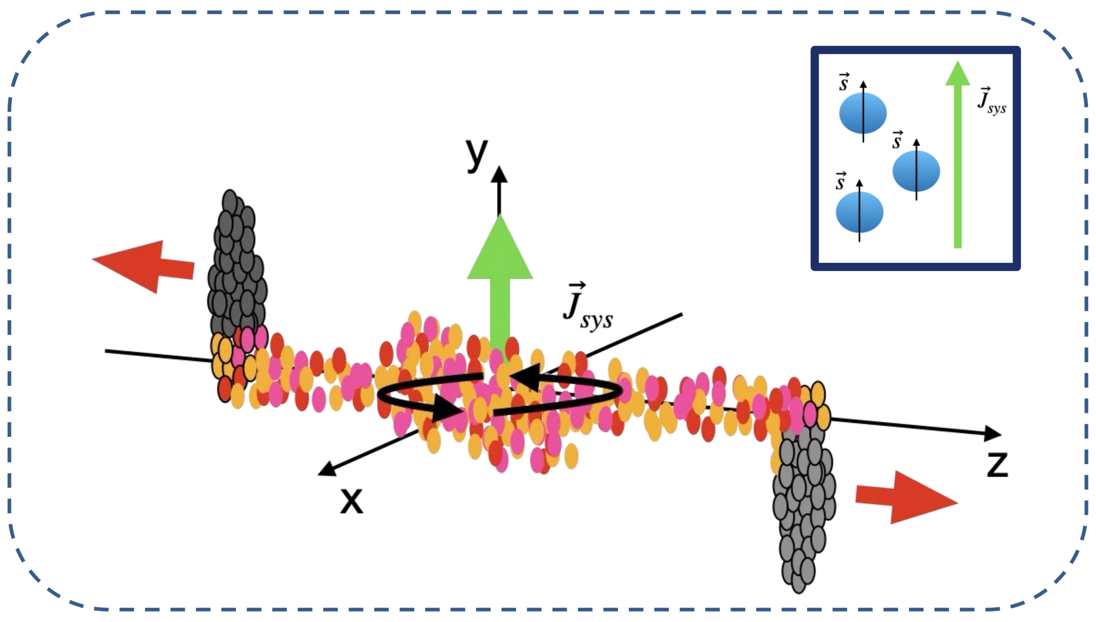
Hadronic scattering effects on Λ polarization in relativistic heavy ion collisions

