03/08/99 Vladimir Savinov

Two-Photon Physics at the Tau-Charm Factory and Selected Topics in Light Meson Spectroscopy

1. Two-Photon Hadronic Physics with the EXACT Detector.
2. Long-Standing Problems in Light Meson Spectroscopy and Final States to Study in Two-Photon Collisions.
3. Selected Topics and New Analysis Ideas for the Tau-Charm Factory (from personal two-photon perspective).
4. Pros and Cons of the τCF in comparison to B Factories ($\gamma\gamma$).
5. Conclusions

Workshop on the Tau-Charm Factory @ SLAC
1999

The Algebra of Two-Photon Collisions

"γγ" Physics $\boxed{e^+e^- \longrightarrow e^+e^- \underbrace{\text{Hadron(s)}}_{C=+1}}$ ①

$e^+e^- \longrightarrow e^+e^- \underbrace{\text{Hadron(s)}}_{C=-1}$ ②

(one of 8 diagrams)

$e^+e^- \longrightarrow \underbrace{\text{Hadron(s)}}_{C=-1}$ ③

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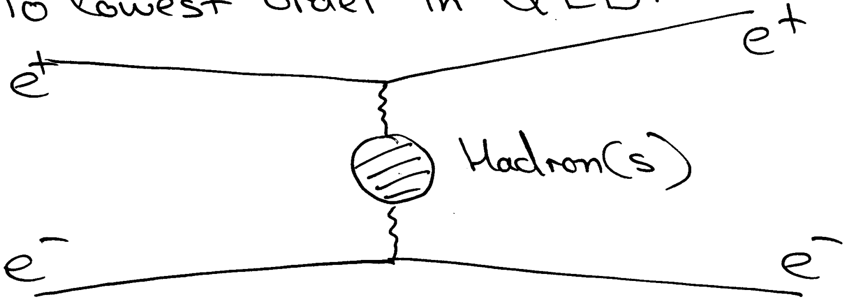
③ QCD studies at fixed invariant mass

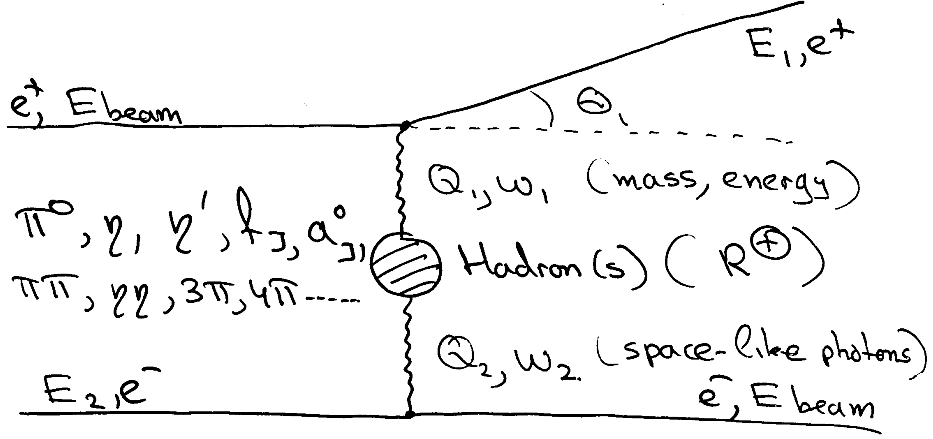
② QCD studies at (some) range of masse

① QCD studies of C = +1 hadronic systems at wide range of inv. mass

To lowest order in QED:



Some Properties of the Two-Photon ③ Matrix Element and Experimental Implications due to its kinematics.



$$\frac{d^2\sigma(e^+e^- \rightarrow e^+e^- R^{\oplus})}{dQ_1^2 \, dQ_2^2} \sim \frac{1}{Q_1^2} \cdot \frac{1}{Q_2^2}$$

$$Q_i^2 = -2 E_{beam} E_i (1 - \cos\Theta_i)$$

$\Rightarrow$ most of the time Θ is small ! and:

$$\frac{d^2\sigma(e^+e^- \rightarrow e^+e^- R^{\oplus})}{d\omega_1 \, d\omega_2} \sim \frac{1}{\omega_1} \frac{1}{\omega_2} \quad \text{but}$$

$\omega_1 + \omega_2 \geq M_{R^{\oplus}} \Rightarrow$ at least one ω is small $\Rightarrow$ BOOST

Thus, the collisions of quasi real photons are characterized by the boost along the e^+e^- collision axis and, most of the time, final state leptons are not detected.

An interesting fact:

$\sigma(e^+e^- \to \Upsilon(4S)) \approx 1.07$ nb ($B\bar{B}$)
(at $\Upsilon(4S)$ energy)

$\sigma(e^+e^- \to e^+e^-\pi^0) \approx 1.46$ nb (π^0)

$\sigma(e^+e^- \to e^+e^-\pi^0)$ ≈ 0.72 nb (3.1 GeV)
(at Tau-Charm Factory)

≈ 0.86 nb (4.0 GeV)

≈ 0.98 nb (5.0 GeV)

An intriguing question: What fraction of these will be detected?

Impose Conditions:

electron ⊕ π^0: $|\cos\Theta_e| \leq \underline{\underline{0.94}}$

$|\cos\Theta_{\pi^0}| \leq \underline{\underline{0.70}}$

$\Upsilon(4S)$: $\approx 1.6\cdot10^{-4}$

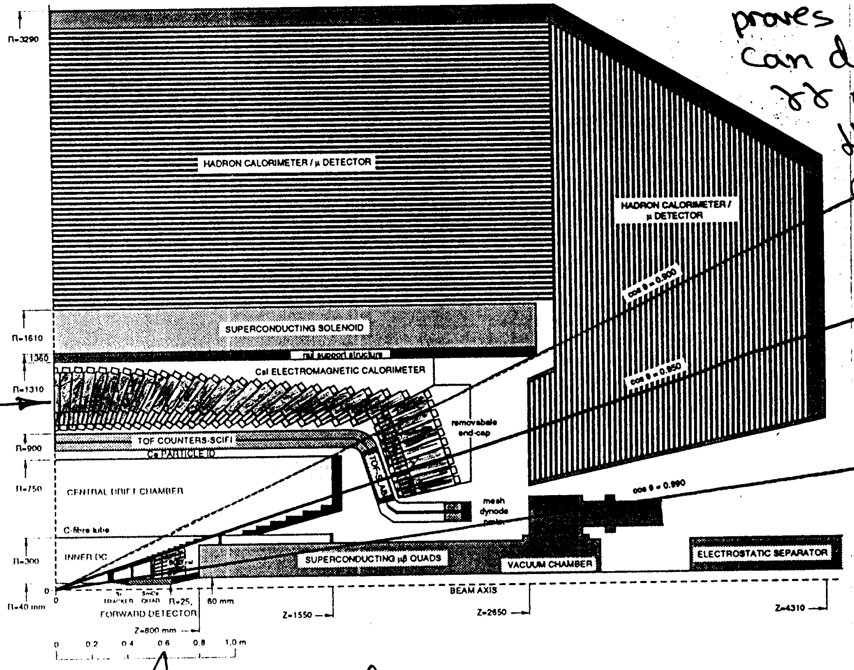
τ-C (4 GeV): $\approx 4.3\cdot10^{-3}$

The EXACT Detector Circa 1995 ⑤

(one quadrant, r-φ view)

Previous Transp. proves that we can do tagged γγ physics bette than B fact. (more later)

CsI



cosθ=0.95

BGO

cosθ=0.99

BGO

Cr.l. 1.12 cm

d.t. 300ns

resolution? 10% would be too good!

