

Working Group on radiative corrections and generators for low energy hadron cross sections and luminosity

27 – 28 September 2012, Mainz



Study of processes via $\gamma\gamma$ interactions at BESIII

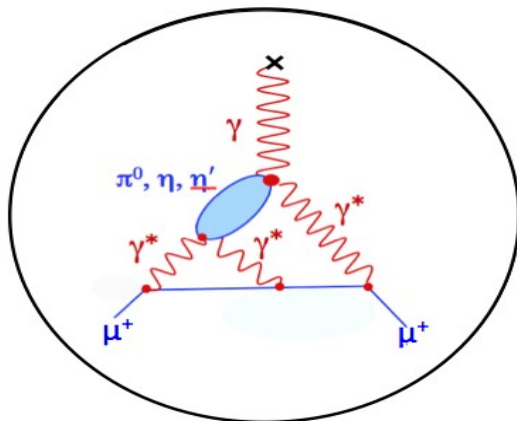
Outline

- ▶ Introduction
- ▶ Motivation
- ▶ The BESIII experiment
- ▶ Two-photon reactions
- ▶ Feasibility studies
- ▶ Experimental results *(WORK IN PROGRESS)*
- ▶ Conclusion and Future Plans

Introduction

- ▶ Transition form factors are important ingredients to understand the nature of mesons and their underlying quark/gluon structures
- ▶ Several reasons to be interested in this field:
 - ◆ quantify the Standard Model value of the **anomalous momentum of the muon**
 - ◆ **high precision measurements** are possible and theoretical calculations are highly needed

Hadronic Light-by-Light Scattering



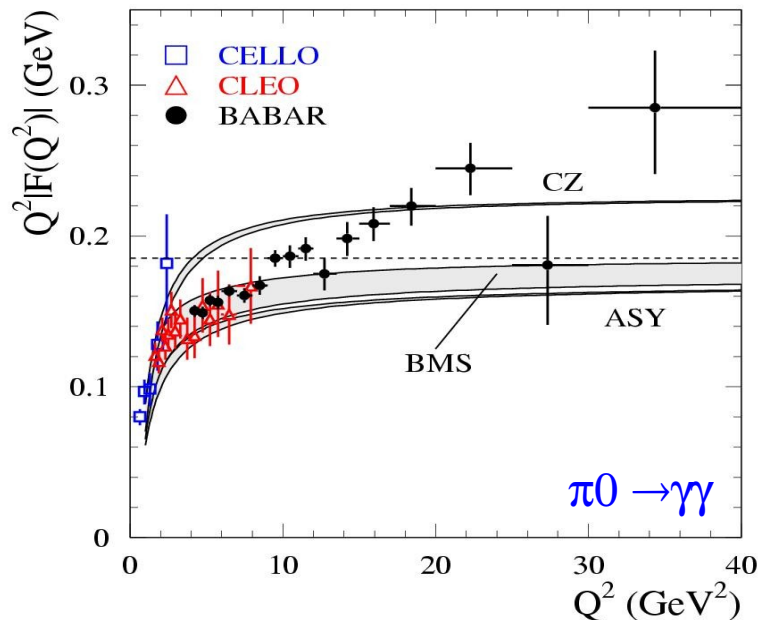
$$a_{\mu}(\text{had}), \text{LbL} = (10.5 \pm 2.6) \cdot 10^{-10} \text{ [1]}$$
$$(11.6 \pm 4.0) \cdot 10^{-10} \text{ [2]}$$
$$(21.6 \pm 9.1) \cdot 10^{-10} \text{ [3]}$$

- [1] J Prades et al, Phys. Rev. Lett. 75, 1447 (1995)
[2] A. Nyffler et al., Phys. Rev. D 65, 073034 (2002)
[3] C.S. Fisher et al, arXiv:1012.3886, 2011

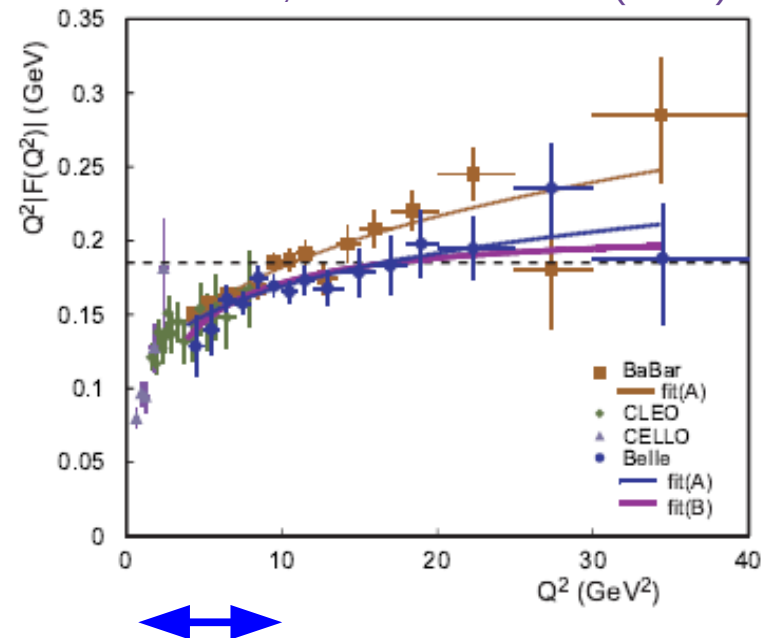
Motivation

- ▶ Experimental results are not in agreement for high Q^2 (BaBar, Belle)
- ▶ For medium-low Q^2 higher precision is needed
- ▶ BESIII can give an important contribution for $Q^2 < 10 \text{ GeV}^2$

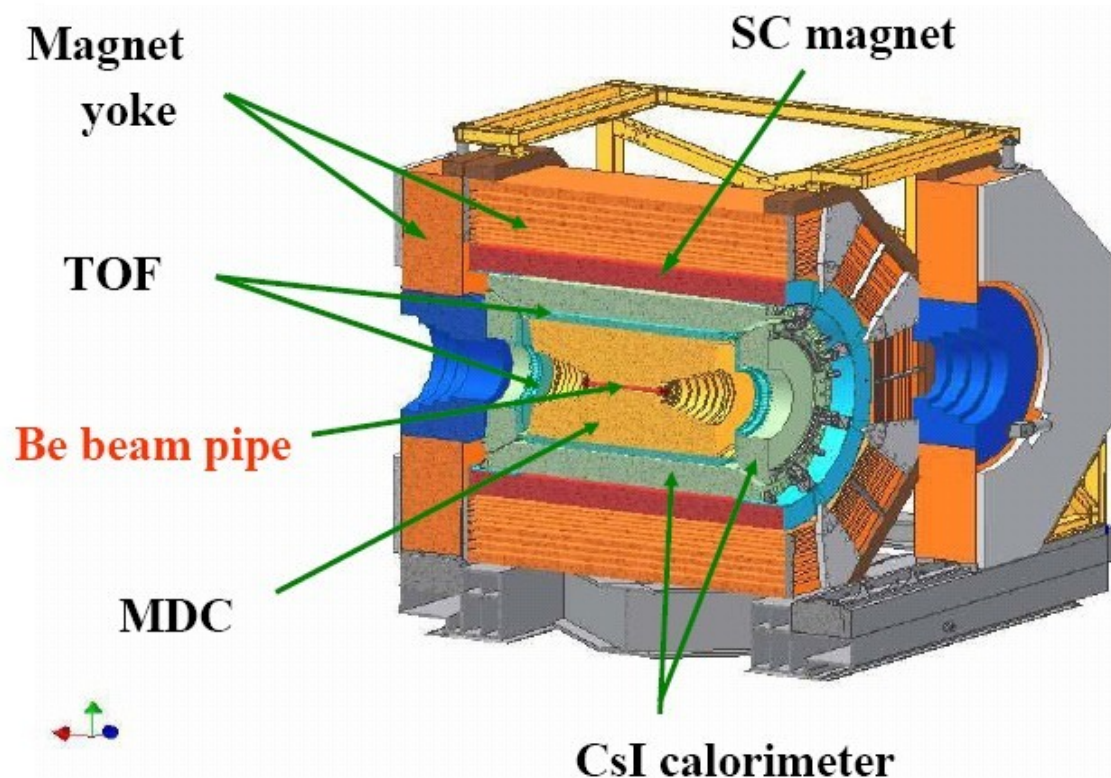
BABAR, PhysRevD.80.052002 (2009)



BELLE, arXiv:1205.3249 (2012)



The BES III experiment



$$\sqrt{s} : 2.0-4.6 \text{ GeV}$$

$B = 1\text{T}$

resolution(MDC): $\sigma_p/P = 0.58\%$

resolution(MDC): $\sigma_E/E = 6.0\%$

resolution(TOF): $\sigma_\tau = 100\text{ps}$

resolution(EMC): $\sigma/E = 2.5\%$

Muon detected: $p > 400 \text{ MeV}/c$

Very good separation e/π

BESIII collected by the end of 2011

J/ψ : 225 Million

Ψ' : 106 Million

$\psi(3770)$: 2.9fb^{-1}

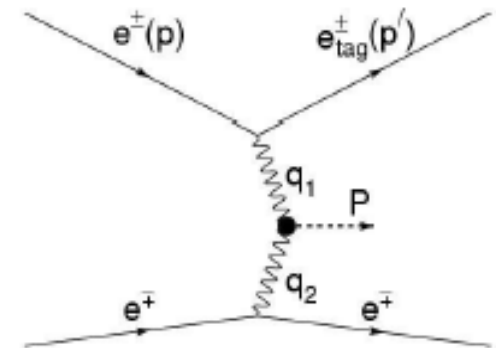
$\psi(4010)$: 0.5fb^{-1}

- BES III detector at BepC (Beijing, China) offers a unique opportunity to perform light hadron physics analyses and transition form factor measurements.

How the form factor can be measured

- Two-photon production of the meson

- $-S + M^2 < q_1^2 < 0, q_2^2 \approx 0, Q^2 \equiv -q_1^2$
- $d\sigma/dQ^2$ falls as $1/Q^6$
- At $\sqrt{s}=10.6$ GeV for $e^+e^- \rightarrow e^+e^- \pi^0$
 $d\sigma/dQ^2(10 \text{ GeV}^2) \approx 10 \text{ fb/GeV}^2$

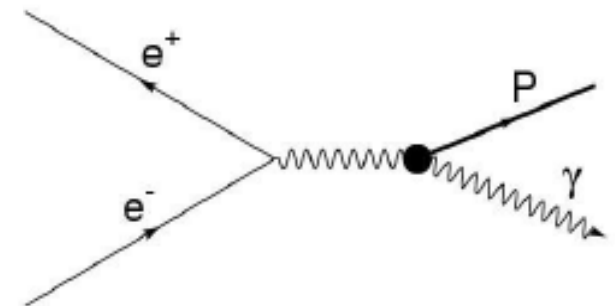


BaBar,
Belle,
BESIII,
....

