



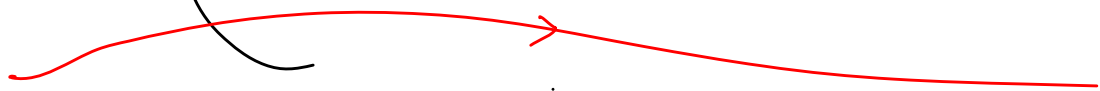
Connecting Fundamental Theory



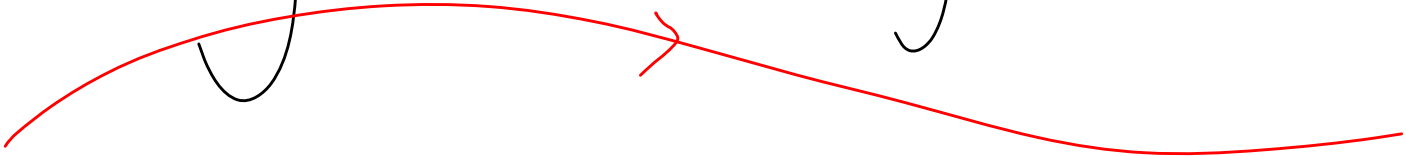
to the



Real World



"Ming Vase" Unification



	$SU(3)_c$	\times	$SU(2)_L$	\times	$U(1)_Y$
Q	3		2		$+\frac{1}{6}$
U^c	$\bar{3}$		-		$-\frac{2}{3}$
D^c	3		-		$+\frac{1}{3}$
L	-		2		$-\frac{1}{2}$
E^c	-		-		+1

3 coupling strengths

\cup

Grand Unification

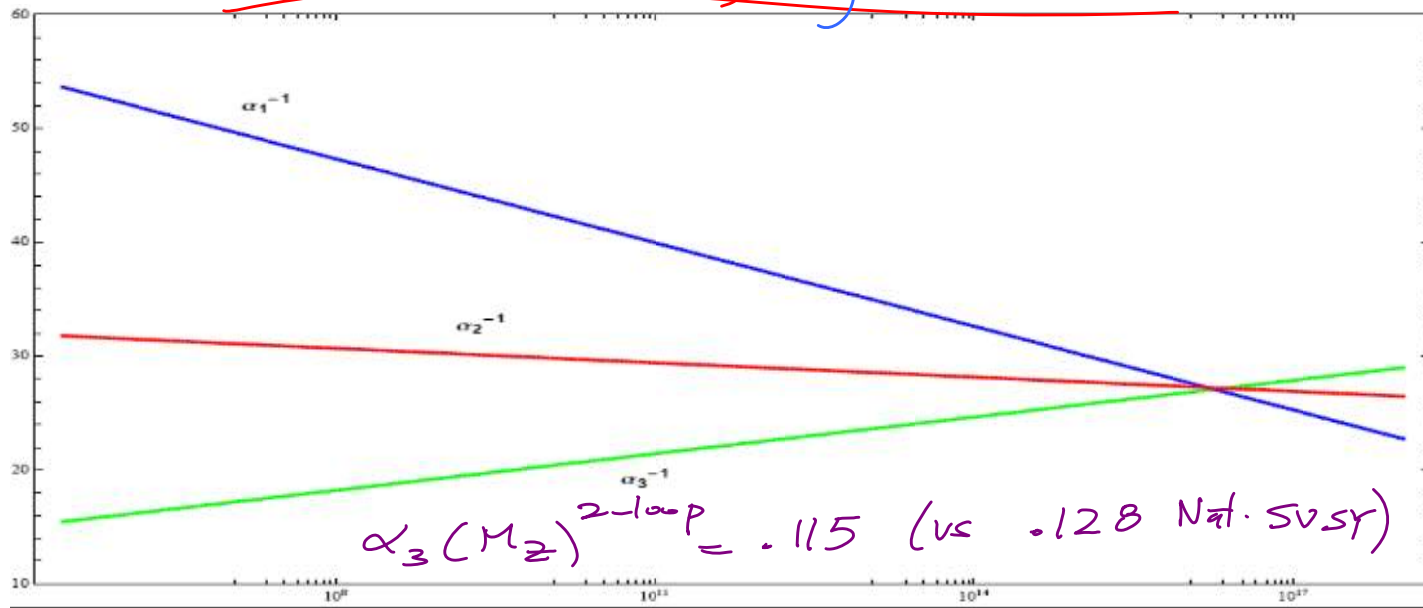
$\bar{5} + 10$ of $SU(5)$!

} 1 coupling strength!

\cup

16 of $SO(10)$! $[- + + - +]$

SUSY Unification

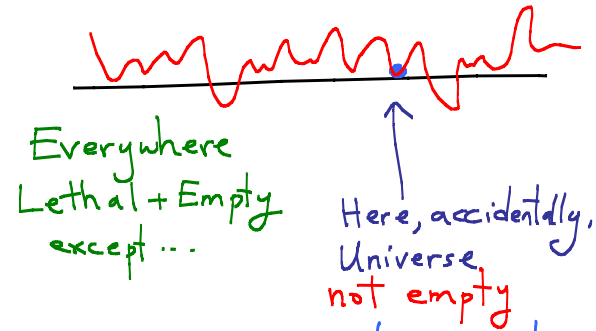
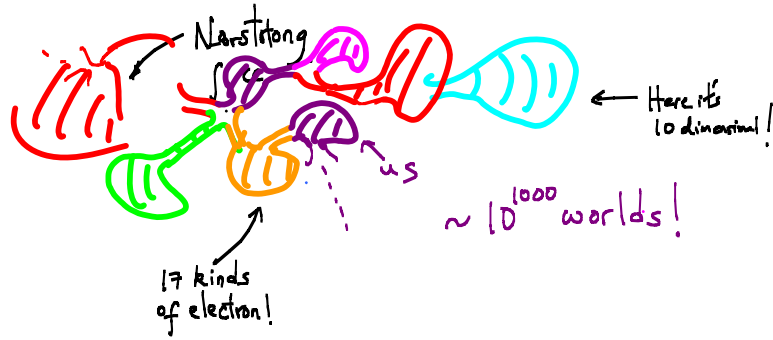


Unified forces close to String Scale!

Stabilizes Weak Scale, WIMP DM

Where The $\chi!P\chi$ Are

SUSY + WIMPS?



Even more extreme unification!

