Meson Transition Form Factors at BES-III

October 29, 2013 | Christoph Florian Redmer
for the BES-III Collaboration

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Outline

- Introduction
- The BES-III Experiment
- Measurement of Space – like Transition Form Factors
  - Example: $\gamma\gamma^* \rightarrow \pi^0$
- Summary

Introduction

Motivation:

Muon Anomaly: $a_\mu = \frac{1}{2}(g_\mu - 2)$

$$a_\mu^{theo} - a_\mu^{exp} \quad \rightarrow \quad 3.4\,\sigma$$

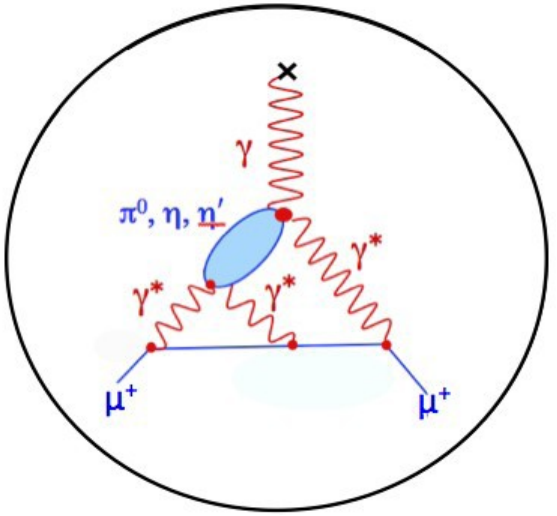
Prediction: $a_\mu^{theo} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$

Completely limited by hadronic contributions !

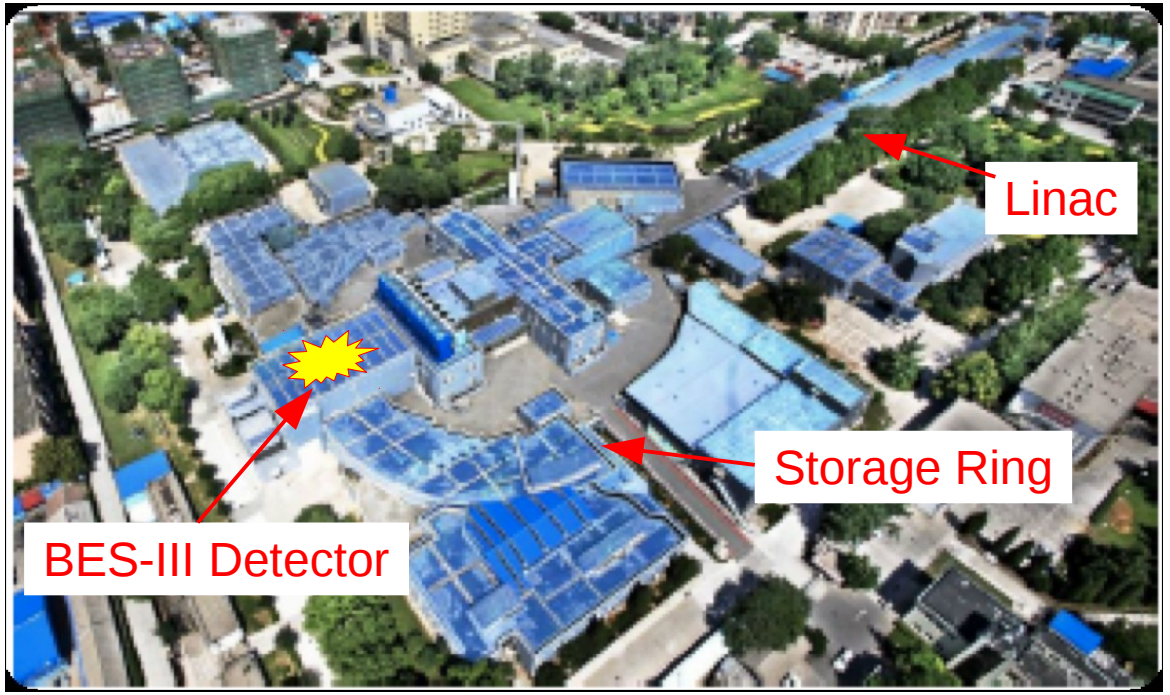
Here: Hadronic Light-by-Light Scattering:

- Perturbative methods not applicable
- Transition Form Factors as input

➔ High precision measurements needed



Beijing Electron Positron Collider BEPC-II



Beam Energy
1.0 - 2.3 GeV

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

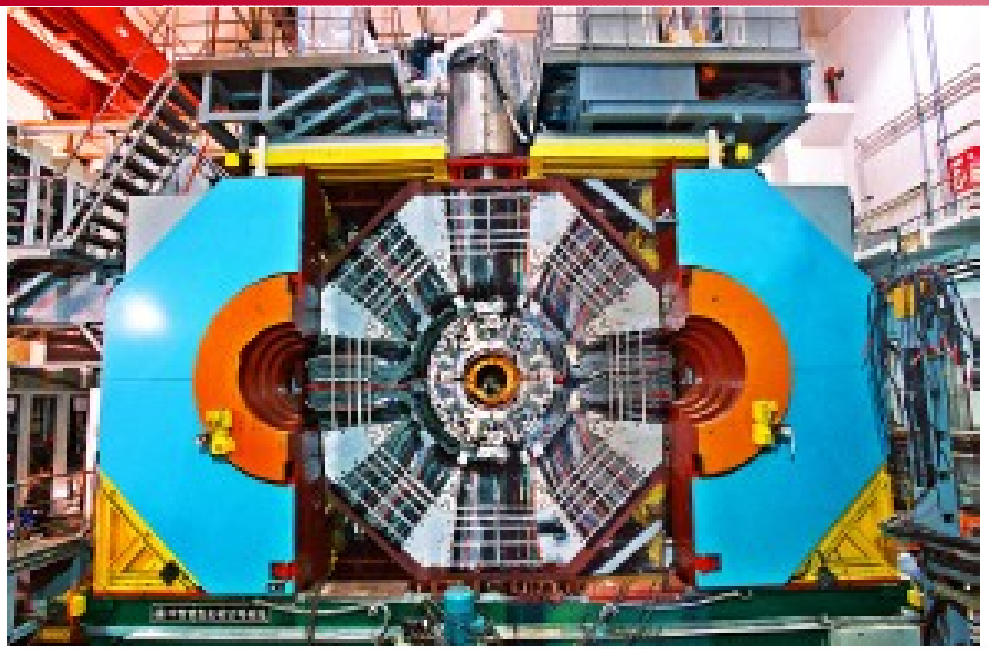
Design Luminosity
10^{33} cm^{-2} s^{-1} @ ψ(3770)

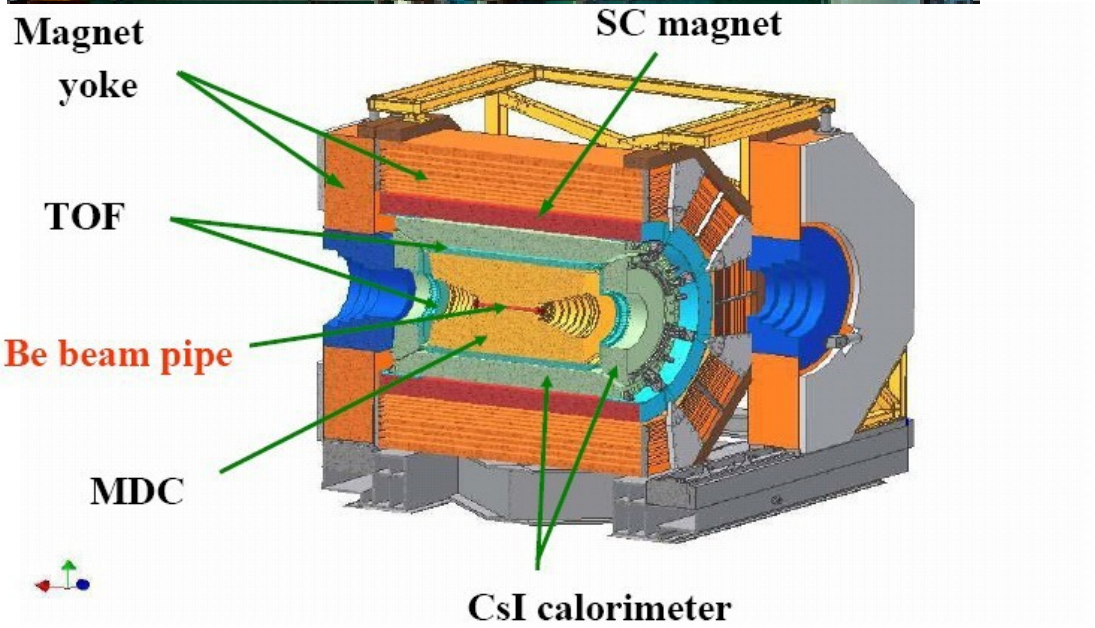
Achieved Luminosity
$0.7 \cdot 10^{33}$ cm^{-2} s^{-1} @ ψ(3770)

