



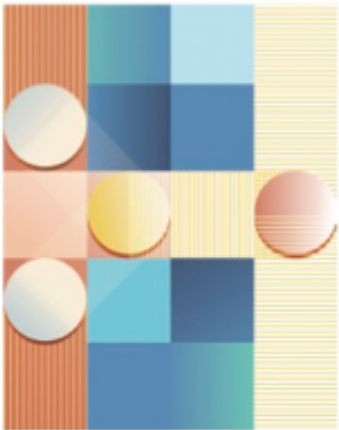
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Theory Strategic Plan

Marcela Carena
Fermilab PAC meeting
January 20th, 2016

Outline

- **Strategic goals**
- **Current efforts and highlights**
- **Personnel**
- **Strategic plan**



Higgs boson



Neutrino mass



Dark matter



Cosmic acceleration



Explore the unknown

Strategic Goals

- **Conduct world-leading theoretical particle physics and theoretical astrophysics research.**
- **Focus effort and core strength in key research areas directly related to the U.S. and worldwide experimental programs.**
- **Influence and motivate the design of experiments, data analyses, and their interpretation.**
- **Train next generation of theorists in data-rich environment and contribute to educating young experimentalists.**
- **Provide a national resource for university physicists.**
- **Foster an intellectually vibrant atmosphere at the lab.**

Theoretical Physics

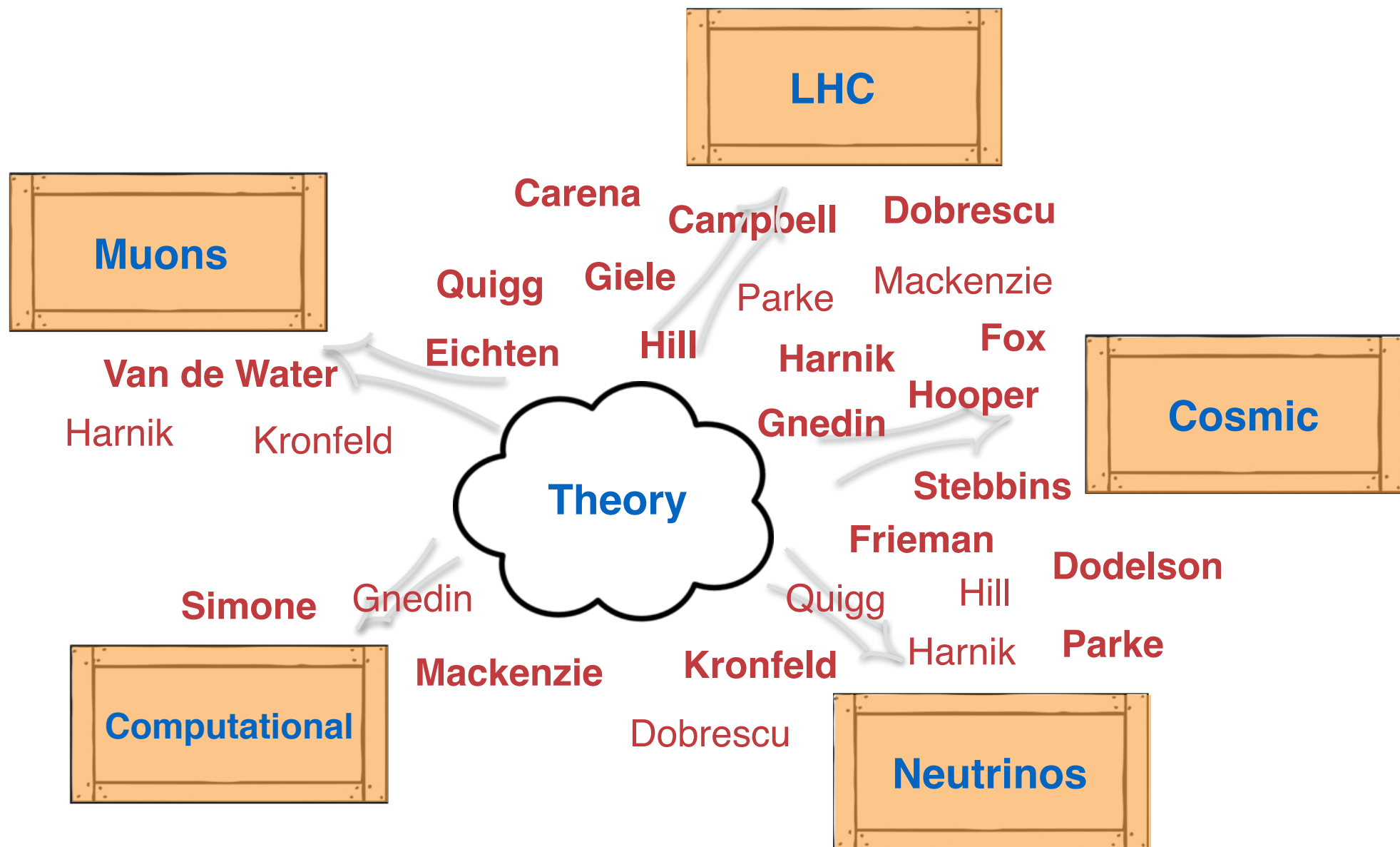
- Focus on aiding the experimental program in direct and indirect searches for New Physics.
- Primarily supports LHC, neutrino and muon programs.
- Key research areas: **collider phenomenology, Higgs physics, flavor physics, BSM model building, neutrino physics, perturbative and lattice QCD, dark matter, baryogenesis.**

