BLACK HOLES AND MANY SPECIES SOLUTION TO THE HIERARCHY PROBLEM (AT LHC)

Gia Dvali

CERN TH
&
NYU

Outline:

(1) From black hole physics we shall prove the bound:

$$\underbrace{M_p^2 \geq N \Lambda^2}$$

$N \equiv$ Number of species

$\Lambda \equiv$ Mass of the speies

(2) Also, any conserved quantum charge Q, not associated with any classical long-range force, must be defined maximum modulo

$$N_{MAX} = \left(\frac{M_P}{\Lambda}\right)^2$$

$\Lambda \equiv$ mass of the charge

The role of Q can be played by Z_N-charge, or by a quantum-mechanical hair.

(3) Then the following "cheap" solutions to the hierarchy problem emerge:

(I) Postulate the existence of $N \sim 10^{32}$ species beyond the Standard Model.

E.g., 10^{32} copies of the Standard Model.

(II) Postulate that there is a Z_N $(N \sim 10^{32})$ exact discrete symmetry.

(III) Postulate that Higgs (or some other state) carries a tiny charge $q \sim 10^{-32}$ of quantum-mechanical hair.

(4) This solutions will be tested by LHC, or else there is a BIG puzzle.

(5) We shall discuss some interesting open questions, and implications for other hierarchies

$$\frac{M_{GUT}}{M_P}, \quad \frac{M_{STRING}}{M_P} \quad \ldots$$

THE BLACK HOLE PROOF:

Consider N species of the quantum fields

$$\Phi_j \quad j = 1, 2 \ldots N$$

of mass Λ.

Assume that this system is invariant under an exact (gauged) discrete symmetry

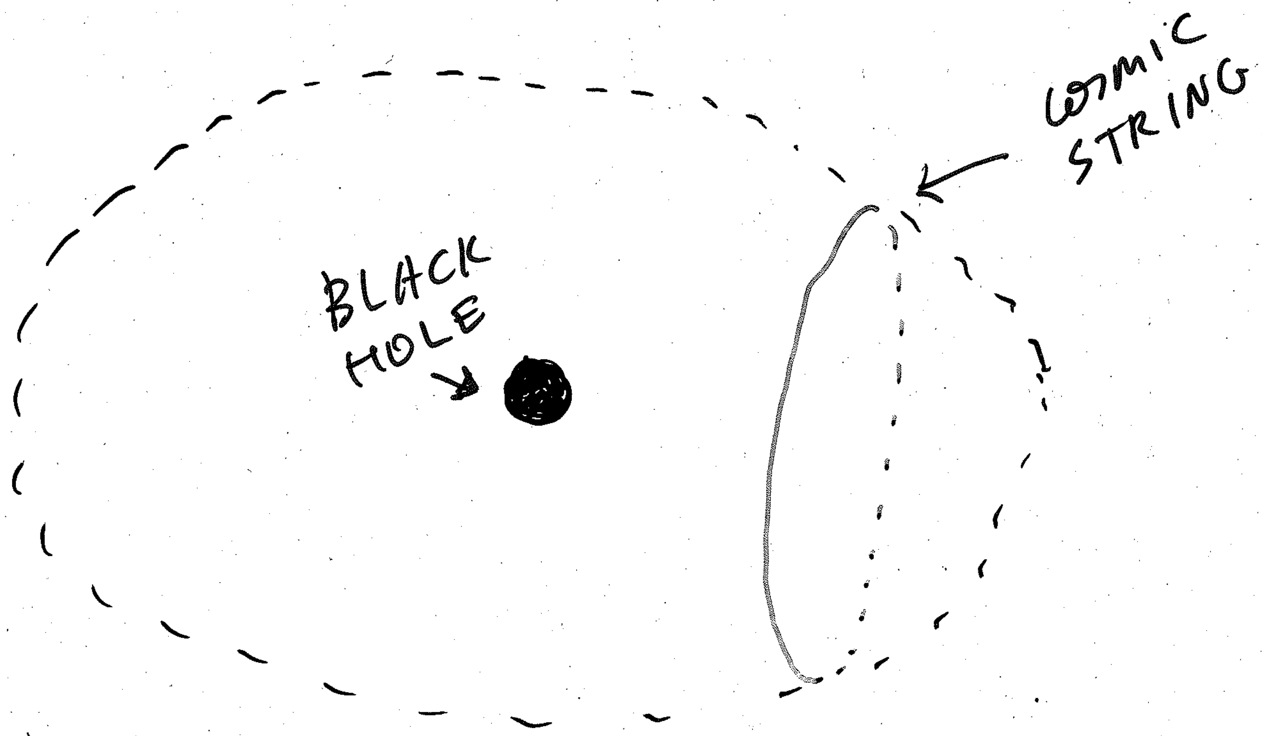
$$Z_2^N \equiv Z_2^{(1)} \times Z_2^{(2)} \times \ldots \times Z_2^{(N)}$$