(for our purposes we can afford even:)

The exact acceptance and performance of the EXACT detector from the two-photon processes perspective will depend on several factors, first of all on (specialized) drift chambers trigger electronics and (energy-based) trigger thresholds.

Tagged electrons + hadrons:

expect 90-100%-efficient trigger for $M_{hadrons}$ from threshold and up (i.e. $\gtrsim 280$ MeV/c^2 !)

Only hadrons: difficult to estimate, however, seems to be feasible:

$\varepsilon_{trigger} \gtrsim 80\%$ for $M_{hadrons^{\pm}} \gtrsim 600$ MeV/c^2

$\varepsilon_{trigger} \gtrsim 50\%$ for $M_{hadrons^{0}} \gtrsim 800-11$

No doubt: $\varepsilon_{trigger} \geq 90\%$ for either mass ≥ 1.0 GeV/c^2
(because we need it!)

Finally, Q^2 acceptance: ⑦

with BGO: $|Q^2| \geq 0.1\ GeV^2$

without BGO: $|Q^2| \geq 0.4\ GeV^2$

(don't forget small fraction of events where both Q^2 are above 0.1 !!!)

DREAM FACT

Why All This? QCD !!! :

Long-Standing Problems in Light Meson Spectroscopy :

Very Many Great Reviews exist.

Most Recent: S. Godfrey, J. Napolitano
(Rev. of Mod. Phys., 12, 1998)
(hep-ph/9811410)

Another great one: T. Barnes (τCF workshop proceedings, 1995)

Not a review but counts as a very good one:
C.A. Meyer (Crystal Barrel)
(τCF workshop proceedings, 1995)

Particle Data Properties: several mini reviews

What exactly are these "issues" in meson spectroscopy?

I am only touching upon **some** of the issues in almost random order!

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① *Among* 90-something non-charmed *resonances what exactly is what?* (mesons, four-quark states, molecules, glueballs, any hybrids?)

② Have we observed glueballs (gg, ggg) and/or hybrids ($gq\bar{q}$) already? *Do these QCD-pred. states exist*

③ Can we, at last, distinguish among these categories? (we seem to know how but "more statistics is needed"). Especially, *how to distinguish mesons from glueballs mixed with mesons*? (or simply have *quantum numbers* allowed for $q\bar{q}$)

PDP-98

Table 13.2: Suggested $q\bar{q}$ quark-model assignments for most of the known mesons. Some assignments, especially for the 0^{++} multiplet and for some of the higher multiplets, are controversial. Mesons in bold face are included in the Meson Summary Table. Of the light mesons in the Summary Table, the $f_0(1500)$, $f_1(1510)$, $f_J(1710)$, $f_2(2300)$, $f_2(2340)$, and one of the two peaks in the $\eta(1440)$ entry are not in this table. Within the $q\bar{q}$ model, it is especially hard to find a place for the first three of these f mesons and for one of the $\eta(1440)$ peaks. See the "Note on Non-$q\bar{q}$ Mesons" at the end of the Meson Listings.

$N\,^{2S+1}L_J$	J^{PC}	$u\bar{d}$, $u\bar{u}$, $d\bar{d}$ $I=1$	$u\bar{u}$, $d\bar{d}$, $s\bar{s}$ $I=0$	$c\bar{c}$ $I=0$	$b\bar{b}$ $I=0$	$\bar{s}u$, $\bar{s}d$ $I=1/2$	$c\bar{u}$, $c\bar{d}$ $I=1/2$	$c\bar{s}$ $I=0$	$\bar{b}u$, $\bar{b}d$ $I=1/2$	$\bar{b}s$ $I=0$	$\bar{b}c$ $I=0$
$1\,^1S_0$	0^{-+}	π	η, η'	η_c		K	D	D_s	B	B_s	B_c
$1\,^3S_1$	1^{--}	ρ	ω, ϕ	$J/\psi(1S)$	$\Upsilon(1S)$	$K^*(892)$	$D^*(2010)$	D_s^*	B^*	B_s^*	
$1\,^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170)$, $h_1(1380)$	$h_c(1P)$		$K_{1B}^{\dagger}$	$D_1(2420)$	$D_{s1}(2536)$			
$1\,^3P_0$	0^{++}	$a_0(1450)^*$	$f_0(1370)^*$	$\chi_{c0}(1P)$	$\chi_{b0}(1P)$	$K_0^*(1430)$					
$1\,^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285)$, $f_1(1420)$	$\chi_{c1}(1P)$	$\chi_{b1}(1P)$	$K_{1A}^{\dagger}$					
$1\,^3P_2$	2^{++}	$a_2(1320)$	$f_2(1270)$, $f_2'(1525)$	$\chi_{c2}(1P)$	$\chi_{b2}(1P)$	$K_2^*(1430)$	$D_2^*(2460)$				
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$\eta_2(1645)$, $\eta_2(1870)$			$K_2(1770)$					
$1\,^3D_1$	1^{--}	$\rho(1700)$	$\omega(1600)$	$\psi(3770)$		$K^*(1680)^{\ddagger}$					
$1\,^3D_2$	2^{--}					$K_2(1820)$					
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$\omega_3(1670)$, $\phi_3(1850)$			$K_3^*(1780)$					
$1\,^3F_4$	4^{++}	$a_4(2040)$	$f_4(2050)$, $f_4(2220)$			$K_4^*(2045)$					
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$\eta(1295)$, $\eta(1440)$	$\eta_c(2S)$		$K(1460)$					
$2\,^3S_1$	1^{--}	$\rho(1450)$	$\omega(1420)$, $\phi(1680)$	$\psi(2S)$	$\Upsilon(2S)$	$K^*(1410)^{\ddagger}$					
$2\,^3P_2$	2^{++}		$f_2(1810)$, $f_2(2010)$		$\chi_{b2}(2P)$	$K_2^*(1980)$					
$3\,^1S_0$	0^{-+}	$\pi(1800)$	$\eta(1760)$			$K(1830)$					

* See our scalar minireview in the Particle Listings. The candidates for the $I=1$ states are $a_0(980)$ and $a_0(1450)$, while for $I=0$ they are: $f_0(400\text{–}1200)$, $f_0(980)$, and $f_0(1370)$. The light scalars are problematic, since there may be two poles for one $q\bar{q}$ state and $a_0(980)$, $f_0(980)$ may be $K\overline{K}$ bound states.

1. ι/iota puzzle: 1980/Mark-II; $J/\psi \to \gamma\,\iota$/iota
I do not think we understand it (even now) !!!
because: a) $\Gamma_{\gamma\gamma}(\eta(1440)) \cdot Br(\eta(1440) \to \eta\pi\pi) \leq 0.3$ keV @ 90% CL
b) $f_1(1420)$ is observed in KK^* with 50 MeV Wd
Does $\eta(1295)$, $\eta(1440)$ mix with η, η', η_c?

2. Spin 1 f mesons: $f_1(1285)$, $f_1(1420)$, $f_1(1530)$; Expect 2, 3 known

3. "Radially excited pseudoscalars": $\eta(1295)$, $\eta(1440)$; Not seen in $\gamma\gamma$!

