Workshop on Meson Transition Form Factors

Recent results and perspectives on pseudo-scalar mesons and form factors at BES III

Elisabetta Prencipe
Johannes Gutenberg
University of Mainz

on behalf of the BES III collaboration

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Outline

- Introduction
- Motivation
- BES III detector
- Analysis $\eta' \to \eta\pi^+\pi^-$
- Analysis $\eta' \to \pi^+\pi^- l^+ l^-$ *BES PRELIMINARY*
- Analysis $\gamma\gamma \to \pi^0/\eta/\eta'$ *FEASIBILITY STUDIES*
- Conclusion

Introduction

- Since its discovery (PRL 12, 527 (1964)), η' decays inspired interest in both, theory and experiments

- η–η' mixing probes strange quark content of light pseudo-scalar mesons and gluon dynamics of *QCD*

- Hadronic decays of η', in particular the ones to 3 pions, have garnered attention because of their large experimental limit and because they can probe isospin symmetry breaking

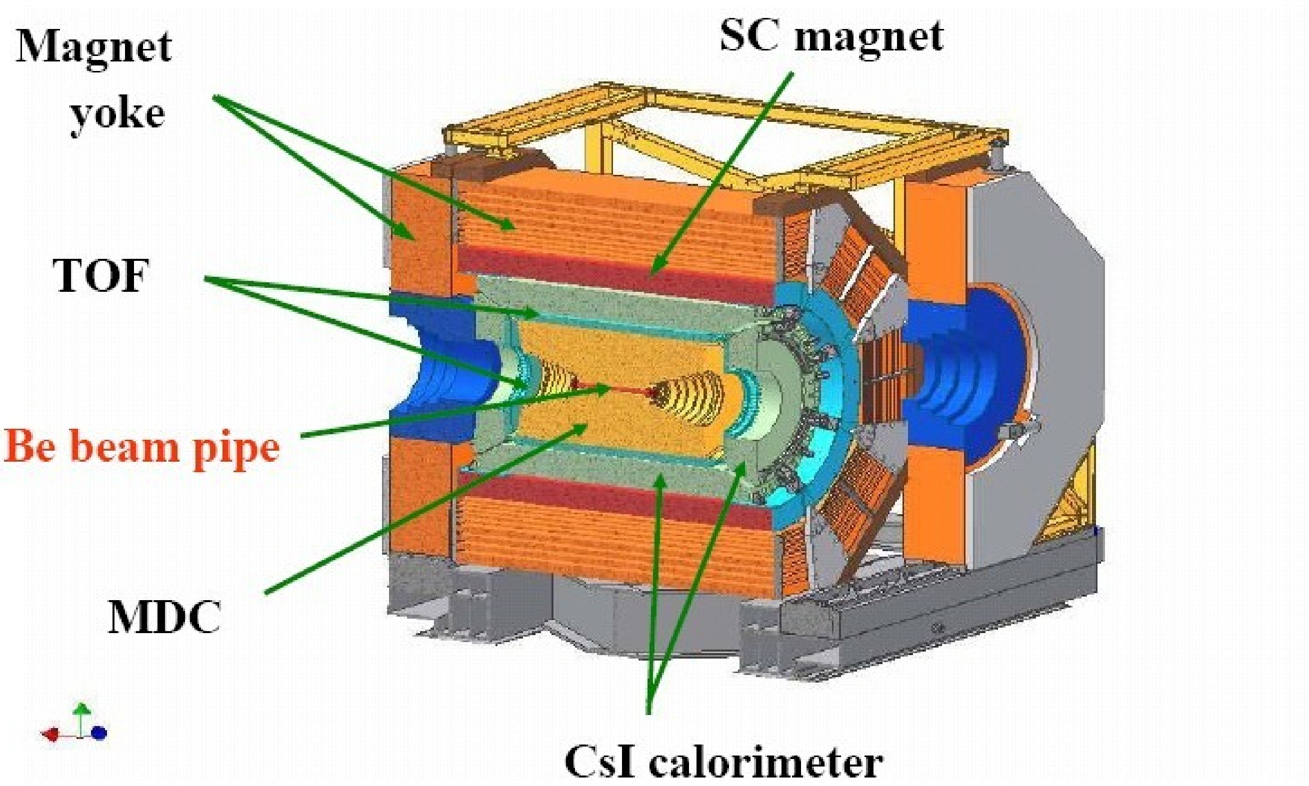
$$r_0 \equiv \mathcal{B}(\eta' \to 3\pi^0)/\mathcal{B}(\eta' \to \pi^0\pi^0\eta) = (75 \pm 13) \times 10^{-4}$$ PLB 667, 1 (2008)

$$r_\pm \equiv \mathcal{B}(\eta' \to \pi^+\pi^-\pi^0)/\mathcal{B}(\eta' \to \pi^+\pi^-\eta)$$

- Under the 2 assumptions that the decay $\pi^+\pi^-\pi^0$ appears only through $\eta'\to\eta\pi^+\pi^-$ followed by $\eta-\pi^0$ mixing and such decays populate uniformly the available *phsp*, $r_\pm$ is found to be proportional to the mass difference *u-d* quark and $r_\pm/r_0 \simeq 0.37$

- A suggestion to use *U(3) chiral effective field* theory to examine η' decays is given (PLB 643, 41 (2006)): $\eta'\to\eta\pi\pi$ Dalitz slope parameters can give large contribution to $\eta'\to\pi^+\pi^-\pi^0$; prediction: $r_\pm/r_0 \simeq 5$

The BES III experiment



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

B = 1T
resolution(MDC): $\sigma_P/P = 0.58\%$
resolution(MDC): $\sigma_E/E = 6.0\%$
resolution(TOF): $\sigma_\tau = 100ps$
resolution(EMC): $\sigma/E = 2.5\%$
Muon detected: p>400 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 mesurements.

Measurement of the matrix element of the decay

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

PRD 83, 012003 (2011)

Analysis $\eta'\to\eta\pi^+\pi^-$: motivation

PRD 83, 012003 (2011)

- The hadronic decay of η' is extremely valuable in studies devoted to the effect of the gluon component in chiral perturbation theory and the possible nonet of light scalars

- Dalitz plot parameters of some hadronic η' decay were already studied

  VES P.L.B 651, 22(2007) $\eta'\to\eta\pi^+\pi^-$
  GAMS-4π P.N. 72, 231 (2009) $\eta'\to\eta\pi^0\pi^0$

- In the isospin limit the values of the Dalitz plot parameters should be the same; however, the experimental results show some discrepancy

Analysis $\eta'\to\eta\pi^+\pi^-$: strategy

PRD 83, 012003 (2011)

- Energy c.m. = J/ψ mass production   225 millions J/ψ

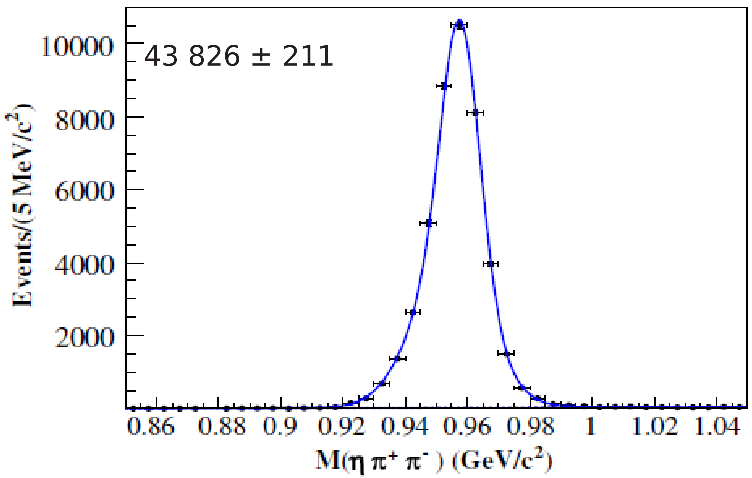
- Reconstruction:

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

$\eta \to \gamma\gamma$ (J/ψ radiative decays)

- Selection:

the candidate events with topology $\gamma\gamma\gamma\pi^+\pi^-$ with minimum χ^2(4C fit)



- Background:

$J/\psi \to \gamma\eta' \to \gamma\gamma\rho^0 \to \gamma\gamma\pi^+\pi^-$

$J/\psi \to \gamma\eta' \to \gamma\gamma\omega \to \gamma\gamma\pi^+\pi^-\pi^0$

No additional peaking background come from f1(1285),η(1405),η(1475), f1(1510) $\to\gamma\eta\pi^+\pi^-$

$$\mathcal{B}(J/\psi \to \gamma\eta') = \frac{N^{\mathrm{obs}}}{N_{J/\psi} \times \varepsilon \times \mathcal{B}(\eta' \to \eta\pi^+\pi^-) \times \mathcal{B}(\eta \to \gamma\gamma)} = (4.84 \pm 0.03(\mathrm{stat}) \pm 0.24(\mathrm{sys})) \times 10^{-3}$$

Analysis $\eta' \to \eta\pi^+\pi^-$: Dalitz plot parameters

PRD 83, 012003 (2011)

- The dynamic of this decay can be described by 2 degrees of freedom, as all particles of this decay have spin = 0
- The Dalitz plot distribution is described by 2 variables and in different parametrization:

$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-})$$

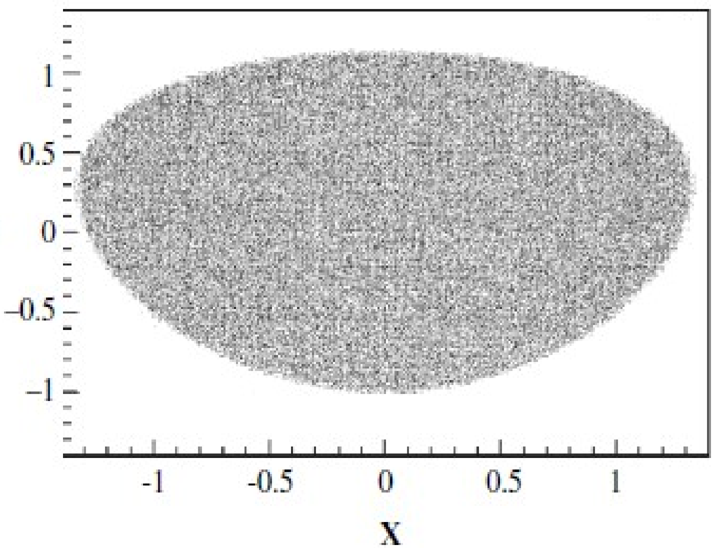
$$Y = \frac{m_\eta + 2m_\pi}{m_\pi}\frac{T_\eta}{Q} - 1$$

$T_{\pi,\eta}$ are the kinetic energies of mesons in the η' rest frame

$$Q = T_\eta + T_{\pi^+} + T_{\pi^-} = m_{\eta'} - m_\eta - 2m_\pi$$

1) $M^2 = A(1 + aY + bY^2 + cX + dX^2)$

is the decay amplitude (general decomposition) expanded in term of Dalitz parameters to be evaluated



- Odd term in X are forbidden in this decay
- The parameter c = 0, $\eta' \to \eta\pi^0\pi^0$; not necessarily 0, $\eta' \to \eta\pi^+\pi^-$

Analysis $\eta'\to\eta\pi^+\pi^-$: Dalitz plot parameters

PRD 83, 012003 (2011)

- A second parametrization is the linear parametrization:

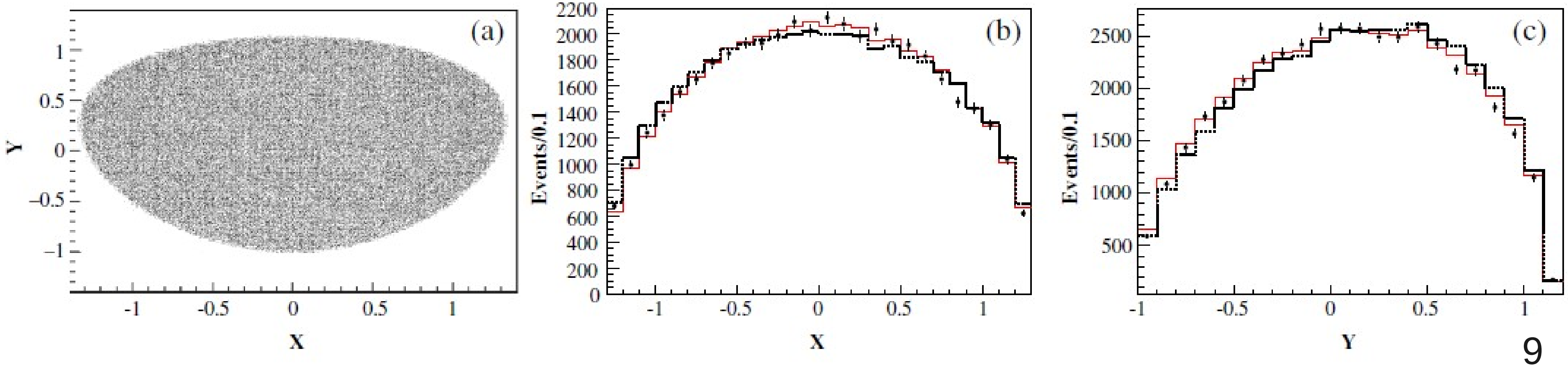
2) $$M^2 = A(|1 + \alpha Y|^2 + cX + dX^2)$$

linear function of the kinetic energy of the η.
α is a complex parameter

- A non zero value of α may represent the contribution of a gluon component in the wave function of the η' in the dynamics of the decay

- For comparison with the parametrization 1):

$$a = 2\,\mathrm{Re}(\alpha)$$
$$b = \mathrm{Re}^2(\alpha) + \mathrm{Im}^2(\alpha)$$



Analysis $\eta'\to\eta\pi^+\pi^-$: results

PRD 83, 012003 (2011)

1) general decomposition parametrization:

$$M_i = \sum_{j=1}^{N_{ev}} (1 + aY_j + bY_j^2 + cX_j + dX_j^2)$$

$$\begin{array}{l} a = -0.047 \pm 0.011 \\ b = -0.069 \pm 0.019 \\ c = +0.019 \pm 0.011 \\ d = -0.073 \pm 0.012 \end{array} \begin{pmatrix} 1.000 & -0.442 & -0.010 & -0.239 \\ & 1.000 & 0.025 & 0.282 \\ & & 1.000 & 0.030 \\ & & & 1.000 \end{pmatrix}.$$

