

THE PARTICLE NEXT DOOR

- A TOP-DOWN PERSPECTIVE
ON^{neutral} LONG-LIVED PARTICLES

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BOTTOM-UP VIEW

- Experiments, hardware, methods for searching for LLPs at high-energy colliders are/would be COOL AND NOVEL, possibly SPECTACULAR
- Such kinematically accessible new physics with low rates may easily have escaped detection by standard searches

- The weak couplings for production/decay from/to SM may involve SM flavor/CP/Higgs non-trivially, and yet be weak enough to not be constrained by the host of precision flavor/CP / Higgs tests
- But EFFORT/INGENUITY/RESOURCES required.

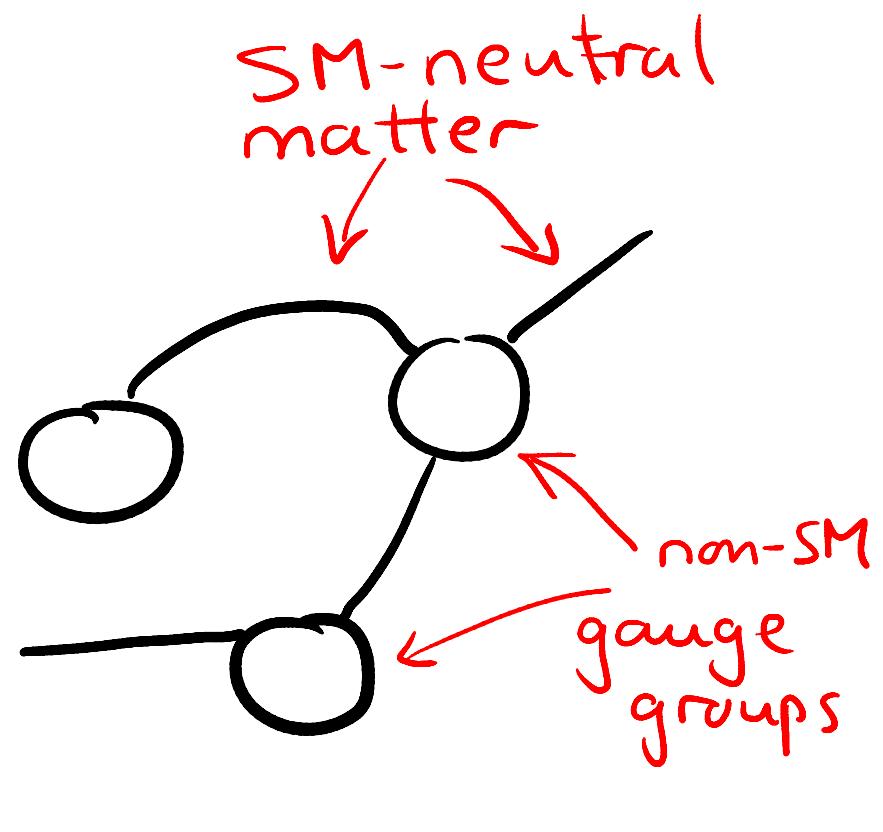
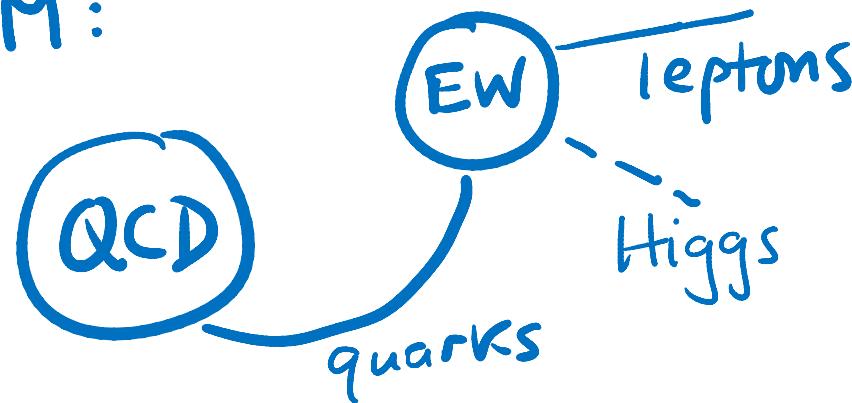
WHY IS THIS DIRECTION A GOOD BET?

A GLIMMER OF LIGHT— DARK MATTER EXISTS

INCREASING SENSITIVITY OF
DM DETECTION EXCLUSIONS
SUGGEST DM MAY WELL BE
WEAKER THAN $WEAK_{SM}$ in its
couplings to SM,
living in NEW DARK SECTORS

GAUGE FIELD THEORY GRAMMAR READILY SUPPORTS DARK SECTORS

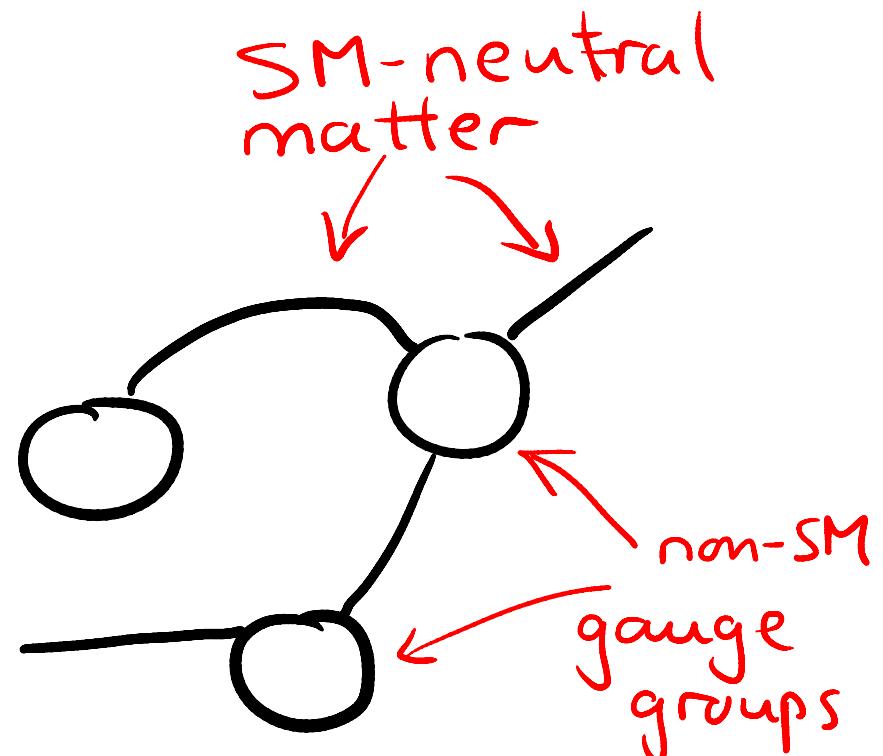
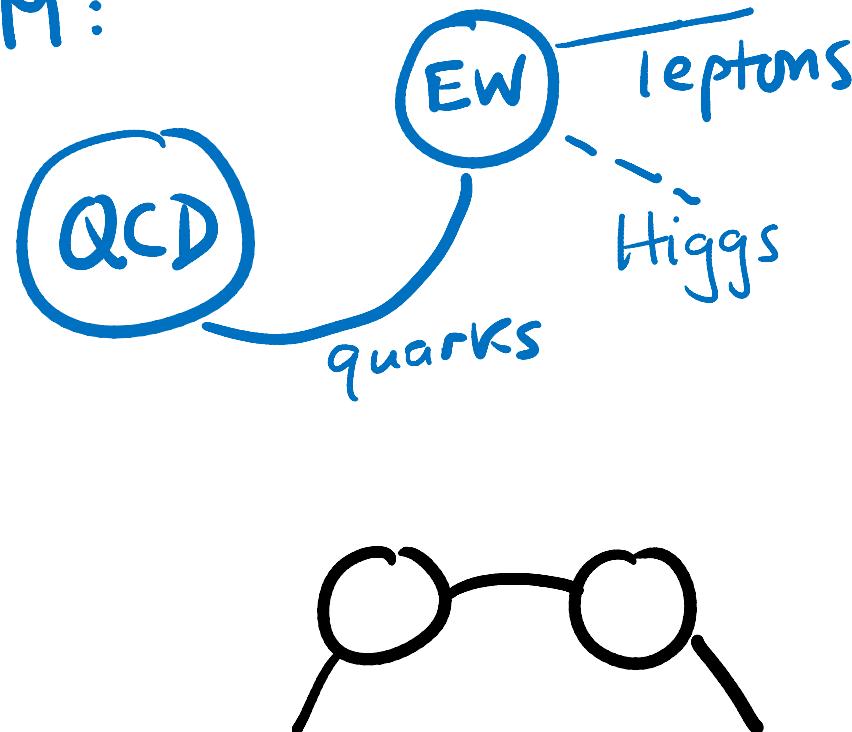
SM:



decoupled from SM (except gravitationally)

