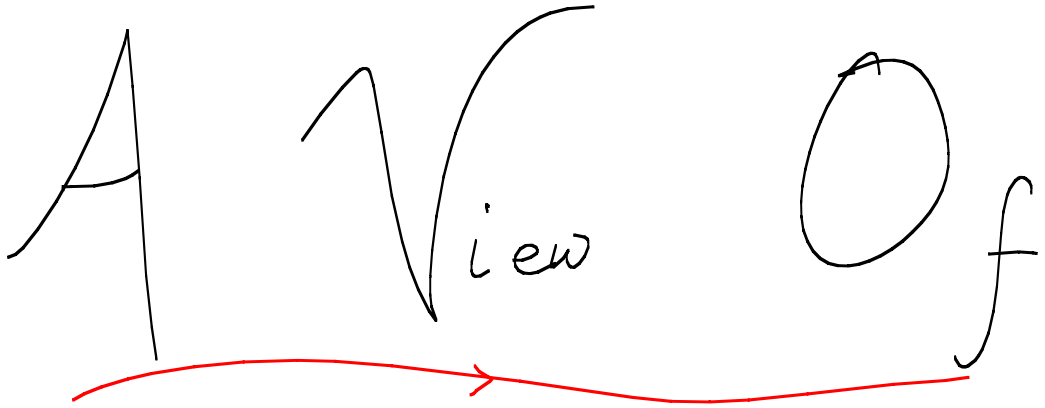
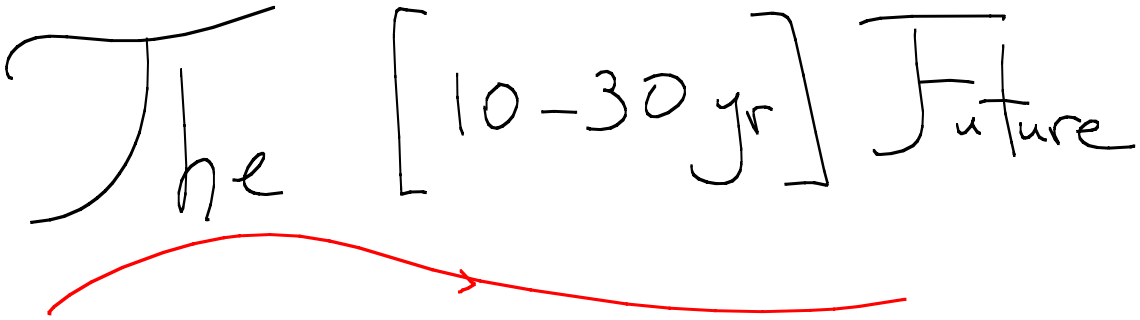

A View Of


The [10-30 yr] Future

We live in a BIG

Space-time, with light

elementary particles governed

by Q-M laws

Triumph of 20th Century

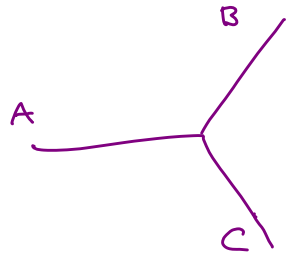
QM + Relativity

↓

Universe is Inevitable

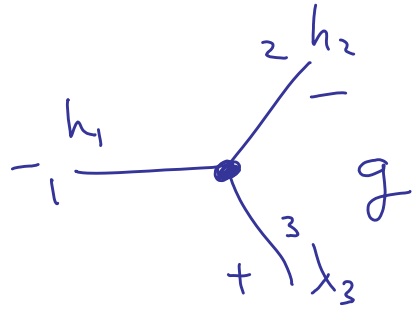
Massless Particles

$$p_{\alpha\dot\alpha} = \begin{pmatrix} p_0+p_3 & p_1-ip_2 \\ p_1+ip_2 & p_0-p_3 \end{pmatrix} = \lambda_\alpha \tilde\lambda_{\dot\alpha}$$



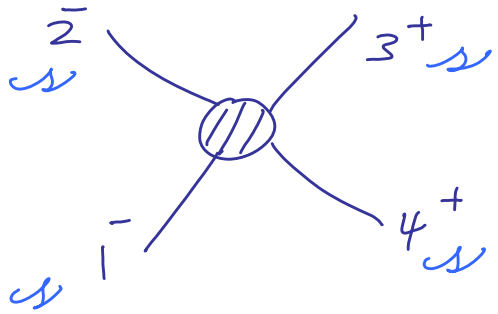
Either $\lambda_A \propto \lambda_B \propto \lambda_C$

$\tilde\lambda_A \propto \tilde\lambda_B \propto \tilde\lambda_C$

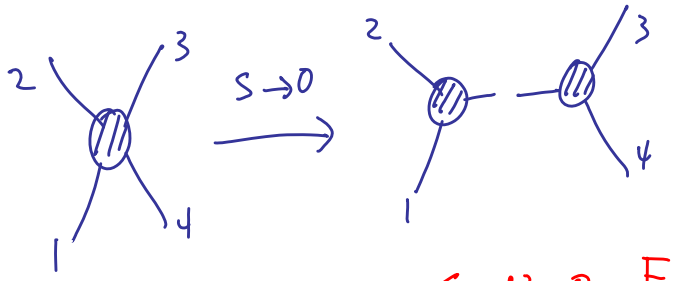


$$g\,\langle 12\rangle^{h_1+h_2-h_3}\langle 23\rangle^{h_2+h_3-h_1}\langle 31\rangle^{h_3+h_1-h_2}$$

COMPLETELY DETERMINED BY POINCARÉ



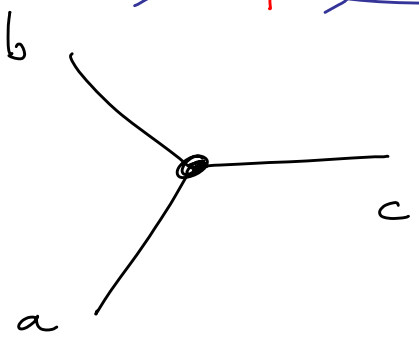
$$\left(\langle 12\rangle [34]\right)^{2s} F(s,t,u)$$



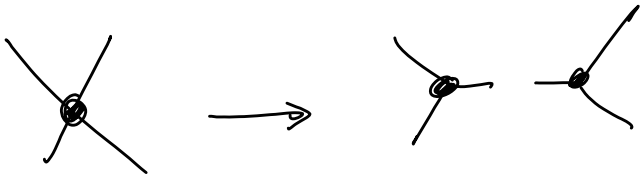
$$\Rightarrow F(s,t,u) \to \begin{cases} \frac{1}{s} \cdot \frac{g^2}{t^s u^s} \\ \frac{1}{t} \quad \frac{g^2}{u^s s^s} \\ \frac{1}{u} \quad \frac{g^2}{s^s t^s} \end{cases}$$

$$\Rightarrow \text{Only} \begin{cases} s=0, \; F = g^2\left(\frac{1}{s}+\frac{1}{t}+\frac{1}{u}\right) \\ s=2 \quad F = \frac{g^2}{stu} \end{cases} !$$

