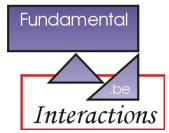
Introduction to the JJC session: Physics Beyond the Standard Model

Laura Lopez Honorez

Service de Physique Théorique
Université Libre de Bruxelles

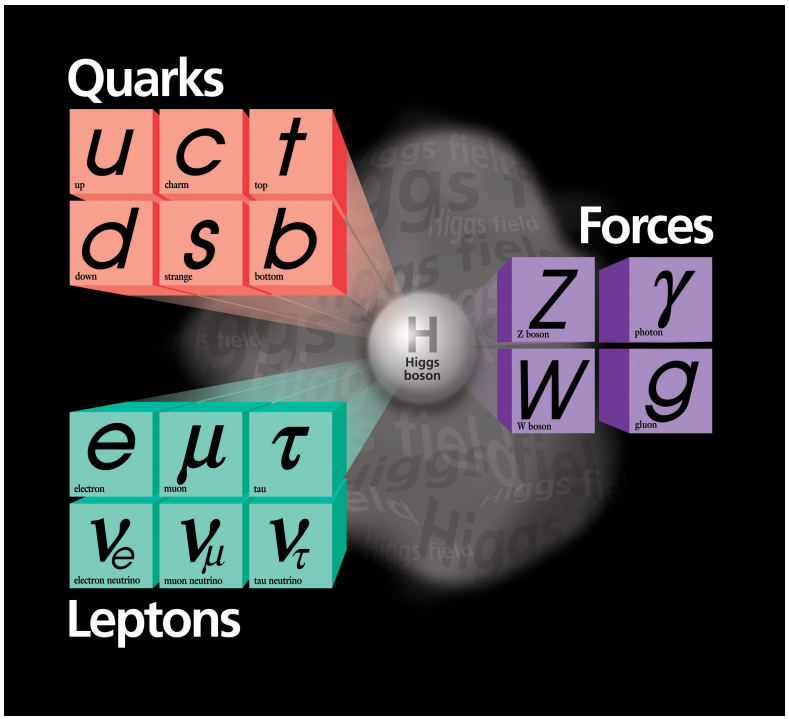


Journées Jeunes Chercheurs 2010 - Angers

The Standard Model of particle physics

...a theory for the electromagnetic, weak, and strong interactions

Particle Content



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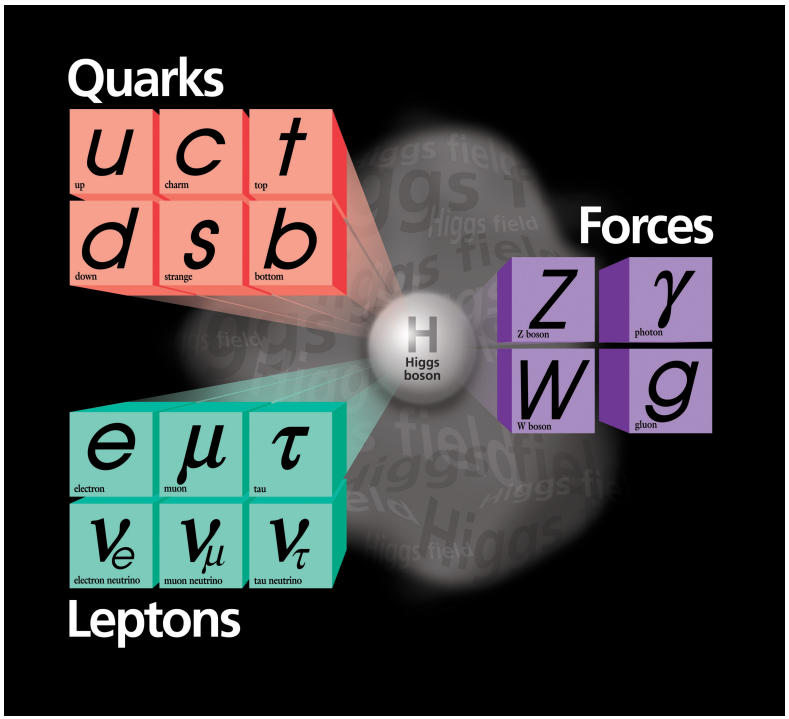

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- 4 types of gauge interaction mediators
- H Brout-Englert-Higgs boson ? ? ?

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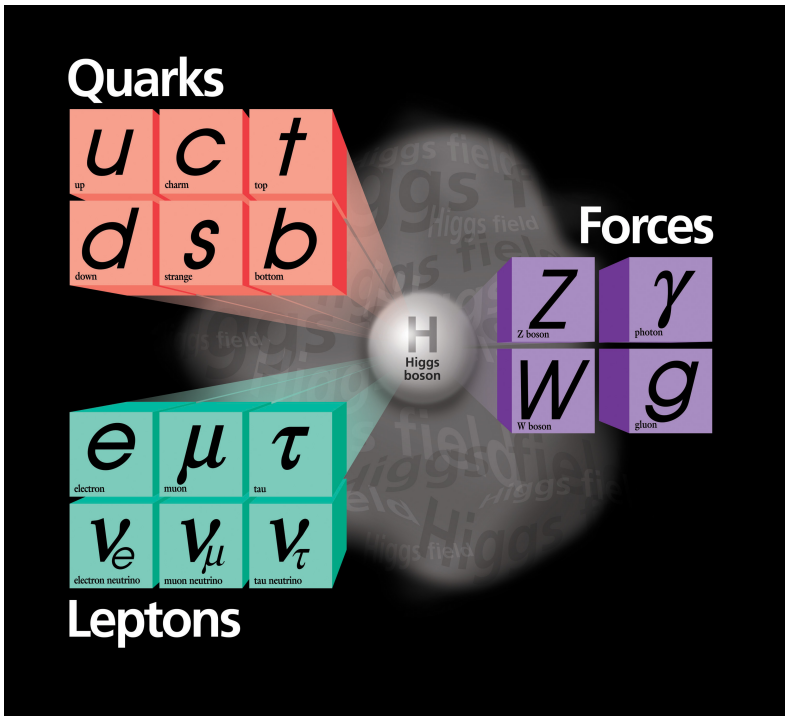

- 3 families of quark and leptons
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- symmetries : $SU(3)_C \times SU(2)_L \times U(1)_Y$

	$SU(3)_C, SU(2)_L, U(1)_Y$	chir
Q	$(3, 2, +1/6)$	L
u	$(3, 1, +2/3)$	R
d	$(3, 1, -1/3)$	R
L	$(1, 2, -1/2)$	L
e	$(1, 1, -1)$	R
H	$(1, 2, -1/2)$	-

$\rightsquigarrow$ weird quantum numbers, isn't it ?

