Effect of q-$\bar{q}$ mutual interaction on q-$\bar{q}$ creation

- speculations on isospin symmetry violation

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Motivation

$$R_K \equiv \frac{\langle K^+ + K^- \rangle}{\langle K^0 + \bar{K}^0 \rangle} = \begin{cases} 1.184 \pm 0.061 \quad \text{Ar-Sc} \;\; @ \;\; \sqrt{s_{NN}} = 11.3 \;\; \text{GeV} \\ 1.128 \pm 0.027 \quad \text{A-A} \;\; \text{world} \;\; \text{data} \end{cases}$$

Quark content

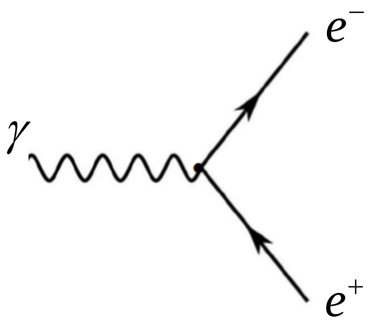
$$K^+ = (u, \bar{s}), \quad K^- = (\bar{u}, s), \quad K^0 = (d, \bar{s}), \quad \bar{K}^0 = (\bar{d}, s)$$

$$R_K > 1 \;\; \Rightarrow \;\; N_{u\text{-}\bar{u}} > N_{d\text{-}\bar{d}}$$

NA61/SHINE & F. Giacosa, M. Gorenstein, R. Poberezhniuk & S. Samanta,
Nature Commun. **16**, 2849 (2025)

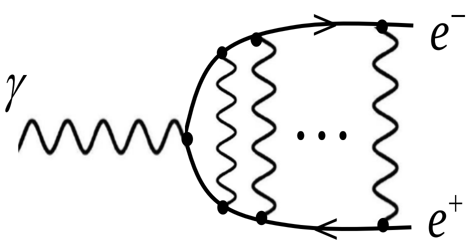
Final state interaction in e^+-e^- production

A chapter of Andrei Sakharov's Ph.D. thesis 1947



no final state interaction

Andrei Sakharov
(1921-1989)



final state interaction inlcuded

A.D. Sakharov, Zh. Eksp. Teor. Fiz. **18**, 631 (1948)

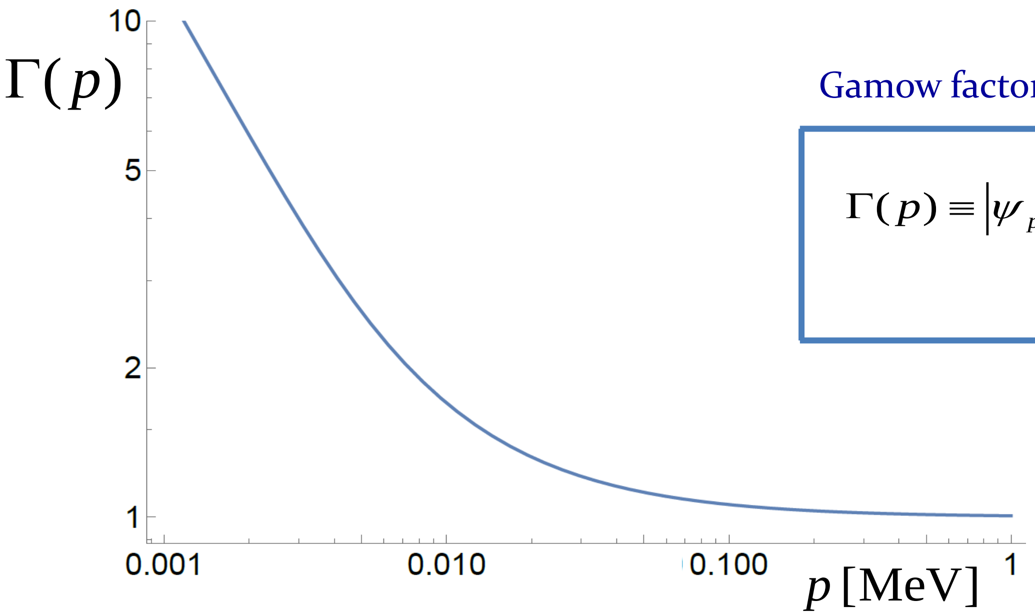
Final state interaction in e^+-e^- production

