Questions for Particle Physics, 2015-35

Maxim Perelstein, Cornell
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Introduction

• Technological developments and new ideas make a dizzying array of experiments in particle physics feasible on the relevant time scales

• However resources and manpower are not limited; somebody, somewhere, somehow, will need to make some choices

• The primary goal of our field is to determine the laws governing Nature at the most fundamental level possible

• Experimental programs should be judged according to how much they advance this goal; we theorists must provide this input. It will be convoluted with technological/political considerations by others.

• In this talk I will focus on three physics questions which (a) I care about; and (b) can be tackled experimentally within relevant time span

• They will be organized according to the three frontiers (thus contradicting the main idea of this workshop - sorry!)
Energy Frontier: Is the Electroweak Scale Natural?
2012: Year of the Higgs
A Lesson from the Higgs Story

- Discovery of the Higgs is wonderful, but it is not surprising

- Since the 1990’s, the existence of the Higgs was very strongly hinted at, and the “where to look” was pretty well constrained, by Precision Electroweak studies

- The observed mass is perfectly consistent with this plot

Figure: LEP EWWG, 2006
• Quantum loops of a heavy Higgs introduce corrections to S and T parameters, which can be predicted from the SM.

• They could have been canceled by contributions from some other new physics, carefully tuned at a \( \sim 1/10 \) or \( \sim 1/100 \) level; they are not.

• Lesson: (yet again) Nature is not a sneaky, mean-spirited, malicious beast. Nature is natural.
Higgs Properties are Beginning to Emerge at the LHC

- Spin-parity: looks like it is indeed $0^+$
- Some alternatives are excluded on very general theoretical grounds (e.g. Landau-Yang theorem)
- Others are increasingly constrained by measurements
Rates: SM-like at ~30% level

**Working Hypothesis:** SM Higgs to “0-th order”;
Deviations from SM, if any, suppressed systematically by a small parameter.
SM Higgs: Lagrangian and Physical Parameters

• The SM Higgs potential has two terms \( V = -\frac{\mu^2}{2} h^2 + \frac{\lambda}{4} h^4 \)

• Higgs gets a vacuum expectation value, known from e.g. the W mass:
  \[ v = \frac{\mu}{\sqrt{\lambda}} \]
  \[ M_W = \frac{g v}{2} = 80.4 \text{ GeV} \rightarrow v = 246 \text{ GeV} \]

• The physical Higgs boson mass is
  \[ m_h = \sqrt{2} \mu \]

• Higgs mass at \( \sim 126 \text{ GeV} \) gives
  \[ \mu = 88.4 \text{ GeV}, \quad \lambda = 0.13 \]

• Question: how reasonable ("natural") are these values?

• Focus on the mass parameter; quartic also important, but more model-dependent
SM Higgs: Renormalization

- Higgs mass parameter receives radiative corrections:

\[-\mu^2 = \mu_{\text{tree}}^2 + \frac{c_X^2}{16\pi^2} \Lambda_X^2, \quad c_X^2 = \kappa_X^2 N_X\]

- \( \kappa_X \) = Higgs-X coupling constant, \( N_X \) = # of d.o.f. in X (X=SM fields)

- Naturalness:

\[\frac{c_X^2}{16\pi^2} \Lambda_X^2 \lesssim \mu^2 \quad \Rightarrow \quad \Lambda_X \lesssim \frac{4\pi\mu}{c_X} \approx \frac{1 \text{ TeV}}{c_X}\]

- Simple measure of unnaturalness:

\[\Delta = \frac{\delta \mu^2}{\mu^2} \quad (\Delta > 1 = \text{fine-tuning})\]

- An alternative measure (usually agree up to \(O(1)\) factors):

\[\delta \mu^2 = f(p_i), \quad \Delta = \max_i \left| \frac{\partial \log \mu^2}{\partial \log p_i} \right|\]
Natural New Physics Scales

• Hierarchy of SM Higgs couplings

\[ \lambda \ll 1 \]

HIGGS

\[ g \sim 0.5 \]

\[ \lambda \sim 1 \]

TOP

\[ g_s \sim 1 \]

SU(2) \times U(1)

Gauge Bosons

SU(3)

Gluons

1st/2nd Gen. quarks, bottom, leptons

• Cutoff scales required by naturalness are inversely related to the couplings:

\[ \Lambda_X \lesssim \frac{4\pi \mu}{c_X} \approx \frac{1}{c_X} \text{TeV} \]

\[ c_X^2 = \kappa_X^2 N_X \]

