Virtual photon polarization and dilepton anisotropy in relativistic heavy-ion collisions

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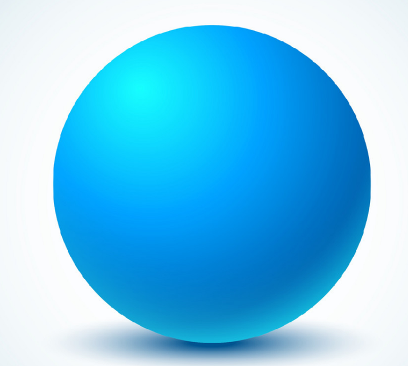
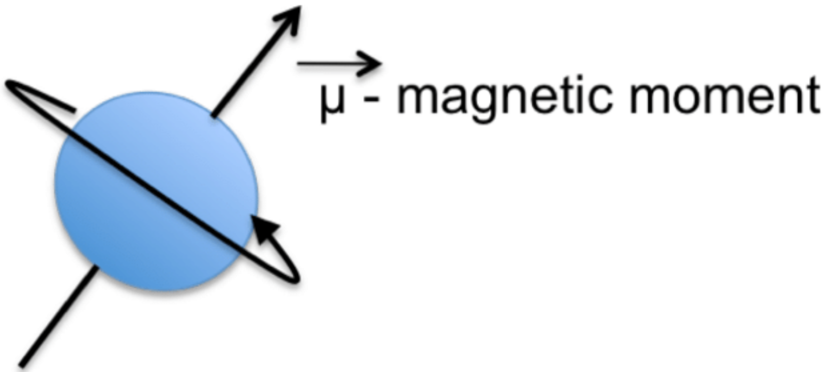
Decay of scalar particles



No anisotropy in the rest frame: isotropic decay products.

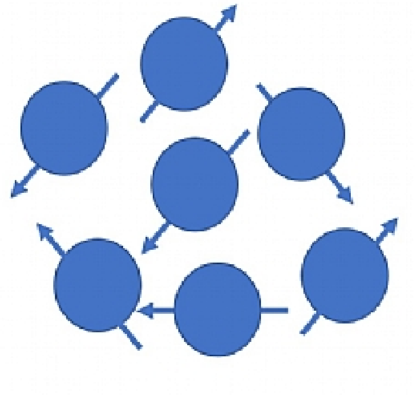
Decay of particles with spin



Preferred direction due to spin: anisotropic decay products

Leads to polarization observables.

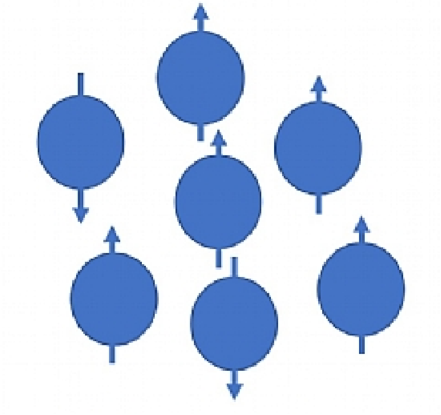
Several random decays



Expectation: Averaging over random decays should lead to isotropic decay products.

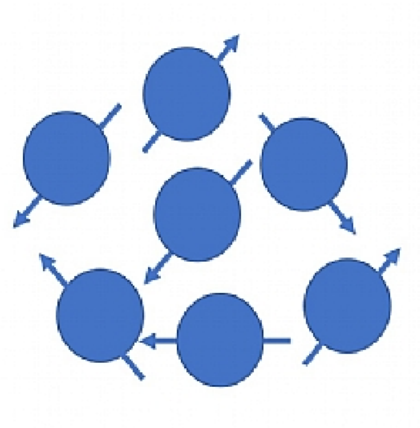
Averaging with thermal distribution.

Decay of spin polarized particles



Averaging over decay of polarized particles should lead to anisotropic decay products.

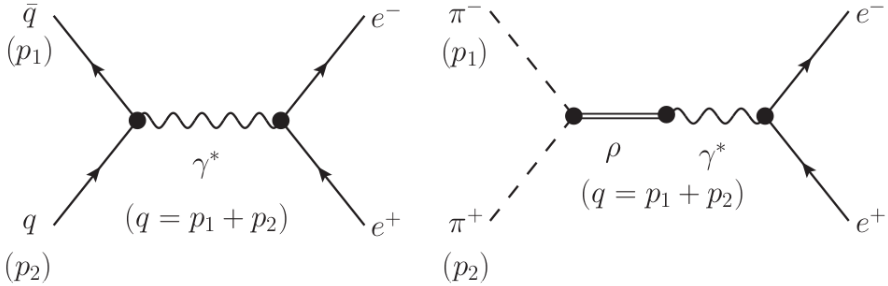
Several random decays



Averaging over random decays also leads to anisotropic decay products. PLB 782 (2018) 395-400.

Averaging with thermal distribution.

