# Closing Remarks

## DPF – Pheno 2024

## May 17

**Tao Han**

**University of Pittsburgh**

# It is a wonderful conference!

DPF-PHENO 2024

13–17 May 2024
University of Pittsburgh / Carnegie Mellon University

**Plenary: Plenary I** — *Sarah Eno*

10 plenary sessions

30 talks + 4 panels

**Welcome**

*Lawrence Hall 121, (overflow in Lawrence Hall 120), University of Pittsburgh* 08:30 - 09:00

**Recent results on the Higgs Boson** — *Andrew Brinkerhoff*

*Lawrence Hall 121, (overflow in Lawrence Hall 120), University of Pittsburgh* 09:00 - 09:30

**Recent Results on b physics** — *Peter Lewis*

*Lawrence Hall 121, (overflow in Lawrence Hall 120), University of Pittsburgh* 09:30 - 10:00

**Future of detector development** — *Gabriella Carini*

*Lawrence Hall 121, (overflow in Lawrence Hall 120), University of Pittsburgh* 10:00 - 10:30

**coffee break**

*University of Pittsburgh / Carnegie Mellon University* 10:30 - 11:00

**Results from T2K and NOVA** — *Prof. Kendall Mahn*

**Funding Agencies: Computational H and AI/ML Session**
*Jeremy Love*

**Forum on early career development: Early Career Froum**
*Mudhat Fareed, Saptaparna Bhattacharya*

290 participants

**Funding Agencies: Energy Frontier**
*Abid Patwa*

7 DOE PI sessions

6 mini-symposia
28 talks

63 parallel sessions
344 talks!

| Minisym… 10 TeV center of mass *Sridhara Dasu* *David La…* 14:00 - … | Dark Matter: PBH and Atomic DM *Yue Zhao, Yue Zhao* *David La…* 14:00 - … | QCD & Heavy Ion Physics: Jets and Energy Correlat… *Keping Xie* *Law 107, …* 14:00 - … | Physics Beyond the Standard Model: Charged Higgs Searches *Prudhvi Bhattiprolu* | Neutrino Physics: Neutrino Mass Models *Saarik Kalia* *David La…* 14:00 - … | Electrow… & Higgs Physics: EW Baryoen… and Phase Transition *David Tucker-Smith* | Gravity & Gravitati… Waves: GW and Particle Cosmolo… *Navin McGinnis* *David La…* 14:00 - … | Axion: Axion Detection and ALPs *Christopher Verhaaren* *Law 109, …* 14:00 - … | Instrume… Neutrinos, Dark Matter, and Scintillati… *Andreas Werner Jung* *Law 111, …* 14:00 - … |
|---|---|---|---|---|---|---|---|---|

**Coffee Break: coffee break**

*Lawrence Hall and Law Building* 15:30 - 16:00

| Minisy… forward physics *Brian Thomas Batell* *David L…* 16:00 … | Dark Matter: Astrop… Probes *Benjamin Lehmann* *David L…* 16:00 … | Quark and Lepton Flavor Physics: Techni… and Algorit… *Gianant… Pezzullo* | Gravity & Gravita… Waves: Gravity and GW Pheno… *Tinatin Kakhnia…* *David L…* 16:00 … | Physic… *Ben Lillard* *David L…* 16:00 … | Neutrino Physics: Neutrino Mixing and Decay *Vedran Brdar, Vedran Brdar* | Electro… & Higgs Physics: Electro… Physics at the LHC *Zack Sullivan* | Cosmol… & Dark Energy: Eary Universe and Stasis *Dr Taewook Youn* | Astro-p… *Javier F…* *Law 10…* 16:00 … | Instrum… ATLAS and CMS *Zhi Zheng* *Law 109, University of Pittsburgh* 16:00 - 17:30 |
|---|---|---|---|---|---|---|---|---|---|