• Top quark:

\[ c_t = 6 \lambda_t^2 \approx 6 \rightarrow \Lambda_t \lesssim 400 \text{ GeV} \]

• This energy scale is already being probed at the LHC, and will be definitively probed in the next decade
Options for New Physics

- Brute-force solution: Strong dynamics at $\Lambda_t$, with Higgs being a composite particle bound by new strong interactions, a la QCD mesons

- However, precision electroweak constraints imply a lower bound on the new strong interactions scale of ~a few TeV

- Thus, such Higgs models are typically fine-tuned at a ~1% level

- Alternative: Naturalness restored by weakly coupled physics at sub-TeV scale

- This would require relations between new particles’ and SM couplings to the Higgs symmetries. Highly non-trivial requirement.

- Two promising solutions: SUSY (complete) and pNGB/Little Higgs (partial, needs to be combined with compositeness/strong coupling at ~10 TeV)

- Definitive experimental tests of naturalness are feasible on the relevant time scales
Top Partners: Direct Searches

- The current “headline” LHC bound on stop mass is \(~700\) GeV; this implies \(~10\%\) fine-tuning

- However, there are several large “holes”:
  
  - No bound at all for \(m(\tilde{\chi}^0_1) > 250\) GeV - “mildly compressed” spectrum
  
  - No bound if \(m(\tilde{t}) \approx m(t)\) - “stealthy” spectrum
  
  - No bound if \(\tilde{t} \rightarrow \bar{b}\tilde{s}\) - R-parity violating models (e.g. MFV/RPV)
Top Partners: Direct Searches

- The bound on $T$ is $\sim 650$ GeV, implies $\sim 10\%$ fine-tuning
- Holes probably exist, papers have not been written due to relative lack of popularity of models compared to SUSY

Spin-1/2 top partner, a.k.a. “big $T$” (e.g. Little Higgs)
Gluinos and Naturalness

- Rad. corrections to the stop mass also need to be cut off (stop=scalar!)

- Dominated by QCD; cut off by the gluino naturalness requires

\[
\begin{align*}
m_g & \lesssim 2m_t \\
& \lesssim 4m_t
\end{align*}
\]

(Majorana gluinos, as in MSSM)
(Dirac gluinos)  
[Brust, Katz, Lawrence, Sundrum, ’11]

Reduces some of the holes: stealthy and RPV stops cannot be fully natural
Future of Direct Searches

- Two obvious directions: up in mass, and close the holes
- The latter requires new ideas/observables [join NP/Top working group!]
- For example, compressed spectrum may be explored with ISR tagging, given enough luminosity
- Important question for Snowmass: Are there holes that can only be closed at a lepton collider? Are those “big” enough to matter?
Tree-Level Tuning in SUSY

- So far, we focused on tree vs. loop tuning, which appears in all models.

- In SUSY, there is a separate issue: two distinct tree-level contributions to $m^2$

  $$m^2 = -m_{H_u}^2 + \mu^2$$

  SUSY-breaking soft mass $\rightarrow$ SUSY-preserving F-term

- Naturalness: $m^2 > \mu^2$ $\rightarrow$ expect light ($\sim 100$ GeV) Higgsinos

Search for Higgsinos decaying to binos; the bound implies $\sim 10\%$ tuning with usual caveats.

If neutral Higgsinos are the only light particles, the LHC will probably not be able to find it (but please prove me wrong!)

"Minimal" (sort of) spectrum
Higgs Couplings and Naturalness

Farina, MP, Rey Le-Lorier, 1305.6068

- One-loop quantum corrections to Higgs potential are given by the Coleman-Weinberg formula:

\[ V_{CW}(h) = \frac{1}{2} \sum_k g_k(-1)^F_k \int \frac{d^4\ell}{(2\pi)^4} \log(\ell^2 + m_k^2(h)) \]

- The only input is Higgs-dependent masses of all particles; focus on tops

- The famous mass renormalization is just \( \delta \mu^2 \equiv \frac{\delta^2 V_{CW}}{\delta h^2} \big|_{h=0} \).

