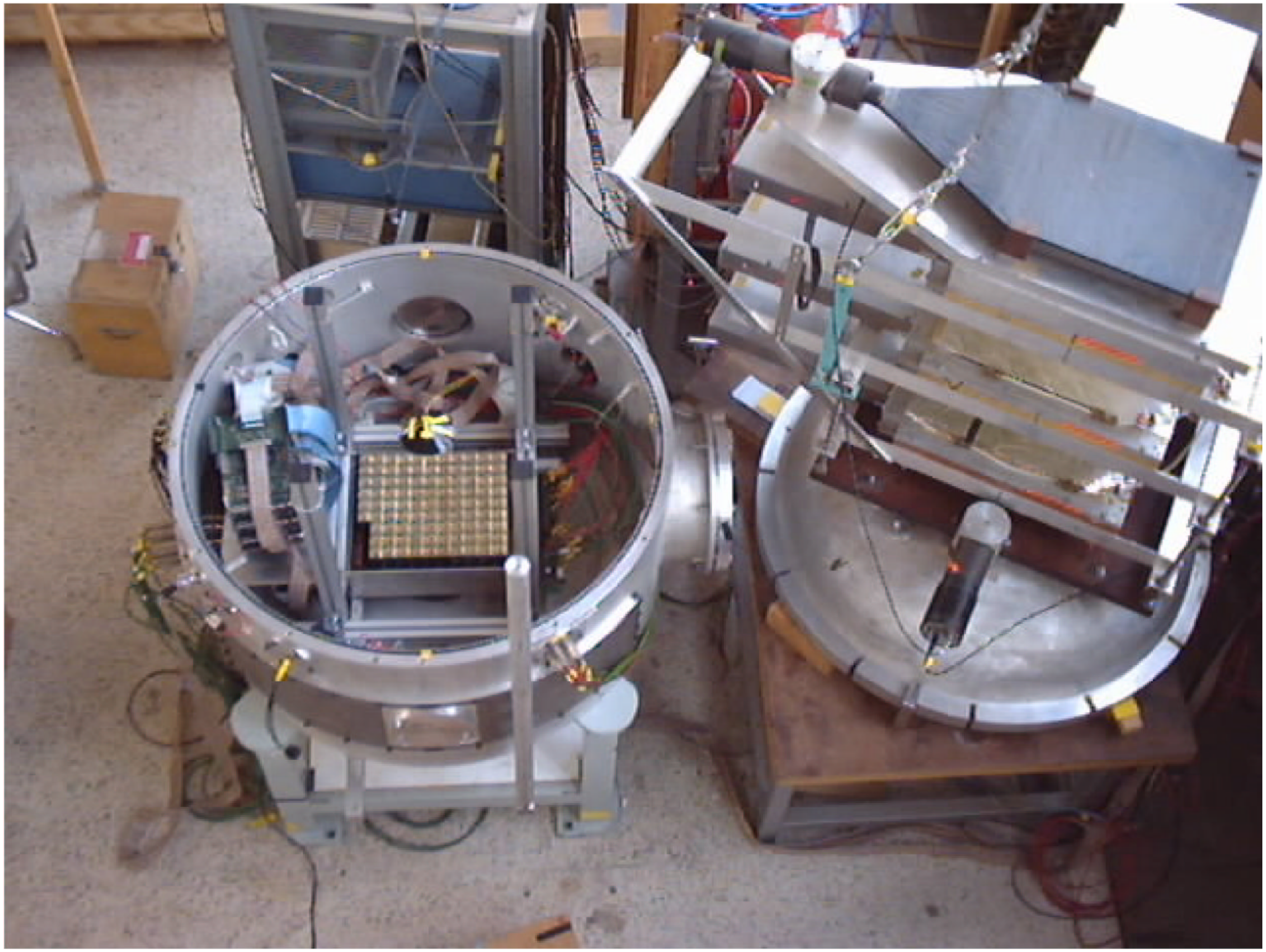
A RICH prototype was built and submitted to cosmic events at the ISN (Grenoble)



