



Fermilab Theory Status and Plans

Marcela Carena

Fermilab PAC Meeting

July 17, 2018

Role of Fermilab theorists

Focus core strengths in key research areas directly related to the Fermilab experimental program

Conduct world-leading theoretical research, and advancing all five P5 science drivers

New Particles and Interactions

New Physics of Dark Matter

Higgs as a Tool for Discovery

Cosmic Acceleration

Physics of Neutrinos

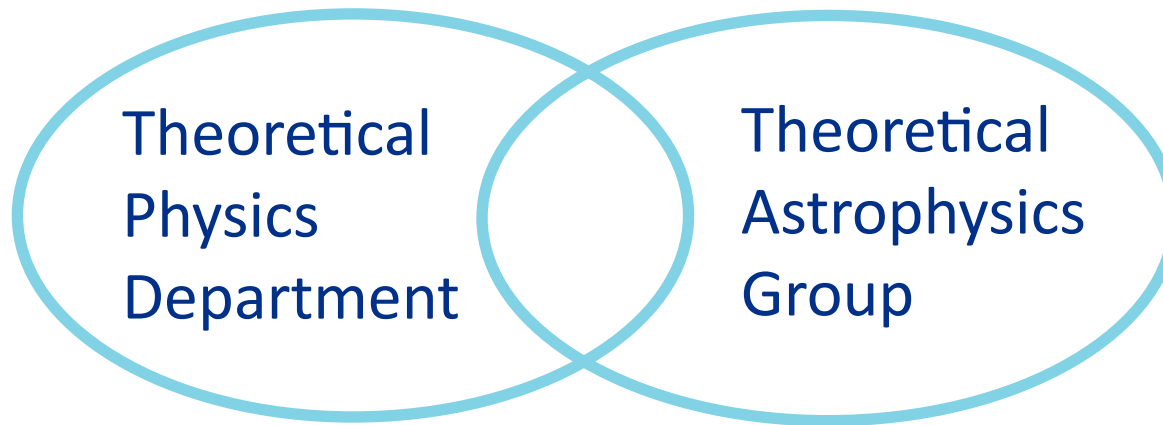
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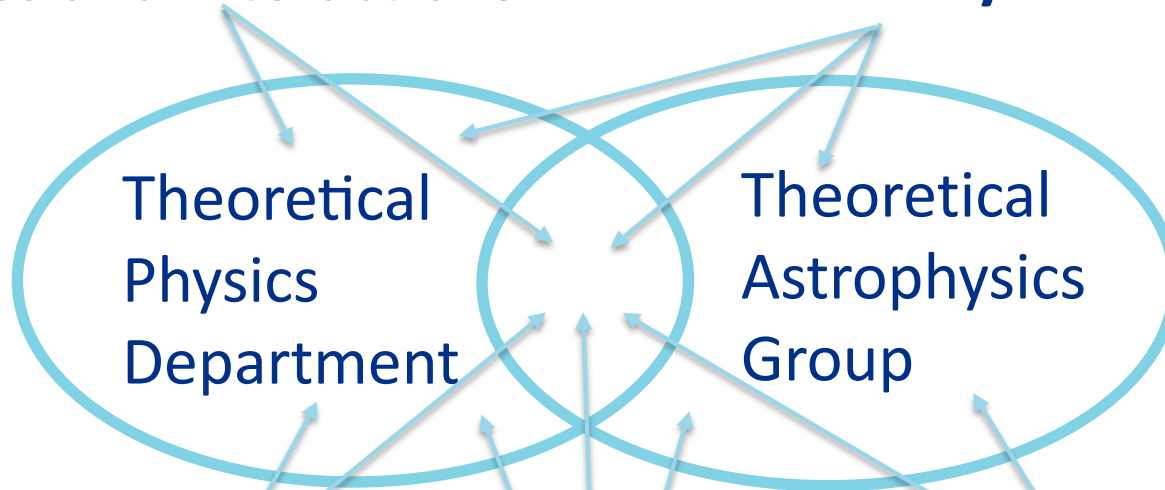
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Theory support for the Fermilab experimental program requires broad coverage, broad expertise

Fermilab based or Fermilab led Experiments:

- **Neutrinos:** DUNE, NOvA, μ BooNE, MINERvA, MINOS+, ICARUS, SBND, ArgoNeut, CONNIE
- **Muons:** Muon g-2, Mu2e
- **Dark Matter, Cosmo/Astro Probes:** DES, ADMX

Experiments with leadership groups based at Fermilab:

- **Higgs, Unknown, Dark Matter @LHC:** CMS
- **Dark Matter, Cosmo/Astro Probes:** SuperCDMS, LZ, DESI, South Pole Telescope

Fermilab based R&D towards future experiments:

- SENSEI and other applications of skipper CCDs
- Quantum sensors for dark matter detection
- MAGIS-100
- etc.

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Experiments with

- Higgs, Unknown
- Dark Matter, C

Fermilab based

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- MAGIS-100
- etc.

Theory
interacts with *all* of these.

Pole Telescope

Fermilab strategic plan for theoretical physics

Produced in 2015 to continue meeting the evolving challenges of the broad Fermilab program. Key features of the plan:

- ❖ **Strengthen neutrino theory while keeping strong support for the broader Fermilab experimental program.**

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 - organize activities that focus theory attention on experimental needs or focus experimental attention on new opportunities developed by theorists
 - foster an intellectually vibrant atmosphere at the lab., e.g. regular number of visitors increased by about a factor of 3 in the review period (leveraging)

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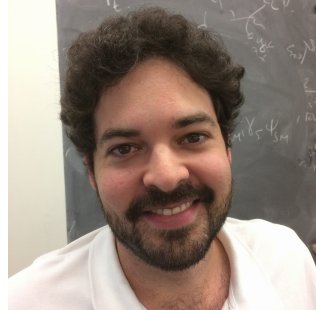
- ❖ **Maintain, and if possible grow, the number of theory RA's at Fermilab**
 - joint appointments with local universities and labs
 - leverage with non-US funding (Humboldt, Swiss NSF)

Fermilab theory scientists and P5 science drivers

Most theorists work on at least two P5 science drivers.

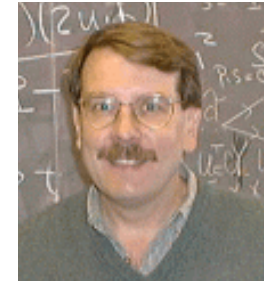


Pilar Coloma
(on leave)



Neutrinos

Pedro Machado
Liaison to
MicroBooNE, SBND



Stephen Parke
Pioneering Co-ordinator of the
Neutrino Physics Center (NPC)
Liaison to DUNE, NOvA



Andreas Kronfeld
Co-founder of Neutrino WG
for TH-EXP and SCD efforts
Board member of NuSTEC



Walter Giele
Liaison to MINERvA
Joining GENIE

Additional efforts from Carena, Dobrescu, Fox, Harnik, Hill, Hooper, Prestel

Significant increase in postdocs: Jessica Turner and Noemi Rocco (joint w/ Argonne PD) + in FY19: Kelly, Martinez-Soler, Perez-Gonzalez (last 2 joint w/ Northwestern U.)

→created a new initiative@Northwestern

Some Recent Neutrino Efforts at Fermilab Theory

Understanding the tau neutrino sector [Coloma, Parke]

Global sterile neutrino fit [Machado et. al.]

