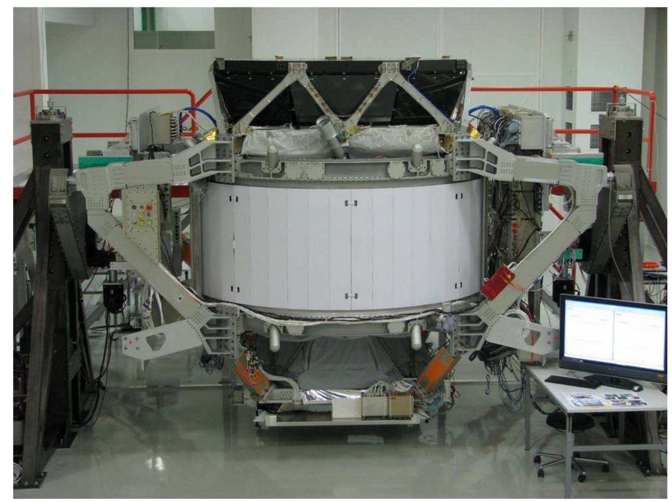
AMS detector performances



Fernando Barao

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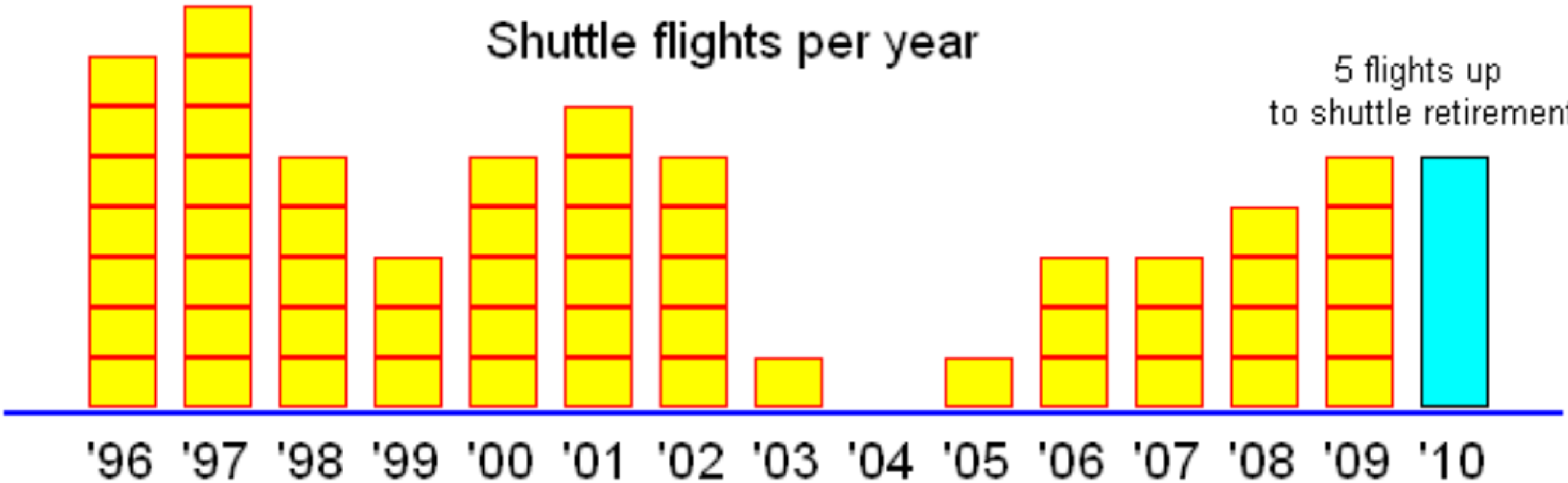
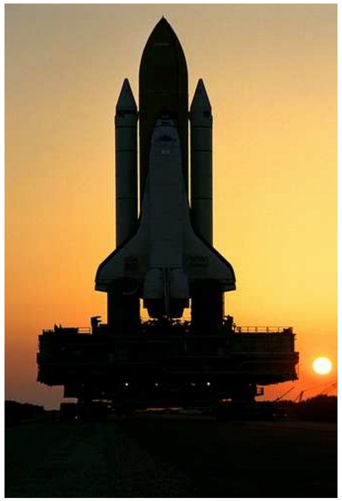
Outline

- ✔ From AMS1 to AMS2
- ✔ AMS physics and requirements
- ✔ AMS sub-detectors
- ✔ Detector measurements and Particle identification
- ✔ Some results from Cosmic and Beam tests
- ✔ Conclusions

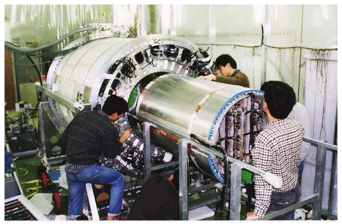
AMS on ISS : a long journey...



STS-91 flight (Jun 98)



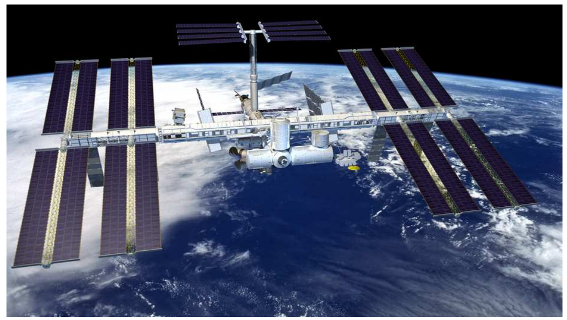
BESS-POLAR (2004, 2007-08)



FERMI (June 2008)

PAMELA (June 2006)

AMS to ISS (2010)



What is aiming AMS ?

- AMS is a large acceptance ($\sim$ 0.5 m^2.sr) spectrometer designed to operate in the International Space Station (ISS) for a long duration stay (3 years)

- Good particle identification power (including photons)
- Able to measure cosmic spectra from 500 MeV to few TeV
- Charge identification up to Iron (Z=26) and light isotopic separation
- Search for antimatter and darkmatter with unprecedent sensitivity

Detector Requirements

Antimatter	DarkMatter	Astrophysics

Antimatter

antinuclei production from matter collisions is strongly suppressed
$(p + ISM \to \bar{N} + \ldots)$

$\frac{\bar{N}}{\bar{p}} \propto \exp\left(-\frac{M_N - m_p}{80\ MeV}\right)$

detection of antinuclei would be a clear signal of existence of antimatter

DarkMatter

- e^+ and $\bar{p}$ produced in $p + ISM$ collisions
- physics background :

$p/e^+ \sim 10^3$

$e^-/\bar{p} \sim 10^2$

signals : $\bar{p}$, e^+, γ, $\bar{d}$

a good e,p separation is needed

$B/S \sim 1\% \Downarrow$

Rejection Factor $\sim 10^5$

Astrophysics

detection of a large range of nuclei (Z)

ability to identify different isotopes

detection of gamma rays

- charge identification
- rigidity measurement
- velocity measurement
- e.m energy measurement
- e/p separation
- albedo rejection
- strong system redundancy

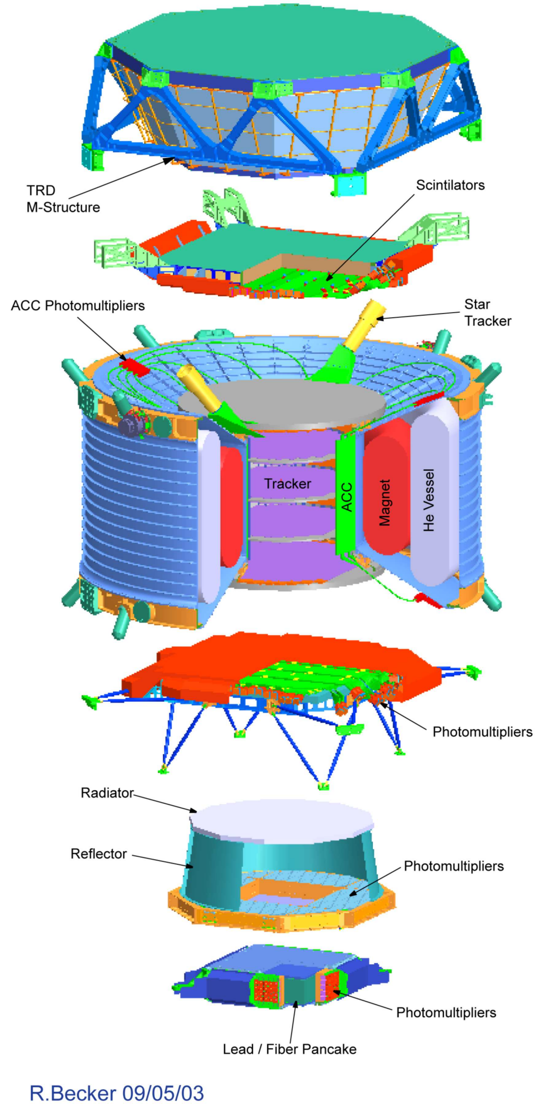
From AMS1 to AMS2

Improved capabilities

- ✔ larger acceptance
  $\sim 0.5\ m^2.sr$
- ✔ Superconducting magnet
  a magnetic field ~ 8 times larger
- ✔ larger silicon Tracker
  8 double-sided layers
  $\sim 6.5\ m^2$ silicon surface
- ✔ a momentum resolution improved
  a factor ~ 10

New Detector systems

- ✔ New Cerenkov Detector (RICH)
- ✔ Electromagnetic Calorimeter (ECAL)
- ✔ Transition Radiation Detector (TRD)



TRD: Transition Radiation Detector

TOF: (s1,s2) Time of Flight Detector

MG: Magnet

TR: Silicon Tracker

ACC: Anticoincidence Counter

AST: Amiga Star Tracker

TOF: (s1,s2) Time of Flight Detector

RICH: Ring Image Cherenkov Counter

EMC; Electromagnetic Calorimeter

AMS Alpha Magnetic Spectrometer Integration MIT

AMS
Sub-detectors

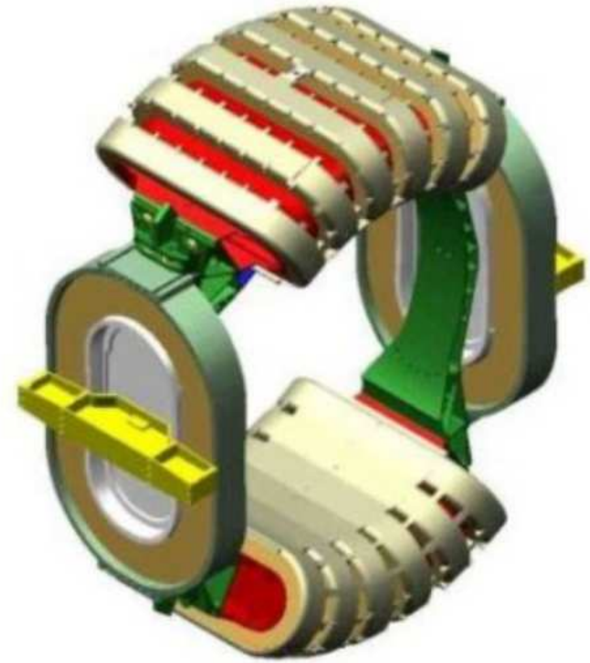
Superconducting Magnet

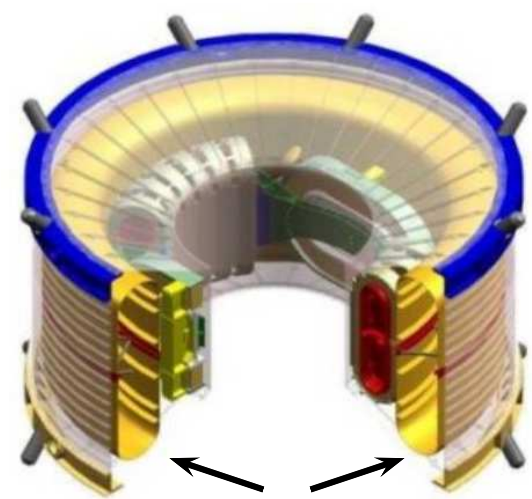
<u>*Construction*</u>

- ✔ 14 superconducting coils
- ✔ geometrical configuration to ensure a null magnetic dipole moment
- ✔ minimization of the stray field outside magnet
- ✔ indirect cooling system based on Superfluid Helium
  - ▶ cold mass : $2000\ kg$
  - ▶ helium vessel capacity : 2500 liters

<u>*It provides*</u>

- ✔ an intense magnetic field : $\sim 0.9\ T$
- ✔ a large bending power : $\sim 0.8\ T.m^2$





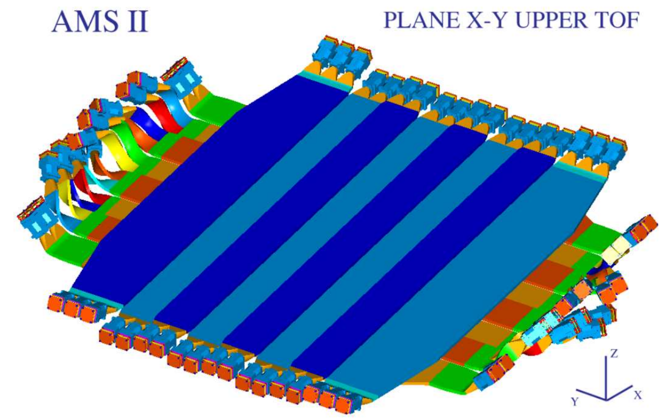
Time-of-Flight (TOF)

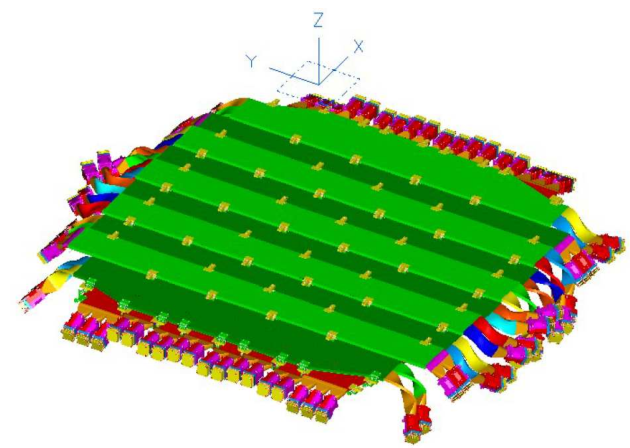
Construction

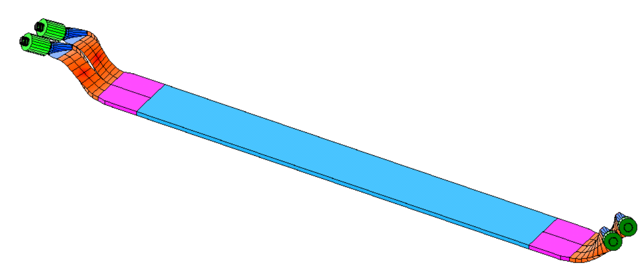
- ✔ 4 scintillator planes
- ✔ a total of 34 paddles large of 12 cm
- ✔ light guides twisted/bended to minimize magnetic field effects
- ✔ $2/3$ PMT's for light readout at both ends

It provides

- ✔ fast trigger (3×4) on 200 $nsec$
- ✔ velocity measurement
- ✔ absolute charge measurement
- ✔ upward/doward particle separation (10^{-9})







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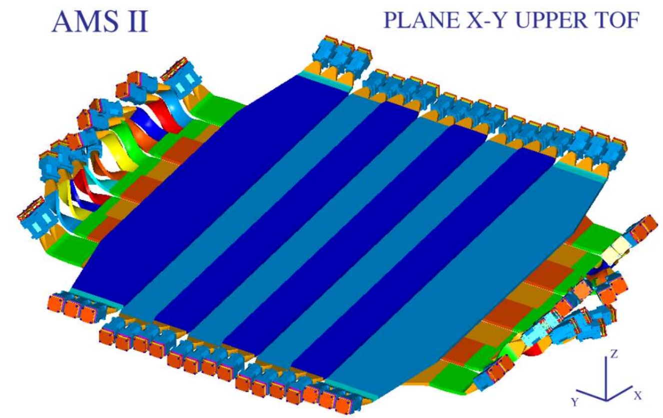
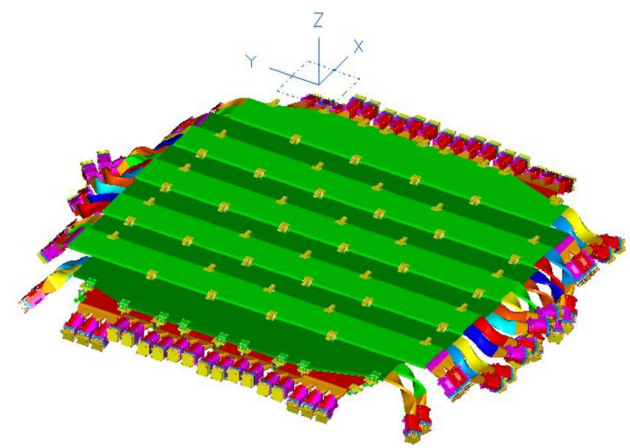
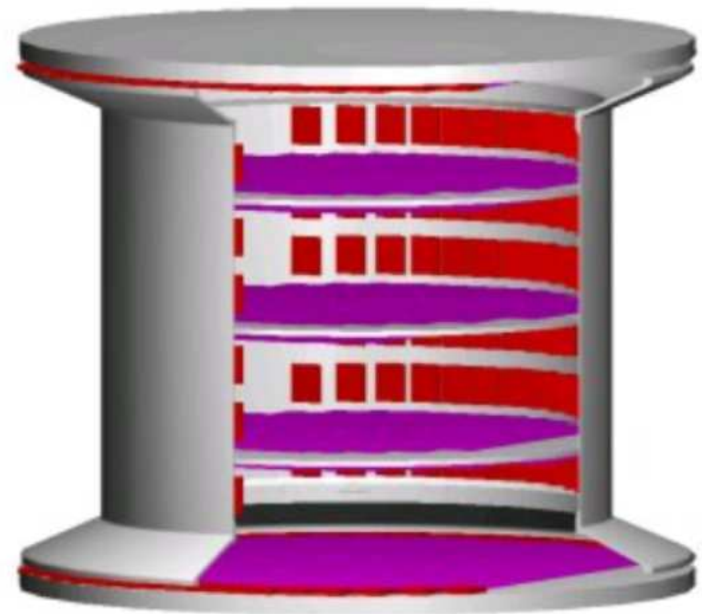


