Collider Physics at Fermilab

Accelerators

Detectors

MSU’s involvement

W and top quark production

Particle Accelerators

First, radioactive sources, then cosmic rays - both difficult, rare, and uncontrolled as "beams"

- Rather, rely on electromagnetism to accelerate charged particles and to bend them where they are to go...

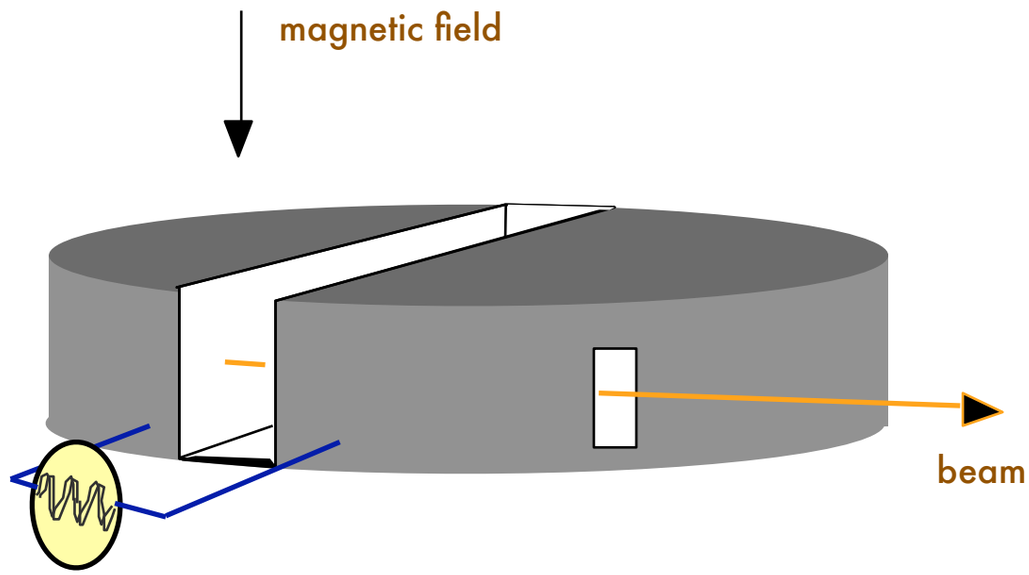
  electric fields accelerate

  magnetic fields bend

  a television set is a little particle accelerator

- Artificial beams were first produced in the late 1940's in the form of cyclotrons

now, these accelerators are used for nuclear physics research



The best example in the world is the National Superconducting Cyclotron Laboratory here on campus

cont.

- Higher energies and particle fluxes required a different approach, the synchrotron

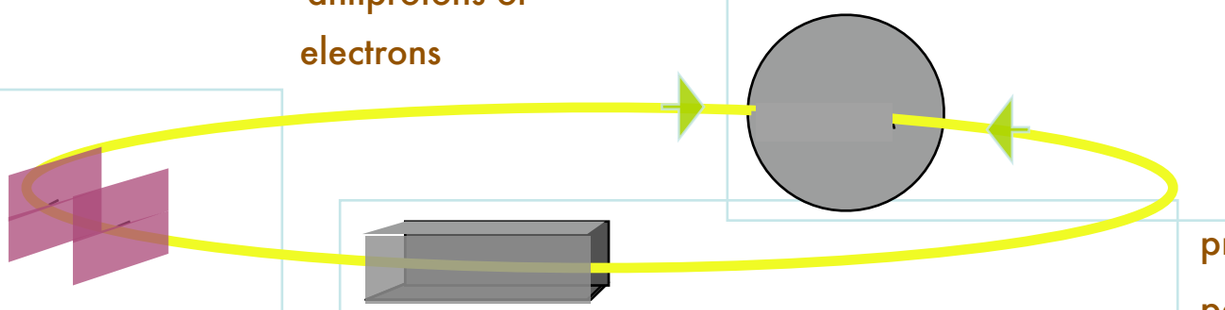
  much higher energies are possible

a cartoon of a colliding beam synchtrotron accelerator

antiprotons or electrons

a detector sits inside the tunnel where the beams are forced to collide head-on

protons or positrons



electric field cavity accelerates particles in the beampipe

magnets all around the ring keep the beam going in a circle

what is Fermilab?

it's many things to me…

it's a dedicated scientific community

made up of:

- 1200 physicists, engineers, and staff
- >1000 faculty, post docs, and students
- from > 80 US & ~20 foreign institutions

it's an amazing scientific instrument

consisting of:

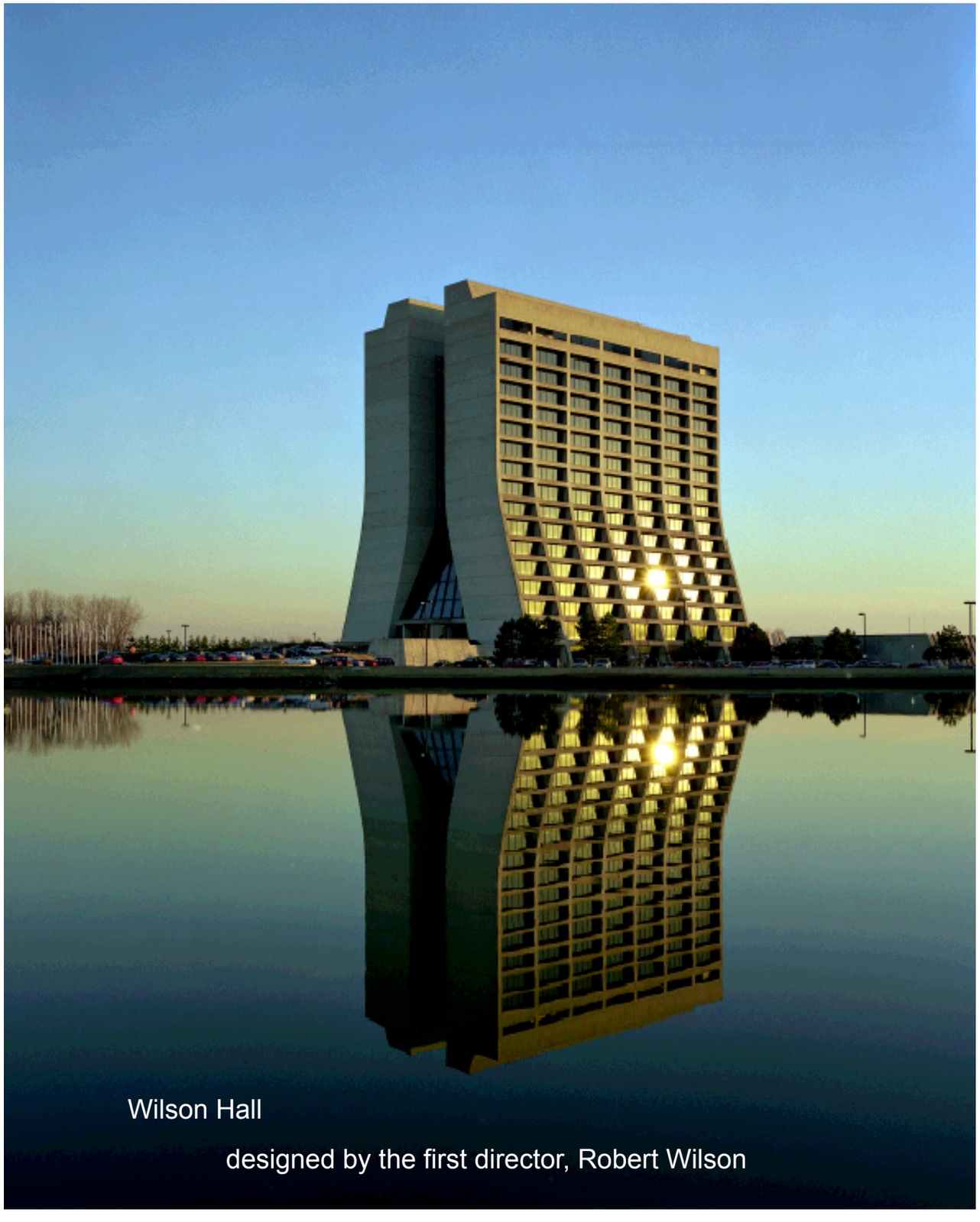
- A time machine
- A particle accelerator for antirotating beams of protons and antiprotons
- hand-made vehicles to explore the current and the very early universe
- A source of high energy/intensity beams of kaons and neutrinos

it's a beautiful single-purpose DOE national lab

located at:

- real space: 60 mi west of Chicago

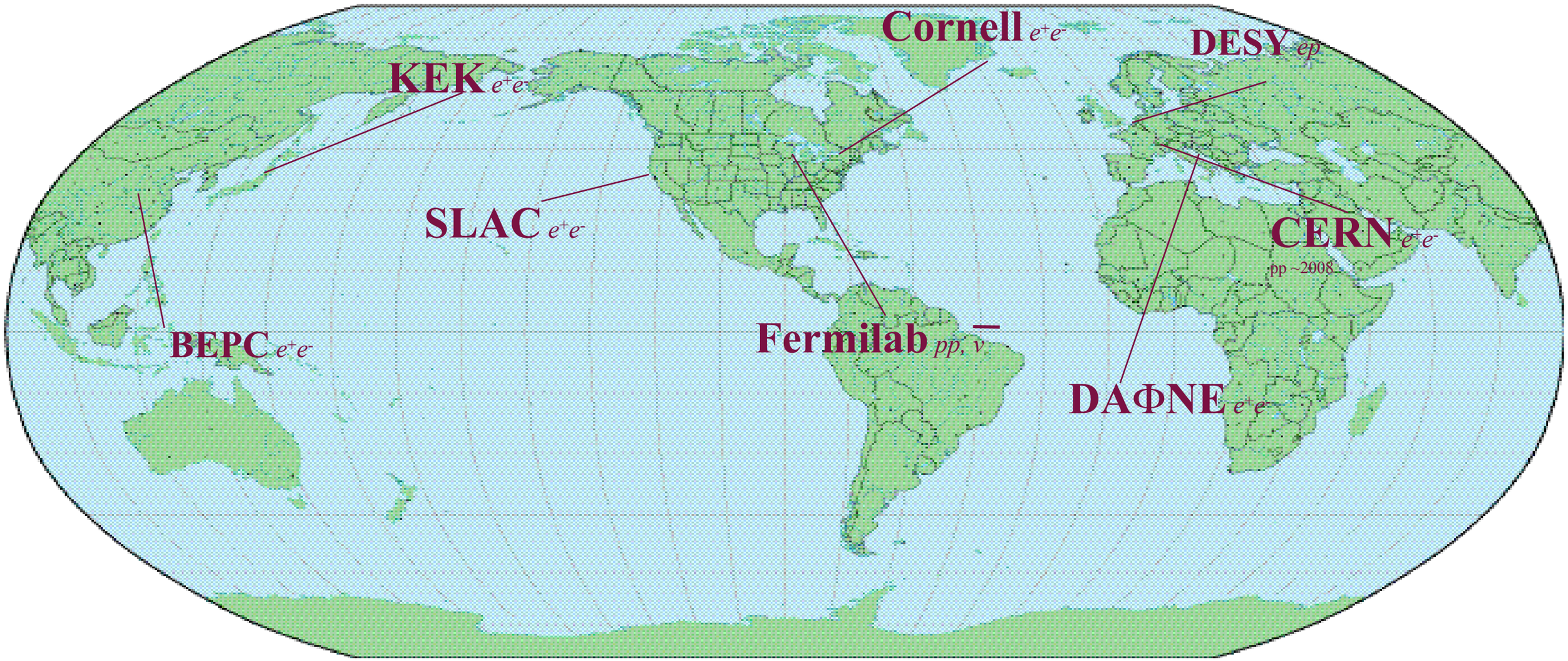
a truly inspiring place to work



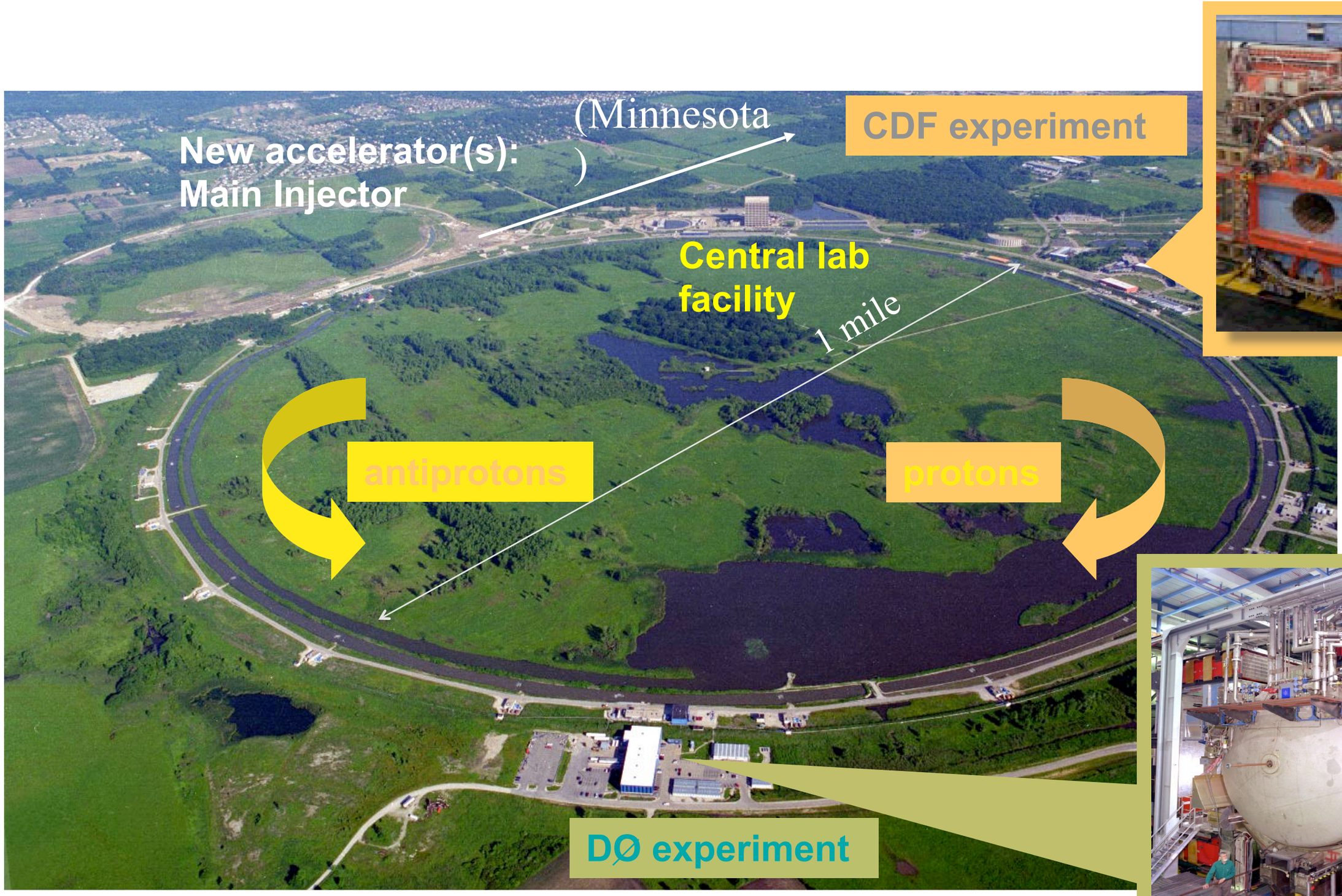
Wilson Hall

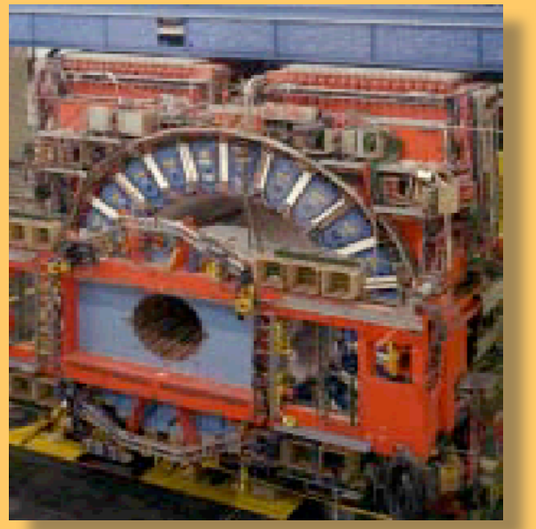
designed by the first director, Robert Wilson

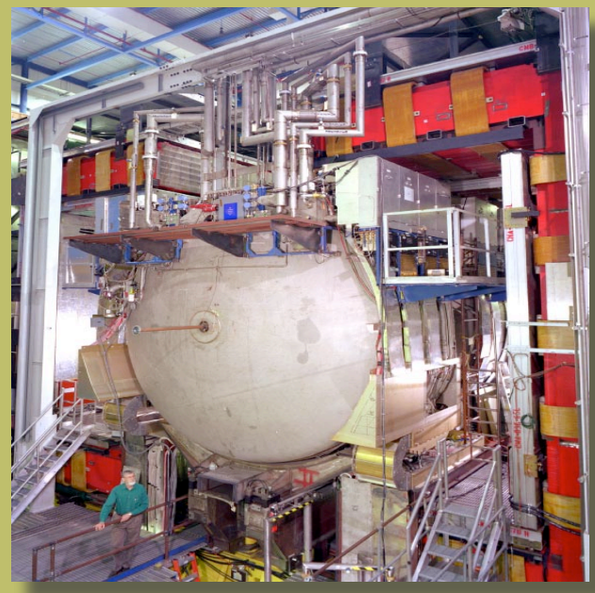
HEP labs around the world, today.



Fermi National Accelerator Laboratory



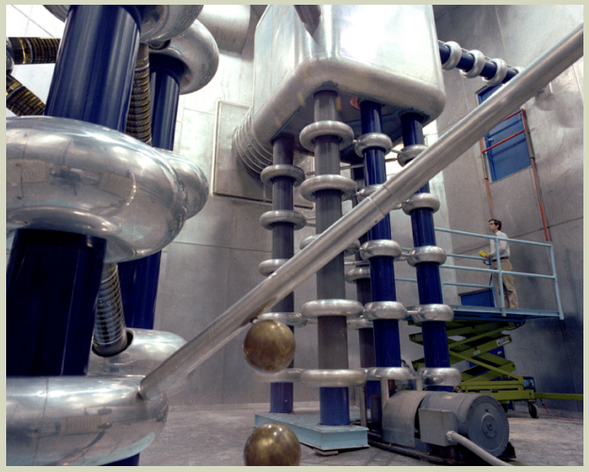


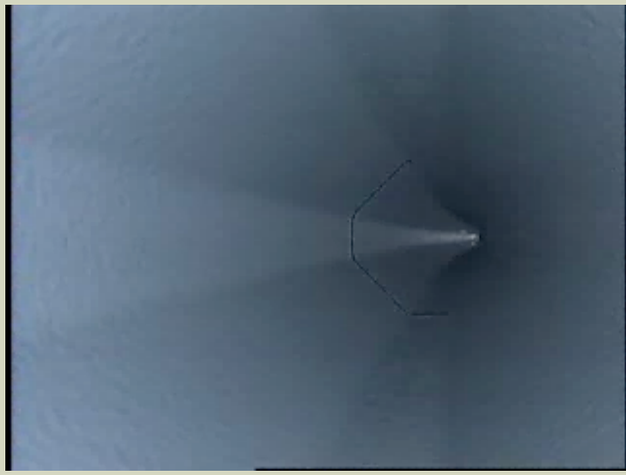


fermilab's back yard

back

Accelerator Complex - the time machine





proton cycle

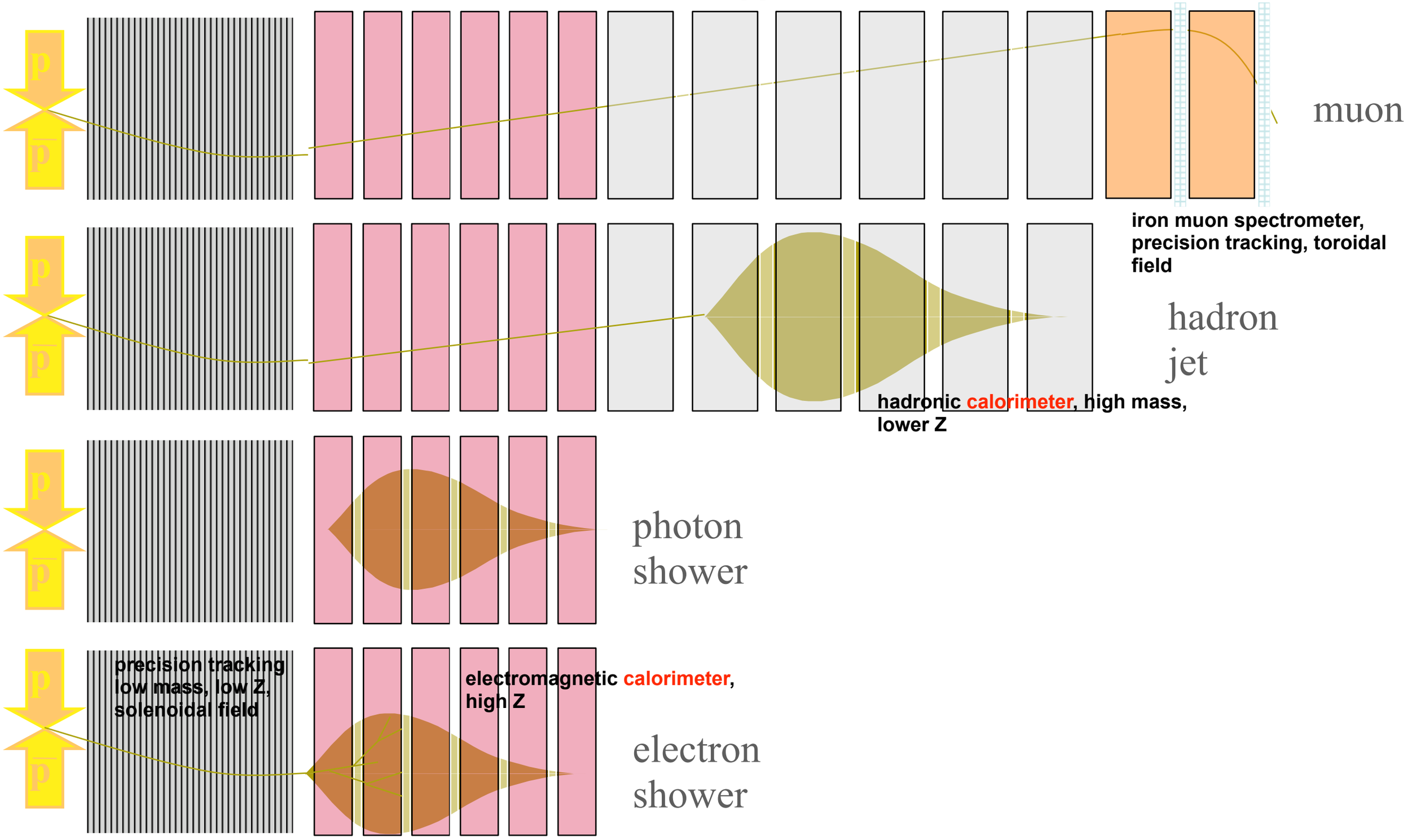
antiproton cycle

or: production of antiprotons

either: coasting protons

how do we detect particles?

