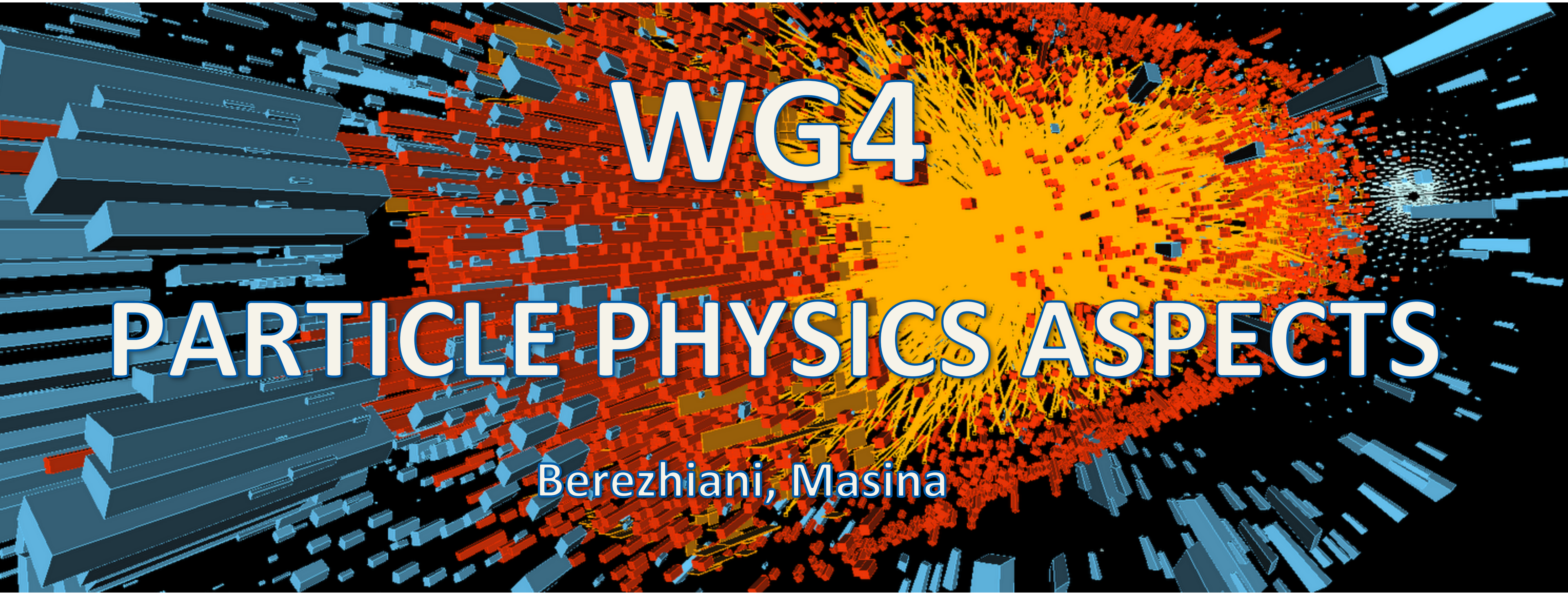
# PRIN 2012 Project
# THEORETICAL ASTROPARTICLE PHYSICS




PRIN 2012 MidTerm Workshop, Torino, 9-10/07/14

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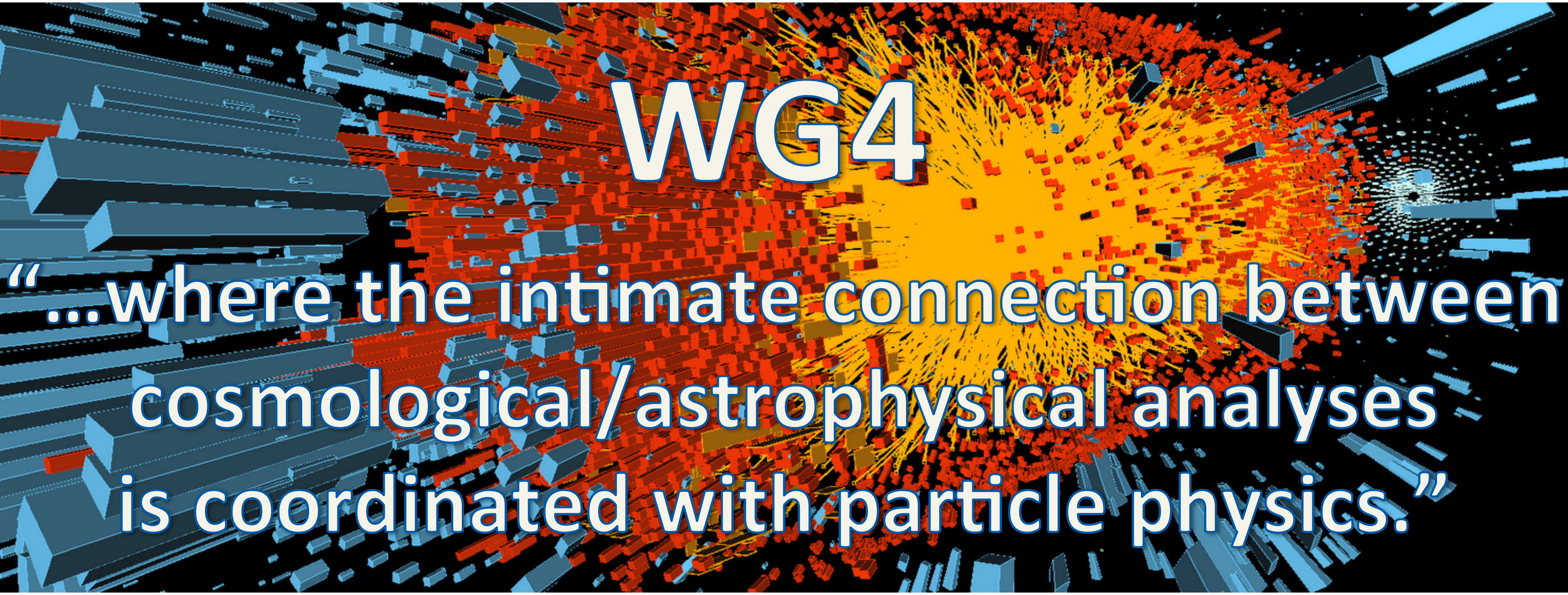


