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.
4. Pros and Cons of the TCF in comparison to B Factories (??)
5. Conclusions

Workshop on the Tau-Charm Factory @ SLAC 1999
The Algebra of Two-Photon Collisions

1. \( e^+e^- \rightarrow e^+e^- \text{ Hadrons, } C=+1 \)
2. \( e^+e^- \rightarrow e^+e^- \text{ Hadrons(s)}, C=-1 \)
3. \( e^+e^- \rightarrow \text{ Hadron(s)} \), C=-1

QCD studies at fixed invariant mass
QCD studies at (some) range of mass
QCD studies of C=+1 hadronic systems at wide range of inv.mass

To lowest order in QED:

\[
\begin{array}{c}
\text{e}^+ \\
\text{e}^- \\
\text{Hadron(s)} \\
\text{e}^+ \\
\end{array}
\]
Some Properties of the Two-Photon Matrix Element and Experimental Implications due to its kinematics.

\[ e^+, E_{\text{beam}} \rightarrow e^+ e^- \]

\[ \pi^0, \gamma, \gamma', f, \bar{f}, d, \bar{d}, \gamma \gamma', \pi \pi, \eta, \eta' \cdots \]

\[ Q_2, w_2 \text{ (space-like photons)} \]

\[ Q_1, w_1 \text{ (mass, energy)} \]

\[ \text{Hadron(s) (R)} \]

\[ E_2, e^- \]

\[ \frac{d^2\sigma}{dQ_1^2 dQ_2^2} \left( e^+ e^- \rightarrow e^+ e^- R \right) \sim \frac{1}{Q_1^2} \cdot \frac{1}{Q_2^2} \]

\[ Q_1^2 = -2 E_{\text{beam}} E_i (1 - \cos \Theta_i) \]

\[ \Rightarrow \text{most of the time } \Theta \text{ is small!} \]

\[ \frac{d^2\sigma}{dw_1 dw_2} \left( e^+ e^- \rightarrow e^+ e^- R \right) \sim \frac{1}{w_1 w_2} \text{ but} \]

\[ w_1 + w_2 \geq M_R \Rightarrow \text{at least one } w \text{ is small} \Rightarrow \text{BOOST} \]
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:

\[ \sigma (e^+e^- \rightarrow Y(4S)) \approx 1.07 \text{ nb} \quad (BB) \]
\[ \sigma (e^+e^- \rightarrow \rightarrow \pi^0) \approx 1.46 \text{ nb} \quad (\pi^0) \]

\[ \sigma (e^+e^- \rightarrow e^+e^- \pi^0) \approx 20.72 \text{ nb} \quad (3.1 \text{ GeV}) \]
\[ \approx 0.86 \text{ nb} \quad (4.0 \text{ GeV}) \]
\[ \approx 0.98 \text{ nb} \quad (5.0 \text{ GeV}) \]

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

Impose Conditions:

\[ |e_2 \cdot e_1| \leq 0.94 \quad Y(4S) : x \approx 1.6 \times 10^{-4} \]
\[ |e_1 \cdot \pi_0| \leq 0.70 \quad CC : \approx 4.3 \times 10^{-3} \]
The EXACT Detector (circa 1995)
(one quadrant, r-p view)

Previous transposes that we can do tagged RS physics better than black (more later)

$\cos \theta = 0.95$

$\cos \theta = 0.99$

$BGO$

BGO (r.l. 1.12 cm)

d.f. 300 ns

resolution? 10% would be too good!
The exact acceptance and performance of the EXACT detector from the two-photon processes perspective will depend on several factors, first of all (specialized) drift chambers, trigger electronics, and (energy-based) trigger thresholds.

**Tagged electrons + hadrons:**
- Expect 90-100% efficient trigger for $M_{hadrons}$ from threshold up.
- ($\rightarrow$ 280 MeV/c^2 !)

**Only hadrons:** difficult to estimate, however, seems to be feasible:
- $\varepsilon_{\text{trigger}} \geq 80\%$ for $M_{hadrons} \geq 600\, \text{MeV}$
- $\varepsilon_{\text{trigger}} \geq 50\%$ for $M_{hadrons} \geq 300-11$

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

- with BGO: $|Q^2| \geq 0.1 \text{ GeV}^2$
- without BGO: $|Q^2| \geq 0.4 \text{ GeV}^2$

(Do not forget small fraction of events where both $Q^2$ are above 0.1 !!!)