4. Isoscalar spin zero f mesons.

$f_0(800) \equiv \sigma(400-1200)$ $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$???

$f_0(980)$: A $K\bar{K}$ molecule ???

$f_0(1370)$: $s\bar{s}$???

$f_0(1500)$: glueball ??? a) C Barrel: $p\bar{p}$ annihilation at rest

b) reanalysis of J/ψ

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5. a_0 - Another $K\bar{K}$ Molecule???

a_1 is what ? Shape (Intrinsic)?

$\left(\Gamma_{\gamma\gamma}(a_0, f_0) \approx 0.3 \text{ keV} \right)$

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6. What is $f_J(1710)$???

$K^*\bar{K}^*$ threshold enhancement ?

Yet another "molecule" ?

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7. What is $f_J(2220)$? Does it exist?

(with apologies...)

8. Where is η'_c ?!!!!!

9. What are $f_6(2510)$, $\eta(2225)$, $f_2(1810)$, ... ???

Finally, can the highly non-perturbative, soft QCD region, i.e. masses of light hadrons be predicted?

see, for instance, results of QCD-inspired models:

in S. Godfrey, N. Isgur (PRD 32, 189 (1985)) (for mesons) and

J. Weinshtein, N. Isgur (PRL 48, 659 (1982), PRD 27, 588 (1983)) (for 4-quark and hybrids)

What can WE do? ($\gamma\gamma$ @ τCF)

① Measure / set upper limits on as many $\gamma\gamma$ partial widths as possible! (nothing new, has been proposed / not done very many times!)

② Measure branchings, masses and widths (especially for η_c – the latter two), the former – for η', for inst.

③ Measure form factor of the $\gamma^*\gamma \to$ meson transitions (in other words, study how quickly two-photon partial width is falling as a function of Q^2 (scatter. angle)).

④ Scan all possible hadronic final states and measure cross sections for $\gamma\gamma$ production including two-photon continuum ! ($\gamma\gamma \to$ hadrons)

⑤ Combine the results of different experiments, such as those on J/ψ radiative decays, $\gamma\gamma$ collisions and $p\bar{p}$ annihilation. τC Factory provides the unique opportunity to study first two classes of processes simultaneously !!!

Examples ?

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① BEP : $f_J(2220)$ is a glueball candidate :

CLEO:

$$\frac{\Gamma(K\bar{K})\cdot\Gamma(\gamma\gamma)}{\Gamma_{total}} \leq 5.6\ \underline{\underline{eV}}\ @\ 90\%\ CL$$

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② CLEO is working on η_c' search

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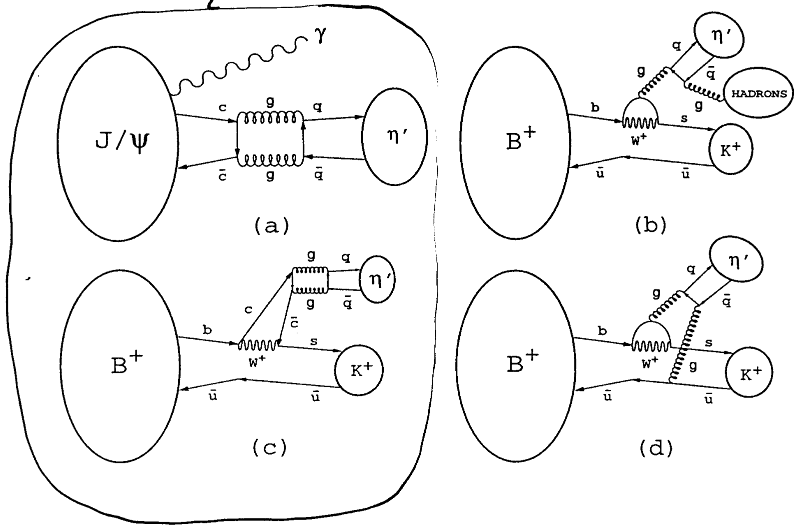
③ From the beloved (I work at SLAC) B physics results: $\underline{\underline{B^+ \to \eta' K^+ \text{ puzzle}}}$

(an example of providing QCD constraints to fix uncertainties in the predictions for hadronic transitions of heavy quarks)

$$\begin{cases} Br\,(\underline{B^+ \to \eta' K^+}) = \underline{(7.4^{+0.8}_{-1.3} \pm 1.0)\ 10^{-5}} \\ Br\,(B^0 \to \eta' K^0) = (5.9^{+1.3}_{-1.0} \pm 0.9)\ 10^{-5} \\ Br\,(B^+ \to \eta' \pi^+) < 1.2 \cdot 10^{-5}\ @\ 90\%\ CL \\ Br\,(\underline{B^+ \to \eta K^+}) < \underline{1.4 \cdot 10^{-5}}\ \text{—''—} \end{cases}$$

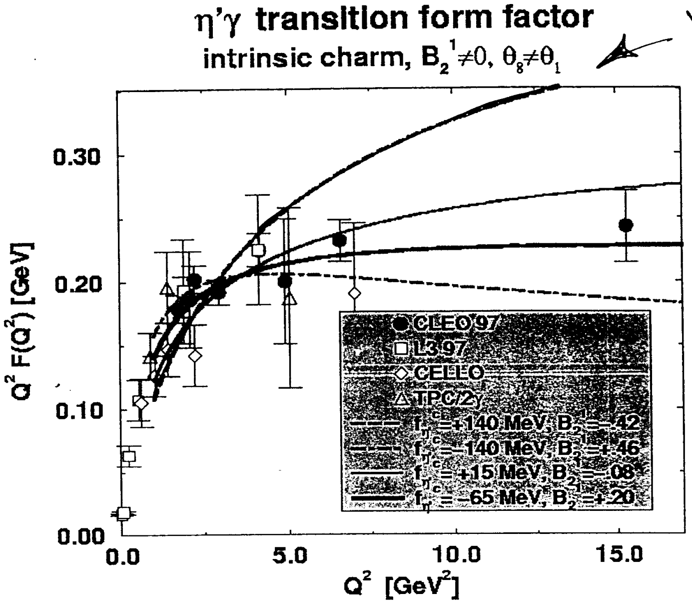
One of proposed explanations (I. Halperin, A. Zhitnitsky, PRD56, 7247(1997)(hep-ph 9704412)) related J/ψ radiative decays to $B^+ \longrightarrow \eta' K^+$ observation:



Halperin and Zhitnitsky predicted the charm content of η' to be (in terms of $\eta' \leftrightarrow c\bar{c}$ coupling constant):

$$\boxed{f_{\eta'}^{cc} \simeq 140 \text{ MeV}}$$

However,



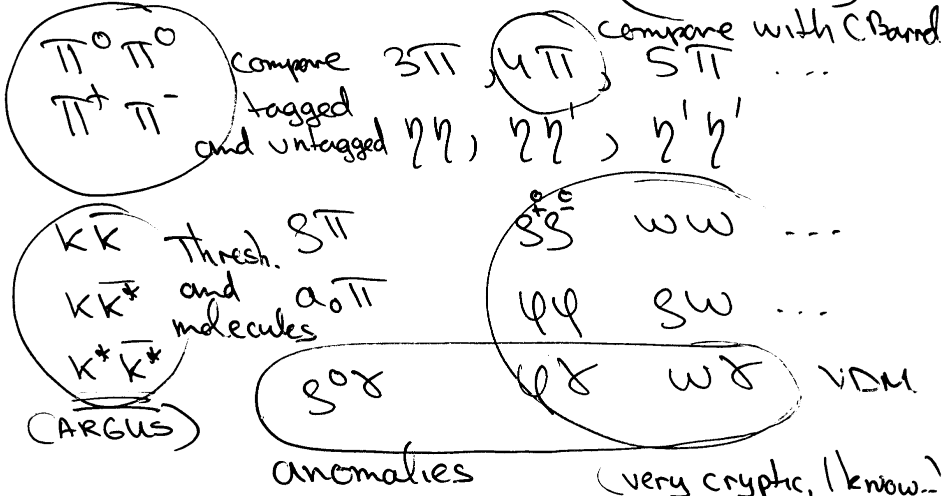
What $\gamma^* \gamma \to \eta'$ form factor would be if Halperin and Zhitnitsky were correct (according to Feldman and Kroll)

