Physics For Everyone
Future Accelerators

- Recent Times
- Why Do This?
- What's Up Next?
- http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf

Physics For Everyone
Future Accelerators

- Recent Times … But first some questions.
- Why Do This?
- What's Up Next?
- http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf

Behind the ...

www.VH1.com

SHOW AIRS: SUN 1/27 at 11pm ET

Behind the ...

www.fnal.gov

BEHIND THE SCIENCE

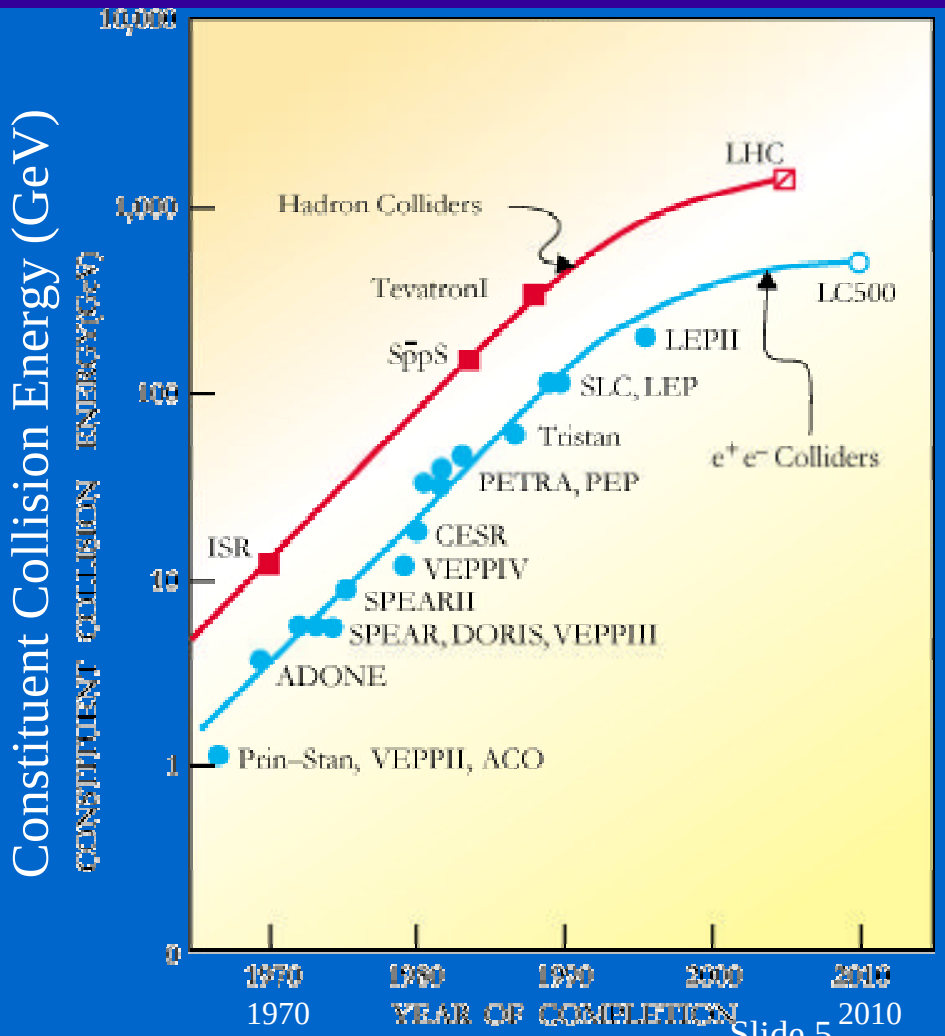
SHOW AIRS: TUE 5/7 at noon CT

Your Host: David Finley
finley@fnal.gov

http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf

Recent Times ...

- **Physics Today** January 2001
  - Maury Tigner (Cornell University)
- Comparing hadrons and leptons
  - Constituent hadron collision energy is about 1/10 of total hadron beam energies
  - Constituent lepton collision energy is all of total lepton beam energies
- Leveling off? … yes … why?
  - It's a fact of life if you keep using the same concepts and evolve with the same basic technology



Year of Collisions

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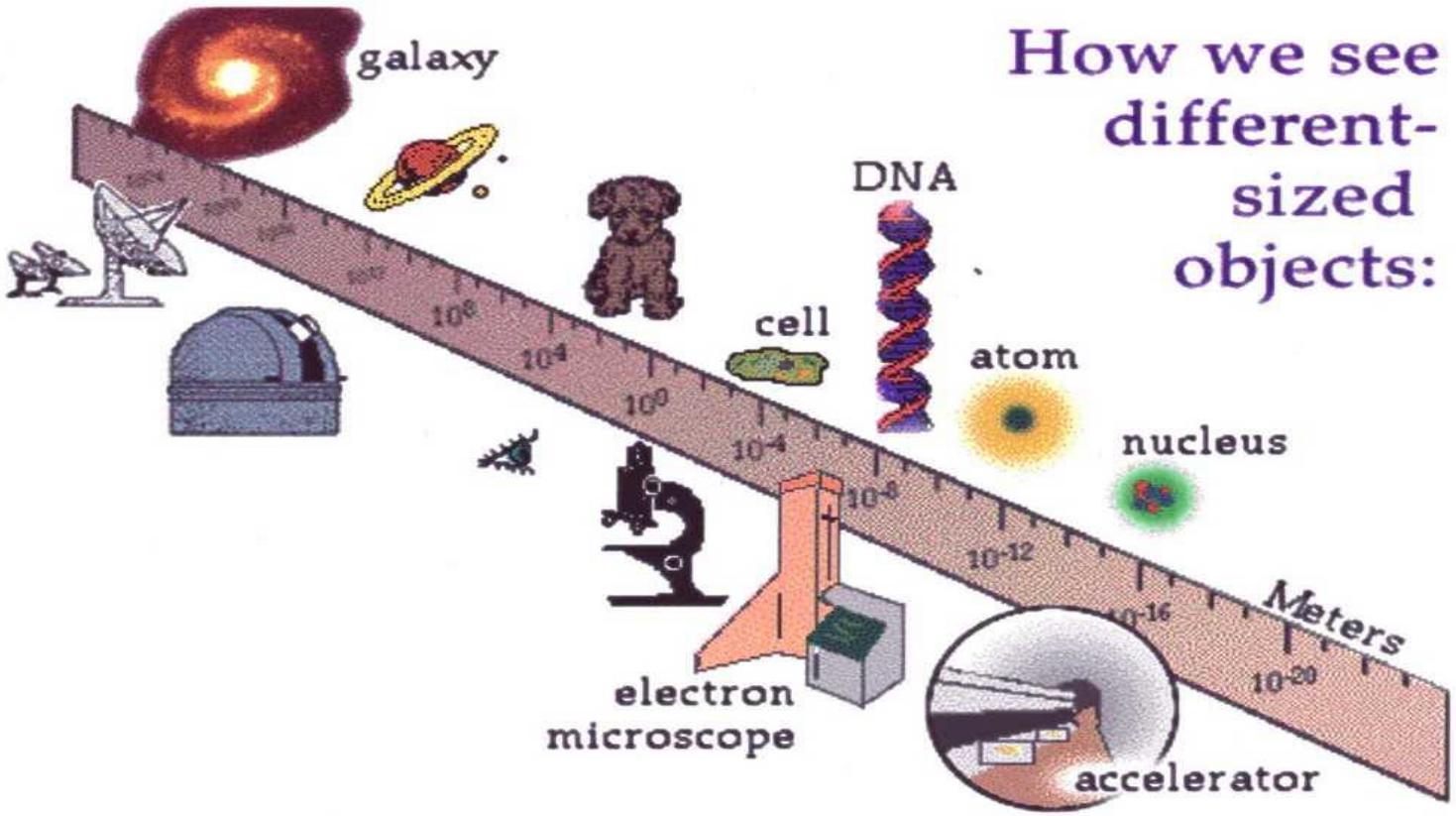
Accelerators - What are they good for?

- Why do this? This = “particle physics”
  - Q1: What’s it all made of?
  - Q2: How does it all behave?
  - Q3: How do particles come by their mass?
  - Q4: How is it that we see more matter than antimatter?
  - And … Q4++
    - So, how is it all distributed anyway?
    - Etc etc



Courtesy E. Malamud malamud@fnal.gov

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Accelerators - What's Up Next?

- What Up Next?
  - electrons and positrons : e^+e^- Colliding Beams
  - protons and protons : pp Colliding Beams
  - muons and muons : $\mu^+ \mu^-$ Colliding Beams
  - neutrino beam : From decaying muons
- And Into The Beyond ...

e^+e^- Linear Colliders

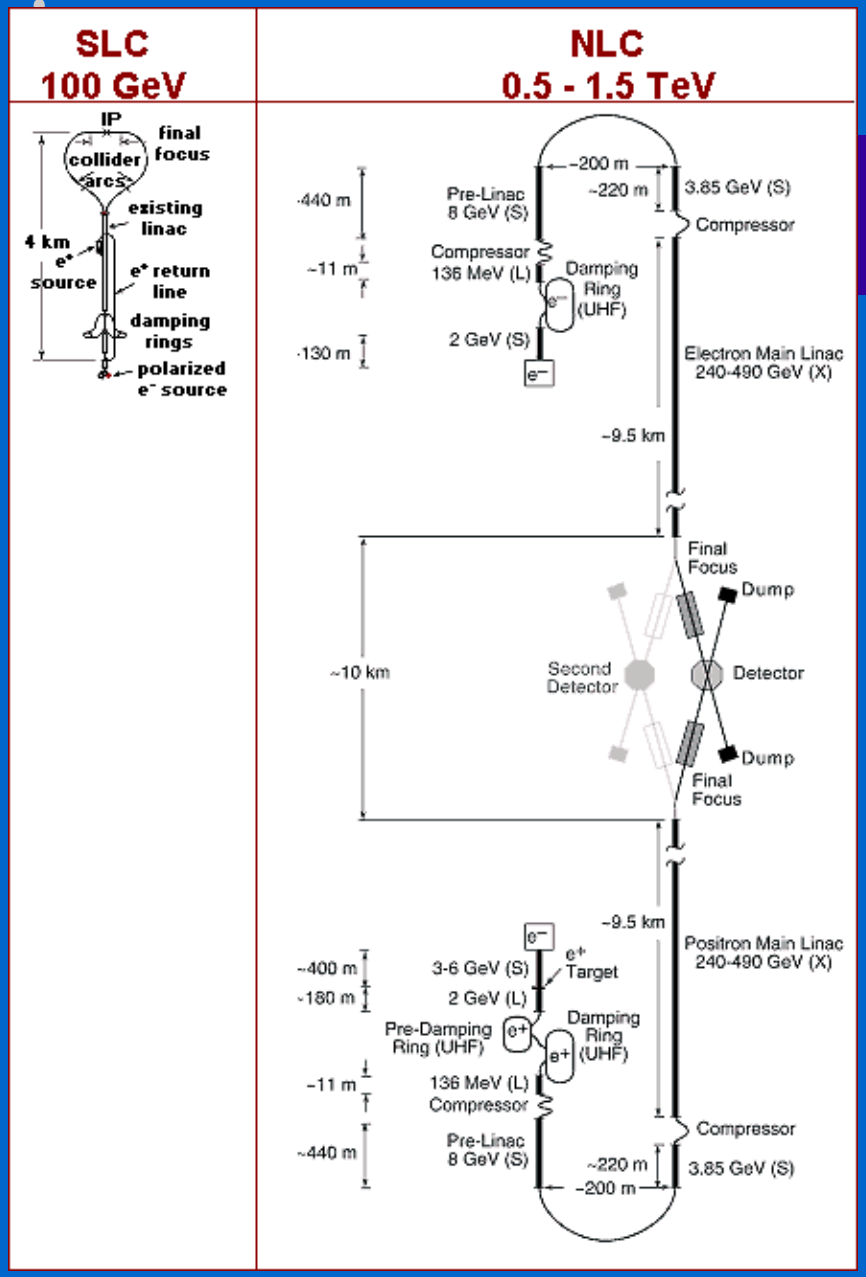
- The good new is:
  - The electron is a lepton
    - A point (so far as we can see)
    - Simple particles give simpler interactions
  - Precision tool (if you know where to look)
    - Q4: How is it that we see more matter than antimatter?
    - Q2: How does it all behave?
- The bad new is:
  - Not much mass …
    - electrons radiate photons like crazy when you deflect them
    - (This is a good thing at Argonne for its synchrotron light source … but a bad thing for e^+ e^-)

Linear Collider At Fermilab !

