



INTERNATIONAL



MASTERCLASSES

hands on particle physics

Standards and not-so-standard physics with QuarkNet

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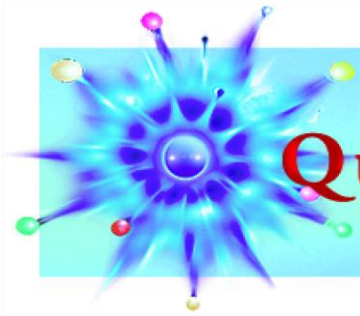


U.S. DEPARTMENT OF
ENERGY

Office of
Science



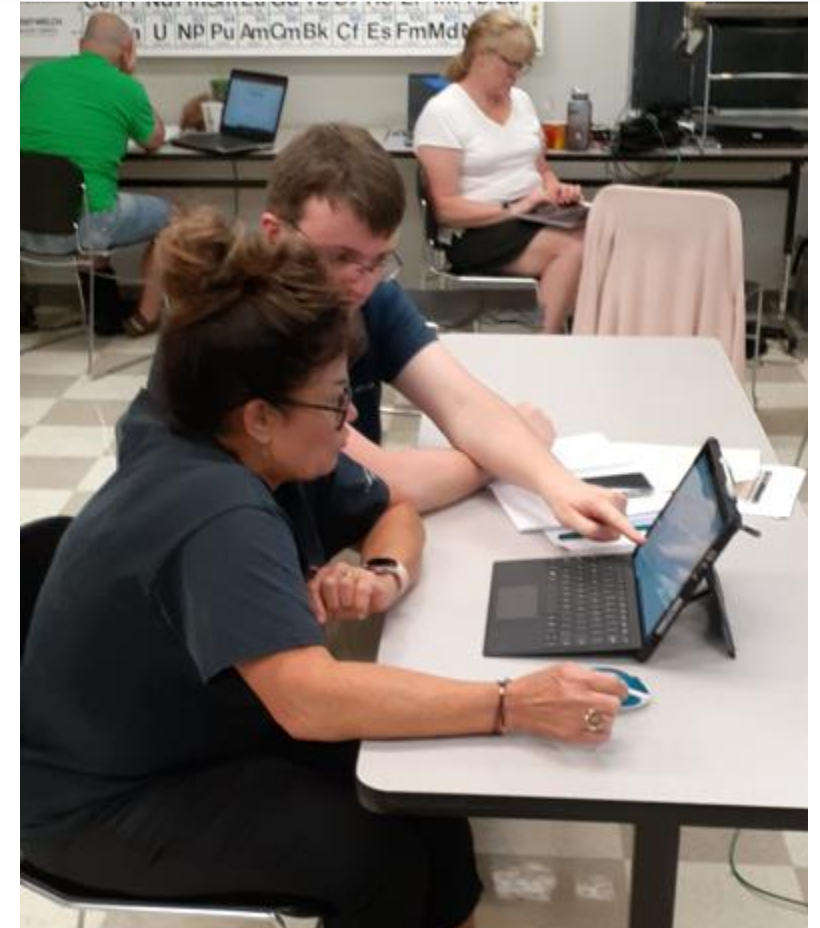
 **Fermilab**



QuarkNet

QuarkNet? What's QuarkNet? And so what?

- Collegial crew of physics teachers, physicists, and other geeks
- Focus on
 - particle physics
 - data
 - how physics gets done
- Local QuarkNet centers at universities or labs
- Small national staff, physicist mentors and teacher leaders at centers
- Local, national, international opportunities

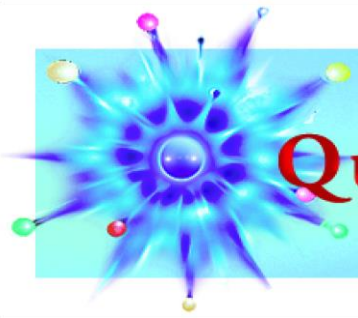




Programs summary

Too much information and still not complete!

