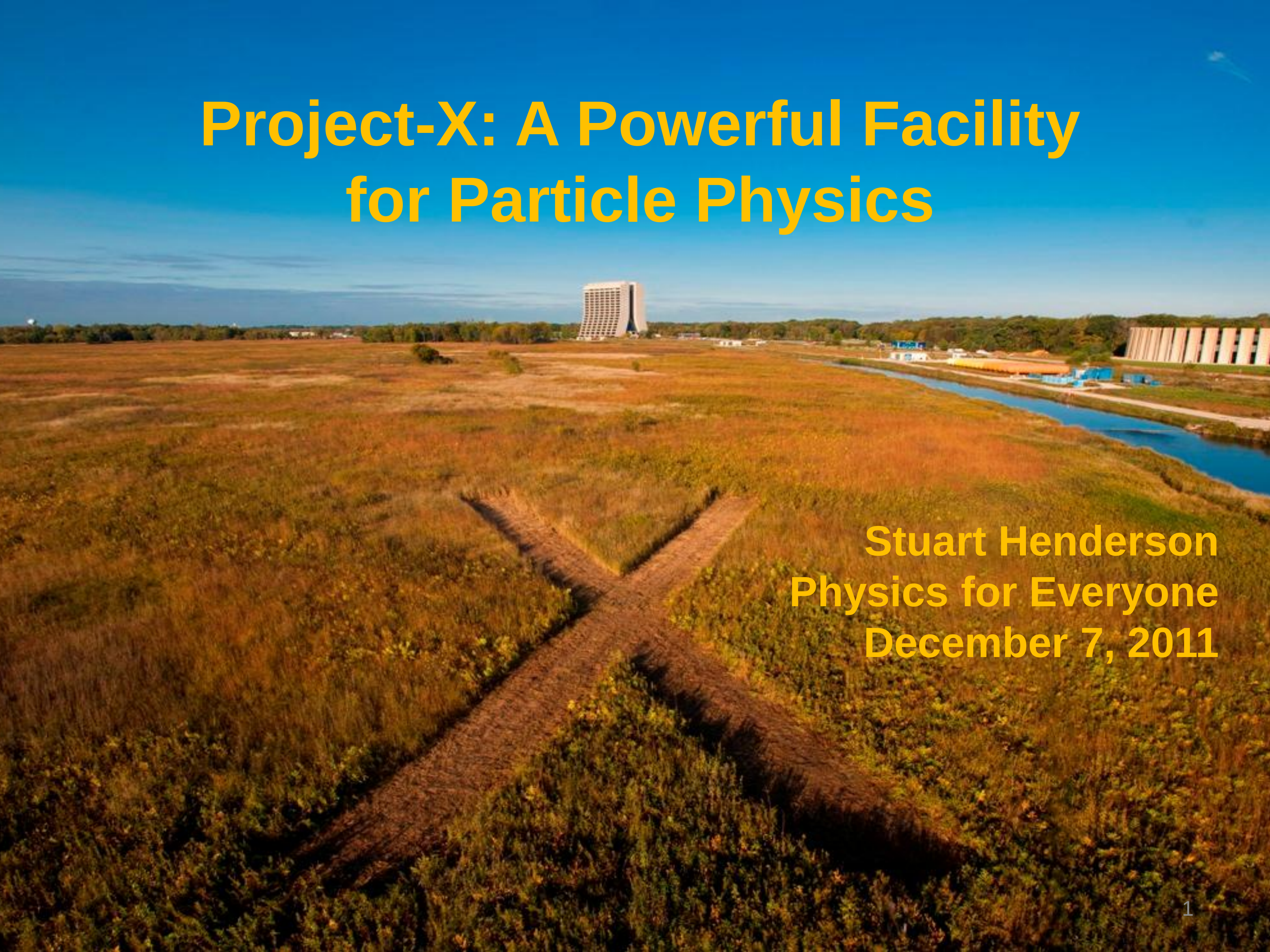
Project-X: A Powerful Facility for Particle Physics



Stuart Henderson

Physics for Everyone

December 7, 2011

Questions I Will Try to Answer

- What brings us to this point?
- What is Project-X and how does it work?
- Why do we need Project-X?
- What else can we do with Project-X?

Fermilab's Legacy of Building Accelerators to Answer the Big Questions

Main Ring Construction (1969-1971)

- Main Ring Groundbreaking: Oct. 3, 1969
- Celebration of last Main Ring magnet: April 16, 1971

Energy Saver/Doubler/Tevatron Construction (1979-1983)

Project approved: July 1979

Last magnet installed: March18, 1983

Antiproton Source Construction (1983-1985)

Antiproton Groundbreaking:
Aug. 16, 1983

First antiprotons collected:
Sep. 6, 1985

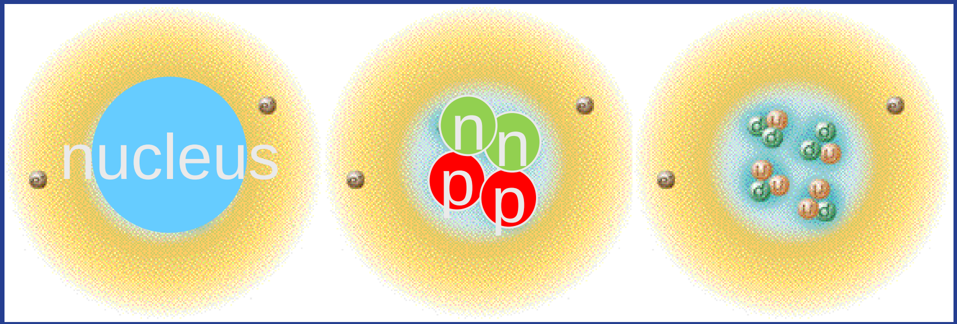
Main Injector Construction (1993-1999)