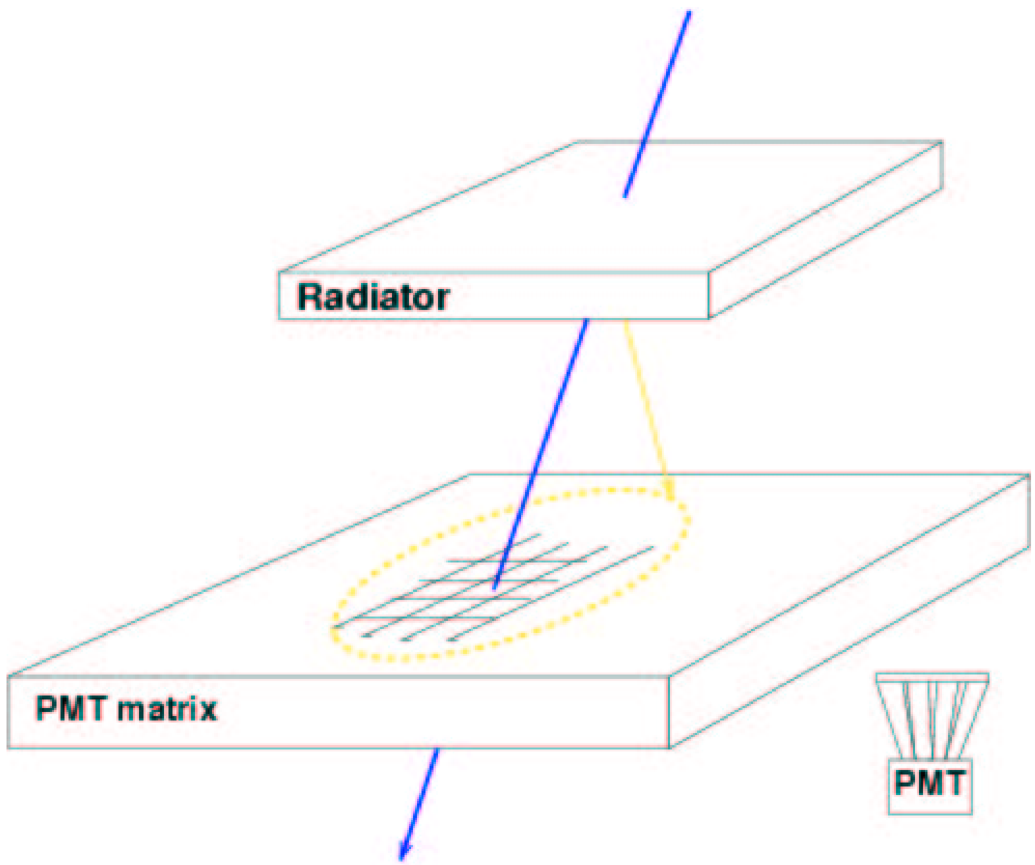


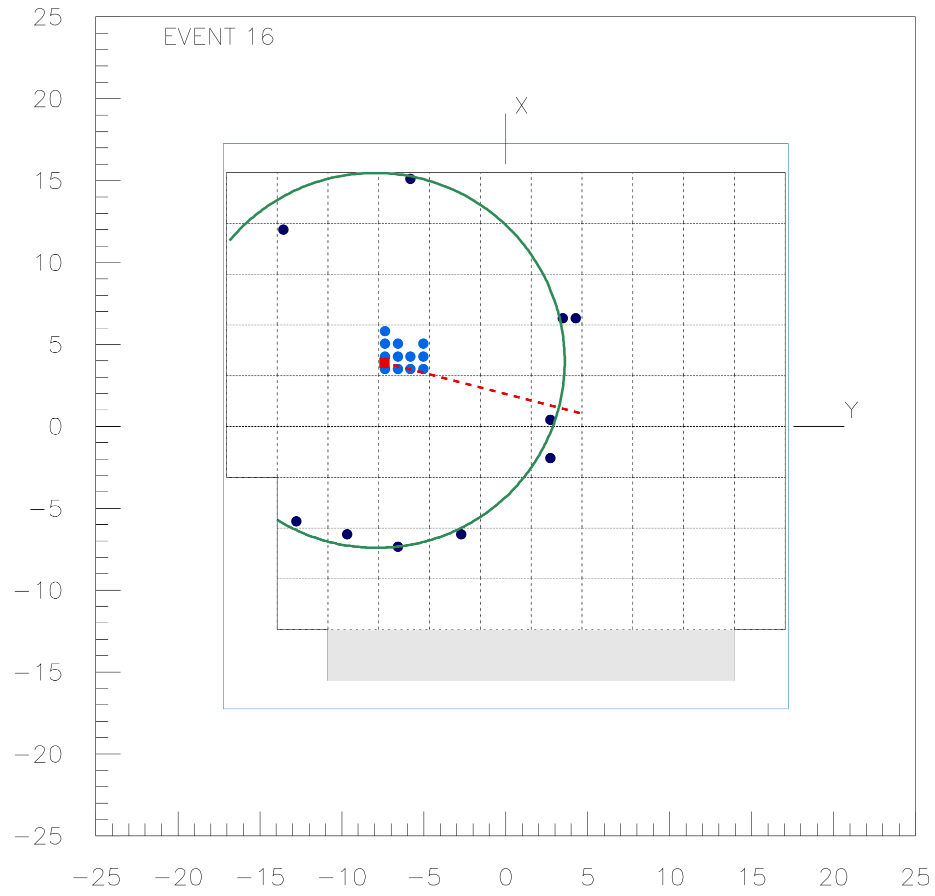
96 PMT's

RICH Prototype



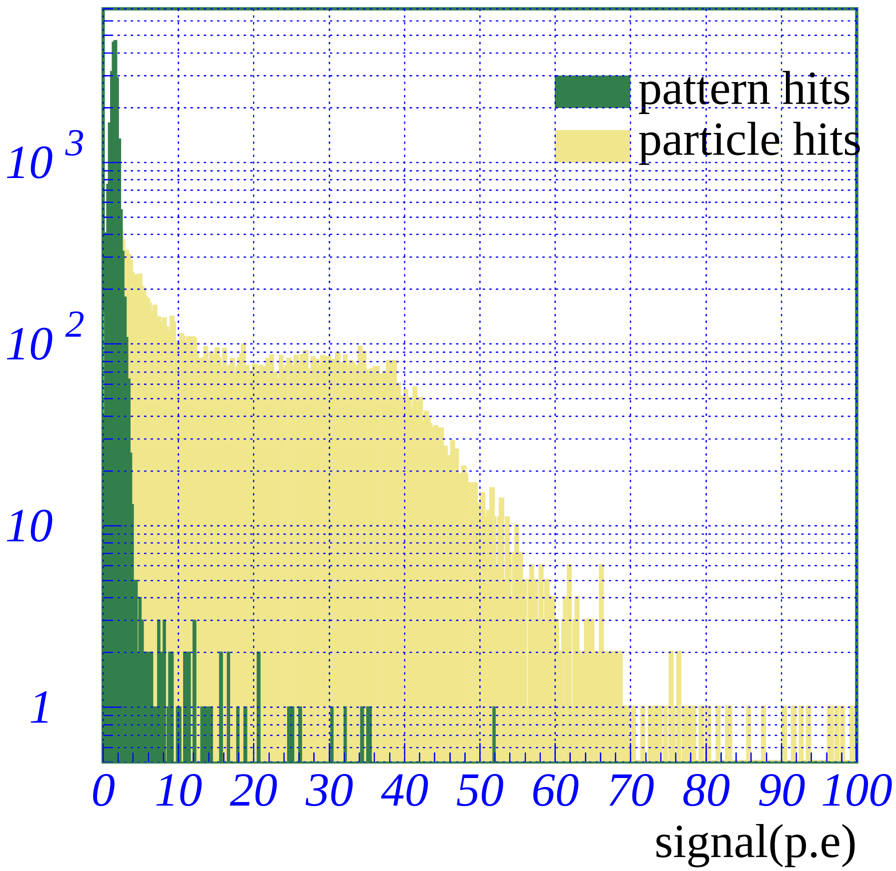
Prototype Data Analysis: an event



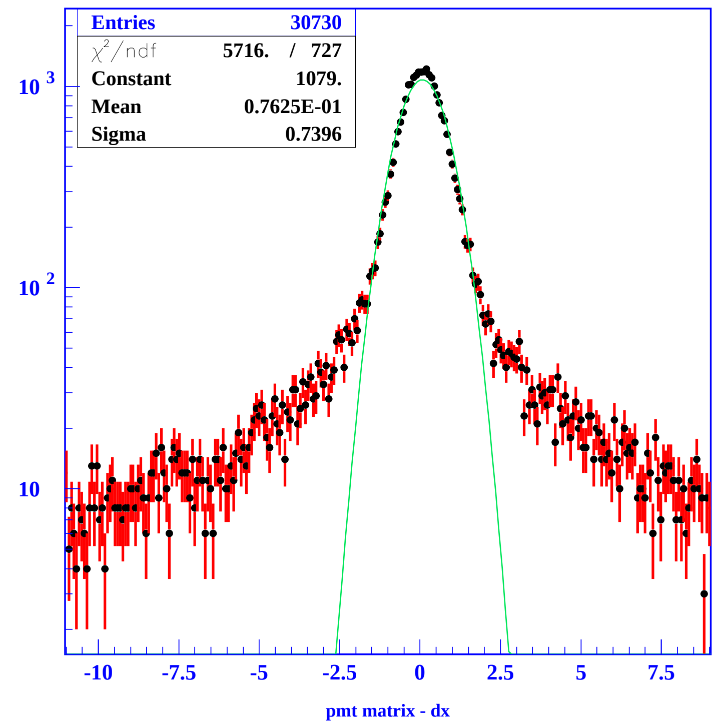


Data Selection event procedure