Theoretical Astrophysics

- Focus on using astrophysical phenomena as a tool for understanding fundamental physics.
- Primarily supports cosmic frontier program.
- Key research areas: **dark matter, dark energy, inflation, CMB, cosmic neutrinos, large scale structure.**

Frequent interaction and collaboration between the two groups

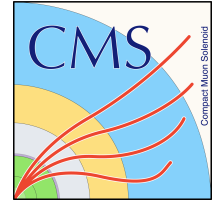
Research overview: broad and interconnected



Synergies with LHC program

calculations in pert.
and lattice QCD

theoretical tools for pheno



extracting Higgs width
and couplings

confronting new
models with data

Quarkonia,
exotic hadrons

Heavy Higgs and SUSY
benchmarks and searches

novel search strategies,
e.g. DM from monojets

- Development of NLO parton level code MCFM: matrix elements used by ATLAS and CMS to improve their Higgs physics results
- Significant contributions to Higgs boson search, discovery and characterization.
- Exploration of signals in extended Higgs sectors followed up by CMS.
- Development of BSM benchmarks and analysis techniques.
 - LPC ties: jointly-organized workshops and the LPC Topic of the Week series.
 - Organization of international conferences and schools, including the CERN-FNAL Hadron Collider Physics Summer Schools

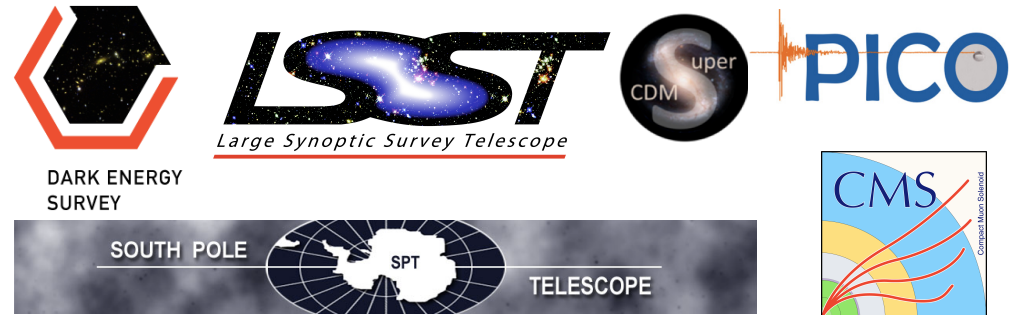
Synergies with cosmic program

dark matter

galaxies and
reionization

dark energy

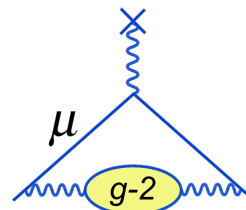
inflation



- **Contributions to direct + indirect DM searches:** extraction of limits from AMS, COGENT, LUX, Fermi-LAT; techniques being adopted by experiments
- **Identification of galactic center excess;** subsequent DM model-building & pheno
- **Pioneered searches for DM at colliders** via mono-jet and mono-photon signatures
- **Combining surveys:** Continued work to optimize survey design to maximize sensitivity to **dark energy** and other cosmic parameters e.g. combining results from CMB [SPT], photometric [DES, LSST] and spectroscopic [DESI] surveys.
 - **FNAL theorists helped initiate experiments:** SDSS, Auger, DES, Holometer, B-mode polarization CMB experiments.