T. Feldman, P. Kroll
(Eur. Phys. J. C5, 327–335 (1998))
combined data on $J/\psi \to \gamma\eta, \gamma\eta'$, two-photon partial widths, $\gamma\gamma^*$ transition form factors and theoretical predictions from chiral pert. theory to make the opposite conclusion: Charm content of η' is small!

④ Other examples include
π^0 wave function ($\gamma^* \gamma \to \pi^0$)
(has been utilized many times)

Let us be kind when B folks ☺
come to beg us for low energy
QCD data in five years... :)

Thus, we should try to use
all these final states (and more):



$\pi^0 \pi^0$
$\pi^+ \pi^-$
compare 3π, 4π, 5π ...
compare with C.Barrel
tagged and untagged $\eta\eta$, $\eta\eta'$, $\eta'\eta'$

$K\bar{K}$
$K\bar{K}^*$
$K^*\bar{K}^*$
(ARGUS)
Thresh. and molecules $\rho\pi$ $a_0\pi$

$\rho^+\rho^-$ $\omega\omega$ ...
$\phi\phi$ $\rho\omega$ ...
$\rho^0\gamma$ $\phi\gamma$ $\omega\gamma$ VDM
anomalies
(very cryptic, I know...)

Selected Topics now:

Selected Topics and New Analysis Ideas for the Tau-Charm Factory from the Two-Photon Perspective

All four proposals require tagged events

1. Use the $\gamma^*\gamma \rightarrow$ resonance transition form factors to distinguish among mesons, molecules, four-quark states, threshold enhancements (and such).

2. Measure relative contribution of helicity amplitudes ±2, ±1, 0 to the $\gamma^*\gamma$ production of (remarkable) meson $f_2(1270)$

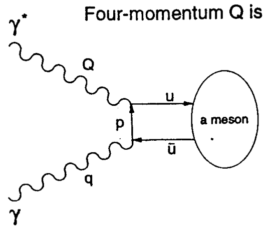
3. Study $\gamma^*\gamma \rightarrow \pi^0$ and $\gamma^*\gamma^* \rightarrow \pi^0$ transitions at $Q^2 \simeq 0.2\text{-}0.8\ \mathrm{GeV}^2$ with very high accuracy.
(challenge for QCD non-pert. theorists!)

4. Measure phase of strong interactions in $\pi^+\pi^-$ tagged final state using charge/hemisphere asymmetry.

① Distinguishing among different hypotheses of internal structure

(a)

Four-momentum Q is redistributed one time (via momentum transfer p)

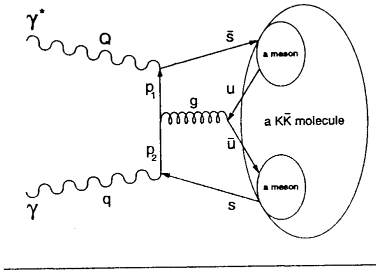


Transition Form Factor (Q^2)
for $\gamma\gamma^* \longrightarrow$ a meson

$$\sim \frac{Q^2}{(\Lambda^2+Q^2)^1} \qquad \cdot A$$

(b)

Four-momentum Q is redistributed two times (via momentum transfers p_1, p_2)

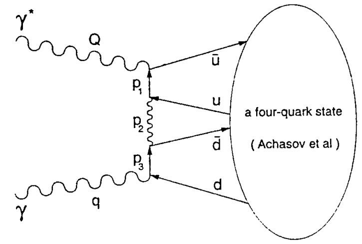


Transition Form Factor (Q^2)
for $\gamma\gamma^* \longrightarrow$ a molecule

$$\sim \frac{Q^2}{(\Lambda^2+Q^2)^2} \qquad - B$$

(c)

Four-momentum Q is redistributed three times (via momentum transfers p_1, p_2, p_3)

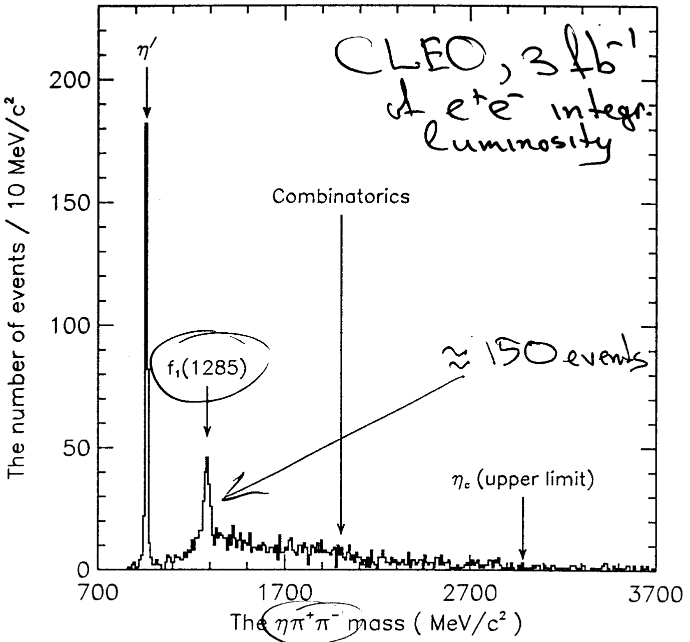


Transition Form Factor (Q^2)
for $\gamma\gamma^* \longrightarrow$ a four-quark state:

$$\sim \frac{Q^2}{(\Lambda^2+Q^2)^3} \qquad \cdot C$$

This is qualitative and the statement here is: Form Factor of $\gamma^*\gamma \rightarrow$ resonance transition falls off much faster for anything but a meson resonance

Is this doable on the Tau-Charm factory ???



CLEO, 3 fb^{-1} of e^+e^- integr. luminosity

$\gtrsim$ 150 events

FIG. 2. The $\eta\pi^+\pi^-$ invariant mass distribution for the single-tagged two-photon data event candidates which pass all selection criteria. Two peaks correspond to the η' and $f_1(1285)$ single-tagged production in the two-photon processes. Random mass combinations have not been subtracted.

$$\frac{\sigma\left(e^+e^- \to e^+e^- f_1(1285)\right)_{\text{CLEO}}}{\sigma\left(e^+e^- \to e^+e^- f_1(1285)\right)^{4\,\text{GeV}}_{\text{TCF}}} \simeq 4$$

Notice that this is highly suppress process !!

now : assume TCF <u>with</u> BGO (so $|\cos\Theta|$ up to 0.985 are accessible)

tracks: up to 0.95 ; ⊕ tag

$$\left(\frac{100}{138}\right)\cdot\left(\frac{100}{551}\right)^{-1} = 4 \text{ compensates}$$!!!

