Particules Élémentaires, Gravitation et Cosmologie
Année 2007-'08

Le Modèle Standard et ses extensions

Where can new physics hide?

Particle Physics in one page

$$\mathcal{L}_{\sim SM} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}\not{D}\psi$$ *The gauge sector* (1)

$$+\psi_i\lambda_{ij}\psi_j h + h.c.$$ *The flavour sector* (2)

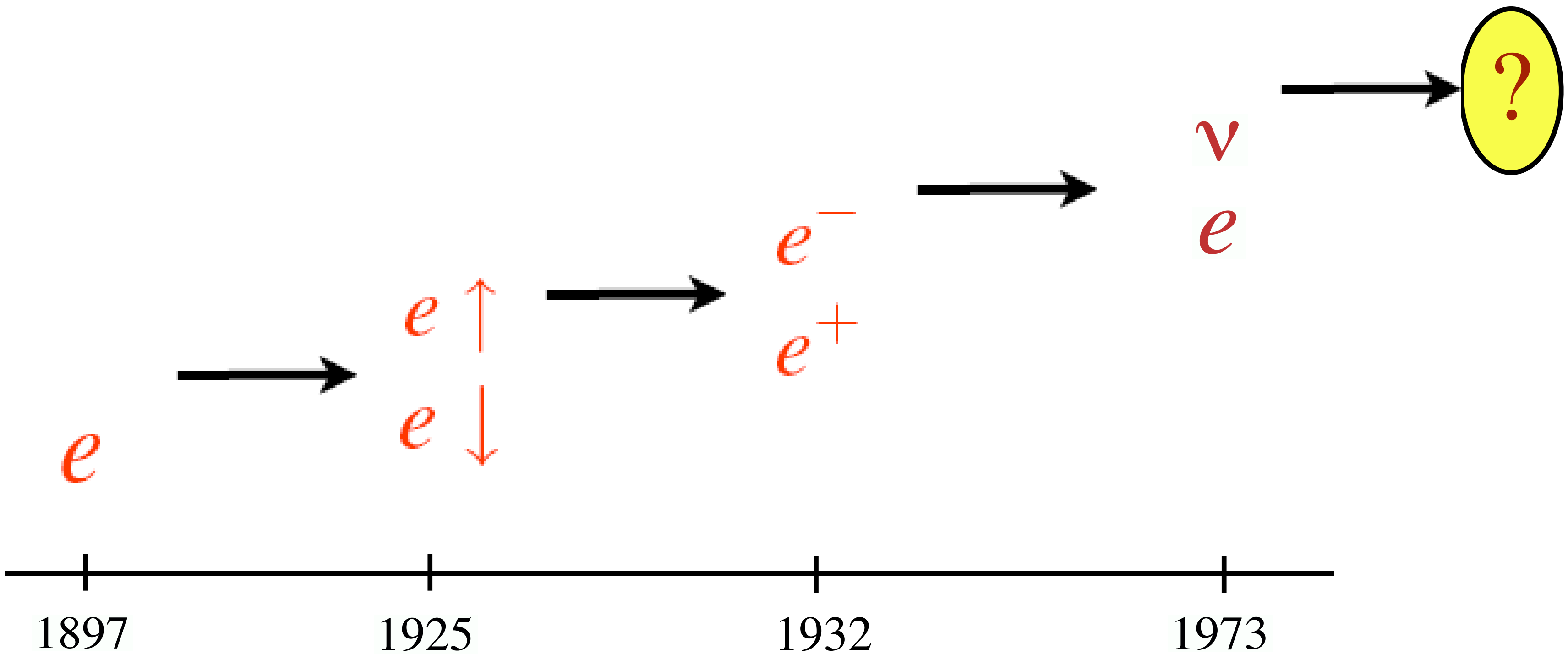
$$+|D_\mu h|^2 - V(h)$$ *The EWSB sector* (3)

$$+N_i M_{ij} N_j$$ *The ν-mass sector (if Majorana)* (4)

What could replace current Page 1?

The central question of particle physics

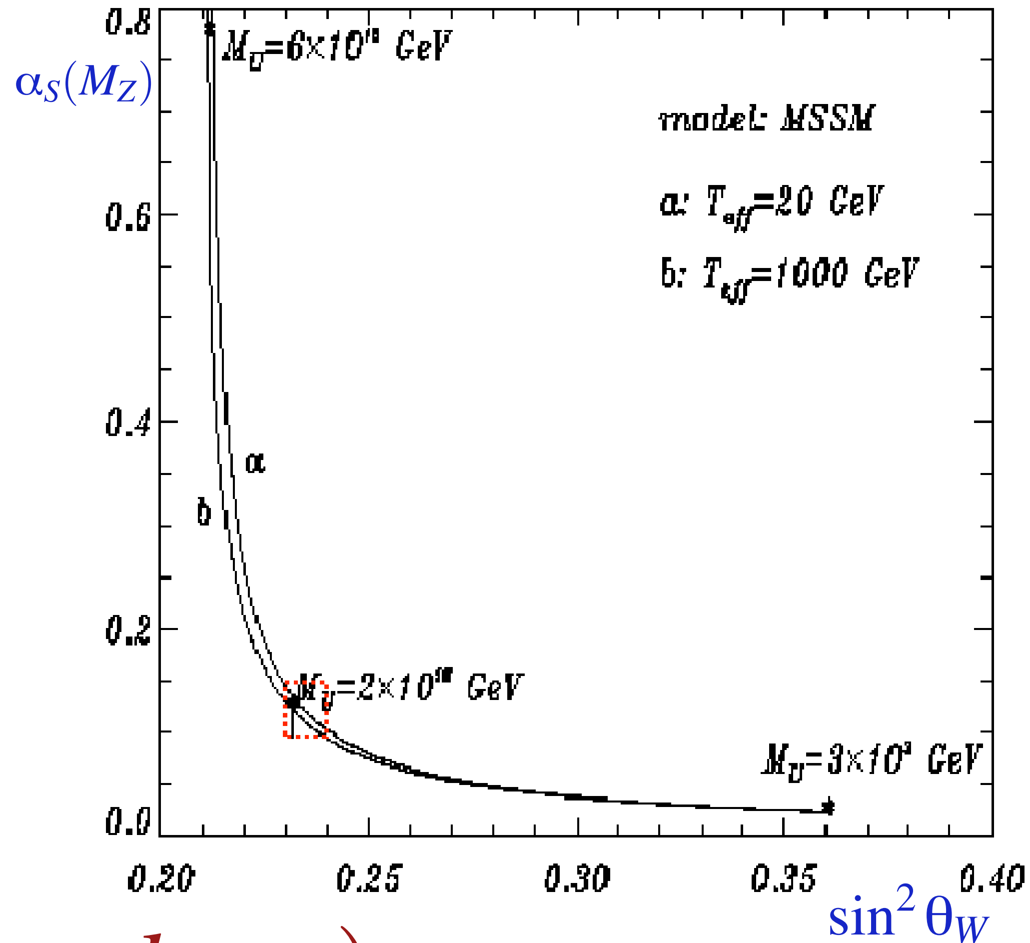
What is the next relevant symmetry in particle physics, if any?