- Top partner mass is \( m^2(T_i) = m_{0,i}^2 + c_i h^2 + \cdots \)

- Cancellation of quadratic divergence gives a sum rule: \( 6y_i^2 = \sum_i g_i(-1)^F_i c_i \)

- Potential fine-tuning comes from the next (log-divergent) term:

\[ \Delta = \frac{\delta \mu^2}{\mu^2} \approx 0.78 \left( \sum_i g_i(-1)^F_i c_i \left( \frac{m_{0,i}}{1 \text{ TeV}} \right)^2 \log \frac{\Lambda^2}{m_{0,i}^2} - 6y_i^2 \left( \frac{m_t}{1 \text{ TeV}} \right)^2 \log \frac{\Lambda^2}{m_t^2} \right) \]
Higgs Couplings and Naturalness

- Low-Energy Theorems give the top partner contributions to $hgg$ and $h\gamma\gamma$ in terms of the same object: Higgs-dependent top-partner mass

$$\mathcal{L}_{h\gamma\gamma} = \frac{2\alpha}{9\pi v} C_\gamma h F_{\mu\nu} F^{\mu\nu}, \quad \mathcal{L}_{hgg} = \frac{\alpha_s}{12\pi v} C_g h G_{\mu\nu} G^{\mu\nu}$$

$$C_\gamma = 1 + \frac{3}{8} \sum_{f} \text{Dirac fermions} \frac{N_{c,f} Q_f^2}{\ln m_f^2(v)} + \frac{3}{32} \sum_s \text{scalars} N_{c,s} Q_s^2 \frac{\partial \ln m_s^2(v)}{\partial \ln v}$$

$$C_g = 1 + \sum_{f} \text{Dirac fermions} C(r_f) \frac{\partial \ln m_f^2(v)}{\partial \ln v} + \frac{1}{4} \sum_s \text{scalars} C(r_s) \frac{\partial \ln m_s^2(v)}{\partial \ln v},$$

- Very general, very robust result: inverse correlation between fine-tuning and non-SM contributions to $hgg$ and $h\gamma\gamma$

- Only exceptions: non-colored, non-charged partners (see M. McCullough's talk on Wed); or accidental cancellations (but Nature's not mean)

- Benchmark example: a single top partner, spin 0 or 1/2, with quantum numbers of the SM top (e.g.: MSSM with degenerate stops)
Higgs Couplings and Naturalness

A 1% measurement of $R_{tg}$ would probe the top partner mass of ~1.2 TeV...

Figure: M. Peskin, 2012
Higgs Couplings and Naturalness

... and imply fine-tuning of at least 1/25 if no deviation from the SM is seen
Higgs Couplings and Naturalness

Precision Higgs coupling measurements give a robust test of naturalness, similar to strongly/weakly-coupled EWSB test via electroweak precision

Complementary to direct stop searches: no compressed, stealthy, RPV holes
Naturalness: What’s at Stake

• Robust experimental probes of naturalness of Electroweak Symmetry Breaking, at a \(\sim 1\%\) level, are within our reach

• My bet: we will discover new physics

• If we don’t, it will be a tremendously important result, with profound implications for our understanding of Nature, and the future of physics

• If no new physics at TeV, the observed value of the electroweak symmetry breaking scale must be regarded as a \(\sim 1/100\) coincidence

• There are examples in Nature of coincidences at this level: e.g. Sun & Moon angular sizes coincide to \(\sim 1/50\) (eclipses)

• We are not surprised: our Solar system is one of billions; we can see others

• The only reasonable framework to make sense of non-natural EWSB is to regard our physical laws as randomly selected from a large set of possibilities

• Unlike the Sun/Moon, we cannot see the patches of the universe where other possibilities are realized; our evidence for this hypothesis has to be indirect
Cosmic Frontier:
Is Dark Matter a Thermal Relic?
The existence of dark matter is an incontrovertible experimental fact

The non-SM nature of dark matter seems overwhelmingly likely

DM is a somewhat massive (> keV), electrically and color neutral, stable (or extremely long lived) particle

There are (too) many particle physics models; a useful zeroth-order classification is by cosmological history: “thermal” vs “non-thermal”

Vanilla thermal relic scenario is rather predictive: total pair-annihilation cross section $\propto$ present density, which is well known

$\sigma(\chi\chi \rightarrow \text{SM}) \sim 1 \text{ pb}$

$\sigma \sim \frac{\pi \alpha^2}{M^2}$

$\alpha \sim 0.1 \ldots 0.01 \rightarrow M \sim 0.1 \ldots 1 \text{ TeV}$

WIMPs!

