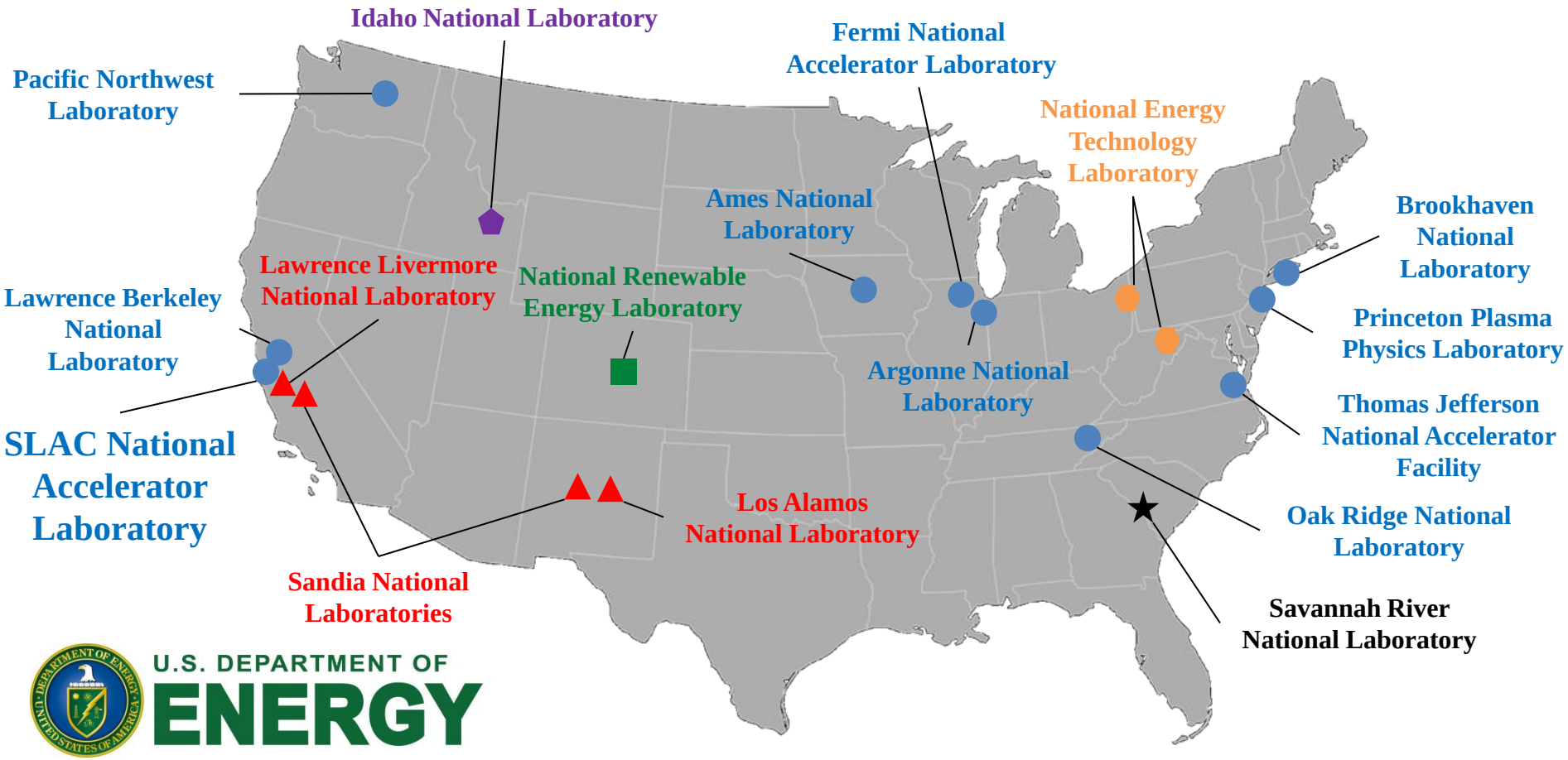

50
SLAC

Welcome!

LINAC: Linear Accelerator
It has driven SLAC science for 50 years

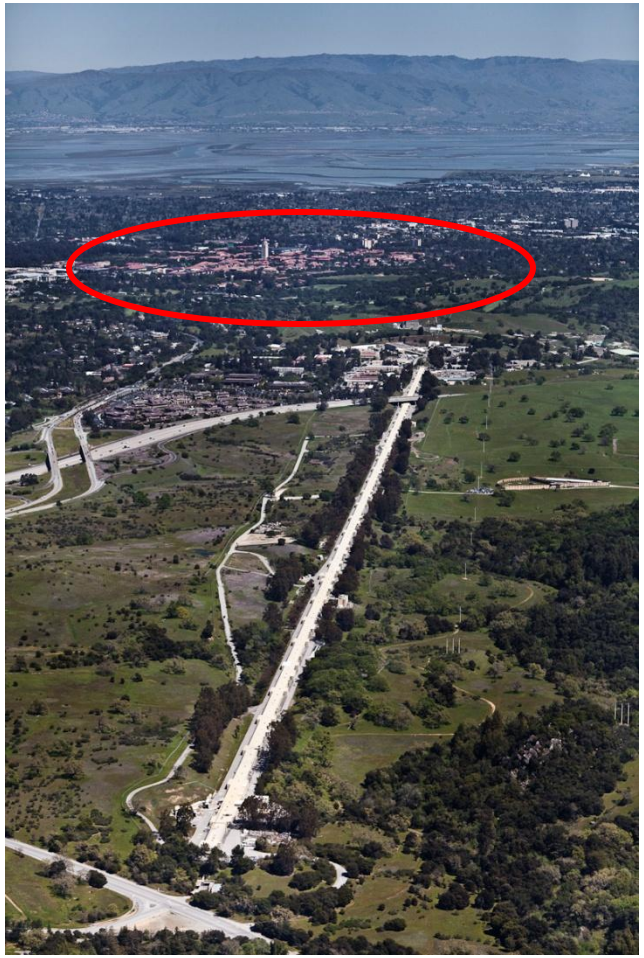
Department of Energy
Office of Science
National Laboratories



U.S. DEPARTMENT OF ENERGY

- National Nuclear Security Administration Lab
- Office of Energy Efficiency and Renewable Energy Lab
- Office of Environmental Management Lab
- Office of Fossil Energy Lab
- Office of Nuclear Energy, Science and Technology Lab
- Office of Science Lab

Stanford University



DOE pays Stanford $1 per year to lease 426 acres of land

240 Universities worldwide use our resources

1,663 Employees from 36 Countries

-205 Postdocs and Grad Students ; 3,100 Facility Users & Visiting Scientists

142 Buildings

1,000 Scientific Papers published each year in peer-reviewed journals

6 Scientists awarded the Nobel Prize for work done at SLAC

1st North American Website

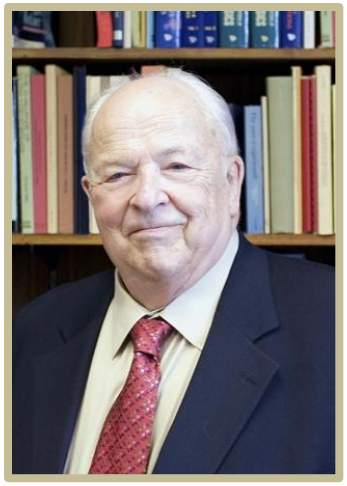
$350,000,000 Budget (10% of this goes for energy consumption)

SLAC NATIONAL ACCELERATOR LABORATORY

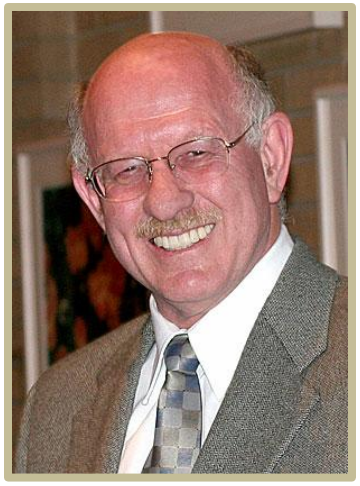
Jan 26, 2012

Our Directors through the years:

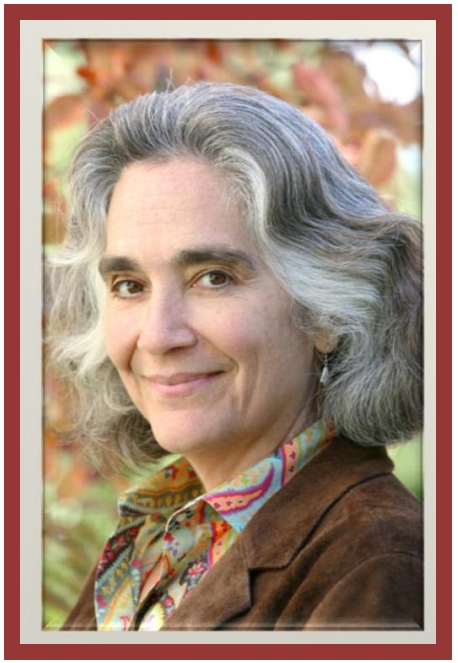
1961-1984
Wolfgang “Pief” Panofsky



1984-1999
Burton Richter



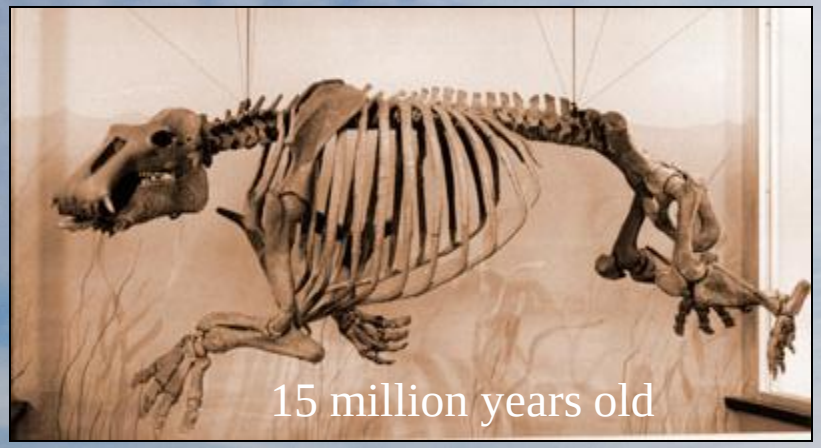
1999-2007
Jonathan Dorfan



2007-Present
Persis Drell

The science done by our staff will drive innovations in our facilities. And then the capabilities of the facilities will drive advances in the science. This has historically been key to SLAC's success, and it is key to our future now as well.” – Persis Drell

SLAC: From Fossils to Photons

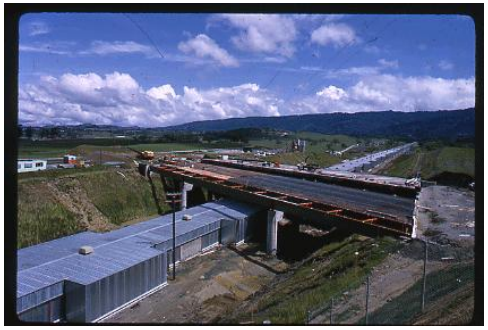


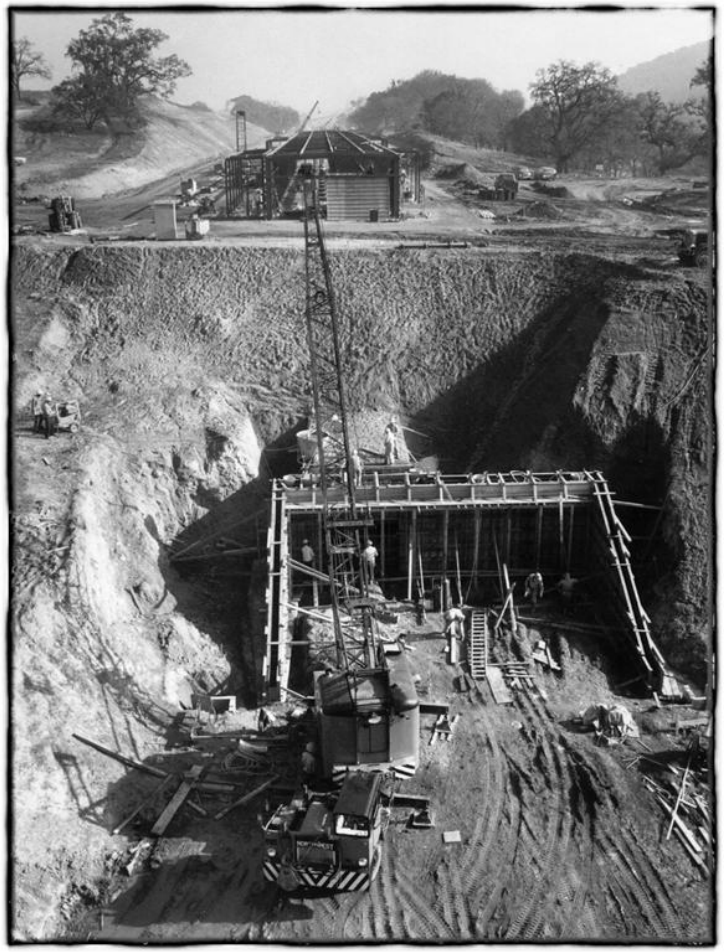
Adele Panofsky

Dolphin Jaw Fossil

Mako Shark Teeth

History of SLAC





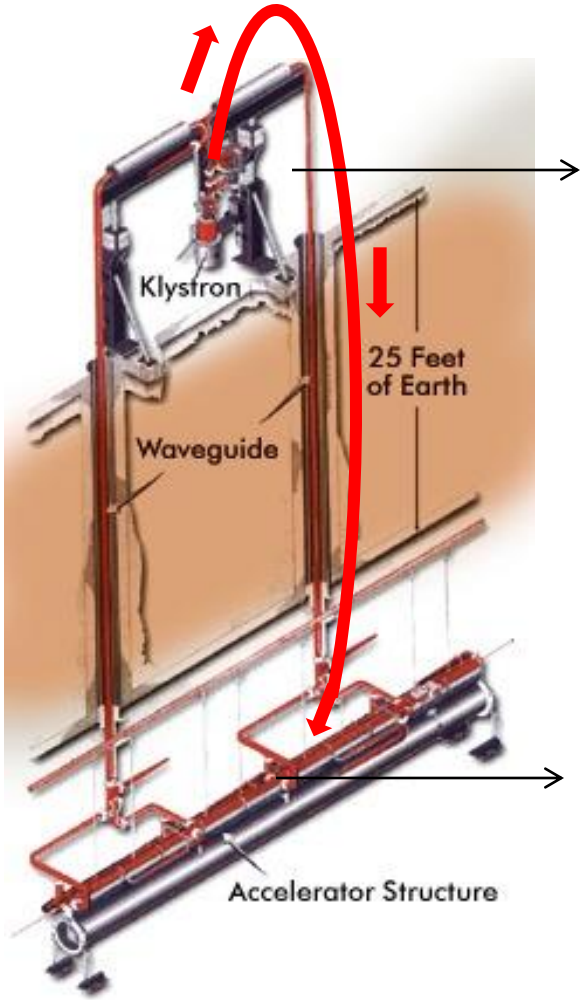
Building the Linear Accelerator

<u>Construction began in 1962</u>
- Originally called Project M
- Stanford Linear Accelerator Center
- SLAC National Accelerator Laboratory

<u>Longest building in the world:</u>
- 3,074 Meters or 1.9 Miles
- Until Beijing…

<u>Three stories underground</u>
- Radiation shielding
- Thermal stability
- Seismic stability

How the LINAC works: Klystrons supply the energy



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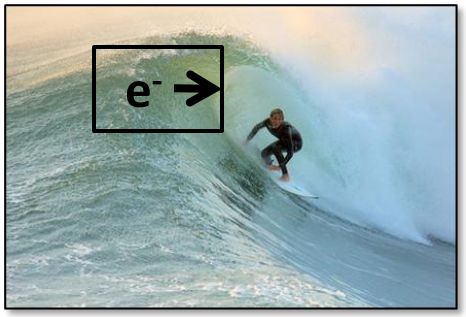
1 Klystron = 60,000 Microwave ovens

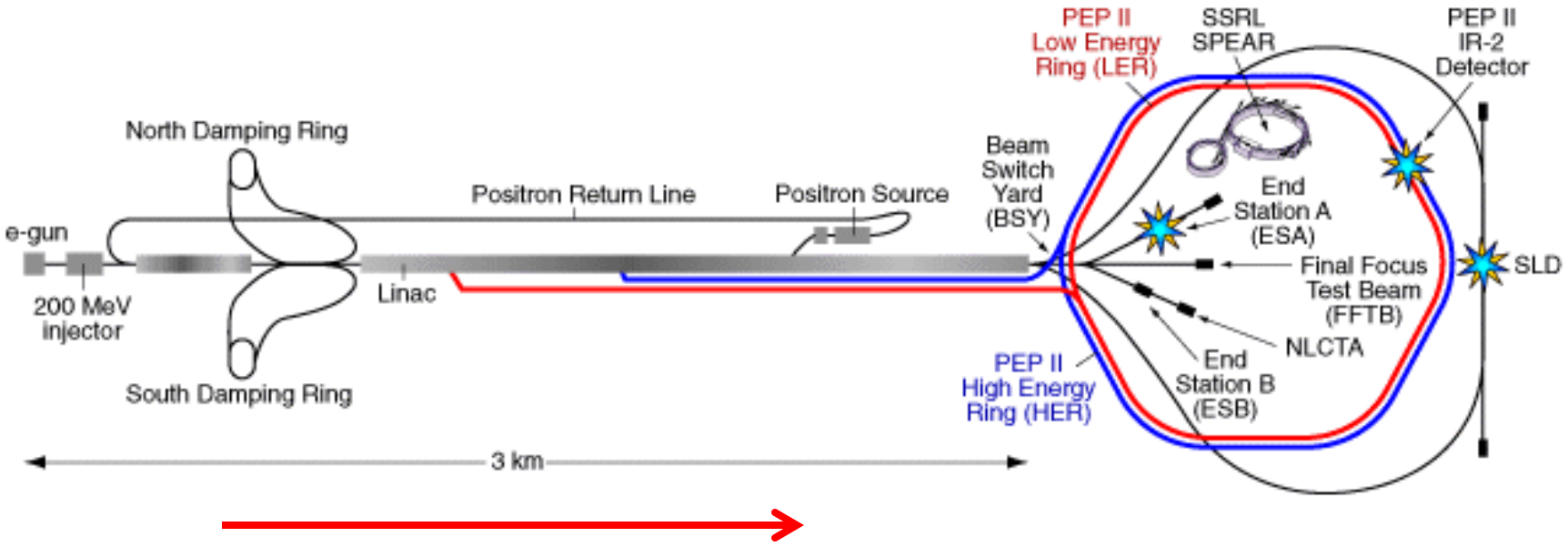
Electrons and positrons ride the electromagnetic wave



How the LINAC works

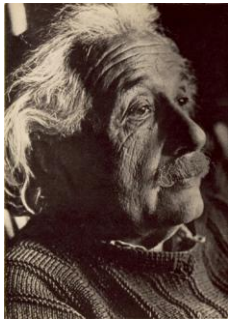
Energies Achieved:
-Accelerate electrons and positrons
-Energy levels to 50 GeV
(50 Billion Electron Volts)

Speed of Electrons:
as percentage of speed of light
- 99.999 % at injector
- 99.999**9999**% at end



Why did we build it?

