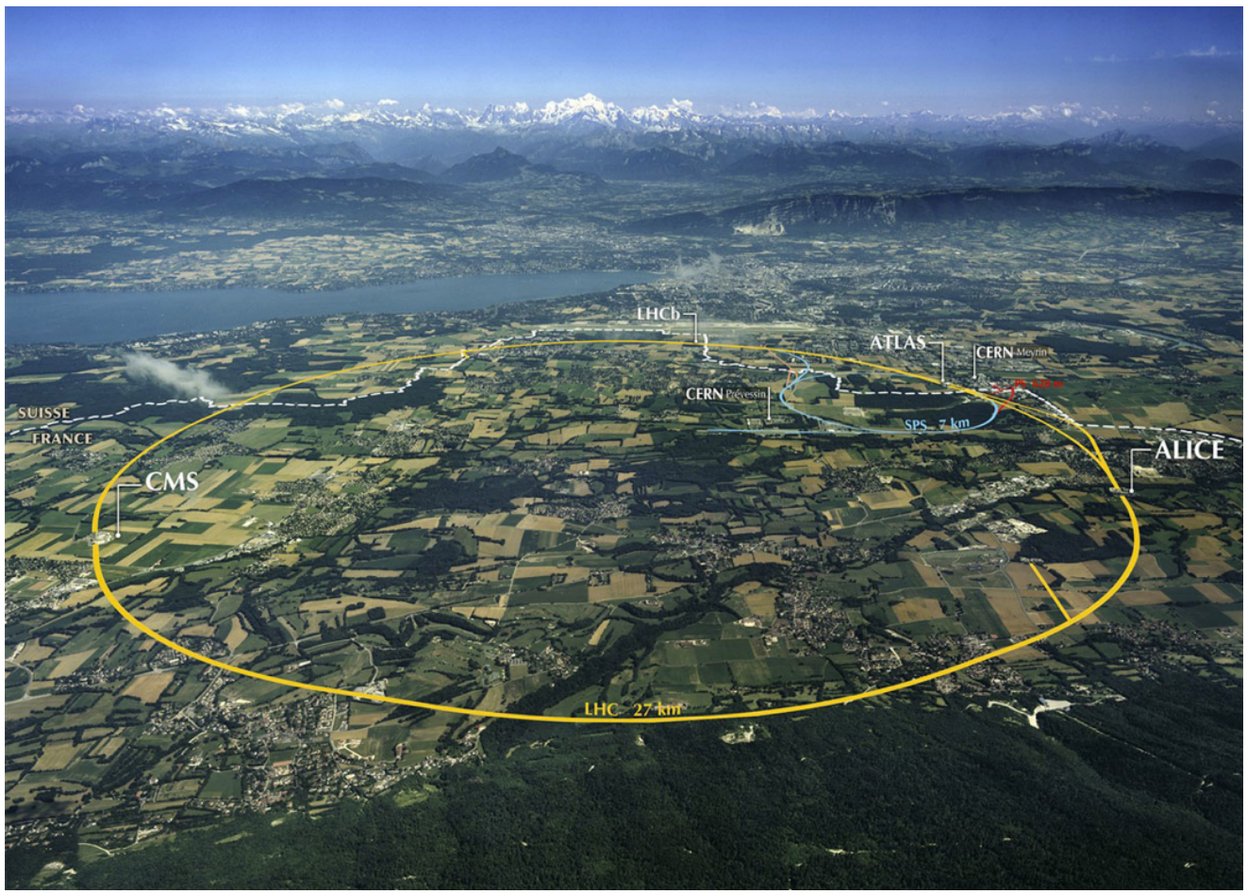
13 TeV vs. Naturalness

Josh Ruderman (NYU)
@DPF 8/4/2015

7/8

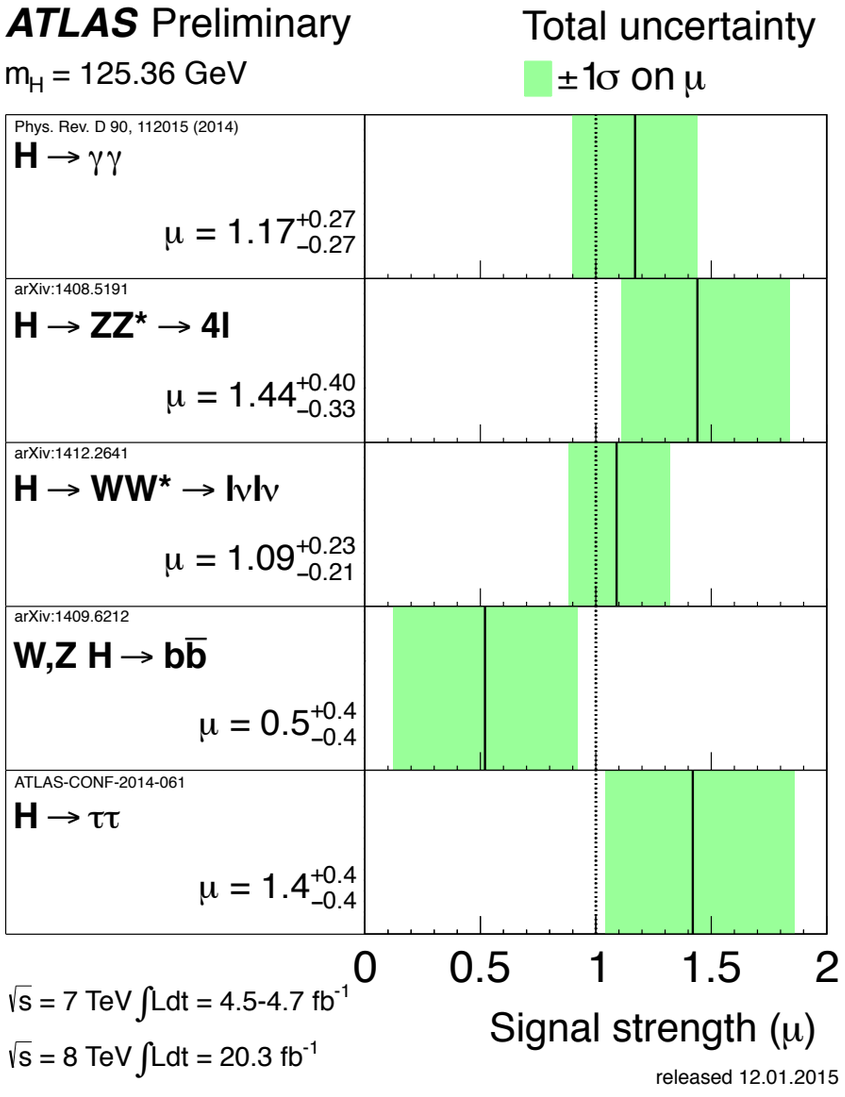
13

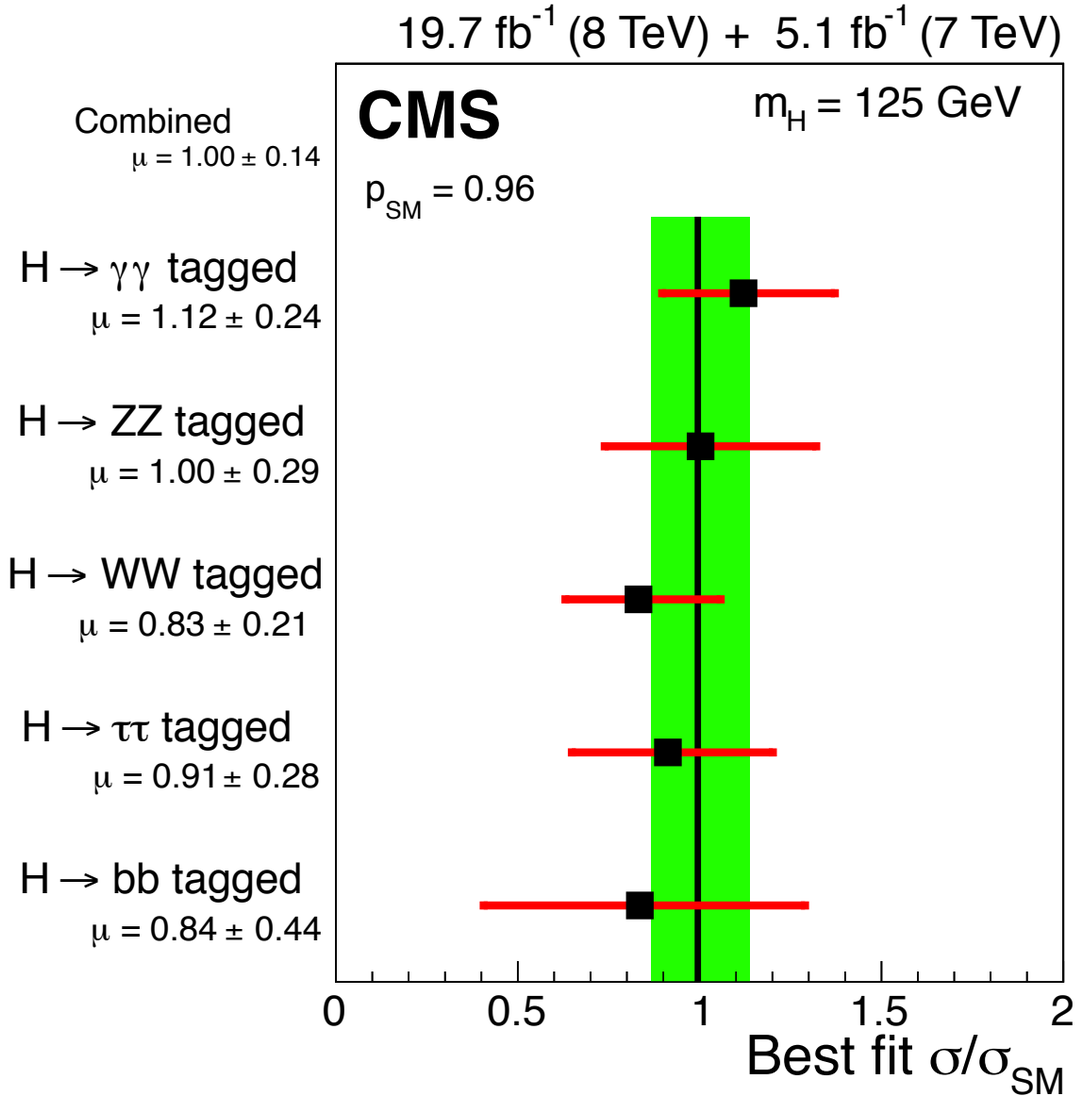
7/8 TeV recap


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

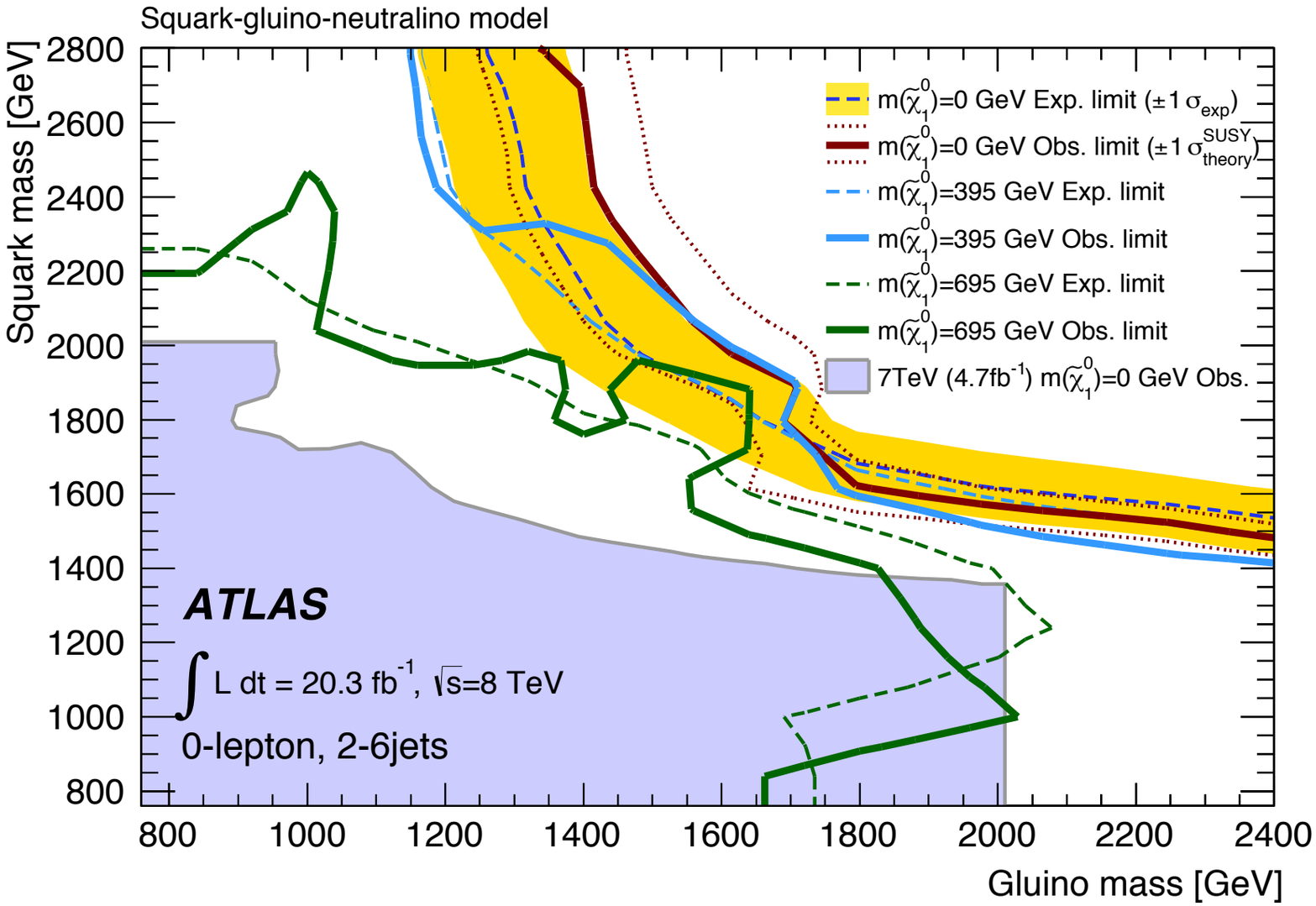
Higgs

$$m_h = 125.09 \pm 0.24 \text{ GeV}$$



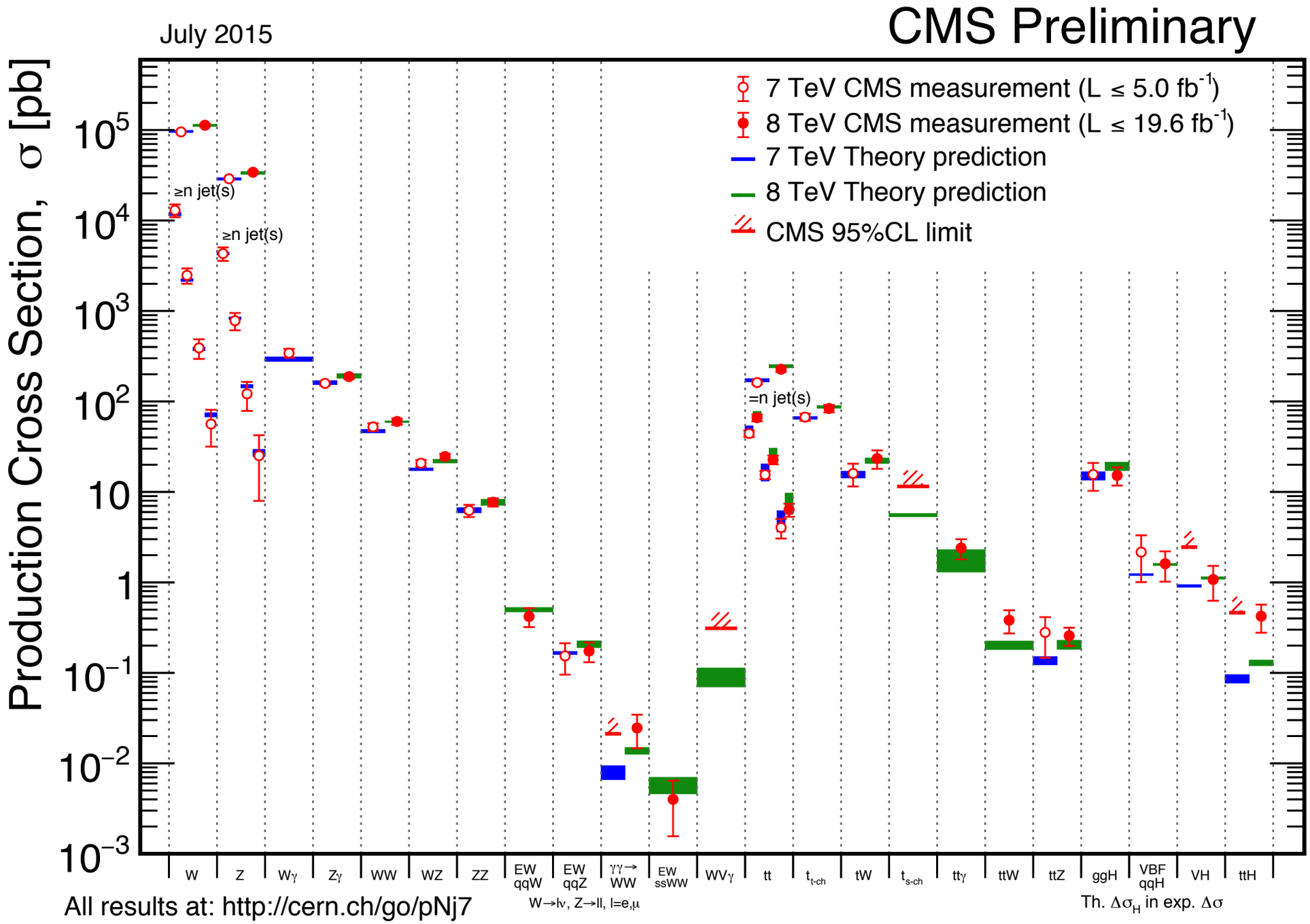


no new particles*



(*but some interesting excesses, see below)

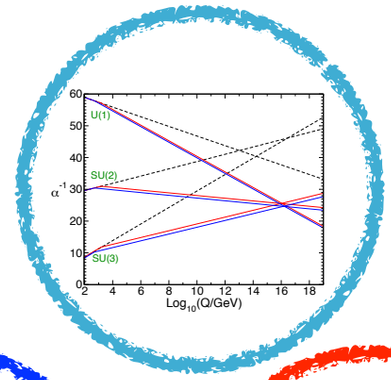
SM looks good



BSM motivations

baryogenesis

