Smashing Atoms

(and a few other things…)

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Fermilab

What You'll hear today.

- High Energy Physics?
  - A little background.
- How Big is the site?
  - How much equipment?
  - Keeping track of it all.
- Maintenance Philosophy.
  - Problems Big and Small.
  - Vendor issues… the devil's in the details.
  - Environmental issues.
- NFPA-70E impact.

Lets visit the ancient Greeks

The world as seen by Empedocles

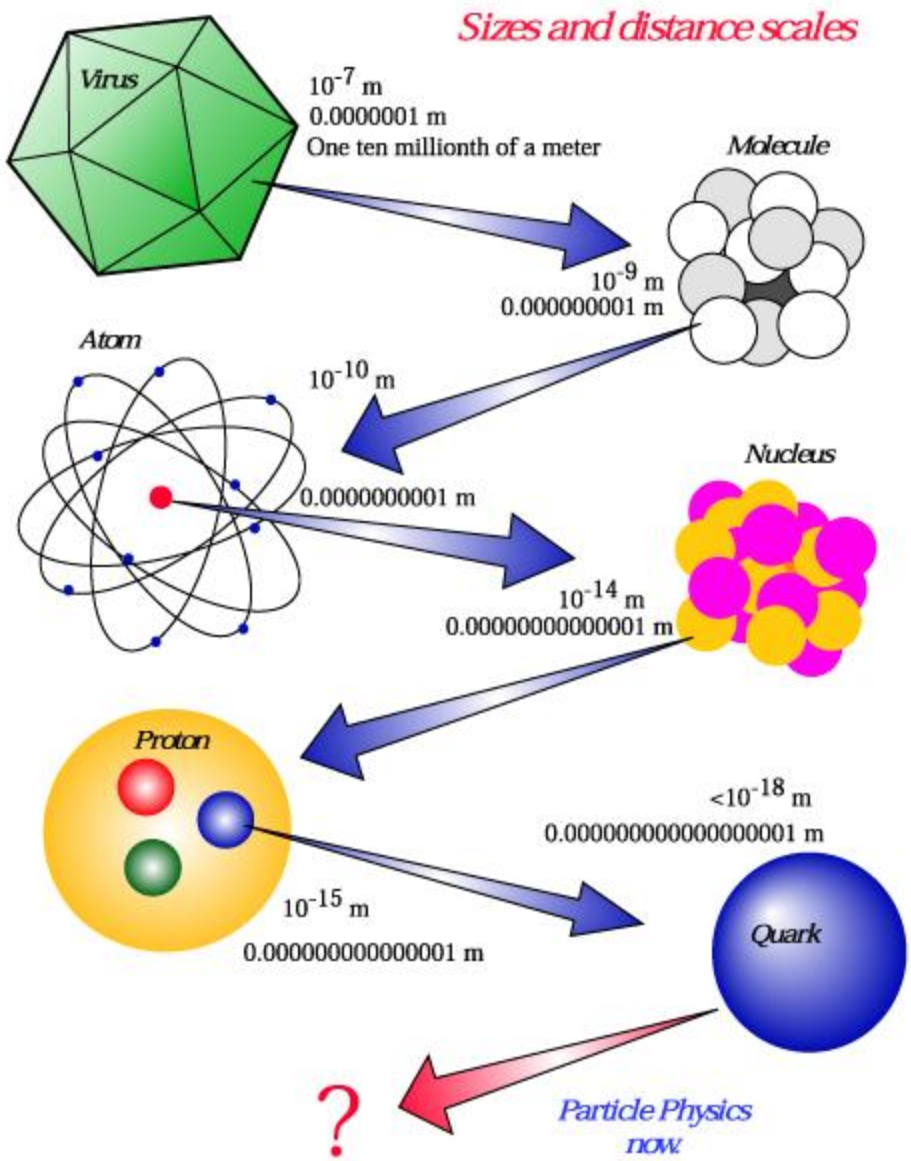
Also had “Love and Strife” as forces of change!

Well, back to the drawing boards

By convention there is color,
By convention sweetness,
By convention bitterness,
But in reality there are atoms and space.
-Democritus (c. 400 BCE)

Are we done yet?

The Greek root for the word atom, "atomon," means "that which cannot be divided." But the entities we call atoms are made from more fundamental particles!



High Energy Particle Physics is a study of the smallest pieces of matter.

It investigates (among other things) the nature of the universe immediately after the Big Bang.

It also explores physics at temperatures not common for the past 15 billion years (or so).

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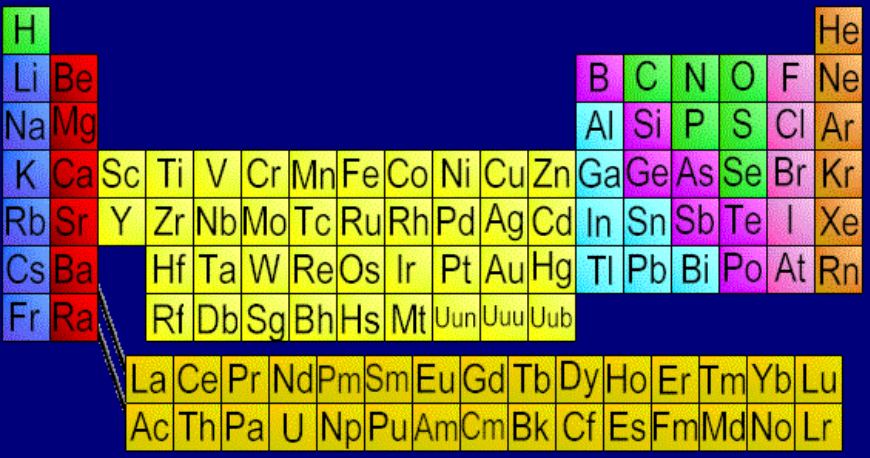
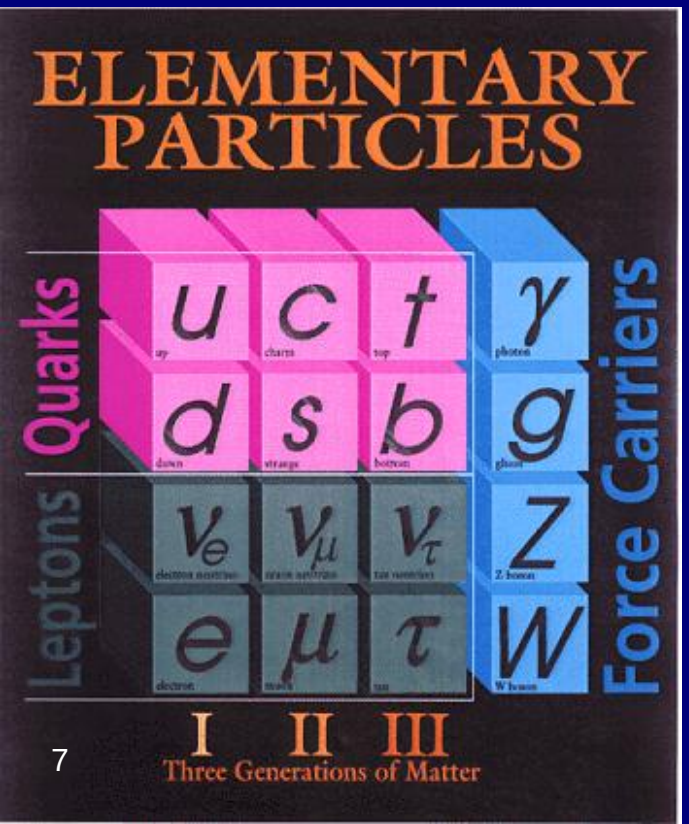
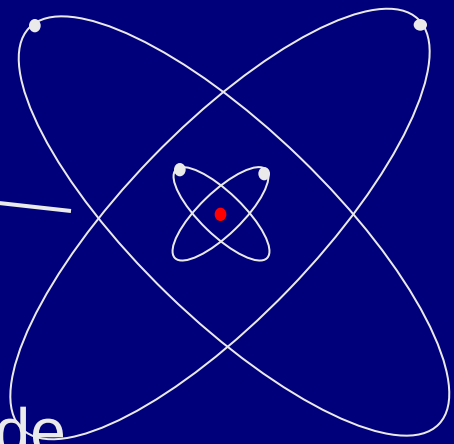
Periodic Table



