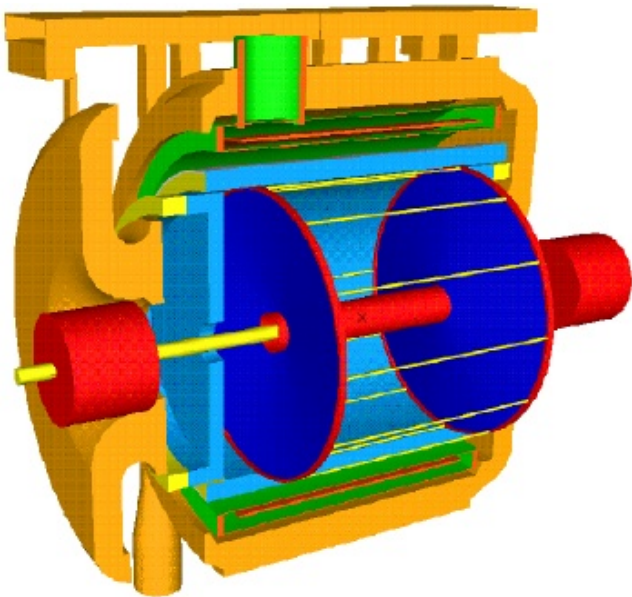




Hadron physics with KLOE and KLOE-2



Andrzej Kupść
Uppsala University
for the KLOE-2 Collaboration



KLOE-2 status

Results KLOE/plans for KLOE-2

Meson Transition Form Factors:

– $\gamma\gamma \rightarrow \eta$ at 1 GeV $\Rightarrow \Gamma_{\gamma\gamma}$

Prel arXiv:1107.3782 [hep-ex]

– $\eta \rightarrow e^+e^-e^+e^-$

PLB702 (2011) 324

– $e^+e^- \rightarrow \phi \rightarrow \eta e^+e^-$ (U boson searches)

PLB706 (2012) 251

– $e^+e^- \rightarrow \gamma \eta$

Prel arXiv:1107.3782 [hep-ex]

– $\eta \rightarrow \pi^+\pi^-\gamma$

Prel arXiv:1107.5733 [hep-ex]

– σ meson radiative width

Prel arXiv:1107.3782 [hep-ex]

KLOE/KLOE-2 talk:

M. Silarski

$K_S \rightarrow 3\pi^0$

Posters:

L. Caldeira-Barkeståhl $\eta \rightarrow \pi^+\pi^-\pi^0$

C. F. Redmer $\eta' \rightarrow \pi^+\pi^-\eta$

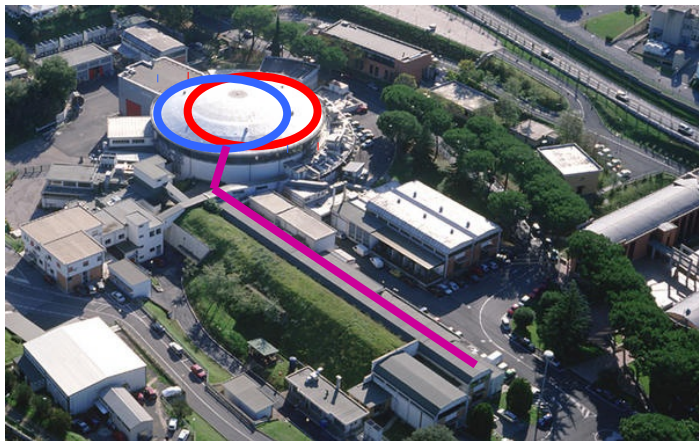


DAΦNE luminosity upgrade



Frascati ϕ -factory

e^+e^- collider $\sqrt{s} = M_\phi$



KLOE-2 IP collisions:

end 2010

Severe HW problems:

long shutdowns

Commissioning for KLOE-2

start Nov 2011

Today: $L = 1.5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

with 1.3 A + 700/800 mA,

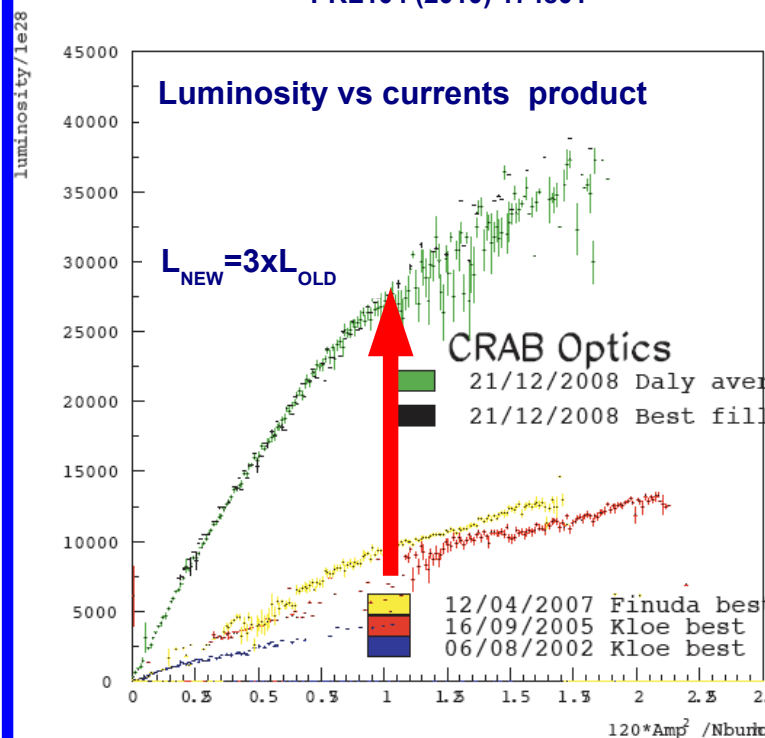
7pb-1/day

Novel interaction scheme:

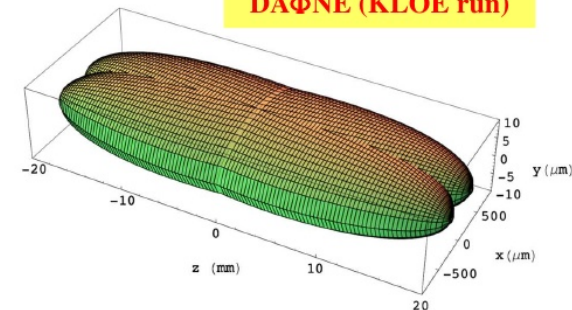
large angle beam crossing

+ crabbed waist sextupoles $\Rightarrow$ SuperB

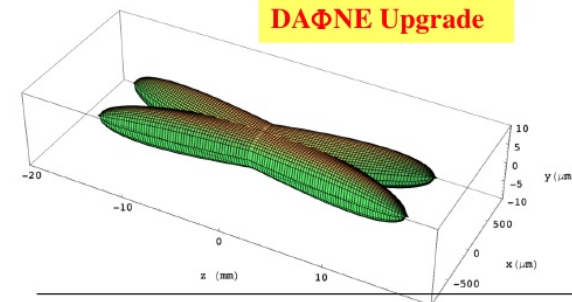
PRL104 (2010) 174801



DAΦNE (KLOE run)



DAΦNE Upgrade



KLOE-2:

Extension of the KLOE physics program at upgraded DAΦNE



KLOE → KLOE-2



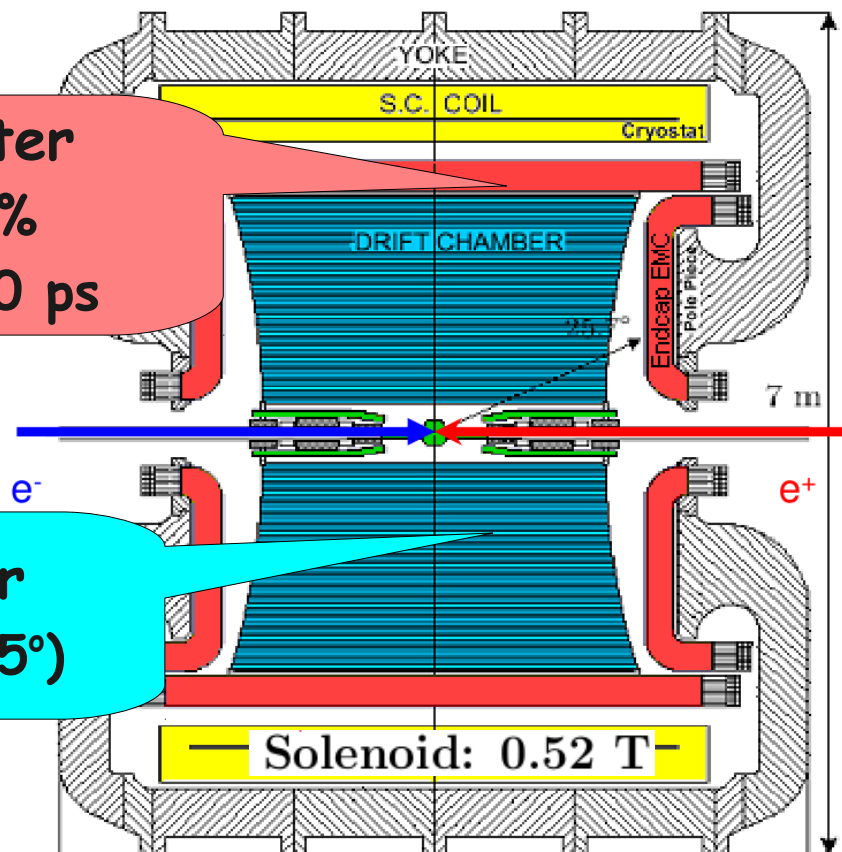
EM Calorimeter

$$\delta E/E = 5.7/\sqrt{E} \%$$

$$\delta t = 57/\sqrt{E} \oplus 100 \text{ ps}$$

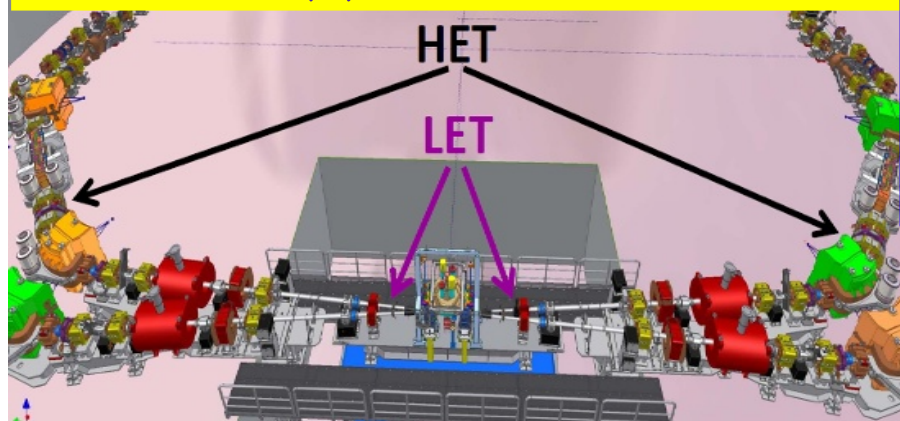
Drift Chamber

$$\delta p_T \sim 0.4\% (\theta < 45^\circ)$$



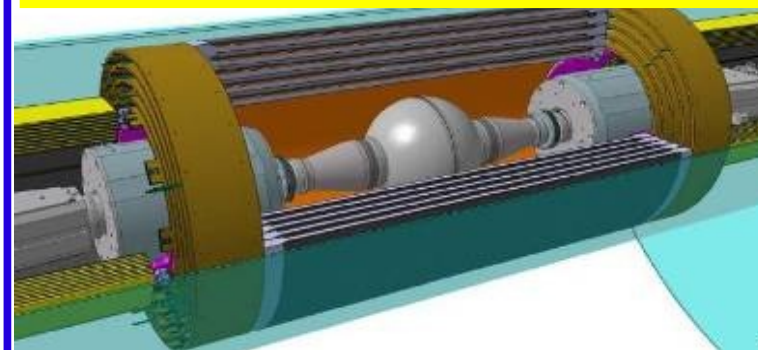
2+2 taggers for:

