



# Cosmic Ray Program

## High School Long-term Collaboration Using HEP Model

Inquiry-based learning with authentic research tasks.

Of **52** centers, **47** have hundreds of detectors (CRMDs) for experiments: muon flux; lifetime; speed.

### Fermilab Support for QuarkNet – 3 Half-Time Positions:

- Cosmic ray coordinator/fellows liaison (Mark)
- Hardware support: Cosmic Ray Muon Detector (CRMD)(Dave)
- IT & e-Lab analysis tools support (Edit)
- Seed money for Cosmic Watch prototype



# Maintenance & Growth

## Long-term Options

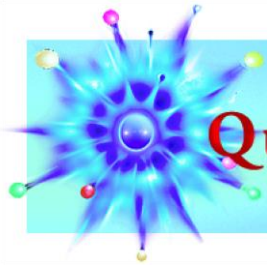
### CRMDs – Maintain current level

- Recycle and re-assign CRMDs for QuarkNet teachers.
- CRMDs are robust and sophisticated.

**e-Lab – EQUIP->PyEQUIP; analyses; jupyter n.b.**

### Cosmic Watch

- Build classroom audience with simpler intro activities.
- Not a substitute for CRMD.
- 48 built at Notre Dame.
- Field testing prototypes with fellows.



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## **“International” CR Efforts?**

### **Non-QNet Center Activities – both Int’l & U.S.**

#### **Participation in Meetings – community PR value**

- **IPPOG Global Cosmics**
- **Ken’s QuarkNet-like Groups (India; Japan; Taiwan; Africa)**

#### **Licensing of DAQs and hardware support**

- **Fermilab/QuarkNet brand DAQ in the field**
- **DESY - 100 DAQs used with their own muon counters**

#### **Participation in Data Activities**

- **International Cosmic Day and International Muon Week**
- **Pyramid imaging project**



# Usage Last Four Years

## Three Eras: Pre-COVID – COVID – 2022

March 20: COVID-19 – Very limited access to CRMDs; teachers in survival mode.

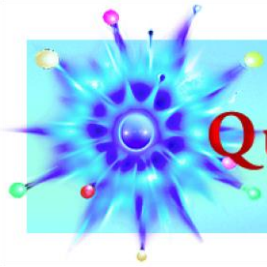
DAQ/Uploads Comparison for 7-Month Periods Apr.–Oct.:

- Pre-COVID Apr.–Oct. 2019 **66 DAQs/2,173 uploads**
- COVID Apr.–Oct. 2020 **27 DAQs/2,733 uploads**
- 2021 Apr.–Oct. 2021 **42 DAQs/2,871 uploads**
- 2022 Apr.–Oct. 2022 **55 DAQs/3,513 uploads**

Analyses run during Octobers:

- In Oct 2020 **2,182** analyses from **26** DAQs
- In Oct 2021 **4,300** analyses from **30** DAQs
- In Oct 2022 **5,005** analyses from **34** DAQs

**Conclusion: During COVID, there were fewer, but more active, users! Constantly improving.**



**QuarkNet**

# Future & Special Projects

## Cosmic Ray Fellows & Staff Spawn Exciting Projects

International Muon Week Low participation in 2022 – **Fellows are building 2023 audience via monthly detector help sessions & videos.**

Inexpensive detector (Cosmic Watch) – beginner classroom (ND FNAL) **Fellows created activities, testing first prototypes for hardware issues.**

Storm Tracking (KSU; UPRM; HI)

Solar Eclipse 2017 (U.S. Centers) Improving technique for total eclipse in 2024

Moon Shadow (UIC)

MUSE 2019 – Cosmic Rays in MINOS tunnel (UIC) Links CR and neutrinos.

Fellows developed virtual workshops; expand use of curated data

Post-Processing – More complex analyses with Coding Fellows, Jupyter notebooks - **Fermilab HS Interns created upward muon search in 2022.**

Pyramid Archaeometry at Chichen Itza (CSU; DU)



