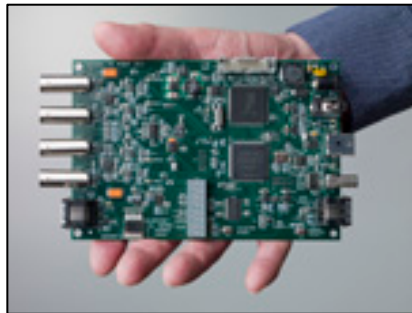




# Cosmic Ray Studies I

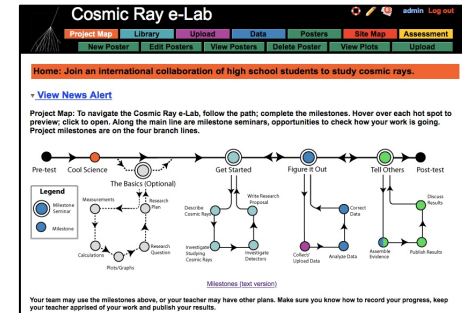
## QuarkNet Student Investigations



DAQ



Detector



e-Lab

Marge Bardeen  
Fermilab



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science



QuarkNet

M. Bardeen, Cosmic Ray Meeting, February 2017



# What is QuarkNet?

**QuarkNet ([quarknet.i2u2.org](http://quarknet.i2u2.org))**

**A long-term national professional development  
program for U.S. high school physics teachers  
supported by the  
particle physics research community**

**50+** centers at universities and labs across the U.S.

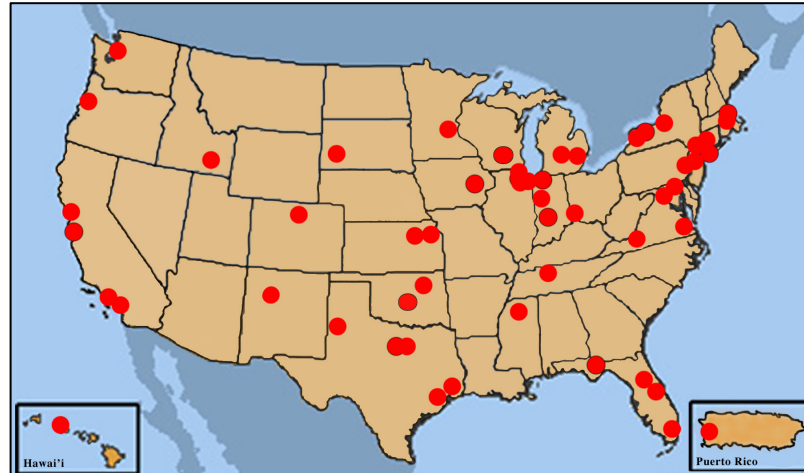
**82** physicists as volunteer mentors

**563** active teachers & their students

**+ International outreach**



# What is QuarkNet?



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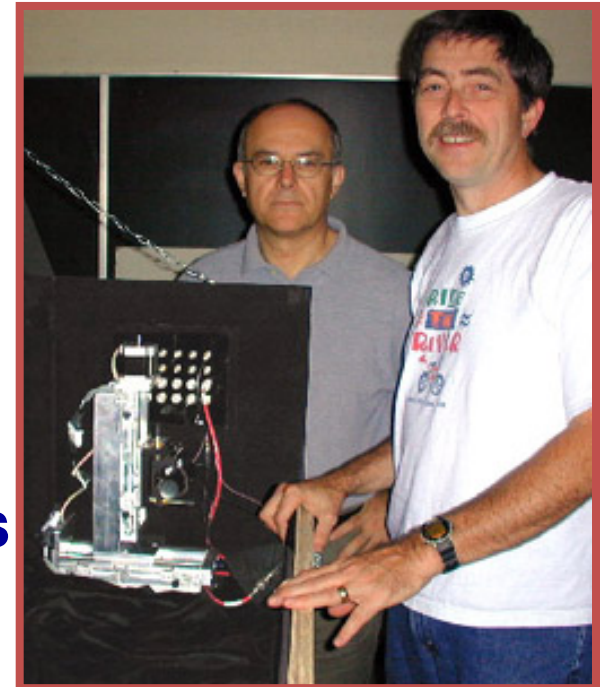
**+ International outreach**



