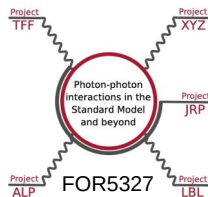# Experimental input from BESIII for the HLbL contribution

7th Plenary Workshop of the Muon g-2 Theory Initiative

2024-09-13 | Christoph Florian Redmer

"Wish List" from 2020 WP

Table 14

Priorities for new experimental input and cross-checks.

issue	experimental input [I] or cross-checks [C]
axials, tensors, higher pseudoscalars	$\gamma^{(*)}\gamma^* \to 3\pi,\ 4\pi,\ K\bar{K}\pi,\ \eta\pi\pi,\ \eta'\pi\pi$ [I]
missing states	inclusive $\gamma^{(*)}\gamma^* \to$ hadrons at 1–3 GeV [I]
dispersive analysis of $\eta^{(')}$ TFFs	$e^+e^- \to \eta\pi^+\pi^-$ [I]
	$\eta' \to \pi^+\pi^-\pi^+\pi^-$ [I]
	$\eta' \to \pi^+\pi^-e^+e^-$ [I]
	$\gamma\pi^- \to \pi^-\eta$ [C]
dispersive analysis of π^0 TFF	$\gamma\pi \to \pi\pi$ [I]
	high accuracy Dalitz plot $\omega \to \pi^+\pi^-\pi^0$ [C]
	$e^+e^- \to \pi^+\pi^-\pi^0$ [C]
	$\omega, \phi \to \pi^0 l^+l^-$ [C]
pseudoscalar TFF	$\gamma^{(*)}\gamma^* \to \pi^0, \eta, \eta'$ at arbitrary virtualities [I,C]
pion, kaon, $\pi\eta$ loops	$\gamma^{(*)}\gamma^* \to \pi\pi,\ K\bar{K},\ \pi\eta$ at arbitrary virtualities,
(including scalars and tensors)	partial waves [I,C]

Phys.Rept. 887 (2020) 1 – 166

"Wish List" from 2020 WP

Table 14
Priorities for new experimental input and cross-checks.

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	$\eta' \to \pi^+\pi^-e^+e^-$ [I]
	$\gamma\pi^- \to \pi^-\eta$ [C]
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(including scalars and tensors)	partial waves [I,C]

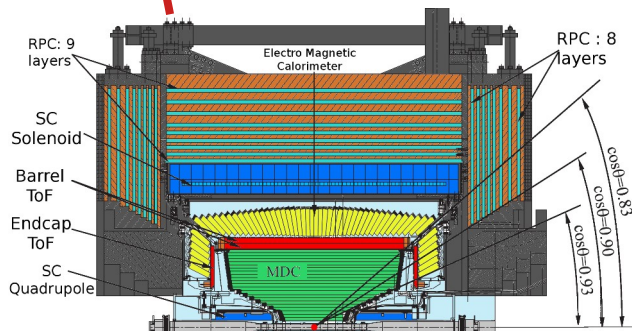Hadronic cross sections

Meson decays

Two-photon reactions

Phys.Rept. 887 (2020) 1 – 166

BESIII at BEPCII

- Center-of-mass energies from 2 – 5 GeV

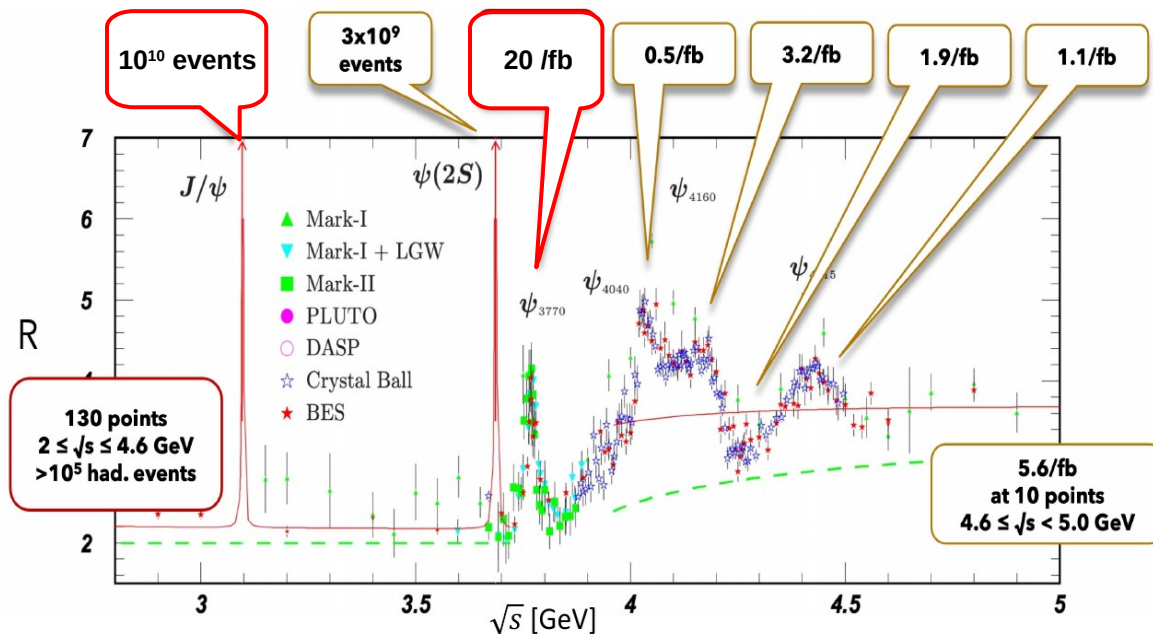- Design luminosity exceeded: 1.1×10^{33} cm^{-2}s^{-1} at 3.77 GeV

