Quarknet Data Camp

Fermilab, July 2016

Duc Ong

Data Camp Overview

- Tours of experiments and facilities
  - MINOS, D0, SIDET
- Talks by physicists
  - Don Lincoln, Chris Polly
- Data Analysis from CMS
  - Upsilon decay
  - W- boson decay
- Quarknet Data Portfolio
  - Implementation of activities

MINOS Neutrino experiments

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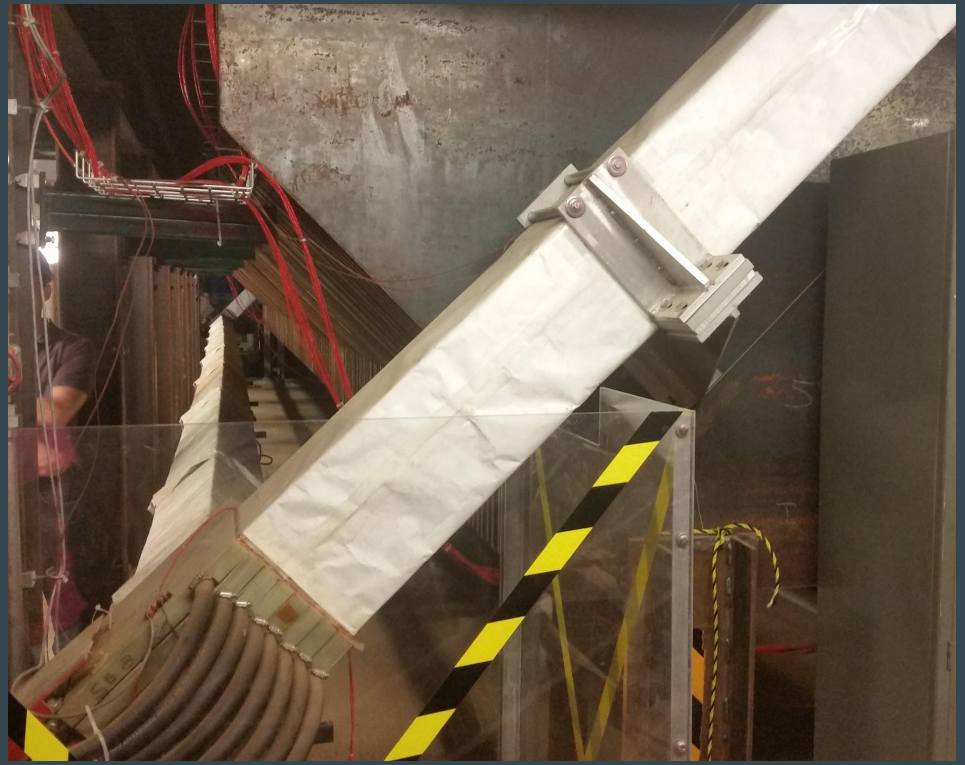
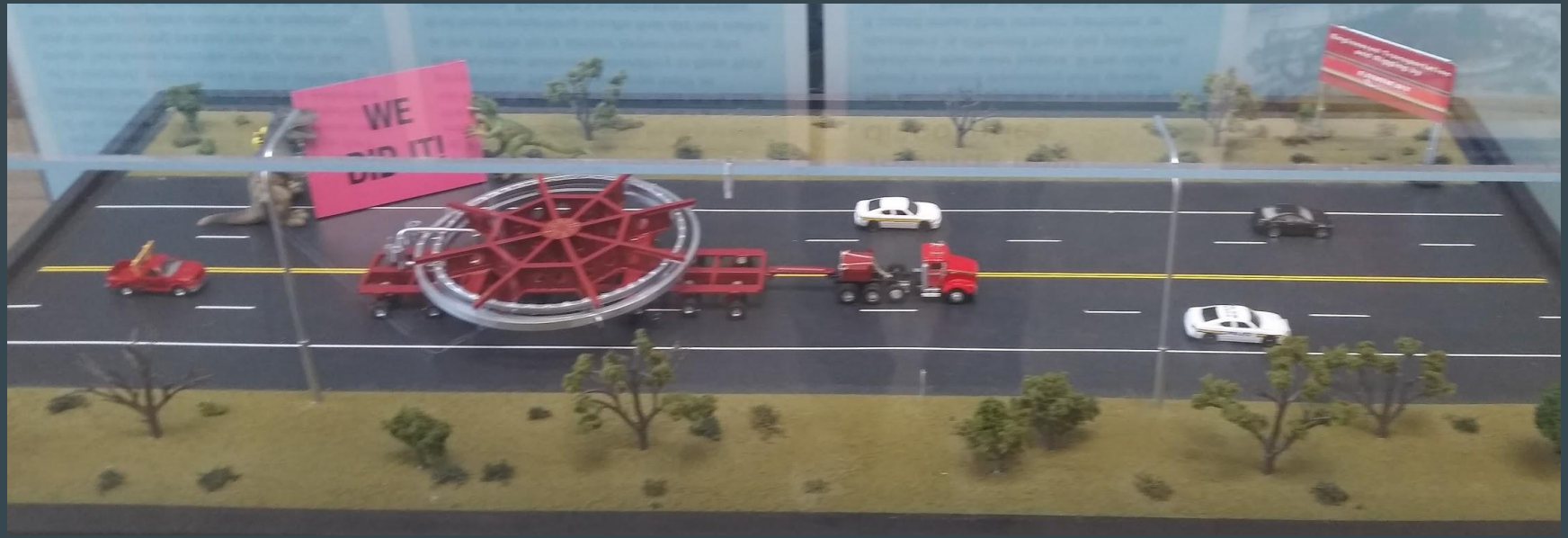


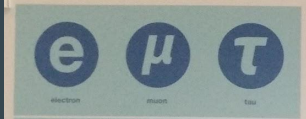
Muon g-2 and Mu2e

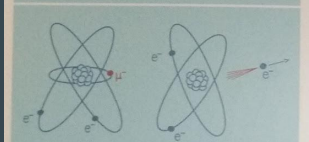
Muon g-2 and Mu2e



Muon g-2 and Mu2e

Mu2e Experiment





The Mu2e collaboration will use aluminum atoms to capture muons produced by Fermilab's particle accelerators. If the detector records electrons escaping with the precise energy of 105 MeV, scientists will have discovered the elusive transformation and signs of new physics.

Oh the particles, they are a-changin'

There are three types of charged leptons: the electron; its heavy cousin, the muon; and the even weightier tau. Other types of elementary particles, quarks and neutrinos, also come in three varieties. But while quarks change into other kinds of quarks and neutrinos change into other kinds of neutrinos, scientists have never seen an equivalent change in charged leptons. The Mu2e (muon to electron) experiment will look for this extremely rare transformation.

? How does it work?

Fermilab's particle accelerators make muons by smashing a beam of protons into a pencil-sized tungsten target, creating a shower of particles. Magnetic fields whisk the muons away through an s-shaped superconducting magnet to their final stop: a two-stage detector that looks for the telltale sign of a muon transforming into an electron. Mu2e will be 10,000 times more sensitive than previous attempts to discover this phenomenon.

For the Mu2e experiment, researchers will wind 45 miles of superconducting nickel-titanium cable to form the s-shaped system of magnets.

Finding New Physics

The Mu2e experiment will be about 75 feet long and more than 10 feet tall, and have the ability to stop roughly 10 billion muons per second.