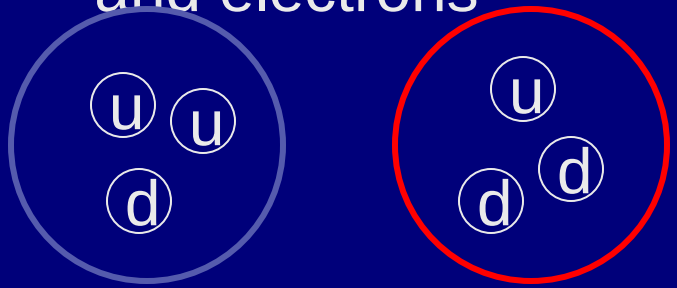


Helium

Neon



All atoms are made of protons, neutrons and electrons

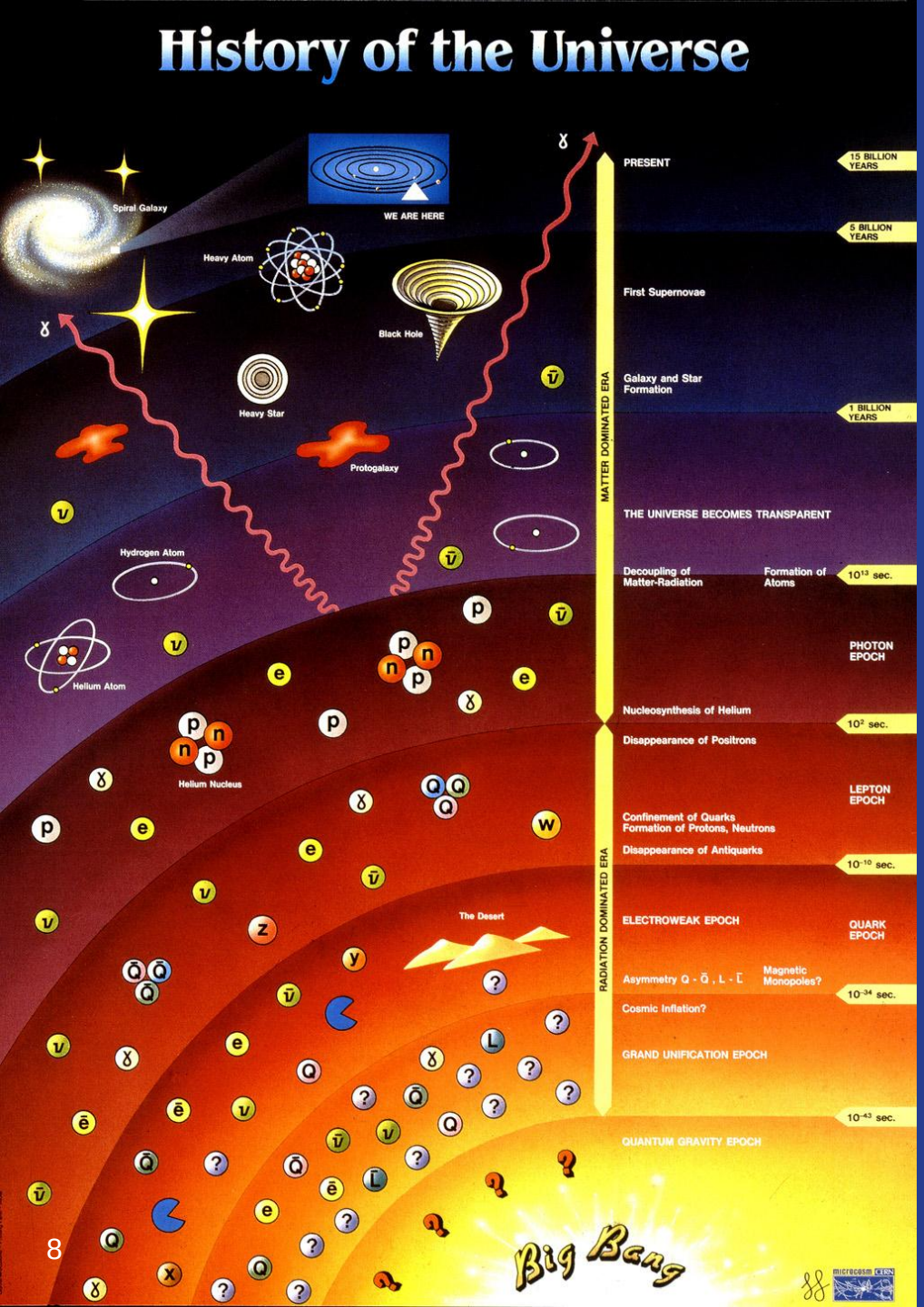


Proton

Neutron

Electron

Gluons hold quarks together
Photons hold atoms together



Now (15 billion years)

Stars form (1 billion years)

Atoms form (300,000 years)

Nuclei form (180 seconds)

Protons and neutrons form (10^{-10} seconds)

Quarks differentiate (10^{-34} seconds?)

??? (Before that)

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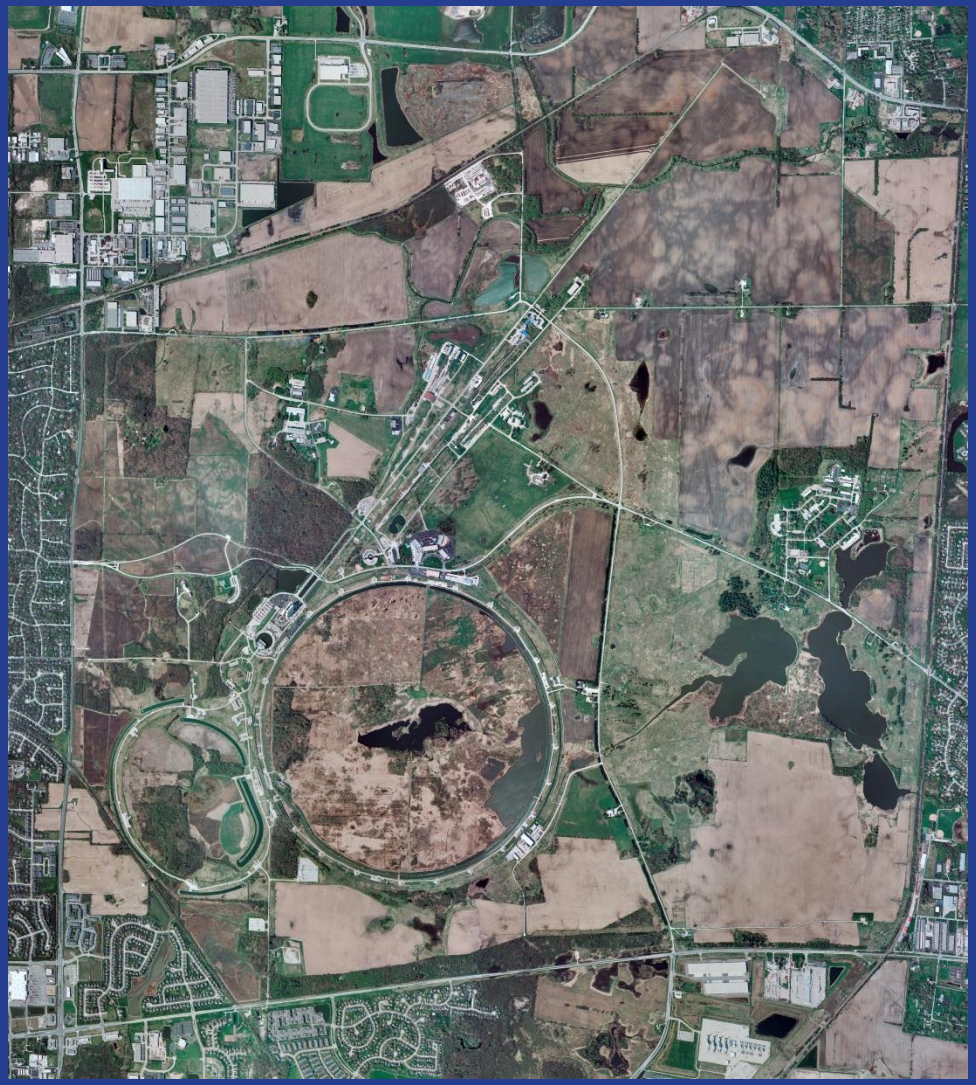
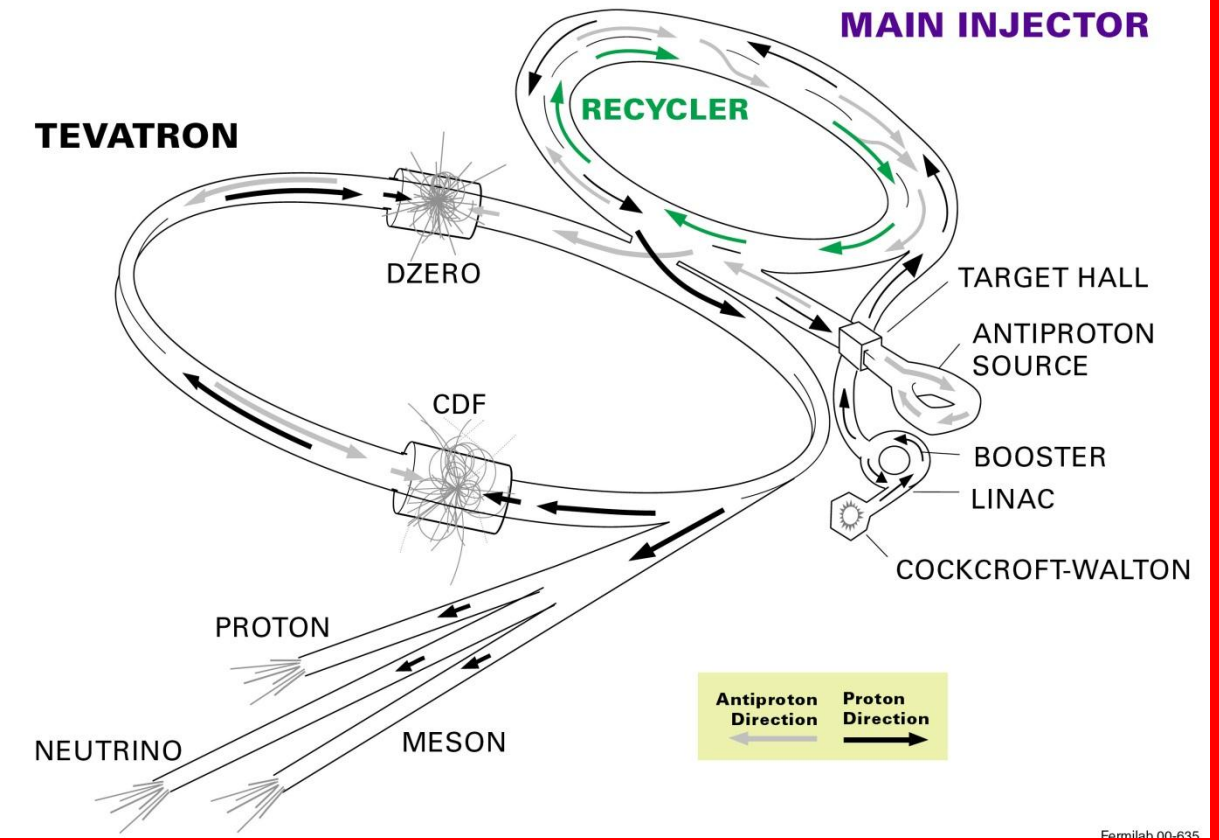
4×10^{-12} seconds
LHC
10^{-13} Seconds

