

# **Particle Physics Science and Technology Connections**

## **Dave Nygren Fest May 2014**

**Dr. James Siegrist, Associate Director,  
Office of High Energy Physics  
Office of Science, U.S. Department of Energy**

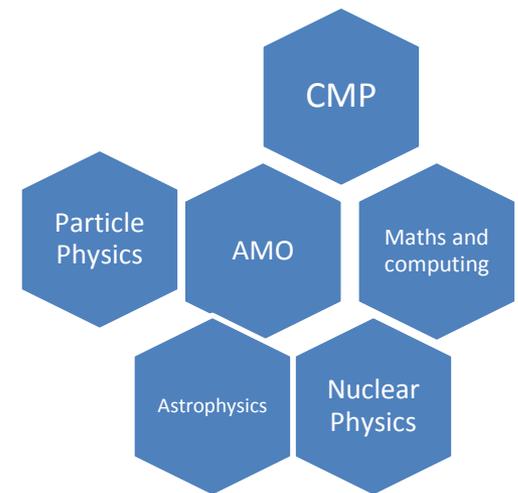
# Benefits to HEP of Connections to Other Fields of Science

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- **The strength of the US S&T enterprise in which US HEP is embedded is a significant technical advantage for US HEP relative to competing regions**
  - Only relevant if HEP community systematically takes advantage of the technical opportunities presented by our sister sciences
  - Need to identify and develop community support around those connections areas with largest promise for impact either in HEP or the allied field.
- **We hope that increasing the strength of HEP connections with the rest of the US S&T enterprise will enhance value to science and society.**
  - This aspect complements the main technical goal above and our primary HEP mission (also much harder to quantify).

# Particle Physics Connections with Other Disciplines

- **Science Connections - to other Science Disciplines via synergies in the underlying physical systems and/or theoretical, mathematical, or computational frameworks that describe their behavior.**
- **Technology Connections - via similar tools and techniques useful in pursuing science priorities of individual programs.**
- **HEP recently charged Two Task Forces to explore some of the connections of Particle Physics with other basic sciences and beyond, and identify science opportunities at the interfaces.**
- **This follows a prior 1998 NAS report that had studied such intersections**



# Connections Task Forces

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## **Science Connections of Particle Physics with other Disciplines**

**Co Chairs: Curt Callan (Princeton U) & Shamit Kachru (Stanford U and SLAC)**

## **Tools, Techniques, and Technology Connections of Particle Physics**

**Co Chairs: Marcel Demarteau (ANL) & Katie Yurkewicz (FNAL)**

**Each task force worked with external consultants from various fields who provided very encouraging individual comments and ideas to the Co Chairs**

**Both Task Forces presented findings at the March 2014 HEPAP and to P5 in 2013. Both point out the need for further work to identify more areas of synergy.**

**Some summary opportunities from the preliminary reports as well as HEP suggestions for paths forward are outlined here.**

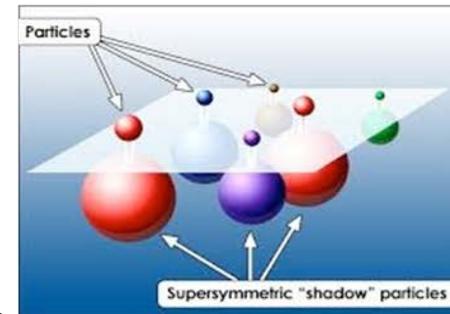
**HEP POC for both reports and for follow up on Opportunities:**

**Lali Chatterjee**

# Science Connections

The Science connection task force has identified an ‘inner circle’ of closely connected fields like

- Condensed Matter Physics (CMP)
- Atomic, Molecular and Optical Physics (AMO)
- Quantum Information Systems
- Nuclear Physics
- Astrophysics



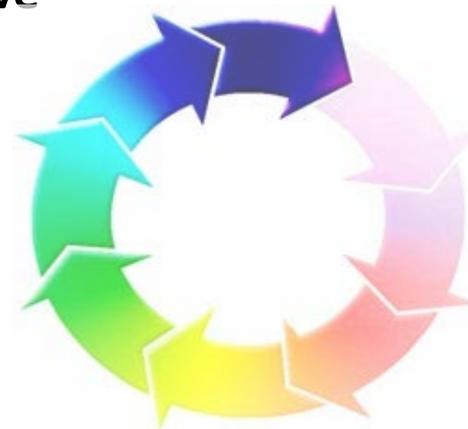
and science opportunities at the interfaces

In addition, they have identified interesting intellectual synergies with **plasma physics** and **climate science** as a ‘middle circle’ of connections, with **biology**, **neurobiology**, and **social sciences** comprising an ‘outer circle’ of potential connections.