Fermilab's Director Mike Witherell stated in his June 12, 2001 presentation to the DOE/NSF HEPAP subpanel:

- "We propose to the U.S. and to the international HEP community that we work together to build a linear collider at or near the Fermilab site."

http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf



- The NLC is an e+e- Option.

(NLC = Next Linear Collider)

Two straight accelerators about 10 km long each providing 250 GeV beams.

- Several smaller (and rather complicated) accelerators and devices to feed them … 2 GeV, 3-6 GeV, positron target, 3.85 GeV, damping rings, compressors

- A pair of final focus lines, a detector, and a beam dump.

- Total Length = about 30 km.

(SLC = SLAC Linear Collider)

(SLAC = Stanford Linear Accelerator Center)

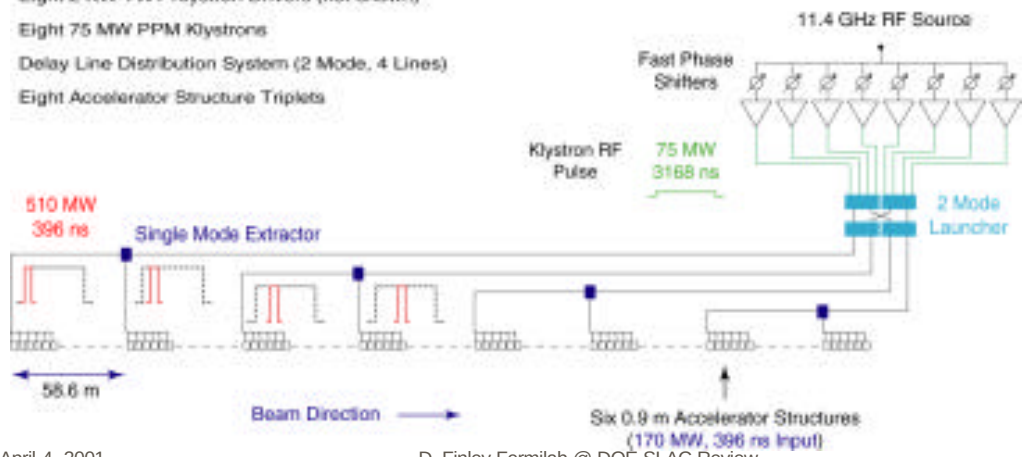
Schematic of NLC RF Test

ETF (Engineering Test Facility)

- March 2001 Version shown
- About 400 meters long
- 6 RDDS 0.9 m structures per girder shown
- Tests Power Sources. DLDS. Structures

NLC Linac RF Unit

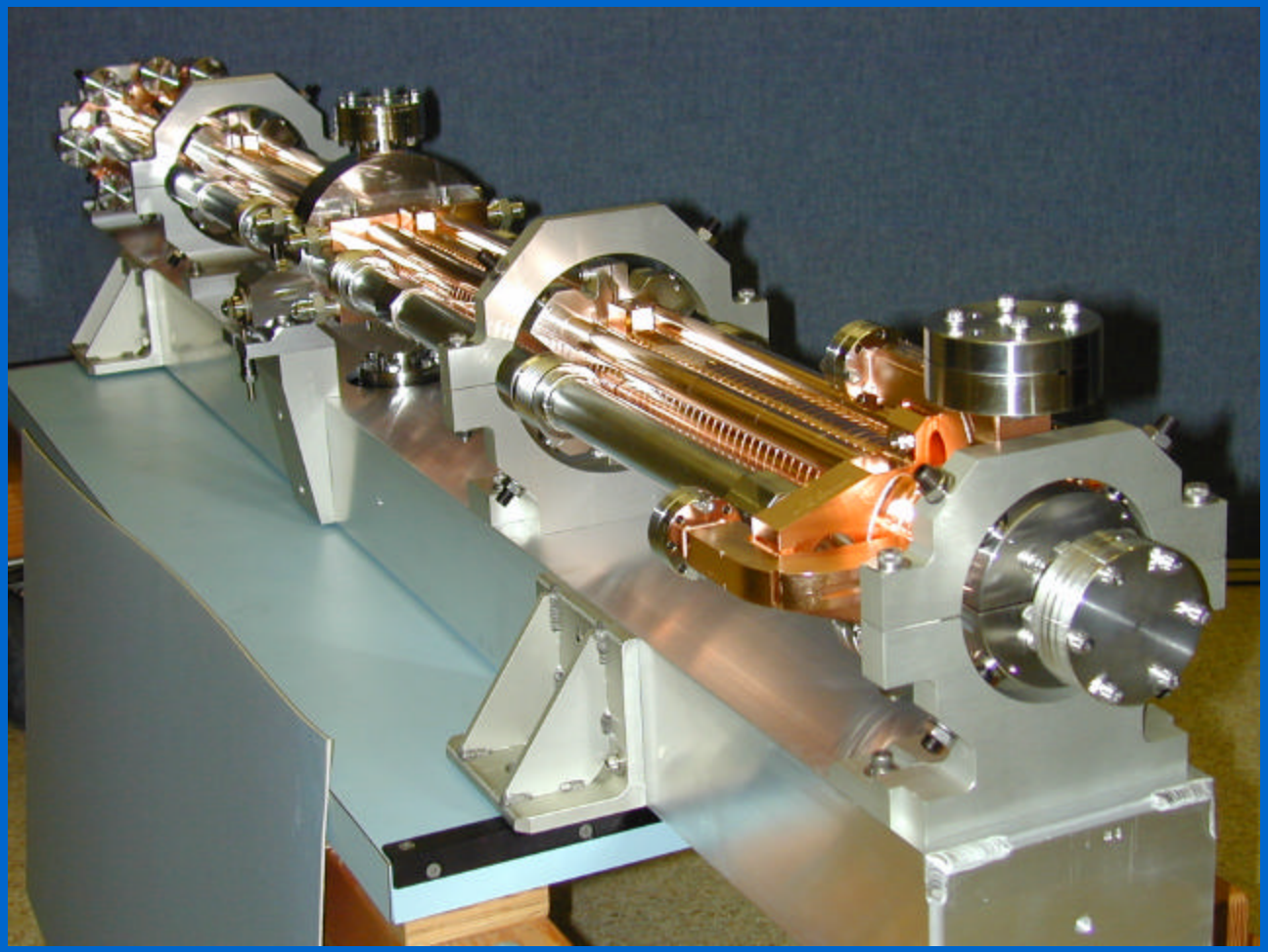
Low Level RF System
One 490 kV 3-Turn Induction Modulator (not shown)
Eight 2 KW TWT Klystron Drivers (not shown)
Eight 75 MW PPM Klystrons
Delay Line Distribution System (2 Mode, 4 Lines)
Eight Accelerator Structure Triplets



April 4, 2001 D. Finley Fermilab @ DOE SLAC Review 3

Fermilab is developing a long term plan for performing this test in a refurbished fixed target beam enclosure …

1.8 meter long NLC RF structure

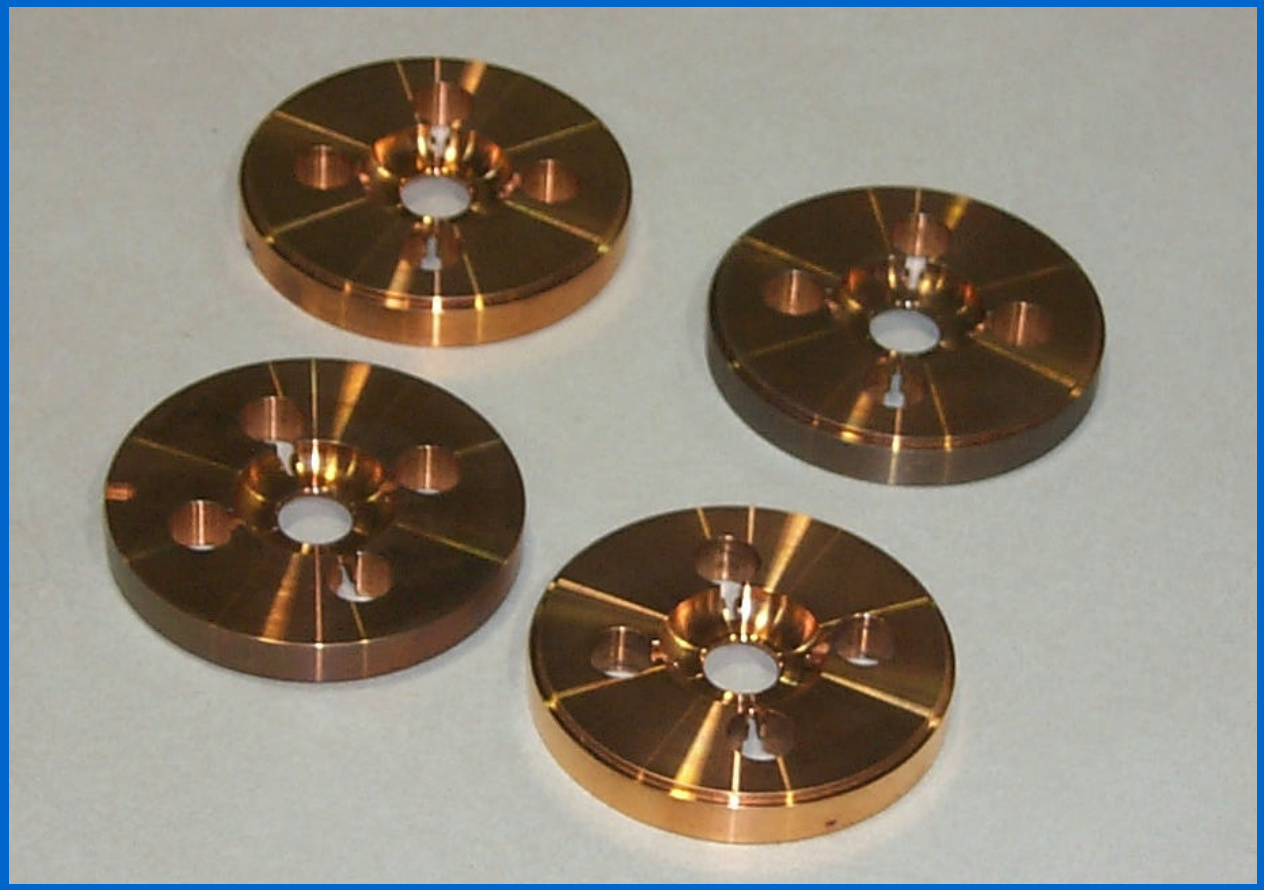


Made by the KEK lab in Japan and tested at the SLAC lab in California

Each structure has 206 disks … see next slide

NLC RF copper disks

Each disk has a 61 mm outer diameter and 8 mm thickness.



The electron or positron beam goes through the center hole and unwanted energy is taken away in the four side channels.