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

BES-III Detector

NIM A614 (2010) 345





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

Acquired Data Sets

- 2008: $14 \cdot 10^6$ Ψ(2S)
- 2009: $106 \cdot 10^6$ Ψ(2S) → **4 × CLEO-c**
  $225 \cdot 10^6$ J/Ψ → **4 × BES-II**
- 2010: ~0.9 fb^{-1} Ψ(3770)
- 2011: ~2 fb^{-1} Ψ(3770) → **3.5 × CLEO-c**
  ~0.5 fb^{-1} @ 4.04 GeV
  τ mass scan 24 pb^{-1}
- 2012: $0.4 \cdot 10^9$ Ψ(2S)
  10^9 J/Ψ
- 2013: 1 fb^{-1} @ 4.23 GeV,
  0.8 fb^{-1} @ 4.26 GeV,
  0.5 fb^{-1} @ 4.36 GeV

BES-III Physics Program

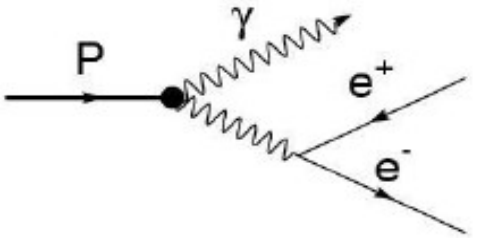
- Charmonium Spectroscopy
- Charm Physics
- Light Hadron Spectroscopy
- τ, R & QCD

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

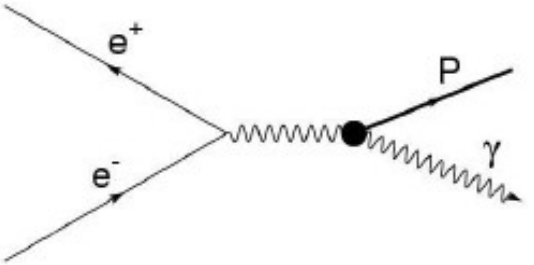
How to measure TFF at BES-III

Time – like Transition Form Factors:

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

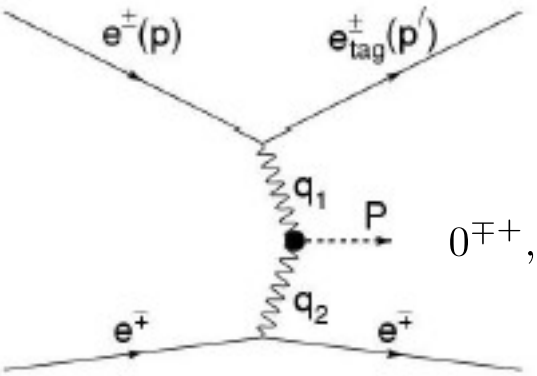


- Annihilation process
  - $q^2 = s > M^2$



Space – like Transition Form Factors:

