The High Energy Physics Landscape in 2019

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High Energy Physics Advisory Panel, Rockville, MD — May 30, 2019

In Anticipation of Snowmass 2020+

How has the physics landscape changed since 2014?

Are there new opportunities on the horizon/table with significant discovery potential?

Disclaimers:

Examples are illustrative, certainly not exhaustive
Apologies if I missed a crucial result/topic

Any opinions are provisional and evolving
Goal is to spark some discussion

How has the physics landscape changed since 2014?

- Review of HEP Landscape and P5
- Solidification of SM / Diversification of BSM
- Progress on All Science Drivers
- Discovery of Gravitational Waves
  (and rise of multi-messenger astrophysics)

The HEP Landscape *(Colloquium Edition)*

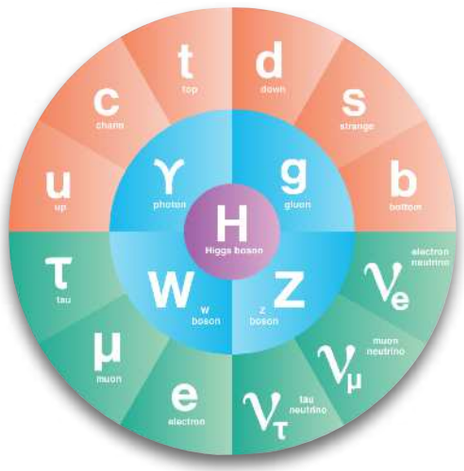
The Universe
Galaxy
Solar System
Planet
Us
Hairs
Cells
Molecules
Electrons
Protons
The TeV Scale
Grand Unification
Quantum Gravity

10^{26} m 10^{11} m 10^{-4} m 10^{-19} m 10^{-34} m

The Standard Model → ?

Dark Matter?

Origin of Mass?
Higgs Boson!



The HEP Landscape *(Colloquium Edition)*

Matter/Anti-Matter?

Three Generations?

Strong CP?

Neutrino Masses?

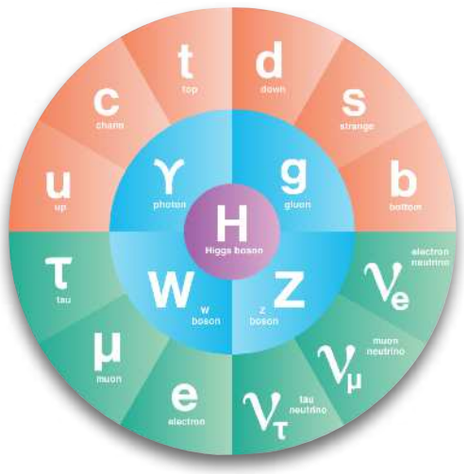
10^{26} m 10^{11} m 10^{-4} m 10^{-19} m 10^{-34} m

The Standard Model → ?

Dark Matter?

Dark Energy?

Inflation?



Origin of Mass?
Higgs Boson!

Grand Unification?

Quantum Gravity?

Hierarchy Problem?

The HEP Landscape *(QFT Edition)*

Standard Model: Leading interactions consistent with these symmetries

$$\mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$$

$$3 \times \Big[q\colon (\mathbf{3},\mathbf{2})_{1/6} \quad u^c\colon (\overline{\mathbf{3}},\mathbf{1})_{-2/3} \quad d^c\colon (\overline{\mathbf{3}},\mathbf{1})_{1/3} \quad \ell\colon (\mathbf{1},\mathbf{2})_{-1/2} \quad e^c\colon (\mathbf{1},\mathbf{1})_{1}\Big] \quad h\colon (\mathbf{1},\mathbf{2})_{1/2}$$

Principles	*Paradigms*
Quantum Mechanics	Chiral Mass Generation
Lorentz/CPT Invariance	Quark Flavor Structure
Spin/Statistics	P/CP Violation
Locality/Causality/Unitarity	Accidental B, L Conservation
Global Symmetries*	Asymptotic Freedom
Conservation Laws	(?) Neutrino Mass Generation
Spontaneous Symmetry Breaking	(?) Dark Matter
Gauge Redundancy	(?) Strong CP
Anomaly Cancellation	(?) Baryogenesis
Renormalization Group Evolution	(?) Unification
Effective Field Theory	(?) Supersymmetry
Naturalness (??)	(?) Extended Space-time
Weak Gravity / Swampland (??)	(?) Inflation
…	…

2014 Science Drivers from P5

Well aligned with core questions in fundamental physics
Effective road map through period of transition in US HEP

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

[U.S. Particle Physics: Building for Discovery]

2014 Science Drivers from P5′

with apologies to the B → K μ⁺ μ⁻ anomaly

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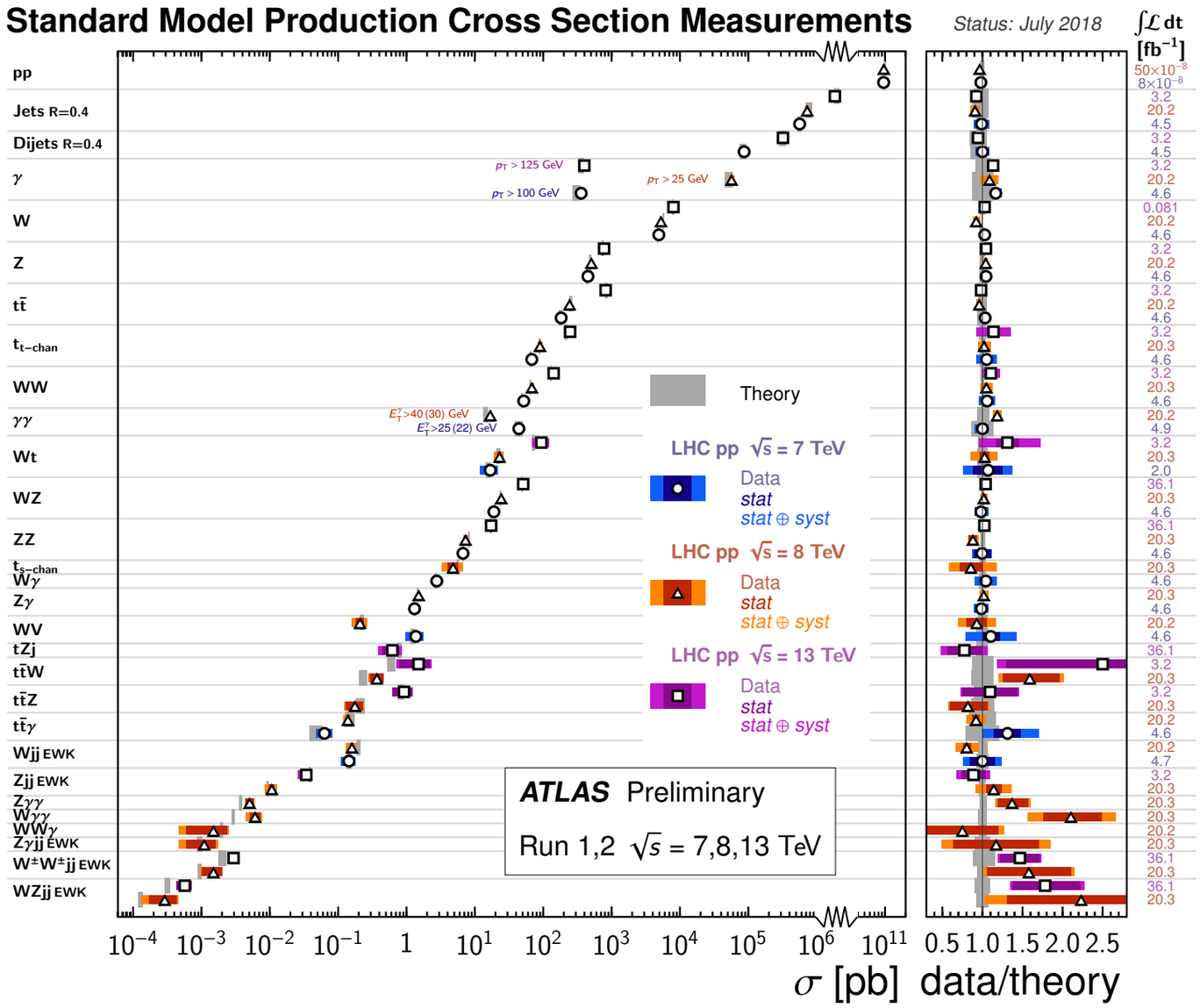
- Develop transformative concepts and technologies to enable future discoveries

In addition to reaping the physics rewards of key investments,
we are continually planting the seeds for future explorations

[U.S. Particle Physics: Building for Discovery]

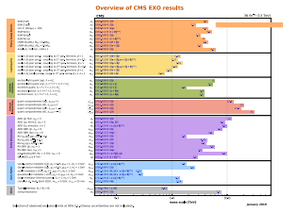
2014 → 2019: Solidification of Standard Model



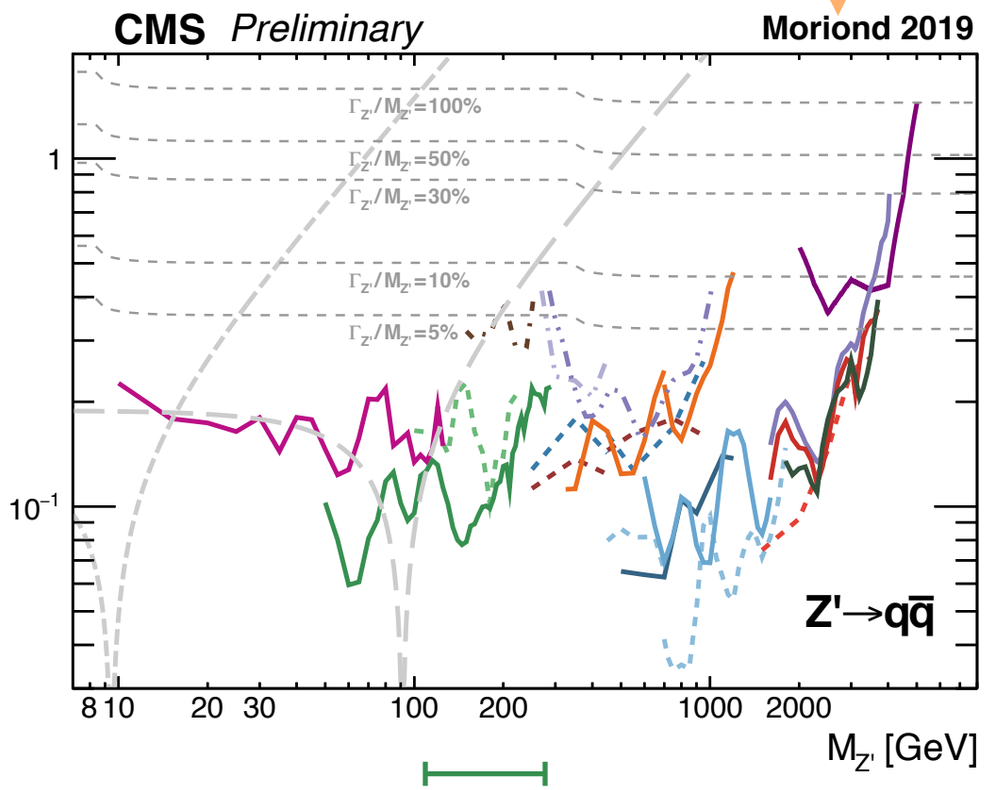
LHC Run 1 & 2: Experimental and theoretical triumph!

(and much more to come with full Run 2 dataset, Run 3, and HL-LHC)

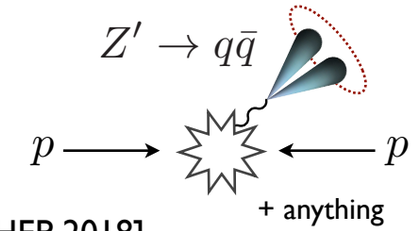
2014 → 2019: Diversification of BSM Searches



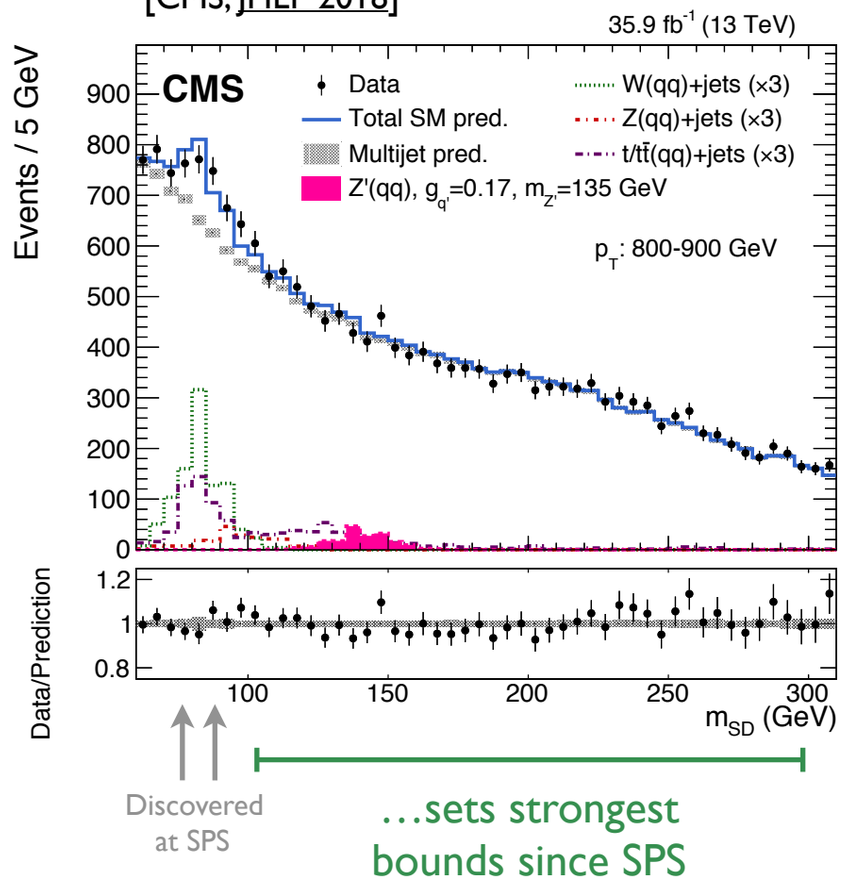
Unpacking one entry in BSM bar chart



Using substructure techniques invented c. 2014…



[CMS, JHEP 2018]



Discovered at SPS

…sets strongest bounds since SPS

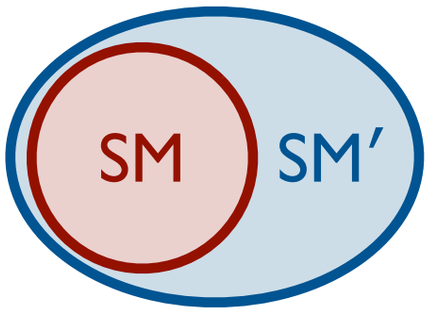
Wide range of innovative analyses with broad coverage!