Spin 1



$(g\ f^{abc})$



$\Rightarrow f^{abc}$ satisfies Jacobi

Gauge "Symmetry" Does Not Exist

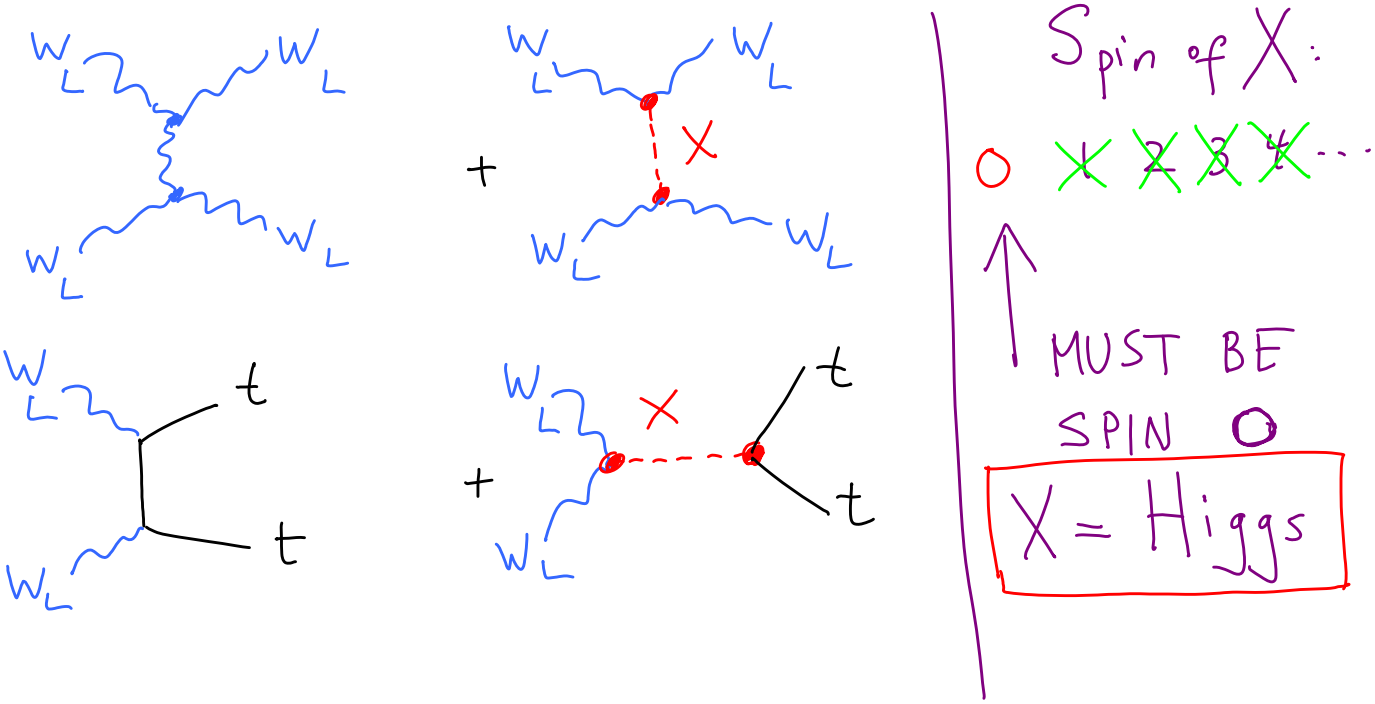
(Sometimes) convenient redundancy to describe physics in manifestly local way.

Poincaré + Consistent Factorization of 4pt

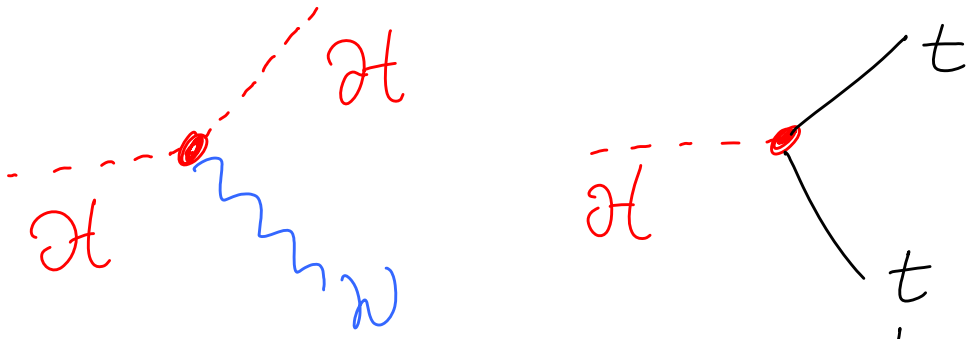
Only consistent interacting massless particles:

spin $0, \frac{1}{2}, 1, \frac{3}{2}, 2$

- 1: YM
- $\frac{3}{2}$: $\mathcal{N} \leq 8$ SUSY
- 2: Unique, GR


W_L
W_L
W_L
W_L
+
X
W_L
W_L
W_L
W_L
t
t
W_L
+
X
W_L
t
t
Spin of X:
0 1 2 3 4 ...
MUST BE
SPIN 0
X = Higgs

At very high energies, H and W_L, Z_L are all united into $\mathcal{H}$.



Usual Allowed Interactions

With the discovery of the Higgs, for the first time in our history, we have a self-consistent theory that can be extrapolated to exponentially higher energies.

Inflationary Grav. Waves

* Deliriously exciting if it holds up!

* TOTALLY VANILLA + REASONABLE THEORETICALLY

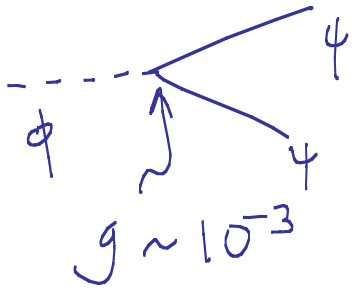
* It's the decade of $m^2\phi^2$!

* Infamous $\frac{\Delta\phi}{M_{pl}} \sim 10$ issue

is a red herring... trivially

natural in EFT

e.g.



[Indeed, oddity is that inflaton is even more weakly coupled than $\frac{1}{M_{pl}}$]

	W/Z	Infl
Golds.	Long. Pol	"Clock"/Inflaton
Approx Glob Symm.	$SU(2)_c$	dS
Simplest UV origin	Higgs Models	Most infl. models
Goldstones not scalars in UV	Technicolor	?

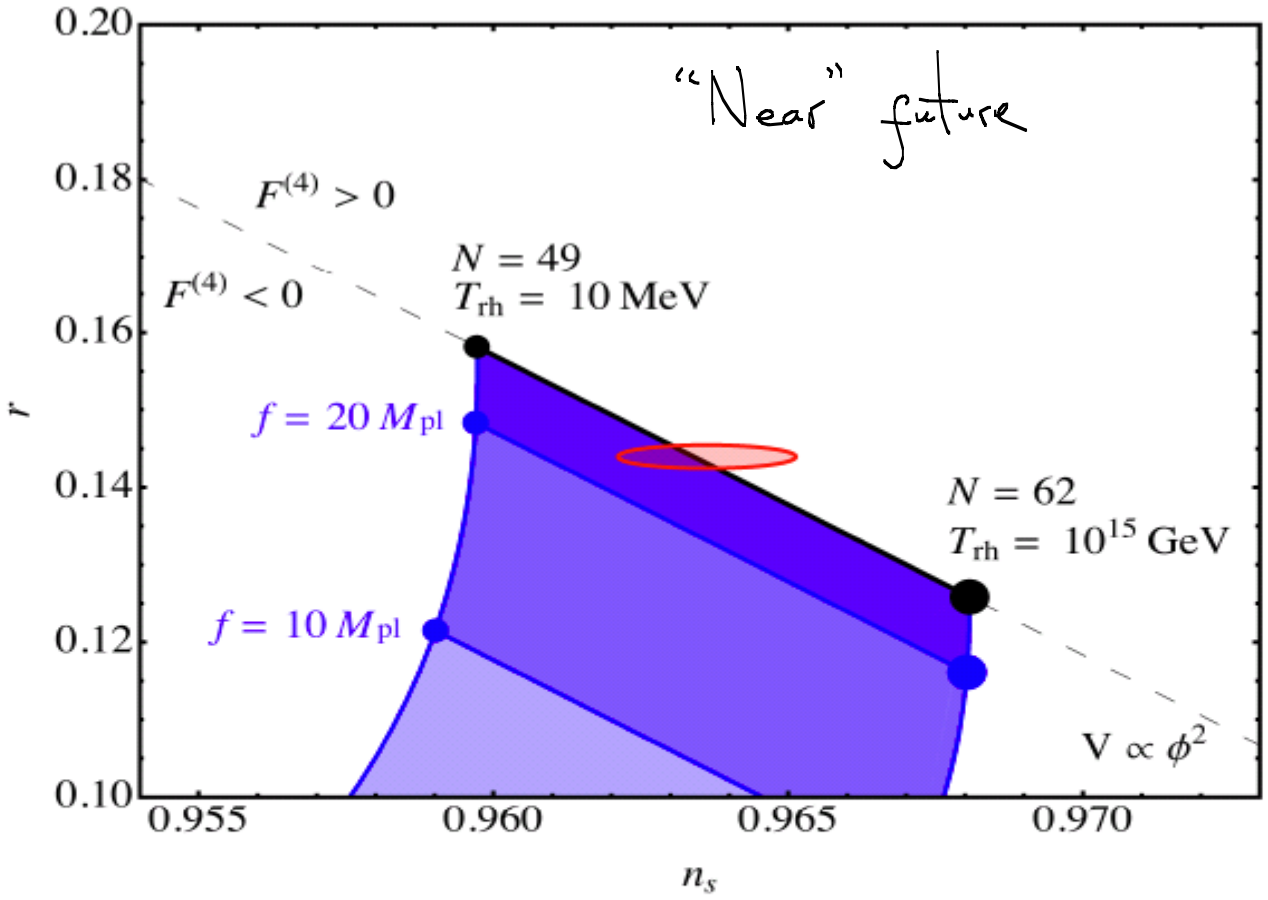
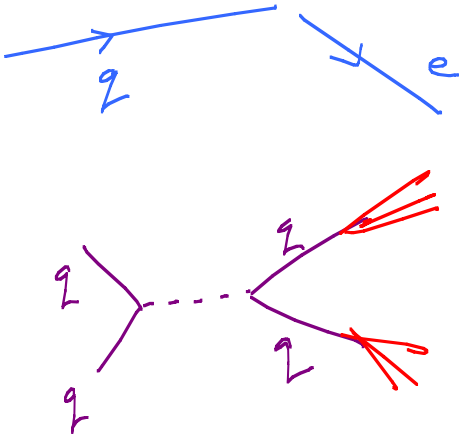


