Presentation by Sau Lan Wu - ATLAS

Sau Lan Wu
Physics Department
University of Wisconsin-Madison

Meeting of the Physics Department Board of Visitors
CERN, Geneva, Switzerland
October 10, 2019
“Three Major Physics Discoveries and Counting” - Quanta Magazine
• **Higgs Discovery** - 2012
• **Gluon Discovery** - 1979
• **$J/\Psi$ Discovery** - 1974
Here I am repeating a part of my talk in 2012.

The Discovery of the Higgs – the God Particle

Sau Lan Wu
Physics Department
University of Wisconsin-Madison
September 20, 2012 at 4:00 pm

Campus Invited Talk, Wisconsin Alumni Research Foundation
Hector F. DeLuca Forum, Wisconsin Institutes for Discovery

Sponsored by the WARF Trustees, the offices of the UW-Madison Chancellor and Provost, the Graduate School, and the College of Letters and Sciences
What is a Higgs particle?

The Higgs particle was the missing cornerstone of the Standard Model of Physics, a theory which describes how the known particles in the Universe interact with one another.

The Higgs particle is responsible for all masses in the Universe.

On December 13, 2011, “tantalizing hints”
July 4, 2012, “Discovery!”

Leon Lederman
Nobel Laureate, 1988
The Standard Model gives a description of the elementary particles (the building blocks of matter) and their interactions (the forces that hold them together).

**Building blocks of matter (elementary particles)**
- 6 quarks
- 6 leptons
- 4 force-carrier particles
The Standard Model

Fundamental building blocks of the Universe - the elementary particles

The elementary particles – Fermions (spin ½)

First generation
- up quark
- down quark
- Electron (e)
- Electron neutrino ($\nu_e$)

Second generation
- charm quark
- Strange (s)
- Muon ($\mu$)
- Muon neutrino ($\nu_\mu$)

Third generation
- Top (t)
- Bottom (b)
- Tau ($\tau$)
- Tau neutrino ($\nu_\tau$)

Only the first generation of elementary particles is needed to account for all the matter we see in the world around us.

up quark
down quark
electron
electron-neutrino
The Standard Model – proton and neutron

Proton (uud)

Neutron (udd)

Gluons
What would happen to me if there were no Higgs field?

- I shall be massless; pieces of my constituents will fly out all over the place with the speed of light just like the photon.
If there were no Higgs field

• The Higgs boson is responsible for all masses, from electrons to humans to galaxies.

• Without this particle, the world would not be anything like what we know.

• There would be no ordinary matter as we know it; there would be no atoms, no molecules, no cells and, of course, no humans.
Where and how was the Higgs particle discovered?

CERN is home to the world’s biggest and most powerful particle accelerator – the 27-km (17 miles) Large Hadron Collider (LHC), where the discovery was accomplished.

Founded in 1954 (12 European States)
Today: 20 Member States

CERN: Conseil Européen pour la Recherche Nucléaire
[Official name: European Organization for Nuclear Research]
The most effective way to produce a Higgs particle is by colliding two gluons

Gluons are in protons. We therefore produce the Higgs particle by colliding two protons.

(I played a leading role in the gluon discovery in 1979)

Very high energies are required to accomplish this.

Large Hadron Collider
was built at CERN in Geneva, Switzerland.
The LHC Experiments

Four large detectors at the LHC to capture the head-on collisions between two proton beams (each 4 TeV)

$1 \text{ TeV} = 10^{12} \text{eV}$

The LHC crosses the French-Swiss border 4 times

CMS

ALICE

LHCb

ATLAS

12,500 tons

7,000 tons, 5 stories tall

Geneva Airport
• To select and record signals from the 400 million proton collisions per second & measure particles traces with high precision

• 100 million electronic channels to track hundreds of particles per event and reconstruct their trajectories with ~10 \( \mu \text{m} \) precision
About 100 million “sensors” each

Much above a 12 megapixel camera, taking 20 million pictures/sec
How to discover the Higgs particle?

The Higgs particle is not stable
The only way we can observe it is to detect its decay products

Higgs decays into 2 photons, or 4 leptons, or other “channels”

About one Higgs every minute

1600 high-tech superconducting magnets
LHC

proton

ATLAS detector

proton

gluon

gluon
How to search for a Higgs particle?