Standard Model works well

Since its formulation in mid 70's :

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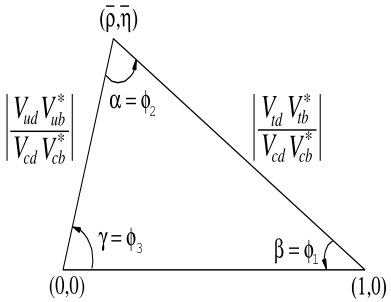
$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + \frac{V_{cd}V_{cb}^*}{V_{cd}V_{cb}^*} + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$



$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right], \quad \beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right], \quad \gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

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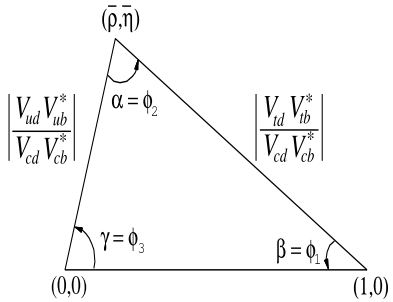

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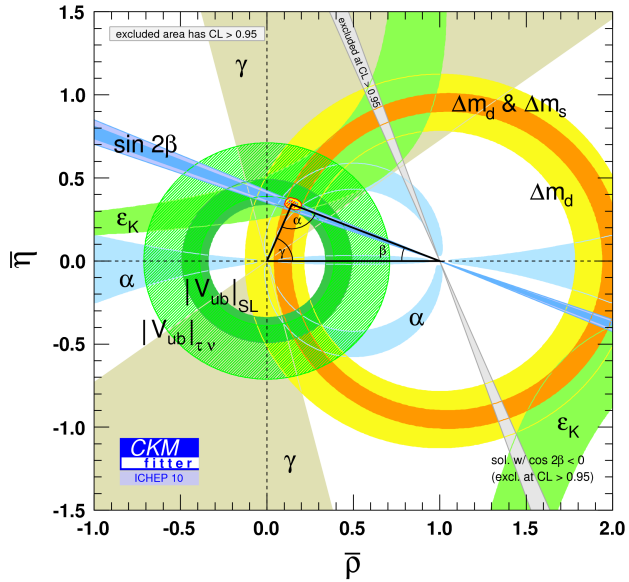

Several experiments overlap consistently in the 95% CL region

Is there still room for new physics ?

$\rightsquigarrow$ see Emilie talk on friday : study the $B_s \to J/\Psi\phi$

Also ...

- discovery of the ν_τ (2000)
- Successful in various experimental tests
  Comparing the fit of several electroweak measurements to their direct measurement
  $\rightsquigarrow$ good agreement

$\rightsquigarrow$ more, see SM session

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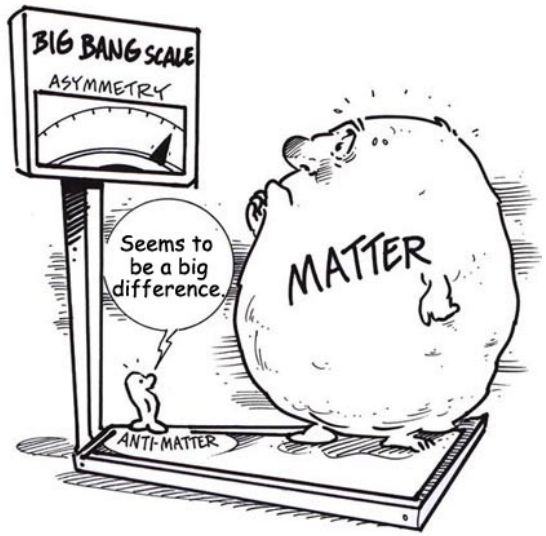

But what about...

- neutrino masses$\rightsquigarrow$ see neutrino session
  from neutrino oscillations we know that $\Delta m^2 \sim 10^{-3}$ and 10^{-5} eV^2.
- not enough CP violation for baryogenesis
  $\rightsquigarrow$ matter antimatter asymmetry ?

But what about...

- Dark matter Dark energy ?

Several sources converges for a universe made of 95% of unknown

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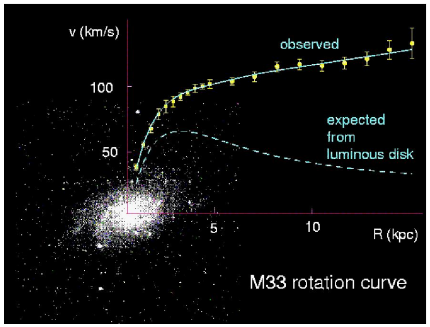

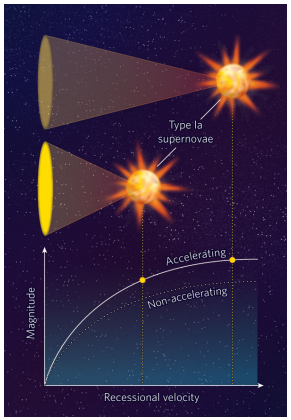

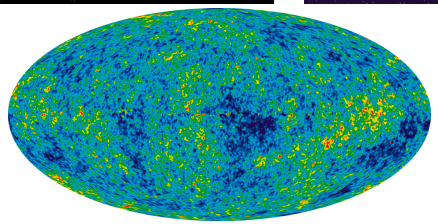

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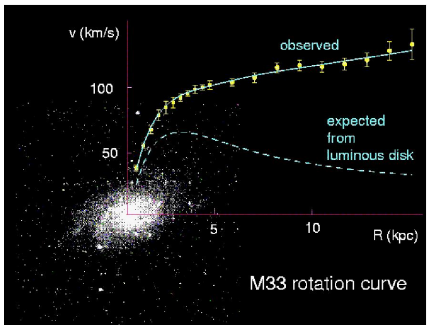

