2010 Prospective Graduate Students Visit

February 27, 2010

High Energy Physics at UR

- History of HEP group
- Collider experiments
- Neutrino experiments
- Dark matter and gravitational wave experiments
- Theory group
- Conclusions

UNIVERSITY of ROCHESTER

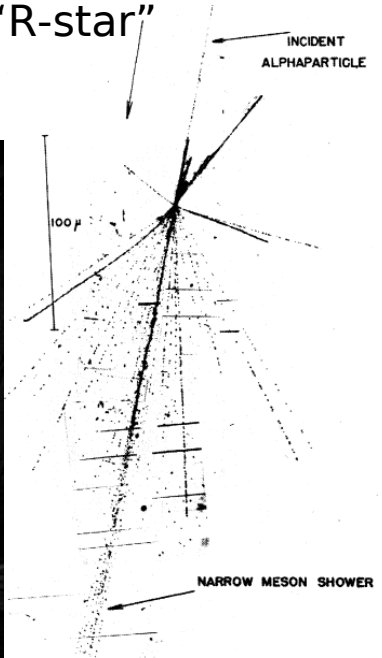
Arán García-Bellido

A distinguished history... and present

- 1935: Lee DuBridge built at UR one of the first cyclotrons
- 1948: cyclotron was briefly the world's highest energy accelerator
- 1949: Kaplon finds evidence for π^0 in "Rochester-star" cosmic ray events
- 1950: Marshak initiated the annual Rochester Conferences in High Energy Physics, which would later become ICHEP
- 1964: Hagen makes founding contribution to Higgs boson theory
- Invention of mass formula for hadrons by Okubo → hadrons are made of quarks
- Detailed study of bottom quark and b-hadrons at CLEO, led by Thorndike
- Discovery of the top quark at CDF and DØ in 1995 (Bodek, McFarland + Demina, Ferbel, Slattery)
- Bodek builds tile fiber scintillation technology for CDF and CMS calorimeters

Lee DuBridge's Cyclotron (1937)

"R-star"



Marshak lecturing at the 1955 Rochester Conference (ICHEP)

Photos from Emilio Serge and Physics Department archives

Notable Faculty Awards

Junior Faculty Development

DOE OJI Awards: Das, Demina, McFarland, Orr

NSF PYI/CAREER Awards: McFarland, Orr

Sloan Fellowhsips: Bodek, Ferbel, McFarland

Research Corporation Cottrell Scholar: McFarland

National Fellowships

Nishina Foundation: Okubo

Guggenheim Fellowship: Ferbel, Okubo, Slattery, Thorndike

Humboldt Fellowship: Ferbel

Fulbright Fellowship: Das (twice!)

Teaching Awards

AAPT Excellence in Undergraduate Teaching Award: Manly (2007)

Carnegie Foundation NY State Professor of the Year: Manly (2003)

Recent Rochester teaching awards: Bodek, Das, Hagen, Manly, Orr, Wolfs

CAREER Recognition Awards

Wigner Medal: Okubo (2006)

Panofsky Prize: Bodek (2004), Thorndike (1999)

Sakurai Prize: Okubo (2005), Hagen (2010)

Recently Elected APS Fellows: Das, McFarland, Orr

The BEHHGK (aka Higgs) boson

2010 J.J. Sakurai Prize

"For elucidation of the properties of spontaneous symmetry breaking in four-dimensional relativistic gauge theory and of the mechanism for the consistent generation of vector boson masses"

Peter W. Higgs
University of Edinburgh

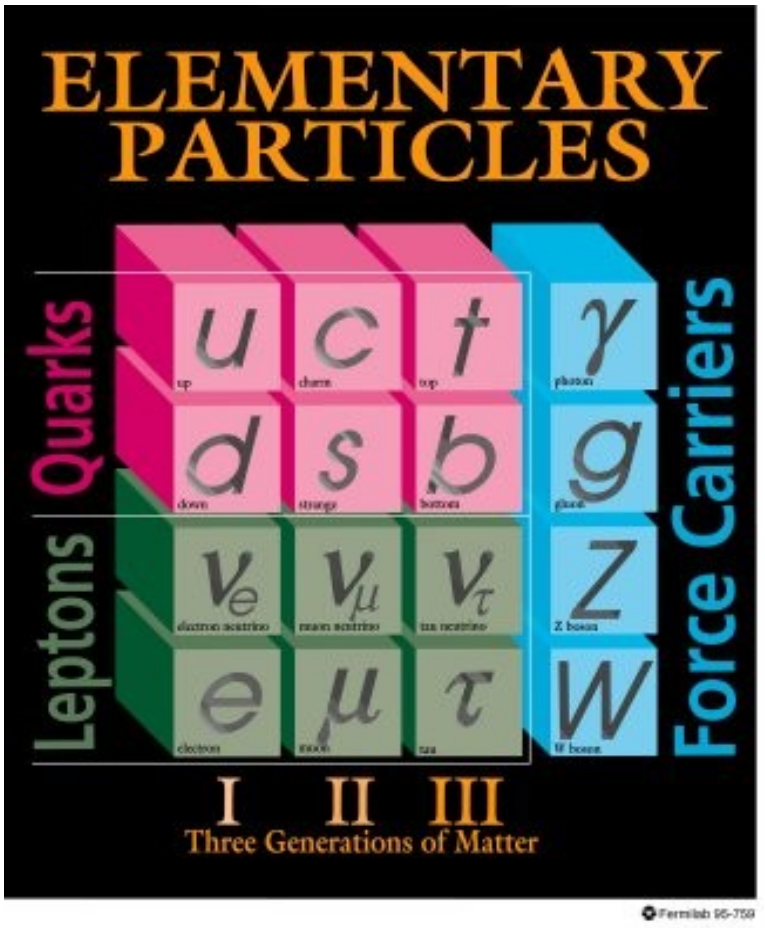
Gerald S. Guralnik
Brown University

Robert Brout
Universite Libre de Bruxelles

Carl R. Hagen
University of Rochester

François Englert
Universite Libre de Bruxelles

T. W. B. Kibble
Imperial College

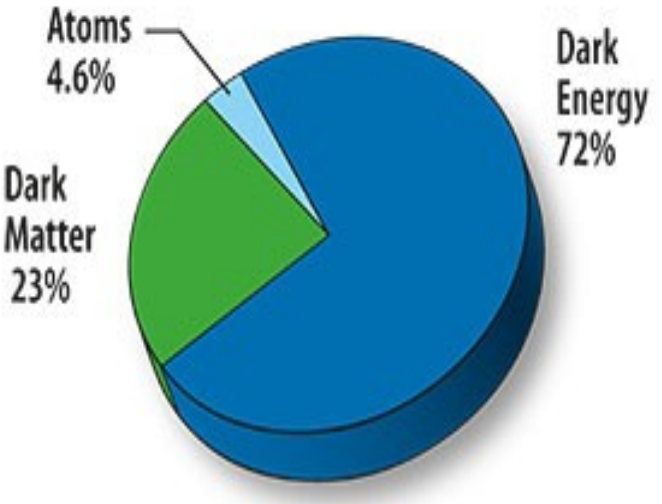


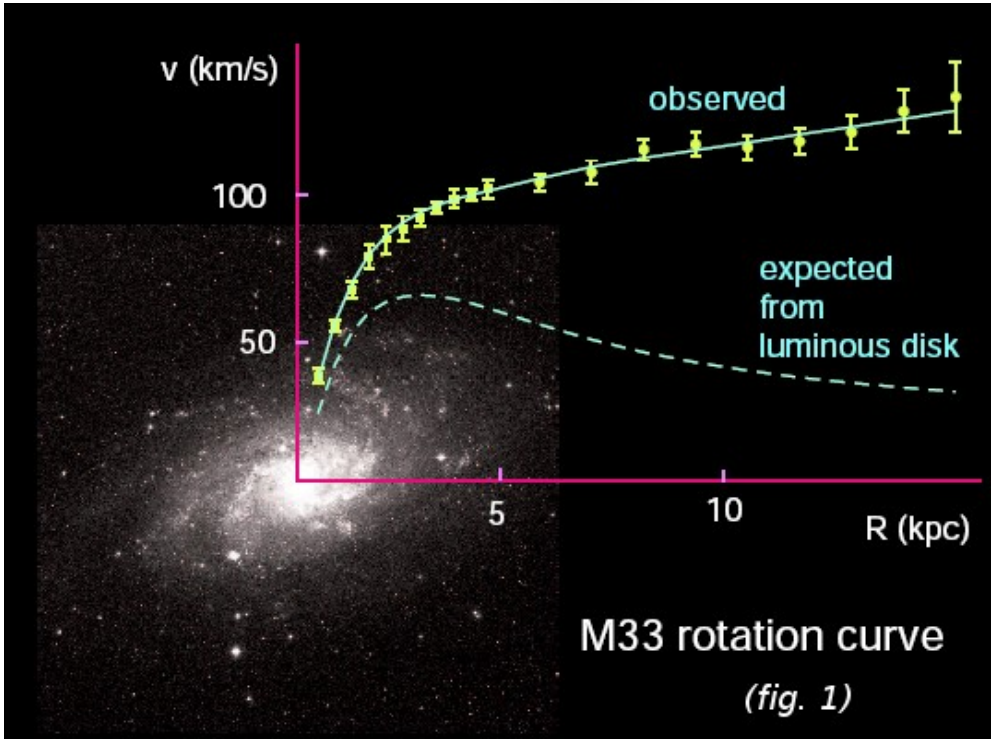
- The Standard Model is an incredibly successful theory!
- All predicted particles have now been discovered, except for the particle responsible for giving mass to the rest: the BEHHGK boson!
- Particle physicists work on going beyond the SM!

