SLOOPS
PRECISE CALCULATIONS IN SUSY FOR COLLIDER AND DARK MATTER

BARO Nans

BOUDJEMA Fawzi, SEMENOV Andrei

LAPTH

Rencontre de Physique des Particules

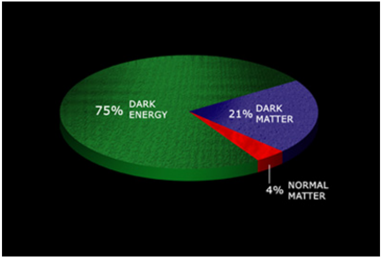
Observations

Modèle Standard

- Hierarchy problem
- WMAP +... $\longrightarrow$ Dark Matter

Experiments

- Future colliders (LHC, ILC)
- Cosmology (Planck, SNAP)



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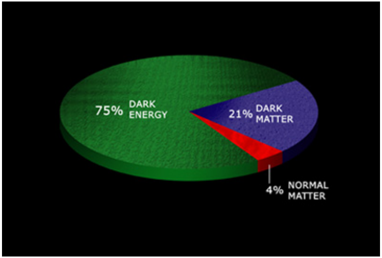

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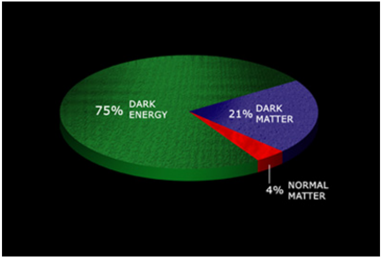
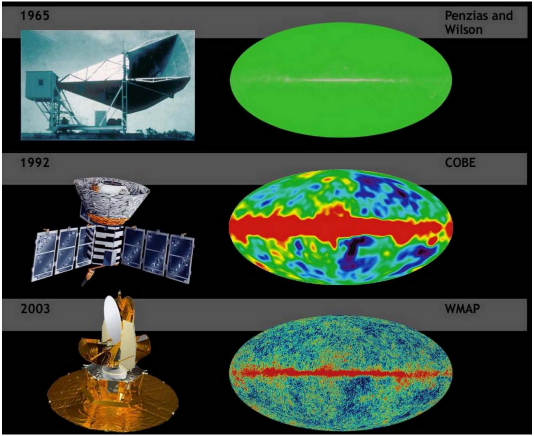


New Physics

Cosmic Microwave Background



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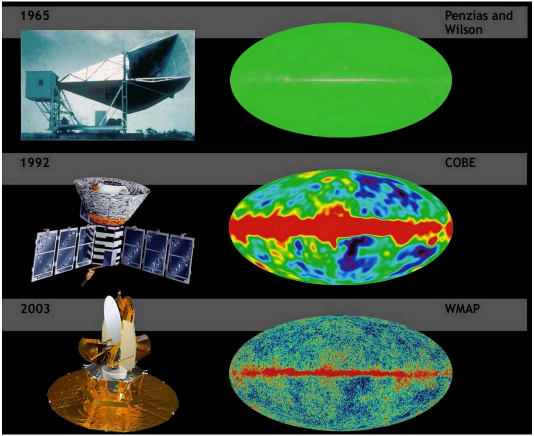

Era of precision measurement

Relic density of Dark Matter

$0.094 < \Omega_{DM} h^2 < 0.129$ Precision 10% $\rightarrow$ 2%!

Cosmology + Particle physics

$$\Omega_{DM} h^2 \propto \frac{1}{< \sigma(\chi^0 \chi^0 \rightarrow SM) v >}$$

Precision

Need to know precisely σ

$\Rightarrow$ Radiative corrections

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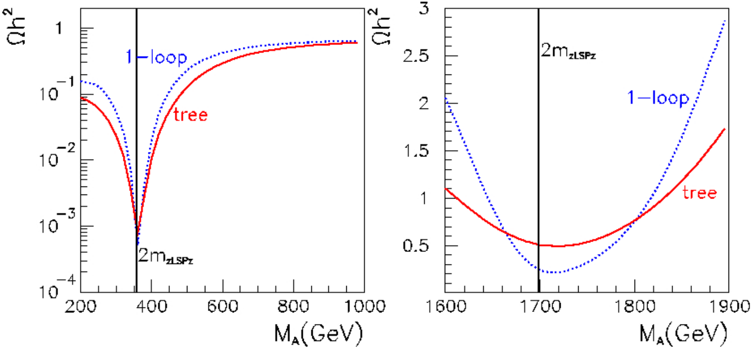