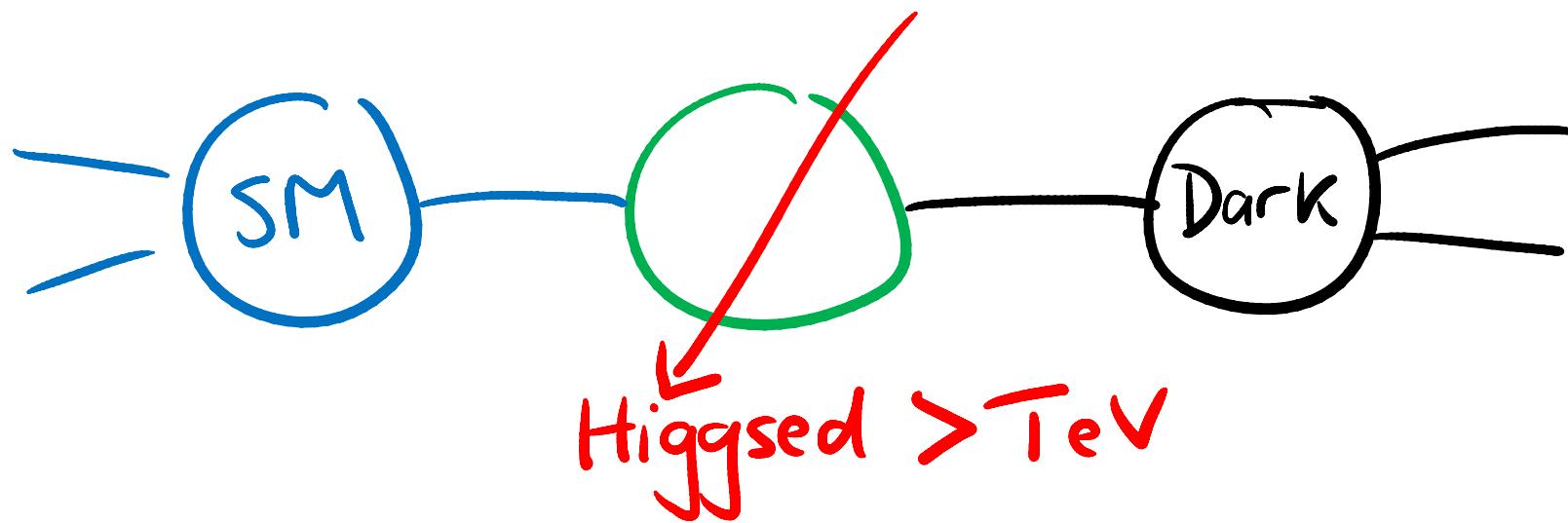
GAUGE FIELD THEORY GRAMMAR READILY SUPPORTS DARK SECTORS

SM:



Relatively unconstrained except for stable cosmological populations: ΔN_{eff} , DM properties

