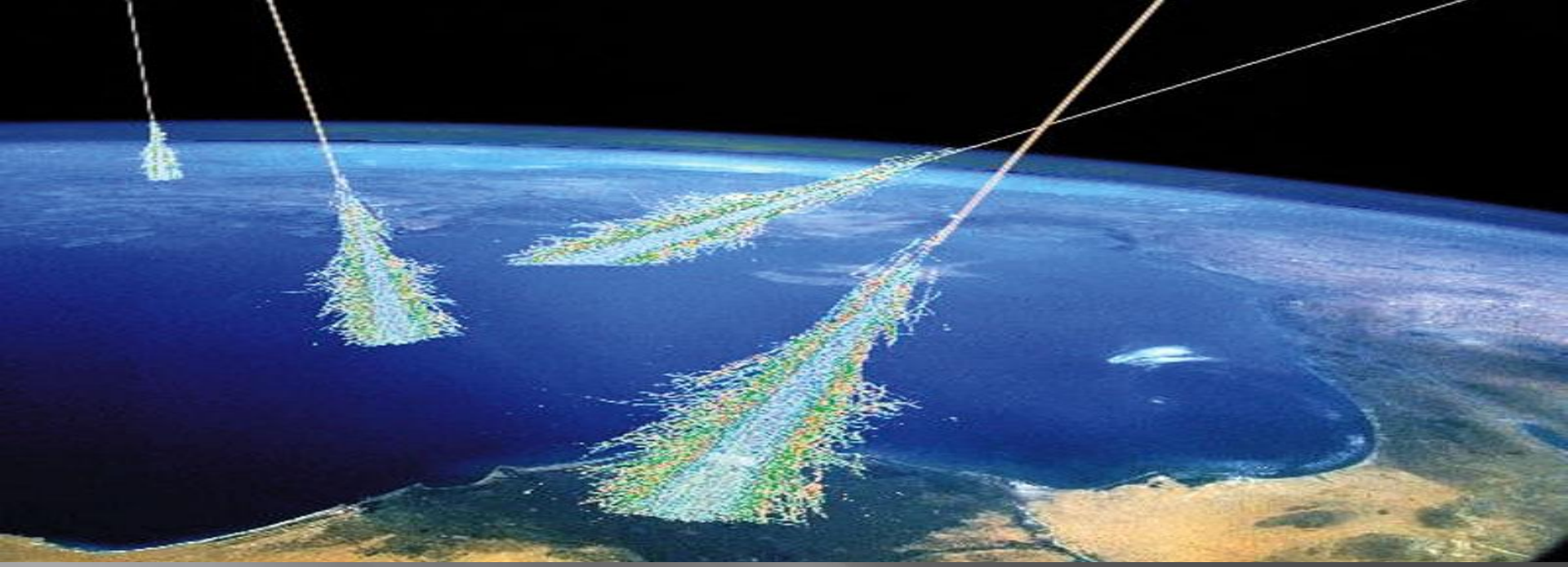


COSMIC RAY MUONS

Anthony Tatum

Outline

- What Is a Muon?
- Cosmic Origin and Interactions
- Muon Production and Path
- Effects in The Atmosphere
- Using Muons to Test Beam Profile Monitor
- Conclusion

What Is a Muon?

- Discovered in 1936
  - Carl D. Anderson and Seth Neddermeyer
- Fundamental Particle
- Similar to Electron
  - Lepton
  - Mass is ~207 Times That of the Electron

