Meson Transition Form Factors at BESIII

April 9, 2014 | Christoph Florian Redmer
for the BES-III Collaboration

SFB1044 Workshop

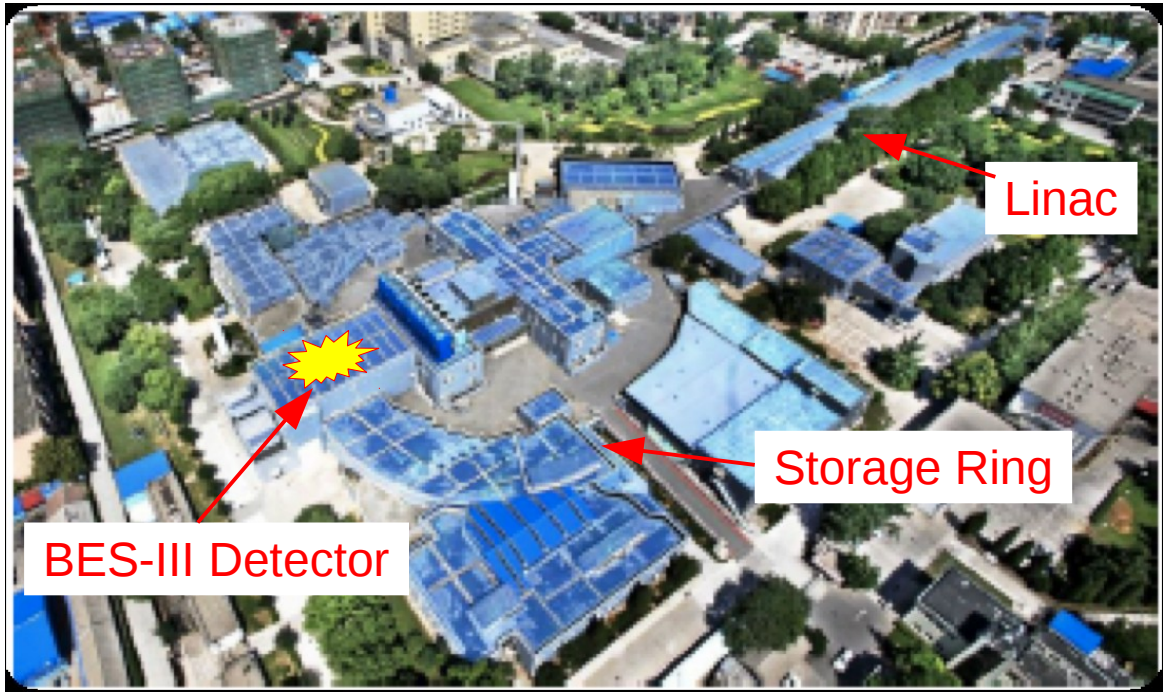
"(g-2)μ : Quo vadis?"

Institut für Kernphysik, Mainz

Outline

- The BES-III Experiment
- Measurement of Meson Transition Form Factors
  - Time - like
  - Space - like
- Summary

Beijing Electron Positron Collider BEPC-II



Beam Energy
1.0 - 2.3 GeV

Energy Spread
$\sigma(E)/E = 5.16 \cdot 10^{-4}$

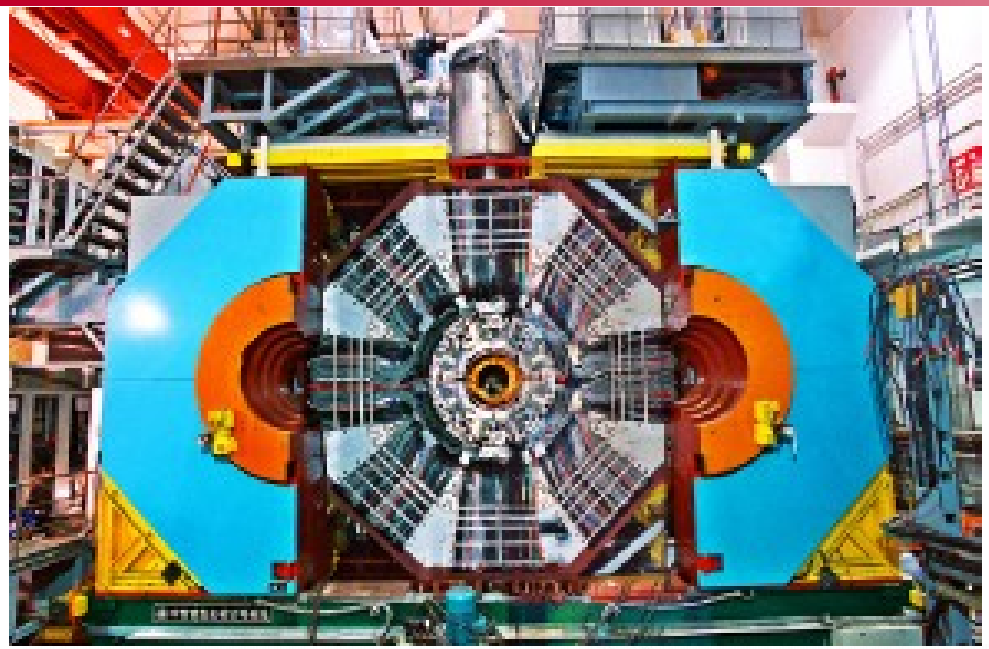
Design Luminosity
10^{33} cm^{-2} s^{-1} @ $\psi(3770)$

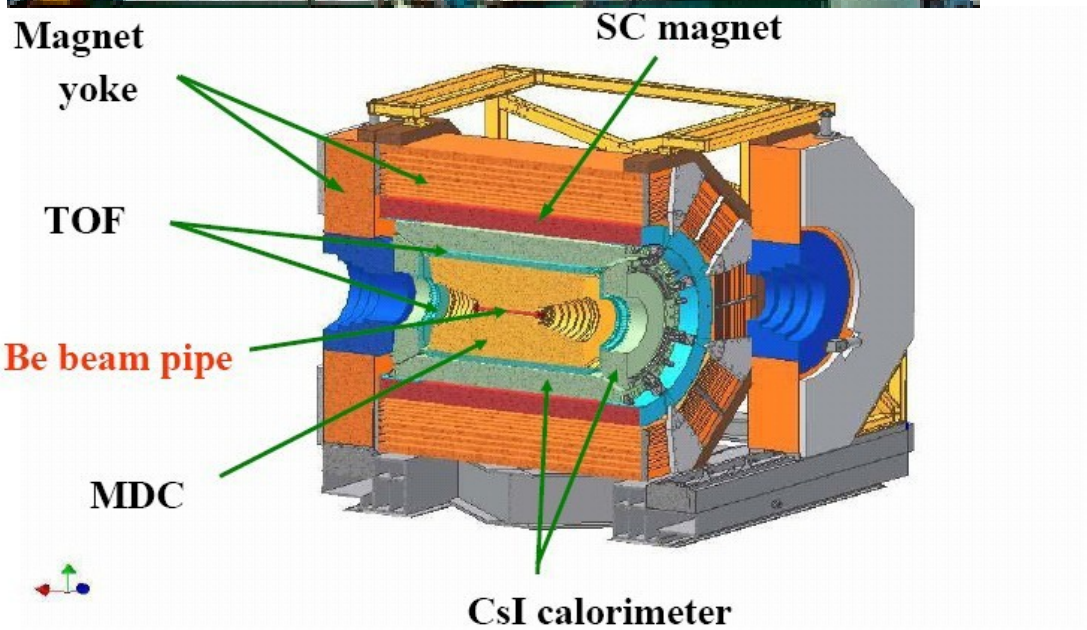
Achieved Luminosity
$0.7 \cdot 10^{33}$ cm^{-2} s^{-1} @ $\psi(3770)$