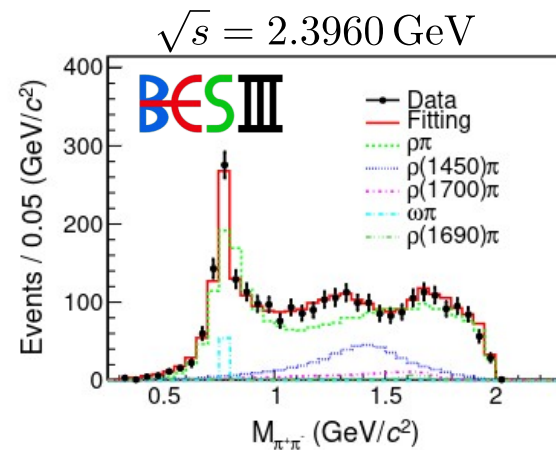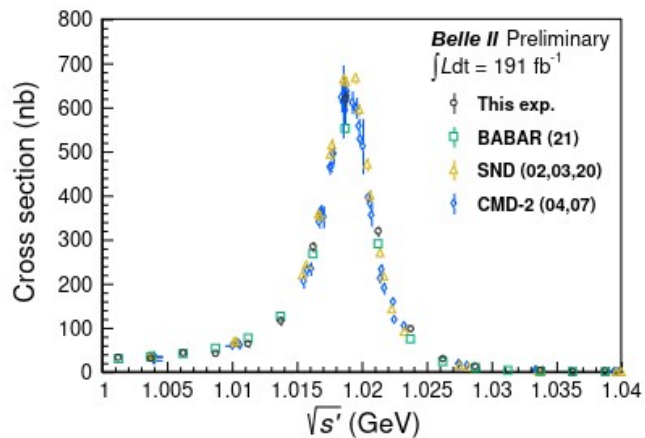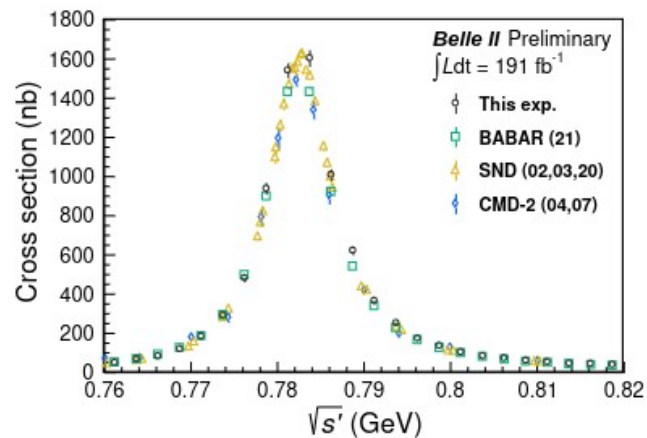Time of Flight   EM Calorimeter   Muon Counter

Drift Chamber   Solenoid

Worlds largest τ-charm data sets in e⁺e⁻ collisions

Hadronic cross sections

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

BaBar	ISR	total cross section	Phys. Rev. D104 (2021) 11203
BESIII	scan	PWA at three energies	Phys. Rev. D110 (2024) 032005
Belle II	ISR	total cross section	arXiv:2404.04915

Hadronic cross sections

$$e^+ e^- \to \pi^+ \pi^- \eta$$
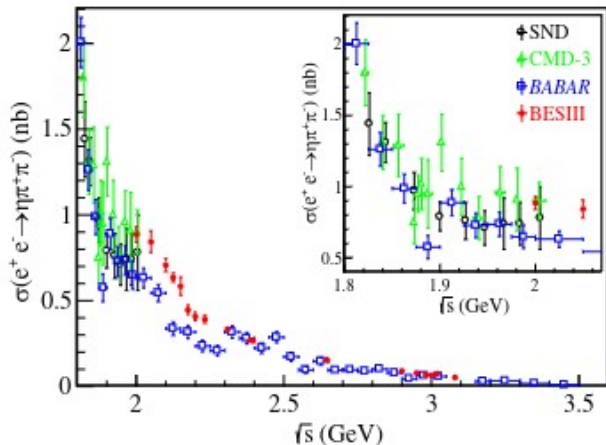
PWA at three energies

Phys.Rev. D108 (2023) 111101

TABLE I. Statistical significances and fit fractions of possible intermediate processes at $\sqrt{s} = 2.125$, 2.396, and 2.900 GeV.

	$\sqrt{s} = 2.125$ GeV			$\sqrt{s} = 2.396$ GeV			$\sqrt{s} = 2.900$ GeV	
Process	Significance (σ)	Fraction (%)	Process	Significance (σ)	Fraction (%)	Process	Significance (σ)	Fraction (%)
$\rho(770)\eta$	>20	58.0 ± 1.0	$\rho(770)\eta$	>20	69.5 ± 2.5	$\rho(770)\eta$	>20	66.8 ± 2.2
$a_2(1320)\pi$	>20	24.1 ± 0.8	$a_2(1320)\pi$	>20	13.0 ± 1.1	$a_2(1320)\pi$	>10	21.7 ± 2.1
$\rho(1450)\eta$	>10	1.8 ± 0.3	$\rho(1450)\eta$	5.1	1.0 ± 0.4	$\rho(1450)\eta$	>10	16.5 ± 0.4
$a_2(1700)\pi$	>10	2.0 ± 0.3	$\rho_3(1690)\eta$	9.7	2.5 ± 0.5	$\rho(1700)\eta$	6.5	2.1 ± 0.1
$\cdots$	$\cdots$	$\cdots$	$a_2(1700)\pi$	6.8	2.7 ± 0.4	$\cdots$	$\cdots$	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\rho(1700)\eta$	5.8	1.9 ± 0.9	$\cdots$	$\cdots$	$\cdots$

