Intensity Frontier Vision

Summary of the workshop
Fundamental Physics at the Intensity Frontier

J. Hewett and H. Weerts
Workshop co-chairs

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

Our Charge

Dear Drs. Hewett and Weerts:

Particle physics is frequently characterized as having three experimental frontiers, the energy, intensity, and cosmic frontiers. Intensity frontier experiments are those that use rare processes to probe for new physics. The study of these rare processes requires intense beams and/or large detectors to provide a measurable effect. It can also require highly precise detectors capable of distinguishing these rare and useful processes from more mundane processes that act as a background.

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 potentially be learned from such experiments, determine which experiments can be done with current facilities and technology, as well as determine which experiments require new facilities or new technology to reach their full potential.

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

The output of your workshop should be a report documenting the findings from the workshop.

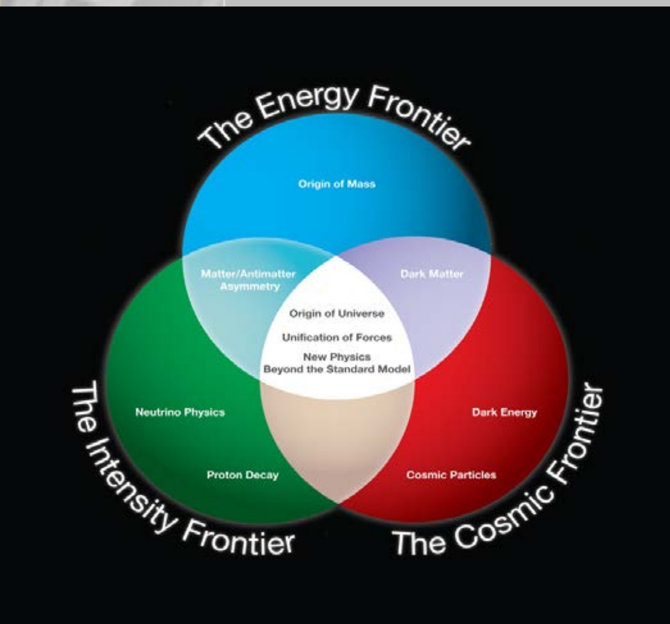
Sincerely,

Michael Procario
Acting Associate Director of Science
Office of High Energy Physics

1. Document (in one coherent report) 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



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

- Shows multi-pronged approach to search for new physics
  - Direct Searches
  - Precision Measurements
  - Rare and Forbidden Processes
  - Fundamental Properties of Particles and Interactions

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Why Broad and 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

J. Hewett

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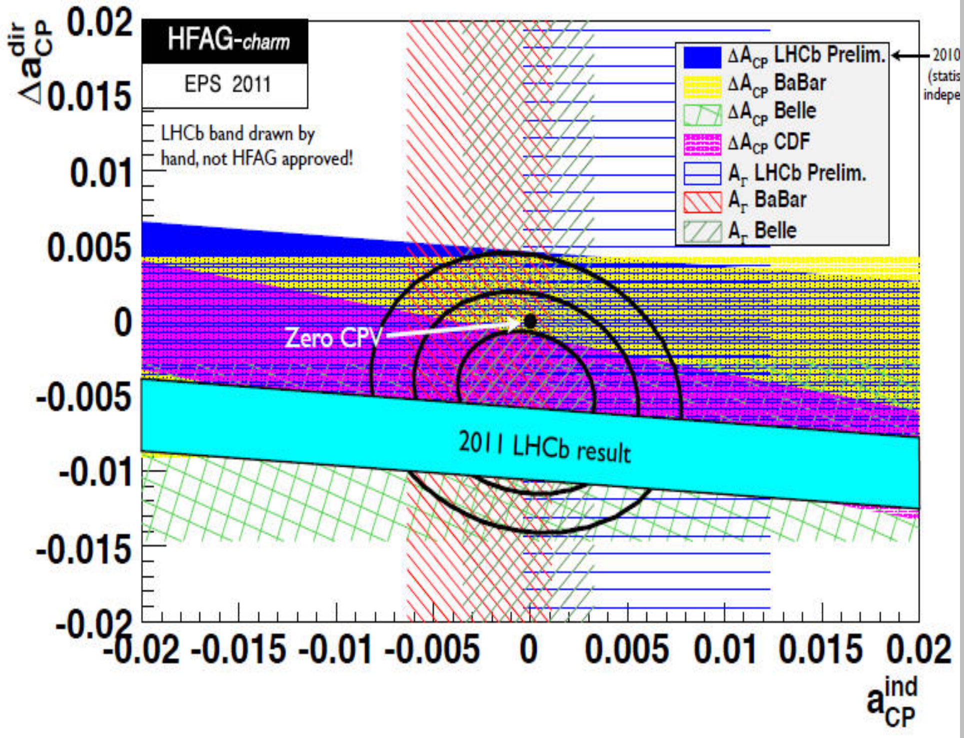
1st surprise from LHC: Direct CPV in Charm decays!



CPV search in $D \to \pi\pi$ vs $D \to KK$

3.5σ signal

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What is the Intensity Frontier?

- Exploration of Fundamental Physics with
  - intense sources
  - ultra-sensitive, sometimes very massive detectors
- Intensity frontier science searches for
  - Extremely rare processes
  - Tiny deviations from Standard Model predictions
- Precision measurements that indirectly probe quantum effects
- Extends outside of HEP – workshop sponsored by offices of HEP and Nuclear Physics