$$Z_2^{(j)} \Rightarrow \quad \Phi_j \to - \Phi_j$$

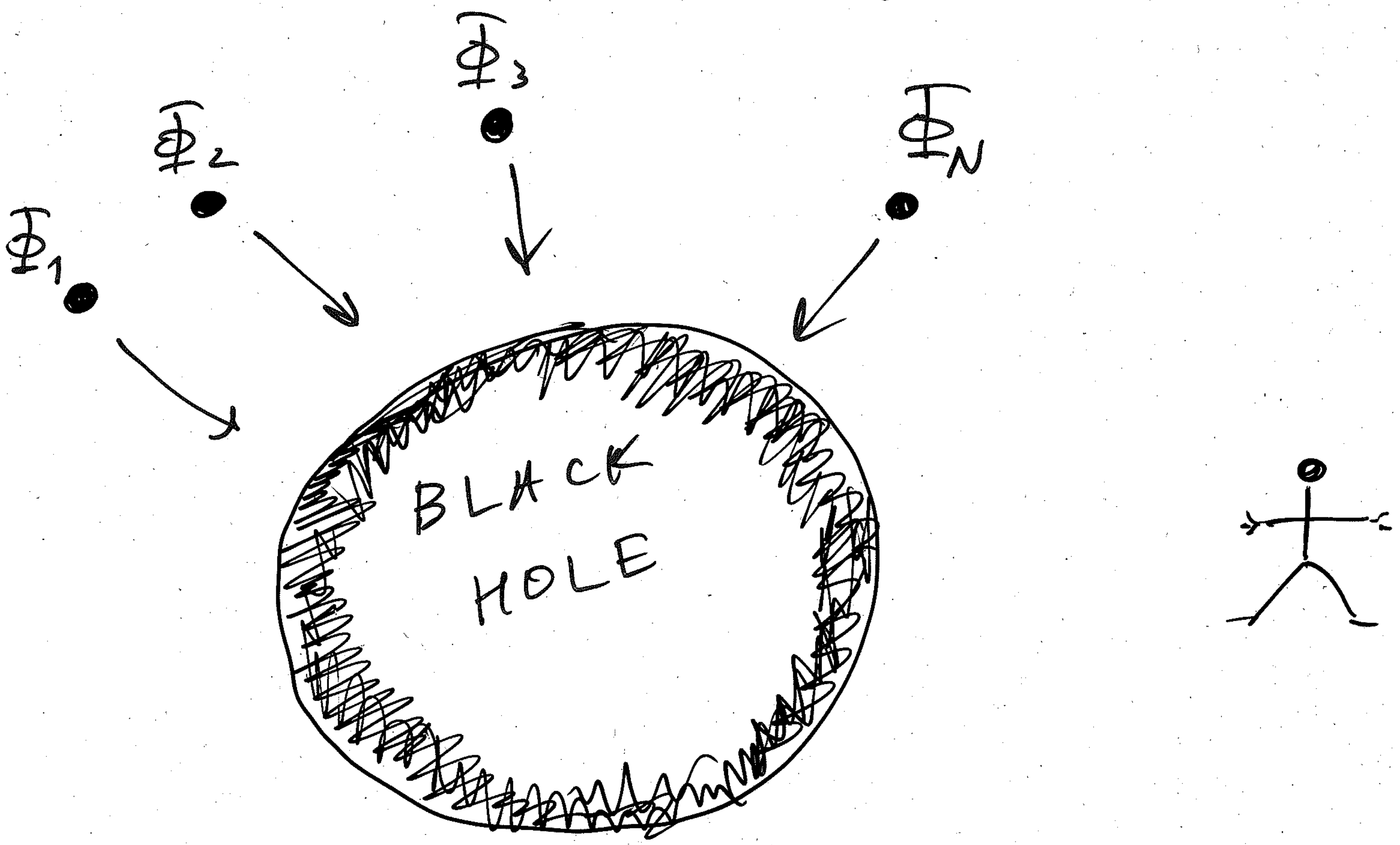
Because Z_2^N is gauged, it is respected by the black hole physics.

