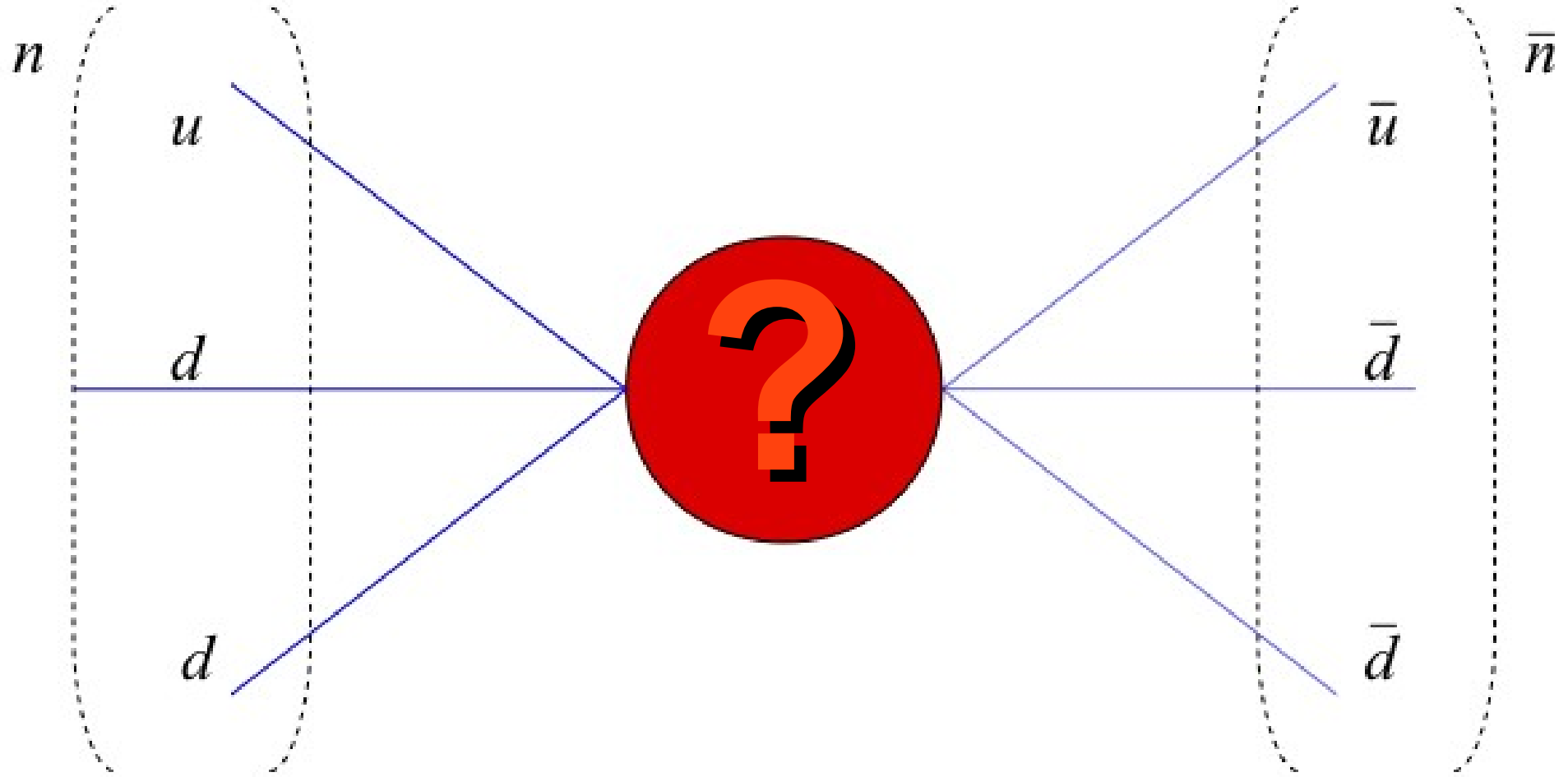
Neutron Majorana mass from exotic instantons



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Max Born Symposium 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.

