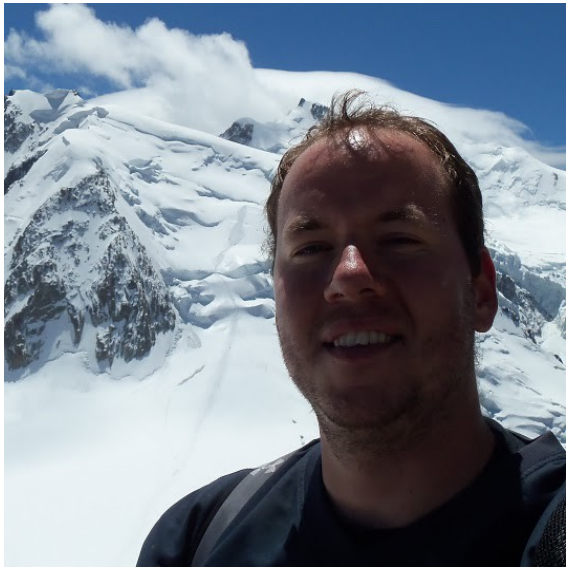
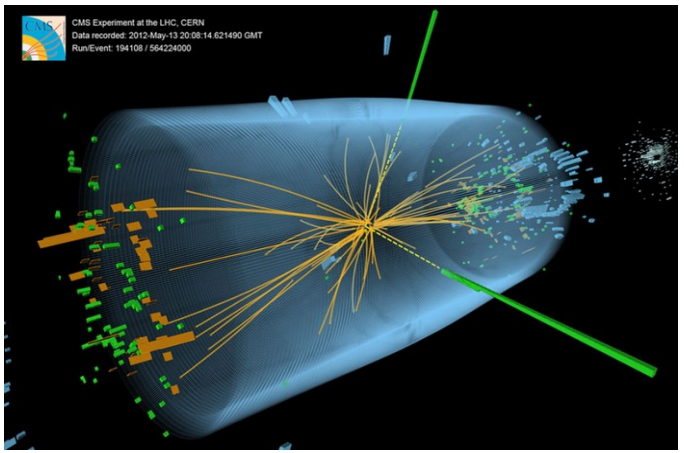
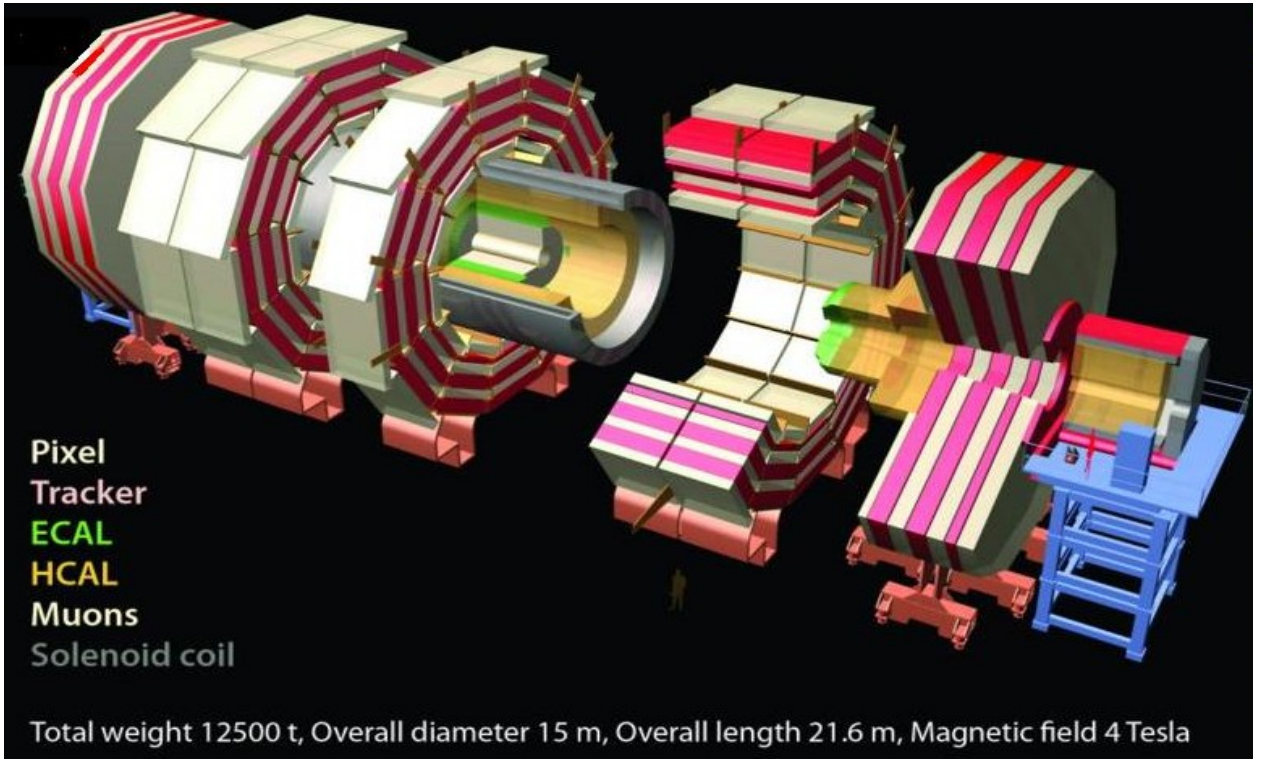
QuarkNet

What is QuarkNet, Anyway?



Jeremy Smith
QuarkNet Fellow / Lead Teacher
Hereford High School
Baltimore, Maryland

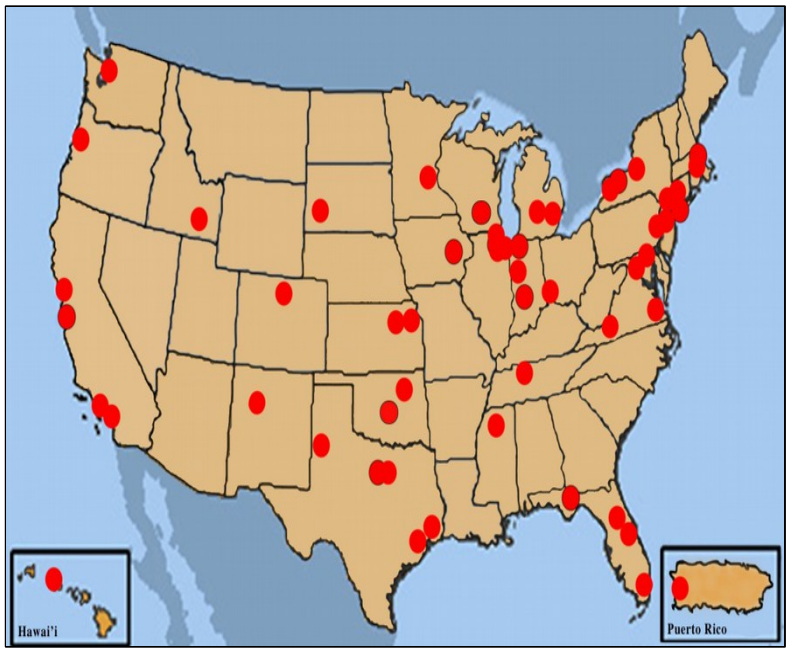




QuarkNet

Helping Develop America's Technological Workforce

Who are we?
What do we do?

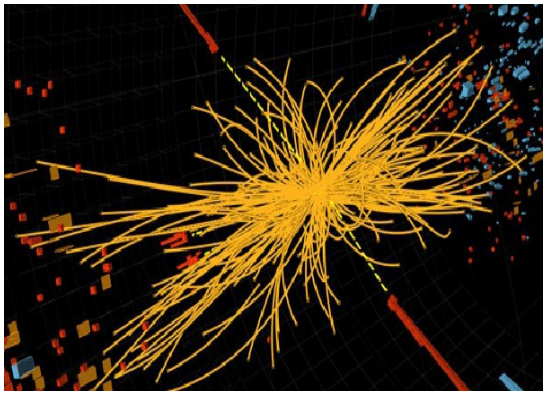


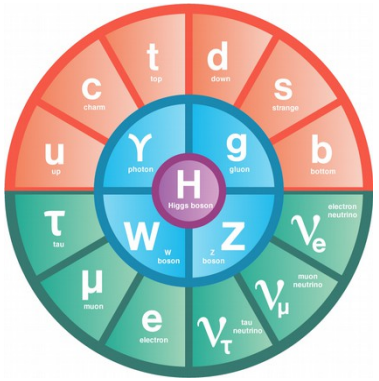
QuarkNet

HEP is super-interesting!

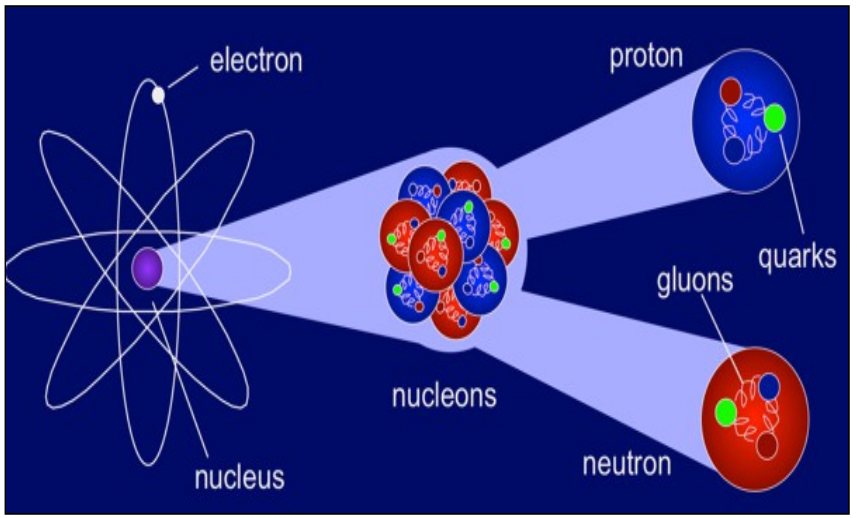
What My Students Think:

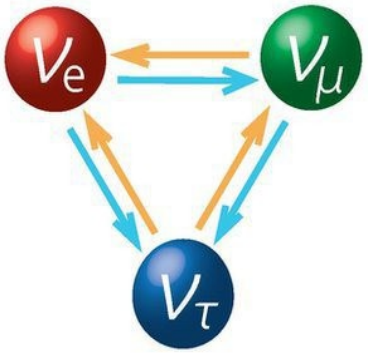
Particle physics is very cool but very difficult.





CERN





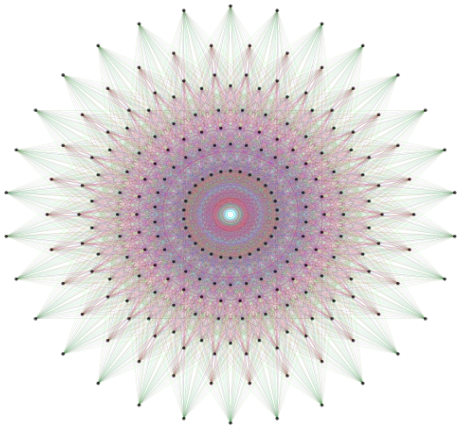
HEP is hard!

What My Students Think:

Particle physics is very cool but very difficult.