 - **Leadership roles in** DES, LSST, South Pole Telescope, Tianlai 21cm redshift survey, Cosmological Computing Initiative

Synergies with muon program

hadronic vacuum polarization
contributions to $(g-2)_\mu$



hadronic light-by-light
contributions to $(g-2)_\mu$

connections between Higgs
boson and flavor violation

- Fermilab lattice theorists undertaking complete four-flavor calculations of HVP and HLbL contributions to $(g-2)_\mu$
- Showed how Mu2e will probe the Higgs flavor violating coupling to μ - e as well as provide tests of PeV Supersymmetry and TeV scale new forces.
- Organized academic lectures on $(g-2)_\mu$ and LFV
- “Lattice meets Experiment”: workshop on the role of lattice QCD in interpreting $(g-2)_\mu$ and Mu2e experiments.

Synergies with computational program

Lattice QCD

Design and Deploy
Community Hardware

Computational Cosmology

Design public Software

- Develop and deploy clusters and software frameworks for use by U.S. lattice-QCD community (USQCD)
- Leading U.S. lattice effort: chair of USQCD exec. committee and PI of LQCD (hardware) and SciDAC (software) grants
- **Hardware synergy with other projects**
 - advanced networking by LQCD basis of DAQs for neutrino and muon experiments.
 - first GPU cluster deployed at Fermilab for LQCD
- **Software collaboration** between LQCD and accelerator simulation
- **Detailed numerical simulations essential to interpreting cosmological data**
- **Develop public codes for analyses of cosmic surveys (CosmoSIS)**

Synergies with neutrino program

strategies for studying
standard ν paradigm

sensitivities of current,
proposed experiments

impact of light sterile ν 's
and non-SM interactions

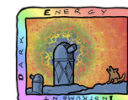
proposals for
future experiments

improved determination of nuclear effects

cosmic neutrinos



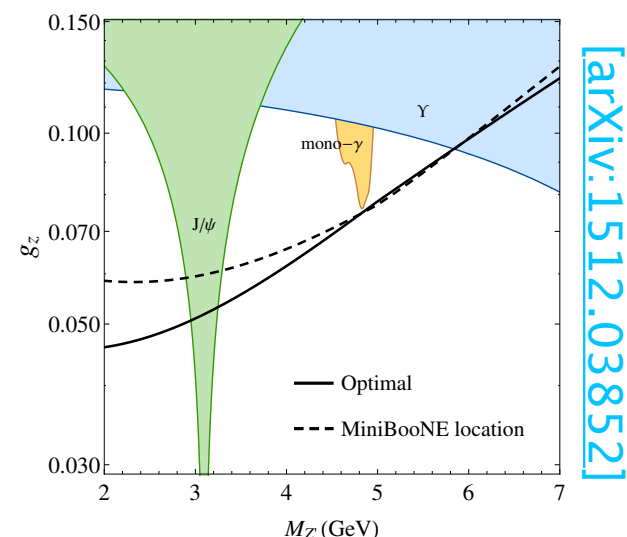
CMB-S4



- “NU@Fermilab” Neutrino Theory and Phenomenology Workshop
- Organized academic lectures on neutrinos at Fermilab
- “New Perspectives on dark matter” workshop on searches with ν beams,
- “Lattice Meets Experiment” workshop highlighting lattice role in ν experiments
- Helped organize international neutrino summer schools