Interaction and Decay Modes

- Interaction
  - Gravitation
  - Electromagnetism
  - Weak Interaction

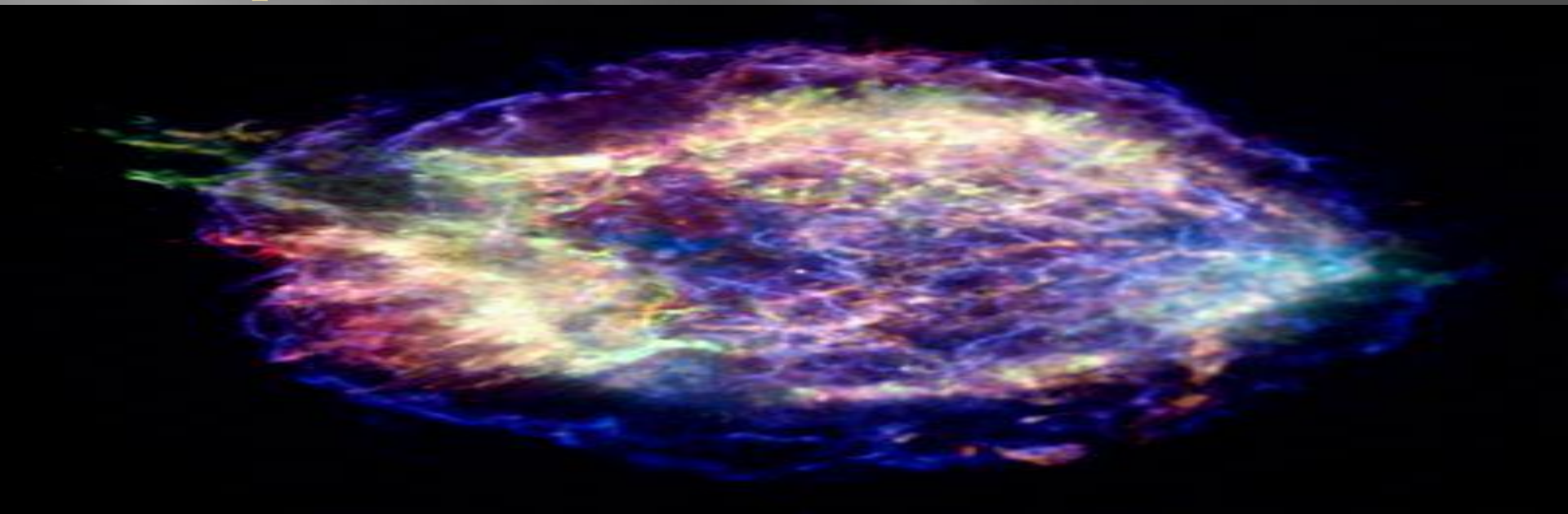
- Primary Decay Mode
  - $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$
  - ~ 100%

Fundamental Properties

Property	Value
Muon Mass	105.6583668 ± 0.0000038 MeV
Muon Electric Charge	e^-, e^+ (anti-muon)
Mean Life	2.19703 ± 0.00004 μ seconds
Spin	1/2
Magnetic Moment Ratio, μ/p	3.18334539 ± 0.00000010
Electric Dipole Moment	$3.7 \pm 3.4\,(10^{-19}\text{ecm})$

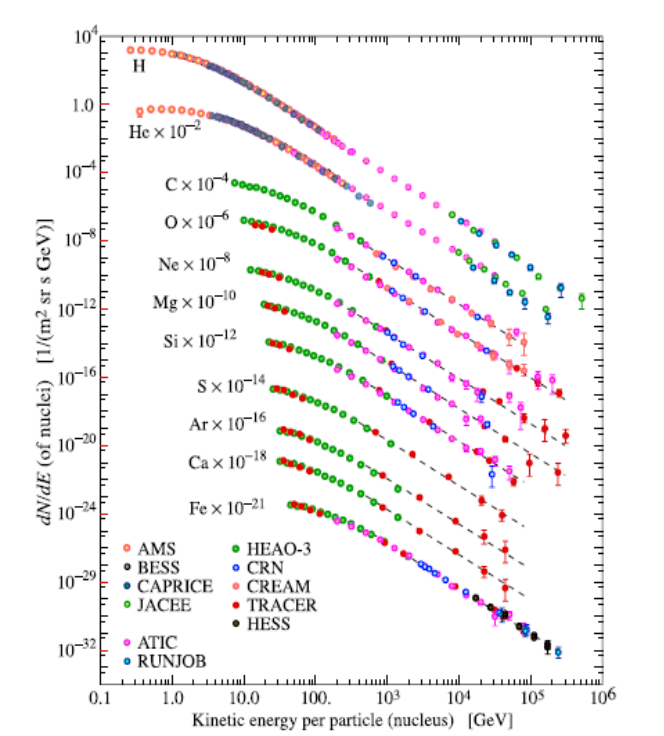
Cosmic Origin and Interactions

- Cosmic ray muons are created when high energy primary cosmic rays interact with earths atmosphere.
- The primary sources of cosmic rays are supernovae