$$\frac{d\sigma^{e^+e^-}}{dp} = \left|\psi_p(\mathbf{r}=0)\right|^2 \frac{d\sigma^{e^+e^-}_{\text{free}}}{dp}$$

separation of energy scales: $2m_e \gg m_e\,\alpha_{\text{EM}}^2$

separation of length scales: $\frac{1}{2m_e} \ll a_B = \frac{2}{m_e\,\alpha_{\text{EM}}}$

$\psi_p(\mathbf{r})$ - Sommerfeld wave function of Coulomb scattering state



Gamow factor

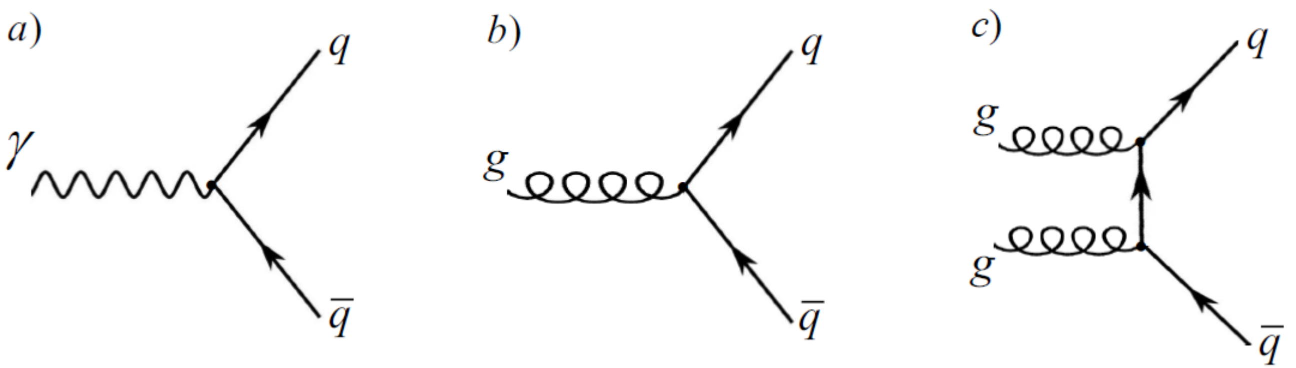
$$\Gamma(p) \equiv \left|\psi_p(0)\right|^2 = \frac{2\pi}{a_B p}\frac{1}{1-\exp\left(-\frac{2\pi}{a_B p}\right)}$$

A.D. Sakharov, Zh. Eksp. Teor. Fiz. **18**, 631 (1948)

q-$\bar{q}$ production

Quark-antiquark pair can be in either singlet or octet state: $\boxed{3 \otimes \bar{3} = 1 \oplus 8}$

production process



singlet octet singlet or octet

In strong interactions production of octet state is expected to dominate.