The Reality:

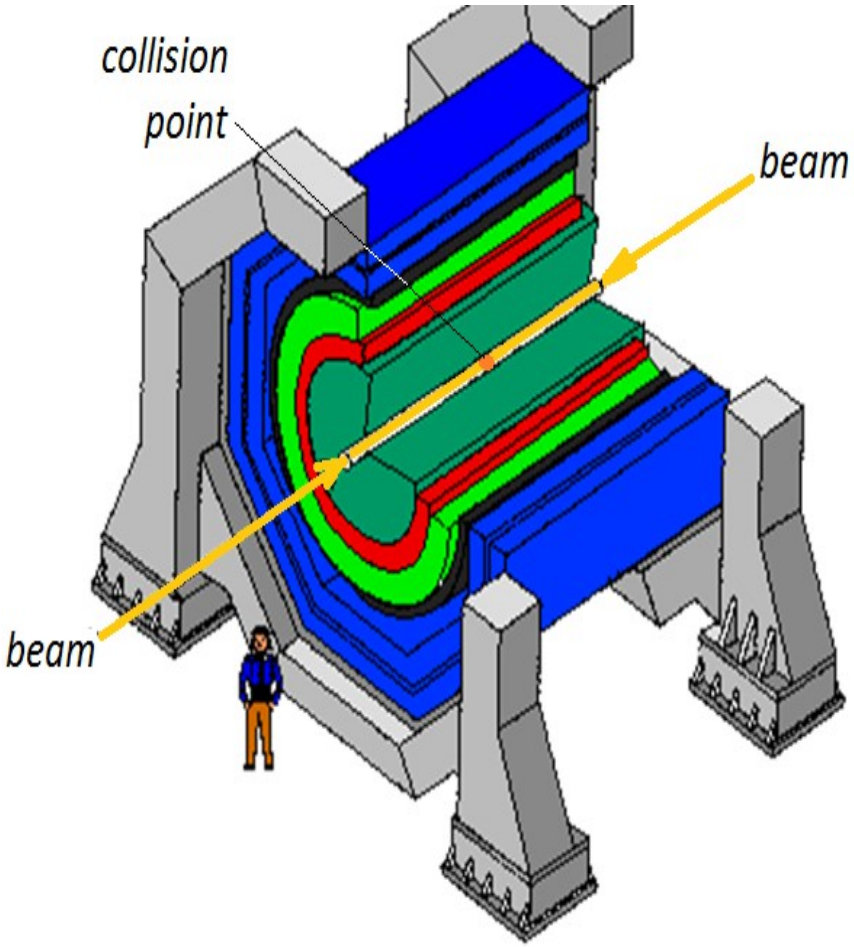
Particle physics is very cool but very difficult.

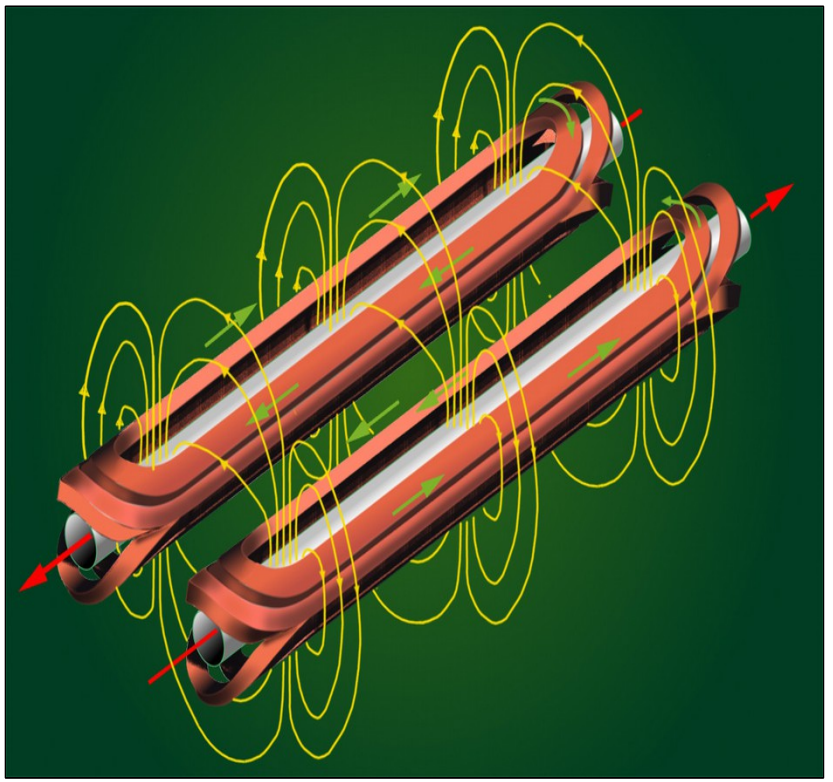


$$
\begin{aligned}
&\mathcal{L}_{SM} = -\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
&M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - \\
&igs_w(\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - \\
&W^-_\nu \partial_\nu W^+_\mu)) - \tfrac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2 (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - \\
&Z^0_\mu Z^0_\nu W^+_\nu W^-_\nu) + g^2 s_w^2 (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w (A_\mu Z^0_\nu (W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \tfrac{1}{2}\partial_\mu H \partial_\mu H - 2M^2 \alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \tfrac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
&\beta_h \left(\tfrac{2M^2}{g^2} + \tfrac{2M}{g} H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-) \right) + \tfrac{2M^4}{g^2}\alpha_h - \\
&g\alpha_h M (H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-) - \\
&\tfrac{1}{8}g^2 \alpha_h (H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2) - \\
&gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_w^2} Z^0_\mu Z^0_\mu H - \\
&\tfrac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
&\tfrac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
&M(\tfrac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - \\
&W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
&\tfrac{1}{4}g^2 W^+_\mu W^-_\mu (H^2 + (\phi^0)^2 + 2\phi^+\phi^-) - \tfrac{1}{8}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu (H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-) - \\
&\tfrac{1}{2}g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \tfrac{1}{2}ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
&W^-_\mu\phi^+) + \tfrac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
&g^2 s_w^2 A_\mu A_\mu \phi^+\phi^- + \tfrac{1}{2}ig_s\lambda^a_{ij}(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + \\
&m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_wA_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
&\tfrac{ig}{4c_w}Z^0_\mu\{(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{d}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - 1 - \gamma^5)d^\lambda_j) + \\
&(\bar{u}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 + \gamma^5)u^\lambda_j)\} + \tfrac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)U^{lep}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
&\tfrac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_e(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m^\lambda_\nu(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1+\gamma^5)e^\kappa)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_e(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa)\right) - \tfrac{g}{2}\tfrac{m^\lambda_e}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \\
&\tfrac{g}{2}\tfrac{m^\lambda_e}{M}H(\bar{e}^\lambda e^\lambda) + \tfrac{ig}{2}\tfrac{m^\lambda_e}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \tfrac{ig}{2}\tfrac{m^\lambda_u}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \tfrac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa - \\
&\tfrac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa + \tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)\right) - \tfrac{g}{2}\tfrac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
&\tfrac{g}{2}\tfrac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \tfrac{ig}{2}\tfrac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \\
&\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \tfrac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \\
&\partial_\mu\bar{X}^+X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \\
&\partial_\mu\bar{X}^0X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+X^+ - \\
&\partial_\mu\bar{X}^-X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+X^+ - \\
&\partial_\mu\bar{X}^-X^-) - \tfrac{1}{2}gM\left(\bar{X}^+X^+H + \bar{X}^-X^-H + \tfrac{1}{c_w^2}\bar{X}^0X^0H\right) + \tfrac{1-2c_w^2}{2c_w}igM(\bar{X}^+X^0\phi^+ - \bar{X}^-X^0\phi^-) + \\
&\tfrac{1}{2c_w}igM(\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-) + igMs_w(\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-) + \\
&\tfrac{1}{2}igM(\bar{X}^+X^+\phi^0 - \bar{X}^-X^-\phi^0)\ .
\end{aligned}
$$

But...

…Particle physics <u>can</u> be accessible to students!





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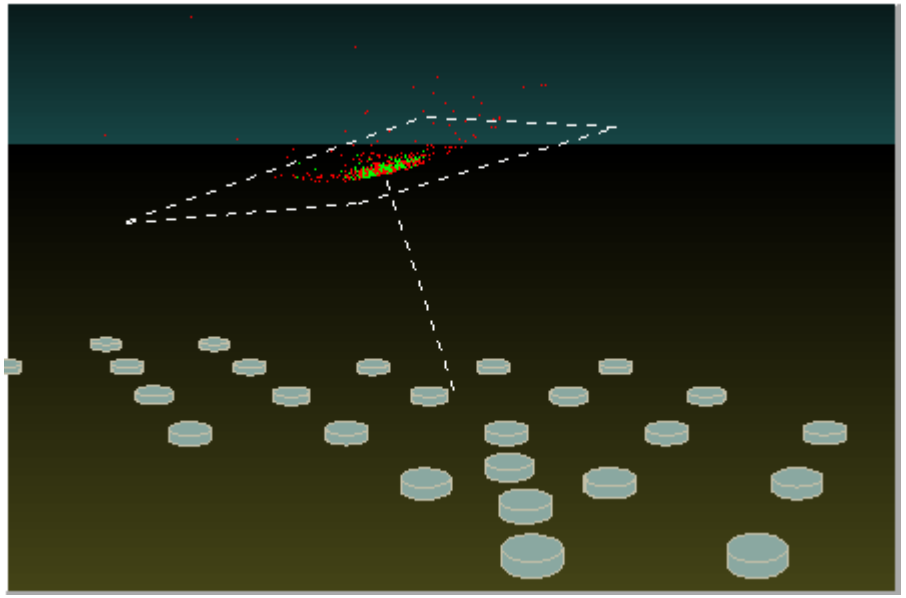
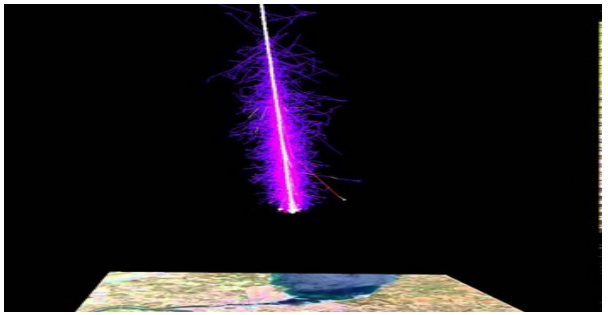
And...

…Particle detectors <u>can</u> live in your classroom!





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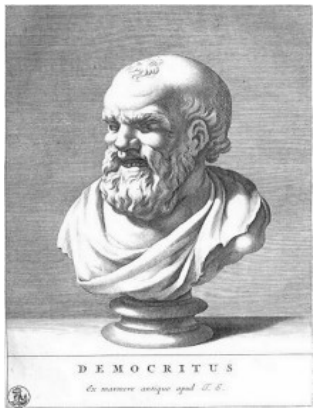
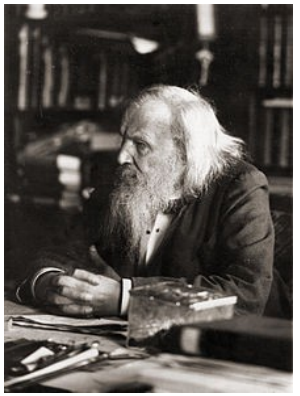
The basics



Dobereiner's triads Known to Mendeleev Unknown to Mendeleev

	H 1.01									
He 4.00	Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Ne 20.2	Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
Ar 40.0	K 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.9	Co 58.9	Ni 58.7
	Cu 63.5	Zn 65.4	Ga 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9			
Kr 83.8	Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Tc (99)	Ru 101	Rh 103	Pd 106
	Ag 108	Cd 112	In 115	Sn 119	Sb 122	Te 128	I 127			
Xe 131	Ce 133	Ba 137	La 139	Hf 178	Ta 181	W 184	Re 186	Os 194	Ir 192	Pt 195
	Au 197	Hg 201	Tl 204	Pb 207	Bi 209	Po (210)	At (210)			
Rn (222)	Fr (223)	Ra (226)	Ac (227)	Th 232	Pa (231)	U 238				



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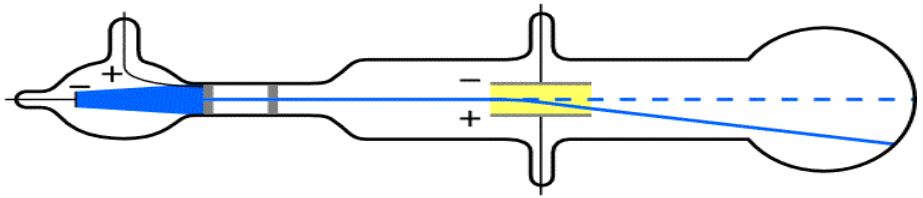
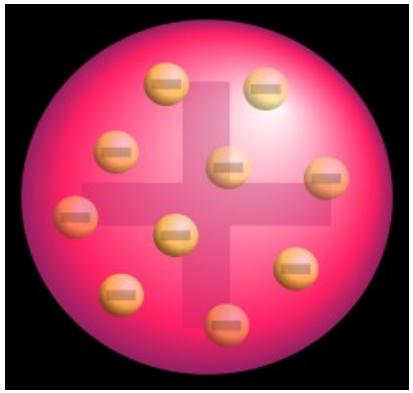
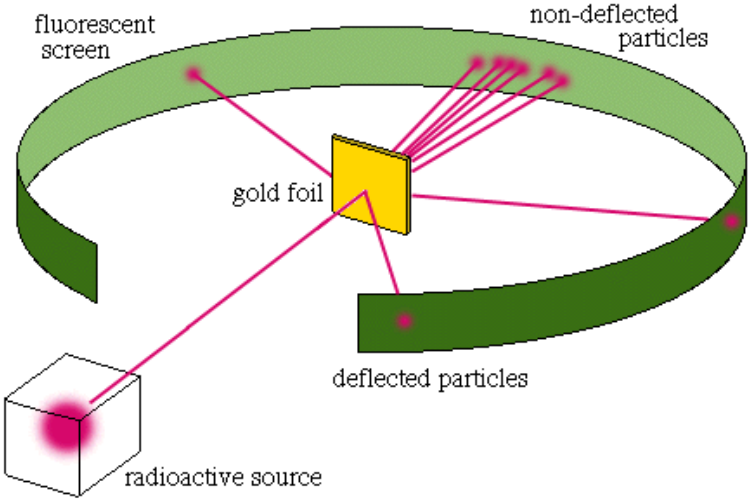
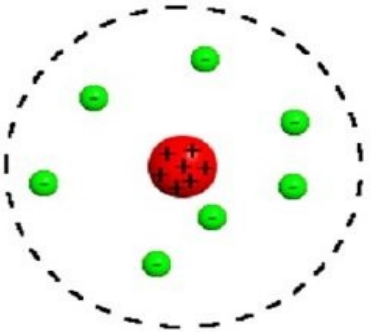
The models