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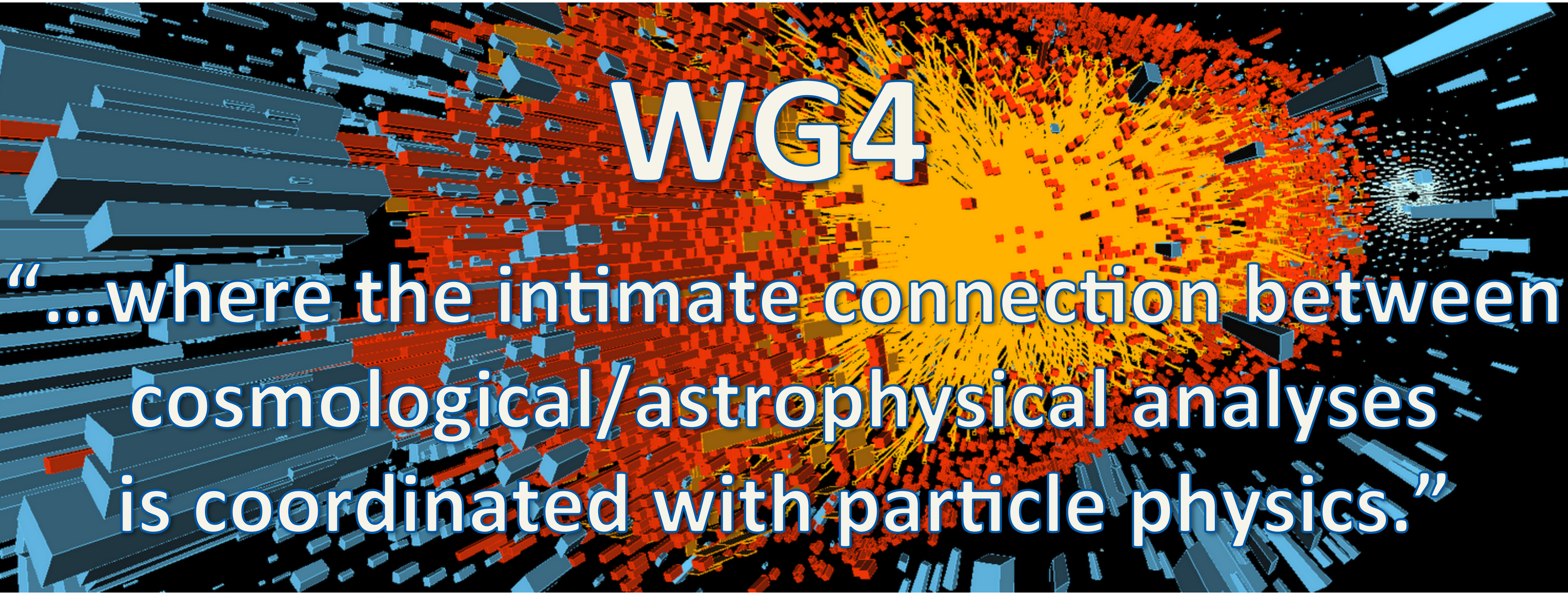
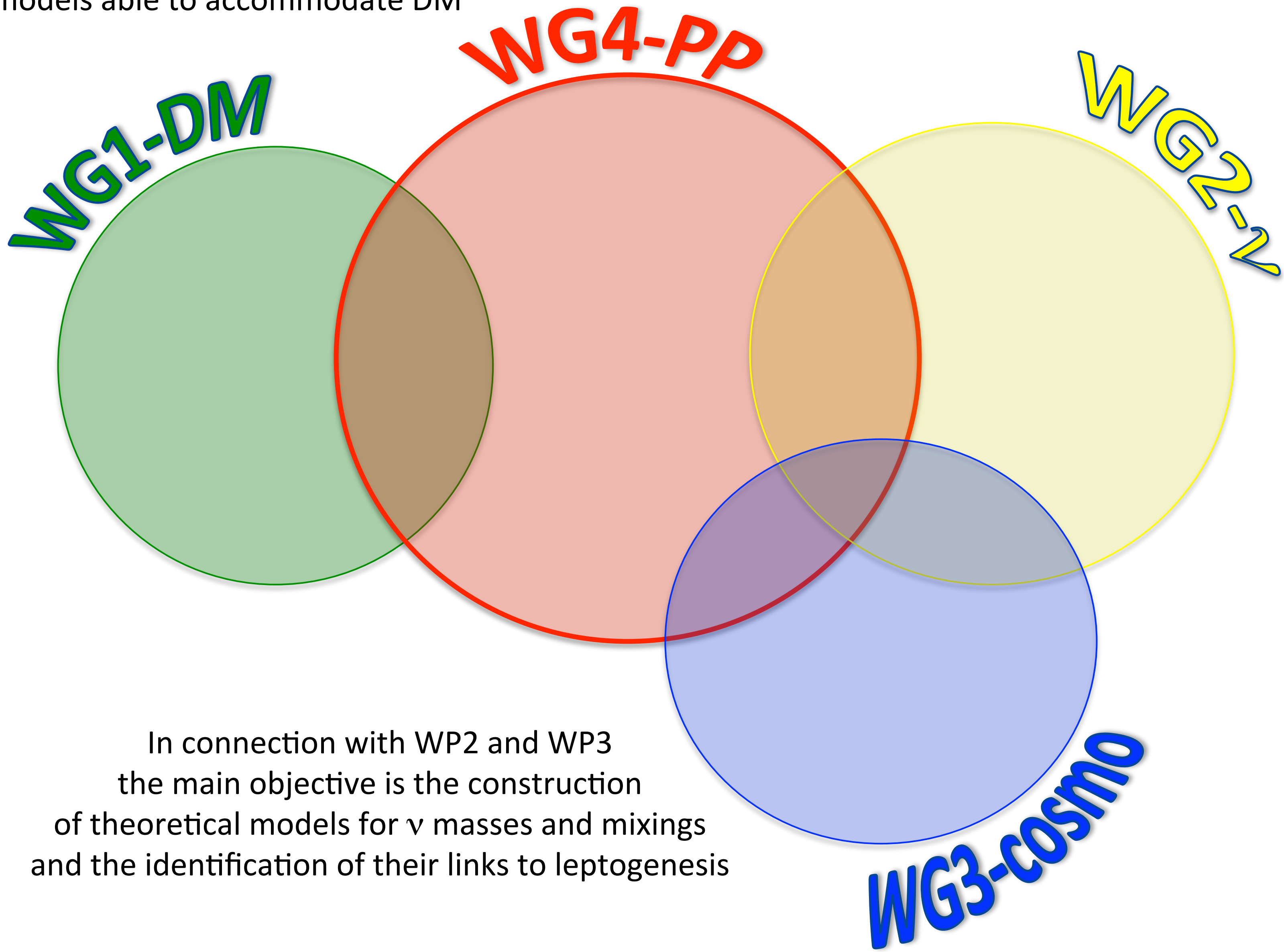



## Goal:

1) To identify a path toward the development of particle physics frameworks beyond the SM able to solve the astroparticle physics puzzles studied in WP1-WP3
2) To attempt, if possible, to find common solutions.

In connection with WP1
the main objective is to identify
NP models able to accommodate DM



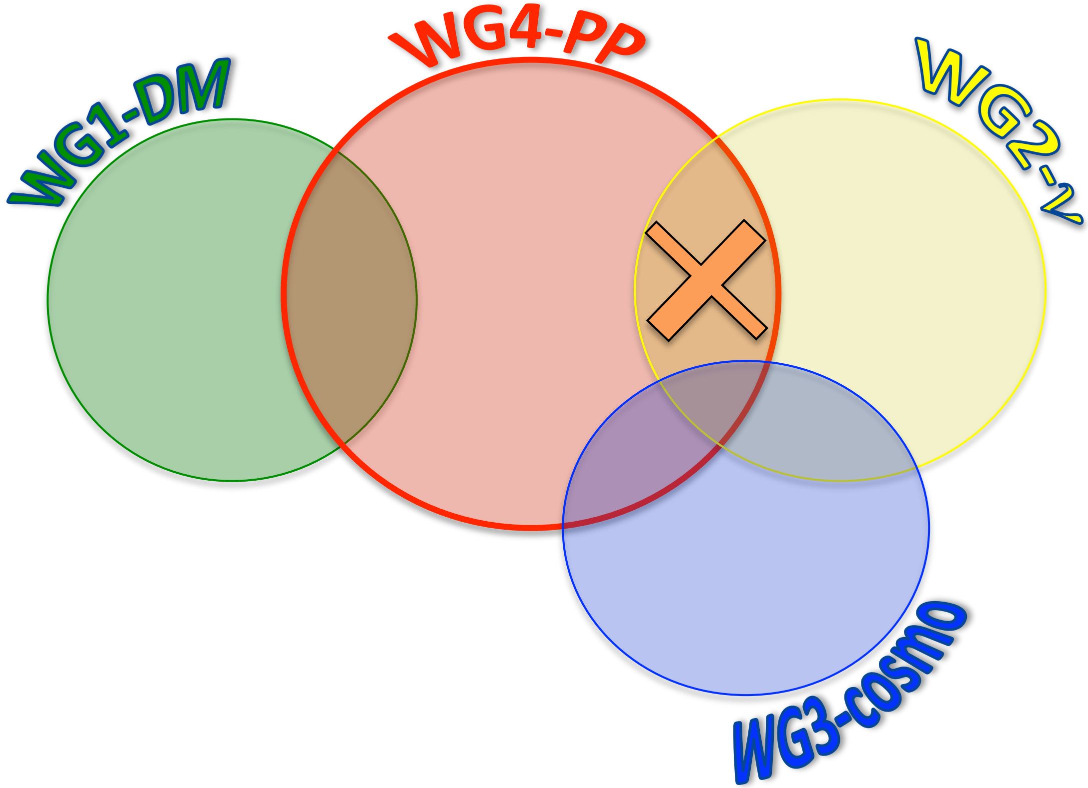

In connection with WP2 and WP3
the main objective is the construction
of theoretical models for ν masses and mixings
and the identification of their links to leptogenesis

## Total n. of papers in area WG4 since PRIN start: about 30

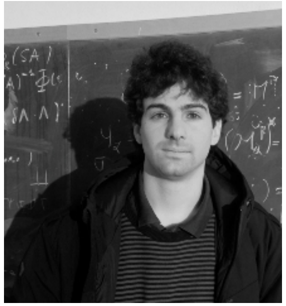
# TOPICS:

| | |
|---|---|
| 1) Lepton flavor and CP (8) | SISSA/LNF-RM/NA-SA |
| 2) Leptogenesis (2) | SISSA/LNF-RM |
| 3) Solar physics constraints (2) | FE/AQ |
| 4) Higgs and inflation (1) | FE |
| 5) Susy and LHC (4) | PD/AQ/NA-SA/FE |
| 6) Quantum theories (7) | TO/NA-SA/AQ |
| 7) Gravity (1) | BA |
| 8) Neutrons and Exotica (5) | AQ |

# 1) WG2/WG4: LEPTON FLAVOR AND CP (SISSA/LNF-RM/NA-SA)






# 1) WG2/WG4: LEPTON FLAVOR AND CP (SISSA/LNF-RM/NA-SA)

1) S. M. Boucenna, R. M. Fonseca, F. Gonzalez-Canales, J. W. F. Valle
Small neutrino masses and gauge coupling unification
arXiv:1411.0566 [hep-ph], Phys.Rev. D91 (2015) 031702