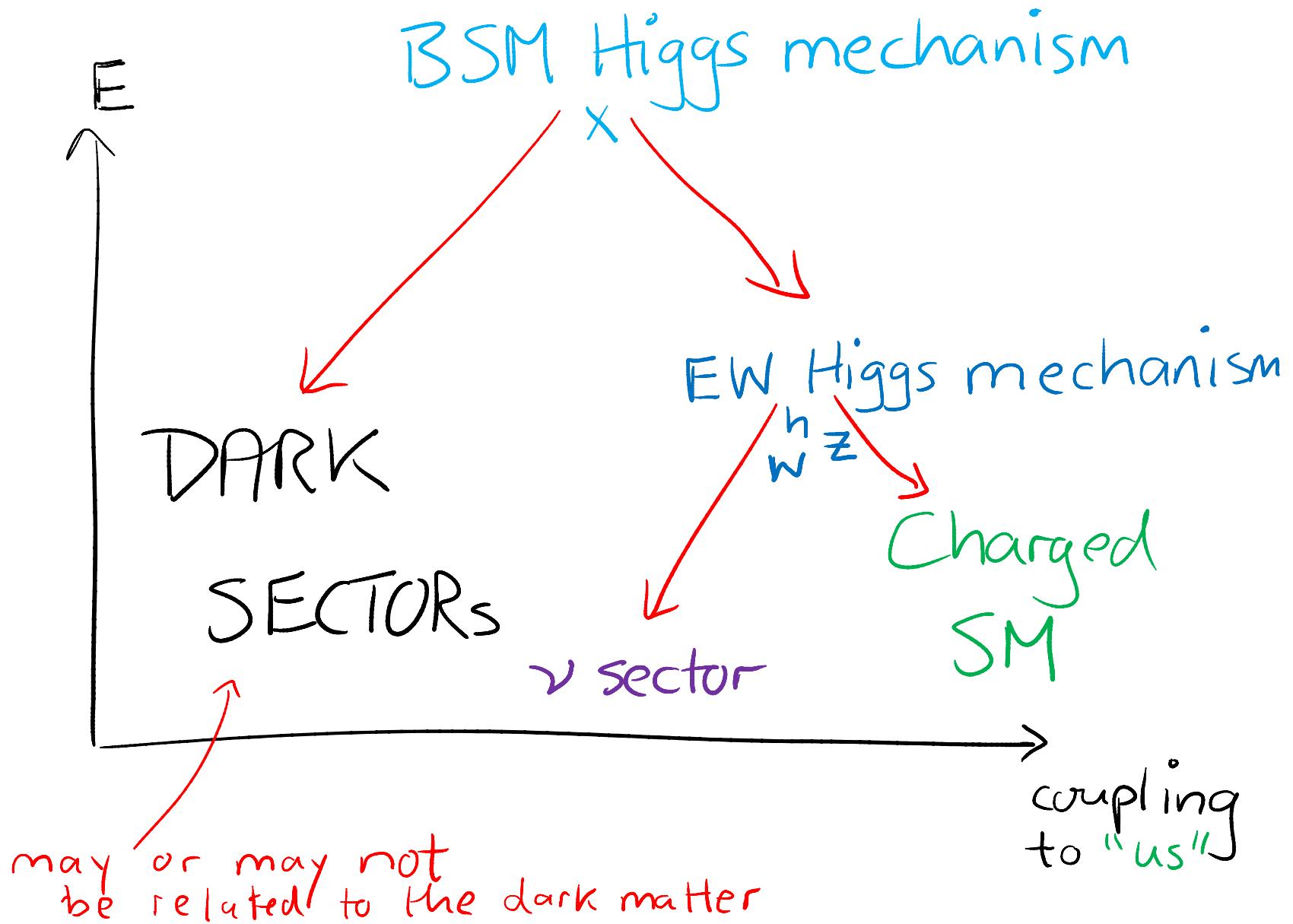
GAUGE FIELD THEORY
GRAMMAR READILY SUPPORTS
DARK SECTORS



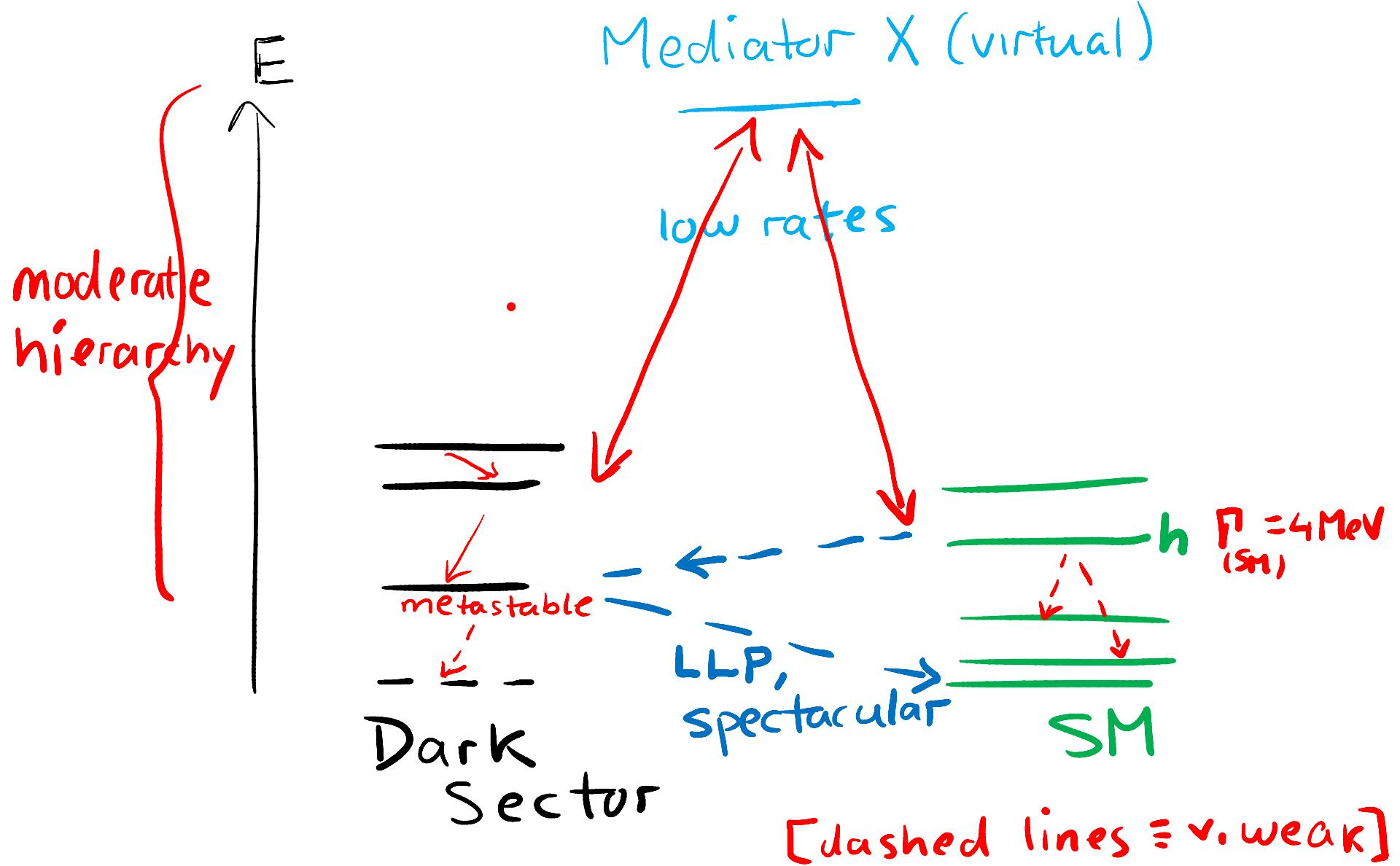
OR very weakly coupled to SM

plausibly → HIDDEN VALLEY

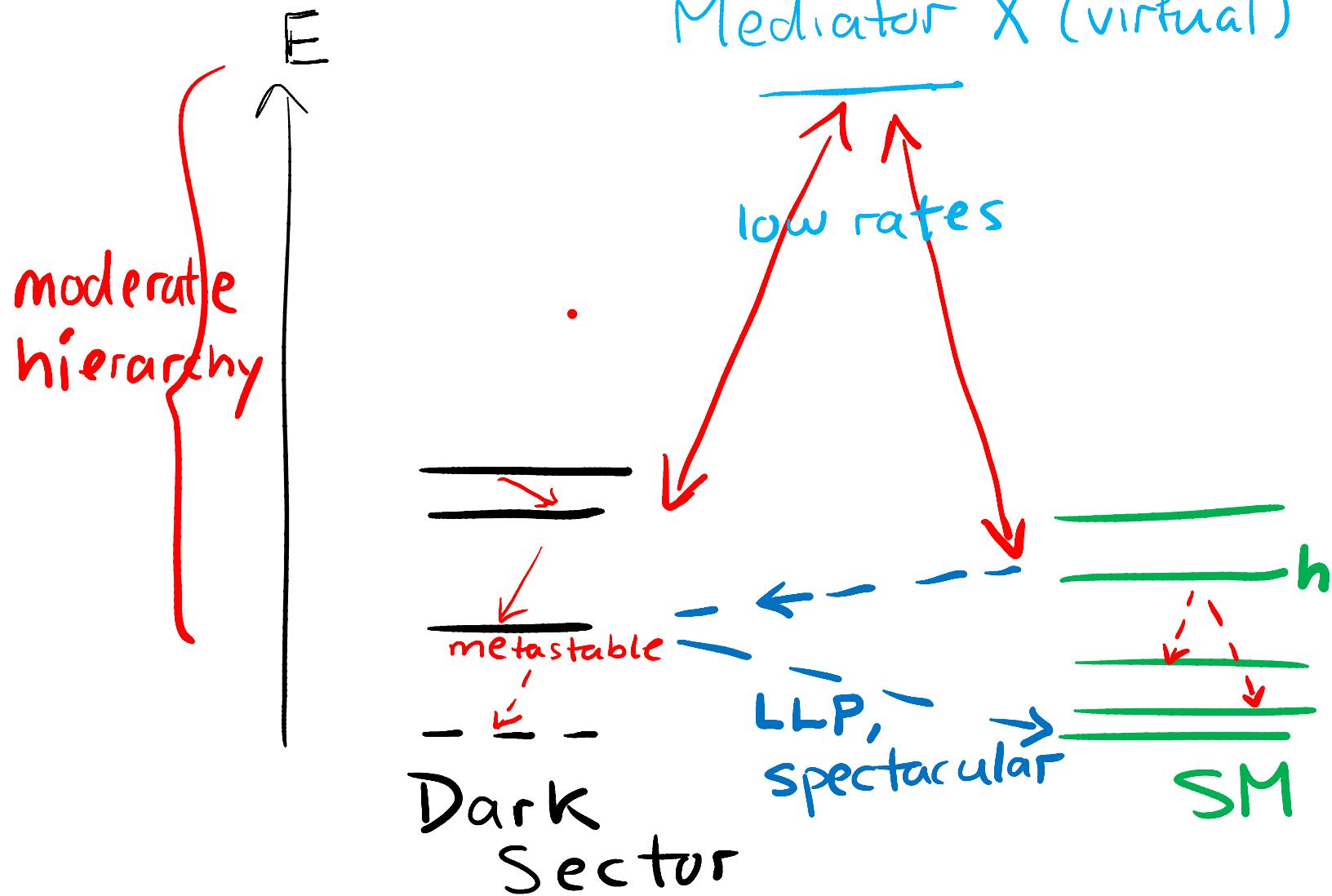
Strassler, Zurek '07



STRENGTH in WEAKNESS



BUT WHY \gtrsim TeV SCALE?