Groundbreaking:
March 22, 1993

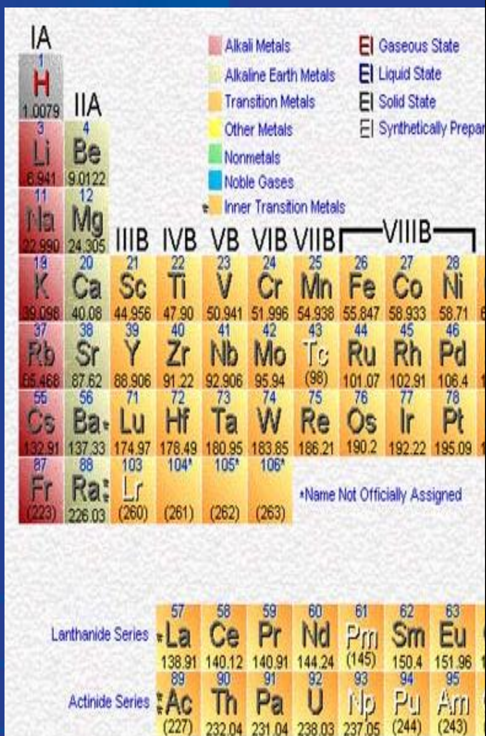
Dedication:
June 1, 1999

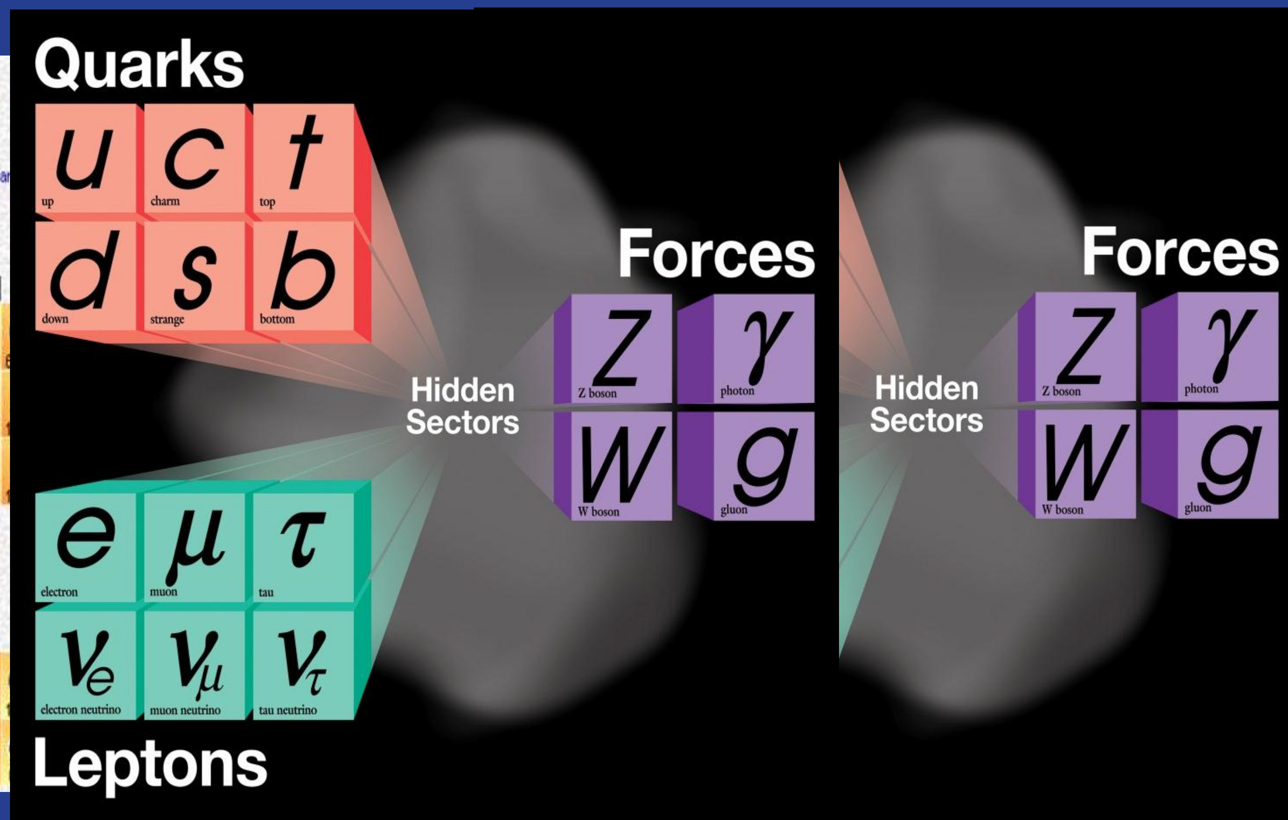
Particle Physics is all about the Big Questions

- How did the universe begin?
- Why are we here and where are we going?
- What is the universe made of?
- How many forces are at work in the universe?



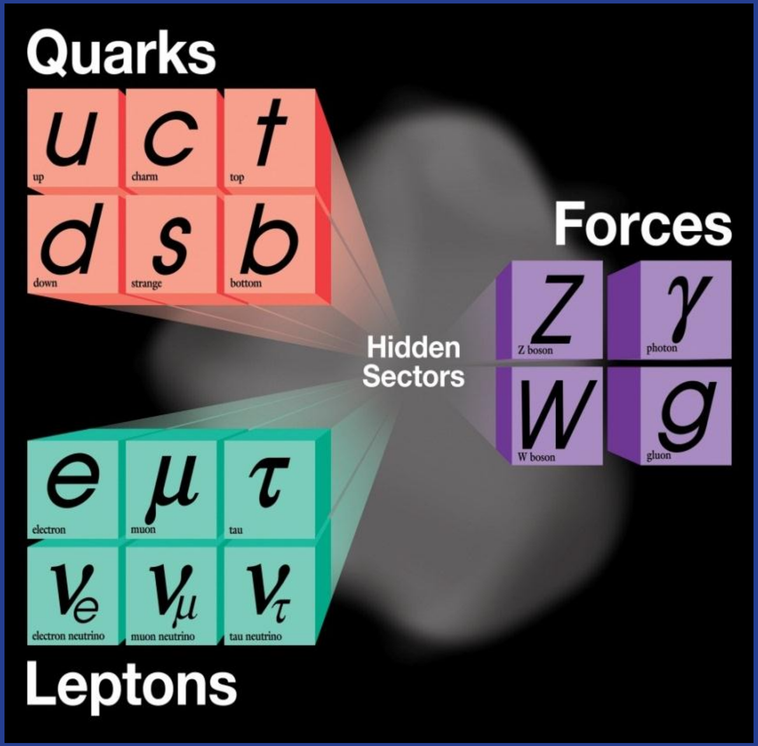
We Have Assembled a Remarkably Powerful Picture of the Subatomic World





Fermilab has Played a Big Role in Answering the Big Questions

- What are the basic building blocks of matter?
- How many families of quarks & leptons are there?
- How do the basic building blocks interact with one another?
- What are the basic forces of nature and how do they act?



- Fermilab has played a central role in constructing this picture:
  - Bottom, top quarks and tau neutrino discovered/observed at Fermilab

But, Big Questions Remain!

- What is the origin of mass?
- Why are there so many kinds of particles?
- Is there a deeper connection between all these building blocks?
- Do all forces become one?
- What do neutrinos tell us?
- What happened to all the antimatter?
- What is dark matter?
- Mystery of dark energy?