Combinatorics? No a_0 mass cut yet! Can do better!

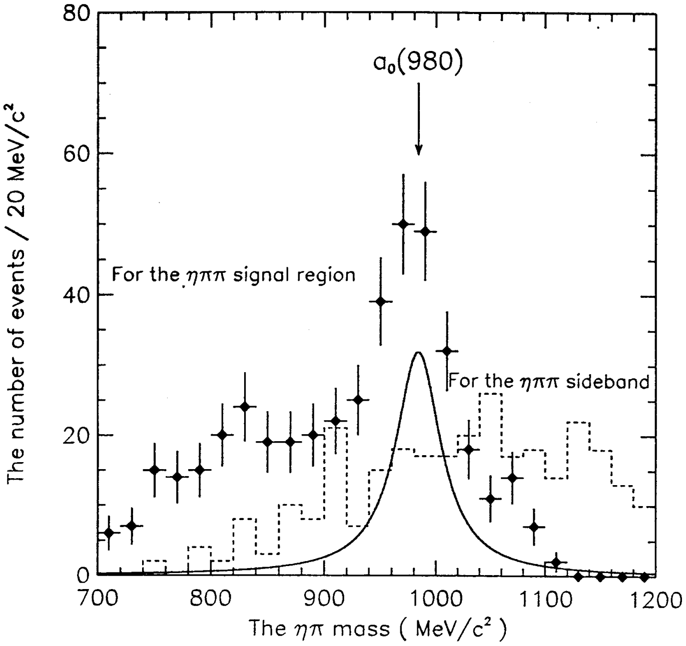


FIG. 6. The $\eta\pi$ invariant mass distributions for the single-tagged two-photon $\eta\pi^+\pi^-$ data event candidates which pass all selection criteria. The points with the error bars are for the signal region (defined as the $\eta\pi^+\pi^-$ mass band between 1245.0 and 1325.0 MeV/c^2) and the dashed line shows the same for the sideband (the $\eta\pi^+\pi^-$ mass between 1450.0 and 1750.0 MeV/c^2). Each distribution has two entries ($\eta\pi^+$ and $\eta\pi^-$) per event. Random mass combinations have not been subtracted. Solid line shows a Breit-Wigner shape for the $a_0(980)$ assuming its mass of 984 MeV/c^2 and the observed width in the $\eta\pi$ decay channel of 50 MeV.

The $\eta\pi^\pm$ mass distribution in data for events in the signal and sideband regions of $f_1(1285) \to \eta\pi^+\pi^-$

For CLEO estimate I assumed detection of scattered electrons (tags) at $|\cos\theta_t| \leq 0.95$

The Two-Photon kinematics does the rest! (so trigger is highly eff.)

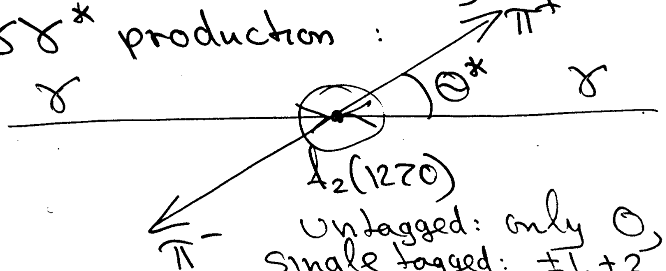
On the Tau-Charm Factory we expect $\mathcal{L}_{ins.} \gtrsim 10^{33}\ s^{-1}\,cm^{-2}$ i.e. at least $10\ fb^{-1}$ / year of integrated e^+e^- luminosity

$\Rightarrow$ at least 500 events detected and reconstructed in the highly suppressed spin-one channel!

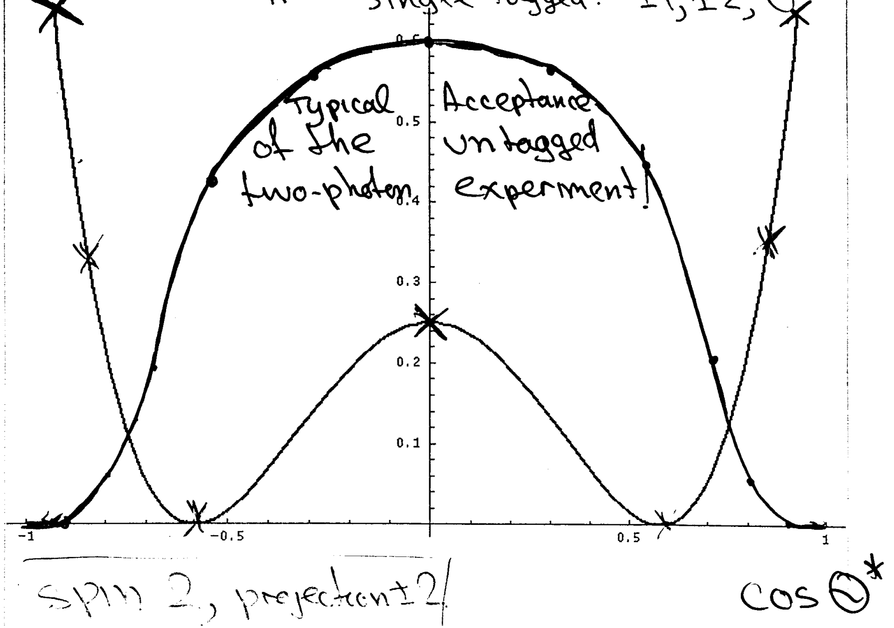
② Helicity amplitudes in tensor meson production:

$(B(J/\psi \to \gamma f_2(1270)) \approx 0.3\, B(J/\psi \to \gamma \eta'))$

Polarization of $f_2(1270)$ in the $\gamma\gamma^*$ production :



Untagged: only 0, ±2
Single tagged: ±1, ±2, 0



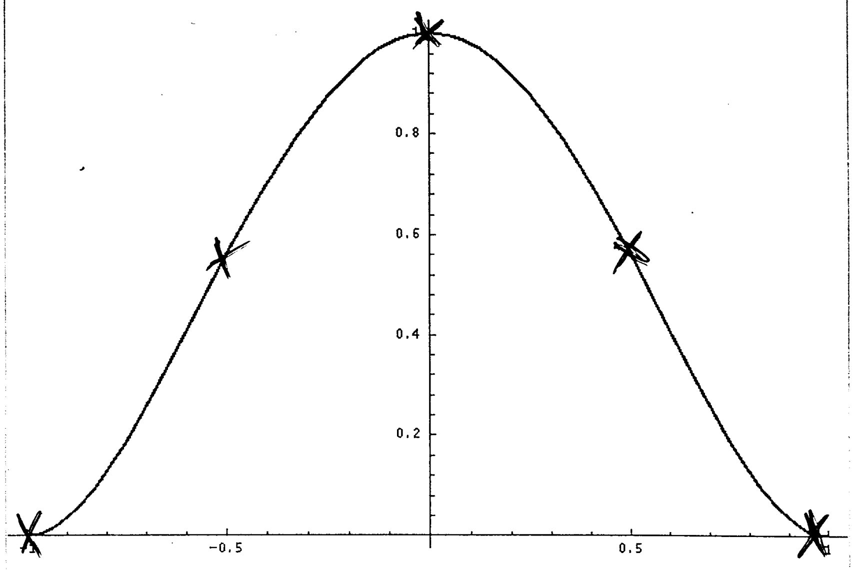
Typical of the two-photon

Acceptance untagged experment!

