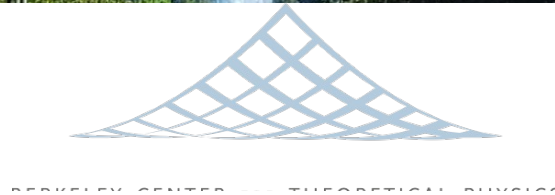


# Theory vision: the questions before us (Working title, may change)

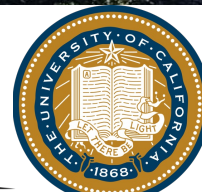
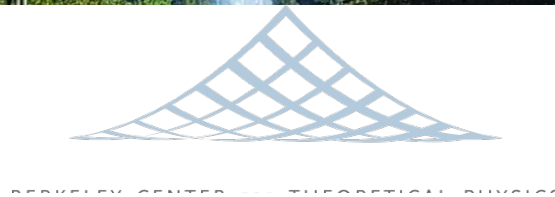
Hitoshi Murayama (Berkeley, Kavli IPMU)  
Snowmass in Seattle, July 17, 2022





# Theory **vision**: the questions before us (Working title, **may change**)

Hitoshi Murayama (Berkeley, Kavli IPMU)  
Snowmass in Seattle, July 17, 2022



# Disclaimer

The following contents are based on personal bias and (lack of) understanding, and the accuracy is not guaranteed. Some of the projects mentioned are hypothetical and may or may not occur. In case of disputes, you cannot file a lawsuit against the speaker.

OK

# Last P5

## Science Drivers:

- 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.

*Still very much true*



- Energy Frontier
- Neutrino Physics Frontier
- Rare Processes and Precision
- Cosmic Frontier
- Theory Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Underground Facilities
- Community Engagement

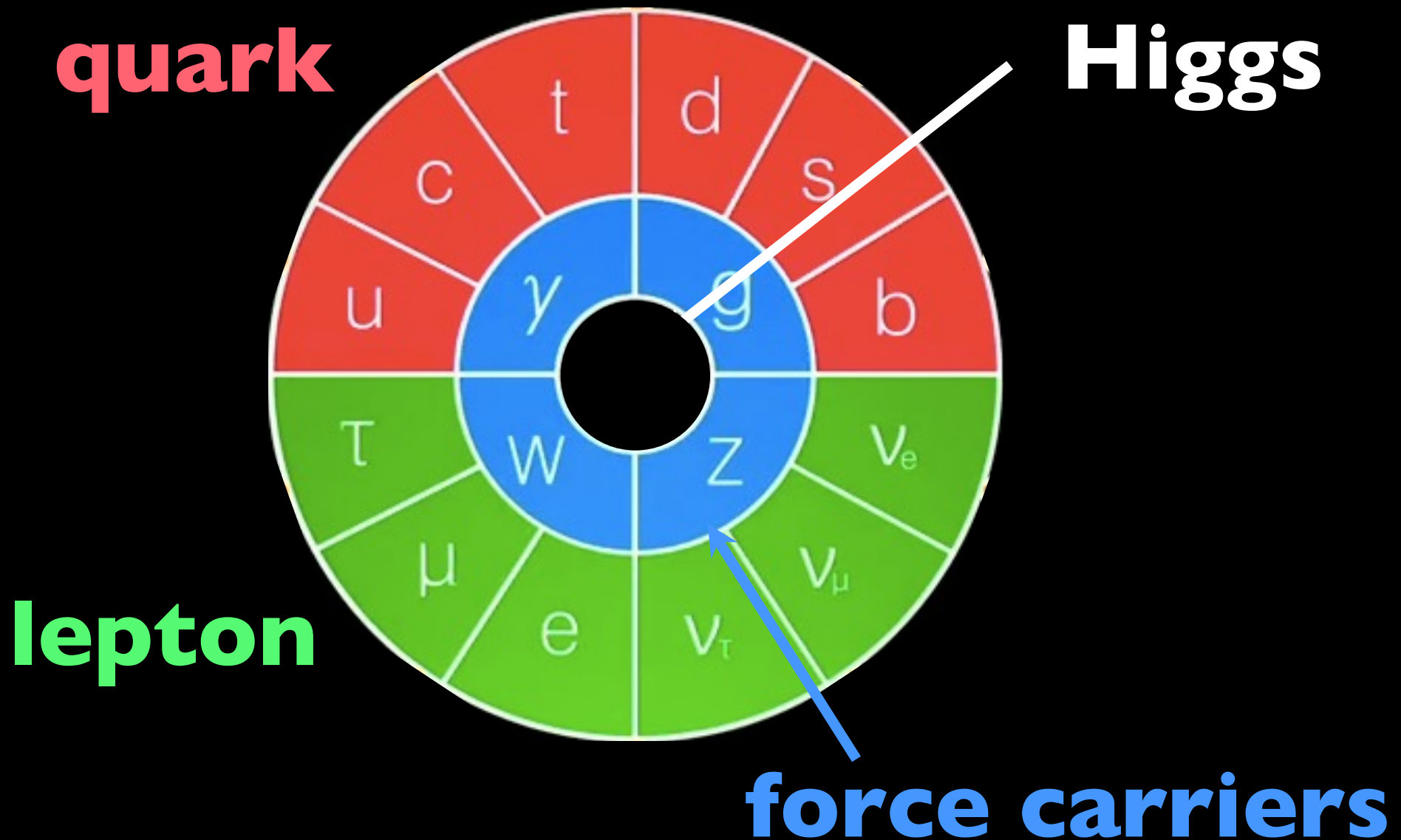
*We need all of them!*

# What we need

- public support to our field is by no means guaranteed
- convincing case of all proposed research
  - nothing is grandfathered in
- percolate individual cases to a cohesive program
  - they are intertwined anyway!
- need a case for the entire field

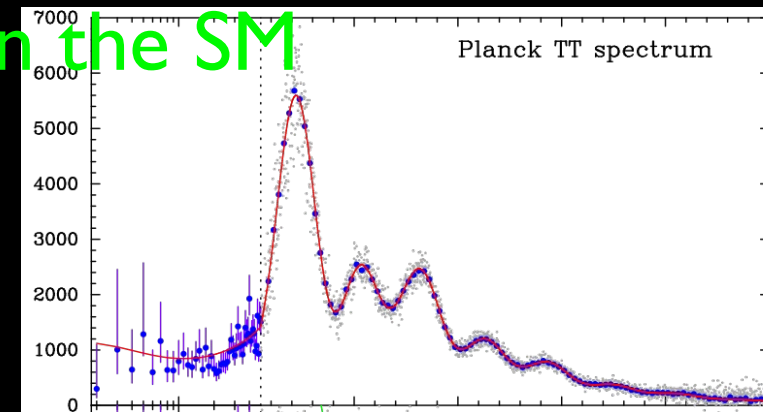


# Standard Model



# Five evidences for physics beyond SM

- at least five missing pieces in the SM
  - dark matter
  - neutrino mass
  - dark energy
  - apparently acausal density fluctuations
  - baryon asymmetry



Unusual in science: the problems are clear!