Answering these questions requires a new, powerfule, accelerator at Fermilab: Project-X

Energy vs. Intensity

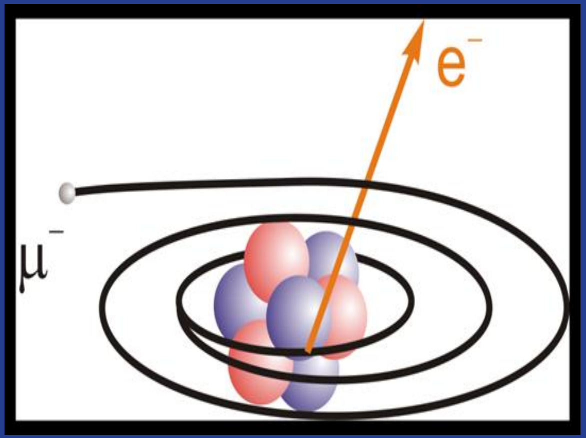
- When you think about particle accelerators you may think of the really big ones that strive for the highest energies:

- The future program at Fermilab relies on making the world's most intense beams of particles, and exploring the physics that can only be studied with such **eXtremely** intense beams

Physics at the Intensity Frontier

Rare Decays and Rare Processes

- Example: a Muon cannot "morph" into an Electron, as far as we know (known processes too small to observe)
- By producing a huge number of muons, we will search for "muon to electron conversion", which if seen, indicates **startling new physics,** perhaps pointing the way to a deeper structure

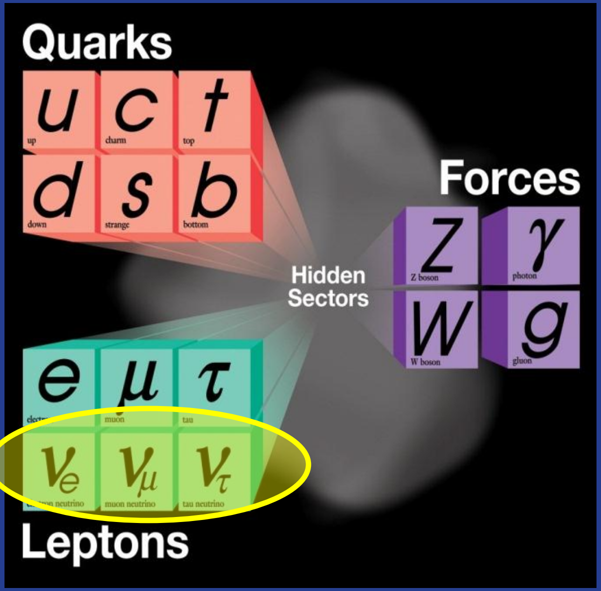


- Fermilab will study 1,000,000,000,000,000,000 muons searching for this…a number equal to the grains of sand on all the world's beaches!
- ***We need a new, very powerful accelerator to search for these very rare processes!***

How do we think about these rare decays?

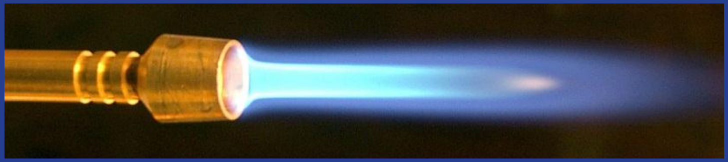
Neutrinos

- Neutrinos are very elusive. We are just beginning to understand what they are and how they work
- They are everywhere!
  - ~100 trillion neutrinos zip through each person every second.
  - There are one billion neutrinos for each proton or electron in the universe



Intense Beams of Neutrinos

- They are weird!
  - They hardly interact with anything – zipping through earth
  - They weigh almost nothing (but not nothing)
  - They "morph" over large distances from one to another
  - Do they travel faster than the speed of light?
- To make sense of them we need to produce them in **Huge** numbers in the lab
- ***We need a new, very powerful accelerator, to make sense of neutrinos!***



Long Baseline Neutrino Experiments

Fermilab's Program

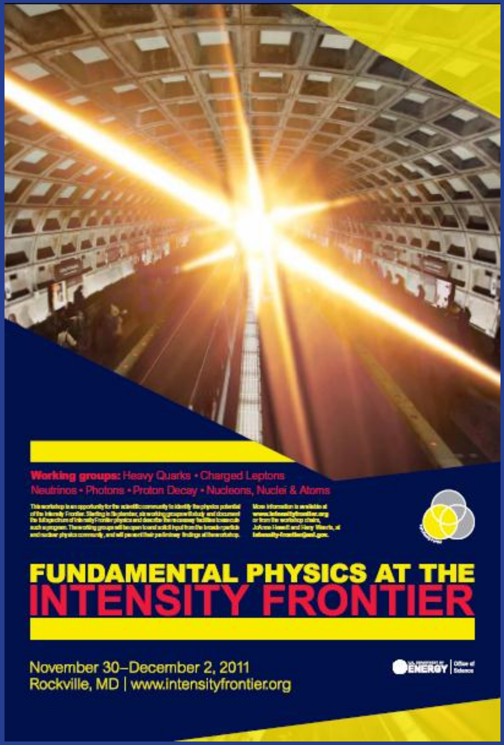
- Fermilab's accelerator-based program is focused on the **Intensity Frontier**
- We intend to build the accelerator facilities, build the experimental facilities and carry out the experiments that will enable Fermilab to be the **leader on the Intensity Frontier**
- Just as Fermilab's Tevatron, built 30 years ago, provided an incredibly powerful platform that enabled three decades of groundbreaking particle physics research
- We are now planning to build the next powerful facility to enable the next three decades of world-leading research with Project-X

The Project-X Accelerator Facility

Project-X Will Be….

