QuarkNet High School Outreach Cosmic Ray Projects

Muon Department Meeting

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Why am I here?

QuarkNet Outreach - Teacher Development Program for over 20 years: NSF, CMS, Atlas, Fermi support

Planning g-2 measurement with cosmic rays – I'm asking for help with magnet design and mentoring

Imagine a baby g-2 travelling around high schools

You may want to participate in QuarkNet beyond Cosmic Rays

QuarkNet dominated by NSF faculty on LHC and Neutrino experiments

Help QuarkNet improve their activities involving spin

My muon background

Muons are long-term hobby for me:

Undergrad – spark chamber muons in cosmic ray air showers

1980s E605 high pt pairs, upsilons, H and t search

E665 muon scattering at 500 GeV

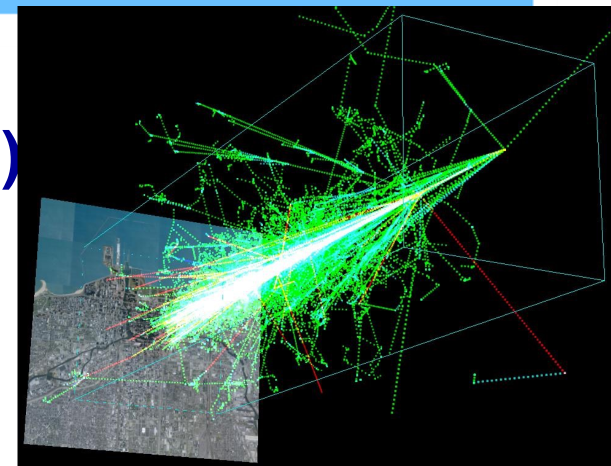
1990s D0 top, dibosons, muons in calorimeter

2000s CMS boosted top for Z' (semi-lepton channel)

Now QuarkNet Cosmic Rays (high school and undergrad)

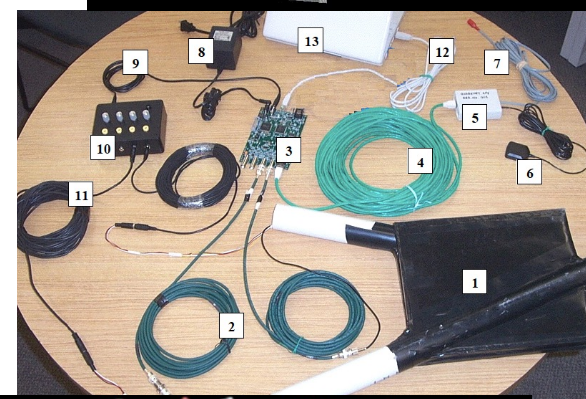
QuarkNet Cosmic Rays

QuarkNet - 50 HEP groups educational outreach effort (LHC, Neutrino, Cosmics)



High schools use HEP technology to detect cosmic ray muons (Eμ > 2 GeV)

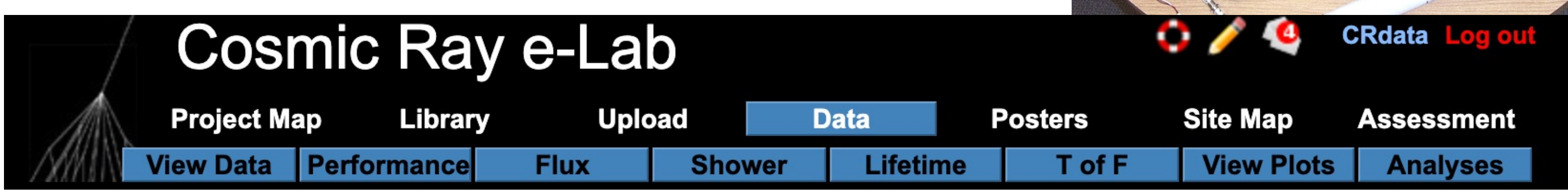
Cosmic rays from exploding stars



Design and perform experiments

Upload data to e-Lab (i2u2.org)

Run analyses on e-Lab.



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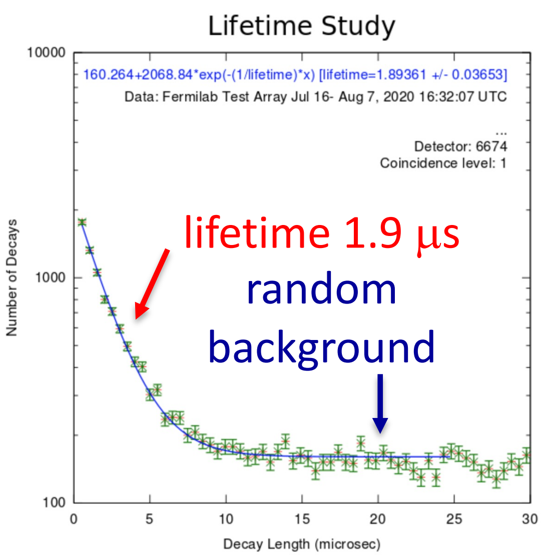
Standard Experiments