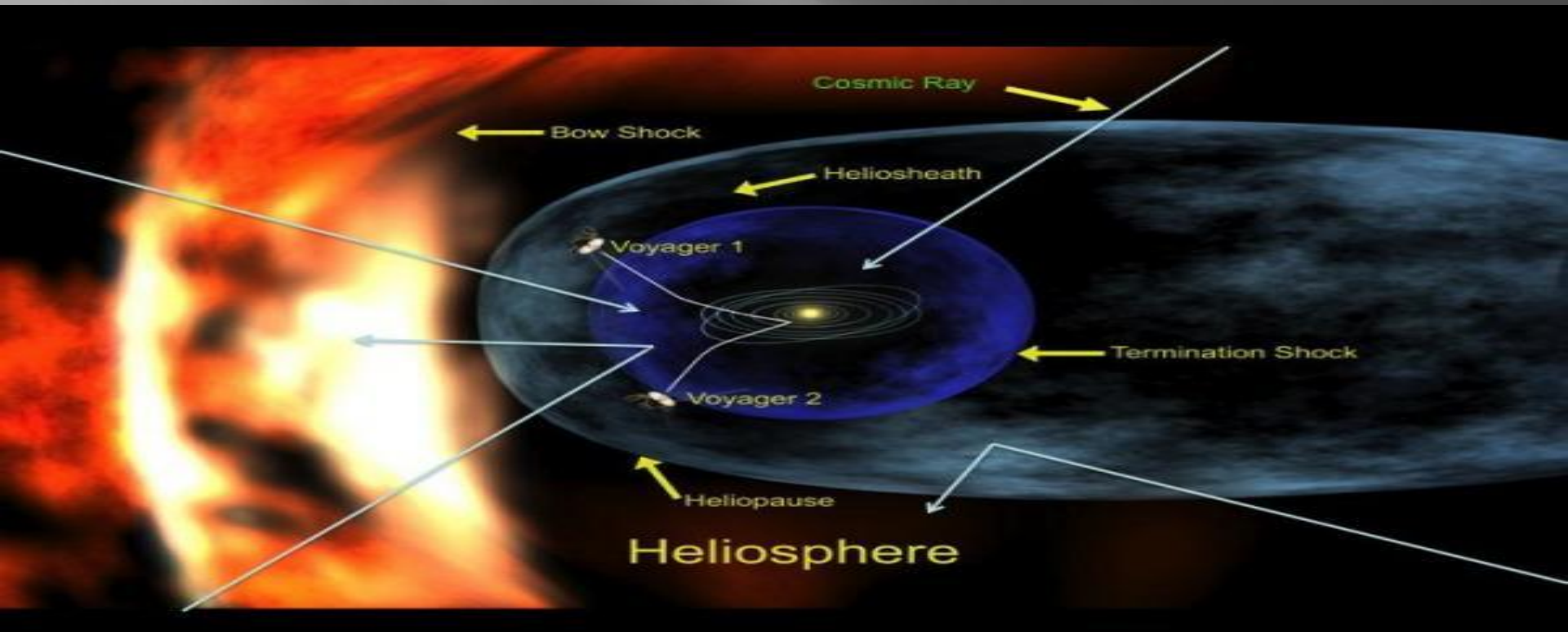
Primary Cosmic Rays

- Components
  - 89% Hydrogen Nuclei (Protons)
  - Remaining 11% includes Helium, Carbon and Oxygen among other less abundant elements



Primary Cosmic Ray Interactions

- Gravitation
- Electromagnetism



Lorentz Force Law

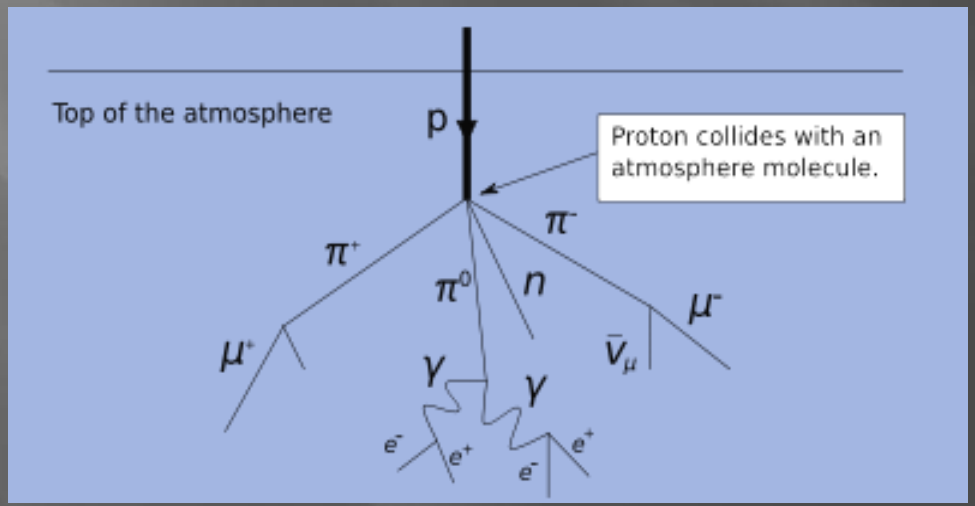
- The equations of motion for primary cosmic rays interacting with earth's magnetic field can be derived from the Lorentz force law.

$$F = ma = q(v \times B)$$

- Manuel Vallarta
  - Earth is approximated as a magnetic dipole

Production and Path

- High energy primary cosmic rays collide with atmospheric molecules at an altitude of ~ 15km to produce secondary cosmic rays
- Most abundant collisions
  - Proton $\rightarrow N_2$ Diatomic Molecule
  - Proton $\rightarrow O_2$ Diatomic Molecule



