Nouvelle physique et matière noire

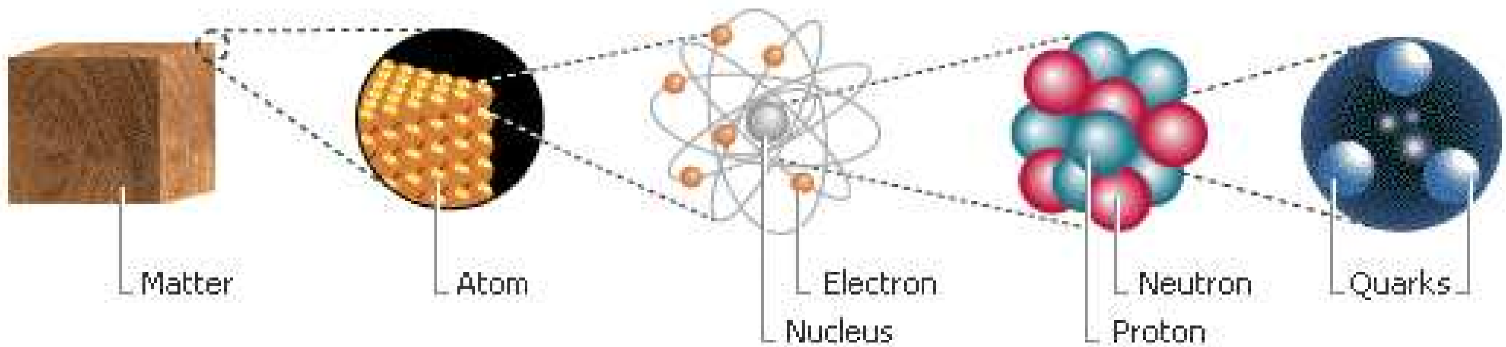
au LHC et dans l'univers

Fawzi LAPTH

PLAN...approximatif

- De quoi sommes nous faits? Quelles particules régissent le monde
- La particule qui nous manque
- La Nouvelle Physique qui nous manque
- La matière noire et l'ère de précision en cosmologie
- Synergie collisionneurs, cosmologie et astrophysique

De quoi sommes nous faits ▶ 1



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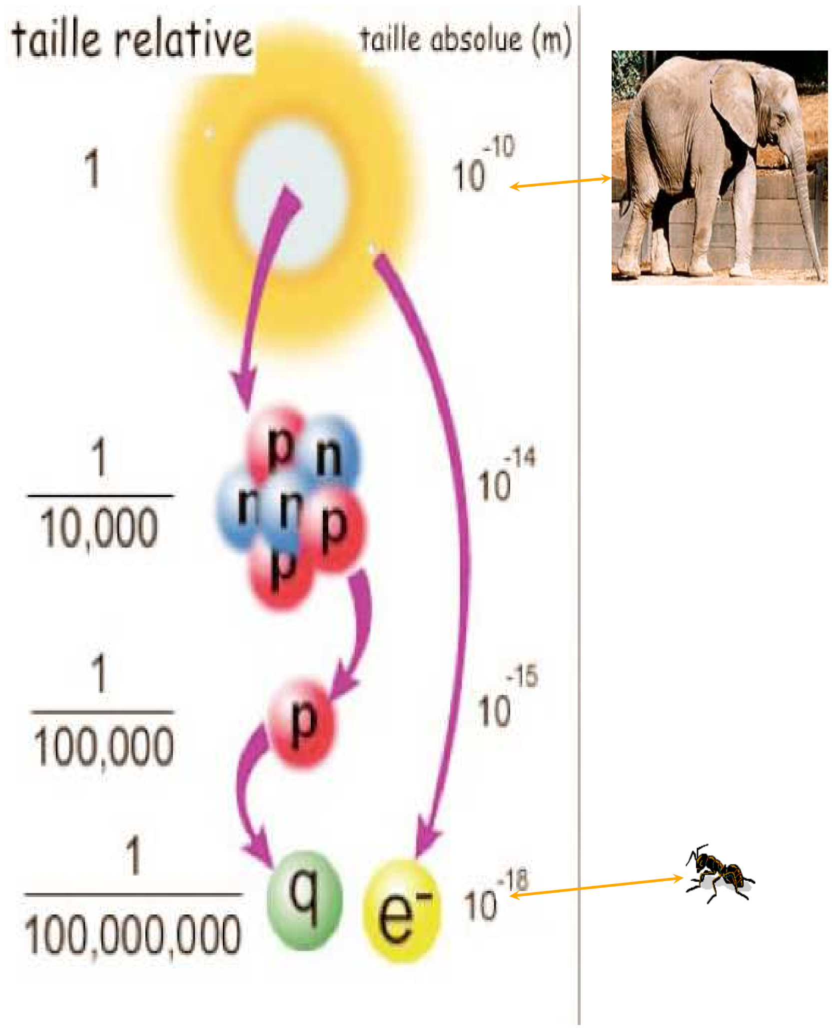
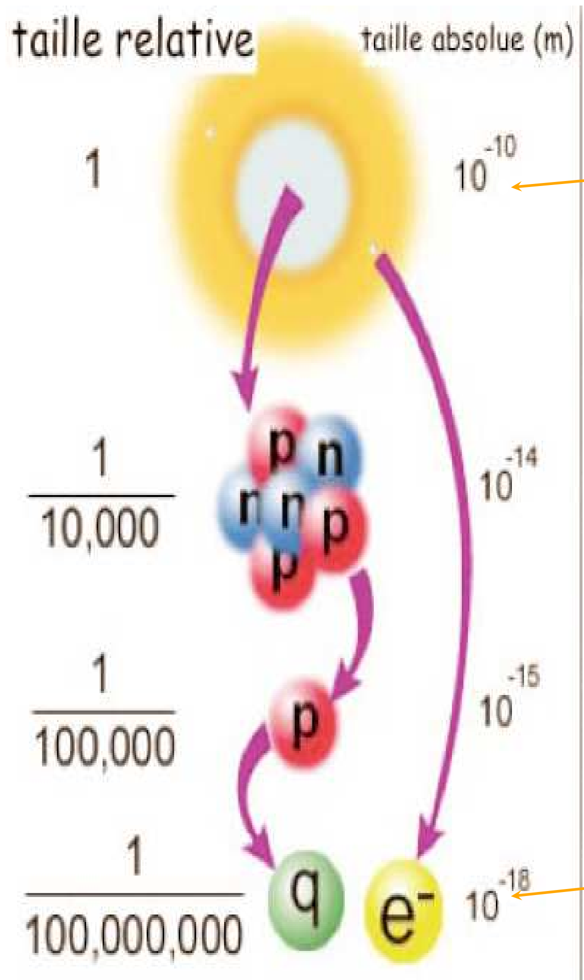
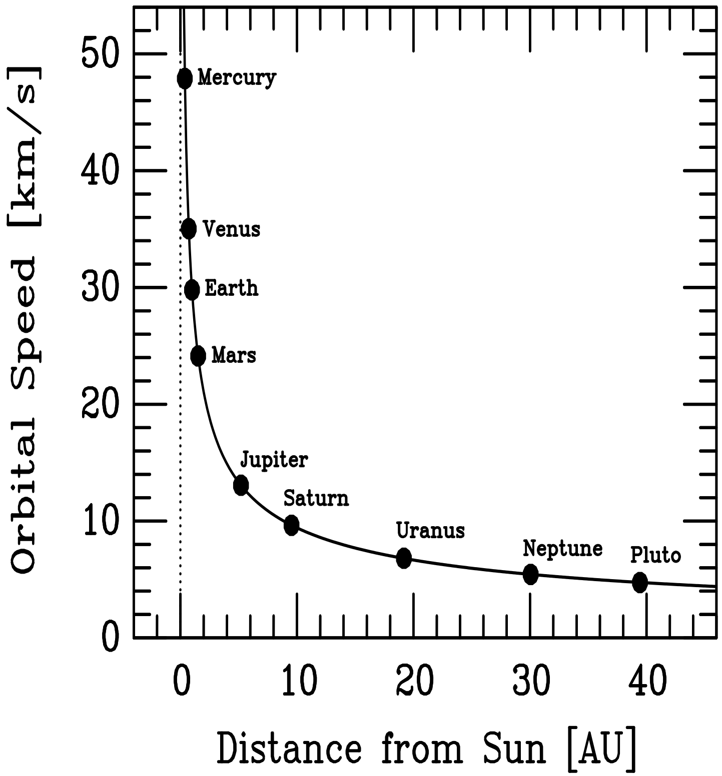




interaction lectromagnetique (QED)

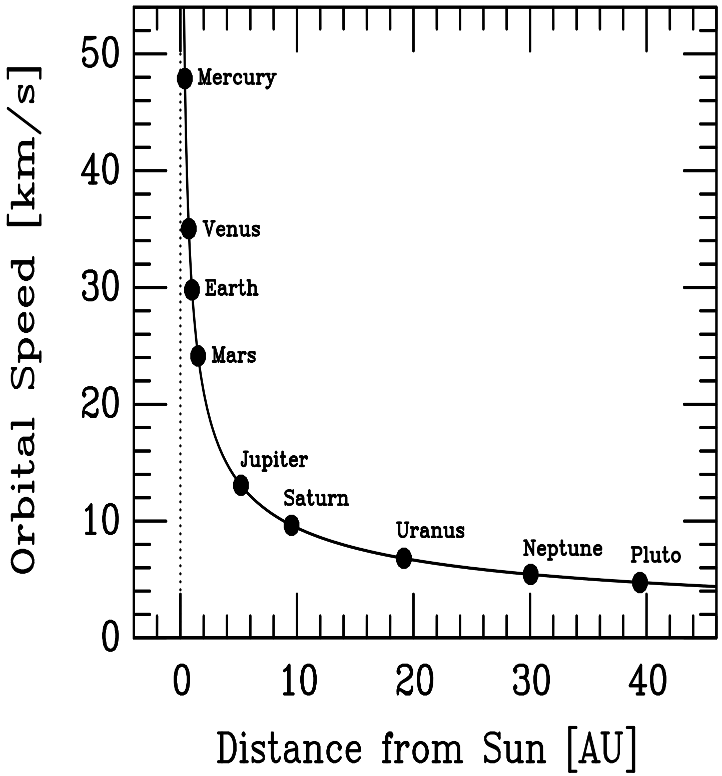
interaction forte (QCD)

Force de gravitation



$$v = \sqrt{GM(r)/r}$$

Force de gravitation



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Interaction faible

vers 1880, D'ou vient l'energie du soleil?

Kelvin, Helmholtz, etc...: "contraction gravitationnelle du nuage solaire..."

age de l'Univers (soleil): qq millions d'annees

Darwin (evolution, erosion,...): milliards d'annees pour la terre!

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desintegration β

$n \longrightarrow p e^- \nu_e$

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desintegration β

$n \longrightarrow p e^- \nu_e$

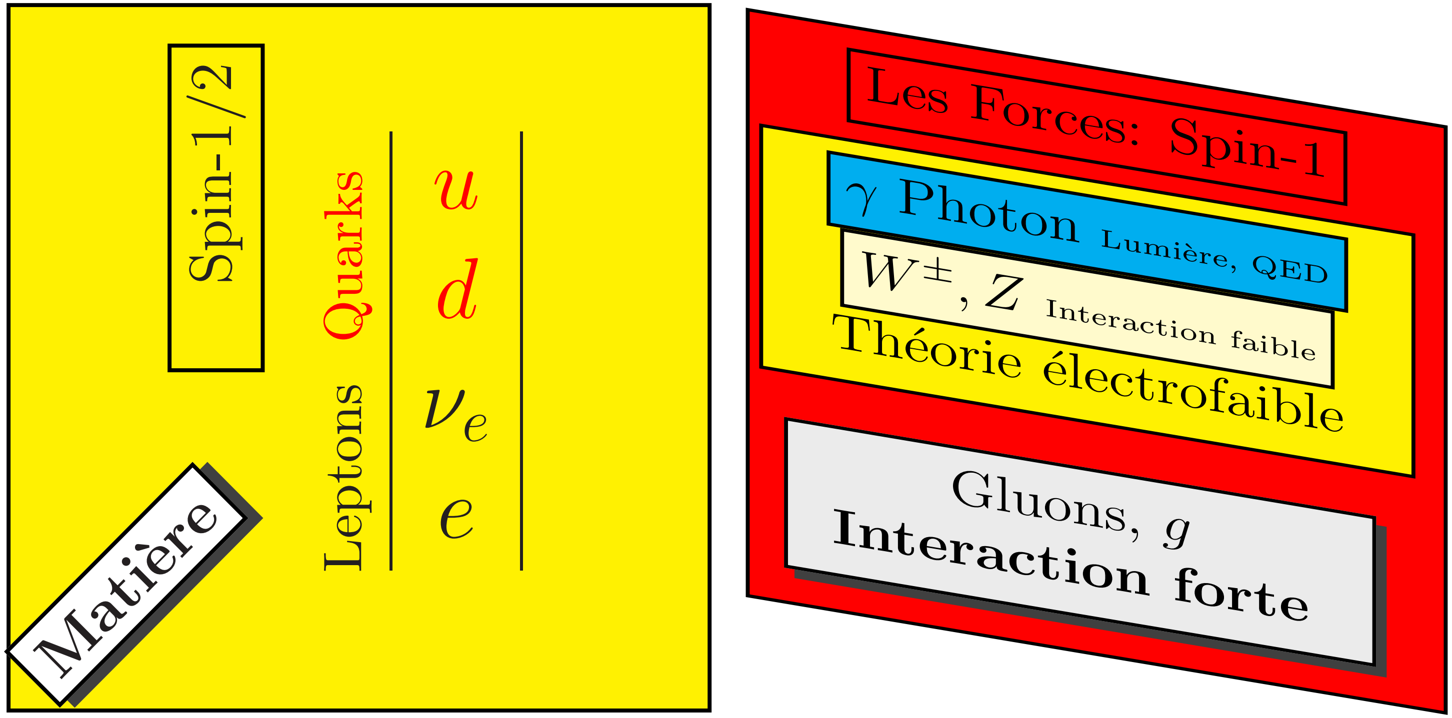
reaction nucleaire: fusion

bruler de l'hydrogene:

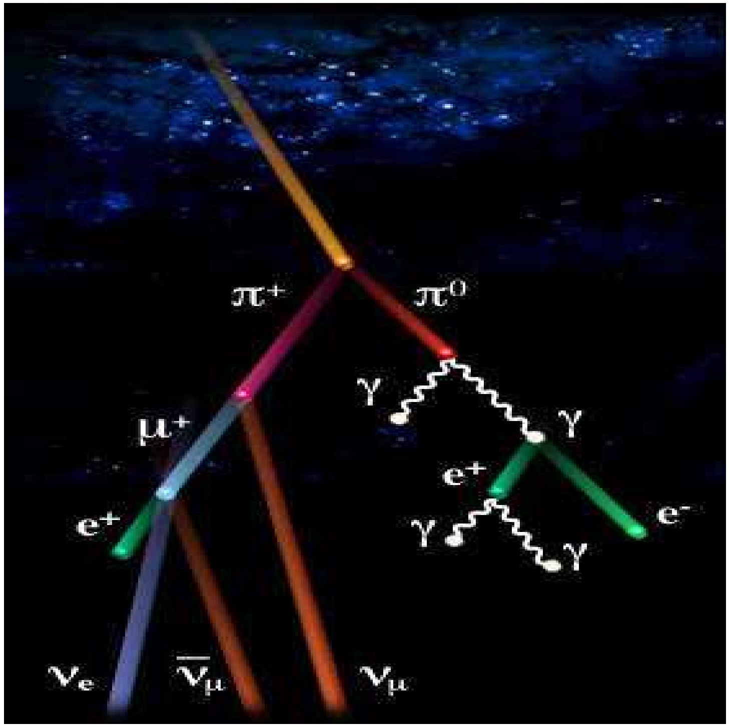
$$4\,^1H + 2e \longrightarrow {}^4He + 2\nu + 6\gamma + \text{Energie}$$

$$(CH_4 + 2O_2 \longrightarrow 2H_2O + \text{chaleur})$$

La premiere famille



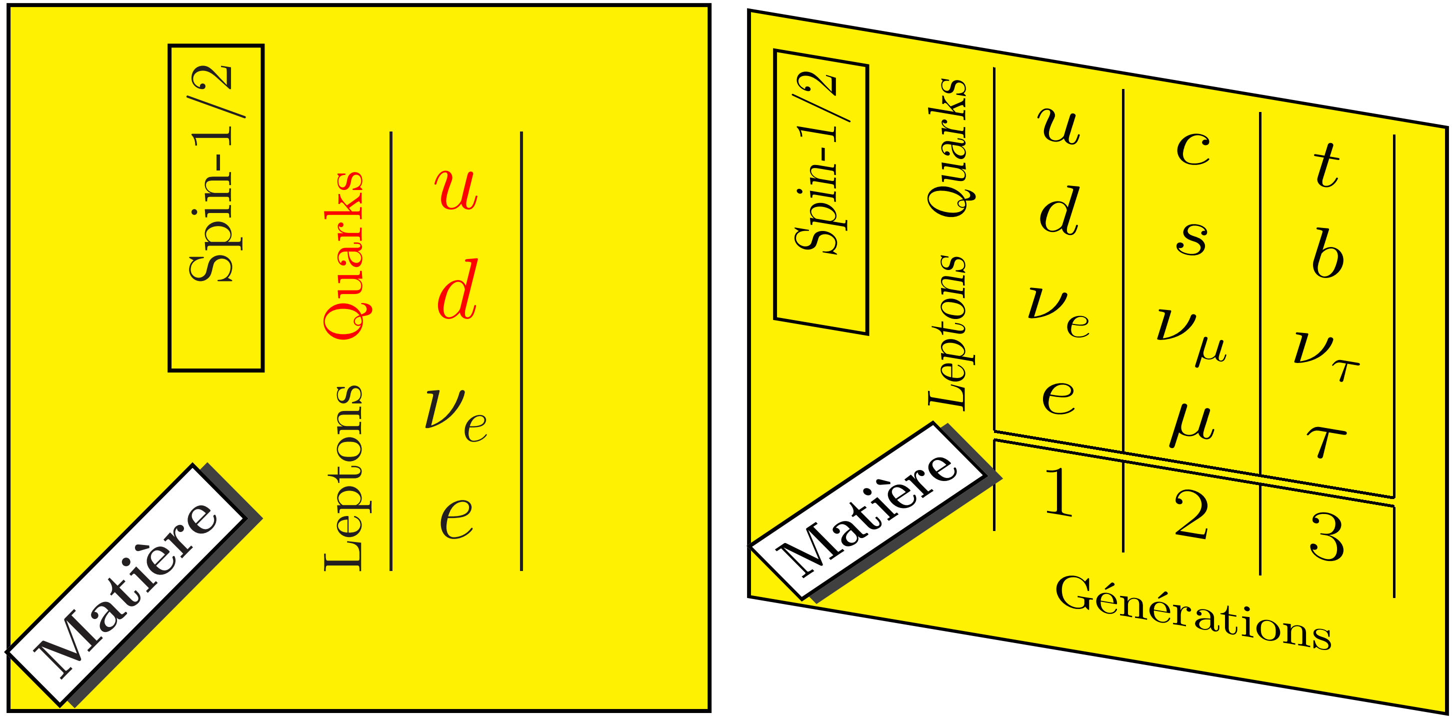
Rayons Cosmiques



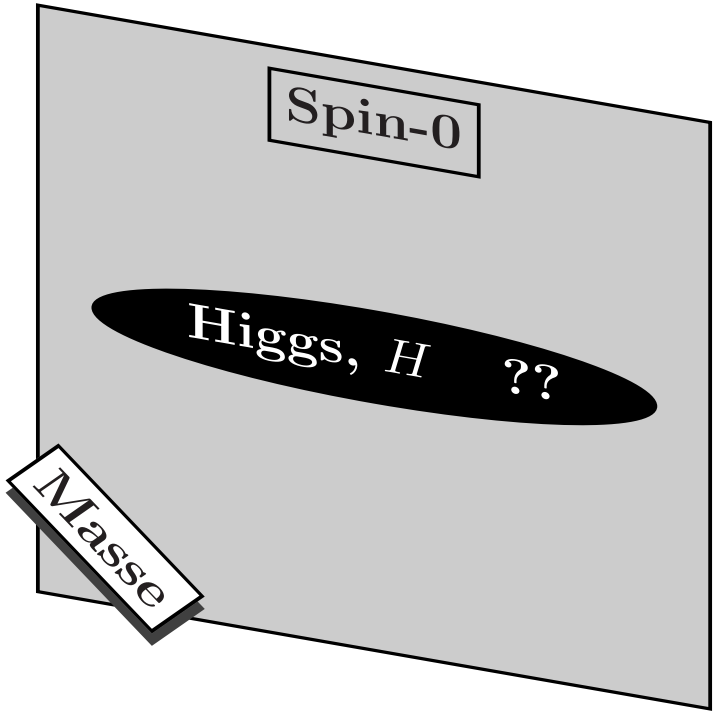
μ: muon a part la masse, en tout point comme l'electron

accelerateurs pour produire ces nouvelles particules ou d'autres pour mieux les etudier

Et!


Spin-1/2
Quarks
Leptons
u
d
ν_e
e
Matière
Spin-1/2
Quarks
Leptons
u c t
d s b
ν_e ν_μ ν_τ
e μ τ
1 2 3
Générations
Matière

Spin-0???

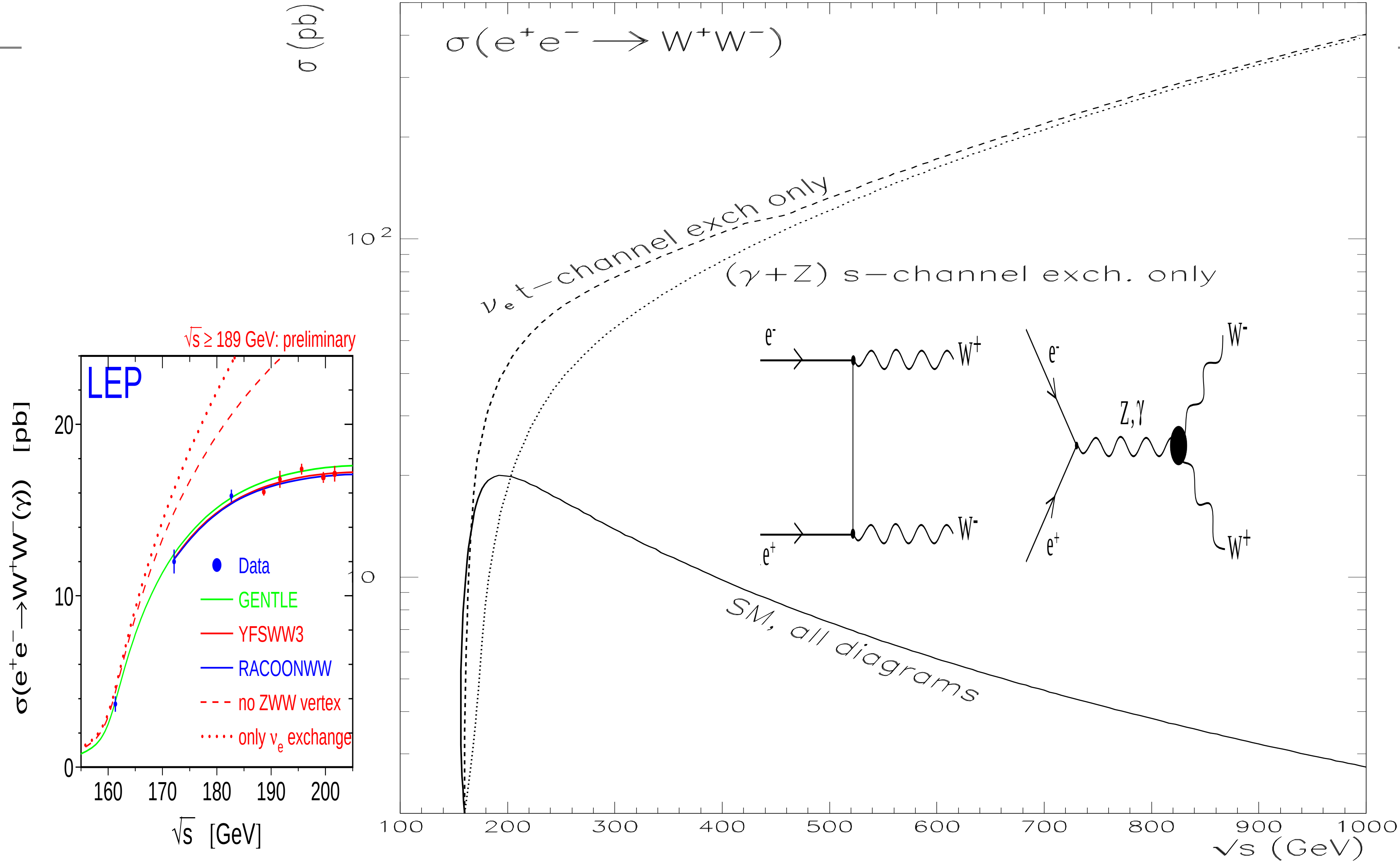


Spin-0???

Nécessité d'une Nouvelle Physique

argument de la probabilite < 1 comme au LOTO

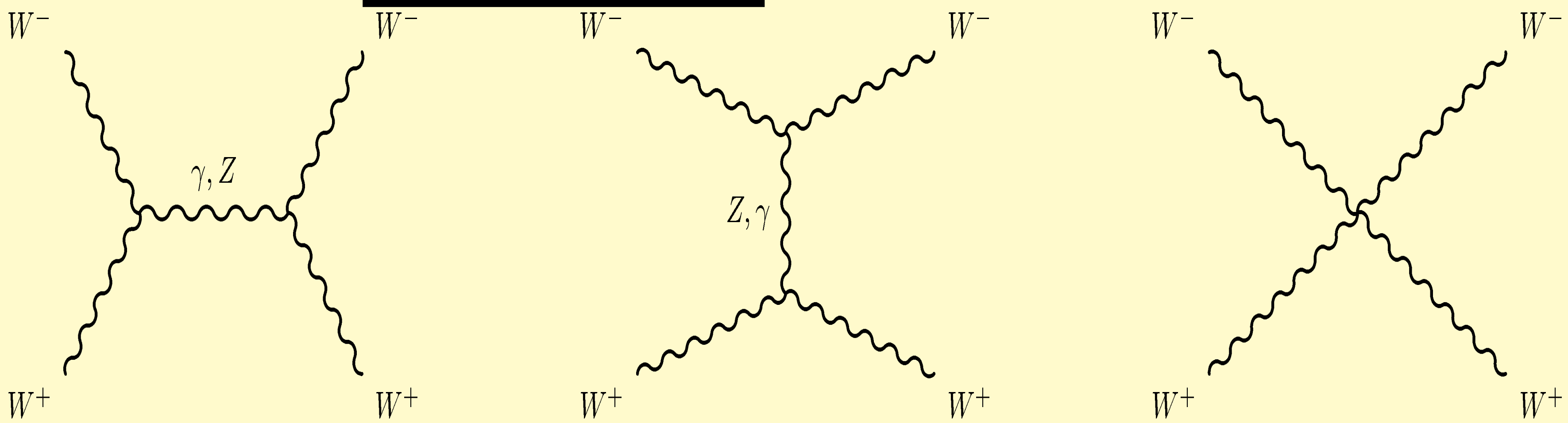
Invariance de jauge: $g_{ffV} = g_{VVV}$



• La section efficace ne peut croitre indéfiniment .

Self-couplings: the Higgs and Symmetry Breaking Connection

$W_L^+ W_L^- \to W_L^+ W_L^-$ *Sans le Higgs*



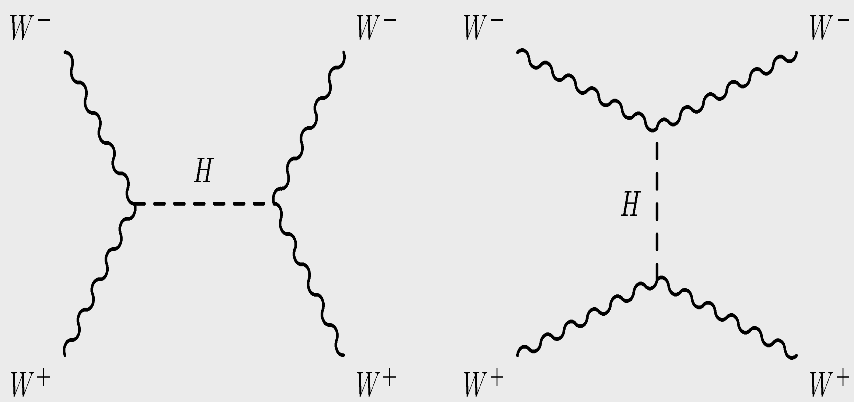
Si $g_{VVVV} \neq g^2_{VVV} \Longrightarrow \mathcal{M}_{LLLL} \propto E^4_W$

dans le MS $\mathcal{M}_{LLLL} \sim \sqrt{2} G_F u \propto E^2_W$

Unitarite sans le Higgs requiert $\sqrt{s_{WW}} \leq 1.2\mathrm{TeV}$

Higgs permet d'aller a des energies plus elevees

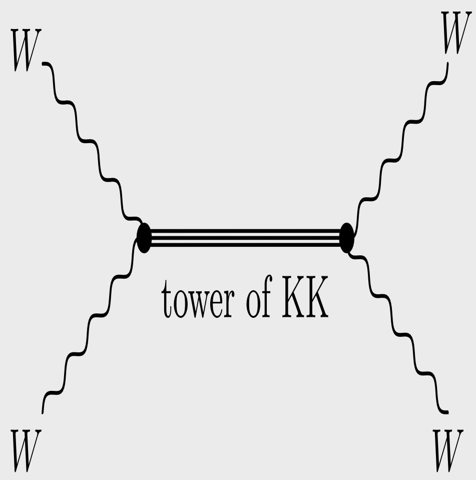
Higgs in SM



$$\mathcal{M}_{LLLL} \sim -\sqrt{2} G_F M_H^2 \left(\frac{s}{s-M_H^2} + \frac{t}{t-M_H^2} \right)$$

Unitarité implique $M_H \leq \frac{4\pi\sqrt{2}}{3G_F} \sim 700\text{GeV}$

Extra-dim with special boundary cdts

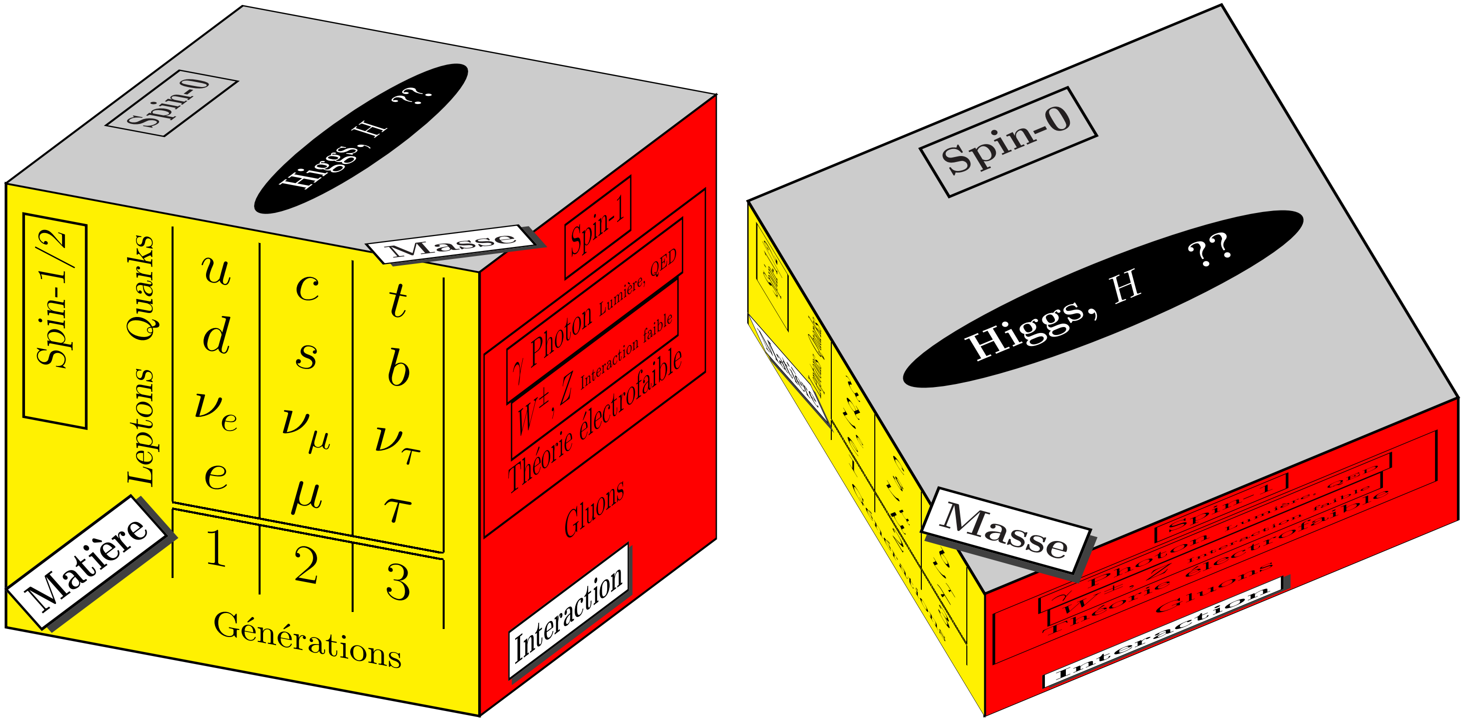


Unitarity is delayed up to a few TeV

cancellation from underlying

5-d gauge symmetry.

