EKHARA
new gamma gamma generator

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Outline

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2. EKHARA Monte-Carlo generator
3. EKHARA generator at work: KLOE-2 case
4. Form factor modeling (π^0, η, η')
5. Summary and plans

Introduction

Objectives

1. Develop and maintain a free and public tool for $e^+e^- \to e^+e^-\mathcal{P}$ simulation (π^0, η, η')
2. Tool for experiment and for theory
3. Account for light meson phenomenology in detail
4. $\Rightarrow$ Contribute to solving the “BaBar puzzle” of $F_{\pi^0\gamma^*\gamma}(Q^2)$

Experiments: $e^+e^- \to e^+e^-\mathcal{P}$

Existing data:

$\Rightarrow$ model improvement

$\Rightarrow$ generator verification

single-tag experiments in *space-like region* ($t < 0$)

- CELLO: $0.5\ \mathrm{GeV}^2 < Q^2 < 2.17\ \mathrm{GeV}^2$

  [Z. Phys., C49, 401-409 (1991)]

- CLEO: $1.5\ \mathrm{GeV}^2 < Q^2 < 9\ \mathrm{GeV}^2$

  [Phys.Rev., D57, 33-54 (1998)]

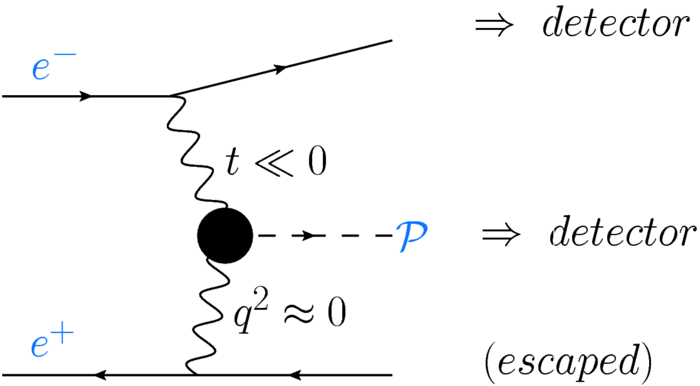
- BaBar: $4\ \mathrm{GeV}^2 < Q^2 < 40\ \mathrm{GeV}^2$

  [Phys.Rev., D80, 052002 (2009)] [Phys.Rev., D84, 052001 (2011)]

"$F(m^2_{\mathcal{P}}, Q^2, 0)$" is measured, where $Q^2 = -t$

Single-tag $e^+e^- \to e^+e^-\mathcal{P}$

By tagging only one lepton, we measure only one invariant, $Q^2 = -t$



Experiments: $e^+e^- \to e^+e^-\mathcal{P}$

New analyses and new experiments:
single-tag and double-tag in *space-like region* ($t < 0$)

- π^0: KLOE-2: $0.01 \text{ GeV}^2 < Q^2 < 0.1 \text{ GeV}^2$

[D. Babusci et al., arXiv:1109.2461 (2011)]

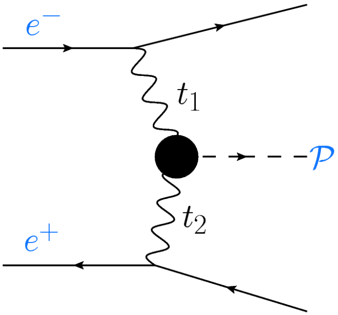
[Amelino-Camelia et al., Eur.Phys.J. C68,619 (2010)]

- $\pi^0, \ldots$: Belle
- $\pi^0, \eta, \ldots$: BES III: $1 \text{ GeV}^2 < Q^2 < 4 \text{ GeV}^2$ (or better)

one can measure "$F(m_{\mathcal{P}}^2, Q^2, 0)$", where $Q^2 = -t$

Double-tag $e^+e^- \to e^+e^-\mathcal{P}$

For example, at KLOE-2 the double-tagging is possible.
By detecting (tagging) both leptons, we get access to both variables: t_1 and t_2