The parameter c is consistent with 0 within 1.8σ

2) linear parametrization

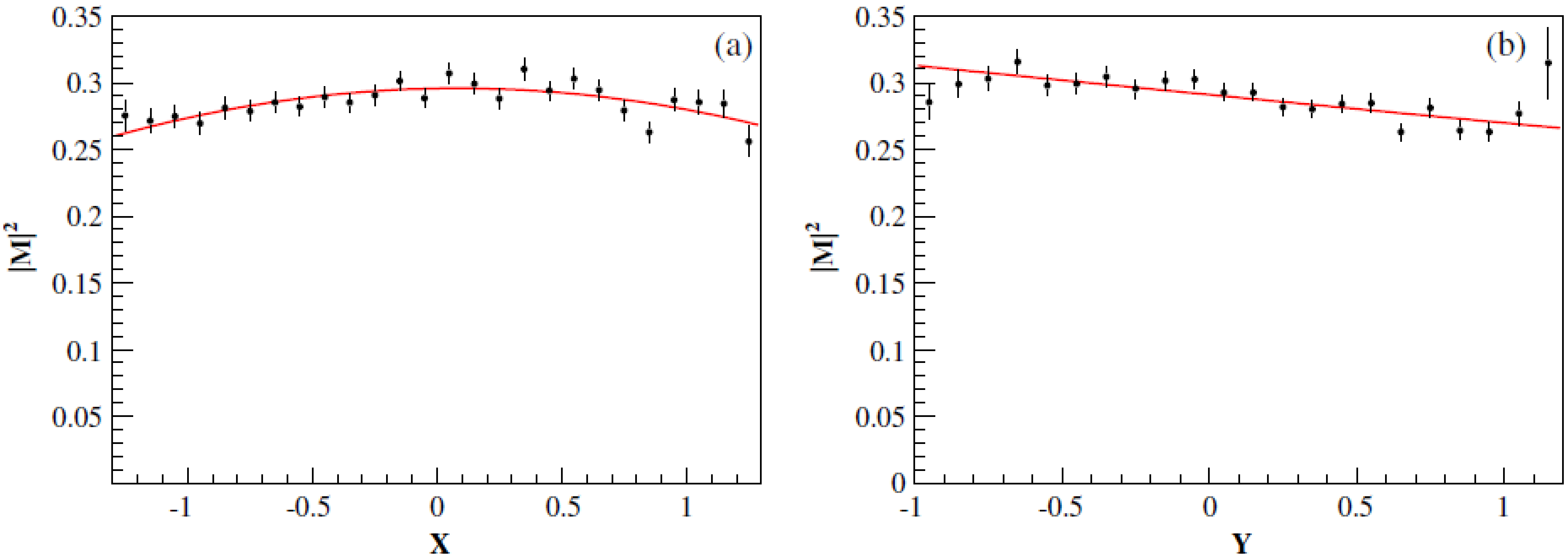
$$M_i = \sum_{j=1}^{N_{ev}} (|1 + \alpha Y_j|^2 + cX_j + dX_j^2)$$

$$\begin{array}{r} \mathrm{Re}(\alpha) = -0.033 \pm 0.005 \\ \mathrm{Im}(\alpha) = 0.000 \pm 0.049 \\ c = +0.018 \pm 0.009 \\ d = -0.059 \pm 0.012 \end{array} \begin{pmatrix} 1.000 & -0.001 & 0.001 & -0.138 \\ & 1.000 & 0.000 & 0.000 \\ & & 1.000 & 0.024 \\ & & & 1.000 \end{pmatrix}$$

The parameter c is consistent with 0 within 2.1σ

Analysis $\eta'\to\eta\pi^+\pi^-$: comparison

PRD 83, 012003 (2011)



Parameter	VES	Theory	This work	Parameter	CLEO	VES	This work
a	-0.127 ± 0.018	-0.116 ± 0.011	-0.047 ± 0.012	$\mathrm{Re}(\alpha)$	-0.021 ± 0.025	-0.072 ± 0.014	-0.033 ± 0.006
b	-0.106 ± 0.032	-0.042 ± 0.034	-0.069 ± 0.021	$\mathrm{Im}(\alpha)$	0.000 (fixed)	0.000 ± 0.100	0.000 ± 0.050
c	$+0.015 \pm 0.018$	$\cdots$	$+0.019 \pm 0.012$	c	0.000 (fixed)	$+0.020 \pm 0.019$	$+0.018 \pm 0.010$
d	-0.082 ± 0.019	$+0.010 \pm 0.019$	-0.073 ± 0.013	d	0.000 (fixed)	-0.066 ± 0.034	-0.059 ± 0.013

The negative value of *b* indicates that the 2 parametrizations are not equivalent

Analysis $\eta' \rightarrow \eta \pi^+ \pi^-$: remarks

PRD 83, 012003 (2011)

- The parameters *a* and *b* are consistent with the ones from GAMS-4π
- X^2 Y^2 value are different from 0
- The 2 parametrizations do not look equivalent because of the estimated value of *b*
- The value *b* shows to be different from the expected chiral Lagrangian model (zero); however, it can be accommodated in a U(3) chiral unitarized model by including final state interactions N.P. A716, 186 (2003)
- The value *c*, which test C-parity violation in the strong interaction, is consistent with 0
- The BR is found consistent with previous BESII measurement and improves the statistical errors PRD 73, 052008 (2006)

Measurement of BF

$$\eta' \to \pi^+ \pi^- l^+ l^-$$

PRELIMINARY RESULTS

Analysis $\eta' \to \pi^+\pi^- l^+ l^-$: motivation

PRELIMINARY

- The BR for $\eta' \to \pi^+\pi^- X$ (X=e,μ) are expected to scale with those for $\eta' \to \gamma X$
- The most copious decay should be $\eta' \to \pi^+\pi^- e^+ e^-$ (experimental limit: 0.6%)
  expected: 0.3%
- Different theoretical approaches provide explanation for ρ^0-dominance for the $\pi^+\pi^-$ invariant mass, e^+e^- mass distribution peaking just above $2m_e$, with long tail extended to ~300 MeV
- The BR limit on $\eta' \to \pi^+\pi^- e^+ e^-$ is expected to be $\sim 2 \times 10^{-5}$
- The analysis from CLEO has been shown the following results:

$$\mathrm{BR}(\eta' \to \pi^+\pi^- e^+ e^-) = (2.5^{+1.2}_{-0.9} \pm 0.5) \times 10^{-3}$$

$$BR(\eta' \to \pi^+\pi^- \mu^+ \mu^-) < 2.4 \times 10^{-4}$$

CLEO PRL 102, 061801 (2009)

Analysis $\eta'\to\pi^+\pi^-l^+l^-$: strategy

PRELIMINARY

- Energy c.m. = J/ψ mass production 225 millions J/ψ

- Reconstruction:

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

The topology of the event studied is $J/\psi \to \gamma\eta'$, $\eta' \to \pi^+\pi^- l^+ l^-$

- Selection:

χ^2 cut (4C fit)

- Background:

The events $J/\psi \to \gamma\eta'$, $\eta' \to \gamma\pi^+\pi^-$ are under exam; other possible sources of background are:

$J/\psi \to \gamma\eta', \eta' \to \gamma\rho^0, \rho^0 \to \pi^+\pi^-$ ← This is the main background source

$J/\psi \to \gamma\eta', \eta' \to \gamma\rho^0, \rho^0 \to \pi^+\pi^-\gamma_{FSR}$

$J/\psi \to \pi^+\pi^-\pi^0\gamma_{FSR}$

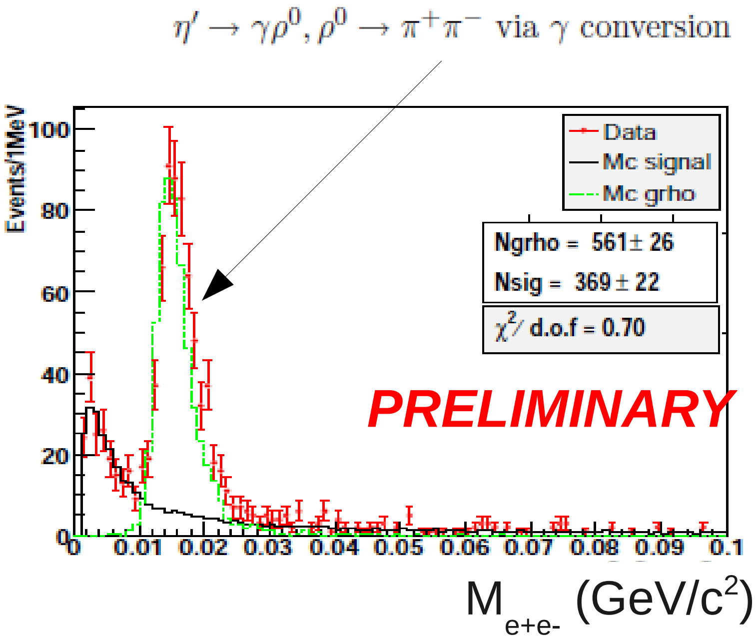
$J/\psi \to \gamma\eta', \eta' \to \gamma\omega, \omega \to \pi^+\pi^-$