$\theta\, G\tilde{G}$



$m^2|H|^2$

quantum gravity

inflation

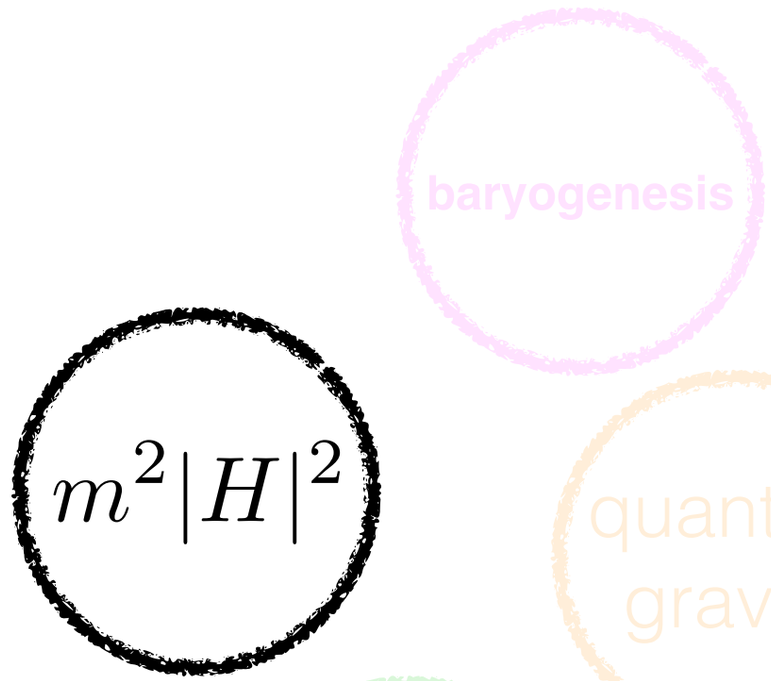
Λ

dark matter

flavorgenesis

m_ν

BSM motivations



(naturalness)

baryogenesis

$\theta\, G\tilde{G}$

quantum gravity

inflation

Λ

dark matter

flavorgenesis

m_ν

plan

1. naturalness and the Higgs
2. hidden particles
3. BSM strategies

naturalness and the Higgs

naturalness

Wilsonian Effective Field Theory:

M_{UV}

m_{IR}

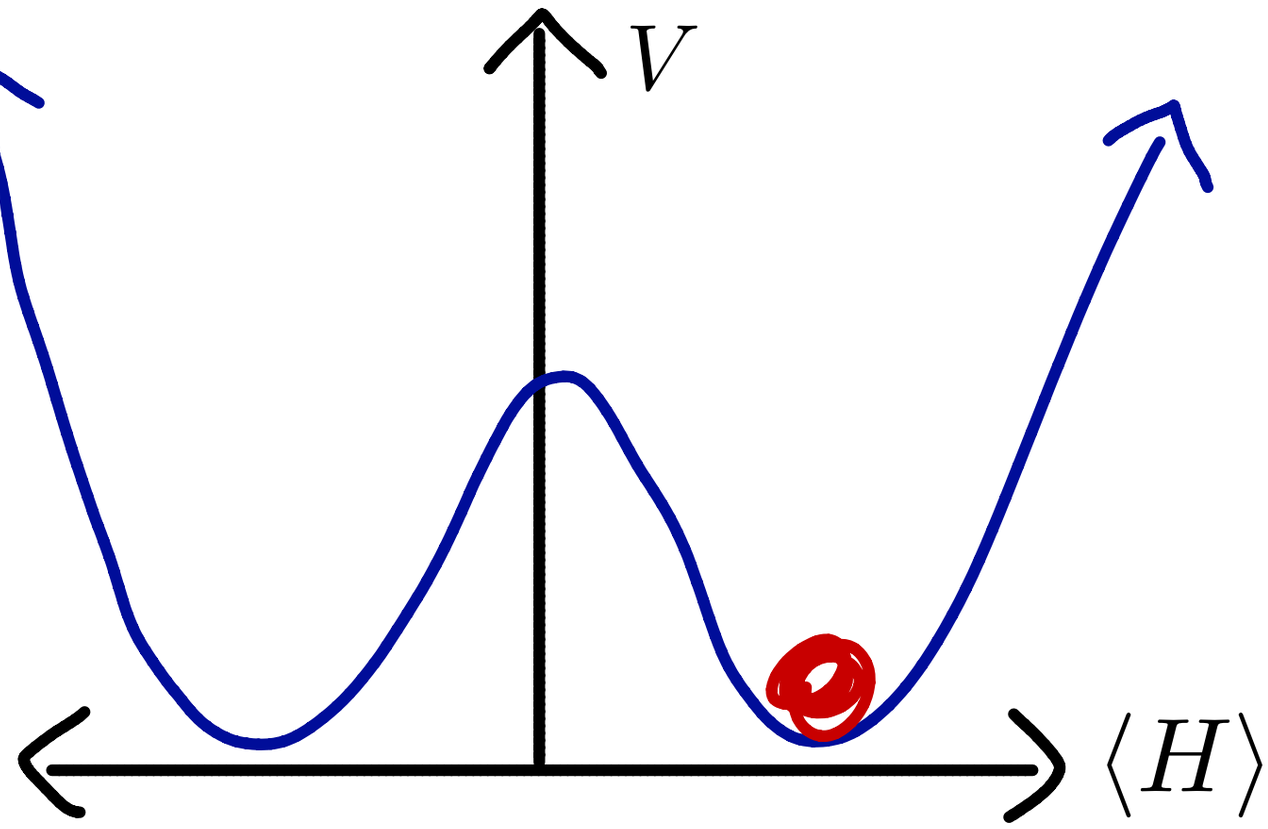
$$\mathcal{L}_{IR} = \Sigma_i \frac{c_i}{M^{d_i-4}} \mathcal{O}_i$$