Related studies at BESIII:

$e^+ e^- \to \omega \pi^0 / \eta$ Phys.Lett. B813 (2021) 136059

$e^+ e^- \to \pi^+ \pi^- \eta'$ Phys.Rev. D103 (2021) 072007

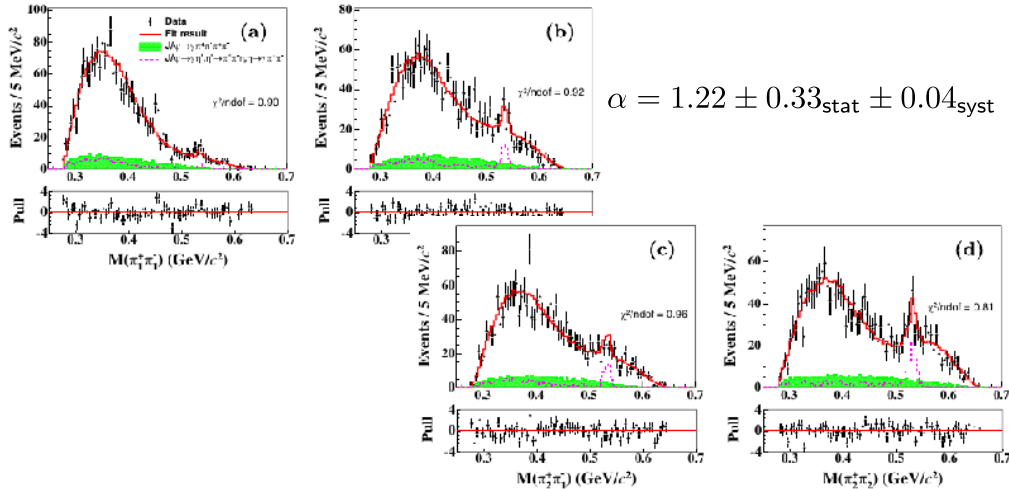$e^+ e^- \to \omega \eta'$ JHEP 07 (2024) 093

Meson decays

$\eta' \rightarrow \pi\pi\pi\pi$ Phys. Rev. D109 (2024) 032006

Mode	N	ε (%)	$\mathcal{B}(\eta' \rightarrow X)$
$\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$	1650 ± 48	36.4	$(8.56 \pm 0.25(\text{stat.}) \pm 0.23(\text{syst.})) \times 10^{-5}$
$\eta' \rightarrow \pi^+\pi^-\pi^0\pi^0$	865 ± 49	7.8	$(2.12 \pm 0.12(\text{stat.}) \pm 0.10(\text{syst.})) \times 10^{-4}$
$\eta' \rightarrow \pi^0\pi^0\pi^0\pi^0$	< 10	1.6	$< 1.24 \times 10^{-5}$

- Access to doubly virtual time-like isovector transition form factor

- Amplitude analysis following Guo, Kubis, Wirzba [PRD 85 (2012) 014014] suggests coupling constants $c_1 - c_2 \approx c_3$

$\alpha = 1.22 \pm 0.33_{\text{stat}} \pm 0.04_{\text{syst}}$

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

$$\mathcal{B}(\eta' \to \pi^+\pi^- e^+ e^-) = (2.45 \pm 0.02(\text{stat.}) \pm 0.08(\text{syst.})) \times 10^{-3}$$

$$\mathcal{B}(\eta' \to \pi^+\pi^- \mu^+ \mu^-) = (2.16 \pm 0.12(\text{stat.}) \pm 0.06(\text{syst.})) \times 10^{-5}$$

TFF studied for different VMD models

$$b_{\eta'} = 1.30 \pm 0.19(\text{GeV}/c^2)^2$$
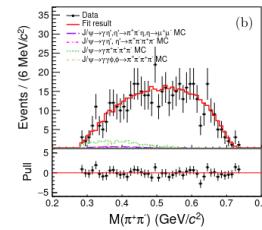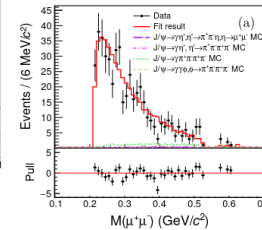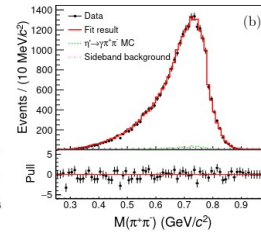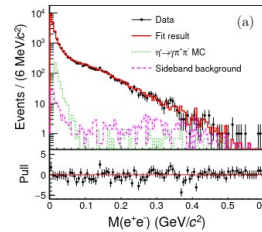
Asymmetry parameter measured

$$\mathcal{A}_{CP}(\eta' \to \pi^+\pi^- e^+ e^-) = (0.21 \pm 0.73(\text{stat.}) \pm 0.01(\text{syst.}))\%$$

$$\mathcal{A}_{CP}(\eta' \to \pi^+\pi^- \mu^+ \mu^-) = (0.62 \pm 4.71(\text{stat.}) \pm 0.02(\text{syst.}))\%$$
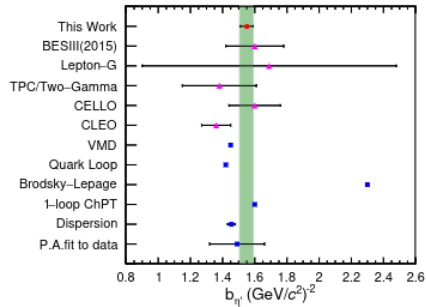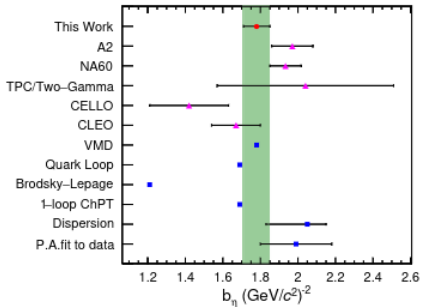
Meson decays