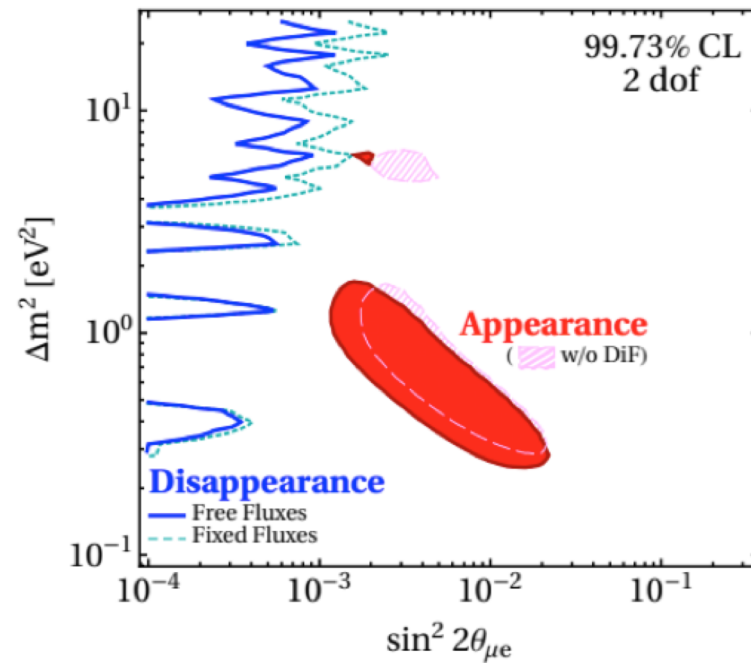
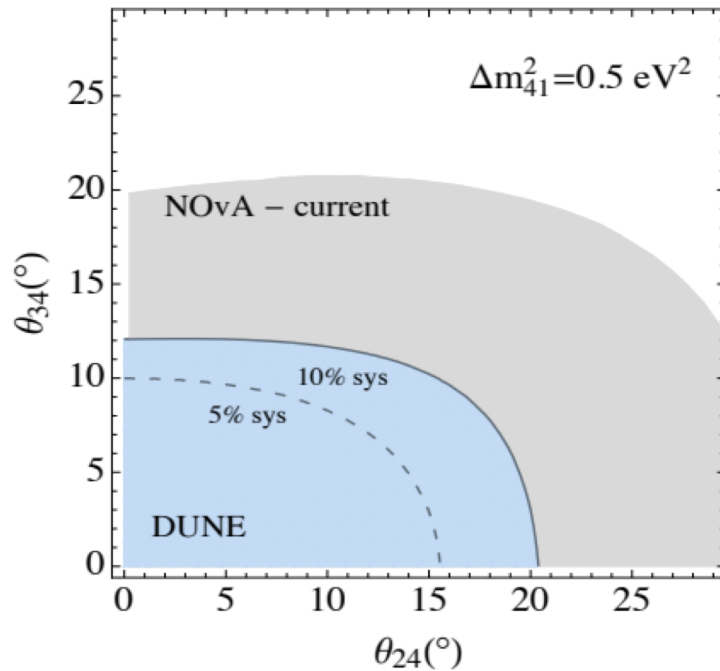
Light Dark Matter in neutrino experiments [Coloma, Dobrescu, Fox, Harnik + RA's]

Novel ideas: ultralight scalars coupled to neutrinos [Machado, RA Krnjaic]

Impact of sterile neutrinos on DUNE [Coloma, Parke]

Neutrinos in extra dimensions [Carena, Machado]; Neutrino Flavor MB [Machado et al.]

How to model neutrino interactions [Kronfeld, Simone, R Hill, + Students]



Fermilab theory scientists and P5 science drivers

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Higgs Physics



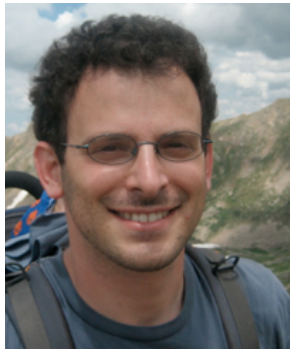
John Campbell
Author of MCFM
Convenor LHCHXS WG



Marcela Carena
Author of Higgs PDG Review



Walter Giele
Author of MCFM



Roni Harnik



Paul Mackenzie



Stefan Prestel
Author of PYTHIA

Additional efforts from Dobrescu, Fox, Hill, Kronfeld, Machado, Van de Water

Examples of Higgs Physics Efforts at Fermilab Theory

Perturbative QCD: key topics (Higgs and Beyond)

- **Extension of parton-level generator MCFM from NLO to NNLO QCD, including also weak effects [Campbell, Giele, Neumann, Distinguished Scholar D. Wackerath]**
 - world-leading calculations of H+jet, Z+jet and direct-photon production
 - public code for Higgs, Drell-Yan, diphoton, $Z\gamma$ production
 - NLO effects for key LHC processes
- **Development of PYTHIA to understand systematic uncertainties [Prestel, Isaacson]**
 - new scheme for matrix-element merging allowing fixed-order uncertainty to be assessed
 - all-order uncertainty in the parton-shower estimated for the first time
 - implementation of parton shower beyond leading color
- **Precision collider phenomenology [Campbell, Prestel, Ye Li]**
 - novel experimental handles on the Higgs boson width at the LHC
 - detailed SM background studies for LHC and future colliders

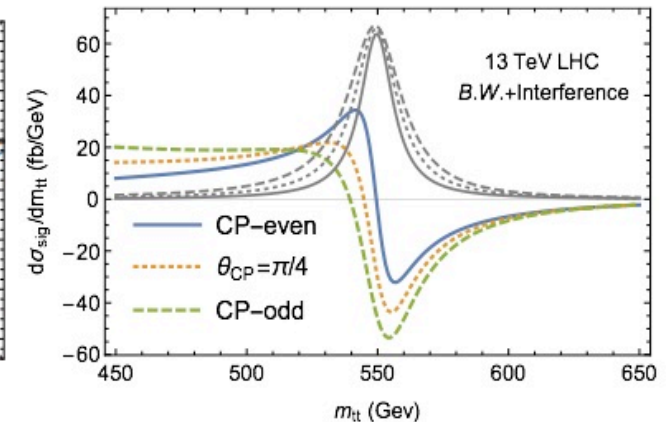
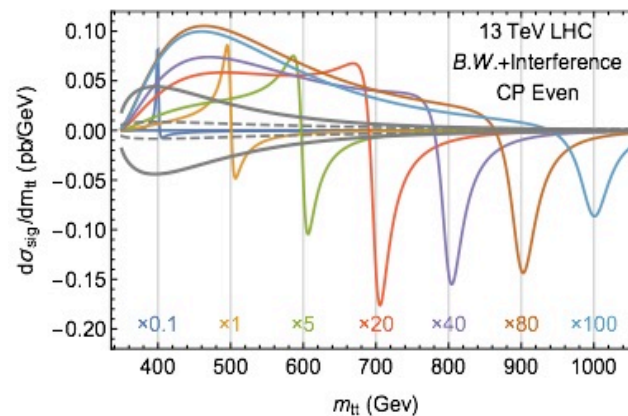
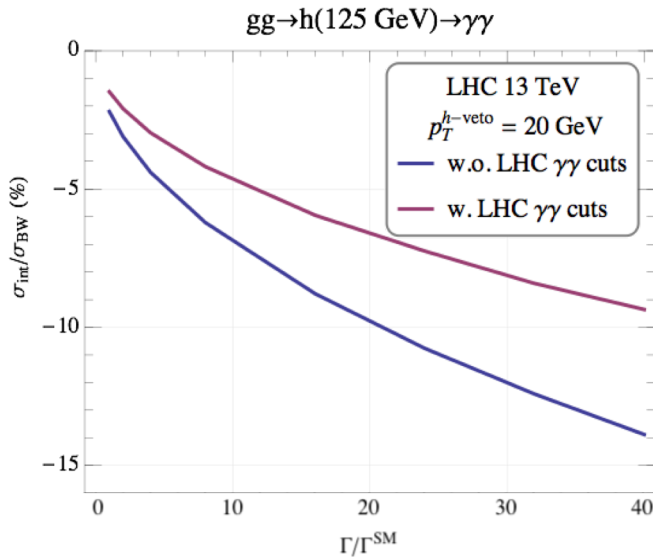
Lattice-QCD

- **Most precise computation of all quark masses (except the top) [Kronfeld et al.]**
 - Fermilab Lattice, MILC, & TUMQCD Collaborations' new HQET method
 - $u, d, s, c,$ and b masses to {2%, 1.2%, 0.75%, 0.56%, 0.33%}