– by the electromagnetic and strong interaction fingerprints that they leave behind in a sandwich of detector types:



Generic colliding beam detector-the vehicles

Muon tracking

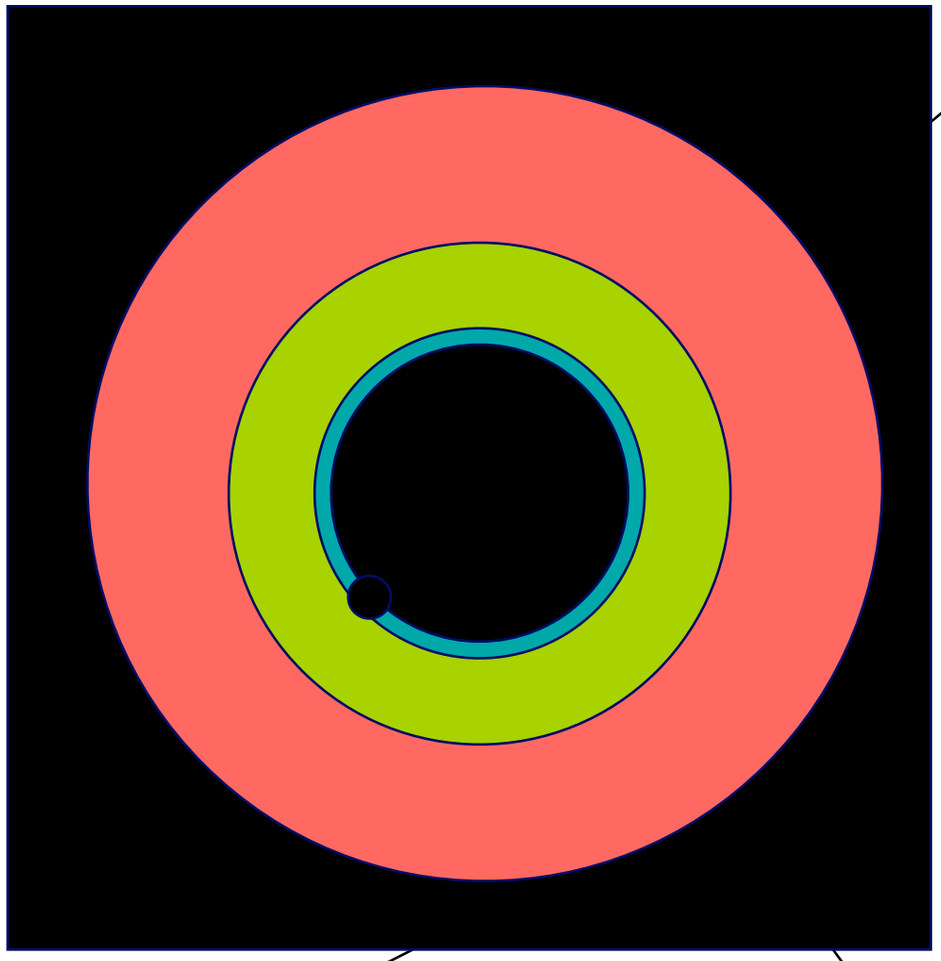
Toroidal field

Iron shield

Charged particle tracking

Solenoidal field

Silicon strips & disks



Hadronic calorimetry

Protons, neutrons, pions, etc.

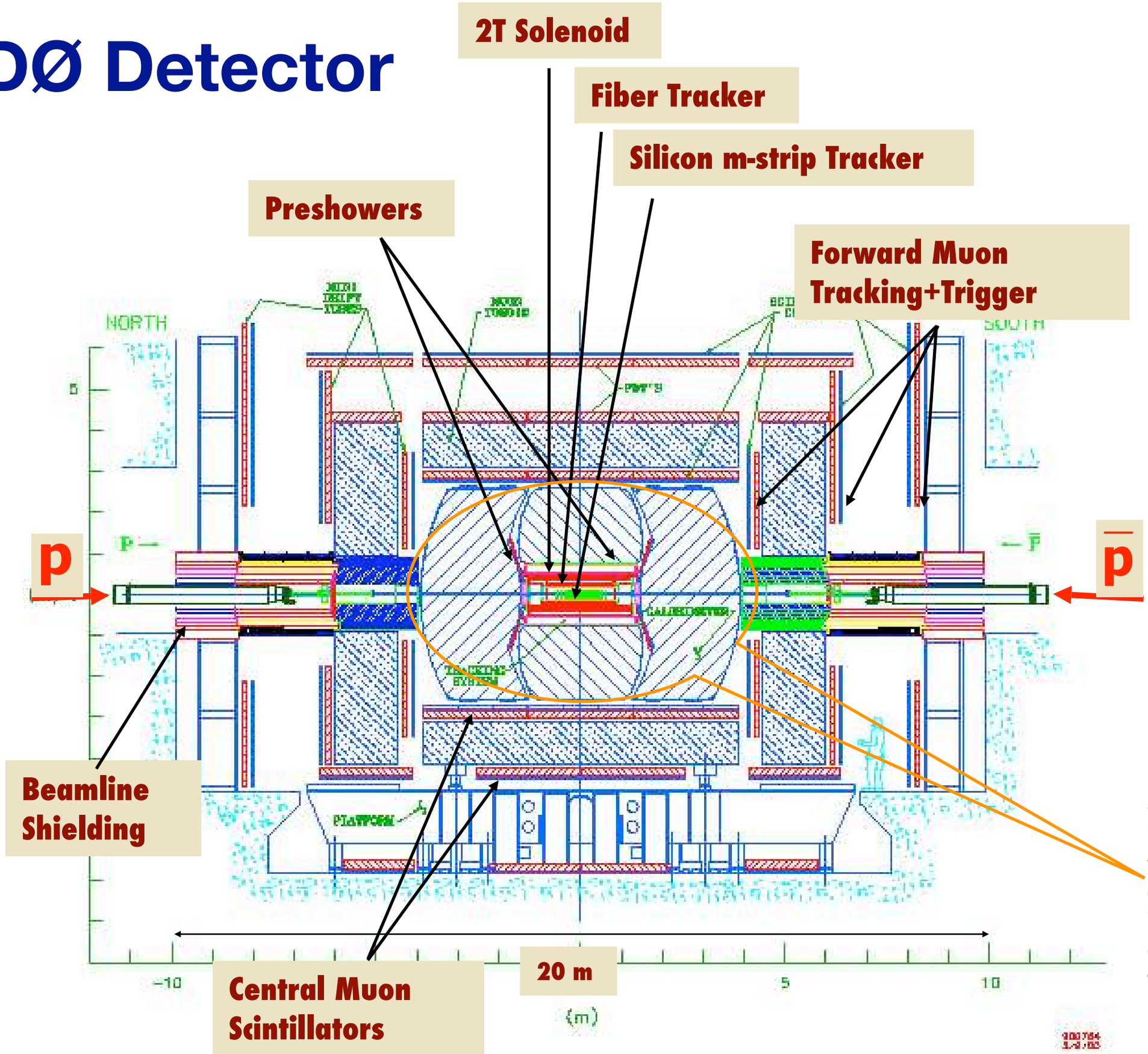
Electromagnetic calorimetry

electrons and photons

The DØ Collaboration, est. 1984:

75 institutions, from 18 countries, 650 Ph.D.'s

The DØ Detector

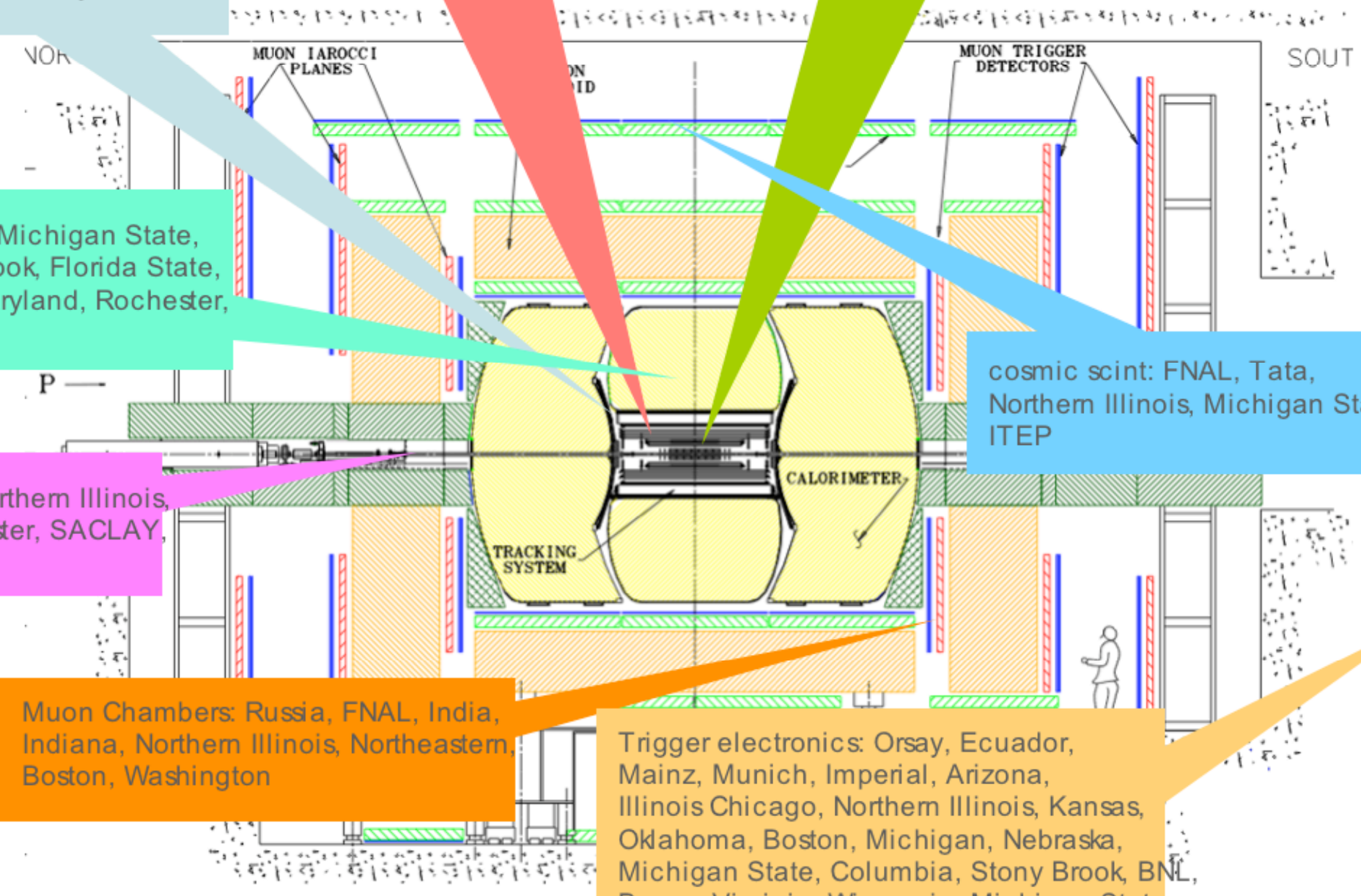


an arbitrary HEP detector:

Fiber Tracker: FNAL, Ecuador, Northern Illinois,Notre Dame, Michigan, Nebraska, Rochester, Stony Brook, BNL, Rice

Si Tracker: FNAL, NIKHEV, Marseille, Mexico, Fresno, Riverside, UIC, Kansas, Kansas State, Oklahoma, Washington

preshower: BNL, Stony Brook, UM



Calorimeter: FNAL, Michigan State, LBL, BNL, Stony Brook, Florida State, Northern Illinois, Maryland, Rochester, Louisiana Tech

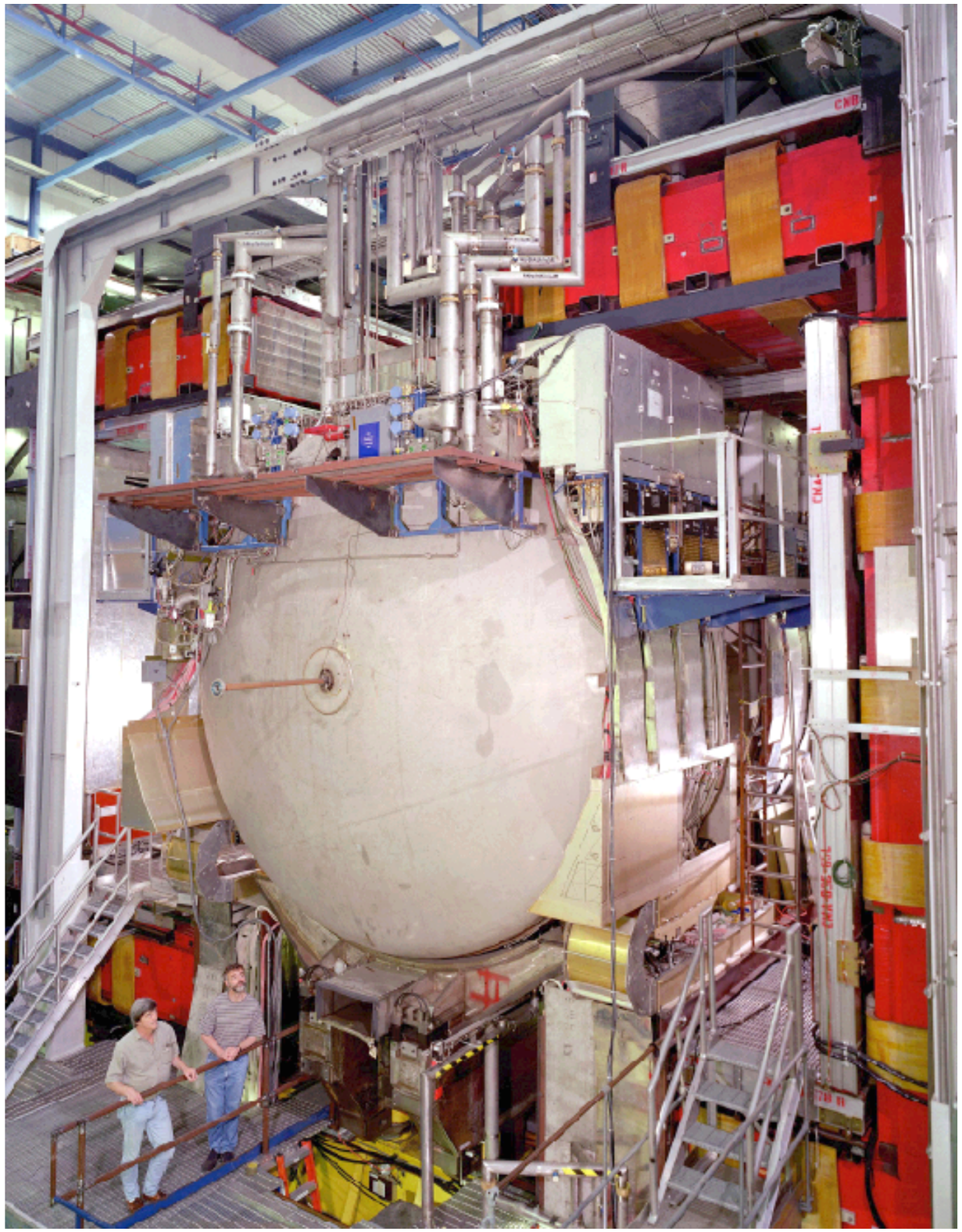
cosmic scint: FNAL, Tata, Northern Illinois, Michigan State, ITEP

