

$$\sigma(v_{\text{rel}}) = \frac{2\pi\beta^2}{m_\phi^2} \left[ \ln(1+r^2) - \frac{r^2}{1+r^2} \right], \quad \begin{cases} \beta = 2k^2\alpha_{\text{SM}}m_\phi/(m_\chi v_{\text{rel}}^2) \\ r = m_\chi v_{\text{rel}}/m_\phi \end{cases}.$$