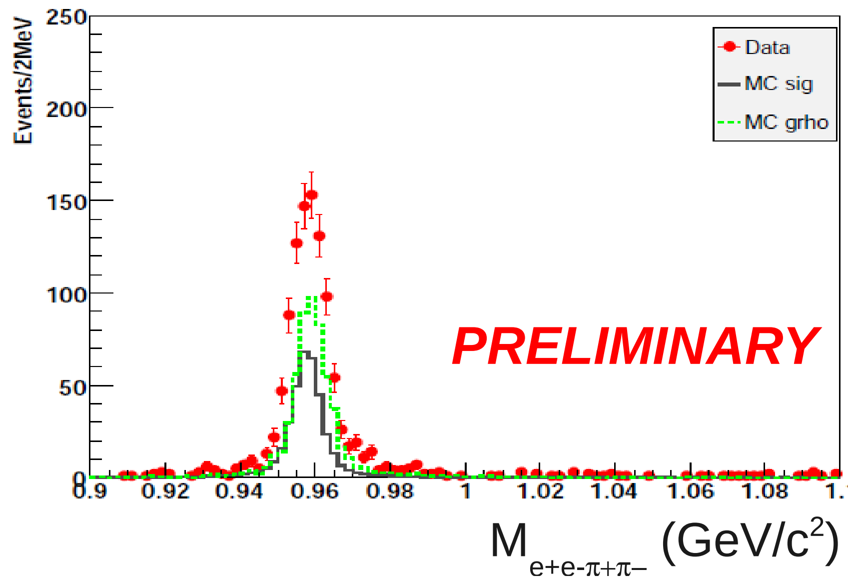
$J/\psi \to h_1(1170)\pi^0, h_1(1170) \to \rho^0\pi^0, \rho^0 \to \pi^+\pi^-$

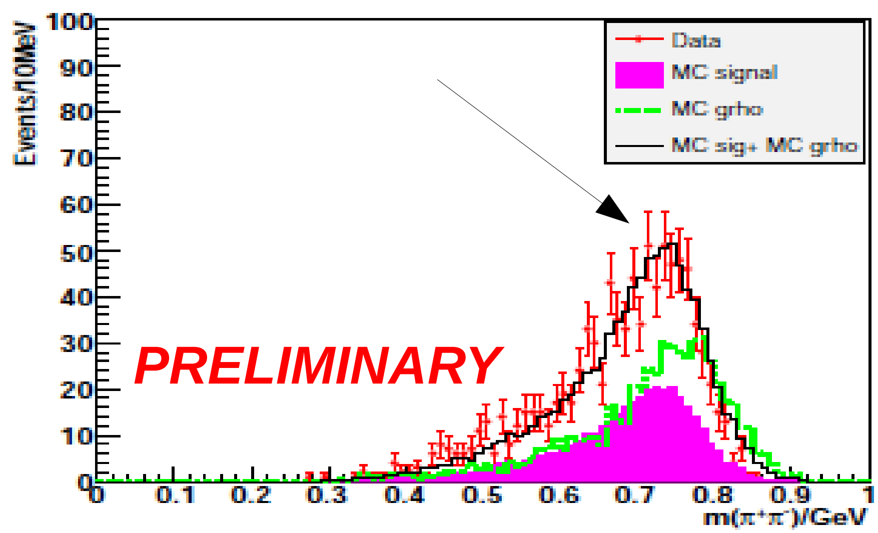
$J/\psi \to \pi^+\pi^-\pi^0$

Analysis $\eta'\to\pi^+\pi^-e^+e^-$: invariant mass

PRELIMINARY



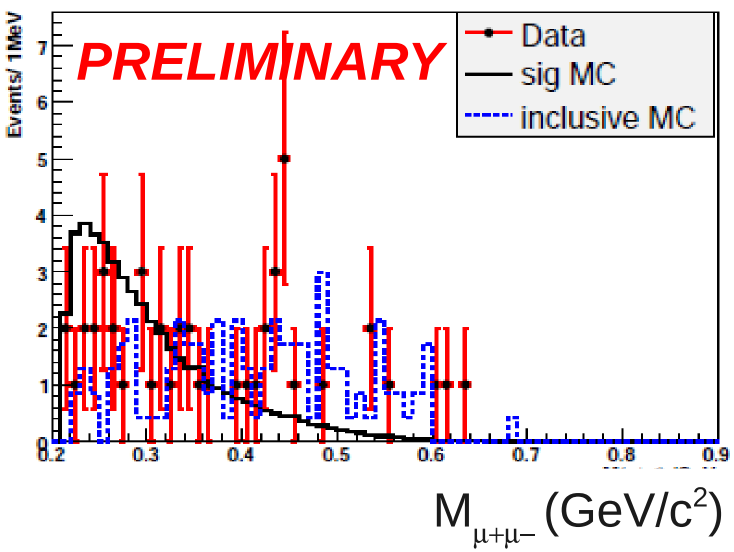


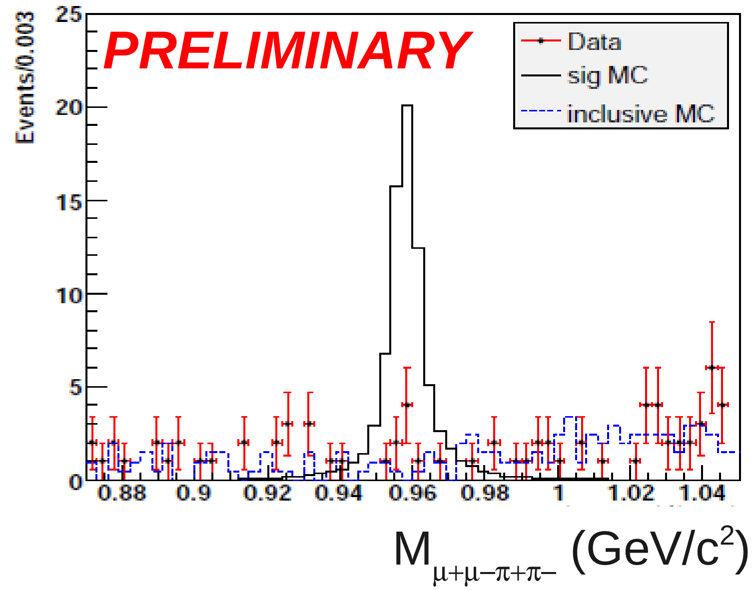


- ✔ As from prediction, a long tail up to ~300 MeV is observed
- ✔ As from prediction, the di-lepton (e^+e^-) mass peaks about ~$2m_e$
- ✔ As from prediction, a huge signal is observed in $e^+e^-\pi^+\pi^-$
- ✔ As from prediction, the ρ^0-dominance is observed in $\pi^+\pi^-$ mass

