Studies of Light Pseudoscalar Mesons at BES-III

October 15, 2013 | Christoph Florian Redmer
for the BES-III Collaboration

Symposium on Lepton and Hadron Physics at Meson Factories, Messina

Outline

- Introduction

- Highlights from η and η' Decays

- Two-Photon Physics

- Summary

# Beijing Electron Positron Collider BEPC-II
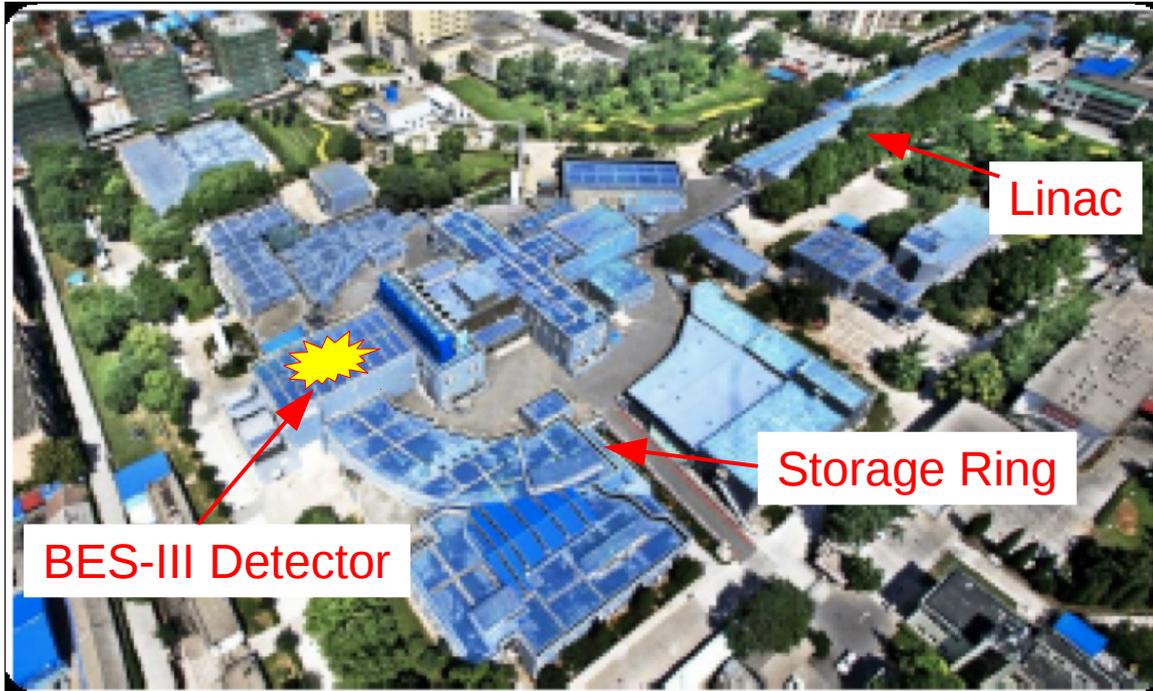
Beam Energy
$$1.0 - 2.3 \text{ GeV}$$

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

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

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

- 2004: start of BEPC-II construction

- 2008: first e^+e^- collisions

- Since 2009: BEPC-II/BES-III data taking

BES-III Detector
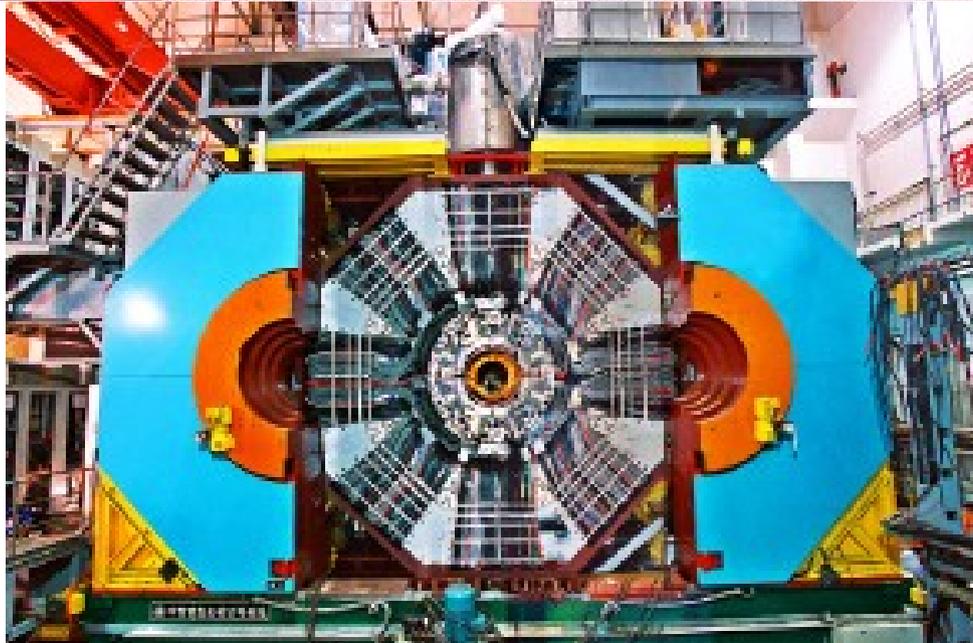
- **Main Drift Chamber (MDC)**
  - $\sigma(p)/p = 0.5\%$
  - $\sigma_{dE/dx} = 6.0\%$

