Determine Yukawa coupling & SMEFT phenomenology

Xiaoze Tan

Theory Fellows meeting, 18 Nov 2024 @DESY

Space-time line

- **Born** in 1994

  Jixi, HeiLongJiang Prov.

- **Bachelor & PhD** at
  Harbin Institute of Technology

  (2012-2022, Harbin)

- **Visiting scholar** at
  University of Pittsburgh

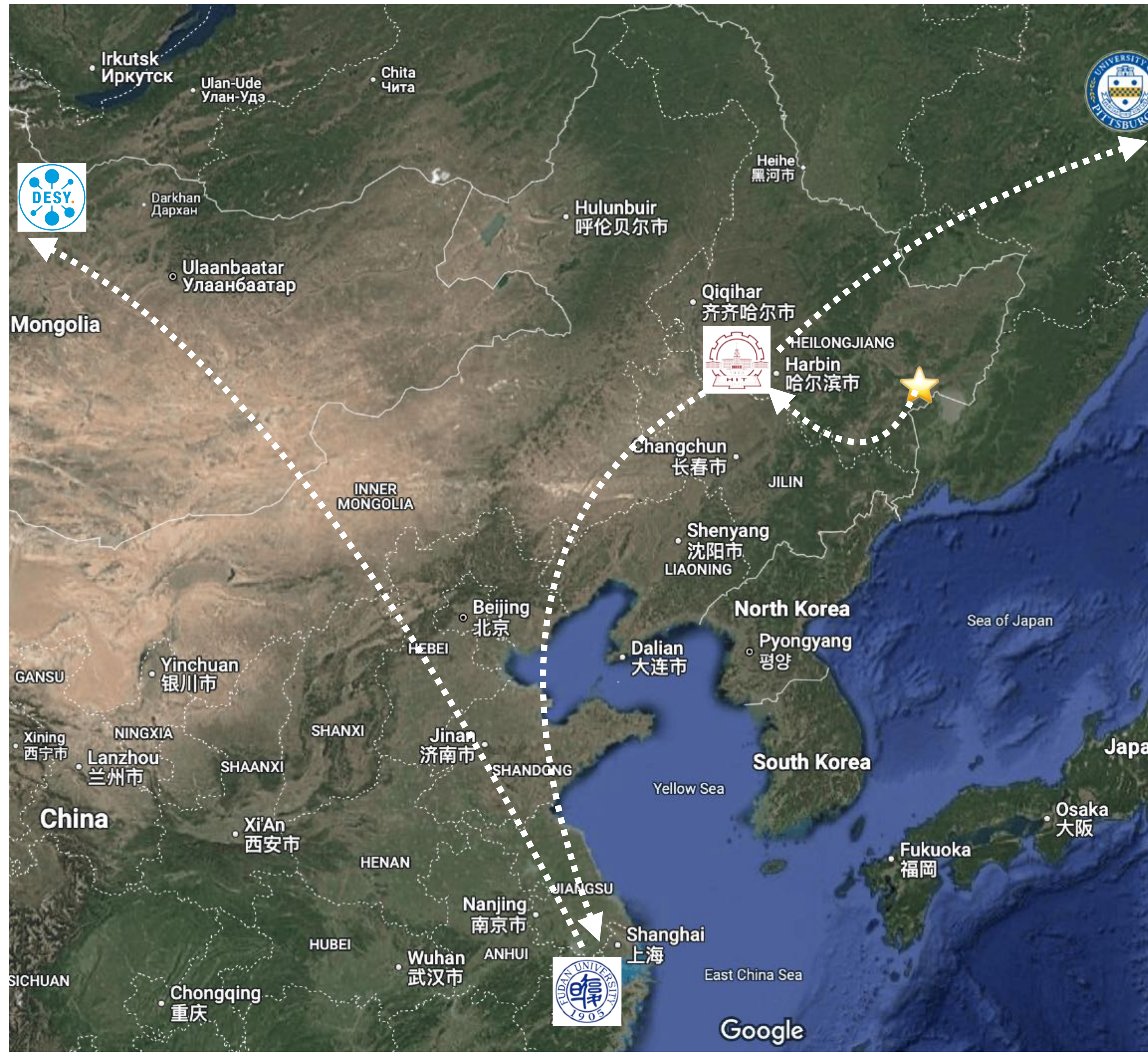
  (2019-2020, Pittsburgh)

- **Postdoc** at Fudan University

  (2022-now, Shanghai)

- **Joint Postdoc** at DESY

  (2024-now, Hamburg)



