The ACROMASS project for the study of the charged components of the atmospheric cosmic radiation

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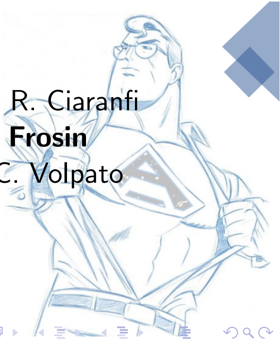

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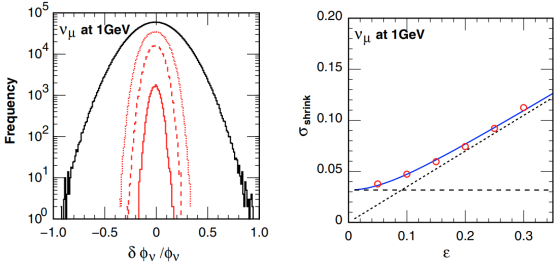
Motivation

- Interest for a precise study of μ spectra and angular distributions for **neutrino physics research**:
  1. Knowledge of the ν_μ flux, ϕ_{ν_μ}, for $E_{\nu_\mu} < 1$ GeV is important for a precision study of the neutrino oscillation parameters
  2. M. Honda et al. (2019) uses a custom simulation based on Monte Carlo techniques to evaluate the ν_μ flux at the altitude of interest
- No systematic study of atmospheric muon spectra: single measurements done at different locations/altitudes, in different momentum and angular ranges, with different detectors and in different phases of the solar modulation $\Rightarrow$ **difficult to combine consistently**
- Applications: muon radiography and tomography.

M. Honda et al., Phys. Rev. D 100, 123022 (2019)

- Atmospheric lepton fluxes ϕ_L are computed using a hadronic interaction model H where random variations are introduced to evaluate uncertainty:
  - ✓ Correlation found between $\delta\phi_\nu$ and $\delta\phi_\mu$
  - ✓ For $E_\nu = 1$ GeV, correlation is large at $p_\mu \lesssim 1$ GeV/c and still present up to $p_\mu \lesssim 10$ GeV/c
- Relative flux variations $\delta\phi_\mu/\phi_\mu$ and $\delta\phi_\nu/\phi_\nu$ follow Gaussian distributions.
- Imposing $\delta\phi_\mu/\phi_\mu < \varepsilon$:
  - ✓ Narrows the distribution of $\delta\phi_\nu/\phi_\nu$
  - ✓ Normalized width σ_{shrink} fits well with: $\sigma_{\text{shrink}} = \sqrt{\zeta_0^2 + \zeta_1 \cdot \varepsilon^2}$



- **Conclusion:** If the simulation is calibrated to reproduce the muon flux accurately, it also predicts the neutrino flux with precision.

Main goals of ACROMASS

Atmospheric **C**osmic **R**ay **O**bservatory using a **M**agnetic **A**ltazimuth **S**ilicon **S**pectrometer

- measurement of the muon spectra with a precision $\frac{\delta\phi_\mu}{\phi_\mu} \leq 5\%$
- measurement of the muon spectra down to $p_{min} \approx 0.1$GeV/c
- measurements to be carried out in the high mountains (3-4.5 km a.s.l.)
- study of the dependence $\phi_\mu(\theta)$ at hig altitude (3-4.5 km a.s.l.)

