

# Construire des modèles en supersymétrie

Jeanne Parmentier,



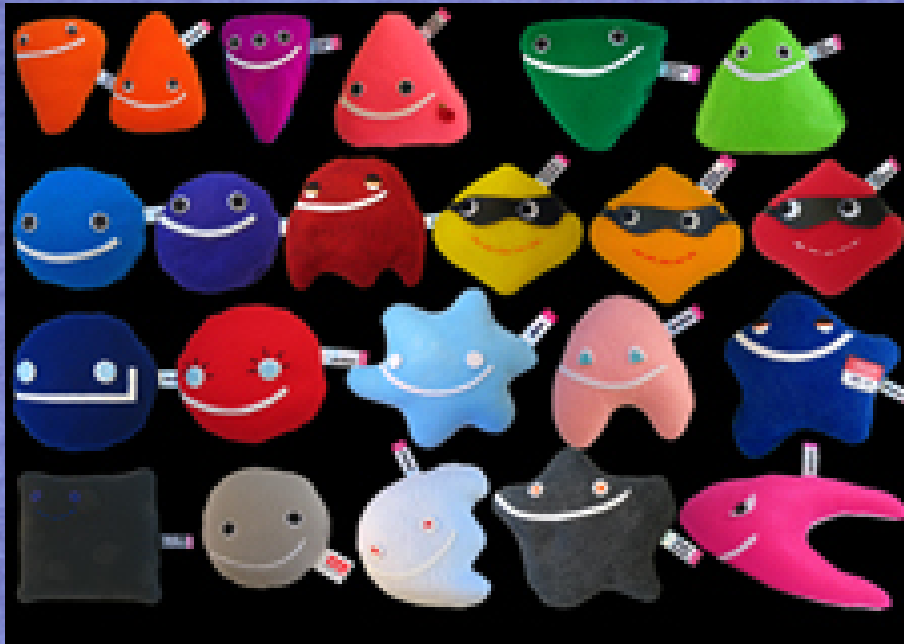
Travail réalisé en collaboration avec,  
Stephane Lavignac, IPhT, CEA Saclay  
Emilian Dudas, CPhT, Ecole Polytechnique



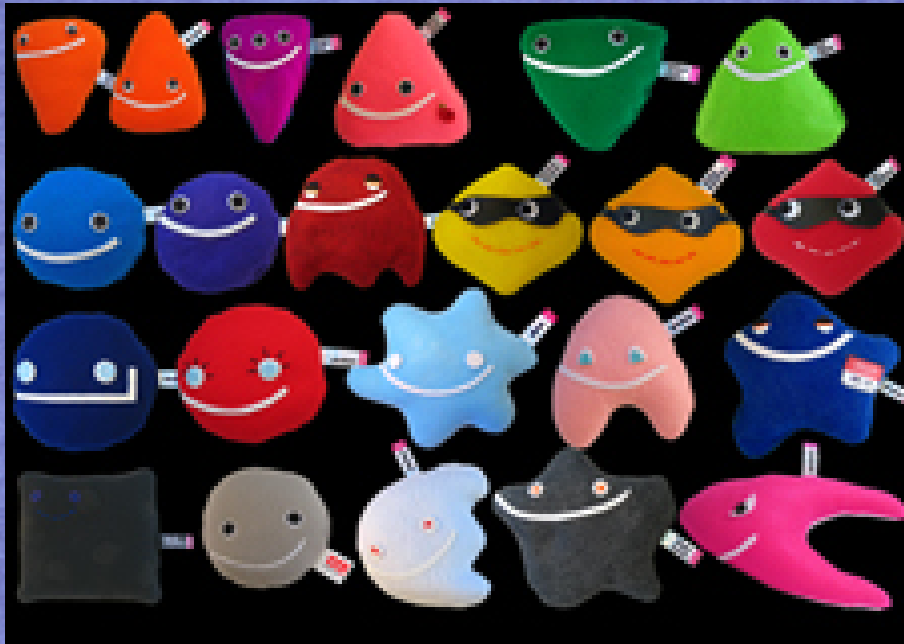
E. Dudas, S.Lavignac., J. P., Nucl. Phys. B808 (2009) 237

E. Dudas, S.Lavignac., J. P., travail en cours

Au delà du modèle standard...

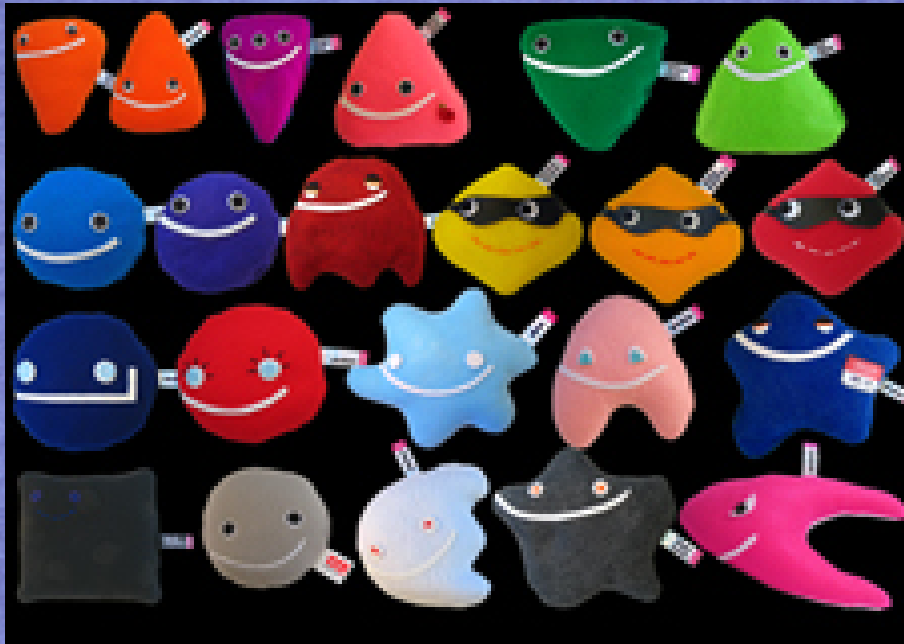


Au delà du modèle standard...



Dimensions  
Supplémentaires?

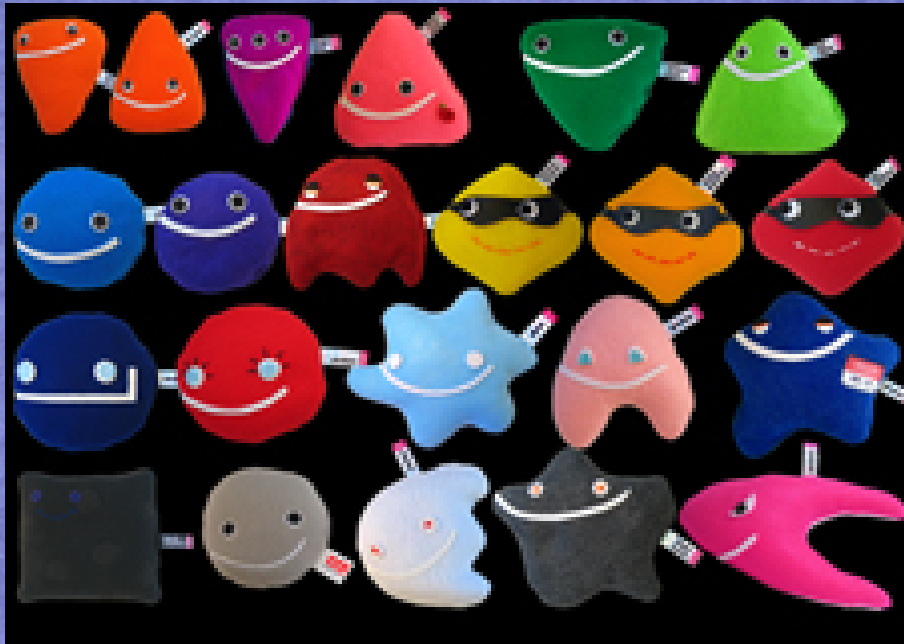
Au delà du modèle standard...



Dimensions  
Supplémentaires?

Supersymétrie?

Au delà du modèle standard...

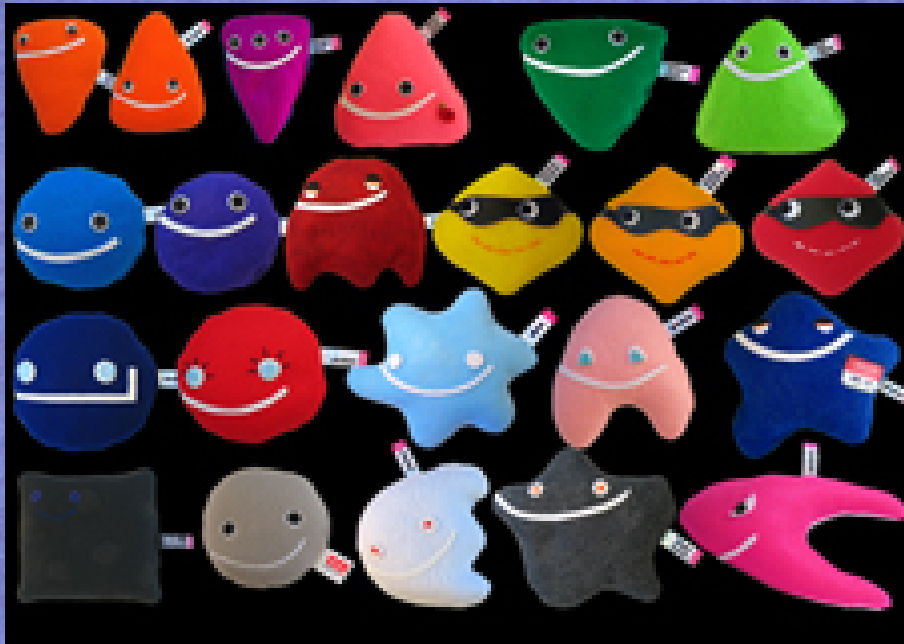


Mondes branaires?

Dimensions Supplémentaires?

Supersymétrie?

Au delà du modèle standard...



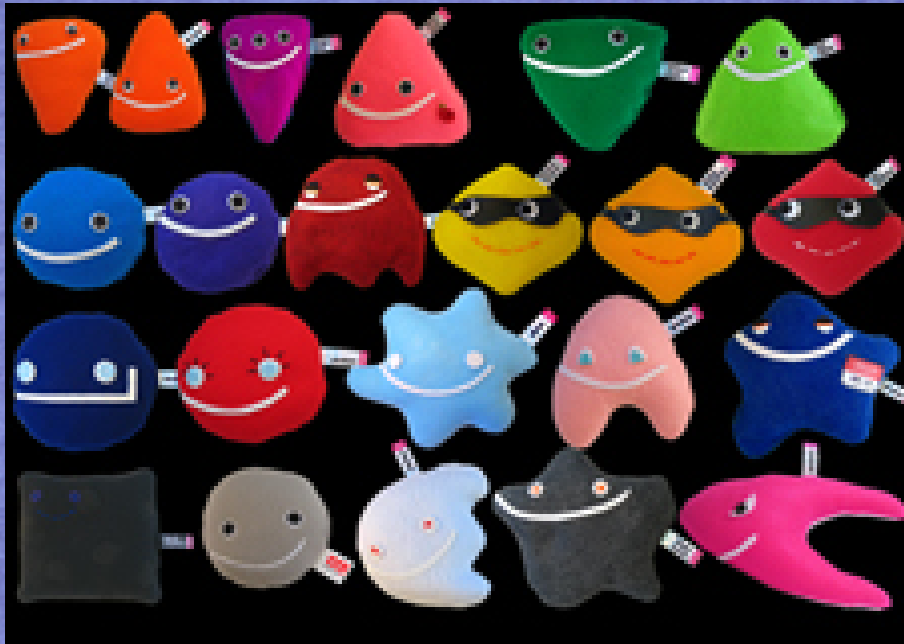
Mondes branaires?

Dimensions Supplémentaires?

Rien du tout?

Supersymétrie?

Au delà du modèle standard...



Dimensions Supplémentaires?

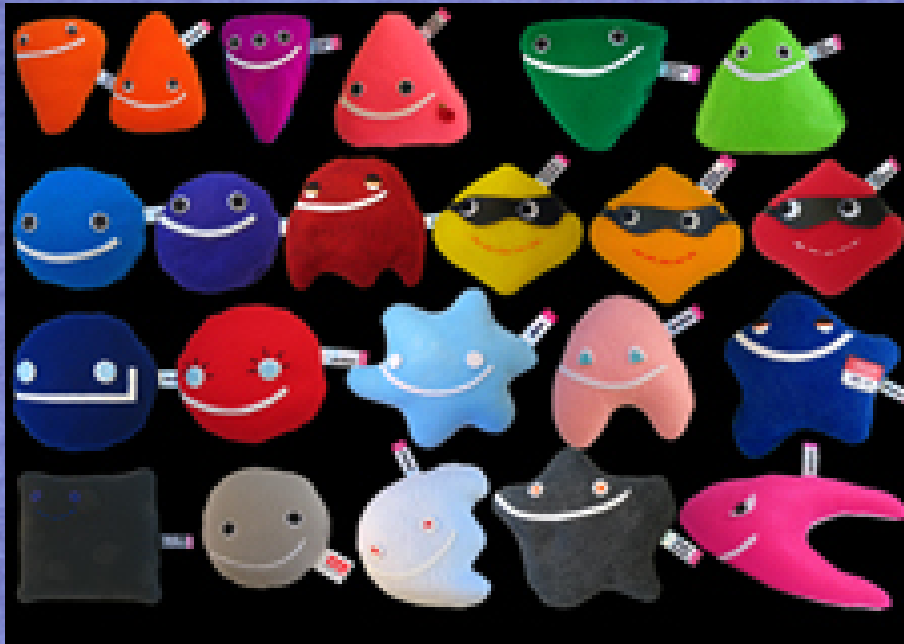
Rien du tout?