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...

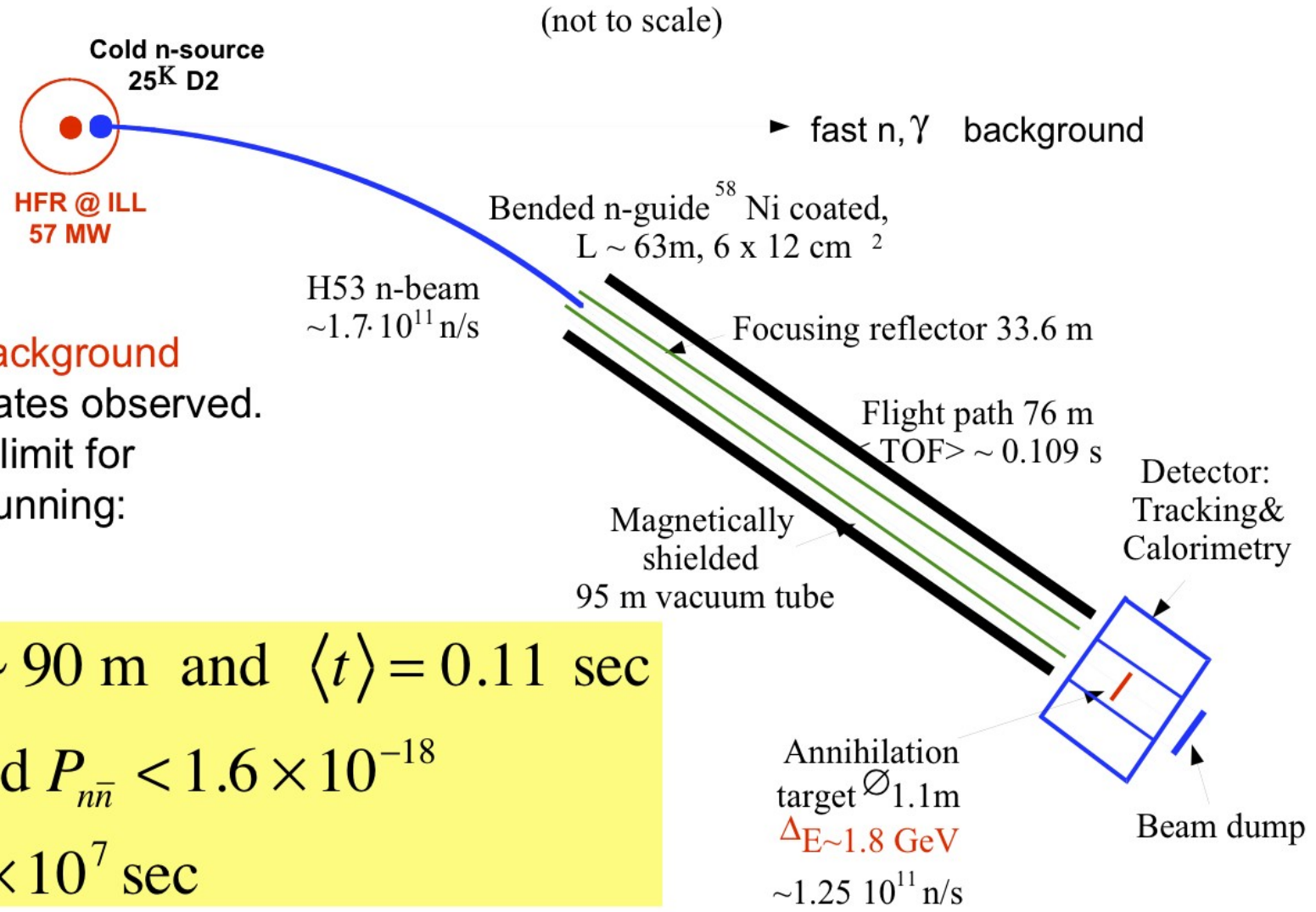
Why New Physics

- B,L are accidental symmetry *of SM lagrangian*
- *Vafa-Witten theorem protects non-perturbative QCD against dynamical violations of vector-like global symmetries, like B-number.*
- *Sphalerons can only change B-violations into L-one and viceversa. They are suppressed as 10^(-120) in laboratory. They are relevant in early thermal bath.*

