FUNDAMENTAL PHYSICS AT THE INTENSITY FRONTIER
November 30 - December 2, 2011
Rockville, MD

Intensity Frontier Workshop

Summary of

Fundamental Physics at the Intensity Frontier workshop

J. Hewett & H.Weerts

workshop co-chairs

Charge to chairs of workshop

Particle physics is frequently characterized as addressing three frontiers in fundamental science; the energy, intensity, and cosmic frontiers. Intensity frontier experiments are those that search for new phenomena by probing rare processes or performing extremely precise measurements of known processes. The facilities that enable this program often require intense particle beams and precision detectors. Searches at the intensity frontier are complimentary to those of the other two frontiers and are part of a three-pronged experimental program that is needed to explore the quantum universe.

The Office of High Energy Physics wishes to identify the most exciting opportunities to carry out experiments on the intensity frontier for our future planning. I request that you organize a workshop to:

- identify these opportunities,
- explain what can be learned from such experiments,
- determine which experiments can be done with current facilities and technology,
- determine which experiments require new facilities or new technology to reach their full potential, and
- produce a final report documenting the results of the workshop

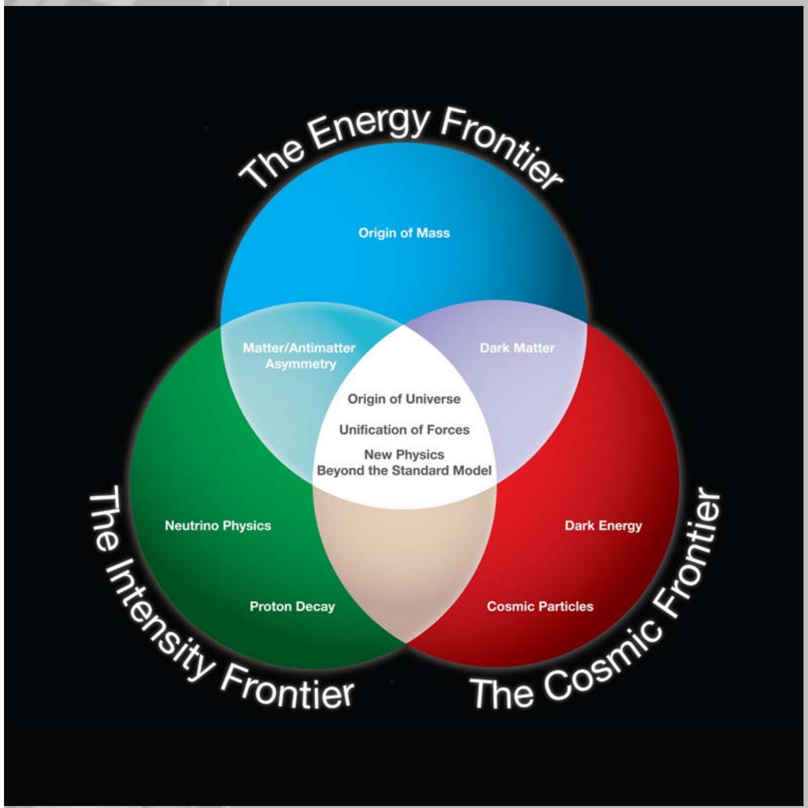
The workshop will be inclusive and open to as wide as possible representation from the entire field of particle physics as well as closely related fields, so that the best ideas can be identified and evaluated by a broad cross-section of the community.

We expect the workshop to be held in the Washington, DC area later this year. We would like to receive the workshop report within 2 months of the close of the workshop. This report will be a valuable document to assist our office in developing an implementation plan that addresses the compelling science of the Intensity Frontier, and hopefully will also serve as a valuable resource and reference for the community.

1. Document (in one coherent document) the physics /science opportunities at the Intensity Frontier.
2. Identify experiments and facilities needed for components of program
3. Demonstrate that community is interested/wants to do the Intensity Frontier physics
4. Educate the community

HEP and the frontiers

Good representation of HEP

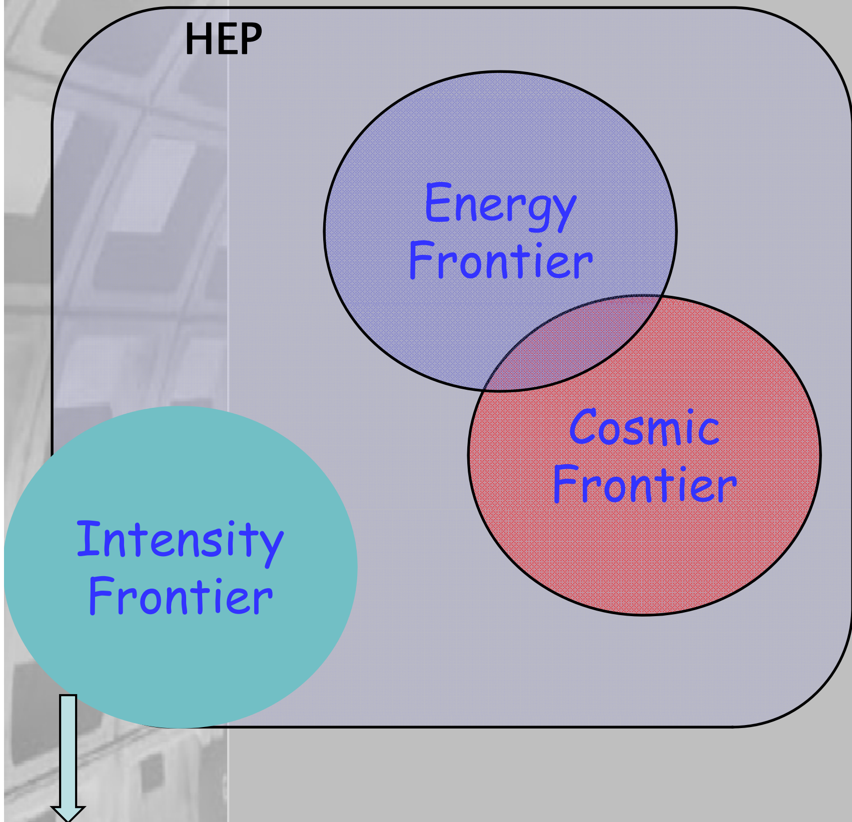


as long as they are all together

Has proven to be very useful and effective in US in terms of funding and communicating HEP program to government.