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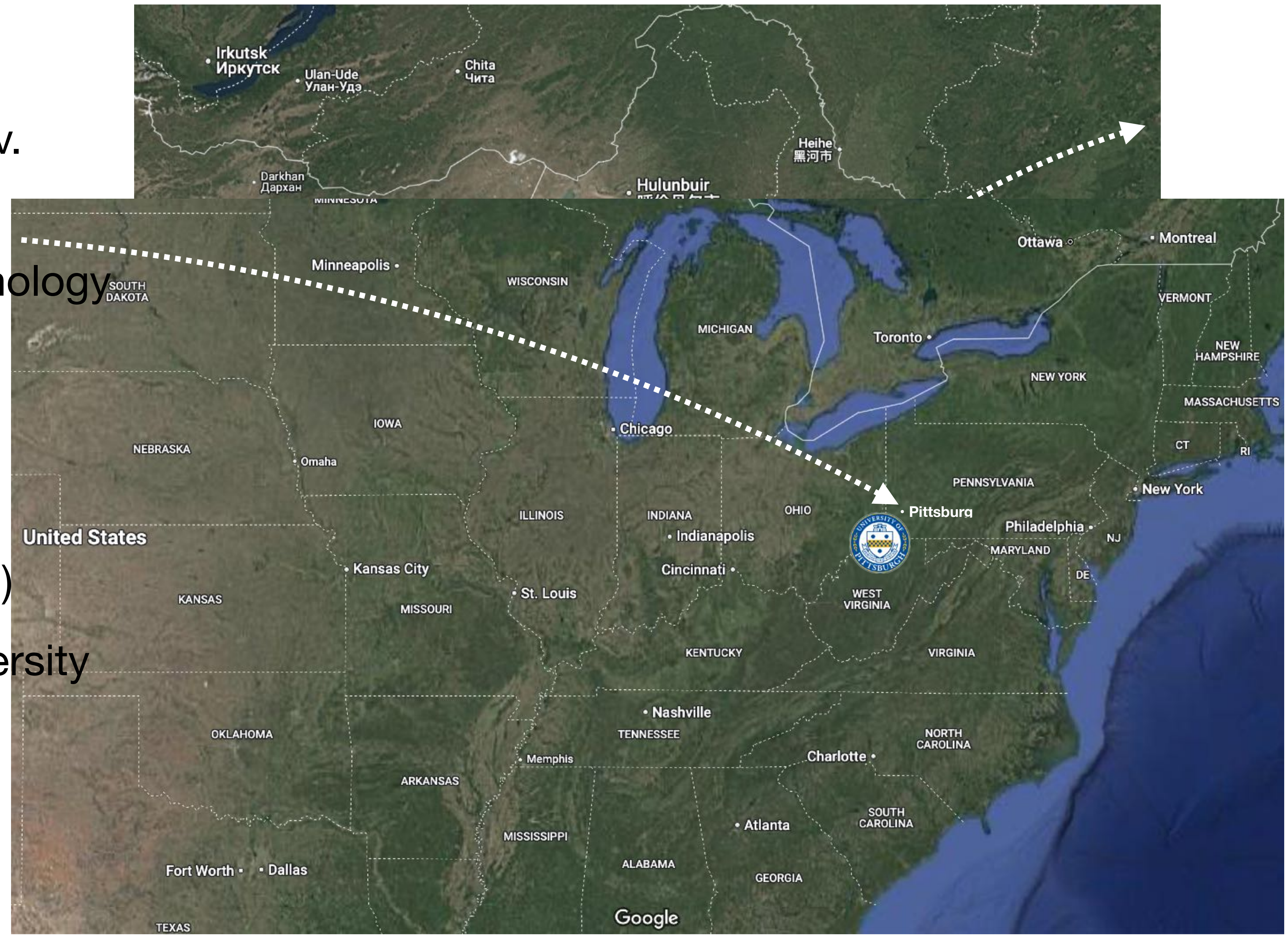

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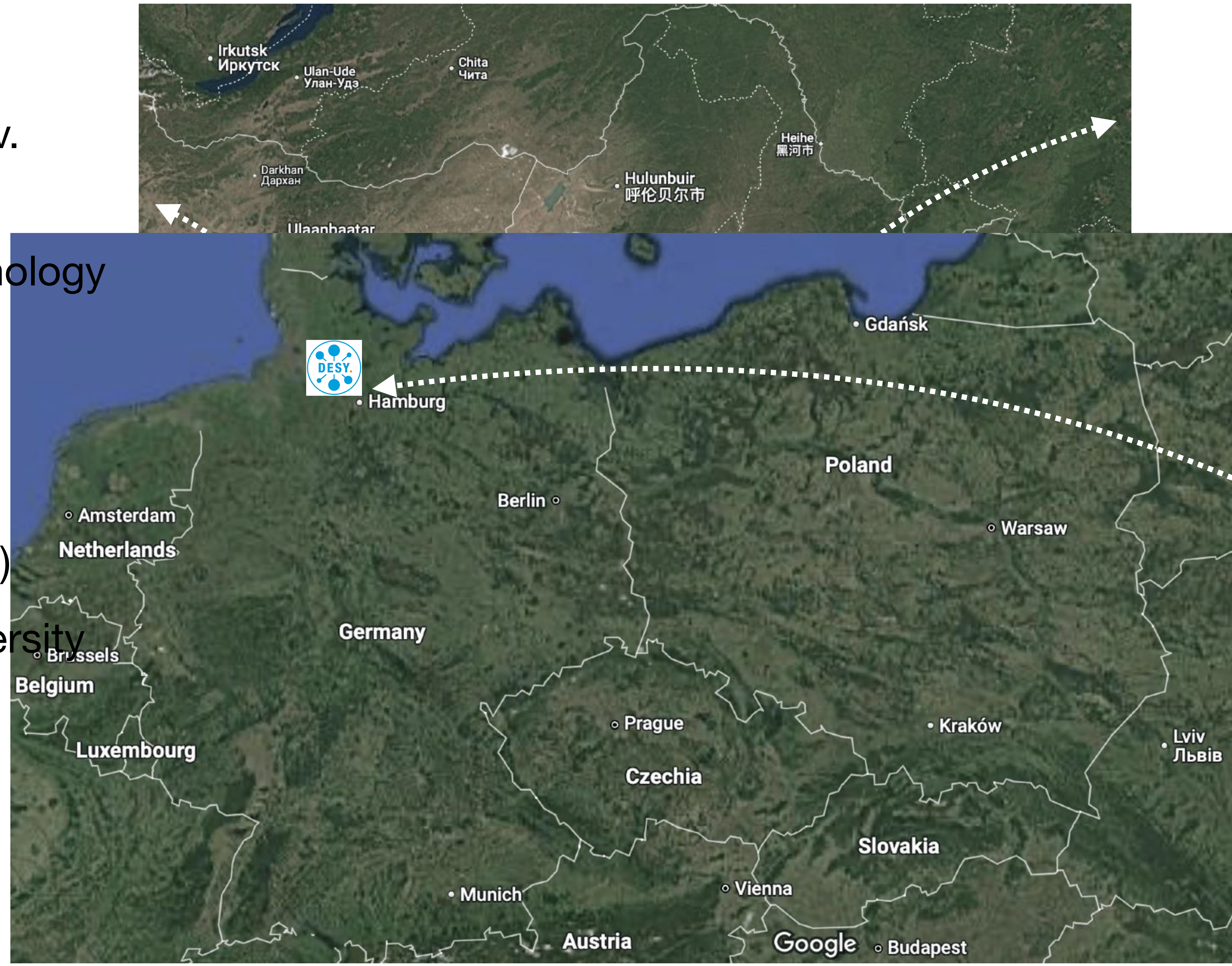