Supersymétrie?

Mondes branaires?

Théories de Grande Unification?

Au delà du modèle standard...



Dimensions Supplémentaires?

Rien du tout?

Supersymétrie?

Higgs composite?

Mondes branaires?

Théories de Grande Unification?



Au delà du modèle standard... SUSY?



Electron  
Spin 1/2



W  
Spin 1



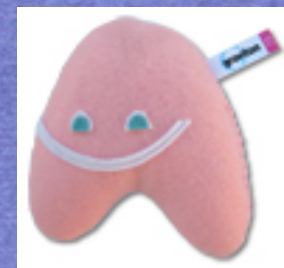
Graviton  
Spin 2



Selectron  
Spin 0



Wino  
Spin 1/2



Gravitino  
Spin 3/2

Au delà du modèle standard... ~~SUSY~~?



Electron  
Spin 1/2



W  
Spin 1



Graviton  
Spin 2



Selectron  
Spin 0



Wino  
Spin 1/2



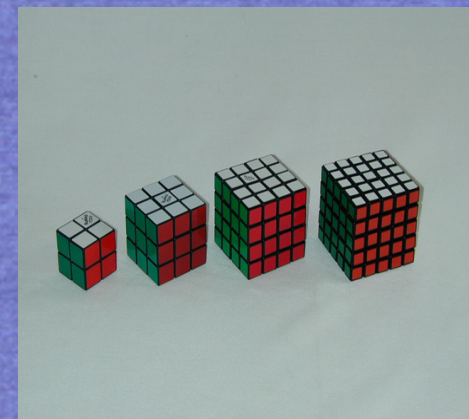
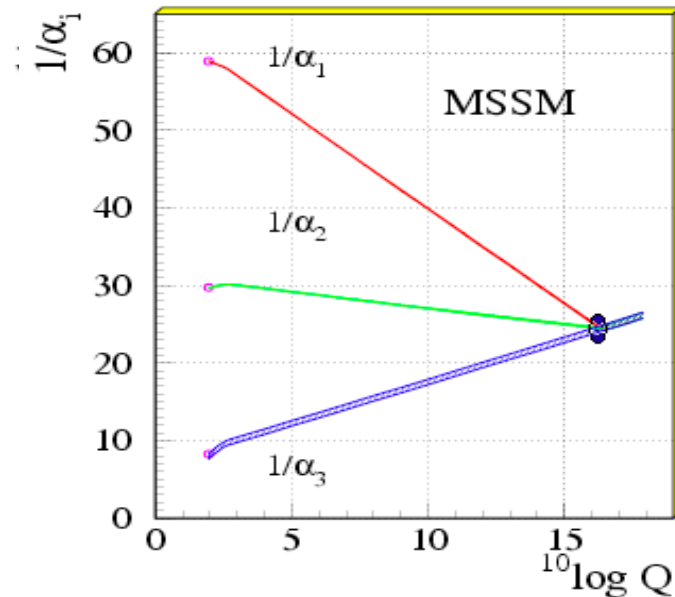
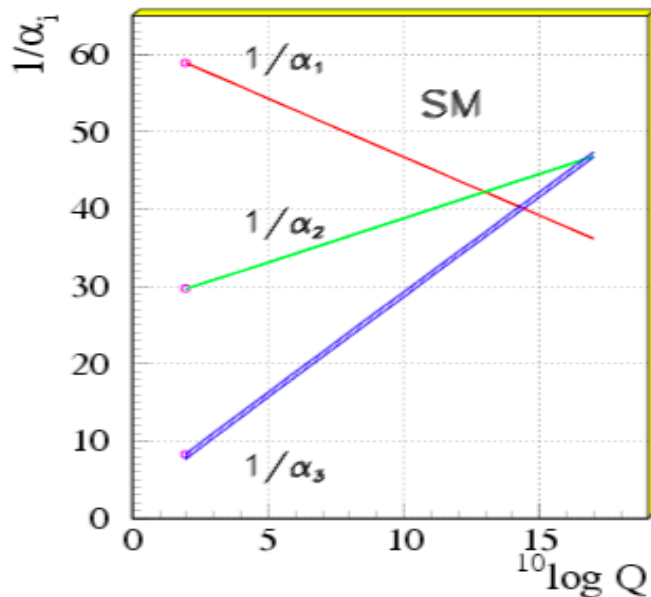
Gravitino  
Spin 3/2

Avantages et contraintes ...

- \* Extension de l'algèbre de Lorentz

- \* Stabilité de la masse du Higgs

# Au delà du modèle standard... l'unification?



$$\text{GUT} = \text{SU}(5), \text{SO}(10) \xrightarrow{\Sigma} \text{SU}(3) \times \text{SU}(2) \times \text{U}(1) \xrightarrow{h} \text{SU}(3) \times \text{U}(1)$$

$10^{16} \text{ GeV}$    $100 \text{ GeV}$

Introduction

Contraintes

Modèle

Résultats

Conclusion

Dans la matière noire

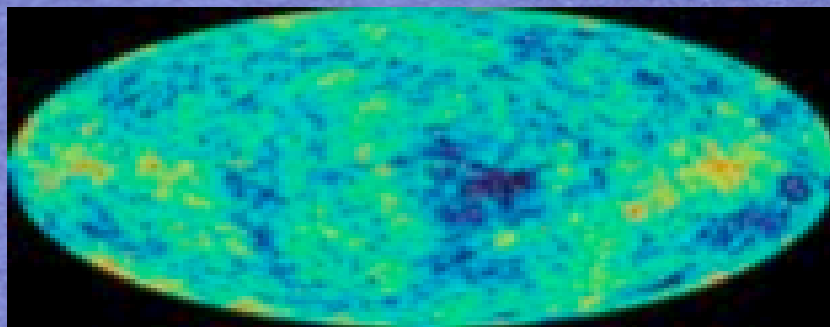
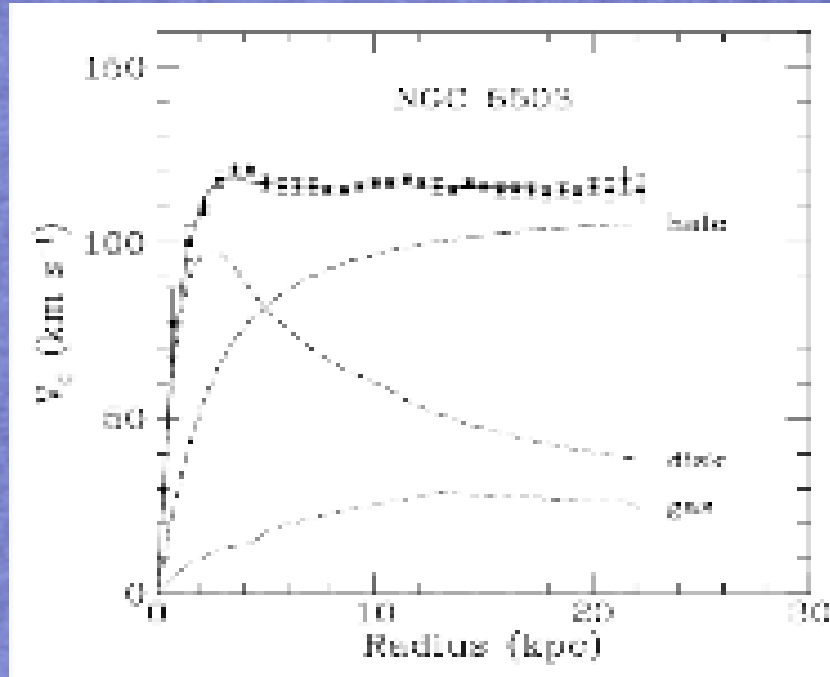
Où est SUSY?

Jeanne Parmentier

JRJC 2009



## Dans la matière noire



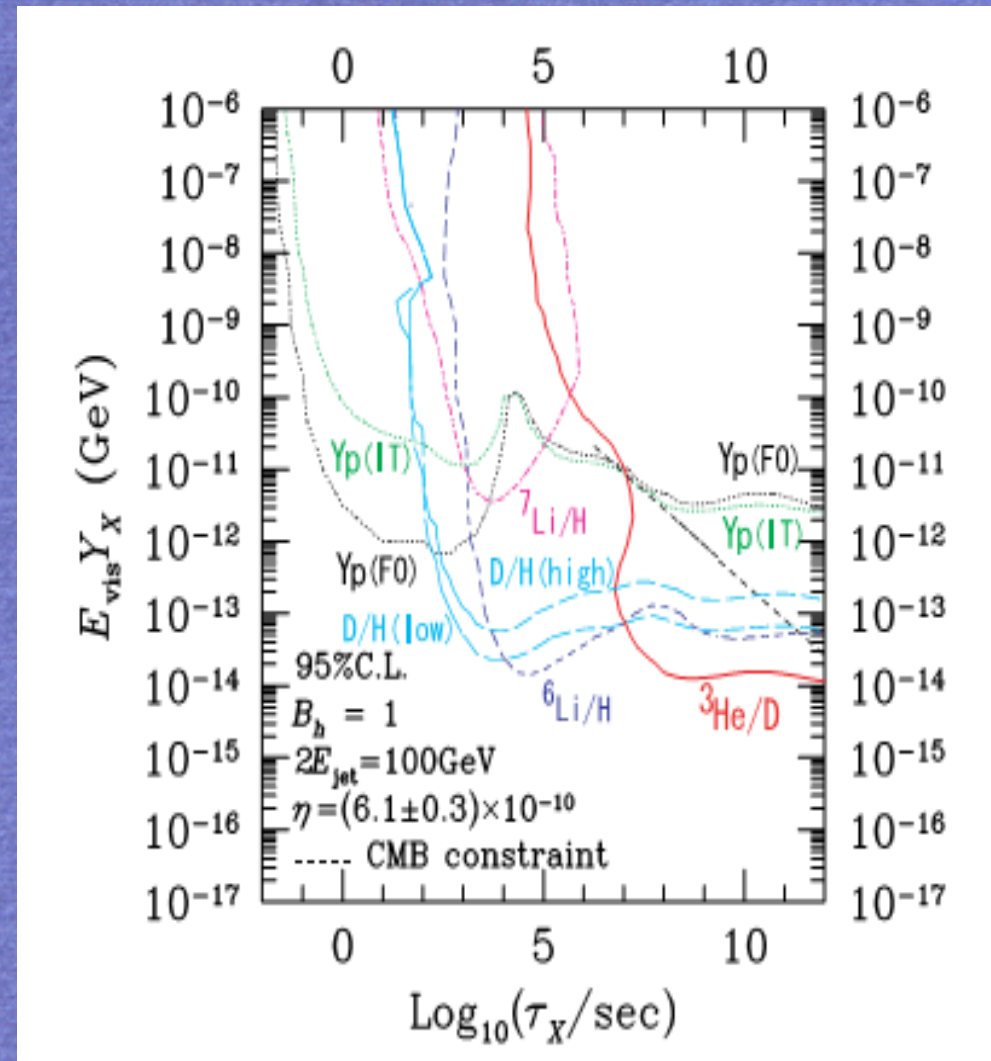
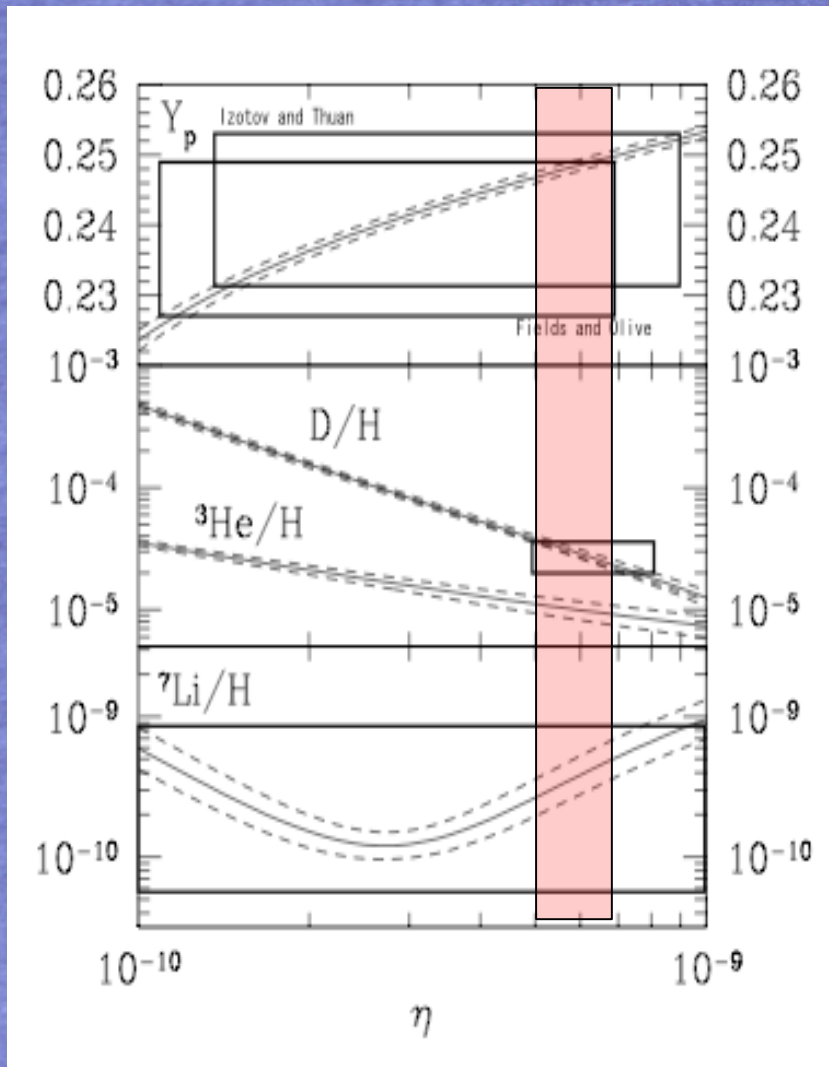
$$\Omega_M \approx 0.26 \pm 0.05$$

