THE FUTURE OF DARK MATTER AND DARK FORCES

International Symposium on the Future of Physics and Astronomy

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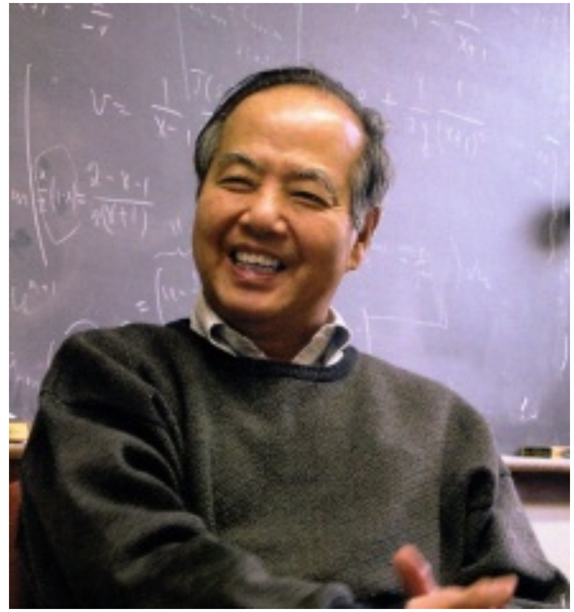
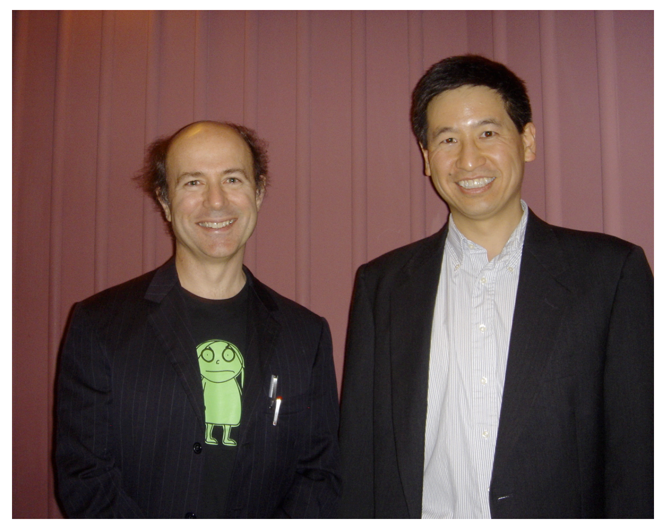
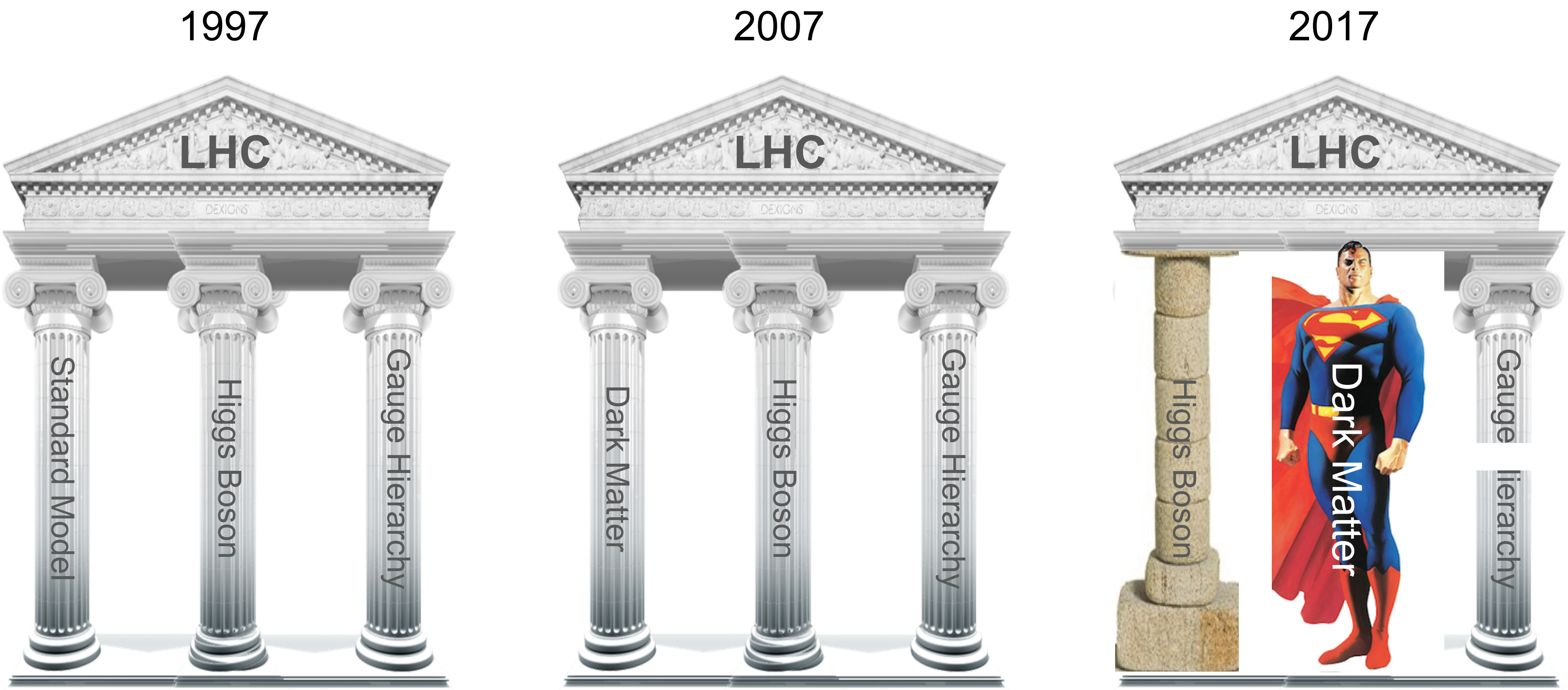
A HAPPY OCCASION