This is because black holes can carry a Z_N quantum mechanical hair, which can be measured at infinity by the Aharonov-Bohm effect.

Krauss & Wilczek.



Now, let us prepare an arbitrarily-large black hole that carries a maximal $\mathbb{Z}_2^N$-charge



and wait.

Because Hawking evaporation is thermal, for

$$T_H = \frac{M_P^2}{M_{BH}} \ll \Lambda,$$

the emission probability of Λ-species is Boltzmann-suppressed by

$$\sim e^{-\frac{\Lambda}{T_H}}.$$

So no matter how large is N, the black hole can only start "giving back" the Z_2^N-charge after

$$T_H \gtrsim T_H^* \sim \Lambda.$$

At this point the mass is:

$$M_{BH}^* = \frac{M_P^2}{\Lambda}$$

Now use conservation of energy. Then, the maximum number of species that can be returned is

$$N_{MAX} = \frac{M_p^2}{\Lambda^2}.$$

Because by Z_2^N-conservation,

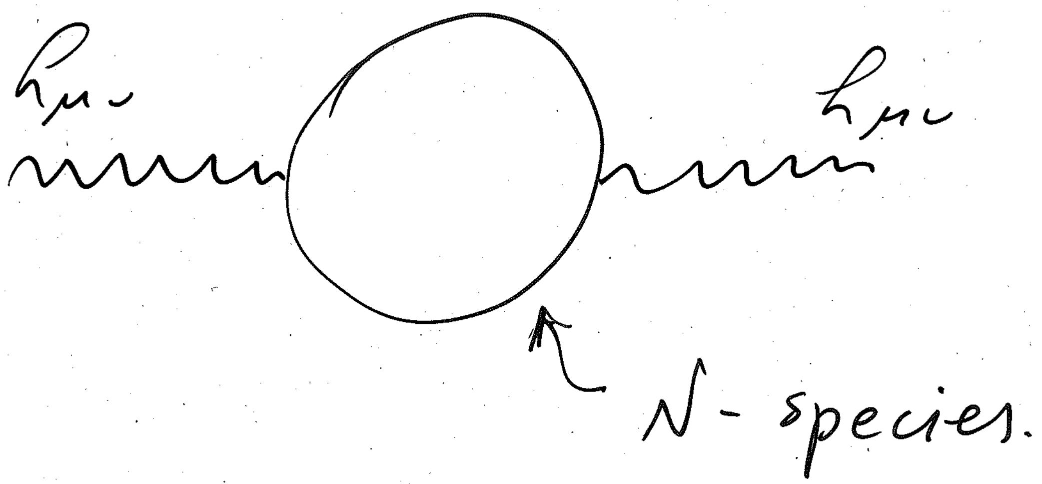
$$N_{MAX} \geq N,$$

we prove the bound

$$M_p^2 \geq N \Lambda^2$$

This bound agrees with the perturbative argument

G.D., Gabadadze, Kolanovic, Nitti; Veneziano



$$\delta M_p^2 \sim N \Lambda^2$$

We can repeat the same proof for a single particle of mass Λ that carries an exactly-conserved quantum charge Q (with no long-range classical force).