HEP and the frontiers

Struggled with definition of Intensity Frontier & continue somewhat



➔

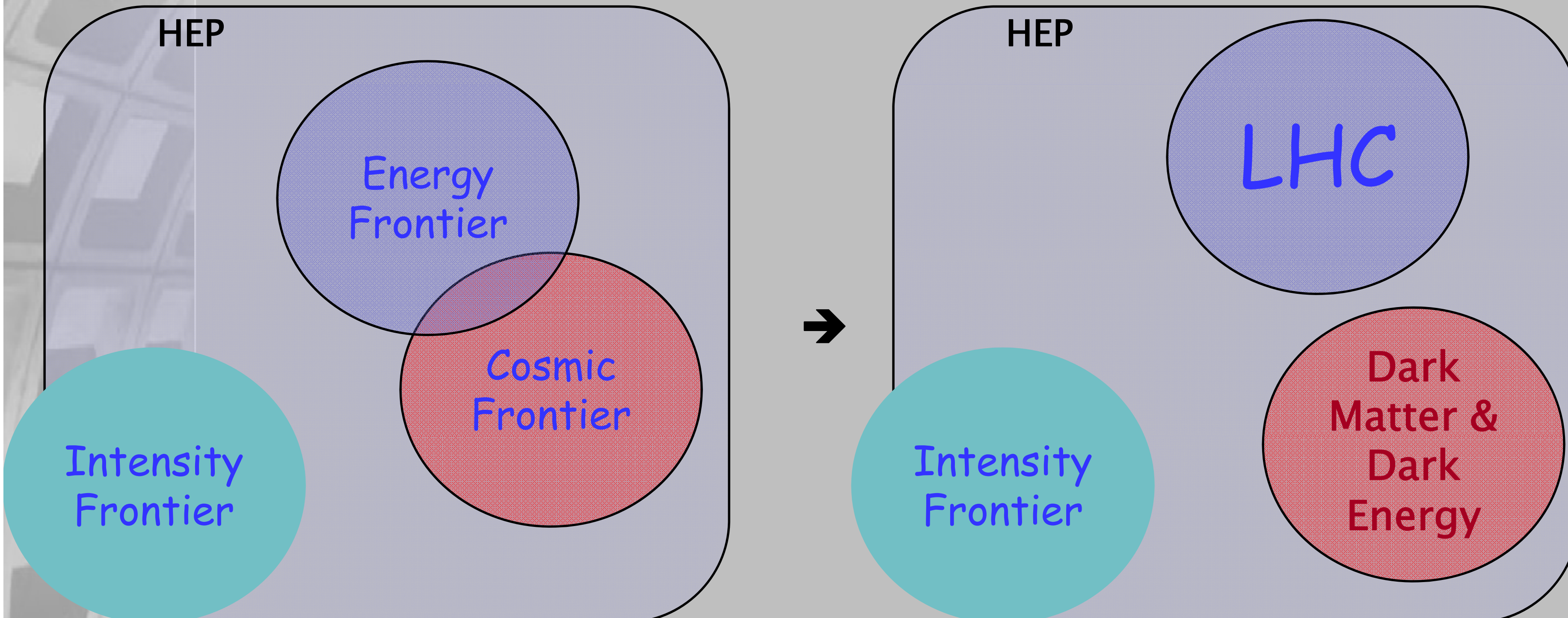
Extends outside "HEP".
This workshop sponsored by Offices of HEP and Nuclear Physics

HEP and the frontiers

progression

Struggled with definition of Intensity Frontier & still are somewhat

Others well defined and becoming more focused & defined

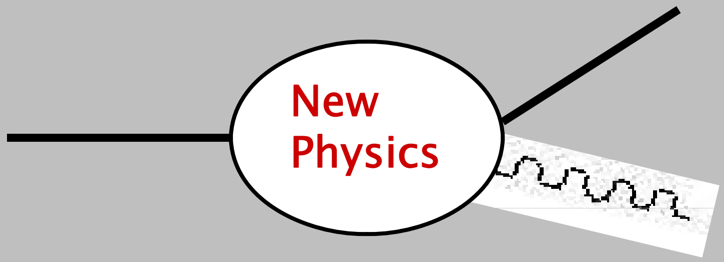


Energy Frontier & Cosmic frontier <u>currently</u> rather well defined and for foreseeable future

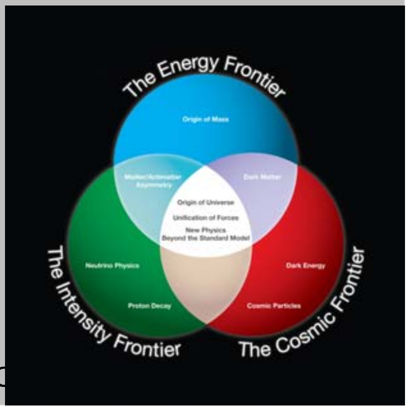
What is the Intensity Frontier?

- Exploration of Fundamental Physics with high intensity beams and/or large sensitive detectors

- Precision measurements that indirectly probe quantum effects



- Must use multi-pronged approach to search for new physics
  - Direct Production
  - Precision Measurements
  - Rare and Forbidden Processes
  - Fundamental Properties of Particles