- **Time-of-flight system (TOF)**
  - $\sigma(t) = 90\text{ps}$ (barrel)
  - $\sigma(t) = 110\text{ps}$ (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
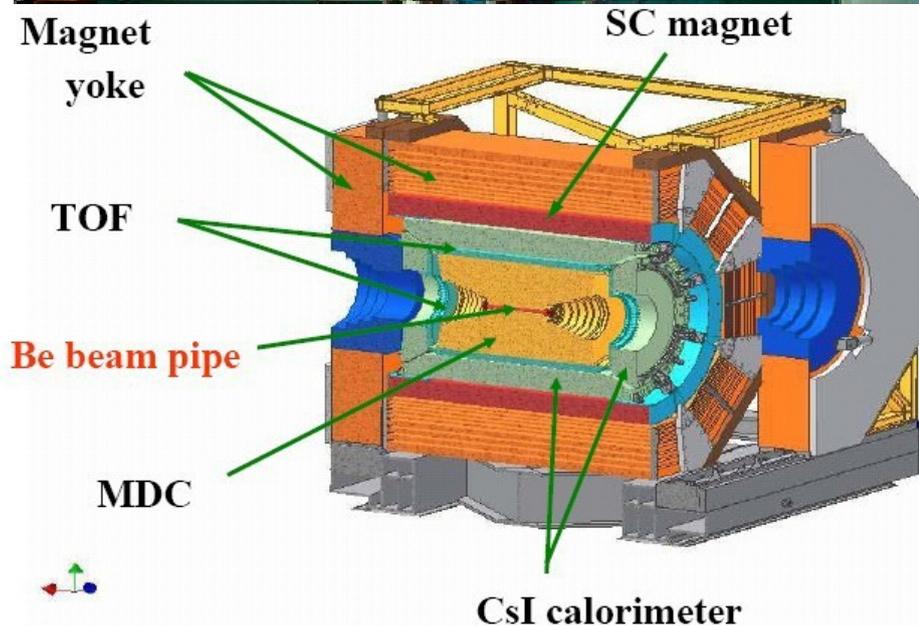
Acquired Data Sets

- 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) ⟶ **3.5 × CLEO-c**

- 2011:   ~2 fb^{-1} Ψ(3770)

  ~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)

η and η' at BES-III

- **η and η' decays are the perfect lab to**
  - test symmetries and symmetry breaking in QCD at low energies
  - search for physics beyond the Standard Model

- **η and η' produced in $225 \cdot 10^6$ J/Ψ decays**
  - B(J/Ψ→γη)   ~ $1.1 \cdot 10^{-3}$ → 2.8×10^5 η events
  - B(J/Ψ→γη')   ~ $5.2 \cdot 10^{-3}$ → 1.2×10^6 η' events
  - B(J/Ψ→φη)   ~ $7.5 \cdot 10^{-4}$ → 1.7×10^5 η events
  - B(J/Ψ→φη')   ~ $4.0 \cdot 10^{-4}$ → 0.9×10^5 η' events

