Study of CHARGE ASYMMETRY in $e^+e^- \to e^+e^- \pi^+\pi^-$ at $\mathrm{D\dot{A}\Phi NE}$

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■The pion pairs in e^+e^- collisions

$\boxed{1)\, e^+e^- \to \pi^+\pi^-\gamma}$ and $\boxed{2)\, e^+e^- \to e^+e^-\pi^+\pi^-}$ separated well via the value of missing mass $M_m^2 = (p_{e^+} + p_{e^-} - p_+ - p_-)^2 \lessgtr M_0^2$ (with $M_0 \sim 100 - 200$ MeV).

At $M_m < M_0 \Rightarrow$ – 1-st process.

At $M_m > M_0 \Rightarrow$ – 2-nd process.

$\boxed{\text{Additional signature for } e^+e^- \to e^+e^-\pi^+\pi^-}$

The statistical significance of charge asymmetry for the second process is maximal at transverse momentum of dipion $\gtrsim 100$ MeV

$$\Downarrow$$

One can record together with pions, the scattered electron or positron with $p'_\perp \gtrsim 100$ MeV.

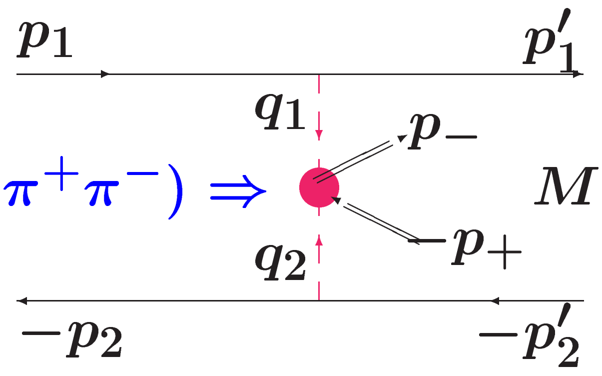
This recording excludes $e^+e^- \to \pi^+\pi^-\gamma$.

$e^+e^- \to e^+e^-\pi^+\pi^-$

(I.F. Ginzburg, A. Schiller, V.G. Serbo, Eur. Phys. J. **C18** (2001) 731 ; first calculations: V.L. Chernyak, V.G. Serbo: Nucl. Phys. **B 67** (1973) 464)

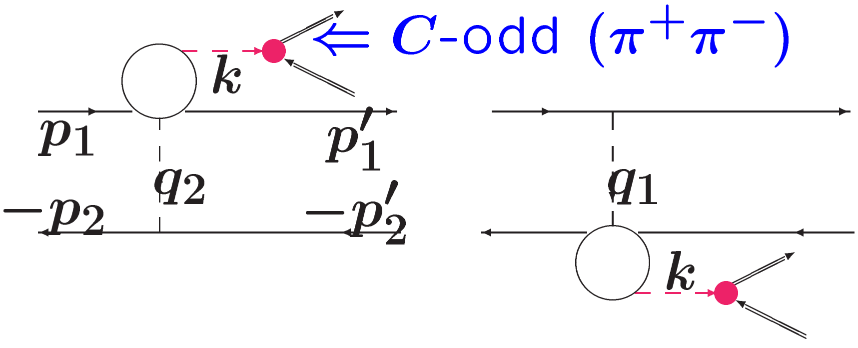
The charge asymmetry of pions in the process is due to an interference between amplitudes given by diagrams:

C-even $(\pi^+\pi^-) \Rightarrow$



$$M^2 = (p_+ + p_-)^2$$

The two–photon production



The bremsstrahlung production

Let pion momenta are
$p_\pm = (\varepsilon_\pm, \boldsymbol{p}_{\pm\perp} \, p_{\pm z})$; $x_\pm = \dfrac{\varepsilon_\pm + p_{\pm z}}{\sqrt{s}}$.
We define

$$k = p_+ + p_- \,, \quad x = x_+ + x_- \,, \quad M = \sqrt{k^2} \,.$$

We define forward–backward (FB) and transverse (T) asymmetry by variables

$$FB : \xi = \frac{x_+ - x_-}{x} \,,$$

$$T : v = \frac{\boldsymbol{p}^2_{+\perp} - \boldsymbol{p}^2_{-\perp} - \xi \boldsymbol{k}^2_\perp}{M|\boldsymbol{k}_\perp|} \equiv \frac{(\boldsymbol{\rho}_\perp \boldsymbol{k}_\perp)}{M|\boldsymbol{k}_\perp|} \,,$$

($\boldsymbol{\rho}_\perp$ – the transverse component of relative momentum of pions.)