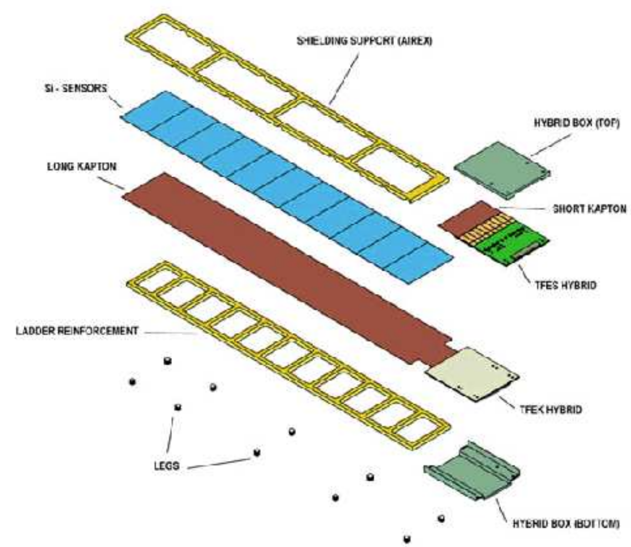


Silicon Tracker



Construction

- a total of 5 *planes* (3 inside the magnet and 2 outside)
- 8 *layers* of double-sided silicon microstrip sensors
- a total of ~ 2500 *sensors* arranged on 192 *ladders*
- $7-15$ sensors per ladder



It provides

- 8 independent position measurements of the particle track
- particle rigidity ($R \equiv \frac{pc}{Z}$) from track reconstruction
- electric charge (Z) from energy deposition (dE/dx)

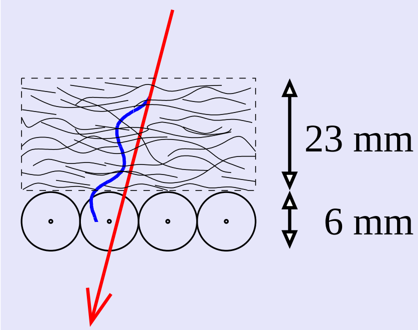
Transition Radiation Detector (TRD)

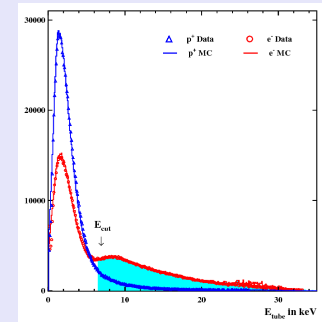
Construction

- ✔ *modules (328) made of fleece radiator and straw tubes*
  - ▶ 16 straw tubes per module
  - ▶ radiator thickness of $23\ mm$
  - ▶ straw tubes ($\Phi = 6\ mm$) filled with Xe/CO_2
- ✔ 20 *layers* assembled on a octogonal shape
  - ▶ 4 layers on upper/lower part along the bending plane
  - ▶ 12 layers on the middle transversally placed

It provides

- ✔ evaluation of the particle $\gamma \equiv \frac{E}{m}$ boost
- ✔ separation of particles with extreme mass differences

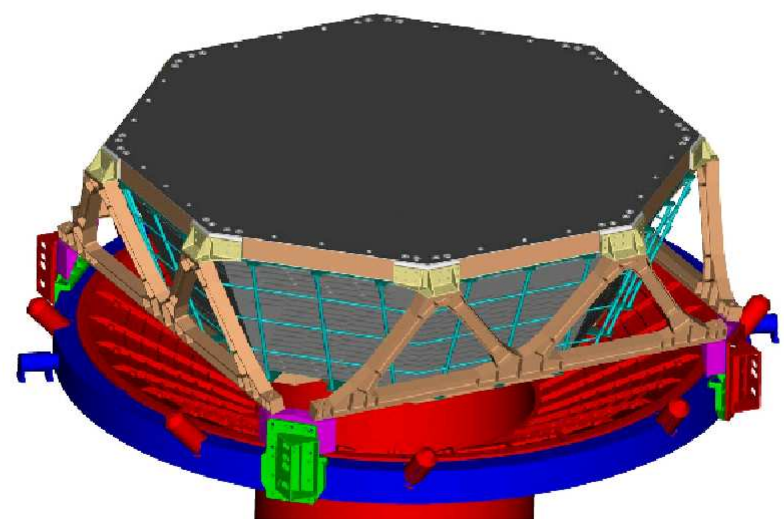




X-ray photons radiated when particle crosses radiator boundaries ($\sim 100\ transitions$)

- $E_\gamma \sim \gamma\ (eV)$
- $N_\gamma \sim \alpha\ N_{transitions}$

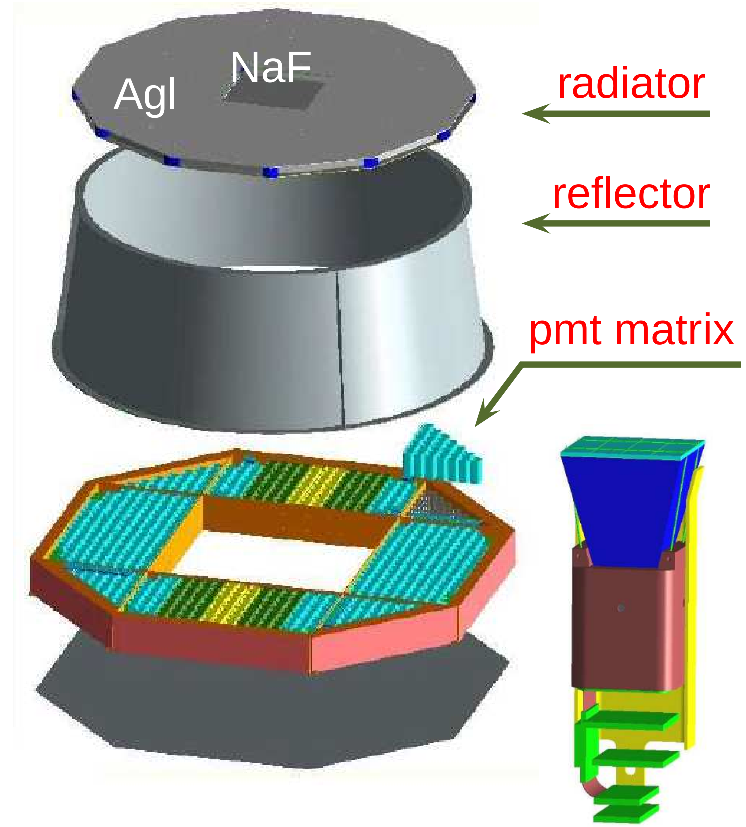
detectable signal for $\gamma \gtrsim 1000$



Ring Imaging Cerenkov Detector (RICH)

Construction

- ✔ proximity focusing Ring Imaging Detector
- ✔ dual solid radiator configuration
  low index aerogel : $n = 1.050$, $2.5\ cm$ thickness
  sodium fluoride : $n = 1.334$, $0.5\ cm$ thickness
- ✔ conical reflector 85% reflectivity
- ✔ photomultiplier matrix
  680 multipixelized (4×4) detectors
- ✔ spatial pixel granularity : $8.5 \times 8.5\ mm^2$



It provides

- ✔ accurate particle velocity measurement
  $\Delta\beta/\beta \sim 0.1\%$ for protons
- ✔ electric charge determination
  $\Delta Z \sim 0.2$
- ✔ albedo rejection
  directional sensitivity

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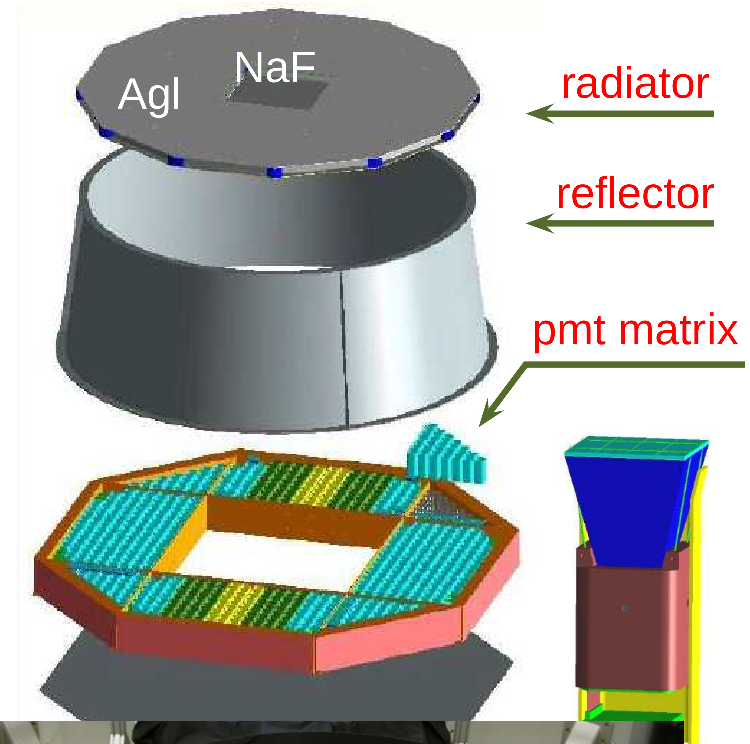
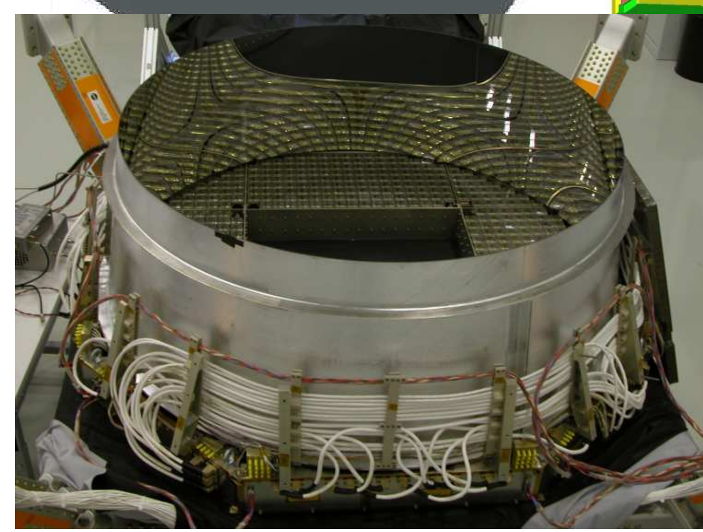




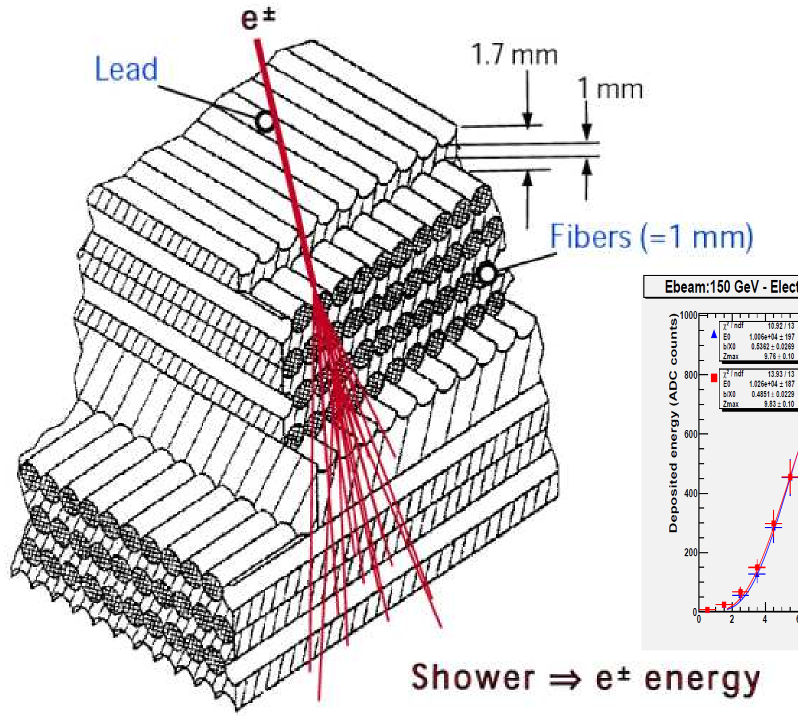
Electromagnetic Calorimeter (ECAL)

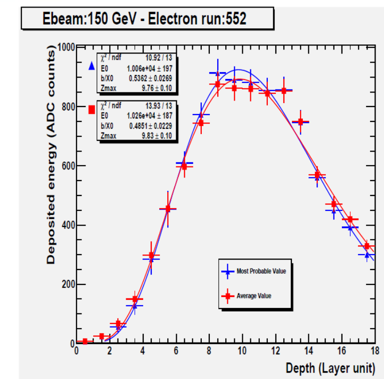
Construction

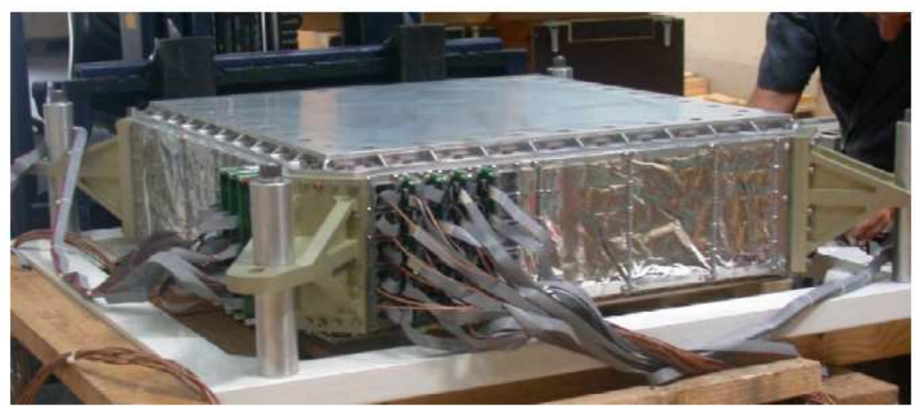
- ✔ sampling e.m. calorimeter
  $658 \times 658 \times 166\ mm^3$
- ✔ lead-scintillating fibers structure
- ✔ 9 superlayers
  10 layers of lead+fibers piled up
  disposed along X and Y alternately
- ✔ $\sim 17 X_0 (\sim 1cm)$ radiation lengths
- ✔ multi-pixel (2×2) photomultiplier's
  large dynamic range
- ✔ cell granularity $\sim 0.5\ R_M$ (35 fibers to PM pixel)
  18 samplings of e.m shower

It provides

- ✔ $e^{\pm}, \gamma$ energy measurement
- ✔ particle direction
- ✔ fast trigger signal for photons tagging (dynode)