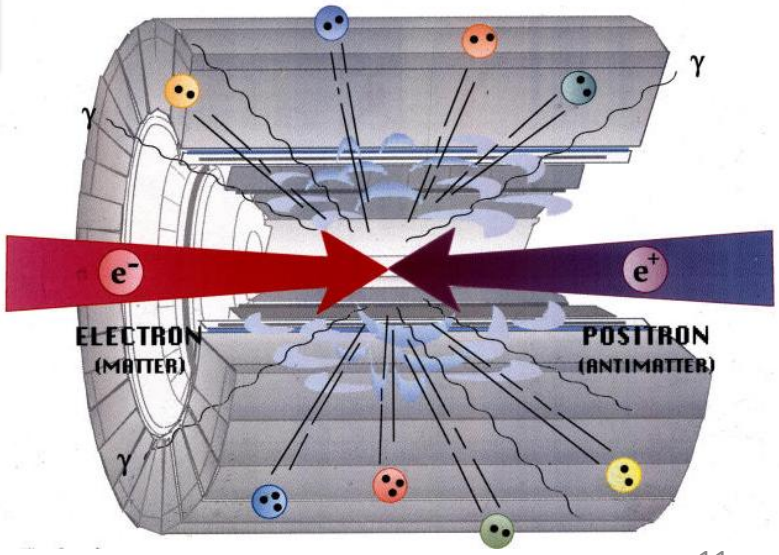
Make electron beams to study the structure of matter, to create known particles and study their nature



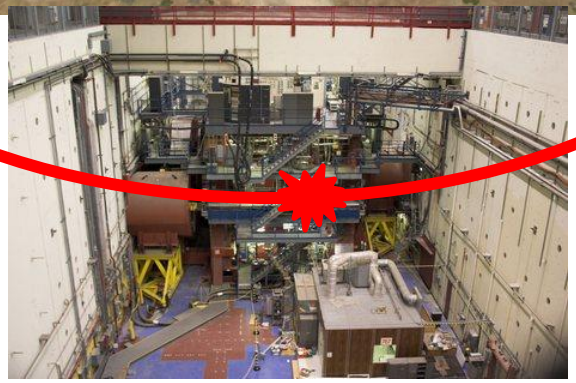
$E = mc^2$

Progress to discover new particles with End Stations (Fixed Target Experiments)

Discover more new particles using electron-positron colliding beams with center-of-mass energies ~3-90 GeV



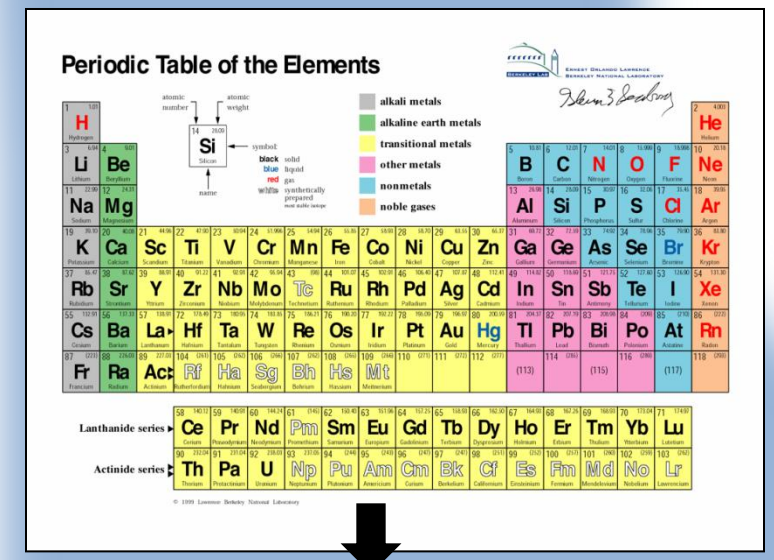
Pioneer Particle Physics Research!



End Stations and Colliders:

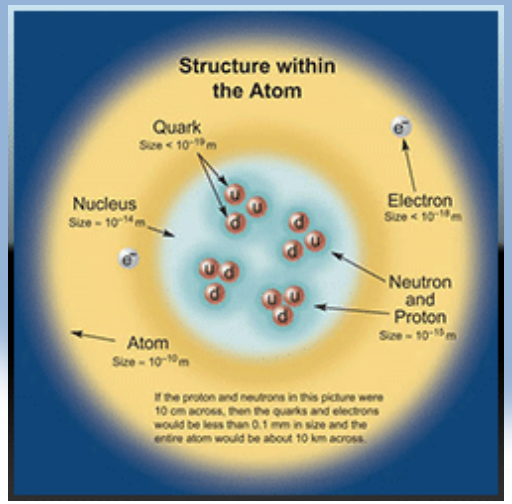
Rich history of discoveries

We did it!
Particle Science Breakthroughs

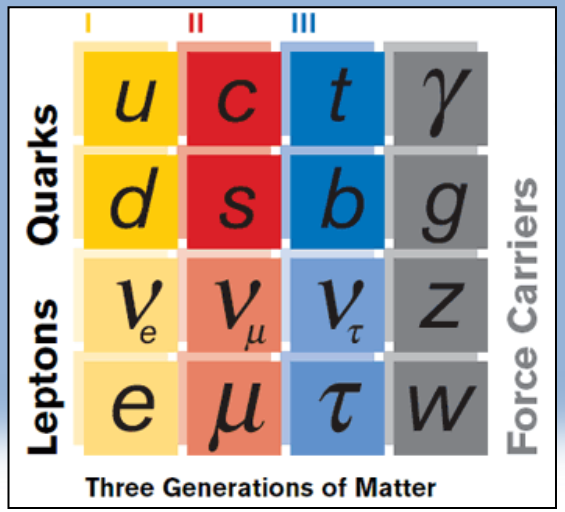


Fundamental Structure of Matter

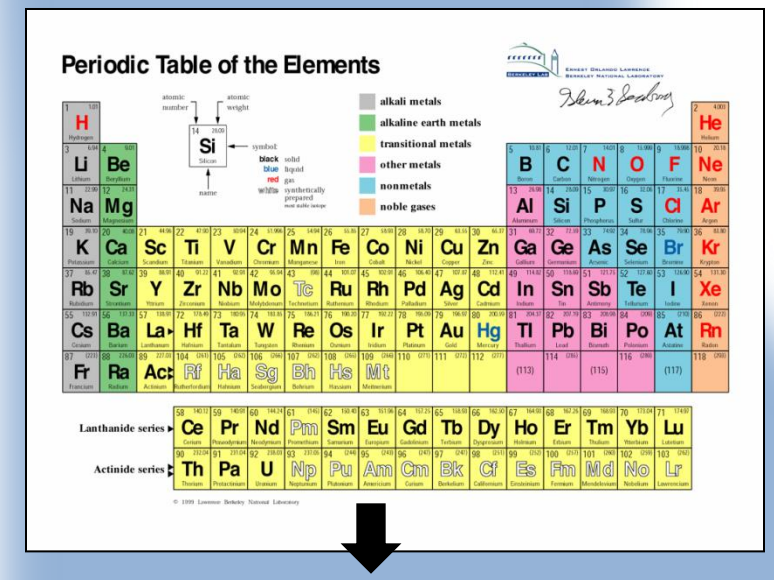
- Molecules
- Atoms
- Nucleus (protons & neutrons)
- Elementary particles



The "Standard Model"



We did it!
Particle Science Breakthroughs



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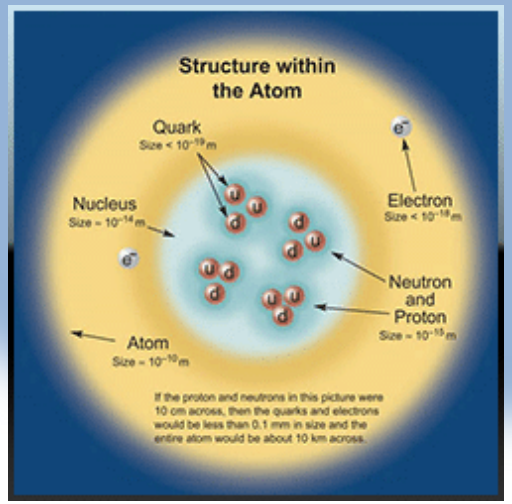

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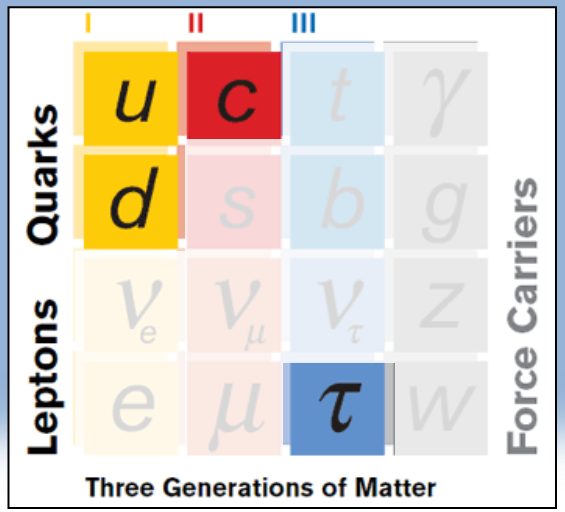

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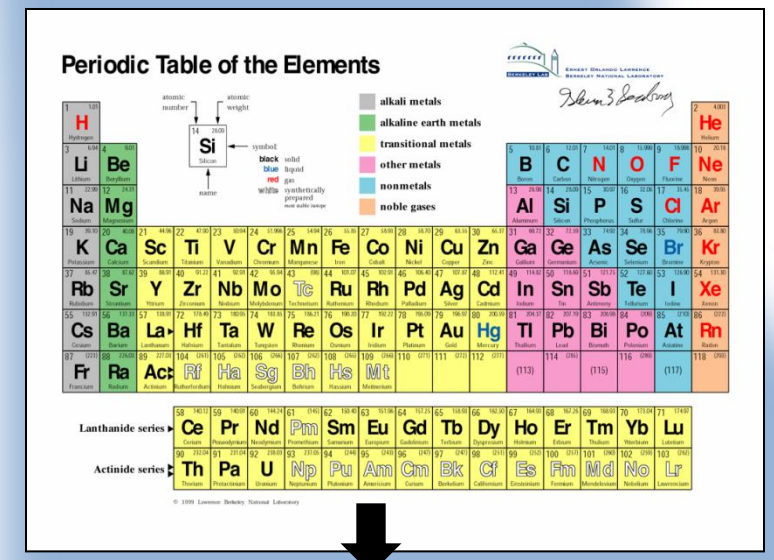
Discovered at SLAC

We did it!
Particle Science Breakthroughs



Fundamental Structure of Matter

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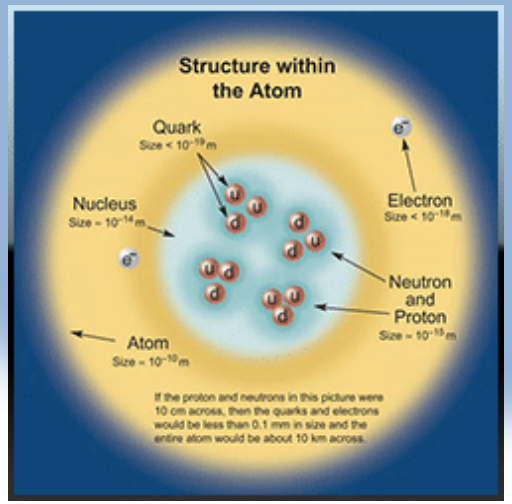

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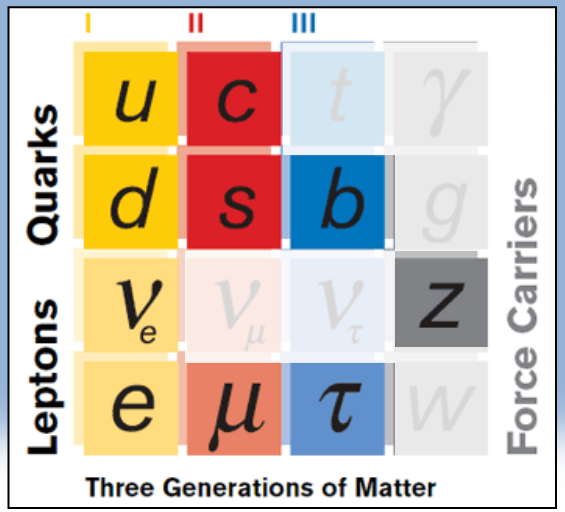
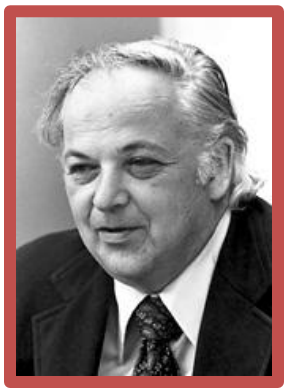


Extensively studied at SLAC

Nobel Prizes

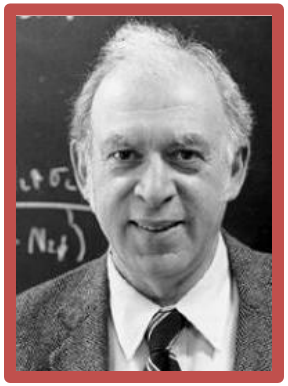


Burton Richter

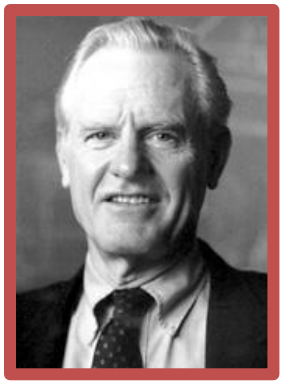
Samuel C.C. Ting

Physics, 1976
Pioneering experimental contributions to lepton physics.

Richard E. Taylor

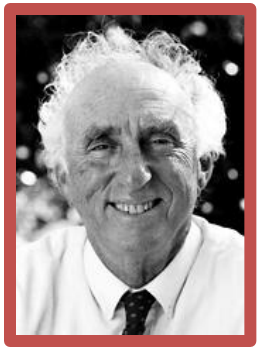


Jerome I. Friedman

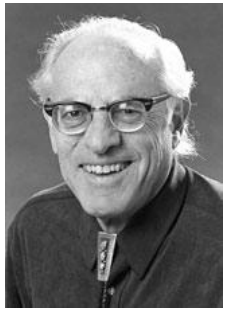


Henry W. Kendall

Physics, 1990
Deep inelastic scattering of electrons on protons and bound neutrons Essential for the development of the quark model

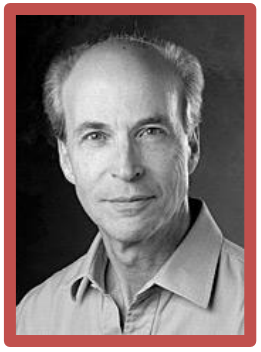


Martin L. Perl



Frederick Reines

Physics, 1995
Discovery of the tau lepton



Roger Kornberg

Chemistry, 2006
Studies of the molecular basis of eukaryotic transcription

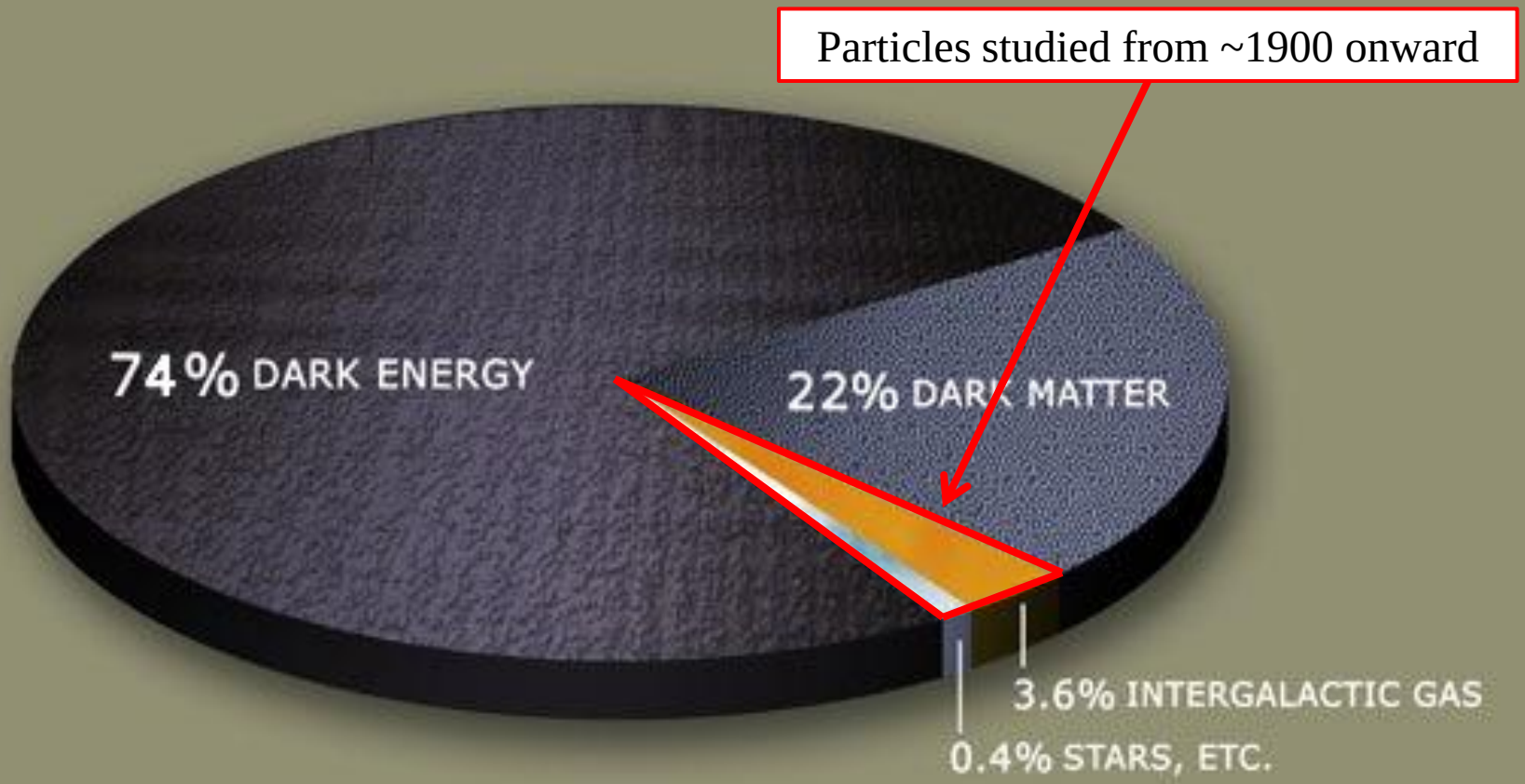
Yoichiro Nambu, Makoto Kobayashi, Toshihide Maskawa

