"The Snowmass Process"

Developing a US Strategy for Particle Physics in a Global Context

http://www.snowmass2013.org

This talk has been constructed by the Conveners and DPF Chairline

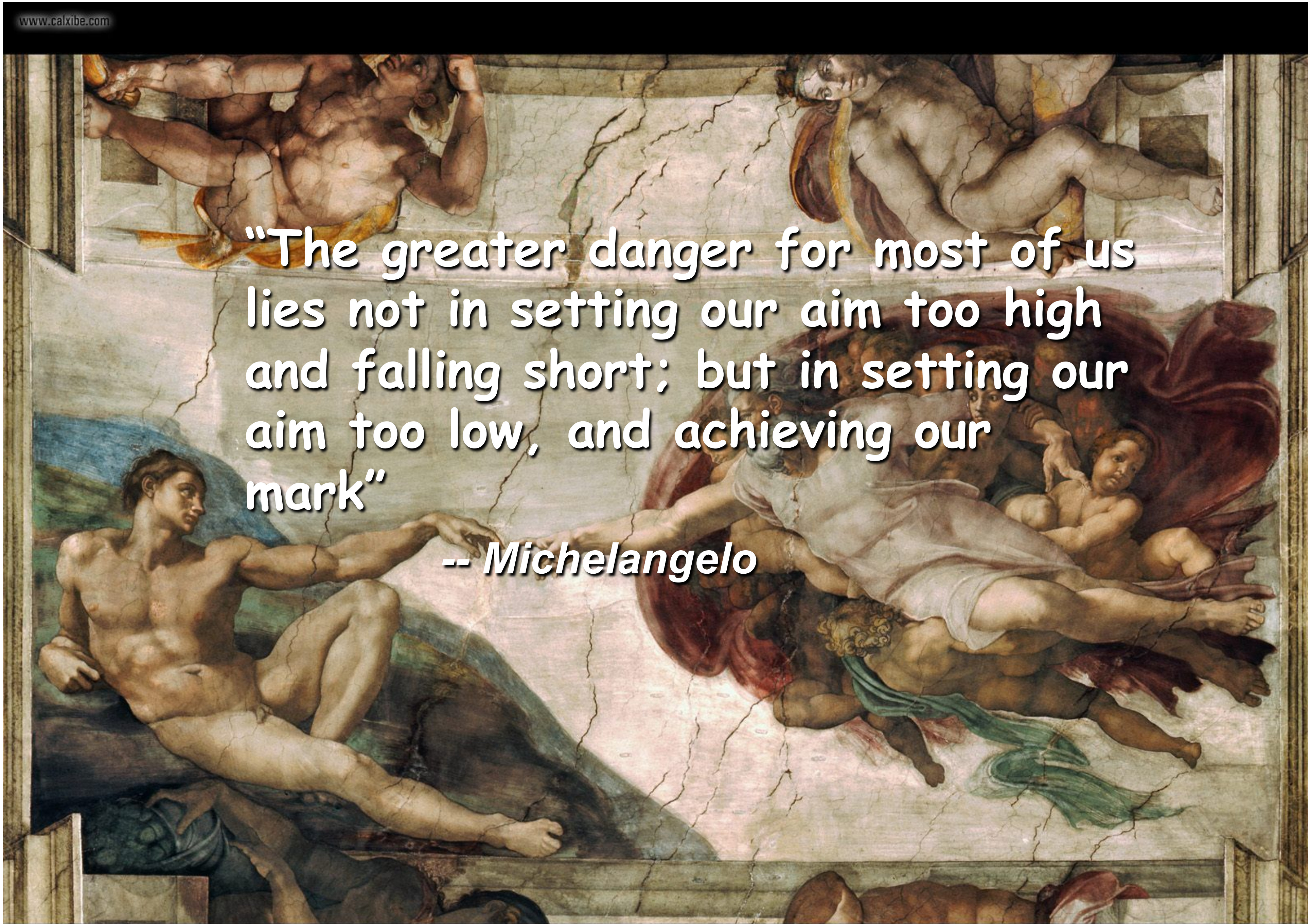
(Not a summary of all the other talks @CSS2013)

“The Snowmass Process”

Developing a US Strategy for Particle Physics in a Global Context

http://www.snowmass2013.org

It is the work of >1,000 colleagues in the US and around the globe
making the studies
making the calculations
and daring to dream



"The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark"

-- Michelangelo

OUTLINE

Snowmass 2013

Physics Aspirations

One field, one voice, one world

Ingredients of a healthy domestic program

Opportunities for achieving "transformational or paradigm-altering" scientific advances: *great discoveries*.

Snowmass Process 2013

Is the high energy physics community-based study of the future of the discipline in the U.S. set within a global context.

It has been held roughly every ten years, historically at Snowmass

Organized by OUR community:
The APS Division of Particles and Fields (3,500 members)

What makes the process crucial and distinct? A “bottom-up” organization, contributions from individuals, experiments and groups, it is not led by funding agencies, but we then partner with the funding agencies to make OUR aspirations reality in a global context

[redacted]

The Charge for Snowmass 2013

To develop the community's long-term physics aspirations. Its narrative will communicate the opportunities for discovery in high-energy physics to the broader scientific community and to the government

Quarks and the Cosmos
The Opportunities for Discovery

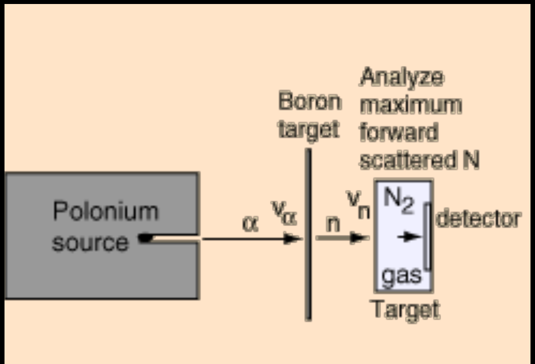
Particle physics studies the fundamental nature of energy, matter, space, and time, and applies that knowledge to understand the birth, evolution and fate of the universe

Our scope is broad and we use many tools accelerator, non-accelerator & cosmological observations all have a critical role to play

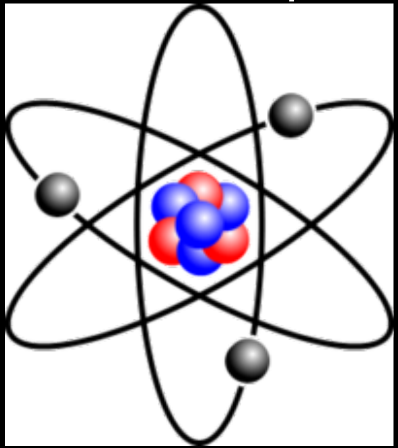
A work a century in the making

From the discovery of the electron in 1896, the nucleus in 1911 to

the neutron in 1932

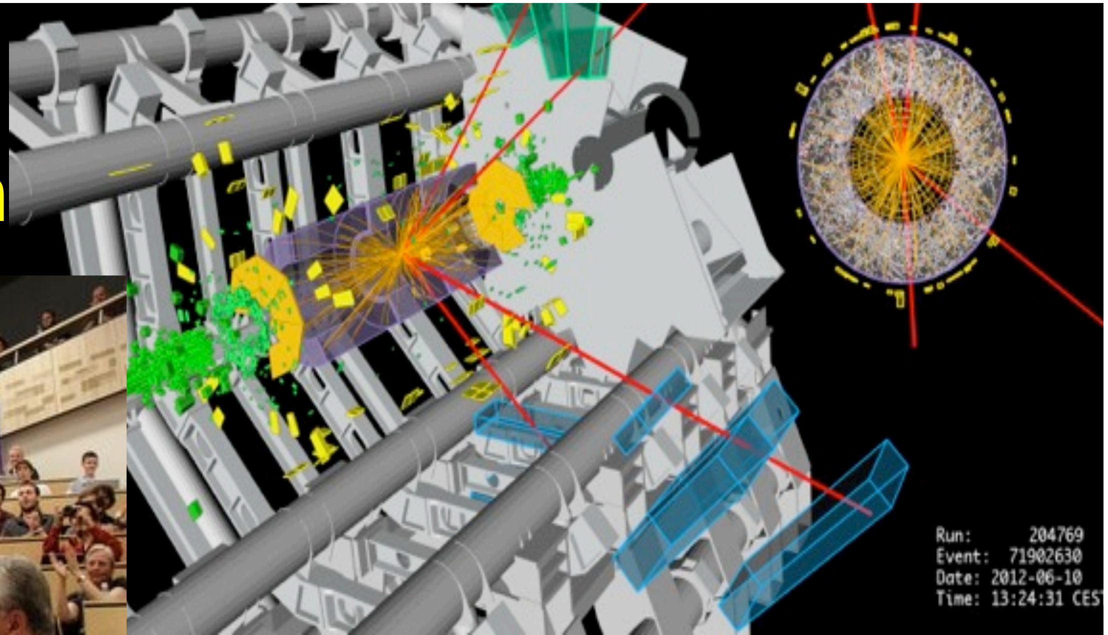


the particles that compose an atom



2012.7.4

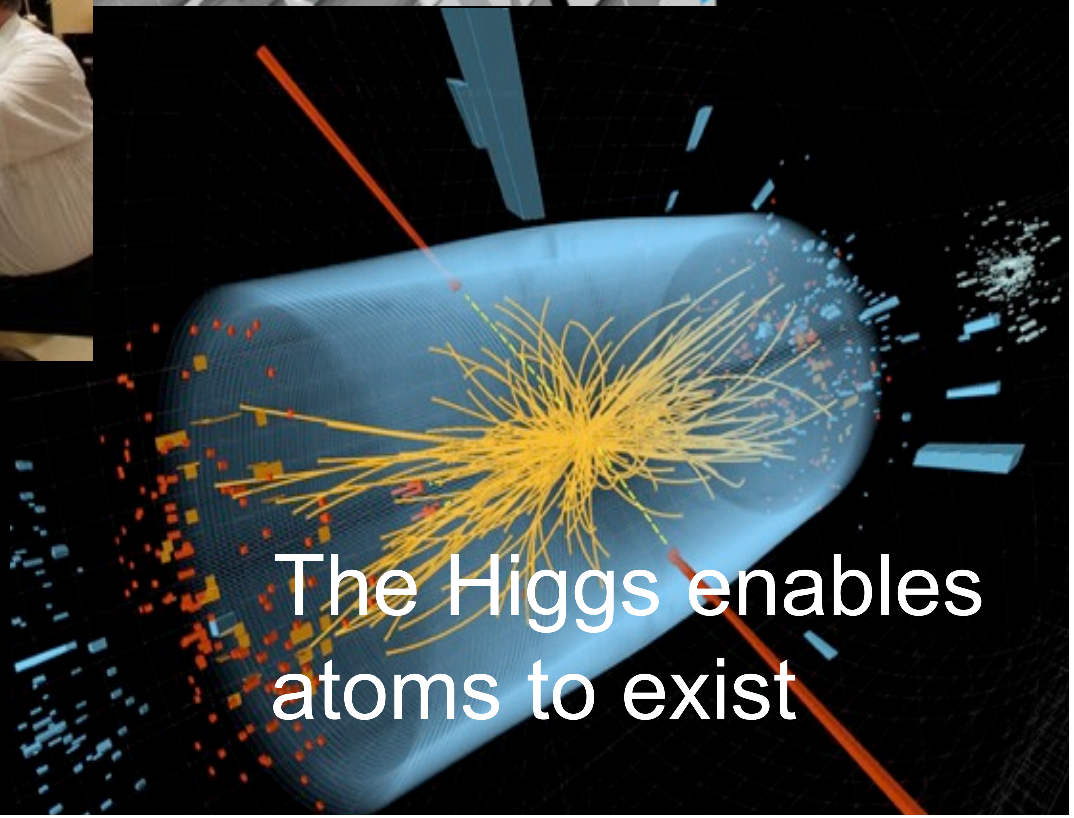
discovery of Higgs boson



theory : 1964

design : 1984

construction : 1998



The Higgs enables atoms to exist

BUILDING AN UNDERSTANDING OF THE UNIVERSE: A WORK A CENTURY IN THE MAKING

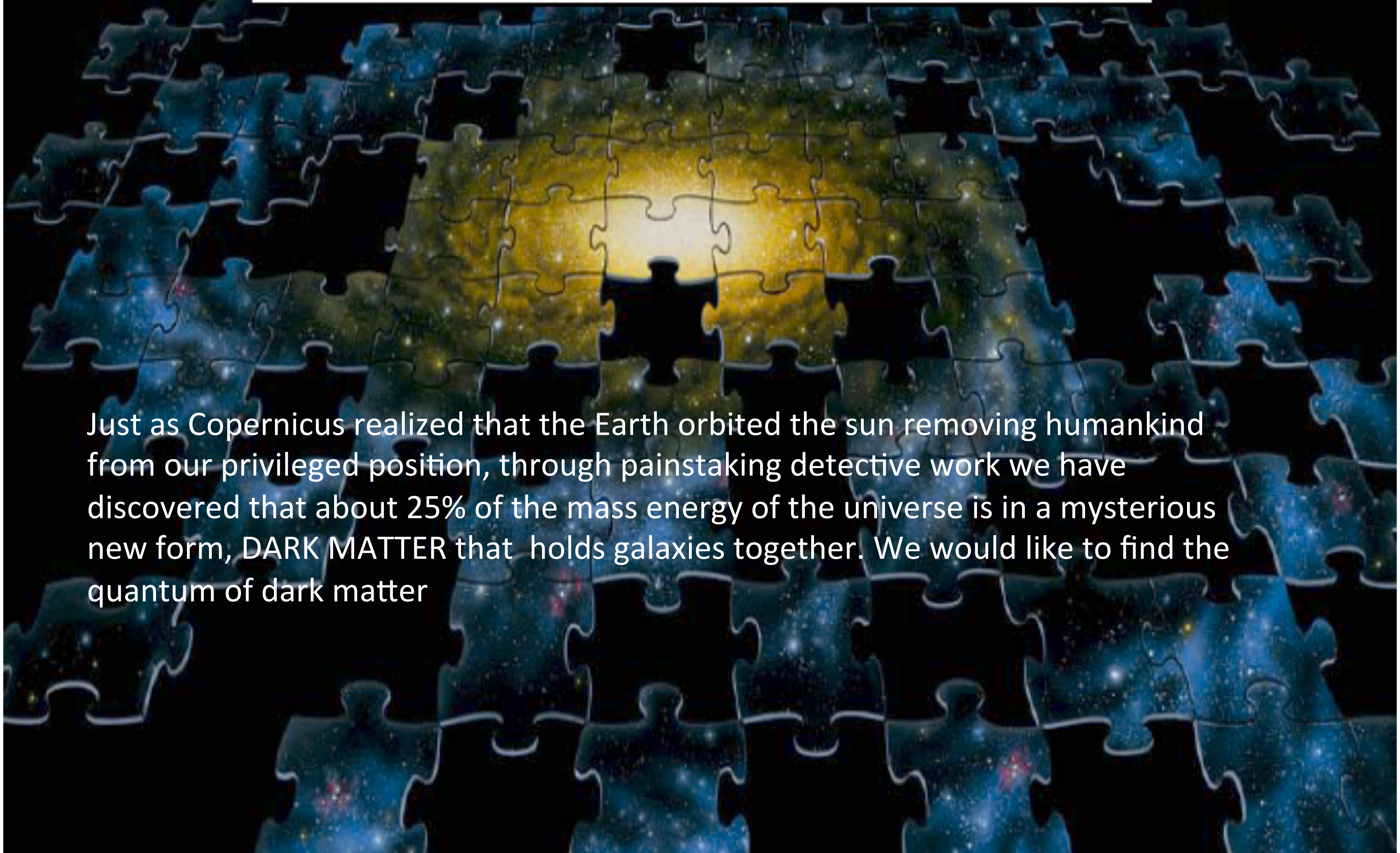
Particle Physics has revolutionized human understanding of the Universe – its underlying code, structure and evolution

Through careful measurement, observation and deduction we have developed remarkably successful prevailing theories the Standard Models of particle physics and cosmology that are highly predictive and have been rigorously tested in some cases to 1 part in 10 billion

These are among the highest intellectual achievements in the history of our species, they will be part of our legacy to future generations for eternity

The potential now exists to revolutionize our knowledge again.

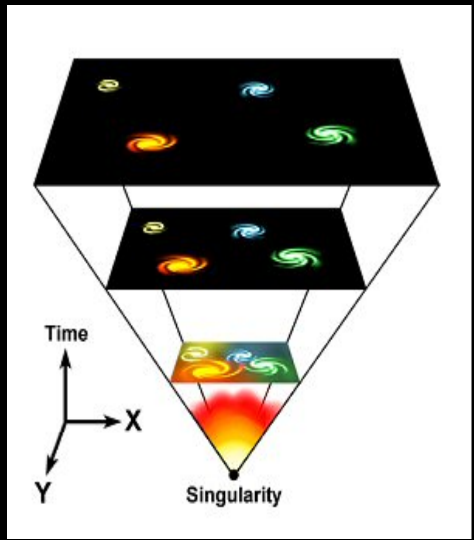
The invisible universe

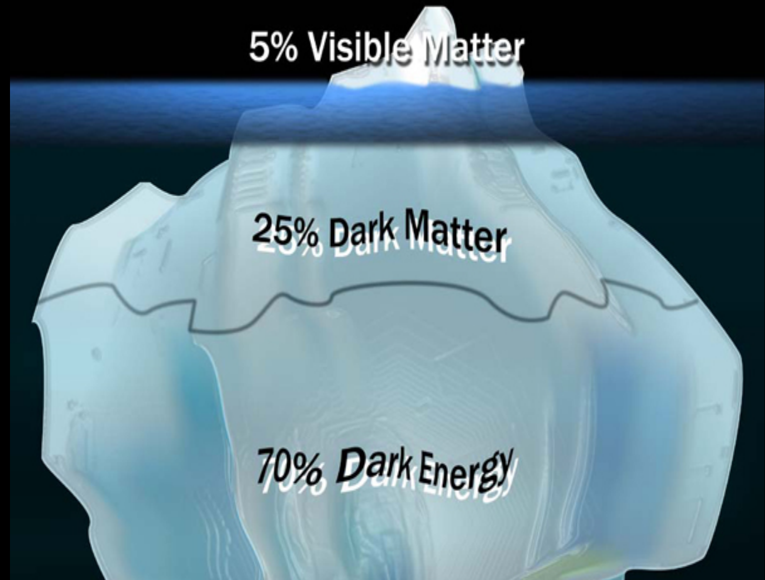


Just as Copernicus realized that the Earth orbited the sun removing humankind from our privileged position, through painstaking detective work we have discovered that about 25% of the mass energy of the universe is in a mysterious new form, DARK MATTER that holds galaxies together. We would like to find the quantum of dark matter

Dark Matter is a mystery 5 times more than visible matter

Mystery: Dark Energy





What we know: just the tip of the iceberg.

…and DARK ENERGY (about 70% of the mass energy) that drives the accelerating expansion of the universe. These mysterious components account for 95% of the mass energy of the universe and there are many more mysteries….

Mystery: how did matter survive the birth of the universe?

1,000,000,001

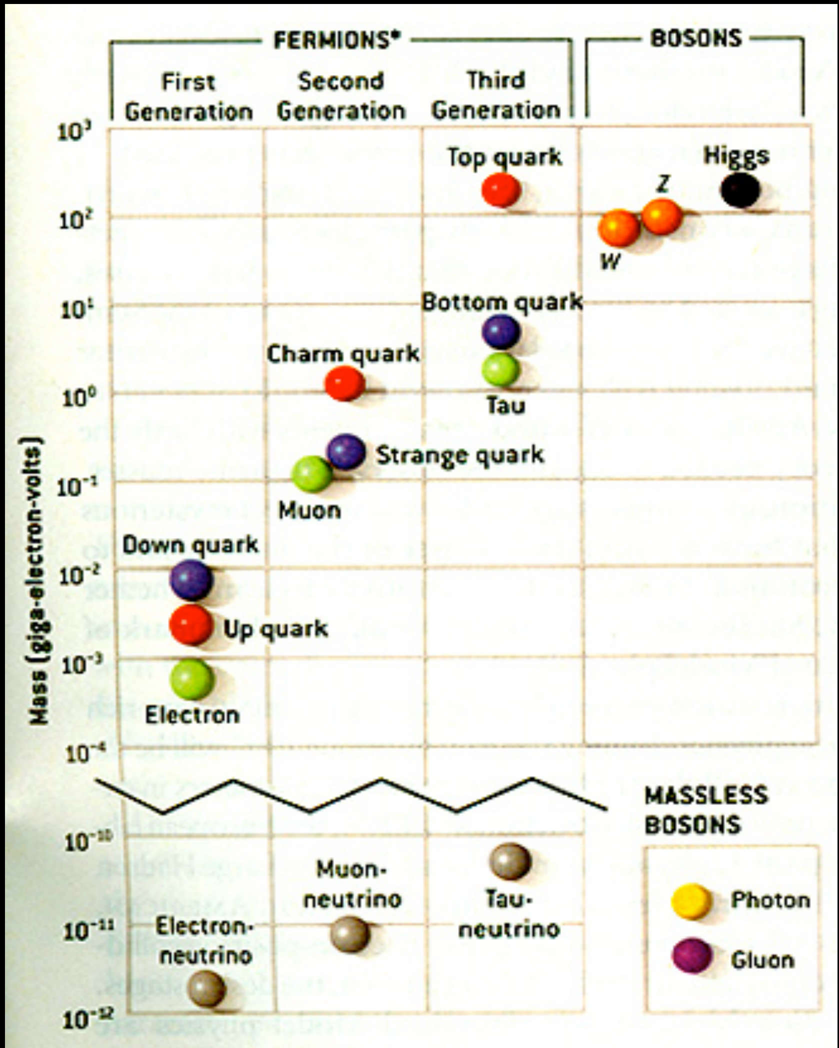
Matter

1,000,000,000

anti-Matter

The baryon asymmetry of the Universe

Mystery: Why are there so many types of particles?

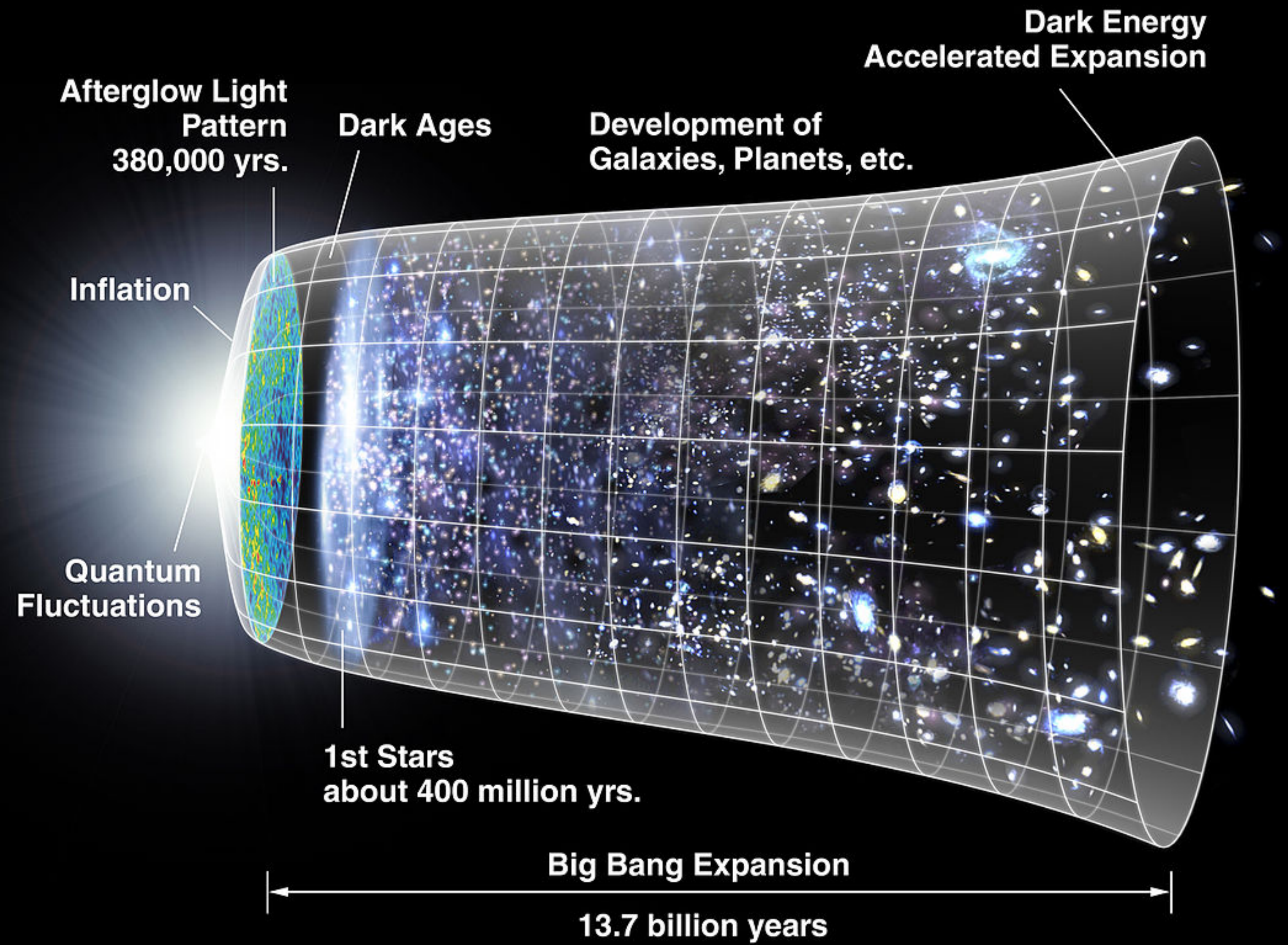


Why do the particles have such a large range of masses?

