National Aeronautics and Space Administration

Second (S)uper (F)luorescence (A)ir (SH)ower experiment, sFLASH2, at SLAC National Accelerator Laboratory

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Program: Spontaneous Concepts

Project Objective:

To study the air fluorescence yield (FY) dependence on the air shower (secondary cascade) peak energy by using an alumina (Al_2O_3) target from 0 to 10 radiation lengths (RL) of thickness radiated by 10 GeV electron beam with up to 0.25 nC charge/bunch (equivalent to ~ 10^{18} eV air shower). If the dependence is confirmed, it will have to be taken into account when measuring energy of ultra-high energy cosmic rays (UHECR) using air fluorescence technique.

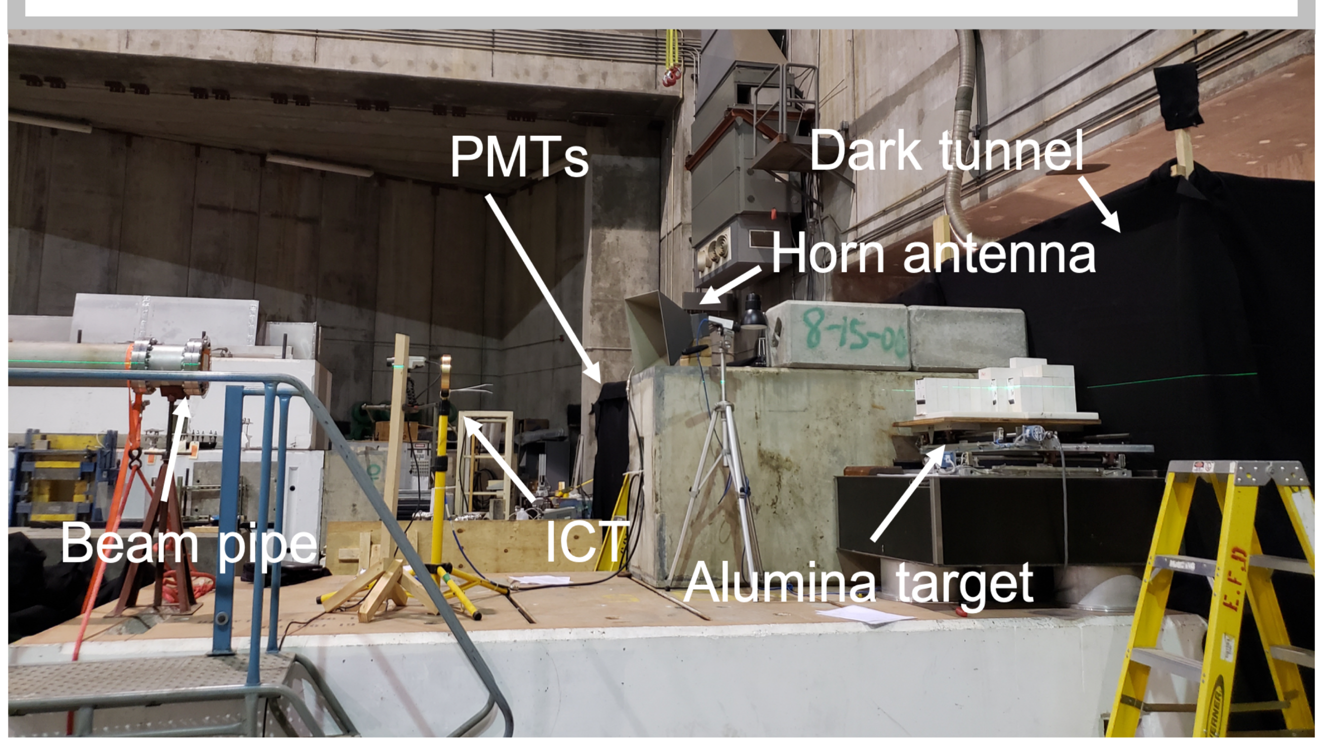

Figure 1. sFLASH2 experimental setup.