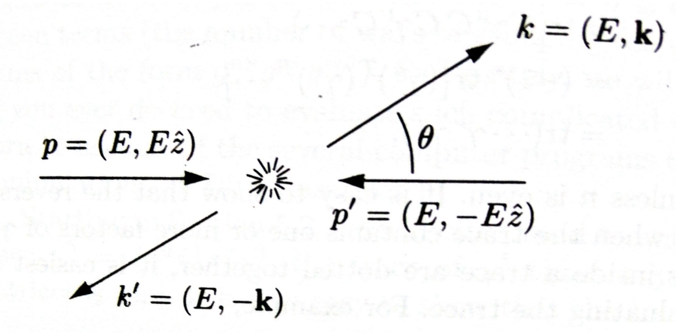
Processes under consideration



Feynman diagrams for the Drell-Yan and pion annihilation.

Peskin-Schroeder: Invitation

$$e^+e^- \to \mu^+\mu^-$$



$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_{\mathrm{cm}}^2}\left(1 + \cos^2\theta\right)$$

Dilepton production rate

- Consider the general process $X_1 X_2 \to \gamma^* \to e^+ e^-$.
- $X_1,\ X_2$: two particles in thermalized medium. γ^*: virtual photon
- The rate per unit volume at finite temperature for this process is

$$\frac{d\Gamma}{d^4q} = \frac{e^2}{q^4} \int \frac{d^3 l_+}{(2\pi)^3 2E_+} \frac{d^3 l_-}{(2\pi)^3 2E_-} \delta^{(4)}(q - l_+ - l_-) W^{\mu\nu} L_{\mu\nu},$$

where $E_\pm = \sqrt{|\mathbf{l}_\pm|^2 + m^2}$, e the electron charge and $L_{\mu\nu}$ the lepton tensor

$$L^{\mu\nu} = 2(-q^2 g^{\mu\nu} + q^\mu q^\nu - \Delta l^\mu \Delta l^\nu).$$

- $q^\mu = l_+^\mu + l_-^\mu$: virtual photon momentum. $\Delta l^\mu = l_+^\mu - l_-^\mu$
- $L_{\mu\nu}$: lepton tensor; $W^{\mu\nu}$: thermal averaged current correlator.

Dilepton production rate contd...

$$\frac{d\Gamma}{d^4q} = \frac{e^2}{q^4}\int \frac{d^3l_+}{(2\pi)^3 2E_+}\frac{d^3l_-}{(2\pi)^3 2E_-}\delta^{(4)}(q-l_+-l_-)W^{\mu\nu}L_{\mu\nu},$$

where $E_\pm = \sqrt{|\mathbf{l}_\pm|^2+m^2}$, e the electron charge and $L_{\mu\nu}$ the lepton tensor

$$L^{\mu\nu} = 2(-q^2 g^{\mu\nu} + q^\mu q^\nu - \Delta l^\mu \Delta l^\nu).$$

$$W^{\mu\nu} = \langle w^{\mu\nu}\rangle,$$

where $w^{\mu\nu}$ is given below and we have introduced the notation

$$\langle A\rangle = \int \frac{d^3p_1}{(2\pi)^3 2E_1}\frac{d^3p_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^{(4)}(q-p_1-p_2)\frac{1}{e^{(u\cdot p_1)/T}\pm 1}\frac{1}{e^{(u\cdot p_2)/T}\pm 1}A.$$

Dilepton production rate contd...

$$W^{\mu\nu} = W_1\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) + W_2\left(u^\mu - \frac{u\cdot q}{q^2}q^\mu\right)\left(u^\nu - \frac{u\cdot q}{q^2}q^\nu\right),$$

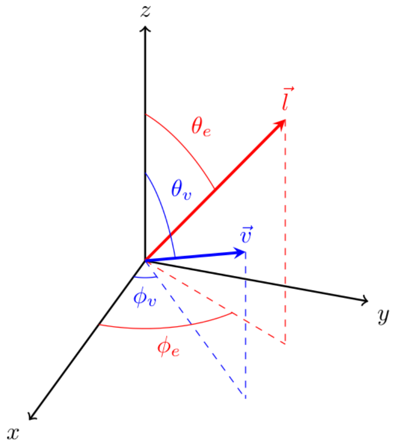
$$W_1 = \frac{\alpha a - \beta}{2a}, \qquad W_2 = \frac{3\beta - \alpha a}{2a^2},$$

$$\alpha \equiv g_{\mu\nu}W^{\mu\nu}, \quad \beta \equiv u_\mu u_\nu W^{\mu\nu}, \quad a \equiv 1 - \frac{(u\cdot q)^2}{q^2}.$$

$$\frac{d\Gamma}{d^4q\, d\Omega_e} \propto \frac{1}{q^4} W_{\mu\nu} L^{\mu\nu}.$$

$$\frac{d\Gamma}{d^4q\, d\Omega_e} \propto \frac{1}{q^4}(-3q^2 - \Delta l^2)W_1 + \frac{1}{q^4}\left[-q^2 + (u\cdot q)^2 - (u\cdot \Delta l)^2\right]W_2.$$