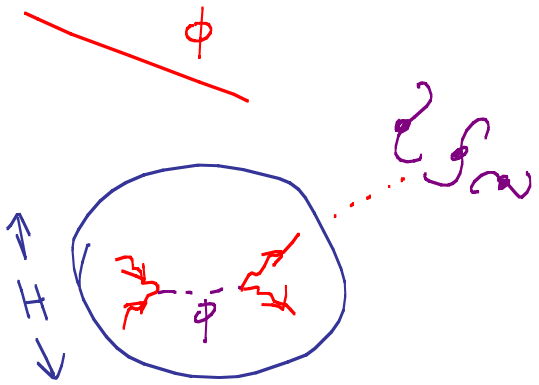
FIG. 1: *Future constraints on f assuming a simple cosine potential. The dashed curve corresponds to Eq. (1) and the black segment covers the interval of reheating temperatures $T_{\rm rh} \in [10\,{\rm MeV}, 10^{15}\,{\rm GeV}]$. A wider range of N is allowed if one considers non-standard cosmological evolutions after in-*

"Far" Future

"Cosmological Collider Physics"



New Particles in accelerators



New particles around $H \sim 10^{14}$ GeV from non-Gaussian patterns in the Sky

The Higgs + Inflation

are (conceptually related)

last chapters of

20th Century Physics

We live in a BIG

Space-time, with light

elementary particles governed

by Q-M laws

HOW + WHY?

★ End of Space-time [Gravity]

Limitations of QM [Cosmology]

★ Why is there a Macroscopic Universe?

Why is it big [CC problem]

with big things in it [hierarchy problem]?

The central questions today are not about details, but concern much deeper, structural issues:

Origin of Space-Time + our MACROSCOPIC universe

Higgs Discovery Crucial

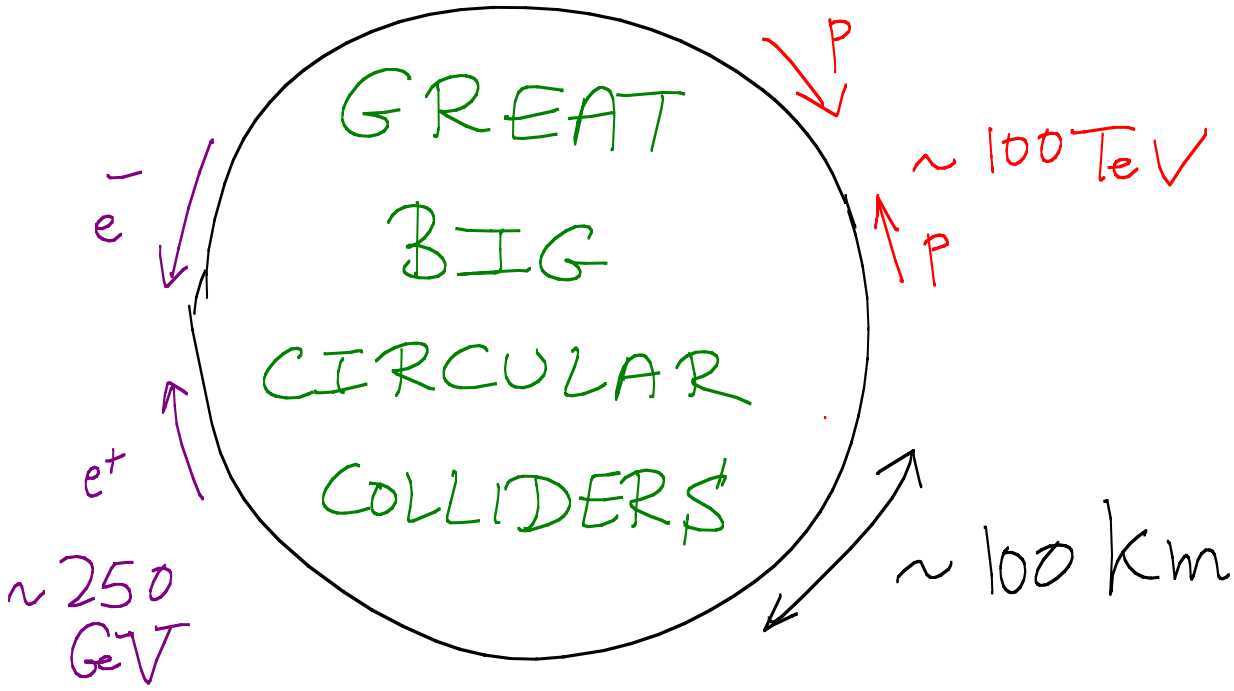
Light Higgs

↓

Our Vacuum is Qualitatively Different than Random C.M. System

[AKA "Random Metal"]

The Expt. Future



OBVIOUS FUTURE

BIG MACHINES,
BIG PHYSICS IDEAS

LIFEBLOOD OF
FUNDAMENTAL PHYSICS

Clearly, how to proceed will depend on first LHC13 results.

But in every scenario I can imagine, we will need these machines

Motivations

(I) Physics of Unbroken EW symmetry

(II) Ultimate Fate of Naturalness

(III) Robust probe of WIMP DM

(IV) Opportunities for Flavor/CP

(I) Physics of unbroken $SU(2) \times U(1)$

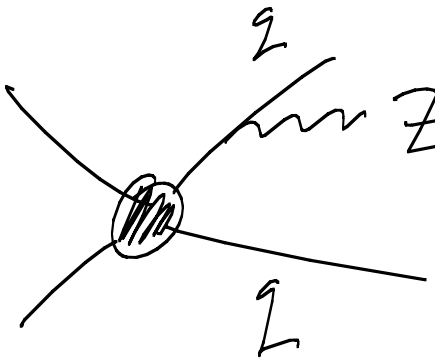
* Probe $W \to V$ [First order still allowed post LHC!]

* $h^\dagger h X$, $h^\dagger h X^\dagger X$, ... (100's GeV)

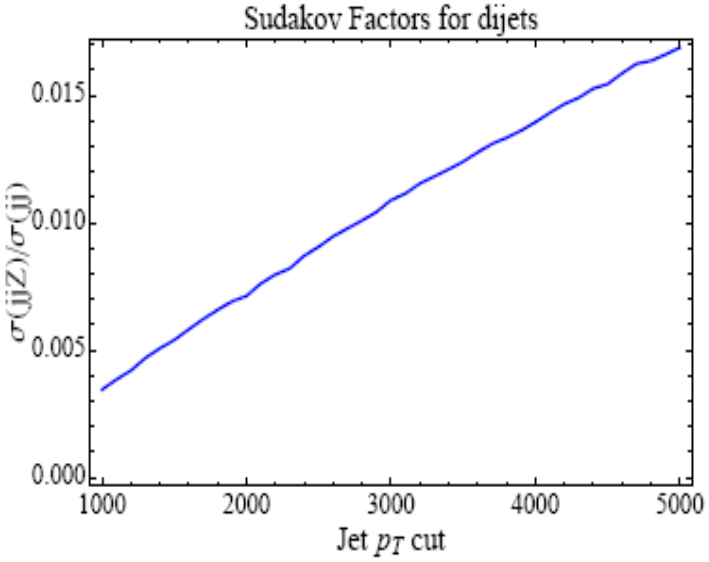
→ Visible deviations @ Higgs Factory

→ Directly produce X @ 100 TeV

Ewk Radiation

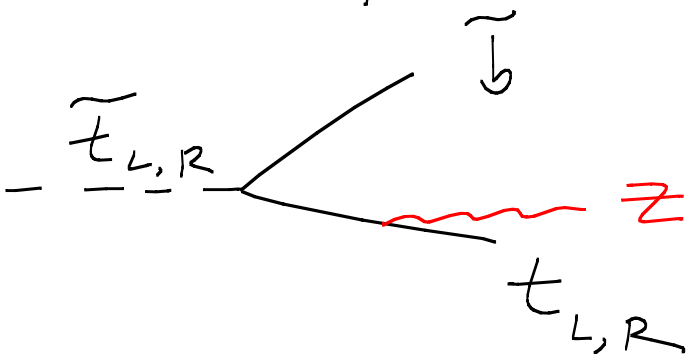


$$\frac{4\alpha_2}{\pi} \log^2\left(\frac{5\,\text{TeV}}{m_Z}\right) \text{ not small}$$