NLC R&D STATUS

Structures Fabrication

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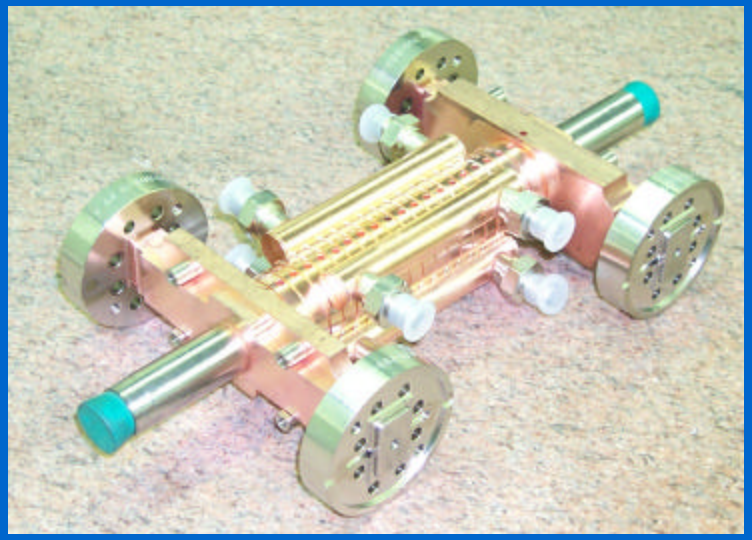


FXA-001

Technical Division

Small furnace and clean room B

Sounds Great …But …

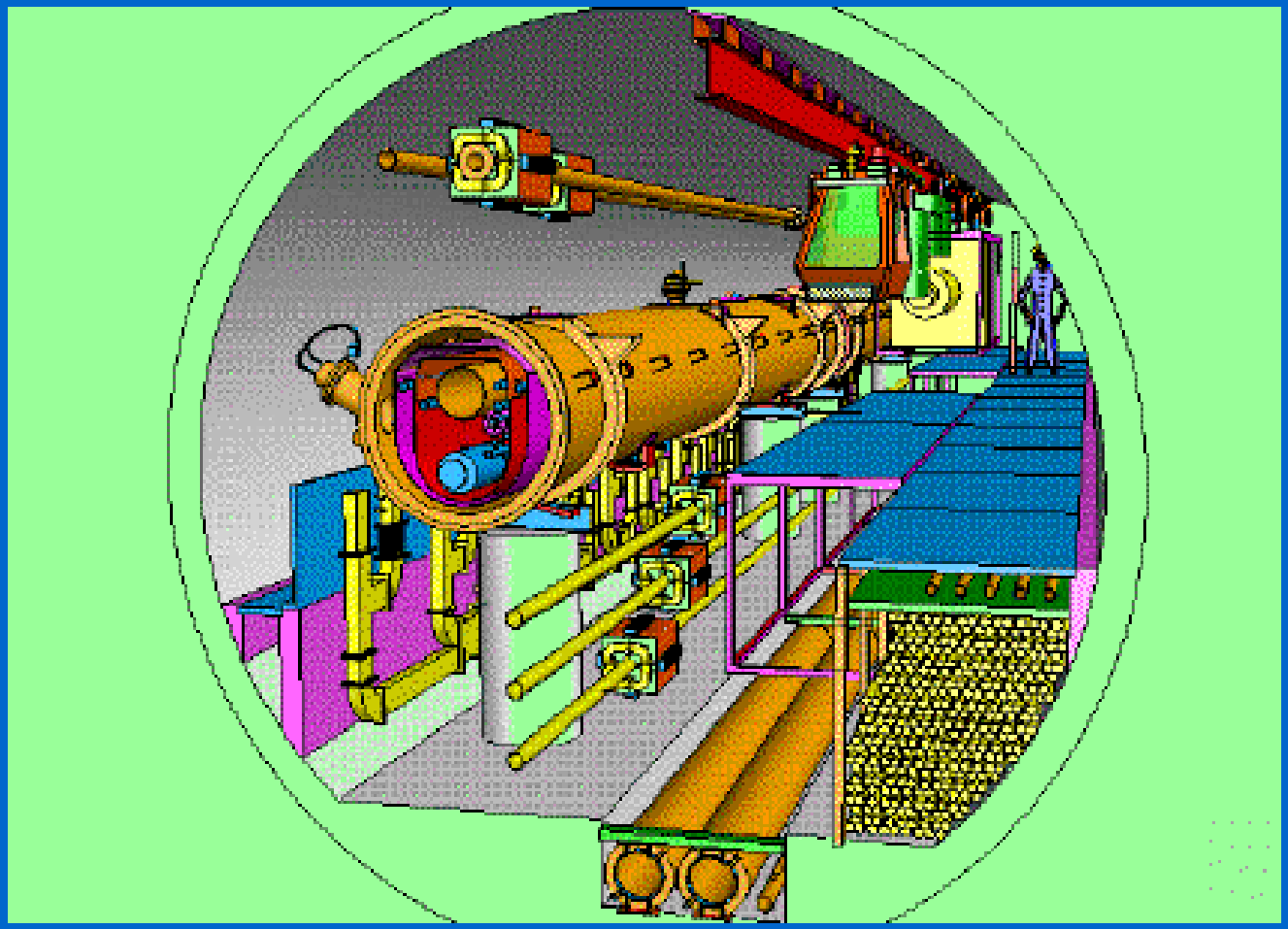
- The 1.8 meter long structure does not work.
- The components for the RF power distribution system have never been tested.
- You need a million precision machined disks just to get to 250 GeV beam energy … and make 10,000 structures.

- Getting the energy is one thing … but getting luminosity, reliability, lots of data, and good data are just as important and even more challenging.

- This is NOT easy … but so what? The easy things are already done.

TESLA from DESY is an e^+e^- Option

(TESLA = TEv Superconcucting Linear Accelerator)



The DESY lab has proposed an e+e- collider.

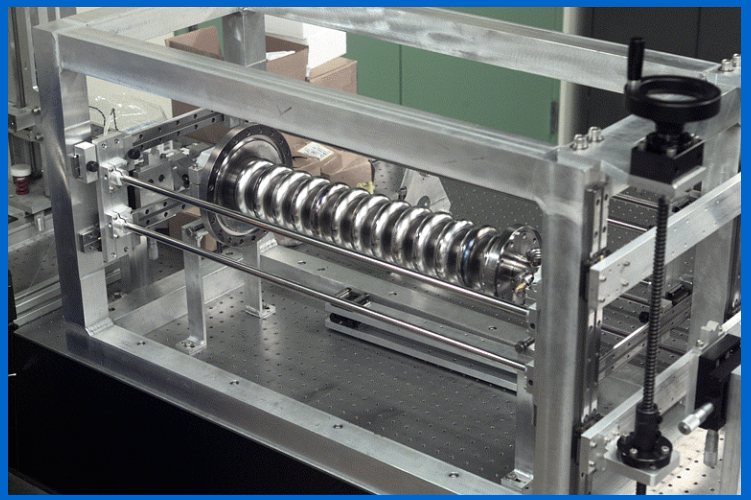
The accelerator is made of superconducting rf cavities.

The tunnel is about 5 meters in diameter.

Superconducting RF … at Fermilab!

Measurement of CP violation in $K^+ \rightarrow \pi^+ \upsilon\upsilon$ (fixed target experiment E921) requires a few 10^{14} K^+

We will create a pure K^+ beam with ~ 6 meters of SCRF cavities operating at 3.9GHz in TM_{110} at 5MV/m P_{TRANS}



13 cell prototype cavity

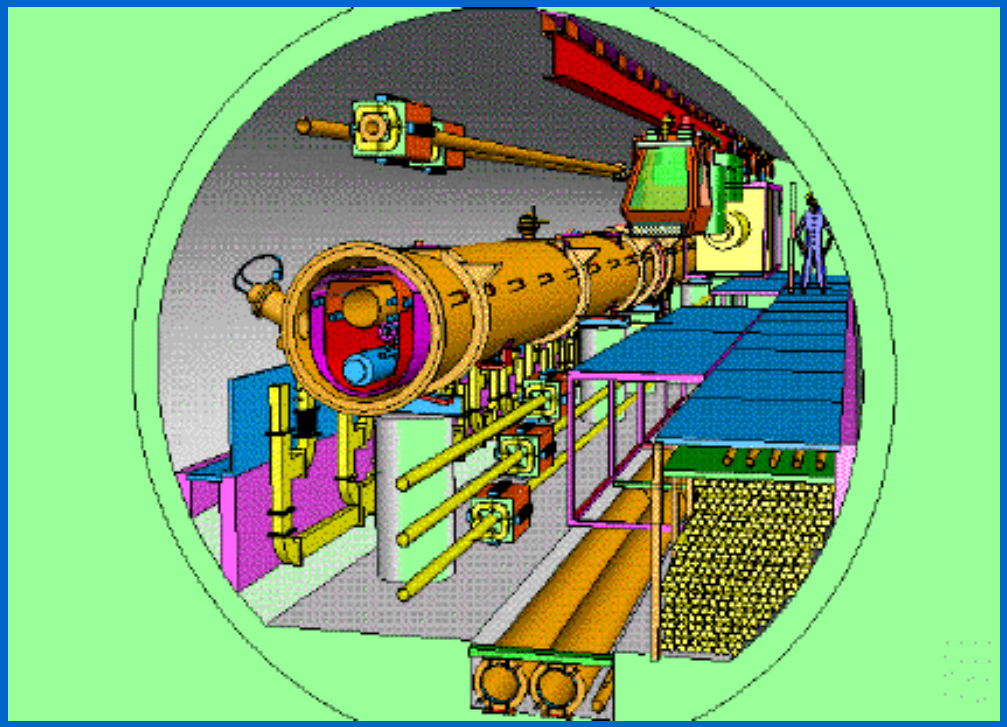
Nb shaped at FNAL, e-beam welded at nearby contractor, chemical and heat treatment for prototypes has been done at Jefferson Lab.

Beams Division and PPD

TESLA & NLC Tunnel Sketches

TESLA Main Linac Beam Enclosure.

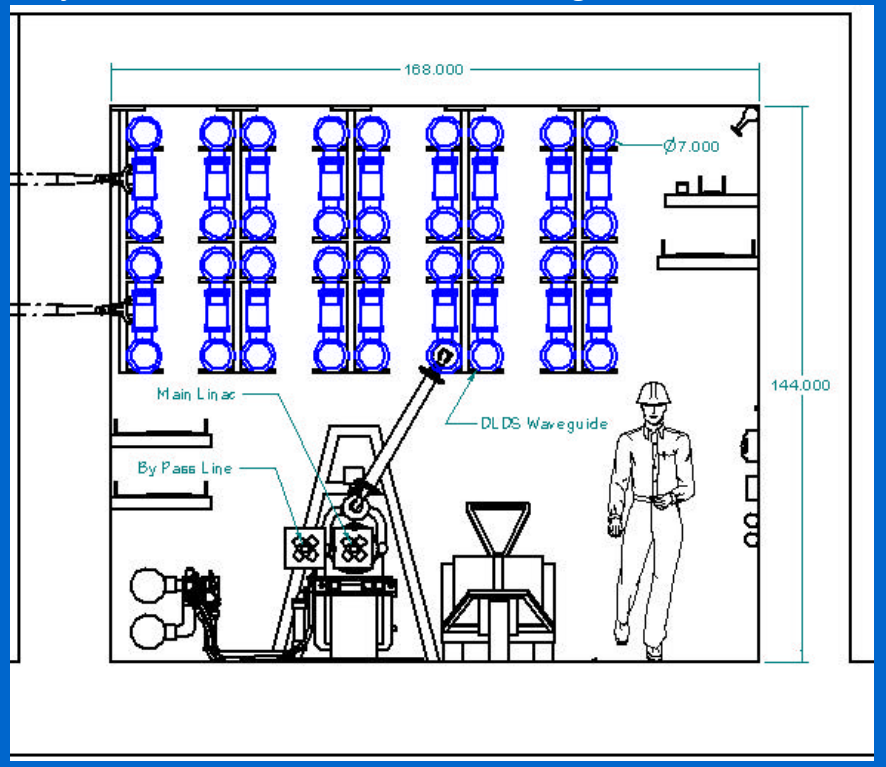
Modulator & refrigerator enclosures / buildings not shown.



Tunnel is 5.2 meter diameter

NLC Main Linac Beam Enclosure.

Klystron & modulator enclosures / buildings not shown.



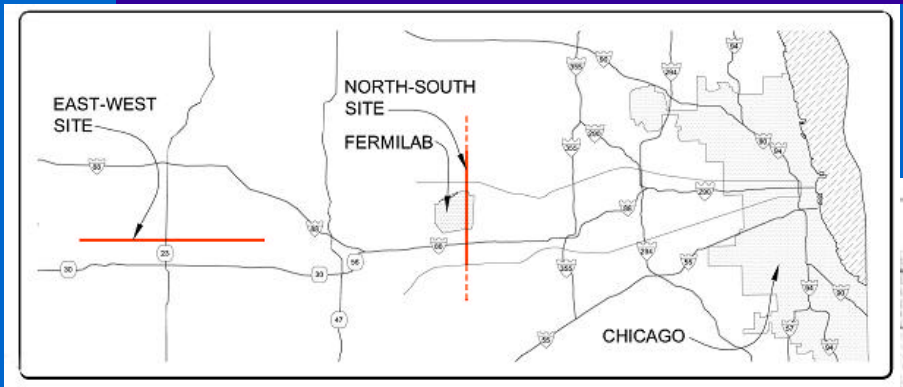
Tunnel is 12’ high and 14 ft wide (3.66 m x 4.27 m)

Which one?

The **U.S. is in a unique position** as the only region in the world in which the technology choice for a linear collider does not appear to be “locked in”.