(The key to the economy of equations)

Have symmetries exhausted their role?

3 possible directions:



1. Unification:

$$e \quad \nu \quad u \quad d$$

2. Supersymmetry:

$$e \quad \tilde{e}$$

3. Strings:

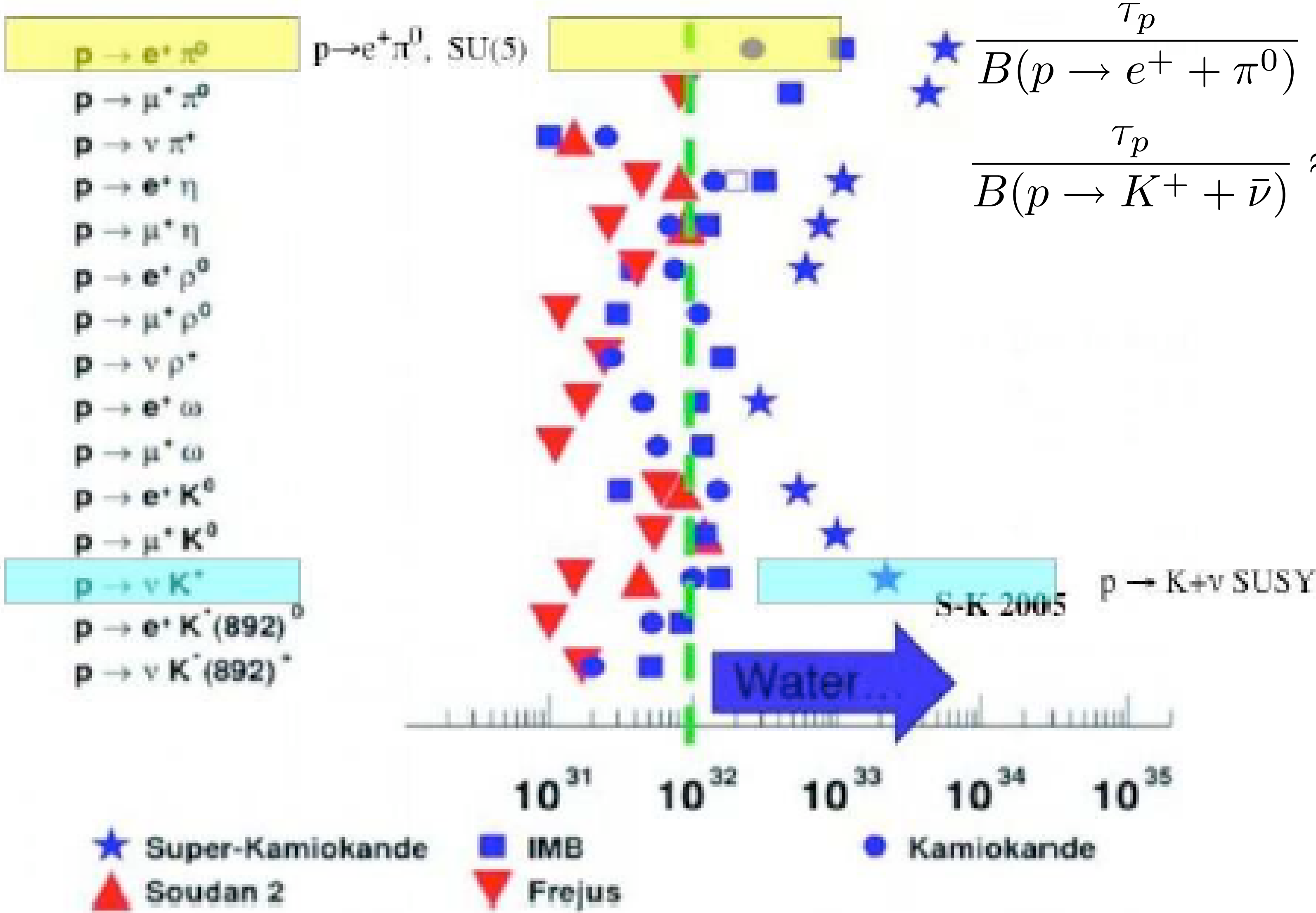
$$X(\sigma,\tau) \subset (e,\nu,u,d,\ldots)$$

not mutually exclusive

The Gauge Sector

Test proton decay

$\Leftarrow$ see lecture 11 by GV



In suspersymmetry:

$$\frac{\tau_p}{B(p \to e^+ + \pi^0)} = 10^{36\pm 2} \ years$$

$$\frac{\tau_p}{B(p \to K^+ + \bar{\nu})} \approx 10^{32 \div 36} \ years$$

Proton Decay

Theory:

$$\frac{\tau_p}{B(p \to e^+ + \pi^0)} = 10^{36\pm2} \ years$$

$$\frac{\tau_p}{B(p \to K^+ + \bar{\nu})} \approx 10^{32 \div 36} \ years$$

Present knowledge (SK):

$\geq 5 \cdot 10^{33}$ *years* | $\geq 6.7 \cdot 10^{32}$ *years*

Future: Megaton Detector (x 10 years):

$\approx 10^{35}$ *years* | $\approx 2 \cdot 10^{34}$ *years* ?