Components of Secondary Cosmic Rays

- Protons, Neutrons, Pions, Kaons, Muons, Electrons and Photons
- Muons are the decay product of Pions and Kaons
  - $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
  - $K^0 \rightarrow \pi^+ + \pi^-$

Path Through The Atmosphere

- The mean energy of muons at the site of production (~15 km alt.) is 6 GeV. This energy corresponds to a velocity of .9998c. This velocity is derived from the relativistic equation for energy

$$E_{\mu}(v) = \frac{m_{\mu_0} c^2}{\sqrt{1 - \frac{v_{\mu}^2}{c^2}}}$$

Path Through The Atmosphere

- Time Dilation
  - The lifetime of a 6 GeV cosmic muon as measured from Earth frame

$$\tau = \gamma\tau_0 = 109 .856 \times 10^{-6} s$$

- The incident angle of the majority of muons at sea level is close to the zero zenith angle
  - ~ 1 muon $/cm^2$ minute

Effects in the Atmosphere

- Temperature Variance
- Interaction With Thunderstorms

Effects Cont'd

- Temperature Variance
  - Cosmic muon flux intensity corresponds directly with the atmospheric temperature at different pressures, altitudes and zenith angles

Effects Cont'd

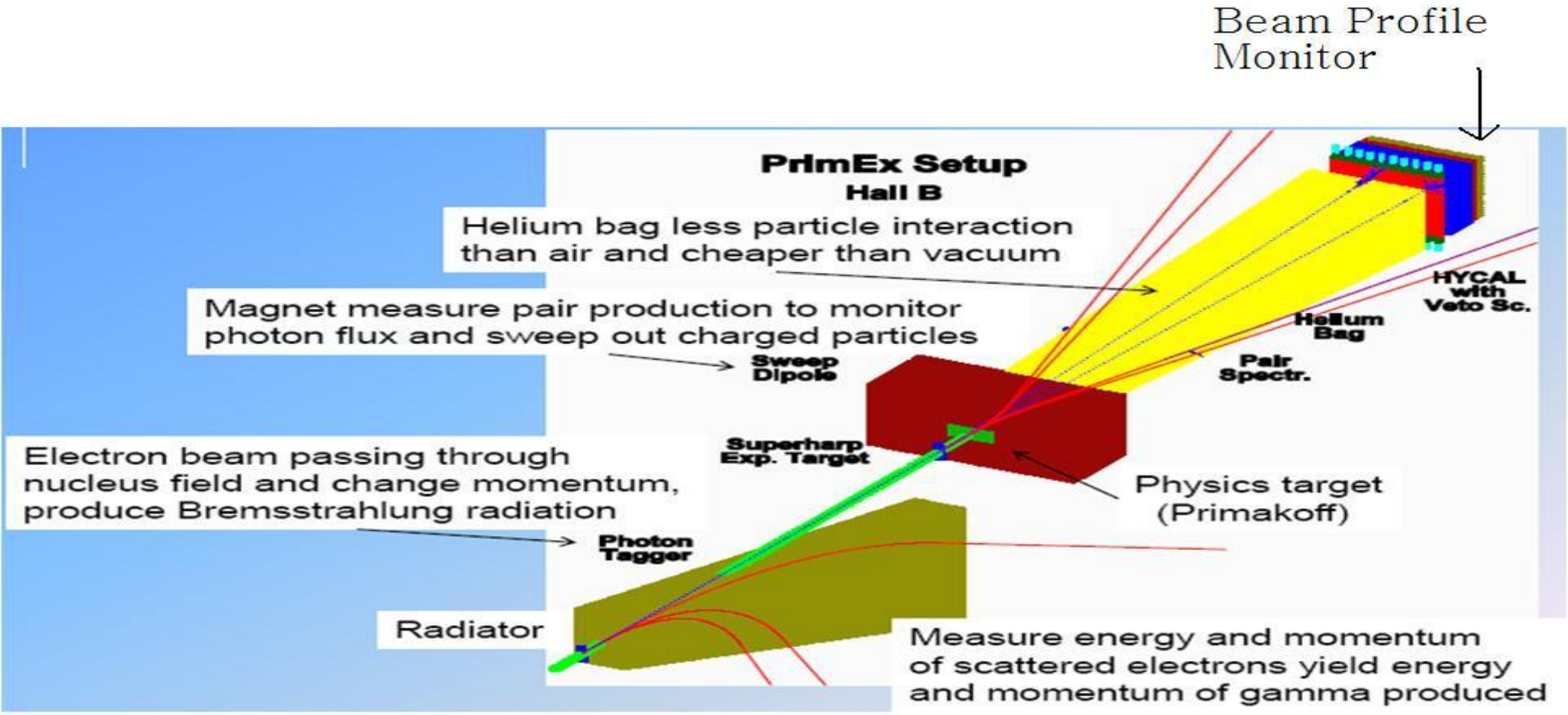
- Interaction With Thunderstorms
  - The mean muon flux intensity has been observed to decrease during and near thunderstorms
  - Lighting also effects the mean muon flux intensity during these thunderstorms