Space-time line (pics)

Credit: internet

- **Harbin, Ice&Snow World ("World's Largest Ice and Snow Theme Park", will be > 1 million m^2 this year)**

- **Shanghai, the Bund & Jing'an Monastery**

- **Pittsburgh, Cathedral of Learning**

Hobbies

🇮🇸

- 📷 Photography (amateur)

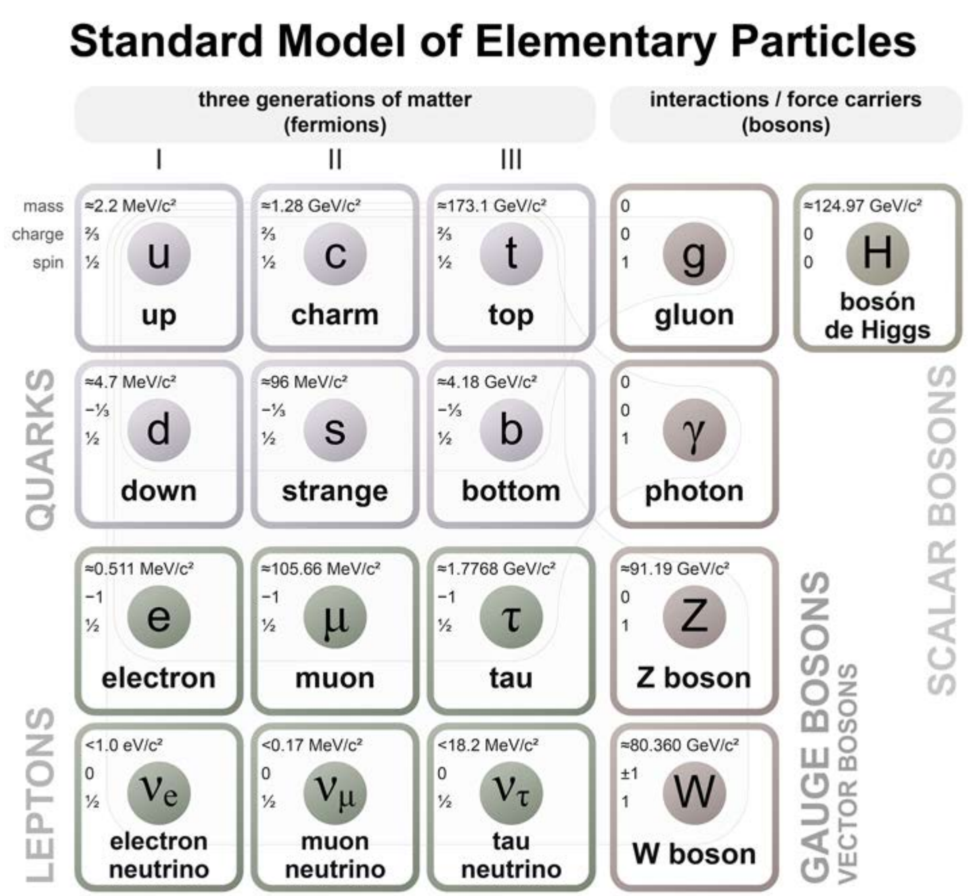
- 🏓 Table tennis & Ping pong
  (but I just broke my racket😅)

club: https://sport.desy.de/table_tennis/index_eng.html

- ✍🏻 Brush Calligraphy

Some physics now…

Before BSM, SM must be measured precisely…



[*In memory of Prof. Peter Higgs]

Higgs is Really New Physics!