Relation to the angles in the dipion c.m.s.:

$$\xi = \cos\theta, \; v = \sin\theta\cos\phi.$$

The charge asymmetric signal is composed from $(\gamma\gamma\,/e^-)$ and $(\gamma\gamma\,/e^+)$ interferences,

$$d\sigma_{asym} = d\sigma_{2e^-} + d\sigma_{2e^+}\,.$$

In the helicity basis for $\gamma^*\gamma^* \to \pi^+\pi^-$

$$d\sigma_{2e^-} = -\frac{\alpha^3}{8\pi^4}\frac{\rho_2^{++}L_2}{(sM)^2 xd}\Big[g^{++}Re(F_\pi^* M_{++}) + g^{+-}Re(F_\pi^* M_{+-}) + g^{0+}Re(F_\pi^* M_{0+})\Big]\,d\Gamma_{\pi\pi}\,;$$

$$d\sigma_{2e^+} = -d\sigma_{2e^-}(p_{1,2}\leftrightarrow p_{2,1}\; q_2 \to q_1)\,,$$

$$M^{ab}(q_1, q_2, \Delta) \to (-1)^{a+b}M^{ba}(q_2, q_1, \Delta)\,.$$

Coefficients are calculated with logarithmic accuracy ($\sim 5\%$), $d\Gamma_{\pi\pi}$ is the pion phase space.

Similar eq. was obtained also in M. Diehl, T. Gosset, B. Pire, Phys. Rev. **D 62** 073014 (2000)

The new feature as compare two–photon case, is the essential impact of amplitude M_{0+}.

At the effective mass of dipion $M < 1$ GeV this asymmetry is directly related to the s- and p-phases of the elastic $\pi\pi$ scattering. Nontrivial effects are given by the first item (with M_{++}) only. For others point–like QED looks good approximation.

At $M \gtrsim 1$ GeV these observations should help to separate different models for resonances having both $\pi\pi$ and $\gamma\gamma$ decays. For example, it can give us a new information about $f_0(980)$ and $f_2(1270)$ mesons, etc.

LIST OF EQUATIONS

$$y_2 = \frac{2q_2P_1}{s} = \frac{M^2 d}{sx(1-x)}, \quad \rho_2^{++} = \frac{2-2y_2+y_2^2}{y_2^2},$$
$$L_2 = \ln\left(\frac{|q_2^2|_{max}(1-y_2)}{m_e^2 y_2^2}\right),$$
$$d = 1 - x + \frac{\mathbf{k}_\perp^2}{M^2}, \quad |q_2^2|_{max} \approx min\left(\frac{\mathbf{k}_\perp^2}{1-y_2}, m_\rho^2, M^2\right),$$

$$g^{++} = (2-x)\xi + v\left[\frac{1-x}{\mathbf{k}_\perp^2} - \frac{2-2x+x^2}{2(1-x)M^2}\right],$$
$$g^{+-} = -\left(1 - x + \frac{x^2}{2} + \frac{\mathbf{k}_\perp^2}{M^2}\right)\frac{v}{\mathbf{k}_\perp^2}$$
$$-\left[(2-x)\xi - \frac{v}{M^2}\right]\cos 2\phi,$$
$$g^{0+} = \sqrt{\frac{2(1-x)}{\mathbf{k}_\perp^2\boldsymbol{\rho}_\perp^2}}\Big[(2-x)\boldsymbol{\rho}_\perp^2 - \xi v + \xi^2\mathbf{k}_\perp^2$$
$$-\frac{2-x}{1-x}\,\frac{2v^2 - \mathbf{k}_\perp^2\boldsymbol{\rho}_\perp^2}{M^2}\Big]$$

The properties at the charge conjugation operation $\hat{C}_\pi$:

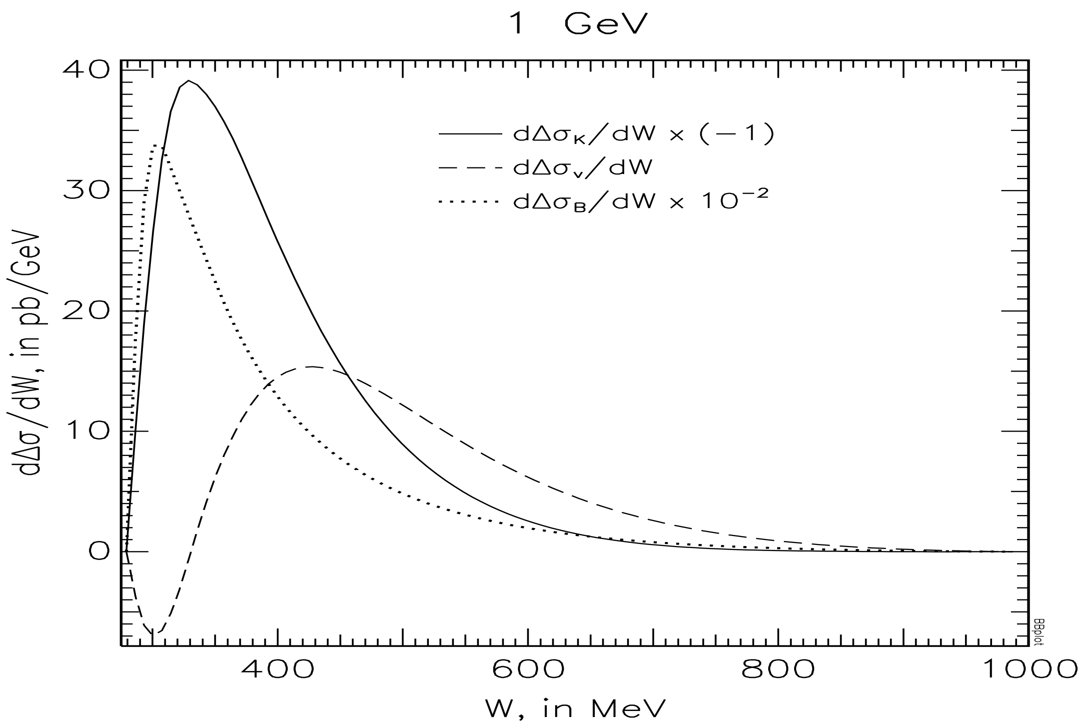
$$\hat{C}_\pi M^{+\pm} = M^{+\pm}, \quad \hat{C}_\pi M^{0+} = -M^{0+},$$
$$\hat{C}_\pi g^{+\pm} = -g^{+\pm}, \quad \hat{C}_\pi g^{0+} = g^{0+}.$$

To join FB asymmetry from electron and positron bremsstrahlung, we consider distribution in
$K_- = \left.\frac{p_z - p_{-z}}{\epsilon_+ + \epsilon_-}\right|_{c.m.s.}$ ($\approx \xi$ at $x \sim 1$).
Observables – integrals over some region of pion phase space

$$FB : \Delta\sigma_K = \int d\sigma(K_- > 0) - \int d\sigma(K_- < 0)\,,$$
$$T : \Delta\sigma_v = \int d\sigma(v > 0) - \int d\sigma(v < 0)\,, \quad \sigma_B = \int d\sigma\,.$$

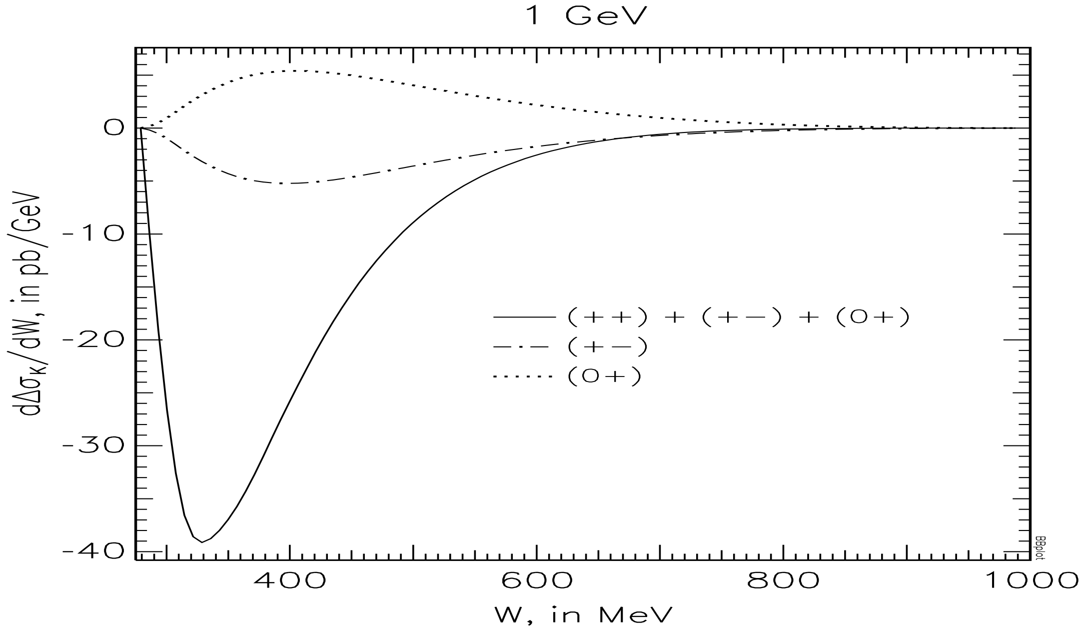
We calculated these quantities for the QED model (*the sensitivity to the strong interaction effects should be studied*).