Figure: Birkedal, Matchev, MP
Indirect Detection

- The most direct prediction of vanilla thermal relic is for indirect detection: same annihilation processes, happening today in our neighborhood.

- An important caveat: only know the total annihilation rate, summed over final states→ need a broad range of probes: photons, neutrinos, positrons, ...

- An equally important caveat: astrophysical backgrounds are in many cases not understood at the level needed to enable a real DM search (a cautionary example: Pamela/AMS)

- Indirect detection experiments will begin to get into the interesting cross range (with caveats)
Colliders

- DM production rates at colliders can be predicted, for a vanilla thermal relic, through a simple, robust, model-independent calculation

\[
\text{WMAP } \Omega_{\text{dm}} \Rightarrow \chi \rightarrow e^- e^+ \Rightarrow \chi \rightarrow e^+ e^- \Rightarrow \chi \rightarrow e^- e^- \Rightarrow \text{ILC } \sigma(\gamma + \bar{\nu})
\]

- Potentially observable rates of tag+MET predicted for both hadron and lepton colliders

- Caveats: Strong dependence on the DM mass; only know the total annihilation rate, summed over final states, but only collide one type of particles at a time

- Still: e.g. ILC can discover DM even if only \(\sim 1\%\) annihilate into electrons

Figure: Bartels and List
Direct Detection

- Unfortunately, prediction of vanilla thermal relic for elastic DM-nucleus scattering (a.k.a. direct detection) requires further theoretical assumptions.

- A simple, general framework in which this can be done is effective operator approach.

- In this framework, current and future direct detection experiments are probing the interesting cross section range, with mass regions complementary to indirect and collider searches.

![Graphs showing cross sections for different interactions with different standard model particles.](image)

Figure: Snowmass DM Complementarity WG
Dark Matter: What’s at Stake

- It seems that on the relevant time scales we might have a chance to test definitively the (vanilla) thermal relic dark matter framework, through a combination of probes.

- It would be nice to have this case clearly spelled out somewhere.

- My bet: we’ll discover it.

- My worry: Indirect detection seems very important, especially at high masses, but how can we eliminate astrophysical explanations? (Smoking-gun line signals are likely suppressed.)

- If I’m wrong: Non-thermal, or non-minimal thermal, DM would not be shocking from theory point of view. However it’s not nearly as predictive - too many options. Some attractive ideas: asymmetric (especially if CDMS’s 3 events are real), or axions.
Intensity Frontier: Is There Grand Unification?
Three strong hints for Grand Unification:

- Electric charge quantization must be embedded in non-Abelian group
- Fermion quantum numbers in the SM beg to be unified in SU(5) or larger multiplets
- Extrapolated SM gauge couplings approximately meet at the high scale, even in the SM (and much better with SUSY)
- Even in an unnatural world, I would bet that some version of gauge unification occurs
• **Neutrino Mass discovery hints at SO(10) unification:**

  • Full SM generation in a single multiplet, right-handed neutrino is mandatory

  • GUT-scale mass for $\nu_R$ is predicted, with light neutrino masses at $\sim \frac{v^2}{m_R}$ via see-saw mechanism

  • Measured $m_\nu \rightarrow$ estimate $m_R \sim 10^{14}$ GeV, reasonably close to the gauge coupling unification scale

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**Figure 4-2. Standard Model fermion masses.**

For the neutrino masses, the normal mass hierarchy was assumed, and a loose upper bound $m_i < 1$ eV, for all $i = 1, 2, 3$ was imposed.

This suspicion is only magnified by the possibility that massive neutrinos, unlike all other fermions in the Standard Model, may be Majorana fermions. The reason is simple: neutrinos are the only electrically neutral fundamental fermions and hence need not be distinct from their antiparticles. Determining the nature of the neutrino – Majorana or Dirac – would not only help guide theoretical work related to uncovering the origin of neutrino masses, but could also reveal that the conservation of lepton number is not a fundamental law of Nature. The most promising avenue for learning the fate of lepton number, as will be discussed in Sec. 4.3, is to look for neutrinoless double-beta decay, a lepton-number violating nuclear process. The observation of a non-zero rate for this hypothetical process would easily rival, as far as its implications for our understanding of nature are concerned, the first observations of parity violation and $CP$-invariance violation in the mid-twentieth century.

