Wakeful Dreams

some ideas and hopes for fundamental physics

“LHC Physics”

Unification of Charges

The quantum numbers of quarks and leptons make a compelling case of something like SO(10) unification, now more than ever:

> Right-handed neutrinos have been “found”. (More precisely, there is evidence for neutrino masses entirely consistent with expectations.)
>
> No exotics have been found.

$$\begin{pmatrix} u & u & u \\ d & d & d \end{pmatrix}^{L}_{1/6}$$

$$\begin{pmatrix} \nu \\ e \end{pmatrix}^{L}_{-1/2}$$

$$\begin{pmatrix} u & u & u \end{pmatrix}^{R}_{2/3}$$

$$\begin{pmatrix} d & d & d \end{pmatrix}^{R}_{-1/3}$$

$$\begin{pmatrix} e \end{pmatrix}^{R}_{-1}$$

$$\nu^{R}$$

$$SU(3) \times SU(2) \times U(1)$$

mixed, not unified

	R	W	B	G	P
u	+	-	-	+	-
u	-	+	-	+	-
u	-	-	+	+	-
d	+	-	-	-	+
d	-	+	-	-	+
d	-	-	+	-	+
u^c	-	+	+	-	-
u^c	+	-	+	-	-
u^c	+	+	-	-	-
d^c	-	+	+	+	+
d^c	+	-	+	+	+
d^c	+	+	-	+	+
ν	+	+	+	+	-
e	+	+	+	-	+
e^c	-	-	-	+	+
N	-	-	-	-	-

Hypercharge Y = -1/6 (R+W+B) + 1/4 (G+P)

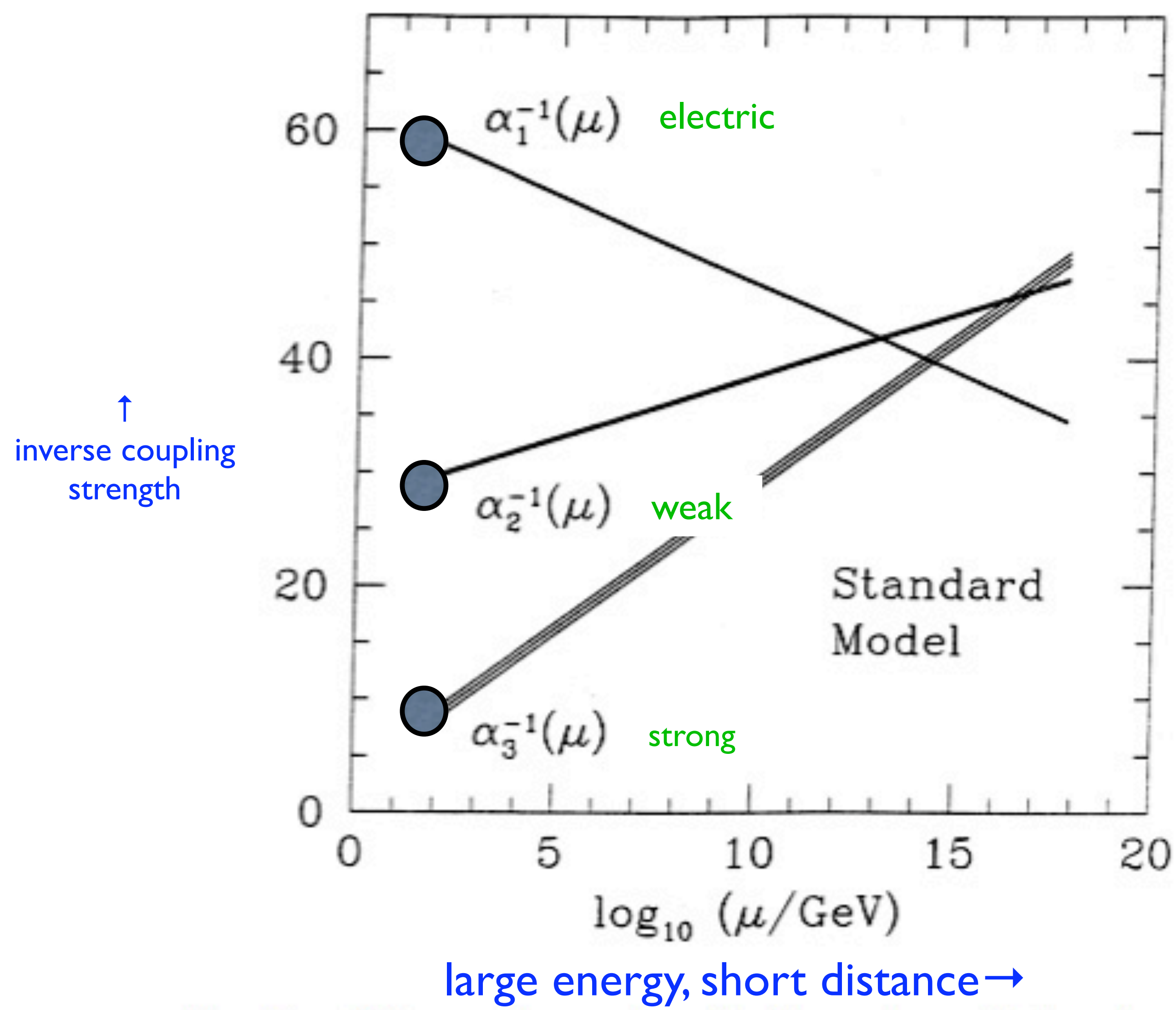
SO(10)