Examples for DAΦNE



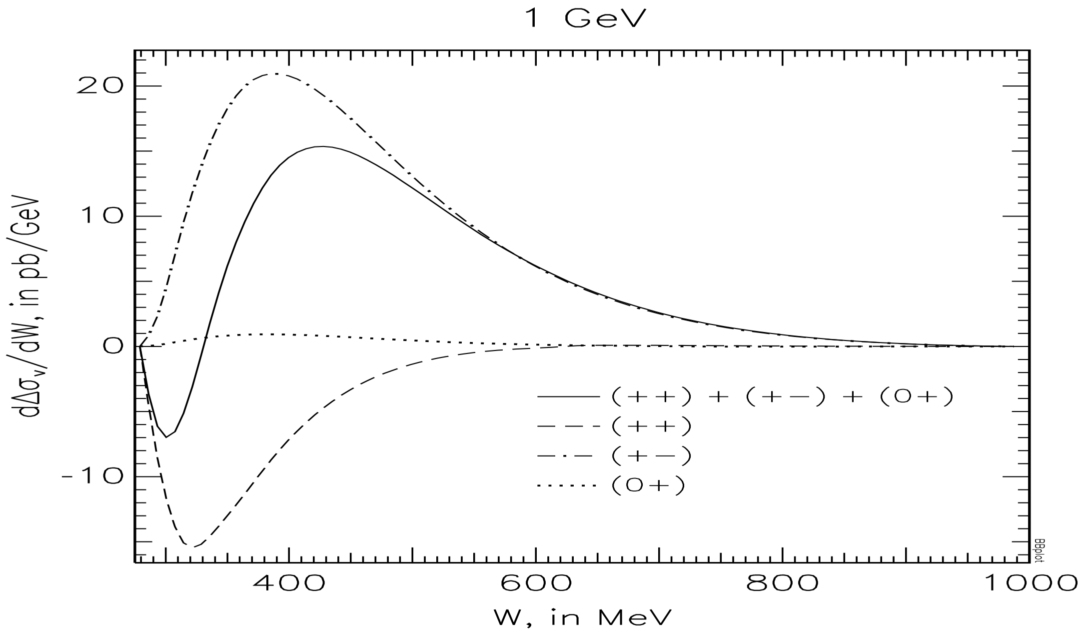
The FB ($\Delta\sigma_K$) and T ($\Delta\sigma_v$) asymmetries and background

Contributions of different helicity amplitudes:



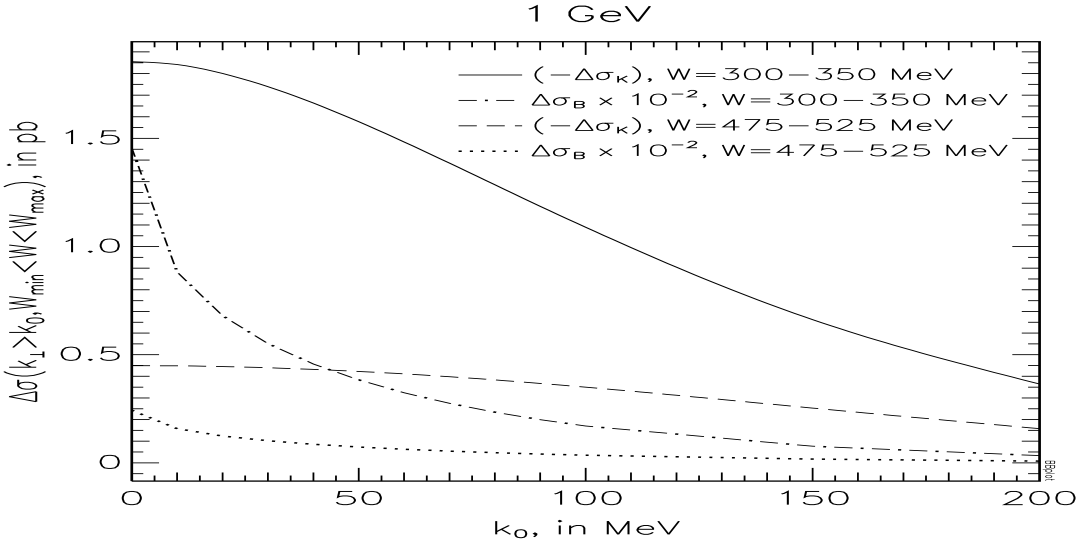
FB asymmetry:

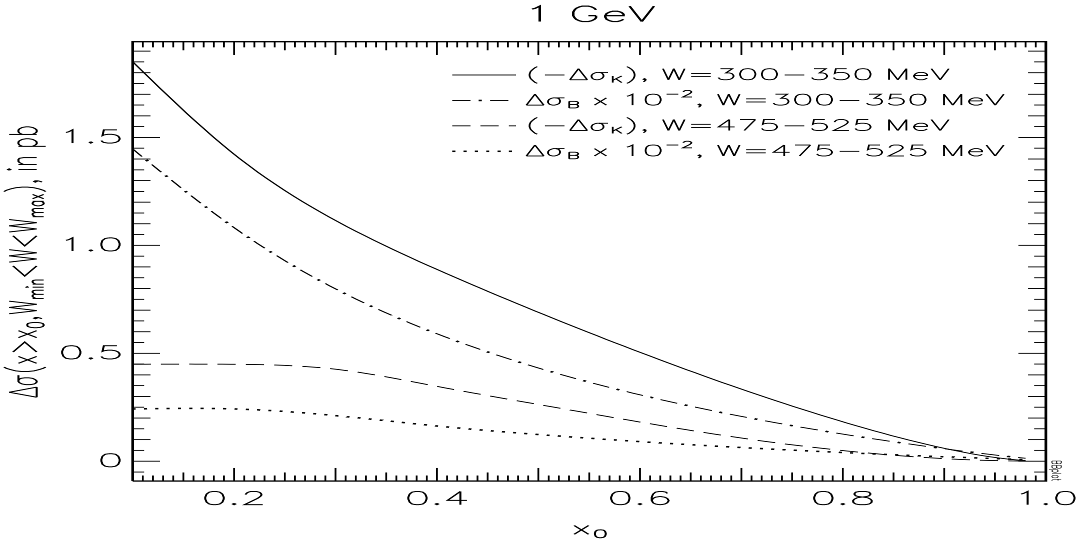
The amplitude M_{++} dominates.



T asymmetry: Effects from M_{++} and M_{+-} almost cancel each other. Strong interaction can destroy this

Effect of cuts in total transverse momentum of pair $k_\perp > k_0$ and its total energy $x > x_0$.





The statistical significance for luminosity integral $\mathcal{L}$ is $SS_{K,v} = \dfrac{\mathcal{L}\Delta\sigma_{K,v}}{\sqrt{\mathcal{L}\sigma_B}}$.

E.g., with cuts $k_\perp >$ 100 MeV, $0.9 > x > 0.4$ at the luminosity integral 500 pb^{-1} $SS_K \approx 7$. The more refined data preparation, including choice of cuts, can improve this estimate significantly.

LIST OF RELATED PROBLEMS

In my review related using of charge asymmetry I discuss following problems.

1. $\boxed{\pi^+\pi^- \text{ pairs in } e^+e^- \text{ collisions, etc.}}$

$e^+e^- \to \pi^+\pi^-\gamma$ for $\sigma(e^+e^- \to hadrons)$;

Phases of $\pi\pi$ scattering, resonances, etc. in $e^+e^- \to e^+e^-\pi^+\pi^-$, $e^+e^-K\bar{K}, \dots$

$c\bar{c}$ and $b\bar{b}$ resonances with $J = 0, 2$ in $e^+e^- \to e^+e^-c\bar{c}$, $e^+e^- \to e^+e^-b\bar{b}$

$\mathcal{CP}$ violation with t–quarks in $e\gamma \to et\bar{t}$.

2. $\boxed{\text{Diffraction type process } \gamma p \to (\pi^+\pi^-)X.}$

Possible discovery of odderon,

$Re(A(\gamma p \to \rho p))$

3. Breaking of quark – hadron duality.

4. $\boxed{\text{Weighted structure functions in DIS.}}$

5. Study of possible strong interaction in the Higgs sector in $\boxed{e\gamma \to eWW}$

6. Charge asymmetry in the polarized $\gamma\gamma$ collisions, like $\gamma\gamma \to \mu^+\mu^-\nu\nu$ or $\gamma\gamma \to \mu^+\mu^-\nu\nu\nu\nu$ or $\gamma\gamma \to \mu^+\mu^-\nu\nu\chi_0\chi_0, \dots$