DARK MATTER

- "The Future of Physics and Astronomy": Identifying dark matter is a central problem in both fields, and appreciation of its importance has grown rapidly in recent years



CLASSIC CANDIDATES

- Three excellent candidates: sterile neutrinos, axions, WIMPs
- Axions are highly motivated by the strong CP problem

Peccei, Quinn (1977); Wilczek (1978); Weinberg (1978)

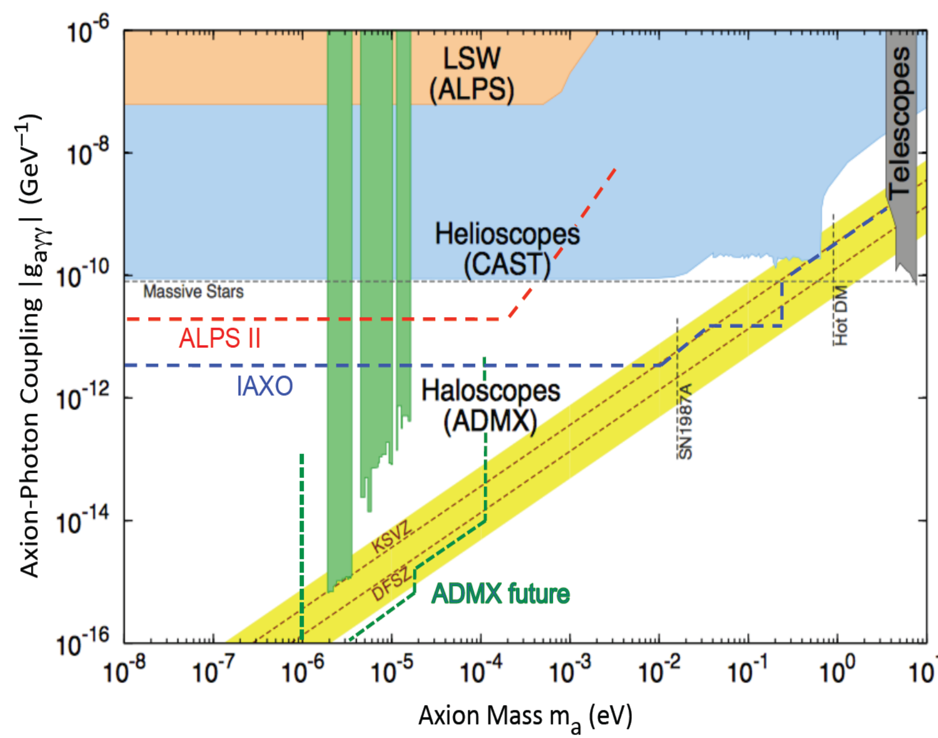
$$m_a \approx 6 \ \mu\text{eV} \left(\frac{10^{12} \text{ GeV}}{f_a} \right)$$

$$\Omega_a \simeq 0.4 \, \theta_i^2 \left(\frac{f_a}{10^{12} \text{ GeV}} \right)^{1.18}$$