**Thank you all for the great contributions!**

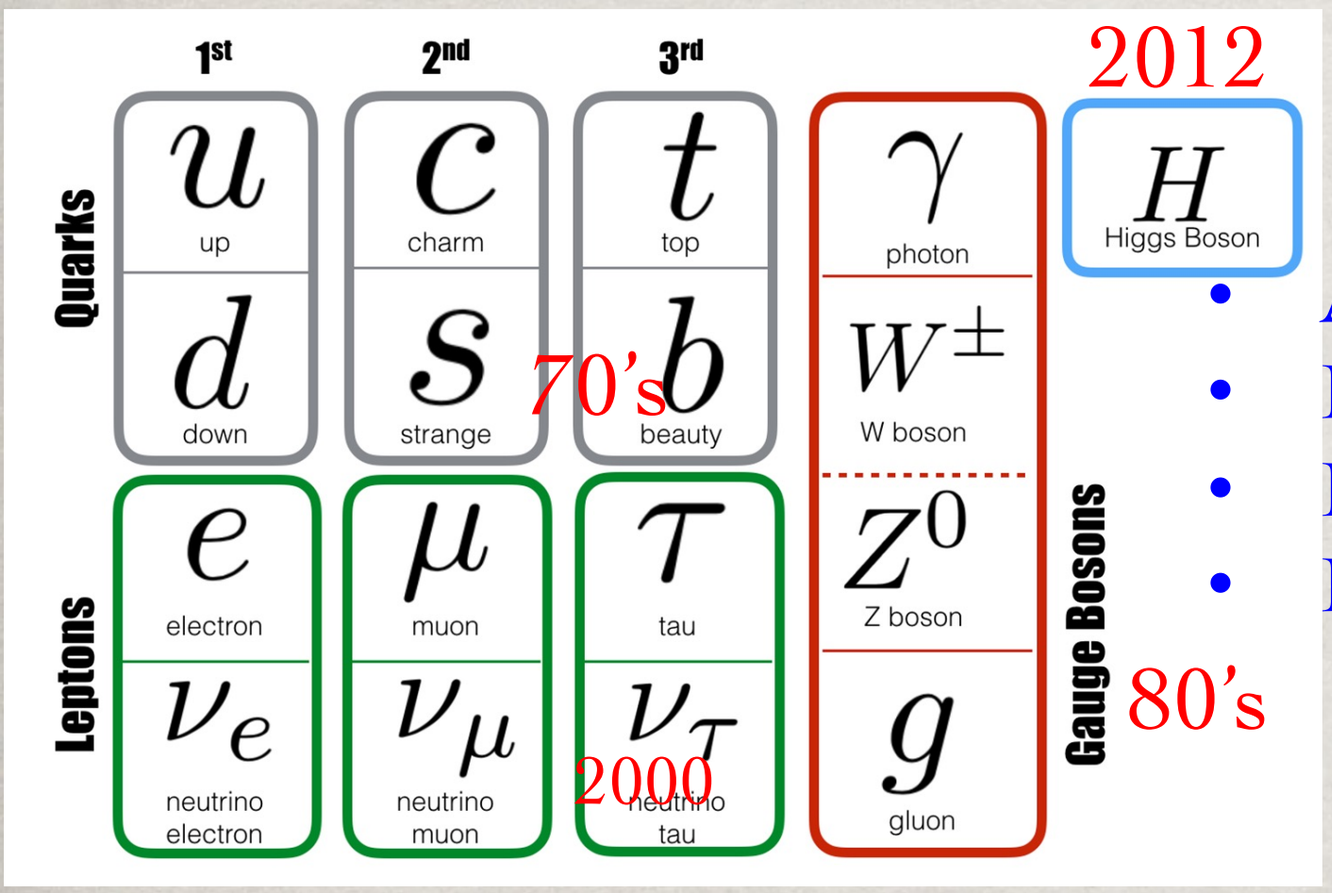
# Very broad topics and coverage:

- Accelerators
- Instrumentation
- Computing, Analysis Tool and Data Handling
- Machine Learning & AI
- Quantum Information & Sensors
- Electroweak & Higgs Physics
- Top Quark Physics
- Quark and Lepton Flavor Physics
- Neutrino Physics
- QCD & Heavy Ion Physics
- Dark Matter
- Physics Beyond the Standard Model
- Astro-particle Physics
- Cosmology & Dark Energy
- Gravity & Gravitational Waves
- Lattice Gauge Theory
- Quantum Field & String Theory
- Outreach, Community Engagement & DEI

**The field is vibrant and dynamic!**

# Particle physics has enjoyed uninterrupted discoveries for several decades: from quarks to the Higgs boson

60's 70's 90's




2012

70's

2000

80's

**The SM is a triumph in science!**

**The first theory:**

- A relativistic & quantum-mechanical
- Perturbative & unitary
- Renormalizable & UV complete
- Potentially valid to the Planck scale!

**All known physics**

$$W = \int_{k<\Lambda} [\mathcal{D}g \ldots] \exp\left\{\frac{i}{\hbar}\int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}R - \frac{1}{4}F^2 + \bar{\psi}i\not{D}\psi - \lambda\phi\bar{\psi}\psi + |D\phi|^2 - V(\phi)\right]\right\}$$

amplitude | current understanding | quantum mechanics | spacetime | gravity | strong & electroweak | matter | Higgs

**An eminent physicist remarked:**

**"... most of the grand underlying principles have been firmly established. The future truths of physical science are to be looked for in the sixth place of decimals. "**

**--- Albert Michelson (1894)**

Michelson–Morley experiment (1887):
"the moving-off point for the theoretical aspects of the second scientific revolution"