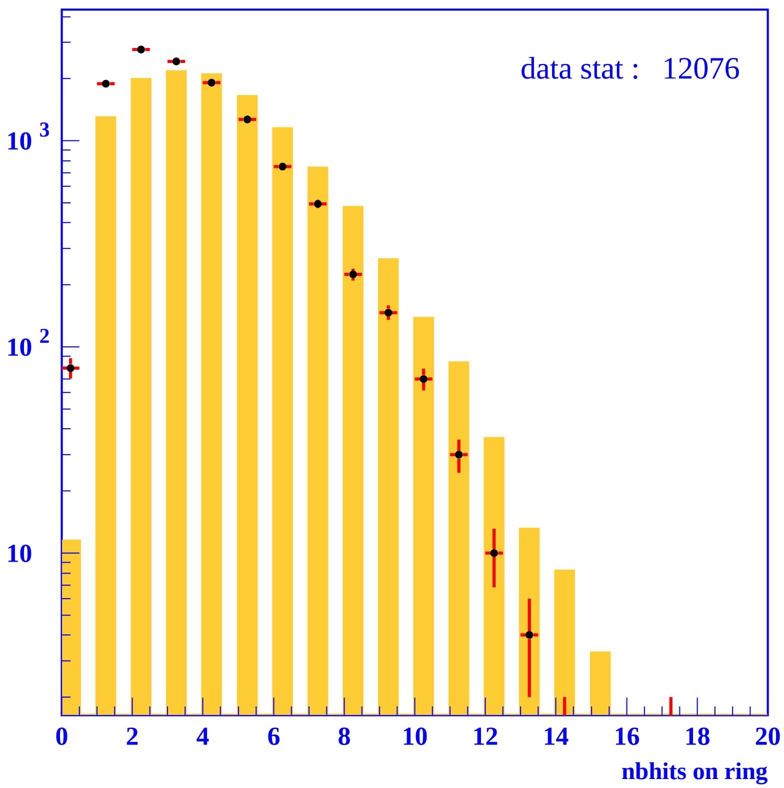
- Look for particle signal in PMT matrix ($> \mathbf{5}$ p.e)



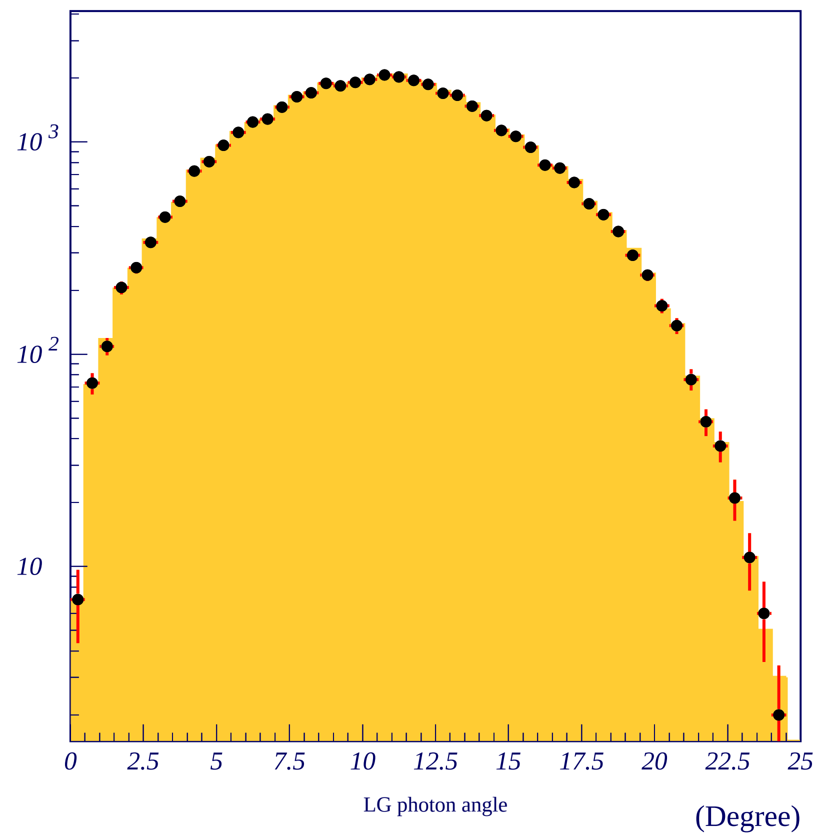
- Compare position of particle cluster to track extrapolation and require events with a good matching ($\boldsymbol{\Delta_x, \Delta_y < 0.75cm}$)