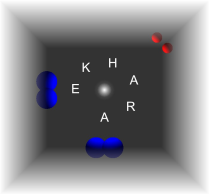
$\Rightarrow$ *detector*

$\Rightarrow$ *detector, or escape*

$\Rightarrow$ *detector*

EKHARA Monte-Carlo generator

EKHARA 2.0



[http://prac.us.edu.pl/˜ekhara]

2.0 $e^+e^- \to e^+e^- \pi^0$

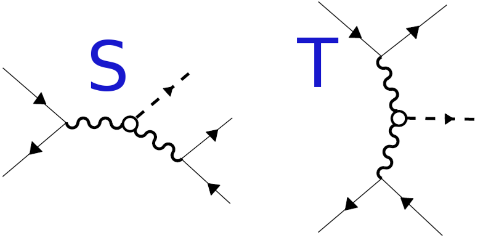
- ✓ free and public
- ✓ full description of virtual photons
- ✓ high generator efficiency

H. Czyż, S. Ivashyn,

Comp.Phys.Comm., 182, 1338 (2011)

EKHARA 2.0 features

- two-photon form factor
  - several recent models from the market
  - can also be provided by user
- types of amplitude
  - s-, t-channel contributions, separate/both, incl. interference



Comput.Phys.Commun., 182, 1338 (2011)

EKHARA version 2.0 Tests

- comparison with GALUGA

  [GALUGA: G.A. Schuler, Comput. Phys. Commun., 1998, 108, 279–303]

  - phase space volume
  - total cross section

- comparison with single-tag data ($d\sigma/dQ^2$)
  - CELLO [Z. Phys., C49, 401-409 (1991)]
  - CLEO [Phys.Rev., D57, 33-54 (1998)]
  - BaBar [Phys.Rev., D80, 052002 (2009)]

Comp.Phys.Comm., 182, 1338 (2011)

EKHARA generator at work: KLOE-2 case

EKHARA at work: KLOE-2 case

New feasibility studies of $e^+e^- \to e^+e^- \pi^0$

D. Babusci et al., arXiv:1109.2461 (2011)

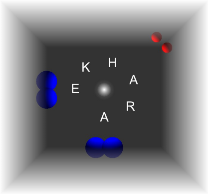
See also my slides at the Satellite Meeting

EKHARA at work: KLOE-2 case

1. a per cent level of precision can be achieved in the measurement of $\Gamma_{\pi^0 \to \gamma\gamma}$ by the KLOE-2 experiment at Frascati
2. KLOE-2 experiment can perform the first measurement of $F_{\pi^0 \gamma^* \gamma}(Q^2)$ in the space-like region in the vicinity of the origin: $0.01 < Q^2 < 0.1$ GeV^2
3. the impact of the proposed measurements on the evaluation of the Standard Model prediction for the anomalous magnetic moment of the muon, a_μ, is estimated

Form factor modeling (π^0, η, η')

η and η' in EKHARA



[http://prac.us.edu.pl/˜ekhara]

$e^+e^- \to e^+e^- \ \eta$

$e^+e^- \to e^+e^- \ \eta'$

- ✓ “realistic” form factors

H. Czyż, S. Ivashyn,
A. Korchin, O. Shekhovtsova

to be published soon

Form factor modeling

[Czyż, Ivashyn, Korchin, Shekhovtsova. to be published.]