$$e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^- X$$

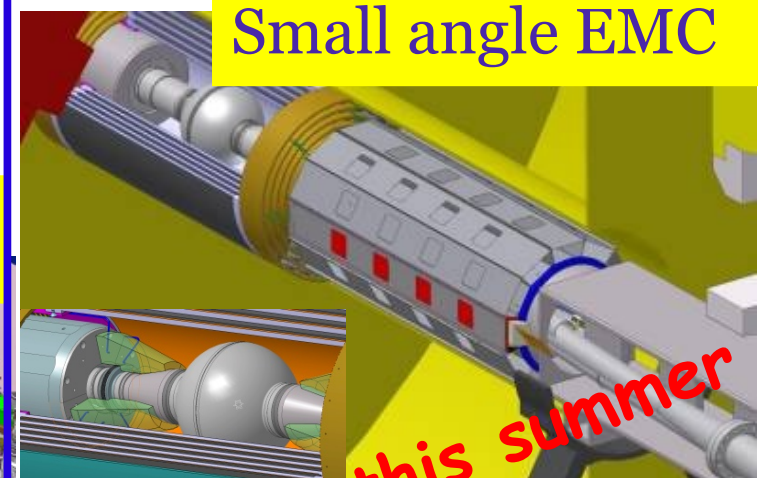


Next upgrades

Inner Tracker: cyl. GEM



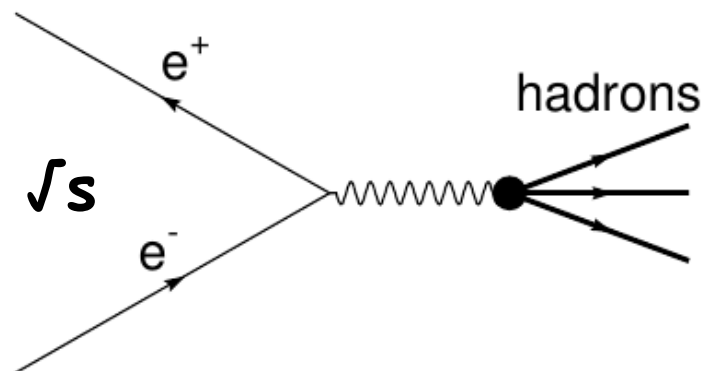
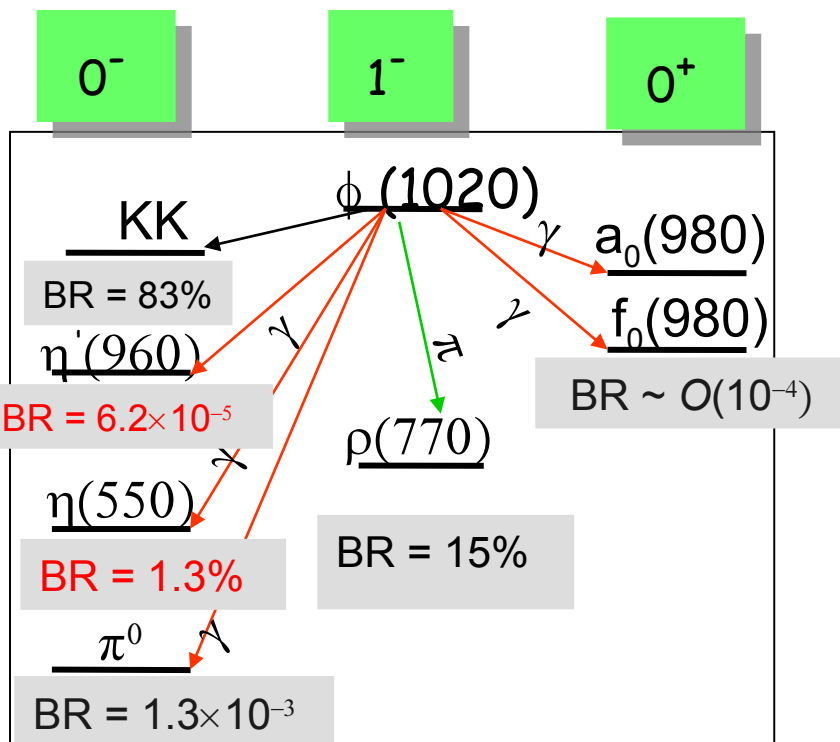
Small angle EMC



Ready this summer



$\gamma^* \rightarrow (\phi) \rightarrow \text{Hadrons}$



ϕ decay	Produced ev/fb^{-1}
K^+K^-	1.5×10^9
$K_L K_S$	1.0×10^9
η	5×10^7
η'	2×10^5

$\sigma_{\text{peak}} \sim 3.1 \mu\text{b}$

KLOE: 2.5 fb^{-1} @ $\sqrt{s} = M_\phi$ ($\sim 8 \times 10^9 \phi$ produced)

+ 250 pb^{-1} @ 1000 MeV (off-peak data)

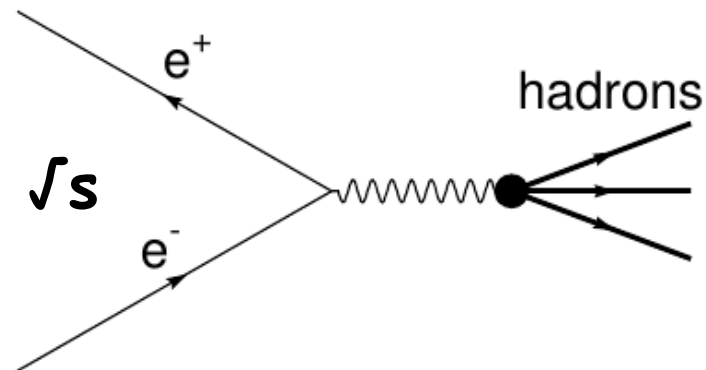
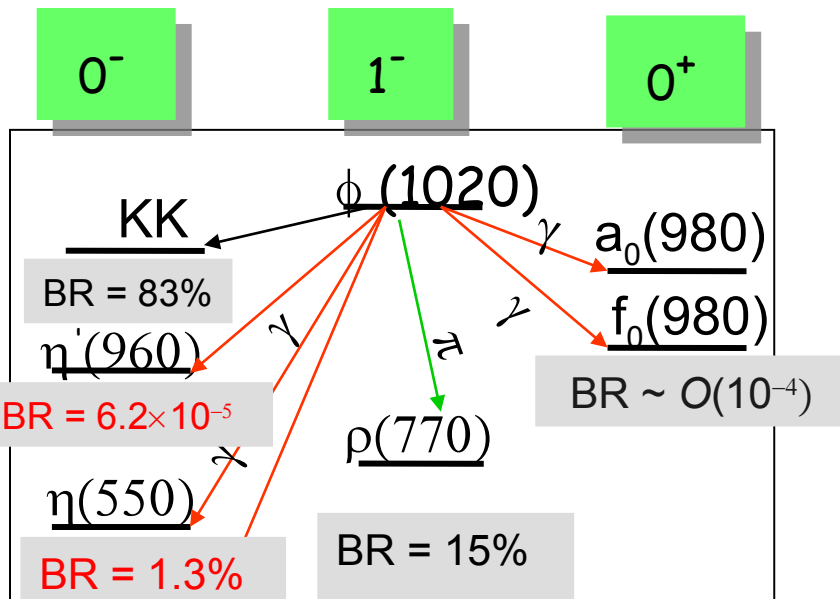
$\sigma_T(1\text{GeV})$ 80 nb

+ scan $\pm 20 \text{ MeV} \sim O(10 \text{ pb}^{-1})$

KLOE 2001-2005 data



$\gamma^* \rightarrow (\phi) \rightarrow \text{Hadrons}$



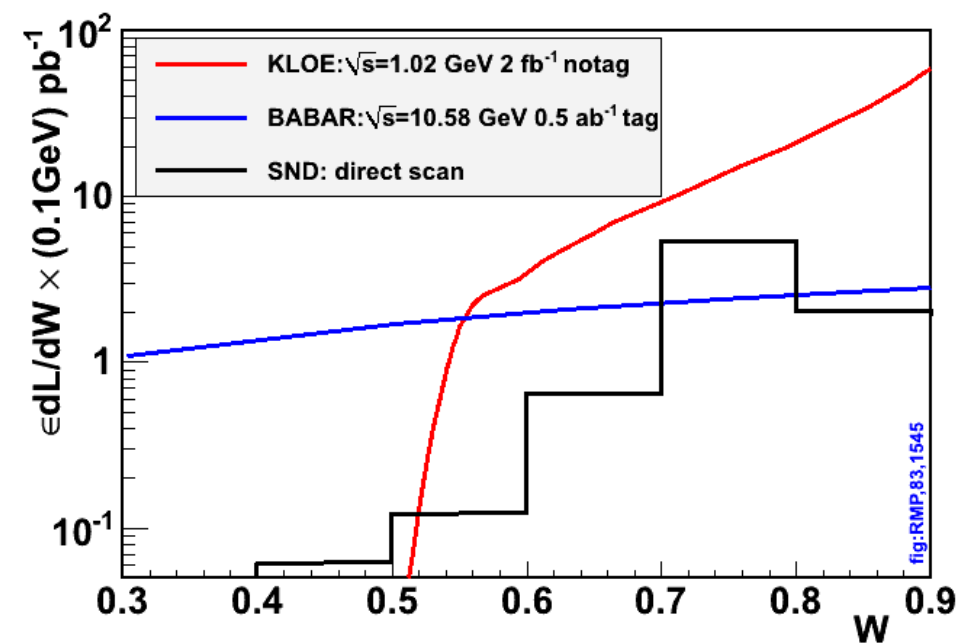
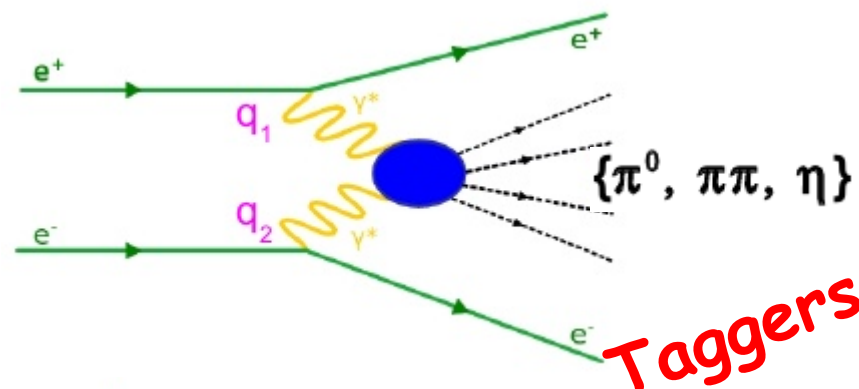
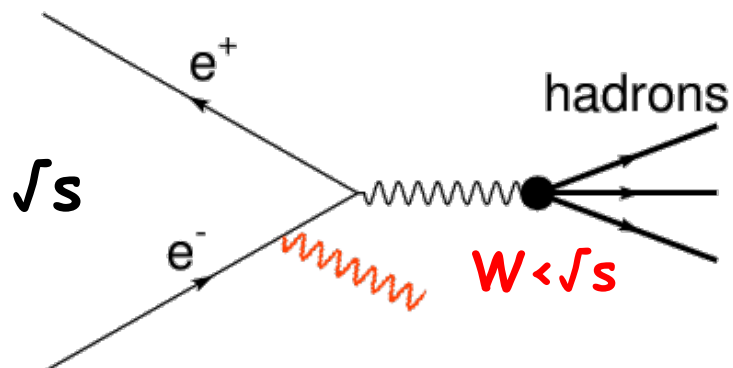
- $\Gamma(\phi \rightarrow \eta' \gamma) / \Gamma(\phi \rightarrow \eta \gamma)$, PLB 541 (2002) 45
- $\phi \rightarrow \eta \pi^0 \gamma$, PLB 536 (2002) 209
- $\phi \rightarrow \pi^0 \pi^0 \gamma$, PLB 537 (2002) 21
- $\phi \rightarrow \pi^+ \pi^- \pi^0$, PLB 561 (2003) 55
- $\eta \rightarrow \gamma \gamma \gamma$, PLB 591 (2004) 49
- $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$, PLB 606 (2005) 12
- $\eta \rightarrow \pi^+ \pi^-$, PLB 606 (2005) 276
- $\Gamma(\phi \rightarrow l^+ l^-)$, PLB 608 (2005) 199
- $\phi \rightarrow \pi^+ \pi^- \gamma$, PLB 634 (2006) 148
- η mass, JHEP 12 (2007) 073
- $e^+ e^- \rightarrow \pi^0 \pi^0 \gamma$, EPJC 49 (2007) 473
- $\Gamma(\phi \rightarrow \eta' \gamma) / \Gamma(\phi \rightarrow \eta \gamma)$, PLB 648 (2007) 267