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, 1988
- (hep-ph/9311410)

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

Not a review but counts as a very good one:
- C. A. Mayer (Crystal Barrel)
- (ECPF 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!

1. Among 40-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 (gqq) already? Do these QCD-predicted 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 gg?)
Table 13.3: Suggested q̅q quark-model assignments for most of the known mesons. Some assignments, especially for the 0^+ and 1^− mesons, are controversial. Mesons in bold face are included in the Meson Summary Table. Of the light mesons in the Summary Table, the 7(1380), 7(1400), 7(1700), 7(2300), 7(2450), and one of the two peaks in the 7(1440) entry are not in this table. Within the q̅q model, it is especially hard to find a place for the first three of these 7 mesons and for one of the 7(1440) peaks. See the “Note on Non-Q Mesons” at the end of the Meson Listings.

| N^f^f| 1 | J^P | I^I | V^V | L^L | I = 0 | I = 1/2 | I = 1/2 | I = 0 | I = 1/2 | I = 0 | I = 0 | I = 0 | I = 0 | I = 0 | I = 0 | I = 0 | I = 0 | I = 0 |
|------|---|-----|----|-----|-----|------|--------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|------|--------|
| 1^− | 0^− | π^− | n^− | n^− | K^− | D^− | B^− | B_s^− | D_s^− |
| 1^− | 1^− | ω^− | ω^− | 7^− | 7(1380) | 7(1400) | 7(1700) | 7(2300) | 7(2450) |
| 2^− | 0^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 1^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 2^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 3^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 4^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 5^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 6^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |
| 2^− | 7^− | 7(1380) | 7(1700) | 7(2300) | 7(2450) | 7(1440) |

* See the scalar summary in the Particle Listings. The candidates for the f = 1 mesons are 7(1380) and 7(1440), while for f = 0 they are 7(2300), 7(2450), and 7(1700).

1. I don't think I understand it (even now)!!!

2. Spin 1/2 mesons: 7(1285), 7(1420), 7(1365), 7(1535), 7(1580); Expect 2; 3 known

3. "Radially excited pseudoscalars": 7(1285), 7(1440); Not seen in ηf.
4. Isoscalar spin zero f mesons

\[ f_0(800) = \sigma(400-1200) \frac{u\bar{u} + d\bar{d}}{f_0^2} \]

\[ f_0(980) : \text{A } K\bar{K} \text{ molecule} \]

\[ f_0(1370) : s\bar{s} \]

\[ f_0(1500) : \text{glueball} \]

a) C Barrel:
   - pp annihilation at rest
   - reanalysis of \( 7 \% \)

b) Reanalysis of \( 7 \% \)

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

\[ a_0, \text{ is what? Shape (Intrinsic)} \]

\[ \Gamma_{\text{tot}}(a_0, f_0) \approx 0.3 \text{ keV} \]

6. What is \( f_3(1710) \)?

- \( K^*\bar{K}^* \) threshold enhancement?
- Yet another "molecule"?

7. What is \( f_3(2220) \)? Does it exist?

(with apologies...)
3. What are \( \psi_c(2510), \eta(2225), \phi(1810) \), ... ???

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:

- S. Godfrey, N. Isgur (PRD 32, 188 (1985))
  (for mesons)
- I. Weiszshen, N. Isgur (PRL 48, 659 (1982),
  PRD 27, 533 (1983))
  (for 4-quark and hybrids)

What can we do? (as @ CCF)

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

2. Measure branchings, masses and widths (especially for \( \psi_c \), the latter two), the former - for \( \psi, \phi, \) not.
3) Measure form factor of the $\phi \rightarrow \text{meson transitions}$
   (in other words, study how quickly the 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 $\phi \phi$ production including two-photon continuum ($\phi \phi \rightarrow \text{hadrons}$).

