Title: Particle Physics Lecture

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Collection: Particle Physics

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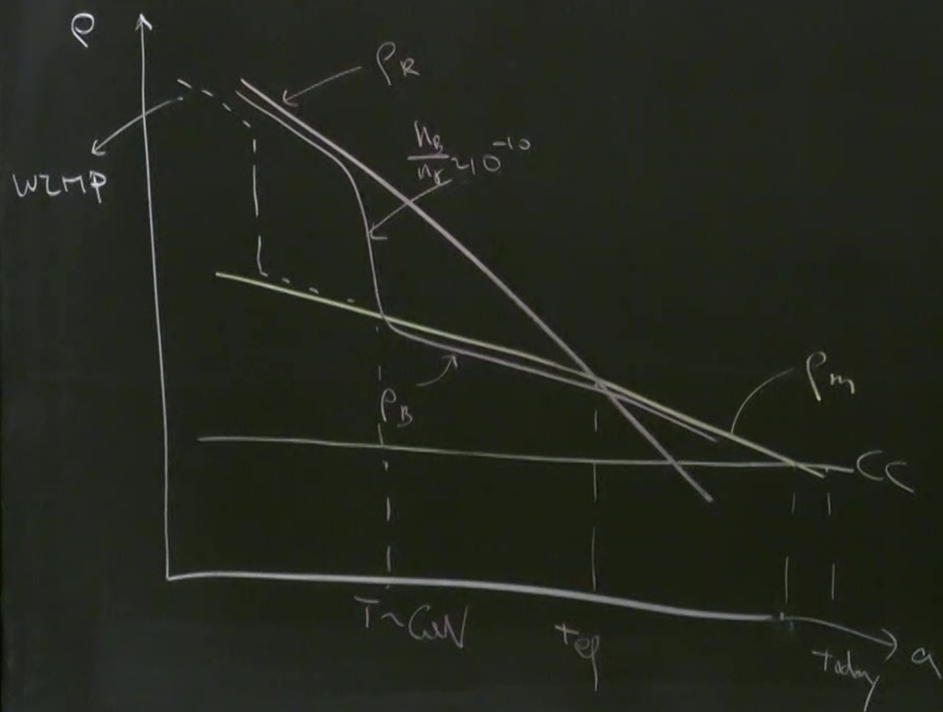
Lecture 8: WIMP