- $\eta \rightarrow \pi^+ \pi^- \pi^0$, JHEP 05 (2008) 006
- $e^+ e^- \rightarrow \omega \pi^0$, PLB 669 (2008) 223
- $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$, PLB 670 (2009) 285
- η / η' mixing, JHEP 07 (2009) 105
- $\eta \rightarrow \pi^+ \pi^- e^+ e^-$, PLB 675 (2009) 283
- $\phi \rightarrow K^0 \bar{K}^0 \gamma$, PLB 679 (2009) 10
- $\phi \rightarrow \eta \pi^0 \gamma$, PLB 681 (2009) 5
- $\eta \rightarrow \pi^0 \pi^0 \pi^0$, PLB 694 (2010) 16
- $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$, PLB 700 (2011) 102
- $\eta \rightarrow e^+ e^- e^+ e^-$, PLB 702 (2011) 324
- $\phi \rightarrow \eta e^+ e^-$, arXiv:1110.0411, subm. to PLB



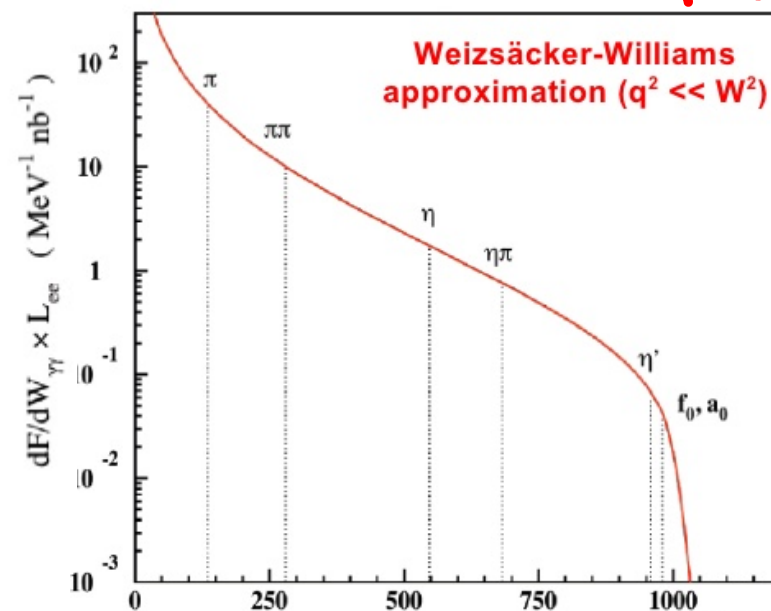
ISR

$\gamma\gamma$



KLOE: $F_V(W)$ in $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$

Luminosity



$$e^+ e^- \rightarrow e^+ e^- \gamma^* \gamma^* \rightarrow \boxed{e^+ e^-} \boxed{X}$$

to taggers
(HET or LET)

in KLOE



Meson Transition Form Factors (TFF)

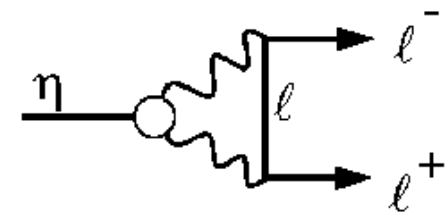
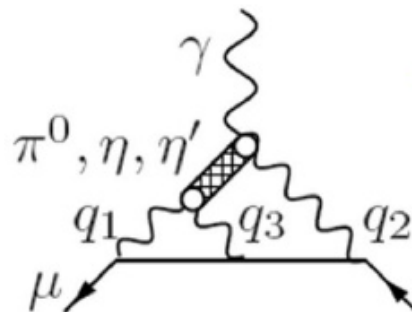
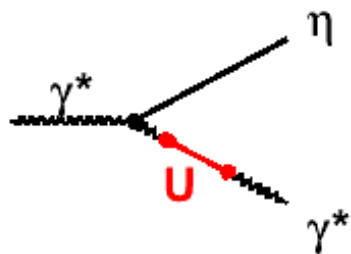
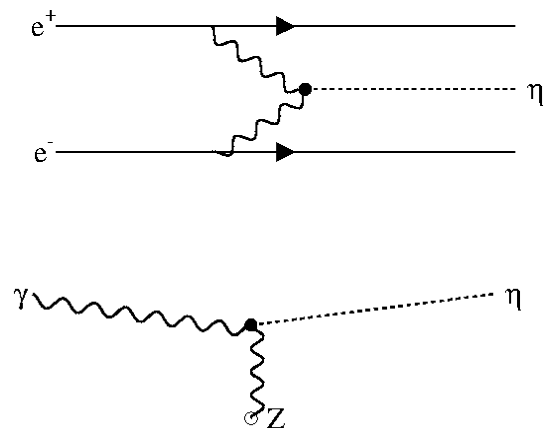
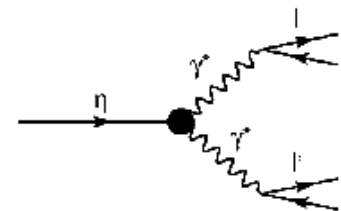
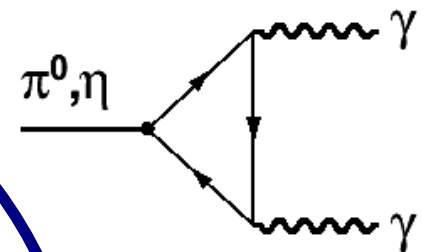
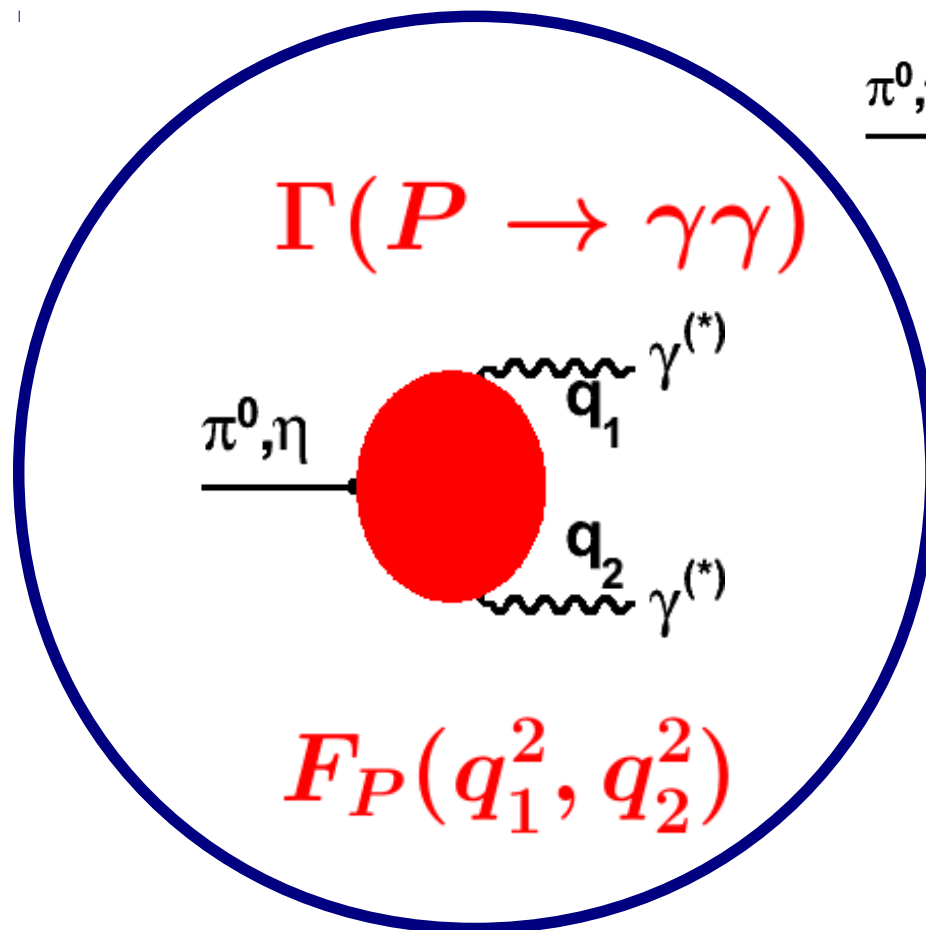