An Overview…

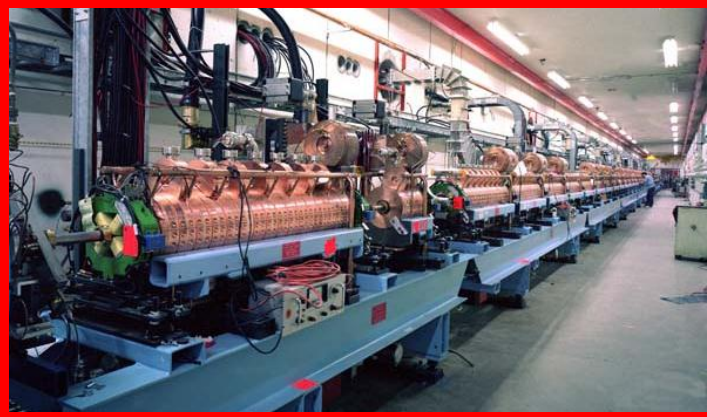


A Closer Look

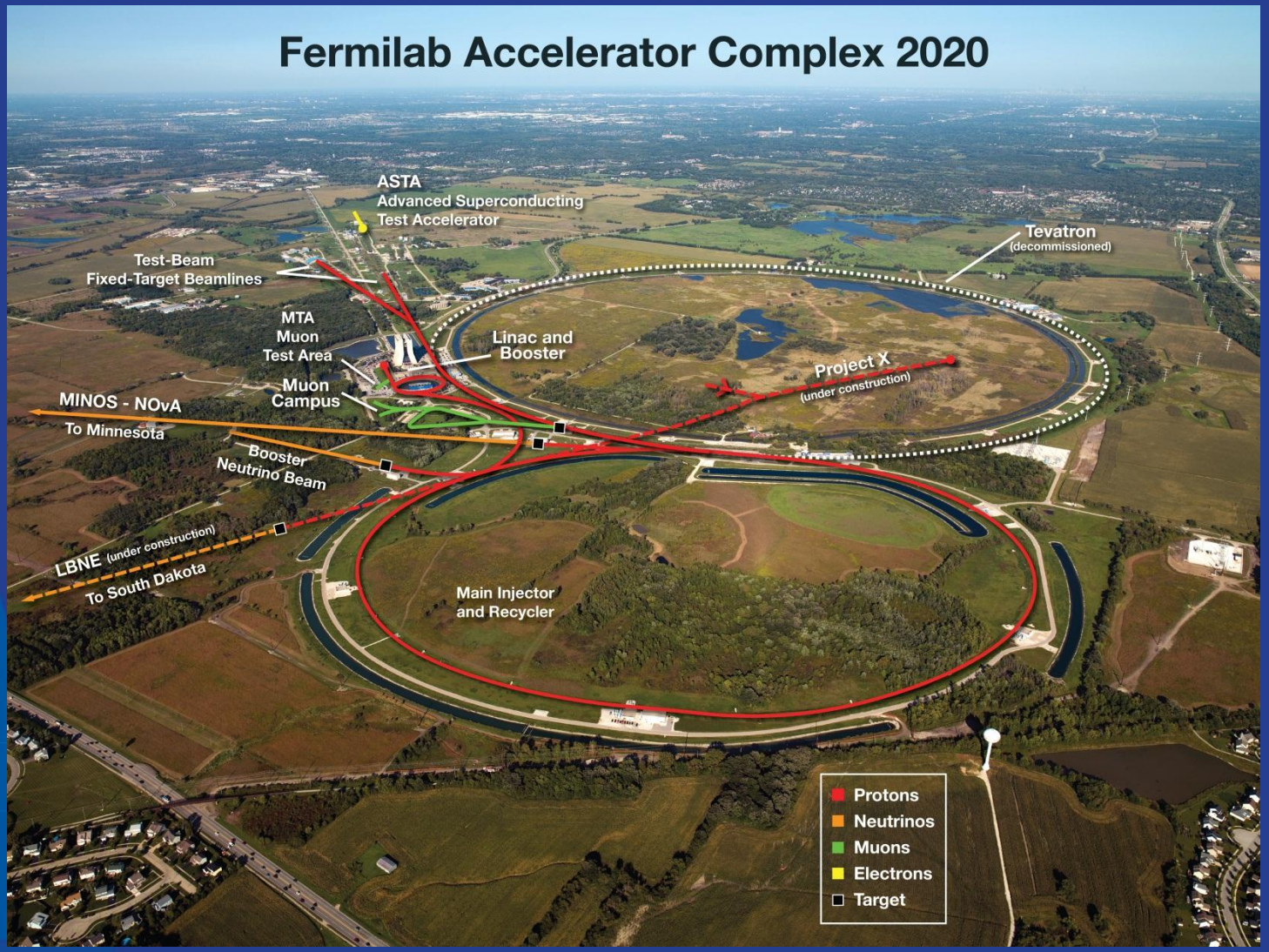
FERMILAB'S ACCELERATOR CHAIN



Fermilab 00-635



A Future Perspective



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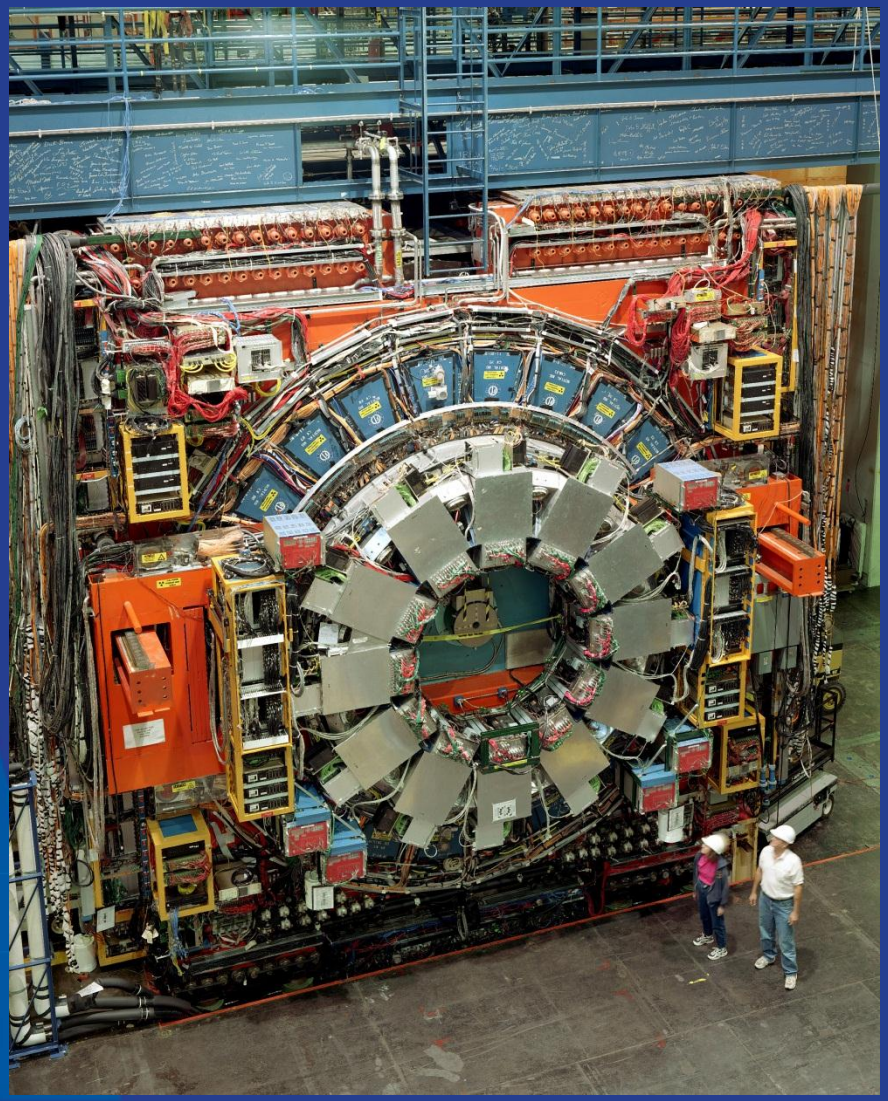
Scale of the “old” configuration problem!

Component Totals – Tevatron tunnel only

- 775 Dipoles
- 223 Quadrupoles
- 208 Spool pieces with Correctors
- 13 Beam scrapers