Prototype Data Analysis: Comparing DATA to MC

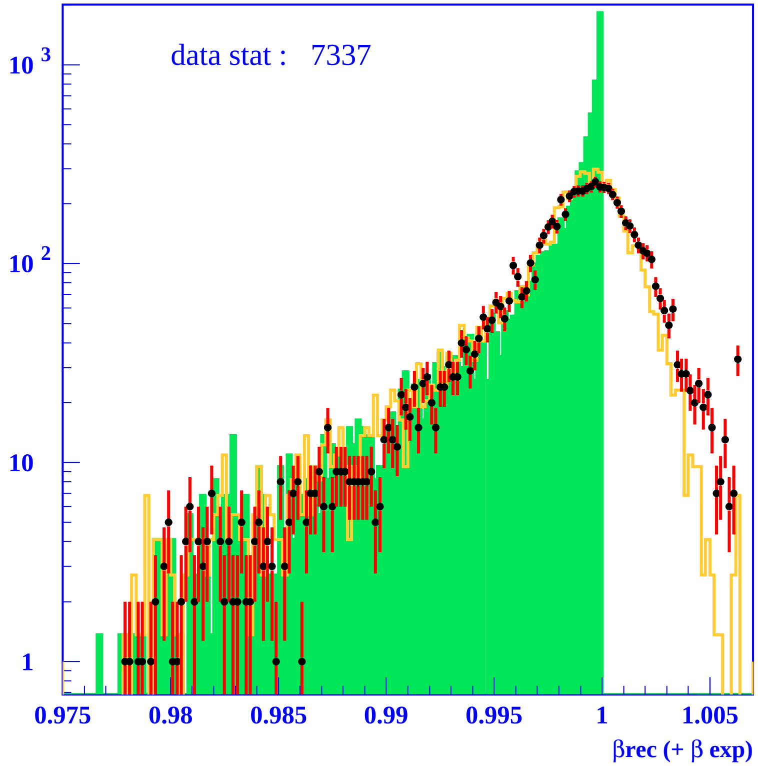


number of hits correlated with the photon pattern

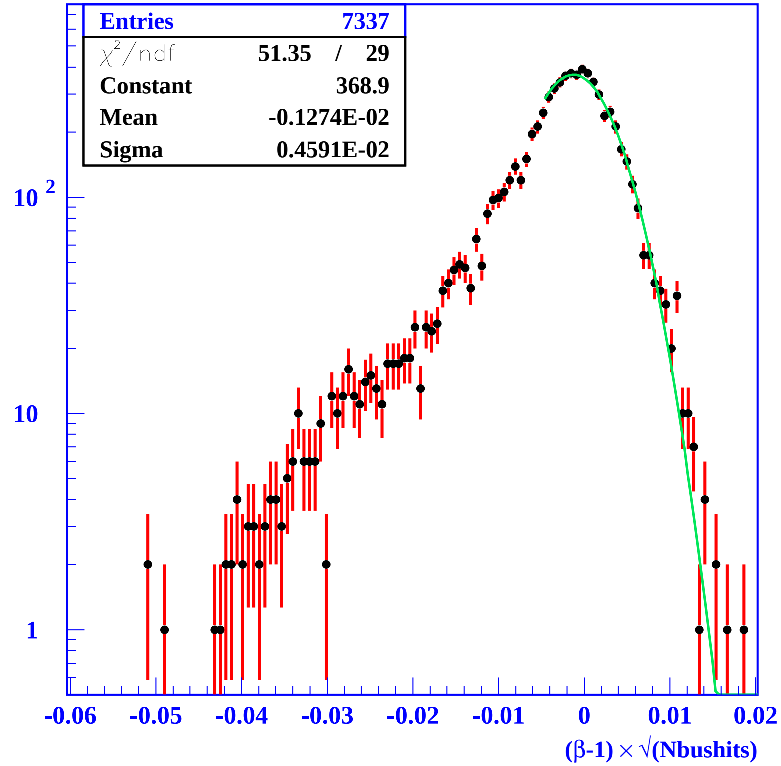


Light Guides behave as expected

Cosmic muons velocity spectrum



Measured β on data and simulation



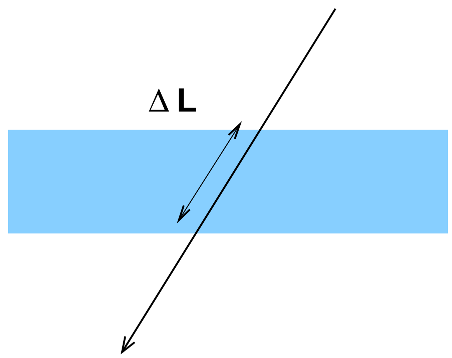
Velocity resolution from one hit

Charge (Z) reconstruction

- the **number of Cerenkov radiated photons** when a charged particle crosses a radiator path $\boldsymbol{\Delta L}$, depends on its **charge Z**

$$N \propto Z^2 \, \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right)$$

- their **detection** upon the PMT matrix close to the expected pattern depends on:
  - **radiator interactions (ε_{rad})**
    - absorption and scattering
  - **geometrical acceptance (ε_{geo})**
    - photons lost through the radiator lateral walls
    - mirror reflectivity
    - photons falling into the non-active area
  - **light guide losses (ε_{lg})**
  - **PMT quantum efficiency (ε_{pmt})**



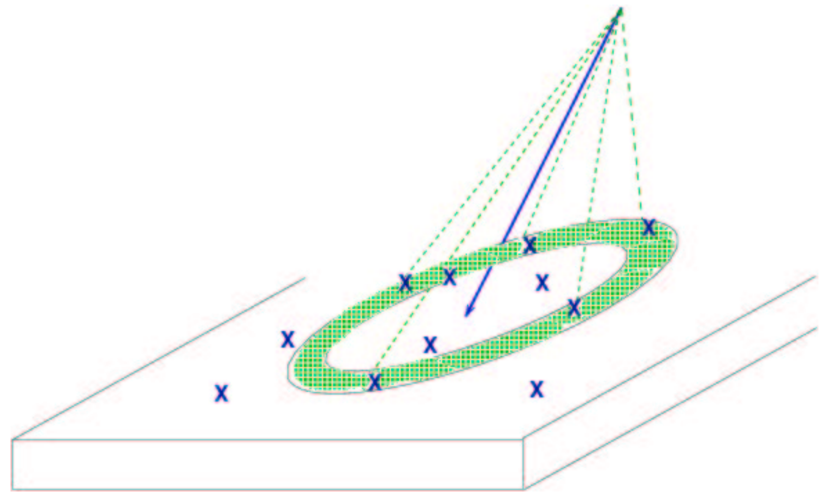
- **the number of photons detected varies from event to event**

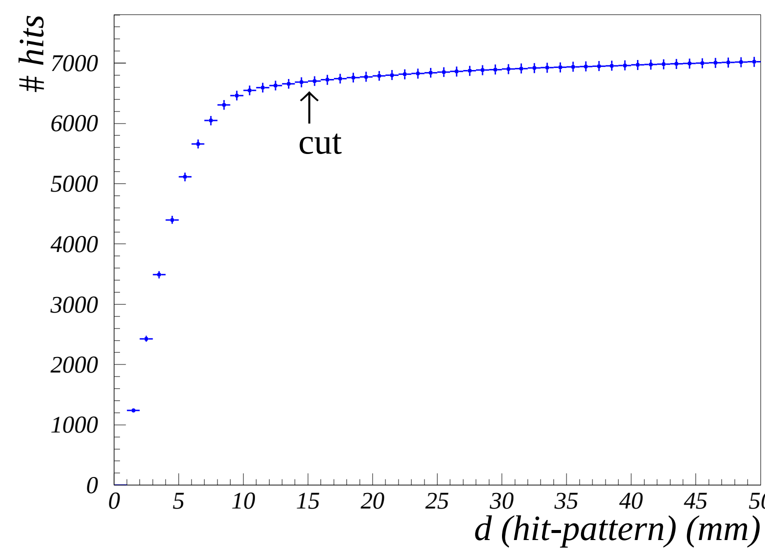
$$n_{p.e} \sim Z^2 \, \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \underbrace{\varepsilon_{rad}\, \varepsilon_{geo}\, \varepsilon_{lg}\, \varepsilon_{pmt}}_{\varepsilon_{tot}(\theta_c,\theta,\phi,P_I)}$$

Charge Reconstruction method

- **cerenkov angle reconstruction**
  Likelihood method applied
- **photoelectron counting**
  the signal (p.e) close to the reconstructed photon pattern is summed up
  $\Delta r \lesssim 1.5\ cm$
- **photon detection efficiency**
  radiator, geometrical acceptance, light guide, PMT...
- **Reconstruct electric charge**

