(Some aspects of) $\gamma\gamma$ physics at Flavour Factories

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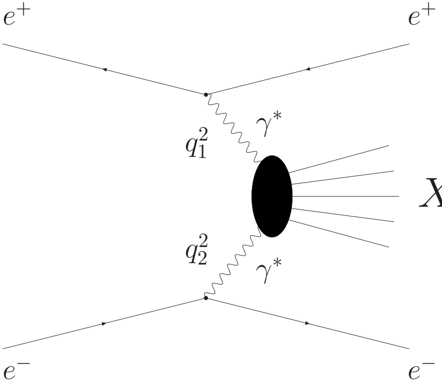
Outline

- Introduction
- the Low function and its accuracy
- accuracy of QED theoretical predictions
- hadronic resonance production
- $\sigma(\gamma\gamma \to \mathrm{hadrons})$
- charmonia and their exotics
- benefit from electron taggers
- Summary

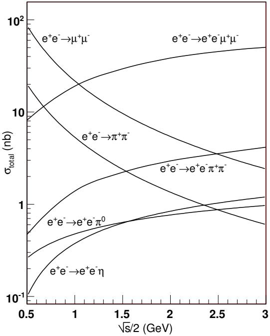
Introduction: $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$



$X = \text{hadrons}, \; l^+l^-, \; \ldots$

Features of two-photon physics

- increasing x-sect's with $\sqrt{s}$

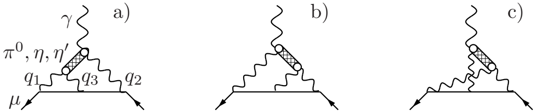


D.M. Asner et al., arXiv:0809.1869[arXiv:hep-ex]

- possible quantum numbers of the produced X system: $J^{PC} = 0^{\pm +}$, $2^{\pm +}$, different from what is accessible through e^+e^- annihilation

Relevance of two-photon physics

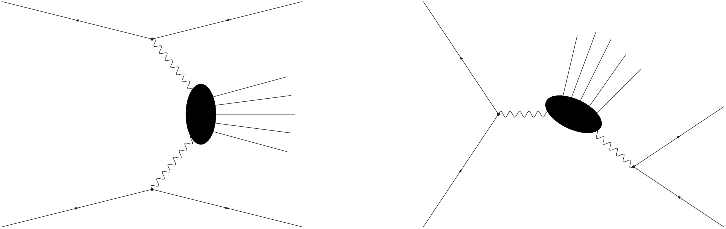
- the coupling of hadronic resonances to $\gamma\gamma$ can be studied in a production process, allowing an independent determination of the width $h \to \gamma\gamma$
  - this can clarify the nature of hadronic resonances such as for instance light scalar mesons $\sigma(600)$, $f_0(980)$
  - charmonia and exotics with $C = +$ and even J
- the knowledge of $\gamma^{(*)}\gamma^{(*)}P(P = \pi^0, \eta, \eta')$ form factors $F(Q^2, q_1^2, q_2^2)$ will be crucial for the determination of light-by-light contribution to $g-2$, which will be the main source of th-uncertainty



The Equivalent Photon Approximation (EPA)

Fermi, Landau-Lifshitz, Weizsäcker-Williams

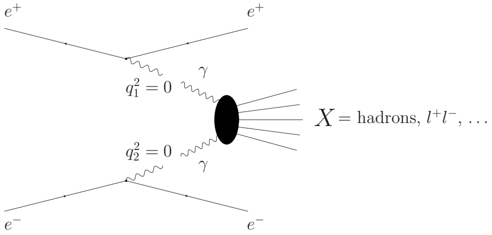
- for a generic process both $t-$ and $s-$ channel topologies contribute



- including in the event selection the collinear regions for electrons, the $1/q^2$ structure of the photon propagators enhances the "$\gamma\gamma$ fusion" diagram

The Equivalent Photon Approximation (EPA)

- in this condition a good approximation is to consider
  - on-shell ($q_i^2 = 0$) incoming photons
  - only transverse photon polarization degrees



$$\sigma(e^+e^- \to e^+e^-X) = \int \frac{dF}{dW_{\gamma\gamma}} \sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})dW_{\gamma\gamma}$$

This is used as a definition of $\sigma_{\gamma\gamma\to X}$

Features of EPA

- the Low function $dF/dW_{\gamma\gamma}$ can be calculated from QED (see following slides