Backup: Rapid progress using novel reconstruction / deep learning to enhance BSM searches

2014 → 2019: Establishing New Paradigms

Not just a response to null results; broadening in thinking even pre-LHC

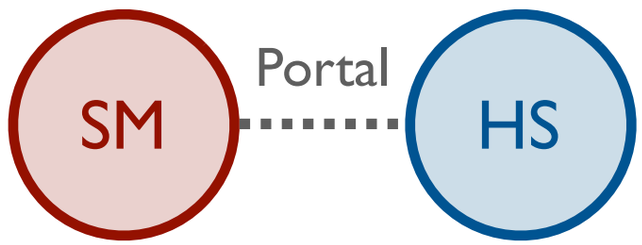
Extended Symmetries



Typical structure to address conceptual shortcomings of SM

e.g. electroweak hierarchy problem
→ softly-broken symmetries
→ TeV-scale partners

Hidden Sectors



Arguably the generic structure of string-theoretic scenarios

e.g. secluded dark matter
w/ thermal relic abundance
→ dark portal searches

Plus intermediate scenarios: split spectra, neutral naturalness, dynamic relaxation, …

New paradigms motivate new search strategies

Can often capitalize on investments in existing projects (more later)

2014 → 2019: Continued Effectiveness of EFTs

In the context of effective field theories, we can already…

$\langle h \rangle = \begin{pmatrix} 0 \\ v/\sqrt{2} \end{pmatrix}$

- Describe process of electroweak symmetry breaking
  ⇒ Higgs mechanism

$c_{ij} \dfrac{\ell_i h \, \ell_j h}{M}$

- Accommodate neutrino masses/mixing
  ⇒ Dimension-5 Weinberg operator (if Majorana)

$\dfrac{a}{f} \dfrac{\alpha_s}{8\pi} G^{\mu\nu a} \widetilde{G}^a_{\mu\nu}$

- Build testable dark matter paradigms
  ⇒ e.g. WIMPs, hidden sectors, axions (with strong CP bonus)

Λ

- Accommodate current acceleration & primordial density fluctuations
  ⇒ Cosmological constant & single-field inflation

$\dfrac{qqq\ell}{M}$

- Motivate why further deviations are suppressed
  ⇒ Approximate symmetries (B, L, CP, GIM, MFV, …)

$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$

- Quantum-mechanically couple SM to gravity in weak-field limit
  ⇒ Einstein-Hilbert graviton with one free parameter (M_{Pl})

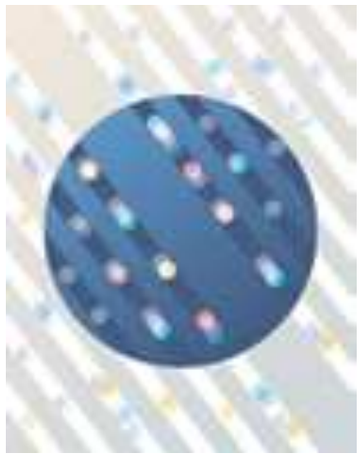
Enables systematic probes for cracks in the SM:

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{M}\mathcal{O}_5 + \frac{1}{M^2}\mathcal{O}_6 + \dots$$

Clear Goal for the Foreseeable Future

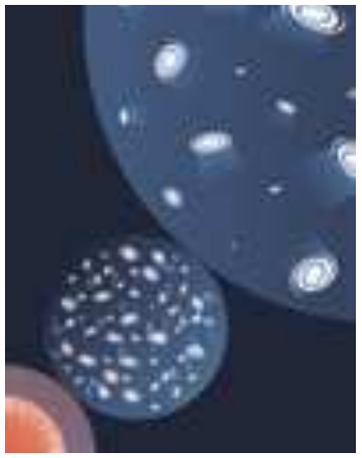
Go beyond EFT description and understand fundamental dynamics behind these phenomena

Higgs boson



Neutrino mass

Dark matter



Cosmic acceleration

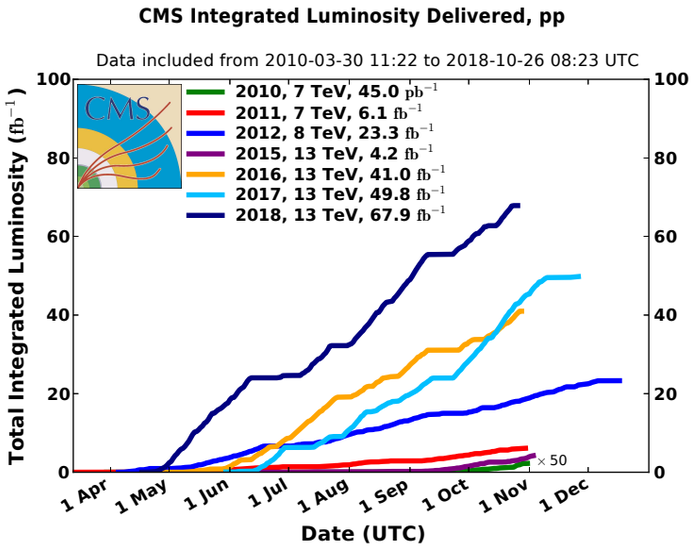
Explore the unknown

2014 → 2019 → …

Impressive progress on all science drivers
A few more examples below (not exhaustive; apologies)
P5: Well-defined path going forward

Excellent Accelerator Performance

CERN:



LHC Run 1: ~30 fb⁻¹ @ 7/8 TeV
⇒ Higgs discovery!

LHC Run 2: ~160 fb⁻¹ @ 13 TeV
⇒ Significant discovery potential

P5: HL-LHC: 3 ab⁻¹ @ 14 TeV
⇒ Legacy proton-proton dataset

Fermilab: Long Baseline: NUMI ↠ NOvA (ν and anti-ν modes)
P5: PIP-II ↠ LBNF/DUNE

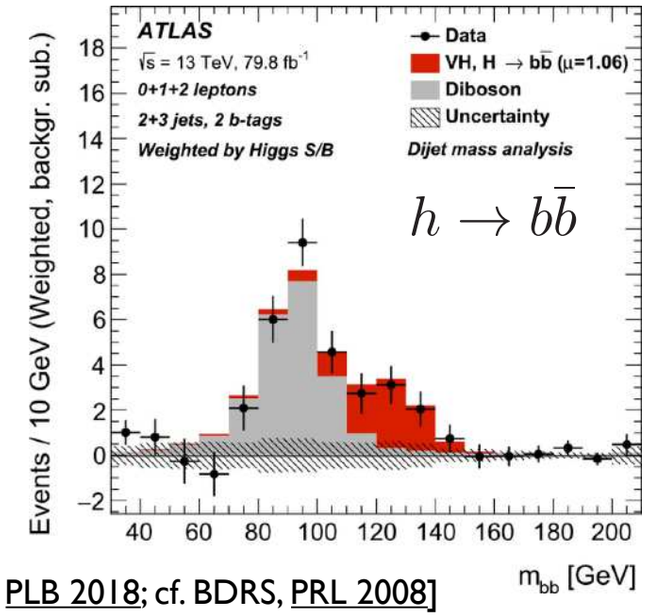
Short Baseline: Booster Neutrino Beam ↠ MicroBooNE
P5: ↠ Full SBN with SBND & ICARUS

Muon Program: Delivery Ring ↠ g–2 Storage Ring (run 2 underway)
P5: ↠ Mu2e

Japan: SuperKEKB ↠ Belle II (first collisions April 26, 2018, aiming for 50 ab⁻¹)
P5: Participate in possible ILC

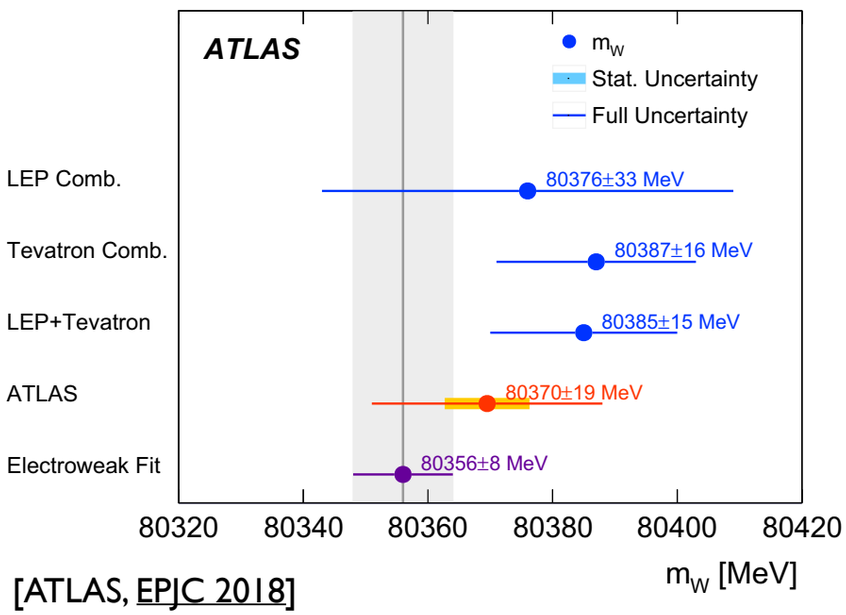
Probing the Higgs Sector

Higgs to Heavy Flavor



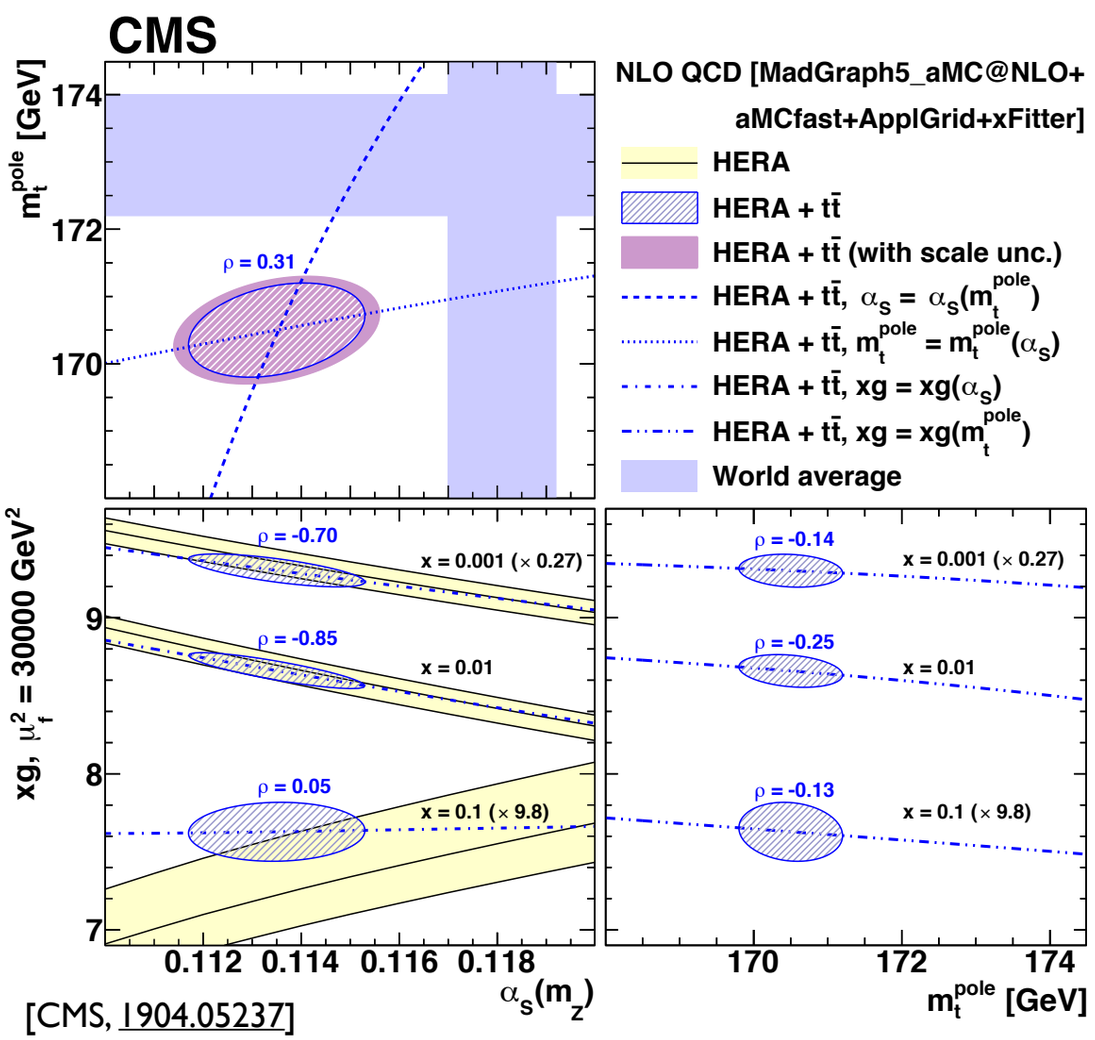
[ATLAS, PLB 2018; cf. BDRS, PRL 2008]

Precision W Mass in pp



[ATLAS, EPJC 2018]