2) Sofiane M. Boucenna, Jose W. F. Valle, Avelino Vicente
Predicting charged lepton flavor violation from gauge symmetry
arXiv:1502.07546 [hep-ph]

3) Sofiane M. Boucenna, Jose W. F. Valle, Avelino Vicente
Are the B decay anomalies related to neutrino oscillations?
arXiv:1503.07099 [hep-ph]

} Connection with gauge symmetries

4) L.L. Everett, T.Garon and A.J. Stuart
A Bottom-Up Approach to Lepton Flavor and CP Symmetries
arXiv:1501.04336 [hep-ph], JHEP 1504 (2015) 069

Talk by Stuart

} Bottom-up approach

# 1) WG2/WG4: LEPTON FLAVOR AND CP (SISSA/LNF-RM/NA-SA)

5) S.T. Petcov
Predicting the values of the leptonic CP violation phases in theories with discrete flavour symmetries
arXiv:1405.6006 [hep-ph], Nucl. Phys. B 892 (2015) 400

6) Cesar Bonilla, Stefano Morisi, Eduardo Peinado, Jose W. F. Valle
Relating quarks and leptons with the T7 flavour group
arXiv:1411.4883[hep-ph], Phys.Lett. B742 (2015) 99

7) Claudia Hagedorn, Aurora Meroni, Emiliano Molinaro
Lepton mixing from D(3n2) and D(6n2) and CP
arXiv:1408.7118 [hep-ph], Nucl.Phys. B891 (2015) 499

8) I. Girardi, S.T. Petcov, A.V. Titov
Determining the Dirac CP Violation Phase in the Neutrino Mixing Matrix from Sum Rules
arXiv:1410.8056 [hep-ph], Nucl. Phys. B 894 (2015) 733

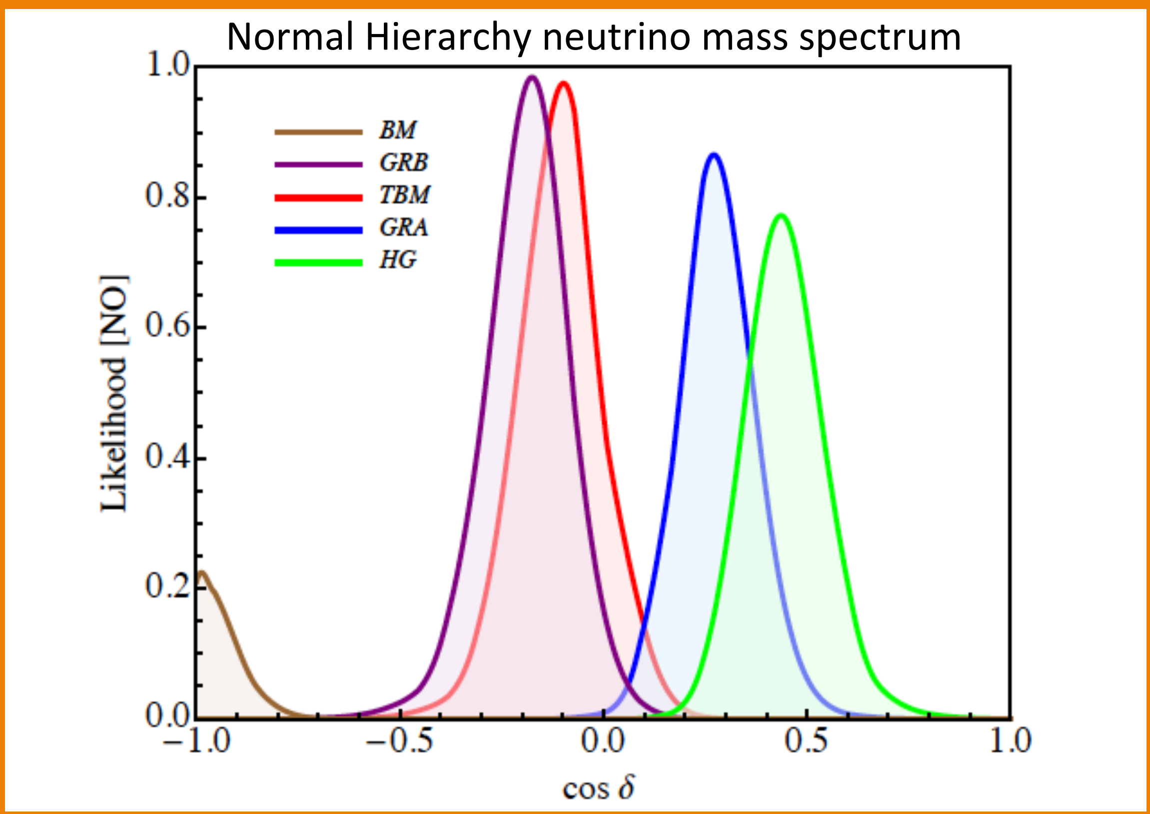
Discrete Flavor symmetries

I. Girardi, S.T. Petcov, A.V. Titov
Determining the Dirac CP Violation Phase in the Neutrino Mixing Matrix from Sum Rules
arXiv:1410.8056 [hep-ph], Nucl. Phys. B 894 (2015) 733

phases

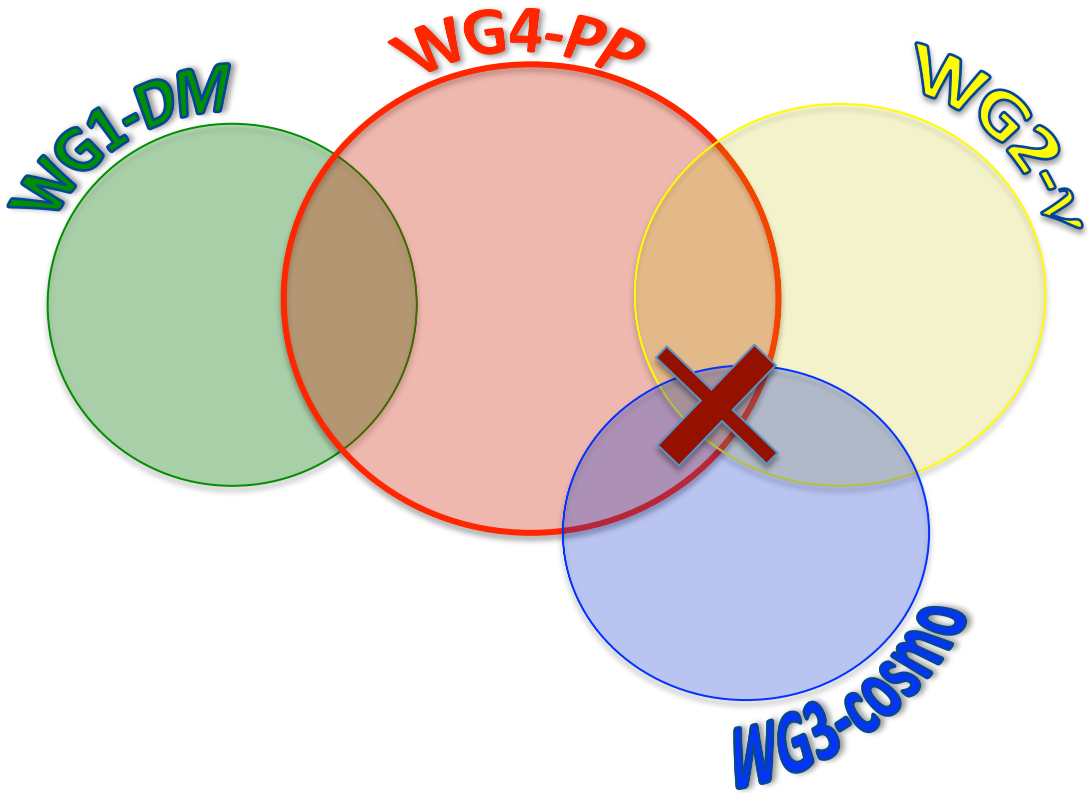
$$U = U_e^{\dagger} \Psi_1 \tilde{U}_{\nu} Q_0$$

BM, TBM, GRA, GRB, HG…




Tension for bimixing
Possible in future to discriminate

# 2) WG2/WG3/WG4: LEPTOGENESIS (SISSA/LNF-RM)




# 2) WG2/WG3/WG4: LEPTOGENESIS (SISSA/LNF-RM)

1) J. Gehrlein, S.T. Petcov, M. Spinrath, X. Zhang
Leptogenesis in an SU(5) x A5 Golden Ratio Flavour Model
arXiv:1502.00110 [hep-ph], Nucl. Phys. B 896 (2015) 311