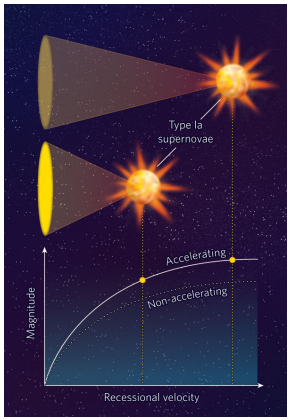

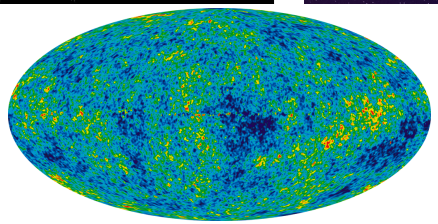

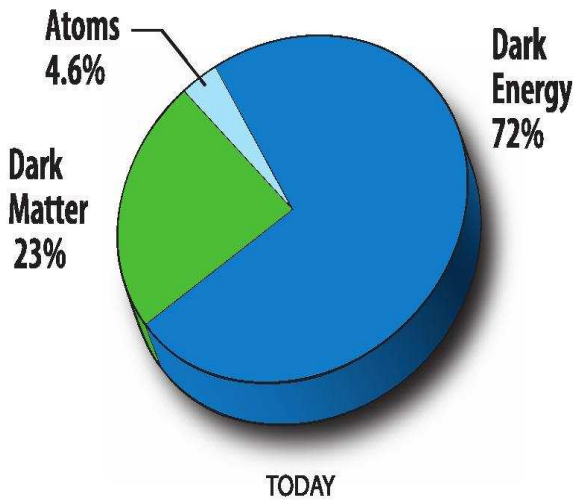

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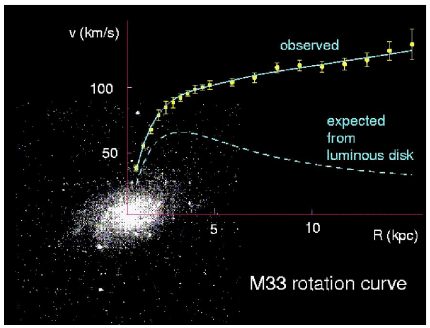

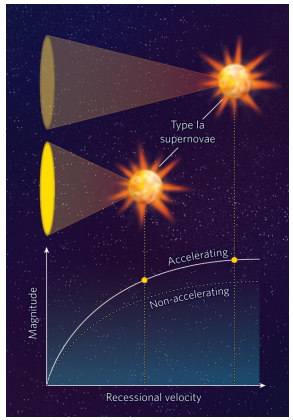

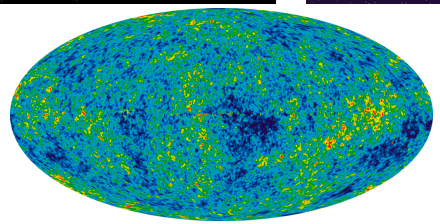

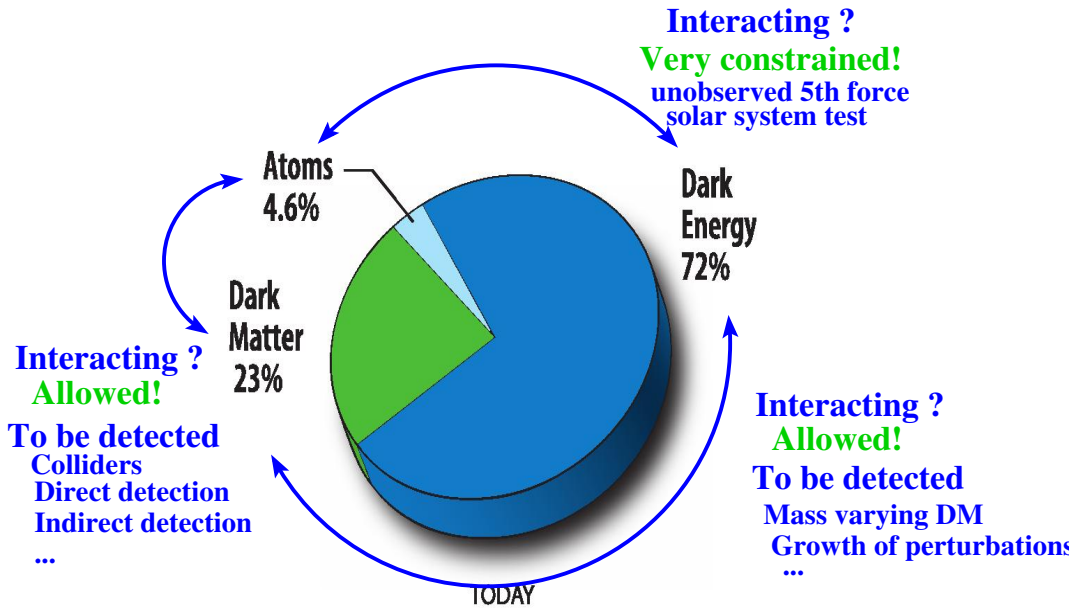

$\rightsquigarrow$ more, see Cosmo, Astroparticle session

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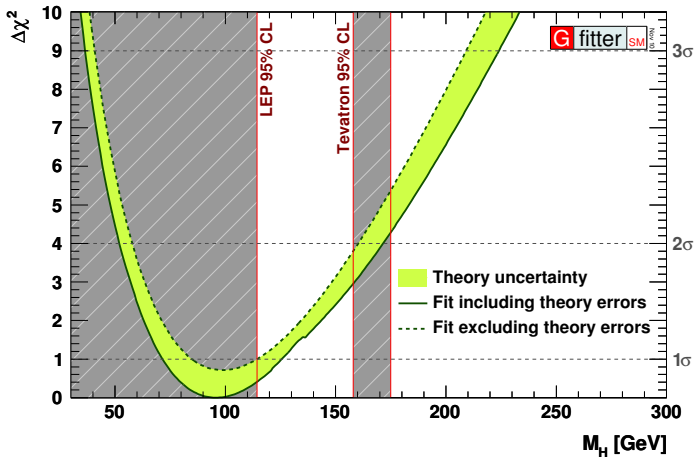
- Higgs particle ?
  - LEP searches $\rightsquigarrow M_H > 114.4$ GeV (95% CL)
  - Tevatron searches $\rightsquigarrow 158 < M_H < 175$ GeV excluded at (95% CL)
  - EW precision test within the SM $\rightsquigarrow M_H < 149$ GeV (95% CL)
  - get large radiative corrections : $\delta m_H \propto \Lambda^2$



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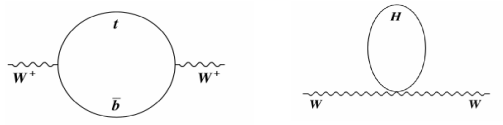
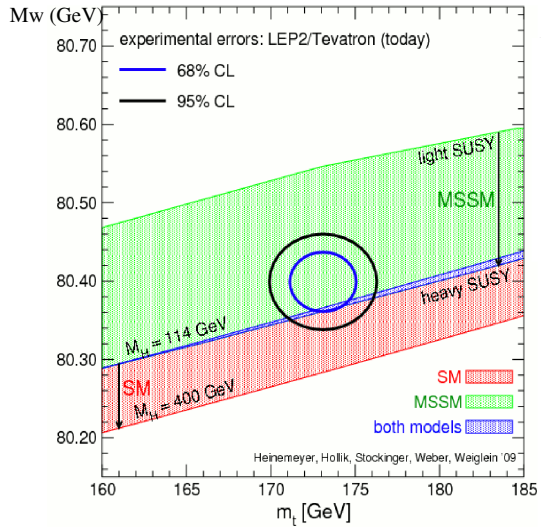
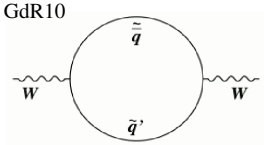
depend on M_t as ~M_t^2 and on M_H as ~log M_H





from J. Stark GdR10



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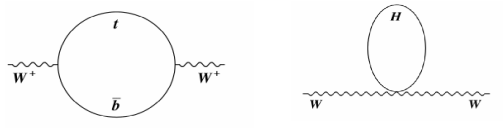