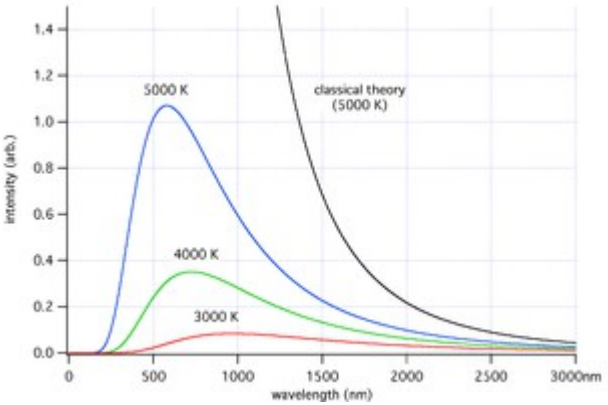


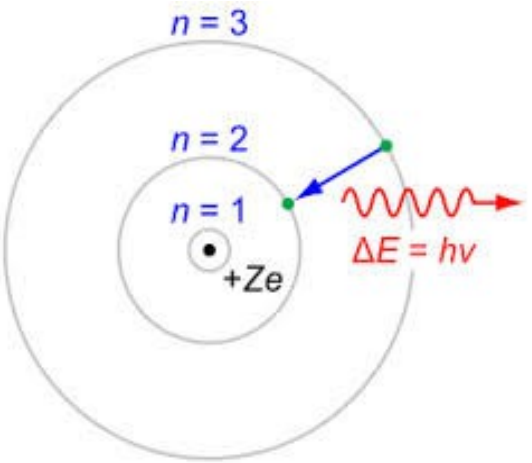


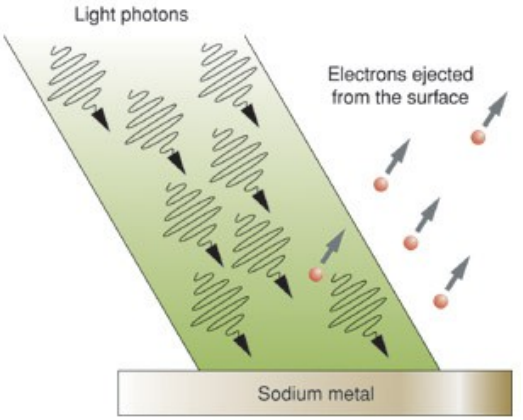


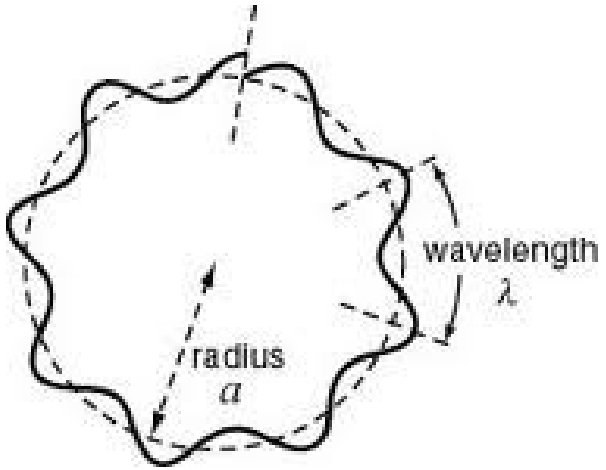
QuarkNet

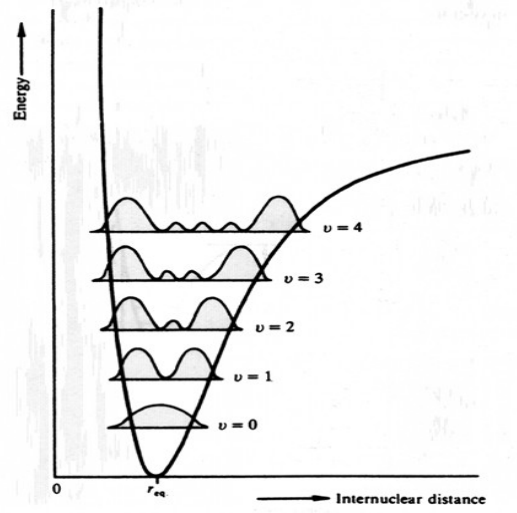
The quantum











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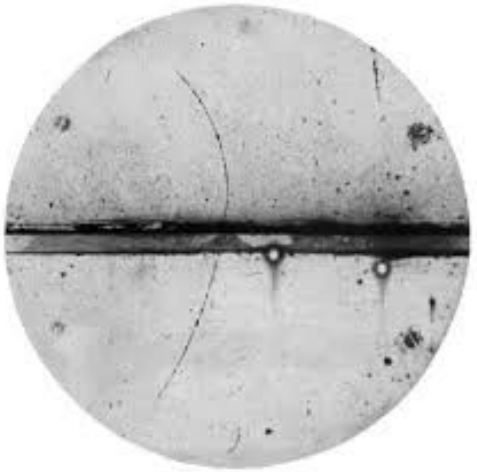
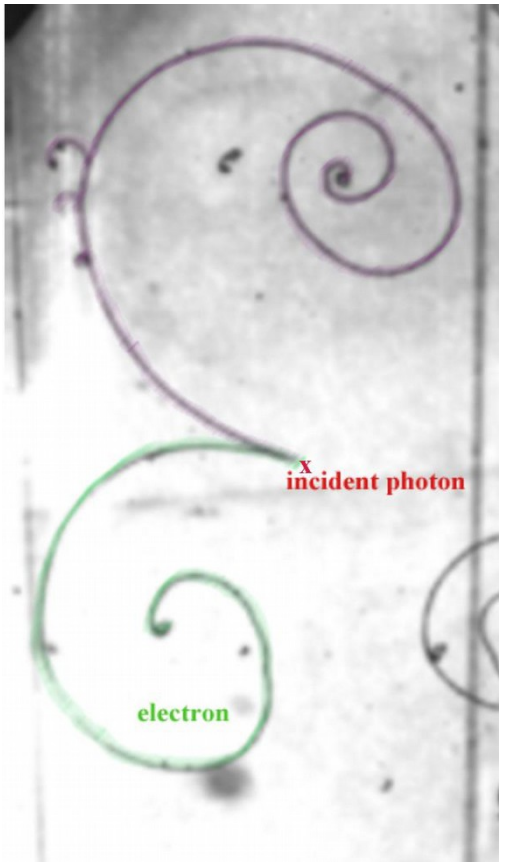
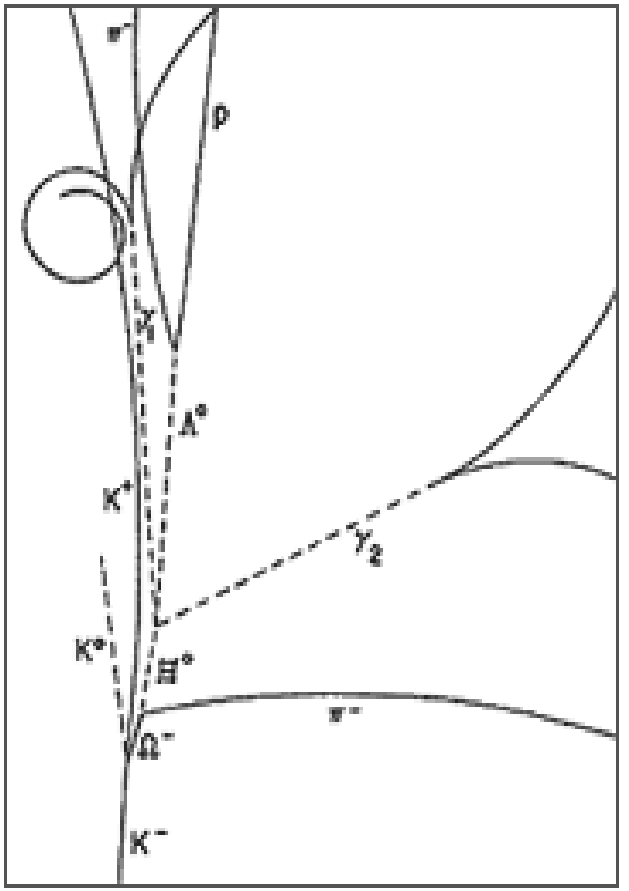
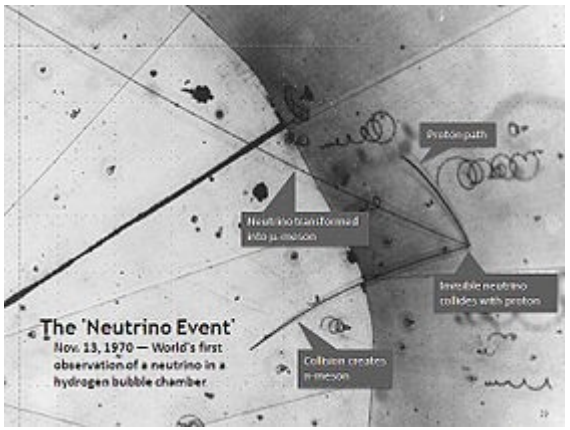
The particles