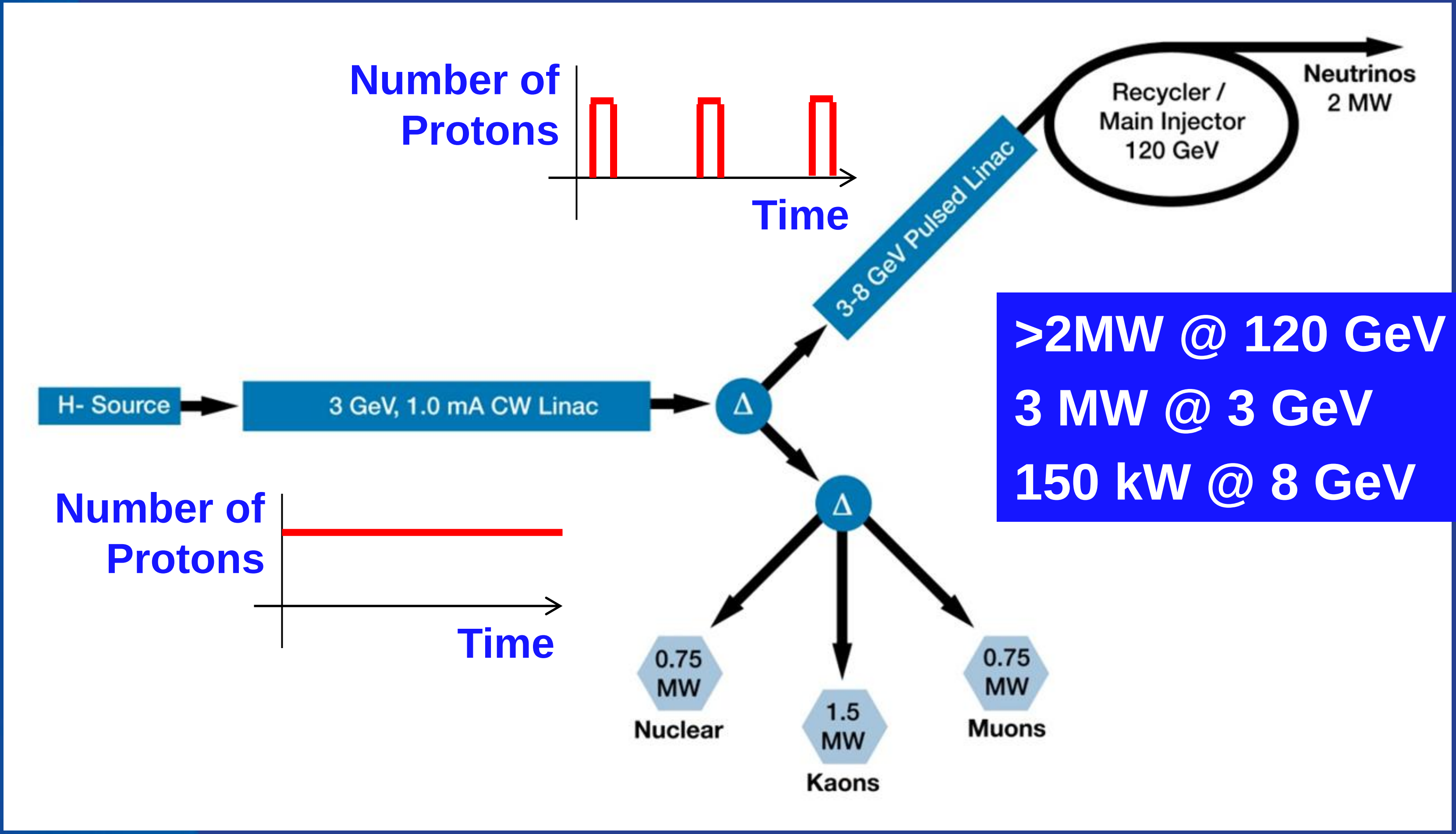
- a state-of-the-art, world-leading accelerator facility at Fermilab
- …providing the world's most powerful beams of protons
- …to make the world's most intense beams of neutrinos, muons, kaons and rare nuclei
- …which will cement Fermilab's position as the world-leader in the Intensity Frontier for decades to come
- …and will also provide a platform for the next accelerator at Fermilab beyond PX

News and Plans



- We are busy building the scientific case, and making that case with our funding agency and the particle physics community
- Last week the physics community came together to assess the scientific opportunities at the Intensity Frontier
- We are advancing Project X technology through a vigorous R&D Program in many areas
- We want to be ready for construction by 2016
- Project X is a national project with international participation. Collaboration is extremely important to the success of Project X!

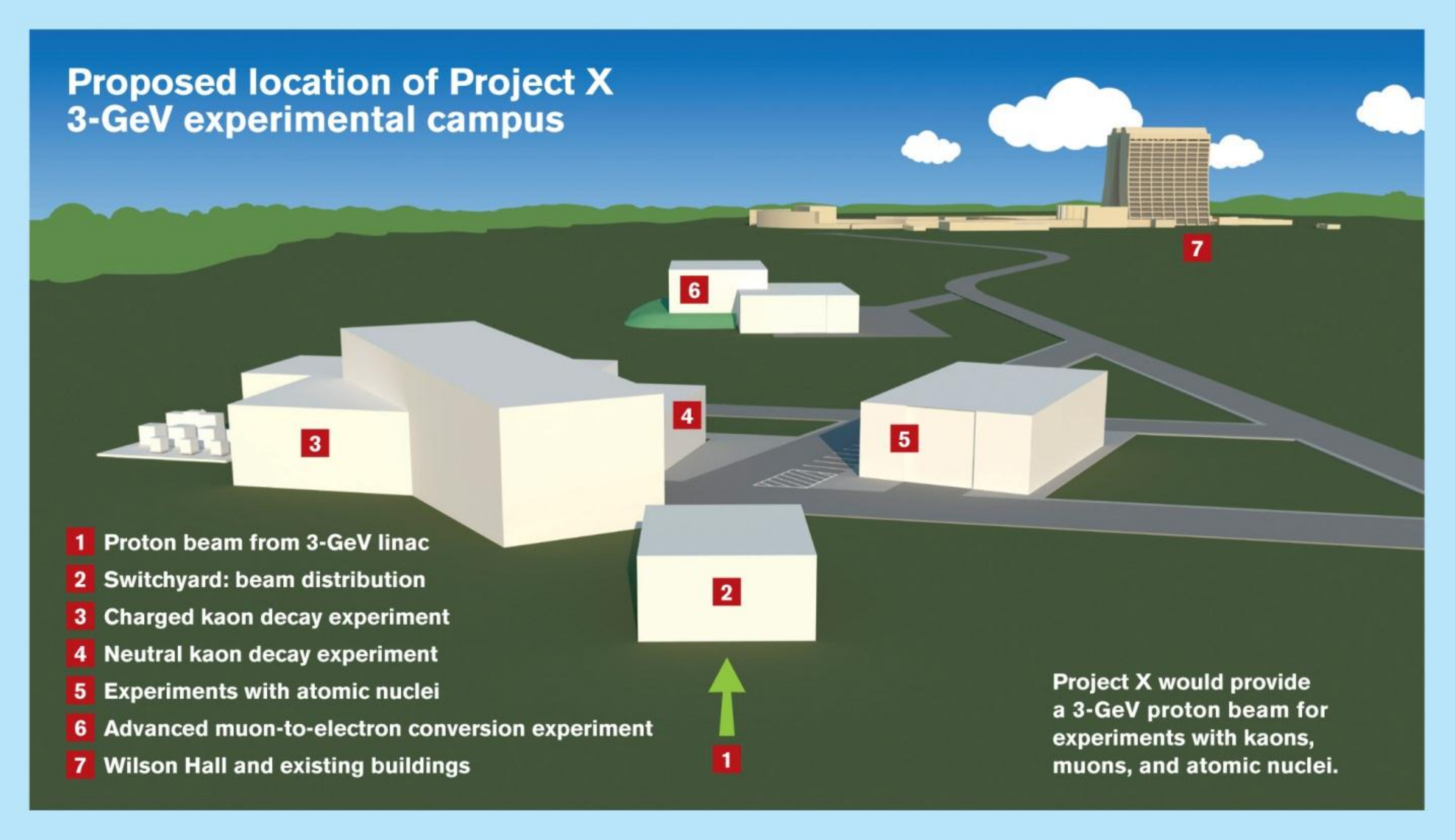
The Project-X Accelerator



>2MW @ 120 GeV
3 MW @ 3 GeV
150 kW @ 8 GeV

Fermilab's Accelerator Complex in the Project X Era

Project X 3-GeV Experimental Campus



In the World of High-Power Proton Accelerators Project-X will be Unique

- Highest proton beam power on the planet
- Broadest range of proton beam energies available: 1-120 GeV
- Ability to provide beams to multiple experiments simultaneously
- Ability to tailor the beam properties to the needs of each experiment
- Upgradeable to very high power

Project-X is the ideal machine for intensity-frontier physics

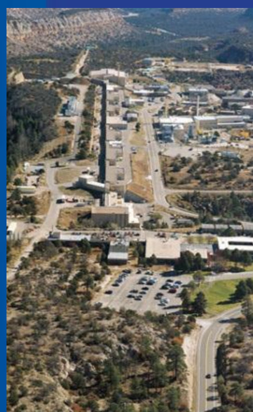
Project-X Will Provide 5 MW of Beam Power: How Much is a MegaWatt?