F. Low Phys. Rev. 120 (1960) 582
Bonneau, Gourdin, Martin, Nucl. Phys. B54 (1973) 573
Brodsky, Kinoshita, Terazawa, Phys. Rev. D4 (1971) 1532
Budnev, Ginzburg, Meledin, Serbo, Phys. Rept 5 (1975) 181

- the hadronic model dependence of the calculation is confined in $\sigma_{\gamma\gamma\to X}$, which is a $2 \to 2$ process and hence easier to be calculated
  - *e.g.* the two-loop ChPT calculation of $\sigma(\gamma\gamma \to \pi^0\pi^0)$

    Bellucci, Gasser and Sainio, Nucl. Phys. B423 (1994) 80

    would be much more complicated for the complete non-factorized process $e^+e^- \to e^+e^-\pi^0\pi^0$
- $\sigma_{\gamma\gamma\to X}$ is a quantity defined independently of the details of the experiment and so it is useful when comparing results of different experiments at different machines
- the factorization introduces an approximation which needs to be quantified with as complete as possible calculations
- This issue becomes important with increasing machine luminosity

The Low function

G.A. Schuler, hep-ph/9610406

$$\sigma = \int_{\tau_{\rm thresh}}^{1} \sigma_{\gamma\gamma}(W^2 = \tau s) F(\tau)$$

$$F = \frac{1}{\tau} \int N(x_1) N(x_2 = \tau / x_1) \frac{dx_1}{x_1}$$

$$N(x_i) = \left(\frac{\alpha}{2\pi}\right) \left\{ \left[1 + (1 - x_i)^2 \log \frac{Q^2_{i{\rm max}}}{Q^2_{i{\rm min}}} \right] - 2 m_e^2 x_i^2 \left[\frac{1}{Q^2_{i{\rm min}}} - \frac{1}{Q^2_{i{\rm min}}} \right] \right\}$$

- $Q^2_{i{\rm min}}$ and $Q^2_{i{\rm max}}$ determined from the experimental conditions on the $e^{\pm}$ scattering angles ϑ_i and energies
- the smaller $\vartheta_{i,{\rm max}}$ the better the approximation

the Low function expression at fixed W^2

$$
\begin{aligned}
L(W^2,s) &= \left(\frac{\alpha}{\pi}\right)^2 \frac{F(W^2,s)}{W^2} \\
F(W^2,s) &= \frac{2}{3}\left(\log\frac{s}{W^2}\right)^3 + 2\left(\log\frac{s}{W^2}\right)^2\left(\log\frac{W^2}{m^2}\right) \\
&+ \left(\log\frac{s}{W^2}\right)\left(\log\frac{W^2}{m^2}\right)^2 - 4\left(\log\frac{s}{W^2}\right)^2 \\
&- 7\left(\log\frac{s}{W^2}\right)\left(\log\frac{W^2}{m^2}\right) - \frac{3}{2}\left(\log\frac{W^2}{m^2}\right)^2 \\
&+ \left(\frac{17}{2} - \frac{2\pi^2}{3}\right)\left(\log\frac{s}{W^2}\right) + \left(\frac{39}{4} - \frac{2\pi^2}{3}\right)\left(\log\frac{W^2}{m^2}\right) \\
&- \frac{7}{2} + \frac{7}{6}\pi^2 - 4\zeta(3) + \mathcal{O}\left(\frac{W^2}{s}\right)
\end{aligned}
$$

Bonneau, Gourdin, Martin, Nucl. Phys. B54 (1973) 573

event selections

- two classes of event selections:
  - untagged events: no detected electrons
    - all recent experimental data analysis at BaBar, Belle and CLEO, aiming at measurements of $\sigma(\gamma\gamma \to \mathrm{hadrons})$, consider untagged events
    - to rely on the factorization approximation a cut $p_\perp \lesssim 0.1$ GeV on the detected hadronic system is imposed
    - usually from comparison between theoretical predictions based on complete diagrammatic calculations and simulations using EPA, a systematic error of the order of 5% is assigned
    - already at present flavour factories, this is about 50% of the total error
  - single-tag events: only one detected electron
    - used for the measurement of form factors $F(Q^2, q^2, 0)$
  - double-tag events: necessary for measurements of $F(Q^2, q_1^2, q_2^2)$. Without forward taggers (as *e.g.* at LEP) generally very low rates

resonance production

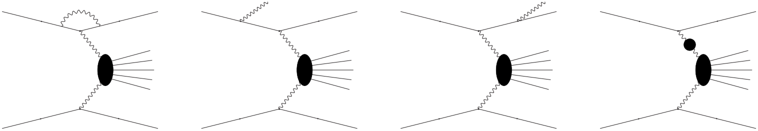
- production cross section of a resonance (using EPA):