Future: Liquid Argon 100 kTon (x 10 years):

$\approx 2 \cdot 10^{34}$ *years* | $\approx 2 \cdot 10^{34}$ *years* ? ?

Not a easy task, to say the least

The Flavour Precision Tests

$\Leftarrow$ see my seminars 1,2

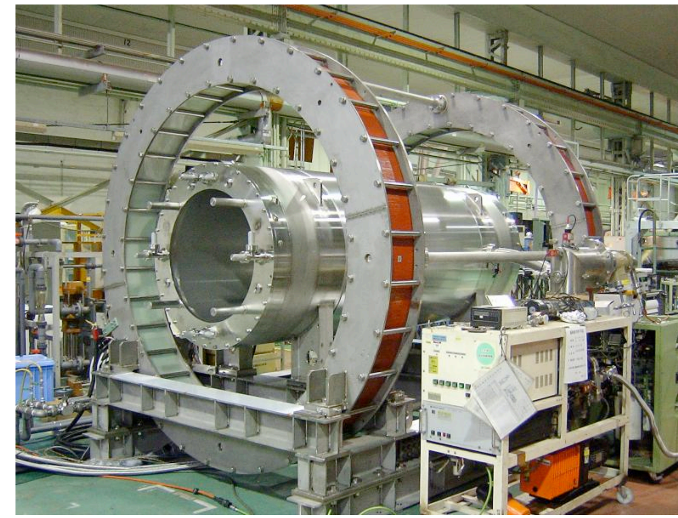
($\Rightarrow$ = of special interest for the future)

	Observable	elementary process	exp. error	theor. error
	ϵ_K	$\bar{s}d \to \bar{d}s$	1%	$10 \div 15\%$
$\Rightarrow$	$K^+ \to \pi^+\bar{\nu}\nu$	$s \to d\ \bar{\nu}\nu$	70%	3%
$\Rightarrow$	$K^0 \to \pi^0\bar{\nu}\nu$	$s \to d\ \bar{\nu}\nu$		1%
	Δm_{Bd}	$\bar{b}d \to \bar{d}b$	1%	25%
	$A_{CP}(B_d \to \Psi K_S)$	$\bar{b}d \to \bar{d}b$	5%	$< 1\%$
	$B_d \to X_s + \gamma$	$b \to s + \gamma$	10%	$5 \div 10\%$
	$B_d \to X_s + ll$	$b \to s + ll$	25%	$10 \div 15\%$
	$B_d \to X_d + \gamma$	$b \to d + \gamma$		$10 \div 15\%$
	$B_d \to \bar{l}l$	$\bar{b}d \to \bar{l}l$		10%
	$B_d \to X_d + \bar{l}l$	$b \to d + \bar{l}l$		$10 \div 15\%$
	Δm_{Bs}	$\bar{b}s \to \bar{s}b$	$< 1\%$	25%
$\Rightarrow$	$A_{CP}(B_s \to \Psi\phi)$	$\bar{b}s \to \bar{s}b$		1%
$\Rightarrow$	$B_s \to \bar{l}l$	$b\bar{s} \to \bar{l}l$		10%

My own favorite test of Flavour Physics

⇐ see my seminar 1

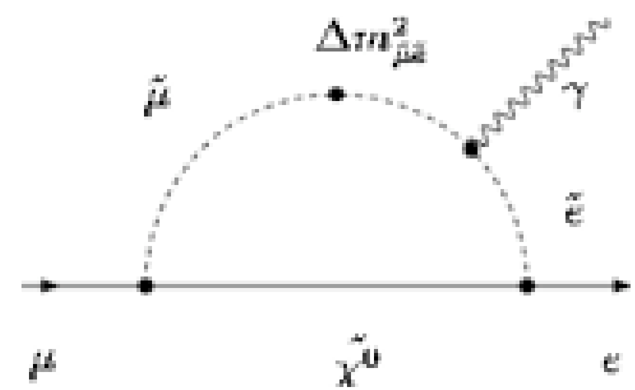
$$\mu \rightarrow e + \gamma$$



(not only the LHC)

Current limit $BR(\mu \rightarrow e + \gamma) < 1.2 \cdot 10^{-11}$

An experiment, MEG, just starting at PSI aiming at a factor of 100 better sensitivity



Not in the SM!

Two good reasons to believe in it:

1. Unification
2. Neutrino oscillations

ν - Masses

$$\mathcal{L}^{(\nu-mass)} = L_i \lambda^{\nu}_{ij} N_j v + N_i M_{ij} N_j$$

(the 4th line of page 1)

$\Leftarrow$ see seminars by FF

1. Three DIRAC neutrinos $\quad M_{ij} = 0$

$\Rightarrow$ Neutrinos are Dirac spinors $(\nu_L, \nu_R \equiv N^C)$, like charged fermions

