Mediator decays at the threshold

Yuki Watanabe collaborated with Shigeki Matsumoto, Yu Watanabe and Graham White

1.Motivation

Light thermal DM scenario

prediction

Mediator particles

detection

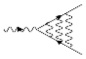
Production at colliders

Light mediators may be easily produced.

Problem

Threshold singularity

Break down of perturbation theory.



is no longer small!

2.Model

Vector mediator

- ✓ $m_{A'} \simeq 2m_\mu$
- ✓ Singlet under the SM gauge symmetries.
- ✓ Weakly interacting with the hypercharge gauge boson.
- ✓ In mass basis the lagrangian is

$$\mathcal{L} \simeq \mathcal{L}_{\rm SM} + \frac{1}{2} A'_\mu \left[\left(\Box + m_{A'}^2 \right) g^{\mu\nu} - \partial^\mu \partial^\nu \right] A'_\nu - \epsilon e A'_\mu J^\mu_{\rm EM}$$

Perturbative decay

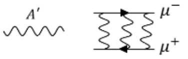
$$\Gamma_0(A' \to \ell_i^- \ell_i^+) \simeq \epsilon^2 \frac{\alpha m_{A'}}{3} \left(1 + 2\frac{m_{\ell_i}^2}{m_{A'}^2} \right) \sqrt{1 - \frac{4m_{\ell_i}^2}{m_{A'}^2}}$$

Suppressed by ϵ^2.

3.Method

Effective d.o.f at the threshold

Mediator & Muon pair



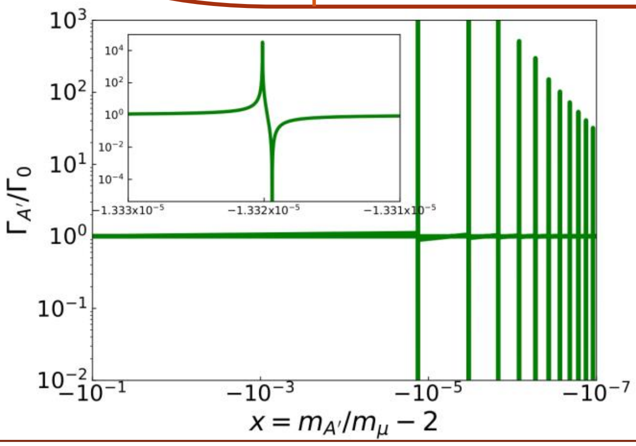
pNR method

Effective lagrangian

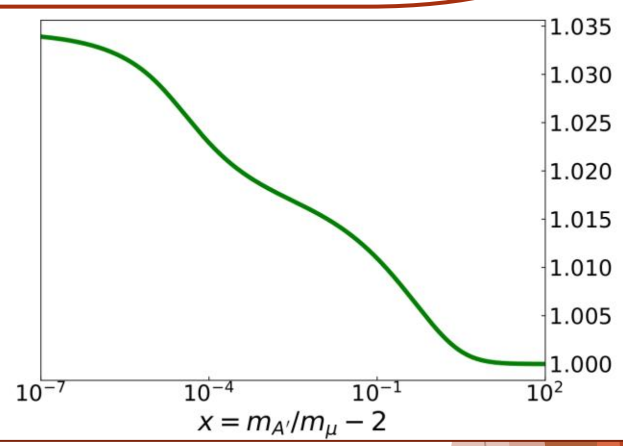
$$\mathcal{L}_V^{(\rm pNR)} \simeq -\frac{1}{2} \vec{A}' \left(\Box + m_{A'}^2 \right) \vec{A}' + \int d^3r\, \vec{\Phi}^\dagger(\vec{r}, x) \left(i\partial_{x^0} + \frac{\nabla_x^2}{4m_\mu} + \frac{\nabla_r^2}{m_\mu} - V(\vec{r}) \right) \vec{\Phi}(\vec{r}, x) + \sqrt{2}\epsilon e \vec{A}' \left[e^{2im_\mu x^0} \vec{\Phi}^\dagger(\vec{0}, x) + e^{-2im_\mu x^0} \vec{\Phi}(\vec{0}, x) \right]$$

$$V(\vec{r}) = -\frac{\alpha}{r} - i\Gamma_\mu - i\frac{2\pi\alpha^2}{3m_\mu^2}\delta(\vec{r})$$

The total decay width of the mediator divided by the perturbative result around the threshold

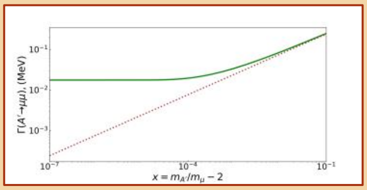


Below the threshold



Above the threshold

4. Above the threshold



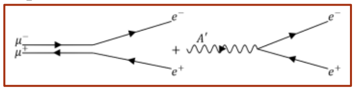
$$\Gamma(A' \to \mu\mu) \simeq \frac{2\pi\epsilon^2\alpha^2 m_\mu^2 \theta(m_{A'} - 2m_\mu)}{m_{A'} \left[1 - \exp\left(-\pi\alpha / \sqrt{m_{A'}/m_\mu - 2} \right) \right]}$$

Sommerfeld enhancement

The plane waves of the out-going particles are distorted by the Coulomb interaction and the decay width is enhanced.

5.Below the threshold

- ✓ Kinetic mixing between the vector mediator and a muonic atom .
- ✓ Interference between their decay processes into the electron-positron pair.



$$\Gamma_n(\tilde{A}' \to e^- e^+) = \frac{\alpha m_{A'}}{3} \left[\epsilon \cos\Theta_n + \frac{e}{\sqrt{\pi}} \left(\frac{\alpha}{n} \right)^{3/2} \left(\frac{m_\mu}{m_{A'}} \right)^2 \sin\Theta_n \right]^2$$

- ✓ Enhancement at a large mixing.
- ✓ Diminishment at a negative mixing.

6.Summary

- ✓ We studied the vector mediator with its mass being twice as a muon pair.
- ✓ The behaver of the decay width around the threshold is drastically changed from those of the perturbative result due to the threshold singularity.
- ✓ Sommerfeld enhancement above the threshold.
- ✓ Kinetic mixing with a muon pair below the threshold.
- ✓ Applications to the thermal history of the universe. (future)