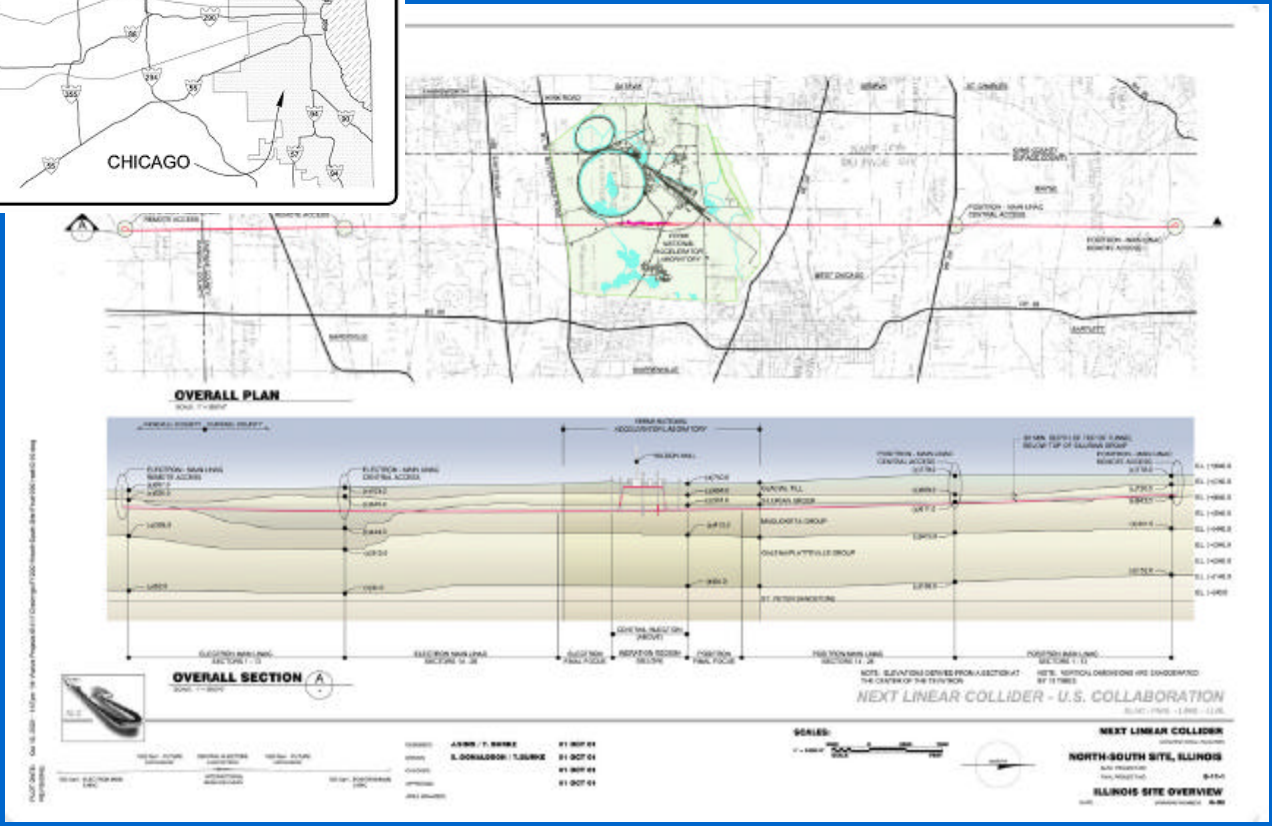
Furthermore, **Fermilab is in a unique position** as the only institution that is a member of both the NLC and TESLA Collaborations.

Linear Collider Site Studies
"at or near" Fermilab



NLC & TESLA look the same.

FESS and SLAC



Accelerators - What's Up Next?

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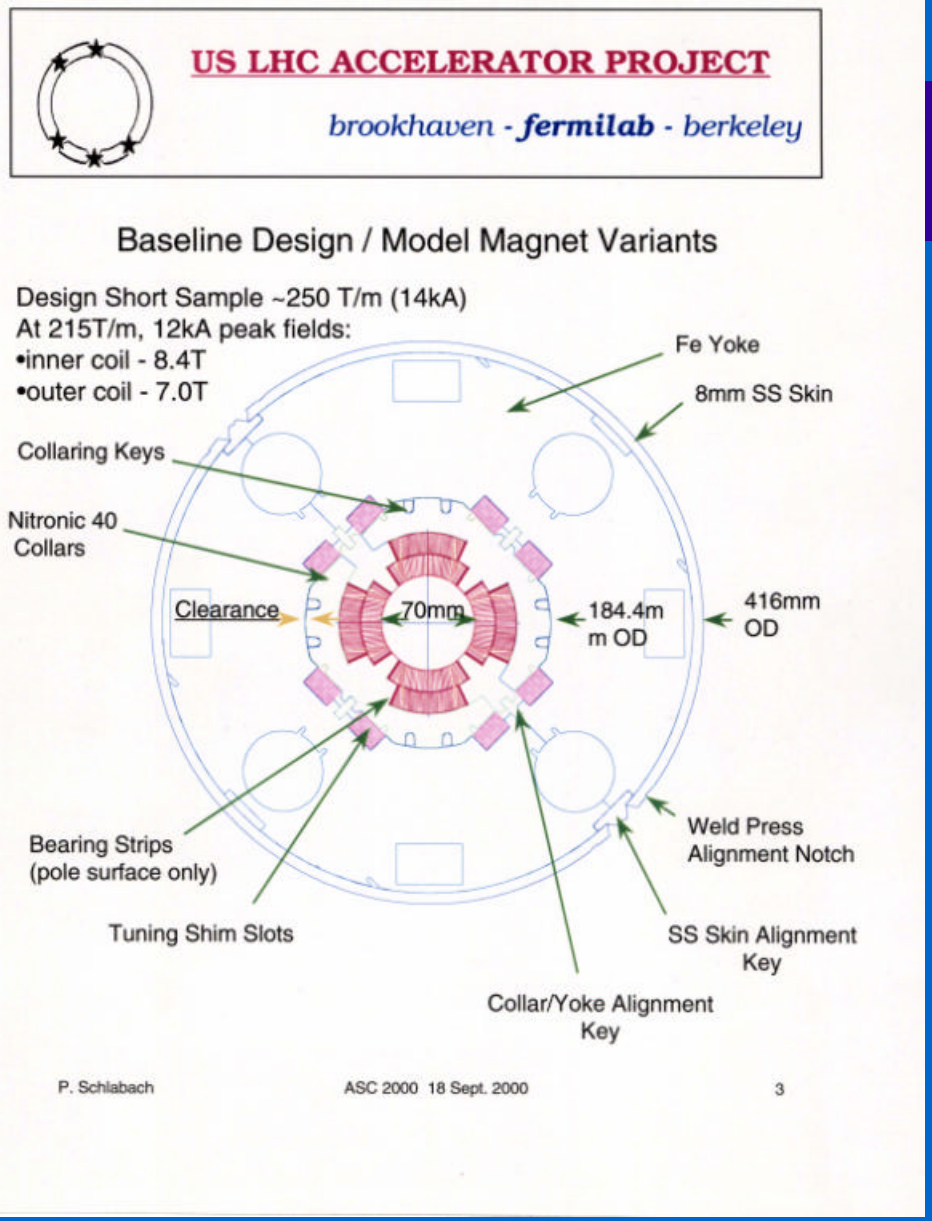
  - neutrino beam : From decaying muons
- And Into The Beyond ...

Protons on protons

- The good news is:
  - We know how to do this … standard techniques (at least compared to the other options)
  - This gives us the energy frontier
  - This is the path to discovery
    - Q1: What's it all made of?
    - Q2: How does it all behave?

- The bad news (if any) is:
  - It gets to be very large …(see later slide)
  - And some* say: "Wait for LHC results."

* "Some" include Directors of the world's HEP labs.



LHC IR Quadrupole Magnet (Cold Mass Only)

This technology pushes limits …

and thus it pushes costs.

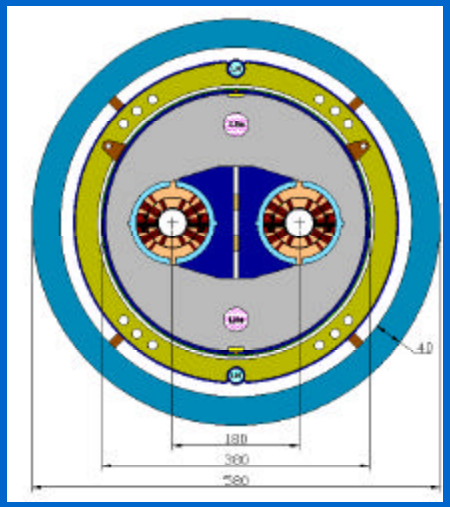
But it doesn't push beyond reality …

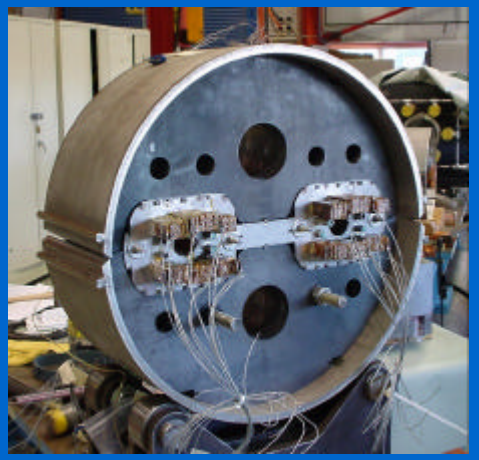
and thus it delivers.

Courtesy Jim Strait, Phil Schlabach et al in the Technical Division

Superconducting Magnet R&D
High Field

- This program is pursuing both cosθ and common coil designs. Both are based on Nb_3Sn.





- Objectives
  - 10-12 Tesla accelerator quality dipole field (Tevatron = 4.4 Tesla)
  - Minimize magnet size and cost

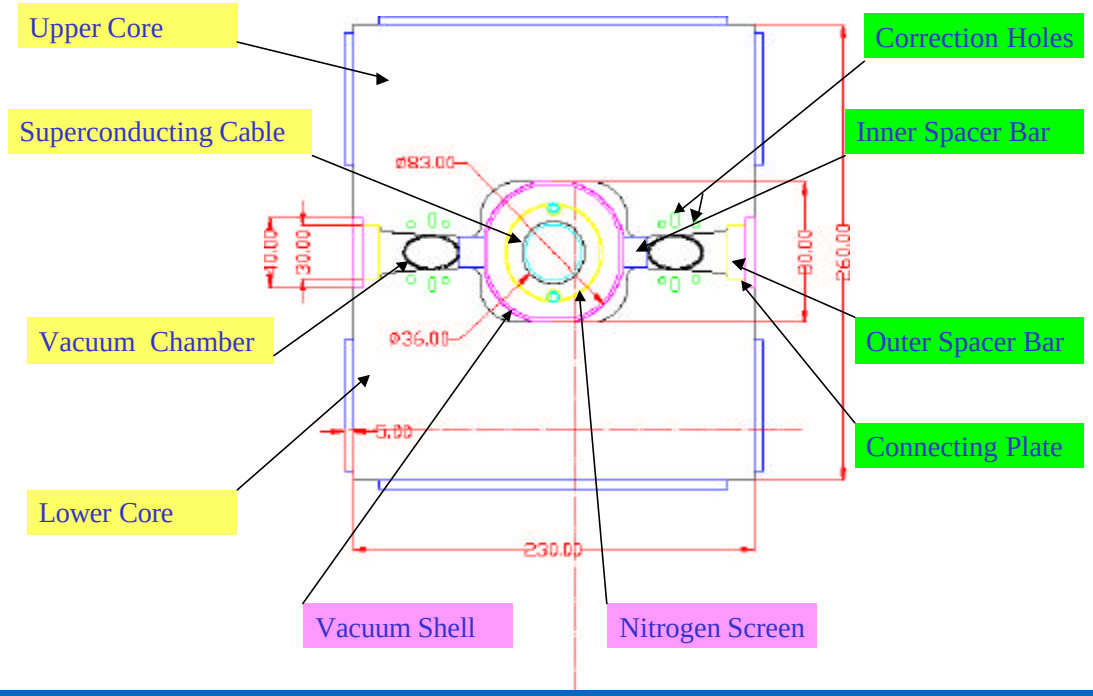
- Design approaches
  - cosθ vs. block type coils
  - low vs high current coils
  - vertical vs horizontal bore
  - cold vs warm iron yoke

Peter Limon and the Technical Division

VLHC - Low Field Option

(Very Large Hadron Collider)