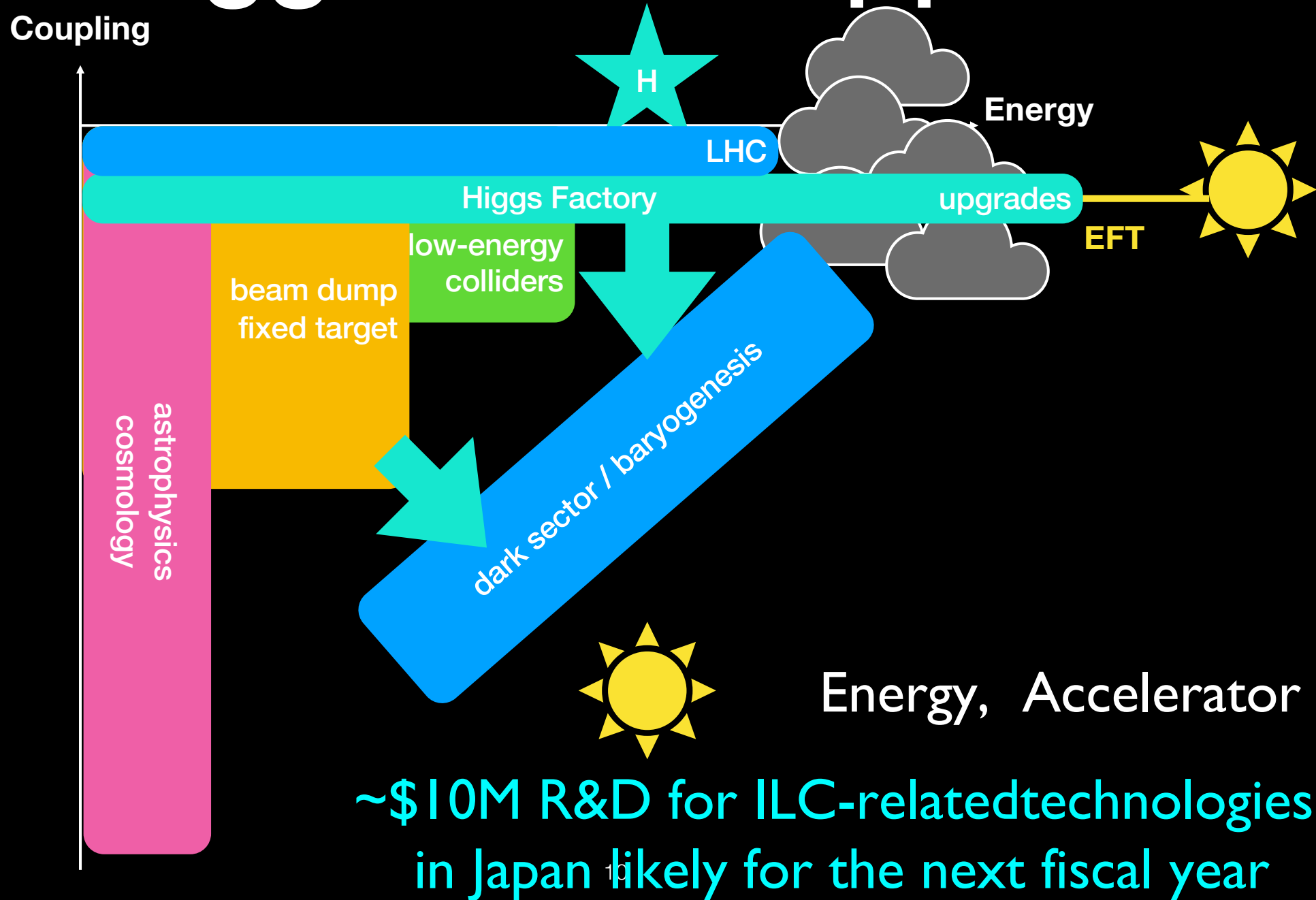
- theoretical problems:
  - hierarchy problem
  - origin of flavor
  - unification of matter and forces
  - quantum gravity

also anomalies ( $H_0$ , flavor,  $g-2$ )

*Where is the next energy scale?*

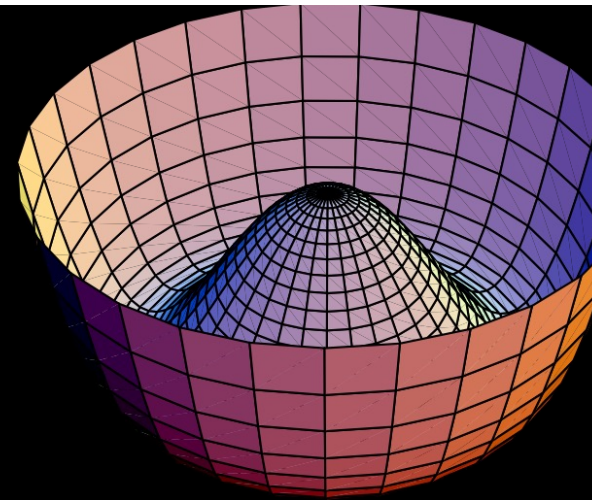


# Higgs as a lamppost



# *I hated it!*

- Higgs boson is the *only spin 0 particle* in the standard model
  - we have never seen one before
  - faceless particle!
  - one of its kind, no context
  - but does the most important job
- looks very artificial
- we still don't know *dynamics* behind the Higgs condensate
- *Higgsless theories*: now dead





# Context for Scalar Bosons?

## Supersymmetry

- Higgs just one of *many* spinless bosons
- SUSY loops make  $m_h^2$  negative
- many superpartners

## composite

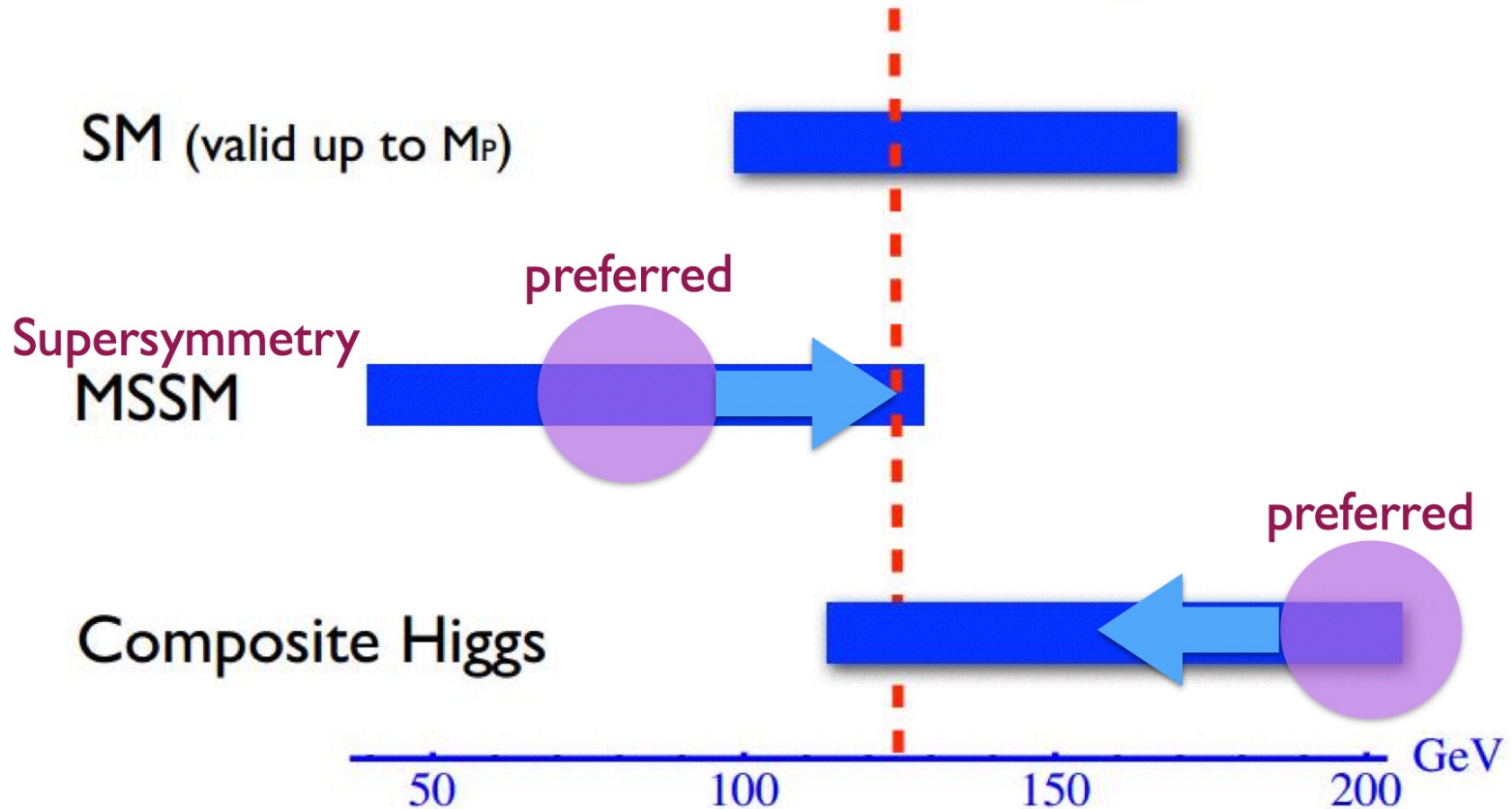
- spins cancel among constituents
- a new strong attractive force
- many new composite particles

## Extra dimension

- Higgs spinning in extra dimensions
- new forces from particles running in extra D
- many KK particles