# QuarkNet Program

## Engagement with Scientific Investigations

- Building long-term relationships
- *Research internships*
- *Research-based workshops*
- Masterclasses
- *Cosmic Ray Studies*
- Instructional materials
- Access to authentic online datasets
- Ongoing support





# Research Opportunities

## Experiencing the Environment of Scientific Collaboration



- **Joining research teams**
- **Making real contributions to experiments**
- **Learning how scientists make discoveries**

Who:	<u>Teachers</u>	<u>Students</u>
How Long:	<b>8</b> weeks	<b>6</b> weeks, typically
When:	Year 1 - <b>2</b> teachers/center Years 3+ <b>1</b> teacher with (up to 25 teams per year)	<b>4</b> -student team





# Research Opportunities

## Attending Research Scenario Workshops

- **Jumping in to learn by doing science**

Who: Teachers

How Long: **2–3** weeks

When: Year 2 - **~8** teachers/center

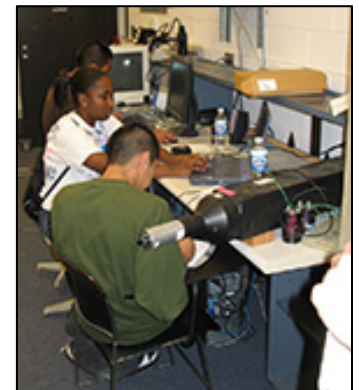
Students

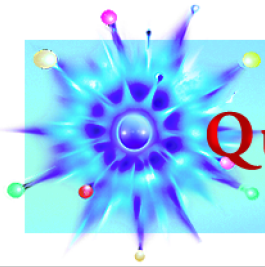
**1** week, typically

Year 3+



Future  
detector  
experts





**QuarkNet**

# **Cosmic Ray Studies**

## **Education Program**

**High school students develop their own research questions, conduct investigations, analyze data & reports results.**

### **Materials Include:**

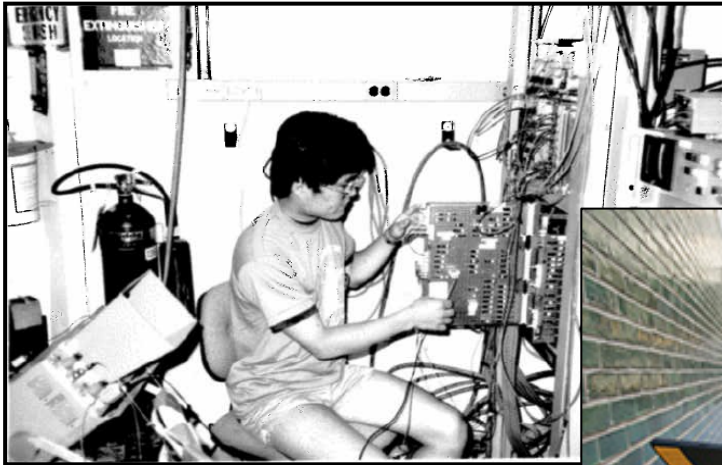
- **Hardware – portable & configurable**
- **Data Analysis Tools – online, browser-based**
- **Cosmic Ray e-Lab – instructional tool for teachers**
- **Professional Development – workshops & help desk**