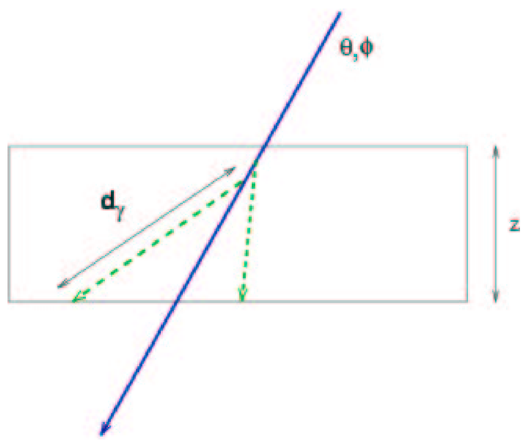
$$Z^2 \sim \frac{n_{p.e}}{\varepsilon_{tot}} \frac{1}{\Delta L} \frac{1}{sin^2\theta_c}$$



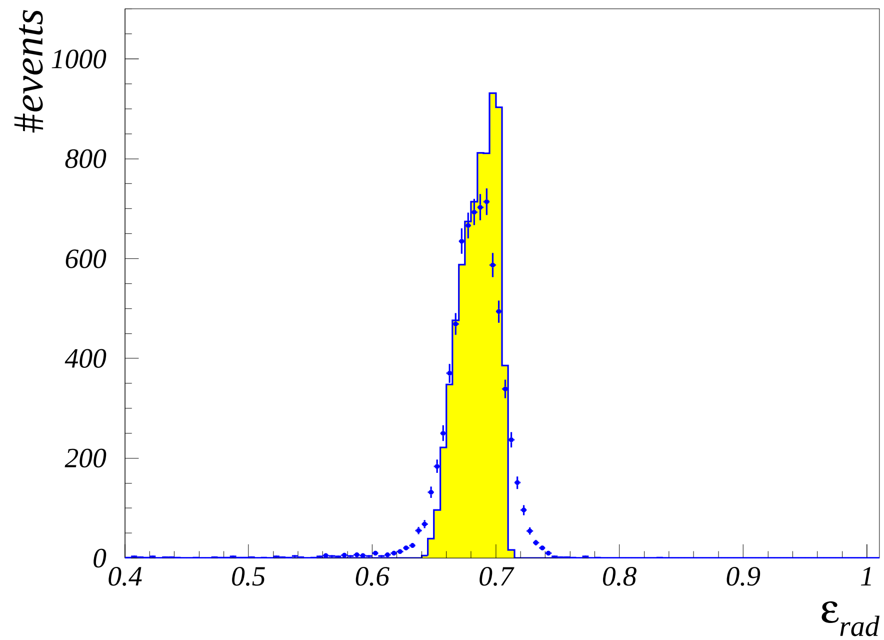


Efficiencies: radiator

☞ **calculate the probability of a radiated photon do not interact in the radiator**



$$\varepsilon_{rad} = \frac{1}{H\ \Delta\varphi} \int_{\varphi_1}^{\varphi_2} e^{-\frac{d_\gamma(\theta_C,\varphi,\theta,\ell)}{\Lambda_{int}}}\ d\varphi\ dz$$



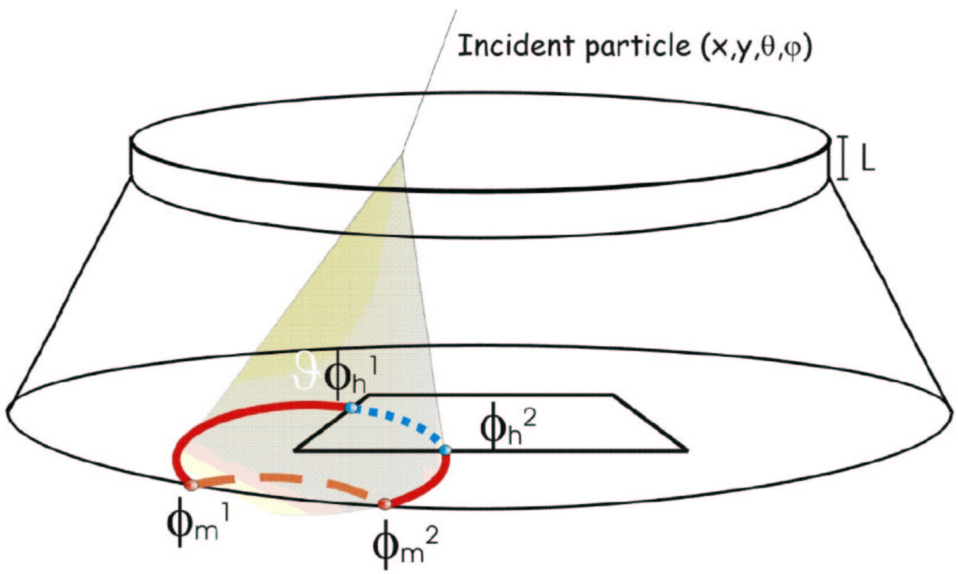
☞ Comparison between analytical calculation and Carbon simulated events