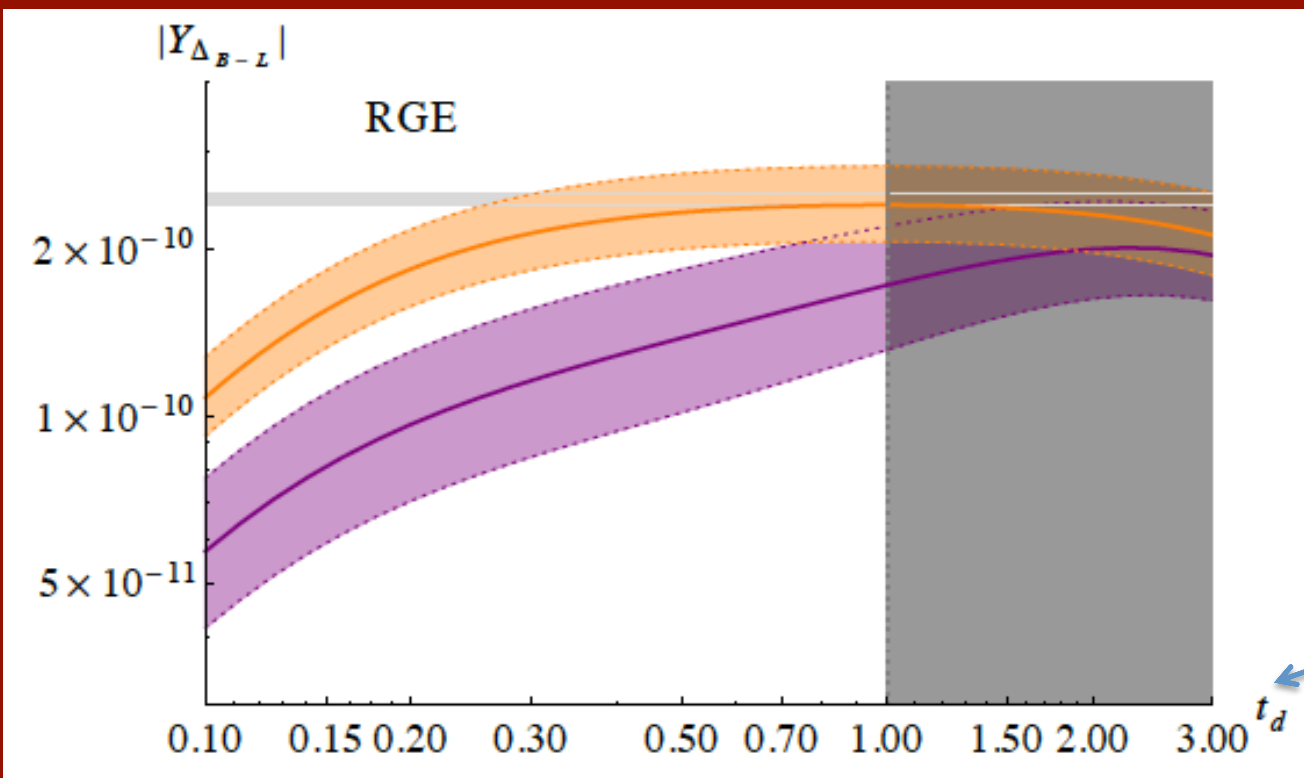
2) Chee Sheng Fong, Davide Meloni, Aurora Meroni, Enrico Nardi
Leptogenesis in SO(10)
arXiv:1412.4776 [astro-ph.HE], JHEP 1501 (2015) 111

Chee Sheng Fong, Davide Meloni, Aurora Meroni, Enrico Nardi

Leptogenesis in SO(10)

arXiv:1412.4776 [astro-ph.HE], JHEP 1501 (2015) 111

In this work we have considered leptogenesis in a non-supersymmetric SO(10) GUT with fermion masses from the $\mathbf{10} \oplus \overline{\mathbf{126}}$ Higgs representations, which can (i) fit well all the low energy data, (ii) successfully account for unification of the gauge couplings, and (iii) allow for a sufficiently long lifetime of the proton. We have shown that, once the model parameters are fixed in terms of measured low energy observables, the requirement of successful leptogenesis can fix the only one remaining high energy parameter. We have

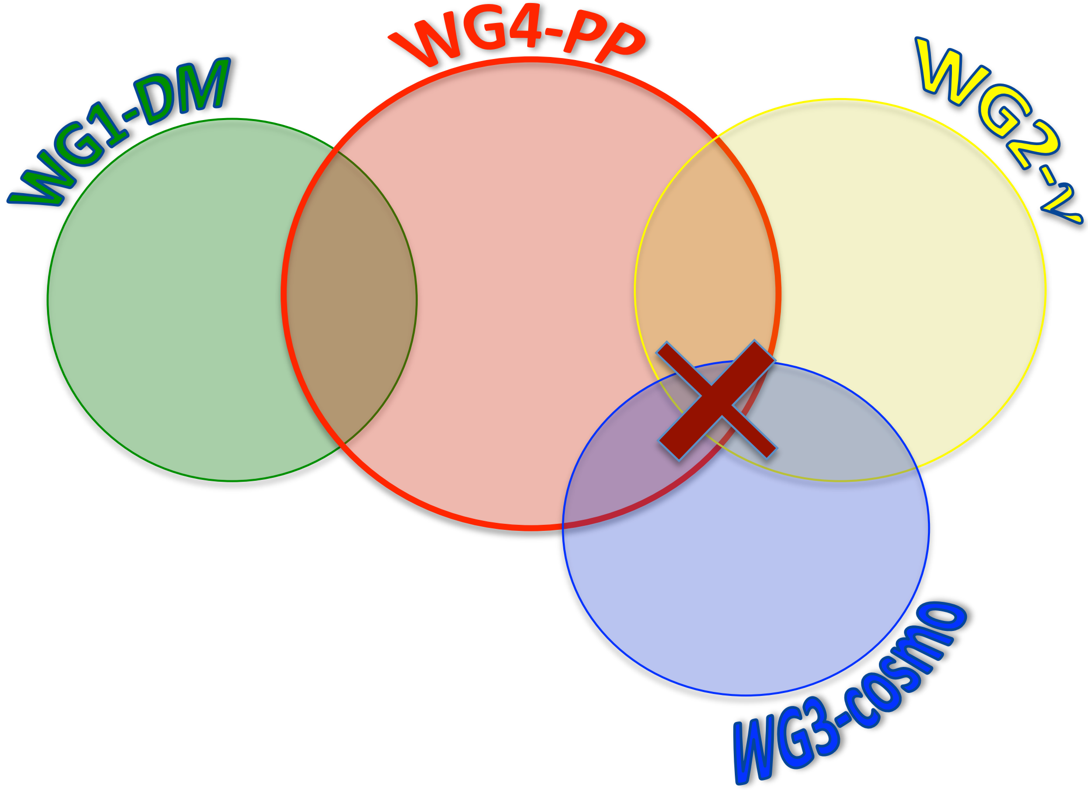



Two conditions

(i) $M_\Delta \gtrsim M_{N_2} \simeq 2.0 \times 10^{11}$

(ii) $0.3 \lesssim \left[\frac{\langle \Sigma_d^\dagger \Sigma_d \rangle}{\langle H_d^\dagger H_d \rangle}\right]^{1/2} \lesssim 1$