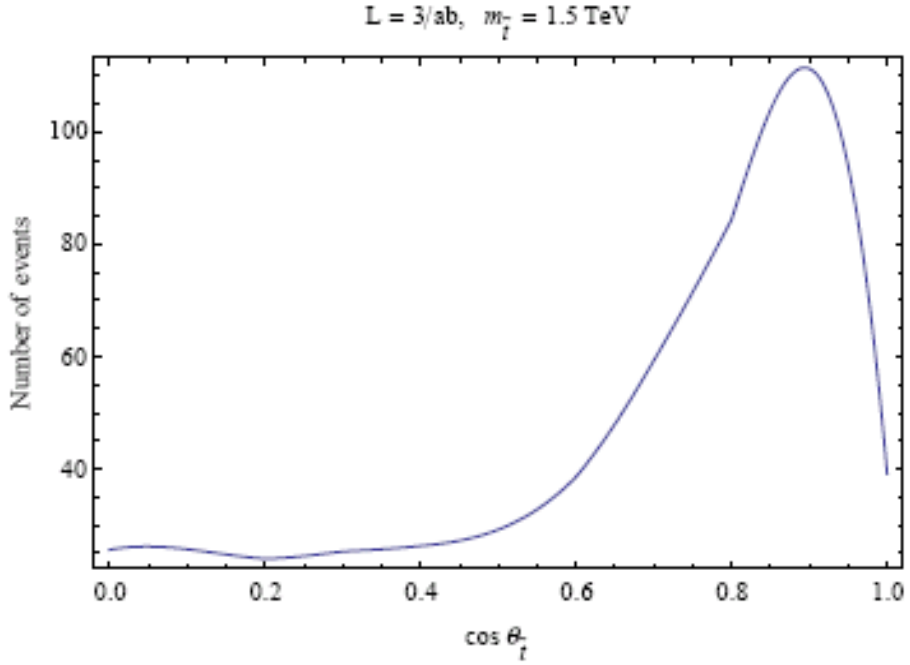


~15% of ~10 TeV jets have a W/Z

Are stops L or R ?



⟸ probes L/R mixture



[Hook, Katz]

II Fate of Naturalness

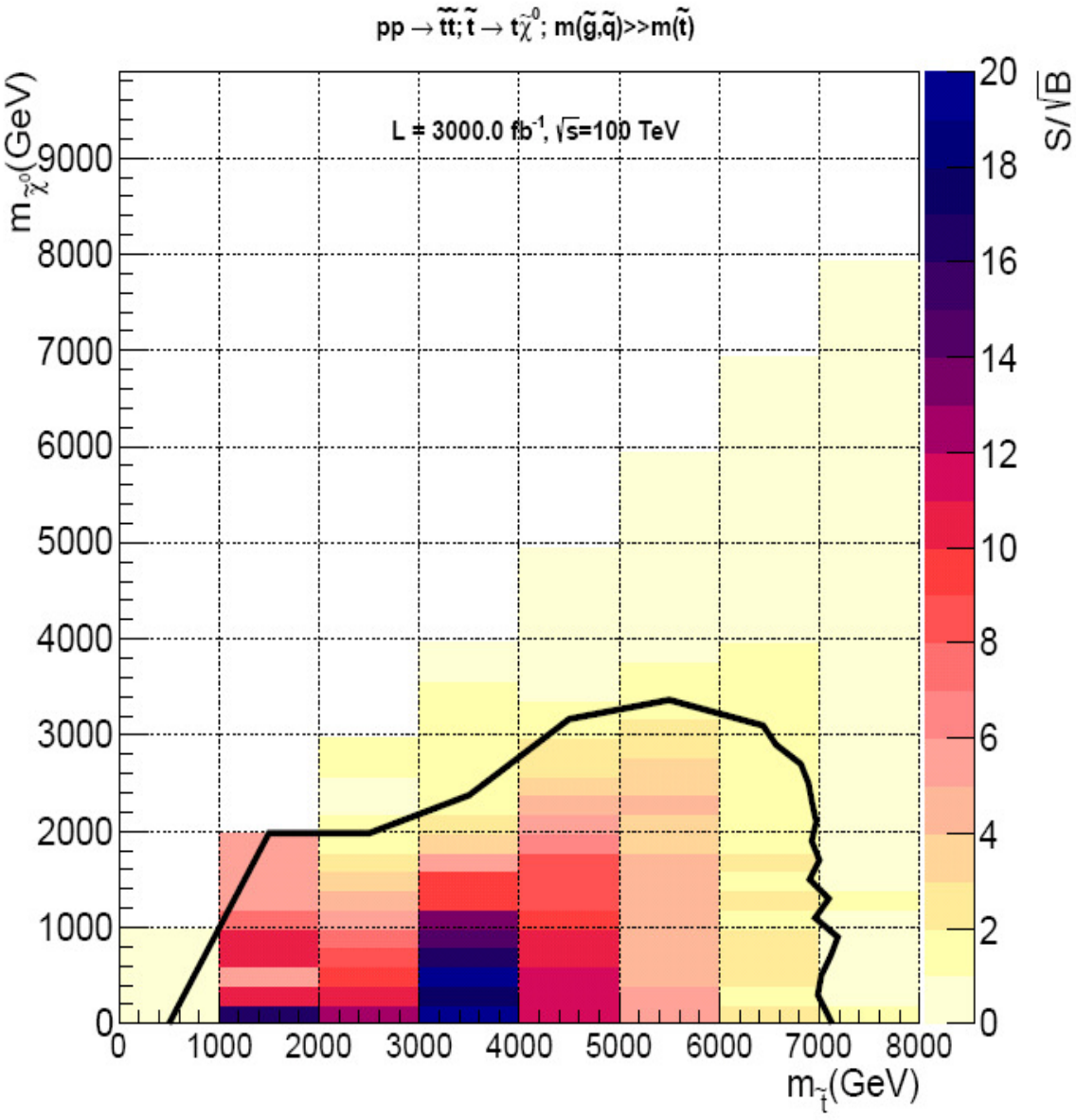
* If nothing beyond Higgs@ LHC:

→ Precision @ Higgs Fact./Tera-Z probe Λ_{UV}

eg $\frac{(\partial h^\dagger h)^2}{\Lambda^2}$

eg $\frac{h^\dagger W h B_{\mu\nu}}{\Lambda^2}$

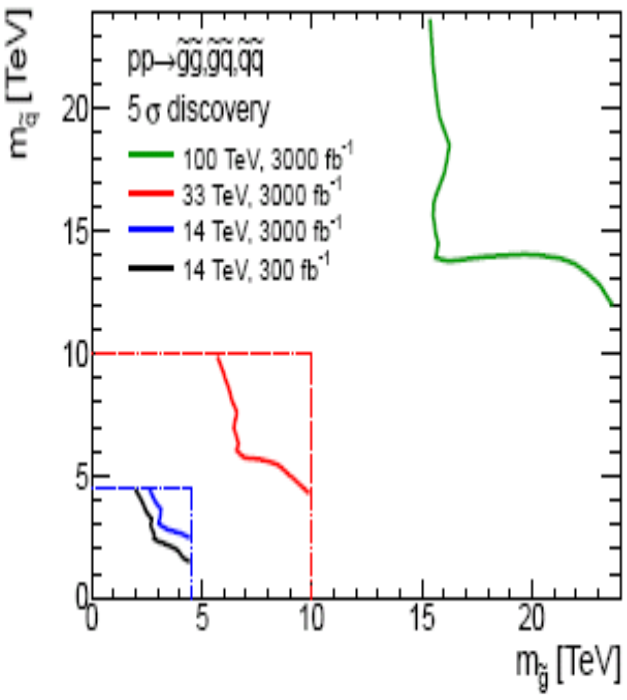
→ Top partners @ 100TeV

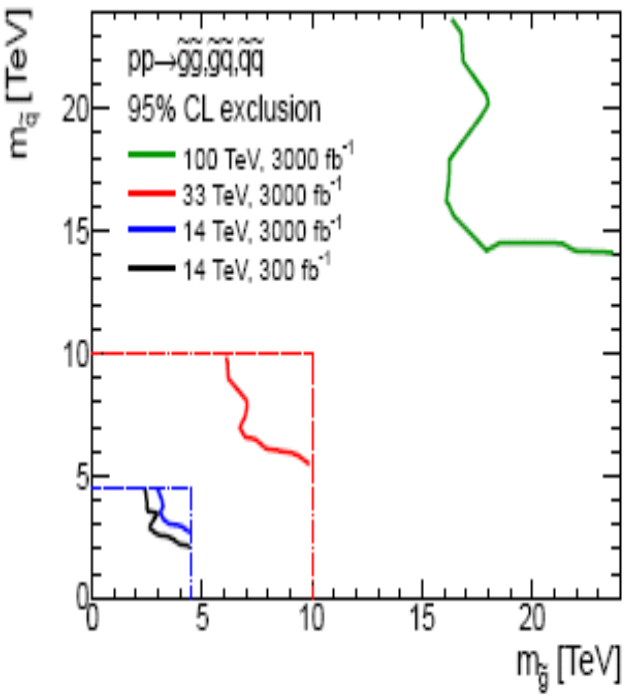


[Cohen
D'Agnolo
Hance
Lou
Wacker]

↓

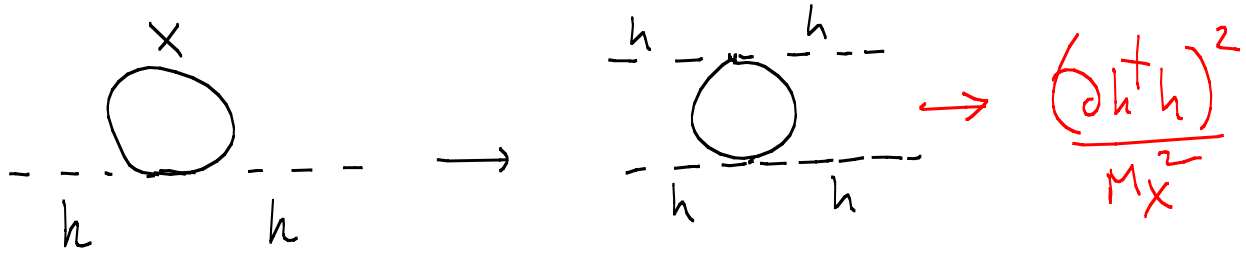
probes
to
$\sim 10^{-4}$
tuning


pp→g̃g̃,g̃q̃,q̃q̃
5 σ discovery
100 TeV, 3000 fb-1
33 TeV, 3000 fb-1
14 TeV, 3000 fb-1
14 TeV, 300 fb-1
m_q̃ [TeV]
m_g̃ [TeV]
0
5
10
15
20


pp→g̃g̃,g̃q̃,q̃q̃
95% CL exclusion
100 TeV, 3000 fb-1
33 TeV, 3000 fb-1
14 TeV, 3000 fb-1
14 TeV, 300 fb-1
m_q̃ [TeV]
m_g̃ [TeV]
0
5
10
15
20

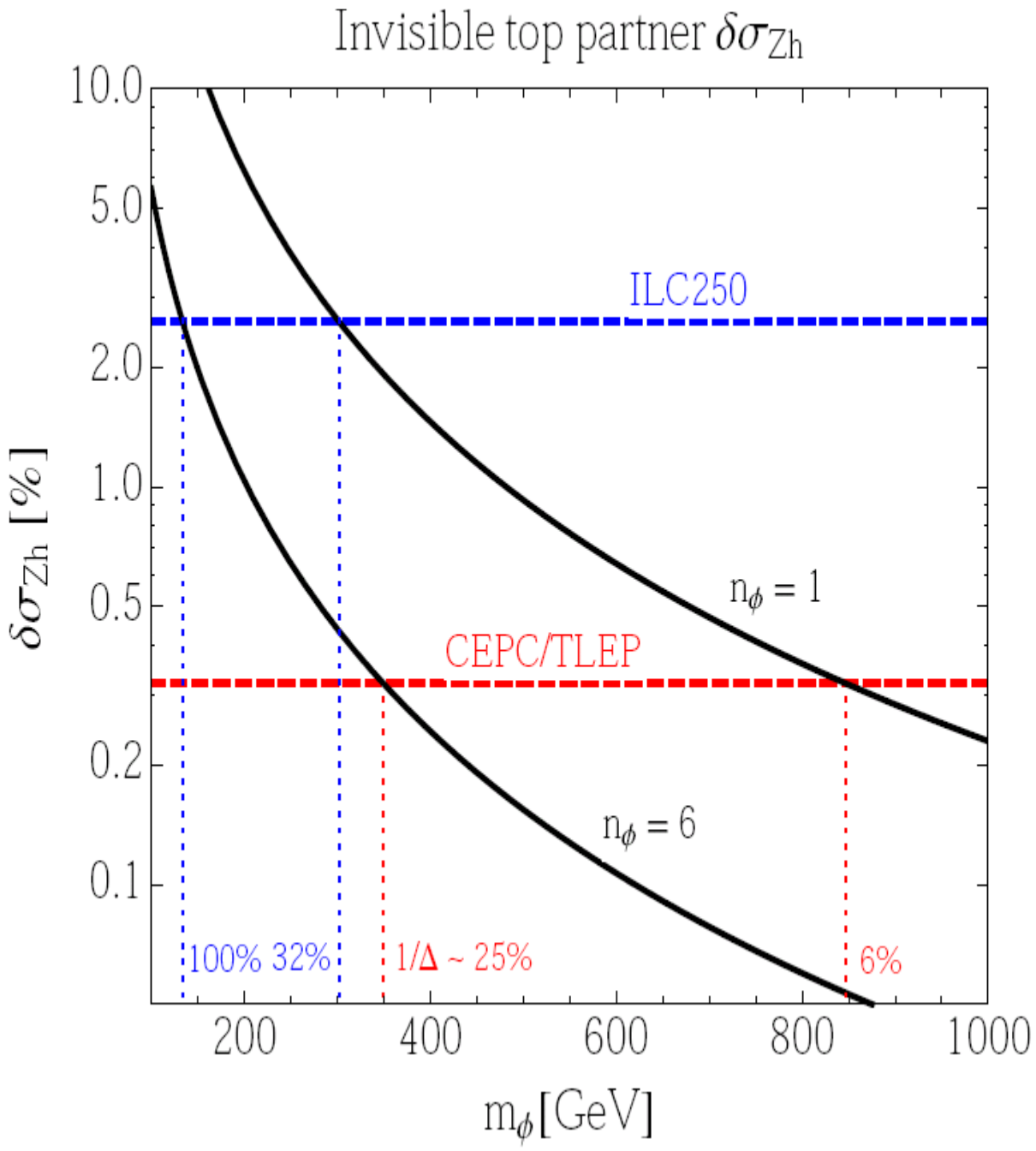
[Cohen et. al.]