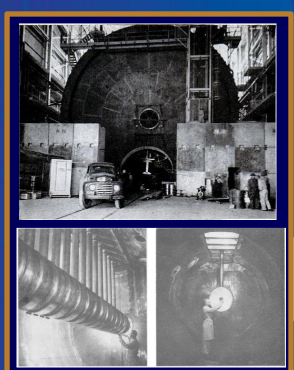
5 MW powers ~4000 homes

Electric locomotive:
5 MW traction power

10 MW solar power plant

High Power Proton Accelerators: Some History





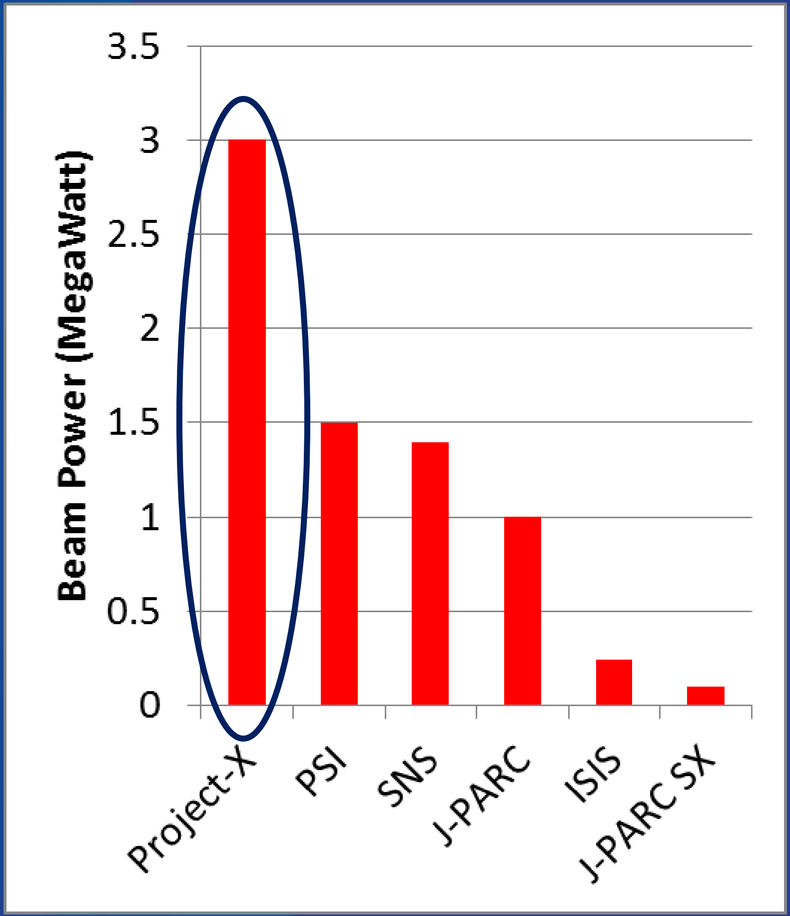
1972: LANSCE

1950s: Materials Test Accelerator

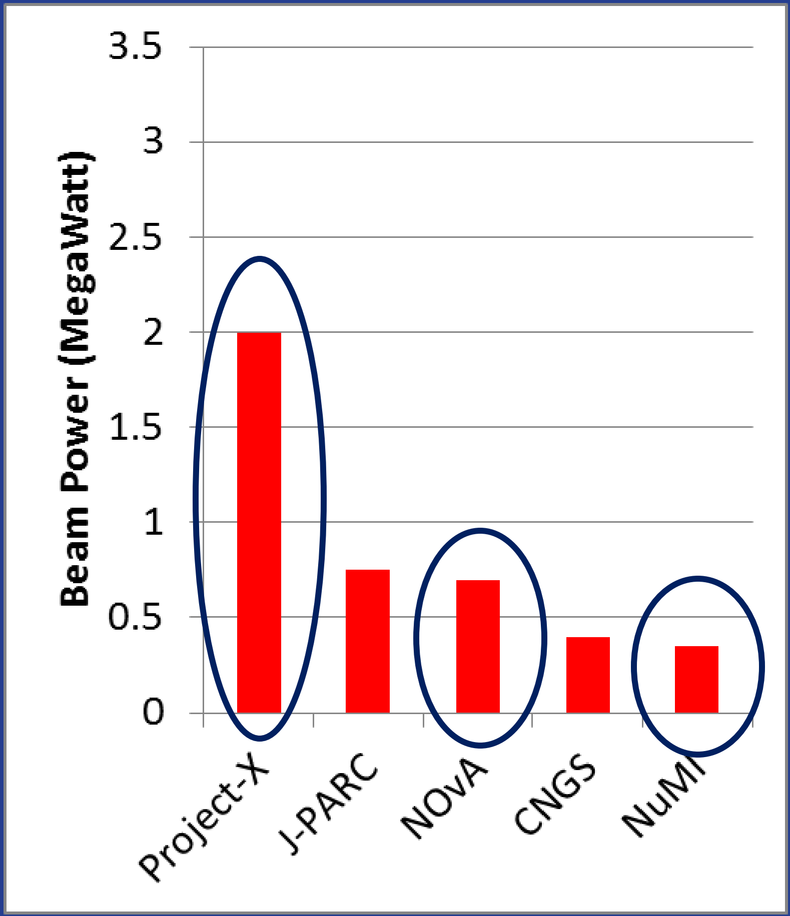
The Landscape of High Power Proton Accelerators

Project-X Beam Power Compared

Muon, neutron, kaon facilities



Long Baseline Neutrino facilities



How Project-X Works

Making a high power beam requires several ingredients

- Source of particles
- A way to control the detailed distribution of beam particles in time (beam chopper system)
- A way to accelerate the particles: Superconducting Radiofrequency Accelerator
- A place to deliver the beam (a target)
- Project X builds upon tremendous developments in the last two decades on **Superconducting Radiofrequency Accelerators**