Why does the pattern of particles repeat three times?

Why do neutrinos have mass at all (they were expected to be massless)?

Mystery: What powered cosmic inflation?



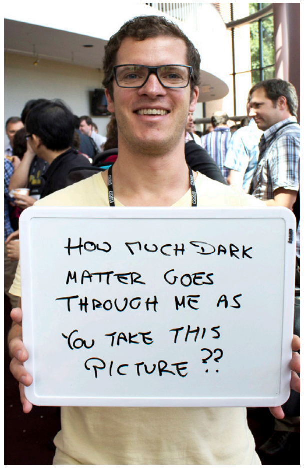
There are many mysteries of the Universe: our big questions

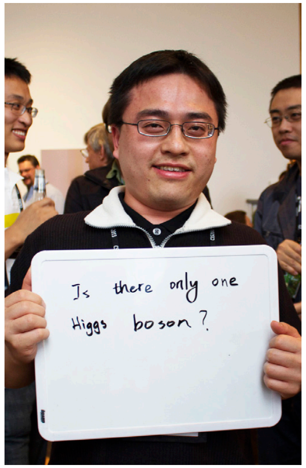
…a partial list

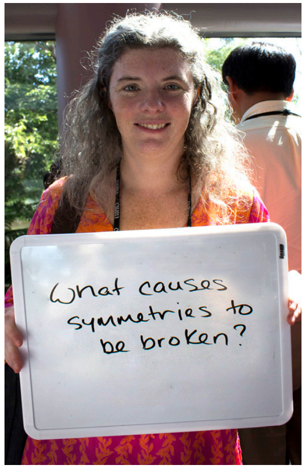
Neutrino Mass / Theory of Flavor
Higgs Boson Naturalness
Dark Matter
Dark Energy and Modified Gravity
Matter Asymmetry
Inflation

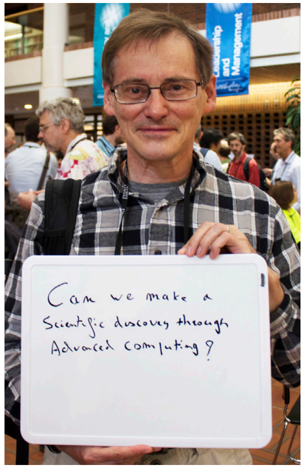
The sense of mystery has never been more acute in our field

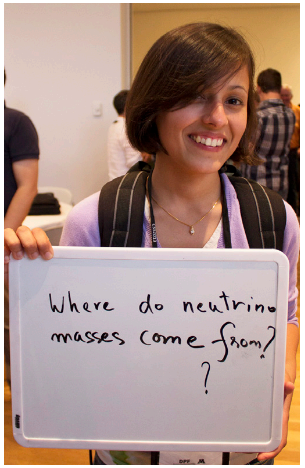
Solving these mysteries and others are the next steps in obtaining a deeper understanding of nature

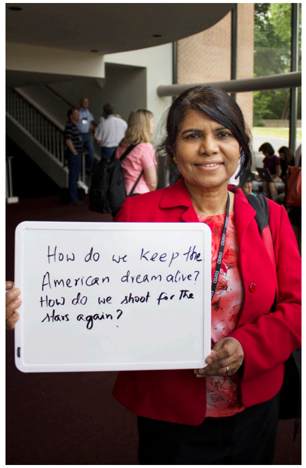


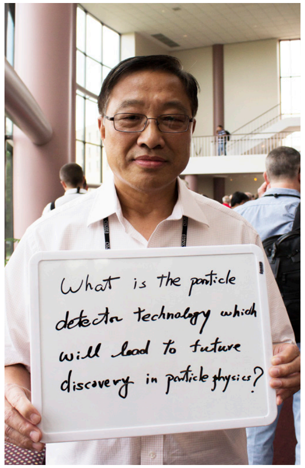


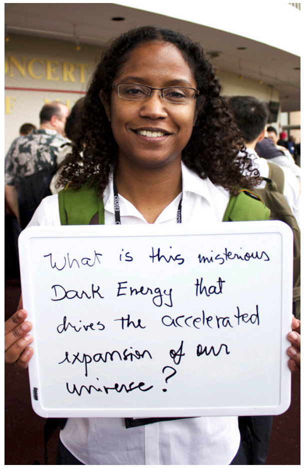


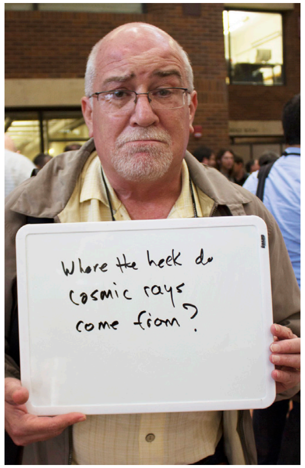


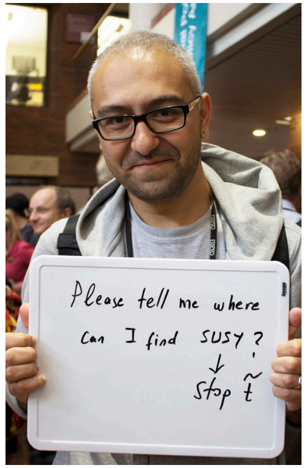


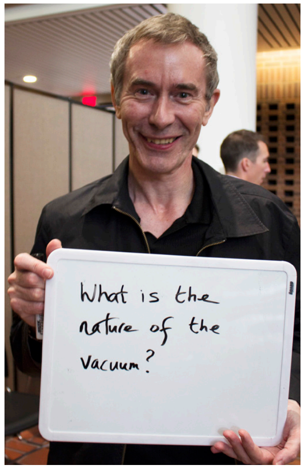


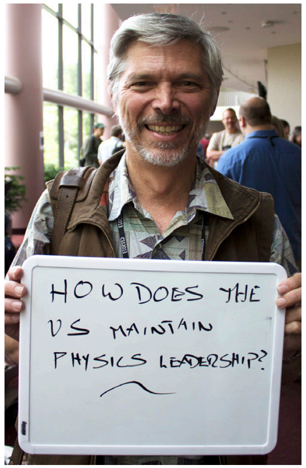


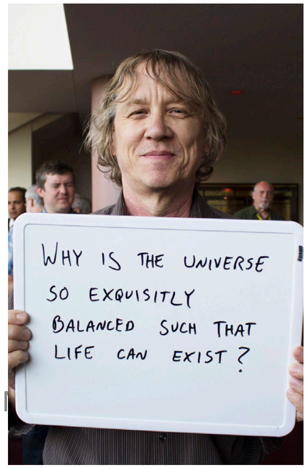


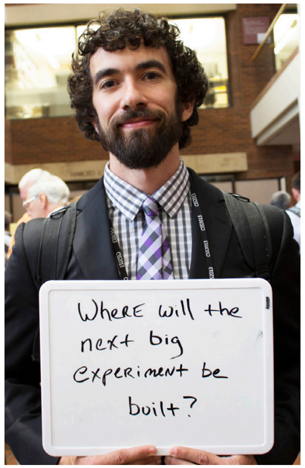












symmetry dimensions of particle physics

symmetrymagazine.org

U.S. DEPARTMENT OF ENERGY | Office of Science

There are many mysteries of the Universe: our big questions

…a partial list

Neutrino Mass / Theory of Flavor
Higgs Boson Naturalness
Dark Matter
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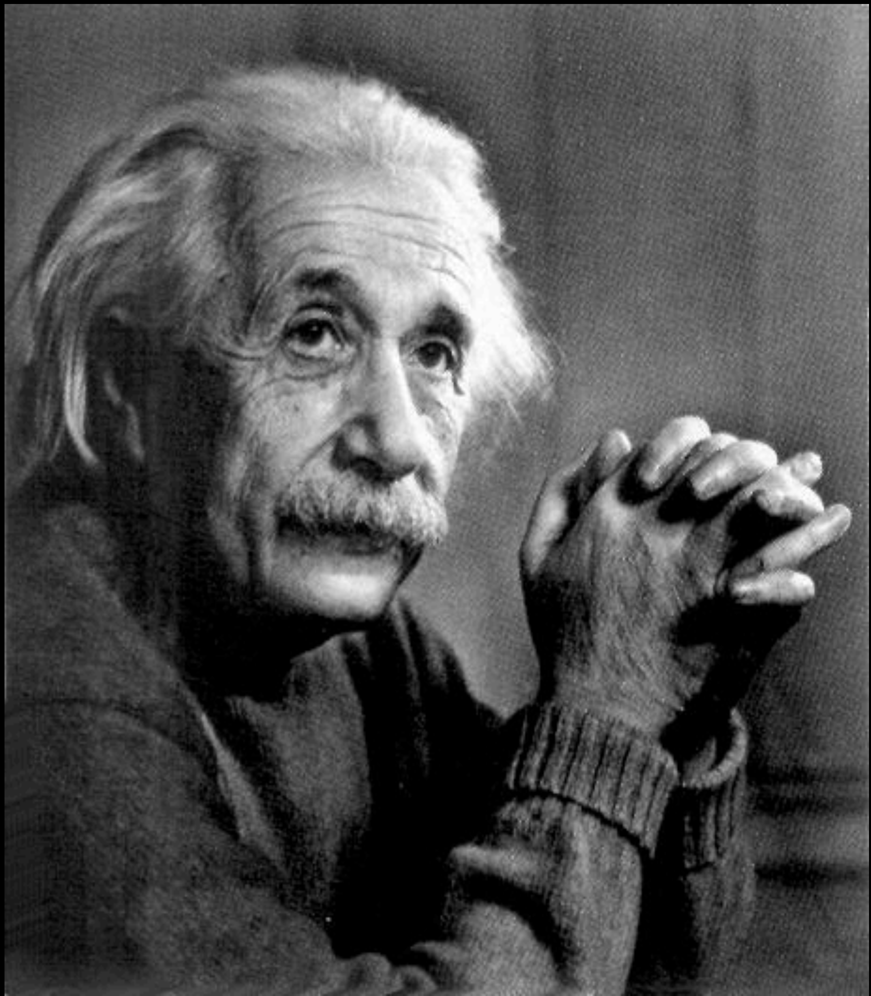
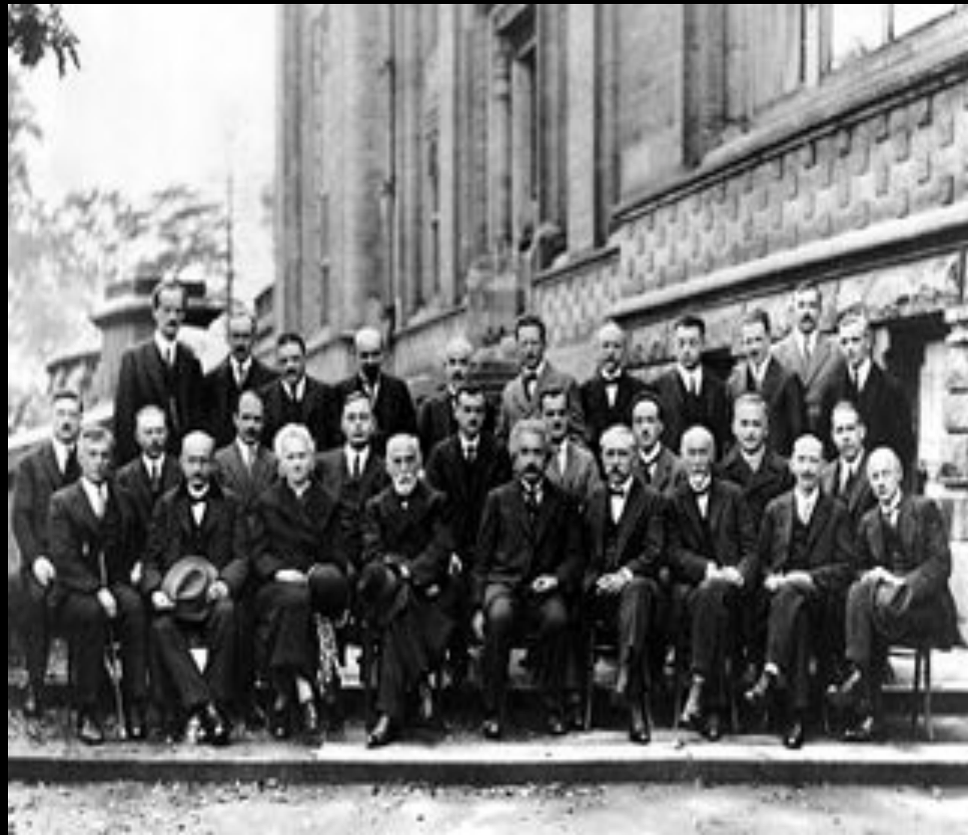
The sense of mystery has never been more acute in our field

Solving these mysteries and others are the next steps in obtaining a deeper understanding of nature

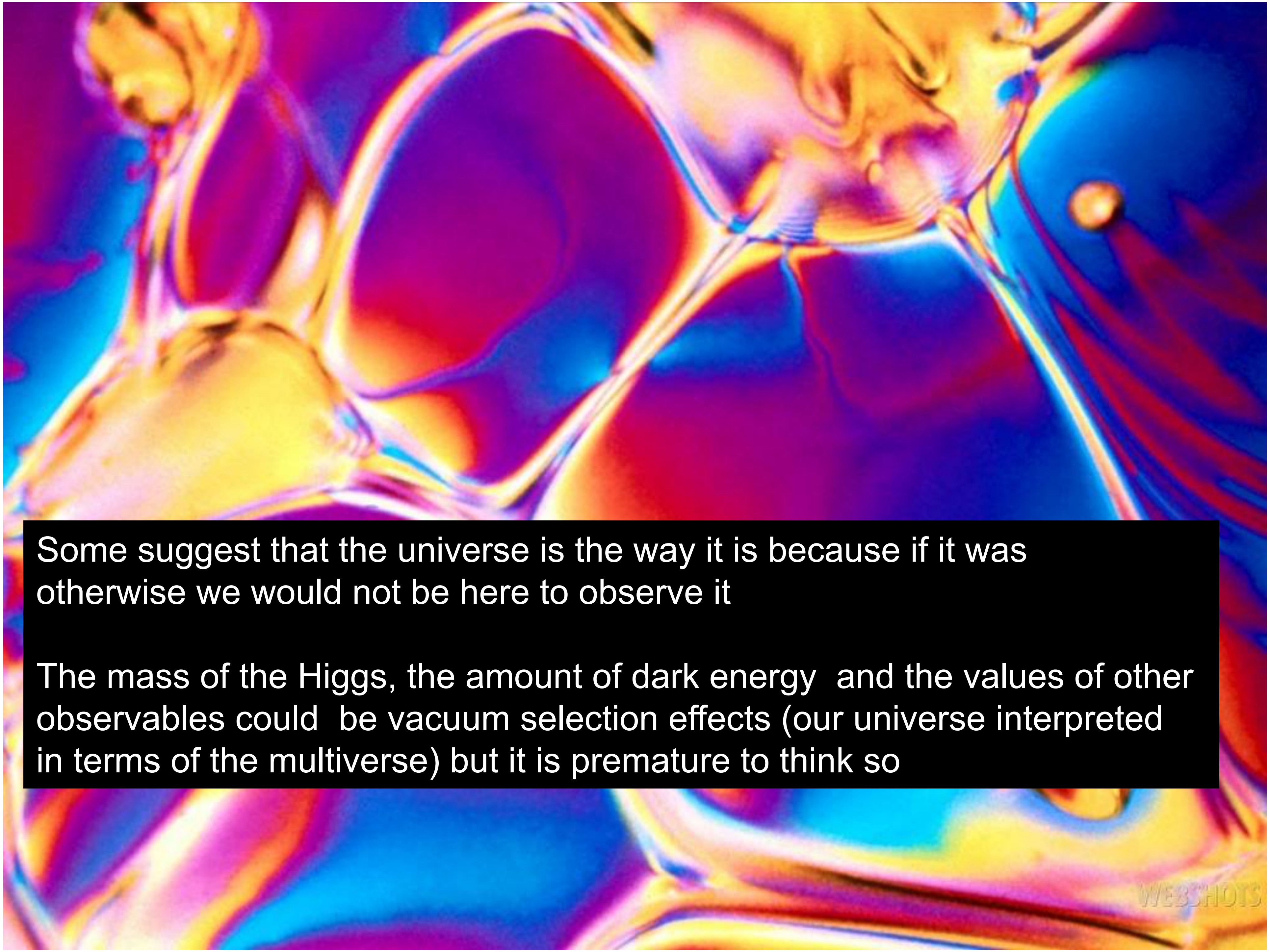
Our work has the potential to lead to a reconciliation of the two great edifices of physics



General Relativity



Quantum Mechanics


Some suggest that the universe is the way it is because if it was otherwise we would not be here to observe it
The mass of the Higgs, the amount of dark energy and the values of other observables could be vacuum selection effects (our universe interpreted in terms of the multiverse) but it is premature to think so

Science progresses by experimentation, observation, and theory

Nobody would have predicted that slight irregularities
in black body radiation would have led to an entirely
new conception of the world in terms of quantum theory

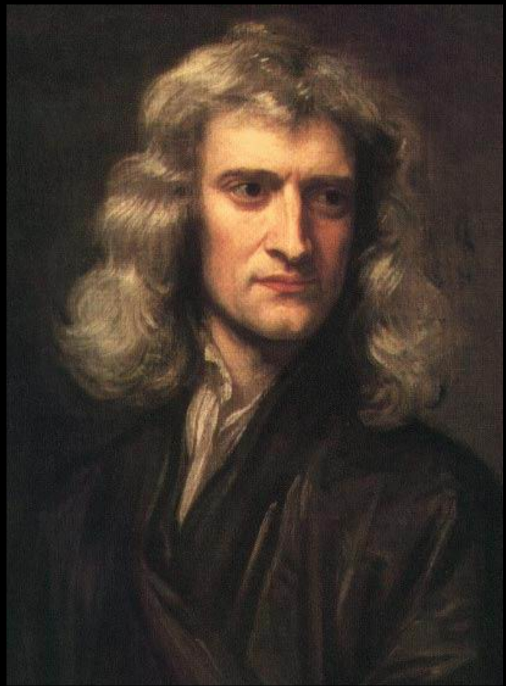
That pondering the constancy of the speed of light would have led to $E= mc^2$

That special relativity and quantum mechanics would have led to anti-matter

Experiments that explore uncharted territory, or study phenomena we do not understand with greater precision, lead to a deeper understanding of nature, the global high energy physics program does that.

The program will continue to reveal a cosmos more wonderful than we can possibly imagine.

To play a major role in this journey of discovery is the aspiration of our field



“What we know is a droplet, what we don’t know is an Ocean”

Sir Isaac Newton (1643-1727)

We are united in these aspirations and have come to be so through this Snowmass process

The only enemies you have are those you have not spoken to (paraphrase) *Henry Wadsworth Longfellow*

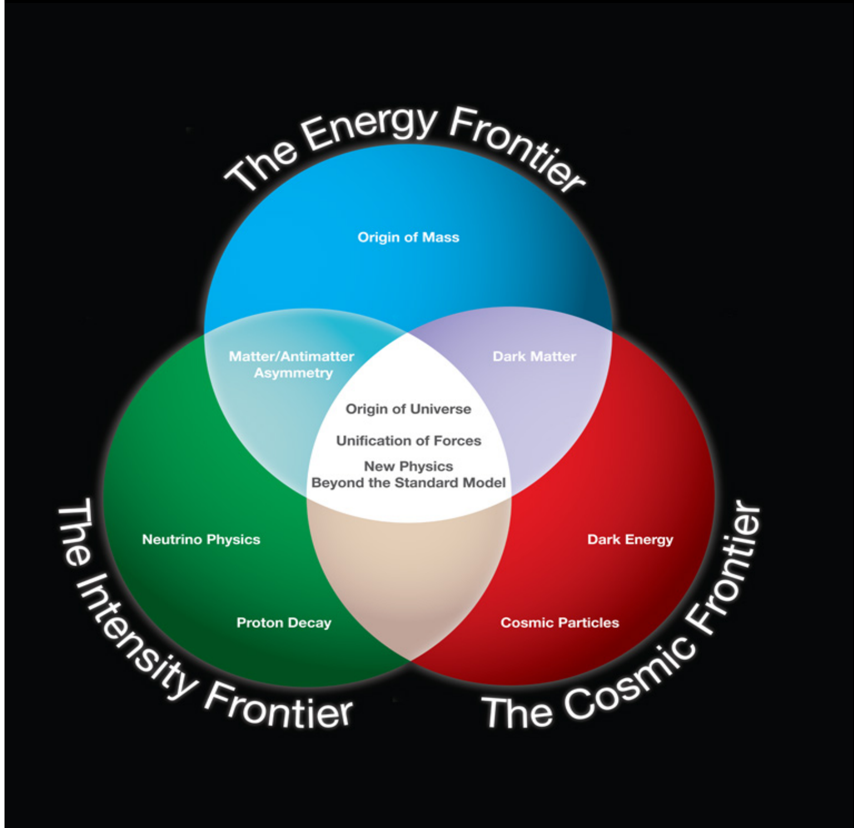
The Snowmass process has built our community anew over the past nine months

The only enemies you have are those you have not spoken to (paraphrase) *Henry Wadsworth Longfellow*

The Snowmass process has given us a deeper appreciation of each other's science

Snowmass organizing principle is frontier-based

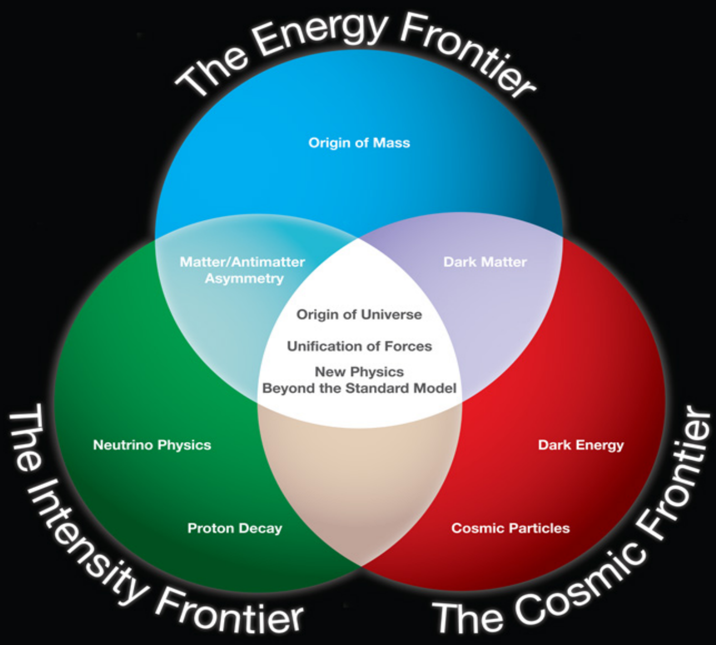
This has been much discussed



Particle Physics organized by DOE by frontiers: reflecting multi-pronged approach to search for new physics

- Direct Searches
- Precision Measurements
- Rare and Forbidden Processes
- Fundamental Properties of Particles and Interactions
- Cosmological observations

Snowmass organizing principle is frontier-based



The frontiers are an effective way to tell the rich story of our field to non-experts

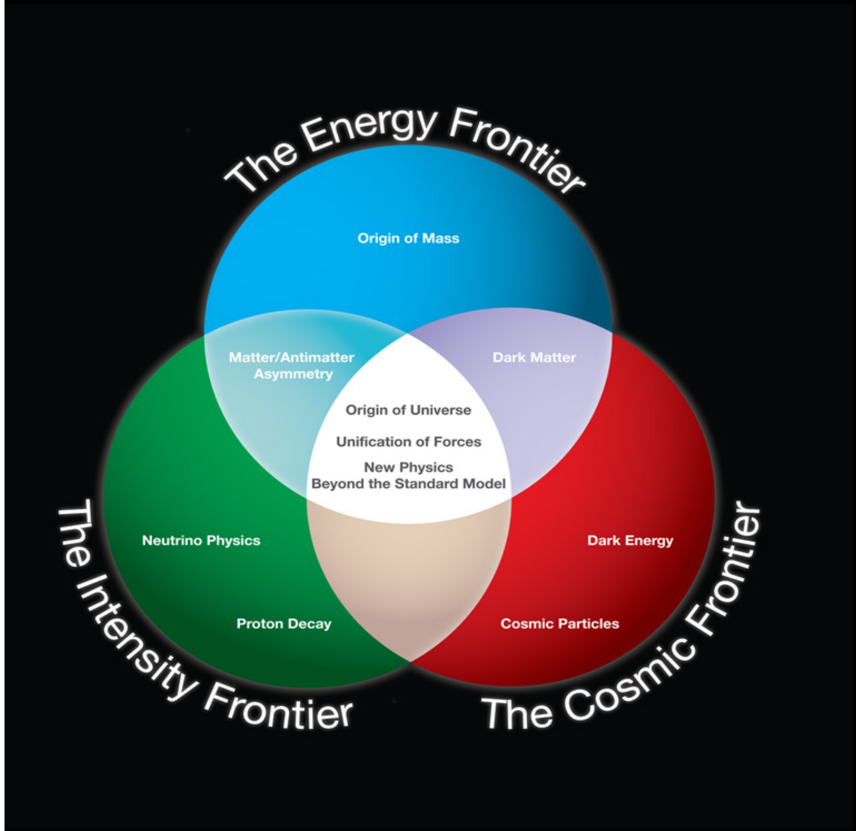
but:
we are united by physics and driven by the questions we ask not by the tools we use