- We apply chiral perturbation theory with resonances as an effective theory

[Ecker et al., Phys.Lett.B223, 425 (1989)]

[Ecker et al., Nucl.Phys.B321, 311 (1989)]

[Prades, Z.Phys. C63, 491 (1994)]

- We require the form factors to vanish at high $|t|$
  (it reduces the number of parameters)

An analogous approach to other processes was used in our previous papers

[Eidelman et al., Eur.Phys.J.C69, 103 (2010)]

[Ivashyn, Korchin, PoS EFT09, 055 (2009)]

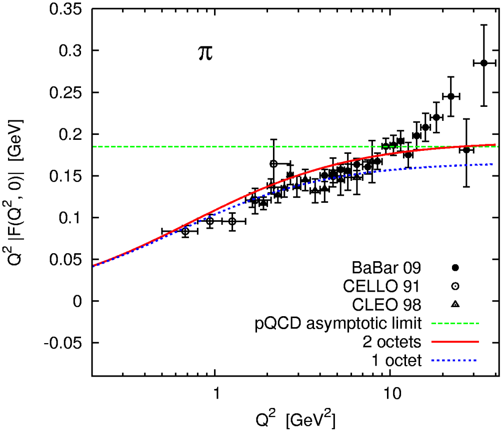
[Ivashyn, Korchin, Eur.Phys.J.C54, 89 (2008)]

[Ivashyn, Korchin, Eur.Phys.J.C49, 697 (2007)]

Quality of the model

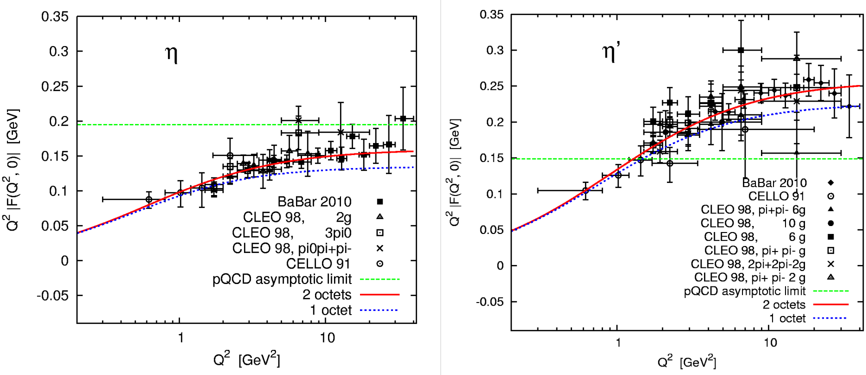
- Global fit of π^0, η and η' form factors
- Only one free parameter: $h_{V_1} = 0.03124(14)$
- Quality of the model: $\chi^2/d.o.f. \approx 1.2$

Form factor $\gamma^*\gamma\pi^0$



- good agreement with CELLO 1991, CLEO 1998
- discrepancy with BaBar 2009

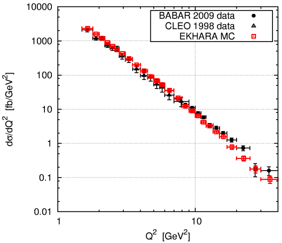
Form factor $\gamma^*\gamma\eta$ and $\gamma^*\gamma\eta'$

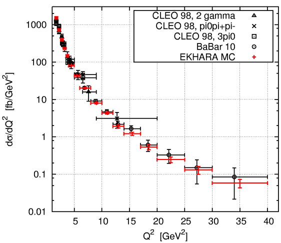


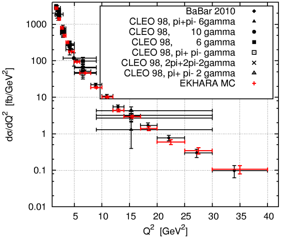
- agreement with CELLO 1991, CLEO 1998 and with BaBar 2010

Cross section $\frac{d\sigma}{dQ^2}$ for $e^+e^- \to e^+e^-\mathcal{P}$

π^0 η η'







- the only discrepancy is with BaBar 2009 (the same pattern as seen in the form factor)

Summary and plans

Summary

- The π^0, η, η' form factors
  - ✓ one model parameter
  - ✓ global fit: $\chi^2/d.o.f. = 1.2$
- The formulae are implemented in the Monte-Carlo generator EKHARA
  - ✓ $\frac{d\sigma}{dQ^2}$ is compared to data
- We expect EKHARA to be used in the data analysis by KLOE-2 and BES III

