



# the International Linear Collider (ILC) (maybe) Fermilab's next Accelerator

**Peter H. Garbincius**  
**Fermilab (30 years)**

**ILC-Global Design Effort**

[www.fnal.gov](http://www.fnal.gov)

[www.linearcollider.org](http://www.linearcollider.org)

- Elementary Particle Physics
- Fermilab (today)
- The Large Hadron Collider (LHC)
- The International Linear Collider (ILC)
  - the machine and some of its physics
- Lots of time for ***discussion***  
***here and on 15<sup>th</sup> floor***

What is the universe made of,  
and how does it work?

What is this made of, Daddy?

What's inside of that?

What's that made of?

What inside of that?

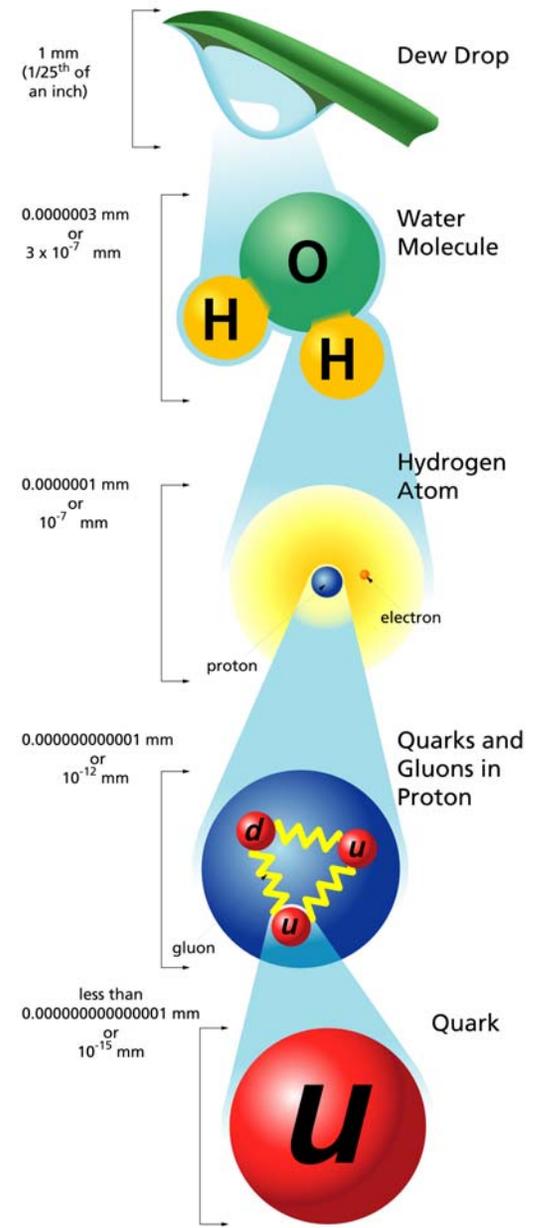
.....

Questions

little children →

ancient Greeks (atoms) →

and today's physicists ask





# irony: to study tiny particles, you need very big machines

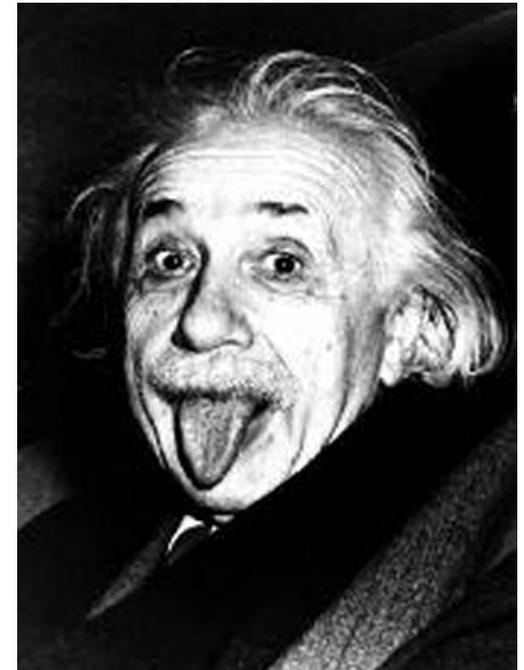
- visible light, x-rays/electron microscope,  
γ-rays => higher energy, *shorter wavelength*
- it's a *Quantum* world in there
- we convert energy into new matter:

$$E = mc^2$$

new matter + anti-matter (balance)

buy energy from Commonwealth Edison

SC Tevatron for higher energy & lower electric bills!





# The general scheme:

**Accelerators give protons lots of energy to make beams of antiprotons, neutrinos, *etc.***

**Collide these beams with protons/neutrons to make interesting “new particles”**

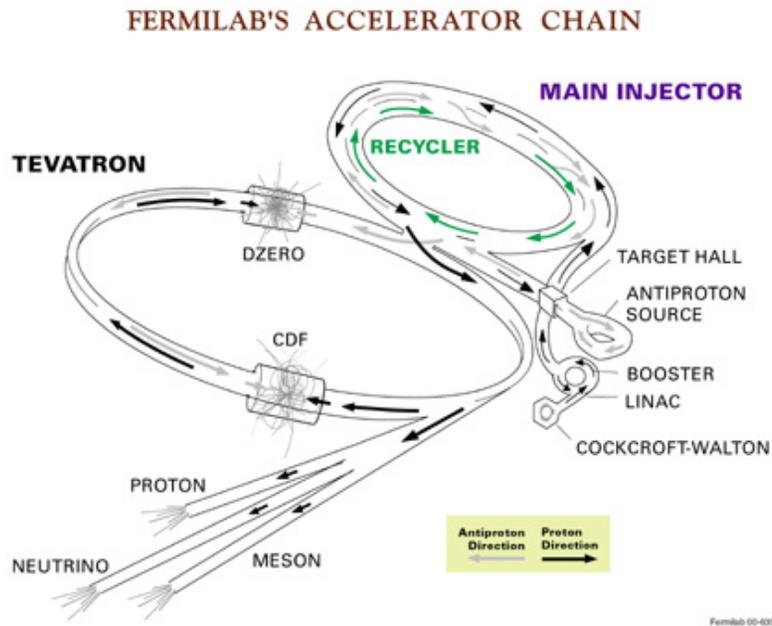
**Study their interactions, properties, & decays with large detectors**



# Fermilab Accelerator Complex

<http://www-bd.fnal.gov/public/>

1 TeV x 1 TeV (6.3 km circumference)

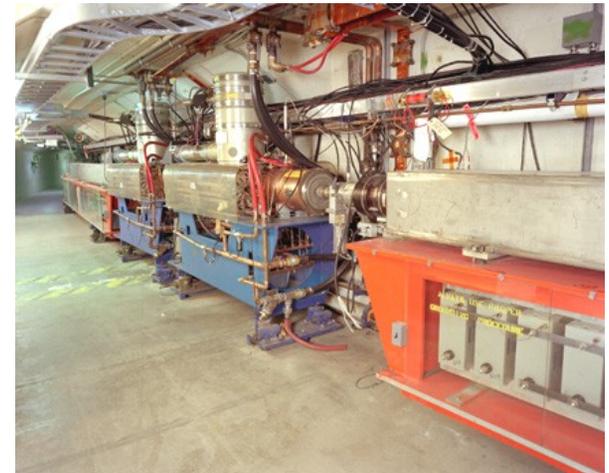




**Cockcroft-Walton 750 KeV**  
*velocity = 0* → *0.04 c*



**LINAC 400 MeV**  
*0.71 c*



**Booster 8 GeV**  
*0.994 c*



**Main Injector 150 GeV**  
*0.994 c* → *0.99998 c*



**Antiproton "Bottle"**  
**@ 8 GeV**

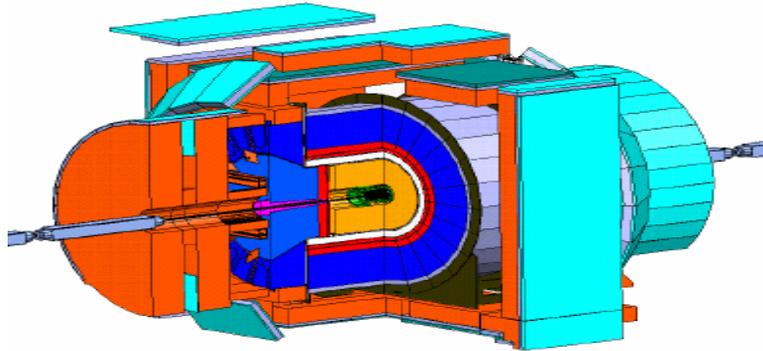


**Tevatron 1000 GeV = 1 TeV**  
*0.99998 c* → *0.9999995 c*

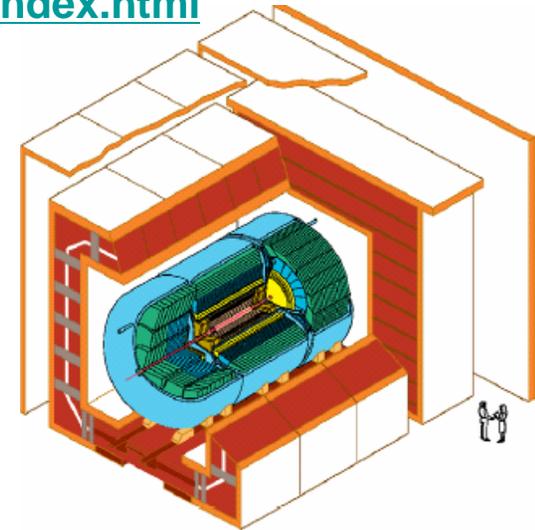


# CDF & D-Zero Experiments

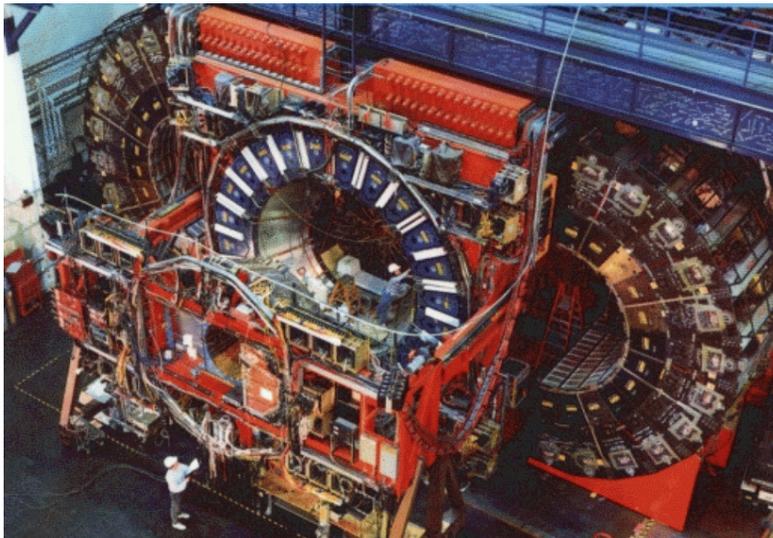
[http://www.fnal.gov/pub/now/live\\_events/index.html](http://www.fnal.gov/pub/now/live_events/index.html)



CDF Detector



DØ Detector

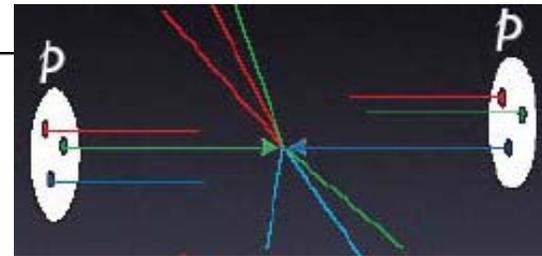
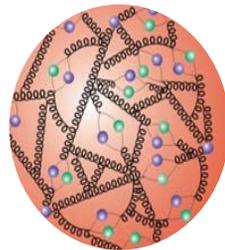
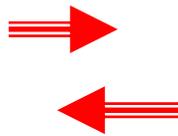
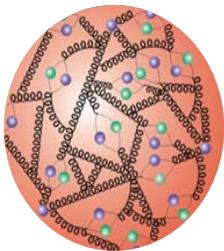
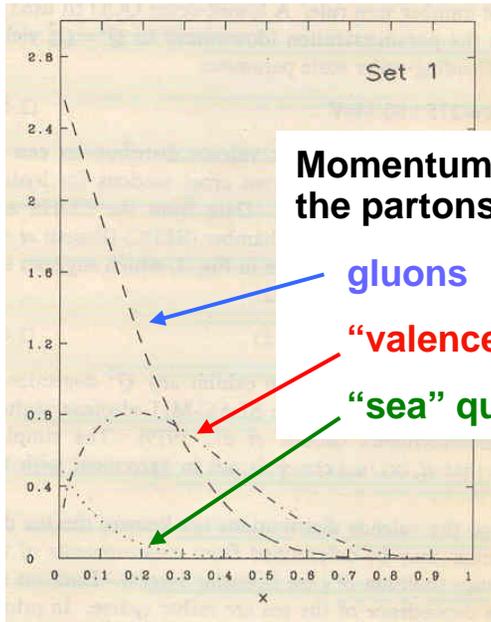