Low energy QCD

l^+l^- spectra for QGP

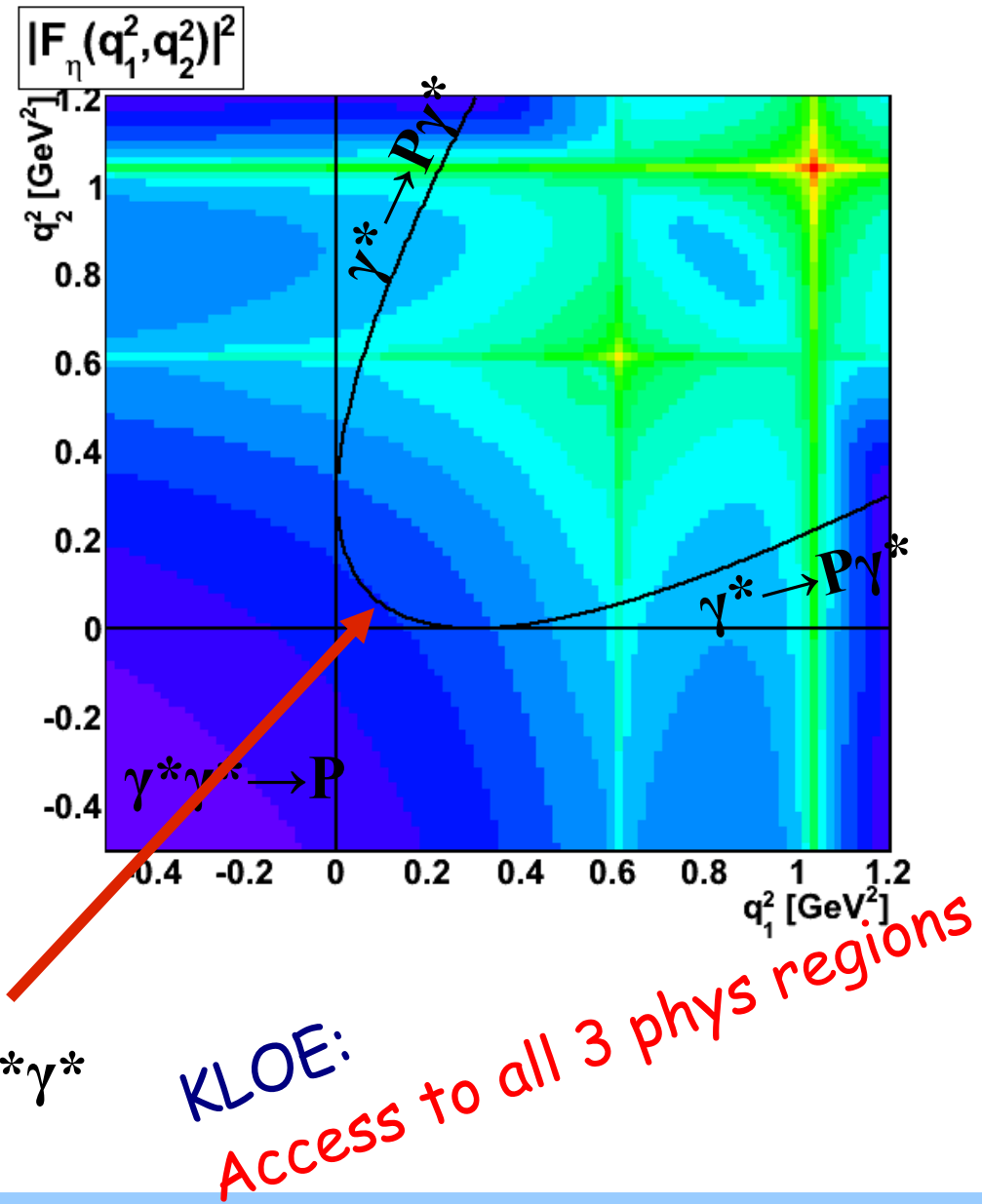
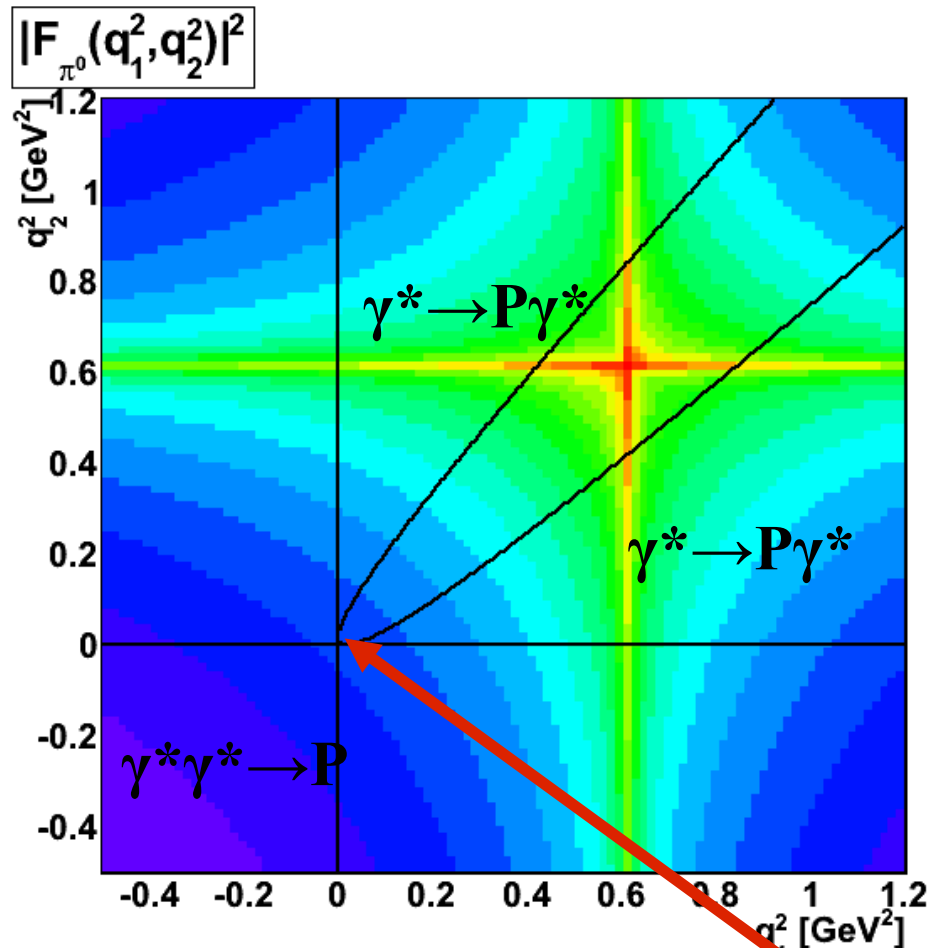
SM contribution to a_μ

U boson





Meson Transition Form Factors



$P \rightarrow \gamma^* \gamma^*$



η, π^0 : narrow and short lived

$$\Rightarrow \Gamma_{\text{tot}} = \Gamma_{\gamma\gamma} / \text{BR}_{\gamma\gamma}$$

Two kind of measurements

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

$$\delta\Gamma(\pi^0 \rightarrow \gamma\gamma) \sim 2.8\%$$

PrimEx PRL 106,162303(2011)

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

$$\sigma(\gamma^*\gamma^* \rightarrow P) = \frac{16\pi^2}{m_P^3} \Gamma_{\gamma\gamma} |F(q_1^2, q_2^2)|^2 \sqrt{(q_1 \cdot q_2)^2 - q_1^2 q_2^2} \delta((q_1 + q_2)^2 - m_P^2)$$

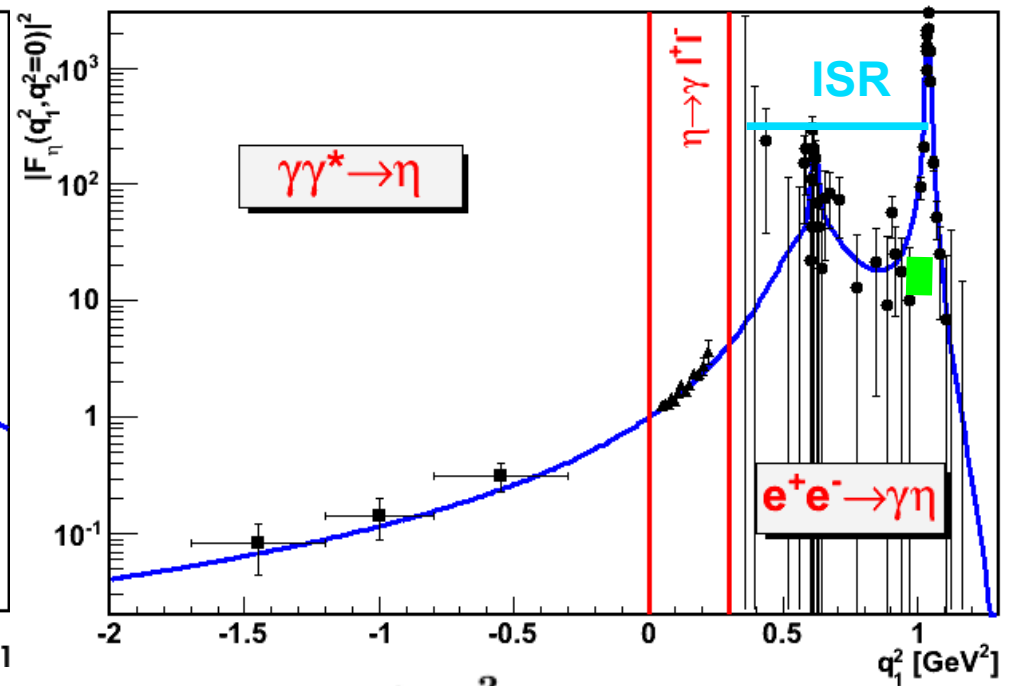
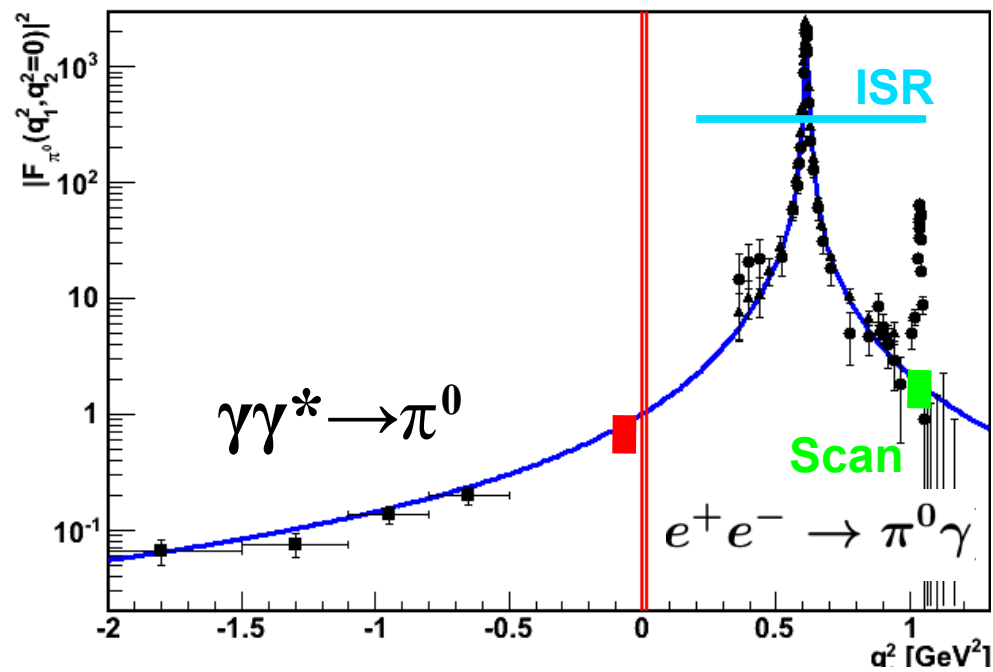
$\Gamma_{\gamma\gamma}$ fundamental parameter

$\Rightarrow$ should be known precisely (eg m_u/m_d)

VALUE (keV)	EVTS	DOCUMENT ID	TECN	COMMENT
0.510 ± 0.026	OUR FIT			
0.510 ± 0.026	OUR AVERAGE			$\delta\Gamma(\eta \rightarrow \gamma\gamma) \sim 5\%$
0.51 ± 0.12 ± 0.05	36	BARU	90 MD1	$e^+e^- \rightarrow e^+e^-\eta$
0.490 ± 0.010 ± 0.048	2287	ROE	90 ASP	$e^+e^- \rightarrow e^+e^-\eta$
0.514 ± 0.017 ± 0.035	1295	WILLIAMS	88 CBAL	$e^+e^- \rightarrow e^+e^-\eta$
0.53 ± 0.04 ± 0.04		BARTEL	85E JADE	$e^+e^- \rightarrow e^+e^-\eta$
*** We do not use the following data for averages, fits, limits, etc. ***				
0.476 ± 0.062	1	RODRIGUES	08 CNTR	Reanalysis
0.64 ± 0.14 ± 0.13		AIHARA	86 TPC	$e^+e^- \rightarrow e^+e^-\eta$
0.56 ± 0.16	56	WEINSTEIN	83 CBAL	$e^+e^- \rightarrow e^+e^-\eta$
0.324 ± 0.046		BROWMAN	74B CNTR	Primakoff effect
1.00 ± 0.22	2	BEMPORAD	67 CNTR	Primakoff effect



η, π^0 single off shell TFF



$$\sigma(e^+e^- \rightarrow P\gamma) = 4\pi\alpha\Gamma_{\gamma\gamma}|F_P(s, 0)|^2 \left(\frac{s - m_P^2}{sm_P} \right)^3$$