# Technology Connections

**The Technology Connection Report identified many areas where particle physics research has**

- \* led to development of tools and techniques that have benefited science and technology**
- \* benefitted from and developed tools based on discoveries in other science areas**
- \* where technology has completed a cycle of connections – starting from HEP, being developed by others and returning to advance HEP**



**The report has identified strong connections for advancing detector technology, computational techniques, algorithms, and data tools, increasing user bases for HEP Facilities, and enhancing the growing connections for accelerator technology amongst other topics.**

**Some Near Term Connections Possibilities and Examples follow**

# Some Near Term Connections Opportunities Identified in the HEPAP Reports

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## **Accelerator Technology -**

LCLS2 for BES expected to use technology developed by HEP and NP

## **Condensed Matter Physics –**

strongly correlated/coupled systems, lattice/ string theory techniques...

## **Atomic and Molecular Physics -**

measuring electron EDMs, axion/gravity wave detection, cold atoms....

## **Materials Science –**

designer materials for radiation detection, instrumentation/data tools

## **Quantum Information Systems –**

topological quantum field theory, string theory, quantum/novel computing

## **Computing –**

data systems/data facilities, multi –science and computing partnerships

## **Particle Physics Facilities –**

expanding users to atmospheric science, muon and neutrino physics/applications....

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# Developing Connections Opportunities and Examples

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- **Partnerships and collaborations come naturally to the particle physics community as evidenced by our large international and multi institutional experiments and projects.**
- **Discussions and community workshops on some of the topics in this talk and the Reports are already underway.**
- **The first steps towards pursuing new opportunities and developing new connections would be to start with discussions that lead to community white papers.**
- **These could form the basis of structured Inter – Disciplinary Office of Science workshops prior to Agency consideration**
- **We at HEP plan to develop systematic identification of potential topics and partnering communities over the Summer**
- **We strongly urge you to contact us (Lali at HEP) prior to contacting partner communities to explore opportunities**
- **Some examples such as Detector Materials & Quantum Computing follow**

# Example 1: Engineered Materials for Radiation Detection

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- **At the level of slogans:**
  - The condensed matter community wants to move from ‘materials property discovery’ to ‘materials property design’, and seem to be making real progress along these lines
  - Can this capability be applied to develop new materials for radiation detection?
- **As in any design problem, progress can’t be made until requirements are sufficiently understood.**
  - Study of the ‘fundamental limits’ (quantum, statistical, or thermodynamic, depending on the system) of system performance all the way thru the readout chain are needed in order to specify materials design
  - Such studies are a lot of work, and require deep understanding of the active material and readout as a combined system to develop a successful design

# Example 1: Nygren's Work with NEXT Collaboration

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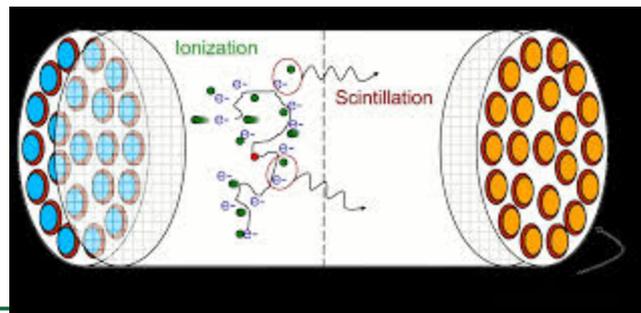
- **Dave and NEXT members realized the 'intrinsic' energy resolution of Xenon high pressure gas was of order 1%.**
- **The measurements showed these good results, but a fundamental (atomic) level understanding of why the resolution behaves that way still eludes us.**
- **A standard TPC arrangement with MWPC readout would spoil this excellent intrinsic resolution because of the statistical bottleneck at the start of the avalanche process at the readout wire.**
- **Dave proposed using the Electro-luminescence process in Xenon to avoid the statistical issues and effectively count individual ionization electrons with very low noise, preserving the 'intrinsic' energy resolution in the Xenon**