$\Rightarrow$ Lepton number is exactly conserved, like Baryon number

2. Three MAJORANA neutrinos $\quad |M_{ij}| >> |\lambda^{\nu}_{ij}| v$

$\Rightarrow$ A basic asymmetry between neutrinos and charged fermions

$\Rightarrow$ Lepton number badly broken

3. More than three light neutrinos $\quad |M_{ij}| \sim |\lambda^{\nu}_{ij}| v$

$\Rightarrow$ Not incompatible with current observations

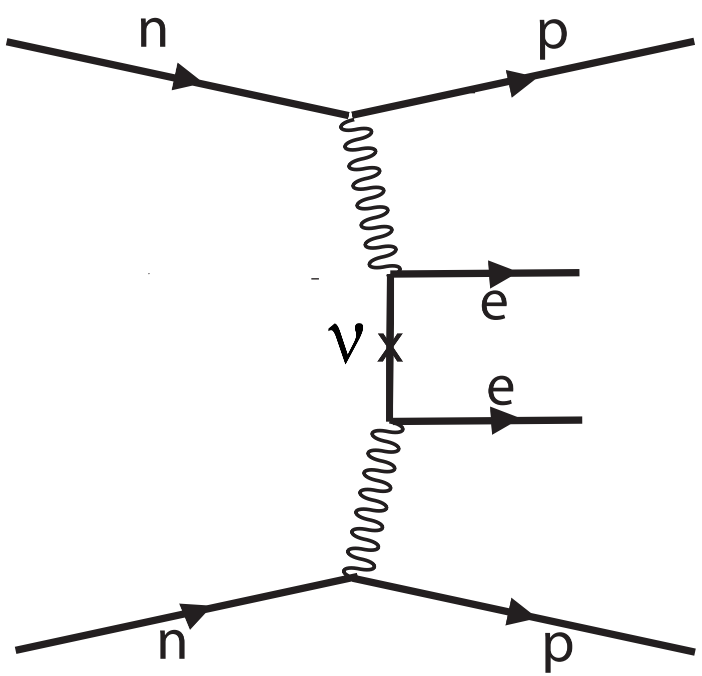
To decide between 1,2,3 at least as important as completing the "standard" picture

A way to decide

⇐ see seminars by FF

3. $\beta\beta_{0\nu}$- decay $(Z,A) \rightarrow (Z+2,A) + 2e$

only if Majorana, since L violated!



$$A \propto \Sigma_i V_{ei}^2 m_i M_{nucl} \equiv m_{ee} M_{nucl}$$

$$T_{1/2} \propto \frac{1}{|m_{ee}|^2 |M_{nucl}|^2}$$

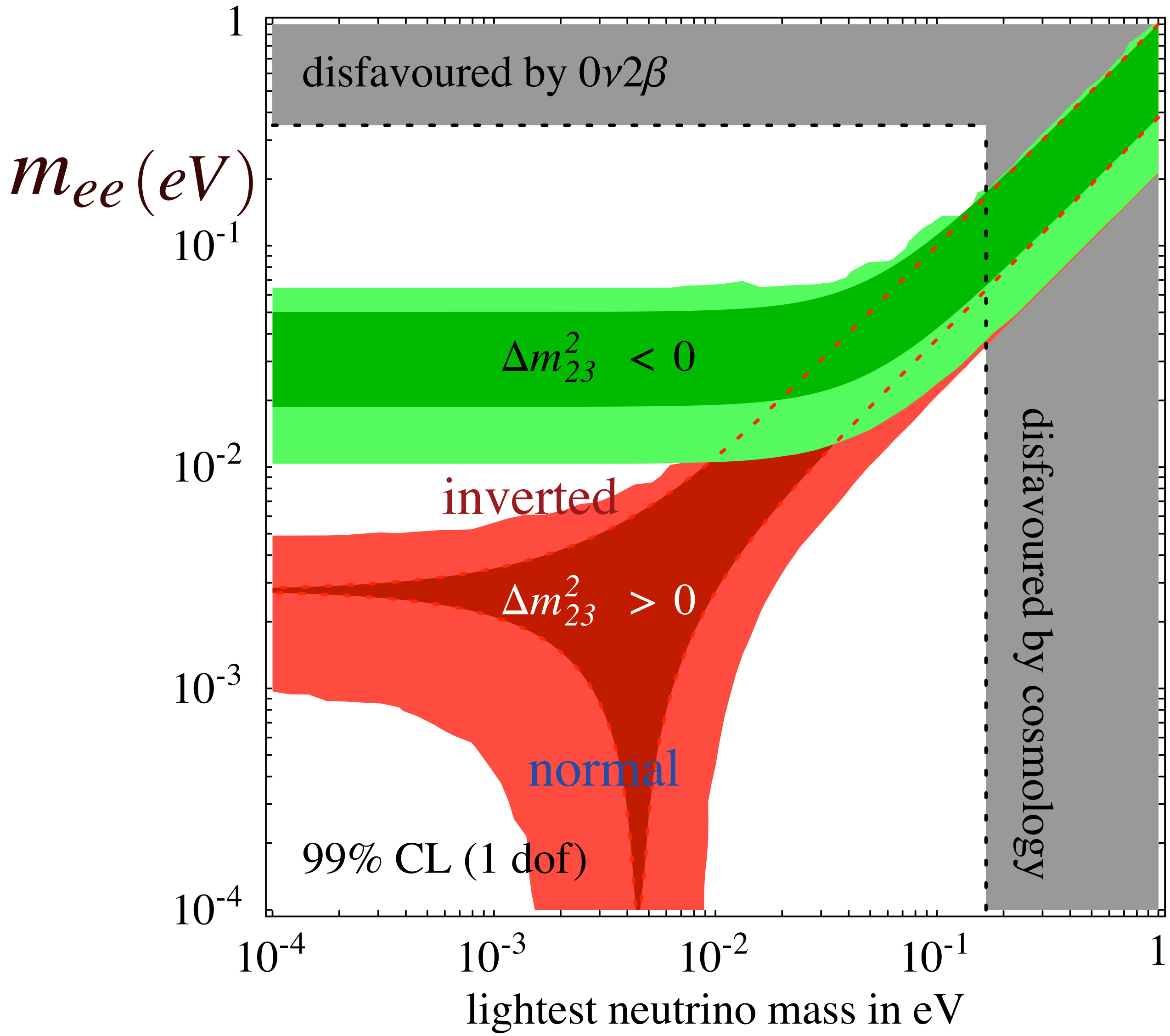
$$m_{ee} = c_{13}^2 (c_{12}^2 m_1 + s_{12} e^{2i\alpha} m_2) + s_{13}^2 m_3 e^{2i\beta}$$