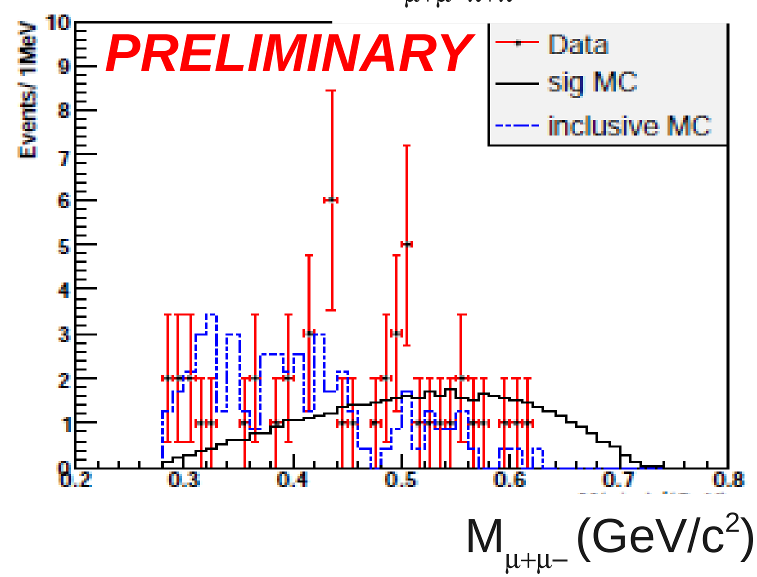
Analysis $\eta' \to \pi^+\pi^-\mu^+\mu^-$: invariant mass

PRELIMINARY





✔ No signal observed on data



Analysis $\eta' \to \pi^+\pi^- l^+ l^-$: results

PRELIMINARY

- A specific MC generator was used to simulate events $\eta' \to \pi^+\pi^- l^+ l^-$, where the form factor (FF) assumption is done (DIY) with Q^2 dependence

- To estimate the uncertainty introduced from the form factor model, a constant value was introduced, to eliminate the dependence of FF from Q^2

- Other sources of uncertainty in this analysis are conventional

$$BR(\eta' \to \pi^+\pi^-\mu^+\mu^-) < \frac{N^{U.L}_{\eta' \to \pi\pi\mu\mu} \times \epsilon_{\eta' \to \gamma\rho^0} \times BR(\eta' \to \gamma\rho^0)}{N_{\eta' \to \gamma\rho^0} \times \epsilon_{\eta' \to \pi\pi\mu\mu}} < 2.62 \times 10^{-5}$$

Good agreement with predictions

$$BR(\eta' \to \pi^+\pi^- e^+ e^-) = \frac{N_{\eta' \to \pi\pi ee}}{N_{\eta' \to \gamma\rho^0}} \times \frac{\epsilon_{\eta' \to \gamma\rho^0}}{\epsilon_{\eta' \to \pi\pi e^+ e^-}} BR(\eta' \to \gamma\rho^0) =$$

$$= (2.13 \pm 0.13(stat.) \pm 0.19(syst.)) \times 10^{-3}$$

Transition meson form factor of

$$\gamma\gamma \rightarrow e^{+}e^{-}\pi^{0}/\eta/\eta'$$

FEASIBILITY study: analysis ongoing

Only feasibility studies are presented here today

Analysis $\gamma\gamma \rightarrow e^+e^-\pi^0/\eta/\eta'$: motivation

PRELIMINARY

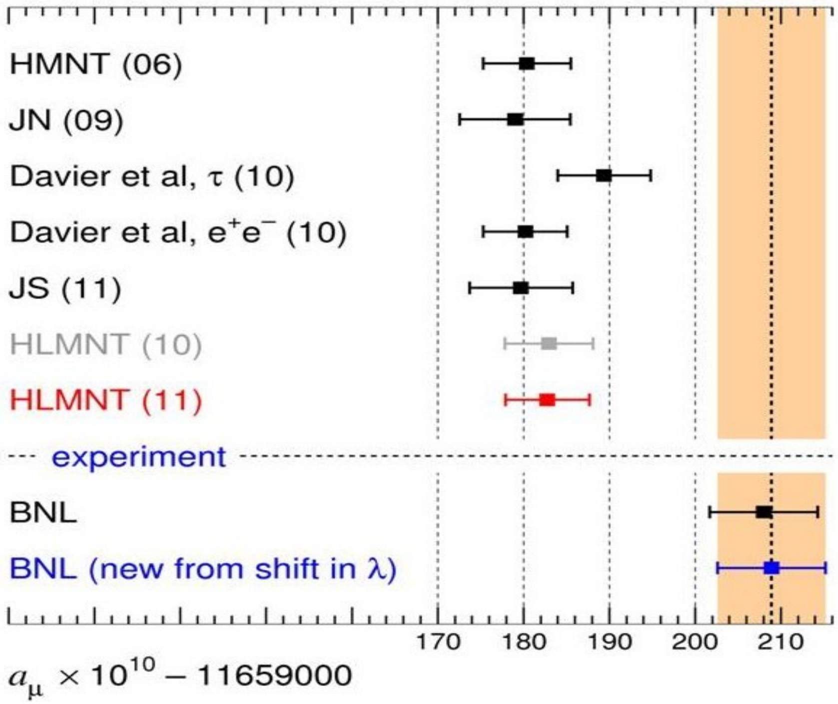
- Anomalous magnetic momentum of the muon $a_\mu = (g-2)_\mu/2$ is a very important observable providing test at the precision frontier of the Standard Model

- Presently **3.6σ deviation observed** between direct measurement of $(g-2)_\mu$ and Standard Model prediction

$$a_\mu(\mathrm{SM}) = (116\ 591\ 594.7\ \pm 70)\times 10^{-11}$$

$$a_\mu(\mathrm{SM}) = a_\mu(\mathrm{QED}) + a_\mu(\mathrm{hadronic}) + a_\mu(\mathrm{weak})$$

$$a_\mu(\mathrm{New\ Physics}) = a_\mu(\mathrm{Measured}) - a_\mu(\mathrm{SM})$$



- Contribution from strong interactions not calculable within perturbative QCD

Contribution to the measurement of a_μ

PRELIMINARY

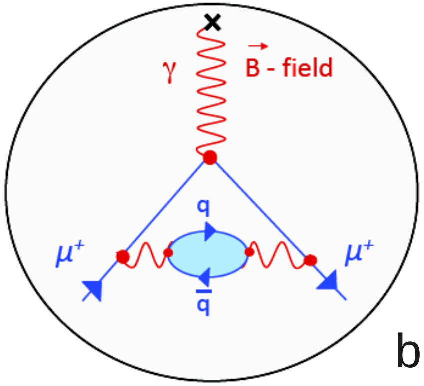
QED contribution $= (11\,658\,471.810 \pm 0.016) \times 10^{-10}$

Weak contribution $= (15.4 \pm 0.2) \times 10^{-10}$

Hadronic vacuum polarization $= (695.5 \pm 4.1) \times 10^{-10}$

Hadronic Light-by-light scattering $= (10.5 \pm 2.6) \times 10^{-10}$

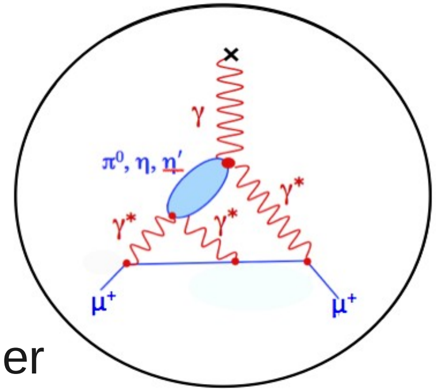
Hadronic vacuum polarization



Standard Model precision limited by strong contribution

Hadronic LBL contribution still smaller compared to *Hadronic vacuum polarization*, but its uncertainty is calculated of the same order

