Neutrosophic Knowledge, Vol. 9, 2026
University of New Mexico

Article

Unmatter in High Energy Physics: Theoretical Foundations, Experimental Verification, and Emerging Applications

Florentin Smarandache[1,*]

[1] University of New Mexico, Mathematics, Physics, and Natural Sciences Division, 705 Gurley Ave., Gallup, NM 87301, USA
* Correspondence: smarand@unm.edu

Received: Month Day, Year; *Accepted:* Month Day, Year; *Published:* Month Day, Year

Abstract: Unmatter—a state of matter defined by the stable or quasi-stable coexistence of intertwined matter and antimatter components—represents a significant departure from classical annihilation paradigms. Emerging from the nexus of neutrosophic logic, paradoxist philosophy, and high-energy particle physics, the concept provides a framework for understanding indeterminate material states. This paper synthesizes the conceptual evolution of unmatter and reviews the seminal 2015 Rutherford Appleton Laboratory (RAL) experiment, which successfully generated a high-density, charge-neutral electron-positron ($e^{-}e^{+}$) plasma, serving as the experimentum crucis for macroscopic unmatter. Furthermore, we survey contemporary research (2024–2025) that integrates unmatter into Quantum Chromodynamics (QCD), exotic plasma dynamics, and neutrosophic computational models. Finally, we propose future research trajectories, including the application of super-hypergraph modeling to complex unmatter systems and the exploration of novel energy-generation architectures.

Keywords: Unmatter, Neutrosophic Logic, High-Energy Physics, Antimatter, Electron-Positron Plasma, Rutherford Appleton Laboratory (RAL), Quantum Chromodynamics (QCD), Super-Hypergraph Modeling, Bound States.

1. Introduction

The conceptual framework of **unmatter** [11, 12] was first introduced by Smarandache as a physical extension of **neutrosophy**—a branch of philosophy concerned with the nature of neutralities and the spectrum of indeterminacy [10]. In neutrosophic logic, any proposition is characterized by a triad of truth (T), indeterminacy (I), and falsity (F). When mapped onto the ontologies of high-energy physics [1], this triad challenges the traditional binary of matter versus antimatter.

Classical particle physics generally views matter and antimatter as mutual antagonists that undergo rapid annihilation upon contact. In contrast, unmatter posits the existence of **stable or metastable configurations** where matter and antimatter components coexist in a bound or intertwined state. This transition from "annihilation partners" to "coexistence partners" marks a paradigm shift in how we categorize composite particles and exotic states of matter.

The relevance of unmatter to contemporary **High-Energy Physics (HEP)** [15] is demonstrated through several critical intersections:

- **Quantum Chromodynamics (QCD)** [7] **and Meson Physics** [18]: At the subatomic level, mesons—composed of a quark (q) and an antiquark ($\bar{q}$)—serve as the most fundamental realization of unmatter. Because they are neither purely matter nor purely antimatter, they embody the neutrosophic "neutral" state.

- **Unparticle Physics** [4, 5]: The theoretical construct of "unparticles," which exhibit scale-invariance and fractional excitations, can be interpreted as a specialized manifestation of unmatter. In this context, the indeterminate component (*I*) describes the non-integer nature of the particle's scaling dimension.
- **Exotic Plasma Dynamics** [19]: On a macroscopic scale, the generation of **charge-neutral electron-positron** (e^-e^+) **plasmas** via ultra-intense laser-matter interactions provides a laboratory for studying unmatter in bulk. These plasmas do not immediately annihilate but instead exhibit collective electromagnetic behaviors, creating a macroscopic "unmatter environment."
- **Computational and Mathematical Modeling:** Beyond physical particles, the neutrosophic triplet (*T*, *I*, *F*) offers a robust logical substrate for modeling the stochastic and indeterminate interactions within complex particle systems, leading to the development of **neutrosophic computational frameworks** for HEP data analysis.

By synthesizing these diverse domains, the study of unmatter moves beyond speculation into a rigorous inquiry of the fundamental symmetries—and asymmetries—of the universe.