N.B.: One hand rules them all!

Unification of Couplings

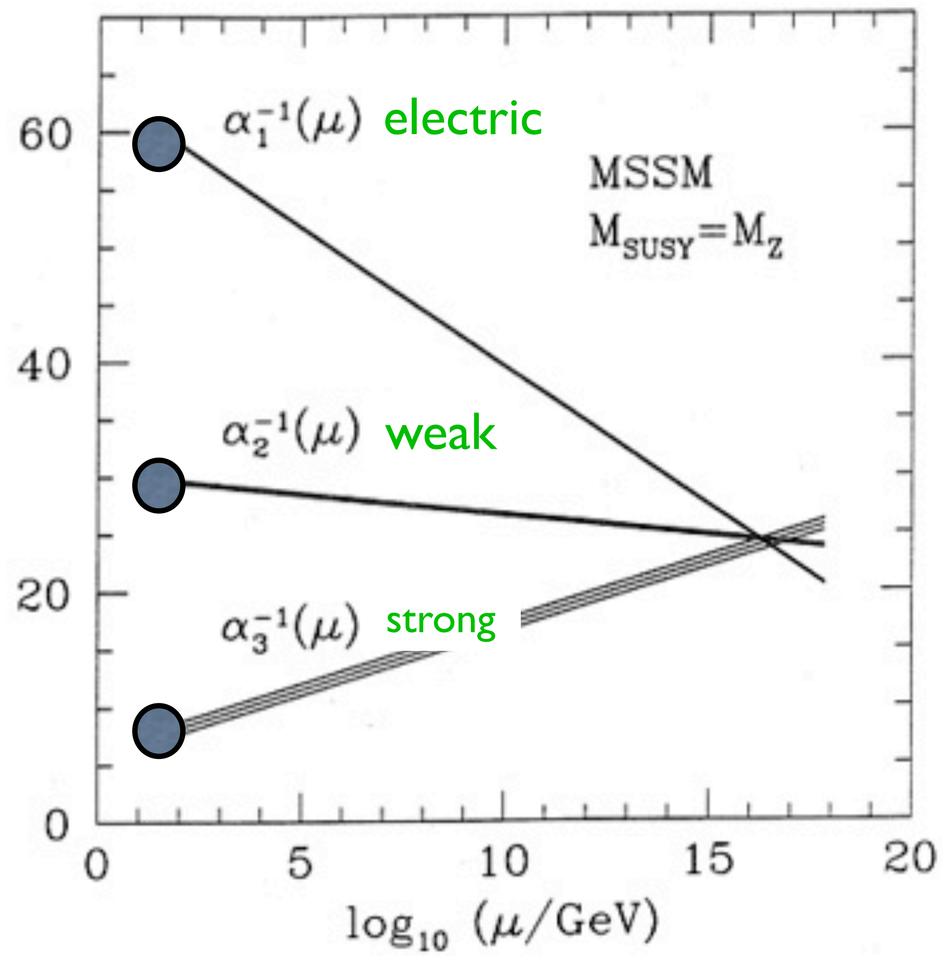
The unification of couplings does not work well if we extrapolate the minimal standard model.

It works much better if we include low-energy supersymmetry (SUSY).