- 2004: start of BEPC-II construction
- 2008: first e^+e^- collisions
- Since 2009: BEPC-II/BES-III data taking

BESIII Detector

NIM A614 (2010) 345





- Main Drift Chamber (MDC)
  - $\sigma(p)/p = 0.5\%$
  - $\sigma_{dE/dx} = 6.0\%$
- Time-of-flight system (TOF)
  - $\sigma(t) = 90ps$ (barrel)
  - $\sigma(t) = 110ps$ (endcap)
- EMC
  - 6240 CsI(Tl) crystals
  - $\sigma(E)/E = 2.5\%$
  - $\sigma_{Z,\Phi}(E) = 0.5 – 0.7$ cm
- Muon Chambers
  - 8 – 9 layers of RPC
  - $p>400$ MeV/c
  - $\delta R\Phi = 1.4 \sim 1.7$ cm
- Superconducting Magnet
  - 1 T magnetic field

Acquired Data Sets

- $1.23 \cdot 10^9$ J/Ψ
- $0.52 \cdot 10^9$ Ψ(2S)
- 2.9 fb^{-1} Ψ(3770)
- 0.5 fb^{-1} @ 4.04 GeV
- 1 fb^{-1} @ 4.23 GeV
- 0.8 fb^{-1} @ 4.26 GeV
- 0.5 fb^{-1} @ 4.36 GeV
- 24 pb^{-1} τ mass scan
- 800 pb^{-1} R scan (104 points from 3.85 to 4.6 GeV)

BES-III Physics Program

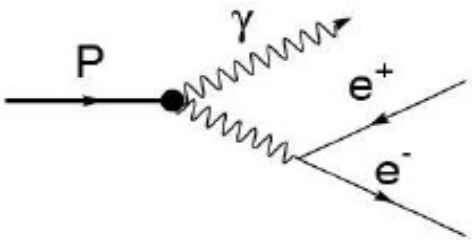
- Charmonium Spectroscopy
- Charm Physics
- Light Hadron Spectroscopy
- τ, R & QCD

World's largest samples of J/Ψ, Ψ(2S), and Ψ(3770)

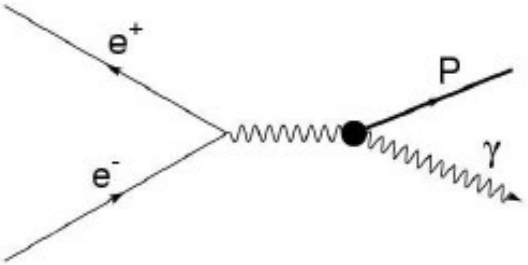
How to measure TFF at BES-III

Time – like Transition Form Factors:

- Dalitz decays
  - $0 < q^2 < M^2$

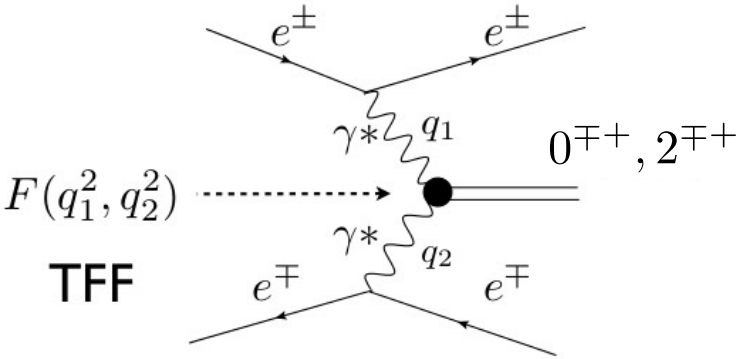


- Annihilation process
  - $q^2 = s > M^2$



Space – like Transition Form Factors:

- Two-photon production of mesons
  - $F(Q_1^2, Q_2^2), \quad Q^2 = -q^2$



Time-like TFF

Dalitz decays $J/\Psi \rightarrow P\, e^+e^-$

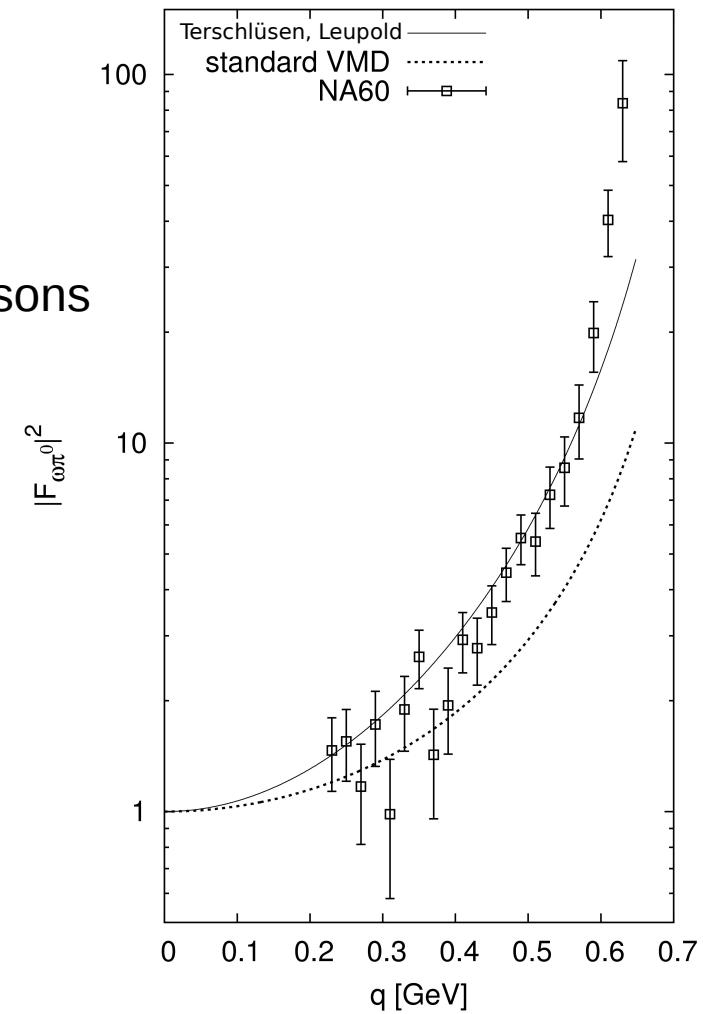
- Unmeasured, rare processes
  - $BR_{theo} = 10^{-5} - 10^{-7}$ J. Fu, H.B. Li, X. Qin and M.Z. Yang, Mod. Phys. Lett. A 27 1250223 (2012)