Energy Loss In The Atmosphere

- Ionization and excitation processes
- Brehmsstralung
- Photonuclear and photonucleon interactions
- Primary mode of energy loss for low energy muons (~ 6 GeV) is through Ionization and Brehmsstralung

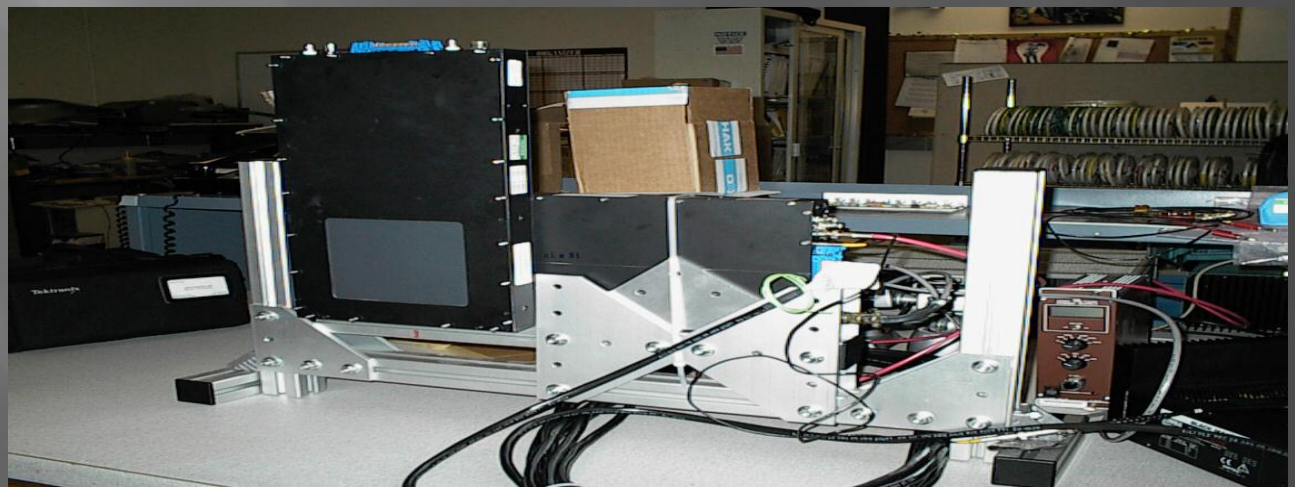
Testing the Beam Profile Monitor

- Thomas Jefferson National Laboratory
  - PrimEx Experimental Setup



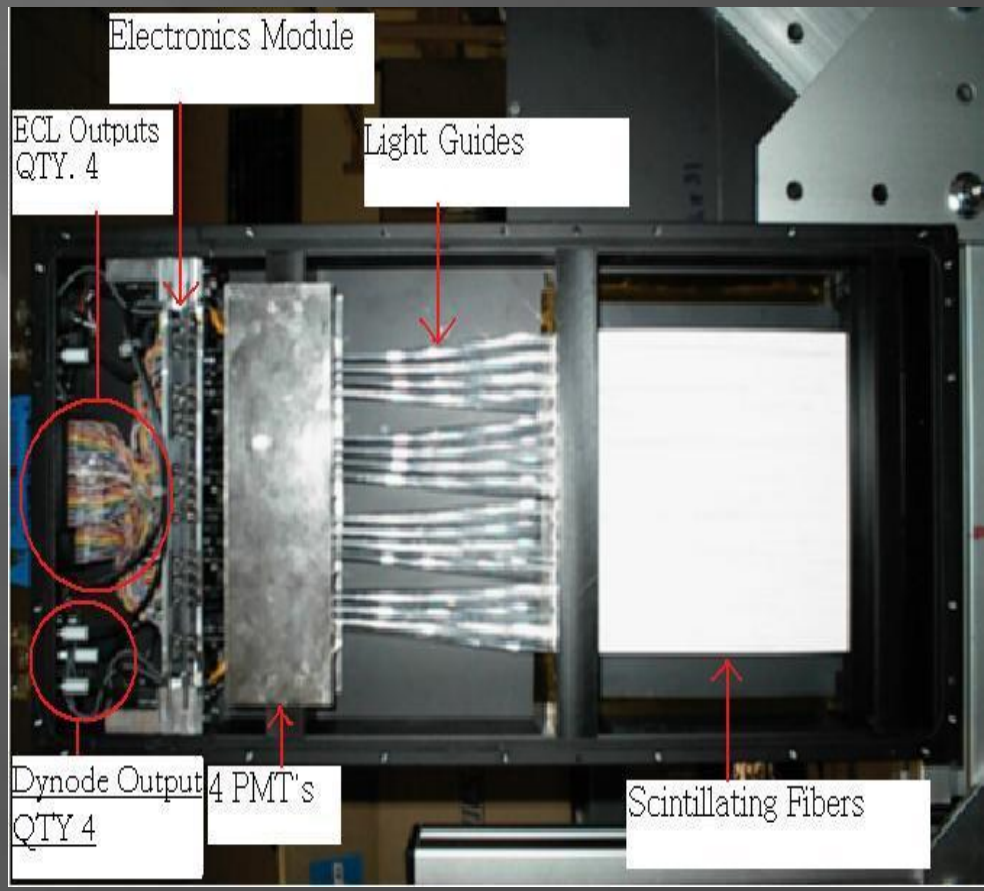
Testing Cont'd

- Purpose of the Beam Profile Monitor (BPM)
  - Determine the beam position and entrance angles as well as its' spatial and angular divergence