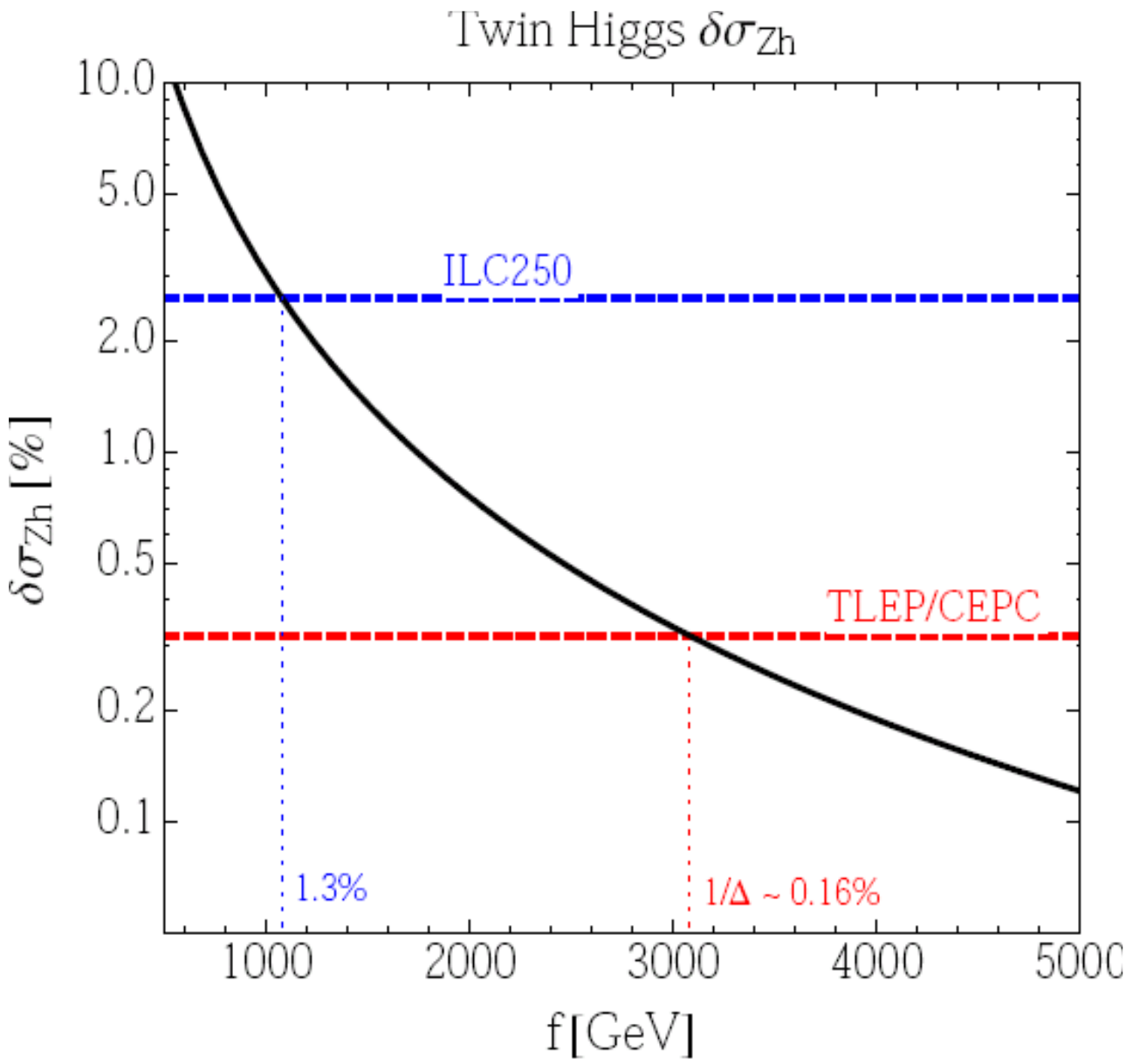
* $\sqrt{}$ aturalness "no lose thm" even with uncolored top partners [Craig et.al.]



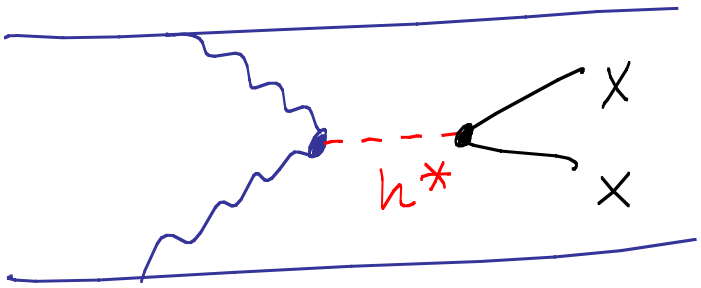
$\longrightarrow$ Visible deviations @ CEPC

$\longrightarrow$ Produce X @ SPPC


Invisible top partner $\delta\sigma_{Zh}$
10.0
5.0
2.0
1.0
0.5
0.2
0.1
$\delta\sigma_{Zh}$ [%]
ILC250
CEPC/TLEP
$n_\phi = 1$
$n_\phi = 6$
100% 32%
1/Δ ~ 25%
6%
200
400
600
800
1000
m_ϕ[GeV]


Twin Higgs $\delta\sigma_{Zh}$
10.0
5.0
2.0
1.0
0.5
0.2
0.1
$\delta\sigma_{Zh}$ [%]
ILC250
TLEP/CEPC
1.3%
1/Δ ~ 0.16%
1000
2000
3000
4000
5000
f[GeV]

+ Obvious follow-up in pp collisions e.g. in VBF

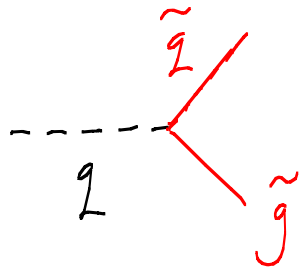


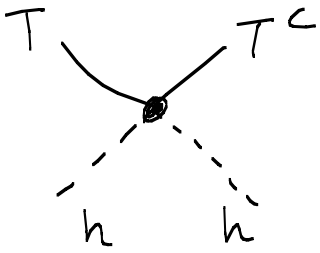
* If we do see new physics @ LHC:

- Unlikely we will see whole spectrum @ LHC e.g. —— $\tilde{f}_{1,2}$ 5 TeV —— $\tilde{f}_3$ 700 GeV

Will see @ SPPC [ $m_{\tilde{f}_{1,2}} \lesssim 10$ TeV]

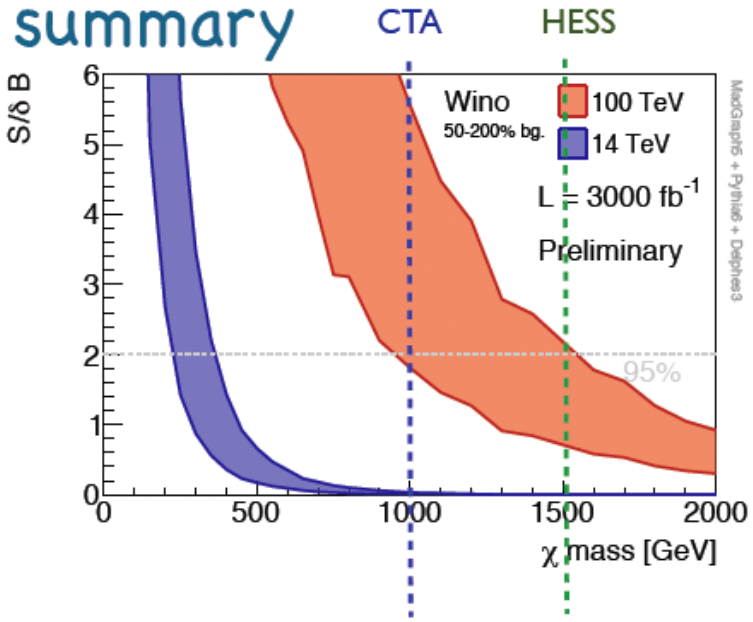
- Directly probe:





III WIMP DM, e.g. in monojets

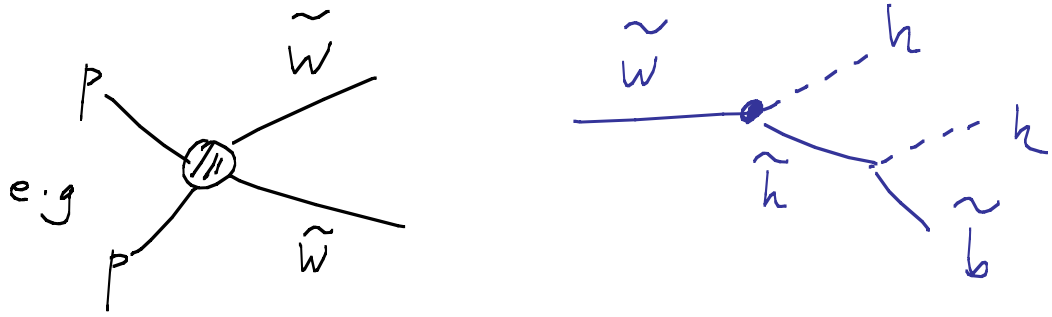
Wino summary



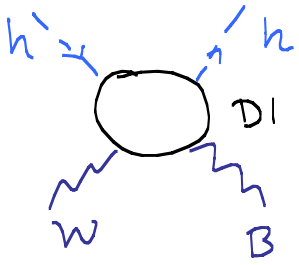
[Low, Wang]

- In combination with indirect detection, there is hope to "completely cover" the wino parameter space.