- Recent interest in $V \rightarrow P\gamma$ transitions of light unflavored mesons
  - NA60 result on $\omega \rightarrow \pi^0 e^+e^-$ not described by VMD
  - Recent measurements at SND, CMD-2, and KLOE on Φ

➔ Test VMD

$$|F_{VP}(q^2)| = \frac{1}{(1 - q^2/\Lambda^2)}$$

- Important for understanding of $P \rightarrow \gamma$ transitions



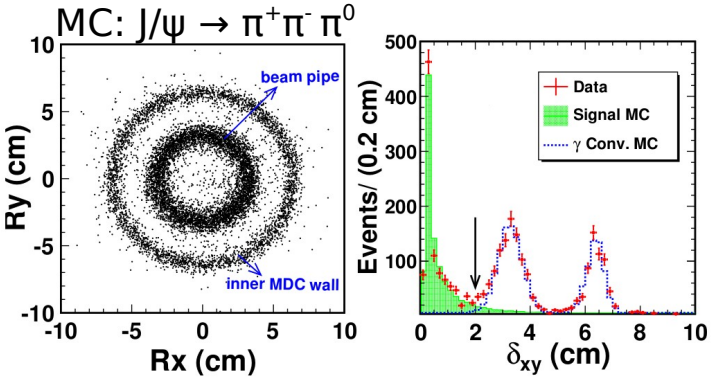
Dalitz Decays of J/Ψ

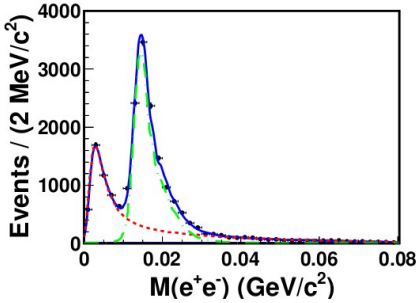
arXiv:1403.7042
Submitted to PRD

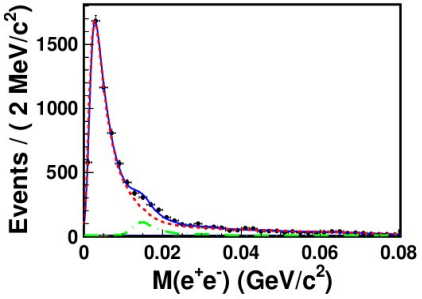
- $J/\psi \to P\, e^+e^-$, with $P = \pi^0, \eta, \eta'$

$$\eta' \to \pi^+\pi^-\gamma$$
$$\to \pi^+\pi^-\eta \hookrightarrow \gamma\gamma$$
$$\eta \to \pi^+\pi^-\pi^0 \hookrightarrow \gamma\gamma$$
$$\eta \to \gamma\gamma$$
$$\pi^0 \to \gamma\gamma$$

  - Background from other J/ψ decays removed by kinematic cuts
  - External conversion is main source of background



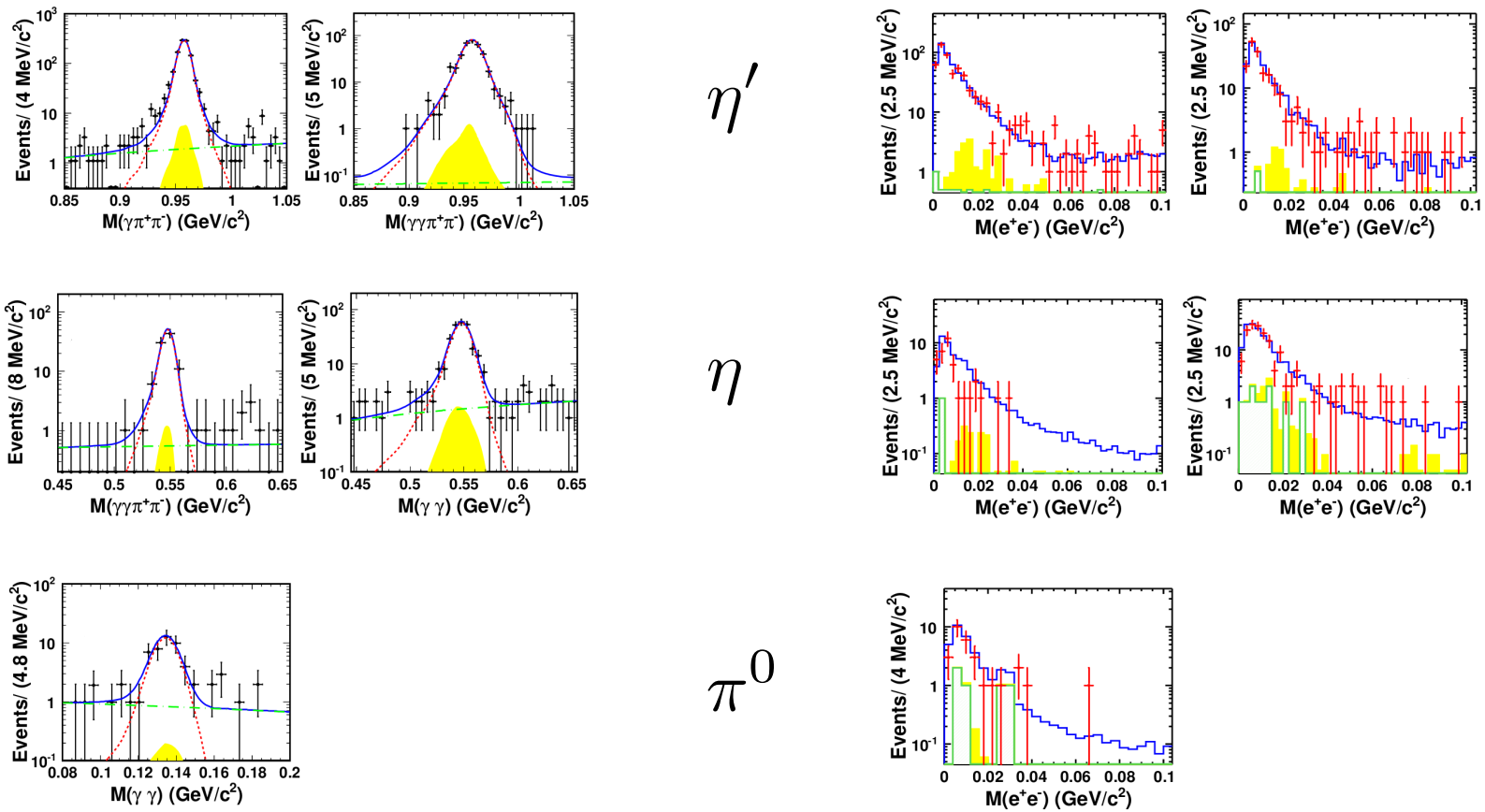




Analysis

arXiv:1403.7042
Submitted to PRD

- 225 · 10^6 J/ψ decays analyzed
- Background well under control
- Good agreement of data and MC