# Example 1: Continued

- **The NEXT example is a good lesson for what needs to be done to take advantage of developing capability in the condensed matter community for HEP:**
  - Ideally, we would understand radiation interactions with matter at a more fundamental level so that we could compute fluctuations in the depositions, and be able to propose promising combinations of materials to overcome ‘intrinsic’ limits
- **E.g. In Xenon,**
  - What processes are really setting the measured ‘intrinsic’ energy resolution limits?
  - Are more measurements (eg. Light emission across a broader spectral range) needed to understand this?
  - Can additives recycle the energy going into ‘lost’ modes that are driving the fluctuations in such a way that we improve on pure Xenon performance?

# Example 1 Continued

- Such a much deeper understanding of Xenon behavior may be of intrinsic interest to the AMO/condensed matter community, a necessary requirement for successful joint work.
- To move this ahead in this area, more work is needed than the usual workshop approach. A series of studies are needed from the HEP side to try to understand what interesting requirements look like, and how to couple 'signal' to 'readout'.
- Because of the need to push back the 'sensitivity frontier' in the dark matter direct detection experiments, noble gases/liquids seem one of the promising, scalable media worthy of more study...
- Generally, verifying and further developing our understanding of media we use now for radiation detection should be a promising avenue



# Other Radiation Detection Examples

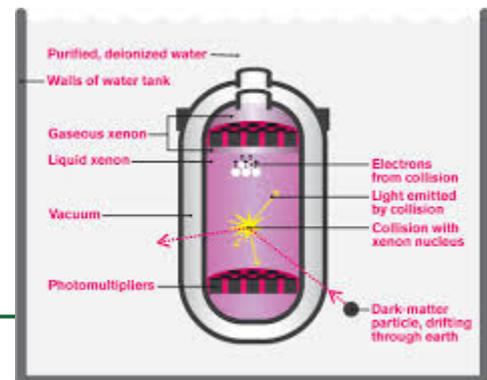
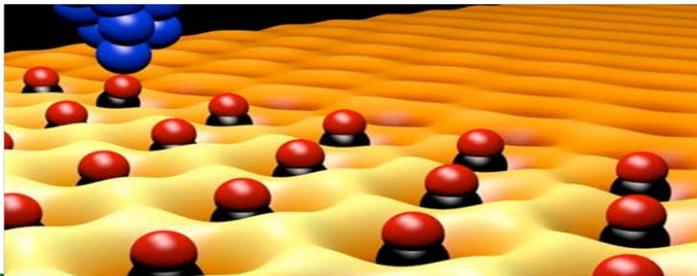
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- **The Snowmass reports already identified high-impact areas both within and outside HEP where further detector developments seem promising (See Marcel's summary talk for example, which had a table for this)**
- **These promising high impact areas are a good place to also take a hard look at detection materials and coupling to readout**
- **E.g. is it possible that an alternative pathway to ultra-thin (massless) charged particle tracking systems exists by use of cleverly engineered materials that carry out the functions of the current carbon-fiber supports, silicon sensors, and silicon readouts in a more closely integrated way? Careful study might give a yes or (more likely?) no answer.**



# Path Forward: Radiation Detection

- Community interest is key for the agencies to consider seeding work in speculative areas like this
- Ideally interested parties should contact us (HEP) for potential connections with AMO/Material Science/CMP/ experts.
- Viable white papers need to emerge from the community identifying the opportunities and limitations of materials of potential interest.
- Such whitepapers could be the basis for an interdisciplinary workshop on ‘Fundamental Limits on Radiation Detection: Engineering Materials for Radiation Detection’



LUX detector



## Example 2: Quantum Computing

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- **‘Quantum Computing’ or ‘Quantum Information Systems’ is another potential connections area that has issues similar to the radiation detection problem discussed above.**
- **SC more generally is likely interested in this area because of the potential impact on our ability to move science forward**
- **The condensed matter community has a ‘killer app’ for quantum computing, as originally laid out by Feynman, in solving for energies in condensed matter systems.**
- **Therefore, we expect quantum computing or novel computing systems will be developed one way or the other over time.**
- **Applicability of quantum computing to the management and analysis of ‘big data’ in HEP (and many other parts of Office of Science) is less clear**