# 3) WG2/WG3/WG4: SOLAR DATA CONSTRAINTS (FE/AQ)

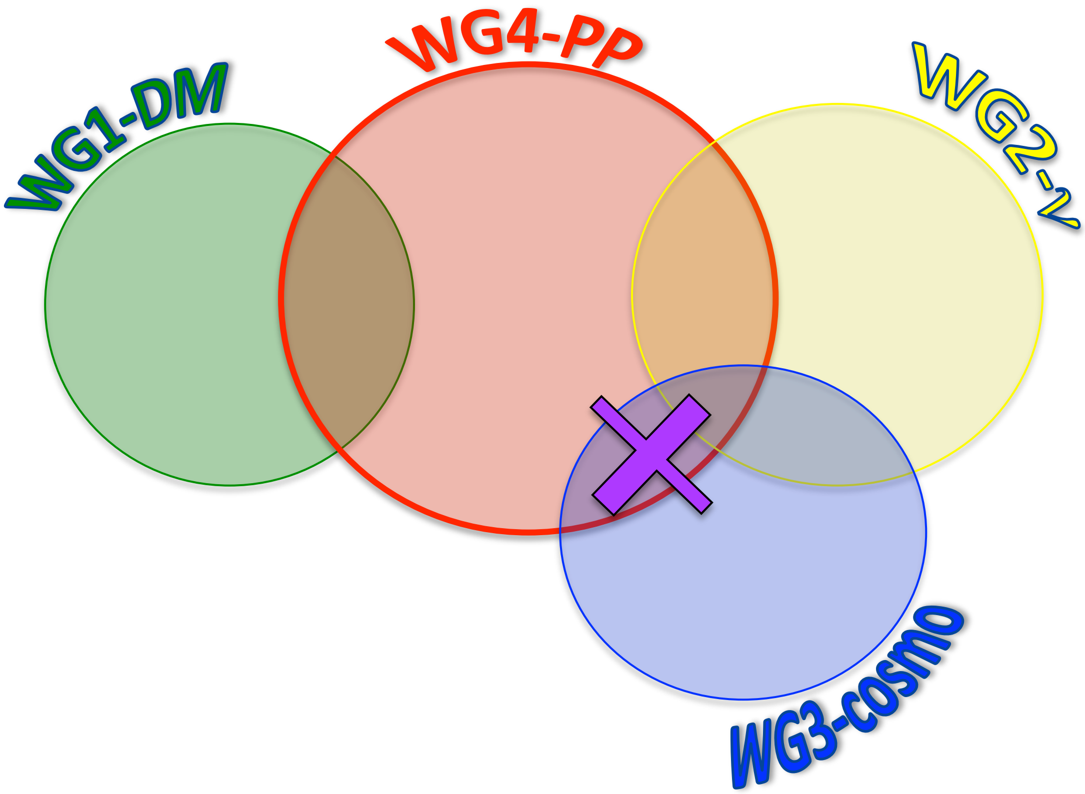



# 3) WG2/WG3/WG4: SOLAR DATA CONSTRAINTS (FE/AQ)

1) N. Vinyoles, A. Serenelli, F.L. Villante, S. Basu, J. Redondo, J. Isern
New axion and hidden photon constraints from a solar data global fit
arXiv:1501.01639 [astro-ph.SR]

2) Andrea Zanzi , Barbara Ricci
Chameleon fields and solar physics
arXiv:1405.1581 [hep-ph], Mod.Phys.Lett. A30 (2015) 10, 1550053

# 4) WG2/WG4: HIGGS AND INFLATION (FE)

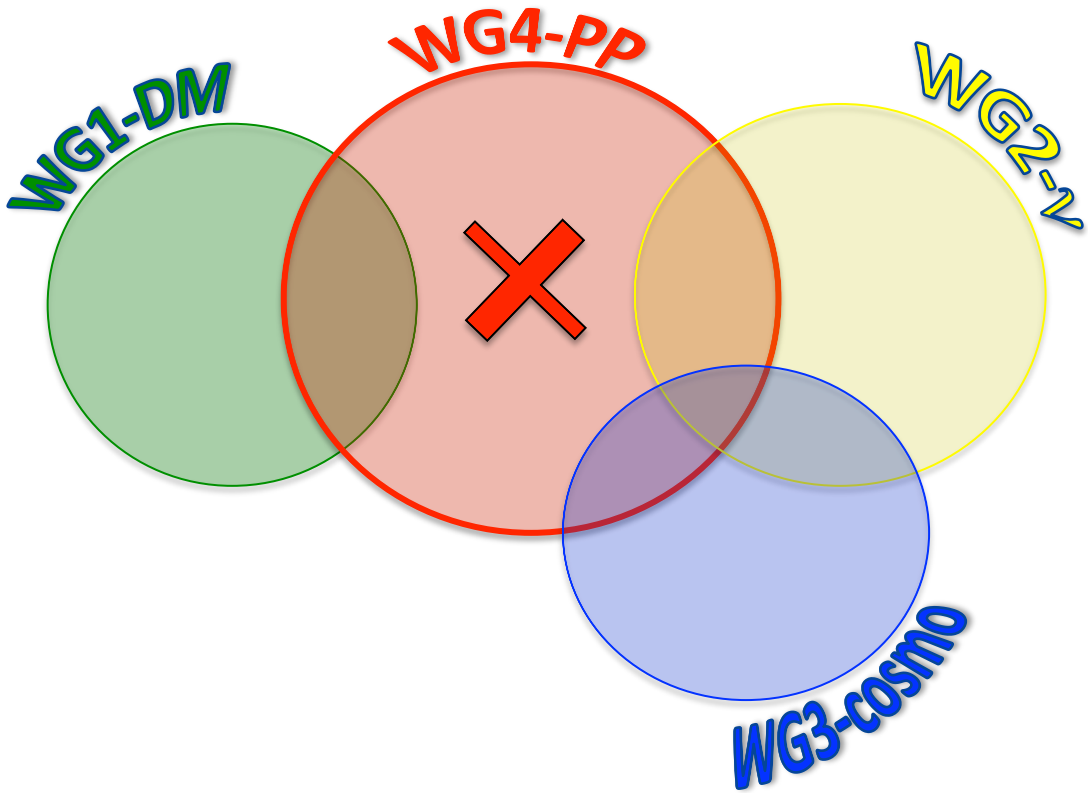



# 4) WG2/WG4: HIGGS AND INFLATION (FE)

1) I. Masina
Gravitational wave background and Higgs false vacuum inflation
arXiv:1403.5244 [hep-ph], Phys. Rev. D 89 (2014) 12, 123505

… work in progress on non-minimal coupling → Talk by Iacobellis

# 5) WG4: SUSY and LHC (PD/FE/AQ/NA-SA)









# 5) WG4: SUSY and LHC (PD/FE/AQ/NA-SA)

Talk by Paradisi

1) L. Calibbi, I. Galon, A. Masiero, P. Paradisi, Y. Shadmi
Charged Slepton Flavor post the 8 TeV LHC: A Simplified Model Analysis of Low-Energy Constraints and LHC SUSY Searches
e-Print: arXiv:1502.07753 [hep-ph]

Talk by Miele

2) Z. Berezhiani, M. Chianese, G. Miele, S. Morisi
Chances for SUSY-GUT in the LHC Epoch
arXiv:1505.04950 [hep-ph]

3) P.P. Giardino, K. Kannike, I. Masina, M. Raidal, A. Strumia
The universal Higgs fit
arXiv:1303.3570 [hep-ph], JHEP 1405 (2014) 046

4) I.Masina, G.Nardini and M.Quiros,
Electroweak vacuum stability and finite quadratic radiative corrections
arXiv:1502.06525 [hep-ph]

Z. Berezhiani, M. Chianese, G. Miele, S. Morisi
Chances for SUSY-GUT in the LHC Epoch
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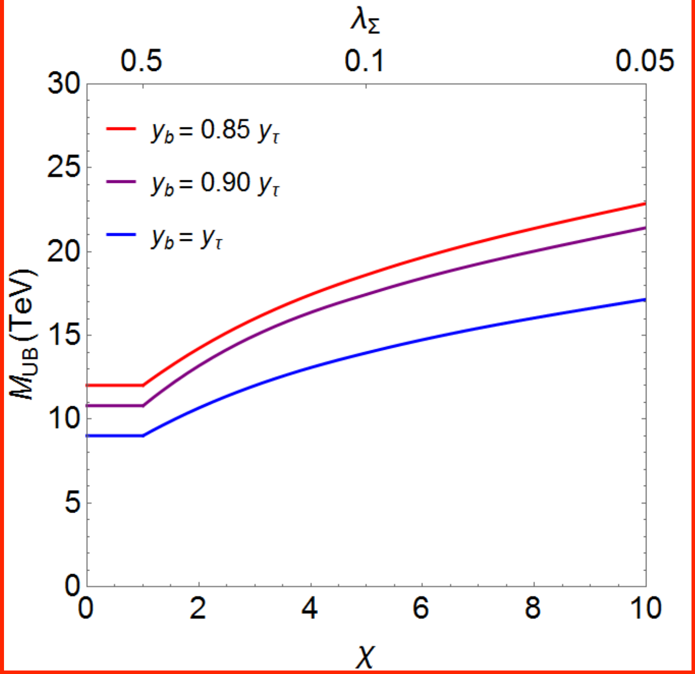
- After LHC run I (8 TeV), for planning new colliders it is of interest:
  - to reanalyze the room still remaining for SUSY-GUT inspired models;
  - to determine the **upper bound** for the energy below which SUSY signatures have to show up.
- Assuming one step unification (SU(5) bottleneck), under natural assumptions we have obtained general bounds on SUSY mass spectrum.