5) Combine the results of different experiments, such as those on $\gamma \gamma$ radiative decays, $\phi \phi$ collisions and $pp$ annihilation. The CC factory provides the unique opportunity to study both two classes of processes simultaneously!!!
Examples?

1. BEP: \( f_2(2220) \) is a glueball candidate.

CLEO:
\[
\frac{\Gamma(K\bar{K})\cdot\Gamma(\phi)}{\Gamma_{\text{total}}} \leq 5.6 \text{ eV} \quad @ \quad 90\% \text{ CL}
\]

2. CLEO is working on \( \eta_c' \) search.

3. From the beloved (I work at SLAC) B physics results: \( B^+ \to \eta' K^+ \) puzzle

   An example of providing QCD constraints to fix uncertainties in the predictions for hadronic transitions of heavy quarks,

\[
\begin{align*}
\text{Br} (B^+ \to \eta' K^+) &= (2.4^{+0.3}_{-1.2} \pm 1.0) \times 10^{-5} \\
\text{Br} (B^c \to \eta' K^0) &= (5.8^{+3.3}_{-10} \pm 0.9) \times 10^{-5} \\
\text{Br} (B^+ \to \eta' \pi^+) &\leq 1.2 \times 10^{-5} \quad @ \quad 90\% \text{ CL} \\
\text{Br} (B^+ \to \eta K^+) &\leq 1.4 \times 10^{-5} \quad @ \quad 90\% \text{ CL}
\end{align*}
\]
One of proposed explanations (14) related to $\Upsilon$ radiative decays to $B^+ \rightarrow \Upsilon' K^+$ observation:

Halpern and Zhifminsky predicted the charm content of $\Upsilon'$ to be (in terms of $g' \leftrightarrow g\bar{c}$ coupling constant):

\[ f \cdot g' \approx 1 \text{ GeV} \]
T. Feldman, P. Kroll
combined data on \( \eta' \rightarrow \pi^0 \pi^0 \).

Two-photon partial widths, 

\( \gamma \gamma^* \) transition form factors and theoretical predictions from chiral pert. theory to make the opposite conclusion: charm content of \( \eta' \) is small.
Other examples include

\[ \pi^0 \pi^0 \]

(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):

- \[ \pi^+ \pi^- \]
- \[ \eta \eta' \]
- \[ \eta \pi^0 \]
- \[ \eta' \pi^0 \]
- \[ \rho \rho \]
- \[ \omega \] (ARGUS anomalies)
- \[ \phi \phi \]
- \[ \eta \eta' \]
- \[ \phi \pi^0 \]
- \[ \eta \eta' \]

... and untagged \[ \pi^+ \pi^- \] reconstruction

Compare with CHAND

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

2. Measure relative contribution of helicity amplitudes $\pm 2, \pm 1, 0$ to the $\phi^*\phi^*$ production of (remarkable) meson $h_2(1270)$

3. Study $\phi^*\phi^* \rightarrow \pi^0$ and $\phi^*\phi^* \rightarrow \pi^0$ transitions at $Q^2 \leq 0.2-0.8$ 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.
Distinguishing among different hypotheses of internal structure

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

\[ \text{Transition Form Factor (Q^2)} \]
\[ \text{for } \gamma \gamma^* \rightarrow \text{a meson} \]
\[ \sim \frac{Q^2}{(\Lambda^2 + Q^2)^2} \]

Four-momentum Q is redistributed two times (via momentum transfers p₁, p₂) (b)

\[ \text{Transition Form Factor (Q^2)} \]
\[ \text{for } \gamma \gamma^* \rightarrow \text{a molecule} \]
\[ \sim \frac{Q^2}{(\Lambda^2 + Q^2)^2} \]

Four-momentum Q is redistributed three times (via momentum transfers p₁, p₂, p₃) (c)

\[ \text{Transition Form Factor (Q^2)} \]
\[ \text{for } \gamma \gamma^* \rightarrow \text{a four-quark state:} \]
\[ \sim \frac{Q^2}{(\Lambda^2 + Q^2)^3} \]

This is qualitative and the statement here is: Form Factor of \( \gamma \gamma^* \rightarrow \text{resonance} \) transition falls off much faster for anything but a meson resonance.
Is this double on the Tau-Charm Factory???