Not so easy!

Needles in a haystack

In ATLAS, up to July 4, 2012:

- A million billion collisions
- 4.2 billion events analyzed
- 240,000 Higgs particles produced
- ~350 diphoton Higgs events detected
- ~8 four-lepton Higgs events detected
Higgs discovery channel #1

$H \rightarrow$ two photons

LHC

proton

gluon

ATLAS detector

proton

gluon

photon

photon
Higgs discovery channel #1

H → two photons

**ATLAS**

- Data S/B Weighted
- Sig+Bkg Fit ($m_H = 126.5$ GeV)
- Bkg (4th order polynomial)

$\sum$ weights / 2 GeV

$\sum$ weights - Bkg

- $\sqrt{s} = 7$ TeV, $\int L dt = 4.8$ fb$^{-1}$
- $\sqrt{s} = 8$ TeV, $\int L dt = 5.9$ fb$^{-1}$

$H \rightarrow \gamma \gamma$

**ATLAS**

Mass = 126.5 GeV

(1 GeV = $10^9$ eV)

**CMS**
**Higgs discovery channel #1**

**H → two photons**

\[ H \rightarrow \gamma\gamma \]

CMS Preliminary

\[ \sqrt{s} = 7 \text{ TeV}, L = 5.1 \text{ fb}^{-1} \]

\[ \sqrt{s} = 8 \text{ TeV}, L = 5.3 \text{ fb}^{-1} \]

- **S/B Weighted Data**
- **S+B Fit**
- **Bkg Fit Component**
- **±1 σ**
- **±2 σ**

**CMS**

**Mass = 125 GeV**

(1 GeV = 10⁹ eV)
Higgs discovery channel #2

$H \rightarrow$ four leptons ($e^+e^-e^+e^-, e^+e^-\mu^+\mu^-,\mu^+\mu^-\mu^+\mu^-$)
Higgs discovery channel #2: $H \rightarrow 4$ leptons

Higgs → 4 muons

Mass = 125 GeV

$\sqrt{s} = 7$ TeV: $\int L dt = 4.8$ fb$^{-1}$
$\sqrt{s} = 8$ TeV: $\int L dt = 5.8$ fb$^{-1}$

$m_{4\mu} = 125.1$ GeV
**Higgs discovery channel #2:  $H \rightarrow 4$ leptons**

8 TeV DATA

4-lepton Mass : 126.9 GeV

$\mu^+(Z_1) p_T : 24$ GeV

$e^-(Z_2) p_T : 10$ GeV

$e^+(Z_2) p_T : 21$ GeV

CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115
The moment of 5σ discovery

Combining the results of the two discovery channels $H \rightarrow 2$ photons and $H \rightarrow$ four leptons (2011+2012 datasets):

(plus 2011 data from less strong channels $H \rightarrow WW, H \rightarrow \tau \tau, H \rightarrow bb$)

$p_0$: probability that the background fluctuates to the observed data (or higher)

The chances that the events observed were due to random fluctuations are less than one in three million — corresponding to the stringent “five sigma” gold standard particle physicists insist on to claim a discovery.

CMS: 5σ  (July 4, 2012)
Armed with 5σ significance independently from the ATLAS and CMS experiments, the Director General of CERN, Rolf Heuer, declared:

“I think we have it”

“We have now found the missing cornerstone of particle physics. We have a discovery. We have observed a new particle that is consistent with a Higgs boson.”

July 4, 2012
The moment of $5\sigma$ discovery

On July 31, 2012
ATLAS and CMS submitted papers to Physics Letters B.
ATLAS added 2012 data to the $H \rightarrow WW$ channel $\rightarrow 6\sigma$

For $6\sigma$, the chances that the events observed were due to random fluctuations are less than one in 500 million.

Now published, Physics Letters B 716, 1-29 (ATLAS) 30-61 (CMS), Sept. 17 2012:
The discovery was a culmination of two decades of work by 6000 ATLAS and CMS physicists from 56 nations and about 200 institutions, who

- built and now operate the detectors,
- designed and manage a computer system that distributes data around the world (worldwide computing grid)
- created novel hardware and computer software to identify the most interesting collisions, and
- wrote the algorithms that dig out the most pertinent events from the great morass of data being recorded.

