

Experimental input and cross checks for HLbL contribution to muon g-2 (discussion session)

White Paper draft

TABLE II. Wishlist

issue	helpful experimental information
pseudoscalar TFF	$\gamma^*\gamma^* \rightarrow \pi^0, \eta, \eta'$ at arbitrary virtualities
pion loops	$\gamma^*\gamma^* \rightarrow \pi\pi$ at arbitrary virtualities, partial waves
dispersive analysis of π^0 TFF	high accuracy Dalitz plot $\omega \rightarrow \pi^+\pi^-\pi^0$ $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ $\gamma\pi \rightarrow \pi\pi$ $\omega \rightarrow \pi^0l^+l^-$ and $\phi \rightarrow \pi^0l^+l^-$ as cross check
dispersive analysis of η TFF	$\gamma\pi^- \rightarrow \pi^-\eta$ $e^+e^- \rightarrow \eta\pi^+\pi^-$ $\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$ $\eta' \rightarrow \pi^+\pi^-e^+e^-$
axial and tensor contributions	$\gamma^*\gamma^* \rightarrow 3$ or 4π
missing states	inclusive $\gamma^{(*)}\gamma^* \rightarrow$ hadrons at 1-3 GeV

Precision approach to HVP & HLbL: Data driven dispersive analysis

However:

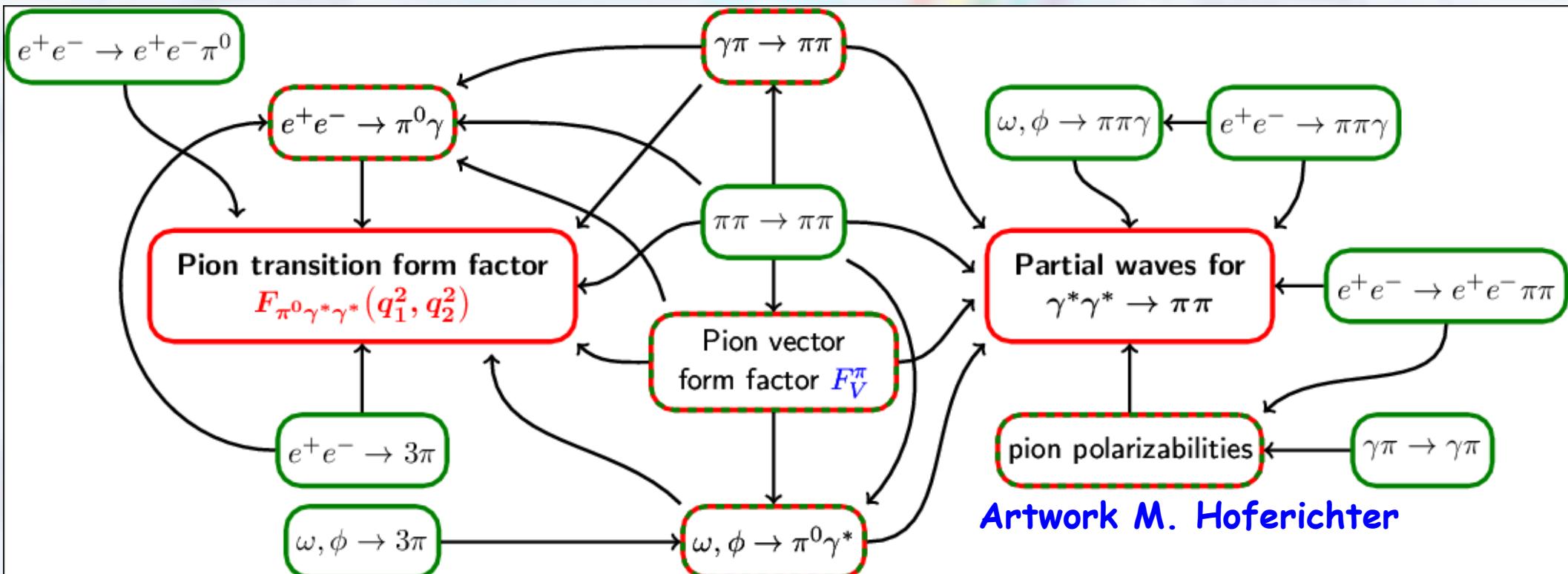
HVP - Experiment coordinated

HLbL - Theory coordinated

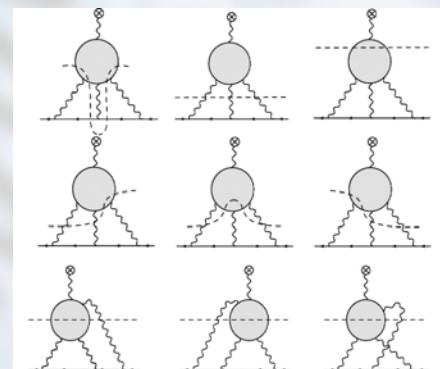
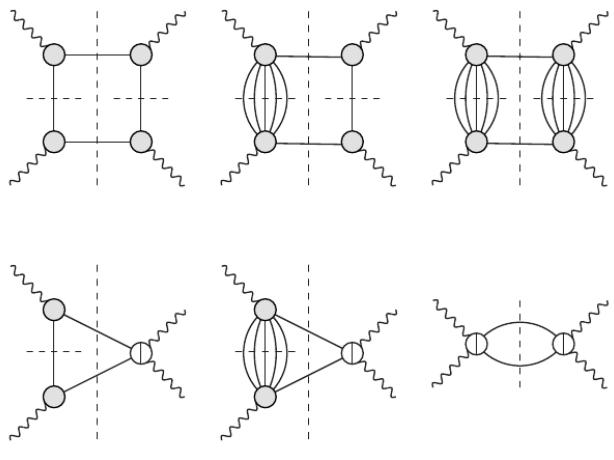
input: hadronic/radiative processes