- For axion DM, if $\theta_i \sim 1$, then

  $f_a \sim 10^{12}$ GeV

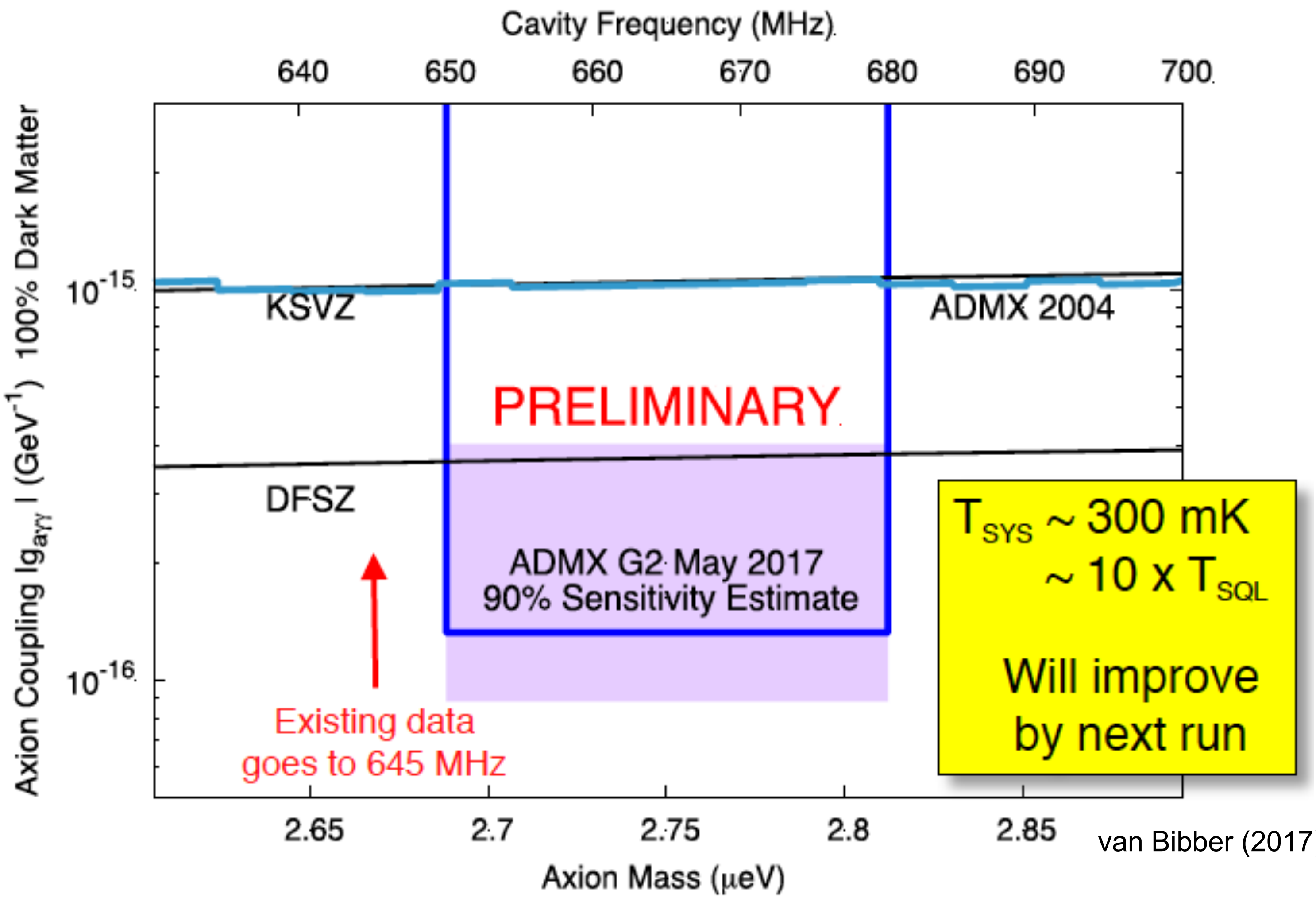
  $m_a \sim$ 1-100 μeV



Graham, Irastorza, Lamoreaux, Lindner, van Bibber (2016)

LATEST RESULTS: ADMX G2

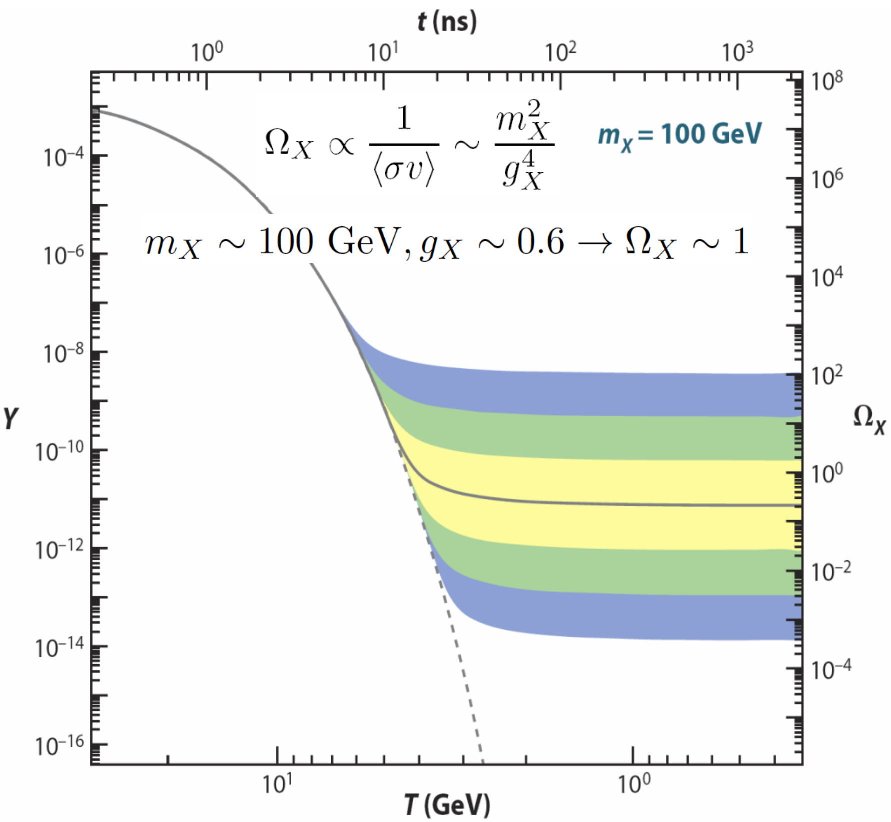
ADMX Gen.2 preliminary result – DFSZ reached!