Singlet vs. octet

attraction

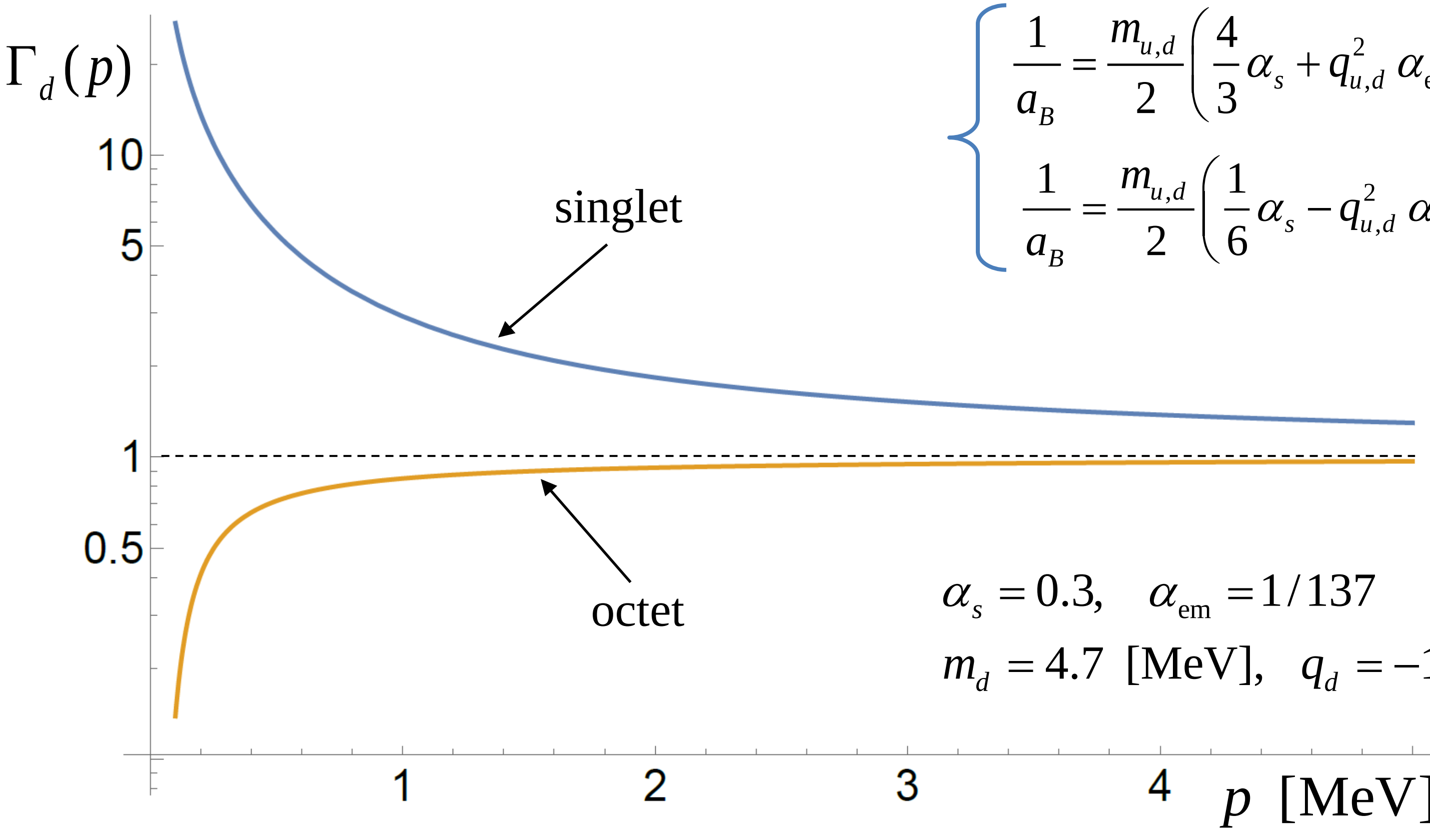
$$V_1(r) = -\frac{4}{3}\frac{\alpha_s}{r}$$

repulsion

$$V_8(r) = \frac{1}{6}\frac{\alpha_s}{r}$$

$$\boxed{\Gamma(p) = \pm\frac{2\pi}{a_B p}\frac{1}{\exp\left(\pm\frac{2\pi}{a_B p}\right)-1}}$$

$$\begin{cases} \dfrac{1}{a_B} = \dfrac{m_{u,d}}{2}\left(\dfrac{4}{3}\alpha_s + q_{u,d}^2\,\alpha_{\rm em}\right) & \text{singlet} \\ \dfrac{1}{a_B} = \dfrac{m_{u,d}}{2}\left(\dfrac{1}{6}\alpha_s - q_{u,d}^2\,\alpha_{\rm em}\right) & \text{octet} \end{cases}$$