SINGLE TAG technique

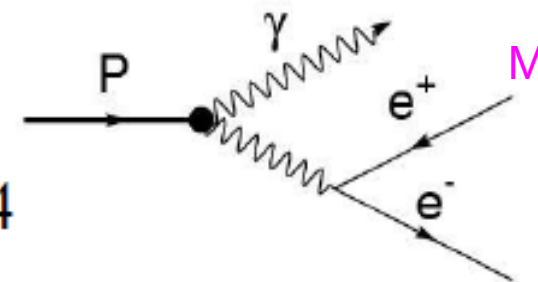
- Annihilation process $e^+e^- \rightarrow P\gamma$

- $Q^2 = S > M^2$
- $\sigma \propto 1/S^2$
- $\sigma(e^+e^- \rightarrow \eta\gamma) \approx 5 \text{ fb}$ at $\sqrt{s}=10.6 \text{ GeV}$



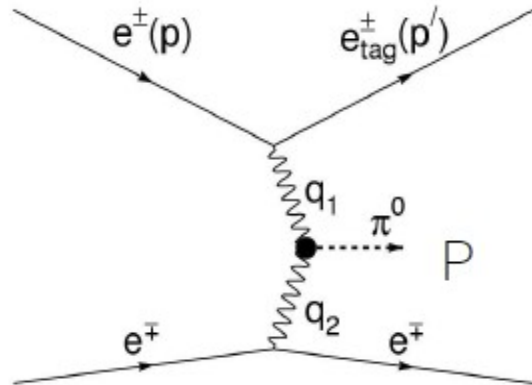
- Dalitz decay $P \rightarrow \gamma e^+e^-$

- $0 < Q^2 < M^2$
- $M^2 d\Gamma/dQ^2 \approx (2\alpha/\pi) \Gamma(P \rightarrow \gamma\gamma)$ at $Q^2/M^2 \approx 1/4$



MAMI

Two-photon reaction $e^+e^- \rightarrow e^+e^-P$: strategy



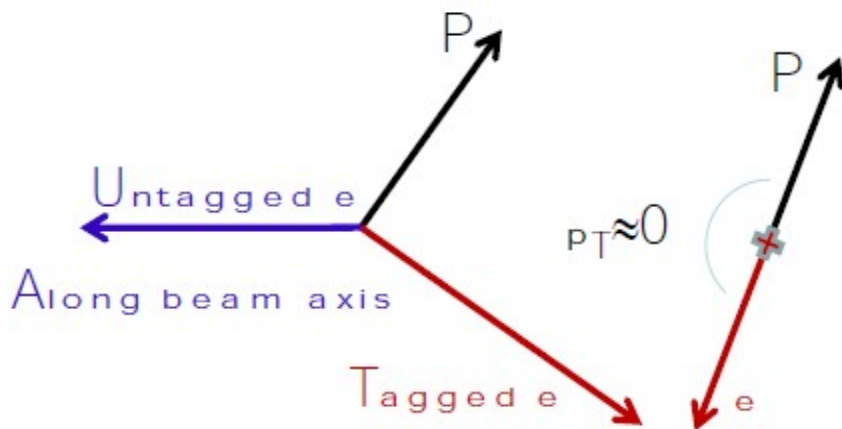
- ▶ Electrons (positrons) are scattered predominantly at small angles

Single tag mode:

one of the 2 leptons is detected

$$Q^2 = -q_1^2 = 2EE'(1-\cos\theta)$$

$$q_2^2 \approx 0$$

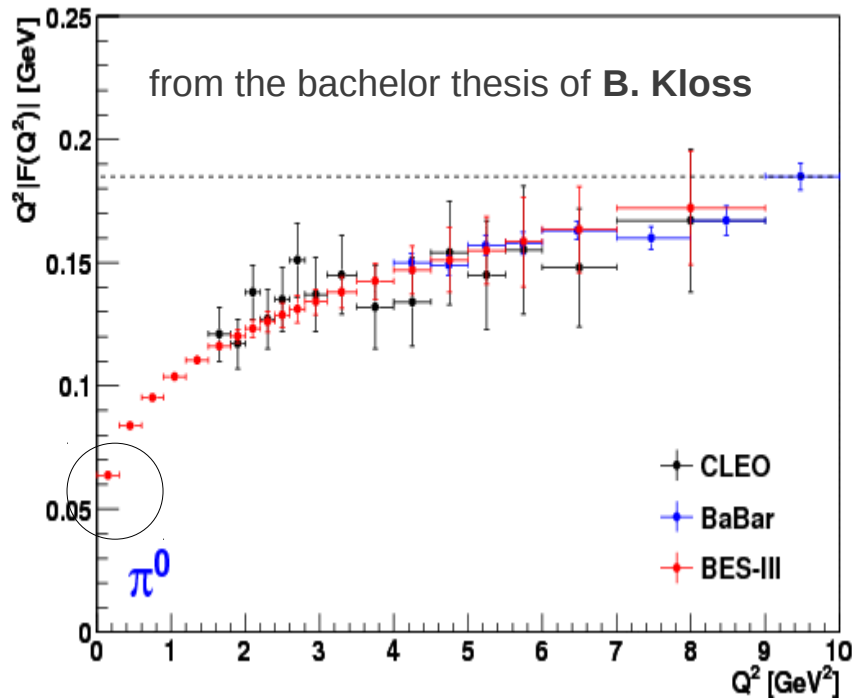


- ▶ Positron (electrons) is detected
- ▶ Meson P (π^0, η, η') are detected and fully reconstructed
- ▶ Positron (electron) + meson has low p_T
- ▶ Missing mass in an event is close to 0

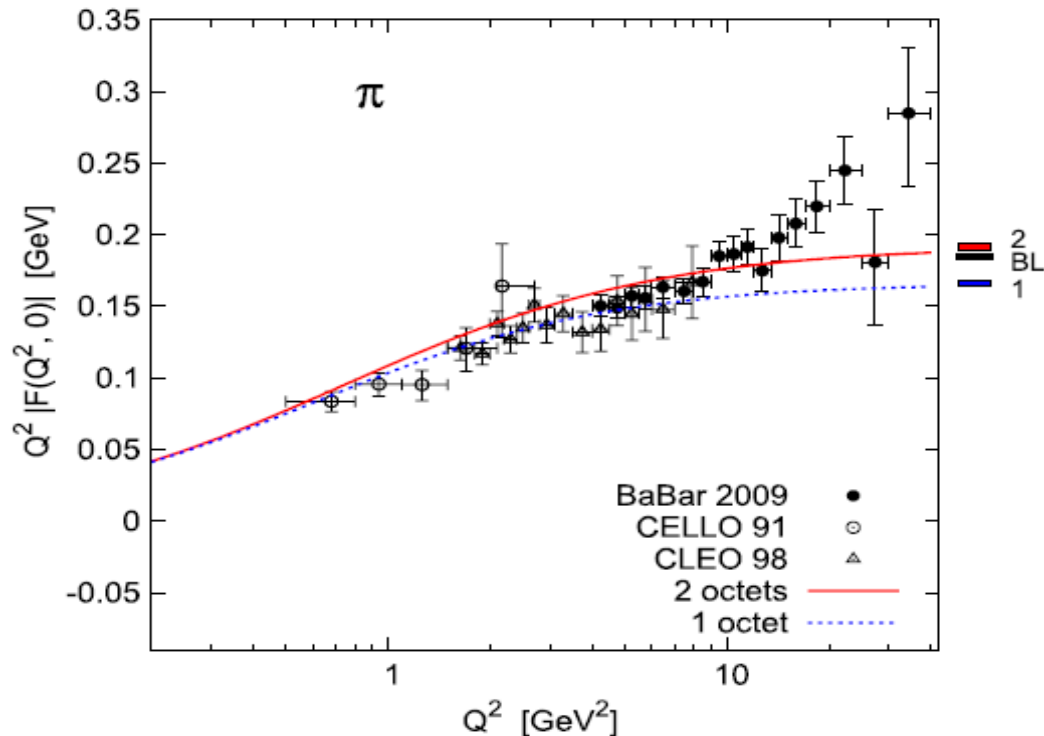
$$dN/dQ^2 \longrightarrow d\sigma/dQ^2 \longrightarrow |F(Q^2)|$$

This analysis in BES III: $e^+e^-\pi^0$

► Step 0: feasibility study (no detector simulation included) performed on 10fb^{-1}



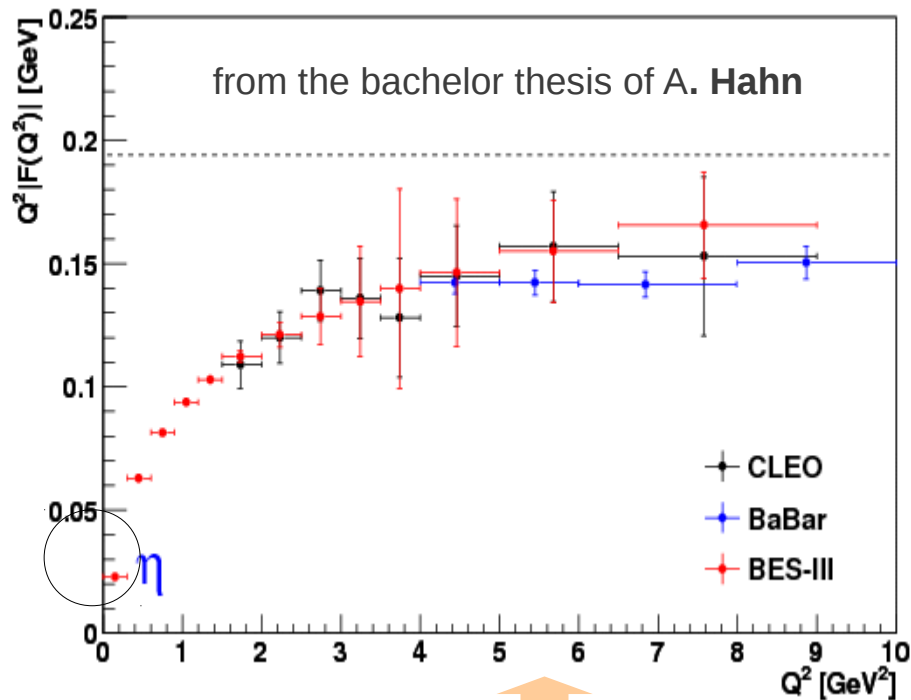
Possibility to check precisely $Q^2 \in [0.3; 1.5]$
 Cross check CLEO data for $Q^2 \in [1.5; 4]$
 Cross check BaBar/Belle for $Q^2 \in [4; 10]$
 Error sensitively reduced at very low Q^2



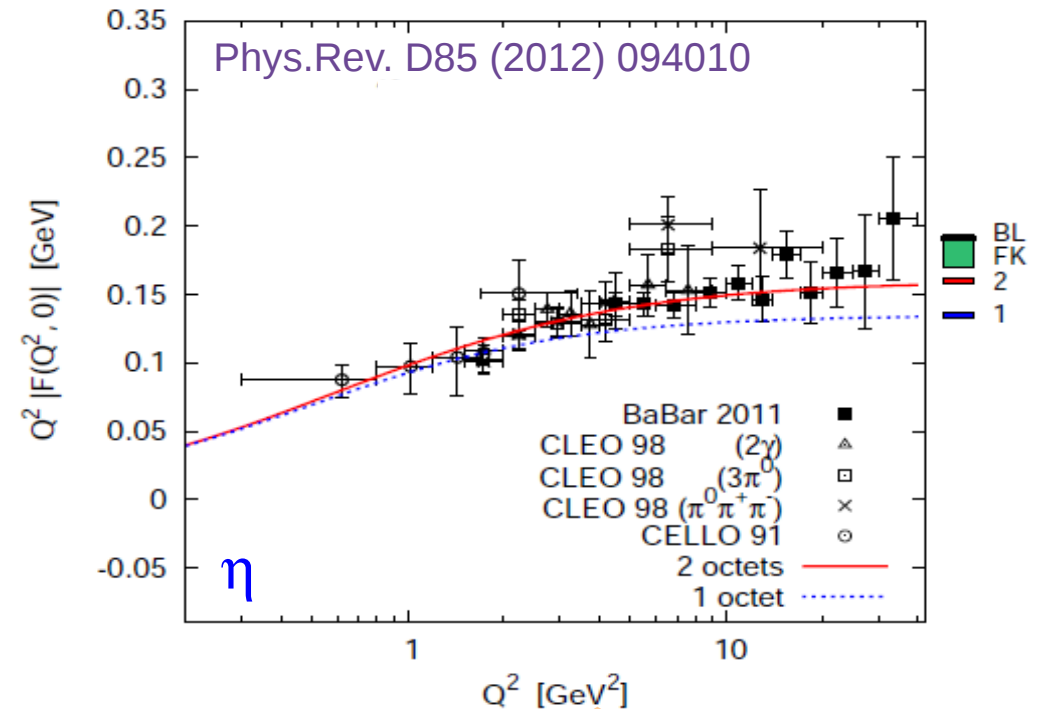
Double octet model, used for BESIII simulations, in the next slides

This analysis in BES III: $e^+e^-\eta$

► Step 0: feasibility study (no detector simulation included) performed on 10fb^{-1}