Plans

- Radiative corrections
- Comparison with `GGRESRC` — the generator of Druzhinin, Kardapoltsev and Tayursky (arXiv:1010.5969)

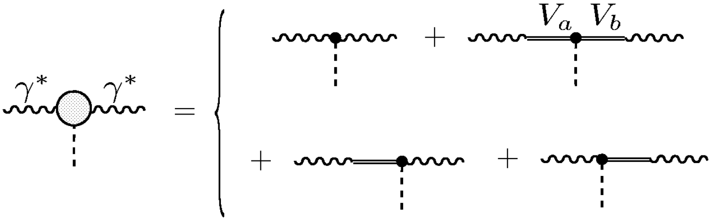
Spare slides

Recent interest in $\mathcal{P}\gamma^*\gamma$

- P.Kroll EPJ C71, 1623 (2011)
- S.Brodsky et al. PR D84, 033001 (2011)
- K.Kampf, J.Novotny PR D84, 014036 (2011)
- P. Lichard PR D83, 037503 (2011)
- E.Ruiz Arriola, W.Broniowski PR D81, 094021 (2010)
- …and many others …

mainly triggered by new experimental data and open problems in calculation of the hadronic light-by-light part of muon a.m.m.

$\gamma^*\gamma^*\mathcal{P}$ diagrams



dashed	pseudoscalar meson $\mathcal{P}$
solid	vector mesons
wavy	(virtual) photons

$V_a \neq V_b$ in $\gamma^*\gamma^*\pi^0$ diagrams
$V_a = V_b$ for $\gamma^*\gamma^*\eta$ and $\gamma^*\gamma^*\eta'$ diagrams

Quality of the model

The χ^2 per experiment and the total χ^2. Number of data points (n.d.p.) is also given for each experiment. In all given experiments the pseudoscalar meson is produced in a two-photon process $e^+e^- \to e^+e^-\mathcal{P}$, but the decay channels for $\mathcal{P}$ identification vary. The “2 octets” column is calculated with the parameter values given by the global fit.

experiment	1 octet $\chi^2/n.d.p.$	2 octets $\chi^2/n.d.p.$
CELLO ($\pi^0 \to \gamma\gamma$)	0.29/5	0.46/5
CLEO ($\pi^0 \to \gamma\gamma$)	6.27/15	20.52/15
BABAR ($\pi^0 \to \gamma\gamma$)	124.83/17	55.49/17
CELLO ($\eta \to \gamma\gamma$)	0.24/4	0.13/4
CLEO ($\eta \to \pi^+\pi^-\pi^0$)	19.28/6	11.18/6
CLEO ($\eta \to \gamma\gamma$)	8.55/8	2.11/8
CLEO ($\eta \to \pi^0\pi^0\pi^0$)	10.91/5	5.64/5
BABAR ($\eta \to \gamma\gamma$) arXiv	82.75/11	8.64/11
CELLO ($\eta' \to \gamma\gamma$)	0.11/5	0.29/5
CLEO ($\eta' \to \gamma\gamma\pi^+\pi^-$)	19.90/6	7.61/6
CLEO ($\eta' \to \gamma\gamma\pi^+\pi^-\pi^+\pi^-$)	2.61/5	1.44/5
CLEO ($\eta' \to \gamma\pi^+\pi^-$)	14.01/6	4.72/6
CLEO ($\eta' \to 6\gamma$)	21.54/5	12.74/5
CLEO ($\eta' \to 10\gamma$)	0.49/2	0.23/2
CLEO ($\eta' \to \pi^+\pi^-6\gamma$)	5.93/5	4.79/5
BABAR ($\eta' \to \gamma\gamma$) arXiv	31.82/11	2.75/11
total	349.55/116	138.74/116