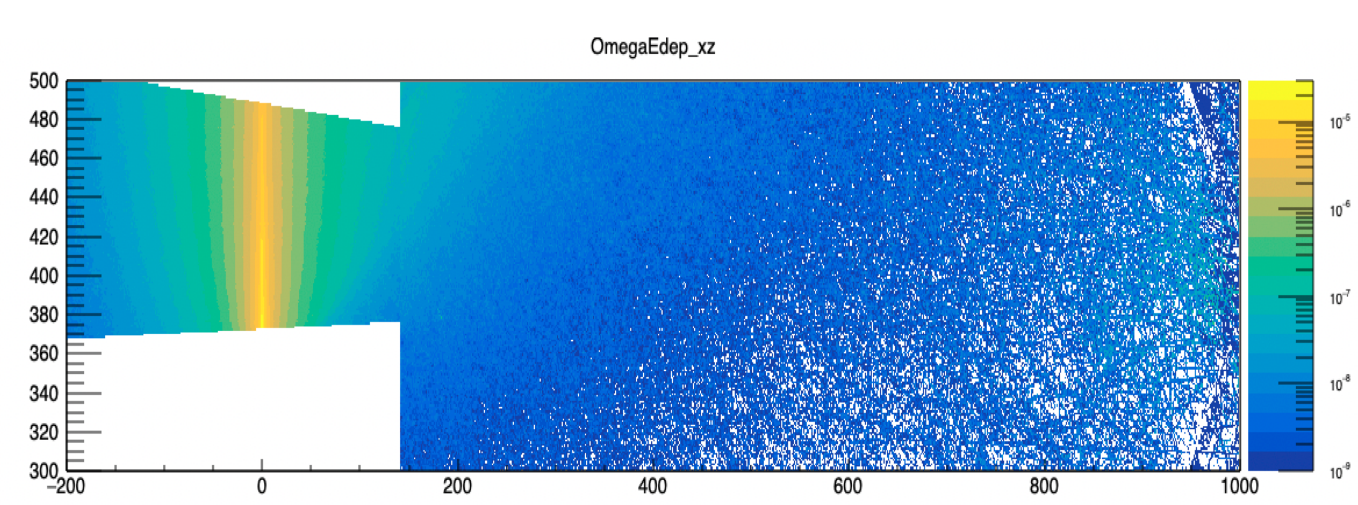

Figure 2. Air shower energy deposit from GEANT4 MC simulations.

FY18/19 Results:

sFLASH2 was conducted at SLAC in November of 2018, see Figure 1.

An alumina target was placed at the end of the beam pipe to allow the secondary cascades to pre-shower. The cascades than exited the target into 7 m of the open air and the fluorescence photons were measured by a UV-sensitive photomultipler tubes (PMTs) located 13 m from the beam axis – far enough to reduce the radiation background noise. Low 1 Hz repetition rate further reduced the radiation background allowing up to 10 RL target without triggering the radiation safety switches.

The beam charge was monitored by an Integrated Charge Transformer, ICT, and an S-band horn antenna measuring the transition radiation at the beam pipe exit. This setup provided shot by shot beam charge measurements with <1% uncertainty. The accurate measurement of the beam charge is essential for this experiment as it directly contributes to the systematic error.

Air fluorescence yield (*AFY*) is determined as $\frac{N_p}{N_e E_{dep} \Omega}$, where N_p is the number of photons measured by a PMT, N_e is the number of the electrons in the beam (beam charge) measured by ICT, E_{dep} is the total energy deposited into the solid angle Ω, calculated from ray tracing. The energy deposition is determined from an extensive Monte Carlo simulations. We used GEANT4 and FLUKA packages in order to validate the simulations and to estimate the systematic uncertainty on the modeling. An example of the energy deposition calculations using GEANT4 is shown in Figure 2.

The air shower size (number of particles) as the function of the target thickness is shown on the plot in Figure 3. The shower reaches maximum, X_{max}, at around 4.5 RL.

The preliminary result of the air fluorescence yield dependence on the air shower peak energy (target thickness) is shown on the plot in Figure 4. The *AFY* dependence on the shower size is clear, thanks to sFLASH2 small systematic errors. It is also important that sFLASH2 was able to reproduce the sFLASH results from 2016, demonstrating stability of the experimental setup.