- Cosmic Ray Studies
 - Cosmic Ray Detectors at schools
 - Cosmic Ray e-Lab online
 - Cosmic workshops
 - International Muon Week (Feb-Mar)
 - International Cosmic Day (Nov)
- Teaching, learning, skills
 - Data Camp (Jul)
 - Coding Camps (Jun-Jul)
 - Coding workshops
- Data Activities
 - <http://cern.ch/qndap>
- LHC@CERN
 - Masterclass CMS and ATLAS (Mar)
 - World-Wide Data Day (Oct-Nov)
 - CMS e-Lab
 - LHC workshops
- Neutrino studies
 - MasterClass MINERvA and NOVA (March)
 - Neutrino workshops
- Summer Workshops at Centers
 - <http://cern.ch/qnwkshp>



- **HS-PSII-10.1.* Describe the Standard Model and explain the composition and decay of subatomic particles using the Standard Model and Feynman diagrams.**
- **HS-PSII-10.2.* Explain the stability of the nucleus considering the electromagnetic repulsion in the nucleus and how forces govern binding energy and radioactive decay for different elements.**
- **HS-PSII-10.3.* Qualitatively compare and contrast how particle interactions, fission, and fusion can convert matter into energy and energy into matter and calculate the relative amounts of matter and energy in such processes.**
- **HS-PSII-10.4.* Apply the conservation of mass, conservation of charge, and conservation of linear momentum principles to describe the results of a radioactive particle undergoing either alpha or beta decay.**
- **HS-PSII-10.5.* Know and describe how a particle accelerator functions and how current high energy particle physics experiments are being used to develop the Standard Model.**



In addition:

Unit 7: Quantum, Atomic, and Nuclear Physics

7.1 Systems and Fundamental Forces

7.2 Radioactive Decay

7.3 Energy in Modern Physics (includes $E=mc^2$)

7.4 Mass-Energy Equivalence

7.5 Properties of Waves and Particles

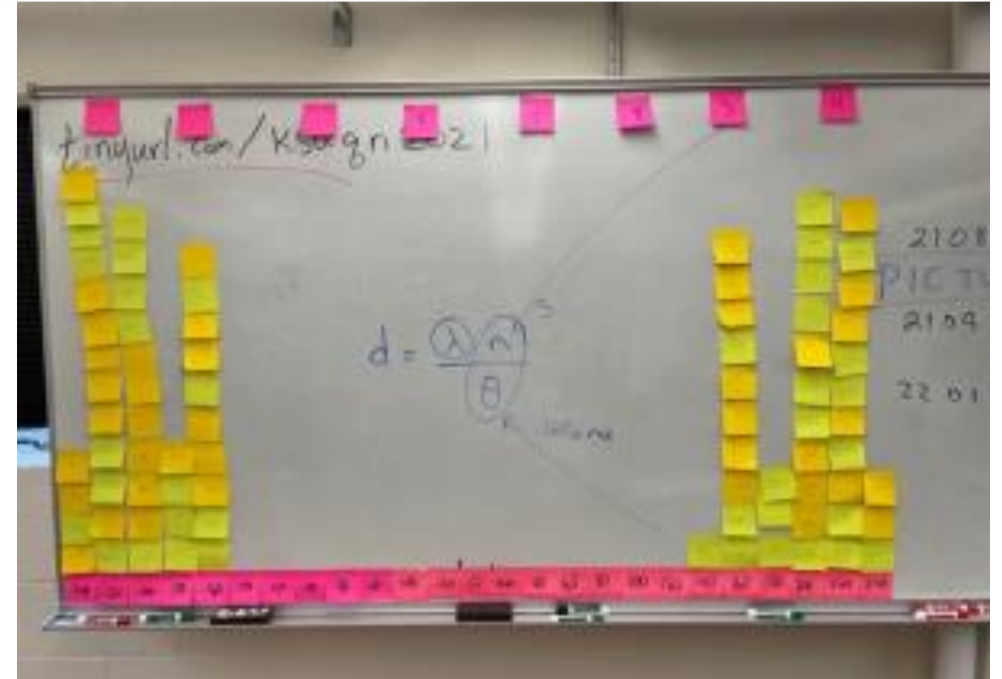
7.6 Photoelectric Effect

7.7 Wave Functions and Probability

IB Physics

Core Topic 7: Atomic, nuclear, and particle physics

Additional Higher Level Topic 12: Quantum and nuclear physics





Centers in the national program



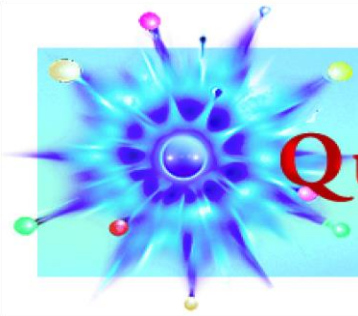


University of Notre Dame
Notre Dame/South Bend

Purdue University Northwest
Hammond

Purdue University (main campus)
West Lafayette

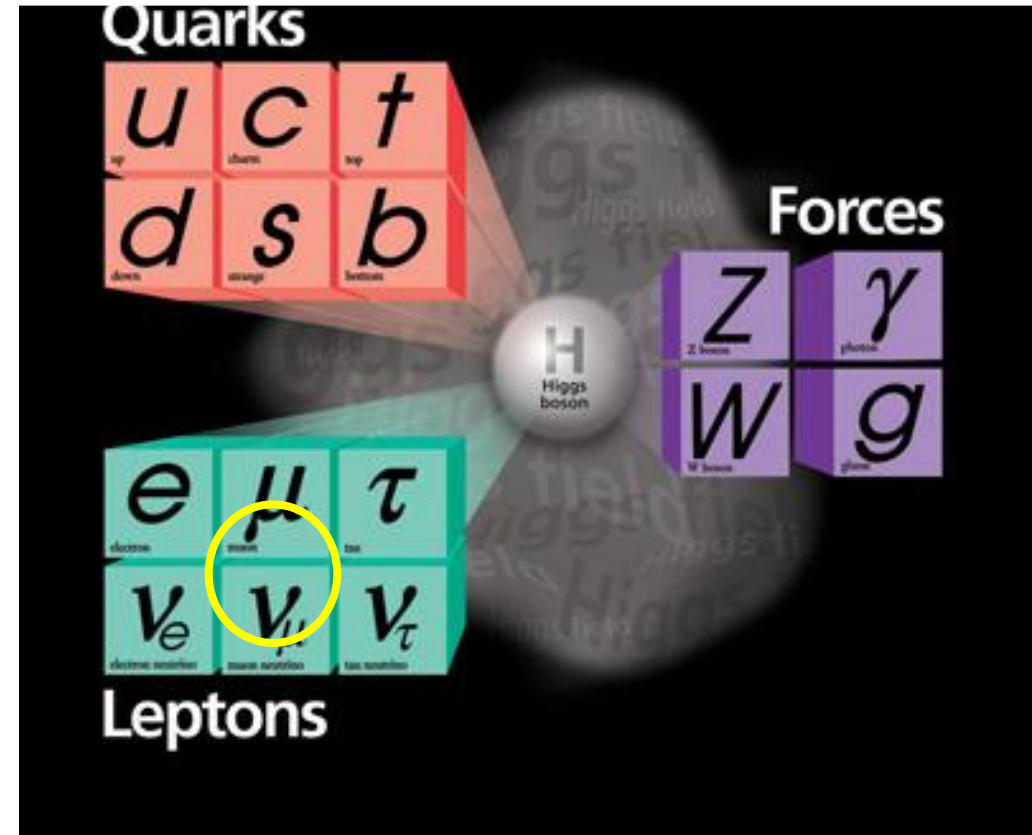
University of Cincinnati
Cincinnati OH



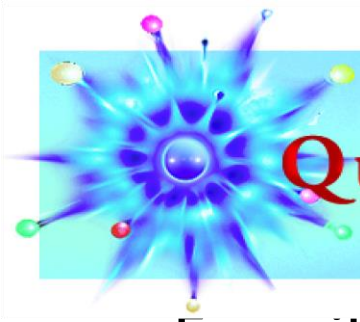
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It's the data: two examples with muons

- Muons are sort of like heavy electrons
 - or so they tell us
- How do they compare to electrons?
- How can we tell?
- *But they are rare, weird, exotic particles that don't matter to real life! Right?*



<https://fnal.gov/pub/science/particle-physics-101/images/05-0440-01D-sm.jpg>



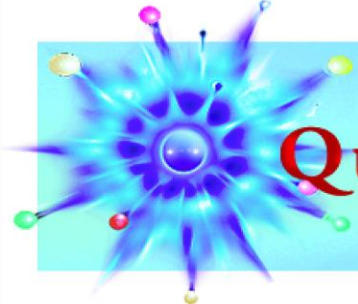
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Data from the MINERvA neutrino experiment

