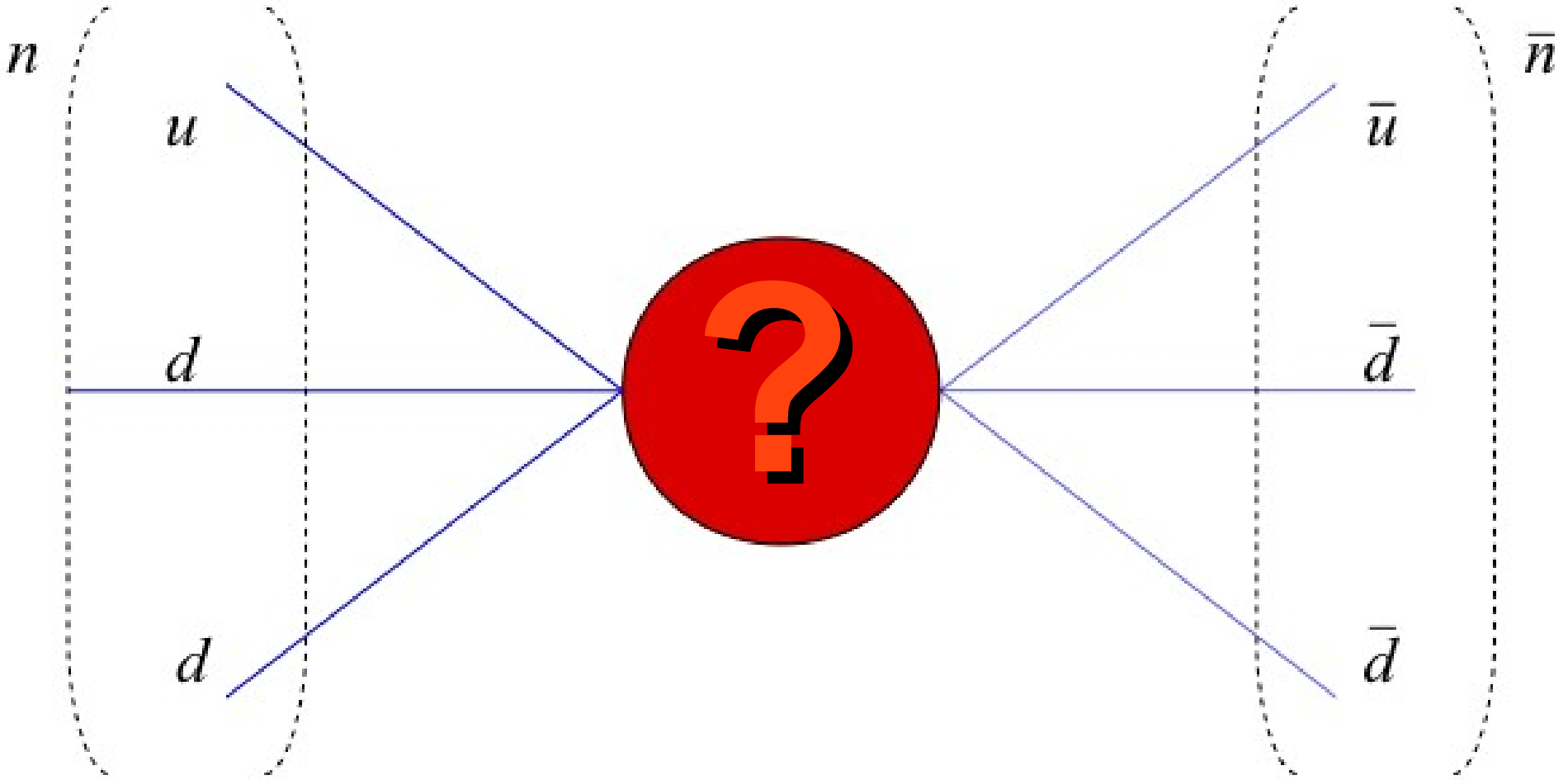
Direct generation of a Majorana mass for the Neutron from exotic instantons!