# Example 2: Quantum Computing and HEP

- HEP can showcase a ‘big data’ example in the LHC data which is relatively well understood, and has had significant involvement from HEP and ASCR experts in setting up the system. Lessons learned about applicability of quantum computing to the LHC computing environment are likely to be widely applicable to data analysis computing across SC
- Most thinking about quantum computing employs an architecture where the quantum machine is an ‘oracle’ that answers the hard (NP-Hard?) parts of the problem, and the standard X86 machines do the data sifting/sorting. (NP - Non Deterministic Polynomial)
  - NP-Hard problems (e.g. travelling salesman) are usually solved by an algorithm that performs adequately. Any truly computationally difficult parts of the LHC data have work-around algorithms already. We don’t usually think of HEP computing in terms of a ‘computational complexity’ viewpoint
- We are not aware of a computational complexity analysis of the complete LHC computing system, as it exists today, to understand how a quantum architecture might fit in.

# Quantum Computing and HEP

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- **If the result of analysis shows that quantum computing could be useful in HEP's 'big data' challenges, then it may be possible to consider partnership workshops within SC to explore next steps – (after all, in HEP we support already quite a few quantum mechanics!)**
- **There are many technical roadblocks that impede realization of a practical quantum computer. Some members of our community with QFT expertise may be interested in looking for solutions to these problems.**
- **The community needs a more clear picture of what the impact of such investigations might be. (If Google and Lockheed-Martin are looking into this, is HEP missing something?)**

# Path Forward: Quantum Computing

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- **An open-minded analysis would need to be done in advance of a formal workshop of the complexity issues presented by the LHC analysis system to be able to make steps toward understanding if a quantum computing based architecture could have a positive impact. The outcome of such a pilot study is not clear.**
- **As mentioned, it is important to do this analysis correctly and creatively since the potential impact for HEP could be significant and also possibly across SC, as ‘big data’ issues appear in many parts of the SC portfolio.**
- **Again, a community white paper based on careful analysis needs to emerge so that any workshops can have maximum impact and the agencies can consider efforts in this area.**

# Other Examples and Paths Forward: CMP and AMO

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## **Condensed Matter Physics (CMP)–**

**Workshops at the interface of condensed matter and particle physics have been ongoing in areas of strongly correlated systems, lattice/ string theory techniques...and agencies are aware of these. A formal joint workshop might be a good starting point to identify the most productive collaborative ventures.**

## **Atomic and Molecular Physics -**

**One of the findings of the Science Connections report is that there is community interest in exploring multi Lab efforts to provide fast turnaround results in measuring electron EDMs in atomic systems, axion/gravity wave detection efforts, and manifestations of string theory predictions in cold atoms....**

**AMO Connections with HEP would have to start with initial investigative planning and strong white papers prior to formal workshops to identify next steps –**

**Reminder – HEP (Lali) should be contacted prior to planning white papers on potential ‘connections’.**

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# Overall Paths Forward

- As noted for the examples to move forward - white papers need to emerge from the community identifying the opportunities and limitations of topics of potential interest
- Ideally interested groups should contact us prior to working jointly with potential partnering communities.
- Interdisciplinary whitepapers could be the basis for partnership workshops identifying specific opportunities and possible plans.
- Office of Science has a (labor-intensive) method for carrying out this process which is called 'Basic Research Needs' evaluation. In order to seek partnerships with other parts of SC, we have to follow this process. A link with description can be found here: [http://science.energy.gov/~media/bes/pdf/reports/files/brn\\_workshops.pdf](http://science.energy.gov/~media/bes/pdf/reports/files/brn_workshops.pdf)
- Previous workshop reports all follow a similar format. BRN examples are found here: <http://science.energy.gov/bes/news-and-resources/reports/>.
- ***Suggested Prescription for Action on 'Connections': Extensive community white paper work and consensus building...leading to workshops....Build opportunity the old fashioned way...EARN it***

# Remarks About Dave

- Dave is truly remarkable. I am at a loss for words. He is inspirational and wise beyond his years (which is getting really difficult)
- In addition to everything else, he also has solved the US HEP budget problems with the sign he sent me to put up in my office. Our donation jar runneth over...