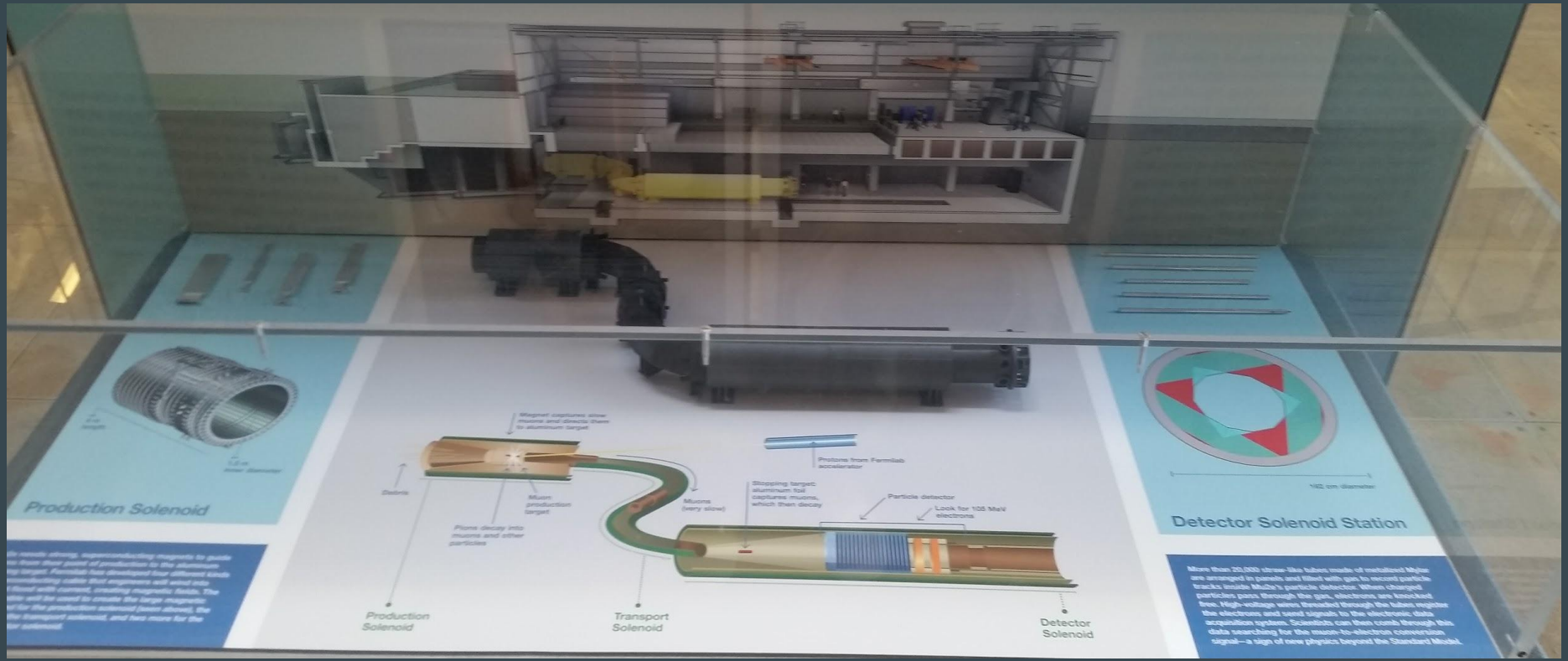
105 MeV The magic number

It's a rare occasion for an experiment, especially in particle physics, to have a signal that screams, "Look at me!" But Mu2e is one of the lucky ones. Experimenters will look for one magic number coming out of the detector: 105. The number refers to 105 MeV, or megaelectron-volts, the amount of energy that indicates a muon has decayed into only an electron instead of a less energetic electron and neutrinos. To make the sensitive apparatus, researchers need new technologies and techniques—including special magnets, superconducting cables, and advanced detectors.

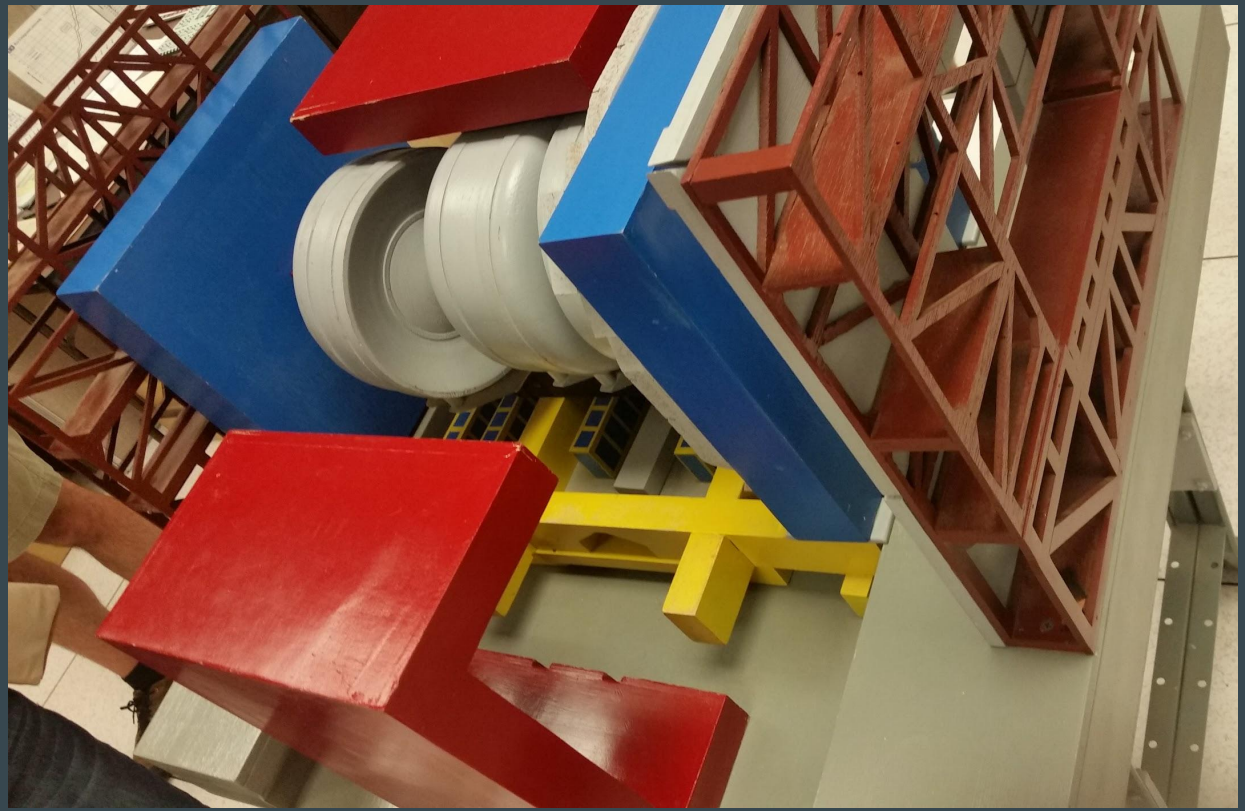
A quest for answers

Finding the muon-to-electron conversion would be a major breakthrough hinting at undiscovered particles or forces underlying the universe – an exciting step beyond the incomplete Standard Model of physics. It would also help researchers understand why particles in the same family decay into others. The experiment complements research at the Large Hadron Collider in Europe, potentially clarifying the origins of new particles. It will help probe theories that offer insight into the evolution of our universe and what actually happens at the smallest scales of matter.

Muon g-2 and Mu2e



DO (Decommissioned Tevatron Detector)



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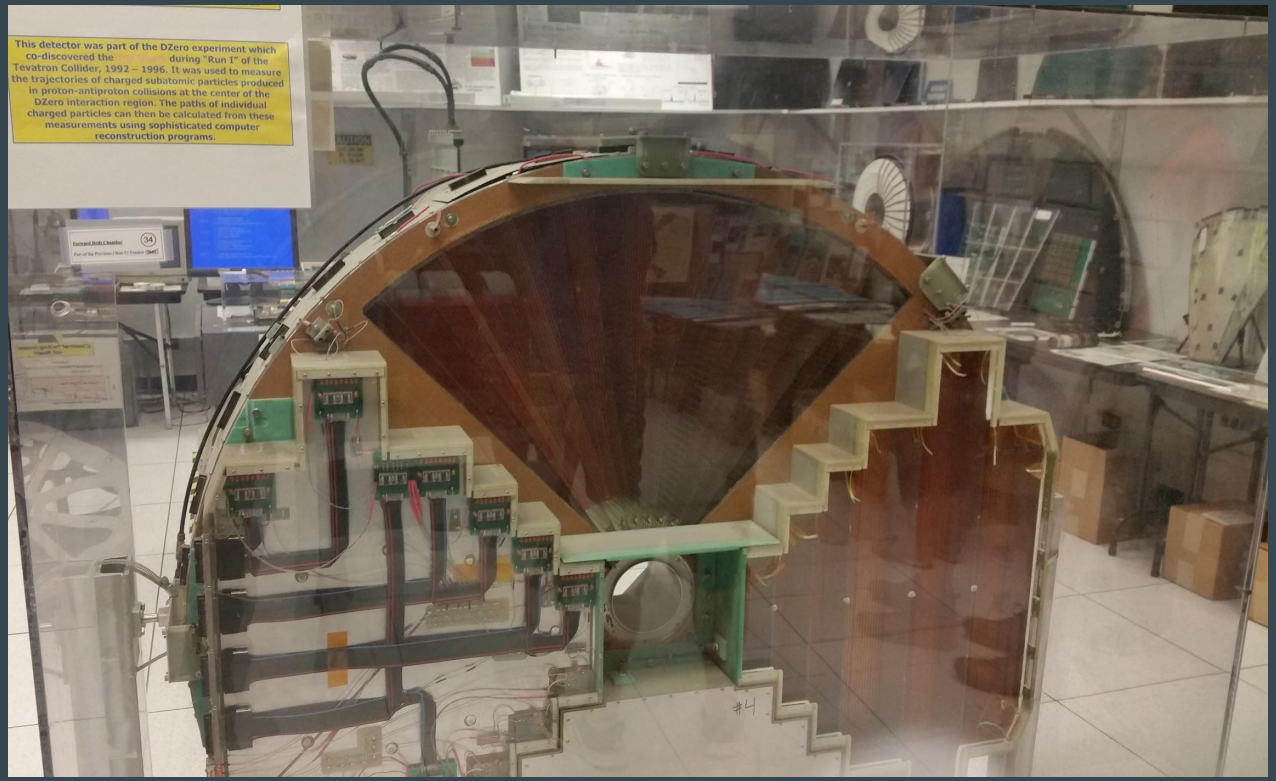