Hadronic light-by-light scattering



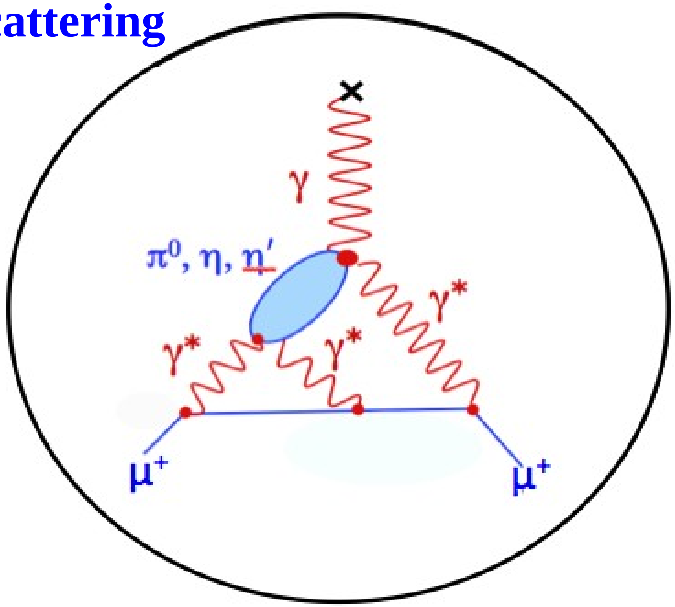
- Measurement of **meson transition form factor** of utmost importance to validate hadronic models

Hadronic LBL correction to $(g\text{-}2)_\mu$

PRELIMINARY

- To solve beyond QED-effects more precision in theory and experiments needs
- Need to study the transition form factor of π^0,η,η' to give new input to the theory
- Due to the upcoming experiment at Fermilab, the hadronic *LBL* correction will become the main uncertainty to evaluate for the precision measurement of $(g\text{-}2)_\mu$

Hadronic Light-by-Light Scattering



$a_\mu(had),LbL = (10.5 \pm 2.6)\cdot 10^{-10}$ Prades et al.

$(11.6 \pm 4.0)\cdot 10^{-10}$ Nyffeler

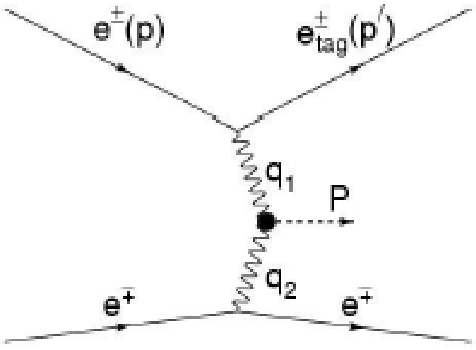
$(21.6 \pm 9.1)\cdot 10^{-10}$ Fischer et al.

How the form factor can be measured

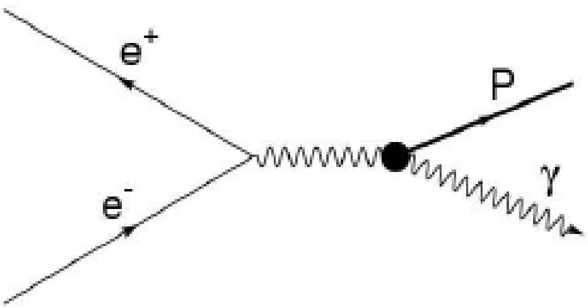
PRELIMINARY

- Two-photon production of the meson
  - $-S+M^2 < q_1^2 < 0,\ q_2^2 \approx 0, \quad Q^2 \equiv -q_1^2$
  - $d\sigma/dQ^2$ falls as $1/Q^6$
  - At $\sqrt{s}$=10.6 GeV for $e^+e^- \to e^+e^- \pi^0$

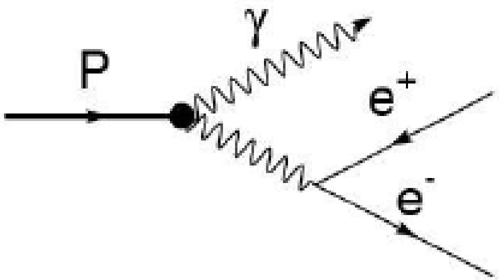
    $d\sigma/dQ^2(10\ \mathrm{GeV}^2) \approx 10\ \mathrm{fb/GeV}^2$



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

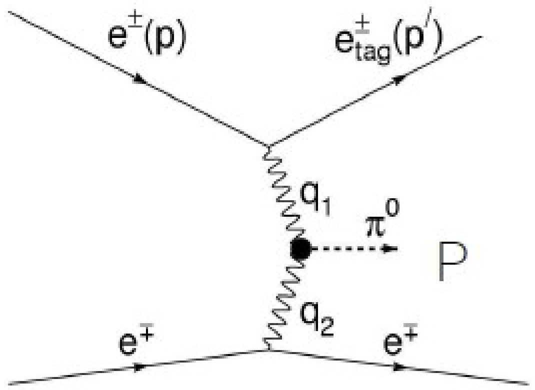


- Dalitz decay $P \to \gamma e^+e^-$
  - $0 < Q^2 < M^2$
  - $M^2 d\Gamma/dQ^2 \approx (2\alpha/\pi)\Gamma(P\to\gamma\gamma)$ at $Q^2/M^2 \approx 1/4$

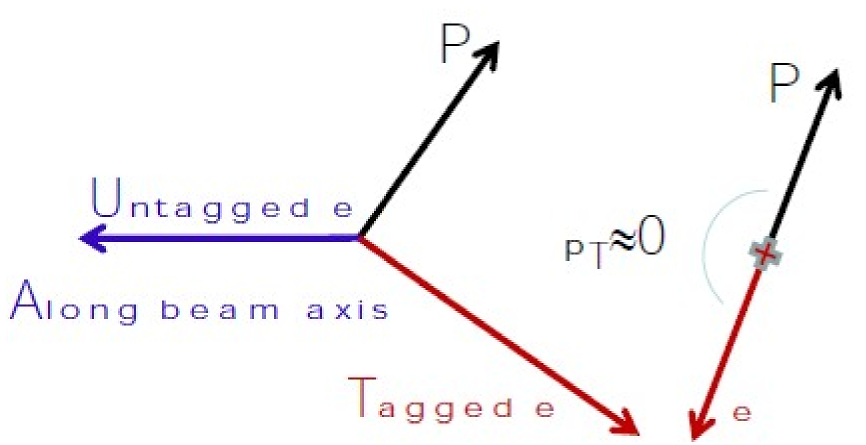


Analysis $\gamma\gamma \rightarrow e^+e^-\pi^0/\eta/\eta'$: strategy

PRELIMINARY



- Electrons are scattered predominantly at small angles
- Single-tag mode technique:
  - one electron is detected
  - $Q^2 = -q_1^2 = 2EE'(1-\cos\theta)$
  - $q^2_2 \approx 0$