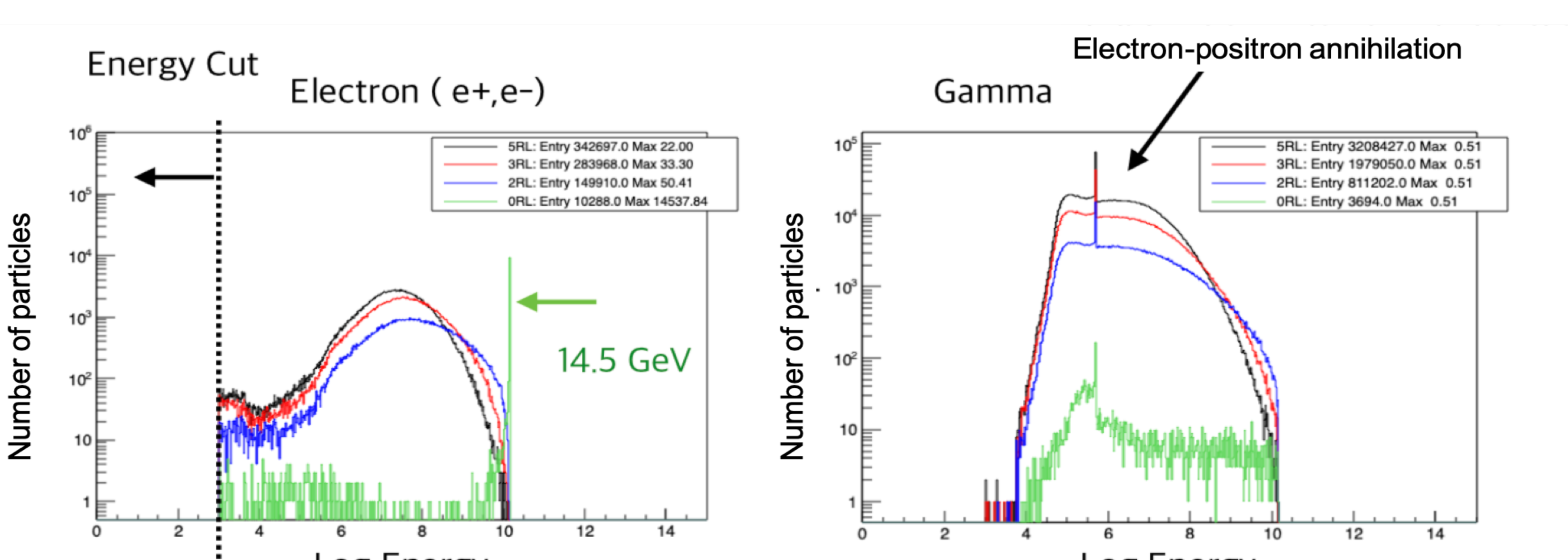

Figure 3. Air shower size for different target thicknesses.

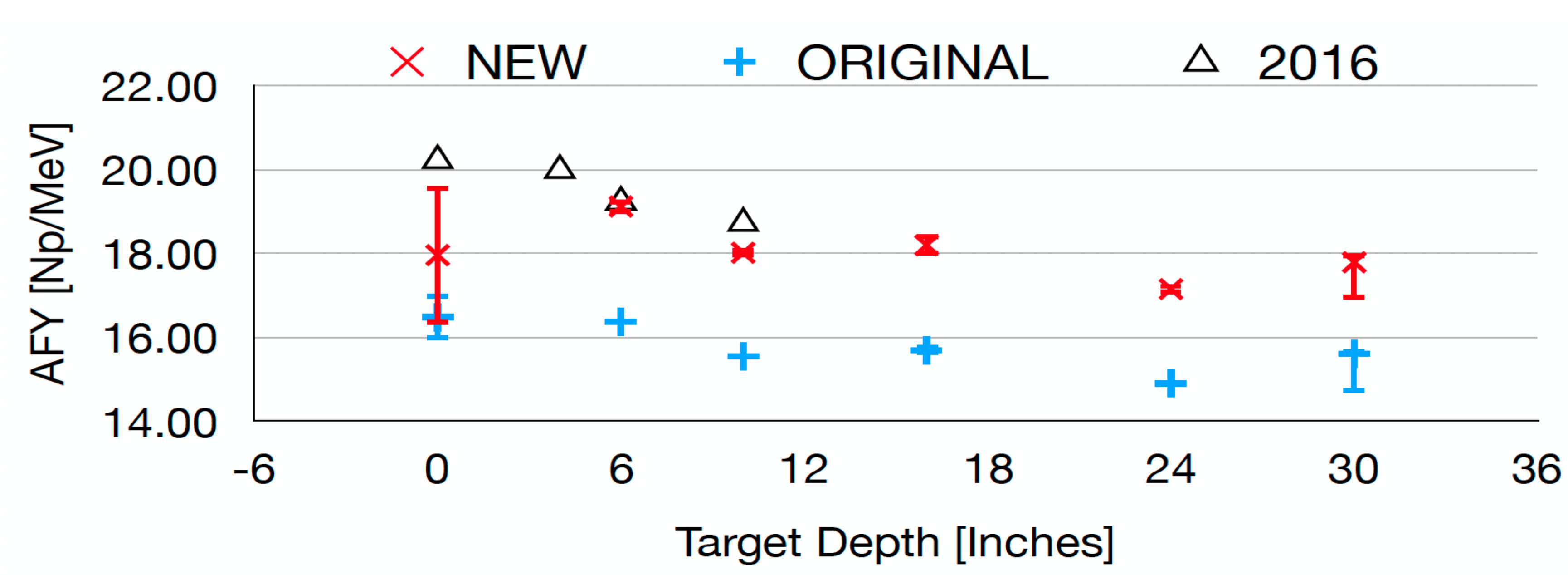

Figure 4. AFY vs air shower size (target thickness). Red –sFLASH2, blue-sFLASH2 uncalibrated, 2016 – sFLASH result from 2016 run.

Significance of results:

sFLASH2: 1. demonstrated air fluorescence yield dependence on air shower size; 2. reproduced the sFLASH results validating the experimental setup; 3. reduced the uncertainty of the air fluorescence yield measurements.

This result will be directly applied to energy measurements by existing ultra-high energy cosmic ray observatories using air fluorescence technique like Auger [1] and Telescope Array [2], as well as by the future space-based observatories like POEMMA [3], which should help to answer the question about the origin of cosmic particles with the highest energy known to humans. The uncertainty of the air fluorescence yield is the largest contributor to the uncertainty of the cosmic ray energy measurements. Reducing this uncertainty will reduce the error in estimation of the cosmic ray deflection by the galactic and extragalactic magnetic fields, helping to pinpoint the locations of the objects in the Universe that produce the particles with such an extreme energy.

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References:

1. Pierre Auger Observatory, https://www.auger.org
2. Telescope Array Observatory, http://www.telescopearray.org
3. Anchordoqui, Luis A. et al., "UHECRs with POEMMA", https://arxiv.org/abs/1907.03694

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