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

\[
\frac{\sum (e^+e^- \rightarrow e^+e^- f_1(1285))_{\text{CLEO}}}{\sum (e^+e^- \rightarrow e^+e^- f_1(1285))_{\text{CF}}} \approx 4
\]

Notice that this is highly suppressed process!!

Now: assume CCF with B60

(\(\sim 0.01\%\) up to 0.985 accessible)

tracks: up to 0.95; \(\circ\) tag

\[
\left(\frac{30}{138}\right) \cdot \left(\frac{100}{551}\right)^{-1} = 4 \text{ compensates} \]
Combinatorics? No a 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 1400.0 and 1700.0 MeV/$c^2$). Each distribution has two entries ($\eta\pi^+\pi^-$ and $\eta\pi^+\pi^-$) 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 30 MeV.

The $\eta\pi^+$ mass distribution in data for events in the signal and sideband regions of $f_1(1285) \rightarrow \eta \pi^+\pi^-$. 
For CLEO estimate I assumed detection of scattered electrons (tagged) at $|c \cdot \theta + 1| \leq 0.95$

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

On the Tau-Charm Factory we expect $L_{\text{ins.}} > 10^{33}$ s$^{-1}$ cm$^{-2}$
i.e. at least $10^{36}$ /year of integrated $e^+e^-$ luminosity
$\Rightarrow$ at least 500 events detected and reconstructed in the highly suppressed spin-overt channel!

2. Velocity amplitudes in tensor meson production:

$\mathcal{B}(\psi' \rightarrow \phi \phi(1270)) \approx 0.3 \mathcal{B}(\psi' \rightarrow \phi \pi')$
Polarization at $J_2(1270)$ in the $\gamma \gamma^*$ production:

- $\pi^+$
- $\pi^-$
- Untagged: only $0 \pm 2$
- Single tagged: $\pm 1, \pm 2, \pm 3$

Typical acceptance of the untagged two-photon experiment:

$$ \frac{S_{11}^2 \gamma_{projected}^2}{(3 \cos^2 \theta - 1)^2} $$

$$ \cos \theta^* $$
Spin 2, projection
\[ \sin^4 \theta \]
Spin 2, projection ±1
\[\cos^2 \theta \cdot \sin^2 \theta\]
On a different subject!!

This is a living proof that detection efficiency is flat in \(|\cos \theta^*|\) in single-tagged two-photon production.

Points: \( \gamma^* \rightarrow g^0 \chi \) (data)

Histogram: \( \gamma^* \rightarrow g^0 \chi \) (MC)

Dotted line: \( \sin^2 \Theta \) \( \chi^* \rightarrow \gamma^* \sin \Theta^* \)

Thus, can disentangle helicities!!!
(3) $\phi^* \phi \rightarrow \pi^0 \phi^* \phi \rightarrow \pi^0$ (important but not discussed here)

$Q^2 \approx 0.2 - 0.8$ GeV$^2$

Why care to measure?

Perturbative part (QED)

Non-perturbative part ($\pi^0$ wave function)

$\phi^* \phi \rightarrow \pi^0$ transition probes the intrinsic structure of $\pi^0$

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

$\Gamma_{\phi^*} (\pi^0) = F^2 (Q^2)$
Why care to measure $\psi^* \psi \rightarrow \eta^0$? 

The momentum transfer $Q^2$ (GeV$^2$)

This is where the CC Factory can contribute high precision data! Highly non-perturbative QCD region. Any volunteers to predict the form factor there?
Is this study feasible?  Yes!

![Gamma mass distribution graph](image)

Even CLEO can do it 😊

Single-tagged \( \pi^0 \)s from CLEO: \( \approx 1300 \) after event quality cuts: \( L \approx 3 \times 10^{-4} \). Tags are at \( |\cos \theta| \leq 0.95 \).