* We've never seen anything like it
* Harbinger of Profound New Principles at work in quantum vacuum

PUT IT UNDER MICROSCOPE

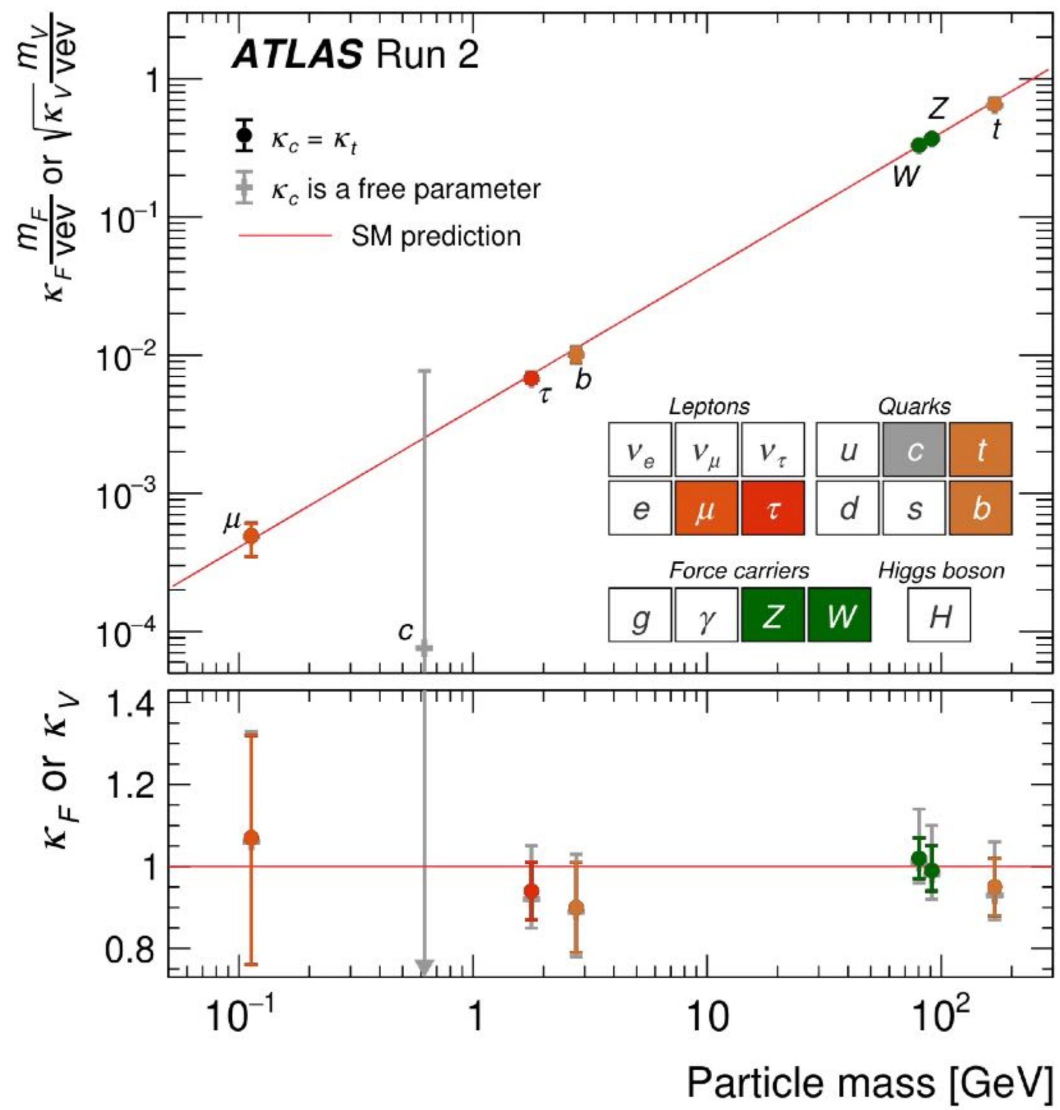
STUDY IT TO DEATH

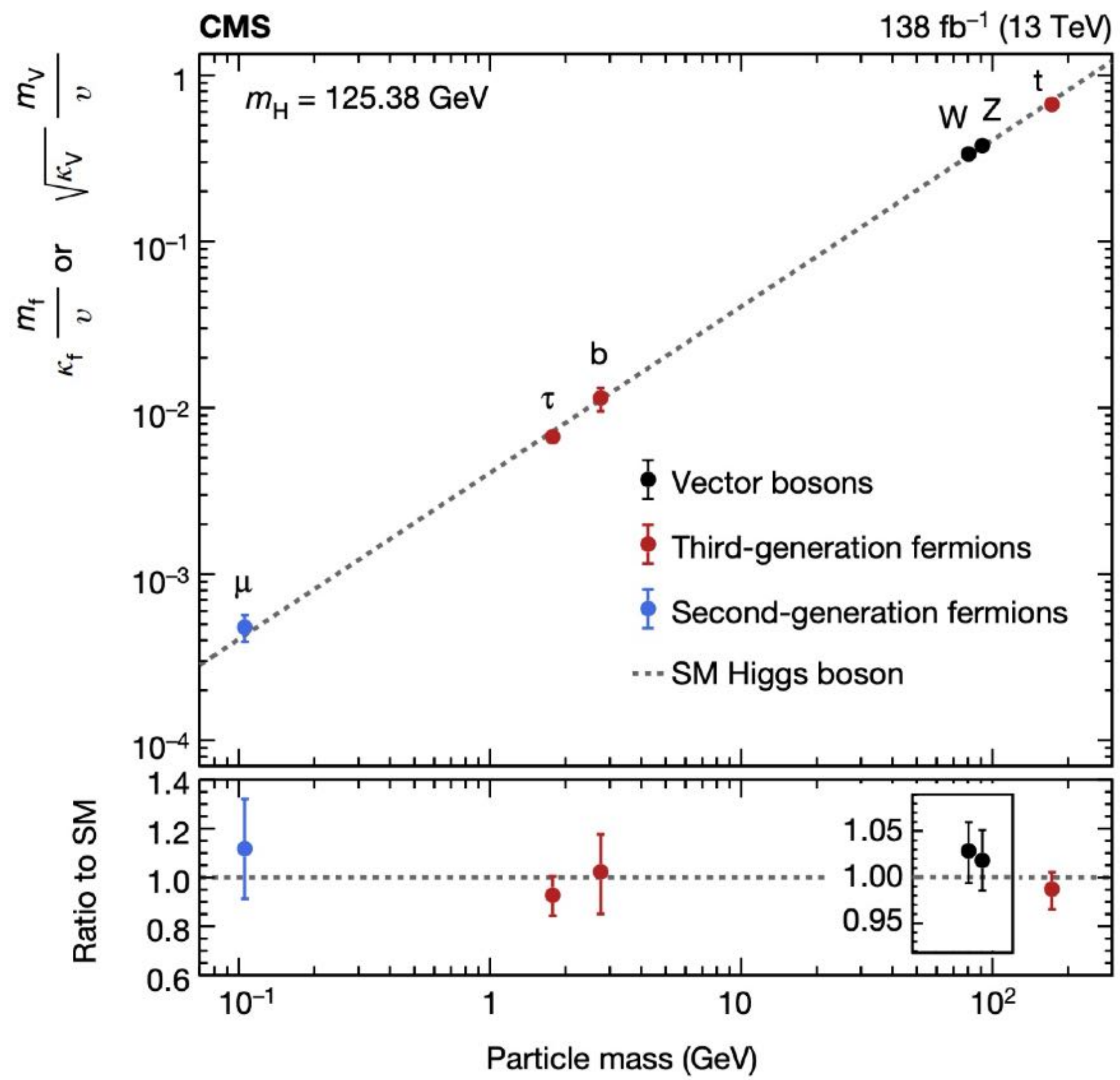
[@Nima ArkaniHamed]

Charm Yukawa

(*my story about Charm mesons ⇔ Charm Yukawa)

[Nature 607, 52–59 (2022)]





[Nature 607, 60–68 (2022)]

Next target
⇒Higgs-charm coupling

Charm Yukawa

[JHEP 08 (2022) 073]

- Smaller mass ⇒ Smaller branching fraction: BR($H \to \bar{c}c$) ≈ 2.9%
- Large QCD background at hadron colliders ⇒ *c*-tagging challenging
- Our idea:

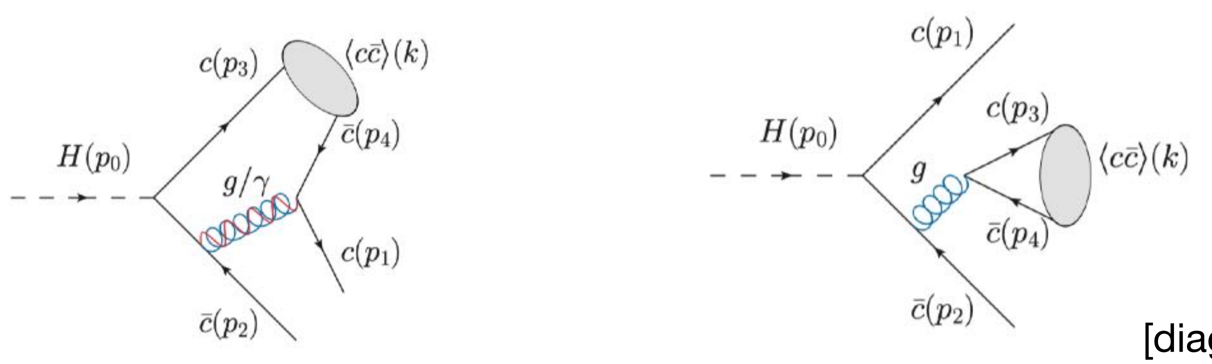
$$H \to c + \bar{c} + J/\psi \text{ (or } \eta_c)$$

- NRQCD:

$$\Gamma = \sum_{\mathbb{N}} \hat{\Gamma}_{\mathbb{N}}(H \to (Q\bar{Q})[\mathbb{N}] + X) \times \langle \mathcal{O}^h[\mathbb{N}] \rangle, \quad \hat{\Gamma}_{\mathbb{N}} = \frac{1}{2m_H} \frac{|\mathcal{M}|^2}{\langle \mathcal{O}^{Q\bar{Q}} \rangle} \Phi_3$$

- Charm quark fragmentation:

both **color-singlet** and **color-octet** contributions are considered



[diagrams for example only]

Charm Yukawa

[JHEP 08 (2022) 073]

- Our results:

$$\mathrm{BR}(H \to c\bar{c} + J/\psi) = (2.0 \pm 0.5) \times 10^{-5},$$
$$\mathrm{BR}(H \to c\bar{c} + \eta_c) = (6.0 \pm 1.0) \times 10^{-5}$$

- The signal event number (roughly):

$$N = L\sigma_H \,\epsilon\, \mathrm{BR}(c\bar{c} + \ell^+\ell^-) \approx 12\ \kappa_c^2 \times \frac{L}{\mathrm{ab}^{-1}} \times \frac{\epsilon}{10\%},$$