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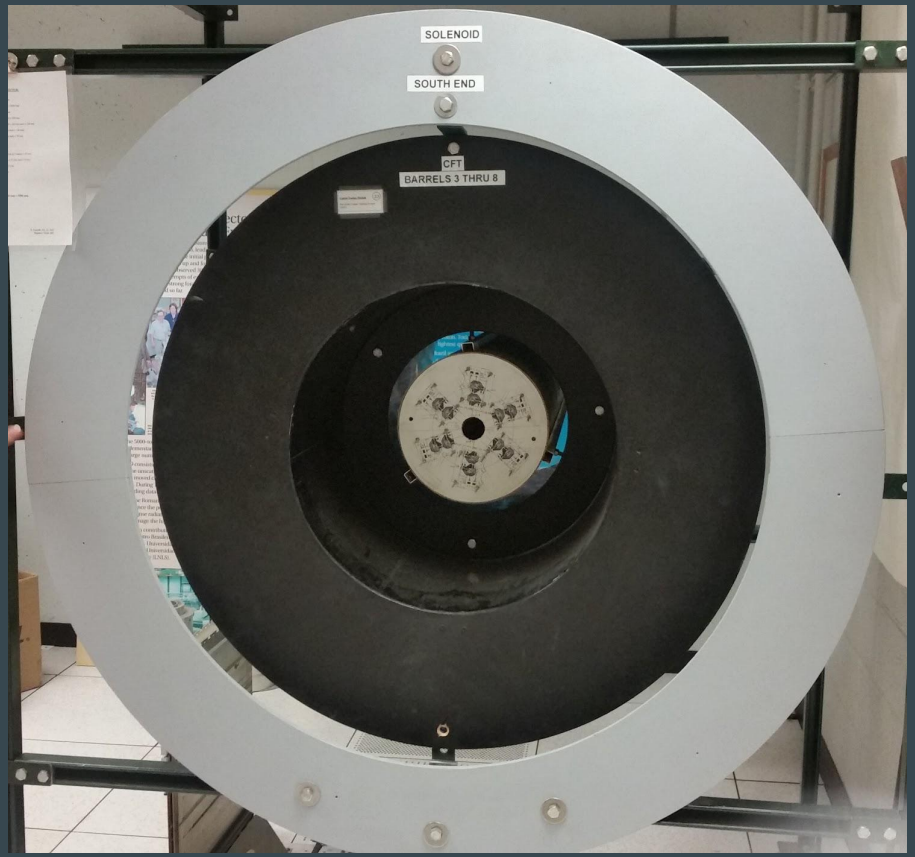

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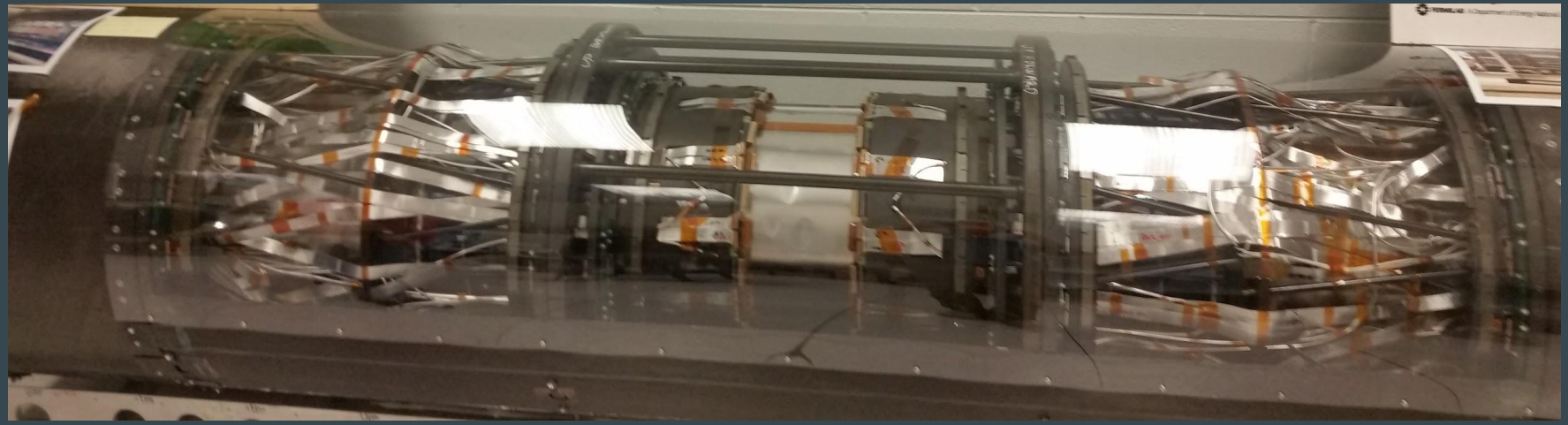

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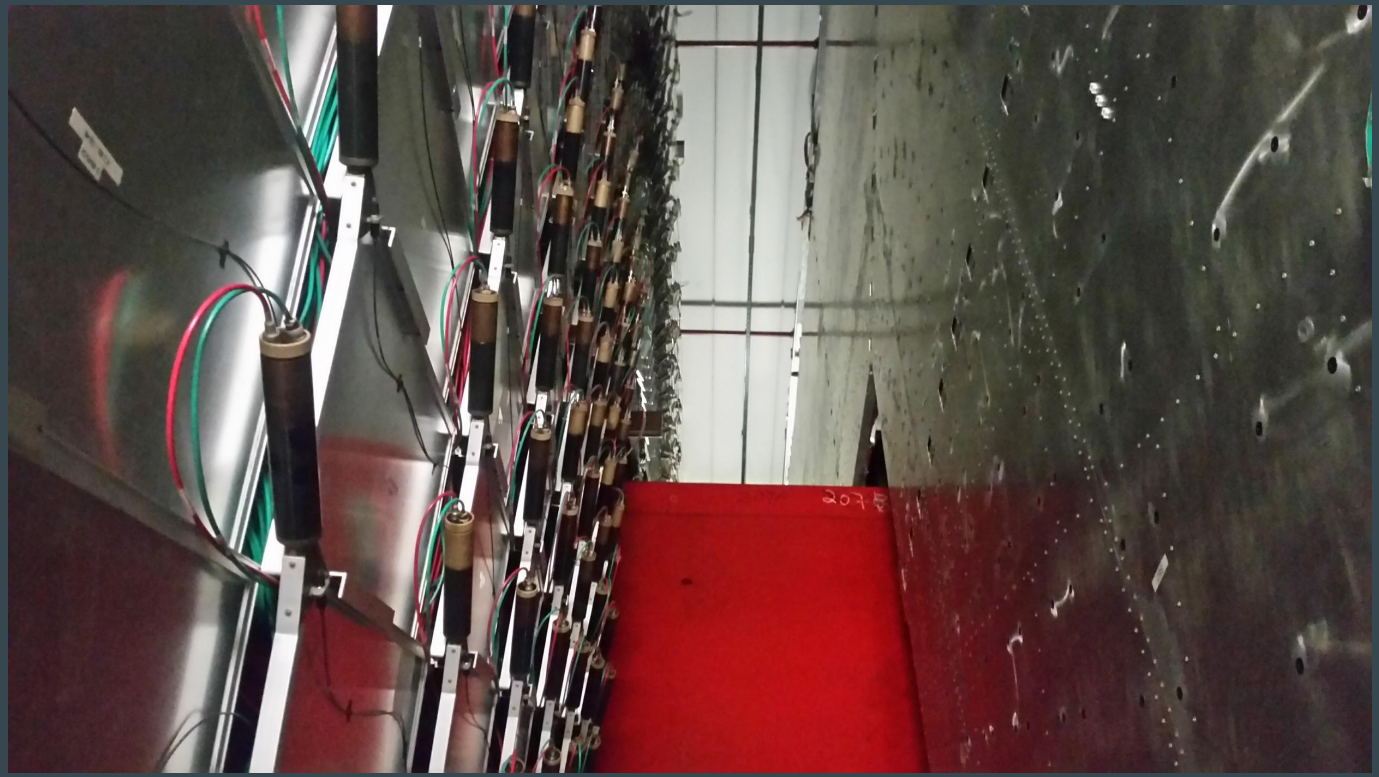