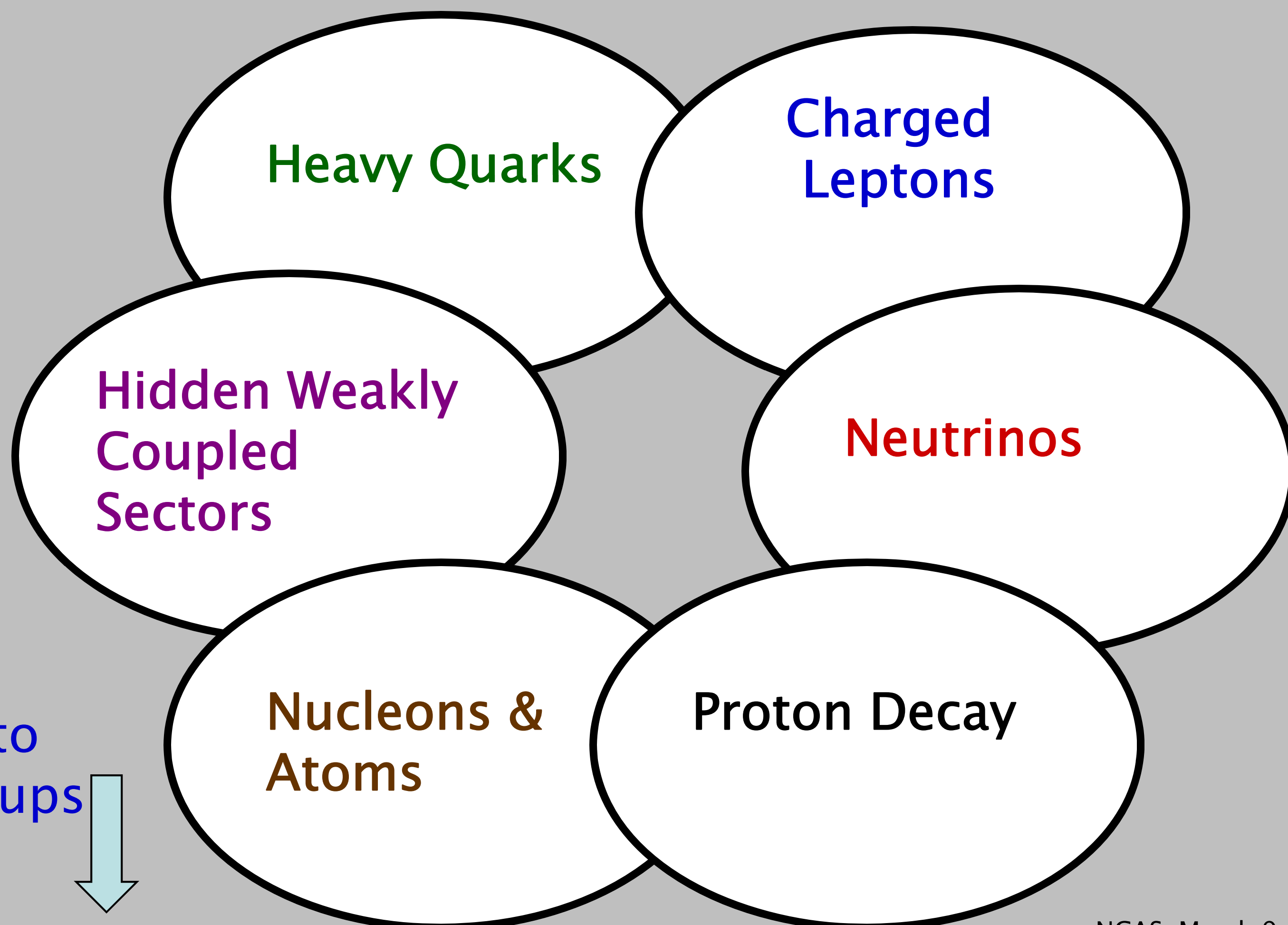


NC

What is the Intensity Frontier?

So at outset (without quite knowing where we were going)
we set up the following areas for study

Study existing particles/
look for new ones



Mapped on to
working groups

"The Intensity Frontier Workshop" exercise

FUNDAMENTAL PHYSICS AT THE INTENSITY FRONTIER
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Really: Through working groups, meetings, workshops over October & November 2011 identify physics opportunities & needed facilities at the Intensity Frontier

Topic	Experiment	Theory	Observer	
Heavy Quarks	Joel Butler, Jack Ritchie	Zoltan Ligeti	Ritchie Patterson	Physics: *s,c* & *b* quarks final states
Charged leptons	Brendan Casey	Yuval Grossman	Aaron Roodman	Muons, taus
Neutrinos	Sam Zeller, Kate Scholberg	Andre deGouvea	Kevin Pitts	All experiments for properties of neutrinos. Accelerator & non-accel.
Hidden Sector Photons, Axions & WISPs	John Jaros	Rouven Essig	Juan Collar	"Dark" photons, paraphotons, axions, WISPs
Proton decay	Chang-Kee Jung	Carlos Wagner	Chip Brock	Proton decay
Nucleons, Nuclei & Atoms	Zheng-Tian Lu	Michael Ramsey-Musolf	Wick Haxton	Properties of nucleons, nuclei or atoms (EDM)
Topic	Experiment	Theory	Observer	

It is not just ν oscillations

"The Intensity Frontier Workshop" exercise

Really: **Through working groups, meetings, workshops over October & November 2011 identify physics opportunities & needed facilities at the Intensity Frontier**

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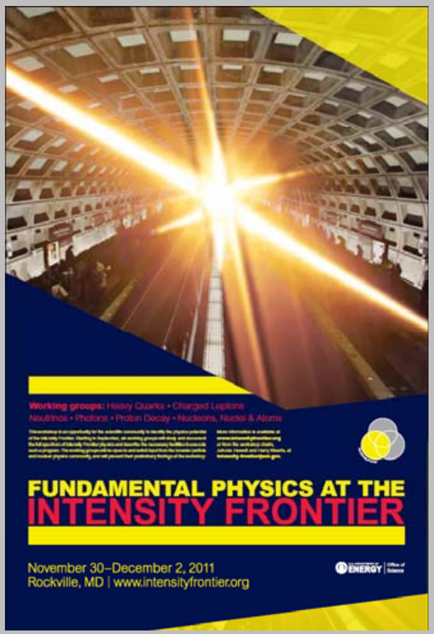
Proton decay	Chang-Kee Jung	Carlos Wagner	Chip Brock
Nucleons, Nuclei & Atoms	Zheng-Tian Lu	Michael Ramsey-Musolf	Wick Haxton
Topic	Experiment	Theory	Observer

Summarize findings, more community input & inform community at Intensity Frontier workshop: Nov 30–Dec 2, 2011, Rockville, MD



What is the Intensity Frontier?