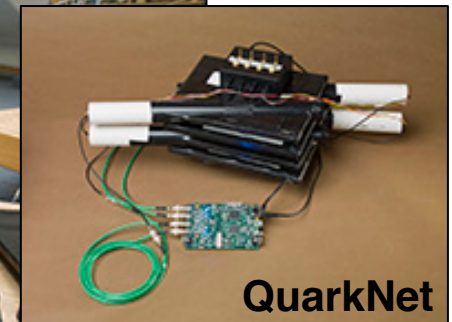
# Hardware

## Something Old: Something New

1988



1999







# Hardware

## Detector Kit



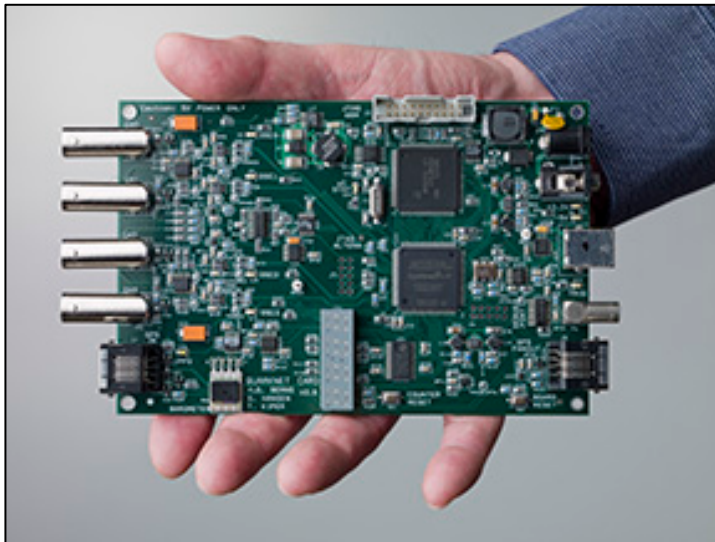
**4 counters w/PMTs**  
**Power box (low voltage)**  
**DAQ (developed by FNAL)**  
**GPS w/antenna**  
**Temperature & pressure sensors**  
**Cables**  
*(Raspberry Pi w/EQUIP)*

DAQ creates formatted message sent to a computer & collected in text data file through USB interface. EQUIP computer commands set parameters for each investigation, monitor data stream & display parameter settings & other info.



# Hardware

## Detector Kit

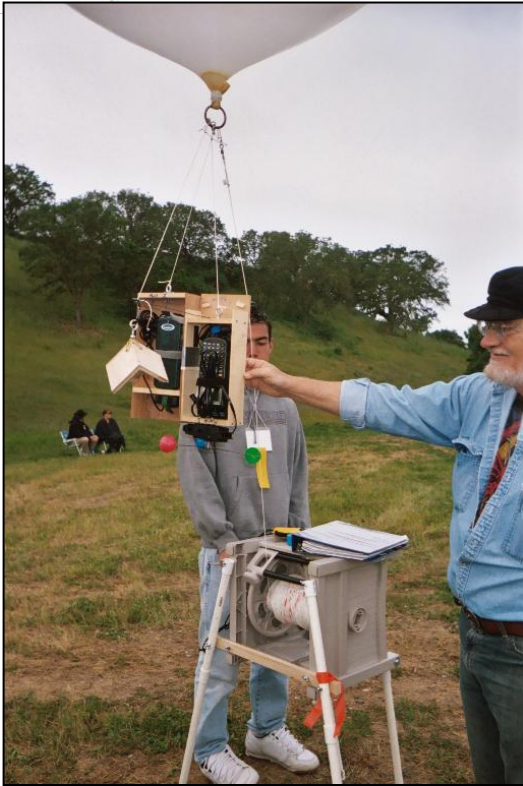


**4 counters w/PMTs**  
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# Where are the 840 DAQs?



- 260 detectors deployed in QuarkNet
- 450 in 32 countries:
  - Education - 294
  - Science
  - Museums - 13
- 130 in inventory