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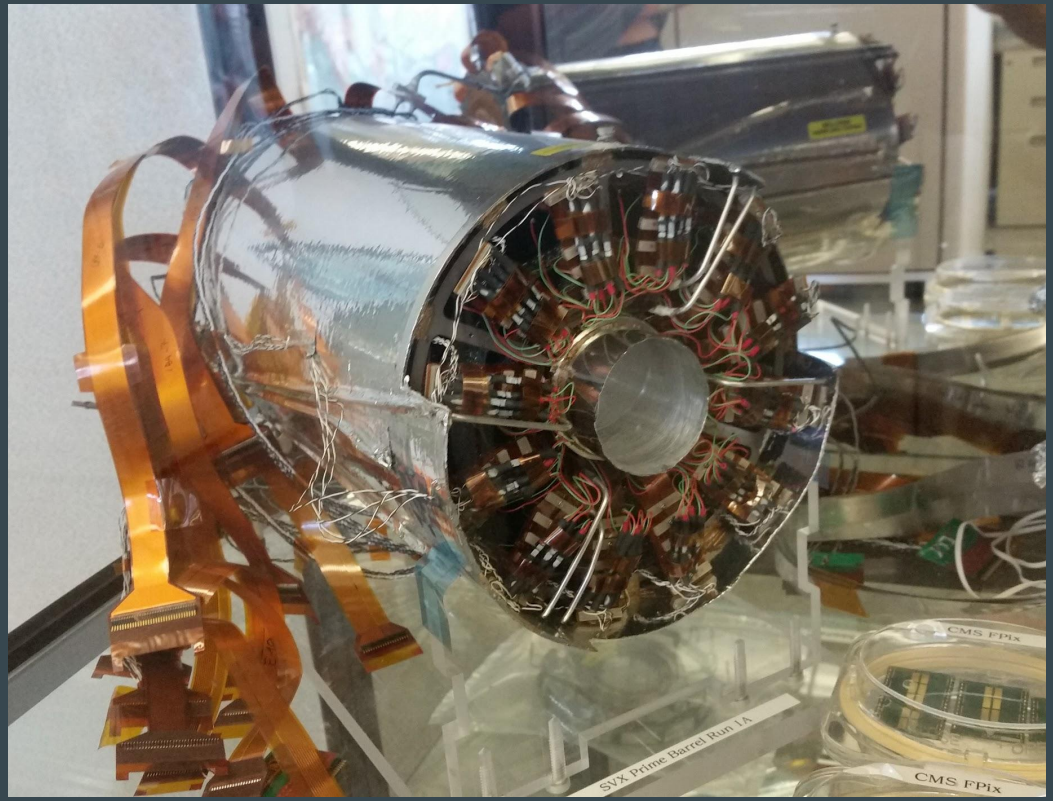

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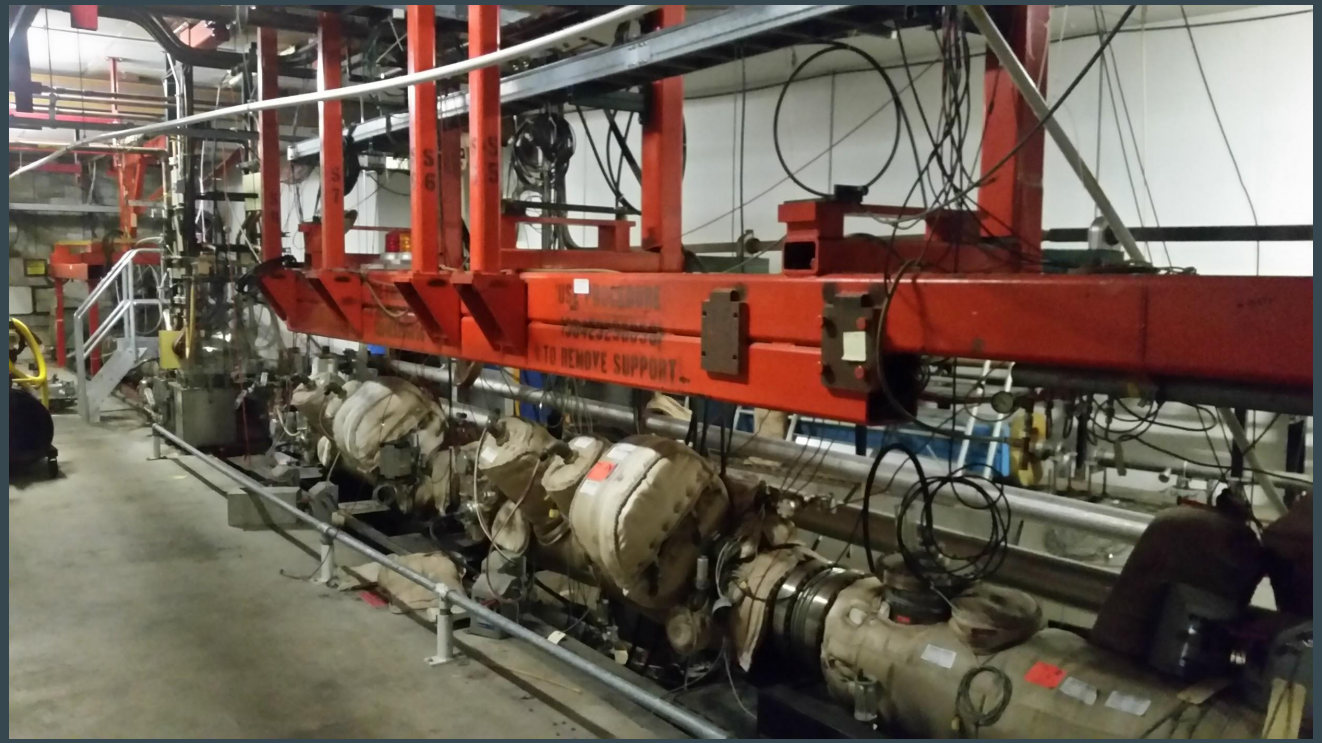
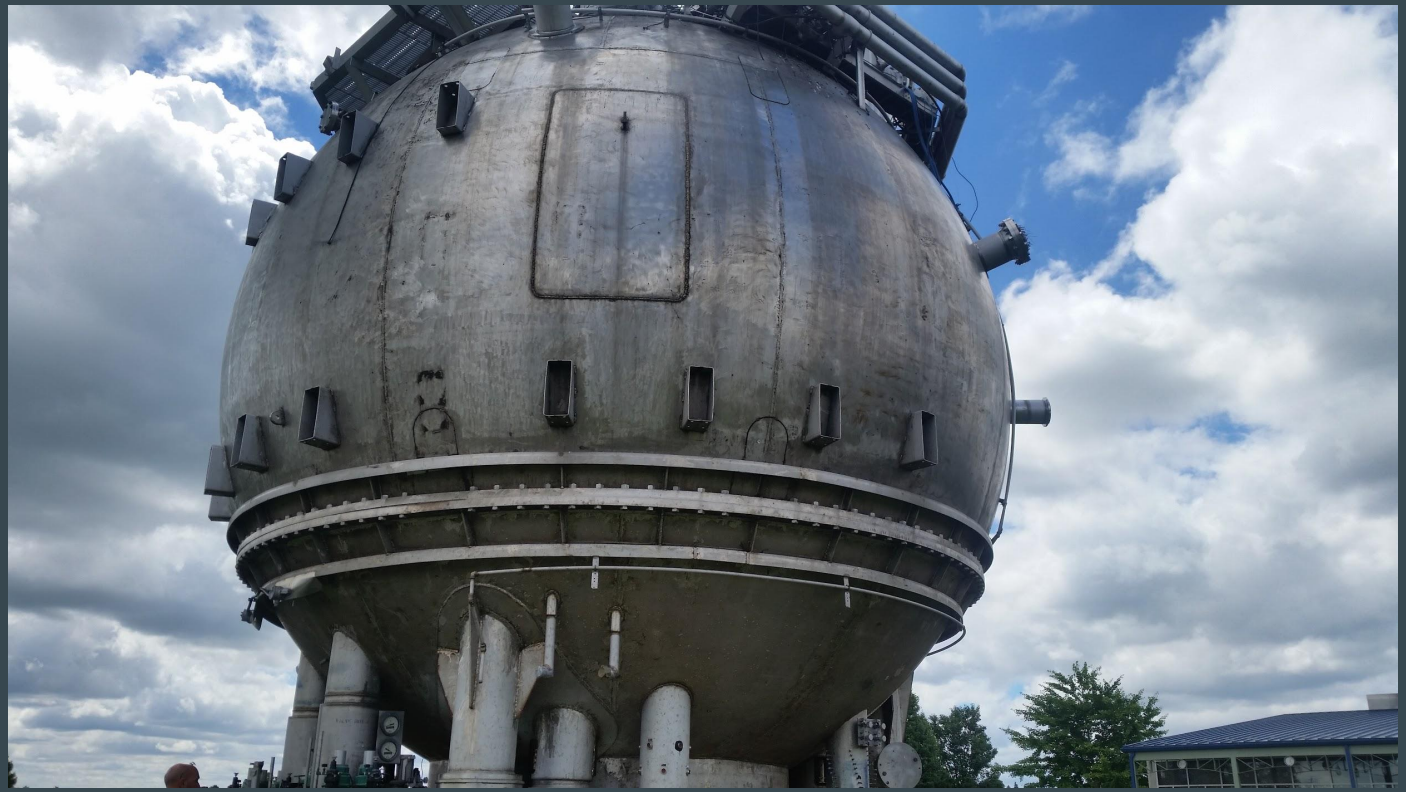