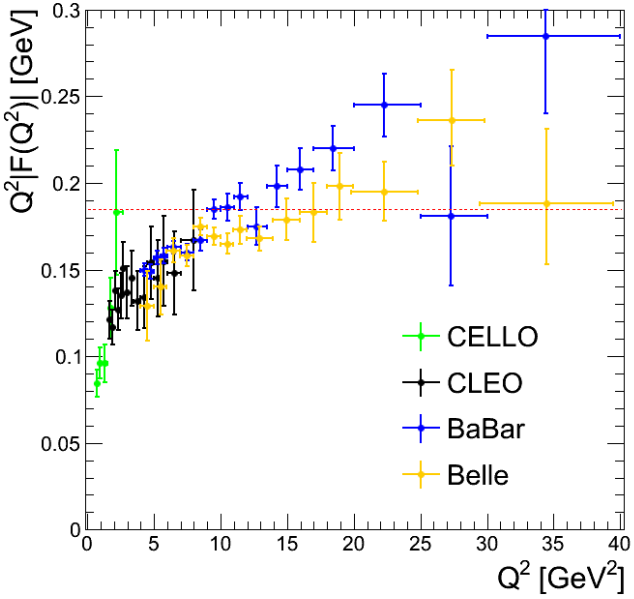
- Two-photon production of mesons
  - $F(Q_1^2, Q_2^2), \quad Q^2 = -q^2$
  - $M^2 - s < Q_1^2 < 0, \quad Q_2^2 \approx 0$ (single tag)