n-nbar experiments*

See talks of Snow, Young and Kamyshkov at BLV 2011

Heidelberg - ILL - Padova - Pavia $n\bar{n}$ search experiment at Grenoble 89-91



No GeV background

No candidates observed.

Measured limit for a year of running:

with $L \sim 90$ m and $\langle t \rangle = 0.11$ sec

measured $P_{n\bar{n}} < 1.6 \times 10^{-18}$

$\tau > 8.6 \times 10^{7}$ sec

Baldo-Ceolin M. et al., Z. Phys. C63,409 (1994).

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** connects **nnbar with p-decays**...Extra protecting symmetries?*
Alternatively?

***2) Babu-Mohapatra GUT SO(10)** without susy, 126 Multiplets*

***3) Bary-majoron**: Mohapatra, Barbieri, Dvali, Berezhiani*
Bary-majoron and RH-neutron

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

Don't worry be happy: no matter destabilization during my PHD

$$\mathcal{H}_{\text{eff}} = \begin{pmatrix} m_n - V_n & \alpha \\ \alpha^* & m_n - V_{\bar{n}} \end{pmatrix} \tag{1}$$

where V_n and $V_{\bar{n}}$ are the binding energies in the nucleus for a neutron and an antineutron. $V_{\bar{n}} << V_n$, $|V_{\bar{n}} - V_n| = \Delta V \sim V_n \sim -10\text{MeV}$. The neutron in the nucleus is 'free' for a time that can be estimated from the indetermination principle

$$\Delta E \Delta t \sim 1 \longrightarrow t_{\text{free}} \sim \frac{1}{E_{\text{leg}}} \sim 10^{-23}\text{s}$$

The oscillation probability is

$$P_{n\bar{n}} = \frac{\alpha^2}{\alpha^2 + \Delta V^2} \sin^2 \sqrt{\alpha^2 + \Delta V^2} t \simeq \frac{4\alpha^2}{(\Delta V)^2} \longrightarrow \tau_a = \frac{1}{p_A} \sim 10^{30}\,\text{yr}$$

where τ_A is the internuclear transition lifetime, and p_A the transition probability per second.

Why the suppression of the Magnetic Field (with t<<Beta decay)

$$\mathcal{H}_{eff} = \begin{pmatrix} m + 2\omega & \alpha \\ \alpha^* & m - 2\omega \end{pmatrix}$$

with $2\omega = |\mu B|$. Rotated, with mixing angles

$$\tan 2\theta = \frac{\alpha}{\omega}; \quad \sin^2 2\theta = \frac{\alpha^2}{\alpha^2 + \omega^2}$$

With $\Omega = \sqrt{\alpha^2 + \omega^2}$, the transition probability has the form

$$\mathcal{P}_{n\bar{n}} = \sin^2 2\theta \sin^2(\Omega t) = \frac{\alpha^2}{\alpha^2 + \omega^2} \sin^2(\sqrt{\alpha^2 + \omega^2} t)$$

$B_{\text{Earth}} \sim 0.5\,\text{Gauss} \longrightarrow \omega >> \alpha \sim 10^{-23}\text{eV} \longrightarrow \sqrt{\alpha^2 + \omega^2} t \gg 1,$

from (4) $\longrightarrow \mathcal{P}_{n\bar{n}} = \frac{\alpha^2}{2\omega^2} \simeq 0$, there aren't any chances to try $n - \bar{n}$

Challenge accepted!!!