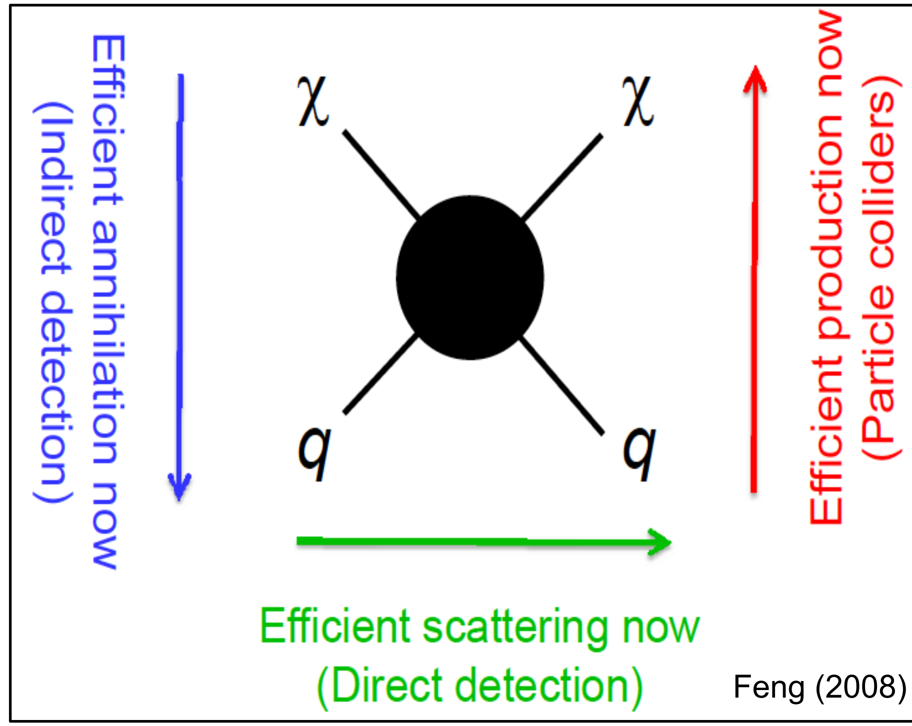
van Bibber (2017)