[But not "Ming Vase" hope—naively dead here]

Note: Now $\sim 5\sigma$ "Hubble Tension" could potentially demolish this picture

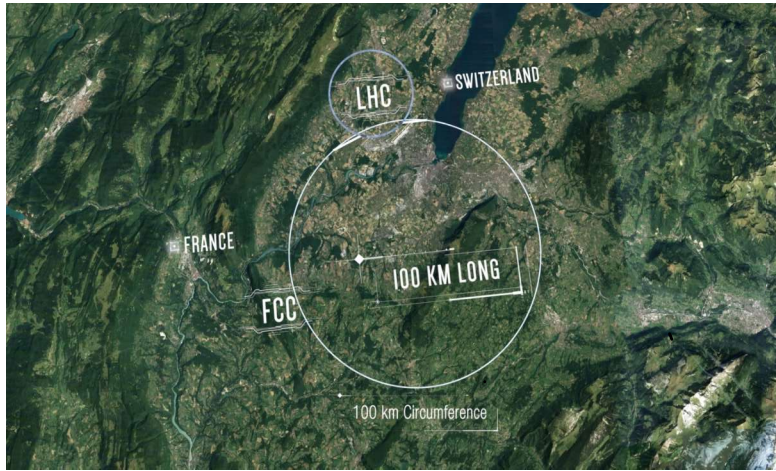
Some Experimental Frontiers

- * High Energy
- * Higher dim ops + broken symmetry
- * Weakly coupled light states

Future Colliders



100 Km Circular Collider

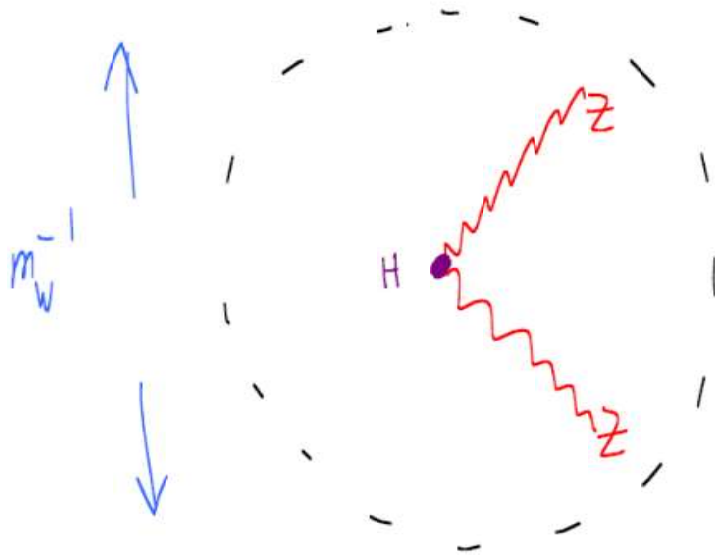


FCC ee
hh

CEPC
SPPC

Higgs Factory + 100 TeV Collider

Never Seen Pion-Like Scalar

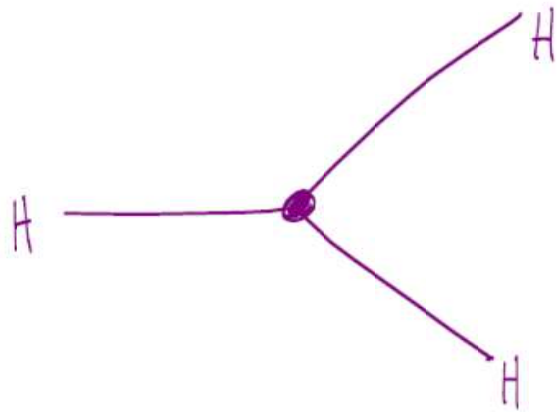


Higgs Factory
+

We will know

FOR SURE
if it's "like a Pion"

Never Seen Self-Interacting Fundamental Particles



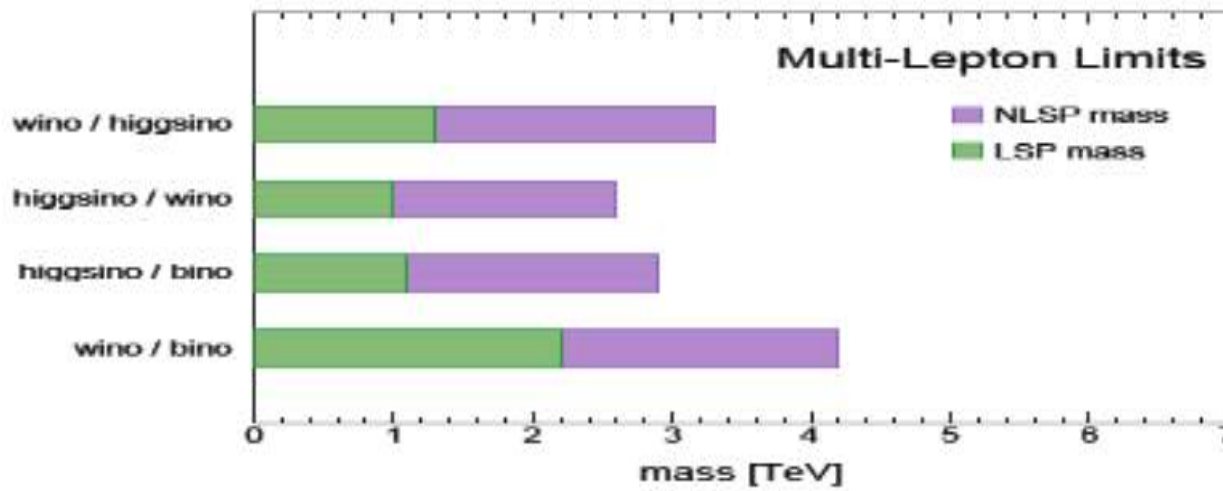
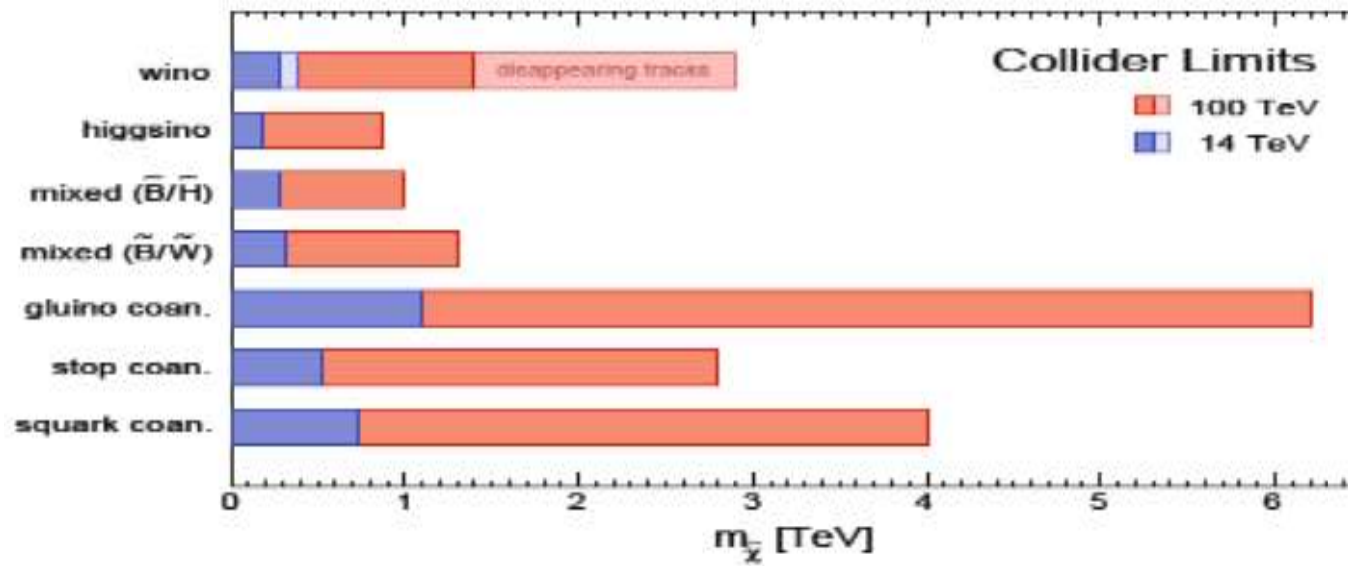
100 TeV Collider