2. Conceptual Foundations

2.1. Neutrosophic Logic and the Neutral State

At its core, **neutrosophy** defines three independent components for any logical statement or physical system: **Truth (*T*)**, **Indeterminacy (*I*)**, and **Falsity (*F*)**. Unlike classical fuzzy logic, these components range over the non-standard unit interval $]^-0, 1^+[$, and are not necessarily constrained by the sum $T + I + F = 1$. [10]

In the context of high-energy physics, we map these components onto the material composition of a system:

- ***T* (Matter):** The presence of matter particles (e.g., quarks, electrons).
- ***F* (Antimatter):** The presence of antimatter particles (e.g., antiquarks, positrons).
- ***I* (Indeterminacy/Unmatter):** The degree of binding, neutral coexistence, or "neutrality" where the identity of the system as purely matter or antimatter is lost.

The **neutral element (*n*)** corresponds to a region where *I* is maximized and *T*≈*F*. Mathematically, an unmatter entity *U* can be represented by a composition vector:

$$\mathrm{V_U} = \begin{pmatrix} M \\ I \\ A \end{pmatrix}$$

where *M* is the matter percentage, *A* is the antimatter percentage, and *I* represents the indeterminate interaction term. For a perfectly balanced unmatter system, such as a neutral pion (π^0), the vector approaches (α, *I*, α), where the interaction term *I* accounts for the gluon field and binding energy that prevents immediate annihilation.

2.2 Physical Realizations: From Microscopic to Macroscopic

Unmatter is not merely a speculative construct; it manifests across various energy scales. The following descriptions categorize these realizations by their physical structure:

- **Mesons (π, K, …):** These are the most common microscopic realizations. As bound states of a quark (q) and an antiquark ($\bar{q}$), they exist in a state of constant "internal tension" between matter and antimatter, governed by the Strong Force.
- **Unatoms:** In the realm of nuclear physics, unatoms are hypothetical nuclei consisting of both nucleons and antinucleons (e.g., a system of $p + \bar{p}$). While highly unstable, they represent a complex "neutral" material state.
- **Electron-Positron** (e^-e^+) **Beam Plasma:** This represents a **macroscopic** realization. When ultra-intense lasers interact with high-Z targets, they create a dense, charge-neutral plasma where matter and antimatter are spatially intertwined. Unlike individual particle pairs, this plasma exhibits collective electromagnetic modes (see §4).

- **Unparticles:** Emerging from scale-invariant sectors of theoretical physics, unparticles can be modeled as a continuous superposition of unmatter states. Their lack of a definite mass shell reflects the "indeterminacy" (I) component of neutrosophic logic.

These realizations demonstrate that unmatter is an essential category for describing particles and states that do not fit the binary "matter vs. antimatter" classification.

3. Historical Development

The trajectory of unmatter research is characterized by an increasing convergence between abstract logic and high-energy experimental physics. The following milestones delineate this evolution:

3.1. The Ontological Proposal (2004)

The term "unmatter" was formally introduced by **Smarandache** in 2004 [11]. Grounded in the principles of **neutrosophy**, the original proposal argued that the exclusion of "neutral" states in particle physics was a limitation of binary logic. By defining unmatter as a combination of matter and antimatter that is neither purely one nor the other, Smarandache provided a theoretical bridge for understanding complex bound states that do not undergo immediate annihilation.

3.2. The Unparticle Connection (2008)

A pivotal theoretical expansion occurred when **Goldfain and Smarandache** (2008) [6] linked unmatter to the emerging field of **unparticle physics**. Unparticles represent a scale-invariant sector of physics that does not consist of standard particles with definite mass. By interpreting these fractional field quanta as mixed matter-antimatter states, the researchers suggested that unmatter could provide the physical substrate for non-standard scaling dimensions in quantum field theory.

3.3. Dissemination via the American Physical Society (2008–2017)

Throughout the period of 2008–2017, a series of technical abstracts were presented at **American Physical Society** (APS) meetings, covering various facets of unmatter. These range from nuclear models (the Brightsen Nucleon Cluster Model) to the 2017 interpretation of the "Angel Particle" as an experimental manifestation of unmatter. This persistent presence in APS proceedings—spanning the divisions of Plasma, Nuclear, and Atomic physics—underscores a sustained dialogue between neutrosophic theory and the broader high-energy physics community. (See *Supplemental References, 20-31*, for a detailed list of these proceedings.)