$c_i \sim \mathcal{O}(1)$ unless a symmetry is restored when $c_i \to 0$

predicts: $M^2 |H|^2$

Higgs potential

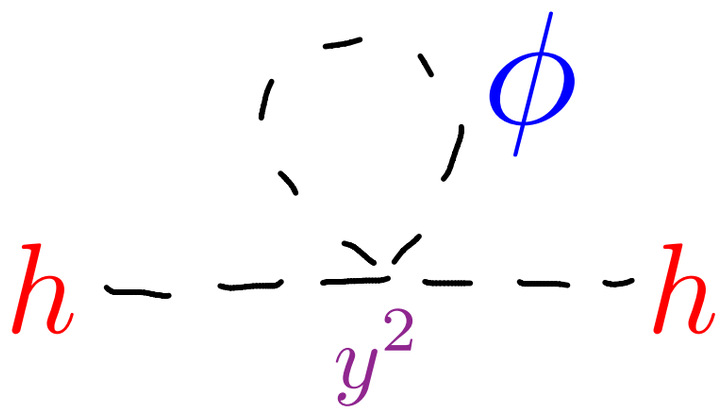
$$V \supset \lambda |H|^4 + m^2 |H|^2$$

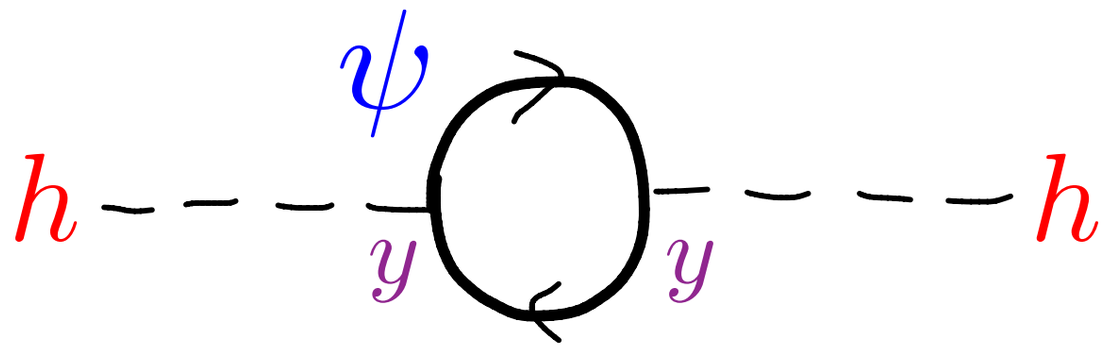


$$-2\,m^2 = m_h^2 \approx (125\ \mathrm{GeV})^2$$

naturalness and the Higgs

$$V \supset \lambda |H|^4 + \left(m_{H^0}^2 + \delta m_H^2\right) |H|^2$$





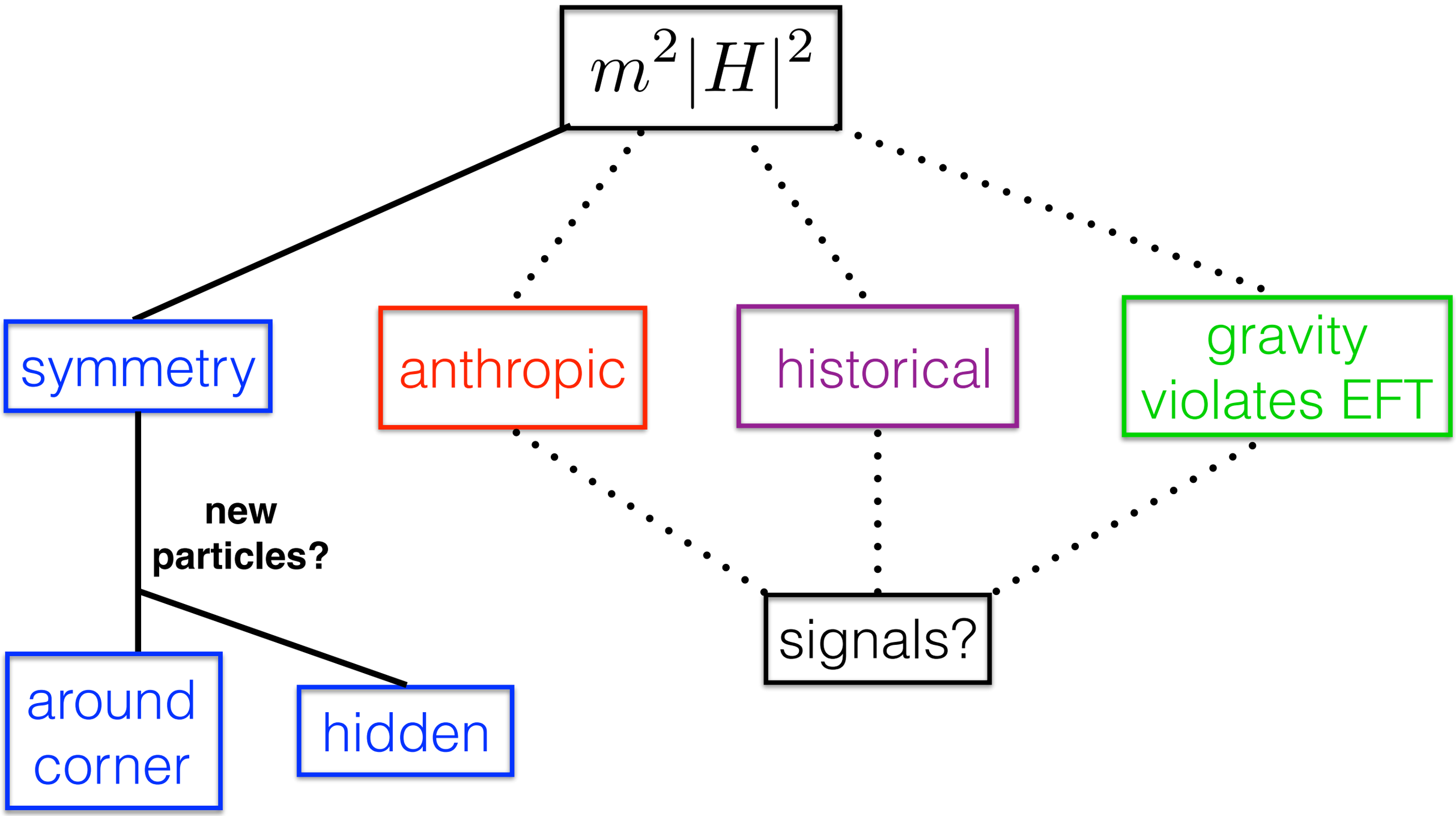
M ϕ ψ

$$\delta m_H^2 \sim \frac{y^2}{(4\pi)^2} M^2$$

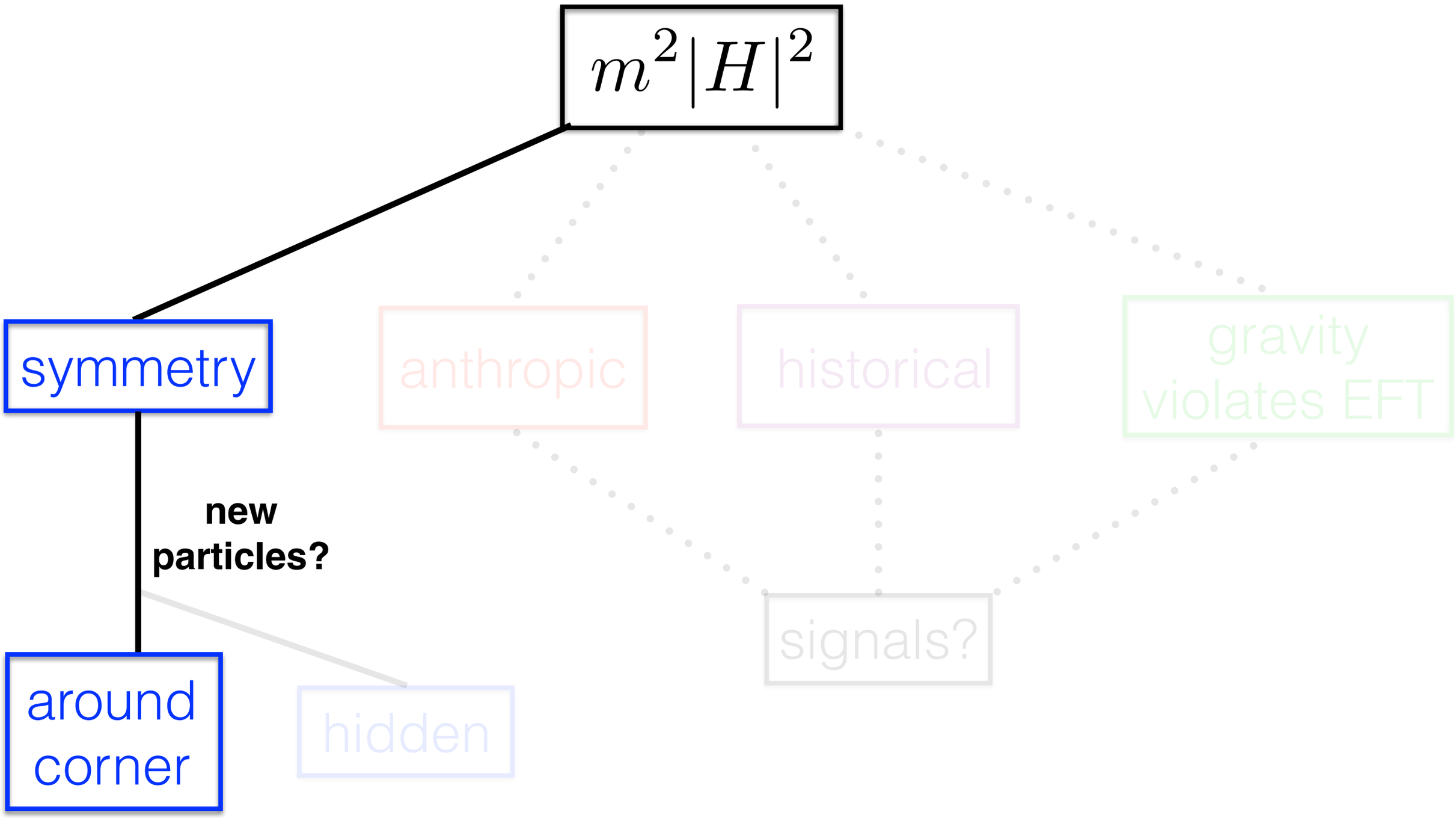
m_h h

tuning: $\delta m_H^2 \gg m_h^2$

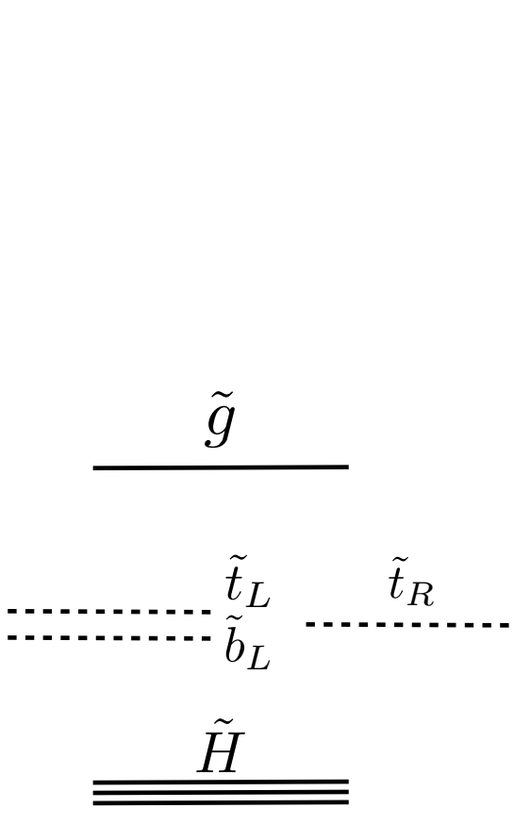
origin of the Higgs mass



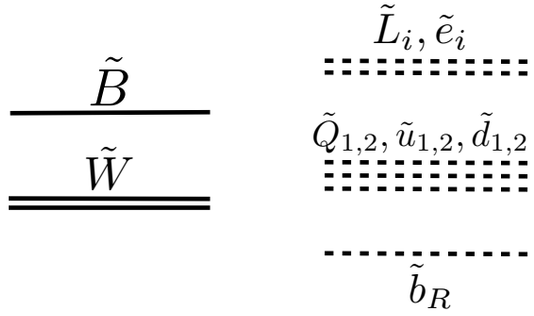
origin of the Higgs mass



Natural SUSY



natural SUSY



decoupled SUSY

10% tuning:

$$m_{\tilde{H}} \lesssim 300 \text{ GeV}$$

$$m_{\tilde{t},\tilde{b}_L} \lesssim 800 \text{ GeV}$$

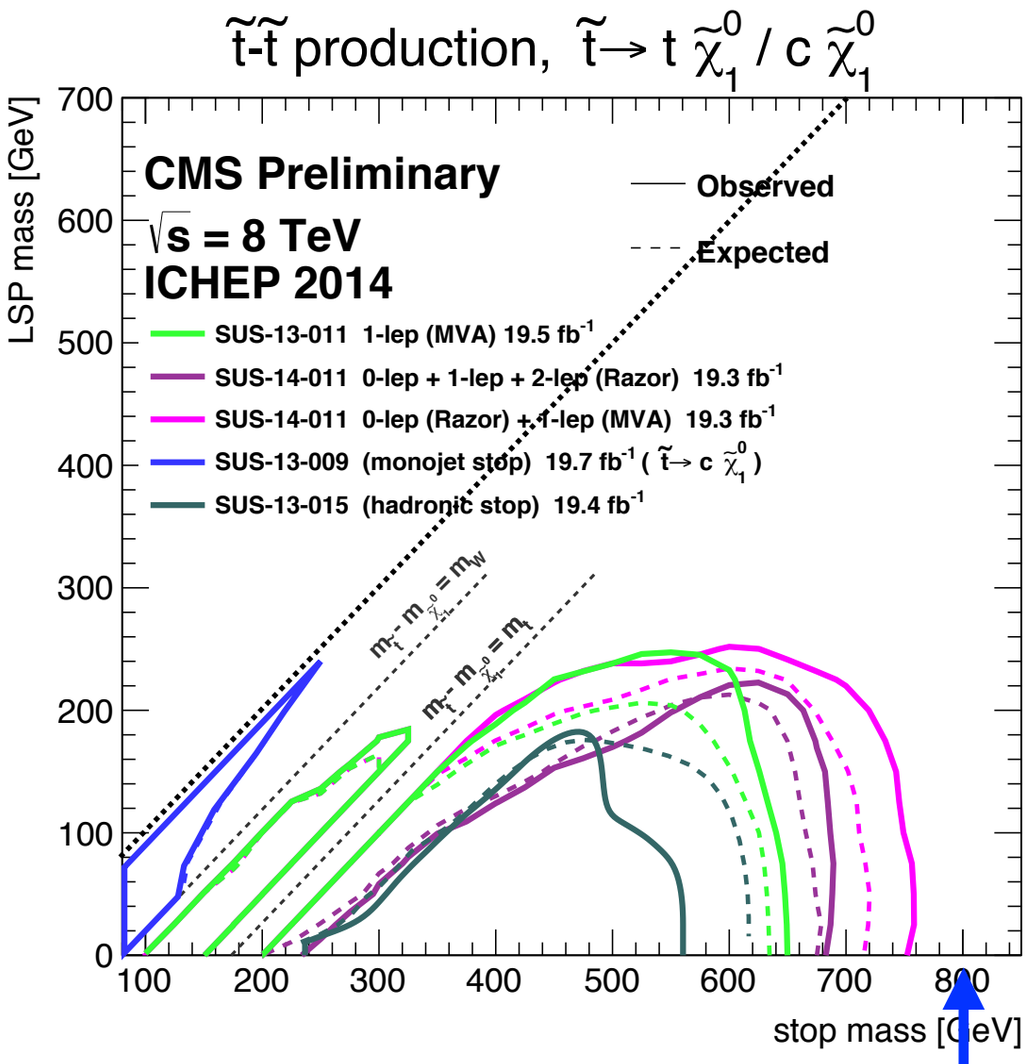
$$m_{\tilde{g}} \lesssim 1.1 \text{ TeV}$$

$$\Delta \propto \tilde{m}^2$$

- Barbieri, Giudice, 1988
- Dimopoulos, Giudice, 9507282
- Cohen, Kaplan, Nelson, 9607394
- Papucci, JTR, Weiler, 1110.6926