Andrea Addazi (Aquila, LNGS, INFN)

Hot problems in particle physics, LNGS 2015

References

1) A. Addazi and M. Bianchi, arXiv:1407.2897

2) A. Addazi, arXiv:1501.04660

3) A. Addazi and M. Bianchi, arXiv:1502.01531

4) A. Addazi and M. Bianchi, arXiv:1502.08041

5) A. Addazi, arXiv:1504.06799 [hep-ph];

6) A. Addazi, arXiv:1505.00625 [hep-ph].

7) A. Addazi, arXiv:1505.02080 [hep-ph].

8) A.Addazi, arXiv:1506.06351.

…. other works under discussions with

M.Bianchi, G.Dvali, J.Valle, S.Morisi, G.Ricciardi ...

Majorana mass for a neutron?

A crazy idea suggested by Ettore Majorana

Nuovo Cimento '37'

(Idea reconsidered some years later by Bruno Pontecorvo..)

$$(udd)^2 / \mathcal{M}^5_{n\bar{n}}$$

$$\Delta B = 2$$

$$\alpha\, n\, n + \text{h.c.}$$

Physics Beyond Standard Model!
Baryogenesis, Leptogenesis...

NNBar, why not??? ….KKbar oscillations observed...

Very interesting if we compare this one with Proton decay limit (33th order higher) and Neutrinoless Double Beta decay (23th order)

Theoretical side?

***1) R-breaking MSSM** generically connects **nnbar with p-decays**...Extra protecting symmetries (flavor, discrete abelian symmetries ???)*

***2) Babu-Mohapatra GUT SO(10)** without susy, 126 Multiplets....Or maybe 1000000000 multiplets....*

***3) Bary-majoron**: Berezhiani*
Bary-majoron and RH-neutron. Vafa-Witten violated???

***4)** other unesthetic **toy-models**, 'ad hoc' with colored sextets, triplets, 1000000000000000000-plets*

A radical idea (I'm too young to be conservative...):

A Majorana mass induced by Non-perturbative effects of quantum gravity.

Exotic Instantons in String theories!

Not existing at all in gauge theories

(out of ADHM classifications)

Yang-Mills instantons in a nutshell

Classical solutions of the Euclidean path integral, solution of EoM in vacuum. They are self-dual

$$F = \pm \tilde{F} \qquad e^{-8\pi/g^2} \qquad S_I = \frac{8\pi^2}{g^2}|K| \qquad K = \frac{g^2}{32\pi^2}\int d^4x F^a_{\mu\nu}\tilde{F}^a_{\mu\nu}$$

1) tunneling among topologically different vacua

2) Discovered by t'Hooft, Axial symmetry, CP problem in QCD (another story...).

3) Exploring no-perturbative QCD? IR divergence!

A rigorous classification of YM instantons

Atiyah,Drinfeld, Hitchin and Manin '78'

Based on self-duality $F_{mn} \sim \sigma_{mn}$

$$A_m = \bar{U}\partial_m U \qquad \bar{U}\,U = \mathbb{1}_{[N\times N]}$$

$$\bar{\Delta}U = \bar{U}\Delta = 0 \qquad \bar{U}\,U = \mathbb{1}_{[N\times N]}$$

$$\Delta = \mathbf{a} + x_n\,\mathbf{b}^n = \begin{pmatrix} w_{u,i\dot{\alpha}} \\ a_{i\alpha,j\dot{\alpha}} \end{pmatrix} + x_n \begin{pmatrix} 0 \\ \sigma^n_{\alpha,\dot{\alpha}}\delta_{i,j} \end{pmatrix}$$

$$w_{ui\dot{\alpha}}(\sigma^a)^{\dot{\alpha}}{}_{\dot{\beta}}\bar{w}_j^{\dot{\beta}u} + \eta^a_{\mu\nu}[X^\mu, X^\nu]_{ij} = 0$$

U=[n,n+2k], Delta=[2k,n+2k] matrices, n of U(n), k=topological charge

ADHM construction classifies all self-dual connections with twistors' variables.

Instantons in String theory

A simple geometric interpretation:
nothing but "special D-branes",
Eucliden D-branes (E-branes) wrapping an internal cycle, that could intersect the `physical' D-branes.