Particle measurements

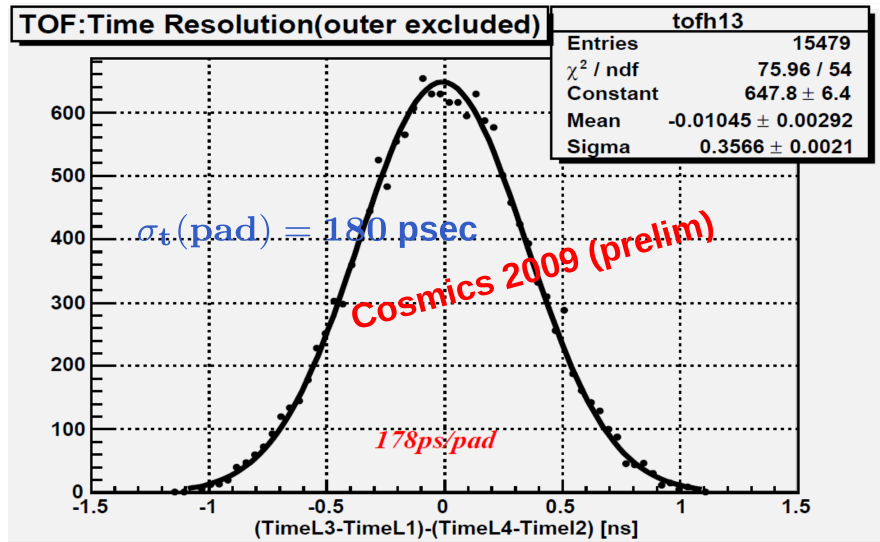
velocity, charge, energy, momentum

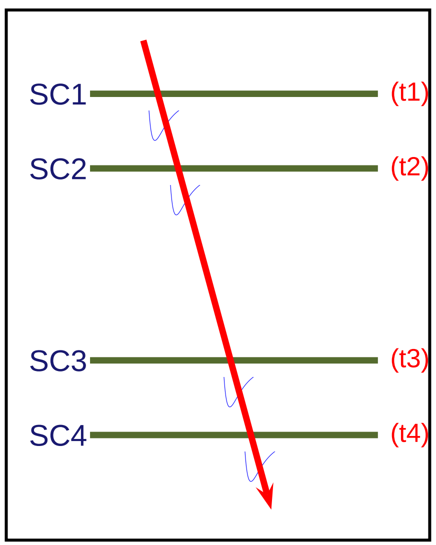
Velocity measurement (β) with TOF

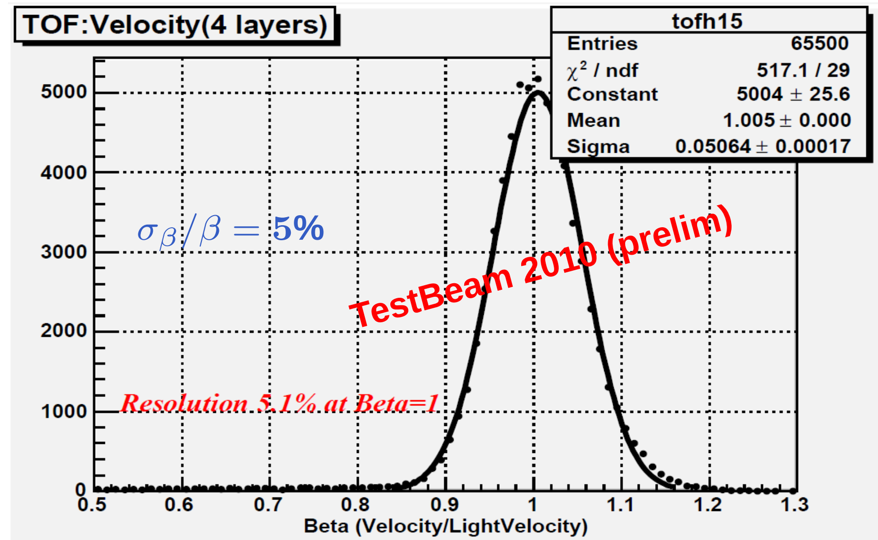
- ✔ the particle velocity is derived from measuring the time difference (Δt) between the upper and lower scintillator planes and the track length (Δs)

$$\beta = \frac{\Delta s}{c \Delta t}$$

$$\frac{\sigma_\beta}{\beta} = \frac{\beta c}{\Delta s}\sigma_t$$





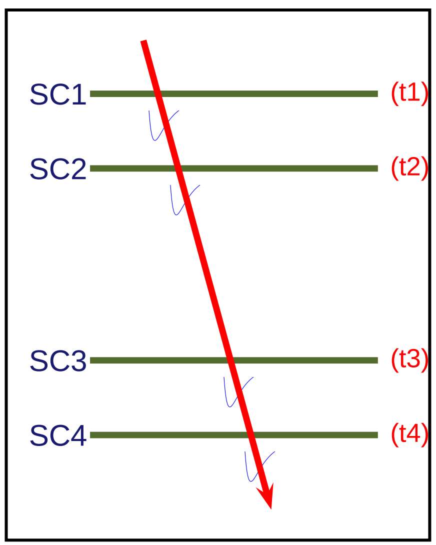


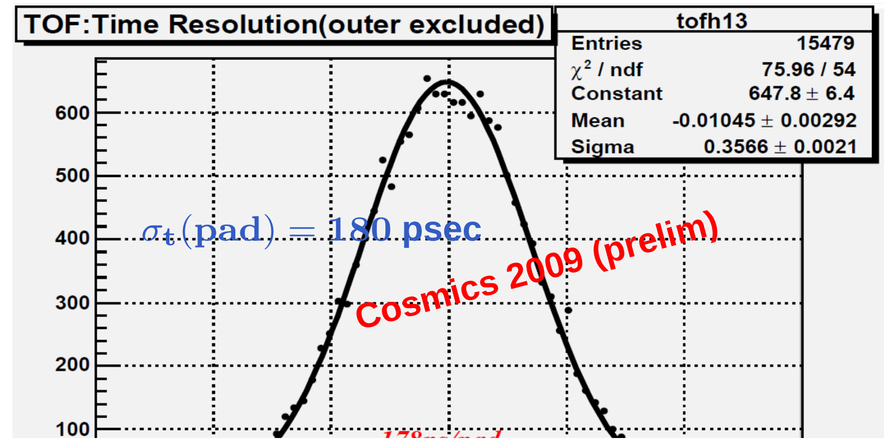
Velocity measurement (β) with TOF

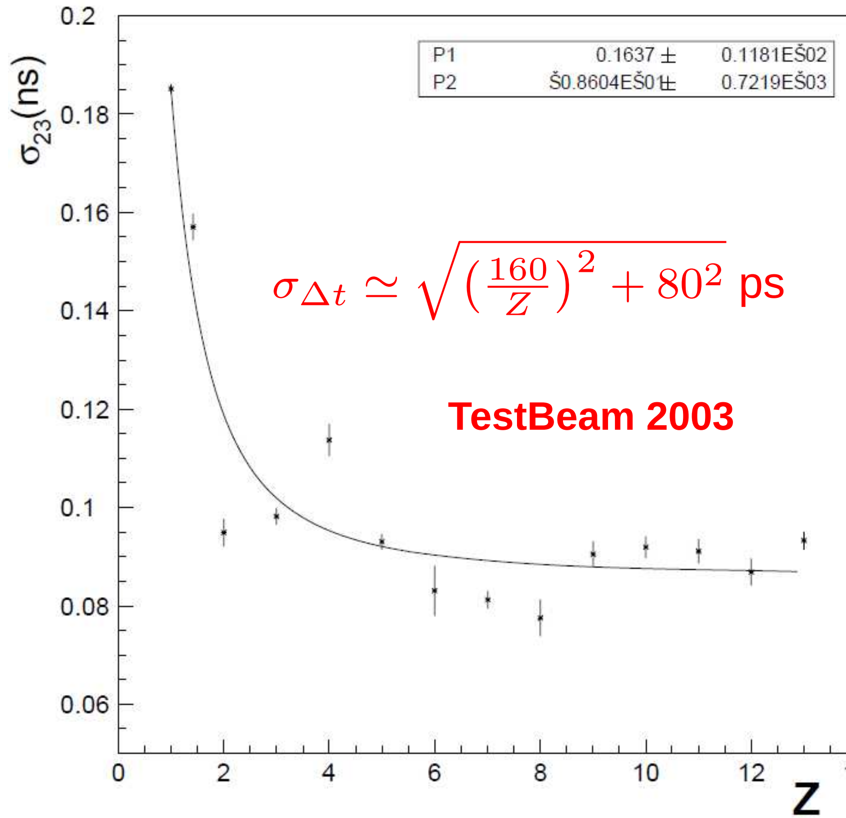
- ✔ the particle velocity is derived from measuring the time difference (Δt) between the upper and lower scintillator planes and the track length (Δs)

$$\beta = \frac{\Delta s}{c \Delta t} \qquad \frac{\sigma \beta}{\beta} = \frac{\beta c}{\Delta s} \sigma_t$$

- ✔ single pad error (σ_t) depends on :
  - signal shape $(\sigma_1/\sqrt{N})$
  - photons path length dispersion $(\sigma_2\, d/\sqrt{N})$
  - electronic noise (σ_3)



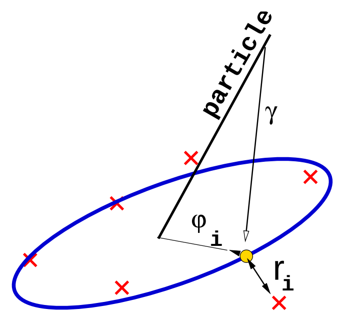


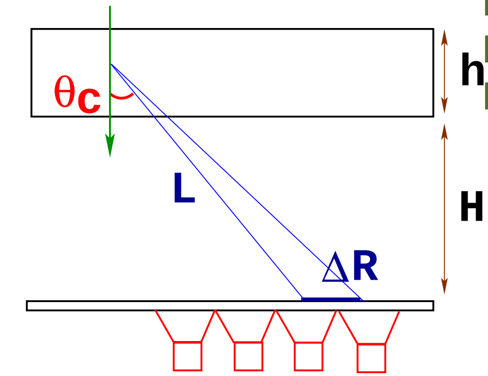


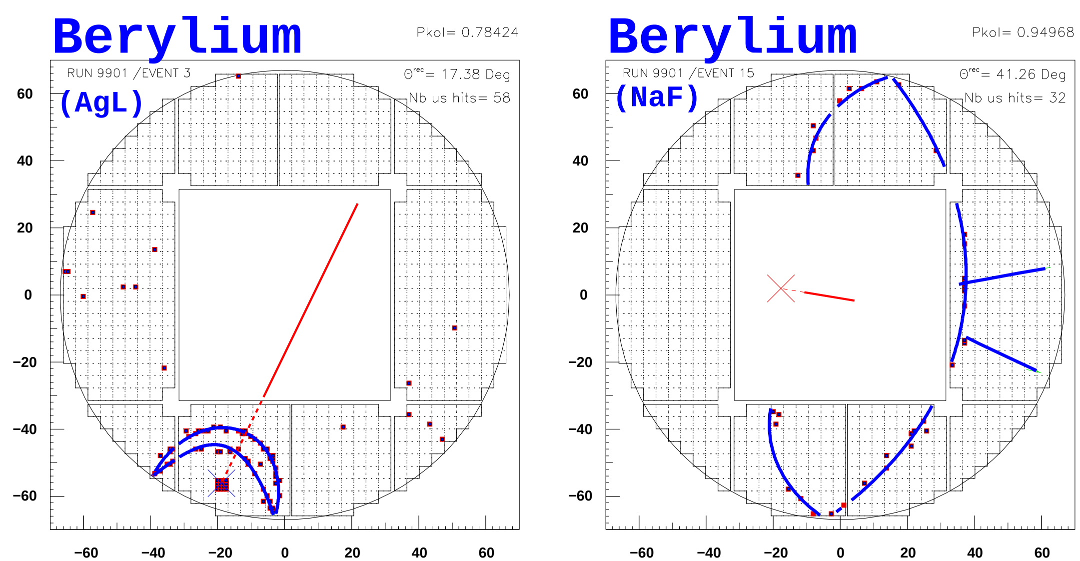
Velocity measurement with the RICH

- ✔ The AMS Tracker provides the **particle direction** (θ, ϕ) and **impact point** at the RICH radiator
- ✔ **Ring of cerenkov photons** is function of θ_c
  geometrical and likelihood methods applied to reconstruct θ_c
- ✔ Velocity obtained from θ_c measurement

$$\beta = 1/n \ \cos\theta_c$$







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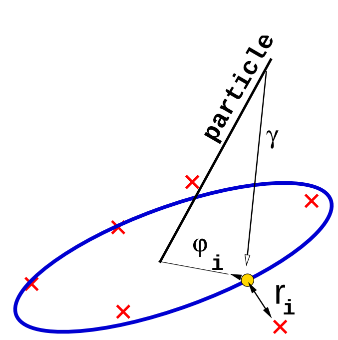

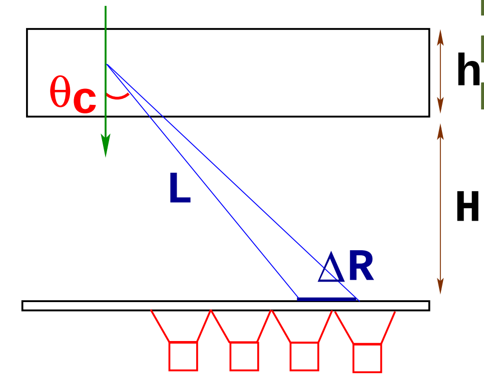

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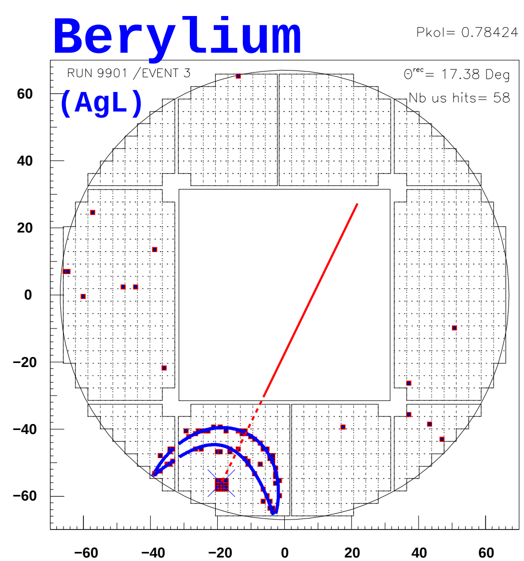
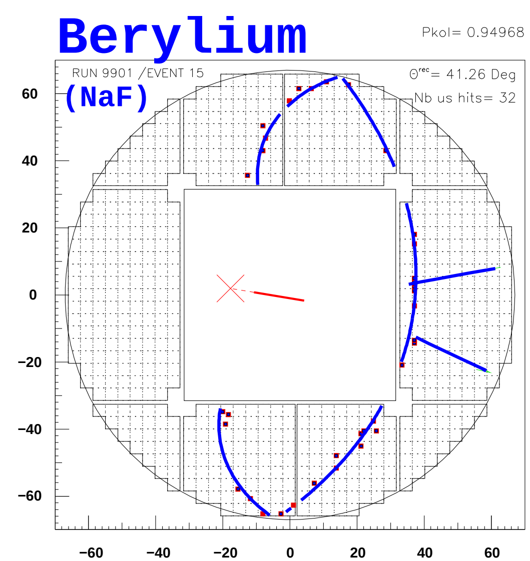
  geometrical and likelihood methods applied to reconstruct θ_c
- ✔ Velocity obtained from θ_c measurement

$$\beta = 1/n \ \cos\theta_c$$

- ✔ sources of β uncertainties :
  - ▶ pixel size (8.5 mm)
  - ▶ radiator chromaticity, $n(\lambda)$
  - ▶ radiator thickness $(h \tan\theta_c)$
    photon emission point unknown



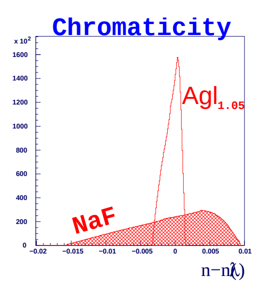


$$\frac{\Delta\beta}{\beta} = \tan\theta_c \frac{\Delta\theta_c}{\sqrt{N_{pe}}}$$

$$\Delta\theta_c = (\Delta\theta_c)^{pixel} \oplus (\Delta\theta_c)^{thick} \oplus (\Delta\theta_c)^{chrom}$$

$$\Delta\theta_c^{(i)} \simeq \frac{\Delta R_i}{H} \cos^2\theta_c$$ i=pixel,thickness

$$\Delta\theta_c^{(i)} \simeq \frac{1}{\tan\theta_c} \frac{\Delta n}{n}$$ i=chromat.