spin 2, projection ±2

$$\left(\frac{3\cos^2\theta^*-1}{2}\right)^2$$

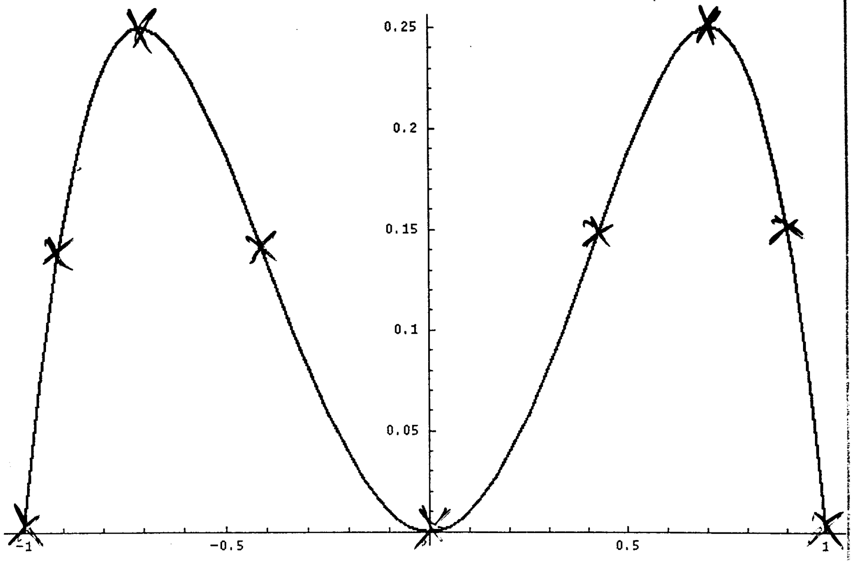
㉒



spin 2, projection ⓪

$\sin^4\theta^*$

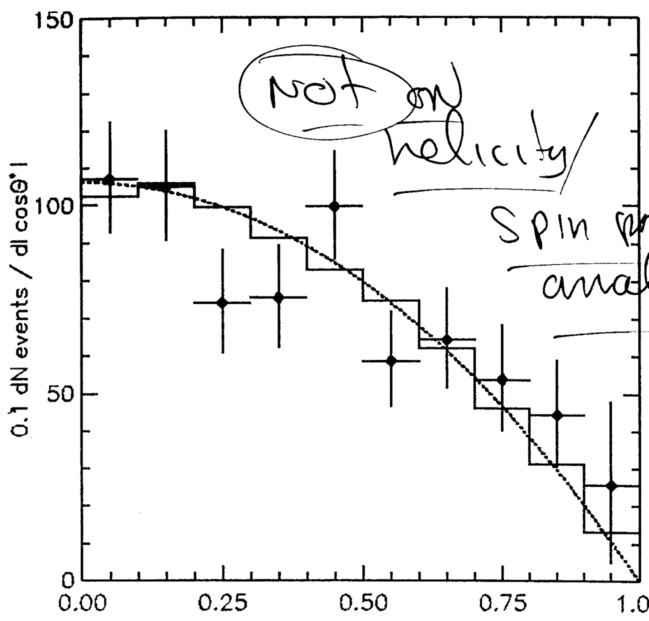
(23)



Spin 2,
projection ±1

$\cos^2\Theta^* \cdot \sin^2\Theta^*$

On a different subject !!!



NOT on helicity/ Spin projection analysis!

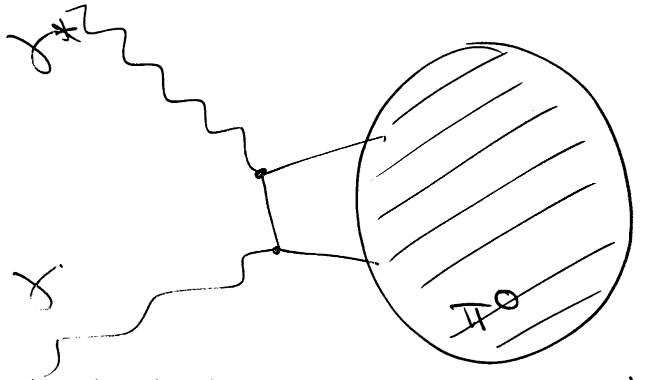
|cos Θ*|

This is a living proof that detection efficiency is flat in |cos Θ*| in single-tagged two-photon production!

Points: $\eta' \to \rho^0 \gamma$ (data)
Histogram: — " — (MC)
Dotted line: $\sin^2\Theta$ ($Y^1_1 \sim \sin\Theta^*$)
Thus, can disentangle helicities!!!

③ $\gamma^* \gamma \to \pi^0$, $\gamma^* \gamma^* \to \pi^0$ ㉕
(important but not discussed here)

$Q^2 \approx 0.2 - 0.8\ \mathrm{GeV}^2$; Why care to measure?



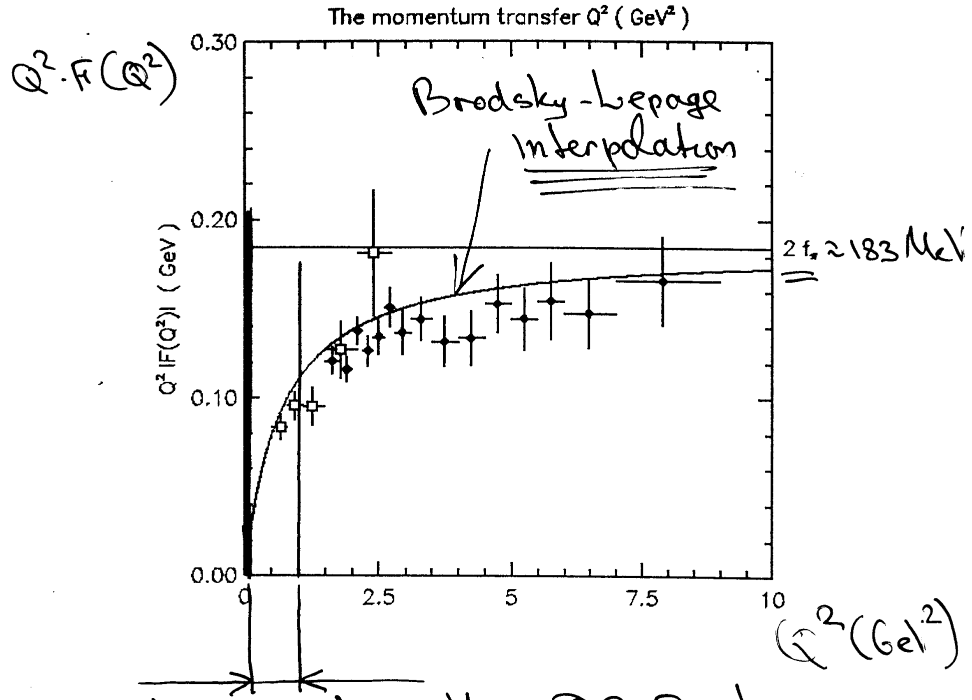
Perturbative part (QED)   Non-perturbative part (π^0 wave function)