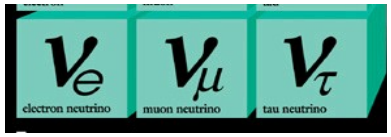
Big puzzling issues

- It seems ordinary matter (stuff like us) only makes up 5% of the Universe
- Dark matter: possibly in the form of cold (heavy) weakly interacting particles (WIMPS)
- Dark energy: biggest puzzle of all!
- Gravity is not included in the SM
- Last remaining undiscovered symmetry Supersymmetry (SUSY): fermions ↔ bosons
  - Many more particles!
  - SUSY provides a natural dark matter candidate
- We don't observe galaxies of antimatter: Why do we live in a matter dominated universe?

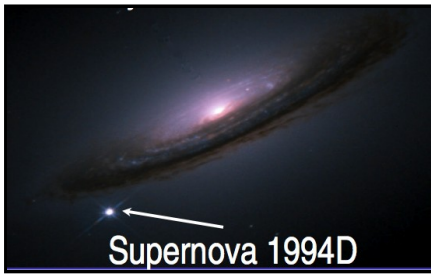
Energy content of the universe



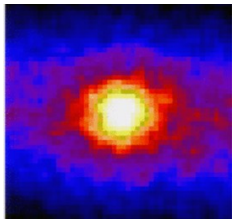


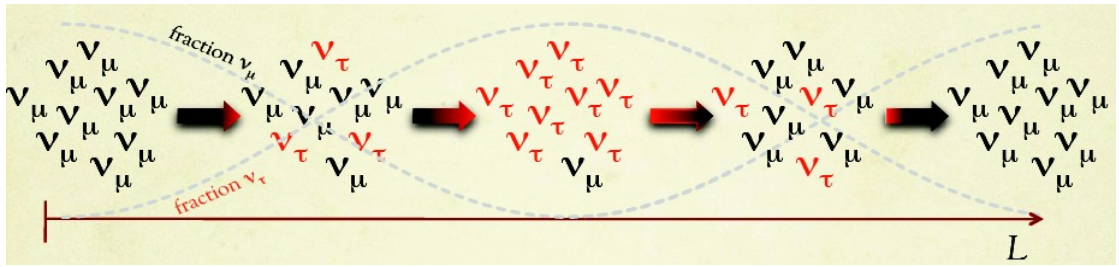


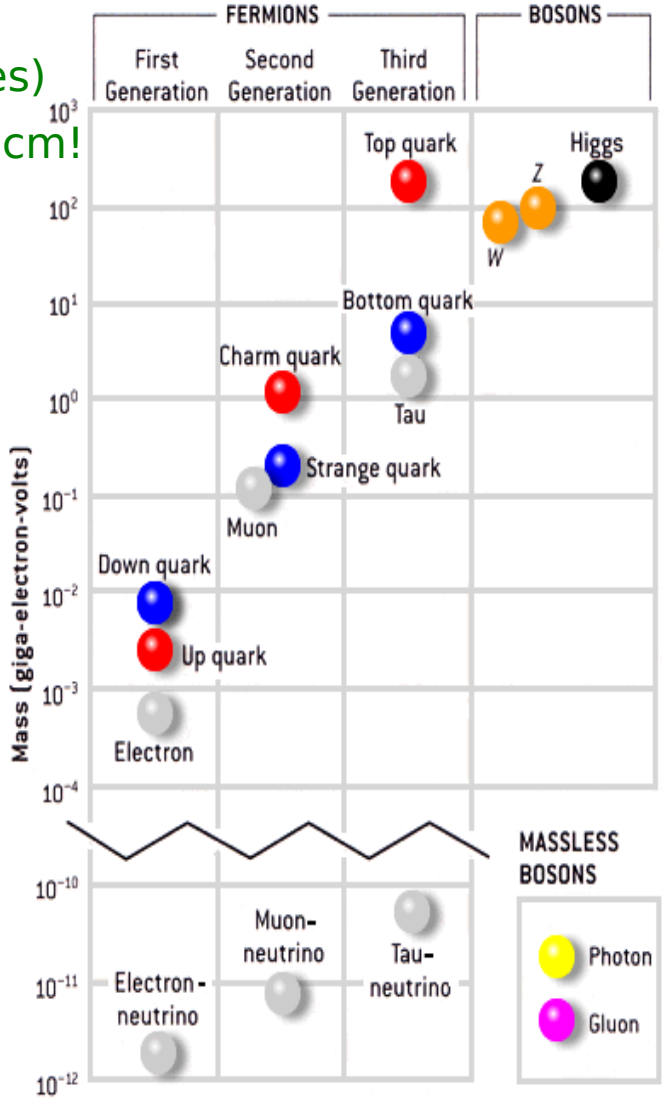
Neutrinos



- A billion times more neutrinos than quarks in the Universe!
- Critical component of nuclear processes that power stars
- 60×10^{15} ν from the Sun will pass through your body during this talk
- Extremely weak interaction with ordinary matter. Mean free-path in Pb:
  - ν from Sun (MeV): $d_{Pb} \sim 10^{16}$ m (one light year of lead!)
  - ν from accelerators (GeV): $d_{Pb} \sim 10^{12}$ m of Pb (1 Billion miles)
  - For reference, a proton with GeV energy would stop in 10 cm!
  - Incontrovertible evidence for ν oscillations: **neutrinos have mass!**







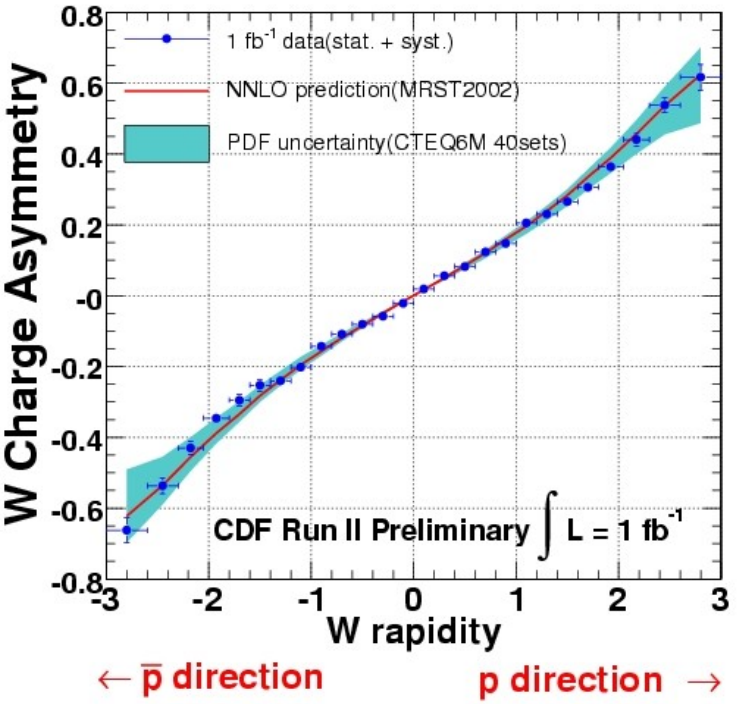
- Big remaining questions: Why is mass so small and what is its absolute value? Hierarchy between neutrino flavors? Are there only three?
- Do they explain the asymmetry of matter and antimatter in the Universe?