Simultaneous Fit for m_t/α_S/PDF

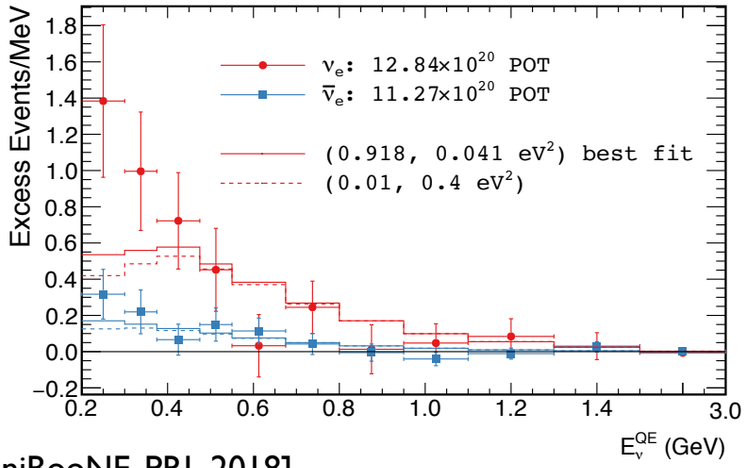


[CMS, 1904.05237]

Remember, precision Higgs physics requires precision top/EW/QCD as well

Probing the Neutrino Sector

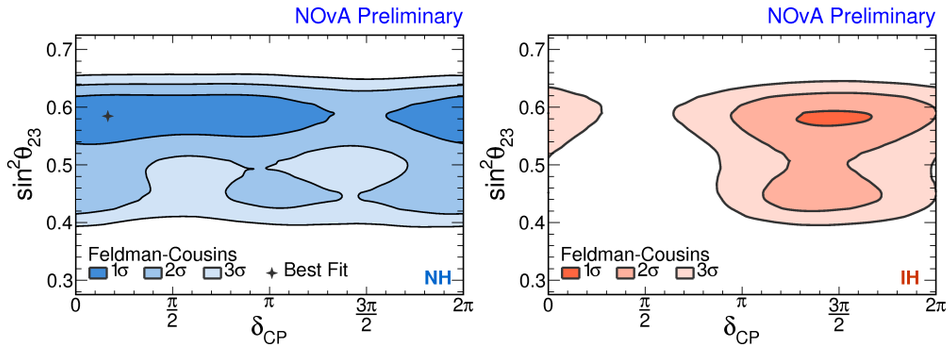
Persistent Appearance Excess

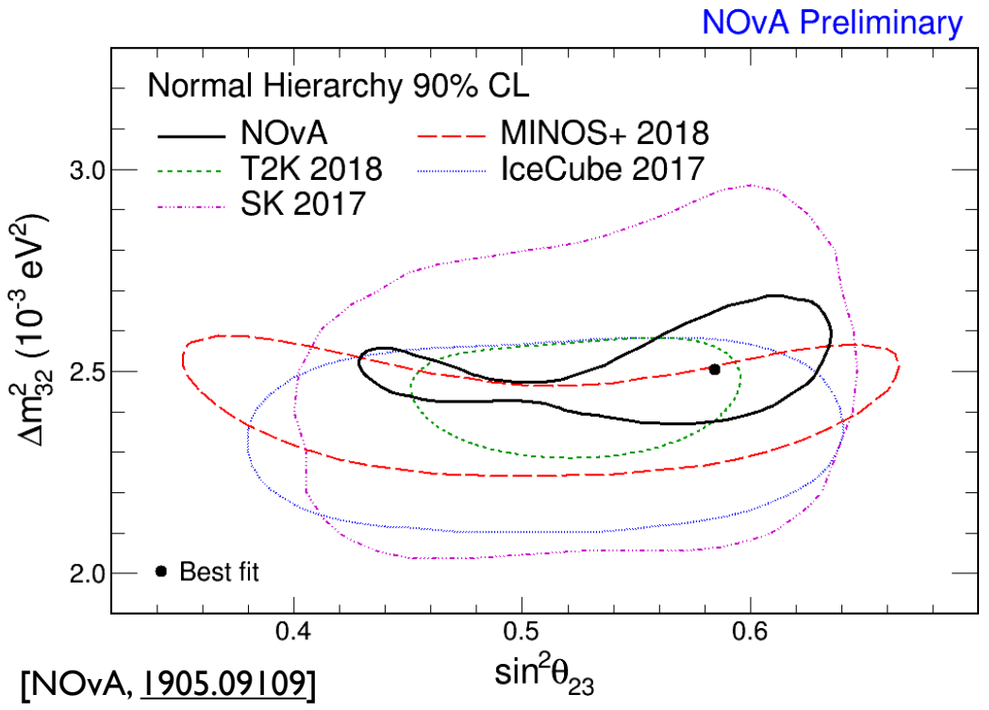


[MiniBooNE, PRL 2018]

With both ν & anti-ν

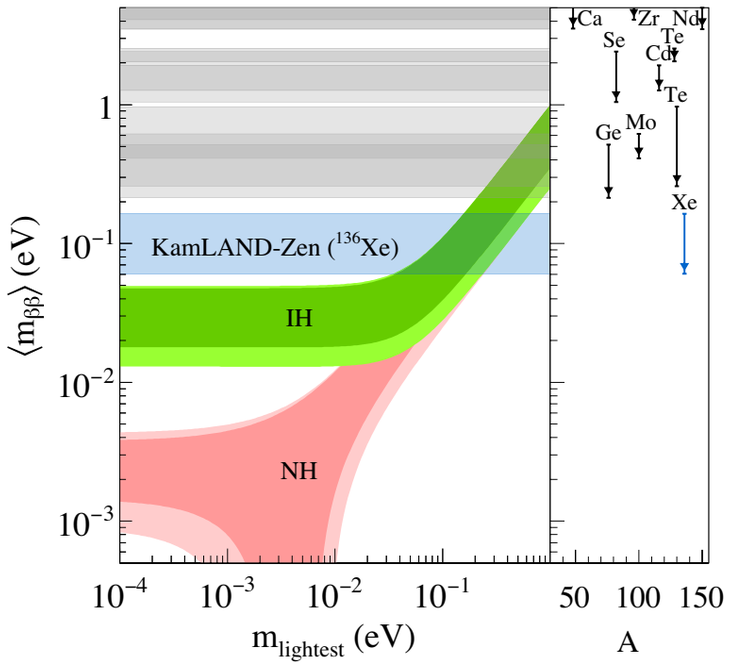
Closing in on Mass Ordering & δ_{CP}





[NOvA, 1905.09109]

Pursuing Majorana with 0νββ

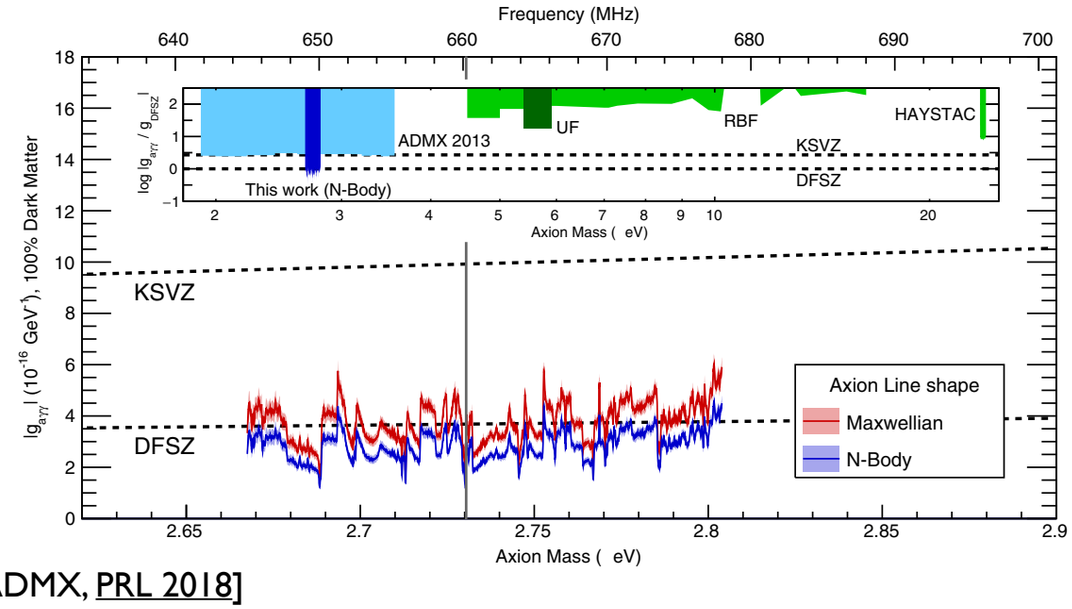


[KamLAND-Zen, PRL 2016]

Setting the stage for the future long baseline neutrino program

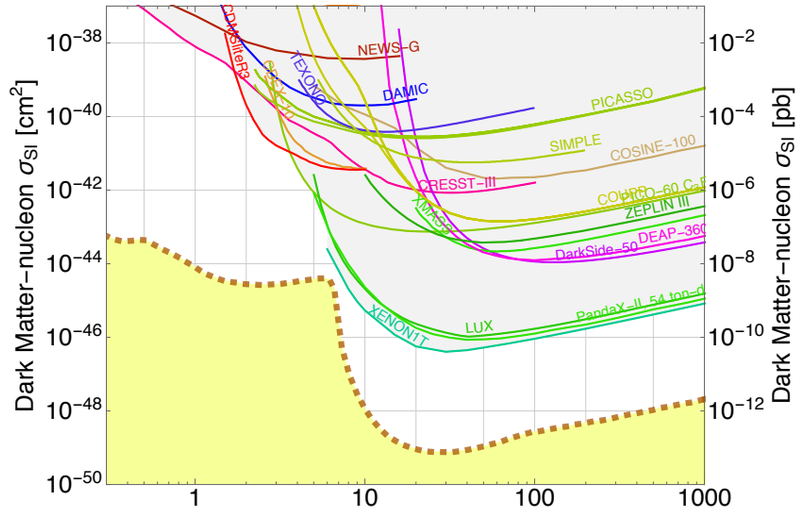
Hunting for Dark Matter

First Results from ADMX-G2



[ADMX, PRL 2018]

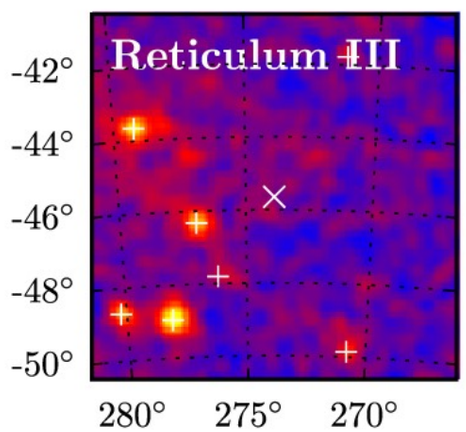
WIMP Direct Detection



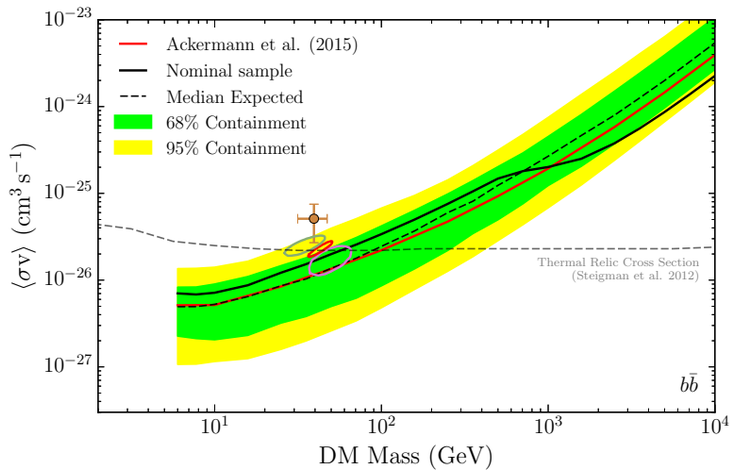
[DM Limit Plotter]

P5: LZ, SuperCDMS-SNOLAB, eventually DM G3

Indirect Detection of Dwarf Galaxies



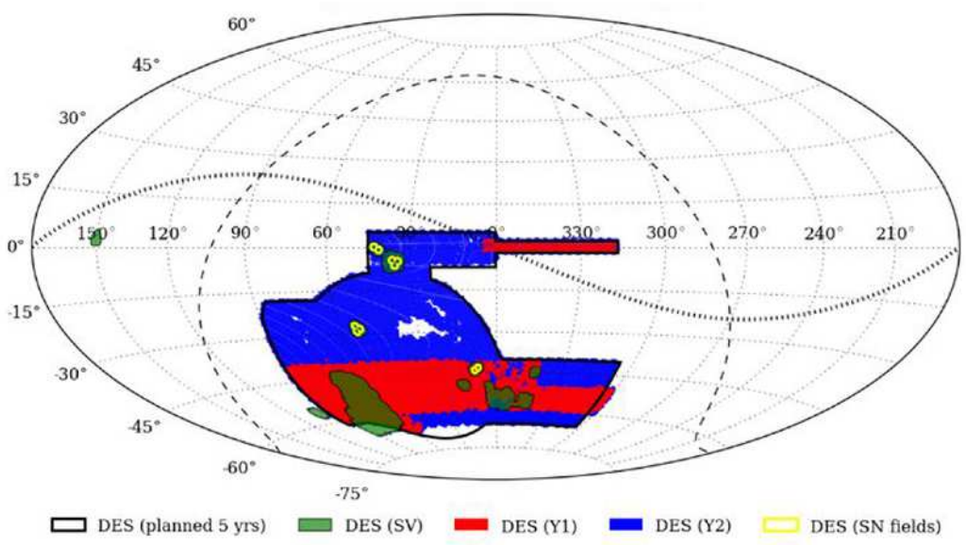
[FERMI-LAT+DES, ApJ 2017]