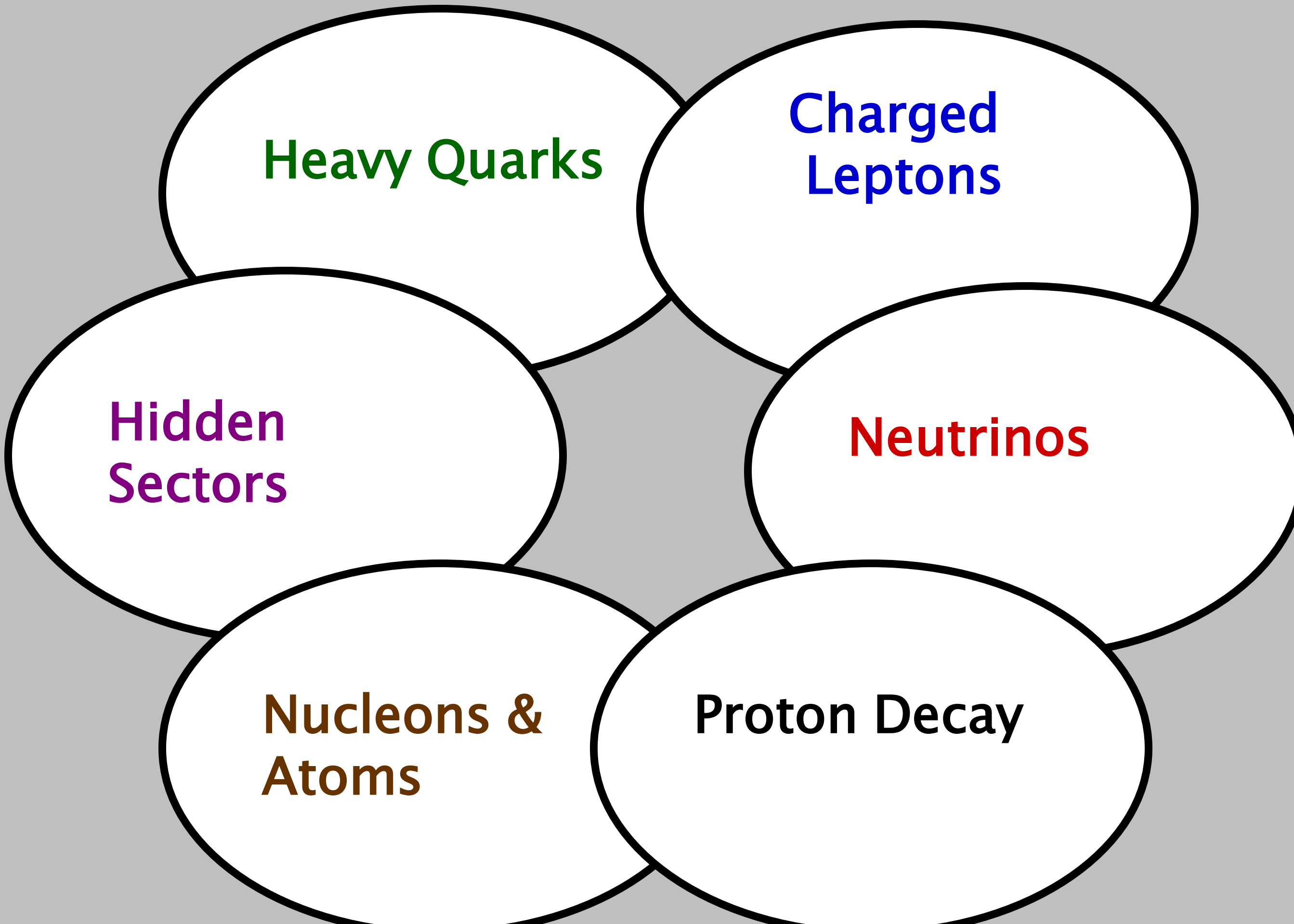
What is the Intensity Frontier?

The Intensity Frontier addresses fundamental questions:

- Are there new sources of CPV?
- Is there CPV in the leptonic sector?
- Are ν's Majorana or Dirac?
- Do the forces unify?
- Is there a weakly coupled Hidden Sector linked to Dark Matter?
- Are apparent symmetries (B,L) violated at high scales?
- What is the flavor sector of LHC discoveries?
- Can we expand the new physics reach of the energy frontier?

What is the Intensity Frontier?

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



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Working Groups

Topic	Experiment	Theory	Observer
Heavy Quarks	Joel Butler, Jack Ritchie	Zoltan Ligeti	Ritchie Patterson
Charged leptons	Brendan Casey	Yuval Grossman	Aaron Roodman
Neutrinos	Sam Zeller, Kate Scholberg	Andre deGouvea	Kevin Pitts
Hidden Sector Photons, Axions & WISPs	John Jaros	Rouven Essig	Juan Collar
Proton decay	Chang-Kee Jung	Carlos Wagner	Chip Brock
Nucleons, Nuclei & Atoms	Zheng-Tian Lu	Michael Ramsey-Musolf	Wick Haxton
Topic	Experiment	Theory	Observer

K, D & B Meson decays/properties

Muons, taus

All experiments for properties of neutrinos. Accelerator & non-accel.

"Dark" photons, paraphotons, axions, WISPs

Proton decay

Properties of nucleons, nuclei or atoms (EDM)

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Before Workshop:

- Working group meetings
- Regular convener meetings
- Solicited written contributions

Focus is on science, rather than facilities

What is the Intensity Frontier?

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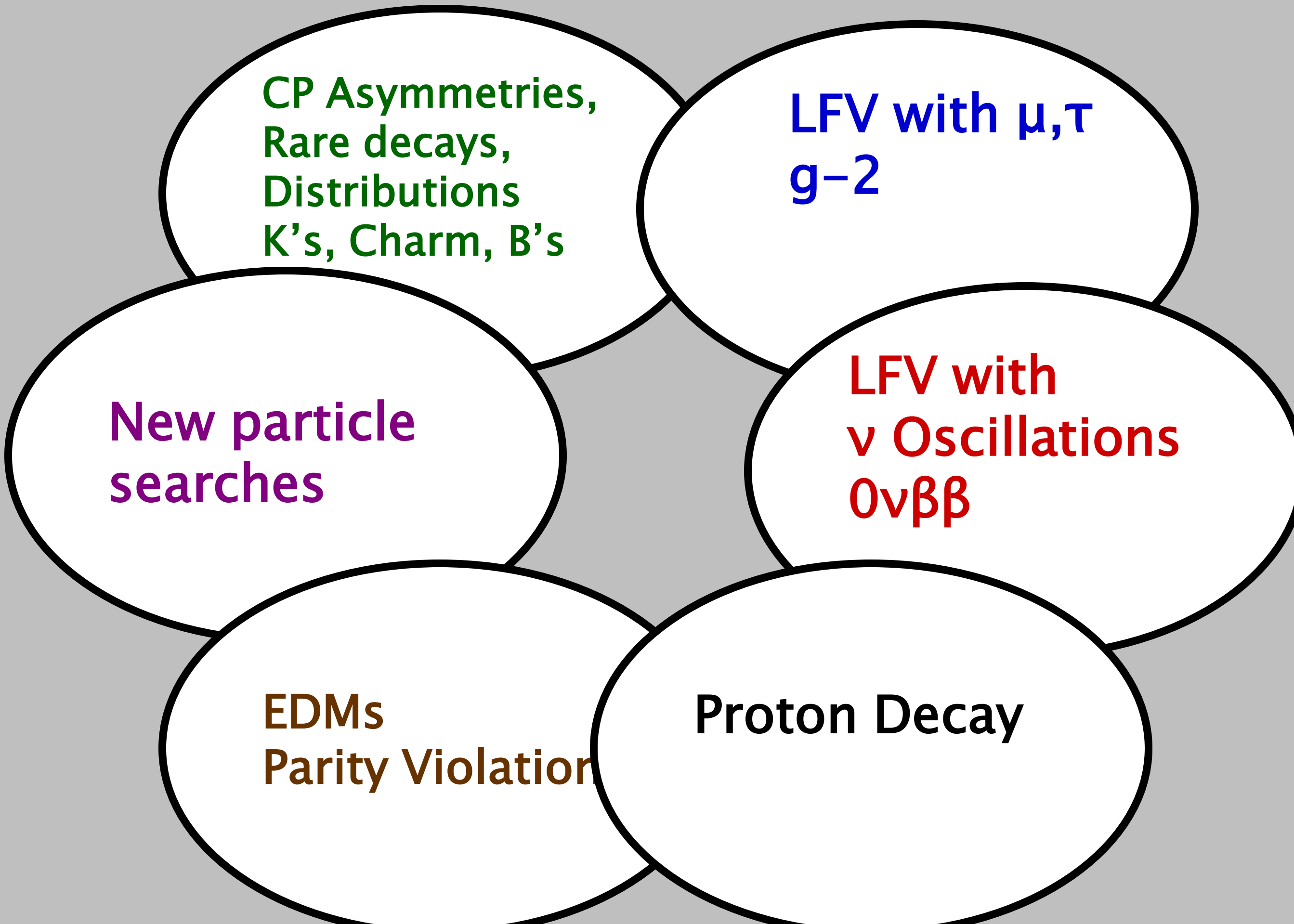