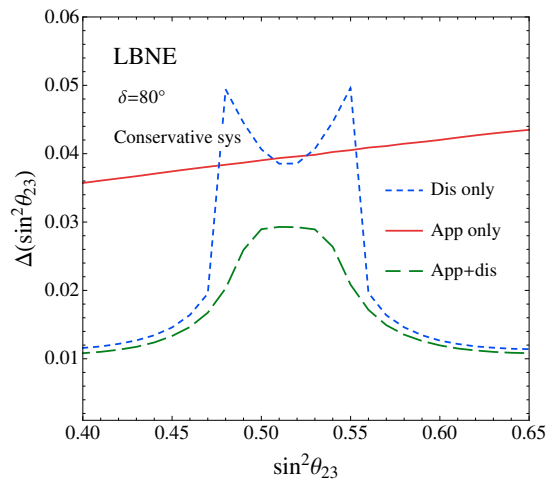
Diverse neutrino efforts

- Nucleon axial-vector form factor is an important input in CCQE cross section determination for NOvA and DUNE
 - can be computed from first principles using analyticity and lattice QCD; lattice calculation in progress
- Working with experimentalists and UChicago theorists to include lattice QCD input in GENIE MC
- Use Fermilab neutrino expts. to search for DM
- LBNF near detectors can be sensitive to GeV DM
- Also vice-versa: DM detectors as probes of non-standard neutrino interactions
- Large-scale structure constrains sum of neutrino masses
 - explored future constraints from DESI and CMB-S4 and relation to neutrino-less $\beta\beta$ decay experiments

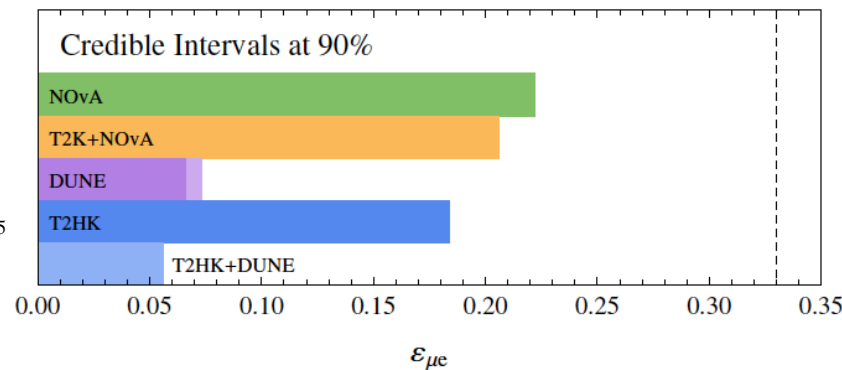


Diverse neutrino efforts (cont'd)

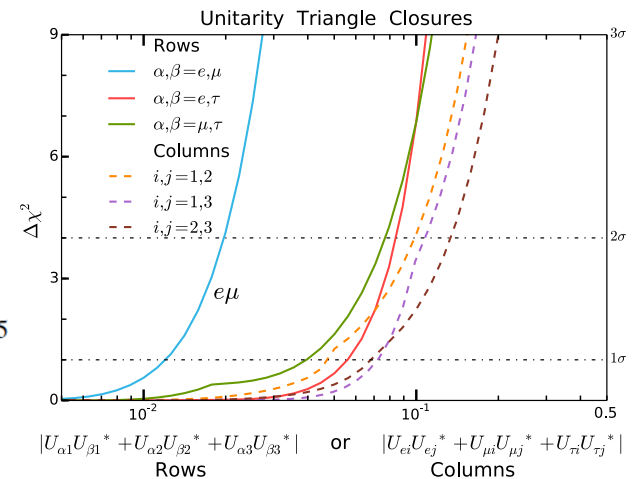
- Continuous involvement in SBN Programs: **SBND**, **MicroBooNE**, **ICARUS**, and LBN programs and studies: **MINOS+**, **NOvA** & **(Proto)DUNE**
- Determination of θ_{23} using appearance and disappearance channels and the impact of θ_{23} on the determination of the CP-violating parameter δ
 - Global fit of the **PMNS matrix without imposing Unitarity**
 - Probing non-standard interactions with DUNE



