BEN WILKINSON-ZAN

DR. DANIEL STOLARSKI

ASYMMETRIC DARK MATTER

PREDICTING THE ENERGY DENSITY RATIO OF THE UNIVERSE

OVERVIEW

- Asymmetric Dark Matter
- The Proton
- Dark QCD and the Dark Baryon
- Quadrification
- Generating Particle Asymmetries

TEXT

DARK MATTER

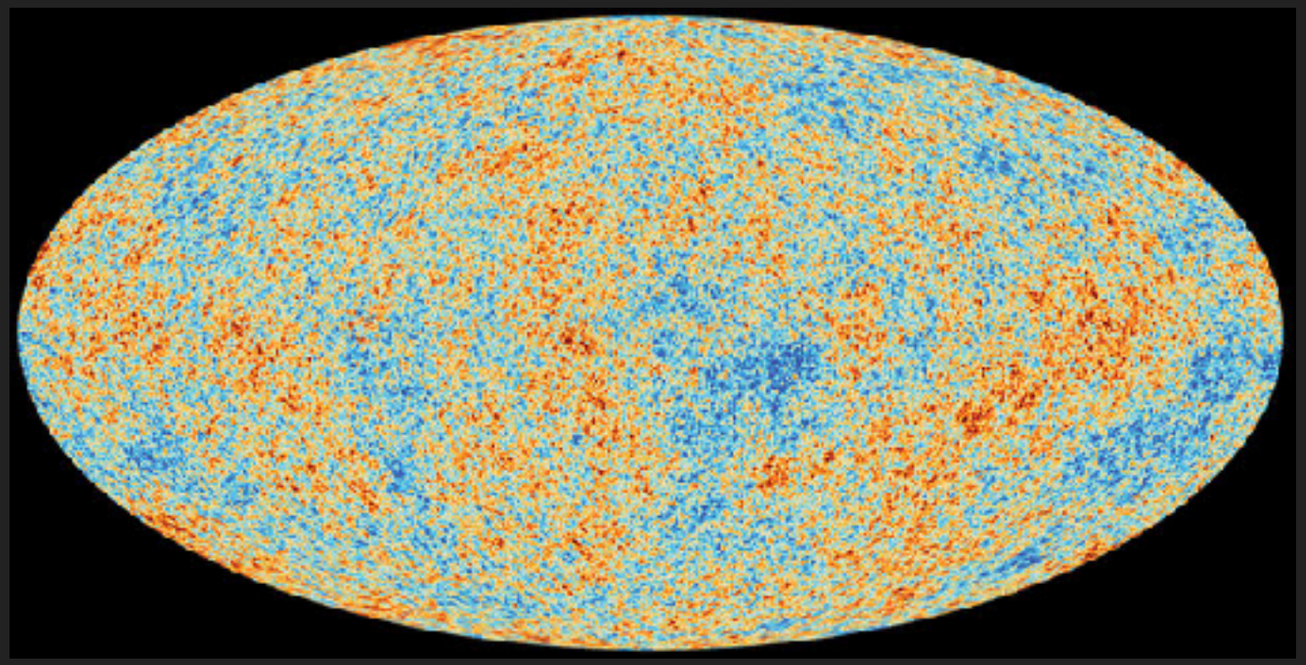


Image: ESA/Planck

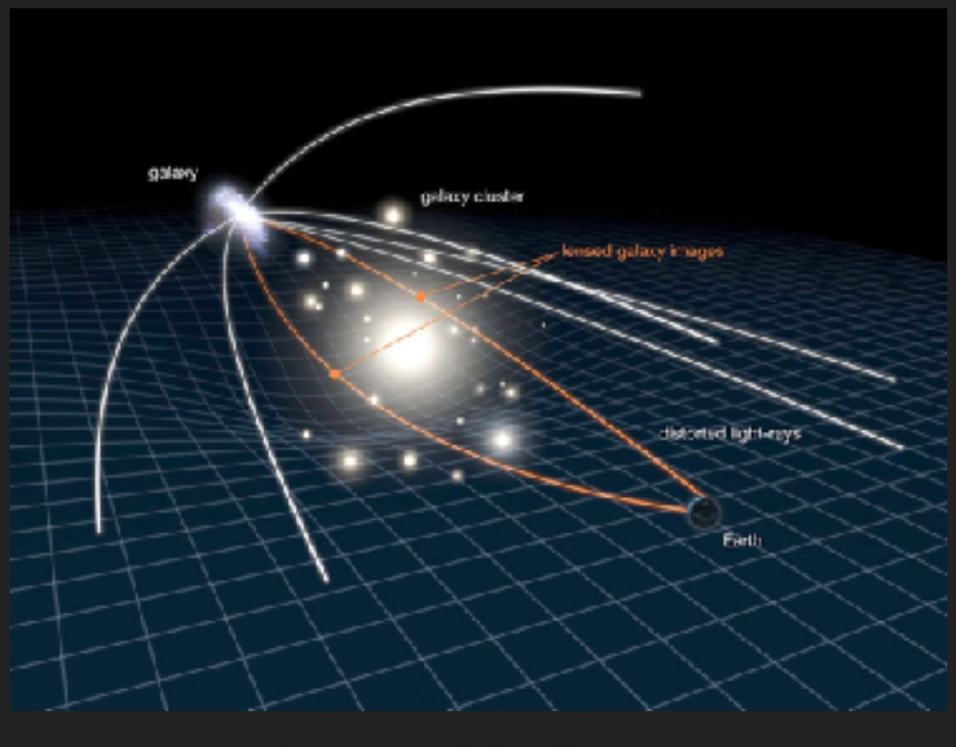