SIDET (Silicon Manufacturing Site)

15 Foot Bubble Chamber



Don Lincoln Talk

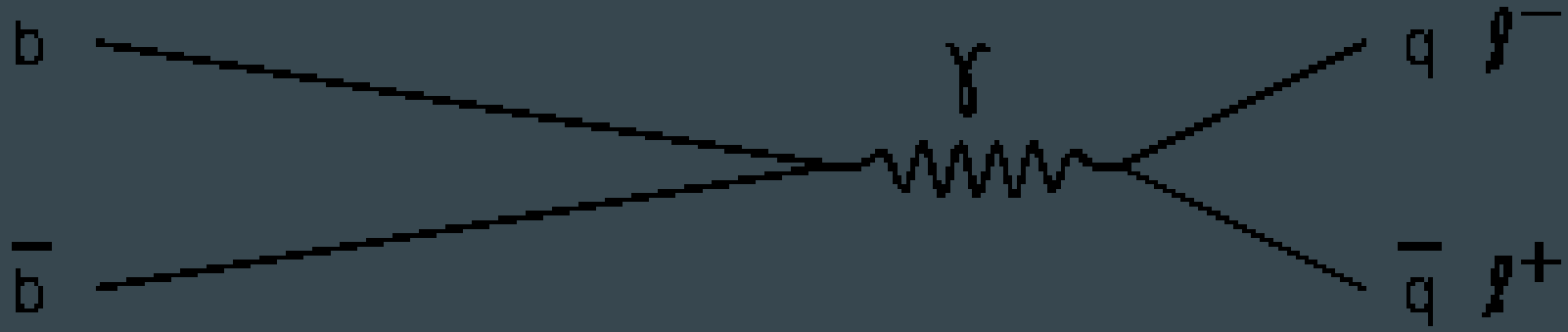
- Intro to Particle Physics Research
- Top Quark discovery at D0 (Fermilab)
- LHC at CERN
- Higgs Boson Discovery
- Videos

Chris Polly Talk

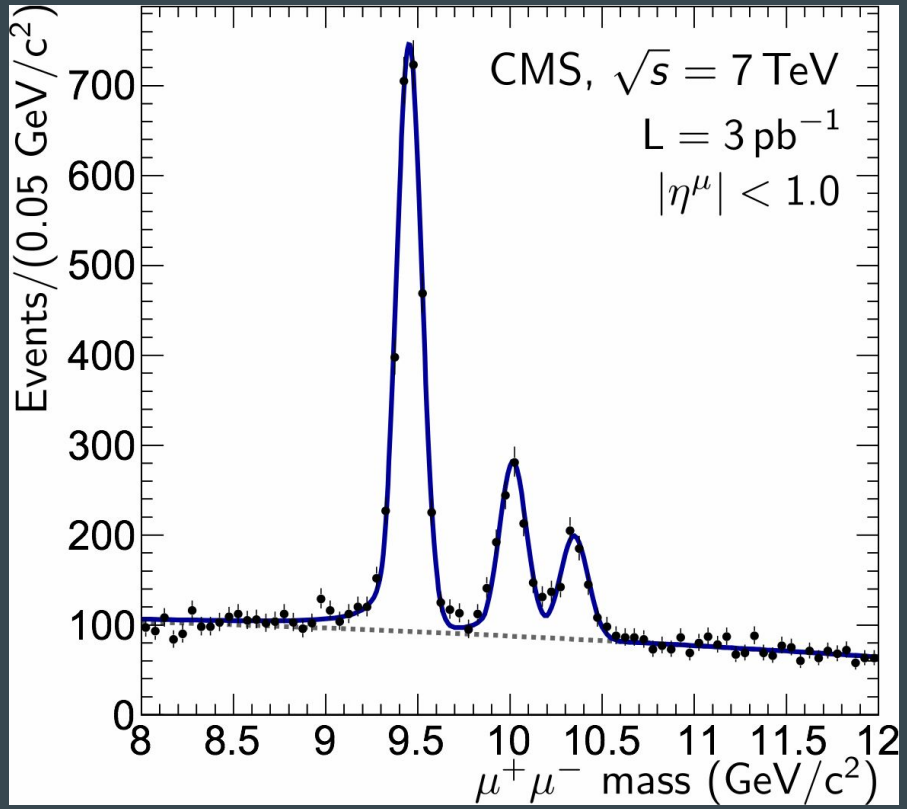
- Muon g-2
  - Moved from BNL
  - g-2 is one of the most precise measurements in Physics
  - Could shed light on many topics such as supersymmetry and dark matter
- Mu2e
  - New facility being built
  - Designed to observe super rare event of a muon turning into an electron

Upsilon Decay

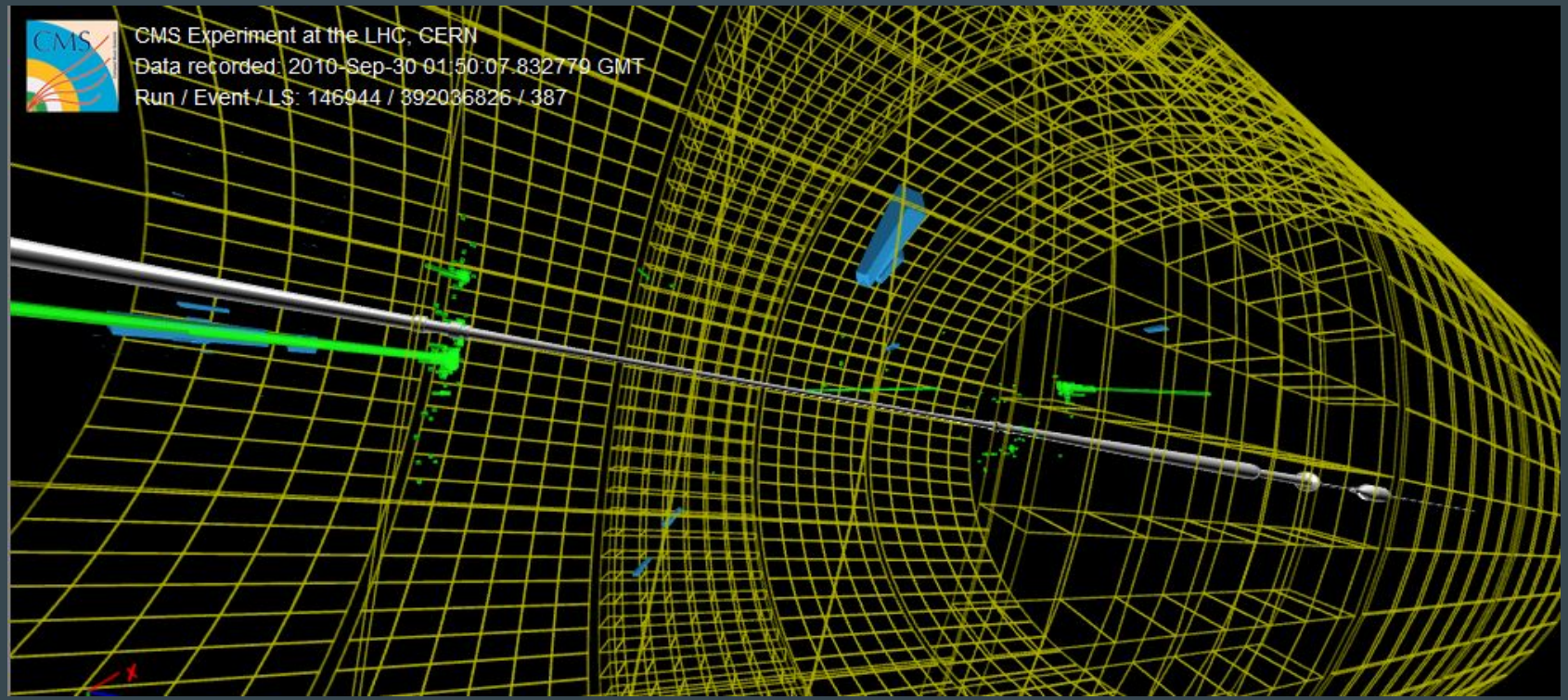
Analyzed CMS data to determine invariant mass of the Upsilon (4S)