Physics, 2008
Theory of broken symmetries later observed by BaBar

Ada Yonath

Chemistry, 2009
Studies of the structure and function of the ribosome, foundation studies at SSRL

We're not done yet…

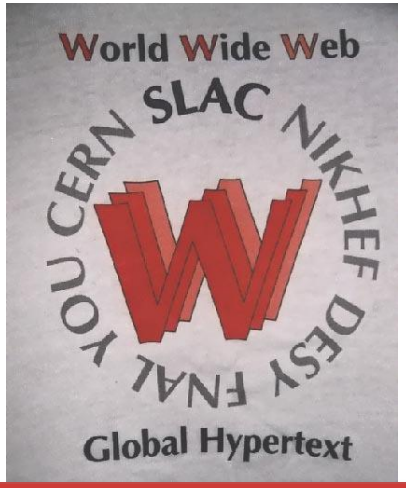


Atoms only make up 4% of the Universe

First Western Hemisphere Website

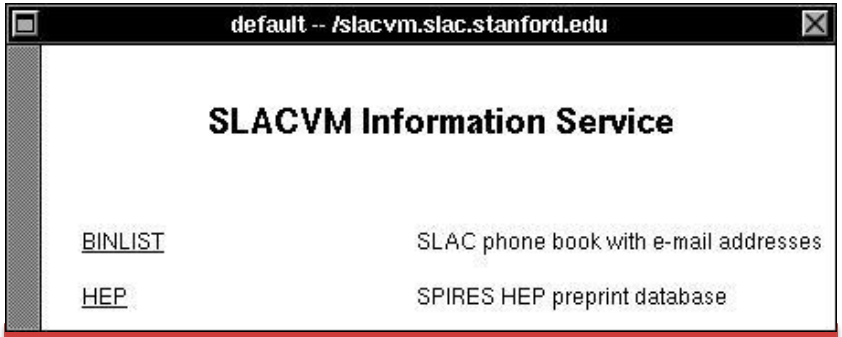
- December 1991
- Installed on IBM VM/CMS

- From desire to share data with sister lab, CERN in Switzerland



T-Shirt with first 5 Users

NeXT computer
used to create Western Hemisphere first website



First North American Website Page

Our Mission Today

Our programs explore the ultimate structure and dynamics of matter and the properties of energy, space and time - at the smallest and largest scales, in the fastest processes and at the highest energies - through robust scientific programs, excellent accelerator based user facilities and valuable partnerships.

- Explore
- Smallest to Largest Scales
- Fastest
- Highest Energies ⇒ LINAC

How do we do this now?

Present and Future:
Diversified Portfolio

X-ray Science

SUNCAT
CENTER FOR INTERFACE SCIENCE AND CATALYSIS

PULSE

SIMES
Energy solutions through materials science

Super-Computing:
All areas of the LAB

Astrophysics

Kavli Institute for Particle Astrophysics and Cosmology

KIPAC

High Energy Physics

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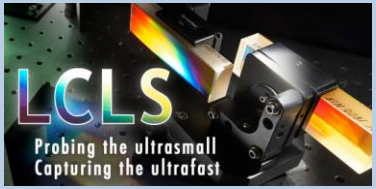
ATLAS

Future Accelerators

FACET

Facility for Advanced Accelerator Experimental Tests

Facilities for Scientific Users



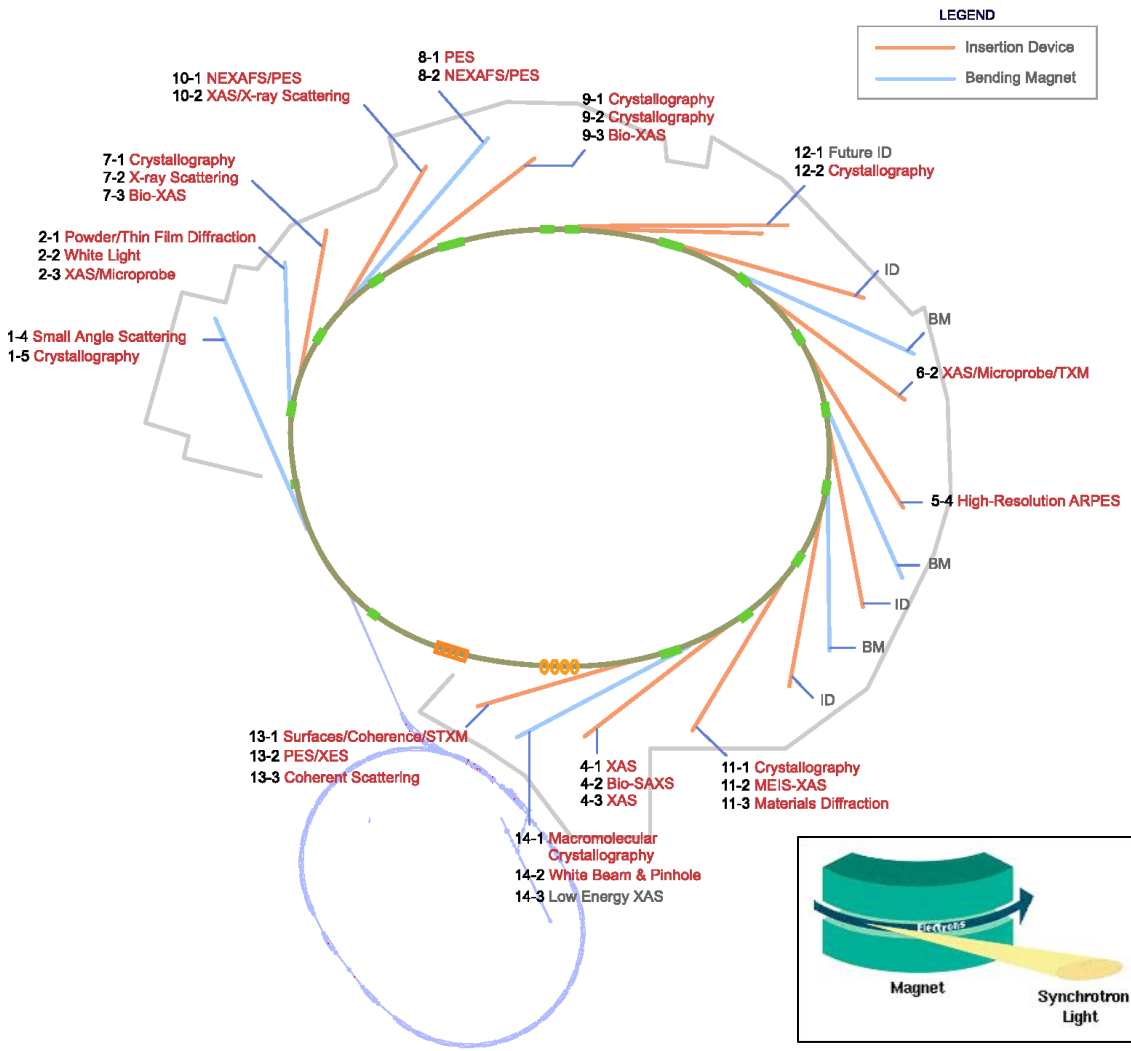
Linac Coherent Light Source

SSRL

Stanford Synchrotron Radiation Lightsource

SSRL: Science

SSRL Beam Line Map

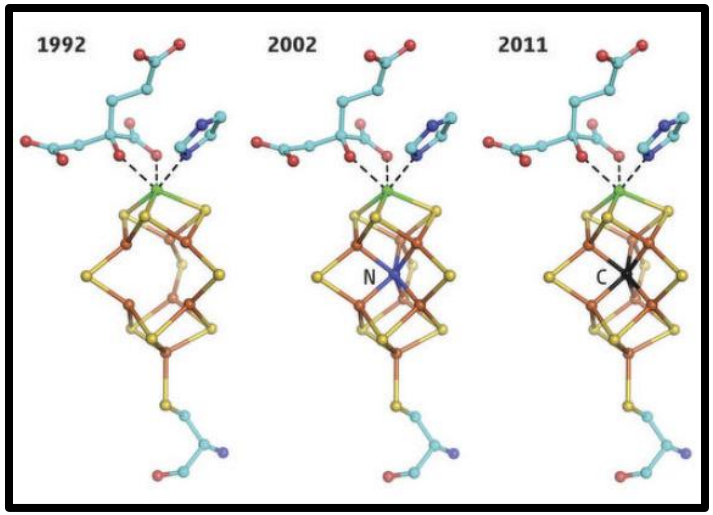


SSRL: Experimental Stations

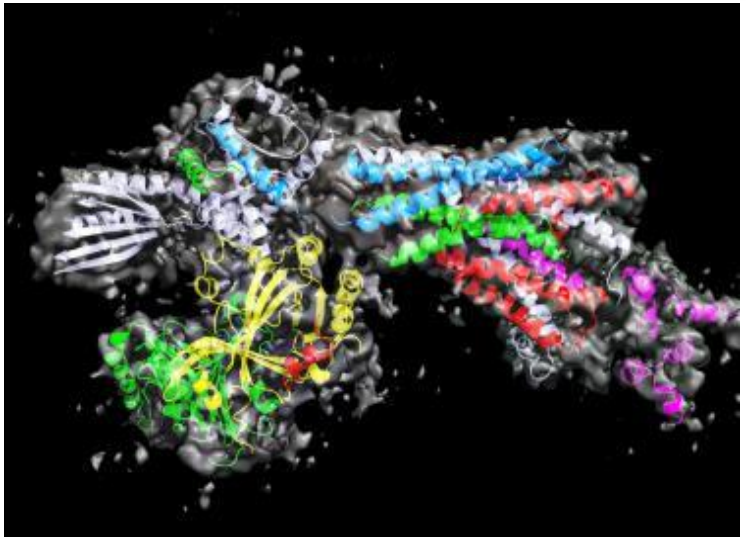
Scientific Techniques Used at SSRL

- Accelerator Physics
- Macromolecular Crystallography
- Materials Scattering
- Molecular Environmental
- Small Angle Scattering
- Powder Diffraction
- X-ray Spectroscopy
- Angle-Resolved Photoelecton Spectroscopy
- X-ray Absorption Spectroscopy
- Material Science
- Magnetic Dichroism Spectroscopy & Microscopy

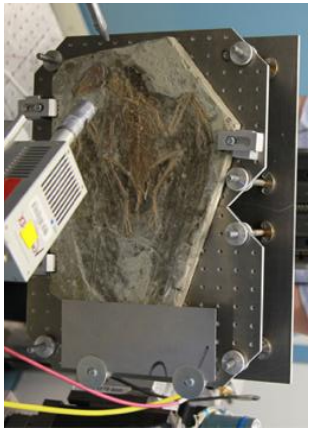
SSRL: Results

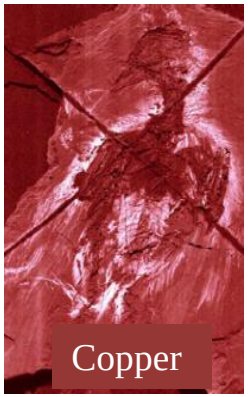


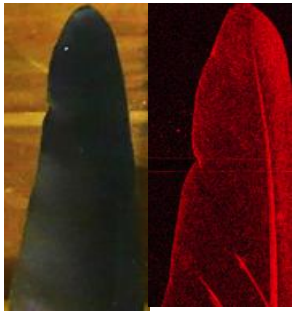
Identified key atoms in nitrogenase enzyme critical in food supply



Deciphered the structure of Mediator, a molecular process for regulating transcription of DNA



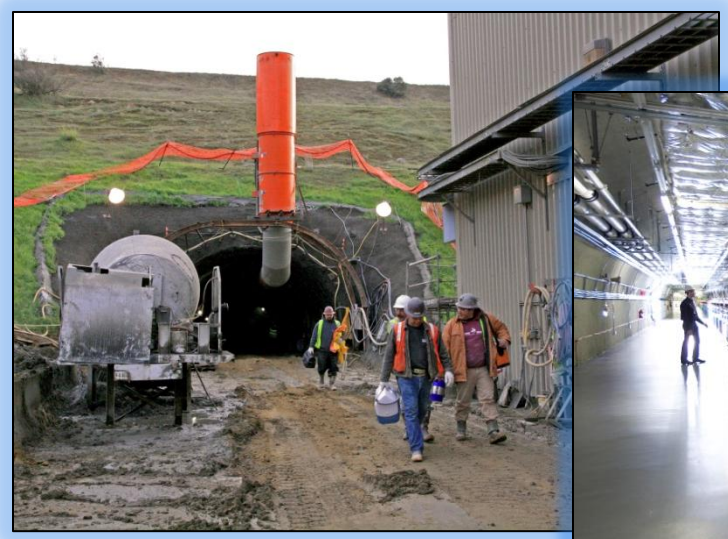


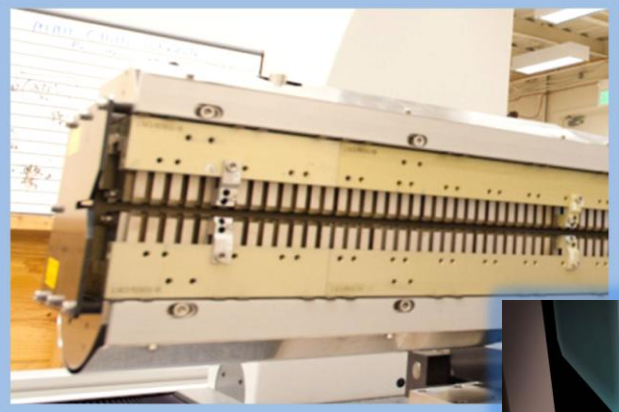


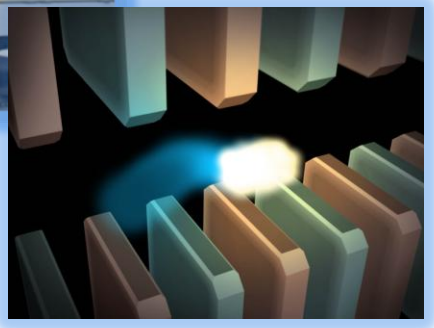
Confuciusornis unequivocally shows copper correlates with tight groups of body feathers and with regions associated with wings.

Confuciusornis sanctus, ~120 million year old, the oldest documented bird. Chemical traces of elements are revealed at SSRL.

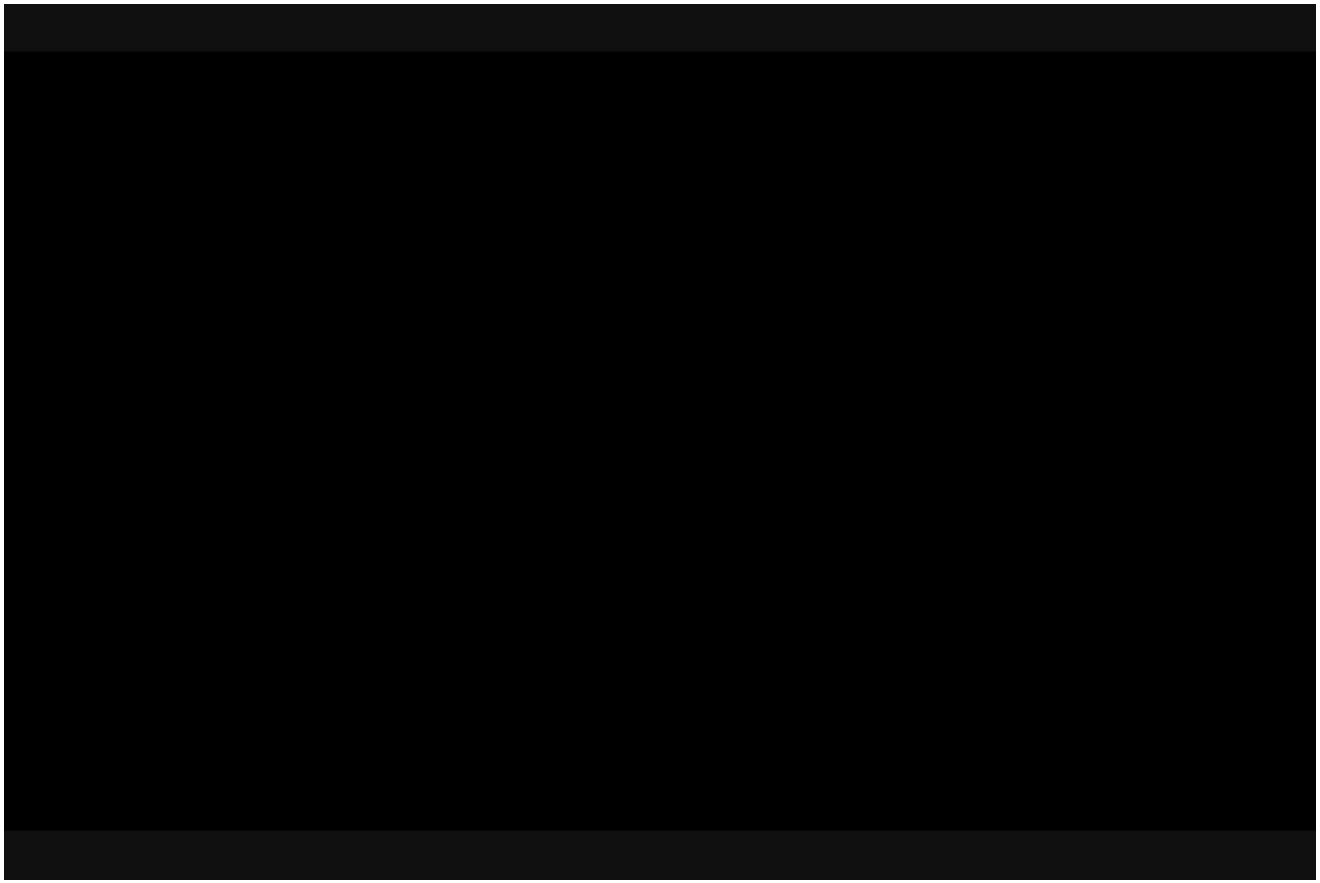
LCLS: X-ray Science







LCLS: How it Works
Molecular Imaging (Movie)