They all worked feverishly, anticipating a discovery.
The day we got $\sigma$
The moment we got $5\sigma$ (5 sigma) June 25, 2012, 3 pm

$5\sigma$: chances that these events were the result of random fluctuations were less than one in three million.
On July 4, 2012 the Higgs working group had a celebratory drink. Everyone is watching the corks of the champagne bottles flying up to the ceiling.
On July 4, at the end of the CERN seminar I went to shake hands with Prof. Higgs. I told him “I have been looking for you for over 20 years”. He replied “now, you have found me”.

Higgs

Englert

On July 4, 2012

The day of the CERN public announcement of the discovery
Discovery of the Gluon
The gluon was discovered at the electron-positron collider PETRA of DESY, Germany, in late spring of 1979.

The exchanged particles responsible for the interactions are called gauge particles.

The gluon is the second gauge boson to have been discovered experimentally, the first one being the photon more than 50 years earlier.
Yang and Mills predicted that there is a fundamental difference between the gluon and the photon: while a photon cannot emit or absorb another photon, the gluon can emit and absorb another gluon.

The gluon is the gauge particle for strong interactions. The strong interactions between quarks are mediated by the gluon.
The gluon discovery was followed, four years later in 1983, by that of the third and the fourth gauge particles, the Z and the W, by Carlo Rubbia and Simon Van der Meer, CERN.

The gluon discovery is accomplished through the observation of three-jet events from the process

$$e^+ e^- \rightarrow q \bar{q} g$$
The discovery of the gluon requires direct observation.

Since the gluon is the gauge particle for strong interactions, the simplest way to produce a gluon is by the gluon bremsstrahlung process:

\[ e^+ e^- \rightarrow q \bar{q} g \]
In 1975, SPEAR at SLAC was first to observe a two-jet structure in $e^+ e^- \rightarrow q \bar{q}$. Since the gluon, similar to the quark, is expected to hadronize into a jet, this process leads to three-jet events.
Discovery of the Gluon

First three-jet event from PETRA shown by B. Wiik of TASSO at Bergen Conference 1979
The following is quoted from Wiik’s Bergen Conference talk: (First Results from PETRA, in Proceedings of Neutrino 79, International Conference on Neutrinos, Weak Interactions and Cosmology, Volume 1, Bergen, June 18–22 1979, pp. 113–154)

“If hard gluon bremsstrahlung is causing the large $p_{\perp}$ values in the plane then a small fraction of the events should display a three jet structure. The events were analyzed for a three jet structure using a method proposed by Wu and Zobernig\textsuperscript{27}) . . . A candidate for a 3 jet event, observed by the TASSO group at 27.4 GeV, is shown in Fig. 21 viewed along the $\hat{n}_3$ direction. Note that the event has a three clear well separated jet and is just not a widening of a jet.”

As soon as I returned from Bergen, I wrote a TASSO note with Zobernig on the observation of this three-jet event.
The search for the three-jet events at PETRA was motivated by the gluon bremsstrahlung process $e^+ e^- \rightarrow q \bar{q} \ g$. After such events have been found, the next question is:

**What can the three jets be?**

Since quarks and antiquarks are fermions and two fermions ($e^+, e^-$) cannot turn into three fermions, these three jets cannot all be quarks and antiquarks.

The experimental observation of three-jet events in $e^+ e^-$ annihilation, implies the discovery of a **NEW PARTICLE** (a new boson).
The important role of gluon in the Higgs discovery

\[ H \rightarrow \text{two photons} \]
• Since its first observation thirty nine years ago, the importance of the gluon in particle physics has grown significantly.

• An especially noticeable example is its essential role in the discovery of the Higgs particle produced through gluon-gluon fusion in 2012 by the ATLAS Collaboration and the CMS Collaboration at the Large Hadron Collider at CERN.

• If there were no gluon, the Higgs particle could not have been discovered so soon in 2012!
Discovery of the $J/\Psi$
45 Years ago, on November 11, 1974, the High Energy Physics Community of the whole world was stunned by the joint announcement by Sam Ting and Burt Richter of the discovery of the J/Ψ particle observed at the Brookhaven National Laboratory and at SLAC.