Exotic instantons are represented by E-branes not wrapping the same cycles of the ordinary D-branes!

They are not in ADHM contruction!

On the other hand, gauge instantons are wrapping the same cycles.

Gauge Vs Exotic instantons

'Gauge' instantons: $F = \tilde{F}$, EDp-branes wrapping the same cycle C as a stack of background D(p+4)-branes, strength

$$e^{-W_{p+1}(C)/g_s\ell_s^{p+1}} = e^{-1/g_{YM}^2}$$

roughly speaking 4 N-D directions (spacetime)

'Exotic' instantons: $F \neq \tilde{F}$, EDp'-branes wrapping a cycle C' not wrapped by any stack of background D(p+4)-branes, strength

$$e^{-W_{p'+1}(C')/g_s\ell_s^{p'+1}} \neq e^{-1/g_{YM}^2}$$

roughly speaking 8 N-D directions (spacetime + internal)

Examples:

I) in (un)oriented type IIA, instantons are E2 branes wrapping 3 cycle

II) type I, E5 in internal space, with same magentization of D9 (wrapping the entire CY3)

III) in (un)oriented IIB E(-1) or E3 wrapping wrapping the same holomorphic divisor as a stack of physical D7...etc..

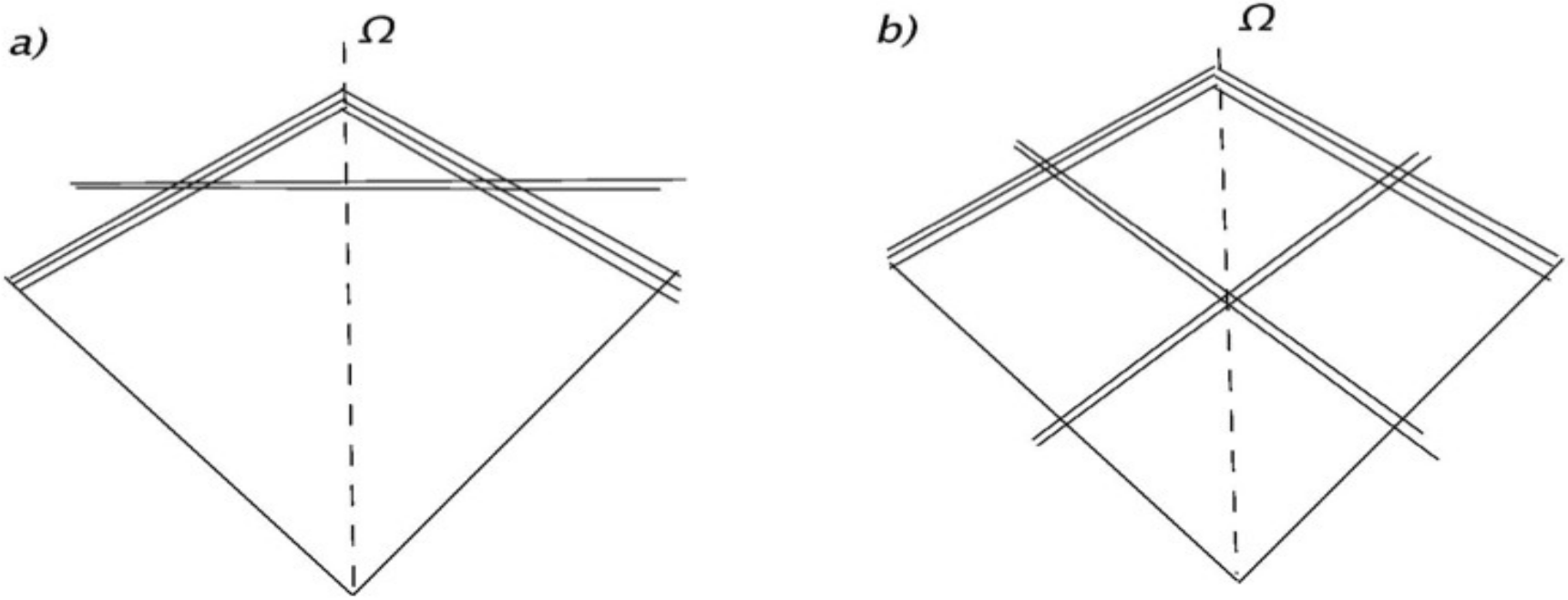
We consider a simple class of models:

Instruments: unoriented string theory, D6-branes stacks Wrapping 3-cycles in CY3, Antisymmetric Mirror plane, E2-branes (gauge and exotic instantons).