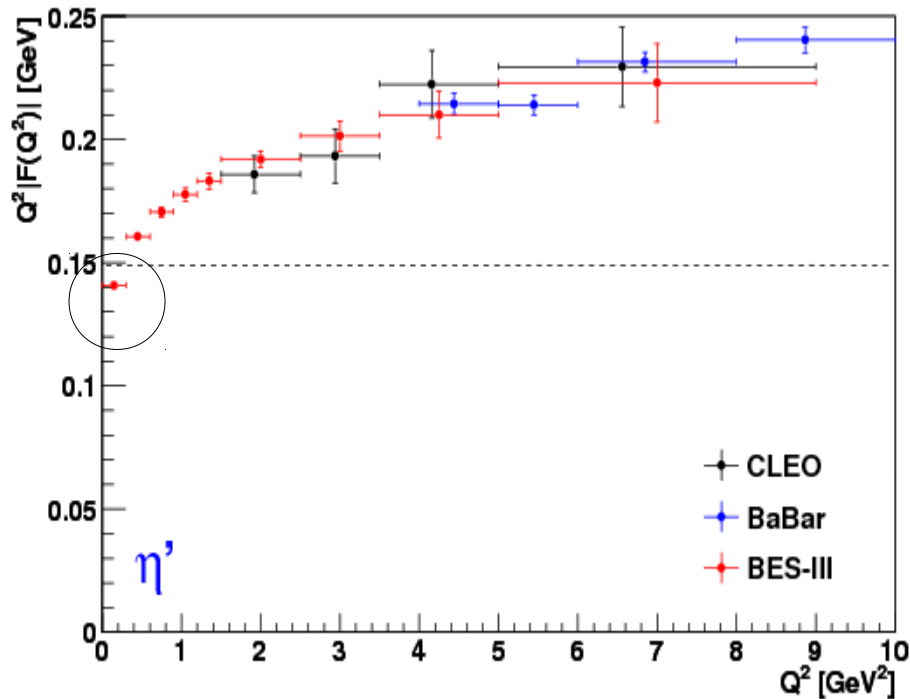
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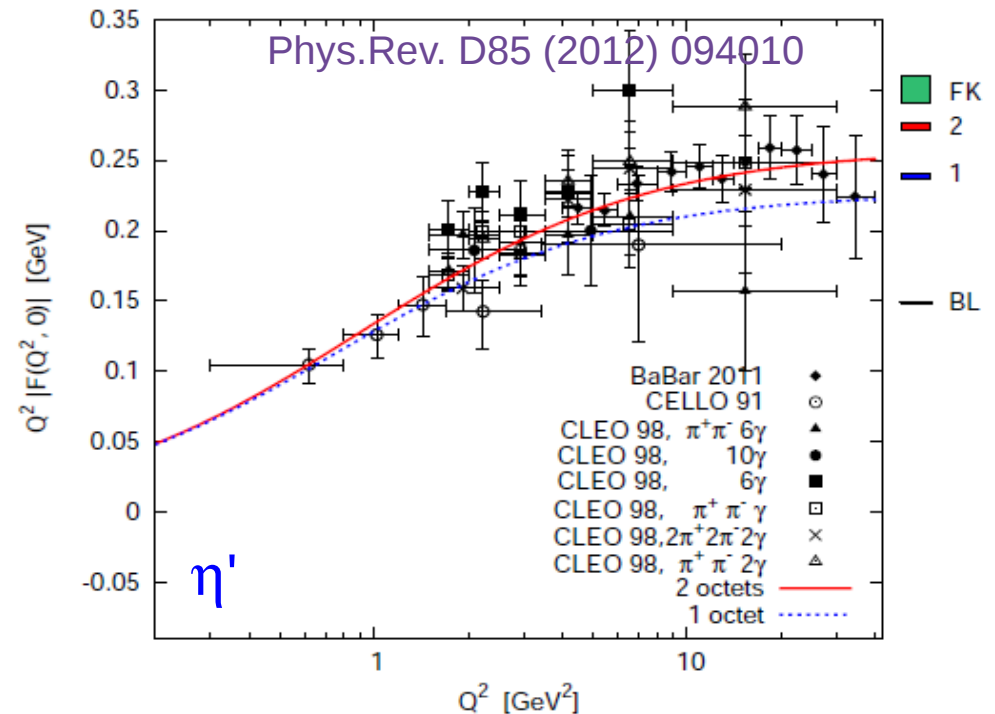
Double octet model, used for BESIII simulations, in the next slides

This analysis in BES III: $e^+e^-\eta'$

► Step 0: feasibility study (no detector simulation included) performed on 10fb^{-1}



Possibility to check precisely $Q^2 \in [0.3; 1.5]$
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 Error sensitively reduced at very low Q^2



Double octet model, used for BESIII simulations, in the next slides

Cross section from MC simulations

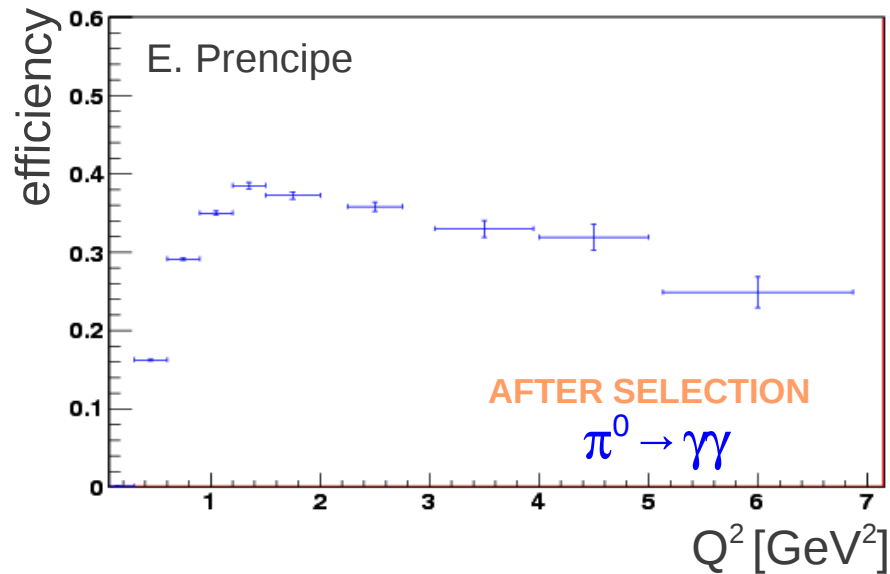
► **E c.m. = 3.77 GeV**; it reduces the background due to e^+e^- from J/ψ

EKHARA simulation	$e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- \pi^0$ (nb)	$e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- \eta$ (nb)	$e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- \eta'$ (nb)
Non tagged	$(832.2 \pm 2.9) \times 10^{-3}$	$(297.2 \pm 1.0) \times 10^{-3}$	$(212.2 \pm 1.1) \times 10^{-3}$
► Tagged e^+ $21.6 < \theta < 158.4$	$(6.672 \pm 0.059) \times 10^{-3}$	$(5.240 \pm 0.019) \times 10^{-3}$	$(6.776 \pm 0.039) \times 10^{-3}$

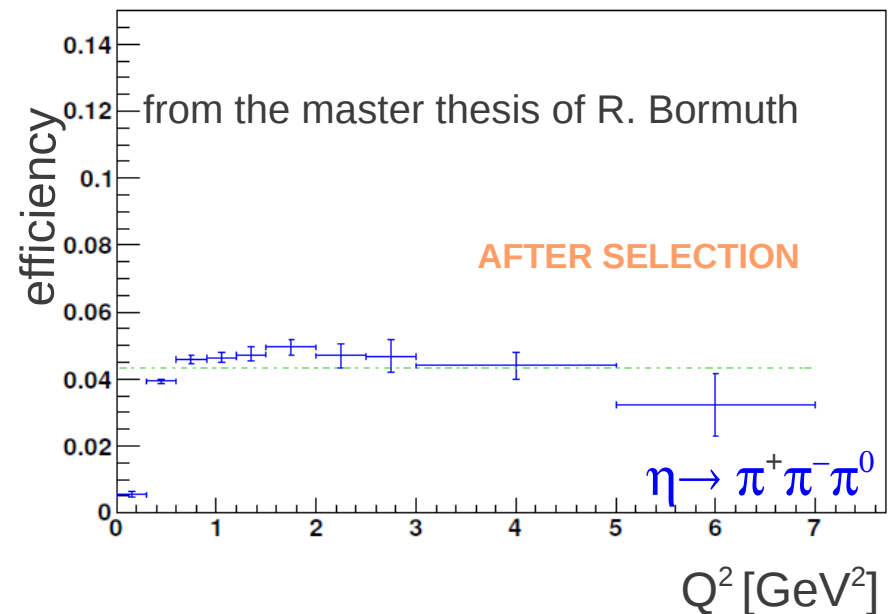
► @BESIII we can perform the analysis $\gamma\gamma^* \rightarrow P$ tagging one lepton

Step 1: reconstruction efficiency

work
in
progress



- ▶ e^+ is tagged, P is reconstructed
- ▶ signal MC simulation: EKHARA
- ▶ 1M generated events (signal MC)



Step 2: identification of background sources

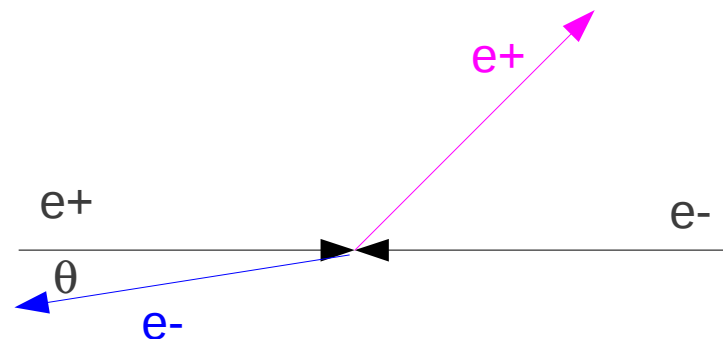
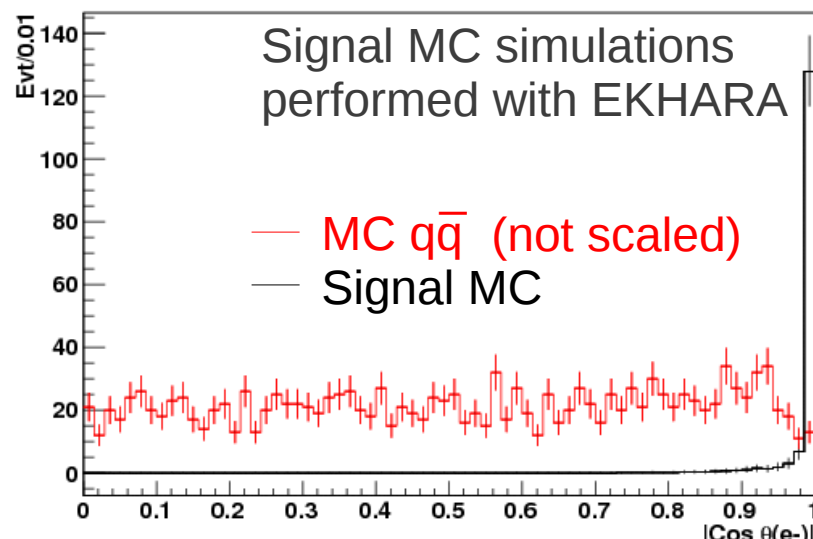
$e^+e^-\pi^0$

- ▶ Virtual Compton Scattering process (VCS) $e^+e^-\rightarrow e^+e^-\gamma$
 - main source of bkg
 - huge cross section
 - VCS photon + soft photon from beam pipe = invariant mass close π^0/η
No MC generator is available for such background: we will use data
- ▶ e^+e^- annihilation into hadrons
 - tagged lepton has a definite p_z sign (positive for e^+ , negative for e^-)
- ▶ Improperly reconstructed QED events
- ▶ Bhabha events
- ▶ Conversion of photons into e^+e^- pair in Dch volume
- ▶ Combinatorial ($q\bar{q}$)
- ▶ Peaking background: $e^+e^-\pi^0\pi^0$, $e^+e^-\pi^0\eta$

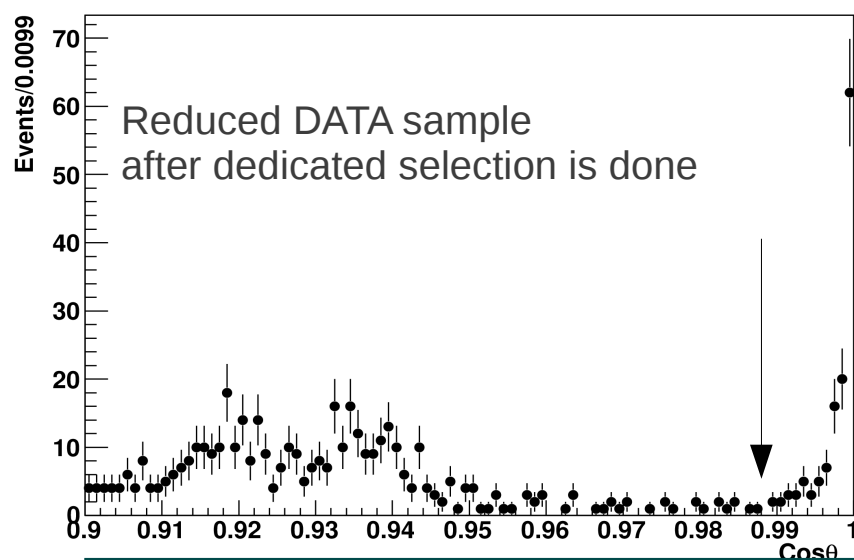
Step 3: study of selection variables (I)