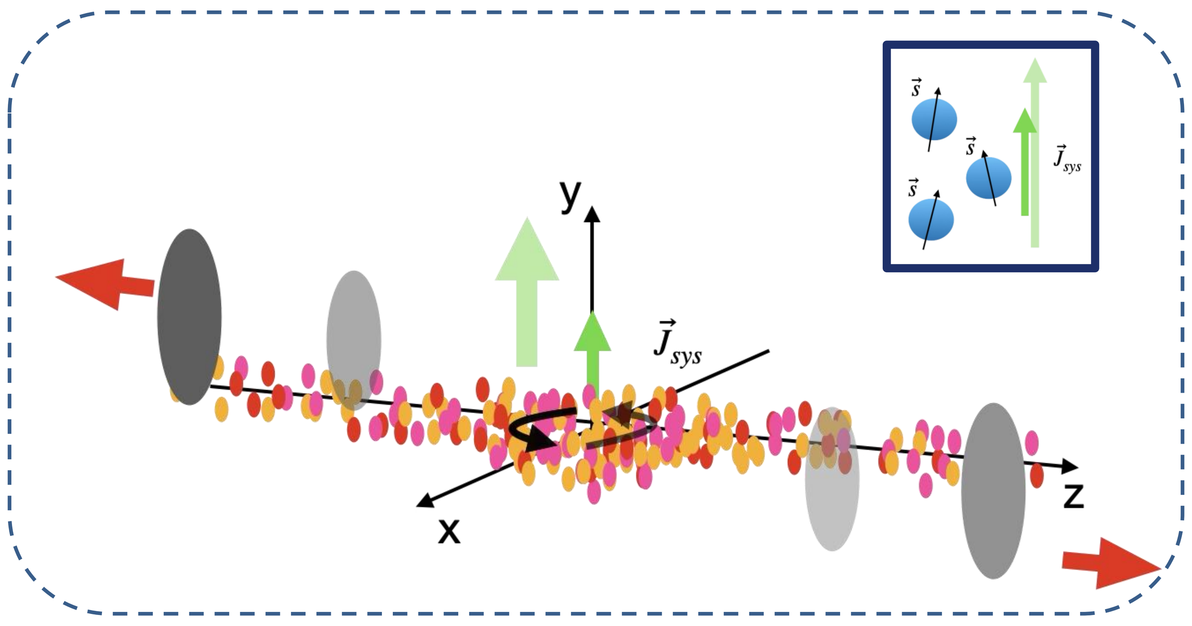
Haesom Sung, Che-Ming Ko, Su Houng Lee

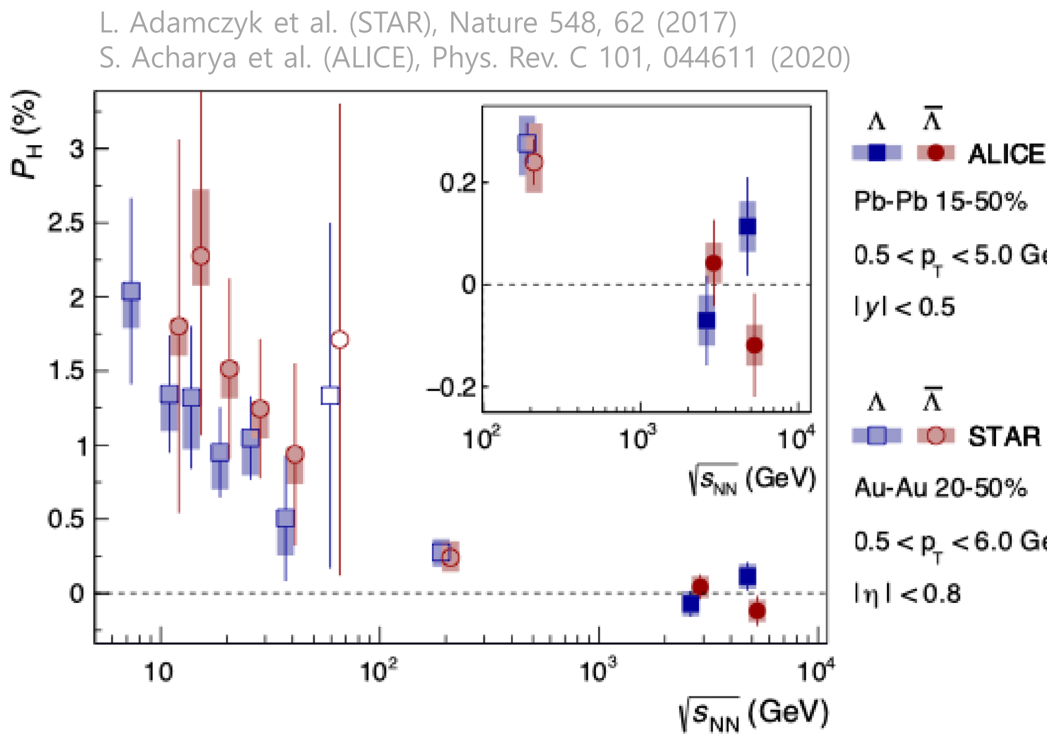
Abstract

The effect of $\Sigma^*(1385)$ baryon resonance on the time evolution of the Λ hyperon polarization in hadronic matter is studied using a kinetic approach. This approach explicitly includ es the production of the Σ^* resonance from the Λ−π and Σ(1192)−π scatterings as well as its decay into Λ+π or Σ+π. The resulting coupled kinetic equations governing the time e volution of Λ, Σ and Σ* numbers and polarizations are solved for Au-Au collisions at $\sqrt{s_{NN}}$=7.7 GeV and 20-50% centrality, using initial values determined by thermal yields and the thermal vorticity at chemical freeze-out temperature. As the hadronic matter expands and cools, the Λ polarization is found to increase slightly during early times and then decreases very slowly afterwards, while the Σ polarization remains nearly constant and the Σ^* polarization continuously decreases. Including feed-down contributions to the Λ polar ization from the decays of partially polarized Σ^0, Σ^* and Ξ(1322) hyperons, where the Ξ polarization is obtained by solving coupled kinetic equations for the Ξ and Ξ*(1532) system, the resulting Λ polarization becomes smaller and decreases over time. In both cases, however, the time variation of the Λ polarization is sufficiently small to support the assumptio n of an early freeze-out of Λ spin degree of freedom in relativistic heavy ion collisions.