60
40
20
0
0
5
10
15
20
$\alpha_1^{-1}(\mu)$
electric
$\alpha_2^{-1}(\mu)$
weak
$\alpha_3^{-1}(\mu)$
strong
Standard Model
↑ inverse coupling strength
$\log_{10}(\mu/\text{GeV})$
large energy, short distance→

Unification ♥ SUSY



↑ inverse coupling strength

large energy, short distance→

The unification calculation is only mildly sensitive to SUSY masses, but marginally favors heavy (multi-TeV) sfermions.

More generally, the unification is only mildly sensitive to addition of complete SU(5) multiplets.

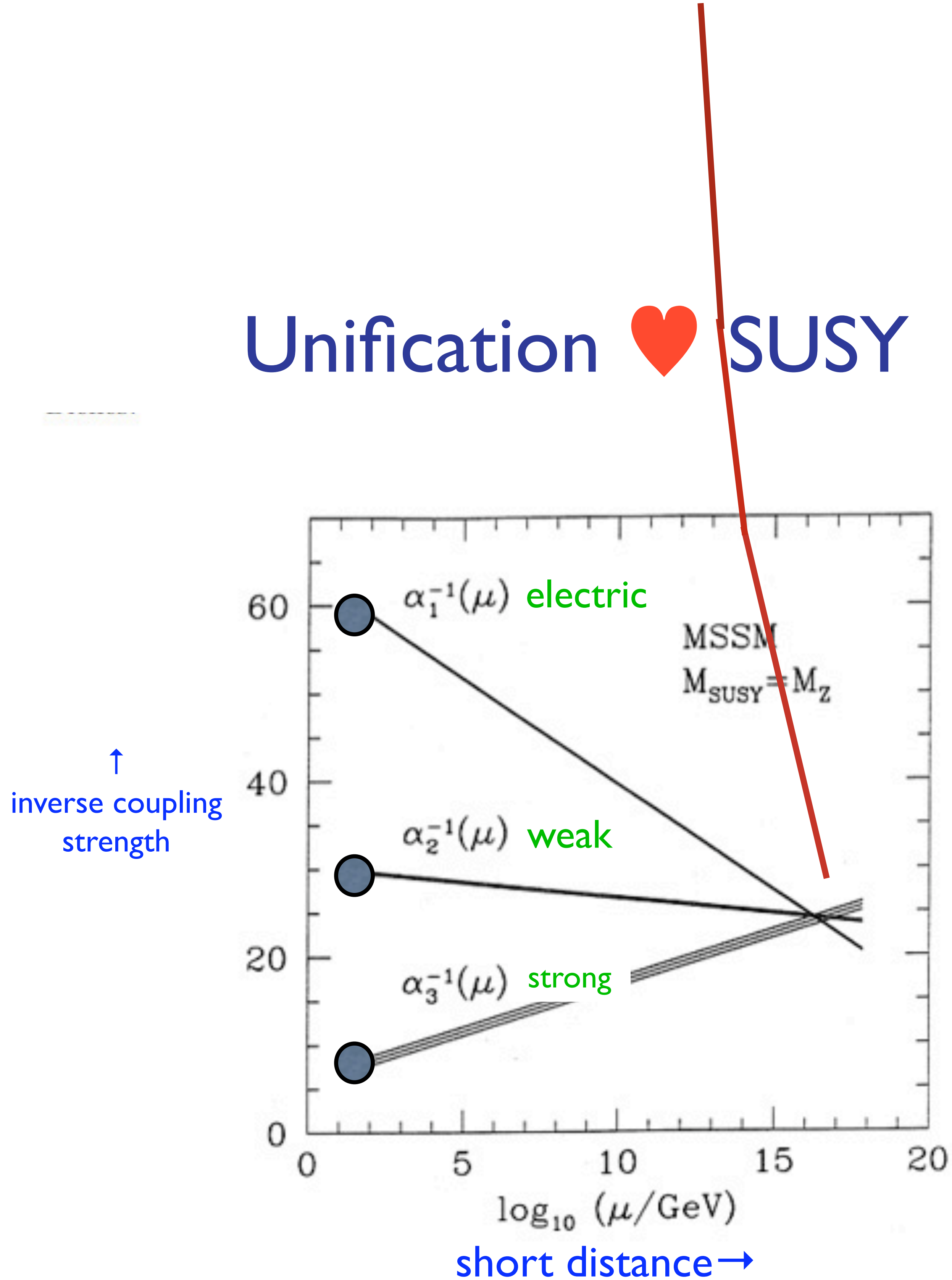
The emergence of a new, very high scale through unification is profoundly significant:

It makes unification including gravity plausible.

It suppresses proton decay*.