  - The detector is situated to measure the x and y coordinates of the incident photon beam (Horizontal and Vertical from the lab frame)



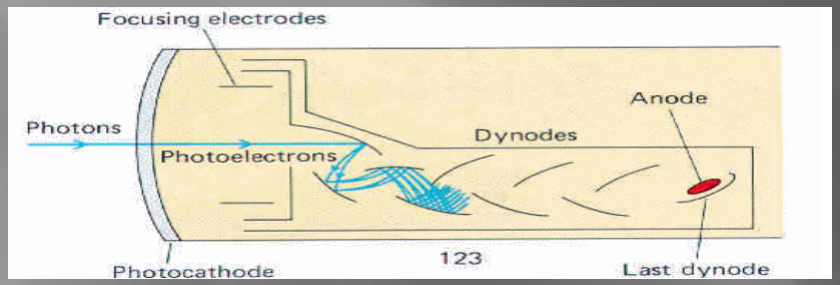
Testing Cont'd

- Internal structure of BPM (per module)
  - ~ 64 Scintillating Fibers (2mm x 2mm x 13 cm)
  - 4 groups of 16 light guides direct light into 4 photomultiplier tubes (PMT)
  - 16 anode signals per PMT are processed by a discriminator
  - One dynode signal per PMT

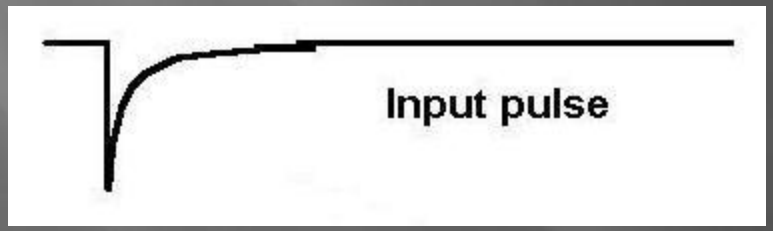


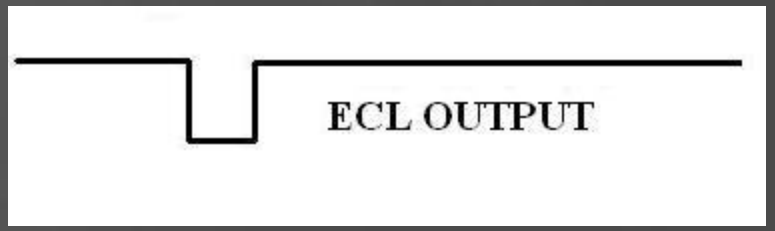
Testing Cont'd

- Photomultiplier Tube (PMT)



- Discriminator
  - Only allows anode signals that meet the prescribed parameters