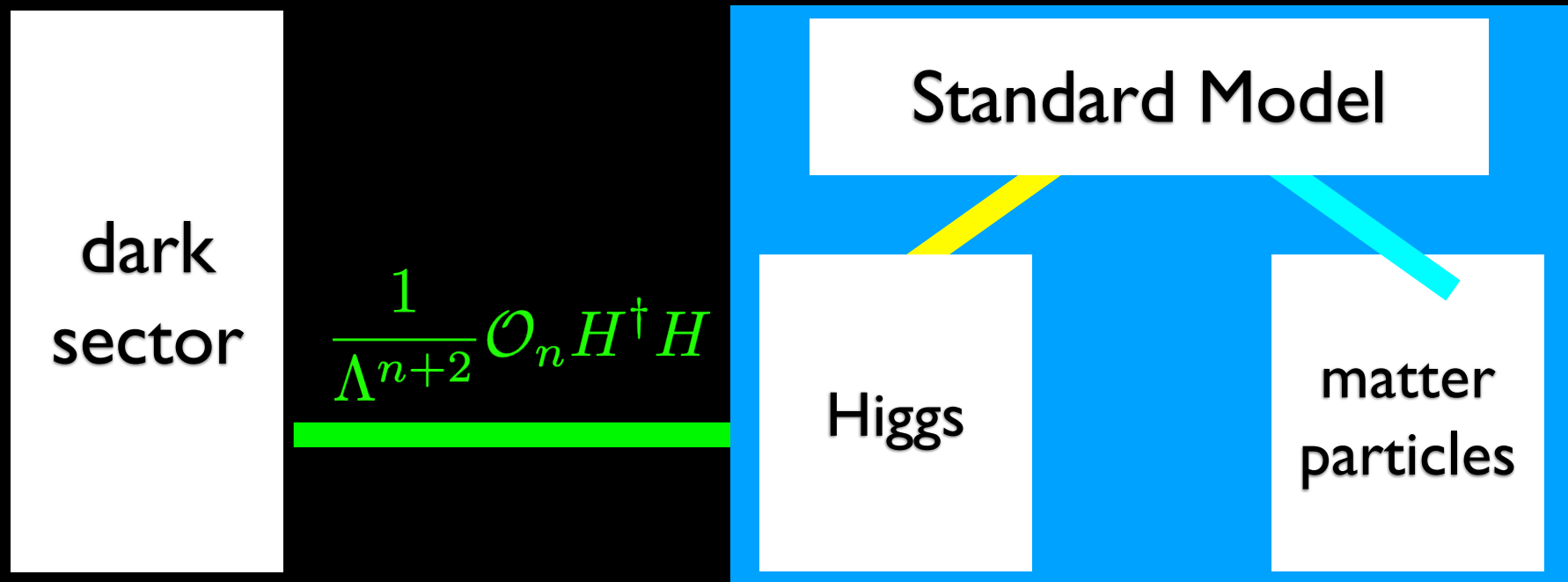
looking for new laws of physics

# Higgs mass range



By A Pomarol

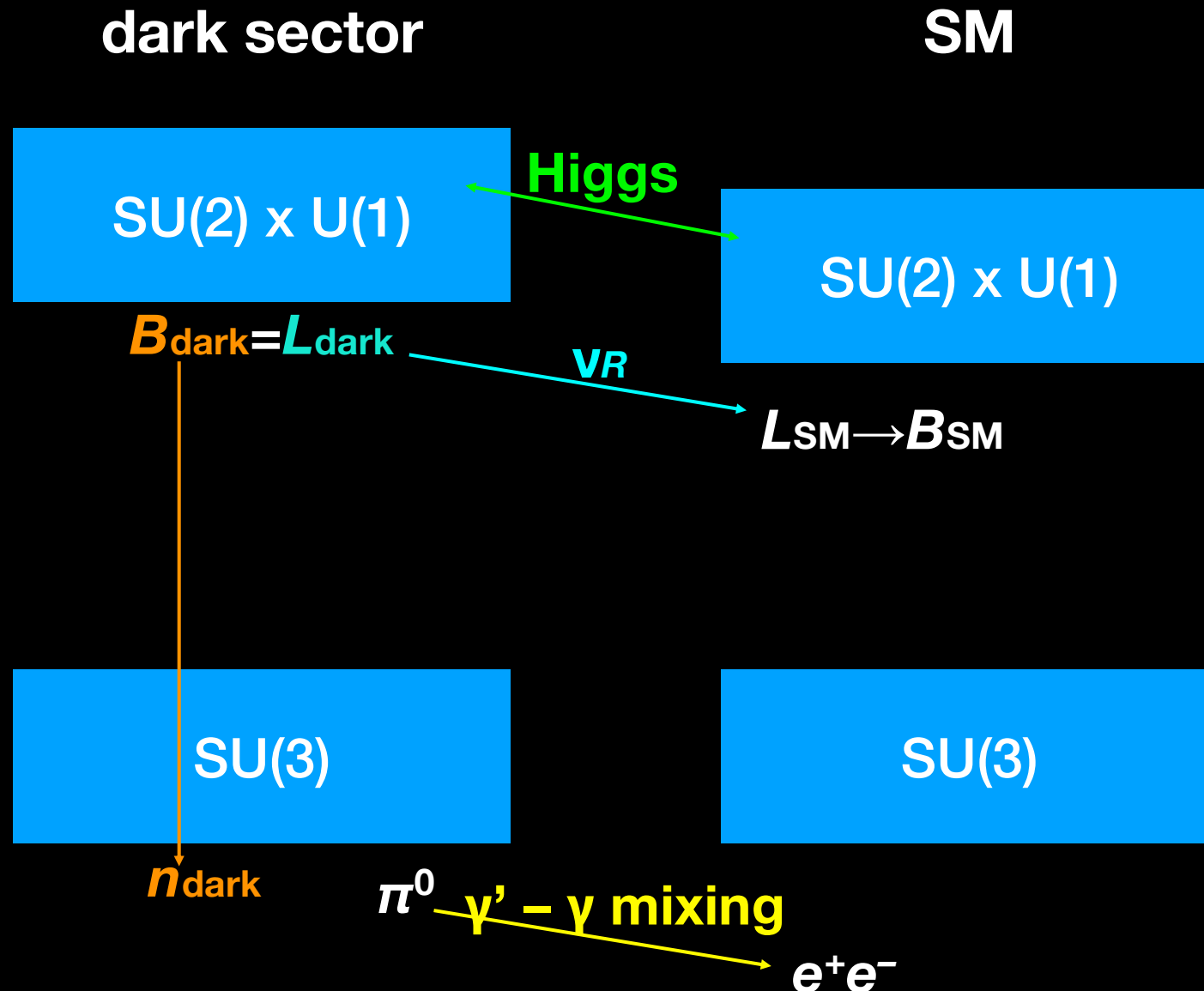
# portal



*cf.*  $\frac{1}{\Lambda^{n+4}} \mathcal{O}_n F_{\mu\nu} F^{\mu\nu}$



# baryogenesis + DM

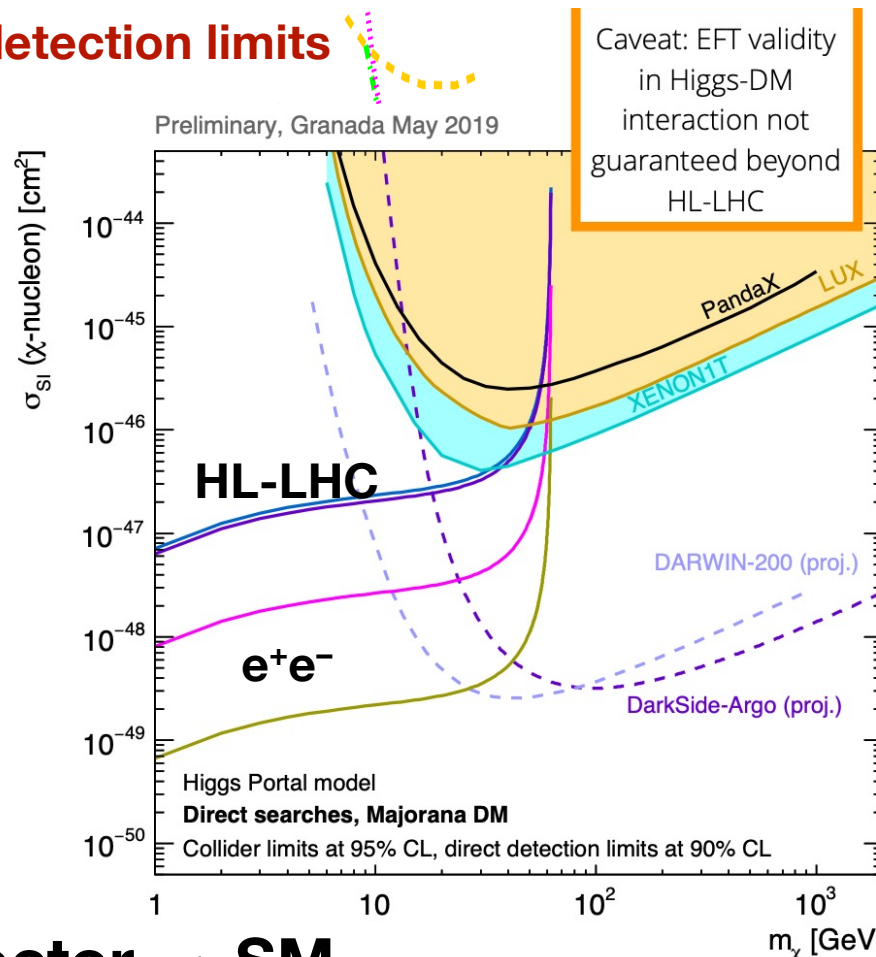


Dark baryon:  $\sim 1.5$  GeV (or  $\sim 60$  GeV)