Examples of Higgs Physics Efforts at Fermilab Theory

Higgs and BSM phenomenology and model building

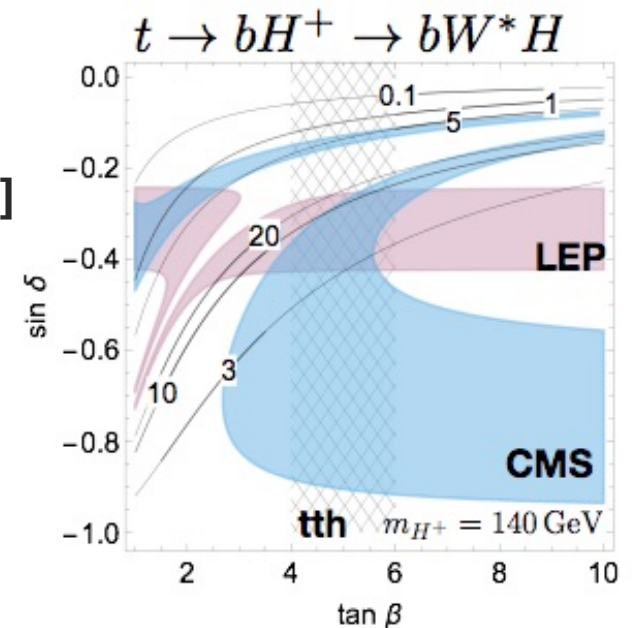
- **Novel way to probe the width of the Higgs boson:** [Campbell, Carena, Harnik, Liu]
pQCD and BSM expertise cross-fertilization
 - destructive interference between $H \rightarrow \gamma\gamma$ signal & QCD background
 - measurable change in cross-section (not just mass shift);
 - on-shell method, complementary to other techniques
- **Interference effects in $gg \rightarrow A/H \rightarrow tt$:** [Carena, Liu]
 - Breit Wigner structure can be dramatically altered by loop effects
 - Detailed study of line shapes *improved ATLAS PRL*
 - Need to re-optimize searches for “bump-dip” structure



Examples of Higgs Physics Efforts at Fermilab Theory

Higgs and BSM phenomenology and model building

- **Di-Higgs production in extended Higgs sectors** [RA Bauer, Carena, Carmona]
[Carena, RA Liu, Rimebau]
 - Correlation between enhanced Higgs-fermion couplings and di-Higgs production in 2HDMs w/ flavor symmetry \rightarrow visible in resonant & non-resonant, dedicated CMS (LPC) search
 - Interference effects in SM + Singlet extends sensitivity of di-Higgs in 1st OPT region@HL-LHC
- **Higgs-photon resonance** [Dobrescu, Fox, RA Kearny]
 - Motivated a *new* diboson resonance search; provided critical support to ATLAS and CMS
- **Twin-Higgs (Naturalness) dedicated studies**
[Harnik + RAs Howe and Kearny]
- **Light Higgs Bosons and Light Signal** [Fox, Weiner]
 - Long standing LEP excess, Tevatron $t\bar{t}h$ anomalies, CMS $\gamma\gamma$: all explained by a 95 GeV CP-even Higgs
- **Current and future constraints on Higgs couplings in the nonlinear Effective Theory**
[RA Krause]



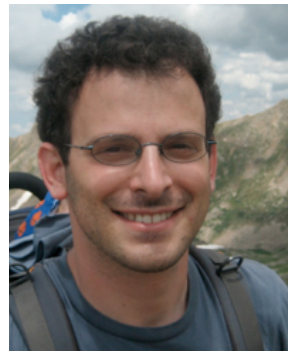
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Dark Matter



Patrick Fox
Liaison to LZ, CDMS
Convenor of
Cosmic Visions DM



Roni Harnik
Liaison to CONNIE, SENSEI, DAMIC, TD
Scientific Advisor for Cosmic Visions DM



Christopher Hill
Liaison to ADMX

Dan Hooper



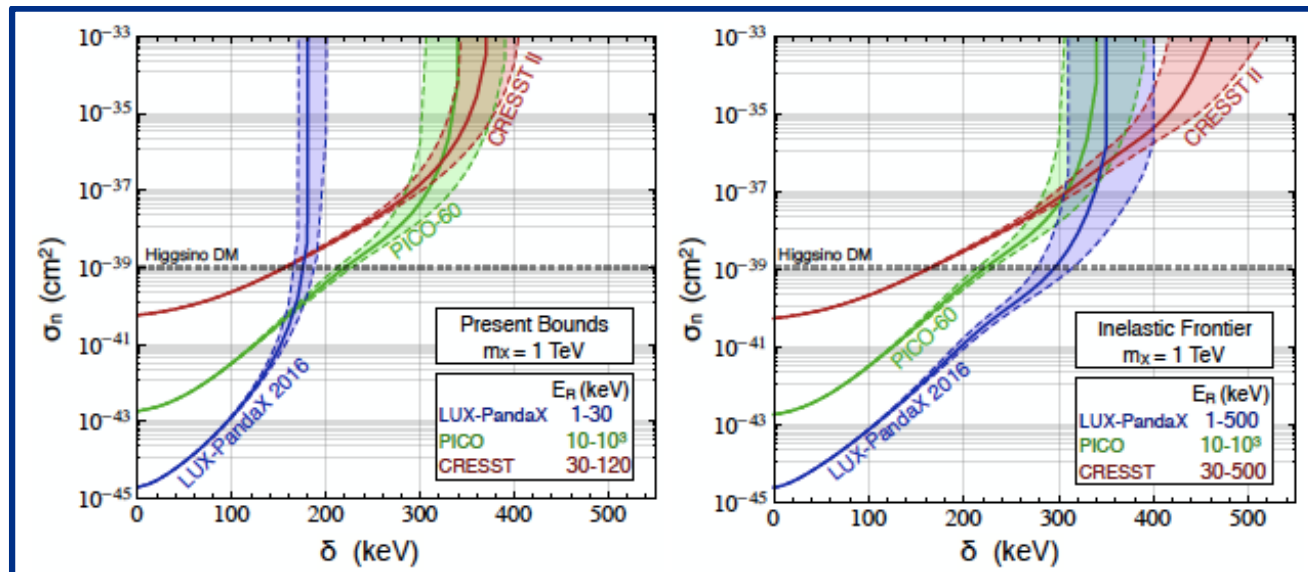
Nick Gnedin

Additional efforts from Carena, Dobrescu

Examples of Dark Matter Efforts at Fermilab Theory

Direct Detection: Interpreting Results + Novel Methods and Strategies

- Halo-independent analysis [Fox]
- Constraining DM w/ large cross sections with nucleons [Hooper, RA McDermott]
- WIMP effective theory [R. Hill]
- SUSY blind spots [Carena et al.]
- Direct detection with ν -detectors [Harnik, RA Zhang]
- The inelastic frontier [Fox]
 - Implemented in recent analyses by XENON100, PandaX



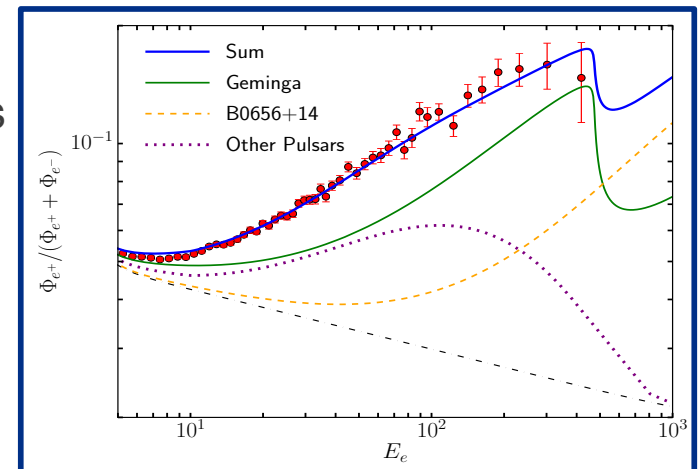
Examples of Dark Matter Efforts at Fermilab Theory

Indirect Detection

- **The Galactic Center gamma-ray excess** [Hooper, Fox, McDermott, Agrawal, Harnik, Witte, Escudero, Mohlabeng]
 - Data analysis; Model building; Backgrounds: pulsars, cosmic ray outbursts
- **Other gamma-ray searches** [Hooper, Bertoni]
 - Dwarf galaxy analysis and strategy; Searches for nearby dark matter subhalos; Novel signatures of very heavy (\sim PeV) DM
- **Cosmic ray searches** [Hooper] \rightarrow
 - Nearby pulsars and positron excess; Quantifying effects of solar modulation; Scrutinizing antiproton spectrum

Dark Matter @LHC (in close connection w/ LPC)