- **Recent BES-III Results**
  - Matrix element for η'→π$^+$π$^-$η   Phys. Rev. D83, 012003, (2011)
  - Search for CP violation η/η'→π$^+$π$^-$,π^{0}π^0 Phys. Rev. D84, 032006, (2011)
  - BF measurement of η'→π$^+$π$^-$π^0,π^{0}π^{0}π^0 Phys. Rev. Lett 108, 182001, (2011)
  - BF measurement of η'→π$^+$π$^-$e$^+$e$^-$,π$^+$π$^-$μ$^+$μ$^-$ Phys. Rev. D87, 092001, (2013)
  - Search for η/η' invisible decays   Phys. Rev. D87, 012009, (2013)
  - Search for η/η' weak decays   Phys. Rev. D87, 032006, (2013)

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- η and η' decays are the perfect lab to

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- η and η' produced in $225 \cdot 10^6$ J/Ψ decays

  - $B(J/\Psi \to \gamma\eta)$ ~ $1.1 \cdot 10^{-3}$ → 2.8×10^5 η events
  - $B(J/\Psi \to \gamma\eta')$ ~ $5.2 \cdot 10^{-3}$ → 1.2×10^6 η' events
  - $B(J/\Psi \to \phi\eta)$ ~ $7.5 \cdot 10^{-4}$ → 1.7×10^5 η events
  - $B(J/\Psi \to \phi\eta')$ ~ $4.0 \cdot 10^{-4}$ → 0.9×10^5 η' events

- Recent BES-III Results

  - Matrix element for $\eta' \to \pi^+\pi^-\eta$ Phys. Rev. D83, 012003, (2011)
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η / η' → invisible

- **window for physics beyond Standard Model**

  - SM process η / η' → $\nu\bar{\nu}$ is helicity suppressed

  - possible contribution from light dark matter η / η' → χχ

    - B(η → χχ) ~ $7.4 \cdot 10^{-5}$
    - B(η' → χχ) ~ $8.1 \cdot 10^{-7}$

      Theory Estimate: B. McElrath
       Phys.Rev.D72, 103508 (2005), eConf C070805, 19 (2007)

  - Experimental upper Limit from BES-II

    - B(η → invisible) < $6.0 \cdot 10^{-4}$ 90% CL
    - B(η' → invisible) < $1.4 \cdot 10^{-3}$ 90% CL

      Phys.Rev.Lett. 97, 202002 (2006)

η / η' → invisible

- **Tagging of η / η' with J/Ψ → φη/η'**
  - two-body decay
  - narrow width of φ resonance
- **Normalization to η → γγ cancels systematics**
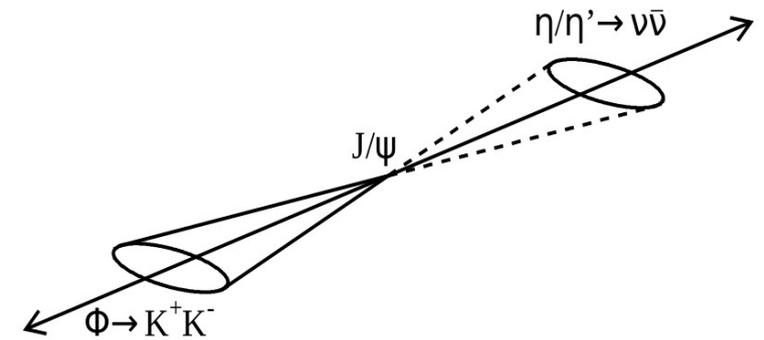
$$B(\eta \to \text{invisible}) / B(\eta \to \gamma\gamma) \quad < 2.6 \cdot 10^{-4}$$
$$B(\eta' \to \text{invisible}) / B(\eta' \to \gamma\gamma) \quad < 2.4 \cdot 10^{-2}$$
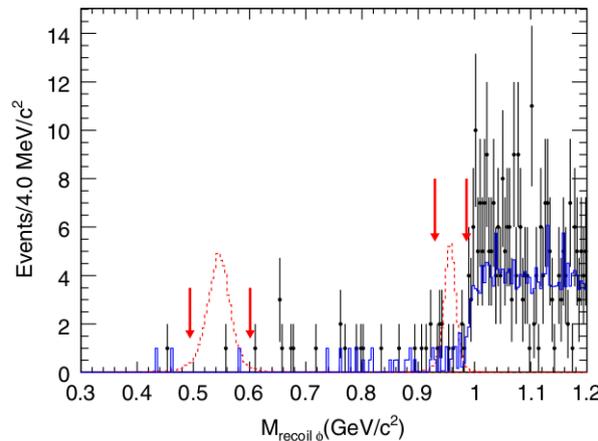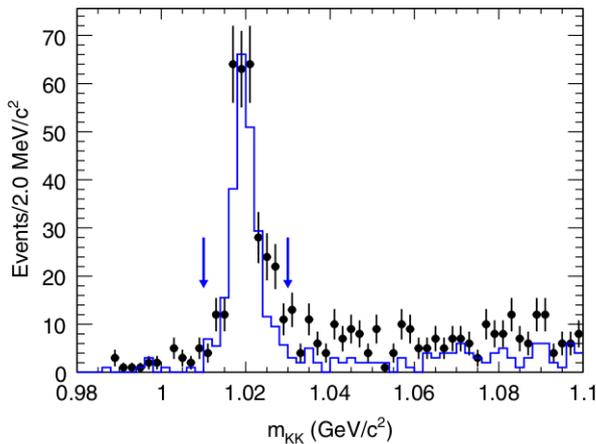
90% CL