FPD: Brazil, Arlington, Northern Illinois, Czechoslovakia, Manchester, SACLAY, Los Andes

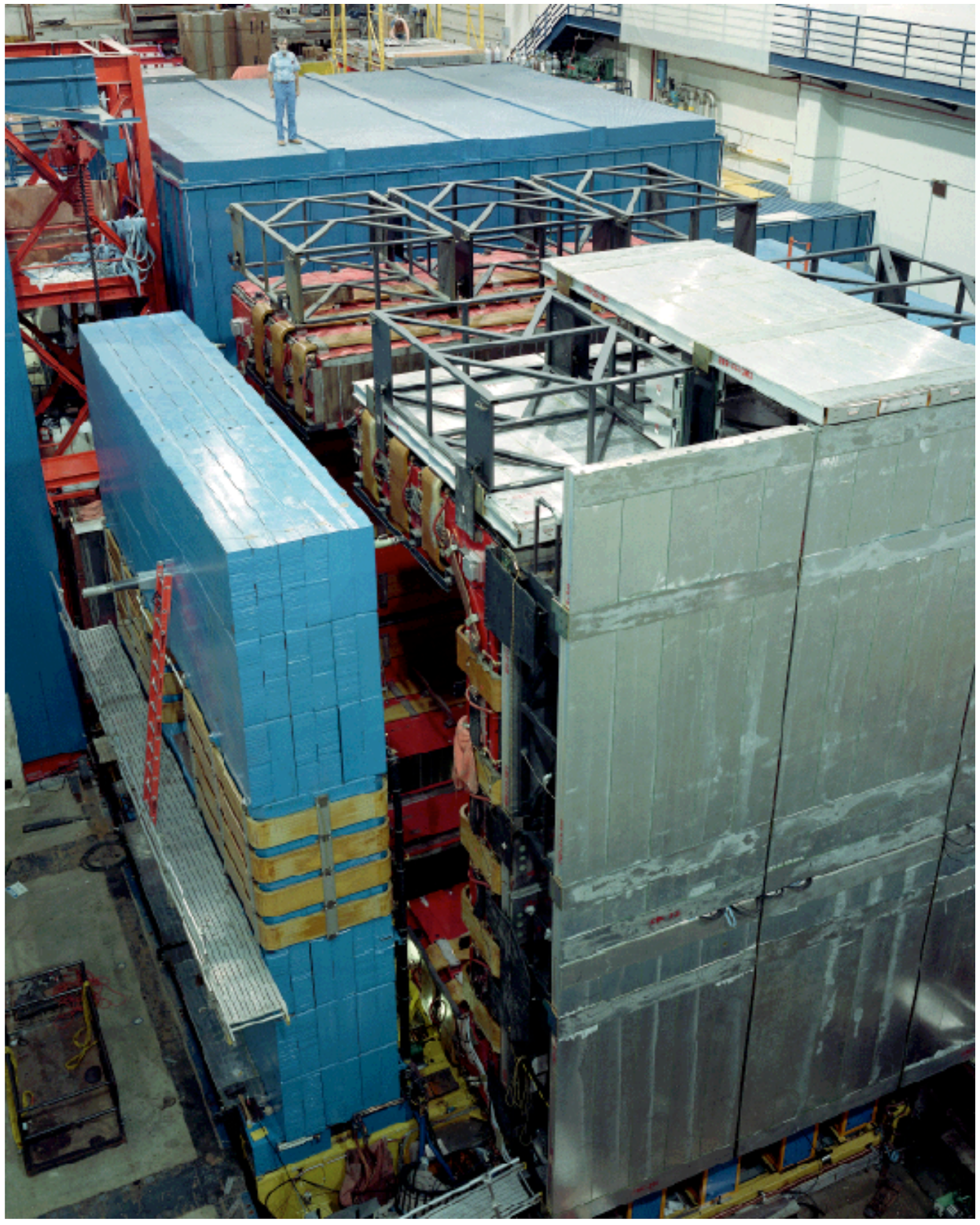
Muon Chambers: Russia, FNAL, India, Indiana, Northern Illinois, Northeastern, Boston, Washington

Trigger electronics: Orsay, Ecuador, Mainz, Munich, Imperial, Arizona, Illinois Chicago, Northern Illinois, Kansas, Oklahoma, Boston, Michigan, Nebraska, Michigan State, Columbia, Stony Brook, BNL, Brown, Virginia, Wisconsin, Michigan State

...inside

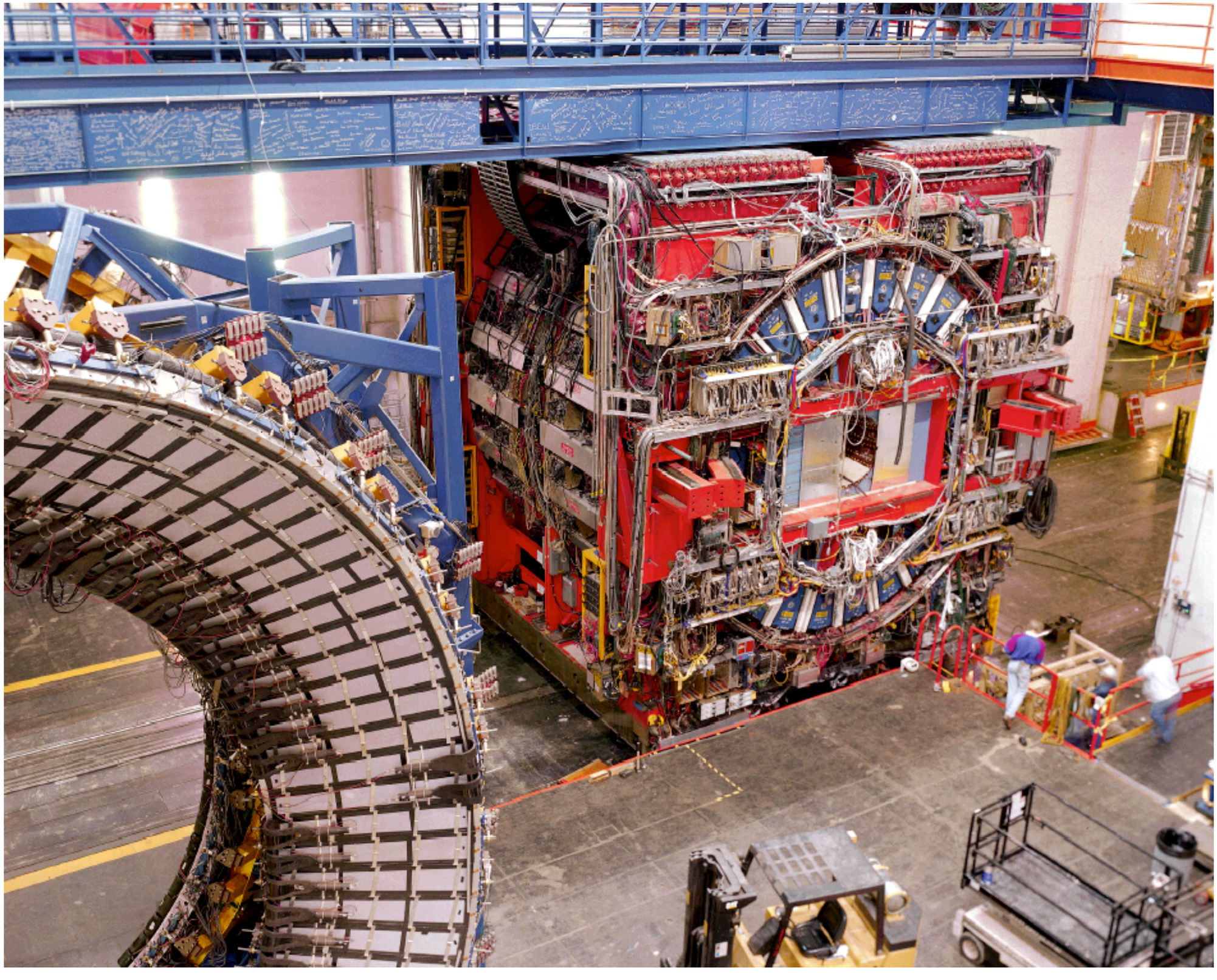


the DØ detector




DETECTOR REMOVAL
03/12/96 M15 C15 07:56:49

the other detector…CDF



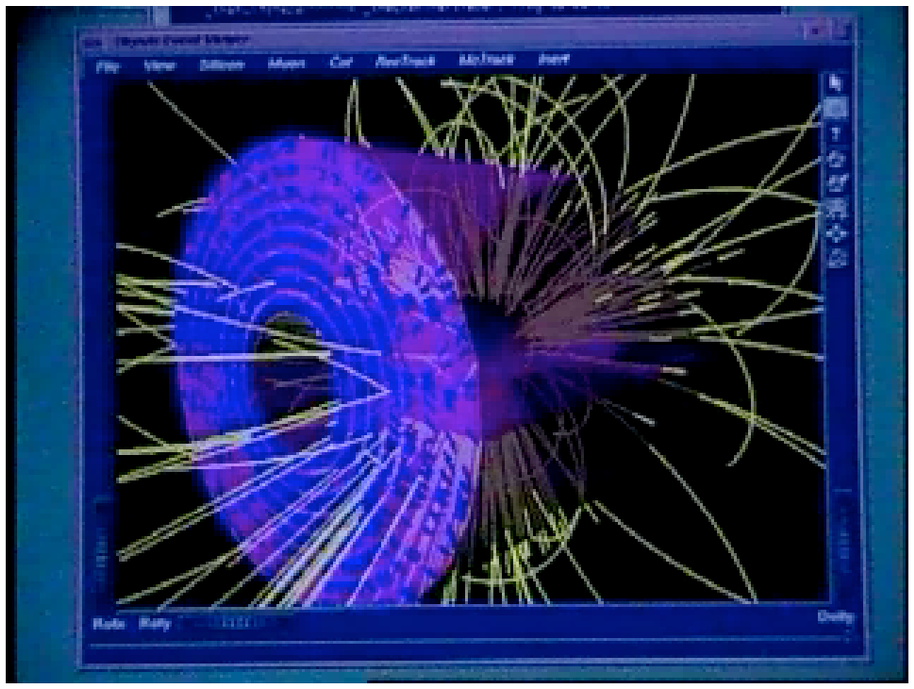
accelerator delivers, detector reads, computers analyze:

Every 396 ns…396 x 10^{-9} s

- the proton & anti proton beams are brought close together inside the detectors

  there, the actual interaction rate is 7.5MHz, 7.5x10^{6} interactions per second

  each event record is ~250kB, so this would be a rate of 1.9TB/s - impossible



The experiment is outfitted with near-real time electronics, designed and produced here in our group

- which analyzes what's happening in each collision

  reading the information from ~500,000 electronic channels

- picks out those events which appear to match (much debated) physics priorities

  and processes 6kHz of these potentially interesting data to a series of dedicated, home-built processors (again, designed and built at MSU)