Introduction







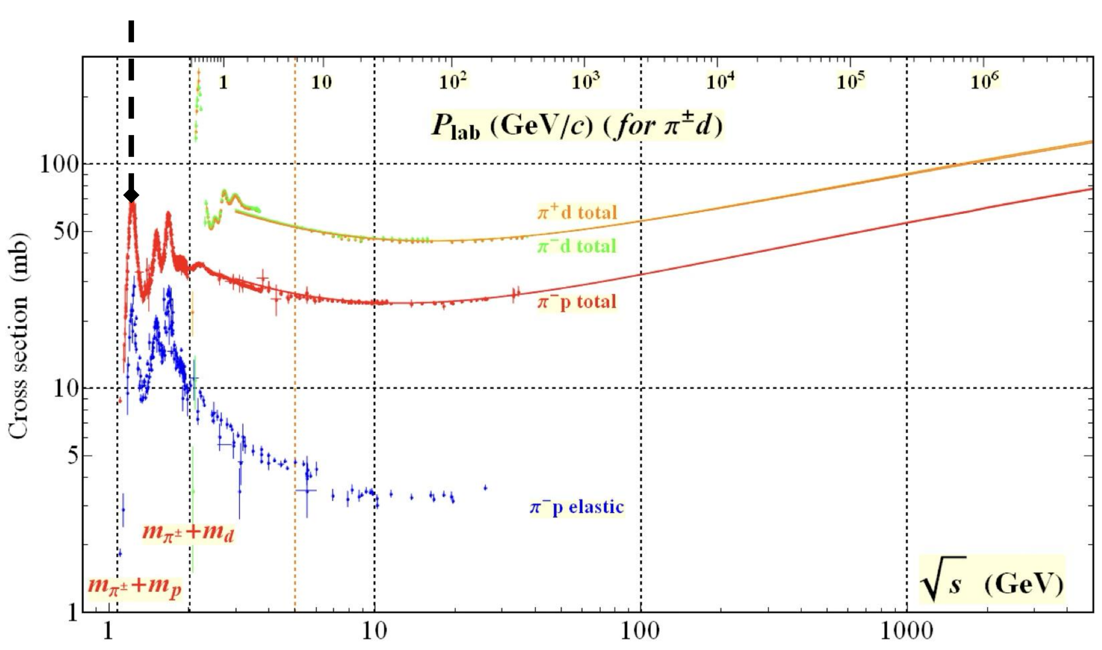
- Vorticity is getting weak with expanding of system
- We thought that collisions with other hadrons in the hadronic phase make the initial polarization to disappear

→ Lambda polarization in early stage of system remains after scattering during hadron phase

Methods

1. $\Lambda + \pi \leftrightarrow \Sigma^* \leftrightarrow \Sigma + \pi$ scattering

Δ resonance



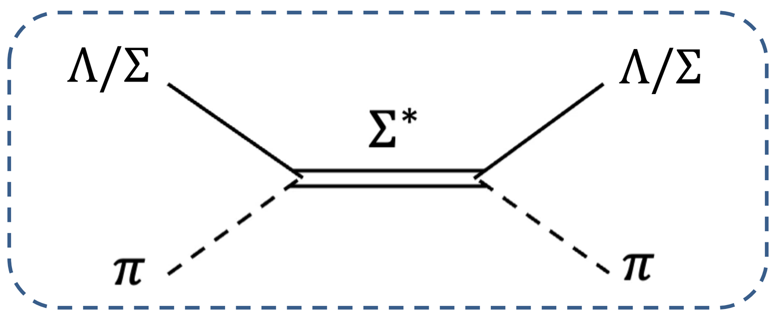
Polarization:

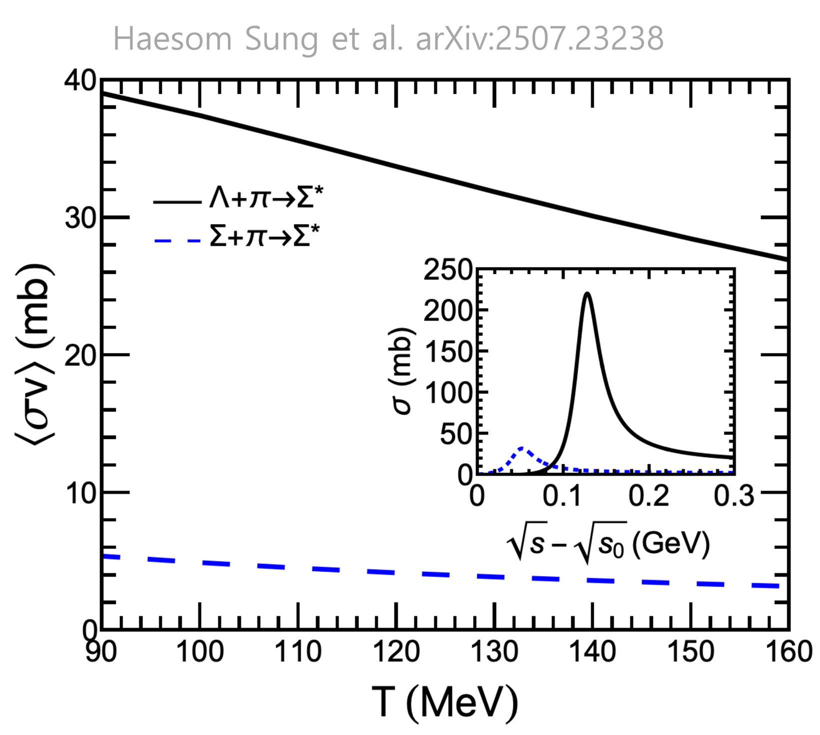
$$P_Y = \frac{N_{Y_{1/2}} - N_{Y_{-1/2}}}{N_{Y_{1/2}} + N_{Y_{-1/2}}}, \quad Y = \Lambda, \Sigma$$

$$P_{\Sigma^*} = \frac{N_{\Sigma^*_{3/2}} + \frac{1}{3}N_{\Sigma^*_{1/2}} - \frac{1}{3}N_{\Sigma^*_{-1/2}} - N_{\Sigma^*_{-3/2}}}{N_{\Sigma^*_{3/2}} + N_{\Sigma^*_{1/2}} + N_{\Sigma^*_{-1/2}} + N_{\Sigma^*_{-3/2}}},$$

Scattering $p + \pi^-$ (p-wave):
$\Delta(s = \frac{3}{2})$ resonance is dominant

➔ **Σ^* resonance** is dominant in $\Lambda + \pi$ scattering





2. Kinetic equations for Λ, Σ, and Σ^*

$$\frac{dN_{Y_{1/2}}}{d\tau} = \frac{1}{3}\langle\Gamma_{\Sigma^*\to Y+\pi}\rangle\left(3N_{\Sigma^*_{3/2}} + 2N_{\Sigma^*_{1/2}} + N_{\Sigma^*_{-1/2}}\right) - \langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} N_{Y_{1/2}}, \quad Y = \Lambda, \Sigma$$

$$\frac{dN_{Y_{-1/2}}}{d\tau} = \frac{1}{3}\langle\Gamma_{\Sigma^*\to Y+\pi}\rangle\left(N_{\Sigma^*_{1/2}} + 2N_{\Sigma^*_{-1/2}} + 3N_{\Sigma^*_{-3/2}}\right) - \langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} N_{Y_{-1/2}}, \quad Y = \Lambda, \Sigma$$

$$\frac{dN_{\Sigma^*_{3/2}}}{d\tau} = \frac{1}{2}\sum_{Y=\Lambda,\Sigma}\left[\langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} N_{Y_{1/2}} - \langle\Gamma_{\Sigma^*\to Y+\pi}\rangle N_{\Sigma^*_{3/2}}\right],$$

$$\frac{dN_{\Sigma^*_{1/2}}}{d\tau} = \frac{1}{6}\sum_{Y=\Lambda,\Sigma}\left[\langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} (2N_{Y_{1/2}} + N_{Y_{-1/2}}) - \langle\Gamma_{\Sigma^*\to Y+\pi}\rangle N_{\Sigma^*_{1/2}}\right],$$