What is the Intensity Frontier?

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

New sources of CPV – Indirect new Physics Search

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Explore DM and other weakly coupled sectors

Fundamental Properties: CPV Dirac/Majorana Hierarchy

New sources of CPV – Indirect new Physics Search – Fundamental measurements

Test of unification and fundamental symmetries

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What is the Intensity Frontier?

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

Broad program with many connections

One outcome of workshop

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Physics #Intensity Frontier: Heavy Quarks

Heavy Quark Chapter Conclusions:

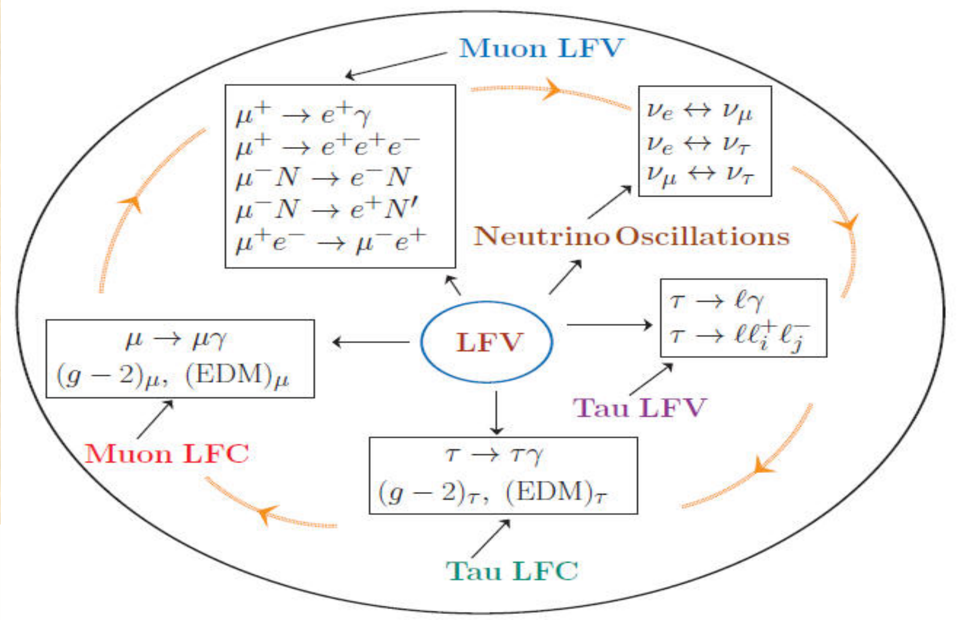
- Essential component of world-wide balanced physics program
- Compelling physics case not predicated on theoretical progress
- Several exp’ts underway abroad – US should be involved
- US has opportunity to mount its own program in K Decays

Observable	SM Theory	Current Expt.	Super Flavor Factories
$S(B \to \phi K^0)$	0.68	0.56 ± 0.17	± 0.03
$S(B \to \eta' K^0)$	0.68	0.59 ± 0.07	± 0.02
γ from $B \to DK$		$\pm 11°$	$\pm 1.5°$
$A_{\rm SL}$	-5×10^{-4}	-0.0049 ± 0.0038	± 0.001
$S(B \to K_S \pi^0 \gamma)$	< 0.05	-0.15 ± 0.20	± 0.03
$S(B \to \rho\gamma)$	< 0.05	-0.83 ± 0.65	± 0.15
$A_{\rm CP}(B \to X_{s+d}\gamma)$	< 0.005	0.06 ± 0.06	± 0.02
$\mathcal{B}(B \to \tau\nu)$	1.1×10^{-4}	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 0.05 \times 10^{-4}$
$\mathcal{B}(B \to \mu\nu)$	4.7×10^{-7}	$< 1.0 \times 10^{-6}$	$\pm 0.2 \times 10^{-7}$
$\mathcal{B}(B \to X_s\gamma)$	3.15×10^{-4}	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 0.13 \times 10^{-4}$
$\mathcal{B}(B \to X_s \ell^+\ell^-)$	1.6×10^{-6}	$(3.66 \pm 0.77) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$\mathcal{B}(B \to K\nu\overline{\nu})$	3.6×10^{-6}	$< 1.3 \times 10^{-5}$	$\pm 1 \times 10^{-6}$
$A_{\rm FB}(B \to K^*\ell^+\ell^-)_{q^2<4.3\,{\rm GeV}^2}$	-0.09	0.27 ± 0.14	± 0.04

Report shows future sensitivities for K Decays, as well as Charm & bottom processes at Super-Flavor Factories and upgraded LHCb

Physics #Intensity Frontier: Charged Leptons

- Charged Leptons easy to produce & detect
  ⇒ precise measurements are possible
- Hadronic uncertainties insignificant or controlled by data
- SM rates negligible in some cases so new physics stands out
- Directly probe couplings of new particles to leptons
- Diverse set of independent measurements