From preliminary estimation based on the ADAMO spectrometer measurements we estimated the feasibility of the measurement with ACROMASS at low energy, to reach 5% fluctuation in the lowest energy bin as:

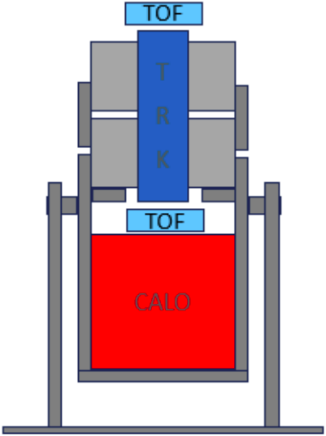
- Vertical ($0° < \theta < 10°$) $\Rightarrow \Delta t_{acq} \approx$3 days
- Intermediate($40° < \theta < 50°$) $\Rightarrow \Delta t_{acq} \approx$8 days
- High ($70° < \theta < 80°$) $\Rightarrow \Delta t_{acq} \approx$2 months

From ADAMO to ACROMASS

- Spectrometer designed for the PAMELA satellite experiment.
- 5 double sided Hamamatsu μ–strip silicon of 300 μm for the tracking module: 5x7 cm^2, σ_x =3μm (bending view) and σ_y =10μm
- Trigger system: 4 scintillator layers
- Magnet: NdFeB alloy, 1.3T residual magnetization with average B of 0.4 T
- Mass: approximately 100 kg
- G_F = 6.7 cm^{2}sr and MDR=250 GV/c
- No PID: in the low energy region possible contamination from e$^\pm$

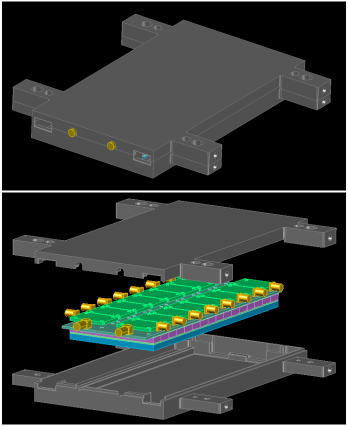
From ADAMO to ACROMASS

- Subdetectors for PID (e,p,μ)
  - ≫ ToF system: σ_t =100 ps
  - ≫ Sampling E.M. calorimeter
- Semplification of the detector's structure
  - ≫ New DAQ system with Ethernet communication protocol
  - ≫ Small electronics' box to have a portable DAQ and Slow Control system (20 W total)



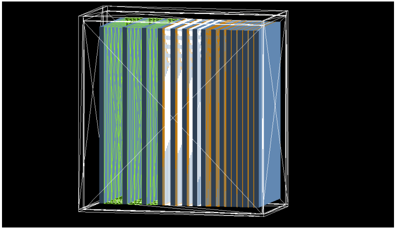
The ACROMASS ToF

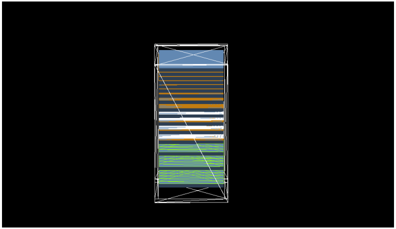
- Upper layer:
  - One plane segmented in 16 bars (12x80x5) cm^3
  - Fast plastic scintillatore EJ-232Q
  - σ_t =100 ps $\Rightarrow$ separation of p/μ up to 1 GeV/c and separation of e/μ up to 0.2 GeV/c
- Lower layer: single plane as trigger
  - Plastic scintillator BC-408
  - Layer size: (192x80x5) cm^3
- Readout:
  - ONSEMI J-SERIES SiPM (3x3) mm^2
  - Fast low noise RF amplifiers and Fast SAMPIC digitizer module