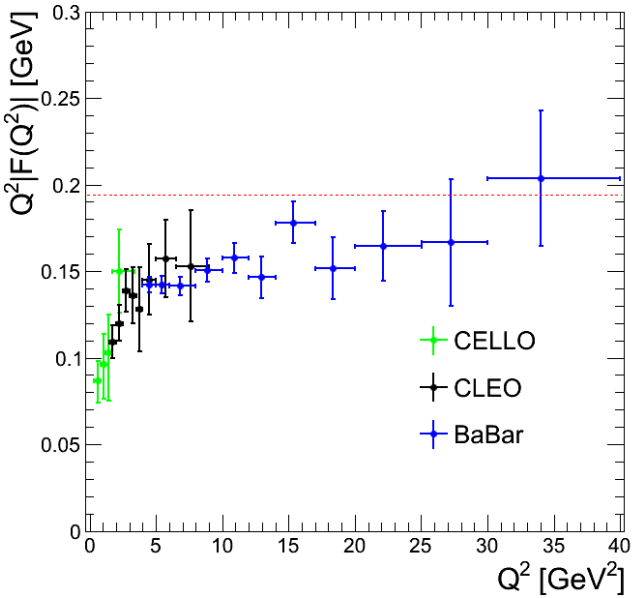
Previous Measurements

First Step: Focus on pseudoscalar mesons

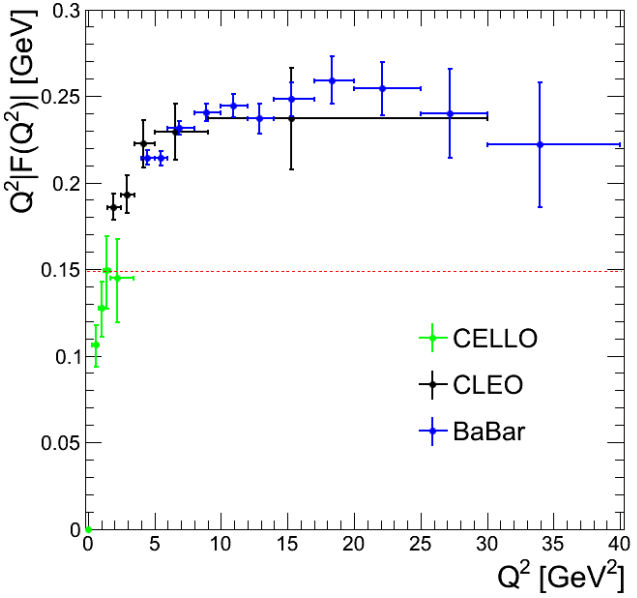
$e^+e^- \rightarrow e^+e^- \pi^0$



$e^+e^- \rightarrow e^+e^- \eta$



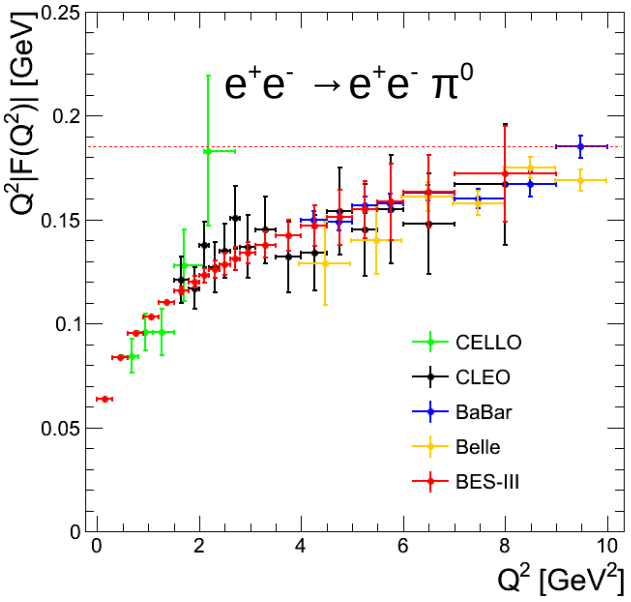
$e^+e^- \rightarrow e^+e^- \eta'$

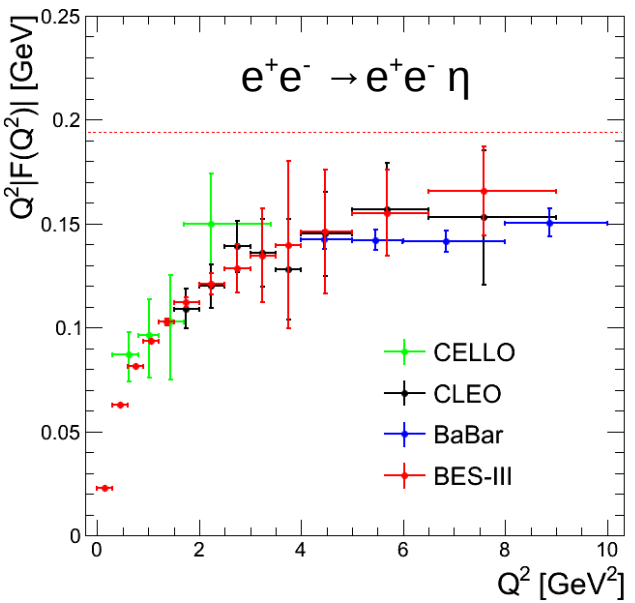


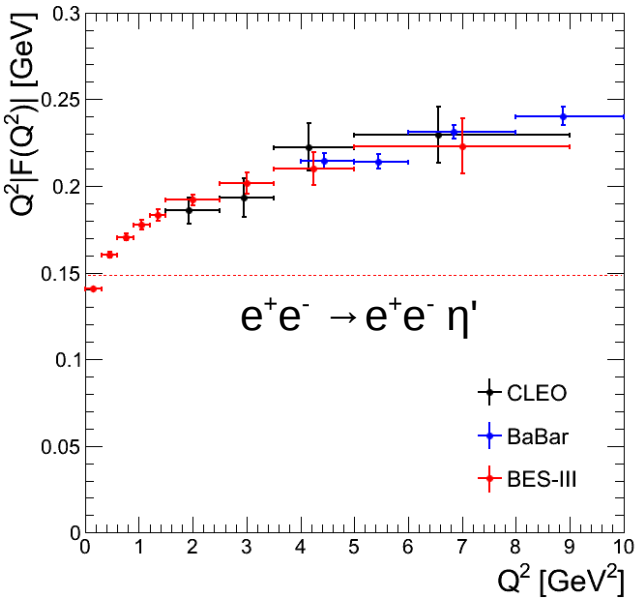
- Recent results from B-factories cover only large Q^2 ($5 < Q^2$ [GeV^2] < 40)
  - Discrepancy for π^0 between BaBar and Belle
- Data scarce at lowest Q^2
  - Region of relevance for (g-2)μ

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 Example: π^0 / η

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Plots on the following slides show MC only!