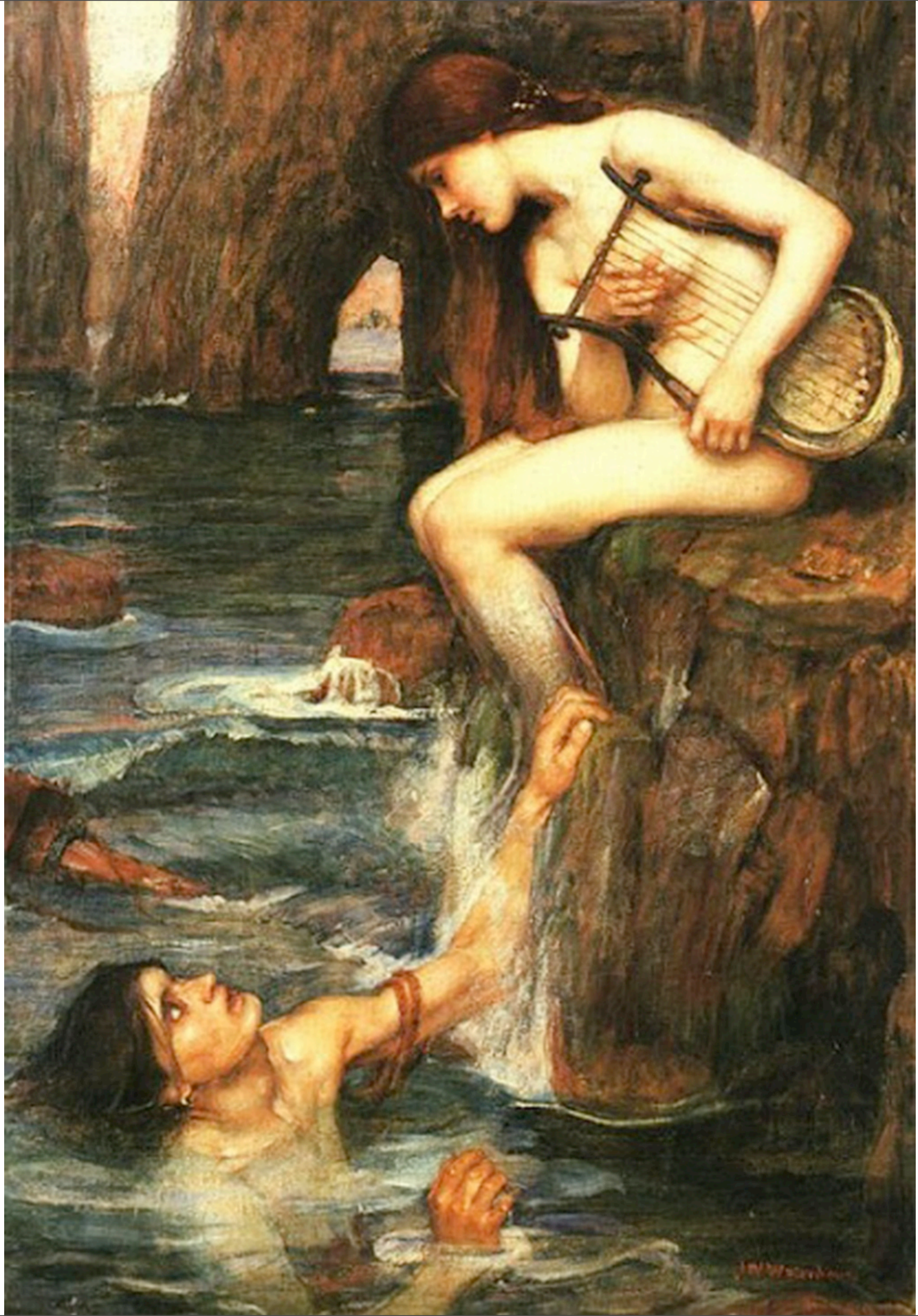
*But the safety margin is thin!

Unification ♥ SUSY



Gravity fits too!
(roughly)

What Kind of Girl is this SUSY?