The ACROMASS Calorimeter

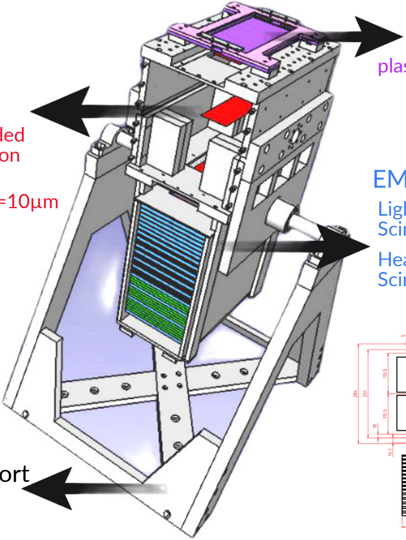
- Characteristics:
  - $\sim 22 X_0$, $\sim 1 \lambda_i$, $\sim$76 kg
  - Custom DAQ board based on the CITIROC 32ch chip
  - ADVANSID NUV SiPM (4x4) mm^2
- Materials
  - 16 plastic scintillators (8 mm) in blue
  - 21 Cu absorber layers (1 and 1.5 mm) in brown
  - 16 W absorber layers (1.6 mm) in white
  - 12 Pb absorber layers (6 mm) in green





Light Part: Scintillator + Cu. Optimized for muon/electron separation at low momentum (down to 100 MeV/c). **Heavy Part:** Scintillator + W + Pb Optimized for muon/proton separation from $\sim$1 GeV/c

From ADAMO to ACROMASS



Time of Flight

plastic scintillators + SiPM

σ =100 ps

Si-Tracker

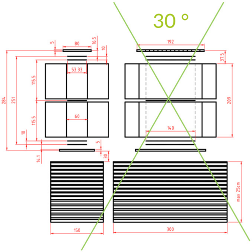
5 double sided
μ–strip silicon
of 300 μm

σ_x =3μm - σ_y =10μm

EM Calorimeter

Light Part:
Scintillator + Cu

Heavy Part:
Scintillator + W + Pb



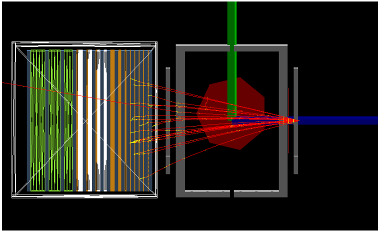
Mechanical support

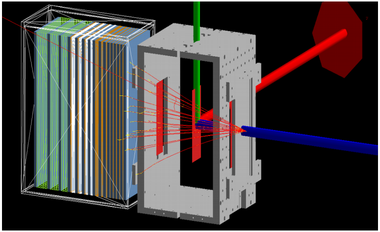
altazimuth pointing

Preliminary Simulations

- Study of e^- vs μ discrimiation at low energy <1 GeV/c with the energy deposition profile in the EM calorimeter in GEANT4
- Study efficiency and rejection power as a function of a χ^2 discrimiation variable cut
- Will test how these performances vary in different configurations
- Final validation will come from the test beam runs at PS and SPS at CERN

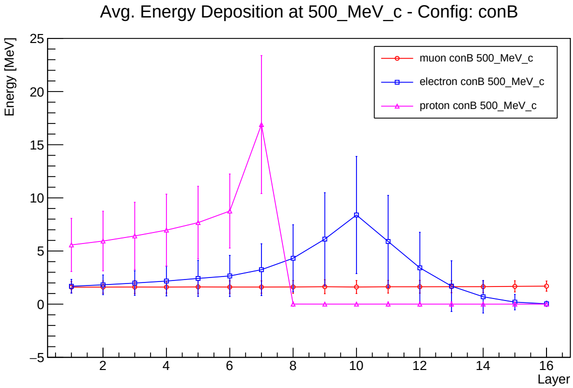
Preliminary Simulations





- Standard *FTFP BERT* and *EM4* physics list
- CAD mesh library to define the geometry of the different components
- Magnetic field implemented according to experimental scanning including outside of the box
- Simulated 10000 muons, electrons and protons for each configuration (i.e. vertical central tracks with magnetic field etc.)

