Experimental Particle Physics at SLAC

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Stanford Graduate Student Orientation

September 17, 2015

The Best of Times

- **We've found the Higgs** but have just scratched the surface of what a new, fundamental scalar means for particle physics

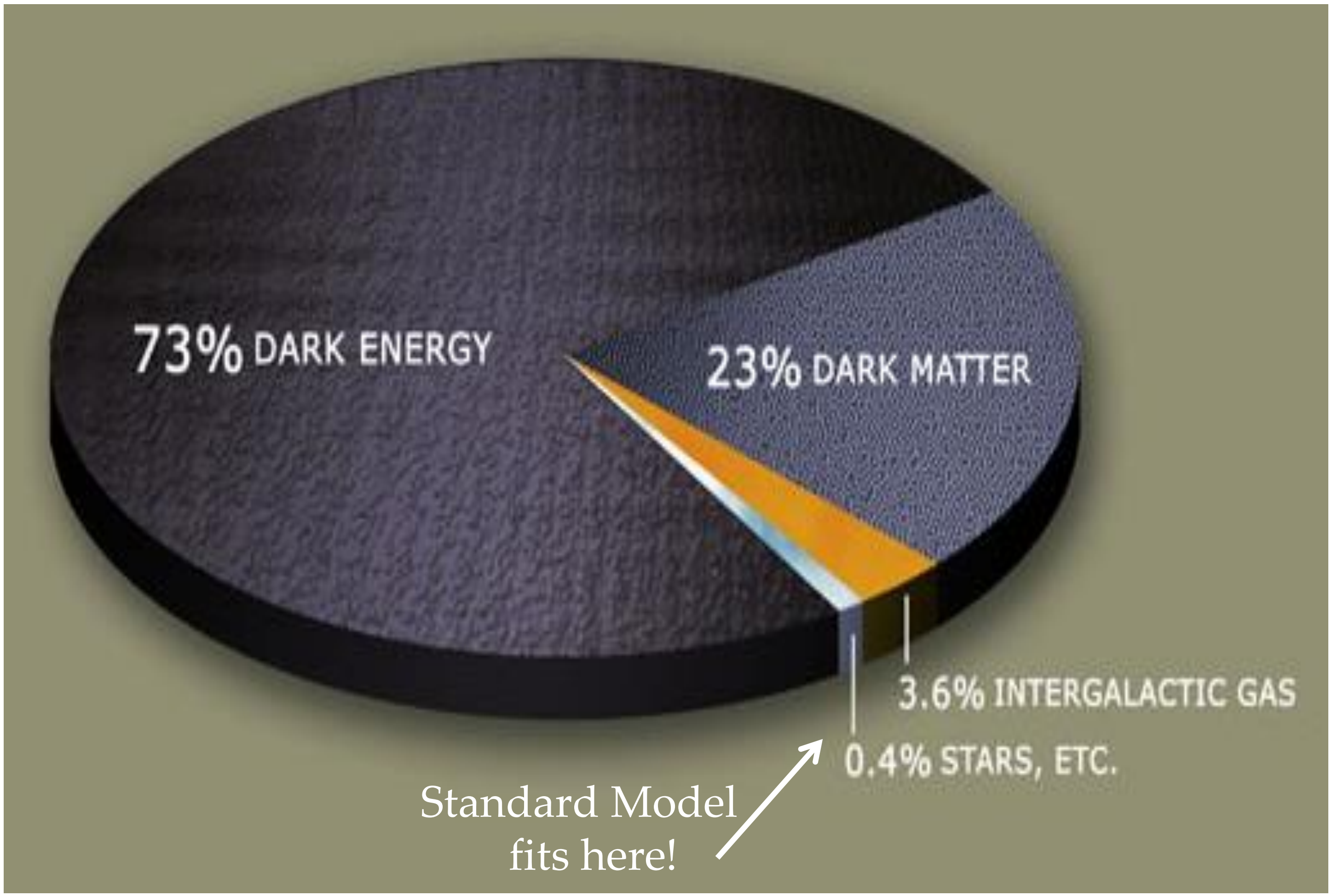
- **The LHC** is offering us our first glimpse of the highest energy collisions ever made on earth—13 TeV. What new physics is waiting to be discovered?

- **Neutrinos have mass and mix!** Pinning down masses, mixing angles, and CP violation in the neutrino sector could lead to understanding why baryons dominate anti-baryons in the universe.

- **Dark Matter detection** could be just around the corner! Will it be Wimps, Axions, Hidden Sector Particles, or something we haven't yet imagined?

Job Security

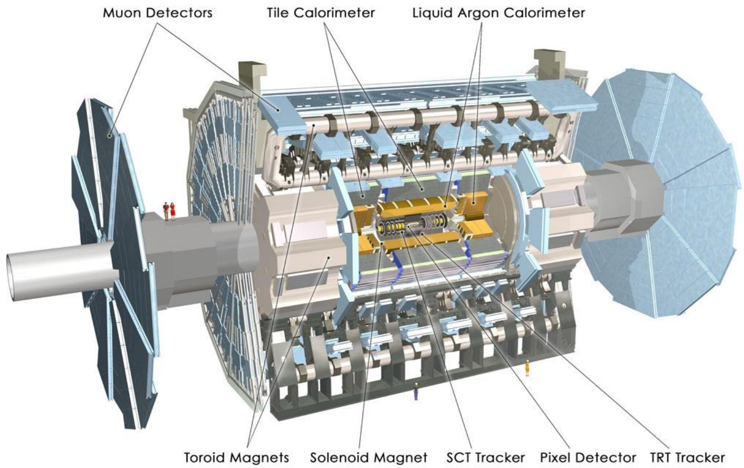
96% of the Mass and Energy in the Universe has yet to be accounted for.
Particle Physics has just begun!



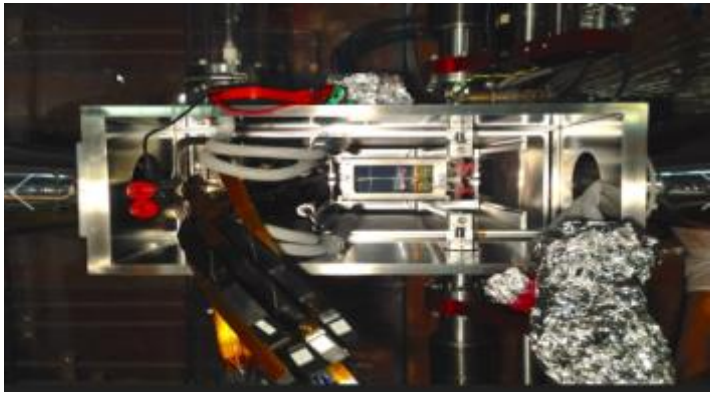
Big Questions motivate SLAC's Experiments

- What exactly is the Higgs?
- Are there new particles, new forces, hidden sectors?