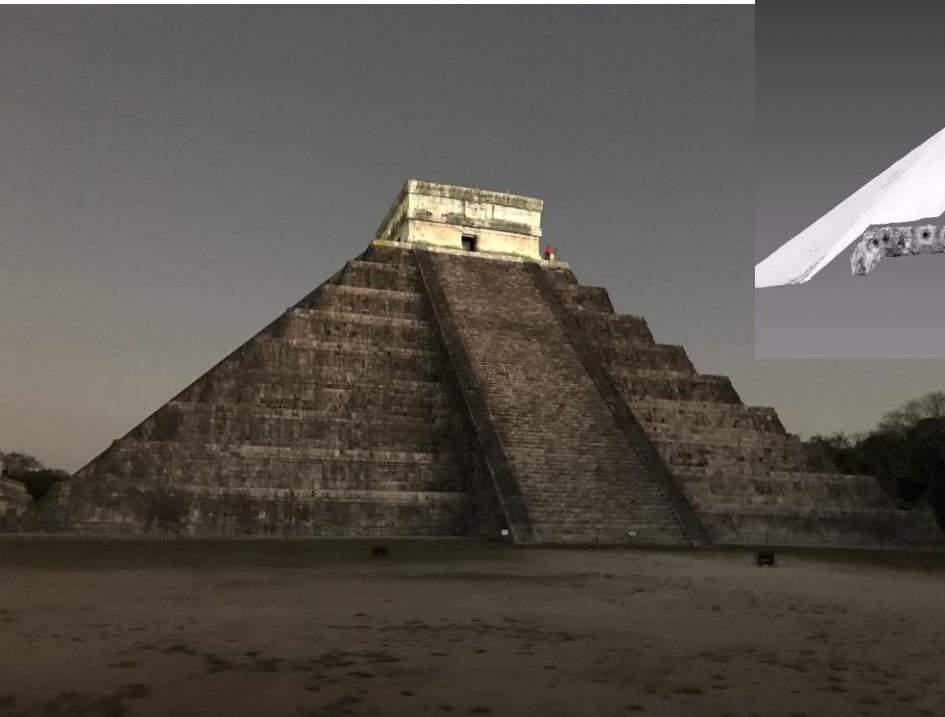
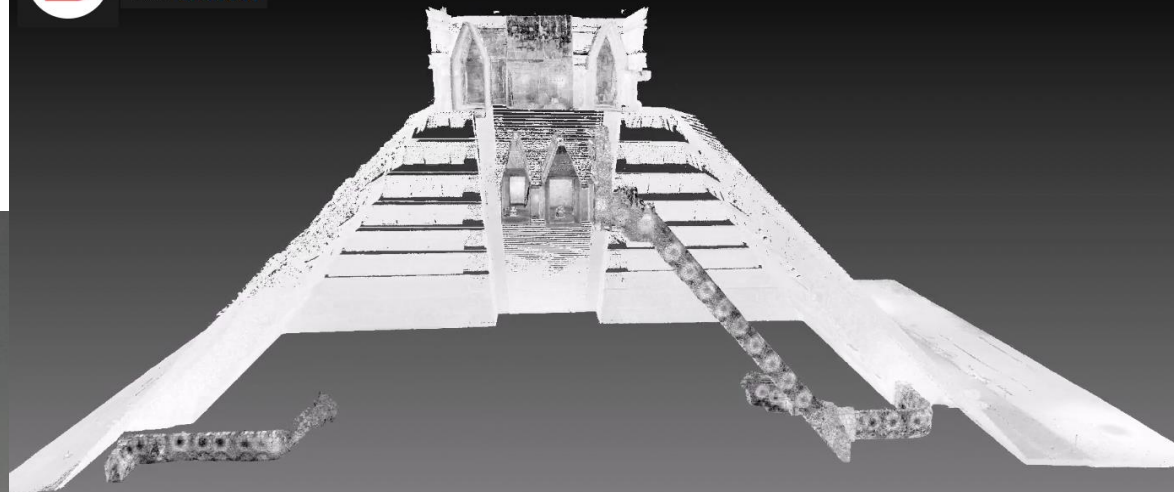
# QuarkNet collaborates with NSF Muography Project

QuarkNet plans to host data on e-Lab and develop displays and public analyses.

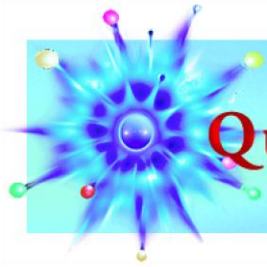


Chichen Itza - El Castillo Point Cloud Flythrough

from Skender



Search for hidden chambers



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# **Cosmic Rays – International**

## **Global Outreach Activities**

**IPPOG – Global Cosmics follows masterclass examples.**

**International Cosmic Day (DESY) in November.**

**International Muon Week (QuarkNet-Fermilab) in March. (fellows run)**

**Eclipse Project 2017 (30 U.S. high schools plus several non-U.S. locations)**

**Teacher presentations at AAPT, ICRC 2019, 2021, and 2022.**

## **DAQ Licensing (Goodwill for FNAL)**

**400 DAQs in 31 countries used for outreach & research.**

**Uploads from 92 DAQs in 27 countries.**