- We claim that if a SUSY-GUT model is the proper way to describe physics beyond the SM, the lighest gluino or higgsino cannot have a mass larger than

**20 TeV**

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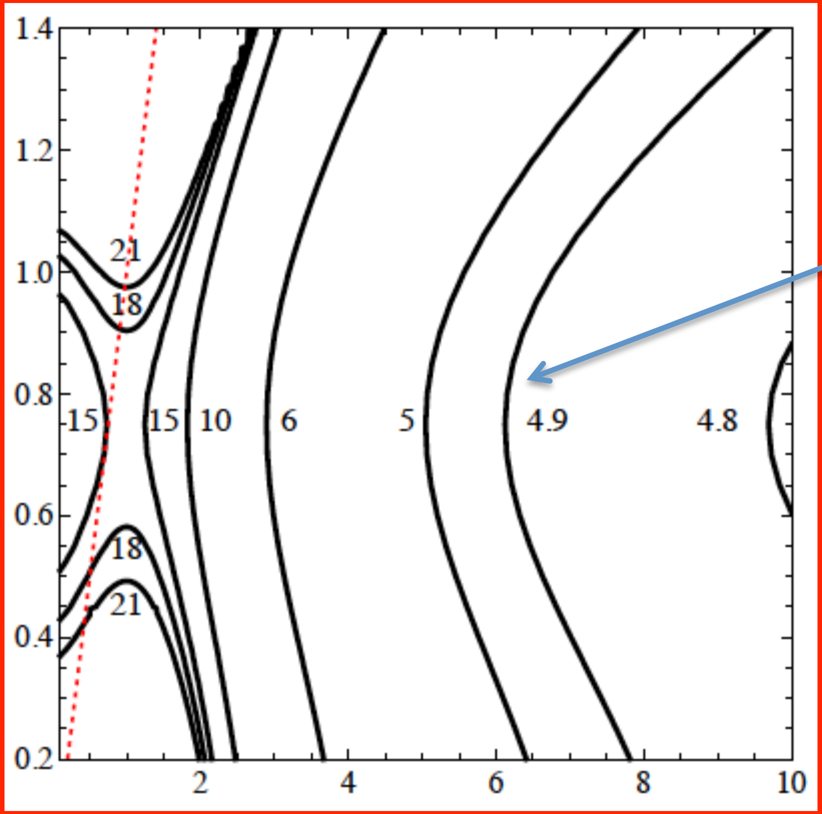
I.Masina, G.Nardini and M.Quiros,
Electroweak vacuum stability and finite quadratic radiative corrections
arXiv:1502.06525 [hep-ph]

Assuming the MSSM is the SM UV completion, we calculated the quadratic corrections to the (SM) Higgs mass: they turn out to be equivalent to finite threshold contributions

$$\begin{aligned}
-\Delta m^2 = \frac{1}{32\pi^2}\Big\{ & 6y_t^2[G(m_Q^2)+G(m_U^2)] + 6y_b^2[G(m_Q^2)+G(m_D^2)] + 2y_\tau^2[G(m_L^2)+G(m_E^2)] \\
& + 6y_t^2 X_t^2 \frac{G(m_Q^2)-G(m_U^2)}{m_Q^2-m_U^2} + 6y_b^2 X_b^2 \frac{G(m_Q^2)-G(m_D^2)}{m_Q^2-m_D^2} + 2y_\tau^2 X_\tau^2 \frac{G(m_L^2)-G(m_E^2)}{m_L^2-m_E^2} \\
& - g_Y^2\left(G(m_Q^2) - 2G(m_U^2) + G(m_D^2) - G(m_L^2) + G(m_E^2)\right)\cos 2\beta \\
& - 6g_2^2 \frac{M_2^2 G(M_2^2) - \mu^2 G(\mu^2)}{M_2^2-\mu^2} - 2g_Y^2 \frac{M_1^2 G(M_1^2) - \mu^2 G(\mu^2)}{M_1^2-\mu^2} \\
& - \left(12 g_2^2 M_2 \mu \frac{G(M_2^2)-G(\mu^2)}{M_2^2-\mu^2} + 4g_Y^2 M_1\mu \frac{G(M_1^2)-G(\mu^2)}{M_1^2-\mu^2}\right)\sin\beta\cos\beta \\
& + G(m_H^2)\left(-6g_Z^2\cos^2 2\beta + 2g_Z^2 + g_2^2\right)\Big\}\,, \qquad (46)
\end{aligned}$$

Depending on the values of the different susy mass scales, these contributions can cancel even in the multi-TeV range
(unlike the case of a single susy mass scale, where the Veltman result is obtained)

I.Masina, G.Nardini and M.Quiros,
Electroweak vacuum stability and finite quadratic radiative corrections
arXiv:1502.06525 [hep-ph]

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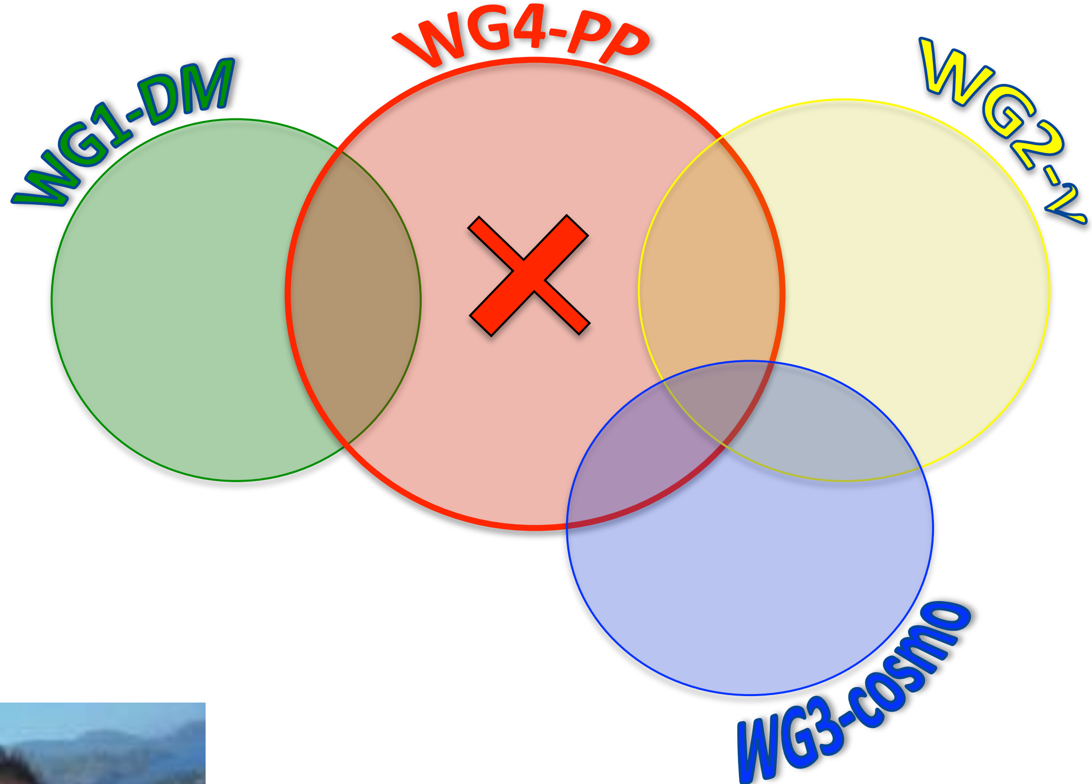
# 6) WG4: QUANTUM THEORIES (TO/NA-SA/AQ)



# 6) WG4: QUANTUM THEORIES (TO/NA-SA/AQ)

1) S.A. Alavi, C. Giunti
Which is the Quantum Decay Law of Relativistic Particles?
arXiv:1412.3346 [quant-ph], Europhys.Lett. 109 (2015) 6, 60001

2) G. Esposito, G. Marmo, G. Miele, G. Sudarshan
Advanced concepts in quantum mechanics
Published by Cambridge University Press , 2015

3) A. Addazi, G. Esposito
Nonlocal quantum field theory without acausality and nonunitarity at quantum level: is SUSY the key?
arXiv:1502.01471 [hep-th], Int.J.Mod.Phys. A30 (2015) 1550103