η, π^0 single off shell TFF

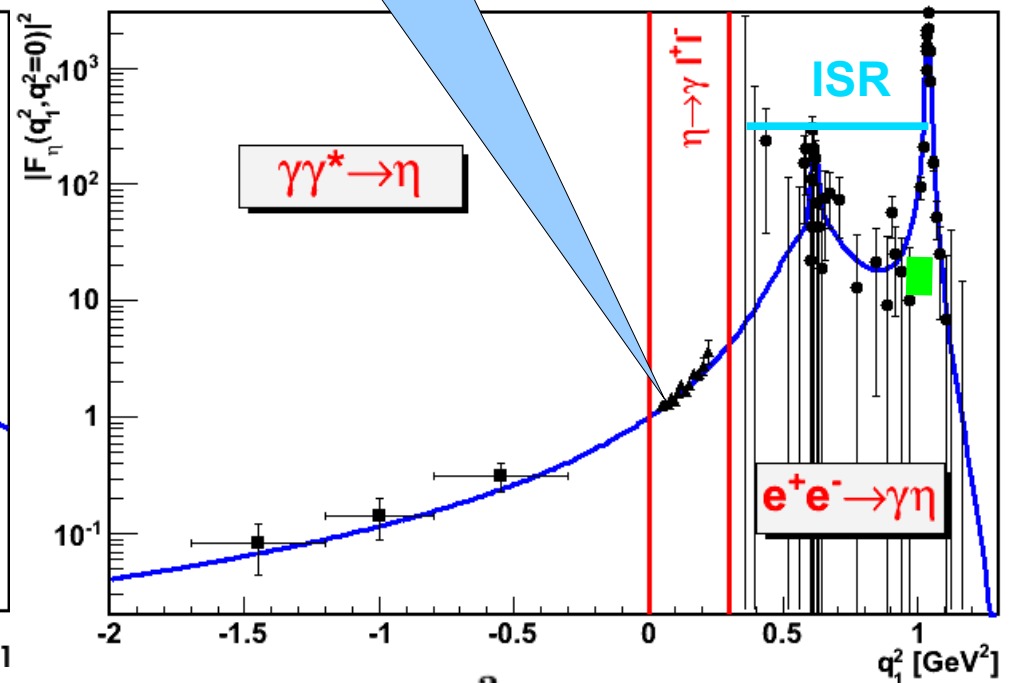
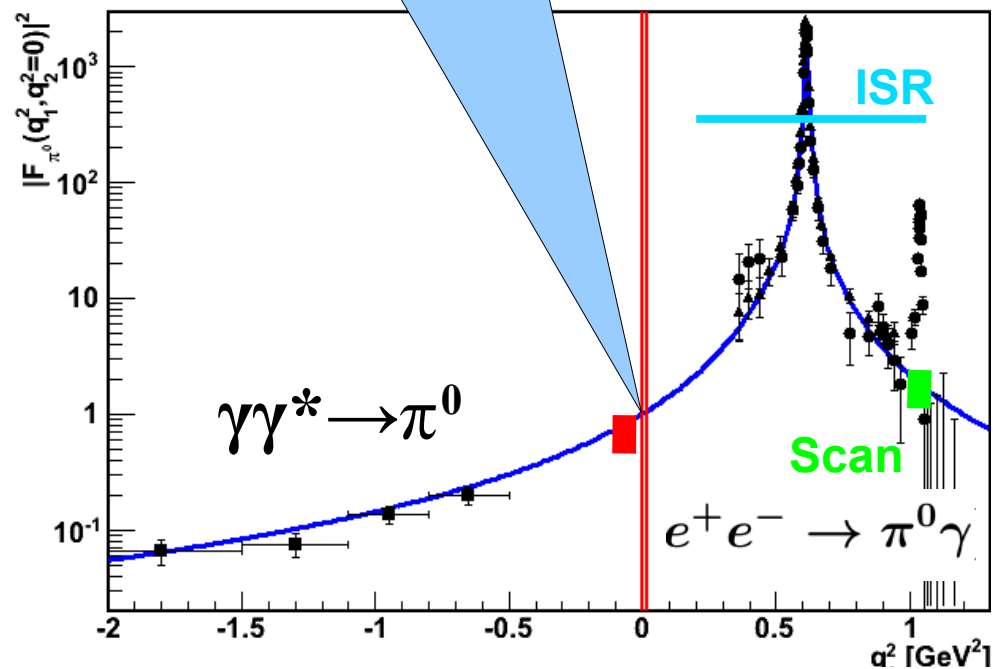


Details: [EPJC 72, 1917 (2012)]

KLOE-2 Taggers
 $5\text{fb}^{-1} \Rightarrow \delta\Gamma_{\gamma\gamma} \sim 1\%$

A.Nyffeler talk

$\eta \rightarrow \pi^+ \pi^- \gamma$



$$\sigma(e^+e^- \rightarrow P\gamma) = 4\pi\alpha\Gamma_{\gamma\gamma}|F_P(s, 0)|^2 \left(\frac{s - m_P^2}{sm_P} \right)^3$$



η, π^0 single off shell TFF



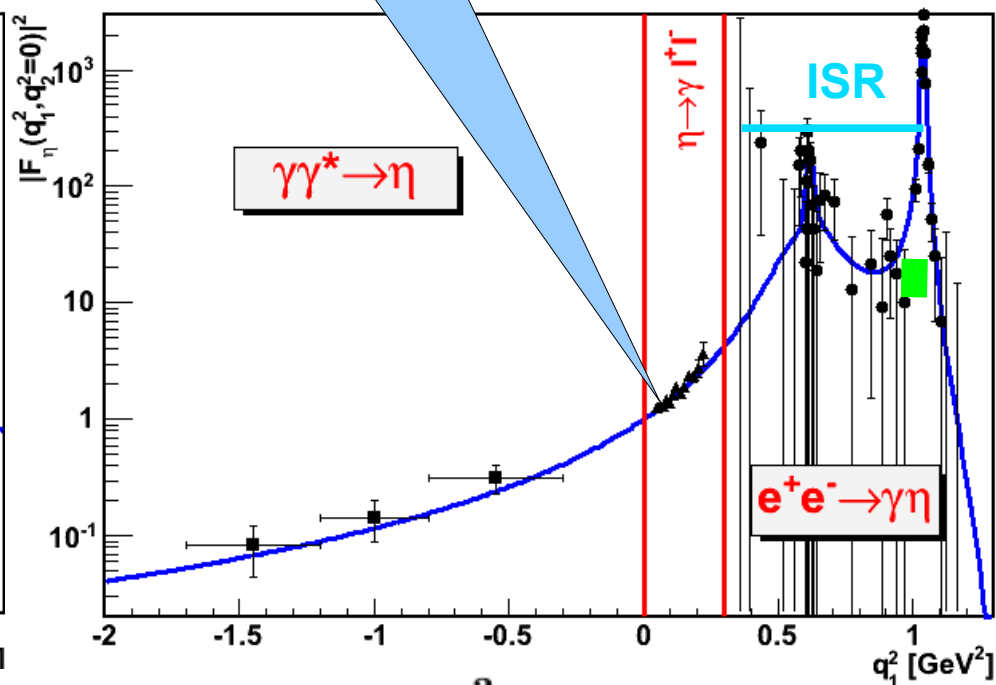
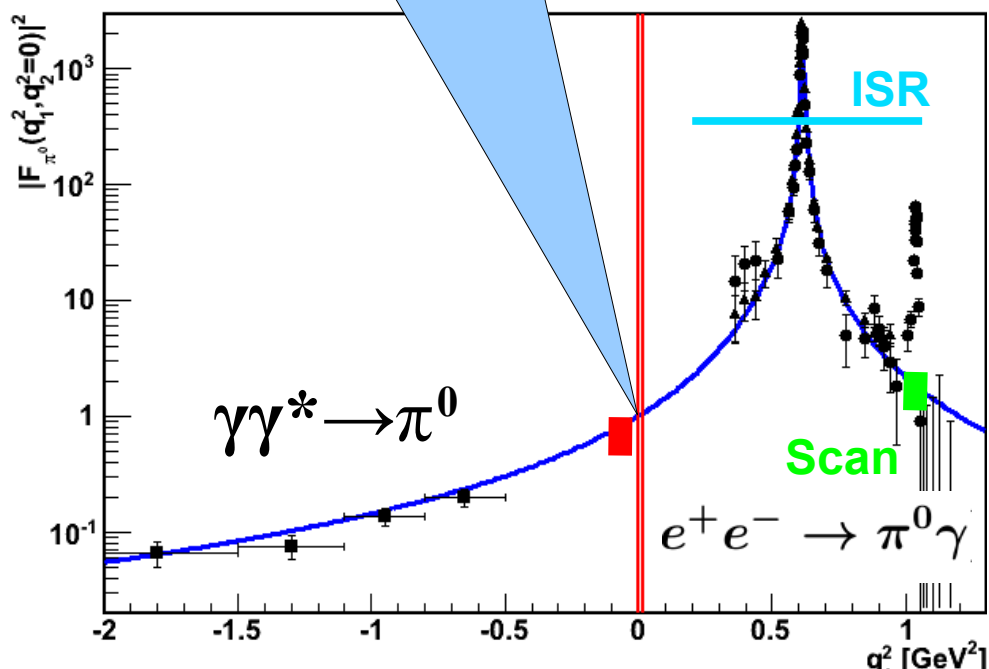
Details: [EPJC 72, 1917 (2012)]

KLOE-2 Taggers

$5\text{fb}^{-1} \Rightarrow \delta\Gamma_{\gamma\gamma} \sim 1\%$

A.Nyffeler talk

$\eta \rightarrow \pi^+ \pi^- \gamma$



$$\sigma(e^+e^- \rightarrow P\gamma) = 4\pi\alpha\Gamma_{\gamma\gamma}|F_P(s, 0)|^2 \left(\frac{s - m_P^2}{sm_P} \right)^3$$

An independent $\Gamma_{\gamma\gamma}$ measurement?

$\Rightarrow \delta\sigma \sim \text{few\%}$ $q < 0.6 \text{ GeV}$ $O(100\text{pb})$