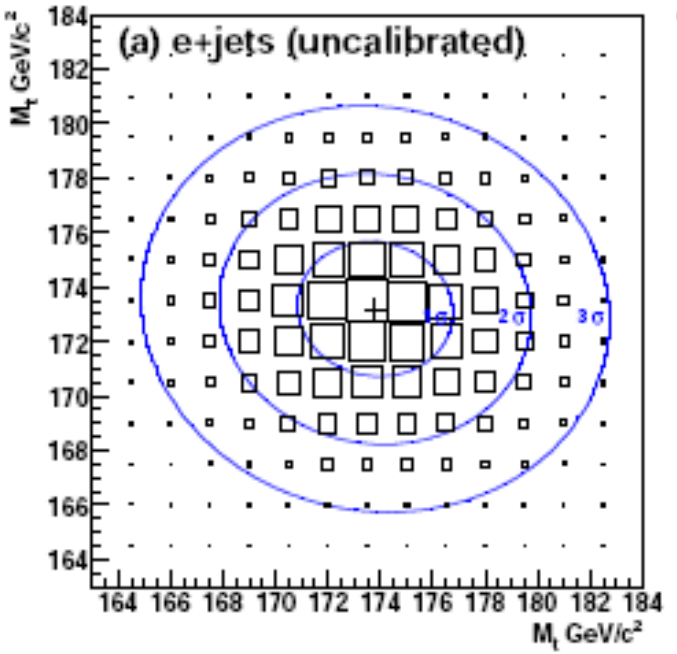
CDF and DØ at the Tevatron

Superb performance

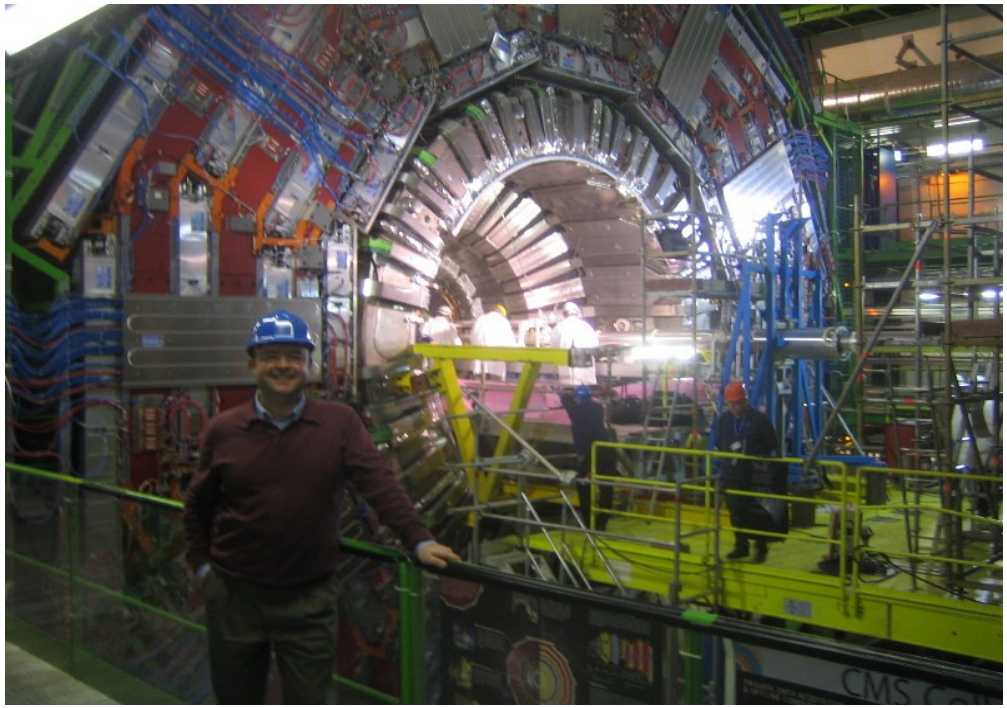
Tons of data to analyze!

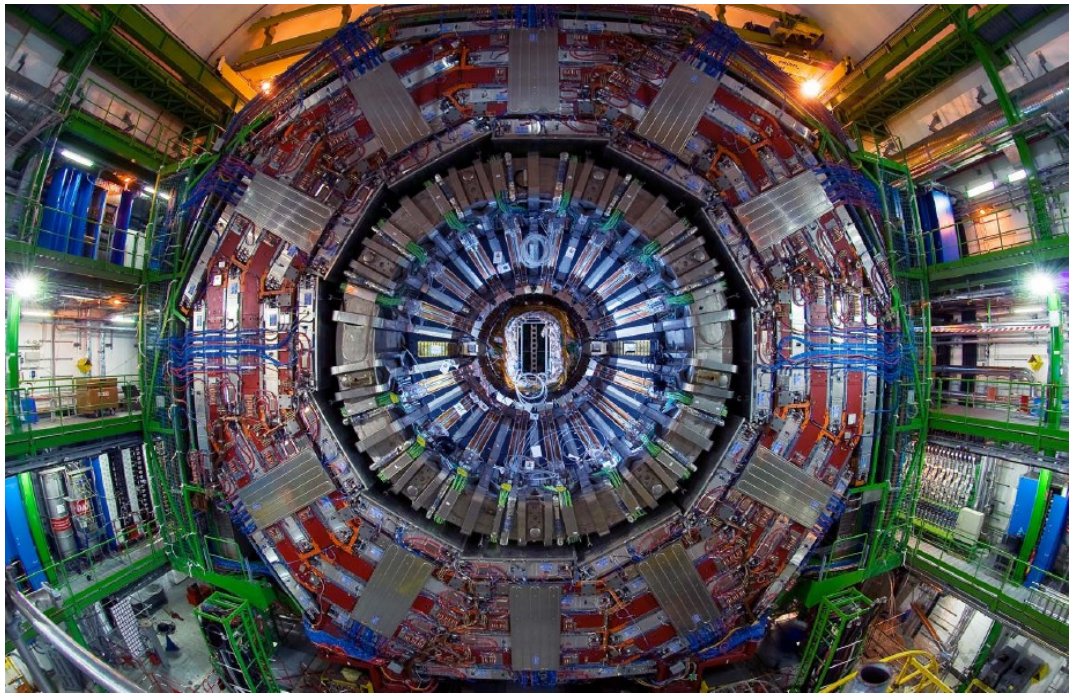
- CDF: 2 faculty, 3 res faculty, 2 postdoc, 1 student
  - Detector operations, calorimeter, L3 farm
  - W charge asymmetry, Z angular distribution and forward-backward asymmetry, top charge, charged Higgs production, rare top decays
- DØ: 4 faculty, 2 res faculty, 2 postdoc, 2 students
  - Detector operations, fiber tracker, online and L3, silicon upgrade
  - Jet reconstruction, top quark mass and production, top charge and mass asymmetry, single top production, searches for SUSY and Higgs
- Strong participation in top quark physics (discovery, precise measurements, searches)
- Pioneered "Matrix Element" technique to precisely measure the top mass (Nature, 3rd Tanaka prize)