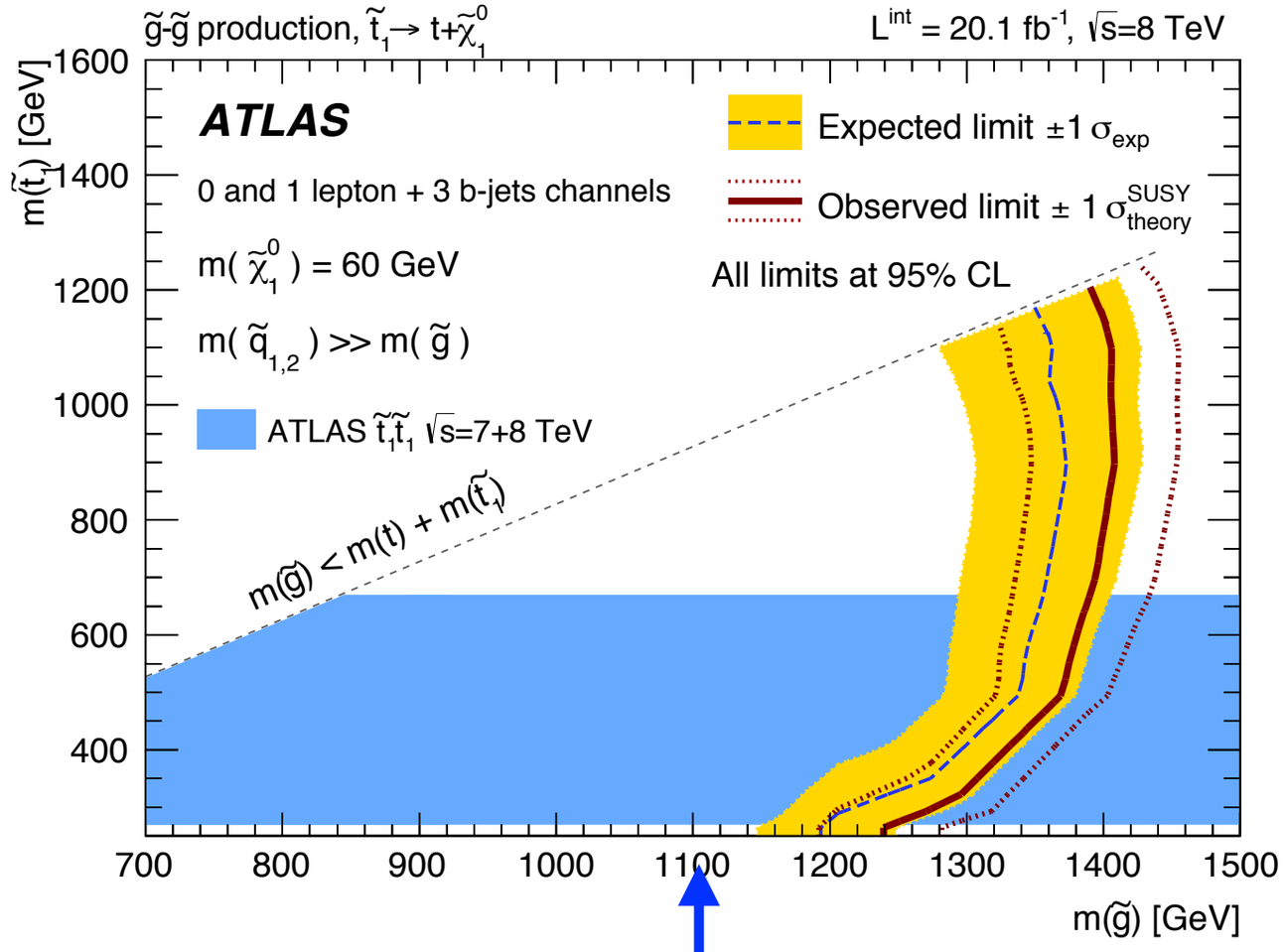
stop/gluino limits

stop



~10%

gluino



~10%

Dirac Gluinos

Majorana: Dirac:

$$\frac{1}{2} m_M \, \tilde{g}\tilde{g} \qquad m_D \, \tilde{g}a$$

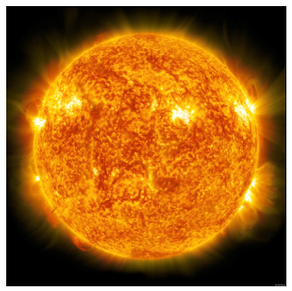
10% tuning: $m_{\tilde{g}} \lesssim 1 \text{ TeV}$ $m_{\tilde{g}} \lesssim 5 \text{ TeV}$

- Fox, Nelson, Weiner, 0206096
- Kribs, Martin 1203.4821
- Nelson, Roy, 1501.03251
- Alves, Galloway, McCullough, Weiner, 1502.03819, 1502.05055

unlucky?

max angular size:

$0.558°$



$0.545°$

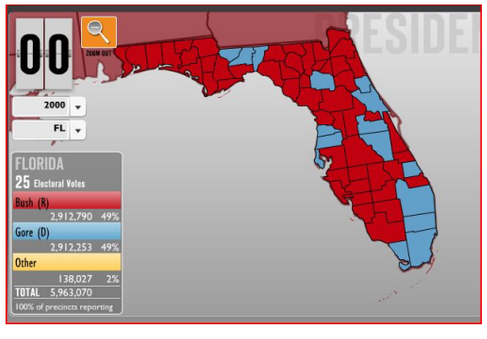
tuning: $\sim 2\%$

$m_{\tilde{t}} \sim 1.7$ TeV

Bush v Gore Florida:

$(537/5.8 \times 10^6)$

$m_{\tilde{t}} \sim 27$ TeV

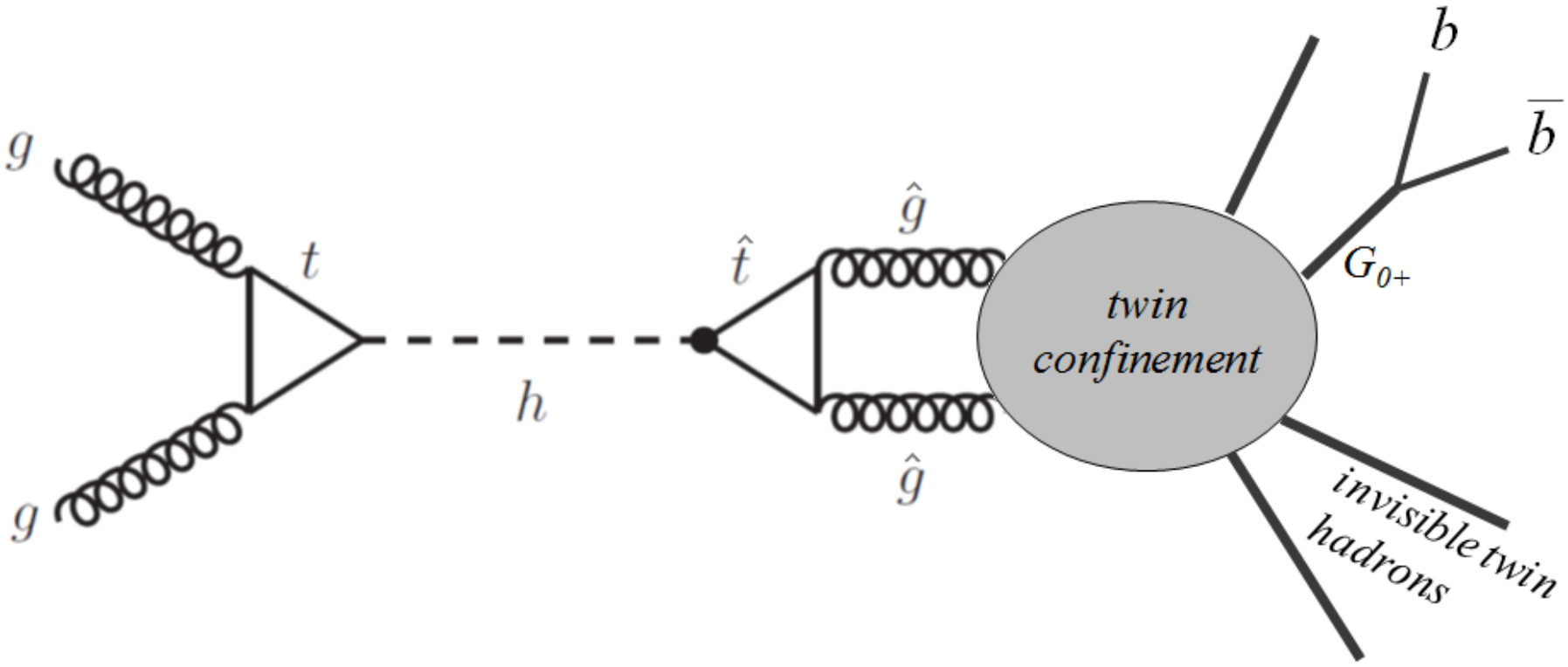


top partner variations

color \ spin	scalar	fermion
triplet	SUSY	composite Higgs
neutral	folded SUSY	twin Higgs

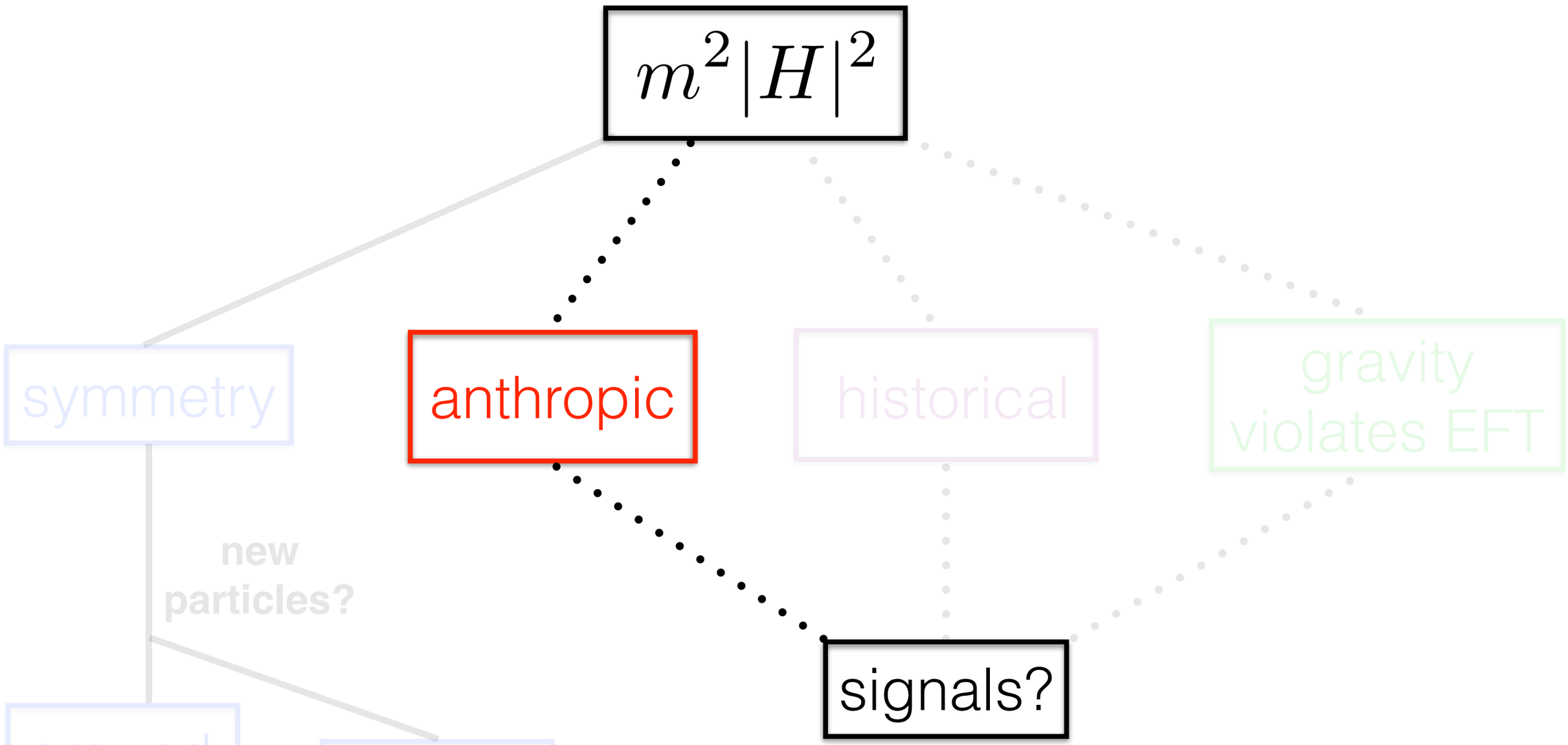
- **twin:** Chacko, Goh, Harnik, 0506256
- **folded**: Burdman, Chacko, Goh, Harnik, 0609152