WIMPs

The WIMP Miracle

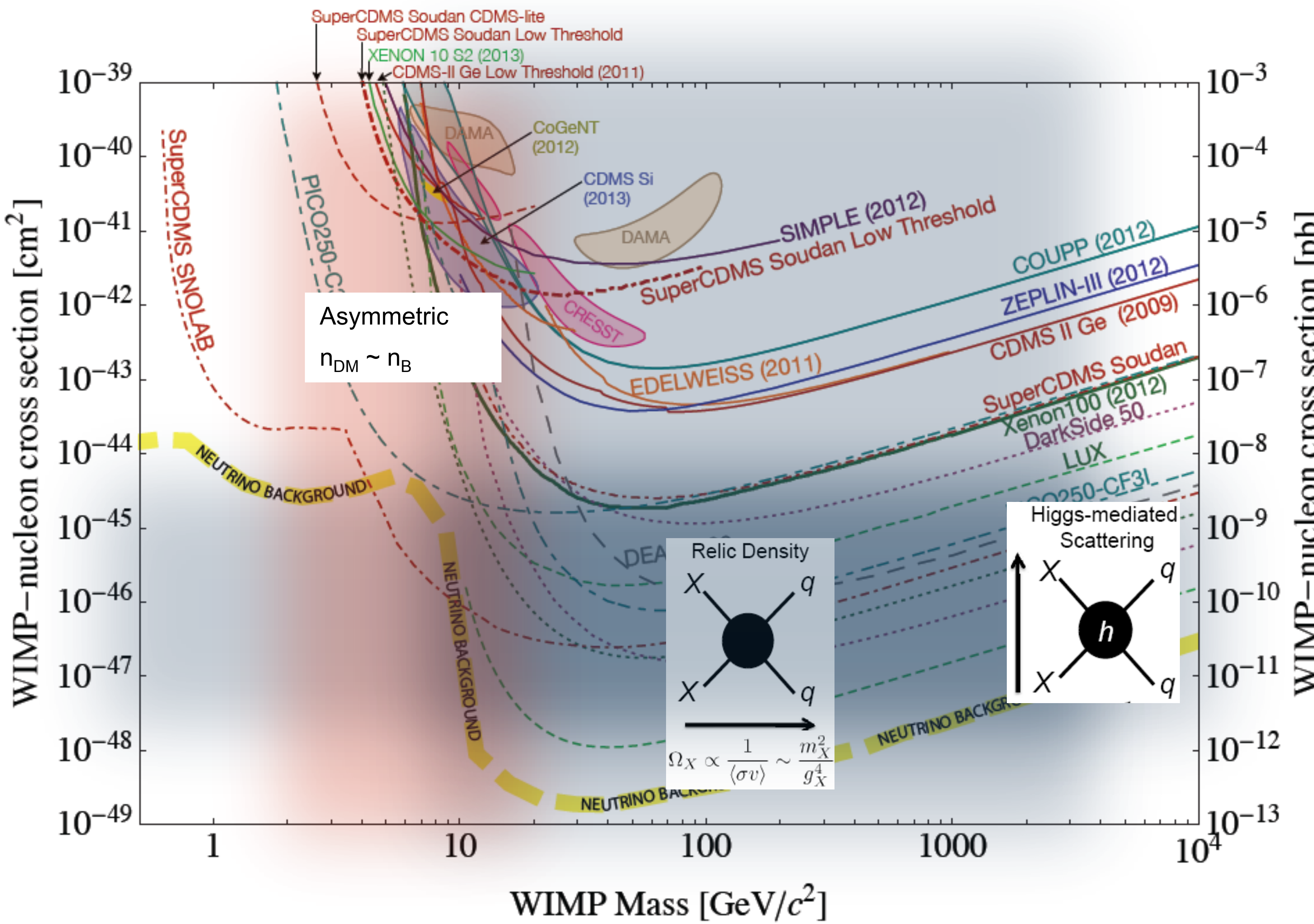


WIMP Searches

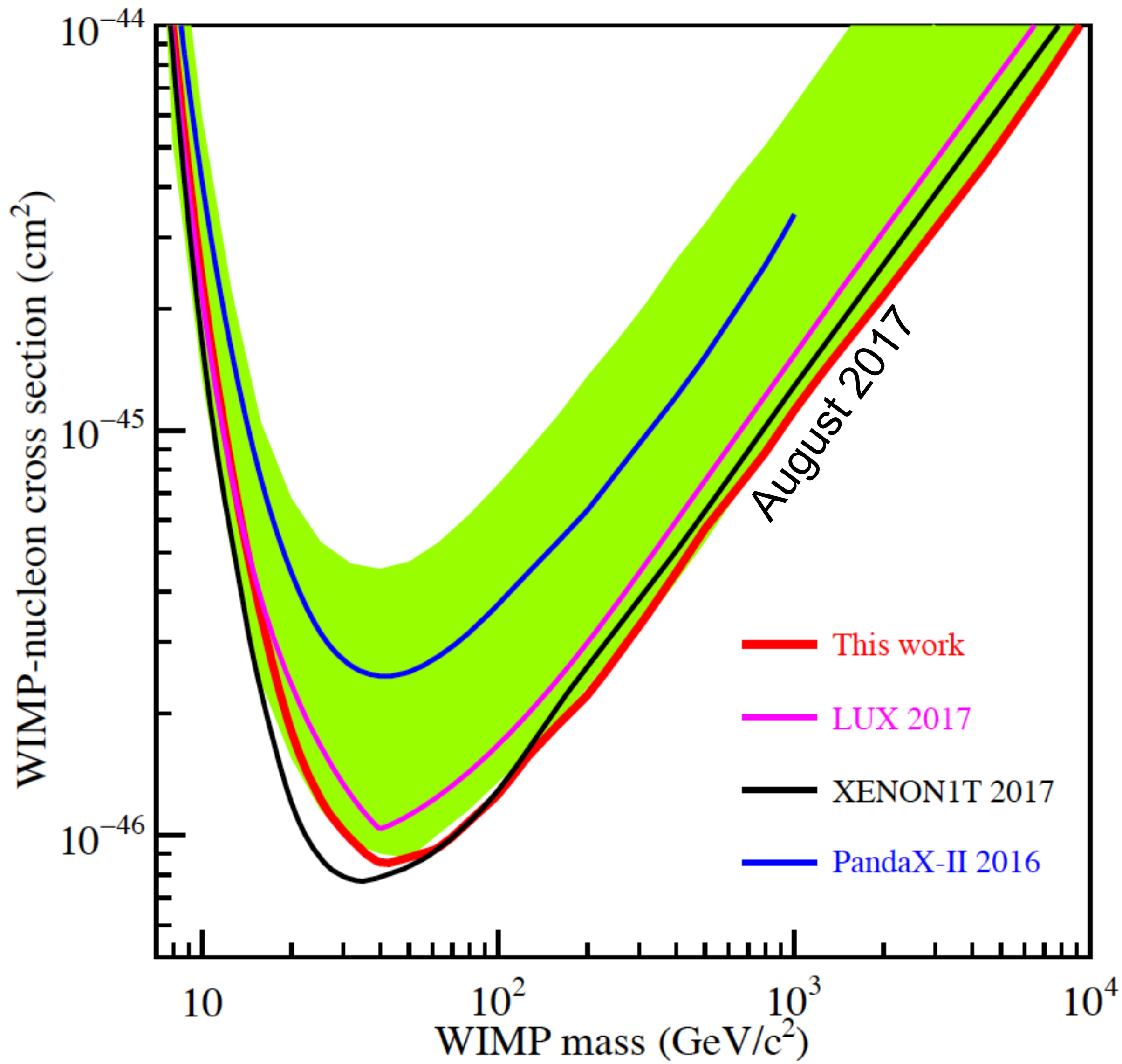


- The WIMP miracle motivates diverse experiments that are (unfortunately) bigger, longer, and more expensive

DIRECT DETECTION EXPERIMENTS (2013)