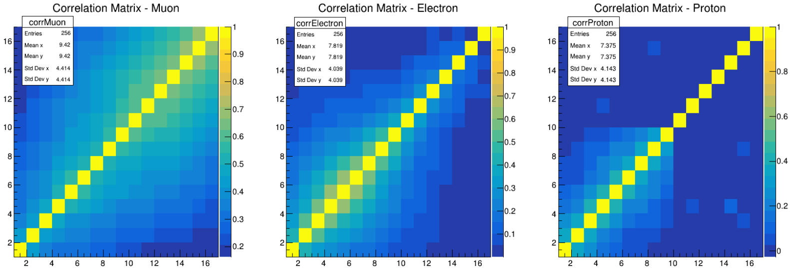
Preliminary Simulations



Average energy deposition profile for the 16 layers of the ECAL @ $p =$500 MeV/C. Vertical tracks at top.

Use the average energy deposition profile for each particle as a PID information. Construct the vector of mean values and covariance for inter-layer correlation.

Preliminary Simulations



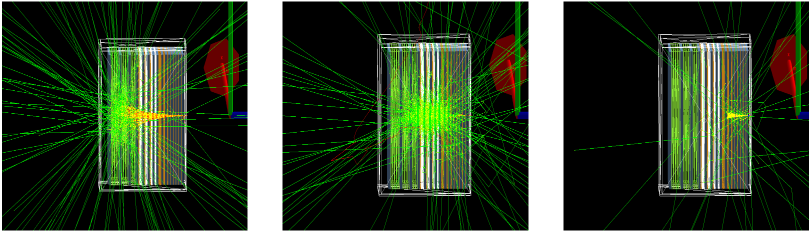
Correlation Matrix for the 16 layers of the ECAL @ p =500 MeV/C

$$\chi^2_{like} = \frac{1}{N}\sum_i (S_i - < S >)^T \, V^{-1} \, (S_i - < S >)$$

where $< S >$ is the mean value vector and V is the covariance matrix

Preliminary Simulations

Muon **Electron** **Proton**

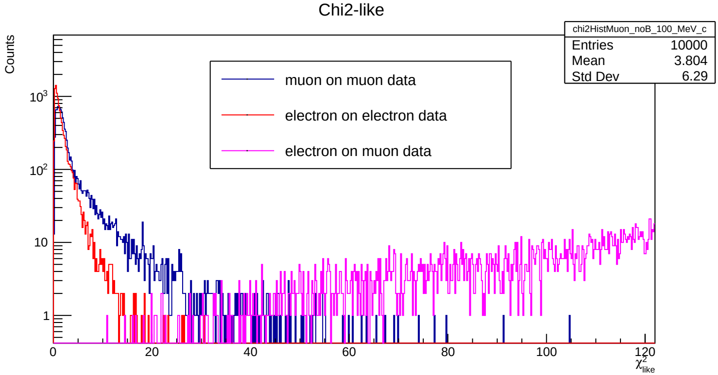


Energy release in the ECAL @ 500 MeV/c

$$\chi^2_{like} = \frac{1}{N} \sum_i (S_i - <S>)^T \, V^{-1} \, (S_i - <S>)$$

where $<S>$ is the mean value vector and V is the covariance matrix

Preliminary Simulations



χ^2_{like} using 6 layers @ p =100 MeV/c. Vertical tracks at top.

$$\chi^2_{like} = \frac{1}{N} \sum_i (S_i - < S >)^T \, V^{-1} (S_i - < S >)$$

$\Rightarrow$Almost 100% efficiency in discrimination of e^- vs μ^- up to 1 GeV/c

Summary and Outlook

So far ...

- Design and development of the new trigger/ToF system
- Production of an EM calorimeter and mechanics
- Design, prototyping and test of the DAQ and SC boards
- Assembling and lab test of the new ACROMASS apparatus
- Performed preliminary simulations with GEANT4: to be calibrated with beam data

Summary and Outlook

Near Future

- **PS and SPS test beam** in September and October at CERN
- **Testa Grigia** (research station of CNR) measurements over Plateau Rosa, near the border between Italy and Switzerland (**3479 m** above sea level).
- Expression of interest from **Norikura Solar Observatory** (**2770 m** above sea level)