The charm quark was discovered!

In the December 2, 1974 issue of PRL, three papers on the discovery of the J/Ψ particle by MIT/BNL, SLAC, and ADONE/FRASCATI were published back-to-back.
Experimental Observation of a Heavy Particle $J^+$


Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee

Brookhaven National Laboratory, Upton, New York 11973
(Received 12 November 1974)

We report the observation of a heavy particle $J$, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \text{Be} \rightarrow e^+ + e^- + x$ by measuring the $e^+e^-$ mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.
Discovery of a Narrow Resonance in $e^+e^-$ Annihilation


Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and


Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720

(Received 13 November 1974)
On November 10, 1974, I was on evening shift with Min Chen. A young physicist with black beard walked into our trailer and said to us: "Have you heard that SPEAR has found a narrow resonance at 3.1 GeV with a width of less than 2MeV? People at SLAC are celebrating with champagne!" I had never met him before or after.

Min Chen and I looked at each other with tears in our eyes. Call Sam! But he was on a TWA flight to SLAC for a Program Advisory Committee meeting on November 11.
I called TWA to leave an urgent message for Ting at the SF Airport to call us. By the time he called at 1 am, I convinced myself that it was a practical joke by Mel Schwartz to collect his $10 bet. I went back to the women's dorm - the Curie House -- to sleep.

At 2:30 AM, a loud knock at my door by Ingrid Schultz, Sam's loyal technical assistant, "Come back to the trailer; it is true!"
Soon after Sam Ting got to his motel, Flamingo Motel (now called Creekside Inn) in Palo Alto, he received a call from Martin Deutsch of MIT.

Deutsch confirmed the news from SLAC.

All through the night, the operator at Flamingo was bombarded with requests to connect calls to Ting's room. Sam had me call the Directors of CERN, DESY, and FRASCATI.
With bloodshot eyes, I and others joined the BNL Director for a press conference in the morning.

3,000 miles away at SLAC, Sam Ting went to Panofsky's office and met Burt Richter there.

"Burt," Ting said to Richter, "I have some interesting physics to tell you."

"Sam," Richter said to Ting, "I have some interesting physics to tell you."

**J/ψ was born!**

This led to the 1976 Nobel Prize shared by Burt Richter and Sam Ting.
Discovery of the $J/\Psi$
Discovery of the $J/\Psi$

Laboratory Director George Vineyard (right) with Y.Y. Lee, Sau Lan Wu and Samuel Ting (left to right) in the MIT trailer where the $J$-particle was discovered.
Discovery of the $J/\Psi$
EDUCATION – OUR MISSION
EDUCATION – Our primary mission

Training of Graduate Students:

61 Grad. students have obtained Ph.D. degrees under my supervision: 10 in TASSO, 23 in ALEPH, 9 in Babar and 19 in ATLAS

Faculty Positions of Former Postdocs and Graduate Students

36 Former Postdocs and Grad Students are faculty members mainly in major universities (27 full professors, 5 associate professors with tenure and 4 assistant professors)

Another 13 are permanent staff members at major High Energy Physics laboratories, including Saul Gonzalez, now Program Director at NSF

Eighteen Ph.D. students have obtained their Ph.D. doing ATLAS research under my supervision.
61 Grad. students have obtained Ph.D. degrees under my supervision:

4) H. Venkataramania 1985 Yale 15) Yibin Pan 1991 Wisconsin
8) Steven Ritz 1988 Columbia 19) Michael Walsh 1995 Rutgers
9) David Muller 1989 Stanford 20) Leo Bellantoni 1995 Fermilab Lederman Fellow followed by Wilson Fellow
### EDUCATION