The Intensity Frontier is a broad and diverse set of science opportunities

They look for, study, address following science

CP Asymmetries,
Rare decays,
Distributions
K's, Charm, B's

LFv with μ,τ
g-2

New particle searches

ν Oscillations
LFv in ν's
0νββ

EDMs
Parity Violation

Proton Decay

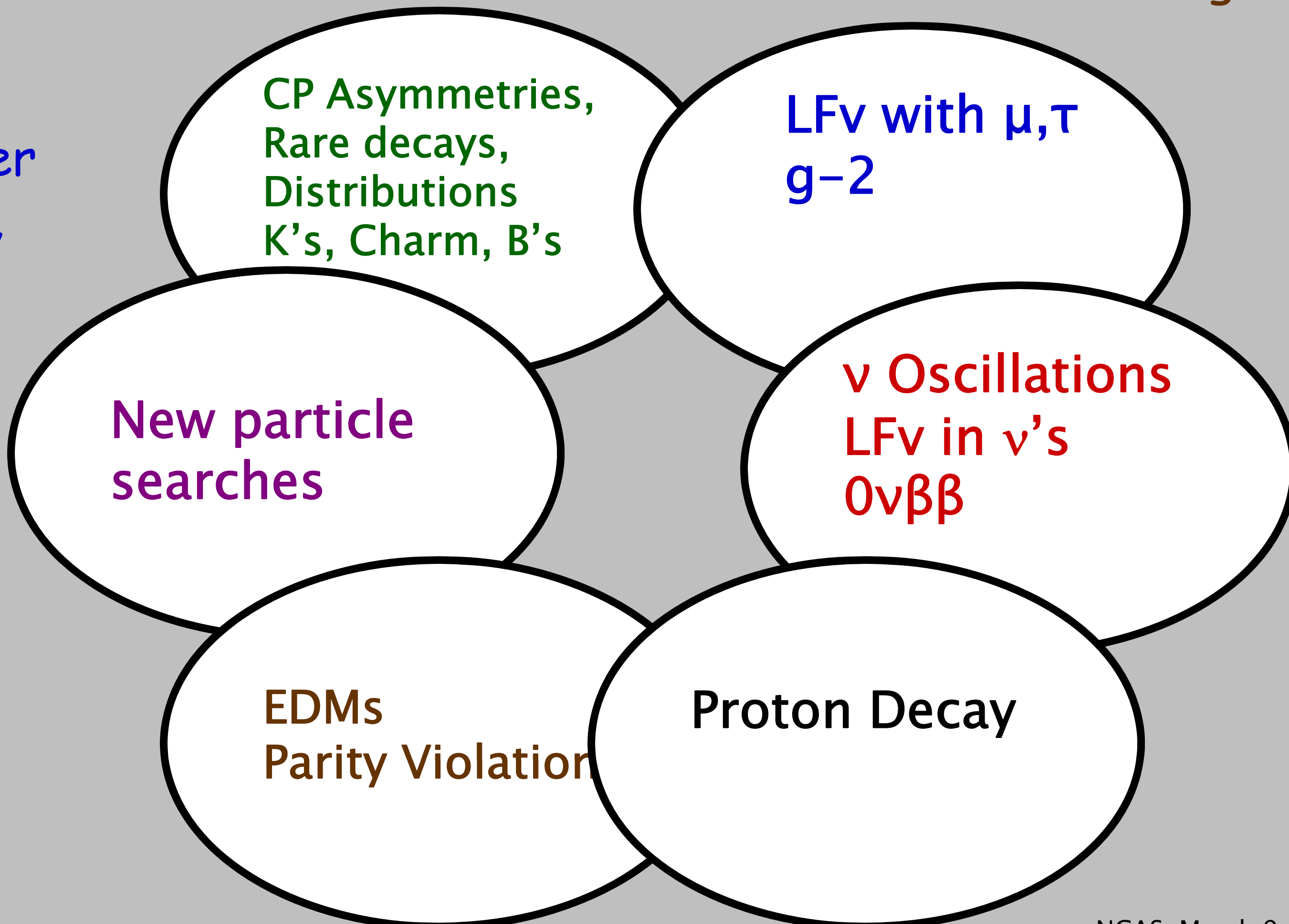
LFv = Lepton Flavor number violation

The Intensity Frontier

The Intensity Frontier is a broad and diverse set of science opportunities

They look for, study, address following science

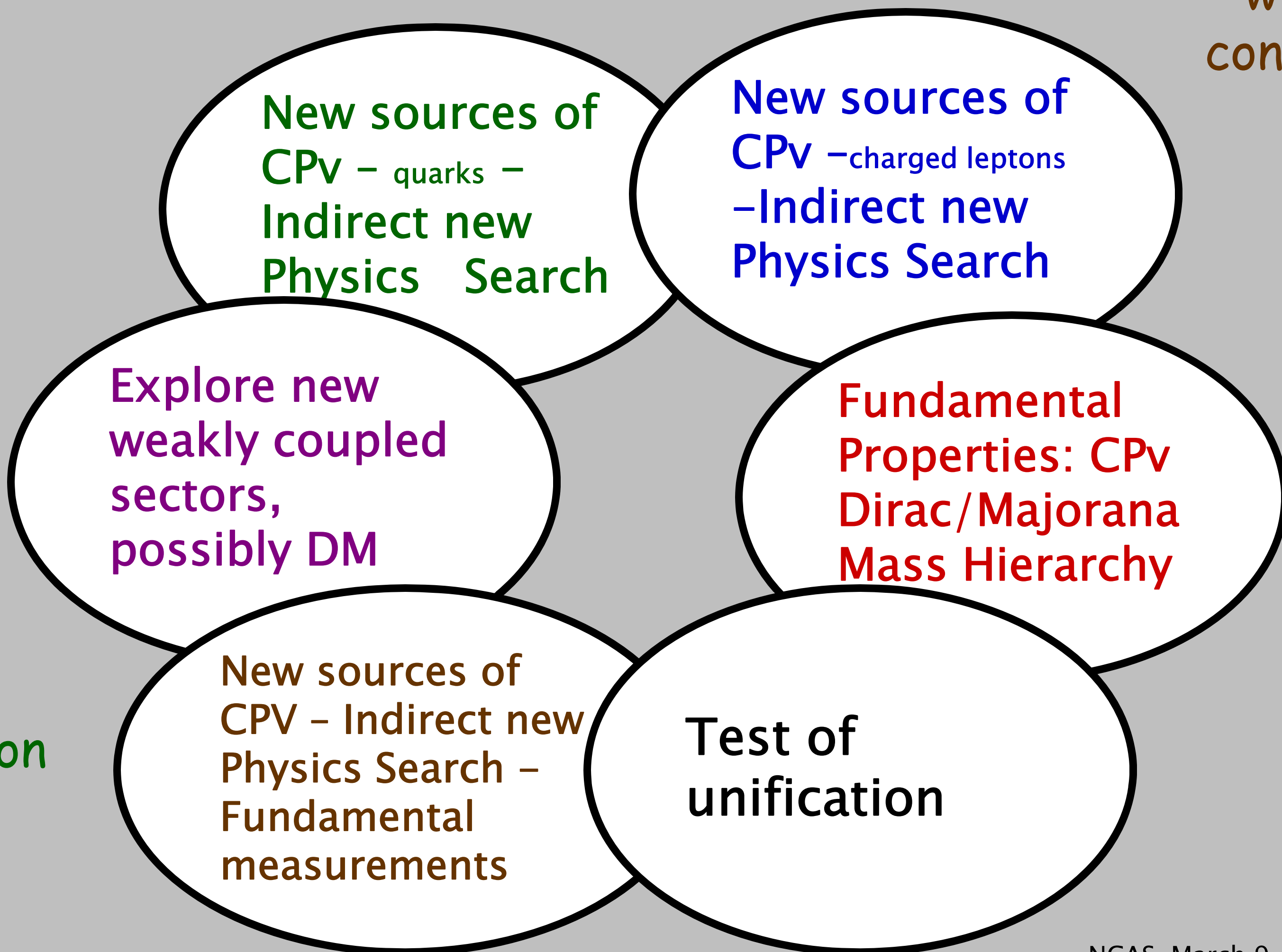
Experiments planned, under construction, wishful thinking, etc



The Intensity Frontier

The Intensity Frontier is a broad and diverse, but connected, overlapping , set of science opportunities.