Image: CFHTLens

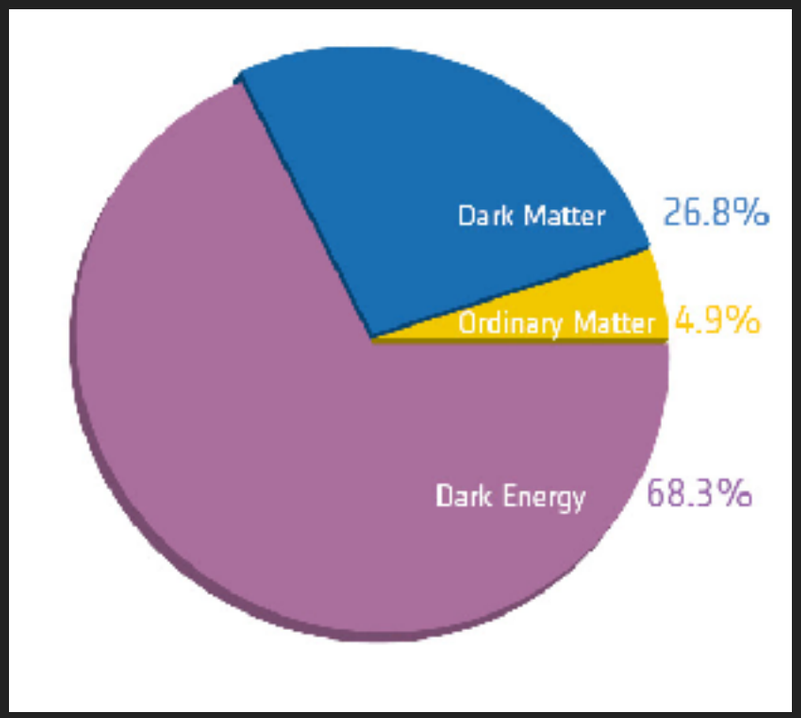


Image: ESA/Planck

$$\frac{\Omega_D}{\Omega_B} \approx \frac{n_D m_D}{n_B m_B} \approx 5$$

BARYON ASYMMETRY IN THE UNIVERSE

- Current universe has a baryon - anti baryon asymmetry
  - More protons than anti protons
- Baryogenesis: Asymmetry generated via particle interactions