- Eventually, the information is reduced, combined, filtered to an output stream of 50Hz, at 250kB per event

These data are then processed on a dedicated computer farm of ~500 linux Pentium processors of the ~2GHz class

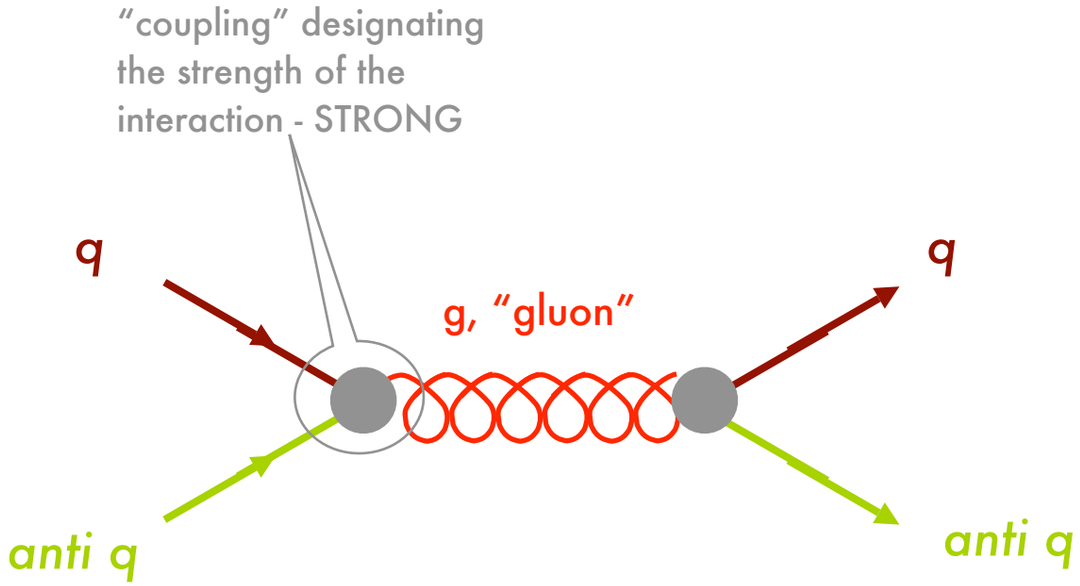
The overall data load of the experiment will be in the 5-8 PB (petabyte 10^{15} B… information

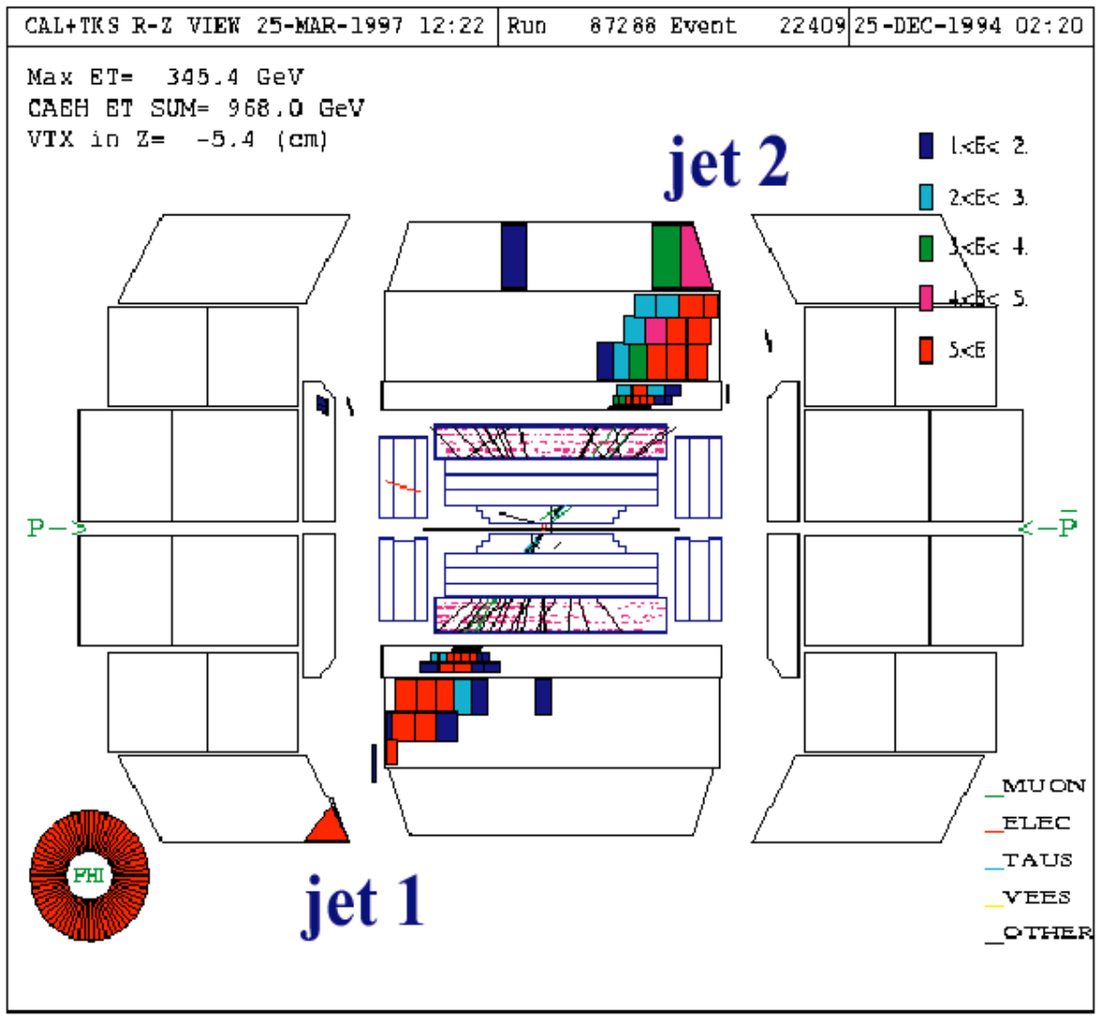
- in CD's: the height of ~100 Sears Towers
- processed and analyzed at institutions on 4 continents in a ~2000 processor computational grid

most violent elementary particle collision produced on earth

Rutherford Scattering of one quark in the proton off of another quark from the antiproton

with the exchange of a "gluon" a photon-like particle that transmits only the STRONG force.





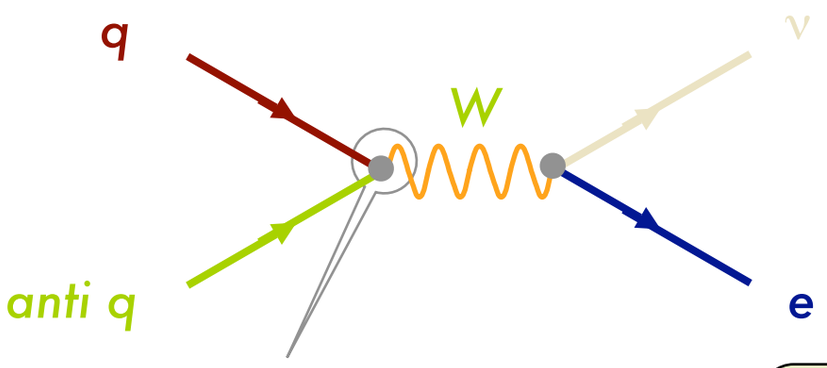
It required that
the quarks annihilated within 10^{-19} m of
one another or
1/10,000 the size of a proton

The energetics of this event is consistent with
interactions in the
early universe ~10^{-20} s after the big bang

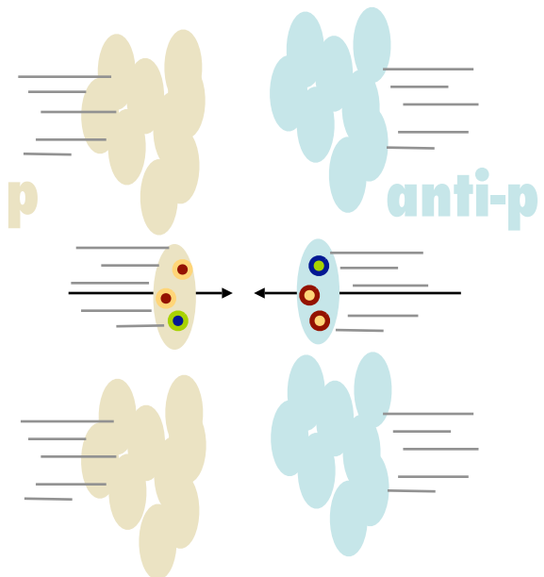
2 events: W boson production & detection

p + antip → W + uninteresting stuff

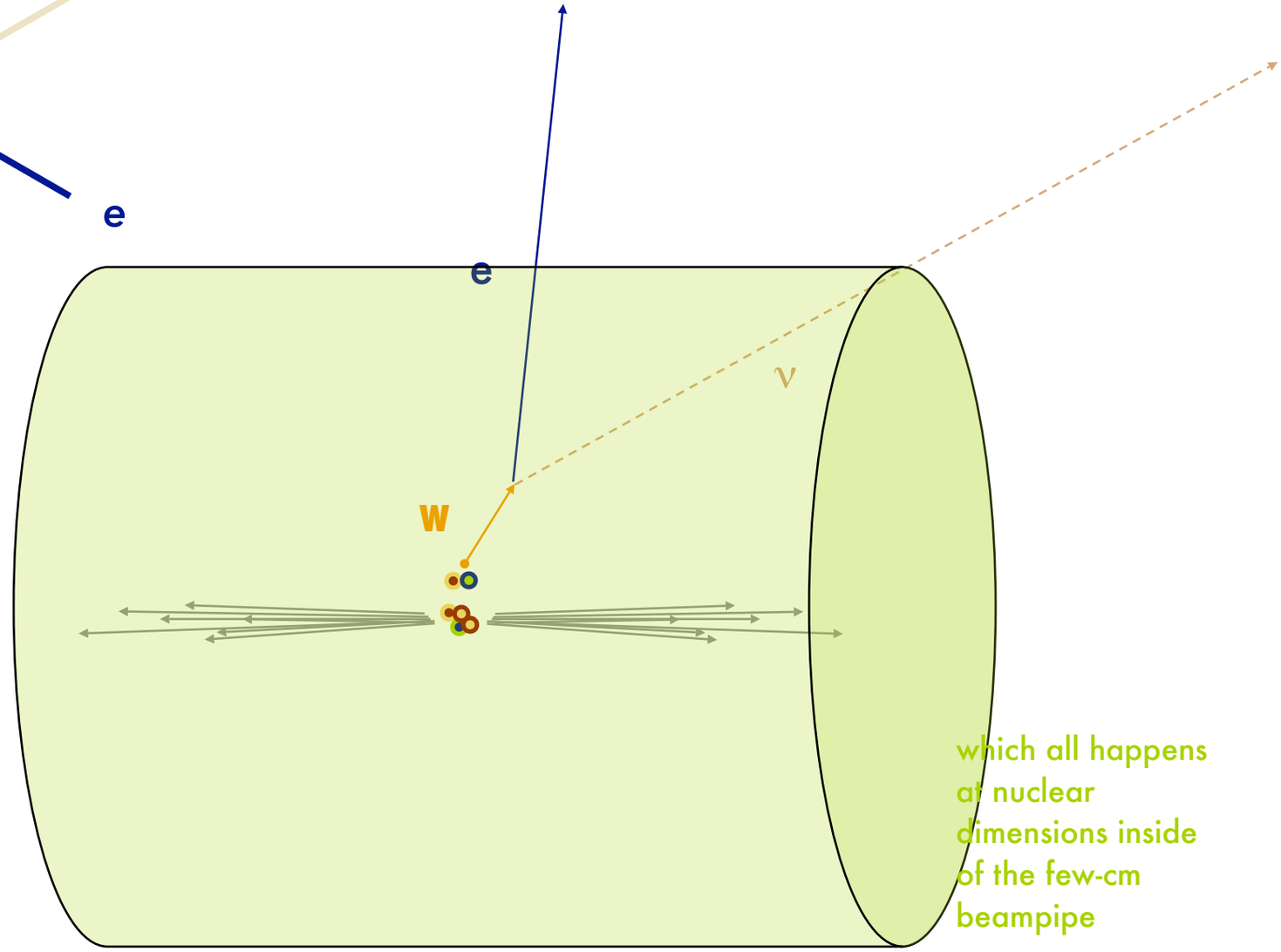
with W → e + ν



"coupling" designating
the strength of the interaction - WEAK



every few hundred
nanoseconds - 10^{12} or so
protons and antiprotons
encounter one another



most go by without interacting

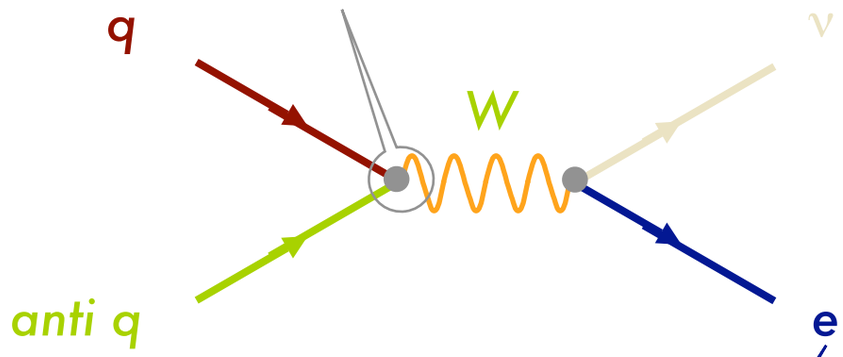
occasionally, a quark from the p and a quark from the anti-p are at particularly large momentum and annihilate, head-on with one another...