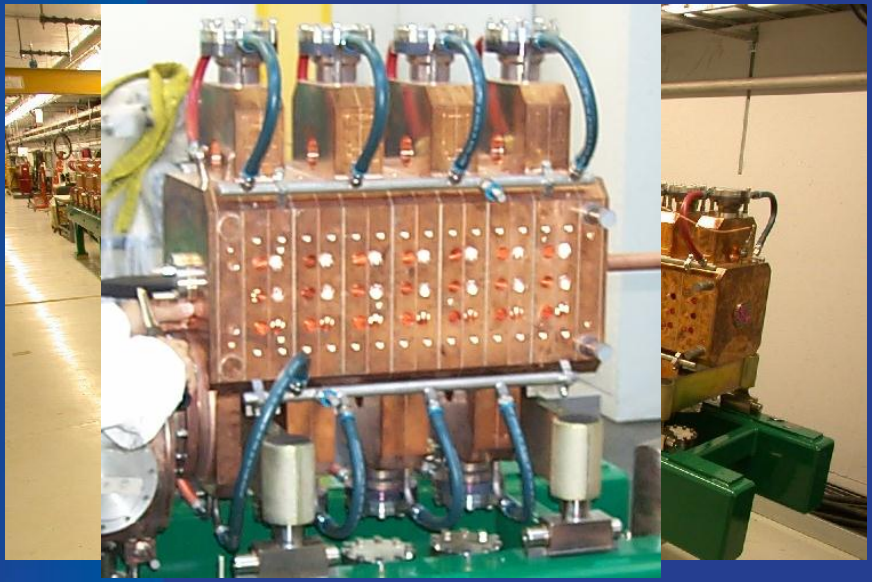
Superconductivity

- Normal conducting metals heat up when an electrical current is passed through them

- Superconductors are amazing materials that don't heat up when an electrical current is passed through them
- Some materials become superconducting when they are cooled to a few degrees above absolute zero (−460 °F)
- This means they can carry tremendous electrical currents

Normal Conductors vs. Superconductors

Normal Conducting Accelerating Cavity

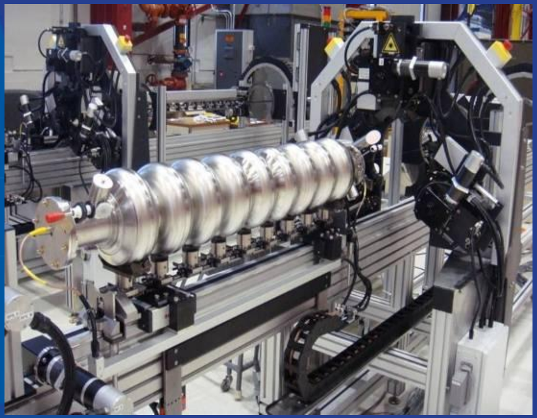


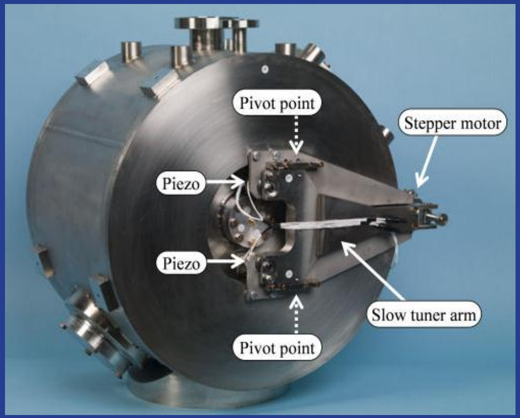
- 1 Million Volts/meter;
- ~2 Million Watts RF power dissipated
- Long and inefficient

Super Conducting Accelerating Cavity

- 15 Million Volts/meter
- ~10 Watts RF power dissipated
- Short and efficient

Superconducting Linear Accelerator for Project-X





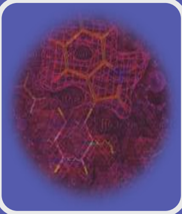
Project-X: A Powerful Facility for Particle Physics *and Beyond*

What else can we do with Project-X?

- A multi-MegaWatt high energy proton accelerator is a national resource, with potential application that goes beyond particle physics
- Such facilities are sufficiently expensive that the U.S. will not invest in multiple facilities with duplicative capabilities
- With proper design we can share Project-X beams with non-particle physics activities
- Some of these non-particle physics activities can have a very big impact on problems of national importance, like energy

Applications of High Power Proton Accelerators

Materials Science

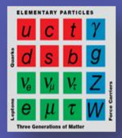


- Neutron/Muons to develop materials for energy

Energy & Environment

- Nuclear Energy
- Fusion Energy

Particle Physics

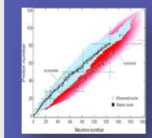


- Intensity Frontier experiments

Medicine

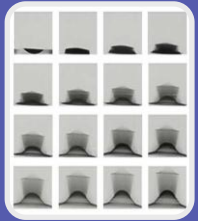
- Isotopes for medical diagnosis

Nuclear Physics



- Astrophysics (origin of chemical elements)

National Security



- Proton Radiography

Potential Benefits of Project-X: Materials Irradiation for Nuclear Energy

- Some materials used in nuclear reactors suffer from degraded properties after many years in the reactor environment
- Materials for next generation nuclear reactors need an order of magnitude greater radiation resistance than those in use today
- One can build a facility to study materials in extreme radiation environments