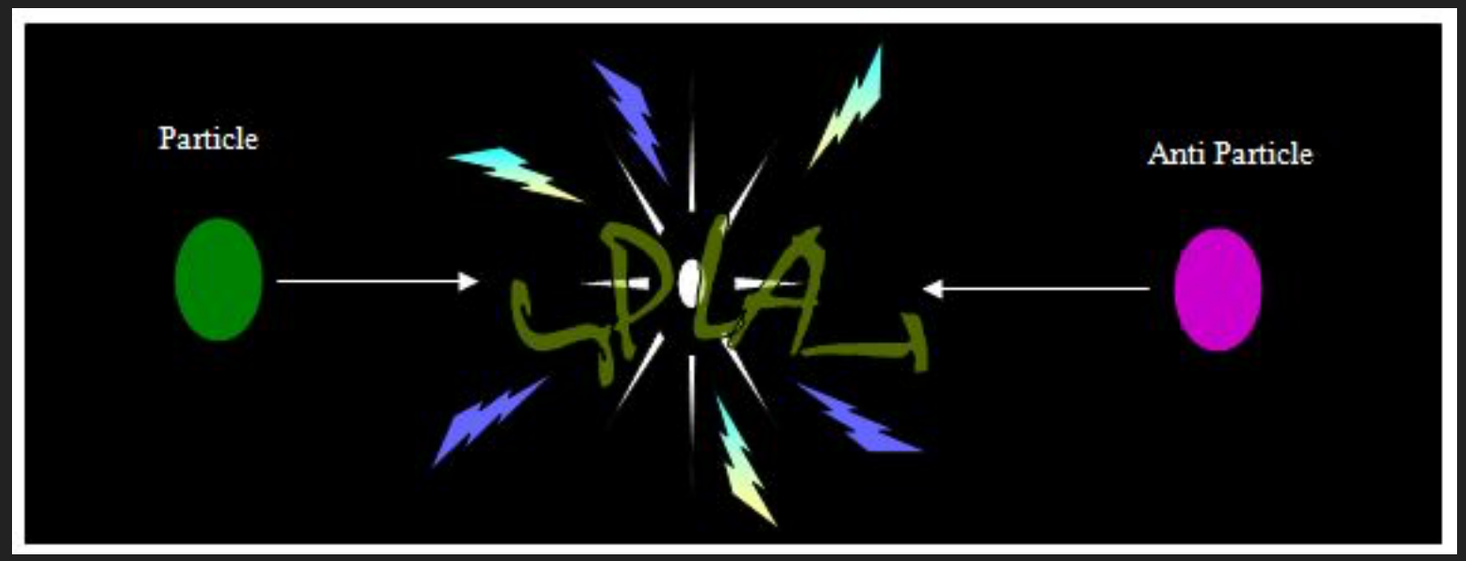


Image: https://www.antonine-education.co.uk/Pages/Physics_1/Particles/PP06/particles_page_6.htm

ASYMMETRIC DARK MATTER

- Energy density ratio is an order 1 number

$$\frac{\Omega_D}{\Omega_B} \approx \frac{n_D m_D}{n_B m_B} \approx 5$$

- If the same mechanism controls n_D and n_B, we can have

$$\frac{n_D}{n_B} \approx \mathcal{O}(1)$$

- Asymmetry in baryon and dark sector via same mechanism
  - Dark matter cannot be its anti particle
- We now must turn to explaining $\frac{m_D}{m_B} \approx \mathcal{O}(1)$

THE MASS OF THE PROTON (QCD)

- Proton composition: 2 up quarks + 1 down quark
- Naively: $2m_u + m_d \approx 0.01 m_p$
- The other ~99% of the proton mass arises from the energy of the interaction in the strong force
- Related to Λ_{QCD} , which describes the energy at which the strong forces "confines" the quarks together

Yang Bai and Pedro Schwaller. Scale of dark QCD. *Phys. Rev., D89(6):063522, 2014.*

DARK QCD AND THE DARK BARYON

- Theorized that dark matter is “QCD-like” i.e. SU(3)
- The the lightest dark baryon has its mass determined by the scale Λ_{dQCD} (dark quark masses are small)
- Hence

$$\frac{\Omega_D}{\Omega_B} \approx \frac{n_D \Lambda_{dQCD}}{n_B \Lambda_{QCD}} \approx 5$$

- Suggests we should look for models where

$$\Lambda_{dQCD} \approx \Lambda_{QCD}$$

QUADRIFICATION

- Generate Λ_{dQCD} via Grand Unified Theory (GUT)
- Particle content and masses influence coupling strengths
- Dark quarks charged only under dark QCD (hence DM is stable)