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

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progress



Positron is tagged and reconstructed
Electron is identified by mean of this cut
Important to reject VCS background

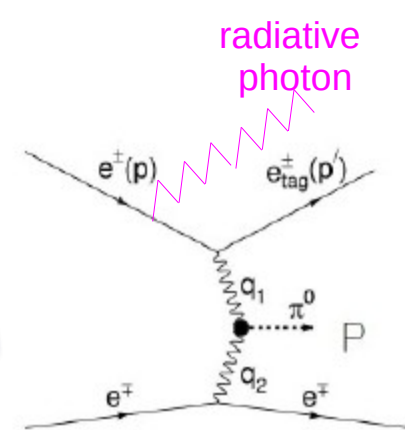


A study in bins of Q^2 was performed
to optimize this cut, bin by bin, and
maximize the reconstruction efficiency

This study is repeated for each
selection variable **SEE BACKUP SLIDES**

Step 3: study of selection variables (II)

work
in
progress



$$r = \frac{\sqrt{s} - E_{e\pi}^* - p_{e\pi}^*}{\sqrt{s}}$$

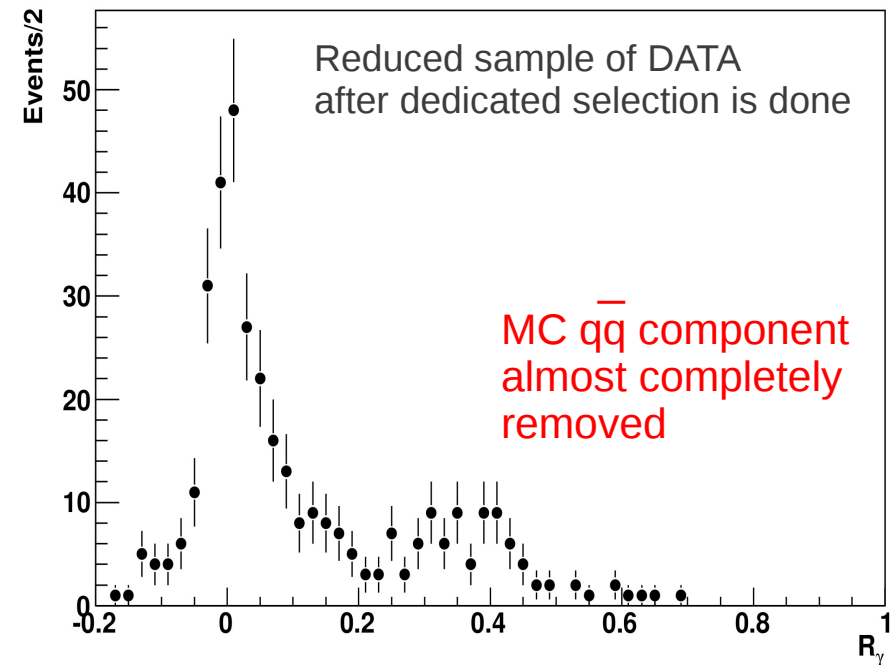
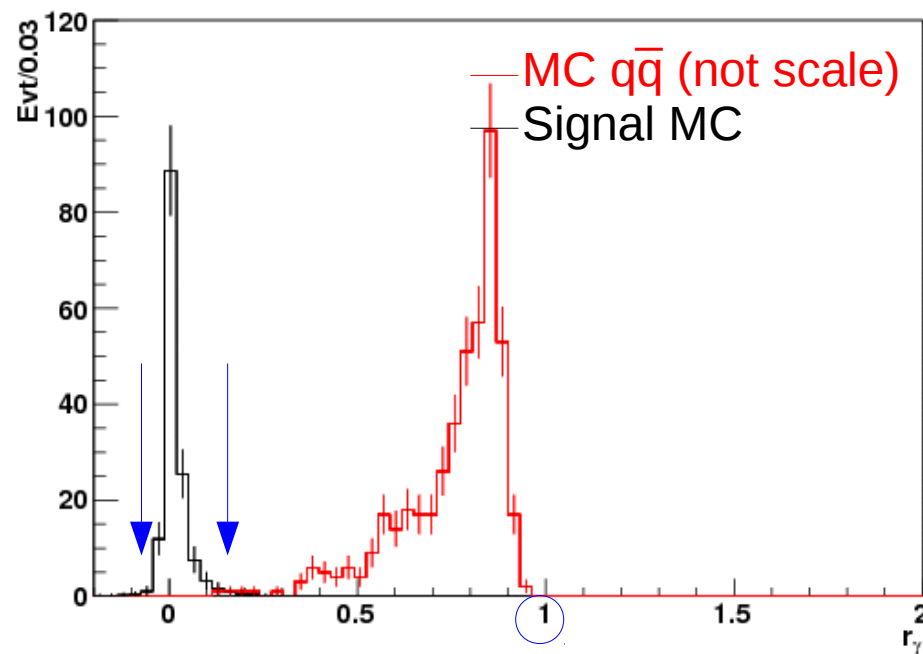
\sqrt{s} = c.m. energy

$E_{e\pi}^*$ = c.m. energy in [eP] system

$p_{e\pi}^*$ = magnitude of momentum in [eP] system

$$-0.025 < r_\gamma < 0.08$$

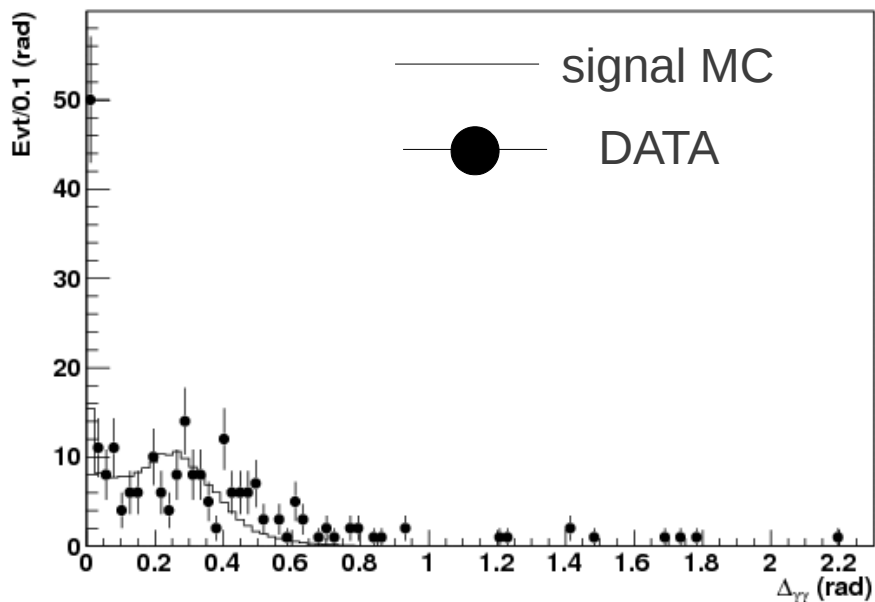
The study of this variable is important to restrict the energy of **ISR photons**



Step 3: study of selection variables (III)

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

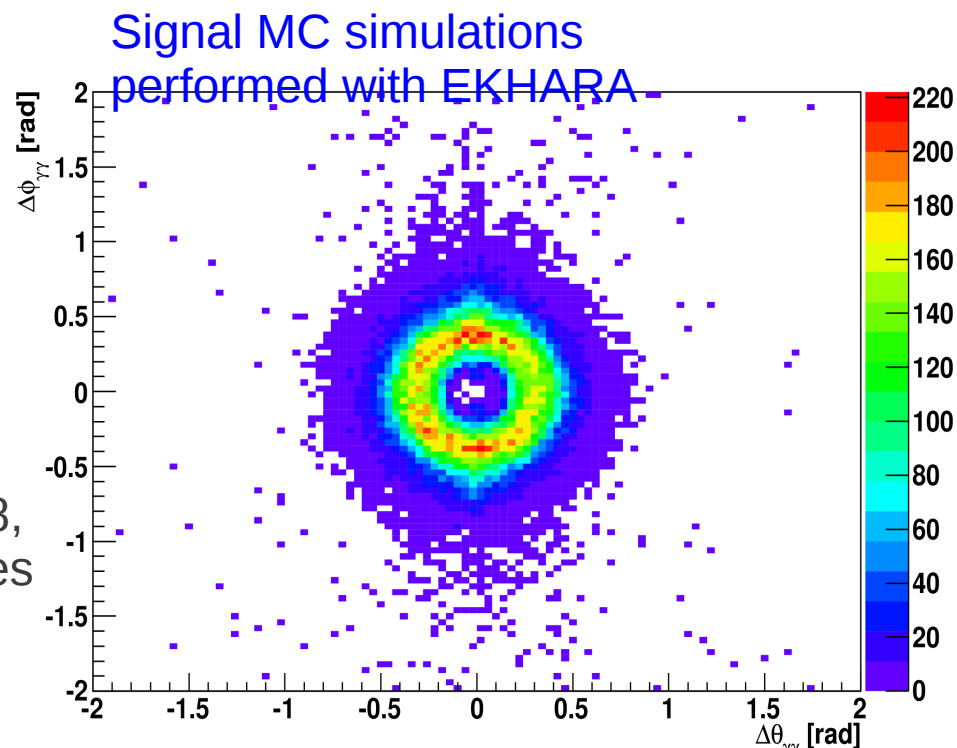
work
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progress



Difference of the polar angle of the 2 photons in the lab system

This cut is useful to reject VCS bkg where photons convert to e^+e^- within Dch volume

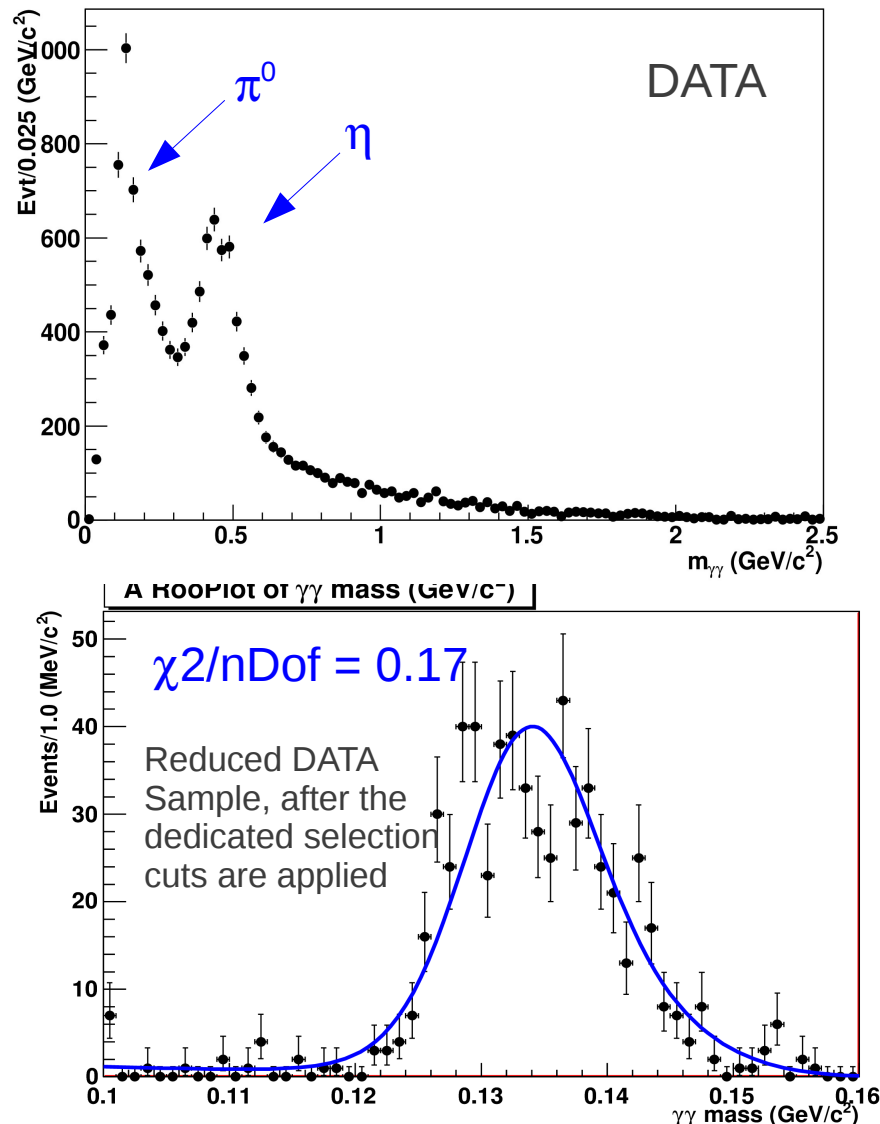
Another important angular cut is $|\cos(H)| < 0.8$, where H is the helicity angle. This cut removes mainly combinatorial background