Flux – rate vs time

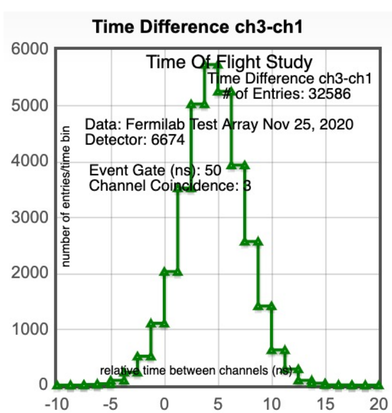
Time of Flight – speed = c

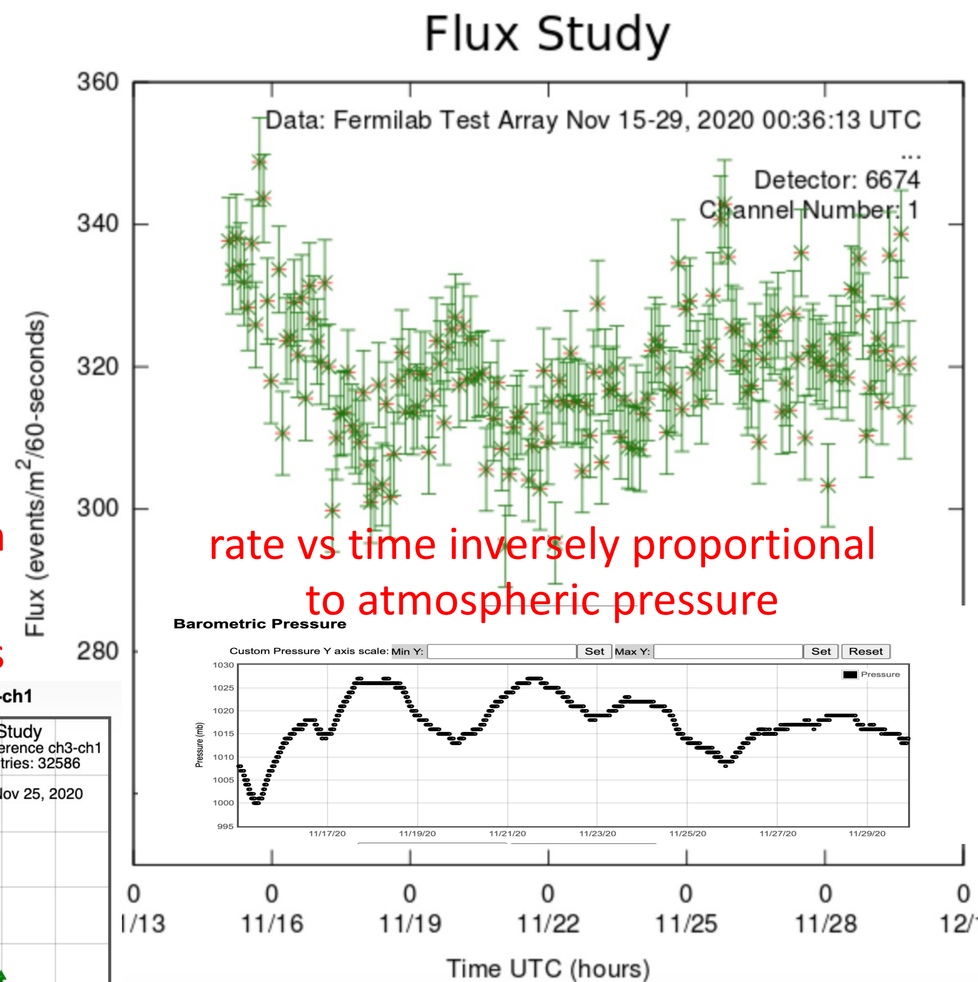
Muon Lifetime – 2 μs

Shower – multiple muons from one air shower



time between two counters





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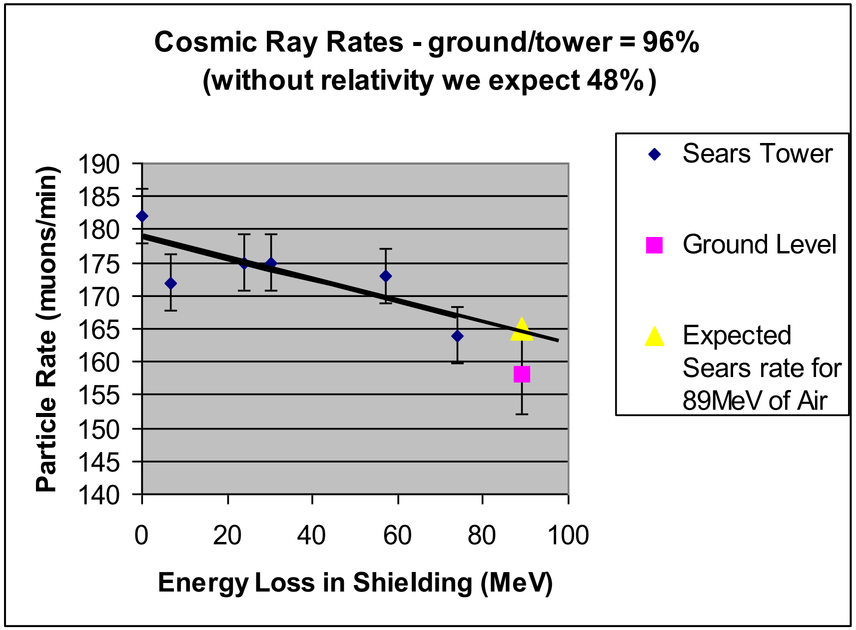
More Sophisticated Exps

Time dilation



★ **Expected without time dilation**

Helping Develop America's Technological Workforce

QuarkNet Is Sun a Source of Cosmic Rays?

Example: Large Collaborative Experiment

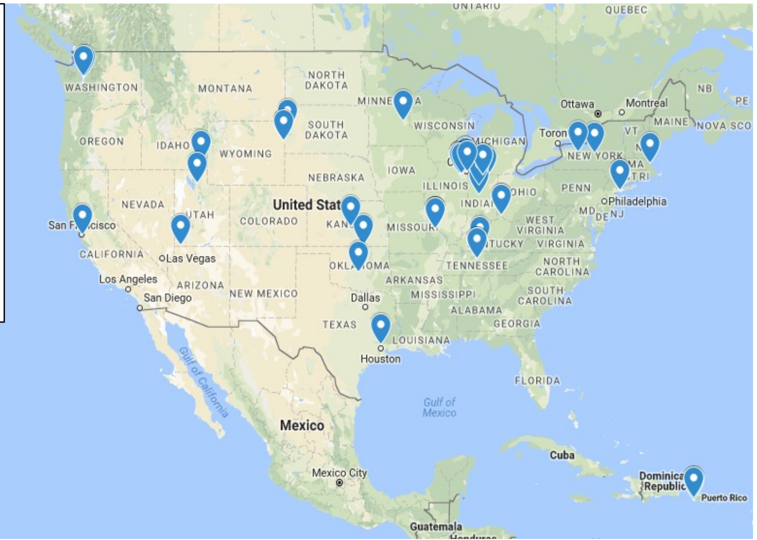
Measure Cosmic Rays during 2017 Total Eclipse