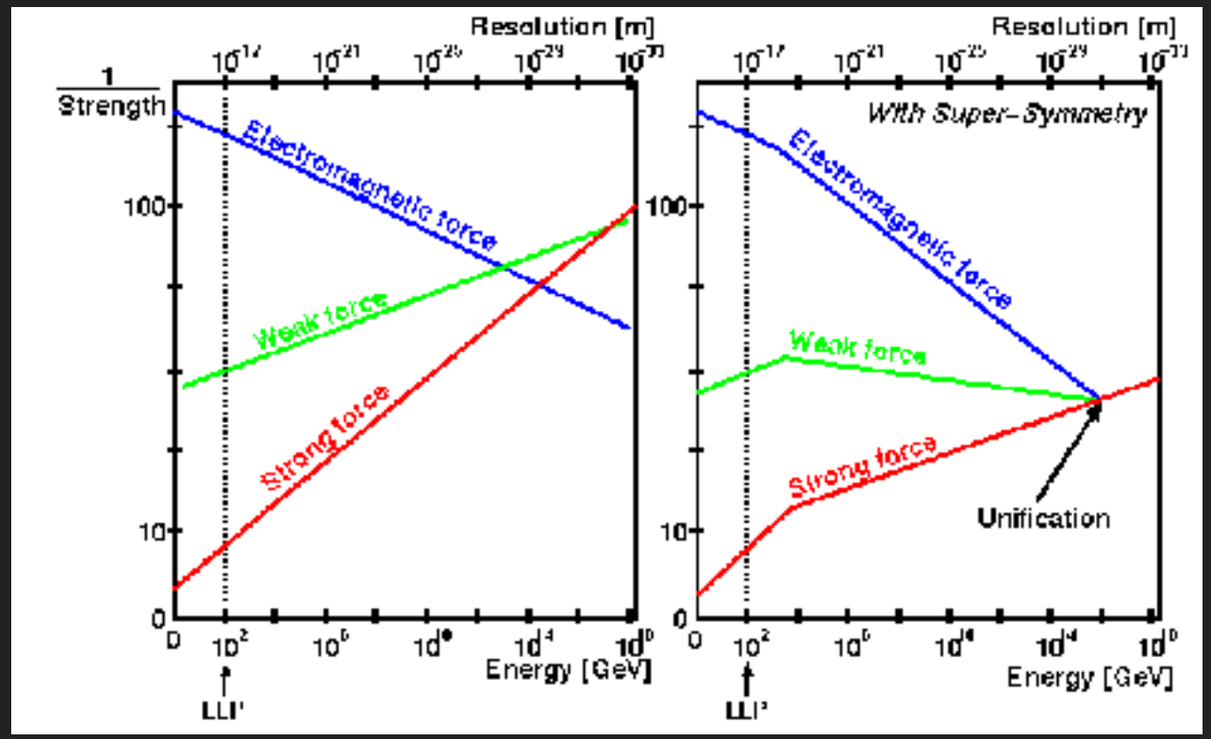


Image: https://physics.stackexchange.com/questions/254369/supersymmetry-and-grand-unification