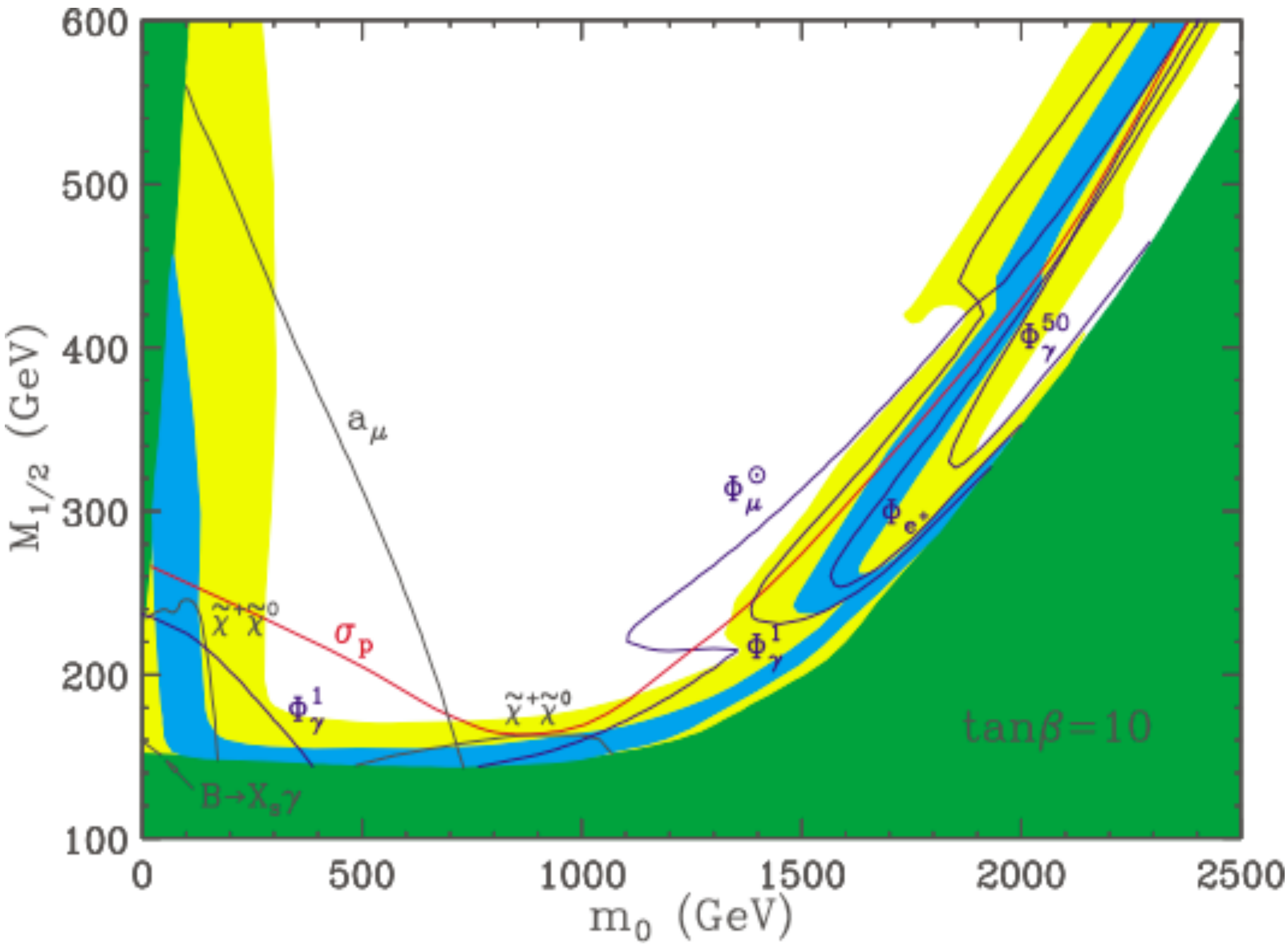

Susy?

Shy, for one thing: many suggested consequences (CP violation, flavor violation, proton decay, radiative corrections ...) have *not* been seen.

(Note that this is an equally or more severe problem for ideas that propose more powerful and less cancellation-prone interactions, e.g. - technicolor, not-so-small extra dimensions.)

Those unobserved effects are uniformly suppressed for heavy sfermions; so this too suggests that the sfermions are heavy.

A possible difficulty with heavy sfermions is too much dark matter, i.e. overproduction of the *nominal* lightest supersymmetric particle (NLSP).