Weak cross section:

$$\langle \sigma_{\text{ann}} v \rangle \approx \frac{\alpha_w^2}{M^2} \approx \frac{\alpha_w^2}{1 \text{ TeV}^2}$$

$$\Rightarrow \Omega_X \sim \mathcal{O}(\text{few } 0.1)$$

# La Nucléosynthèse Primordiale







Les changements de



saveur



$$m = \begin{pmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{pmatrix}$$



Changements  
de saveur

Modèle quelconque

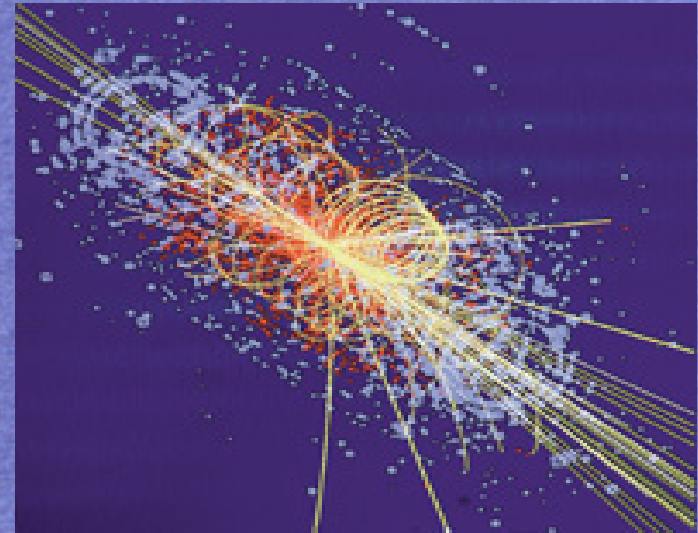
Solutions: Alignement

Universalité

$$\tilde{M} = \begin{pmatrix} \tilde{m}_1 & 0 & 0 \\ 0 & \tilde{m}_2 & 0 \\ 0 & 0 & \tilde{m}_3 \end{pmatrix}$$

$$: \tilde{M} = \tilde{m} 11$$

# Les contraintes aux collisionneurs



46 GeV



Neutralino

73 GeV



Sélectron

94 GeV



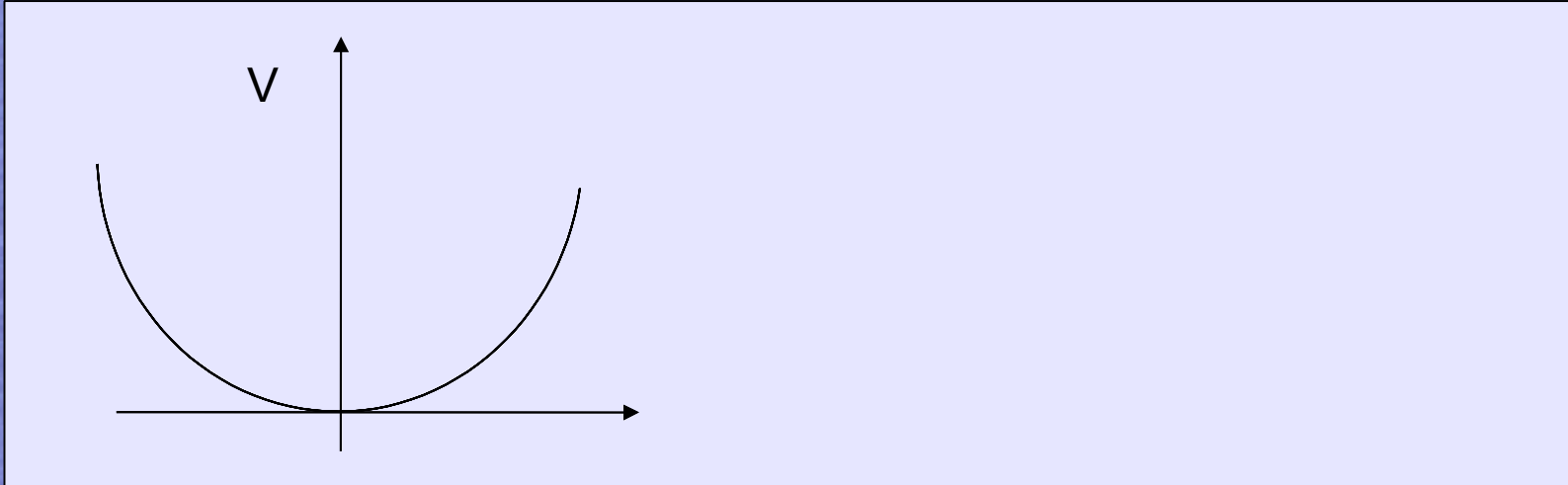
Wino

308 GeV

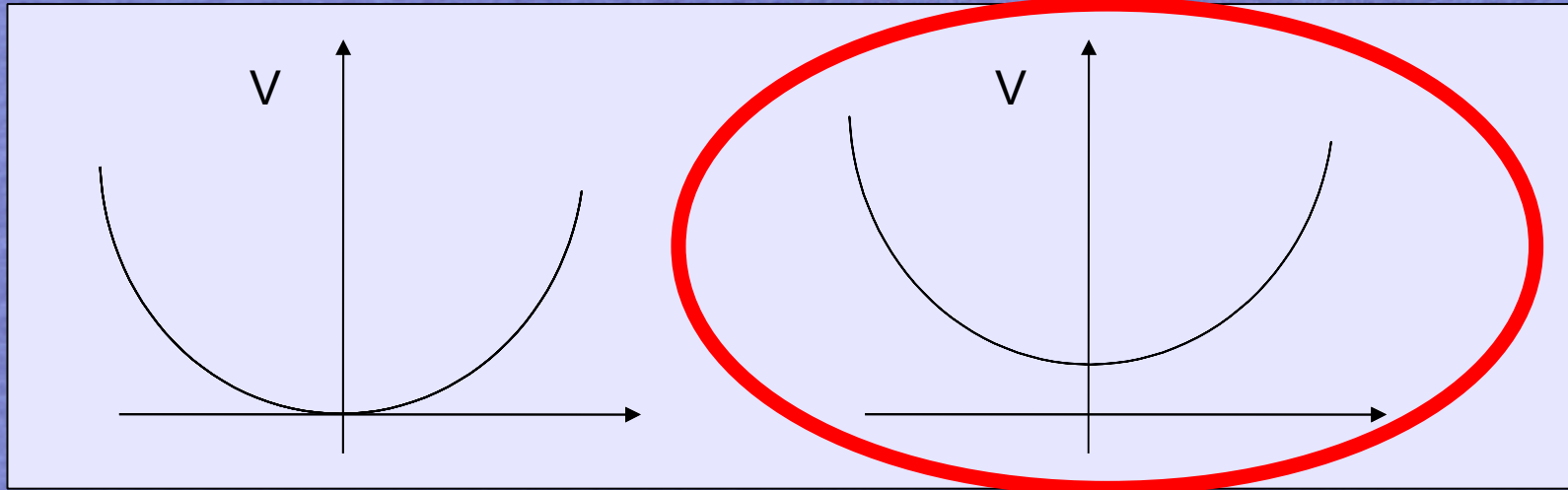


Gluino

## Les contraintes théoriques



## Les contraintes théoriques

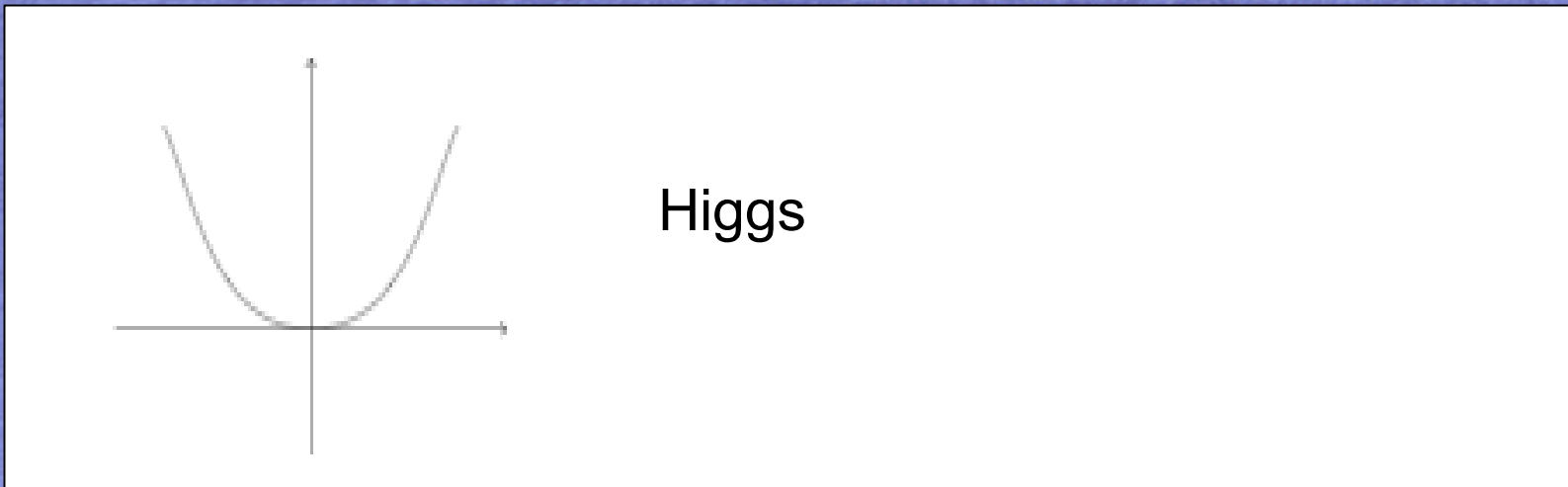
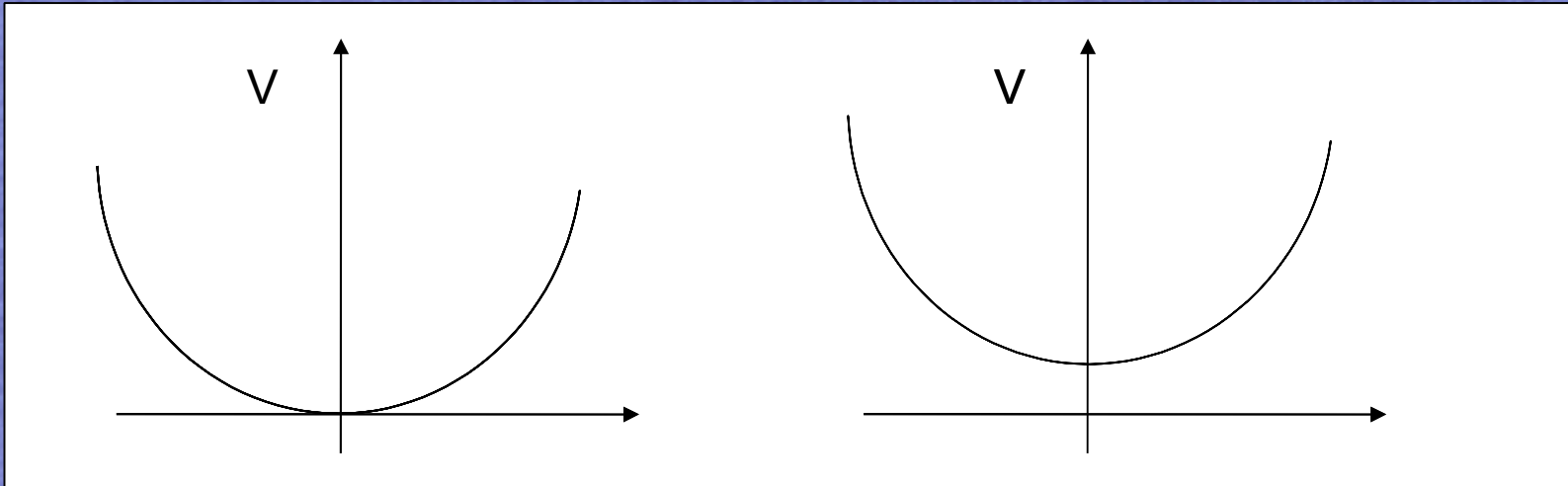