We are not the former pre-P5 classification: protons, electrons and non-accelerator

We are not the currrent post-P5 classification: energy intensity cosmic

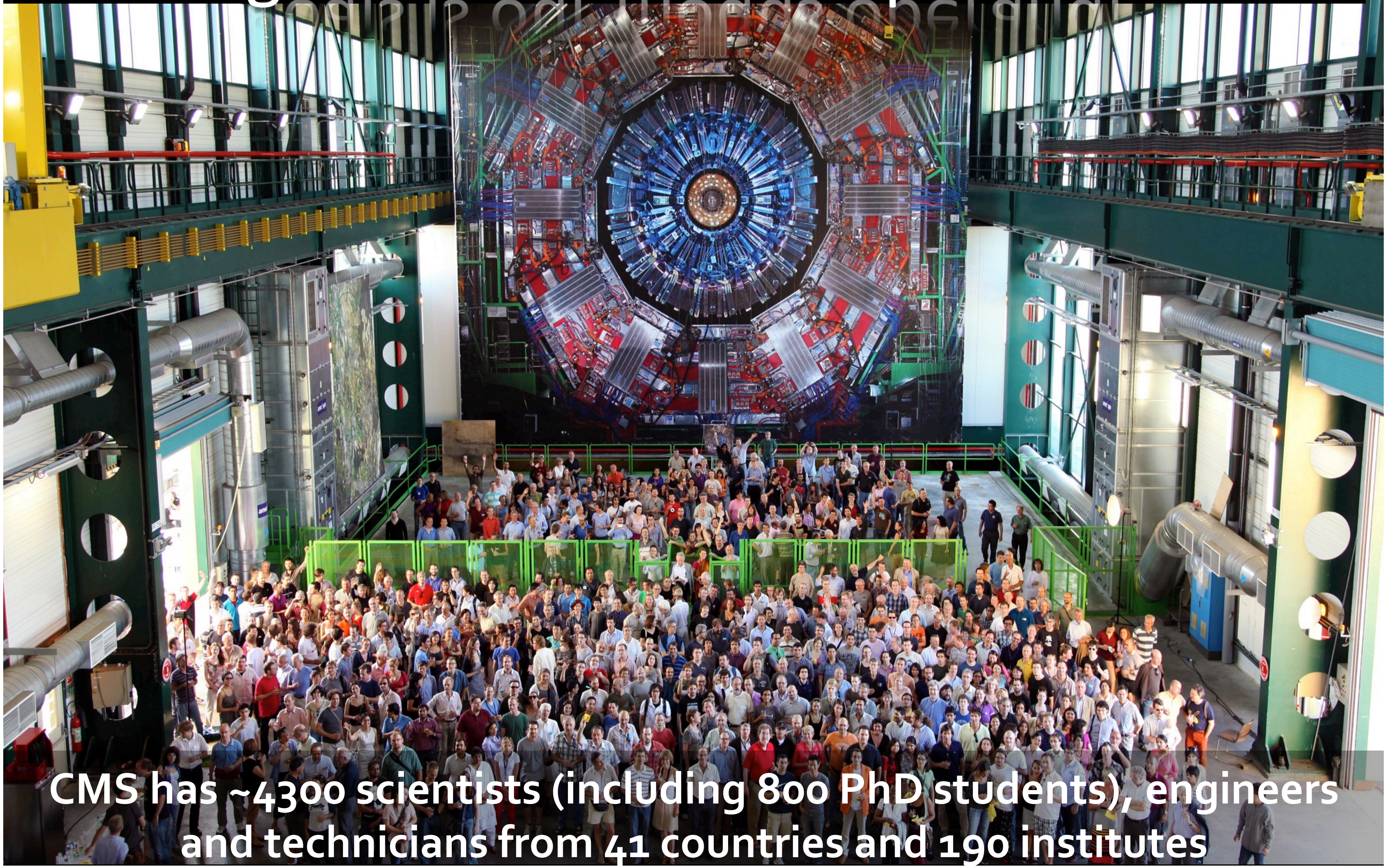
We transcend frontiers; we are one field

We transcend frontiers; we are one field united



A united field speaking with one voice.
The Snowmass process is making this a reality

Working together to achieve scientific goals is our modus operandi



CMS has ~4300 scientists (including 800 PhD students), engineers and technicians from 41 countries and 190 institutes

Working together to achieve scientific goals is our modus operandi

Our international collaborations inspire, made up of myriad individuals with diverse interests working together to achieve scientific goals

CMS has ~4300 scientists (including 800 PhD students), engineers and technicians from 41 countries and 190 institutes

Given the magnitude and breadth of the opportunities in front of us, the resources required to grasp them and the global nature of our field, our long term strategy has to maintain an international perspective, and strong international partnerships will be crucial to our future health.

We are coming to view our entire field as one great global collaboration, all the regions working together to achieve our scientific goals

The Snowmass process began with the creation of seven working groups

Conveners of seven "Frontiers"

- **Energy Frontier**
  - Chip Brock (Michigan State), Michael Peskin (SLAC)
- **Intensity Frontier**
  - JoAnne Hewett (SLAC), Harry Weerts (Argonne)
- **Cosmic Frontier**
  - Jonathan Feng (UC Irvine), Steve Ritz (UC Santa Cruz)
- **Frontier Capabilities**
  - William Barletta (MIT), Murdock Gilchriese (LBNL)
- **Instrumentation Frontier**
  - Marcel Demarteau (ANL), Howard Nicholson (Mt. Holyoke), Ron Lipton (Fermilab)
- **Computing Frontier**
  - Lothar Bauerdick (Fermilab) and Steven Gottlieb (Indiana)
- **Education and Outreach**
  - Marge Bardeen (Fermilab), Dan Cronin-Hennessy (U of M)

Each Frontier is organized in subgroups

What Snowmass is:

We evaluate by benchmarking
We speculate by calculating
We dream about following the physics
We propose the methods and experiments to make discoveries

What Snowmass is not:

We do not make funding recommendations

Or more formally stated…

The Snowmass process has identified, asked and answered key hard questions at the Energy, Intensity and Cosmic Frontiers and these are being summarized in a resource book that will be the primary input to the deliberations of the DOE/NSF Particle Physics Project Prioritization Panel (P5).

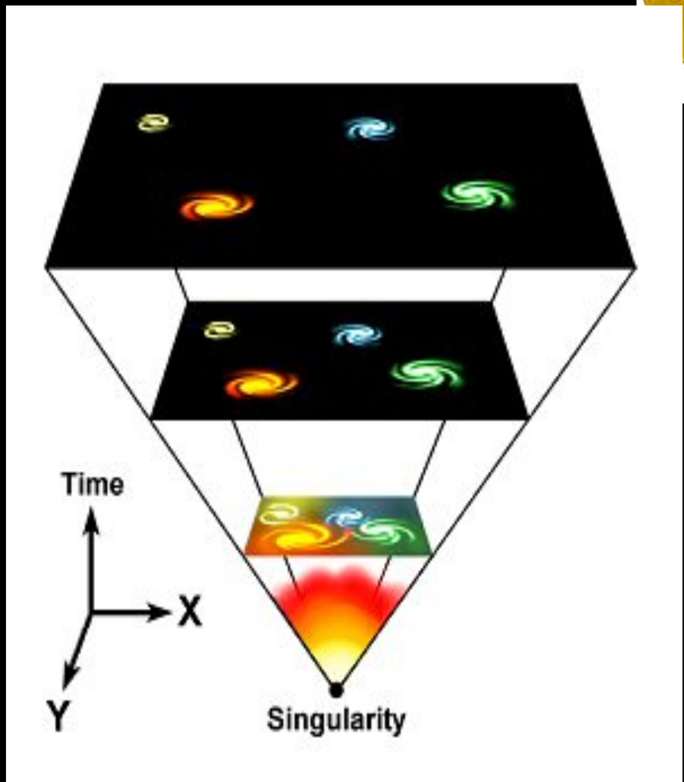
The purpose of P5 is to judge the questions and answers and place them within a realistic budgetary framework.

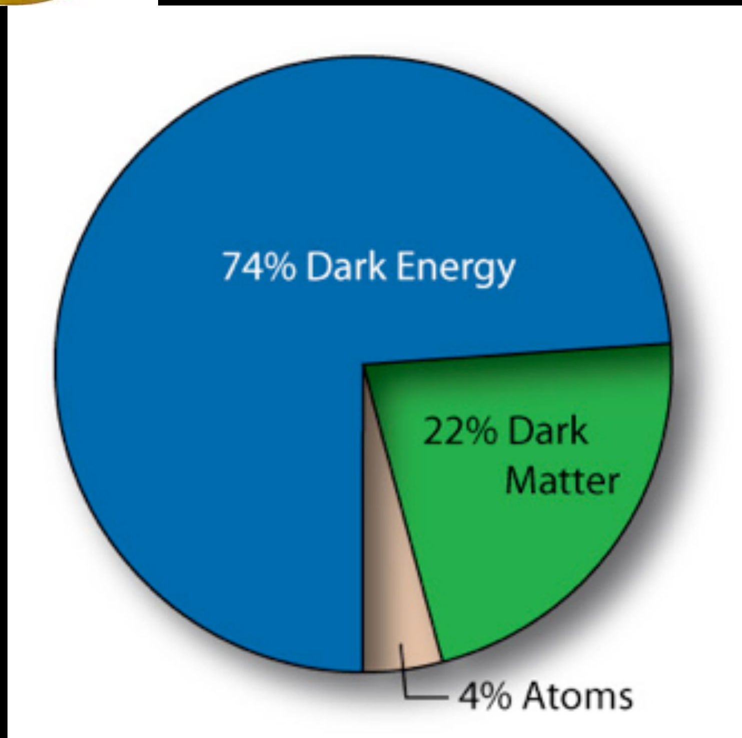
Snowmass 2013 has been a nine month study

Reflecting our era of high bandwidth communication, shared desktops & near effortless remote collaboration on a daily basis, Snowmass 2013 is not a 3-week meeting in Snowmass but a 9 month study

We began the Snowmass process at a special time

- October 2011: Nobel Prize for the discovery of dark energy

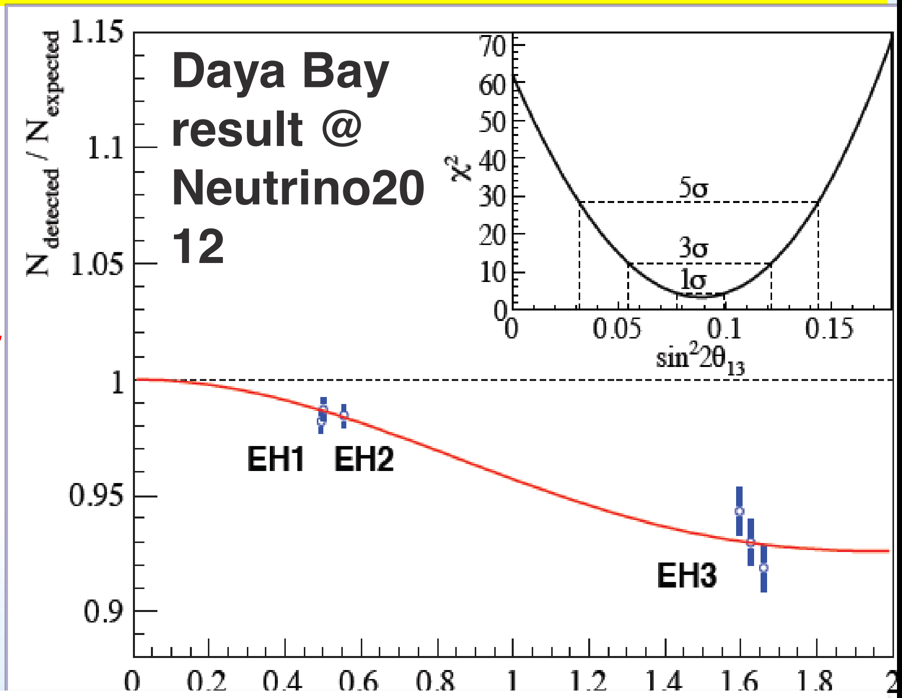




A special time….

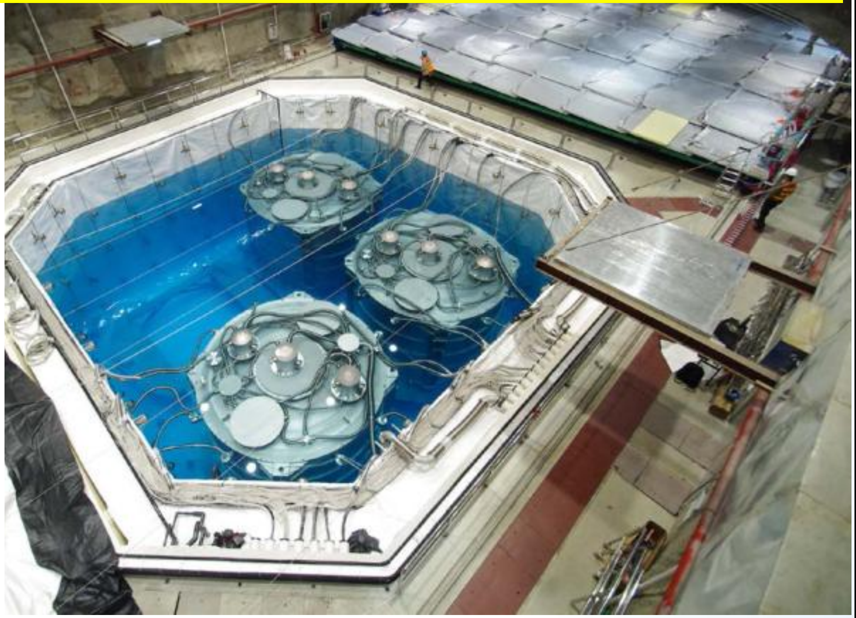
- March 2012: First results from Daya Bay:

Daya Bay - Large $Sin^2 2\theta_{13}$

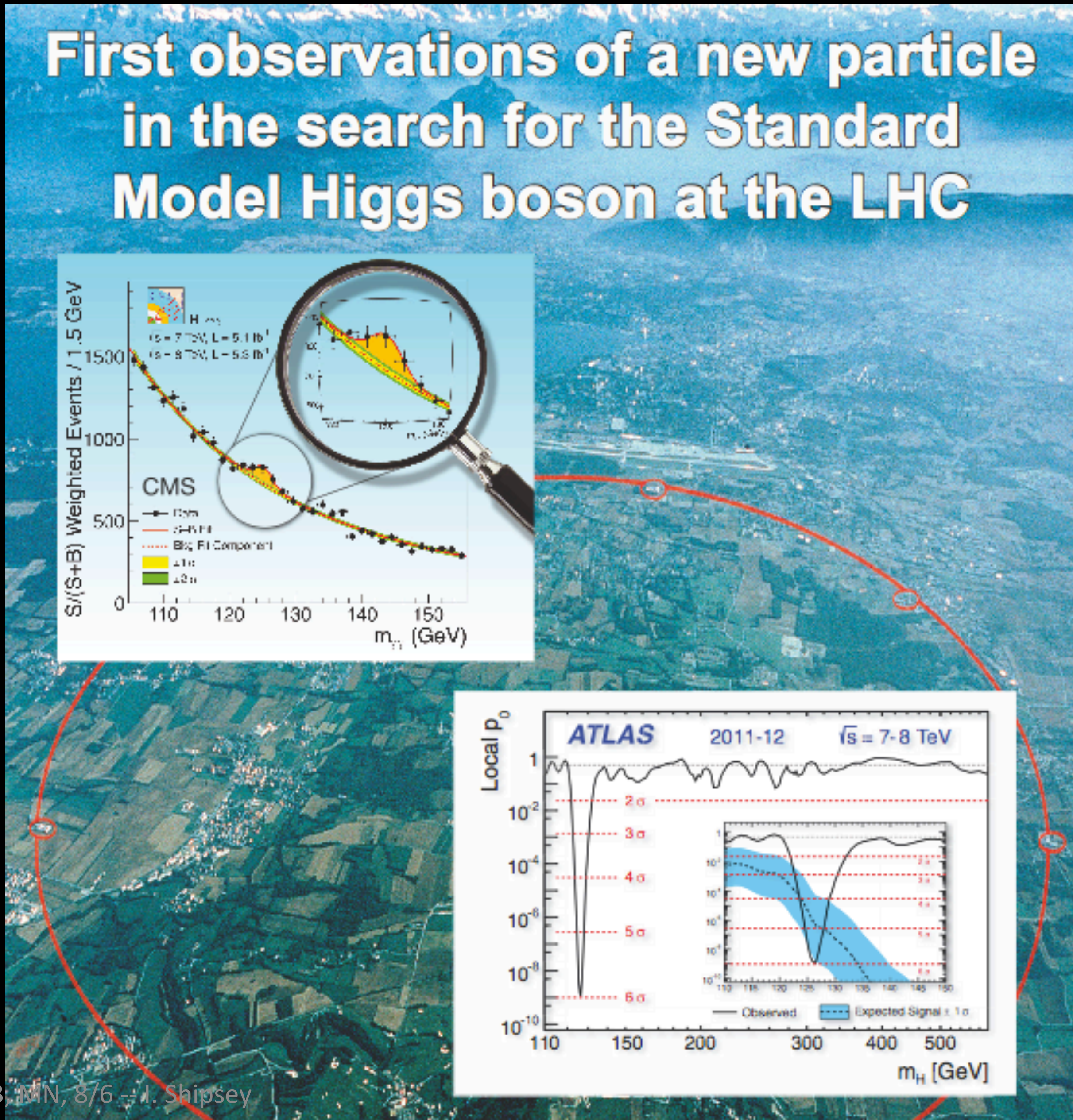


$\sin^2 2\theta_{13} = 0.089 \pm 0.010 \text{ (stat)} \pm 0.005 \text{ (syst)}$

Daya Bay - Far Det.



A special time….



The LHC, the experiments and the observation of a Higgs boson is a global phenomenon

A global and US success story
US is 25% of ATLAS and CMS
Out of scores of countries the US has some of the largest contributions to the detectors & key contributions to the LHC accelerator complex and R&D with LARP

Unprecedented Reach and Impact

17,000
news articles in
108
countries in
2
days

> 1 billion
people saw TV footage
1,034
TV stations
5,016
Broadcasts

Convincing current and next generation voters
Influencing decision makers

The public are very
Interested in science.
Combined with the
unprecedented global impact
of the Higgs discovery
this provides
an opportunity to
expand engagement
with the public
our colleagues
and the government.

To communicate what we have
learned and the opportunities for
discovery in particle physics
The narrative of our field

Education and Outreach Frontier

The narrative must explain to government and the public why we need a healthy particle physics program in the US:

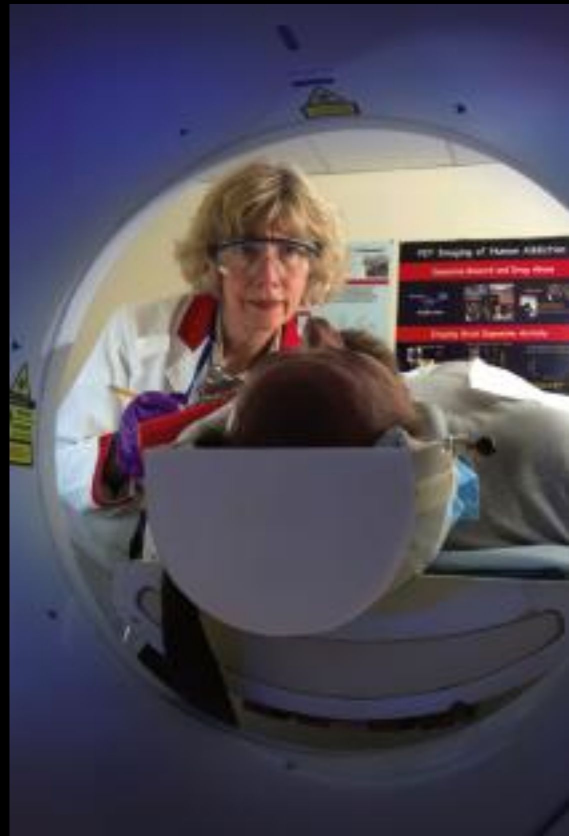
#1 Our science is important for our Nation to pursue

What is the world made of?
What holds the world together?
How did the world begin?

For millenia all great societies have asked these questions

#2 The big questions we ask attract young talent to *all* of the sciences

#3 Particle physics is an essential part of the fabric of the physical sciences in the Nation
It contributes broadly to other physical sciences:



Accelerator science
Detector development
Large Scale computing driven by large collaborations

What does a healthy particle physics program in the US look like?

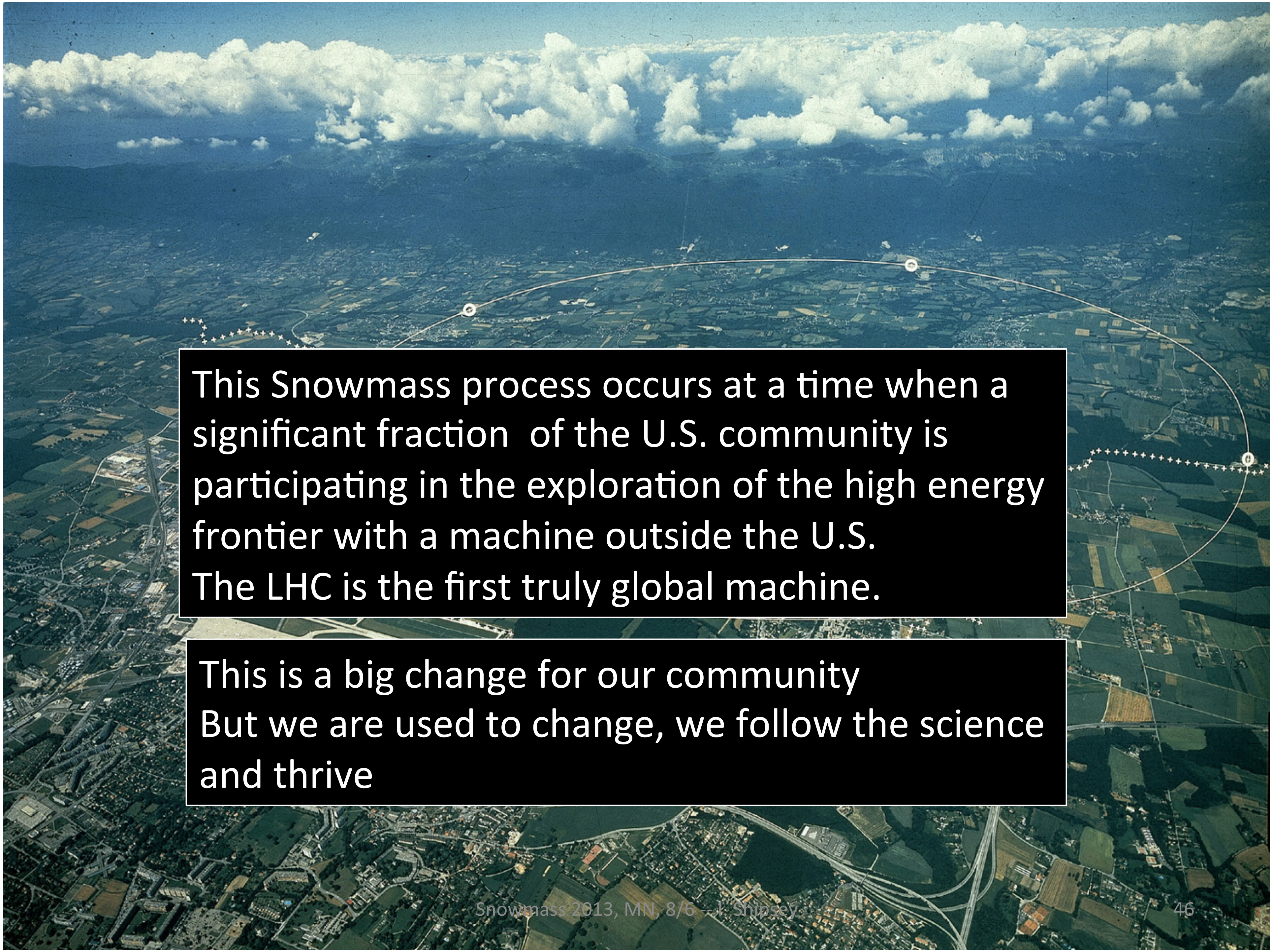
Some of the essential ingredients are:

A program focused on the most compelling science

Infrastructure to support the development of our tools

A long term vision and strategy to guide the program for future decades.

This Snowmass process occurs at a time when a significant fraction of the U.S. community is participating in the exploration of the high energy frontier with a machine outside the U.S.
The LHC is the first truly global machine.



This Snowmass process occurs at a time when a significant fraction of the U.S. community is participating in the exploration of the high energy frontier with a machine outside the U.S.
The LHC is the first truly global machine.