Magnet Cross-section



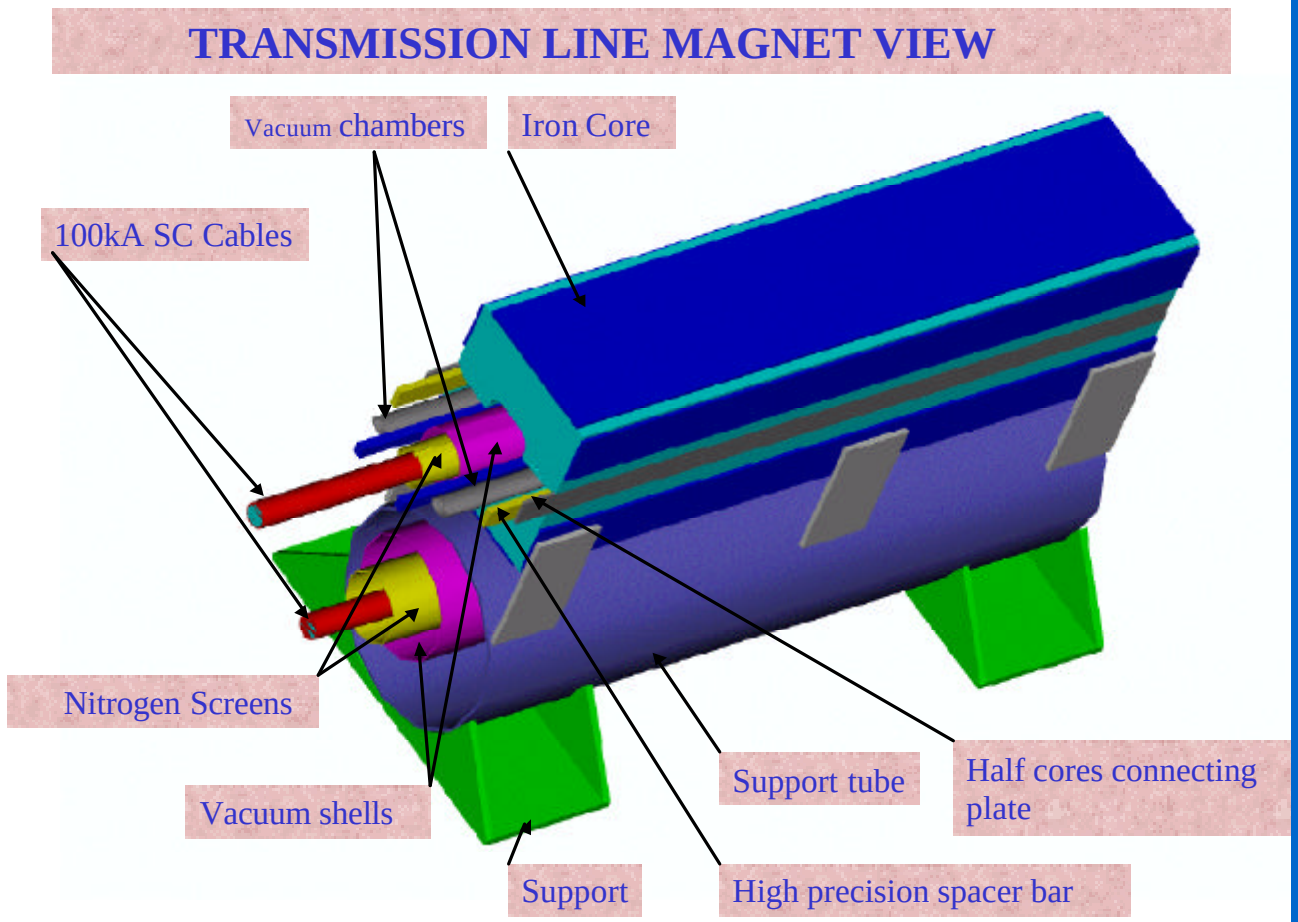
G. W. (Bill) Foster and V. Kashikhin May 2000

This approach does NOT push limits or costs (as much as high field).

It is a new and good idea.

But it does require a big tunnel to deliver.

VLHC - Low Field Option



G.W. Foster and V. Kashikhin

May 2000

Note: 100,000 Amps

VLHC - Low Field Option

Test Stand for the Field Measurement

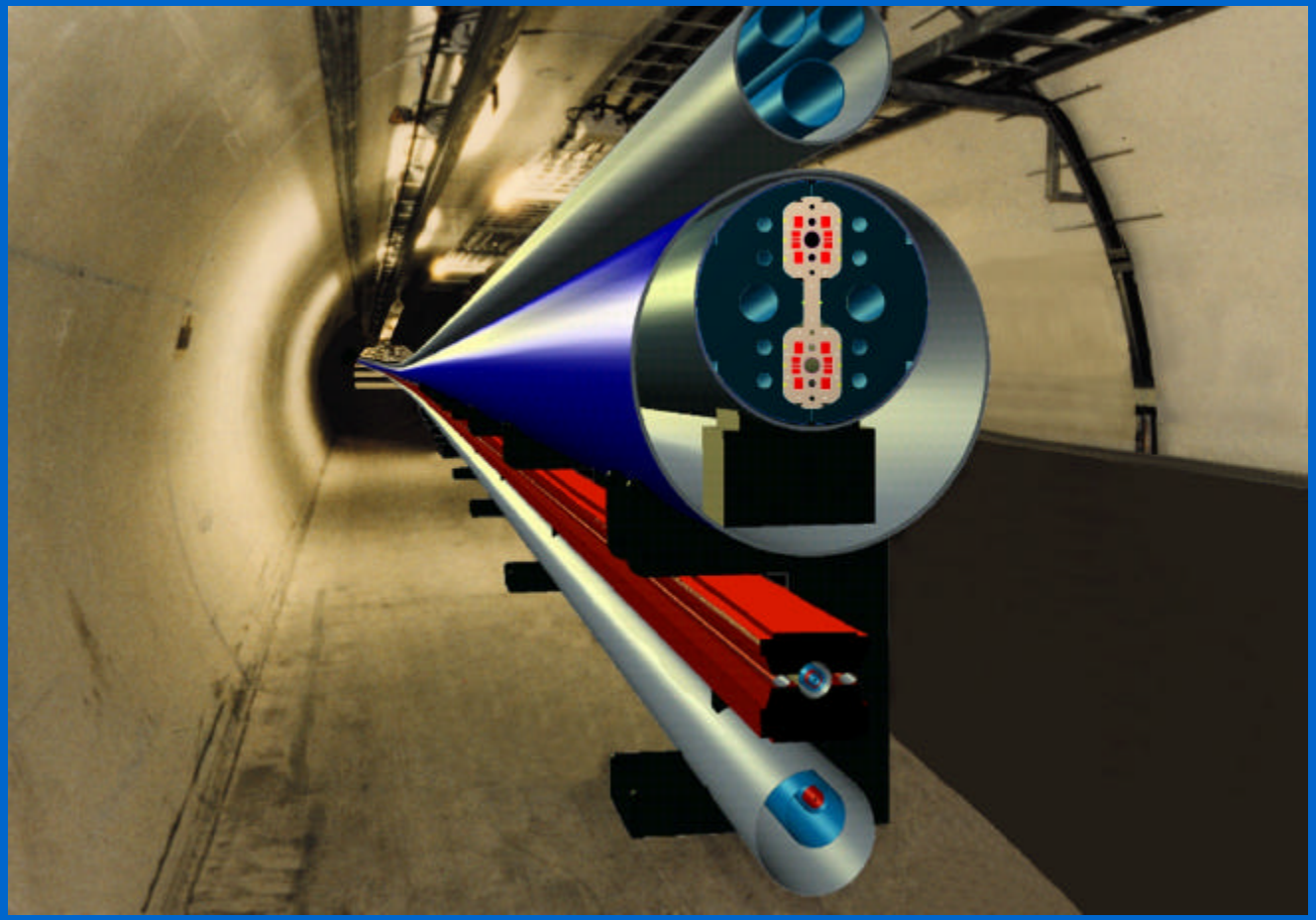
G.W. Foster and
V. Kashikhin

May 2000

They actually put 100,000 amps in it and it did <u>not</u> blow up.

A Tunnel Vision for the VLHC

Both high and low field options are shown in the LEP tunnel as an example.



The low field is on the bottom, the high field is on the top.

The tunnel is real and is about 12 feet in diameter.

http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf

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Circle shown on map is larger than latest design …

VLHC

Recall it is named “very large” for a good reason.

It would not really be “at Fermilab”.

Rather it would be under “Northern Illinois”

But the NuMI neutrino beam already will go from Fermilab to northern Minnesota.

(Yes, under Wisconsin!).

Courtesy E. Malamud
malamud@fnal.gov

Accelerators - What's Up Next?

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Muons on Muons

- The good news is:
  - Just another simple lepton … just like the electron
  - But heavier than the electron
    - They don't radiate photons like crazy
    - They interact better (40,000 times better) with the Higgs
      - Q3: How do particles come by their mass?
- The bad news is:
  - They only stay around for 0.000 002 seconds (or so)
  - They spit out electrons … which then radiate like crazy
  - And they spit out neutrinos … hmmm …
  - Is this short lifetime so bad?
  - Can it be used to our advantage? >>> See next slides …

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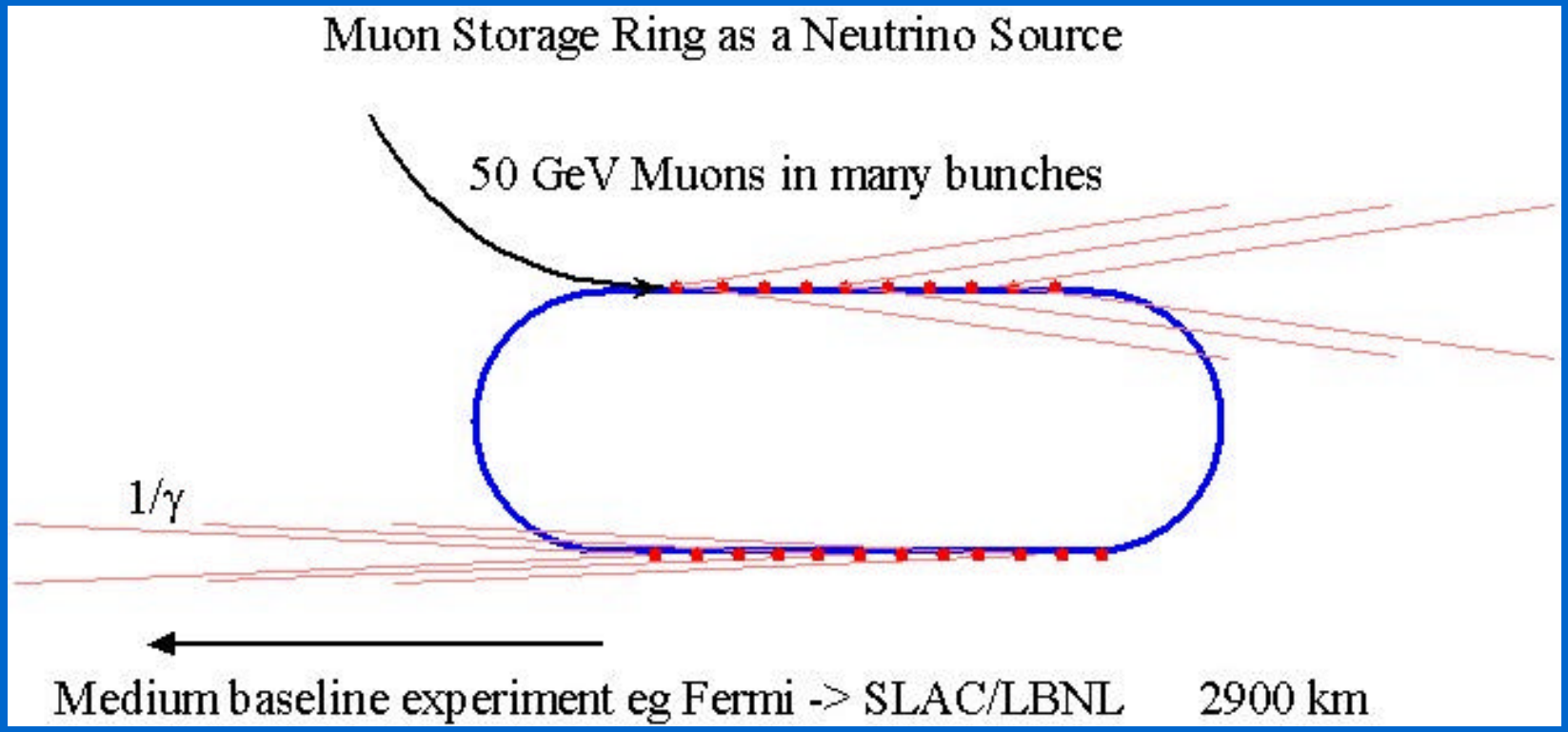
Neutrino Beam