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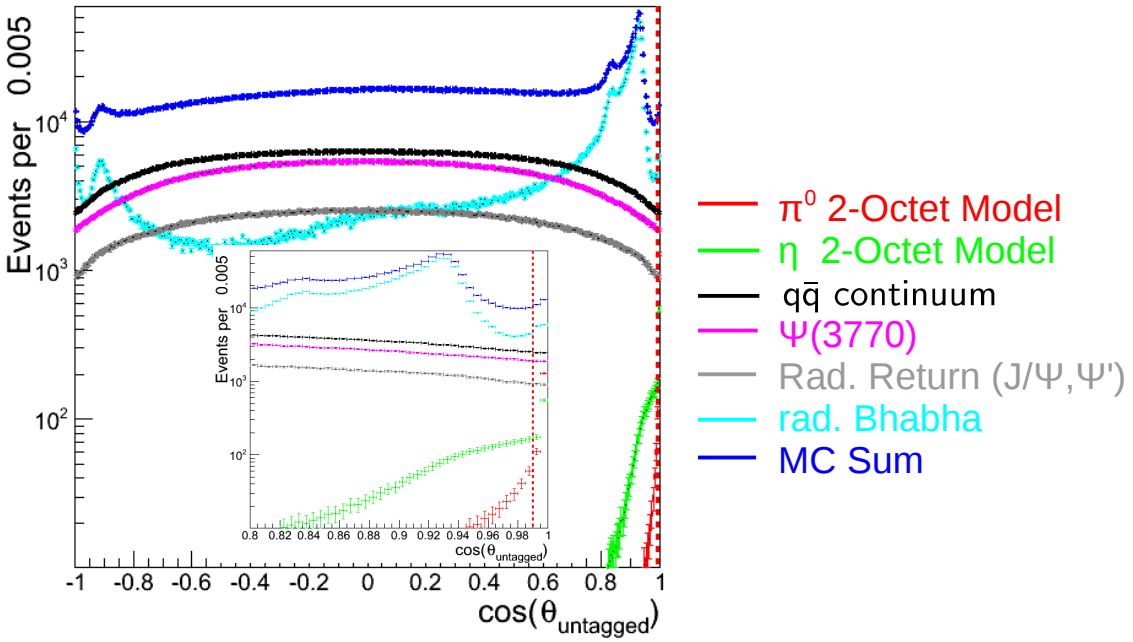
Analysis Steps

Low $Q^2_{untagged}$ Condition

- Reconstruct untagged lepton
  - 4-Momentum conservation
- Reject events with $\cos(\theta_{untagged}) > 0.99 \cdot q_{untagged}$