$$SU(3)_d \times \underbrace{SU(3)_C \times SU(3)_L \times SU(3)_R}$$

$$\downarrow$$

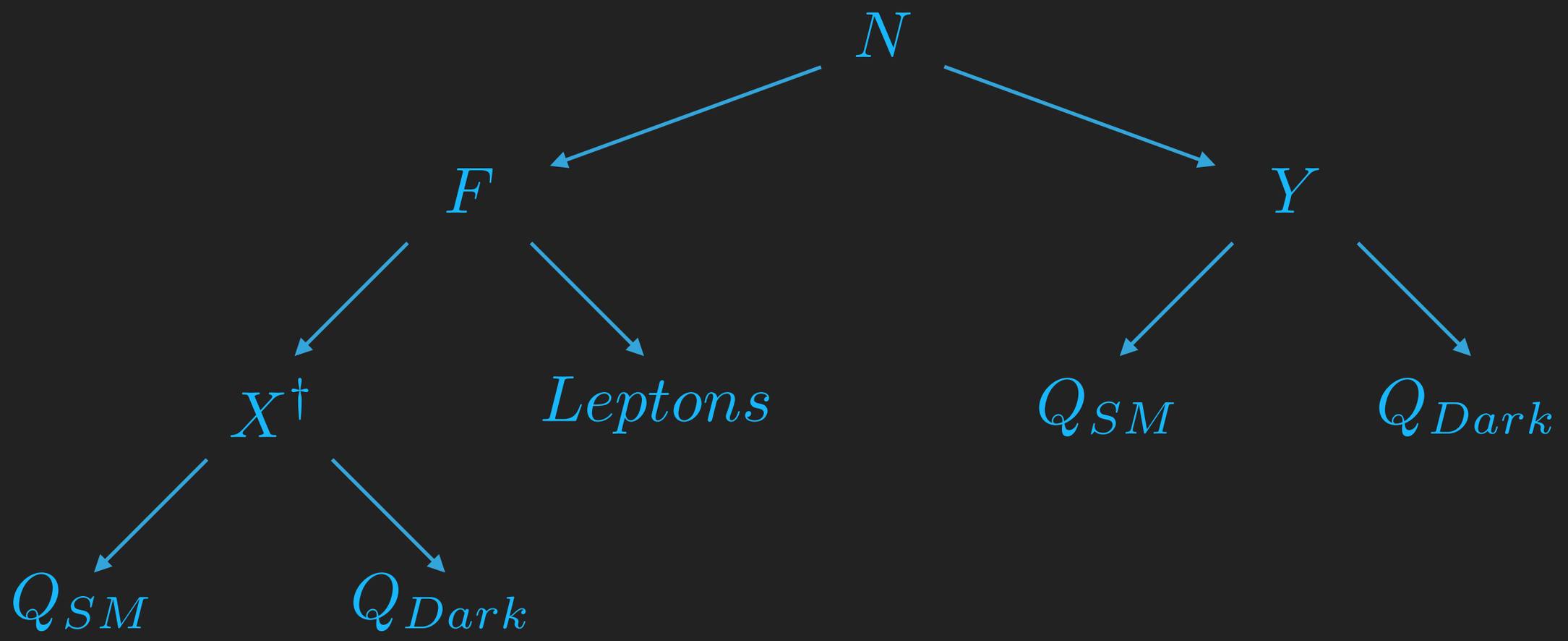
$$SU(3)_d \times G_{SM}$$

Yang Bai and Pedro Schwaller. Scale of dark QCD. *Phys. Rev., D89(6):063522, 2014.*

GENERATING PARTICLE ASYMMETRIES

- Bi-fundamental: charged under QCD and dark QCD
- Bi-fundamental scalars (X, Y) that decay into a SM quark and dark quark
- Heavy neutrino, N, which has an asymmetric decay into a bi-fundamental fermion F, and a bi-fundamental scalar Y
- Decay chain down to SM leptons and quarks (forming baryons) and dark quarks (forming dark baryons)

