

QuarkNet

Helping Develop America's Technological Workforce

## The QuarkNet Story

### Developing our “e-Lab” for High School Students & Their Teachers



Marge Bardeen, Fermilab  
Mike Wilde, Argonne & U. Chicago



M. Bardeen, M. Wilde, UUEO Meeting, April 2004



## LHC Education Commitment



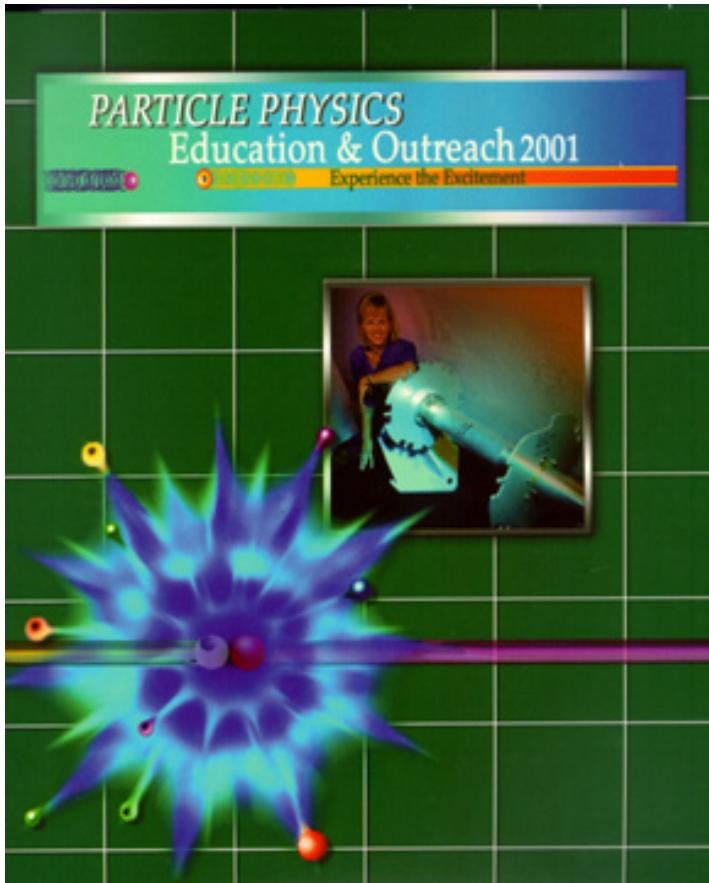
Neal Lane

“Major discoveries like the Top Quark and antimatter make headlines on the front pages of the world's major newspapers. Whether readers fully appreciate the significance of these breakthroughs is another matter altogether. That is why this agreement places such a high priority on public education and outreach. Each of the U.S. detectors has named an education coordinator to its senior project management teams. You'll also see that the integration of research and education stands out as a primary objective and responsibility within the overall U.S. investment strategy—just as it now guides NSF's programming in general.”

*(at the signing of the LHC agreement)*

M. Bardeen, M. Wilde, UUEO Meeting, April 2004

# Particle Physics Education & Outreach



**What are particle physicists  
doing in education and outreach?**

**Survey**

**FY96-97: 172 major activities**

**FY00-01: 255 major activities**



# A Coherent Education Program

**2** DOE labs host project offices.

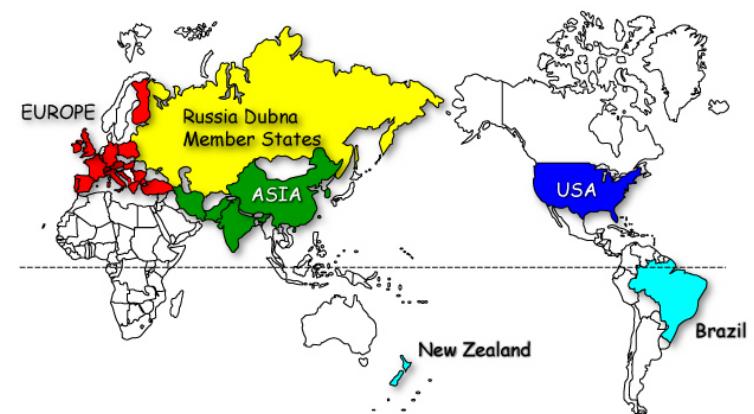
**4** Experiments (ATLAS, CMS, CDF, DØ)

**10** Years just to build detectors

**60** Research groups

**1,000s** of scientists worldwide

**Petabyte-scale computing**



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## QuarkNet Design Team



### Physicists:

**Keith Baker, Hampton University  
Michael Barnett, ATLAS Ed Coordinator  
Randy Ruchti, CMS Ed Coordinator**

### Educator:

**Marge Bardeen, Fermilab Ed Office**



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## QuarkNet Design Team



**Physicists brought experience with:**

- **Science.**
- **Research.**
- **Data.**

**Educator brought experience with:**

- **High schools, students & teachers.**
- **Education reform.**
- **Best practice professional development.**



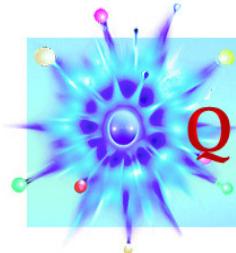
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## The QuarkNet Collaboration



**A lasting research community of physicists, high school teachers & their students**

- Physicists as mentors & colleagues
  - Teachers as researchers & classroom research leaders
  - Students as researchers
- 
- Engaging teachers, and subsequently their students, in scientific investigations
  - Confronting particle physicists with current issues in science education



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## The QuarkNet Collaboration

### Program Profile

720 teachers & their students  
(120 leads & 600 associates)