600
500
400
300
200
100
0
500
1000
1500
2000
2500
$M_{1/2}$ (GeV)
m_0 (GeV)
a_μ
σ_p
$\tilde{\chi}^+\tilde{\chi}^0$
$\tilde{\chi}^+\tilde{\chi}^0$
Φ_γ^1
Φ_γ^1
$\Phi_\mu^\odot$
Φ_{e^+}
Φ_γ^{50}
$B \to X_s\gamma$
$\tan\beta=10$

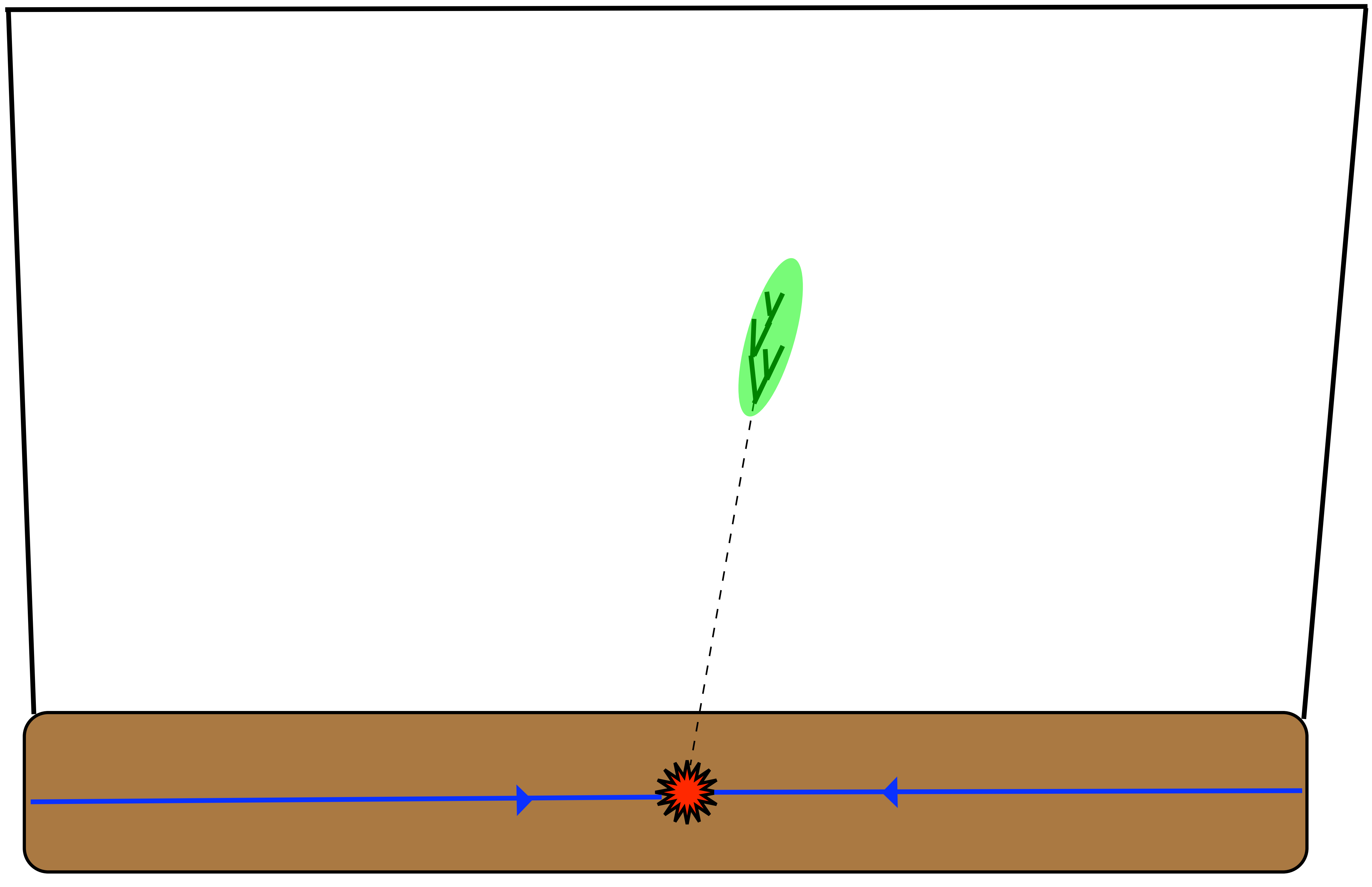
A logical, and I think beautiful, possible explanation is that the nominal LSP decay into a much lighter, very feebly interacting particle, specifically:

$$\tilde{\chi} \rightarrow \tilde{\mathrm{a}} + \gamma$$

This, and several other, ideas suggest the possibility of long-lived ($\tau \gtrsim 10^{-5}$ s.) heavy, very weakly interacting particles.

Detecting these will be a challenge.