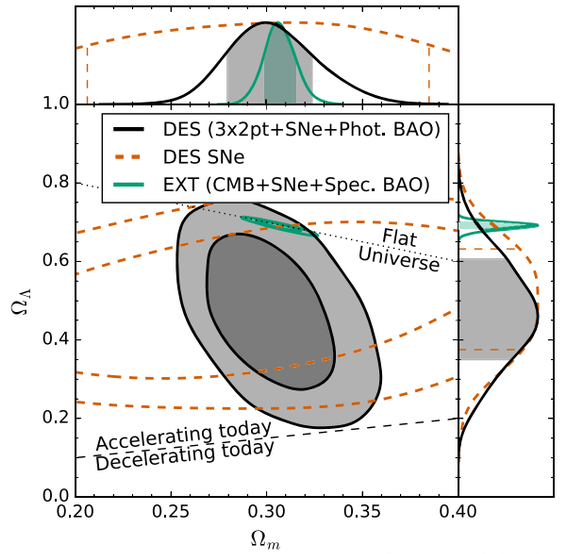


Highlights growing connection between HEP questions and astrophysical observations

Mapping the Cosmos

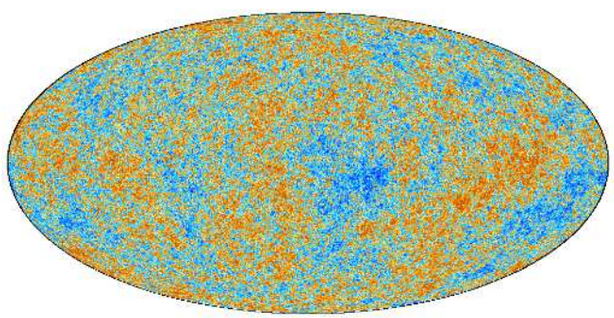
DES: Supernovae + BAO + Weak Lensing + Galaxy Clustering ⇒ P5: DESI & LSST

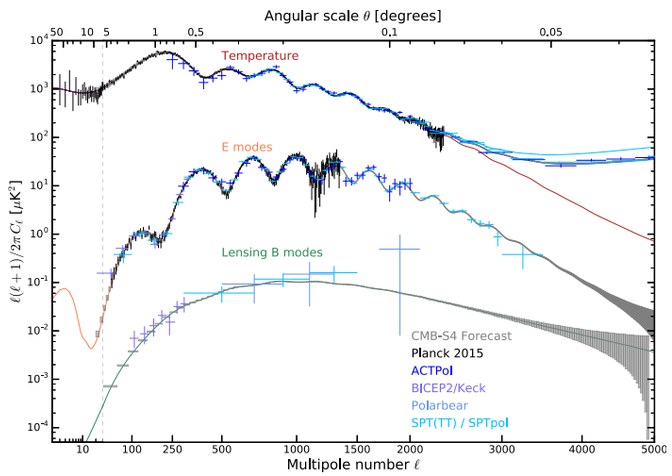




[DES, PRL 2019]

Planck Legacy Archive (July 2018) + S3 ⇒ P5: CMB S4

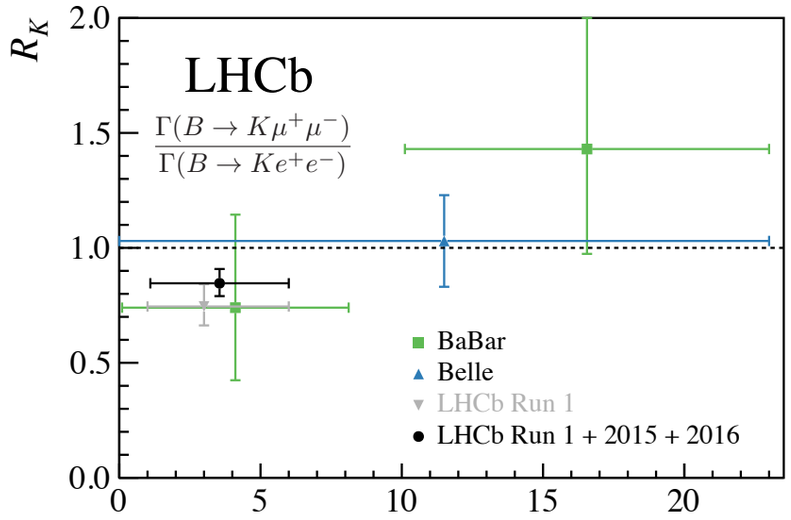




Probes of cosmic acceleration are also crucial probes of neutrinos and dark matter

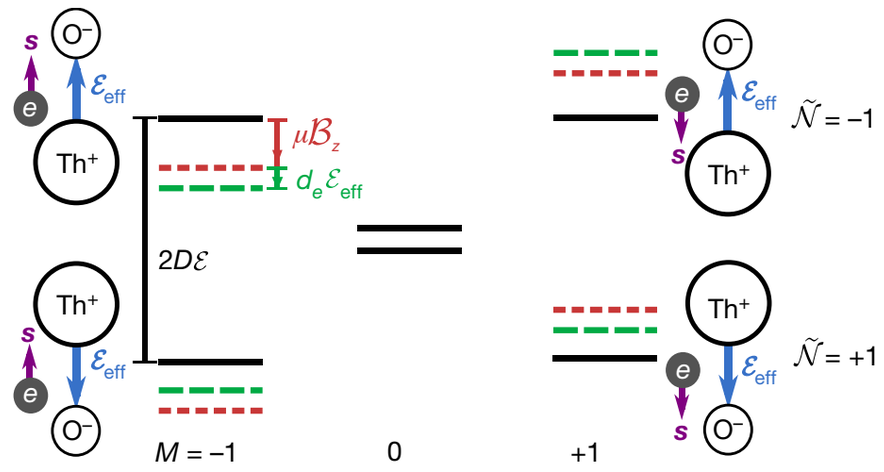
Reaching into the Unknown

Lepton Universality Violation?



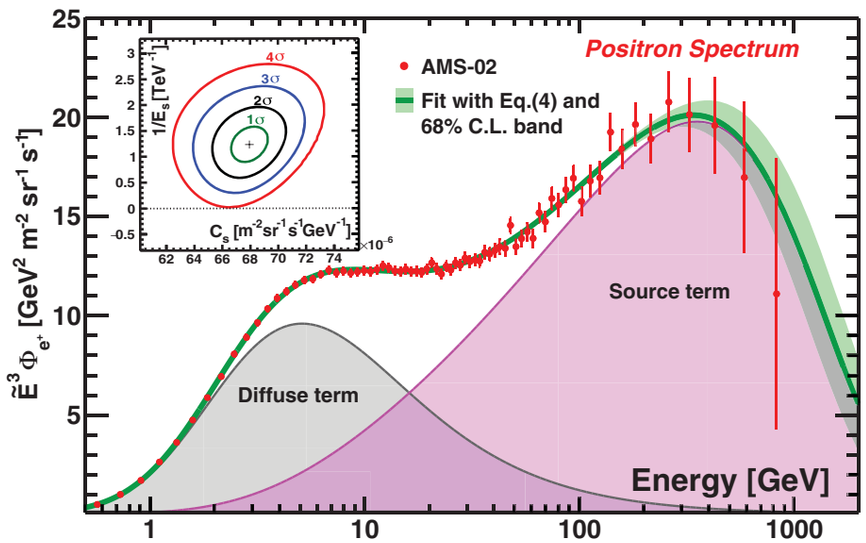
[LHCb, PRL 2019]

Electric Dipole Moments? (not yet)



[$|d_e| < 1.1 \times 10^{-29}$ e cm, ACME II, Nature 2018]

Cosmic Ray Injections?



[AMS-02, PRL 2019]

New physics could show up in many different places

Motivates a diversity of approaches across a range of scales, and a persistent pursuit of new paradigms

Discovery of Gravitational Waves

And the rise of multi-messenger astrophysics

Truly inspiring scientific story!

HEP Connections?

Primordial Black Holes as Dark Matter

Standard Sirens for Cosmological Evolution

Phase Transitions in the Early Universe

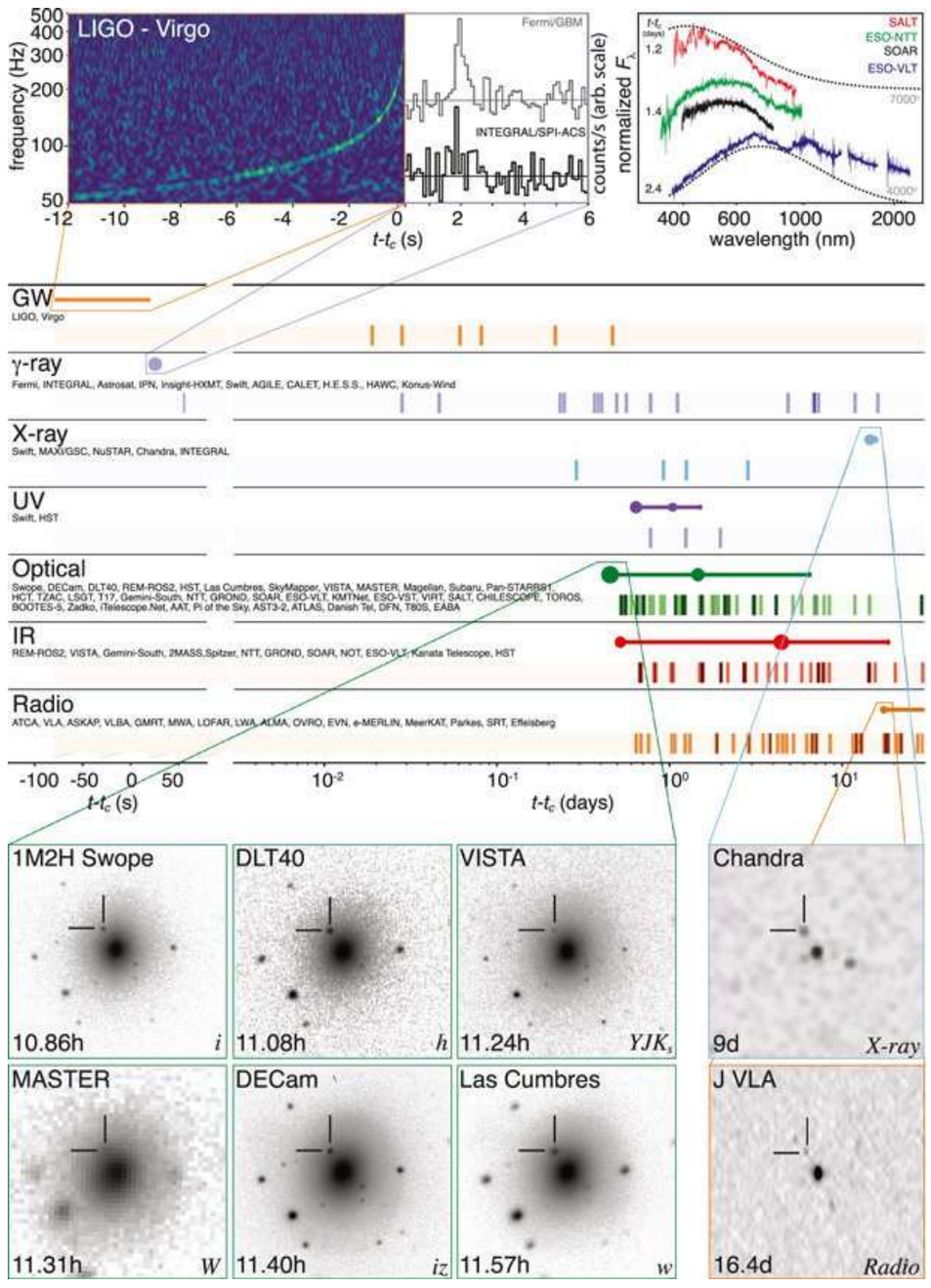
Exotic Compact Objects

…

Likely Needs Broad Frequency Coverage

e.g. PTA, LISA, BBO, DECIGO, MAGIS, …

Binary Neutron Star Merger



[figure from GW170817; see of course GW150914]

Are there new opportunities on the horizon/table with significant discovery potential?

- Setting the Stage for a Higgs Factory
- New Dark Matter Paradigms
- Small-Scale Experiments / Curiosity-Driven Research
- Quantum Information Science

Pushing to the Multi-TeV Scale

Chiral Symmetry Breaking $\xrightarrow{\times 10^3}$ *Electroweak Breaking*

10 GeV ····· 10 TeV

1 GeV ····· 1 TeV

p n

ρ: Γ/m ≈ 0.2

σ: Γ/m ≈ O(1)

K

π^0 $\pi^\pm$

0.1 GeV ····· 0.1 TeV

f_π

? ? ?

Indirect LEP Bounds

compositeness?
supersymmetry?
extended space-time?
…

v_{EW}

t

h^0: Γ/m < 10^{-4}

$W^\pm$ Z^0

LHC Reach

Explorations via Precision Higgs

$$V(h) = -m^2 h^\dagger h \quad + \lambda_h (h^\dagger h)^2$$

Higgs self-coupling

+ |h|⁶ ?

Higgs compositeness

+ V(h₂,s,…) ?

extended Higgs sectors

$$\mathcal{L} \supset y_\psi \psi h \psi^c$$

x |h|² ?

mass/coupling relations

+ |h† Dμ h|² ?

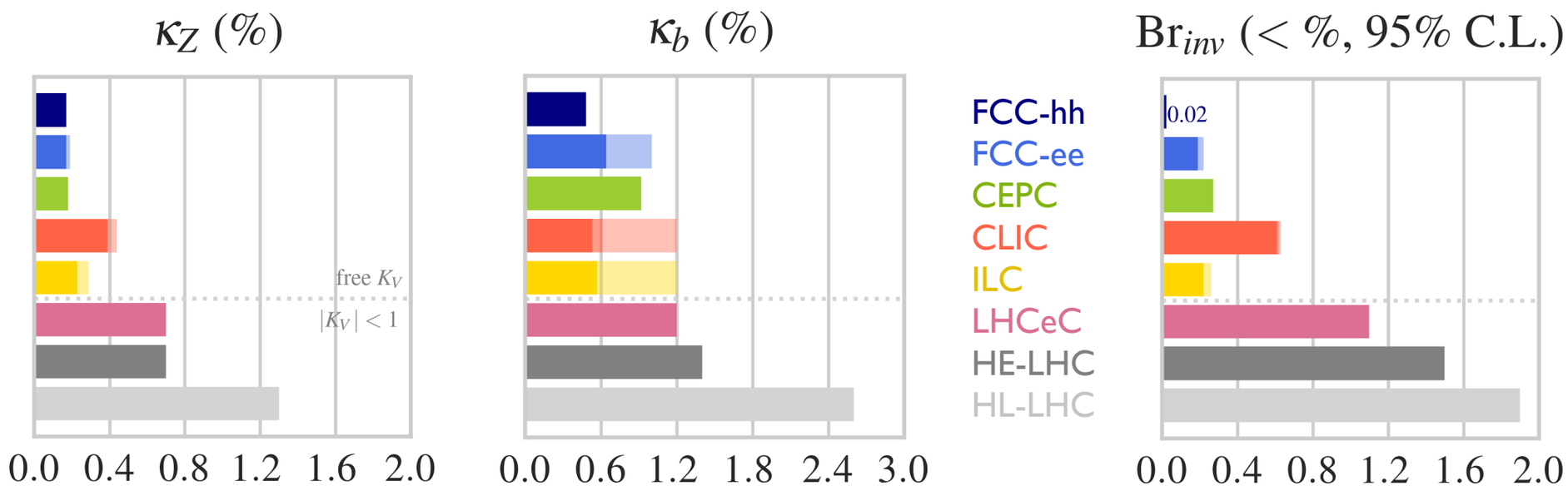
precision electroweak

+ |h|² O_BSM ?