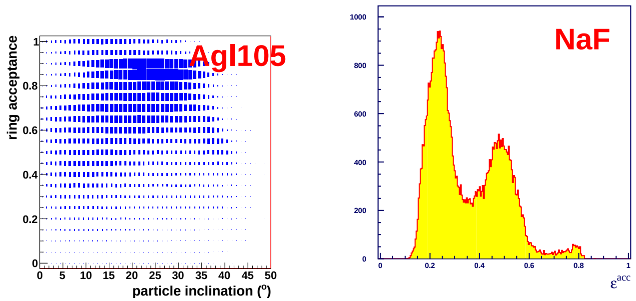


	$\Delta\theta_c^{geom}$ (mrad)		$\Delta\theta_c^{chrom}$	$\Delta\theta_c$	$(\Delta\beta/\beta)_{hit}$
	$\Delta\theta_c^{thick}$	$\Delta\theta_c^{pixel}$	(mrad)	(mrad)	$(\beta \simeq 1)$
AGL	3.3	4.6	3.2	6.5	$\mathbf{2.1\ 10^{-3}}$
NaF	0.3	0.6	4.8	4.8	$\mathbf{4.2\ 10^{-3}}$

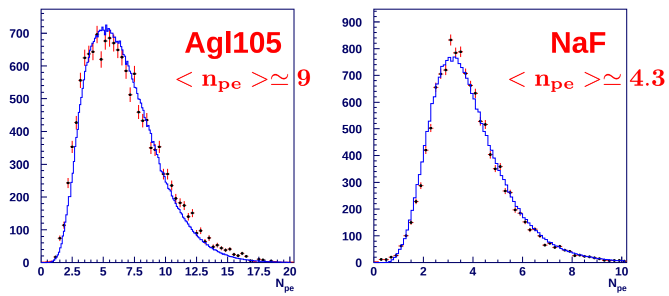
RICH velocity reconstruction : results

Simulation results

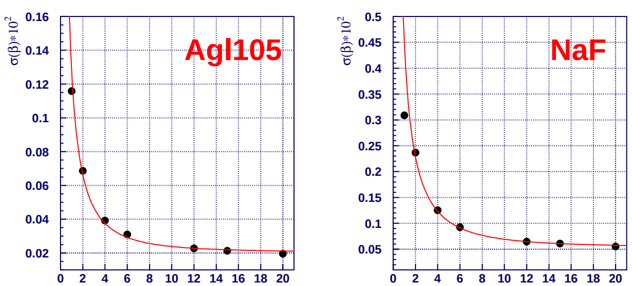
Geom acceptance



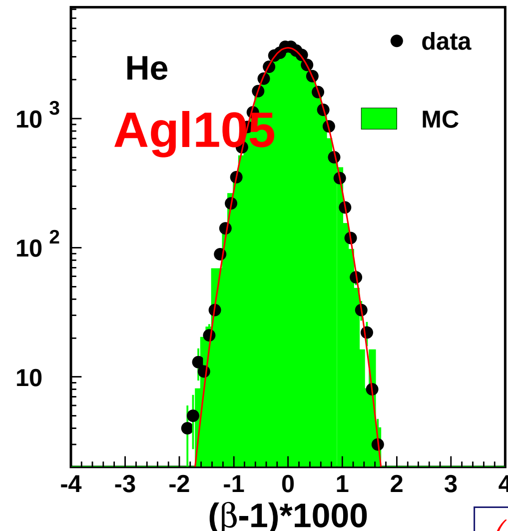
number of photoelectrons

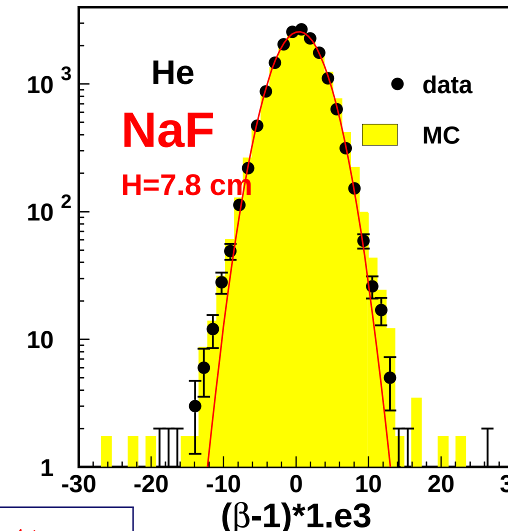


velocity reconstr error

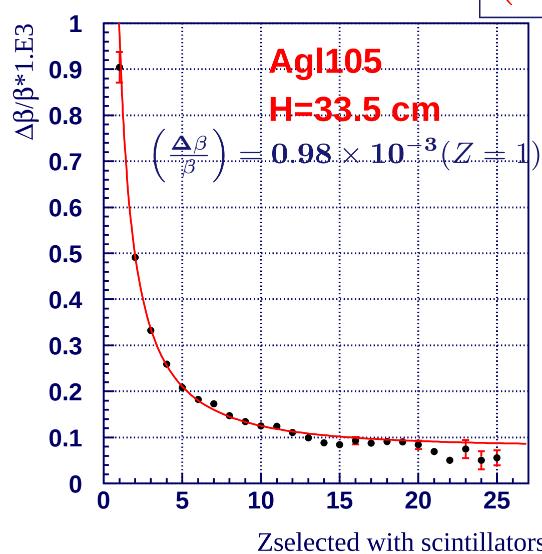


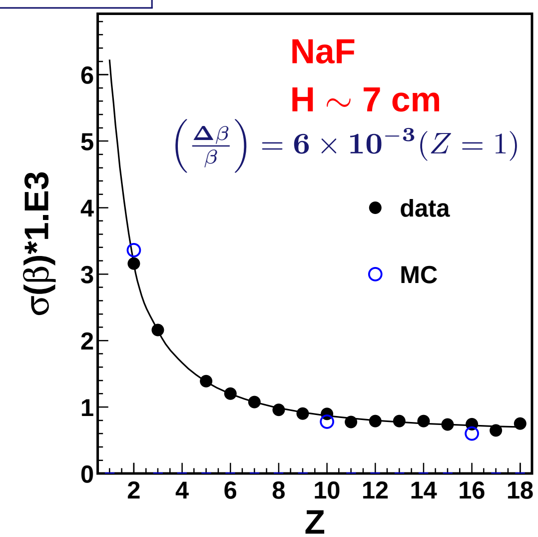
Test Beam (2003) results : fragmented ions





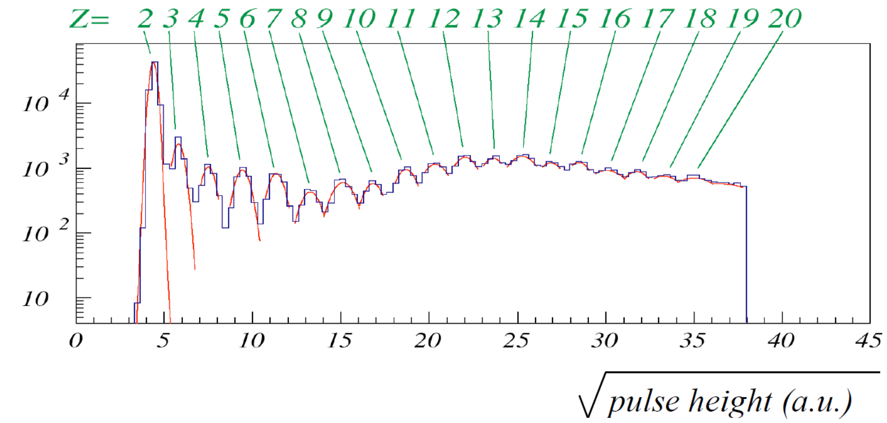
$$\left(\frac{\Delta\beta}{\beta}\right) = \left(\frac{A}{Z}\right) \oplus B$$



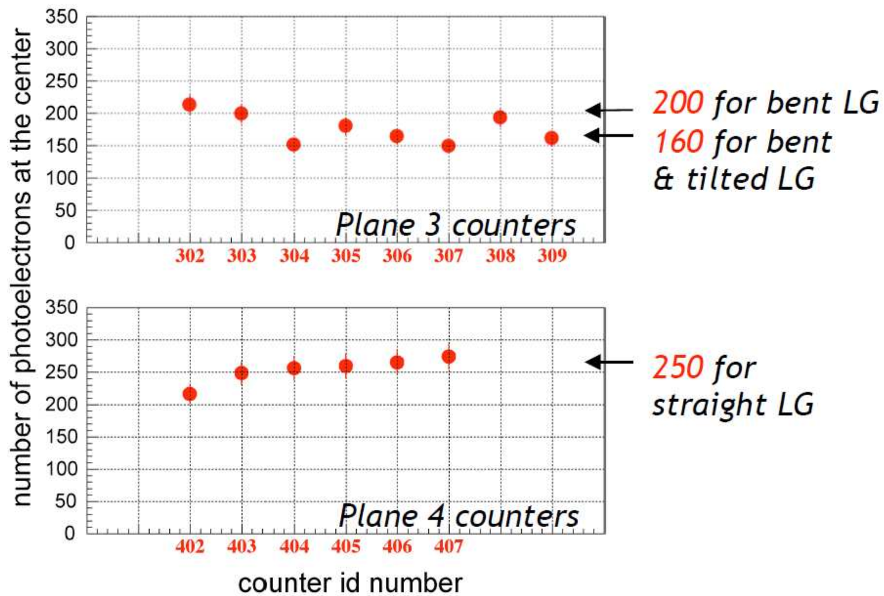


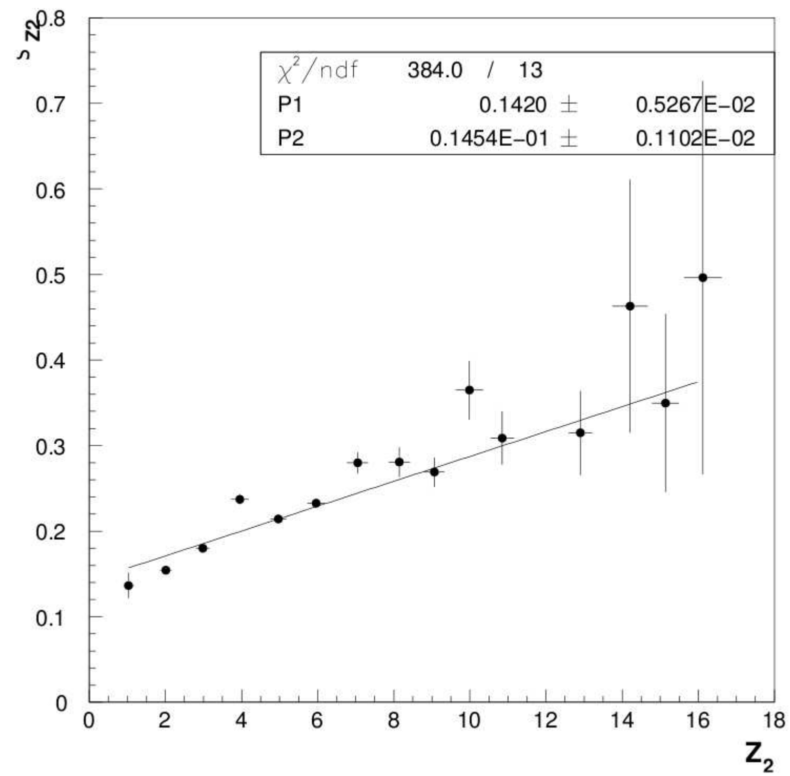
Charge measurement (Z) with TOF

- ✔ energy deposited on scintillator
  $\Delta E \propto Z^2$
- ✔ up to 4 ΔE samplings
- ✔ dominant uncertainty comes from energy deposition fluctuations
- ✔ test beam data with fragmented ions
  charge separation up to $Z \sim 15$



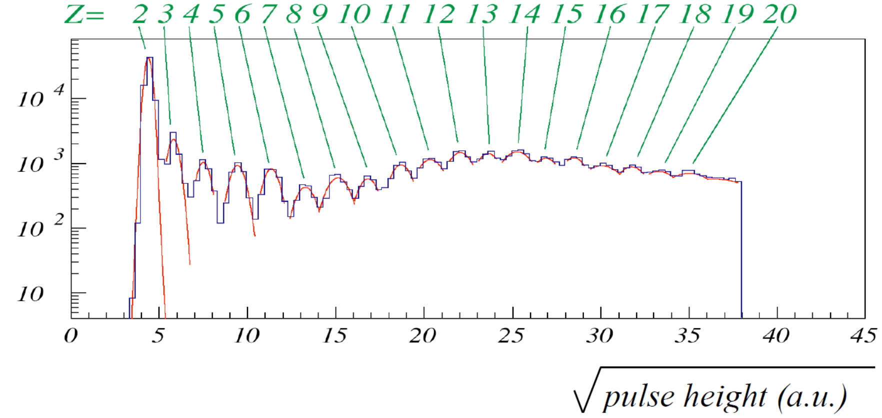
Measured number of photoelectrons



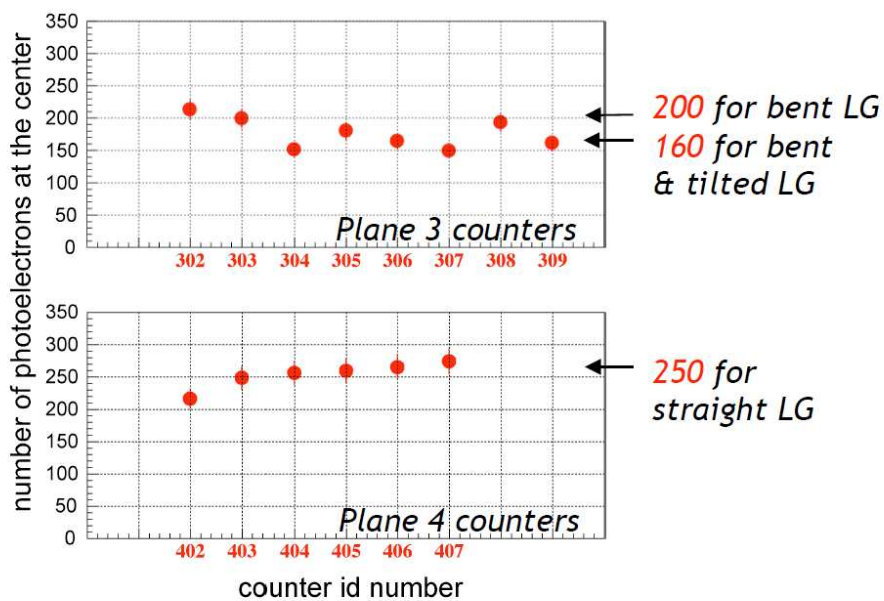


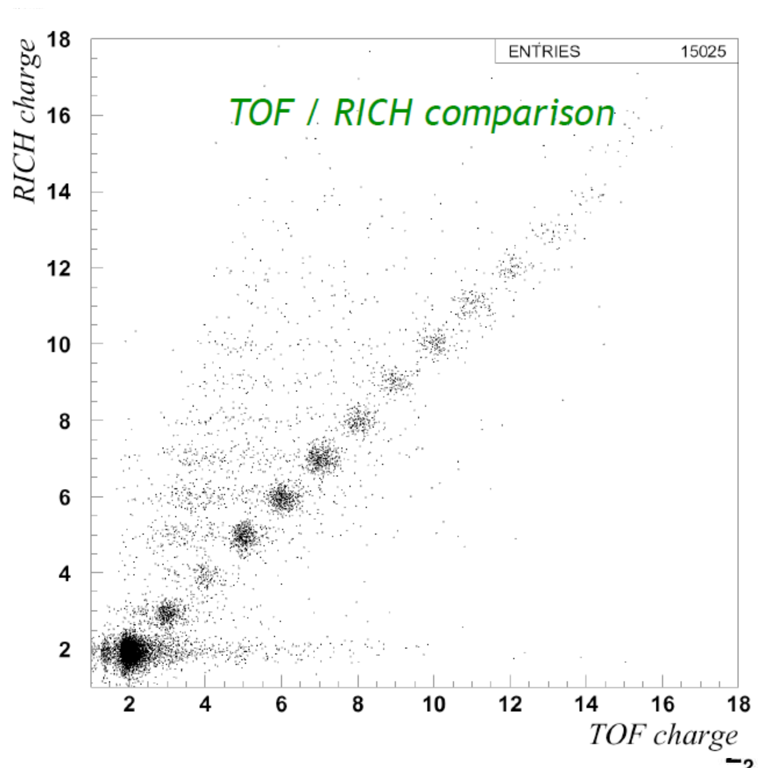
Charge measurement (Z) with TOF

- ✔ energy deposited on scintillator
  $\Delta E \propto Z^2$
- ✔ up to 4 ΔE samplings
- ✔ dominant uncertainty comes from energy deposition fluctuations
- ✔ test beam data with fragmented ions
  charge separation up to $Z \sim 15$