**Training of graduate students**

61 Grad. students have obtained Ph.D. degrees under my supervision:

<table>
<thead>
<tr>
<th>Class Year</th>
<th>Name</th>
<th>University</th>
<th>Advisor</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Jane Nachtman</td>
<td>Fermilab Wilson</td>
<td>P. McNamara</td>
<td>2002</td>
</tr>
<tr>
<td>1998</td>
<td>Jim Grahl</td>
<td>Iowa State</td>
<td>Steve Sekula</td>
<td>2004</td>
</tr>
<tr>
<td>1998</td>
<td>Peter Elmer</td>
<td>Princeton</td>
<td>Ran Liu</td>
<td>2004</td>
</tr>
<tr>
<td>1998</td>
<td>Steve Armstrong</td>
<td>CERN Fellow</td>
<td>Jinwei Wu</td>
<td>2004</td>
</tr>
<tr>
<td>1998</td>
<td>William Orejudos</td>
<td>Berkeley</td>
<td>Zhitang Yu</td>
<td>2005</td>
</tr>
<tr>
<td>1999</td>
<td>Xidong Wu</td>
<td>SBC Com.</td>
<td>Mousumi Datta</td>
<td>2005</td>
</tr>
<tr>
<td>1999</td>
<td>Owen Hayes</td>
<td>Booz Allen Hamilton</td>
<td>Baosen Cheng</td>
<td>2005</td>
</tr>
<tr>
<td>1999</td>
<td>Tom Greening</td>
<td>CERN Fellow</td>
<td>Attila Mihalyi</td>
<td>2005</td>
</tr>
<tr>
<td>2001</td>
<td>Doug Ferguson</td>
<td>Wisconsin</td>
<td>Kyle Cranmer</td>
<td>2005</td>
</tr>
<tr>
<td>2001</td>
<td>Jason Nielsen</td>
<td>Berkeley</td>
<td>Karina Loureiro</td>
<td>2006</td>
</tr>
</tbody>
</table>

*Presidential Early Career Award for Scientists and Engineers 2007*
### EDUCATION  Training of graduate students

61 Grad. students have obtained Ph.D. degrees under my supervision:

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Year</th>
<th>Institution</th>
<th>Degree/Position</th>
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<tbody>
<tr>
<td>45</td>
<td>Alden Stradling</td>
<td>2008</td>
<td>U of Texas-Arlington</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Yaquan Fang</td>
<td>2008</td>
<td>Wisconsin</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>William Quayle</td>
<td>2008</td>
<td>US ATLAS Analysis Fellow</td>
<td></td>
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<tr>
<td>48</td>
<td>Xin Chen</td>
<td>2009</td>
<td>Wisconsin</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>Elizabeth Castaneda</td>
<td>2011</td>
<td>Foreign Academic Fellowship, Conacyt, Mexico</td>
<td></td>
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<tr>
<td>50</td>
<td>Haifeng Li</td>
<td>2012</td>
<td>SUNY-Stony Brook</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>G. Carrillo Montoya</td>
<td>2012</td>
<td>CERN Fellow</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>A. Castenada</td>
<td>2012</td>
<td>U of Texas – A&amp;M</td>
<td></td>
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<tr>
<td>53</td>
<td>Haichchen Wang</td>
<td>2013</td>
<td>Chamberlain Fellow at Berkeley</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>Haoshuang Ji</td>
<td>2014</td>
<td>CONVIVA (real-time big data processing platform)</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>Yao Ming</td>
<td>2016</td>
<td>Amazon</td>
<td></td>
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<tr>
<td>56</td>
<td>Hongtao Yang</td>
<td>2016</td>
<td>Chamberlain Fellow at Berkeley</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>Andrew Hard</td>
<td>2016</td>
<td>Google</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Fangzhou Zhang</td>
<td>2017</td>
<td>Ernst &amp; Young</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>Fuquan Wang</td>
<td>2017</td>
<td>Yelp</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Laser Kaplan</td>
<td>2017</td>
<td>Accenture</td>
<td></td>
</tr>
<tr>
<td>61</td>
<td>Xiangyang Ju</td>
<td>2018</td>
<td>Berkeley</td>
<td></td>
</tr>
</tbody>
</table>
36 Former Postdocs and Graduate Students are (or have been) faculty members mainly in major universities and 13 are permanent staff members at major High Energy laboratories. (27 full professors, 5 associate professors with tenure and 4 assistant professors)