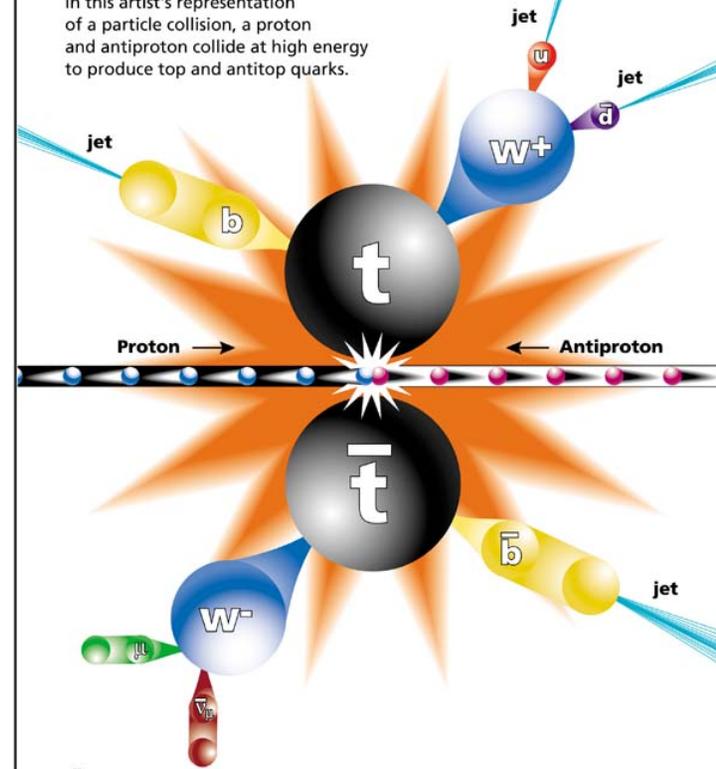
# Quarks & Gluons

$$E = mc^2$$

protons are bags (garbage cans) of quarks & gluons (partons)

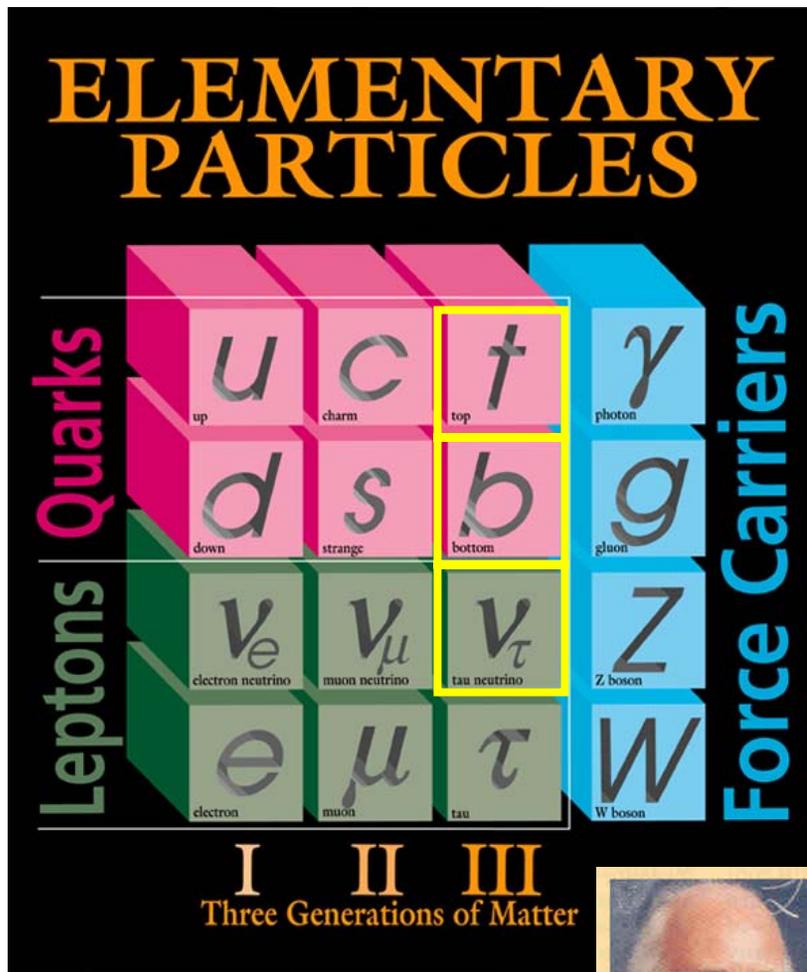


In this artist's representation of a particle collision, a proton and antiproton collide at high energy to produce top and antitop quarks.



Fermilab 95-754

# Our “Periodic Table”



Quarks, Leptons, & Forces

**b, t,  $\nu_\tau$**  were discovered at FNAL

Electromagnetism

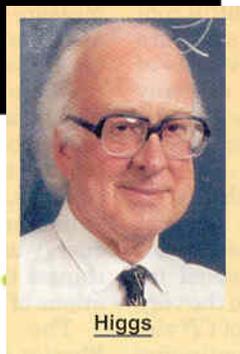
Strong Nuclear Force

Weak Nuclear Force  
(radioactive decay)

Gravity is too weak  
for Fermilab to study

fundamental particles  
no size – without parts  
can't break them apart  
(at least with today's  
accelerators)

Looking for Higgs at Tevatron today!



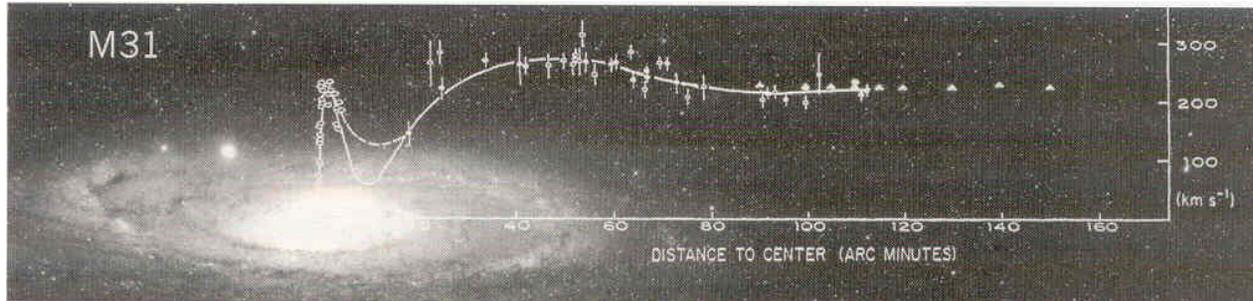
Higgs

Design Effort



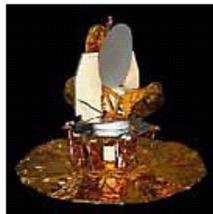
# dark matter & dark energy in the universe

**“dark” => doesn't emit or absorb light**

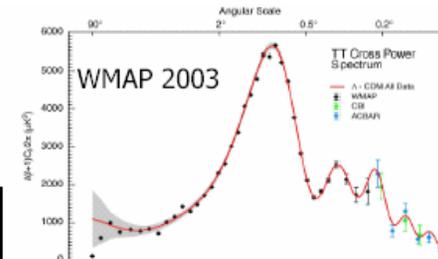
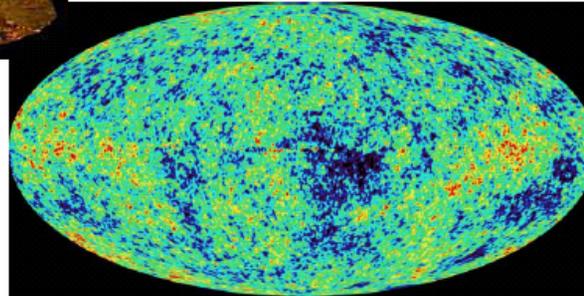


Rotational velocity of stars in galaxies (should fall as 1/r)  
 Clumpiness of cosmic microwave background radiation

WMAP satellite



About six to seven times more mass in the universe ( $27 \pm 4\%$ ) than there is baryonic matter ( $4.4 \pm 0.4\%$ )



What is this stuff? How can we get a firmer understanding of it?

Accelerators

**Rate of expansion of universe seems to be increasing! Dark Energy**

**Much more mass-energy than (known) quarks & leptons!**

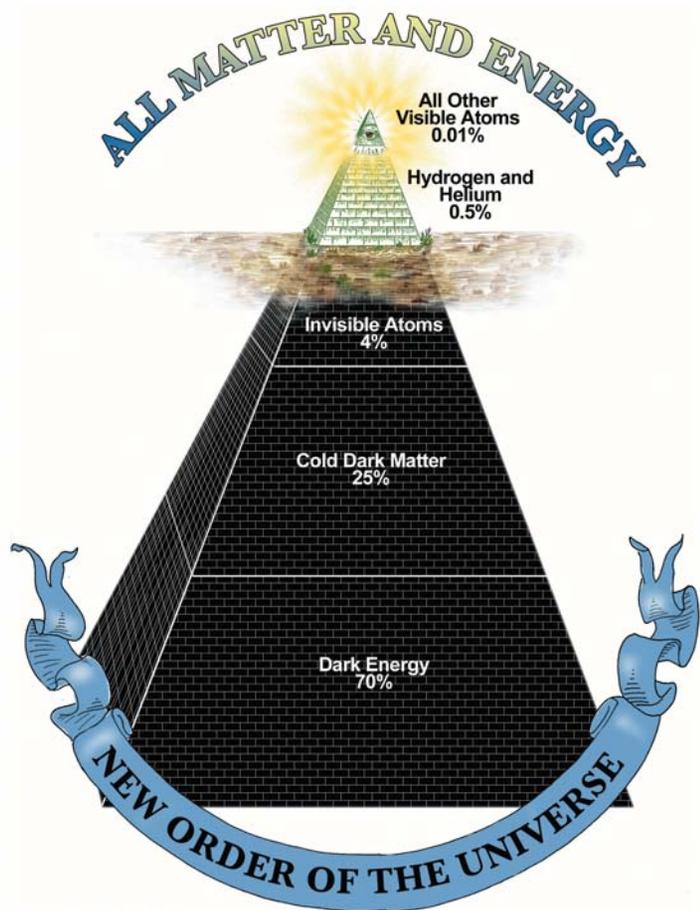
**We only know (understand?)  $\leq 5\%$  !!!**