- Much more powerful probes with cascades @ 100 TeV



- Precision Ewk deviations

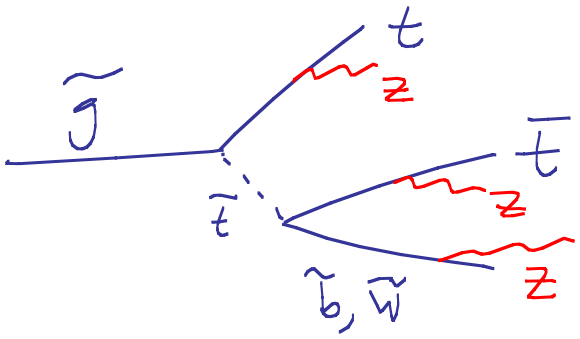


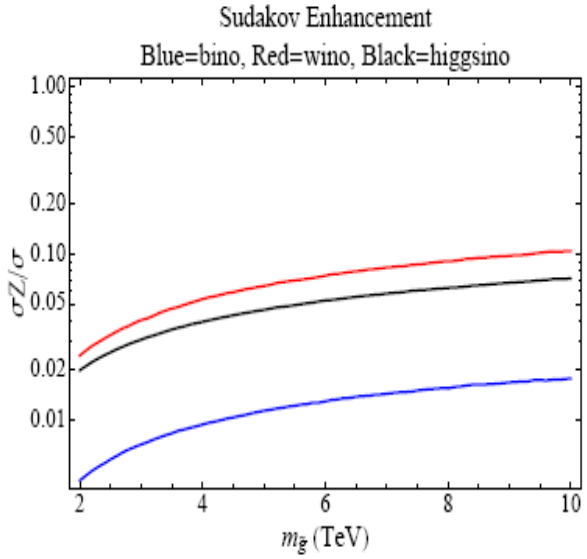
$$\lambda^2 \frac{\alpha}{\pi} \frac{h^\dagger W_{\mu\nu} h B^\mu}{M_{DM}^2}$$

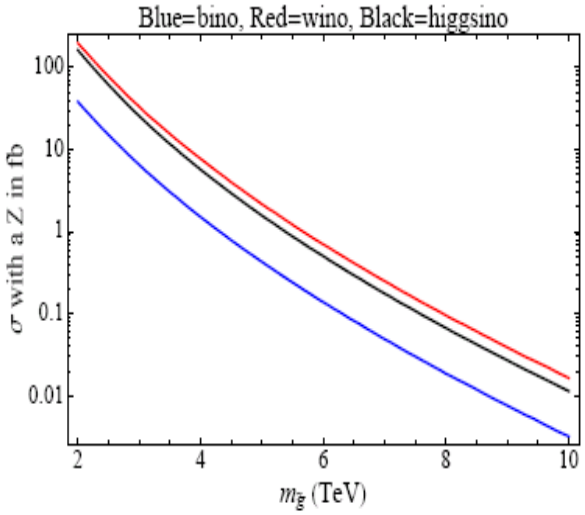
visible @ Tera-Z

- Probe ewk quantum #'s of DM

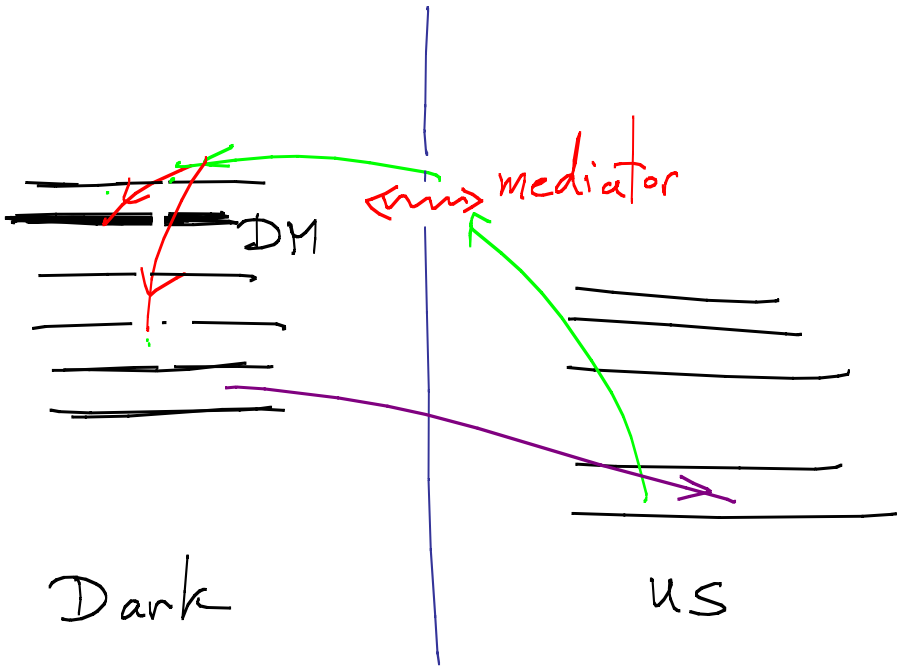
e.g.







Dark Sectors



Powerful Reach @ 100 TeV

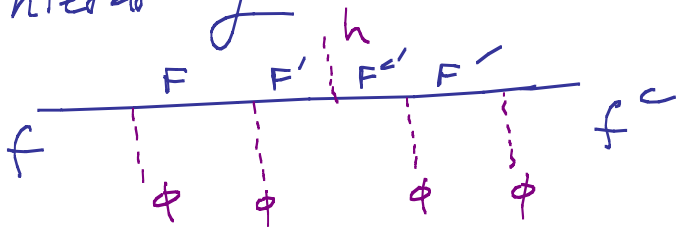
(IV) Rich new opportunities in Flavor + CP

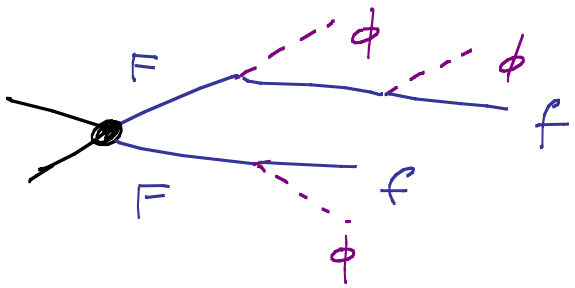
- E.g. ~ Tera Top !

  Probe $\mathcal{B}r(t \to cZ) \sim 10^{-6} - 10^{-7}$ [int. level]

- Probe for underlying theory of fermion mass hierarchy

e.g.