Le Modèle Standard

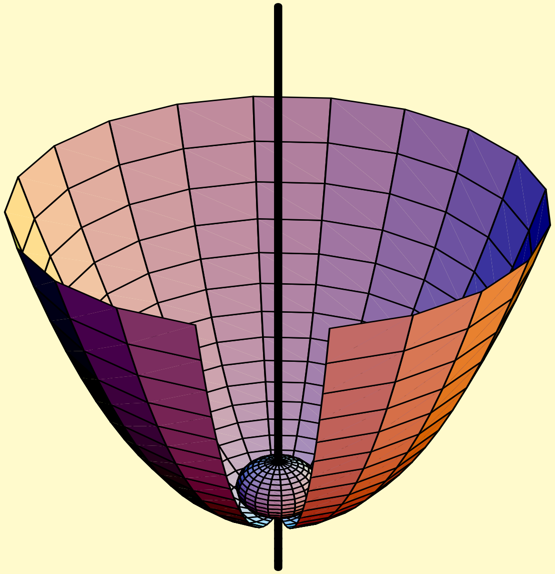


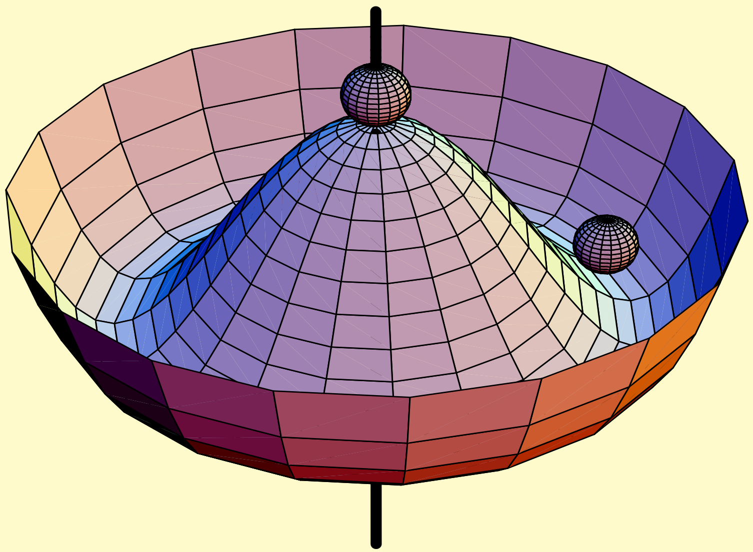
Modele Standard

$$\mathbf{\Phi} = \begin{pmatrix} \varphi^+ \\ \frac{1}{\sqrt{2}}(v + H + i\varphi_3) \end{pmatrix}$$

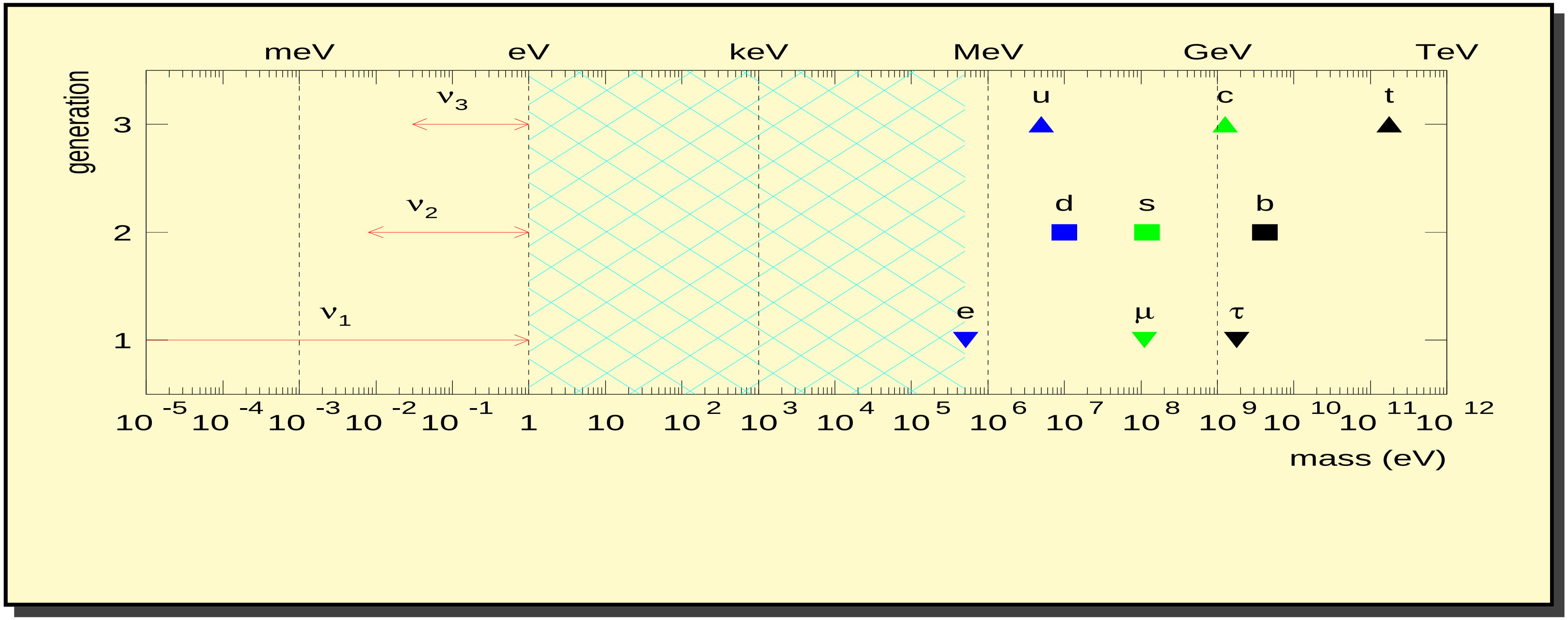
Le mysterieux Potentiel

$$\mathcal{V}_{\mathbf{SSB}} = \lambda \left[\mathbf{\Phi}^\dagger \mathbf{\Phi} \ - \frac{\mathbf{v^2}}{\mathbf{2}}\right]^{\mathbf{2}} = \lambda \left[\mathbf{\Phi}^\dagger \mathbf{\Phi}\right]^{\mathbf{2}} - \mu^{\mathbf{2}} \ \mathbf{\Phi}^\dagger \mathbf{\Phi} + \lambda \frac{\mathbf{v^4}}{\mathbf{4}}$$