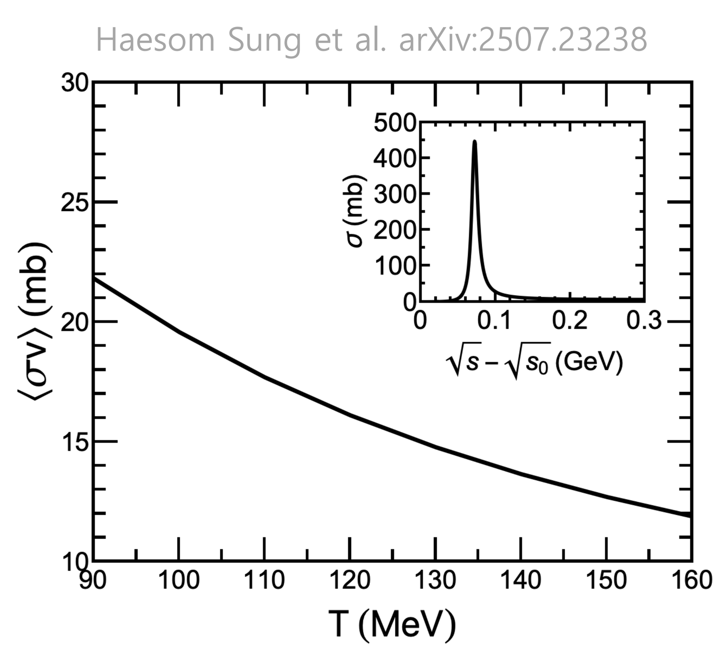
$$\frac{dN_{\Sigma^*_{-1/2}}}{d\tau} = \frac{1}{6}\sum_{Y=\Lambda,\Sigma}\left[\langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} (N_{Y_{1/2}} + 2N_{Y_{-1/2}}) - \langle\Gamma_{\Sigma^*\to Y+\pi}\rangle N_{\Sigma^*_{-1/2}}\right],$$

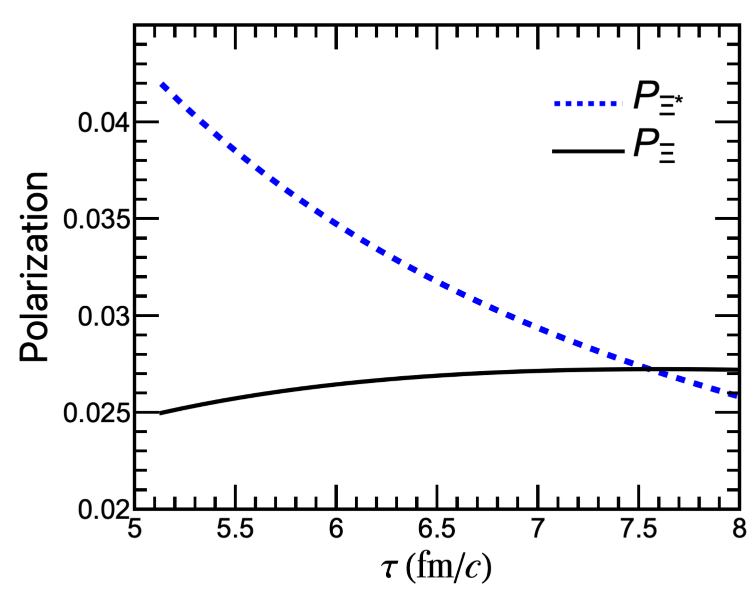
$$\frac{dN_{\Sigma^*_{-3/2}}}{d\tau} = \frac{1}{2}\sum_{Y=\Lambda,\Sigma}\left[\langle\sigma_{Y+\pi\to\Sigma^*}v\rangle z_\pi^{(T)} n_\pi^{(T)} N_{Y_{-1/2}} - \langle\Gamma_{\Sigma^*\to Y+\pi}\rangle N_{\Sigma^*_{-3/2}}\right].$$