NATURALNESS

OF EW HIERARCHY

STRONGLY MOTIVATES

BSM PHYSICS $\gtrsim v_{\text{weak}}$

NATURALNESS

OF EW HIERARCHY

STRONGLY MOTIVATES

BSM PHYSICS $\gtrsim v_{\text{weak}}$

YES, I BELIEVE !!

ABSENCE OF BSM

THUSFAR . . .

⇒ EW NATURALNESS
IMPERFECTLY REALIZED

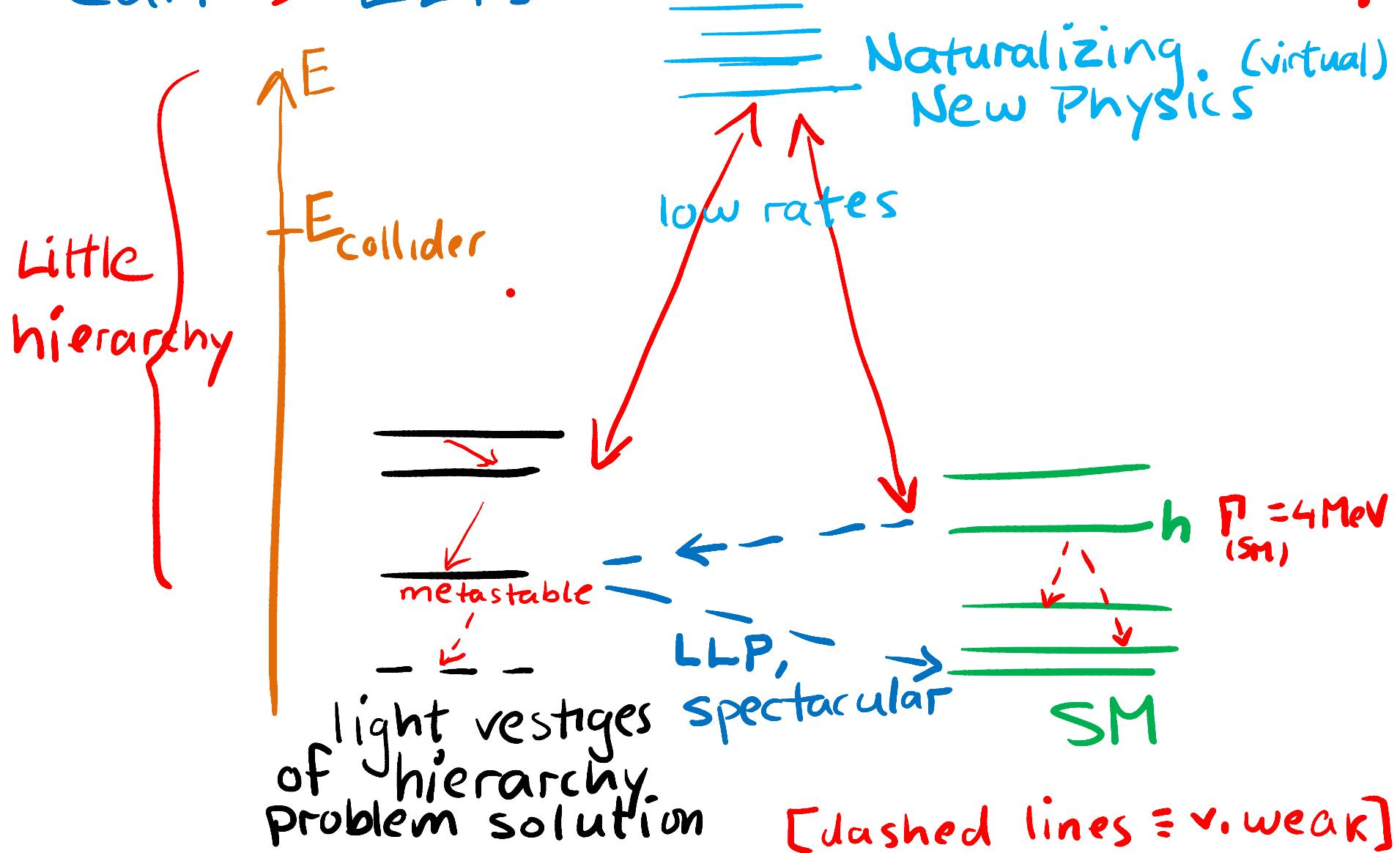
SM unnatural \gtrsim few 100 GeV



LITTLE HIERARCHY PROBLEM

can → LLPs

~~OPPORTUNITY!~~



MOST POWERFUL & ELEGANT NATURAL MECHANISMS

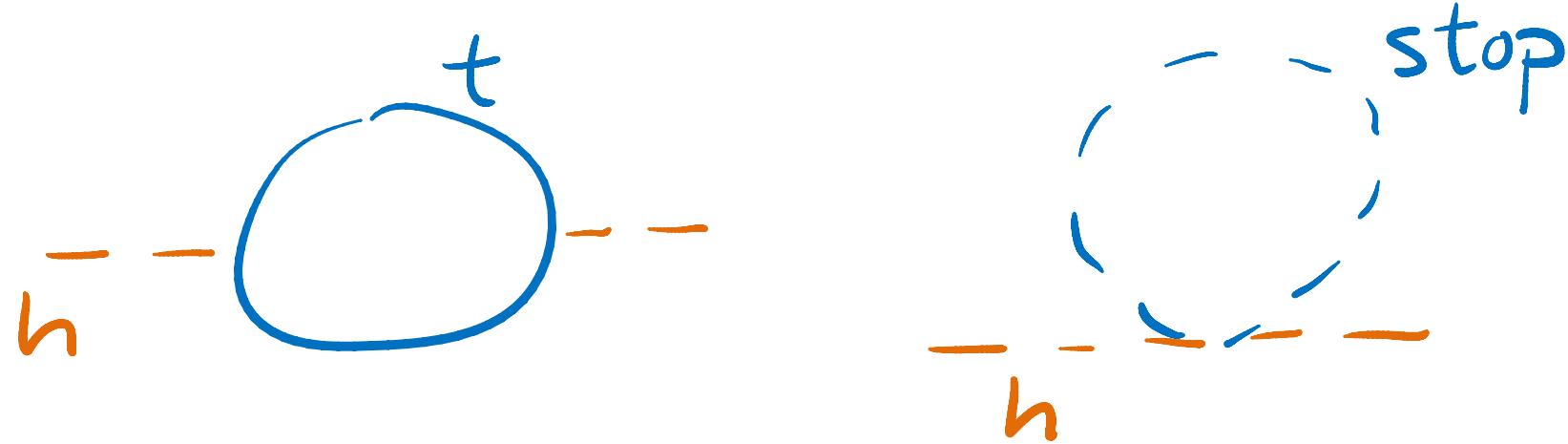
SUSY

RS1 / Composite Higgs

equivalent via \uparrow AdS/CFT duality!