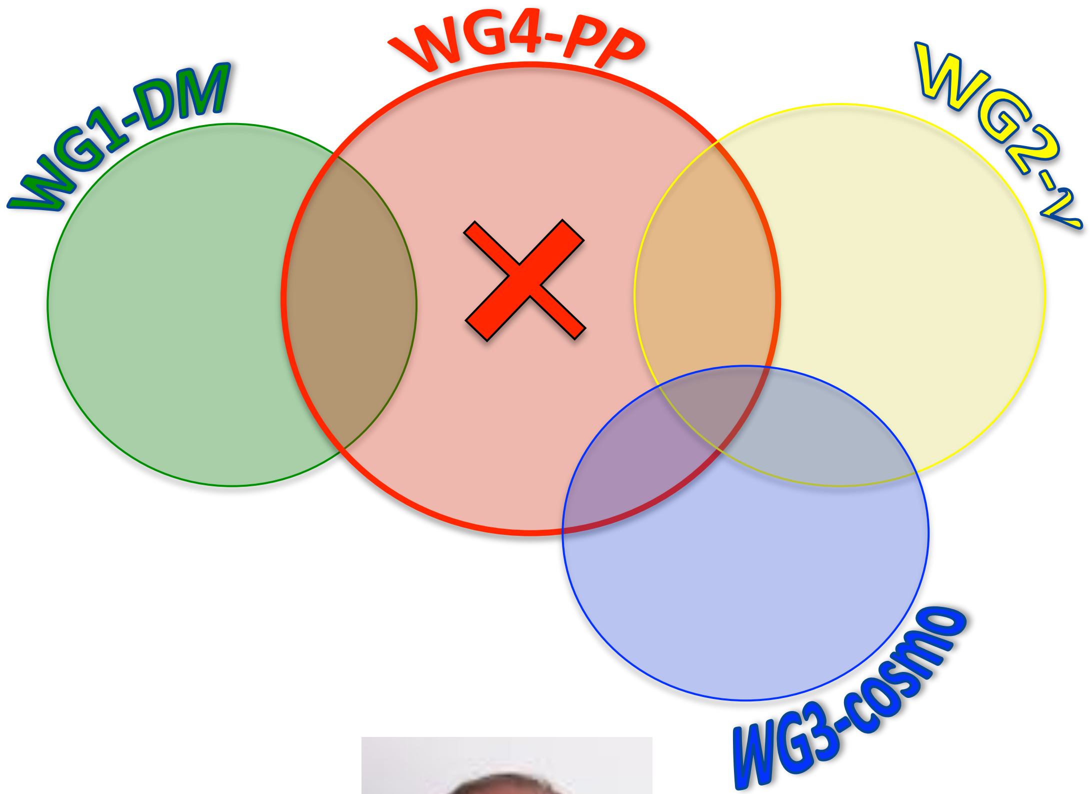
4) A. Iorio, G. Lambiase
Quantum Field Theory in curved graphene spacetime, Locachevsky geometry, Weyl symmetry, Hawking effect, and all that
arXiv:1308.0265 [hep-th], Phys. Rev. D 90 (2014) 025006

5) Luigi Rosa, Lucia Trozzo
Casimir energy in a spherical surface within surface impedance approach: the Drude model
e-Print: arXiv:1408.2366 [hep-th]

6) F.E. Canfora, D. Dudal , I.F. Justo, P. Pais, L. Rosa, D. Vercauteren
Effect of the Gribov horizon on the Polyakov loop and vice versa
e-Print: arXiv:1505.02287 [hep-th]

7) F. Canfora, M. Kurkov, L. Rosa, P. Vital
The Gribov problem in Noncommutative QED
e-Print: arXiv:1505.06342 [hep-th]

# 7) WG2/WG4: GRAVITY (BA)




# 7) WG2/WG4: GRAVITY (BA)

1) M. Gasperini
The twin paradox in the presence of gravity
arXiv:1409.1818 [gr-qc], Mod. Phys. Lett. A29 (2014) 1450149

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The twin paradox in the presence of gravity
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Conventional wisdom, based on kinematic (flat-space) intuition, tell us that a static twin is aging faster than his traveling twin brother. However, such a situation could be exactly inverted if the two twins are embedded in an external gravitational field, and if the (dynamical) distortion of the space-time geometry, due to gravity, is strong enough to compensate the kinematic effect of the relative twin motion.

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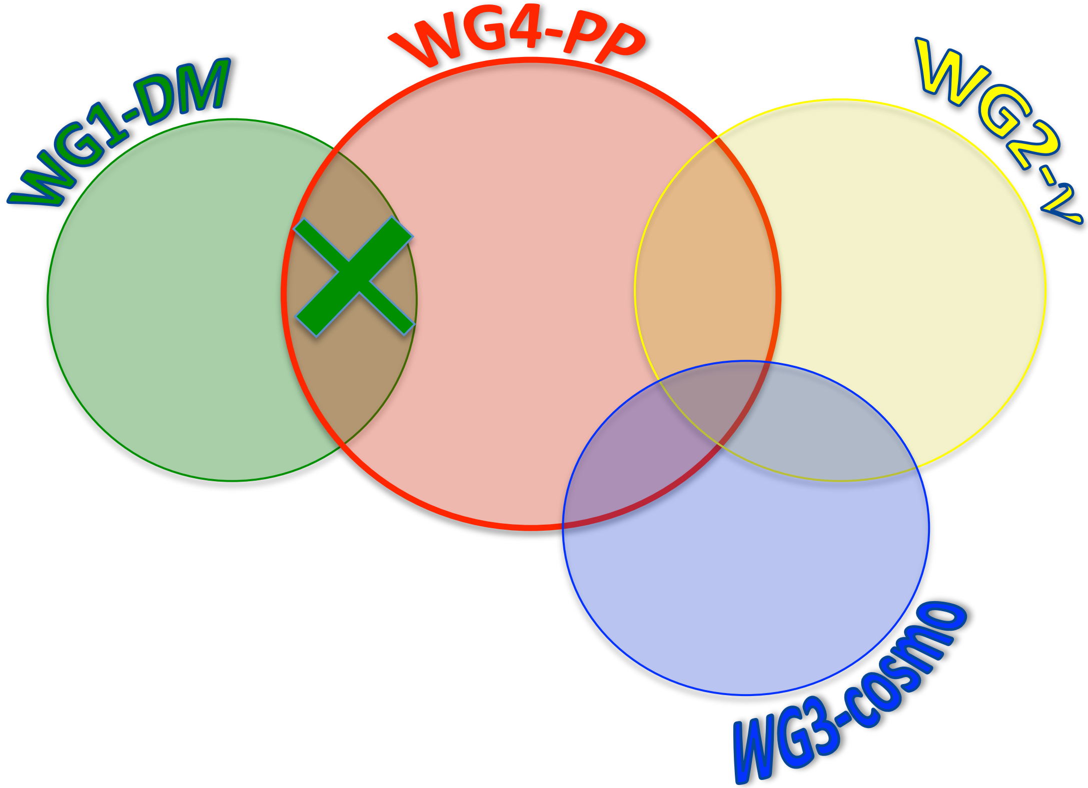
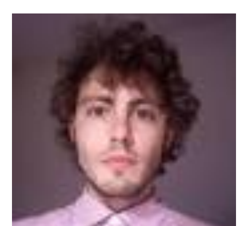
Let us hope that future technology will be able to apply this exceptional virtue of gravity to keep us young, as long as possible!

# 8) WG4: NEUTRON-ANTINEUTRON (AQ)



# 8) WG4: NEUTRON-ANTINEUTRON (AQ)

1) D.G. Phillips, W.M. Snow, K. Babu, S. Banerjee, D.V. Baxter, Z. Berezhiani et al.
Neutron-Antineutron Oscillations: Theoretical Status and Experimental Prospects
arXiv:1410.1100 [hep-ex], Accepted in Phys. Rept.

2) Z. Berezhiani, A. Vainshtein
Neutron-Antineutron Oscillation as a Signal of CP Violation
arXiv:1506.05096 [hep-ph]

Talk by Berezhiani

Neutron-antineutron oscillations phenomenology

3) A. Addazi, M. Bianchi
Neutron Majorana mass from exotic instantons
arXiv:1407.2897 [hep-ph], JHEP 1412 (2014) 089

4) A. Addazi, M. Bianchi
Neutron Majorana mass from Exotic Instantons in a Pati-Salam model
arXiv:1502.08041 [astro-ph.CO], JHEP 1506 (2015) 012

5) A. Addazi
Exotic vector-like pair of color-triplet scalars
arXiv:1501.04660 [hep-ph], JHEP 1504 (2015) 153

DM and Neutron oscillations and/or exotica

Z. Berezhiani, A. Vainshtein

Neutron-Antineutron Oscillation as a Signal of CP Violation

arXiv:1506.05096 [hep-ph]

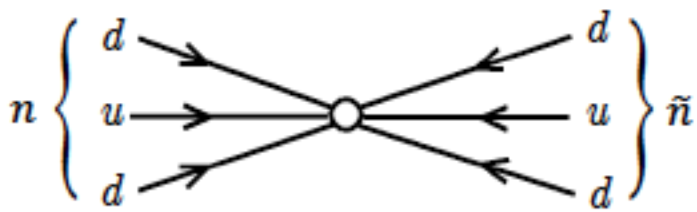
Assuming the Lorentz and **CPT** invariances we show that neutron-antineutron oscillation implies breaking of **CP** along with baryon number violation. Presence of external magnetic field does not add any new operator to mixing of neutron and antineutron.