Higgs portal to new physics

Plus electroweak phase transition, new physics in loops, neutral naturalness, vacuum stability…

Deviations ~ (v/f)² ⇒ Sub-percent accuracy to probe multi-TeV scale



[Higgs at Future Colliders Working Group (2019)]

Setting the Stage for a Higgs Factory

3 ab^{-1}: ~150 million Higgs

Backup: Importance of archiving collider data

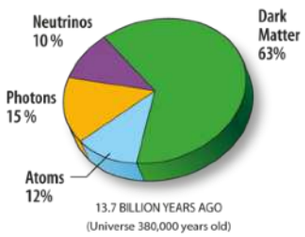
Opportunities to further advance Higgs/top/EW/QCD physics:

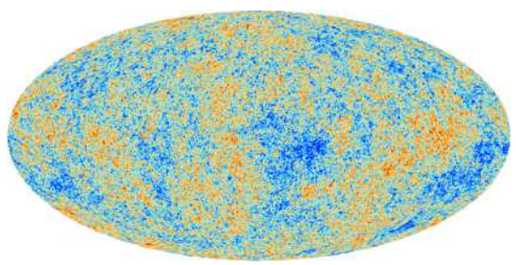
Opportunities to push energy frontier: HE-LHC, ILC-1000, SPPC, FCC-hh, CLIC-3000, …

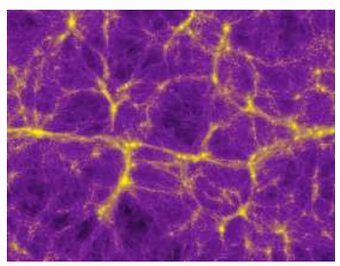
Backup: In the context of the European Strategy Update

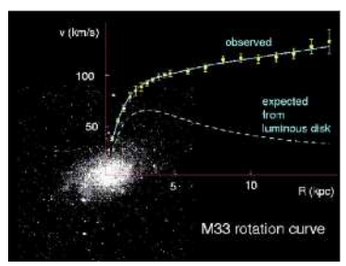
What is Dark Matter?

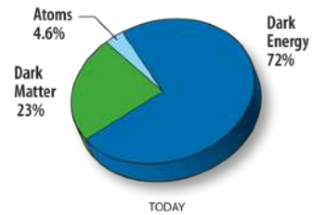
Overwhelming gravitational evidence across multiple space/time scales







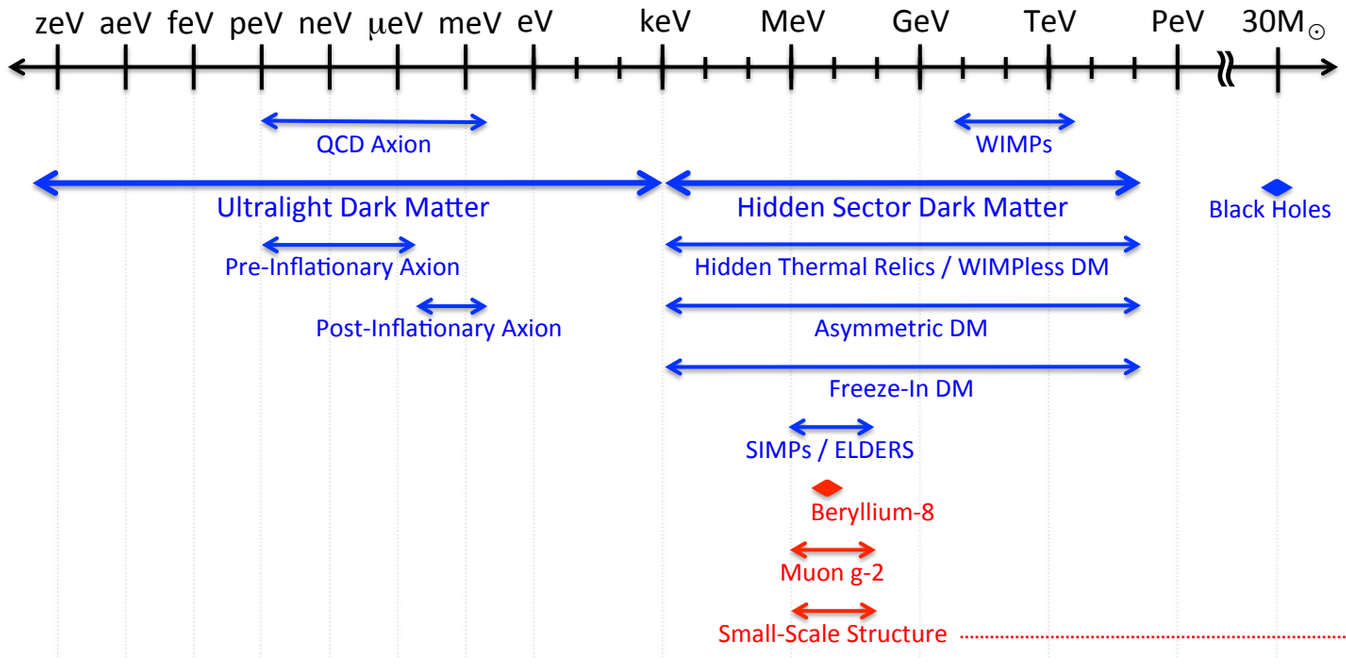




(actually more)

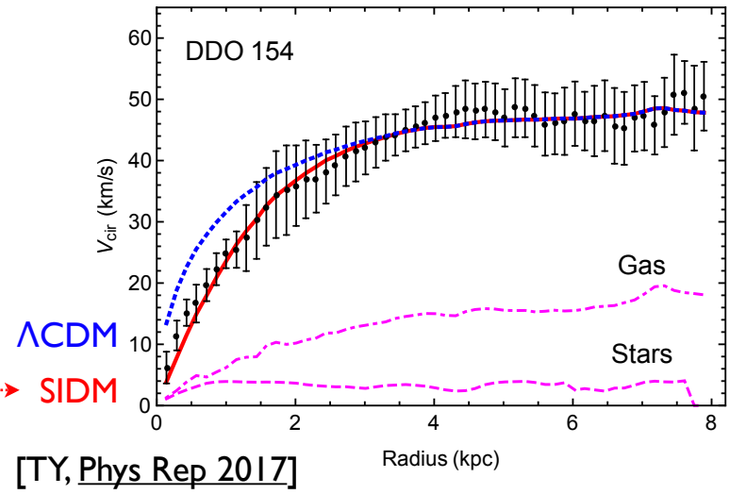
(assuming it even is a particle)

But 36 orders of magnitude of plausible DM masses!



[US Cosmic Visions Community Report (2017)]

Tantalizing small scale structure anomalies



[TY, Phys Rep 2017]

New Dark Matter Paradigms

G2 Targets: WIMP DM & QCD Axions

(motivated by thermal freeze out and electroweak hierarchy) (motivated by strong CP problem)

straightforward generalization

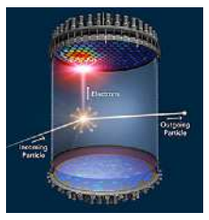
straightforward generalization

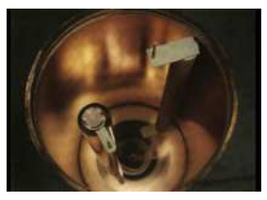
G2′ Targets: Hidden Sector, Asymmetric, Freeze In, SIMPs, Ultralight, …

(motivated by consistent cosmological histories and tantalizing anomalies)

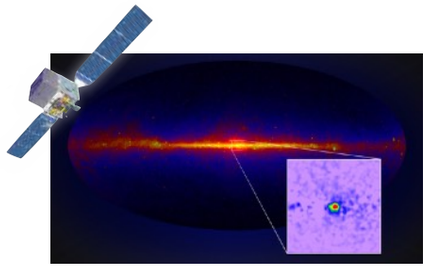
Fundamentally, we don't know what DM is, but we have a growing catalog of well-motivated targets

Natural extension of three-prong strategy:

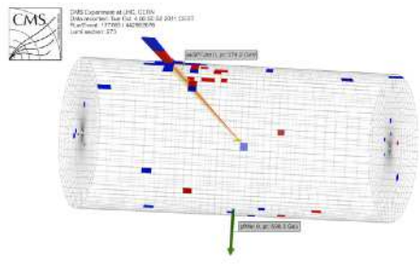




Direct Detection

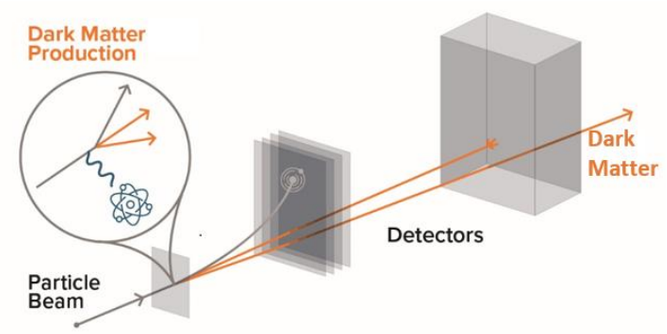


Indirect Detection



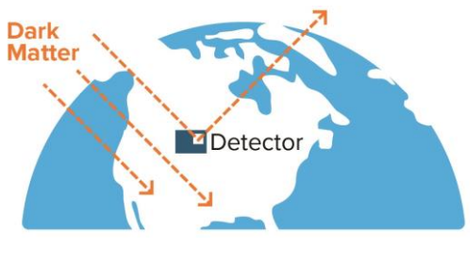
Collider Production

G2′: New Experimental Targets



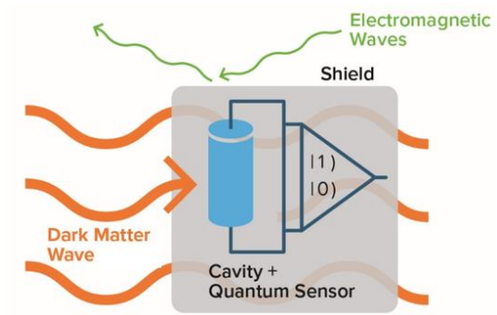
Production/Detection Experiments
(make dark matter beams)

Neutrino connections

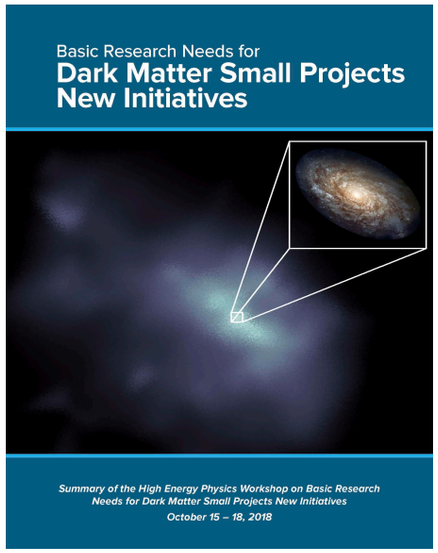


Low Threshold Direct Detection
(sub-GeV dark matter)

QIS connections



Ultralight Dark Matter Detection
(sub-eV coherent fields)



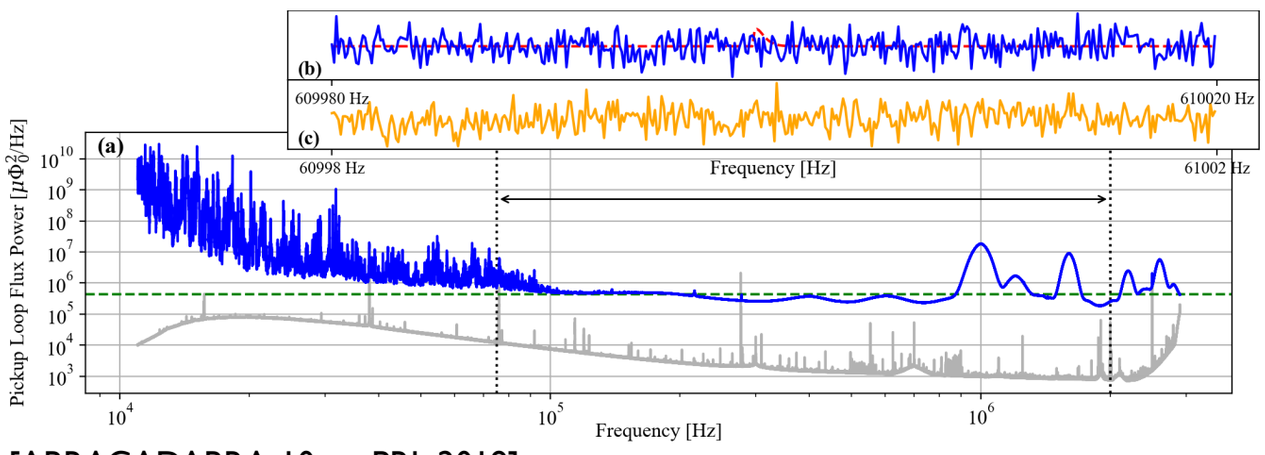
Dark matter is becoming a defining question for my HEP generation