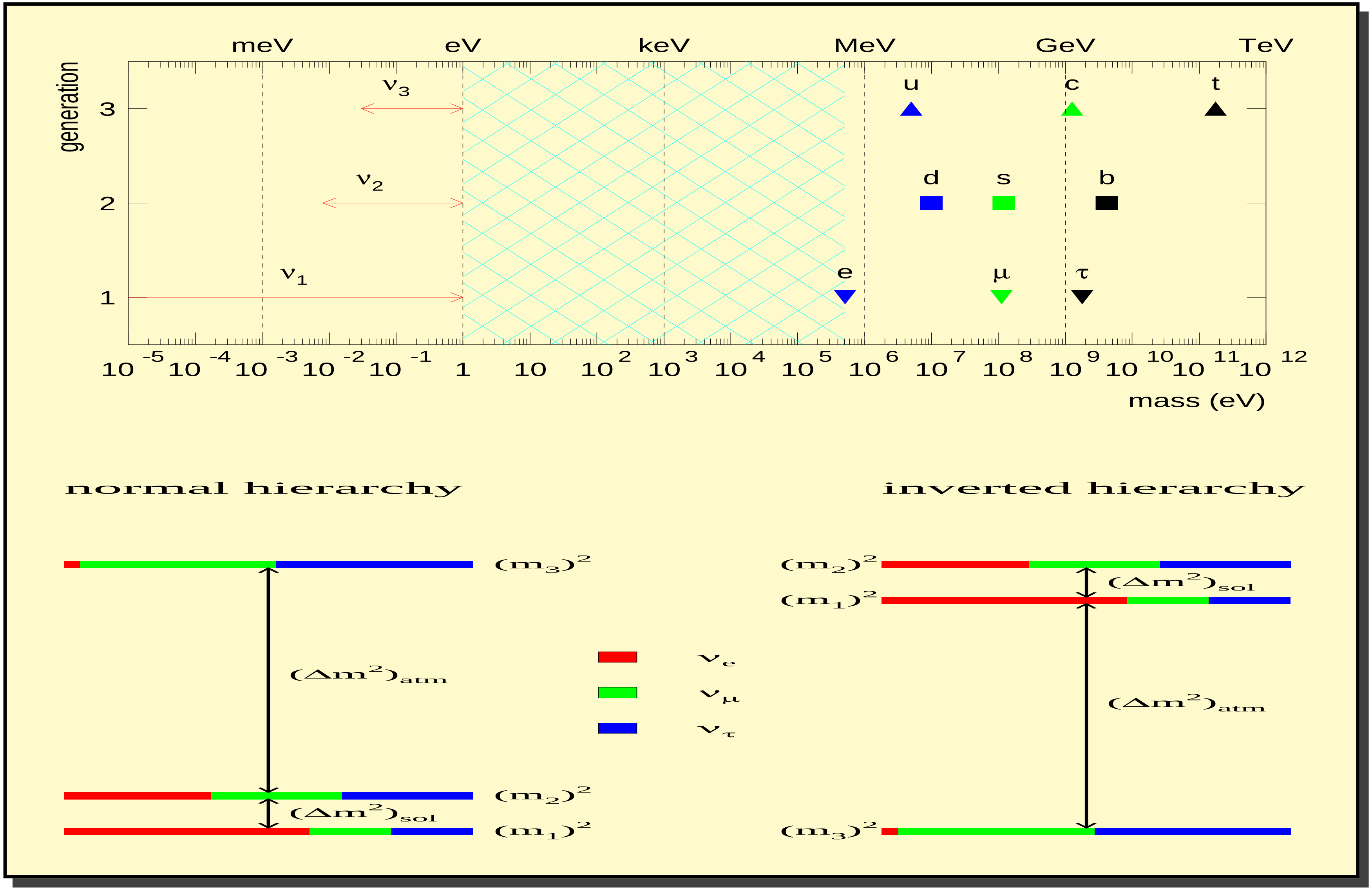




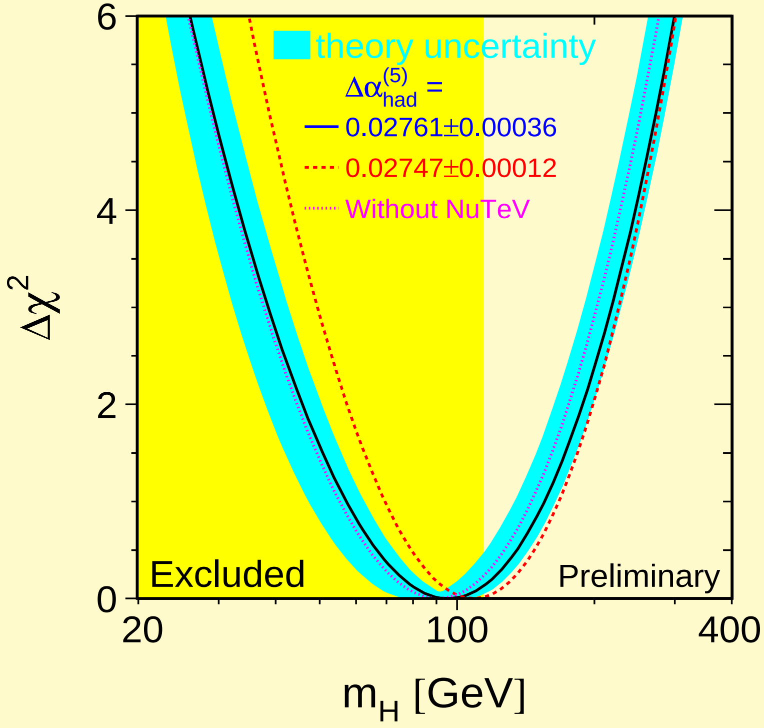
Masses des neutrinos et melanges

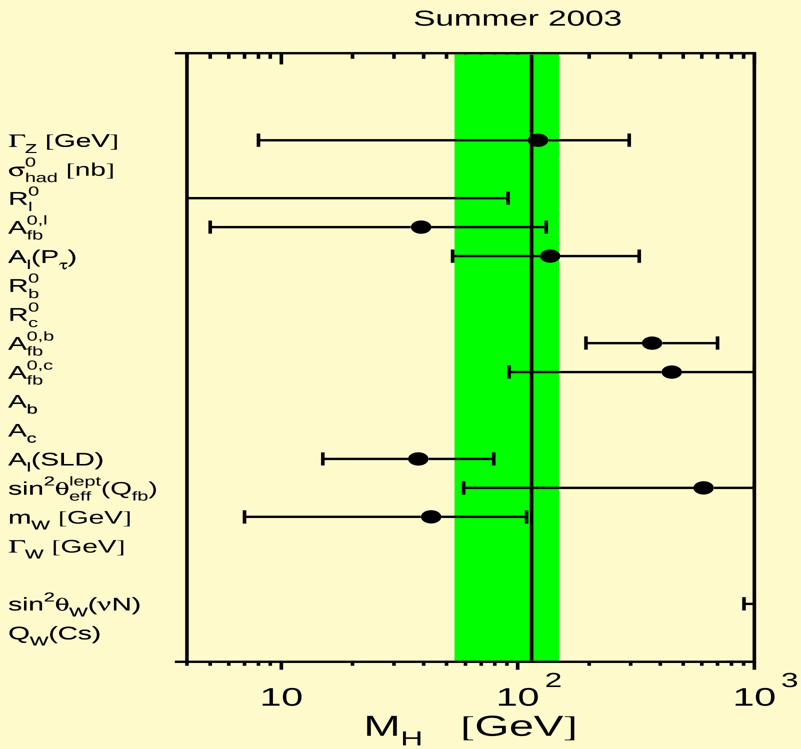


Masses des neutrinos et melanges



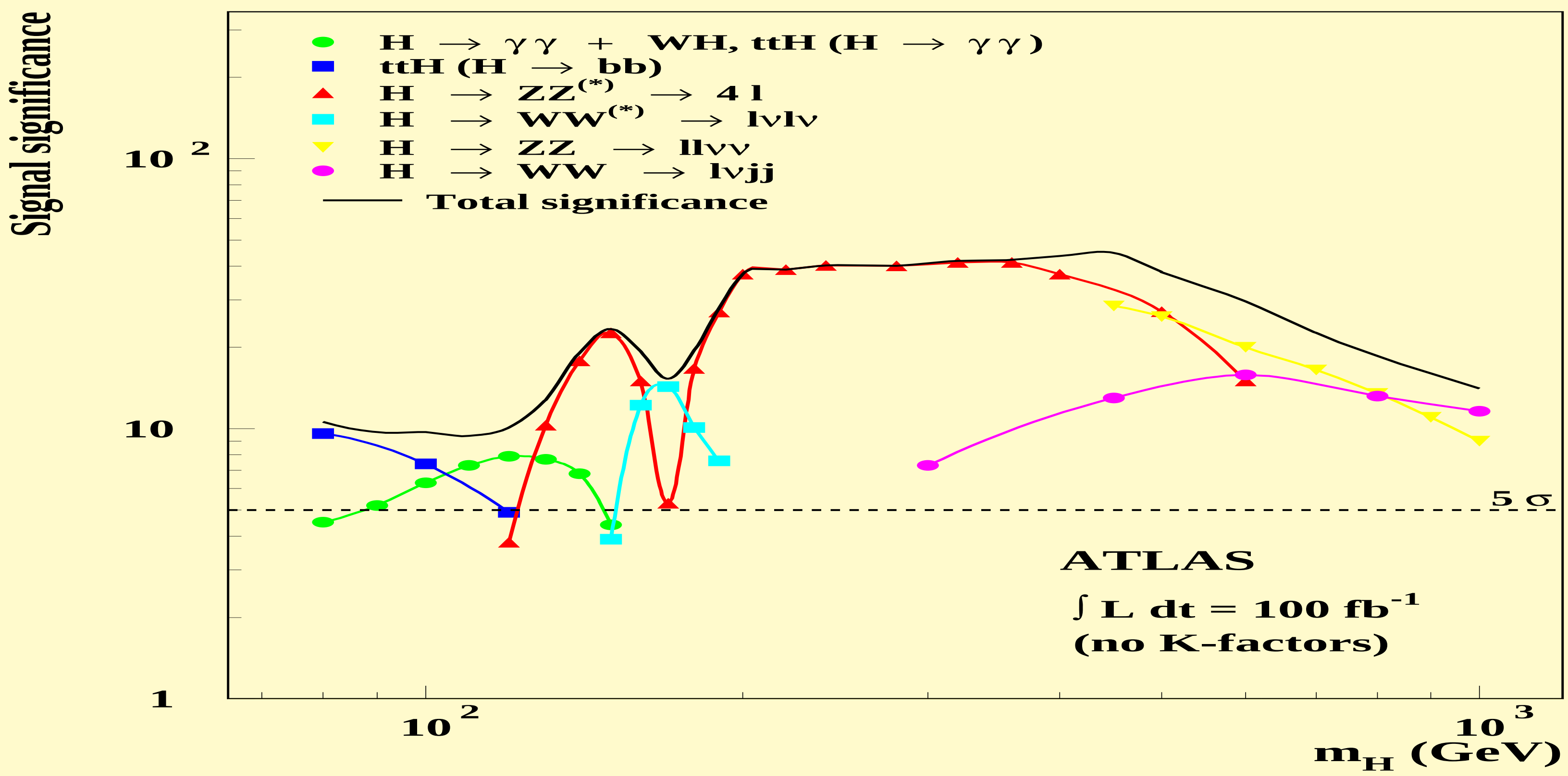
Modele Standard





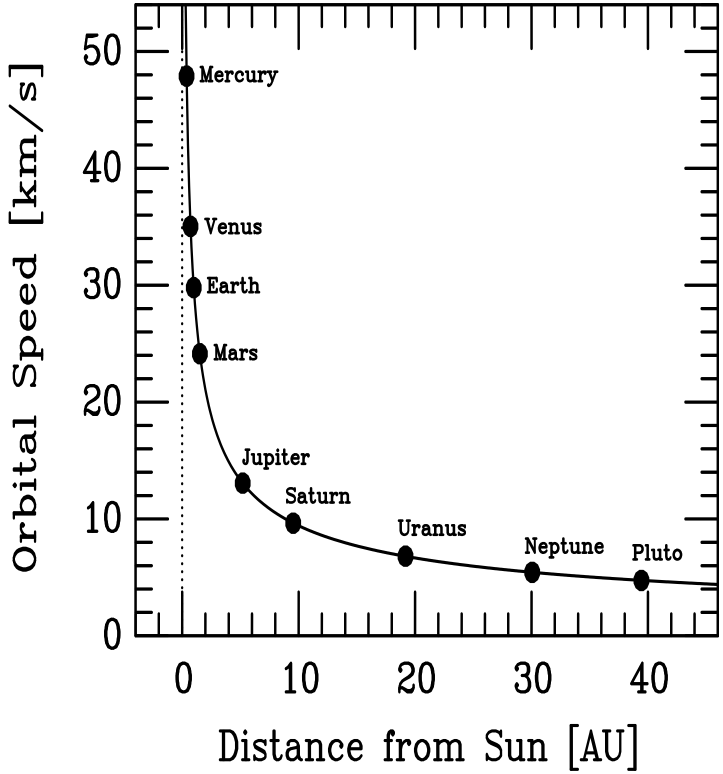
Priorite des Priorites: Higgs au(x) collisionneur(s)

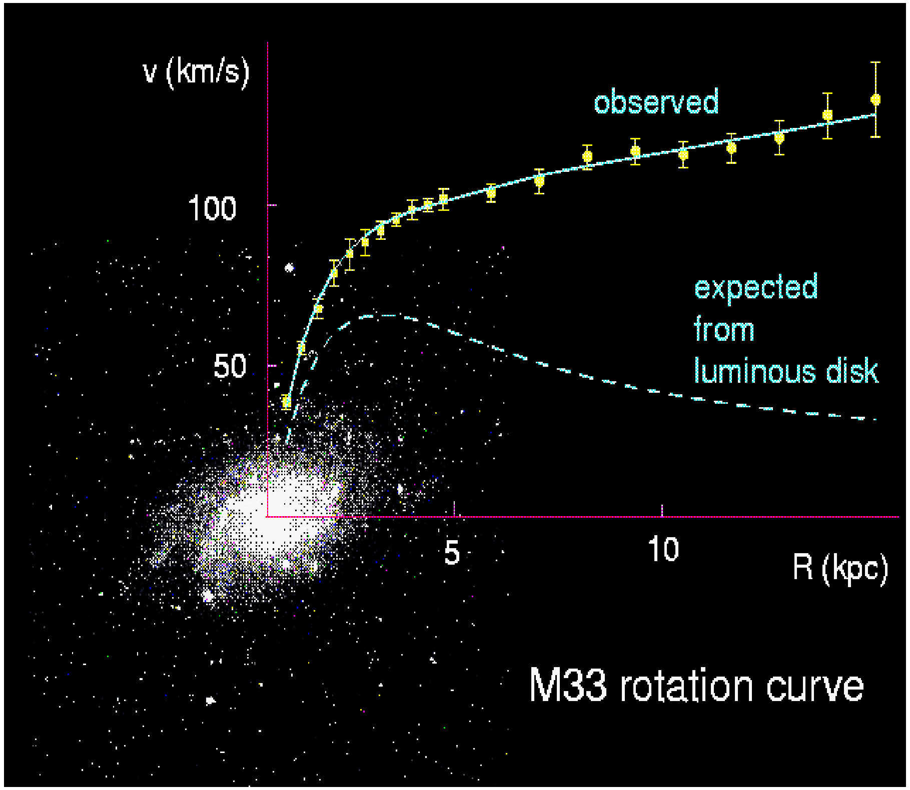
Le Higgs du MS au LHC: decouverte garantie (meme en invisible)



Matière Noire

Loi de Newton $\longrightarrow$ $v^2_{\text{rot.}}/r = G_N M(r)/r^2$





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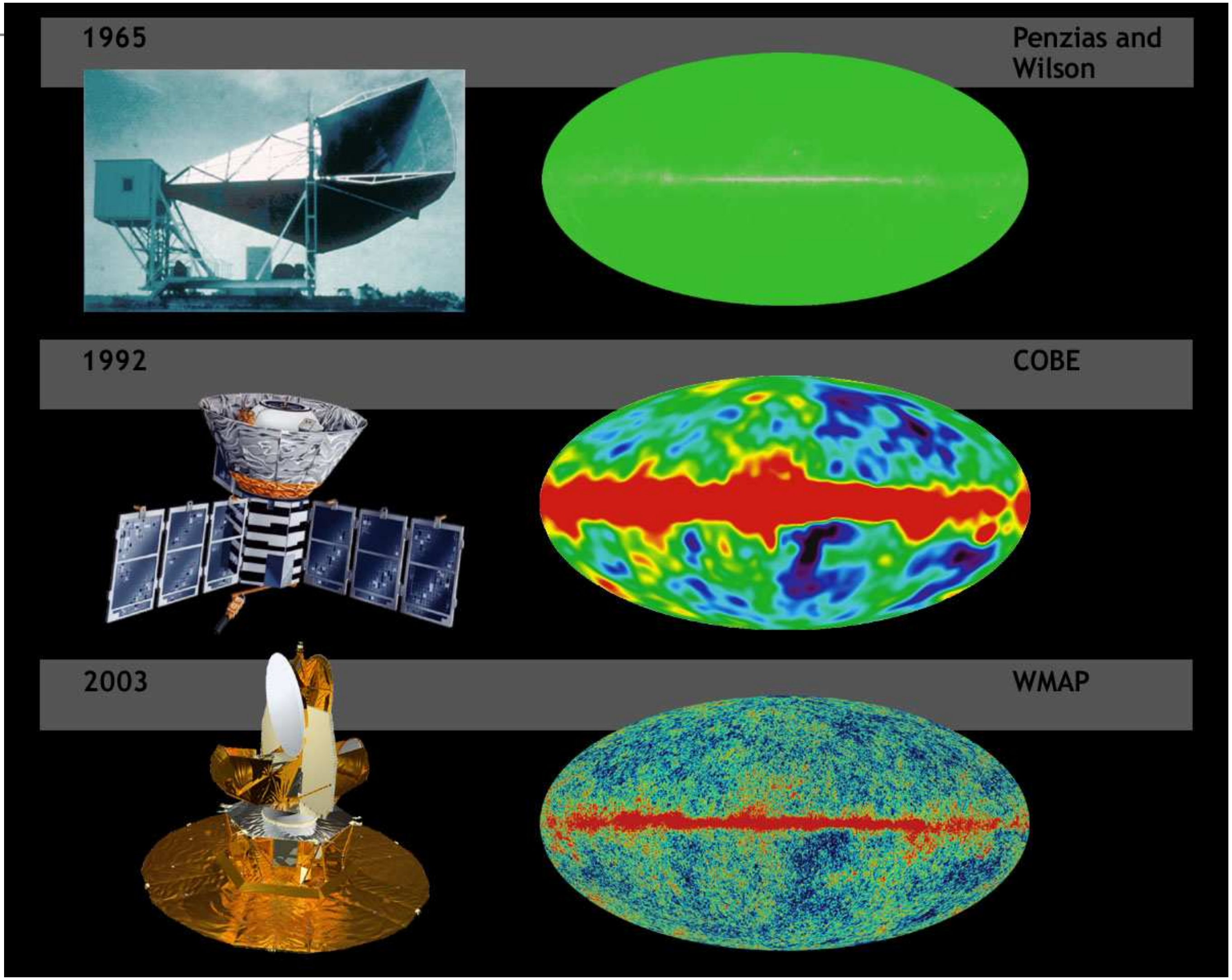
Matiere Noire= Nouvelle Physique