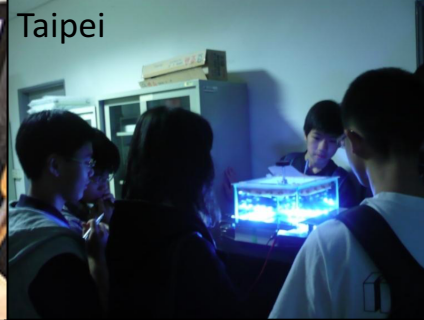


# Users World-Wide

Vancouver



Taipei



Cincinnati



Radley College UK



Addis Ababa

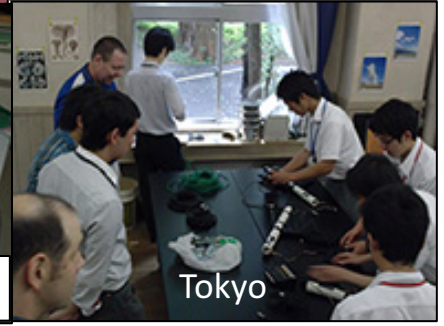
U.S. Congress



Tbilisi



Thailand

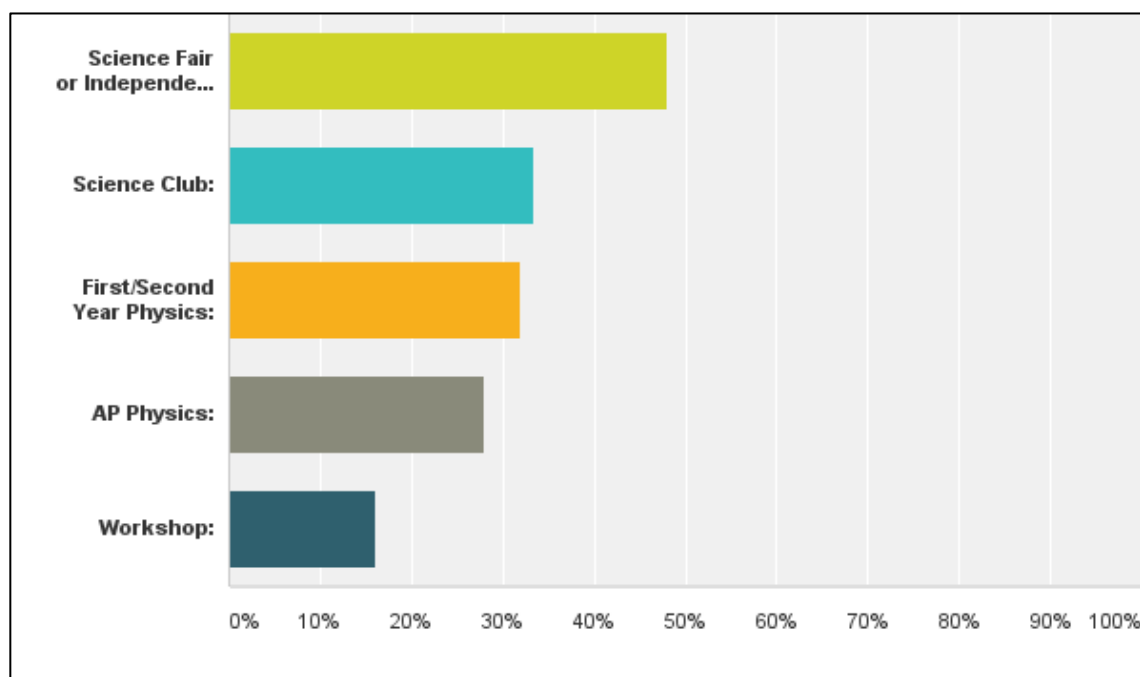


Tokyo



# Usage in QuarkNet

## Which students used the detectors.



47% of the students uploaded data.  
25% used data from other schools.





# Cosmic Ray e-Lab

## e-Lab

### Enables:

- Guided inquiry
- Data sharing
- Flux, shower, lifetime, time-of-flight studies
- Sharing with posters
- Global collaboration