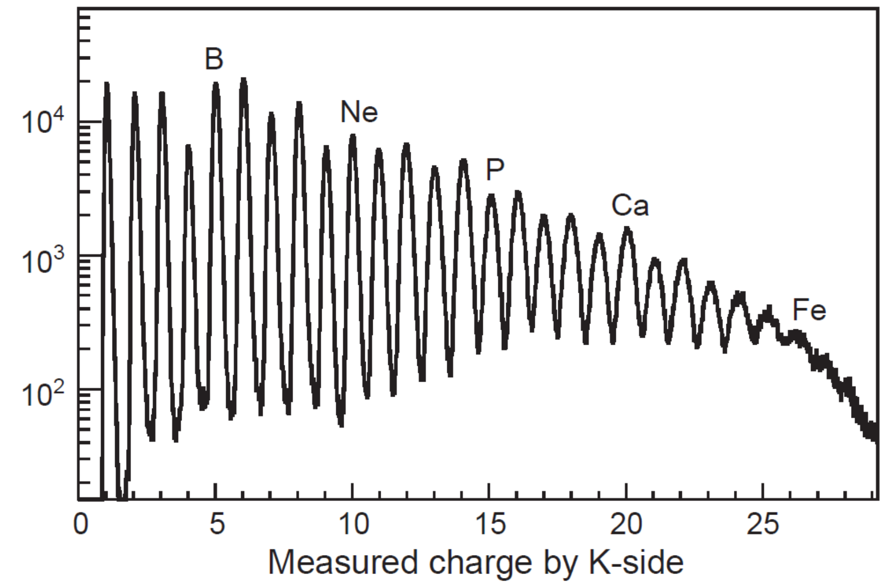
Measured number of photoelectrons

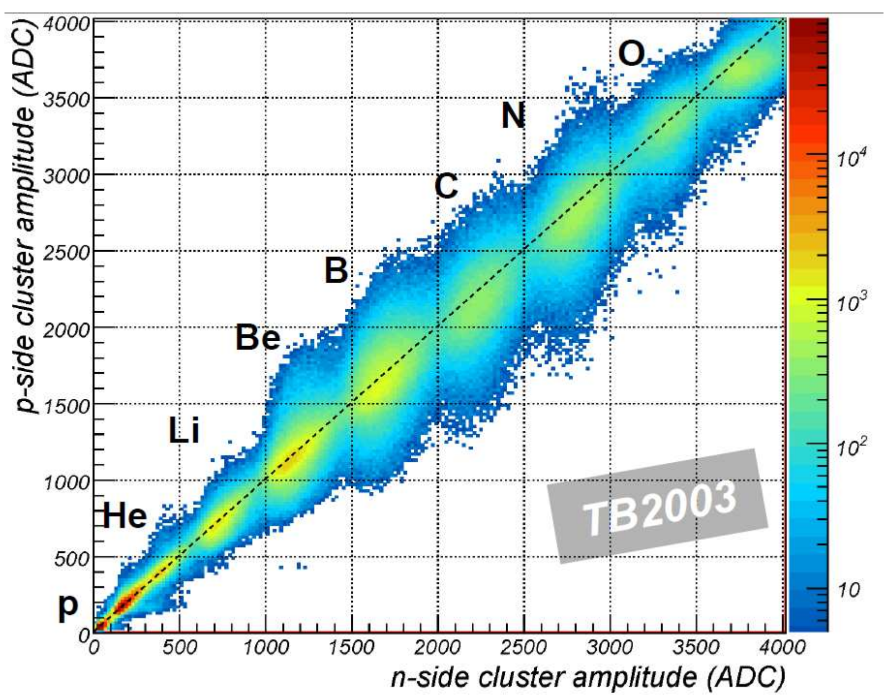


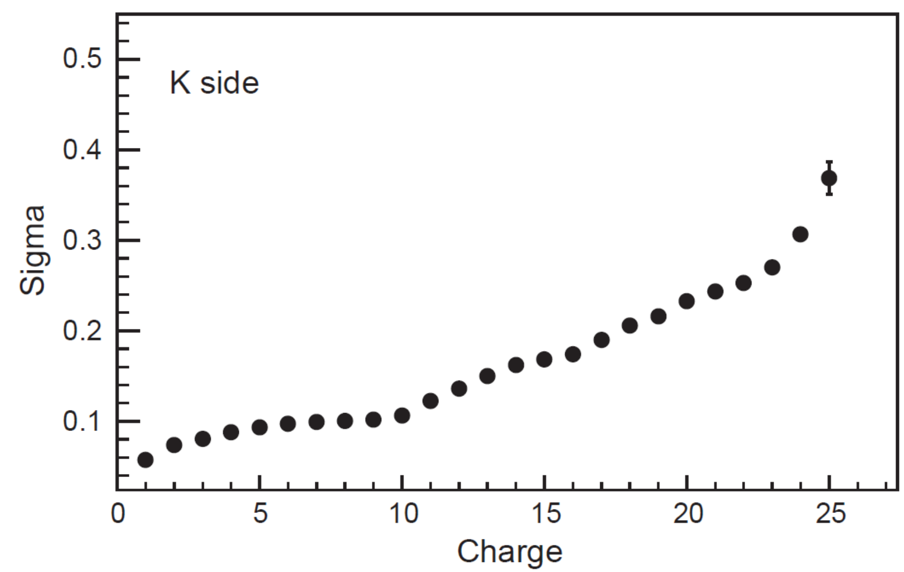


Charge measurement (Z) with Tracker

- ✔ energy deposited on silicon sensors ($300\ \mu$m)
  $\Delta E \propto Z^2$
- ✔ up to 8 ΔE samplings
- ✔ 6 ladders were tested (2003) with fragmented ions
  charge separation up to $Z \sim 26$







Charge measurement (Z) with Tracker

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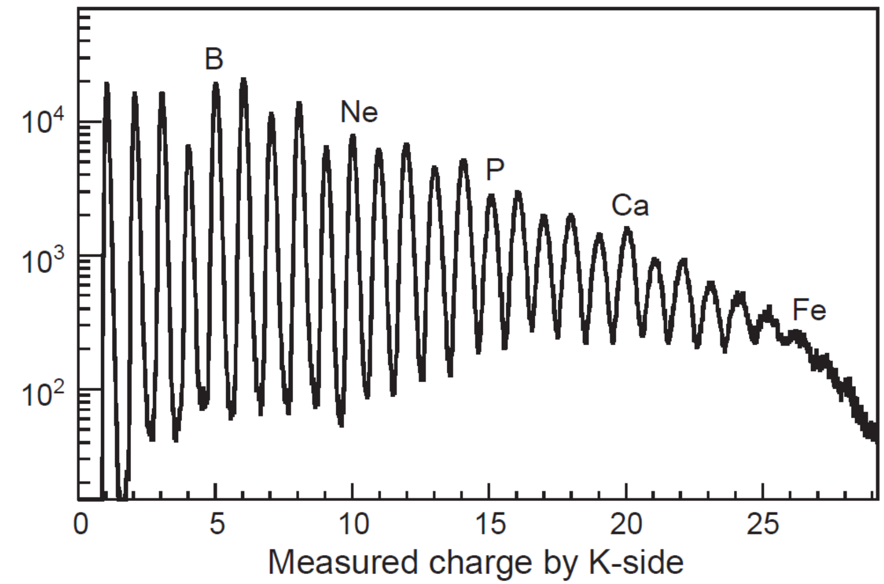
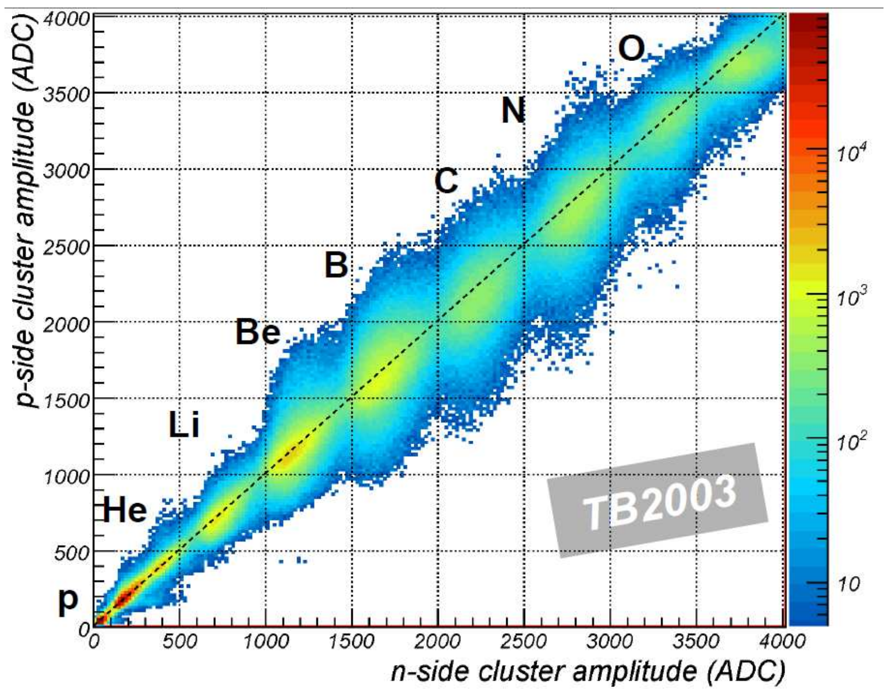
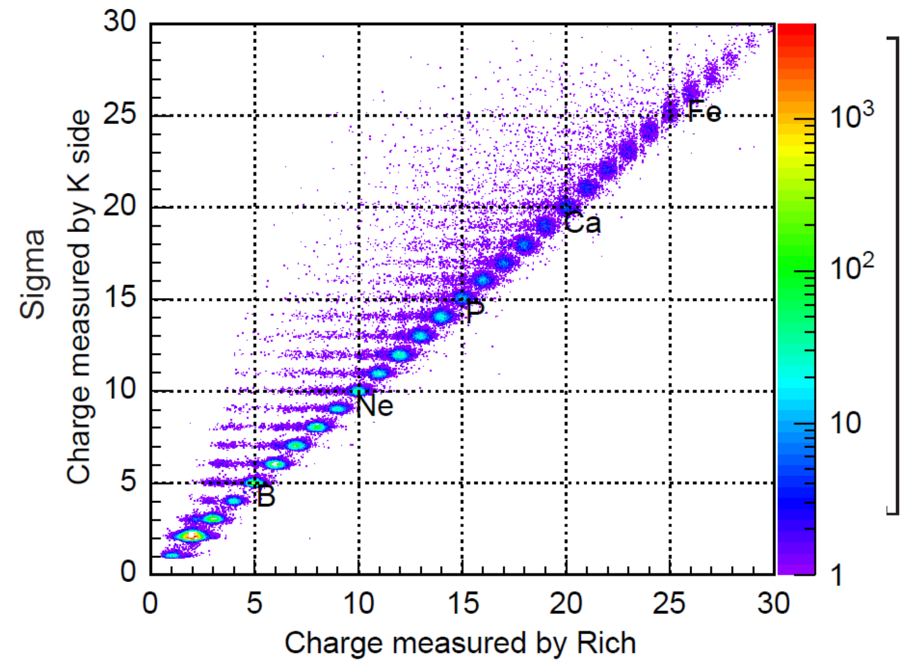






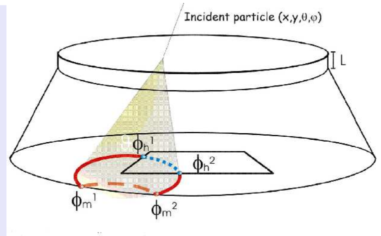
Charge determination with the RICH

✔ Charge determination :

$$Z^2 \propto \frac{N_{p.e}}{\varepsilon}$$

$\varepsilon \equiv$ ring efficiency

ring acceptance, γ absorption,...

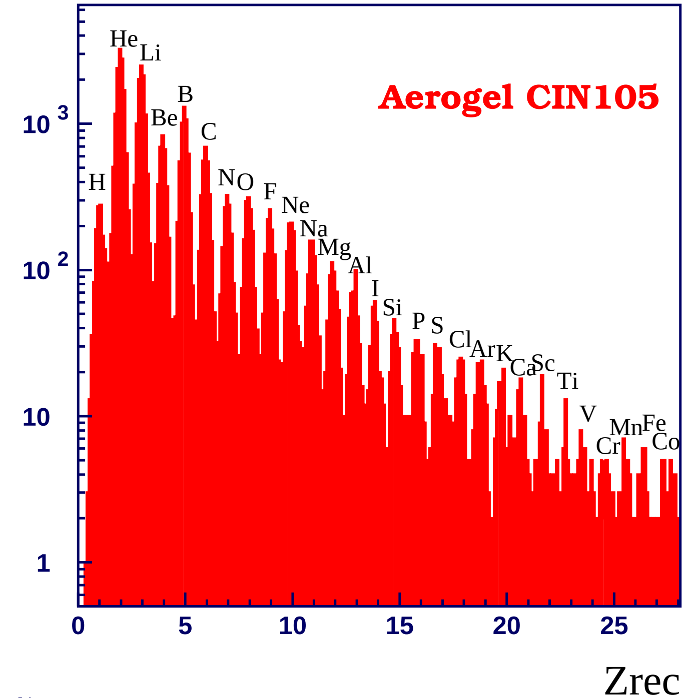


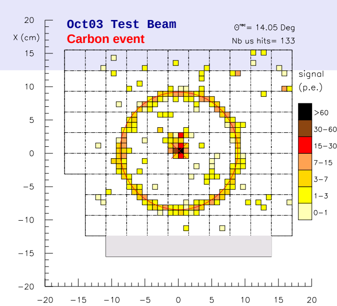
✔ Z Uncertainties :

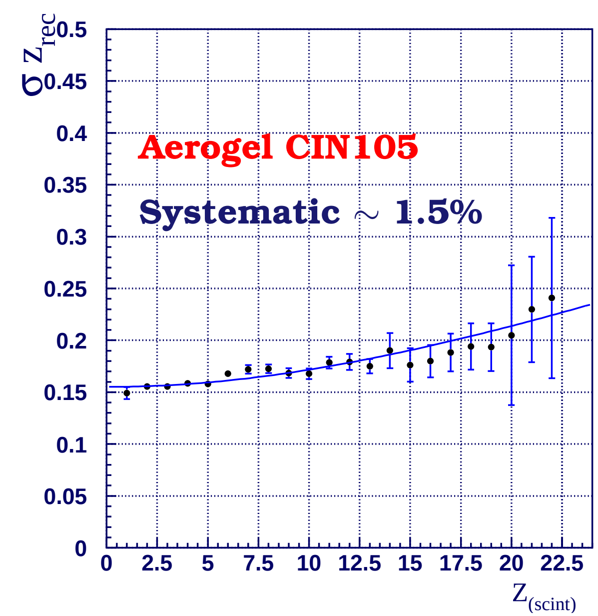
- statistical : $\Delta N_{p.e} = \sqrt{N_{p.e}\left(1+\sigma^2_{p.e}\right)}$
- systematics from non-uniformities :
  - radiator : n, thickness, clarity, ...
  - detection : LG, PMT, temperature effects, ...

$$\Delta Z = \frac{1}{2}\sqrt{\frac{1+\sigma^2_{p.e}}{N_0} + Z^2\left(\frac{\Delta\varepsilon}{\varepsilon}\right)^2}$$

✔ results from test beam (2003) with fragmented ions

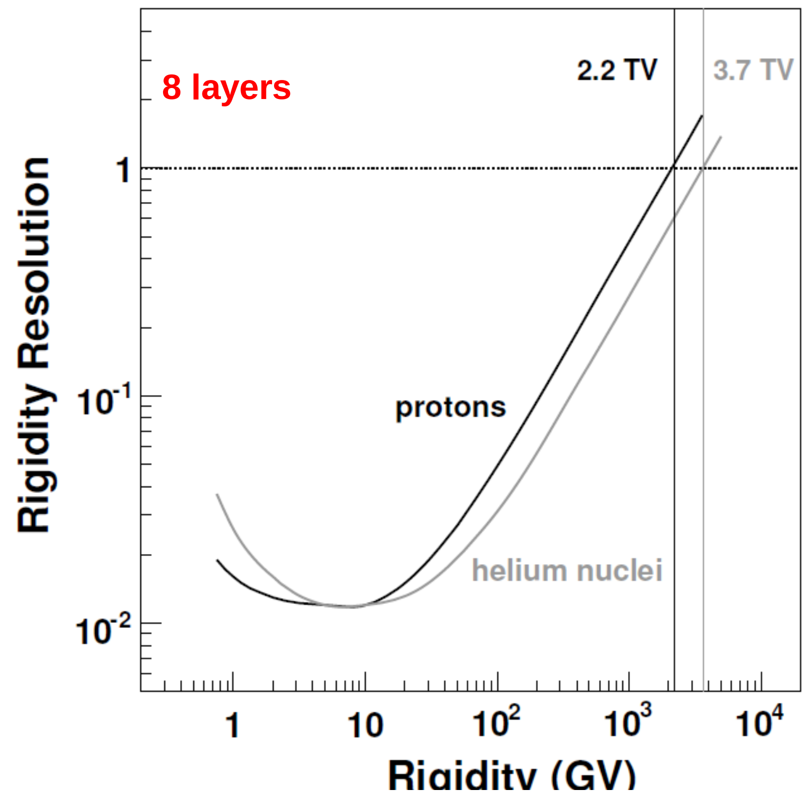


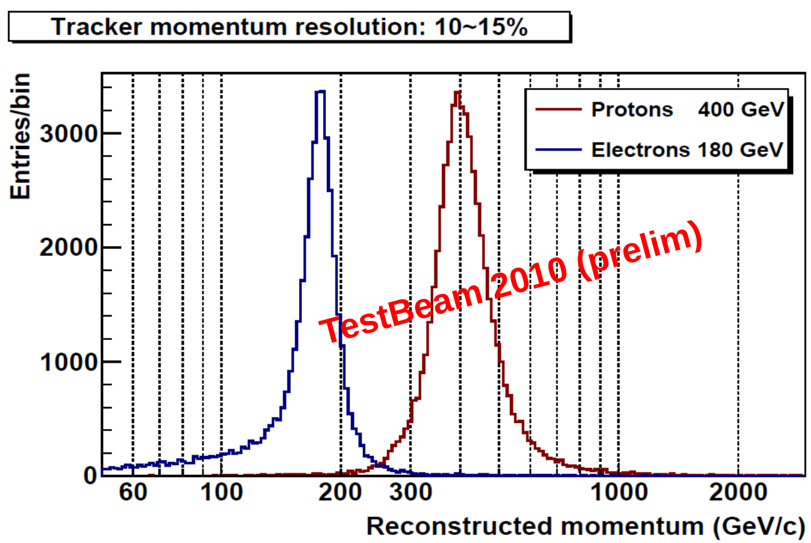


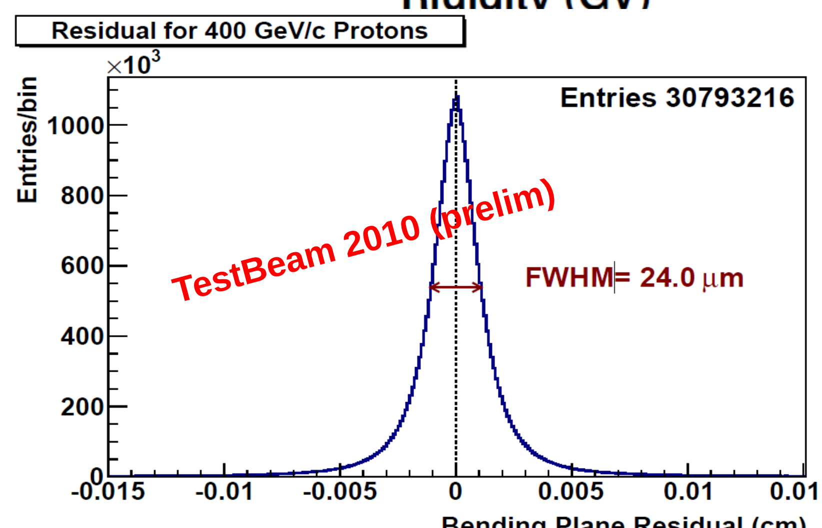


Rigidity measurement

- ✔ charged particles bend under magnetic field ($B \sim 0.8$ T)
- ✔ 8 silicon double-sided layers crossed
- ✔ *spatial resolution*
  $10\ \mu m$ on bending plane
  $30\ \mu m$ on non-bending plane
- ✔ rigidity, $R = pc/Ze$, is measured
- ✔ expected resolution
  $\sim 1\%$ at 10 GV and MDR $\sim\ 2$ TV for protons