- 26 Electrostatic separators
- 8 RF Cavities
- 36 Cryogenic Isolation Valves
- 5 Flourinert® pump skids
- 229 Ion pumps
- 49 Sublimation pumps
- 310 Vacuum valves
- 350 Vacuum gauges
- 43 Various Beam diagnostics
- Variety of tunnel support (sump pumps, air handlers, phones, etc.)
- And all the wiring and buss work
- 389 remaining Main Ring magnets
- Does not include CDF or DØ detectors

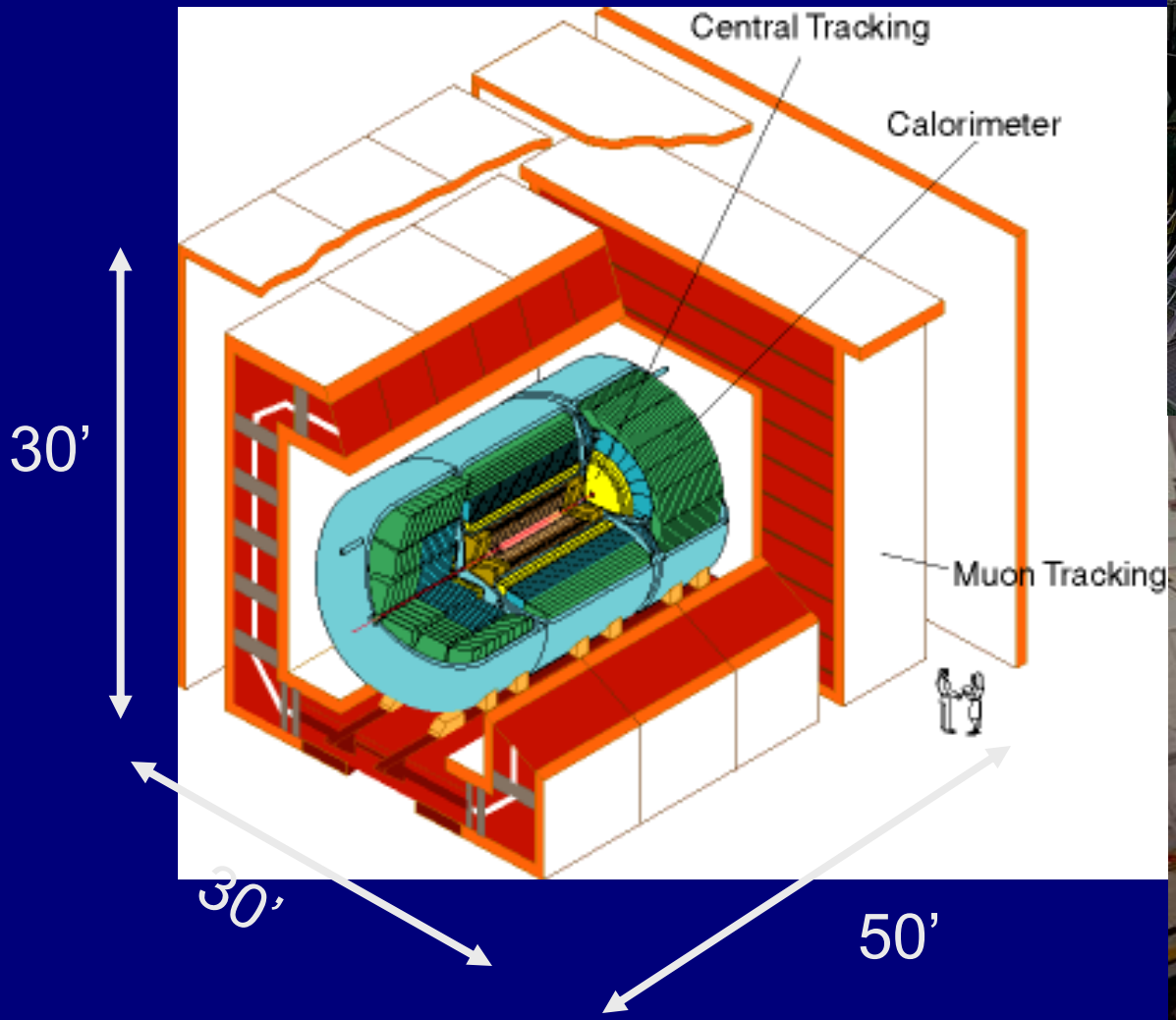
CDF(Colliding Detector Facility) Detector