**Students draw conclusions supported by evidence and provide reasoning.**








Helping Develop America's Technological Workforce

# Cosmic Ray e-Lab

**Cosmic Ray e-Lab**    admin Log out



Project Map Library Upload Data Posters Site Map Assessment

Text Version Cool Science About Us

**Cosmic Ray e-Lab**    admin Log out

Project Map Library Upload Data Posters Site Map Assessment

View Data Performance Flux Shower Lifetime T of F View Plots Analyses

**Cosmic Ray e-Lab**    admin Log out

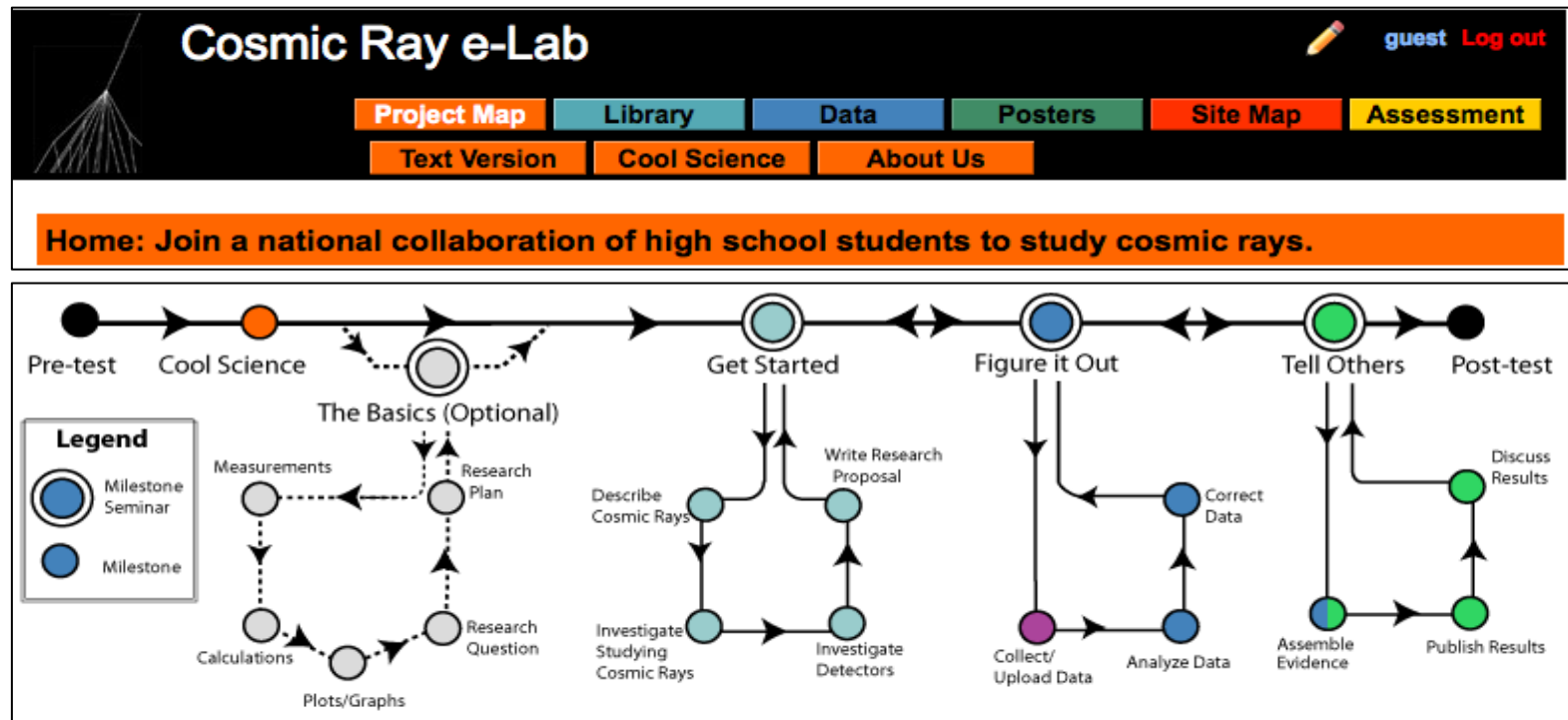
Project Map Library Upload Data Posters Site Map Assessment

New Poster Edit Posters View Posters Delete Poster View Plots Upload



QuarkNet

# Guided Inquiry



We jumped in deep with this *exploration* of the data.



QuarkNet

# Guided Inquiry

**All Entries**

- ☐ if entry exists
- ☐ if new comment exists
- ☐ [general](#)

**Milestones from Research Basics and Study Guide**

- ☐ [Research Basics](#)
- ☐ [measurements](#)
- ☐ [calculations](#)
- ☐ [graphs](#)
- ☐ [research question](#)
- ☐ [research plan](#)

**A: Get Started**

- ☐ [cosmic rays](#)
- ☐ [cosmic ray study](#)
- ☐ [detector](#)
- ☐ [research proposal](#)

**Milestone: Describe cosmic rays in simple terms.**

Scientific research involves observing nature to learn new facts or test applications of theories to known facts. Scientists write a proposal to get support for their research projects.

You live in a continuous shower of cosmic ray muons. What are they? Where do they come from? Where do they get all that energy? Some background reading will tell you what we know.

[Wikipedia](#) is a good place to start.