cross-check: $\gamma^{(*)}\gamma^{(*)} \rightarrow \text{hadrons}$

Data driven dispersive HLB



$$\gamma^*\gamma^* \rightarrow \pi^0, \pi\pi$$



JHEP 1409 (2014) 091

G. Colangelo, M. Hoferichter, M. Procura and P. Stoffer

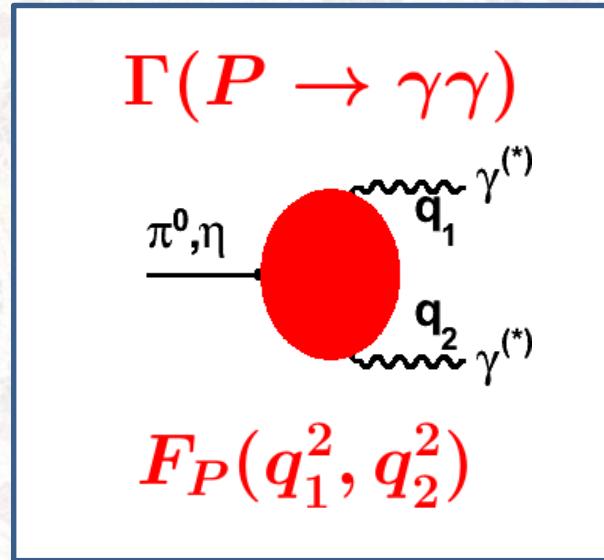
PRD90 (2014)113012

M. Vanderhaeghen, V. Pauk

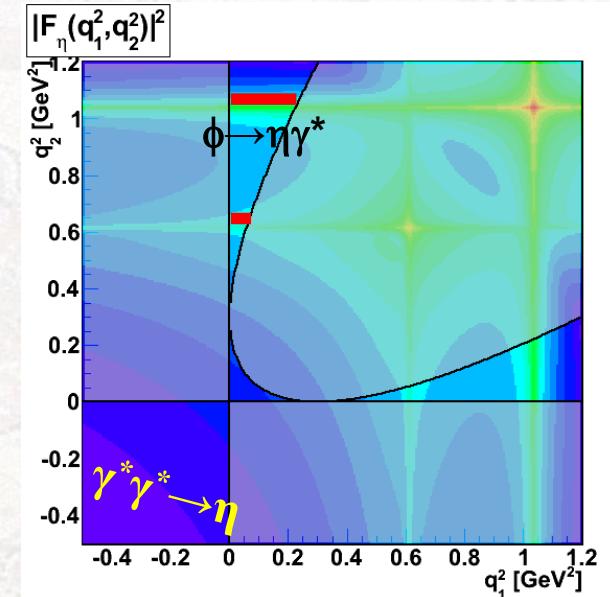
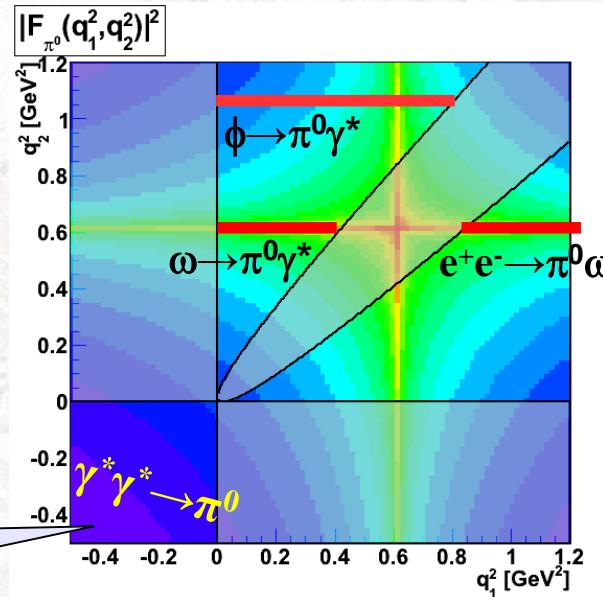