# Higgs decay to dark matter

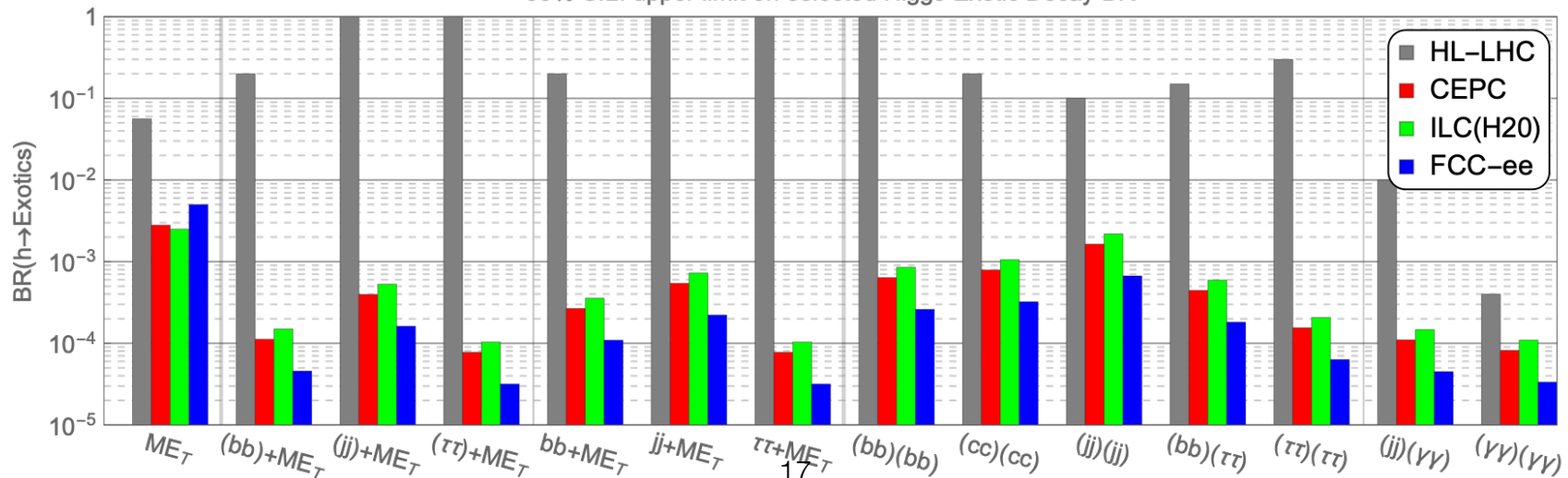
x10 HL-LHC

direct detection limits



## Higgs → dark sector → SM

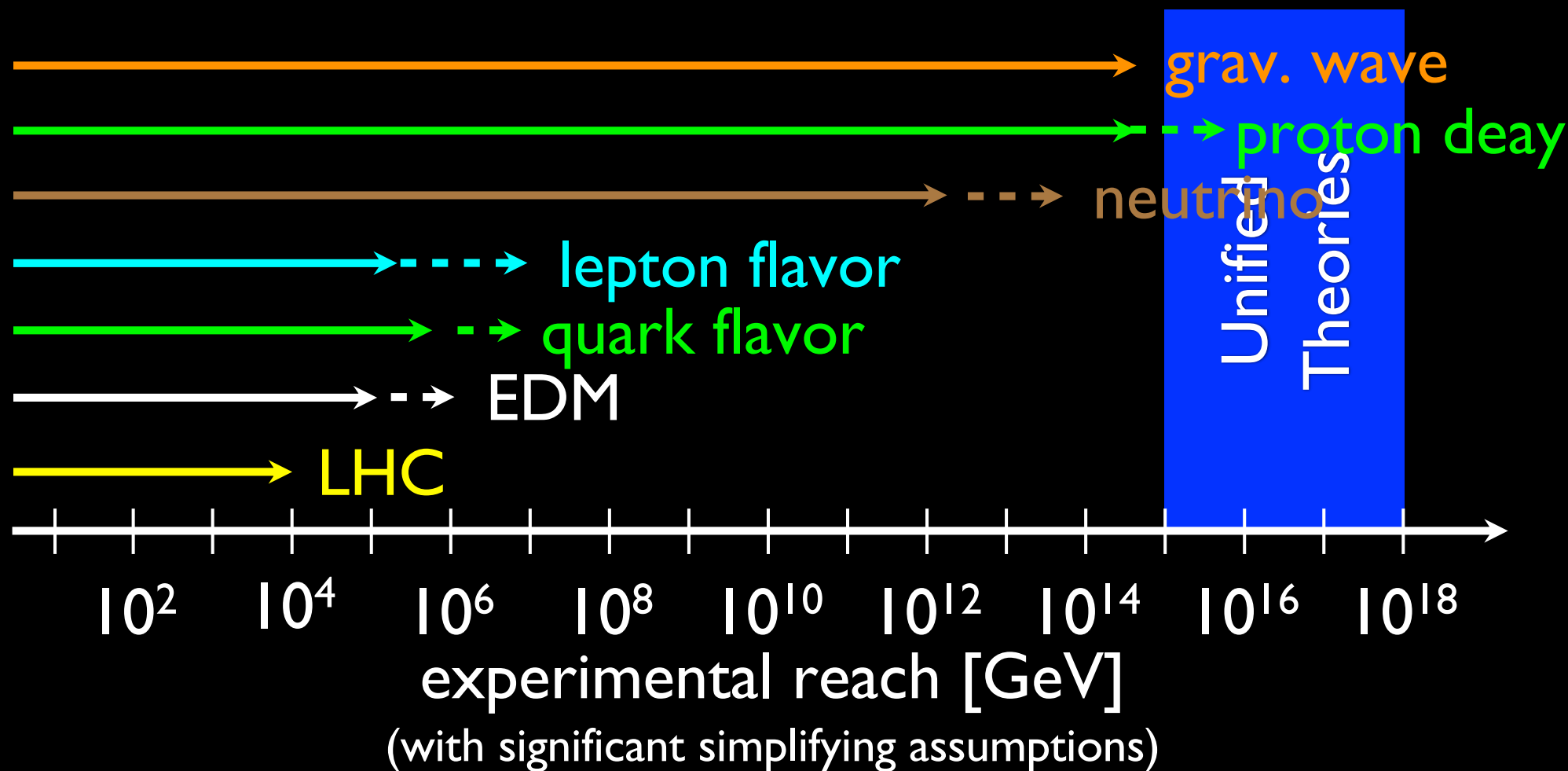
95% C.L. upper limit on selected Higgs Exotic Decay BR