Upsilon Decay

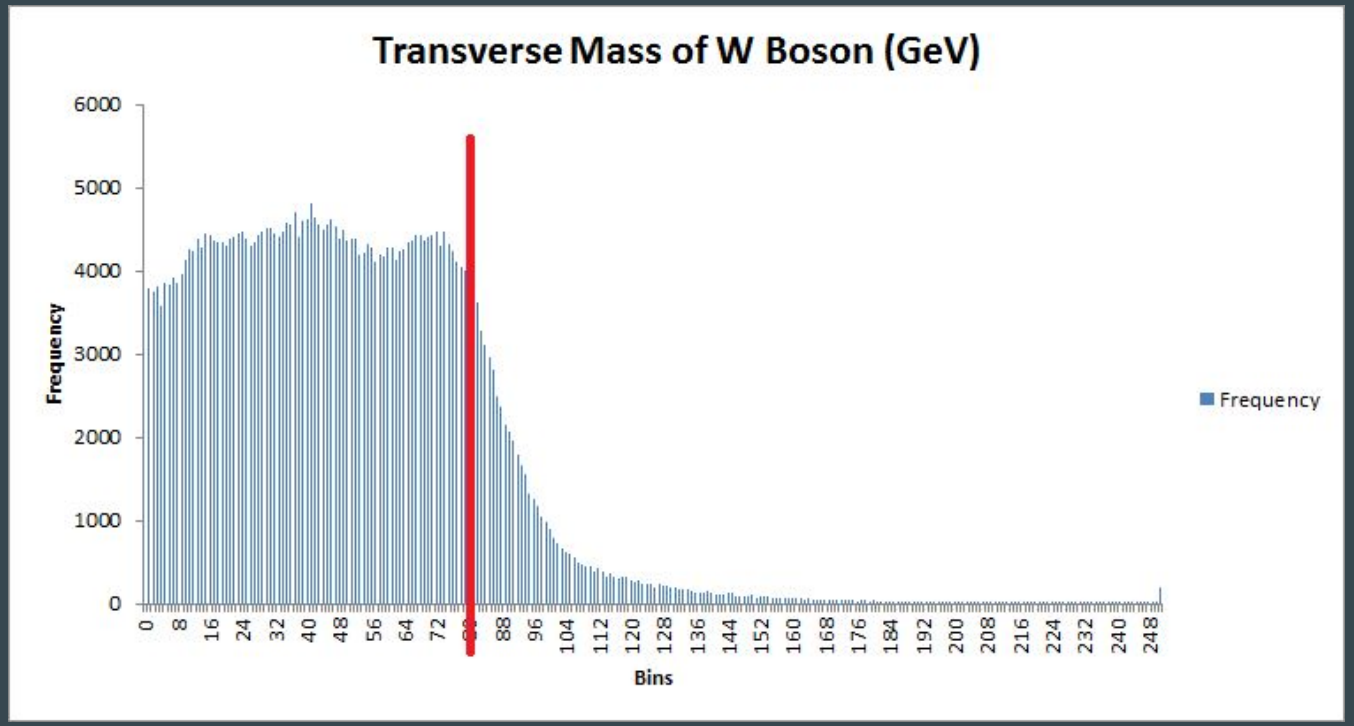


W^- Boson Decay



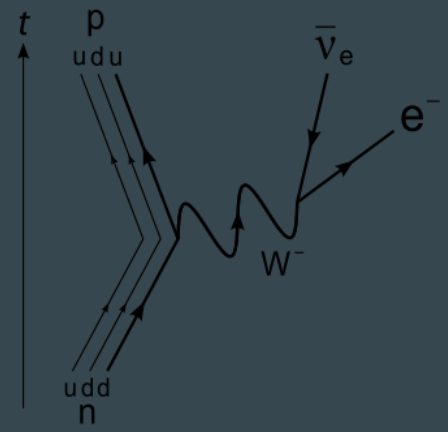
Claim

W boson has an Invariant Mass of approximately 80 GeV



The W Boson

- The Electroweak Theory predicted the charged W^+, W^- and the chargeless Z bosons in 1968; observed in 1983; very short half-life $\cong 3 \times 10^{-25}$s
- The W bosons mediate neutrino absorption or emission by inducing electron or positron absorption or emission
- W bosons are instrumental in **β** decay



- Example: $^{60}_{27}Co \longrightarrow {}^{60}_{28}Ni + e^- + \bar{\nu}_e$

Where a single neutron $n^0 \longrightarrow p^+ + e^- + \bar{\nu}_e$

Since udd uud

W changes the flavor of a single quark! $d \longrightarrow u + W^-$;

$W^- \longrightarrow e^- + \bar{\nu}_e$

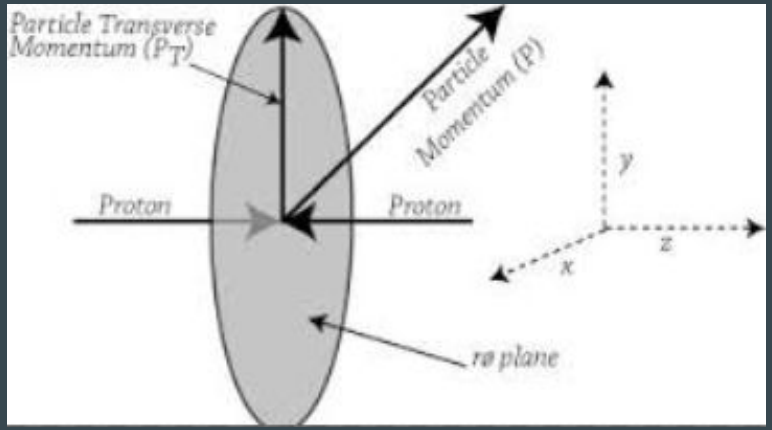
Transverse Energy

Transverse energy: the effective “transverse component” of the Energy, which is perpendicular to the beam axis.

Assuming that the e- and antineutrino mass is negligible compared to the parent particle (W- boson), we can ignore these in calculations

Given data only on the missing transverse energy of the missing component (antineutrino), we can only calculate the transverse mass of the parent particle (W- boson)

Total Transverse Energy = Transverse Energy of Electron + Missing Transverse Energy (antineutrino)



Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Run	Event	pt	eta	phi	Q	type	delEta	delPhi	sigmaEtaEta	HoverE	isoTrack	isoEcal	isoHcal	MET	phiMET
2	167676	328843401	38.6387	-0.8499	1.84857	-1	EB	0	0	0.00948452	0	0	1.22409	0	46.7884	-1.38857
3	167676	328884653	73.4109	-1.39509	2.00521	-1	EB	0	0	0.0100056	0	22.8584	8.01506	8.29506	3.28583	-0.77393
4	167676	328990625	53.9565	0.277265	2.8181	-1	EB	0	0	0.00959905	0.02341	8.64138	4.1638	0	19.437	-0.18973
5	167676	329087071	37.7199	-1.47483	-2.27041	-1	EB	0	0	0.00597462	0.022207	0	1.38791	0.71592	17.4309	1.01692
6	167676	329124215	32.5664	-0.4162	-0.14881	-1	EB	0	0	0.00916134	0	0	1.27207	0.83353	59.3997	2.90825