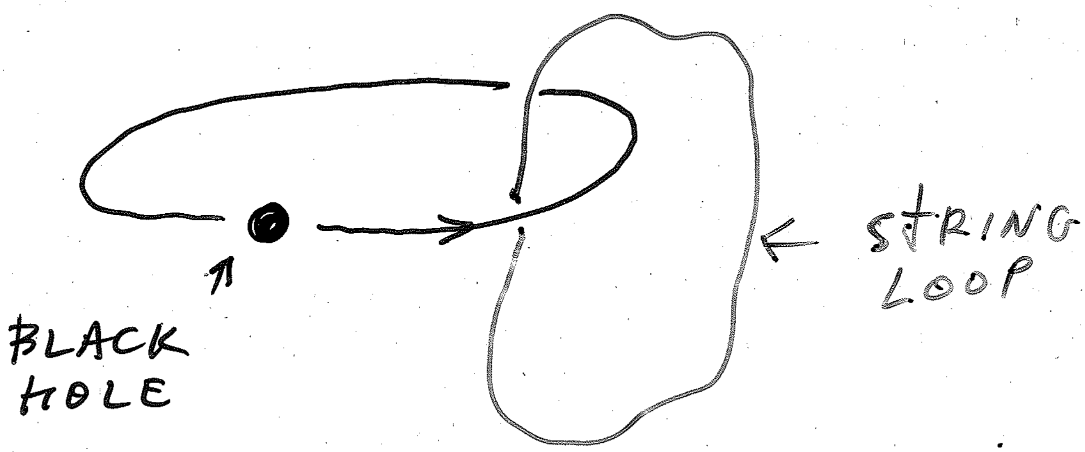
Then by exactly the same reasoning, we prove that Q must be defined modulo

$$N_{MAX} = \left(\frac{M_P}{\Lambda}\right)^2$$

Q can be a Z_N-charge, or a charge under a quantum-mechanical hair.

What is a quantum-mechanical hair?

In any theory with classically-unbreakable strings (or flux lines) we can define a number μ, that counts how many times a black hole (or a particle) went trough a string loop



The resulting Aharonov-Bohm phase shift is:

$$\text{PHASE SHIFT} = \mu \, 2\pi n$$

(2) Alternative is to postulate the existence of a huge discrete symmetry

$$\mathbb{Z}_{10^{32}}$$

or of a tiny quantum hair charge $\sim 10^{-32}$.

If the Higgs can carry such, then we are done.

The following solutions of the hierarchy problem emerge:

(1) Take $N \sim 10^{32}$ copies of the Standard ~~Mo~~ Model.

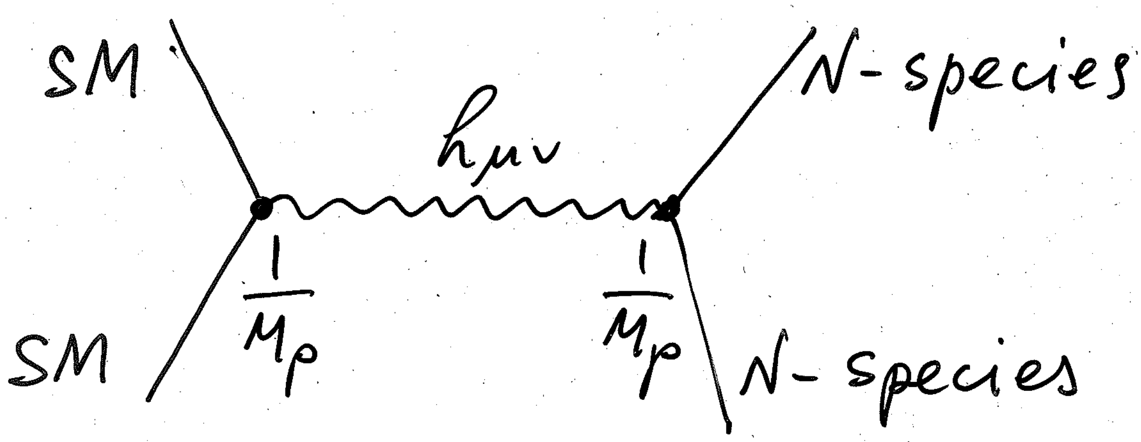
Although a low energy observer from each SM-replica would be puzzled by the smallness of the weak scale versus the Planck mass, the hierarchy will be guaranteed by the consistency of the theory with black hole physics, which implies

$$m_H^2 \leq M_P^2 \cdot 10^{-32}$$

LHC physics.

If the hierarchy problem is solved because of number of species (or large Z_N, or small μ?) LHC should see <u>quantum</u> <u>gravity</u>.