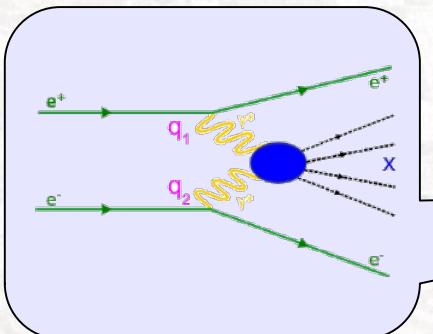
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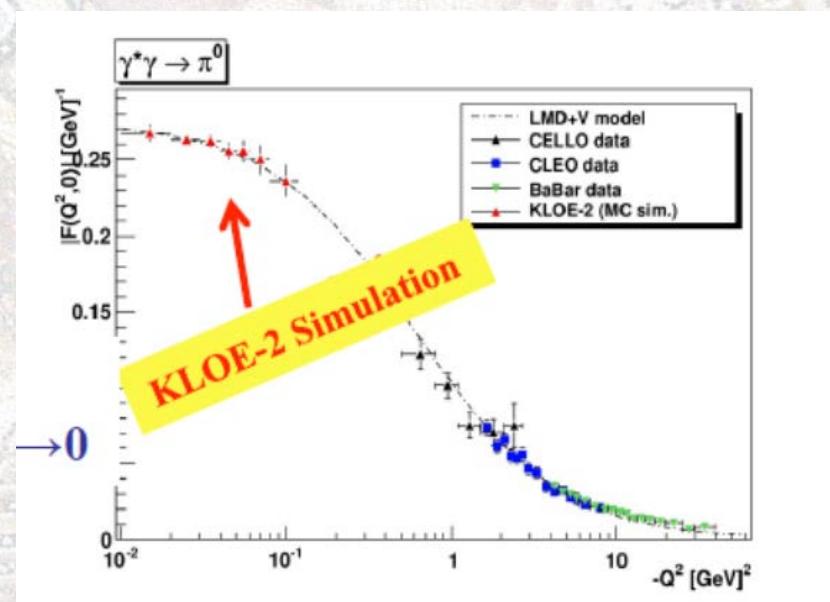
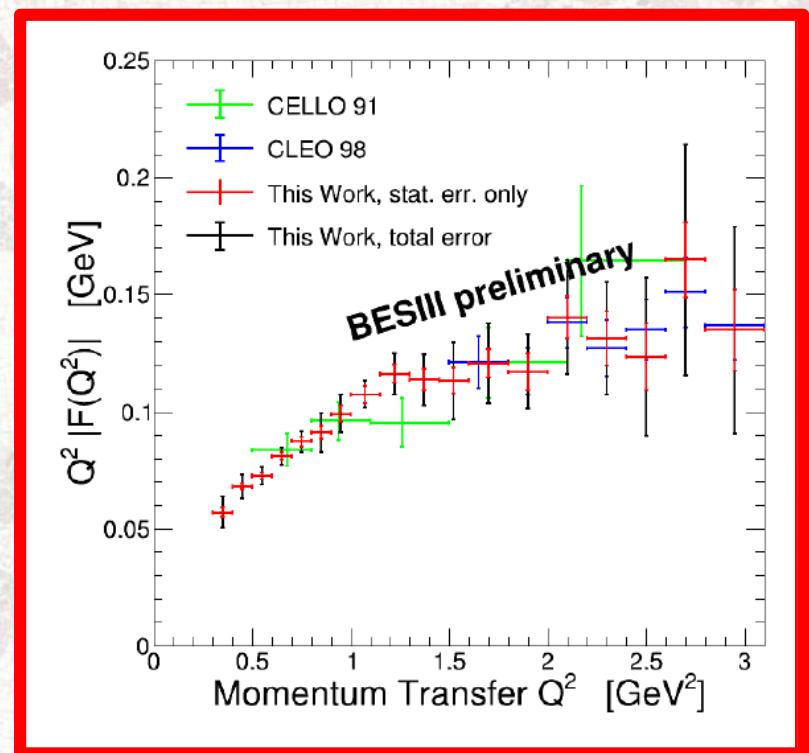
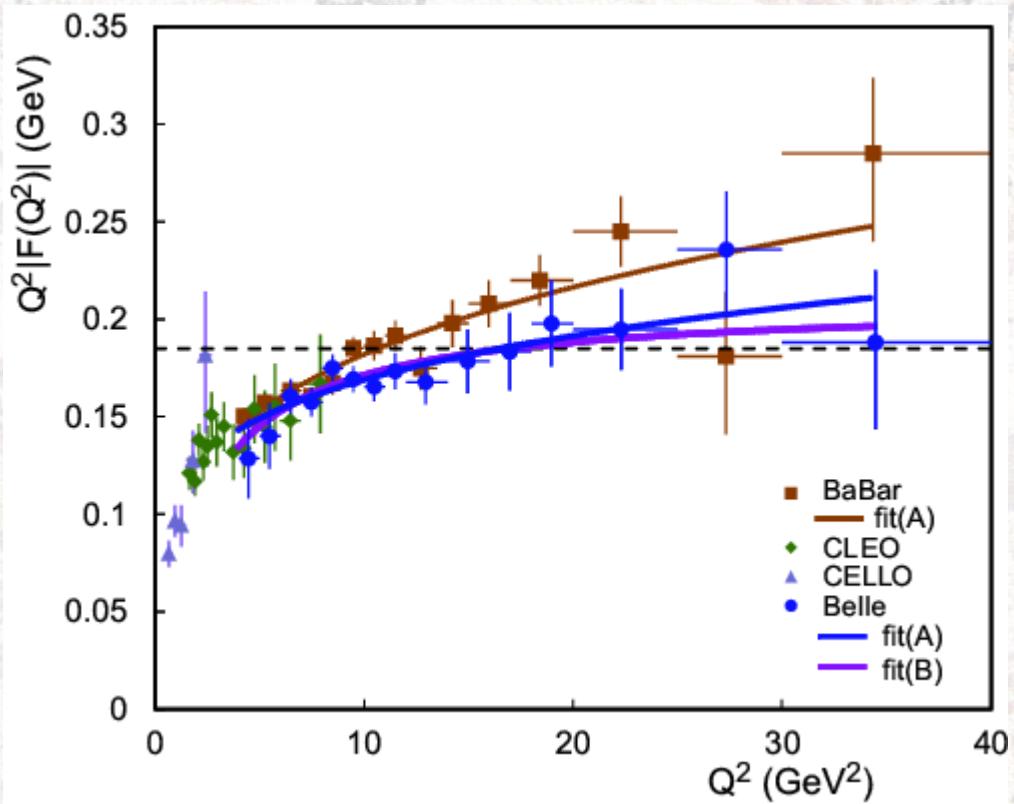
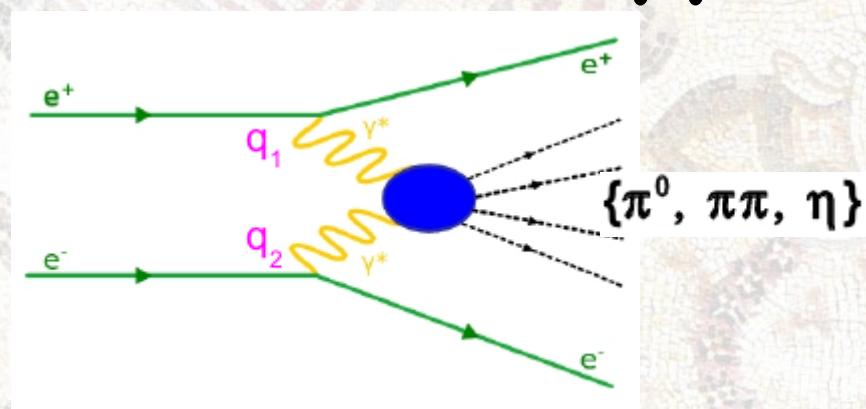
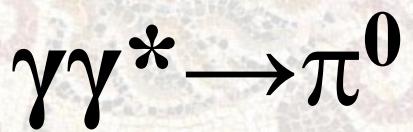
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π^0, η, η' Transition Form Factors (TFF)