- Considering the statistical error only:

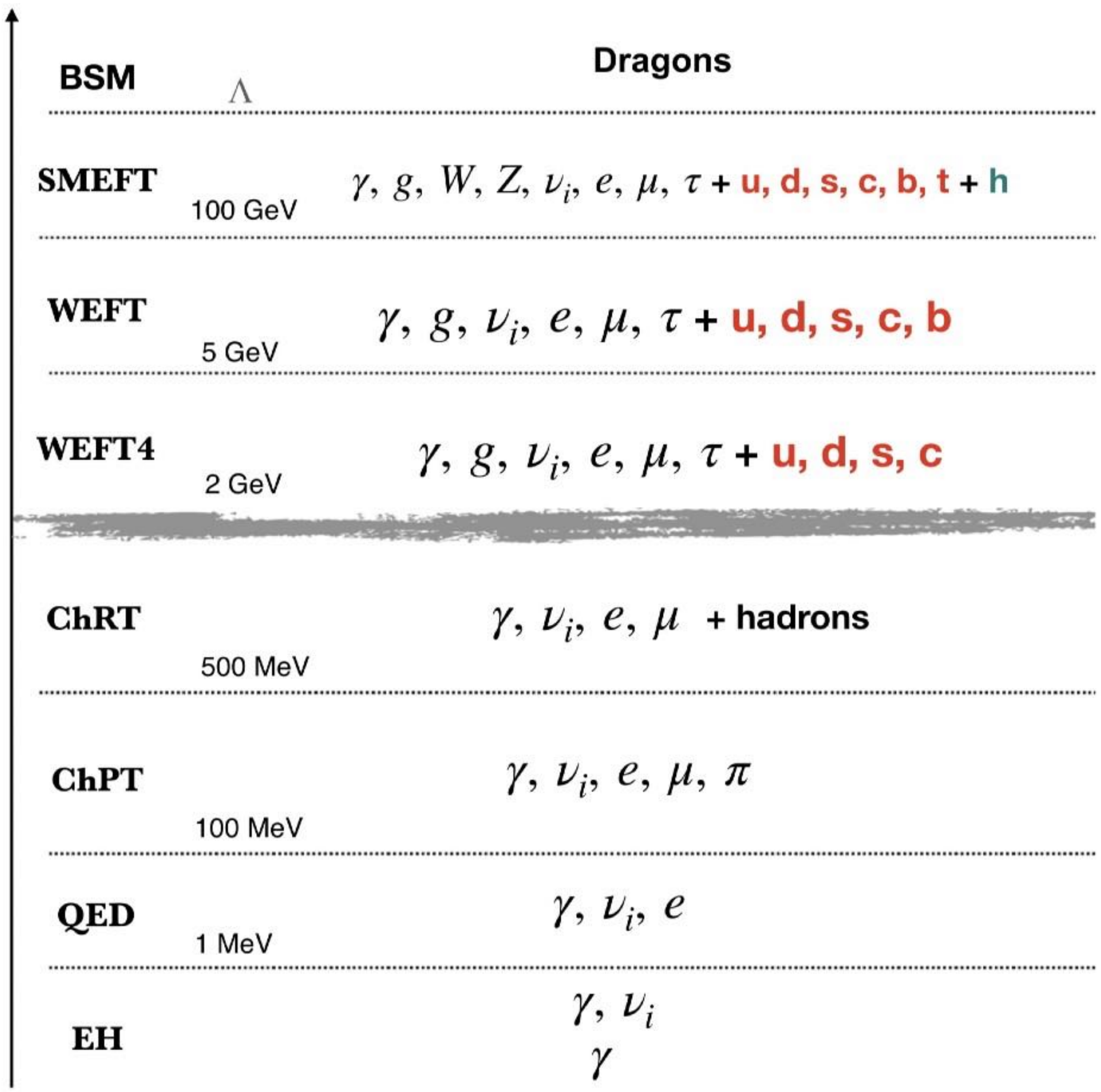
$$\Delta\kappa_c \approx 15\% \times (\frac{L}{\mathrm{ab}^{-1}} \times \frac{\epsilon}{10\%})^{-1/2}$$

- Sensitivity $S \approx N_{signal}/\sqrt{N_{background}}$

⇒ It is possible to reach 2σ for $\kappa_c \approx 2.4$ (at hadron collider).

SMEFT pheno ($Zb\bar{b}$ dipole)

- 'SM is EFT', All Things EFT... [S. Weinberg 2101.04241]



[Lectures on SMEFT, A. Falkowski]

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d>4} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)} ,$$

SMEFT pheno ($Zb\bar{b}$ dipole)

[2410.05398]

- Long standing ~2σ deviation from LEP era:

$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01617 ± 0.00007
$A_{FB}^{(0,b)}$	0.0996 ± 0.0016	0.1029 ± 0.0002
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0735 ± 0.0002

