Last time: hierarchy problem \rightarrow new physics at $\sim$TeV scale

Sohn's: strong coupling (RS, large X-dim)
Cancellations (SUSY, CH, GHU)

Or, get rid of the Higgs! Alternative EWSB mechanisms without an elementary scalar: Technicolor, Higgsless

Another reason to expect new physics: Dark Matter

Cosmological observations indicate $\rho_m \gg \rho_c$

$\sim$ non-relativistic matter

\rightarrow stable ($t > 10^{10}$ yrs), heavy, non-baryonic, no el. charge,
no QED charge (from exotic isotope searches) particle.
No SM candidate! \implies first observational evidence for BSM.

DM detected through gravity. Gauge charges? None-
irrelevant for colliders. Yes (weak only allowed \implies Weakly
Interacting Massive Particle, or WIMP) \implies may be discovered
at colliders!
"Thermal Delic" \[ \begin{array}{c}
\text{SM} \\
\text{Sm}
\end{array} \]

\[ \begin{array}{c}
T > \lambda_x \text{ Equilibrium: } \ n_x(B^0) \geq H \Rightarrow T^2 \\
M_{\chi}
\end{array} \]

\[ \begin{array}{c}
T \approx \lambda_x \text{ Decoupling: } \ n_x \approx \frac{M_{\chi}^2}{M_{\chi} \cdot b}
\end{array} \]

\[ \begin{array}{c}
T < \lambda_x \text{ Dilution: } \ n_x(t) \Rightarrow \frac{M_{\chi}^2}{M_{\chi} \cdot b} \cdot (\frac{T}{M_{\chi}})^3
\end{array} \]

\[ \begin{array}{c}
P_x(t) \approx \frac{M_{\chi}^2}{M_{\chi} \cdot b} \cdot n_x(t) \Rightarrow \frac{T^3}{M_{\chi} \cdot b}
\end{array} \]

For \( T = T_\text{c} \), \( b \approx \frac{1}{M_{\text{EW}}^2} \), get \( P_x \approx \text{finite} \) - "WIMP miracle".

\( \Rightarrow \) DM-EW scale connection! Many candidates in explicit ESM models

at the EW scale. Stable WIMP => "missing energy" signature

(model-independent, although scales are model-dep.)

(D) Unification: \( SU(3) \times SU(2) \times U(1) \rightarrow SU(5), SO(10) \)

Typical scales \( \gg \text{TeV, not directly relevant for colliders} \)

(E) Why Not? Examples: extra gauge groups \( (Z', W', q') \)

4th generation \( (t', b') \)

2-Higgs-Doublet models
Simple Extensions

1) Extra U(1) — a "Z'"

Must be broken \( \Rightarrow M_{Z'} \) free parameter

Assume it couples to both quarks and leptons; then at a hadron collider can search for

\[
\begin{array}{c}
\bar{q} \\
q \\
\end{array}
\begin{array}{c}
\rightarrow \ Z' \\
\rightarrow \ e^+ e^- \\
\end{array}
\]

\( l = e \) or \( \mu \)

(\( Z', Z' \rightarrow BGs \))

Search for resonance at \( (p_{Z'} + p_{e^-})^2 = M_{Z'}^2 \).

[Teuton search slides] \( \delta_{Z'} Br(Z' \rightarrow e^+ e^-) < f(M_{Z'}f_{Z'}) \)

Interpretation:

\[
L = \left( \sum_{\chi} (Q_{\chi i} \delta_{\chi i} Q_{\chi i} g_{\chi e} + U_{\nu i} \overline{\nu}_i U_{\nu i} g_{\nu e} + d_{\nu i} \overline{d}_{\nu i} g_{d_{\nu i}} + l_{\nu i} \overline{l}_{\nu i} g_{l_{\nu i}} + e_{\nu i} \overline{e}_{\nu i} g_{e_{\nu i}}) \cdot Z' \right)
\]

Free par's: \( 1 + 5 \times 3 = 16 \) (or \( 6 \) if flavor independence assumed)

\[
\delta(p^2 \rightarrow Z') = f(g_{\nu e}, g_{\nu e}, g_{e e}) ; \quad Br(Z' \rightarrow e^+ e^-) = \frac{\Gamma(e^+ e^-)}{\Gamma_{Z'}} = f(\text{all s})
\]
Current approach: pick a few points in the 6D space, place a bound on the mass.

[slide: interpretation of the bound]

What if you have a 2D model with parameters NOT corresponding to one of these random points?