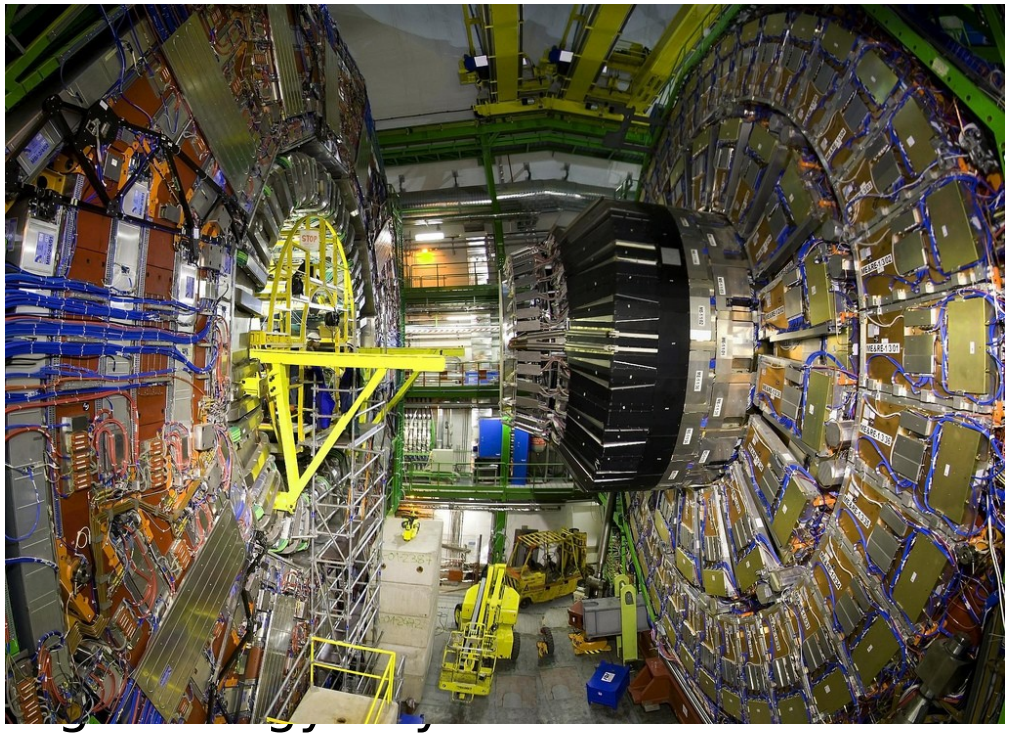


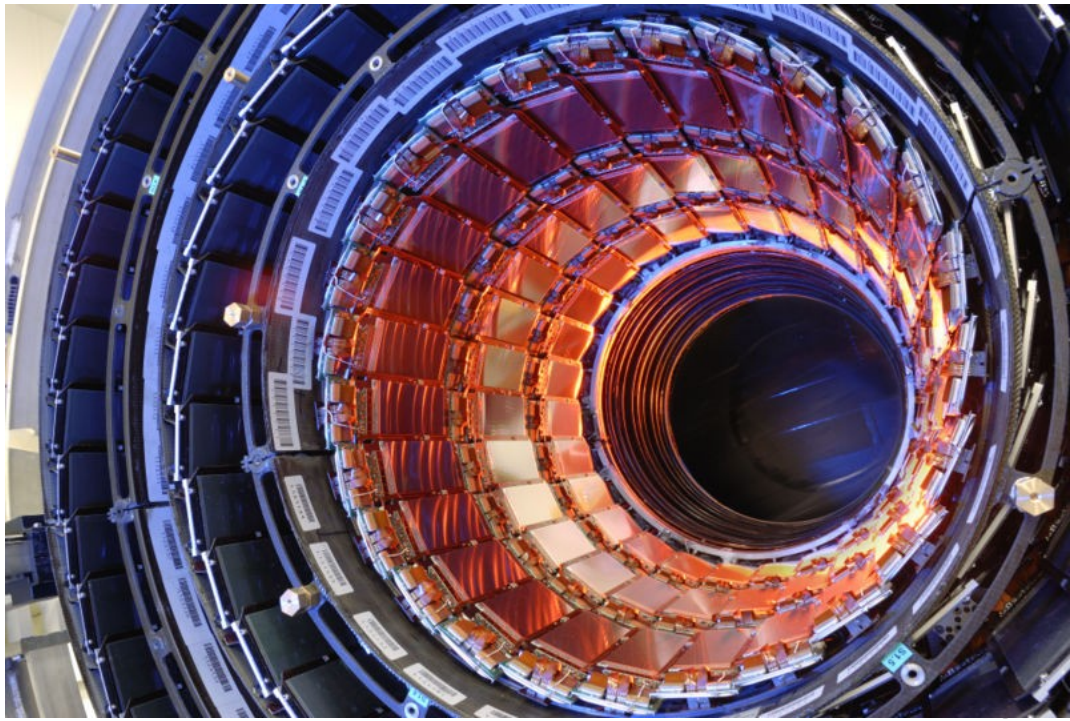


Compact Muon Solenoid at the LHC

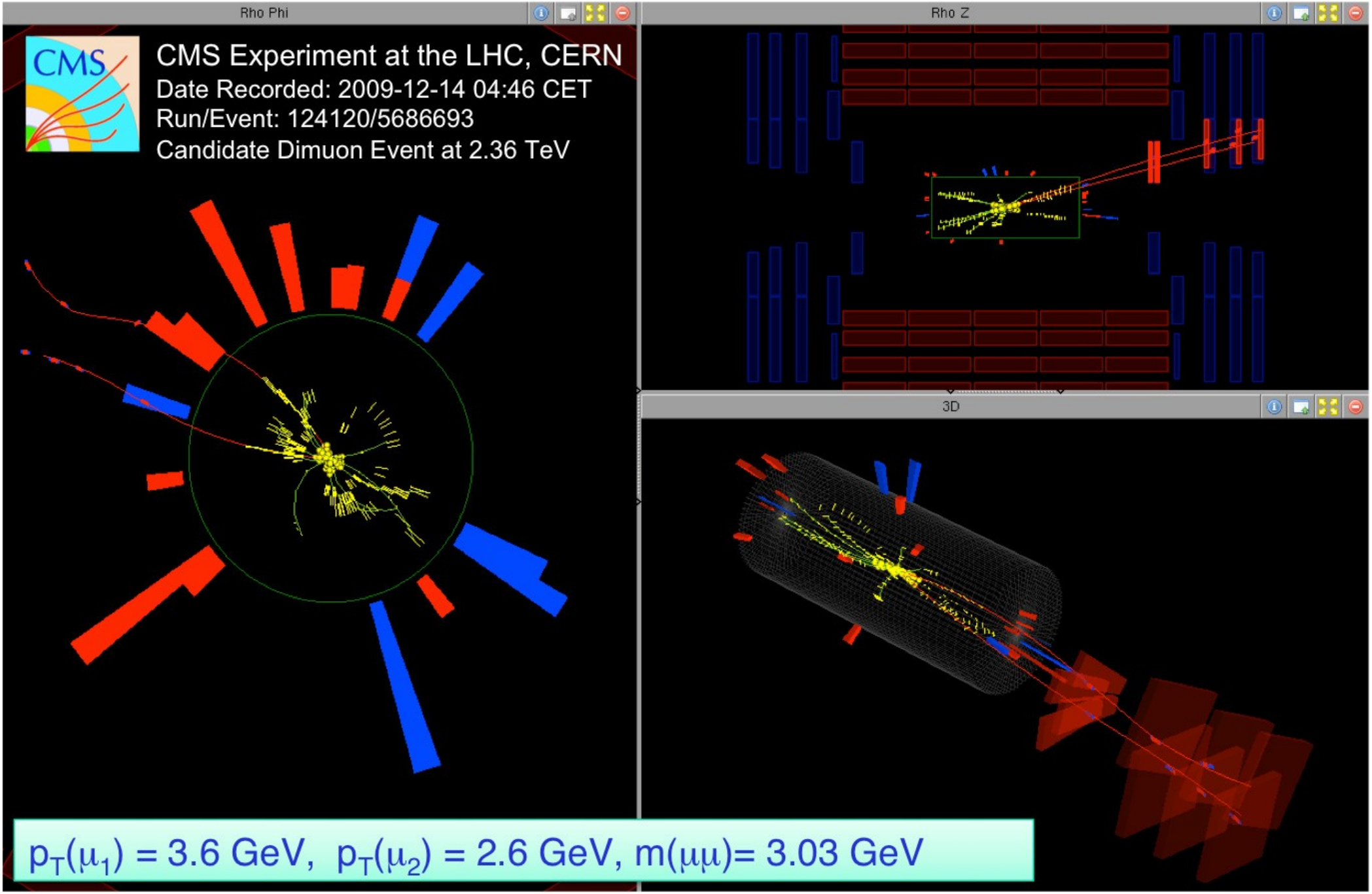








CMS taking collision data!

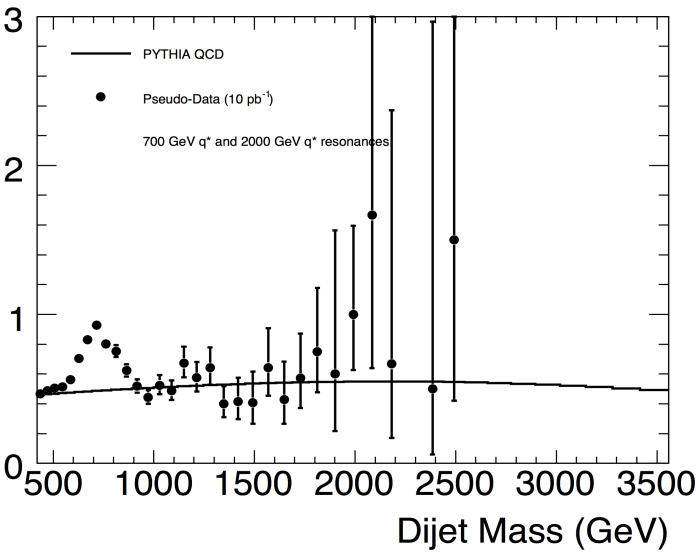


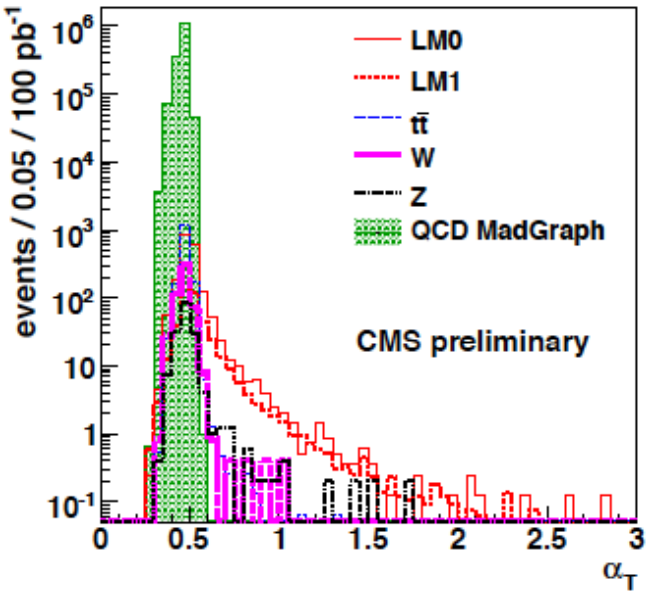
CMS summary

5 faculty, 4 res. faculty, 6 postdocs and 4 grad. students, several undergrad

Ready for analysis of real data:

- Jet and MET reconstruction & corrections
  - Zielinski co-convener JETMET group
- Physics with high energy jets: dijet mass and angular distributions
  - Demina co-convener of SUSY commissioning
  - Flächer leader of SUSY prompt data validation
- Wealth of interesting physics topics to choose for a thesis!
  - Precision measurements with advanced analysis techniques
  - Supersymmetry
  - Higgs boson searches
  - Extra dimensions
  - Exotic decays in SM
  - ... the unexpected!

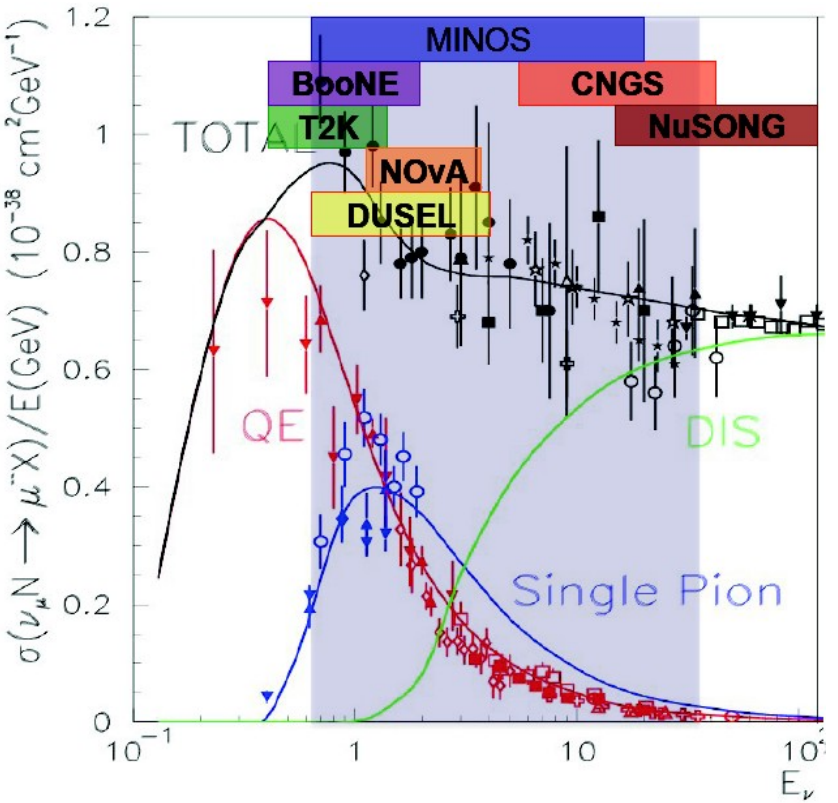


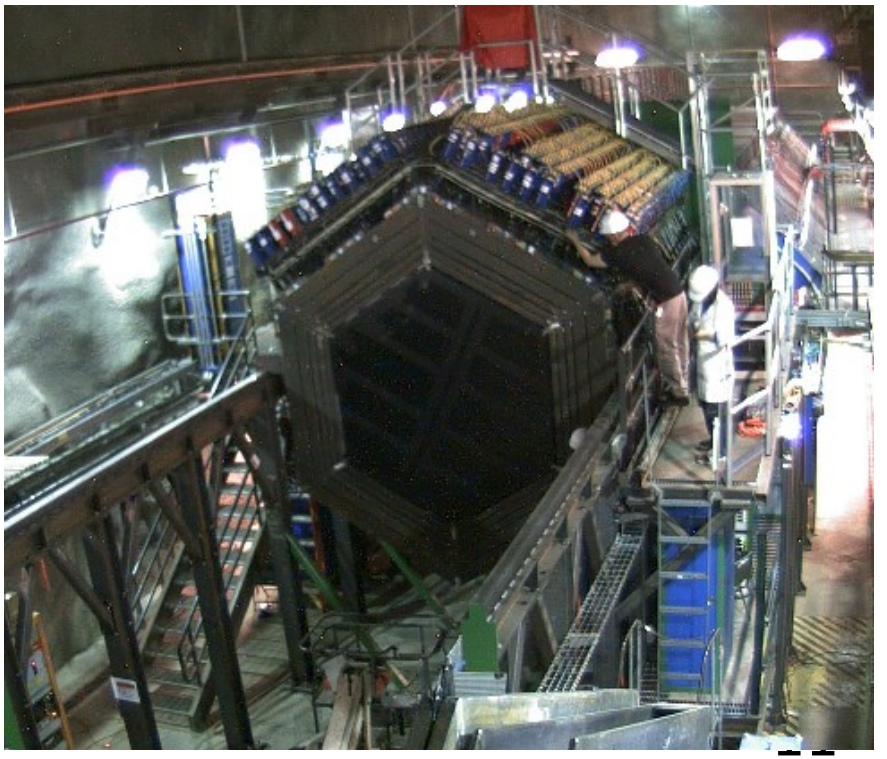


(b) Distribution of α_T for events with $n = 3 \ldots 6$ jets.

MINERνA

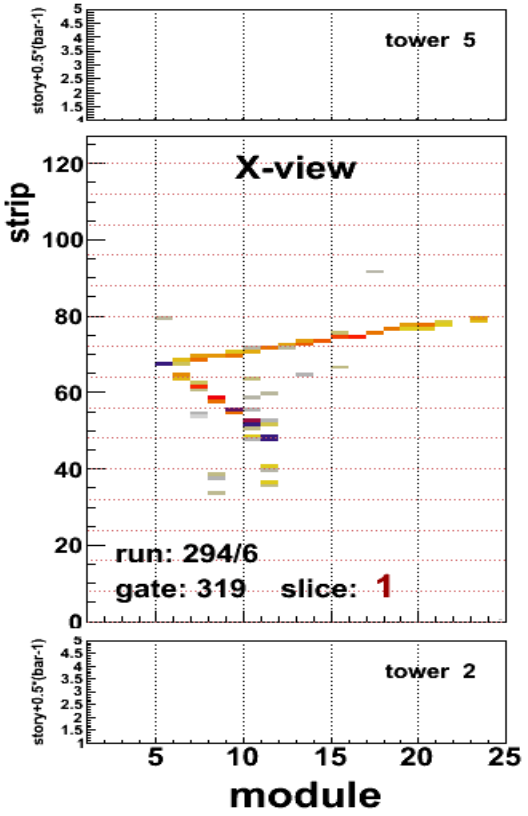
- Minerνa is designed to study neutrino-nucleus interactions with unprecedented detail
- Measure the effect of nuclear medium on signal and background processes over a wide neutrino energy range
- Nuclear effect models are inconsistent: transition region from scattering from nucleons to quarks
- Test nuclear targets: He, C, Fe, Pb
- **Will provide crucial input to current and future oscillation measurements**
- 23 institutes, ~100 members
- UR group is involved in all aspects of detector