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

$$\mathcal{B}(\eta \to \gamma e^+ e^-) = (7.07 \pm 0.05(\text{stat.}) \pm 0.23(\text{syst.})) \times 10^{-3}$$

$$\mathcal{B}(\eta' \to \gamma e^+ e^-) = (4.83 \pm 0.07(\text{stat.}) \pm 0.14(\text{syst.})) \times 10^{-4}$$

$\Lambda_\eta = (0.749 \pm 0.027 \pm 0.008) \, \text{GeV}/c^2$ $\qquad \Lambda_{\eta'} = (0.802 \pm 0.007 \pm 0.008) \, \text{GeV}/c^2$

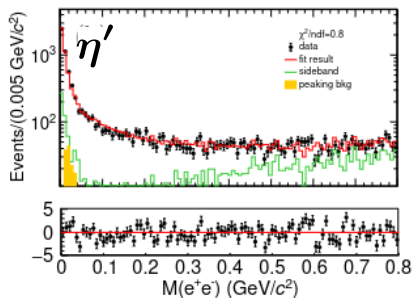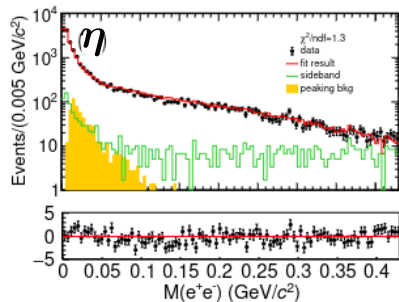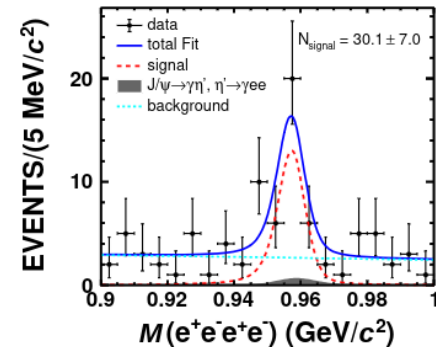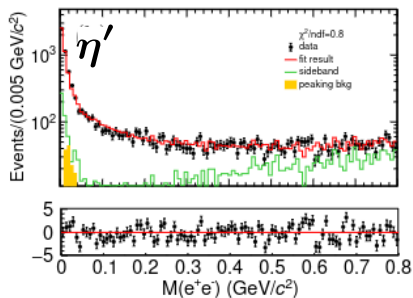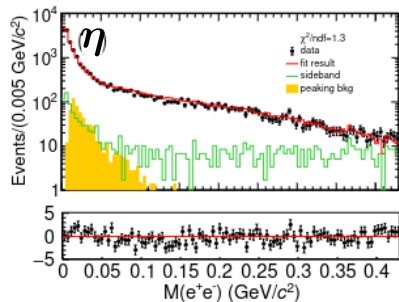$\gamma_{\eta'} = (0.113 \pm 0.010 \pm 0.002) \, \text{GeV}/c^2$

Meson decays

$\eta/\eta' \rightarrow \gamma e^+ e^-$
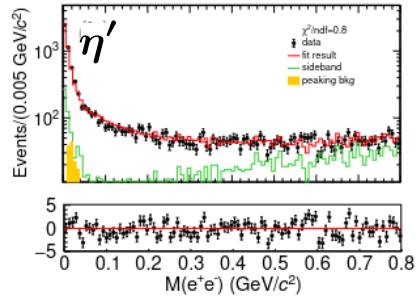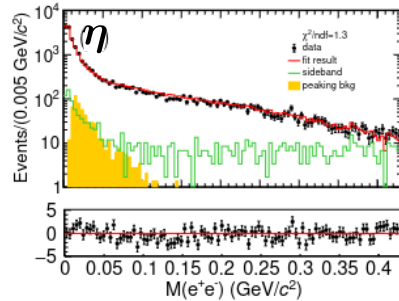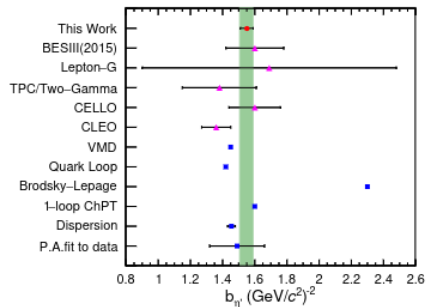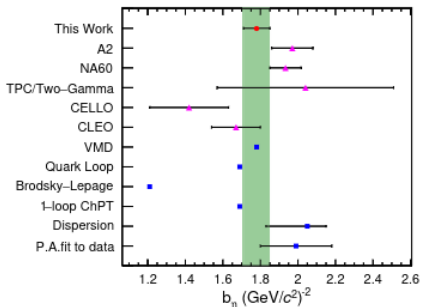
Phys.Rev. D109 (2024) 072001

$$\mathcal{B}(\eta \rightarrow \gamma e^+ e^-) = (7.07 \pm 0.05(\text{stat.}) \pm 0.23(\text{syst.})) \times 10^{-3}$$
$$\mathcal{B}(\eta' \rightarrow \gamma e^+ e^-) = (4.83 \pm 0.07(\text{stat.}) \pm 0.14(\text{syst.})) \times 10^{-4}$$