**Faculty positions of former postdocs and grad students**

<table>
<thead>
<tr>
<th>Full Professors</th>
<th>Columbia University</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Allen Caldwell</td>
<td>Columbia University</td>
</tr>
<tr>
<td>2. Steven Ritz</td>
<td>UC Santa Cruz</td>
</tr>
<tr>
<td>3. David Strom</td>
<td>University of Oregon</td>
</tr>
<tr>
<td>4. Michael Cherney</td>
<td>Creighton Univ.</td>
</tr>
<tr>
<td>5. David Cinabro</td>
<td>Wayne State Univ.</td>
</tr>
<tr>
<td>6. Doug Cowen</td>
<td>Penn. State University</td>
</tr>
<tr>
<td>7. Robert Johnson</td>
<td>UC Santa Cruz</td>
</tr>
<tr>
<td>8. Vivek Sharma</td>
<td>UC San Diego</td>
</tr>
<tr>
<td>9. Joe Izen</td>
<td>Univ. of Texas, Dallas</td>
</tr>
<tr>
<td>11. Yuanning Gao</td>
<td>Tsinghua Univ. in Beijing</td>
</tr>
<tr>
<td>12. Shan Jin</td>
<td>IHEP, Beijing</td>
</tr>
<tr>
<td>13. Hongbo Hu</td>
<td>IHEP, Beijing</td>
</tr>
<tr>
<td>14. John Conway</td>
<td>UC Davis</td>
</tr>
<tr>
<td>15. Haibo Li</td>
<td>IHEP, Beijing</td>
</tr>
<tr>
<td>16. Haiping Peng</td>
<td>USTC, China</td>
</tr>
<tr>
<td>17. Joe Boudreau</td>
<td>University of Pittsburgh</td>
</tr>
<tr>
<td>19. Yaquan Fang</td>
<td>IHEP, Beijing</td>
</tr>
<tr>
<td>20. Stathes Paganis</td>
<td>National Taiwan Univ.</td>
</tr>
<tr>
<td>21. Bruce Mellado</td>
<td>U. of the Witwatersrand, Johannesburg</td>
</tr>
<tr>
<td>22. Jason Nielsen</td>
<td>University of California, Santa Cruz</td>
</tr>
<tr>
<td>23. Lianliang Ma</td>
<td>Shandong Univ. , China</td>
</tr>
<tr>
<td>24. Haifen Li</td>
<td>Shandong Univ. , China</td>
</tr>
<tr>
<td>25. Yongsheng Gao</td>
<td>California State Univ.-Fresno</td>
</tr>
<tr>
<td>27. Isabel Pedraza</td>
<td>Benemérita Universidad Autónoma de Puebla</td>
</tr>
</tbody>
</table>
36 Former Postdocs and Graduate Students are (or have been) faculty members mainly in major universities and 13 are permanent staff members at major High Energy laboratories. (27 full professors, 5 associate professors with tenure and 4 assistant professors)

**Associate Professors with tenure**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Institution</th>
</tr>
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<tbody>
<tr>
<td>28.</td>
<td>Yibin Pan</td>
<td>Univ. of Wisconsin</td>
</tr>
<tr>
<td>29.</td>
<td>Trevor Vickey</td>
<td>Sheffield University, UK</td>
</tr>
<tr>
<td>30.</td>
<td>Jane Nachtman</td>
<td>Univ. of Iowa</td>
</tr>
<tr>
<td>31.</td>
<td>Gerald Rudolph</td>
<td>Universitat Innsbruck</td>
</tr>
<tr>
<td>32.</td>
<td>Stephen Sekula</td>
<td>Southern Methodist University</td>
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**Assistant Professors**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>33.</td>
<td>Luis Flores Castillo</td>
<td>Chinese University of Hong Kong</td>
</tr>
<tr>
<td>34.</td>
<td>Swagato Banerjee</td>
<td>University of Louisville</td>
</tr>
<tr>
<td>35.</td>
<td>Xin Chen</td>
<td>Tsinghua University, Beijing</td>
</tr>
<tr>
<td>36.</td>
<td>Haichen Wang</td>
<td>UC Berkeley</td>
</tr>
</tbody>
</table>

ATLAS: 20  CMS: 6  ALICE: 1
## EDUCATION  Permanent Staff at Major Research Laboratories