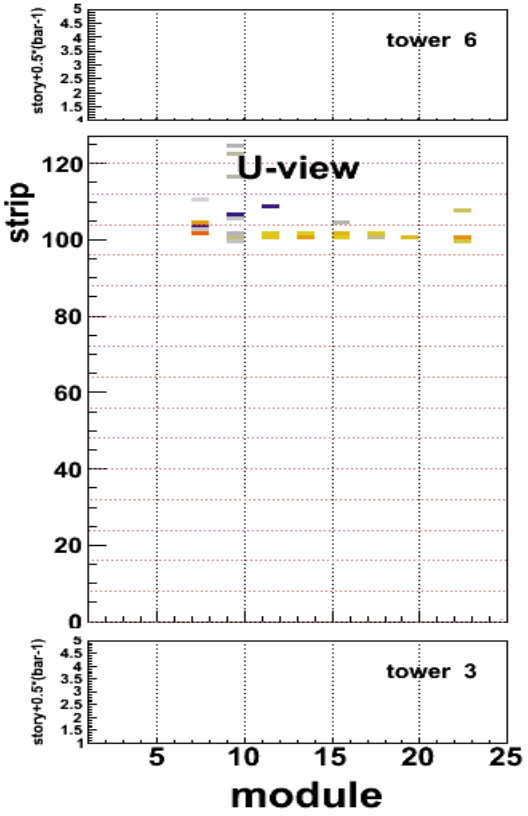


Minerva prototype taking data

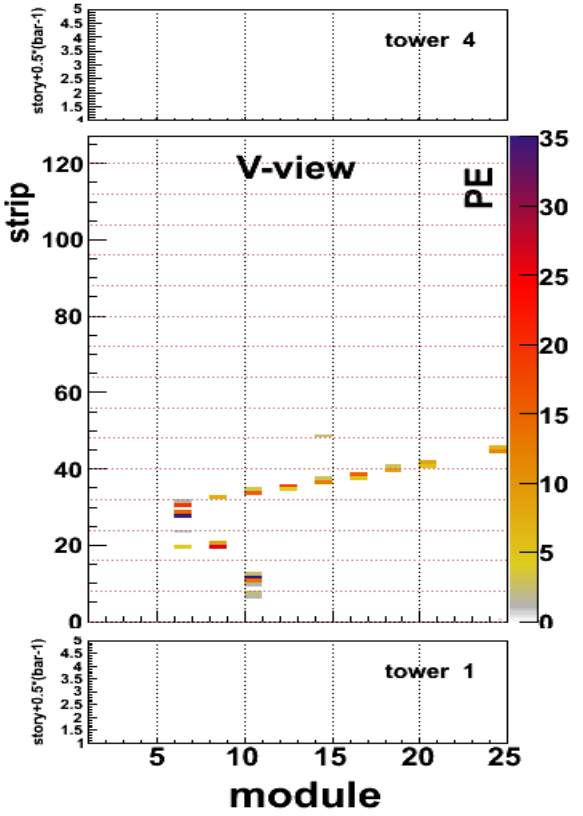
quasi-elastic ν_μ cc event



ν_μ cc event with π



quasi-elastic ν_e cc event



- Full detector installed and operational April 2010
- Brand new detector to squeeze data from
- Lots of room for high-impact contributions
- Operate and analyze data for 5 years

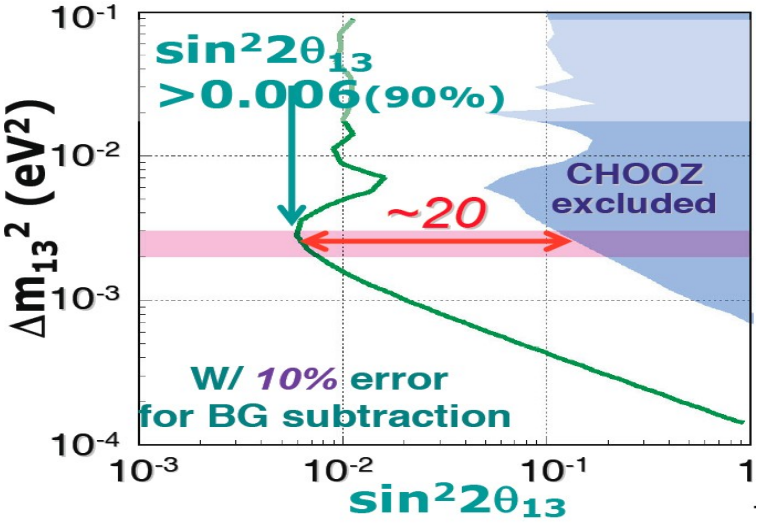
Perfect timing for graduate analysis!

~3 more students needed!

Neutrinos galore

Tokai to Kamioka (T2K) experiment

- Search/measure neutrino oscillations: $\nu_\mu \rightarrow \nu_e$ (undiscovered) and measure precisely $\nu_\mu \rightarrow \nu_\tau$
- 65 institutes, 385 members
- UR involved since inception in 2001
  - Building of near detectors to measure flux and neutrino cross sections
  - Implement cross-section models
- Synergy with Minerva construction: overlap of hardware experience and tools
- Started operation in 2009
- UR in fantastic position to apply results and techniques at T2K



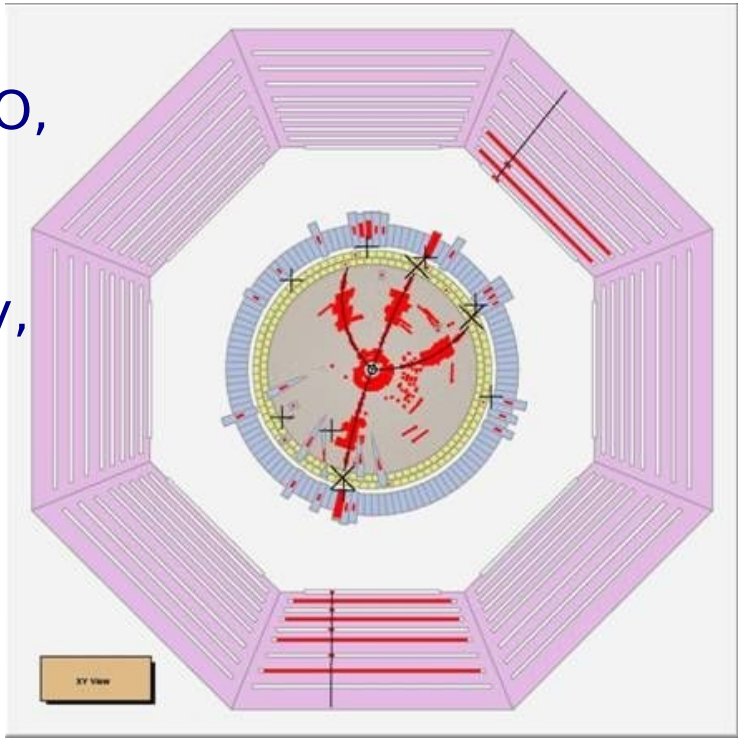
Neutrino detectors summary:

- 3 faculty, 2 res. faculty, 2 postdocs, 6 students
- Strong group in detector construction, data analysis and model building
- Goal is to answer the main questions remaining about neutrino oscillations

Electron colliders

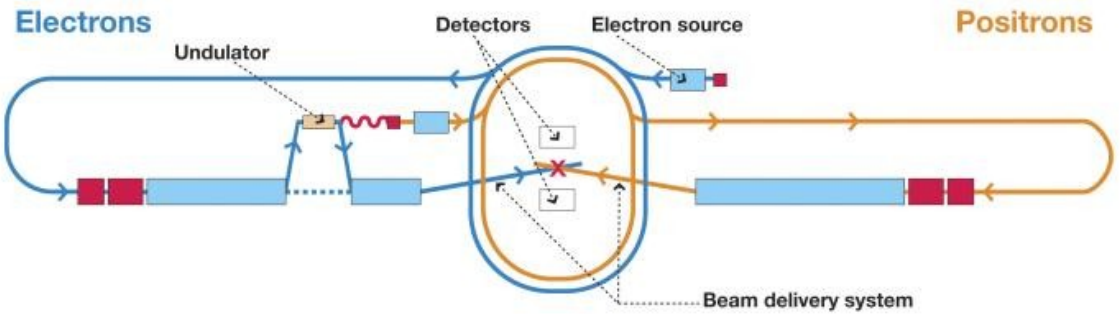
CLEO at Cornell and BES in Beijing

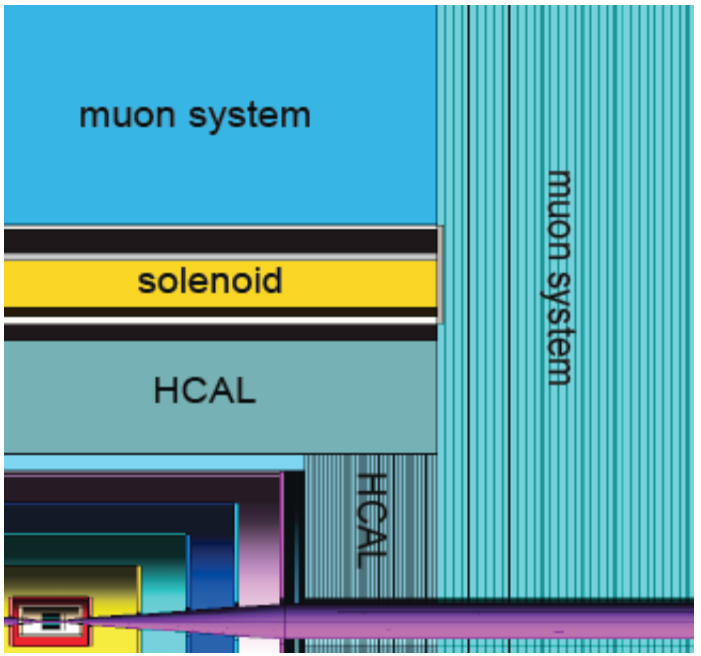
- Prof. Thorndike has worked for 25 years in CLEO, 8 of them as spokeperson!
- Detailed studies of charm and bottom quark physics (collisions at 3.5-12 GeV): spectroscopy, decay rates, couplings...
- 2 postdocs, 2 students
- BES (Beijing) taking data now!
- Several openings to work with new data