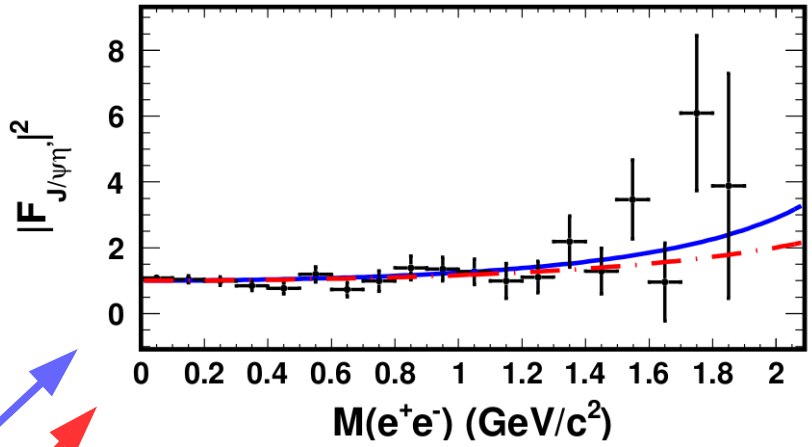


Transition Form Factor

arXiv:1403.7042
Submitted to PRD

- TFF used to estimate systematic error

$$|F_{VP}(q^2)| = \frac{1}{(1 - q^2/\Lambda^2)}$$



- Example : η'
  - Fit: $\Lambda = (3.1 \pm 1.0)$ GeV/c^2
  - $\Lambda = m_{\psi'} = 3.686$ GeV/c^2

Branching Ratios

arXiv:1403.7042
Submitted to PRD

Mode	Branching fraction	Combined Result	Theoretical prediction
$J/\psi \to \eta' e^+e^-(\eta' \to \gamma\pi^+\pi^-)$	$(6.01 \pm 0.20 \pm 0.34) \times 10^{-5}$		
$J/\psi \to \eta' e^+e^-(\eta' \to \pi^+\pi^-\eta)$	$(5.51 \pm 0.29 \pm 0.32) \times 10^{-5}$	$(5.81 \pm 0.16 \pm 0.31) \times 10^{-5}$	$(5.66 \pm 0.16) \times 10^{-5}$
$J/\psi \to \eta e^+e^-(\eta \to \pi^+\pi^-\pi^0)$	$(1.12 \pm 0.13 \pm 0.06) \times 10^{-5}$		
$J/\psi \to \eta e^+e^-(\eta \to \gamma\gamma)$	$(1.17 \pm 0.08 \pm 0.06) \times 10^{-5}$	$(1.16 \pm 0.07 \pm 0.06) \times 10^{-5}$	$(1.21 \pm 0.04) \times 10^{-5}$
$J/\psi \to \pi^0 e^+e^-(\pi^0 \to \gamma\gamma)$	$(7.56 \pm 1.32 \pm 0.50) \times 10^{-7}$	$(7.56 \pm 1.32 \pm 0.50) \times 10^{-7}$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$

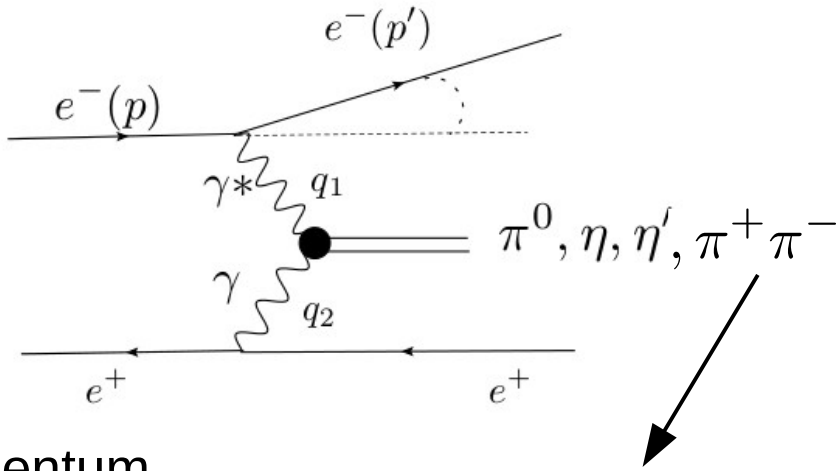
- First measurement of Dalitz decays $J/\psi \to P\, e^+e^-$, with $P = \pi^0, \eta, \eta'$
- BR of decays with $P = \eta, \eta'$ in agreement with Theory
- 2.5 σ difference for $P = \pi^0$

J. Fu, H.B. Li, X. Qin and M.Z. Yang,
Mod. Phys. Lett. A 27 1250223 (2012)

Space-like TFF

Single Tag Technique

- Measure only
  - One scattered lepton
  - Decay products of meson
- Reconstruct second lepton from missing momentum
- Require small scattering angle