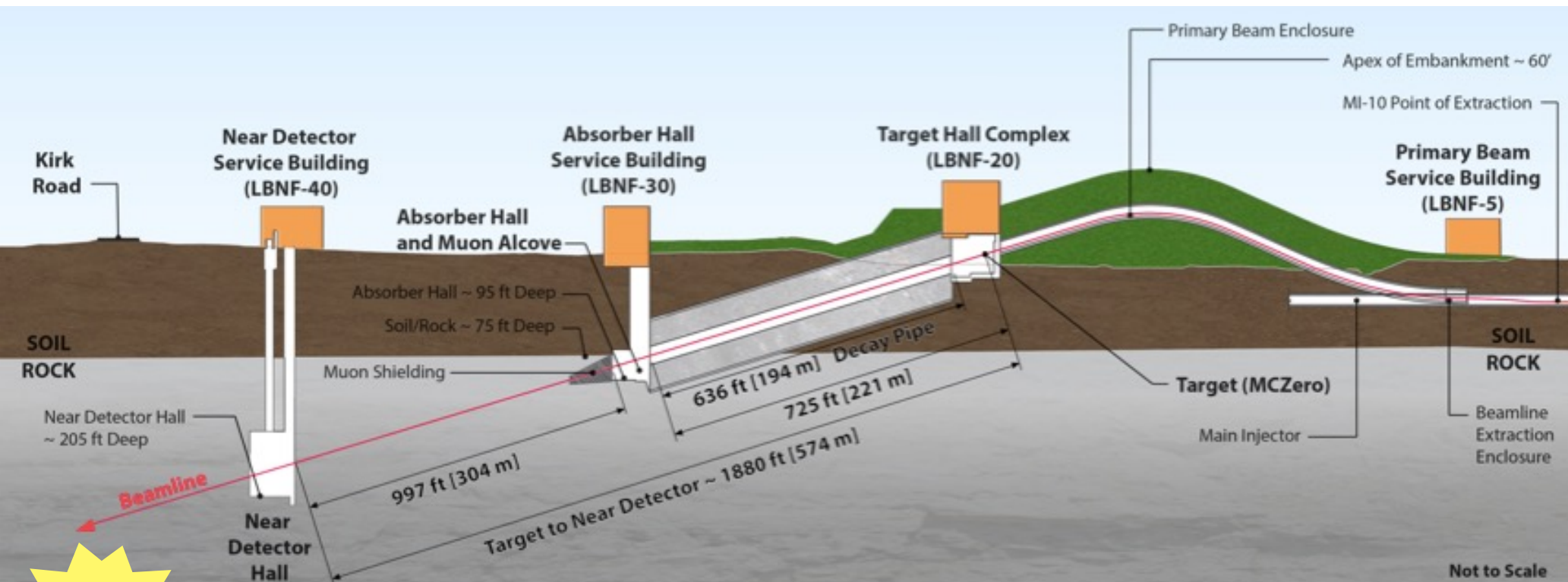
x1000–10000 HL-LHC

## exotic Higgs decays

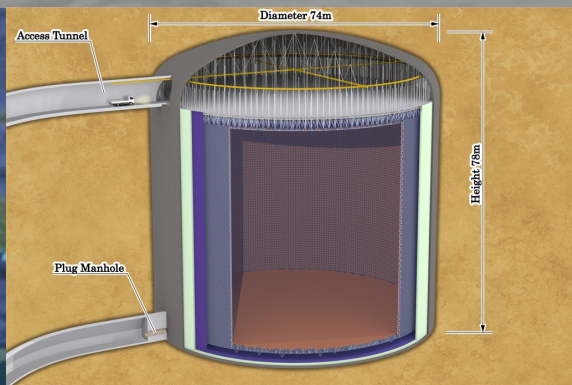
# Power of Expedition







**Proton  
Decays**



Hyper-K



V



J-PARC









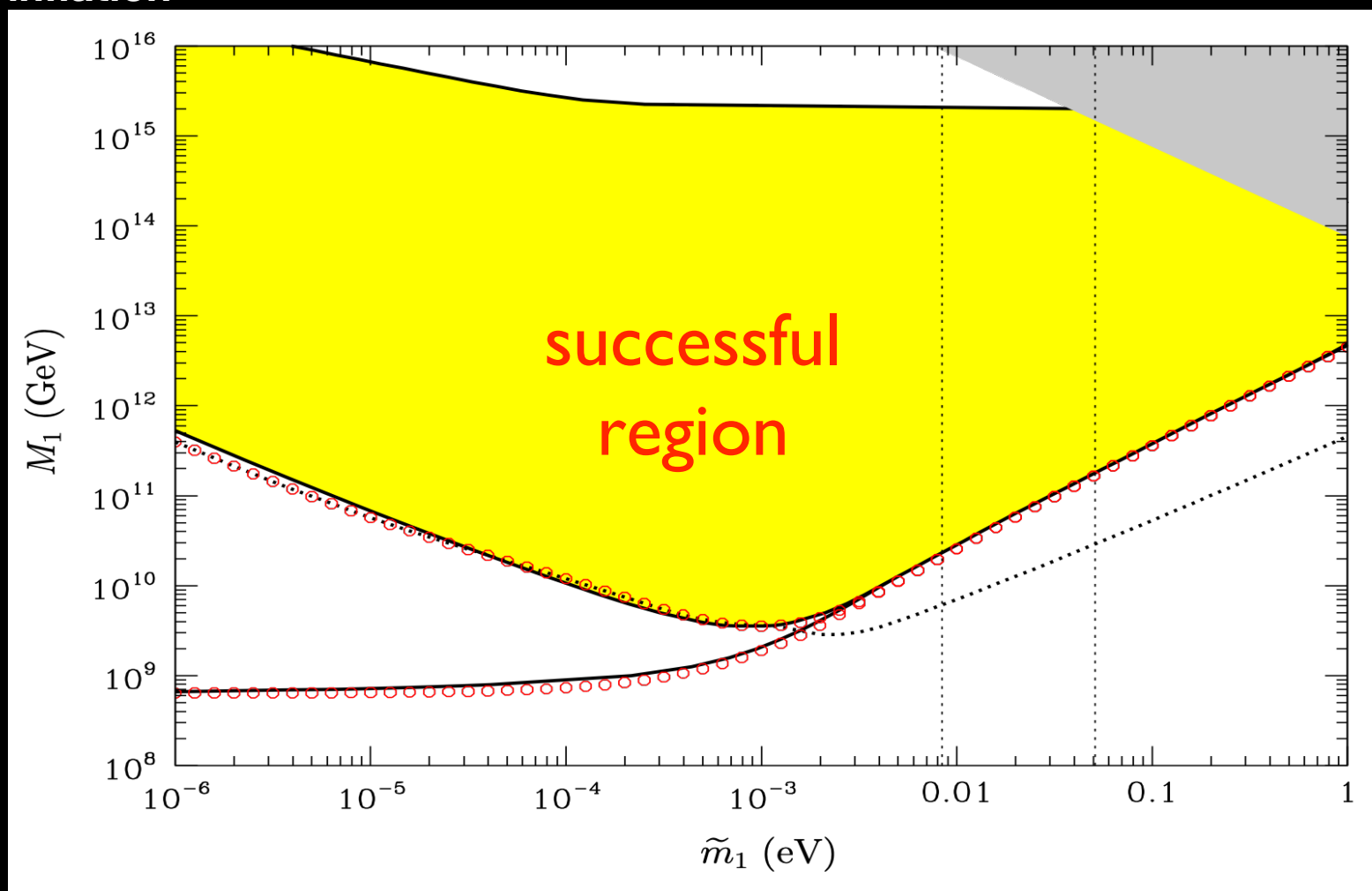
Underground Facilities, Neutrino



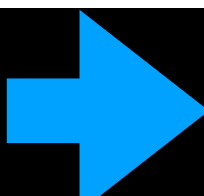
$M_{PI}$

Natural to think  $M$  is induced from symmetry breaking  
e.g.  $\mathcal{L} = -y \langle \phi \rangle N N$