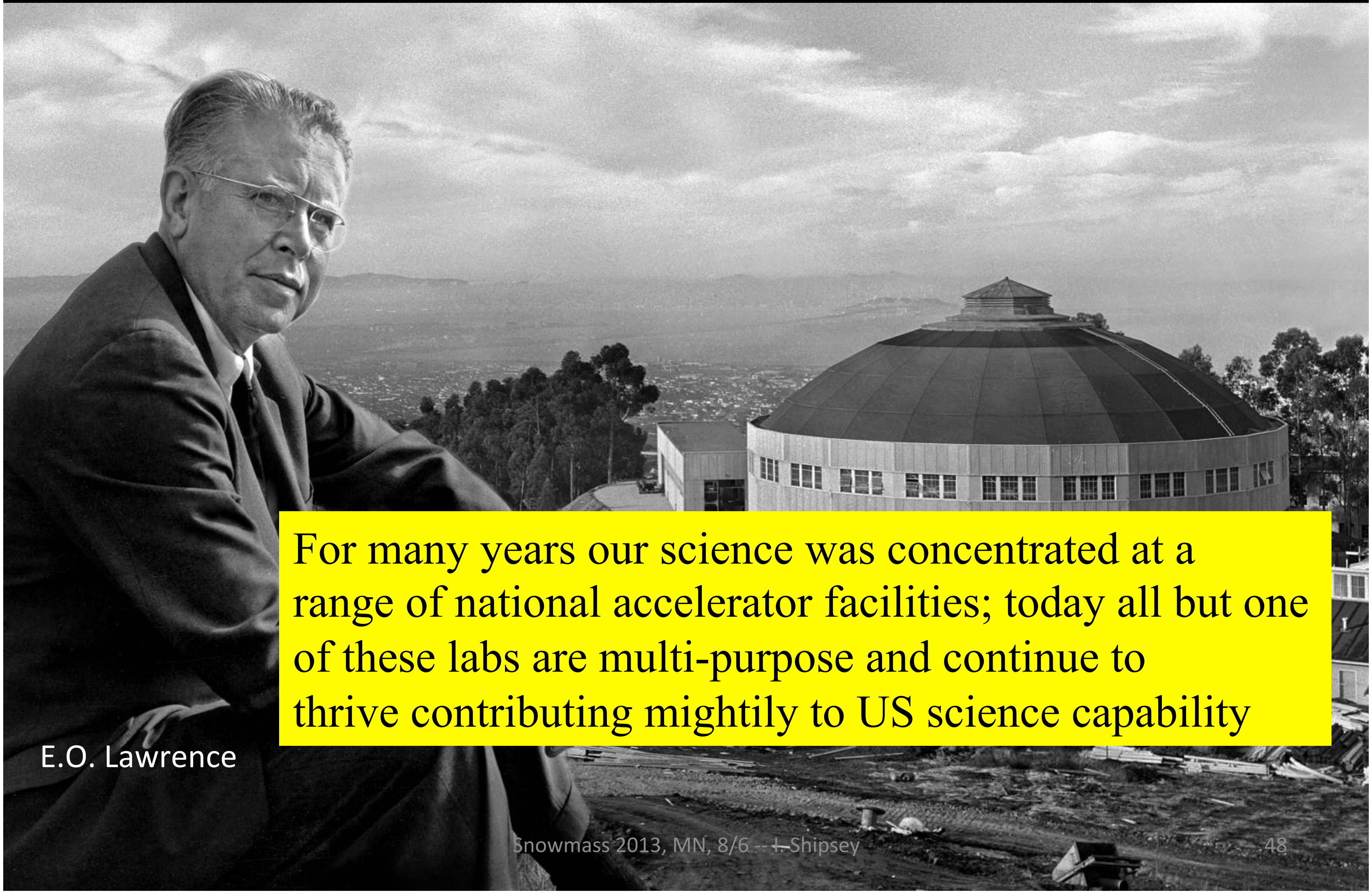
This is a big change for our community
But we are used to change, we follow the science and thrive

The only constant is change itself

Harvard Cyclotron

For many years there were university-based accelerators and local experiments. They were closed or repurposed, the university community thrived moving to the labs

The only constant is change itself



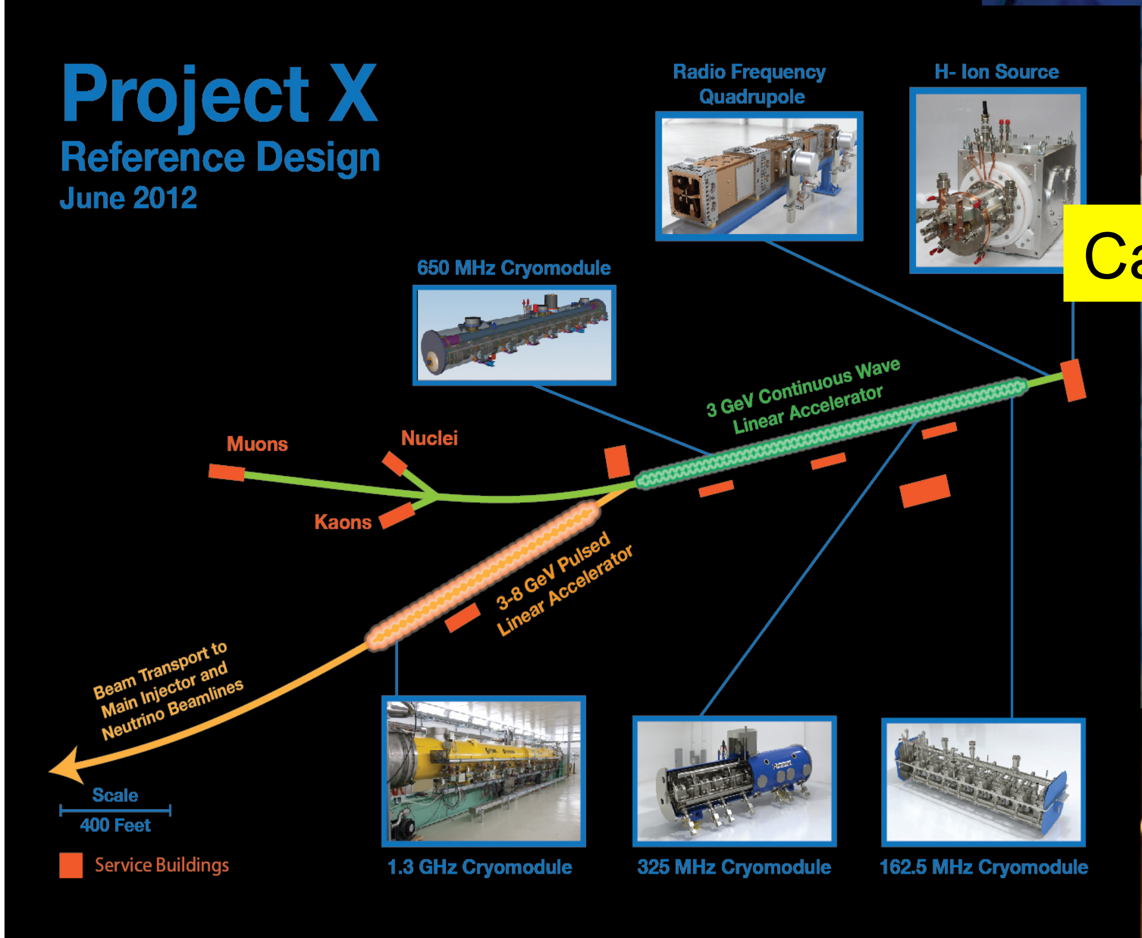
For many years our science was concentrated at a range of national accelerator facilities; today all but one of these labs are multi-purpose and continue to thrive contributing mightily to US science capability

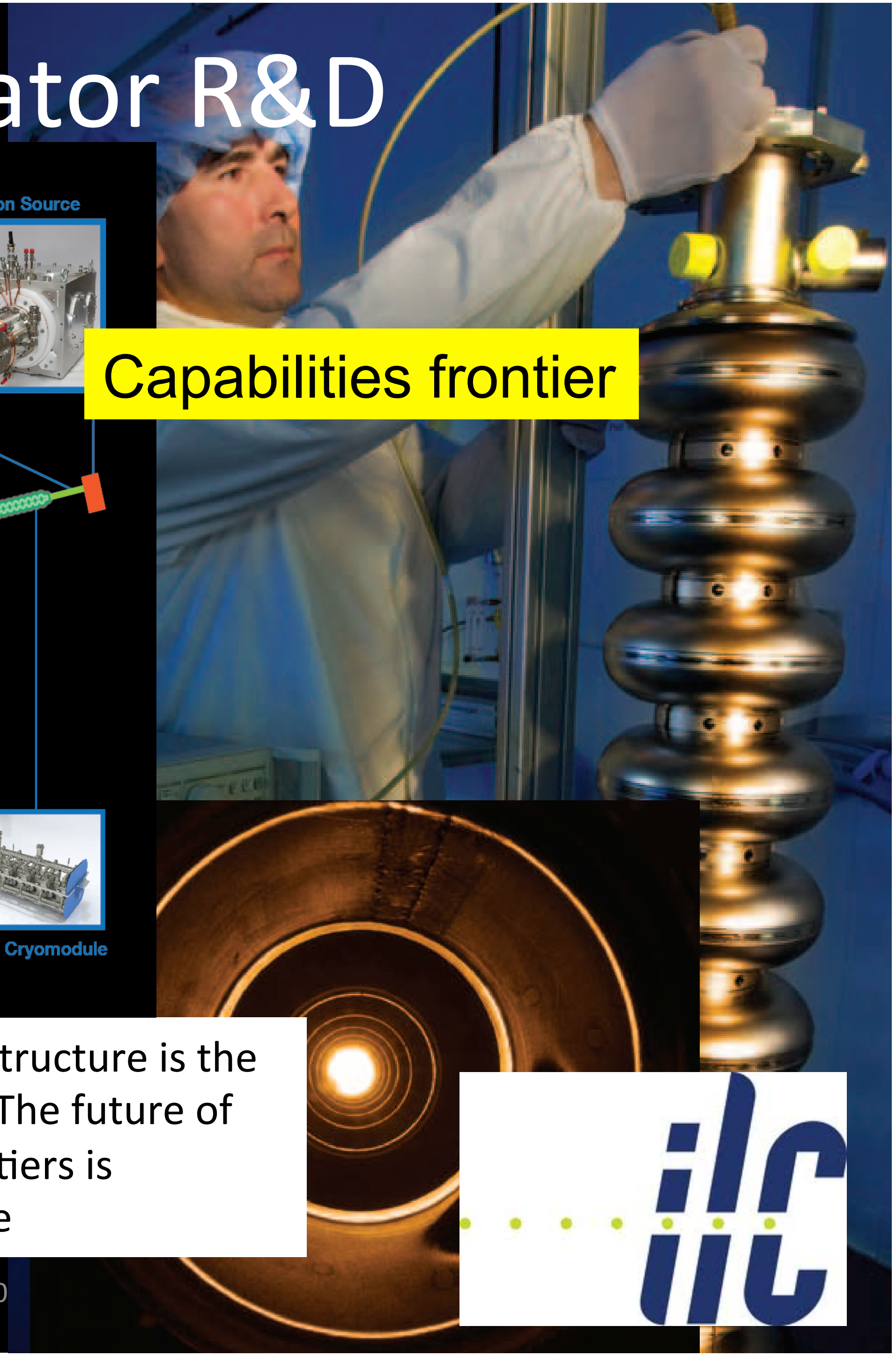
Wilson Hall, inspired by a Gothic cathedral in Beauvais, France, is the focal point for administrative and scientific activity at Fermilab.

Our big science with big tools requires the infrastructure to support the development of those tools for today and for the future in the US and to contribute to international projects

This infrastructure exists at FNAL our sole HEP lab FNAL, with ANL, BNL, LBNL, SLAC providing important and complementary capability.

Accelerator R&D





Capabilities frontier

Intimately related to the need for healthy infrastructure is the need for a strong program in accelerator R&D. The future of particle physics at the energy and intensity frontiers is dependent on innovations in accelerator science

Energy Frontier Goals:

Concrete Goals: the science cases

I. What are the scientific cases which motivate HL LHC running:

"Phase 1": circa 2022 with $\int \mathcal{L}\, dt$ of approximately 300 fb $^{-1}$

"Phase 2": circa 2030 with $\int \mathcal{L}\, dt$ of approximately 3000 fb $^{-1}$

How do the envisioned upgrade paths inform those goals?
Specifically, to what extent is precision Higgs Boson physics possible?

II. Is there a scientific necessity for a precision Higgs Boson program?

III. Is there a scientific case today for experiments at higher energies beyond 2030?

High energy lepton collider?
A high energy LHC?
Lepton-hadron collider?
VLHC?

The Higgs Boson message

1. Direct measurement of the Higgs boson is the key to understanding Electroweak Symmetry Breaking.

   The light Higgs boson must be explained.

   An international research program focused on Higgs couplings to fermions and VBs to a precision of a few % or less is required in order to address its physics.

2. Full exploitation of the LHC is the path to a few % precision in couplings and 50 MeV mass determination.

3. Full exploitation of a precision electron collider is the path to a model-independent measurement of the width and sub-percent measurement of couplings.

Origin of EWSB **Origin of matter** **Naturalness** **Unification** **New forces**

Dark matter **Elementary?**

The NP Physics Message

1. TeV mass particles are needed in essentially all models of new physics. The search for them is imperative.
2. LHC and future colliders will give us impressive capabilities for this study.
3. This search is integrally connected to searches for dark matter and rare processes.
4. A discovery in any realm is the beginning of a story in which high energy colliders play a central role.

Origin of EWSB | Dark matter | Origin of matter | Naturalness | New spacetime | Unification

New forces | Elementary? | Origin of flavor | ν mass

LHC: 300 fb^{-1}

Higgs EW Top QCD NP/flavor

1. **Clarification of Higgs couplings, mass, spin, CP to the 10% level.**
2. First direct measurement of top-Higgs couplings
3. Precision W mass below 10 MeV.
4. First measurements of VV scattering.
5. Theoretically and experimentally precise top quark mass to 600 MeV
6. Measurement of top quark couplings to gluons, Zs, Ws, photons with a precision potentially sensitive to new physics, a factor 2-5 better than today
7. **Search for top squarks and top partners and ttbar resonances predicted in models of composite top, Higgs.**
8. New generation of PDFs with improved g and antiquark distributions.
9. Precision study of electroweak cross sections in pp, including gamma PDF.
10. **x2 sensitivity to new particles: supersymmetry, Z', top partners – key ingredients for models of the Higgs potential – and the widest range of possible TeV-mass particles.**
11. Deep ISR-based searches for dark matter particles.

LHC: 3000 fb^{-1}

Higgs EW Top QCD NP/flavor

1. **The precision era in Higgs couplings: couplings to 2-10% accuracy, 1% for the ratio gamma gamma/ZZ.**
2. Measurement of rare Higgs decays: mu mu, Z gamma with 100 M Higgs.
3. **First measurement of Higgs self-coupling.**
4. Deep searches for extended Higgs bosons
5. Precision W mass to 5 MeV
6. **Precise measurements of VV scattering; access to Higgs sector resonances**
7. Precision top mass to 500 MeV
8. Deep study of rare, flavor-changing, top couplings with 10 G tops.
9. Search for top squarks & partners in models of composite top, Higgs in the expected range of masses.
10. Further improvement of q, g, gamma PDFs to higher x, Q^2
11. A 20-40% increase in mass reach for generic new particle searches - can be 1 TeV step in mass reach
12. **EW particle reach increase by factor 2 for TeV masses.**
13. Any discovery at LHC–or in dark matter or flavor searches–can be **followed up**

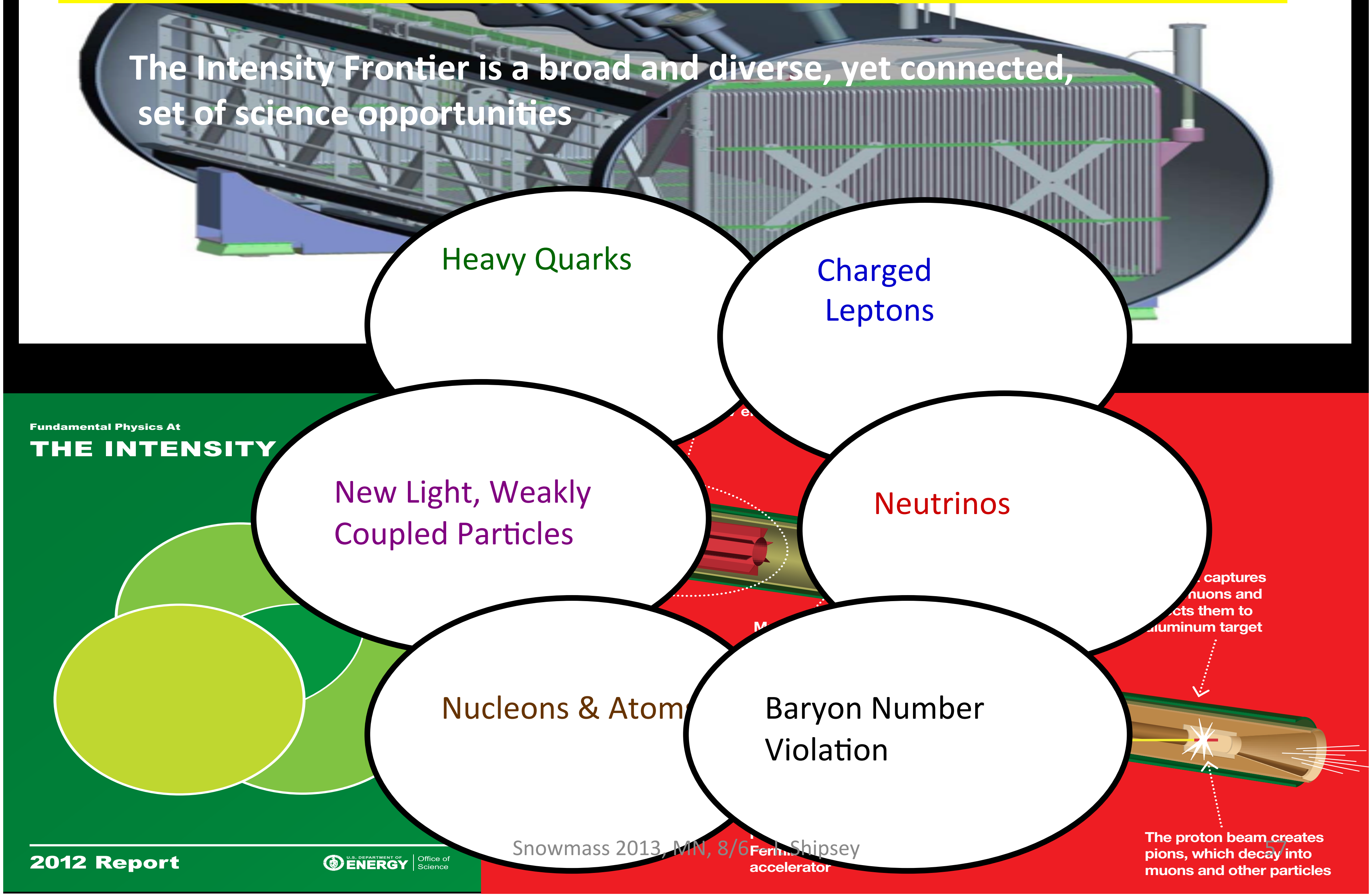
ILC, up to 500 GeV

1. **Tagged Higgs study in e+e–> Zh: model-independent BR and Higgs Γ, direct study of invisible & exotic Higgs decays**
2. **Model-independent Higgs couplings with % accuracy, great statistical & systematic sensitivity to theories.**
3. Higgs CP studies in fermionic channels (e.g., tau tau)
4. **Giga-Z program for EW precision, W mass to 4 MeV and beyond.**
5. Improvement of triple VB couplings by a factor 10, to accuracy below expectations for Higgs sector resonances.
6. Theoretically and experimentally precise top quark mass to 100 MeV.
7. **Sub-% measurement of top couplings to gamma & Z, accuracy well below expectations in models of composite top and Higgs**
8. Search for rare top couplings in e+e- -> t cbar, t ubar.
9. Improvement of α_S from Giga-Z
10. No-footnotes search capability for new particles in LHC blind spots -- Higgsino, stealth stop, compressed spectra, WIMP dark matter