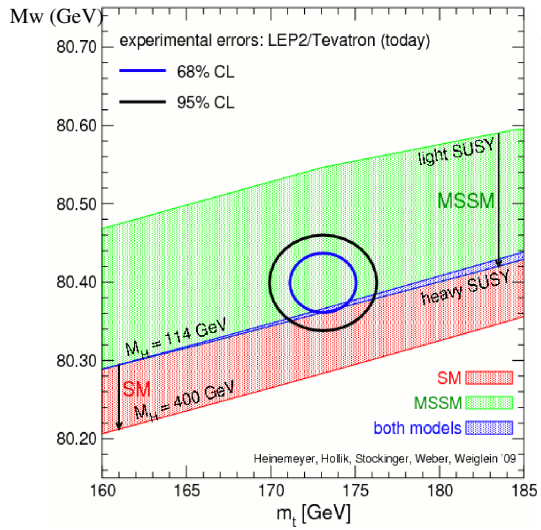

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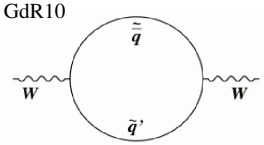

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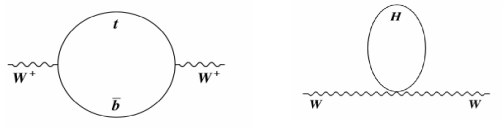

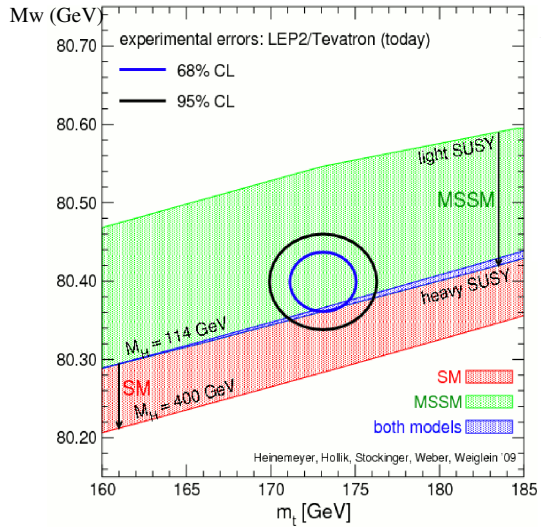

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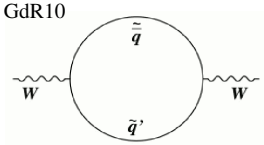

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- gravitation not included
- why 3 generations of particles not more ?
- ....

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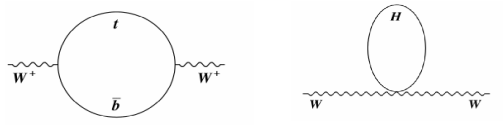

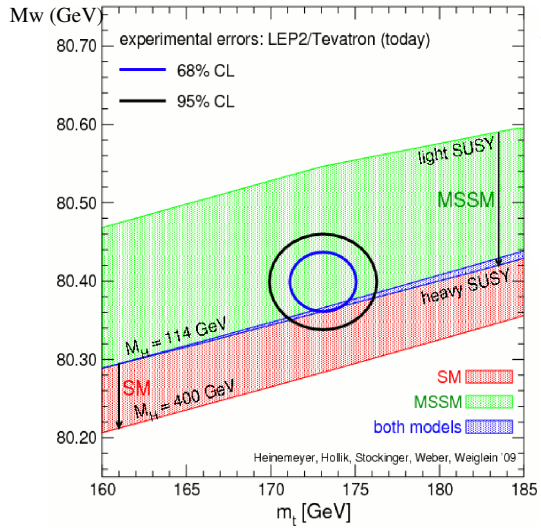

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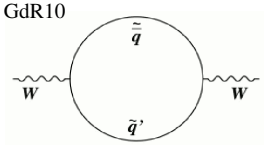
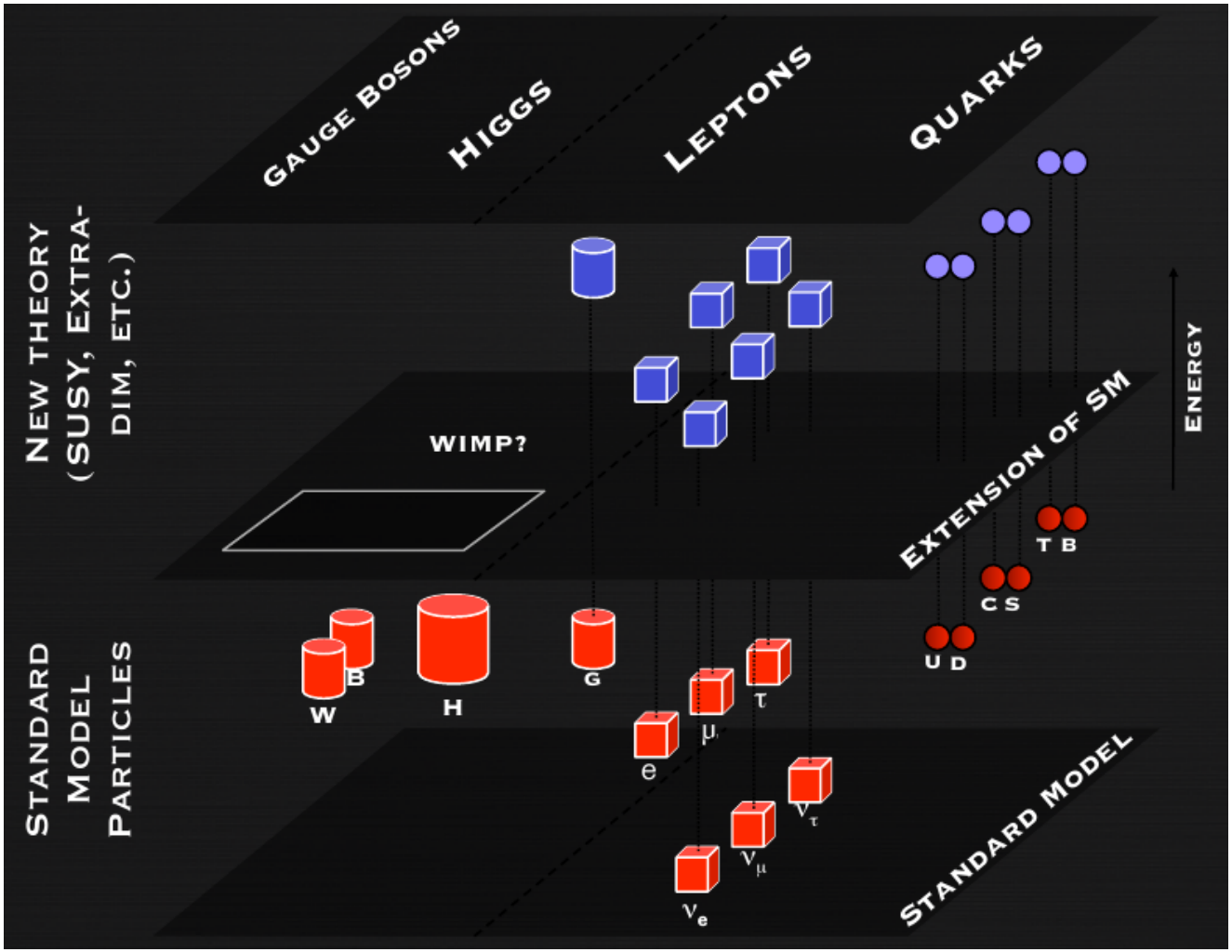