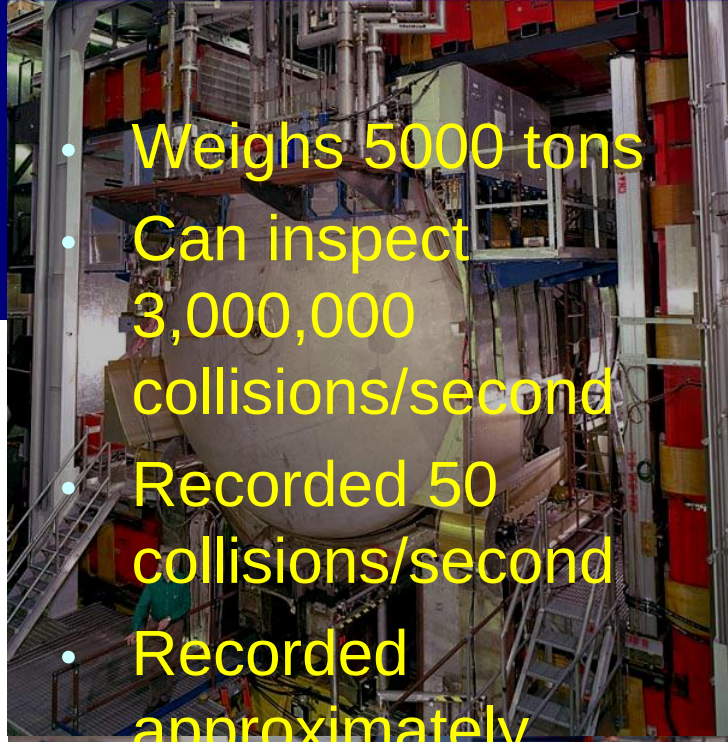


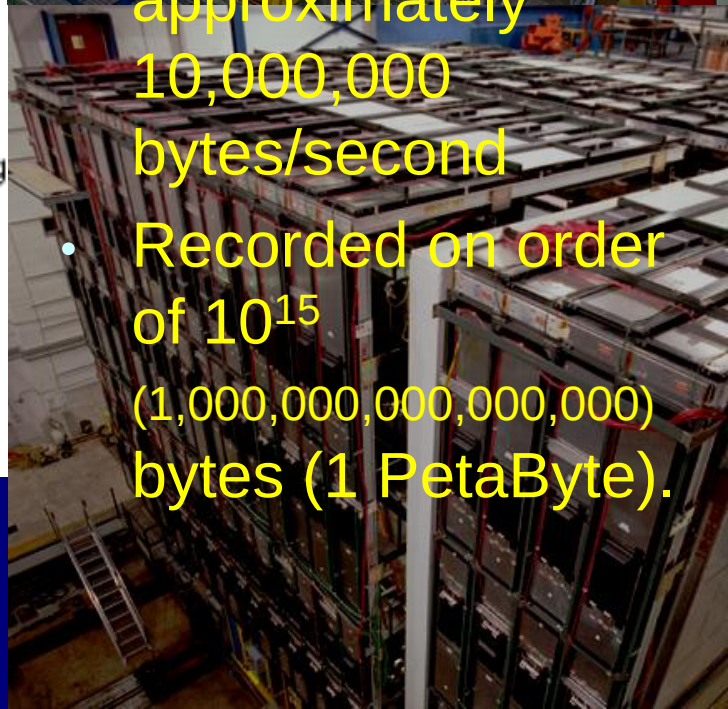
4500 tons of moving detector!

Moved into Collision hall on air pads. Only moved in and out a couple times in its history!

DØ Detector: Run II

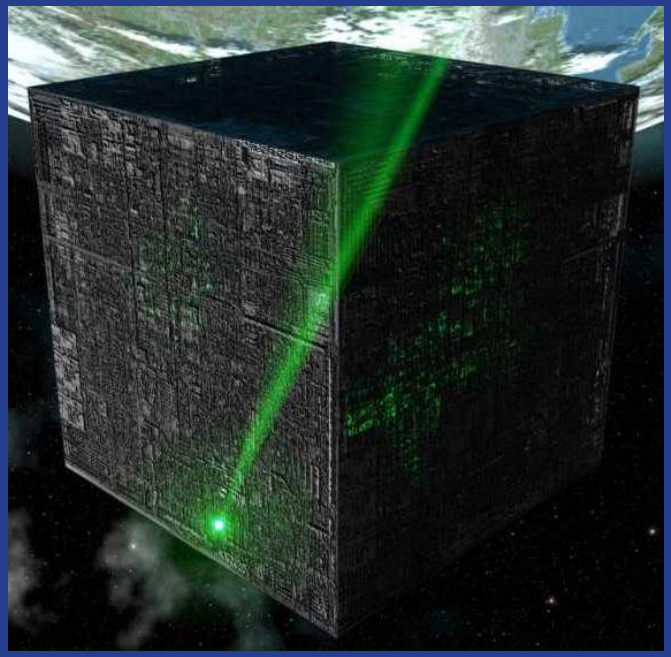




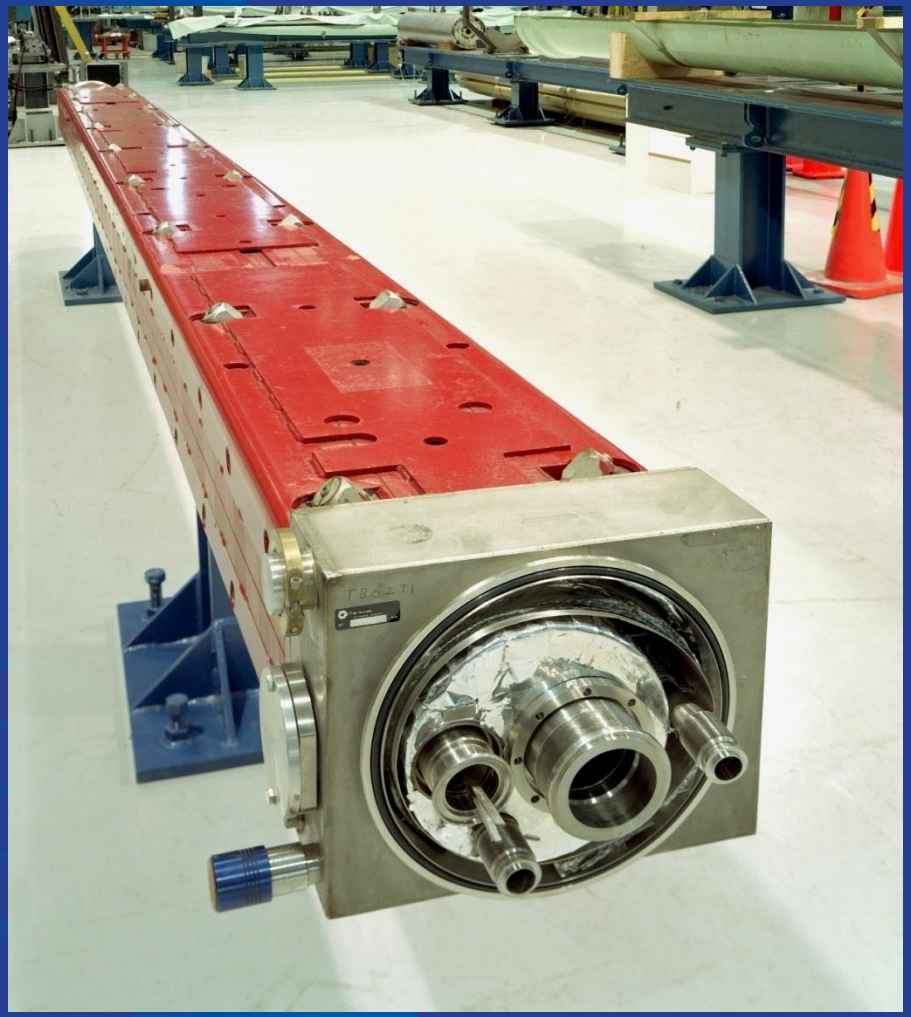


- Weighs 5000 tons
- Can inspect 3,000,000 collisions/second
- Recorded 50 collisions/second
- Recorded approximately 10,000,000 bytes/second
- Recorded on order of 10^{15} (1,000,000,000,000,000) bytes (1 PetaByte).

DØ vs. Borg



Superconducting Magnet



- A Tevatron dipole is:
  - 21 feet long 18 inches wide
  - 8700 pounds
  - 775 Installed
- We needed full “quality” information on each magnet and had to match them if we changed a failed magnet.
- Requires liquid Helium at approximately 4Cº
- Also uses a liquid Nitrogen shield.
- Require very good vacuum for insulating properties and in the “beam chamber”.

Tevatron Cryogenics

- 4.5 miles of liquid helium / liquid nitrogen distribution transfer line.
- > 5000 control and monitoring points
- 40,000 liquid liters of helium being circulated
- 83 pieces of rotating equipment operating at any given moment.

Configuration nightmare!

- There are 108,000 ACNET (accelerator network) devices in the accelerator control system.
- There are 303,000 ACNET device properties in the control system.
- There are 550 distributed Front end computers in the control system.
- There are 320 CAMAC (and VME) crates with > 6000 modules installed.

Tools to Track Problems

- The Primary tool available to all support departments is the Downtime log and the Downtime Summary.

- This is an electronic database in which any downtime is entered by the Operations Crew.
- Operators are first line of defense.

- Individual components are the responsibility of the owning department, i.e. EE, Mechanical, Cryogenic, Instrumentation, Controls, RF.