ATLAS Experiment at the
Large Hadron Collider (LHC)



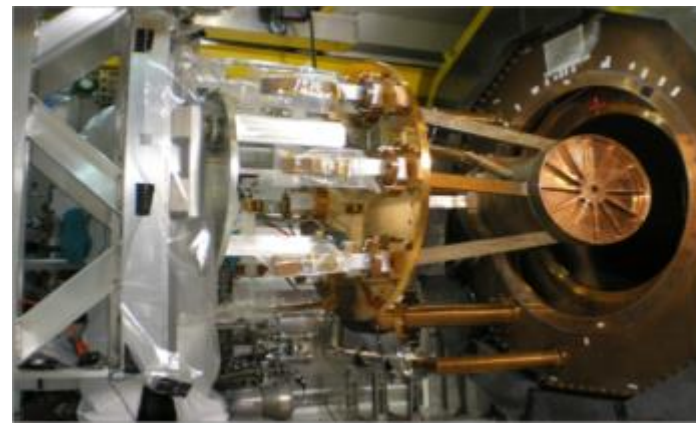
Heavy Photon Search at JLAB



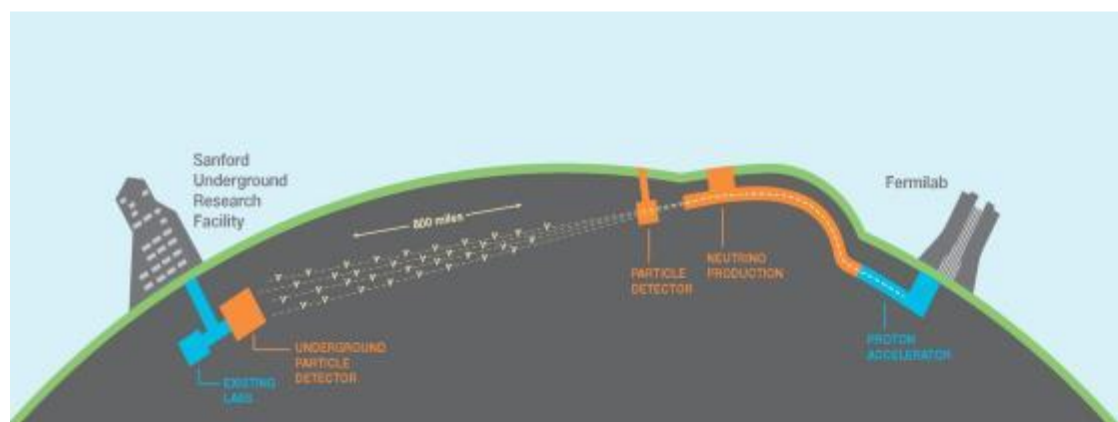
Big Questions motivate SLAC's Experiments

- What is the nature of the neutrino?
- What can neutrino mixing reveal?

Enriched Xenon Observatory (EXO200 and nEXO)



DUNE, MicroBooNE, and ICARUS

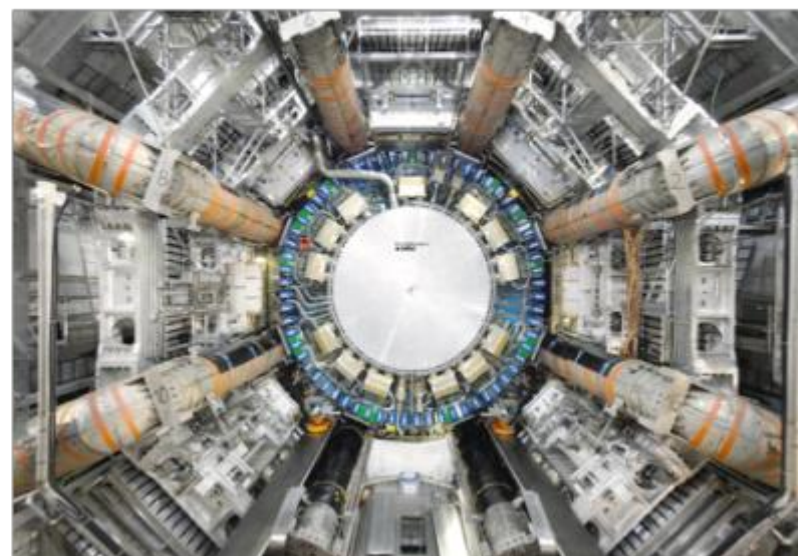


ATLAS Experiment at LHC

- **World's most powerful particle accelerator**

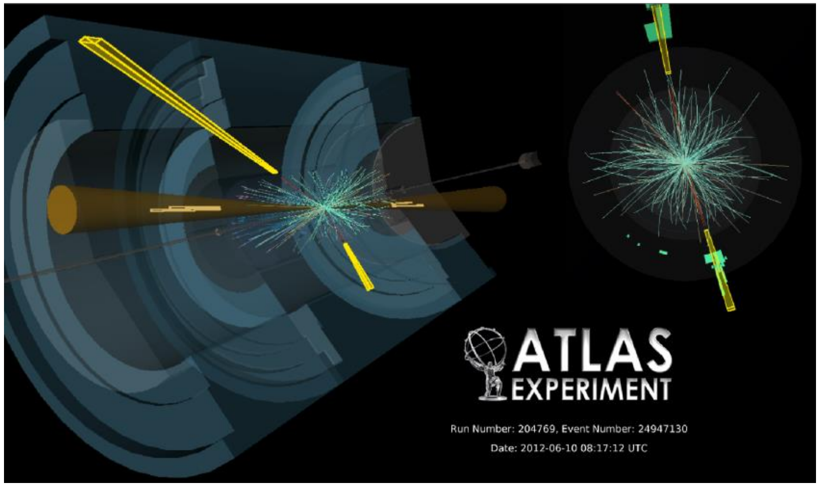
- **Explorations at the energy frontier**
  - **Understanding the Higgs boson**
    - Does it give neutrinos mass?
    - Does it couple to Dark Matter?
    - Are there more Higgses?
  - **Searching beyond the Standard Model**
    - Are there WIMPS at LHC?
    - High mass SUSY?

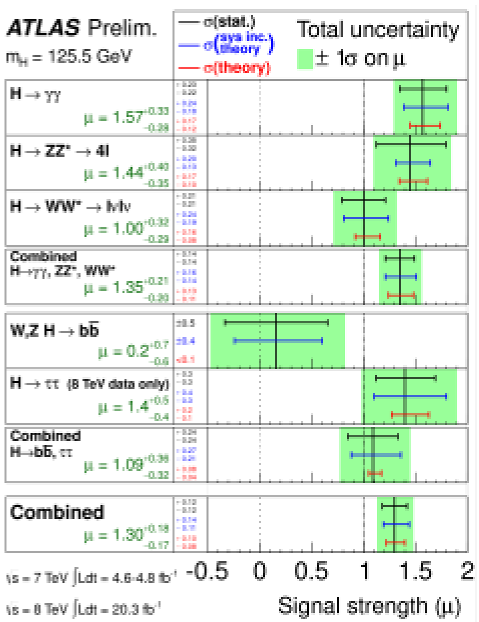
- **Unprecedented detector capabilities for a hadron collider:**
  - **Lives in a hostile radiation environment**
  - **Extremely high rate capability**
  - **Disentangles ~25 *overlapping* events**