[arXiv:1406.2551]



[arXiv:1511.06357]



[arXiv:1508.05095]

Theory Research Associates

Exceptional postdoc outcomes

- Both theory groups attract first-rate talent, mentor them in a broad and data-rich environment
- Theory postdocs often work with other postdocs, define their own research program
- **Theory postdocs move on to faculty or lab staff positions at a high rate**

TH Physics:

FY15: 8 postdocs => 3 BSM/collider, 2 lattice, 2 pQCD, 1 v's

FY16: 8 postdocs => 4 BSM/collider, 2 lattice, 1 pQCD, 1 v's,

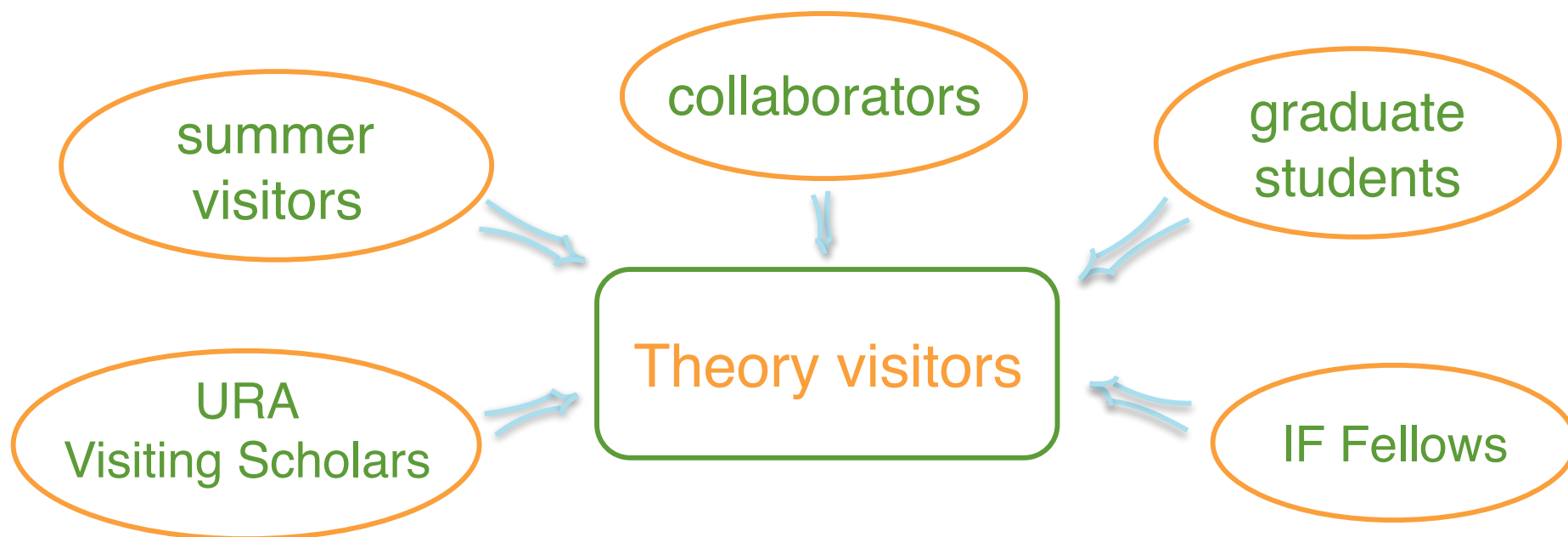
FY17: 9 postdocs => 4 BSM/collider, 2 lattice, 1 pQCD, 2 v's