International Linear Collider

- Prof. Manly is working on the R&D of one of the proposed detectors of the future ILC (ee collisions at 200-800 GeV)

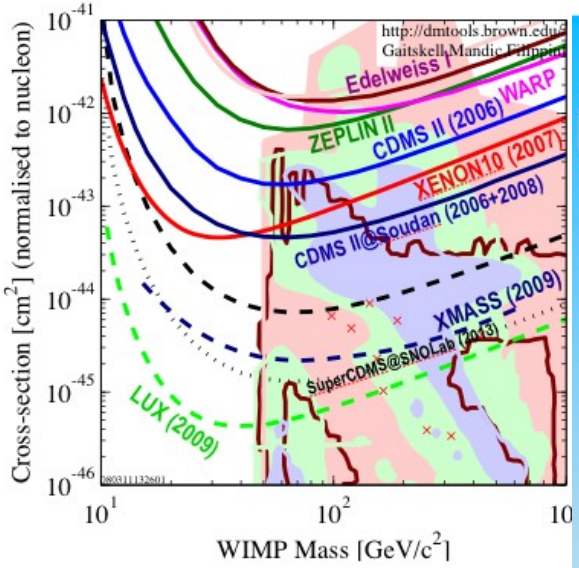


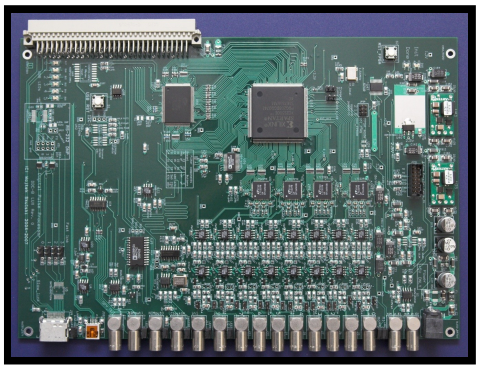


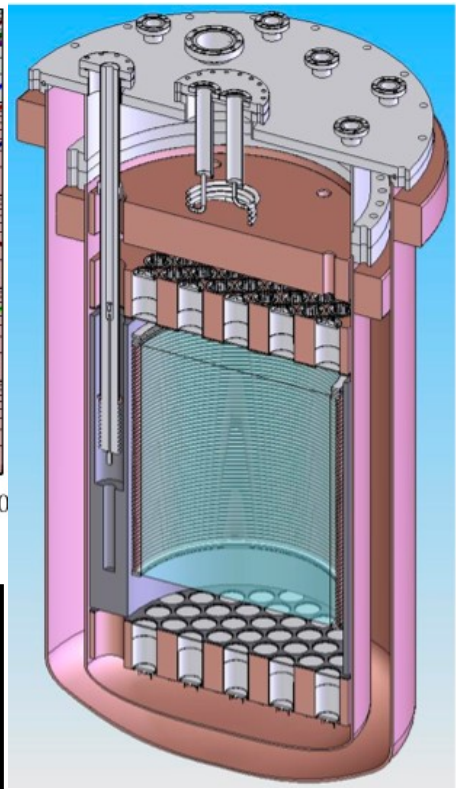
Dark Matter & Gravitational Waves

Large Underground Xenon (LUX), Homestake, SD

- Detector of 300 kg of liquid Xe
- Dark matter particles can leave a trace of light and ionization on Xe
- LUX will be two orders of magnitude more sensitive
- Key: low backgrounds (deepest mine in North America, improve radiopurity of detector materials, large mass)
  - 1 background event/300 days
  - ~4 signal events expected
- Prof. Wolfs responsible for the design and construction of the trigger electronics







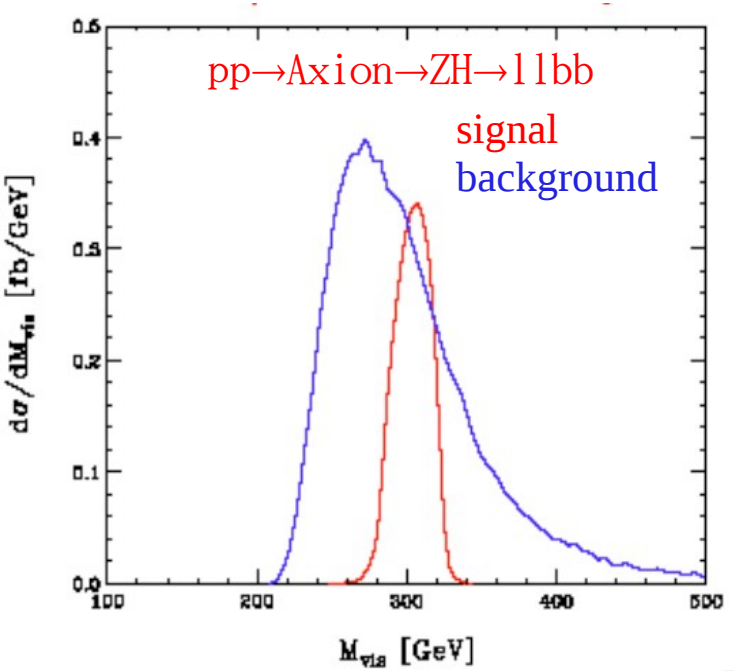
Laser Interferometer Gravitational wave Observatory

- Gravitational wave has an amplitude of 10^{-22} m
- Like observing the orbit of Saturn shift closer to the sun by the diameter of a single Hydrogen atom
- Prof. Melissinos is a member of the collaboration

Theory group

4 faculty, 2 postdocs, 4 students

- At the forefront of particle theory research: mathematical physics, quantum field theory and phenomenology
- **Okubo**: algebras with applications to physics (octonions, Lie groups)
- **Das**: Quantum field theory, string theory, integrable systems … and several books along the way!
- **Rajeed**: Dynamics of quantum field theory, quantum thermodynamics, general relativity, black holes
- **Orr**: connecting theory and experiment
  - Motivation: what lies beyond the Standard model, what is the mechanism for mass, how can we study these experimentally?
  - Large impact on top quarks, Higgs, SUSY



Theory group students consistently earn top prizes in the university!

And very prestigious subsequent positions

UR HEP group at a glance

Collider Physics

- CDF: 2 faculty, ramping down
- DØ: 4 faculty, ramping down
- CLEO: 1 faculty, ramping down
- CMS: 5 faculty, 15+ years of discoveries ahead of us!
- BES: 1 faculty, next generation ee facility for charm/bottom studies
- ILC: 1 faculty, 300-800 GeV ee collider, future detector development

Neutrino physics

- MINERνA: 3 faculty, mid-construction, start data now
- T2K: begin transition soon, wealth of thesis topics
- Phenomenology: strong contributions to neutrino-nucleon interactions