***Whoops!***

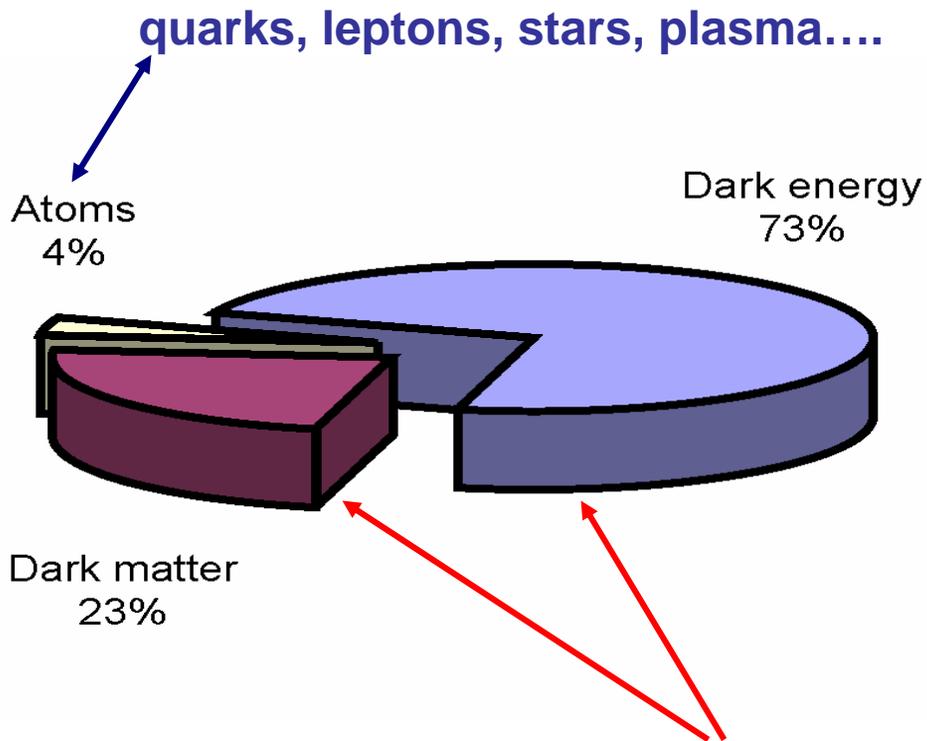


Luminous matter (pink): Plasma - Chandra X-ray

Total matter (blue): Optical (gravitation lensing) – Hubble



© 2006 Abrams and Primack, Inc



**So what is all of this “stuff”?**

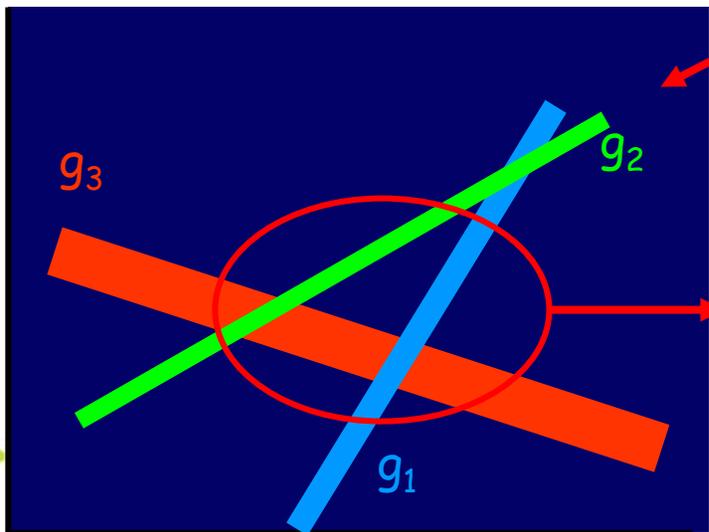
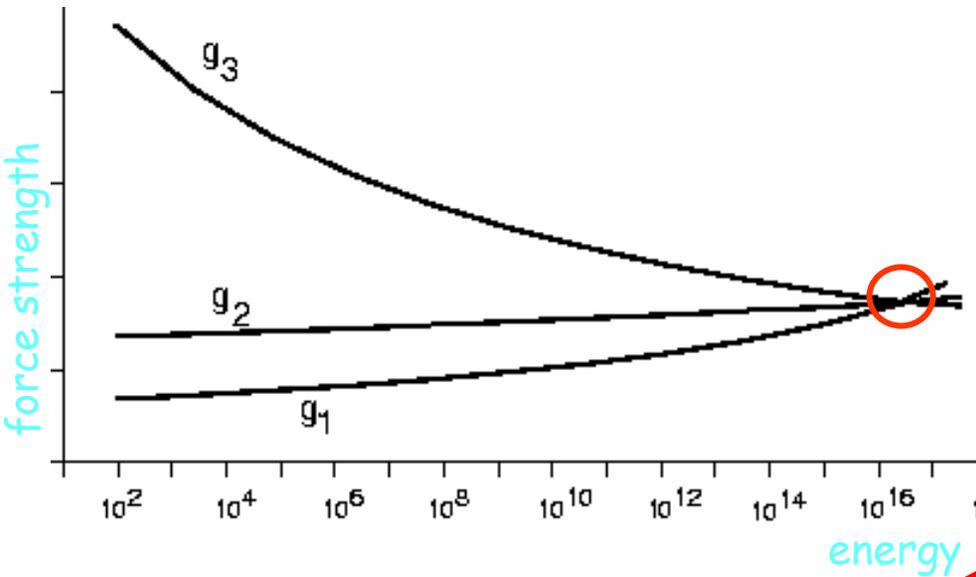
**I thought we knew  
what the universe is all about!**



# Seeking Unification

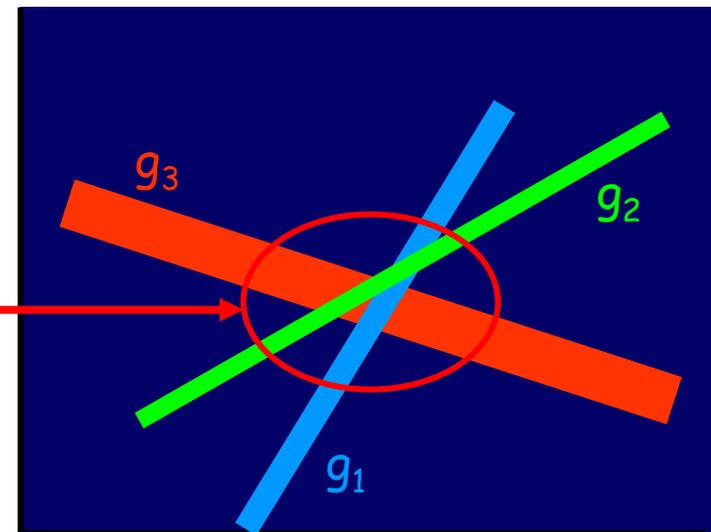
Present data show that the three forces (strong, EM, weak) have nearly the same strength at very high energy – indicating unification??

A closer look shows it's a near miss!



With **supersymmetry**, ILC and LHC can find force unification!

Global Design Effort



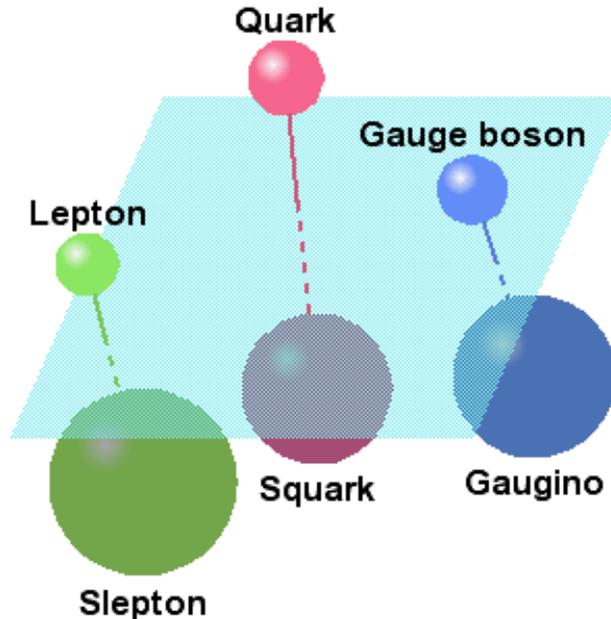
## *SuperSymmetry*

**Bosons**  $\longleftrightarrow$  **Fermions**

**Particles**

$S = 1/2$     $S = 1$

Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$	$Z$
	$e$	$\mu$	$\tau$	$W$
Quarks	$u$	$c$	$t$	$\gamma$
	$d$	$s$	$b$	$g$



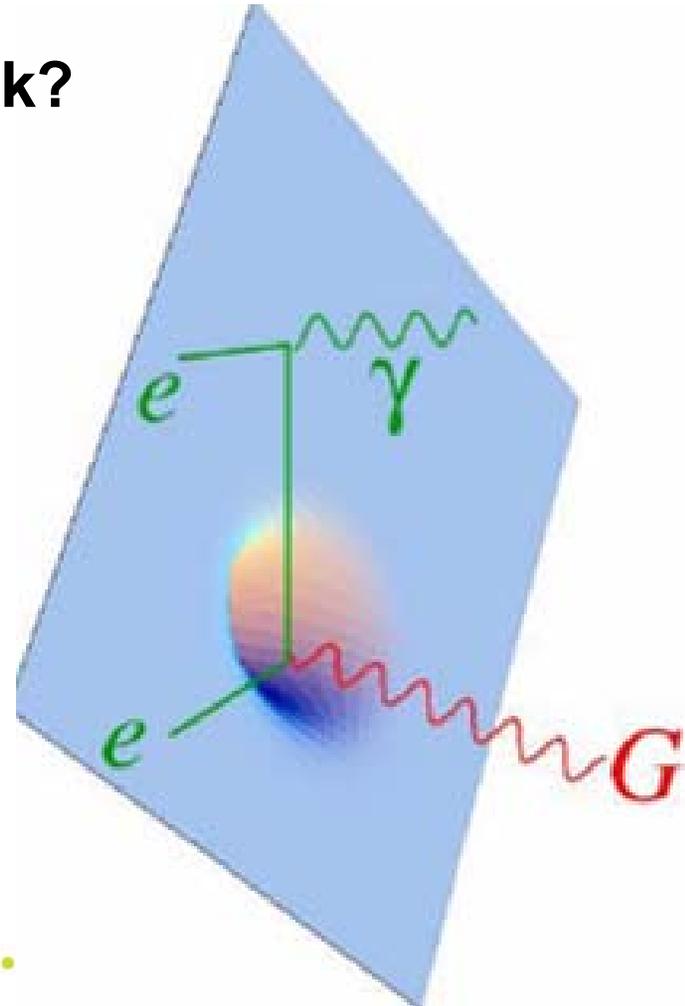
**SUSY Sparticles**

$S = 0, 1$     $S = 1/2$

Leptons	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{Z}$
	$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{W}$
Quarks	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\gamma}$
	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	$\tilde{g}$

How can we observe it?

Is that why gravity is so weak?



# Today's Questions:

1. Are there undiscovered principles of nature:  
**New symmetries, new physical laws?**
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter?  
**How can we make it in the laboratory?**
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

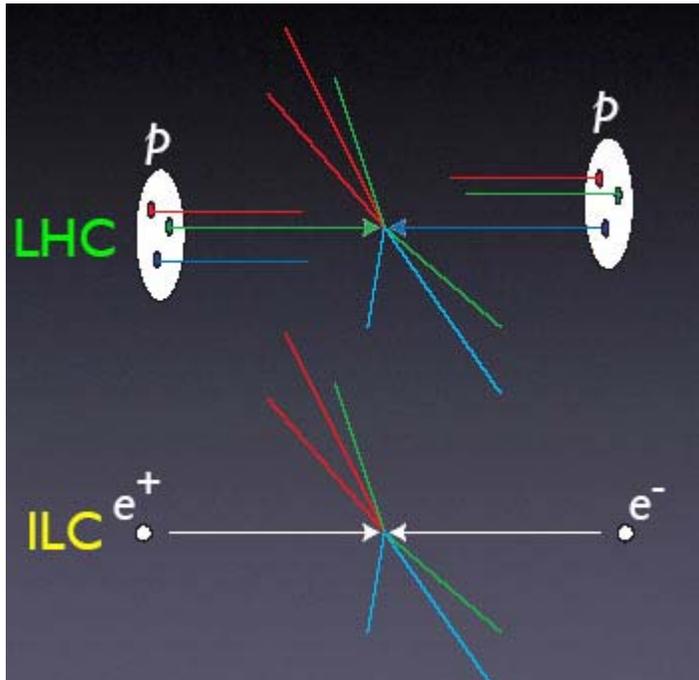


# CERN is now building the LHC

## a 7 TeV x 7 TeV Collider



Large Hadron Collider (LHC)  
27 km circumference  
Test run in late 2007 –  
Operations in 2008  
Fermilab's 1 TeV x 1 TeV  
Tevatron is > 20 yrs old  
Energy Frontier will pass  
to Europe (*not the U.S.!*)  
DOE plans to shut down  
Tevatron in 2009  
(still do neutrino physics)  
**What will Fermilab do next?**



hadron collider: a blunt object!

high raw energy for discovery

collides bags of partons, each w/  
fraction of proton's energy

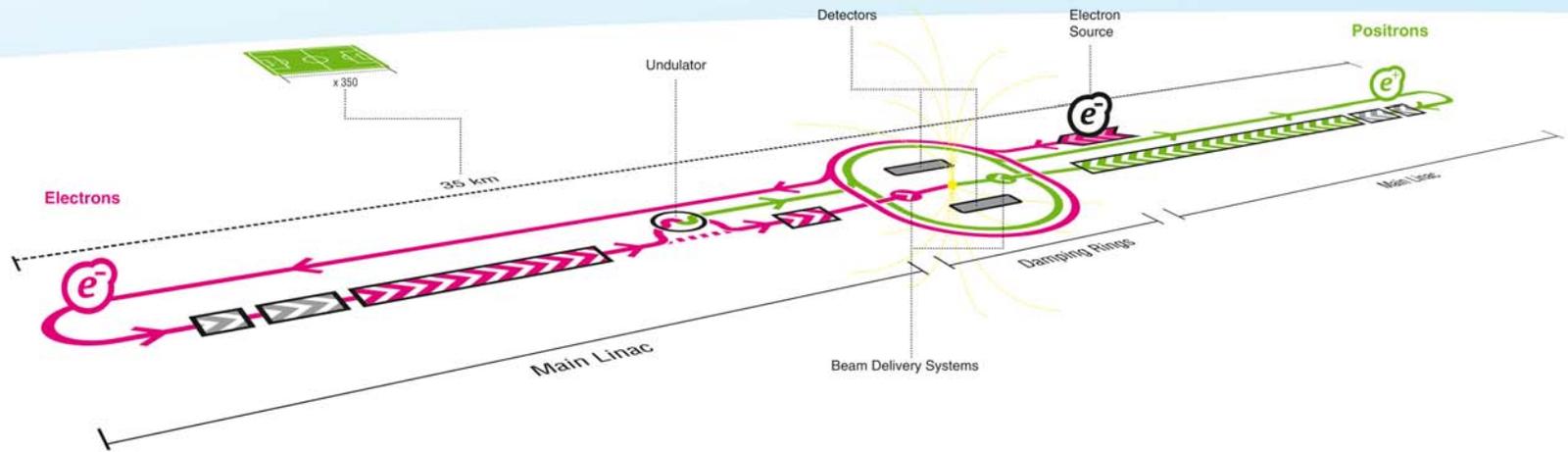
but, colliding electrons & positrons:  
elementary, fundamental particles  
point-like, without internal structure  
all energy is available to interact  
can understand initial conditions

→ a tool for precision measurements  
complementary to hadron colliders

**rationale for the International Linear Collider (e+e-)**



# The International Linear Collider



a 250 GeV x 250 GeV  $e^+e^-$  collider ~ 31 km long!