3.4. The "Experimentum Crucis" at RAL (2015)

The year 2015 marked the transition from theoretical conjecture to empirical verification. Conducted at the **Rutherford Appleton Laboratory (RAL)** using the **Astra Gemini laser**, a landmark experiment [9, 17] led to the generation of a high-density, charge-neutral electron-positron ($e^{-}e^{+}$) plasma.

- This achievement was hailed as the "experimentum crucis" for unmatter, as it realized a macroscopic state where matter and antimatter components coexisted and exhibited collective behavior before annihilation.
- Unlike individual pair production, this "unmatter plasma" allowed for the study of global electromagnetic properties of intertwined matter-antimatter systems [13].

3.4. Modern Synthesis and Super-Hypergraphs (2024–2025)

In recent years, interest in unmatter has shifted toward **computational and structural modeling**. Recent publications in journals such as *Neutrosophic Sets and Systems* (https://fs.unm.edu/NSS/) have integrated unmatter into:

- **Super-hypergraph models**: Used to map the multidimensional interactions within unmatter-related systems.
- **Decision-making under uncertainty:** Applying the *I* (Indeterminacy) component of unmatter to model high-risk variables in energy-analysis frameworks.
- **Exotic Plasma Engineering:** Exploring the potential for unmatter states to serve as precursors for novel energy-generation schemes.

4. Experimental Verification: The 2015 RAL "Experimentum Crucis"

The experiment was conducted at the **Central Laser Facility (CLF)** using the **Astra Gemini laser system**. Led by Gianluca Sarri (Queen's University Belfast) and an international team, the study successfully generated a high-density, quasi-neutral electron-positron ($e^- e^+$) plasma. This result provided the first empirical evidence that macroscopic "unmatter" could be sustained long enough to exhibit collective plasma dynamics. [9, 17]

4.1 Technical Methodology

The experiment utilized a two-stage approach to overcome the traditional difficulty of creating and merging separate matter and antimatter populations:

1. **Laser-Driven Acceleration:** The Astra Gemini laser (delivering ultra-short pulses of ≈40fs) was focused onto a gas jet (helium and nitrogen). This created a **Laser Wakefield Accelerator (LWFA)**, propelling a beam of electrons to ultra-relativistic energies (ranging from 500 to 600 MeV).
2. **The Cascade Process:** This high-energy electron beam was directed into a thick, high-*Z* target (specifically **lead**). As the electrons traversed the lead, they underwent a two-step electromagnetic cascade:
   - **Bremsstrahlung:** Electrons interacted with the electric fields of the lead nuclei, emitting high-energy gamma-ray photons.
   - **Pair Production:** These photons, in turn, interacted with the nuclear fields to produce electron-positron pairs ($e^- e^+$).

4.2 Results and "Unmatter" Characteristics

The experiment yielded a beam consisting of an approximately equal number of electrons and positrons. Key parameters included:

- **Charge Neutrality:** The resulting beam achieved a positron-to-electron ratio near unity.
- **High Density:** The pair density reached $\approx 10^{15}$cm^3, with a total yield of $\approx 10^9$ to 10^{10} pairs per shot.
- **Collective Behavior:** Crucially, the **Debye length** (the scale over which charges screen each other) was much smaller than the beam size. This is the defining characteristic of a **plasma** versus a collection of individual particles, confirming that the system was a single, intertwined "unmatter" state.

4.3 Why "Experimentum Crucis"?

In neutrosophic terms, this experiment moved the study of unmatter from the microscopic (individual mesons) to the **macroscopic**. By creating a bulk state where matter and antimatter are not merely "annihilation partners" but are part of a shared, stable-velocity plasma, RAL demonstrated that the *Indeterminacy (I)* component—the neutral coexistence of the system—is a controllable physical reality.

5. Theoretical Implications

5.1 Quantum Chromodynamics (QCD) and Confinement [16]

Unmatter serves as a unique laboratory for probing the **confinement mechanism** of quarks. In classical Lattice QCD, simulations often struggle with the "sign problem" when dealing with high-density systems. However, unmatter configurations—by maintaining approximate matter-antimatter neutrality—can be modeled to enforce $T \approx F$ (Truth $\approx$ Falsity), potentially simplifying the study of gluon-mediated bound states. This allows for:

- **Probing the Flux Tube:** Analyzing how the "indeterminate" (*I*) energy of the gluon field fluctuates in stable $q\bar{q}$ clusters.
- **Mixed-System Confinement:** Testing if exotic neutral mesons (such as the hypothesized **X17** or **E38** particles) follow the structural rules of macroscopic unmatter.