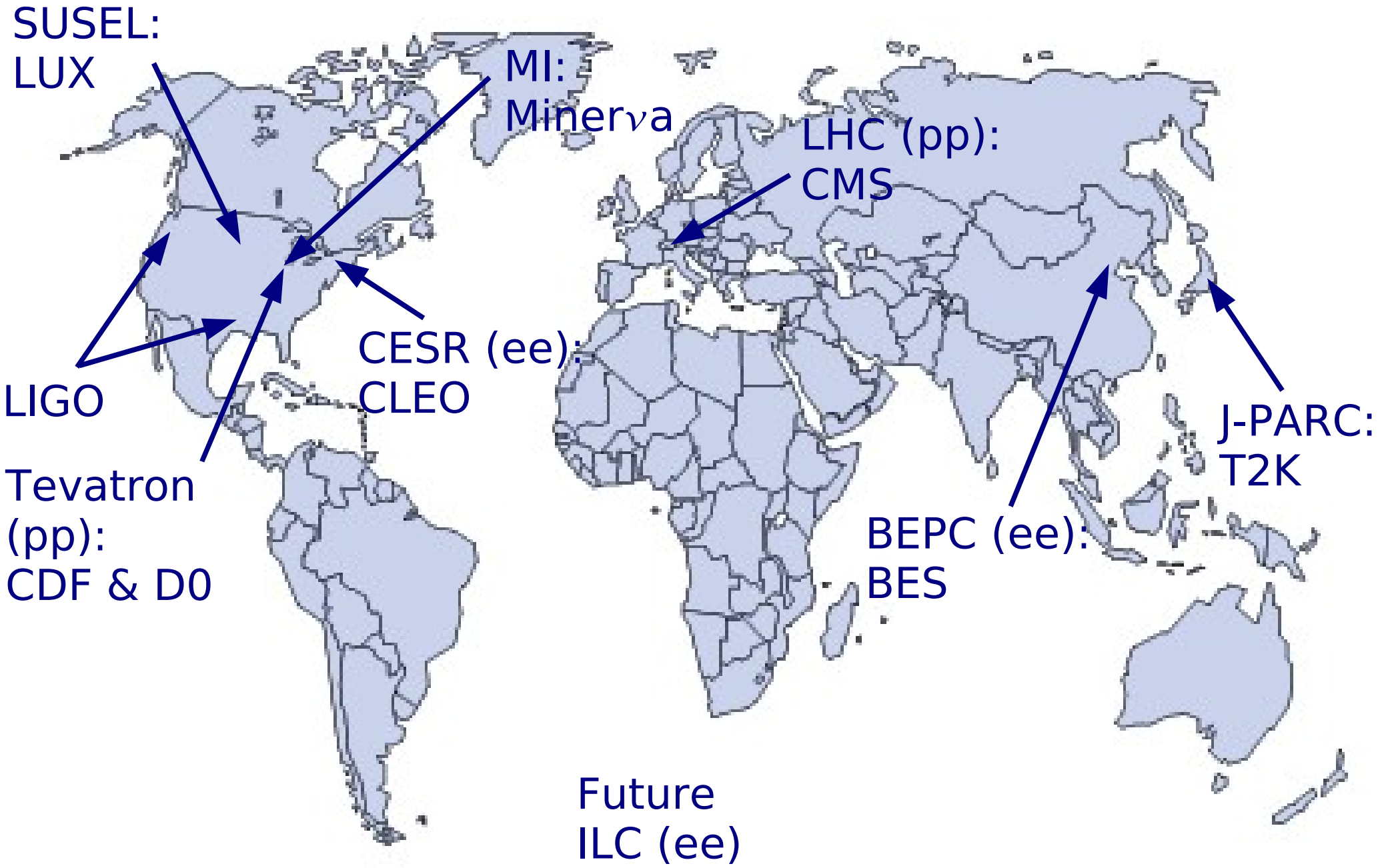
Dark Matter/GR

- LUX: 1 faculty, dark matter sensitivity improves x100, begins data taking in 2009
- LIGO: 1 faculty, running

Theory

- Collider Phenomenology: 1 faculty, plenty of work to respond and anticipate LHC challenges
- Mathematical Formal Theory: 3 faculty, really cutting edge physics

UR HEP around the world



Life as a UR HEP grad student

- First two years:
  - Lots of **classes**: study hard!
  - TA two semesters
  - Pass qualifying **exam**
  - Spend **summers starting research/hardware**
- Next 2/3 years
  - Be **based at experiment** in laboratory (or not)
  - Take **shifts**, become an on-call **expert**, build sub-detector hardware
  - Contribute to algorithms to reconstruct different particles into events
  - Make **physics analysis** (search for new particles, measure something precisely)
  - Give weekly **talks**, collaborate with many, many, many people
  - Go to international 2-week summer schools
  - Go to **conferences**
  - **Publish**

Retina scan to access CMS

Conclusions

- High Energy Physics is at a really exciting juncture:
  - New energy frontier starting now: discoveries at hand
  - Hopefully Nature has some surprises for us in this new regime
  - Dark matter, mass hierarchy, origin of mass, matter antimatter asymmetry
- Rochester is strongly positioned to play an important role on all fronts
- Rich history of contributions in the advancement of the field
- We have a large HEP group with diverse interests offering students the opportunity to make an impact in solving a few of the big questions in physics
- Our group provides excellent student mentoring
  - 15 faculty, 5 research faculty and help from experienced postdoctoral research associates
  - Stays at lab sites to build detectors and analyze the data
  - Interaction within the collaborations and exposure to many different Universities and cultures!
  - Promote attendance to conferences and presentation of results

Lots of new data (surprises!) coming, unique point in our field

Extra

Collider Physics

- CDF: strong contributions to calorimeter, trigger/DAQ and operations. Top, weak boson and BSM physics
- DØ: crucial roles in fiber tracker readout, online software, luminosity monitoring, silicon upgrade, technical coordination. Top physics
- CMS: leadership of hadronic calorimeter, silicon tracker, software work at LPC, installation and commissioning, jet and EWK physics
- Contributed to electron cooling at Tevatron and LC injector R&D
- CLEO:

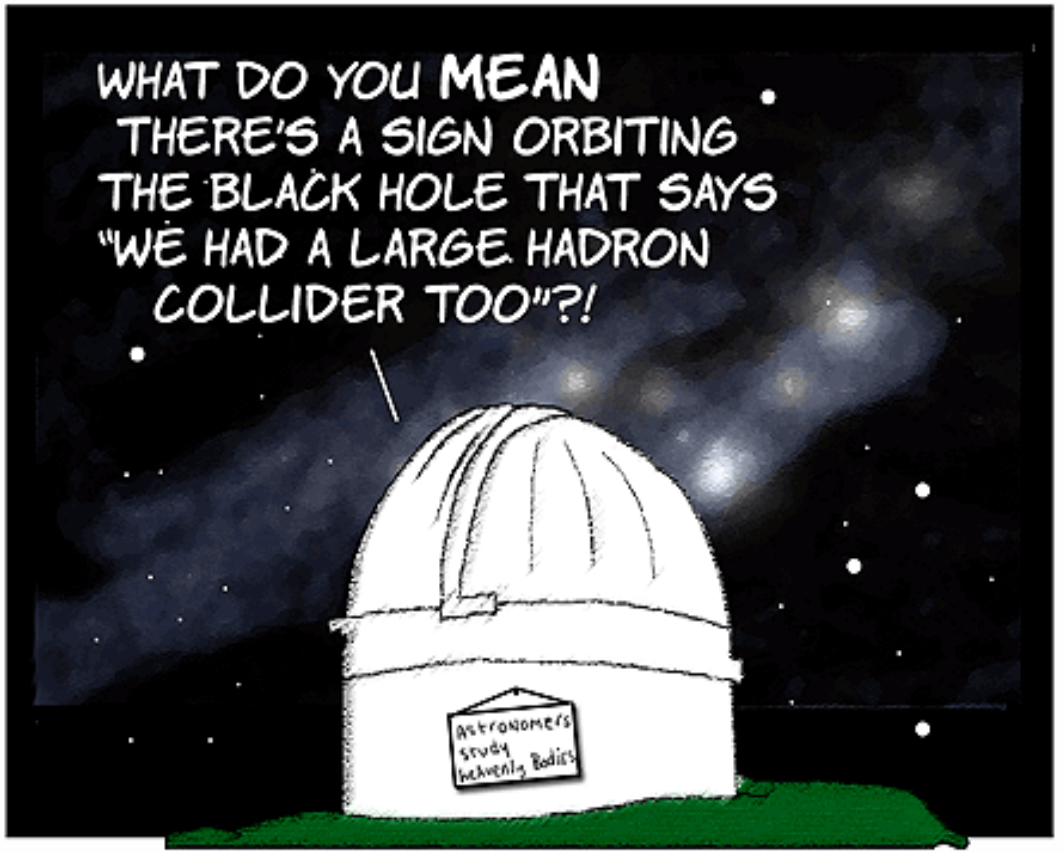
Neutrino physics

- Proposed MINERvA experiment, lead institution in the collaboration
- Founding role in T2K near detector, beam studies and backgrounds
- Leaders in phenomenology of neutrino cross-sections

Theory

- Collider Phenomenology and Mathematical Formal Theory
- Programs that complement above activities

THE SMALLEST BLACK HOLE YET DISCOVERED BY HUMANS LOCATED AT BINARY XTE J1650-500.



UserFriendly.Org

12 years in detector evolution