Relevant angles



$$u^\mu = \gamma(1, |\mathbf{v}| \sin\theta_v \cos\phi_v, |\mathbf{v}| \sin\theta_v \sin\phi_v, |\mathbf{v}| \cos\theta_v),$$
$$\Delta l^\mu = (0, 2|\mathbf{l}| \sin\theta_e \cos\phi_e, 2|\mathbf{l}| \sin\theta_e \sin\phi_e, 2|\mathbf{l}| \cos\theta_e),$$

Anisotropic rate

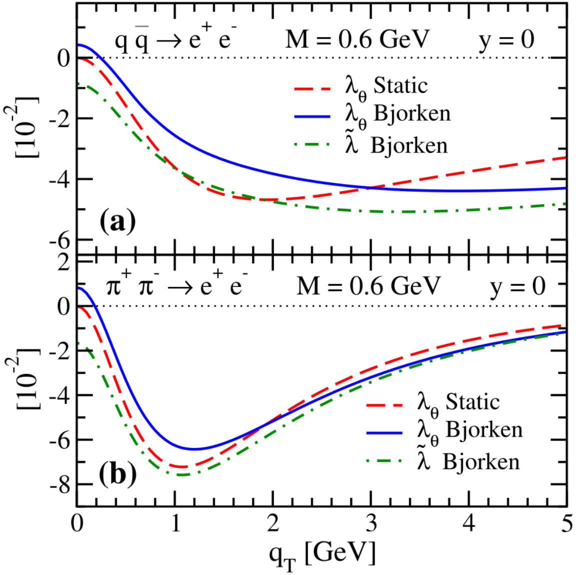
$$\frac{d\sigma}{d\Omega_e} \propto \mathcal{N}(1 + \lambda_\theta \cos^2\theta_e + \lambda_\phi \sin^2\theta_e \cos 2\phi_e + \lambda_{\theta\phi} \sin 2\theta_e \cos\phi_e + \lambda_\phi^\perp \sin^2\theta_e \sin 2\phi_e + \lambda_{\theta\phi}^\perp \sin 2\theta_e \sin\phi_e),$$

$$\lambda_i = -W_2 4\gamma^2 |\mathbf{v}|^2 |\mathbf{l}|^2 \lambda_i',$$

$$\mathcal{N} = (-3q^2 - \Delta l^2)W_1 + [-u^2q^2 + (u\cdot q)^2 - 4\gamma^2|\mathbf{v}|^2|\mathbf{l}|^2\lambda_0']W_2,$$

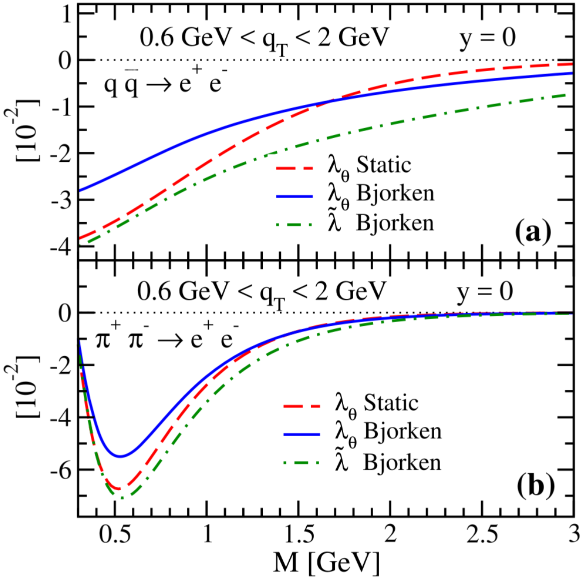
$$\tilde{\lambda} \equiv \frac{\lambda_\theta + 3\lambda_\phi}{1 - \lambda_\phi}.$$

Results



q q̄ → e⁺ e⁻
M = 0.6 GeV
y = 0
λθ Static
λθ Bjorken
λ̃ Bjorken
(a)
[10⁻²]
0
-2
-4
-6
π⁺ π⁻ → e⁺ e⁻
M = 0.6 GeV
y = 0
λθ Static
λθ Bjorken
λ̃ Bjorken
(b)
[10⁻²]
2
0
-2
-4
-6
-8
0
1
2
3
4
5
qT [GeV]

Results contd...



References

- Virtual photon polarization and dilepton anisotropy in relativistic nucleus-nucleus collisions: [E. Speranza, A. Jaiswal, B. Friman, Phys.Lett.B 782 (2018) 395-400]. (Presented.)
- Virtual photon polarization in anisotropic medium (momentum anisotropy): [G. Baym, T. Hatsuda, M. Strickland, Phys. Rev. C 95 (2017) 044907].
- Polarization of direct photons from gluon anisotropy: [G. Baym, T. Hatsuda, PTEP 2015 (2015) 3, 031D01].

Thank you!