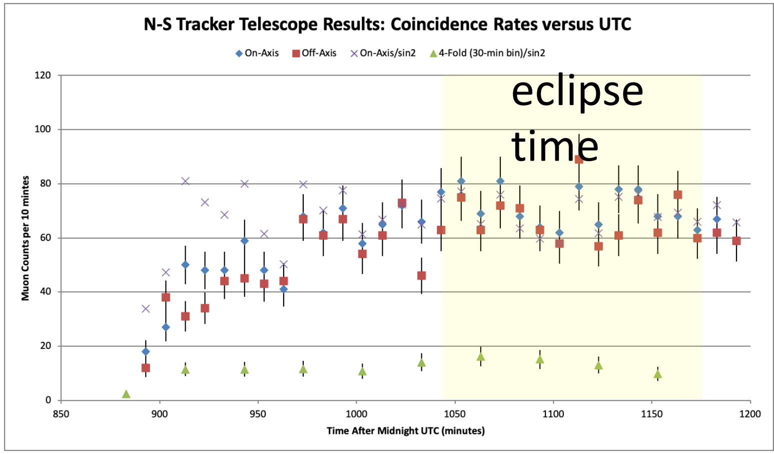
Fewer muons when moon blocks sun?

Over 48 groups operated detectors

Large improvement over 1936 result!

2017 Solar Eclipse
Data from 56 detectors;
48 QuarkNet groups;
Three tracking telescopes;
Over twenty fixed-angle telescopes;
Remaining detectors were stacked vertically.





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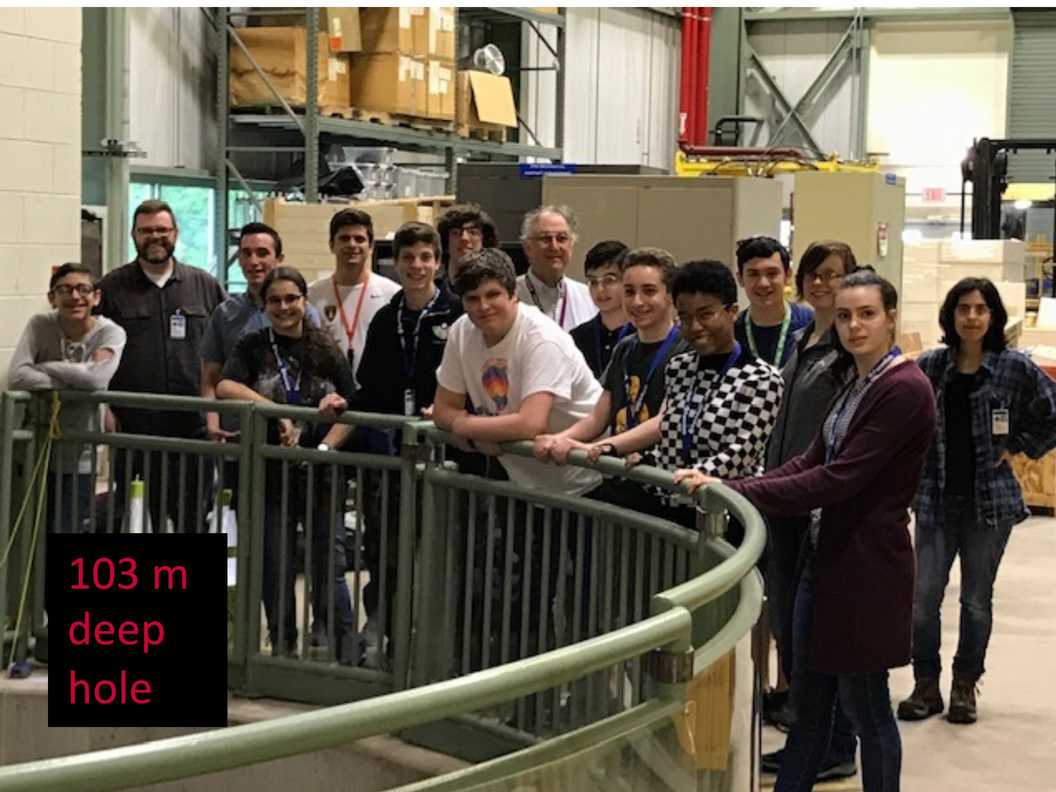
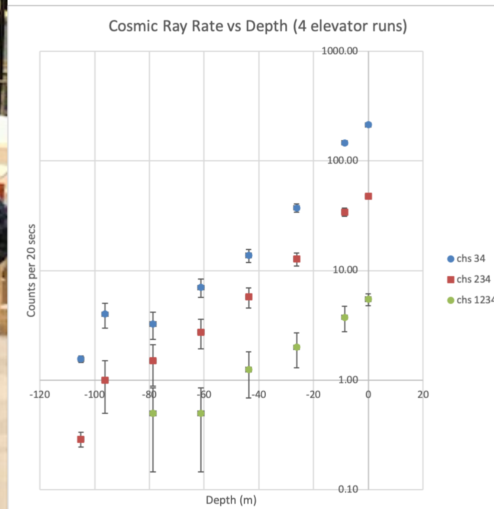
QuarkNet MUSE High School Collaboration

MUSE - Muon Underground Shielding Experiment

Proposal to Fermilab in MINOS neutrino area 103m underground – Measure Cosmic Rays; image access shaft