WIMP: SUSY lecture

"χ" Higgsino

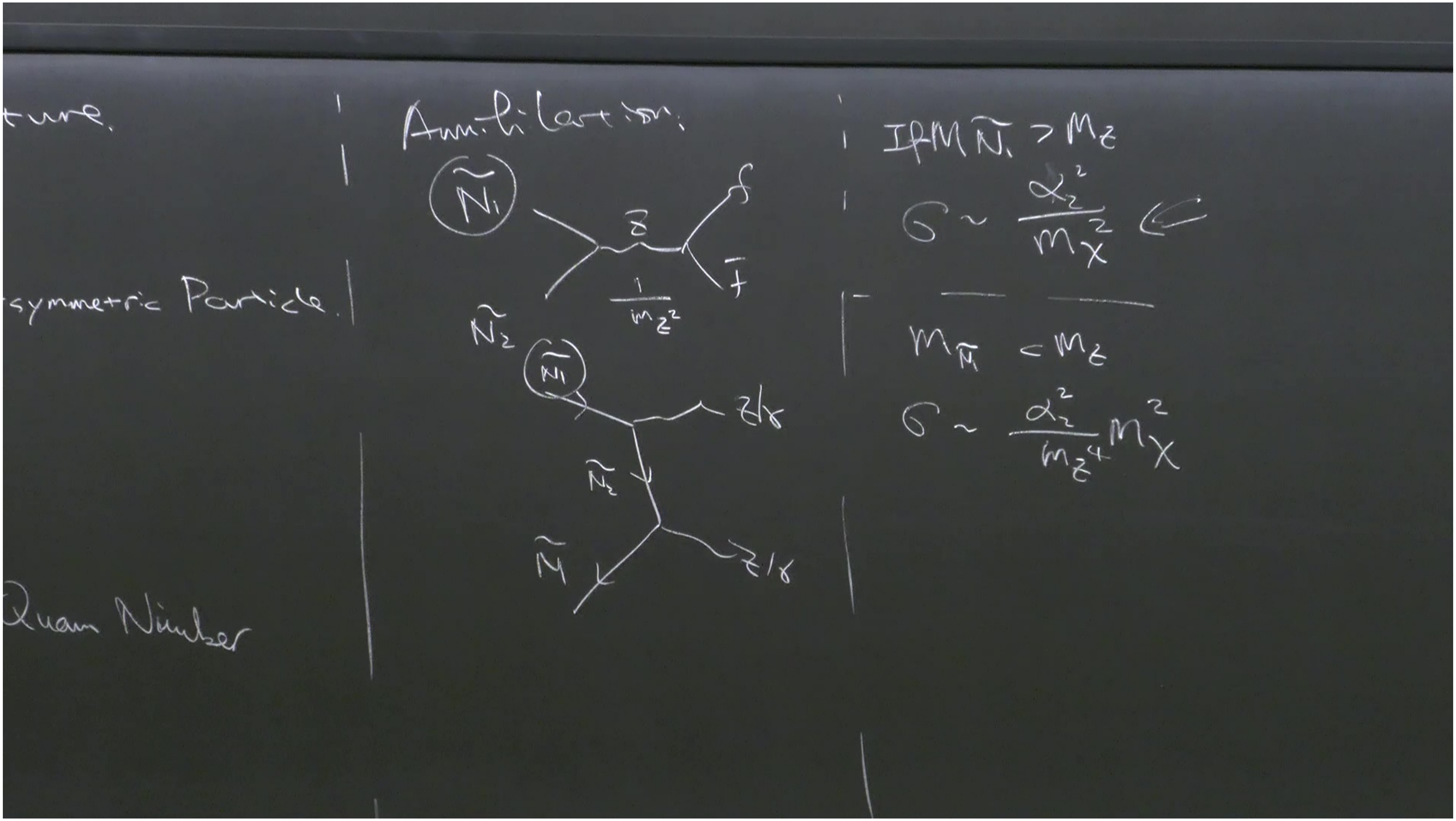
1. LSP: Lighted Supersymmetric Particle

$\Gamma = \alpha_2 \cdot M_\chi$?

$ns / T_{age} \sim 10^{-40}$

R-parity — Conserved Quan Number

$\Gamma_{Decay} = 0$

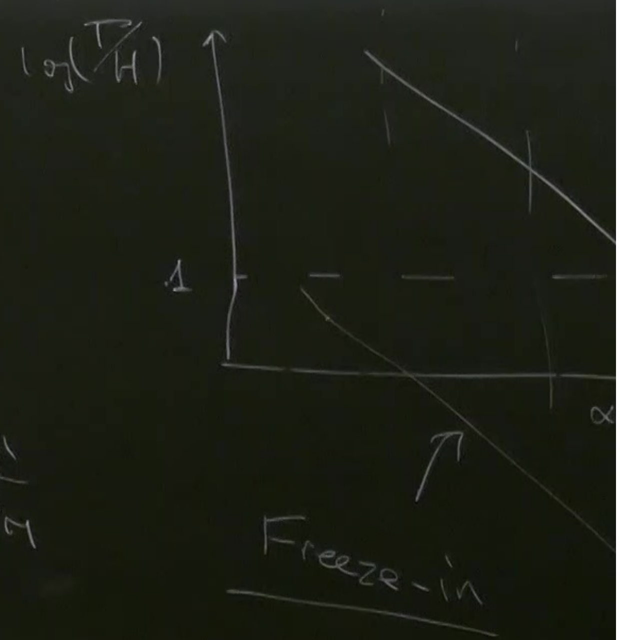

ture.
symmetric Particle
Quam Number
Annihilation:
$\tilde{N}_1$
$\tilde{N}_2$
Z
$\frac{1}{m_Z^2}$
f
$\bar{f}$
Z/γ
If $M_{\tilde{N}_1} > M_Z$
$\sigma \sim \frac{\alpha_2^2}{m_\chi^2}$
$m_{\tilde{N}_1} < m_Z$
$\sigma \sim \frac{\alpha_2^2}{m_Z^4} m_\chi^2$

① $T \gg M_\chi$

$$n_\chi \sim T^3 \qquad \sigma \sim \frac{\alpha_2^2}{T^2}$$

$$\Gamma = n_\chi \sigma \sim \alpha_2^2 T$$

$$\frac{\Gamma}{\underbrace{H}_{\sim \frac{T^2}{M_{pl}}}} = n\sigma \frac{1}{H} \sim \alpha_2^2 \frac{M_{pl}}{T_{SM}}$$