120 mentors  
60 centers

6-8 experiments

6 staff members  
4 PIs

DOE - NSF

### Managed Like an HEP Project

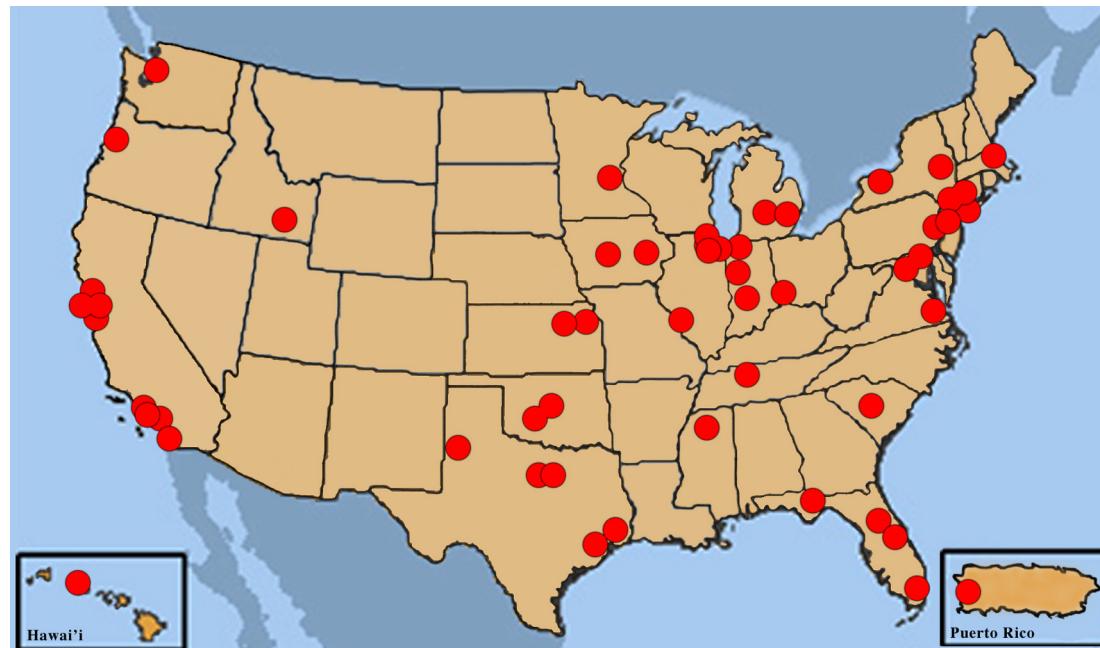
- Long-term
- Central oversight, resources & support
- Flexible local programs
- Distributed among 60 research groups
- Leveraged local resources
- Research-based professional development
- Online instructional resources for student research



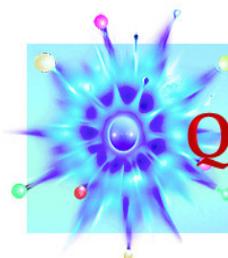
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## QuarkNet Infrastructure



**48 centers: 208 mentors & 474 teachers  
+ 4 new centers in FY04**



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## Student Outcomes

Students learn fundamental physics by:

- **Analyzing real data delivered online.**
- **Collaborating with students worldwide.**
- **Participating in inquiry-oriented investigations.**
- **Experimenting using classroom cosmic ray detectors.**
- **Visiting research groups & experiments.**
- ***Constructing & testing detector components.***



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### **Year 1 — 2 lead teachers**

- **One-week summer institute at Fermilab**
- **Seven-week summer research appointments**

### **Year 2 — 2 lead teachers and 10 associate teachers**

- **Three-week research-based summer institutes**

### **Following Years**

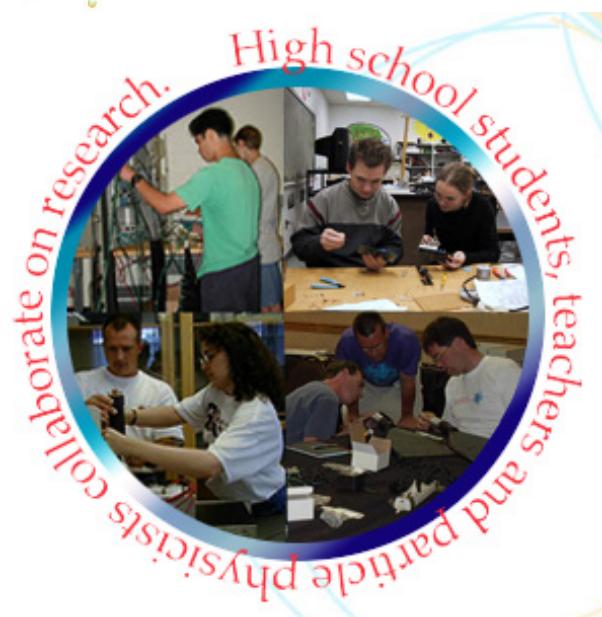
- **One-week follow-on activities**

### **QuarkNet Website**



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Website



[quarknet.fnal.gov](http://quarknet.fnal.gov)

[At Work](#)

[Join Us](#)

[For Educators](#)

[For Students](#)



This project is supported in part by the National Science Foundation and the Division of High Energy Physics, Office of Science , U.S. Department of Energy. Opinions expressed are those of the authors and not necessarily those of the Foundation or Department.

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## Online Data Delivery

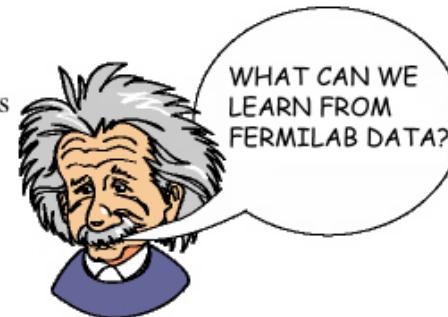
**Technology supports problem-based student investigations.**

### Searching for Top

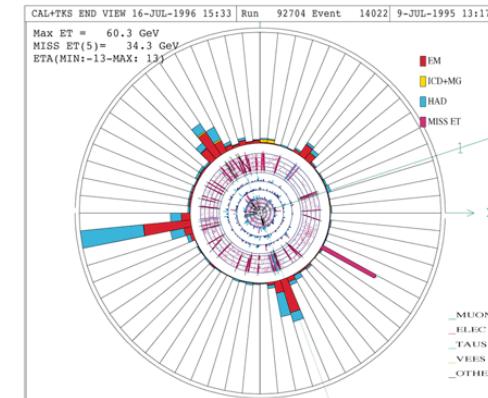
**How do today's scientists use conservation of momentum?**

Particle physicists verify Einstein's famous equation  $E=mc^2$  every day in accelerators around the world. They convert energy into mass almost as commonly as you flip through channels on the television.

