(Prospects for) new data relevant for the HLbL contribution

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JG|U

“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 $\eta^{(\prime)}$ 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 (including scalars and tensors)	$\gamma^{(*)}\gamma^* \to \pi\pi,\ K\bar{K},\ \pi\eta$ at arbitrary virtualities, partial waves [I,C]

Phys.Rept. 887 (2020) 1 – 166

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Hadronic cross sections

Meson decays

Two-photon reactions

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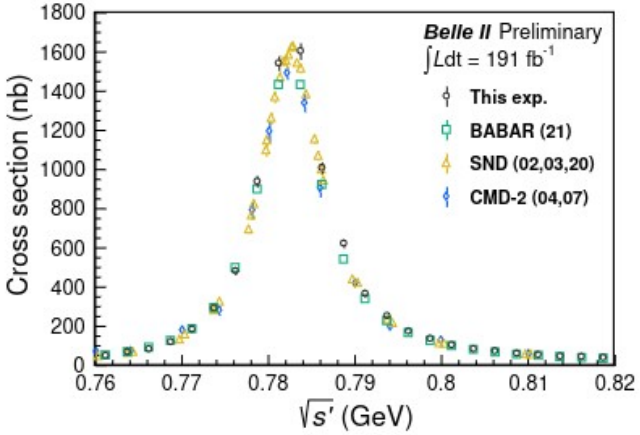
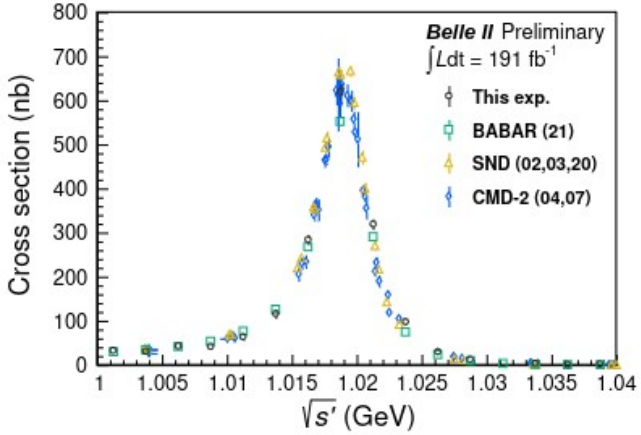
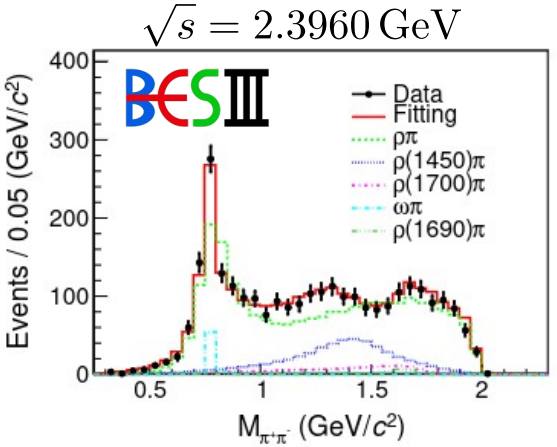
Hadronic cross sections

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

BaBar	ISR	total cross section	Phys.Rev. D104 (2021) 11203
BESIII	scan	PWA at three energies	arXiv:2401.14711
Belle II	ISR	total cross section	arXiv:2404.04915







Hadronic cross sections

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

scan PWA at three energies

Phys.Rev. D108 (2023) 111101

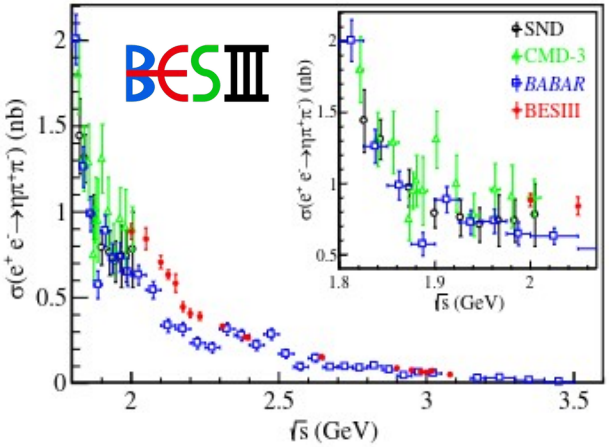


TABLE I. Statistical significances and fit fractions of possible intermediate processes at $\sqrt{s} = 2.125$, 2.396, and 2.900 GeV.