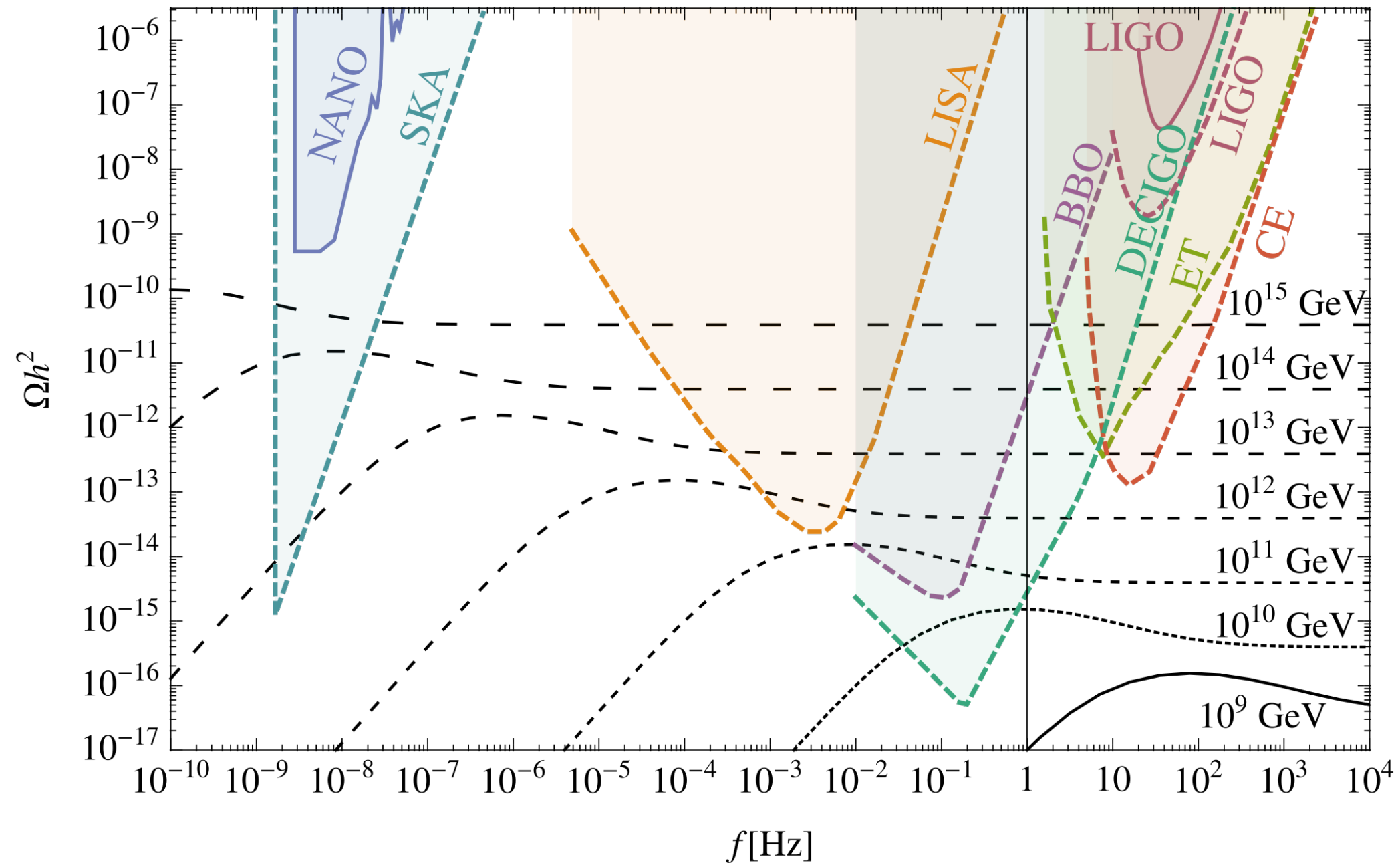
inflation



Phase Transition

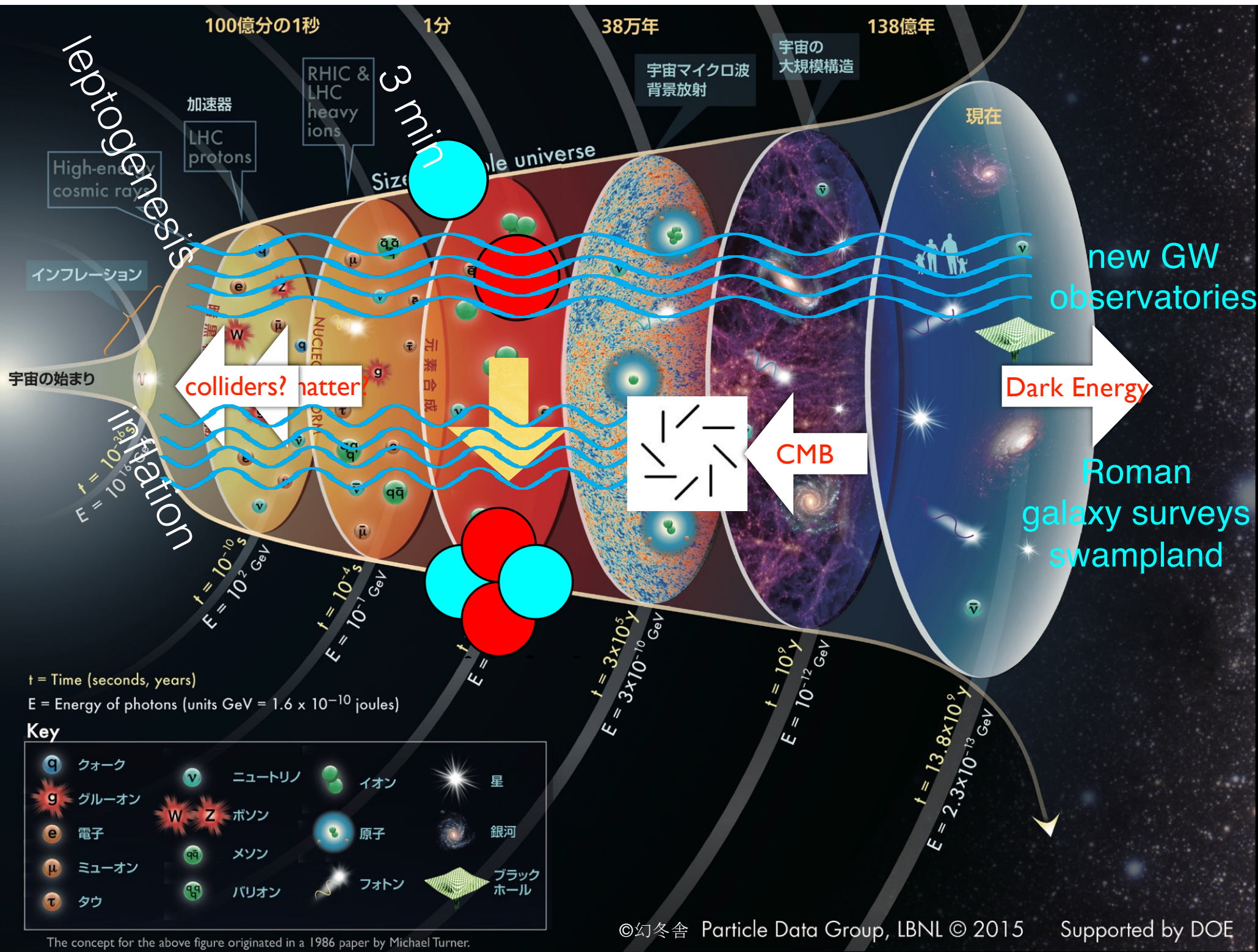


Gravitational Waves?



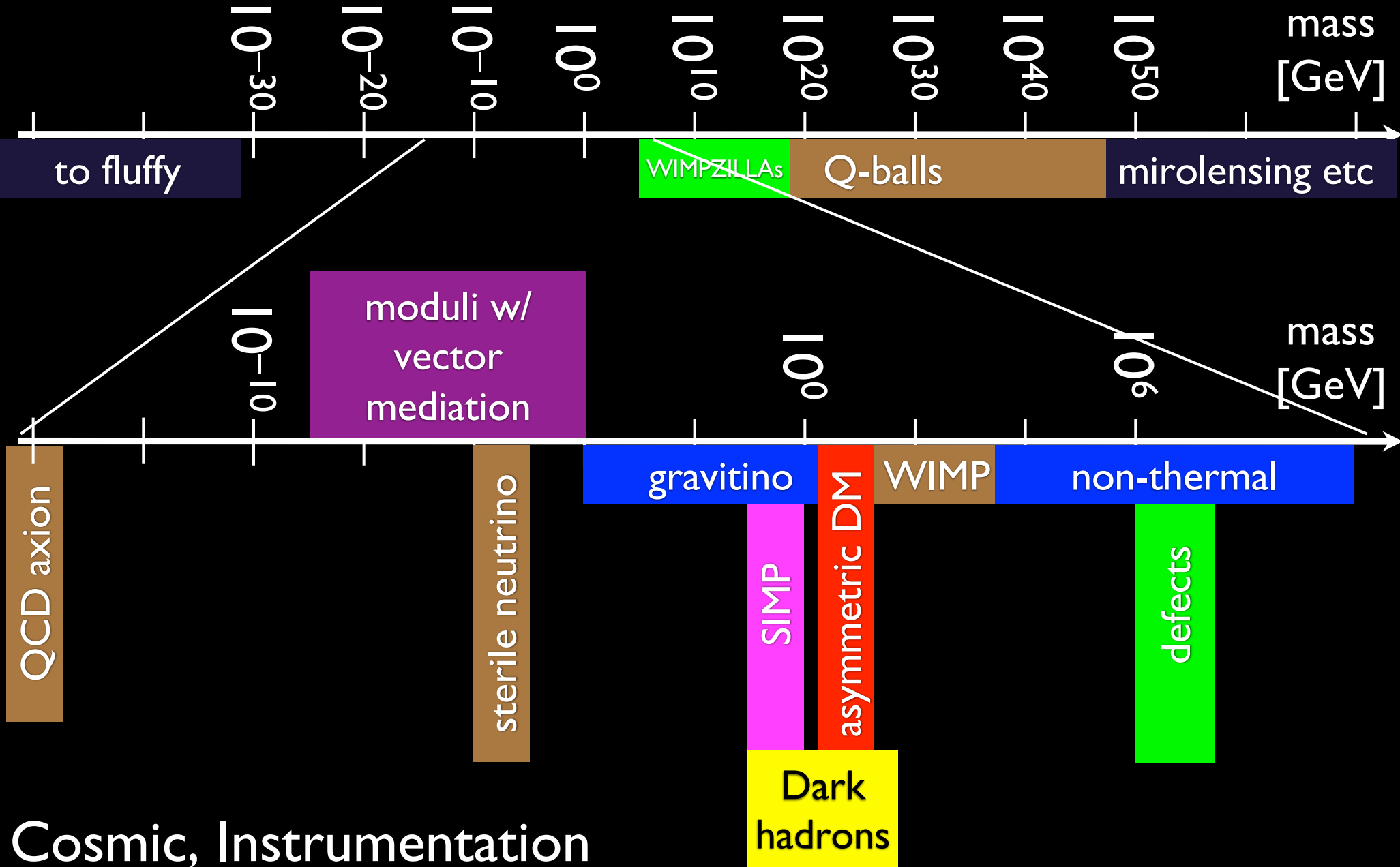
J. Dror, T. Hiramatsu, K. Kohri, HM, G. White, arXiv:1908.03227