- **Support to CMS DM searches in mono-X** [Fox]
- **Precision calculations— γ +jet at NNLO; critical for monojet searches for DM** [Campbell]
- **Part of ATLAS/CMS Dark Matter Forum, and the DM@FNAL WG** [Fox, Harnik]
- **New dark matter signals** [Fox, Harnik, Altmannshofer]



Examples of Dark Matter Efforts at Fermilab Theory

Dark Matter Model Building

- **DM in Higgs portal models** [Carena, DiFranzo, Bauer, Altmannshofer]
- **Dirac DM in split SUSY** [Fox]
- **DM in left-right symmetric models** [Fox, Hooper, Mohlabeng]
- **Non-standard early universe scenarios** [Hooper, Krnjaic, McDermott]
- **Axion assisted production of sterile neutrino DM** [Hooper]
- **The 3.5 keV line from “Exciting DM” without a hidden sector** [Hooper]
- **Models for the Galactic Center excess** [Agrawal, Hooper, McDermott, Fox, Harnik, Witte, Escudero]

Dark Matter Searches Beyond the WIMP

- **Testing hidden sector coannihilation scenarios at neutrino experiments (DUNE, MiniBooNE)** [Krnjaic]
- **Axion electrodynamics and detection strategies** [Hill]
- **Precision atomic spectroscopy** [Harnik]
- **Dark matter mediated by light axial forces** [Krnjaic]
- **Fixed Target DM Searches** [Krnjaic, Dobrescu, Frugiuele]
- **The Muon Missing Momentum (M3) Project** [Krnjaic]

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Cosmological and Astrophysics Probes



Nick Gnedin
Developer of ART



Josh Frieman
Director DES
Cosmic Visions DE panel
PPD Head (April 2018)



Scott Dodelson
Co-chair DES SC
Convenor DES Theory &
Combined Probes WG
Leader of CosmoSIS
(on leave)

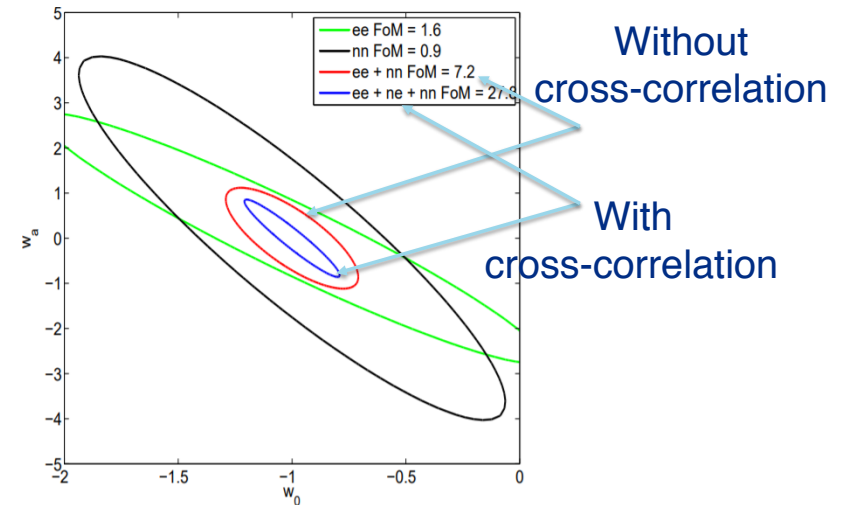


Albert Stebbins
Head of Analysis for Tianlai
21cm Cosmology Project

Additional efforts from Hill and Hooper

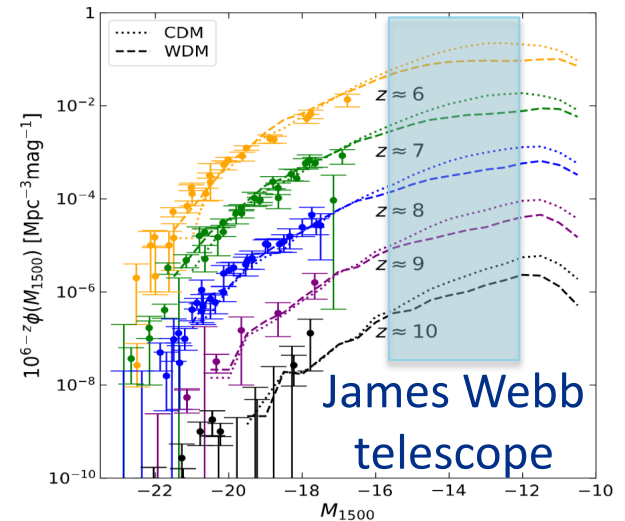
Examples of Cosmological and Astrophysics Probes Efforts at Fermilab Theory

- **Unification of inflation and origin of mass [Hill]**
- **Study of “Baryonic Effects” (Jargon for the effects of baryonic physics on matter clustering & its observational indicators (like galaxies) [Dodelson, Gnedin]**
 - ultimate constraints from current (DES) and future (LSST, DESI) observational surveys can only be reached by accounting for the complexity of real-life physics.
- **Theory/analysis support for DES, weak lensing, supernovae, combining → multiple probes [Frieman]**
- **Novel approaches in 21 cm cosmology to interpreting & analyzing data, predictions for cosmological constraints [Stebbins]**
- **Warm Dark Matter cosmology [Gnedin, Mena]**
 - search for sterile neutrino as a WDM candidate
 - effect of any WDM model is to suppress small scale power – only dwarf galaxies affected, hence the need to look at them at early times, when they are bright (James Webb telescope)
- **Early ionization as a probe of DM annihilation signal: [Gnedin, Hooper]**
- **Primordial Supermassive Black Holes [Stebbins] (in tension with age of the universe)**



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Exploring the Unknown: Precision SM Calculations



John Campbell



Paul Mackenzie



Ruth Van de Water

Liaison to Muon $g-2$ Experiment
Author PDG review on

Leptonic decays of charged pseudo-scalar mesons
Flavor Lattice Averaging Group advisory board



Stefan Prestel



Jim Simone
(joint SCD)

Additional efforts from Giele, Kronfeld

Exploring the Unknown Sample Efforts at Fermilab Theory

Muon $g-2$ Hadronic Vacuum Polarization [Van de Water]

- First calculation on HVP strong isospin-breaking
- First Calculation on NLO HVP

HPQCD + Van de Water found HVP to 2% and a_μ^{tot} to be 3σ away from SM.

Fermilab Lattice, HPQCD, & MILC

[[PRL 120 \(2018\) 152001](#)], with

1+1+1+1 & 2+1+1 sea quarks:

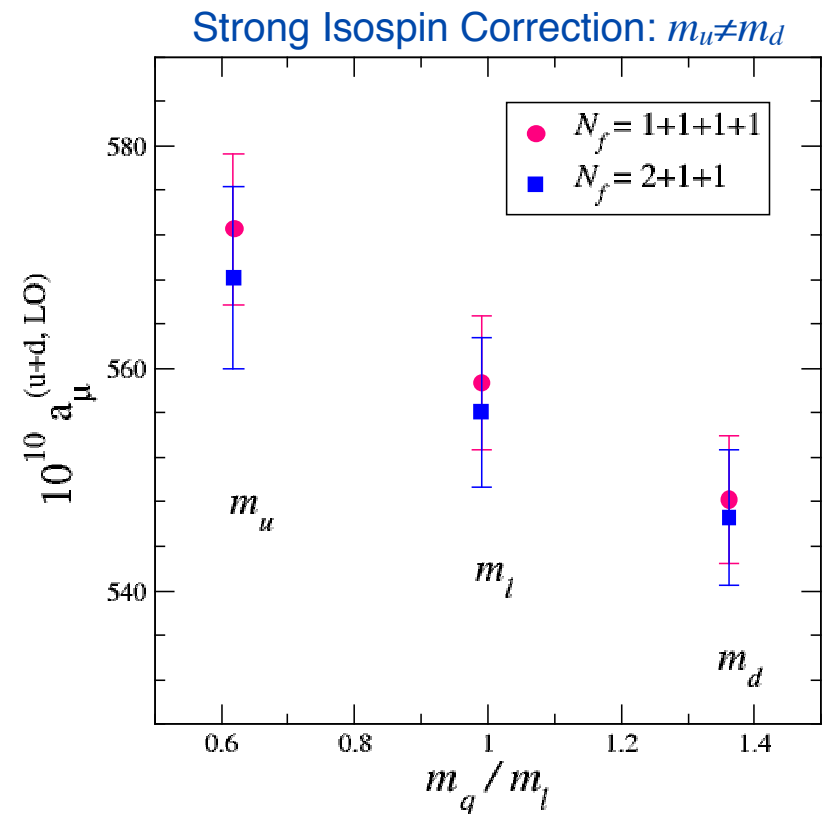
– fix $m_u/m_d = 0.4582$ [Van de Water & Zhou with MILC —[arXiv:1606.01228](#)];