As you begin your research, you should get used to keeping daily notes in a logbook. Check to see if you should be using our **e-Logbook**.

[Leo's Logbook](#) - Scientific logbooks are bound so that the pages cannot be lost or removed. The pages are numbered also, so that if the book is photocopied, it is easy to reassemble the copies in the right order. The paper is of high quality so that this record will last for many years. There have actually been cases where patent rights of considerable commercial value have been assigned in court on the basis of logbook records.

Now, write your own description of cosmic rays in your logbook.

**Logbook**

**Logbook Entry for Group "admin"**

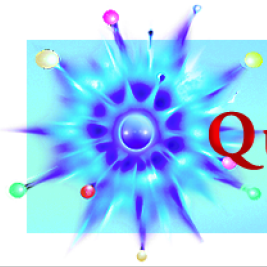
[View Instructions](#)

Your New Log Book Entry

No entries for "cosmic rays: Description of cosmic rays in simple terms."

[Plots/Graphs](#)

We jumped in deep with this *exploration* of the data.



**QuarkNet**

# **Professional Development**

## **3-Day Workshop: CR 101**

### **Student Hat**

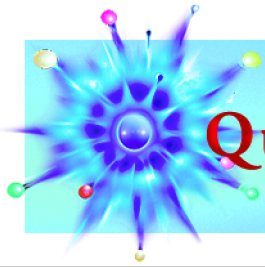
- **Assemble detector.**
- **Take data overnight.**
- **Use analysis tools.**
  - **Upload data.**
  - **Analyze data.**
  - **Create plot.**
  - **Create poster.**
- **Conduct mini-project.**

### **Teacher Hat**

- **Reflect each day.**
- **Present results.**
- **Develop classroom plan.**
- **Share plan.**

**We also offer CR 102.**





**QuarkNet**

# Professional Development

**To be successful teachers need to be:**

- **Confident** - to use the detector and analysis tools.
- **Comfortable** - to step back.
- **Clever** - to convince administrators.

**Our *Data Portfolio* offers a broad approach.**

**A range of student engagement:**

**Introduction – Survey – Investigation – *Exploration*  
*e-Lab***



# Data Portfolio

## QuarkNet Data Portfolio

### Cosmic Ray

Activities are based on techniques that physicists use to make discoveries. We have included activities that use data from Cosmic Ray studies and activities that help students explore the concepts in this experiment.

#### Filter Activities

Level Next Generation Science Standards (NGSS)

<Any>

<Any>

Apply

Topic

<Any>

#### Activity Name

Data Strand

Level

NGSS Practices

Topic



#### Calculate the Top Quark Mass (3 comments)

Students use conservation laws and vector addition to calculate the top mass from event displays.

Cosmic Ray, LHC

Level 1

1 4 5 7

Data Analysis, Momentum Conservation



#### Quark Workbench (3 comments)

Students use Standard Model rules to build hadrons and mesons from quarks.

Cosmic Ray, LHC

Level 1

2 6

Particle Composition



#### Mass of U.S. Pennies (0 comments)

Students create and interpret a histogram of penny masses.

Cosmic Ray, LHC

Level 1

1 3 4 7

Data Analysis, Measurement



#### Rolling with Rutherford (5 comments)

Students use statistics to make an indirect measurement they can easily confirm.

Cosmic Ray, LHC

Level 1

1 3 4 7

Data Analysis, Measurement



#### Dice, Histograms & Probability (0 comments)

Students roll dice, record the resulting individual values as well as the sum of the values, create histograms of the data.

Cosmic Ray,

Level 1

1 2 3 4 5 6

Data Analysis,

#### View by Data Strand

- Cosmic Ray
- LHC
- LIGO

#### View by Level

- Level 1
- Level 2
- Level 3

#### Recently Read

Nothing has been read yet.



# e-Lab Data Interface

## Cosmic Ray e-Lab



admin Log out

Project Map

Library

Upload

Data

Posters

Site Map

Assessment

View Data

Performance

Flux

Shower

Lifetime

T of F

View Plots

Analyses

### Data: What can you learn? Choose data and conduct a study

#### Analysis

[Performance Study](#) - Look at data from a detector. Is the data reliable?