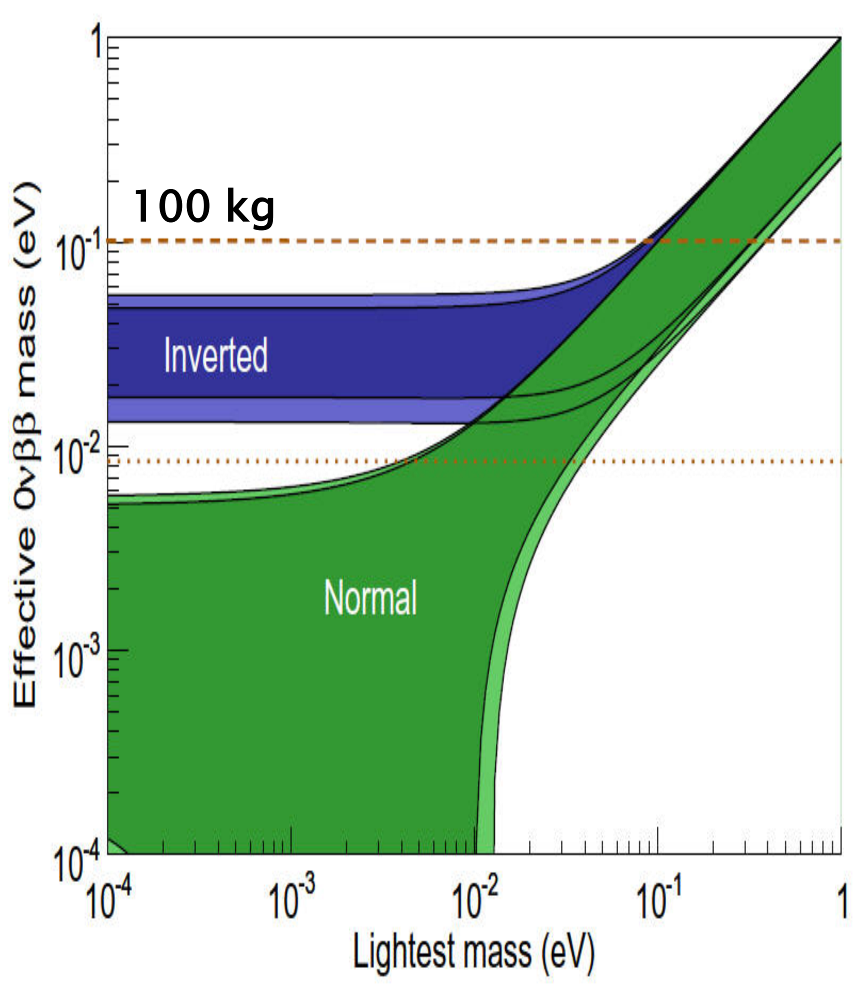


95% CL limits in CLFV with muons

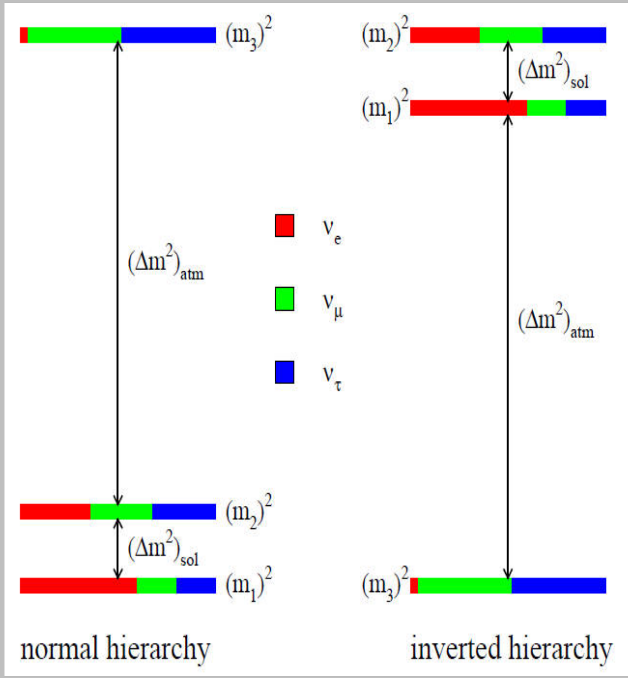
Process	Current limit	Expected limit 5-10 years		Expected limit 10-20 years
$\mu^+ \to e^+\gamma$	2.4×10^{-12} PSI/MEG (2011)	1×10^{-13} PSI/MEG		1×10^{-14} PSI, Project X
$\mu^+ \to e^+e^-e^+$	1×10^{-12} PSI/SINDRUM-I (1988)	1×10^{-15} Osaka/MuSIC	1×10^{-16} PSI/$\mu 3e$	1×10^{-17} PSI, Project X
$\mu^- N \to e^- N$	7×10^{-13} PSI/SINDRUM-II (2006)	1×10^{-14} J-PARC/DeeMee	6×10^{-17} FNAL/Mu2e	1×10^{-18} J-PARC, Project X

Physics #Intensity Frontier: Neutrinos

Neutrinoless Double Beta Decay



- Tests fundamental Nature of the neutrino
- Tests Lepton Number Violation



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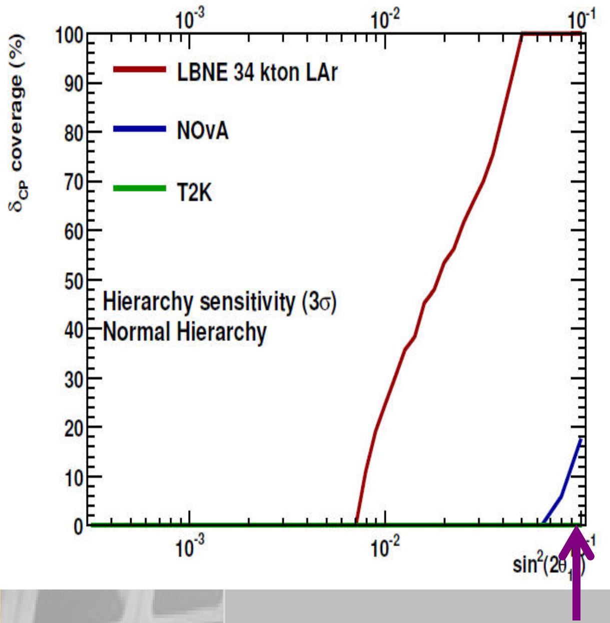
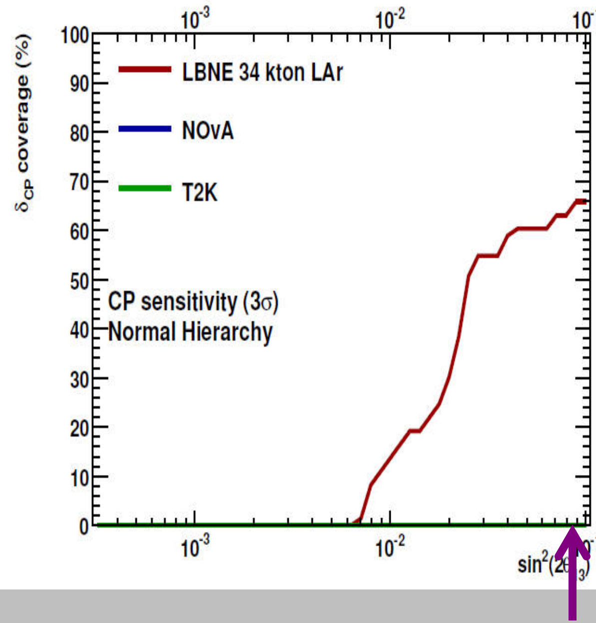
Physics #Intensity Frontier: Neutrinos