LATEST RESULTS: PandaX-II



RECENT DEVELOPMENTS

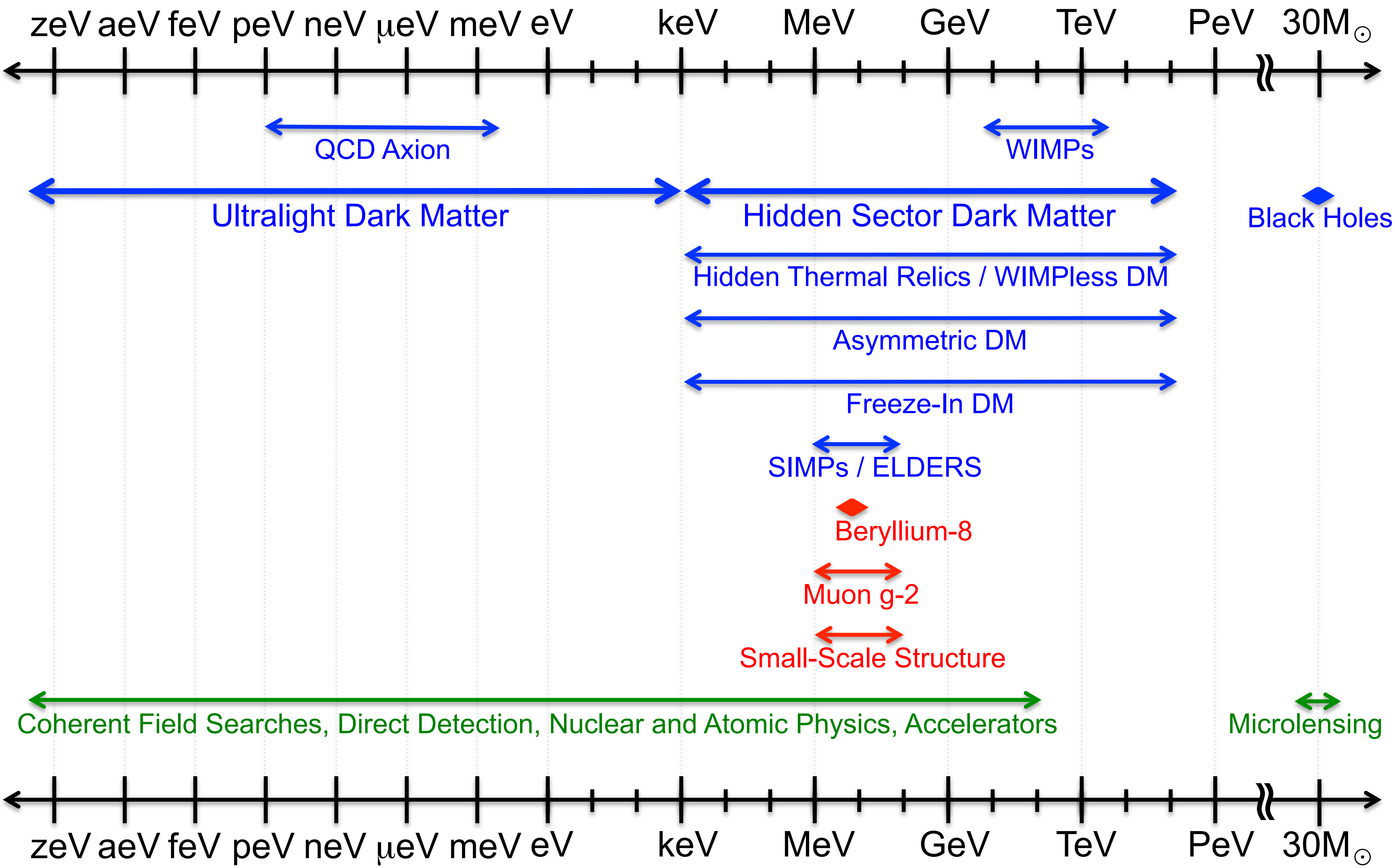
- In the last few years, these classic candidates have been generalized to broad classes of dark matter

Axions → Axion-like Particles (ALPs) → Ultralight DM

WIMPs → WIMPless DM→ Hidden Sector DM

- New motivations, new anomalies, and new experimental search techniques have been identified, leading to a flurry of activity

DM CANDIDATES, ANOMALIES, SEARCH TECHNIQUES



Cosmic Visions White Paper (2017)

DARK SECTORS

- All evidence for dark matter is gravitational. Perhaps it's in a hidden sector, composed of particles with no SM gauge interactions (electromagnetic, weak, strong)

Lee, Yang (1956); Kobsarev, Okun, Pomeranchuk (1966); Blinnikov, Khlopov (1982); Foot, Lew, Volkas (1991); Hodges (1993); Berezhiani, Dolgov, Mohapatra (1995); ...

- This hidden sector may have a rich structure with matter and forces of its own

WIMPLESS DARK MATTER

Feng, Kumar (2008); Feng, Tu, Yu (2008)