# Back Up

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- **BACK UP**



# Big Picture Comments and Observations

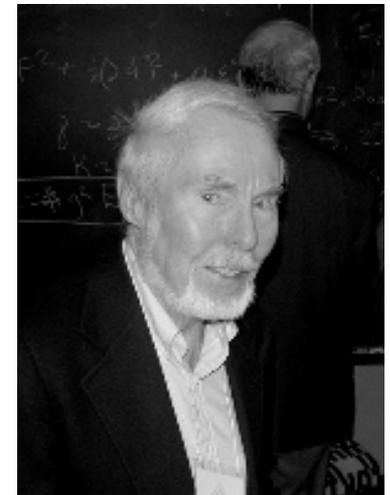
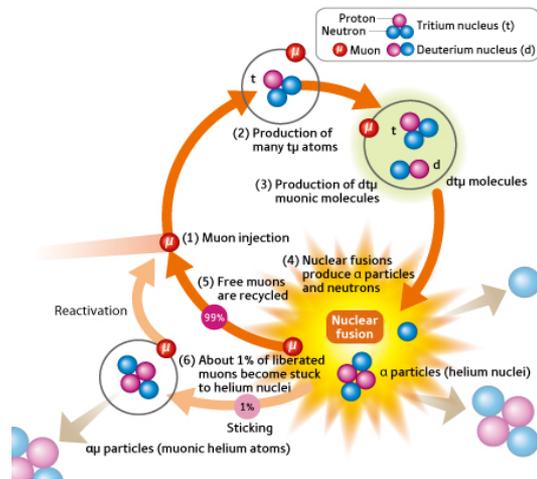
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There have been suggestions for

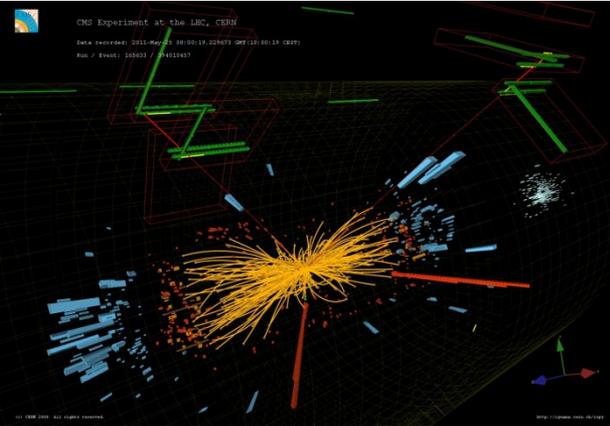
- **New partnerships on plasma and climate modeling perhaps multi- program with computing**
- **Expand partnerships with astrophysics – perhaps also in computing areas**
- **Development of detector technology in partnership with nuclear physics**
- **What role might particle physics investigators, and perhaps DOE Lab expertise, play in advancing big science projects in biology, especially the Brain Activity Map project?**
- **In addition to the examples mentioned – particle physics facilities could work on expanding their user bases by the same processes and the computational partnerships would expand and enhance existing collaborations with ASCR**

# Example -Muon Connections

The interdisciplinary phenomenon of muon catalyzed fusion was discovered by L Alvarez (accidentally) in the sixties, explained by E Teller, and calculated exhaustively one weekend by JD Jackson. There were prior theoretical predictions by A. Skhariv and Sir Charles Frank. The intriguing cycle of a negative muon stopping in heavy Hydrogen, forming atoms and molecules, catalyzing sub barrier nuclear fusion, and being released to restart the cycle - portrays connections across intersecting fields that nature sometimes exploits. Other muon connections include volcano imaging (also initiated by Alvarez) and muon spin resonance studies.



# Using Quantum Computers (QC) for HEP



D. Lidar<sup>1</sup>, A. Mott<sup>2</sup>, M. Spiropulu<sup>2</sup>, et al  
<sup>1</sup>USC  
<sup>2</sup>Caltech

- First HEP application of quantum computing
- Simulated Higgs and background events are encoded into a format suitable for the QC
- QC builds a classifier that discriminates signal from background
  - Use large amount of event information
  - Intractable on classical computer
- Benchmarking for QC
  - Known signal, so efficiency of quantum machine learning can be measured

Encode simulated and real events onto QC

K. Pudenz, D. Lidar.  
 arXiv:1109.0325