Echelle de brisure  
donnée  
Par F ou D

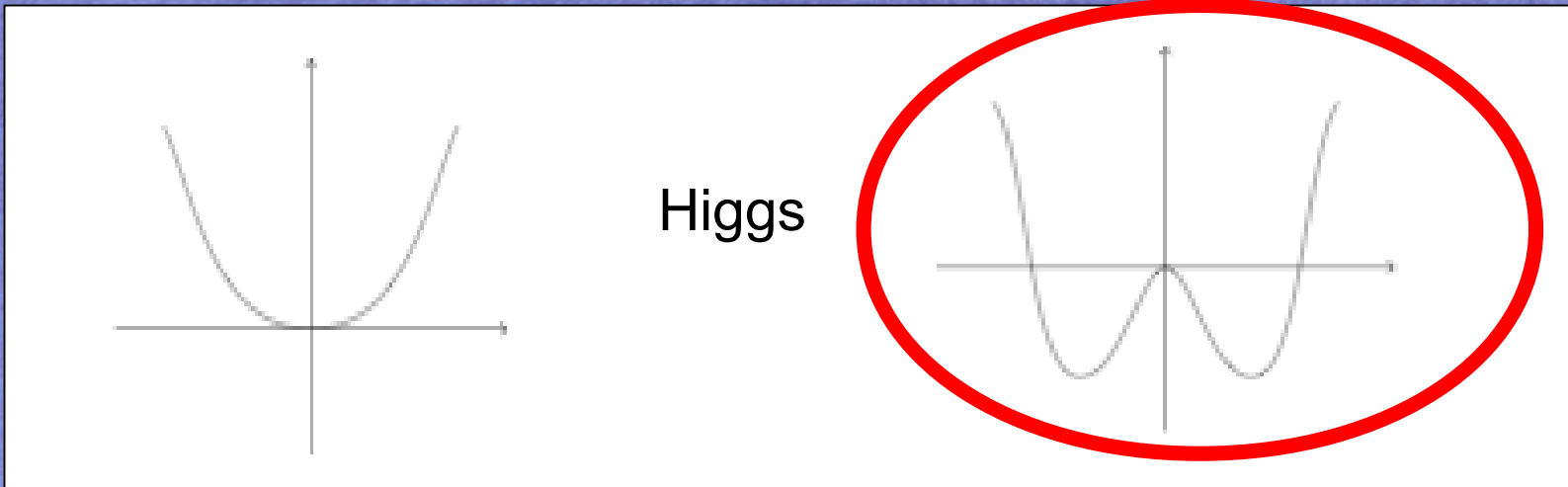
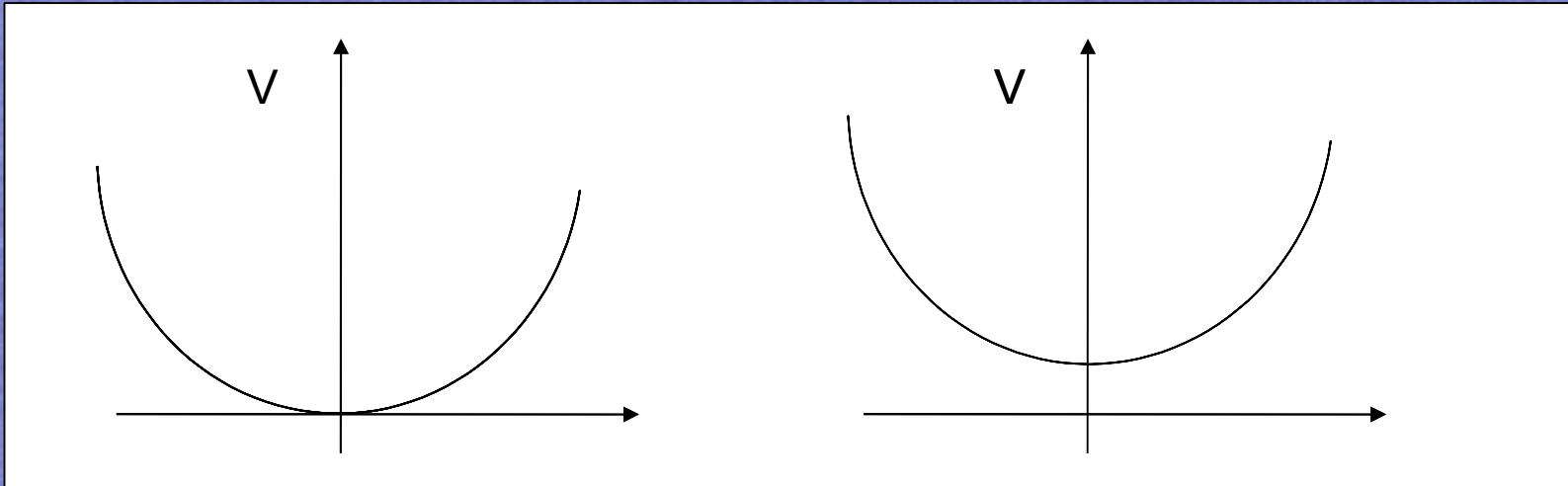
$$V \sim F^2, D^2$$



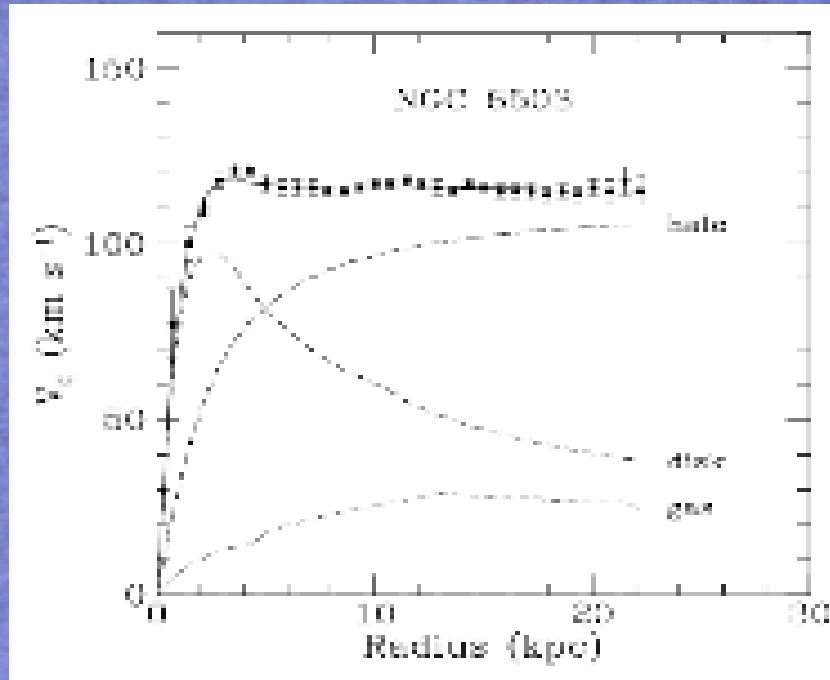
# Les contraintes théoriques



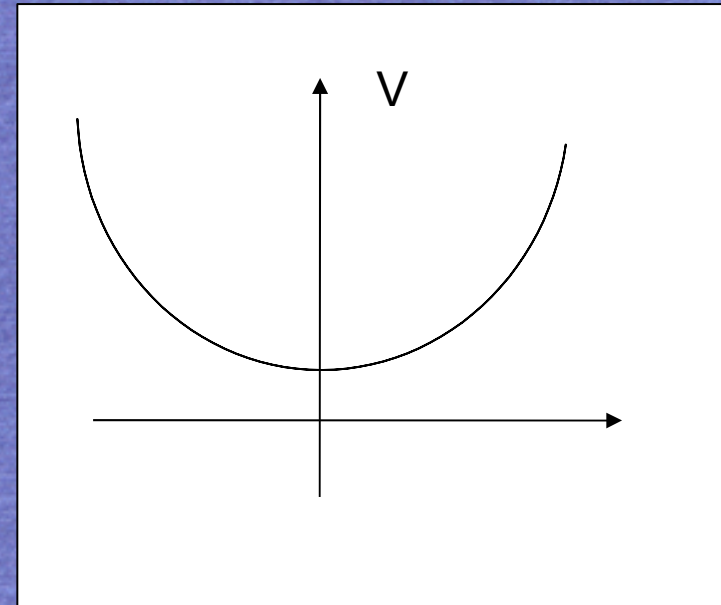
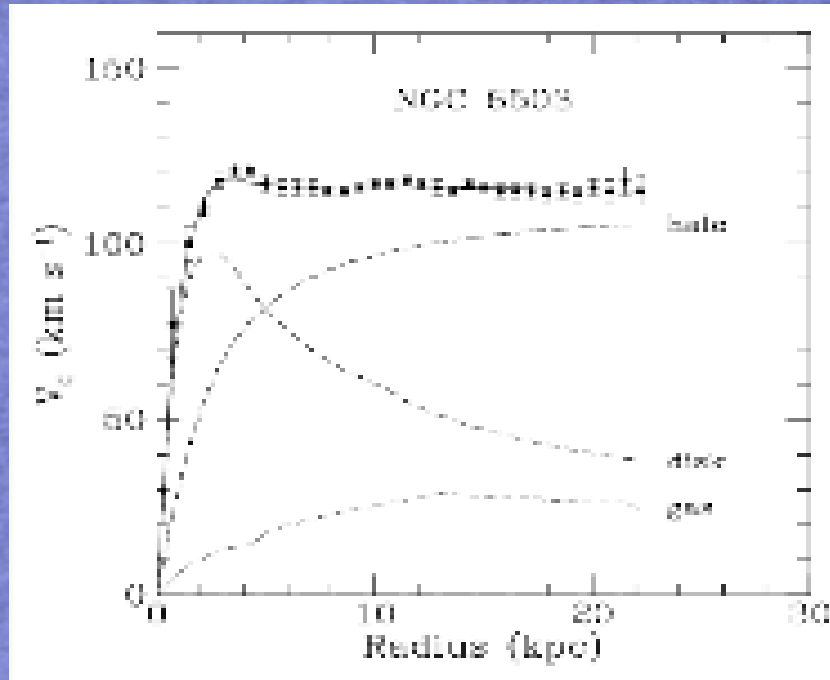
# Les contraintes théoriques



Il faut démêler tout ça...