Nous ne sommes pas fait du meme materiau qui constitue la majorite de l Univers

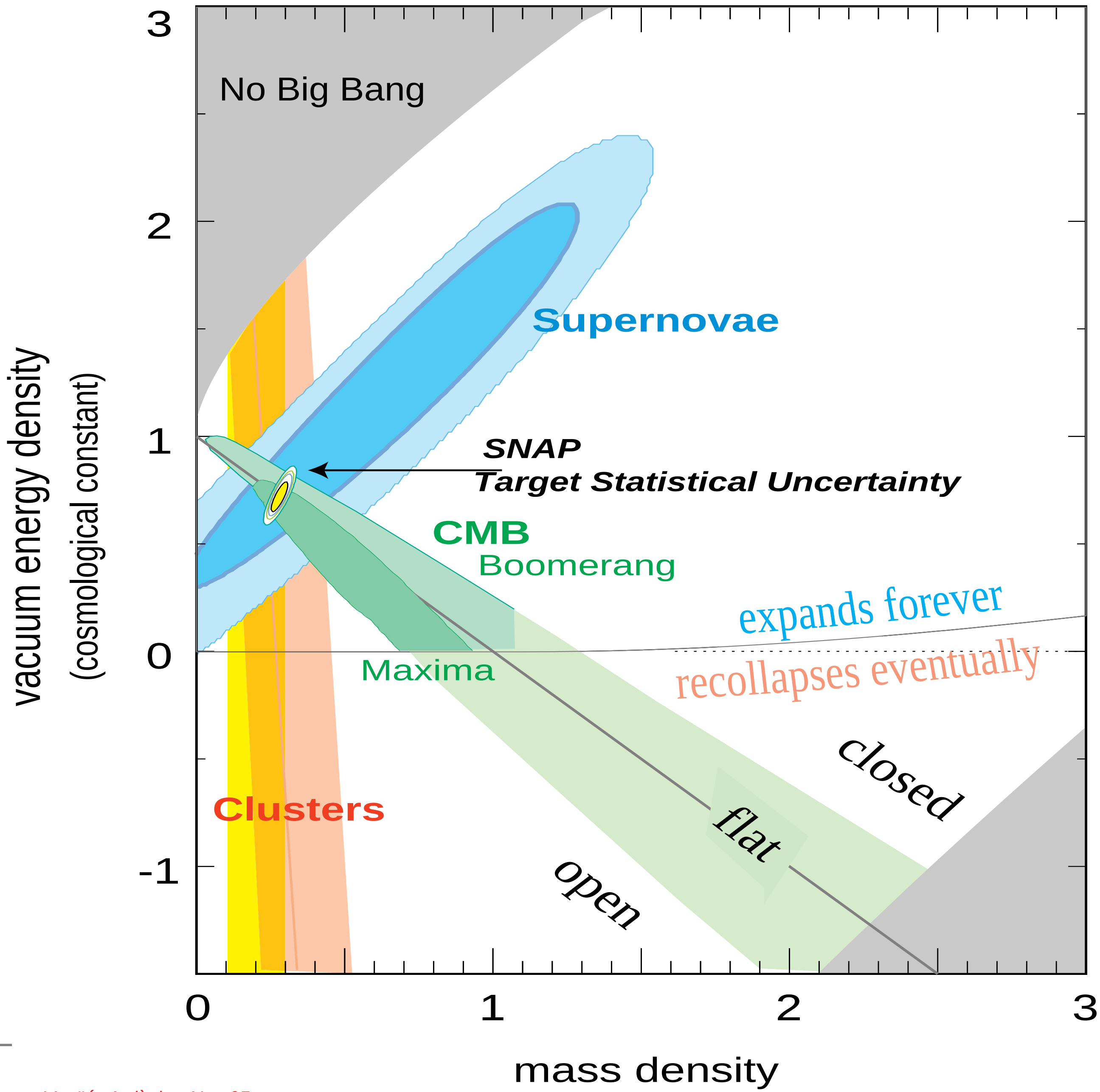
Nous sommes insignifiants

Cosmologie à l’ère des mesures de précision 1: CMB



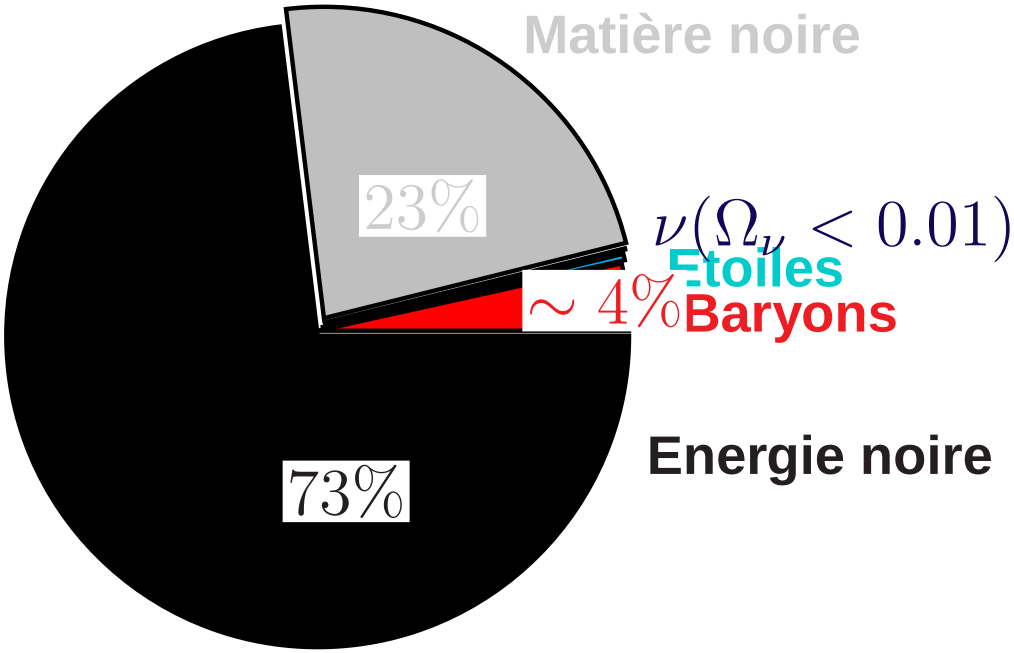
anisotropies de température observees
$$10^{-5}$$
(celles-ci sont reliees a la densite de fluctuations au temps de l’emission)
germes des galaxies etc..

Cosmologie à l’ère des mesures de précision 2: supernovae



observed luminosity and red-shift exploits the different z dependence of matter/energy density

matter budget and Precision 1.



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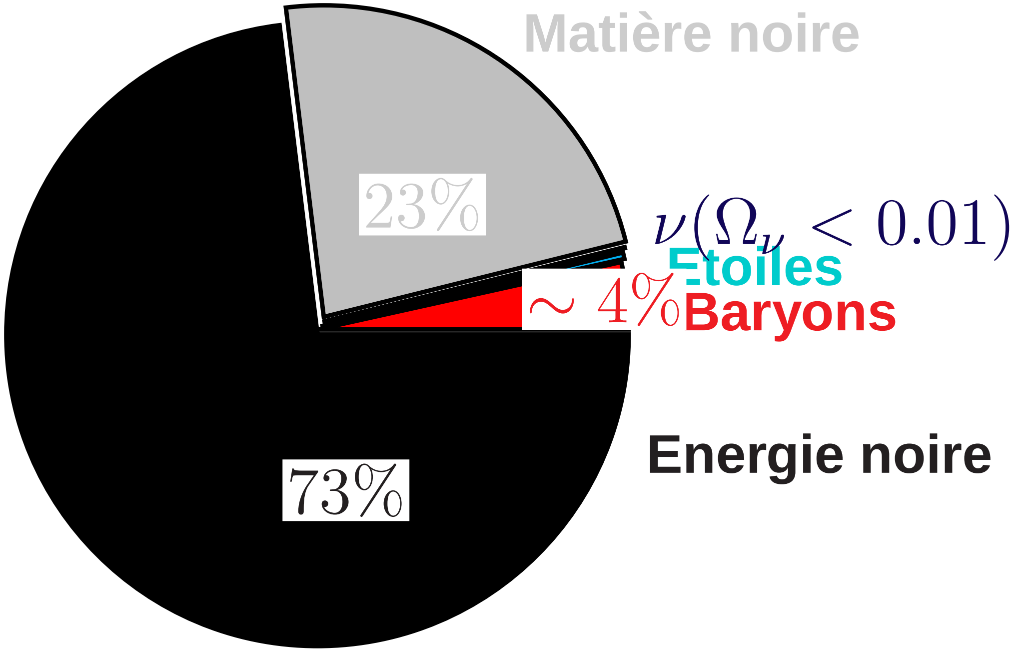
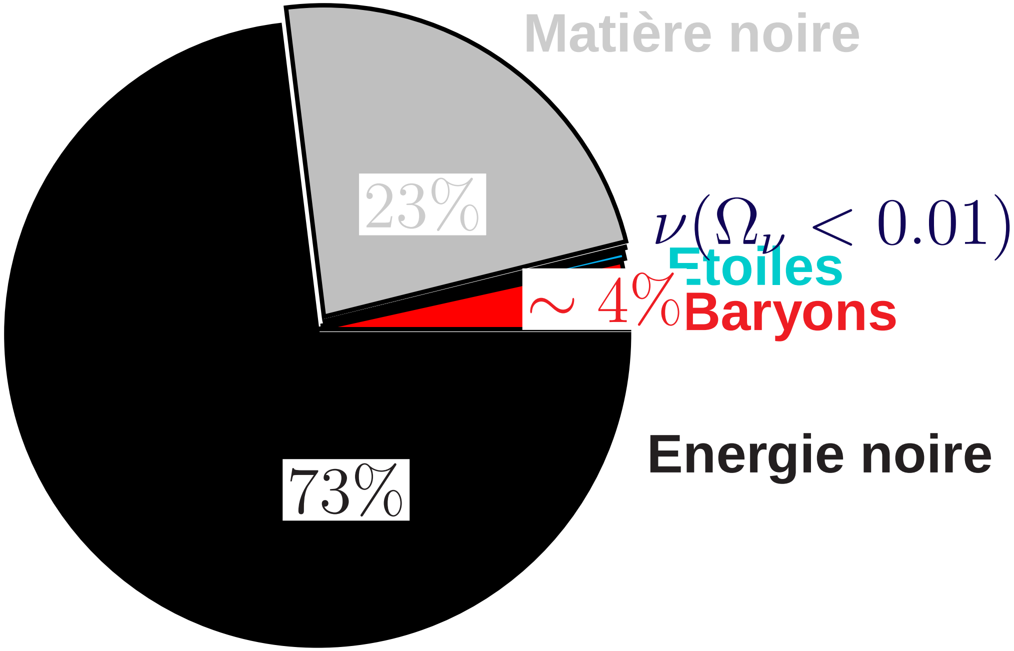


Asymetrie baryonique?

$\Delta B/B = 10^{-10}$!!!

matter budget and Precision 1.

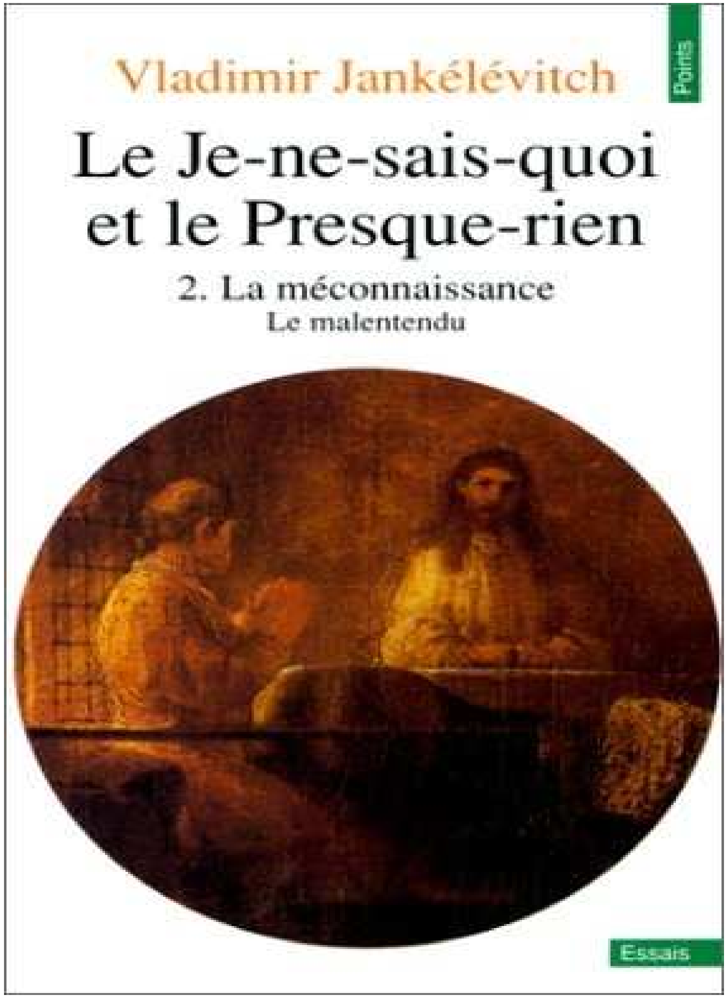


Et pas d'anti-matière!!

Asymetrie baryonique?

$\Delta B/B = 10^{-10}$!!!

$\mathbf{t_0 = 13.7 \pm 0.2}$ **Gyr** $\mathbf{(1.5\%)}$	$\alpha^{-1} = \mathbf{10 t_0 (10^{-7}\%)}$
$\mathbf{\Omega_{tot} = 1.02 \pm 0.02 (2\%)}$	$\rho = \mathbf{\Omega_{tot} (\sim 0.1\%)}$
$\mathbf{\Omega_{DM} = 0.23 \pm 0.04 (17\%)}$	$\sin^2\theta_{\text{eff}} = \mathbf{\Omega_{DM} (0.08\%)}$


Points
Vladimir Jankélévitch
Le Je-ne-sais-quoi et le Presque-rien
2. La méconnaissance
Le malentendu
Essais


SARTRE
L'être et le néant
Essai d'ontologie phénoménologique
tel gallimard

Probleme du Higgs dans le Modele Standard:
Description pathologique: Pourquoi $\mathrm{M}_H < 1TeV$??

a une boucle:

Spin-1, Symetrie de jauge locale

$$\mathbf{M}_\gamma^2 = M_{\gamma,0}^2 = 0$$

Spin-1/2, Symetrie chirale (globale)

$$\mathbf{m_e = m_e^0\left(1 + \frac{3}{2}\frac{\alpha}{\pi}\log(\Lambda^2/m_e^2)\right) \quad \Lambda = \Lambda_P \Longrightarrow \delta_m \sim 30\%}$$

Spin-0,

$$\mathbf{M_H^2 - M_{H,0}^2 \sim \frac{\alpha}{\pi}\Lambda^2}$$

Reglage fin

Nouvelle Physique doit expliquer pourquoi:

$$\mathbf{M_H} , \mathbf{v} \quad \ll \quad \mathbf{\Lambda}_{\rm Planck}$$

3 Solutions

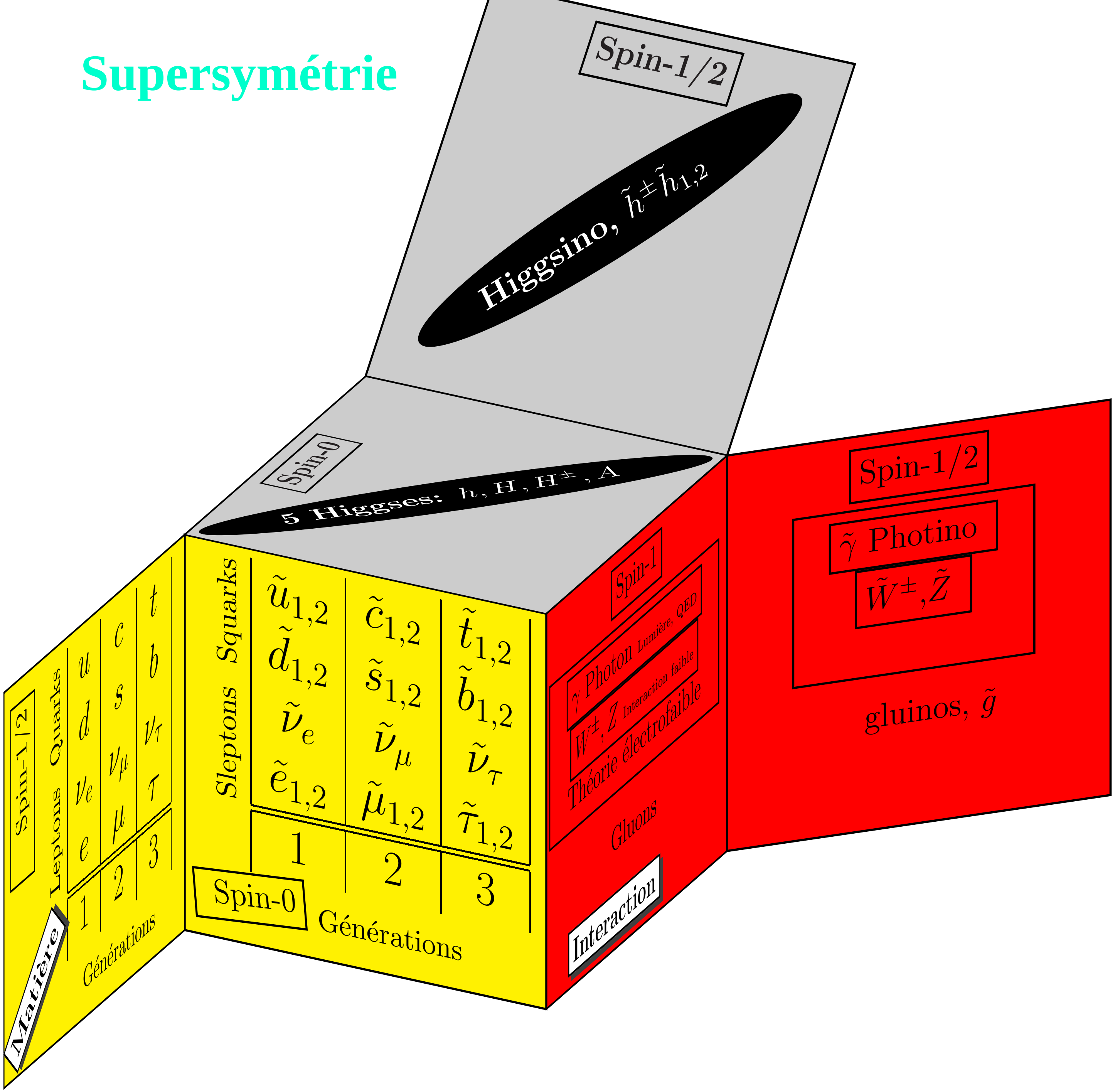
- Modele sans Higgs
- $\Lambda \sim 1, 10, , , 100$TeV: Dimensions supplementaires, “Petit Higgs”,..
- $\ll$: symetrie=supersymetrie