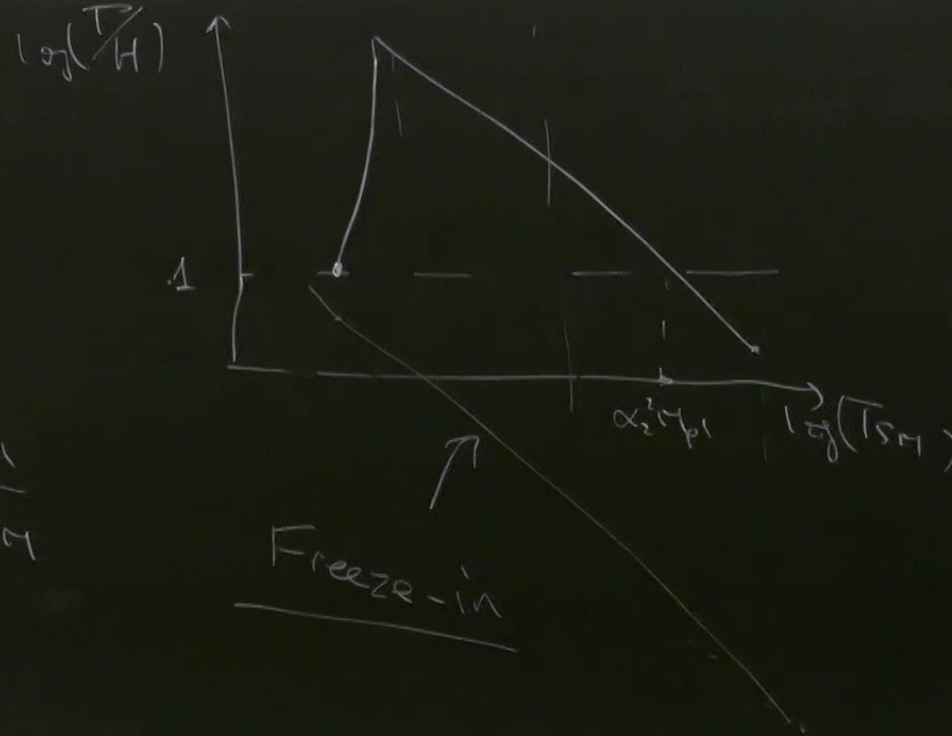
① $T \gg M_X$

$$n_X \sim T^3 \qquad \sigma \sim \frac{\alpha_2^2}{T^2}$$

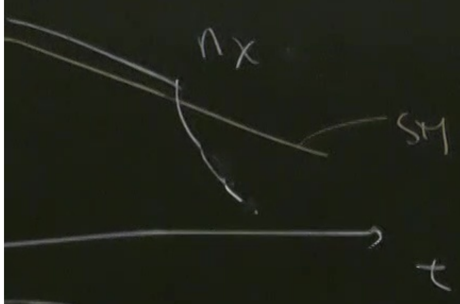
$$\Gamma = n_X \sigma \sim \alpha_2^2 T$$

$$\frac{\Gamma}{H} = n\sigma \frac{1}{H} \sim \alpha_2^2 \frac{M_{pl}}{T_{SM}}$$

$$H \sim \frac{T^2}{M_{pl}}$$



$T \sim m_\chi > m_Z$



$$\frac{\Gamma}{H} = \frac{n_\chi \cdot \alpha_2^2 M_{pl}}{m_\chi^2 \; T^2} = \frac{n_\chi \, \alpha_2^2 M_{pl}}{m_\chi^2 T_\chi^2} \sim 1$$

At this point:

$$n_\chi \Big|_{\Gamma/H = 1} = \frac{m_\chi^2 \cdot T_\chi^2}{\alpha_2^2 M_{pl}}$$

What about today?

T_χ vs m_χ?

What about today?

From T_X the X redshift like matter.

$$\frac{n_X(T)}{n_X(T_X)} = \left(\frac{T}{T_X}\right)^3$$

$$\frac{n_X}{n_\gamma} = \text{Constant}$$

$$\rho_X = m_X \left(\frac{T}{T_X}\right)^3 \frac{m_X^2\, T_X^2}{\alpha_2^2 M_{pl}} = \frac{T^3\, m_X^3}{T_X\, \alpha_2^2 M_{pl}}$$

$$\frac{\rho_X}{\rho_\gamma} = 1 \quad @ \; T = T_{eq}$$

$$\frac{x^2 \; T_X^2}{{}_2^2 \, M_{pl}}$$

$$\rho_X\Big|_{T=T_{eq}} = \frac{T_{eq}^3 \, m_X^3}{T_X \, \alpha_2^2 \, M_{pl}} \simeq \rho_\gamma = T_{eq}^4$$