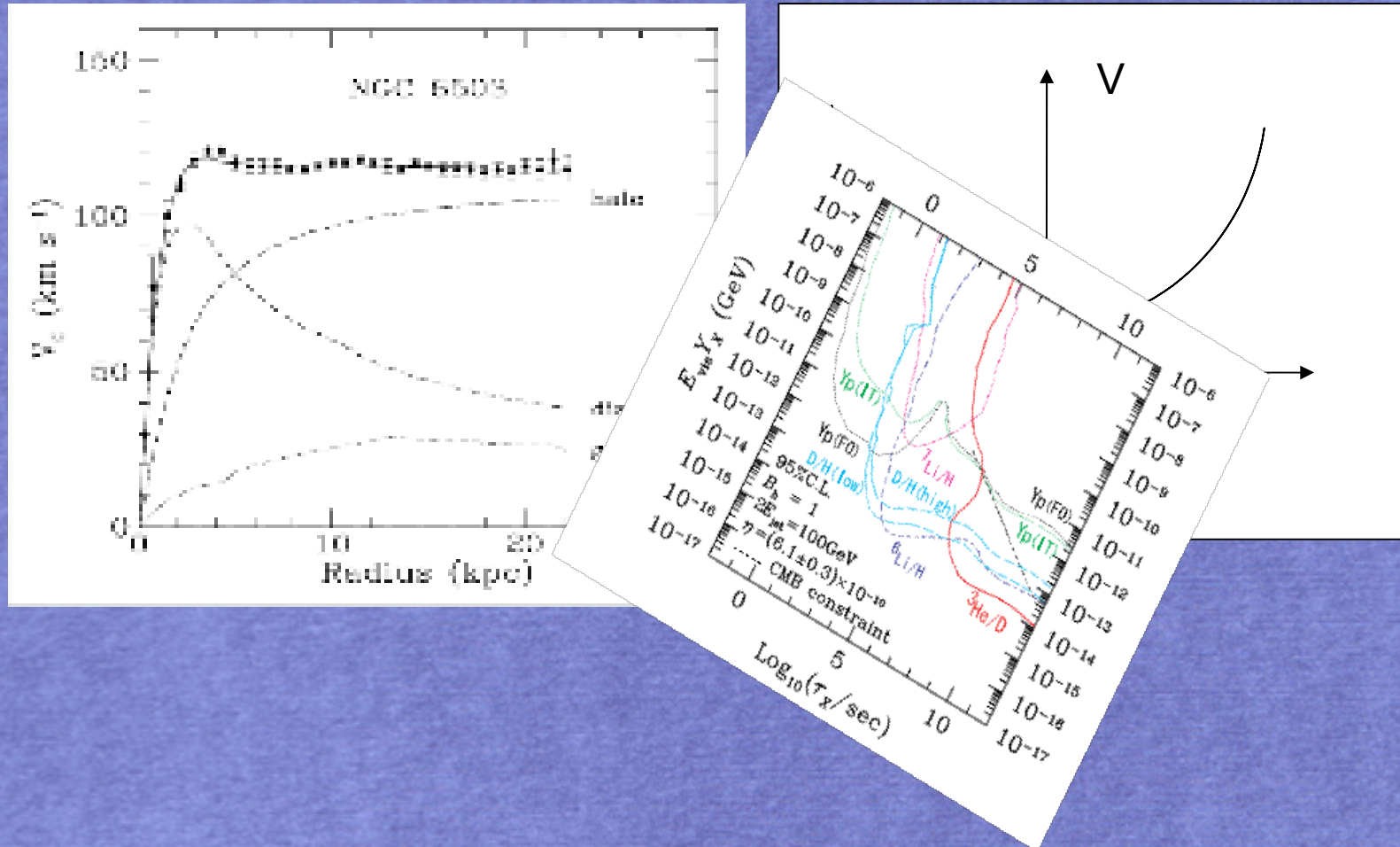


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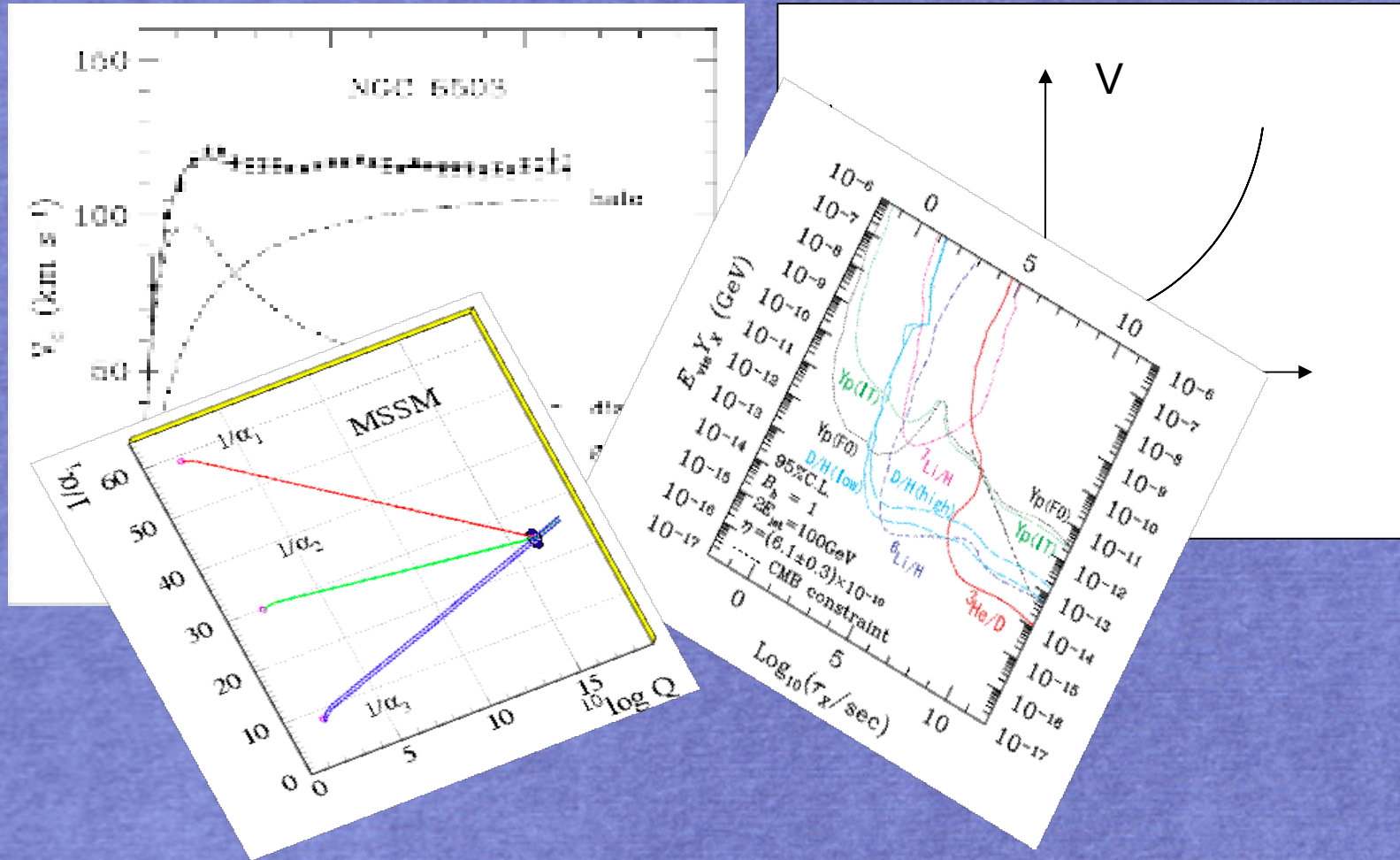




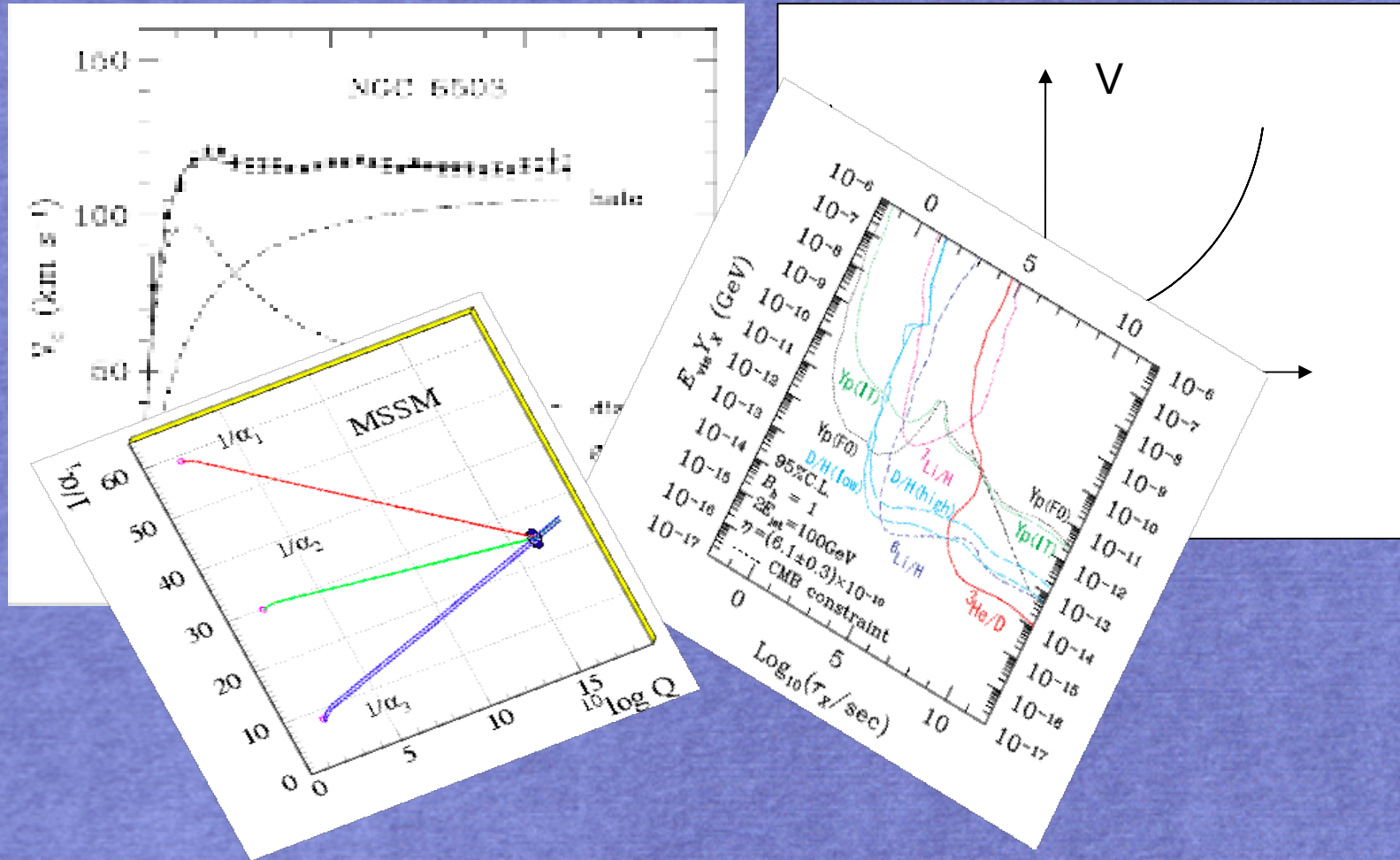
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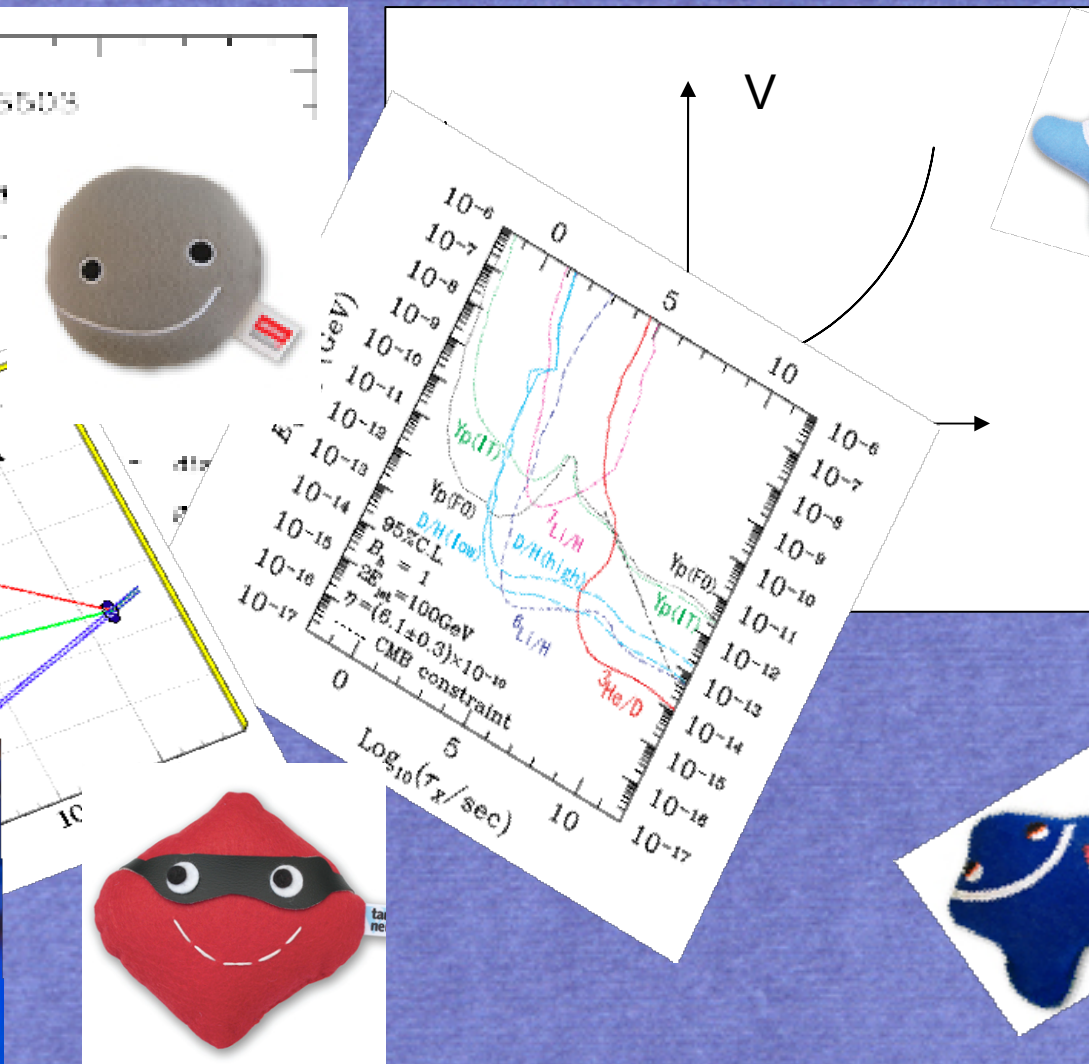
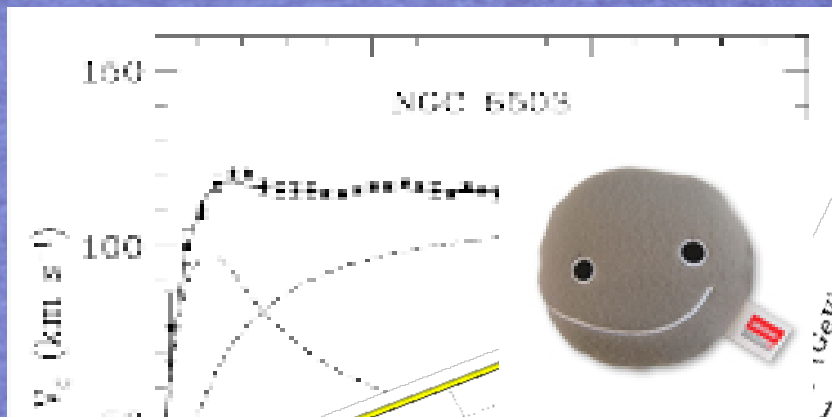
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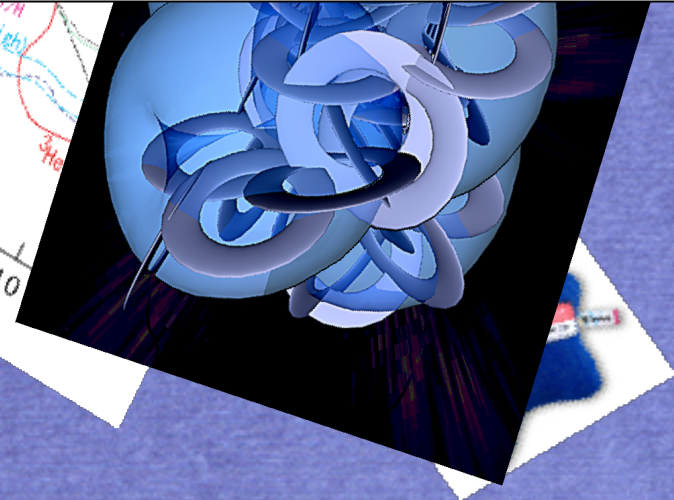
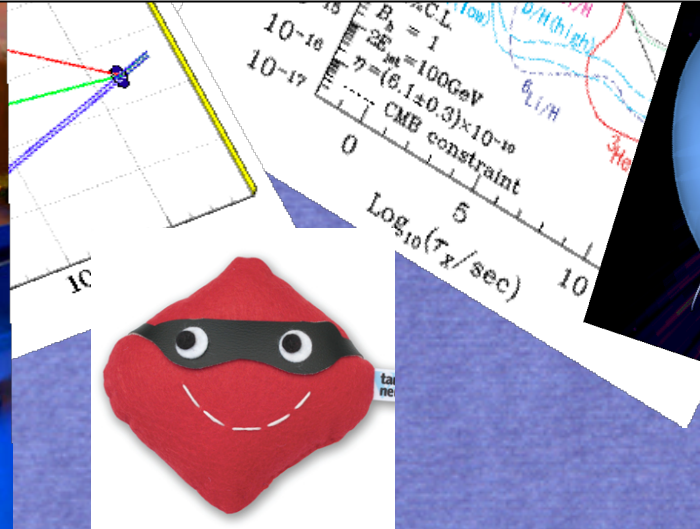
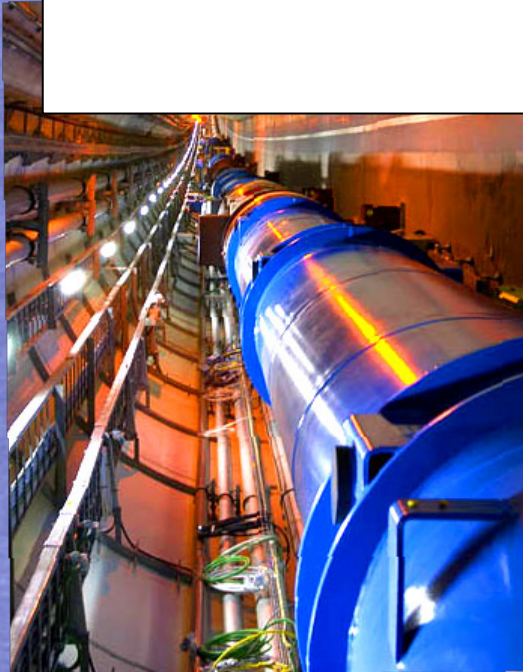
Il faut démêler tout ça...