– set $m_q = \{m_u, m_l = (m_u + m_d)/2, m_d\}$
& compute a_μ :

$$\delta a_\mu^{\text{HVP}, m_u \neq m_d} = +1.5(7)\%$$

Subsequent result from RBC/UKQCD

$$\delta a_\mu^{\text{HVP}, m_u \neq m_d} \sim 1.6\% \text{ [arXiv:1801.07224].}$$



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Exploring the Unknown: BSM phenomenology



Marcela Carena

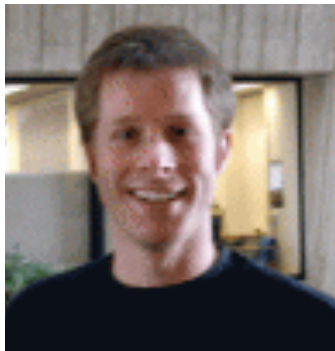


Bogdan Dobrescu

Liaison to the LHC Physics Center
Author PDG Reviews on Z'/W' Boson Searches



Estia Eichten

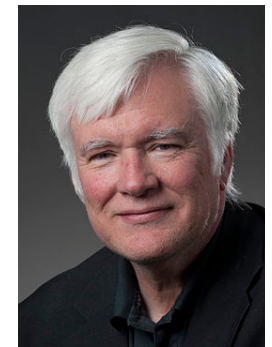


Patrick Fox



Roni Harnik

Christopher Hill



Additional efforts from Hooper, Machado, Parke

Exploring the Unknown Sample Efforts at Fermilab Theory

New Particles and New Interactions at the LHC

- **New Interactions/New Gauge bosons: Z' and W'**
 - Top-phylic Z' [Fox, RA Zhang, Low]
 - Cascade decays of Z' via Anomalons [Dobrescu] (being searched by CMS)
 - Z' coupled to $L_\mu - L_\tau$ and vector like Fermions [Altmannshofer, Carena, Crivellin]
 - W' decays into heavy Higgs Bosons [Dobrescu, RA Liu]
 - W' and Z' signals in a minimal $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ model [Dobrescu, Fox]
 - Bump Hunt with Machine Learning ($W' \rightarrow W X$), [RA Howe et al]
 - etc.
- **Neutrino masses from a pseudo-Dirac Bino** ($U(1)_R$ supersymmetric models) [Coloma, RA Ipek]
- **LHC tests of the neutrino seesaw mechanism** [Machado et al.]
- **Models with Vector-like Quarks** [Dobrescu et al.; Fox et al.]
- **Coloron decays into scalars** [Dobrescu, RA Yu]
- **Long-Lived (Super)particles with Hadronic Decays** [Ra Liu et al]
- etc

Fermilab theory postdocs (in this review period)

Fermilab theorists train and mentor postdocs in a unique data-rich environment; 85% go on to successful academic careers, including leading positions around the world.

- Prateek Agrawal (2012–2015)
- Andrew Hearin (2012–2014)
- Claudia Frugieuele (2012–2015)
- Raoul Rontsch (2012–2015)
- Katrin Gemmler (2012–2015)
- Martin Bauer (2012–2015)
- Elisabetta Furlan (2013–2015)
- Daniel Mohler (2013–2015)
- Pilar Coloma (2014–2016)
- Elise Jennings (2014–2016)
- Ran Zhou (2014–2016)
- Seyda Ipek (2014–2017)
- Jack Kearney (2014–2017)
- Kiel Howe (2014–present)
- Irshad Mohammed (2015–2017)
- Ye Li (2015–2017)
- Zhen Liu (2015–2018)
- Aarti Veernala (2015--present)
- Pedro Machado (2016–2017)
- Ciaran Hughes (2016—present)
- Gordan Krnjaic (2016—present)
- Josh Isaacson (2017—present)
- Tobias Neumann (2017—present w/ IIT)
- Jessica Turner (2017—present)
- Sam McDermott (2017—present)
- Yue Zhang (2017—present; w/ NW)
- Claudius Krause (2018—present)
- Noemi Rocco (2018—present w/ ANL-PD)

Particle Theory Astrophysics Leveraged/External funding



Fermilab theory research opportunities for students

During review period, DOE HEP dedicated funding ended. Now replaced by SCGSR and non-Fermilab DOE sources (typically 0.5 – 1 year long in 2014-2018)

Bridget Bertoni (U. Washington, SCGSR)

Ross Cawthon (U. Chicago, non-DOE)

Chia Cheng Chang (U. Illinois, partial URA)

Peter Denton (Vanderbilt U.)

Anthony DiFranzo (UC Irvine)

P. Villanueva Domingo (Valencia, non-DOE)

Joshua Eby (U. Cincinnati, SCGSR)

Miguel Escudero (U. Valencia, non-DOE)

Zechariah Gelzer (U. Iowa, URA)

Antigoni Georgiadou (FSU, non-DOE)

James Gludemans (U. Illinois, SCGSR)

Alexander Kaurov (U. Chicago)

James Lasker (U. Chicago, non-DOE)

Gabriela Lichtenstein (Sao Paulo, non-DOE)

Yin Lin (U. Chicago, URA)

Zhen Liu (U. Pittsburgh)

Alejandro Lopez (U. Michigan, SCGSR)

Camila Machado (Sao Paulo, non-DOE)

Aaron Meyer (U. Chicago, SCGSR)

Gopolang Mohlabeng (U. Kansas)

Jason Poh (U. Chicago, non-DOE)

Ananth Tenneti (CMU)

Kuang Wei (U. Chicago, non-DOE)

Blake Witherton (U. Wisconsin, SCGSR)

Sam Witte (UCLA, SCGSR)

Yikun Wang (U. Chicago, non-DOE)

Keping Xie (Southern Methodist, NSF)

Xining Zhang (U. Chicago, non-DOE)

Zhuowen Zhang (U. Chicago, non-DOE)

Fermilab theorists' Awards and Honors for their research & scientific trajectories (selected sample)

Fellows of the American Physical Society

Campbell (2014), Carena (2002), Dobrescu (2013), Dodelson (2004), Eichten (1988), Fox (2016), Frieman (1997), Giele (2012), Gnedin (2013), Hill (1989), Hooper (2017), Kronfeld (2002), Mackenzie (1996), Parke (1997), Quigg (1983), Stebbins (2011).

Fellows of the American Association for the Advancement of Science

Carena (2017), Kronfeld (2013), Frieman (2004), Mackenzie (2011), Quigg (1992)

Alexander von Humboldt Foundation Senior Scientist Award:

Quigg (2007), Carena (2011)

Alexander von Humboldt Fellowship for Experienced Researchers: Fox (2015)

Hans Fischer Senior Fellowship Prize, IAS, TUM: Kronfeld (2014)

J. J. Sakurai Prize of the American Physical Society

Eichten (2011), Ellis (2009), Quigg (2011)

Member, American Academy of Arts and Sciences: Frieman (2016)

Honorary Fellow, Royal Astronomical Society: Frieman (2014)

Medaille de l'Institute d'Astrophysique de Paris: Stebbins: (2014)

New initiative: Fermilab Distinguished Scholars

- Launched in 2016 to strengthen the role of Fermilab theory as a hub for university theorists: Theoretical Physics Department & Theoretical Astrophysics Group jointly
- Rotating multi-year appointments for U.S. theorists at Fermilab, with at least one month residence per year. Scholars bring their students and postdocs with them
- This program not only strengthens the connections between lab and university theory, but also increases the local expertise supporting Fermilab experiments
- Appointments recommended to Fermilab by a rotating advisory board composed of six U.S. university professors and two Fermilab theorists

New initiative: Fermilab Distinguished Scholars

2016



Aida El-Khadra
(UIUC)



Patrick Huber
(Virginia Tech)

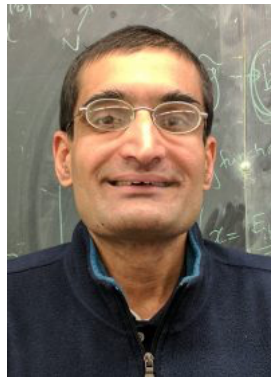


Ann Nelson
(U. Washington)



Doreen Wackerroth
(SUNY Buffalo)

2017



Kaustubh Agashe
(U. Maryland)

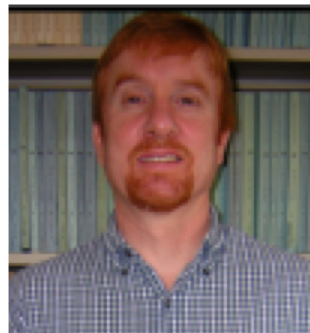


Kaladi Babu
(Oklahoma State U.)