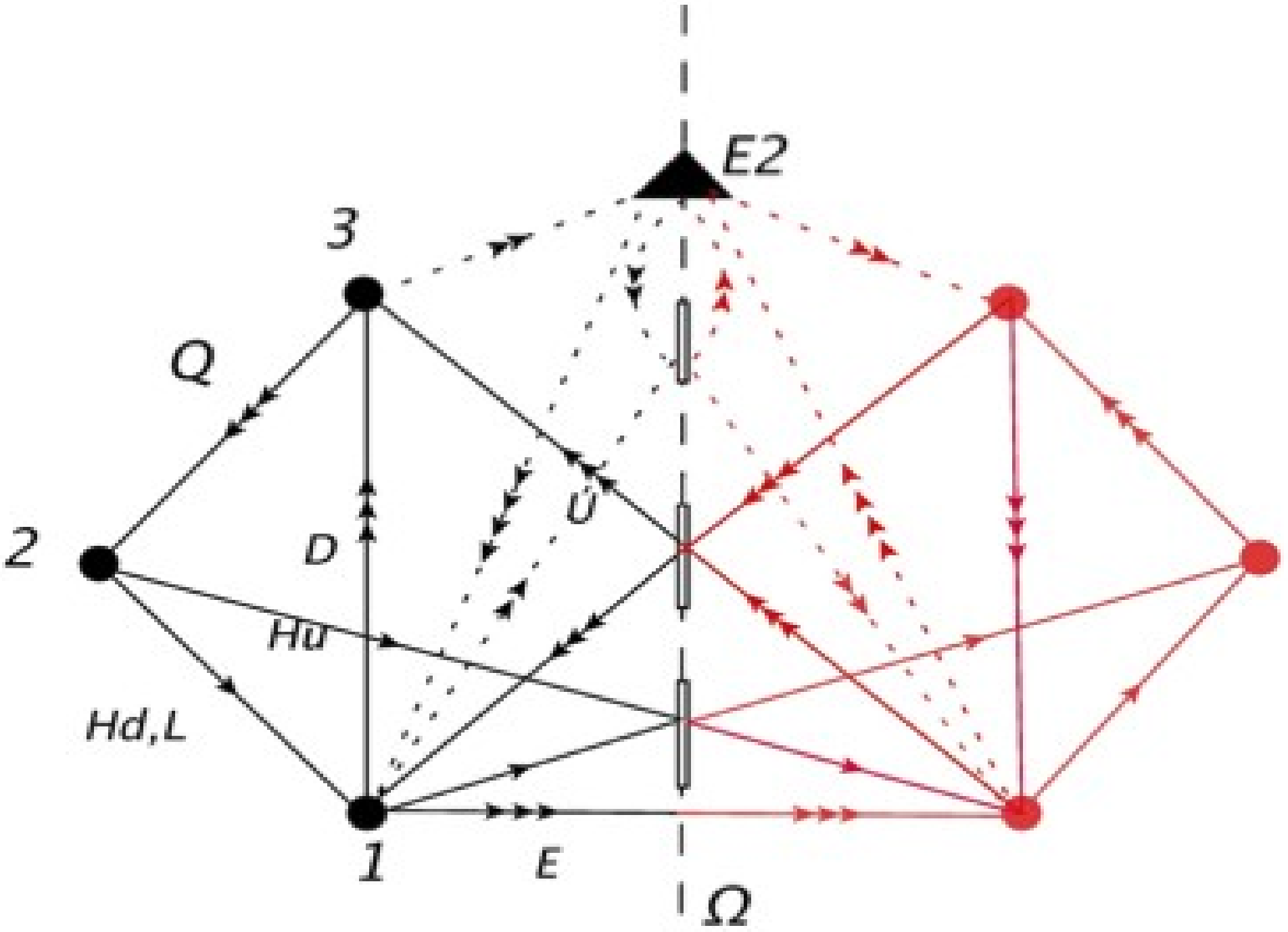
"Music": (MS)SM + 4 extra U(1)