$$B(\eta \to \text{invisible}) \quad < 1.0 \cdot 10^{-4}$$
$$B(\eta' \to \text{invisible}) \quad < 5.3 \cdot 10^{-4}$$

90% CL

Phys. Rev. D87, 012009, (2013)

Weak Decays of η / η'

- **within Standard Model :**

 - $B(\eta \rightarrow \pi^- e^+ \nu + c.c.) \sim 2 \cdot 10^{-13}$

    H. Neufeld and H. Rupertsberger,
    Z. Phys. C 68, 91 (1995)

- **Considernig scalar or vector type interactions:**

  - $B(\eta \rightarrow \pi^- e^+ \nu + c.c.) \sim 10^{-8} - 10^{-9}$

    P. Herczeg,
    Prog. Part. Nucl. Phys. 46, 413 (2001)

- **Tagging in J/Ψ → φη/η'**
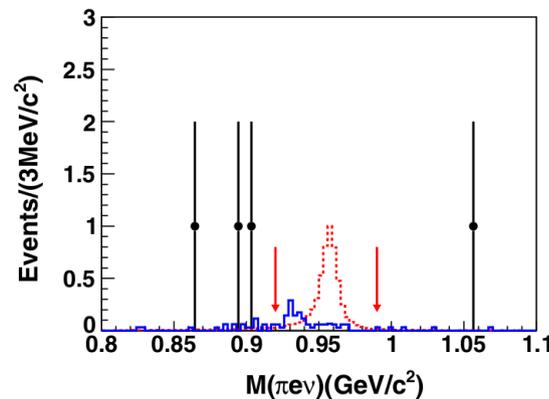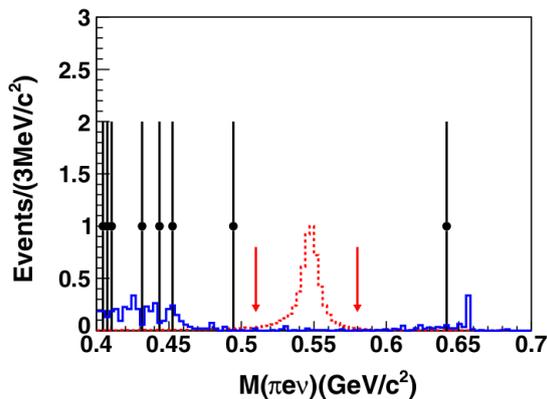
$B(\eta \rightarrow \pi^- e^+ \nu + c.c.) < 1.7 \times 10^{-4}$

@90% CL

$B(\eta' \rightarrow \pi^- e^+ \nu + c.c.) < 2.2 \times 10^{-4}$

Phys. Rev. D87, 032006, (2013)

Two-Photon Physics at BES-III

Aim: Determination of space-like electromagnetic transition form factors

Motivation:

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

$$a_\mu^{theo} - a_\mu^{exp} = 27.6 \pm 8.0 \cdot 10^{-10} \quad \rightarrow \quad 3.4\,\sigma$$