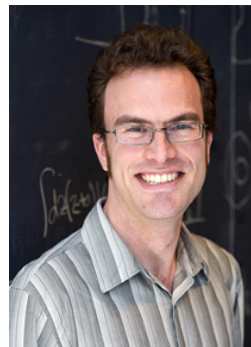


John Beacom
(Ohio State U.)

2018



Thomas Blum (U. Conn)



Tracy Slatyer (MIT)



Jesse Thaler (MIT)

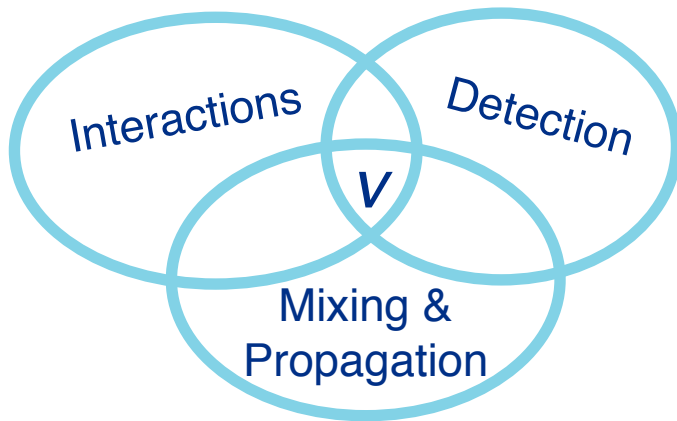
New initiative: Neutrino Theory Network (NTN)

- An effort to strengthen the U.S. neutrino theory community and its impact on the U.S. neutrino experimental program. **Carena** is the NTN PI.
- **Network activities target to primarily support theorists at universities with very limited support available for DOE labs.**

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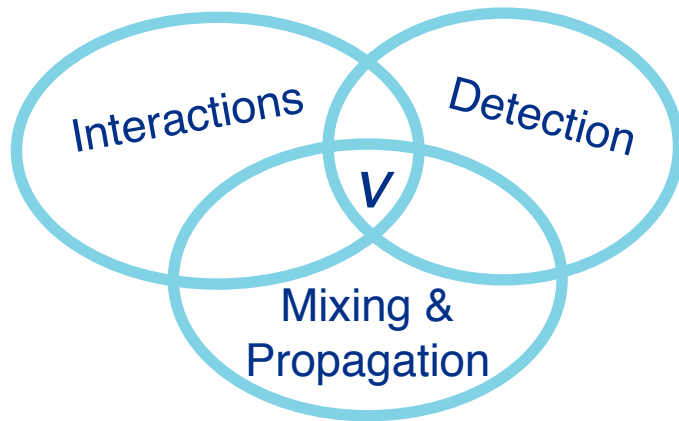
Initial scope



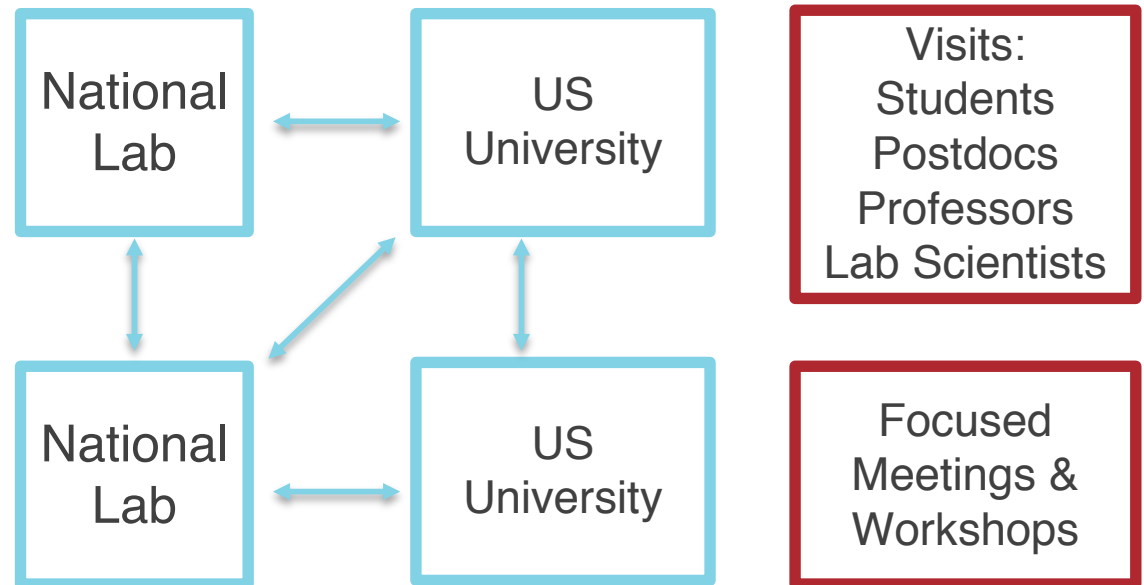
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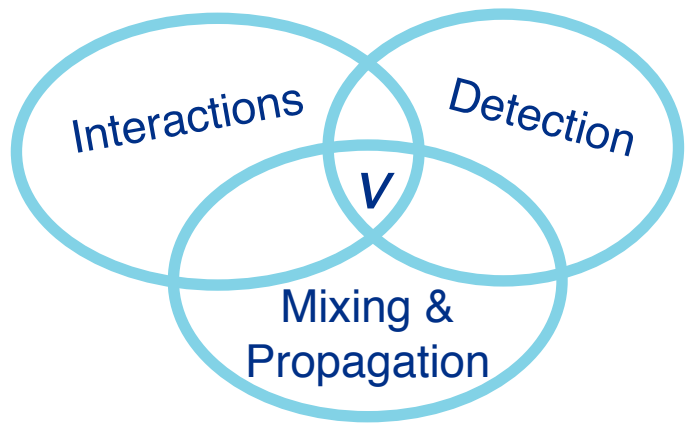
Funding Opportunities/Activities



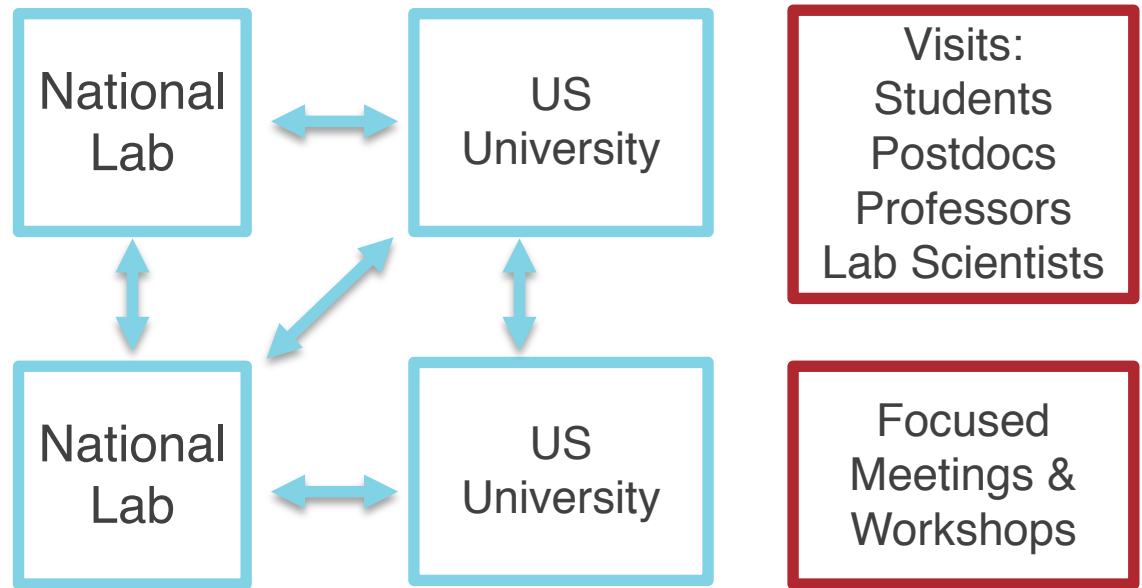
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Initial scope



Funding Opportunities/Activities



First set of proposals reviewed in May/June 2018 by a Scientific Advisory Board, formed by U.S. and international scientists, including experimenters.