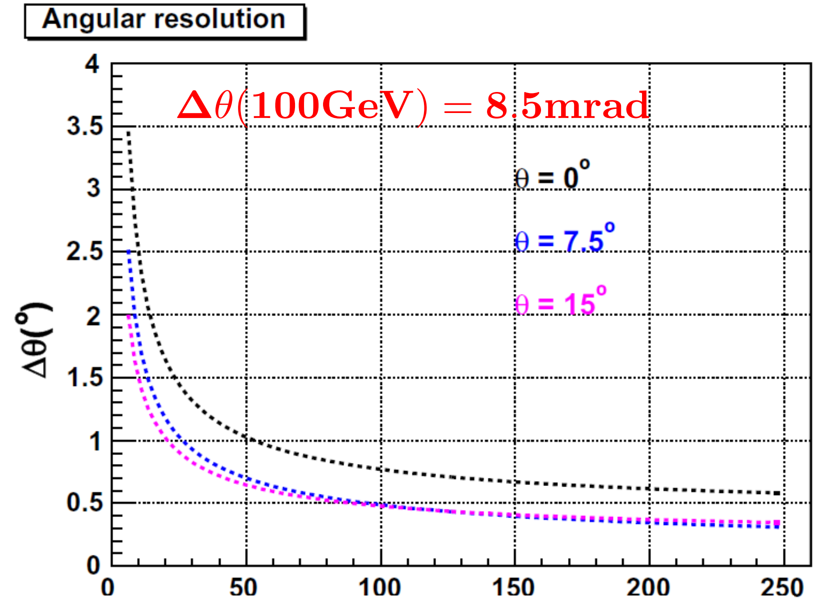


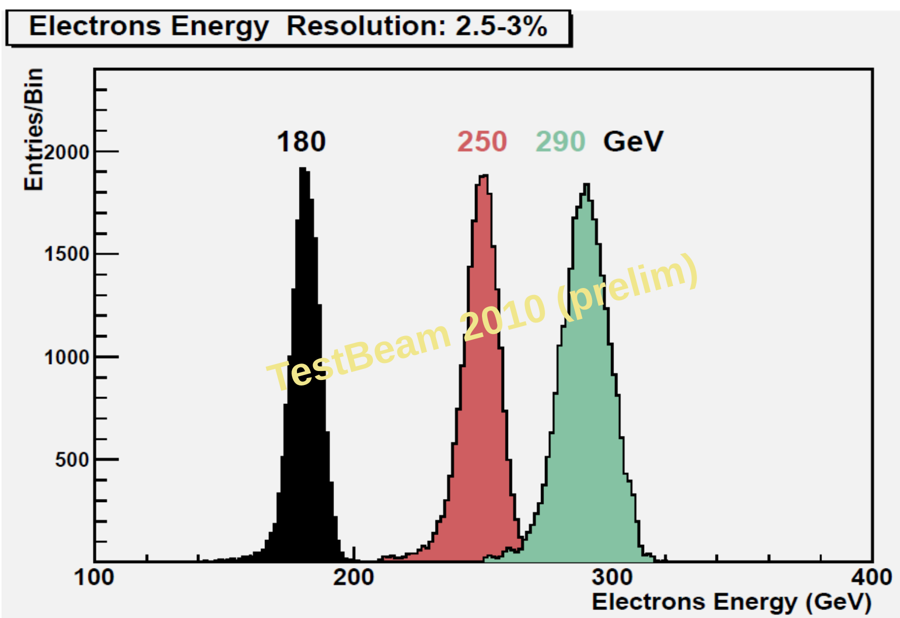


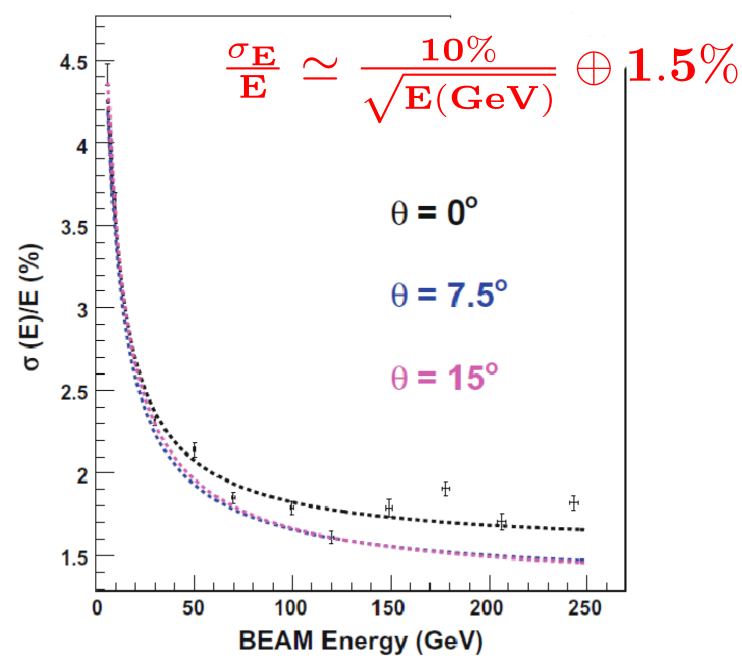


Electromagnetic energy measurement

- ✔ electromagnetic shower sampled 18 times
- ✔ energy linearity within 2% (up to 250 GeV)
- ✔ test beam results (2007) : electrons 6-250 GeV

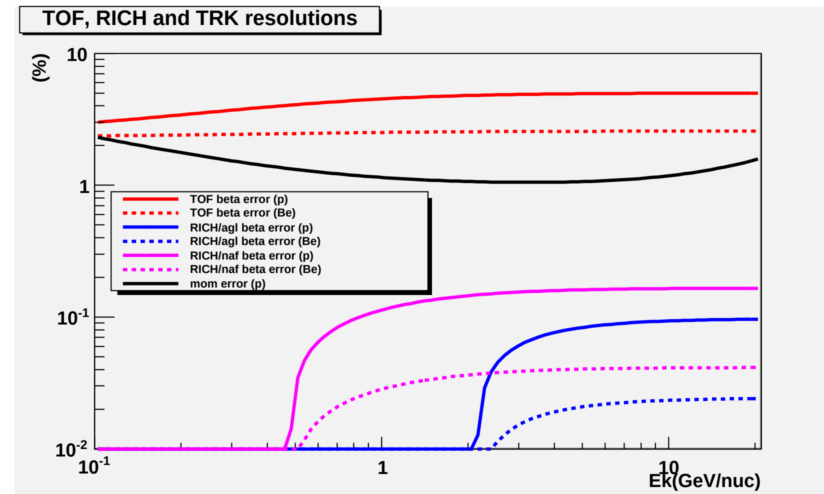






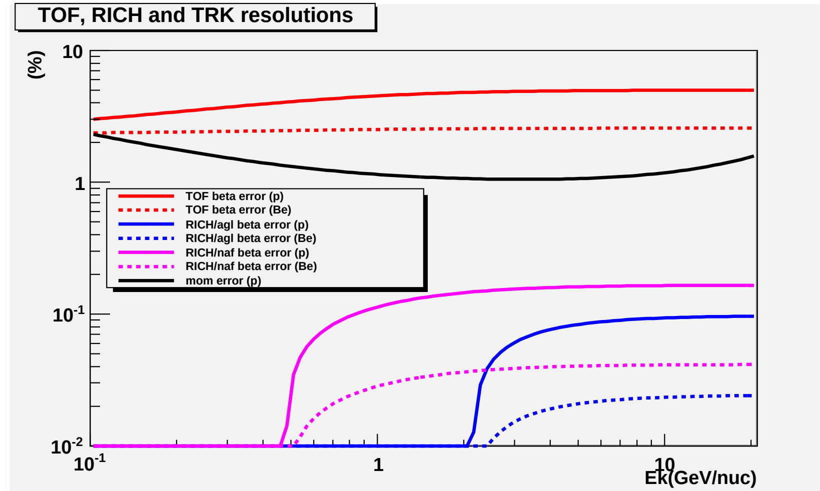
Mass reconstruction

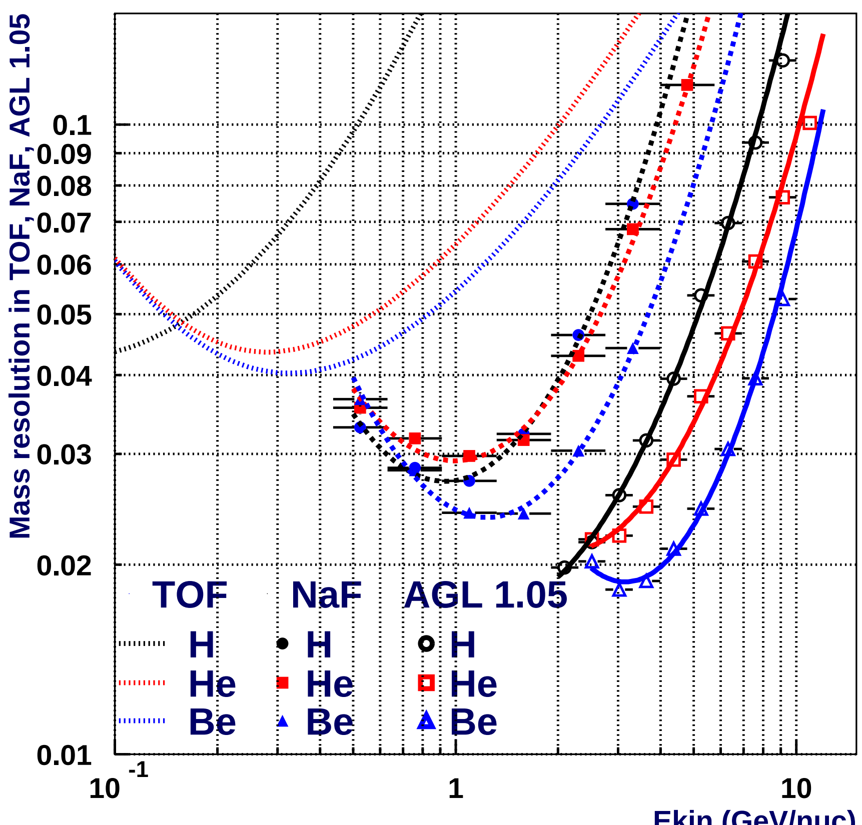
$$\left(\frac{\sigma_{\mathbf{m}}}{\mathbf{m}}\right) = \left(\frac{\sigma_{\mathbf{p}}}{\mathbf{p}}\right) \oplus \gamma^{\mathbf{2}} \left(\frac{\sigma_{\beta}}{\beta}\right)$$

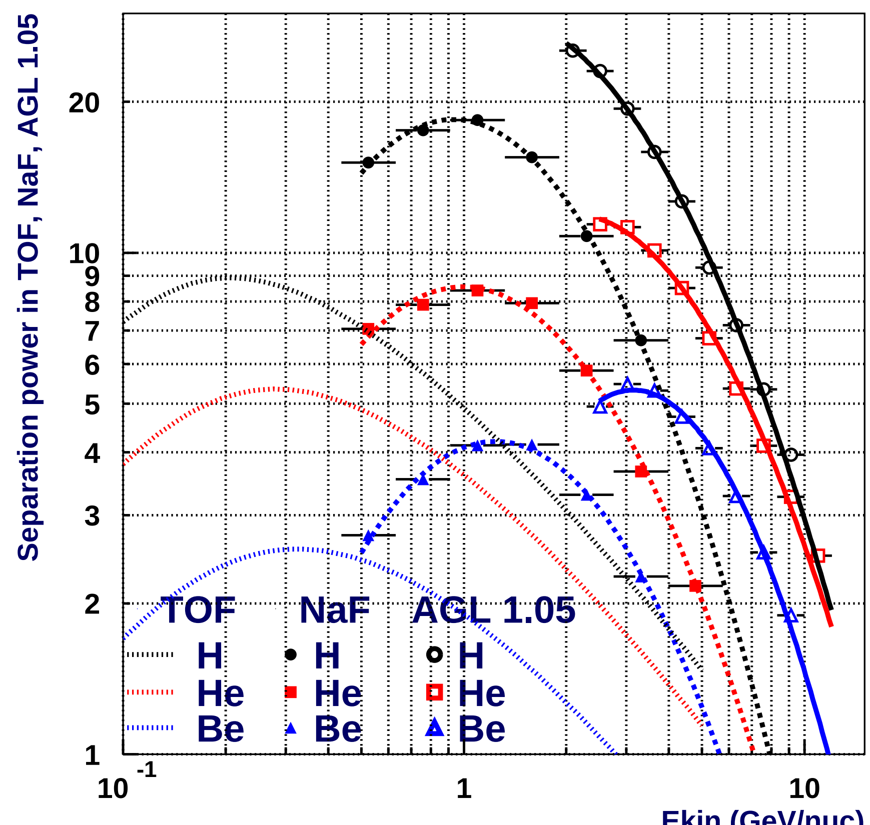


Mass reconstruction

$$\left(\frac{\sigma_m}{m}\right) = \left(\frac{\sigma_p}{p}\right) \oplus \gamma^2 \left(\frac{\sigma_\beta}{\beta}\right)$$