5.2 Neutrosophic Computational Models: Super-HyperGraphs [3]

A major breakthrough has been the application of **Neutrosophic Super-HyperGraphs (NSHG)** [14] to model the hierarchical complexity of unmatter plasmas.

- **Super-Vertices:** Instead of individual particles, super-vertices represent **clusters of particles** that act as coherent units within the plasma.
- **Super-Edges:** These represent the collective fields (electromagnetic and nuclear) that bind the vertices together.

This mathematical framework allows researchers to propagate uncertainty across scales, from the subatomic level up to the macroscopic plasma bulk, providing a more accurate representation of the "Indeterminacy" inherent in unmatter.

5.3 Energy-Release Scenarios

The traditional view of matter-antimatter interaction is one of pure loss (conversion to gamma-ray photons). Unmatter theory suggests that **controlled collisions** between unmatter plasma and conventional matter may follow different decay channels. By utilizing the collective shielding effects of the e^-e^+ plasma, energy may be released through directed kinetic channels rather than isotropic radiation.

5.4 Case Studies in Material Engineering

The transition from unmatter theory to material engineering has been facilitated by the development of **Physical Super-HyperStructures**. Recent 2025 studies demonstrate the following applications:

- **Grain Boundary Networks & Crystal Graphs:** Engineers have introduced **Grain Boundary Super-HyperNetworks** to model the hierarchical architecture of polycrystalline materials. [2] By treating grain boundaries as "super-edges" in a **Crystal Super-HyperGraph**, it is now possible to perform multi-scale analysis of how microscopic defects influence the macroscopic structural integrity of high-strength alloys.
- **Thermoelectric Material Discovery:** Researchers are combining **Crystal Graph Neural Networks** with neutrosophic logic to map the relationship between atomic structures and thermoelectric efficiency (η). [8] This "material mapping" accounts for structural indeterminacy—a key characteristic of unmatter states—facilitating the discovery of novel superconductors and high-efficiency thermal conductors.
- **Sustainable Power Plant Synthesis:** A 2025 paper formalized the use of **Physical Super-HyperStructures** to model "meta-ensembles" of steady-state power plants. [3] This framework captures the inherent uncertainty in energy balances (analogous to the dynamics in **unmatter plasma reactors**) and propagates it through multi-layered hierarchical interactions to optimize plant-wide synthesis.

6. Emerging Applications

The convergence of neutrosophic modeling and high-energy experiment has led to several prospective applications:

Table 1: *Emerging Trajectories for Unmatter Technologies: From Medical Diagnostics to Deep-Space Propulsion*

Domain	*Potential Role of Unmatter*
Space Propulsion	**High-Density Fuel:** Using unmatter-matter collisions to generate thrust. The neutral nature of unmatter reduces the magnetic shielding weight required for storage compared to pure antiproton fuels.
Medical Imaging	**Neutrosophic PET:** Enhanced diagnostics using "mixed-state" signatures. Instead of simple annihilation counts, unmatter-informed algorithms can filter signal noise (Indeterminacy) to provide higher-resolution voxel mapping.
Material Science	**Neutrosophic Metamaterials:** Designing materials guided by Super-HyperGraph models whose electromagnetic responses mimic the neutral distributions of unmatter.
Smart-Grid Optimization	**Indeterminate Dispatch:** Using neutrosophic algorithms to manage the "indeterminate" power output from theoretical **unmatter-based micro-reactors**, allowing grids to balance supply/demand in real-time under extreme volatility.

7. Conclusion

Unmatter bridges philosophical notions of neutrality with tangible high-energy phenomena. The 2015 RAL electron-positron plasma experiment substantiates its existence at macroscopic scales, while ongoing theoretical work situates unmatter within QCD, unparticle physics, and neutrosophic computation. By leveraging super-hypergraph representations and uncertainty-aware decision frameworks, researchers can explore novel energy-conversion schemes, advanced diagnostic technologies, and materials with engineered neutral charge characteristics. Continued interdisciplinary effort—uniting particle physics, logic theory, and computational modeling—will be essential to unlock the full scientific and technological potential of unmatter.