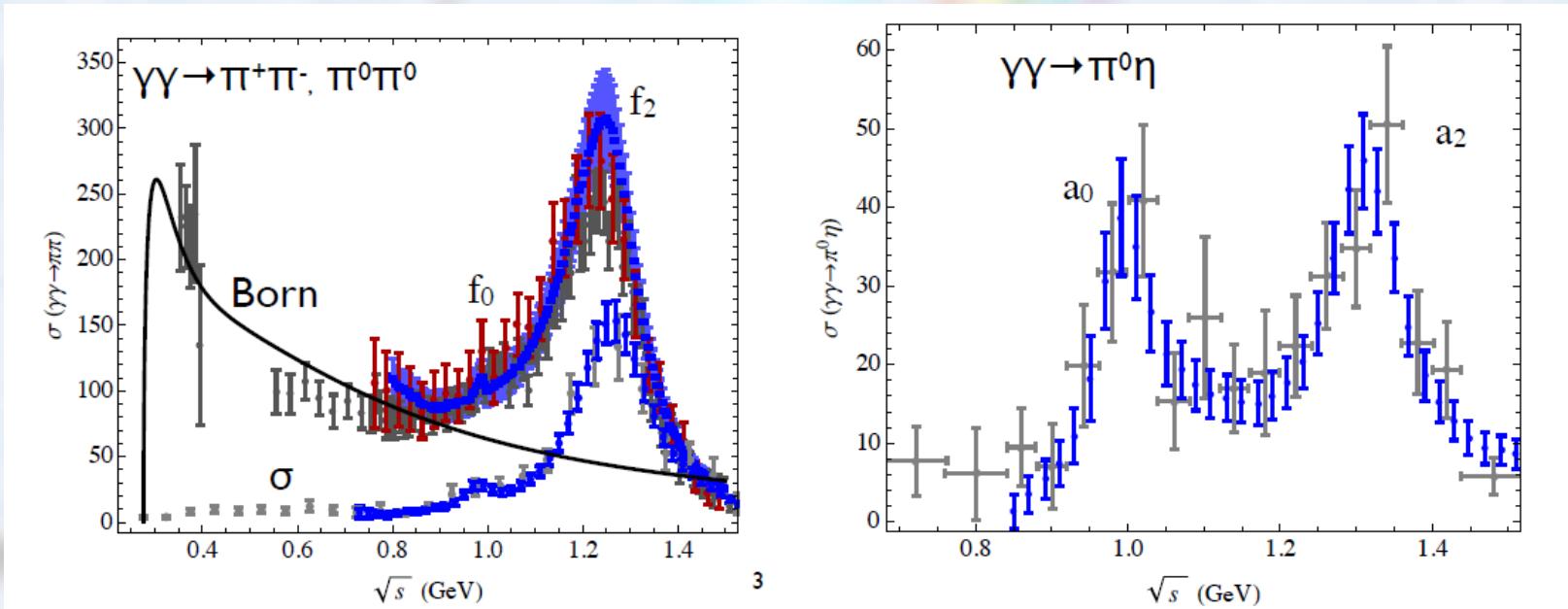


Access to $q^2 < 0$



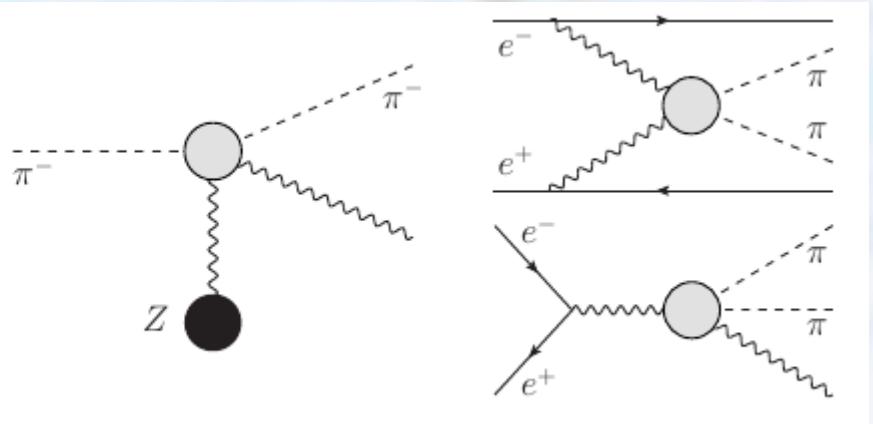


$\gamma^{(*)} \gamma^{(*)} \rightarrow \pi\pi; \eta\pi; K\bar{K}$

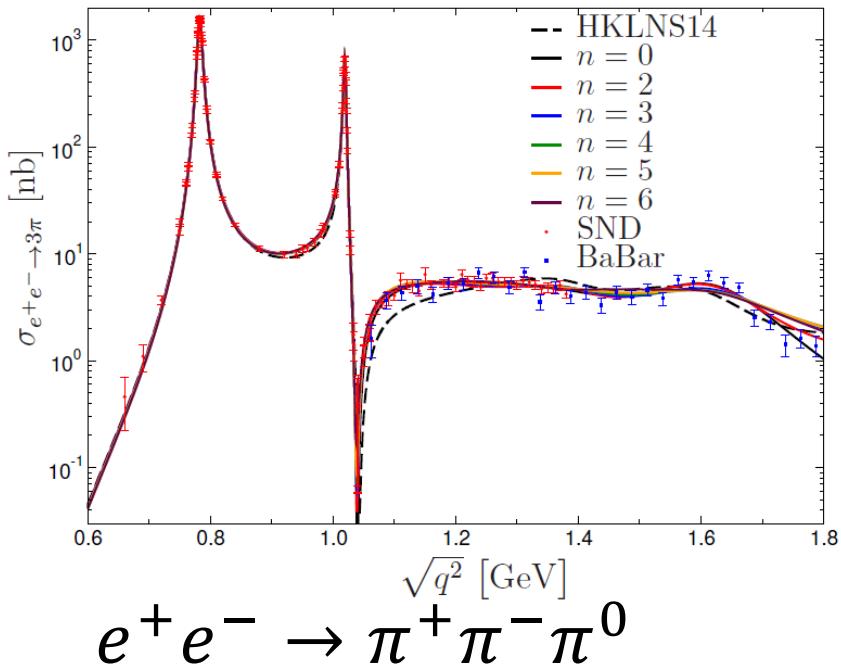


$\gamma\gamma \rightarrow \pi\pi, K\bar{K}, \eta\eta, \pi\eta$ (Belle: 07,08, 09,10, ..)
 $\gamma\gamma^* \rightarrow \pi\pi, \pi\eta$ (BESIII in progress)

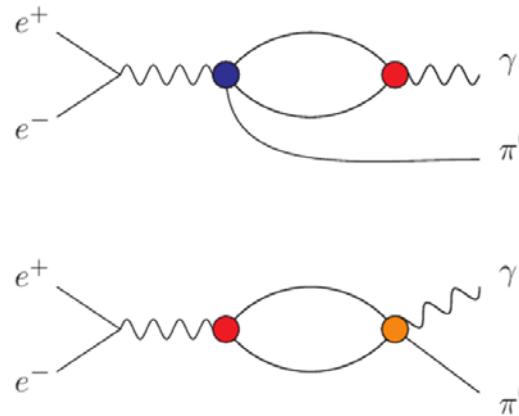
- ▶ Low energy: pion polar., ChPT
- ▶ Primakoff: $\gamma\pi \rightarrow \gamma\pi$ at COMPASS, JLAB
- ▶ Scattering: $e^+e^- \rightarrow e^+e^-\pi\pi$, $e^+e^- \rightarrow \pi\pi\gamma$
- ▶ Decays: $\omega, \phi \rightarrow \pi\pi\gamma$



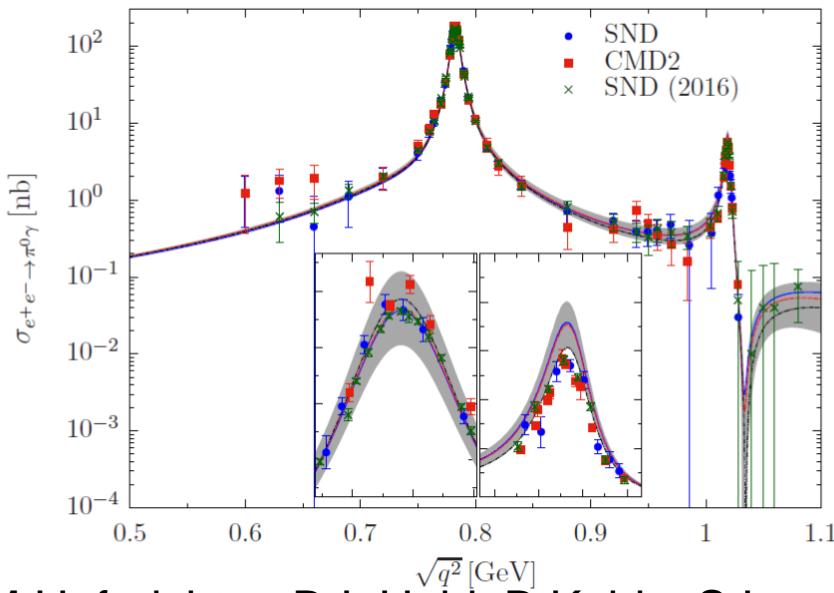
DP: $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ to π^0 TFF