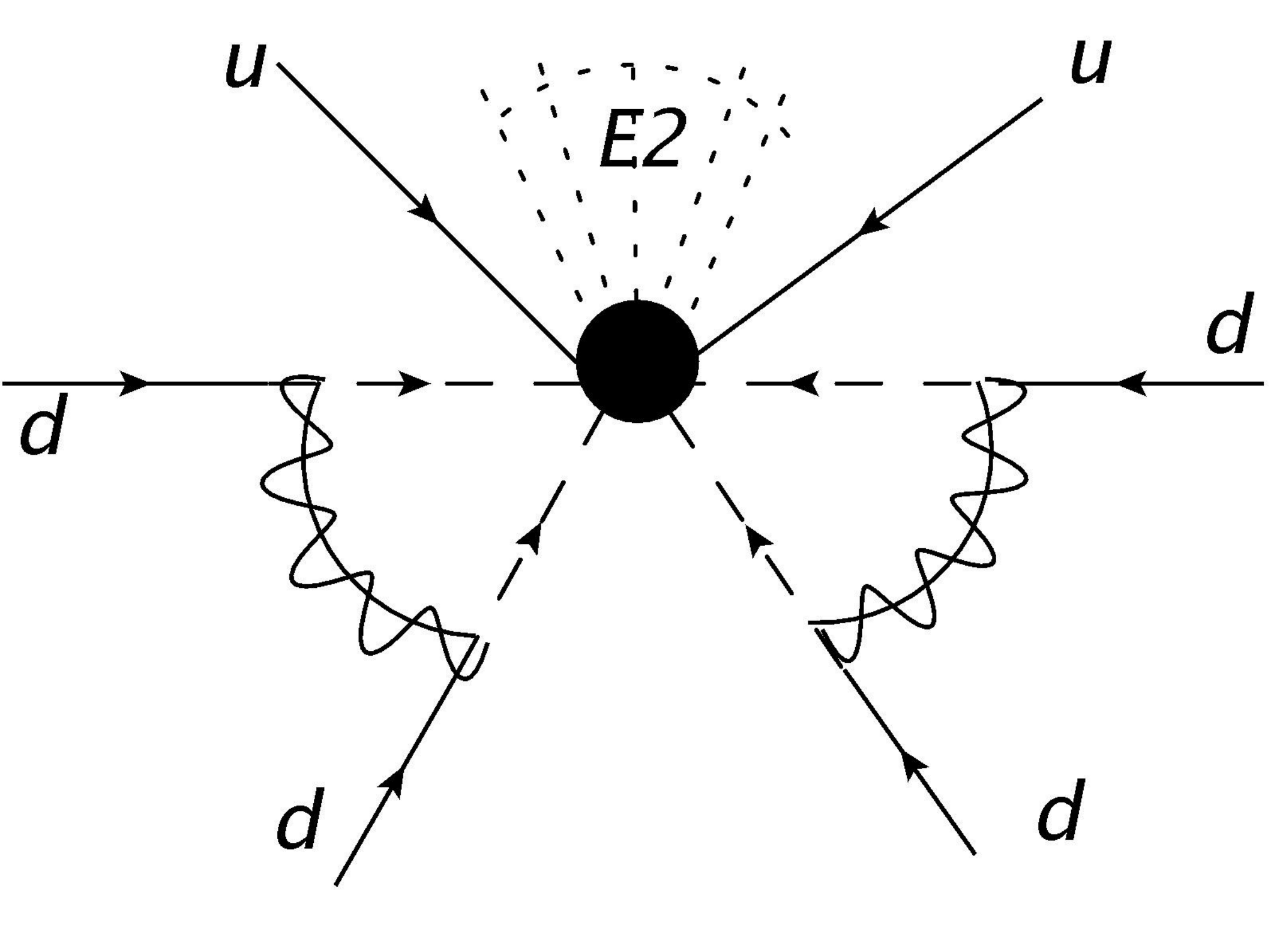
D. Cremades, L. E. Ibanez and F. Marchesano, JHEP 0307, 038 (2003) [hep-th/0302105]. (And other many papers)