Higgs EW Top QCD NP/flavor

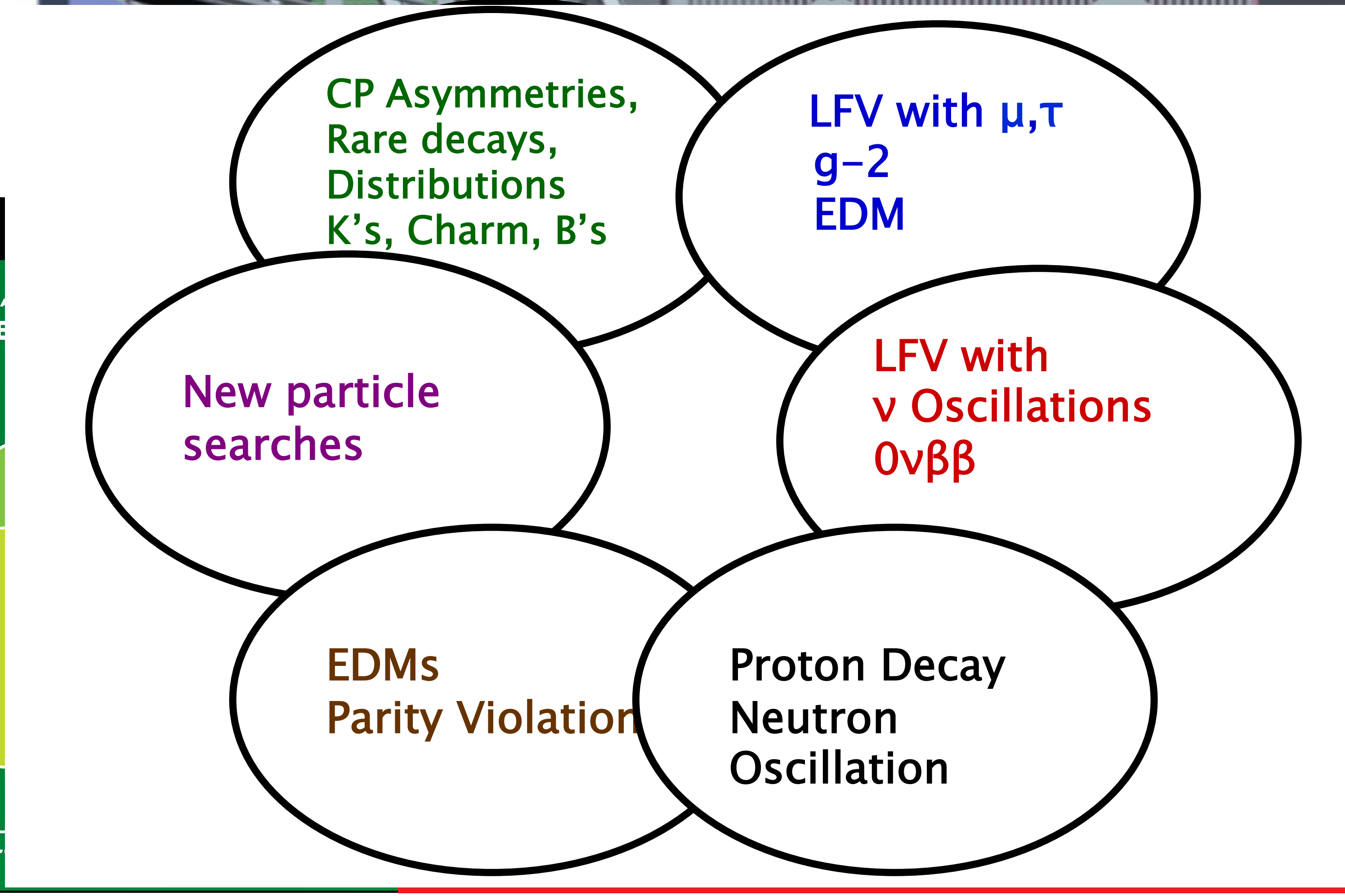
The Intensity Frontier

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

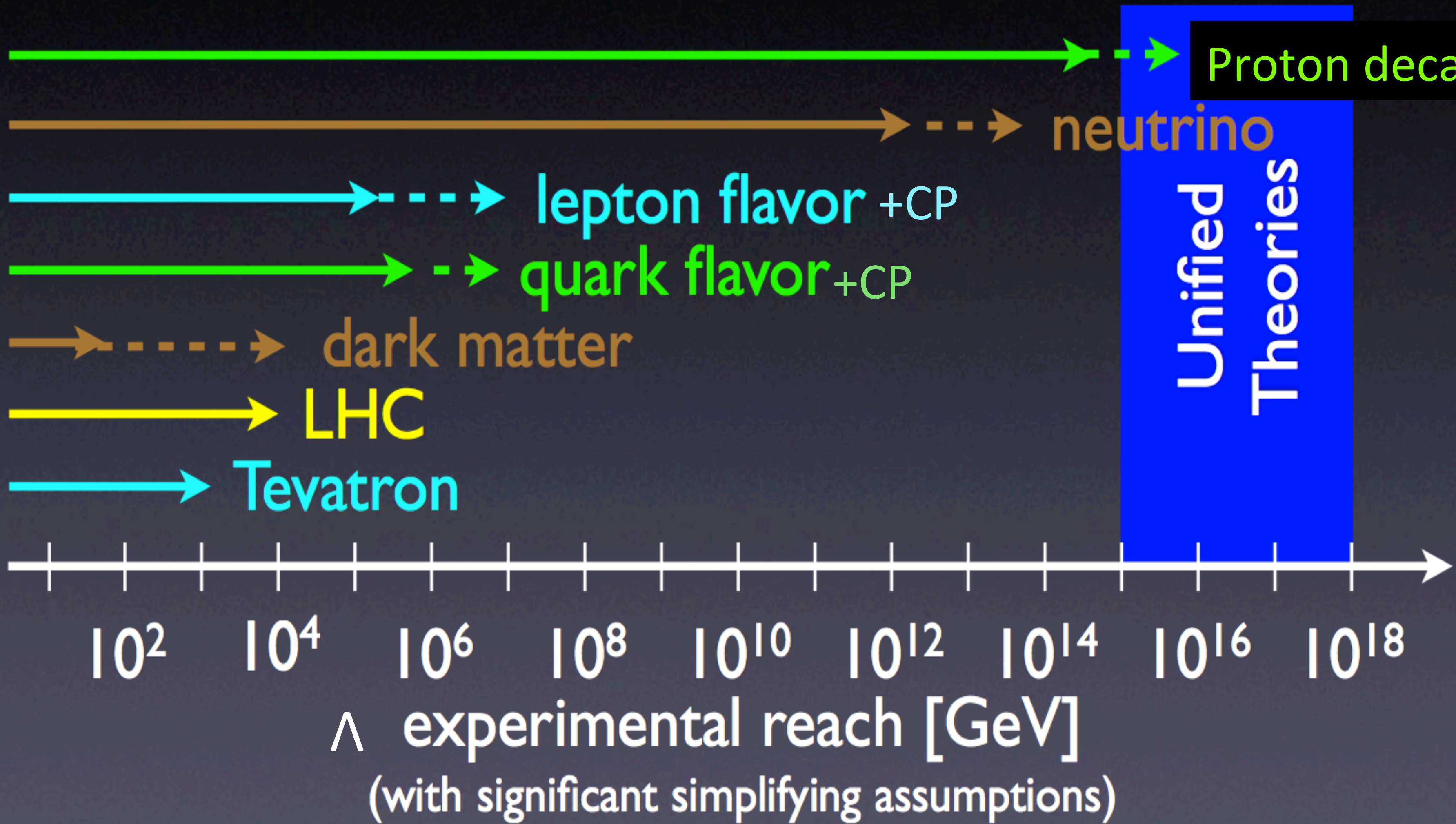


The Intensity Frontier

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



Power of Expedition



courtesy Ligeti/Murayama

The Nature of Neutrinos

- Our questions are very fundamental

  - *what is the absolute neutrino mass scale*

  - *are neutrinos Majorana or Dirac?*

  - *what is the neutrino mass ordering?*

  - *is CP violated in the neutrino sector?*

  - *to what extent does the 3n paradigm describe nature?*

  - *are there hints of new physics in existing data?*

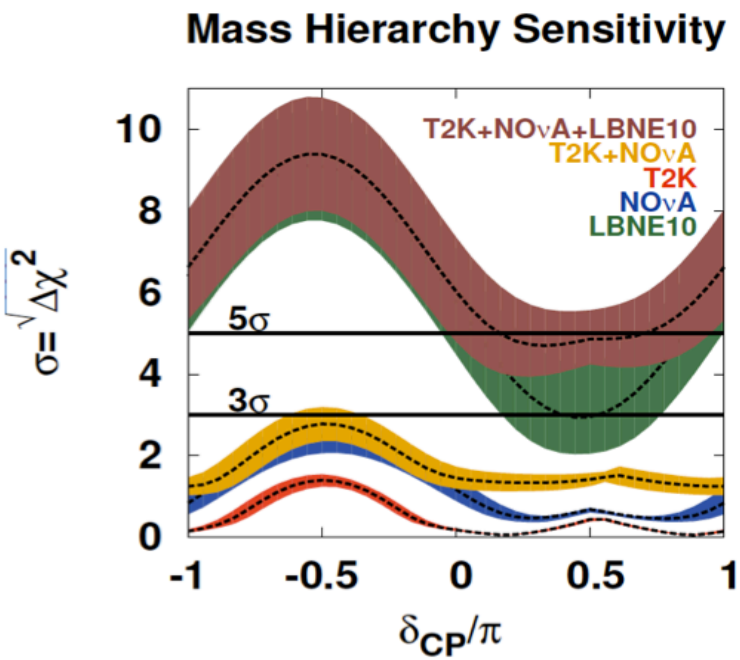
  - *what new knowledge will neutrinos from astrophysical sources bring?*

- We know this information for every other particle!
- We know more about the Higgs than we do about neutrinos

Neutrino Oscillations

- The U.S. with the Long-Baseline Neutrino Experiment (LBNE) and a future multi-megawatt beam from Project-X is uniquely positioned to lead an international campaign to test the 3-flavor paradigm, measure CP violation and go beyond.
- An underground location for a far detector significantly enhances the physics breadth & allows for the study of atmospheric n’s, nucleon decay, & precision measurement of n’s from a galactic supernova explosion

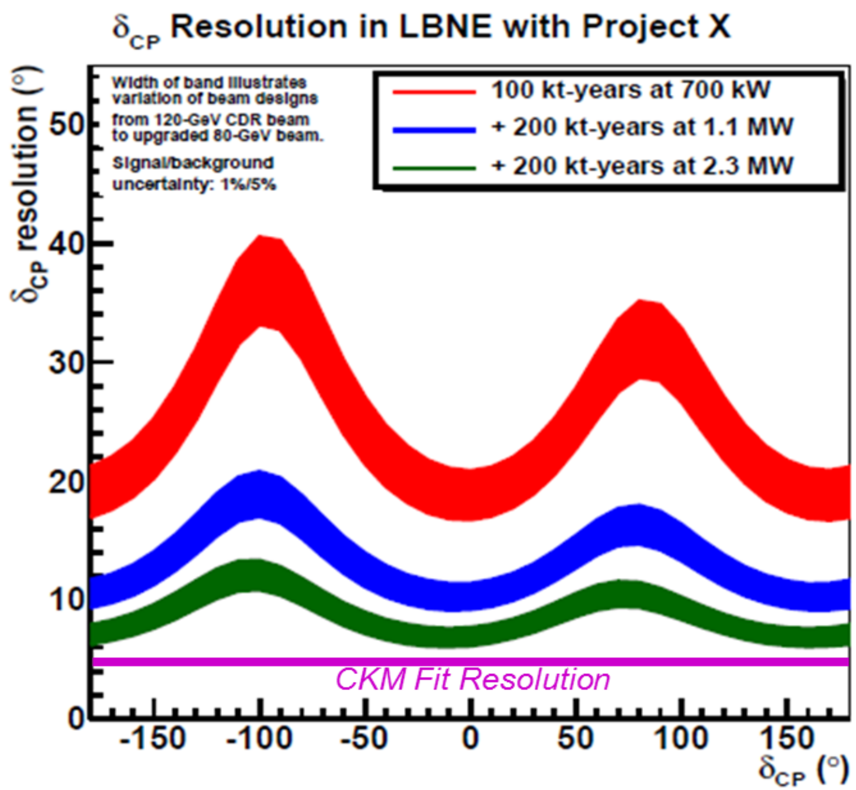
Mass hierarchy



- MH determination by long-baseline experiments "guaranteed" with sufficient exposure

CP Violation

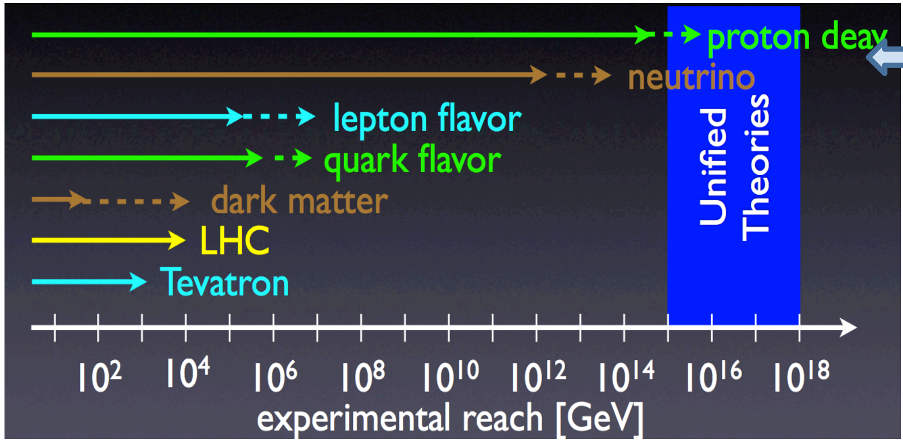
δ_{cp} Resolution



LBNE + Project X enable an era of high-precision neutrino oscillation measurements.

Intensity Frontier Science Summary

Precision neutrino physics in next two decades



Quark & Charged Flavor experiments

Electric Dipole Moments (EDMs)

Proton Decay & NNbar oscillations

New light, weakly coupled particles

Rapid progress from last 2 years will continue

Intensity & Cosmic Frontiers

Probe mass scales of possible New Physics with multiple approaches

Particle explanation of Dark Sector

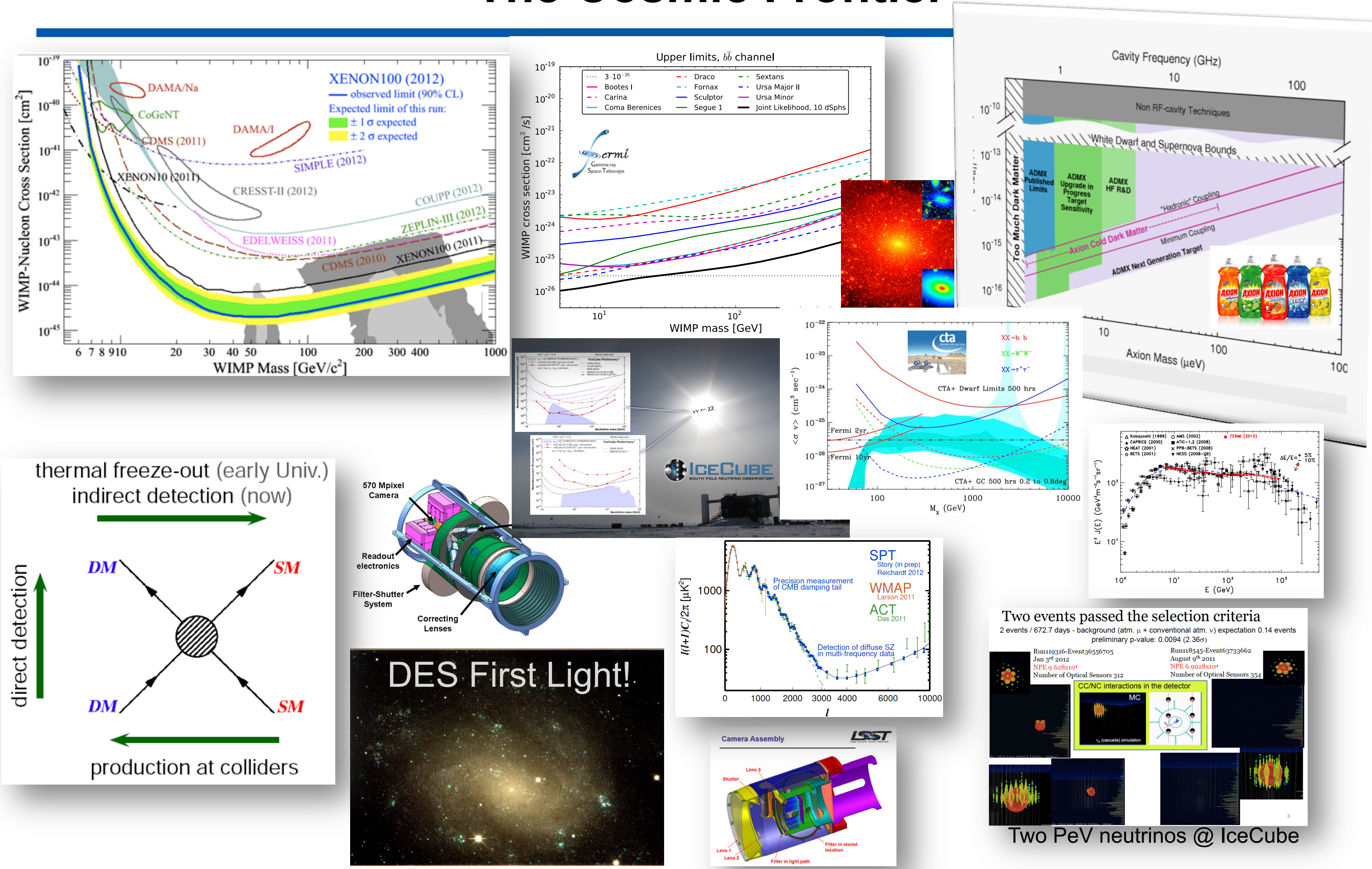
Intensity Frontier Science summary II

All the questions

- **Are there sources of CP Violation beyond θ_{CKM}?**
- **Is there CP Violation in the leptonic sector?**
- **What are the properties of the neutrino?**
- **Do the forces unify?**
- **Is there a weakly coupled Hidden Sector linked to the Dark Side?**
- **Are apparent symmetries (B,L) violated at high scales?**
- **What can we learn about the flavor sector of new physics?**
- **What is the new physics mass scale?**

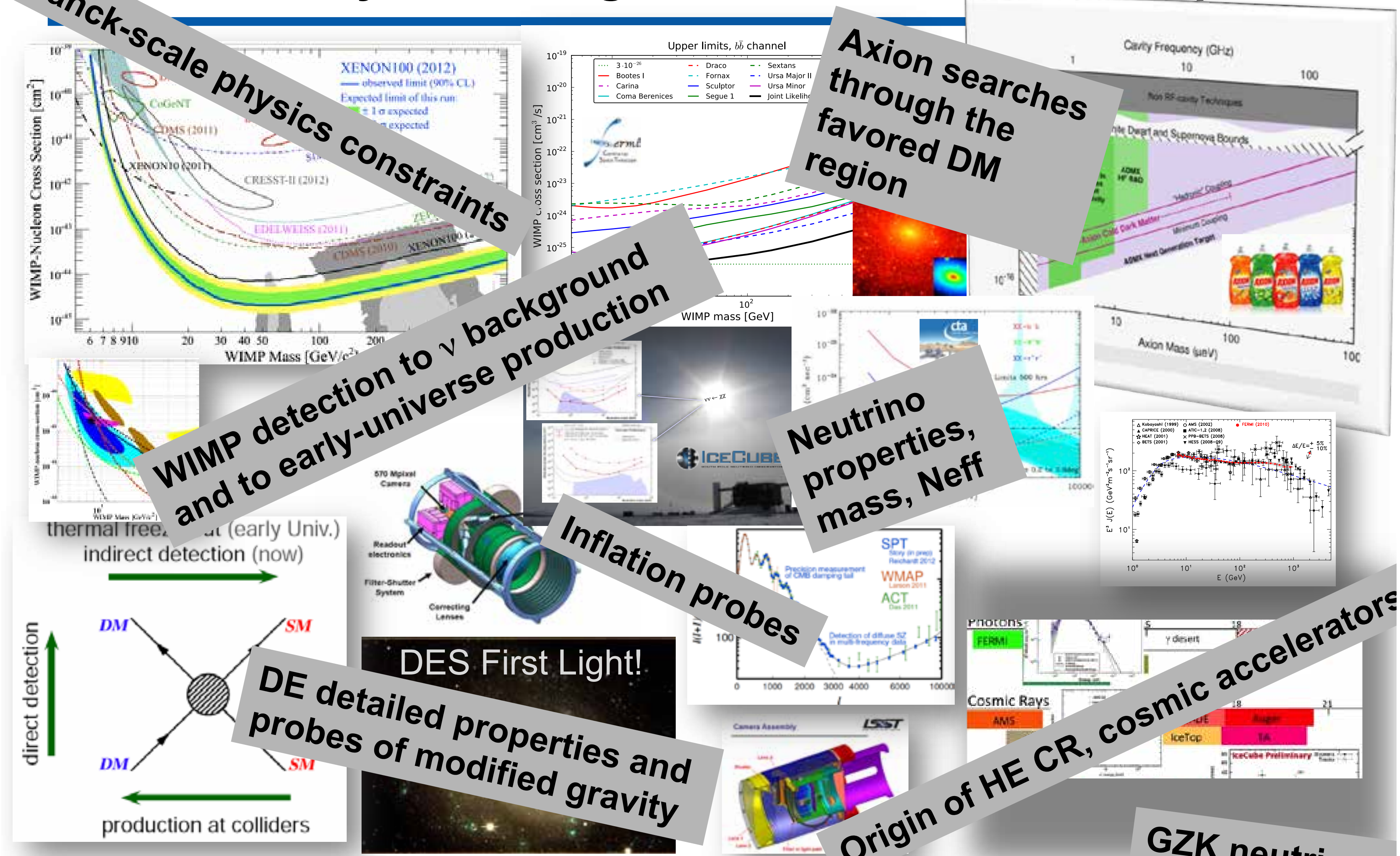
- *Intensity Frontier addresses these questions with a diverse and focused program*
- *Potential of paradigm-changing discoveries*
- *Synergy with other frontiers* ➔ *stronger HEP program*

The Cosmic Frontier



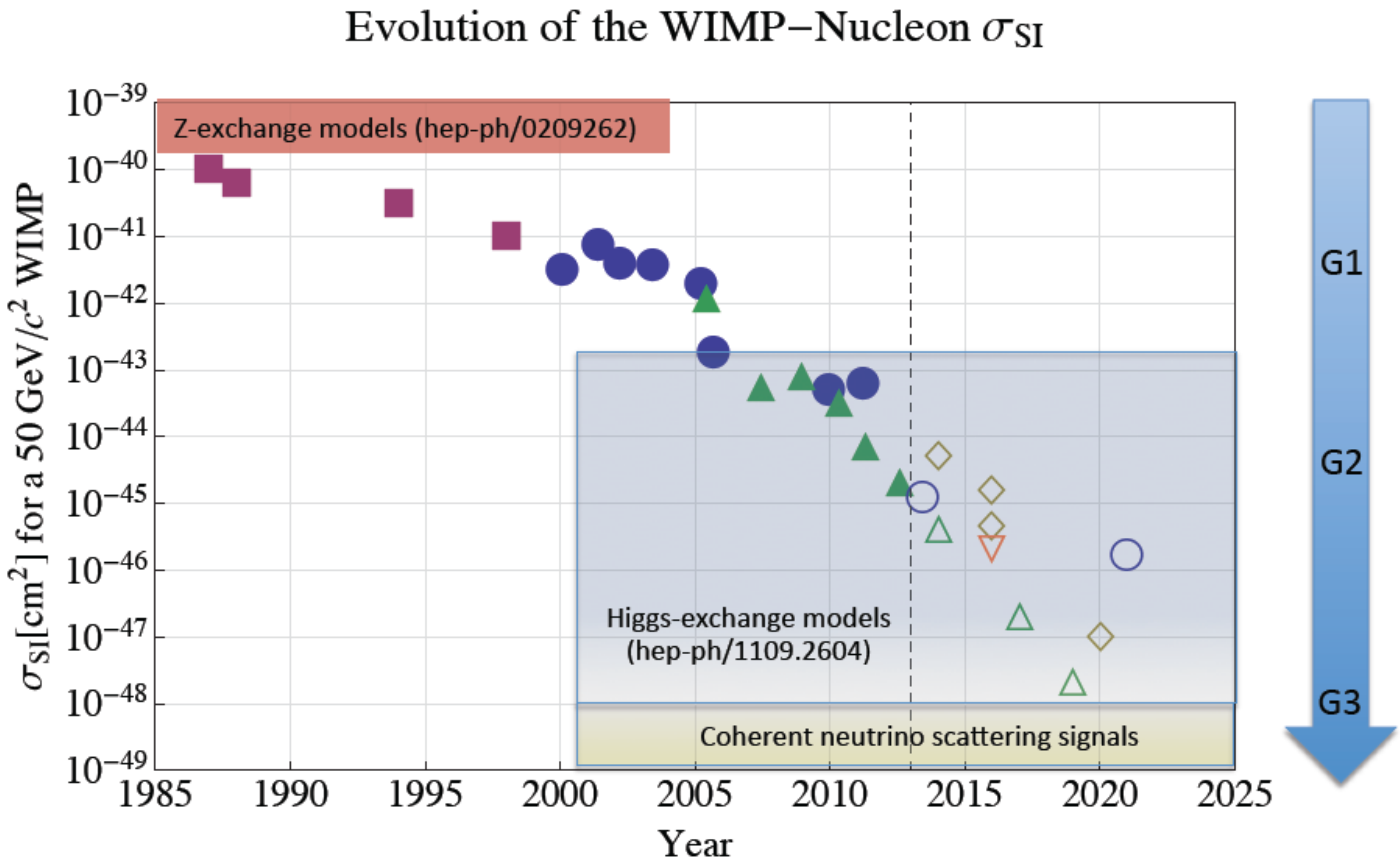
Activities at the Cosmic Frontier are marked by rapid, surprising, and exciting developments

Particle Physics Using Cosmic Frontier Techniques



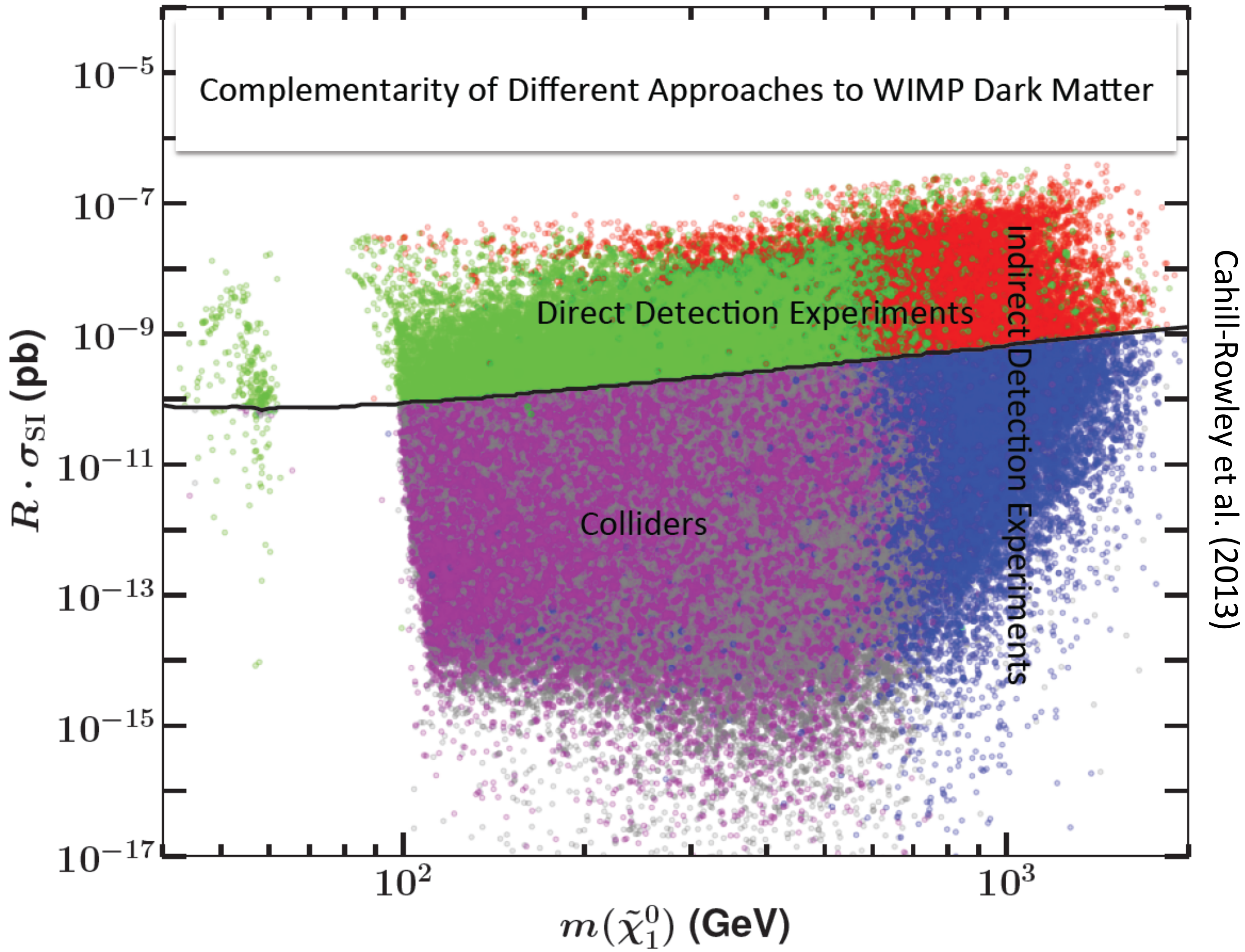
Activities at the Cosmic Frontier are marked by rapid, surprising, and exciting developments

MOORE'S LAW FOR DARK MATTER



COMPLEMENTARITY: FULL MODELS

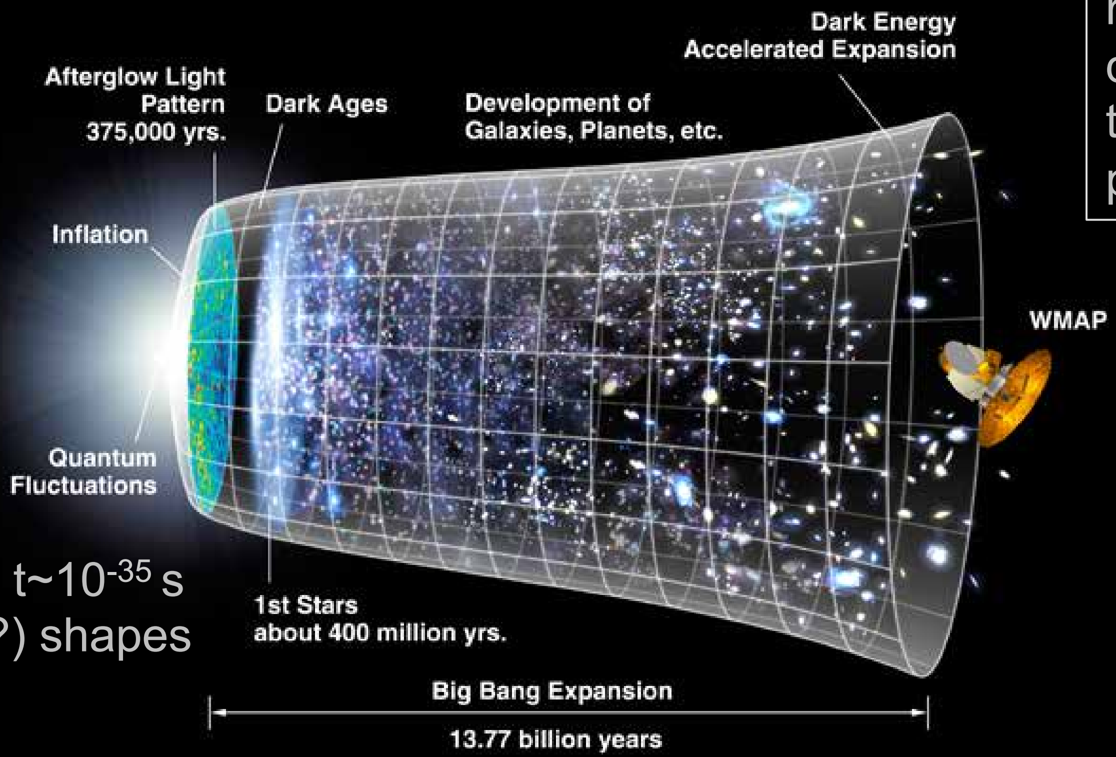
pMSSM 19-parameter scan of SUSY parameter space



Different SUSY models are probed by different experiments

Cosmic Surveys: The Big Picture

Detailed comparisons of different observations with much richer data sets will directly address these topics, and likely also provide more surprises.