The other quarks interact, but with much lower initial momenta

which all happens
at nuclear
dimensions inside
of the few-cm
beampipe

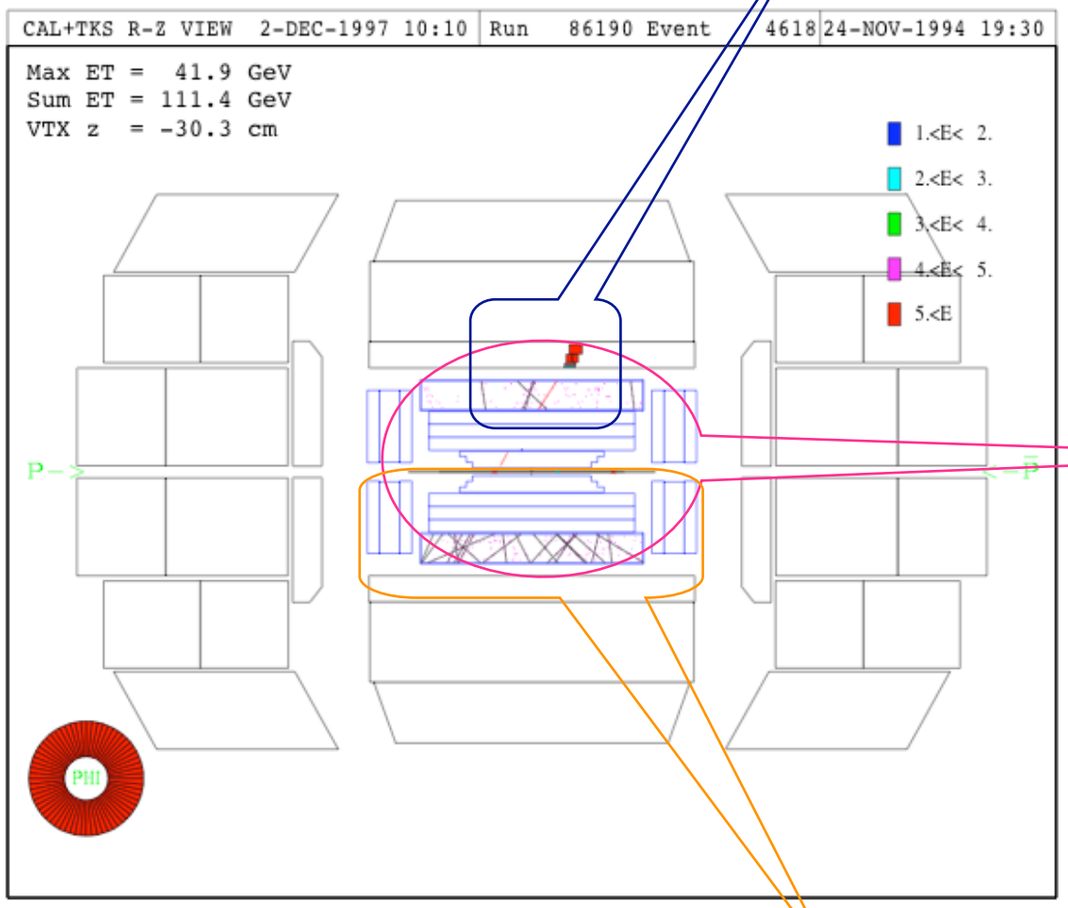
what the detector "sees"

"coupling" designating
the strength of the interaction - WEAK

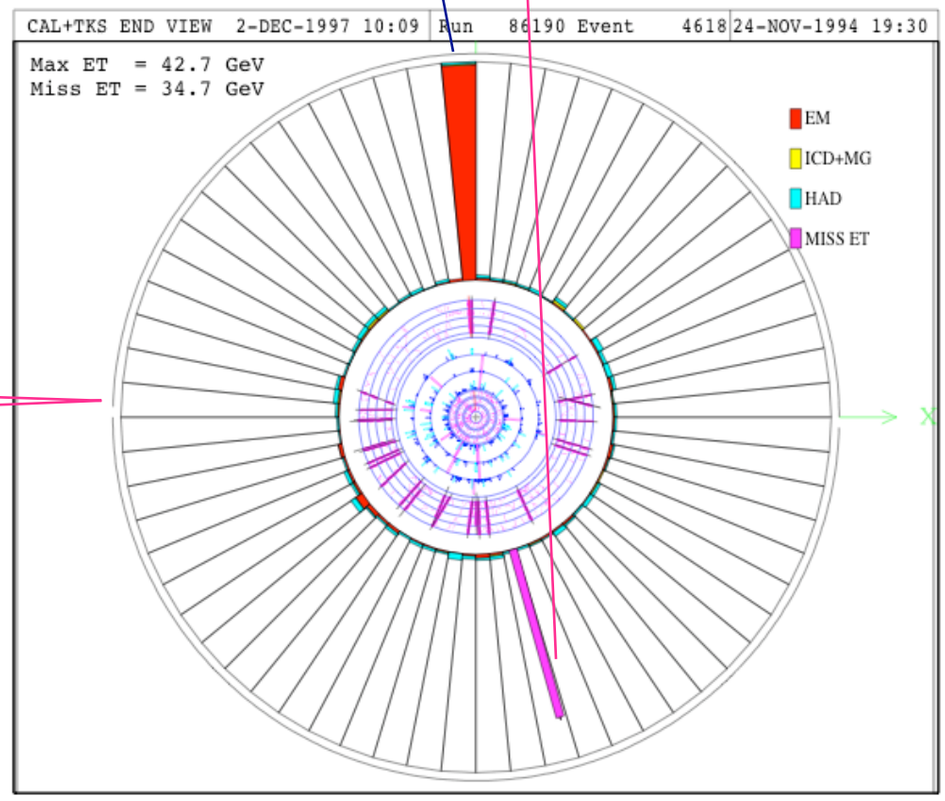


the computer's calculation of the balancing momentum - presumed to be the neutrino's momentum

the length of this bar is proportional to the amount of energy deposited...it's a measured quantity