good agreement

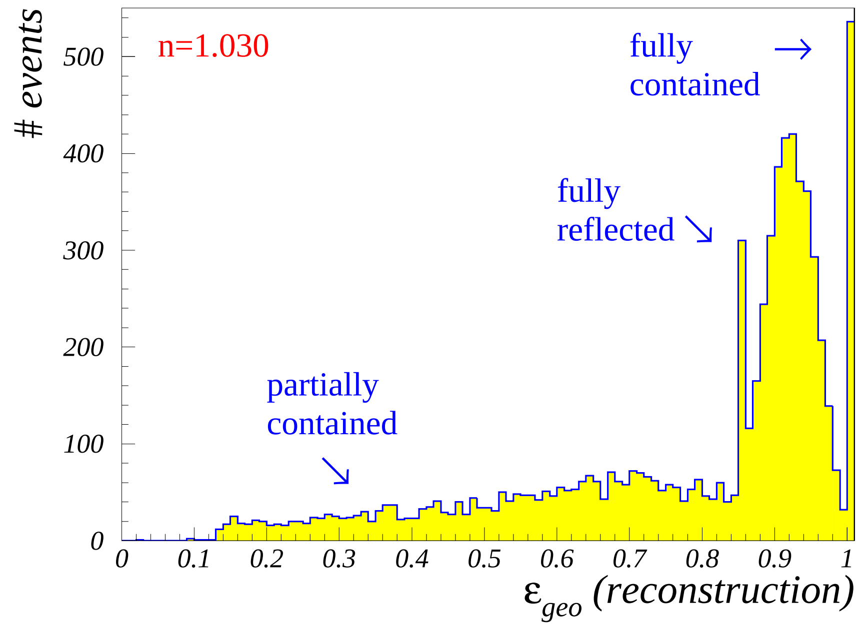
Efficiencies: geometrical acceptance

☞ **calculate the visible fraction of photons**

❏ $dN/d\varphi$ **is uniform**



$$\varepsilon_{geo} = \frac{\Delta\varphi_{vis}}{2\pi}$$

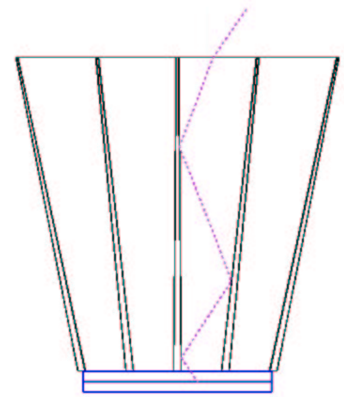


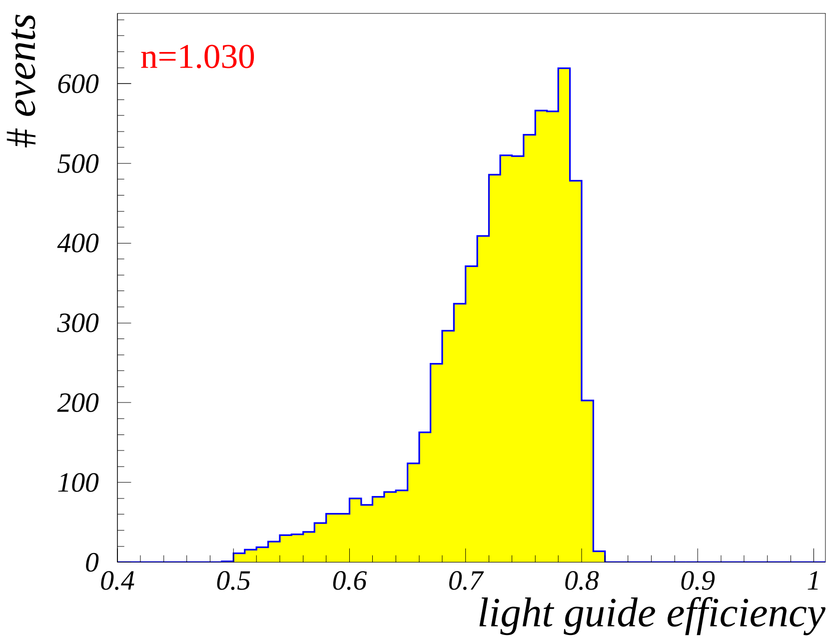
☞ $\sim$ 60% of the events with $\varepsilon_{geo} > 60\%$

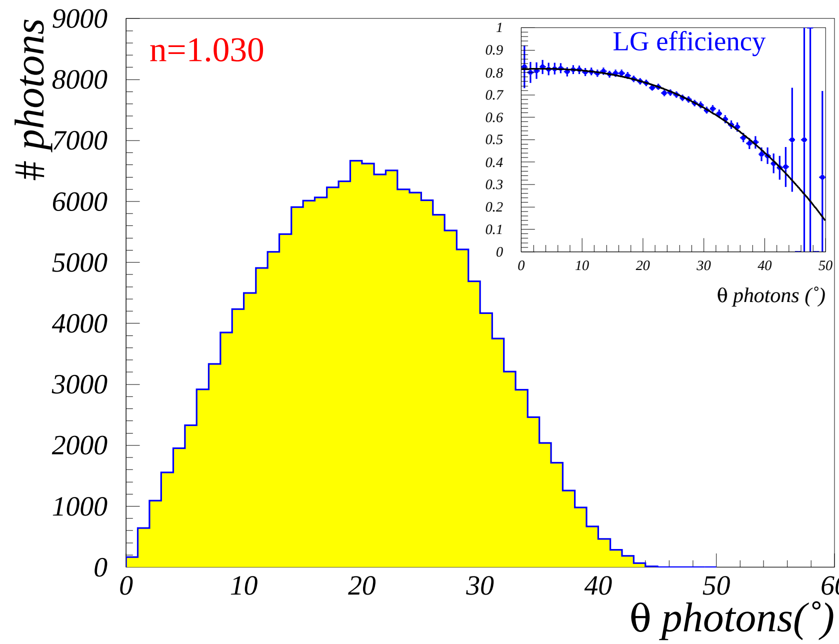
Efficiency : Light Guide/PMT

- the probability of a photon surviving LG depends on its incident angle $\boldsymbol{\theta_\gamma}$
- LG efficiency/event

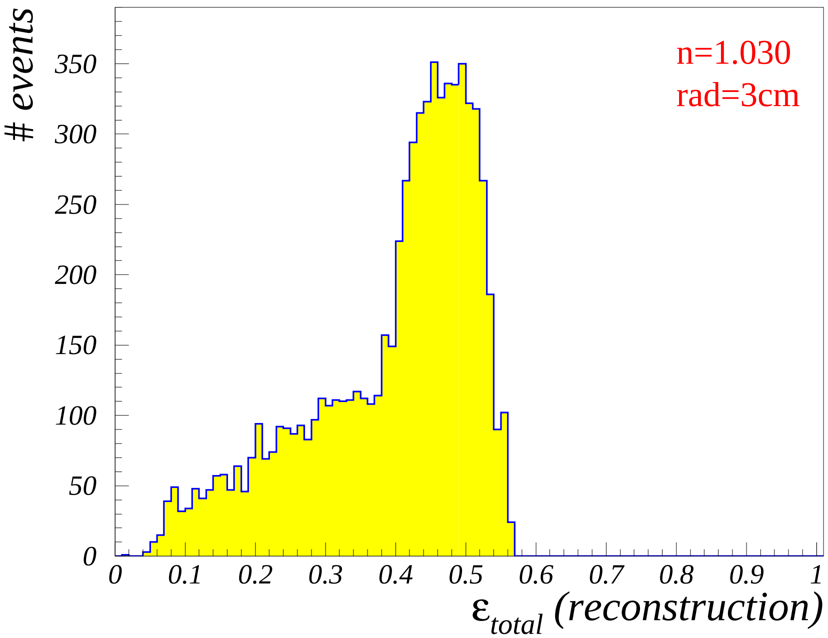
$$\varepsilon_{lg/PMT} = \frac{1}{\Delta\varphi}\int_{\varphi_1}^{\varphi_2} \varepsilon_{lg}\{\theta_\gamma(\theta,\theta_c,\varphi)\}\; d\varphi$$