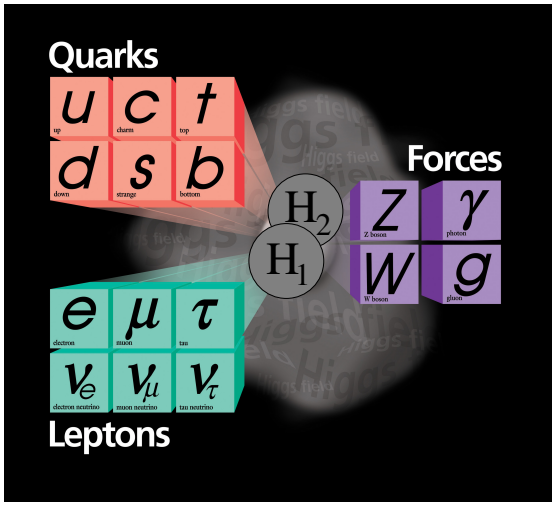
Extensions of the standard Model



courtesy to G. Bertone

Extensions of the standard Model
Bottom-Up approach

Bottom-Up approach : Let's add particles...



- A second Higgs doublet :

  2HDM are typical of e.g. supersymmetry
  $\rightsquigarrow$ pheno good to be understood
  $\rightsquigarrow$ see talk of Audrey and
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  today ! !

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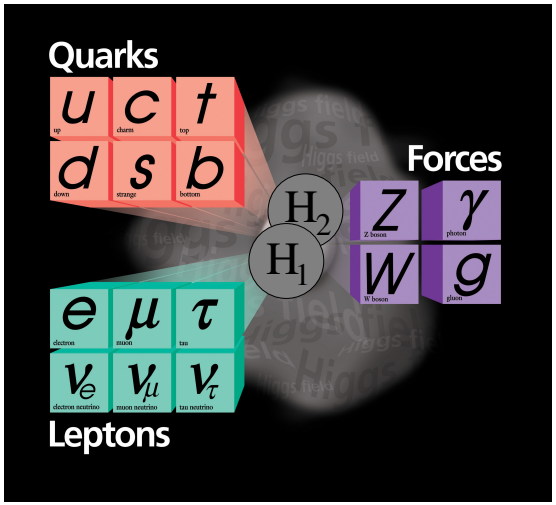

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- A Z_2 symmetry

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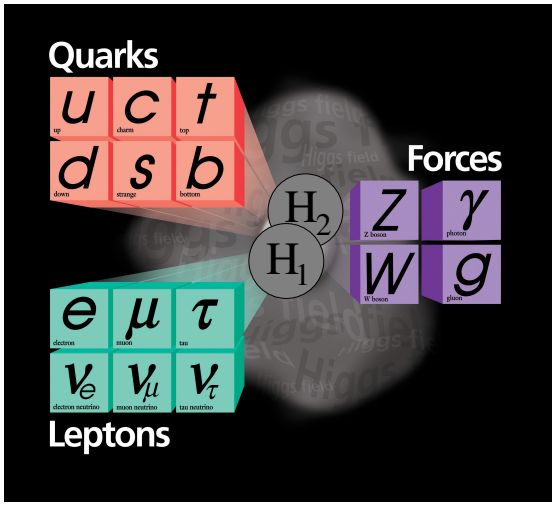

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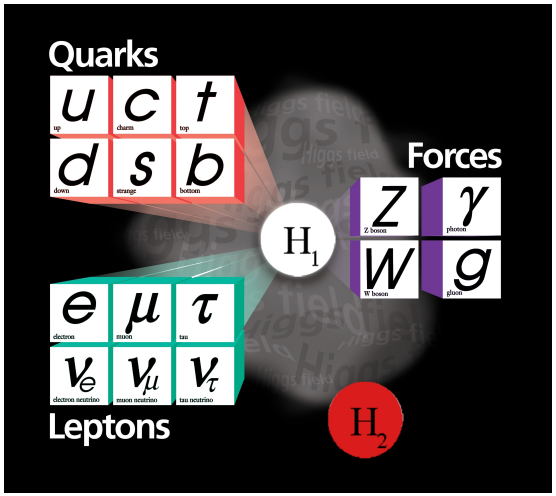

... & and symmetries

- A Z_2 symmetry
  - e.g. in a 2HDM : $H_2 \rightarrow -H_2$, $SM \rightarrow SM$
    $\rightsquigarrow$ great candidate for DM

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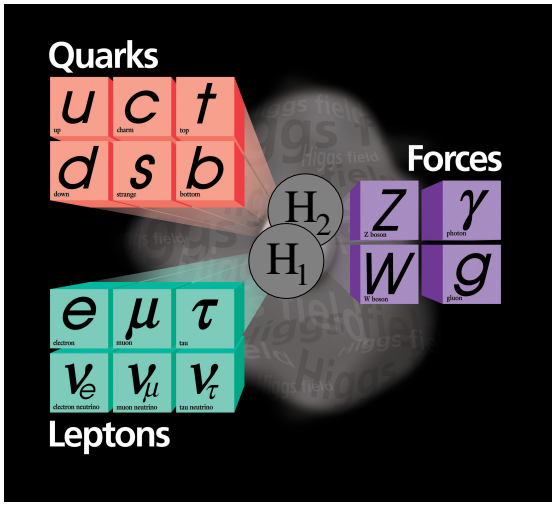