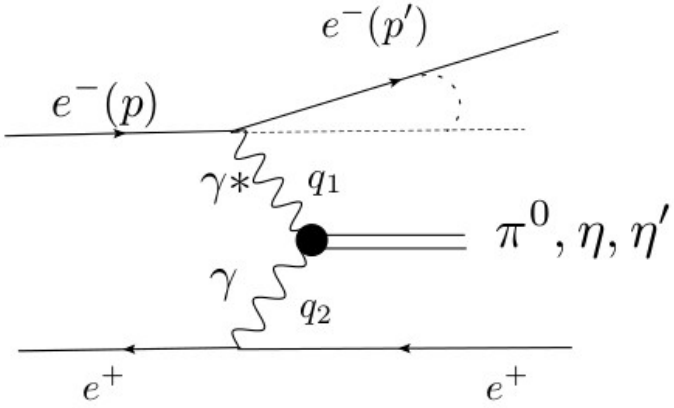


Talk by Y. Guo
Tomorrow

Space-like TFF

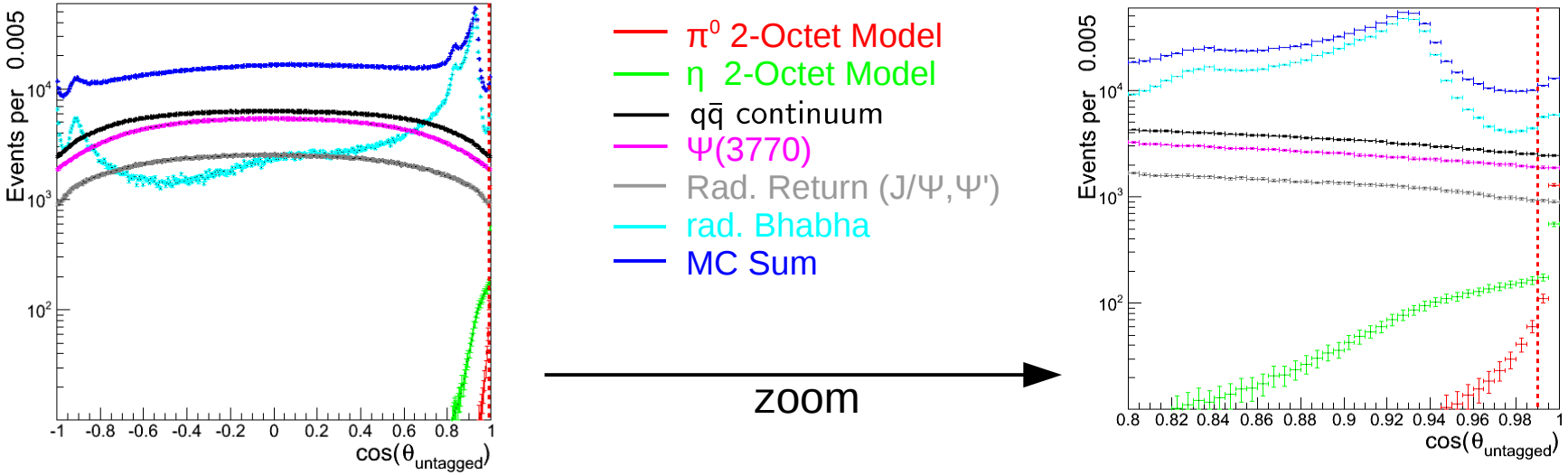
Single Tag Technique

- Measure only
  - One scattered lepton
  - Decay products of meson



- Reconstruct second lepton from missing momentum
- Require small scattering angle

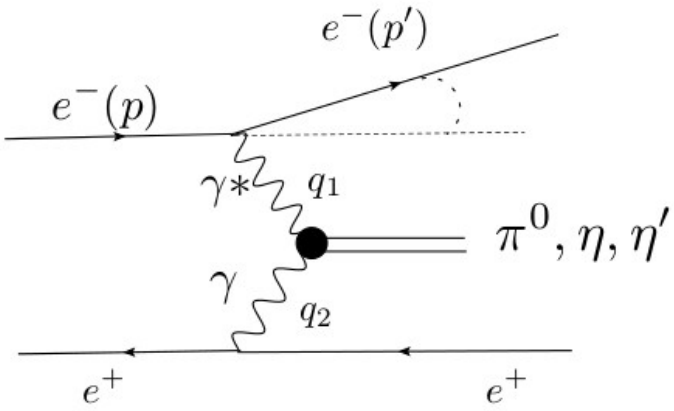
Example: Monte Carlo, Ψ(3770), L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



Space-like TFF

Single Tag Technique

- Measure only
  - One scattered lepton
  - Decay products of meson



- Reconstruct second lepton from missing momentum
- Require small scattering angle

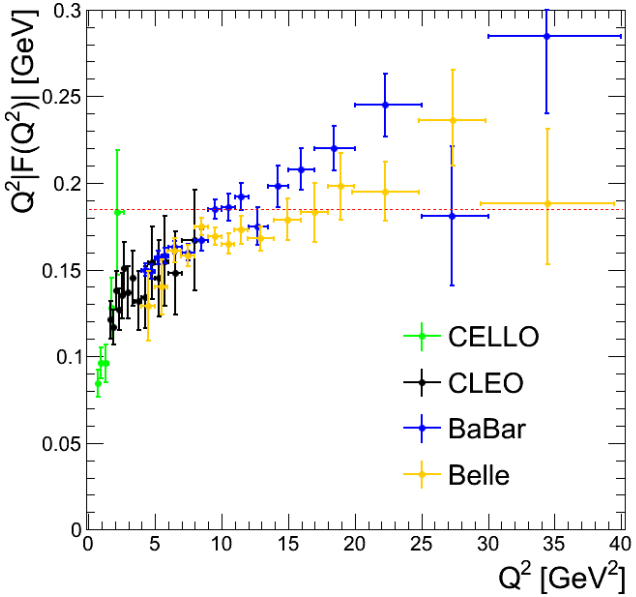
Q_1^2 : high virtuality

Q_2^2 : quasi real

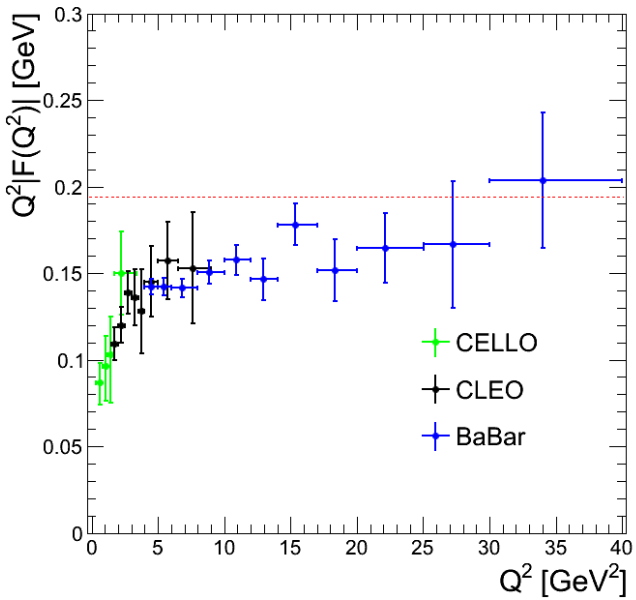
$$|F(Q_1^2,Q_2^2)|^2 \longrightarrow |F(Q_1^2,0)|^2 \longrightarrow |F(Q^2)|^2$$