TH Astro => FY15: 2 postdocs, increasing to 3 in FY16 and beyond

Increase follows the recommendations of the comparative review

Theory visitors

Visitor programs and workshops create bridges in many directions



- Successful Graduate Student program launched in FY11 (1 year visitors)
- Summer visitor program reduced by budget pressures
=> support requested from the director for FY16

Distinguished Fermilab Scholars [NEW]

- New initiative to appoint U.S. particle theorists to rotating terms as DFS, to spend at least one month total per year for 2 years (+1 year ext.) in residence at Fermilab.
- DFS may be accompanied by one or two of their students or postdocs.
- Candidates are recommended by an external advisory committee
- DFS program is accompanied by workshops of longer duration
- **Program supported by Fermilab Directorate**
- **Main Goals: make Fermilab more a hub for US particle theory and allow the flexibility to rapidly increase resident Fermilab expertise in targeted physics areas**

FY16: 1 Lattice, 1pQCD, 2 v's (1 TBC), 1 v's/BSM,
including 4 female DFS

Changes in FNAL Theory Scientists FY13 -> FY16

Physics:

Beginning of FY13: total of 16.5 Scientists supported by DOE Theory,

- FY13: Boris Kayser retired, no replacement
- FY14: Joe Lykken —> Directorate, no replacement
- FY15: Keith Ellis —> Director of IPPP Durham, no replacement
- FY16: Marcela Carena 0.5 supported by Directorate

Beginning of FY16:

- DOE Theory supports 11.5 Scientists,
- A 30% cut in the number of Scientists from FY13
- Leaves holes in Neutrino theory and in QCD

Astrophysics:

- FY13* to FY16 ~5 Scientists supported by DOE Theory

Plan for Theoretical Physics

- Maintain a broad theory effort aligned to the lab program
- Maintain, and to the extent possible grow, the postdoc cohort
- Strengthen the visitor programs
- Strengthen the theory effort in neutrinos, as recommended by both the comparative and institutional reviews.

=>This will require recruiting at least two new neutrino theorists, supplemented by longer-term visitors, including Scholars, and through the theory connection to the Neutrino Physics Center

- Maintain strength in BSM, pQCD, and lattice QCD, and crosscutting cosmic research

=> this will require a new hire in pQCD

- Maintain the Graduate Student research program

Plan for Theoretical Astrophysics

- Maintain a broad theory effort to study fundamental physics related to astronomy: i.e. dark matter, dark energy, cosmic and astrophysical neutrinos, early universe.
- Help train next generation of cosmic scientists by maintaining a strong postdoc recruitment program exposing them to the broad spectrum of current cosmic research.
- Continued active support of current DOE cosmic program (DES, DESI, LSST, SPT) including development of methods and extraction of scientific results
- Continued work to develop future cosmic research beyond cosmic program (e.g. 21cm surveys)
- Continued participation in Graduate Student research program

Theoretical Physics: Opportunities, Concerns, Questions

- Expect ~ 5 retirements in the next ten years
- DOE theory budget “gap”: 30% cut already eats first two retirements
- New hires in next few years contingent on increased support from DOE
- Need to optimize how neutrino theory interacts with neutrino experiment and the newly formed Neutrino Division; special concern for neutrino-nuclear theory