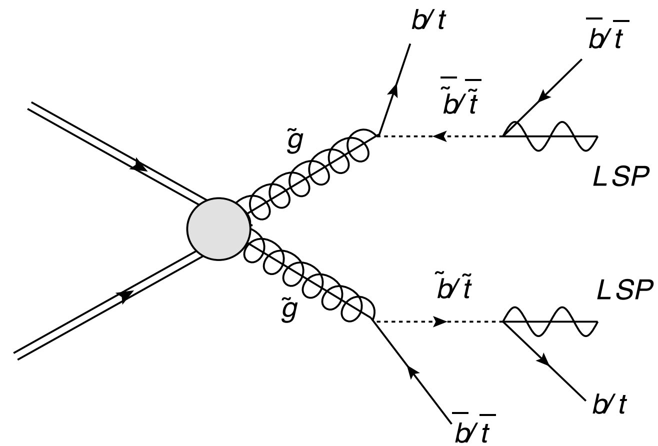
SLAC/ATLAS Physics

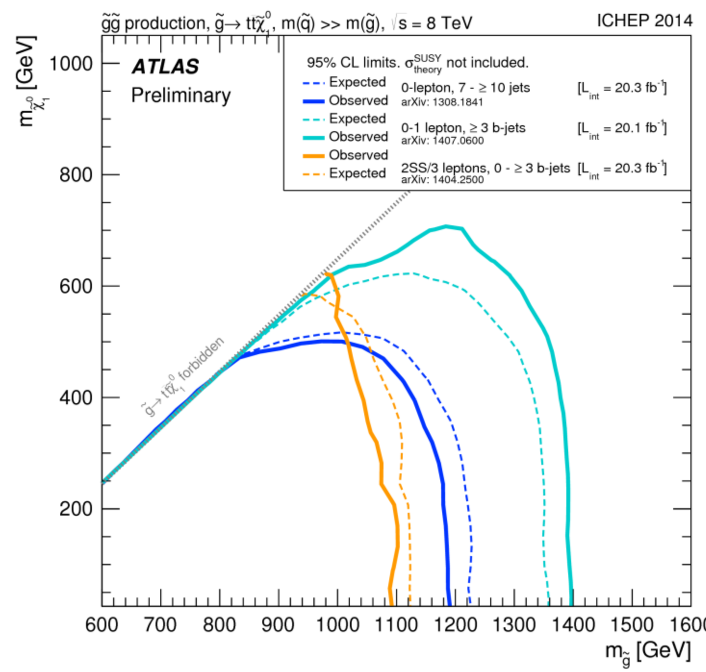
Higgs





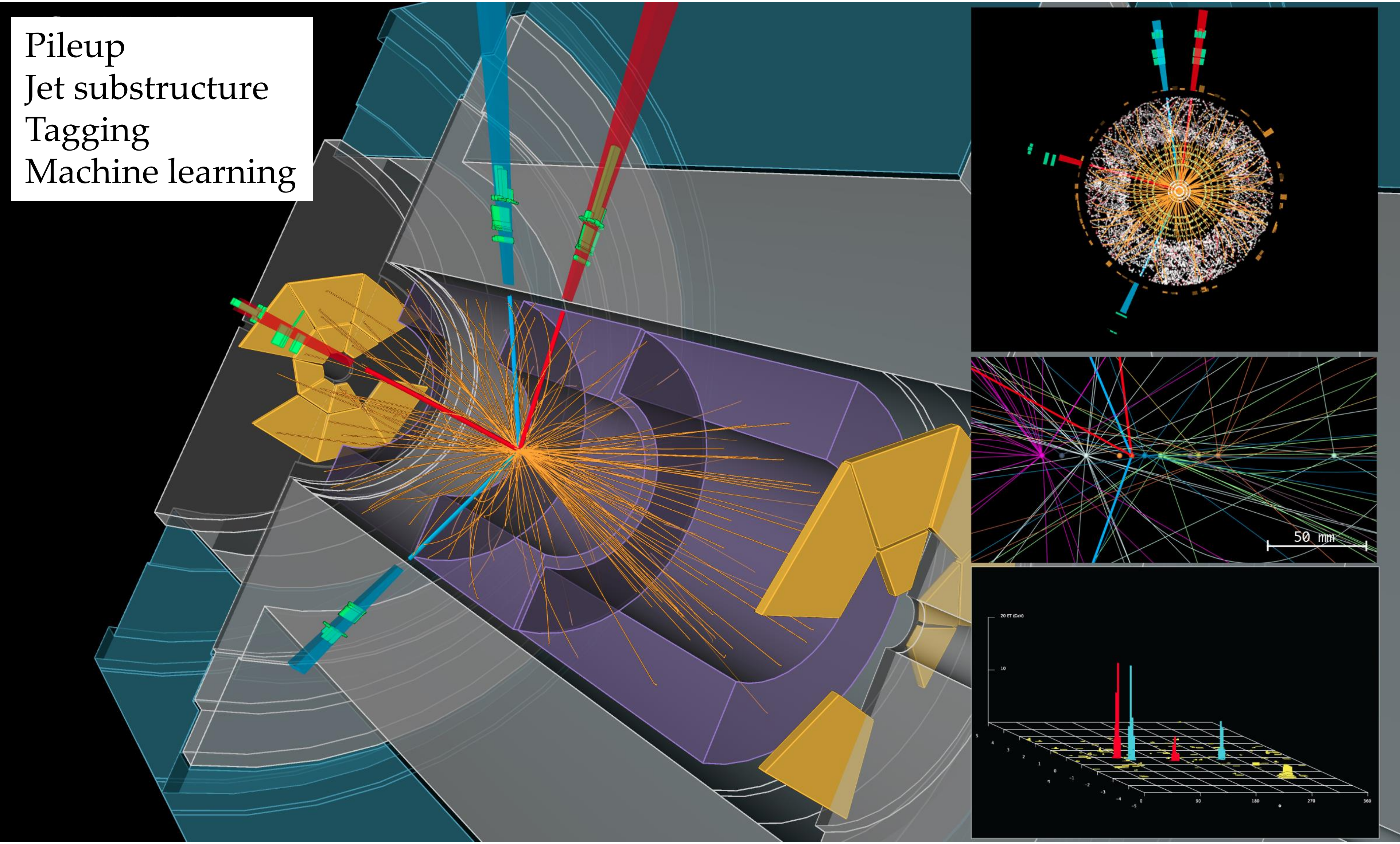
SUSY Searches





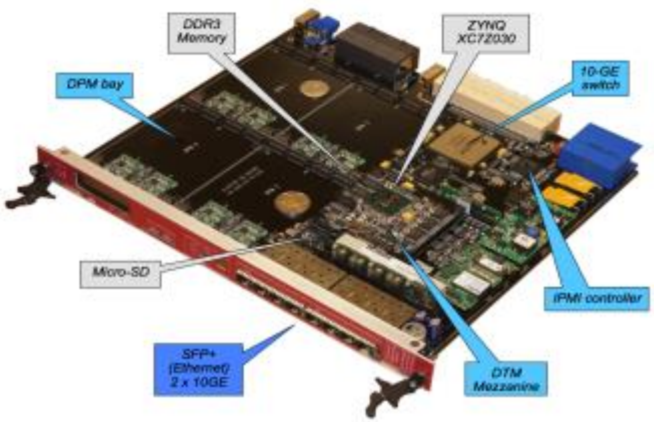
Physics Event Reconstruction

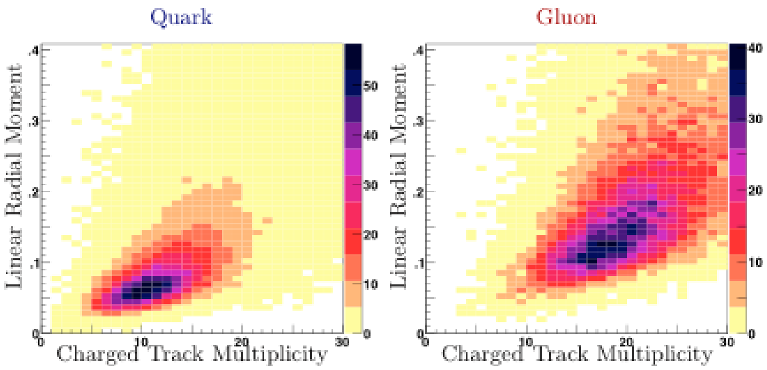
- Pileup
- Jet substructure
- Tagging
- Machine learning



Research opportunities

- **Detector activities:**
    - State-of-the-art data acquisition concept for high luminosity upgrade
    - Pixel detector upgrade and sensors
    - Trigger algorithms and online infrastructure
- **Physics analysis and development of physics tools:**
    - Jet substructure techniques
    - Higgs→bb and beyond the Standard Model Higgs searches
    - Super-symmetry searches
    - Searches for new phenomena





Collaborate with
Prof. Lauren Tompkins on Campus

SLAC ATLAS contact info