Rate (log) vs depth



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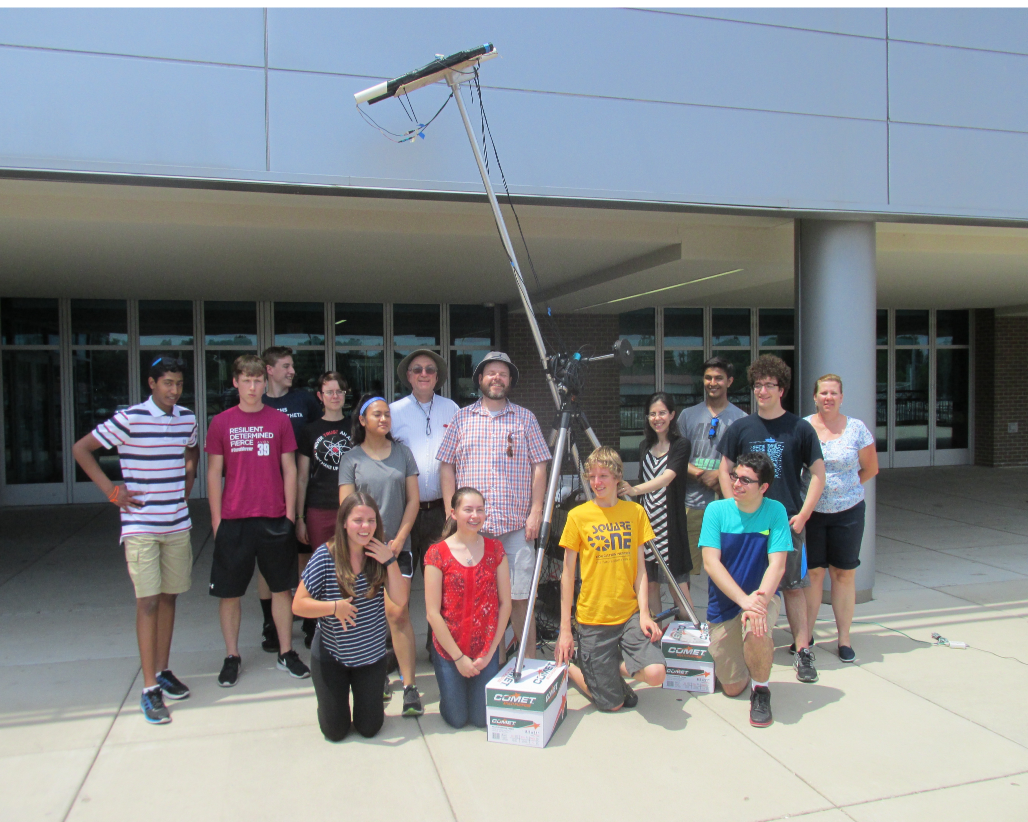
QuarkNet Design to AAPT presentations

Eclipse prototyping 2017

MUSE

AAPT presentation 2021



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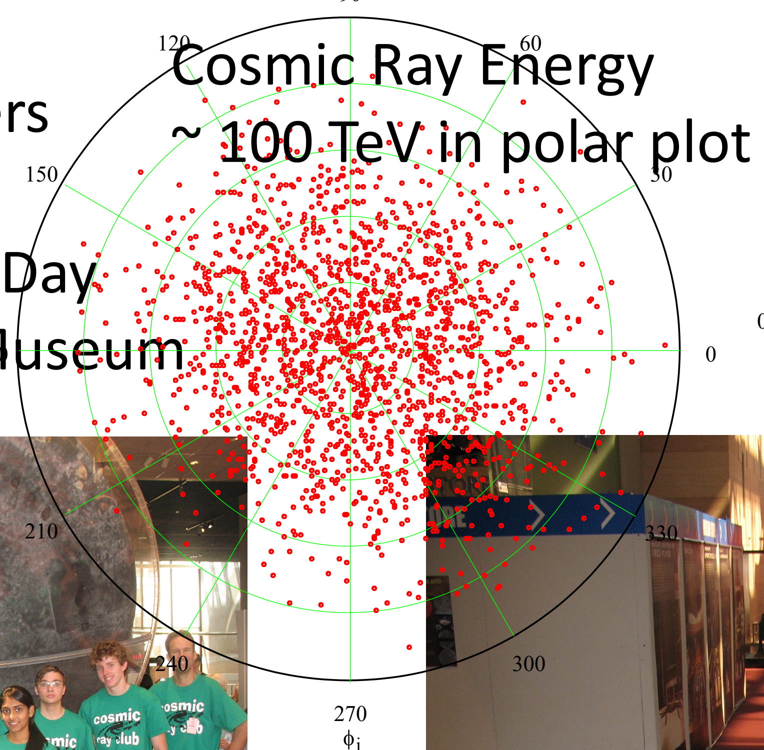
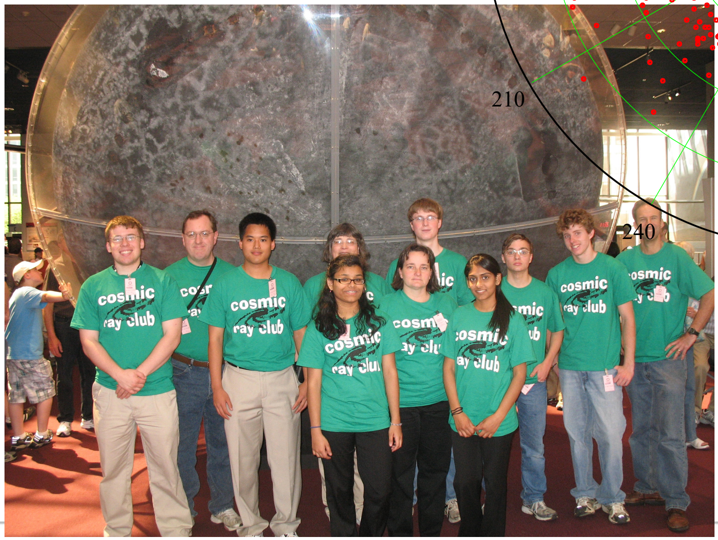
Name, Event, Date