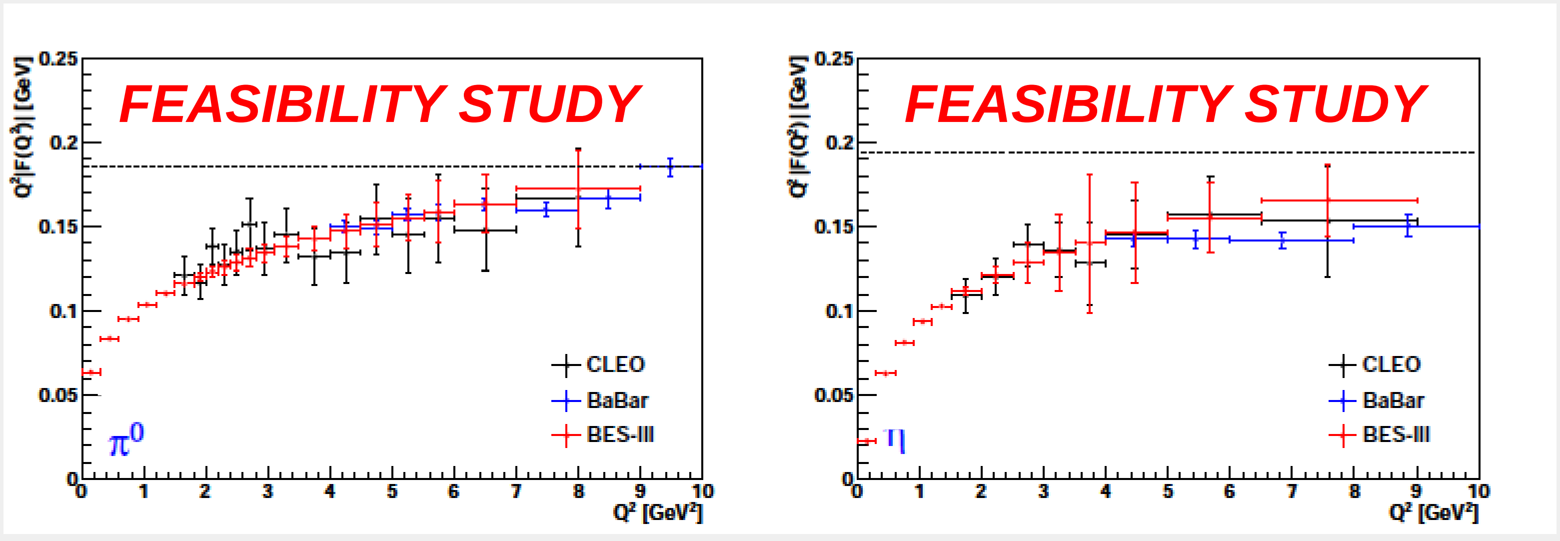
- electron is detected and identified
- the meson is detected and fully reconstructed
- electron + meson system has low p⊥
- missing mass in an event is close to 0

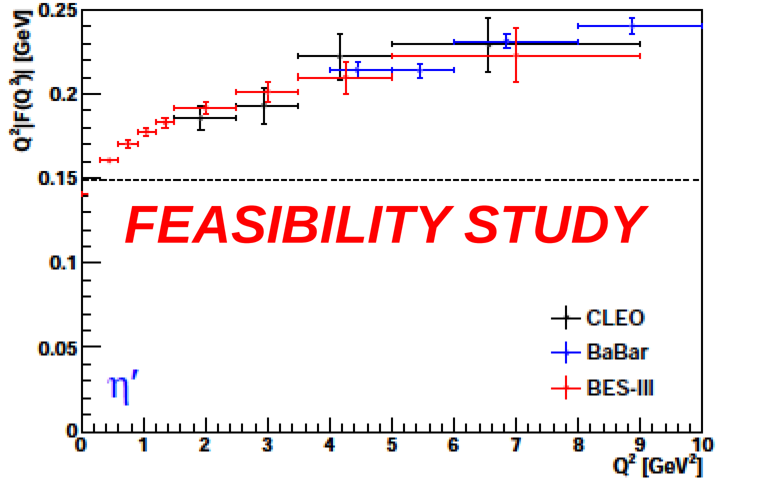
$$dN/dQ^2 \Rightarrow d\sigma/dQ^2 \Rightarrow |F(Q^2)|$$

Analysis $\gamma\gamma \rightarrow e^+e^-\pi^0/\eta/\eta'$: feasibility study

PRELIMINARY

All simulation are performed with EKHARA 2.0: no detector simulation included





- Errors definitively reduced: <u>high precision!</u>
- Possibility to check very low Q^2
- Cross check the BaBar/Belle data up to 10GeV^2
- Cross check CLEO data from Q^2=1.5 up to 7GeV^2

Analysis $\gamma\gamma \rightarrow e^+e^-\pi^0/\eta/\eta'$: cross section

PRELIMINARY

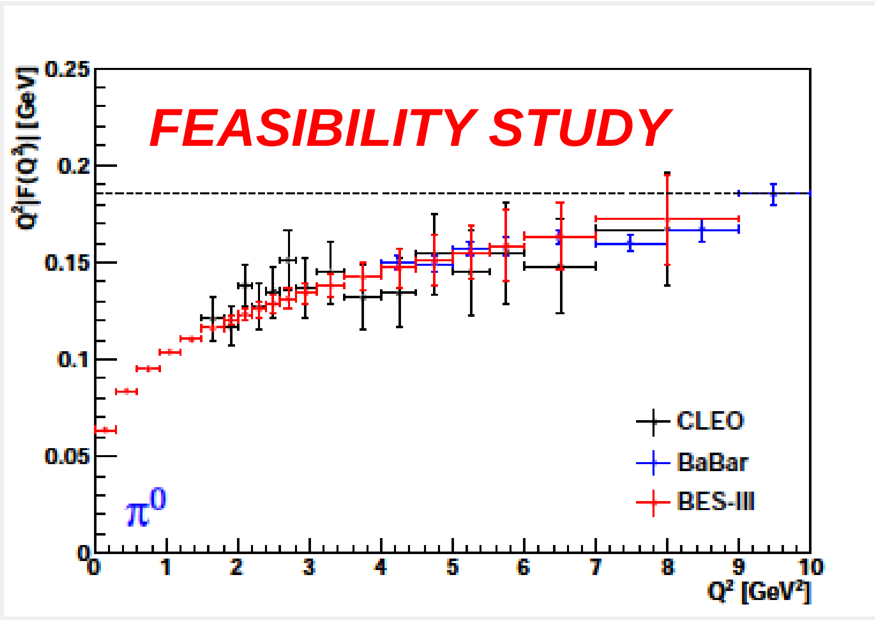
- **E c.m. = 3.77 GeV**; it reduces the background due to e^+e^- from J/ψ

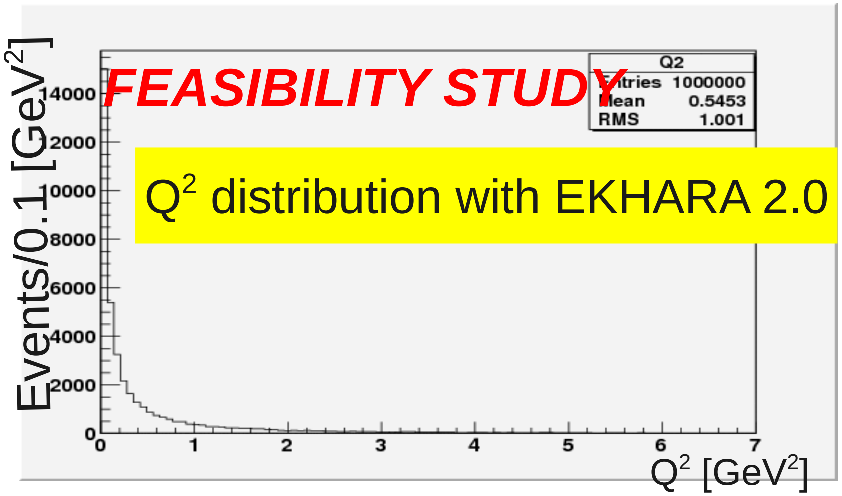
EKHARA simulation	$e+e- \rightarrow e+e-\gamma\gamma \rightarrow e+e-\pi^0$ (nb)	$e+e- \rightarrow e+e-\gamma\gamma \rightarrow e+e-\eta$ (nb)	$e+e- \rightarrow e+e-\gamma\gamma \rightarrow e+e-\eta'$ (nb)
Non tagged	$(832.2 \pm 2.9) \times 10^{-3}$	$(297.2 \pm 1.0) \times 10^{-3}$	$(212.2 \pm 1.1) \times 10^{-3}$
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