Collider Run IIA
03/01/01 - 10/06/02

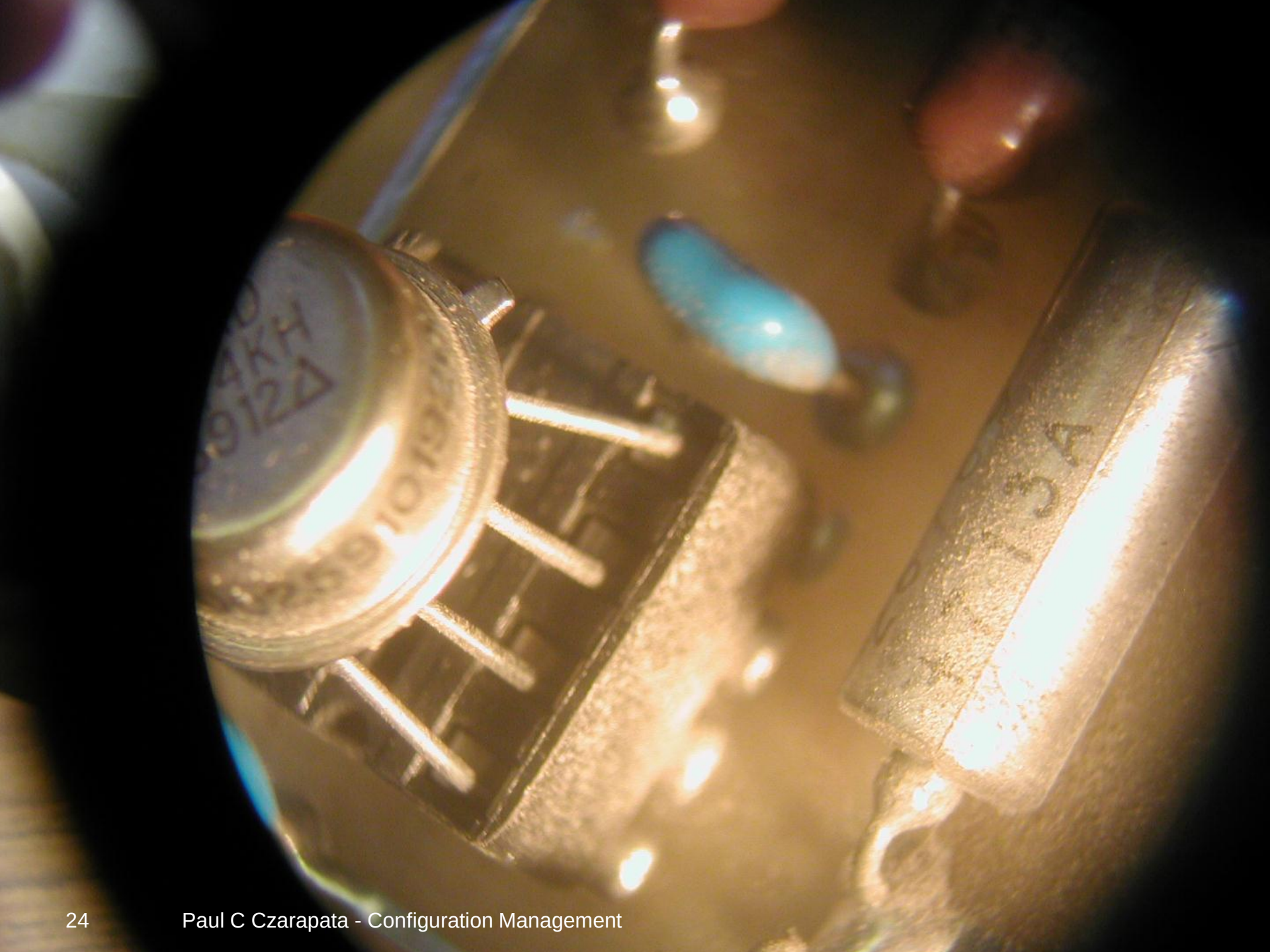
Reason for Terminating Store:	Number of Stores Terminated	Store Hours
Intentional	200	3463.23
Controls	7	64.43
Correction Magnet Systems	1	2.23
Cryogenics	14	132.92
Experimental Areas	3	65.76
Glitches/Lightning	13	157.96
Human Error	2	46.65
Instrumentation	0	0.00
Kickers	2	12.90
Low Beta Quadrupoles	4	39.02
Magnet Failure	2	26.55
Miscellaneous	3	25.93
Quench	9	81.52
Quench Protection System	19	165.49
Separators	3	8.31
Tevatron Power Supplies	6	40.04
Tevatron RF	3	10.45
Utilities	0	0.00
Vacuum	1	7.58

There have been 292 stores with a total store time of 4350.97 hours for an average store length of 14.90 hours

200 stores were ended intentionally with an average store length of 17.32 hours

92 stores were ended by failure with an average store length of 9.65 hours

68.5% of the stores have been ended intentionally



Spares?

- Given the age of many of the systems at the laboratory, obsolescence is a serious problem.

- We keep as many spares as possible for the systems we have and prioritize the systems that can be replaced given limited resources. (a.k.a. Money!)

Sample of the items identified as a vulnerability

Component	No.	Spares	Risk	Comment
Harmonic Filter Damping Resistors	2	1	H	Requires a double failure, but could occur in either Main Injector or Tevatron (See discussion of Power Grid in Site Infrastructure section.)
Dipole PS Transformers	12	1	H	These are long-lead time items that could reduce the physics program for up to 6 months (See discussion below.)
Quad PS Transformers	6	1	H	These are long-lead time items that could reduce the physics program for up to 6 months (See discussion below.)
Main Injector Quadrupoles	269	26	M	Had a number of failures, but able to keep up with replacement rate so far (See the section on the TD/AD Study on Magnet Spares.)
Kicker Magnets	6	1	L	One spare for each type (See the general discussion below.)

Maintenance and Reliability

- Trends in system failures and major vulnerabilities are tracked and mitigated as soon as possible. Examples of past problems:
  - Abort kicker prefires.
    - After extensive work, no prefires in over two years.
  - Quench Protection Monitor failures causing aborts.
    - Major overhaul of the system resulted in 0 false aborts over a year due to the QPM system
  - Linac 7835 Power Amplifier tubes.
    - Working group formed that worked with the vendor and ultimately placed a “reserve stock” order for 12 tubes.
    - 12 tubes are in reserve and new tubes are cycled through the reserve to keep the tubes fresh i.e. a new tube goes into reserve and a reserve tube is withdrawn.
    - Vendor has made a major upgrade to their facility and to their process control.

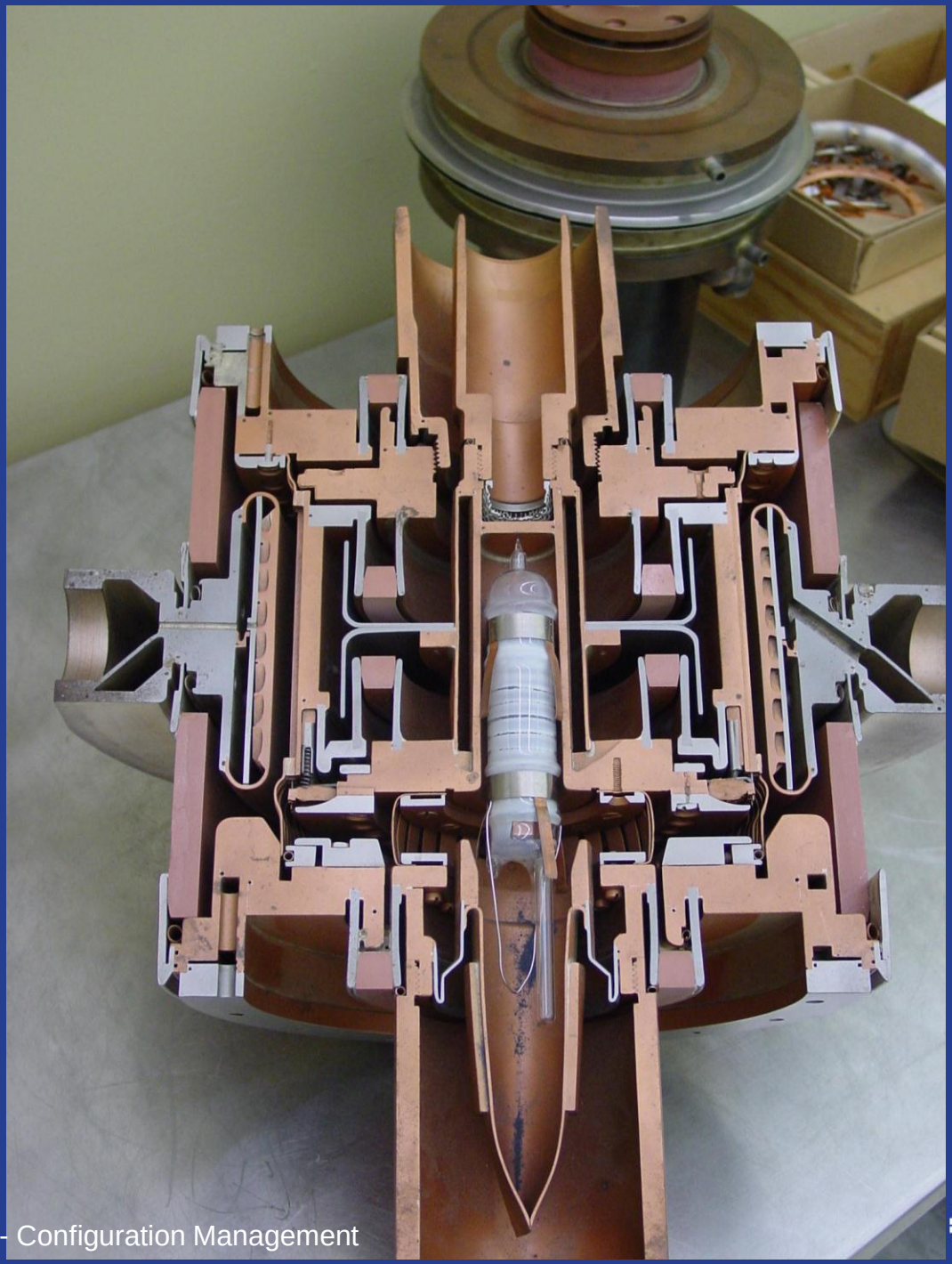
Linac Power Amplifier Tube

5MW peak pulse.