$\Rightarrow$ precision TFF



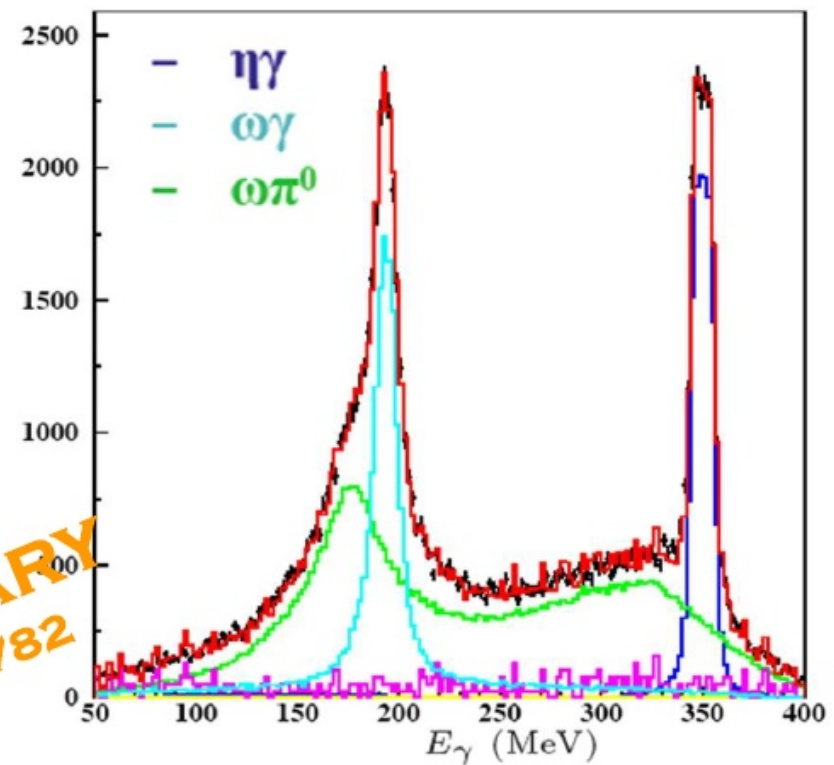
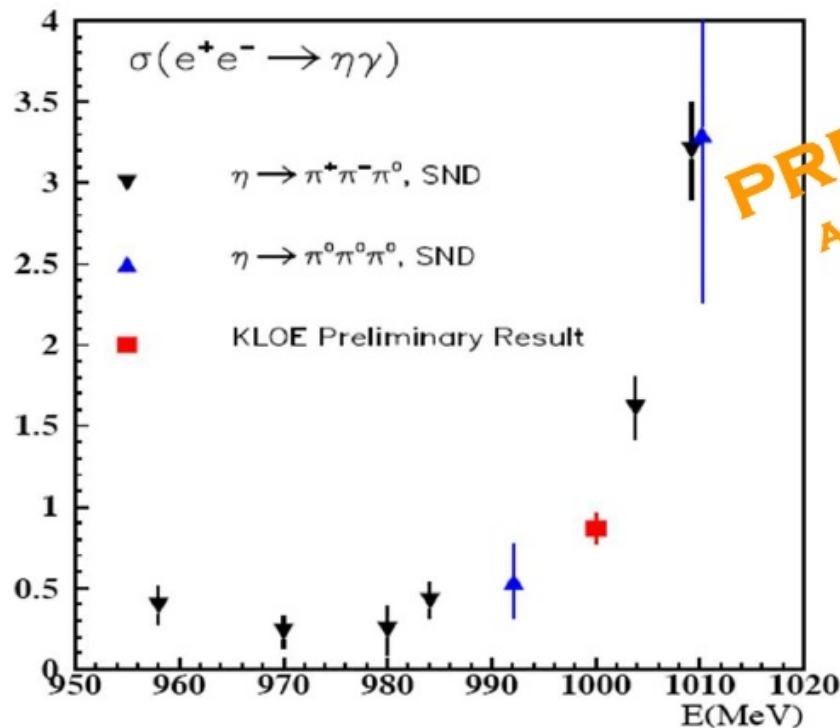
$e^+e^- \rightarrow \eta\gamma$ at 1 GeV



$e^+e^- \rightarrow \eta\gamma \rightarrow \pi^+\pi^-\pi^0\gamma$: 3 photons + 2 tracks

- pion ID
- kinematic cuts to suppress bckg from kaons
- kinematic fit

$$\sigma(e^+e^- \rightarrow \eta\gamma, 1\text{GeV}) = (0.866 \pm 0.009 \pm 0.093) \text{ nb}$$



PRELIMINARY
ARXIV:1107.3782

In agreement with the result from $\eta \rightarrow \pi^0\pi^0\pi^0$
(6γ 's with imposed π^0 , η masses + miss. E)

$$\sigma(e^+e^- \rightarrow \eta\gamma, 1\text{GeV}) = (0.875 \pm 0.018 \pm 0.035) \text{ nb}$$

Background for $\gamma\gamma \rightarrow \eta$ accurately measured
from the same 240 pb^{-1} sample

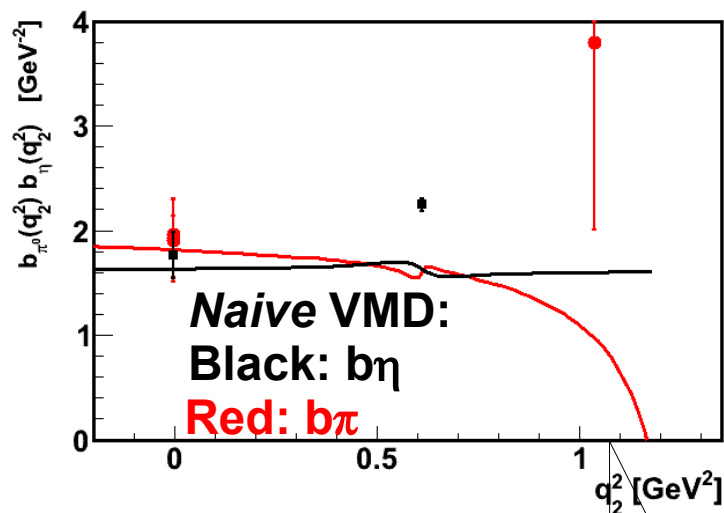


Double off shell TFF



slopes b_π , b_η

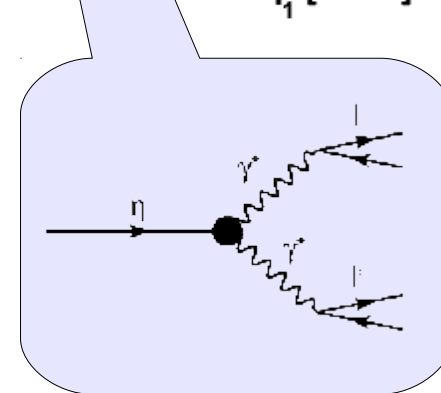
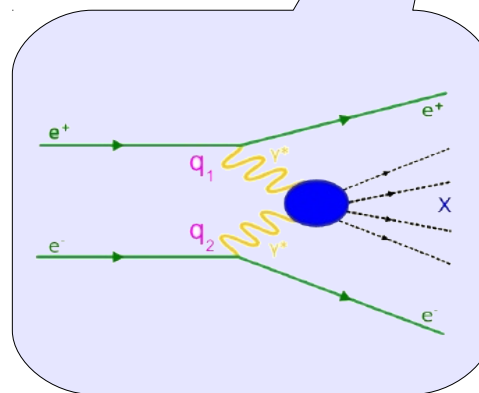
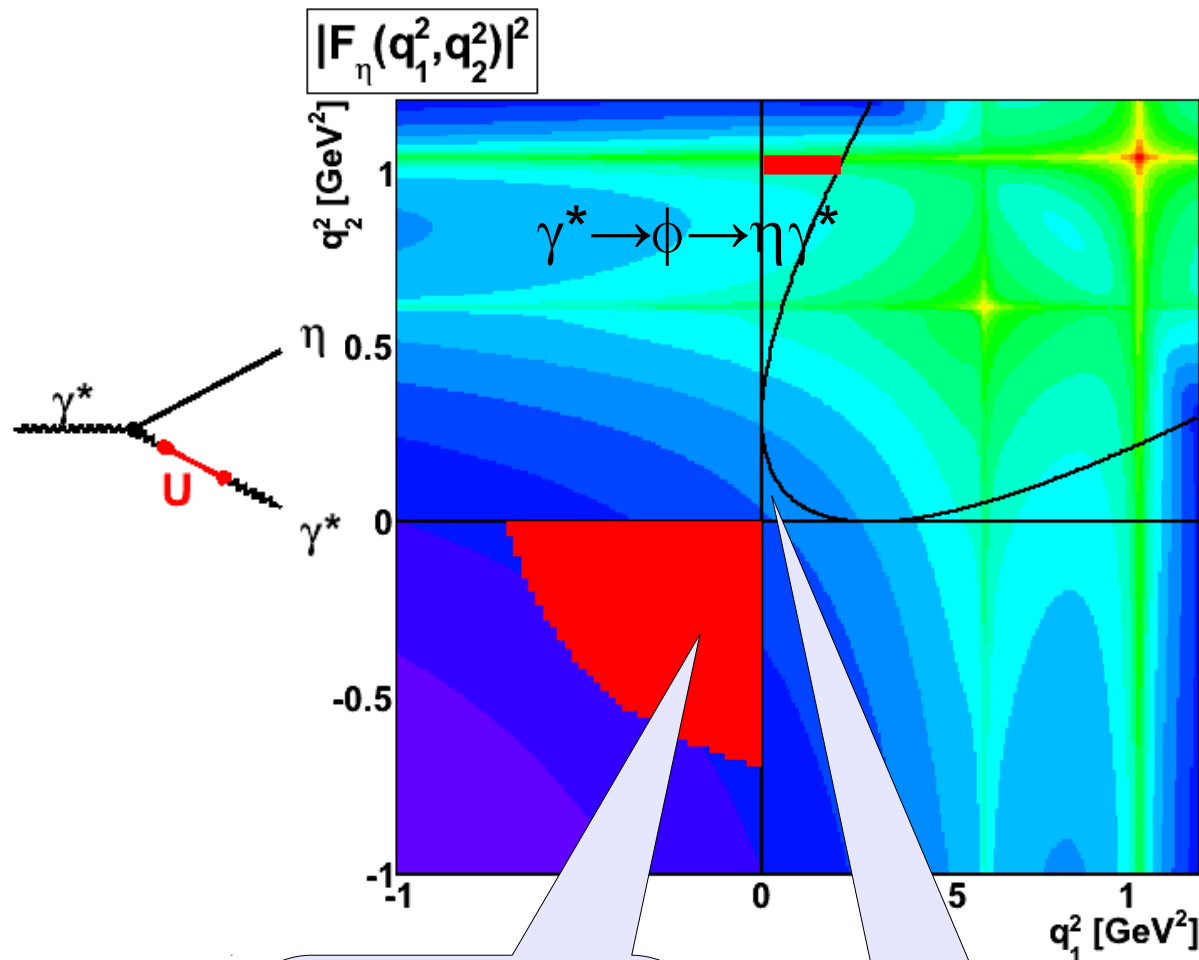
$$b_P(q_2^2) = \left. \frac{\partial \ln |F(q_1^2, q_2^2)|}{\partial q_1^2} \right|_{q_1^2=0}$$



KLOE goal: measure $b_\eta(m_\phi^2)$

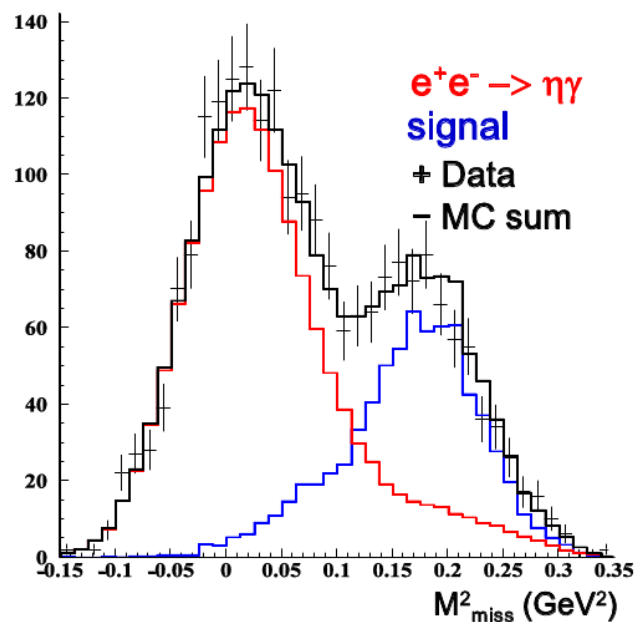
$\phi \rightarrow \eta \gamma^*$ BR 10^{-4}