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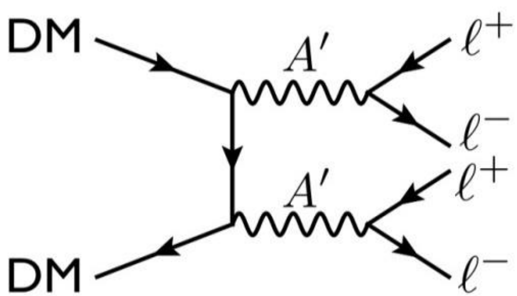
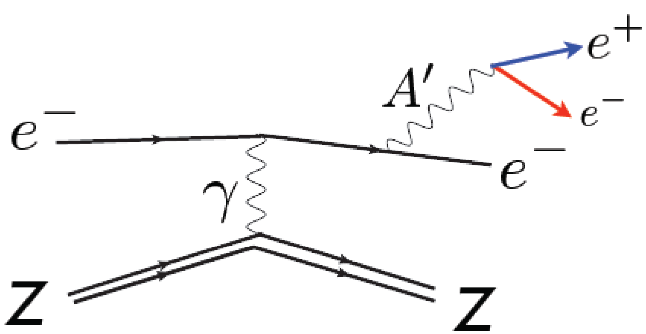
Detailed info on ATLAS@SLAC for students:
http://www.slac.stanford.edu/exp/atlas/students/

Heavy Photon Search



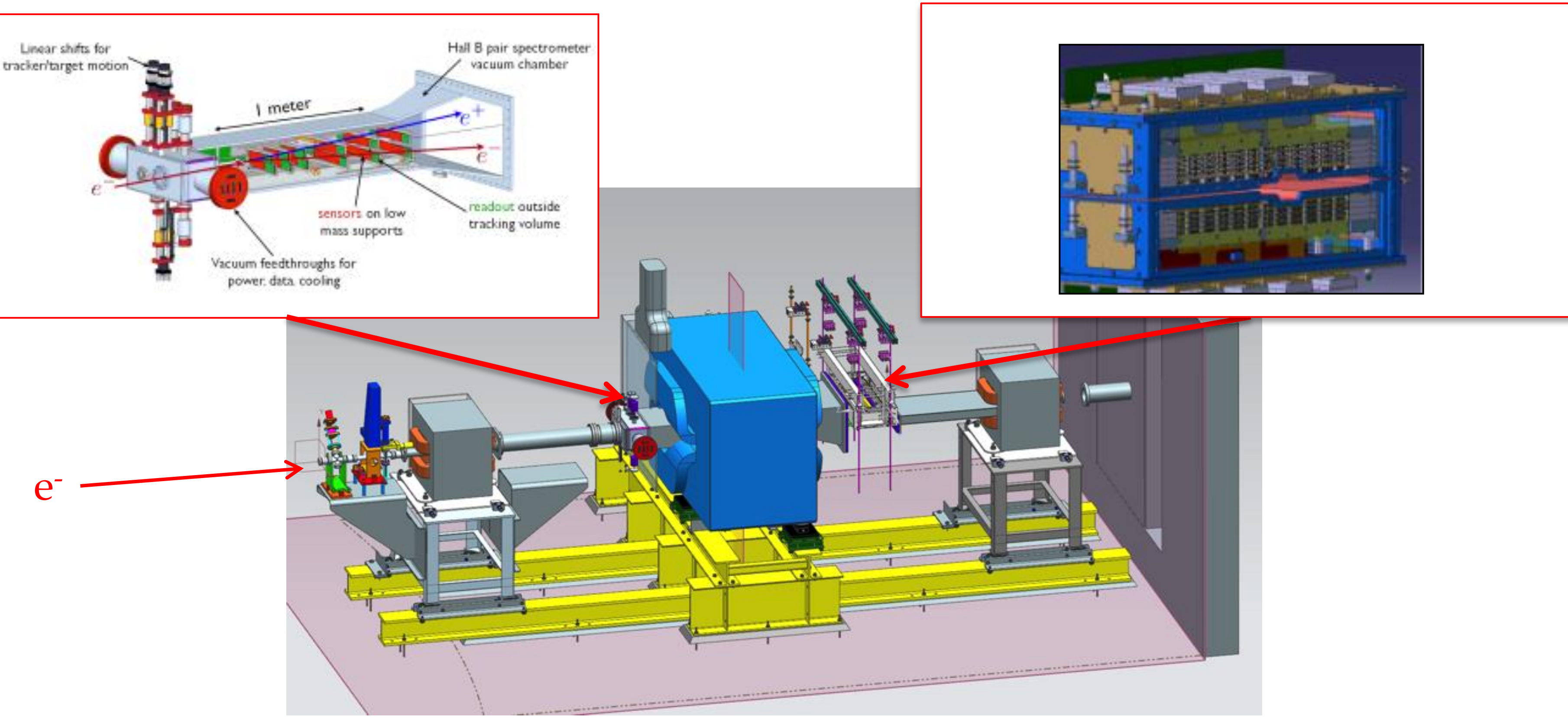


- **Evidence for Dark Matter is compelling,** but there's still no direct evidence for Dark Matter particles.
- **The absence of SUSY at the LHC** is stimulating non-WIMP explanations for Dark Matter.
- **Dark matter may reside in a "hidden sector",** carry an analogue of electric charge and couple to a "heavy photon" (A').
- **Heavy photons will mix with regular photons,** so they can be produced by, and decay into electrons and positrons.
- **The Heavy Photon Search looks for a new** vector gauge boson *(a heavy photon)* radiated by electron beams, decaying to e^+e^-.