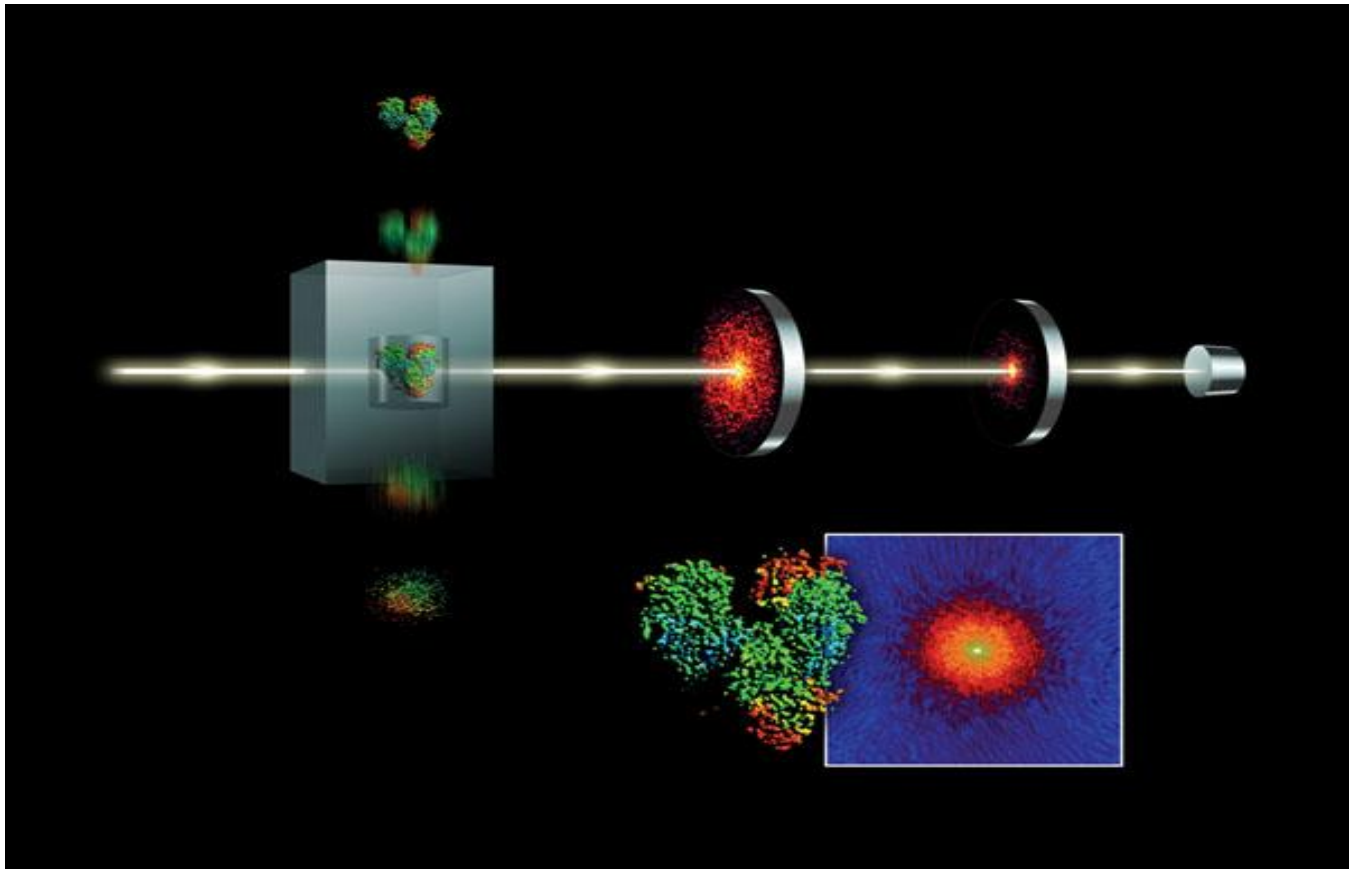
X-ray ‘camera’ with shutter speed of 0.00000000000001 sec (femtosecond)

1 fs = 10^{-15} s = 1 thousandth of a millionth of a millionth second

See atoms and electrons moving on their natural timescale to watch a chemical reaction atom by atom

LCLS: How it Works
Molecular Imaging

(Slide)



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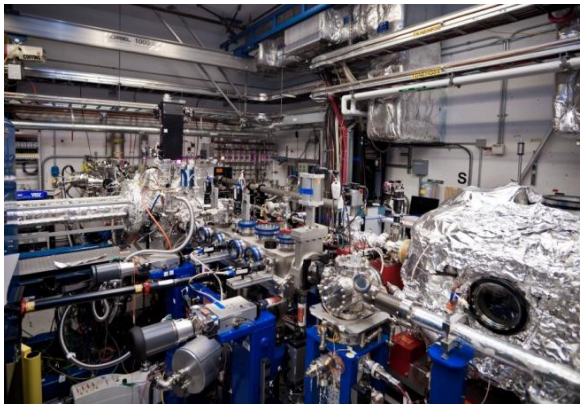
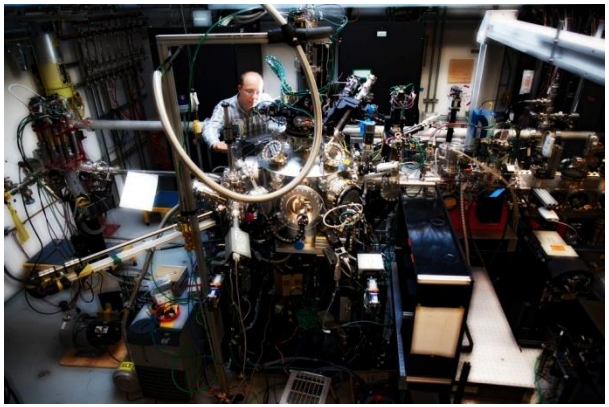
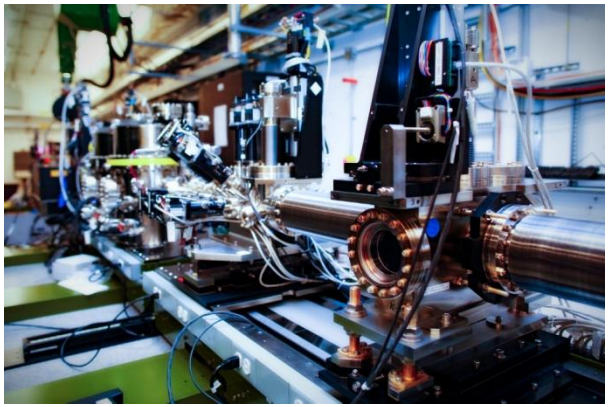


Hutch 1: AMO
Atomic, Molecular, and Optical

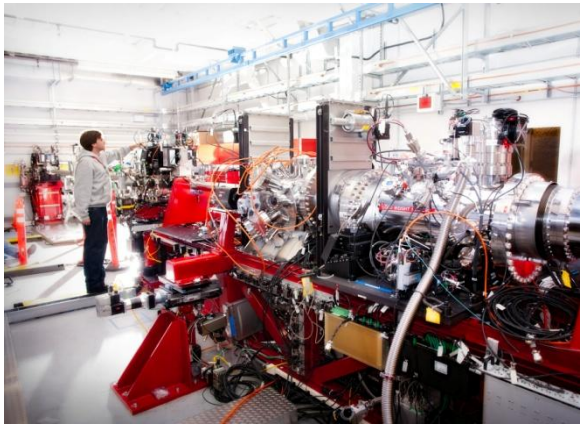


Hutch 2: SXR
Soft X-ray

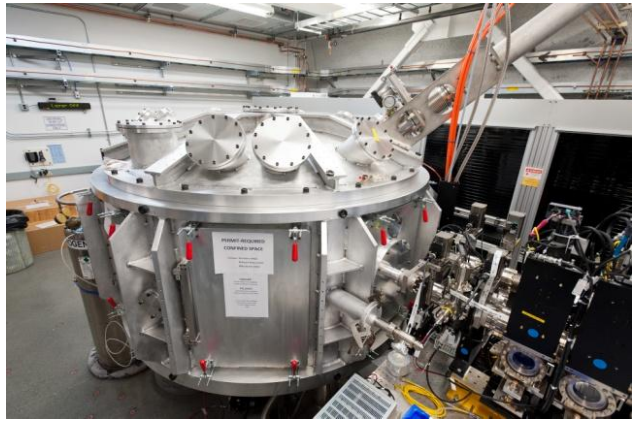


Hutch 3: XPP
X-ray Pump Probe

Hutch 4: XCS
X-ray Correlation Spectroscopy

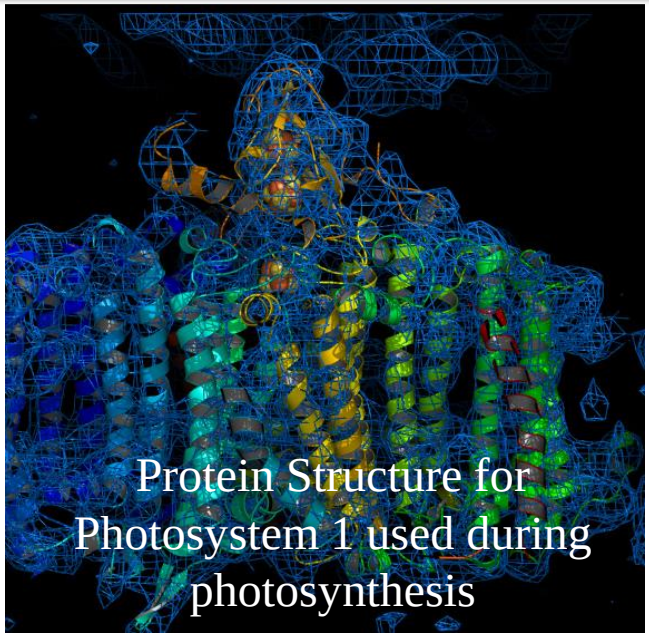


Hutch 5: CXI
Coherent X-ray Imaging

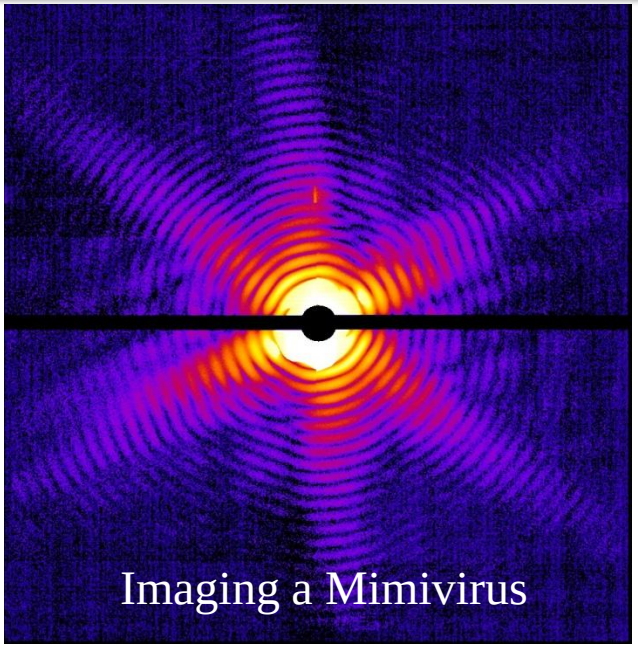


Hutch 6: MEC
Matter in Extreme Conditions

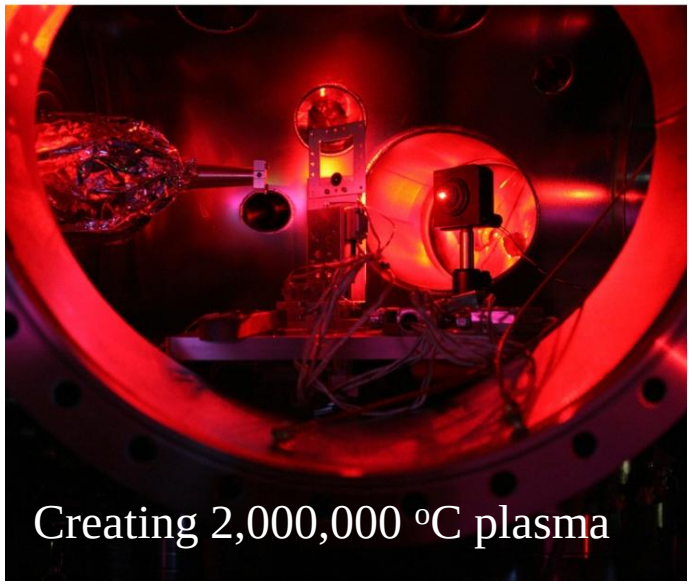
LCLS: Results



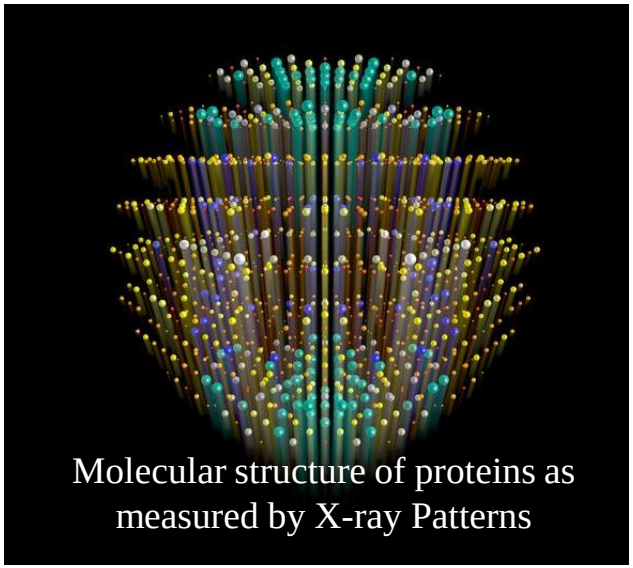
Protein Structure for Photosystem 1 used during photosynthesis



Imaging a Mimivirus

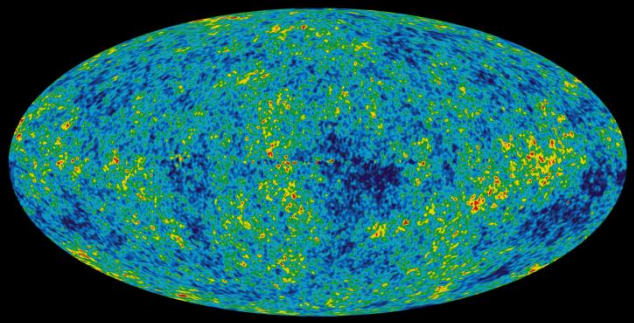


Creating 2,000,000 ^{o}C plasma



Molecular structure of proteins as measured by X-ray Patterns

Astrophysics
Using the Entire Universe as our Laboratory



How did the Universe begin?

How is it changing today?