Broad program with many connections



CPv = Charge Parity violation

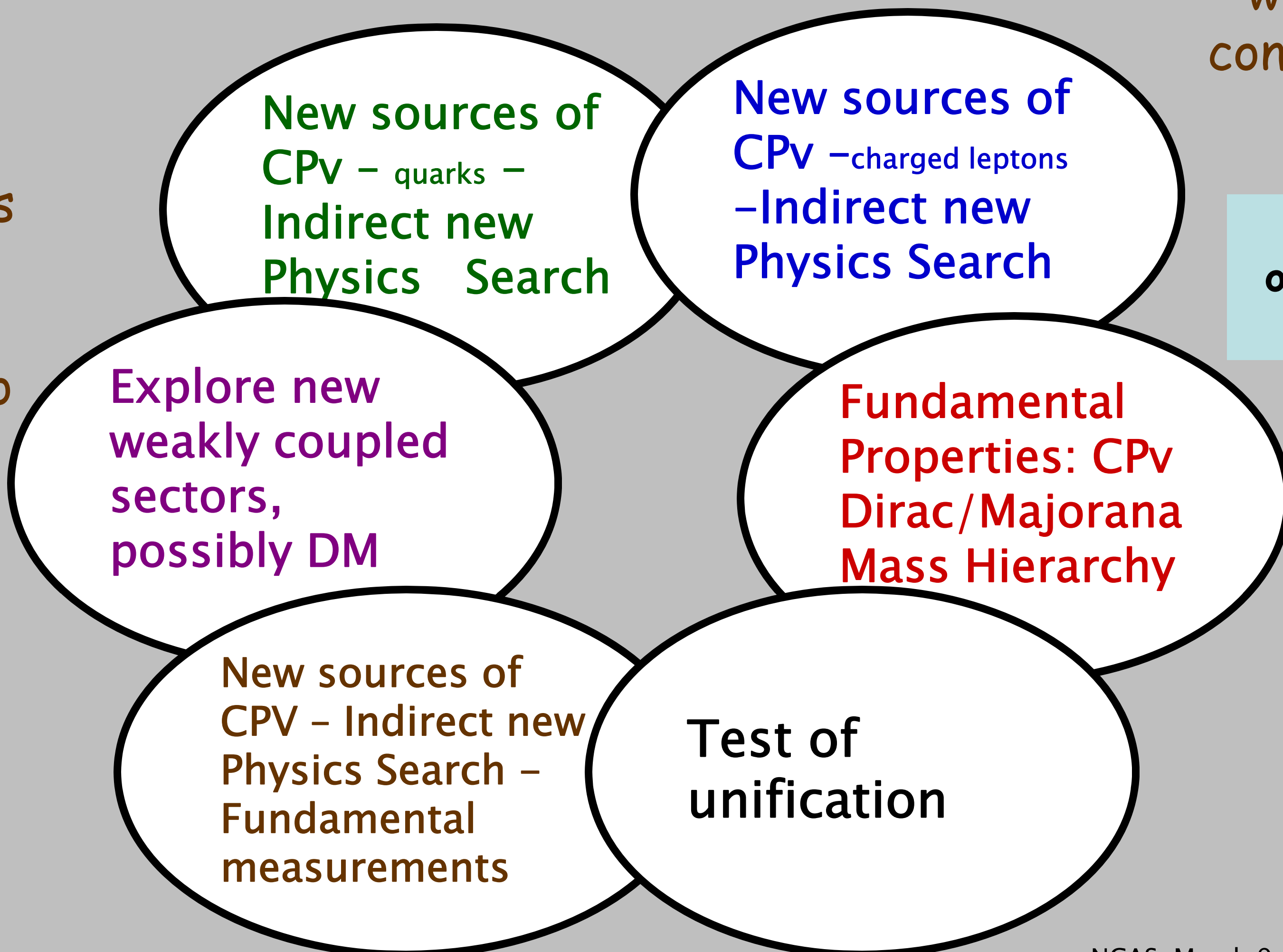
The Intensity Frontier

The Intensity Frontier is a **broad and diverse**, but connected, overlapping , set of science opportunities.

NOT a priori clear which is most important. We should do them all if possible.

Broad program with many connections

One outcome of workshop



Why broad & diverse?

The Intensity Frontier is a broad and diverse set of science opportunities

- Why is it important to be broad and diverse?

Anticipated discoveries at the LHC with 1st data:

Murayama

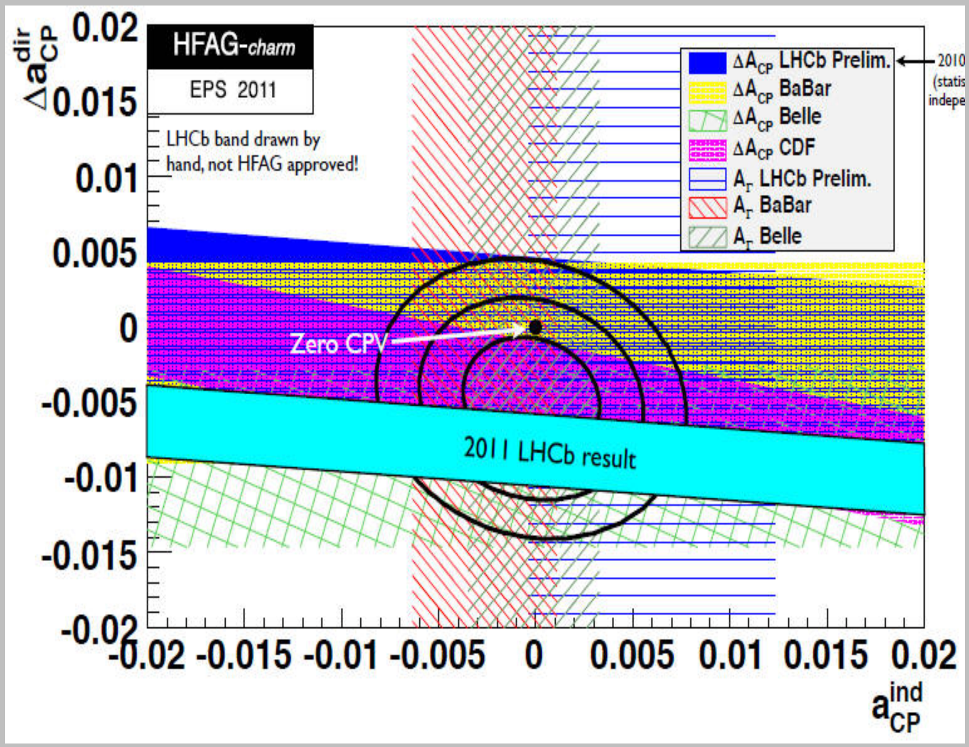
Why broad & diverse?

Expectations for LHC new physics output were high, BUT

"New physics not rolling out every week"

1st surprise from LHC: Direct CPV in Charm decays!

i.e. Intensity frontier



CPv search in $D \rightarrow \pi\pi$ vs $D \rightarrow KK$

3.5σ signal

What Next?

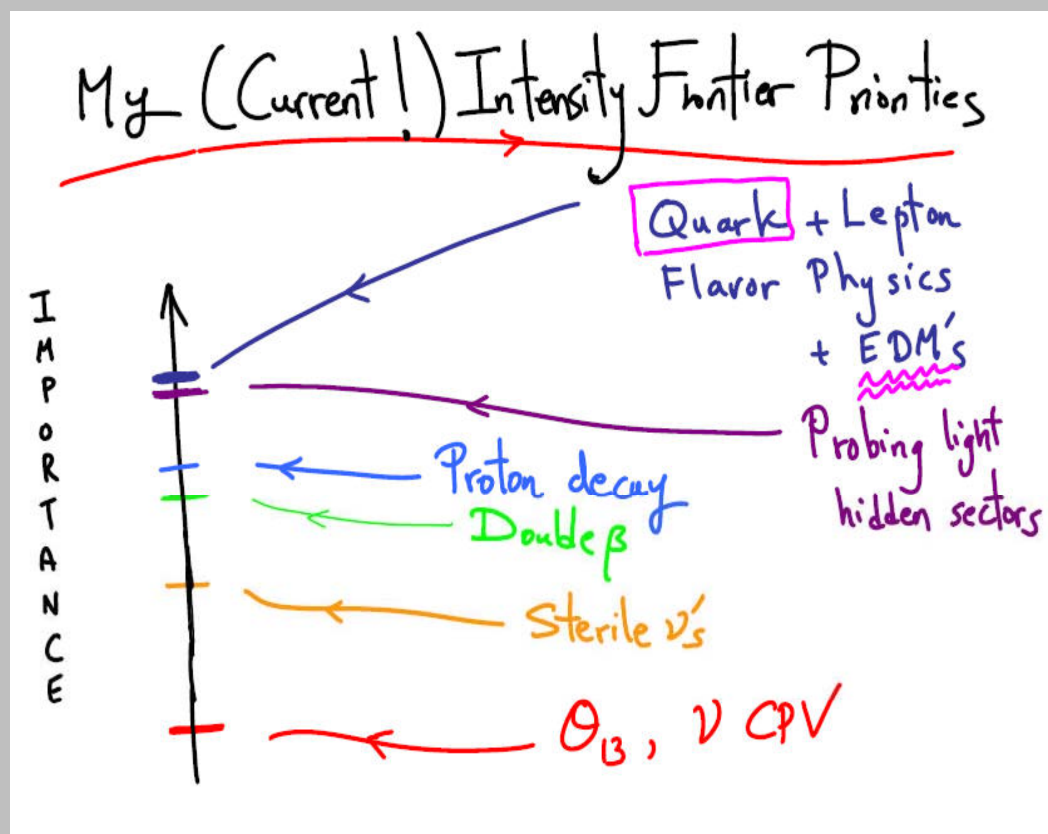
Proponents must engage, and make their case to, the community!