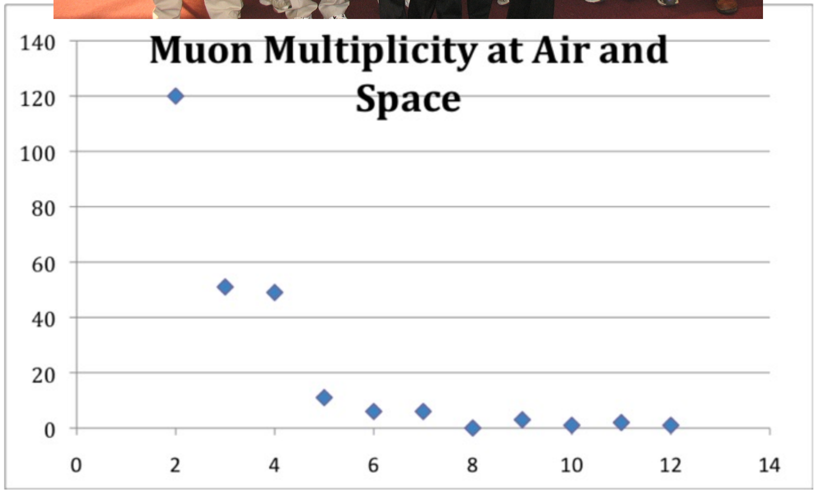
Cosmic Ray Showers

April National Lab Day at Air and Space Museum

Cosmic Ray Energy ~ 100 TeV in polar plot

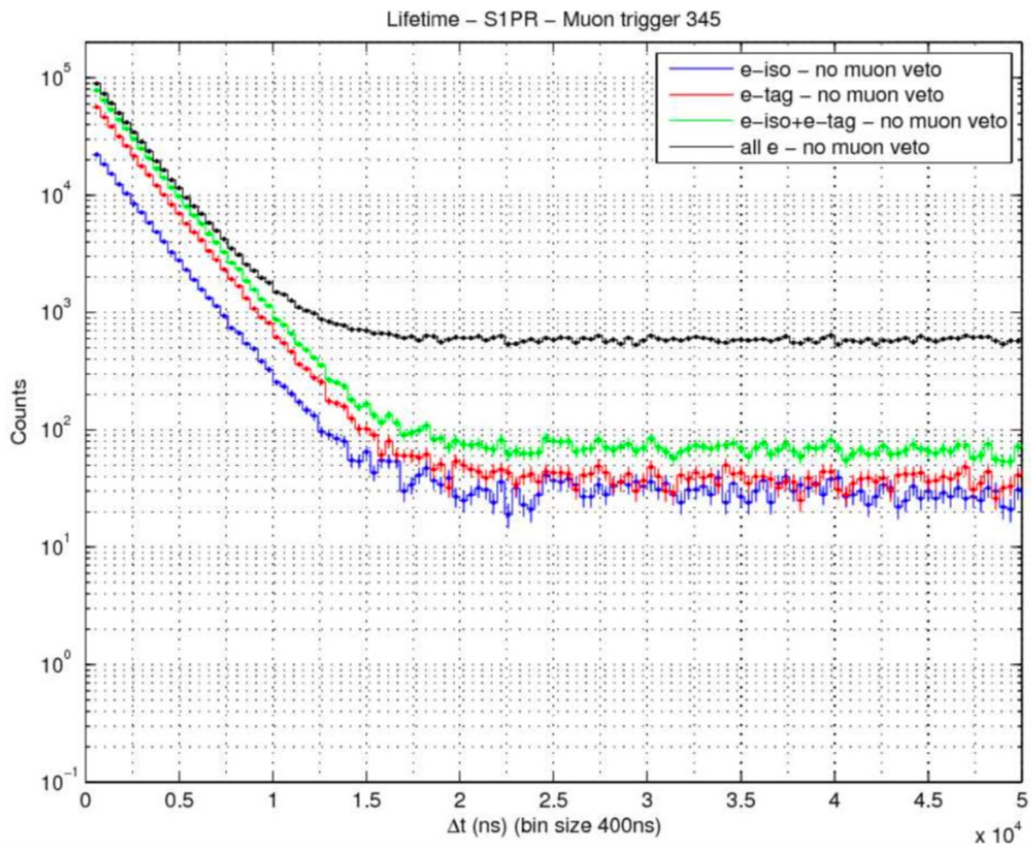


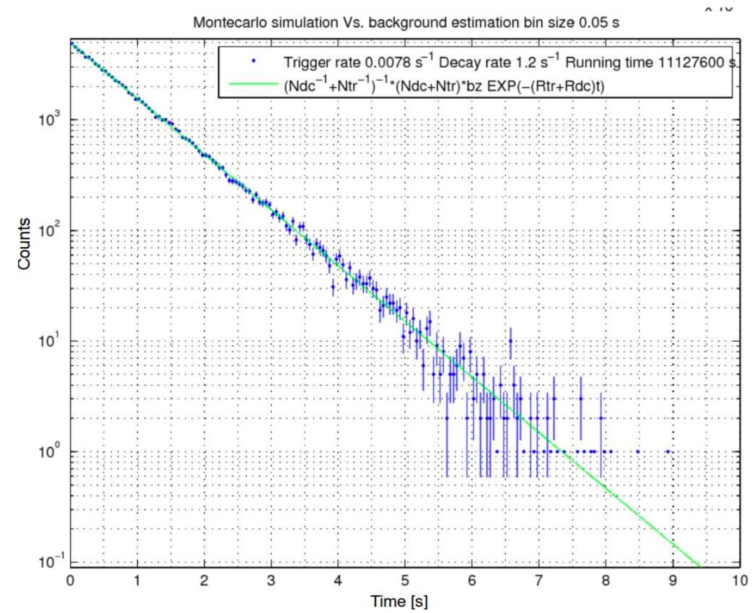




demonstrate your science to public; meet your congressman

Search for CHAMP (decaying charged particle with lifetime > muon's) – reduce randoms' tail





0 - 50 microseconds

Decays and random hits (not flat)

0 -10 seconds

Random hits

Name, Event, Date

Studies of Cosmic Ray Muon Radiation and its Application to Archaeometry:

The Pyramid of Kukulcan at Chichen Itza, México.

Pyramid (tracker based on mu2e readout)

QuarkNet hopes to host data on e-Lab so teachers can participate

Fun working environment

I hope that I've convinced you that working with teachers and students can be exciting and fulfilling

Now - look at QuarkNet's amateur cosmic ray g-2 effort

2018 a few teachers discussed building g-2 cosmic rays exp

2019 We designed/gathered detectors and imagined a magnet

Panic – why would muon at rest have any polarization?