Allocations of funds by a Steering Committee formed by U.S. university and lab scientists, following the recommendations of the SAB is in progress.

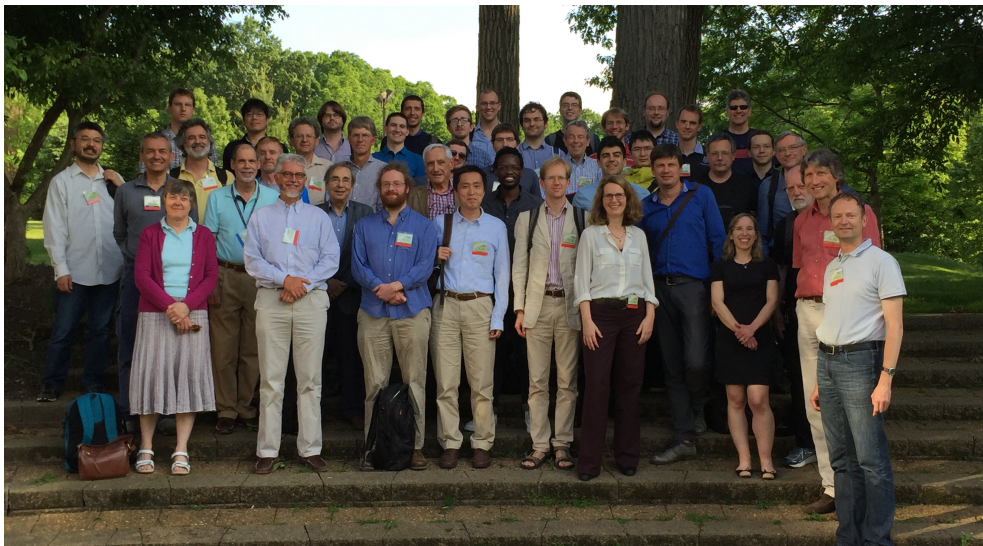
New initiative: Muon $g-2$ Theory Initiative

An example of the value added by the Fermilab Distinguished Scholar program

- Originated by FDS Aida El-Khadra during her time at Fermilab.
- Van de Water plays an essential role in this effort

Goal: bring together the $g - 2$ world wide theory community to obtain/agree upon the best theoretical predictions, in advance of the coming experimental results from the Fermilab Muon $g - 2$ experiment.

- El-Khadra and Christoph Lehner (BNL) chair the steering committee



1st Meeting, FNAL, June 2016



2nd Meeting, Mainz, June 2018

Fermilab theory: software supporting experiments

Develop important software packages broadly used by HEP exp.

- **GENIE** [Giele]
- **MCFM** [Campbell, Ellis, Giele]
- **PYTHIA** [Prestel]

**This cannot occur without
Lab support and infrastructure**

Prestel is co-PI of DOE SciDAC award (joint with SLAC Theory and Argonne ATLAS) for development of Event Generators for High-Performance Computing

Enable new levels of precision in the extraction of HEP parameters and in cosmological simulation codes:

- **ART**: Adaptive Refinement Tree cosmological simulation code [Gnedin] and SciDAC project Computation-Driven Discovery for the Dark Universe [Gnedin, Dodelson]
- **Fermilab Lattice Collab.** [Kronfeld, Mackenzie, Van de Water, Simone] engaged with Fermilab-based experiments (Muon $g-2$, MINERvA, NOvA, and DUNE)
- **USQCD and Lattice Infrastructure** [Mackenzie (former) and Kronfeld (present) spokespersons and chairs of the USQCD Executive Committee]
- **CosmoSIS**: code for extraction of cosmological parameters from cosmic surveys (e. g. DES, LSST) [Dodelson]

Fermilab theorists direct connections to experiments (selected examples):

**For the TCR we got testimonial letters
from experimentalists/spokespersons**

Neutrinos:

- Parke contributed to the NOvA doc 25833, a comparison of NOvA code for calculating the oscillation probabilities in matter
- Machado provided theory support to the MINOS analysis of large extra dimensions and neutrino oscillations (MINOS Collaboration, Phys. Rev. D 94 (2016) 111101)
- Machado and Parke are members of the DUNE collaboration, and Parke contributed especially to the DUNE Conceptual Design Report
- Fox, Harnik and Machado formed a joint Exotics Working Group for the short baseline neutrino program (e.g. SBND, MicroBooNE, ICARUS).
- Harnik and Machado are collaborating with CONNIE on an analysis they proposed to search for neutrino dipole moments and new light mediators.
- Harnik and RA Liu proposed and are supporting a new search for milli-charged particles by ArgoNeut.

Fermilab theorists direct connections to experiments (selected examples):

**For the TCR we got testimonial letters
from experimentalists/spokespersons**

LHC:

- MCFM papers by Campbell, Ellis and Giele, *produced during the review period*, have already been cited in 100+ experimental publications by the ATLAS and CMS collaborations
- Dobrescu provided theory support to CMS analyses “Search for pair-produced resonances decaying to jet pairs”, CMS-EXO-12-052, and “Search for neutral color-octet weak-triplet scalar particles”, CMS-EXO-12-007.
- Prestel is an ATLAS Analysis Consultant & Expert (ACE) (2016–present).
- Dobrescu and Fox provided MadGraph model files for Z'/W' searches and other Higgs- γ resonance searches by CMS and ATLAS
- Carena and RA Liu contributed extensively to the theory input for the ATLAS-CONF-2016-073: Search for heavy Higgs bosons decaying to a top-quark pair.
- Carena, RA Liu et al. are collaborating with Fermilab CMS experimentalists, N. Strobbe and Nhan Tran on an analysis on “Diagnostic Angular Observables in $t\bar{t}$ Resonances”, for the specific cases of scalar, vector and spin 2 resonances.

Fermilab theorists direct connections to experiments (selected examples):

**For the TCR we got testimonial letters
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Dark Matter:

- Fox and Harnik are working with the CONNIE and DAMIC collaborations on a modulation analysis to place limits on strongly coupled DM
- Hooper is currently working with the Fermi Collaboration on an analysis of the Galactic Center point source population
- Fox working with LZ experimentalist B. Penning on an analysis to search for Inelastic DM.

Dark Energy:

- Frieman is a co-founder and Director of the Dark Energy Survey (DES),
- Dodelson is a co-chair of the DES Science Committee and a co-convenor of the DES Theory & Combined Probes Working Group.
- Frieman and Dodelson led most of the DES analysis and cosmological results.
- Gnedin is the primary developer for the ART code, the main cosmological simulation code used for cluster simulations by DES.

Fermilab theory as a hub: [Summary] connecting experiments to the broader theory community

- **Neutrino Theory Network**
- **Muon $g-2$ Theory Initiative.**
- **Neutrino Physics Center**
- **Parke** established Fermilab as associate node of the European theory networks Invisibles, Invisibles Plus & Elusives, **which so far brought 50 visitors to the lab.**
- **Carena and Prestel** established Fermilab as a new member of the MCnetITN3 Skodowska-Curie Early Stage Researchers team (covers year-long stays for network students@ Fermilab)
- **Kronfeld and Giele:** co-conveners of the working group on neutrino-nuclear strong interaction physics, with participation by Carena, R. Hill, Machado, and Prestel.
- **R. Hill and Kronfeld:** board members of NuSTEC, the Neutrino Scattering Theory-Experiment Collaboration, and co-authors of the NuSTEC whitepaper
- **Fox and RA Liu:** current co-coordinators of the LPC Topic-of-the-Week seminar series, while Harnik and Dobrescu fulfilled this role in 2014–2016.
- **Carena and RA Liu:** co-organizers the 2018 ATLAS/CMS/THEO workshop on HH physics at the LPC/FNAL with th/exp. colleagues from around the world.