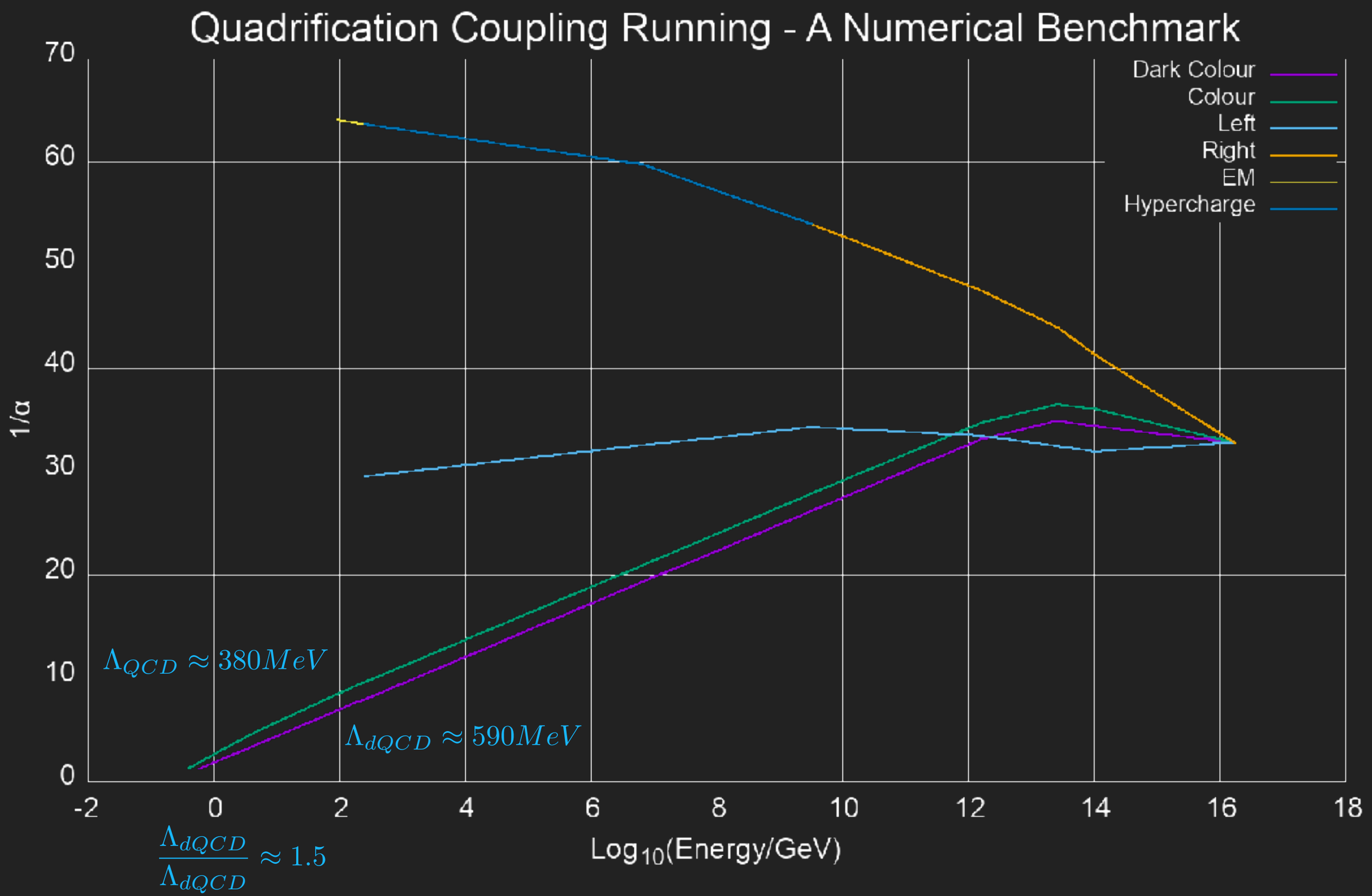
DECAY CHAIN IN QUADRIFICATION



Counting particles in final states, we obtain $\frac{n_D}{n_B} = 3.4$

Suggests looking for models where $\frac{\Lambda_{dQCD}}{\Lambda_{QCD}} \approx 1.5$