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
</table>
| **1. Saul Gonzalez** | Program Director of Experimental Elementary Particle Physics at NSF;  
Former Assistant Director for Physical Sciences at The White House Office of Science and Technology Policy;  
Former Program Manager for Proton Accelerator Physics, Physics Research Division of Office of High Energy Physics, DOE |
| **2. Pierre Lecomte** | Staff Physicist, ETHZ (Switzerland) |
| **3. Tom C.Meyer** | Staff Physicist at CERN |
| **4. John Walsh** | Researcher, INFN, Italy |
| **5. Mathew Graham** | Staff Physicist, SLAC |
| **6. James Freeman** | Scientist II, Fermilab |
| **7. Tim Barklow** | Staff Physicist at SLAC |
| **8. David Muller** | Staff Physicist at SLAC |
| **9. Eric Wicklund** | Staff Physicist at Fermilab |
| **10. Leo Bellantoni** | Scientist I, Fermilab (former Wilson and Lederman Fellows at Fermilab) |
| **11. Joleen Pater** | Staff Physicist at the University of Manchester |
| **12. Eric Charles** | Staff Physicist at SLAC |
| **13. Peter Elmer** | Research staff at Princeton University |
An interesting development is that high energy physicists are entering the workforce of well-known industries. Having been well trained in the high technology environment of large international physics collaborations, members of our group are extremely well suited to provide the functionality of technology transfer, always on the leading edge. For example, former postdocs and former graduate students who have held positions in companies are: (The list is not fully up to date)

1. **Ian Scott** – Partner Chief Data Scientist Deloitte Canada. Former VP customer Solutions at Lattice Engines. Former Chief Technology Officer at Angoss Software; former Director of Client Services.

2. **John Yamartino** – Director of Analytics at Lam Research. Former Senior Data Scientist at IBM (Greater New York City Area). Former Engineering Program Manager at Applied Materials, Inc., Silicon Valley.

3. **Makoto Takashima** – Executive Director in Equities Division at Morgan Stanley in London.

4. **Zhong Feng** – Lead System Engineer at Raytheon for NASA/Goddard Space Flight Center

5. **John Hilgart** – Senior Internet Infrastructure Architect at BASF ; former eCommerce Infrastructure Architect.
6. Fred Weber – Senior Research Scientist, Columbia University Earth Institute (subject: Spoken Language Technology for Development: Communication as Empowerment); former Senior Research Scientist at ScanSoft, Inc. (Boston) for speech recognition.

7. Jim Wear – Senior Scientist at GE Medical Systems


9. Xidong Wu – Lead Member of Technical Staff in Telecommunications at AT&T (San Francisco Bay Area). Former Software Engineer at SBC Communications.

10. Owen Hayes – Founder and Partner of Jorgeson Trading, former Director of Strategy & Technology at Thomson Reuters, Former Business Technology Director at Elsevier (Greater Philadelphia Area). Former Senior Associate at Booz Allen Hamilton Consulting Firm.

11. Thomas Greening – Senior Scientist at Apple (San Francisco Bay Area); former Principal Scientist at Honeywell; recipient of Technical Achievement Award (2003) and Outstanding Engineer of the Year Award (2002).

12. Stephen Armstrong – Senior Director – Corporate Capital and Financial Strategy at Lonza (Basel, Switzerland). Former Assistant Vice President, SGS Group management Ltd, Switzerland.

13. Zhitang Yu – Senior Software Development Engineer at Mentor Graphics (San Francisco Bay Area); former Research and Development Engineer at ClearShape Technologies.
14. Baosen Chen – Software Engineer at Plaxo (San Francisco Bay Area). Former Software Engineer at Avestar-IP.


17. William Orejudos – Senior Member, Energy and Environmental Services, SRA International (Charlottesville, Virginia Area).


19. Sanjay Padhi – Global Scientific Computing Principal at Amazon Web Services

20. Lashkar Kashif – Business Associate – Data Science at Gartner Inc
21. Haoshuang Ji – Senior Software engineer at Conviva

22. Yao Ming – Software Development Engineer at Amazon corporate LLC.


25. Fangzhou Zhang – Senior Consultant at Ernst & Young.


27. Xiangyang Ju - High Performance Computing Postdoctoral Scholar at Berkeley