Step 3: study of selection variables (iV)

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

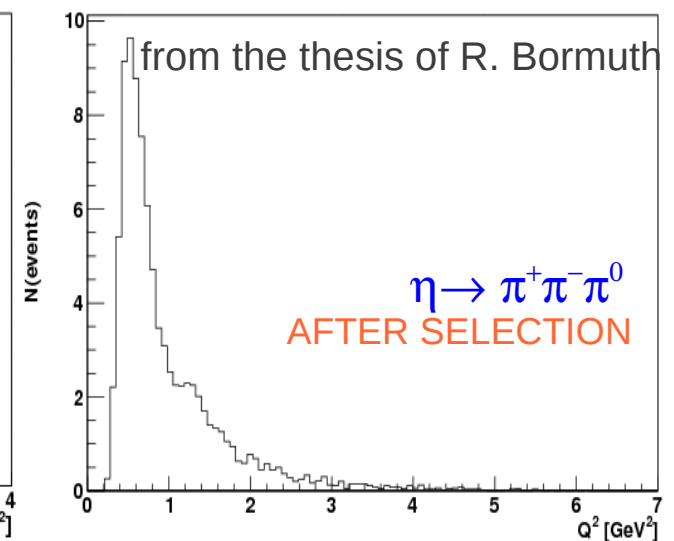
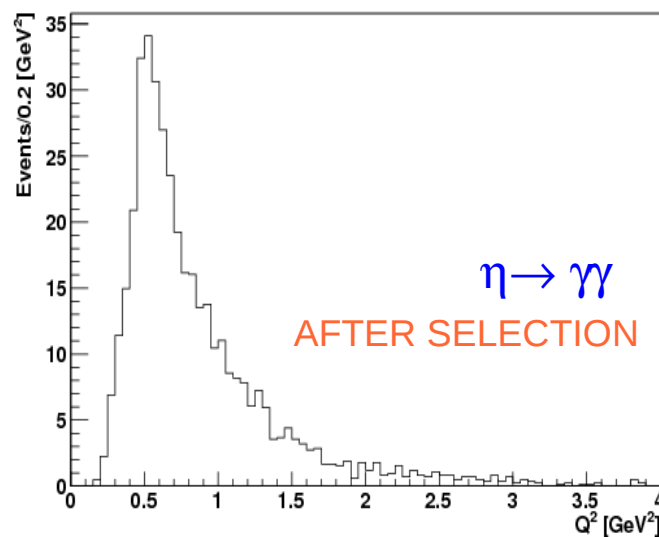
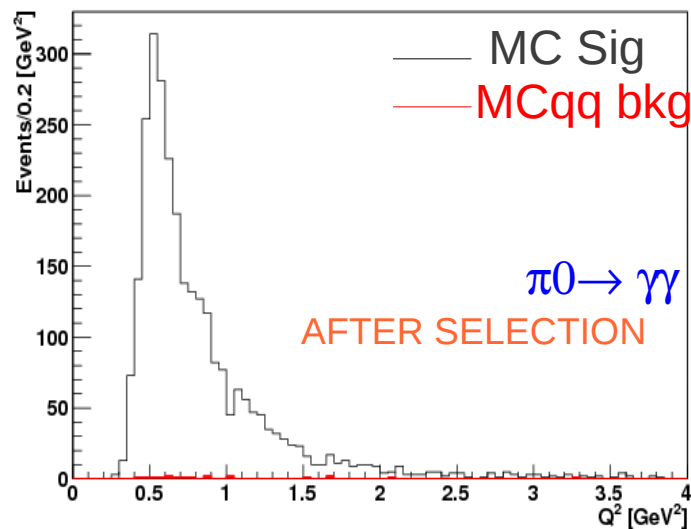
work
in
progress



Transfer momentum Q^2

work
in
progress

(MC simulation) Only e+ tagged



on 2.9 fb⁻¹

$$\text{BR}(\pi^0 \rightarrow \gamma\gamma) = (98.823 \pm 0.034)\%$$

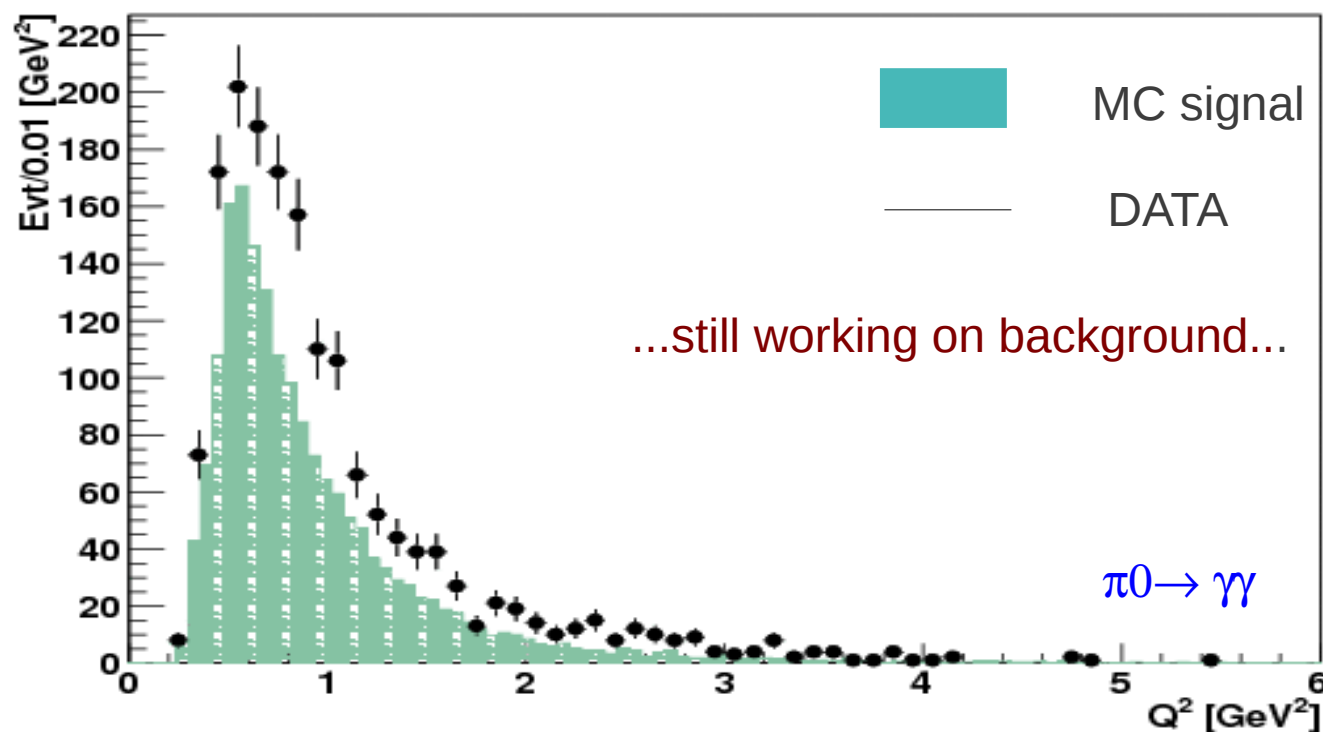
$$\text{BR}(\eta \rightarrow \gamma\gamma) = (39.31 \pm 0.20)\%$$

$$\text{BR}(\eta \rightarrow \pi^+\pi^-\pi^0) = (28.06 \pm 0.34)\%$$

Preliminary results on data

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

work
in
progress



Step 3: Cross section and $|F(Q^2)|^2$ calculation

work
in
progress

- ▶ Need to evaluate on MC simulation (generator level) the cross section as function of Q^2 when $|F_p(Q^2)|^2 = 1$

$$d\sigma/dQ^2 = dN/dQ^2 / (L * \epsilon)$$

L = equivalent luminosity
 $\epsilon(Q^2)$ = global efficiency

$$\frac{\left. \frac{d\sigma}{dQ^2} \right|_{\text{data}}}{\left. \frac{d\sigma}{dQ^2} \right|_{\text{MC, } F_p=1}} = |F_p(Q^2)|^2 \longrightarrow |F_p(Q^2)|^2 * Q^2$$

Azimuthal angular correlation (MC study)

$$e^{\pm} + e^{\mp} \rightarrow e^{\pm} + e^{\mp} + X$$

$$p_1(E, \vec{p}_1), \quad p_2(E, -\vec{p}_1) \quad \text{incoming}$$

$$E = \sqrt{s}/2 \quad s = (p_1 + p_2)^2$$

$$q_1 = p_1 - p'_1, \quad q_2 = p_2 - p'_2 \quad \text{outcoming}$$

$$d\sigma = F \left\{ v_{TT} \sigma_{TT} + v'_{TT} \cos(2\tilde{\phi}) (\sigma_{\parallel} - \sigma_{\perp}) \right. \\ \left. + h_1 h_2 v''_{TT} \frac{1}{2} (\sigma_0 - \sigma_2) + v_{LL} \sigma_{LL} + v_{TL} \sigma_{TL} \right. \\ \left. + v_{LT} \sigma_{LT} + v'_{TL} \cos(\tilde{\phi}) \tau_{TL} + h_1 h_2 v''_{TL} \cos(\tilde{\phi}) \tau_{TL}^a \right\}$$

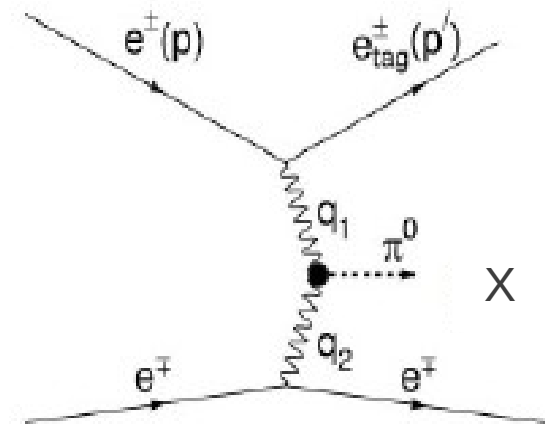
For pseudoscalar mesons, only $\sigma_{\perp} = \sigma_0 = 2\sigma_{TT}$ are non-zero

Two-photon states: $C = +1$; for 2 real photons $\gamma\gamma \rightarrow X$

$J = 1$ is forbidden (Landau-Young theorem)

$J = 0$: 0^{+-} (pseudo) and 0^{++} (scalar)

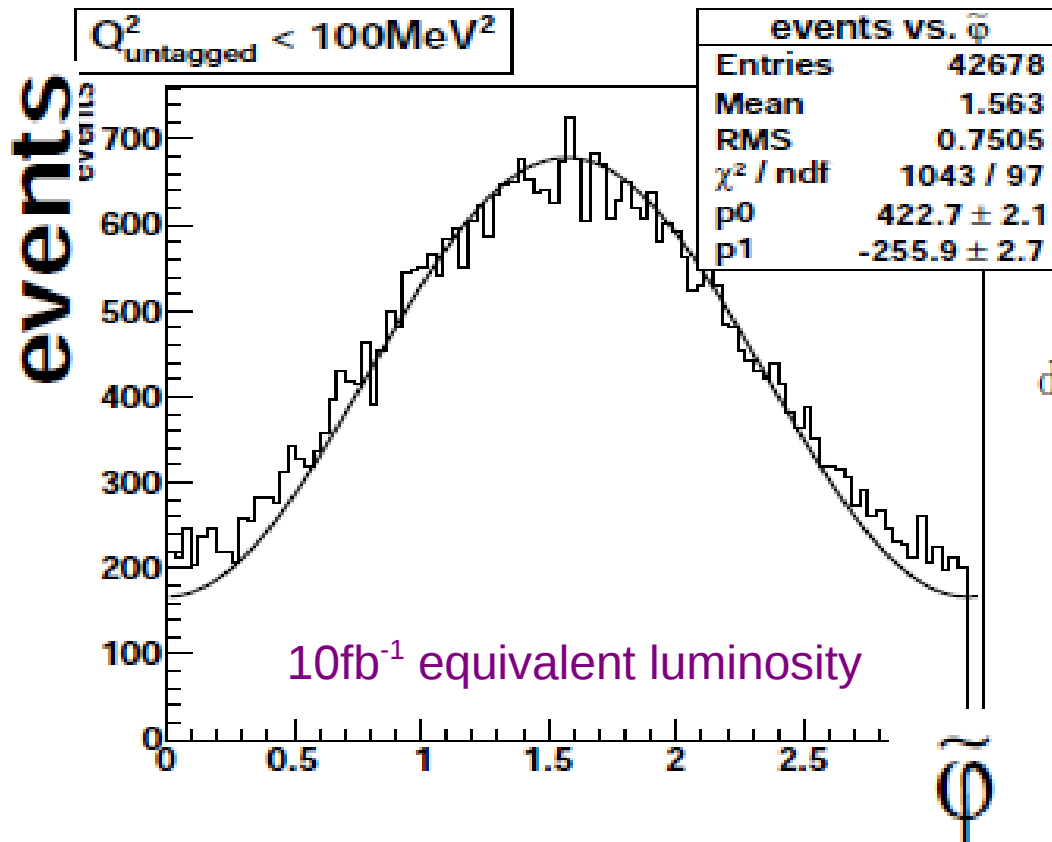
$J = 2$: 2^{++} (tensor)



Azimuthal angular correlation access to tensor: first ever extraction in e^+e^- colliders!