**Will History repeat itself (soon)?**

# The Standard Model: "UV completion"

- QED is UV complete, but doesn't go beyond O(GeV)

  e.g. $(g\text{-}2)_e$ versus $(g\text{-}2)_\mu$ Ethan Neil's talk

- QCD is UV complete, could be dynamically extrapolated to an exponentially high scale Q

$$\alpha_s(Q^2) \approx 1/\ln(Q^2/\Lambda^2_{QCD}) \Rightarrow \Lambda_{QCD} \approx Q\exp(-1/2\alpha_s)$$

But new physics comes in at $v \sim 250$ GeV

- The SM with the Higgs IS UV complete,

but what confidence do we have to extrapolate it to $O(M_{PL})$?

Talks by Andrew Brickerhoff, Valentina Dutta, Aram Apyan …

**→UV completion needs NOT to be a completion!**

***i.e.* Go for BSM!**

# The Standard Model: "EFT"

"The present educated view of the standard model, and of general relativity, is again that these are the leading terms in effective field theories." S. Weinberg, hep-th/9702027

"We are all Wilsonians now."

- J. Preskill, Quantum Frontier (2013)

In terms of a new physical scale $\Lambda$ , below which the theory is valid:

$$\mathcal{L} = \sum c_i \Lambda^n \mathcal{O}_n = \underbrace{c_0 \Lambda^4 + c_2 \Lambda^2 \mathcal{O}_{\text{dim 2}} + c_3 \Lambda \mathcal{O}_{\text{dim 3}}}_{\text{(relevant operators)}} + \underbrace{c_4 \mathcal{O}_{\text{dim 4}}}_{\text{(marginal operators)}} + \underbrace{\frac{c_6}{\Lambda^2} \mathcal{O}_{\text{dim 6}} + \ldots}_{\text{(irrelevant operators)}}$$

**The 1st (most) "relevant operator":** $c_0\Lambda^4$

Known physics scales and the observation:

$$(M_{PL}/\Lambda_{cosm})^4 \sim 10^{120}\,! \quad (\Lambda_{QCD}/\Lambda_{cosm})^4 \sim 10^{44}\,!$$

Wilsonian argument failed (badly)!

"… I do not understand (quantum) gravity" --- William Bardeen

**The 2nd "relevant operator":** the Higgs boson mass

$$\mathbf{V = -\mu^2|\phi|^2 + \lambda|\phi|^4}$$

$c_2\Lambda^2 \sim m_h^2 :\ \lambda v^2 \sim \mu^2 \sim (100\ \mathrm{GeV})^2 \sim (10^{-16} M_{\mathrm{Planck}})^2$

"… scalar particles are the only kind of free particles whose mass term does not break either an internal or a gauge symmetry." Ken Wilson, 1970

**→We are only in command with "marginal & irrelevant operators"!**

**Anything big missing?**

Observationally,

**Three Problems**

that we must find BSM solutions!

# BSM 1: Neutrinos ARE massive

## $\nu$'s: the most elusive/least known particle in the SM:

- How many species: $3\ \nu_L$'s + $N_R$?
- Absolute mass scale: $m_\nu \sim y_\nu\, v < 1$ eV?

  or a new physics scale via "see-saw": $m_\nu \sim \kappa \frac{\langle H^0 \rangle^2}{M}$

- Flavor oscillations & CP violation?
- Mixing with sterile/Majorana $\nu$'s?
- Portal to dark sector?

Studying neutrino physics has been rewarding:
$6^+$ Nobel Prizes related to $\nu$'s!

Great playground for theory & experimentation.

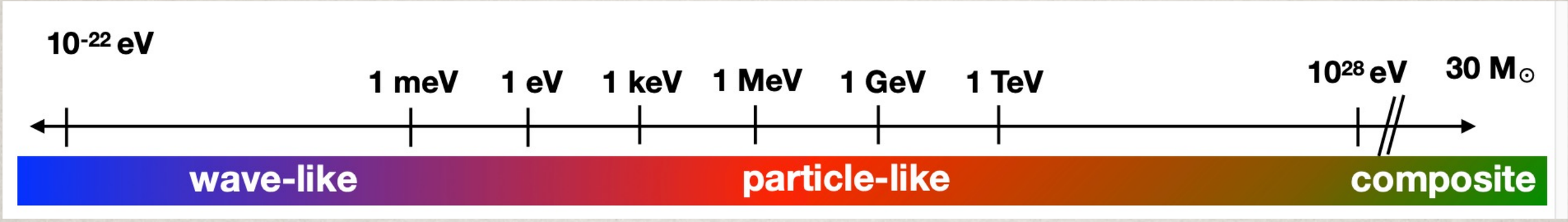
**→ Determine the masses & their generation mechanism!**