Measured to $\sim 5\%$

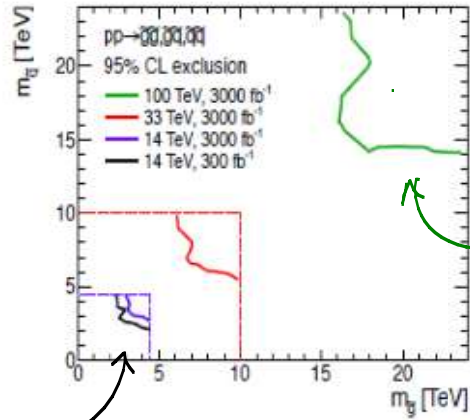
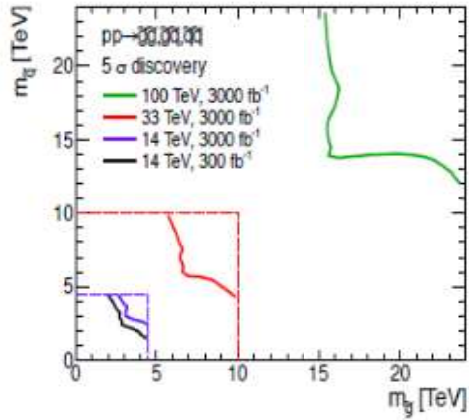
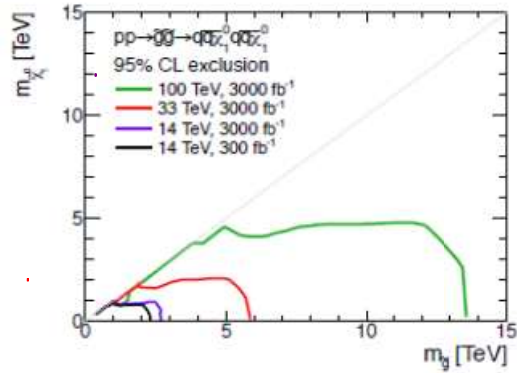
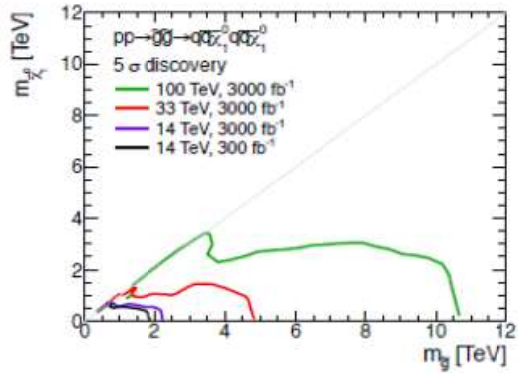
WIMP Dark Matter

- * Still our only **calculable** model of DM
- * Simplest models are alive + well!
 - Doublet "Higgsinos" $\sim 1 \text{ TeV}$
 - Triplet "Winos" $\sim 3 \text{ TeV}$
- * Too heavy to be produced @ LHC, have tiny ($\sim 10^{-46} - 10^{-47} \text{ cm}^2$) direct detection σ .
- * Needs 100 TeV pp collider to make them!

Robust Coverage For WIMPs




SUSY Can't Hide



100 TeV
Collider

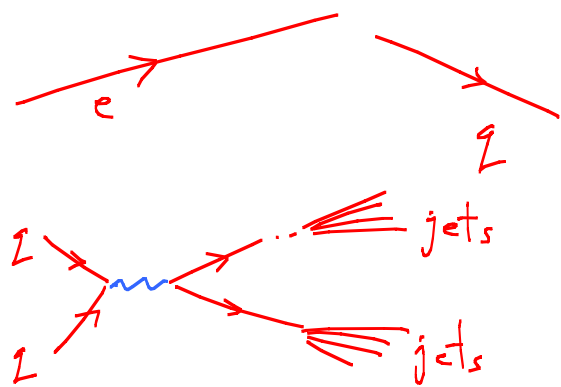
LHC

Inflation + "Cosmological Collider"