Projected sensitivities
LBNE: 5+5 yrs @ 700kW with 34 kt LAr
Nova: 3+3 yrs

Large θ_{13} allows for measurement of fundamental neutrino properties: CVP, Mass Hierarchy

Expt. Type	$\sin^2\theta_{13}$	$\mathrm{sign}(\Delta m^2_{31})$	δ	$\sin^2\theta_{23}$	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{12}$	Δm^2_{21}	NSI	ν_s
Reactor	⋆⋆⋆	⋆	–	–	⋆	⋆⋆	⋆⋆	–	⋆⋆
Solar	⋆	–	–	–	–	⋆⋆⋆	⋆	⋆⋆	⋆⋆
Supernova	⋆	⋆⋆⋆	–	–	–	⋆	⋆	⋆⋆	⋆⋆
Atmospheric	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆⋆	–	–	⋆⋆⋆	⋆⋆
Pion DAR	⋆⋆⋆	–	⋆⋆⋆	⋆	⋆⋆	⋆	⋆	–	⋆⋆
Pion DIF	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆	⋆	⋆	⋆⋆	⋆⋆
Coherent ν–A	–	–	–	–	–	–	–	⋆⋆⋆	⋆⋆⋆
μ DIF	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆	⋆	⋆⋆	⋆⋆
β Beam	⋆⋆⋆	–	⋆⋆⋆	⋆⋆	⋆⋆	⋆	⋆	–	⋆⋆

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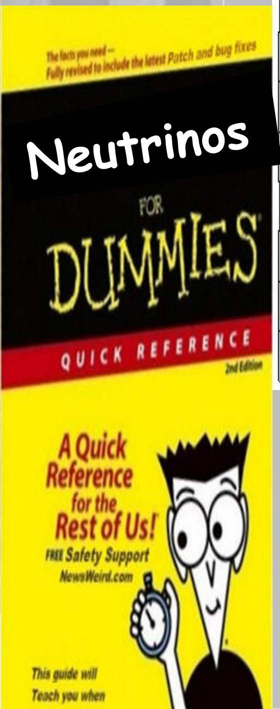
Physics #Intensity Frontier: Neutrinos

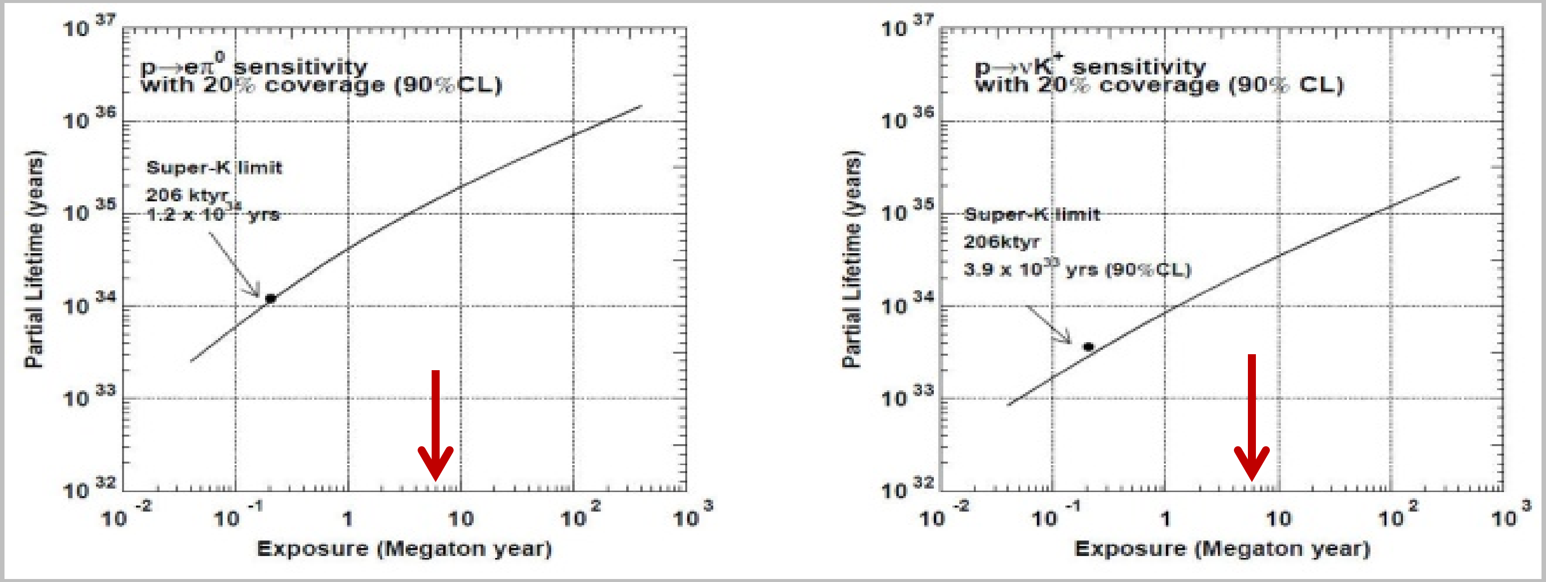
Guide to Neutrino Experiments for Dummies

Expt. Type	ν_e disapp	ν_μ disapp	$\nu_\mu \leftrightarrow \nu_e$	ν_τ app[1]	Examples
Reactor	√√	–	–	–	KamLAND, Daya Bay, Double Chooz, RENO
Solar[2]	√√	–	√	–	Super-K, Borexino, SNO+, Hyper-K (prop)
Supernova[3]	√√	√	√√	–	Super-K, KamLAND, Borexino, IceCube, LBNE (prop), Hyper-K (prop)
Atmospheric	√	√√	√	√	Super-K, LBNE (prop), INO (prop), IceCube, Hyper-K (prop)
Pion DAR	√	–	√√	–	DAEδALUS
Pion DIF	–	√√	√√	√	MiniBooNE, MINERνA[4], MINOS(+, prop), T2K NOνA, MicroBooNE, LBNE (prop), Hyper-K (prop)
Coherent ν–A[5]	–	–	–	–	CLEAR (prop), Ricochet (prop)
μ DIF[6]	√	√√	√√	√	VLENF, NuFact
β Beam	√	–	√√	–	



Physics #Intensity Frontier: Proton Decay

Proton decay experiments test theories of unification and baryon number violation



Future sensitivities at predicted levels for SUSY GUT models and related to LHC SUSY