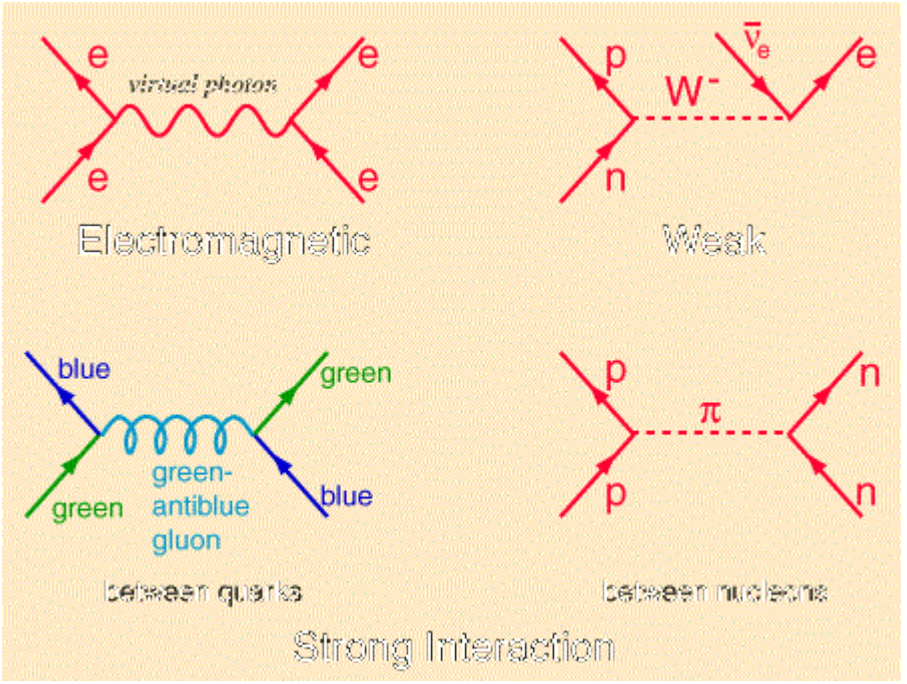


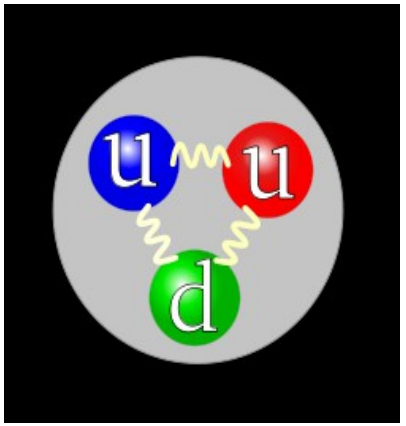


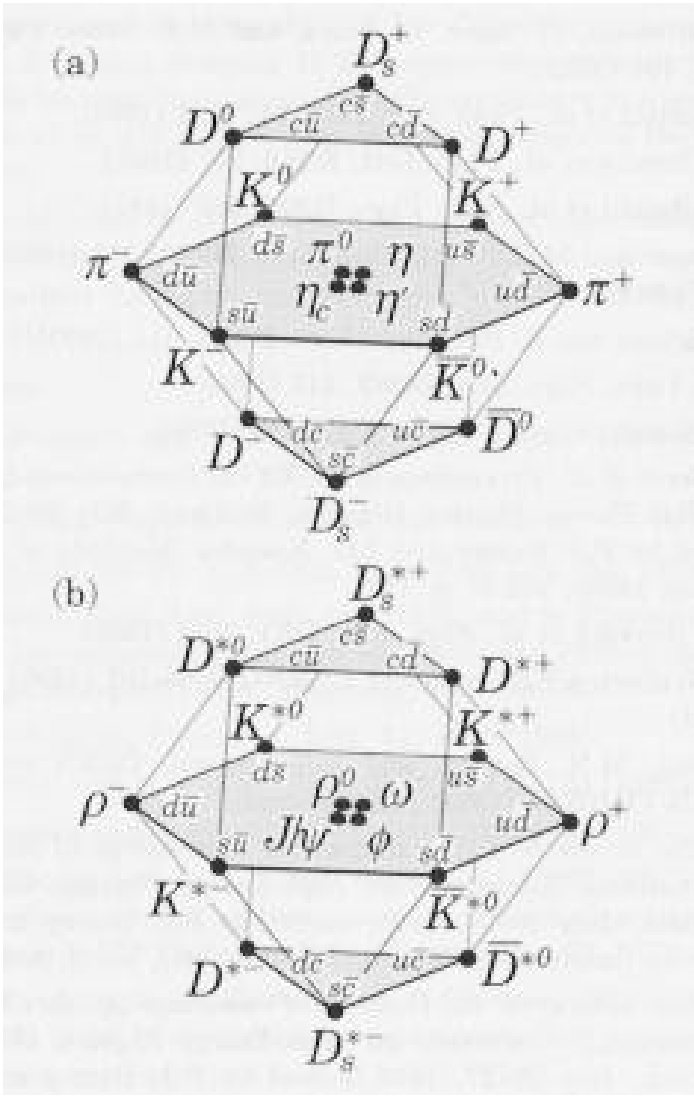


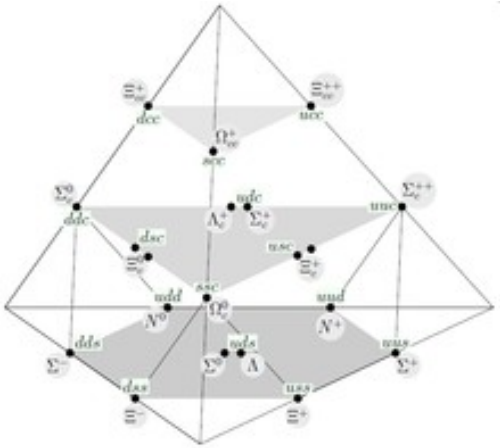
QuarkNet

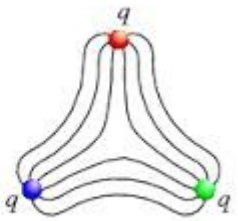
The fields





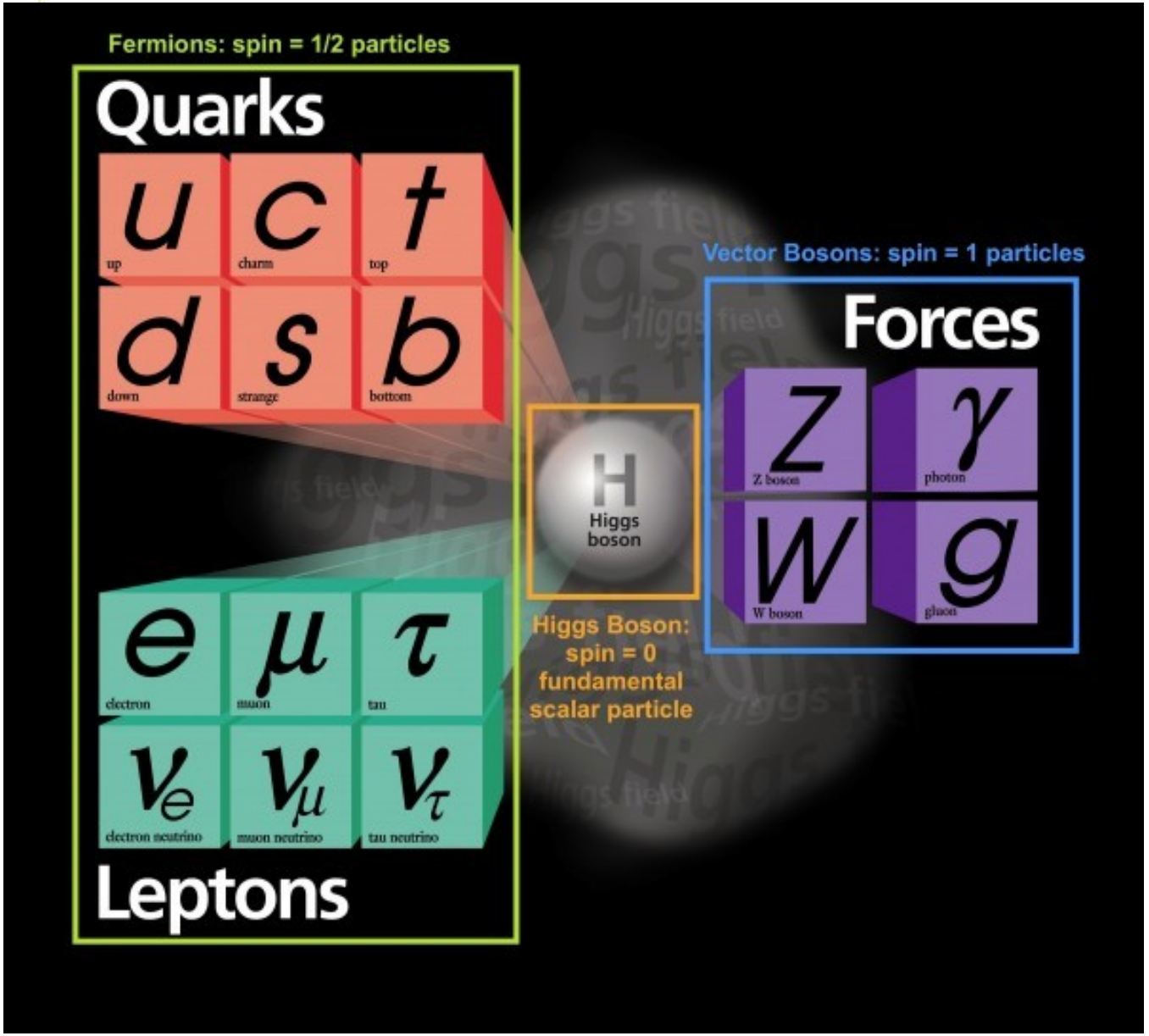






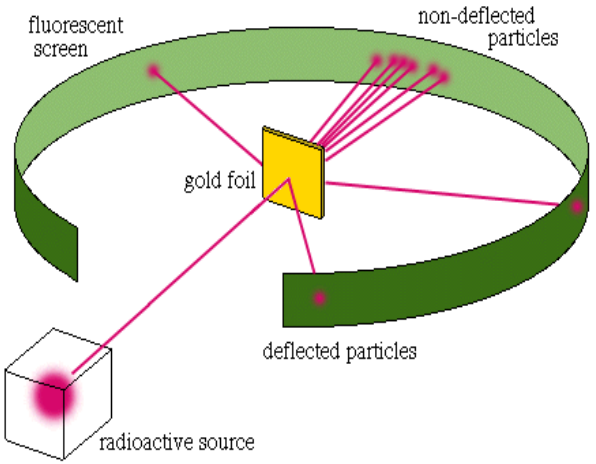
QuarkNet

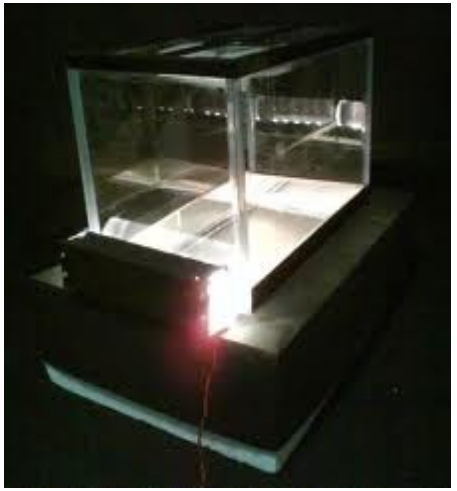
The new periodic table

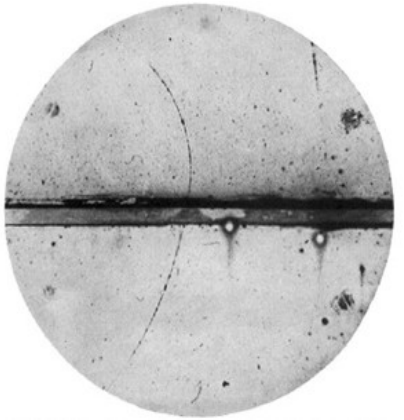