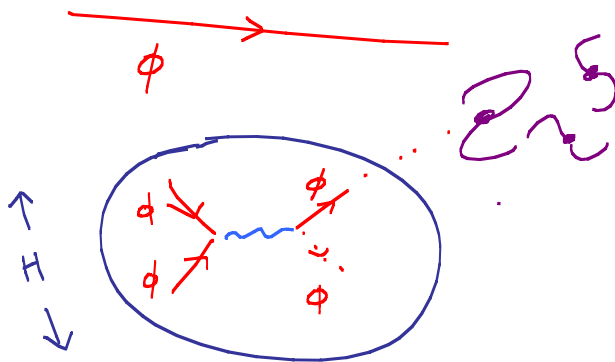


* Inflationary Gravitational Waves $r \sim 10^{-3}$

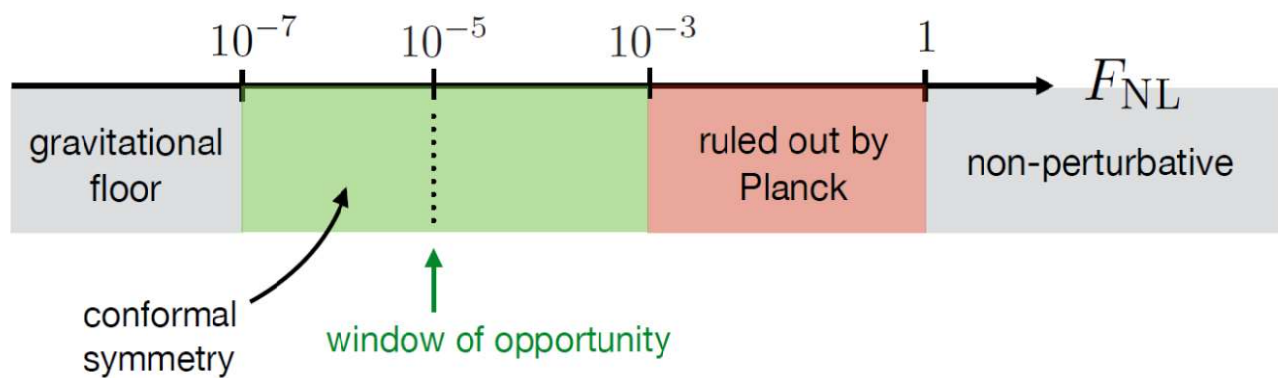
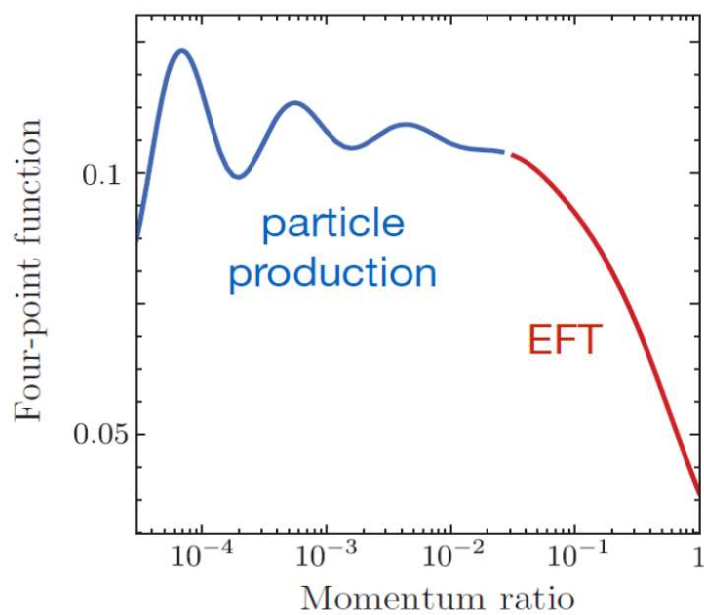
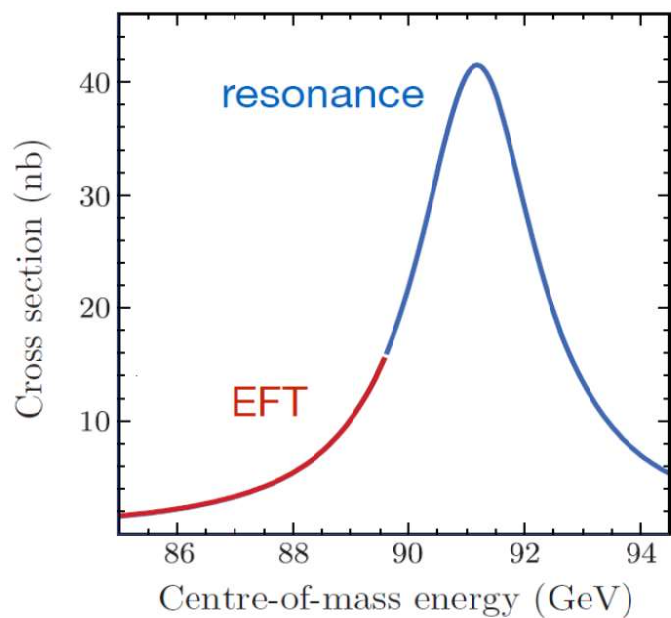
* Possible access to physics up to $H_{\text{inf}} \sim 10^{14}$ GeV



New Particles in
accelerators from
features in cross-sections



New Particles from
patterns in non-Gaussianities




Higher \mathbb{D} im. \mathcal{O}_S

* Proton decay: hyper-K can improve by factor of ~ 10 ; then atmospheric ν floor. [c.f. ν floor for WIMP detection].

* Most exciting: ACME bound on electron edm = 10^{-29} ecm (!!). Claim 10^{-32} ecm feasible in \sim decades (!!!!!)

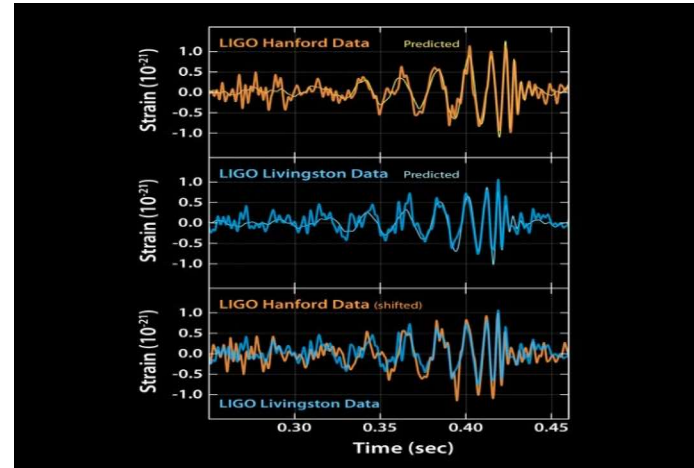
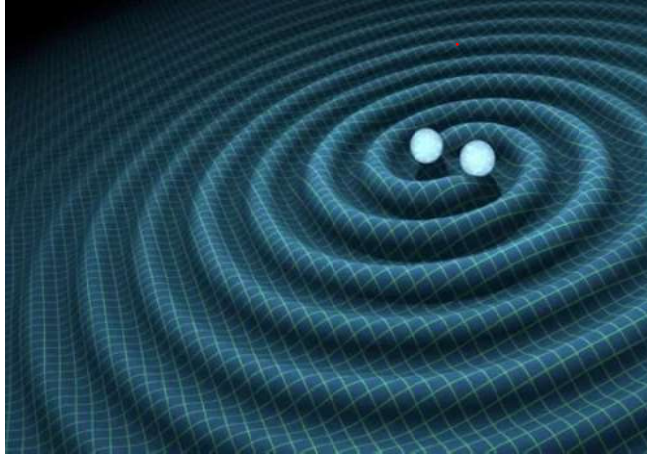
Sensitivity to 2-loop up to $\sim 10^{2-3}$ TeV!