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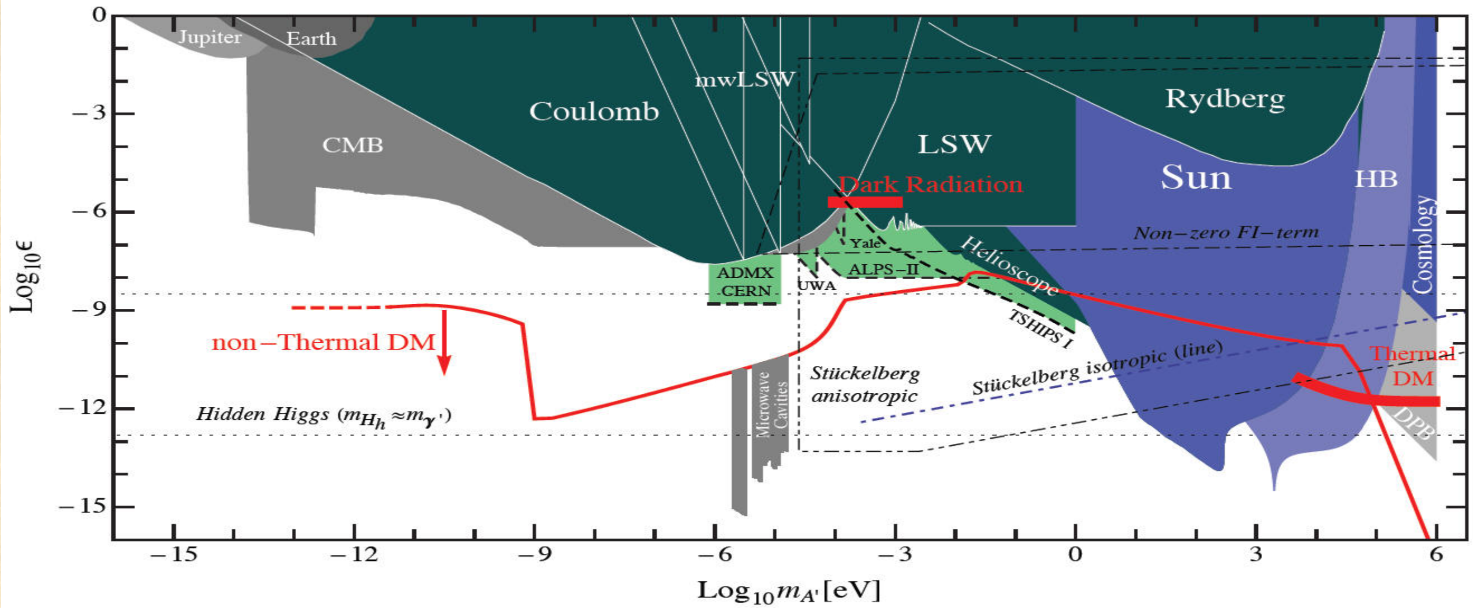
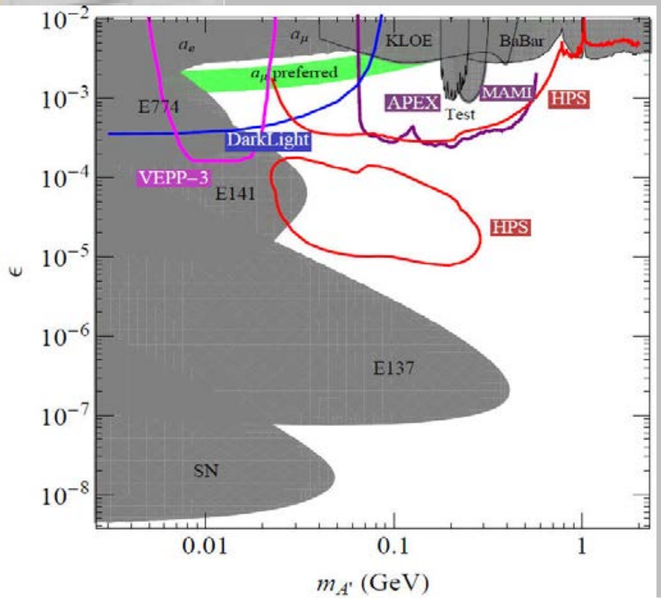
Physics #Intensity Frontier: Ultra-weak Hidden Sectors



Effective coupling to SM vs Mass plane

$m_{A'} < 1$ev



Hidden Sector Vector Portal/Heavy Dark Sector Photons:
Couplings to SM small enough to have missed so far, but big enough to find

Theories motivated by cosmic frontier
Signatures at Intensity and (Energy) frontiers

$m_{A'} > 1$ev

Physics #Intensity Frontier: Nucleons, Nuclei and Atons

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

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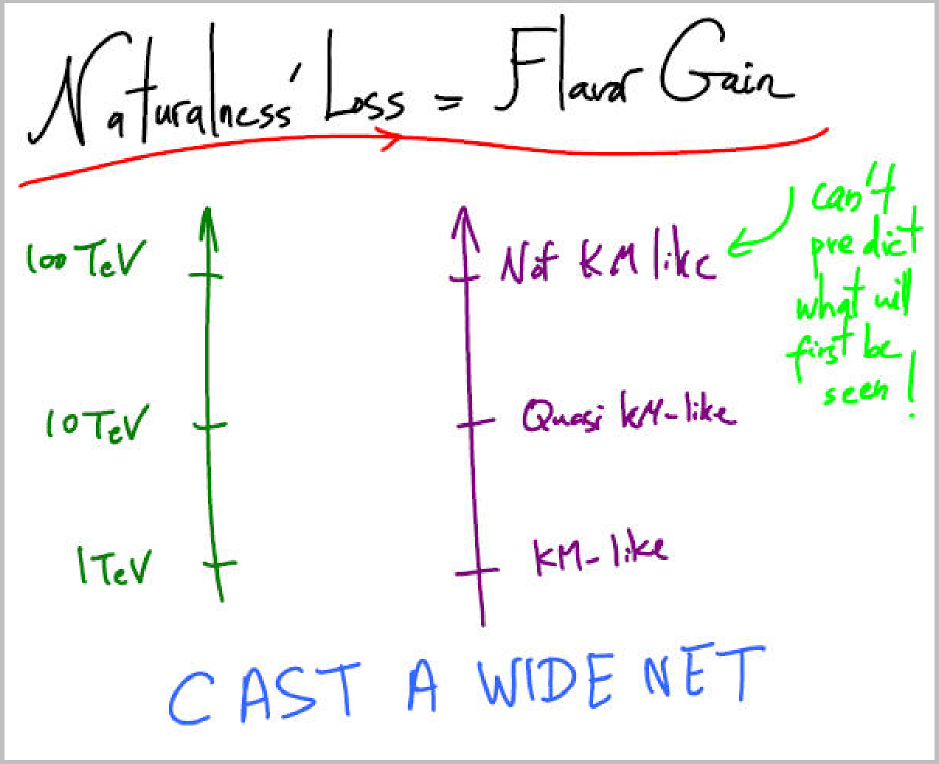
Intensity Frontier Linked to Other Frontiers

The science of the Intensity Frontier is connected to the Energy and Cosmic Frontiers