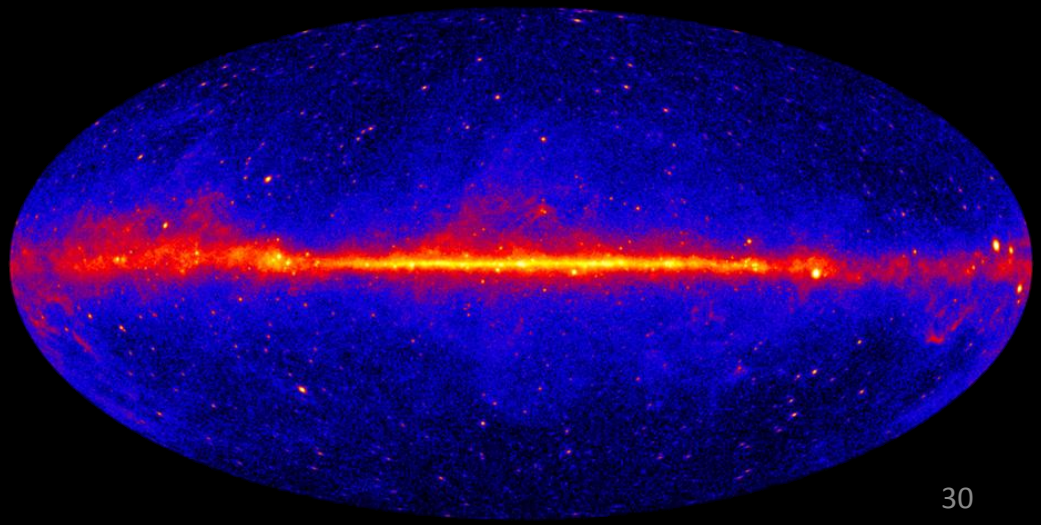
Studying the most extreme objects in the Universe

Searching for Dark Matter

Astrophysics: Active Facilities

One example:

Fermi Gamma-ray Space Telescope

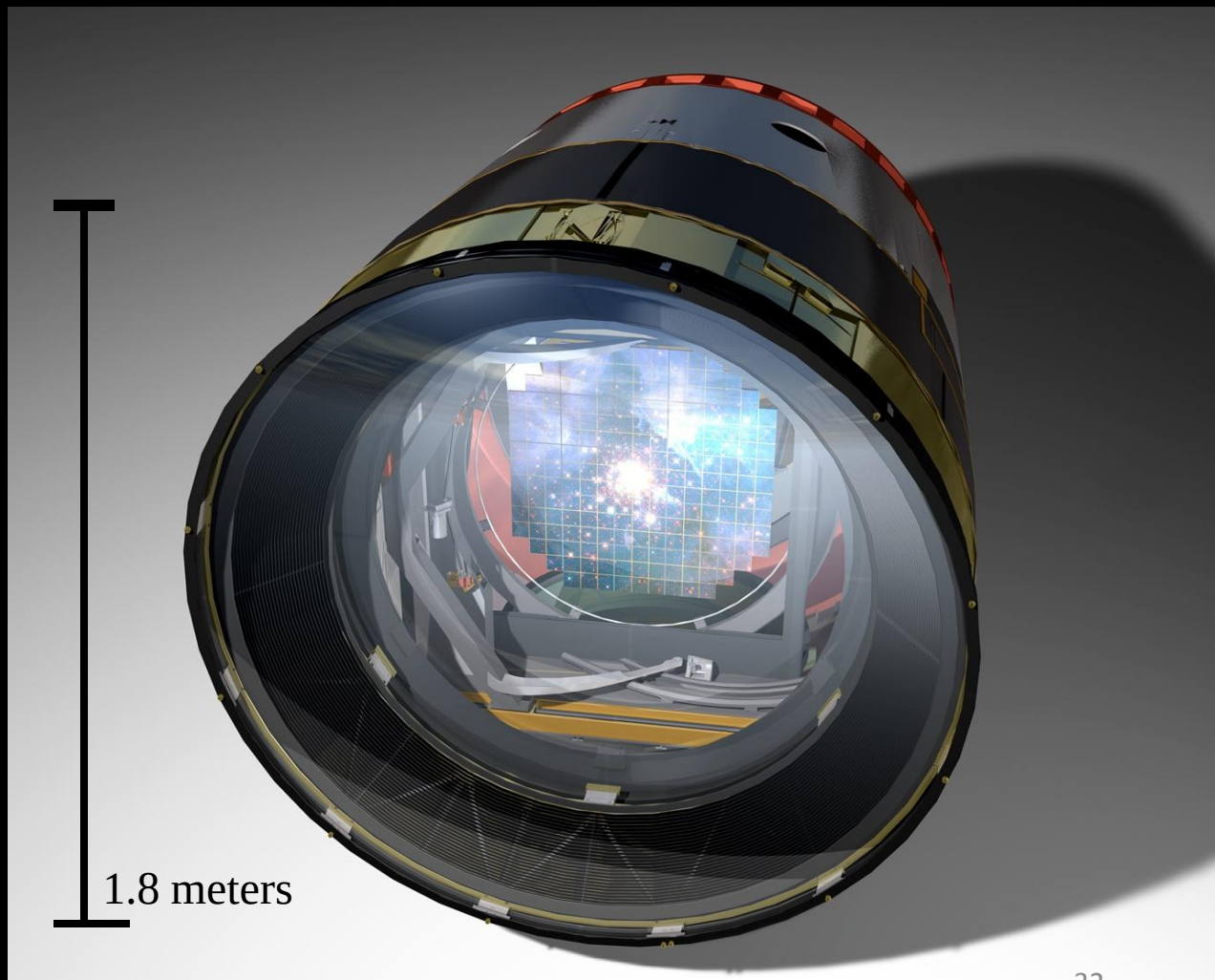


Astrophysics: The Future

Astrophysics: The Future

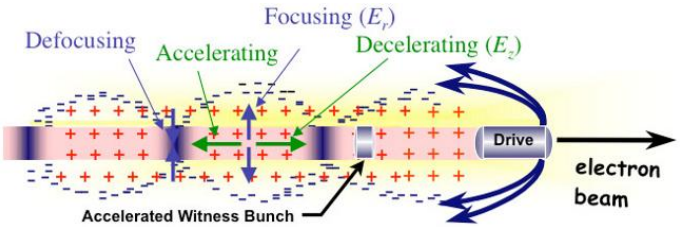
LSST
Large Synoptic Survey Telescope

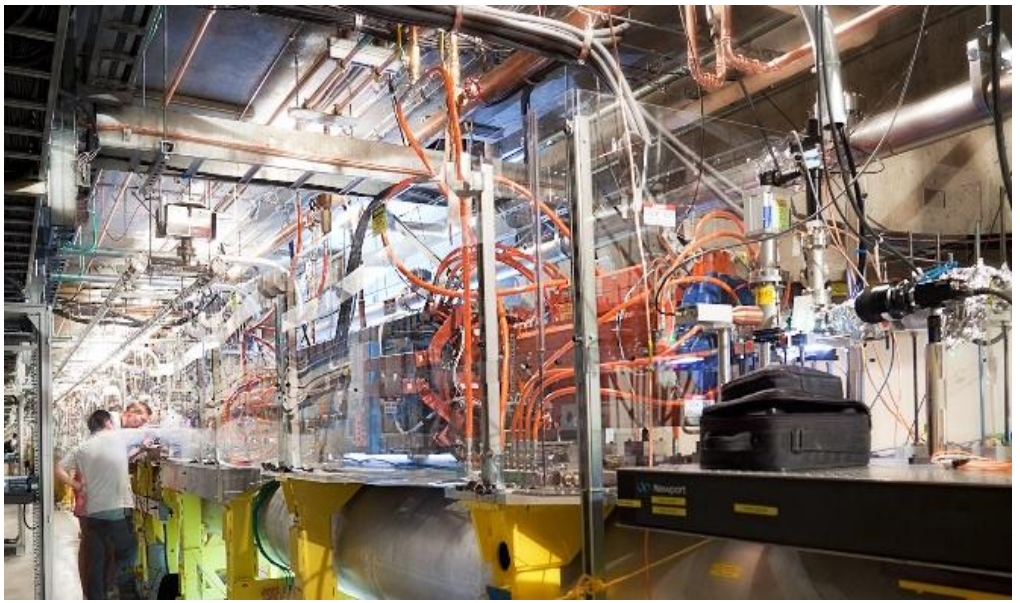
SLAC is designing the world's largest digital camera – 3200 Megapixels!



FACET: Next Generation Accelerator

- Exploring new technologies for particle acceleration.
- Much smaller and less expensive!
- Hope to do what the 3 km LINAC does in a few meters by means of plasma and/or laser acceleration.





Will advance accelerator, medical, and energy sciences

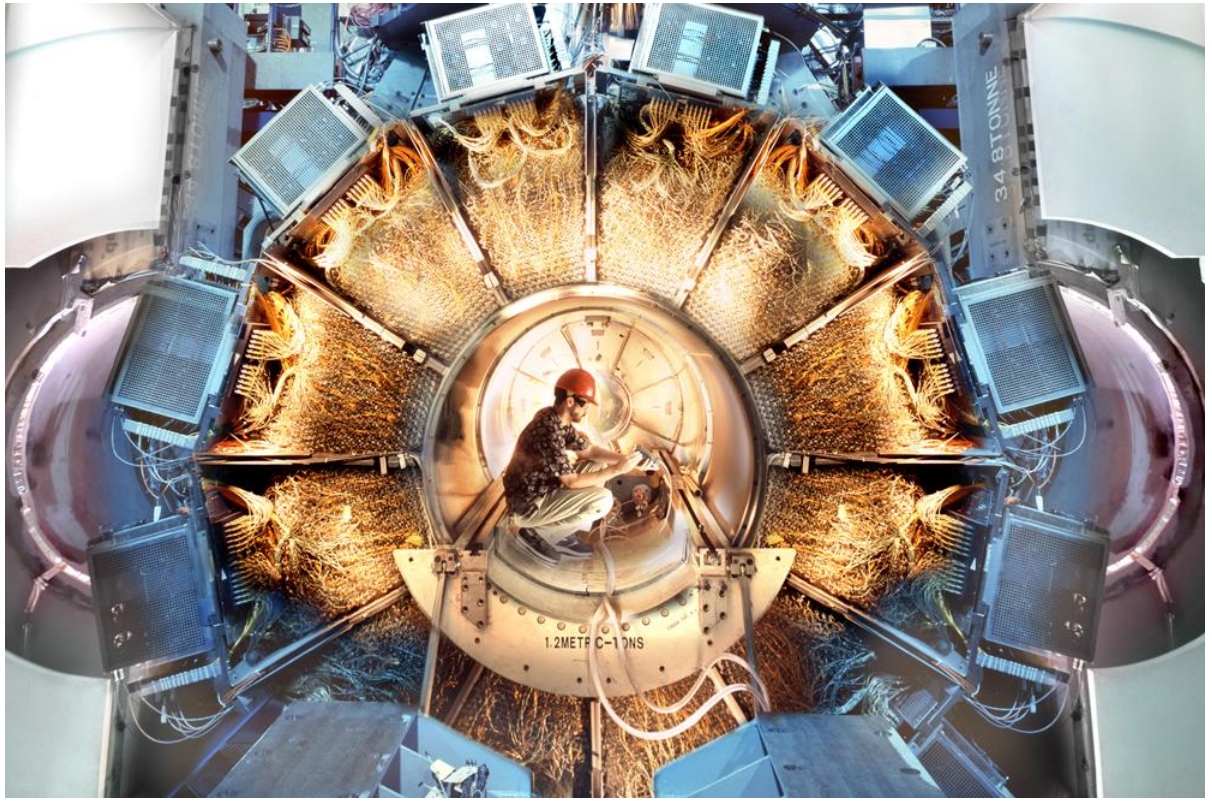
Super Computing: Global Partnerships

ATLAS Detector records enough data to fill six million CDs every minute.
SLAC analyzes a total of 3 billion megabytes of raw recorded data each year as a global partner.

Safety

We have been radiologically safe for 50 years!

Questions?



What I do at SLAC:

See below for extra slides
Any slide you use should have images that are clear and new as you can find for the subject matter
Use Times New Roman Font

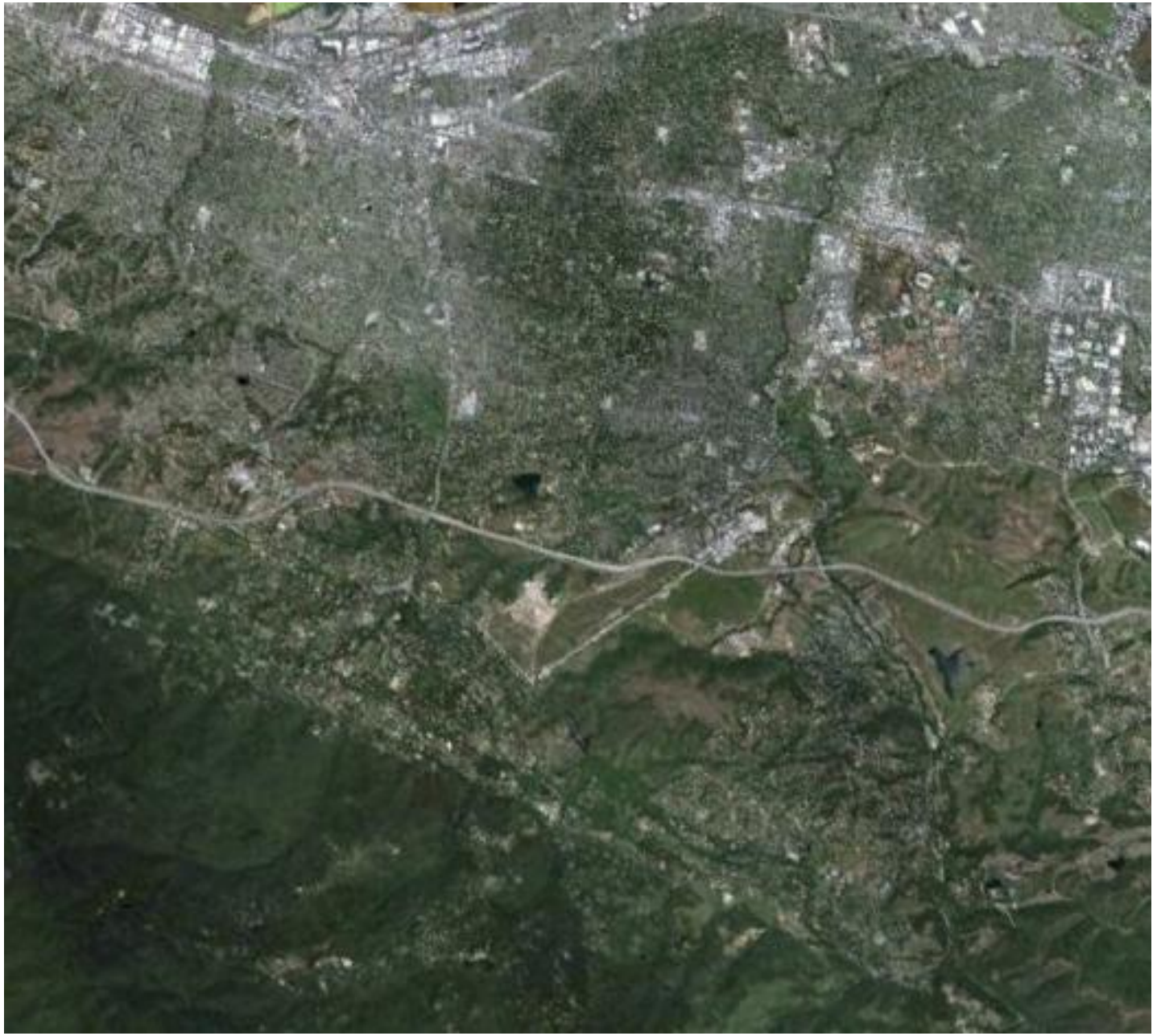
Archaeopteryx

More Dinosaur than bird

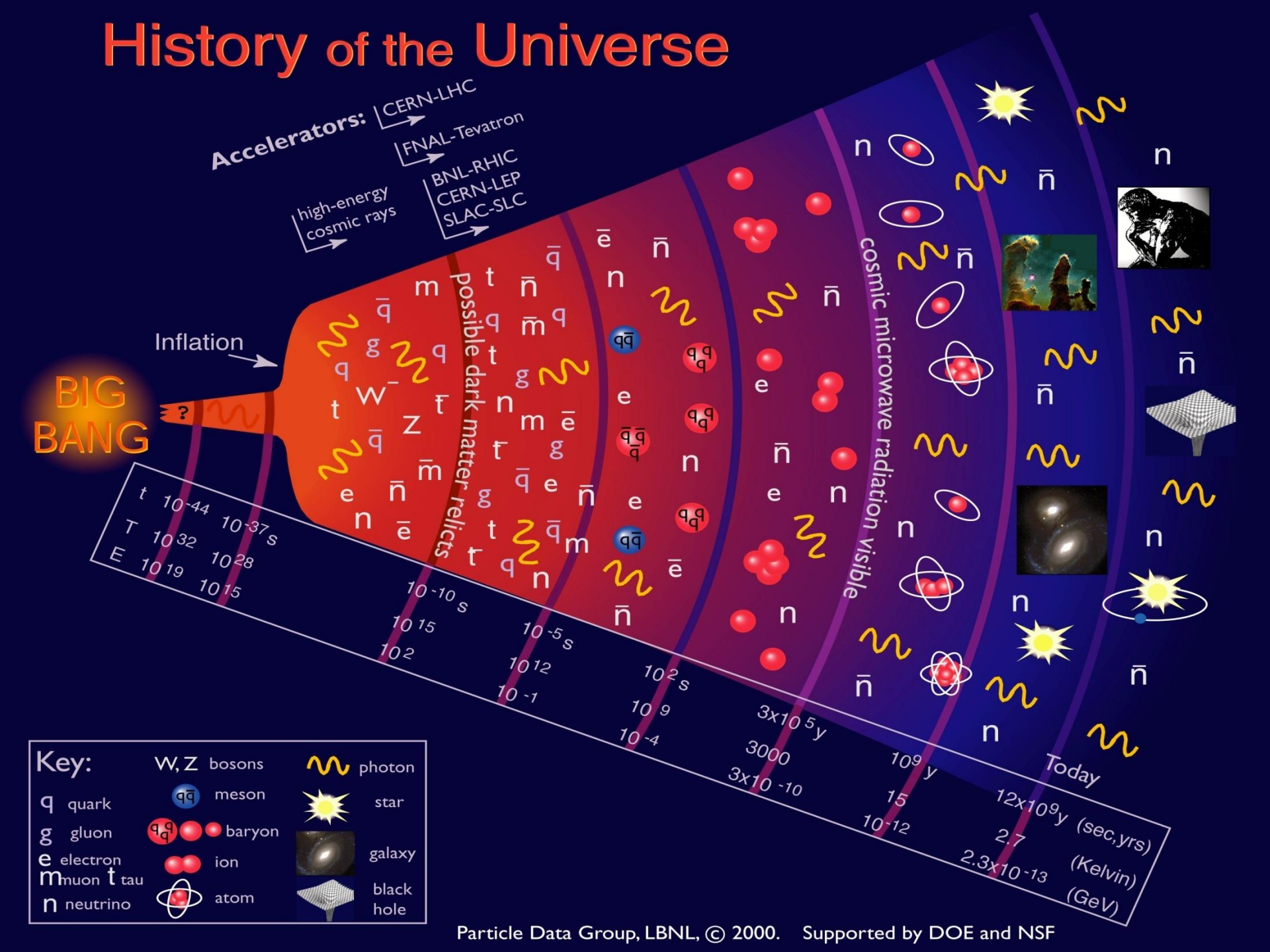
ἀρχαῖος (archaīos) = ancient
πτέρυξ (ptéryx) = feather