^{1/2}
Weakly Coupled Frontier



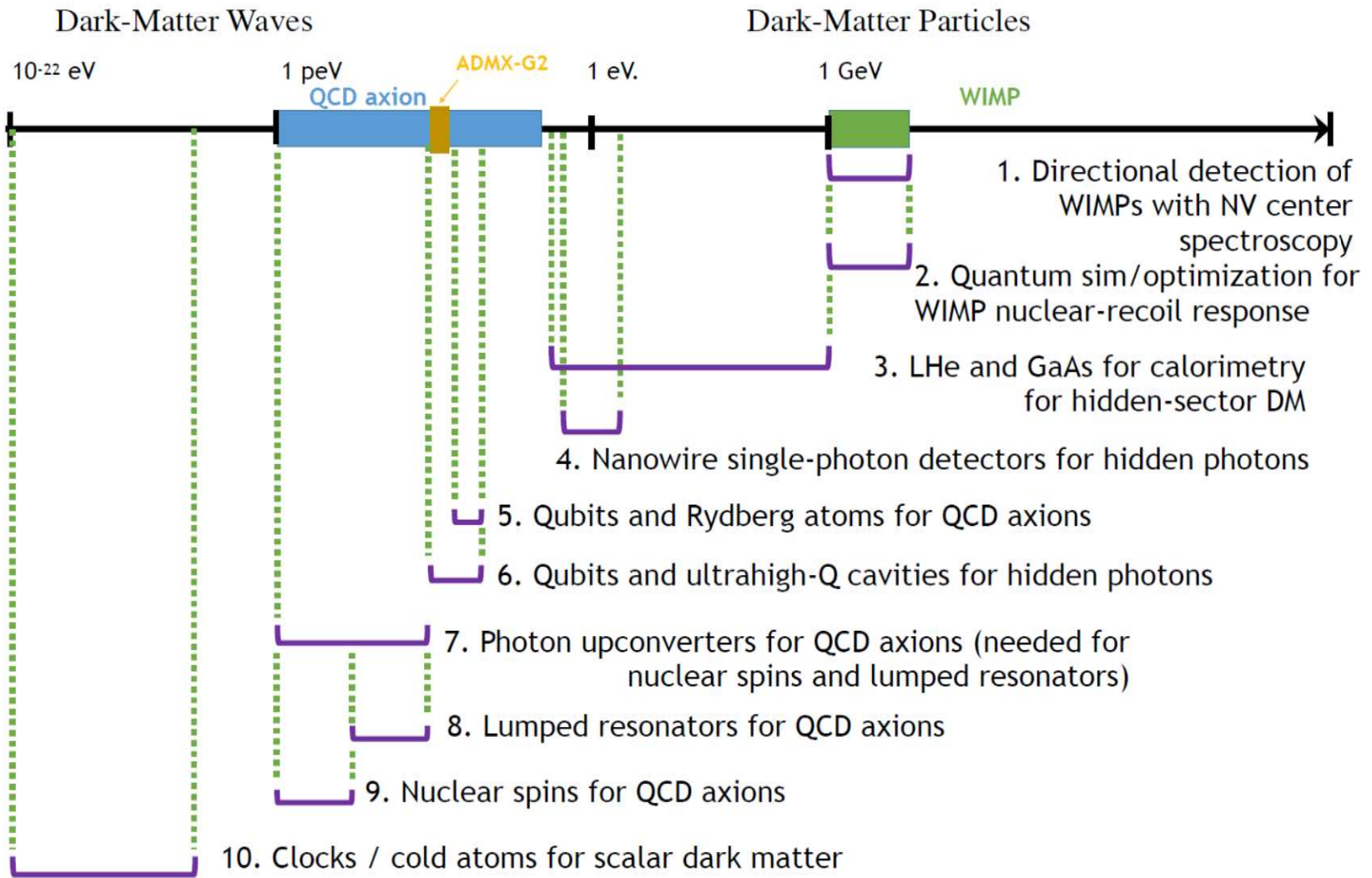
*

Gravity Waves!





Direct Probe of Colliding Horizons

* Novel proposals for Atom Interferometers on earth + in space to look for GW.



Axions

* A_s DM:  

Collectively can probe $f_a \rightarrow M_{\text{str}}$!

* If not DM: spinning down (near-extremal)
Kerr BH's by super-radiance,
 $m_a^{-1} \sim 10 \text{ km}$

My Own Best Bet

(Since ~ 2004/2005)

Minimal Split SUSY

Minimal Split SUSY

Reason
for splitting:
fermions
carry R symmetry,
scalars don't

100's
TeV

TeV



Scalars

Unification ✓

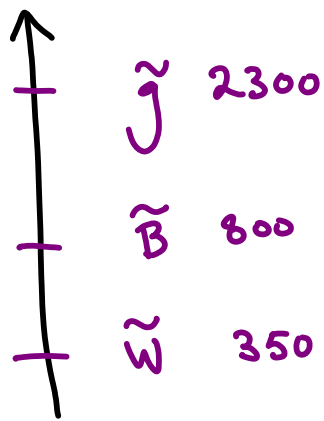
Dark Matter ✓

No Flavor,
CP, moduli, ...
problems

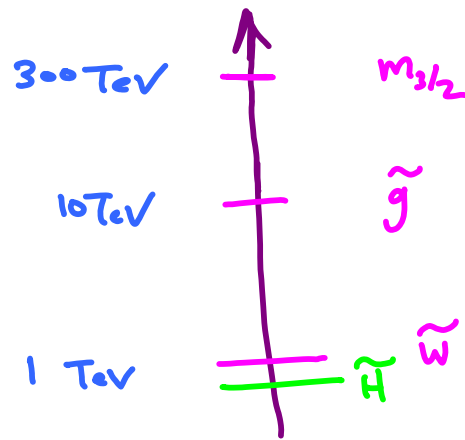
Fermions

Correctly predicted

$$120 \text{ GeV} < m_h < 135 \text{ GeV}$$

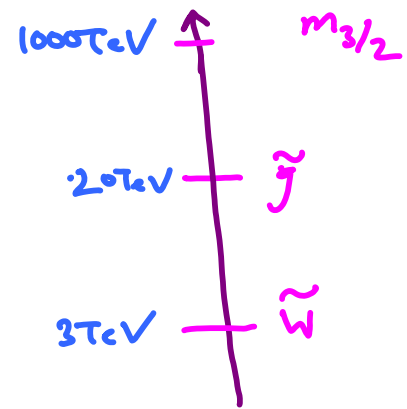


LHC Accessible

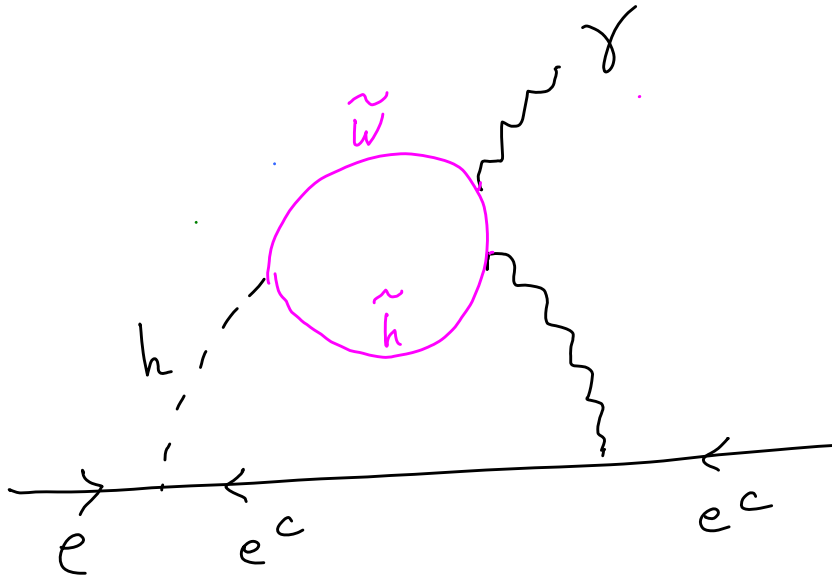


LHC Inaccessible

Also simplest WIMPS!