HPS Setup at JLAB

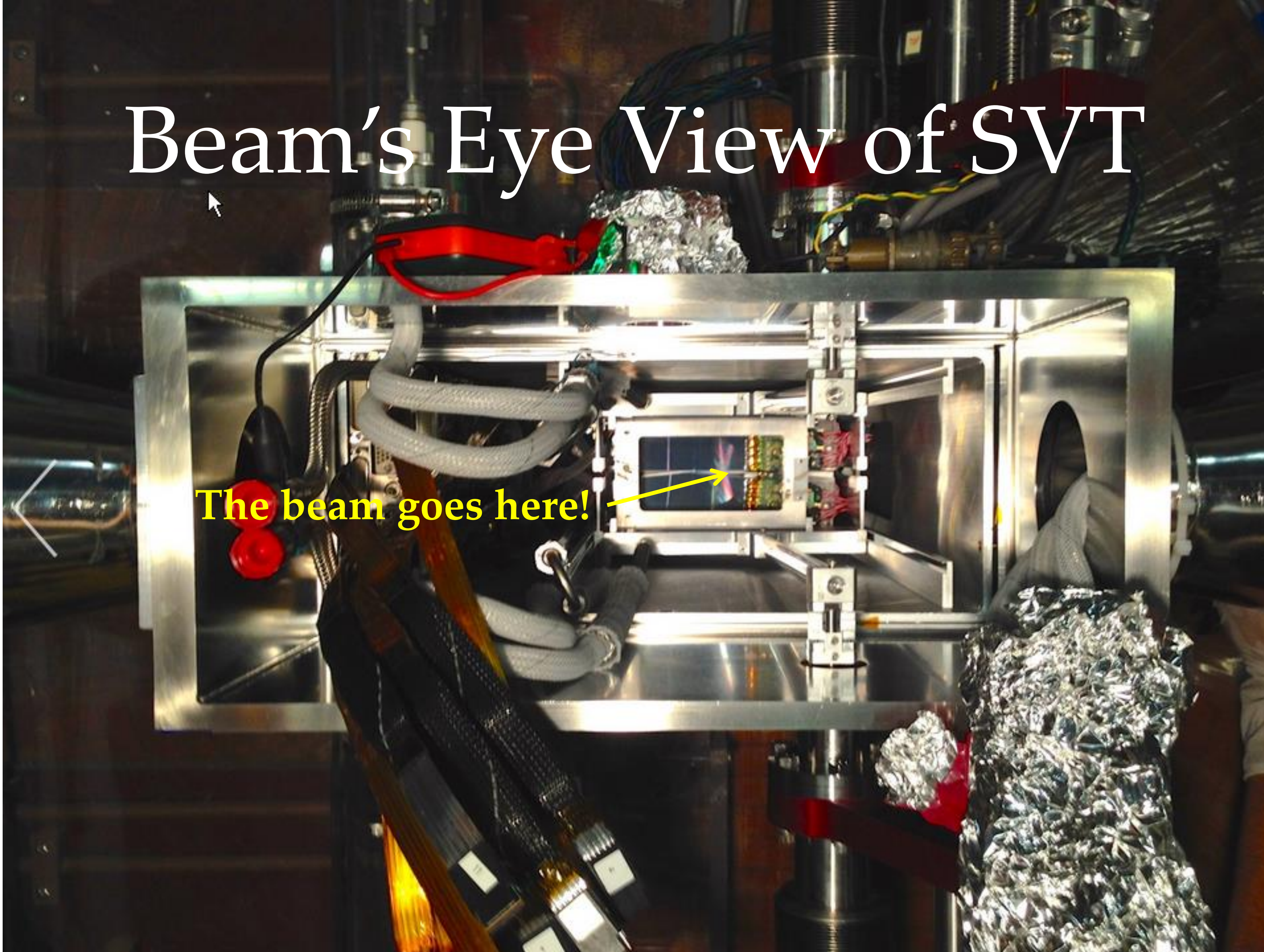
Si Vertex Tracker

$PbWO_4$ Electromagnetic Calorimeter



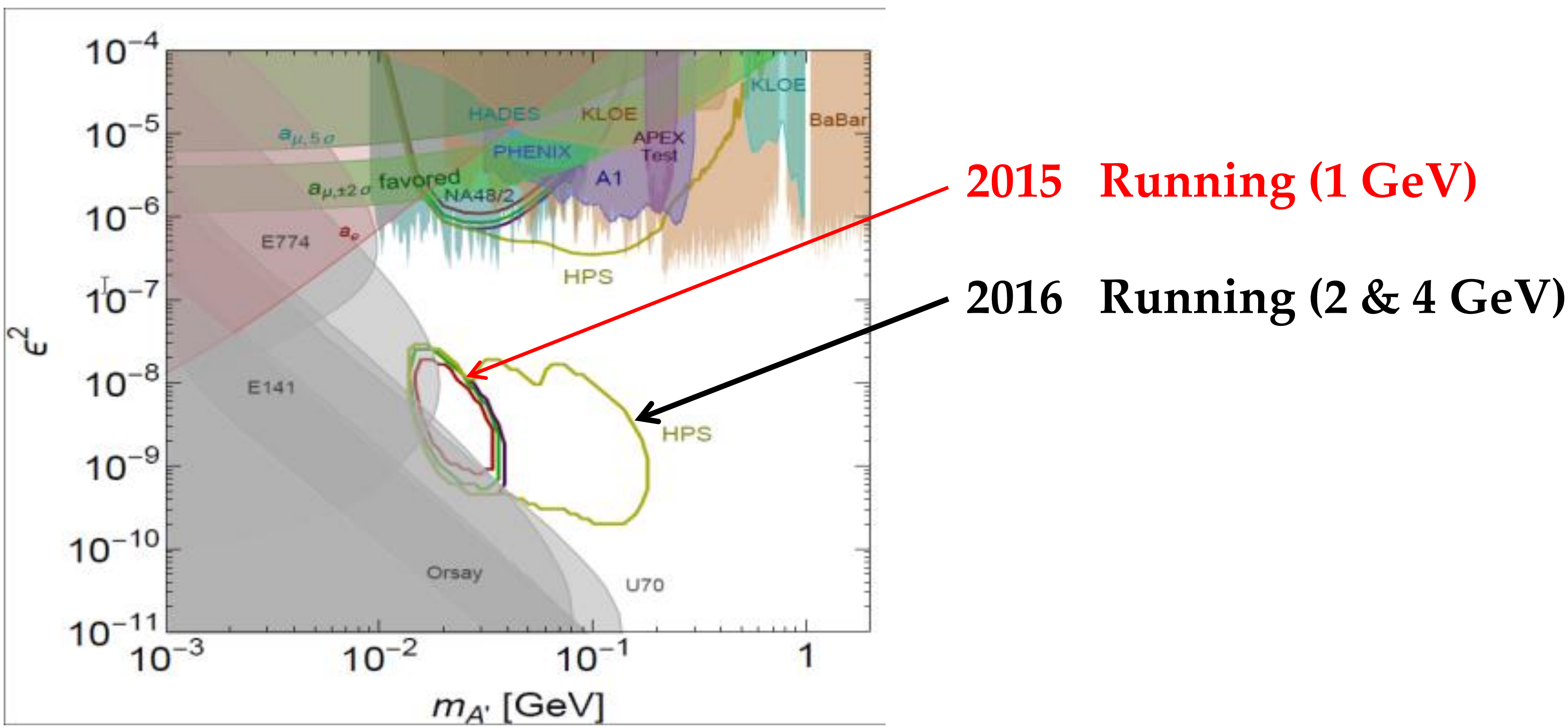
The JLAB electron beam is directed onto a W foil target, producing heavy photons. They decay to e^+e^- pairs, which are measured by the Si vertex tracker inside an analyzing magnet. The $PbWO_4$ ECal provides a fast trigger. https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment

Beam’s Eye View of SVT



Status and plans

- HPS was installed, commissioned, and took its first data in an "Engineering Run" at JLAB this past Spring.
- Physics Running is planned for 2015-2016 and 2017-2018
- HPS will search a large and unexplored region of the A' mass/coupling plane



Opportunities for students

- **Opportunities for new students**
  2015-16 Data taking, analysis, and planning upgrades
  2016-17 Build and install HPS upgrades
  2017-19 Data taking and analysis

Learn the trade

Data for theses

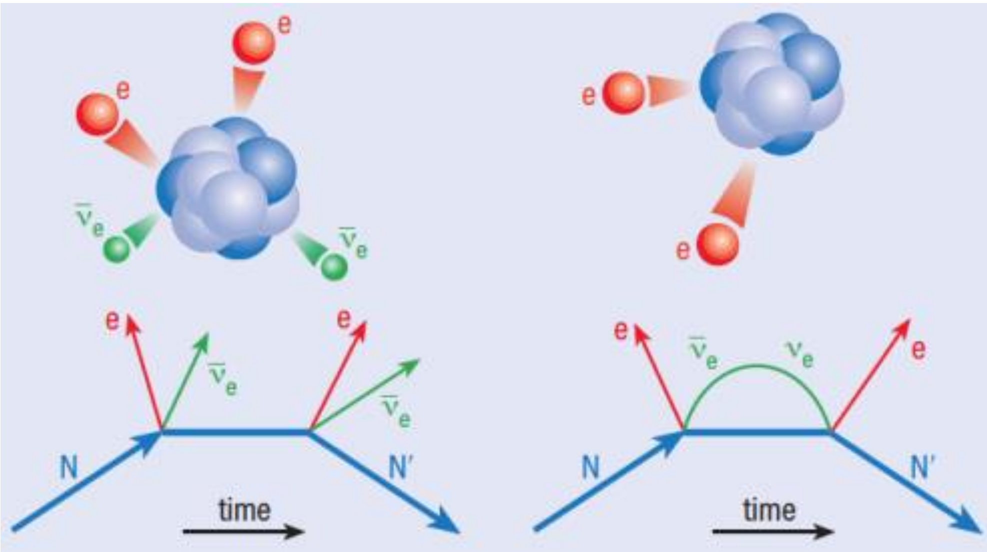
- **Small Experiments provide training in *all* aspects of HEP experimentation**
  Physics Analysis
  Experiment design
  State of the art hardware construction
  Running experiments

Contact: Prof John Jaros (john@slac.stanford.edu)

Rotation Projects are available on HPS this year:

https://confluence.slac.stanford.edu/display/hpsg/Stanford+Rotation+Projects+in+Heavy+Photon+Search

Enriched Xenon Observatory



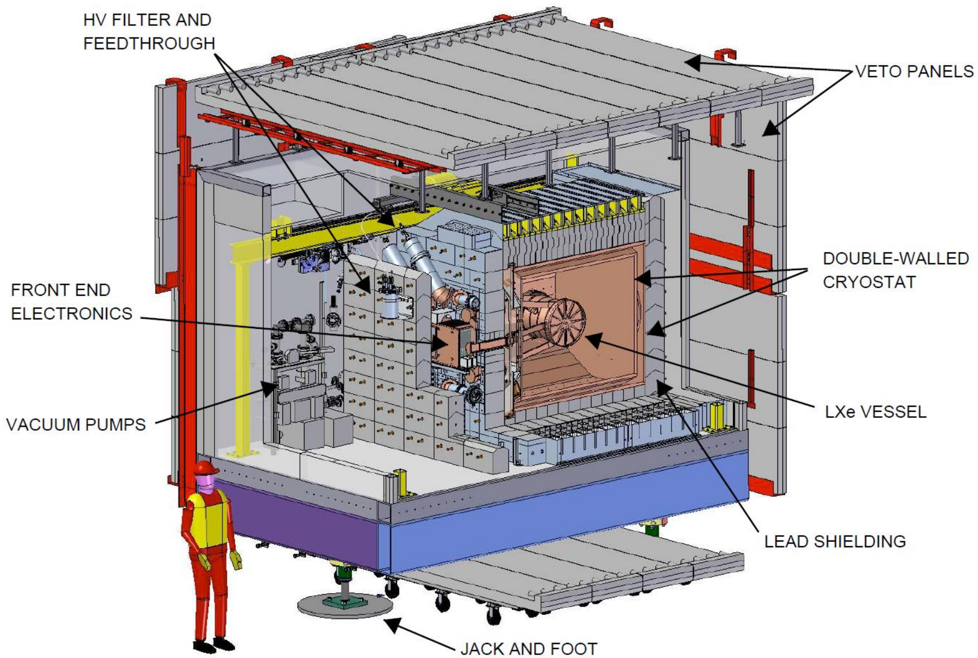
$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba}^{++} + 2e^{-}(+2\bar{\nu})$$

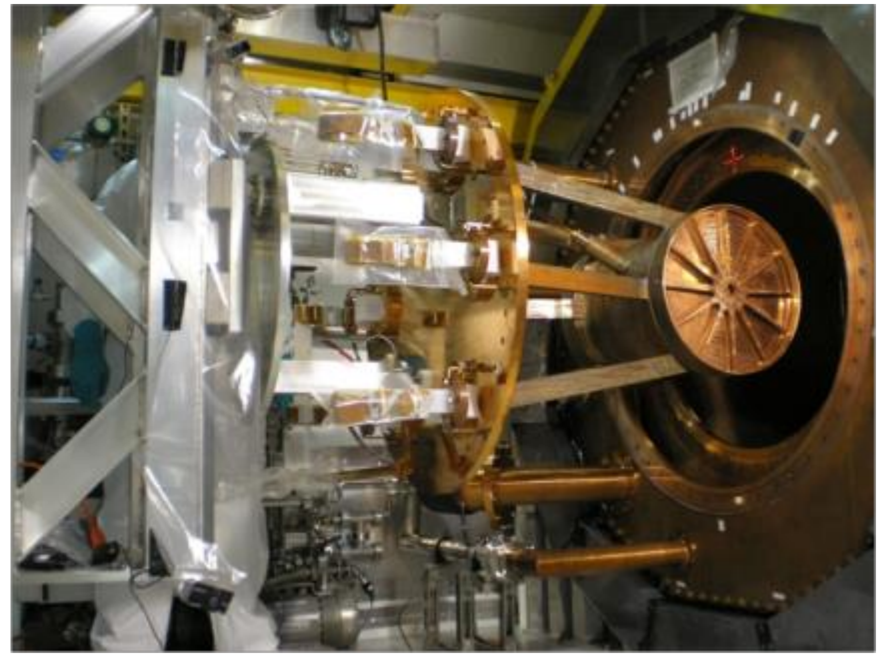
$$\frac{1}{t^{0\nu}_{1/2}} = G^{0\nu}\left|M^{0\nu}\right|^2 m^2_{\beta\beta}$$