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
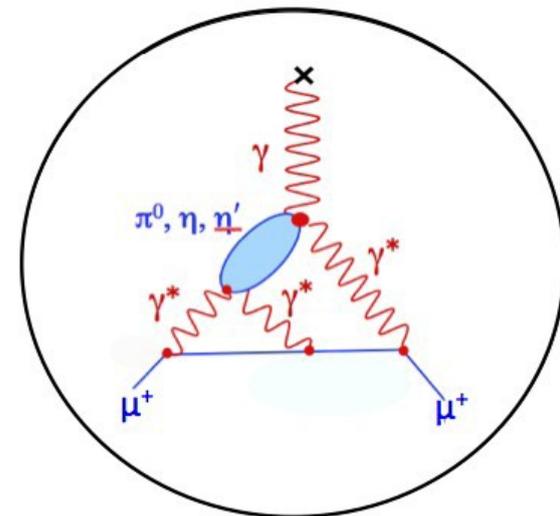
Measurement Strategy

Meson Production in Two-Photon Collisions

- $F(Q_1^2, Q_2^2)$, $Q_i^2 \equiv -q_i^2$
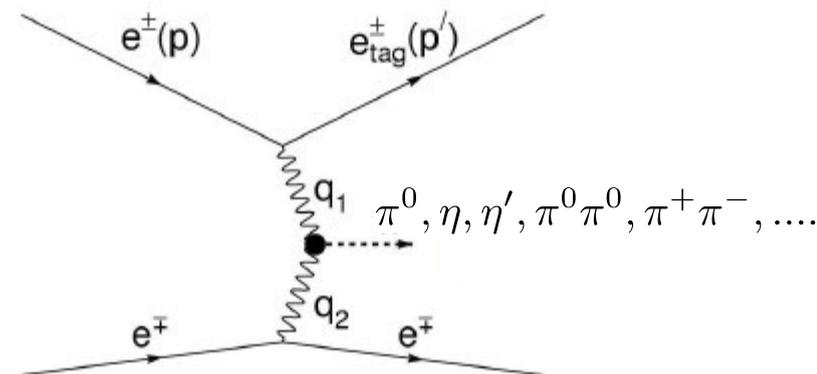
Single Tag Technique

- only one scattered lepton and all decay products measured

- small angle of missing momentum required

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

Feasibility Studies
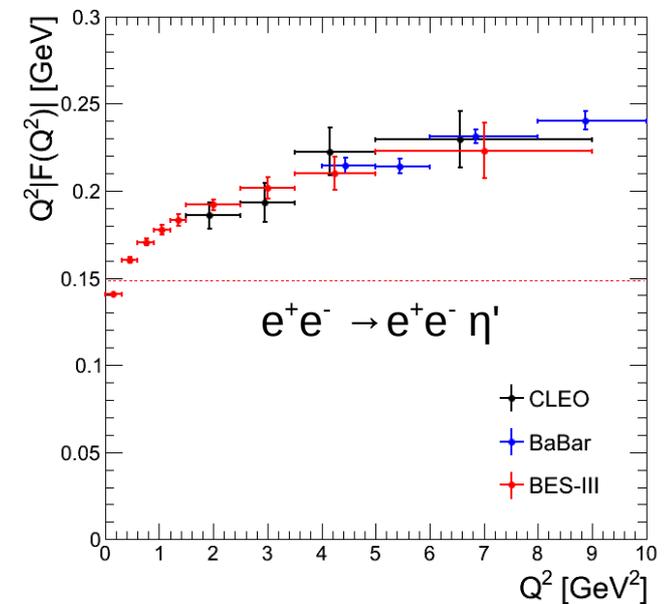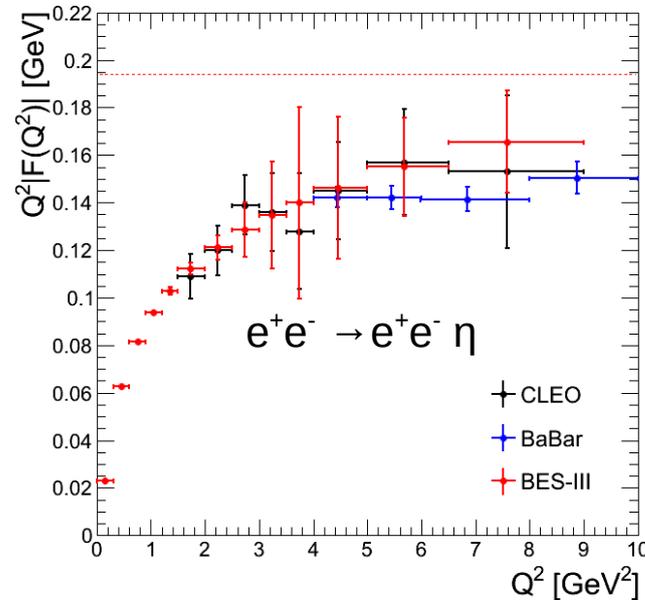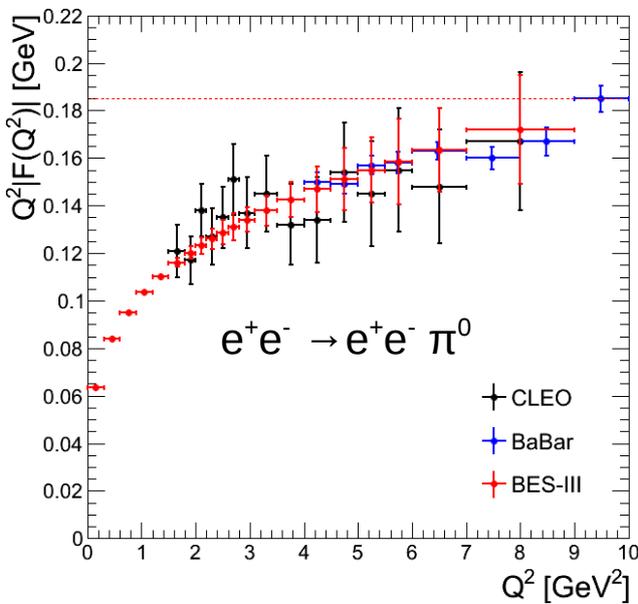
BSc Theses: A. Hahn, B. Kloss