See talks by Kendall Mahn, Mayly Sanchez, Kevin Kelly, …

# BSM 2: Dark Matter exists

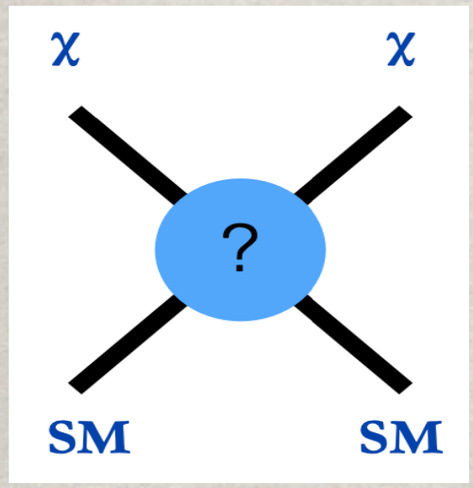
## Mounting evidences for DM, thus BSM

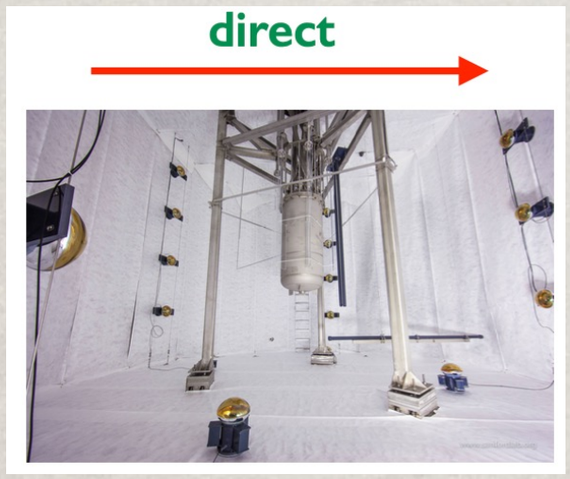
## Dark Matter in theory: "embarrassment of riches"



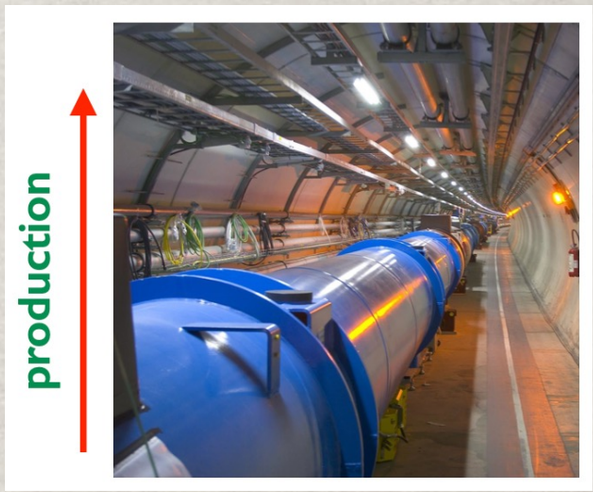

axions, dark photons …  sterile $\nu$'s  WIMPs  WIMPzillas  PBH?

## Dark Matter in practice:








Much more recent activities in light DM detection!

→ **Possible next breakthrough: WIMPs, ALPs …**

See talks by Kathryn Zurek, Carter Hall, Elliot Lipeles, …

# BSM 3: Our existence -- Baryogenesis

## The observed baryon dominance → BSM

Sakharov conditions:

- Baryon # violation (EW sphalerons)
- C & CP violation (BSM)
- Out of equilibrium (1st order PT, BSM)

## Many BSM theories to accommodate

- Affleck-Dine mechanism (primordial universe)
- Lepto-genesis ($\Delta$B = $\Delta$L via sphalerons)
- EW baryogenegis (1st order PT, BSM)

Observationally,

$\Delta$B ≠ 0 → proton decay, $n - \bar{n}$ oscillation

$\Delta$L ≠ 0 → Majorana neutrinos

Plus extra Higgs bosons to search for

Stochastic gravitational waves …

# Puzzles

that we may or may not find a solution

- Mass hierarchy: "Naturalness"?
- Flavors: "minimal flavor violation"?
- New dynamics: "Composite"? Jure Zupan, Peter Lewis …
- Extended symmetry: SUSY?
- Unified forces: GUTs?
- Extra dimensions / Quantum gravity?
- … …

# Snowmass 2021 & the P5 recommendatons

http://seattlesnowmass2021.net

https://www.usparticlephysics.org/2023-p5-report/

## Explore the Quantum Universe


Decipher the Quantum Realm


Explore New Paradigms in Physics


Illuminate the Hidden Universe

**EXCITING JOURNEY AHEAD!**

# Thank you all!

# Hope to see you at Pheno 25!