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

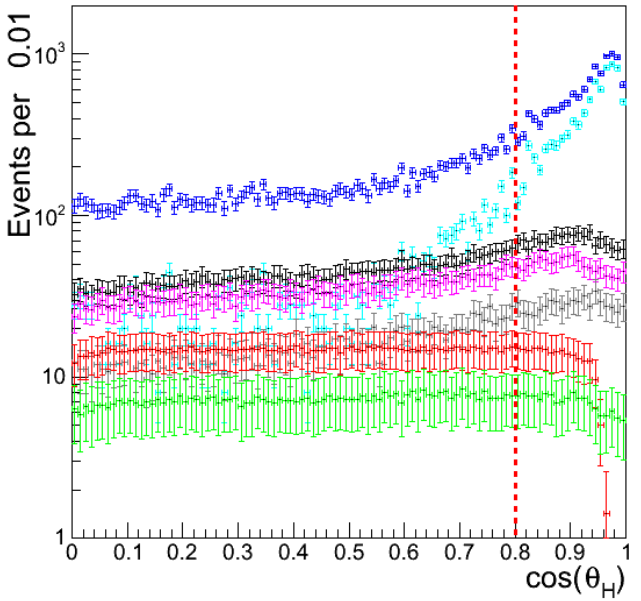


- background reduced by two orders of magnitude

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^-



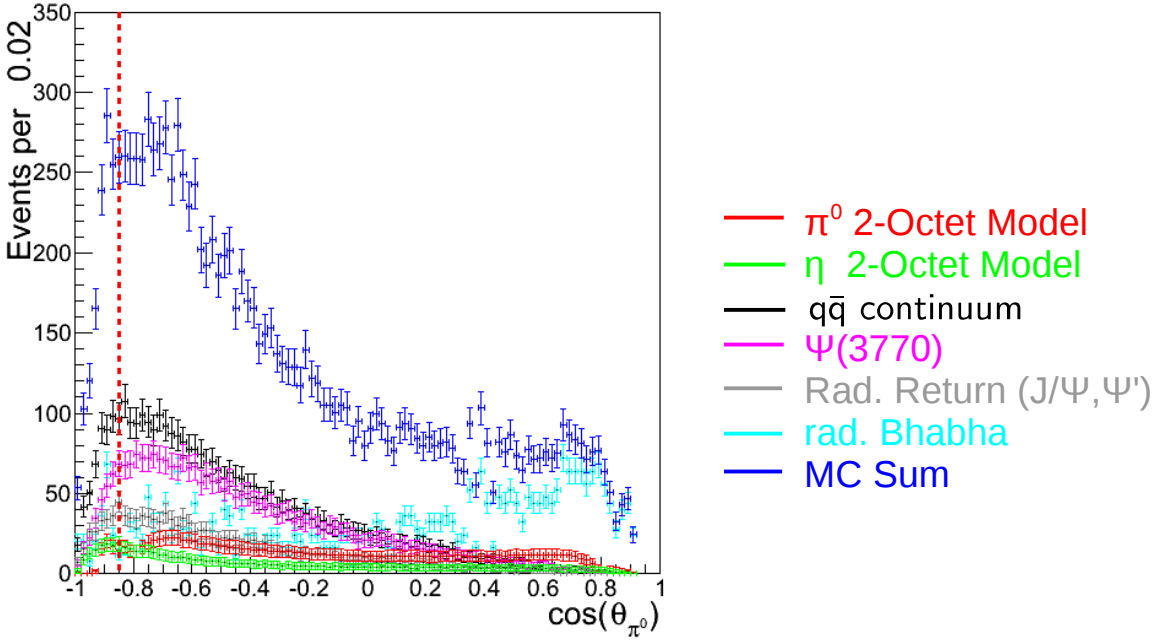
- reduction of QED background

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^-

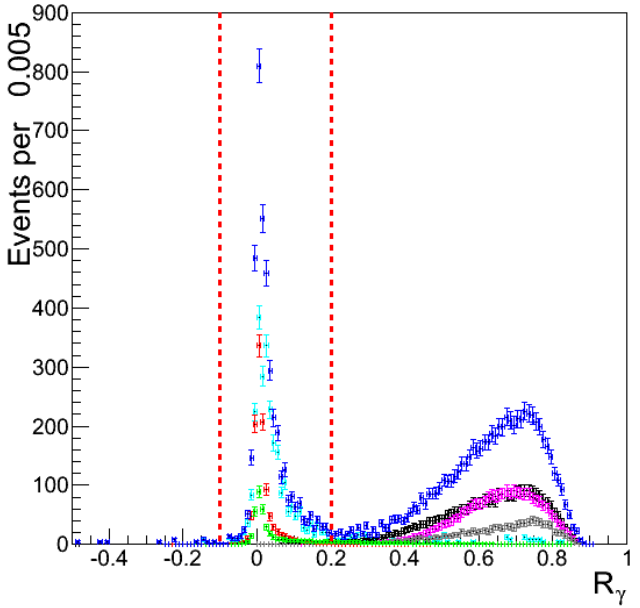


- Data/MC difference
- QED background reduced

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, $r_\gamma = \frac{2E_\gamma}{\sqrt{s}}$
- Reject events with $r_\gamma < -0.1$ and $r_\gamma > 0.2$