Previous Measurements

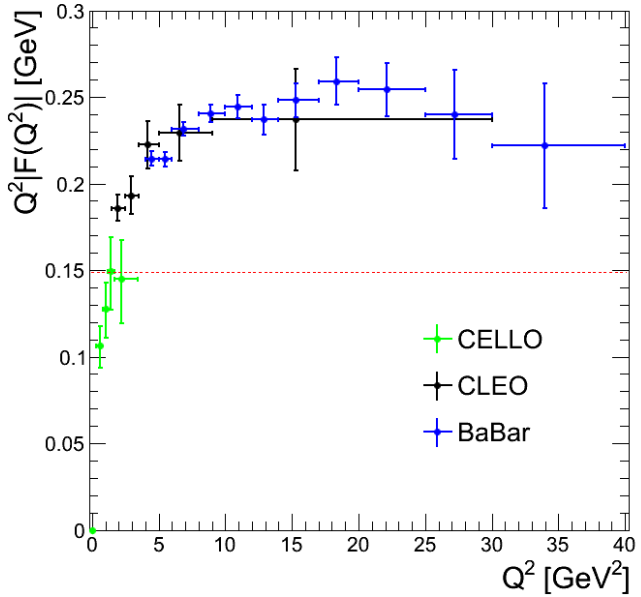
$e^+e^- \to e^+e^- \pi^0$



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



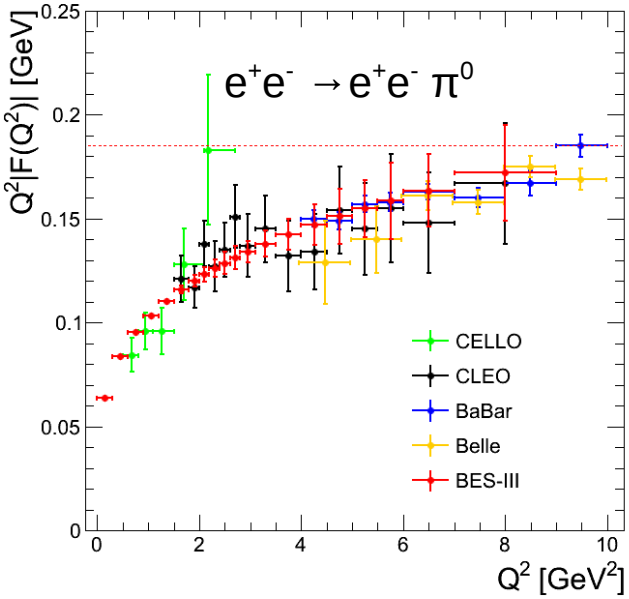
$e^+e^- \to e^+e^- \eta'$

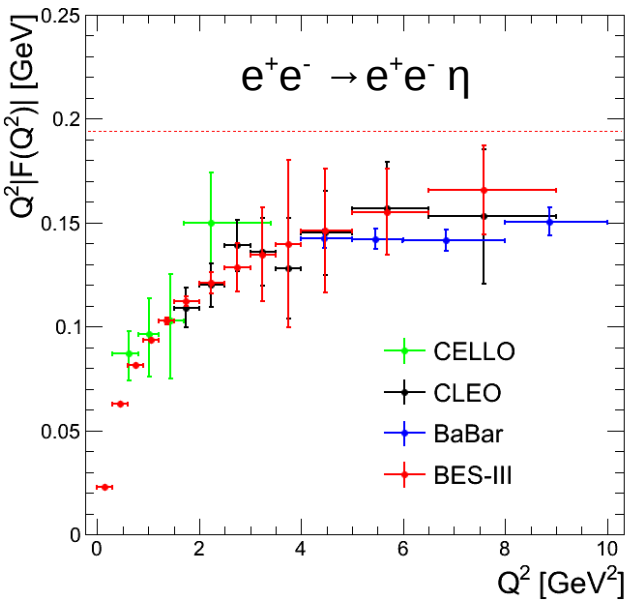


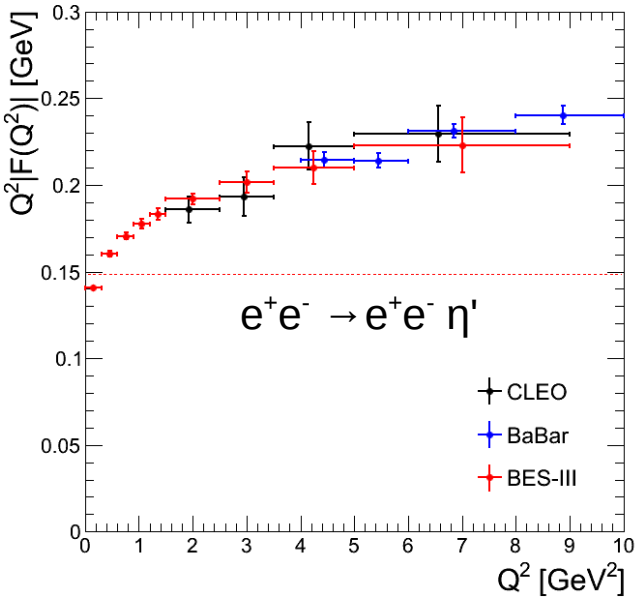
- Recent results from B-factories cover only large Q^2 ($5 < Q^2$ [GeV^2] < 40)
  - Discrepancy for π^0 between BaBar and Belle
- Data scarce at lowest Q^2
  - Region of relevance for (g-2)μ

CELLO: Z.Phys.C49 (1991) 401
CLEO: Phys.Rev.D57 (1998) 33
BaBar: Phys.Rev.D80 (2009) 052002
Phys.Rev.D84 (2011) 052001
Belle: Phys.Rev.D86 (2012) 092007

Feasibility Studies







BSc Theses: A. Hahn, B. Kloss

Assumptions:

- $\sqrt{s}$ = 3.773 GeV
- L_{int} = 10 fb^{-1}
- Only detector geometry

Result:

- TFF measurable up to Q^2 = 10 GeV^2
- Unprecedented accuracy below 4 GeV^2
- Above 4 GeV^2 accuracy comparable to CLEO

Analysis Example: π^0 / η

Data

- $\Psi(3770)$ on-peak, available: 2.92 fb^{-1}
- Monte Carlo
  - Signal: Ekhara 2.1
  - Background: Babayaga 3.5, KKMC

Event Selection:

- exactly one lepton candidate
- At least two, max four photons

Expected Background Channels

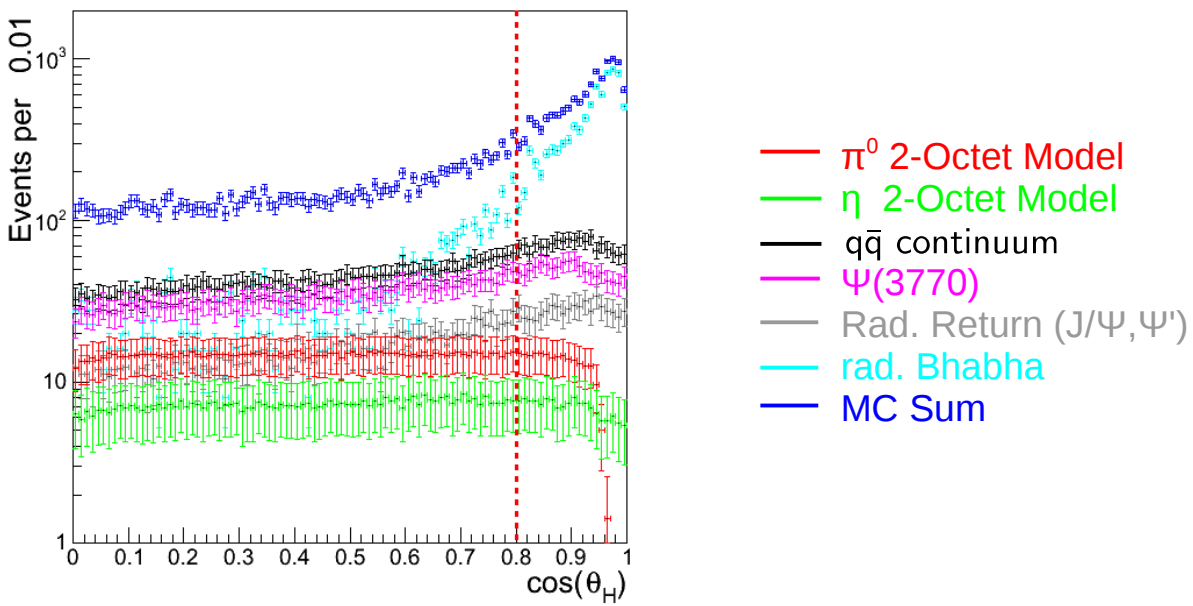
- Radiative Bhabha Scattering
- Hadronic Final States
- Two-Photon Production with ISR
- Two-Photon Production of other mesons

Analysis Steps

Helicity Condition for π^0

- Angle between γ in π^0 rest frame and π^0 in lab
- Flat for signal
- Peaked for background
- Reject events with $\cos(\theta_H) > 0.8$

L_{int}: 927 pb^{-1} , Tagged Lepton: e^-

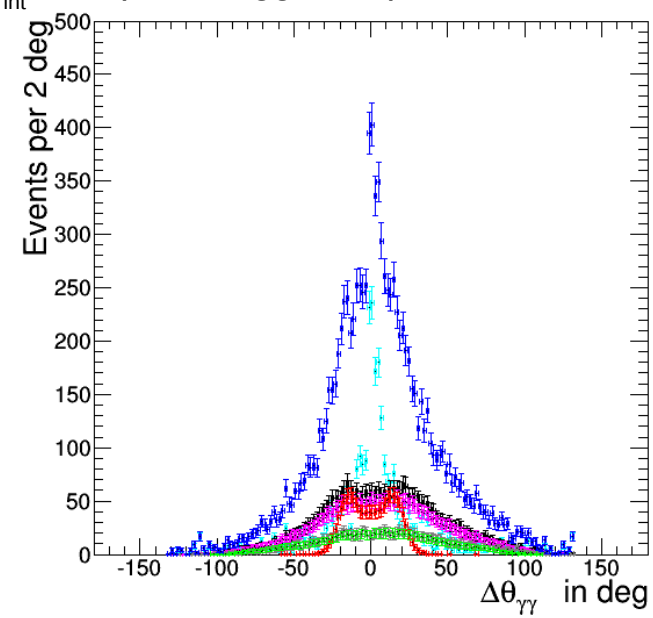


- reduction of QED background

Polar angle difference of γ pair

- Strongly peaked for QED background
- Flat for hadronic background
- Dip for signal
- Reject events with $|\Delta\theta_{\gamma\gamma}| < 1.5°$

L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



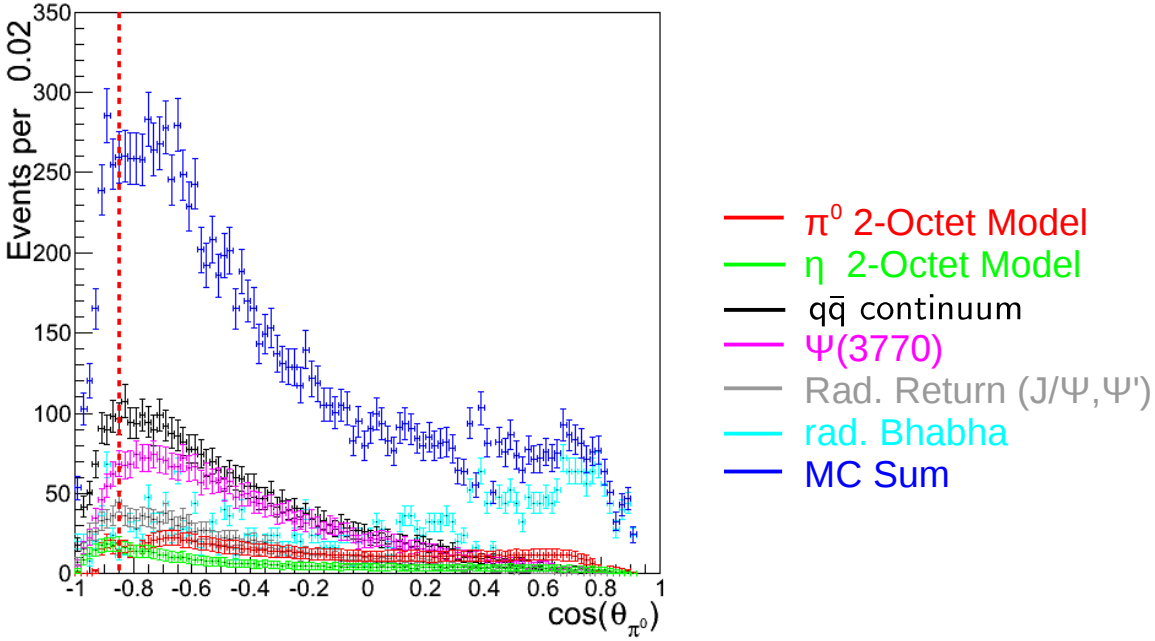
- reduction of QED background

Analysis Steps

Polar angle of π^0

- Background enhanced at large $\cos(\theta_\pi)$
- Signal almost evenly distributed
- Reject events with $\cos(\theta_\pi) \cdot q_{tagged} > 0.8$