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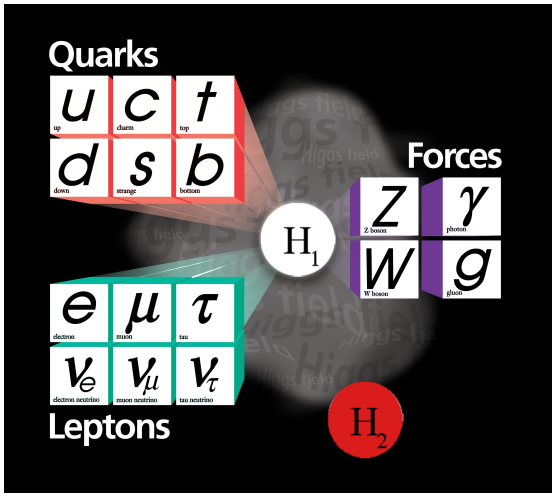

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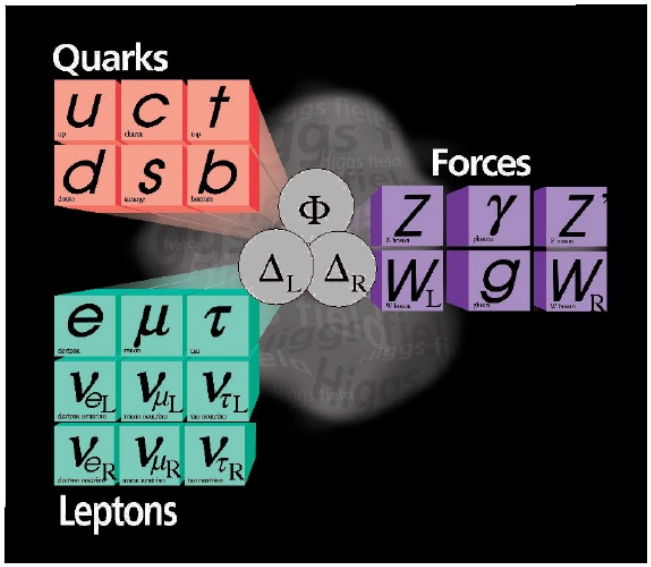
    $\rightsquigarrow$ great candidate for DM
  - necessary in SUSY to avoid rapid decay of the proton (R parity)

Bottom-Up approach : Let's add Particles & Symmetries

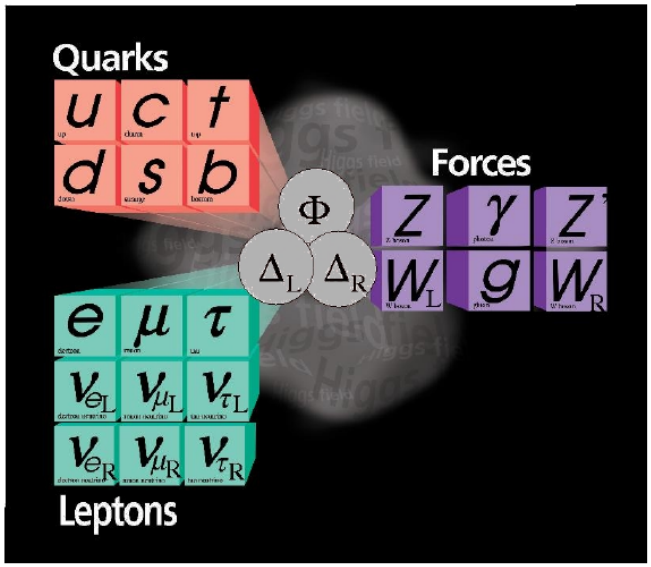
- L-R symmetry $SU(3)_c \times SU(2)_R \times SU(2)_L \times U(1)$
  (similar to those embedded in symmetry breaking patterns of GUT)

  - ν_R automatically presents,
    better for neutrino masses

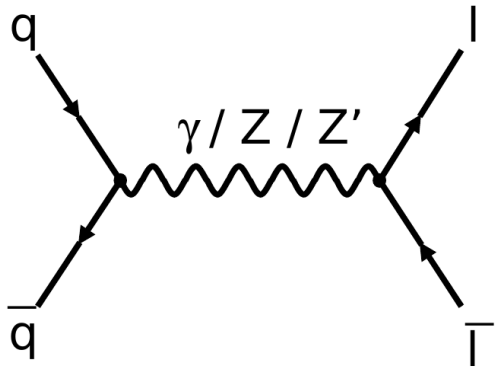


Bottom-Up approach : Let's add Particles & Symmetries

- L-R symmetry $SU(3)_c \times SU(2)_R \times SU(2)_L \times U(1)$
  (similar to those embedded in symmetry breaking patterns of GUT)



- ν_R automatically presents,
  better for neutrino masses
- Among the new physics involved :
  new gauge bosons of spin 1 Z'



$\rightsquigarrow$ prospects for detection at LHC :
see talks of Vincent today for CMS
and Ludovica for Atlas on friday

Extensions of the standard Model
Top-Down approach : Hierarchy and Unification

Top Down approach : Extra dimensions

Large Extra Dimensions : $R \gg 1/\,\text{TeV} = 10^{-17}$ cm
gravity propagate in the entire bulk
and SM fields stuck on a brane

- $r \ll R : V(r) = -\frac{m_1 m_2}{M_f^{N+2} r^{N+1}}$
- $r \gg R : V(r) = -\frac{m_1 m_2}{M_{pl}^2 r}$

$\rightsquigarrow$ Gravitation is feeble because ED are large

$$M_{pl}^2 = R^N M_f^{2+N}$$

for $M_f = \text{TeV}$, need at least $N = 3$

$R = 10^{15}$ cm $(N = 1)$, $R = 10^{-1}$ cm $(N = 2)$, $R = 10^{-6}$ cm $(N = 3)$.