De plus en plus

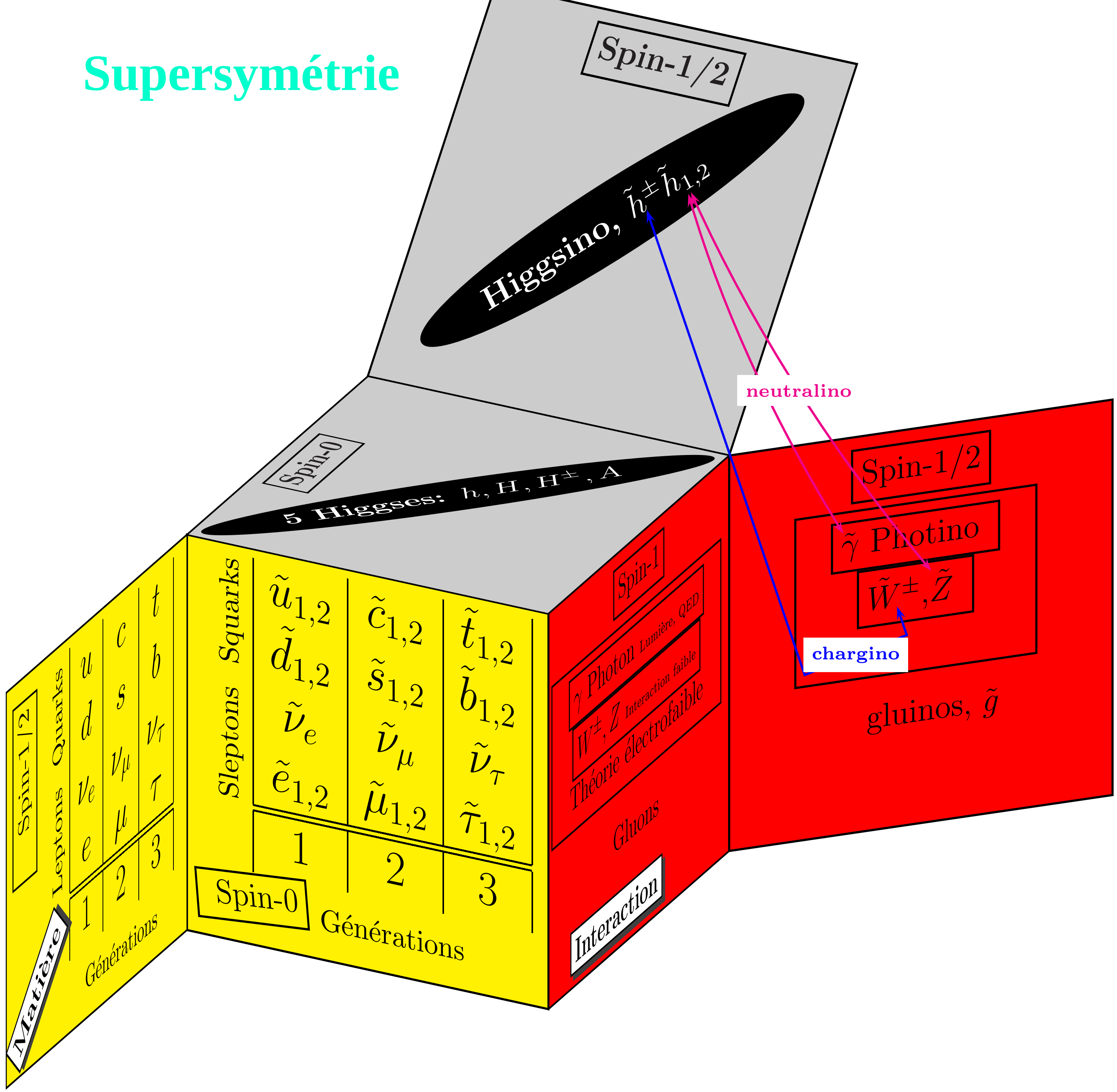
un melange des trois.....

rejet de l’argument de reglage fin

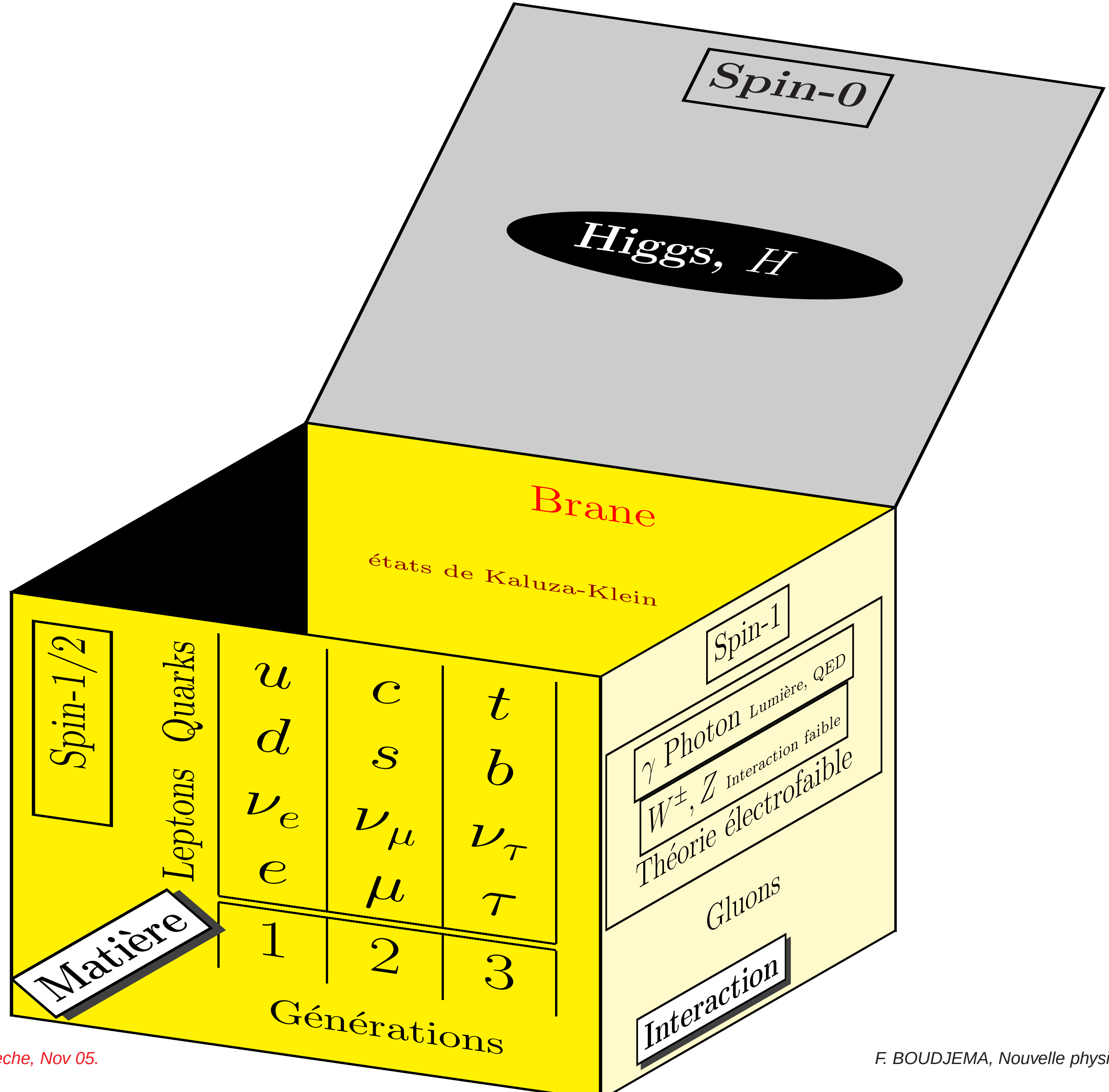
Supersymétrie

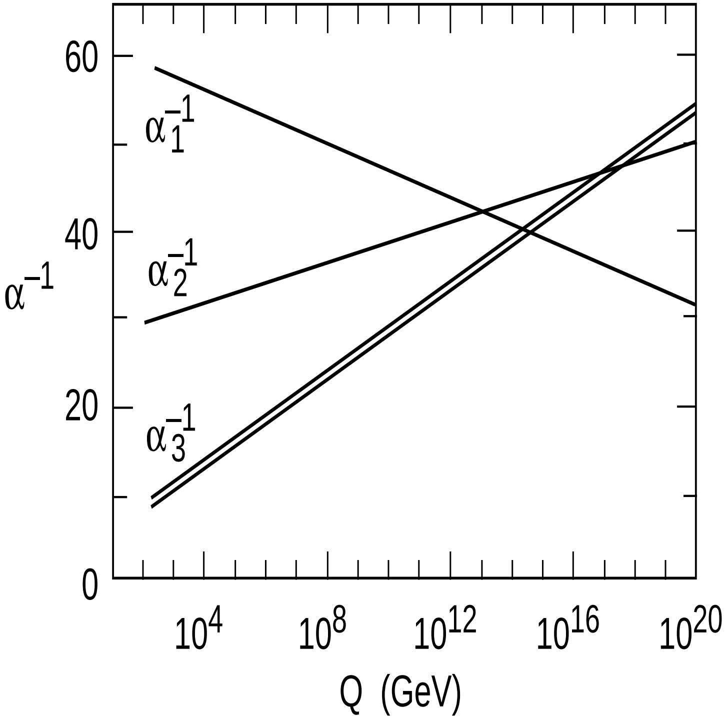


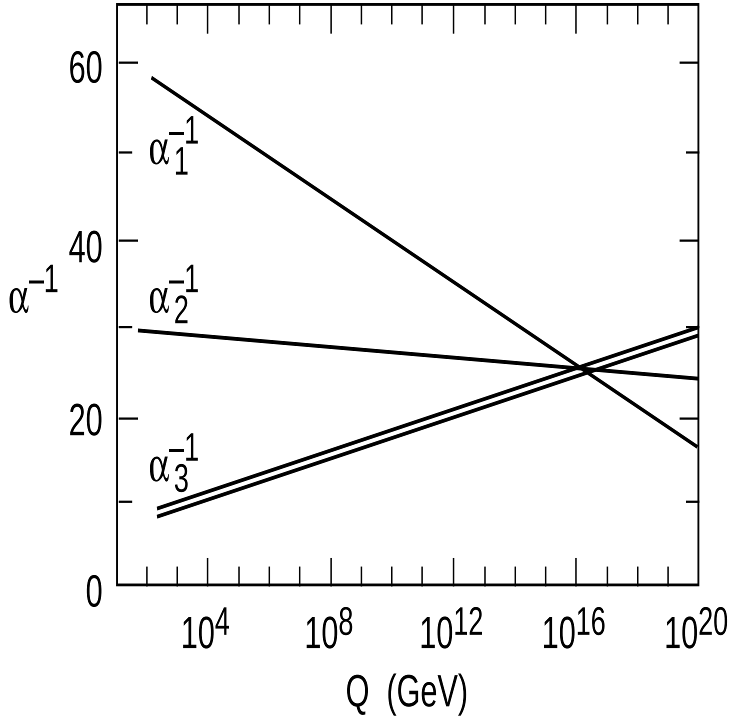
Supersymétrie



Dimension Supplémentaires





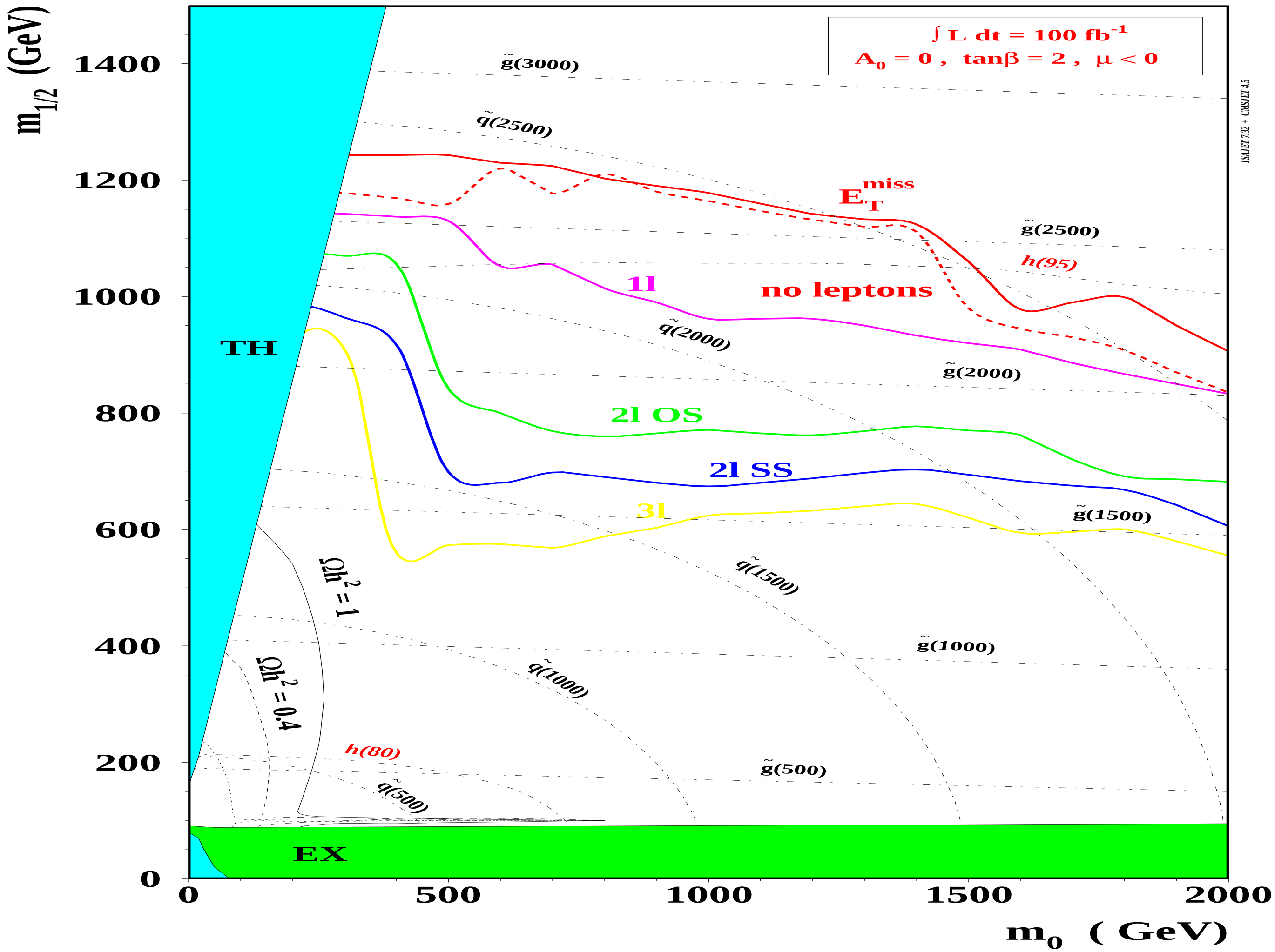


Unification, simplicité sous jacente?

$\Lambda_{\rm unif} \sim 2\ 10^{16}$GeV si $m_{susy} \sim 1TeV$

$\Lambda_{\rm unif} \sim 1 - 100$ TeV dans des modeles extra-dim! sans cependant l'assurance de decouvertes de particules nouvelles a l'echelle du TeV.