covers pretty much the entire range for leptogenesis!



The concept for the above figure originated in a 1986 paper by Michael Turner.

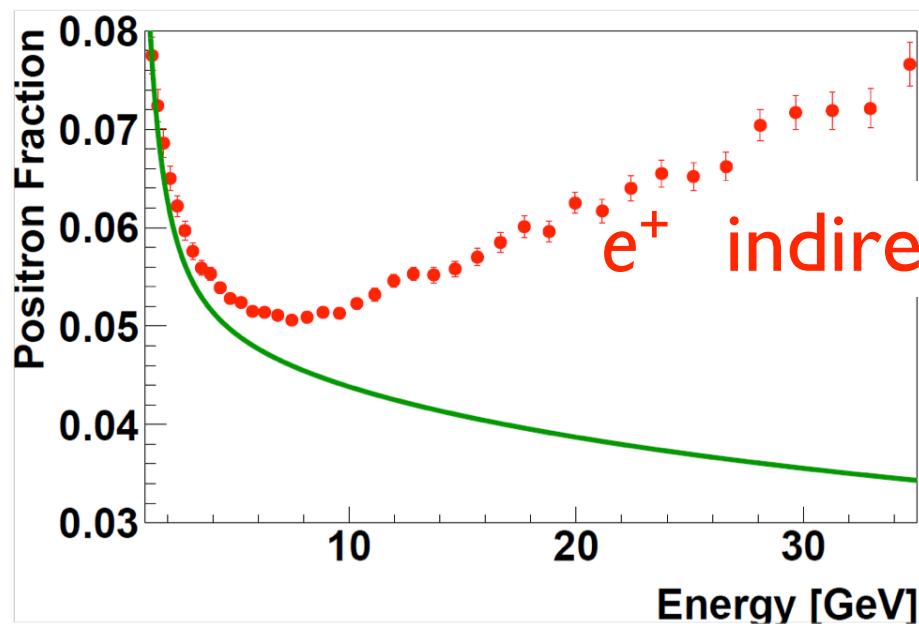
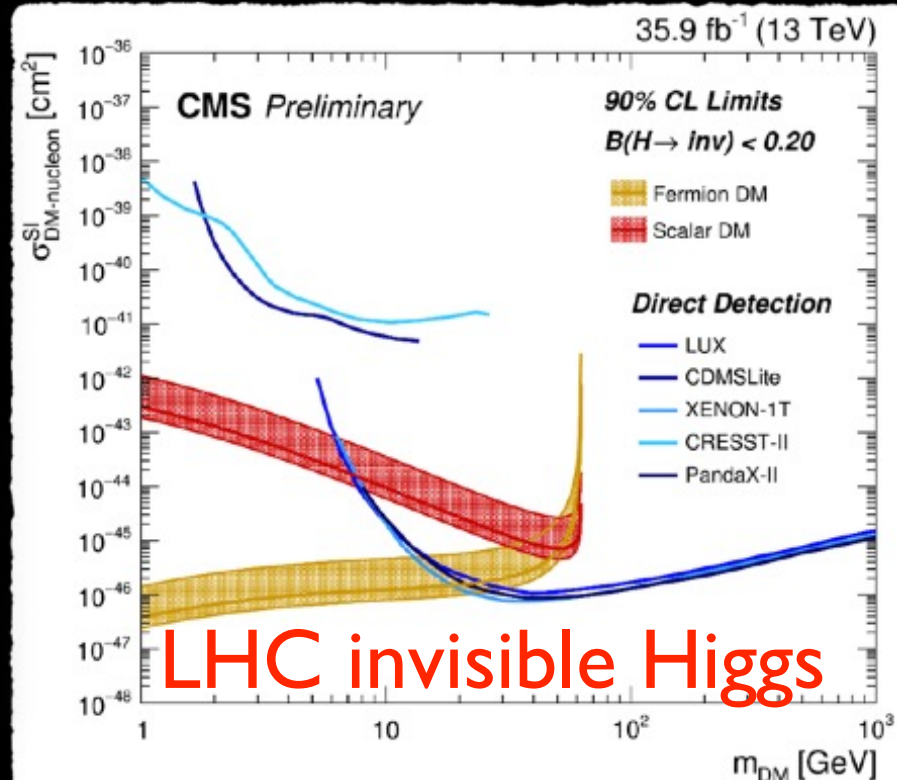
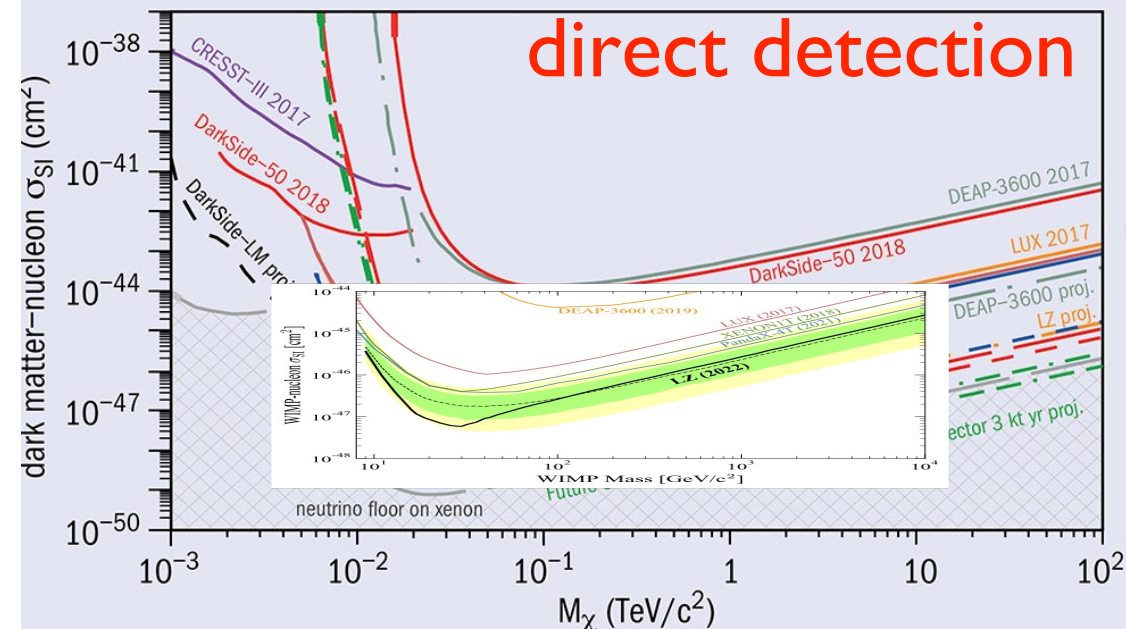
# Dark Matter