Dave Hertzog described his senior lab setup at UIUC for us and let us know that it was probably too difficult for us

2020 Of course, we started testing prototypes

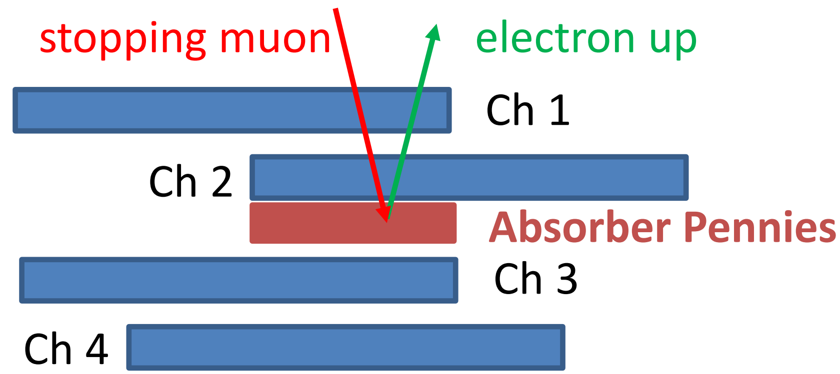
copper absorber (to remove μ^-)

Developed new e-Lab lifetime analysis package

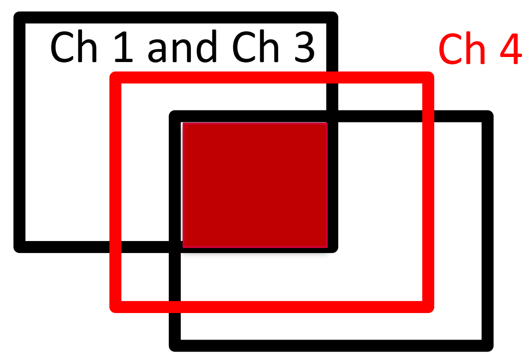
We are here, asking for help, particularly with magnet design

As you may know – muon lifetime is about 2 microseconds

g-2 prototype measurements (no B field) – understand up-down asymmetry, signal purity, absorber materials, rates



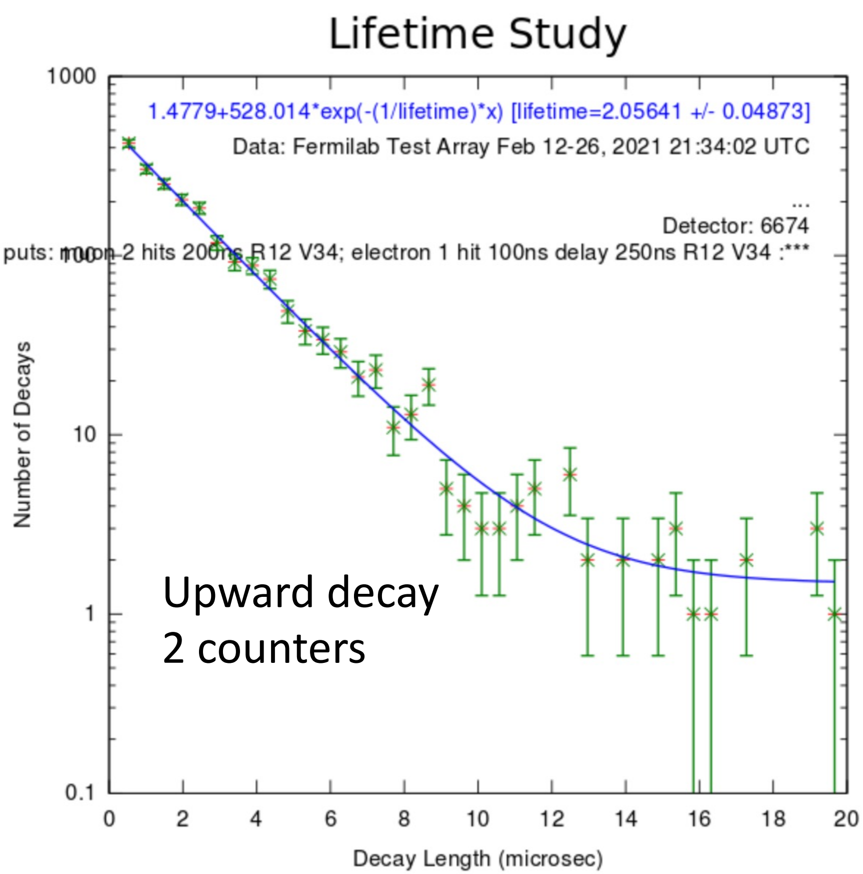
Top View

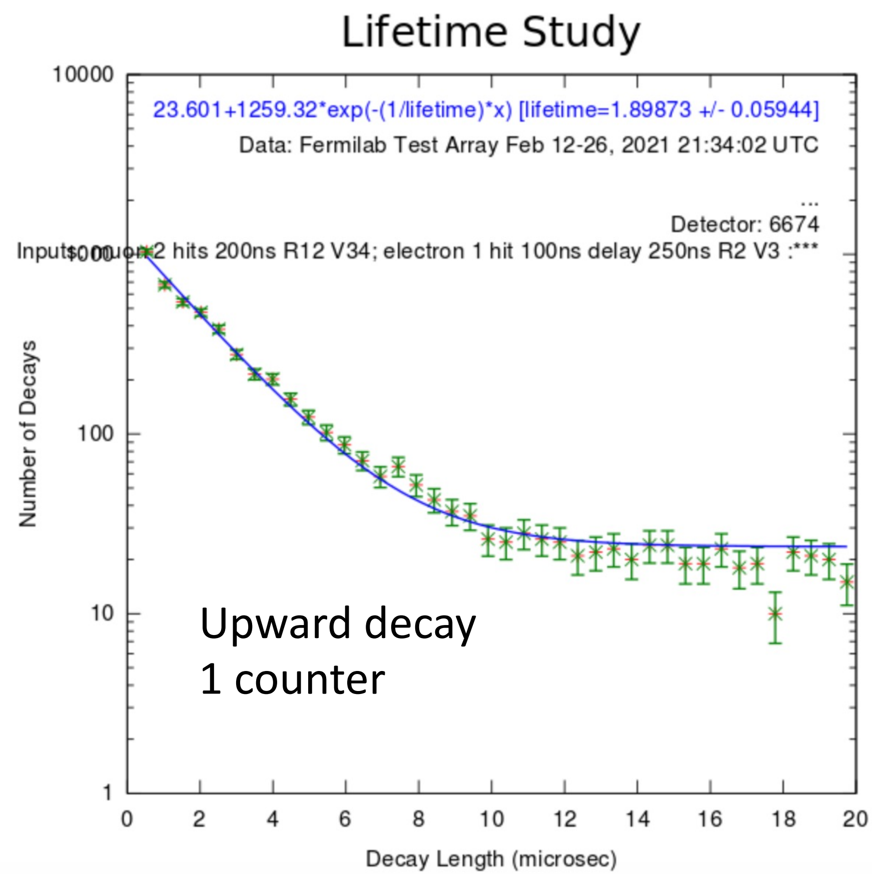


Name, Event, Date

Typical Muon Lifetime

Electrons with 2 hits are less efficient but with reduced random tail background





2 weeks of data – enlarged absorber and active area, plus moderator would yield statistics for g-2 in less than a month