It is natural to ask what augmented, "new" Standard Model ($\nu$ SM) leads to non-zero neutrino masses. The answer is that we are not sure. There are many different ways to modify the Standard Model in order to accommodate neutrino masses. While these can differ greatly from one another, all succeed – by design – in explaining small neutrino masses and all are allowed by the current particle physics experimental data. The most appropriate question, therefore, is not what are the candidate $\nu$ SM's, but how can one identify the "correct" $\nu$ SM? The answer lies in next-generation experiments, which will be described throughout this chapter.

For concreteness we discuss one generic mechanism in more detail. The effect of heavy new degrees of freedom in low-energy phenomena can often be captured by adding to the Standard Model higher-dimensional operators. As first pointed out in [27], given the Standard Model particle content and gauge symmetries, one is allowed to write only one type of dimension-five operator – all others are dimension-six or higher:

$$1 \leftrightarrow (L^\dagger H + H^\dagger L) + v^2 \nu^\dagger + \text{h.c.},$$

where $L$ and $H$ are the lepton and Higgs boson $SU(2)_L$ doublets, and the arrow indicates one of the components of the operator after electroweak symmetry is broken. $v$ is the vacuum expectation value of the neutral component of $H$, and $\nu$ is the effective new physics scale. If this operator is indeed generated by some new physics, neutrinos obtain Majorana masses $m_\nu \sim \frac{v^2}{\nu}$. For $\nu \sim 10^{15}$ GeV, $m_\nu \sim 10^{1}$ eV, in agreement with the current neutrino data. This formalism explains the small neutrino masses via a seesaw mechanism:
Neutrinos: Next Steps

- Overall mass scale (CMB+LSS)
- Normal vs. Inverted mass hierarchy (CMB+LSS, LBNE)
- CP Violation (LBNE)
- BSM searches: sterile neutrinos, non-standard interactions, ... (my bet: no)

Figure: Intensity Frontier Report, 2011
GUTs: What’s Next

- Physical scales involved in GUTs are probably too high for a precise, definitive experimental proof of this paradigm

- Instead, proceed by collecting low-energy hints ("echoes"), and gradually building up confidence

- Neutrino mass/CP measurements cannot, in my opinion, make a significant impact on the overall case for GUTs, though they may help those who already believe in it to refine their models

- A striking, generic, not-yet-confirmed prediction of GUTs is violation of baryon and lepton number

- If either is observed, the case for GUTs would receive another major boost
B Violation: Proton Decay

- Theoretical predictions highly uncertain: both operators and scales are model-dependent

\[ \tau \sim \left( \frac{\Lambda}{10^{16} \text{ GeV}} \right)^4 \times 10^{34} \text{ yrs} \]

- But: Dim-6 operator gives

Figure: Intensity Frontier Report, 2011
5.2 Current and Proposed Proton Decay Search Experiments

Figure 5-4. The LBNE projected sensitivities for proton decay searches as a function of calendar year. Left panel: the sensitivity of the liquid argon detector option for the $p \rightarrow \nu K^+$ mode; Right panel: the sensitivity of the water Cherenkov detector option for the $p \rightarrow e^+ \pi^0$ mode. The dashed arrow marked as "WC 560" is the expected sensitivity by Hyper-K around year 2040, assuming, of course, it will be built as proposed.

K2K experiment, which also validated the neutrino simulations used for the water Cherenkov experiments. The level of expected background is 2 events/Mton/year, all from atmospheric neutrino interactions. The right panel in Fig. 5-4 shows the sensitivity that could be reached in this mode assuming no background improvements are made (red line). In fact, it may be possible to significantly reduce this background if a neutron detection capability (such as addition of Gadolinium) is realized. This is due to the fact that while 80% of proton decays in water should not have associated neutrons, atmospheric neutrino interactions are likely to produce one or more neutrons. These neutrons come from direct production via anti-neutrinos on oxygen, final state scattering of hadrons and $\pi^0$ capture on oxygen, and nuclear de-excitation. The figure shows the sensitivity reached if improvements allow rejection of all atmospheric neutrino backgrounds (blue line). The actual efficiency for background rejection will require measurements in a neutrino beam, and such an experiment is being planned for the FNAL booster neutrino beam.