Hidden Valley Signals from Twin Higgs



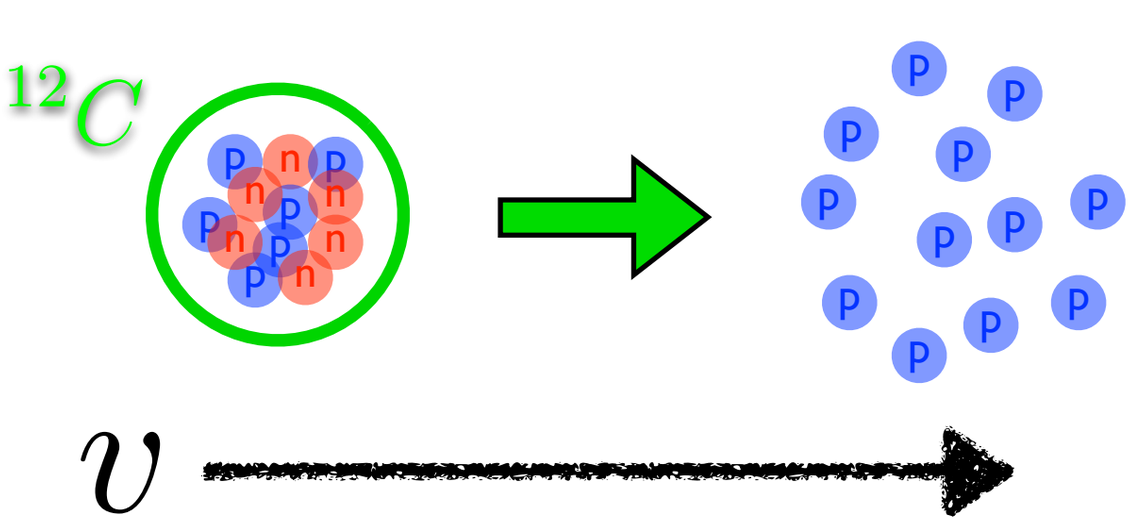
- Strassler, Zurek, hep-ph/0604261
- Craig, Katz, Strassler, Sundrum, 1501.05310

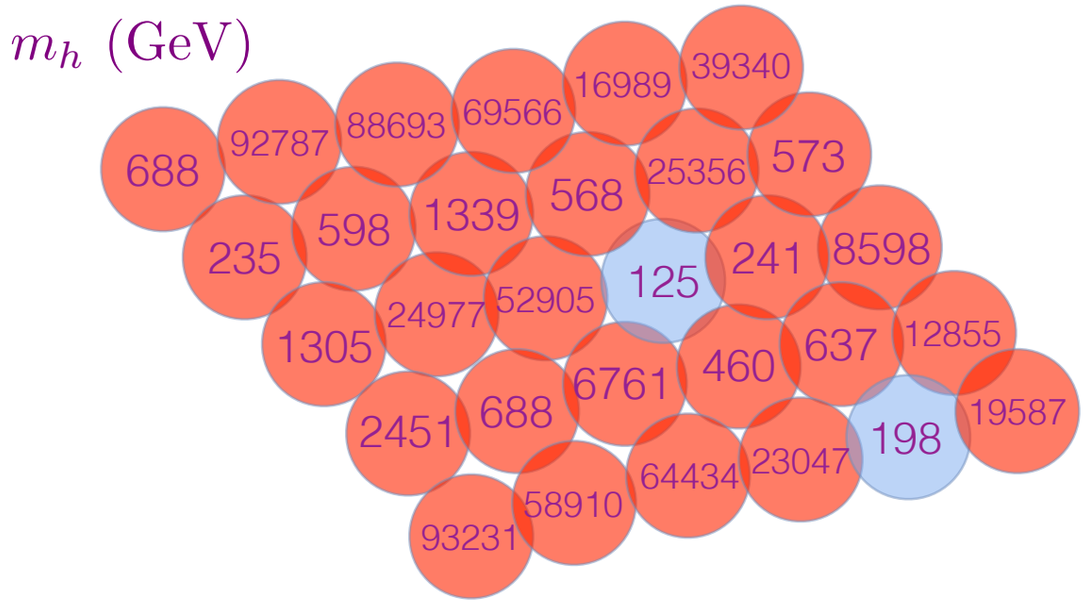
origin of the Higgs mass



anthropic Higgs mass?

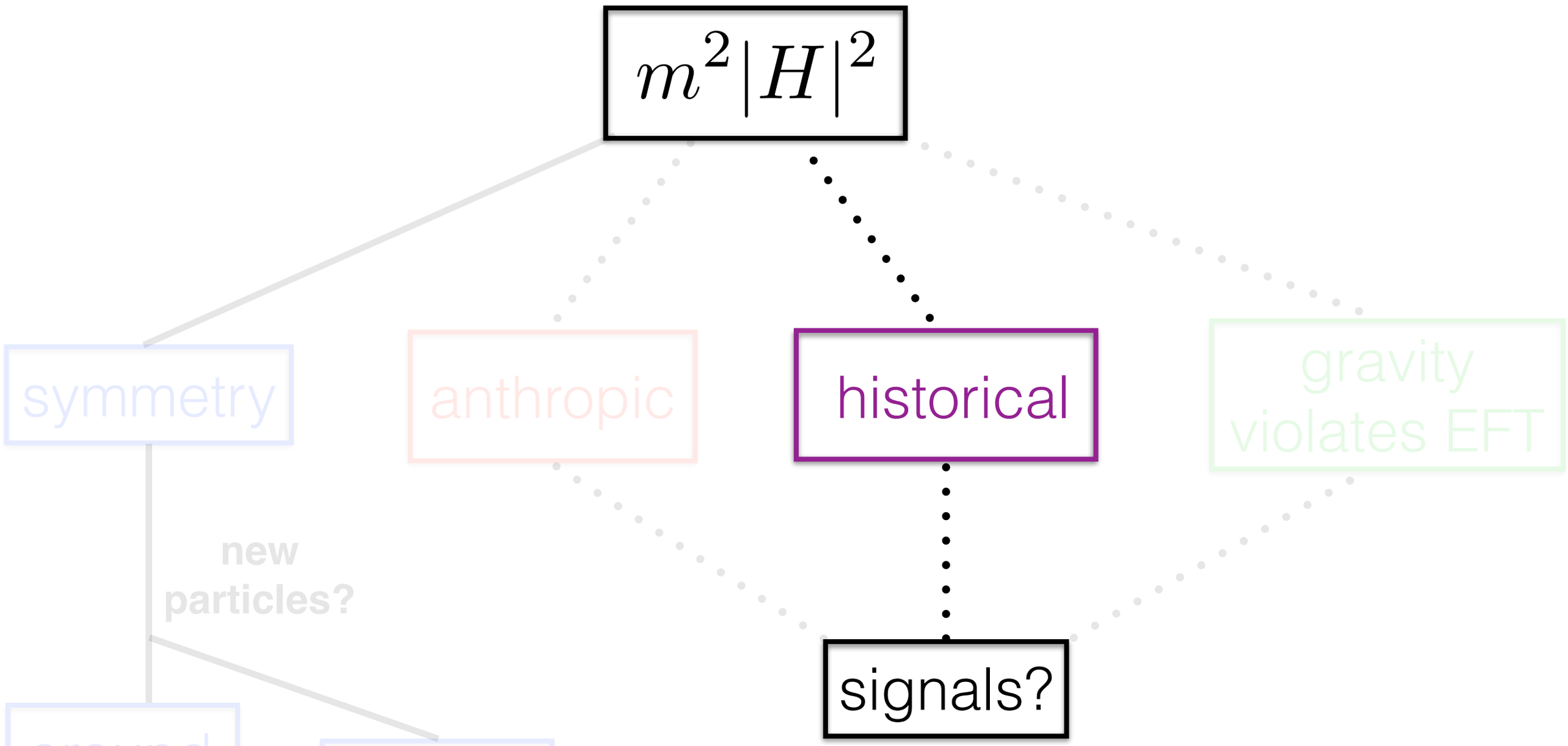
multiverse?





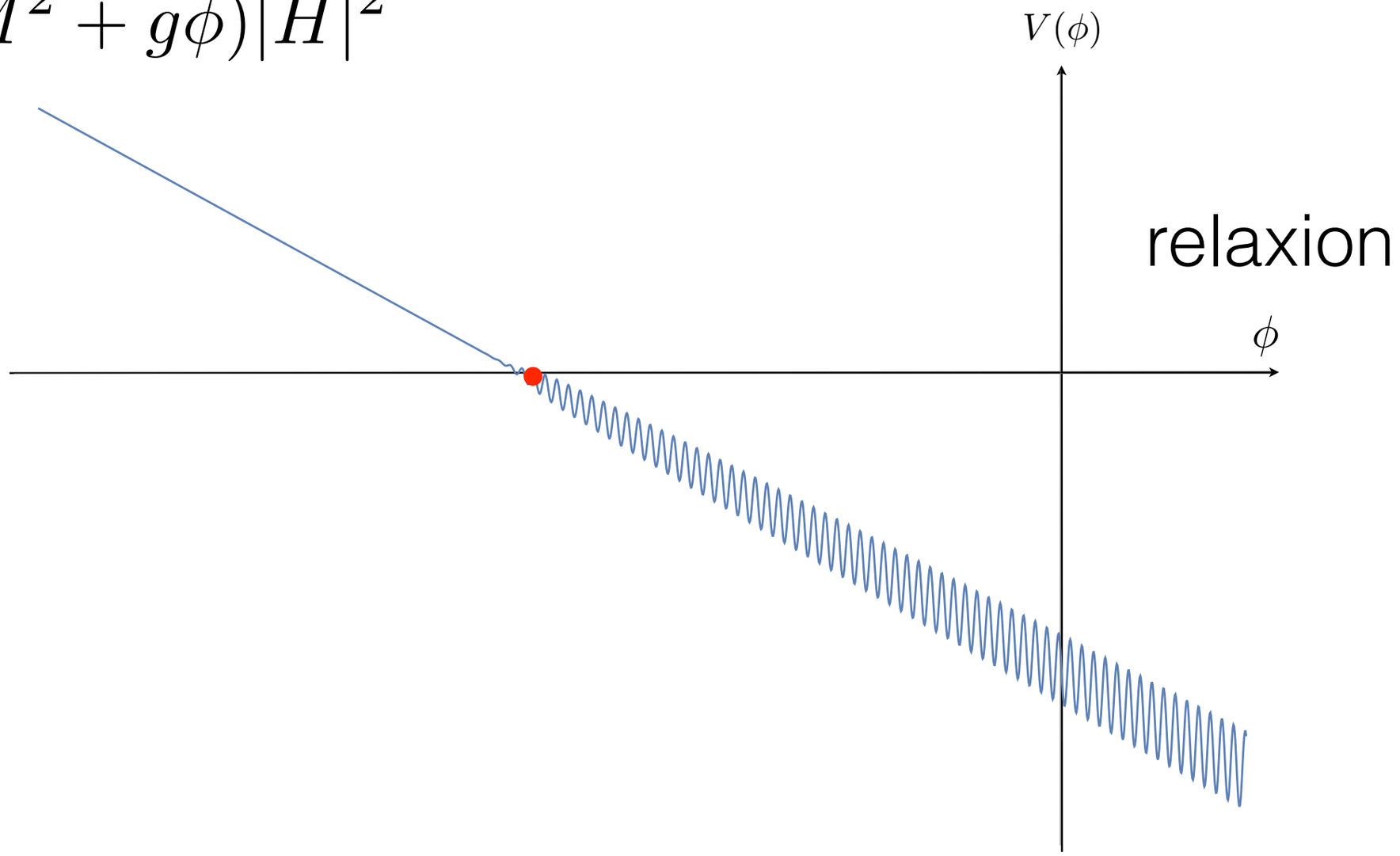
- Agrawal, Barr, Donoghue, Seckel, 9707380