Otherwise, you may not like the resulting priorities

No consensus on science priorities yet.

Case for each will have to be made.

Also have to fold in other constrains ($, time line, other regions)



One example, one point of view

Arkani-Hamed

Some outcomes of the workshop

- > 500 participants
  - Overflowed meeting space and had to limit attendance
  - Exceeded our expectations (Organizers & DOE !)
- Workshop peppered with ideas and enthusiasm
  - > 100 Parallel session talks
  - Much discussion! Sessions, posters, hallways, twitter
- Demonstrates a large, young community that wants to do this science

Intensity Frontier science program

- Intensity Frontier is a broad set of precision measurements of properties of known particles
- It is a multi pronged, inter connected program (not just one approach) AND global program
- We have "only" presented the science case

Developing a strategy & program to be executed is later….

Workshop Deliverables

Technical Report Timeline (for community):

- 1st draft due around end of 2011-- done
- Working group report reviewedby community ~ end January 2012—done
- Working group reports complete by end of February 2012 --done
- Make available to HEPAP in March 2012 for comments
- Final Report by end of March 2012

- Everyone who contributes will be an author
- Website to sign up in support of the described science opportunities

Glossy Brochure (outside community) :

- **Communicators in charge**
- **Ready by end of March**

------ End of "Workshop" -------

Outline of report

Title page
Complete author list & Affiliations
Executive Summary
Introduction
Working group 1 -- with conveners & authors
….
Working Group 6
Summary
Attachments

Total report about 220 pages

Example of working group report

1

Report of the Heavy Quarks Working Group

Conveners: J.N. Butler, Z. Ligeti, J.R. Patterson, J.L. Ritchie

N. Arkani-Hamed, D.M. Asner, A.J. Bevan, M. Blanke, G. Bonvicini, R.A. Briere, T.E. Browder, D.A. Bryman, P. Campana, R. Cenci, N.H. Christ, D. Cline, J. Comfort, D. Cronin-Hennessy, A. Datta, S. Dobbs, M. Duraisamy, J.E. Fast, R. Forty, K.T. Flood, T. Gershon, D.G. Hitlin, A. Jawahery, C.P. Jessop, A.L. Kagan, D.M. Kaplan, M. Kohl, P. Krizan, A.S. Kronfeld, K. Lee, L.S. Littenberg, D.B. MacFarlane, P.B. Mackenzie, B.T. Meadows, J. Olsen, M. Papucci, G. Paz, G. Perez, K. Pitts, M.V. Purohit, B.N. Ratcliff, D.A. Roberts, J.L. Rosner, P. Rubin, J. Seeman, K.K. Seth, A. Soni, S.R. Sharpe, B. Schmidt, A.J. Schwartz, A. Shopper, T. Skwarnicki, S. Stone, R. Sundrum, R. Tschirhart, A. Vainshtein, Y.W. Wah, R.S. Van de Water, G. Wilkinson, M.B. Wise, J. Xu, T. Yamanaka, J. Zupan

1.1 Quark Flavor as a Tool for Discovery

An essential feature of flavor physics experiments is their ability to probe very high mass scales, beyond the energy accessible in collider experiments. In addition, flavor physics can teach us about properties of TeV-scale new physics, which cannot be learned from the direct production of new particles at the LHC. This is because quantum effects allow virtual particles to modify the results of precision measurements in ways that reveal the underlying physics. (The determination of the $t - s, d$ couplings in the standard model (SM) exemplifies how direct measurements of some properties of heavy particles may only be possible in flavor physics.) Even as the Large Hadron Collider (LHC) at CERN embarks on probing the TeV scale, the ongoing and planned precision flavor physics experiments are sensitive to beyond standard model (BSM) interactions at mass scales which are higher by several orders of magnitude. These experiments will provide essential constraints and complementary information on the structure of models put forth to explain any discoveries at LHC, and they have the potential to reveal new physics that is inaccessible to the LHC.

Summary of areas covered in report

Program in place to measure all

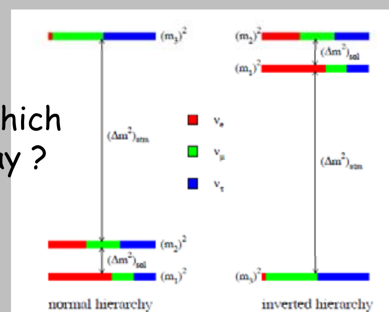
Neutrino oscillations:

Mixing matrix — State @ workshop time

$$\Delta m^2_{21} = 7.59^{+0.20}_{-0.18} \times 10^{-5}\ \mathrm{eV}^2,\ \Delta m^2_{31} = 2.50^{+0.09}_{-0.16} \times 10^{-3}\ \mathrm{eV}^2\ \ (-2.40^{+0.08}_{-0.09} \times 10^{-3}\ \mathrm{eV}^2),$$
$$\sin^2\theta_{12} = 0.312^{+0.017}_{-0.015},\quad \sin^2\theta_{23} = 0.52 \pm 0.06,\quad \sin^2\theta_{13} = 0.02 \pm 0.01.$$

Daya Bay (3/8/2012): $\sin^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$.

Which way ?