Broader lessons: Small-scale experiments, curiosity-driven research

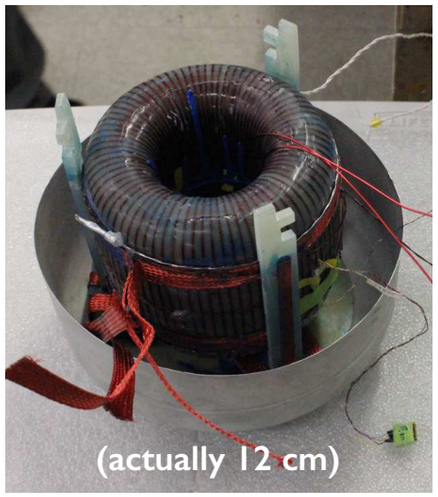
[Dark Matter BRN Report (2019)]

A Big Role for Small-Scale Experiments

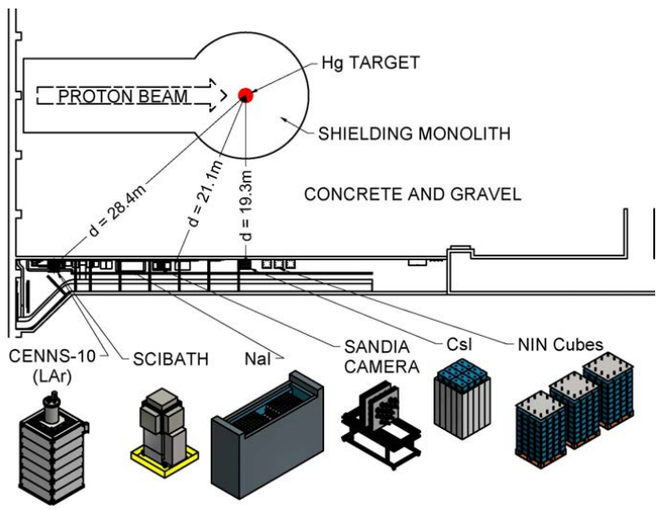
e.g. Searches for Ultralight Axion-like Dark Matter



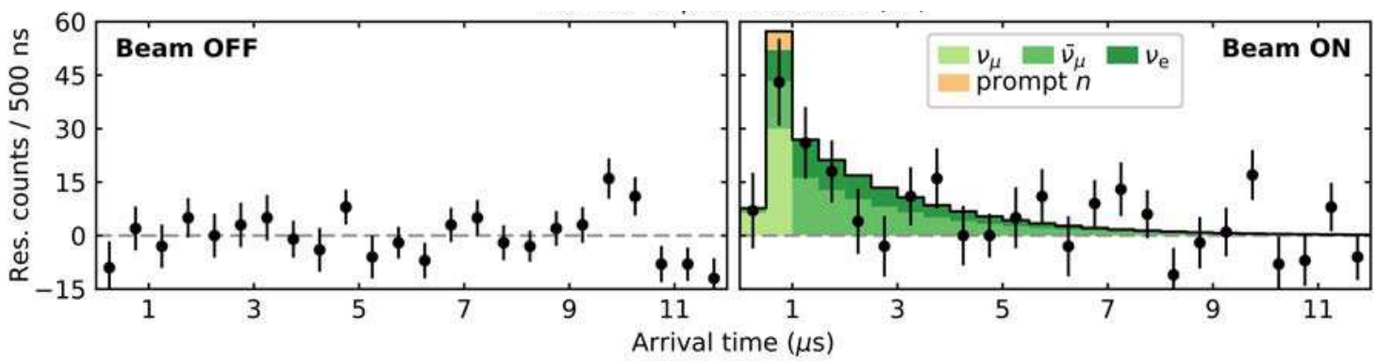
[ABRACADABRA-10cm, PRL 2019]



e.g. Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)



"Put the detector where the accelerator is"
(cf. IsoDAR: "Put the accelerator where the detector is")

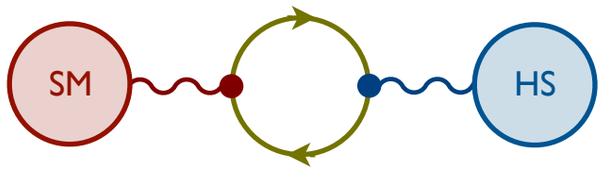


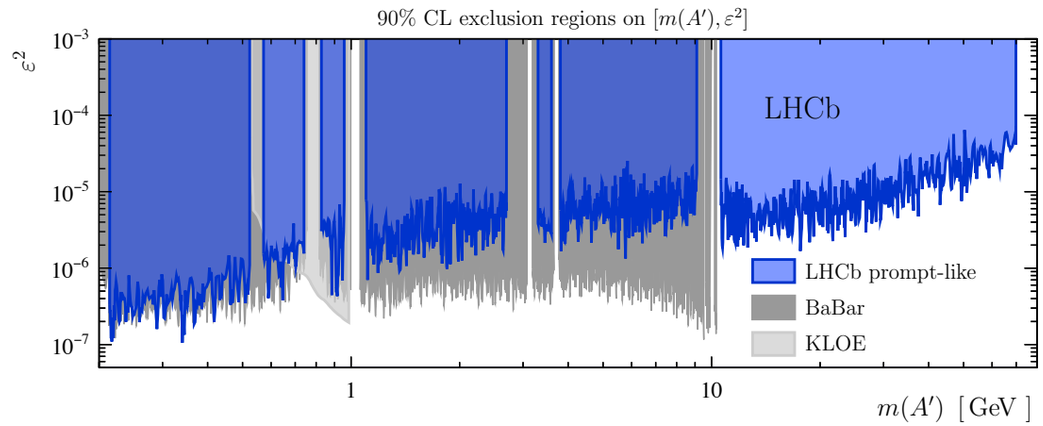
[COHERENT @ SNS, Science 2017; cf. Freedman, PRD 1974]

[see also Physics Beyond Colliders at CERN;
"Table Top Experiments with Skyscraper Reach", MIT, August 2017]

Impact of Curiosity-Driven Research

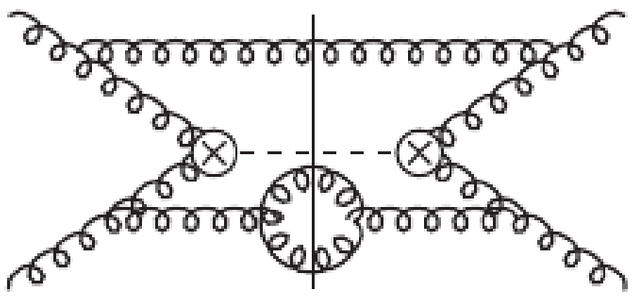
e.g. Paraphotons anticipating Dark Photons, Hidden Sectors





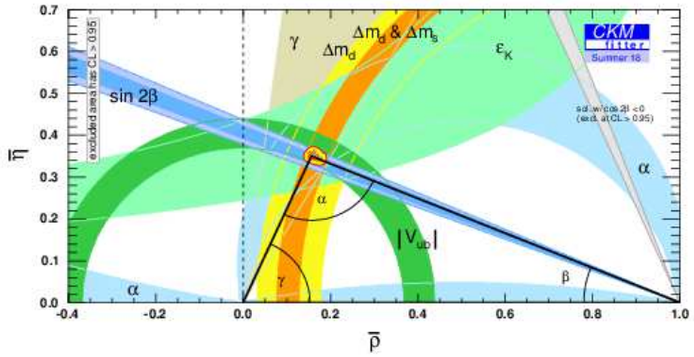
[Okun, JETP 1982; see also Gallison, Manohar, PLB 1984; Holdom, PLB 1986 ⇒ PRV, PLB 2008; AFSW, PRD 2009 ⇒ BEST, PRD 2009 ⇒ … ⇒ LHCb, PRL 2018]

e.g. Integration By Parts for N³LO Higgs Cross Section



[Tkachov, PLB 1981; + Chetyrkin, NPB 1981 ⇒ ADDHM, PRL 2015]

e.g. Lattice Gauge Theory for Precision Flavor Physics



[Wilson, PRD 1974 ⇒ … ⇒ CKM Fitter]

In both theory and experiment, big ideas start small

Highlighting Theory and R&D (and QIS)

- Develop transformative concepts and technologies to enable future discoveries

My wording

Official wording

The particle physics theory community will continue to play key roles interpreting results from current experiments, motivating future experiments, and pursuing answers to the deepest questions.

U.S. researchers are pursuing R&D on advanced technologies to enable future generations of accelerators and detectors with a wide variety of applications.

Theoretical and experimental particle physicists are advancing Quantum Information Science (QIS), providing solutions to problems in computation, data analysis, sensors, and simulations.

Also, important R&D efforts in classical software and computing, including machine learning

Basic research helps drive progress on the science drivers

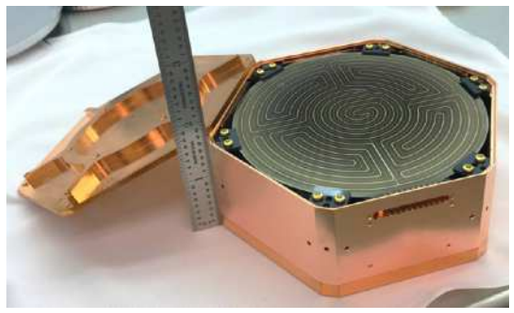
[from 2019 Particle Physics Progress and Priorities]

HEP and the National Quantum Initiative

Quantum: Manipulating individual quantum states
Using superposition, entanglement, squeezing, etc.

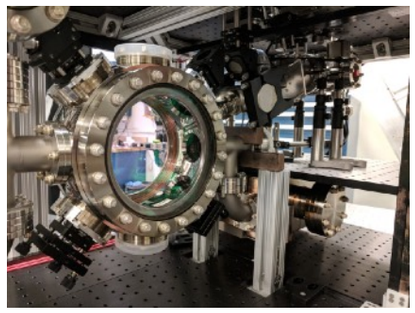
Already developing/exploiting Quantum Sensing technologies

Transition Edge Sensors



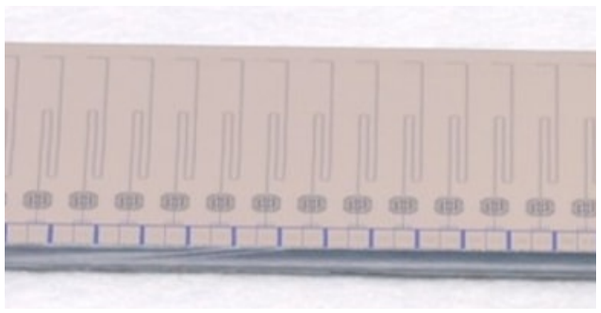
[SuperCDMS]

Atom Interferometry



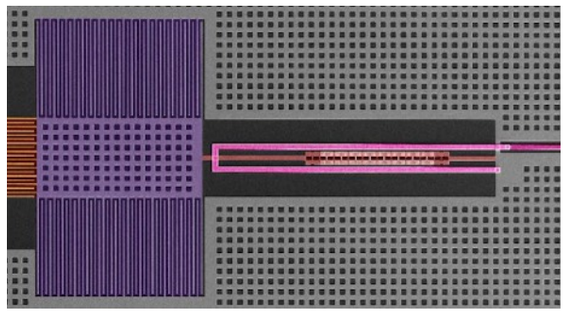
[MAGIS-100]

Microwave SQUID Multiplexers



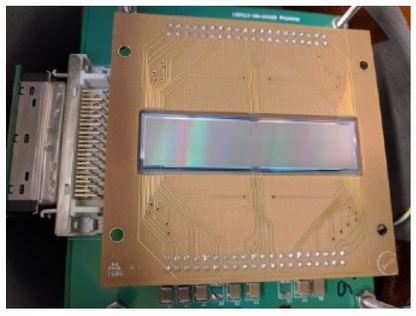
[Simons Observatory]

Squeezed State Receivers



[HAYSTAC]

Skipper CCDs



[SENSEI]

And More!

NMR, superfluid helium, graphene, atomic clocks, cold atoms, …

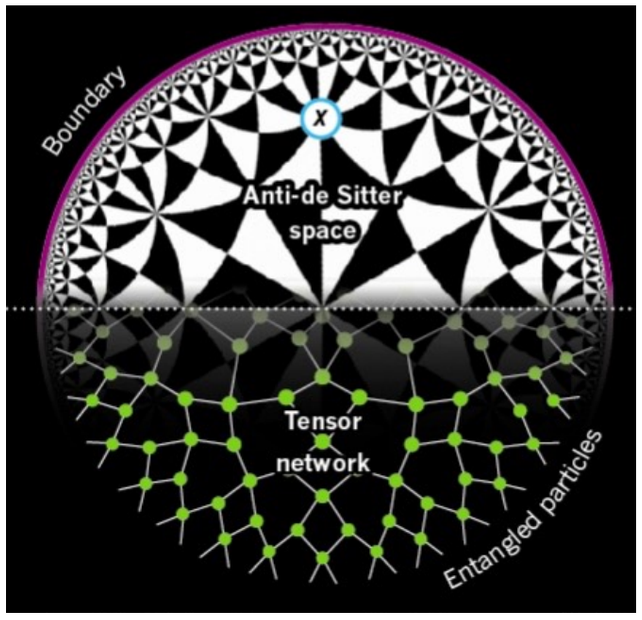
[see Nov 2018 HEPAP Meeting; Quantum Sensing for HEP (2018); 2019 Kavli ACP Workshop, Intersections QIS/HEP]

HEP and the National Quantum Initiative

Quantum: Manipulating individual quantum states
Using superposition, entanglement, squeezing, etc.