Within Reach of 100 TeV Collider



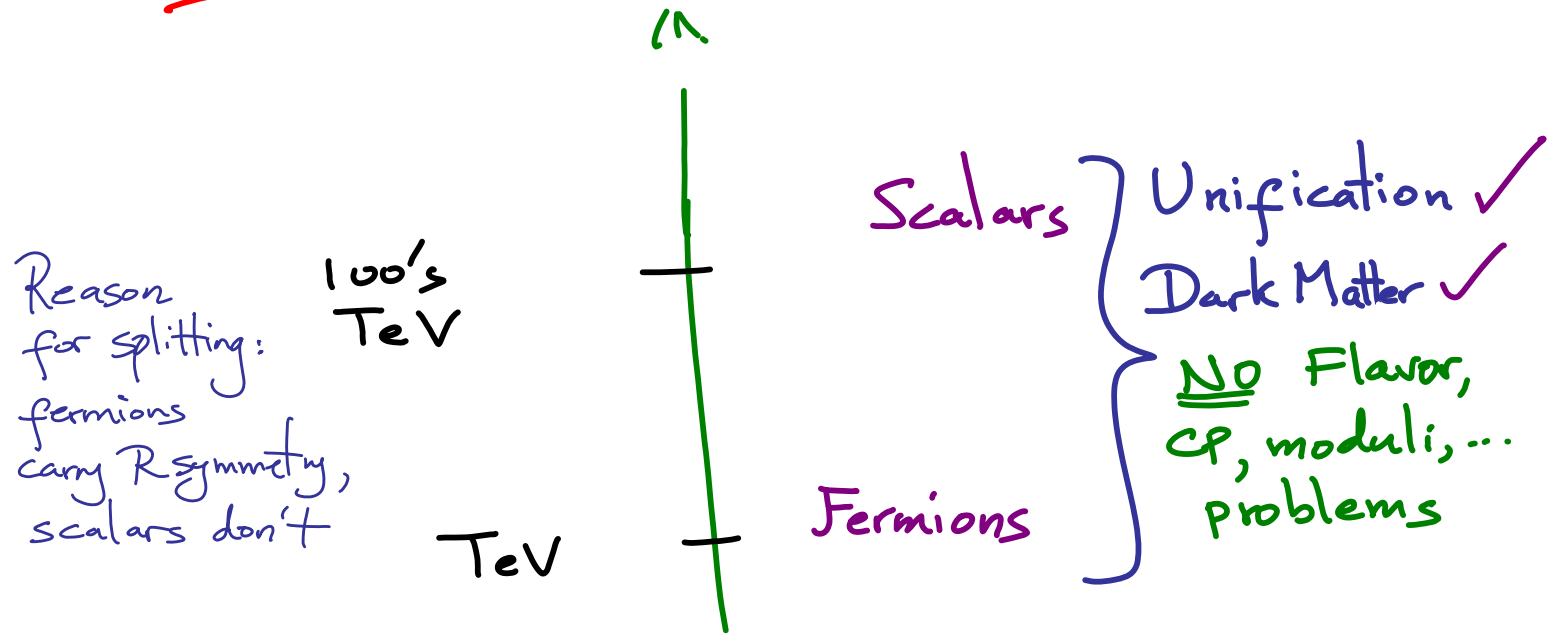
EDM in Split SUSY (max ϕ)

$$d_e \sim 10^{-28} \rightarrow 10^{-32} \text{ ecm}$$

↑ minimal split

Sensitivity to 2-loops up to $\sim 10^{2-3} \text{ TeV}$

Minimal Split SUSY



Crazy Without Landscape, Reasonable with it

Funny Clues?

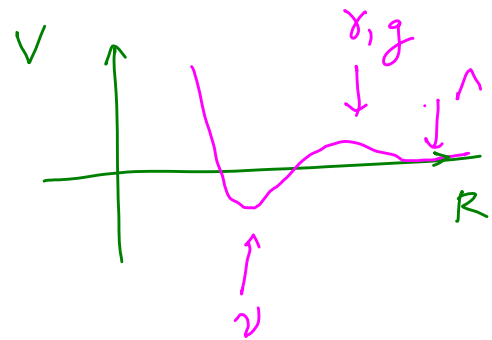
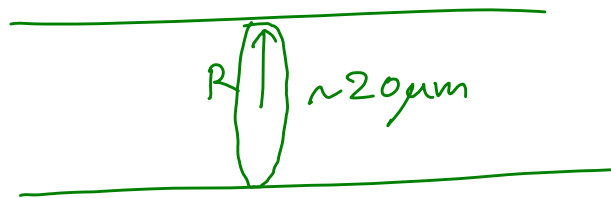
* $\sin \theta_c = \sqrt{\frac{m_d}{m_s}}$

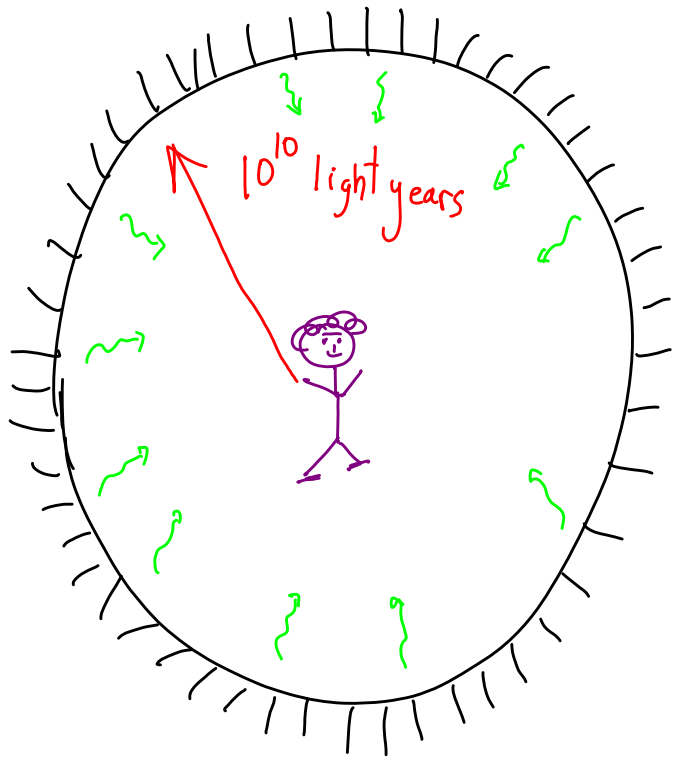
$\lambda = \begin{pmatrix} 0 & A \\ A & B \end{pmatrix}$ textures