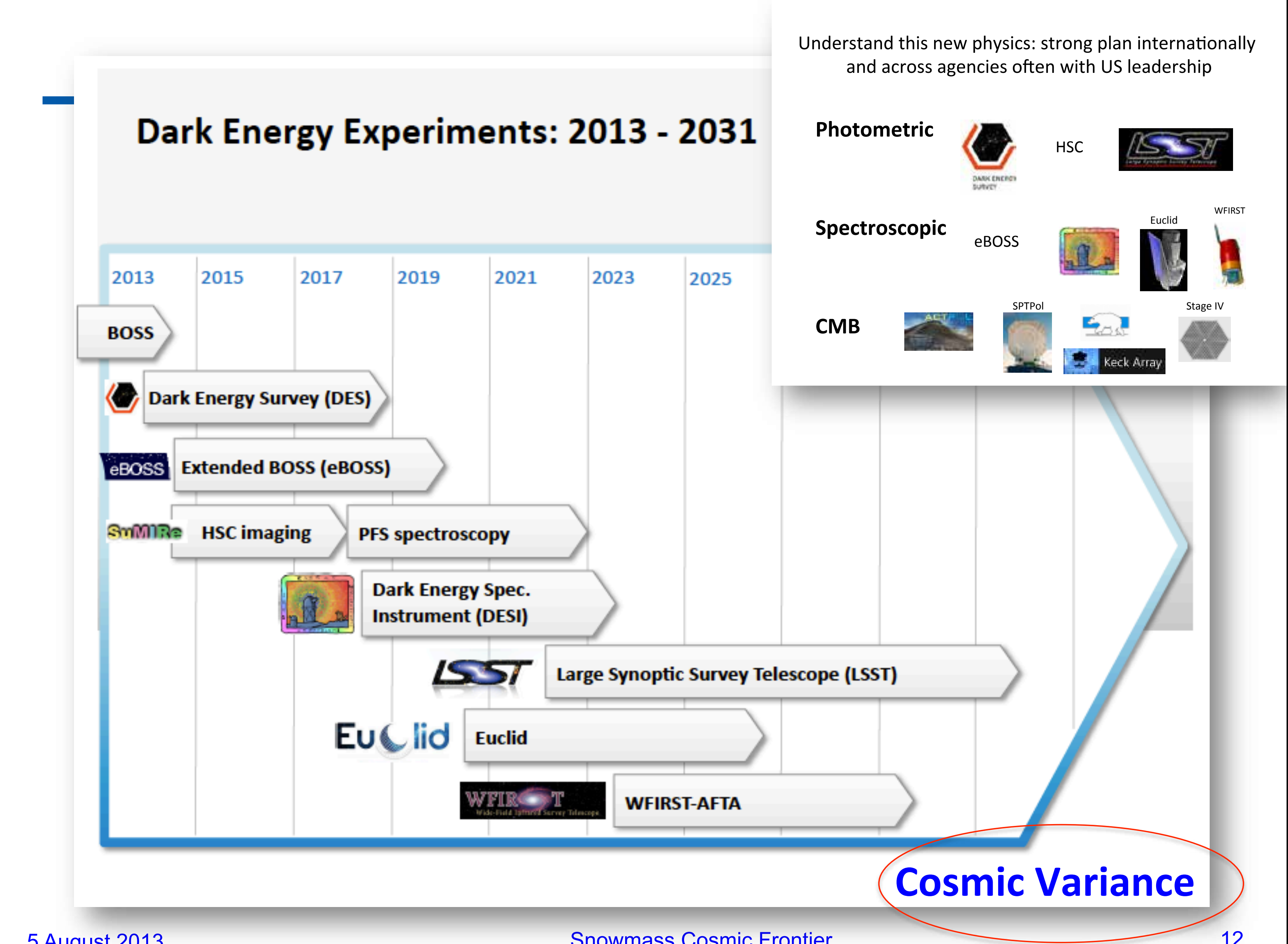


Inflation at $t \sim 10^{-35}$ s (driven by ?) shapes the…

…CMB map at t~300,000 years, which, seeds structure formation driven by **Dark Matter** producing the growth of structure, which…

…is then driven by **Dark Energy...**

…and Neutrinos (N_{eff} and ($\Sigma m_\nu > 0$) have a significant impact on the growth of structure at small scales


Dark Energy Experiments: 2013 - 2031
2013
2015
2017
2019
2021
2023
2025
BOSS
Dark Energy Survey (DES)
eBOSS
Extended BOSS (eBOSS)
SuMIRe
HSC imaging
PFS spectroscopy
Dark Energy Spec. Instrument (DESI)
LSST
Large Synoptic Survey Telescope (LSST)
Euclid
Euclid
WFIRST
WFIRST-AFTA
Understand this new physics: strong plan internationally and across agencies often with US leadership
Photometric
HSC
Spectroscopic
eBOSS
Euclid
WFIRST
CMB
SPTPol
Stage IV
Keck Array
Cosmic Variance

The take home message from the Cosmic Frontier

- **<u>Together with the other Frontier areas</u>**, the "Cosmic Frontier" provides to Particle Physics:
  - Clear evidence for physics Beyond the Standard Model
  - Profound questions of popular interest.
  - Frequent new results, surprises, with broad impacts.
  - Large discovery space with unique probes.
  - Important cross-frontier topics
  - Full range of project scales, providing flexible programmatic options.
  - **US Leadership**

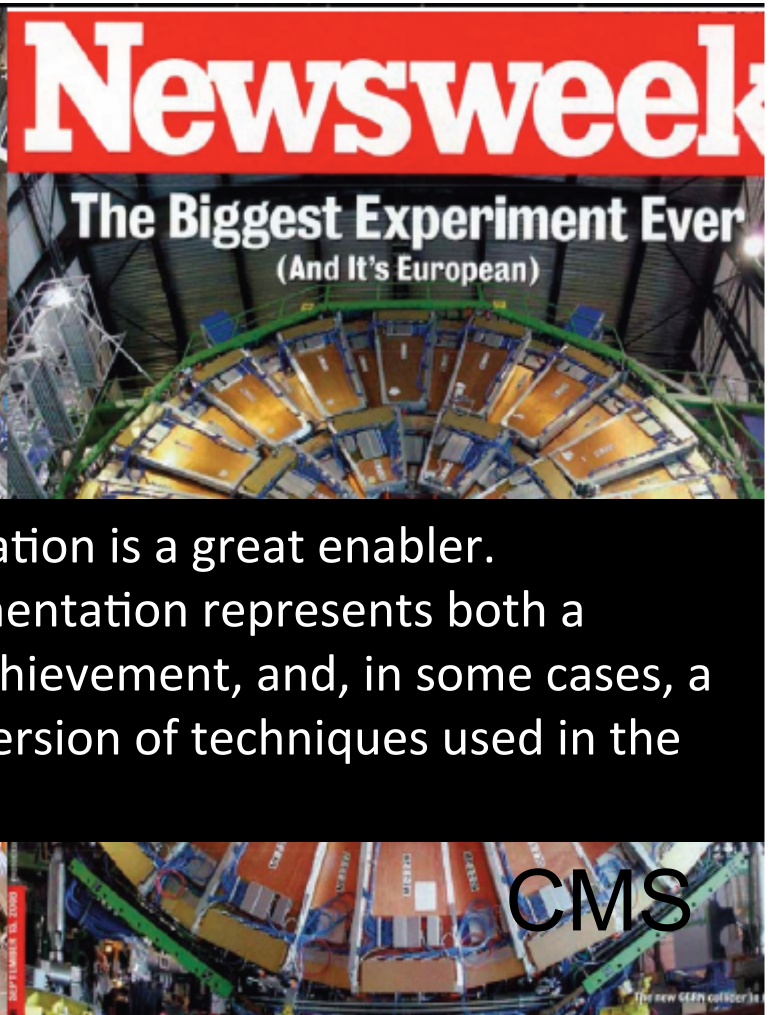
The Instrumentation Frontier

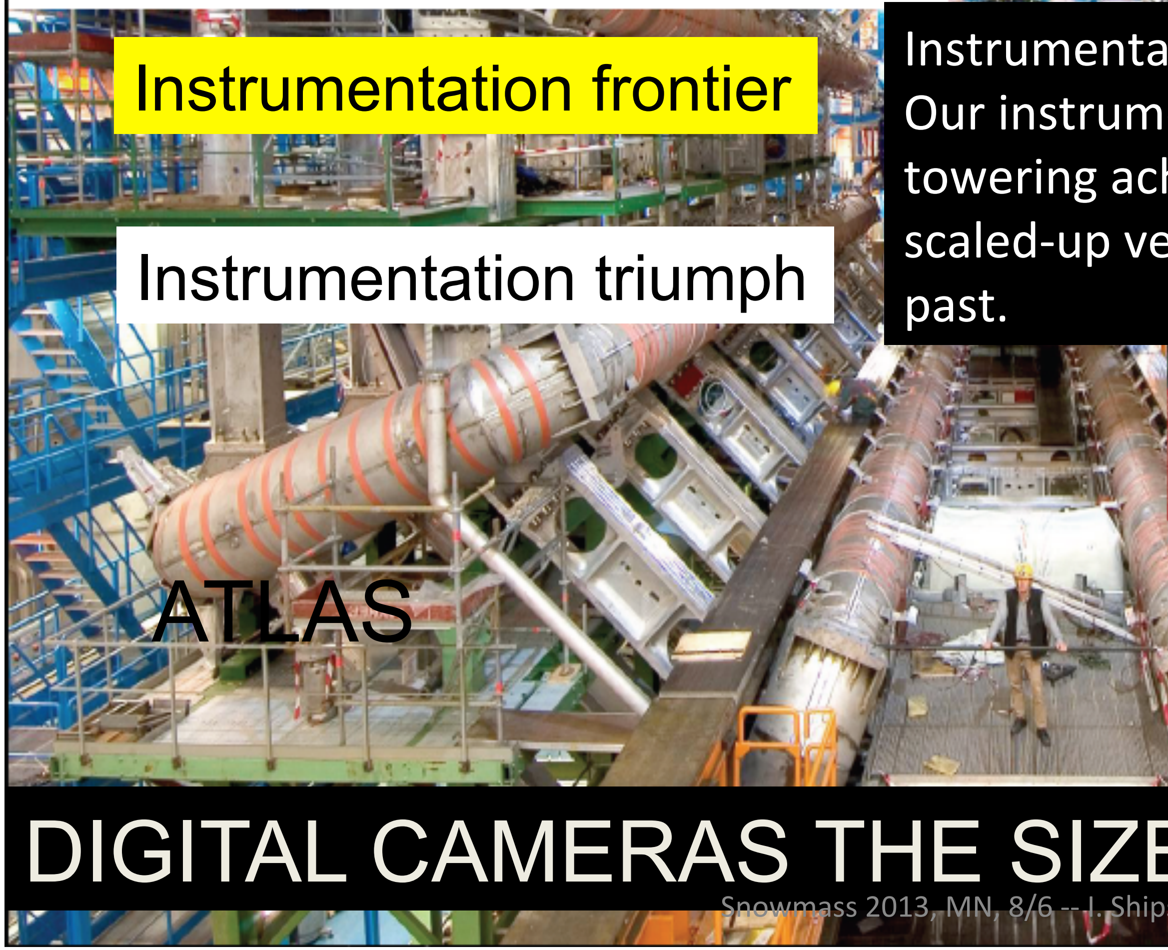
"New directions in science are launched by new tools much more often than by new concepts.

The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained"

Freeman Dyson

Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
USS John McCain	8,300
CMS	12,500





Instrumentation frontier

Instrumentation triumph

Instrumentation is a great enabler.
Our instrumentation represents both a towering achievement, and, in some cases, a scaled-up version of techniques used in the past.

CMS

ATLAS

DIGITAL CAMERAS THE SIZE OF CATHEDRALS

Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
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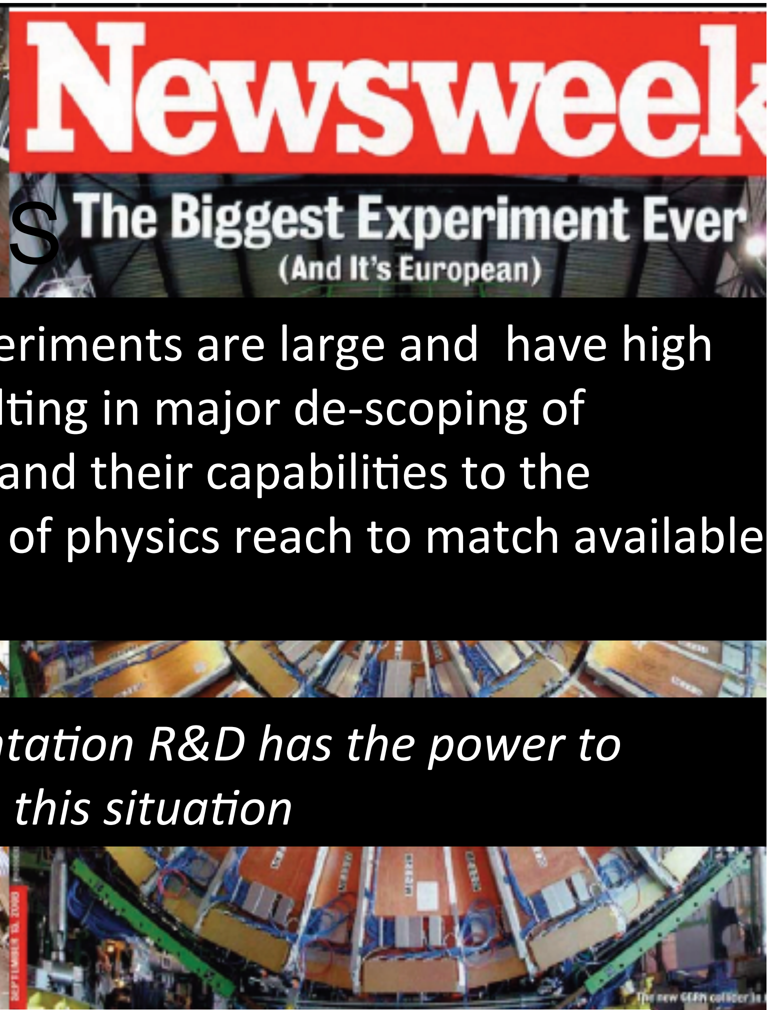
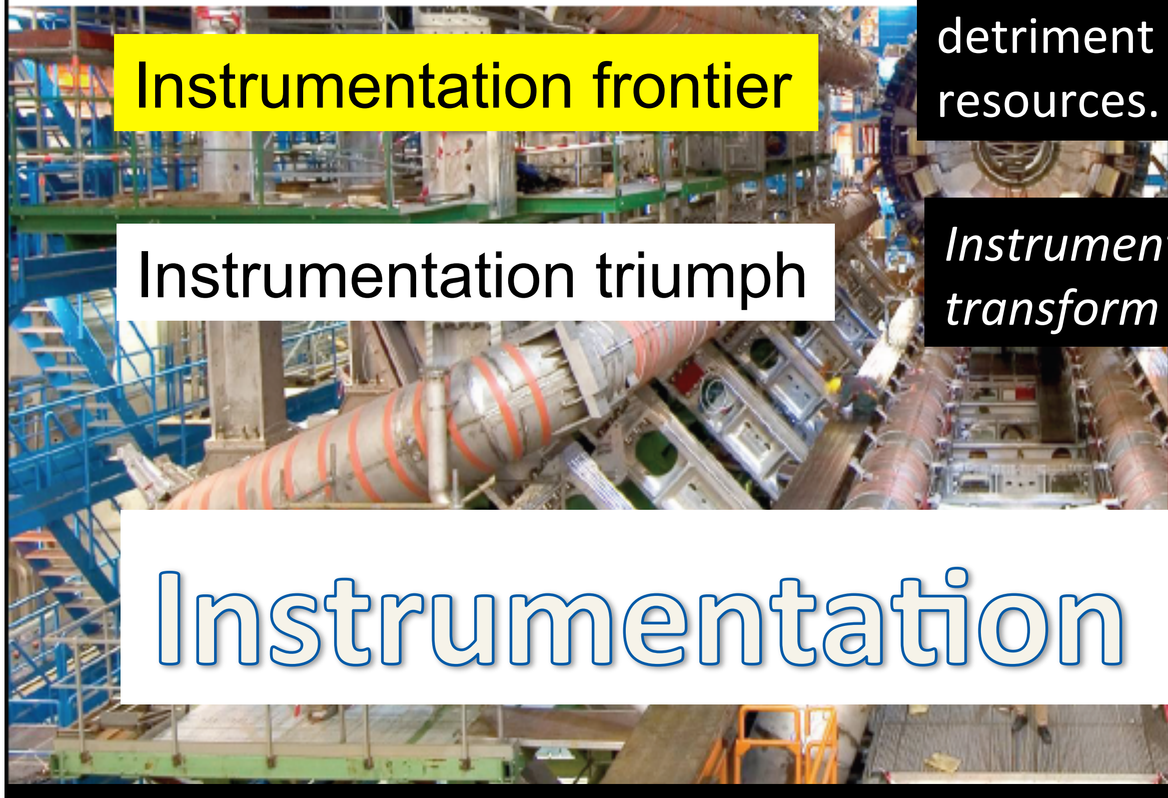
CMS	12,500



CMS

Many experiments are large and have high costs resulting in major de-scoping of detectors and their capabilities to the detriment of physics reach to match available resources.