origin of the Higgs mass



historical Higgs

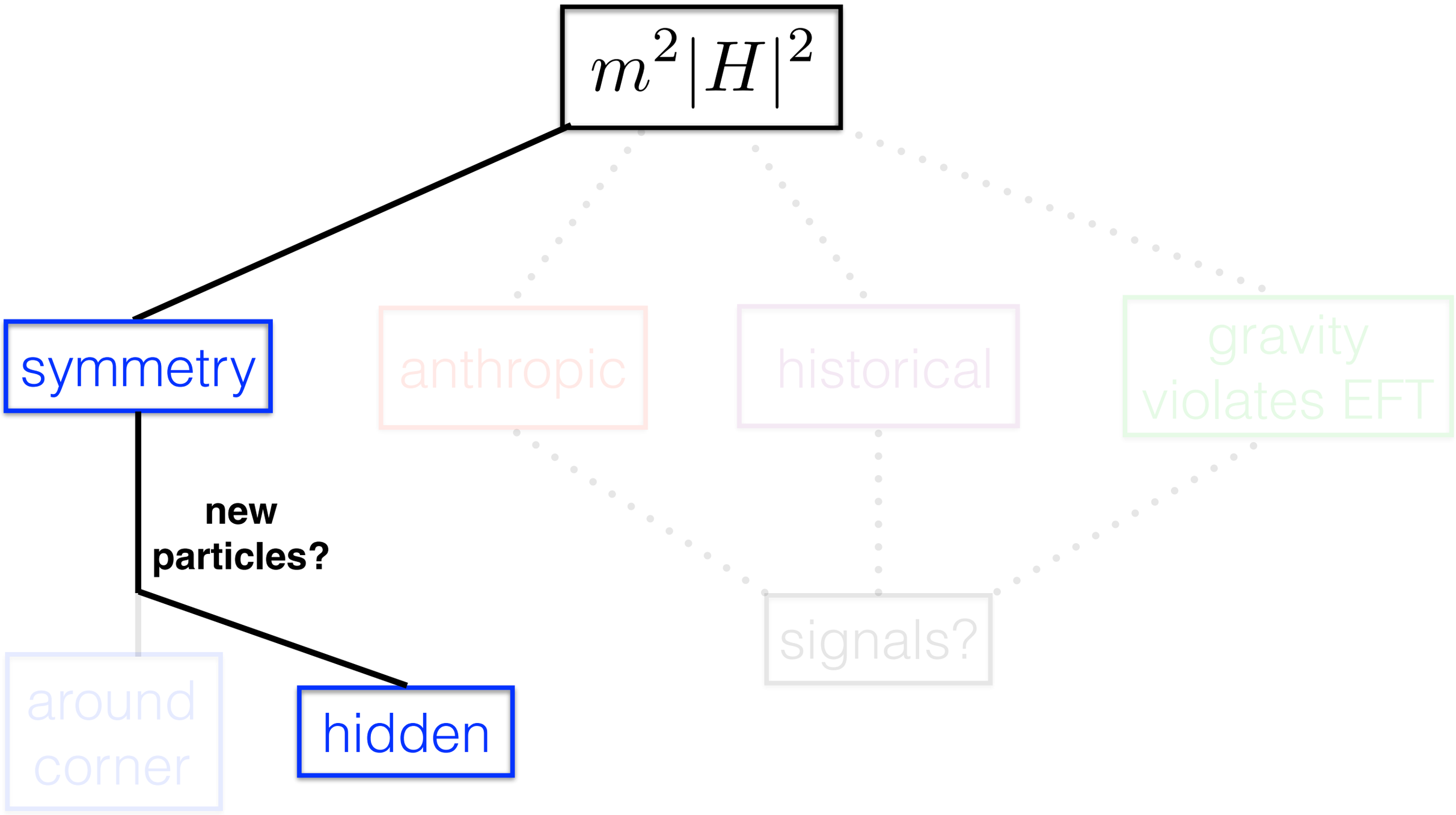
$$V \supset (-M^2 + g\phi)|H|^2$$



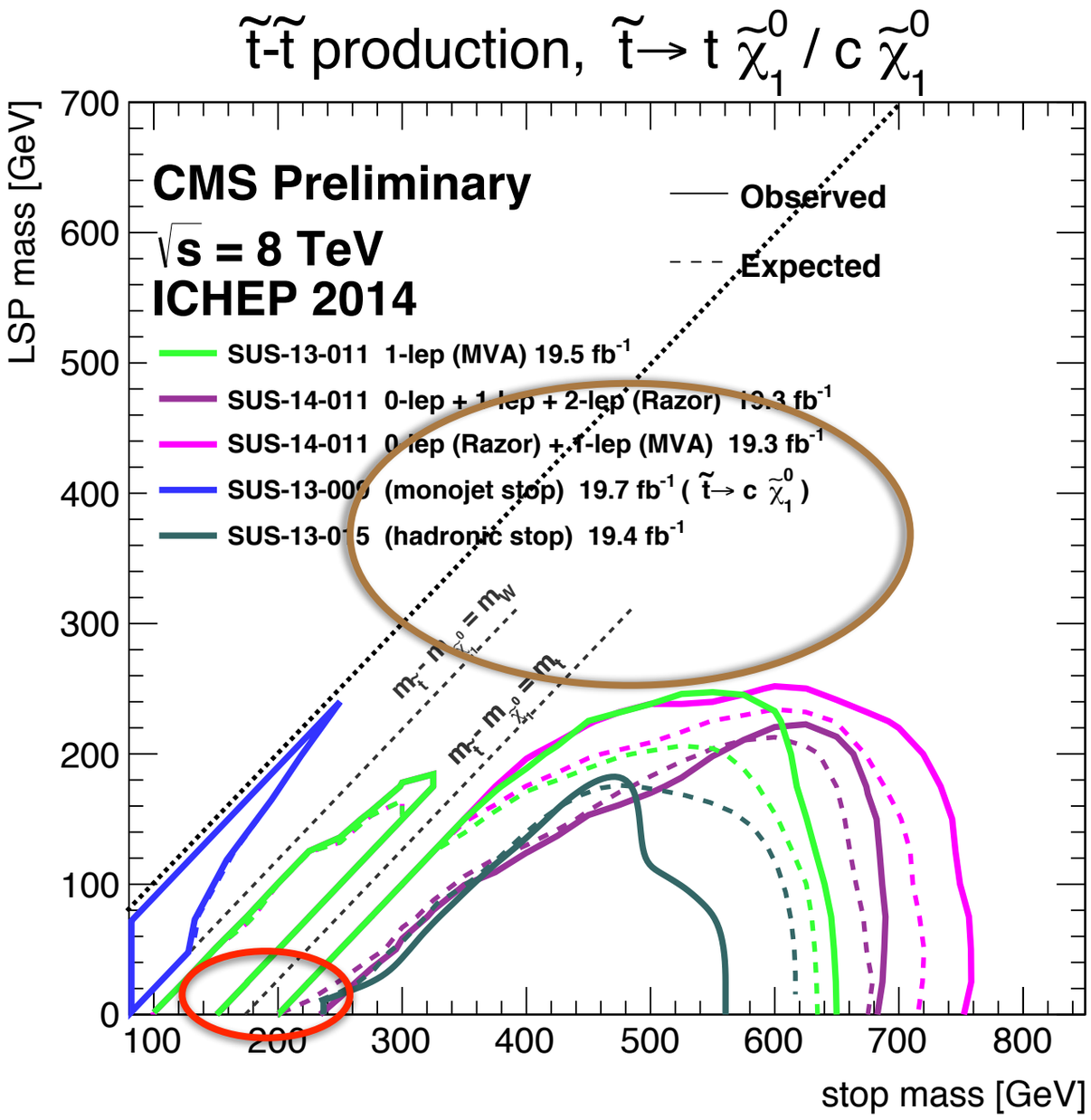
- Graham, Kaplan, Rajendran, 1504.07551

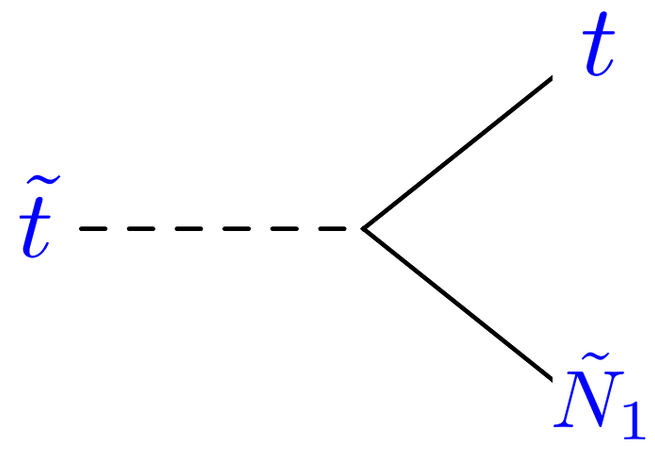
Hidden Particles

origin of the Higgs mass



gaps in stop limits





compressed SUSY:

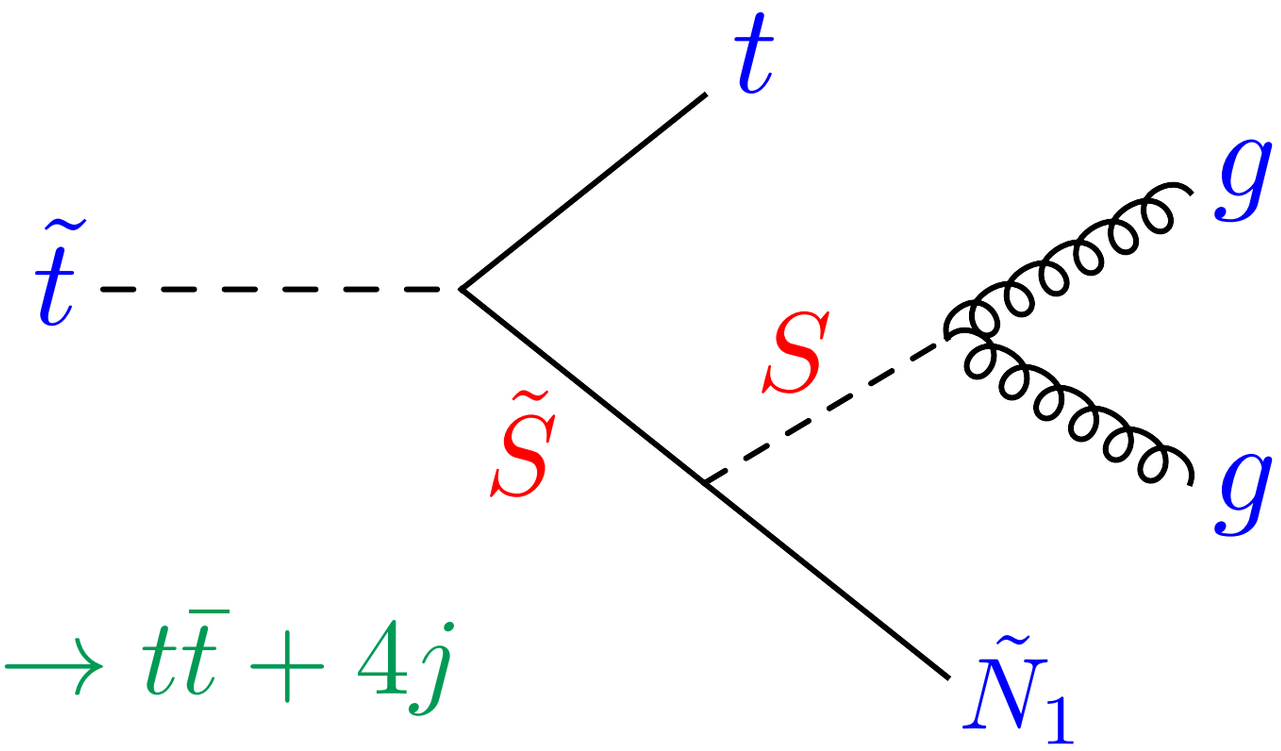
$$m_{\tilde{t}} \sim m_{\tilde{N}_1}$$

stealth kinematic regime:

$$m_{\tilde{t}} \approx m_t$$

$$m_{\tilde{N}_1} \approx 0$$

Stealth SUSY



$$m_{\tilde{S}} \approx m_S$$

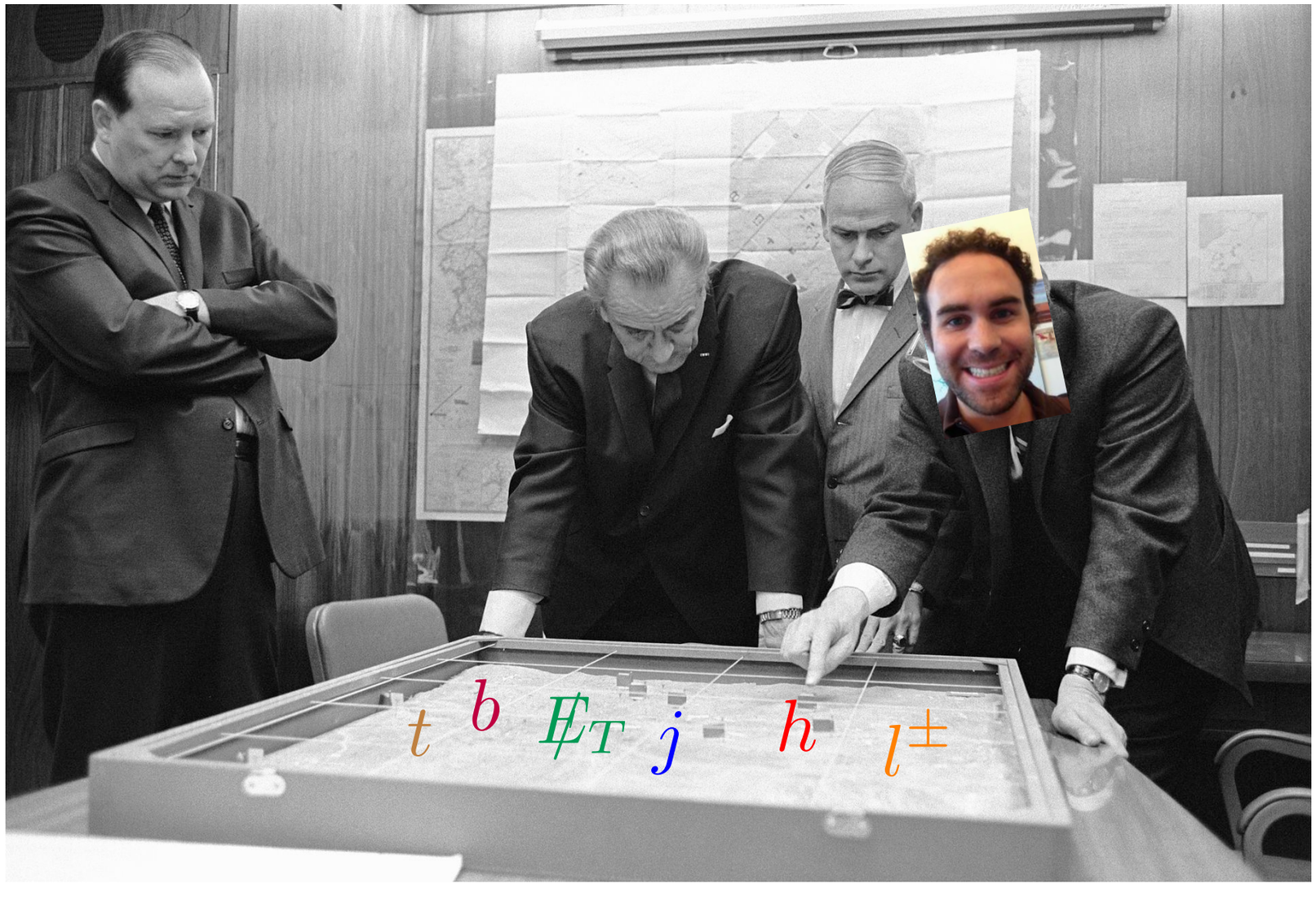
$$m_{\tilde{N}_1} \approx 0$$

$$\tilde{t}\tilde{t}^* \to t\bar{t} + 4j$$

no limits!

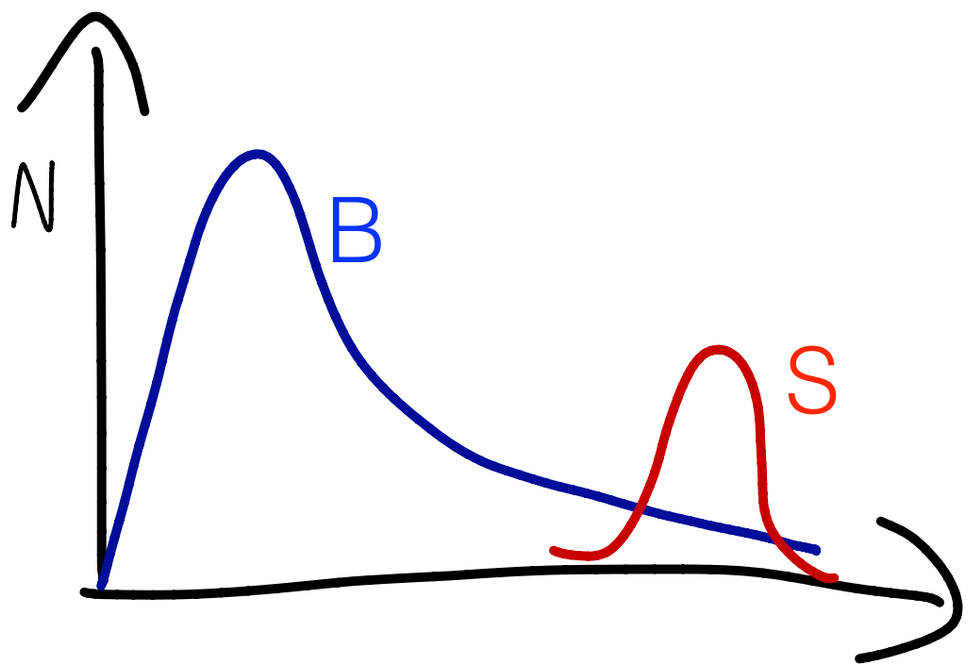
- Fan, Reece, JTR, 1105.5135, 1201.4875
- Fan, Krall, Pinner, Reece, JTR, *to appear.*

BSM strategy

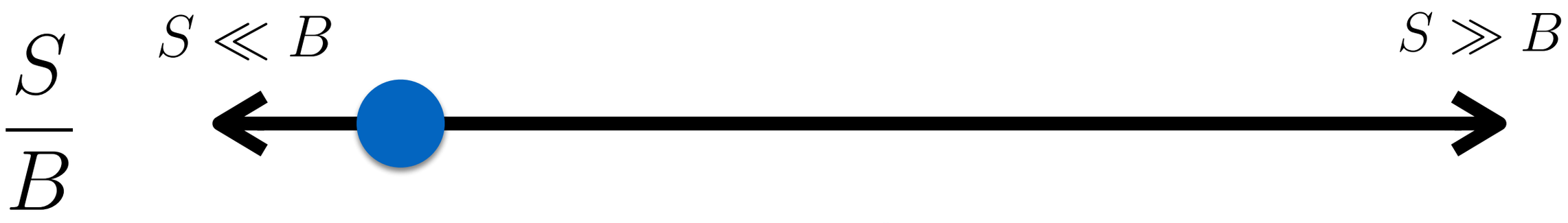


signal v. background

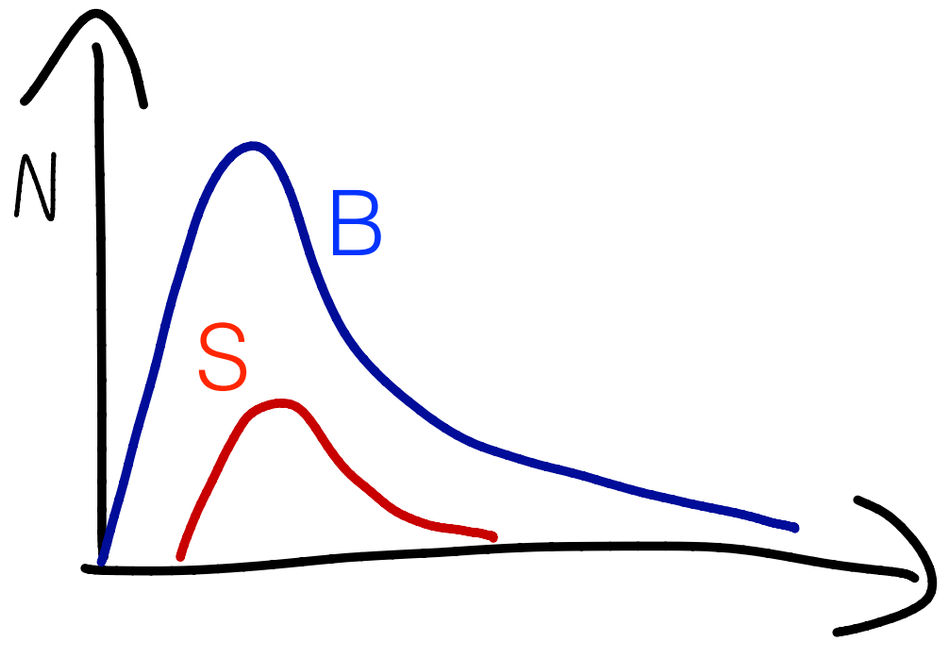
we usually try to separate new physics from backgrounds



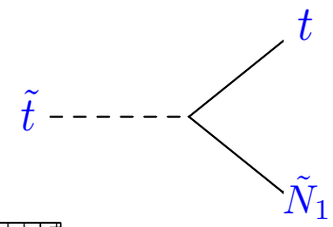
signal v. background



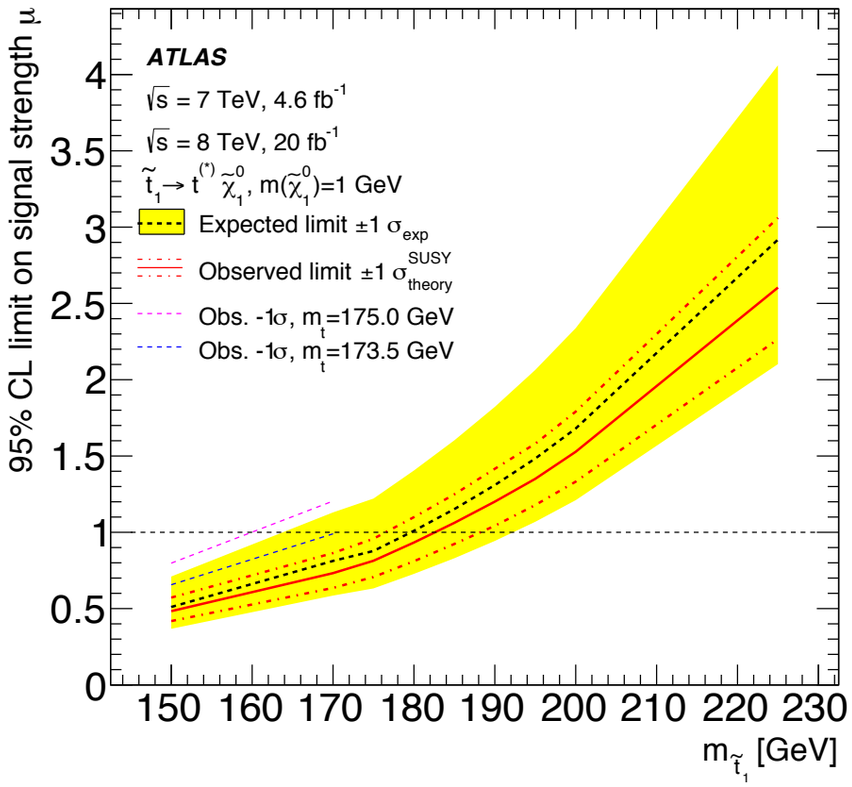
we can also search for new physics by precisely studying the background