* $\Lambda^{1/4} \sim \frac{m_W^2}{M_{pl}} \sim m_\nu$

* SM just barely has $AdS_3 \times S_1$ vacuum

$L_{AdS_3} \sim \frac{1}{3} H^{-1}$

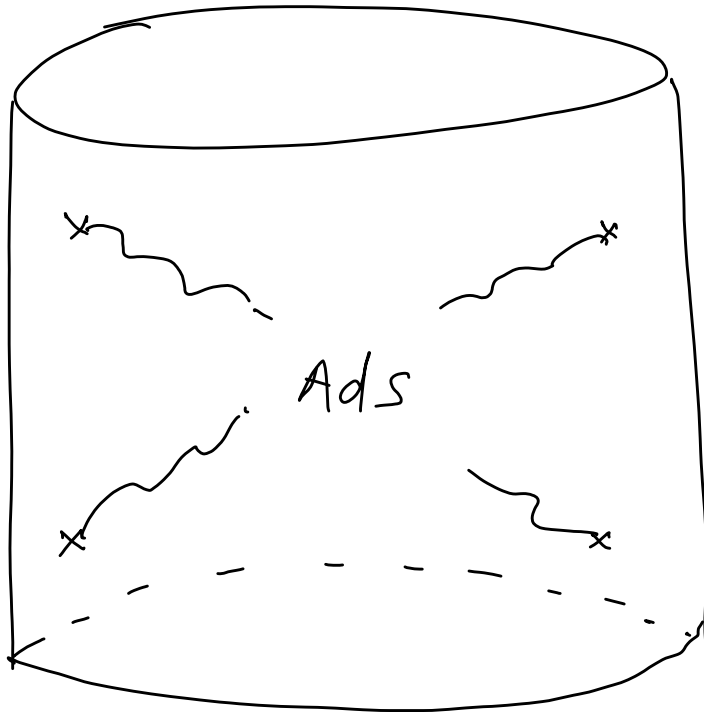




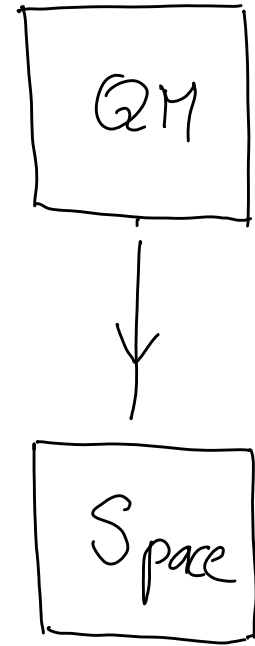
What are
the correct
observables??

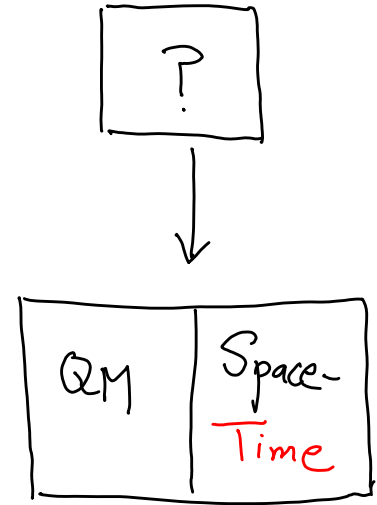
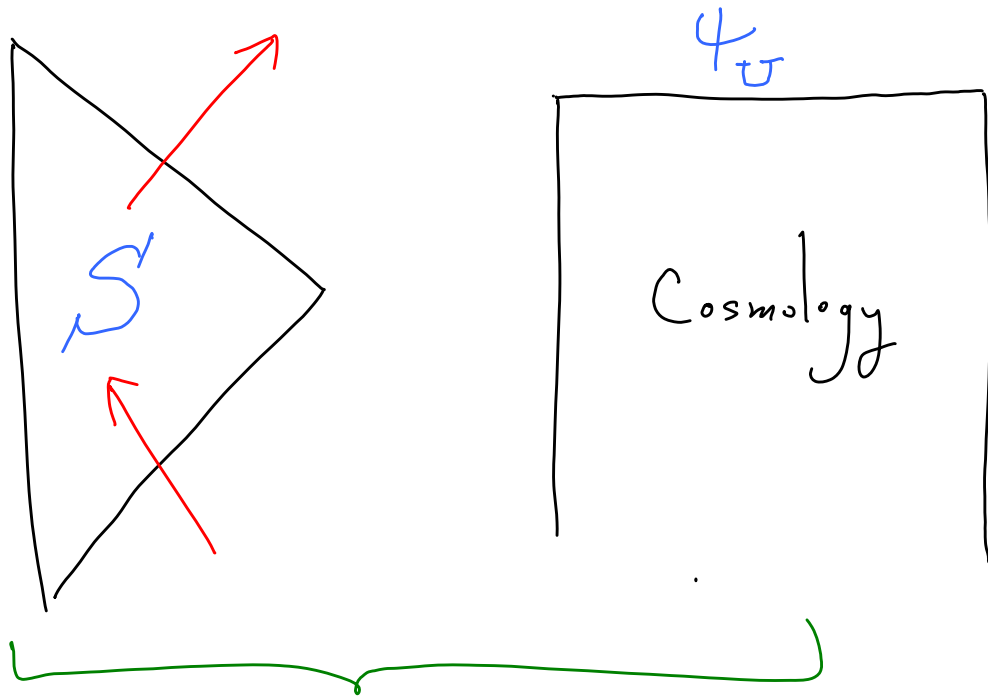
Emergent
Extension of

Space-Time
Quantum Mechanics?



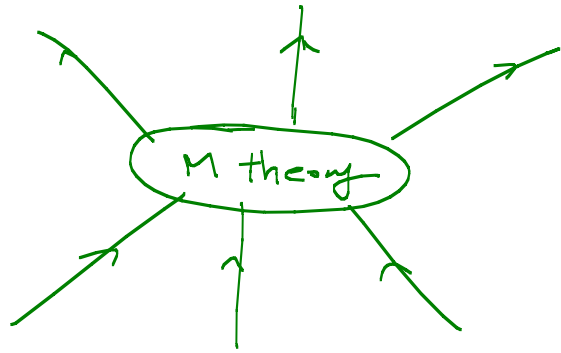
↑
time



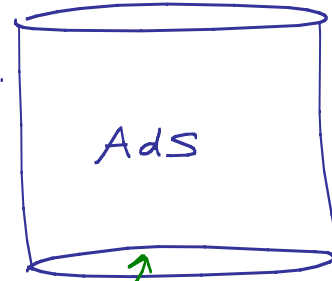


Unlike 2AdS, no
obvious notion of time+locality

Big Tension



v.s.



Any
Quantum
Theory

One Unified Theory!
Landscape of connected
solutions. UNIFIED
in FLAT SPACE

Is a different
theory in AdS!

Dream: more universal/unified "bulk" description.
Likely less "manifestly QM". Likely more abstract,
less familiar principles. Strategy: study flat space
S-matrix without shackles of QM, ST ideas to
get a hint of what these more abstract ideas are like.