5.2.2.2 Proton Decay Searches with the Hyper-Kamiokande Experiment

A next-generation underground water Cherenkov detector, Hyper-Kamiokande (Hyper-K), is proposed in Japan. If built, it will serve as a far detector of a long baseline neutrino oscillation experiment envisioned for the upgraded J-PARC, and as a detector capable of observing nucleon decays, atmospheric neutrinos, and neutrinos from astronomical origins. The baseline design of Hyper-K is based on the highly successful Super-K, taking full advantage of a well-proven technology. The total (fiducial) mass of the detector is 0.99 (0.56) million metric tons, which is about 20 (25) times larger than that of Super-K. The details of the proposed experimental setup are described in the earlier sections, and also can be found in the recently published Hyper-K Letter of Intent Abe:2011ts.

The sensitivity of Hyper-K for nucleon decays has been studied with a Monte Carlo (MC) simulation based on the Super-Kamiokande analysis. An estimate of the atmospheric neutrino background is necessarily included in the study.

Fundamental Physics at the Intensity Frontier

Proton Decay Future

Real chance (though no guarantee) of discovery!
L Violation: Neutrino-less Double Beta Decay

- If neutrino masses are indeed from unification/see-saw, they are Majorana and so, L-violating
- Fairly robust predictions for the rate of $0\nu\beta\beta$
- If inverted mass hierarchy, good chance of discovery in the conceivable future

Figure 4-7. Allowed values of $h_m$ as a function of the lightest neutrino mass for the inverted and normal hierarchies. The dark shaded regions correspond to the best-fit neutrino mixing parameters from [71] and account for the degeneracy due to the unknown Majorana phases. The lighter shading corresponds to the maximal allowed regions including mixing parameter uncertainties as evaluated in [71]. The dashed line shows expected sensitivity of next-generation $\sim 100$ kg class experiments and the dotted line shows potential reach of multi-ton scale future experiments.

There is one controversial result from a subset of collaborators of the Heidelberg-Moscow experiment, who claim a measurement of the process in $^{76}$Ge, with 70 kg-years of data [72]. These authors interpret the observation as giving an $h_m$ of 440 meV. Recent limits from NEMO-3 and Cuoricino (see below) are impinging on this $h_m$ regime, for $^{100}$Mo and $^{130}$Te respectively.

There is a large number of current neutrinoless double-beta decay search efforts, employing very different techniques; a recent review is [73]. Here we will highlight some for which there is a component of effort from physicists based in the US. These represent different kinds of detectors and experimental approaches.

The MAJORANA [74, 75, 76] experiment employs the germanium isotope $^{76}$Ge, to be enriched. The current phase of the experiment is the "Demonstrator", which will employ 30 kg of Ge enriched to 86% $^{76}$Ge and 10 kg of Ge P-type point contact detectors, with an aim of being underground at the Sanford Underground Research Facility (SURF) in 2013. The MAJORANA collaboration is planning a ton-scale effort in collaboration with its European counterpart GERDA.

The "bolometric" CUORE experiment [77], located at Gran Sasso National Laboratory in Italy, employs $^{130}$Te in the form of TeO$_2$ crystals. This is a cryogenic setup that determines energy loss via temperature rise measured with thermistors. The first phase of this experiment, Cuoricino, ran from 2003-2008 with 11.3 kg of $^{130}$Te mass. The current version of the experiment, CUORE-0, has 11 kg, and the plan for full CUORE starting in 2014 will have 206 kg.

Figure: Intensity Frontier Report, 2011

~100 kg: CUORE, EXO-200, MAJORANA, SNO+, ...

~1 Ton
GUTs: What’s at Stake

• Observation of B or L violation would make the case for GUTs overwhelming

• Even in an unnatural universe, I would bet on grand unification

• I would not bet on discovery on the relevant time scale, but the odds look decent

• In general, lack of discovery at this point would not have strong implications due to strong uncertainties in theoretical predictions

• However, if it turns out that neutrino mass hierarchy is inverted, neutrino-less double beta decay will provide a very robust test of L in a not-too-far-distant future
Summary

• In this talk, I shared my views about some of the important physics questions that may be addressed by experimental programs under discussion

• Probing naturalness of the electroweak scale seems to me the single most important issue on this list

• A combination of direct probes and precision Higgs physics offers an opportunity to settle this issue; huge impact on physics whichever way it goes

• I hope that the US community will have an opportunity to make a major contribution to this quest

• Wait, that’s not all...
Visions for Snowmass

Love Fest?

戦国時代 (The Warring States)?

Symposium

What we do best: Free and honest discussion of physics

Thanks to KITP and the Workshop Organizers!