Instrumentation frontier

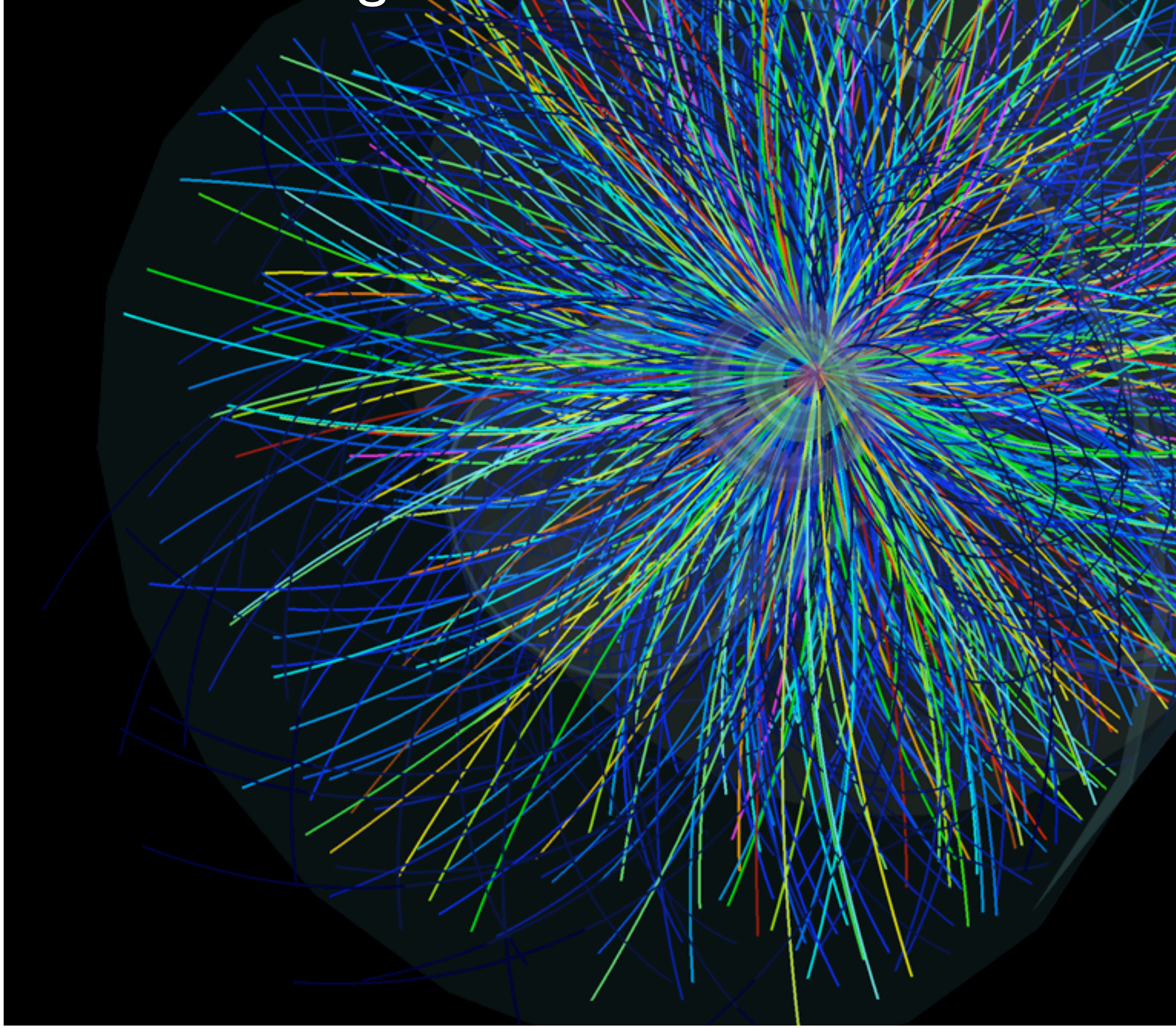
Instrumentation triumph

Instrumentation R&D has the power to transform this situation

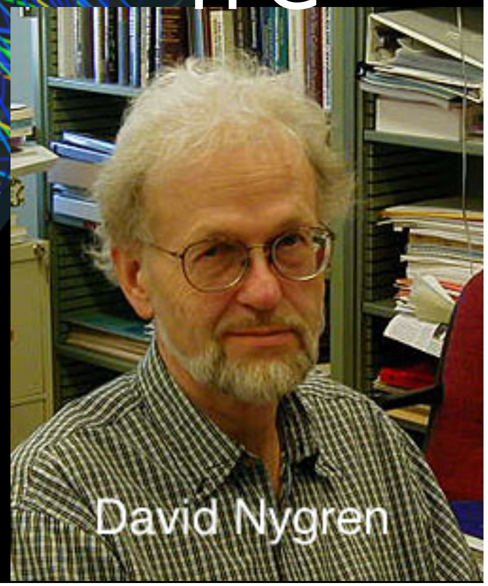
Instrumentation Challenge

DIGITAL CAMERAS THE SIZE OF CATHEDRALS

need to develop new technologies

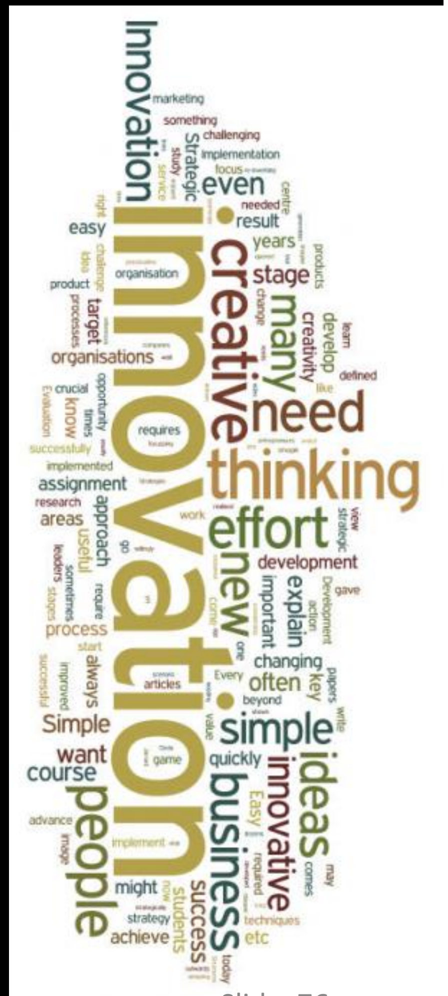


TPC



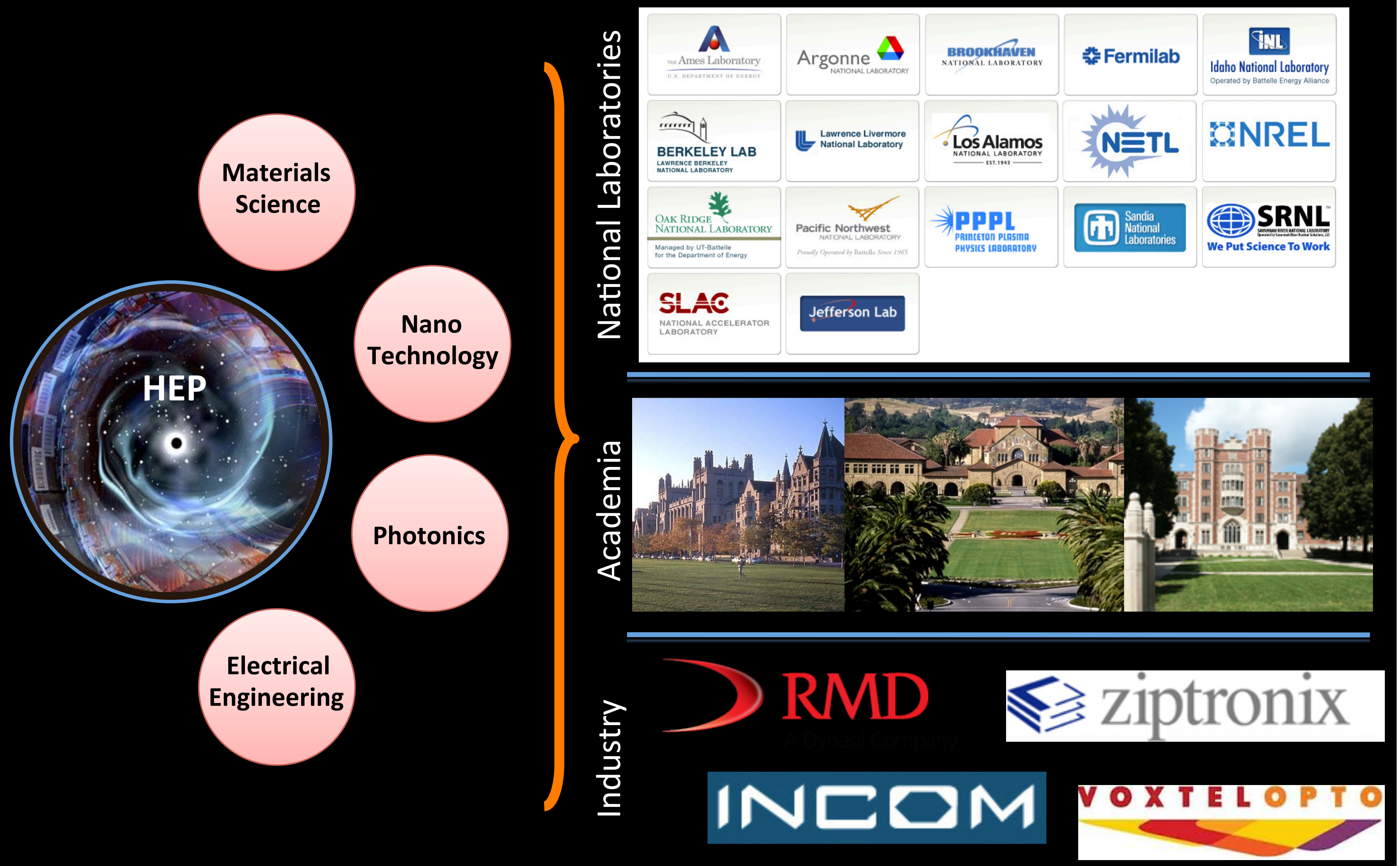
Instrumentation Frontier

- **Innovation in instrumentation is central to discovery science.**
- **The field of high-energy physics has a long history of invention that has led to fundamental discoveries in particle physics**
- **In the 21st century multi-disciplinary research is where progress is being made.**
- **Key strategic areas were identified for investment in cost-effective technologies that would maintain leadership and benefit the national interests.**
- **Support for new instrumentation development is an investment in the future**
- **Instrumentation provides a means for training new generations, provides challenging opportunities, retains expertise, enable leadership position for experiments off-shore, develop new, cost-effective technologies**



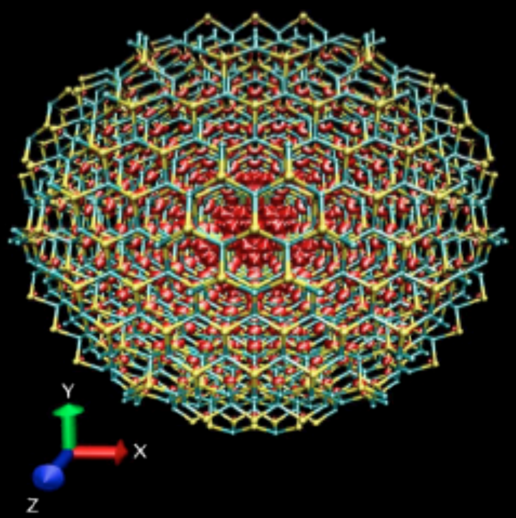
Need innovation !

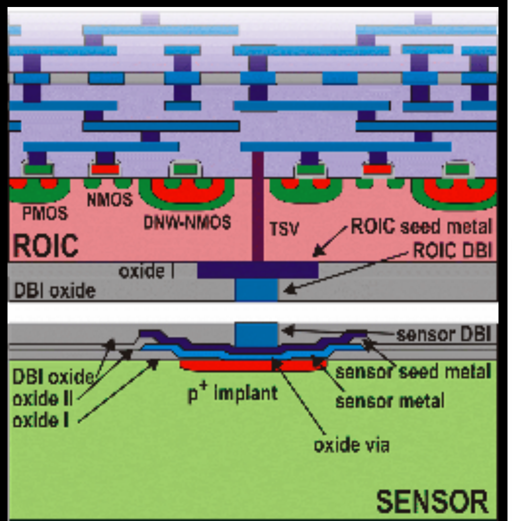
Innovation Through Partnerships

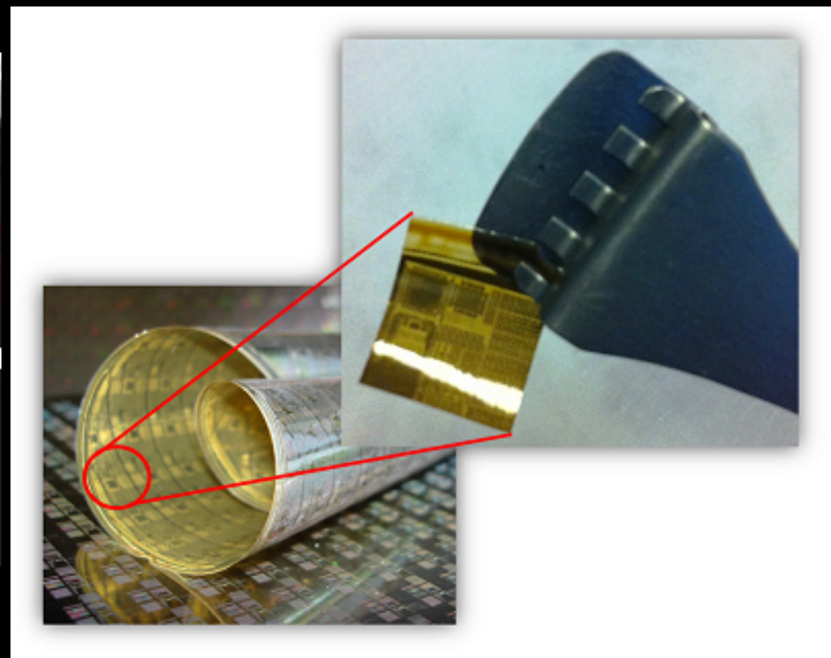


Funding Balance .... "The 1% Tax"

- What is the right balance between funding to support the needs of specific projects and funding to support generic detector development ?
- **What if 1% of the OHEP budget were set aside for the development of potentially transformative technologies ?**
- What technologies could be developed?







Strategic Themes

- Identified various strategic themes common to many experiments that could serve as “grand challenge” supported by the tax

Technology	Implementation
Pixelization	Silicon pixels, MKID, CCD, LAPPD, MSGC->large area
ASIC and electronics	Everywhere…
Trigger and DAQ	Stream everything if possible, intelligent front ends
Mechanics and power	Low mass materials, foams, power conversion
Photosensors	SiPM, MCP, Cathodes-> large area, fast
Speed	Fast silicon, crystals, photosensors, electronics
Resolution	Crystals, dual readout or PFA calorimeters,

Instrumentation

- **Investing in detector development is an investment in the future:**
  - **Hold promise of substantial cost saving**
  - **In young people**
  - **In training and education**
  - **In university and laboratory infrastructure**
  - **In new multi-disciplinary technologies**
  - **In cost effectiveness**
  - **In providing opportunities for broad societal benefit**

  - ***It's the foundation for the viability of our field***

CPAD

Coordinating Panel for Advanced Detectors

- CPAD: to promote, coordinate and assist in the research and development of instrumentation for High Energy Physics nationally, and to develop a detector R&D program to support the mission of High Energy Physics for the next decades.

- CPAD Membership
- From Universities
  - Jim Alexander (Cornell)
  - Marina Artuso (Syracuse)
  - Ed Blucher (Chicago)
  - Ulrich Heintz (Brown)
  - Howard Nicholson (Mt. Holyoke)
  - Abe Seiden (UCSC)
  - Ian Shipsey* (Purdue)

CPAD appointed spring 2012

http://www.hep.anl.gov/cpad/

- From Laboratories
  - Marcel Demarteau* (Argonne)
  - David Lissauer (Brookhaven)
  - David MacFarlane (SLAC)
  - Ron Lipton (Fermilab)
  - Gil Gilchriese (LBNL)
  - Bob Wagner (Argonne)
- International
  - Ariella Cattai (CERN)
  - Junji Haba (KEK)

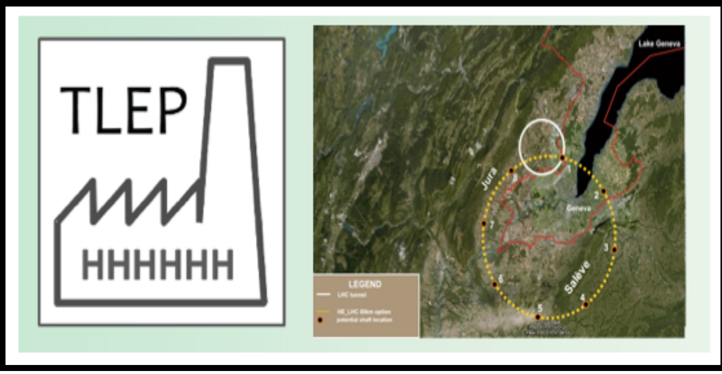
(*) = co-chair

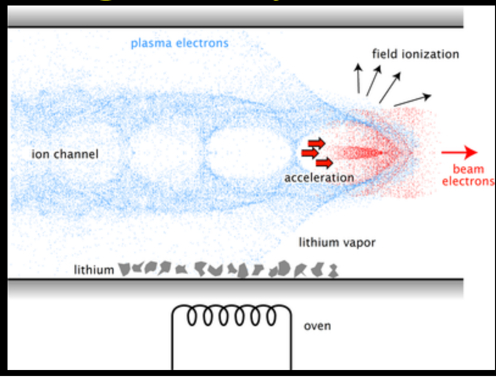
What are long term "big questions"?

regarding accelerator-based HEP capabilities

- *How would one build a 100 TeV scale hadron collider?*
- *How would one build a lepton collider at >1 TeV?*
- *How would one generate 10 MW of proton beam power?*
- *Can multi-MW targets survive? If so, for how long?*
- *Can plasma-based accelerators achieve energies & luminosities relevant to HEP?*
- *Can accelerators be made 10x cheaper per GeV? Per MW?*

These are issues for the long term future





Priority: Full exploitation of LHC

- => Strong LHC Accelerator Research Program continuing to U.S.-LHC high luminosity construction project
- Continue a focused integrated laboratory program (LARP-like) emphasizing engineering readiness of technologies suitable for High Energy-LHC
  - Next generation high field Nb_3Sn magnets (~15 Tesla)
  - Beam control technology
- This is most critical technology *development* toward higher energy hadron colliders in the near to mid-term
- Reach of an LHC energy upgrade is very limited
  - No engineering materials beyond Nb_3Sn
  - Difficult synchrotron radiation management

Proton colliders beyond LHC

- US multi-lab study of VLHC is still valid (circa 2001);
  - Snowmass has stimulated renewed interest/effort in US
    - 2013 Snowmass white paper
- We recommend participating in international study for colliders in a large tunnel (CERN-led)
- Study will inform directions for expanded U.S. technology reach & guide long term roadmap
  - Beam dynamics, magnets, vacuum systems, machine protection, …

Extensive interest expressed in this possibility

We welcome the initiative for ILC in Japan

- U.S. accelerator community is capable to contribute
  - Supported by the physics case as part of a balanced program
- ILC design is technically ready to go
  - TDR incorporates leadership U.S. contributions to machine physics & technology
    - SRF, high power targetry (e+ source), beam delivery, damping rings, beam dynamics
- Important that there is an upgrade path of ILC to higher energy & luminosity (> 500 GeV, > 10^{34} $cm^{-2}s^{-1}$)

We are experienced & ready to do it

Higgs factory: Alternate approaches

- Circular e+e- in very large tunnel (50 – 100 km)
  - Substantial extrapolation albeit from large experience base
    - LEP/LHC tunnel not preferred for physics & programmatic reasons
  - Energy reach & luminosity are very strongly coupled – details!
    - Very large luminosity at Z peak: falls rapidly as √s increases
    - Tight linkage to 100 TeV proton collider opportunity
- Muon collider: Feasibility study is underway (see next slide)
  - Could provide options from Higgs to multi-TeV
- Gamma-gamma collider
  - Basis is US leadership in "industrial strength," high energy lasers
  - Can be ILC option or stand-alone facility
  - Laser technology overlap with laser wakefield accelerators

Caveat emptor: It is difficult to compare mature,
detailed engineering designs with parameter studies

Recommendations: Increase research effort toward a compact, muli-TeV lepton collider

- Vigorous, integrated R&D program toward demonstrating feasibility of a muon collider (Muon Accelerator Program)
  - Current support insufficient for timely progress
  - Closely connected with intensity frontier & intense neutrino sources
- Stay involved in high gradient, warm linac approach (CLIC)
  - Practical energy reach: wakefield control, accelerating gradient
  - Industrialization path to be developed
- Continue R&D in wakefield accelerators (plasmas & dielectric)
  - Fruitful physics programs with high intellectual content
  - Feasibility issues: Positron acceleration, multi-stage acceleration, control of beam quality, plasma instabilities at 10's of kHz rep rate
  - All variants require an integrated proof-of-principle test

Motivations: Lower cost, smaller footprint, higher energy

Project X: a world leading facility for Intensity Frontier research

- Based on a modern multi-MW SCRF proton linac
  - Flexible "on-demand" beam structure
- Could serve multiple experiments over broad energy range
  - 0.25 – 120 GeV
- Platform for future muon facilities (νFactory/muon collider)
- Complete, integrated concept Reference Design Report
  - arXiv:1306.5022
- R&D program underway to mitigate risks in Reference Design
  - Undertaken by 12 U.S. & 4 Indian laboratories and universities

Could initiate construction in the second half of this decade

The stewardship of accelerator science and technology by the Office of High Energy Physics has been and will continue to be crucial to the vitality of accelerator-based high energy physics.

Underground Facilities

- Underground facilities and capabilities essential to support experiments that are central to the world-wide and U.S. scientific program
  - Direct dark matter experiments
  - Neutrinoless double-beta decay ($0\nu\beta\beta$) experiments
  - Atmospheric, long-baseline, reactor, solar, supernova…. neutrino experiments
  - Proton decay
  - Connections to astrophysics, nuclear science, earth science and detectors for non-proliferation

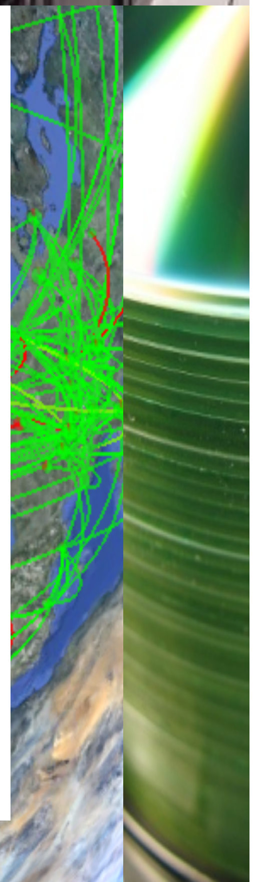
Underground Capability - Summary

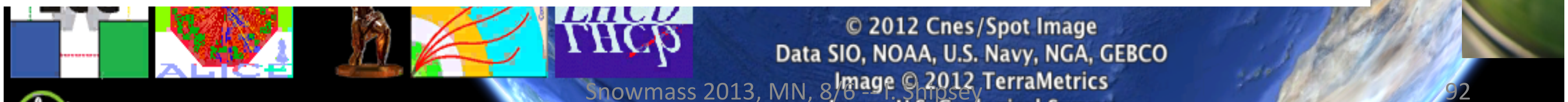
- Substantial expansion in non – U.S. underground capabilities by 2016-2020.
- Critical that U.S. scientists continue to be supported in the future to take full advantage of international and domestic underground facilities.
- Key underground facilities goals for upcoming U.S. planning
  - Put LBNE underground to realize its full science potential. This would also make it an anchor of possible future domestic underground capabilities at SURF.
  - The U.S. has leading roles in many of the future dark matter, $0\nu\beta\beta$ and a large variety of ν experiments.
  - More coordination and planning of underground facilities(overseas and domestic) is required to maintain this leading role, including use of U.S. infrastructure.
  - Maintaining an underground facility that can be expanded to house the largest dark matter and $0\nu\beta\beta$ experiments would guarantee the ability of the US to continue its strong role in the worldwide program of underground physics.

Computing frontier

Computing has become essential to advances in experimental and many areas of theoretical physics. Research requirements in these areas have led to advances in computational capabilities.

- What are the computational requirements for carrying out the experiments that will lead to advances in our physics understanding?
- What are the computational requirements for theoretical computations and simulations that will lead to advances in our physics understanding?
- What facility and software infrastructure must be in place in order to meet these requirements, and what research investments does it require in computing, storage, networking, application frameworks, algorithms, programming, etc. to provide that infrastructure?
- What are the training requirements to assure that personnel are available to meet the needs?





Conclusions on Computations

- Challenging resource needs require efficient and flexible use of all resources
  - HEP needs both Distributed High-Throughput computing (experiment program) and High-Performance computing (mostly theory/simulation/modeling)

- To stay on the Moore's law curve, need to proactively make full/better use of advanced architectures
  - with the need for more parallelization the complexity of software and systems continues to increase: frameworks, workload management, physics code
- Unless corrective action is taken we could be frozen out of cost effective computing solutions on a time scale of 10 years.
  - There is a large code base to re-engineer
  - We currently do not have enough people trained to do it

Conclusions on Data

- The growth in data drives need for continued R&D investment in data management, data access methods, networking
  - Continued evolution will be needed in order to take advantage of new network capabilities, ensure efficiency and robustness of the global data federations, and contain the level of effort needed for operations
- Networks can be relied on to serve as foundation of data intensive distributed computing
  - emerging network capabilities and data access technologies improve our ability to use resources independent of location, over the network
- Have to learn to do more with less. This requires being more flexible and perhaps tolerating higher levels of risk

Need for Training and Career Paths

- Encourage training, as a continuing activity
- Provide young scientists with opportunities to learn computing and software skills that are marketable for non-academic jobs
- Training and career paths (including tenure stream) for researchers who work at the forefront of computation techniques and science is critical

Overarching Communication, Education & Outreach Goals

Communication, Education and Outreach Frontier

1. To ensure that the U.S. particle physics community has the resources necessary to conduct research and maintain a world leadership role.

2. To ensure that the U.S. public appreciates the value and excitement of particle physics.

3. To ensure that a talented and diverse group of students enter particle physics and other STEM careers, including science teaching.

Needs Drive Our Implementation Plans

Overarching strategies that serve all audiences and all goals

- Developing a central, comprehensive communication, education and outreach resource with training materials.
- Recognition within our community that these activities are critical to the success and health of our field; should be formally recognized; and require time, effort and funding.
- Augmenting existing national particle physics communication efforts with additional personnel and resources dedicated to nationwide coordination, training and support

Needs Drive Our Implementation Plans

Strategies for different audiences

- Policy makers: Year-round campaigns with support; impact quantification; third-party advocates.
- The general public: Wide range of outreach activities; value to society; emphasize role of U.S. scientists.
- Teachers and students: Physicists directly engage; research-based professional development; opportunities for students of all ages.
- The science community: Develop consensus and support plan; foster dialog and unite with other fields.

Our work starts now!

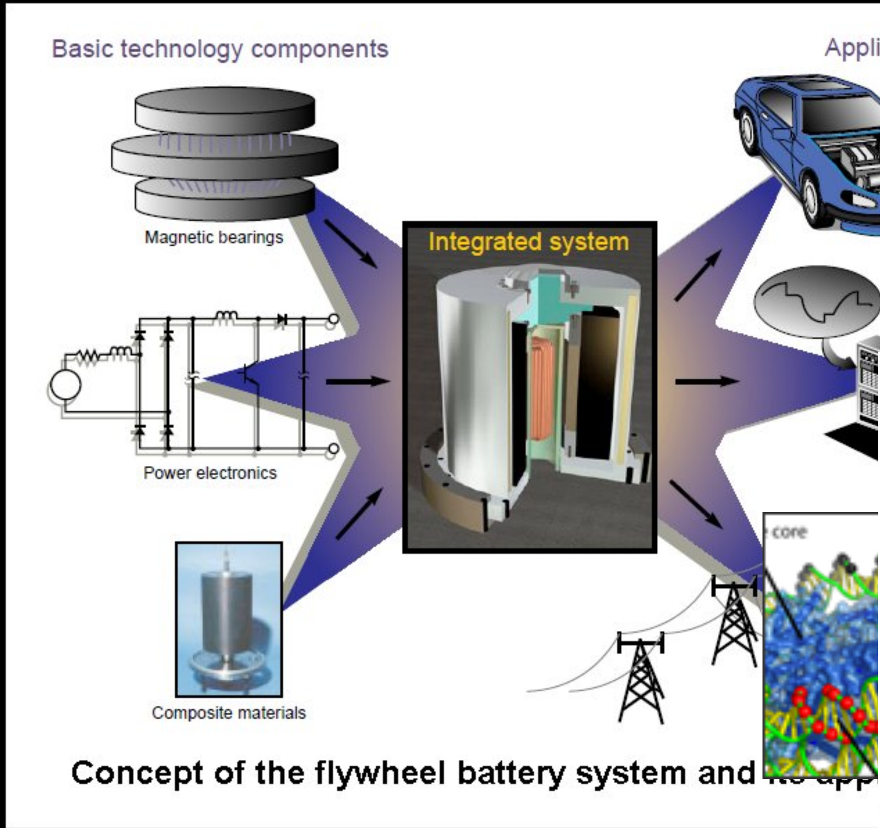
We need to make a coherence, compelling case consistently, starting with how we talk about the outcomes of Snowmass and continuing through and after P5.