Fermilab theory transitions since 2014

TCR Slides

- Chris Quigg retired.
- A second retirement is anticipated at the end of 2018.
- Keith Ellis departed to become Director of IPPP Durham.
- Scott Dodelson departed to Carnegie Mellon University as Head of its Department of Physics.
- Joseph Lykken appointed Fermilab Deputy Director and CRO.
- Josh Frieman appointed head of the Fermilab Particle Physics Division.

Additions:

Pilar Coloma (neutrinos), Pedro Machado (neutrinos)
and Stefan Prestel (perturbative QCD)

Richard Hill (neutrinos) position seeded at U. Kentucky (2017-2019)

But:

Pilar Coloma is on extended leave of absence (Sep 2017 — Oct 2018).

Stefan Prestel will go on leave to Lund University in September 2018.

Van de Water on partial leave in FY 2019.

Fermilab theory budgets: FY2015 through FY2018

During this period, the Fermilab theory budget **decreased by 22%**

- FY2015 actual: \$9.991M
- FY2016 actual: \$8.631M
- FY2017 actual: \$8.848M
- FY2018 actual: \$7.850M

Number of supported FTE's, including postdocs:

31.4 FTEs in FY2015 to 23.1 FTEs in FY 2018 (very strong attrition)

Fermilab theory budgets: FY2015 through FY2018

During this period, the Fermilab theory budget **decreased by 22%**

We have been forced to delay scientist replacements

We have managed to do more with less via:

- Leveraging with joint positions and non-DOE-Theory funding sources
- Support from the laboratory: e.g. use overhead to bridge retirements and launch the Fermilab Distinguished Scholars
- Leveraging other funds (to enhance the visitor program)

However, if constrained to FY18 level (or worse) going forward, significant de-scoping would be inevitable:

- Reduce significantly the number of postdocs
- Reduce scientific staff to levels that can no longer provide theory support to large parts of the Fermilab and US experimental program
- Reduce/roll back new initiatives

FNAL – General remarks

► Findings:

- FNAL has a central place in the HEP theory program with many notable strengths
- They have been very active in implementing the strategic plan of 2015.

► Comments:

- We commend the efforts of management, particularly Carena, and the scientific staff for dedicating the talents and resources necessary to implement this plan.
- They have made good use of leveraged resources in implementing innovative and impactful programs like the distinguished scholars program and the neutrino theory network
- We note the activity to connect to outside sources to bring students and postdocs to the lab.
- The liaisons to individual experiments is a good innovation.

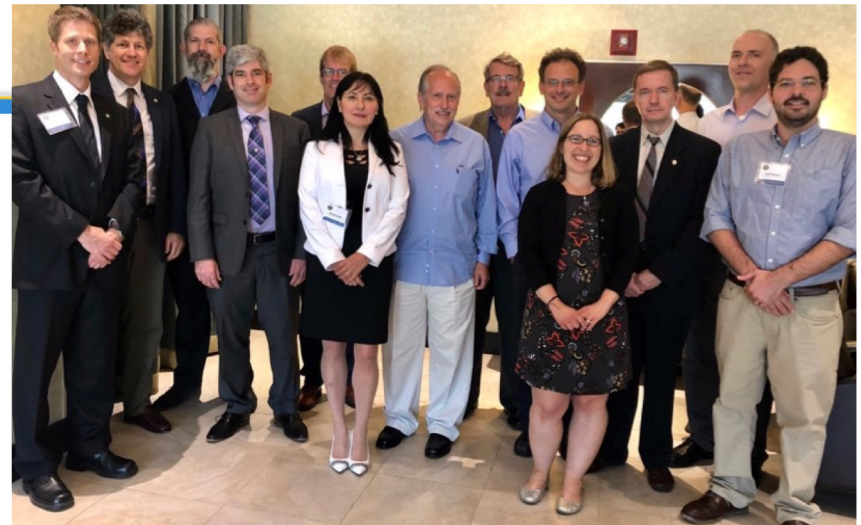


U.S. DEPARTMENT OF
ENERGY

Office of
Science

July 12, 2018

**Fermilab Theory
got a strong endorsement
last week from the DOE HEP
Comparative Review panel**



FNAL – Neutrinos

▶ Finding:

- ▶ The neutrino theory program has made great strides
- ▶ There are innovative, proactive efforts to build a neutrino theory community

▶ Comments:

- ▶ We commend the group on the hire of dynamic junior staff members, Machado and Coloma

FNAL – BSM

▶ Findings:

- ▶ The BSM effort is strong, versatile, and well-aligned with lab activities and HEP priorities.

▶ Findings:

- ▶ The lattice QCD effort is very strong but faces challenges.
- ▶ The shift in focus from flavor physics to neutrino-nucleon interactions and $g-2$ is well aligned with lab and national priorities.

▶ Comments:

- ▶ Maintaining the strength of this effort may require consideration of a targeted hire for an established leader in this area.

Kronfeld has recently accepted the leadership of the USQCD program
[previous spokesperson: Mackenzie, 2009-2018]

USQCD is a federation of Lattice Gauge Theory collaborations, steward for lattice-QCD resources: allocations on leadership-class machines; software & hardware projects

FNAL – pQCD

▶ Findings:

- ▶ The pQCD effort around the MCFM code has significant impact on the LHC program
- ▶ The loss of effort from departures and redirections may leave Campbell as the only full-time contributor to this activity.

▶ Comments:

- ▶ This level of effort would be sub-critical and may require additional personnel.

FNAL – Astro-particle

▶ Findings:

- ▶ The astro-particle group is highly productive and involved in leading work in the field.

▶ Comments:

- ▶ We are concerned that future hires may not re-establish the group's important connections to surveys or experiments

Fermilab theory short term plan

- Develop a strategy for the Theoretical Astrophysics Group as part of the Cosmic Frontier Strategic Planning group at the lab that will come out with a plan, including the cosmic neutrino initiative, later this year [see Josh's talk]
- A search is underway for a new Associate Scientist hire in the Theoretical Astrophysics Group as that group has seen two staff departures in the last year.
- A second hire in the Theoretical Astrophysics Group will be needed depending/guided by the outcome of the Cosmic Frontier Strategic Planning group
- Due to reductions in efforts, a new hire in LQCD will be desirable to secure the sustainability of the lattice QCD effort.
- Due to departures, new Associate Scientist hires in pQCD and Neutrinos (broadly defined) in the Theoretical Physics Department will be needed.
- Aim at maintaining the level of postdocs at current numbers, using also leveraging.
- Aim at maintaining the strong and diverse visitor program, with crucial funding from external, non-Fermilab Theory DOE sources

Executive Summary

By 2018, key features of the 2015 Fermilab theory plan successfully implemented.

- Strong neutrino effort while keeping strong support for all P5 science drivers
- Strong involvement with the larger U.S. and international theory communities to connect them more effectively with the Fermilab program
- Maintain, and if possible grow (through leverage) the number of theory RA's

Plan for the next few years:

- **Keep at the forefront in theory ideas in close connection w/ HEP experiments in Neutrinos, Dark Matter, Colliders and Cosmo/Astrophysical probes**
- **Develop new techniques and computational tools to allow the most precise understanding of Higgs Physics and Exploration of the Unknown**
- **Work closely with experimental colleagues to provide theoretical insight useful for R&D towards future experiments**
- **Develop a Cosmic Neutrino Initiative**
- **Contribute to Fermilab Quantum Science Initiative**

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Plan for the next few years:

- Keep at the forefront in Neutrino

Maintain a broad and strong scientific program while expanding scope to support new experiments and initiatives

- ... to allow the most precise exploration of the Unknown
- ... theoretical colleagues to provide theoretical insight towards future experiments
- **Develop a Cosmic Neutrino Initiative**
- **Contribute to Fermilab Quantum Science Initiative**