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

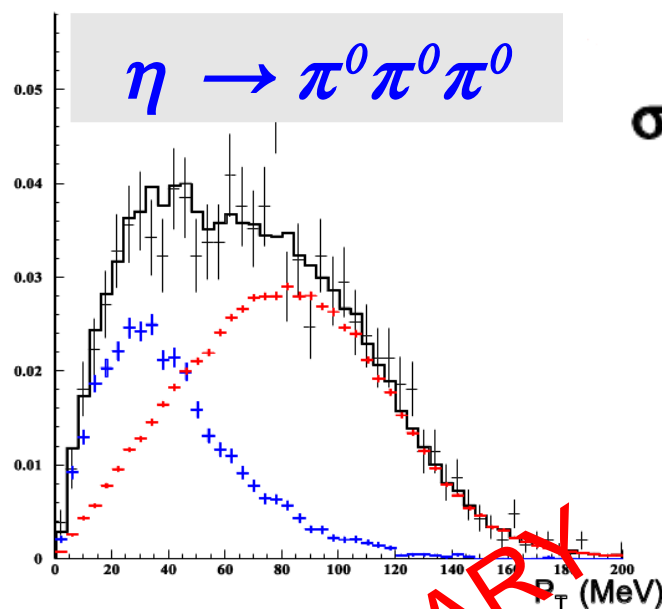




η meson radiative decay width



$$= [32.0 \pm 1.5_{\text{stat}} \pm 0.8_{\text{syst}}] \text{ pb}$$



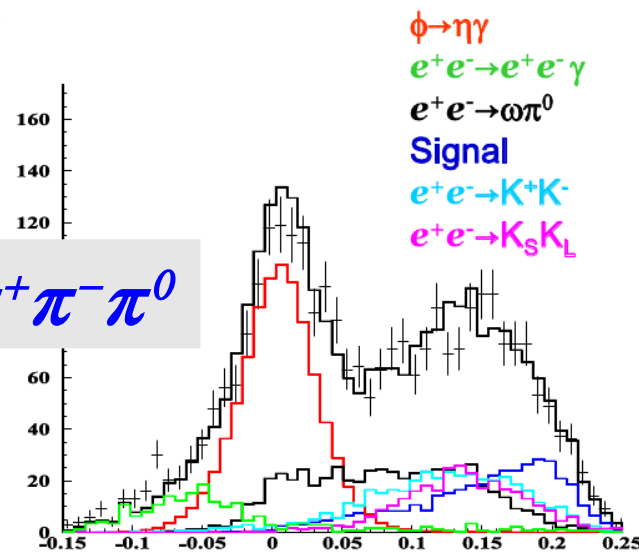
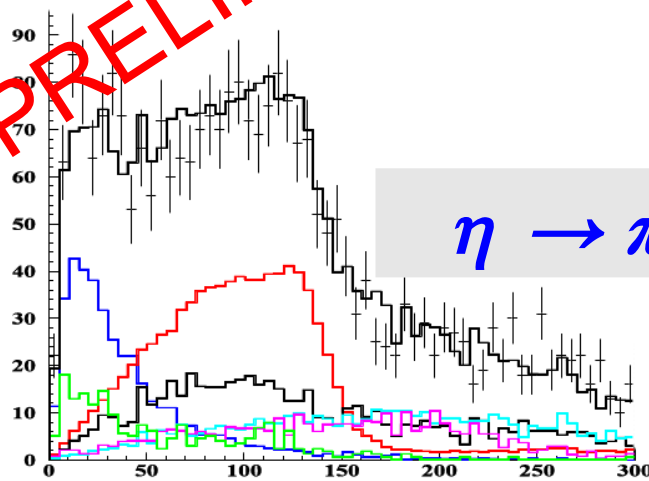
PRELIMINARY

$$\sigma(e^+e^- \rightarrow e^+e^-\eta, \sqrt{s}=1\text{GeV})$$

$$L=240 \text{ pb}^{-1}$$

Insensitive to TFF

$$\Rightarrow \delta\Gamma_{\gamma\gamma} \sim 5-8\%$$



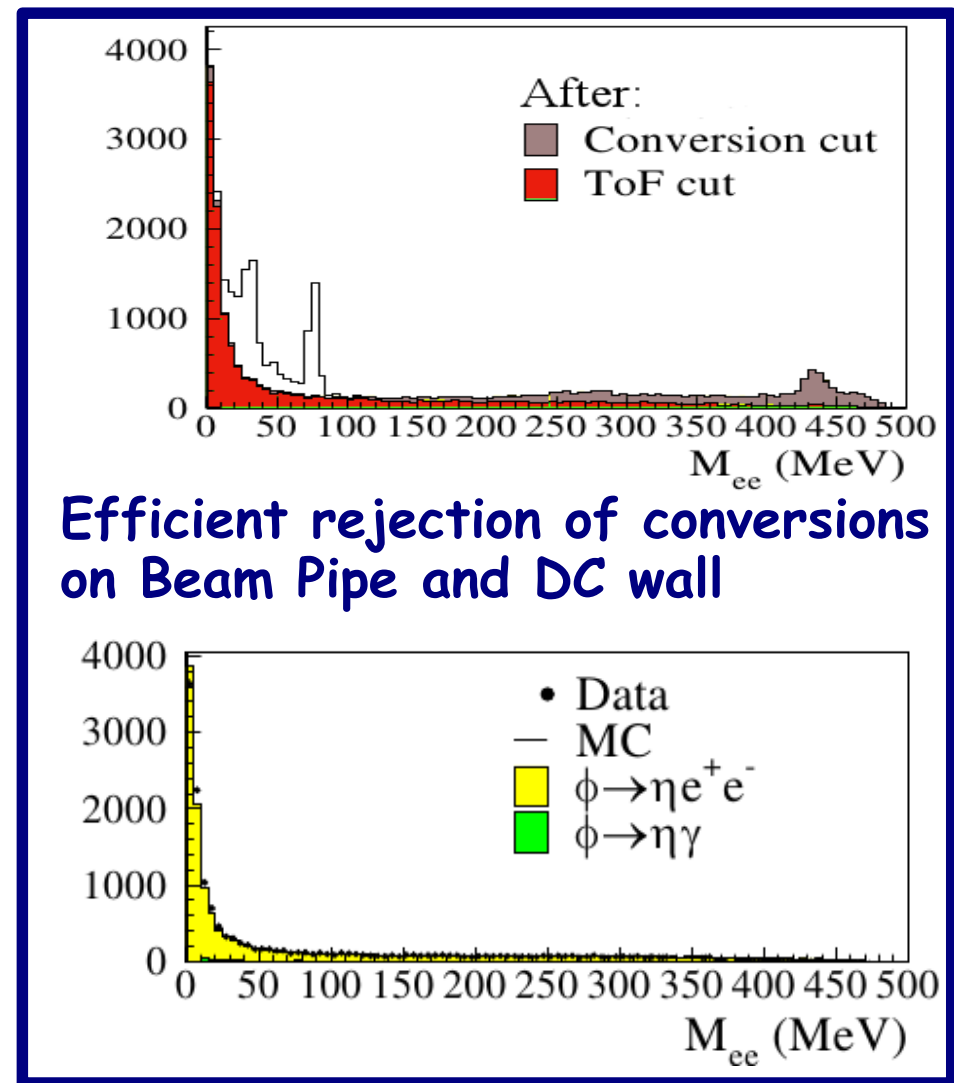
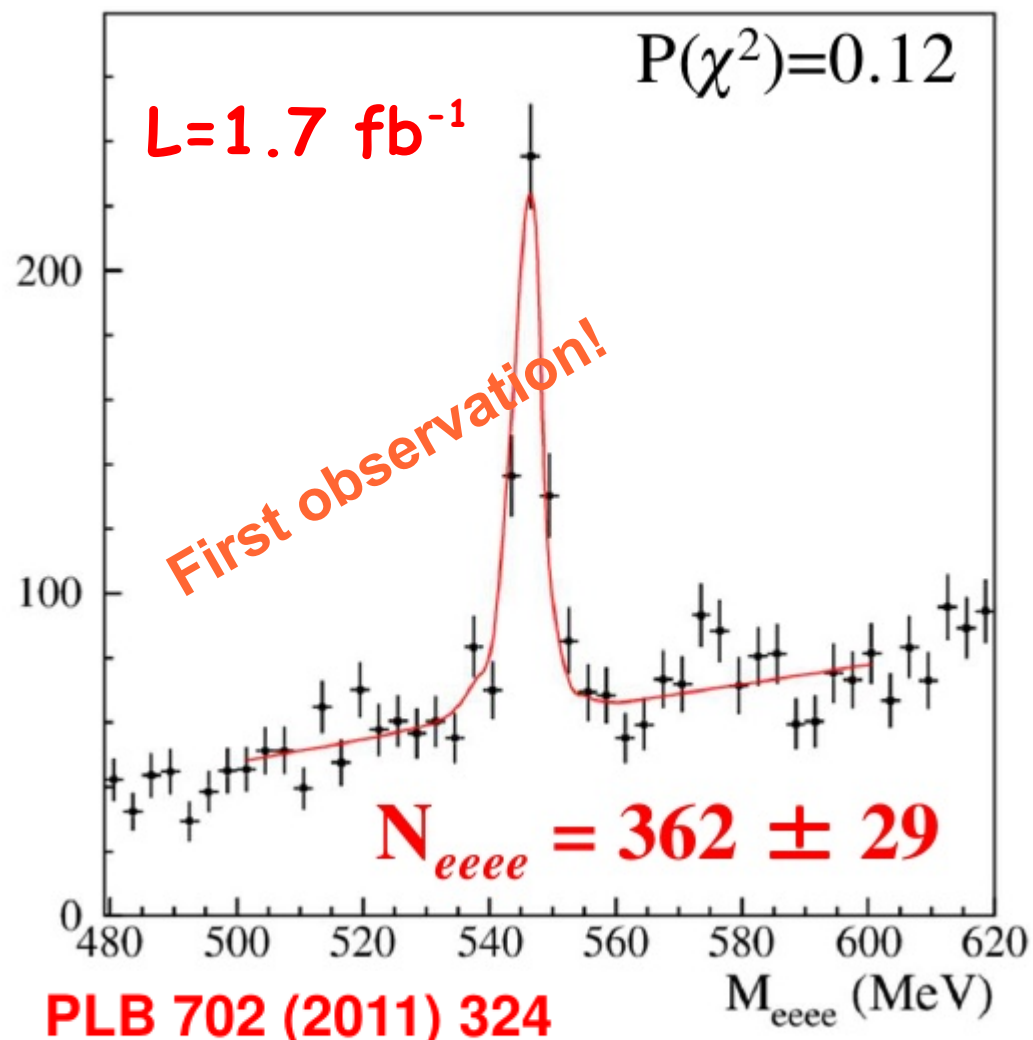
$$= [34.5 \pm 2.6_{\text{stat}} \pm 1.0_{\text{syst}}] \text{ pb}$$