$\gamma^* \gamma \to \pi^0$ transition probes the intrinsic structure of π^0

From $e^+ e^- \to e^+ e^- \pi^0$ cross section we can derive

$$\boxed{\Gamma_{\gamma\gamma}(\pi^0) \cdot F^2(Q^2)}$$

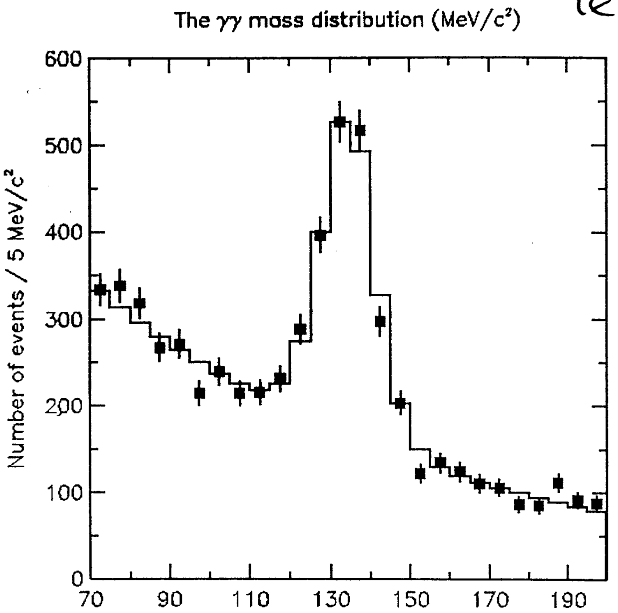
Why care to measure $\gamma^*\gamma \to \pi^0$? ㉖



This is where the τC Factory can contribute high precision data! Highly non-perturbative QCD region. Any volunteers to <u>predict</u> the form factor there?

Is this study feasible?

Yes!



Even CLEO can do it

☺

Single-tagged π^0s from CLEO: ≈ 1300 after event quality cuts. $\mathcal{L} \approx 3\ fb^{-1}$

Tags are at $|\cos\Theta| \leq 0.95$

$\pi^0 \rightarrow \gamma\gamma$: in barrel CsI: ≤ 0.70

Now let us see what we expect on the τCF:

Estimating the number of detected and reconstructed π^0 on the Tau-Charm Factory (assuming FF to be 0.9 of BL interp.)

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① $\sigma(e^+e^- \to e^+e^-\pi^0) = 0.86$ nb
$(E_{beam} = 2$ GeV$)$ $\Rightarrow 8.6 \cdot 10^6\ \pi^0/_{year}$

② Scattered electron : $(10\,fb^{-1}/10^{33})$
$|\cos\Theta_{tag}| \leq 0.985$

③ Photons from π^0 decay:
$|\cos\Theta_\gamma| \leq 0.7$

$\Rightarrow$ 1.6% survive (this IS GREAT!)

__BUT__ while typical $E_{tag} \gtrsim 1.8$ GeV,
$E_{\pi^0} \approx 350$ MeV (difficult to trigger upon these conditions)

Still, : $10\,fb^{-1}_{e^+e^-} \approx 135{,}000\ \pi^0/_{year}$

Another, more realistic in terms of triggering estimate:

$$|\cos\Theta_{tag}| \le 0.96$$

$$|\cos\Theta_{\gamma}| \le 0.70$$

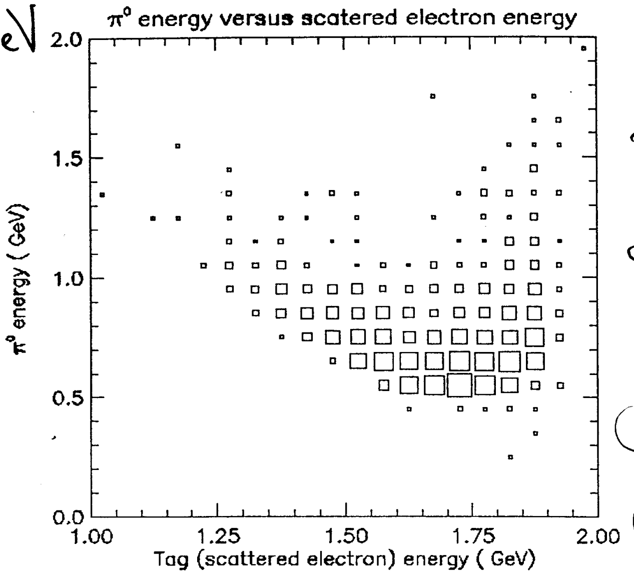
$\Rightarrow$ 0.68% survive, out of these events 99% have $E(\pi^0) > 500$ MeV, $E_{tag} > 1.0$ GeV

$\Rightarrow$ reduce by 10% (just in case)

$\Rightarrow \approx \underline{50{,}000}$ single tagged π^0s per year at the τC Factory of $\underline{\underline{10\ fb^{-1}/year}}$ with $\underline{\underline{E_{beam} = 2\ GeV}}$

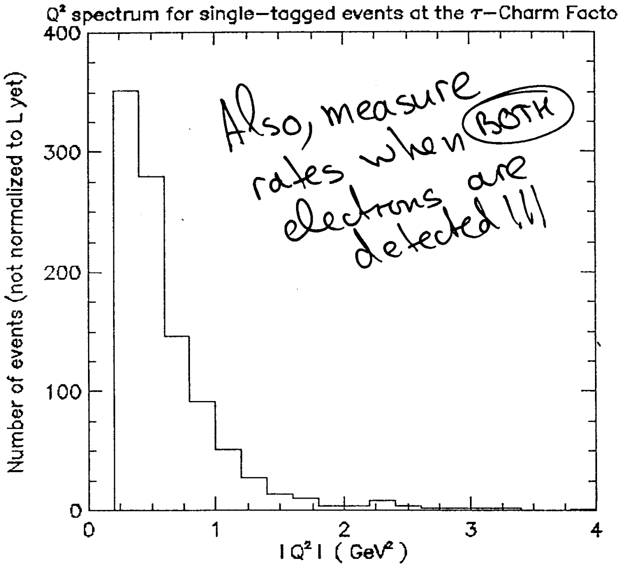
These π^0s are (mainly) at $Q^2 \in [0.2 - 1.0]$ GeV^2

GeV



π^0 energy vs Scattered electron energy (40-60 cm between γ in CsI)

GeV

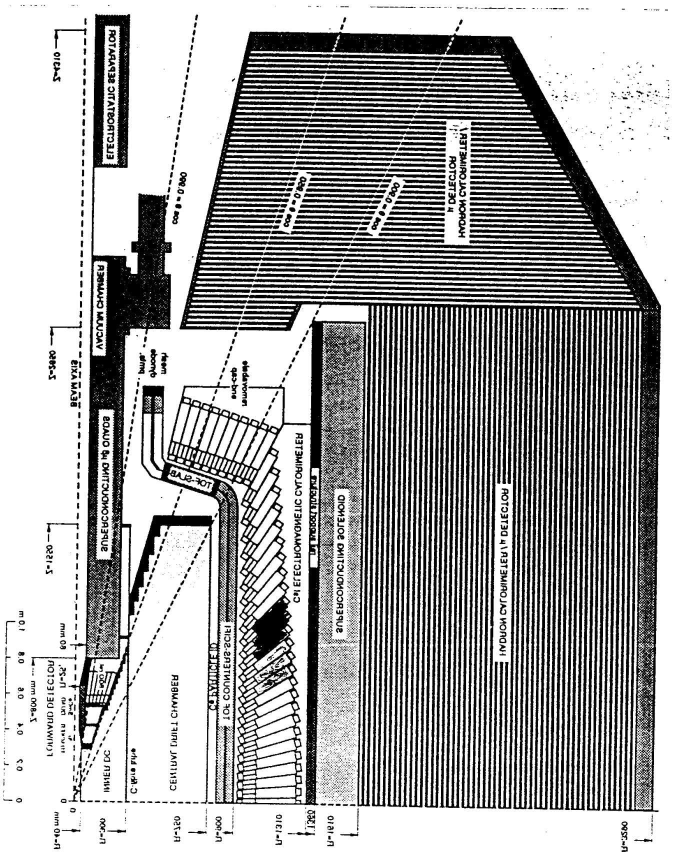


Also, measure rates when BOTH electrons are detected!!!