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

Data

- $\Psi(3770)$ on-peak, available: 2.92 fb^{-1}

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Plots on the following slides show MC only!

Event Selection:

- exactly one lepton candidate

- At least two, max four photons

**Expected Background Channels**

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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$^-$

- π^0 2-Octet Model
- η 2-Octet Model
- $q\bar{q}$ continuum
- rad. Bhabha
- MC Sum
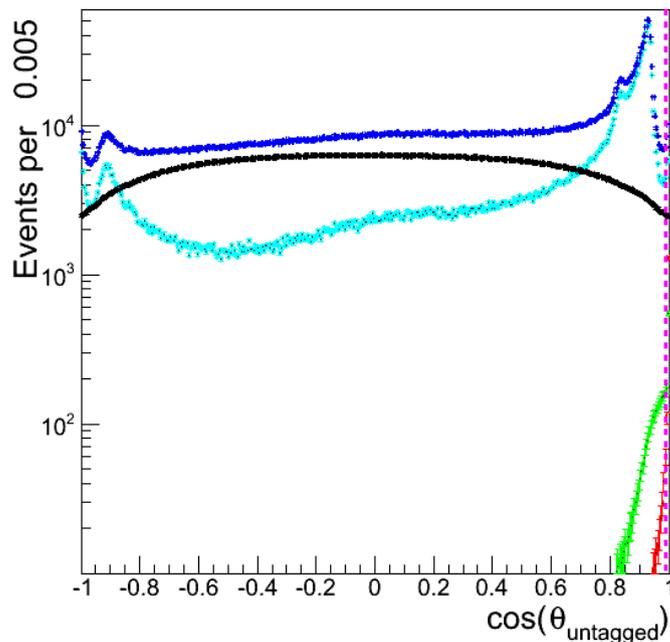
- background reduced by two orders of magnitude

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$^-$
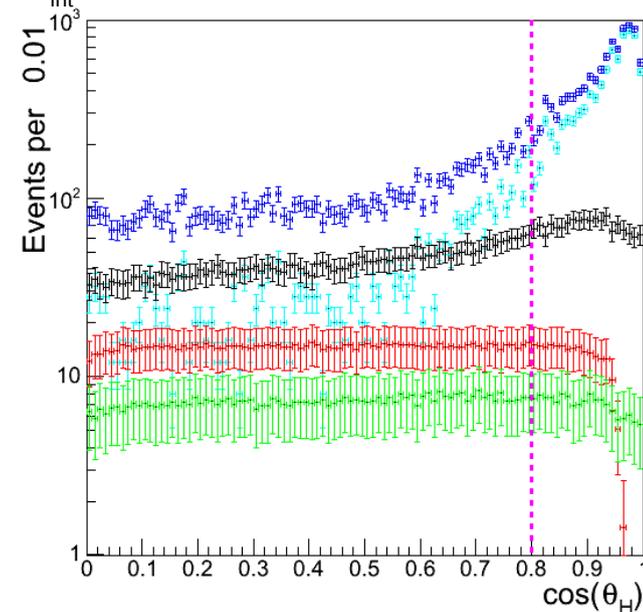
- reduction of QED background

