FLASH

FLuorescence in Air from SHowers
(SLAC E-165)

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Fluorescence from Air in Showers (FLASH)

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* Collaboration Spokespersons
Ultra High Energy Cosmic Rays

- Cosmic Rays have been observed with energies beyond $10^{20}$ eV
- The flux (events per unit area per unit time) follows roughly a power law: $\sim E^{-3}$
- Changes of power-law index at “knee” and “ankle”.
  - Onset of different origins/compositions?
  - Where does the spectrum stop?
Discrepancy Between Two UHECR Experiments

HiRes

AGASA

HiRes

AGASA

Flux*E^3 / 10^{24} (eV^2 m^{-2} s^{-1} sr^{-1})

log_{10}(E) (eV)
UHECR: From Source to Detector

Cosmic Microwave Background At 2.7 K

GZK limit on proton energy: $\sim 5 \times 10^{19}$ eV

Acceleration

Propagation

Detection
Greisen-Zatsepin-Kuzmin Cutoff

- Protons above $6 \times 10^{19}$ eV will lose sizable energy through CMB.
- Super-GZK events have been found with no identifiable local sources.
Extensive Air Showers

Primary Cosmic Ray

UV Fluorescent photons Isotropic Emission

Charged particles of Electromagnetic Shower

Cerenkov Radiation Forward Emission

Ground Array

Zoom on next slide
FLASH useful for future UHEC Experiments

- Ground-Based: The Pierre Auger Observatory
- Space-Based: EUSO, OWL/AirWatch

- Hybrid detection
- Relies purely on Fluorescence
Issues of Fluorescence

• Detailed shape of the fluorescence spectrum
  – Spectrally resolve fluorescence yield
  – Use narrow band filters or spectrometer

• Pressure dependence of the fluorescence yield
  – Total and individual line pressure dependence

• Effects of impurities on fluorescence yield
  – CO₂, Ar and H₂O

• Effects of electron energy distribution on yield
Importance of Spectral Distribution

- At large distances of up to 30 km, which are typical of the highest energy events seen in a fluorescence detector, knowing the spectral distribution of the emitted light becomes essential due to the $\lambda^{-4}$ attenuation from Rayleigh scattering.

Bunner (1967)
Previous Fluorescence Measurements

  - Compiled a spectrum from many sources.
  - Unknown systematic errors.
- F. Kakimoto et al., NIM (1996)
  - Measured 3 narrow band lines not a spectrum.
- M. Nagano, FIWAF presentation (2002)
Why Measuring Fluorescence at SLAC?

- Extensive Air Showers (EAS) are predominantly a superposition of EM sub-showers.
- FFTB beam-line provides energy equivalent showers from $\sim 10^{15}$ to $\sim 10^{20}$ eV.
  - $10^7$-$10^{10}$ electrons/pulse at 28.5 GeV.
Objectives

• Spectrally resolved measurement of fluorescence yield to better than 10%.
• Investigate effects of electron energy.
• Study effects of atmospheric impurities.
• Observe showering of electron pulses in air equivalent substance ($\text{Al}_2\text{O}_3$) with energy equivalents around $10^{18}$ eV.
THIN TARGET STAGE

• Pass electron beam through a thin-windowed air chamber.
  – Measure the yield over wide range of pressures at and below atmospheric.
  – Measure the total fluorescence yield in air.
  – Measure emission spectrum using narrow band filters or spectrometer.
  – Effects of N$_2$ concentration. Pure N$_2$ to air. Also H$_2$O, CO$_2$, Ar, etc.
FLASH Experimental Design

Thin Target Stage

- Electron beam passes (5x10^7-5x10^9 e^-/pulse) through a chamber of air. 1x1 – 2x2 mm beam spot.
- HiRes PMTs are used to measure the fluorescence signal.
- 1 cm gap well defined by interior tubes.
- Interior blackened and baffled.
FLASH Experimental Design

Thin Target Stage

- Opposing LED calibration source.
- Remotely controllable filter wheel.
- Post filter LED calibration sources (4)
- Signal PMT.
- Symmetric system allows for 2 of each.
FLASH September 2003 Run
Background Subtraction

ADC Counts In Dry Air Measured On North Side
FLASH September 2003 Run
Fluorescence Spectrum Using Filters

Spectrum In Dry Air Measured On North Side

P > 200 torr
FLASH September 2003 Run

Effect of Humidity

Dry (red) vs SLAC (blue) Air as Measured on North Side (ADC + Filter + QE)

P > 200 torr

Around 5% lower but within error. Expectation from Theory is that 1% H$_2$O gives 6% reduction in yield.

SLAC Air is 1.3 % H$_2$O.
FLASH September 2003 Run
Effect of Contamination

Luminescence yield versus pressure

yield: PMT \(_{s} \) / \( N_{e} \) \( \gamma/e^-/m \)

\( 0.0e+000 < N_{e} <= 1.0e+009 \)

- **pure \( N_2 \)**
- **75% \( N_2 \)**
- **60% \( N_2 \)**
- **50% \( N_2 \)**
- **25% \( N_2 \)**
- **pure dry air**

Pressure [torr]
FLASH Spectrograph

To cross check the fluorescence spectrum measurement made using narrow band filters.

Almost zero noise. Noise looks like Bunner!
Preliminary result: A few calibrations still pending.
FLASH September 2003 Run
Pressure Dependence of Spectrum

Dry air: Fraction of photons in various wavelength bands
FLASH Future Runs

• We have two more runs scheduled for June and July of 2004. Both runs will be in thick target mode (described briefly on next slides).

• The third run may be a simultaneous run of thick target and spectrograph system.
FLASH Experimental Design

Thick Target Stage

- We will shower the FFTB beam through a range of shower depths in air “equivalent” material (Al₂O₃).
- Do shower models correctly predict the fluorescence signal?
- Does the signal deviate from dE/dx?
- Are there any visible effects from the change in the distribution of electron energy?
FLASH Experimental Design

Thick Target Stage

• In addition to effects caused by impurities in the air (humidity) we also plan to study the effects of the electron energy distribution.

• $10^7$ e$^-$ showering at 30 GeV approximately reproduces a $3 \times 10^{17}$ UHECR shower (near shower max).

• 2, 6, 10, and 14 radiation lengths.
Conclusion

• We have measured the spectrum and total yield of air fluorescence.
• We expect to resolve the spectral shape very well with our combined method of narrow band filters and spectrograph.
• Works on calibration and systematics are ongoing.
• We expect a total systematic uncertainty of 10%.
• Thick Target runs coming soon (next week!)