Produced for the military in the 1950's

No current direct replacement

Single vendor



What we found!

- Vendors – going out of tube business
- Few if any new young “cathode experts”
- Not seen as “good” buisiness market
- New designs – Tube planned for another lab won’t produce our needed power
- We reverse engineered the tube BUT concluded it would be an art not a science to replicate.

Lets Talk Maintenance

- In the beginning (October of 1972 for me!) we ran until the wheels fell off then fixed things.
  - Wheels often fell off at very inopportune times!
- Later we built in weekly maintenance periods and often broke the machines in the process.
  - Thermal cycling of systems caused failures.
- Now we follow what is referred to by industry as: Reliability-Centered Maintenance.

RAC & RCM

- I followed the developments in the reliability area as described by the Reliability Analysis Center – this was a DoD Information Analysis Center Sponsored by the Defense Technical Information Center and Operated by IIT Research Institute. Now an independent company.

- “Prior to the development of RCM, it was widely believed that everything had a “right” time for replacement or overhaul. Many maintenance personnel believed that by replacing parts of a product or overhauling the product (or reparable portions thereof), the frequency of failures during operation could be reduced.”

Overview of the Concept

- Despite this commonly accepted view, the results we saw seemed to tell a different story.
- In far too many instances, Periodic Maintenance seemed to have *no beneficial effects*.
- Indeed, in many cases, PM actually made things *worse* by providing more opportunity for maintenance induced failures or thermal cycling failures of the components.

What is RCM

- The objective of maintenance is to preserve and item's function(s).
- RCM focuses on the end system. (accelerator for us)
- Reliability is the basis for decisions.
  - Failure characteristics of the item in question must be understood to determine the efficacy of preventive maintenance. (vibration signature, noise, temperature, etc.)

RCM cont.

- RCM is driven first by safety.
  - Safety must always be preserved. When safety is not an issue, PM must be justified.
- RCM acknowledges design limitations.
  - Maintenance cannot improve the inherent reliability – it is dictated by design. This is one of the reasons for design reviews.
- RCM is a continuing process.
  - Differences between the perceived and actual design life and failure characteristics are addressed through age (or life) exploration. Like the Cryogenic Wet Engine maintenance periods.

The Bottom Line

- Maintenance and Infrastructure are expensive items. The accelerator complex and supporting infrastructure are reaching 42 years of age for our oldest machines.
- Infrastructure does have consequences for machine operation. HVAC, power grid, building roofs, etc. can all conspire to end a store or limit luminosity or end data taking.

When are spares not spares?

Whoops!

The cause

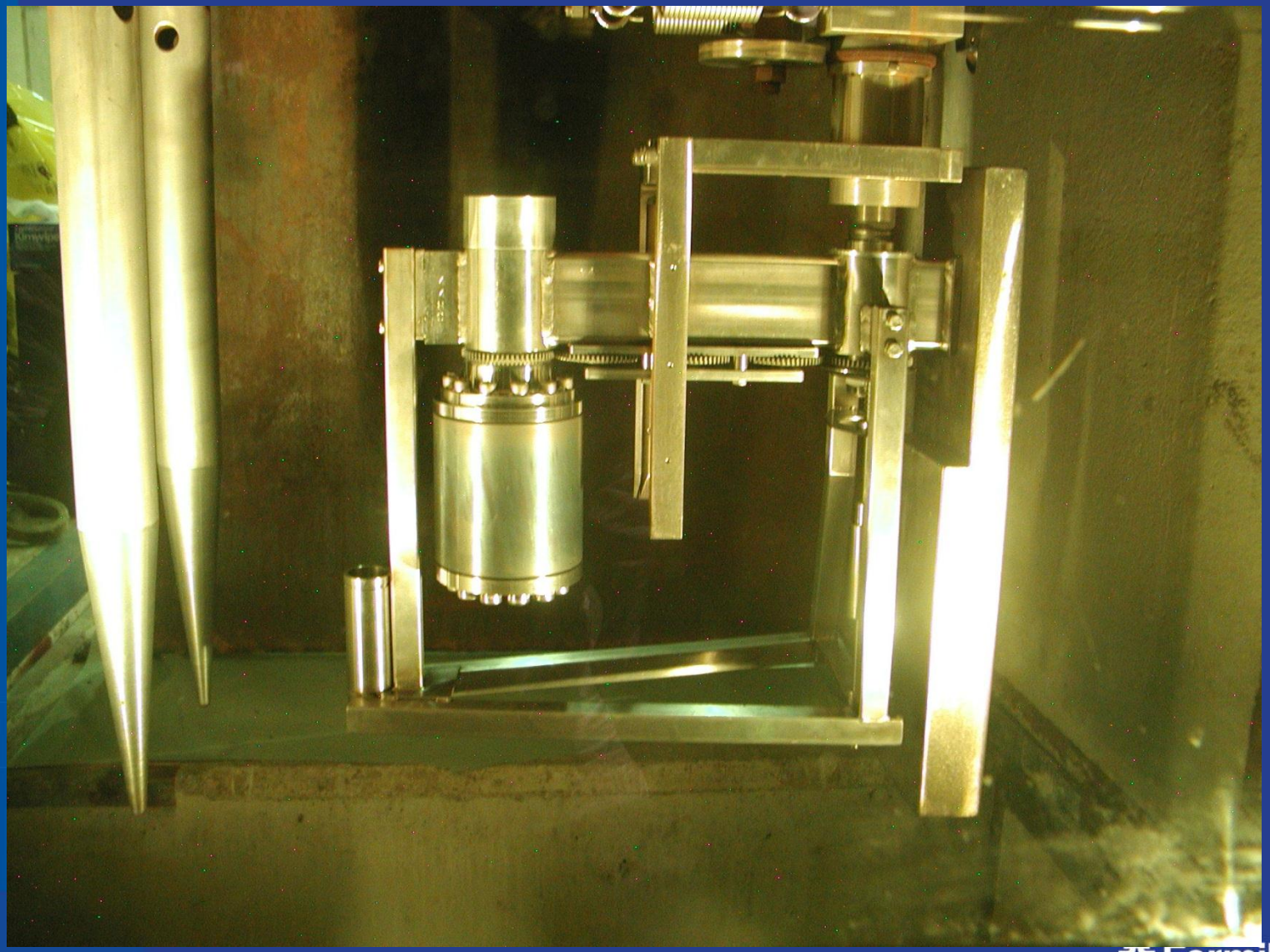
- The manufacturer had changed insulating materials to a urethane based epoxy encapsulated system for the Potential Transformers WITH THE SAME PART NUMBER
  - The original PT's were purely epoxy encapsulated.
  - An outside company was hired to investigate the cause of the uncontained explosion.
  - The findings were that, due to voids in the urethane, corona discharge caused a gas buildup.
    - Among the gases formed were Pentane, and OXYGEN!
    - The corona ignited the mixture causing a chemical explosion and that explosion caused a plasma that started an arc across the 13.8KV distribution system.
  - The cabinet could not possibly contain the energy of the combined fault.

One of the results of the blast!

Result of a mouse incursion – 13.8KV

Bad O – Ring … wrong compound!