EXCLUSION OF MODELS

Have to take into account at least the one-loop corrections

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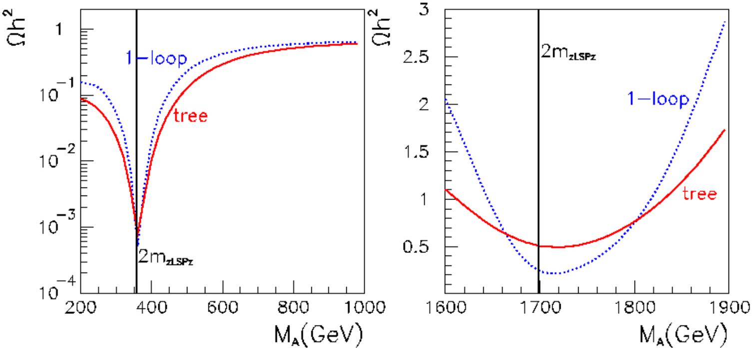

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Minimal Supersymmetric Standard Model

Example of physics Beyond Standard Model

- Fermion/Boson symmetry
- Hierarchy problem
- Unification of coupling
- Good candidate for Dark Matter: Neutralino χ^0

A lot parameters ($\sim$100 without CP violation)

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SECTORS OF THE MSSM (ELECTROWEAK)

Fermion sector	f
Gauge sector	γ, Z^0, $W^\pm$
Higgs sector	H^0, h^0, A^0, $H^\pm$
Sfermion sector	$\tilde{f}$
Chargino/neutralino sector	$\chi_i^\pm$, χ_i^0

A lot of vertices! ($\sim$ 5000)

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→ Automatic tools

A code for the calculation of loops diagrams in the MSSM with application to collider physics, astrophysics and cosmology

Complete and coherent renormalization of the MSSM

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Code

LanHEP

Lagrangian
Particles
Renormalization scheme

FeynArts-FormCalc

Mass corrections
Decays
Cross sections

Features of the code

- Flexibility (between renormalization schemes)
- Non linear gauge fixing

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Gauge Fixing

$$
\begin{aligned}
\mathcal{L}^{GF} &= -\frac{1}{\xi_W}|\partial_\mu W^{\mu+} + i\xi_W \frac{g}{2} v G^+|^2 \\
&- \frac{1}{2\xi_Z}(\partial_\mu Z^\mu + \xi_Z \frac{g}{2c_W} v G^0)^2 - \frac{1}{2\xi_A}(\partial_\mu A^\mu)^2
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$\xi = 1$ (loop library)

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Non Linear Gauge Fixing

$$
\begin{aligned}
\mathcal{L}^{GF} &= -\frac{1}{\xi_W}|(\partial_\mu - ie\tilde{\alpha}A_\mu - igc_W\tilde{\beta}Z_\mu)W^{\mu+} \\
&+ i\xi_W\frac{g}{2}(v + \tilde{\delta}h^0 + \tilde{\omega}H^0 + i\tilde{\kappa}G^0 + i\tilde{\rho}A^0)G^+|^2 \\
&- \frac{1}{2\xi_Z}(\partial_\mu Z^\mu + \xi_Z\frac{g}{2c_W}(v + \tilde{\epsilon}h^0 + \tilde{\gamma}H^0)G^0)^2 - \frac{1}{2\xi_A}(\partial_\mu A^\mu)^2
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Non linear

Non linear gauge introduces some modifications in the *WI*

$$
\begin{aligned}
& m_A^2 \times A^0 \dashrightarrow \circlearrowleft \dashrightarrow Z^0 + m_Z \times A^0 \dashrightarrow \circlearrowleft \dashrightarrow G^0 \\
= \quad & -(m_A^2 - m_Z^2)\frac{ie}{s_{2W}}[\tilde{\epsilon} \times \circlearrowleft^{G^0}_{h^0} \dashrightarrow A^0 + \tilde{\gamma} \times \circlearrowleft^{G^0}_{H^0} \dashrightarrow A^0] \\
\neq \quad & 0!
\end{aligned}
$$

Check

At Tree Level

Comparison with public codes: `Grace` and `CompHEP`

At one-loop

Physical results

- UV finite
- IR finite
- Gauge independent

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t_β doesn't represent a physical/measurable quantity