EXTRAS

Theory Group Alumni: postdocs

Elisabetta Furlan	ETH Zurich	Post-doc	2015
Prateek Agrawal	Harvard	Post-doc	2015
Claudia Frugiuete	Weizmann	Post-doc	2015
Raoul Rontsch	Karlsruhe	Post-doc	2015
Daniel Mohler	Mainz	Post-doc	2015
Martin Bauer	Heidelberg	Post-doc	2015
Katrin Gemmler	Munich	Post-doc	2015
Felix Yu	Mainz	Post-doc	2014
Ethan Neil	Colorado	Assistant Professor	2013
Ciaran Williams	SUNY Buffalo	Assistant Professor	2013
Wolfgang Altmannshofer	Perimeter	Post-doc	2013
Joachim Kopp	Univ. of Mainz	Assistant Professor	2012
Adam Martin	Notre Dame	Assistant Professor	2012
Nausheen Shah	Wayne State	Assistant Professor	2012
Gerben Stavenga	UCLA → Google		2012
Johann Alwall	National Taiwan University → Chi Foundation		2012
Maria Elvira Gamiz	Granada	Profesora Titular	2011
Anupama Atre	MSU	postdoc	2010
Yang Bai	Wisconsin	Junior Faculty	2010
Jon Bailey	Seoul Nat'l University	Junior Faculty	2010
Jan Winter	Max Planck Munich	Post doc	2010
Kyoungchul (K.C.) Kong	Kansas	Assistant Professor	2009
Enno Scholz	Regensburg	Junior Faculty	2009
Rakhi Mahbubani	EPFL Lausanne	Post-doc	2009
Enrico Lunghi	Indiana U.	Associate Scientist	2008
Ruth Van de Water	Fermilab	Scientist	2008
Richard Hill	Chicago	Assistant Professor	2008

Jay Hubisz	Syracuse	Associate Professor	2007
Jose Santiago	Univ. Granada	Faculty	2007
Jack Laiho	Syracuse	Assistant Professor	2007
Mu-Chun Chen	Univ. of Cal (Irvine)	Assoc Professor	2006
Olga Mena	Univ. of Valencia	Faculty	2006
Ayres Freitas	Pittsburgh	Junior Faculty	2005
Ulrich Haisch	University of Oxford	Lecturer	2005
Giulia Zanderighi	University of Oxford	Professor	2005
Zack Sullivan	IIT	Associate Professor	2005
Masataka Okamoto	KEK	Post-doctoral	2005
Eduardo Ponton	ICTP Sao Paolo	Scientist	2004
Tim Tait	UC Irvine	Associate Professor	2004
Andre DeGouvea	Northwestern U.	Associate Professor	2003
Gabriela Barenboim	U. of Valencia	Tenured Professor	2003
Adam Leibovich	Univ of Pittsburgh	Associate Professor	2003
Massimo Di Pierro	Depaul Univ	Professor	2002
Heather Logan	Carleton Univ.	Professor	2002
David Rainwater	U. Texas, Applied Research Labs, Space & Geophysics Lab.	Staff Scientist	2002
Jing Wang	Wharton School of Business		2002
Andrea Romanino	SISSA	Associate Professor	2001
John Campbell	Fermilab	Scientist	2001
Keisuke (Jimmy) Juge	University of the Pacific	Associate Professor	2001
Bogdan Dobrescu	Fermilab	Scientist	2000
Konstantin Matchev	Univ of Florida, Gainesville	Associate Professor	2000
Ulrich Nierste	Karlsruhe	Professor	2000
Hsin-Chia Cheng	UC Davis	Professor	1999
Sinead Ryan	Trinity College, Dublin	Tenured faculty	1999

National community service, Lab service (select list)

- APS Council, current DPF chair-elect, three past DPF chairs, officers of DAP, many other APS committees
- Snowmass conveners and co-authors of 18 Snowmass reports
- HEPAP, P5, NAS BPA, PASAG, AAAC, CAA, DOE COV, NSF COV etc
- CERN SPC, DESY PRC, ILC PAC, other international panels
- Chair of International Neutrino Commission
- Fermilab PAC, Sanford (SURF) PAC
- Fermilab Academic Lectures
- Fermilab SAC, LPC, Wilson Fellow Cmte, Joint Expt-Theory seminar
- Public lectures, books, Saturday Morning Physics
- Organize and lecture at workforce training events (schools)
- Organize workshops and conferences
- Fermilab physics studies