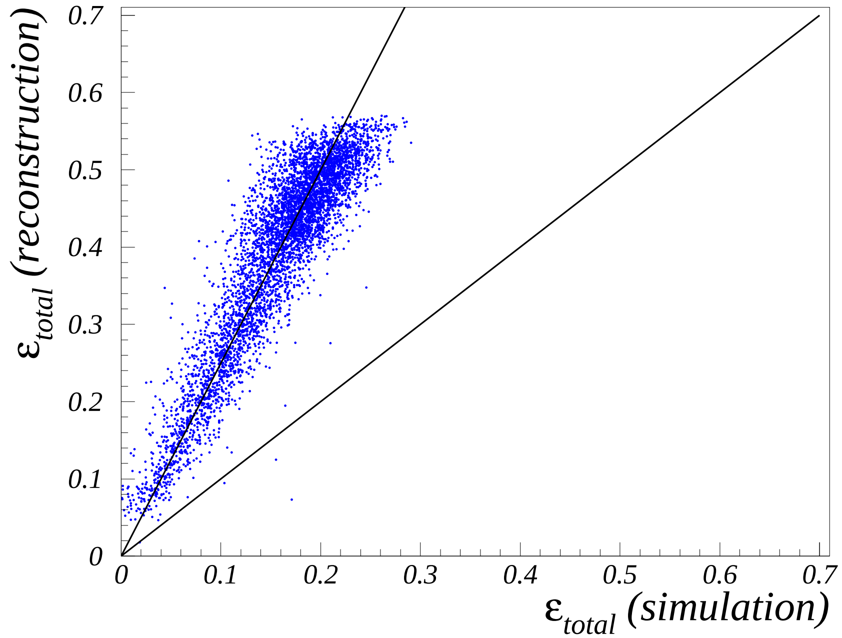






Total Reconstruction efficiency

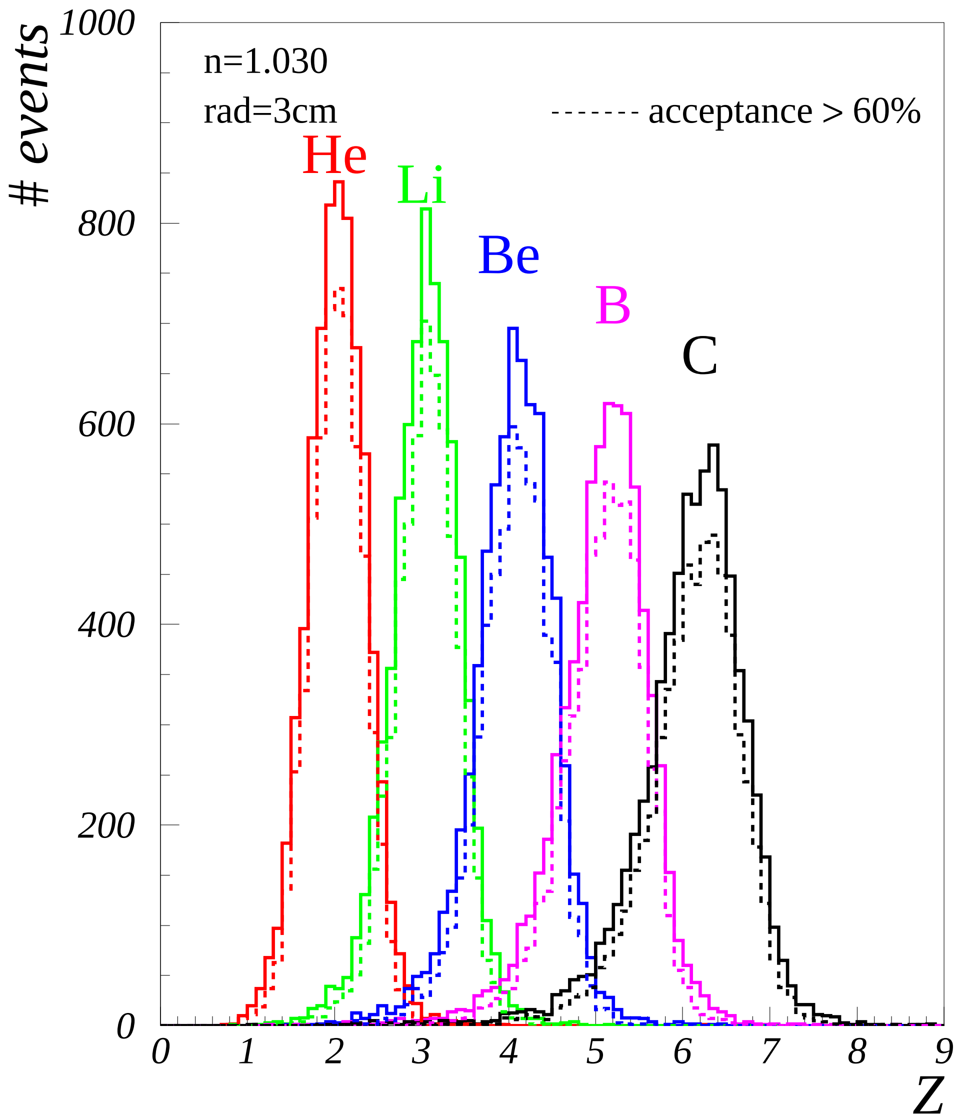


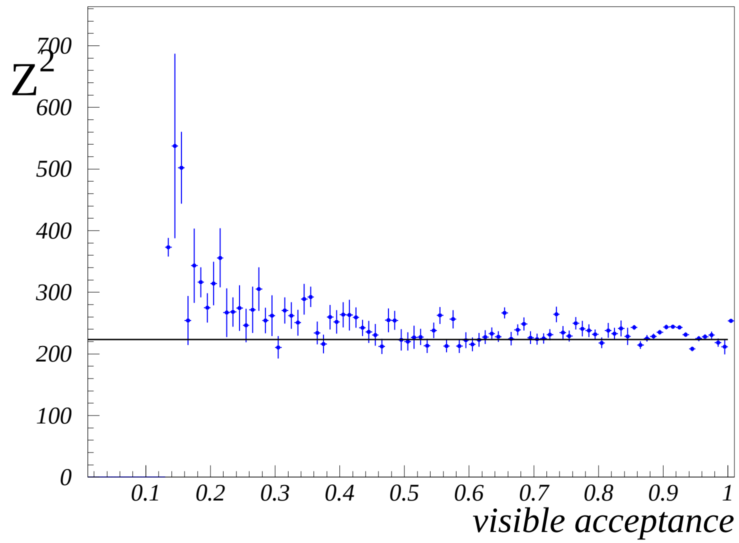


$$\varepsilon_{tot} = \frac{1}{2\pi H_{rad}} \int_0^{H_{rad}} \left\{ \sum_i^{vis.paths} \rho_i \int_{\varphi_i^{min}}^{\varphi_i^{max}} e^{-\frac{d_\gamma}{\Lambda_{int}}} \varepsilon_{lg}\{\theta_\gamma(\theta,\varphi)\} < \varepsilon_{pmt} > d\varphi \right\} dz$$

$\rho_i \equiv$ mirror reflectivity

Charge reconstruction





		$\Delta Z/Z$	
	Z	acc=any	acc. $>$ 60%
He	2	16.4%	15.3%
Li	3	12.3%	11.2%
Be	4	10.1%	9.3%
B	5	9.2%	8.4%
C	6	8.5%	7.7%