Equations

THE Equation.... $E^2 = p^2 + m^2$ *applied to electron ....*

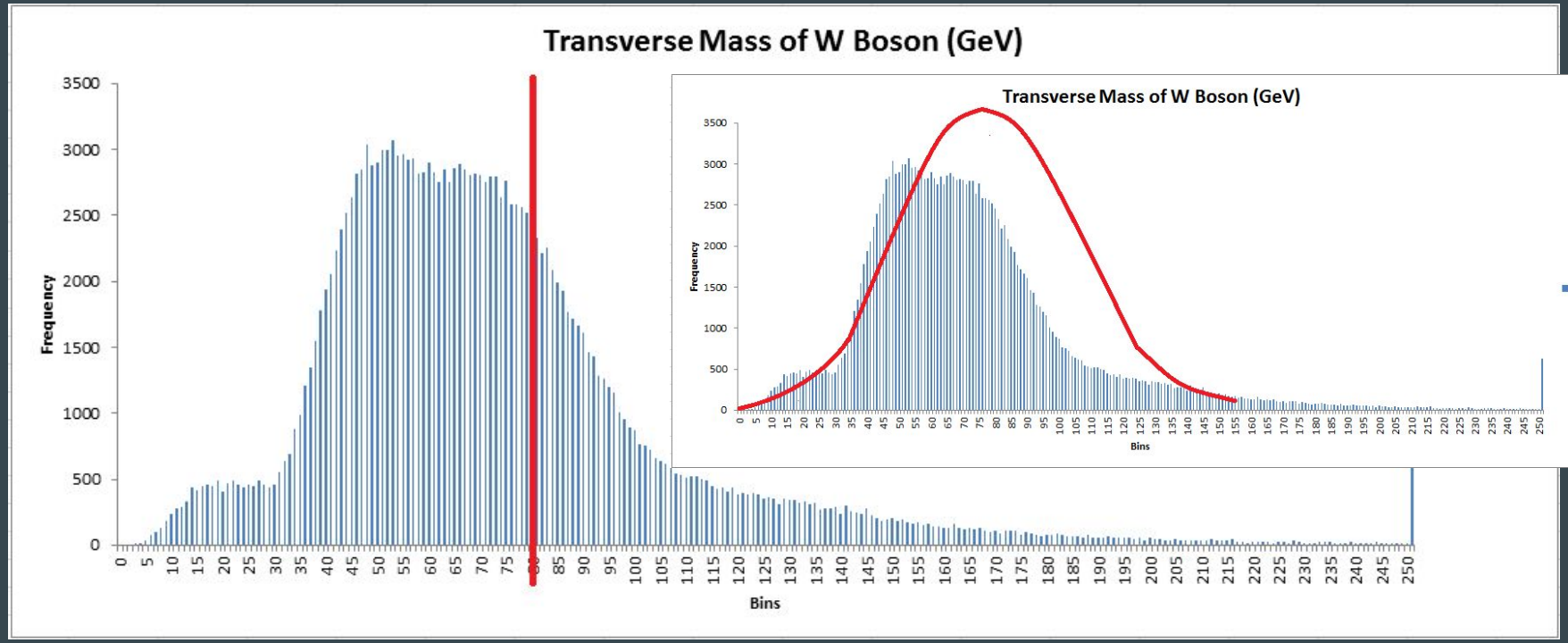
$E_e^2 = (p_{ex}^2 + p_{ey}^2) + p_{ez}^2) + m_e^2$; *can ignore* m_e...

Call $(p_{ex}^2 + p_{ey}^2) = p_{eT}^2 = E_{eT}^2$ $\quad T \rightarrow$ *Transverse*

We know not much about the neutrino...BUT we know its Missing Transverse energy

$E_{\nu T}^2 = p_{\nu T}^2 + m_\nu^2$; *can ignore* m_ν...

$E_{\nu T} = E_{MET} = |p_{\nu T}|$



- 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

What CAN we figure out about the parent W particle?

$E_W^2 = p_W^2 + m_W^2 \rightarrow$ *only have info in the transverse direction so.....*

$m_{WT}^2 = E_{WT}^2 - p_{WT}^2$

$m_{WT}^2 = (E_{eT} + E_{\nu T})^2 - (\vec{p}_{eT} + \vec{p}_{\nu T})^2$

Expand

$m_{WT}^2 = E_{eT}^2 + E_{\nu T}^2 - p_{eT}^2 - p_{\nu T}^2 + 2E_{eT}E_{\nu T} - 2\vec{p}_{eT} \bullet \vec{p}_{\nu T}$

Remember... $E_{eT} = |p_{eT}|$ *and* $E_{\nu T} = |p_{\nu T}|$

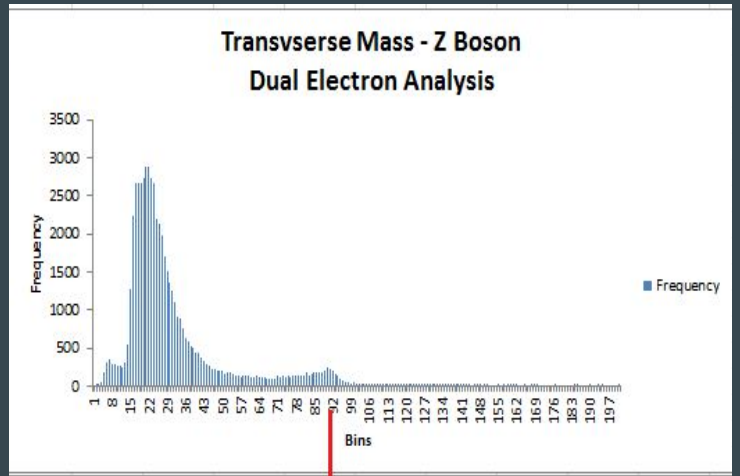
and cancel equivalent terms.... and you get

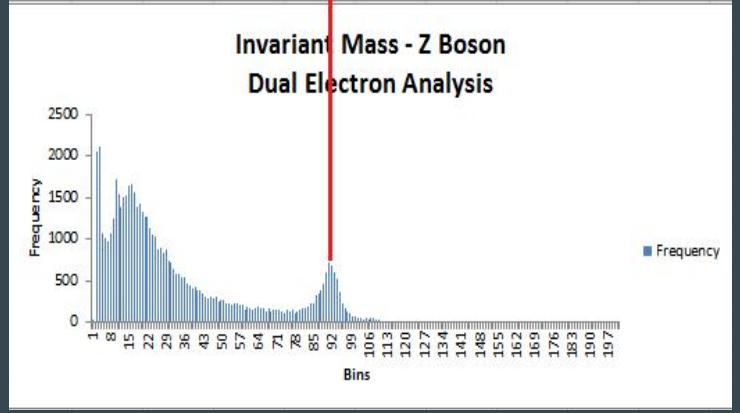
$$m_{WT}^2 = 2E_{eT}E_{\nu T}(1 - \cos\phi)$$

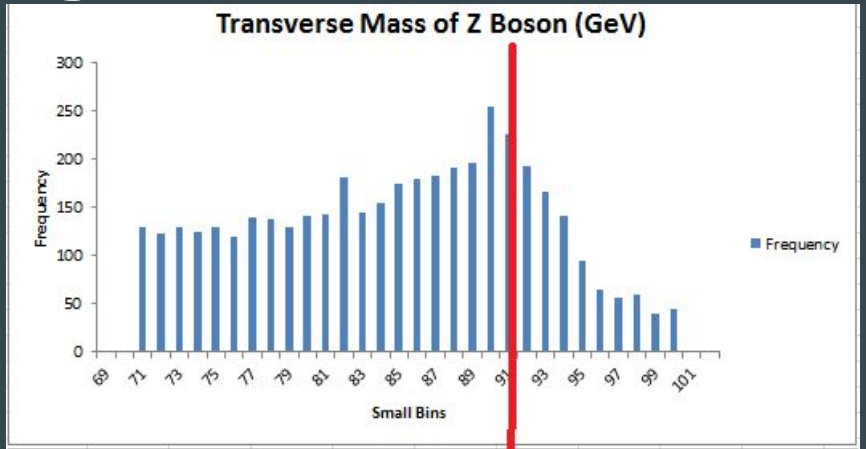
where $\phi = \phi_e - \phi_{MET}$ *= angle between the direction of electron and 'missing energy' direction*