Design criteria:

Must use DAQ 4-channel readout card

Rewritten lifetime e-Lab controls
define muon logic and gates
define electron logic and gates

Design of magnet will determine size
of scintillation counters. B horizontal

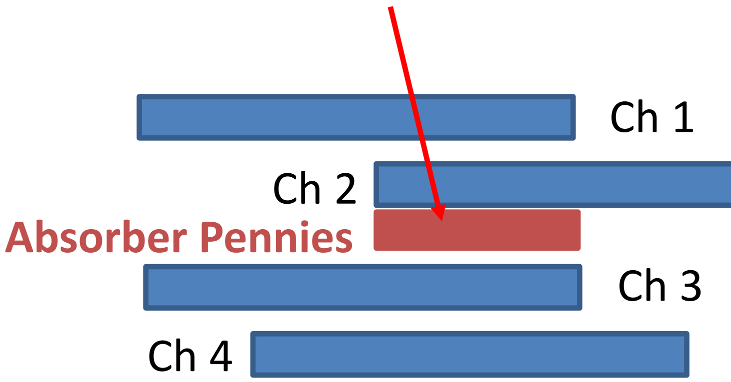
Month of data is reasonable scale for
final experiment

QuarkNet g-2 first prototype rates

Define muon as 12 3b4b and electrons ~ 300ns later

1eU = 2 3b4b 2eU = 12 3b4b

1eD = 3 1b2b 2eD = 34 1b2b



Number of decays in 6M muons

E defn	#Decays	#decays-random tail	Subtract No Absorber # Decays-tail	U/D	Signal/ #Decays
2eU	2357	2323	1351	1.32	0.58
2eD	1435	1349	1026		0.76
1eU	5480	4520	2574	1.56	0.57
1eD	3129	2109	1643		0.78

20 times this data set should lead to ~5% on g-2

Conclusions from Prototypes

1. There is an asymmetry #Up/#Down >1.8
2. 1 or 2-counter electron tags similar behavior
3. There is an asymmetry #Up/#Down >1.3 after empty target subtraction
4. Decay signal from absorber vs total (absorber +scintillator) is 0.58 U and 0.76 D

New studies but this 4-counter design works

1. Get more absorber and measure with full counter overlaps
2. Thinner scintillators to improve signal from absorber
3. Investigate lead above to increase # muons that stop (lower incoming energy)
4. Design counters that have PMTs removed from scintillator
5. Design ~50 Gauss Magnet

Name, Event, Date

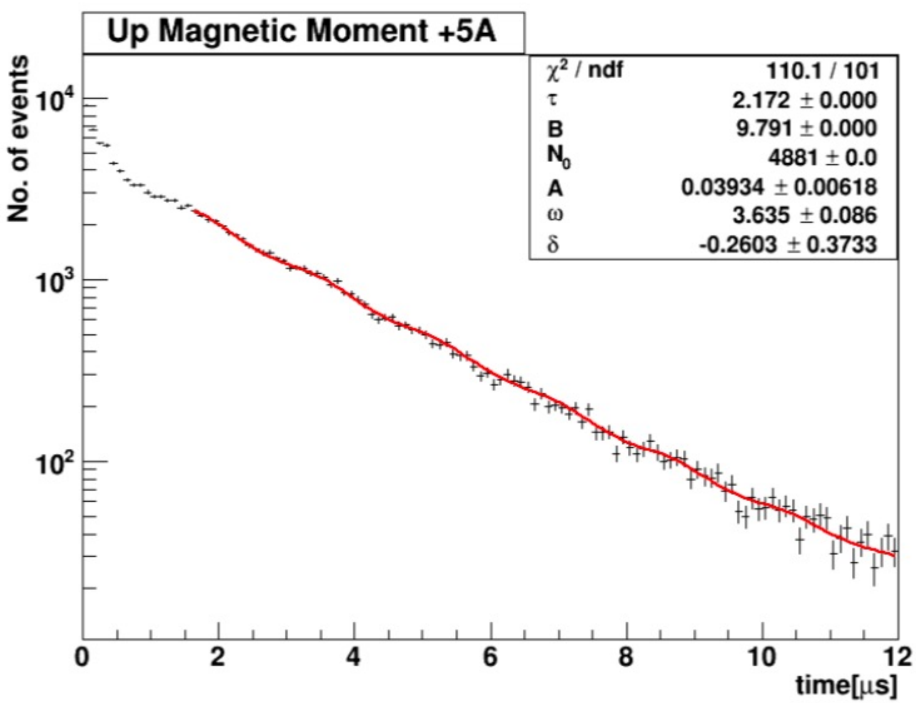
Example of possible results

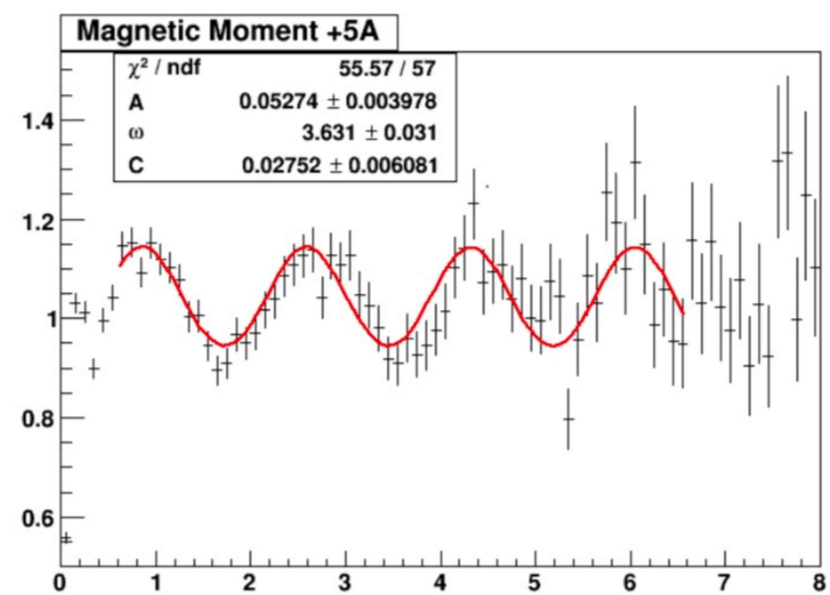
$$N(t) = N_0 e^{-t/\tau} + B$$

In the presence of an external field, Larmor frequency $\omega = egB/2m_\mu$

$$N = N_0 e^{-t/\tau}[1 + A\cos(\omega t + \delta)] + B$$

Lab report by Francois Drielsma (U. Geneve) using Helmholtz coils; g-2 to 1 percent