$\sqrt{s} = 2.125$ 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
...	...	...	$a_2(1700)\pi$	6.8	2.7 ± 0.4	...	...	...
...	...	...	$\rho(1700)\eta$	5.8	1.9 ± 0.9	...	...	...

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
$e^+e^- \to \omega\eta'$	arXiv:2404.07436

Meson decays

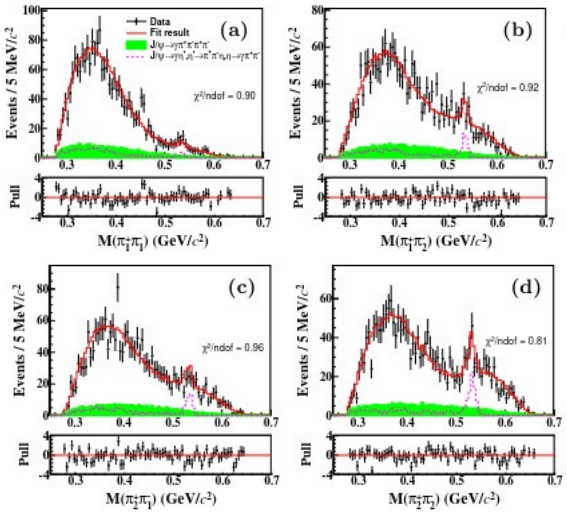
$\eta' \to \pi\pi\pi\pi$

arXiv:2311.12895

Based on $10^{10} J/\psi$ events

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

Amplitude analysis following PRD 85 (2012) 014014 suggests coupling constants $c_1 - c_2 \approx c_3$