Particle identification

anti-protons, positrons, gammas, isotopes

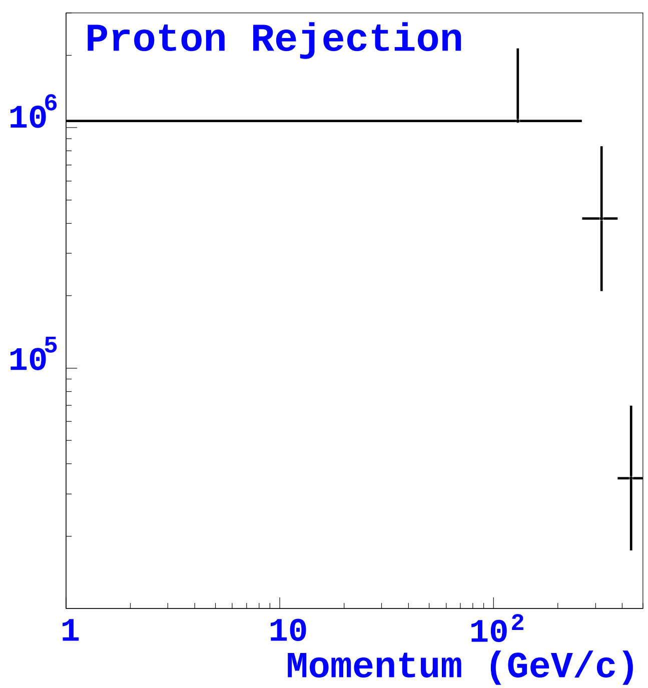
antiproton ($\bar{p}$) detection

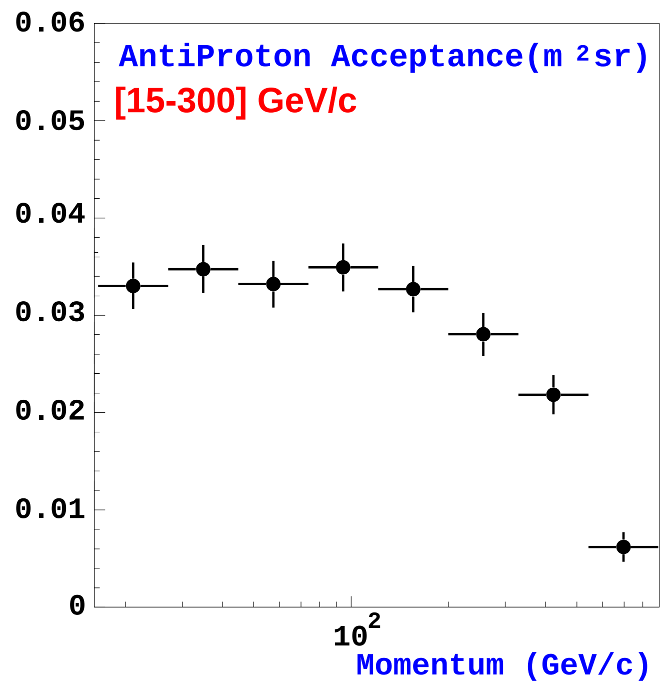
- ✔ backgrounds

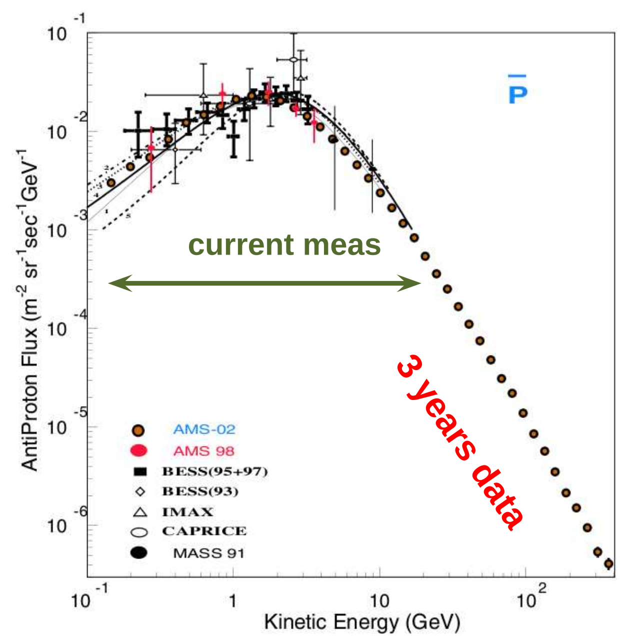
$\Phi_p/\Phi_{\bar{p}} \sim 10^4 - 10^5$	$\Phi_{e^-}/\Phi_{\bar{p}} \sim 10^2$

- ✔ selection
  - TRD : e/p discrimination
  - Tracker : sign
  - TOF/RICH : velocity (low energy region)
  - ECAL : E/P (high energy region)

- ✔ background rejection
  - $\mathbf{p} : 10^6 - 10^4$ (up to 400 GeV/c)
  - $\mathbf{e^-} : 10^3 - 10^4$
- ✔ $\bar{\mathbf{p}}$ acceptance
  - $\sim$ 0.16 m^2.sr (up to 16 GeV/c)
  - $\sim$ 0.03 m^2.sr (16-300 GeV/c)







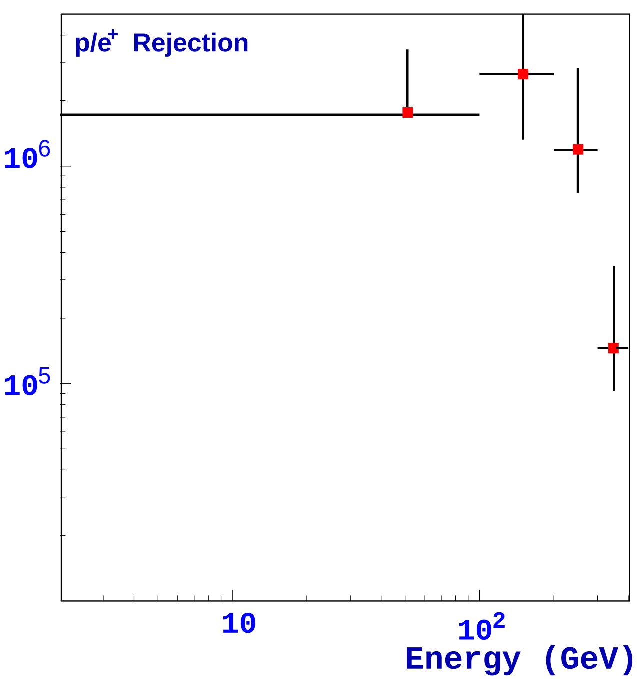
positron (e^+) detection

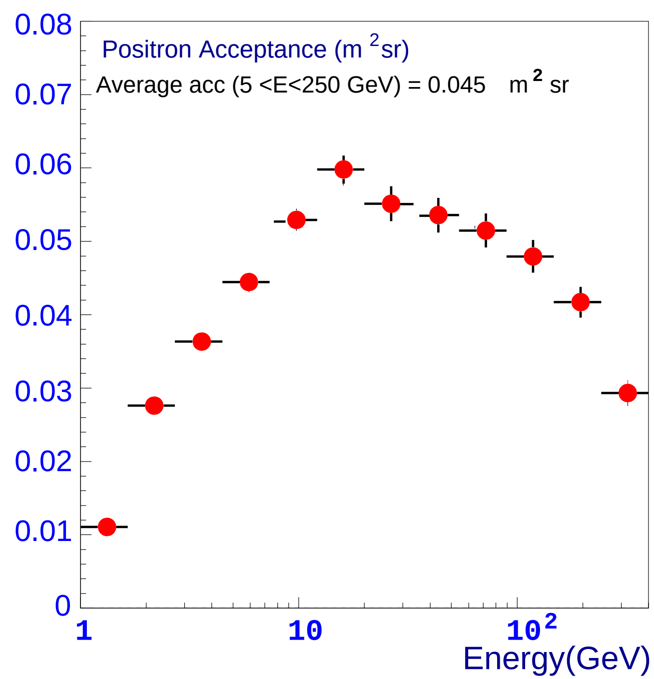
- ✔ backgrounds

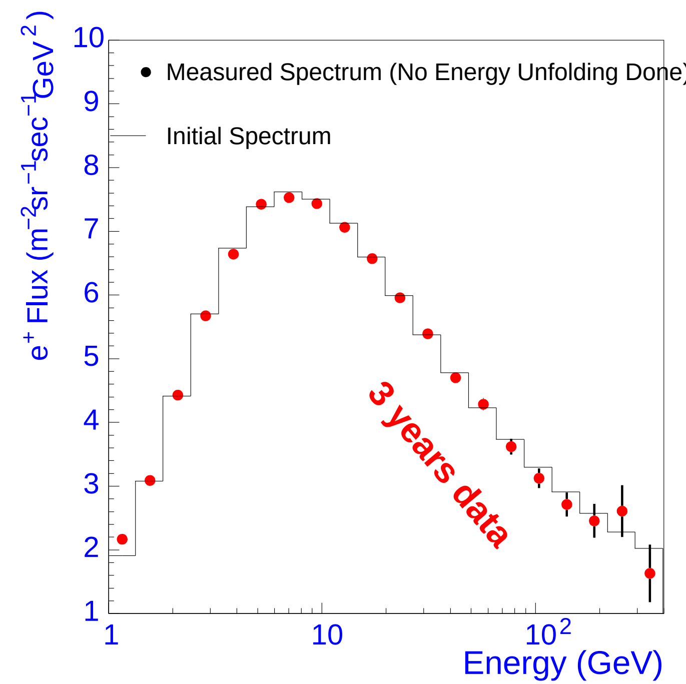
$\Phi_p/\Phi_{e^+} \sim 10^3 - 10^4$	$\Phi_{e^-}/\Phi_{e^+} \sim 10$

- ✔ selection
  - TRD : e/p discrimination
  - Tracker : sign
  - TOF/RICH : velocity (low energy region)
  - ECAL : E/P (high energy region)

- ✔ background rejection
  - $\mathbf{p} : \sim \mathbf{10^6}$ (up to 400 GeV/c)
  - $\mathbf{e^-} : \sim \mathbf{10^4}$
- ✔ $\bar{\mathrm{p}}$ acceptance
  - $\sim \mathbf{0.15}$ m^2.sr (up to 10 GeV/c)
  - $\sim \mathbf{0.04}$ m^2.sr (10-300 GeV/c)





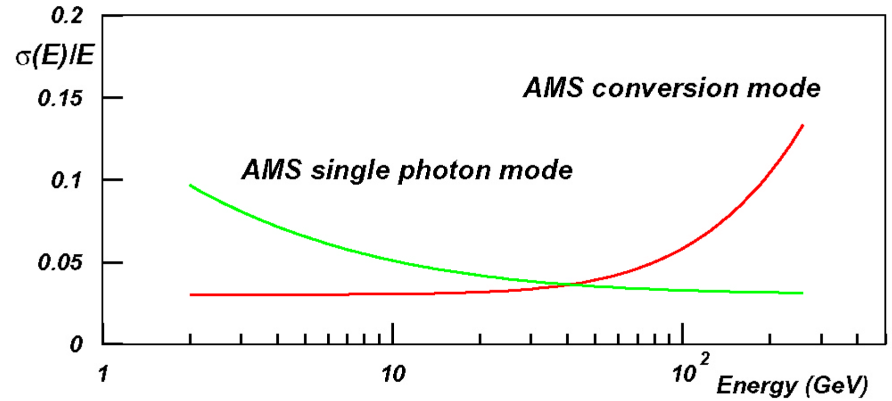


photon (γ) detection

Converted photon $\gamma \rightarrow e^- e^+$

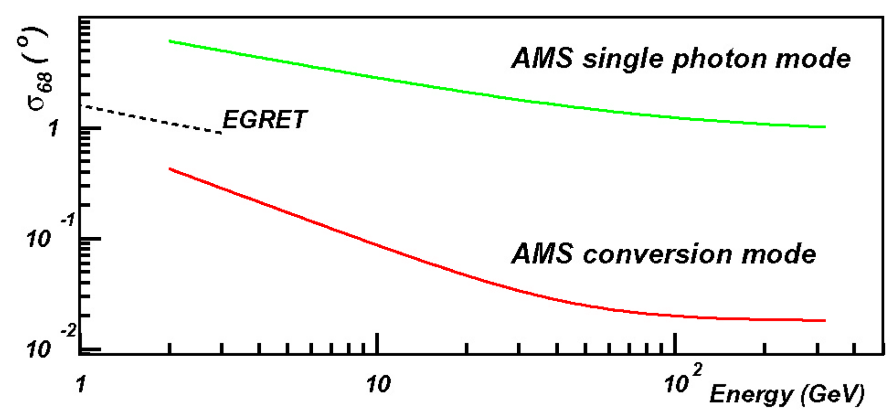
- some matter before the 1st TOF layer
  $\ell \sim 0.25\ X_0$
  conversion probability $\sim 20\ \%$
- γ energy and direction reconstructed from charged pair
- energy range limited by double track reconstruction **(**$E \sim 200\ GeV$**)**
- large angular view **(**$\theta_{max} \sim 42°$**)**

mean acceptance $(10 - 250 GeV)$
$\sim \mathbf{0.05\ m^2.sr}$



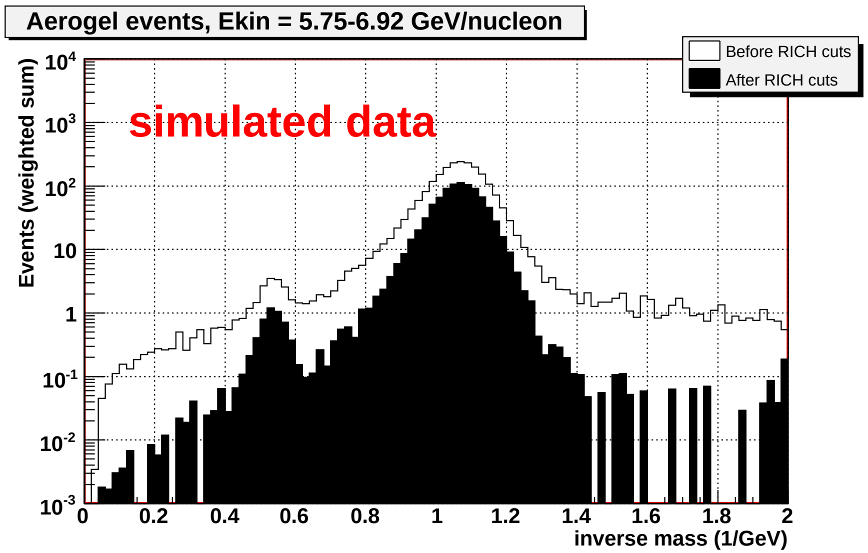
Non-converted photon

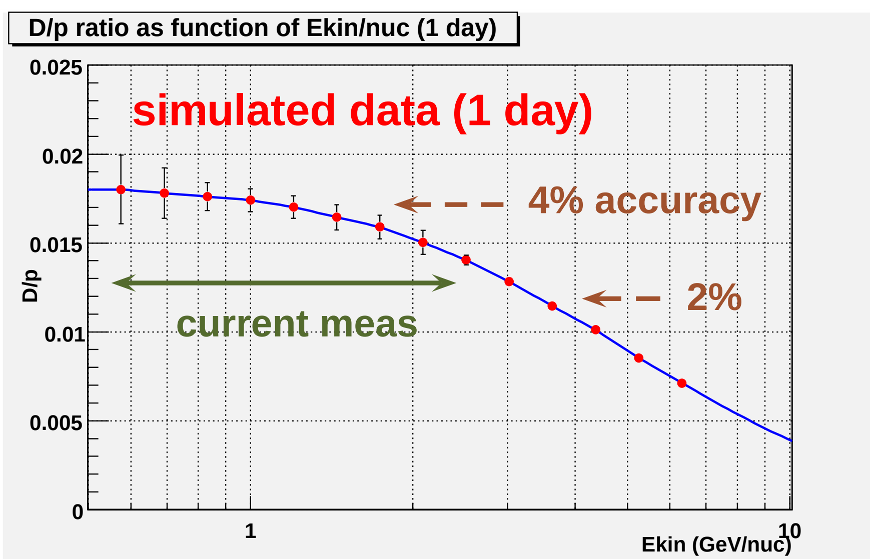
- direction of reconstructed photon inside fiducial region **(**$\theta_{max} \sim 22°$**)**
- large rejection power against protons and electrons **(** $\sim 10^6$**)**
- large energy range **(**$8\ GeV - 10^3\ GeV$**)**