- Connections between LHC results and flavor factories



Forced to choose between MFV and Naturalness

Arkani-Hamed

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Intensity Frontier Linked to Other Frontiers

The science of the Intensity Frontier is connected to the Energy and Cosmic Frontiers

- Connections between LHC results and flavor factories
- When (not IF) LHC discovers New Physics we will need to know its flavor sector

Generic amplitude for flavor process

$$A = A_0 \left[c_{SM} \frac{1}{M_W^2} + c_{NP} \frac{1}{\Lambda^2} \right]$$

trivial kinematical factors → A_0

(adimensional) effective couplings → c_{SM}, c_{NP}

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Intensity Frontier Linked to Other Frontiers

Operator	Bounds on Λ [TeV] ($C=1$)		Bounds on C ($\Lambda = 1\,\text{TeV}$)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2	2.2×10^2	7.6×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $S_{\psi\phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	3.7×10^2	7.4×10^2	1.3×10^{-5}	3.0×10^{-6}	Δm_{B_s}; $S_{\psi\phi}$

Generic amplitude for flavor process

$$A = A_0 \left[c_{SM} \frac{1}{M_W^2} + c_{NP} \frac{1}{\Lambda^2} \right]$$

trivial kinematical factors

(adimensional) effective couplings

Flavor non-diagonal measured in LFV and heavy quark physics

LHC measures this!

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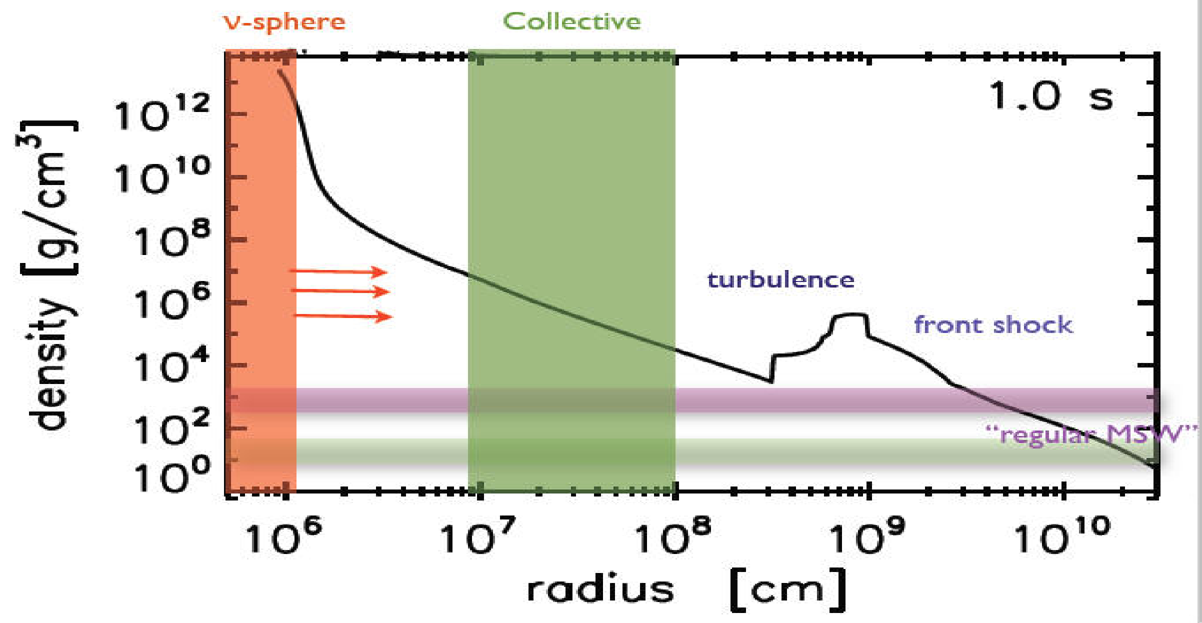
Intensity Frontier Linked to Other Frontiers

LBNE as a Neutrino Telescope – Synergy with Cosmic Frontier

Supernova Neutrinos: 10^{58} ν's/sec

⇒ Truly at the Intensity Frontier!

- ν's come from center of explosion during 1st 10 sec
- Can measure detailed ν spectrum, yielding valuable information on evolution supernova mechanism



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This Workshop

- > 500 participants
  - Overflowed meeting space and had to limit attendance
  - Exceeded our expectations
  - Many international participants!
- Workshop peppered with ideas and enthusiasm
  - > 100 Parallel session talks
  - Much discussion! Sessions, posters, hallways, twitter
  - Valuable keynote talks – Drell, Murayama, Perez
- Demonstrated that a large community wants to do this science
- We have documented the science case
- Developing a strategy and program to be executed comes later.....

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Workshop Deliverables: Technical Report

Technical Report Timeline:

- 1st draft due ~ end of 2011 -- Done!
- Working group reports reviewed by community ~ end Jan 2012 --Done!
- Make available to HEPAP in March for comments -- (almost) Done!
- Final Report by ~ end of March 2012
- Will be posted on the arXiv

- Everyone who contributed is an author
  ~ 440 authors to date
- Total report ~ 220 pages
- Website to sign up in support of science opportunities will be available

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Example of Working Group Chapter