One possibility might be to adapt cosmic ray (e.g., "Fly's Eye") techniques:

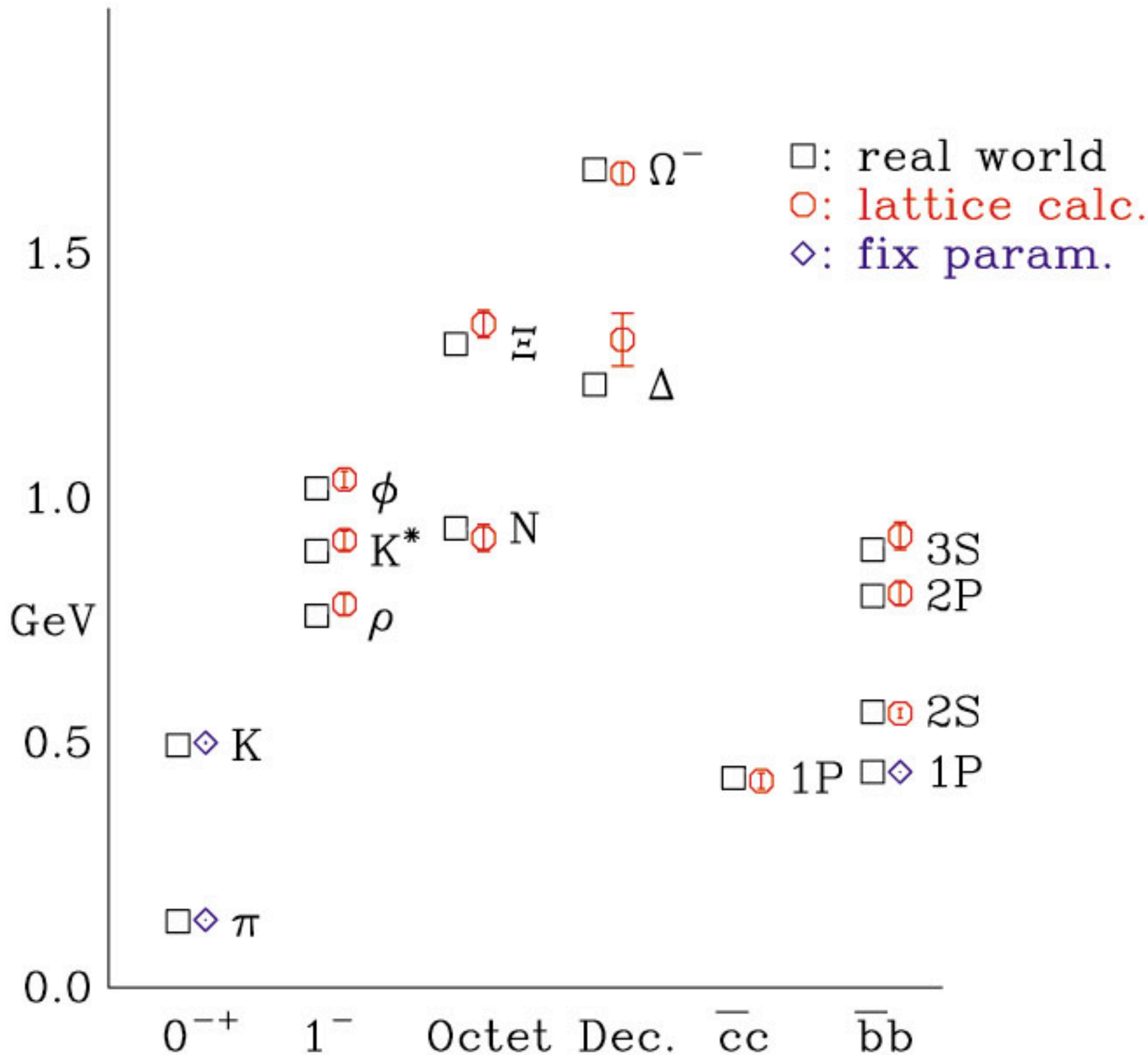


Of course there's infinitely more one might say about LHC physics ...