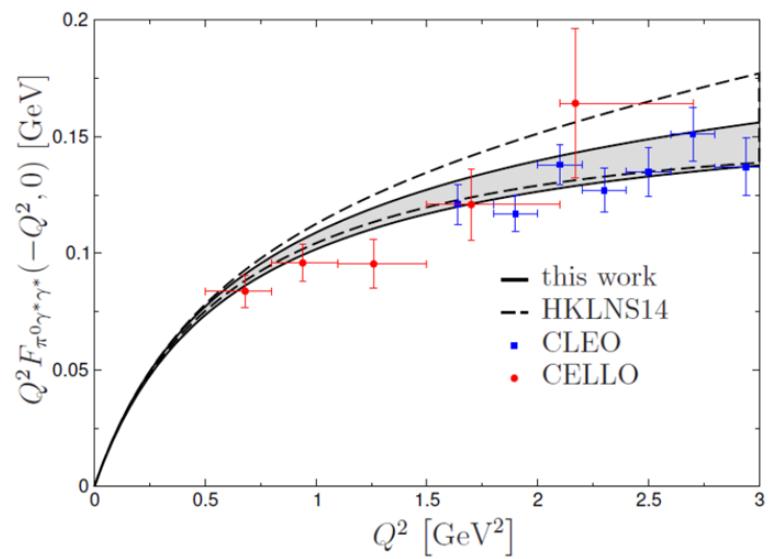
$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$



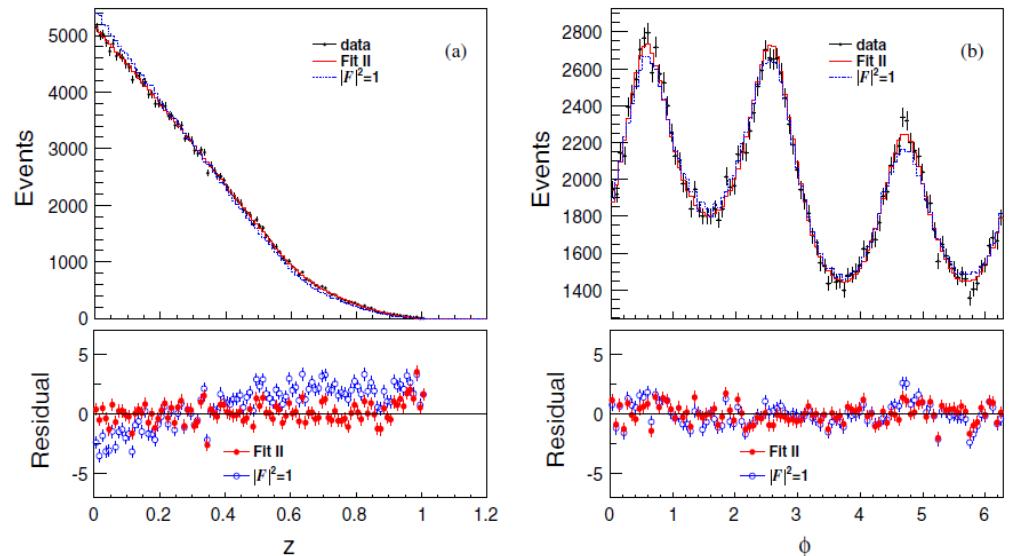
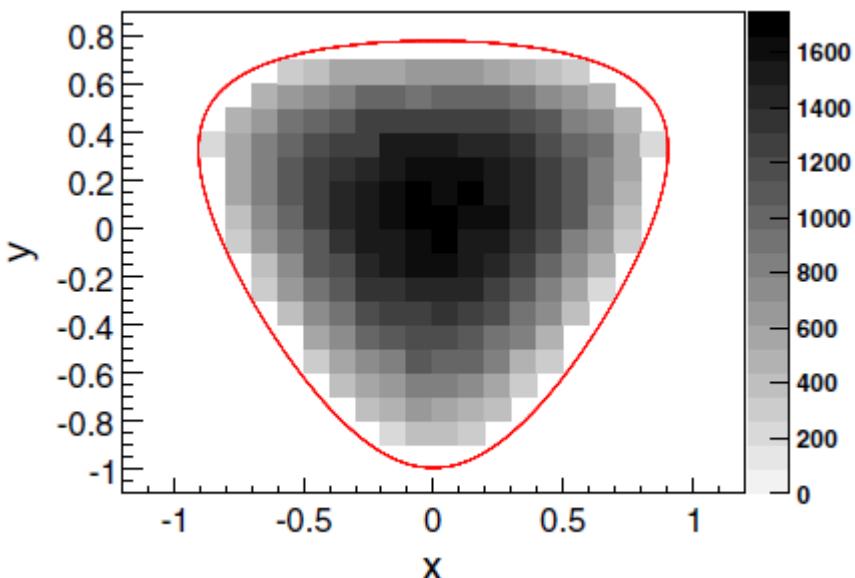
$\pi\pi$ phase shifts + $e^+e^- \rightarrow 3\pi$ data
Eur.Phys.J. C74 (2014) 3180



M Hoferichter, B-L Hoid, B Kubis, S Leupold, S P. Schneider
arXiv:1808.04823



$$\omega/\phi \rightarrow \pi^+ \pi^- \pi^0$$



BESIII: PRD98, 112007(2018)

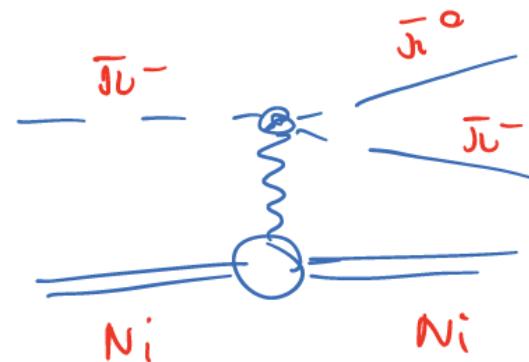
TABLE III. Predictions and fit results for the \mathcal{F} parametrizations. The predictions are from Danilkin *et al.* [4], Niecknig *et al.* [5], and Terschlüsen *et al.* [19]. Theoretical predictions without incorporating crossed-channel effects are indicated by w/o and those with crossed-channel effects by w.