$B$ can be broken by two units via Majorana terms $\Delta\mathcal{L}_{\not B} = -\frac{1}{2}\epsilon\left[n^T C n + \bar{n} C \bar{n}^T\right]$

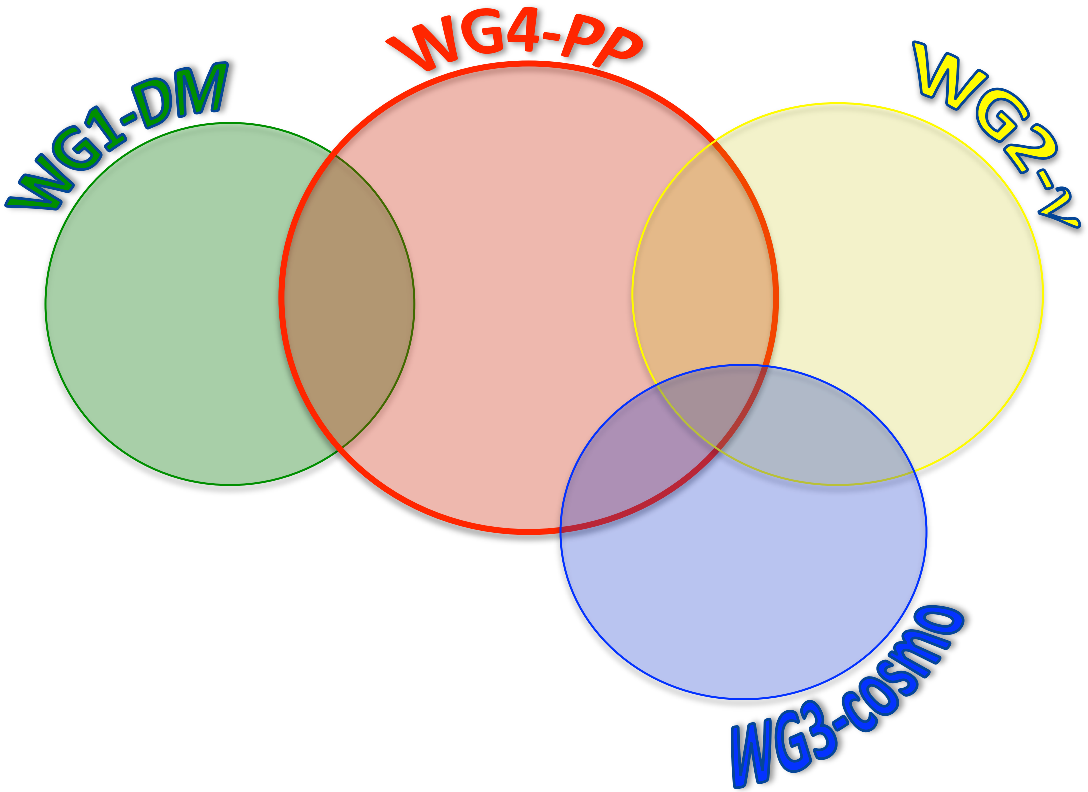
$\Delta\mathcal{L}_{\not B}$ relevant for $n - \bar{n}$ oscillation (generates mass splitting): *conserves* **C** but *breaks* **P** and **CP**

Neutron antineutron oscillation emerges in BSM physics via six-quark effective operators

$$\mathcal{O} = \frac{1}{M^5}\, uddudd$$




automatically satisfy two (in fact all three) of Sakharov's conditions.




… buon lavoro!

From Miele's talk

# Beyond Standard Model

Several phenomena or open problems suggest the presence of physics beyond Standard Model (SM):

- hint of gauge unification;
- structure of fermion masses;
- hierarchy problem;
- baryogenesis.

- The Supersymmetric Grand Unified Theories (SUSY-GUTs) are able to address part of these problems.

- After the 8 TeV LHC run I, we try:
  - to reanalyze the room still remaining for SUSY-GUT inspired models;
  - to determine the **upper bound** $M_{UB}$ for the energy below which SUSY signatures have to show up.

# Assumptions

From Miele's talk

To perform our study, we require:

- One step gauge unification at a single energy scale $M_{GUT}$, without intermediate symmetry scales;

→ **SU(5) Bottleneck**

- Consistency of third family fermion masses and possible Yukawa b-τ unification;

$$y_{\rm b}(M_{\rm GUT}) = y_\tau(M_{\rm GUT}) \left(1 + \mathcal{O}\left(\frac{y_\mu(M_{\rm GUT})}{y_\tau(M_{\rm GUT})}\right)\right)$$

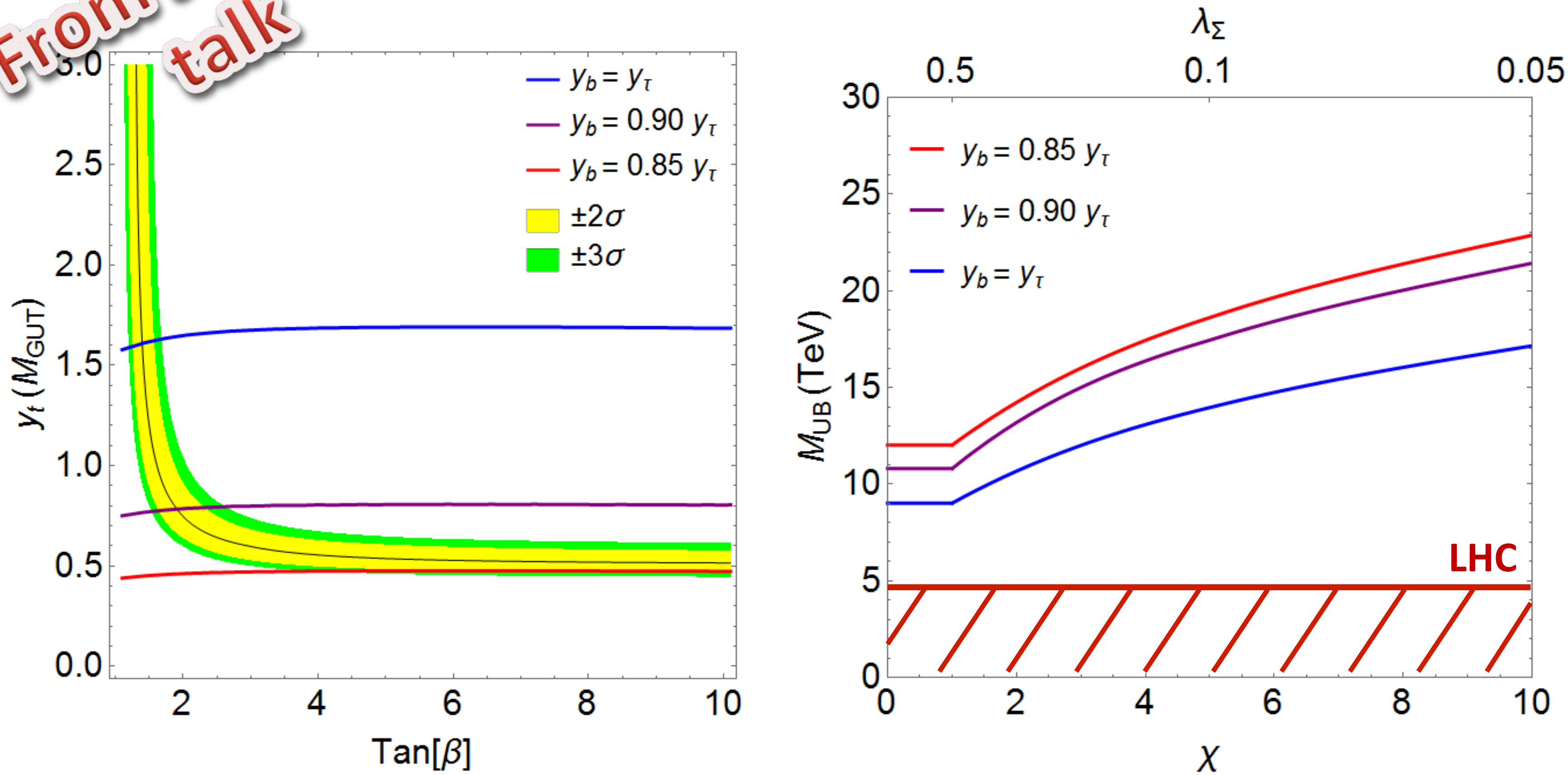
- Consistency with the experimental limit on proton decay;

- Absence of special fine tunings among the parameters in the GUT scenario, implying couplings O(1) above $M_{GUT}$.

→ **Naturalness**

# Upper bound for SUSY physics

From Miele's talk




- Larger values for GUT threshold χ are not allowed since:
  - naturalness requirement implies $\lambda_\Sigma \sim \mathcal{O}(1)$;
  - $M_{GUT}$ unnaturally approaches $M_{Plack}$.

→ $M_{UB} \sim 20$ **TeV**

From Miele's talk

# Conclusions

After LHC run I (8 TeV), for planning new colliders it is of interest:

- to reanalyze the room still remaining for SUSY-GUT inspired models;
- to determine the **upper bound** $M_{UB}$ for the energy below which SUSY signatures have to show up.

- Assuming one step unification (SU(5) bottleneck), under natural assumptions we have obtained general bounds on SUSY mass spectrum.

- We claim that if a SUSY-GUT model is the proper way to describe physics beyond the SM, the lighest gluino or higgsino cannot have a mass larger than

$$M_{UB} \sim 20 \text{ TeV}$$