We propose the possibility that such a NNbar transition, competitive with future experiments, can be generated by

Non-perturbative effects of quantum gravity.

Exotic Instantons in String theories!

Not existing at all in gauge theories

(out of ADHM classifications)

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.

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..

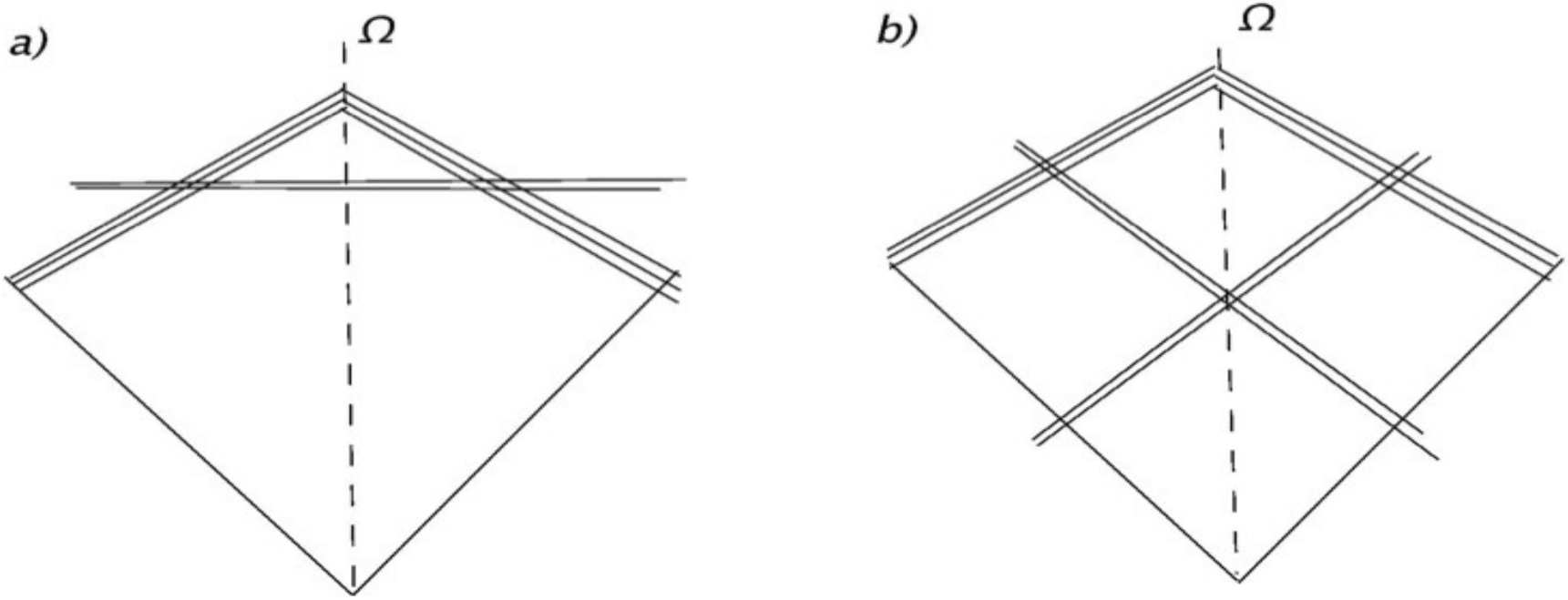
We consider a simple class of models:

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

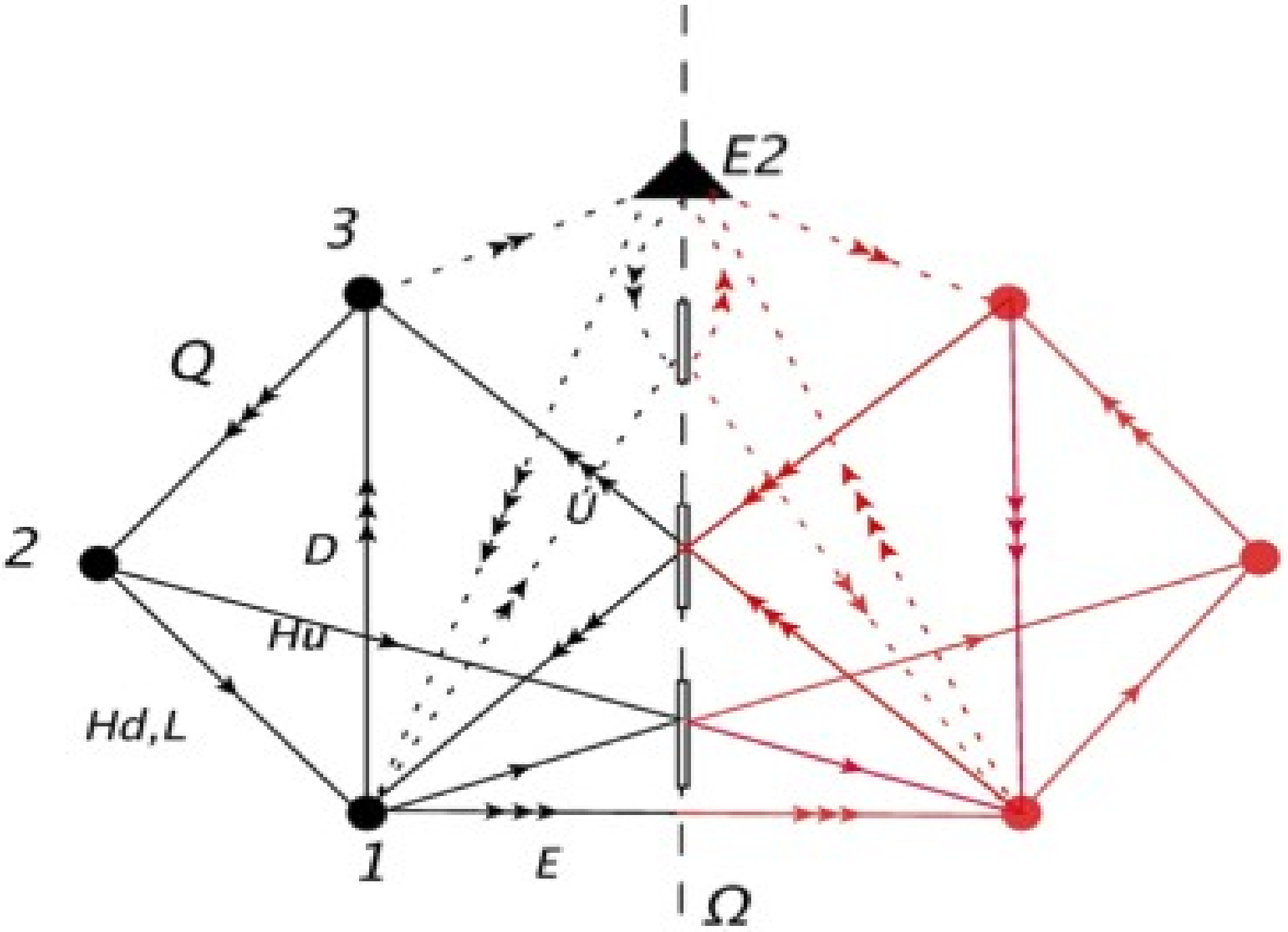
"Music": (MS)SM + 4 extra U(1)