Para. $\times 10^3$	Theoretical predictions				Experiment	
	Ref. [4]		Ref. [5]		Ref. [19]	BESIII
	w/o	w	w/o	w		
Fit I	α	136	94	(137,148)	(84,96)	202
Fit II	α	125	84	(125,135)	(74,84)	190
	β	30	28	(29,33)	(24,28)	54
						$132.1 \pm 6.7 \pm 4.6$
						$120.2 \pm 7.1 \pm 3.8$
						$29.5 \pm 8.0 \pm 5.3$

Goal of COMPASS experiment

- ▷ Test ChPT predictions for pion-photon reactions $\pi^- \gamma \rightarrow X^-$ with various final states X^-

$$\pi^- + \gamma^{(*)} \rightarrow \begin{cases} \pi^- + \gamma & \text{Compton reaction, pion polarisabilities} \\ \pi^- + \pi^0 & \text{single-pion production, chiral anomaly} \\ \pi^- + \pi^0 + \pi^0 & \text{double-pion prod., chiral tree \& loop} \\ \dots \end{cases}$$



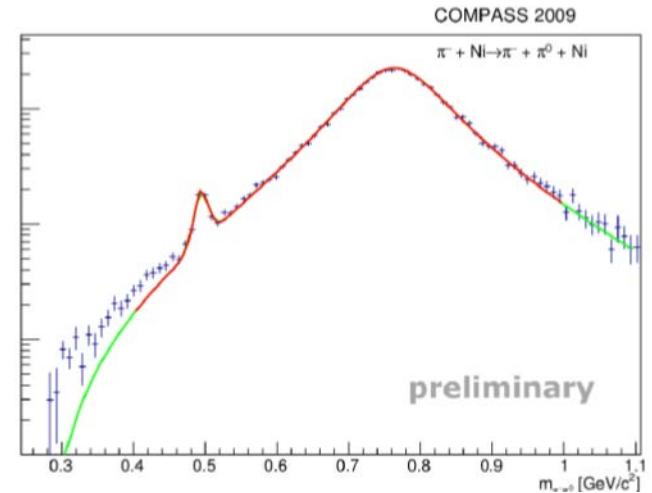
Dominik Steffen | g-2 workshop Mainz | 19.06.2018

COMPASS has acquired large Primakoff data set

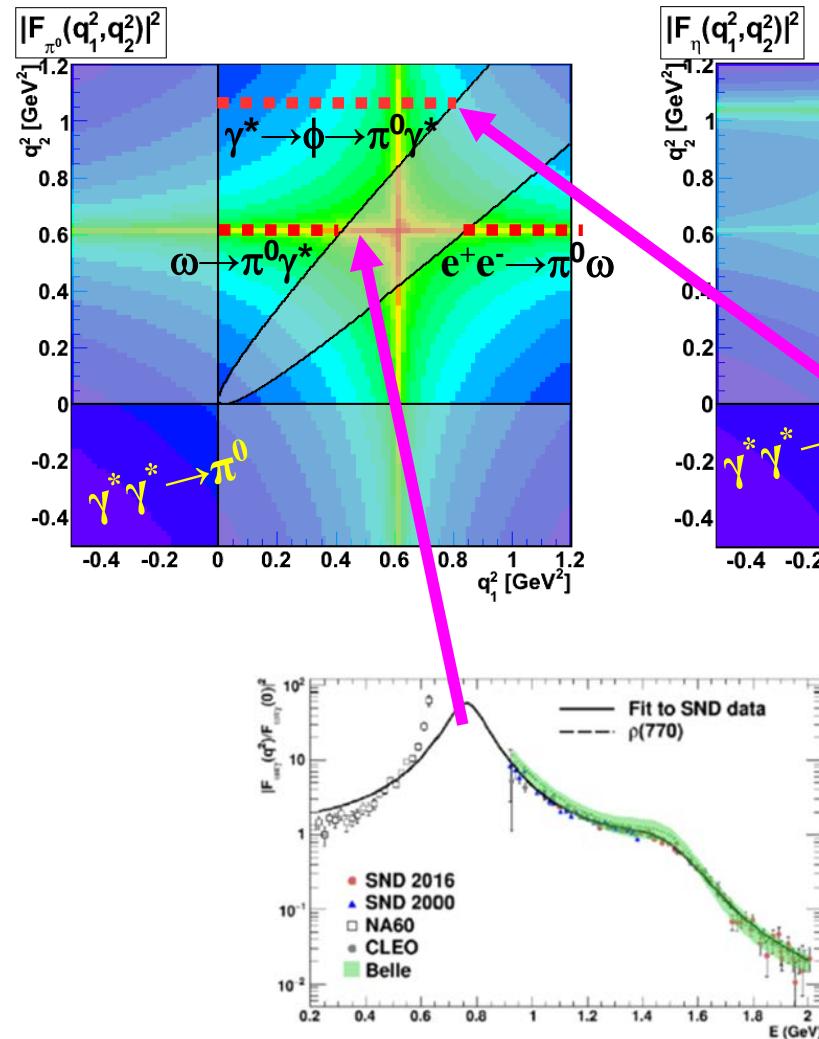
- ▷ Measurements from channel $\pi^- + \gamma^{(*)} \rightarrow \pi^- \pi^0$:
 - Chiral anomaly $\gamma \rightarrow 3\pi$
 - Radiative width of light-quark isovector mesons ($\rho(770)^- \rightarrow \pi^- \gamma$)
- ▷ Data from run 2009 give consistent picture:
 - Fit in good agreement with data
 - Normalizing to radiative width of $\rho(770)$ yields value for $F_{3\pi}$ in agreement with theoretical result
- ▷ 4x larger data set to come from 2012 data
- ▷ Possibility to extend analysis to measure radiative couplings of excited ρ states