L_{int}: 927 pb^{-1} , Tagged Lepton: e^-

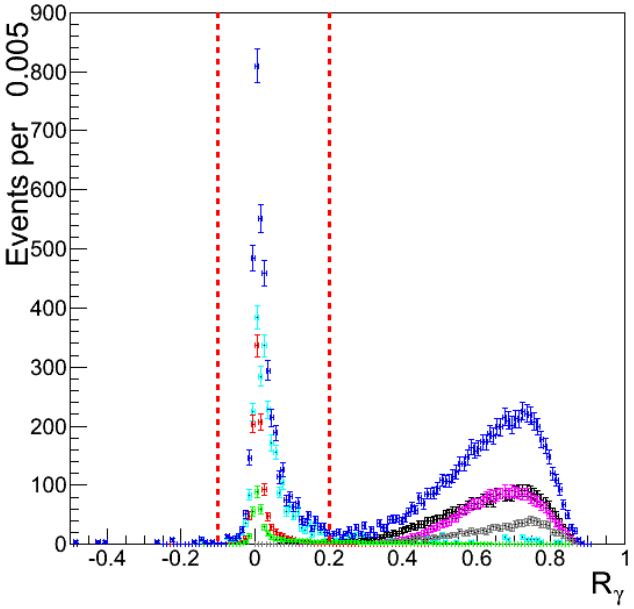


- Data/MC difference
- QED background reduced

Condition on ISR

- ISR results in wrong Q^2
- Useful observable: $r_\gamma = \frac{\sqrt{s} - E^{CMS}_{e^\pm \pi^0, \eta} - p^{CMS}_{e^\pm \pi^0, \eta}}{\sqrt{s}}$
- If ISR, $r_\gamma = \frac{2 E_\gamma}{\sqrt{s}}$
- Reject events with $r_\gamma < -0.1$ and $r_\gamma > 0.2$

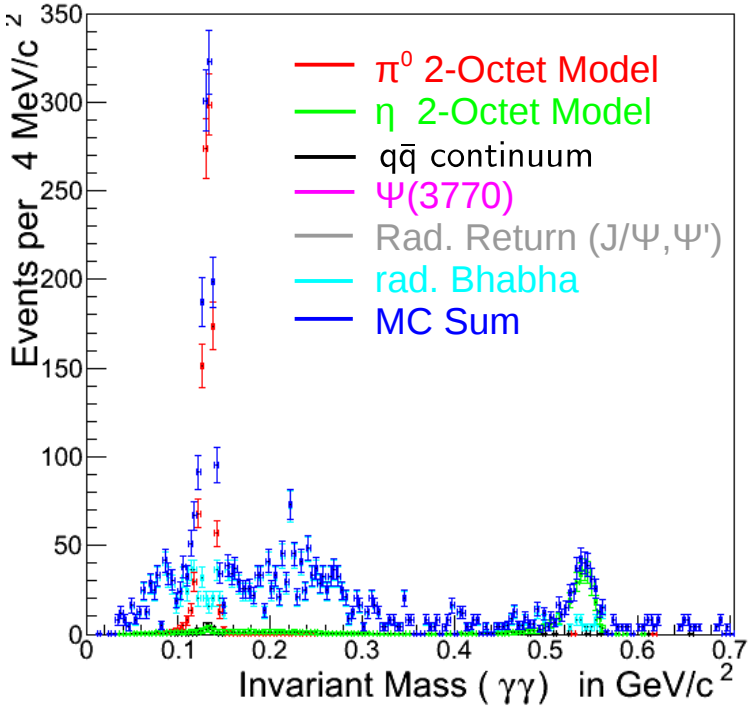
L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



- Hadronic background almost completely removed

Analysis Steps

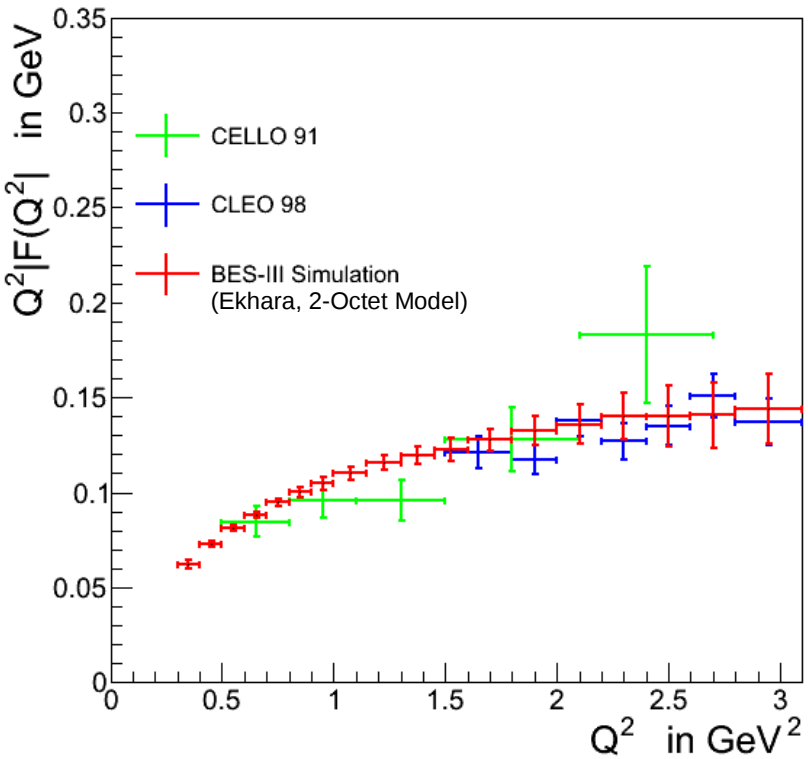
L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



- Clear signals from π^0 / $\eta \rightarrow \gamma\gamma$
- Data: Background underestimated
  - ➔ Use better MC generators
    - modified Babayaga@NLO
    - two-photon generator

- Study differential cross section $d\sigma/dQ^2$
- Bin wise back ground subtraction
- Statistics from Ψ(3770) data only sufficient for π^0 TFF up to $Q^2 = 3$ GeV^2
  - Include large samples from XYZ searches

Expectations for π^0 TFF



- Full Simulation
  - L_{int}: 2.92 fb^{-1}
  - Single Tag with both, $e^{\pm}$
- Extract TFF for $0.3 \leq Q^2[GeV^2] \leq 3.1$
- Expected statistical precision:
  - Unprecedented below $Q^2 = 1.5\ GeV^2$
    - ➔ Important for $(g-2)_\mu$
  - Compatible with CLEO

Next steps:

- Study systematics
  - Largest contribution expected from background subtraction
- Include high energy data
- Other final states

Summary

- BESIII is a good place to study time- and space-like meson transition form factors
- First measurement of Dalitz decays in the charmonium region
- $\gamma\gamma$ Physics program started at BES-III
  - Single tagged measurements of space-like TFF of π^0, η, η'
  - Significant contribution for $Q^2 < 10$ GeV^2
  - First result for π^0 expected soon
    - 0.3 GeV^2 < Q^2 < 3.1 GeV^2 covered
    - Agreement with CELLO and CLEO measurements
    - Unprecedented accuracy for $Q^2 < 1.5$ GeV^2
  - Analyses of η and η' ongoing

- Long Term Plan
  - Measurements of scalar and tensor mesons
  - Measurements of polarization observables
  - Double tagged measurements

Talk by Yuping Guo Tomorrow