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$^-$
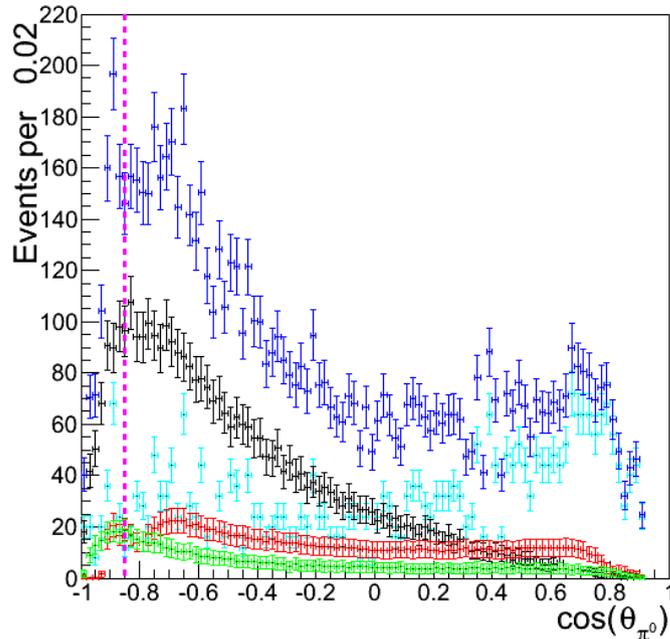
- Data/MC difference

- QED background reduced

Condition on ISR

- ISR results in wrong Q^2

- Useful observable: $r_\gamma = \dfrac{\sqrt{s} - E_{e^+\pi^0}^{CMS} - p_{e^+\pi^0}^{CMS}}{\sqrt{s}}$

- If ISR, $r_\gamma = \dfrac{2 E_\gamma}{\sqrt{s}}$

- Reject events with $r_\gamma < -0.1$ and $r_\gamma > 0.2$

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

— π^0 2-Octet Model
— η 2-Octet Model
— $q\bar{q}$ continuum
— rad. Bhabha
— MC Sum
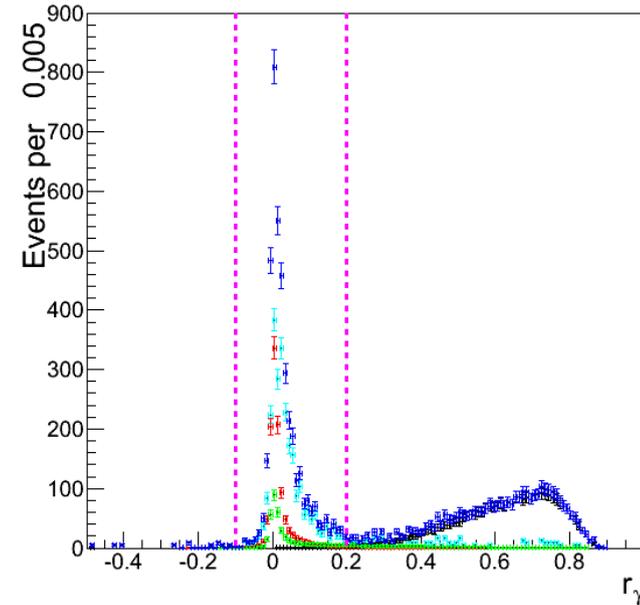
- Hadronic background almost completely removed