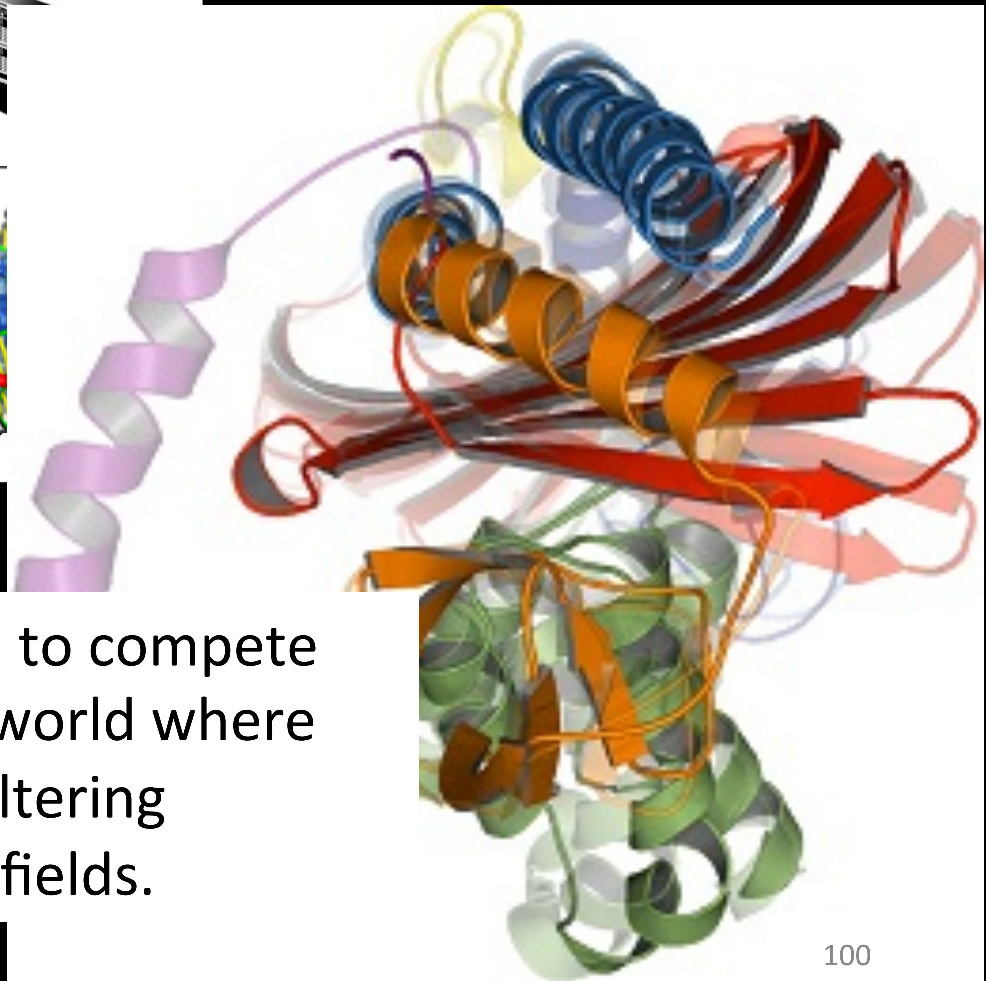
We all need to up our game in consistently reaching out, informing, inspiring and educating.

We must recognize—formally and informally—the importance of the CE&O work of our colleagues, postdocs and students and encourage that work to continue.





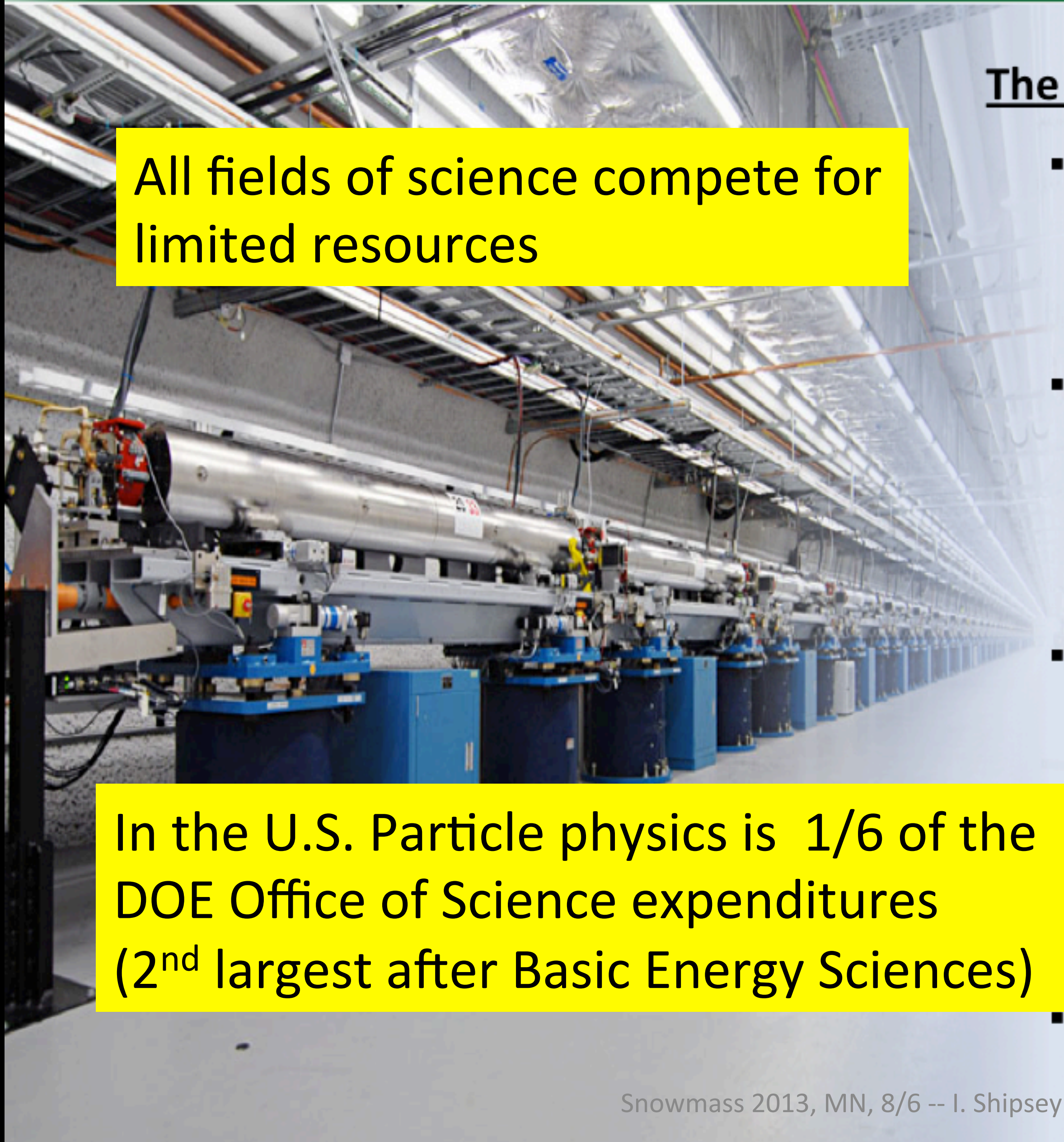




Our science is compelling enough to compete favorably for the best talent in a world where transformational and paradigm-altering advances are happening in other fields.

Office of Science

Science to Meet the Nation's Challenges Today and into the 21st Century



All fields of science compete for limited resources

In the U.S. Particle physics is 1/6 of the DOE Office of Science expenditures (2nd largest after Basic Energy Sciences)

The Frontiers of Science

- Supporting research that led to over **100** Nobel Prizes during the past **6** decades—more than **20** in the past **10** years
- Providing **45%** of Federal support of basic research in the physical and energy related sciences and key components of the Nation's basic research in biology and computing
- Supporting over **25,000** Ph.D. scientists, graduate students, undergraduates, engineers, and support staff at more than **300** institutions

Century Tools of Science

- Providing the world's largest collection of scientific user facilities to over **26,500** users each year

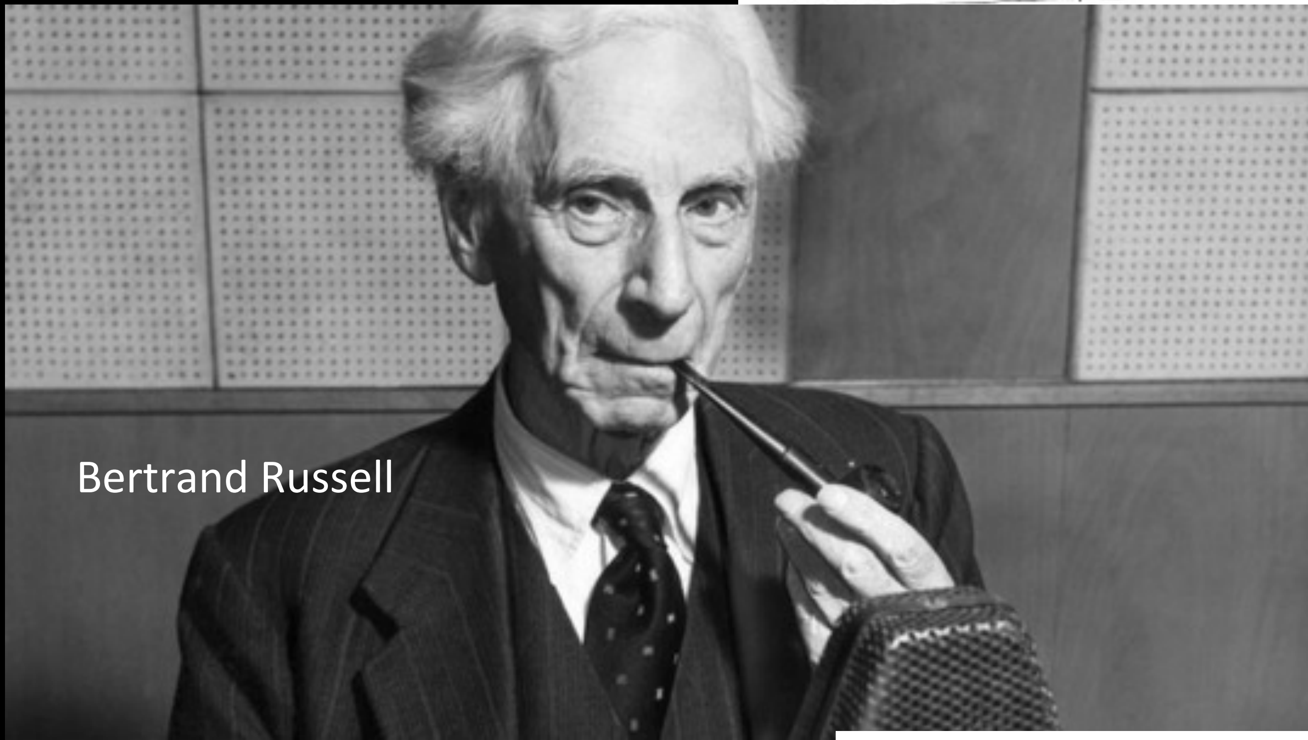
There is no entitlement for particle physics funding.

We must compete favorably with other opportunities on all the playing fields: in the agencies in Congress

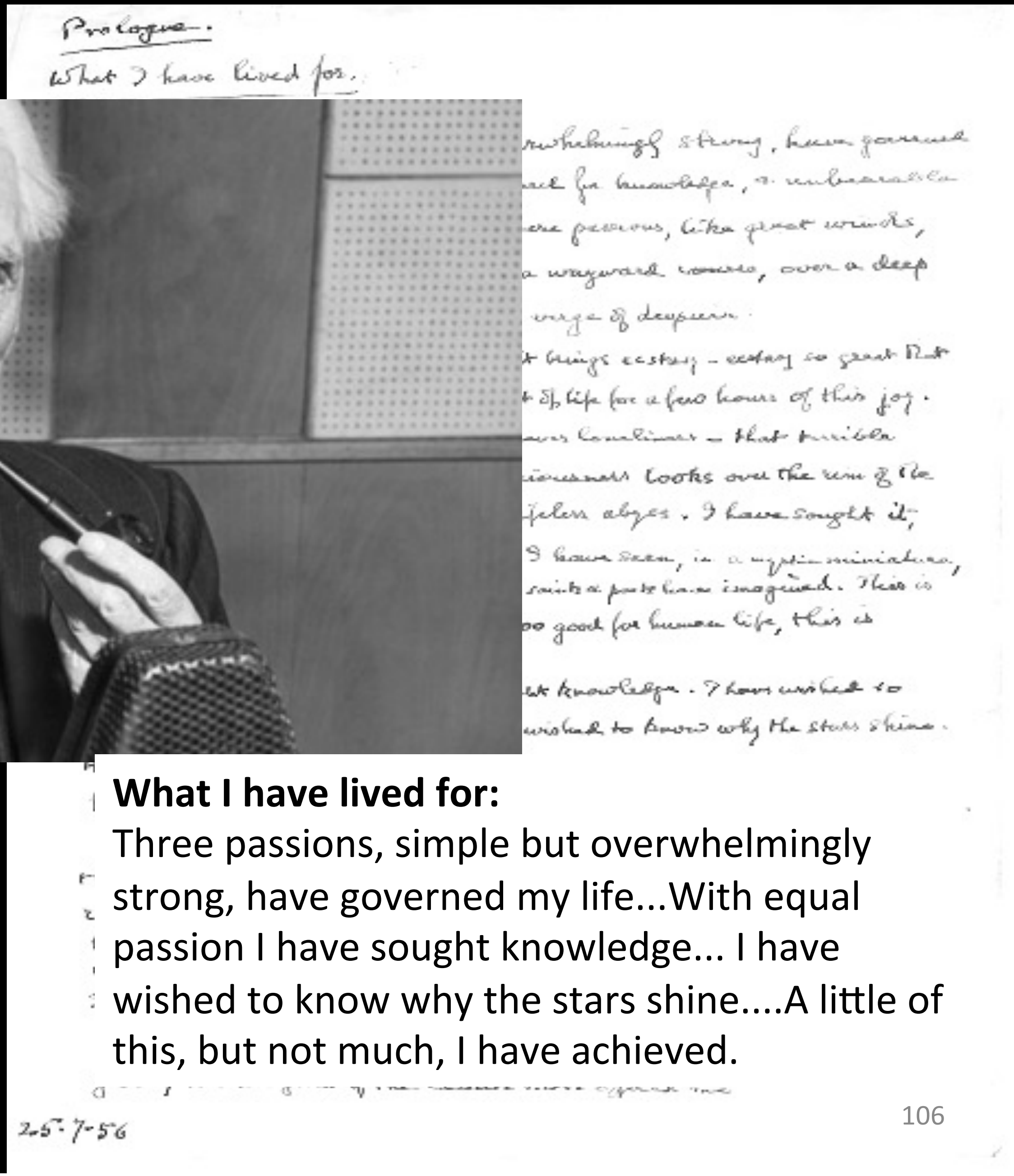
and in academia.

We see our science as compelling and we need to convince others it is compelling as well.

We will achieve that with a clear and articulate narrative there are many good examples to draw from:

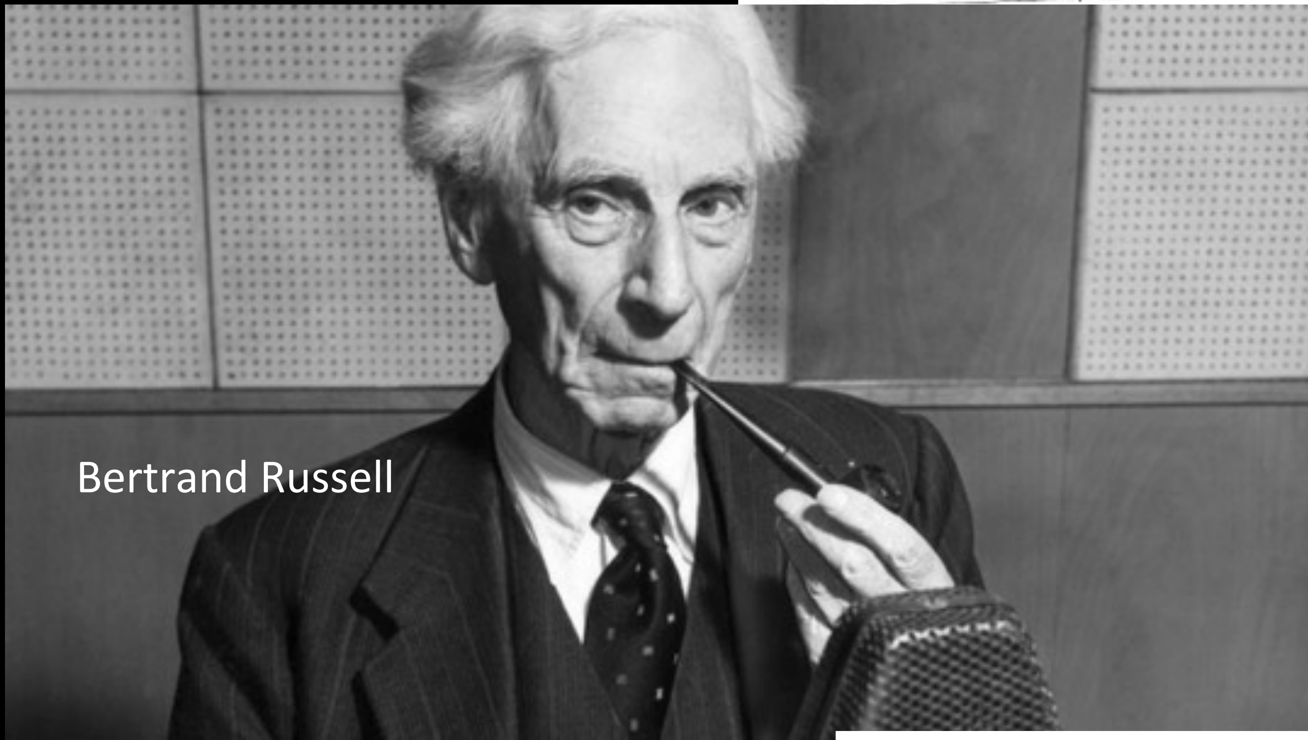


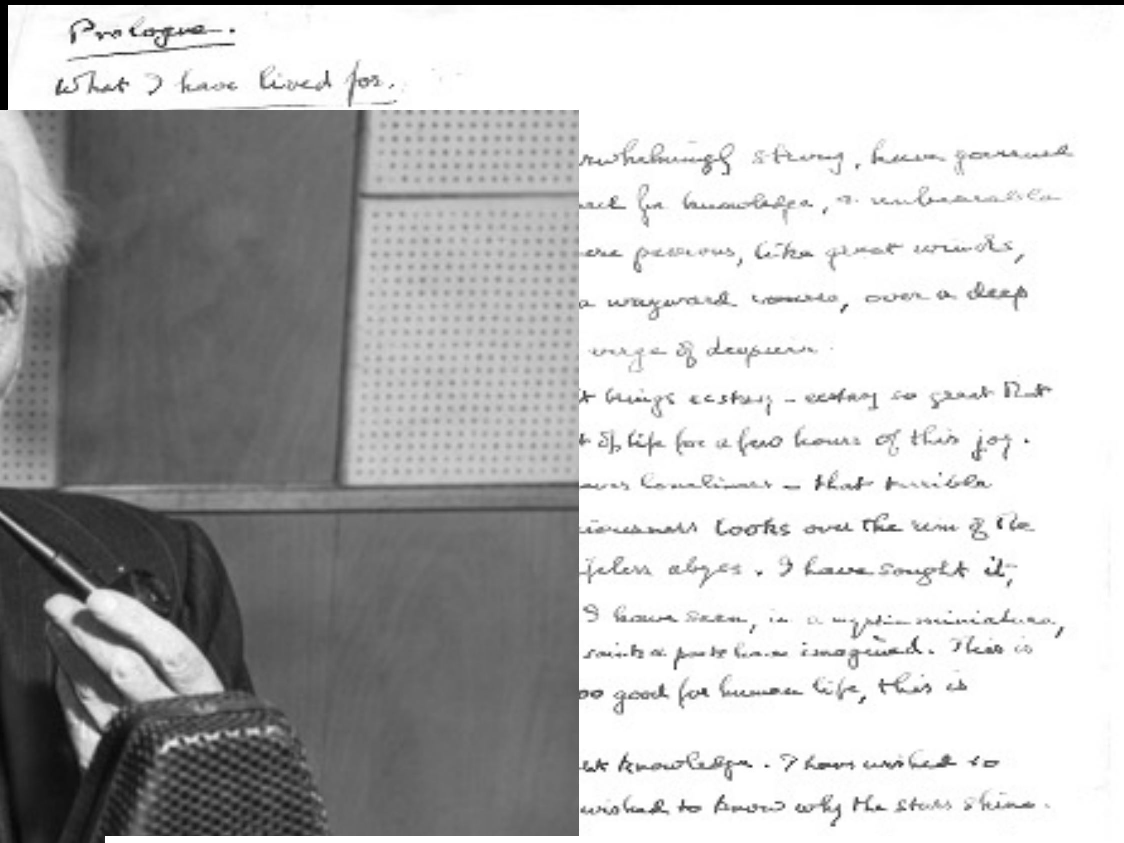
Bertrand Russell



What I have lived for:
Three passions, simple but overwhelmingly strong, have governed my life...With equal passion I have sought knowledge... I have wished to know why the stars shine....A little of this, but not much, I have achieved.

We will achieve that with a clear and articulate narrative there are many good examples to draw from:





We strive to be similarly articulate in our narrative

What I have lived for:
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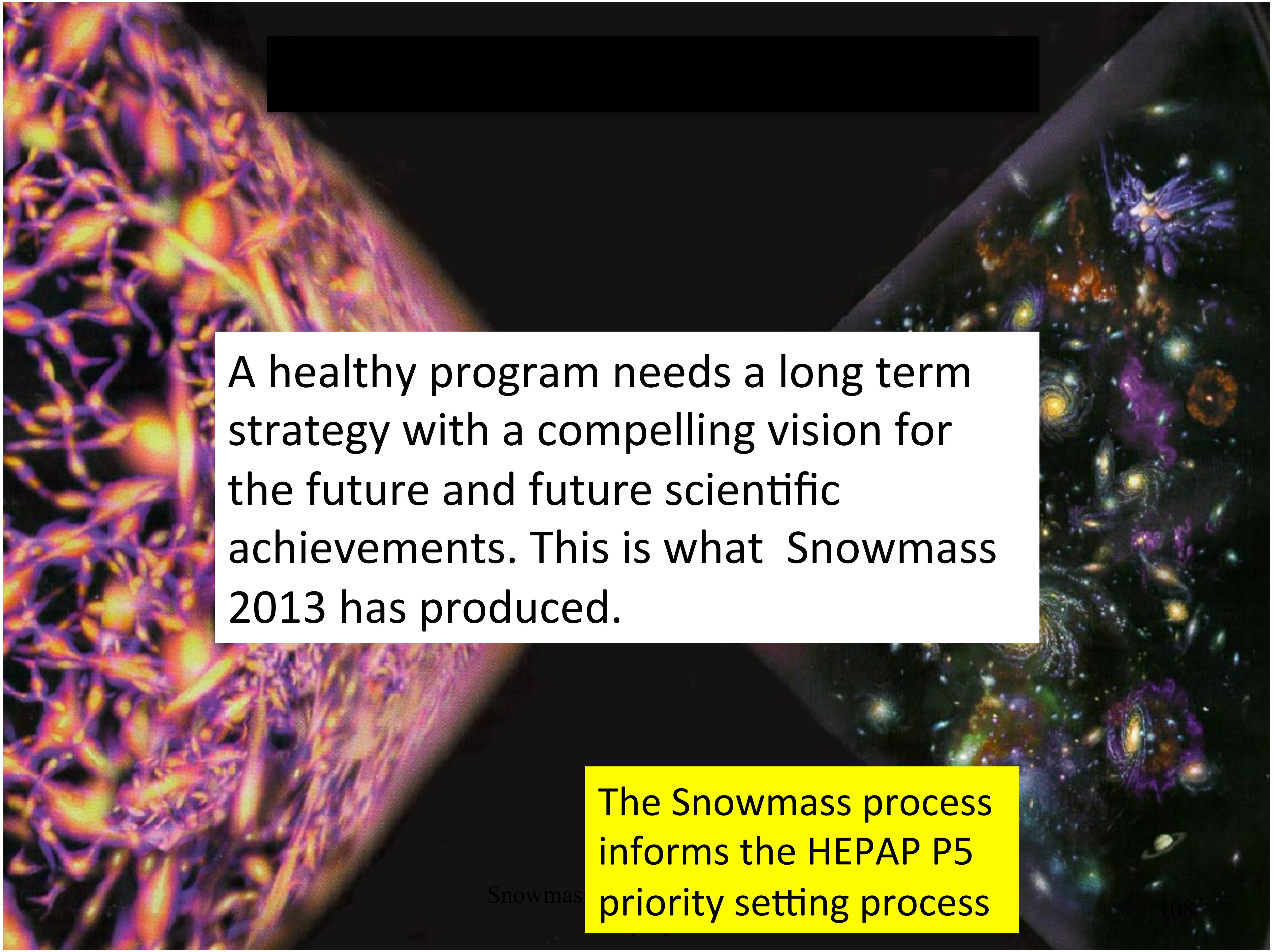

[redacted]
A healthy program needs a long term strategy with a compelling vision for the future and future scientific achievements. This is what Snowmass 2013 has produced.
The Snowmass process informs the HEPAP P5 priority setting process

These are your long term aspirations & narrative

You have thought large, and smart. You have identified compelling opportunities at all scales

You participated vigorously in the kick off meeting, the frontier pre-meetings and here at Snowmass; return to your institutions and inform them of what we have accomplished together

Give input to the P5 process

Continue to reach out to our community; especially to younger colleagues, give them roles; they are the future

Maintain the high level of interaction between the different parts of our community. The only enemies you have are those you have not spoken with. We are one field with one voice.

The DPF, for its part, will endeavor to develop structures that will maintain the new sense of community established through the Snowmass process

Who said this?

Snowmass is a good gig

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Snowmass is cool

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The talks are very interesting, although I don't have a background in this subject

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If you come back to Minnesota please get in touch
I am eager to hear what new discoveries you will make

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Snowmass makes me wish I was a physicist

Answer: Dan's team of helpers

The Division of Particles and Fields of the American Physical Society would like to thank

Conveners

Energy Frontier: Chip Brock, Michael Peskin

Intensity Frontier: JoAnne Hewett, Harry Weerts

Cosmic Frontier: Jonathan Feng, Steve Ritz

Capabilities: William Barletta, Murdock Gilchriese

Instrumentation: Marcel Demarteau, Ron Lipton, Howard Nicholson

Computing: Lothar Bauerdick, Steve Gottlieb

Education and Outreach: Marge Bardeen, Dan Cronin-Hennessy

The Division of Particles and Fields of the American Physical Society would like to thank

And a cast of >1,000
Colleagues in the U.S. and around the globe
making the studies
making the calculations
and daring to dream