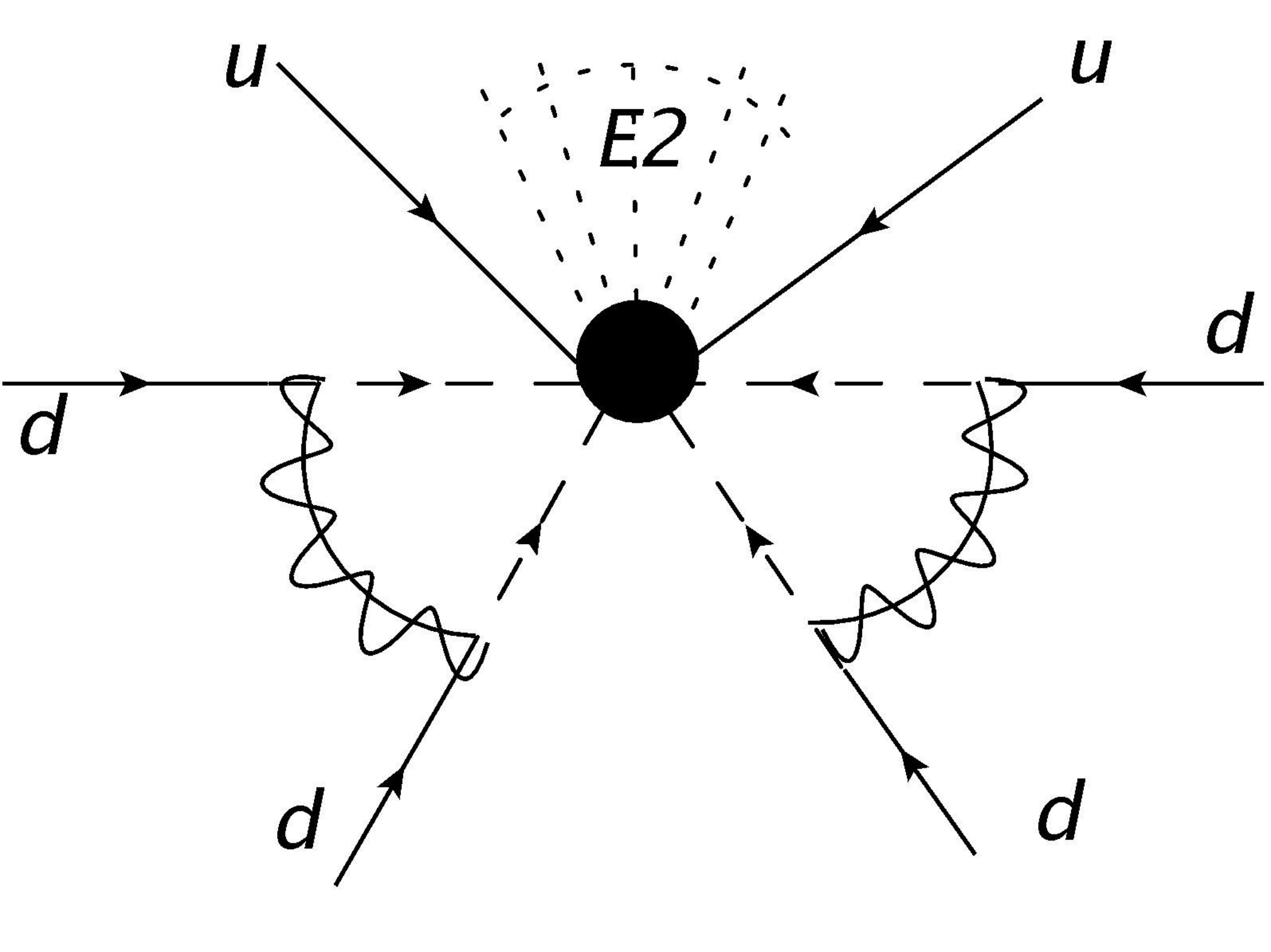
D. Cremades, L. E. Ibanez and F. Marchesano, JHEP 0307, 038 (2003) [hep-th/0302105]. (And other many papers)

Non perturbative Mixing generated by exotic instantons



Direct Generation

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Calculations from mixed disk amplitudes

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

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

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

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

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

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**
- **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.

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.

Exotic Instantons could be the portal to Quantum Gravity, inducing no-perturbative coupling at scale like 1000TeV.

THANK YOU!!!