Q^2 spectrum for these events

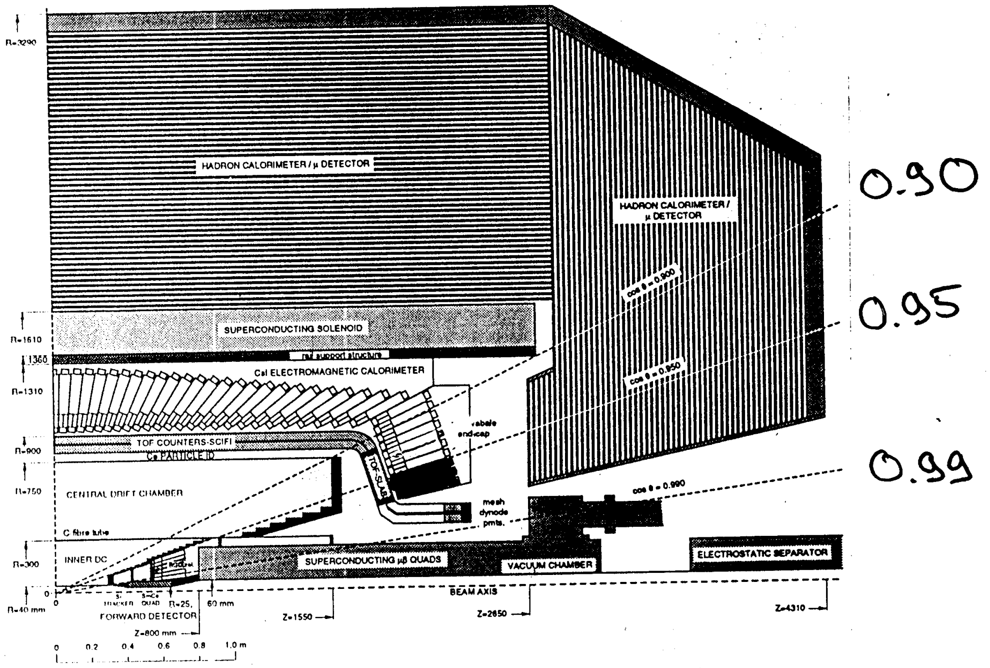
GeV^2

30"


ELECTROSTATIC SEPARATOR
VACUUM CHAMBER
BEAM AXIS
SUPERCONDUCTING Q4 QUADS
TOF-SLAB
FORWARD HADRON CALORIMETER/μ DETECTOR
CsI ELECTROMAGNETIC CALORIMETER
SUPERCONDUCTING SOLENOID
HADRON CALORIMETER/μ DETECTOR
CENTRAL DRIFT CHAMBER
INNER DC
TOF COUNTERS/RICH
FORWARD DETECTOR
cos θ = 0.980
cos θ = 0.960
cos θ = 0.900

● Scenario n° 1 (tag: ≤0.985, π^0: ≤0.7)

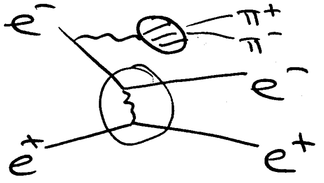
● Scenario n° 2 (tag: ≤ 0.96, π^0: ≤0.7)



④ Phase of strong interaction in the $\pi^+\pi^-$ scattering ㉛

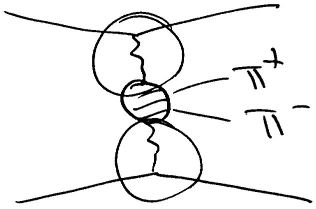
The idea: $e^+e^- \to e^+e^-\pi^+\pi^-$ process goes through two channels:

① $C=-1$ $\pi^+\pi^-$:



(+ 7 other diagrams)

② $C=+1$ $\pi^+\pi^-$:



Total cross section for ② >>> ①, however, for tagged events ② becomes similar to ① !

⇒ The larger is electron scattering angle, the large is interference!

The cross sections integrated over this (tiny) fraction of phase space become similar in magnitudes because while at small polar angles (of final state leptons)

C = +1 cross section $\sim \frac{1}{Q_1^2} \cdot \frac{1}{Q_2^2}$

and

C = −1 cross section $\sim \frac{1}{Q^2}$?

at large angles they diverge similarly (i.e. NO double ln for C = +1 process)!

Interference is not realized until we distinguish between positively and negatively charged pions... But we <u>DO</u>! $\Rightarrow \frac{d\sigma}{d\Theta}$ for π^+, π^-

---

The interference results in sizable charge / hemisphere asymmetry which I did observe on CLEO. ⇒ Doable!

Do you want to see more on the comparison between τCF and a B factory? ㉜

For these estimates I assumed:

$$2 \times E_{beam}^{\tau CF} = E_{cm}^{\tau CF} = 4.0 \text{ GeV}$$

$$2 \times E_{beam}^{B} = E_{cm}^{B} = 10.58 \text{ GeV}$$

All numbers are for $\frac{\sigma(\text{B factory})}{\sigma(\tau CF)}$

(σ: $e^+e^- \to e^+e^- R^{\oplus}$)

π^0: 1.7

η: 2.2

η': 2.8

$f_1(1285)$: 4.0

$f_2(1270)$: 3.3

$f_0(1500)$: 3.5–4.0

(width: 110–150 MeV)

$\eta_c(2980)$: 11.5

(compensation (boost) IS NOT taken into account!)

Even for η_c we can do not as bad as I originally thought!

Pros and Cons of the τCF in comparison to B factories from the (narrow-minded ? ☺) two-photon perspective

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⊕
① Smaller boost along z-axis
② Less biased (than on B factories) trigger
③ Forward tagger (B60)
④ Better geometrical acceptance
⑤ Less Background

⊖
① No efficient access (or no access at all) to high invariant mass
② No high Q^2
③ Does not exist (yet?) with 10 fb^{-1}/year ☺

Conclusions

1. There are many important, interesting and challenging analysis opportunities arising from collisions of quasi-real photons at the high luminosity Tau-Charm Factory

2. Studies of hadronic production in two-photon collisions will provide us with unique information about soft QCD region. This should stimulate non-perturbative QCD (theoretical) studies.

3. The Tau-Charm Factory is the right (and a better than a B factory) place to do the two-photon physics for hadrons with masses at and below η_c (depending on exact beam energy chosen for a year-long run). TPP is the important and necessary part of the TCF physics program!