Recherche de Nouvelles Particules: Synergie: Collisionneurs-Cosmo-Astro: mesures de prcision, Exemple: SUSY au LHC: si cosmo correct on a une idee ou chercher



Budget Matiere et Precision 3: Test de la cosmologie

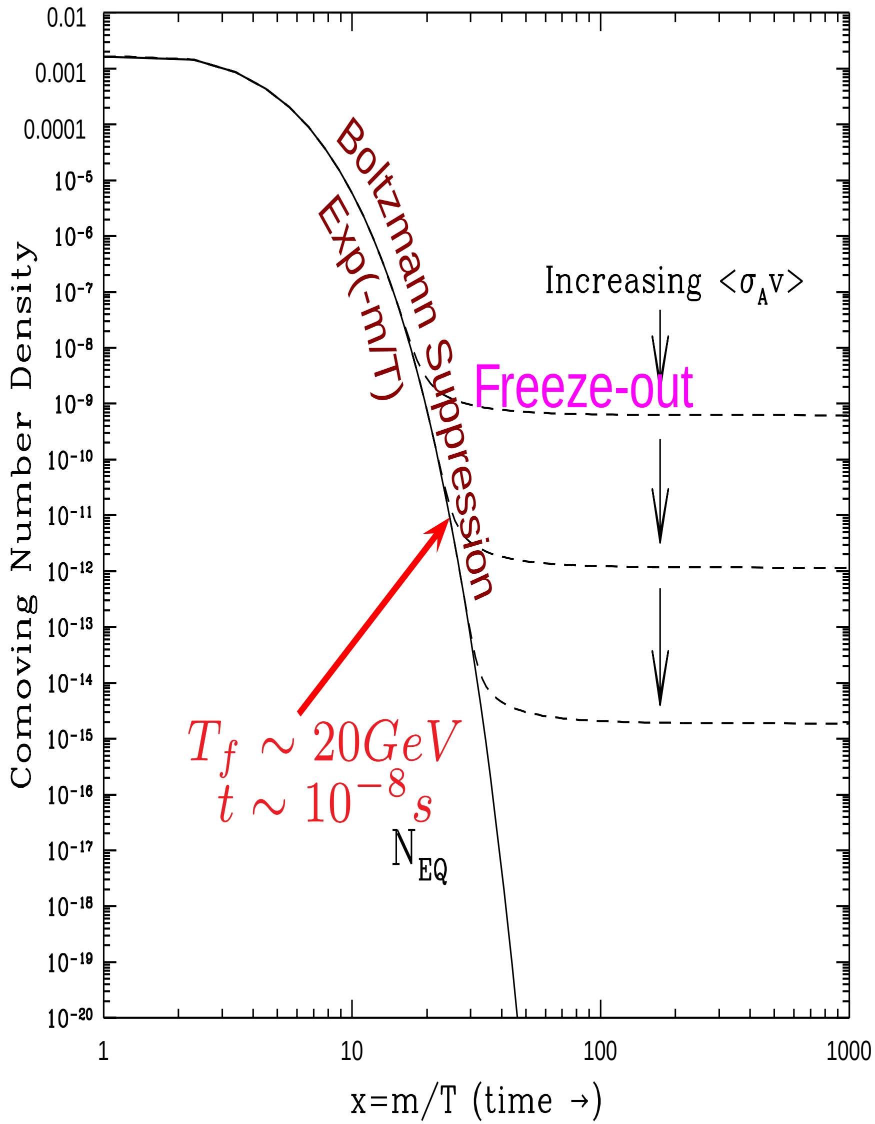
mesures actuelles donnent 2σ $\boxed{0.094 < \omega = \Omega_{\rm DM}h^2 < 0.129}$ **(10%)**

future ((SNAP+)Planck) $\longrightarrow$ 2%

Physique des Particules $\leftrightarrow$Cosmologie à travers de ω

- is wholly New Physics
- Mais est ce que le LHC (et l'ILC) verra la meme physique?
- Nouveau paradigme pour une nouvelle precision
- ω jusqu'il y a qq annees servait a contraindre la NP: (choix des points LHC susy, benchmarks,....)
- Si une nouvelle physique est trouvee au LHC, quelle precision sur les experiences aux collisionneurs 9et sur la theorie) pour contraindre la cosmologie? (Allanach, Belanger, FB, Pukhov JHEP 2004)
- strategies/demandes sur la theorie et les collisonneurs pour etre a la hauteur de la precision future sur ω

Relic Density: derivation



- At first all particles in thermal equilibrium
- universe cools and expands: interaction rate too small to maintain equilibrium
- (stable) particles can not find each other: freeze out and leave a relic density

dilution due to expansion

$$dN/dt = -3HN - <\sigma v> (N^2 - N_{eq}^2)$$

$$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to X \qquad X \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

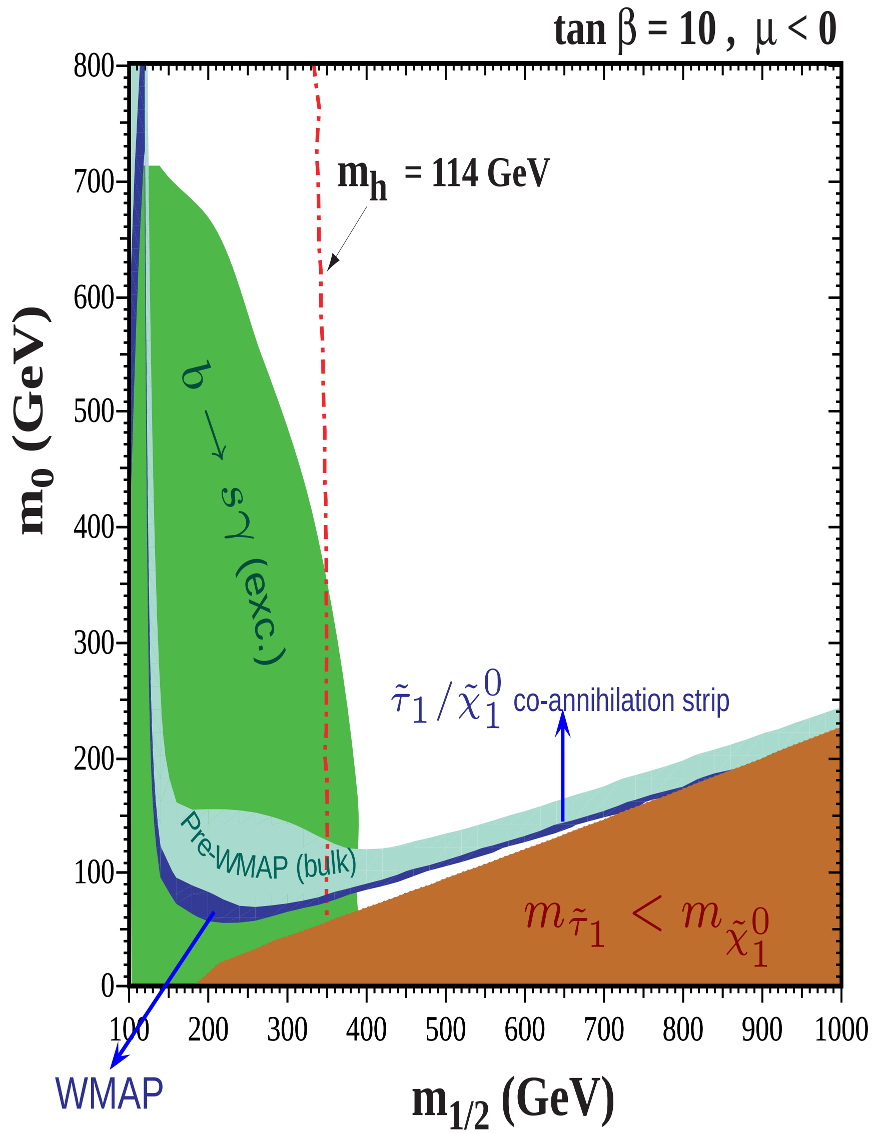
$$\Omega_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_1^0} N_{\tilde{\chi}_1^0} / \rho_{\rm cri},$$

$$\rho_{\rm cri} = 3H_0^2/8\pi G_N$$

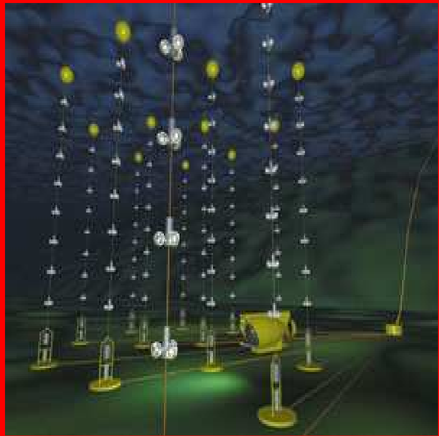
$$\rho_{\rm cri} = h^2 1.9\ 10^{-29} gcm^{-3} \to$$

$$\boxed{\Omega_{\tilde{\chi}_1^0} h^2 \propto 1/\sigma_{\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to X}}$$

- At early times Universe is radiation dominated: $H(T) \propto T^2$ ▶
  ($n_{eq}^{\gamma} \sim T^3$ relativistic particles are not Boltzmann suppressed)
- Expansion rate can be enhanced by some scalar field (kination), extra dimension
  $H^2 = 8\pi G/3\ \rho(1 + \rho/\rho_5)$, anisotropic cosmology,...
- Entropy non-conservation, e.g., through decays(entropy increase will reduce the relic abundance for example)

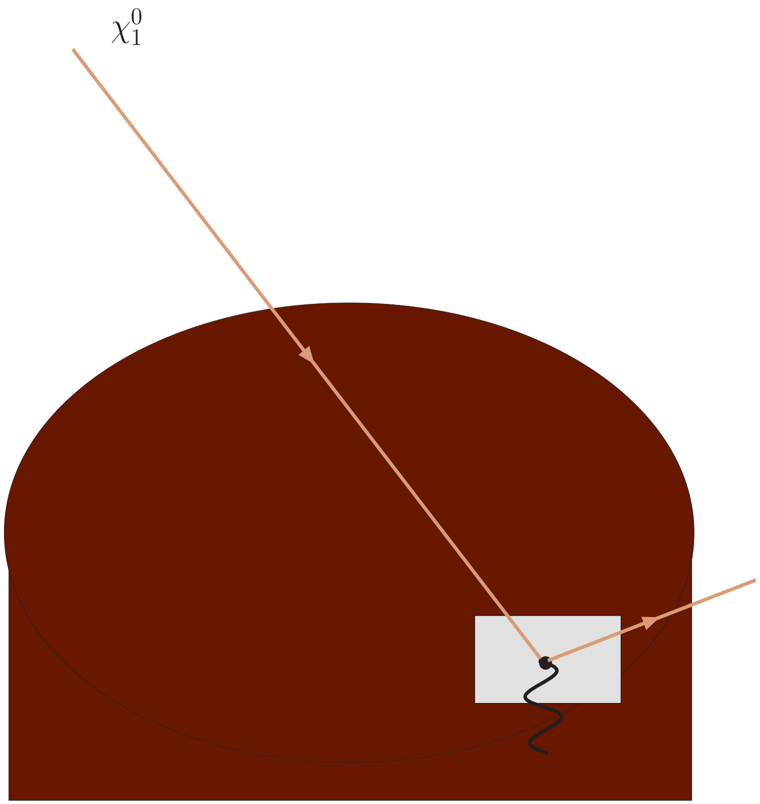


- Bulk region: bino LSP, $\tilde{l}_R$ exchange, (small $m_0, M_{1/2}$)
- $\tilde{\tau}_1$ co-annihilation: NLSP thermally accessible, ratio of the two populations $exp(-\Delta M/T_f)$ small m_0, $M_{1/2}: 350 - 900$GeV
- Higgs Funnel: Large $\tan\beta$, $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow A \rightarrow b\bar{b}, (\tau\bar{\tau})$, $M_{1/2}: 250 - 1100$GeV, $m_0: 450 - 1000$GeV
- Focus region: small $\mu \sim M_1$, important higgsino component, requires very large TeV m_0

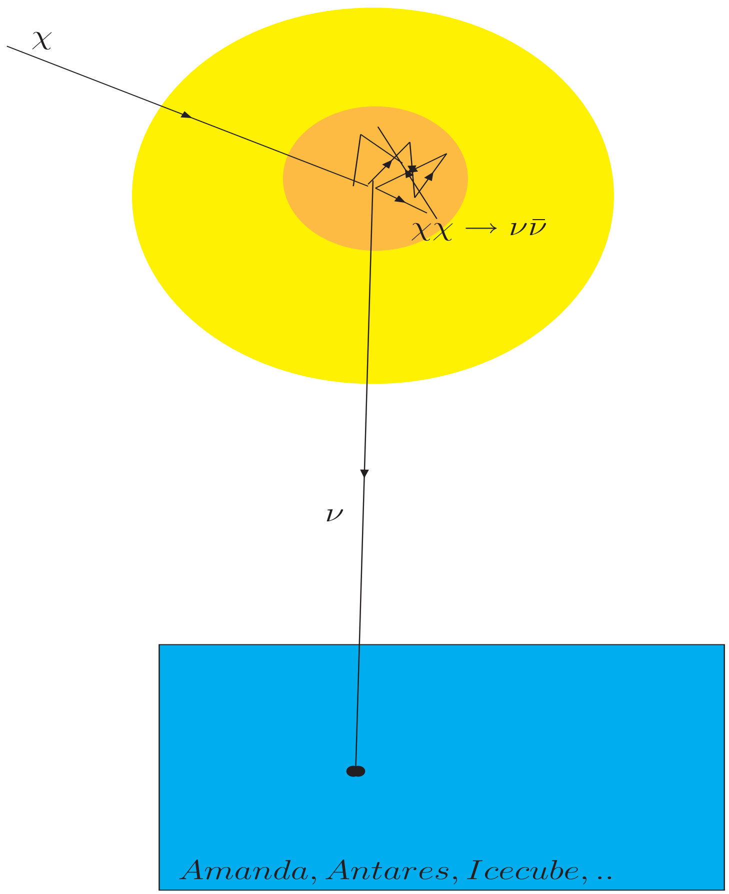


Detection Directe et Indirecte

$$\bar{p},\ e^{+}\ ,\gamma,\ \nu, \ldots$$



$CDMS, Edelweiss, DAMA, Genuis, ..$

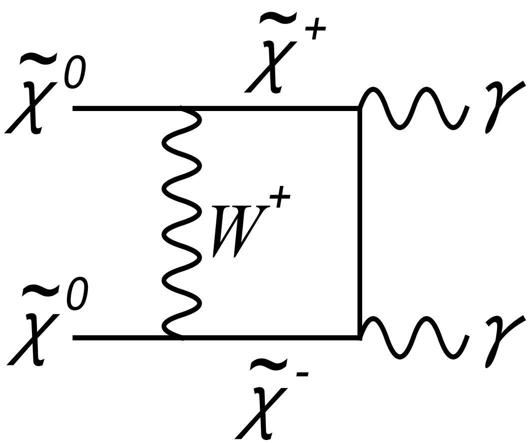


Annihilation en photons

$$\frac{d\Phi_\gamma}{d\Omega dE_\gamma} = \sum_i \underbrace{\frac{dN^i_\gamma}{dE_\gamma}\sigma_i v \frac{1}{4\pi m_\chi^2}}_{\text{Physique des Particules}} \underbrace{\int \rho^2 dl}_{\text{Astro}}$$

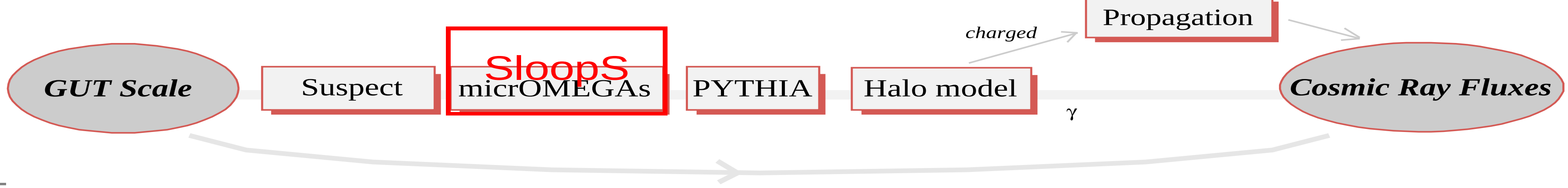
$\gamma' s$: Pointe la source, independent du modele de propagation