- Fermilab experiment
- Muon enters detector, stops at time t_1
- Muon decays into three particles at time t_2
 - Two “invisible”
 - One “visible” – record energy deposited
 - $E=mc^2$
- Decay time = $t_2 - t_1$
- Repeat, repeat, repeat,....
- Look up *Muon Lifetime Part 3: MINERvA* in Data Activities



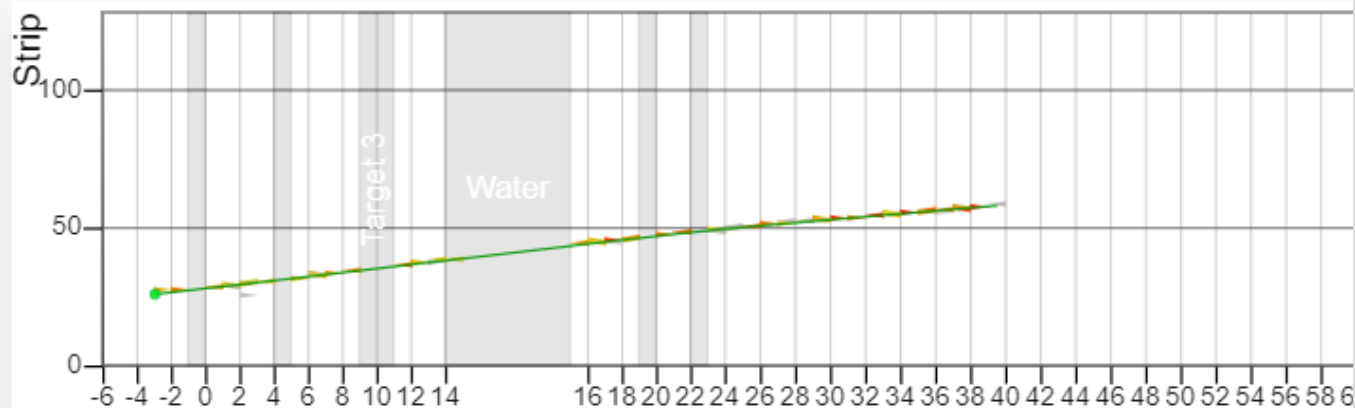
<https://minerva.fnal.gov/wp-content/uploads/2016/01/MINERvAcollab-1.jpg>



QuarkNet

Data from the MINERvA neutrino experiment

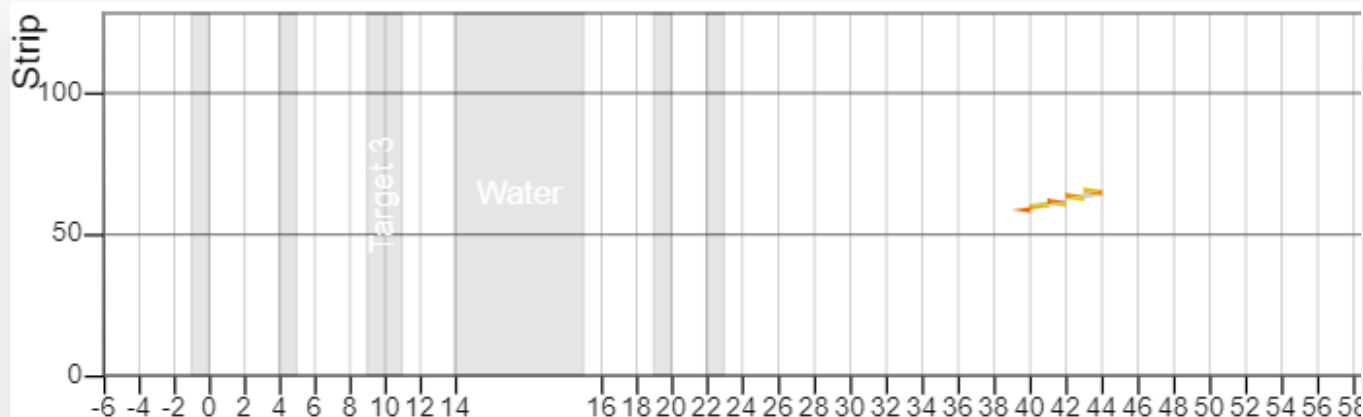
Big Hitmap



Slice Info

Slice	6 of 11
Event ID	MV 2072 33 1106
Time	(13.0 years ago)
Hits	289
Mean time	5434 ns
Total PE	1653 pe
Visible Energy	316.4 MeV