Analysis Steps

L_{int}: 927 pb^{-1} , Tagged Lepton: e$^-$
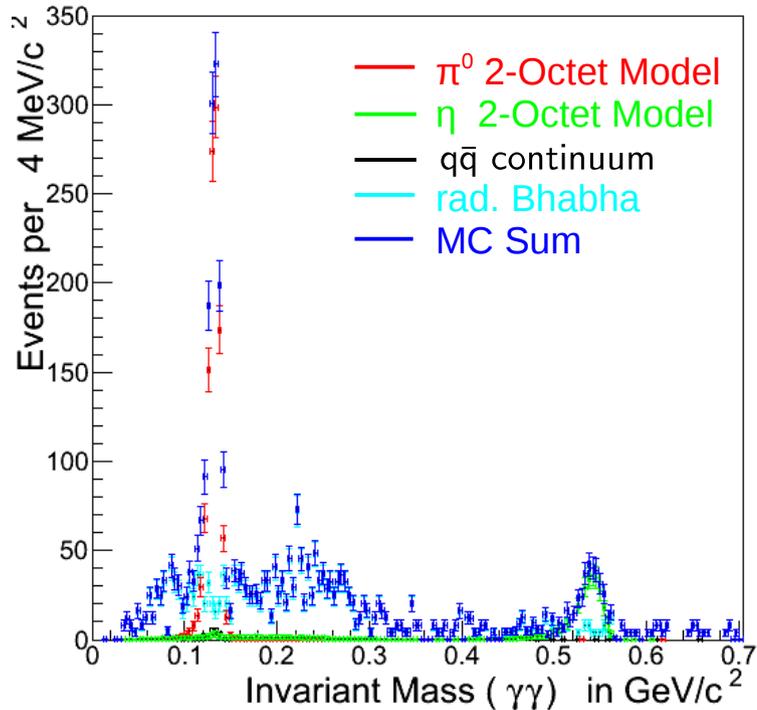
- Clear signals from π^0 / $\eta \to \gamma\gamma$

- 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 $\Psi(3770)$ 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

- CELLO 91
- CLEO 98
- BES-III Simulation (Ekhara, 2-Octet Model)

- **Full Simulation**
  - L_{int}: 2.92 fb^{-1}
  - Single Tag with both, e$^{\pm}$
- **Extract TFF for $0.3 \leq Q^2[\text{GeV}^2] \leq 3.1$**

- **Expected statistical precision:**
  - Unprecedented below $Q^2 = 1.5$ GeV^2
    - ➔ Important for (g-2)$_\mu$
  - Compatible with CLEO
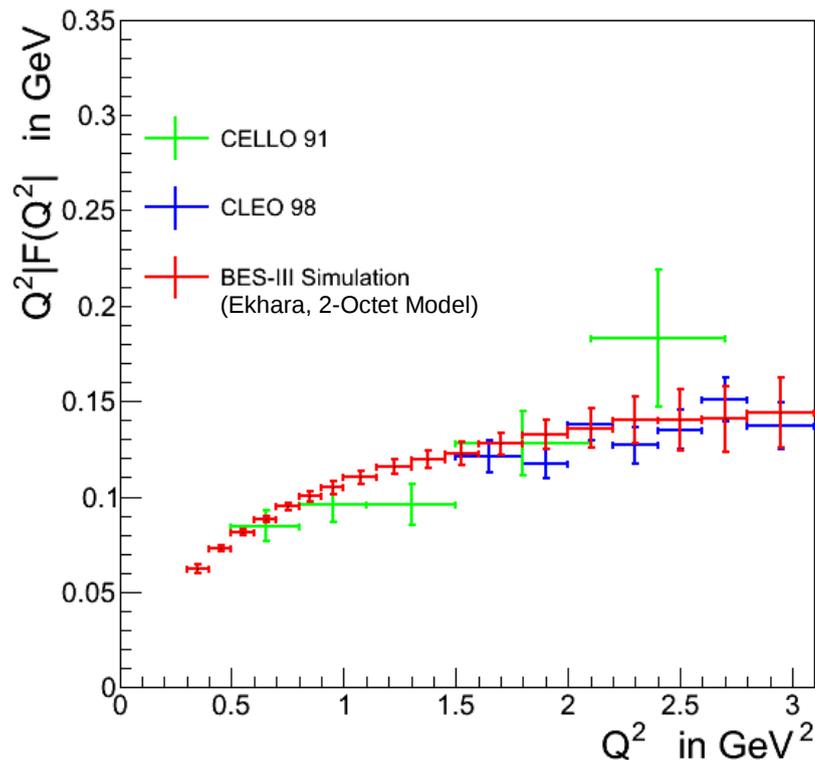
Next steps:

- Study systematics
- Include high energy data
- Other final states

Summary

- η/η' decays perfect lab to test symmetries, symmetry breaking and the SM

- BES-III is the perfect lab to study η/η' decays

  - Matrix element for $\eta' \to \pi^+\pi^-\eta$ Phys. Rev. D83, 012003, (2011)
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- $\gamma\gamma$ 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'
  - 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

  - Investigation of $\pi^+\pi^-$ just started