exhibit tensions with
“low” energy data
if they appeared \lesssim TeV

SUSY

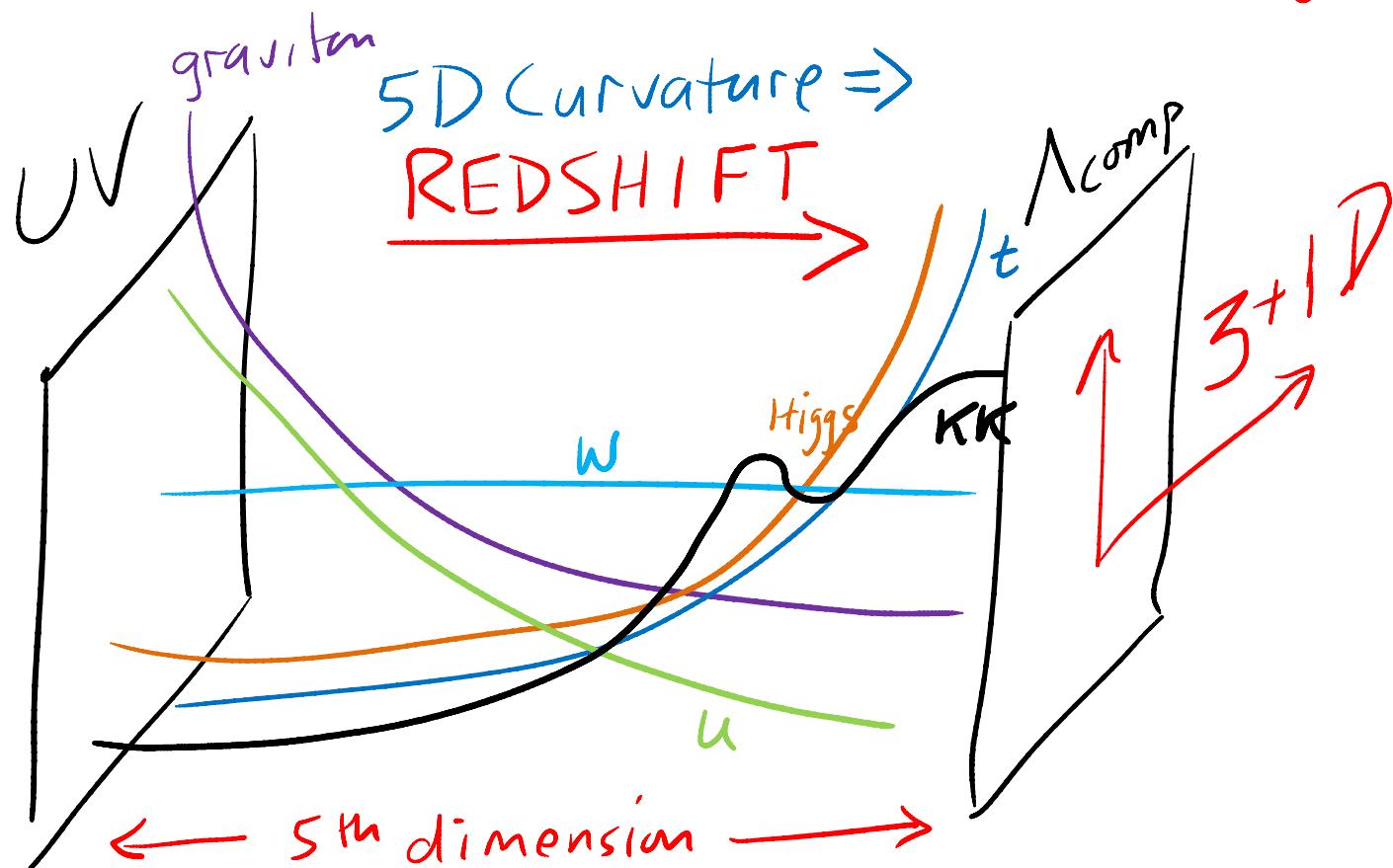


has difficulty accommodating
 $m_h = 125 \text{ GeV}$ with full naturalness,
 $m_{\text{superpartners}} \lesssim \text{TeV}$
But tensions disappear for $m_{\text{super}} \sim 10 \text{ TeV}$

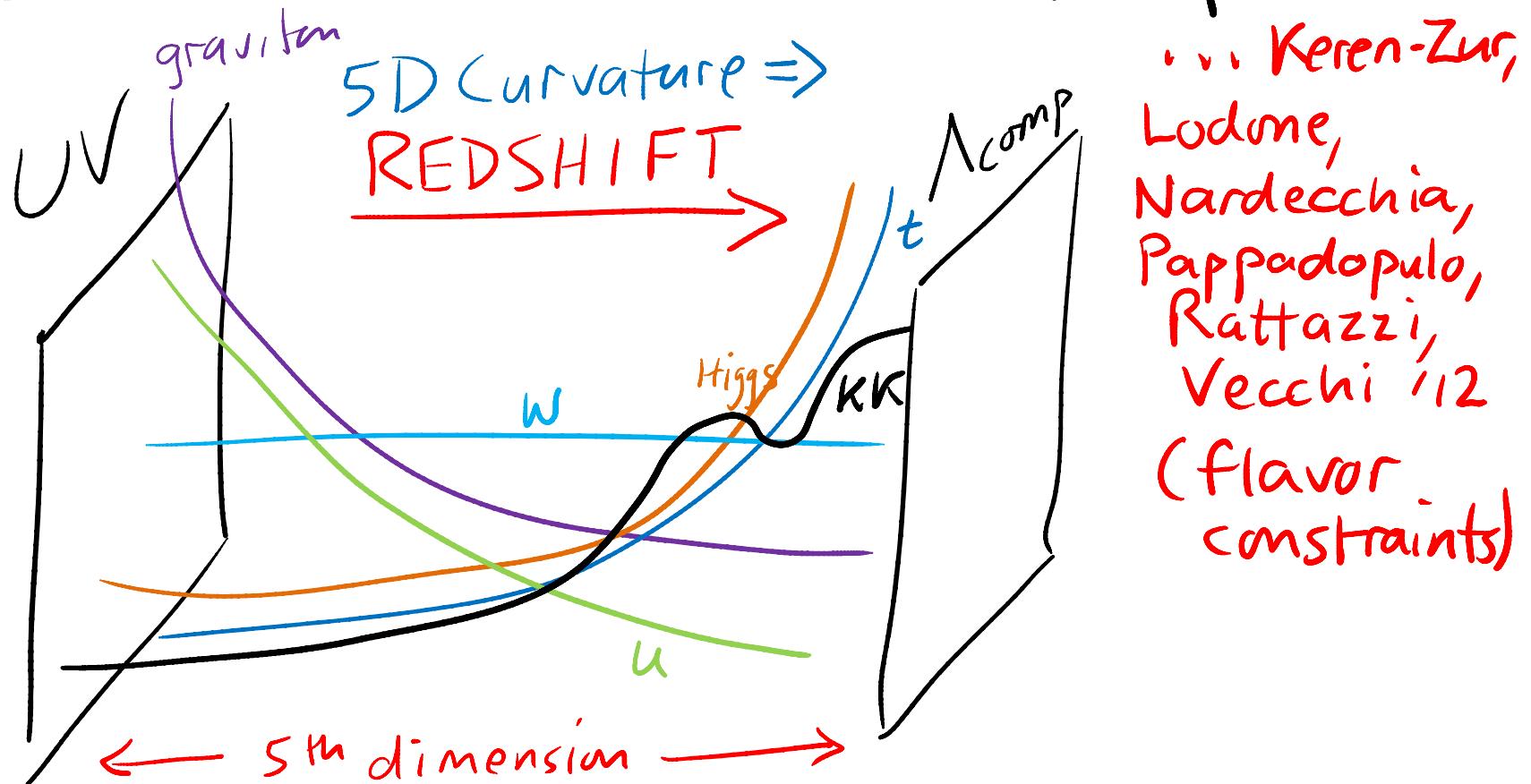
RS1/COMPOSITE HIGGS is also a THEORY OF FLAVOR

≡ "PARTIAL COMPOSITENESS"

Kaplan '91
Gherghetta, Pomarol '00
:

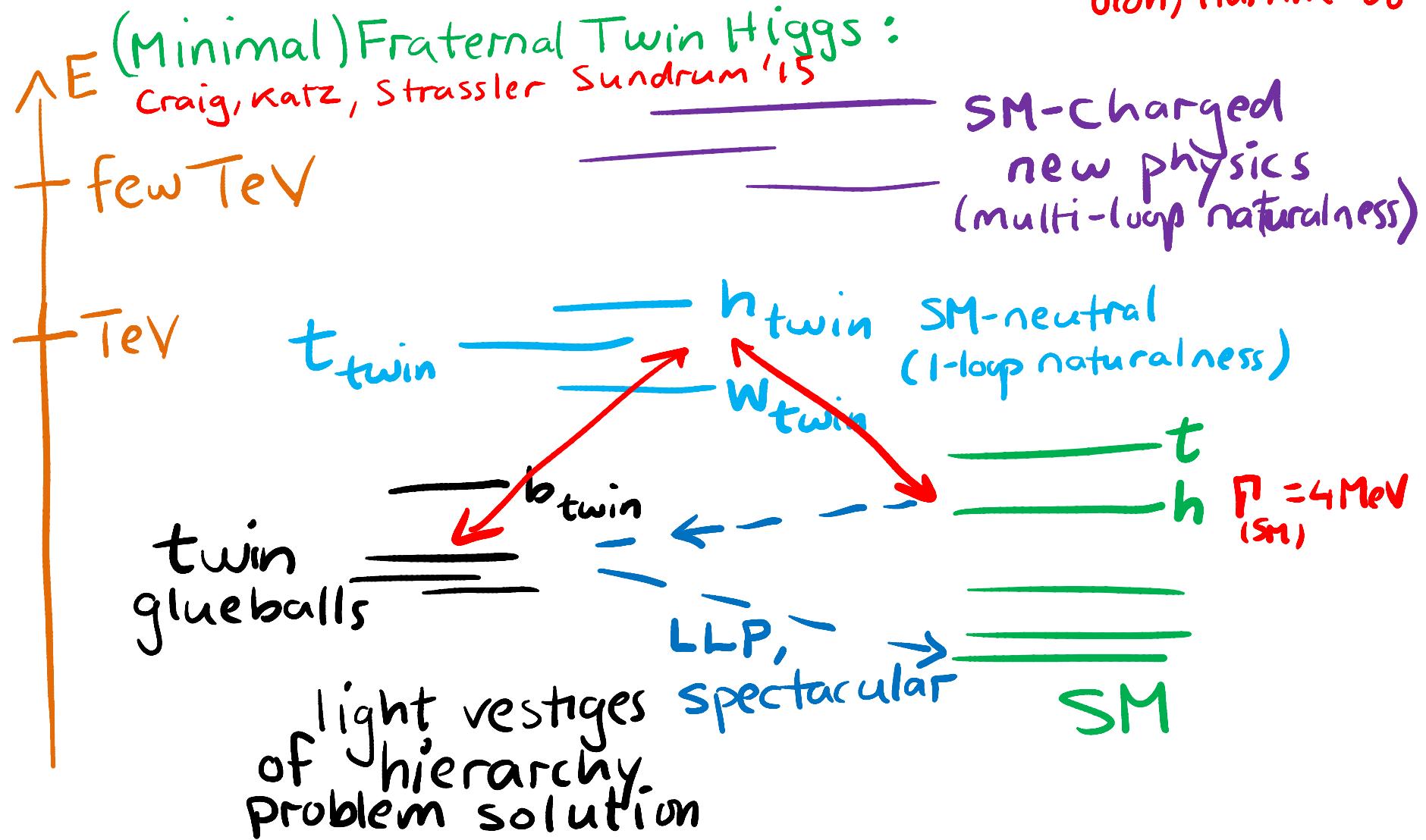


Powerful generalized GIM
 but flavor/CP/EW tensions
 persist for $m_{KK/composites} \lesssim \text{TeV}$.
 Tensions disappear $m_{KK/comp} \gtrsim 10 \text{ TeV}$

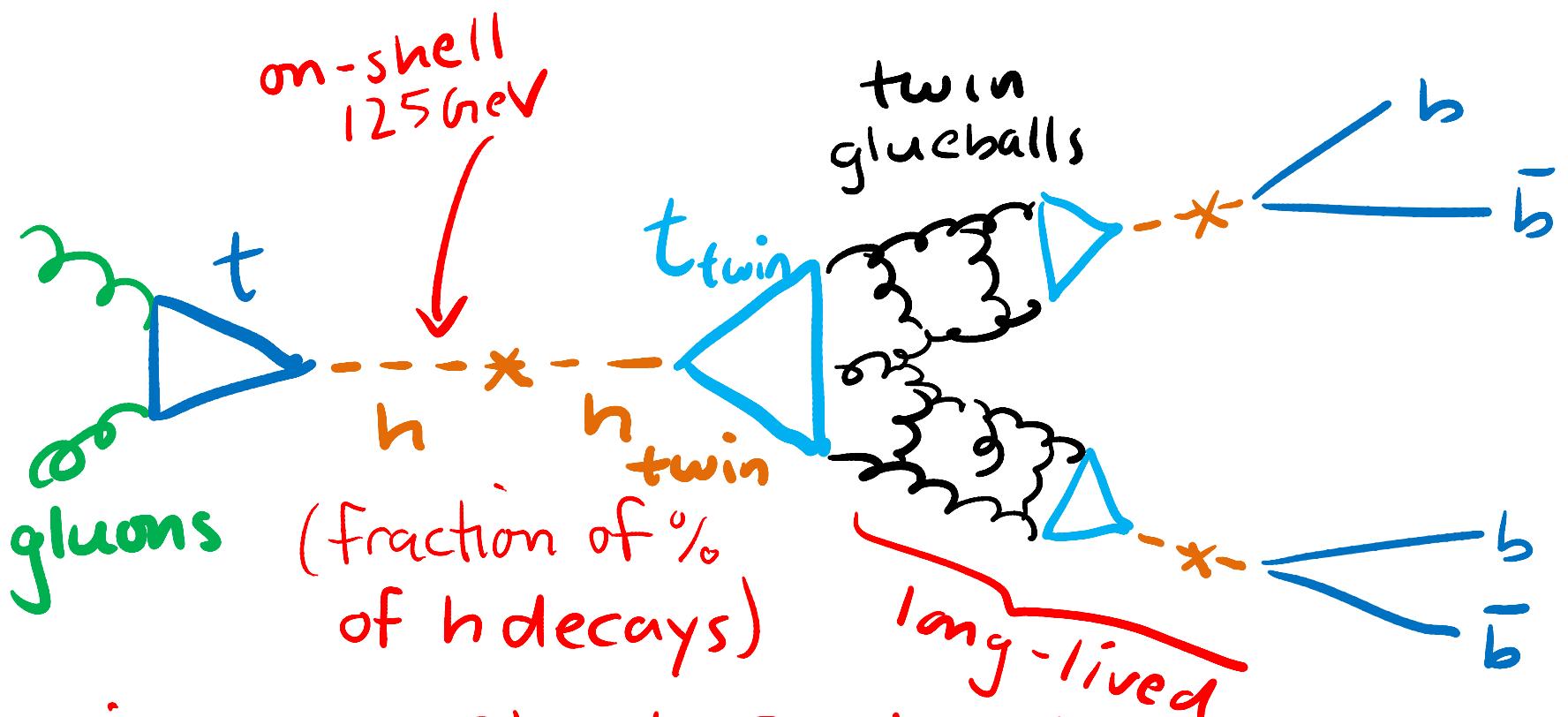


Neutral Naturalness

Twin Higgs Chacko, Groh, Harnik '06 Folded SUSY Burdman, Chacko, Groh, Harnik '06



⇒ Long-lived twin glueballs



Craig, Katz, Strassler, Sundrum '15
(presaged by Juknevich '10)