In 1995 physicists who work at Fermilab created the last and most massive quark ever discovered, the top quark, by converting mass into energy and then energy into mass!



**You can use the principle of conservation of momentum which you have been studying and 1995 experimental data to determine the mass of the top quark. [The D-Zero Experiment](#)**





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# Along Came Grids

New players bring virtual data tools & techniques.

The collage includes several screenshots from the QuarkNet Cosmic Ray Collaboration website:

- Cosmic Ray Collaboration - Home Page:** Shows a "Comments for Project website" section with checkboxes for "Project code name" (e.g., "1a-2004 1-25 Satellites Philadelphia"), "From Teacher", and "Add Your Comments". Below it is a map of the United States with icons representing data collection sites.
- Cosmic Ray Collaboration - Resources:** A page titled "Cosmic Ray Data from a Detector" showing a table of data with columns for X, Y, Z, and V. It also features a "Classroom Cosmic Ray Detector" diagram illustrating its internal components: Antennae, TPC Board, and Power Supply.
- Cosmic Ray Collaboration - Data Analysis:** A page titled "Detector Performance" with sections for "Single Particle Reconstruction" and "Multi-particle Reconstruction". It includes a "Data Collection Application" link and a "Submit Data" button.
- Cosmic Ray Collaboration - Poster Session:** A page titled "Cosmic Ray Collaboration" with sections for "Poster Session", "Resources", "Data Analysis", "Poster Session", "One Index", and "Assessment". It features a "QuarkNet" logo and a "Research Studies - From: Science Education Institute" link.
- Cosmic Ray Collaboration - One Index:** A page titled "One Index" with sections for "Cosmic Ray Collaboration", "Resources", "Data Analysis", "Poster Session", and "Assessment". It includes a "Log In" button and a "Logout" link.
- Cosmic Ray Collaboration - Assessment:** A page titled "Assessment" with sections for "Assessments", "Log In", "Logout", "Data Analysis Tools", "Practice Tests", and "Using Your Project". It also includes a "QuarkNet" logo and a "Research Studies - From: Science Education Institute" link.
- Cosmic Ray Collaboration - Classroom Cosmic Ray Detector:** A large image of a classroom detector setup with multiple vertical rods and a central computer monitor.
- Cosmic Ray Collaboration - One Index:** A smaller image of the "One Index" page.
- Cosmic Ray Collaboration - Assessment:** A smaller image of the "Assessment" page.
- Cosmic Ray Collaboration - Classroom Cosmic Ray Detector:** A large image of the classroom detector setup.

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## What makes a virtual data portal special?

- Data processing tools are neatly packaged and described.
- Workflows can be cataloged to describe and reuse processes.
- Facilitates search and discovery through uniform interfaces.
- Steps are logged automatically for reference and uniform communications.
- Provides a “backplane” for science modules.
- Can run larger computations on the Grid, seamlessly – simulations and real science codes.



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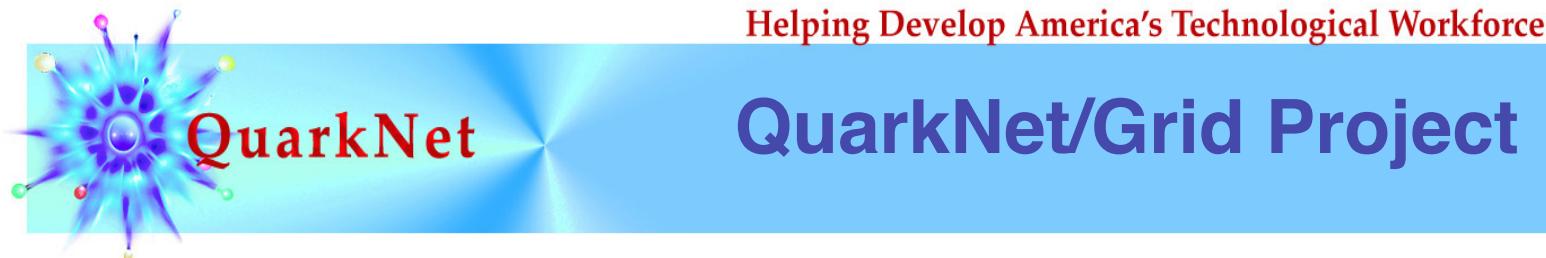
## Along Came Grids

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- Cosmic Ray Collaboration - Home Page:** Shows a "Comments for Project website" section with a form for reporting detector status and a map of the United States showing detector locations.
- Cosmic Ray Collaboration - Resources:** A page titled "Cosmic Ray Data from a Detector" showing a table of particle tracks with columns like X, Y, Z, T, and P.
- Cosmic Ray Collaboration - Data Analysis:** A page titled "Classroom Cosmic Ray Detector" showing a diagram of a detector setup with components labeled "Anodes", "PMT Board", and "Processor Board".
- Cosmic Ray Collaboration - Poster Session:** A page titled "Cosmic Ray Collaboration" featuring a large image of a particle track and text about the collaboration's goals and resources.
- Cosmic Ray Collaboration - One Index:** A page titled "One Index" listing various links for "Investigation", "Resources", "Data Analysis", "Poster Session", and "Assessment".
- Cosmic Ray Collaboration - Assessment:** A page titled "Assessment" with sections for "Investigation", "Resources", "Data Analysis", "Poster Session", and "One Index".