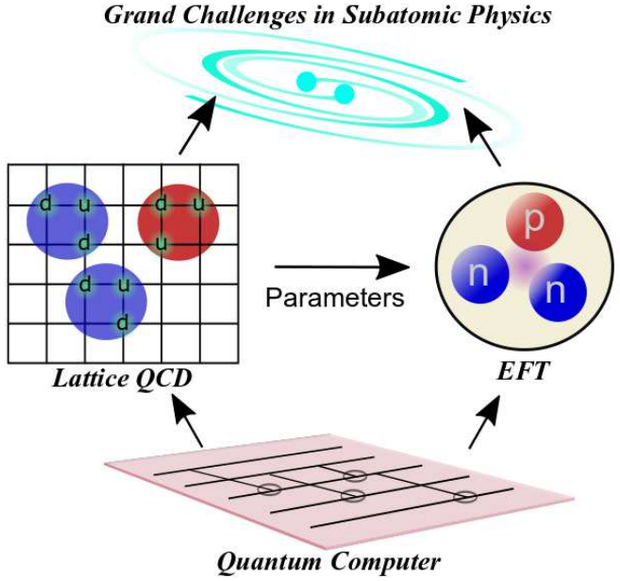
Fertile intersection between HEP and QIS
Potentially transformative, requires robust theory/R&D effort

Entanglement ⇔ Geometry



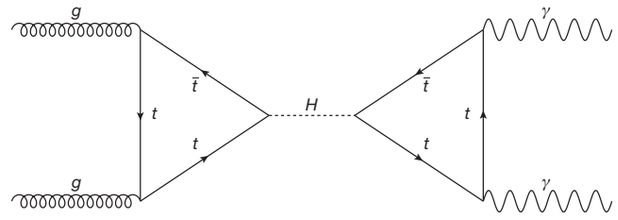
[figure from Nature 2015]

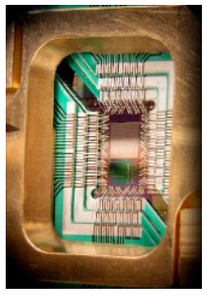
Simulation

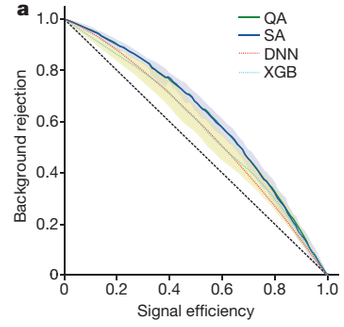


[figure from 1810.03959]

Computation/Analysis







[MJVLS, Nature 2017]

Final Comments

- Looking Towards Snowmass 2020+
- Cultivate a Vibrant, Inclusive HEP Community
- Summary of Topics

Looking Towards Snowmass 2020+

The physics priorities of our field are largely the same, but the toolbox and targets have expanded

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

- Develop transformative concepts and technologies to enable future discoveries

Looking Towards Snowmass 2020+

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- Develop transformative concepts and technologies to enable future discoveries
- Cultivate a vibrant, inclusive, and supportive scientific community

The success of our endeavors depends on "4π coverage" in identifying and cultivating talent at all career stages

Backup: Example of MIT Physics Community Values

Summary of Topics

How has the physics landscape changed since 2014?

- Review of HEP Landscape and P5
- Solidification of SM / Diversification of BSM
- Progress on All Science Drivers
- Discovery of Gravitational Waves (and rise of multi-messenger astrophysics)

New opportunities with significant discovery potential?

- Setting the Stage for a Higgs Factory
- New Dark Matter Paradigms
- Small-Scale Experiments / Curiosity-Driven Research
- Quantum Information Science

Additional topics in backup:

- Physics Community Values
- Novel Reconstruction / Deep Learning
- Archival Collider Data
- Relevance of HEP to Society
- European Strategy Update

Inevitably, I have forgotten something important. Looking forward to *full* community input at Snowmass 2020+!

Backup Topics

- Physics Community Values
- Novel Reconstruction / Deep Learning
- Archival Collider Data
- Relevance of HEP to Society
- European Strategy Update

MIT Physics Community Values

Towards a more vibrant, inclusive, and supportive scientific community

Well-being

We support each other at all times and remember that we are not alone.

Respect

We value the multitude of ways to be a physicist and the many paths through our field and Department.

Inclusion

We strive to speak and act in ways that support and include all members of our community.

Collaboration

Physics is a social endeavor and we proudly collaborate with others to advance the field.

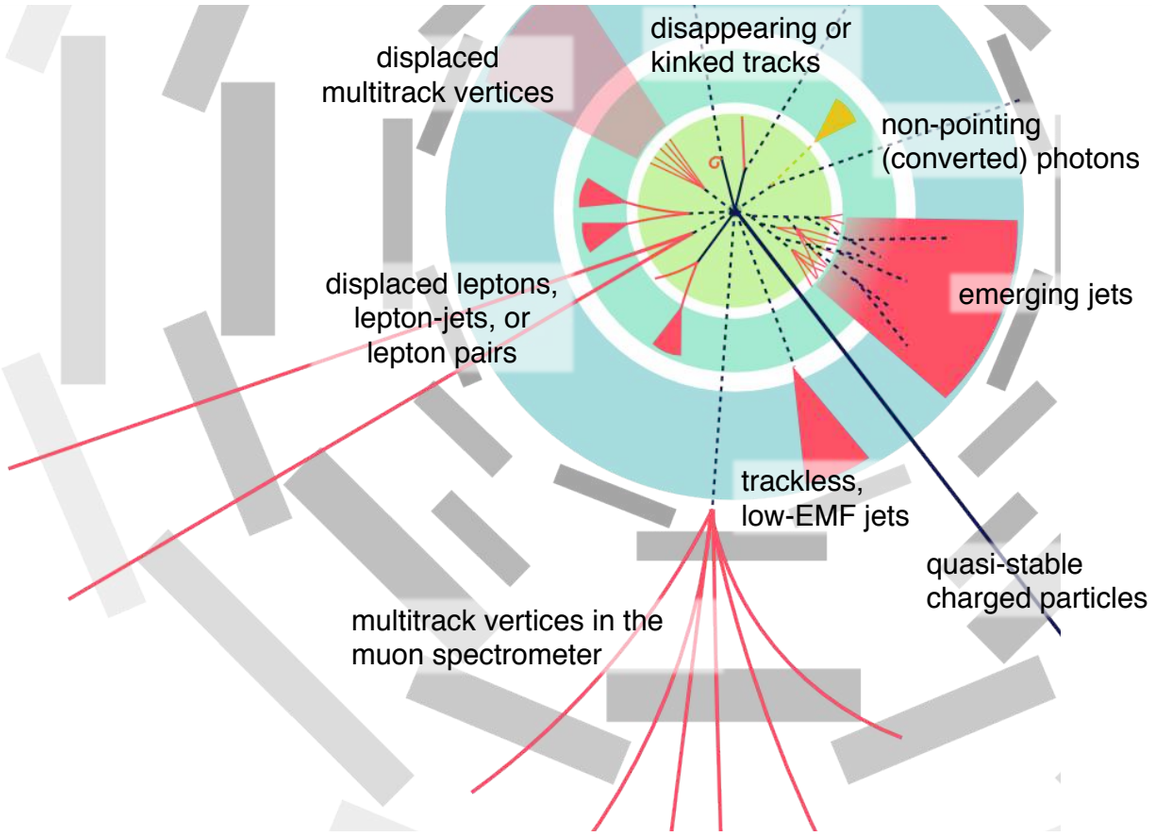
Mentorship

All physicists are here because of the mentorship we have received and continue to receive, and the mentorship we offer to others.

[MIT Physics Community Values, including input from my former undergraduate students Eleanor Hall and Radha Mastandrea; see also Fermilab Statement of Community Standards, CERN Code of Conduct, Code of Conduct for APS Meetings]

Novel Reconstruction Strategies

Exotic objects, rare phenomena, extreme phase space, anomaly detection, …



Plausible BSM scenarios that would be missed (or even vetoed) by standard quality cuts

Motivates collider add-ons for long-lived particles: FASER, CODEX-b, MATHUSLA, milliQan, …

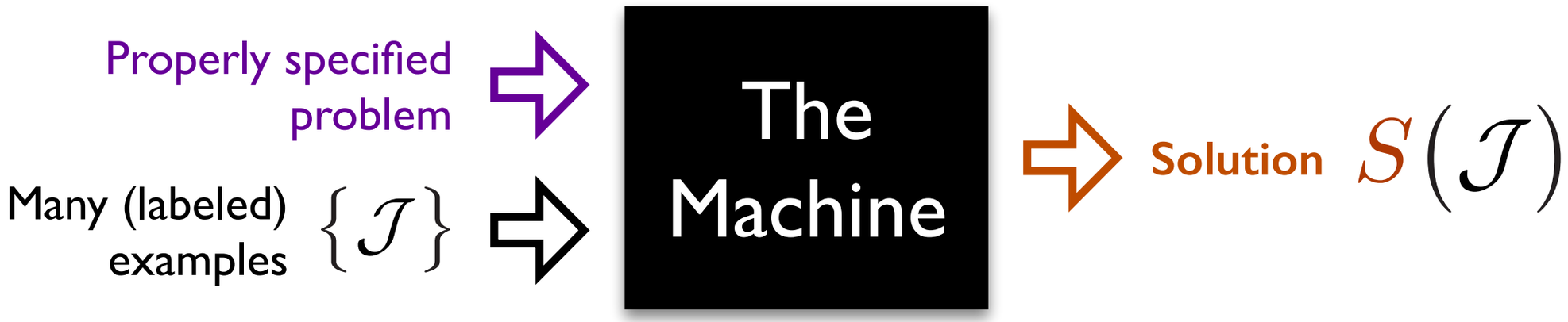
Also motivates new fixed target experiments: HPS, BDX, LDMX, SeaQuest, SHiP, …

LHC Run 3 / HL-LHC: Natural shift to "signal-limited" BSM searches where significance can grow faster than sqrt(luminosity)

[see e.g. LHC Long-Lived Particle Community Report (2019)]

The Rise of Deep Learning

Carton of Machine Learning: Optimize over examples to define functions



Extensively applied in HEP for decades (e.g. Boosted Decision Trees)

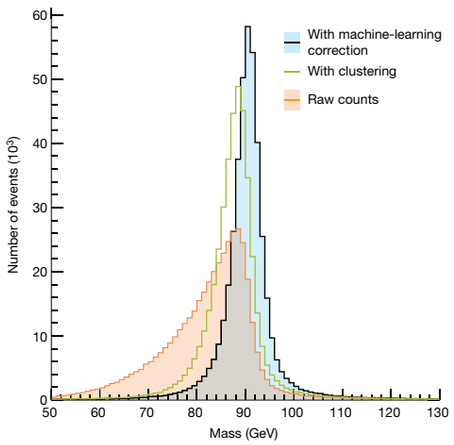
New Opportunity: "Deep" architectures with improved performance, faster training, built-in symmetries, and industry backing

Key Challenges: Validation, calibration, interpretation, visualization

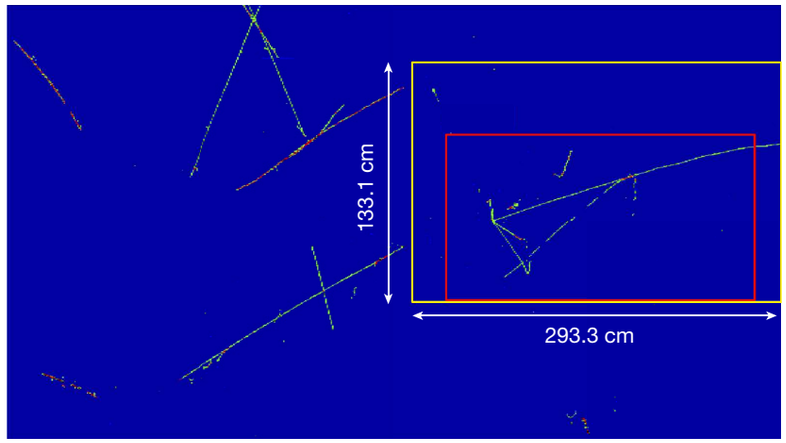
[see e.g. Machine Learning in HEP Community White Paper (2018)]

Examples of Machine Learning in HEP

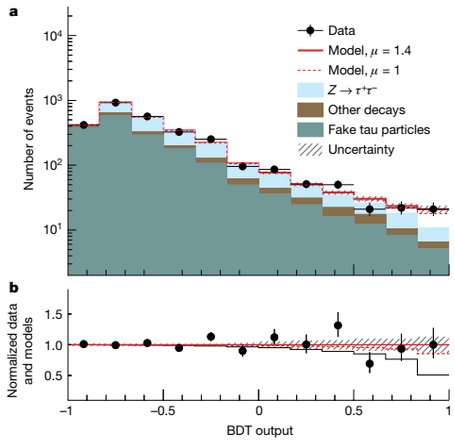
CMS: $Z \rightarrow e^+e^-$ calibration



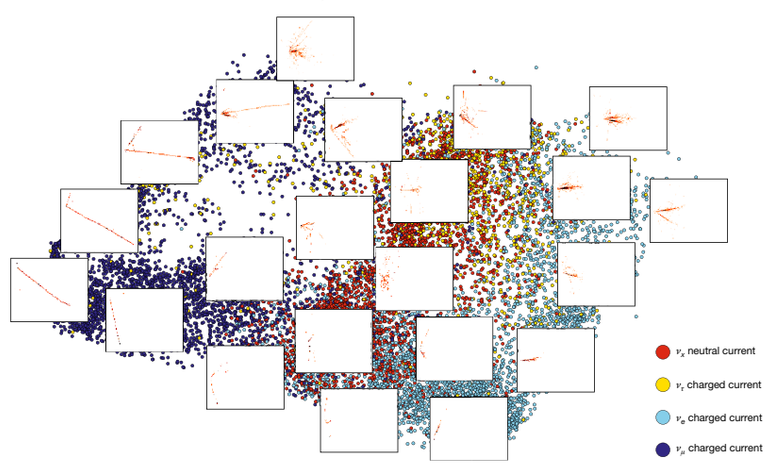
MicroBooNE: Object Identification



ATLAS: $H \rightarrow \mu^+\mu^-$ search



NOvA: Object Classification



Area of rapid development, directly relevant to P5 science drivers
Opportunity to engage with partners in industry

[figures from Nature 2018]