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

Phys.Rev. D105 (2022) 112010

$$\mathcal{B}(\eta' \rightarrow e^+ e^- e^+ e^-) = (4.5 \pm 1.0(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{-6}$$

$\Lambda_\eta = (0.749 \pm 0.027 \pm 0.008)\,\text{GeV}/c^2$
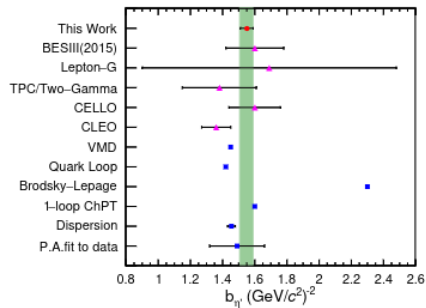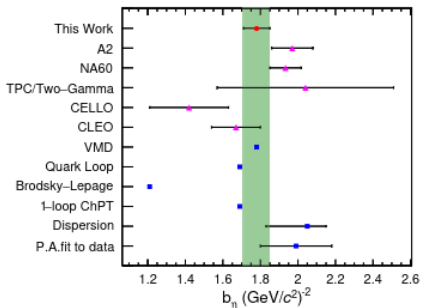
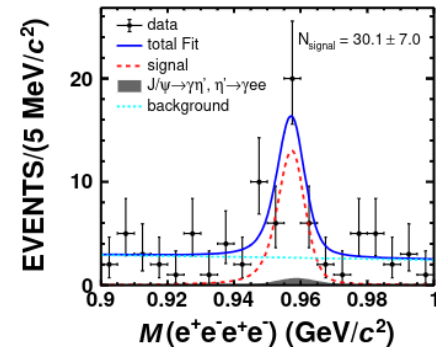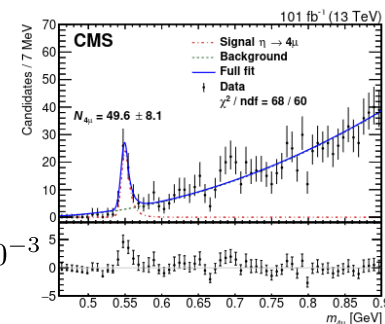$\Lambda_{\eta'} = (0.802 \pm 0.007 \pm 0.008)\,\text{GeV}/c^2$
$\gamma_{\eta'} = (0.113 \pm 0.010 \pm 0.002)\,\text{GeV}/c^2$

Meson decays

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

Phys.Rev. D109 (2024) 072001

$\mathcal{B}(\eta \to \gamma e^+ e^-) = (7.07 \pm 0.05(\text{stat.}) \pm 0.23(\text{syst.})) \times 10^{-3}$
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$\Lambda_\eta = (0.749 \pm 0.027 \pm 0.008)\ \text{GeV}/c^2$
$\Lambda_{\eta'} = (0.802 \pm 0.007 \pm 0.008)\ \text{GeV}/c^2$
$\gamma_{\eta'} = (0.113 \pm 0.010 \pm 0.002)\ \text{GeV}/c^2$

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

Phys.Rev. D105 (2022) 112010

$\mathcal{B}(\eta' \to e^+ e^- e^+ e^-) = (4.5 \pm 1.0(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{-6}$