- Focus on $Zb\bar{b}$ dipole:

$$\mathcal{O}_{bW} = (\bar{q}_L \sigma^{\mu\nu} b_R)\, \sigma^i H W^i_{\mu\nu}\,,$$

$$\mathcal{O}_{bB} = (\bar{q}_L \sigma^{\mu\nu} b_R)\, H B_{\mu\nu}\,,$$

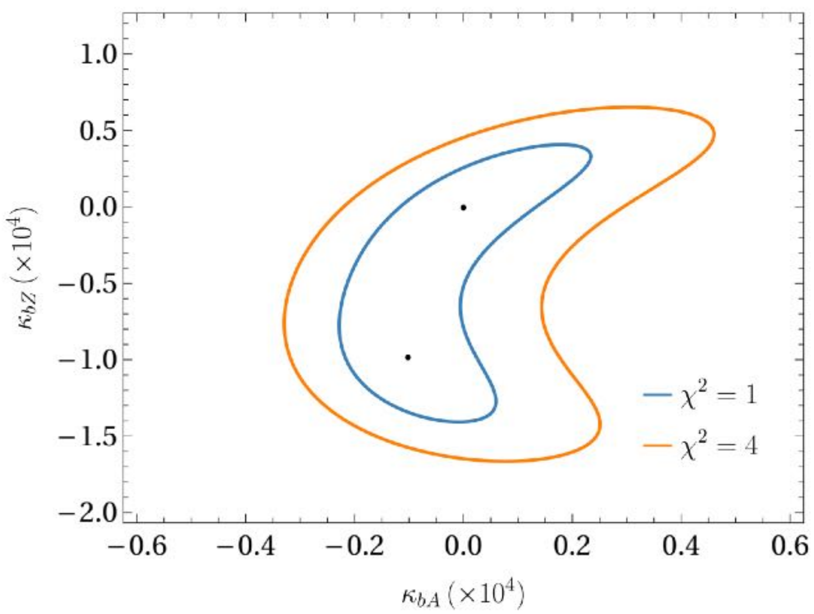
- Effective coupling & lagrangian:

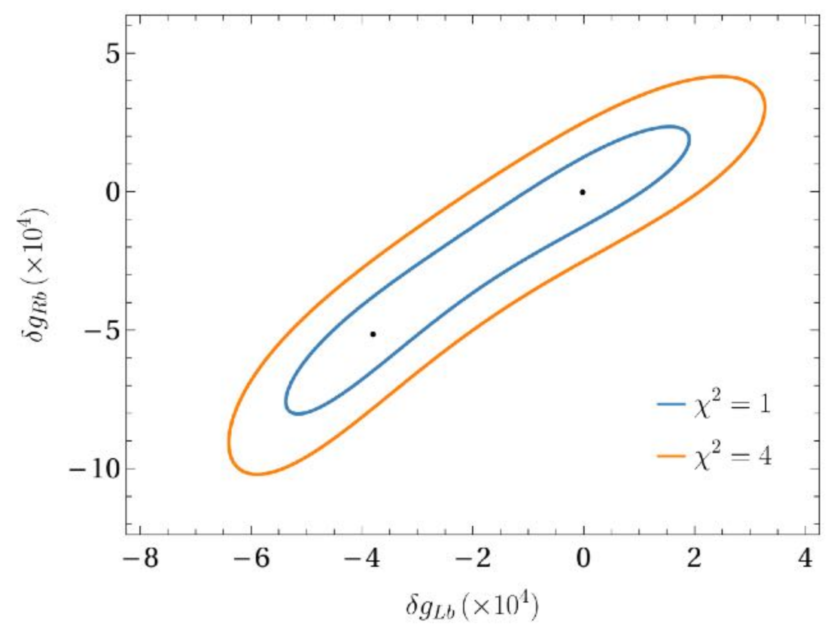
$$\mathcal{L} \supset -eA_\mu \bar{b}\gamma^\mu b - \frac{g}{\cos\theta_W} Z_\mu \left(g_{Lb}\bar{b}_L\gamma^\mu b_L + g_{Rb}\bar{b}_R\gamma^\mu b_R\right) + \frac{\kappa_{bA}}{m_b}\left(\bar{b}\sigma^{\mu\nu}b\right) A_{\mu\nu} + \frac{\kappa_{bZ}}{m_b}\left(\bar{b}\sigma^{\mu\nu}b\right) Z_{\mu\nu}\,,$$

SMEFT pheno ($Zb\bar{b}$ dipole)

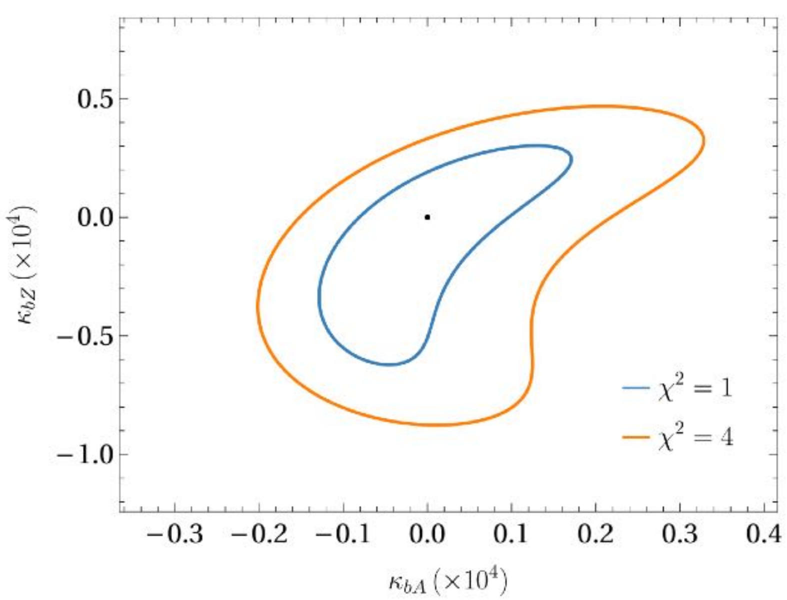
[2410.05398]