+ complex phase δ (CP-violation)

Not measured; only contributes if θ_{13} is non zero

Neutrino Fundamentals:

1. Measure Neutrino mass
2. Neutrinos Majorana or Dirac

US: combination of HEP & NP

Sterile Neutrinos:

Short baseline experiment ~2σ anomalies may indicate additional sterile neutrinos

Neutrino-N scattering:

Measure neutrino interaction cross sections better and target or A dependence of them

Summary of areas covered in report

Program in place to measure all

Electric dipole moments:

Excellent probes of new physics

Neutrons

SM-theory: 10^{-31} *e* cm — Exp: <2.9×10^{-26} *e* cm ➔ 5×10^{-28} *e* cm

2018 ➔ 10^{-28} *e* cm

Nucleus (Hg)

SM-theory: 10^{-33} *e* cm — Exp: <10^{-27} *e* cm ➔ 10^{-32} *e* cm

Electrons (cold molecules of YbF, ThO possible Fr)

SM-theory: 10^{-38} *e* cm — Exp: <1.05×10^{-27} *e* cm ➔ 3×10^{-31} *e* cm

Weak decays:

$$R^{\pi}_{e/\mu} \equiv \frac{\Gamma(\pi \to e\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))}$$

Th: 1.2351 (2) x 10^{-4}
Exp: 1.2300 (40) x 10^{-4} – 0.3% go to 0.05%

+ Kaons

Nuclear β decay: precise measurement of V_{ud}, future measurement of *n* lifetime and decay correlations

Neutral Currents:

Asymmetries

Polarized electron scattering from unpolarized targets & electrons (Moeller scatter)➔ precision measurements of weak mixing angle over large Q^2

Executive summary points

Slide version of Executive Summary of Intensity Frontier:

before

Program directed at new physics i.e. Beyond Standard Model physics

Six working groups; three conveners each; prepare during Fall of 2011

Three day workshop ~Dec 2011;

after

large interest by community; ~500 participants; much discussion & vibrant atmosphere

Science is broad and diverse but interconnected

Science reach of each area documented and clear progress; this decade & next

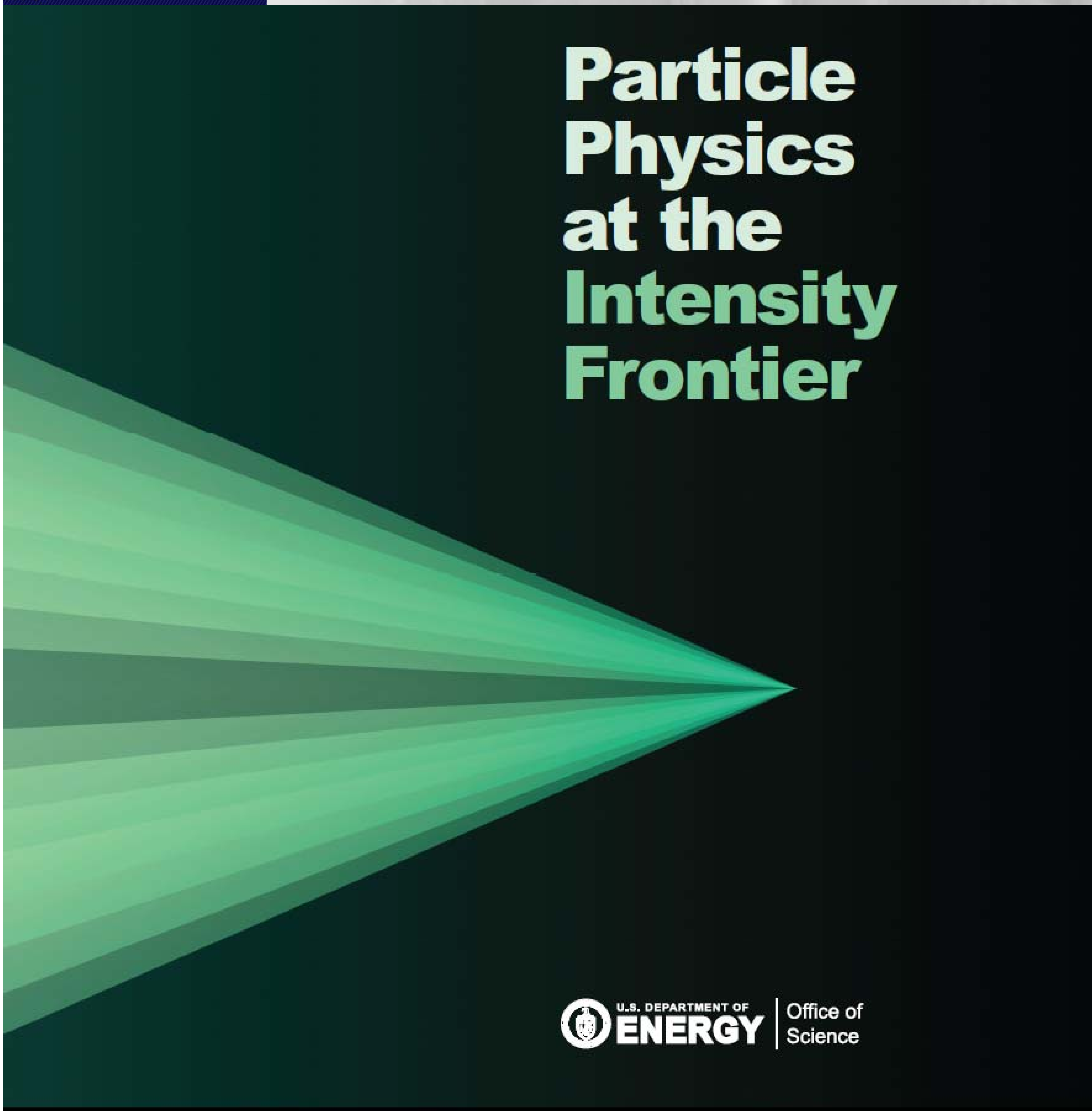
<u>Continue</u> broad based science discussion of Intensity Frontier as new results arrive; future workshops

Describe science & serve as input into strategic planning; this is step 1

Nuclear Physics aspects

- Workshop was organized along science not funding sources
- Nucleons, Nuclei & Atoms separate working group
- Neutrino working groups -- both NP and HEP
- NP obviously part of Intensity Frontier or vice versa (address same physics)
- Intensity Frontier should continue to be science based and not funding based --
  - We should keep an eye on this…
  - Upcoming: Snowmass 2013 & other "HEP" meetings-- example
  - Comments from NSAC ?

Nuclear Physics aspects



Address brochure

Current layout of brochure is very HEP centric.

Cause for concern ?

Need some feedback……

Nuclear Physics aspects

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Brochure : Layout (details still in flux) of brochure

Particle physics explores the universe on three frontiers.

The three frontiers of particle physics ask different questions and use different tools and techniques, but ultimately aim at the same transformational science.

On the Intensity Frontier, scientists search for nature's rarest processes—once-in-a-lifetime events that give us a better understanding of matter, energy, space and time. This approach requires intense beams of particles and ultra-sensitive detectors.

At the Energy Frontier, high-energy collisions create particles that have not existed since the earliest moments of the universe and that illuminate the nature of our world.

At the Cosmic Frontier, scientists use the universe as a lab. High-energy particles from space hold clues to the nature of dark matter and dark energy, mysterious phenomena that make up 96 percent of the universe.

FIG 01 | The three frontiers of particle physics use complementary and interdependent techniques to answer fundamental questions about the laws of nature and cosmos.

FIG 02 | Neutrinos leave tracks as they pass through a liquid-argon detector. This technology is under investigation for future large-scale neutrino detectors.