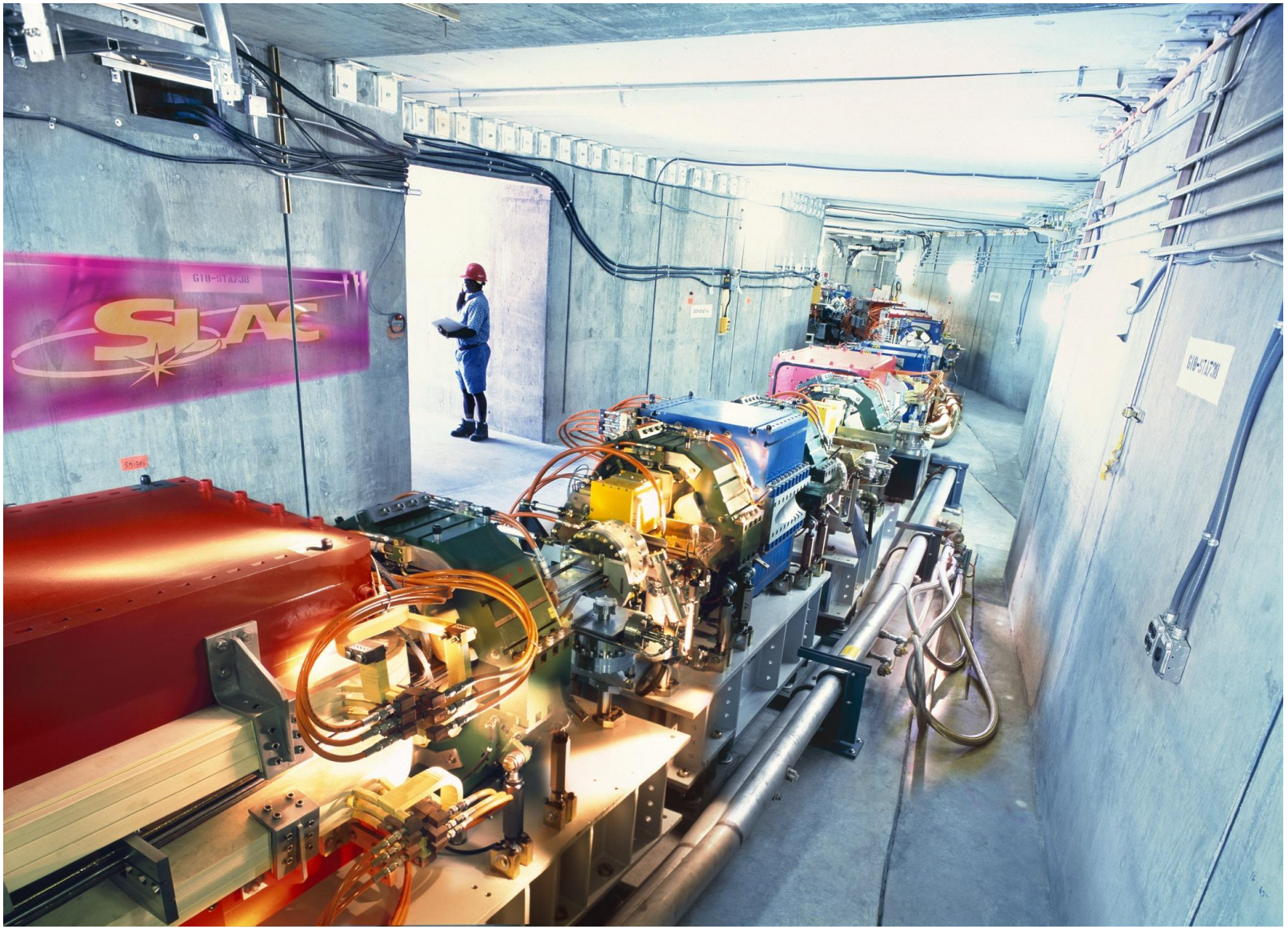
Reptile Traits:
- Toothed Beak
- Wing Claws
- Long tail w/vertebrae

Bird Traits:
- Airfoil Wings
- Contour Feathers
- Size of present day raven



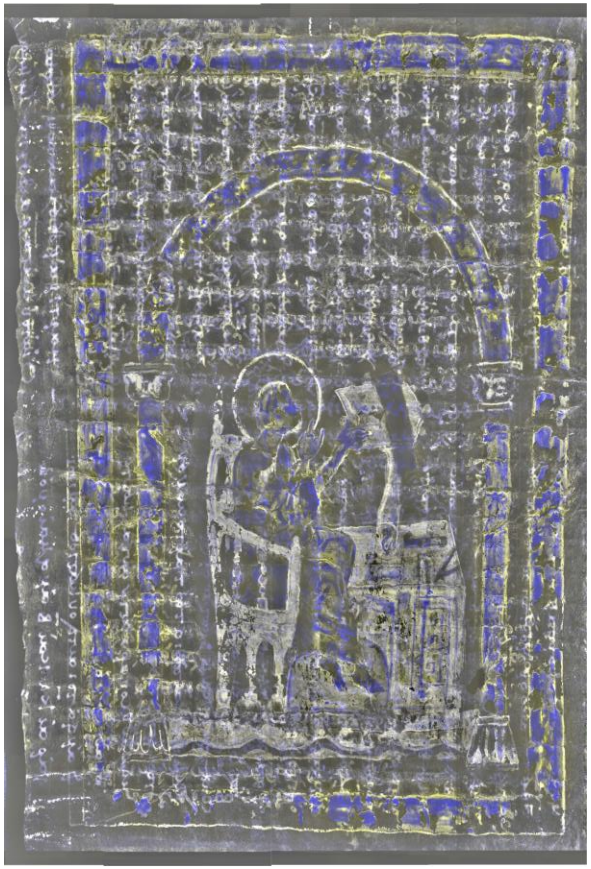
History of the Universe

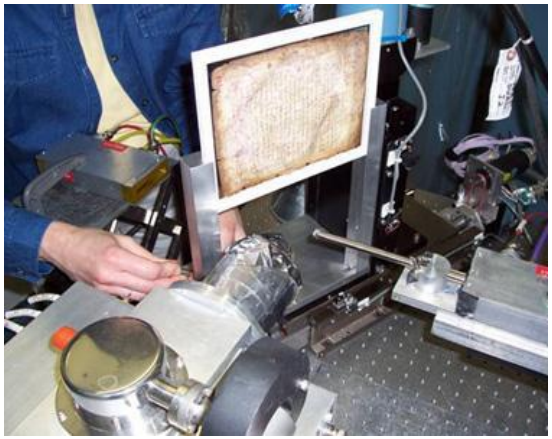




Don’t use this slide unless we manage to change the old SLAC Logo

Archimedes Palimpset





When hit by the synchrotron X-rays the iron pigment in the original ink fluoresced and allowed researchers to see the text for the first time.

Our Past Missions and Successes

End Station B
- Advanced Accelerator R&D

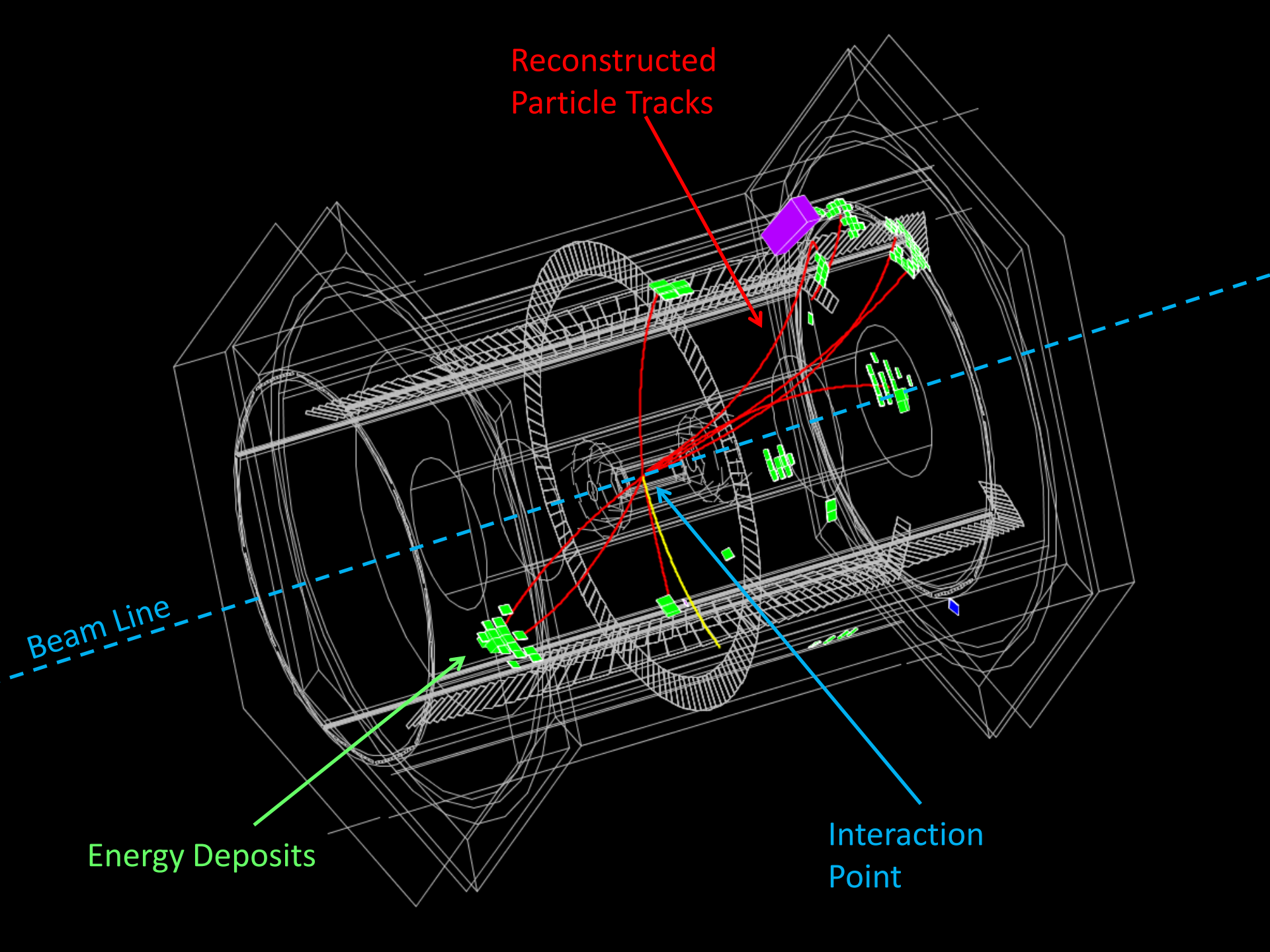
End Station A
- Electroweak unification
- Quarks in protons, neutrons

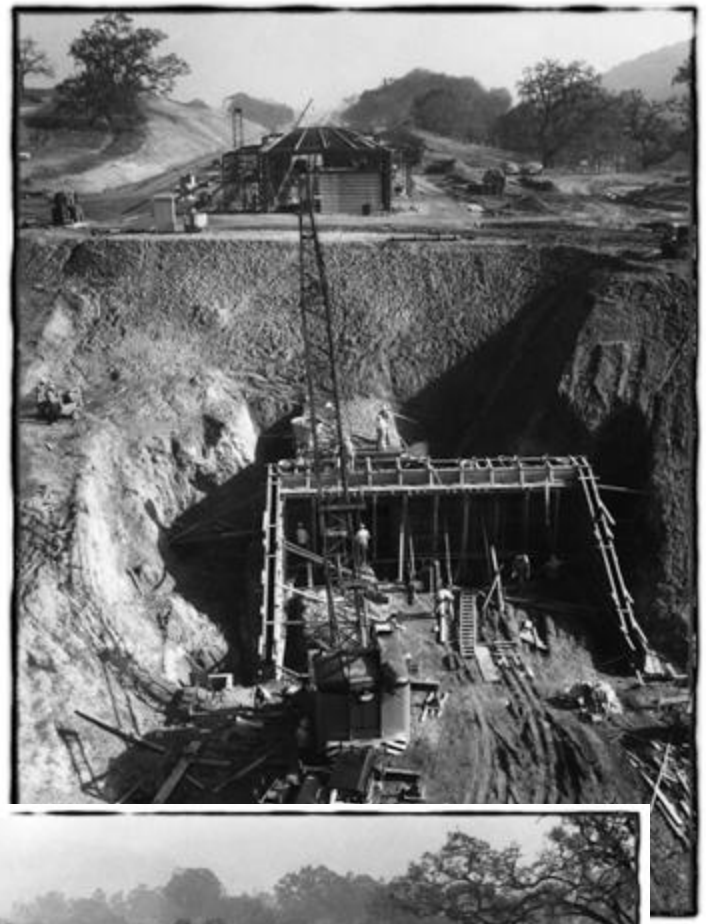
SPEAR
- Original charm quark discovery: J/psi
- Discovery of tau lepton

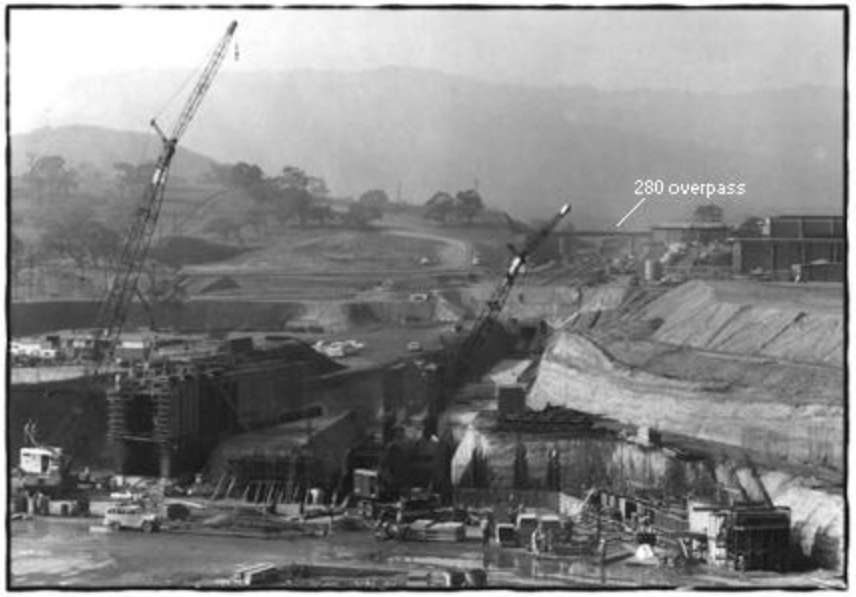
Final Focus Test Beam
- Advanced accelerator R&D
- Test beams

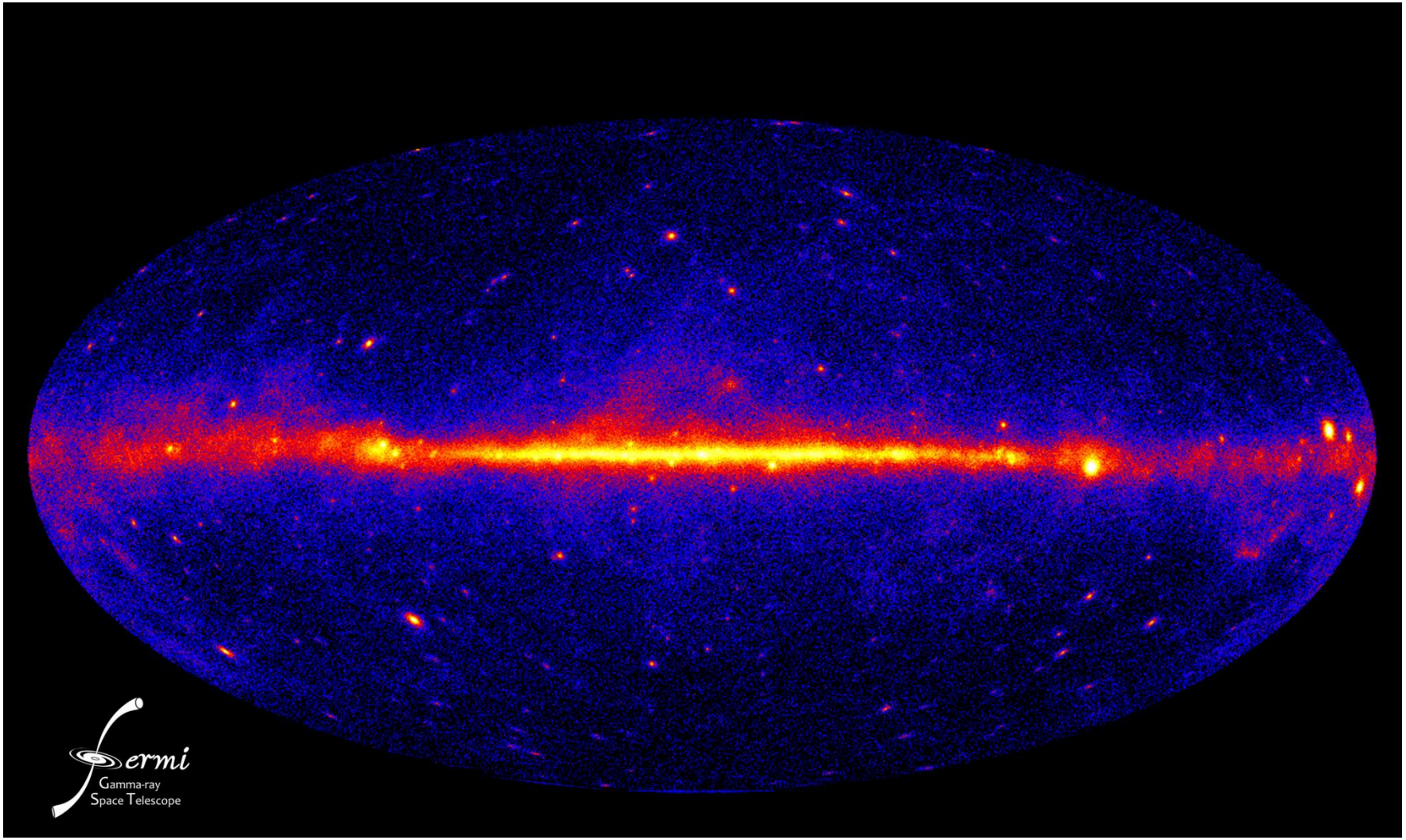
BaBar
- Detector at PEP II
- Matter - Antimatter Asymmetry
- Data set still being used