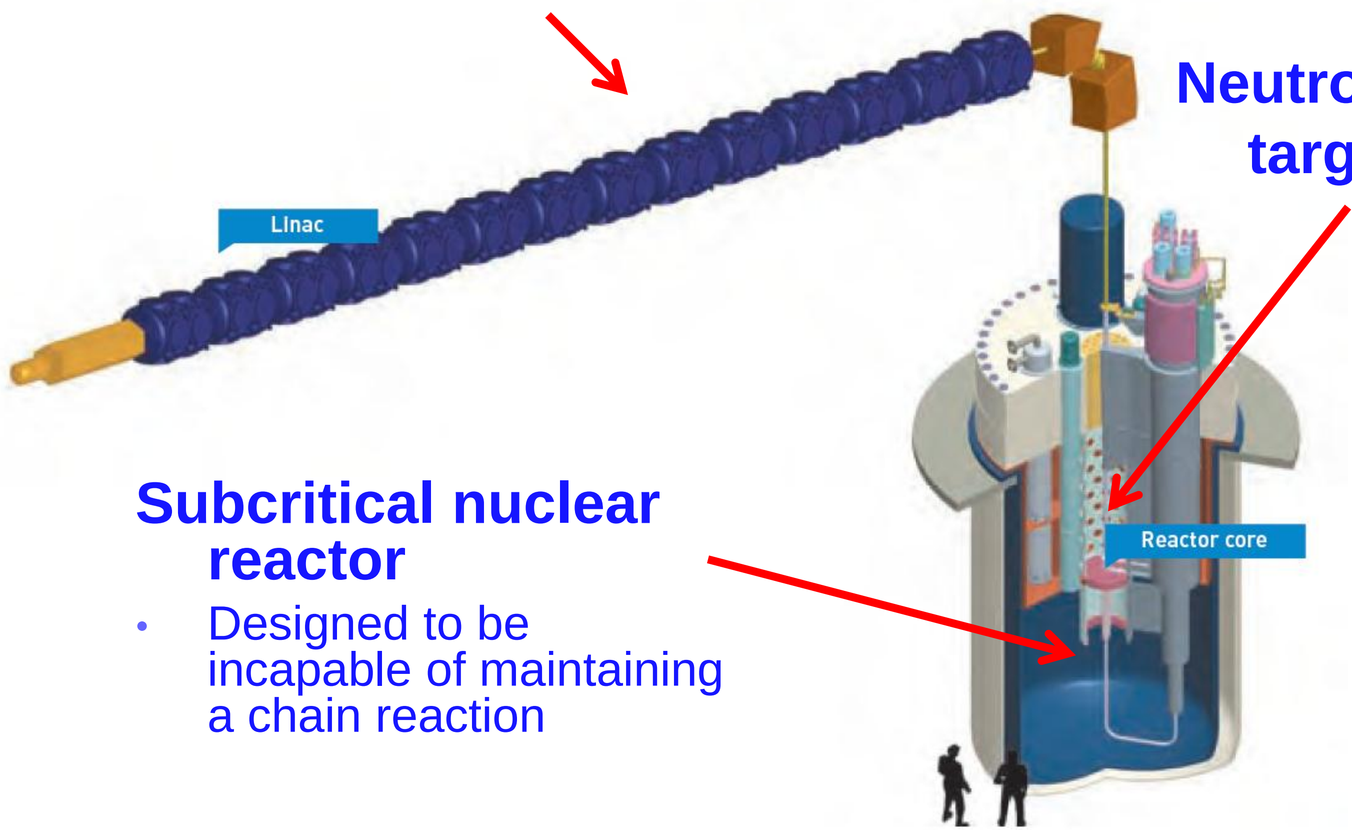
Swelling of Stainless Steel

Fermilab

Accelerator Driven Reactors

High-power, highly reliable proton accelerator

Neutron-producing target system



Subcritical nuclear reactor

- Designed to be incapable of maintaining a chain reaction

Applications: Accelerator Driven Subcritical Reactor Systems

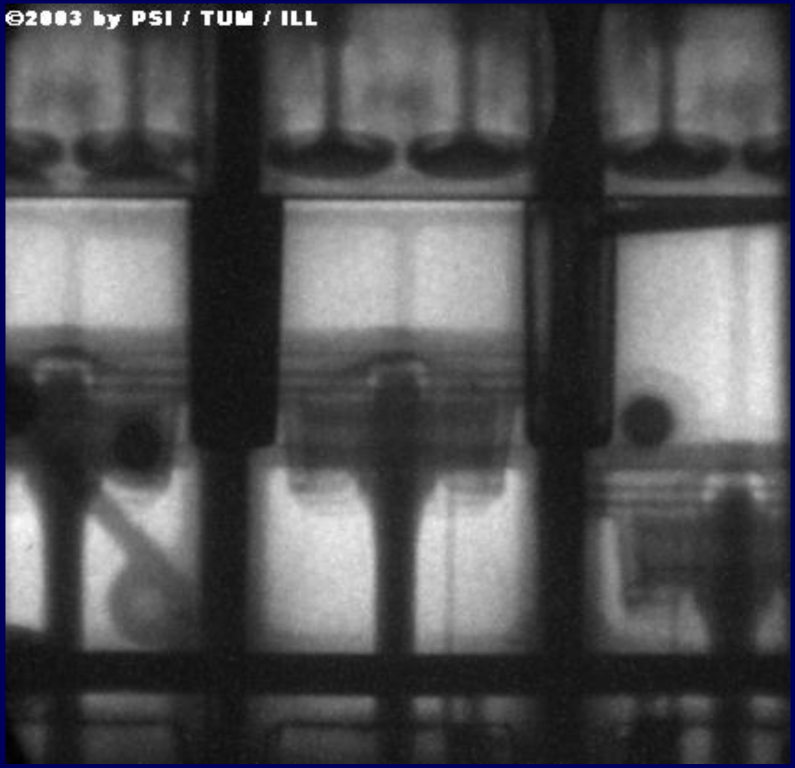
- Accelerator Driven Reactors may be useful for
  - Generating electrical power with inherent safety (just shut off the accelerator)
  - Transforming highly radioactive nuclear waste to much less radioactive forms to help solve the country's nuclear waste problem

- Project-X could help to develop this technology for use elsewhere

Applications: Neutron Imaging

- Today's highest-power proton accelerators are utilized to produce neutron and muon beams for materials science
- Neutrons have unique properties, which make them very useful for imaging

Neutron imaging of a BMW engine showing oil flow and lubrication (B. Schillinger et. al., Physica B 385 (2006) 921)



Project-X Will Be a Very Versatile Tool

Long-baseline Neutrinos

Rare Kaon Decays

Short-baseline Neutrinos

Muon Physics

Standard Model tests with Nuclei

Cold muons/ neutrons for materials sci.

Accelerator Driven Systems

Materials Irradiation

Conclusion

- Fermilab is going after the most exciting questions in particle physics, the most interesting questions about the nature and future of our universe.
- We are planning to build a next generation, world's most powerful proton accelerator to power Fermilab and the nation's particle physics program for the next three decades.

There are complementary approaches:

The Energy Frontier exploits Einstein's mass-energy relation

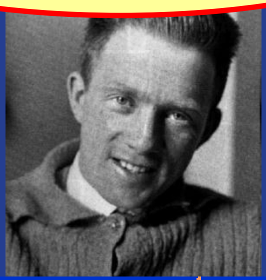
$E=mc^2$

appearance of **real** new particles

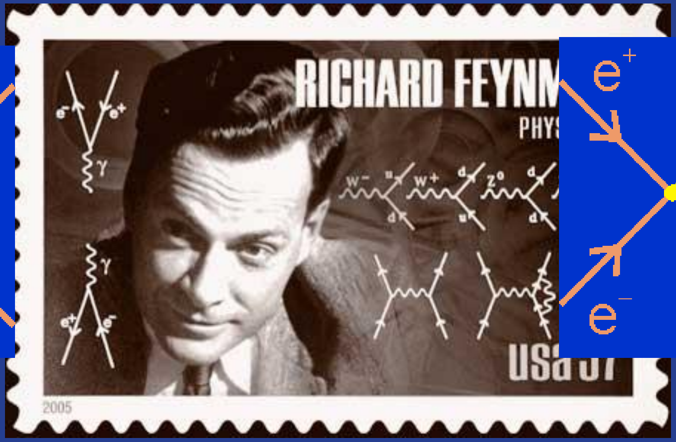
The Intensity Frontier exploits Heisenberg's uncertainty principle