Non perturbative Mixing generated by exotic instantons



Direct Generation




u
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E2
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Calculations from mixed disk amplitudes

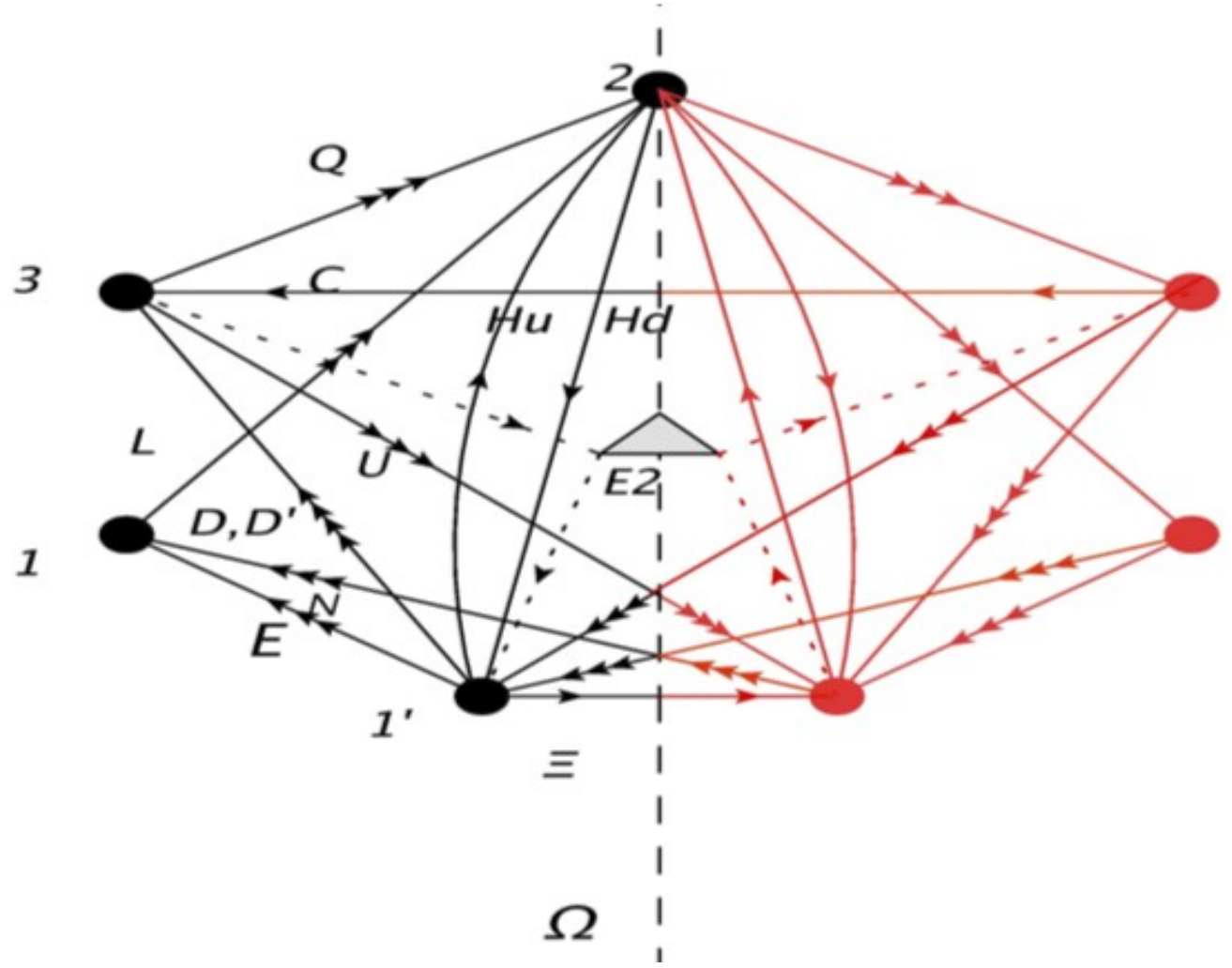
$$\mathcal{L}_{eff} \sim k_f^{(1)} U_f^i \tau_i \alpha + k_f^{(2)} D_f^i \tau_i \beta$$