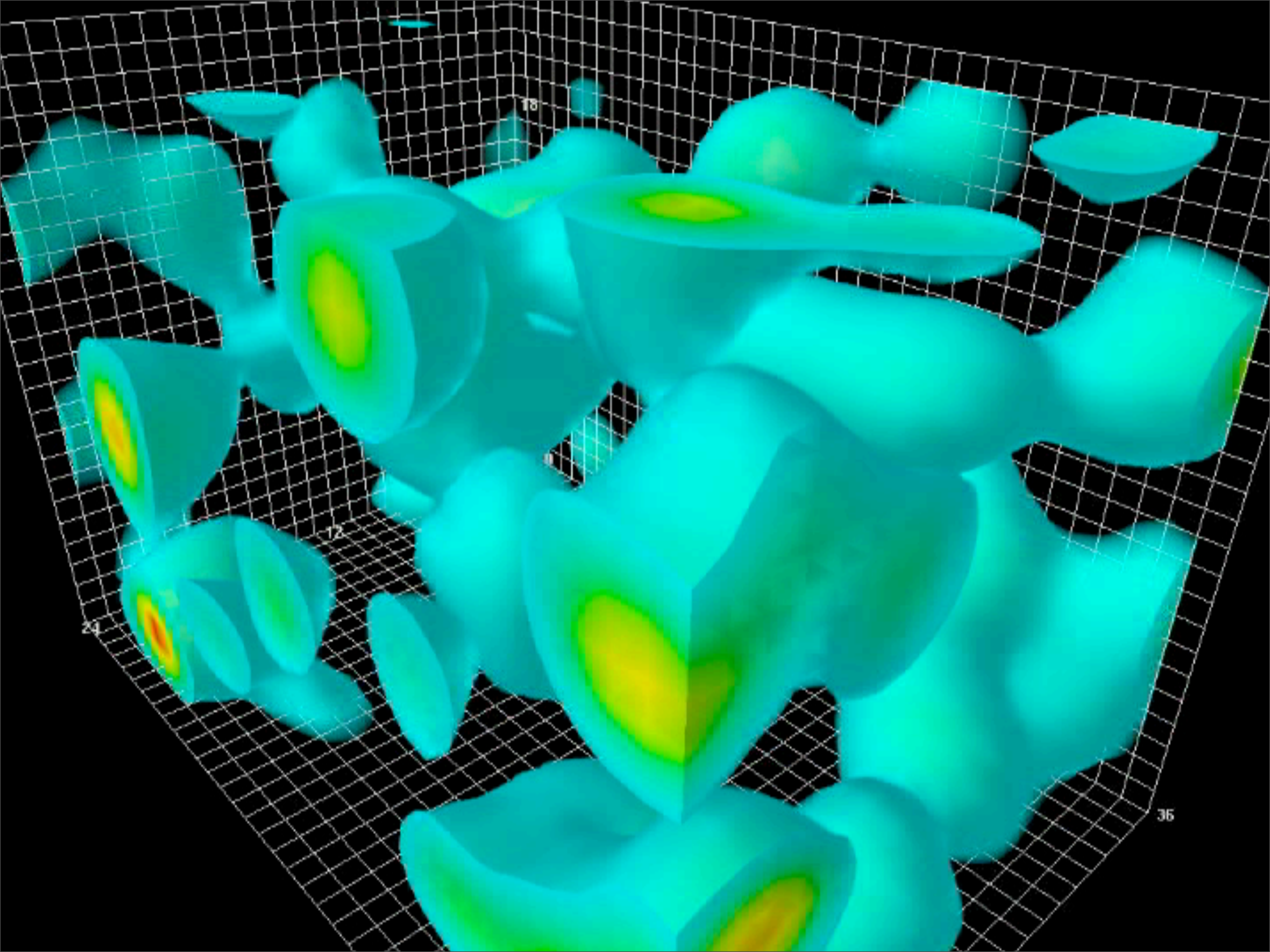
... but what we really want is for the machine to start talking!

“QCD Physics”

triumphs, challenges



□: real world
○: lattice calc.
◇: fix param.
GeV
1.5
1.0
0.5
0.0
π
K
ρ
K*
ϕ
N
Ξ
Δ
Ω⁻
1P
1P
2S
2P
3S
0⁻⁺
1⁻
Octet
Dec.
c̄c
b̄b


18
12
24
36

Many qualitative challenges remain, e.g. glueball clarification, "Regge" spectroscopy, nuclear and ultranuclear physics ... as well as bread-and-butter, useful matrix element calculations.

Finite baryon density is very hard to handle, due to the notorious sign (actually, phase) problem. This problem plagues condensed matter physics, and for that matter chemistry, as well.

There is an idealized version that does seem approachable, with interesting connections to the Mott problem.

What Happens?

8	8	8
8	8	8
8	8	8

low density:
separate glueballs (?) — "insulator"

high density:
screening plasma (?) — "metal"

intermediate density:
pairing (??) — "!"

And in Conclusion ...

What Does It All Mean?

Facts?

Process?

New powers?

Inspiration