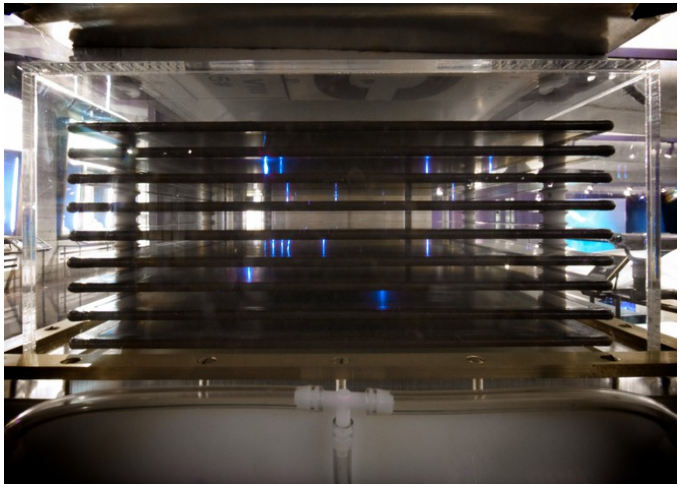
QuarkNet

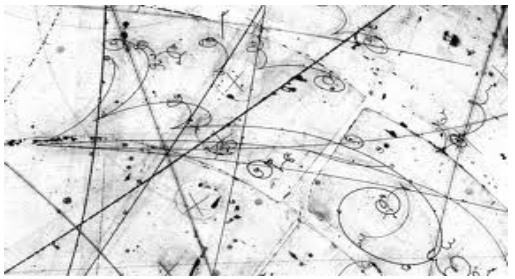
The detectors







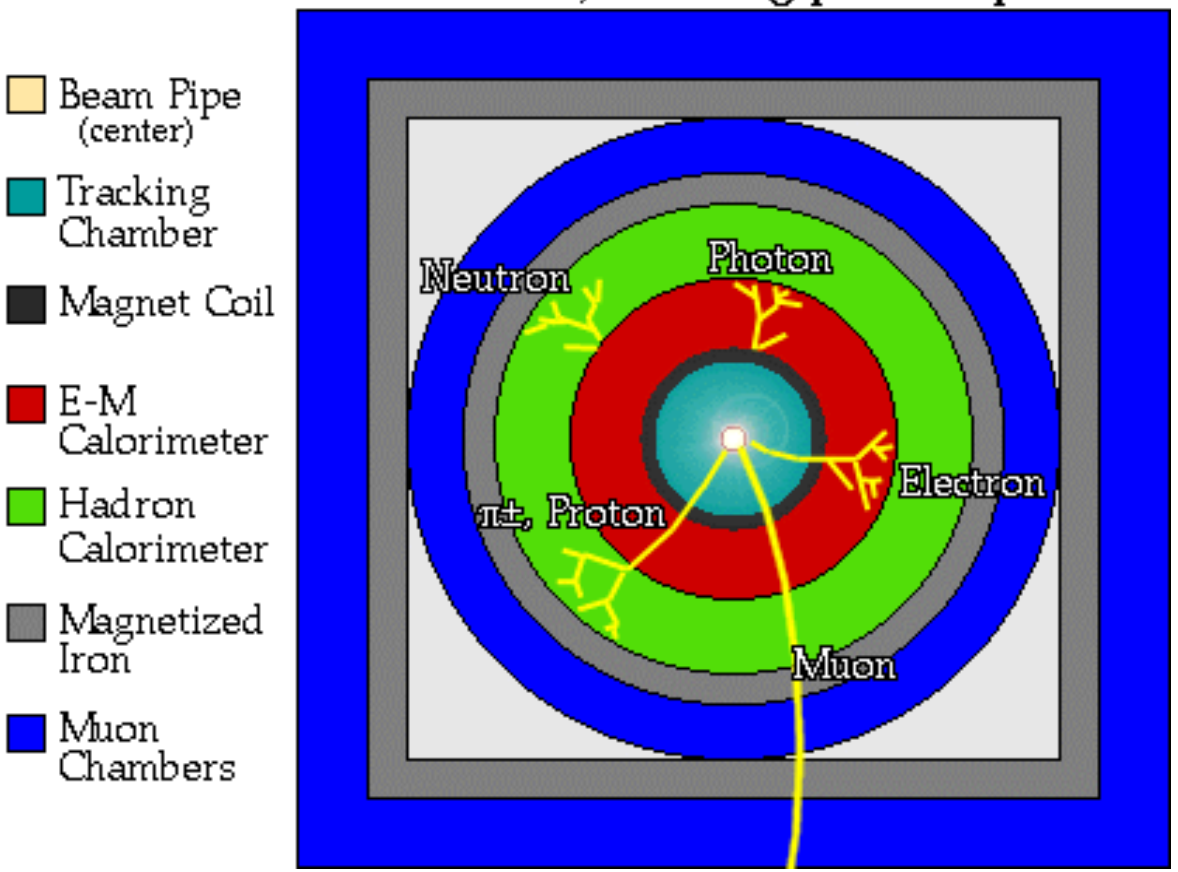


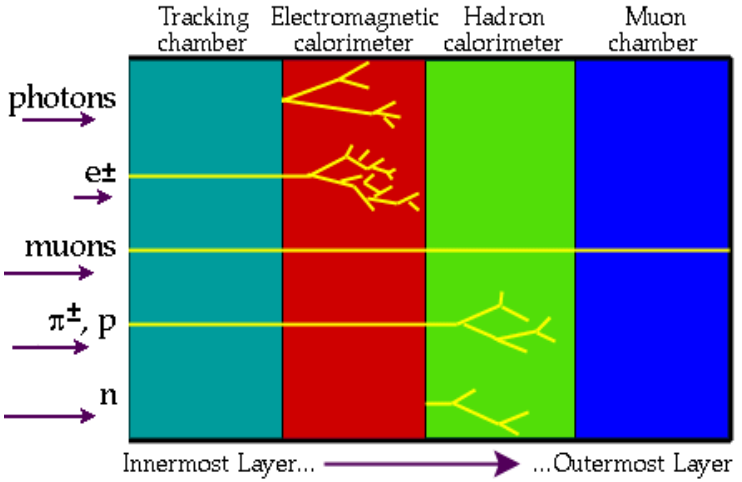


QuarkNet

Modern detectors

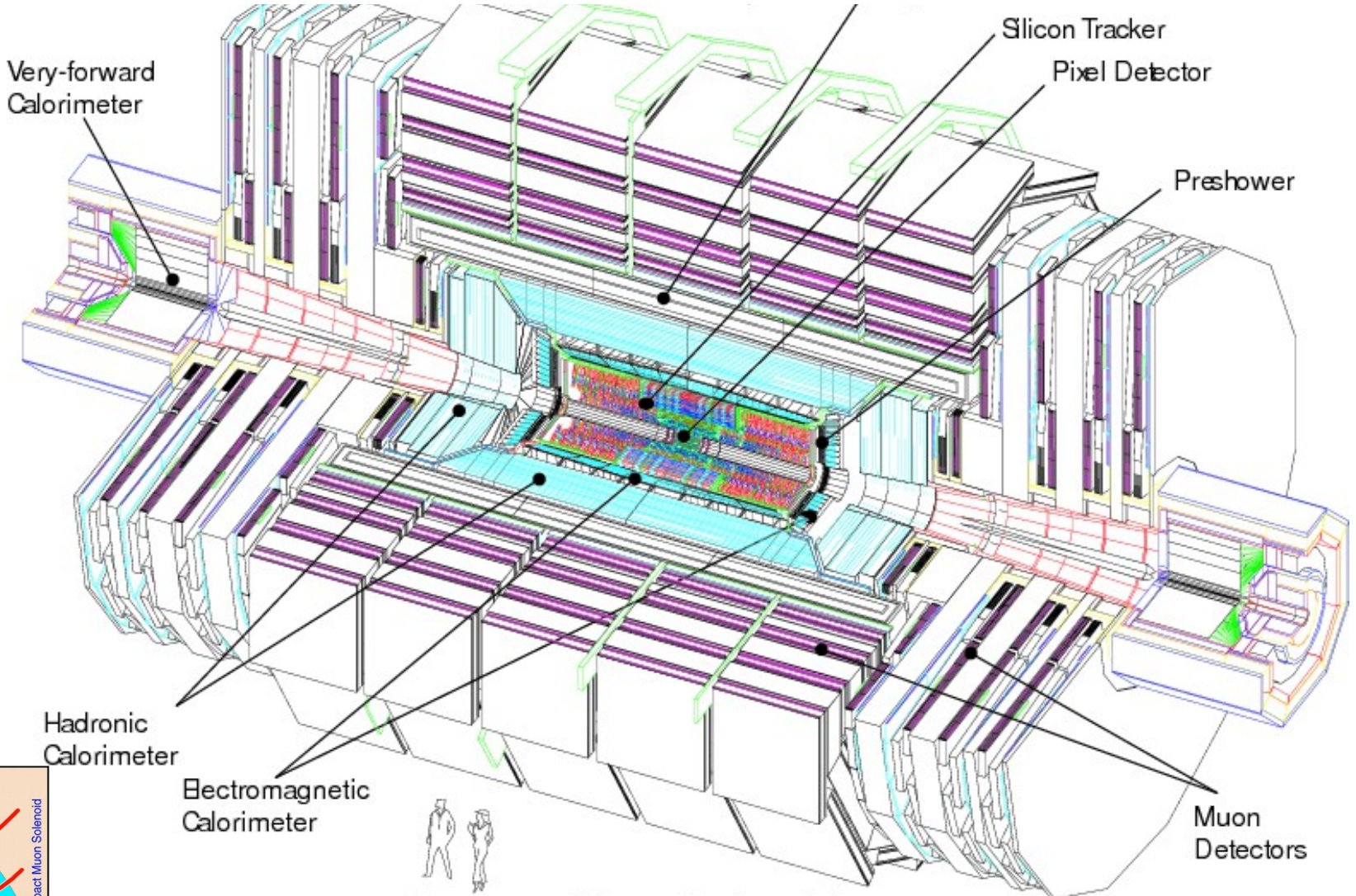
A detector cross-section, showing particle paths





QuarkNet

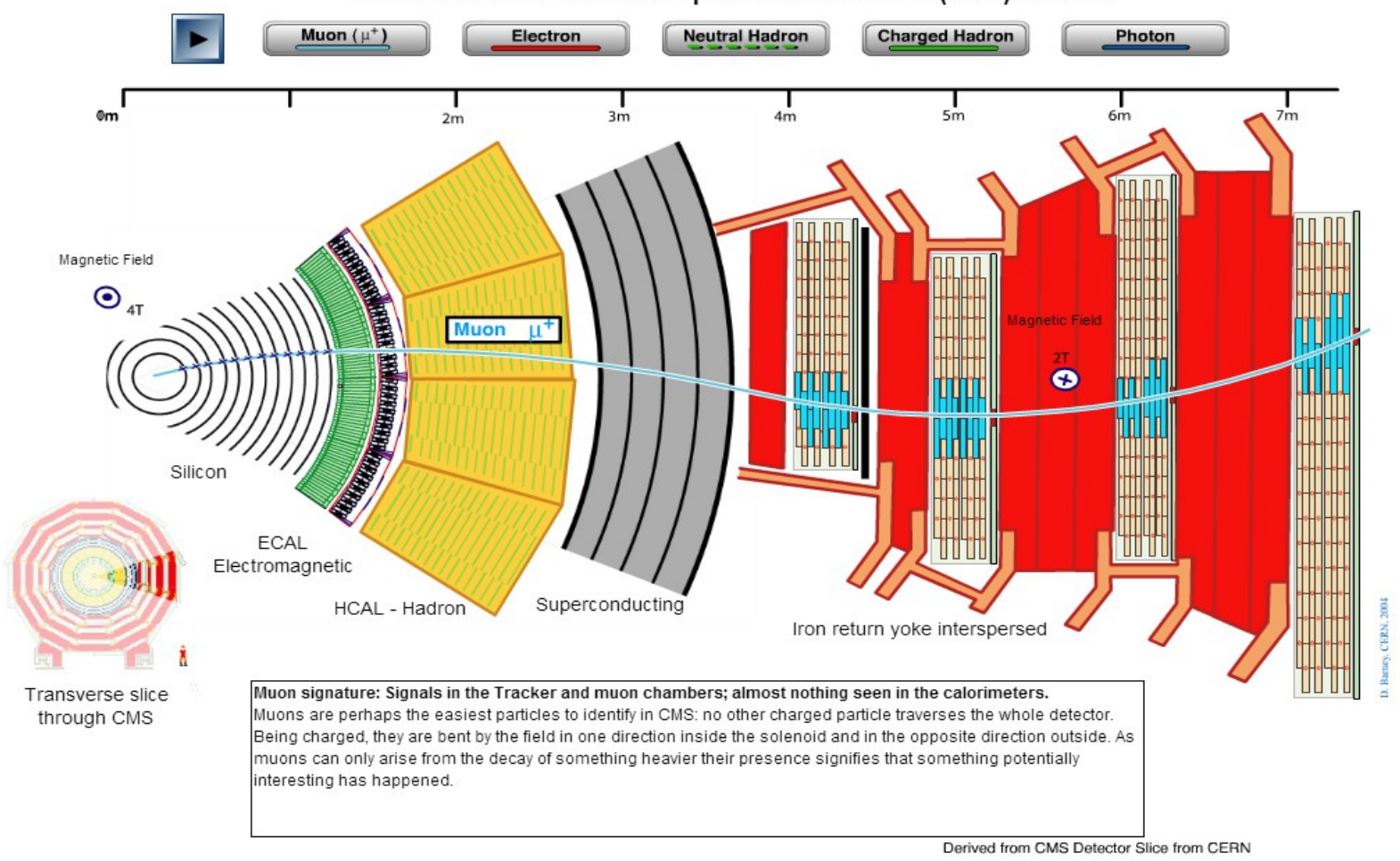
The "compact" muon solenoid



CMS Compact Muon Solenoid

QuarkNet

So how do we do it?