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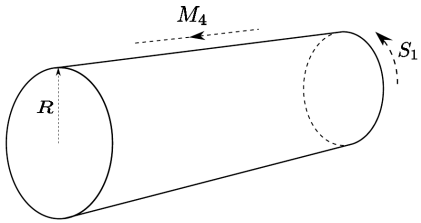

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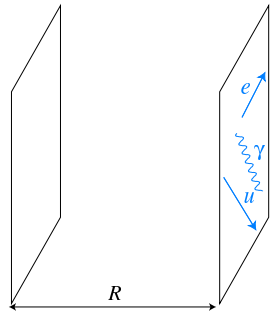

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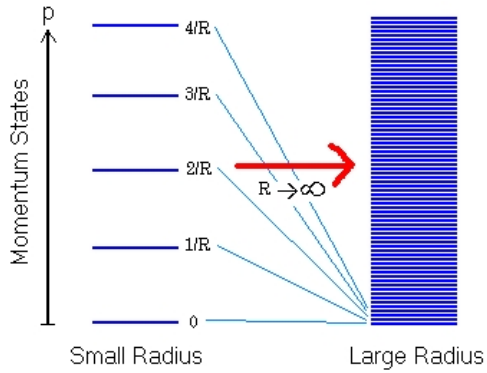
Kaluza Klein towers for $M^4 \times S_1$:
a free massless particle in the 5D space can be expanded : $\Phi(x^\mu, z) = \sum \phi_n(x^\mu) e^{inz/R}$

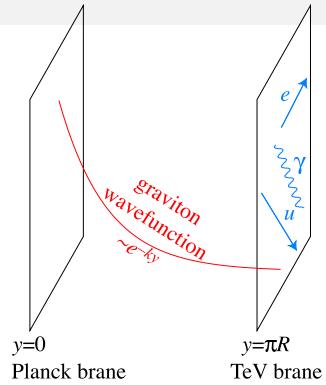


$\rightsquigarrow$ from the 4D point of view : tower of $\phi_n(x^\mu)$ with increasing mass $m_n^2 = p^\mu p_\mu = n^2/R^2$

Top Down approach : Extra dimensions

Small ED : Randall Sundrum, Warped extra dimensions

- metric $ds^2 = e^{-2ky}\ g_{\mu\nu}\ dx^\mu dx^\nu + dy^2$
  e^{-2ky} is the wrap factor decreasing along y at the origin of the hierarchy TeV-M_{pl} scale.



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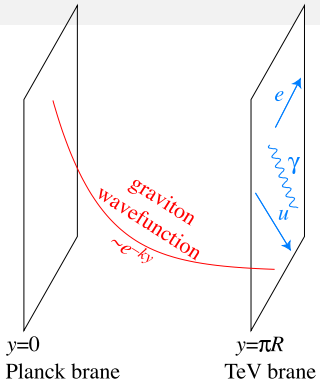

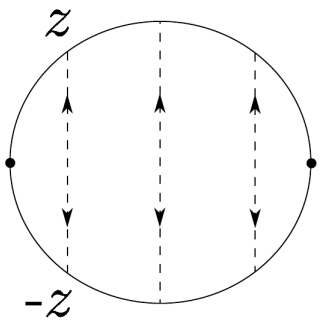

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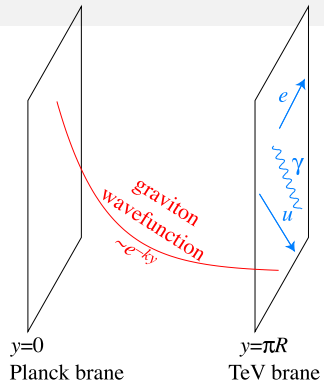

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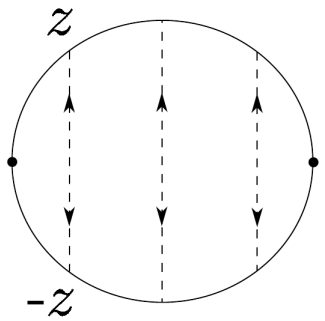
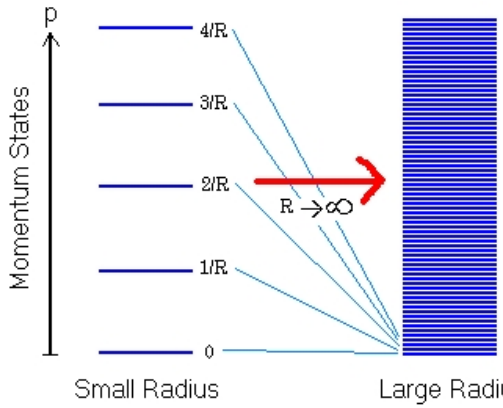


- We live on the brane at $y = \pi R$, a field of mass m_0 appear to have a physical mass $m(y) = e^{-ky} m_0$
  $\rightsquigarrow$ TeV mass scale $m(\pi R)$ is obtained from $m_0 = M_{pl}$ for $kR \sim \mathcal{O}(10)$
- no large hierarchies necessary all the mass scale are of the same order : $k, 1/R, \sim M_{pl}$
  small extra dimensions $R \sim 1/M_{pl} \sim 10^{-33}$cm
- new physics involved, see also talk of Vincent and Ludovica



Supersymmetry

- quadratic corrections to the Higgs mass (almost) cancel out if for each fermion we have a complex scalar with the same quantum numbers :

$$\Delta m_H \propto (-\lambda_f + \lambda_S)\Lambda^2$$

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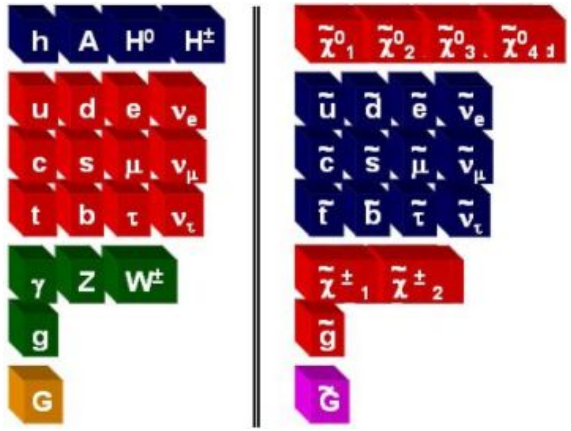
- Supersymmetry doubles the dof of the SM model

MSSM

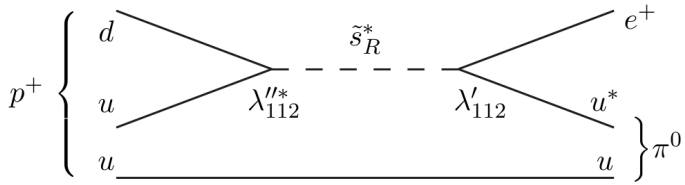
Standard Model particles and fields		Supersymmetric partners			
		Interaction eigenstates		Mass eigenstates	
Symbol	Name	Symbol	Name	Symbol	Name
$q = d, c, b, u, s, t$	quark	$\tilde{q}_L$, $\tilde{q}_R$	squark	$\tilde{q}_1$, $\tilde{q}_2$	squark
$l = e, \mu, \tau$	lepton	$\tilde{l}_L$, $\tilde{l}_R$	slepton	$\tilde{l}_1$, $\tilde{l}_2$	slepton
$\nu = \nu_e, \nu_\mu, \nu_\tau$	neutrino	$\tilde{\nu}$	sneutrino	$\tilde{\nu}$	sneutrino
g	gluon	$\tilde{g}$	gluino	$\tilde{g}$	gluino
$W^\pm$	W-boson	$\tilde{W}^\pm$	wino		
H^-	Higgs boson	$\tilde{H}_1^-$	higgsino	$\tilde{\chi}^\pm_{1,2}$	chargino
H^+	Higgs boson	$\tilde{H}_2^+$	higgsino		
B	B-field	$\tilde{B}$	bino		
W^3	W^3-field	$\tilde{W}^3$	wino		
H_1^0	Higgs boson	$\tilde{H}_1^0$	higgsino	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
H_2^0	Higgs boson	$\tilde{H}_2^0$	higgsino		



2 Higgs doublets+ Gauge bosons+ SM fermions and their superpartners

Supersymmetry

- R parity has to be introduced for proton stability : $R = (-1)^{3(B-L)+2s}$ like a Z_2 symetry $\rightsquigarrow$ DM ! !