TEXT

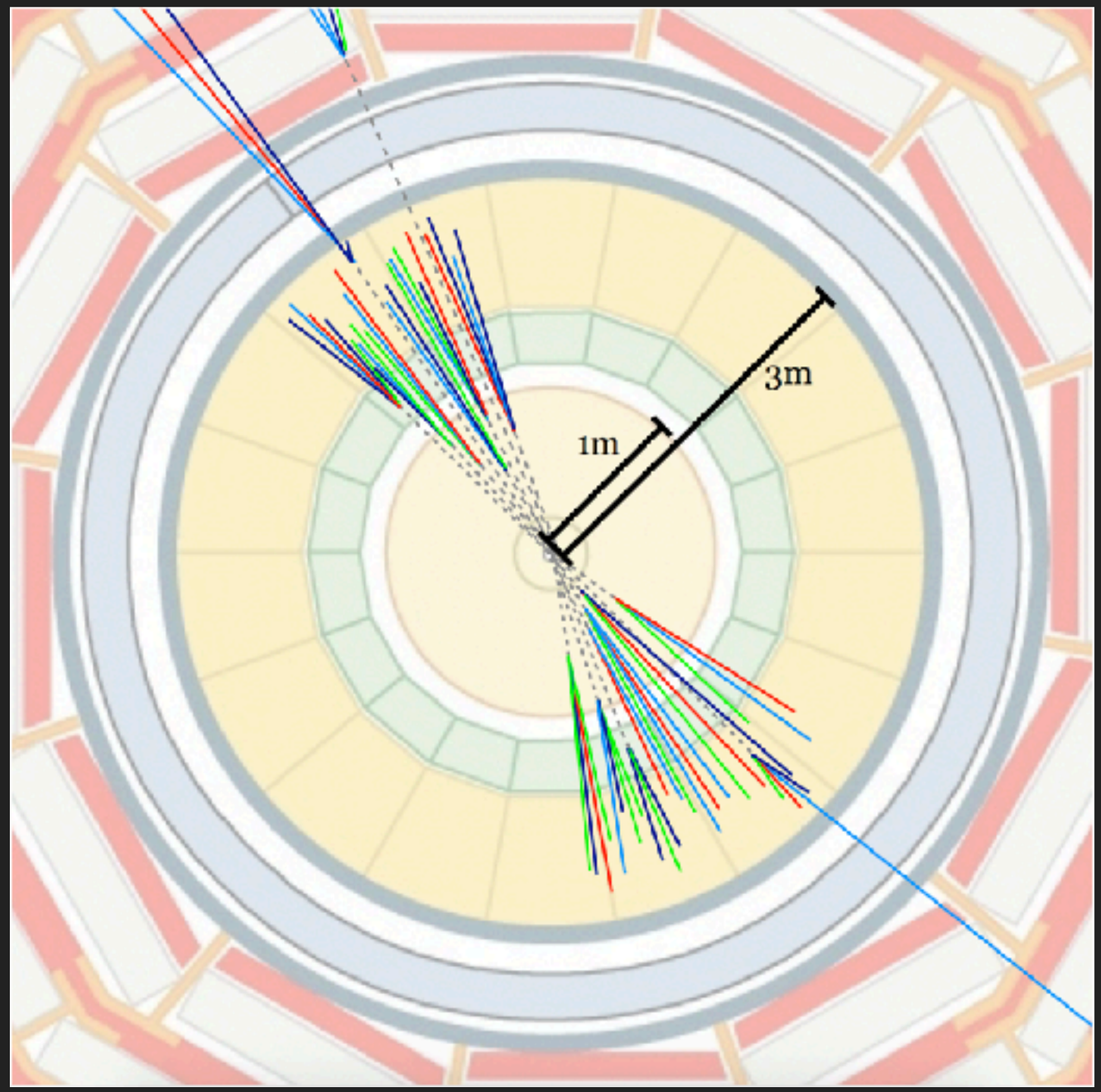

Quadrification Coupling Running - A Numerical Benchmark
Dark Colour
Colour
Left
Right
EM
Hypercharge
1/α
70
60
50
40
30
20
10
0
-2
0
2
4
6
8
10
12
14
16
18
Log10(Energy/GeV)
$\Lambda_{QCD} \approx 380MeV$
$\Lambda_{dQCD} \approx 590MeV$
$\frac{\Lambda_{dQCD}}{\Lambda_{dQCD}} \approx 1.5$

Pedro Schwaller, Daniel Stolarski, and Andreas Weiler. Emerging Jets. *JHEP*, 05:059, 2015

DETECTING DARK QCD

- Dark pions could be formed at detectors (dashed lines)
- No interaction with detector, but would decay into SM particles (solid lines)
- Research is currently being done to search for these types of decays at LHC

Image: Schwaller, Stolarski, Weiler



CONCLUSION

- Asymmetric DM: n_D and n_B share generation mechanism
  - Naturally explains order 1 ratio
- Combined with Dark QCD in a GUT, the energy density ratio of the universe can be predicted
  - Quadrification can predict $\Omega_D/\Omega_B \approx 5$
- Current searches for dark QCD at LHC focussing on dark jets

EXPERIENTIAL LEARNING

- Technical Skills
  - C++, Matlab, LaTex, group theory, basic QFT
- Communication Skills
  - Presentations, explaining difficult concepts, student-supervisor relation, technical writing
- Other Skills
  - Long-term project organization, effectively reading papers and textbooks