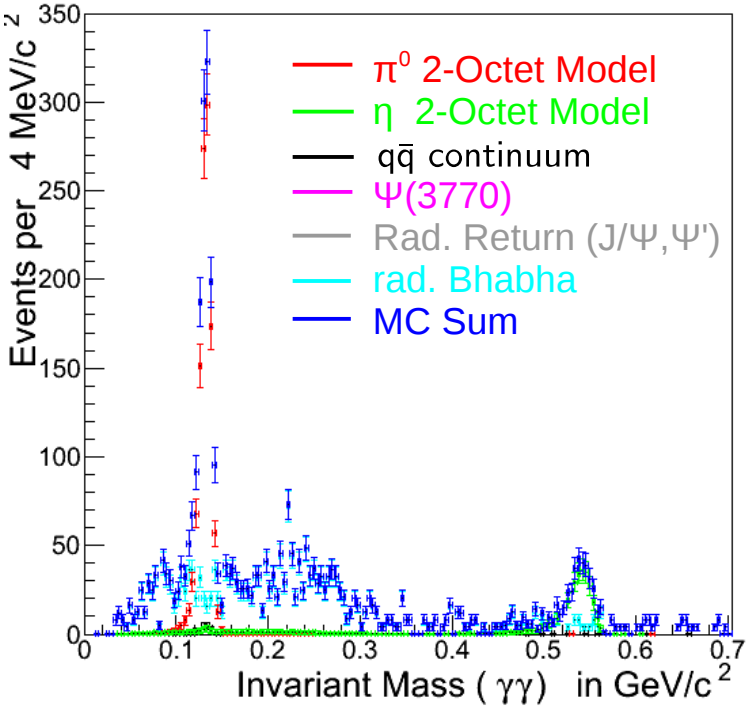
L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



- Hadronic background almost completely removed

Analysis Steps

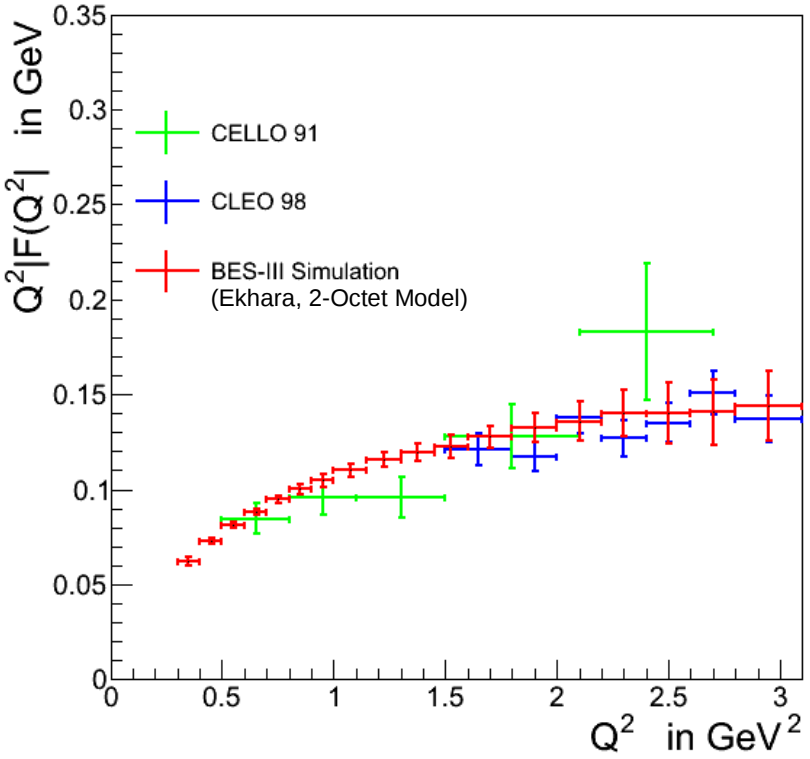
L_{int}: 927 pb^{-1} , Tagged Lepton: e^-



- 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 $(g\text{-}2)_\mu$
  - Compatible with CLEO

Next steps:

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

Summary

- $\gamma\gamma$ Physics program started at BES-III
  - Measurement of space-like TFF of pseudoscalars, scalars, and tensors
  - Currently : single tagged measurements of π^0, η, η'
  - Significant contribution for $Q^2 < 10$ GeV^2
  - 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
  - Investigation of $\pi^+\pi^-$ just started
- Long Term Plan
  - Measurements of scalar and tensor mesons
  - Measurements of polarization observables
  - Double tagged measurements