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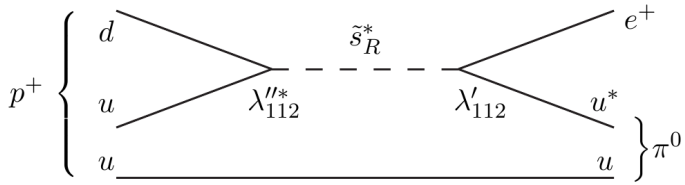

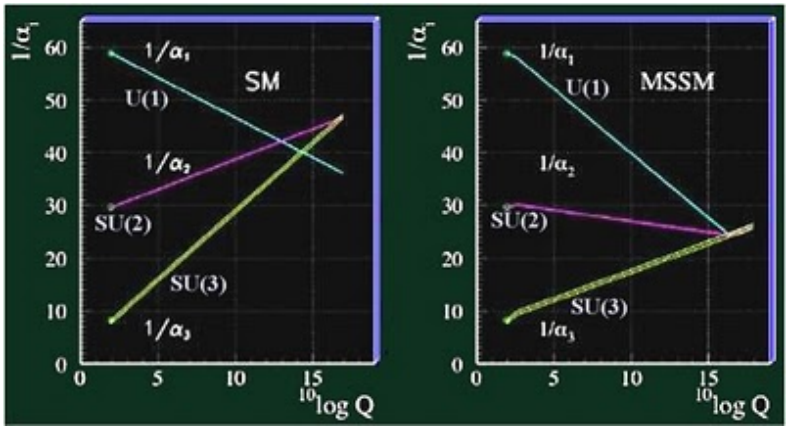

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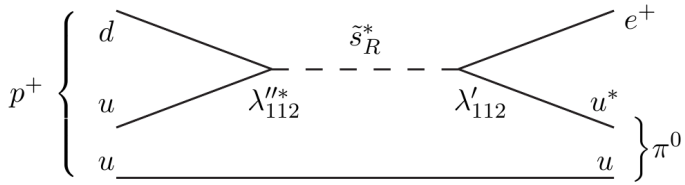
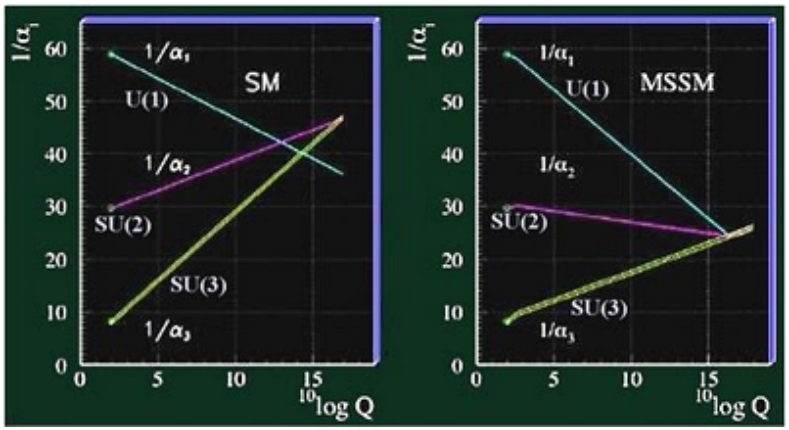
- gauge couplings corresponding to $SU(3)_c$, $SU(2)_L$, $U(1)_Y$ unify at the GUT scale $M_{GUT} \sim 10^{16}$ GeV
- testing new physics that can be related to supersymmetry : see talks of Guillaume and Karim for CMS today and talks of Adrien for Atlas (friday)





More searches on new physics...

- David today for CMS : Methods of identification of the τ lepton and implications for searches of new physics
- Cosme on friday for LHCb : Search for BR($B_s \to \mu^+\mu^-$)

Program of the BSM Session

- Today Monday 22/11 :

  9h00-9h30 Intro Laura Lopez Honorez
  9h30-10h00 DRIEU LA ROCHELLE, Guillaume : *Signature de Higgs Supersymmetriques au delà du MSSM*
  10h00-10h35 DAVID, BODIN : *CMS, Méthodes d'identification du lepton* τ

  11h05-11h30 : DERO, Vincent : *CMS ; étude du spectre de masse invariante des paires* e^+e^-
  11h30-11h55 : KARIM, mehdi : *CMS, Recherche de Supersymmetrie avec violation de R-parité*
  11h55-12h25 : DEGEE, Audrey : *approche géometrique pour étudier 2HDM*

- Friday 26/11

  15h00-15h35 : MAURICE, Emilie : *LHCb, Nouvelle physique dans les désintégrations* $B_s \to J/\psi\phi$
  15h35-16h00 : ADROVER PACHECO, Cosme : *LHCb, Search for* $BR(B_s \to \mu^+\mu^-)$

  16h30-17h05 :LUDOVICA, Aperio Bella : *Atlas, searches for high mass dilepton resonance*
  17h05-17h30 :RENAUD, Adrien Altas : *Recherche de Supersymmetrie au LHC*

This is the End

Thank you for your attention ! !

Backup

gauge theory based on the $SU(3) \times SU(2) \times U(1)$ gauge group with the Lagrangian

$$\begin{aligned}\mathcal{L}_{SM} = & -\frac{1}{4g'^2}B_{\mu\nu}B^{\mu\nu} - \frac{1}{2g^2}\mathrm{Tr}(W_{\mu\nu}W^{\mu\nu}) - \frac{1}{2g_s^2}\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu}) \\ & + \bar{Q}_i i\not{D} Q_i + \bar{L}_i i\not{D} L_i + \bar{u}_i i\not{D} u_i + \bar{d}_i i\not{D} d_i + \bar{e}_i i\not{D} e_i \\ & + (Y_u^{ij}\bar{Q}_i u_j \tilde{H} + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + \text{h.c.}) \\ & + (D_\mu H)^\dagger (D^\mu H) - \lambda (H^\dagger H)^2 - m^2 H^\dagger H \end{aligned} \quad (1)$$

This is the true End