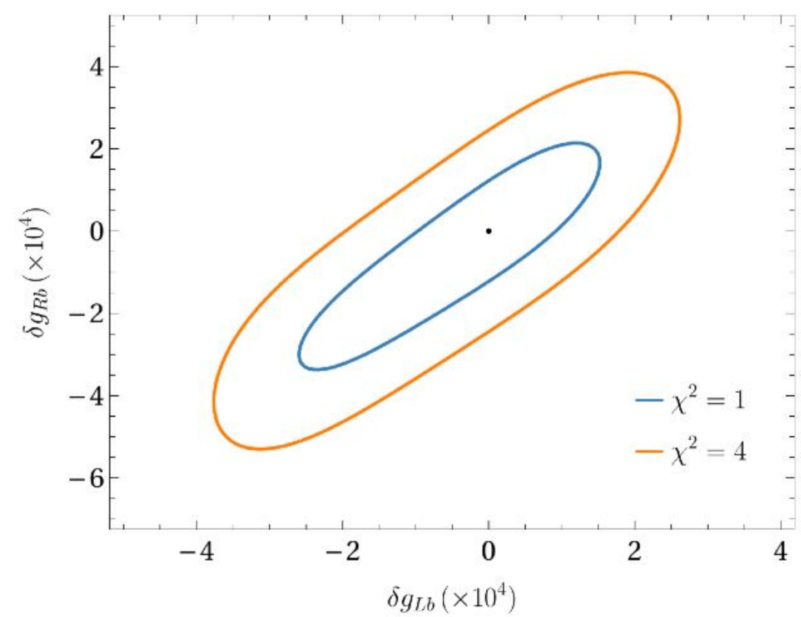
- Some results (@future lepton collider scenario):





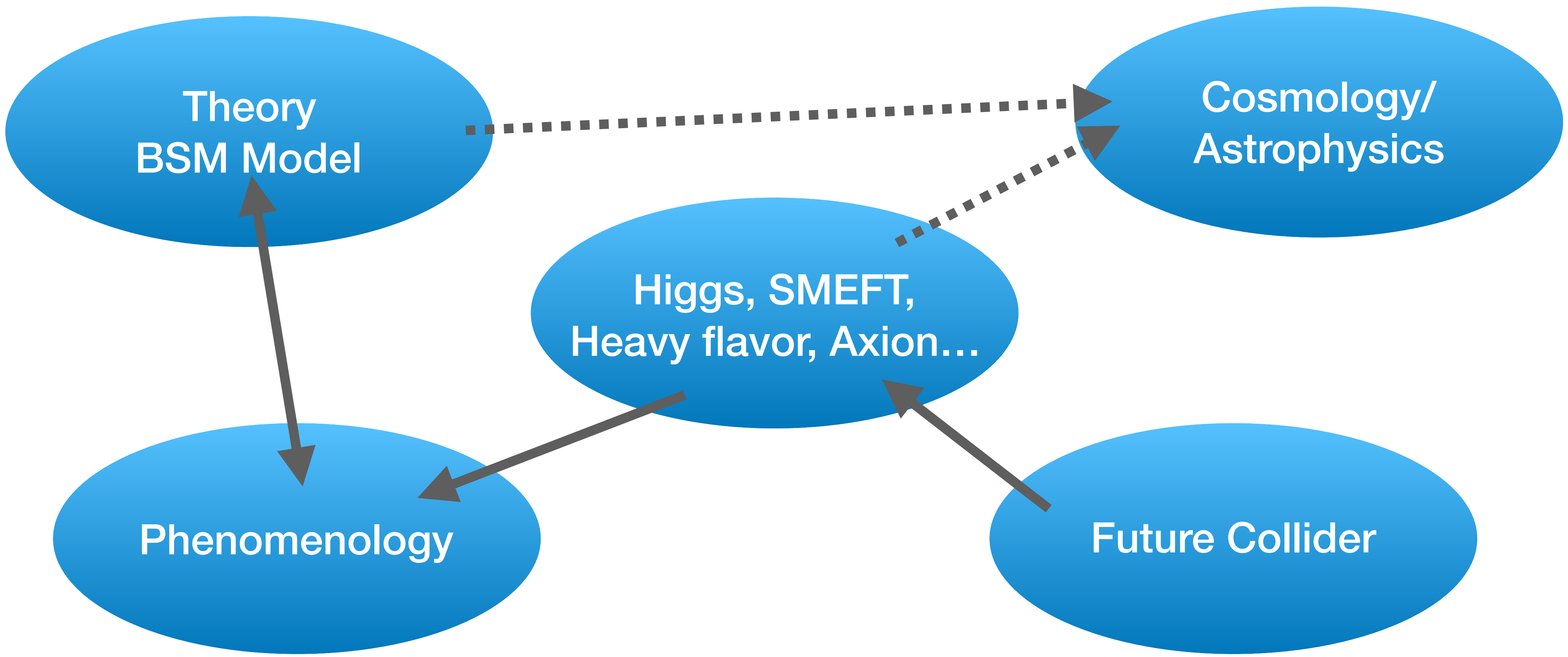
- keeping the full dependence, Zpole+240GeV run





- keeping the full dependence, Zpole+240GeV+360GeV run

Doing & Next…



Thank you!