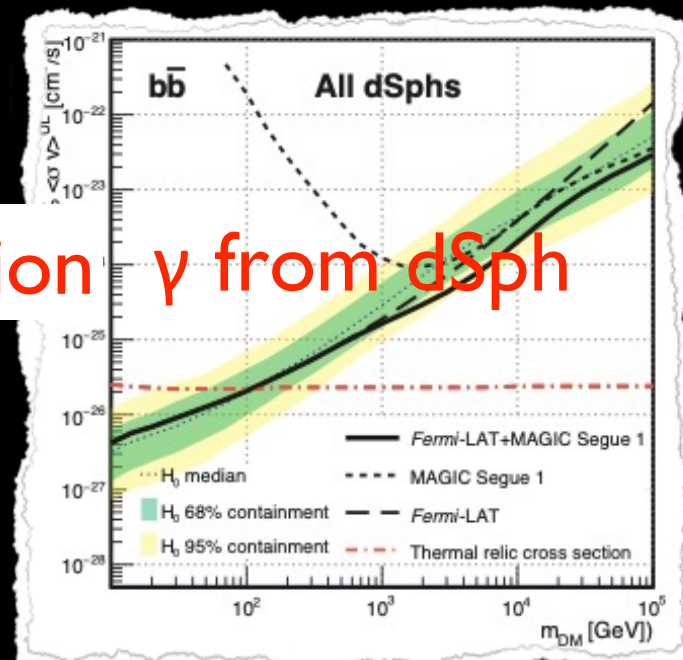
Cosmic, Instrumentation

*Can't do justice to many many ideas submitted to Snowmass!*





**$e^+$  indirect detection  $\gamma$  from dSph**



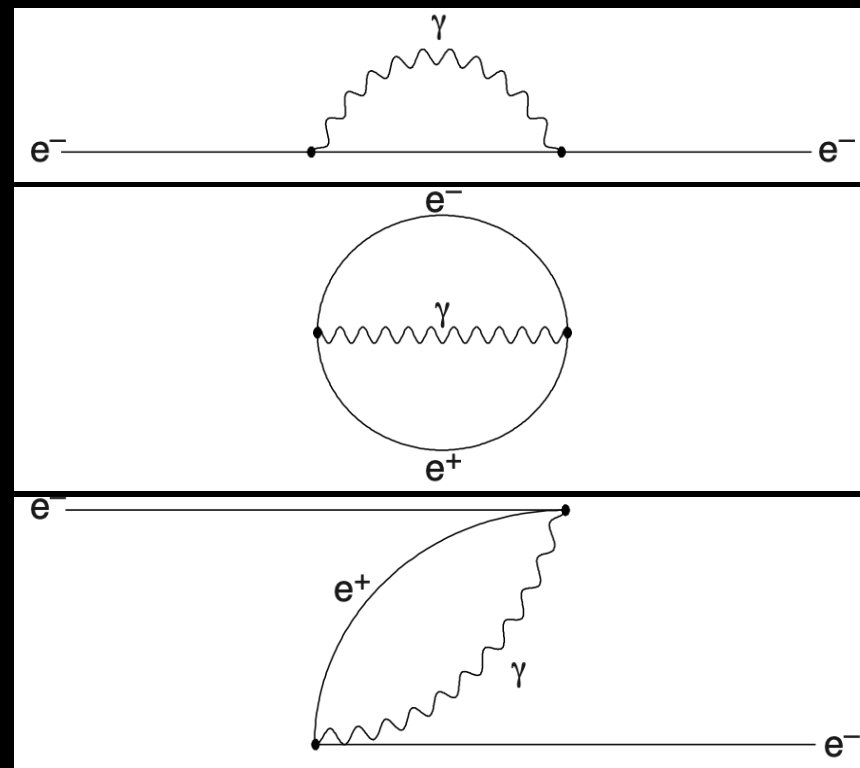
# Explosion of ideas

- many new dark matter models
- many new experimental proposals
  - direct detection with noble gas, quantum sensors, cavities, radio, chemistry, ...
  - indirect detection with  $\gamma$ , anti-matter, neutrinos
- WIMPs should be searched down to  $\nu$  floor
- other opportunities should be pursued

Theory, Instrumentation, Cosmic, Underground

# Electron mass is natural by doubling #particles

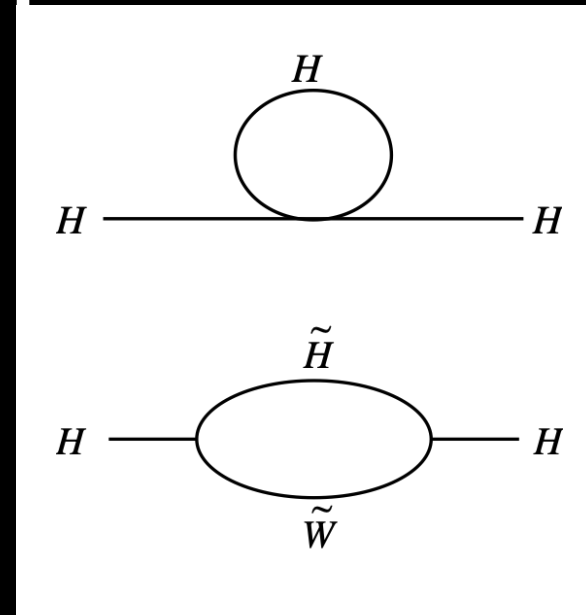
- Electron creates a force to repel itself  $\sim \frac{e^2}{r_e} \sim \text{GeV}$   $\frac{10^{-17} \text{cm}}{r_e}$
  - $10^{-4}$  fine-tuning?  $r_e$
  - quantum mechanics and anti-matter
- $\Rightarrow$  only 10% of mass even for Planck-size  $r_e \sim 10^{-33} \text{cm}$



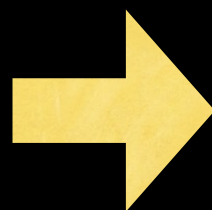
$$\Delta m_e \sim m_e \frac{\alpha}{4\pi} \log(m_e r_e)$$

# Higgs mass is natural by doubling #particles?

- Higgs also repels itself
- Double #particles again  
⇒ superpartners
- only log sensitivity to UV
- Standard Model made  
consistent up to higher  
energies



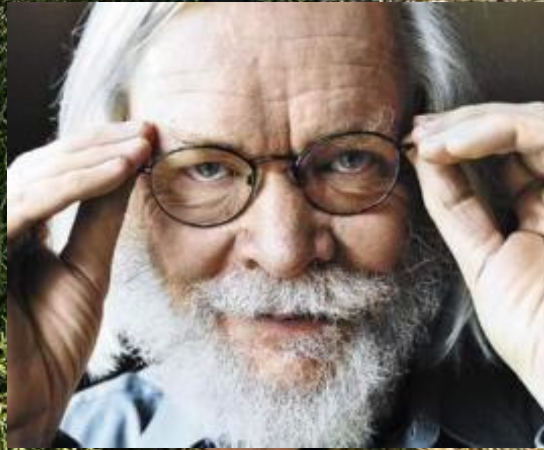
$$\Delta m_H^2 \sim \frac{\alpha}{4\pi} m_{SUSY}^2 \log(m_H r_H)$$



I still take it seriously



R-parity violation  
compressed spectrum  
disappearing tracks



Better Late Than  
Never

clever analysis  
precision Higgs, flavor  
HL-LHC  
FCC,  $\mu$ , plasma

time	A 3 0	1 2:4 0	DELA
R'S	A 3 1	1 2:4 5	YED
AKFURT	B 0 1	1 2:4 5	DELA
YORK	A 1 9	1 2:4 5	YED
SELS	B 1 3	1 2:4 5	DELA
	A 2 7	1 2:5 0	YED
JANEIRO	A 3 7	1 3:0 0	DELA
	A 4 0	1 3:0 0	YED
	A 2 8	1 3:1 0	DELA
M	A 3 4	1 3:1 5	YED
	A 2 2	1 3:2 0	DELA
	B 0 9	1 3:3 0	YED
	A 2 7		DELA
			YED

# In all of this:

- **theory** and **computation** provide (mis)guidance, testable theories, support, precision predictions, and **excitement**
- **community engagement** is crucial to sustain healthy community as well as to obtain support from policymakers and public at large
- Support for “Research” and diversity (both people and science) are absolutely critical

# What we need

- public support to our field is by no means guaranteed
- convincing case of all proposed research
  - nothing is grandfathered in
- percolate individual cases to a cohesive program
- they are intertwined anyway!
- need a case for the entire field



A person is riding a bicycle with a child seat attached to the front. They are silhouetted against a large, bright full moon. The scene is set at night, with the dark outlines of trees visible in the lower right corner. The overall mood is peaceful and hopeful.

*many things  
to look forward to!*