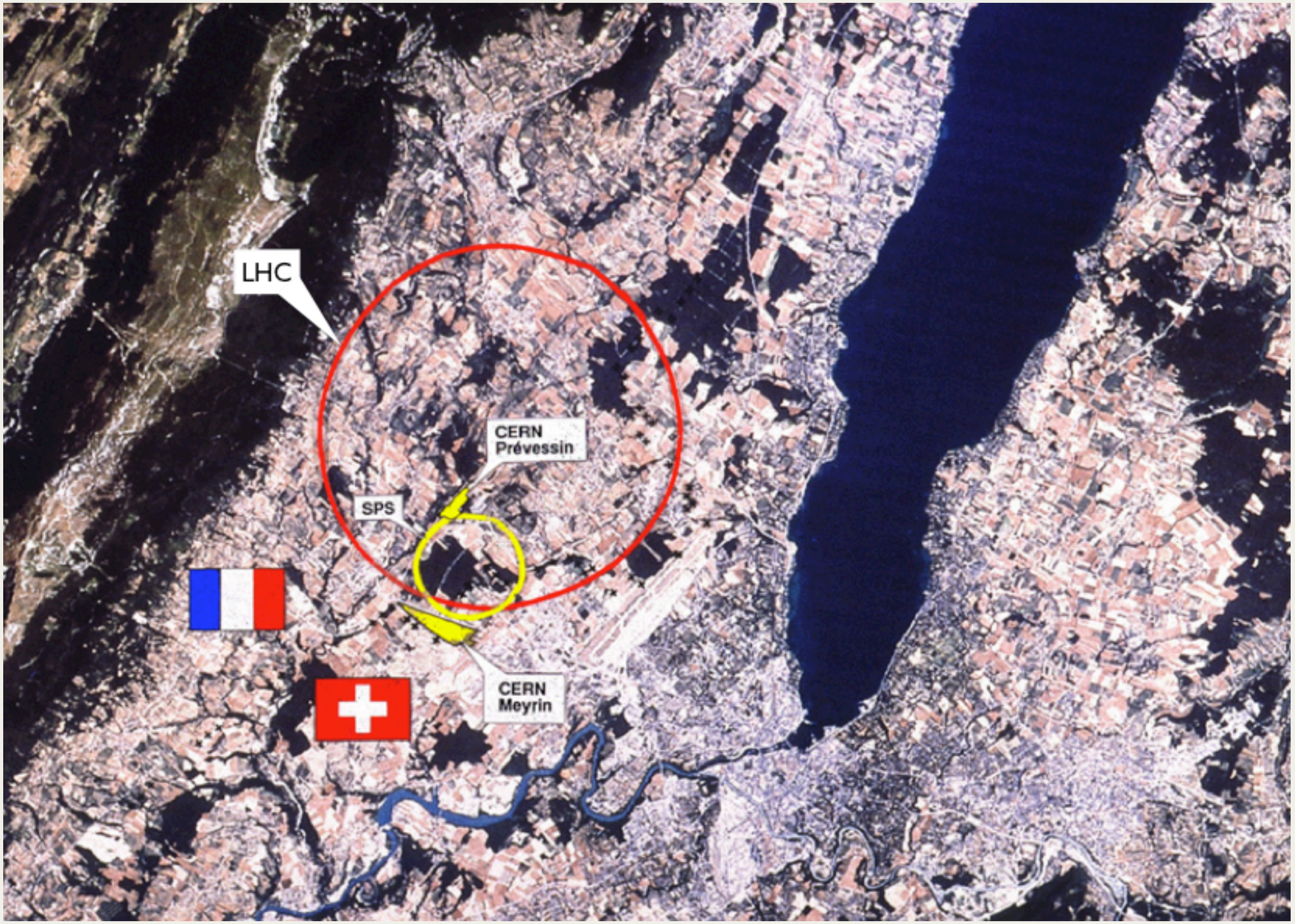


side view



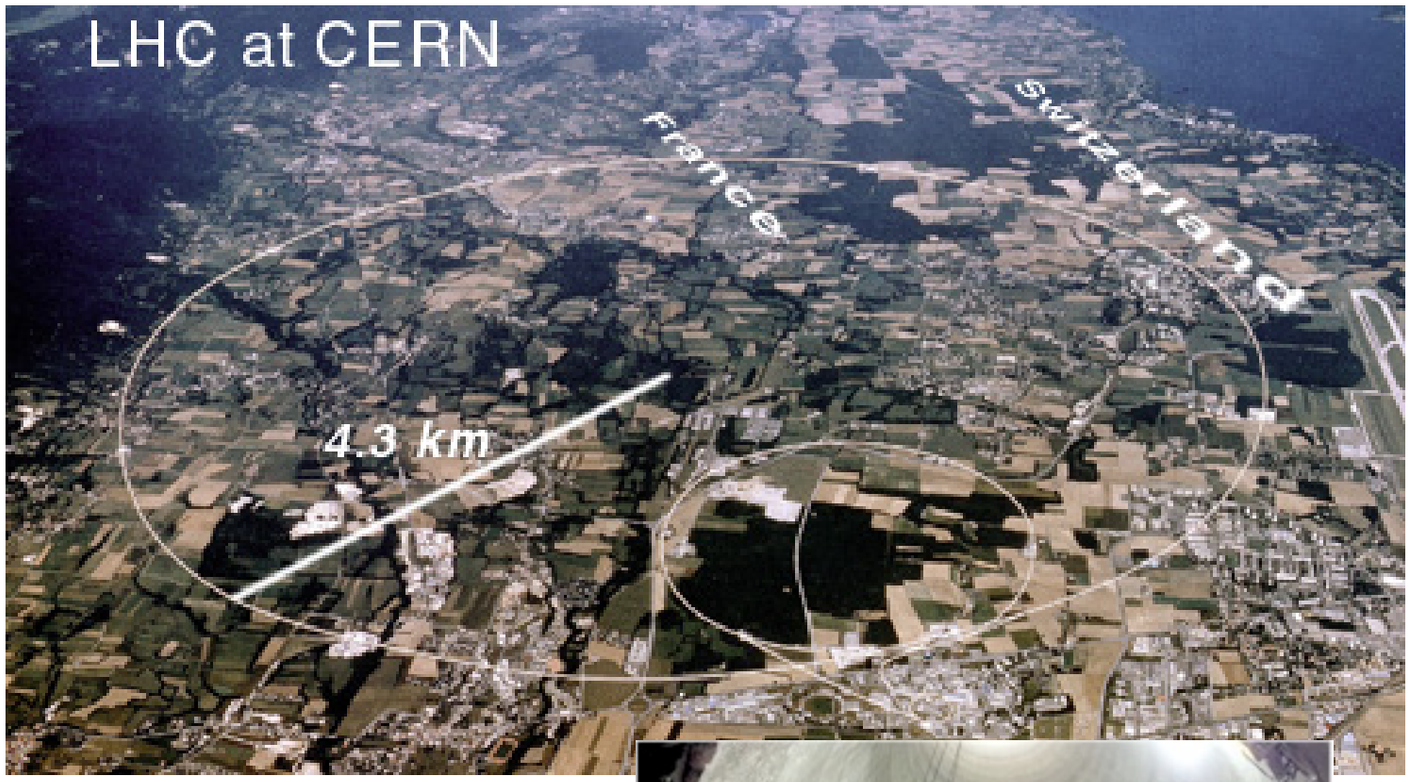
end view

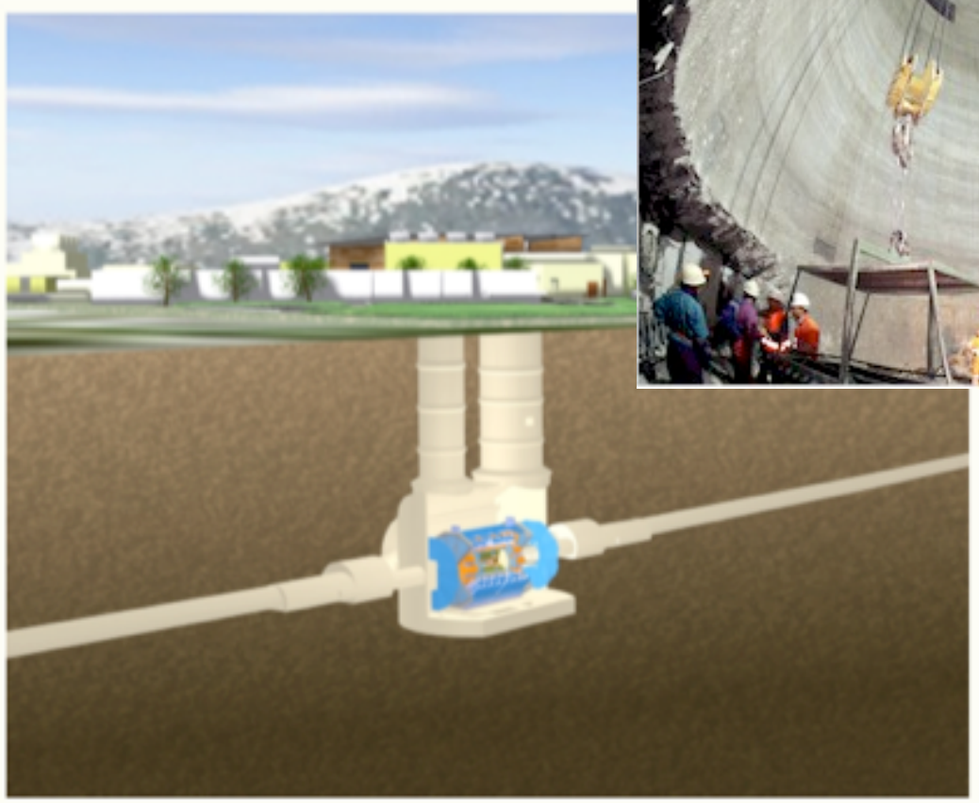
nothing counterbalancing momentum on the other side...suggest the missing neutrino

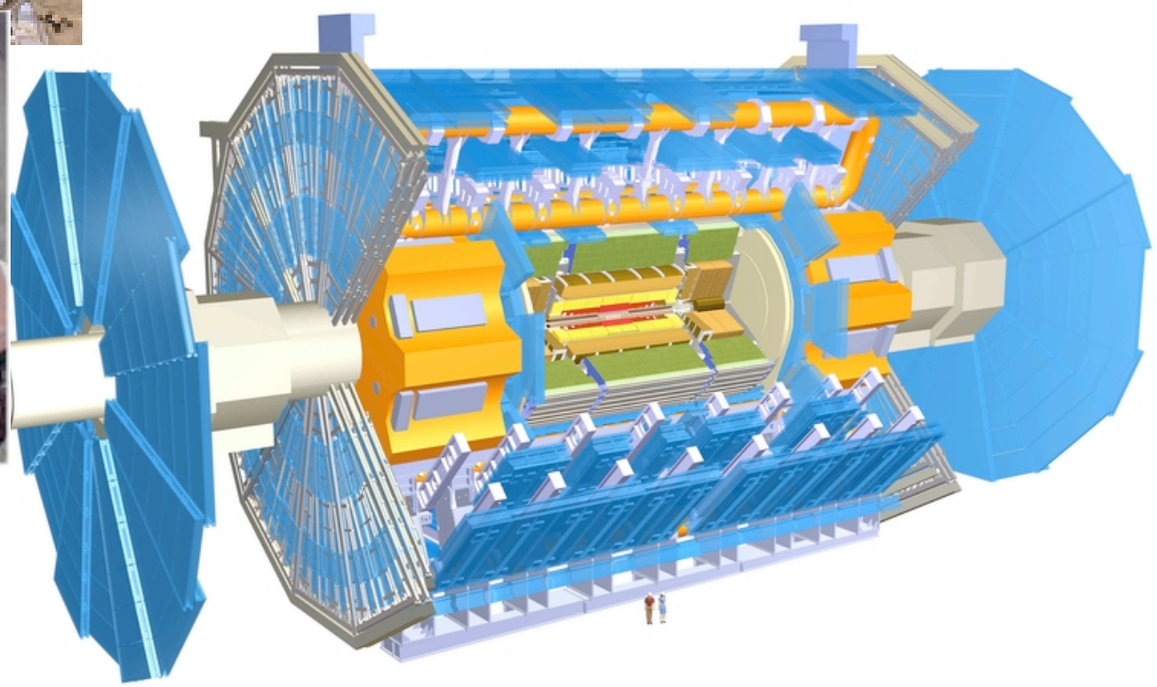

LHC
CERN
Prévessin
SPS
CERN
Meyrin

The next generation is in Europe...~2008

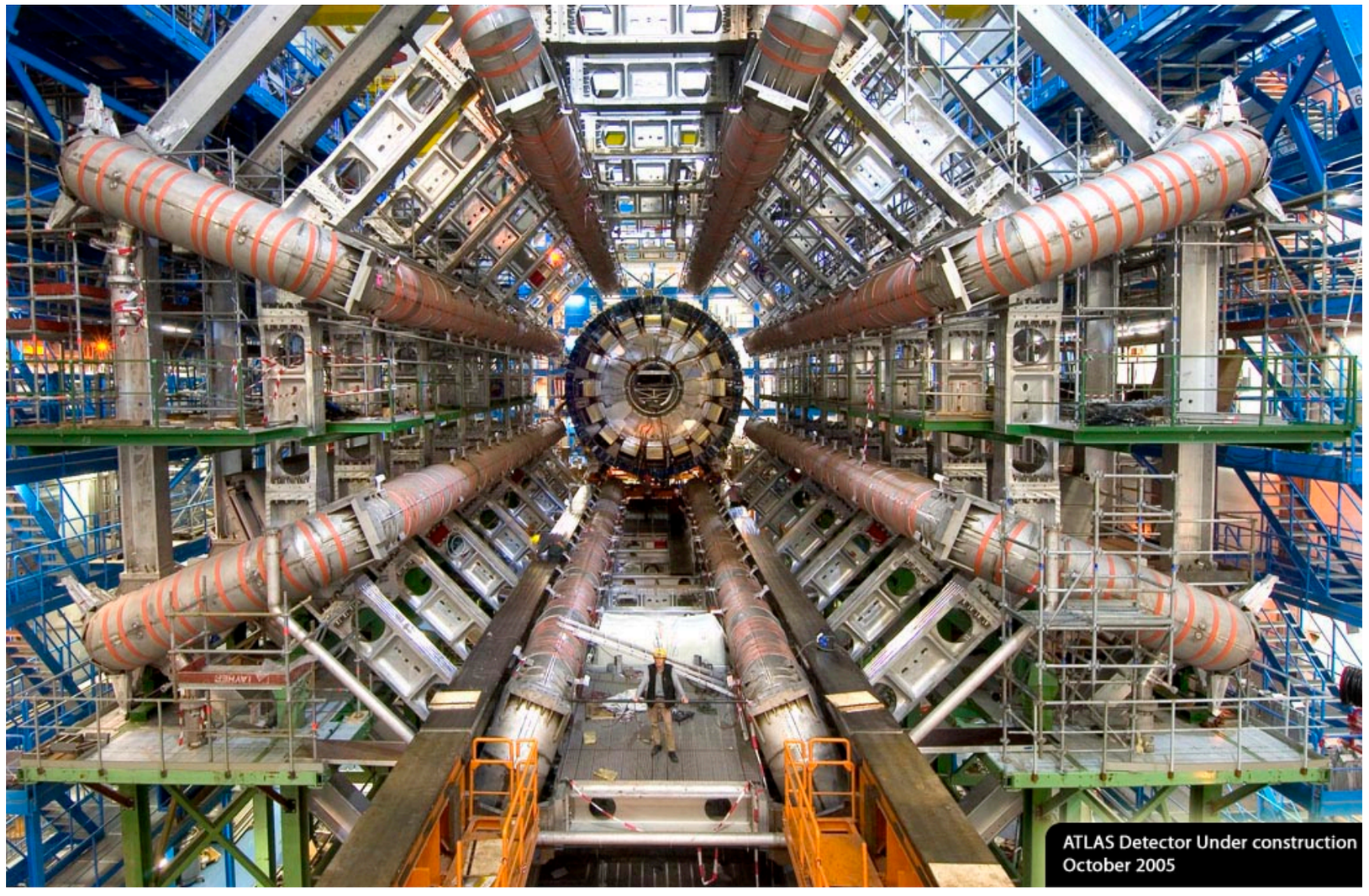
The “Atlas Experiment”





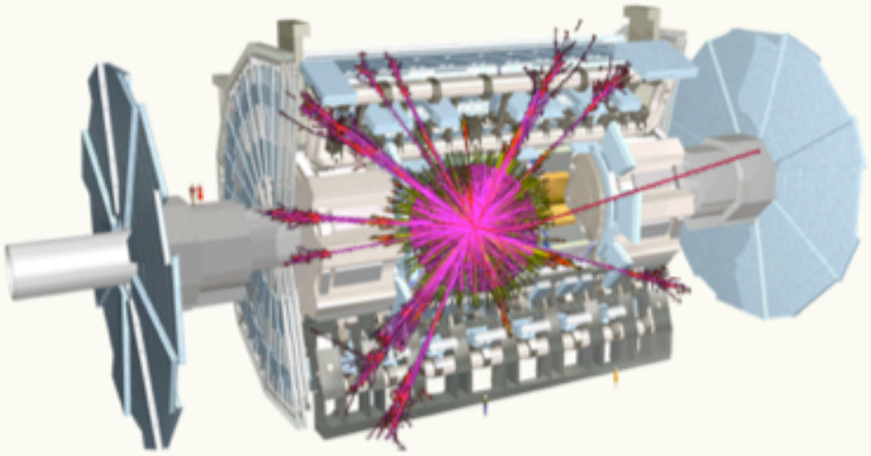


Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*



ATLAS Detector Under construction
October 2005


2006 2 21



PByte/s

real-time DAQ

<GB/s

CERN facility:
cpu~5MSI2k
storage~1 PB

10 GB/s

Tier 1

9x  &

In: France, Germany, Spain, Britain, Taiwan, Canada, Italy, Netherlands, Sweden/Norway