Big Hitmap



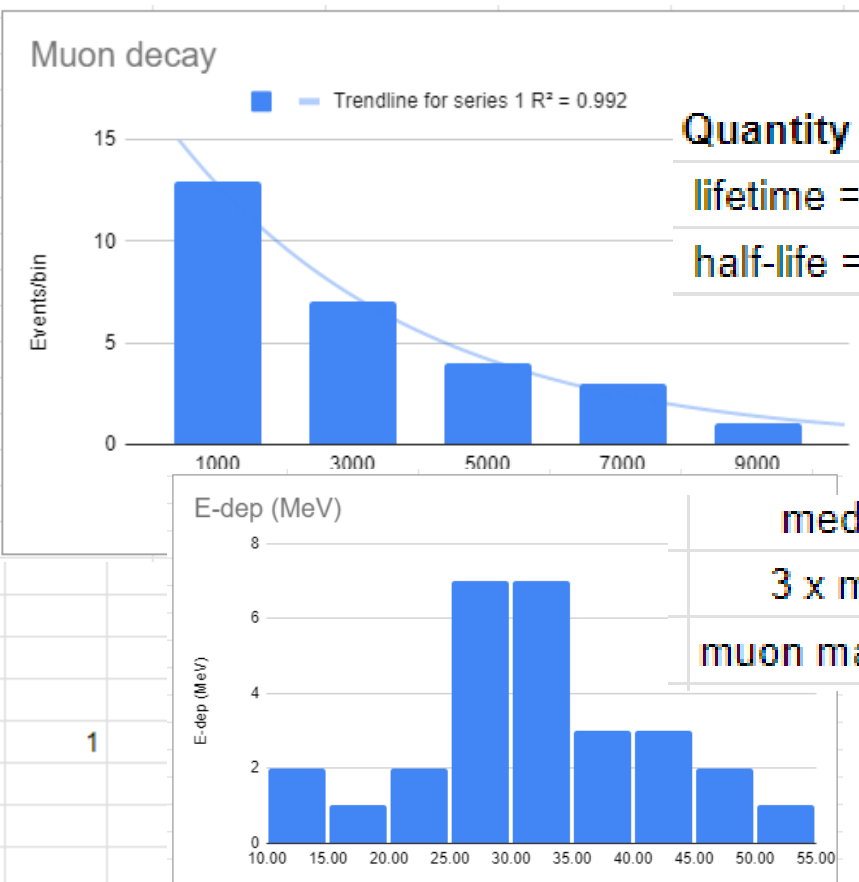
Slice Info

Slice	8 of 11
Event ID	MV 2072 33 1106
Time	(13.0 years ago)
Hits	49
Mean time	6130 ns
Total PE	248 pe
Visible Energy	51.4 MeV



Results

t1 (ns)	t2 (ns)	delta-t (ns)	E-dep (MeV)
5434	6130	696	51.4
3735	5133	1398	13.2
7397	8200	803	34.5
7045	8232	1187	20.1
3092	8418	5326	36.8
3784	4912	1128	37.9
9522	13976	4454	31.8
8019	9560	1541	33.1
2465	4911	2446	29.9
6400	7691	1291	32.8
7197	10207	3010	40.8
2324	5215	2891	44.2
4494	8548	4054	25.1
7511	12311	4800	28.3
5542	12631	7089	31.6
3521	5471	1950	46.5
4669	8101	3432	47.2
7477	14505	7028	28.9
9227	11995	2768	29.6



Quantity	Exp value	Pub value
lifetime =	3600 ns	2200 ns
half-life =	2500 ns	1500 ns

median =	32	MeV
3 x med =	96	MeV
muon mass =	106	MeV

And now for something completely different: <http://cern.ch/muons-inaapt23>.



Thanks!

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Slides and more from QuarkNet-INAAPT2023 at
<https://web.quarknet.org/files/inaapt23/>.