References

1. Braibant, S.; Giacomelli, G.; Spurio, M. (2009). *Particles and Fundamental Interactions: An Introduction to Particle Physics*. Springer.
2. Fujita, Takaaki. (2025). "Unifying Grain Boundary Networks and Crystal Graphs: A HyperGraph and SuperHyperGraph Perspective in Material Sciences." *Asian Journal of Advanced Research and Reports*, 19:344-379. DOI: 10.9734/ajarr/2025/v19i51023.
3. Fujita, Takaaki. (2025). "Toward a Formal Framework of Physical SuperHyperStructures: Multi-Layered Extensions of Hyperstructures in Physics." *Neutrosophic Optimization and Intelligent Systems*, 8:1-18. DOI: 10.61356/j.nois.2025.8631.
4. Georgi, Howard (2007). "Unparticle physics." *Physical Review Letters*, 98(22), May 2007.
5. Georgi, Howard (2007). "Another odd thing about unparticle physics." *Physics Letters B*, 650(4):275–278, July 2007.
6. Goldfain, E., & Smarandache, F. (2008). "On Emergent Physics, Unparticles and Exotic Unmatter States." *Progress in Physics*, 4:10-15, 2008, https://fs.unm.edu/PP-15-02.pdf .
7. Greiner, Walter; Schramm, Stefan; Stein, Eckart (2007). *Quantum Chromodynamics*. Springer.
8. Jia, X., Aziz, A., Hashimoto, Y. et al. (2024). "Dealing with the big data challenges in AI for thermoelectric materials." *Sci. China Mater.* 67, 1173–1182.

9. Sarri, G., Poder, K., Cole, J. et al. "Generation of neutral and high-density electron–positron pair plasmas in the laboratory." *Nature Communications* 6, 6747 (2015). https://doi.org/10.1038/ncomms7747
10. Smarandache, Florentin (2002). *A Unifying Field in Logics: Neutrosophic Logic. Neutrosophy, Neutrosophic Set, Neutrosophic Probability* (3rd edition), Am. Res. Press. www.gallup.unm.edu/~smarandache/eBook-Neutrosophics2.pdf
11. Smarandache, Florentin (2004). "Matter, antimatter, and unmatter." CERN, EXT-2004-142, 1-4. https://cds.cern.ch/record/798551/files/ext-2004-142.pdf
12. Smarandache, Florentin (2005). "A New Form of Matter — Unmatter, Composed of Particles and Anti-Particles." *Progress in Physics*, 1:9-11. https://digitalrepository.unm.edu/math_fsp/51
13. Smarandache, Florentin (2015). "Unmatter Plasma Discovered." *Progress in Physics*, 3:246-246. https://digitalrepository.unm.edu/math_fsp/50
14. Smarandache, Florentin (2020). "Introduction to the n-SuperHyperGraph - the most general form of graph today." *Neutrosophic Sets and Systems*, 33:289-295. https://doi.org/10.5281/ZENODO.3783103
15. Smarandache, Florentin (2024). "Partial Collisions of Unmater-Matter, Unmatter-Antimatter, and $Unmatter_1$-$Unmatter_2$ to Generate High Energy." *Progress in Physics*, 20(1):33-35, https://fs.unm.edu/Physics/PartialCollisionsUnmaterMatter.PDF
16. Smith, C.H.L. (1980). *Topics in Quantum Chromodynamics*. In: Mahanthappa, K.T., Randa, J. (eds) *Quantum Flavordynamics, Quantum Chromodynamics, and Unified Theories*. NATO Advanced Study Institutes Series, vol 54. Springer. https://doi.org/10.1007/978-1-4613-3099-8_2
17. Warwick, J.; et al., "Experimental observation of a current-driven instability in a neutral electron-positron beam," *Physical Review Letters*, Vol. 119, 185002, 2017. https://doi.org/10.1103/PhysRevLett.119.185002
18. Weinberg, Steven (1983). *The Discovery of Subatomic Particles*. Scientific Amer.
19. Xian, Y., Zhang, P., Lu, X. et al. (2013). "From short pulses to short breaks: exotic plasma bullets via residual electron control." *Sci. Rep*. 3, 1599. https://doi.org/10.1038/srep01599

Supplemental References (International Conference Abstracts from the American Physical Society, https://www.aps.org/)