Report of the Heavy Quarks Working Group

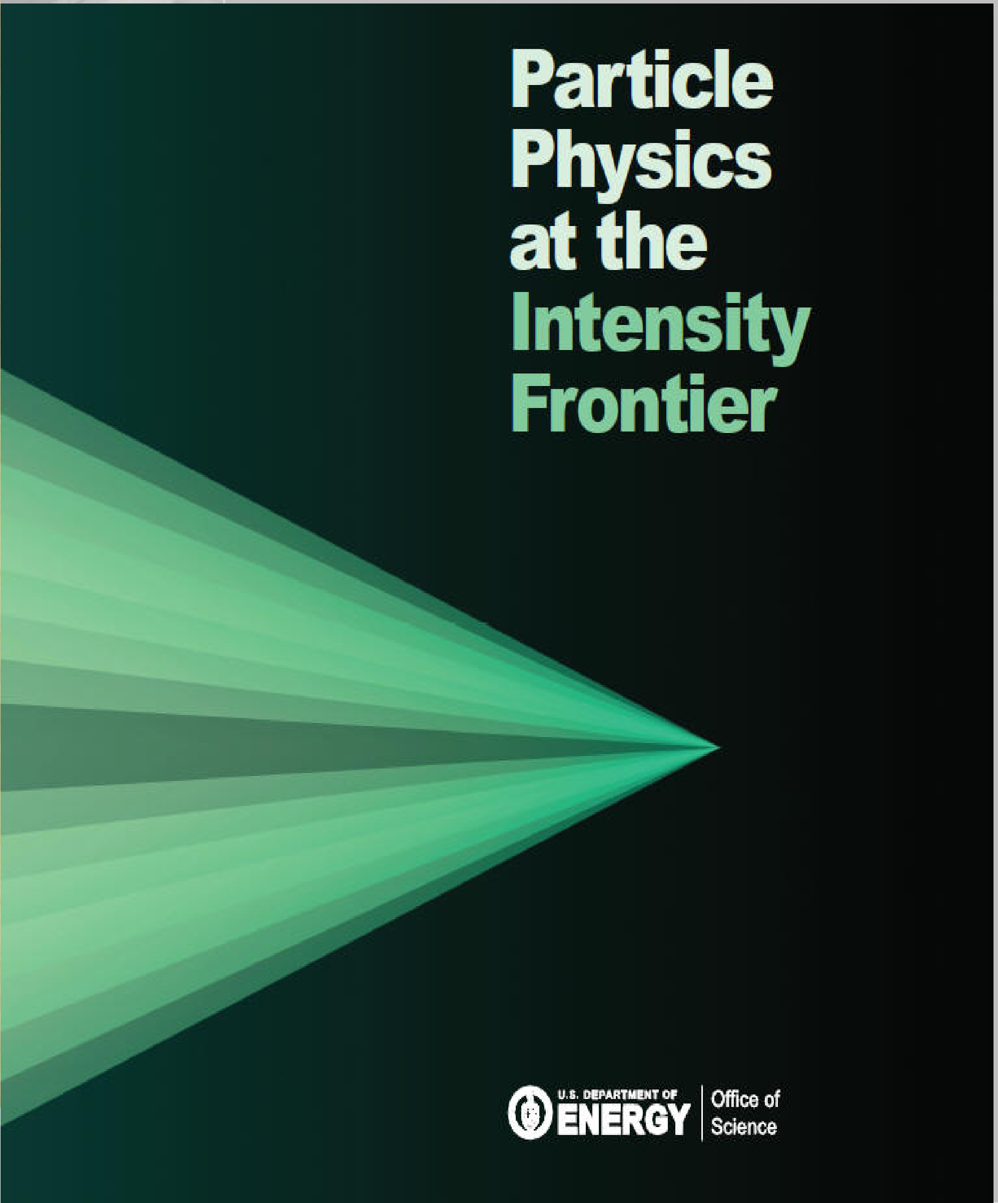
Conveners: J.N. Butler, Z. Ligeti, J.R. Patterson, J.L. Ritchie

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. Schopper, 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.

Workshop Deliverables: Glossy Brochure



Glossy Brochure:

- Communicators (FNAL, SLAC) in charge
- Ready by end of March

Workshop Deliverables: Glossy 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.

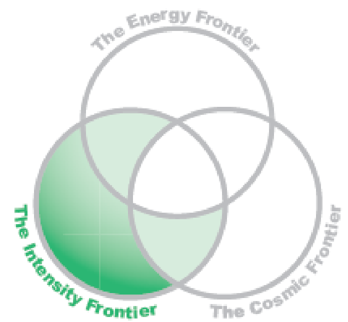


FIG 01 |

Q. Are there undiscovered laws of nature?

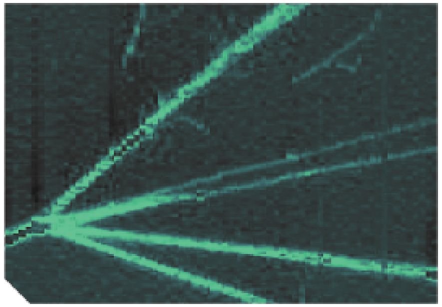
In their search for new fundamental particles and forces, particle physicists need to go beyond what they can learn from particle collisions or cosmic exploration. The Intensity Frontier lets them look at things from a new angle—for instance, searching for unexpected ways that one particle can change 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 |



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

What Next?

This workshop is just a step in the process towards making this program a reality

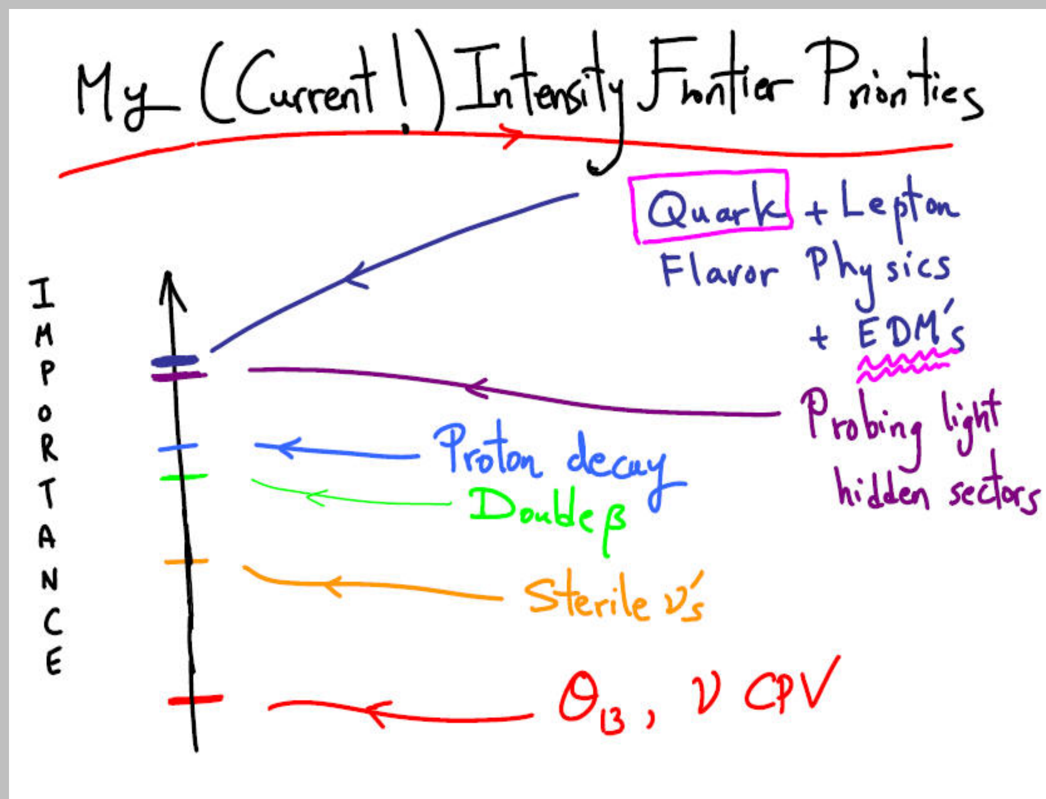
- See Glen's talk

- Broad Intensity Frontier discussion must continue
  - Centered on science opportunities
  - Communities should support each other
  - Community must be educated
  - Working groups should continue in some form

Engage the HEP Community

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

Otherwise, you may not like the resulting priorities!



Arkani-Hamed

Future workshops

Snowmass June 2- 22, 2013

--See Ramond's talk

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

Executive summary points

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

Continue 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

J. Hewett