$$\sigma_{th}(M_{nucl}) = O(M_{nucl})$$

Currently: a claimed observation at $0.17eV < |m_{ee}| < 2.0eV$

The experimental prospects in Neutrino-less double-beta decay

⇐ see seminars by FF



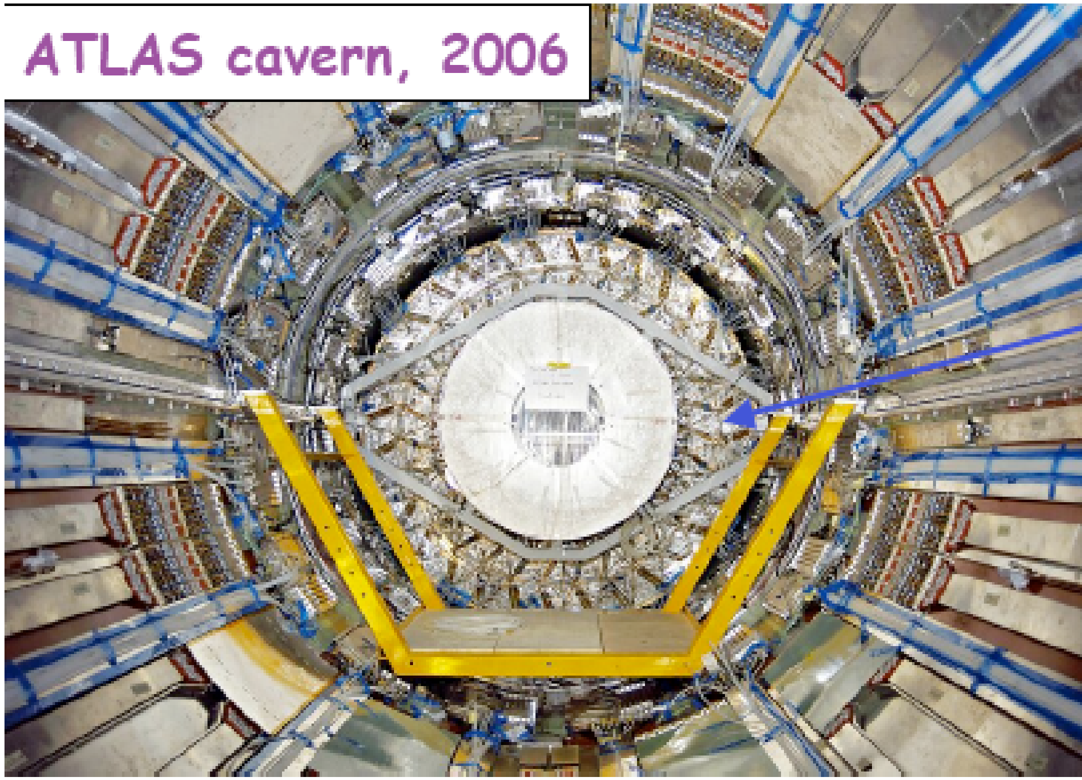
$$\Gamma(2\beta^{0\nu}) \propto |m_{ee}|^2$$

$$m_{ee} = \Sigma_i V_{ei}^2 m_i$$

Exp.s promise a few x 10 meV

significant (although maybe not enough)

The Large Hadron Collider: where will it lead us?