The Canvas

* Physical momenta

* "Twistor" variables

* "Celestial Sphere"

⋮
* Spatial Future

Kin. Space
 $\sim \mathcal{D}$ Minkowski

(Amps)

(Ψ_{Univ})

What ideas
breathe
physics-life
into this
space?

The Canvas

* Physical momenta	Kin. Space $\sim \mathcal{D}$ Minkowski
* "Twistor" variables	(Amps)
* "Celestial Sphere"	
⋮	
* Spatial Future	(Ψ_{Univ})

Emerging Picture:

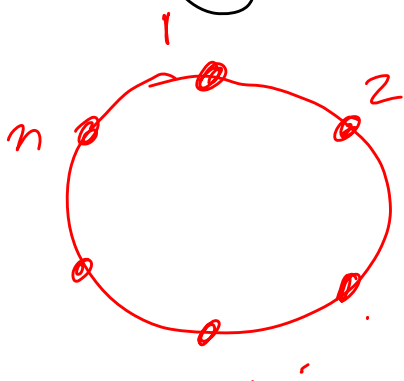
Combinatorics

Positive Geometries

Canonical Forms

- * Amplituhedra, Associahedra, Cosmological Polytopes, ...
- * Describes real-world physics in reasonable approx,
exposes hidden symmetries + structures - there
is hidden magic in the real world under our noses.

These structures are deeply connected to
 + generalize stringy ideas.



$G_+(2n)$, $G_+(2n)/T$
 Twistor Strings String WS/Assoc.

Cluster
 $A+X$
 varieties



Amplituhedron

$G_k [m, k]$
 winding # = 4.

A Long-Shot Fantasy

There is a dual formulation of physics that represents physical amplitudes/observables in terms of "integrals over abstract geometries" as we've seen with positive geometries.

In this formulation — $\Lambda + m_h^2$ obviously exp. small | But not obviously "local physics". Another formulation separates into different number-theoretic parts + looks like local physics — But "appears fine tuned".

Tuning + Transcendentality

UV-sensitivity + hierarchy problem:

$$V^{1-loop} = \text{STr } M^4(k) \log M^2(k)$$

$$= \lambda_t^4 h^4 \log(\lambda_t h^2) + \underbrace{(M_{\text{Pl}}^2 h)^4 \log(M_{\text{Pl}}^2 h)^2}_{\text{UV states}}$$

Why should "tree"
cancel "loop"?

$$\subset \lambda^2 M^2 h^2 + \dots$$

Calculable...

+

Tree = "Rational"

Loop = "Transcendental"

... but long known "funny tunings" in
QFT computations

e.g. $\Gamma(\text{positronium}) = \dots \times \underbrace{\left(\frac{\pi^2}{11} - 9\right)}_{\text{Accidentally Small?}}$

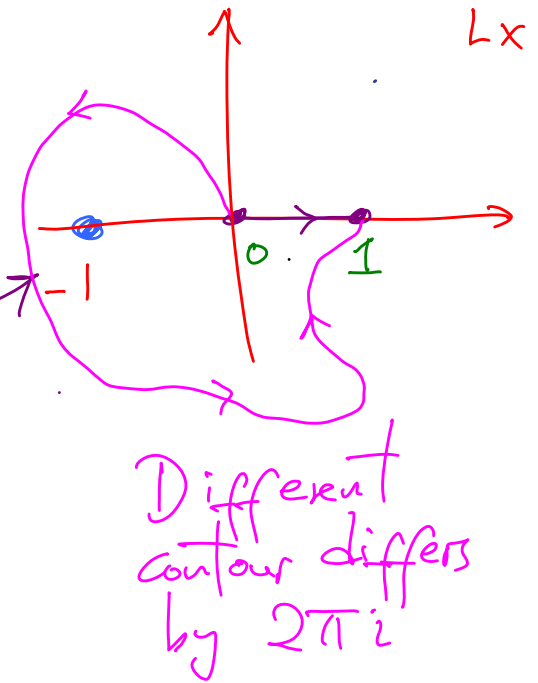
No! There is a mechanism @ work here....

Rational Approximations to Transc. Numbers

$$\log 2 = \int_0^1 \frac{dx}{1+x}$$

↑
transcendental

↑
because
of simple
pole @ $x=-1$



$$\text{So } I = \int_0^1 \frac{dx}{1+x} \cdot P(x) = P(-1) \log 2 + \text{Rational}$$

$$\int_0^1 \frac{dx}{(1+x)} \left[\frac{x(1-x)}{2} \right]^N = \pm \log 2 + \text{Rational}$$

$\underbrace{\hspace{10em}}_{< \left(\frac{1}{8}\right)^N!}$

\Rightarrow Huge "Apparent tuning" \rightarrow Rational Approx to $\log 2$

e.g. $N=5$: $\log 2 - \frac{2329}{3360} \sim 10^{-5}!$

{ Same idea:

$$4 \int_0^1 \frac{dx}{(1+x^2)} \left(\frac{x(1-x)}{4} \right)^{4N} = \pi + \text{rational}$$

$$N=1$$

$$\pi - \frac{22}{7} \sim 10^{-3}$$

$$N=2$$

$$\pi - \frac{47171}{15015} \sim 10^{-6}$$

}

Concrete Example

$$F(h) = \int_h^1 \frac{dx (x-h)^4}{1+x} \left(\frac{x(1-x)}{2} \right)^N$$

$$V(h) = F(h) + F(-h)$$

$$= \underbrace{\sum_{\pm} (1 \pm h)^4 \log(1 \pm h)}_{\text{"UV loop"}} + \underbrace{\text{Rational}}_{\text{"free"}}$$

BUT GUARANTEED TO BE "TUNED"!

So e.g. $N=5$:

"tree"

$V(h)$

$$= \frac{142733}{102960} + \frac{97411 h^2}{73920} - \frac{1557 h^4}{560} + \frac{h^6}{15} + \frac{h^8}{140} + \frac{31 h^{10}}{20160} + \frac{h^{12}}{3960} + \frac{h^{14}}{160160} - \text{Log}[4] - h^4 \text{Log}[4] - 2 h^2 \text{Log}[64] + \underbrace{(-1+h)^4 \text{Log}[1-h] + (1+h)^4 \text{Log}[1+h]}_{\text{"1-loop"}}$$

$$= \left(\frac{142733}{102960} - \text{Log}[4] \right) + \left(\frac{614851}{73920} - 2 \text{Log}[64] \right) h^2 + \left(\frac{2329}{1680} - \text{Log}[4] \right) h^4 - \frac{h^{10}}{20160}$$

$$= 10^{-6} + 10^{-5} h^2 + \dots + h^{10}!$$

"tuned" Λ !

"tuned" m_h^2

Surprise: h^6, h^8 MISSING!

New Stakes for Precision Higgs

Signal for "tuning mechanism": not just m_h^2 looks tuned, but. pattern of higher-dimension corrections to higgs eff. theory might also look "fine-tuned".

Think About The Real World

(not primarily PUNITIVE,
but fundamentally CREATIVE)