Sum rules

$$\delta m^2_{H^0} + \delta m^2_{h^0} = \delta m^2_A + \delta m^2_Z + \delta m^2_{G^0}$$
$$\delta m^2_{H^\pm} = \delta m^2_A + \delta m^2_W$$

"Usual" scheme

m_{A^0}, $t_\beta \to m_{H^\pm}, m_{h^0}, m_{H^0}$

SloopS scheme

$m_A, m_{H^0} \to m_{H^\pm}, m_{h^0}$

RENORMALIZATION OF " $\tan\beta$" $= \frac{v_2}{v_1}$ *(Higgs sector)*

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SLOOPS SCHEME

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SloopS scheme

$m_A, m_{H^0} \rightarrow m_{H^\pm}, m_{h^0}$

$\delta \tan\beta$

$$\frac{\delta t_\beta}{t_\beta}^{\text{OS}} = \frac{1}{s_{2\beta} s_{2(\alpha-\beta)} M_{A^0}^2}\Big[\frac{g}{2M_W}\big(c_{\alpha-\beta}(1+s_{\alpha-\beta}^2)\delta T_{H^0} + s_{\alpha-\beta} c_{\alpha-\beta}^2 \delta T_{h^0}\big) + Re\Sigma_{H^0 H^0}(M_{H^0}^2) - s_{\alpha-\beta}^2 Re\Sigma_{A^0 A^0}(M_A^2) - c_{\alpha+\beta}^2 Re\Sigma_{ZZ}(M_Z^2)\Big]$$

$$\frac{\delta t_\beta}{t_\beta}^{\text{DCPR}} = -\frac{1}{M_Z s_{2\beta}} Re\Sigma_{A^0 Z}(M_A^2)$$

$$\frac{\delta t_\beta}{t_\beta}^{\overline{\text{DR}}} = \frac{1}{2c_{2\alpha}}\left(Re\Sigma'_{h^0 h^0}(M_{h^0}^2) - Re\Sigma'_{H^0 H^0}(M_{H^0}^2)\right)^{\text{div}}$$

nlgs	0	1	10
OS	-9.87	-9.87	-9.87
DCPR	-9.87	-13.80	-49.18
$\overline{\text{DR}}$	-9.87	-7.40	14.78

$\propto \infty$ of δt_β

OS	94.76	41.82	0.65
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Δm_{h^0}

$\delta \tan \beta$

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Δm_{h^0}

Decoupling

$\sqrt{s} = 200$ GeV

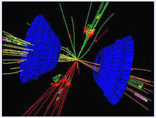
M_S (GeV)	10^2	10^3	10^4
$\nu_e \nu_e \to ZZ$			
SM	21.5549	21.5565	21.5567
MSSM	21.0751	21.5488	21.5566
$\nu_e \nu_e \to \nu_\mu \nu_\mu$			
SM	20.8221	20.8261	20.8265
MSSM	20.1975	20.8185	20.8264
$e^+ e^- \to W^+ W^-$			
SM	25.0832	25.0868	25.0872
MSSM	24.5006	25.0768	25.0871

Applications & Tests

Mass correction

- $H^\pm$, h^0
- $\tilde{b}_2$ (Hollik and Rzehak *hep-ph/0305328*)
- χ_2^0, χ_3^0, χ_4^0 (Fritzsche and Hollik *hep-ph/0203159*)

Colliders



- Decays: $\chi_i^0 \to \chi_j^0 Z^0, H^0 Z^0$
- Cross sections: $e^+e^- \to$ ...
- Collaboration with the `Grace` group

$m_A = 150$ GeV, $M_2 = 200$ GeV, $A_f = M_{\tilde{f}R} = M_{\tilde{F}L} = 300$ GeV

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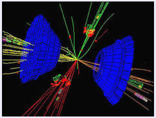