The **draft** Reference Design Report (RDR) for the ILC including **preliminary** cost and labor estimates was made public in Beijing, Thursday, February 8, 2007

**ilc** international linear collider

FOR COLLABORATORS   FOR THE PRESS   FOR COMMUNICATORS   FOR STUDENTS AND EDUCATORS   SEARCH  GO

**What is the ILC?**  
Global Design Effort  
ILC Document Server/ILC Agenda Server  
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Reports and Statements  
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Beijing ILC Workshop 2007, 4-7 February (Image Courtesy IHEP)

**Current News**

**From *iTWire*** | 11 February 2007  
[International Linear Collider proposed to explore origins of universe](#)  
"An international high-energy physics research project was proposed on Thursday, February 8, 2007, at a meeting in Beijing, China. The project intends to design and build the International Linear Collider that is proposed to consist of a 30-kilometer (20-mile) linear particle accelerator..."

**From *Zeit online*** | 10 February 2007  
[Wer soll das bezahlen?](#)  
"5,5 Milliarden kostet einem neuen Bericht zufolge der modernste Teilchenbeschleuniger der Welt. Deutsche Physiker würden ihn gerne nahe Hamburg aufbauen. Von Björn Schwentker..."

**From *Le Figaro*** | 10 February 2007  
[Un accélérateur pour éclairer le big bang](#)  
"Le schéma technique du futur accélérateur de particules international a été présenté à Pékin. Coût estimé : 5,5 milliards d'euros."

**Features**

**Draft Reference Design Report Released**

- [Report](#) (10MB pdf)
- [Report](#) (10MB pdf) (Mirror-Asia)
- [RDR Summary](#) (1.6MB pdf)
- [Companion Document](#) (1.5MB pdf)
- [The Estimate Explained](#) (pdf)
- [ILC by the Numbers](#) (pdf)
- [More materials and images](#)

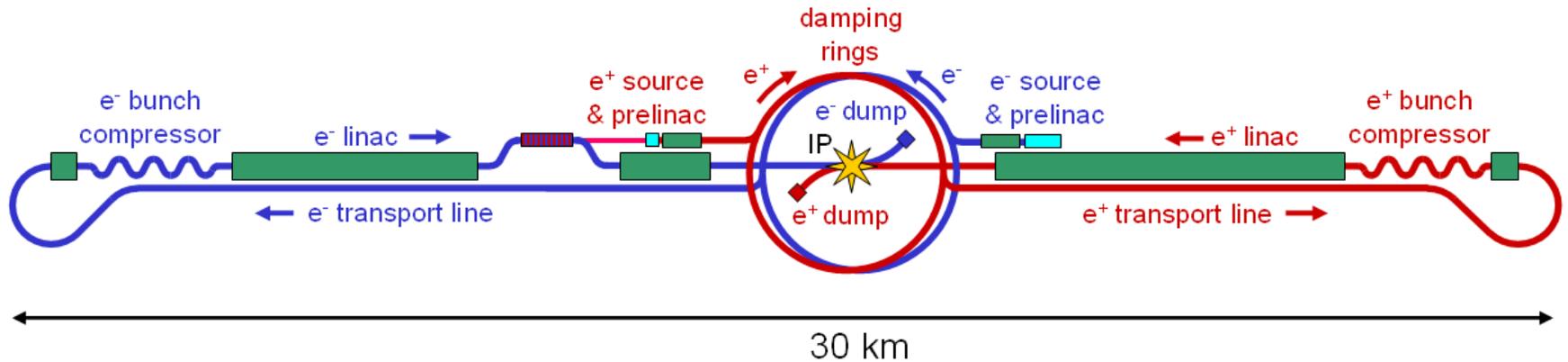
**For the Press**  
Get additional information about the ILC at our [Media Advisory](#) page.

**ILC NewsLine** | 8 February 2007

Ni Hao! View some highlights from the Beijing ILC Workshop.

Report,  
Companion  
Document,  
Graphics,  
and more...

# Main components of the ILC



**peak Luminosity =  $2 \times 10^{34} \text{ cm}^{-2}\text{sec}^{-1}$**

that means if you have a reaction cross section of

$$\sigma = 10^{-34} \text{ cm}^2$$

you would get an event rate of 2 events per second



# Gee Whiz (all pushing industry):

16,088 SC Cavities: 9 cell, 1.3 GHz

1848 CryoModules: 2/3 containing 9 cavities,  
1/3 with 8 cavities + Quad/Correctors/BPM

613 RF Units: 10 MW klystron, modulator, RF distribution

72.5 km tunnels ~ 100-150 meters underground

13 major shafts  $\geq$  9 meter diameter

443 K cu. m. underground excavation: caverns, alcoves, halls

10 Cryogenic plants, 20 KW @ 4.5° K each

plus smaller cryo plants for e-/e+ (1 each), DR (2), BDS (1)

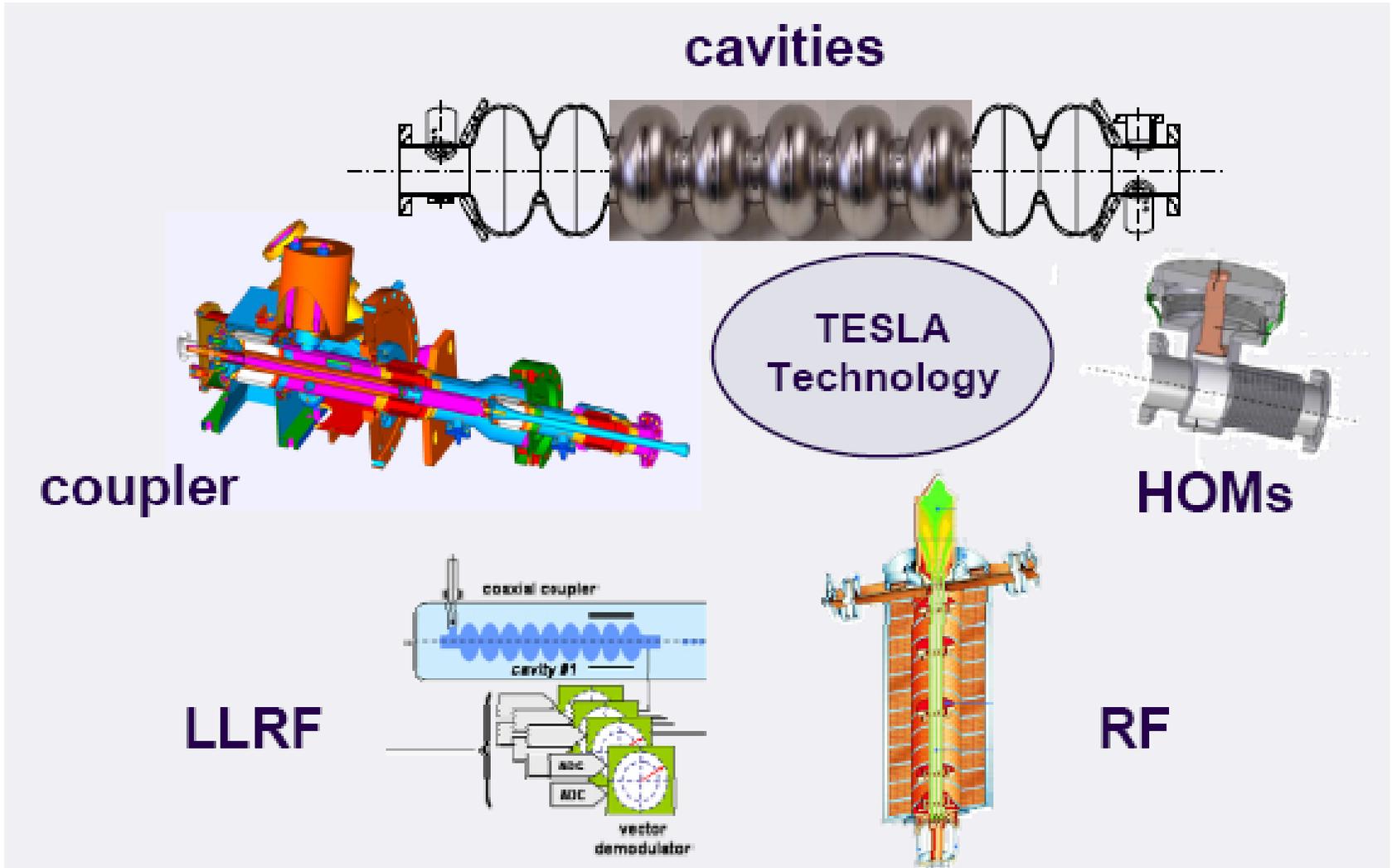
92 surface “buildings” (for Americas’ site), 52.7 K sq. meters