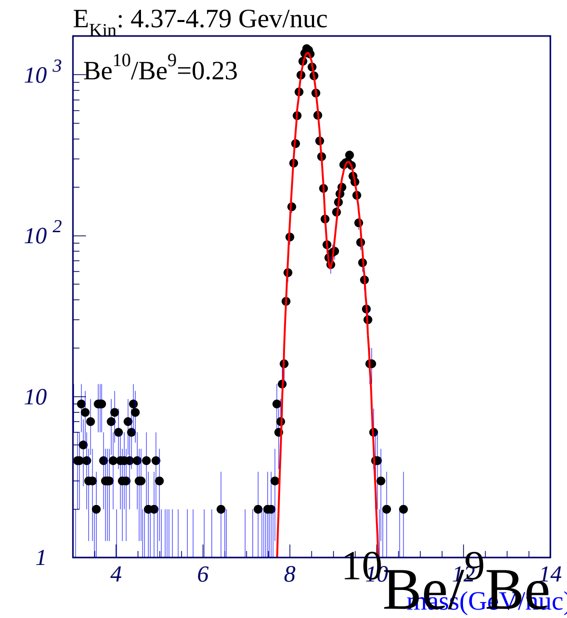
Light isotopes

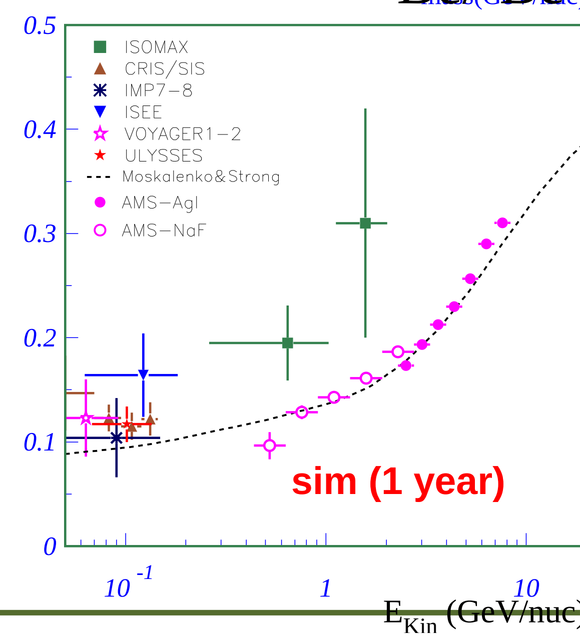
d/p





Be^{10}/Be^{9}





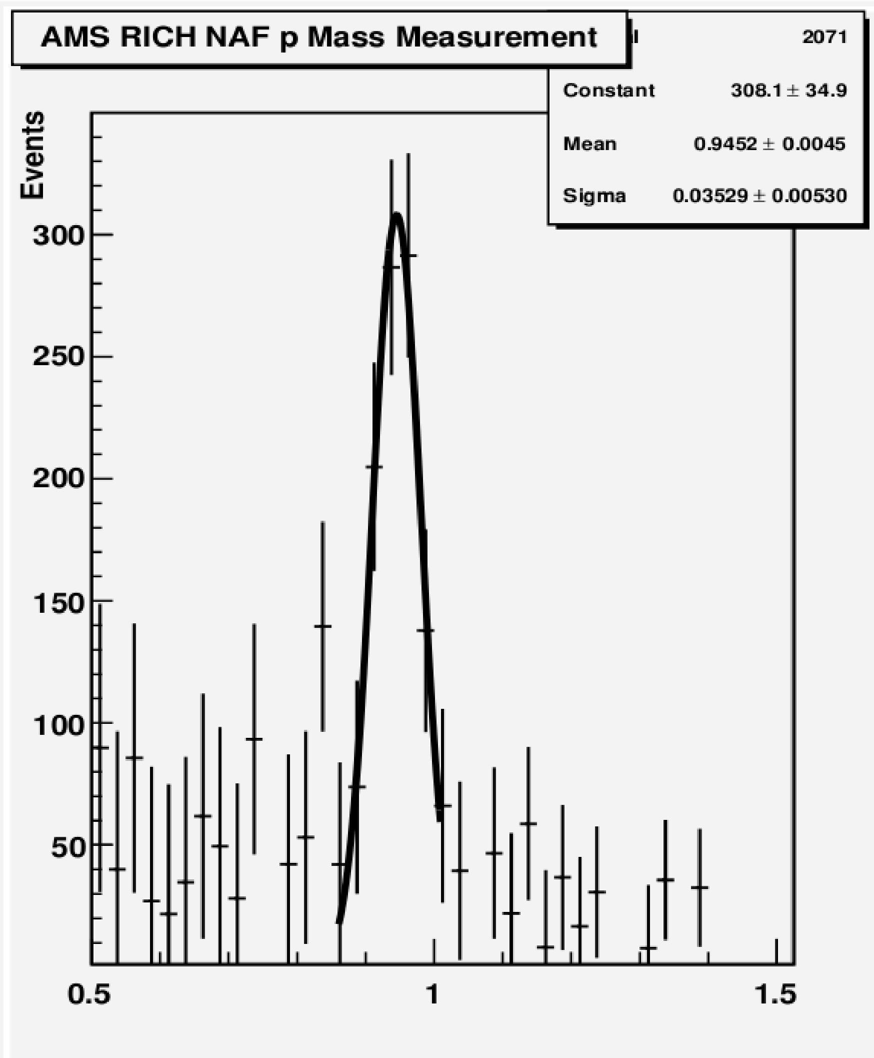
Some preliminar results

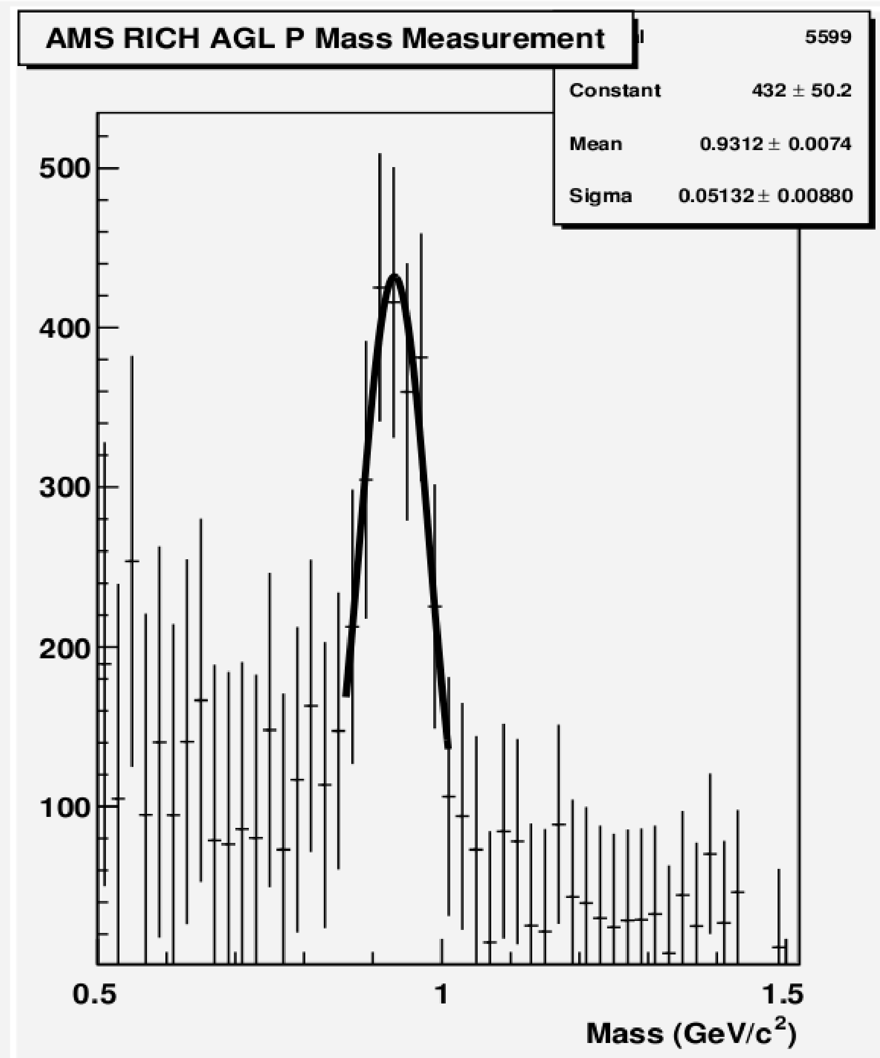
Cosmic runs (Dec 2009)

Test Beam (Feb 2010)

Cosmic runs 2009 : RICH mass reconstruction

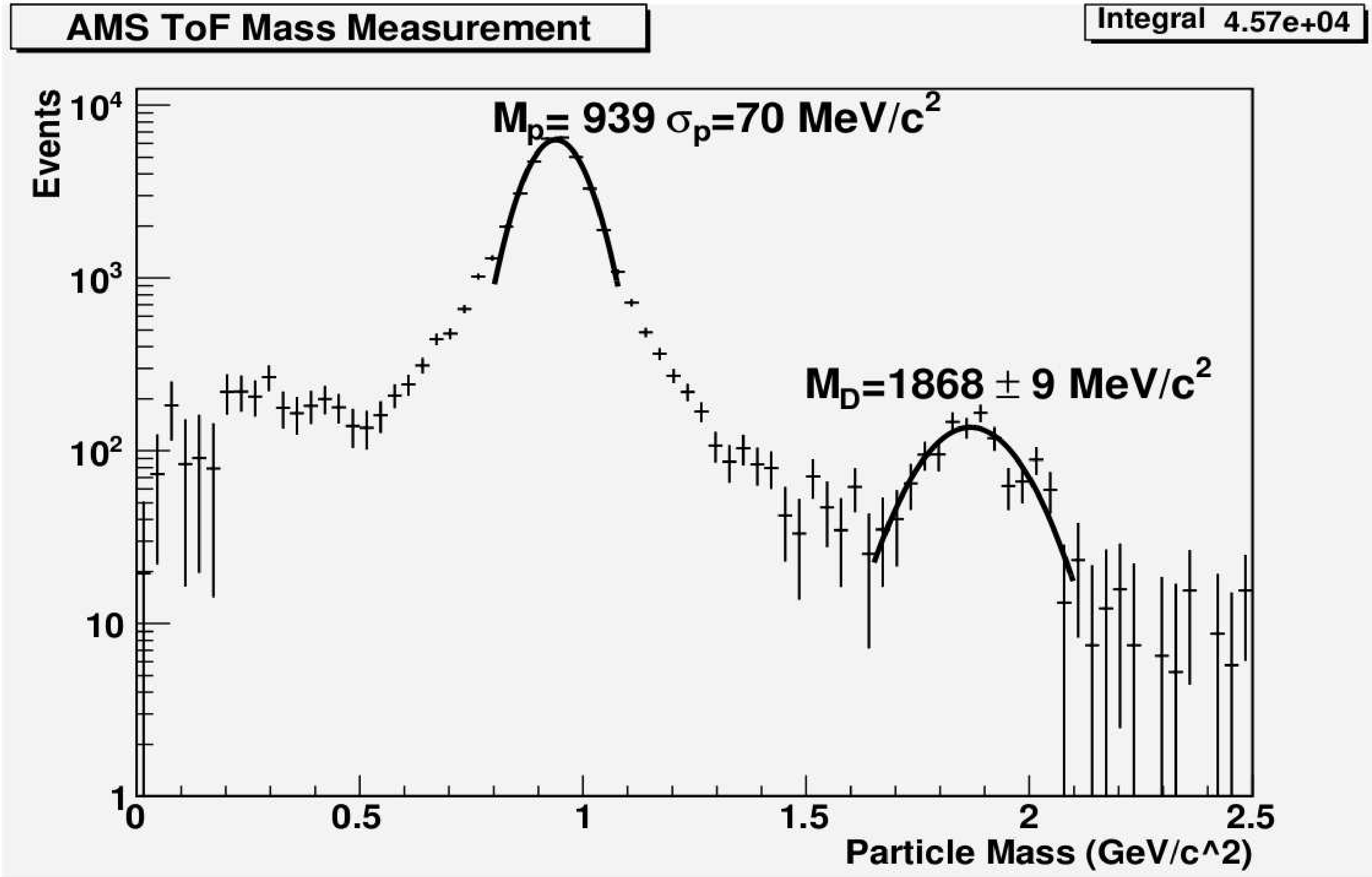
✔ cosmic rays : proton mass reconstructed with the RICH (aerogel and NaF radiators)





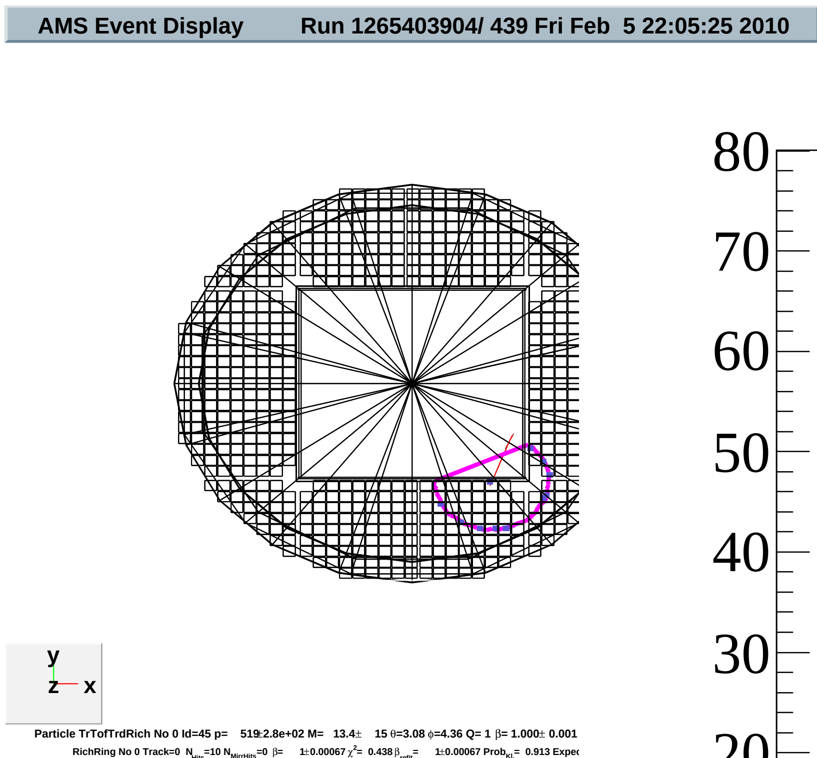
Cosmic runs 2009 : TOF mass reconstruction

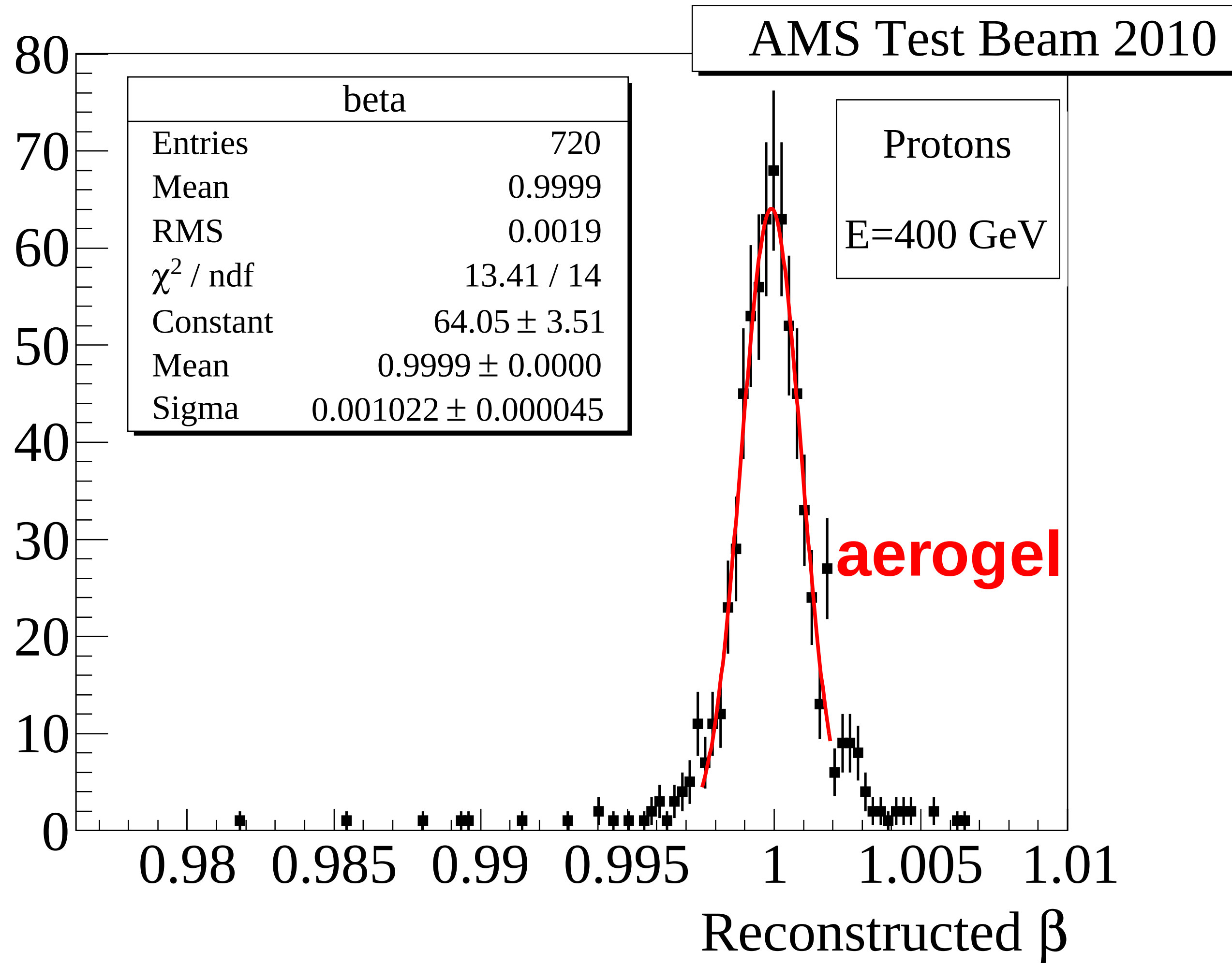
✔ cosmic rays : proton and deuteron masses reconstructed with the TOF



Test Beam 2010 : RICH β reconstruction

✔ 400 GeV protons with the magnet switched on at 400 Amps





Conclusions

Measurement	statistics	energy	physics goals
e^+	$\sim 10^7$	400 GeV	**Dark Matter**
$\bar{p}$	$\sim 10^6$	400 GeV	
γs	$\sim 10^5$	10^3 GeV	
$\overline{\mathrm{D}}$	~ 10	8 GeV/A	
D	$\sim 10^8$	8 GeV/n	**Astrophysics**
^{3}He	$\sim 10^8$	8 GeV/n	
^{10}Be	$\sim 10^5$	7 GeV/n	

Measurement	sensitivity	rigidity	physics goals
$\overline{\mathrm{He}}/\mathrm{He}$	10^{-9}	10^3 GV	**Antimatter**
$\overline{\mathrm{C}}/\mathrm{C}$	10^{-8}	10^3 GV	