$\eta \to \mu^+ \mu^- \mu^+ \mu^-$

Phys.Rev.Lett. 131 (2023) 091903

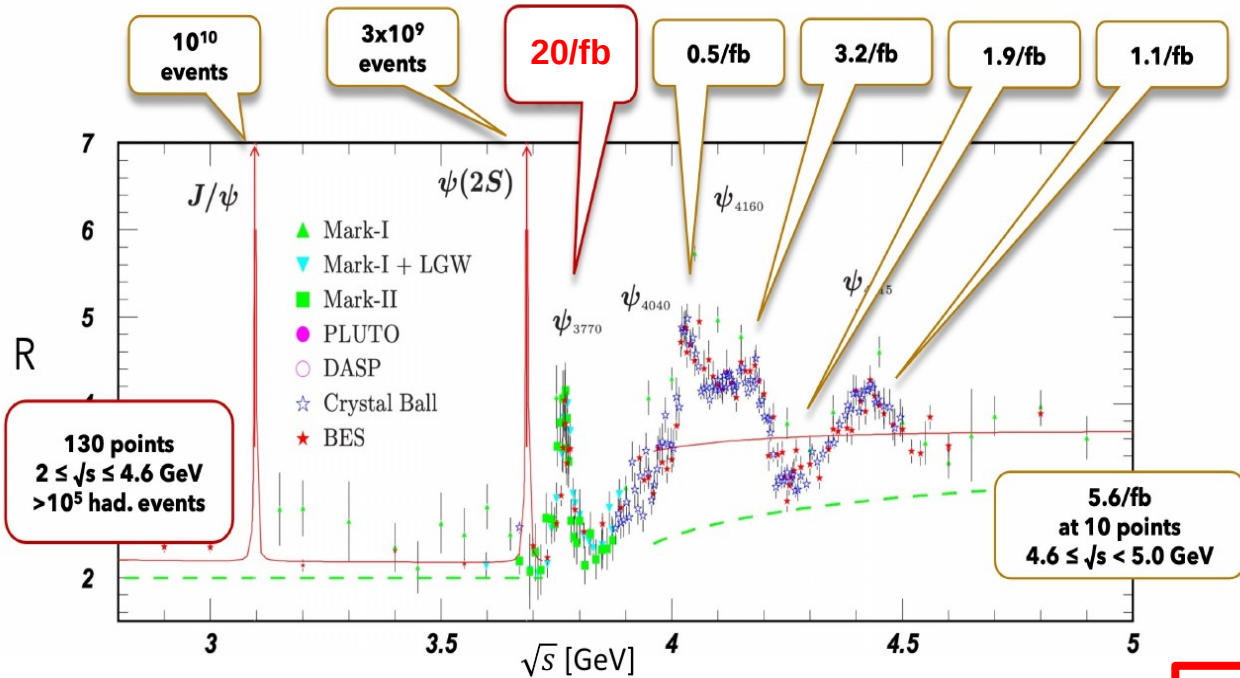Normalized to $\eta \to \mu^+ \mu^-$

$\dfrac{\mathcal{B}_{4\mu}}{\mathcal{B}_{2\mu}} = (0.86 \pm 0.14(\text{stat}) \pm 0.12(\text{syst})) \times 10^{-3}$

$\gamma^{(*)}\gamma^*$ results to be expected from BESIII

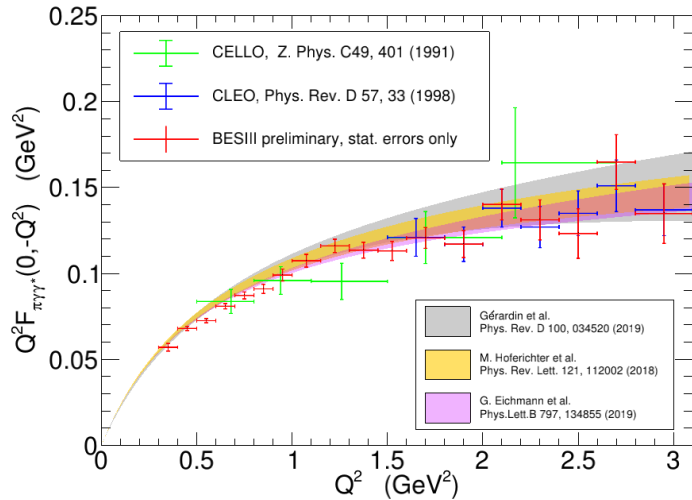- Richest data above open charm threshold
  - Access to
    - Hadronic masses up to 2 GeV
    - $0.2 \leq Q^2[\text{GeV}^2] \leq 3$

- Access to smaller Q^2 values at $\sqrt{s} \approx 2$ GeV (limited statistics)

New data at 3.77 GeV most relevant!
Data taking finished June 2024

$$\gamma^{(*)}\gamma^* \to \pi^0, \eta, \eta'$$
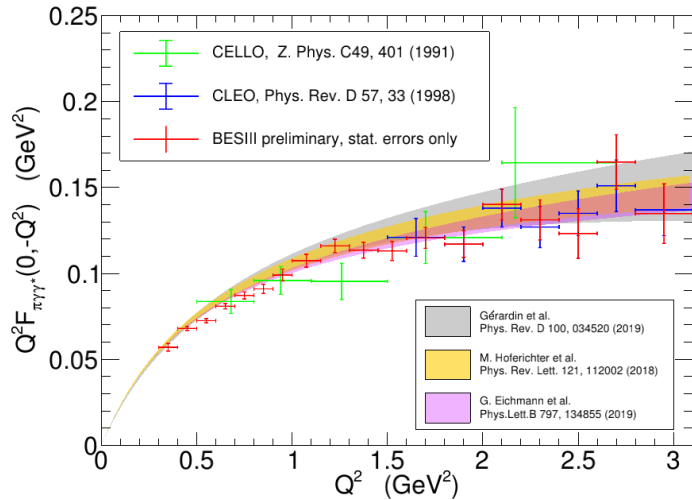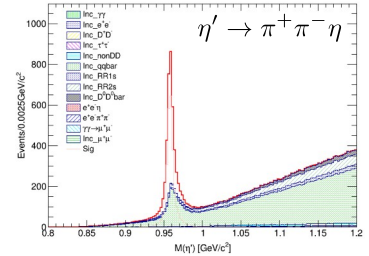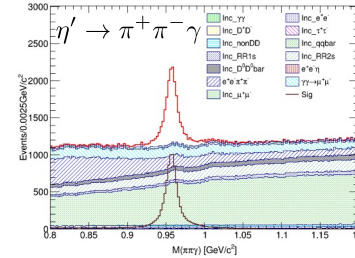
$\gamma\gamma^* \to \pi^0$

Since preliminary:

- Improved systematics
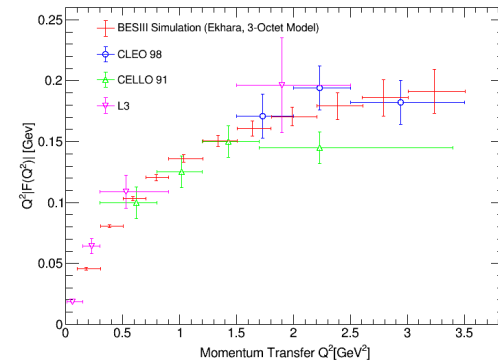- Included radiative corrections based on Ekhara3