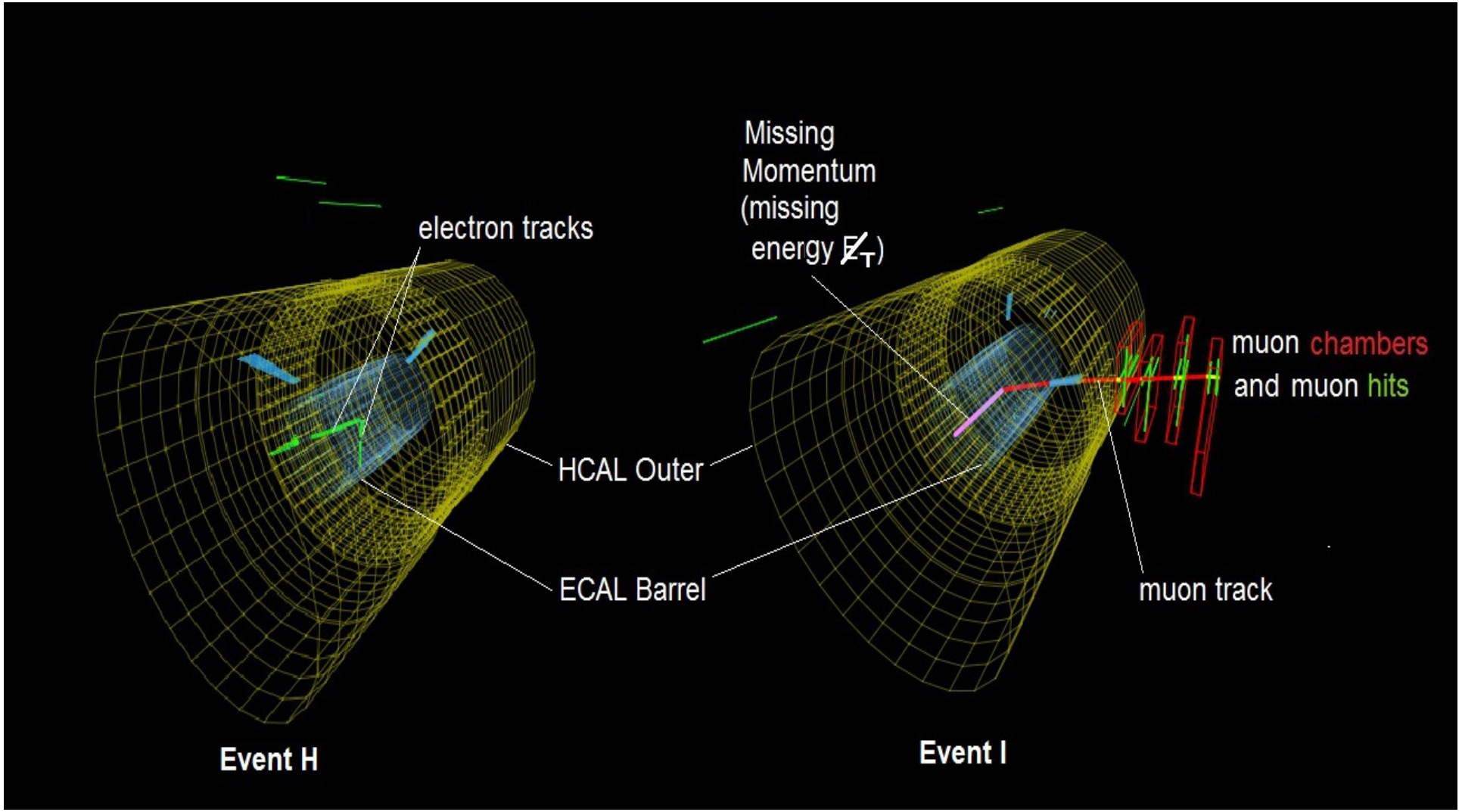


- Web

QuarkNet

Event Display

(All praise to Tom McCauley!)



QuarkNet

So how do we do it?

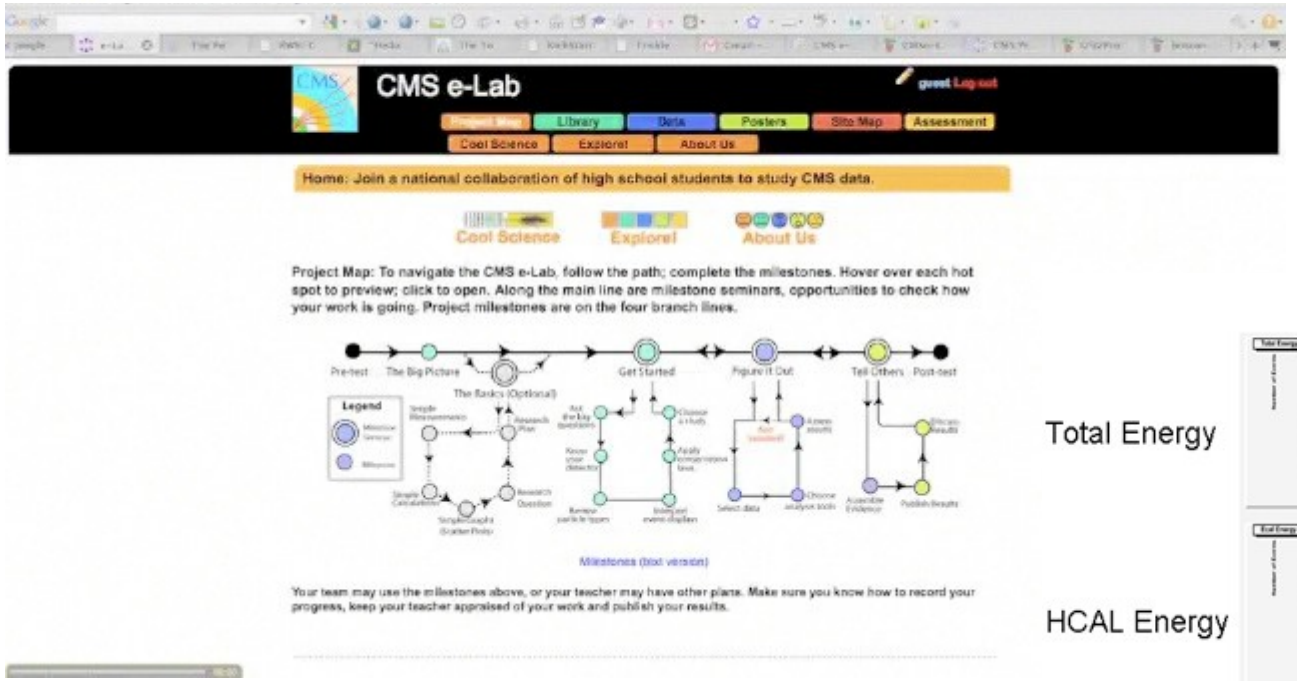
Focus on the Conservation Laws:

- Energy
- Momentum
- Charge

Run	Event	E1	px1	py1	pz1	pt1	eta1	phi1	Q1
147390	543767492	24.521	3.89773	-16.1627	-18.0237	16.626	-0.939585	-1.33416	-1
147390	551904480	42.8325	-16.4724	4.63309	-39.266	17.1116	-1.56816	2.86741	1
147390	286521299	78.6993	20.7346	-22.7603	72.4267	30.7889	1.59096	-0.831937	-1
147390	348830108	35.7096	-12.6783	10.2126	-31.7827	16.2799	-1.42208	2.4635	1
147390	348839604	12.8308	-9.97245	-5.51779	-5.89352	11.3972	-0.496456	-2.63622	-1
147390	349394529	7.56567	4.40404	-1.89451	-5.85275	4.79423	-1.02921	-0.406246	-1
147390	355531024	16.3413	-2.45327	-14.7782	6.52859	14.9805	0.423073	-1.7353	1
147390	5827229	17.0766	-10.7266	9.22474	-9.56319	14.1476	-0.632858	2.43133	1
147390	580193569	16.2956	12.8777	2.01408	9.78035	13.0342	0.693436	0.155144	1

QuarkNet

Get into the data



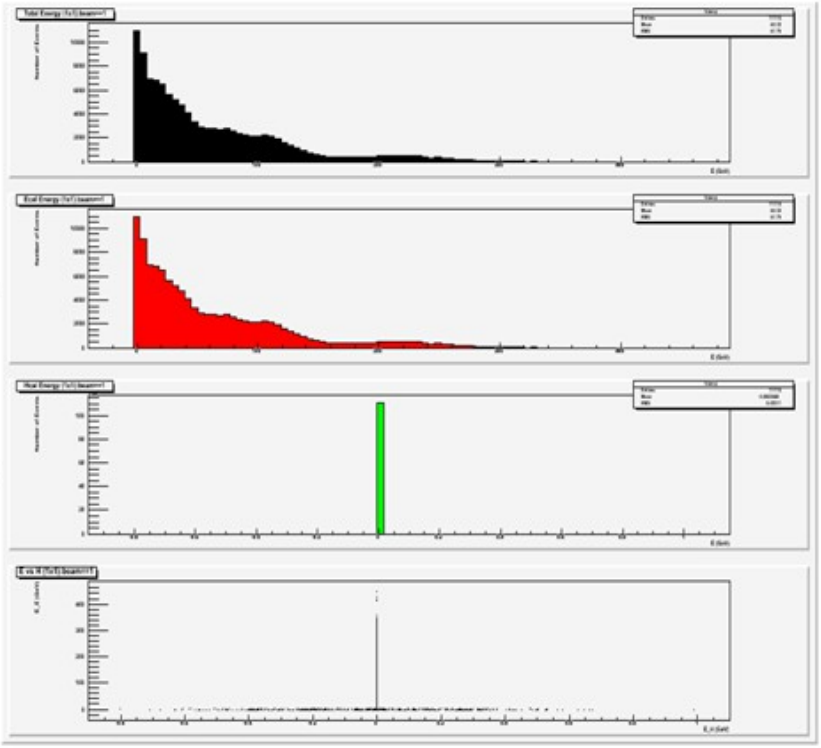
4 plots for all pions

Total Energy

HCAL Energy

ECAL Energy

E vs. H



QuarkNet

Completely unsalable skills

ROOT has a steep learning curve.

And these files are *YUGE*.

From the CMS OpenData website:

003DD74E-653E-E311-9F63-002590494D18.root	xrootd	Size: 4.2 GB
004978E1-433E-E311-9E08-003048F0107A.root	xrootd	Size: 3.7 GB
0059D787-243E-E311-B28B-C860001BD85C.root	xrootd	Size: 4.2 GB
007228EF-523E-E311-AD79-0025904B2FD8.root	xrootd	Size: 4.2 GB
00B2E805-643E-E311-BFCC-C860001BD85A.root	xrootd	Size: 4.2 GB

Workarounds?

ROOT is not accessible for most physics teachers and students.

But we can use spreadsheets. ☺

Gradebook

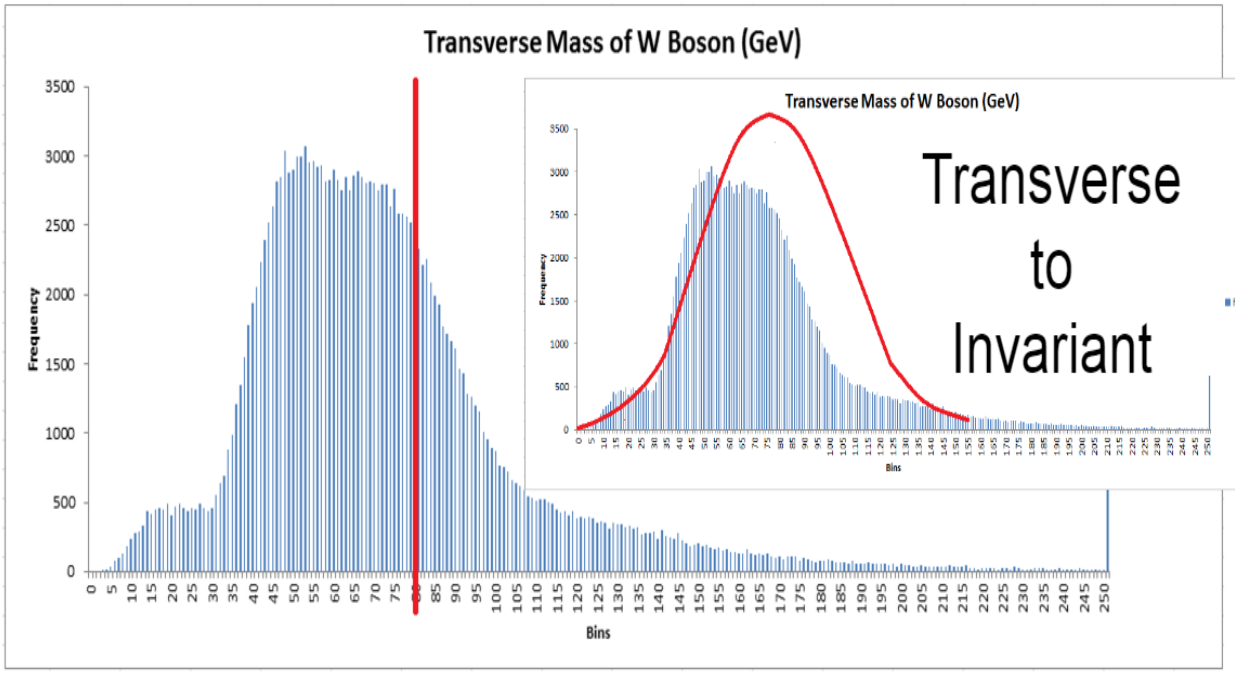
[Course Name]
[Instructor]
[Room/Time]