SLD: Stanford Large Detector
- Detector for SLC
- Produced Z^0 particle

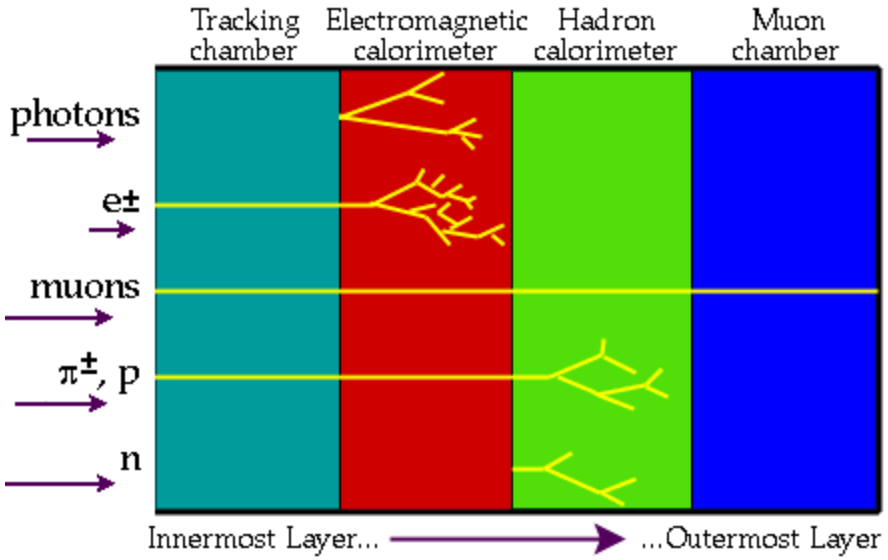

Reconstructed
Particle Tracks
Beam Line
Energy Deposits
Interaction
Point

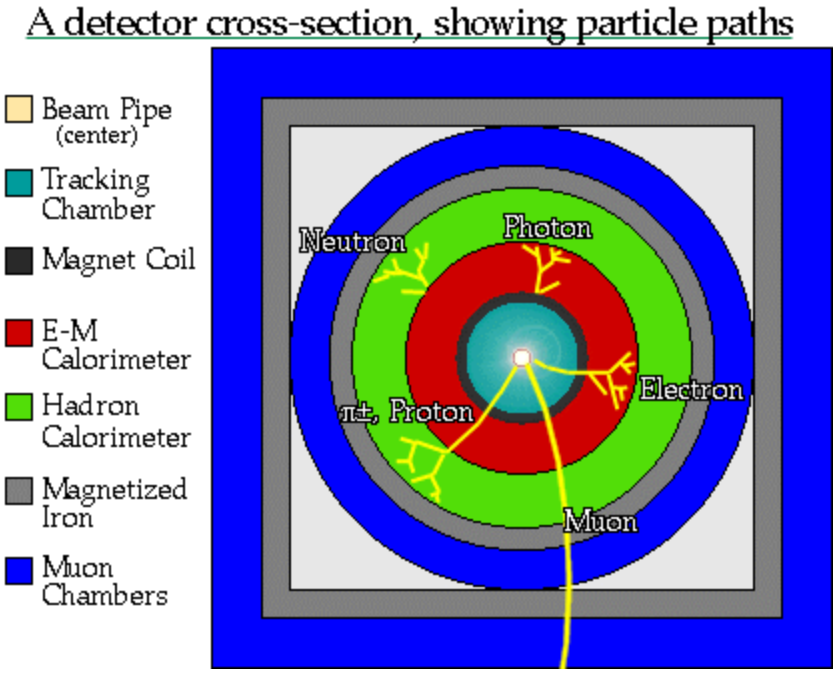


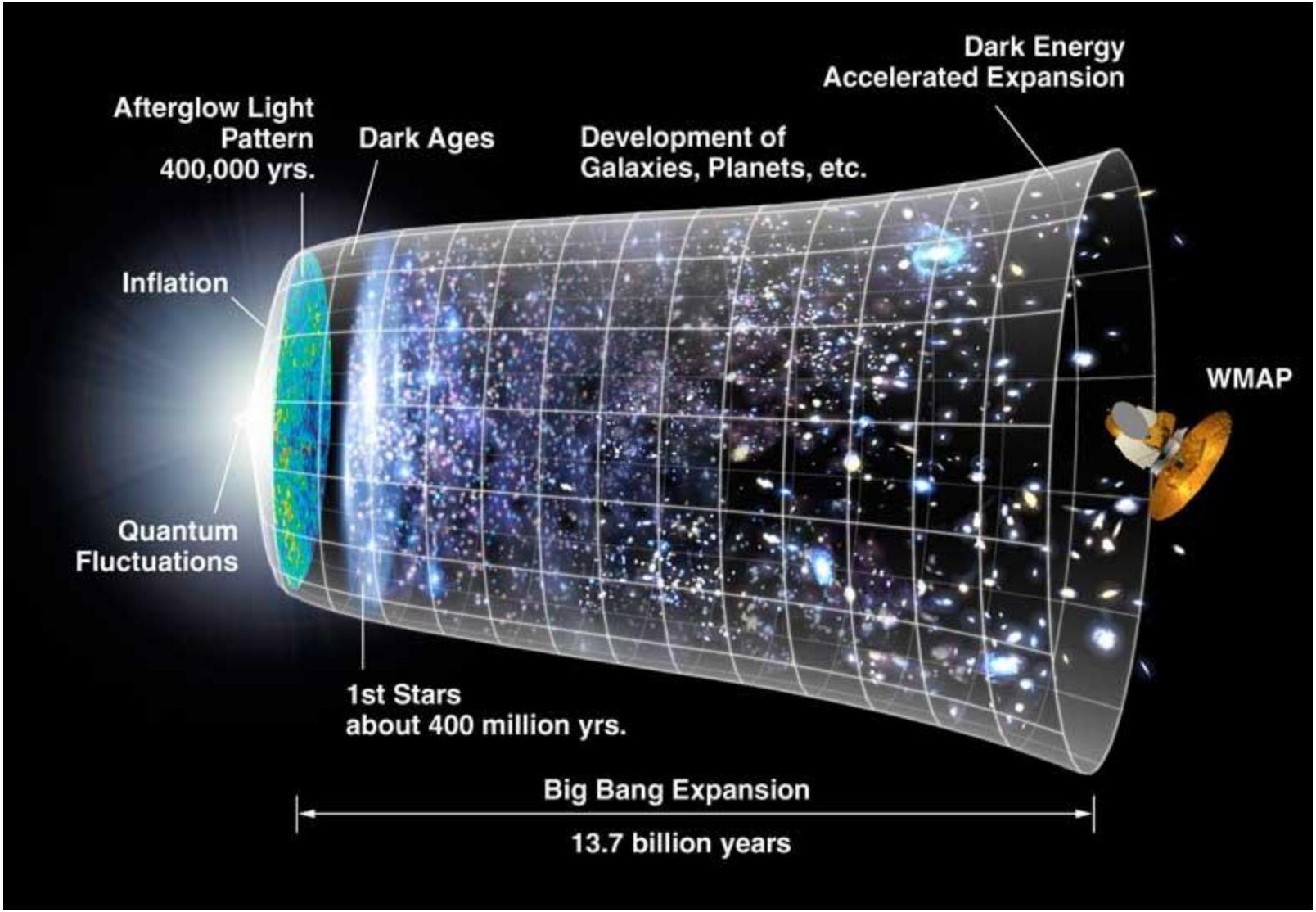

280 overpass


Fermi
Gamma-ray
Space Telescope

Particle Signatures






Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

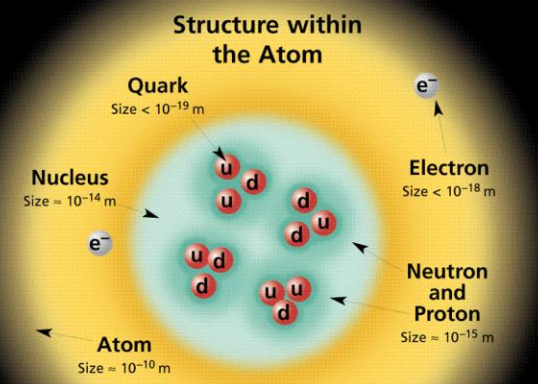
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

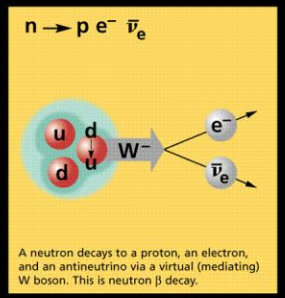
Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

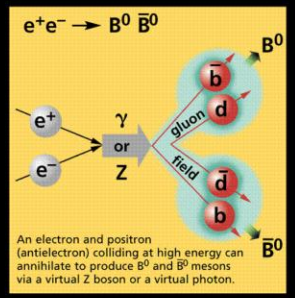
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

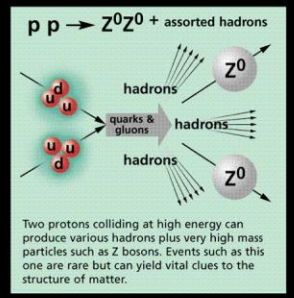
Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.

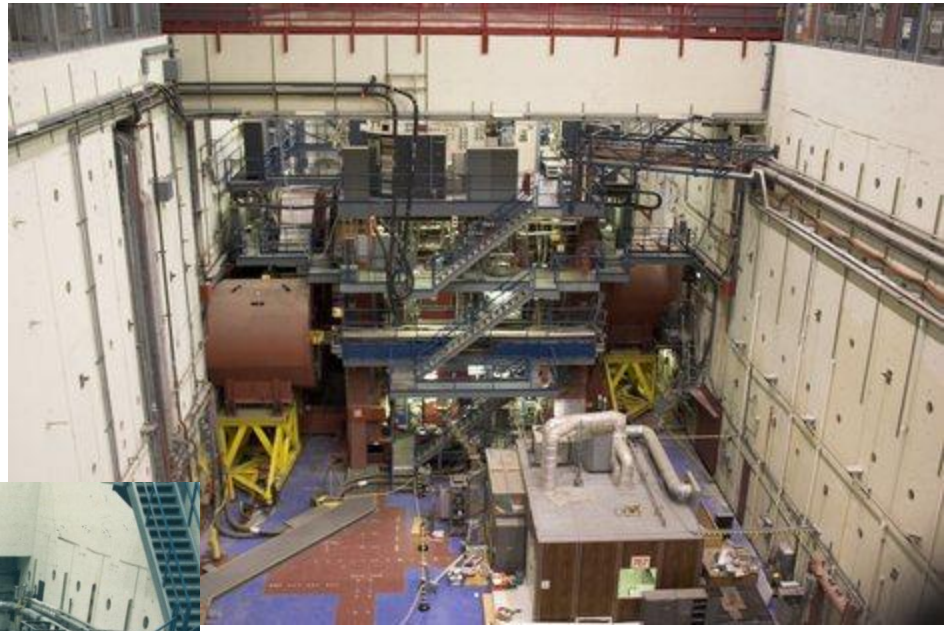


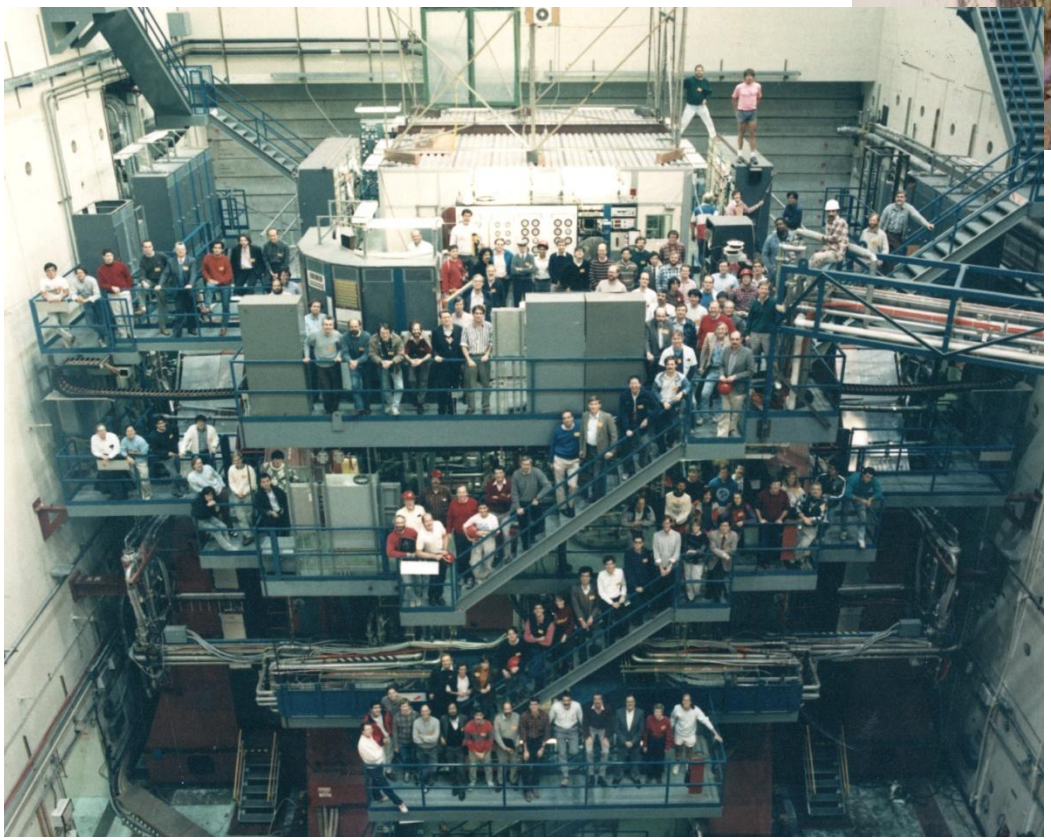
Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

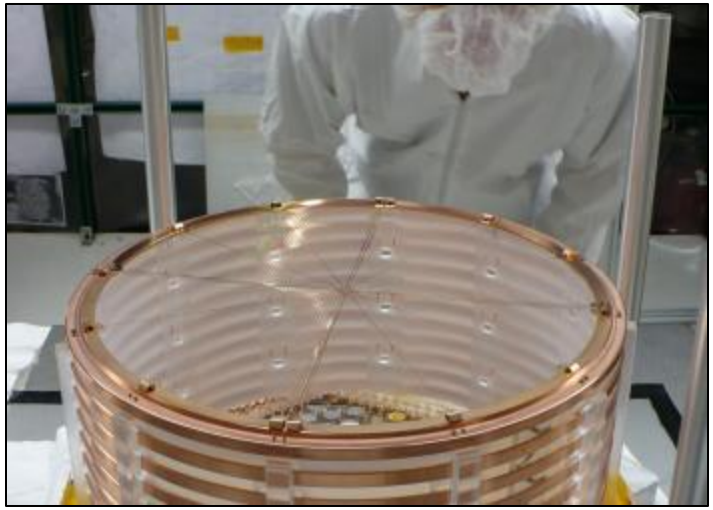
SLD:
Stanford Large Detector





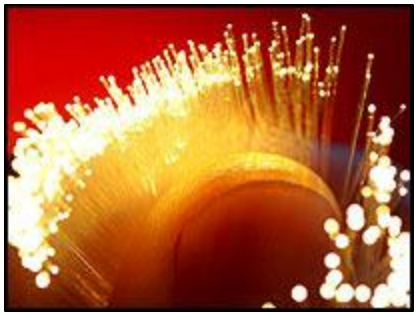
Guinness Book of World Records
and other notable milestones

2011:The slowest Standard Model process ever measured



The EXO 200 detector is the first to capture the 2nubb or "two-neutrino double-beta decay", a rare type of particle decay undergone by certain forms of radioactive elements.

2003: Internet speed record



Transferring 6.7 gigabytes of data across 10,978 kilometres (6,800 miles), from SLAC to Amsterdam, in less than one minute.

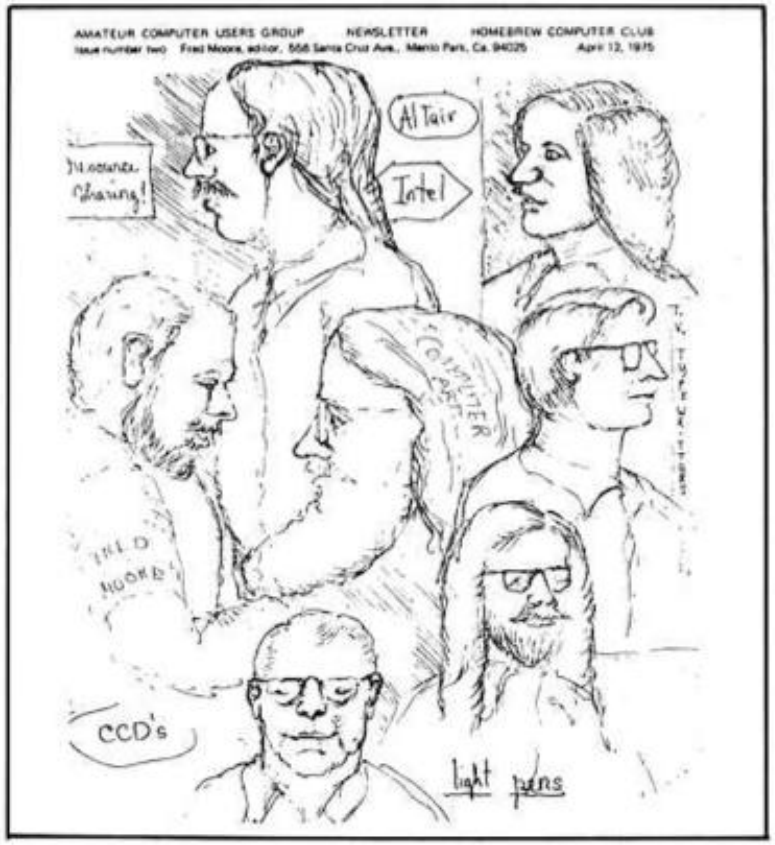
SLAC Noted for “groundbreaking work in manipulation and transfer of enormous datasets.”

Longest linear accelerator in the world, amongst the world's straightest objects.

At one time, SLAC accumulated the largest known database in the world, which grows at one terabyte per day.

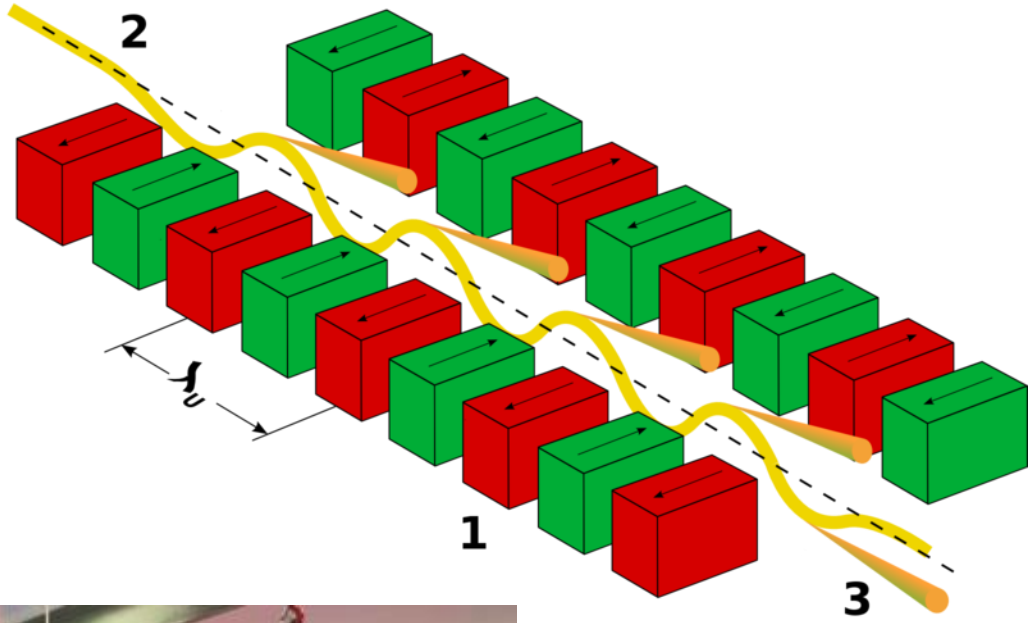
Homebrew Computer Club

The cover of the Homebrew Club's first newsletter.