\( \pi^0 \to 2\gamma \): m barrel CsI: \( \leq 0.20 \)

Now let us see what we expect on the TCF:
Estimating the number of detected and reconstructed $\pi^0$ on the Tau-Charm Factory (assuming $e^+e^-$ cross section)

\[ \sigma(e^+e^- \rightarrow e^+e^- \pi^0) = 0.86 \text{ nb} \]
\[ \text{E beam} = 2 \text{ GeV} \]
\[ \Rightarrow 8.6 \times 10^6 \pi^0/\text{year} \]

2. Scattered electron:
\[ |\cos \Theta_{\text{tag}}| \leq 0.985 \]

3. Photons from $\pi^0$ decay:
\[ |\cos \Theta_{\gamma}| \leq 0.7 \]
\[ \Rightarrow 1.6\% \text{ (this IS GREAT!)} \]

\[ \text{survive} \]

BUT while typical $E_{\text{tag}} \approx 1.8 \text{ GeV}$,
\[ E_{\pi^0} \approx 350 \text{ MeV} \text{ (difficult to trigger upon these conditions)} \]
\[ \Rightarrow 10^6 \approx 135,000 \pi^0/\text{year} \]
Another, more realistic in terms of triggering estimate:

$$|\cos \Theta_{\text{tag}}| \leq 0.96$$

$$|\cos \Theta_{\ell}| \leq 0.70$$

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

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

$$\Rightarrow 50,000 \text{ single tagged } \pi^0 \text{ 's per year at the TC Factory at } 10 \text{ fb}^{-1}/\text{year with } E_{\text{beam}} = 2 \text{ GeV}$$

These $\pi^0$'s are (mainly) at $Q^2 \approx 0.2 - 1.02 \text{ GeV}^2$
Tag energy vs scattered electron energy (40-60 cm between Λ in GeV < 1)

Q^2 spectrum for single-tagged events at the τ-Charm Factory

Also measure rates when both electrons are detected III

Q^2 spectrum for these events

GeV^2
Phase of strong interaction in the $\pi^+\pi^-$ scattering

The idea: $e^+e^- \rightarrow e^+e^- \pi^+\pi^-$

Process goes through two channels:

1. $C = -1$  
   $\pi^+\pi^- : \begin{array}{c}
   e^+ \rightarrow e^+ \\
   e^- \rightarrow e^- \\
   \end{array}$

   $+$ 2 other diagrams

2. $C = +1$  
   $\pi^+\pi^- : \begin{array}{c}
   e^+ \rightarrow e^+ \\
   e^- \rightarrow e^- \\
   \end{array}$

Total cross section for 2 $\gg 1$.

However, for tagged events 2 becomes similar to 1.

$\Rightarrow$ The larger is electron scattering angle, the larger 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)
\[C = +1 \text{ cross section } \sim \frac{1}{Q^2 Q_z^2}\]
and
\[C = -1 \text{ cross section } \sim \frac{1}{Q^2 Q_z^2}\]
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 DO! \(\Rightarrow \frac{\Delta C}{d\Omega}\) for \(\pi^+, \pi^-\)

The interference results in sizeable charge hemisphere asymmetry which I did observe on CLEO. \(\Rightarrow\) Double!
Do you want to see more on the comparison between TCF and a B factory?

For these estimates I assumed:
\[ 2 \times E_{\text{beam}}^{\text{TCF}} = E_{\text{cm}}^{\text{TCF}} = 4.0 \text{ GeV} \]
\[ 2 \times E_{\text{beam}}^{B} = E_{\text{cm}}^{B} = 10.58 \text{ GeV} \]

All numbers are for \( \sigma (\text{B factory}) / \sigma (\text{TCF}) \):
\( \sigma : e^+e^- \to e^+e^-\pi^0 \)

\[ \pi^0 : 1.7 \quad f_2 (1270) : 3.3 \]
\[ \eta : 2.2 \quad f_0 (1500) : 3.5-4.0 \]
\[ \eta' : 2.8 \quad \text{(width: 110-150 MeV)} \]
\[ f_1 (1285) : 4.0 \quad \eta_c (2980) : 11.5 \]

Even for \( \eta_c \) we can do not as bad as originally thought!
Pros and Cons of the TCF in comparison to B factories from the (narrow-minded? : ) two-photon perspective

+ 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 $\sqrt{s}$ (depending on exact beam energy chosen for a year-long run). I PP is the important and necessary part of the TCF physics program.