half life → neutrino mass

- Search for **neutrino-less double beta decay** of Xe-136
- 2 modes of ββdecay:
  - **(2vββ)**: allowed in SM, but extremely rare process (half-life~10^{20} years)
  - **(0vββ)**: only 2 electrons are emitted
    - Lepton number violation (**not allowed in the SM**)
    - Only possible if neutrinos have mass and are Majorana particles (neutrino=anti-neutrino)
- **EXO-200 discovered the (2vββ) decay mode in Xe, provides the most precise measurement of any (2vββ) rate and has demonstrated the best sensitivity to the (0vββ) decay mode**

EXO-200 Experiment

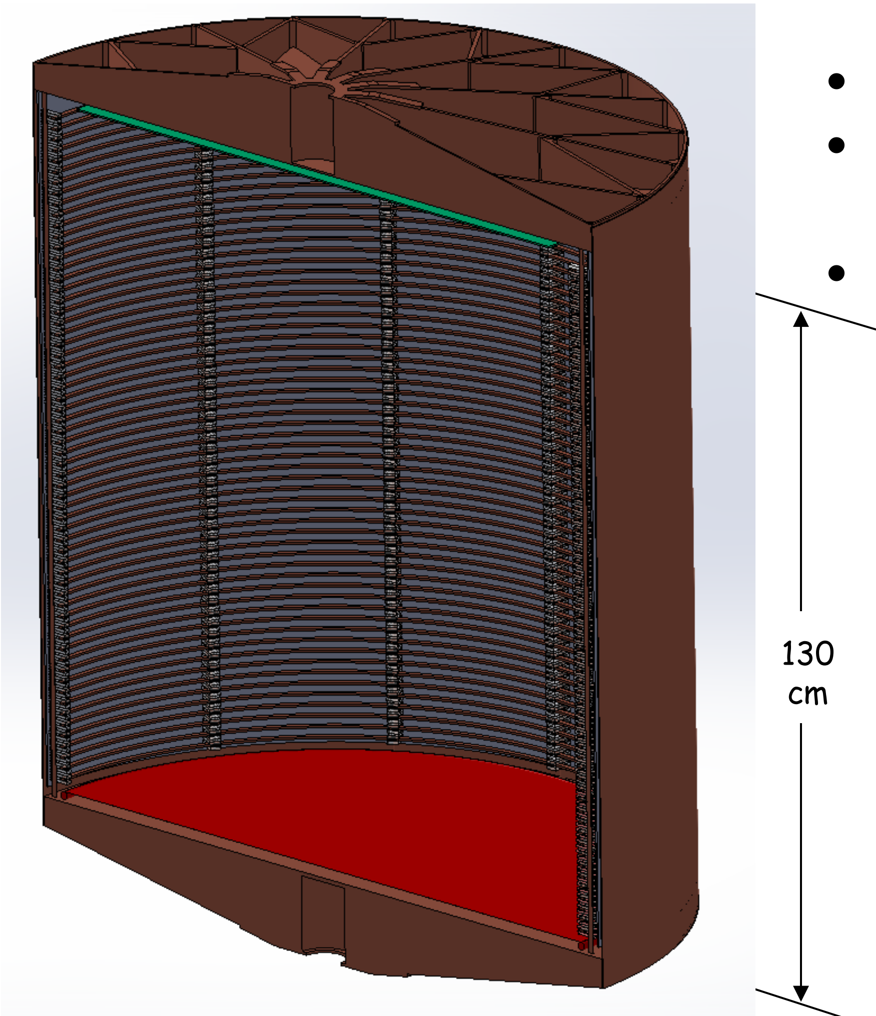




- **500m underground** in New Mexico
- **TPC** (Time Projection Chamber) **measures energy** (scintillation light in photo-detectors) **and longitudinal position** (from drift time)
  - Signal reconstructed as single-cluster events
  - Gamma-ray backgrounds produce multiple clusters

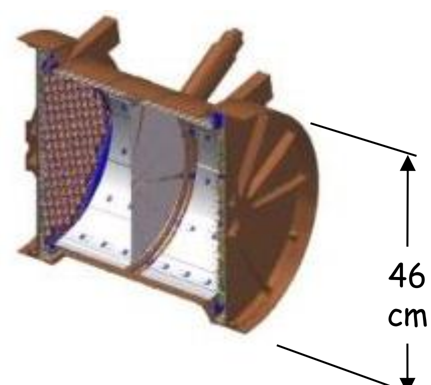
The Next Step: nEXO

R&D for a ton-scale experiment



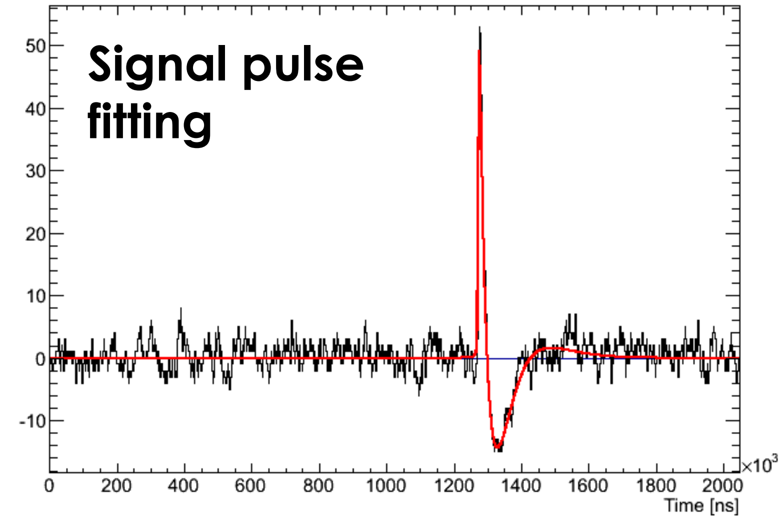
- 5 tons of enriched ^{136}Xe
- Improved charge/light collection, → spatial and energy resolution.
- Second phase may employ Ba daughter ion identification.