- The good new is:
  - 100% of the muons decay to electrons and neutrinos
  - Never been done … surprises probably in store
    - Q1, Q2, Q3, Q4, Q4++
- The bad news is:
  - Not discovery, not simple … So, maybe not “interesting”?
- Aside: Really global-sized experiments

Neutrino Factory

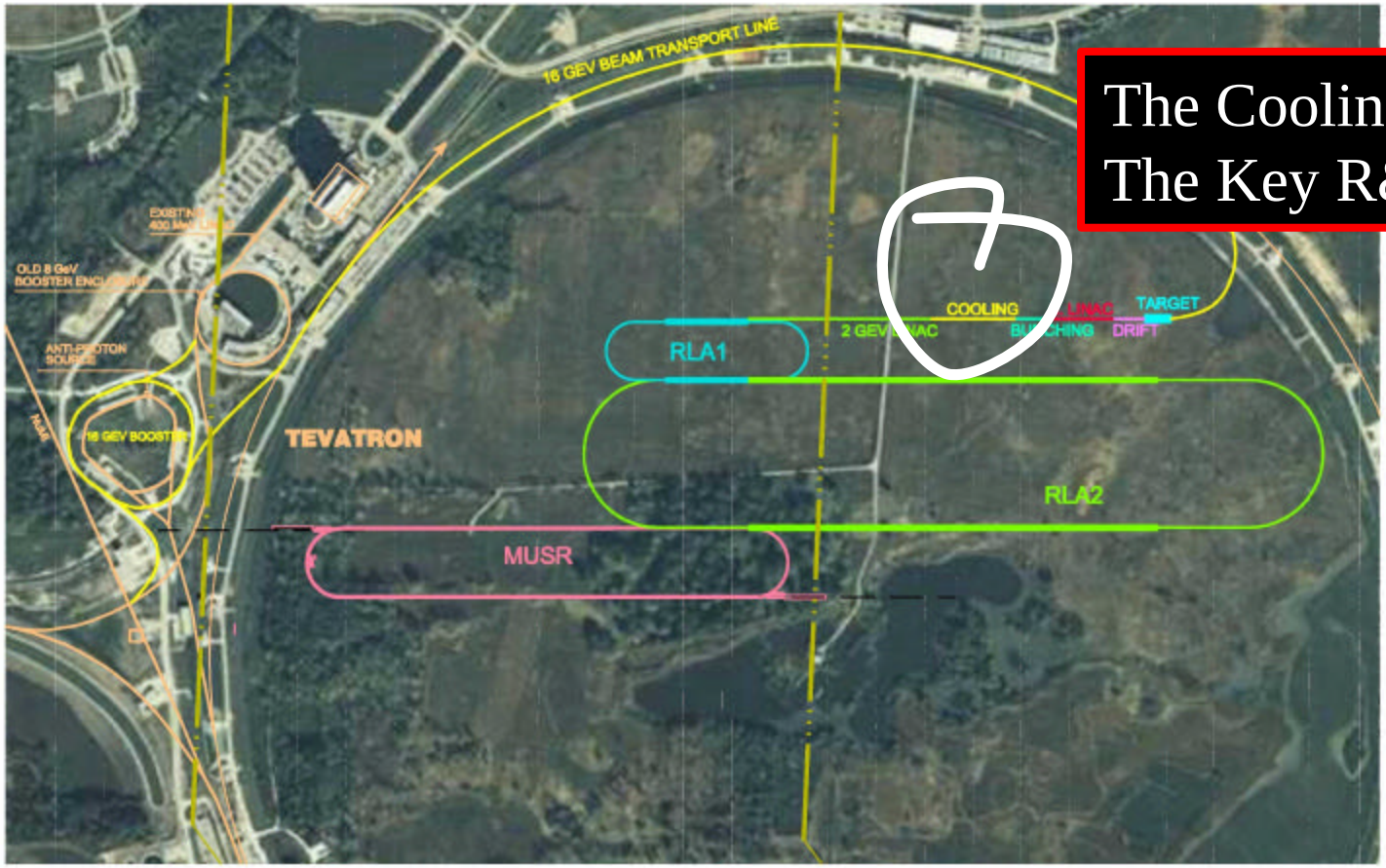
Concept a la Steve Geer / PPD



A Neutrino Factory at Fermilab

Norbert Holtkamp, David Finley / BD (at the time), Jeff Sims / FESS et al

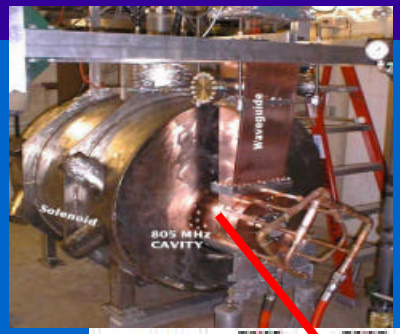
A Neutrino Factory at Fermilab

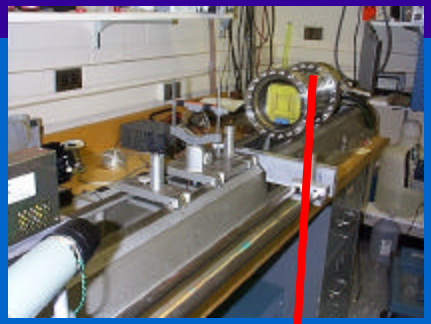


The Cooling is The Key R&D.

Muon Beam R&D
MUCOOL Accomplishments

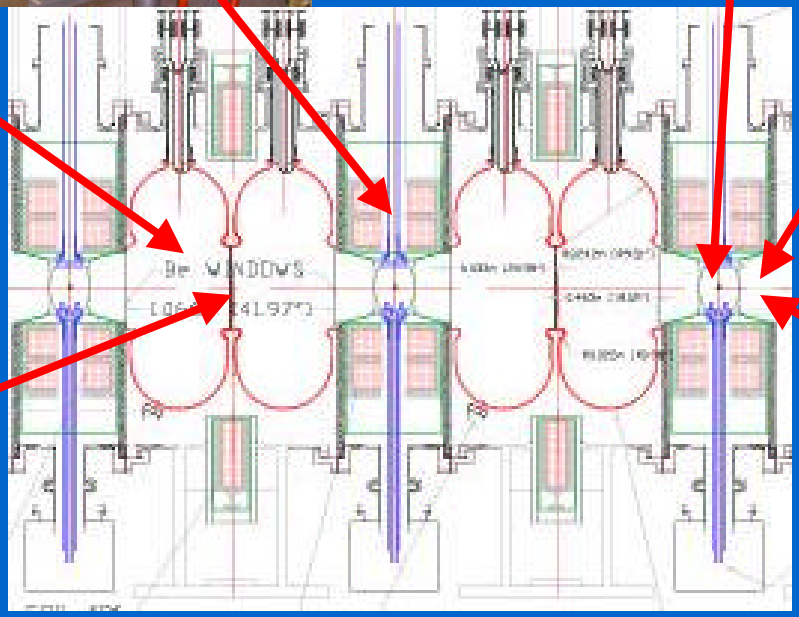
5T Cooling Channel Solenoid – LBNL & Open Cell NCRF Cavity operated at Lab G – FNAL



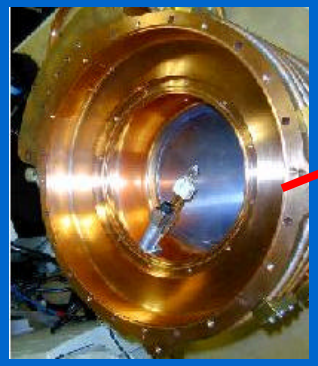


Bolometer detectors for Window Beam profile Measurements– U. Chicago

High-Gradient RF Tests in High Magnetic Field – FNAL



Liq.H Absorber – KEK To be tested at FNAL



Tested Be-Windows for RF Cavities -- LBNL May 7, 2002

Liq. H RF Liq. H RF Liq. H

Thin absorber windows Tested – new technique – ICAR Universities

Muon Beam R&D

MUCOOL Test Facility

MUCOOL Test Facility at end of Fermilab 400 MeV Linac

- Fill Liq. H absorbers: U.S. prototype & Japanese prototype
- High-Power tests of 201 MHz & 805 MHz Cavities
- Full engineering test of Absorber – Cavity –Solenoid system
- Development of new beam diagnostics
- Eventual engineering test in high-intensity Linac beam

Longer term: Fully international (US-Europe-Japan) collaboration has been formed to propose a cooling demonstration experiment.

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  - neutrino beam : From decaying muons
- And Into The Beyond ...

And Into the Beyond ...

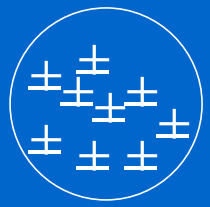
- The good news and the bad news is:
  - Hasn't been done before …
  - For good reasons, usually ...
- One example is Plasma acceleration
  - 100 TeV center of mass … and ...
  - All the equipment fits on the Fermilab site
  - But … it costs too much to operate …
  - Even if you can get it to accelerate to high energy …
  - At least … using today's ideas and technology
- But that's no reason to not do the R&D …

Plasma

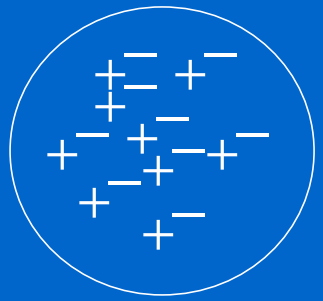
Ideal (but highly unstable)

But a terrific electric field!

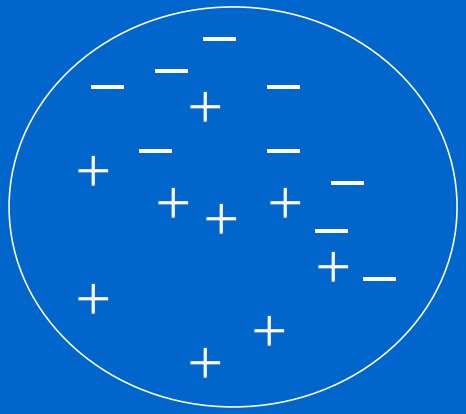
- How is it made?