Testing Cont'd

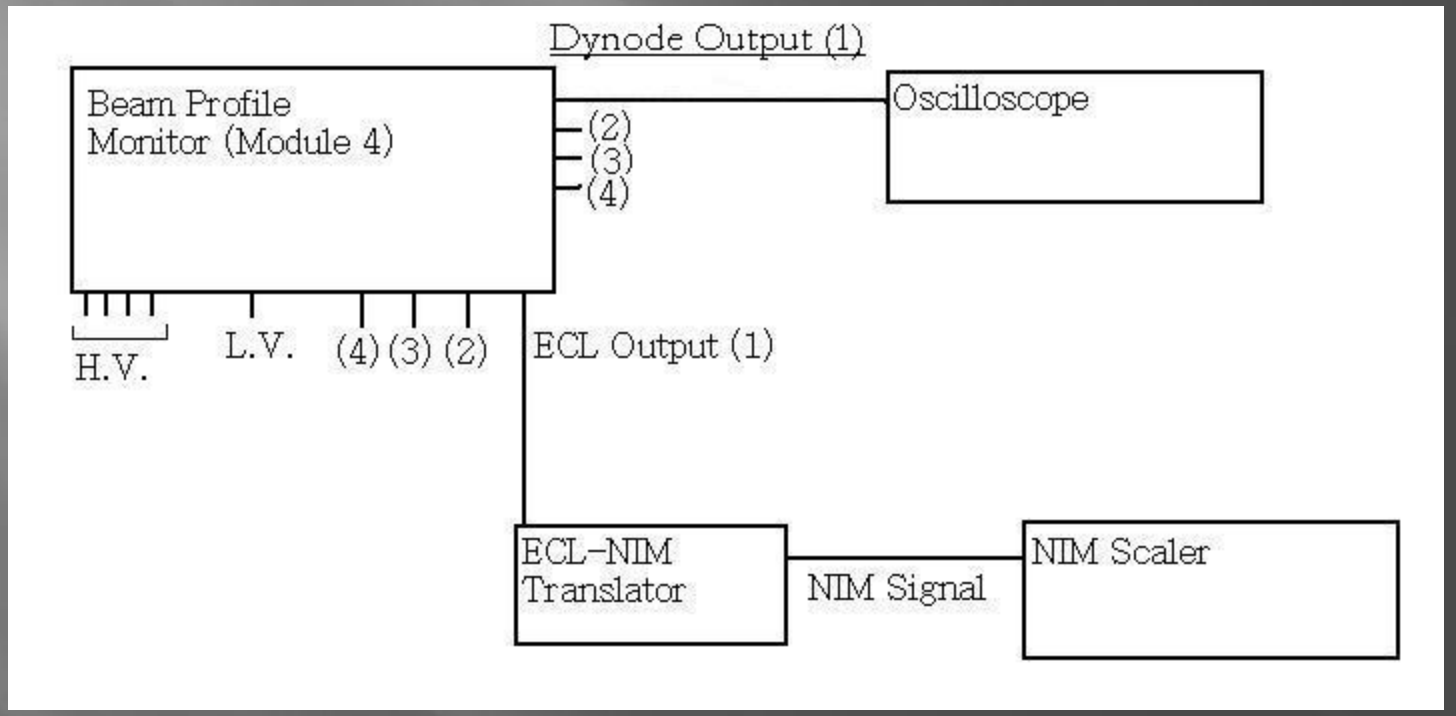
- ECL Output
  - Read on Scaler
  - Defined logical signal when event occurs
- Analog Output
  - Read on Oscilloscope
  - Shows a more detailed signal

Testing Cont'd

- Process
  - High voltage power supply ~ - 850 V per PMT
  - Low voltage power supply (electronic module)
  - Connect detector to Oscilloscope and Scaler

Testing Cont'd

- Setup

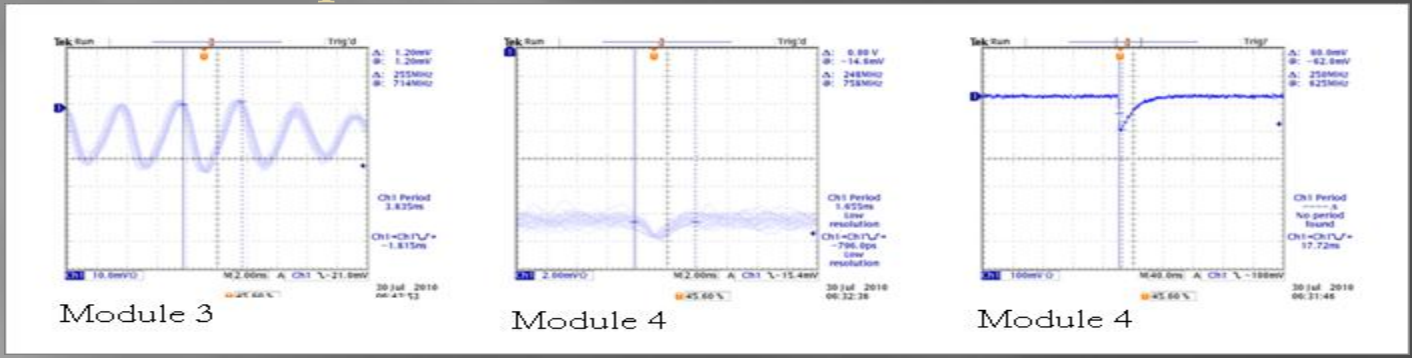


Testing Cont'd

- Process Cont'd
  - Ensure detector is free from light leakage
  - Check for faults
  - Measure event rate on the scaler and event amplitude on oscilloscope