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## QuarkNet/Grid Project

**Provides access to innovative computing and *real* scientific data for students who would not otherwise have such opportunities.**

**Uses the potential of frontier science and Grid computing to transform science teaching and learning.**

**May provide infrastructure for “federating” with other experiments using the Grid.**





**Students participate in a scientific collaboration and make real contributions to a scientific field.**

**Students use virtual data tools and techniques to upload, access, process and publish data, report their results as online posters, and have online discussions about their work with peers.**

**Educational researchers evaluate the effectiveness of such an endeavor.**

**Grid specialists explore interface designs that enhance accessibility to Grid data and computational resources.**



**It's an experiment—a scientific workstation—that gives students the means to:**

- **Discover and apply datasets, algorithms and data analysis methods.**
- **Collaborate by developing new ones and sharing results and observations.**
- **Learn data analysis methods that will ready and excite them for a scientific career.**

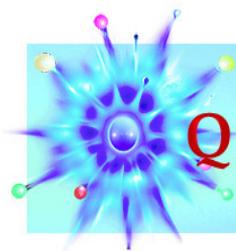
**And in later steps, we may actually use *the Grid*!**



**It's just a web site! ☺ . . . and more. It's a place to:**

- **Keep and organize datasets.**
- **Perform computations on the data.**
- **Create new computations and analyses.**
- **View and share results.**
- **Experiment and discover.**
- **Annotate and enquire (using metadata).**
- **Communicate and collaborate.**

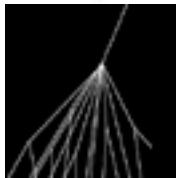
**It's easy to use, ubiquitous, no tools to install.**



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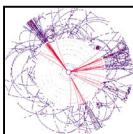
**QuarkNet e-Lab**



**V 0.3 Cosmic ray studies with student data  
(Virtual data tools and techniques)**

*SRCH*  *EPCF*

**V 1.0  $\alpha$  - Professional development**  
**Collaboration meeting simulation**  
**Test beam data**  
**Data simulations**



**V 2.0 pre- $\alpha$  - HEP Data from the Grid**

**Tools for “federation” with other physics experiments?**



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## Development Team

### Computing/Web/Design

M. Wilde - ANL & UC  
L. Quigg - FNAL  
M. Clayton - FNAL

### Physicist

R. Ruchti - UND

### QNet Educators

M. Bardeen - FNAL  
T. Jordan - FNAL  
B. Marchant - UND  
P. Mooney - UND

### Evaluator

J. Young

### Teachers

E. Fidler - Boston MS  
L. Rose - Penn HS

### Grad Student

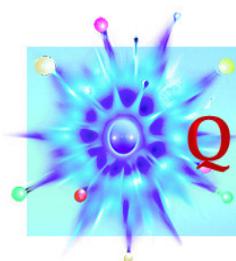
Y. Zhao - UC

### Undergrad Students

P. Nepywoda - U of I  
E. Peryshkin - U of I  
Y. Wu - MIT

### High School Students

A. Bahal - IMSA  
J. Frankle - LaLumiere HS  
J. Shreve - LaLumiere HS



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**V 0.3 Science**

## **Cosmic Ray Mysteries**



**Where do highly energetic cosmic rays come from?**

**Where do they get their energy?**

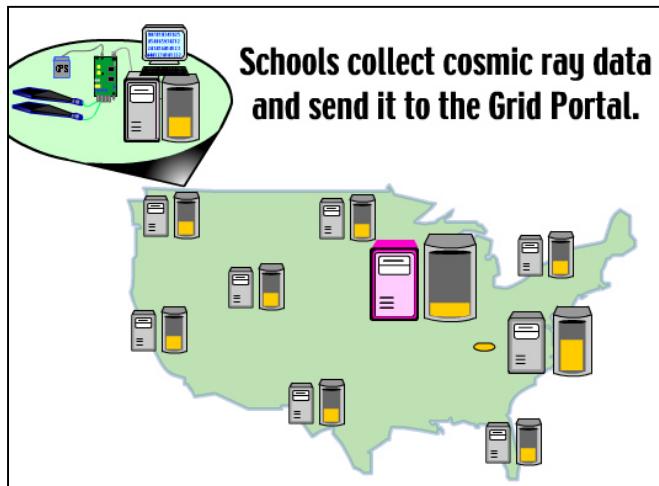
**What secrets do they hold about the early universe?**

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## Classroom Cosmic Ray Detector

This is a typical setup for a classroom cosmic ray detector. Roll over the different parts to learn what their functions are.



### Cosmic Ray Collaboration

Investigation Resources Data Analysis Poster Session Site Index Assessment

Who writes the rules for your world? Einstein or Newton? You probably recognize both names; each one is responsible for describing physics that fills chapters of your physics book. But whose laws describe what you see in your life? What about other parts of the universe? Whose laws dictate what happens there?

Join a unique collaboration of high school students, teachers and scientists in the exploration of the universe around us by studying particles made in galaxies far away but leaving signatures in Earth's atmosphere. Do these particles obey Newton or Einstein? Whose rules must we use to explain the source of these particles?

We use simple detectors arrayed in high schools in many locations. These machines are commissioned and maintained by students and teachers. Perhaps the data from these arrays will yield answers to questions about the origins of our universe. Join up and contribute to the effort.

Experienced with problem-based investigations? The note cards below outline resources on this website.

Inexperienced? [More details here.](#)

**STOP** Make sure you understand how you will:  
Form research teams.  
Record your progress.  
Contribute posters to the collaboration.

**Log on** (Function not implemented yet.)  
[Need logon information?](#)  
[Check with your teacher.](#)  
[Not working with a class?](#)  
[Contact `cosmics@fnal.gov` for registration info.](#)

**Investigation**

**Homepage**

- Research topic.
- Log on.

**Data Analysis**

**Get and Analyze Data**

- Upload data.
- Get data to analyze.
- Practice skills.

**Resources**

**Look for Links**

- Online resources - If you find a really good resource not listed, let us know.
- Physicists - Contacts at QuarkNet centers
- Student Research Groups - Other studies in the field

**Poster Session**

**Sharing Your Research**

- Post results including graphs, notes, calculations.
- Review the work of others.
- Participate in a scientific dialog.