Analysis $\gamma\gamma \rightarrow e^+e^-\pi^0/\eta/\eta'$: acceptance

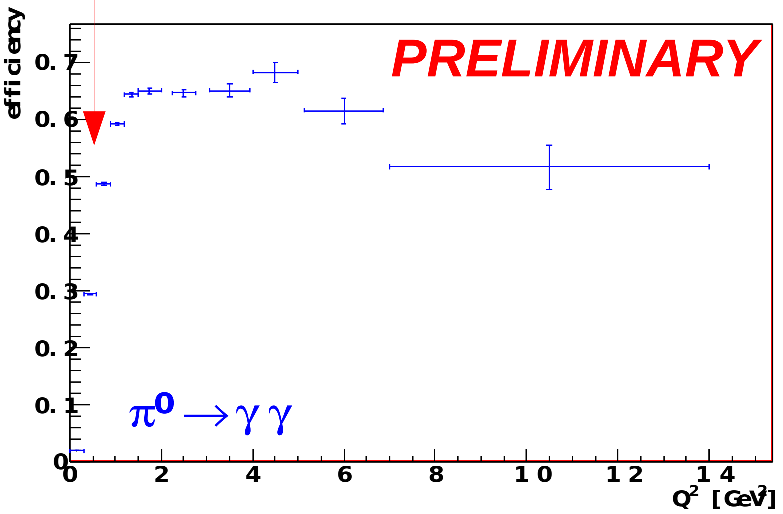
PRELIMINARY



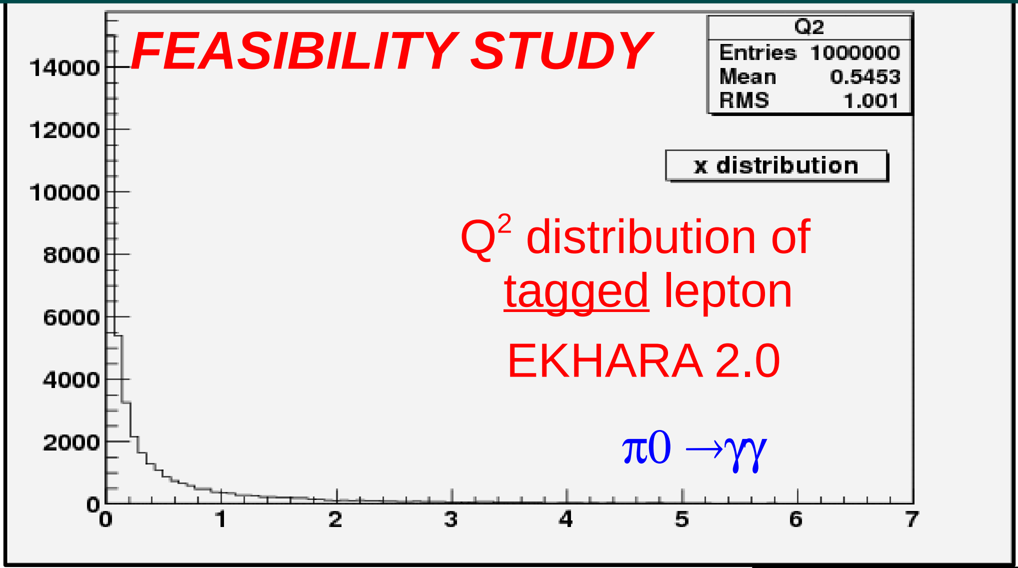


- After the detector acceptance is included, a loss of events is seen at the threshold
- It is due to the photon acceptance

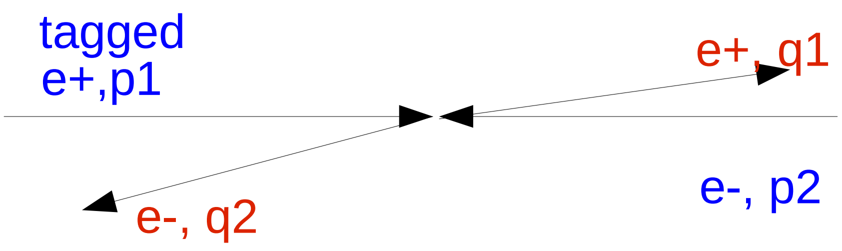
THIS ANALYSIS IS ONGOING....



Analysis $\gamma\gamma \to e^+e^-\pi^0/\eta/\eta'$: Q^2 distribution

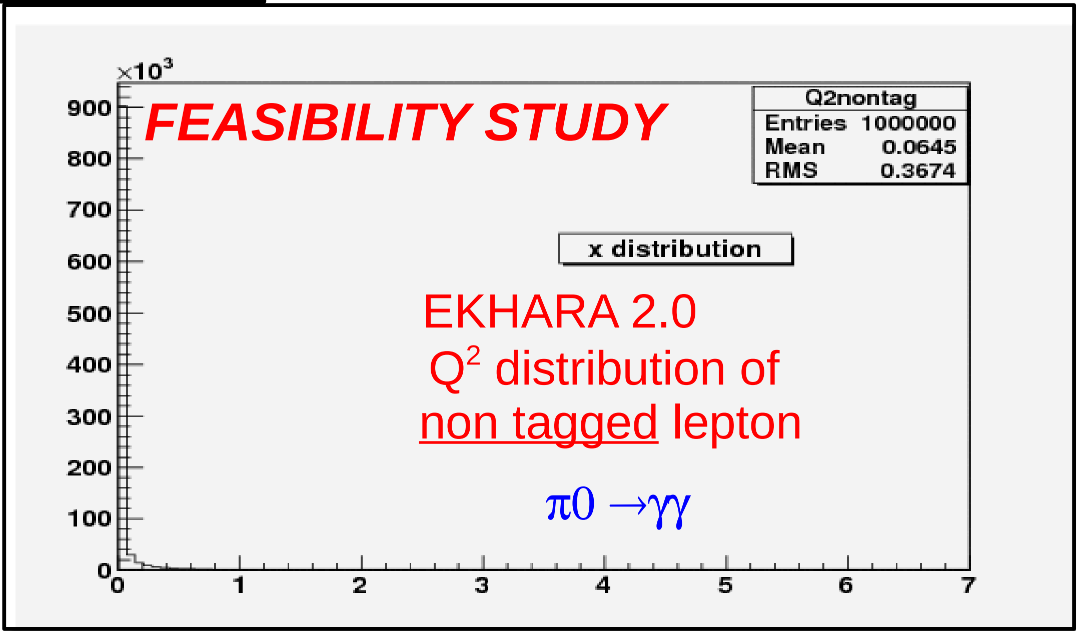


PRELIMINARY



- BaBar could not check very low Q^2 values due to the trigger
- Simulations show that in BESIII it is possible
- $Q^2 \in [1 \div 3]$ GeV^2 is theoretically the best range to test hadronic *LBL* correction to (g-2)μ

INPUT TO THE THEORY!



Conclusion

- The BES III detector collected high quality data, that allow us to do precise and competitive measurements compared to other experiments

- Interesting analysis are going on pseudo-scalar mesons and light hadron physics: BES III can give an important contribution in this sector

- The study of the Dalitz plot matrix elements of $\eta' \to \eta\pi\pi$ allow us to conclude that BES III is in agreement with VES (parameters *c* and *d*) and GAMs-4π (parameters *a* and *b*). As expected, the parameter *c* related to C-parity violation is consistent with 0 (as expected for strong interactions)

- High precision measurement of BF($\eta' \to \pi^+\pi^- l^+ l^-$) has been performed: it confirms the theoretical prediction and it will be published very soon

- The analysis of transition form factor of π^0,η,η' is ongoing at BES III:
  - **Range observable: 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;3]GeV^2
    - complementary measurement to BaBar/Belle experiment (e.g. Q^2 in [4;40]GeV^2)

Thank you!