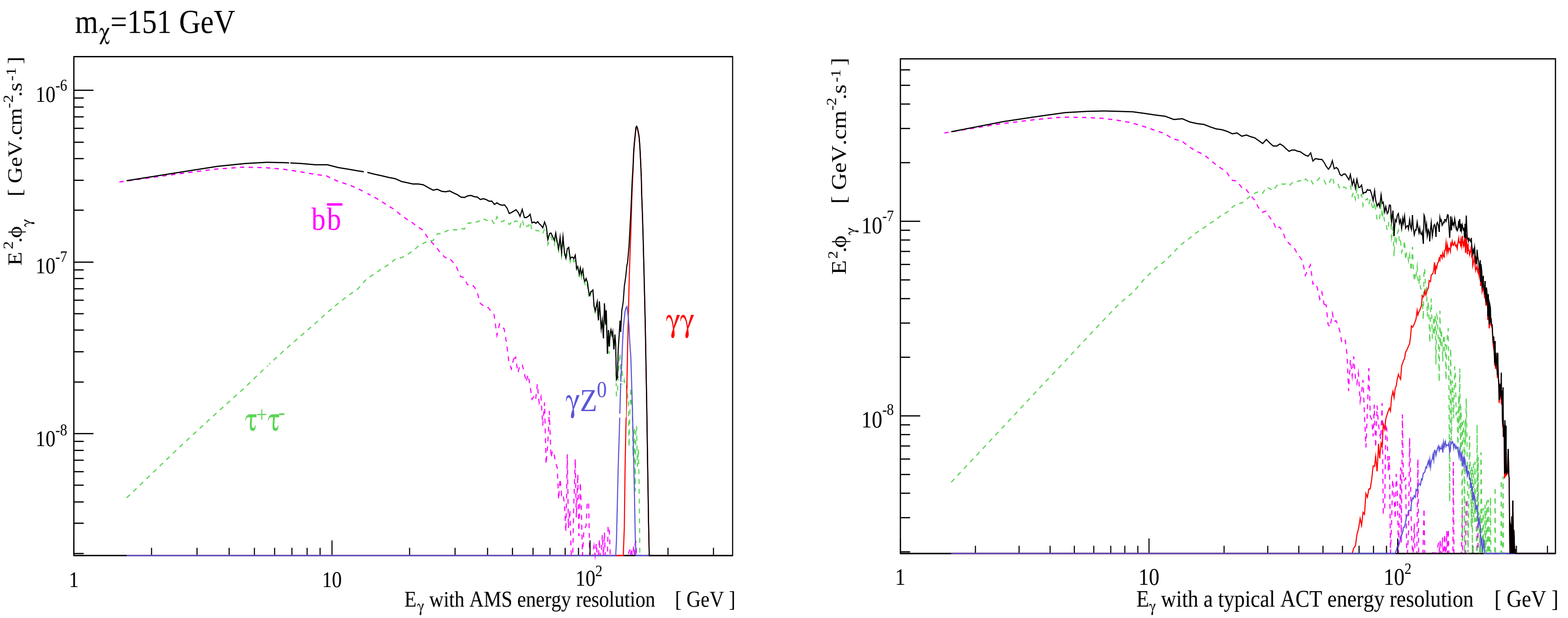
- spectre continue $\tilde{\chi}^0_1\tilde{\chi}^0_1 \to f\bar{f}, \ldots$, hadronisation/fragmentation ($\to \pi^0 \to \gamma$) via isajet/herwig
- photons mono-energetiques, $\gamma\gamma$, $Z\gamma$ final states



ACT: HESS, Magic, VERITAS, Cangoroo, ...

Space-based: AMS, GLAST, Egret,...





SIMULATION: Sylvie Rosier-Lees, Pierre Brun

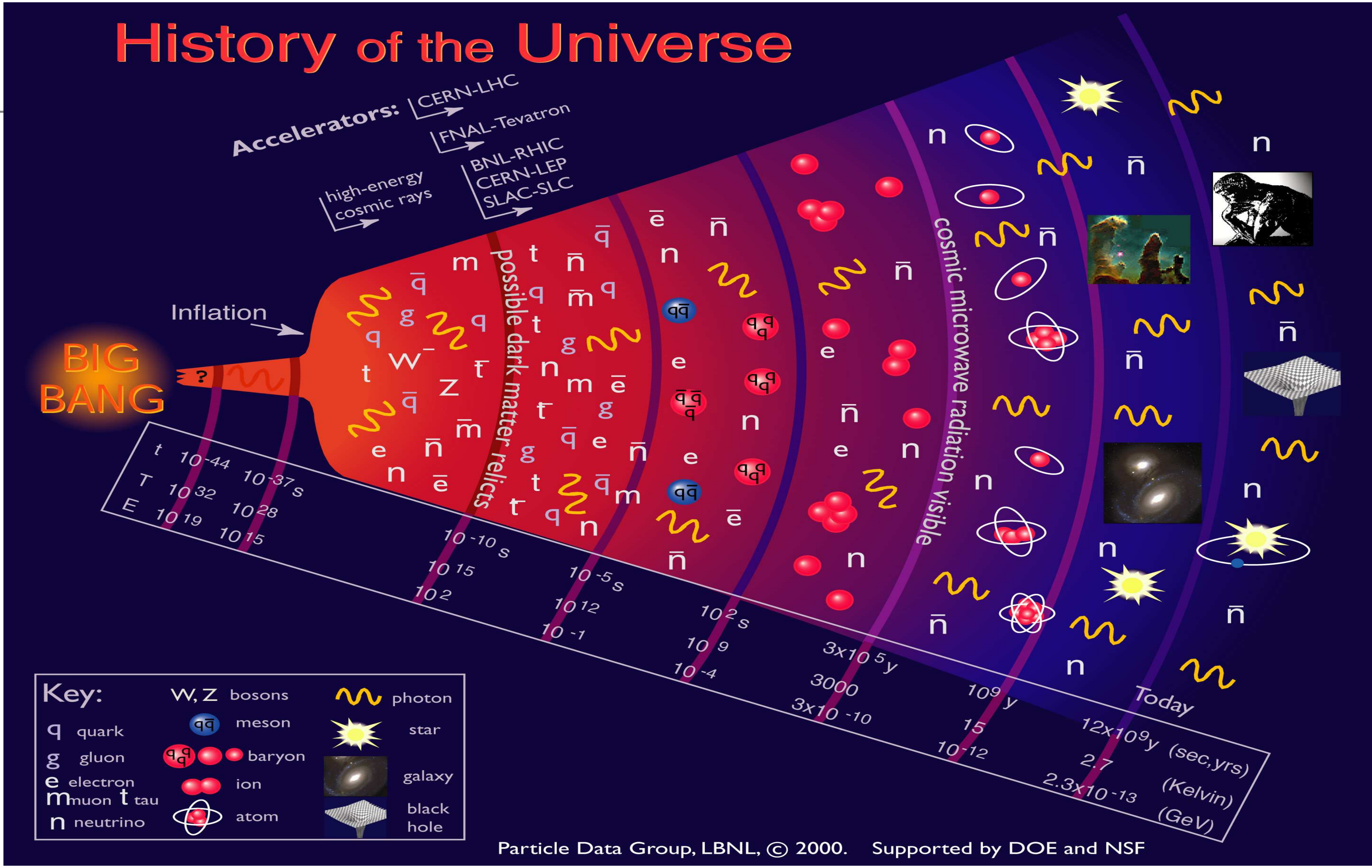
Parameterising the halo profile:

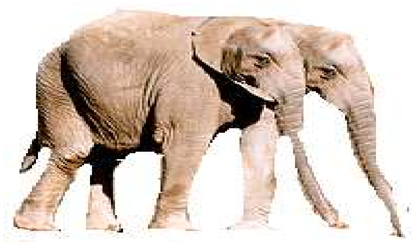
$(\alpha, \beta, \gamma) = (1, 3, 1)$, $a = 25$kpc. (core radius), $r_0 = 8kpc$ (distance to galactic centre), $\rho_0 = 0.3\,GeV/cm^3$ (DM density), opening angle cone 1^o

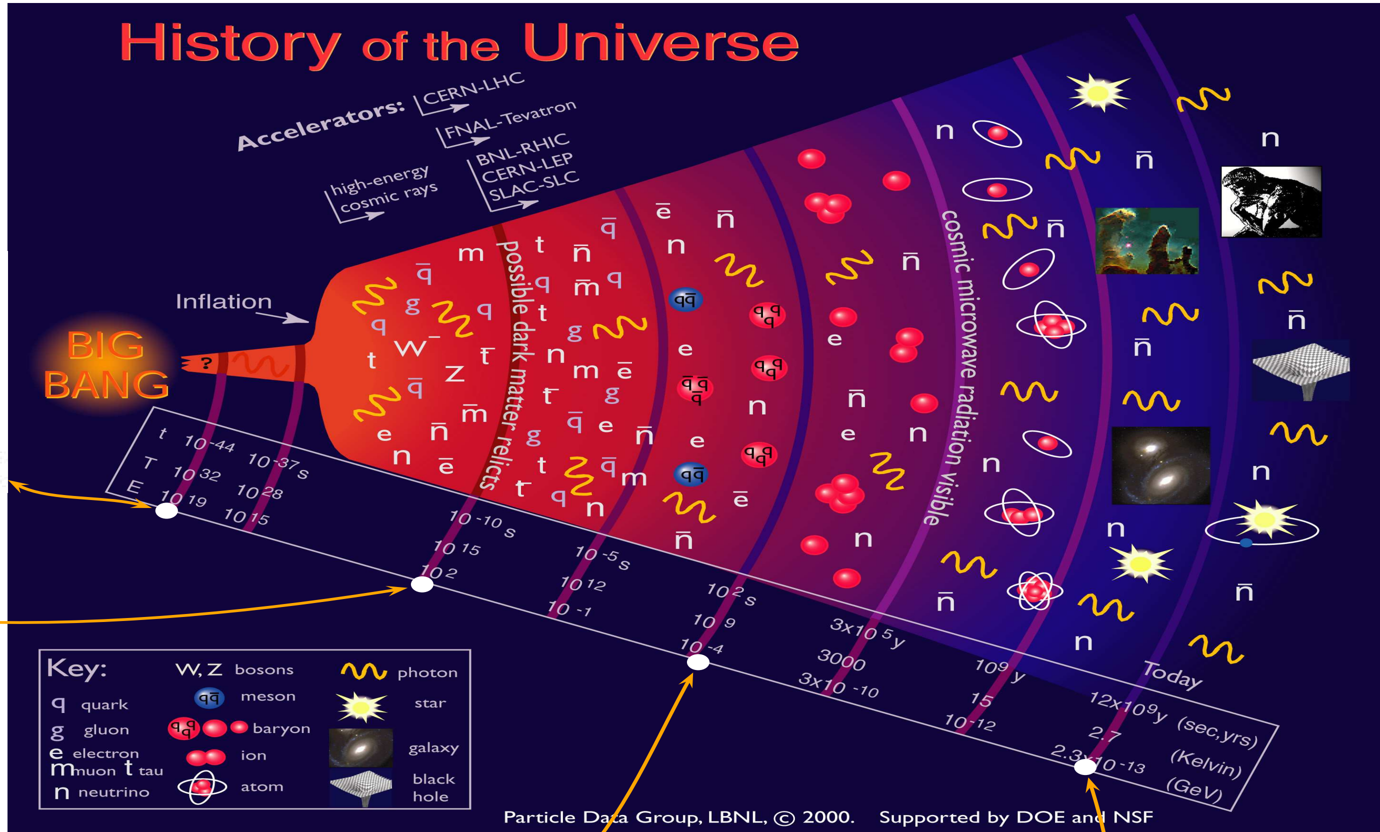
SUSY parameterisation

$m_0 = 113$GeV, $m_{1/2} = 375$ GeV, $A = 0$, $\tan\beta = 20$, $\mu > 0$

γ lines could be distinguished from diffuse background


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10 -44 10 -37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF





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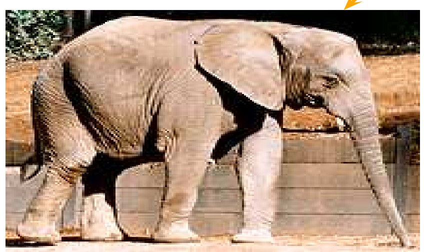

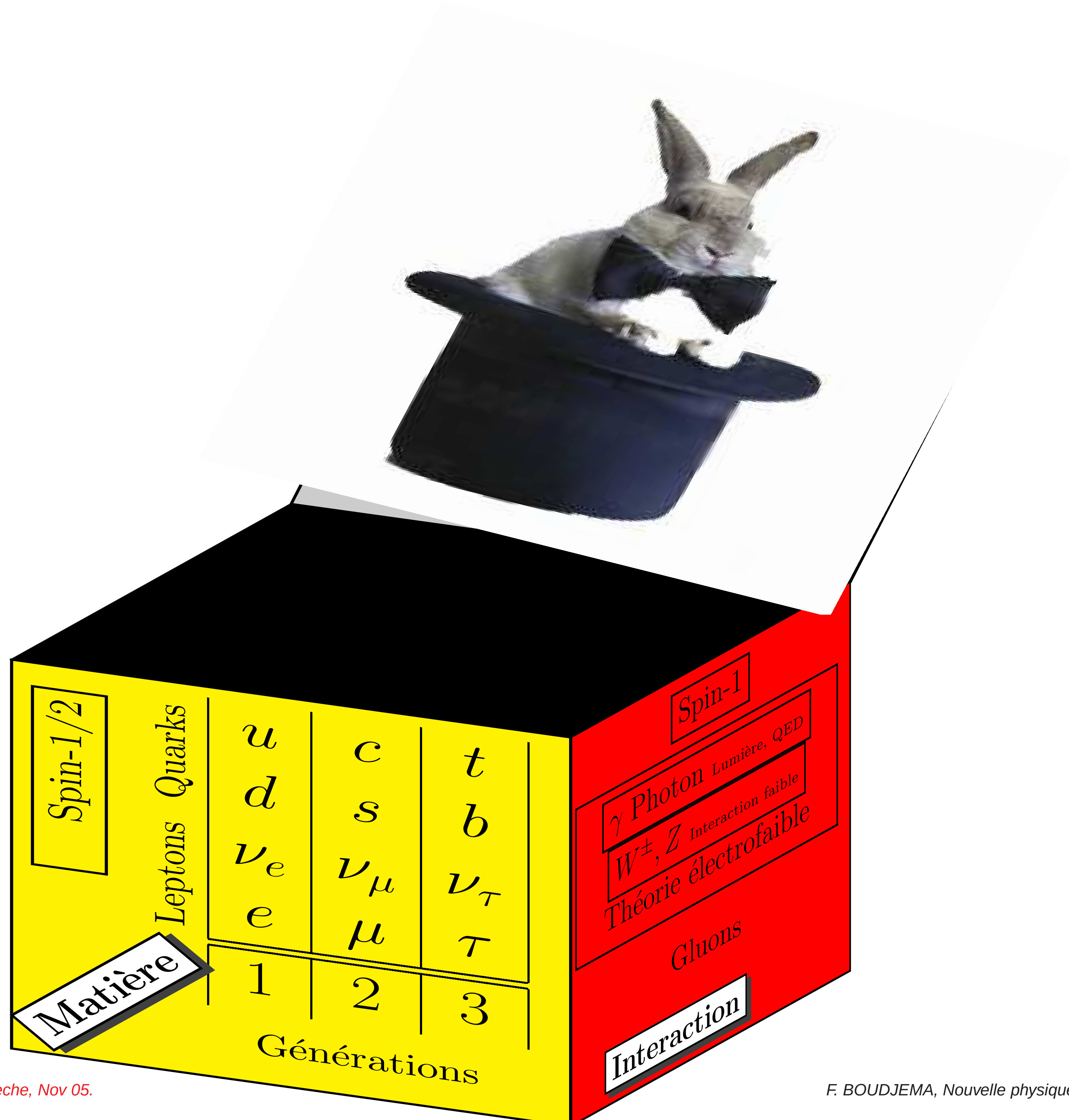
Spin-1/2
Leptons
Quarks
u d ν_e e
c s ν_μ μ
t b ν_τ τ
1 2 3
Générations
Matière
Spin-1
γ Photon Lumière, QED
$W^\pm, Z$ Interaction faible
Théorie électrofaible
Gluons
Interaction