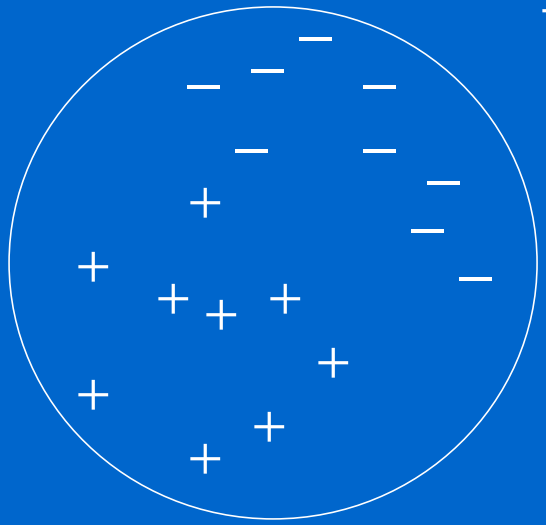
Start with Atoms



Pull Them …

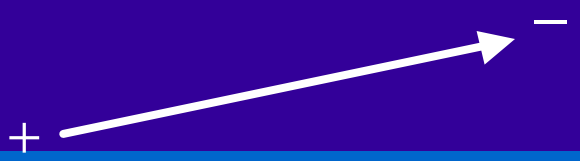


Pull Them …



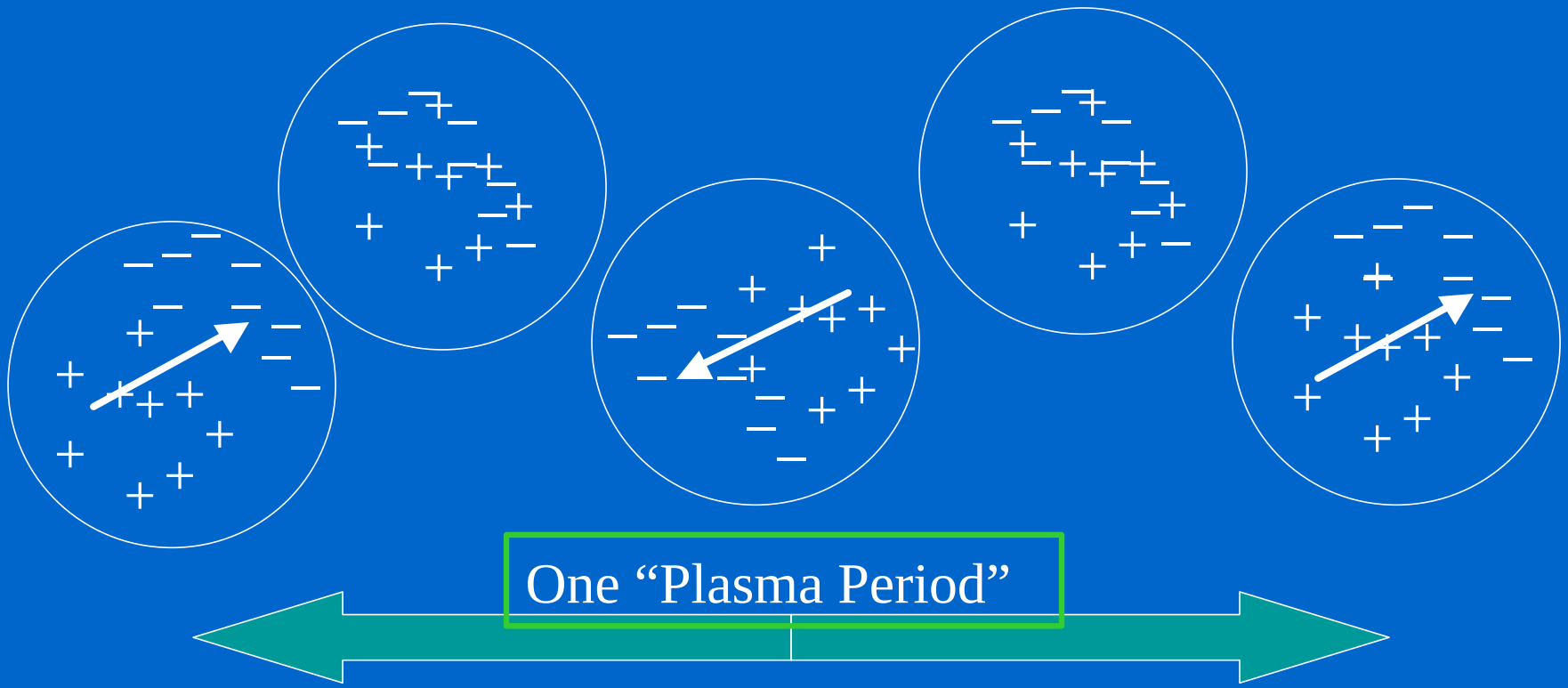
Pull Them Apart!

Plasma

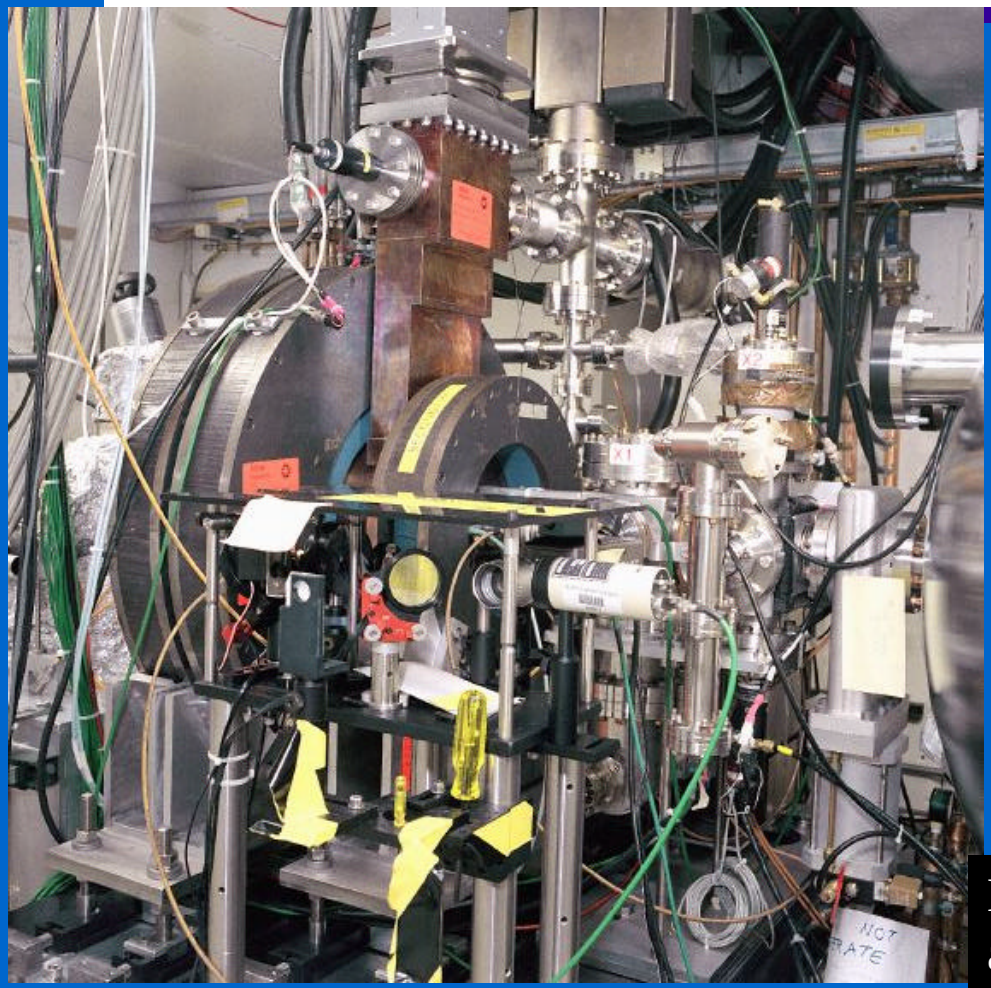


Electric Field

- How does it act?



Photoinjector at Fermilab



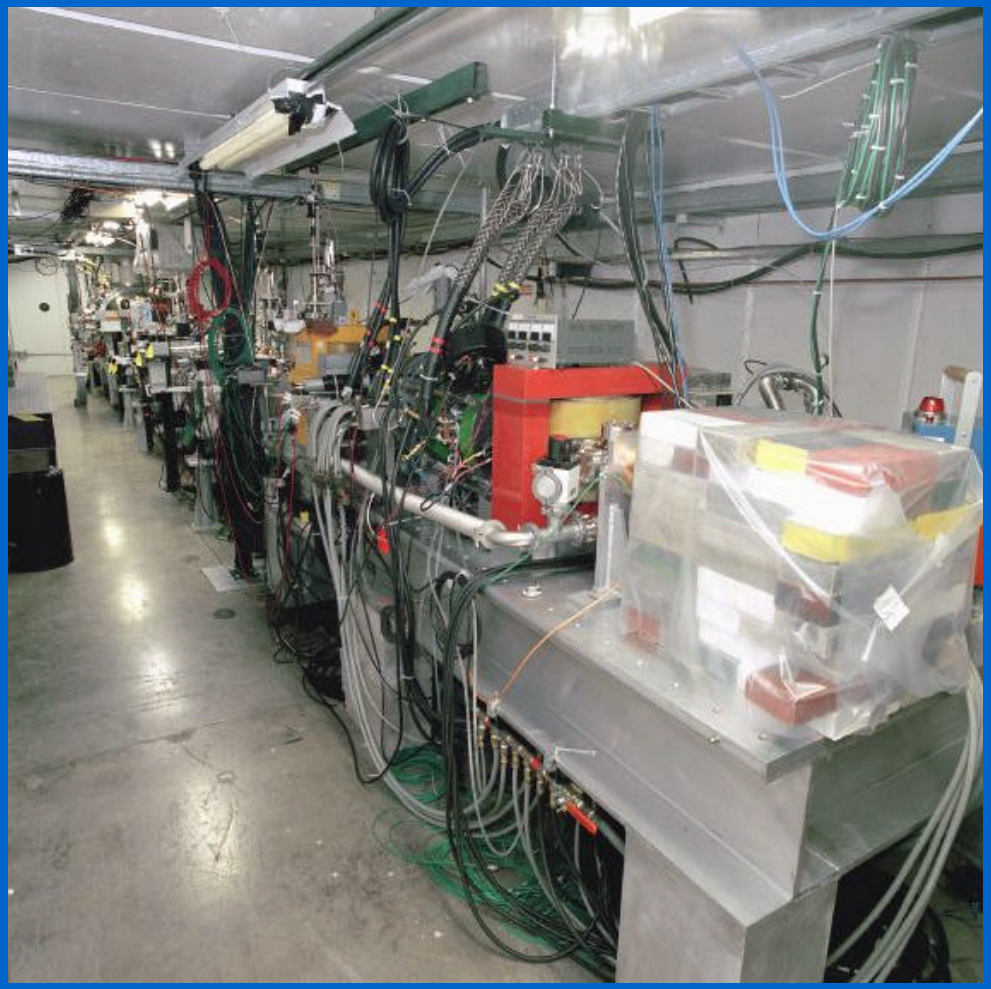
RF Gun and focussing solenoids

NIU (Northern Illinios University) is now heavily involved with this project … now known as FNPL

(Fermilab / NICADD Photoinjector Lab)

Helen Edwards et al / Beams Division and a host of others

Photoinjector at Fermilab



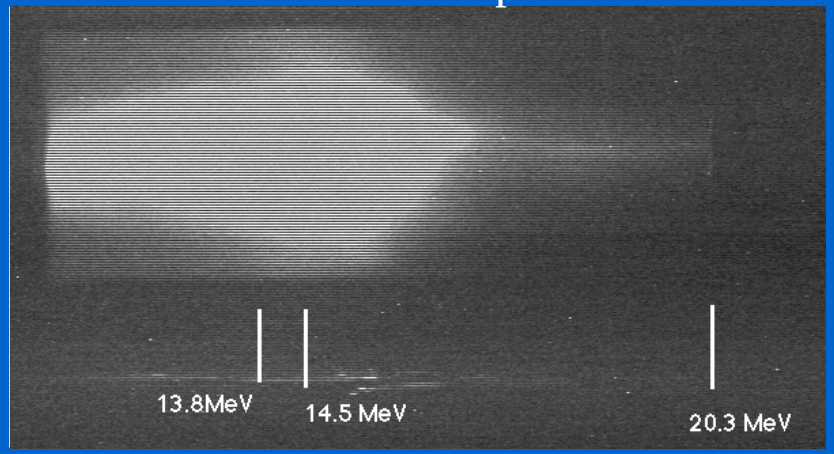
Spectrometer magnets, plasma chamber, and beam dump

http://www-ap.fnal.gov/A0PI/a0pics.html

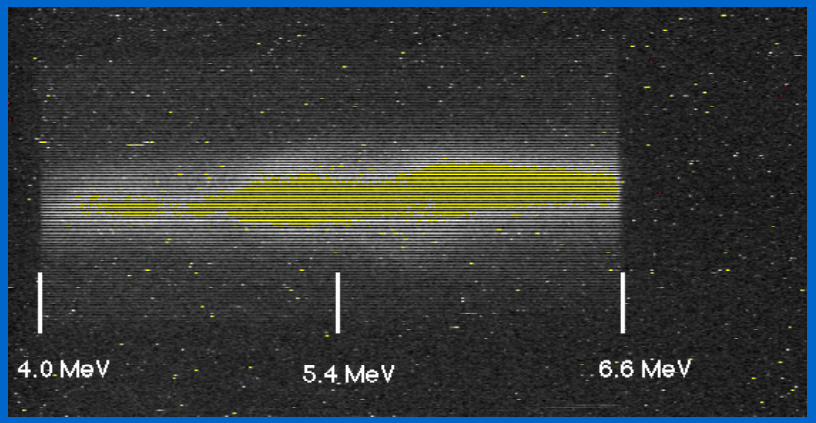
FNPL R&D

Plasma Acceleration Experiment

Accelerated electrons up to 20.3 MeV

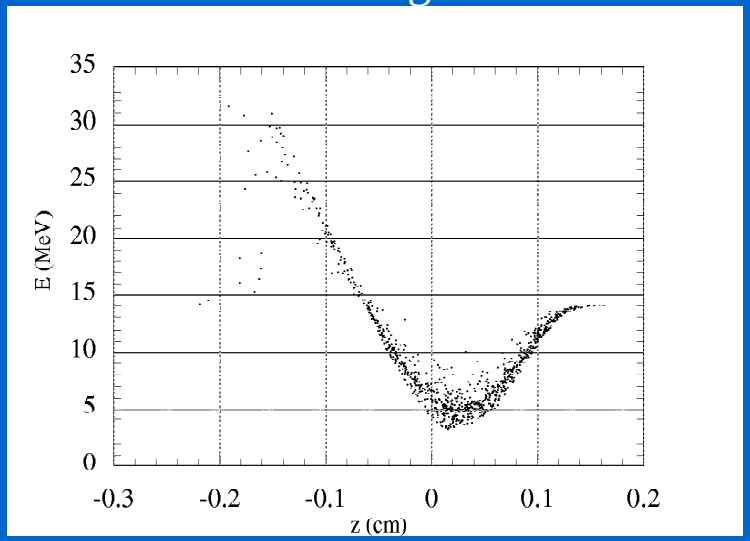


Decelerated electrons down to ~3 MeV:



Parameters:

- Charge: 6-8 nC
- Bunch length: < 1 mm RMS
- Plasma: L=8cm, 10^{14}/cc density
- Initial energy: 13.8 MeV
- Acceleration gradient: 72 MeV/m



Simulation result: final energy spectrum

Nick Barov / NIU et al

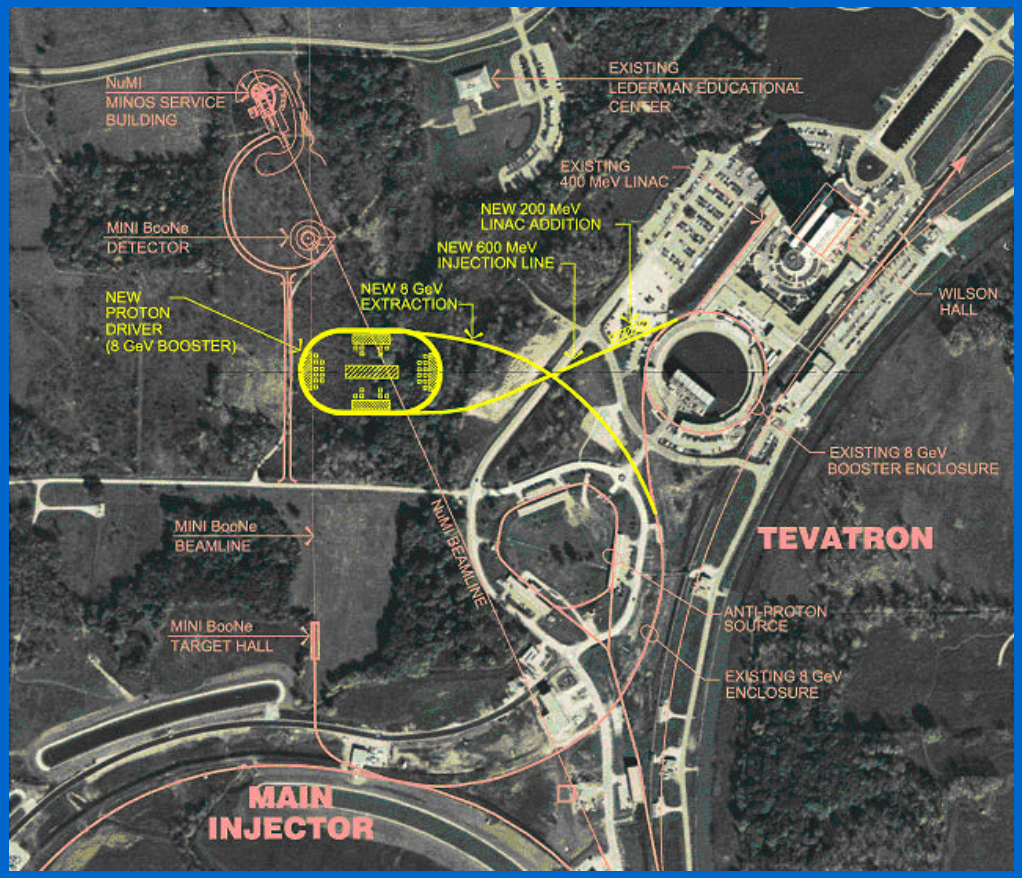
Accelerators - What's Up Next?

- What Up Next?
  - electrons and positrons : e^+e^- Colliding Beams
  - protons and protons : pp Colliding Beams
  - muons and muons : $\mu^+ \mu^-$ Colliding Beams
  - neutrino beam : From decaying muons
- And Into The Beyond ... And Back?

Proton Driver

The Proton Driver represents an option for development of the Fermilab complex in the event that a linear collider is not constructed in “at or near the Fermilab site”.

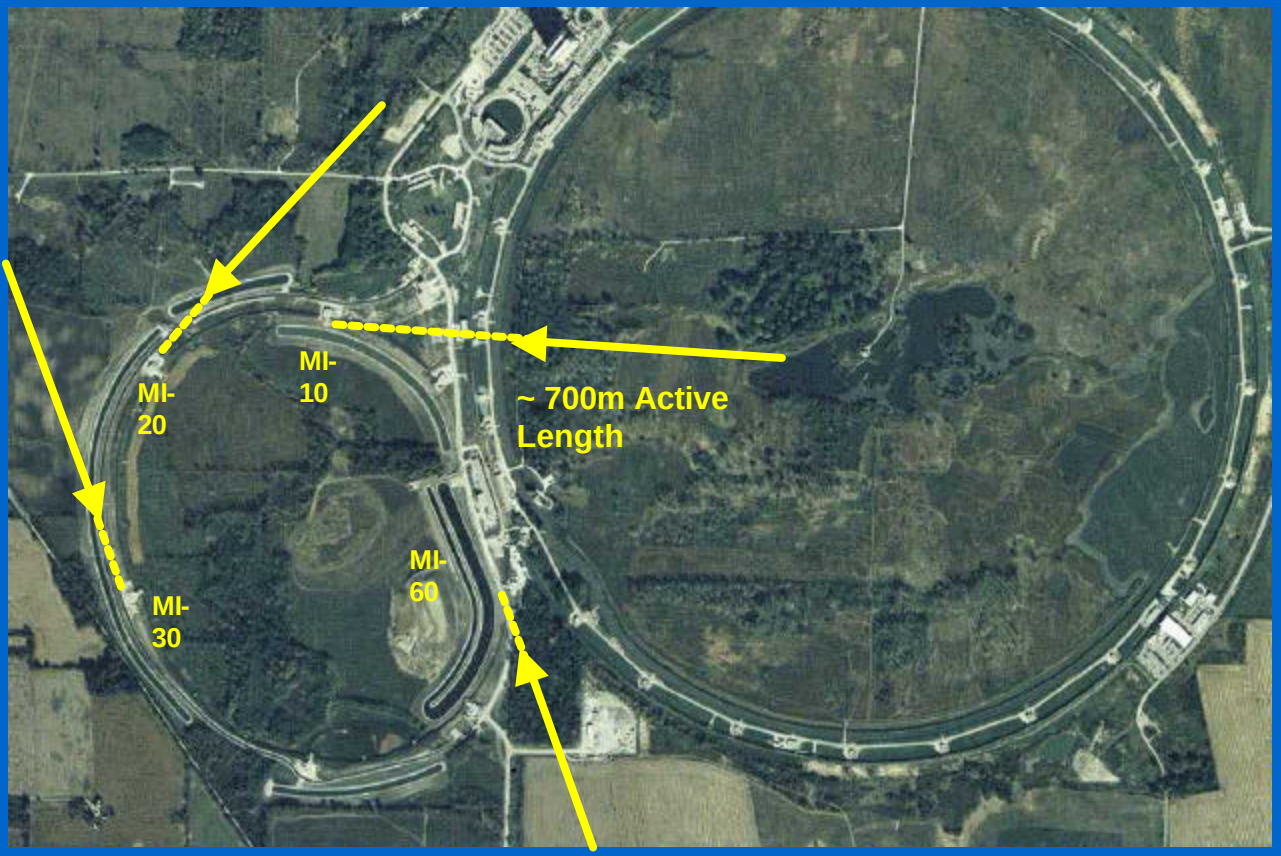
Proton Driver
Synchrotron Option



Hot off the Presses!

Weiren Chou / BD et al

Proton Driver
Superconducting Linac Option



Even Hotter off the Presses!

An 8 GeV Linac based on SNS and TESLA scrf technology

Bill Foster / PPD et al

Summary

- This is still fun.
  - Q1: So what IS it all made of? and
  - Q2: How DOES it all behave? etc etc
- There is still lots to do.
  - Decades (in performance and on calendars)
  - The best ideas are yet to come ...

That's It From Me ...
Any More Questions?

www.fnal.gov

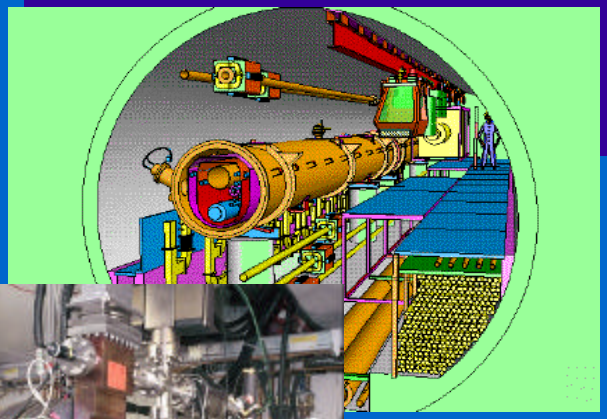
SHOW AIRS: TUE 5/7 at noon CT

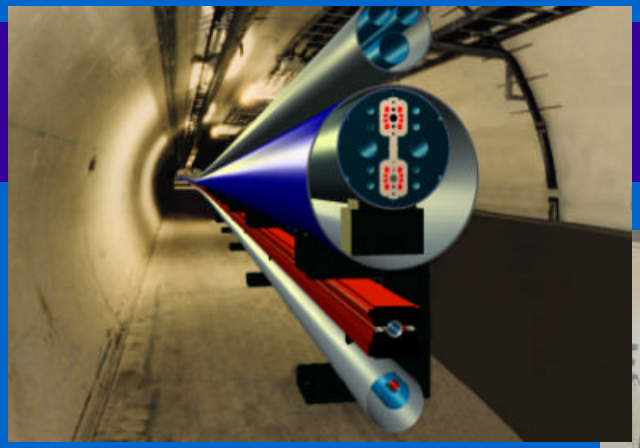
Your Host: David Finley
finley@fnal.gov

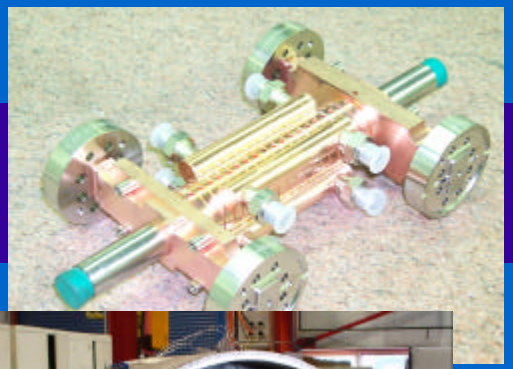
http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf

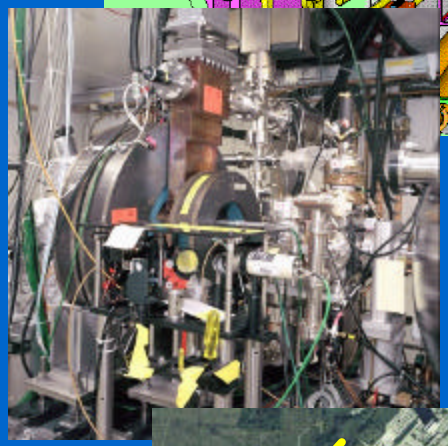
Some Pictures from the Talk

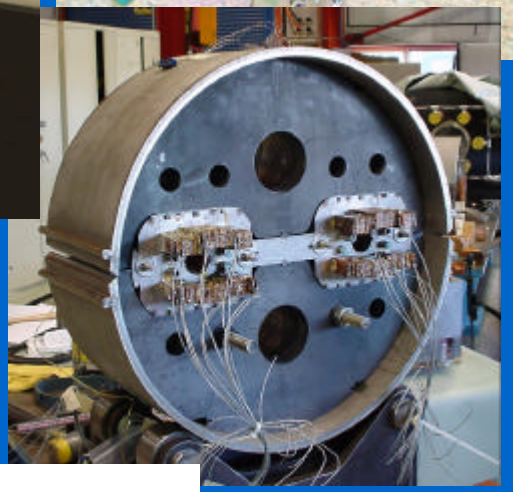
f











http://tdserver1.fnal.gov/Finley/020507Physics4Everyone.pdf