$F_{3\pi}$ at COMPASS

Conclusion



$V \rightarrow P\gamma^*$ and $e^+e^- \rightarrow PV$ processes



KLOE

result $b\eta(m_\phi^2)$
 $\phi \rightarrow \eta \gamma^*$ BR 10^{-4}

Phys.Lett. B742 (2015) 1-6

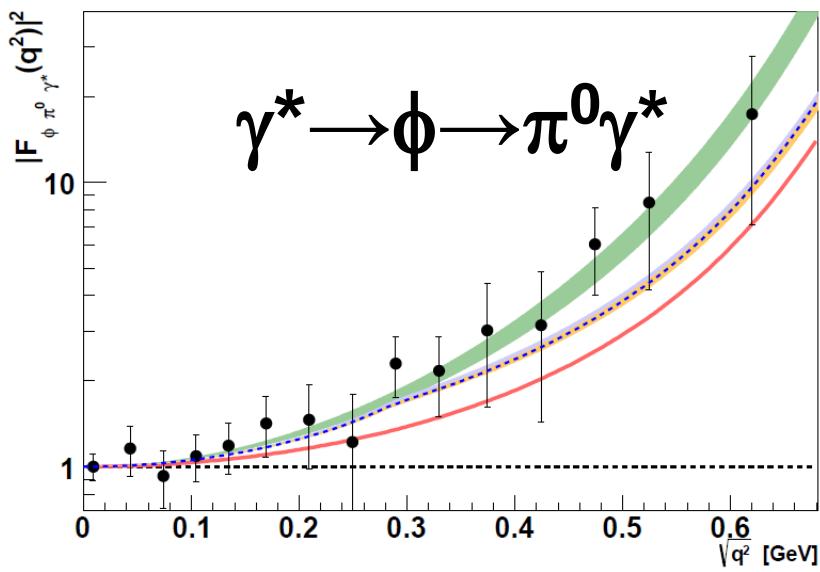
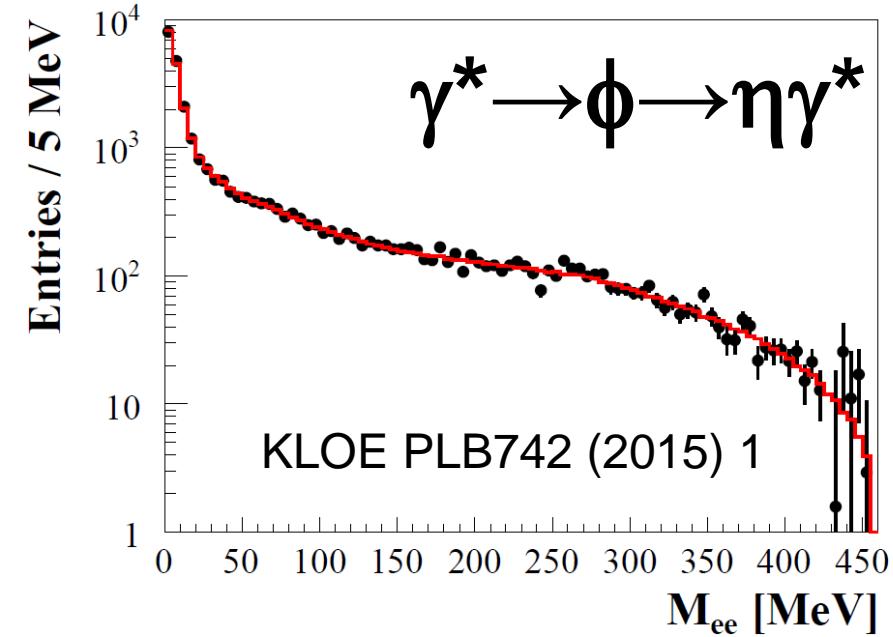
$$b_{\phi\eta} = (1.17 \pm 0.10^{+0.07}_{-0.11}) \text{ GeV}^{-2}$$

$$b\pi^0(m_\phi^2) \phi \rightarrow \pi^0 \gamma^* \text{ BR } 10^{-5}$$

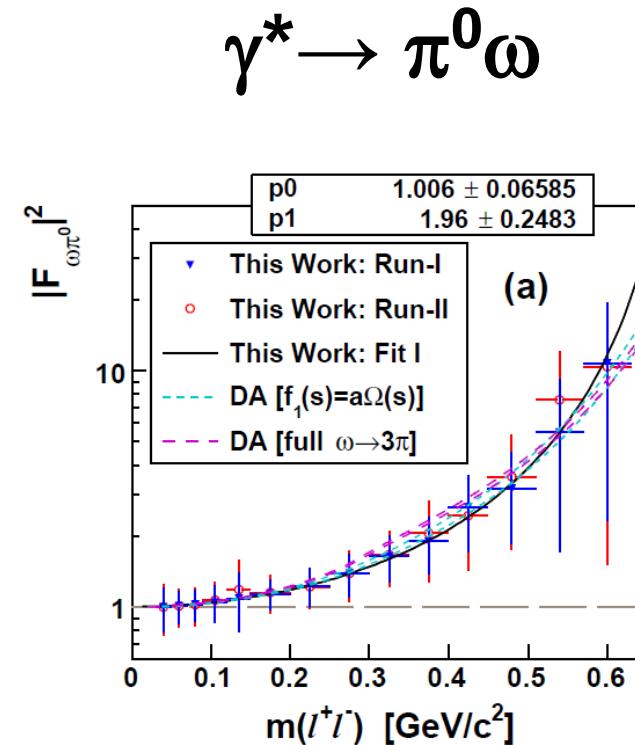
Phys.Lett. B757 (2016) 362-367

In addition to SND and NA60, other data on $\mathcal{F}(\gamma\omega\pi)$ exist:
 CLEO ($\tau^- \rightarrow \omega\pi^-\nu_\tau$), K.W. Edwards et al., Phys. Rev. D61 (2000) 072003
 Belle ($\bar{B}^0 \rightarrow D^{*+}\omega\pi^-$), D. Matvienko et al., Phys. Rev. 92 (2015) 012013
 NA60 studied inclusively $\omega \rightarrow \pi^0 \mu^+ \mu^-$