Testing Cont'd

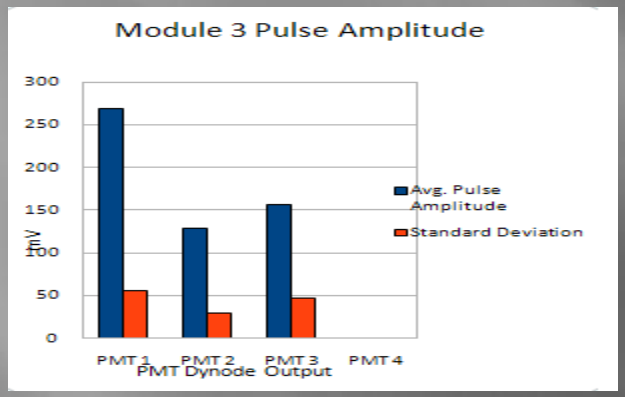
- Data Retrieved
  - Oscilloscope

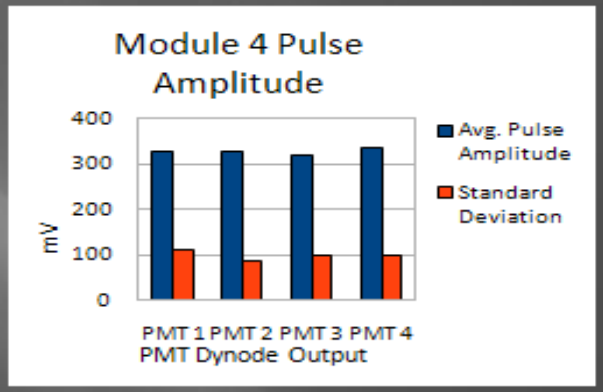


    - Significant electronic noise on module 3
      - Thermionic emission, leakage current
    - Significant after pulsing present
      - Residual gas, electrode glow
    - No light leakage

Testing Cont'd

- Confirmation of results

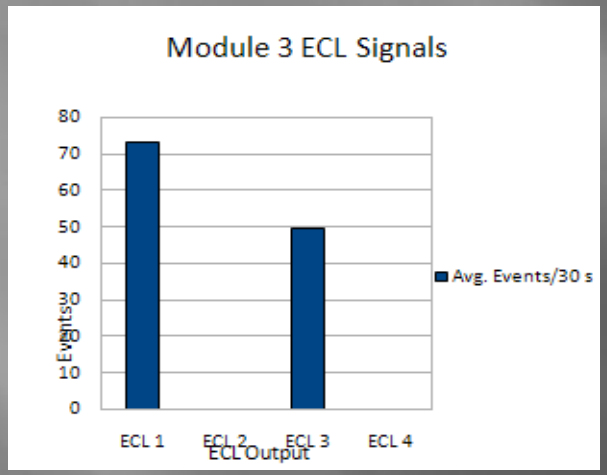


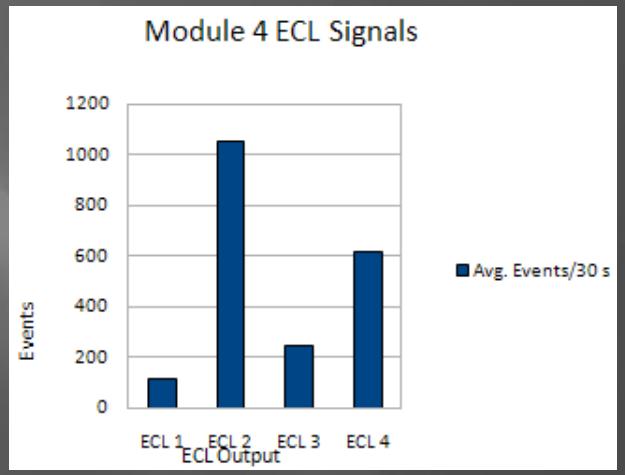


  - Strong detection and signal processing on all channels of module 4
  - Gain deficiency on module 3 PMT's
  - Further investigation required to determine exact cause of the problem

Testing Cont'd

- ECL Signals





- This data confirms the analog data

Testing Cont'd

- Summary of the test
  - PMT 4 on module 3 does not produce any signal
  - The discriminator for PMT 2 on module 3 requires adjustment
  - The high voltage power supply must be individually adjusted for each PMT on both modules
  - Each channel per PMT requires software calibration

Conclusion

- Muons are fundamental particles that interact via gravitation, electro-magnetism and the weak interaction
- Cosmic muons are produced when primary cosmic rays interact with earths atmosphere
- Muon flux and energy is effected by atmospheric conditions
- Muons are beneficial to modern scientific research