The collage features several key elements:

- Top Left:** A plot titled "NGC 6505" showing velocity dispersion  $V_c$  (km/s) on the y-axis (ranging from 50 to 150) against an unlabeled x-axis. It contains several data series represented by different line styles.
- Bottom Left:** A photograph of the LHC tunnel, showing the long, blue-painted superconducting particle accelerator pipes stretching into the distance.
- Center:** A plot showing relic density constraints. The y-axis is  $\Omega_{\text{DM}} h^2$  (ranging from  $10^{-17}$  to  $10^{-6}$ ) and the x-axis is  $\text{Log}_{10}(\tau_x/\text{sec})$  (ranging from 0 to 10). It includes curves for  $\chi_p(\text{DM})$ ,  $\chi_p(\text{DM})$ ,  $\chi_p(\text{DM})$ , and  $\chi_p(\text{DM})$ , along with a "CMB constraint" line. Parameters listed include  $B_p = 1$ ,  $\tau_{\text{int}} = 100 \text{ GeV}$ , and  $\tau = (6.1 \pm 0.3) \times 10^{-10}$ .
- Right:** A 3D visualization of a particle interaction, showing blue, swirling, ribbon-like structures against a dark background.
- Cartoon Mascots:** A grey smiley face, a red smiley face with a black mask, and a blue smiley face with a star shape.

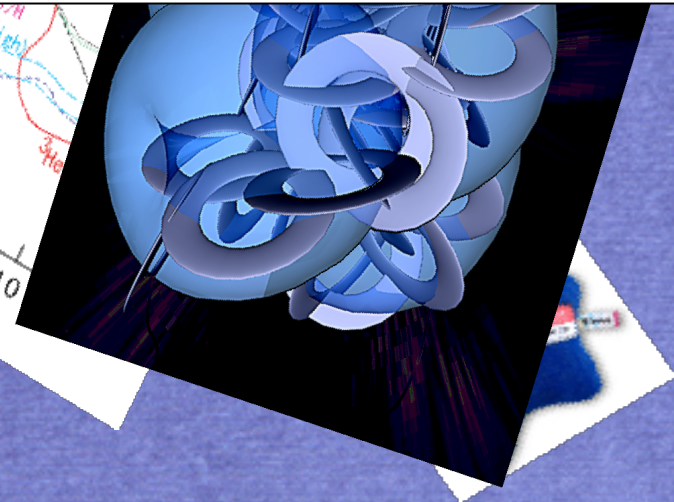
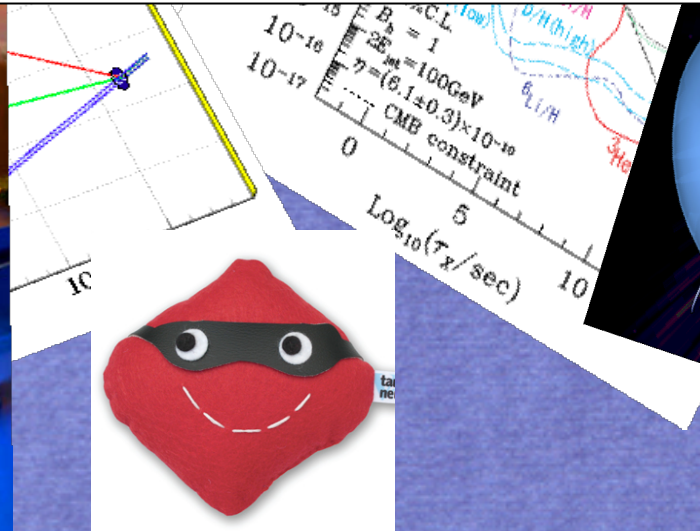
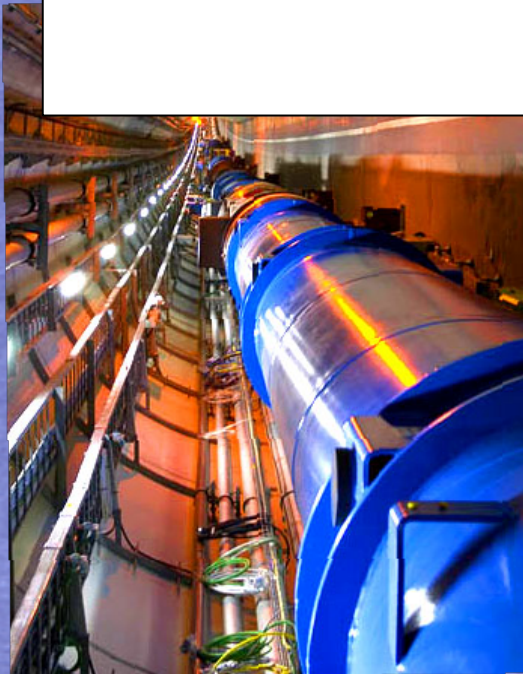
Il faut démêler tout ça...

# Où, où, où, où est SUSY?



Il faut démêler tout ça...

# Où, où, où, où est SUSY?



Il faut démêler tout ça...

# Où, où, où, où est SUSY?

Vous l'avez vue?





# MSSM + Secteur caché = Mediation de jauge?

MSSM

$$\Phi \tilde{\Phi}$$

Secteur Caché

$$\langle X \rangle = M + F\theta^2$$

\*Prédicatif

\*Sans  
changement  
de saveur

Les messagers sont  
chargés  
sous les symétries du MS

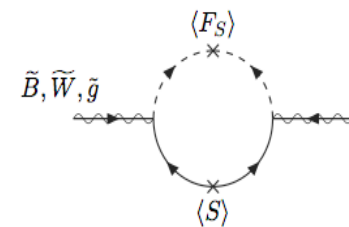
$$W_{mess} = \lambda_X X \Phi \tilde{\Phi}$$



$$M_a(\mu) = \frac{\alpha_a(\mu)}{4\pi} N_m \sum_i 2T_a(R_i) \frac{F}{M}$$



$$m_\chi^2 = 2 N_m \sum_a C_\chi^a \left( \frac{\alpha_a}{4\pi} \right)^2 \sum_i 2T_a(R_i) \left| \frac{F}{M} \right|^2$$



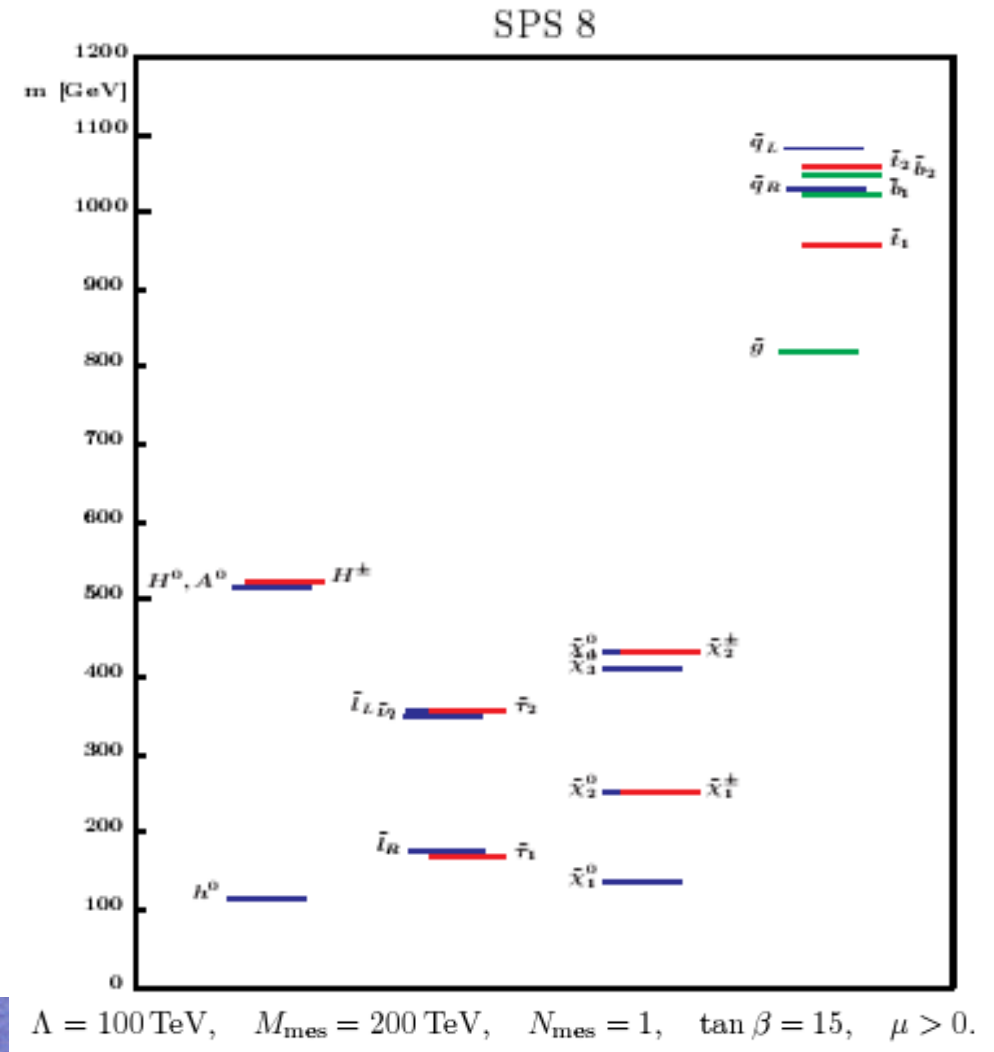
## Mediation de jauge, scénario classique

Masse universelle pour les  
Messagers:  $M_D = M_T \dots$

$$\frac{M_1}{\alpha_1} = \frac{M_2}{\alpha_2} = \frac{M_3}{\alpha_3}$$

$$M_{GM} \equiv \frac{\alpha}{4\pi} \frac{F}{M} \Rightarrow \frac{F}{M} \sim (10 - 100) \text{ TeV}$$

Gravitino léger (jusqu'à l'eV)



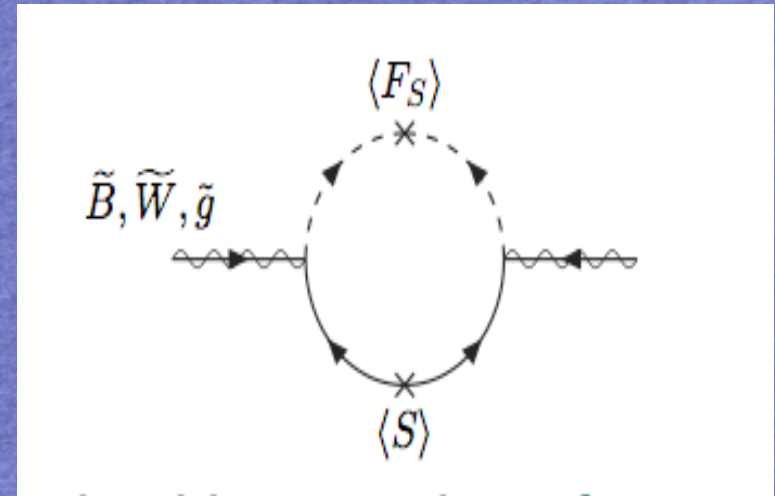
## Mediation de jauge, scenario classique