ATLAS cavern, 2006

Due to start operating in a few months from now

CMS cavern, 2006

The very first exploration of a crucial energy scale

In all of particle physics, as known today: Λ_{QCD}, $G_F^{-1/2}$

A road map to follow the LHC data

1. Higgs-less: a "conservative" view ⇐ see my seminar 4

2. The "naturalness" problem of the Fermi scale ⇐ see lecture 9 by GV

a. Supersymmetry ⇐ see lecture 10 by GV

b. Goldstone symmetry ↕

c. Gauge symmetry in extraD

3. Dark Matter

4. The Planck/Fermi hierarchy ⇔ extraD

a. Gravity weak by flux in extraD

b. $G_F^{-1/2}/M_{Pl}$ as a red shift effect

c. Symmetry breaking by boundary conditions ⇐ see my seminar 4

Examples of supersymmetry signals

$\Rightarrow$ gluino/stop decays

$$pp \to \tilde{t}\tilde{\bar{t}} \to t\bar{t} + \not{E}_T$$

$$\hookrightarrow t + \chi^0$$

$$pp \to \tilde{g}\tilde{g} \to 2t\ 2\bar{t} + \not{E}_T$$

$$\hookrightarrow \tilde{t}\ \bar{t}$$

$$\hookrightarrow t + \chi^0$$

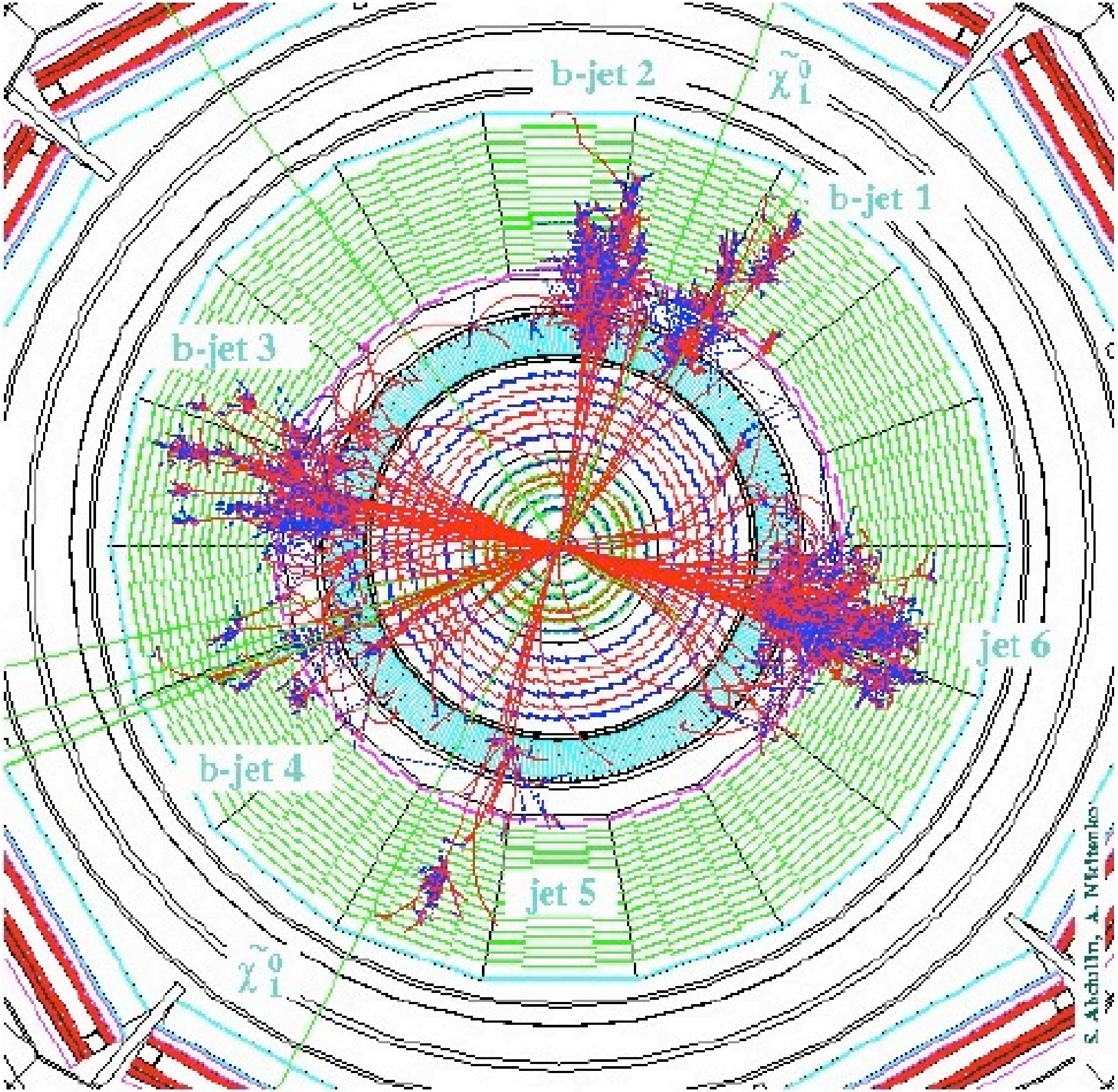
$\Rightarrow$ ew gauge/higgs-ino decays

$$pp \to \chi_1^{\pm}\chi_2^0 \to 3leptons + \not{E}_T$$

$$\hookrightarrow l\bar{l} + \chi^0$$

$$\hookrightarrow l\nu + \chi^0$$

A simulated event at the Large Hadron Collider



$m_{\tilde{g}} = 1266$ GeV

$m_{\tilde{u}_L} = 1450$ GeV

$m_{\tilde{t}_1} = 1026$ GeV

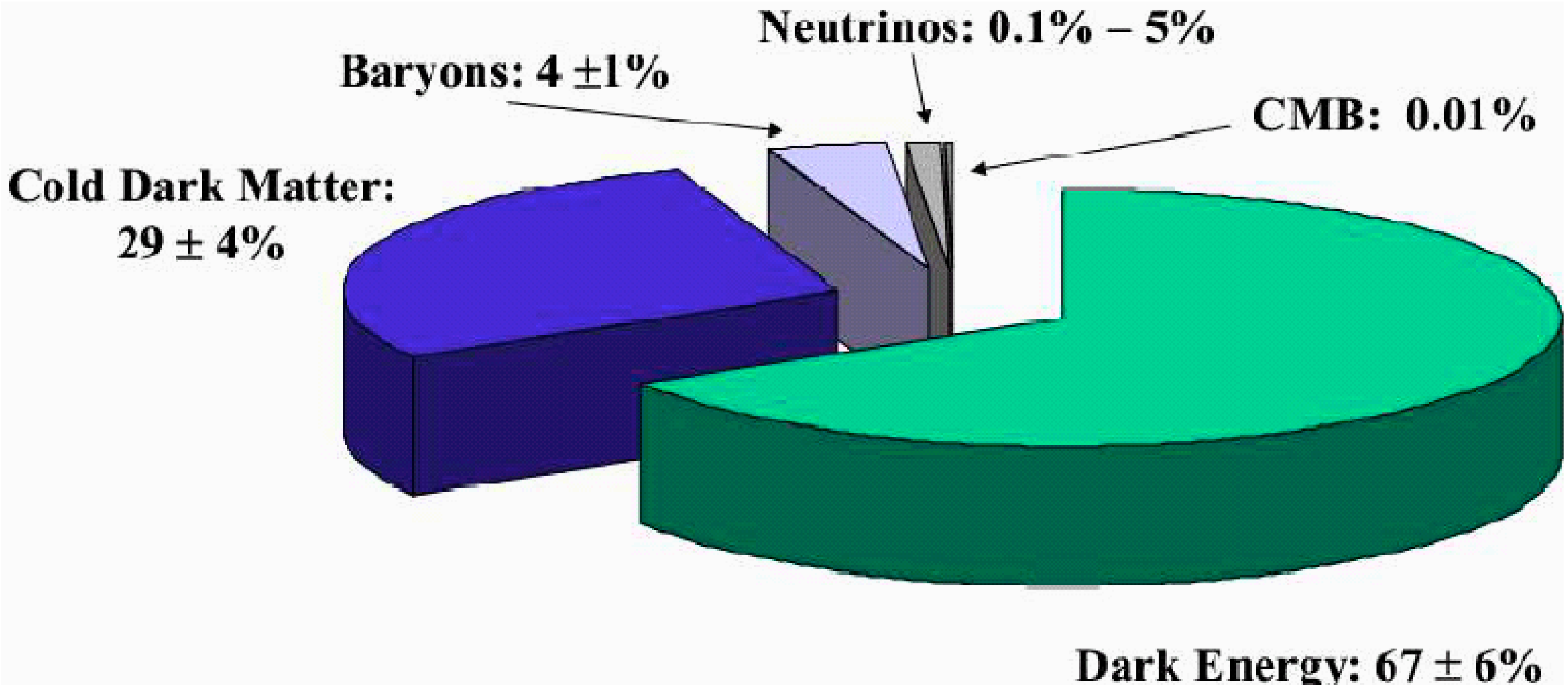
$m_{\tilde{\chi}^0_2} = 410$ GeV

$m_{\tilde{\chi}^0_1} = 214$ GeV

$m_h = 119$ GeV

A candidate for Dark Matter

The matter/energy components of the universe



with the most abundant ones of unknown nature

Calculating the relic abundance of a Weakly Interacting Massive Particle

Suppose you have a stable particle χ
that decouples from the hot primordial plasma by $\chi\chi \to ff$
with a cross section σ*. Then, for its relic density* Ω