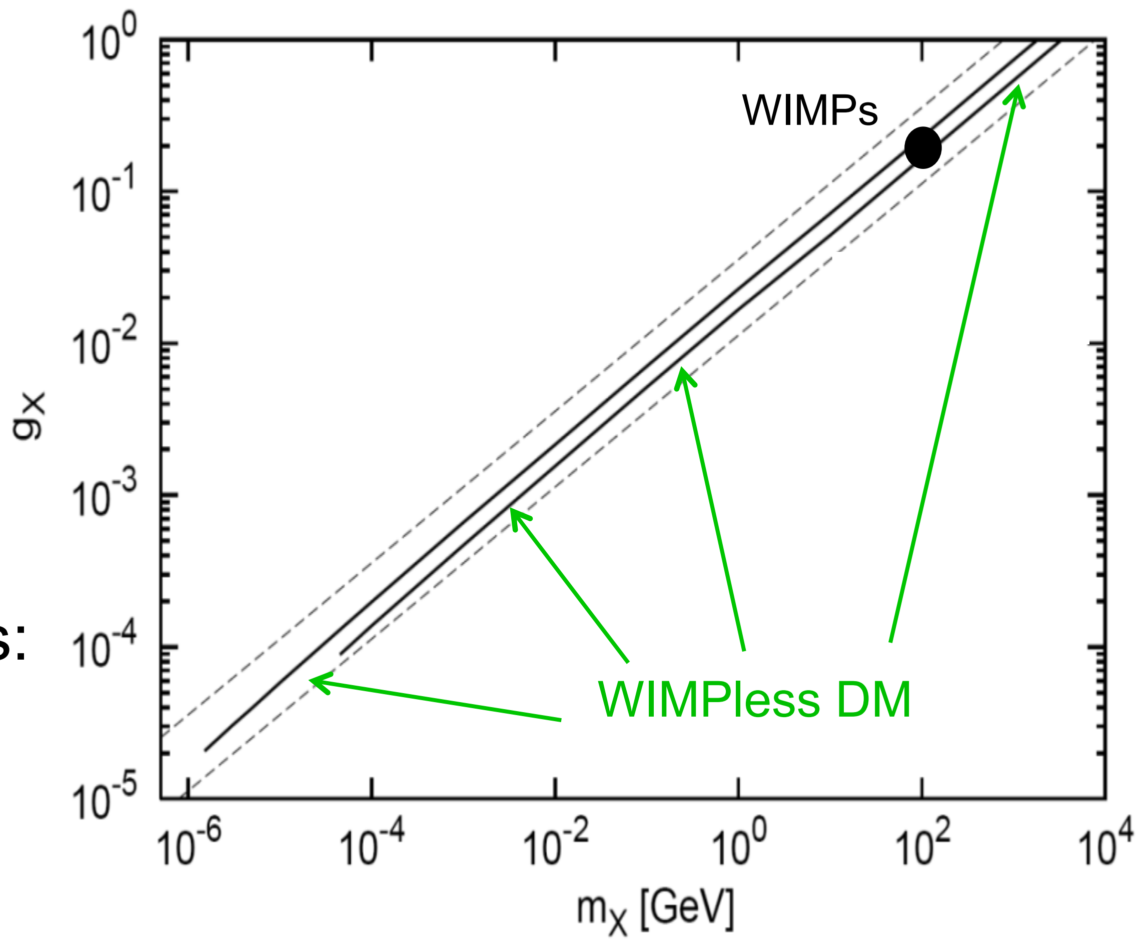
- Recall the WIMP miracle:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

$$\left. \begin{array}{r} m_X \sim 100 \text{ GeV} \\ g_X \sim 0.6 \end{array} \right\} \Rightarrow \Omega_X \sim 1$$

- But now g_X doesn't have to be 0.6!

- Additional motivations: SUSY with GMSB or AMSB, small scale structure, ...



- WIMPless Miracle → light, extremely weakly-coupled particles; new connections to other fields; smaller, faster, cheaper expts

AN EXAMPLE: NUCLEAR PHYSICS

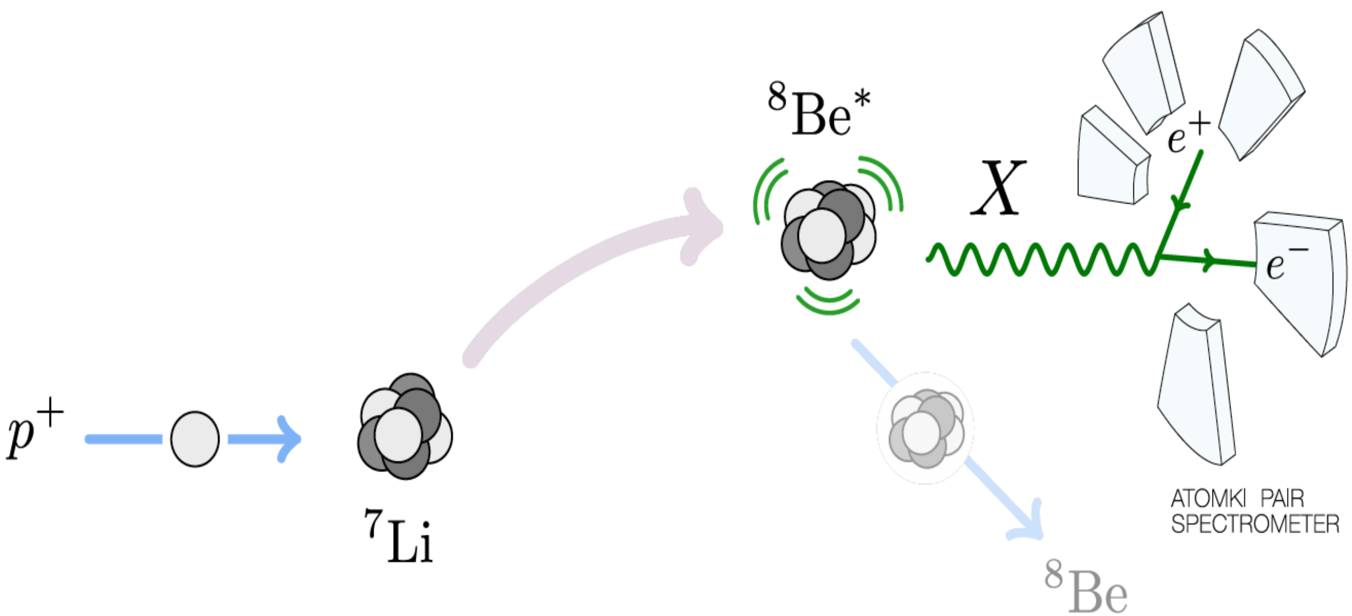
- One can look for < 20 MeV new particles in decays of excited nuclei