230 M Watts continuous power, 345 MW installed capacity

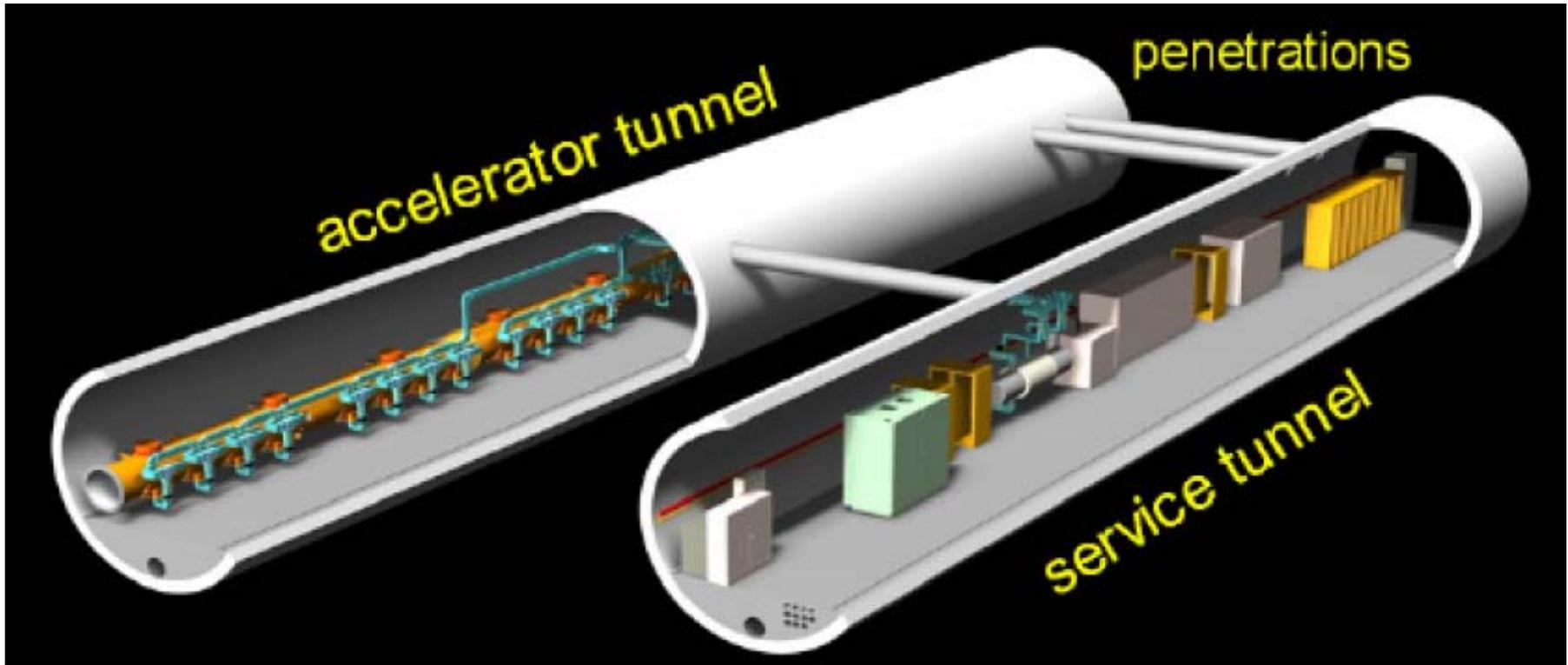
13,200 magnets – 18% superconducting



# Superconducting RF Technology



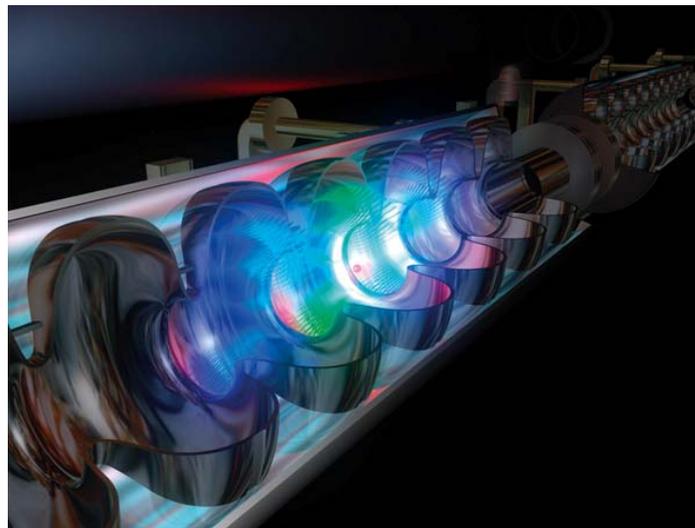
# Main Linac Double Tunnel



**~ 350 - 450 feet deep at Fermilab  
minimal surface disturbance  
off the Fermilab site**

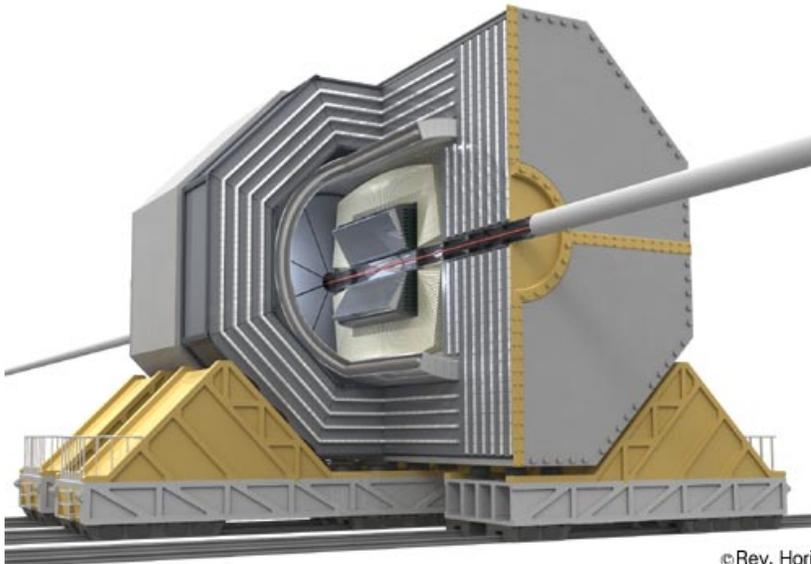
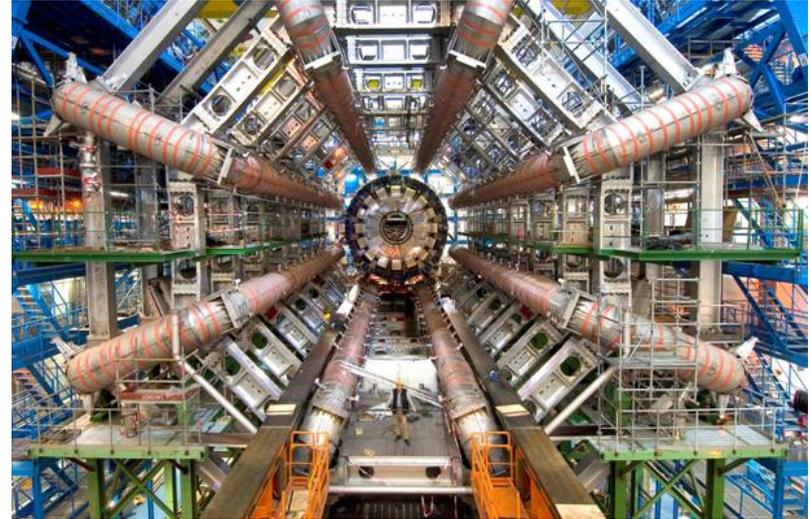
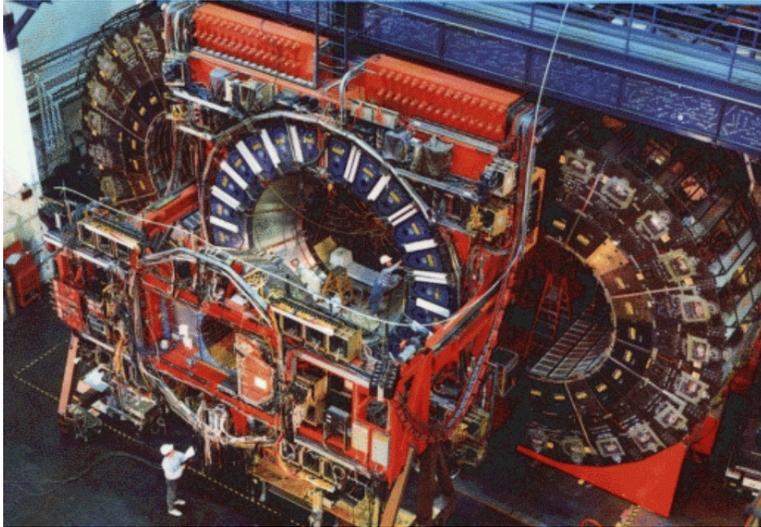


# ~ 16,000 RF Cavities – the accelerator!

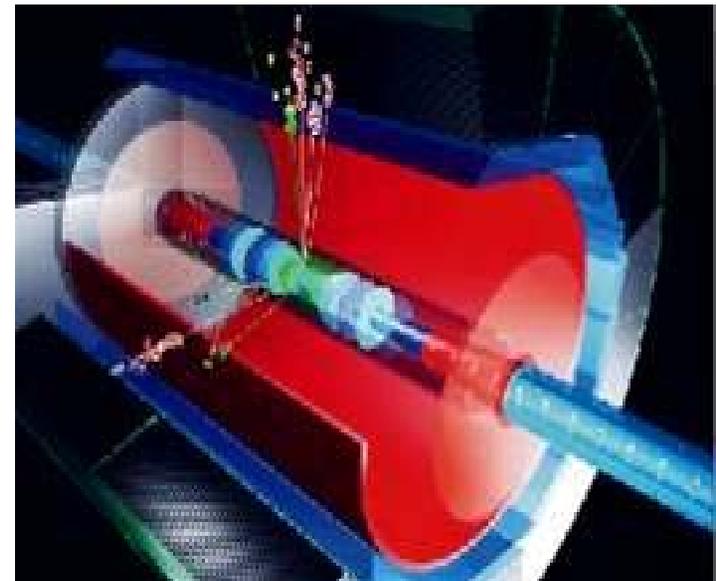




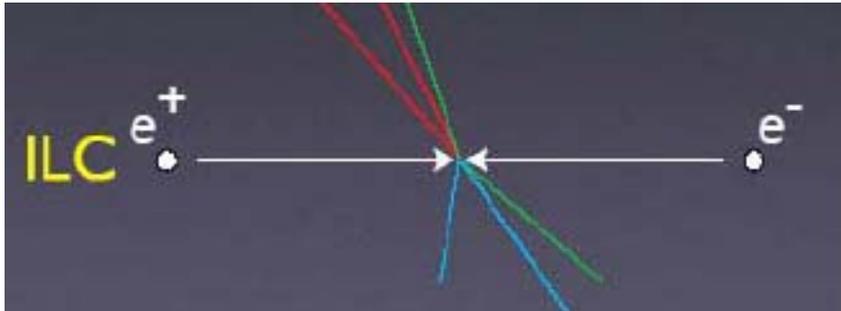
# Detectors: Fermilab, LHC, ILC



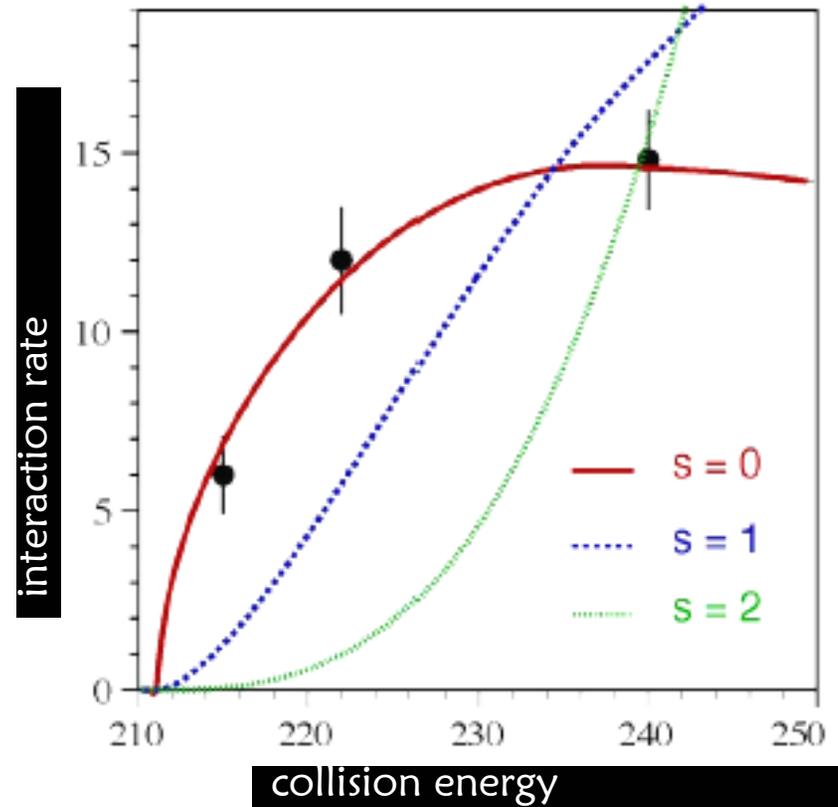
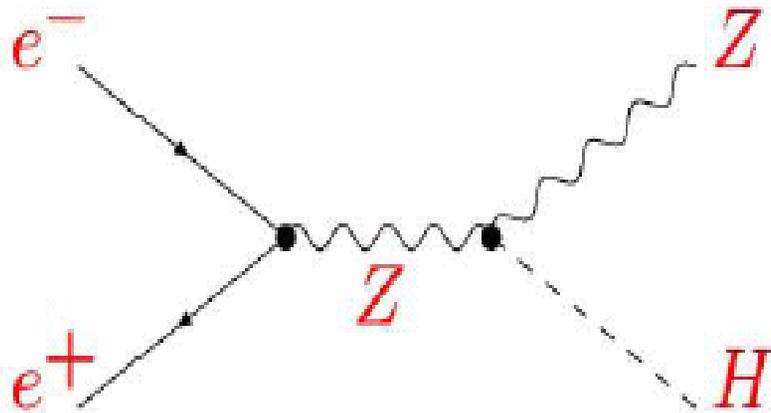
©Rey. Hori



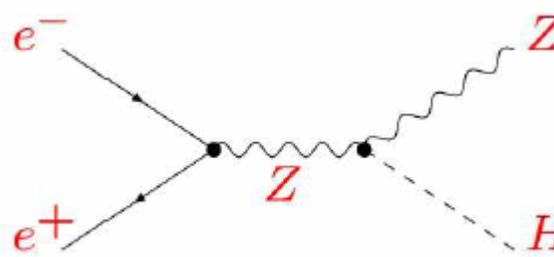
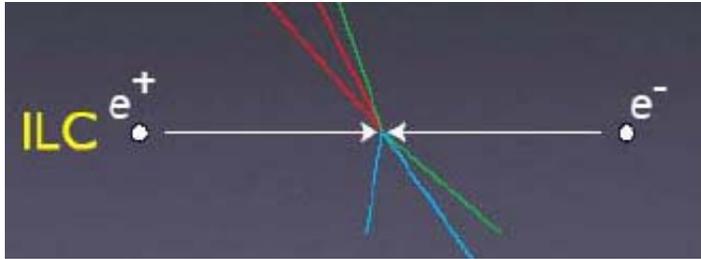
# How we can use the ILC to learn the properties of the Higgs?