Conclusions

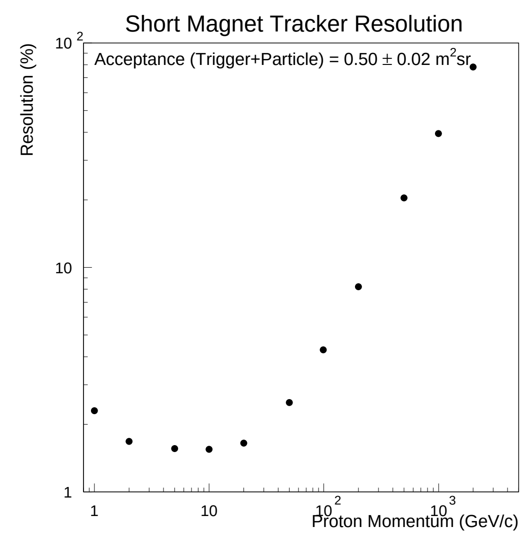
- ✔ After a very successful test flight aboard the Space Shuttle in June 1998, the AMS detector capabilities were extended through the inclusion of new detector systems and larger magnetic field
- ✔ The RICH detector was designed to provide AMS with
  - ❑ very precise velocity measurement ($\boldsymbol{\Delta\beta/\beta \sim 0.1\%}$)
  - ❑ extend the charge identification range
  - ❑ contribute to $\boldsymbol{e/p}$ separation
- ✔ A likelihood method based on the probability of a hit belonging to a cerenkov photon pattern in a presence of a flat background, was developed for the cerenkov angle reconstruction.
- ✔ A charge reconstruction method was developed based on a event-by-event basis estimation of the effects leading to photon losses (radiator, geometrical acceptance, light guide,...)
- ✔ A RICH prototype was built and is currently being tested with cosmic ray events. Performing as expected.
- ✔ Definitive evaluation in a beam test run with Ions at Cern, in October.

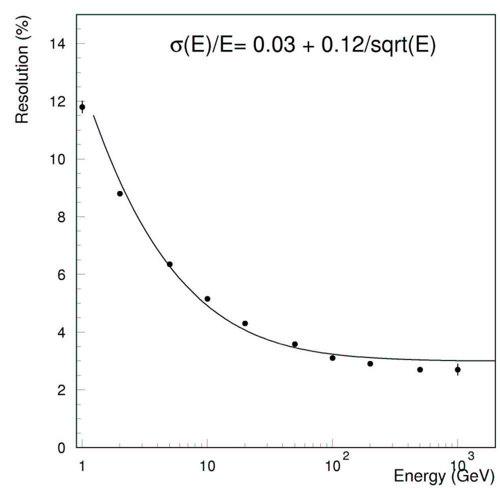
Additional Slides

From AMS1 to AMS2

- larger acceptance
  - ✔ $\sim \mathbf{0.5}\ m^2.sr$
- Superconducting magnet
  - ✔ $B \sim 0.8 - 0.9$ T
- Tracker will be finished
  - ✔ 8 planes
  - ✔ $\sim 6\ m^2$ silicium
  - ✔ $\Delta p/p \lesssim 3\%$ up to 100 Gev/c/nucl
- New Detectors
  - New Cerenkov Detector (RICH)
    - ✔ acceptance $\sim 0.4\ m^2.sr$ (80%)
    - ✔ $\Delta\beta/\beta$ of 0.1%
  - Electromagnetic Calorimeter (ECAL)
    - ✔ Lead/Scintillating fibers ($16X_0$)
    - ✔ $\Delta E/E = 3\% + 12\%/\sqrt{(E)}$
  - Transition Radiation Detector (TRD)
    - ✔ 20 layers of fleece and Xe/CO_2 straw tubes

(V. Shoutko, Trento 2001)



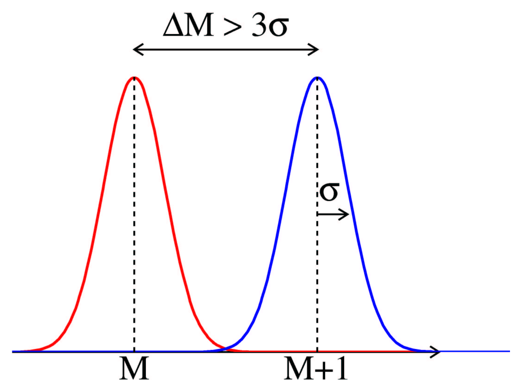


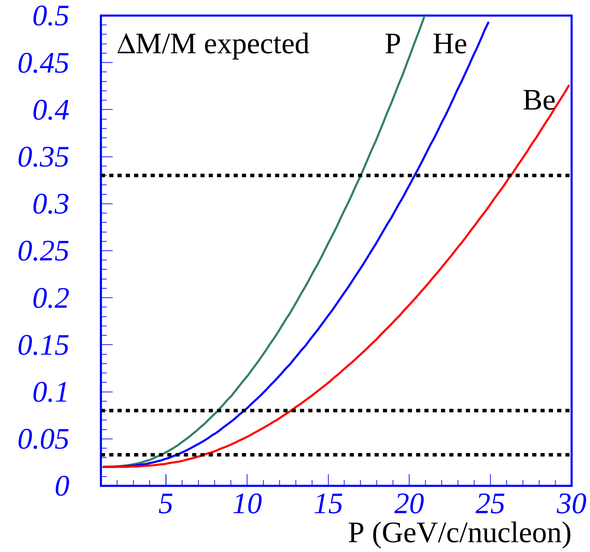
Particle Mass Identification

- Particle mass identification requires precise measurements on **momentum (p)** and **velocity (β)**
- AMS resolutions:
  - $\Delta p/p \lesssim 2\%$ up to 50 GeV/c (protons)
  - A velocity resolution (from simulation studies)

protons	$\Delta\beta/\beta \sim 0.1\%$
heliums	$\Delta\beta/\beta \sim 0.07\%$
berylliums	$\Delta\beta/\beta \sim 0.04\%$

- mass resolution:
  $\frac{\sigma_M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \frac{\Delta\beta}{\beta}$
- Mass separation criterium ($\Delta M > 3\sigma_M$)
  $\frac{\sigma}{M} < \frac{1}{3}\frac{\Delta M}{M}$





RICH Prototype setup

- ✔ radiator
  - ➡ Aerogel (n=1.030,1050) and NaF
  - ➡ 2/3 tiles (**11.5 × 11.5 × 1** cm^3 of aerogel stacked
  - ➡ NaF (0.5 mm thick)
  - ➡ Polyester foil to suport the radiator (0.75mm thick)
- ✔ photomultipliers
  - ➡ Hammamatsu R7600-M16 **4 × 4** pixels
  - ➡ Matrix active area: 3.1 cm pitch
  - ➡ High Voltage 750-850 V
- ✔ Data
  - ➡ Cosmic muon events
  - ➡ Rate 0.5 Hz
  - ➡ (n=1.030) 3 days run ≡ 200K events

AMS2 prototype