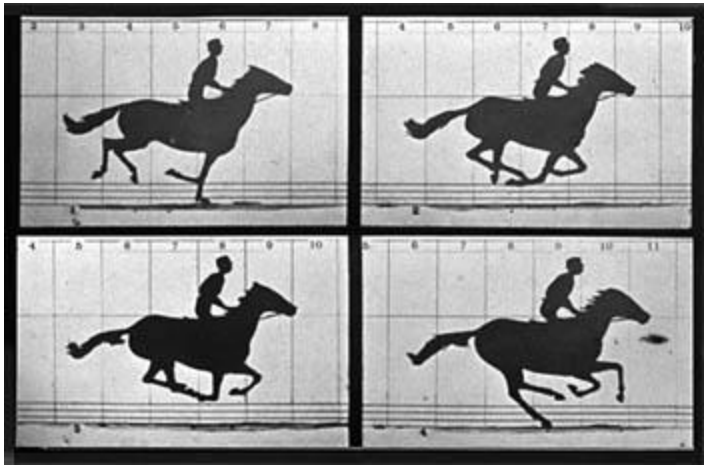


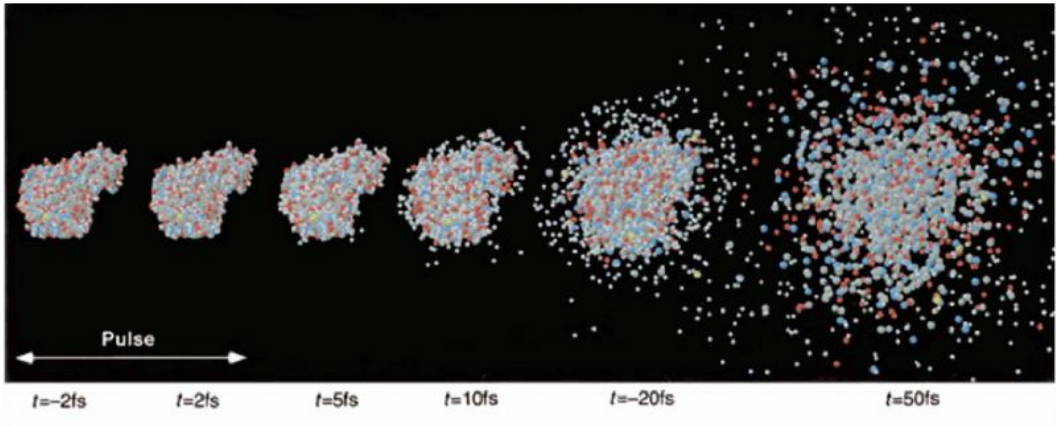
SLAC's Panofsky Auditorium also provided a venue for the Homebrew Computer Club and other pioneers of the home computer revolution of the late 1970s and early 1980s.

Synchrotron Radiation



LCLS: History of imaging breakthroughs



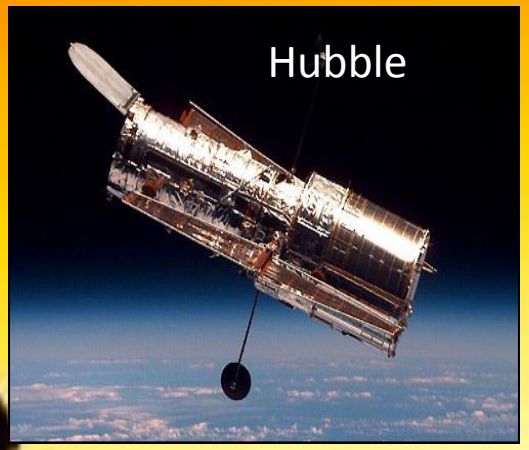


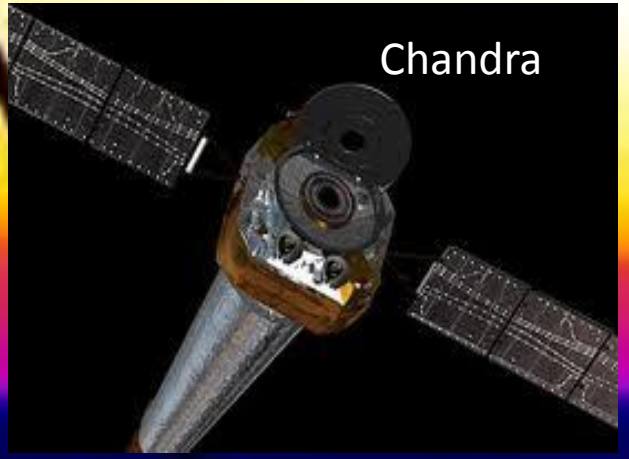
Stop-action imaging at Stanford has roots going back more than 100 years. Around 1872, Eadweard Muybridge started making stop-motion photographs of people, animals, and trains in motion on Leland Stanford's farm. Muybridge set up a bank of cameras to take photographs at a high speed (faster than 1/1000th of a second, he claimed) as Stanford's prized race horses tripped wires connected to the shutters. The images showed the hooves entirely off the ground at the same time, something no eye had ever been quick enough to confirm.

The LCLS provides X-rays of such shortness and precision that stroboscopic experiments can be done with materials on the nanoscale, and even with individual molecules and atoms.

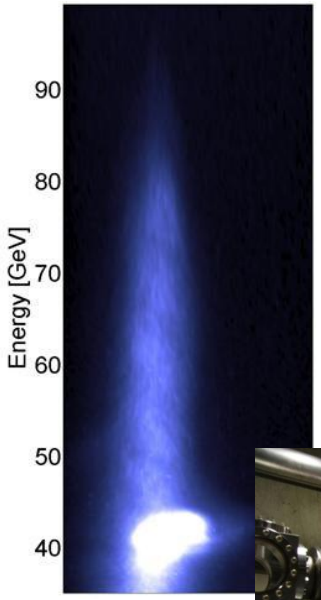
Astrophysics

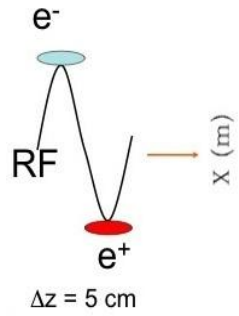
Studying the very large requires scaling up your tools in a very large way!

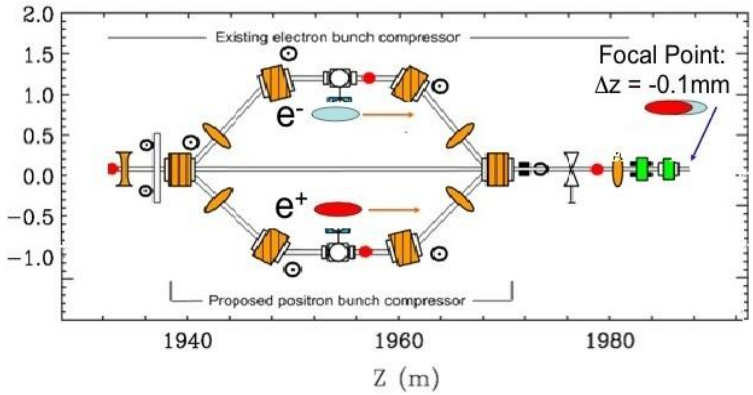


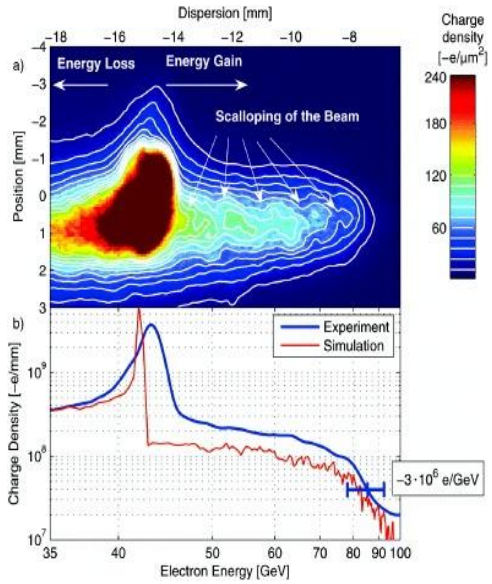


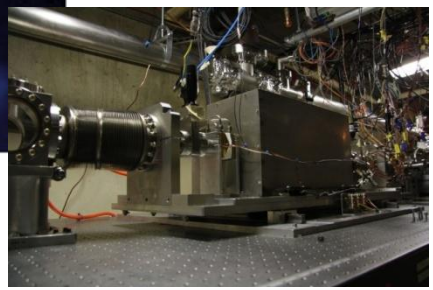
FACET

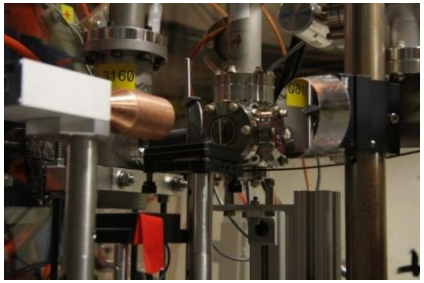


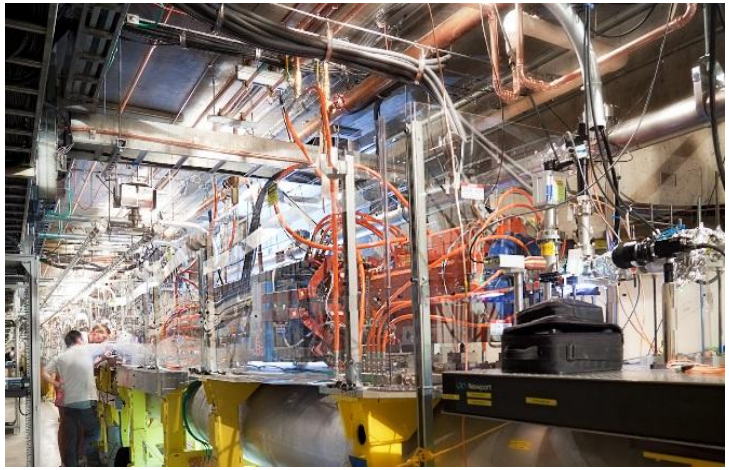












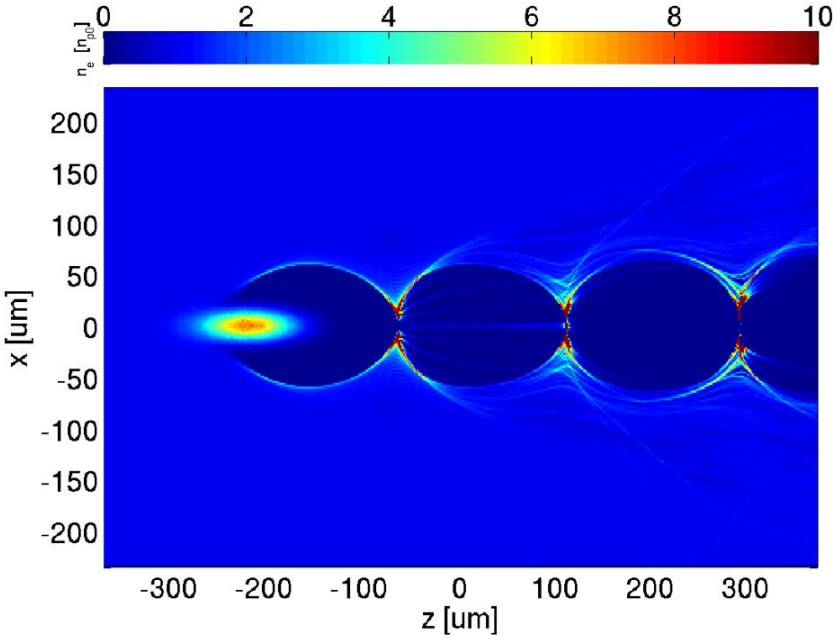
The next generation of particle acceleration
Will advance materials, biological, and energy sciences
Plasma acceleration of electrons and positrons at 23 GeV
Up to 3,000 times the Linac acceleration (50 GeV per meter!)
20,000 Amp peak beam currents

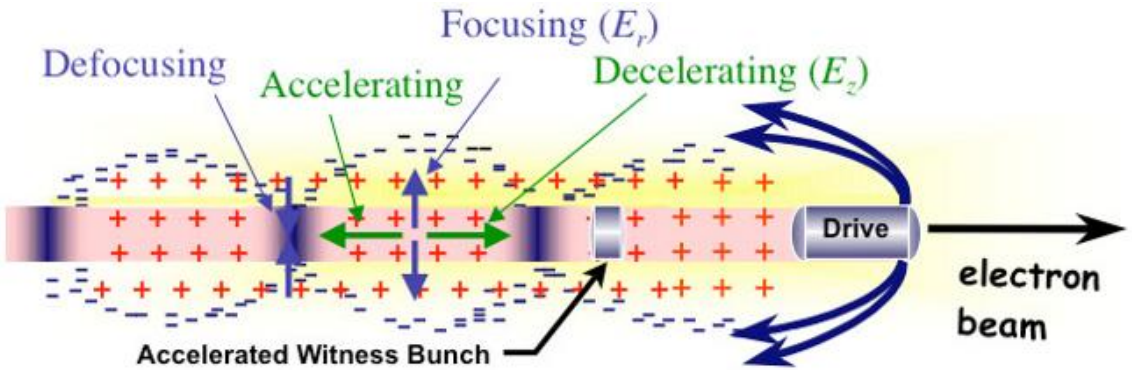
FACET

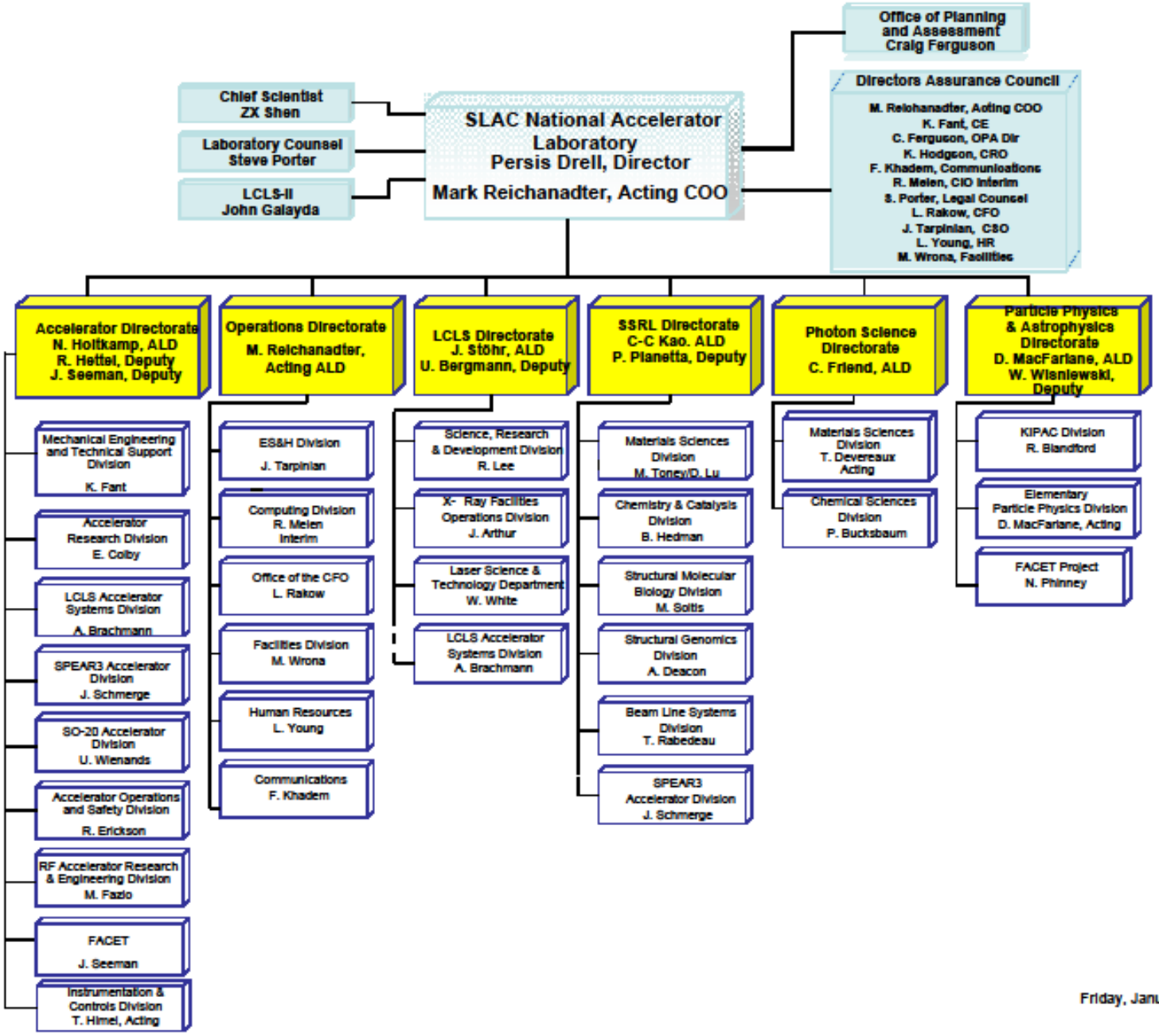
FACET uses the first 2/3 of the SLAC Linac. It includes the damping rings, 2 km of accelerating RF cavities, a compressor chicane in Sector 10, and the W-chicane and experimental area in Sector 20.

FACET: Plasma Acceleration

Plasma Wakefield Acceleration, will be studied at FACET. PWFA produces accelerating gradients that are 1,000 times as strong a those produced by SLAC's RF cavities!







Friday, January 06, 2012

Single Shot Single Cell Imaging