$$b\varphi\pi^0 = (2.02 \pm 0.11) \text{ GeV}^{-2}$$

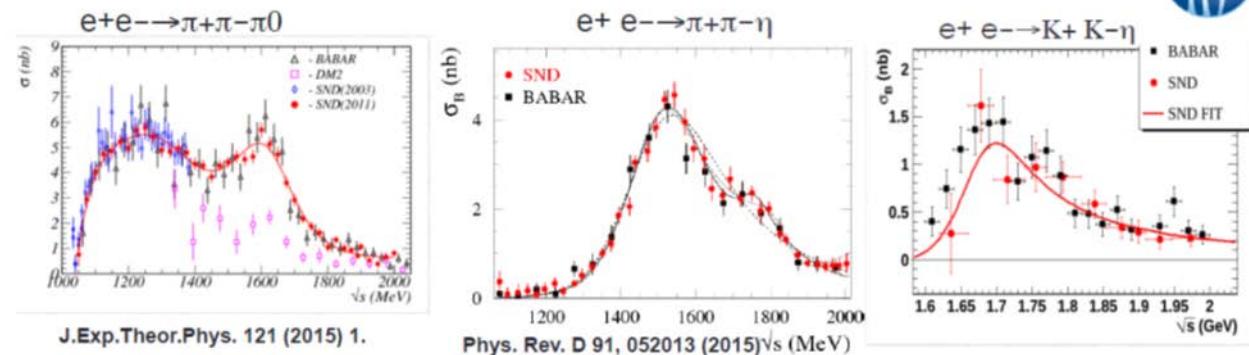


KLOE PLB757 (2016) 362

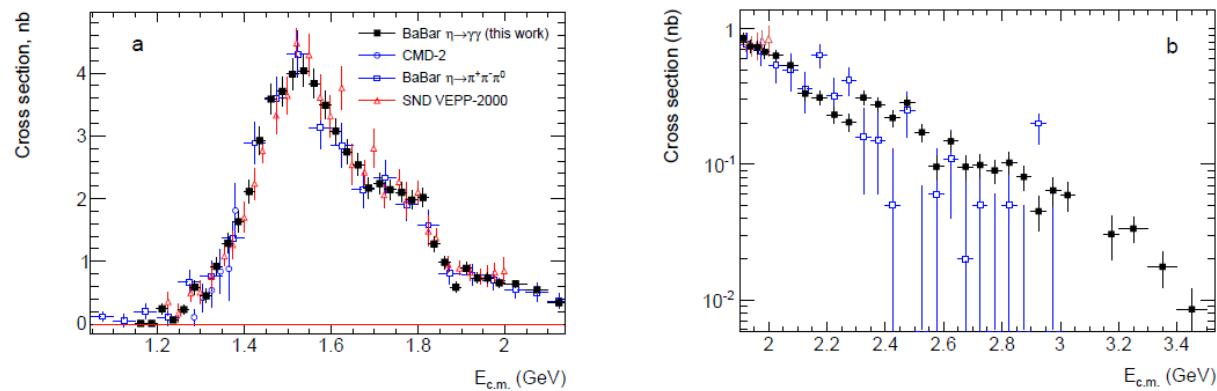


A2 Phys.Rev. C95 (2017) 025202

Some SND results overview



$e^+e^- \rightarrow \eta\pi^+\pi^-$ at BaBar



More precise result \Rightarrow first observation of the $\rho(1700)$ in $\eta\pi^+\pi^-$

J.P. Lees et al., Phys. Rev. D97 (2018) 052007

DR: Similar strategy for η as for π^0
From $e^+e^- \rightarrow \pi^+\pi^-\eta$ to η TFF
arXiv:1509.02194

$\eta' \rightarrow \pi^+\pi^-e^+e^-$
 $\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$] BESIII
in progress

Radiative widths of η, π^0

$\eta: 5 \times 10^{-19}$ s; $\Gamma = 1.3$ keV	$\eta \rightarrow \gamma\gamma$
$\pi^0: 8 \times 10^{-17}$ s; $c\tau = 25$ nm	$\pi^0 \rightarrow \gamma\gamma$

Two exp. techniques:

$\gamma Z \rightarrow \eta, \pi^0$ Primakoff

PrimEx PRL 106, 162303(2011)

PrimEx-II:

$\Gamma(\pi^0 \rightarrow \gamma\gamma) = 7.80 \text{ eV} \pm 0.7\% \text{ stat.} \pm 1.5\% \text{ syst.}$

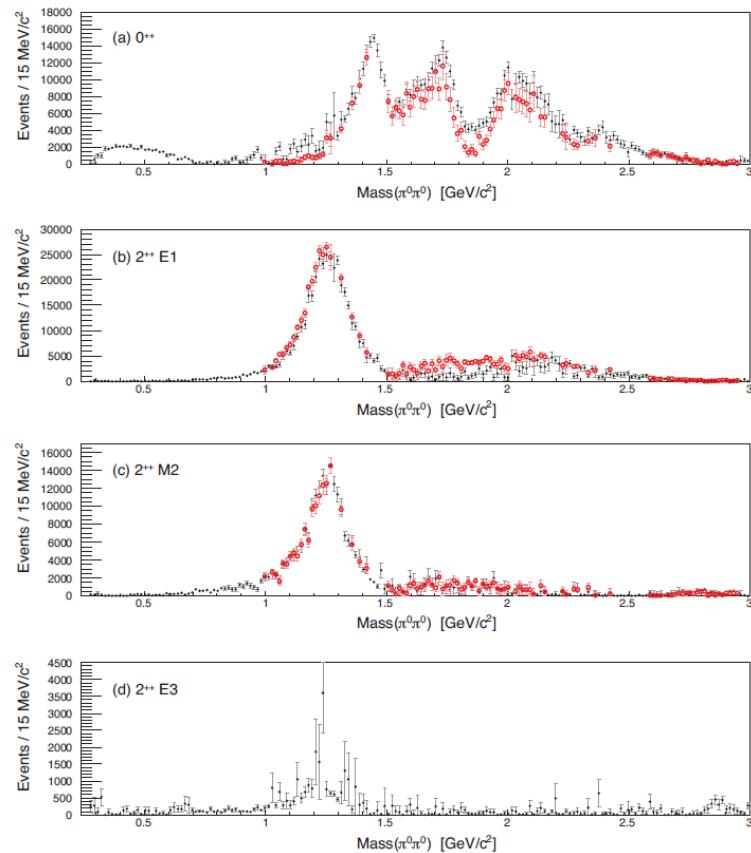
$e^+e^-: \gamma\gamma \rightarrow \pi^0$

KLOE-2 Taggers
 $5 \text{ fb}^{-1} \Rightarrow \delta\Gamma(\pi^0 \rightarrow \gamma\gamma)$

Details: [EPJC 72, 1917 (2012)]

VALUE (keV)	EVTS	DOCUMENT ID	TECN	COMMENT
0.515 ± 0.018	OUR FIT			
0.516 ± 0.018	OUR AVERAGE			
			$\delta\Gamma(\eta \rightarrow \gamma\gamma) \sim 3.5\%$	
$0.520 \pm 0.020 \pm 0.013$		BABUSCI	2013A	$e^+e^- \rightarrow e^+e^-\eta$
$0.51 \pm 0.12 \pm 0.05$	36	BARU	1990	$e^+e^- \rightarrow e^+e^-\eta$
$0.490 \pm 0.010 \pm 0.048$	2287	ROE	1990	$e^+e^- \rightarrow e^+e^-\eta$
$0.514 \pm 0.017 \pm 0.035$	1295	WILLIAMS	1988	$e^+e^- \rightarrow e^+e^-\eta$
$0.53 \pm 0.04 \pm 0.04$		BARTEL	1985E	$e^+e^- \rightarrow e^+e^-\eta$
••• We do not use the following data for averages, fits, limits, etc. •••				
0.476 ± 0.062		1 RODRIGUES	2008	CNTR Reanalysis
$0.64 \pm 0.14 \pm 0.13$		AIHARA	1986	$e^+e^- \rightarrow e^+e^-\eta$
0.56 ± 0.16	56	WEINSTEIN	1983	$e^+e^- \rightarrow e^+e^-\eta$
0.324 ± 0.046		BROWMAN	1974B	CNTR Primakoff effect
1.00 ± 0.22		2 BEMPORAD	1967	CNTR Primakoff effect

Amplitude analysis of the $\pi^0\pi^0$ system in radiative J/ ψ decays



BESIII Phys.Rev. D92 (2015) 052003