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

PRD 103 (2021) 072006
PRD 103 (2021) 092005
arXiv:2402.01993

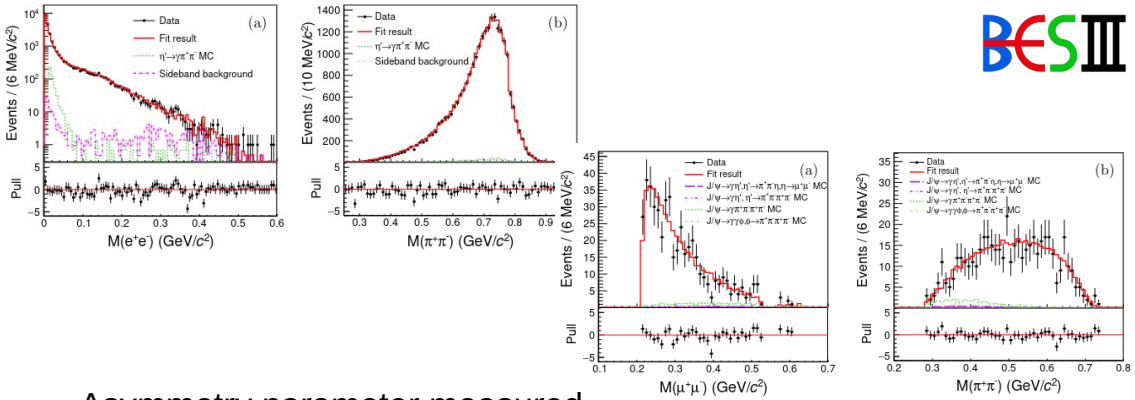
Based on $10^{10} J/\psi$ events

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

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

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

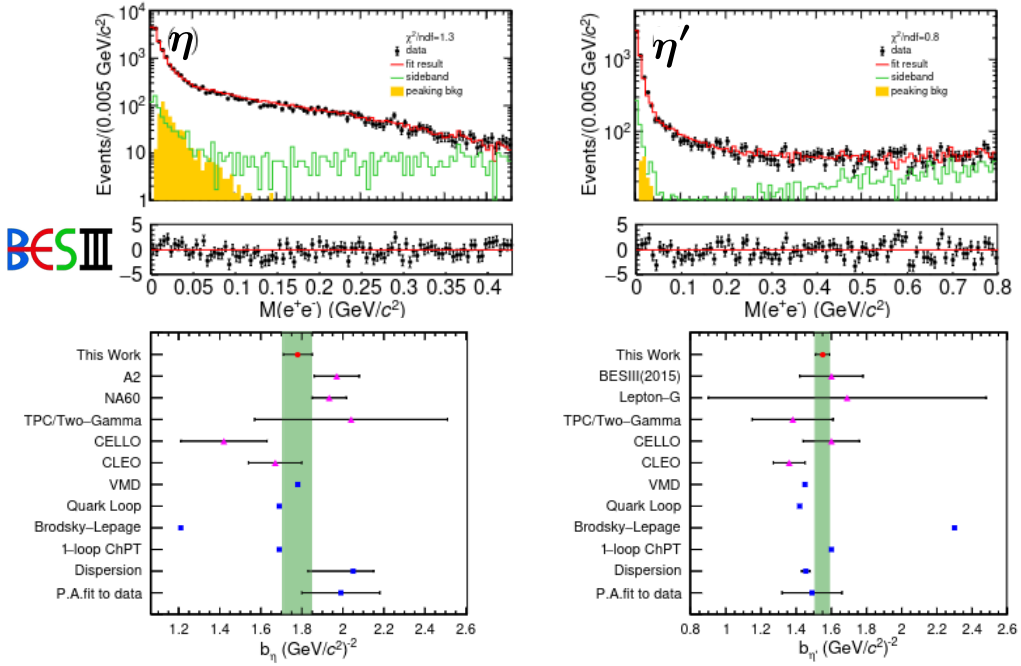
$\eta/\eta' \to \gamma e^+ e^-$

PRD 109 (2024) 072001

Based on $10^{10} J/\psi$ events

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

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

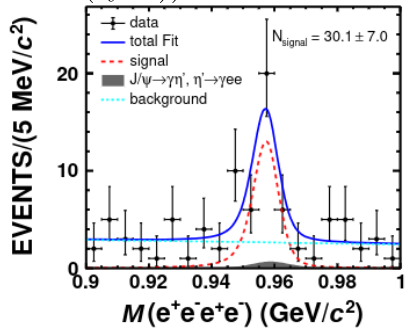


$\eta' \to e^+ e^- e^+ e^-$

PRD 105 (2022) 112010

Based on $10^{10} J/\psi$ events

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

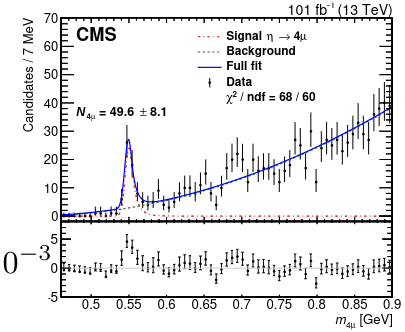


$\eta \to \mu^+ \mu^- \mu^+ \mu^-$

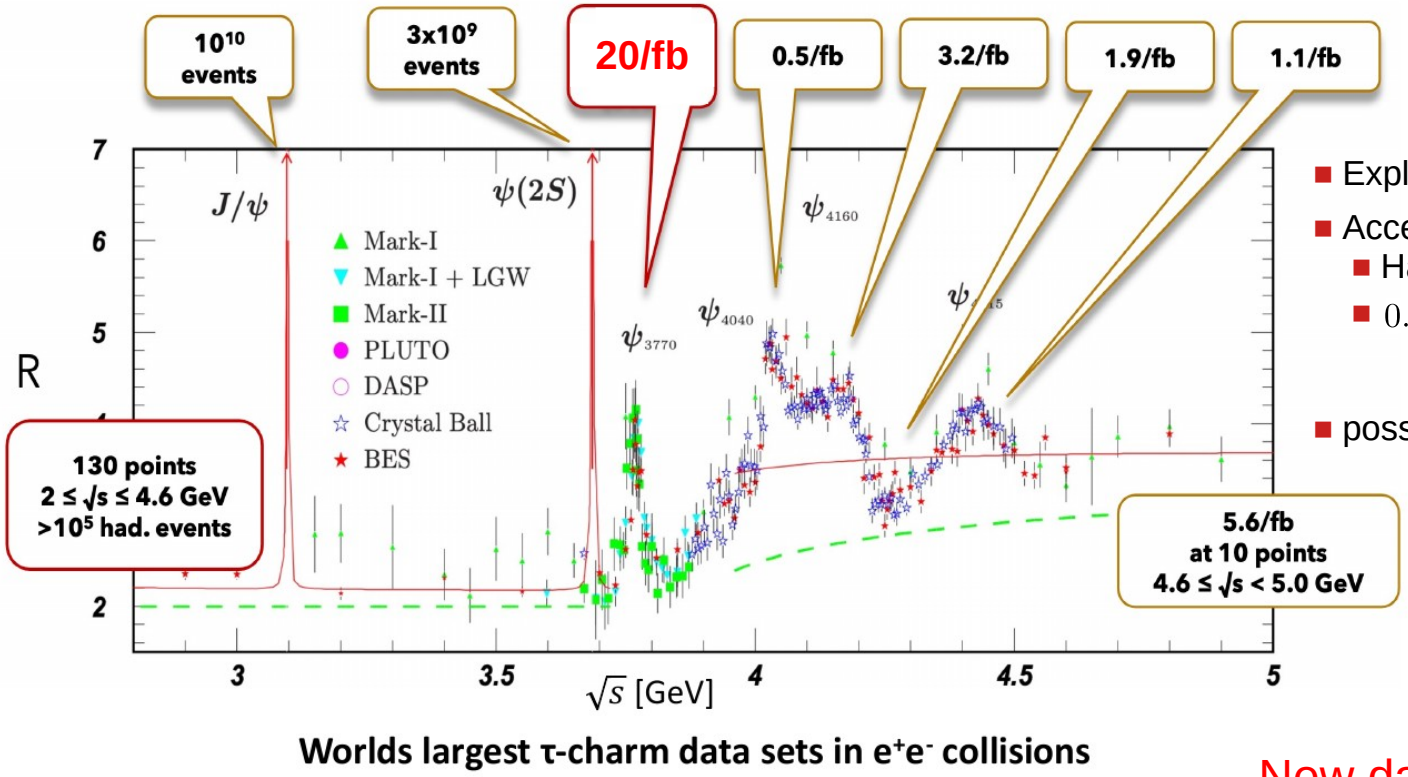
PRL 131 (2023) 091903

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

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



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



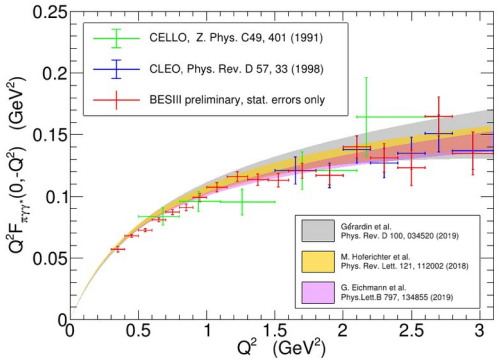
Worlds largest τ-charm data sets in e^+e^- collisions