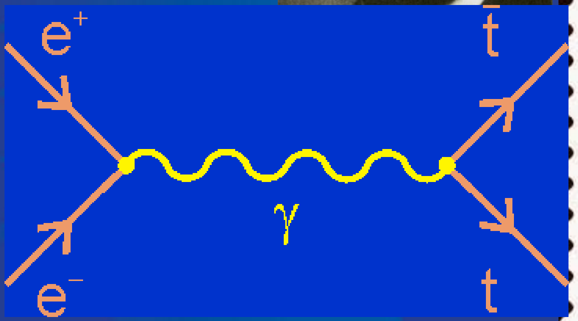
$\Delta E \Delta t \gtrsim \hbar$

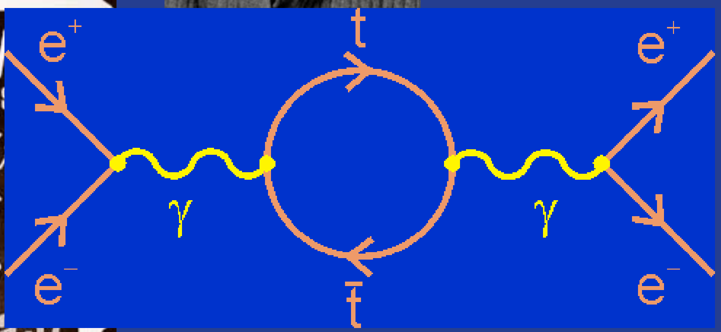
appearance of **virtual** new particles



Feyman's tools







High energy crucial

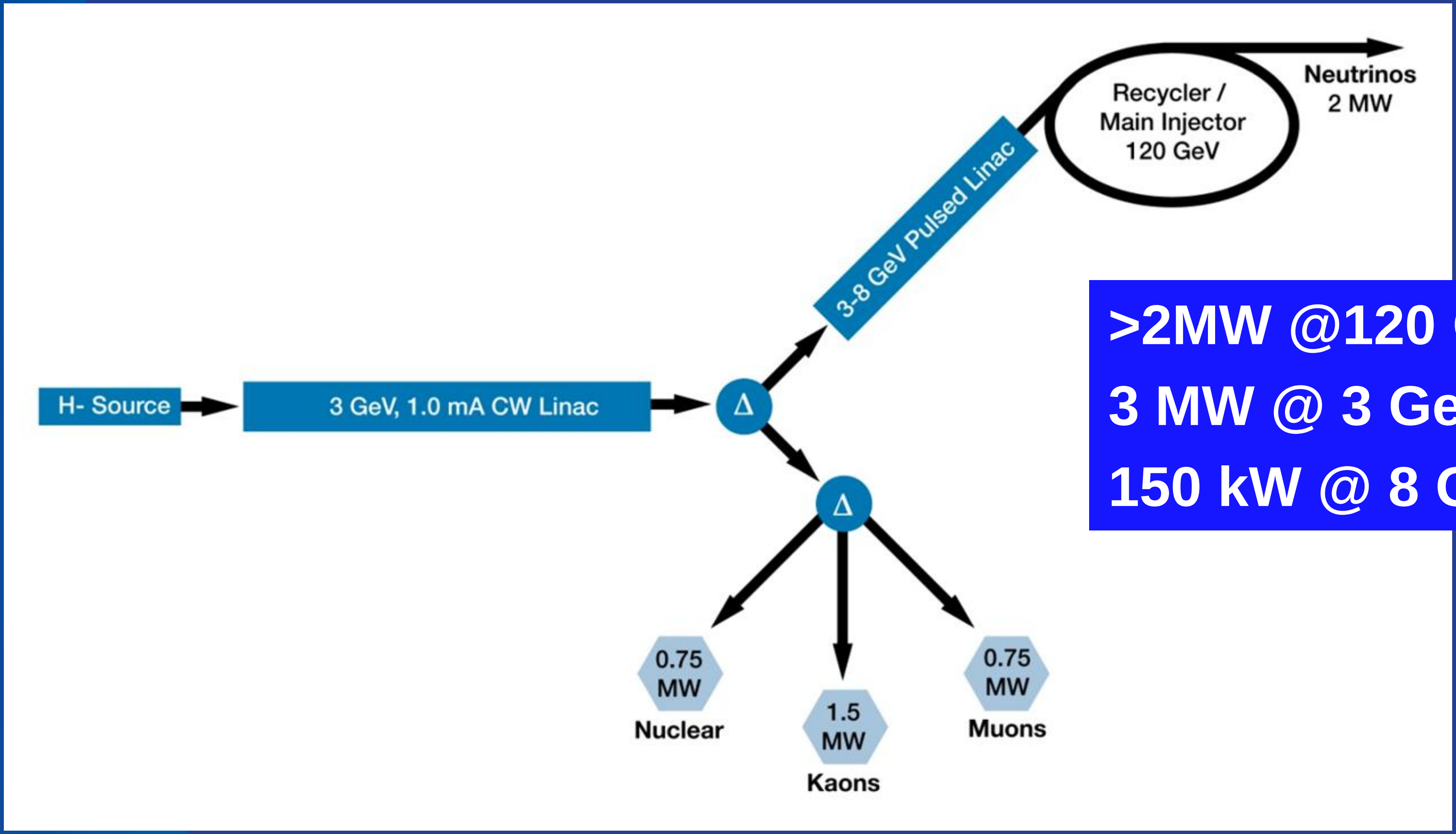
High intensity crucial

Fermilab

Test Facilities: ASTA and CMTF

- Advanced Superconducting Test Accelerator (ASTA) under construction at NML
- Cryomodule Test Facility (CTF) to allow cryogenic and RF testing of assembled cryomodules

Project X Reference Design

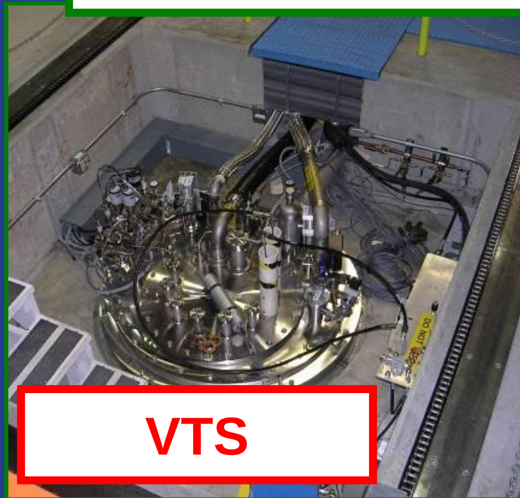


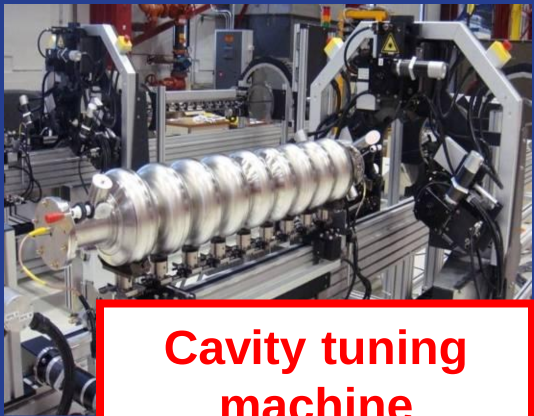
>2MW @120 GeV
3 MW @ 3 GeV
150 kW @ 8 GeV

- Unique capability to provide multi-MW beams to multiple experiments simultaneously, with variable bunch formats.
- **Provides U.S. Intensity Frontier leadership for decades!**

Fermilab SRF infrastructure


VTS


VTS


Cavity tuning machine


HTS


String Assembly


MP9 Clean Room


Final Assembly


1st U.S. built ILC/PX Cryomodule


1st Dressed Cavity