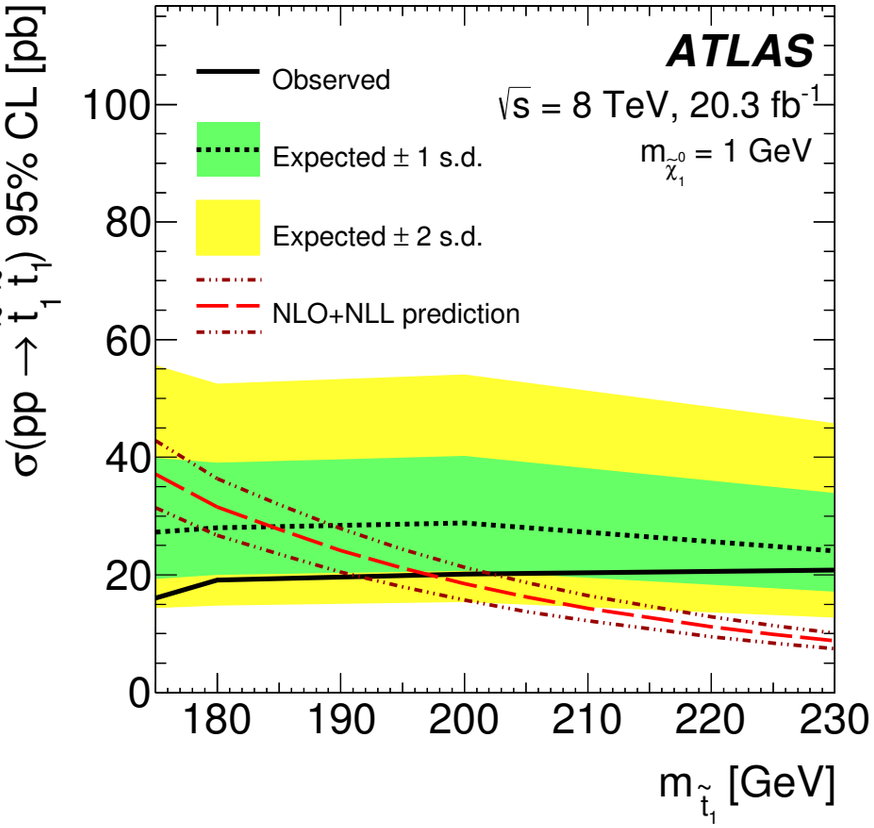
searching for stops with top cross/spin



cross



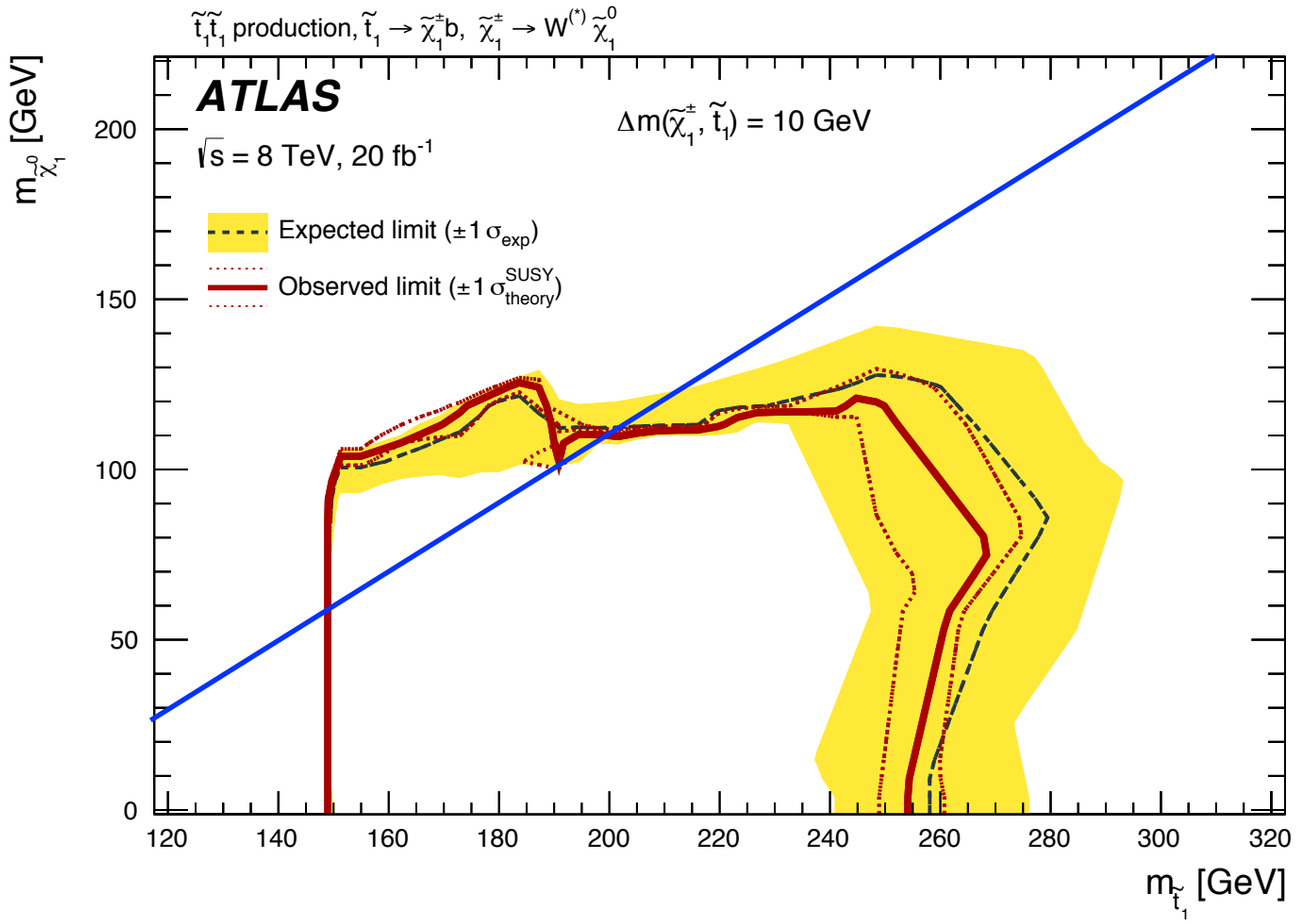
cross+spin

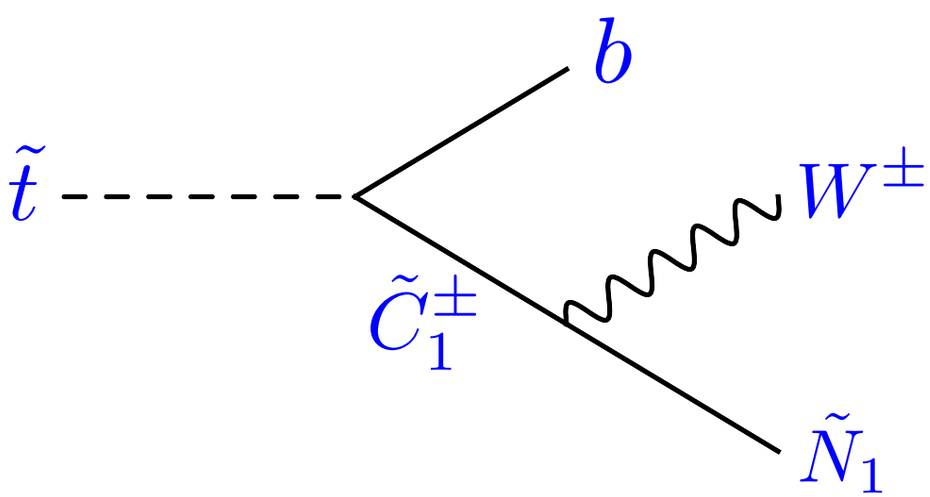


(does stop bias m_t^{exp}?)

- Han, Katz, Krohn, Reece, 1205.5808
- Czakon, Mitov, Papucci, JTR, Weiler, 1407.1043

searching for stops with WW cross





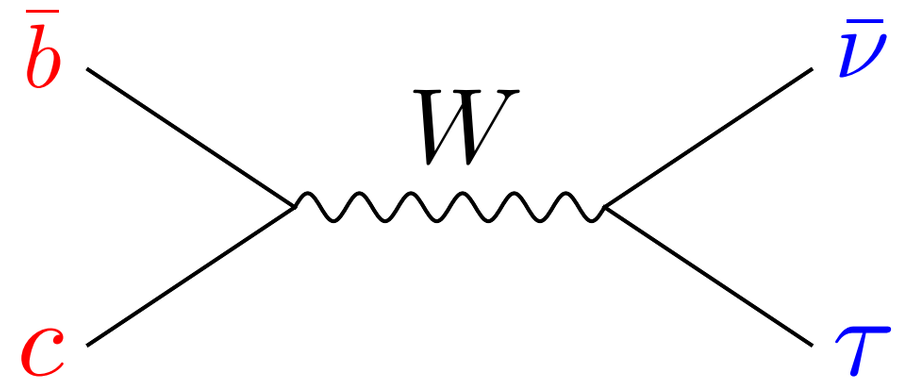
$$m_{\tilde{t}} \sim m_{\tilde{C}_1}$$

$$m_{\tilde{C}_1} - m_{\tilde{N}_1} \sim m_W$$

- Rolbiecki, Sakurai, 1303.5696
- Curtin, Meade, Tien, 1406.0848
- Rolbiecki, Tattersall, 1505.05523

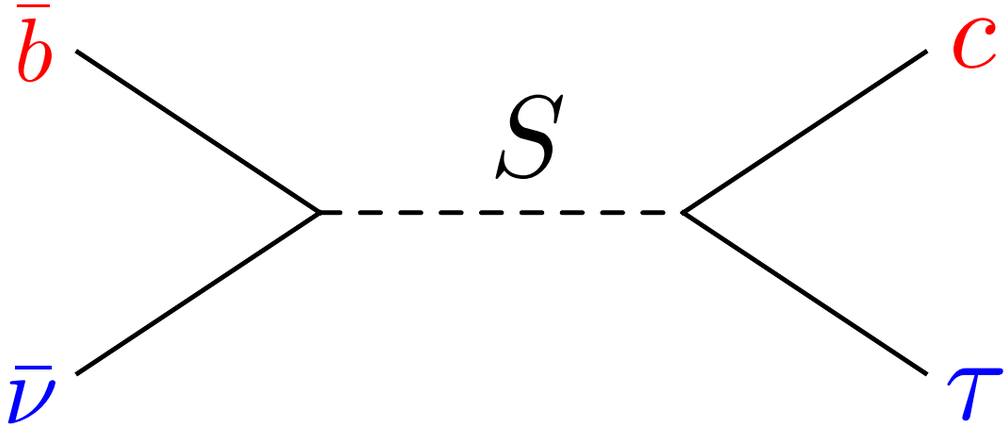
expect the unexpected

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(\bar{B} \to D^{(*)}l\bar{\nu})}$$
$$l = e, \mu$$



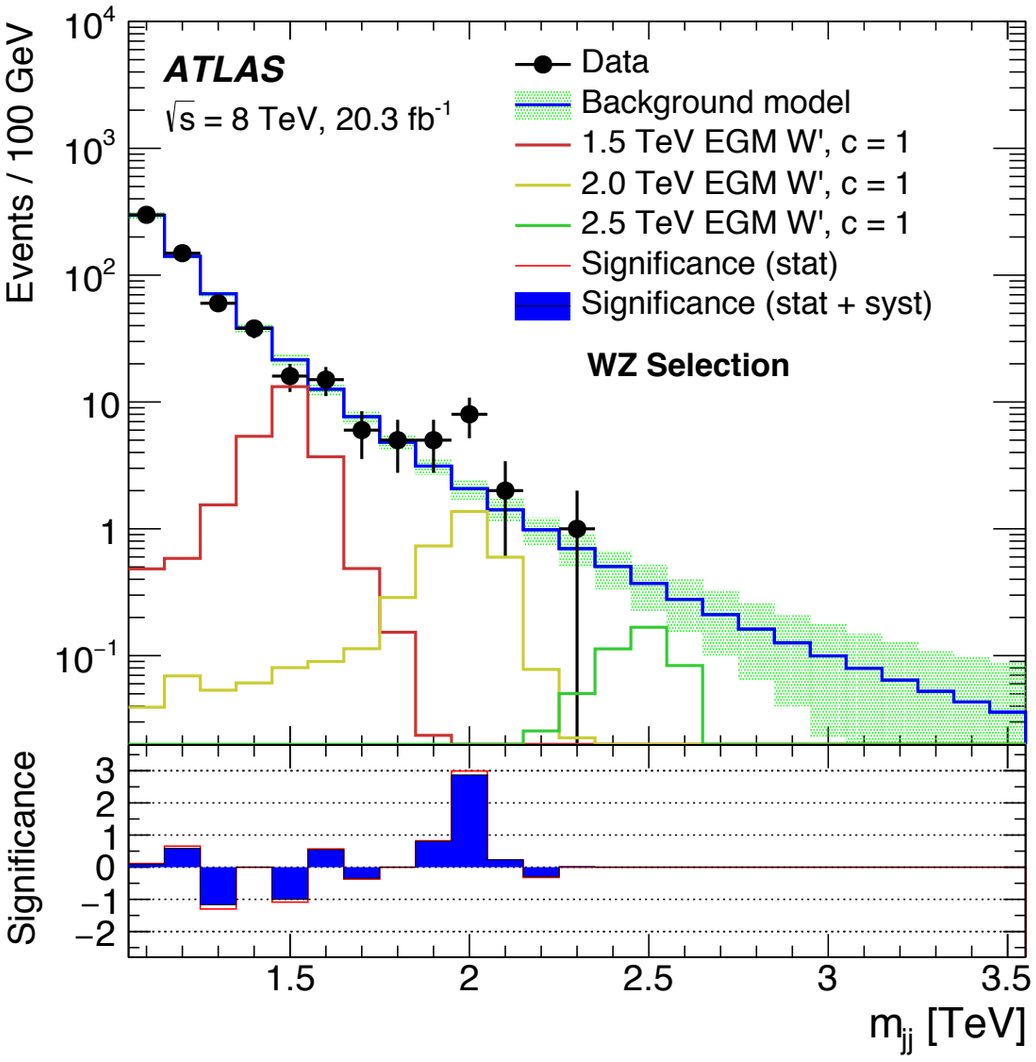
	$R(D)$	$R(D^*)$	Corr.
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$	-0.45
Belle	$0.375^{+0.064}_{-0.063} \pm 0.026$	$0.293^{+0.039}_{-0.037} \pm 0.015$	-0.32
LHCb		$0.336 \pm 0.027 \pm 0.030$	
Exp. average	0.388 ± 0.047	0.321 ± 0.021	-0.29
SM expectation	0.300 ± 0.010	0.252 ± 0.005	
Belle II, 50 ab^{-1}	± 0.010	± 0.005	

$\sim 4\sigma$



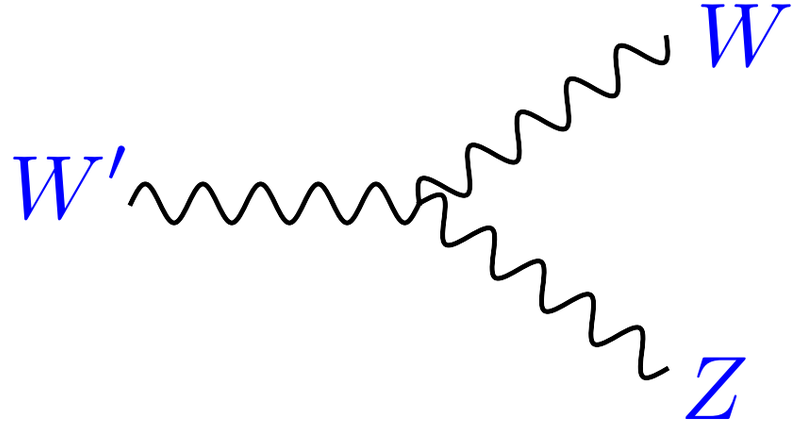
- Freytsis, Ligeti, JTR, 1506.08896

expect the unexpected



2.5σ (global)

$$SU(2)_L \times SU(2)_R \times U(1)'$$



- Dobrescu, Liu, 1506.06736, 1507.01923
- Brehmer, Hewett, Kopp, Rizzo, Tattersall, 1507.00013

take away

- natural models remain viable and will be tested at 13 TeV

  - alternative paradigms may allow for a sparse weak scale

- SM measurements are a promising (and relatively unexplored) way to probe hidden particles

  - expect the unexpected at 13 TeV!!!