spectacular signals reflecting Flavor Symmetry

OBVIOUS FUTURE

BIG MACHINES,
BIG PHYSICS IDEAS

LIFEBLOOD OF
FUNDAMENTAL PHYSICS

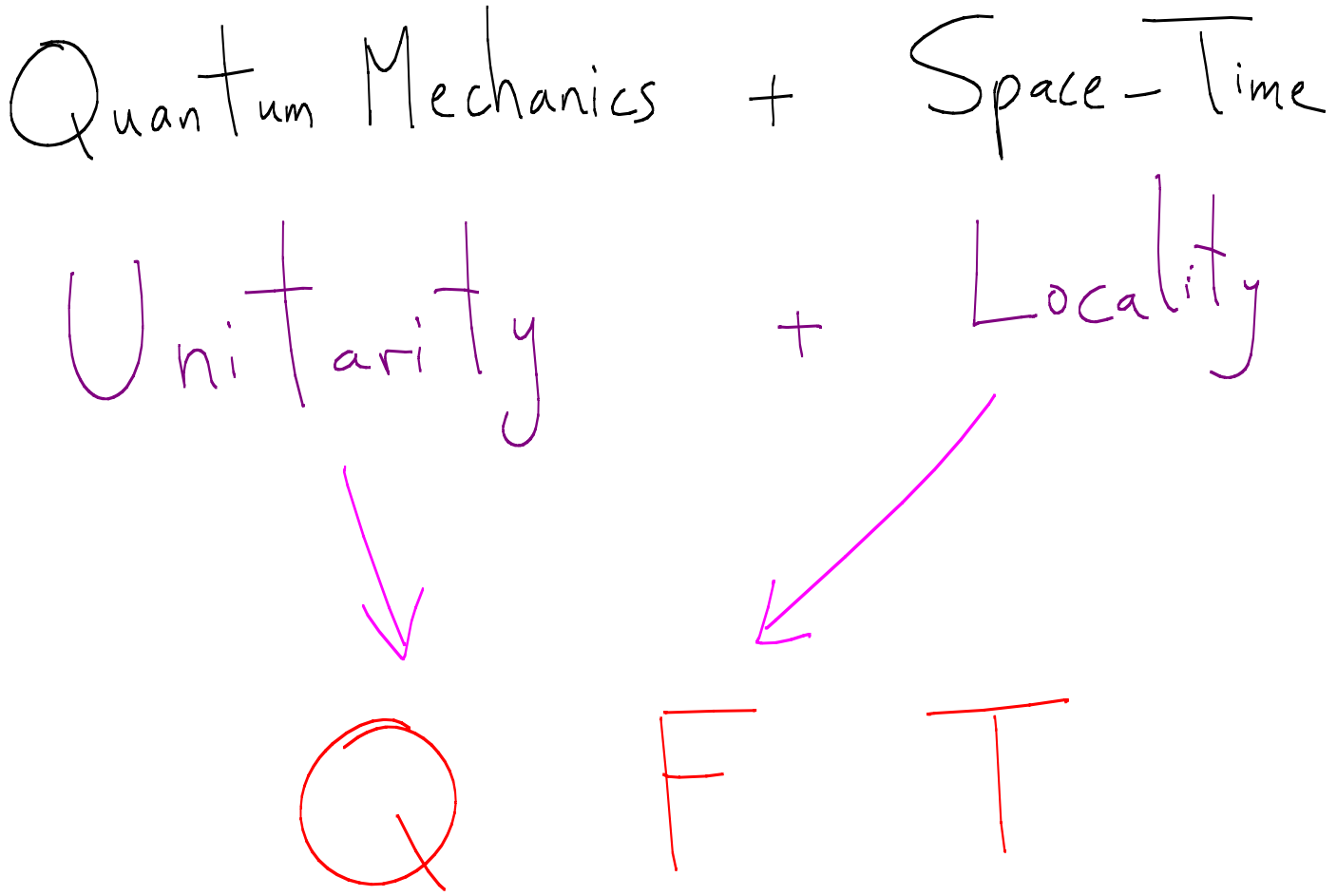
ASK NOT WHAT BIG CIRCULAR COLLIDERS CAN DO FOR YOU, ASK WHAT YOU CAN DO FOR BIG CIRCULAR COLLIDERS!

Please jump into the exciting FCC efforts at CERN, as well as our new "Center for Future HEP" @ IHEP in Beijing.

Theoretical Frontier

How can space-time + QM emerge from more primitive building blocks $\longleftrightarrow$

What is QFT?


Quantum Mechanics + Space-Time
Unitarity + Locality
QFT

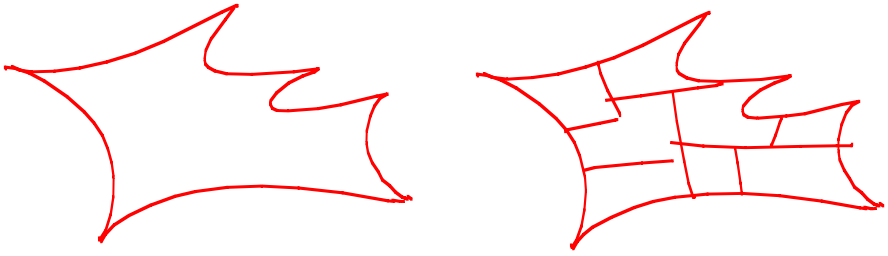
Result of a brute force calculation:

$$k_1 \cdot k_4\, \varepsilon_2 \cdot k_1\, \varepsilon_1 \cdot \varepsilon_3\, \varepsilon_4 \cdot \varepsilon_5$$ + 24 pages

$$(1^- 2^+ 3^- 4^+ 5^+) = \frac{\langle 13\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 45\rangle\langle 51\rangle}$$

An Example

Find a new picture for scatt. amps with no space-time, Hilbert space, no $\mathcal{L}, H$, no $\int \mathcal{D}\varphi\, e^{iS}$, no Gauge Redundancy ....



"The Volume" of "Some Region" in "Some Space"

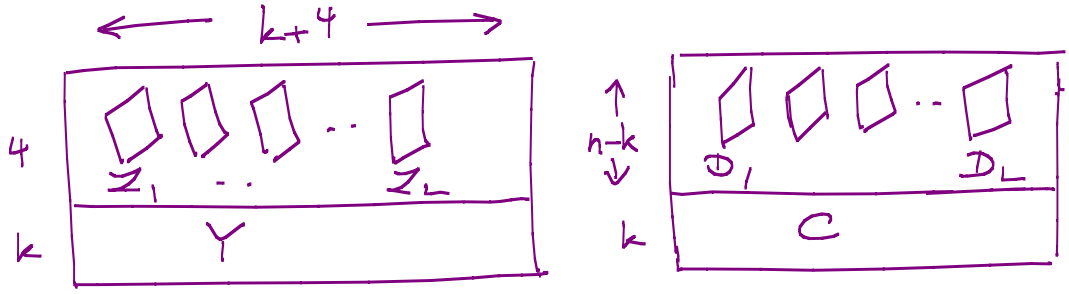
Symmetries Manifest; Loc+Un. Derived

$$\mathcal{M}_{n,k,L}[\mathcal{Z}] = \text{"Vol"}\left[\mathcal{A}_{n,k,L}[\mathcal{Z}]\right]$$

$\mathcal{A}_{n,k,L}[\mathcal{Z}]$: "The Amplituhedron"

{Planar $\mathcal{N}=4$ SYM}

The Amplituhedron $A_{n,k,L}[Z]$

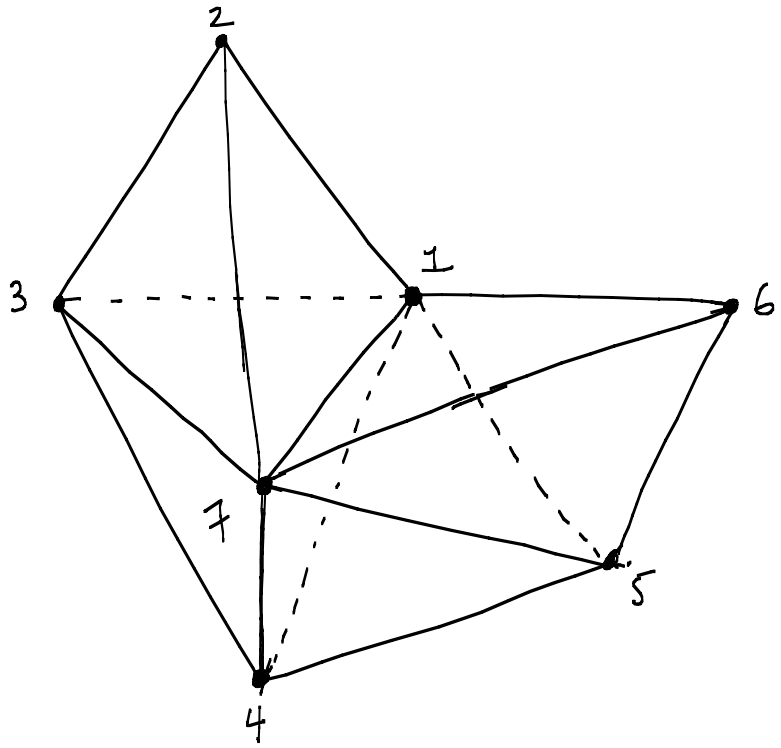


$$\mathcal{Y} = C^{+} \cdot Z^{+}$$

Boundaries → ∂ = + +

Positive Diffs → Yangian Symmetry

A 3D "Face"



Tree Amplitude for $[\bar{1}\,2^{+}3^{+}4^{+}5^{-}6^{+}7^{-}\,8^{-}]$ @LHC!

{ Hundreds of Pages of Feynman Diagrams }

Emergent

Space-Time + QM

In my view, the scientific questions at stake in our field today are the most difficult + profound ones we have faced since the 1930's

The scale of our vision and ambition — both theoretically + experimentally — must be commensurate with the singular tasks at hand

Meanwhile — we wait with

baited breath for the

LHC to usher in

21st century physics

NEXT YEAR!