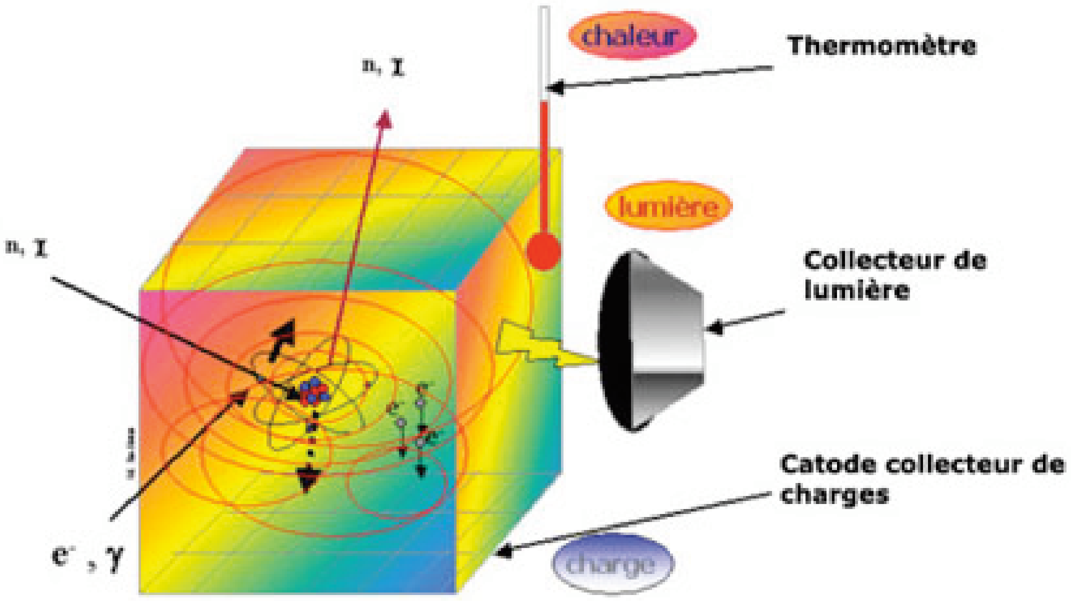
$$\Omega h^2 = \frac{688\pi^{5/2} T_\gamma^3 (n+1) x_f^{n+1}}{99\sqrt{5 g_*}(H_0/h)^2 M_{\rm Pl}^3 \sigma} \approx 0.2 \frac{pb}{\sigma} \quad \Leftarrow$$

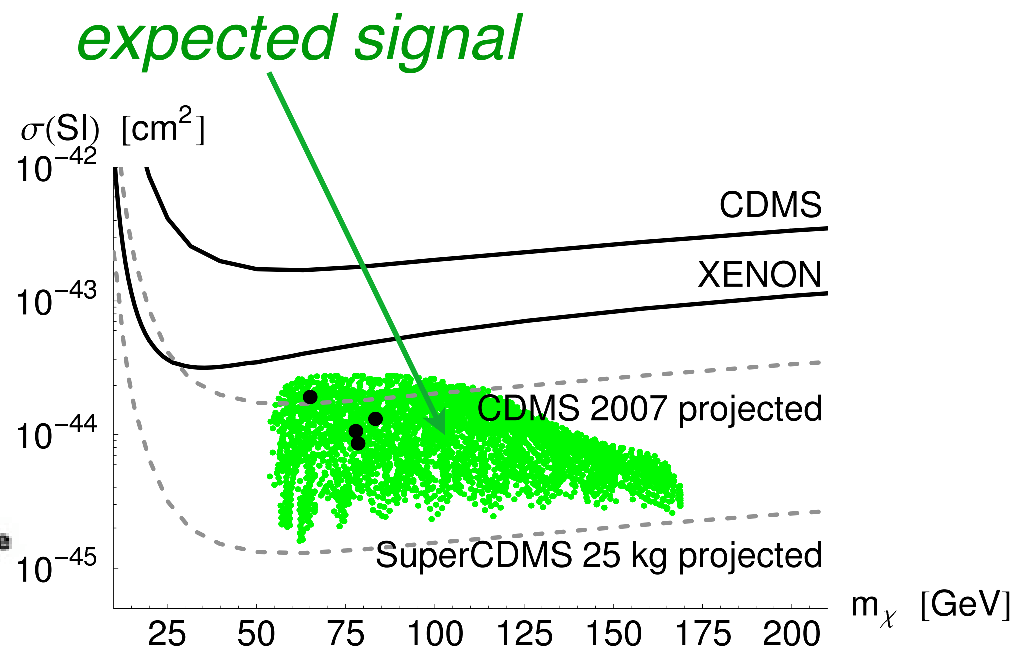
and $\sigma \approx pb$ *is a typical weak interaction cross section*
for a particle of mass $m_\chi \approx G_F^{-1/2}$

against the observed $\Omega_{\rm DM} h^2 = 0.113 \pm 0.009$ $\Leftarrow$

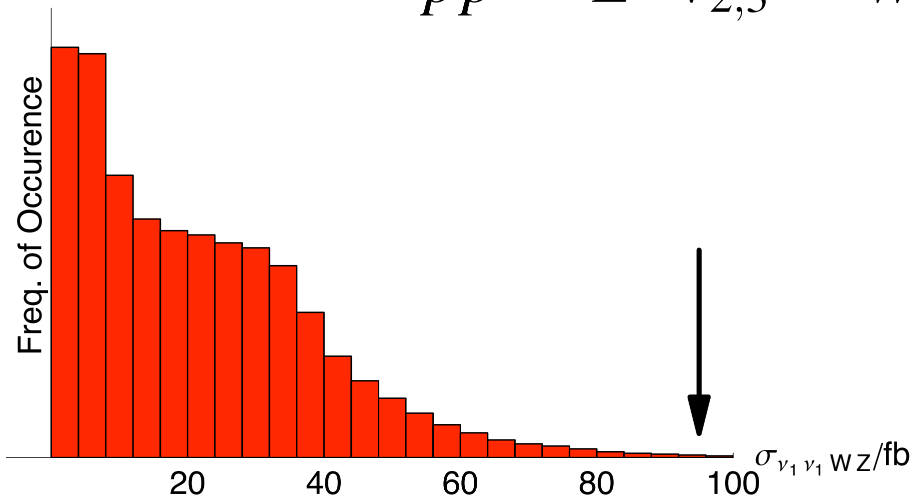
$\Rightarrow$ Perhaps DM is made of WIMPS