Take $N \sim 10^{32}$ copies of SM which are only gravitationally coupled to each other.



$$\Gamma = \frac{E^5}{M_p^4} N = \frac{E^5}{M_p^2 \Lambda^2}$$

The rate of this process goes as:

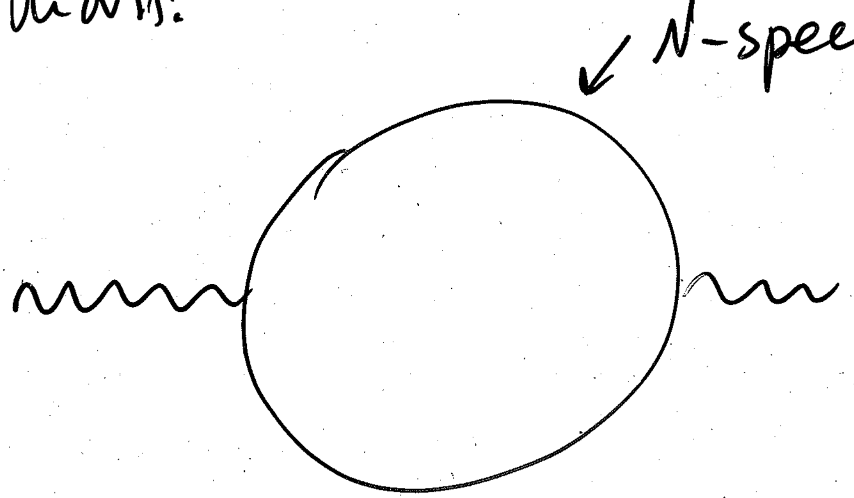
$$\Gamma = \frac{E^5}{(M_p \Lambda)^2} \qquad \Lambda \sim \text{TeV}$$

Naively, although Higgs mass is stabilized at the scale $\Lambda \sim \text{TeV}$, nothing is happening till the scale $\Lambda_c \equiv \sqrt{M_p \Lambda} \sim 10^{11}\,\text{GeV}$!

How can this be?

The following (perturbative) argument suggests that QG scale is actually $\Lambda \sim \text{TeV}$, not $\Lambda_c \sim 10^{11}\,\text{GeV}$

If it were Λ_c, then the contribution to the Planck mass:

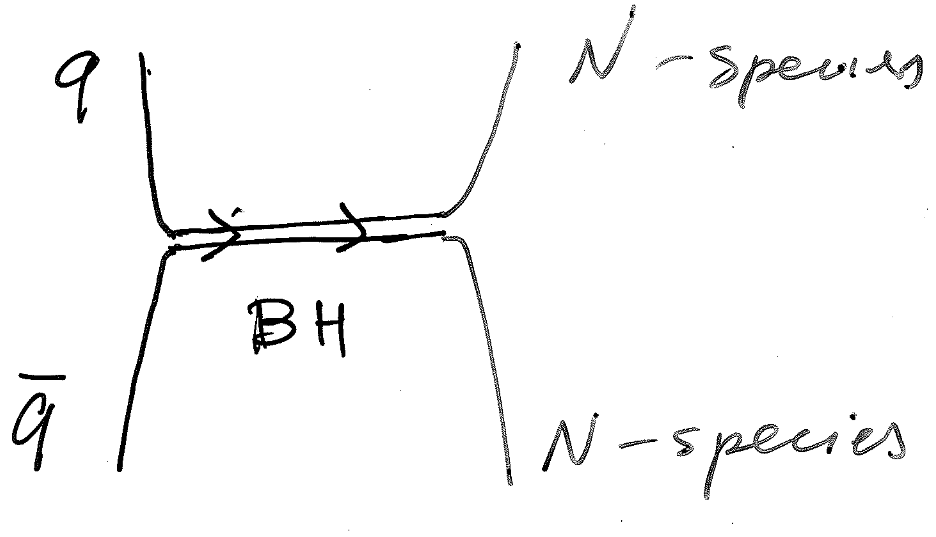


$$\hookrightarrow \delta M_p^2 \sim M_p^2 \left(\frac{\Lambda_c}{\Lambda}\right)^2$$

This suggests ~~th~~ that

$$\Lambda_{QG} = \Lambda \, !$$

Production of the black holes and of the species



Example: ADD

$$M_p^2 = M_*^2 (M_* R)^n$$

$$N \sim 10^{32}$$

Number of KK-species of mass $\sim M_*$.

ADD is one example of many-species solution to the hierarchy problem.

With N-copies of the SM we don't have an issue of radius stabilization.