20. Florentin Smarandache, Dmitri Rabounski: *Discovered "Angel Particle", which is Both Matter and Antimatter, as a New Experimental Proof of Unmatter*. 2017 Annual Meeting of the Far West Section, Friday–Saturday, November 3–4, 2017; Merced, California. http://meetings.aps.org/Meeting/FWS17/Session/E1.16
21. Florentin Smarandache: *Unmatter Plasma revisited*. 59th Annual Meeting of the APS Division of Plasma Physics, Volume 62, Number 12, Monday–Friday, October 23–27, 2017; Milwaukee, Wisconsin. http://meetings.aps.org/Meeting/DPP17/Session/YP11.35
22. Florentin Smarandache, Mumtaz Ali: *Neutrosophic Triplet as extension of Matter Plasma, Unmatter Plasma, and Antimatter Plasma*. 69th Annual Gaseous Electronics Conference, Volume 61, Number 9, Monday–Friday, October 10–14, 2016; Bochum, Germany. http://meetings.aps.org/Meeting/GEC16/Session/HT6.111
23. Florentin Smarandache: *Unmatter Plasma*, 57th Annual Meeting of the APS Division of Plasma Physics, Volume 60, Number 19, Monday–Friday, November 16–20, 2015; Savannah, Georgia, http://meetings.aps.org/Meeting/DPP15/Session/UP12.46
24. Florentin Smarandache, Mumtaz Ali: *Neutrosophic Triplet as extension of Matter Plasma, Unmatter Plasma, and Antimatter Plasma*, 69th Annual Gaseous Electronics Conference, Volume 61, Number 9, Monday–Friday, October 10–14, 2016; Bochum, Germany, http://meetings.aps.org/Meeting/GEC16/Session/HT6.111
25. Florentin Smarandache: *Unparticle, a special case of unmatter*, Bulletin of the American Physical Society, 53rd Annual Meeting of the APS Division of Plasma Physics, Volume 56, Number 16, Monday–Friday, November 14–18, 2011; Salt Lake City, Utah, http://meetings.aps.org/Meeting/DPP11/Event/153509
26. Ervin Goldfain, Florentin Smarandache: *Connection between `unparticle' and `unmatter'*, Bulletin of the American Physical Society, 2010 Annual Meeting of the California-Nevada Section of the APS Volume 55, Number 12, Friday–Saturday, October 29–30, 2010; Pasadena, California, http://meetings.aps.org/Meeting/CAL10/Event/135968
27. Dmitri Rabounski, Florentin Smarandache: *The Brightsen Nucleon Cluster Model Predicts Unmatter Entities inside Nuclei*, Bulletin of the American Physical Society, 2008 Annual Meeting of the Division of Nuclear Physics Volume 53, Number 12, Thursday–Sunday, October 23–26, 2008; Oakland, California, http://meetings.aps.org/Meeting/DNP08/Event/87738

28. Ervin Goldfain, Florentin Smarandache: *On Emergent Physics, Unparticles and Exotic Unmatter States*, Bulletin of the American Physical Society, 2009 Joint Spring Meeting of the New England Section of APS and AAPT Volume 54, Number 5, Friday–Saturday, May 8–9, 2009; Boston, Massachusetts, http://meetings.aps.org/link/BAPS.2009.NES.APSP.2
29. Florentin Smarandache: *Verifying Unmatter by Experiments, More Types of Unmatter, and a Quantum Chromodynamics Formula*, Bulletin of the American Physical Society, 62nd Annual Gaseous Electronics Conference Volume 54, Number 12. Tuesday–Friday, October 20–23, 2009; Saratoga Springs, New York, http://meetings.aps.org/link/BAPS.2009.GEC.KTP.110
30. Florentin Smarandache: *A New Form of Matter -- Unmatter, Composed of Particles and Anti-Particles*, Bulletin of the American Physical Society, 40th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics Volume 54, Number 7. Tuesday–Saturday, May 19–23, 2009; Charlottesville, Virginia, http://meetings.aps.org/link/BAPS.2009.DAMOP.E1.97
31. Florentin Smarandache: *Unparticle, a special case of unmatter*, Bulletin of the American Physical Society, 53rd Annual Meeting of the APS Division of Plasma Physics Volume 56, Number 16. Monday–Friday, November 14–18, 2011; Salt Lake City, Utah, http://meetings.aps.org/Meeting/DPP11/SessionIndex3/?SessionEventID=158034