Anti-Proton Production Target (New)



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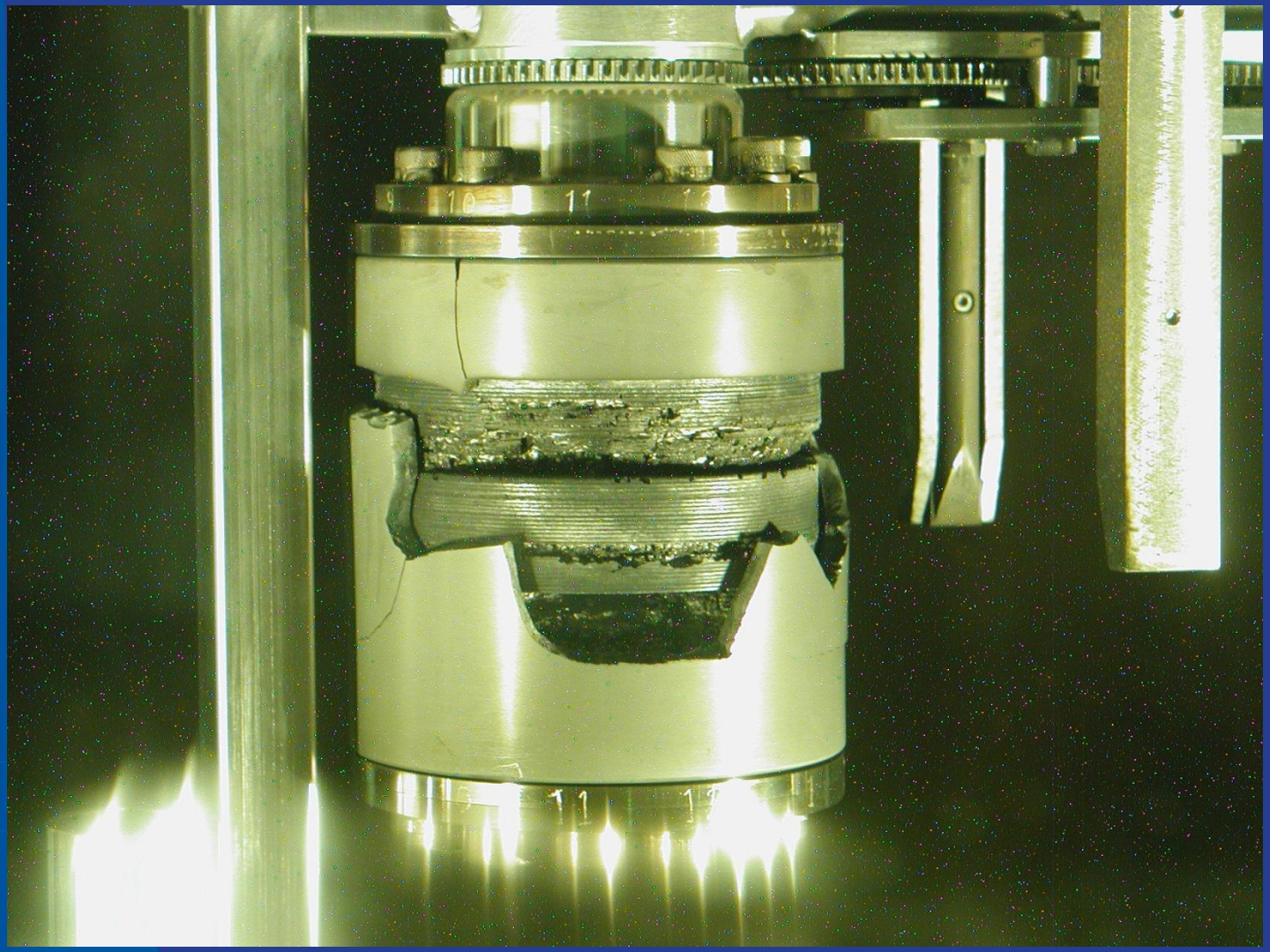
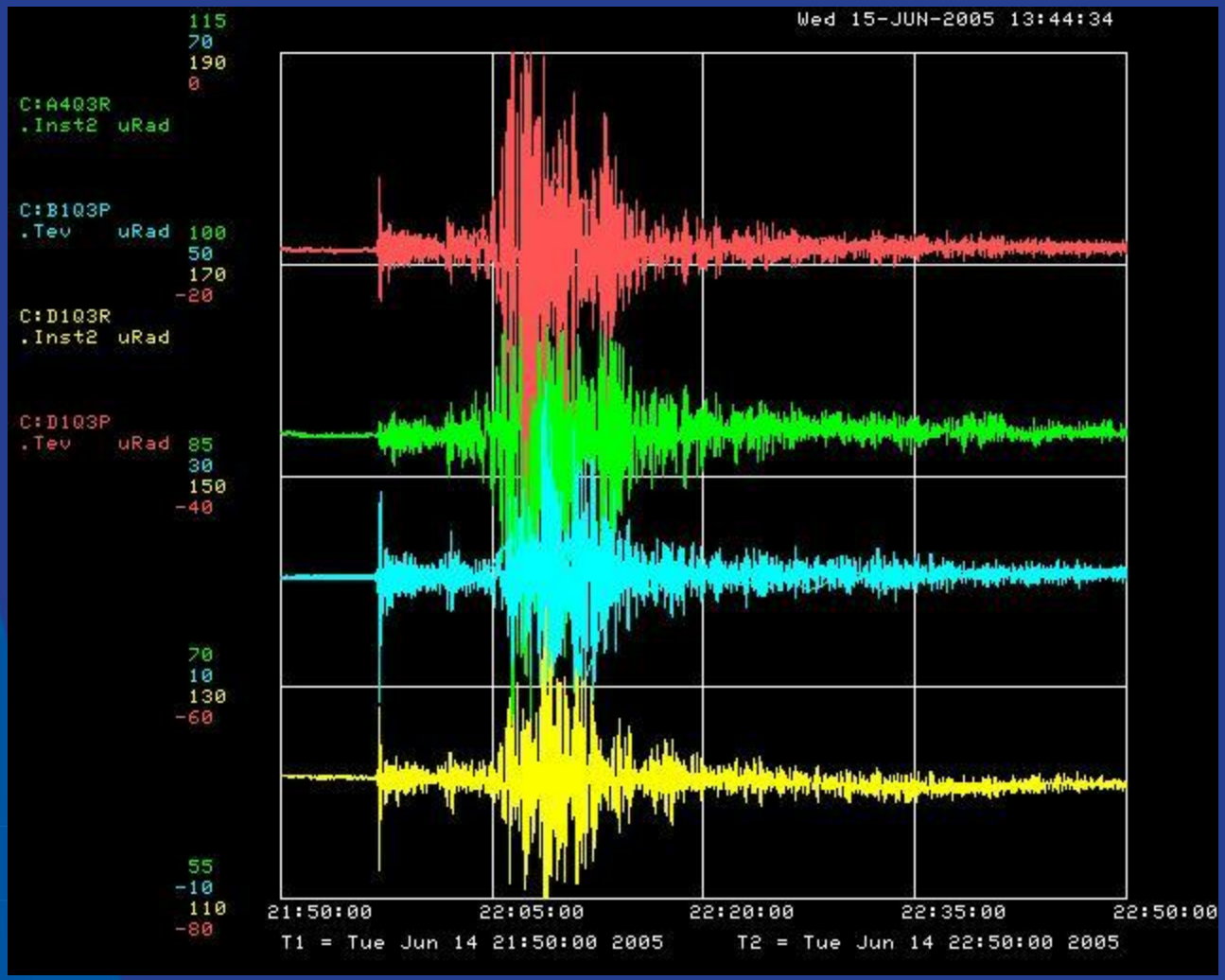


Mother Nature… Our worst enemy!

Very sensitive to lightning

Missing one line cycle would cause a beam abort and subsequent loss of the store. 21μs per rev.

Earthquake detector too!



California earthquake in 2005

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NFPA-70E…

- Sins of the father!
  - Panels are almost all legacy from the beginning of the lab.
    - Continuous battle finding spares.
      - Often only option is to replace entire panel (or switch gear).
  - Currently have:
    - 1142 panels documented in Accel. Div.
    - 600 panels documented in Particle Physics
    - 300 panels documented in Computing Division.
  - And many more yet to be done for arc-flash calculations!

5 KV 1200 Amp Breaker

Motivational picture - Not at Fermilab

Residual Damage
Behind Where the Person was Standing

Residual Damage Above the Gear

40 Cal/cm^2 Arc Flash Suit

40 Cal/cm^2 Arc Flash Suit

Fermilab

40 Cal/cm^2 Arc Flash Suit

Individual spent a week in the hospital but survived!

Summary

- 40+ years of experience have shown us the best maintenance system for our use.
- Tracking and trending of failures can lead to a significant increase in “up time”.
- Changing manufacturers may mean learning the failure modes all over again and some may not be acceptable.
- Changing regulations can have a significant impact on maintenance activities
- Above all else… BE SAFE!

And that’s all for today!

- Questions?