[Flux Study](#) - The shower of particles has many interesting properties including its [flux](#). Are there more in Colorado than there are in South Carolina?

[Shower Study](#) - One can detect an air shower using the four counters at school. Colleagues at other schools can check for coincident showers. One may contribute to cutting-edge research on the origin of high-energy primary cosmic rays.

[Lifetime Study](#) - How long before muons decay? Students can combine a lifetime study with flux studies to determine if they live in Newton's or Einstein's world.

[Time of Flight Study](#) - Using the TOF analysis module, one can measure the average time muons take to travel between two counters and then calculate the average speed.

#### Management

##### VIEW

[Data Files](#) - See what data has been uploaded into the system.

[Plots](#) - Look at what you and other groups have found!

##### DELETE

[Data Files](#) - Delete data your group has uploaded.

[Plots](#) - Delete plots your group owns.

[Delete External Data](#) - Delete uploaded data.

#### CRMD Data Collection

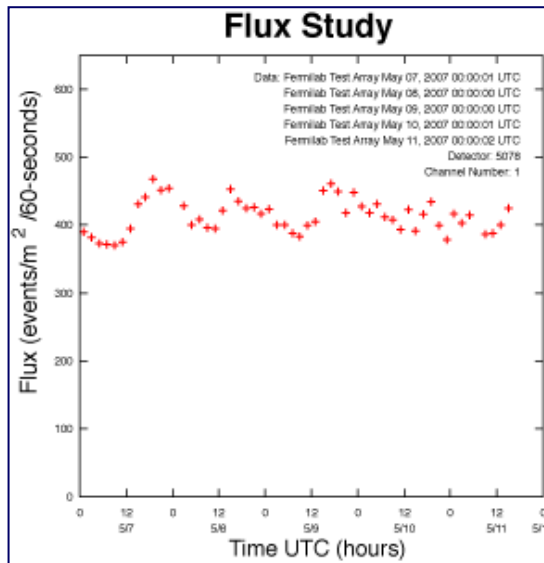
"6000" Series DAQ data collection software: [EQUIP java interface](#)



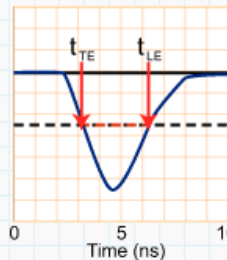
# QuarkNet

## Data Stats

- 81,000 e-Lab data files
- 20,000 plots
- 1,700 posters
- World-wide data: 21 countries & the Antarctic



Columns															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80EE0049	80	01	00	01	38	01	3C	01	7EB7491F	202133.242	080803	A	04	2	-0390
80EE004A	24	3D	25	01	00	01	00	01	7EB7491F	202133.242	080803	A	04	2	-0389
80EE004B	21	01	00	23	00	01	00	01	7EB7491F	202133.424	080803	A	04	2	-0289
80EE004C	01	2A	00	01	00	01	00	01	7EB7491F	202133.242	080803	A	04	2	-0389
80EE004D	00	01	00	01	00	39	32	2F	81331170	202133.242	080803	A	04	2	+0610



The hardware measures times very, very well. It detects when the [photomultiplier \(PMT\)](#) signal starts and ends. We can use that to calculate [signal width](#).

The first 10 columns represent "clock ticks." Ticks in columns 1 & 10 are 24 nanoseconds; ticks in 2-9 are 3/4 nanoseconds.

The last 6 columns provide other information. Many columns are [hexadecimal numbers](#).

Column 1 indicates the tick during which everything in columns 2-9 happened.

Columns 2-9 indicate pulse start (even columns) and end (odd columns) times for channels 1-4.

Column 10 is the tick that corresponds to the [Global Positioning System \(GPS\)](#) time in column 11.

Column 11 is the [Coordinated Universal Time \(UTC\)](#) of the last GPS update.

Column 12 is the date of the last GPS update.

Column 13 shows the validity of the last GPS update.

Column 14 shows the number of GPS satellites in view.

Columns 15 and 16 show data status (15) and time offset information (16).



# Cosmics Team @ FNAL

## Over to Mark



Dave Hoppert  
All Things Detector



Mark Adams  
Cosmics Leader



Sudha Balakrishnan  
IT Specialist