Treiman, Wilczek (1978); Donnelly, Freedman, Lytel, Peccei, Schwartz (1978)

- In particular, in rare internal pair creation events, can look for

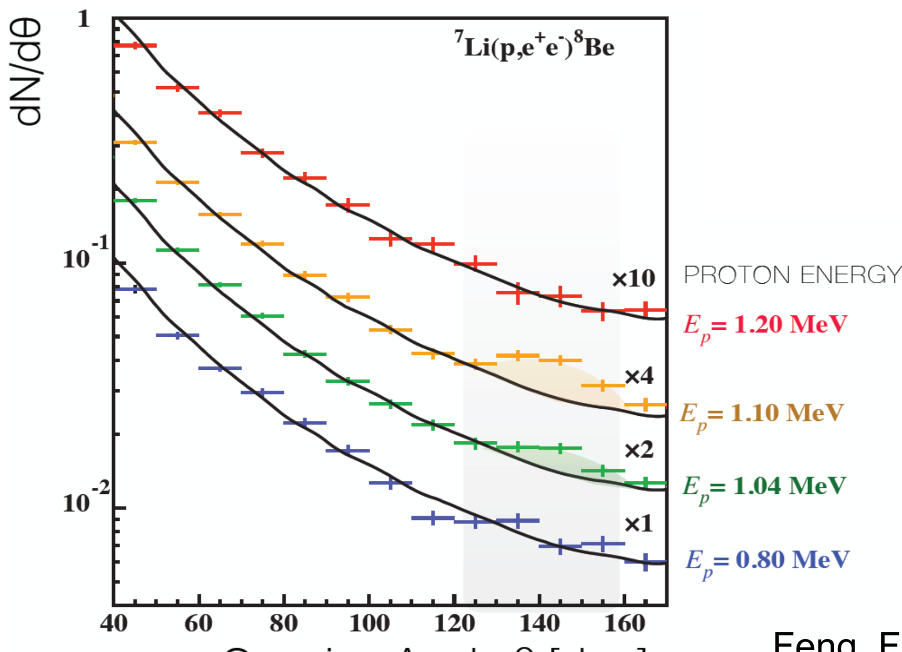
^{8}Be* → ^{8}Be X → ^{8}Be e$^+$ e$^-$ signal

[^{8}Be* → ^{8}Be γ → ^{8}Be e$^+$ e$^-$ background]



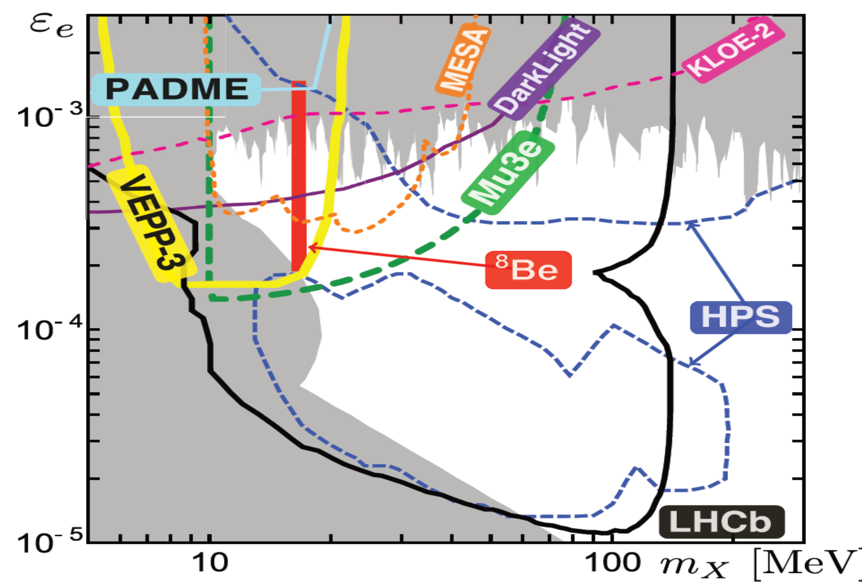
THE BERYLLIUM ANOMALY AND DARK FORCES

- ATOMKI group has seen a 6.8σ excess at e^+e^- opening angles of 135 deg



Krasznahorkay et al. (2015)

- This can be consistently explained by a new 17 MeV boson, 5th force



Feng, Fornal, Galon, Gardner, Smolinsky, Tait, Tanedo (2016); Gu, He (2016); Ellwanger, Moretti (2016); Kozaczuk, Morrissey, Stroberg (2016);...

- There is now preliminary supporting evidence from the ATOMKI group, proposed followups (~$750K, 1 year)

CONCLUSIONS

- Dark matter is one of the great scientific puzzles of our time and is leading evidence for new particles and forces

- Classic candidates remain attractive...
  - Dark matter: sterile neutrinos, axions, WIMPs
  - WIMP miracle: heavy and weakly coupled
  - Experiments: bigger, longer, more expensive

- ...but a new paradigm is also emerging
  - Dark sector: dark Higgs, dark fermions, dark gauge bosons
  - WIMPless miracle: light and extremely weakly coupled
  - Experiments: smaller, faster, cheaper