$$\begin{aligned}
\sigma(e^+e^- \to e^+e^- R) &= \int \sigma_{\gamma\gamma\to R} dL_{\gamma\gamma}(W^2) \\
\sigma_{\gamma\gamma\to R}(W^2, q_1^2, q_2^2) &= 8\pi(2J_R+1)\Gamma_{\gamma\gamma}(R)F(q_1^2, q_2^2) \\
&\times \frac{\Gamma_R}{(W^2 - M_R^2)^2 + M_R^2\Gamma_R^2} \\
F(0,0) &= 1
\end{aligned}$$

- the measured cross section directly proportional to the combination $\Gamma_{\gamma\gamma}(R) \times \mathcal{BR}(R \to h)$, where h is the analysed exclusive final state
- sensitivity to the form factor only with single or double tag events

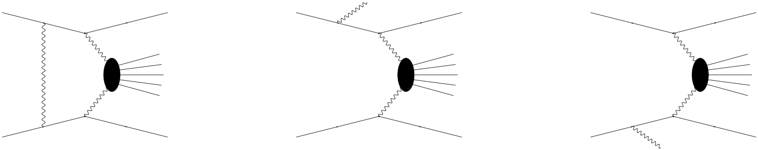
Radiative Corrections

- $t-$channel photonic RC $\oplus$ vacuum polarization (for $\mu^+\mu^-$ production) $\simeq$ few % (for untagged ev. sel.; they become more relevant for single or double tag ev. sel.)



F.A. Berends, P.H. Daverveldt and R. Kleiss, Nucl. Phys. B253 (1985) 421

- up-down interference (for point-like pseudoscalar production) completely negligible



W.L. van Neerven and J.A.M. Vermaseren, Phys. Lett. B142 (1984) 80; Nucl. Phys. B238 (1984) 73

A list of available simulation tools

- Program by A. Courau for $e^+e^- \to e^+e^-\pi^0\pi^0$, $e^+e^- \to e^+e^-\pi^0$
- EKHARA: exact LO matrix elements (with form factors) $e^+e^- \to e^+e^-\pi^+\pi^-$, $e^+e^- \to e^+e^-\pi^0$

  H. Czyz and S. Ivashyn, Comp. Phys. Comm. 182 (2011) 1338
- TREPS: based on EPA for several kernel processes (used for analysis @Belle)

  S. Uehara, KEK-REPORT-96-11
- NPP: exact LO matrix elements for $e^+e^- \to e^+e^-\sigma \to e^+e^-\pi^0\pi^0$, $e^+e^- \to e^+e^-\pi^0/\eta$ (used for analysis @ KLOE)

  F. Nguyen, A.D. Polosa and F. Piccinini, Eur. Phys. J. C47 (2006) 65
- GaGaRes: exact LO simulation of resonance production for ${}^1S_0, {}^3P_J, {}^1D_2$ (used for analysis @ LEP2)

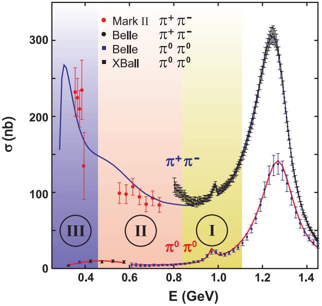
  F.A. Berends and R. van Gulik, Comp. Phys. Comm. 144 (2002) 82
- GALUGA: it adopts the improved EPA (used for analysis @ LEP2)

  G.A. Schuler, Comp. Phys. Comm. 108 (1998) 82
- TWOGAM: $e^+e^- \to e^+e^-P$, with $P = \pi^0/\eta/\eta'$ (used for analysis @ CLEO)

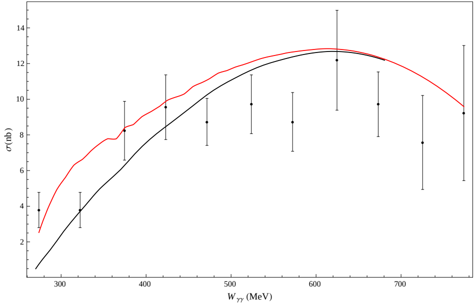
  D.M. Coffman
- TWOGEN: several kernel processes with EPA