Azimuthal angular correlation (MC study)

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



$$d\sigma = F \{ v_{TT} \sigma_{TT} + v'_{TT} \cos(2\tilde{\phi}) (\sigma_{||} - \sigma_{\perp}) + h_1 h_2 v''_{TT} \frac{1}{2} (\sigma_0 - \sigma_2) + v_{LL} \sigma_{LL} + v_{TL} \sigma_{TL} + v_{LT} \sigma_{LT} + v'_{TL} \cos(\tilde{\phi}) \tau_{TL} + h_1 h_2 v''_{TL} \cos(\tilde{\phi}) \tau_{TL}^a \}$$

$$(\cos\phi)_{\text{c.m.}ee} \equiv - \frac{p'_{1\perp} \cdot p'_{2\perp}}{[(p'_{1\perp})^2 (p'_{2\perp})^2]^{1/2}} \quad \text{lepton frame}$$

$$\cos\tilde{\phi} \equiv - \frac{\tilde{p}_{1\perp} \cdot \tilde{p}_{2\perp}}{[(\tilde{p}_{1\perp})^2 (\tilde{p}_{2\perp})^2]^{1/2}} \quad \gamma\gamma \text{ frame}$$

First time that this measurement will be performed in e^+e^- colliders: *BESIII*

Conclusions & future plans

► The study of transition form factors is of utmost importance to understand the internal structure of the mesons

► This preliminary study shows that at BES III this analysis is feasible ($E_{\text{cm}} = 3.77 \text{ GeV}$)

► **Range observable in BES: Q^2 [0.3;10.0] GeV^2**

- improved efficiency compared to other experiments
- never tested the area Q^2 in [0.5;1.5] GeV^2 from other experiments
- possibility to cross check CLEO data at low Q^2 [1.5;4] GeV^2
- complementary measurement to BaBar/Belle experiment in [4;10] GeV^2

► Important study of $F_p(Q^2)$ at low momentum transfer to fix theory

- several channels are under study right now in our group in MAINZ

A. Denig

R. Bormuth, M. Dipfenbach, A. Hahn, B. Kloss, E. Prencipe, C. Redmer

Thank you!

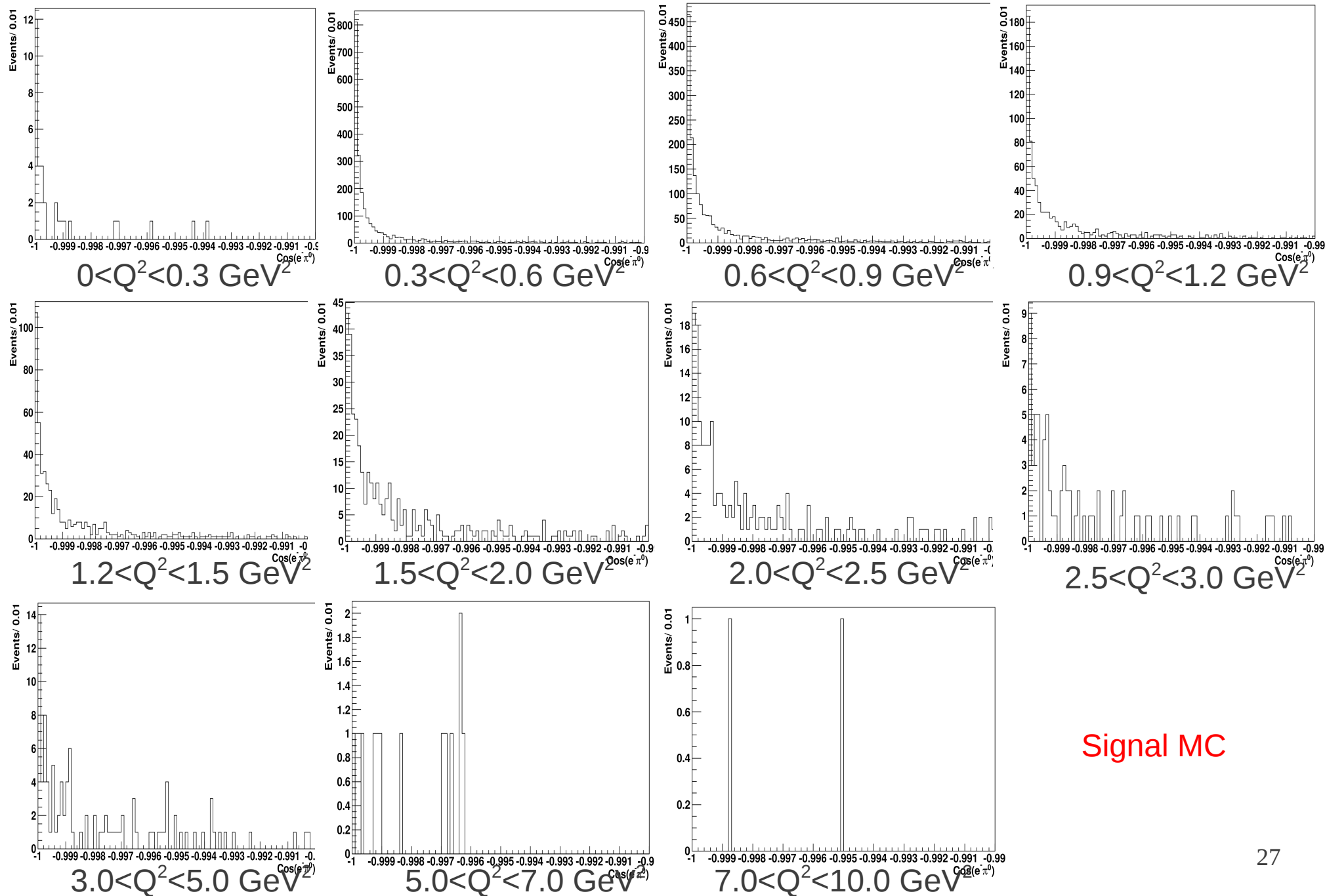


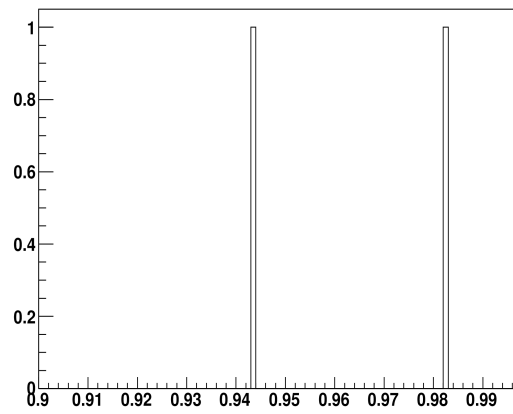
Backup slides

Big open questions

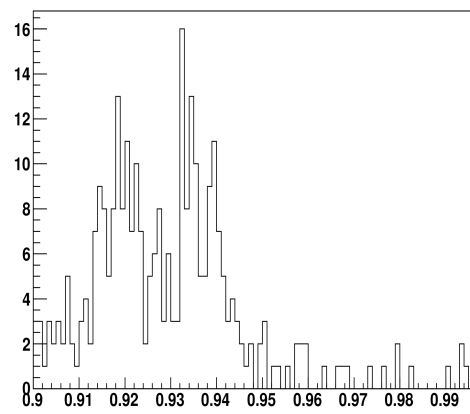
- ▶ Meson distribution amplitudes $\gamma\gamma^* \rightarrow \text{meson}$ transition Form Factor at **large transfer momenta Q^2** are a paradigm for hard processes: the puzzle with the new *BaBar* data in the analysis $\gamma\gamma^* \rightarrow \pi^0$ remains to be understood.
- ▶ Meson distribution amplitudes $\gamma\gamma^* \rightarrow \text{meson}$ transition Form Factor at **low-medium transfer momenta Q^2** are important to study hadronic light-by-light contribution to the measurement of $(g-2)_\mu$: due to the forthcoming experiment at *Fermilab* it will become the largest uncertainty to evaluate
*The dedicate experiment at Fermilab wants to reduce this uncertainty by a factor 4.
It requires improvement from theory side.*
- ▶ Meson transition form factors represent a textbook observable to study transition region from perturbative to non-perturbative QCD