Higgs must have Spin = 0



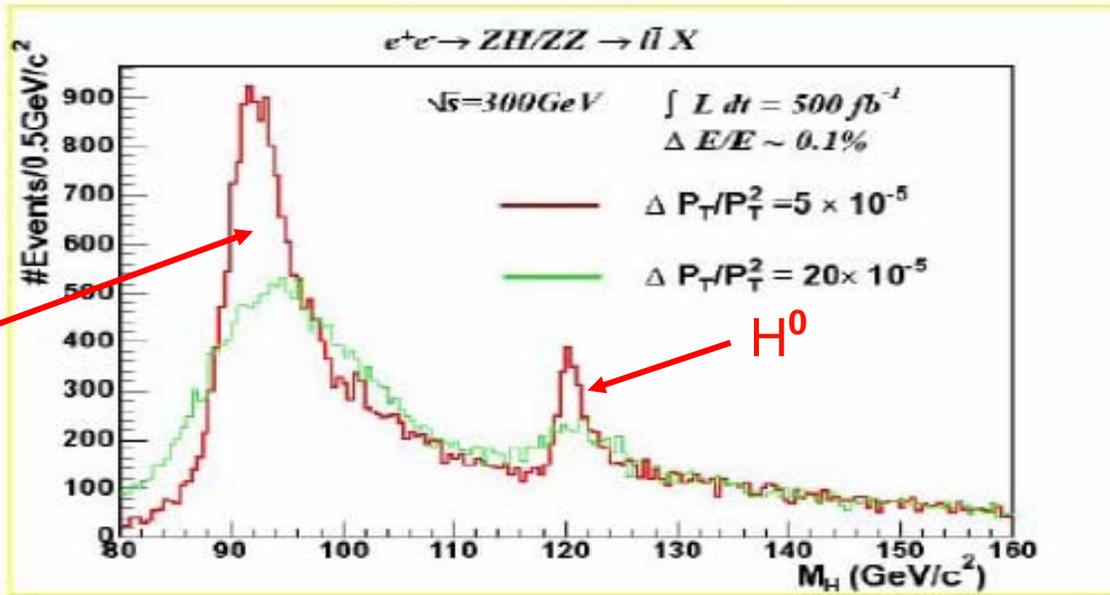
we know  $e^+e^-$  energy  $\rightarrow$  tagged  $H^0$



observe Z, then

infer  $X = H$  or something else (unbiased!) and then study Higgs

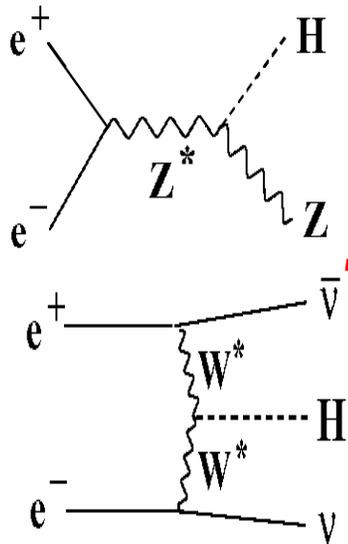
e.g: The Higgs tagging mode  
 $e^+e^- \rightarrow ZH, Z \rightarrow \ell^+\ell^-$



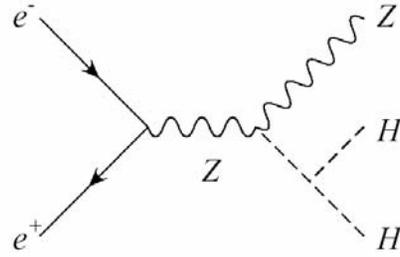
Background  
 $e^+e^- \Rightarrow Z^0 Z^0$

$H^0$

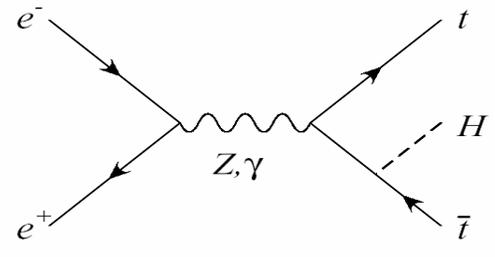
## Gauge Coupling



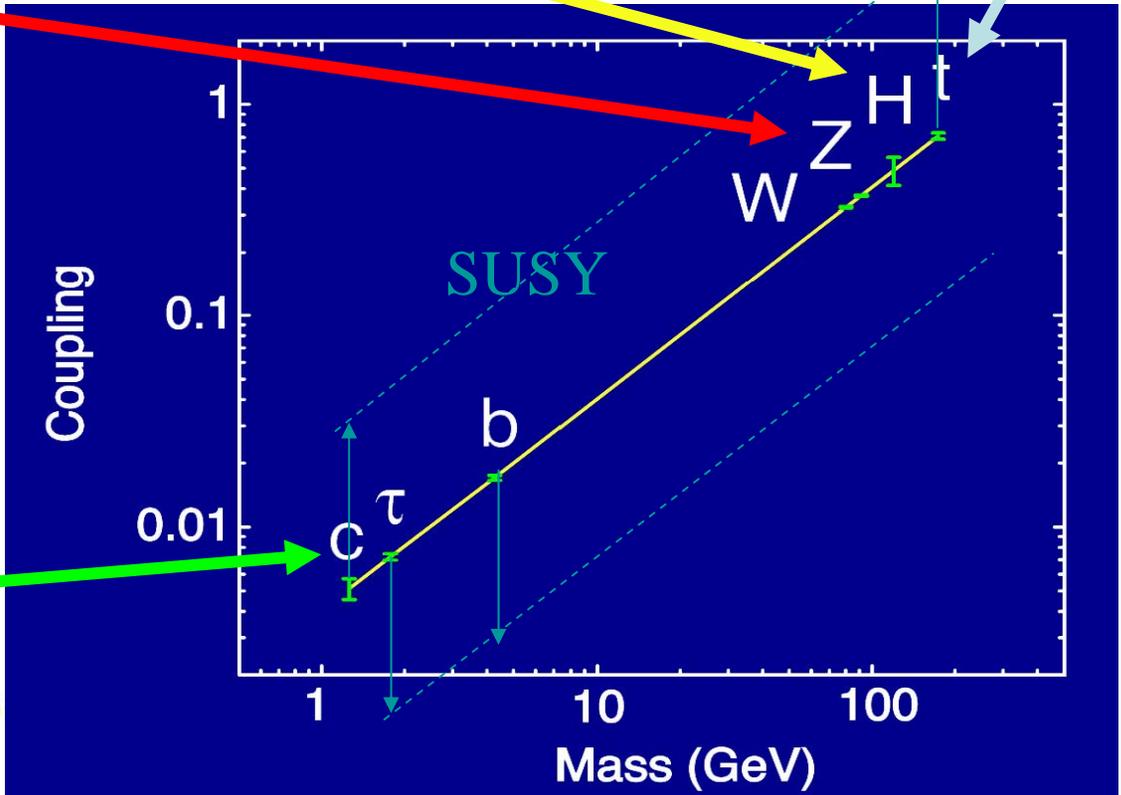
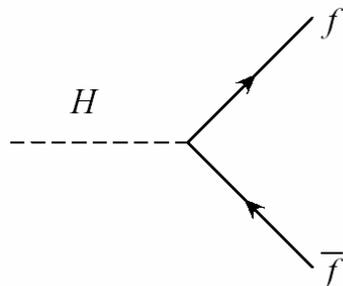
## Self-coupling



## Top Yukawa coupling



## Yukawa coupling

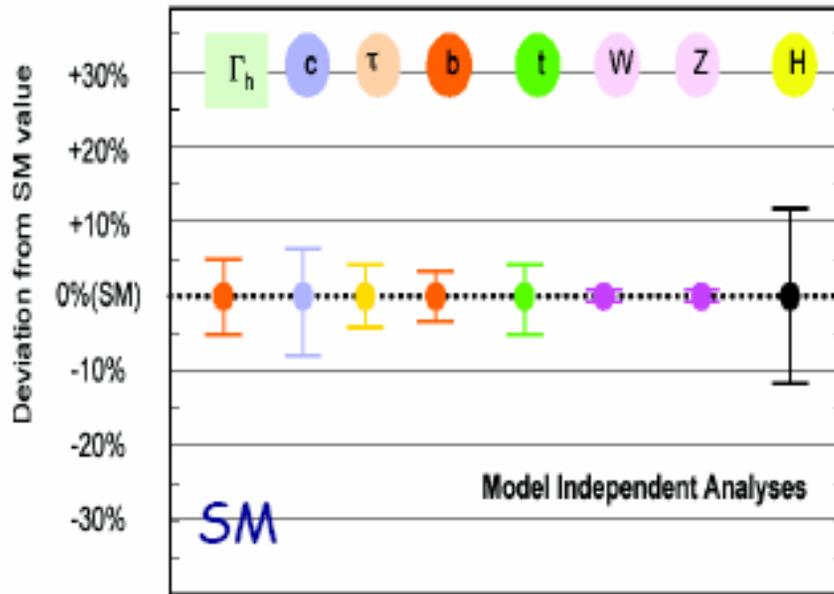




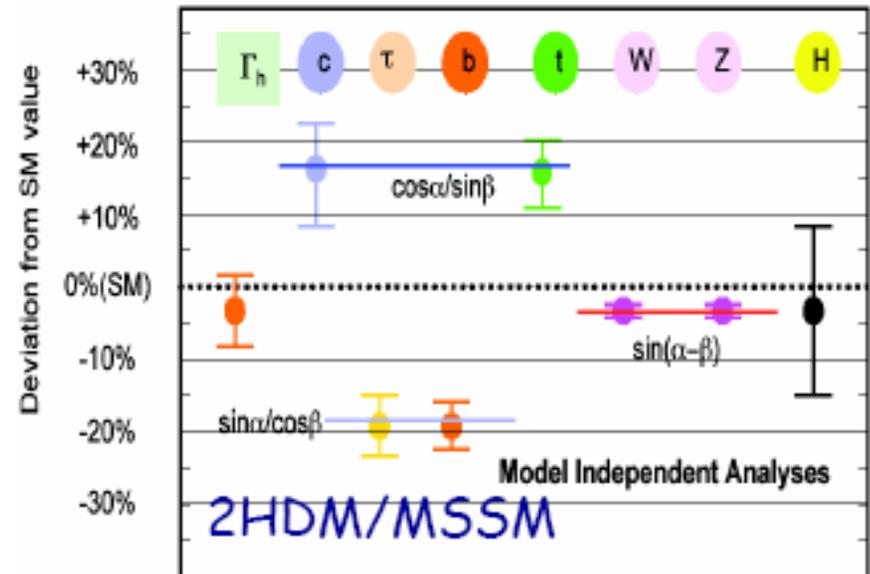
# Determine the Higgs Couplings

Do they agree with what we expect  
in the “Standard Model” (SM)?

Or is there new, unknown physics occurring?