Masse universelle pour les  
Messagers:  $M_D = M_T \dots$

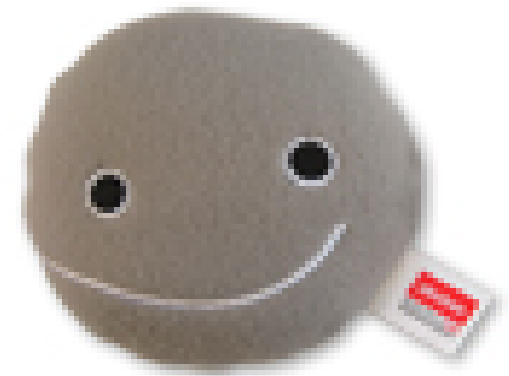
$$\frac{M_1}{\alpha_1} = \frac{M_2}{\alpha_2} = \frac{M_3}{\alpha_3}$$

$$M_{GM} \equiv \frac{\alpha}{4\pi} \frac{F}{M} \Rightarrow \frac{F}{M} \sim (10 - 100) \text{ TeV}$$

Gravitino léger (jusqu'à l'eV)



Neutralino



# Mediation de jauge + GUT = ?

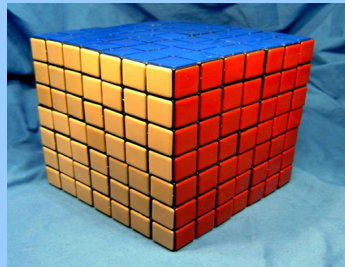
MSSM



Secteur  
Caché



GUT SUSY



## Mediation de jauge + GUT = ?

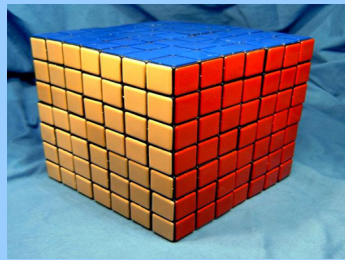
MSSM


 $\Phi\tilde{\Phi}$ 

Secteur Caché



GUT SUSY



$$W_{\text{mess}} = \lambda_X X \Phi \tilde{\Phi} + \lambda_\Sigma \Sigma \Phi \tilde{\Phi}$$

\* Les messagers peuvent avoir des nombres quantiques et des masses différentes → spectres différents

\* Masse pour le gravitino  $m_{3/2} = \frac{F}{3M_p} = O(10)\text{GeV}$  car  $m_{MG} = \frac{\alpha}{4\pi} \frac{F}{M}$



## Méthode pour obtenir des spectres



Choisir

- \* la représentation des messagers
- \* le groupe d'unification
- \* le mécanisme de brisure (Higgs)

Calculer

- \* les couplages possibles entre Higgs et messagers
- \* les masses des messagers
- \* les masses des sparticules dans l'UV
- \* les masses des sparticules à 1 TeV

Messagers dans  $5 - 5$  de  $SU(5)$ 

Choisir

- \* le groupe d'unification
- \* la représentation des messagers
- \* le mécanisme de brisure (Higgs)

$$SU(5)$$

$$\Phi \Phi = 5 \ 5$$

$$\Sigma = 24 = \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & 2 & \\ & & & & -3 & -3 \end{pmatrix}$$

Calculer

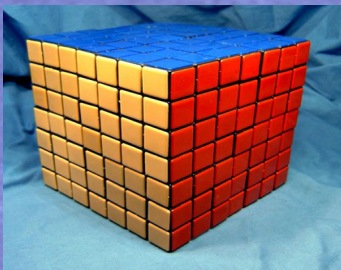
- \* les couplages possibles entre Higgs et messagers
- \* les masses des messagers
- \* les masses des sparticules dans l'UV
- \* les masses des sparticules à 1 TeV

$$W = \lambda_{\Sigma} \Phi \Sigma \Phi$$

$$M_T = 2\lambda_{\Sigma} v_{\Sigma}$$

$$M_D = -3\lambda_{\Sigma} v$$

$$M_1 = 0$$

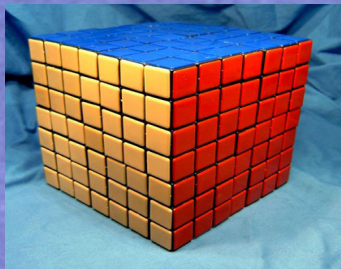


Messagers dans  $5 - 5$  de  $SU(5)$ 

$$M_1 = N_m \frac{\alpha}{4\pi} \sum \frac{Y^2}{M_i} F$$

$$M_1 = N_m \frac{\alpha}{4\pi} \sum \frac{Y^2}{Y} F$$

$$M_1 \sim \text{tr} Y = 0$$



$$SU(5)$$

$$\Phi\Phi=5 \ 5$$

$$\Sigma = 24 = \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix}$$

$$W = \lambda_\Sigma \Phi \Sigma \Phi$$

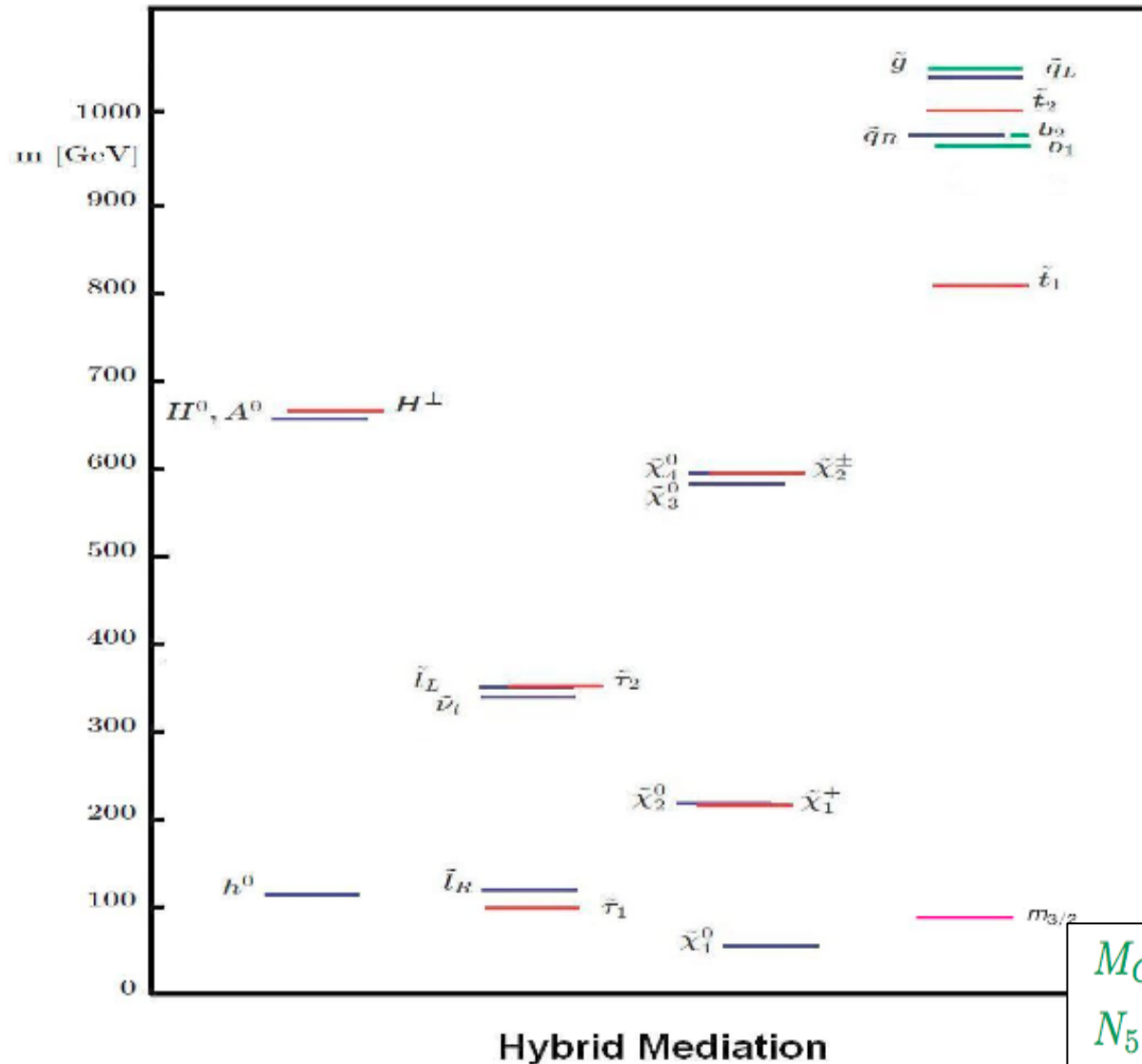
$$M_T = 2\lambda_\Sigma v_\Sigma$$

$$M_D = -3\lambda_\Sigma v$$

$$M_1 = 0$$



## Messagers dans 5 – 5 de SU(5)



Matière noire:  
OK pour 40 GeV

Inférieure aux  
limites usuelles

$M_{GM} = 160 \text{ GeV}$ ,  $M_1 = m_{3/2} = 85 \text{ GeV}$ ,  
 $N_5 = 3$ ,  $N_{10} = 1$ ,  $\tan \beta = 15$ ,  $\mu > 0$

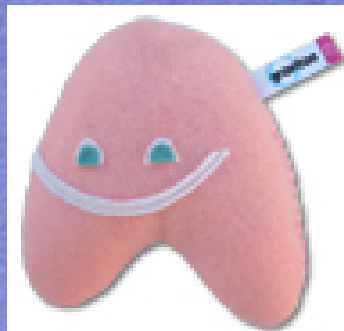
Messagers dans  $5 - 5$  de  $SU(5)$ 

D'habitude



Gravitino Neutralino

Ici,



Neutralino

Gravitino

 $SU(5)$   
 $\Phi\Phi=5\ 5$ 

$$\Sigma = 24 = \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & 2 & \\ & & & & -3 & -3 \end{pmatrix}$$

$$W = \lambda_{\Sigma} \Phi \Sigma \Phi$$

$$M_T = 2\lambda_{\Sigma} v_{\Sigma}$$

$$M_D = -3\lambda_{\Sigma} v_{\Sigma}$$

$$M_1 = 0$$

## SO(10)

Quelques notions sur SO(10):

Higgs :  $54, 45 \sim B-L, 45 \sim T_{3R}$

Messagers :  $10 \times 10 = 1 + 45 + 54$

$16 \times \overline{16} = 1 + 45 + 210$

$54 \ 10 \ 10$

$45 \ B-L \ 10 \ 10'$

$45 \ T_{3R} \ 10 \ 10'$

$45 \ B-L \ 16 \ \overline{16}$

$45 \ T_{3R} \ 16 \ \overline{16}$

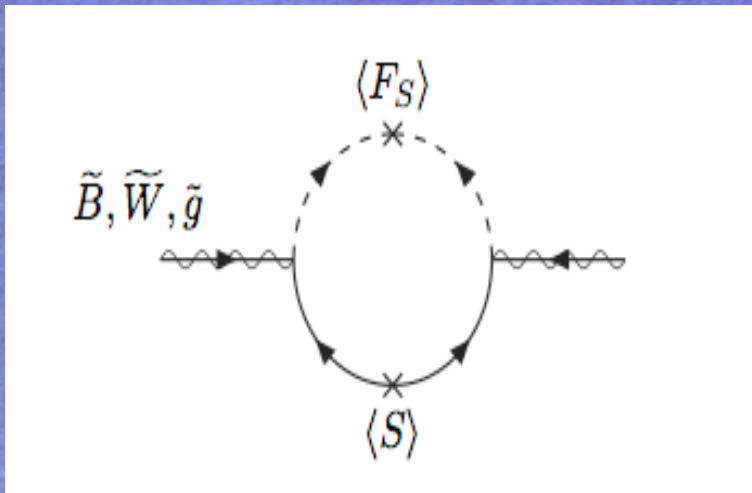
Messagers dans 10 10' de  $SO(10)$ , Higgs = 45  $\sim T_{3R}$