  A. Buijs, W.G. Langeveld, M.H. Lehto, D.J. Miller, Comp.Phys.Commun. 79 (1994) 523

π pair production measurements



G. Amelino-Camelia et al., Eur.Phys.J. C68 (2010) 619

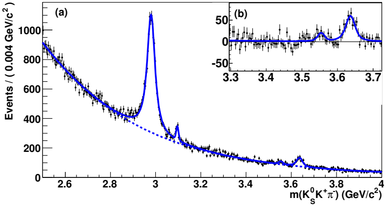


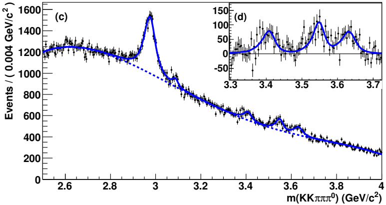
F. Nguyen, A.D. Polosa, F.P., Eur. Phys. J. C47 (2006) 65

- precise Belle data for $W_{\gamma\gamma} > 0.8$ GeV
- KLOE2 will improve for lower $W_{\gamma\gamma}$
- How can improve SuperB in that region?

- ChPT predictions $+ \sigma(600)$ resonance (red curve)

expected and unexpected charmonia





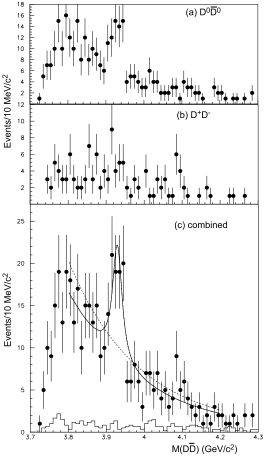
J.P. Lees et al., Phys. Rev. D; V.P. Druzhinin, arXiv:1011.6159

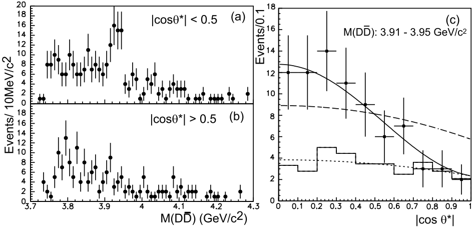
$\Uparrow$ η_c $\Uparrow$ $\eta_c(2S)$ $\Uparrow$ η_c $\Uparrow$ χ_{c0} $\Uparrow$ χ_{c2} $\Uparrow$ $\eta_c(2S)$

η_c and χ_c already seen ten years ago by LEP Collaborations

expected and unexpected charmonia

$$e^+e^- \to e^+e^- D^+D^- / D^0\bar{D}^0$$





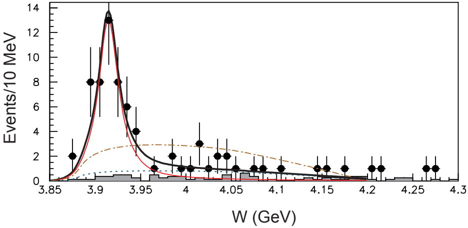
S. Uehara et al., Phys. Rev. Lett. 96 (2006) 082003

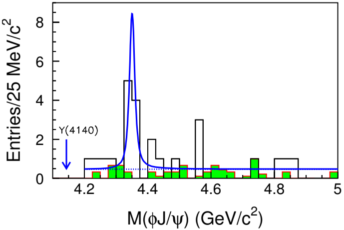
$$Z(3930) = \chi'_{c2}(2^3P_2)?$$

expected and unexpected charmonia

$e^+e^- \to e^+e^- J/\psi\omega$

$e^+e^- \to e^+e^- J/\psi\phi$





S. Uehara et al., Phys. Rev. Lett. 104 (2010) 092001

B. Aubert et al., arXiv:1002.0281[hep-ex]

C.P. Shen et al., Phys. Rev. Lett. 104 (2010) 112004

$X(3915) =$?, J^{PC}?

$X(4350) =$?, J^{PC}?

Summary

- Flavour Factories are sources of (quasi-real) $\gamma\gamma$ interactions with variable c.m. energy
- they could give important information on several subjects:
  - hadronic cross sections of hadron pair production (particularly in the low $\gamma\gamma$ c.m. energy region)
  - study of resonances $\gamma\gamma$ partial widths through the production channel
  - search for new states with $C = +$
  - measurement of form factors
- to fully exploit the huge available statistics, careful checks between (possibly) exact calculations (including radiative corrections) and results in EPA approximation need to be carried out
- such measurements would benefit from the presence of forward electron/positron taggers (see next talk by F. Nguyen)