Cos(e-):study in bins of Q^2

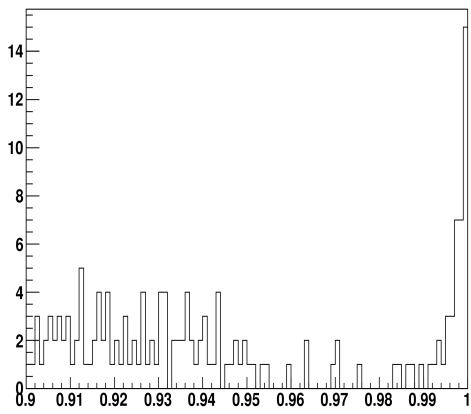




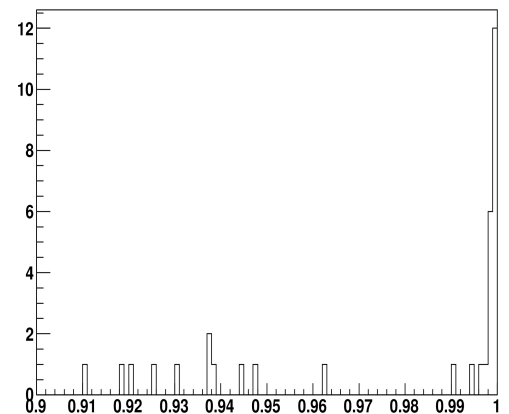
$0.0 < Q^2 < 0.3 \text{ GeV}^2$



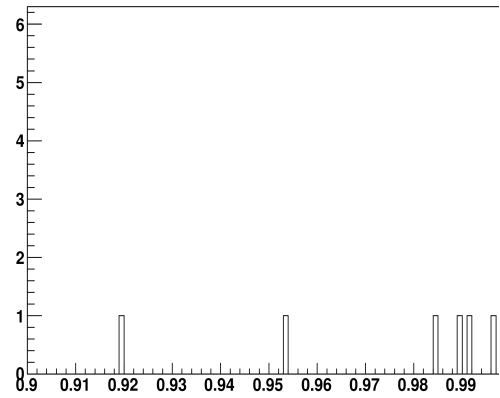
$0.3 < Q^2 < 0.6 \text{ GeV}^2$



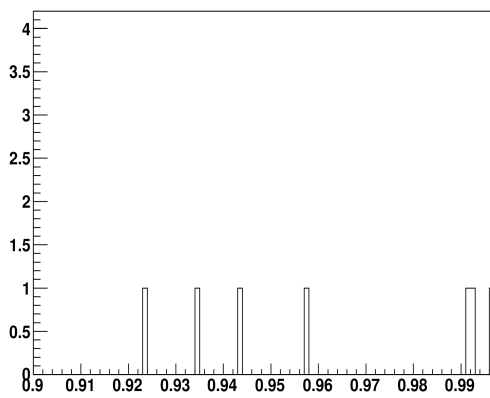
$0.6 < Q^2 < 0.9 \text{ GeV}^2$



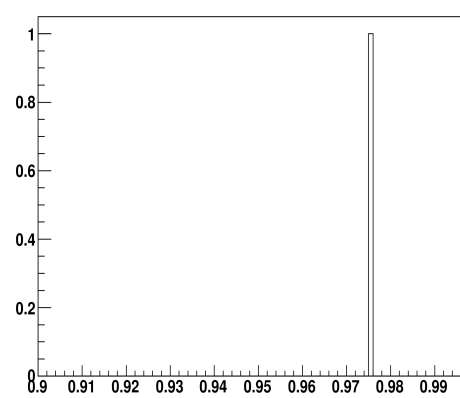
$0.9 < Q^2 < 1.2 \text{ GeV}^2$



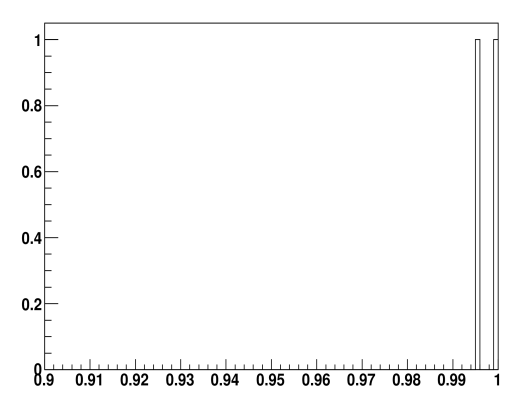
$1.2 < Q^2 < 1.5 \text{ GeV}^2$



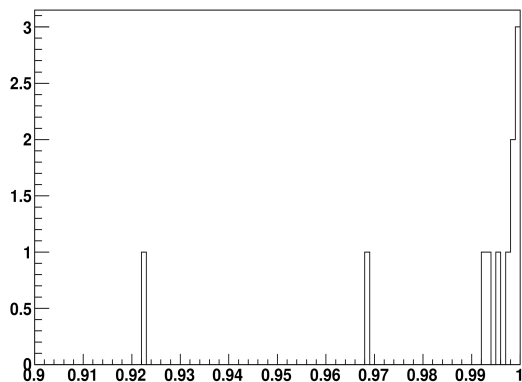
$1.5 < Q^2 < 2.0 \text{ GeV}^2$



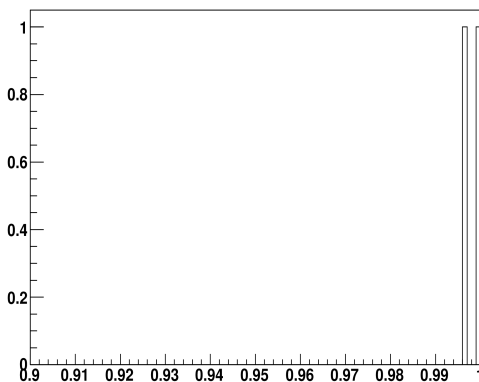
$2.0 < Q^2 < 2.5 \text{ GeV}^2$



$2.5 < Q^2 < 3.0 \text{ GeV}^2$



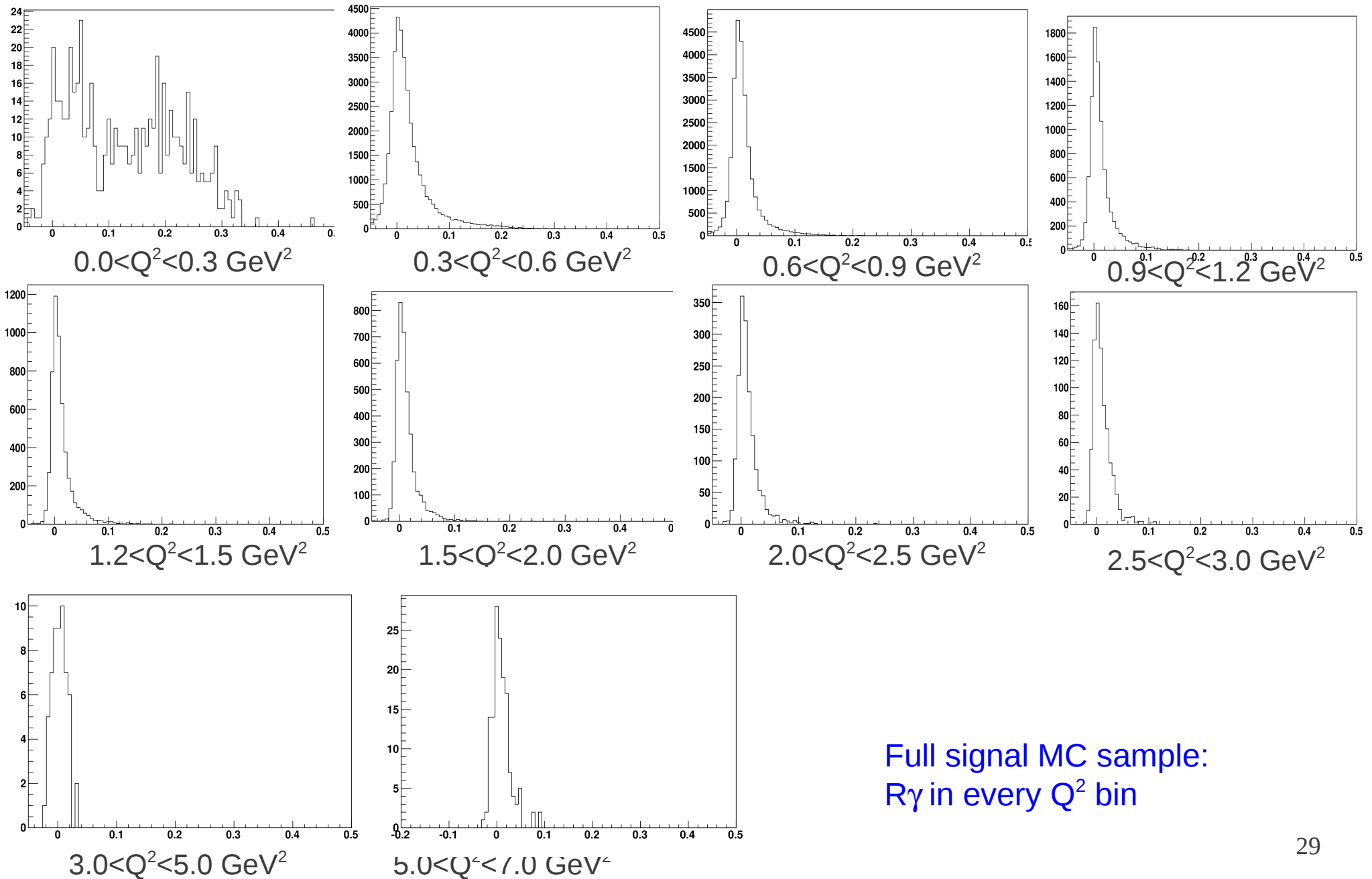
$3.0 < Q^2 < 5.0 \text{ GeV}^2$



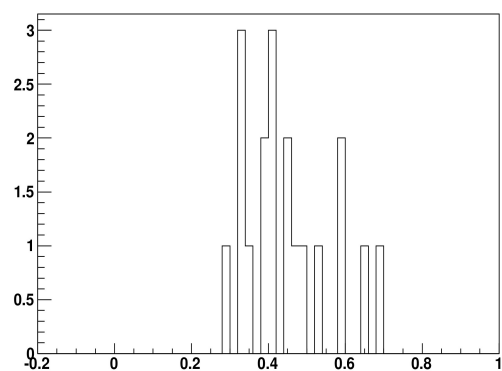
$5.0 < Q^2 < 7.0 \text{ GeV}^2$

Reduced DATA sample:
|Cos(e-)| in every Q^2 bin
(zoom in [0.9;1])

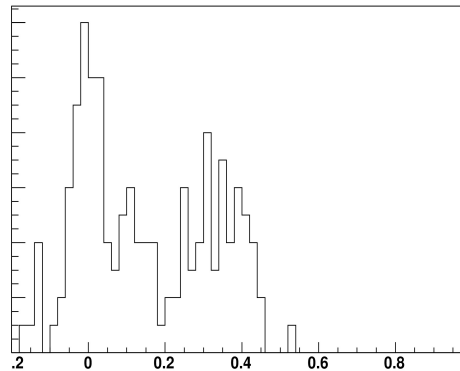
R_γ : study in bins of Q^2



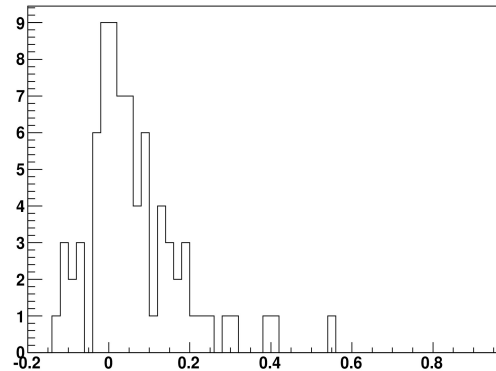
Full signal MC sample:
 R_γ in every Q^2 bin