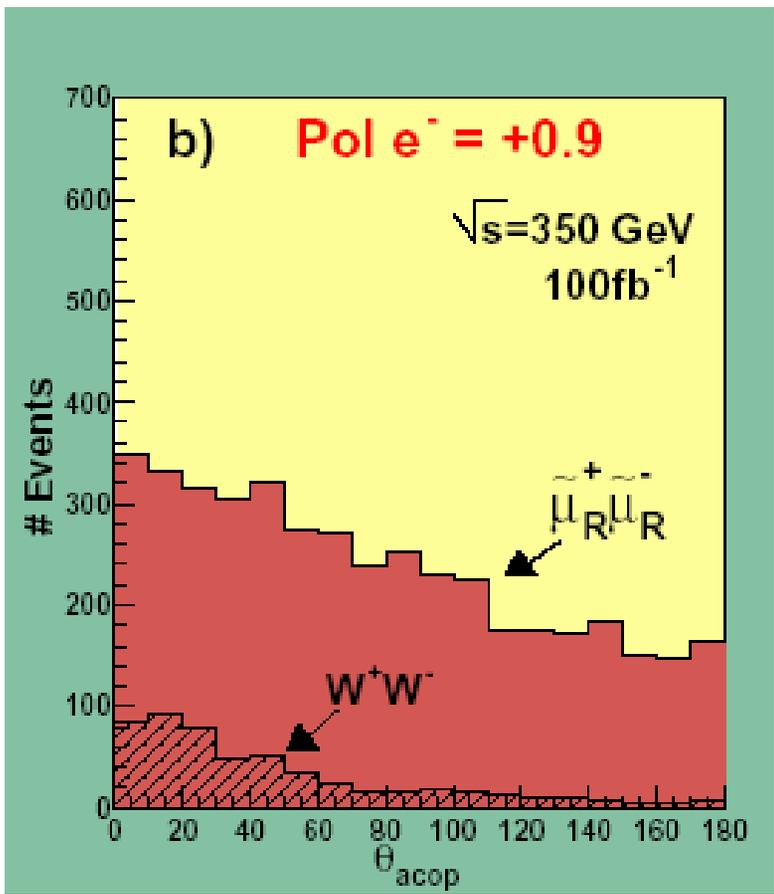


Yamashita et al

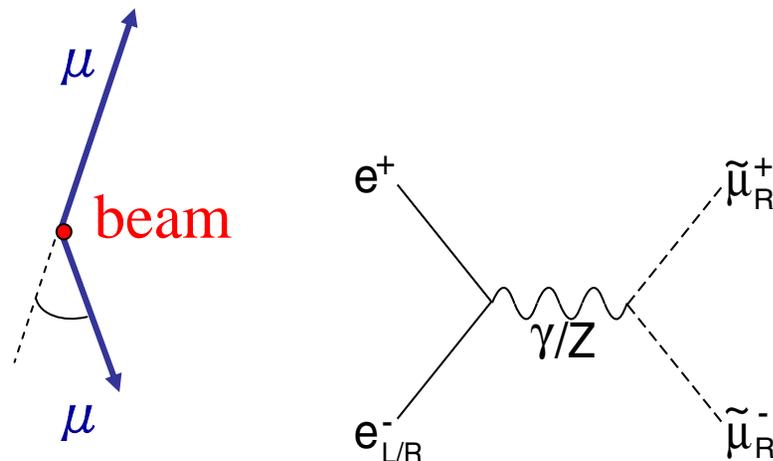


Zivkovic et al

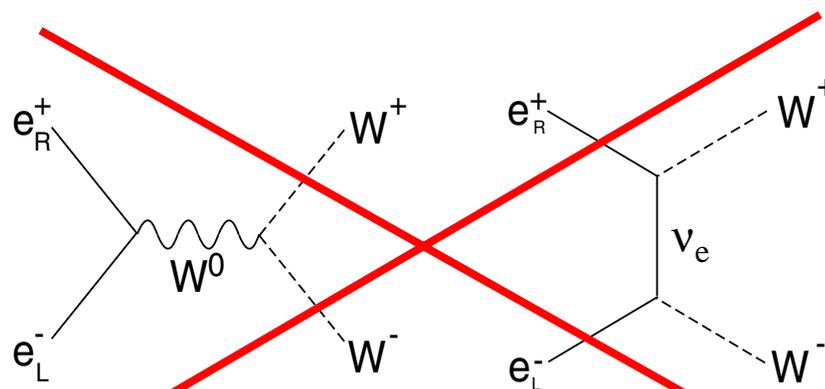
# Power of electron polarization at ILC



Polarized (90%  $e^-_R$ )

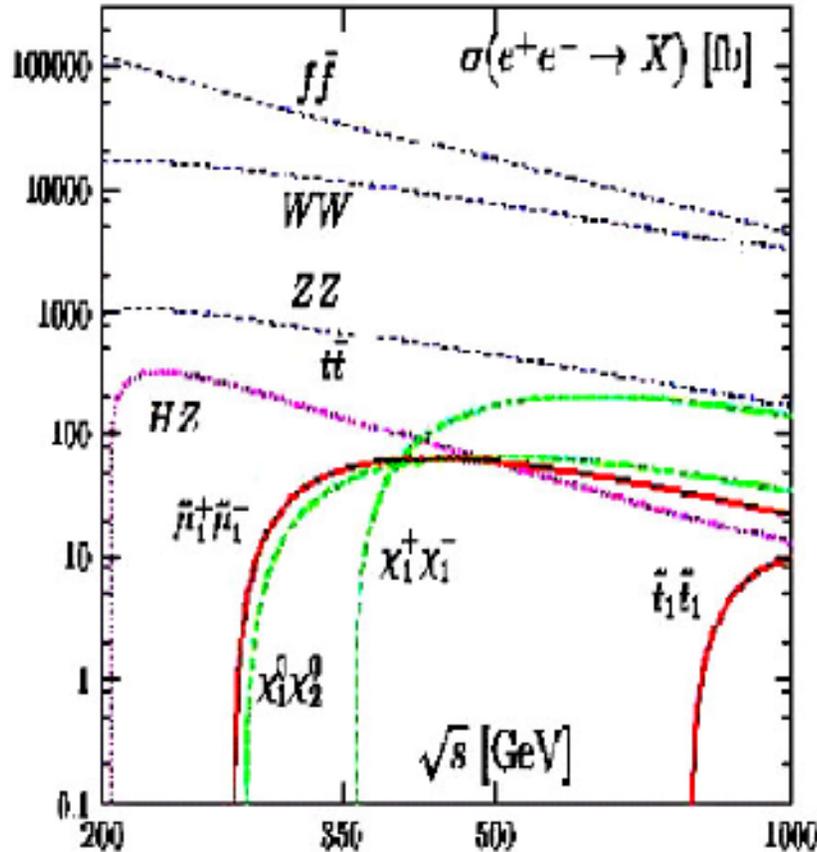


Scalar muon production



Background signal

## $e^+e^-$ production crosssections



- Measure quantum numbers
- Is it MSSM, NMSSM, ...?
- How is it broken?

**ILC can answer these questions!**

- tunable energy
- polarized beams



# What, \$, When, Where?

**500 GeV  $e^+e^-$  collider (250 GeV x 250 GeV),  
but include sizing to enable upgrade to 1 TeV,  
e.g. beam stops, BDS tunnels, identify land**

**Cost ~ \$ 6.7 B (2007\$) (~ same for 3 regions sites)  
plus 13,000 person-years laboratory labor  
plus escalation (inflation) and contingency**

**We are hoping that Fermilab will be the site,  
also investigated sites in Switzerland & Japan.  
This will be a big international decision!**



# The GDE Plan and Schedule

2005

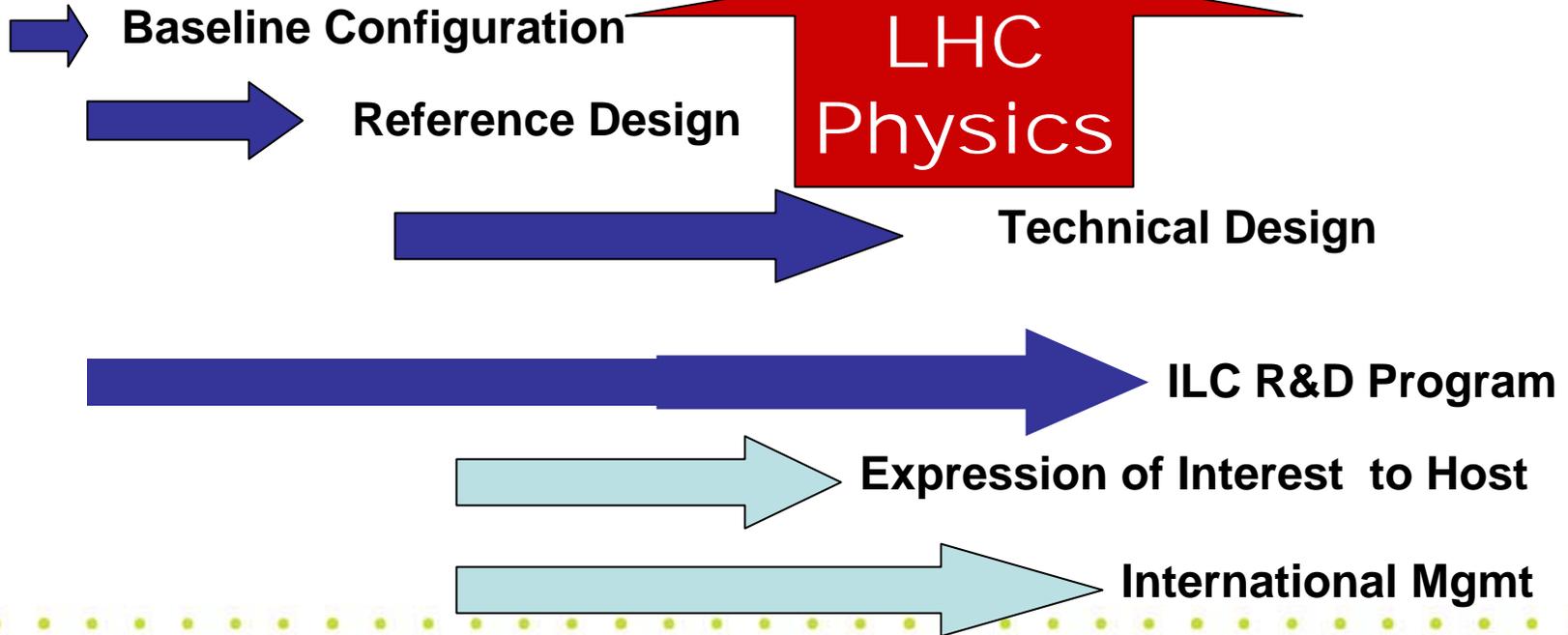
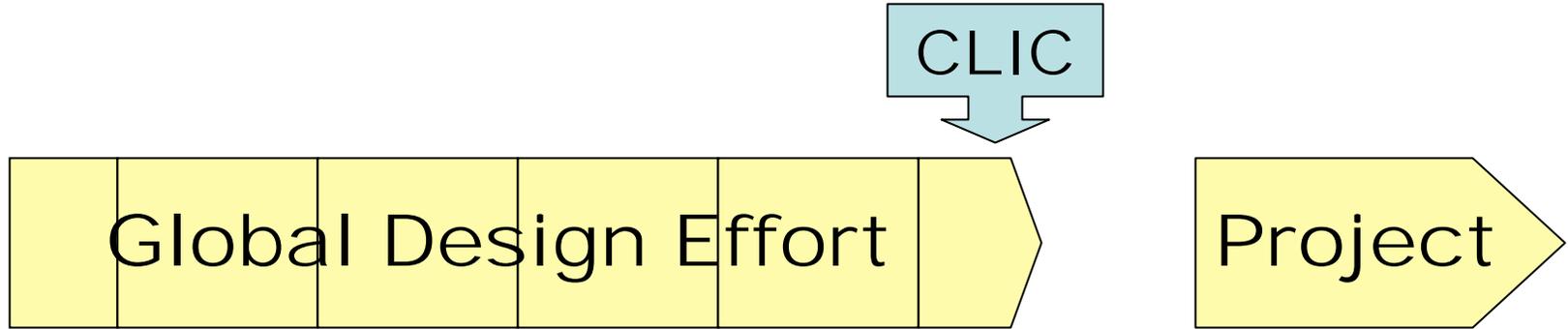
2006