5-year reach in half life ~100 times EXO-200 performance



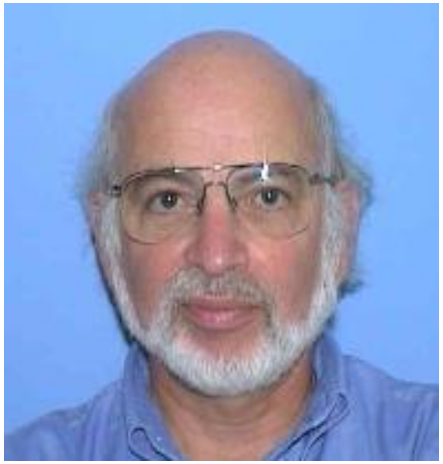
Opportunities for students

- **Design and prototype the nEXO TPC**
- **Conduct R&D** for HV field cage design and LXE purity for nEXO
- **Characterize photodetectors** for LXe
- **Develop detector electronics** for operations at LXe temperature (165 K) to reduce noise
- **Develop Ba^{++} extraction and identification**
  - * Mechanical probe development
- **EXO-200 event reconstruction/calibration**
  - * Improve efficiency and background rejection
  - * Compare calibration source data with simulation



There are many opportunities for rotation students which could lead into an EXO-200 thesis and provide a strong background in detector R&D

EXO Contact info



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EXO-200

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Dr. Peter Rowson
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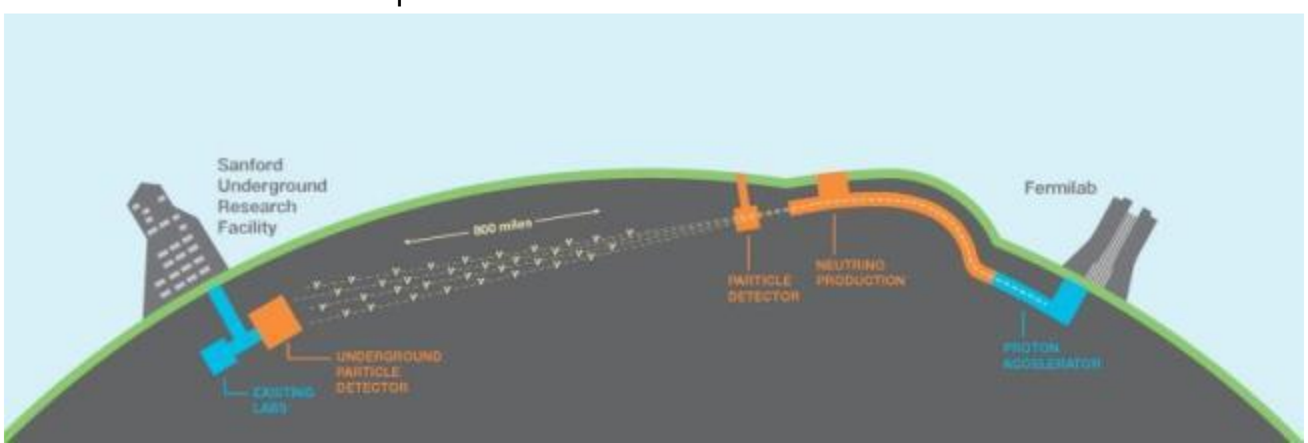
Beam Neutrino Experiments

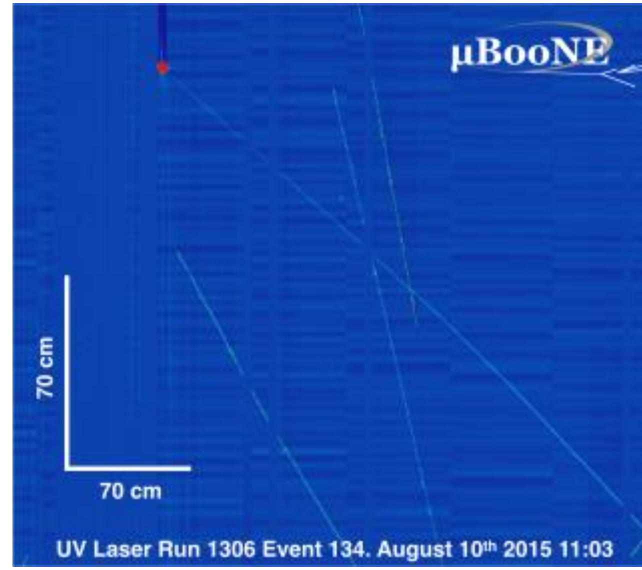
- **Address very fundamental questions**
  - What is the nature of the neutrino? Is there ~~CP~~ in the lepton sector?
- **SLAC group is working on three experiments, all based on Liquid Argon Time Projection Chambers (LArTPC)**
  - **Deep Underground Neutrino Experiment (DUNE)**
    - Measures neutrino oscillations at long baseline (1300 km)
    - Flagship US Accelerator program, <u>takes data after 2020</u>
  - **MicroBooNE**
    - Searching for oscillations at short baseline (800 m)
    - Currently commissioning detector with cosmic rays
    - First beam data expected Fall 2015 (perfect timescale for new students)
  - **ICARUS**
    - Pioneered LArTPC technique
    - Will be moved to Fermilab to augment MicroBooNE
    - First beam data expected in 2018



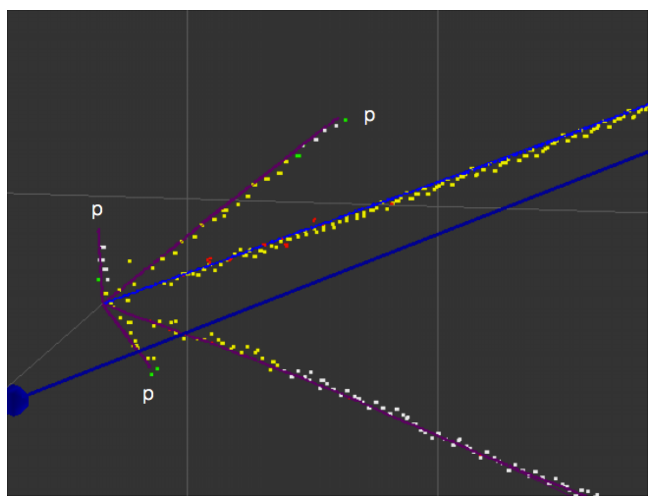
MicroBooNE Status

Installation finished 2014

Commissioning underway



Very exciting time on MicroBooNE!



First beam events expected 2015

Opportunities for Students

- Short-term opportunities
  - MicroBooNE commissioning, initial data-taking and physics analysis
  - ICARUS transition to Fermilab – learn to operate with high rates and high backgrounds
  - Learn LArTPC technology from the world's experts
- Longer-term opportunities
  - DUNE experiment will be flagship on-shore US experiment in 2020's
  - Opportunity to contribute to its design and become an expert in LArTPCs and neutrino physics
- Current SLAC roles (on all three experiments)
  - High-speed Data Acquisition systems
  - Automated event reconstruction
  - Studies of SuperNova burst neutrino detection
  - …

Neutrino Contact info

Dr. Mark Convery
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Summary

- **Current SLAC particle physics experiments address some of the most important questions in physics today:**
  - What is the origin of mass?
  - What constitutes the Dark Matter?
  - Are there new particles or Hidden Sectors?
  - What is the nature of the neutrino?

- **It's a propitious time for particle physics.**

  Powerful new experimental tools can fundamentally change our understanding of the universe.

- **SLAC plays a major role in designing future experiments**

  SLAC is developing state-of-the-art detector and readout technologies and advanced analysis and computing techniques.