$$SO(10) \rightarrow SU(3) \times SU(2)_L \times SU(2)_R$$

$$10 = (3, 2, 1) + (1, 2, 2)$$

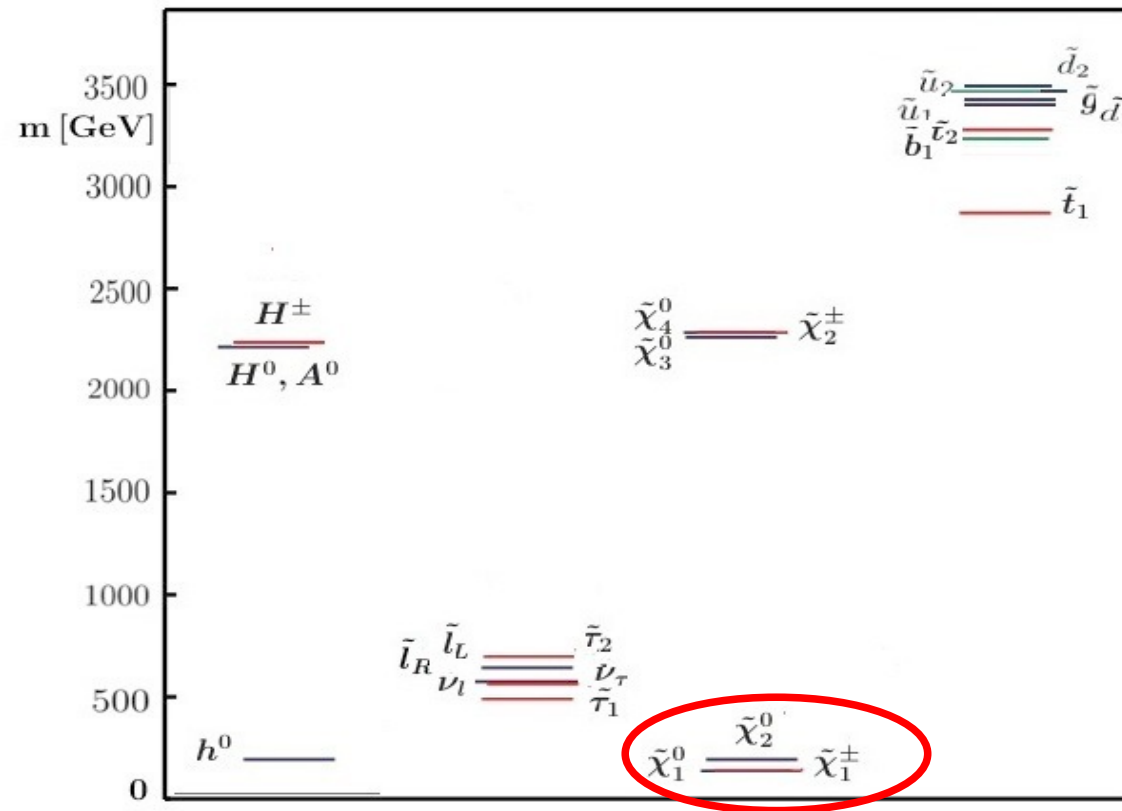
$$M_T \ll M_D \sim v_{45}$$

$$M_2 \ll M_1, M_3$$



Wino NLSP

Messagers dans 10-10' de SO(10), Higgs = 45  $\sim$  T<sub>3R</sub>



$M_{GM} = 775 \text{ GeV}, V_R = 6X_0, \tan \beta = 20, \mu > 0$

Messagers dans 10-10' de SO(10), Higgs = 45 ~ T<sub>3R</sub>

D'habitude



Gravitino



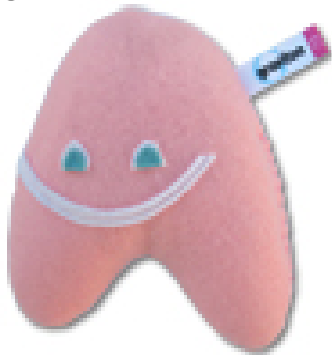
Neutralino



Wino



Ici



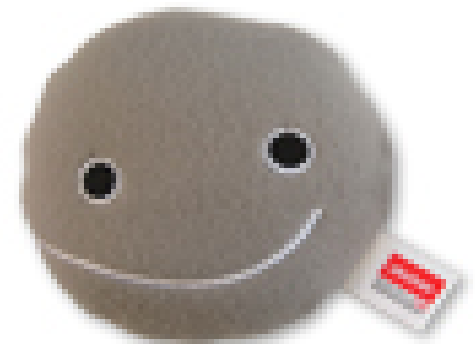
Gravitino



Wino



Neutralino



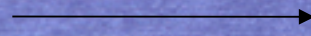
## Messagers dans 16-16 de SO(10), Higgs = 45 ~ B-L

Un résultat remarquable:

$$M_a(\mu) = \frac{\alpha_a(\mu)}{4\pi} \sum_i 2T_a(R_i) \frac{\lambda_X F_X}{M_i}$$

$$M_3 = \frac{\alpha_3}{4\pi} \frac{\lambda_X F_X}{\lambda_{45} V_{B-L}} \left( 2 \times \frac{1}{1/3} + \frac{1}{-1/3} + \frac{1}{-1/3} \right) = 0$$

$$M_3 \ll M_2, M_1$$



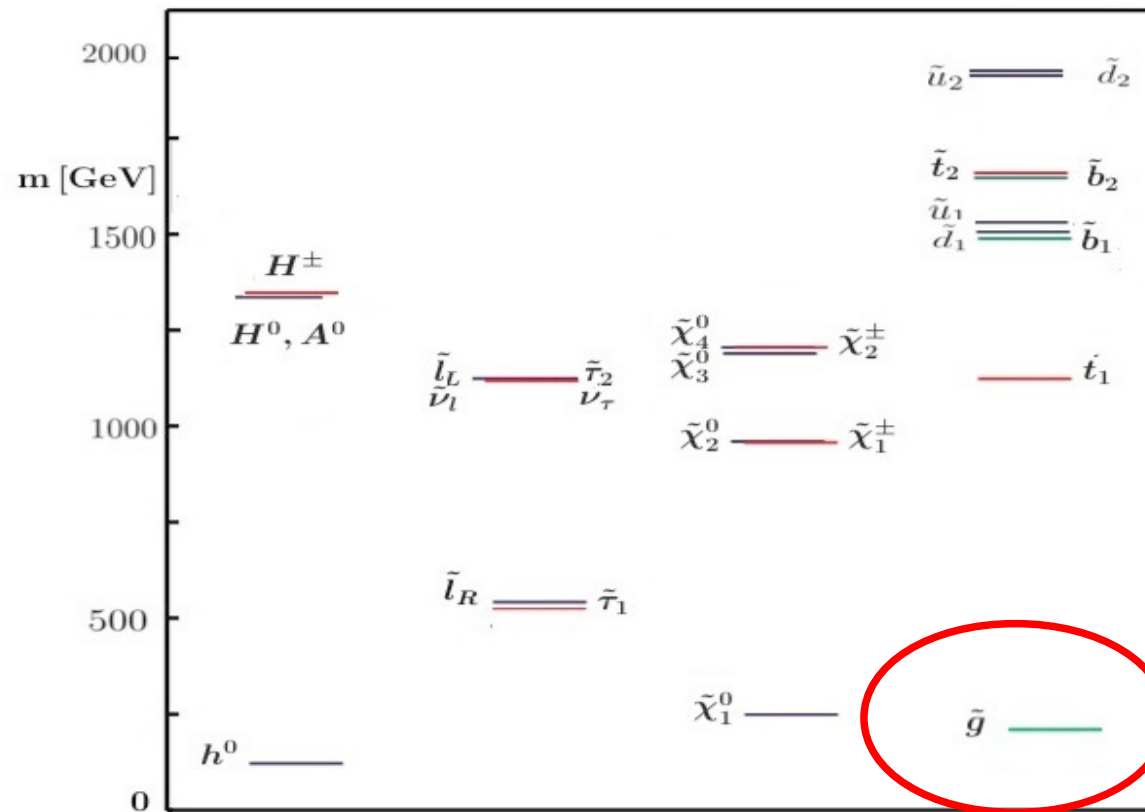
Glino NLSP



$$1/\tau_{\tilde{g}} \approx \frac{m_{\tilde{g}}^5}{48\pi(m_{3/2}M_P)^2} \implies \tau_{\tilde{g}} \sim 10^7 \text{ s for } m_{\tilde{g}} \sim 250 \text{ GeV}$$

( $M_3 = m_{3/2}$ )

## Messagers dans 16- 16 de SO(10), Higgs = 45 ~ B-L

**16\* - 45 (B-L) - 16**

$M_{GM} = 150 \text{ GeV}, M_3 = m_{3/2} = 60 \text{ GeV}, \tan \beta = 20, \mu > 0$



Messagers dans 16- 16 de SO(10), Higgs = 45 ~ B-L

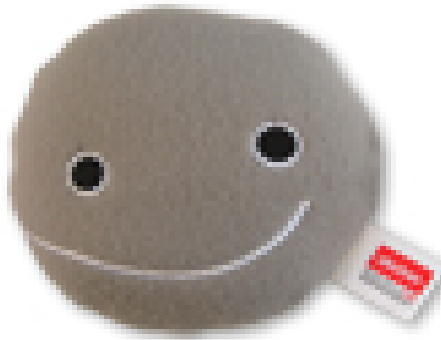
D'habitude



Gravitino

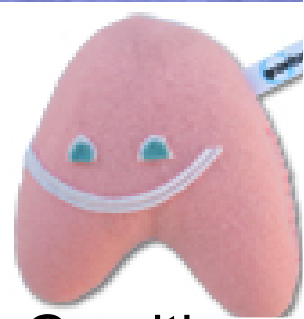


Neutralino



Gluino

Ici



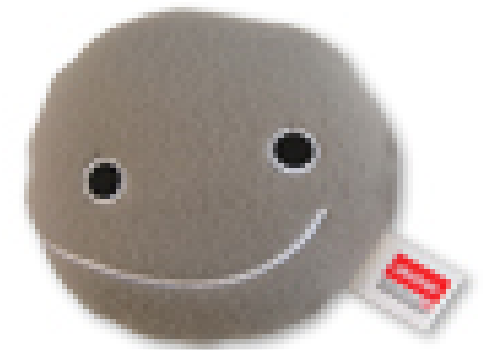
Gravitino



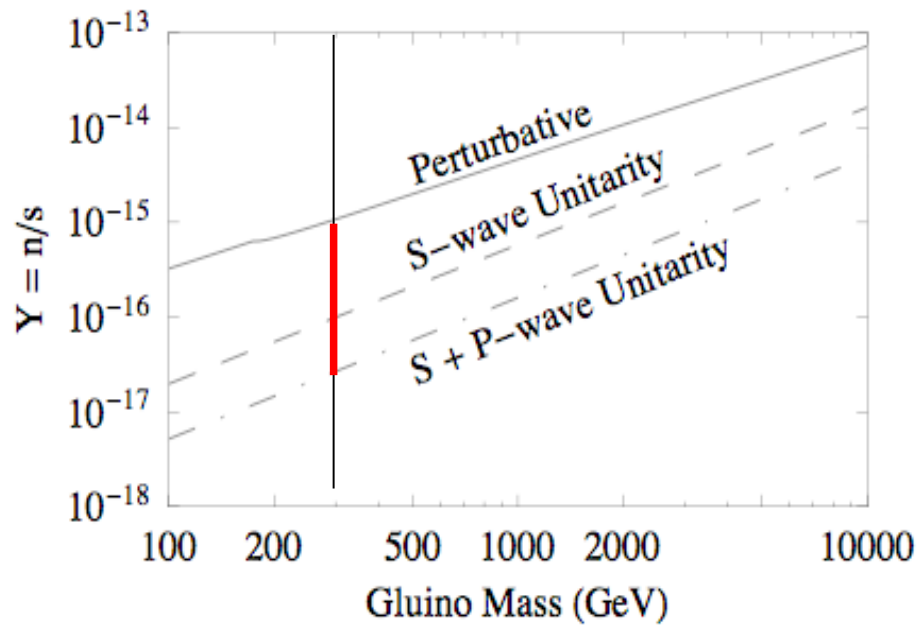
Gluino



Neutralino

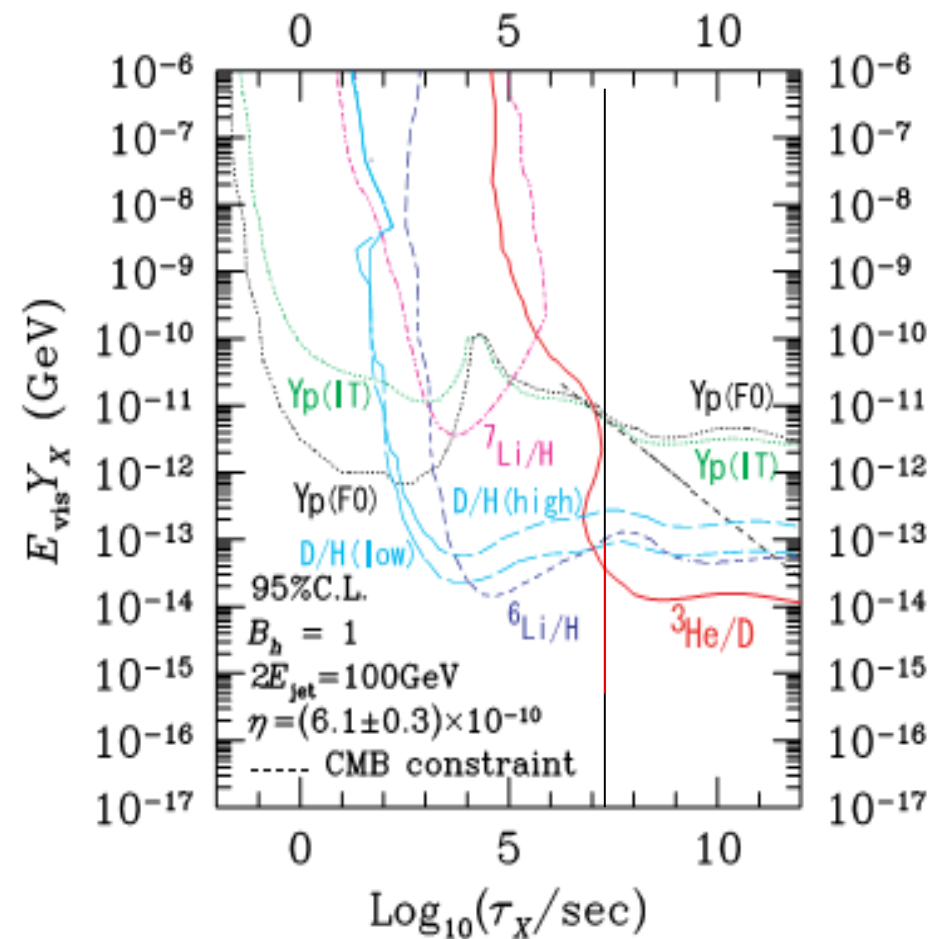


## BBN



hep-ph/0504210

BBN ok



astro-ph/0408426

Rajouter GUT à un scénario de médiation de jauge classique



- \* Prédicativité
- \* Spectres atypiques

$$\frac{M_1}{\alpha_1} = \frac{M_2}{\alpha_2} = \frac{M_3}{\alpha_3} \neq 1:1:1$$



Possiblement neutralino LSP et gluino NLSP  
comme signature

Si jamais  
vous voyez SUSY...



Si jamais  
vous voyez SUSY...

Appelez moi !



*The End*