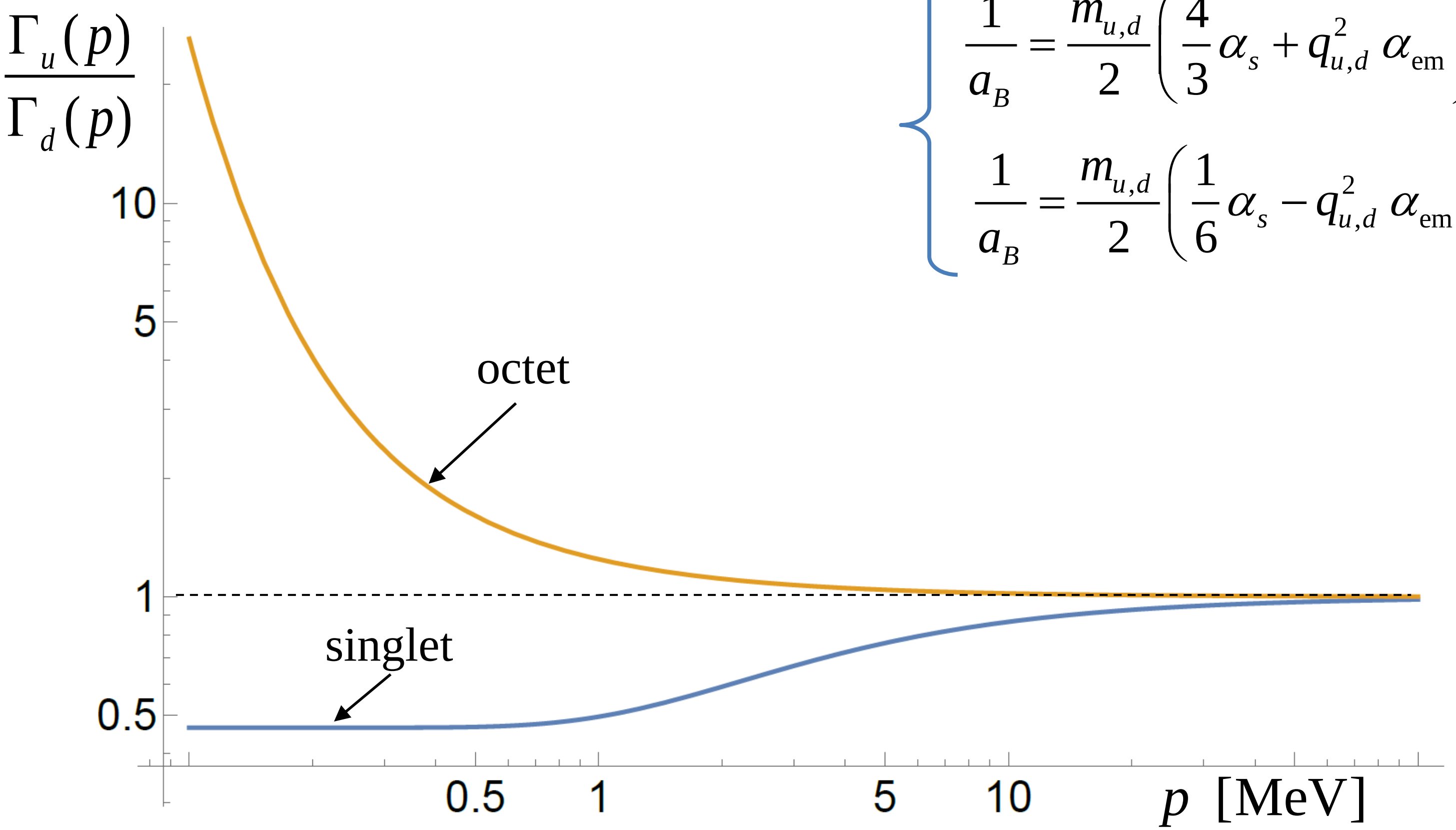
$$\alpha_s = 0.3,\quad \alpha_{\rm em} = 1/137$$