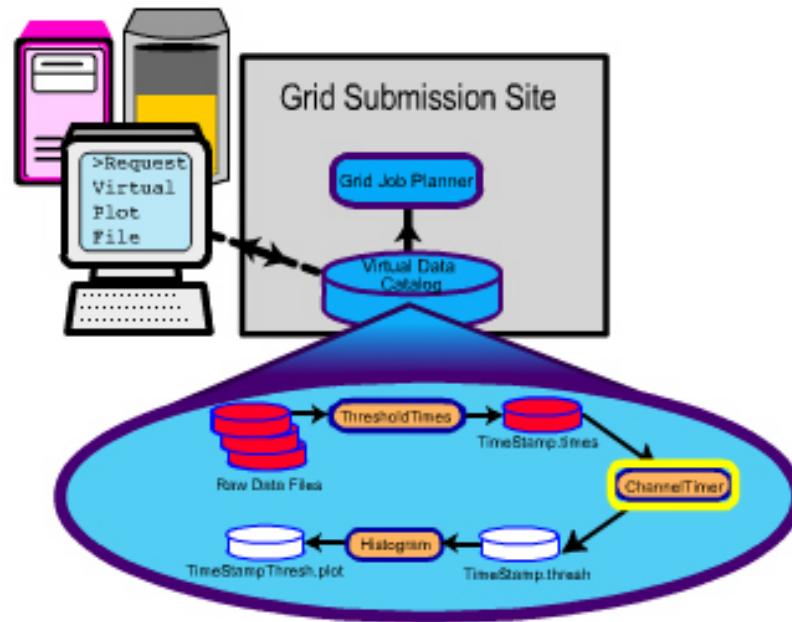
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## V 0.3 Demo

**Grid Virtual Data  
techniques  
underly web-based  
analysis tools for  
students.**



[quarknet.fnal.gov/grid](http://quarknet.fnal.gov/grid)



# Homepage

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Cosmic Ray Collaboration

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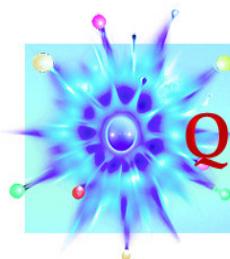
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Sharing Your Research

- Post results including graphs, notes, calculations.
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# Data Analysis

## Cosmic Ray Collaboration

[Investigation](#)[Resources](#)[Data Analysis](#)[Poster Session](#)[Site Index](#)[Assessment](#)

What can you learn? 1) Check detector performance. 2) Choose data and conduct a study.  
3) Some students can upload data.

### Detector Performance

**START HERE!**

[Trust the Hardware](#)  
[Display Uploaded Data](#)

Everyone must learn how to use the data interface to request data and plot graphs. Choose a detector and test its performance by studying each of its four counters. Each counter is assigned to one of four channels.

[Data Collection Animation](#) - (DAQ Board)

### Single-site Analysis

[Data from One School](#)  
[Muon Lifetime](#) - Do you live in Newton's or Einstein's world?

[Muon Flux](#) - The rain of particles has many interesting properties. Are there more in Colorado than there are in South Carolina?

[Air Showers](#) - You can detect an air shower using the four panels at your school. Your colleagues at other schools will want to know when you detect one, so they can check for coincident showers at their school.

### Multi-site Analysis

[Extended Air Showers](#)

Contribute to cutting-edge research on the origin of high-energy primary cosmic rays.

### Upload Data

[Data Upload](#)  
[Geometry Upload](#)

[Locations equipped with detectors can submit their data here.](#) Others can then analyze your data.

**Grids** - These investigations are brought to you by grid computing.

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The image shows the Cosmic Ray Collaboration interface. At the top left is the text "Cosmic Ray Collaboration" next to a small graphic of a detector. Below the title is a navigation bar with three tabs: "Background", "Tutorials", and "Data Analysis".

Upload Raw Data Collected by Cosmic Ray Detector.

Data Already Uploaded:

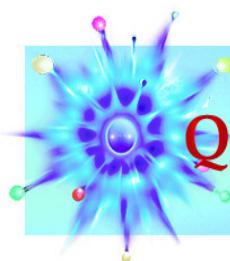
- home
- 119
  - B040903.TXT
  - B030903.TXT

Choose detector:  
**Detector:**

Raw Data File:  no file selected

Split into Julian Day Size Blocks

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# Data Display

## Cosmic Ray Collaboration

Investigation   Background   Tutorials   Data Analysis   Poster Session

Do you trust the detector? Do the data look right?

1. Click on the raw data file to view its content.

119 - 2003.0903

119 - 2 Chiron Virtual Data Portal

You've logged in

Load Application Load Data Load VDL Search TR/DV Search Data Derive Data Load Metadata View Metadata Search by Metadata Log out

Search LFN for Go

Show TR  Show DV

Definition

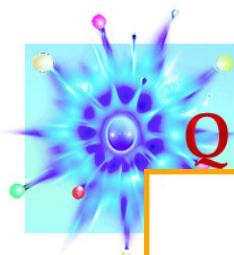
- BTeV
- QuarkNet
- Quarknet
  - Cosmic
    - ChannelTimer
    - Combine
    - EventChoice
    - EventPlot
    - Histogram
    - PerformanceStudy
    - Search
    - Show
    - ShowStudy
    - SingleChannelTimer
    - Sort
    - ThresholdTimes
    - Demo

Annotation for 119.2003.0903

Attribute Name	Type	Value
enddate	date	2003-09-03 23:59:56.0
type	string	split
detectorID	string	119
school	string	IMSA
project	string	cosmics
juliandate	string	2452885
startdate	date	2003-09-03 00:00:13.0
uploaddate	date	2004-02-22 00:00:00.0
blessed	boolean	true
author	string	TheEinstiensGroup

Sponsored by:

- grPhyN Data Mining Below
- IVD gL
- QuarkNet at Work
- TheEinstiensGroup



# QuarkNet

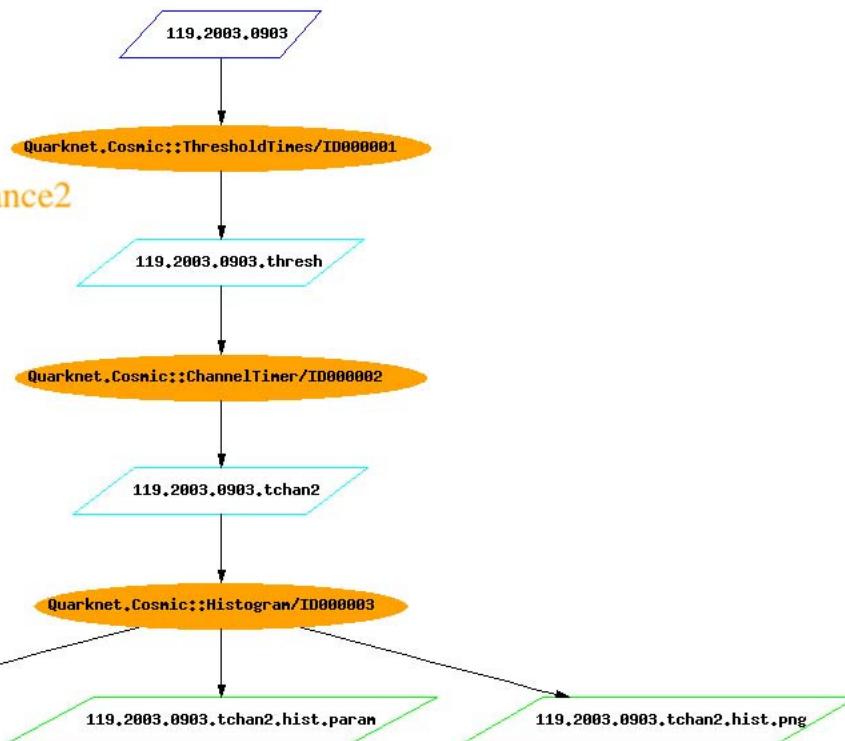
# Equipment Test

DAG  
(Directed  
Acyclic Graph)

Quarknet.Cosmic::performance2

Transformation

```
TR Quarknet.Cosmic::Performance2
detector, none divisions, no plotParam, input rawData, input {
    call Quarknet.Cosmic::ThresholdAll;
    thresholdAll=$output:thresholdAll;
    call Quarknet.Cosmic::ChannelTimer;
    thresholdChan=$output:thresholdChan;
    call Quarknet.Cosmic::Histogram;
    histogram=$output:histogram;
    comment=$comment;
    detector=$detector;
    histData=$output:histData;
    plotParam=$output:plotParam;
}
```



Derive

```

divisions= 51 ,
high="50",
histData=@{output:"119.2003.0903.tchan2.hist.data"|rt},
low="0",
plotFile.png=@{output:"119.2003.0903.tchan2.hist.png"|rt},
plotParam=@{output:"119.2003.0903.tchan2.hist.param"|rt},
rawData=@{input:"119.2003.0903"|rt},
thresholdAll=@{inout:"119.2003.0903.thresh"|rt},
thresholdChan=@{inout:"119.2003.0903.tchan2"|rt},
ymax="300"
);
  
```



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## Typical Plot

Metadata for Plot as seen in Portal		
Annotation for 119-9-3-2003-3.png		
Attribute Name	Type	Value
detectorID	int	119
date	date	2003-09-03 00:00:00.0
source	string	119.2003.0903
project	string	cosmics
ymax	int	275
channel	int	3
bins	int	35
author	string	The Einsteins

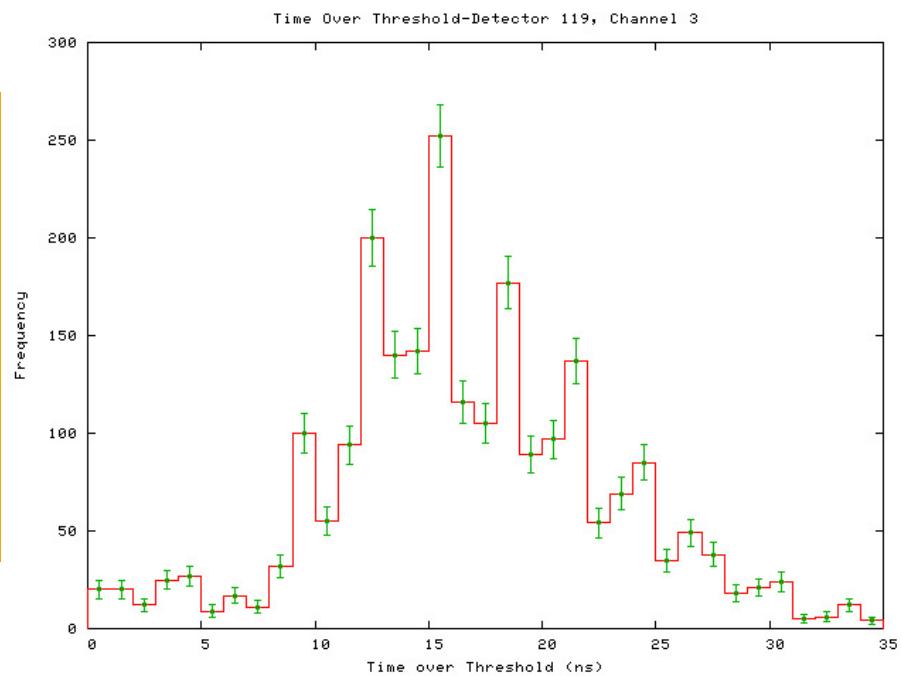
The data table

```

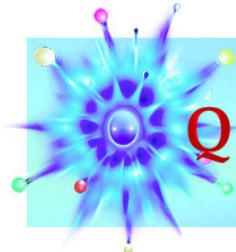
0.5 20 4.47213595499958
1.5 20 4.47213595499958
2.5 12 3.46410161513775
3.5 25 5
4.5 27 5.19615242270663
5.5 9 3
6.5 17 4.12310562561766
7.5 11 3.3166247903554
8.5 22 5.555555555555555
9.5 15 4.47213595499958
10.5 10 3.46410161513775
11.5 12 5.19615242270663
12.5 15 9 3
13.5 17 4.12310562561766
14.5 11 3.3166247903554
15.5 25 5
16.5 27 5.19615242270663
17.5 15 9 3
18.5 17 4.12310562561766
19.5 11 3.3166247903554
20.5 22 5.555555555555555
21.5 15 4.47213595499958
22.5 10 3.46410161513775
23.5 12 5.19615242270663
24.5 15 9 3
25.5 17 4.12310562561766
26.5 11 3.3166247903554
27.5 25 5
28.5 27 5.19615242270663
29.5 15 9 3
30.5 17 4.12310562561766
31.5 11 3.3166247903554
32.5 22 5.555555555555555
33.5 15 4.47213595499958
34.5 10 3.46410161513775
35.5 12 5.19615242270663

```

The graph



To save this plot permanently, enter the new file name you want.  
Then click Save Plot.