US, BNL: 2MSI2k/2PB

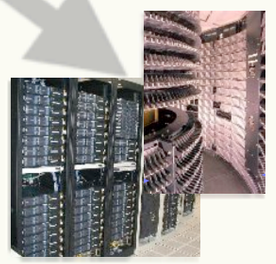
US Tier 2

BU/HU

UTA/UO/
UNM

MSU/UM

SLAC



UC/IU

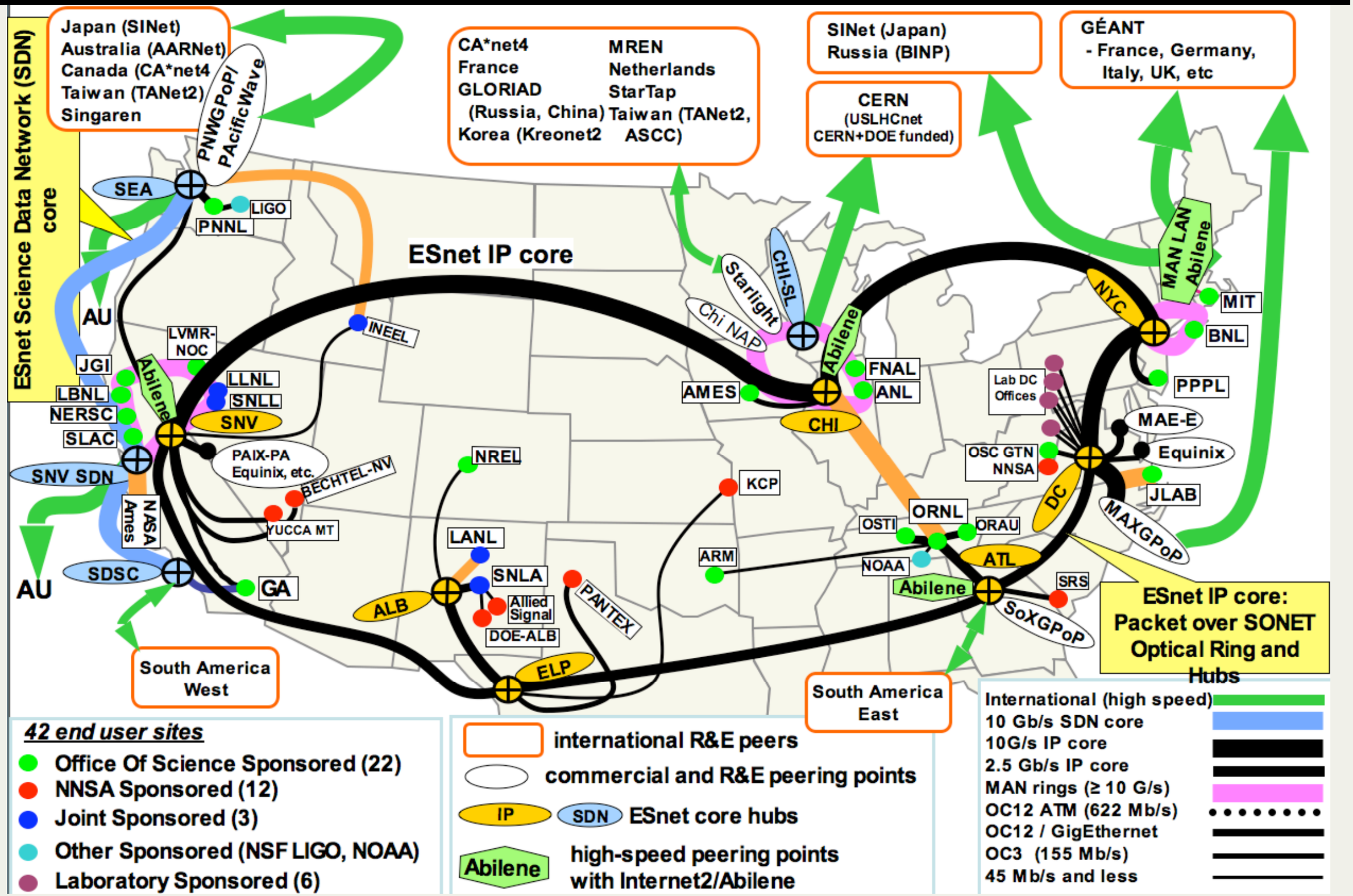
US Tier 3

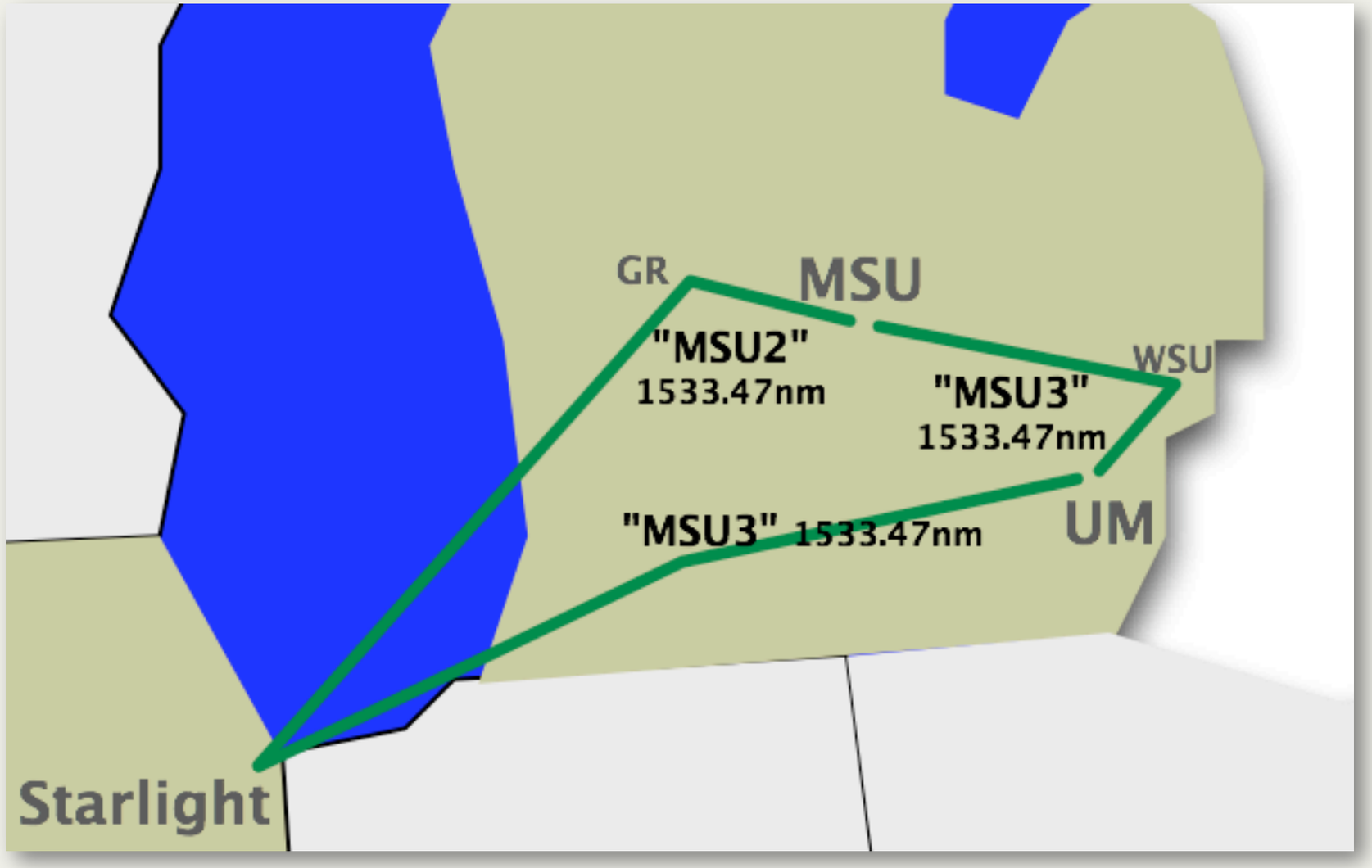
all US universities

~2.5 GB/s

~2.5 GB/s

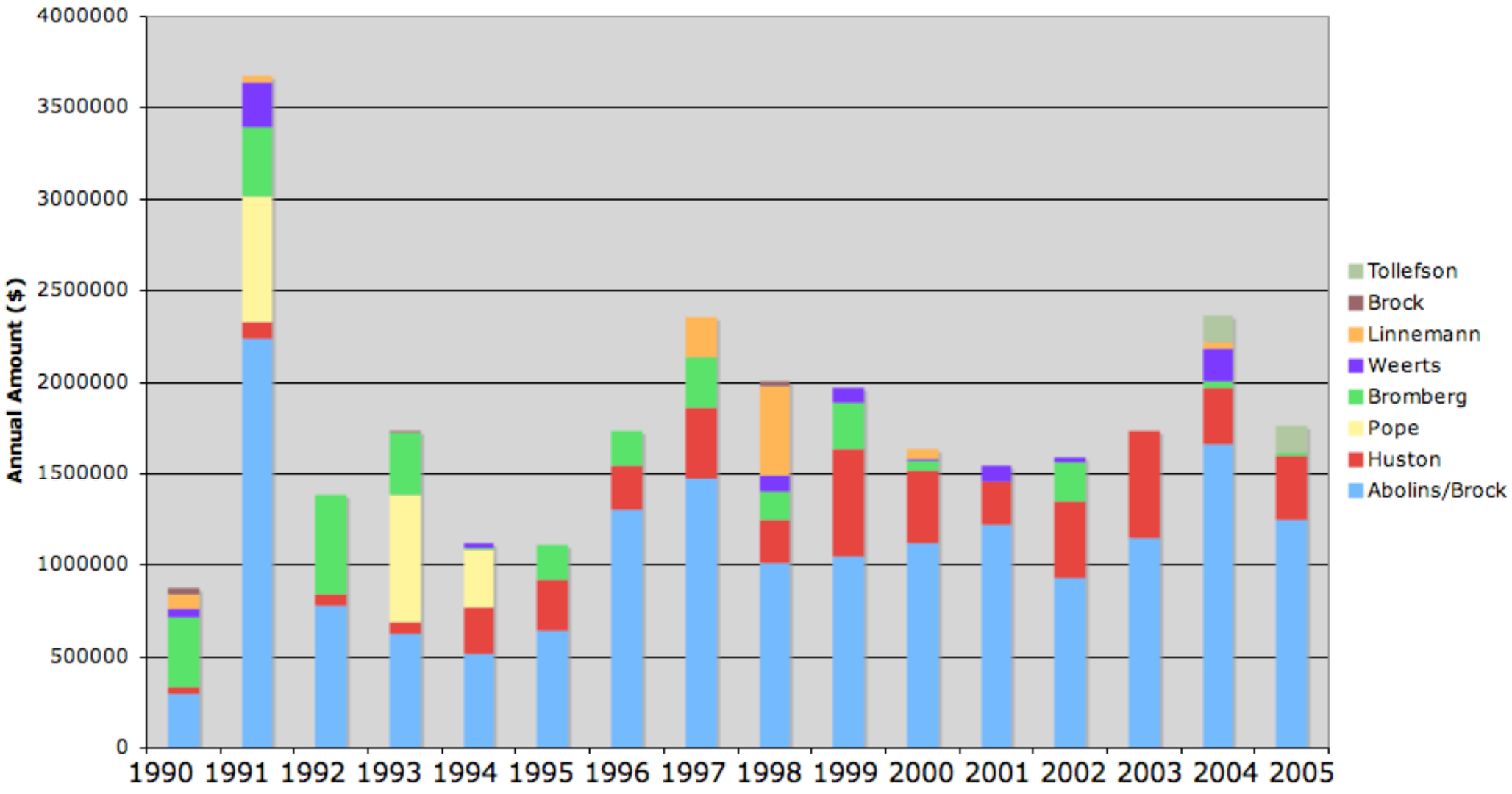
how do data move around?





unique10Gbps connectivity among the 3 Michigan “research universities”

Federal Funds - HEP-E



This’ll keep us busy here at MSU for 20 years.

- better known as “retirement”