$$m_d = 4.7\ \text{[MeV]},\quad q_d = -1/3$$

Up vs. down

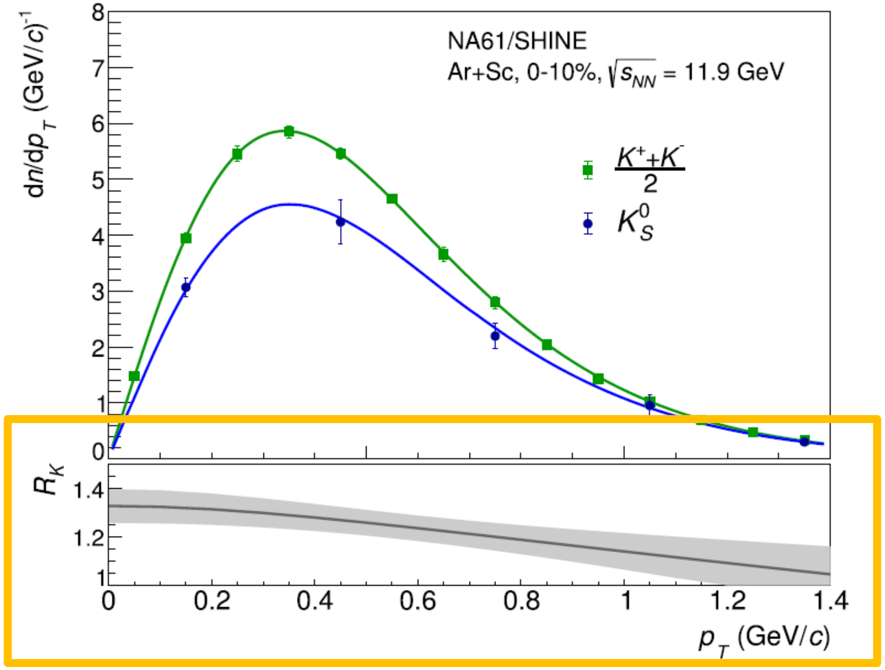
$$m_u = 2.2\ \ [\text{MeV}],\quad q_u = 2/3$$
$$m_d = 4.7\ \ [\text{MeV}],\quad q_d = -1/3$$
$$\alpha_s = 0.3,\quad \alpha_{\text{em}} = 1/137$$

$$\begin{cases} \dfrac{1}{a_B} = \dfrac{m_{u,d}}{2}\left(\dfrac{4}{3}\alpha_s + q_{u,d}^2\,\alpha_{\text{em}}\right) & \text{singlet} \\[2ex] \dfrac{1}{a_B} = \dfrac{m_{u,d}}{2}\left(\dfrac{1}{6}\alpha_s - q_{u,d}^2\,\alpha_{\text{em}}\right) & \text{octet} \end{cases}$$



Discusion

1) The enhancement of production $u\text{-}\bar{u}$ relative to $d\text{-}\bar{d}$ is significant only for small momenta.



Very good news!

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Discusion cont.

2) The Gamow factor is not relativistic but $\Gamma(p) \neq 1$ for small momenta.

Good news!

3) $\alpha_s \approx 0.3$ provides separation of scales.

Good news!

4) The Coulomb potential $V(r)$ makes sense for $\begin{cases} r < \Lambda_{\text{QCD}}^{-1} \approx 1\,\text{fm} & \text{in vacuum} \\ r < \lambda_{\text{D}} \approx 1\,\text{fm} & \text{in QGP} \end{cases}$

$r \sim 1/(2m_u) \sim 40$ fm

Very bad news!

$$\lambda_D^{-2} = m_D^2 = \frac{1}{6} g^2 T^2 (N_f + 2N_c)$$

May be a replacement of the current quarks by constituent ones can rescue the idea.

Conclusion

The q-$\bar{q}$ mutual interaction generates the enhancement of production u-$\bar{u}$ relative to d-$\bar{d}$ but the idea is very speculative.