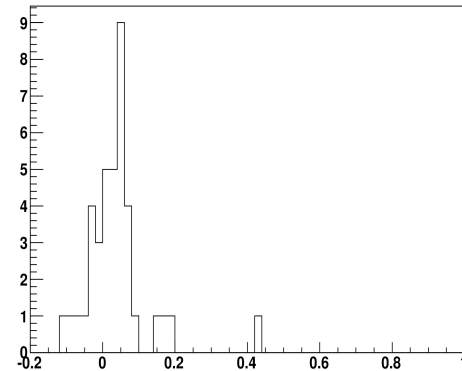
$0.0 < Q^2 < 0.3 \text{ GeV}^2$



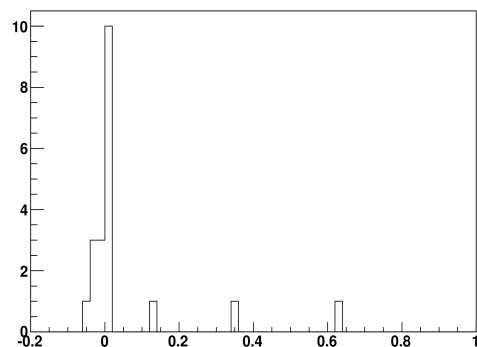
$0.3 < Q^2 < 0.6 \text{ GeV}^2$



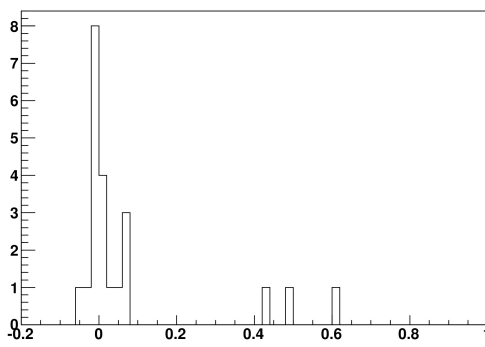
$0.6 < Q^2 < 0.9 \text{ GeV}^2$



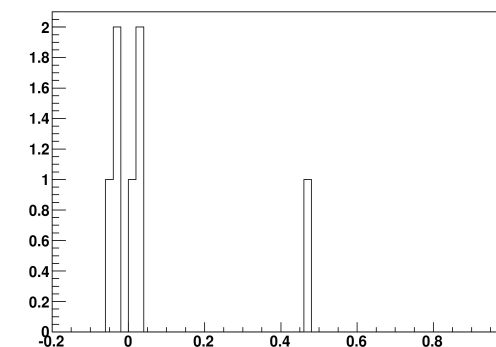
$0.9 < Q^2 < 1.2 \text{ GeV}^2$



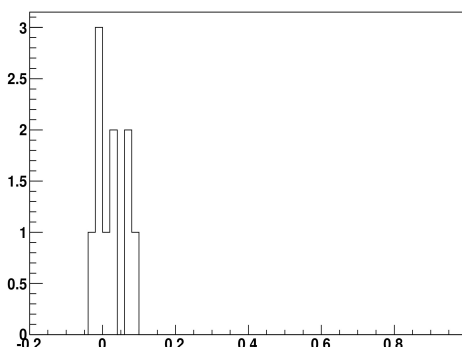
$1.2 < Q^2 < 1.5 \text{ GeV}^2$



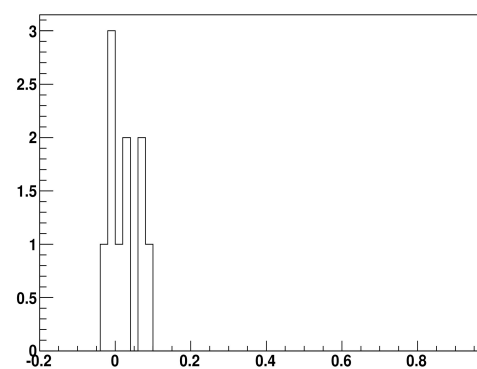
$1.5 < Q^2 < 2.0 \text{ GeV}^2$



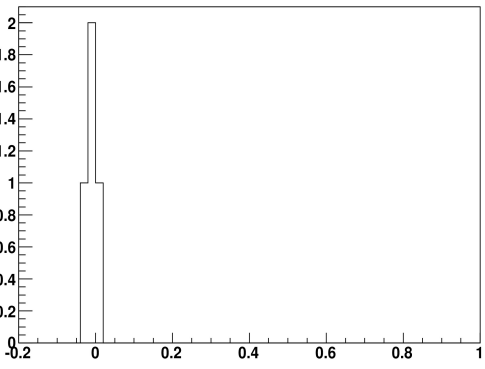
$2.0 < Q^2 < 2.5 \text{ GeV}^2$



$2.5 < Q^2 < 3.0 \text{ GeV}^2$



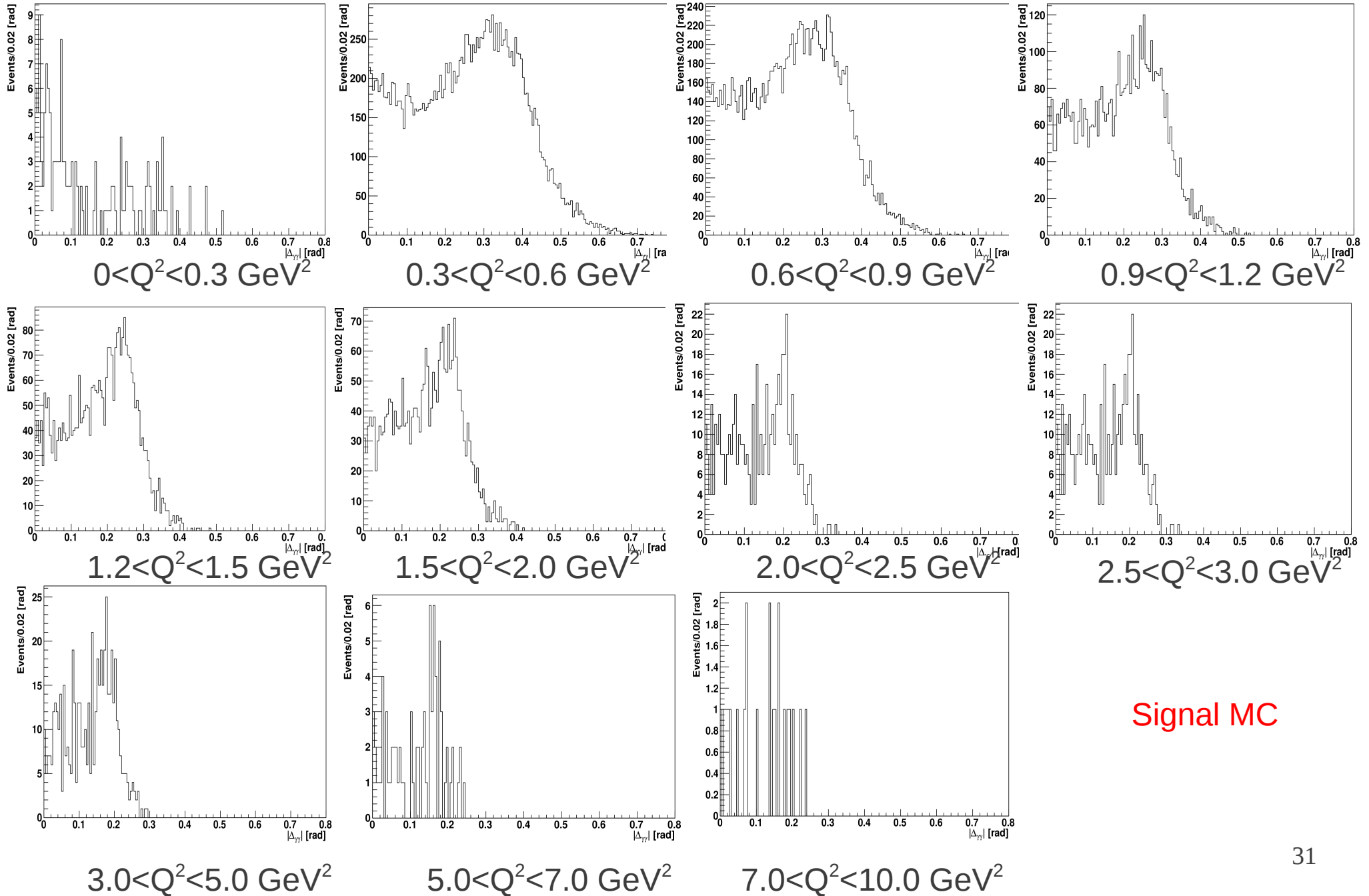
$3.0 < Q^2 < 5.0 \text{ GeV}^2$



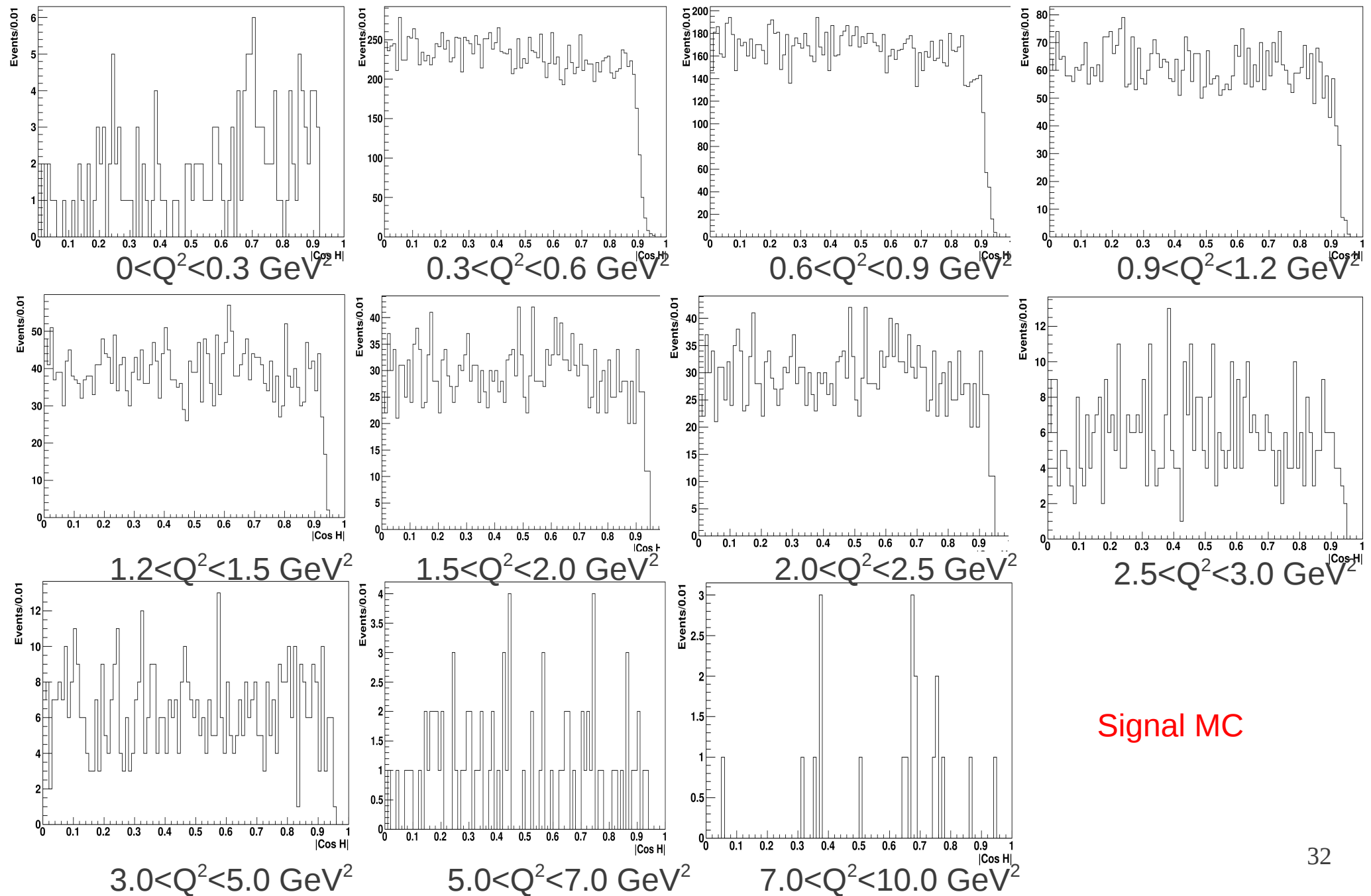
$5.0 < Q^2 < 7.0 \text{ GeV}^2$

Reduced DATA sample:
R_y in every Q^2 bin

$\Delta\gamma\gamma$: Study in bins of Q^2



CosHelicity: study in bins of Q^2



Resolution

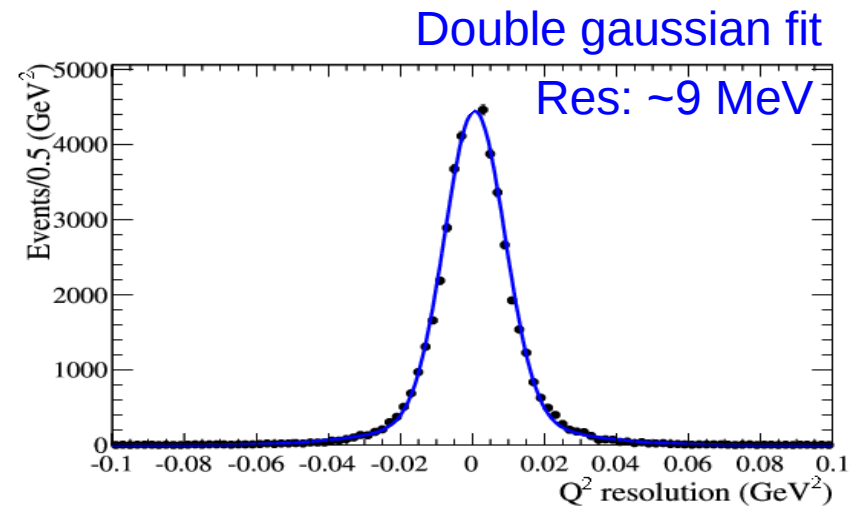
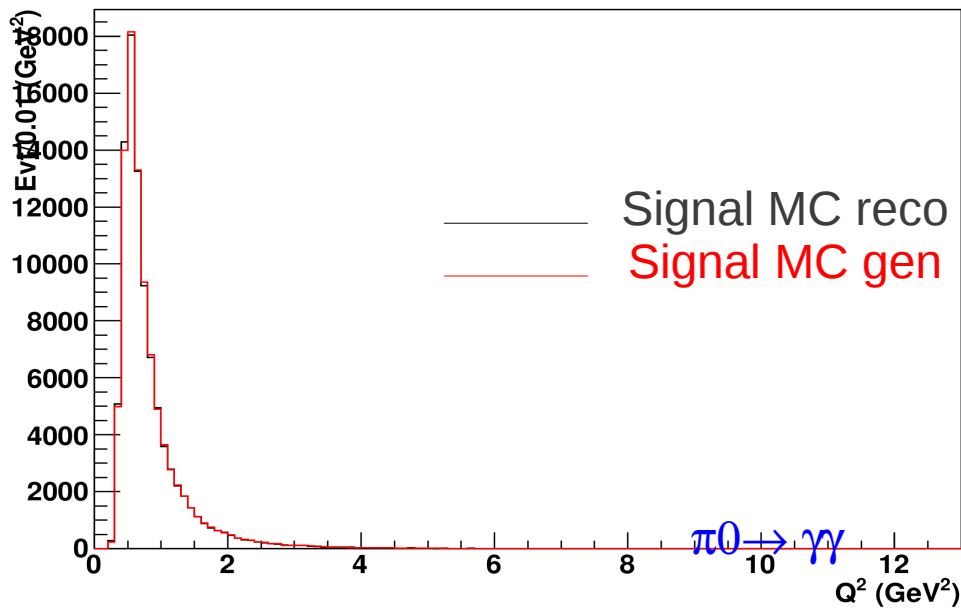
► Simulation of 2.9 fb^{-1} were performed

π^0 : 19 434 generated events (2.9 fb^{-1})

- Many events are not reconstruct efficiently because of:
- photon acceptance
 - detector conditions included

Before dedicated selection cuts are applied: 154904 events (500k events)

After the selection is done: 95701 (500k events) → 17.1% efficient



Thank you!