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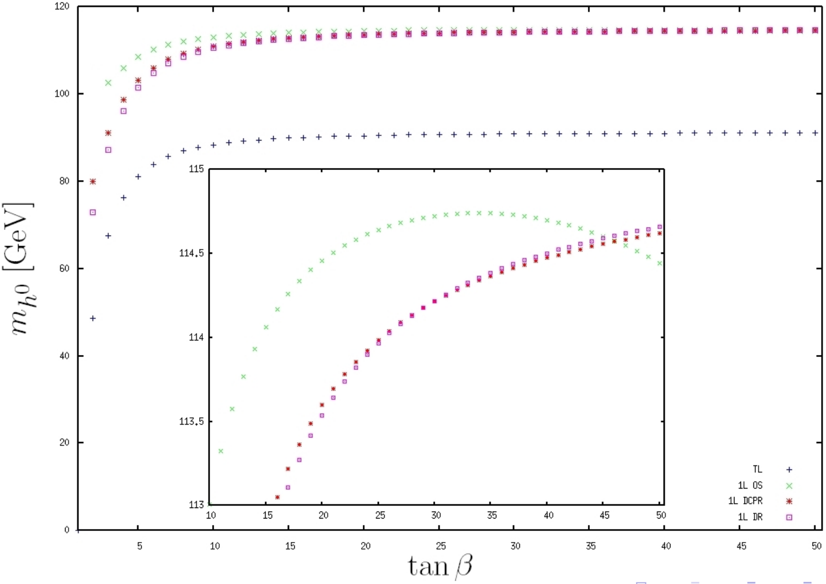

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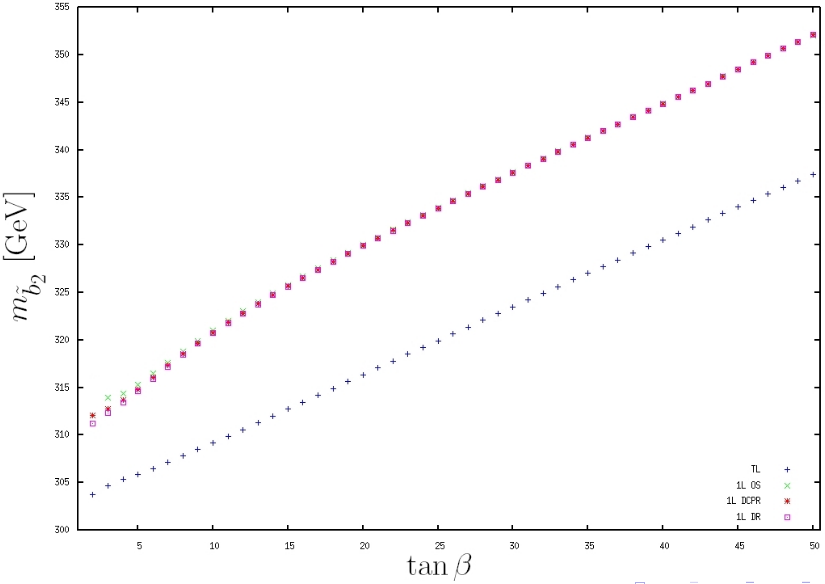

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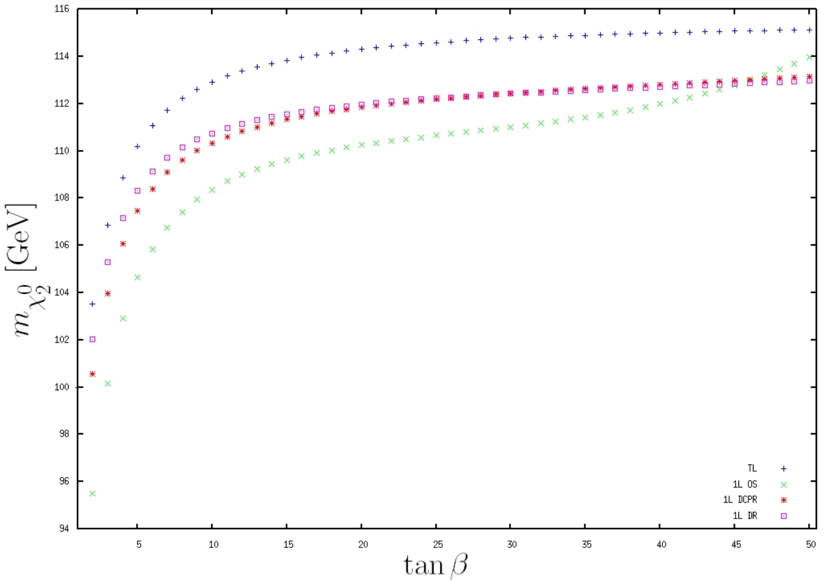

CONCLUSION

- Complete renormalization of the MSSM
- Processus 1 $\longrightarrow$ 2, 2 $\longrightarrow$ 2
- Need more tests
- Application to neutralino Dark Matter very soon
- Others models...