		Assignments																
		HW 1	HW 2	HW 3	HW 4	Exam 1	HW 5	HW 6	HW 7	HW 8	Exam 2	HW 9	HW 10	HW 11	Final			
	Points/Weighting:	50	50	50	50	150	50	50	50	50	150	50	50	50	250	Curve:	0.00%	
	Student															Total	%	Grade
1.	Bob	80.0%	100.0%	98.0%	72.0%											185.0	88.1%	B+
2.	Sally	80.0%	82.0%	56.0%	78.0%											156.2	74.4%	C
3.	Sue	84.0%	84.0%	100.0%	58.0%											171.4	81.6%	B-
4.	Jill	82.0%	92.0%	80.0%	98.0%											185.2	88.2%	B+
5.	Jon	86.0%	96.0%	62.0%	74.0%											168.6	80.3%	B-
6.	Ted	88.0%	98.0%	62.0%	76.0%											171.8	81.8%	B-
7.	Mag	94.0%	90.0%	72.0%	80.0%											177.0	84.3%	B
8.	Jim	90.0%	84.0%	82.0%	52.0%											162.4	77.3%	C+
9.	Jan	98.0%	88.0%	64.0%	74.0%											170.8	81.3%	B-
10.	Todd	84.0%	86.0%	74.0%	96.0%											178.6	85.0%	B
11.	Tim	94.0%	96.0%	100.0%	58.0%											183.6	87.4%	B+
12.	Jake	80.0%	82.0%	68.0%	90.0%											168.2	80.1%	B-
13.	Sam	84.0%	86.0%	94.0%	92.0%											186.6	88.9%	B+
14.	Betty	82.0%	92.0%	88.0%	70.0%											175.2	83.4%	B
15.	Maria	94.0%	100.0%	50.0%	84.0%											174.0	82.9%	B-
16.	Max	92.0%	82.0%	80.0%	80.0%											175.2	83.4%	B
17.	Kate	90.0%	94.0%	92.0%	96.0%											195.4	93.0%	A
18.	Jake	80.0%	86.0%	68.0%	92.0%											171.6	81.7%	B-
19.	Sam	82.0%	80.0%	54.0%	72.0%											152.0	72.4%	C-
20.	Betty	86.0%	94.0%	86.0%	70.0%											177.4	84.5%	B
21.	Maria	84.0%	92.0%	64.0%	94.0%											176.2	83.9%	B
22.	Max	88.0%	88.0%	70.0%	56.0%											159.8	76.1%	C+
23.	Kate	100.0%	92.0%	70.0%	80.0%											180.2	85.8%	B
24.	Sam	92.0%	100.0%	92.0%	64.0%											184.0	87.6%	B+
25.	Maria																	
26.	Max	100.0%	100.0%	100.0%	100.0%											210.0	100.0%	A+
27.																		
28.																		
29.																		
30.																		
	To add rows, copy an existing row and then insert it above this line.																	
	Class Average:	87.8%	90.6%	77.0%	78.2%											Mean:	83.7%	B
	Median:	86.0%	92.0%	74.0%	78.0%											Median:	83.4%	
	StDev:	6.4%	6.4%	15.5%	14.1%											StDev:	5.8%	

QuarkNet

How well do the teachers do?

Sample teacher work from QNet Data Camp 2016:



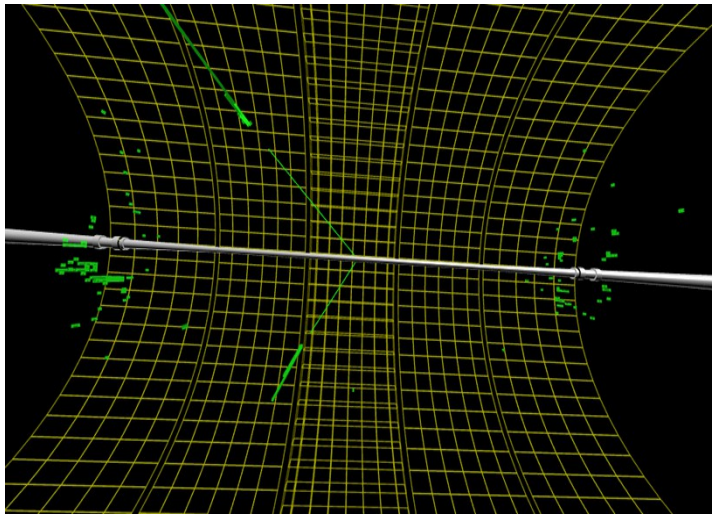
- Transverse Mass Misses "Z" Component. Mass Value is Less & Histogram is Incomplete
- Look to Top End of Standard Deviation of Histogram, Where "Invariant" Peak is Expected

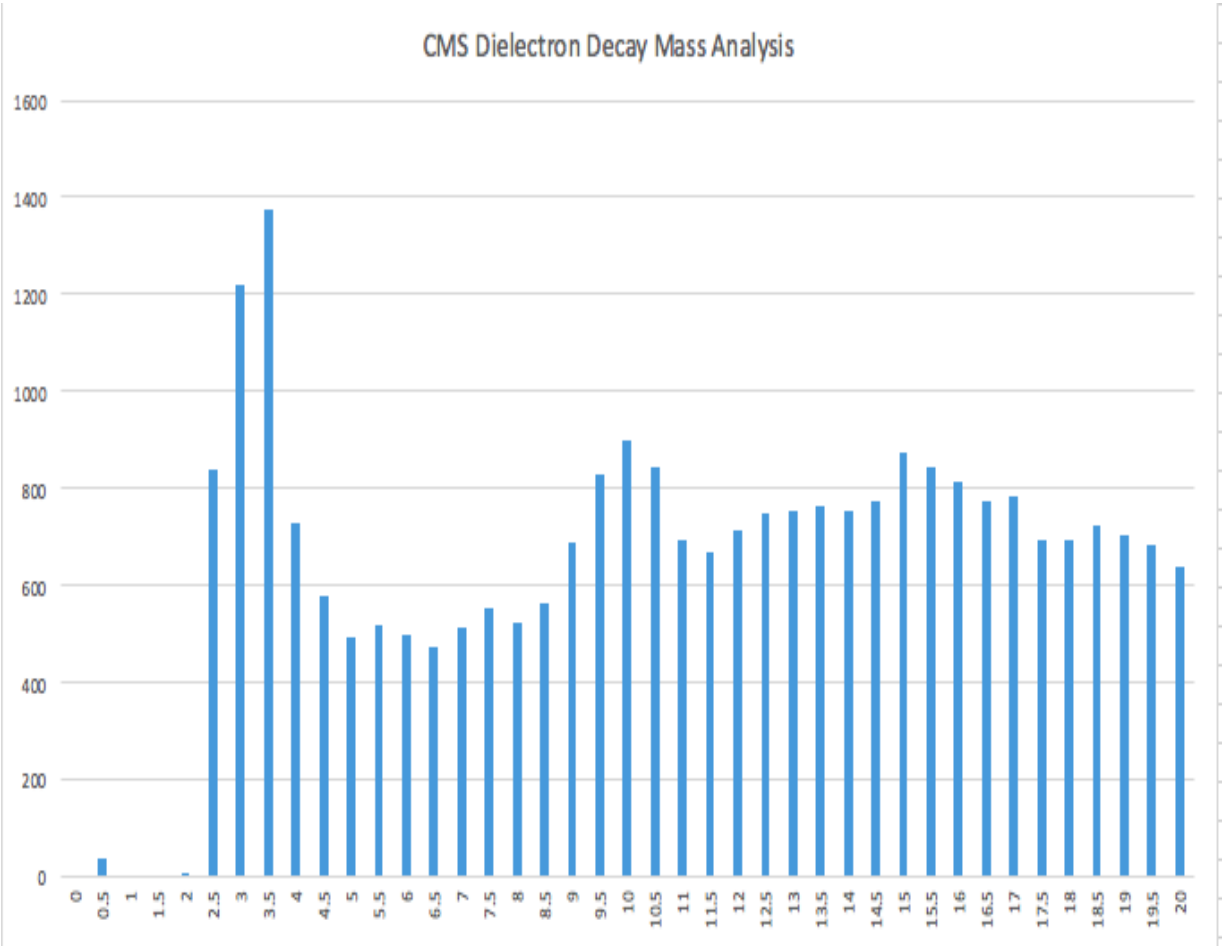
3 days prior, they didn't even know what a W boson is!

QuarkNet

How well do the students do?

Sample *high school student* work, 2017:



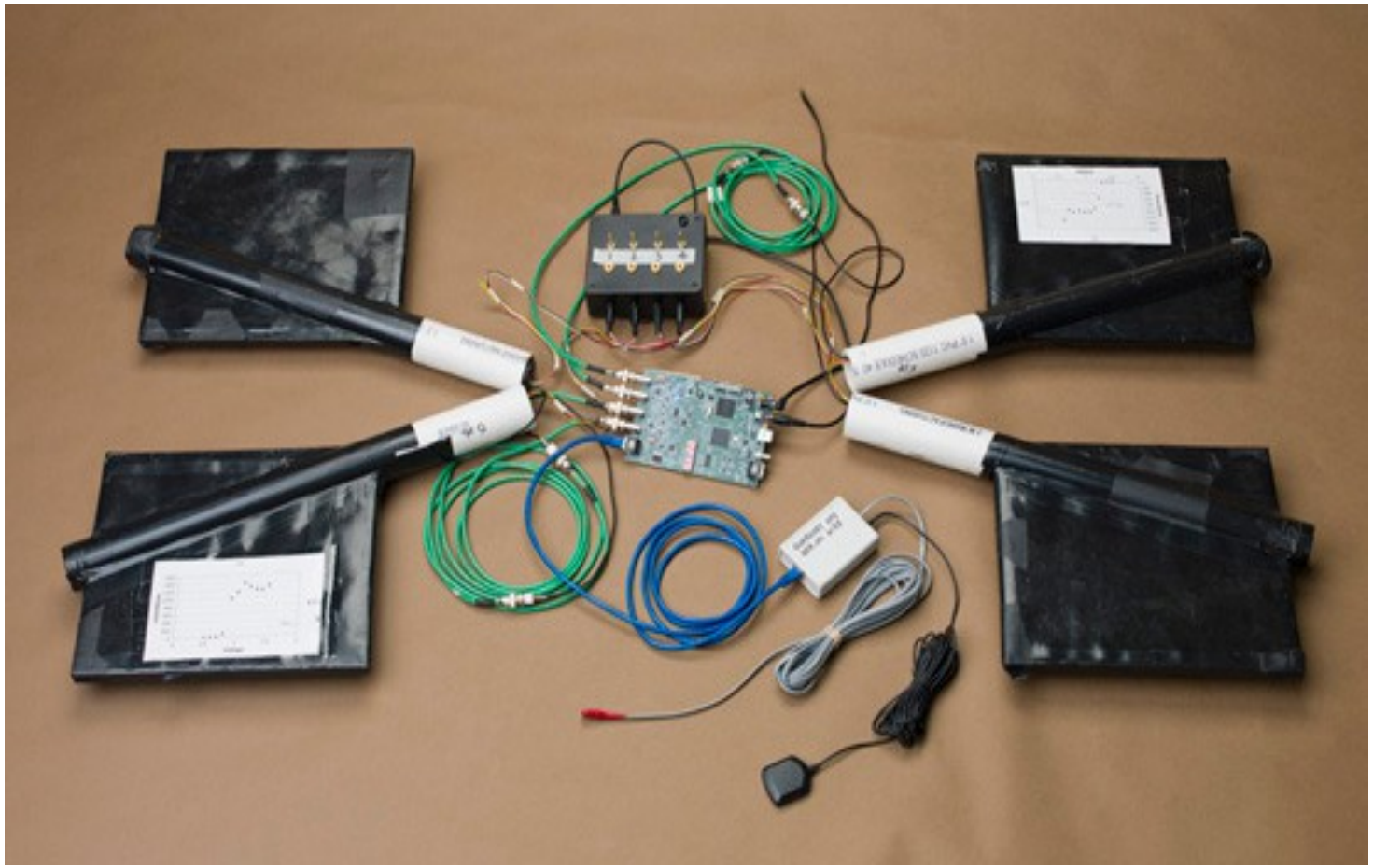


J. Smith, JHU, July 2017

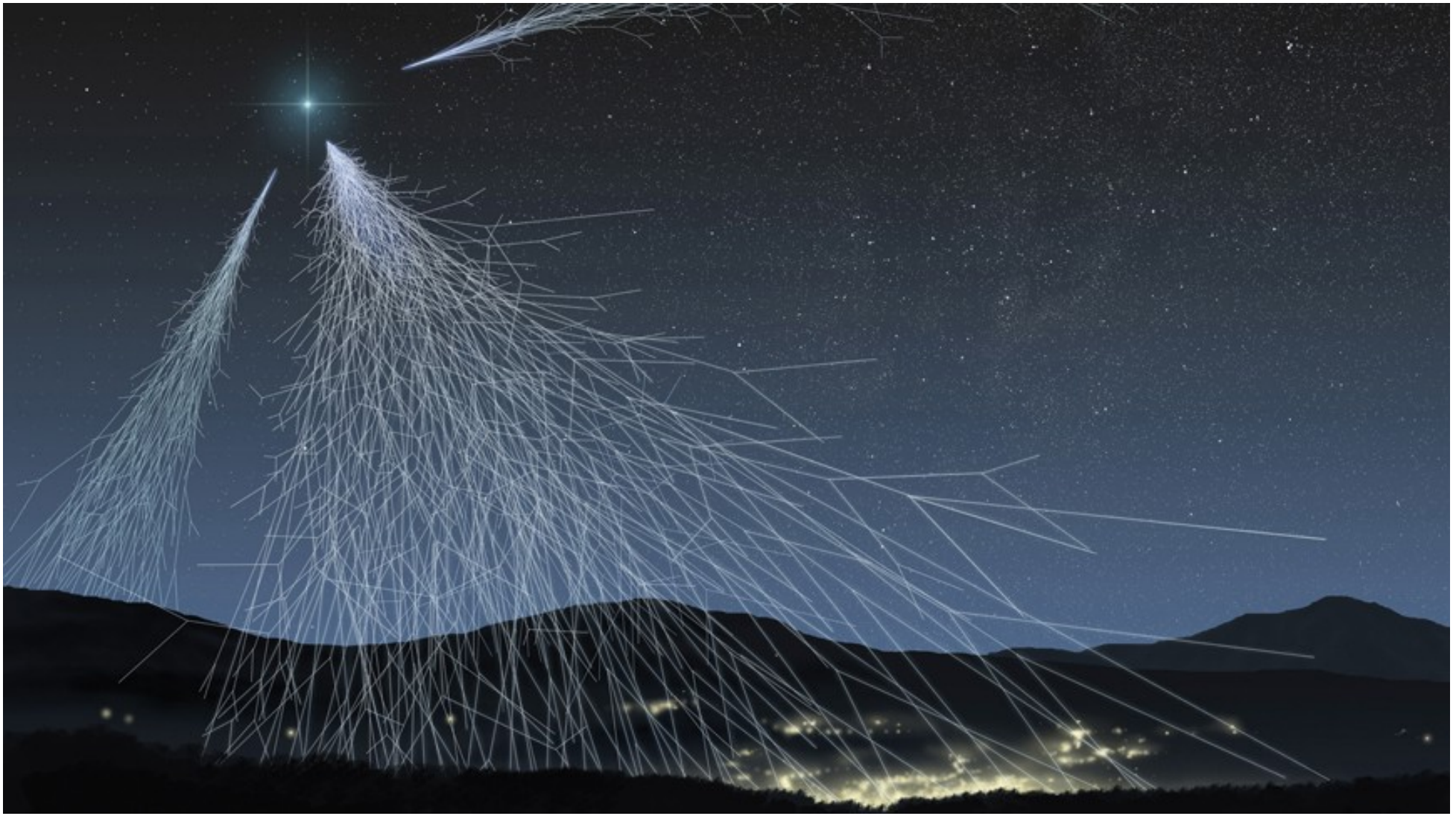
QuarkNet

The CRMD

…Particle detectors can live in your classroom!



The CRMD



QuarkNet

The CRMD

Project Types Available:

- **Flux** (simple "vary X, observe Y" studies – weather, angle, shielding, etc.)
- **Shower** (how far apart are the daughters of an event? How common are the big ones?)
- **Time of Flight** (just how fast are they moving?)
- **Lifetime** (how long do muons live?)

QuarkNet

The CRMD

You don't even need a detector to use the e-lab!

Example: upcoming solar eclipse

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Alternative?

Web

Coding is important in science! High schools are finally starting to understand this.

So: can we get students to use particle physics as a *context* for writing code?

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Jupyter: no need to reinvent wheel!

```
data = pd.read_csv('http://opendata.cern.ch/record/303/files/dimuon.csv')

# Analyze dielectron data instead by referencing this URL:
# http://opendata.cern.ch/record/304/files/dielectron.csv
```

We can view the first few rows of the file we just imported.

In [3]:
```
# The .head(n) command displays the first n rows of the file.
data.head(3)
```

Out[3]:

	Type	Run	Event	E1	px1	py1	pz1	pt1	eta1	phi1	Q1	E2	px2
0	GT	146511	25343052	7.33390	2.060420	5.88580	-3.85836	6.23602	-0.584812	1.234060	-1	5.20755	-1.5501
1	GG	146511	25341481	18.46720	8.033950	-3.94072	-16.15410	8.94839	-1.352990	-0.456026	-1	10.72950	6.2947
2	GG	146511	25390065	7.70222	-0.248771	4.08338	6.52511	4.09095	1.246340	1.631640	-1	6.90202	-3.0243

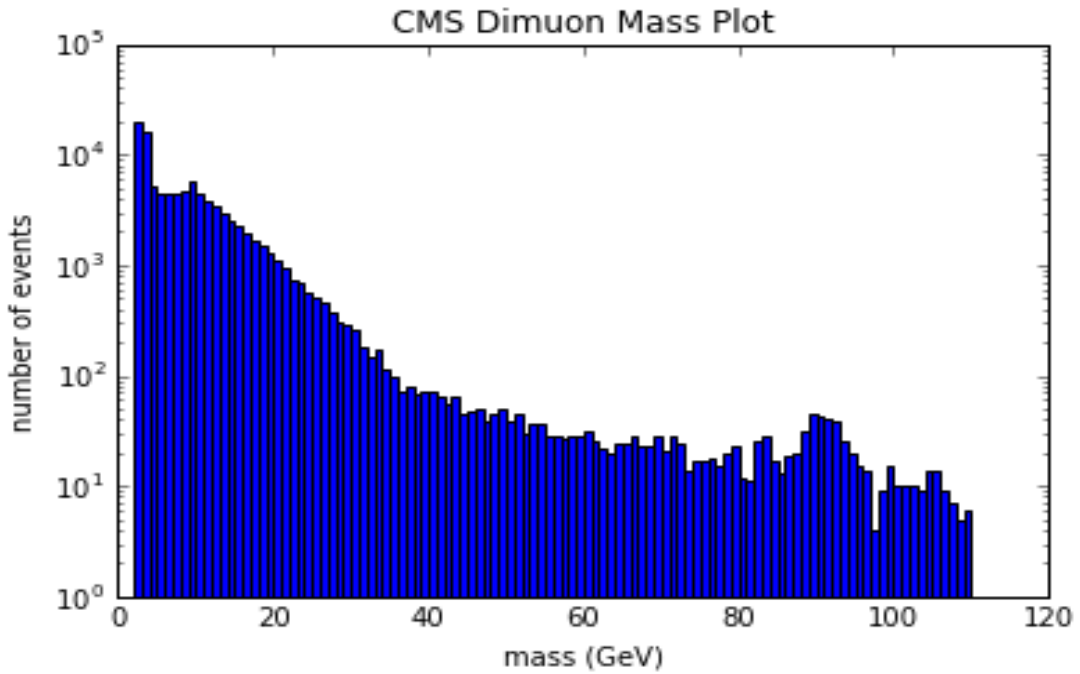
jupyter

QuarkNet

Make plots and tweak them!

In [4]:
```
# adding a ; at the end of the next line will  "suppress" the text output of the hi
le
plt.hist(data.M, bins=120, range=[0,120], log=True)
plt.title("CMS Dimuon Mass Plot")
plt.xlabel("mass (GeV)")
plt.ylabel("number of events")
```

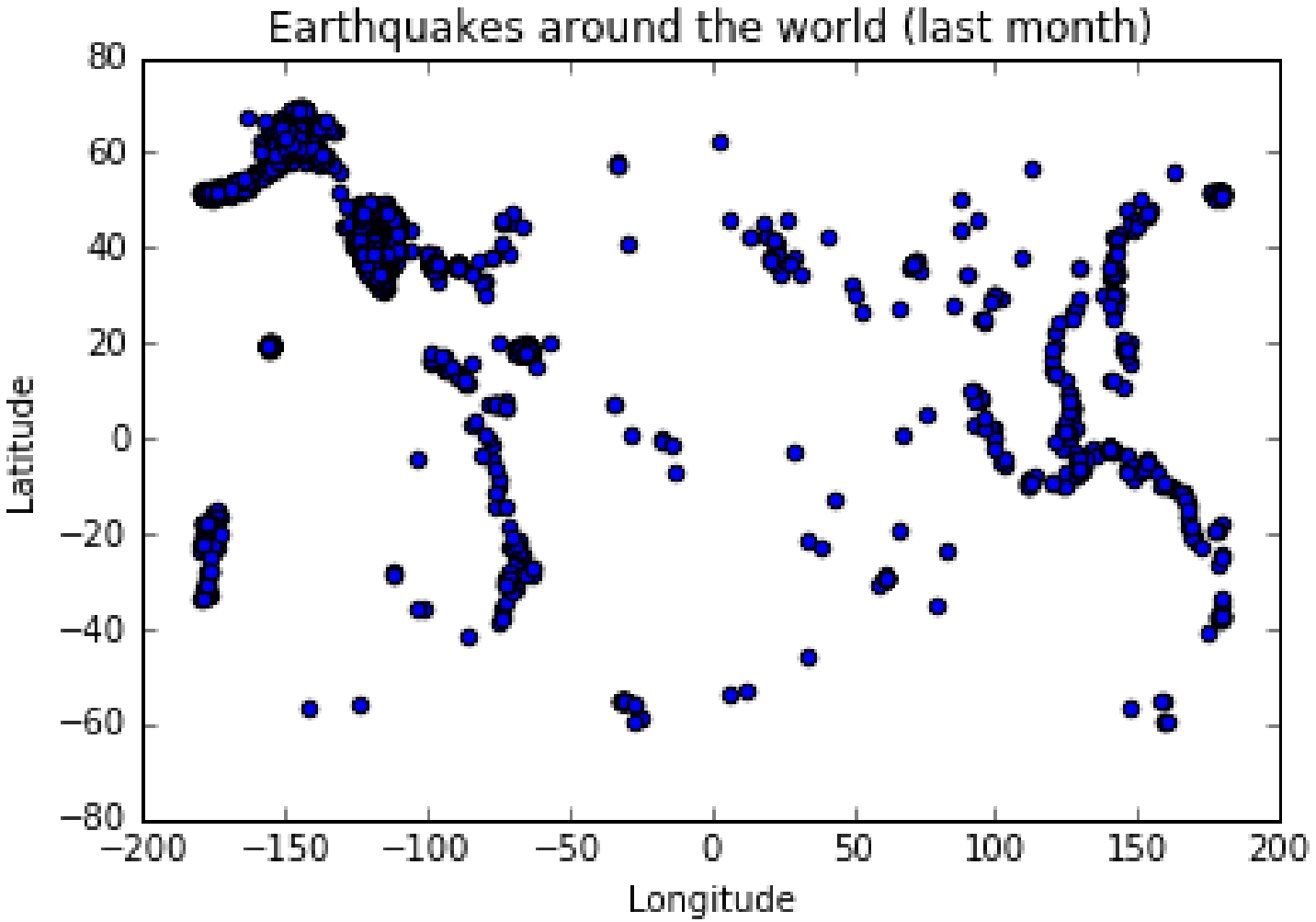
Out[4]: <matplotlib.text.Text at 0x1033eb278>



QuarkNet

Adapt and repurpose!

Same code, adapted for a dataset from the USGS earthquake database:



QuarkNet

In summary

QuarkNet does a lot of things:

- Teacher Workshops
- Masterclasses
- CMS e-lab support
- Cosmic Ray e-lab support (and detectors)
- Trips to CERN, Fermilab, etc.
- Leadership opportunities
- (in works) Coding in K-12
- (in works) Neutrino stuff