FOLDED SUSY variant: Curtin, Verhaaren '16

LLPs AS CONTROL KNOBS OF THE UNIVERSE

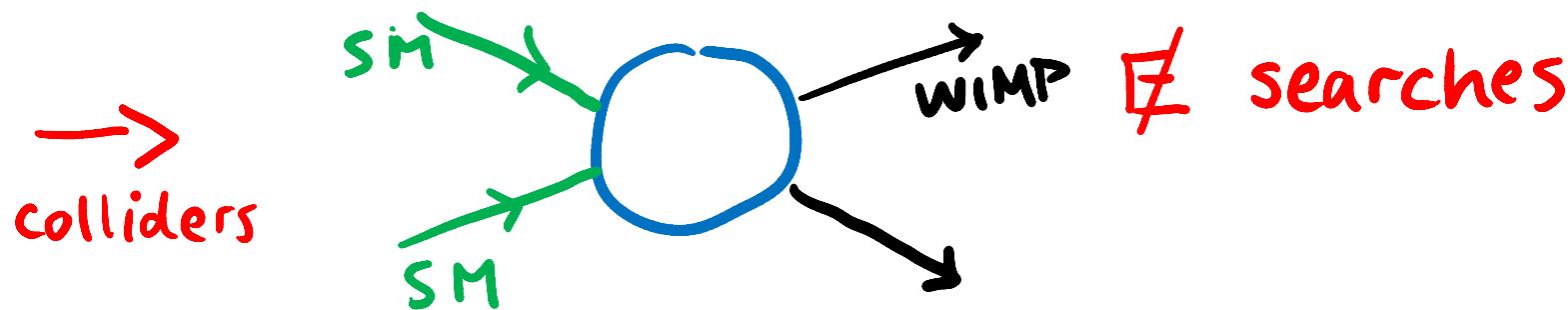
LLPs can naturally decay out of equilibrium in the Early Universe, changing its course & contents

THE OTHER WIMP MIRACLE

Dark Matter WIMP Miracle:

Thermally produced stable WIMPs
with \sim weak-ish annihilations
would freeze out of equilibrium
to \sim observed abundance

$$\Omega_{\text{WIMP}} \approx \Omega_{\text{DM}} \left(\frac{g_{\text{weak}}}{g_{\text{WIMP}}} \right)^4 \frac{m_{\text{mediator}}^4}{m_{\text{WIMP}}^2 \text{TeV}^2}$$

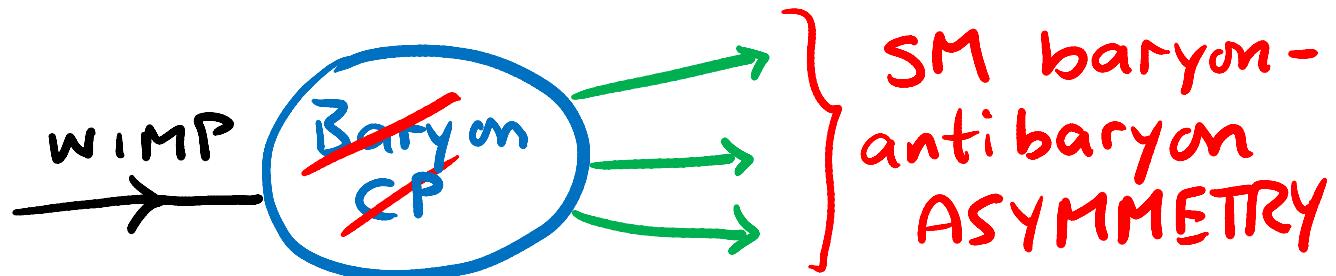


THE OTHER WIMP MIRACLE

Baryogenesis for WIMPs Cui, Sundrum
'13

Thermally produced metastable WIMPs with weakish annihilations would freeze out of equilibrium to $\sim \Omega_{\text{WIMP}}$

BUT LATER



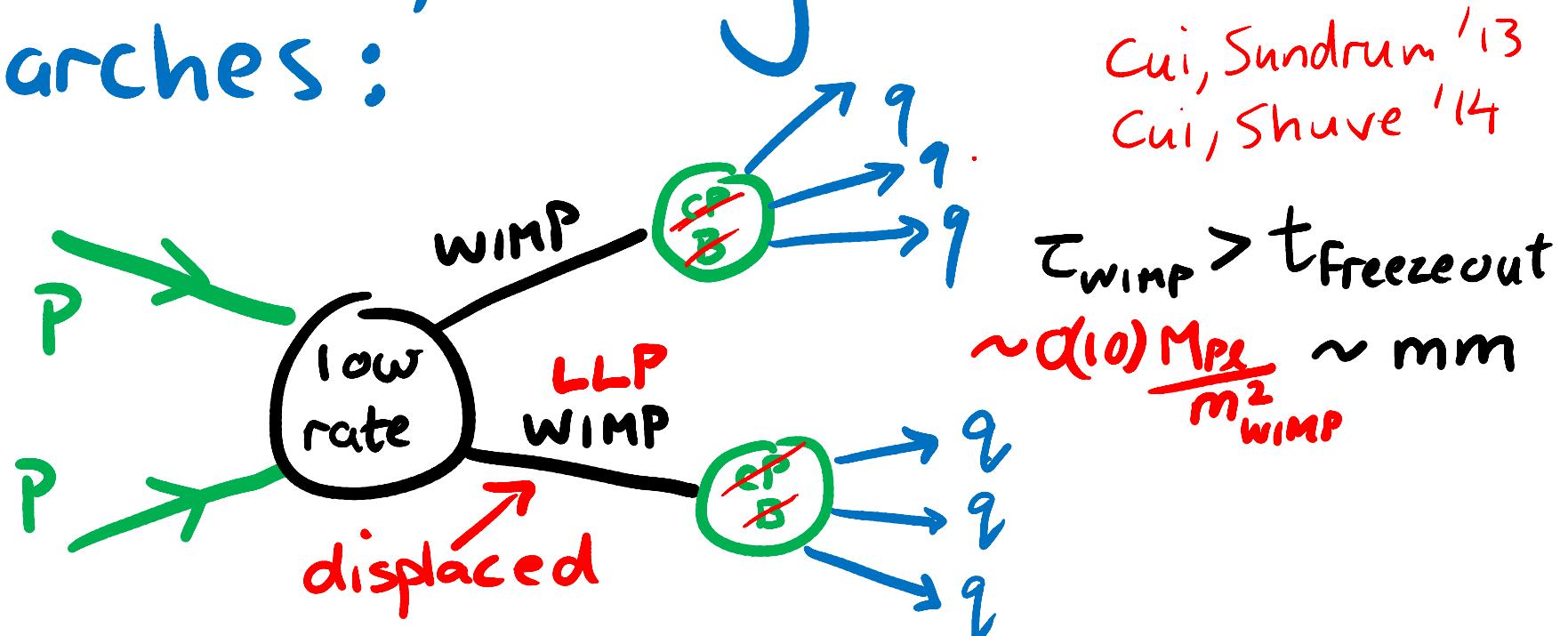
$$\Omega_{\text{baryon}} = \sum_{\text{baryon}}^{\sim \frac{1}{16\pi^2}} \left(\frac{m_{\text{baryon}}}{m_{\text{WIMP}}} \right) \Omega_{\text{WIMP}}$$

$\sim \Omega_{\text{baryon, observed}}$

FINDING OUR PARENTS

Baryogenesis WIMP \equiv Weak Scale LLP

Another robust WIMP search
for LHC, analogous to DM
searches:

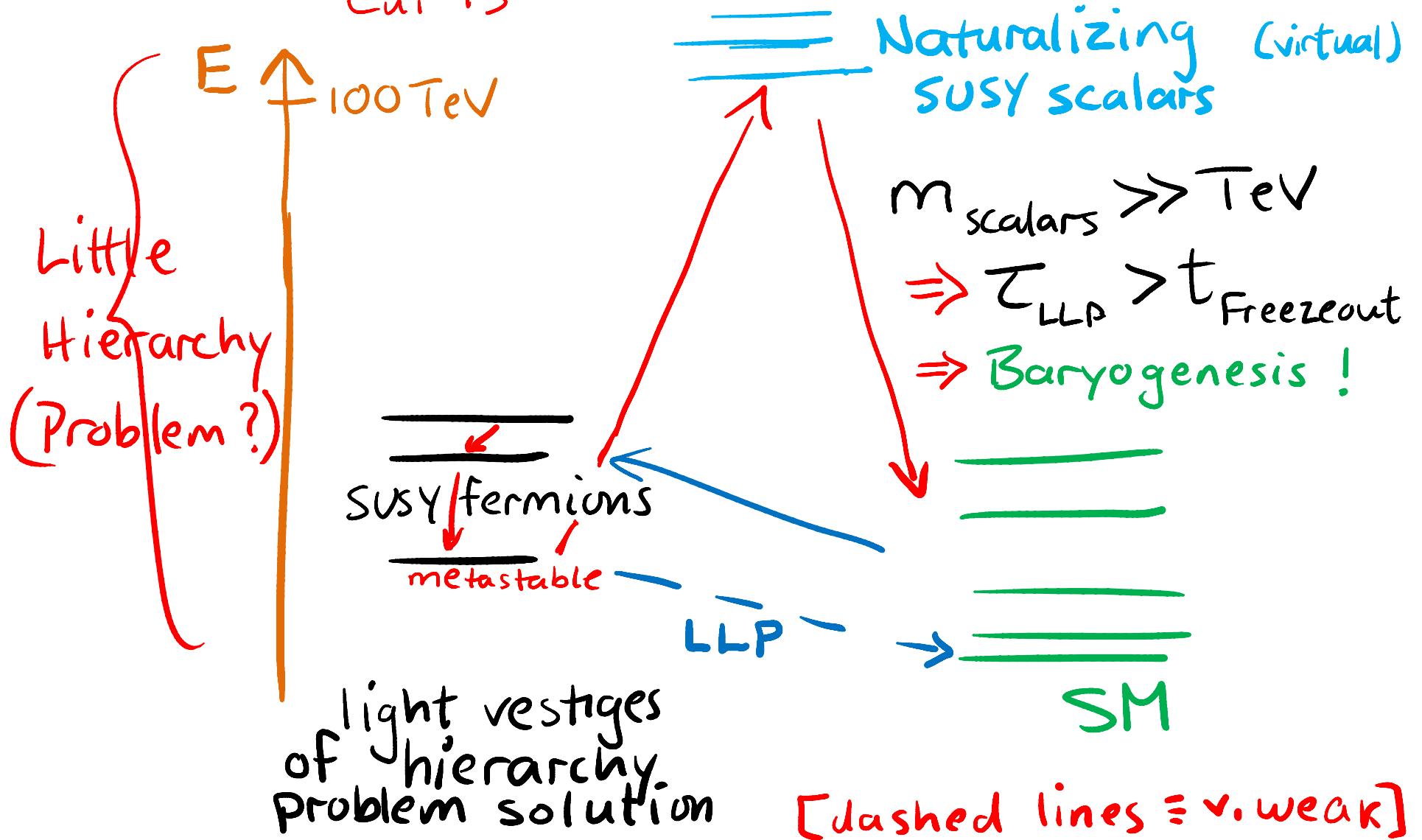


PHILOSOPHICAL INTERLUDE . . .

IF A TREE FALLS IN THE
FOREST, BUT NO ONE
IS AROUND TO HEAR IT,
DOES IT MAKE A SOUND?

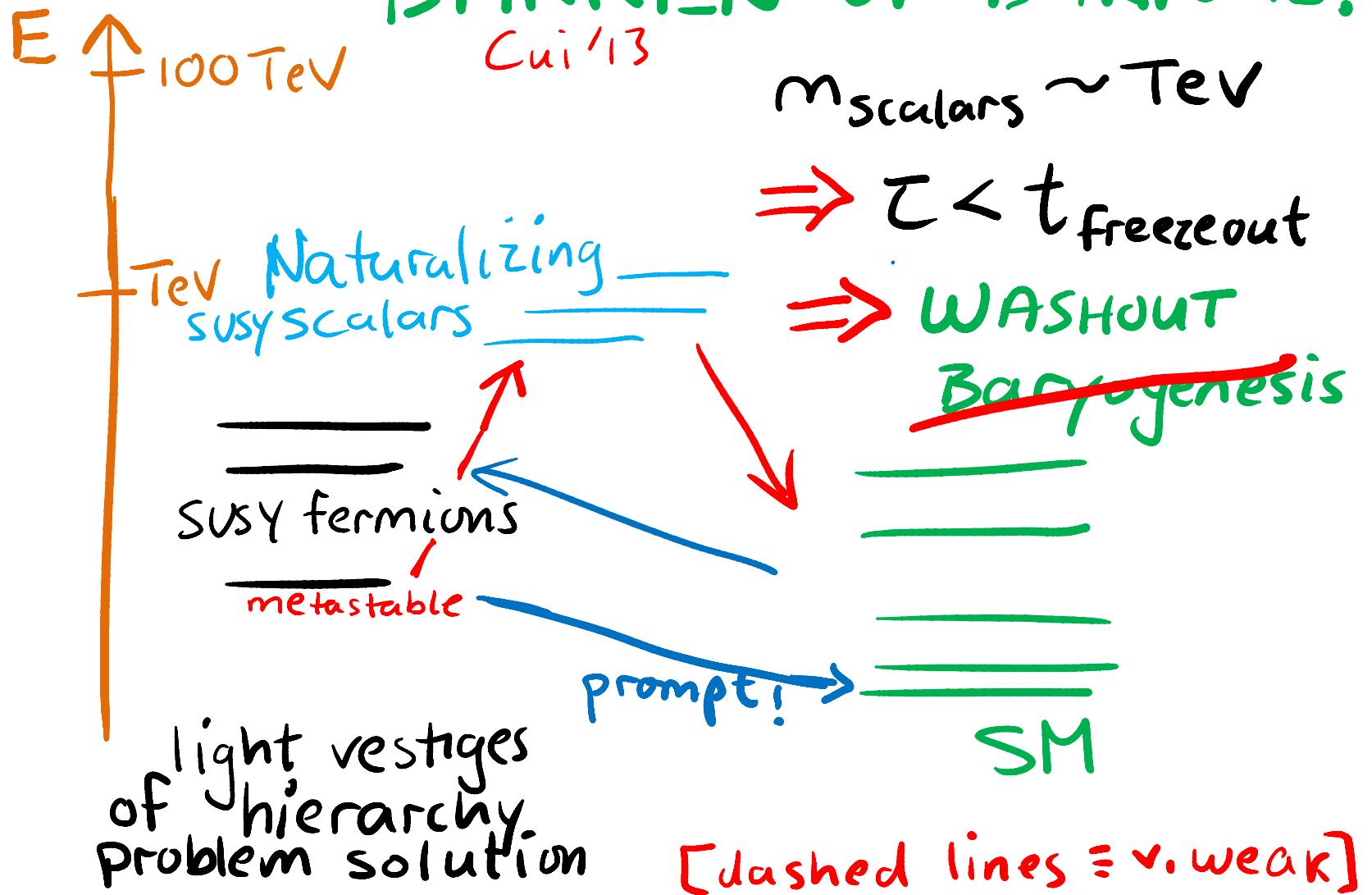
\exists natural (non-minimal SUSY) WIMP Baryogenesis models
Cui, Sundrum '13

But RPV MSSM realization \Rightarrow natural vs. anthropic tension
Cui '13



\exists perfectly natural parts of MSSM parameter space
(Multiverse) but they are

BARREN OF BARYONS!



CONCLUSIONS

- There is a massive ongoing hunt for dark sectors/particles in expts. on dark matter, dark force, dark radiation, dark phase transitions eg. giving stochastic background grav. waves Schwaller '15
- The high energy LLP program fits beautifully into this hunt, with unique phenomenological visibility.
Together, they form a classic, heroic investigation of FUNDAMENTAL NATURE

\sim TeV Scale LLPs

strongly motivated

- by NATURALNESS

even (especially) imperfectly realized

- as central players in Early Universe
(even if only bit players in naturalness)

Theoretical Structures \supset LLPs

are robust within Gauge Field Theory

THEY ARE A GOOD BET!