- Exploit data sets above open charm threshold
- Access to
  - Hadronic masses up to 2 GeV
  - $0.2 \leq Q^2[\mathrm{GeV}^2] \leq 3$
- possible to extend to 0.1 GeV² (limited statistics)

New data at 3.77 GeV most relevant!

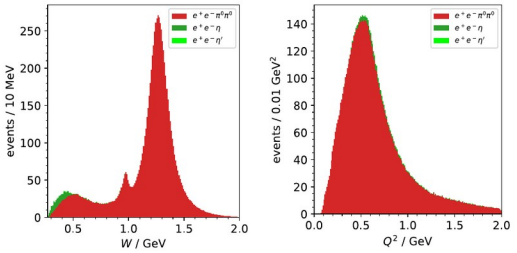
$\gamma^{(*)}\gamma^*$ results to be expected from BESIII

$\gamma\gamma^* \to \pi^0, \eta, \eta'$

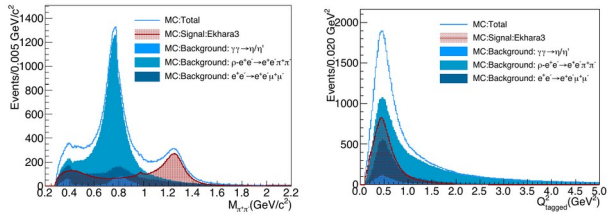


- Final issues for pion TFF publication fixed
- Additional person power acquired (η, η')
- Analyze full data set in a next step

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



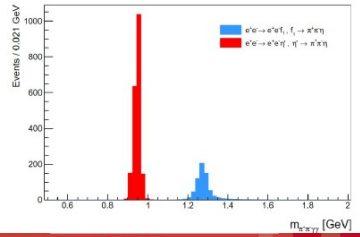
$\pi^0\pi^0$



$\pi^+\pi^-$

- Combining several data sets
- Efficiency corrections ongoing

Ongoing projects: $\gamma\gamma^* \to f_1(1285)$



$\gamma\gamma^* \to \pi^0\eta$
$\gamma\gamma^* \to \pi^+\pi^-\pi^0$
$\gamma\gamma^* \to KK\pi$

$\gamma^*\gamma^* \to \pi^0, \eta, \eta'$

Other Experimental Input

- TFF from coherent electroproduction of mesons (Primakoff contribution)
  - Plans at JLab (Hall B) and MAMI (A1)
  - $0.01 \leq Q^2[\mathrm{GeV}^2] \leq 0.1$
  - 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
  - In contact with Martin and Bastian

- .....