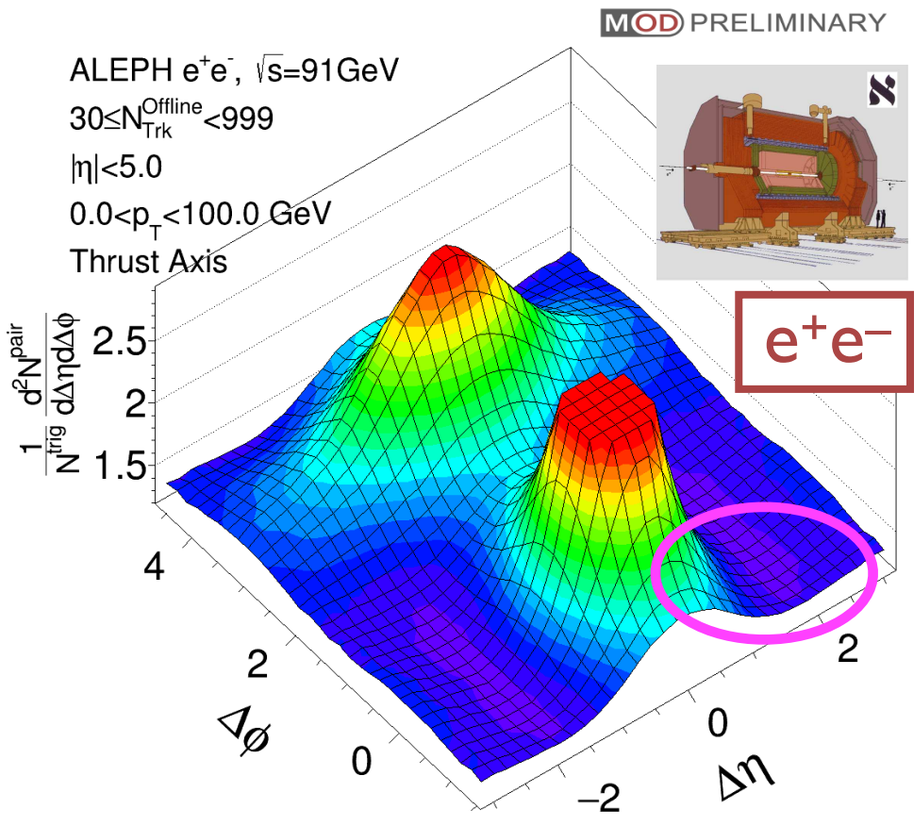
Longterm Relevance of HEP Data

e.g. ALEPH reanalysis confronts CMS ridge

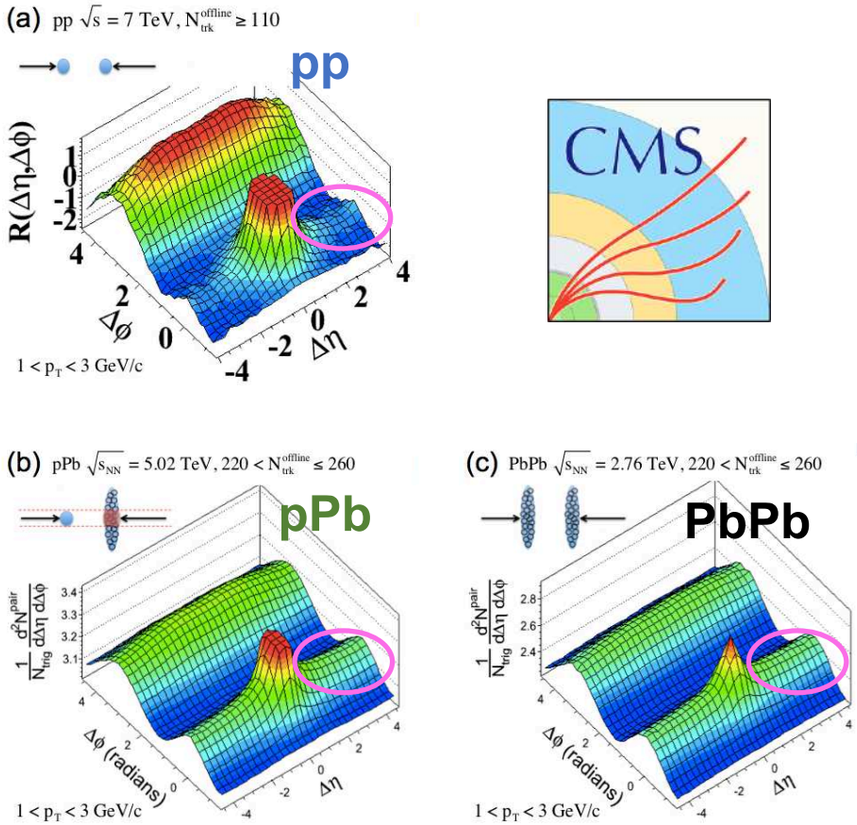
1990–95 e^+e^- data

⇓ ⟵ 2010 pp surprise!

2018 e^+e^- analysis



vs.



[LBBMITPSCM, NPA 2019]

Pathway to Archival Collider Data?

Examples of archiving via public access: Planck, Fermi, LIGO/Virgo, …

Nov 2014: First public release of research-grade collider data:

CERN Open Data Portal:
CMS 2010–2012 (and Opera)

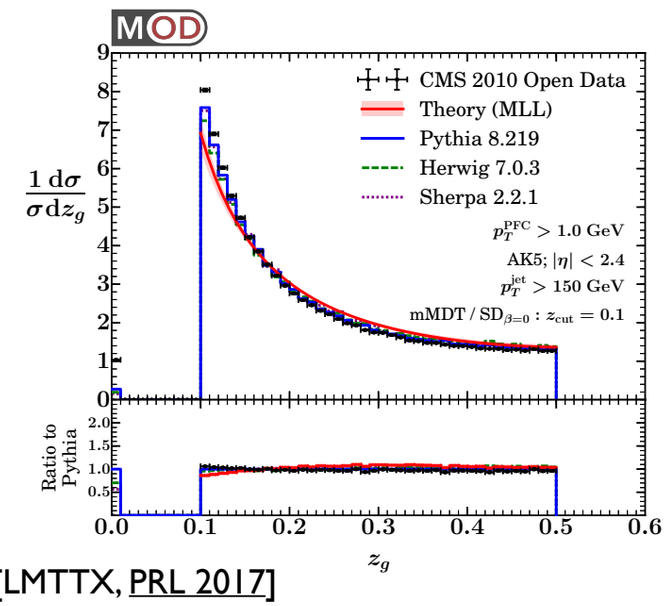
Essential: Ample time delay to avoid competing with collaboration needs

Benefits: Stress-tests archival data strategies
Enables exploratory/proof-of-principle studies
Facilitates theory/experiment dialogue
Educates future scientists

Challenges: Requires significant resources (people, time, ideas, money)

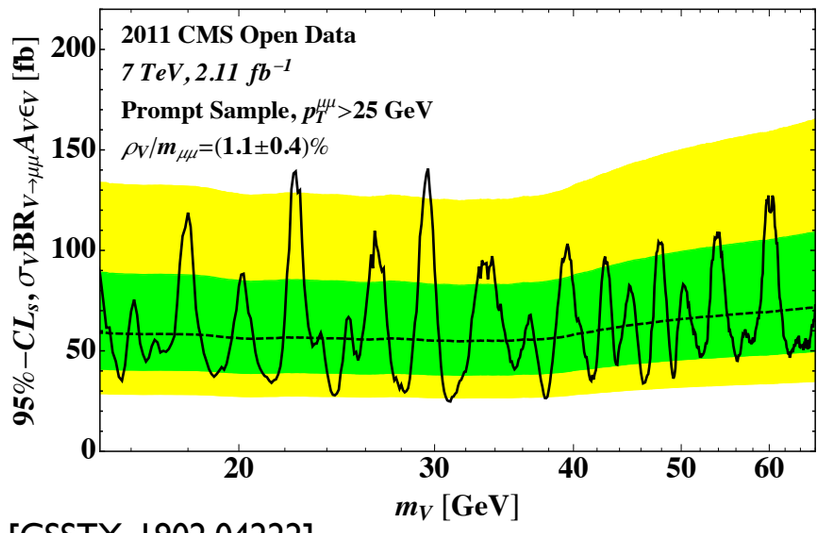
Example CMS Open Data Studies

Momentum Balance in Jets



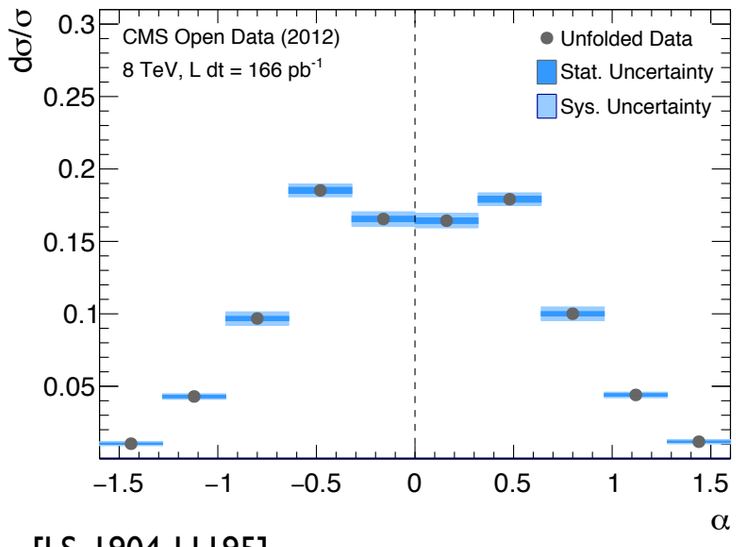
[LMTTX, PRL 2017]

Search for Dimuon Resonances



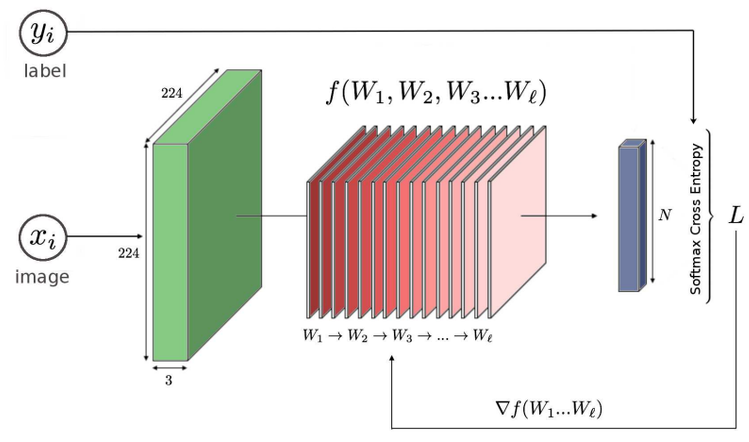
[CSSTX, 1902.04222]

Parity Violation in Jets



[LS, 1904.11195]

Machine Learning Studies



[MCIL, 1708.07034; see also APGP, 1807.11916]

High Energy Physics

HEP is a discovery-focused field

HEP is a curiosity-driven / technology-driven field

We build world-class facilities with world-wide participation,
and we continually push their scope and capabilities

We are inspired and guided by key science drivers,
but we are always seeking new avenues for discovery

Relevance of HEP to Society

Why has the pursuit of science for its own sake
had such a remarkable track record in
generating transformative new technology?

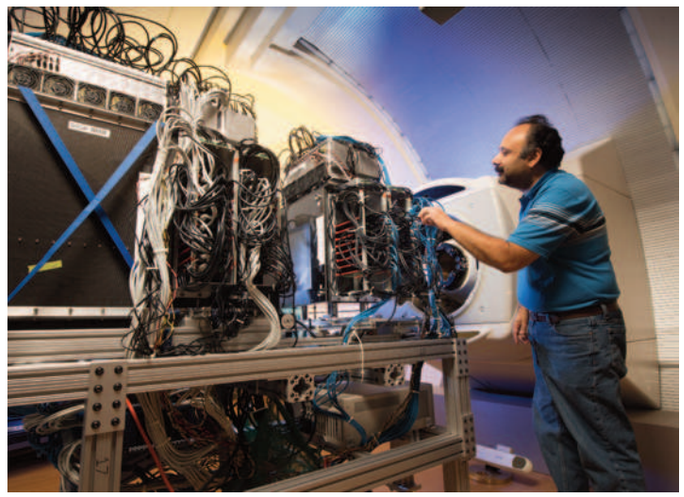
The reason must be that Nature poses deeper and more challenging questions than humans can do, and the struggle to understand Nature forces us to invent better and deeper ideas than we would if left to our devices.

[from Gross, IJMPA 2016]

Some Required Reading

MEDICINE

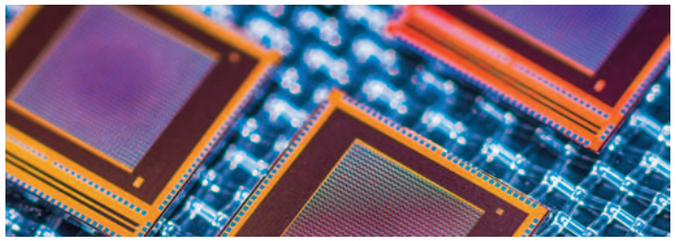
- **Radiation treatment plans for cancer** are powered by software originally developed to model particle detectors, and treatments with gamma rays and protons are delivered using particle accelerator technology.



Proton therapy for cancer

SENSORS

- **Chemistry, biology, and materials science** researchers use sensors developed for particle physics in cameras that collect signals from visible and infrared light and from X-rays.



X-ray sensors

COMPUTING AND SIMULATION

- **The World Wide Web** was first developed by particle physicists to share information quickly and effectively around the world. Particle physicists continue to push the frontiers of big data analysis with global grids and cloud computing.

NATIONAL SECURITY

- U.S. scientists helped create a muon detector system to **safely look inside the nuclear reactors** in Fukushima after the earthquake and tsunami in Japan.

Muon scanning at Fukushima

Important to emphasize that transformative concepts and technologies in HEP are also relevant to society at large

[from Particle Physics Makes a Difference in Your Life (2019)]

The European Strategy Update

Useful Context and Perspectives:

Summary Talks at the Open Symposium (Granada, May 12–19, 2019)

APS Division of Particles and Fields White Papers:
Community Planning and Science Drivers
Tools for Particle Physics

Important Considerations:

Snowmass 2020+ will happen after European HEP strategic planning

CERN is a key international partner, from LHC to protoDUNE

International collaboration will be essential to build and operate next collider(s) beyond HL-LHC