# QuarkNet

Helping Develop America's Technological Workforce

## Studies

### Multi-site Analysis

#### Extended Air Showers

Contribute to cutting-edge research on the origin of high-energy primary cosmic rays.

### Single-site Analysis

**Data from One School**  
**Muon Lifetime** - Do you live in Newton's or Einstein's world?

**Muon Flux** - The rain of particles has many interesting properties. Are there more in Colorado than there are in South Carolina?

**Air Showers** - You can detect an air shower using the four panels at your school. Your colleagues at other schools will want to know when you detect one, so they can check for coincident showers at their school.

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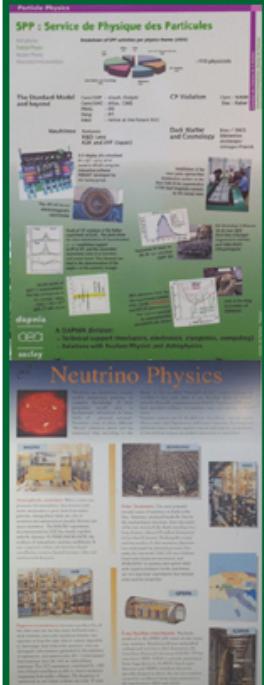


# Poster Session

## Cosmic Ray Collaboration

[Investigation](#)   [Resources](#)   [Data Analysis](#)   [Poster Session](#)   [Site Index](#)   [Assessment](#)

**Post your results. Compare results. Draw conclusions!**



Congratulations! Your team developed a research question and planned and conducted an investigation. You used appropriate tools and techniques to gather and analyze your data.

How do your results stack up against those of other research groups? Will they stand the test of time and peer review?

Submit a poster summarizing your work. Use the poster template. The following elements must be included:

- Title
- Abstract (25 words)
- Results including plots
- Conclusions
- Research group name
- School name, city, state
- School e-mail contact

[View Posters](#) - [Create a Poster](#)

Your work is not over yet! Study the results from other investigations. Look critically and logically at relationships between the data and the explanations. Doubt results, challenge ideas, replicate investigations, propose and analyze alternative explanations. These are all part of doing science.

In the forum you can present your scientific arguments to other research groups.  
(Function not implemented yet.)

[Search for Studies](#) - [Forum](#) - [Scientific Collaboration Animation](#)



QuarkNet

# Student Poster

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## Cosmic Ray Showers in Seattle

A Quarknet Collaboration Experiment  
August 25, 2003

We describe a cosmic ray shower in the Seattle area on March 12th.

### Materials & Methods

We set up an 8x8 array of 1 meter x 0.5 meter scintillation detectors with the detectors 2 meters apart. This covers an area of 396 square meters. We numbered the 64 individual detectors 1-64 going across by rows. We used the electronics board developed at Fermilab to collect data (see Figure 3). Our test stand is pictured in Figure 4. We uploaded the data to the grid and used the grid analysis tools to find the shower. We used the UWashington transform to analyze the data and the Auger transform to plot the data.

### Results

We saw a large cosmic ray shower at 10 AM, March 12, 2003. It lasted from 10:00.02 until 10:00.05 (?). There were coincidences in detectors 1, 2, 4, 9, 10, 11, 12, 17, 18, 19, 20 and 51. The other detectors did not show any coincidences in this same time frame.

- [Figure 1](#): Detector 119 - Channel 1  
7-21-2003
- [Figure 2](#): Detector 119 - Channel 1  
7-22-2003

### Discussions & Conclusions

The accompanying Figures 1 and 2 show the plot of particles that hit our detectors. This array works well as we can identify cosmic ray showers with it. We also searched the data from nearby Gig Harbor to see if they had detected the same shower. It turned out that they did not. We are hoping that another school installs a cosmic ray detector closer to us so that we can compare our data to theirs in the future. There were no coincidences in detector 3 which we would expect, and there were coincidences in detector 51, which we did not expect. After further study, we realized that the pmt had come separated from the scintillator in detector 3. Also, there was a small light leak in detector 51, which could be the cause of coincidences there.

### Authors

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[johnson@seaprep.edu](mailto:johnson@seaprep.edu)



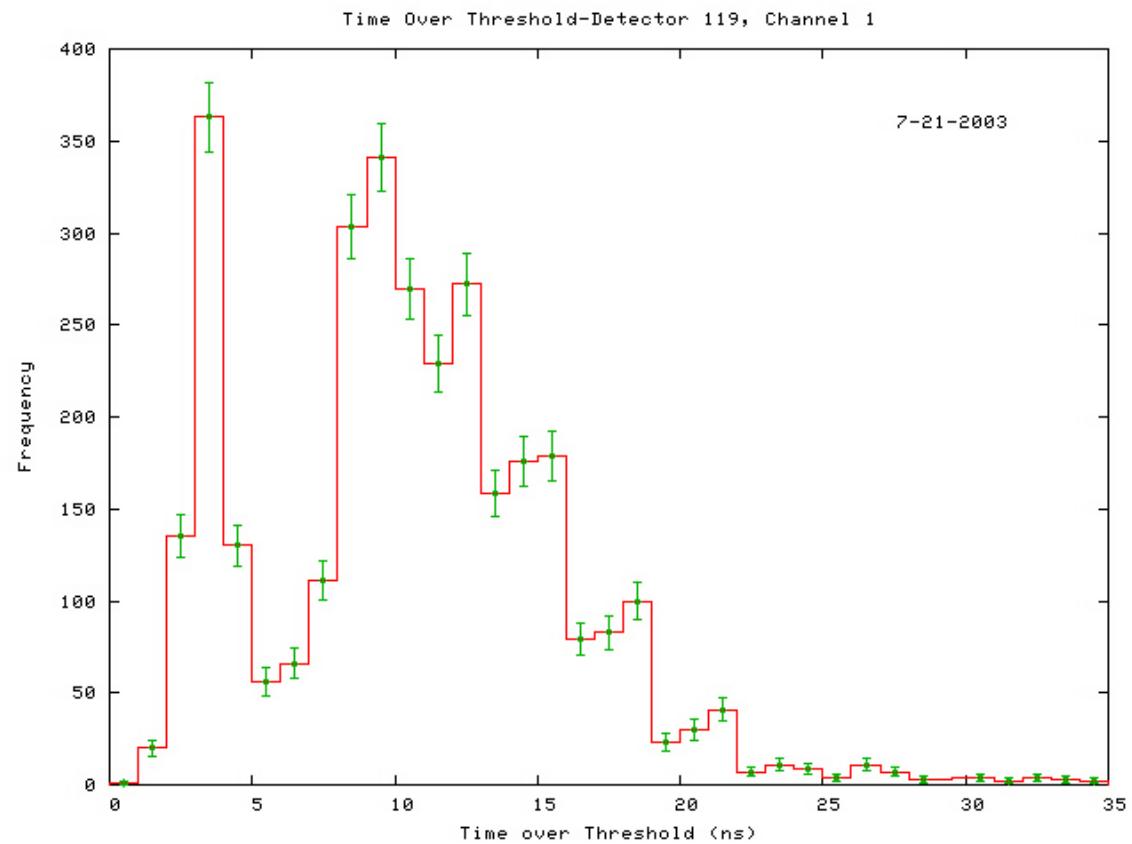
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# Figure