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Current Projects Summary

g-2 – Fundamental measure of the precession of the muon's spin in a magnetic field. The g-2 collaboration at Fermi does it a billion time better. WOW, to do it at "home"!

Remote Experiments – during COVID many users couldn't access their detector. Had access to 500K files on e-Lab.

Storm Tracking – Detectors across Kansas follow storms by measuring cosmic ray rates that change with atmospheric pressure. Hawaii and Puerto Rico also participating using their data and others' data

Moon Shadow – A large uncertainty in setting a limit of cosmic rays from sun during eclipses is where is the moon's cosmic ray shadow? Search for the shadow from the moon directly. Many QuarkNet Centers will participate.

2024 Eclipse – prepare for better upper limit measurement.

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Final Asks and Questions

Recruit Volunteer to help mentor QuarkNet teachers

Develop a g-2 experiment with errors at 10% level (maybe that's measuring g, not g-2)

Magnet design and cost estimation

Advice on B field measurement (Hall probe?) and analysis

If you are interested –

talk to QuarkNet about our other outreach activities, e.g. Master Classes or

joining QuarkNet as a Center

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What do you get out of it?

Help g-2 collaboration with outreach to teachers

Assist QuarkNet teachers to build g-2 magnet

Inspire high school to do science with complex analysis

Develop long-term relationship with teachers and learn more about teaching

Be wowed by what students can accomplish

Extra Slides

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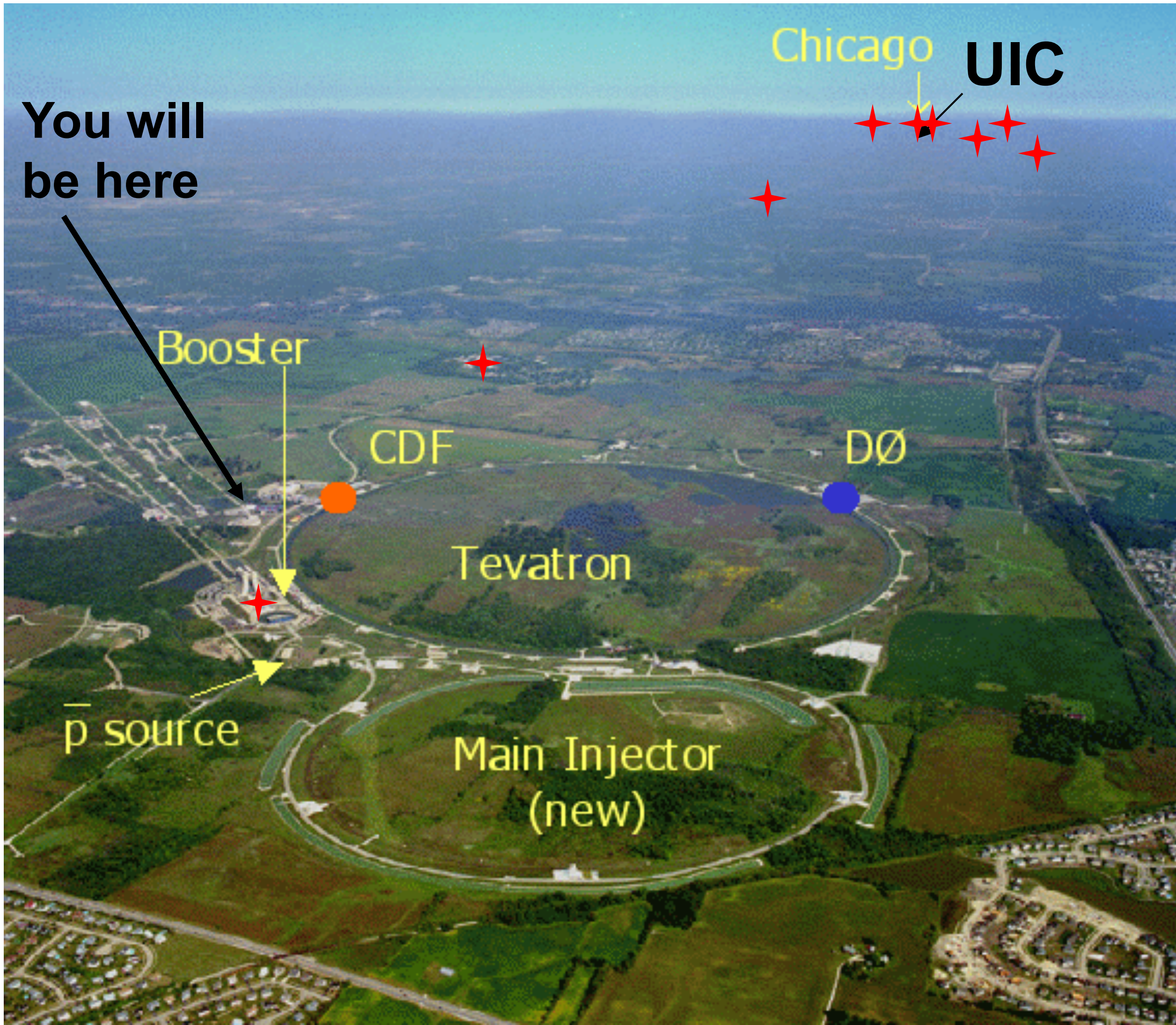
CLASA ARRAY



Fermilab History

proton - antiproton

collisions at

CM energy

1.96 TeV

Cosmic Rays can have higher energies