$$\mathcal{W}_{E2-D6-\hat{D}6} = \int d^6\tau d^4\beta d^2\alpha e^{\mathcal{L}_{eff}} = \mathcal{Y}^{(1)} \frac{e^{-S_{E2}}}{M_S^3} \epsilon_{ijk}\epsilon_{i'j'k'} U^i D^j D^k U^{i'} D^{j'} D^{k'}$$

$$\mathcal{Y}^{(1)}_{f_1 f_2 f_3 f_4 f_5 f_6} = k^{(1)}_{f_1} k^{(1)}_{f_2} k^{(2)}_{f_3} k^{(2)}_{f_4} k^{(2)}_{f_5} k^{(2)}_{f_6}$$

$$\mathcal{O}_{n\bar{n}} + \mathcal{O}_{\Lambda\bar{\Lambda}} = \frac{y_1}{\mathcal{M}_{E2}^3 M_{SUSY}^2} (u^c d^c d^d)(u^c d^c d^c) + \frac{y_2}{\mathcal{M}_{E2}^3 M_{SUSY}^2} (u^c d^c s^c)(u^c d^c s^c)$$

$$\mathcal{M}_{E2}^3 = e^{+S_{E2}} M_S^3,\ y_1 = \mathcal{Y}^{(1)}_{111111} \text{ and } y_2 = \mathcal{Y}^{(1)}_{112112}.$$



Advantages: all MSSM superpotentials are allowed at not perturbative level. No extra matter. In this quiver we introduce an extra vector-like pair for phenomenology, but we can also not consider it. Price? One more node

Phenomenology

Next future on ***NNbar: 1000TeV***

Compatible with:

- ***TeV-susy, MS=10^5 TeV*** *with large (3-cycles)*
- ***MS=MSUSY=10 TeV****, factor 100 (3-cycles).*
- ***MS=MSUSY=100-1000TeV*** *factor 10-1 (3-cycles).*

- **Stringy resonances** and **anomalous Z'** for LHC or future collider
- Exotic instantons are classical configuration in B-violating scattering amplitudes. **Cutoff of the cross section expected. And...duality on heterotic string side!**
- **No proton destabilization, no FCNCs** related to NNbar diagram

Other considerations

- This is a **non-Wilsonian** UV completion of a six quark effective operator.
- R-parity is **dynamically broken**. Subtly compatible with gauge invariance
- Other operator like **Weinberg's W=HLHL/M** can be similarly generated and tested in colliders.

Why string theory

- It remains the best idea for an unification of all particles and interactions, as a natural quantum gravity theory....Ockam's razor? Good: only strings and branes...pay attention to Ockam's razor: we have to apply it to fundamental building blocks not to the number of fields (of course they are infinite in string theories
- Hierarchy problem is strongly alleviated for a low scale string theory
- Perturbative string theory is just ruled out:

  massless moduli!!! Non perturbative string theory is the next frontier

Other alternative models

- Models with a B-violating mixing of a vector-like pair 3(B=-2/3)-3bar(B=-1/3) (A.A, M.Bianchi, JHEP 2014; A.A JHEP 2015; A.A, M.Bianchi, JHEP 2015)
- Pati-Salam like with 10-plets

  (A.A, M.Bianchi JHEP 2015)
- uddX/M, with X a singlet fermion (A.A, 2015)

Conclusions

String theory could have a peculiar phenomenology in neutron physics.
In particular Exotic Instantons could generate a Majorana mass term for the neutron, without other dangerous consequences like fast proton decay or strong FCNCs.

In some subregions of parameters we have other channels interesting for LHC or future colliders.

THANK YOU!!!