## Metadata for file 119-7-21-2003\_c1.png

detectorID: 119  
date: 2003-07-21 00:00:00.0  
source: 119.2003.0721  
project: cosmics  
ymax: 400  
channel: 1  
bins: 35  
author: The Einsteins

## Plot file 119-7-21-2003\_c1.png





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## Peer Comments

### Cosmic Ray Collaboration

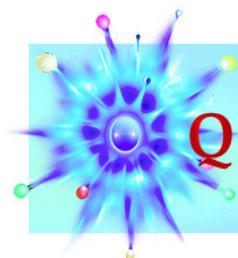
[Investigation](#) [View Posters](#) [Edit Posters](#) [View Plots](#) [New Poster](#) [Poster Session](#) [Data Analysis](#)

#### Comments for Poster seattle

- Enter your name.
- Add your comments in the New Comments field.
- Click **Add Comments**.

Poster Name:	seattle
Current Comments:	2-14-2004 3:25 James Parker, Philadelphia- This was a beautiful experiment. Were you able to solve your problem with the leak? 2-14-2004 3:26 Harry Maxwell, Seattle- Yes, we were able to fix that problem.
Your Name:	<input type="text"/>
Add Your Comments:	<input type="text"/>
<input type="button" value="Add Comments"/>	

M. Bardeen, M. Wilde, UUEO Meeting, April 2004

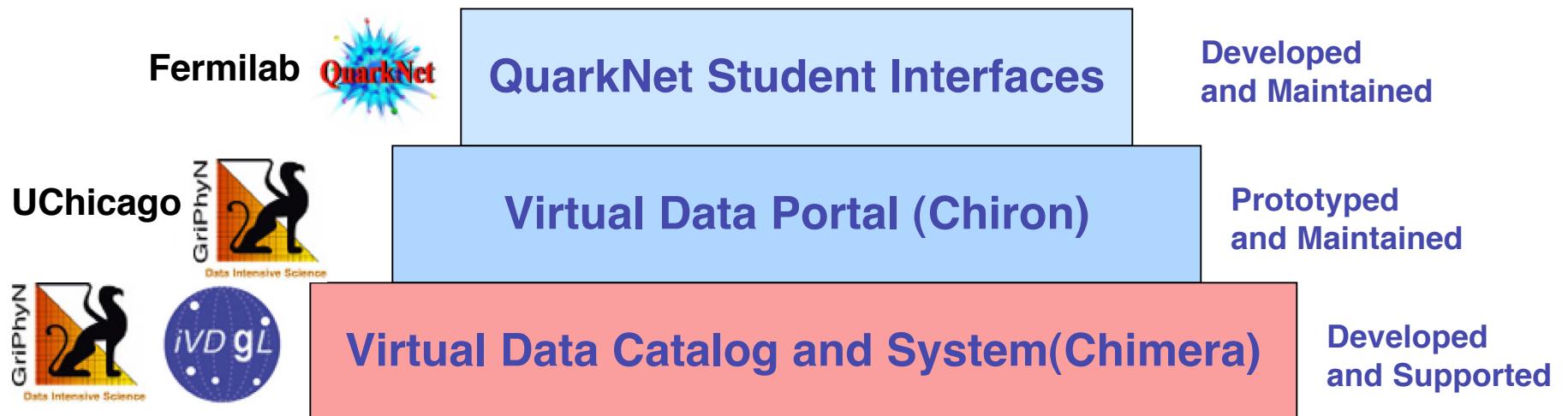


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V 0.3 Demo

## Architecture



# Building an e-Lab

*Application  
modules  
Need 1 FTE  
support*

*Portal needs 1  
FTE developer*

*GriPhyN to  
provide virtual  
data research &  
support through  
8/2005*

*iVDGL to  
support Grid  
testbed through  
8/2006*

## e-Lab Orientation Center

**Cosmic  
Ray**

**Particle  
Physics**

**Particle  
Astro-  
physics**

**Astronomy**

**Bio  
Infor-  
matics**

**Earth  
Systems  
Science**

**Social  
sciences**

**Virtual Data Portal (Chiron)**

**Virtual Data Catalog and System(Chimera)**

**iVDGL/Trillium Grid2003**



## Education – A new style of collaborative learning:

- Investigating highly motivating science content
- Modeling scientific research
  - Analyzing data
  - Publishing and defending results
  - Reviewing results of others
  - Synthesizing findings
- Using Grid tools and techniques
  - Computing resources
  - Data on the Grid
  - Systematized data analysis (metadata)
  - Collaboration tools



## Scientific Research and Computer Science Research

- **Non-traditional participants in the research process**
  - Enriches collaboration in experimental, theoretical and computer science groups
  - Invigorates experiment and software design and construction
  - Invigorates beam tests, experiment operation, simulation studies, data analysis and publication
- **Potential students**
  - Early key contacts in the education system
  - Means to reach underrepresented groups
- **Workforce development**
  - Future research scientists and computer scientists
  - More than just scientists “do science”
  - Proactive response to the question “Where are the Americans?”
- **Public support for scientific research**
  - Participants as Goodwill Ambassadors for science
  - Funding and sustaining science initiatives (often long-term)