Plan:

- Publish 'old' data to be in time from WP2
- Full data set as update

$\gamma^{(*)}\gamma^* \to \pi^0, \eta, \eta'$

$\gamma\gamma^* \to \pi^0$

Since preliminary:

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### $\gamma\gamma^* \to \eta'$

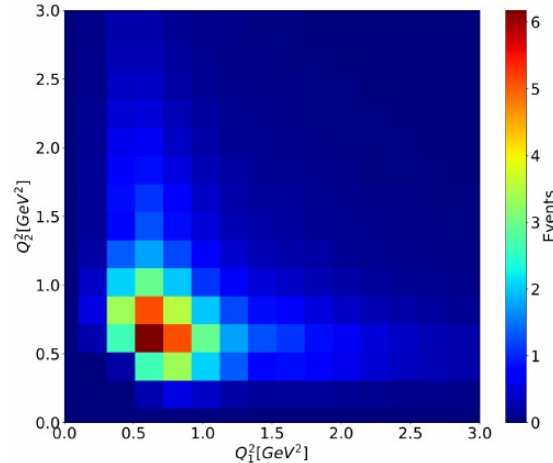Simulations using full 20 fb^{-1}

Kangshuai Zhu

- First direct measurement at $Q^2 < 0.3$ GeV^2
- Unprecedented accuracy

$\gamma^{(*)}\gamma^* \to \pi^0, \eta, \eta'$

$\gamma\gamma^* \to \pi^0$

CELLO, Z. Phys. C49, 401 (1991)

CLEO, Phys. Rev. D 57, 33 (1998)

BESIII preliminary, stat. errors only

Gérard... Phys. R...

M. Hofe... Phys. R...
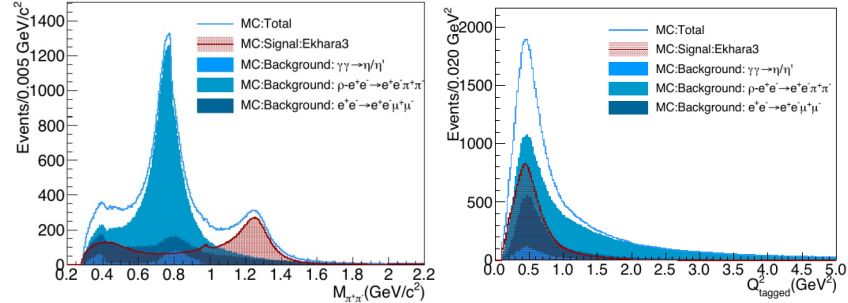
G. Eich... Phys. Le...

Since preliminary:

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Plan:

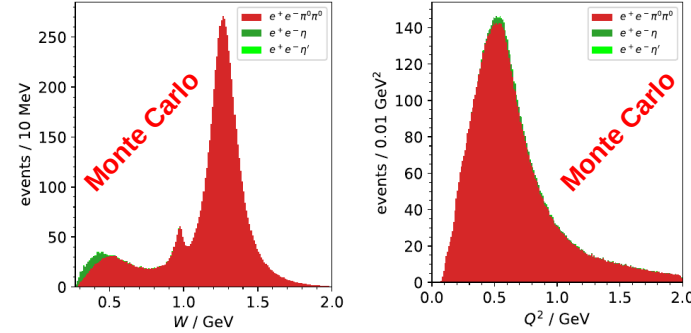- Publish 'old' data to be in time
- Full data set as update

$\gamma^*\gamma^* \to \eta, \eta'$
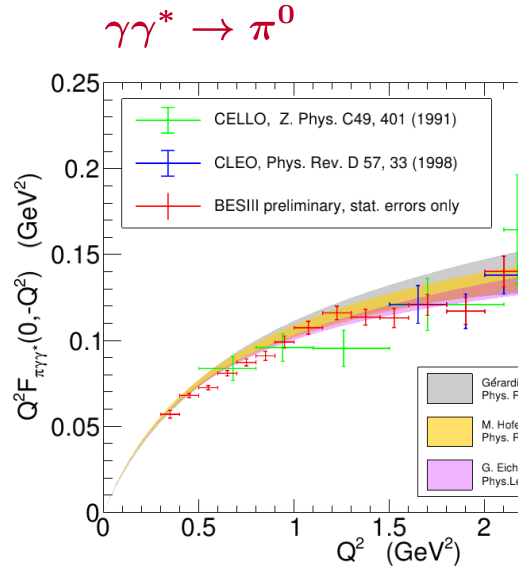
- First studies by Maurice Anderson
  - Using combination of previously available data

Simulation of expected yields for 13 fb^{-1} of data at $\sqrt{s} \geq 3.773$ GeV

- To be done on full data set

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

sing full 20 fb^{-1}

Kangshuai Zhu

at Q^2<0.3 GeV^2

$\gamma^{(*)}\gamma^* \to \pi\pi$

$\gamma\gamma^* \to \pi^+\pi^-$

Yuping Guo

$\gamma\gamma^* \to \pi^0\pi^0$

Max Lellmann

- Combined data
- Irreducible time-like background (rad.Bhabha
- Evaluation of efficiencies ongoing

- Using only new data
- Novel strategy leads to improved Q^2 resolution
  - Study dependency on 2nd virtuality
  - Study angular features of two-photon production
  - Requires different MC generator