$$m_X^2 \simeq \frac{1}{20}$$

$$\sim 10$$

$$\boxed{\frac{m_X^3}{T_X} = (T_{eq} \, M_{pl}) \cdot \alpha_2^2}$$

0.1 eV

$$n_X = (m_X T_X)^{3/2} \cdot \exp(-m_X/T_X) = \frac{m_X^2 \, T_X^2}{\alpha_2^2 \, M_{pl}}$$

$$\Rightarrow \quad \exp(-m_X/T_X) \simeq \frac{m_X}{M_{pl}}$$

10^{18} GeV

$$\frac{T_X}{m_X} = \left[\log\left(M_{pl}/m_X\right)\right]^{-1} \sim \frac{1}{20}$$

$$m_X^2 \simeq \frac{1}{20}\cdot(0.1)^2\cdot\left(10^{-10}\,\mathrm{GeV}\cdot 10^{18}\,\mathrm{GeV}\right)$$

$$\sim 10^5\,\mathrm{GeV}^2$$

$$\sim (300\,\mathrm{GeV})^2$$ WIMP miracle

Higgsino. $M_X = 1.1$ TeV

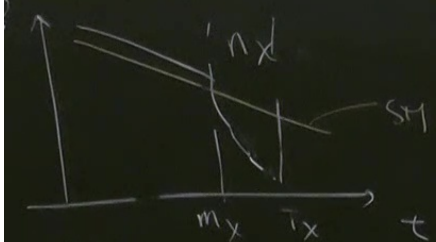
$$\frac{m_X^2\, T_X^2}{\alpha_2^2\, M_{pl}}$$

$$\frac{m_X}{M_{pl}}$$

10^{18} GeV

$$\left|\log\left|M_{pl}/m_X\right|\right|^{-1} \sim \frac{1}{20}$$

$T \sim m_X > m_Z$



$$\frac{\Gamma}{H} = \frac{G_W \cdot m_X \cdot \alpha_2^2 M_{pl}}{m_X^2 \, T^2} = \frac{m_X \, \alpha_2^2 M_{pl}}{m_X^2 T_X^2} \sim 1$$

At this point:

$$n_X \Big|_{\Gamma/H = 1} = \frac{m_X^2 \cdot T_X^2}{\alpha_2^2 M_{pl}} \qquad \left(\frac{T_X^2}{G_W \cdot M_{pl}} \right)$$

What about today?

T_X vs m_X?

$$\Big)^3 \frac{m_X^2\, T_X^2}{\alpha_2^2\, M_{pl}} \cdot \frac{1}{\sigma_W}$$

$$\boxed{\frac{m_X^3}{T_X} = (T_{eq} M_{pl}) \cdot \alpha_2^2}$$

$$\frac{T^3\, m_X^3}{T_X\, \alpha_2^2\, M_{pl}}$$

$$\frac{T_{eq}^3\, m_X}{T_X\, M_{pl}\, \sigma_W} = T_{eq}^4$$

$$n_X = (m_X T_X)^{3/2} \cdot \exp\left(-\overset{0.1\,eV}{m_X/T_X}\right) = $$

$$T = T_{eq}$$

$$\frac{m_X}{T_X} = \sigma_W M_{pl} T_{eq}$$

$$\Rightarrow \qquad \exp\left(-m_X/T_X\right) \sim$$

$$\log\left(\frac{M_{pl}}{m_X}\right) = \sigma_W M_{pl} T_{eq} = \frac{10^{18}\,GeV \cdot 0.1\,eV}{(300\,GeV)^2} = 10$$

$$\frac{T_X}{m_X} = $$

Freeze-in

Became $\exp -\left(\frac{E}{T}\right)$ and

2 SM states. $E > m_\chi$ to produce

a χ through freeze-in

Exponentially small $T_{SM} < m_\chi$

at $T = m_\chi$

$\sigma \sim \frac{\alpha^2}{m_\chi^2}$ $n \sim T^3 \sim m_\chi^3$

$$\frac{\Gamma}{H} = \frac{\alpha^2 m_\chi}{m_\chi^2/M_{pl}} \sim \frac{\alpha^2 M_{pl}}{m_\chi} < 1$$

$$\alpha^2 < \frac{m_\chi}{M_{pl}} = \left(\frac{m_\chi}{GeV}\right) \cdot 10^{-18}$$

$$\alpha < 10^{-9} \left(\frac{m_\chi}{GeV}\right)^{1/2}$$