2007

2008

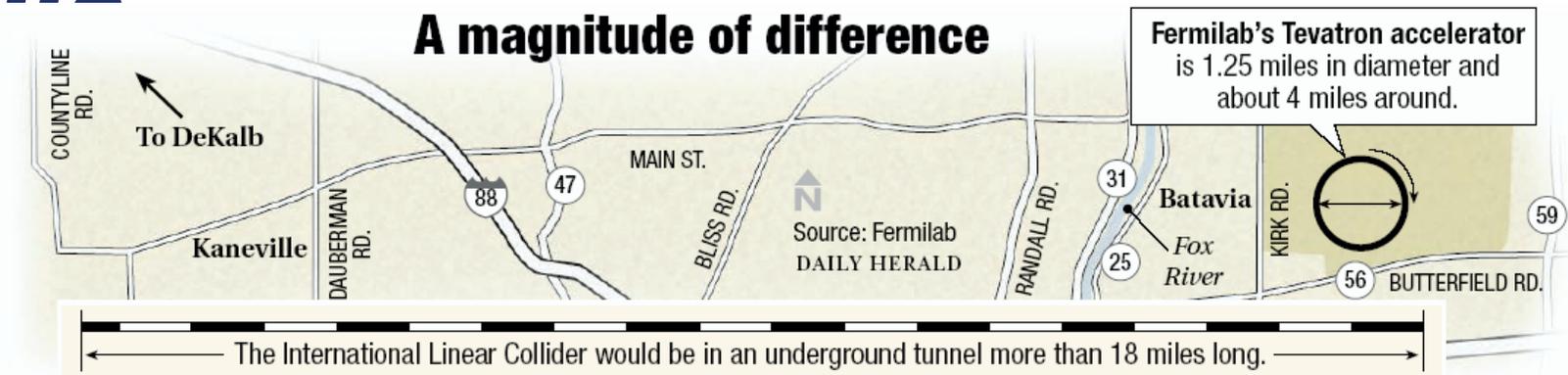
2009

2010

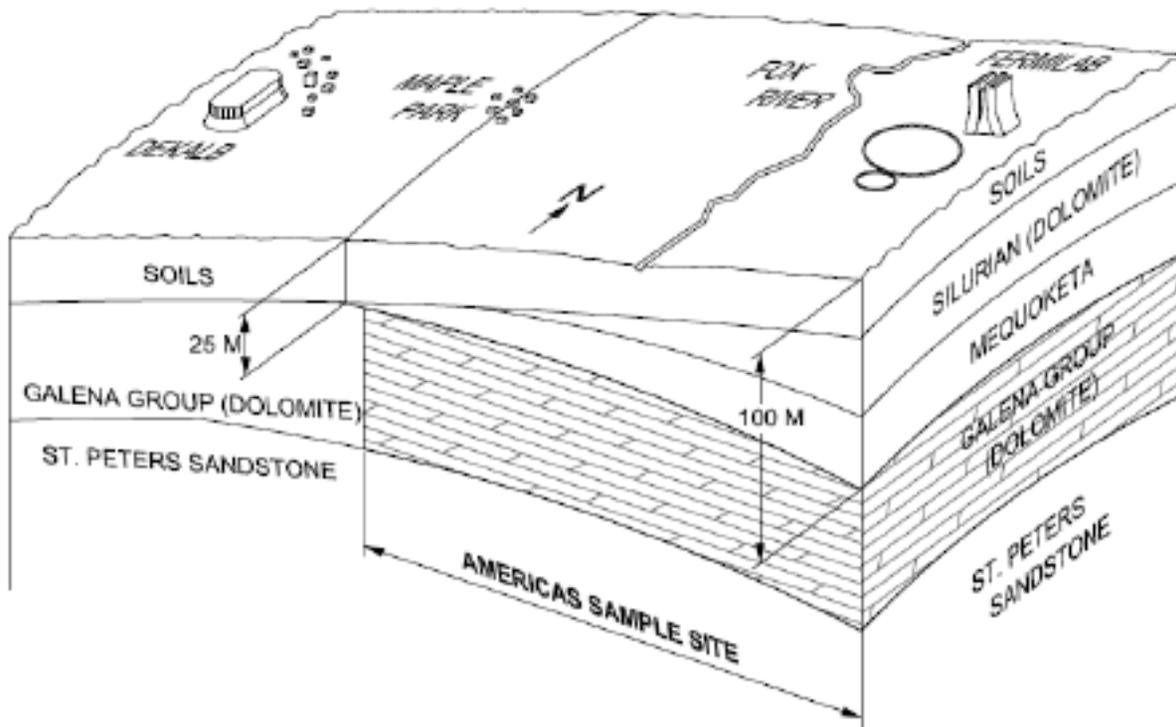


**Global Design Effort**

# A magnitude of difference

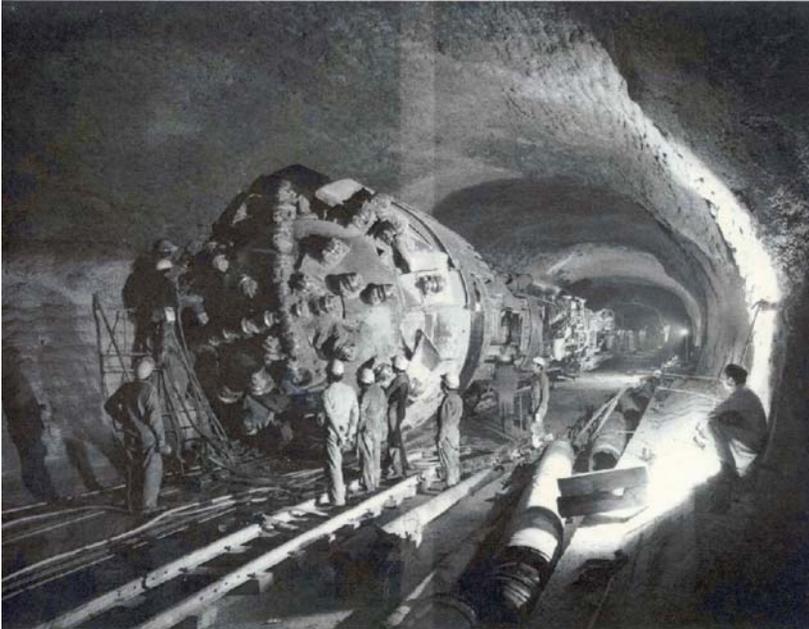


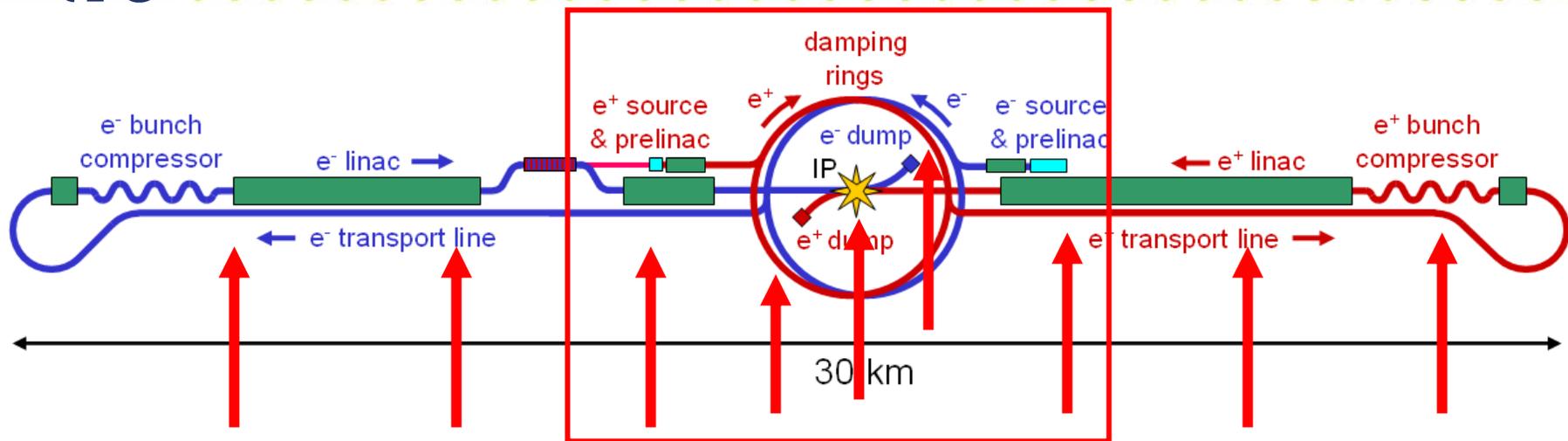
# Americas Sample Plan / Section





# Conco-Western mine – Route 25 & I-88 and TBM (CERN)



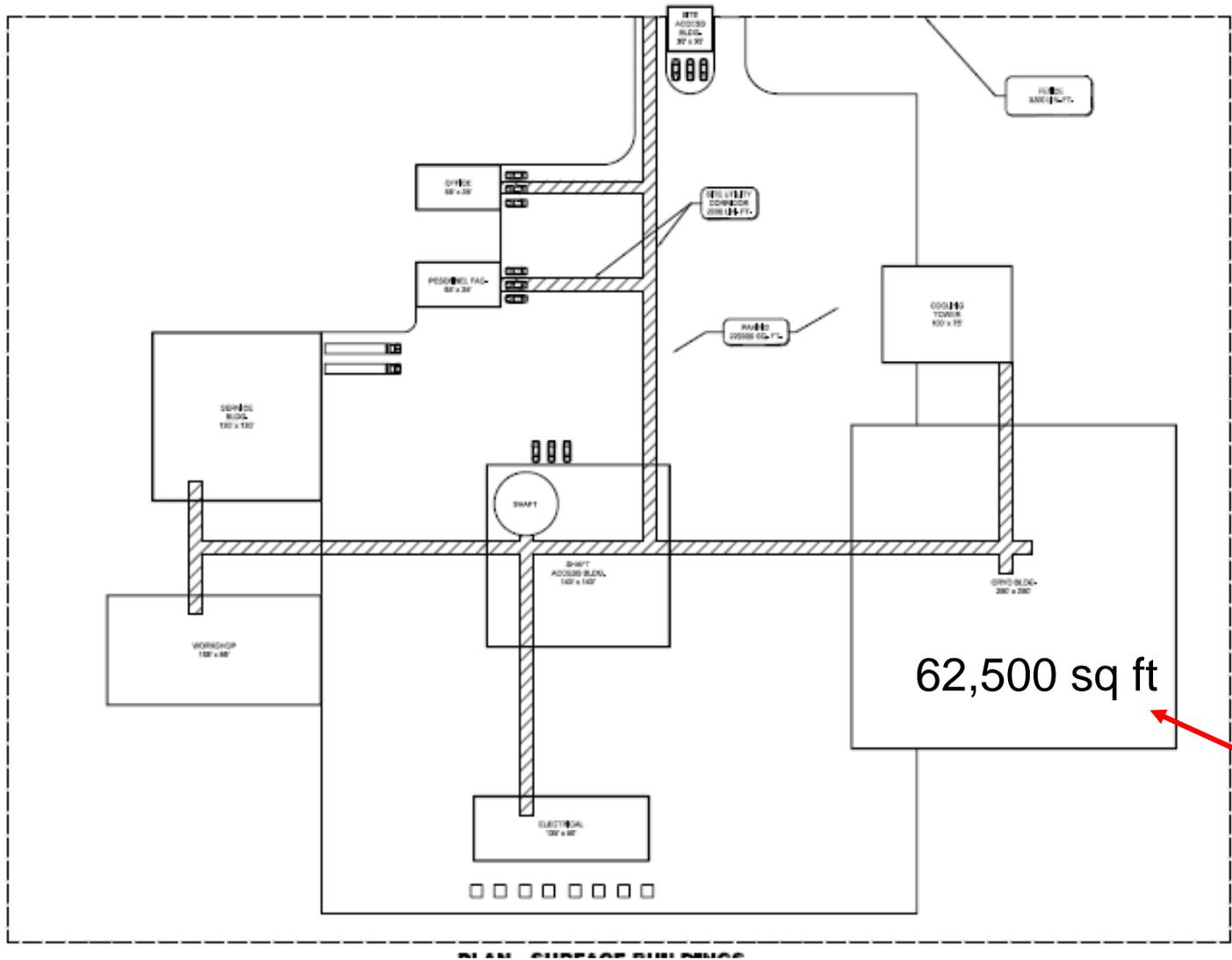


If at Fermilab, the central campus, including experimental hall, 5 major shafts, and service areas would be on the Fermilab site.

The 4 off-Fermilab service sites would have electrical power supplied through the two ILC tunnels.



# off-Fermilab sites (4 @ 500 GeV)



early functional concept

~ 14.5 acres

62,500 sq ft

~ size of the Jewel in Batavia



# Citizens Task Force to Provide Input to Fermilab's Bid to Host the International Linear Collider in Illinois

## Mission of the ILC Citizens Task Force

The ILC Task Force will provide guidance and advice to Fermilab to ensure that community concerns and ideas are included in all public aspects of ILC design to include:

- Orientation of the ILC
  - Location of the underground tunnel
  - Community issues related to locating an underground tunnel
- Surface Structures located off the Fermilab property
  - Locations
  - Aesthetic issues
  - Features that could be included to benefit communities
- Construction of the ILC
  - Timing of activities
  - Safety
  - Mitigating noise, traffic, and other disruptions
- Fermilab-Community Relationships
  - Maximizing economic benefits to the region
  - Communicating and working with neighbors
  - Building effective relationships with local government and communities
  - Strengthening the community role in the long term mission of Fermilab

## Who?

- Residents throughout the region
- Immediate Fermilab neighbors
- Political jurisdictions
- Local business, industry, and real estate
- School districts
- Building trades
- Environment
- Agriculture
- Civic organizations
- Faith-based organizations
- Youth organizations
- Fermilab employees



**That's all folks!**

I'll be happy to answer questions here  
or as part of your tour on the 15<sup>th</sup> floor

<http://www.linearcollider.org>

<http://www.fnal.gov>