- Invariant masses from threshold to 2 GeV
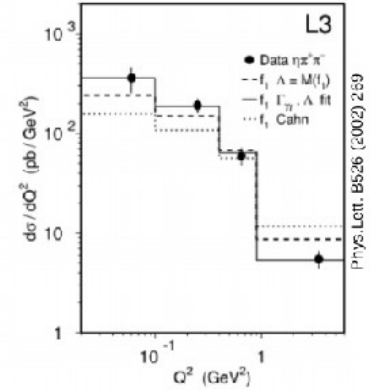- $0.2 \leq Q^2[\text{GeV}^2] \leq 3$
- Full coverage of helicity angle

$\gamma\gamma^* \to f_1(1285)$

- Reconstructing $f_1(1285) \to \pi^+\pi^-\eta$
- Possibility to separate helicity states from fit to angular distributions
- PWA required due to inseparable intermediate states $a_0^\pm(980)\pi^\mp \longleftrightarrow f_0(500)\eta$
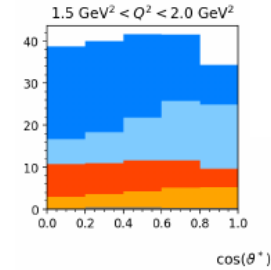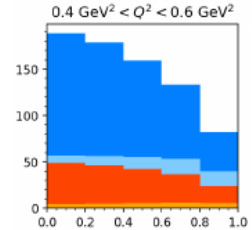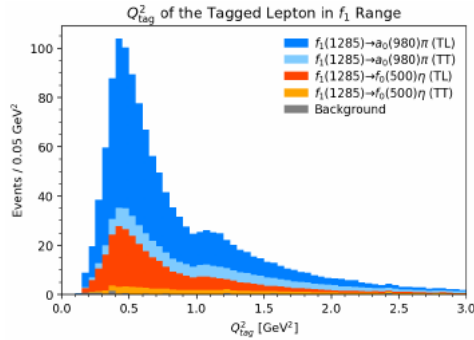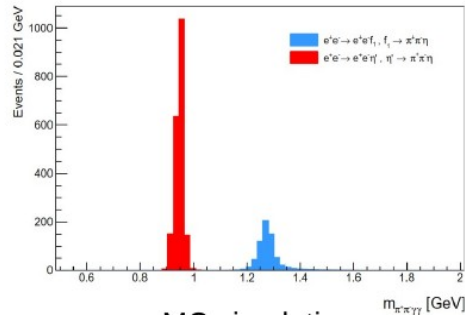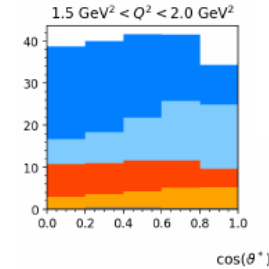

Jan Muskalla

Only availbale data:

$\gamma\gamma^* \to f_1(1285)$

- Reconstructing $f_1(1285) \to \pi^+\pi^-\eta$
- Possibility to separate helicity states from fit to angular distributions
- PWA required due to inseparable intermediate states $a_0^{\pm}(980)\pi^{\mp} \longleftrightarrow f_0(500)\eta$
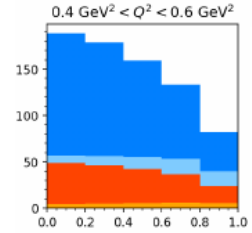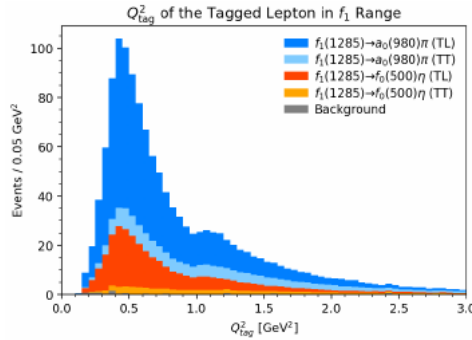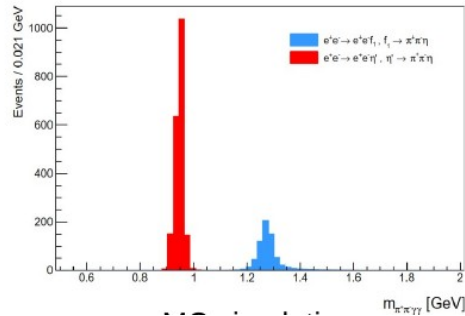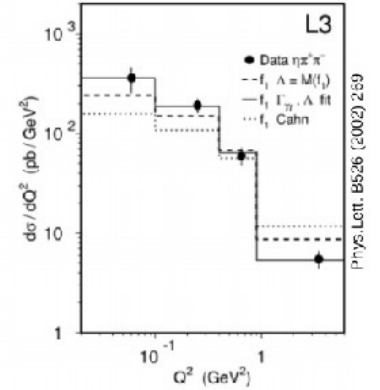
Only availbale data:

Jan Muskalla

Other channels:

- Exploratory studies (B.Sc. thesis level)
$$\gamma\gamma^* \to \pi^0\eta$$
$$\gamma\gamma^* \to \pi^+\pi^-\pi^0$$
$$\gamma\gamma^* \to KK\pi$$

Other Experimental Input

- TFF from coherent electroproduction of mesons (Primakoff contribution)
  - Plans at JLab (Hall B & D) and MAMI (A1)
  - $0.01 \leq Q^2[\mathrm{GeV}^2] \leq 0.1$
  - Primex-η data taking finished
  - A1 data taking probably from next year

- TFF from meson decays
  - update from A2 on π^0 TFF

- Radiative decays of axial vector mesons
  - Work ongoing at BESIII based on J/ψ decays
  - Contact with Martin and Bastian has been established

- …..