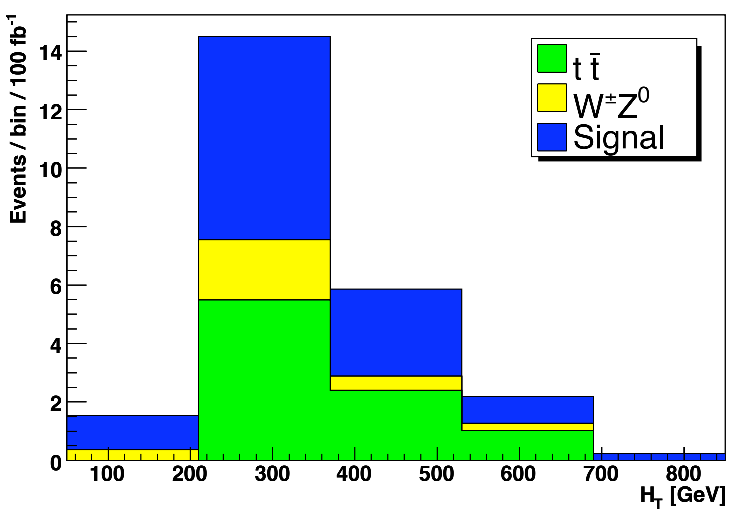
Direct DM detection versus LHC





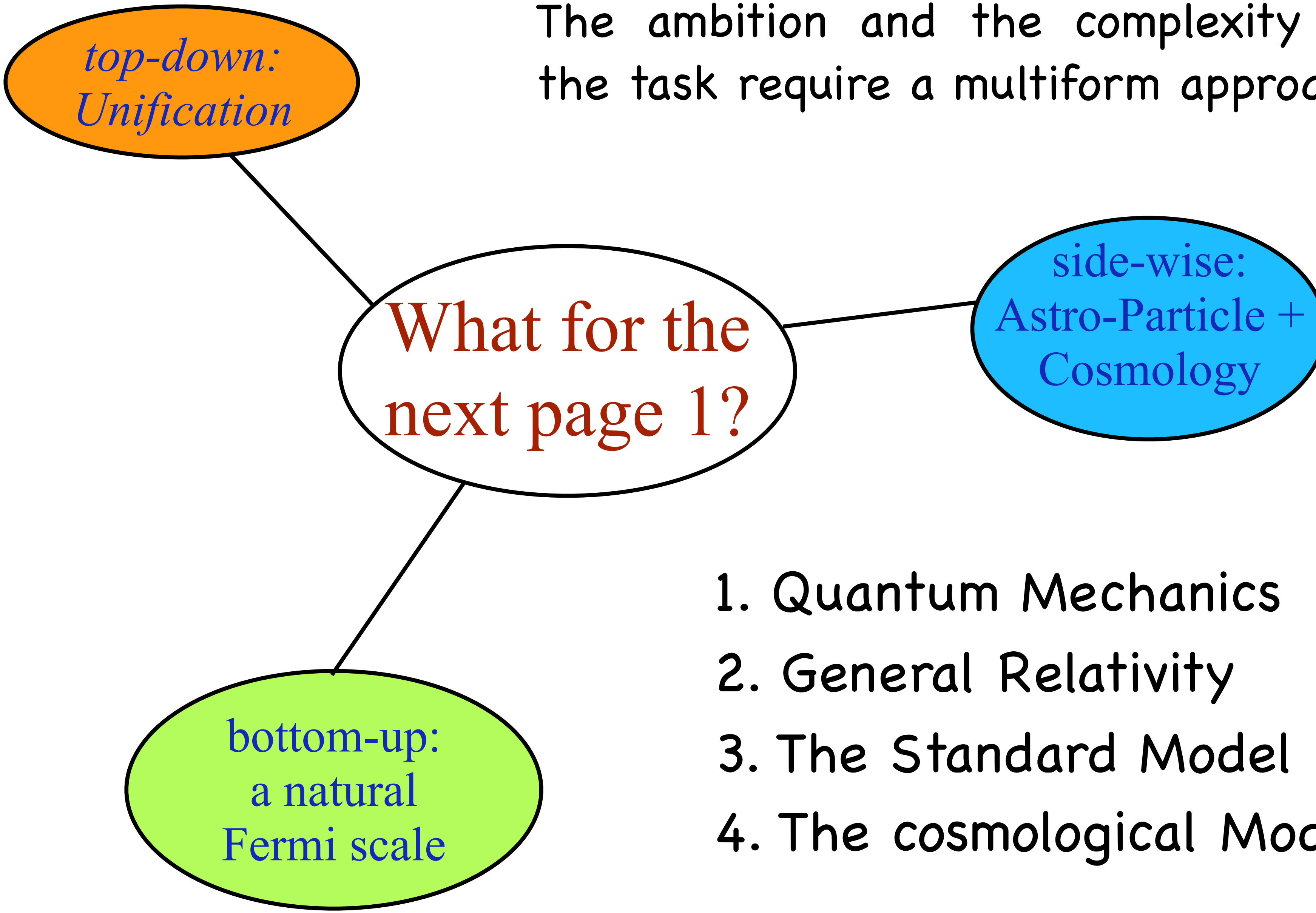
$$pp \rightarrow E^{\pm}\nu_{2,3} \rightarrow W^{\pm}Z\nu_1\nu_1 \rightarrow 3l + \not{E}_T$$





(Not a) Conclusion

The ambition and the complexity of the task require a multiform approach



1. Quantum Mechanics
2. General Relativity
3. The Standard Model
4. The cosmological Model