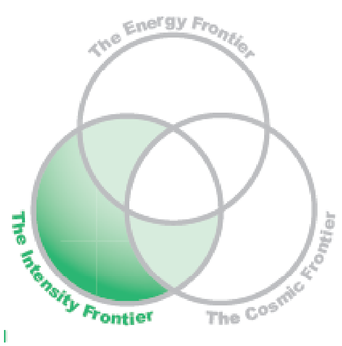


FIG 01 |

Q. Are there undiscovered laws of nature?

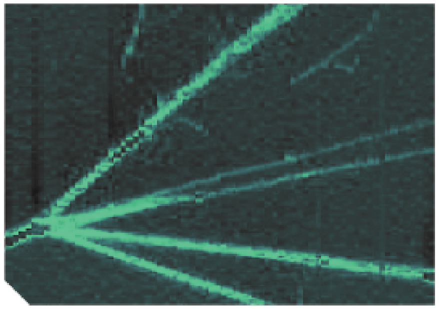
In their search for new fundamental particles and forces, particle physicists need to go beyond what they can learn from particle collisions or cosmic exploration. The Intensity Frontier lets them look at things from a new angle—for instance, searching for unexpected ways that one particle can change into another. These discoveries transform our understanding of what's possible.

Q. What message do neutrinos bring from the beginning of time?

Scientists think the newborn universe should have contained equal amounts of matter and antimatter—particles and antiparticles. Yet today we live in a universe made entirely of matter. What happened? Are some particles their own antiparticles?

Ghostly particles called neutrinos may hold answers. Intensity Frontier scientists are searching for clues using neutrinos created in particle accelerators, nuclear reactors, the Earth's atmosphere and the sun.

FIG 02 |



Seven pages total, so short.

Nuclear Physics aspects

- **Workshop at Wisconsin Fall 2011**

THE UNIVERSITY of WISCONSIN MADISON

Theoretical Nuclear, Particle, Astrophysics, and Cosmology (NPAC)

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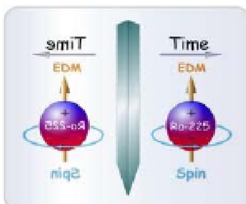
Workshop on Beyond the Standard Model in Nuclear Physics:



Dates: October 15-17, 2011

Location: 4274 Chamberlin Hall, Department of Physics, University of Wisconsin-Madison

Organizing Committee: Michael Ramsey-Musolf (chair), Wei Chao, Martin Gonzalez-Alonso, Aimee Lefkow, Mario Pitschmann

Description: The workshop is sponsored jointly with the nuclear physics program offices at the Department of Energy and National Science Foundation. The goal is to develop a framework for evaluating the prospective impact of nuclear physics studies of fundamental symmetries and neutrinos for physics beyond the Standard Model. Topics will include, but are not limited to:

- Searches for violation of time-reversal, lepton number, lepton flavor
- Weak decays of nuclei, neutrons, pions, and muons
- Parity-violating electron scattering
- Solar and astrophysical neutrinos
- Lepton moments

Scientific Program:

The workshop begins at 9am on October 15 and will conclude by 2pm on October 17. Download the workshop agenda here. Download the working group agenda here.

- **Perfectly in sync with Intensity Frontier workshop**

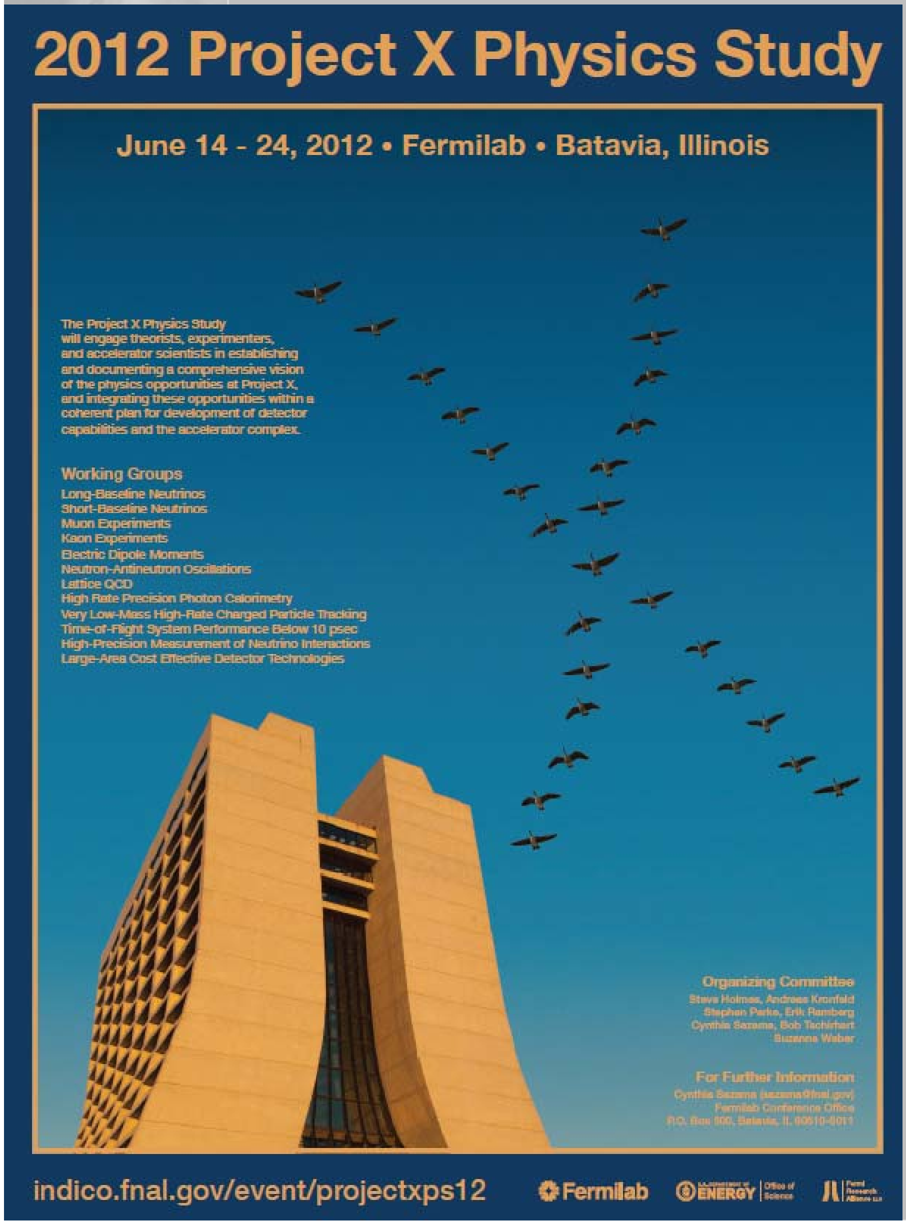
Future:

From: M.Ramsey-Musolf

A group of theorists is preparing a full issue of Progress in Nuclear and Particle Physics, with each article devoted to a different subtopic. These include CPV/EDMs, neutral current studies, charged current studies, neutrino properties, neutrinos and astrophysics/cosmology, muon physics, and dark matter in nuclear physics, as well has hadronic parity violation.

In parallel, a website will be developed similar in spirit to that of the LEP EWWG where recent results and sort of the state of the field can be viewed quickly, including illustrative plots.

Future workshops etc.



Snowmass June 2- 22, 2013

Working groups:

- Energy frontier
- Intensity frontier
- Cosmic frontier
- Frontier facilities
- Instrumentation frontier

Community Planning Meeting (CPM2012), October 11-13, 2012 at Fermilab

Project X Physics Workshop at Fermilab summer 2012

The End