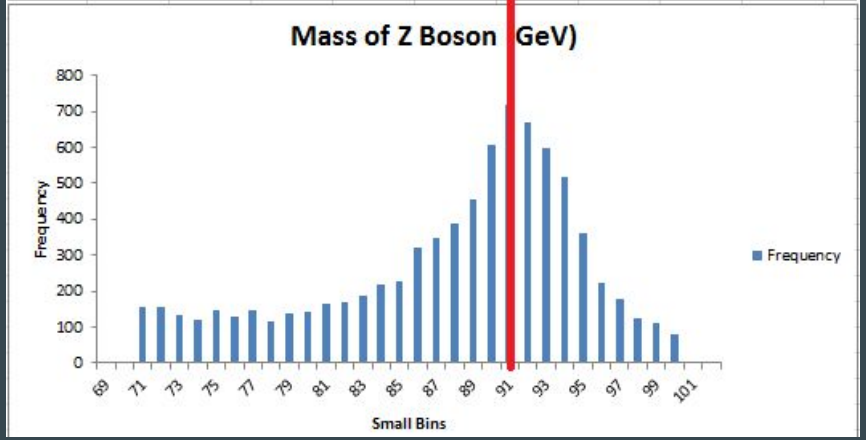
..... ϕ_e *and* ϕ_{MET} *are given in our data!!*

Transverse Mass to Invariant Mass
A Look at the Z-boson to Ignore the z-direction

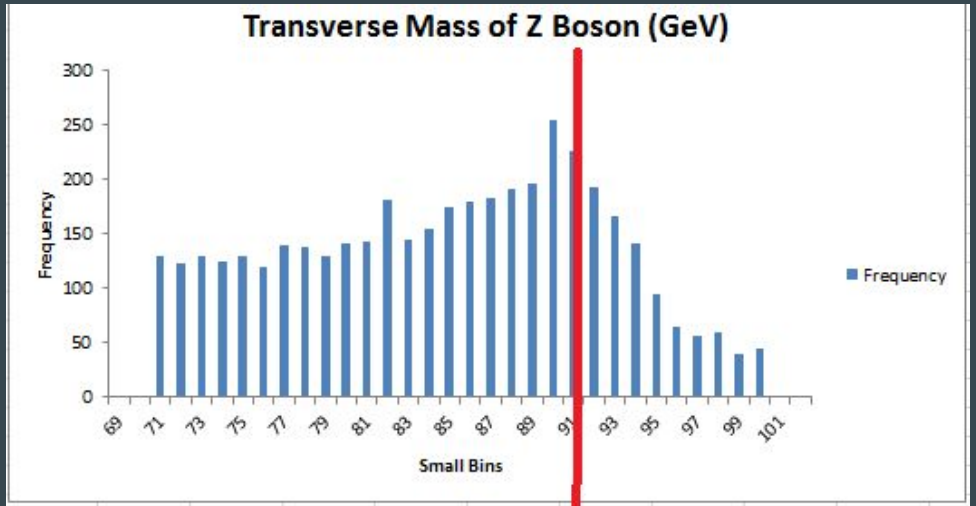


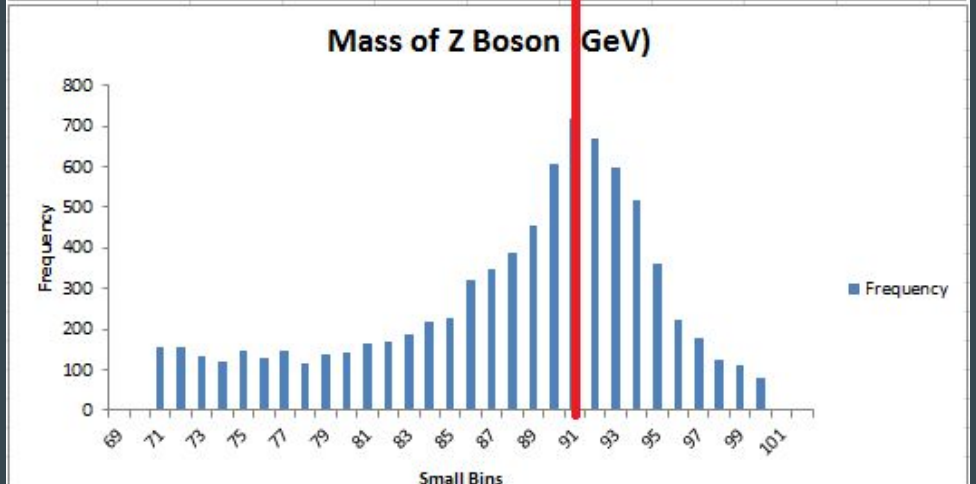




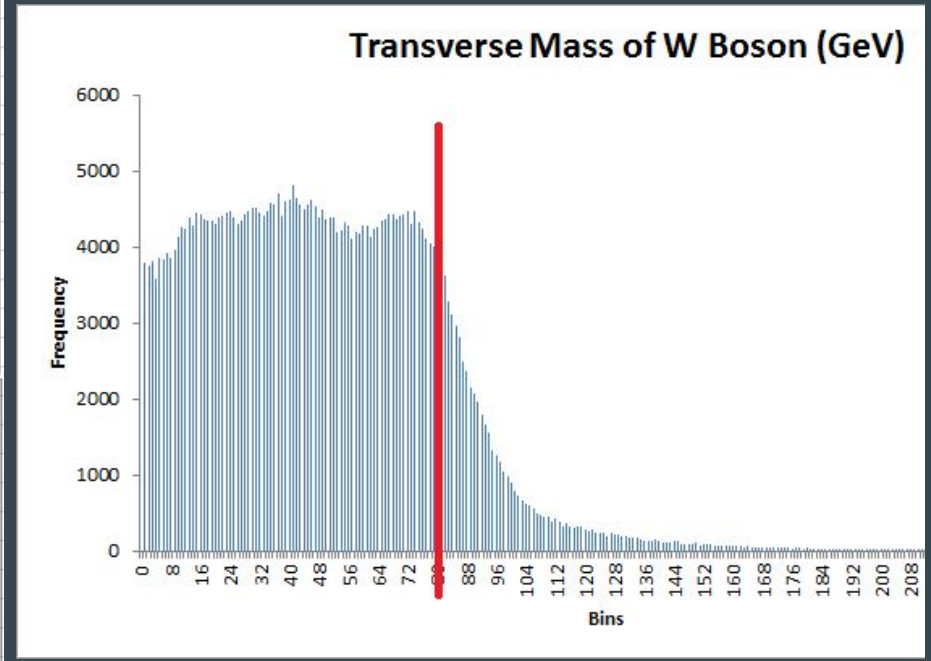


Took at Look at Transverse vs Known mass of Z Boson





Transverse to Invariant Mass



Invariant Mass of W Boson is ~ 80 GeV

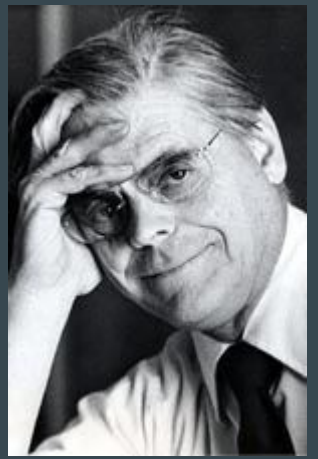
Implementation Plan: Introductory resources

- http://www.particleadventure.org
- https://profmattstrassler.com/new-start-here/
- http://www.quantumdiaries.org/2010/02/14/lets-draw-feynman-diagams/
- http://home.cern/topics/large-hadron-collider
- https://indico.cern.ch/event/197461/contributions/1478917/attachments/290954/406673/CMS_4July2012_Final.pdf
- The Large Hadron Collider video
- The Standard Model video
- Feynman Diagrams video
- Quantum Electrodynamics video
- Intro to Higgs Field video
- Update: Discovery of a Higgs Boson video
- Quantum Field Theories video
- What is Supersymmetry? video
- Quantum Chromodynamics video
- Particle Fever Video

Implementation Plan: Quarknet Data Portfolio Activities

- Quark Workbench
- Rolling with Rutherford
- Making it Round the Bend
- Plotting LHC Discovery
- Calculate Z Mass
- Calculate Top Quark Mass
- Cosmic Rays and the Sun
- CMS Data Express
- CMS Masterclass
- CMS e-lab

Dr. Wilson's defense of Research



SENATOR PASTORE. Is there anything connected in the hopes of this accelerator that in any way involves the security of the country?

DR. WILSON. No, sir; I do not believe so. It only has to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things. It has nothing to do with the military. Only from a long-range point of view, of a developing technology. Otherwise, it has to do with: Are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. In that sense, this new knowledge has all to do with honor and country but it has nothing to do directly with defending our country except to help make it worth defending.