3. Feed-down contributions from Ξ and Ξ^* to Λ polarization

$\Sigma^0 \to \Lambda + \gamma$
$\Sigma^* \to \Lambda + \pi$
$\Xi \to \Lambda + \pi$

$$P_\Lambda^{\rm FD} = \frac{\sum_{Y=\Lambda,\Sigma^0,\Sigma^{*+},\Sigma^{*0},\Sigma^{*-},\Xi^0,\Xi^-} C_Y P_Y N_Y}{\sum_{Y=\Lambda,\Sigma^0,\Sigma^{*+},\Sigma^{*0},\Sigma^{*-},\Xi^0,\Xi^-} N_Y},$$





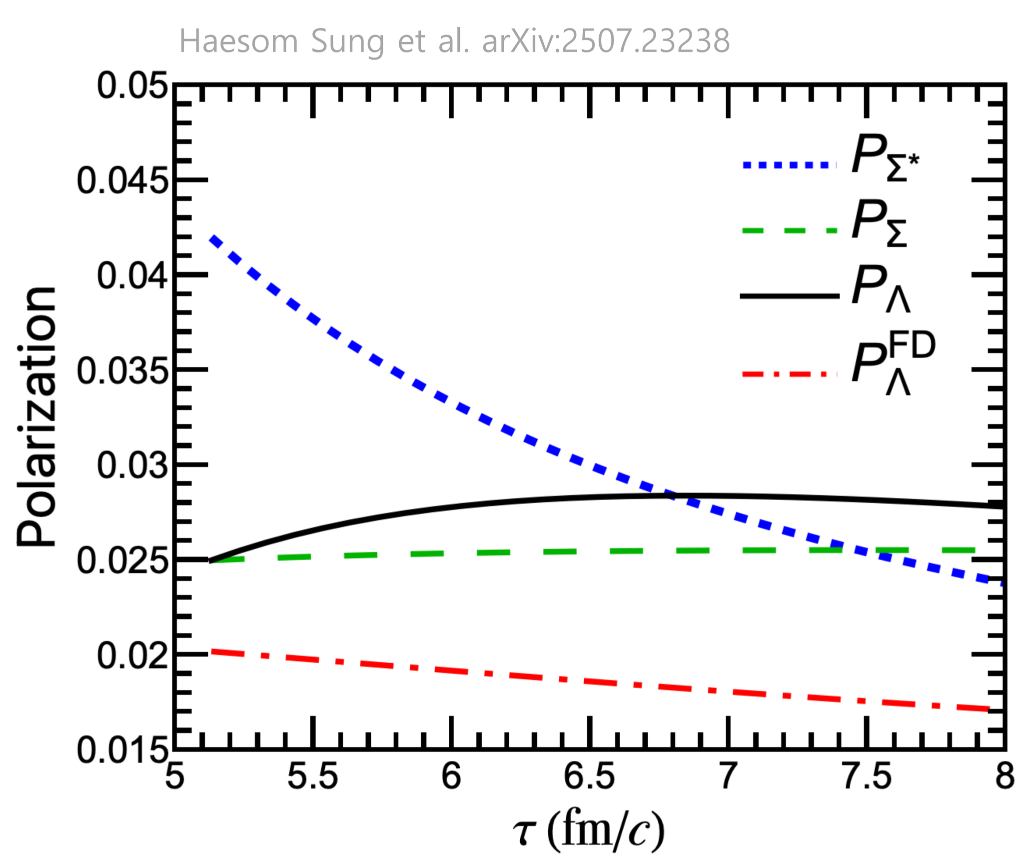
Result

Initial conditions:

$P_\Lambda^{(0)} = 0.025$

$P_{\Sigma^*}^{(0)} = 5/3 P_\Lambda^{(0)} = 0.042$

Phys. Rev. C **96**, 054908
Phys. Rev. C **95**, 054902



Conclusion

- Considering Σ^* resonance Λ polarization increases slightly when Σ^* polarization is larger than Λ polaization
- The Λ spin polarization with feed-down contribution reduces and shows a decreasing trend during the expansion of the hadronic matter.

[1] Haesom Sung et al. arXiv:2507.23238
[2] Haesom Sung, C. M. Ko, and S. H. Lee, Phys. Lett. B 858,139004 (2024), arXiv:2404.15890