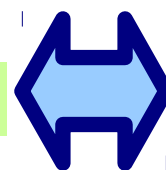
η Double Dalitz decay



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



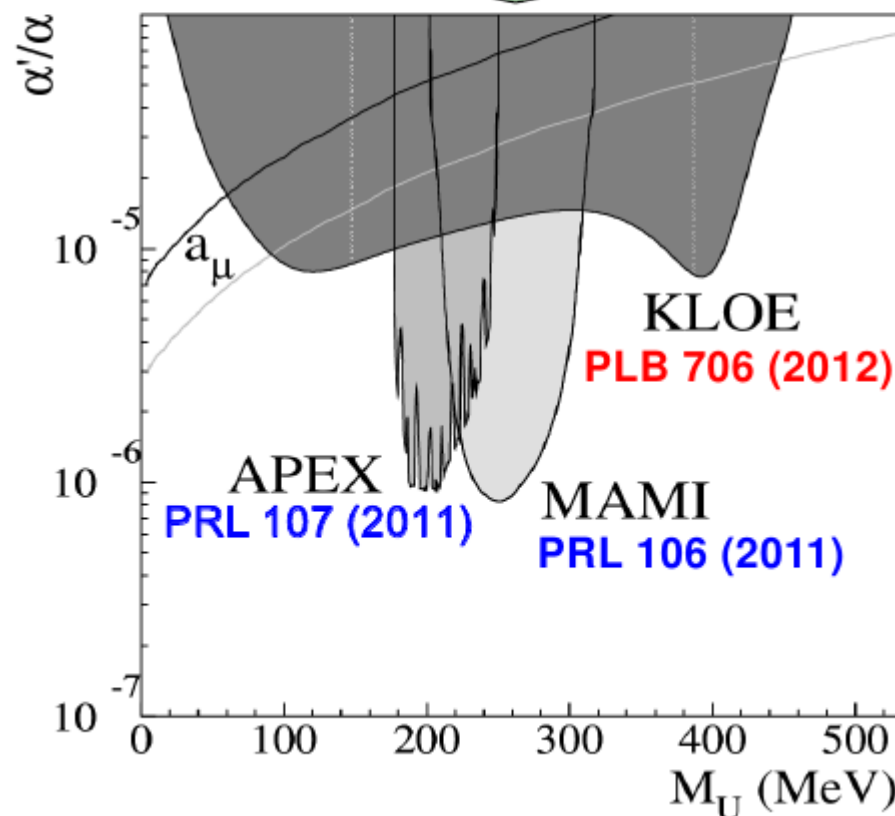
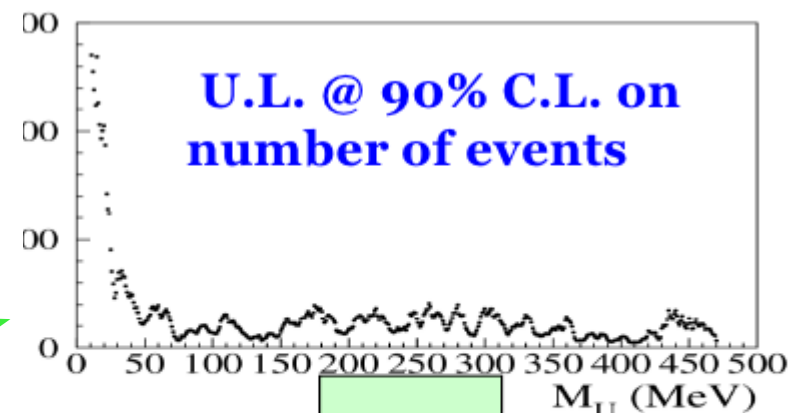
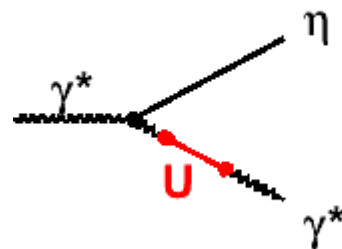
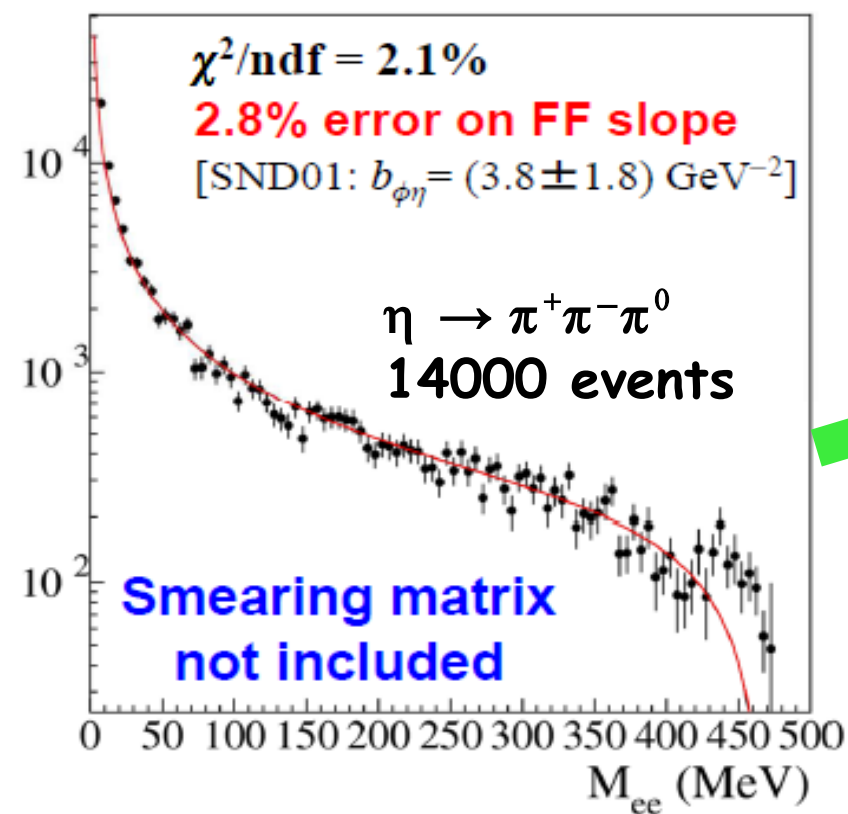
$$\text{BR}(\eta \rightarrow e^+ e^- e^+ e^- (\gamma)) = (2.4 \pm 0.2_{\text{stat}} \pm 0.1_{\text{syst}}) \times 10^{-5}$$



$$\begin{aligned} \text{TFF} = 1 &\Rightarrow \text{BR} = 2.5 \times 10^{-5} \\ \text{TFF} \neq 1 &\Delta \text{BR} \sim 5\% \end{aligned}$$



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



U boson limits

$L \sim 1.5 \text{ fb}^{-1} \Rightarrow 10^6 \varphi \rightarrow \eta e e \text{ prod}$

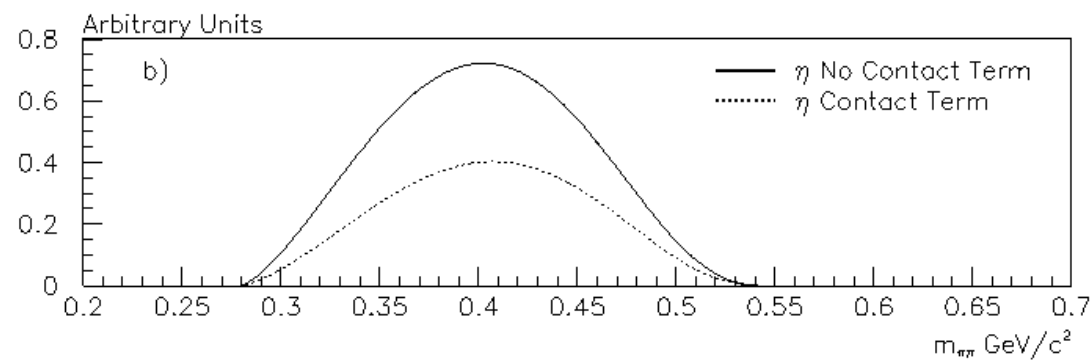
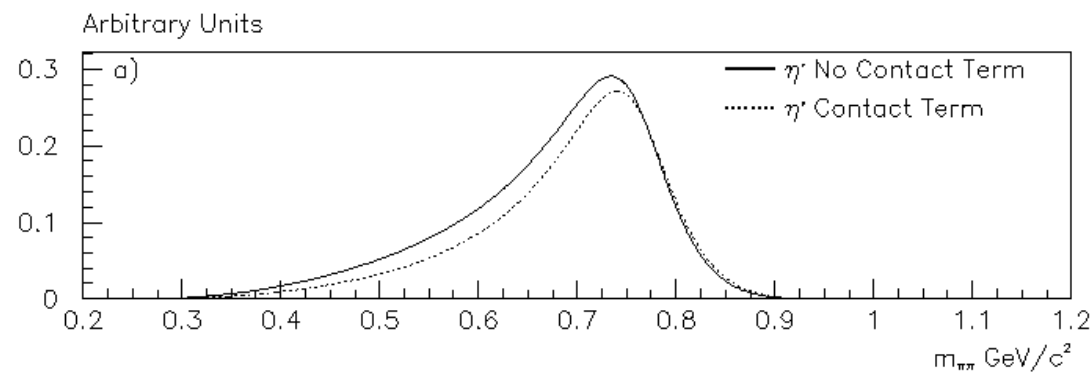
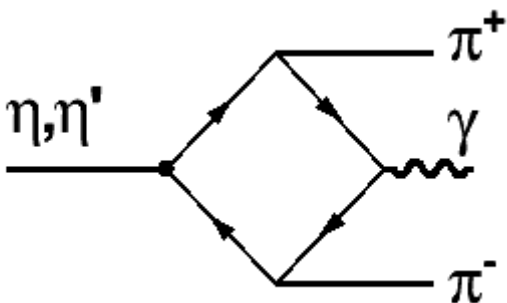
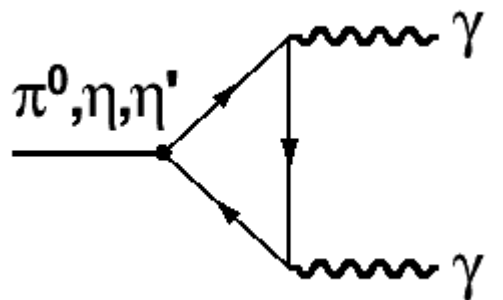
$\eta \rightarrow 3\pi^0$ 26000 events

TFF: more work on background
subtraction/systematics

2 PhD theses 2012: J. Zdebik,
I. Sarra



$\eta \rightarrow \pi^+ \pi^- \gamma$



$$\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma) / \Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)$$

value	events	author	year
0.203 ± 0.008	PDG average		
$0.175 \pm 0.007 \pm 0.006$	859	Lopez	2007 CLEO
0.209 ± 0.004	18 k	Thaler	1973
0.201 ± 0.006	7250	Gormley	1970



$$\eta \rightarrow \pi^+ \pi^- \gamma / \eta \rightarrow \pi^+ \pi^- \pi^0$$



- No kin fit: use DC resolution
- Not use EMC Energy

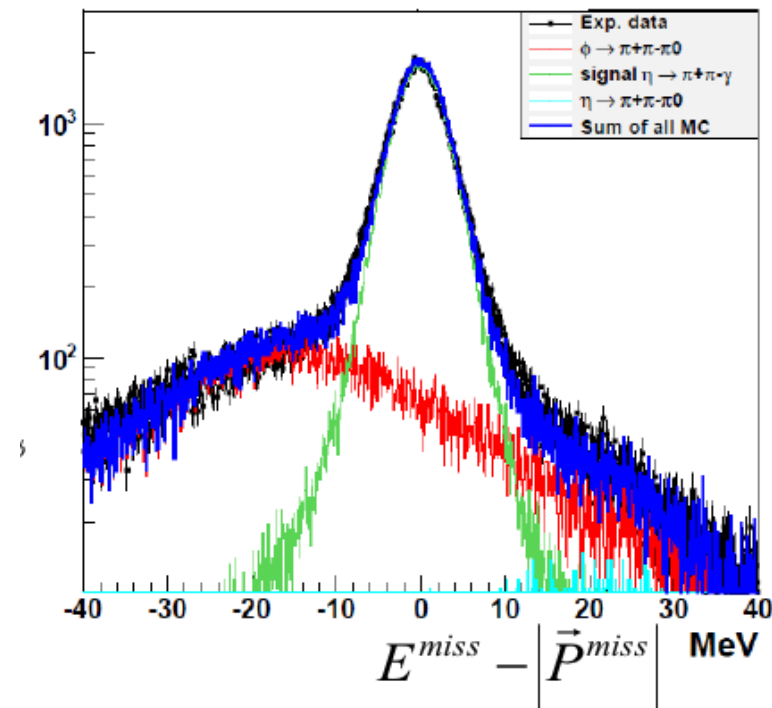
$$L = 558 \text{ pb}^{-1}$$

204 950 events

eff=21%

S/B=10

$$\eta \rightarrow \pi^+ \pi^- \gamma$$



Normalization $\eta \rightarrow \pi^+ \pi^- \pi^0$

Selection $1.2 \cdot 10^6$ $\varepsilon \sim 23\%$

B:S=0.65%

BR=(22.41 $\pm$ 0.03 $\pm$ 0.35)%

PDG10= (22.74 $\pm$ 0.28)%

=> New DP analysis

Poster Li Caldeira-Balkesthahl

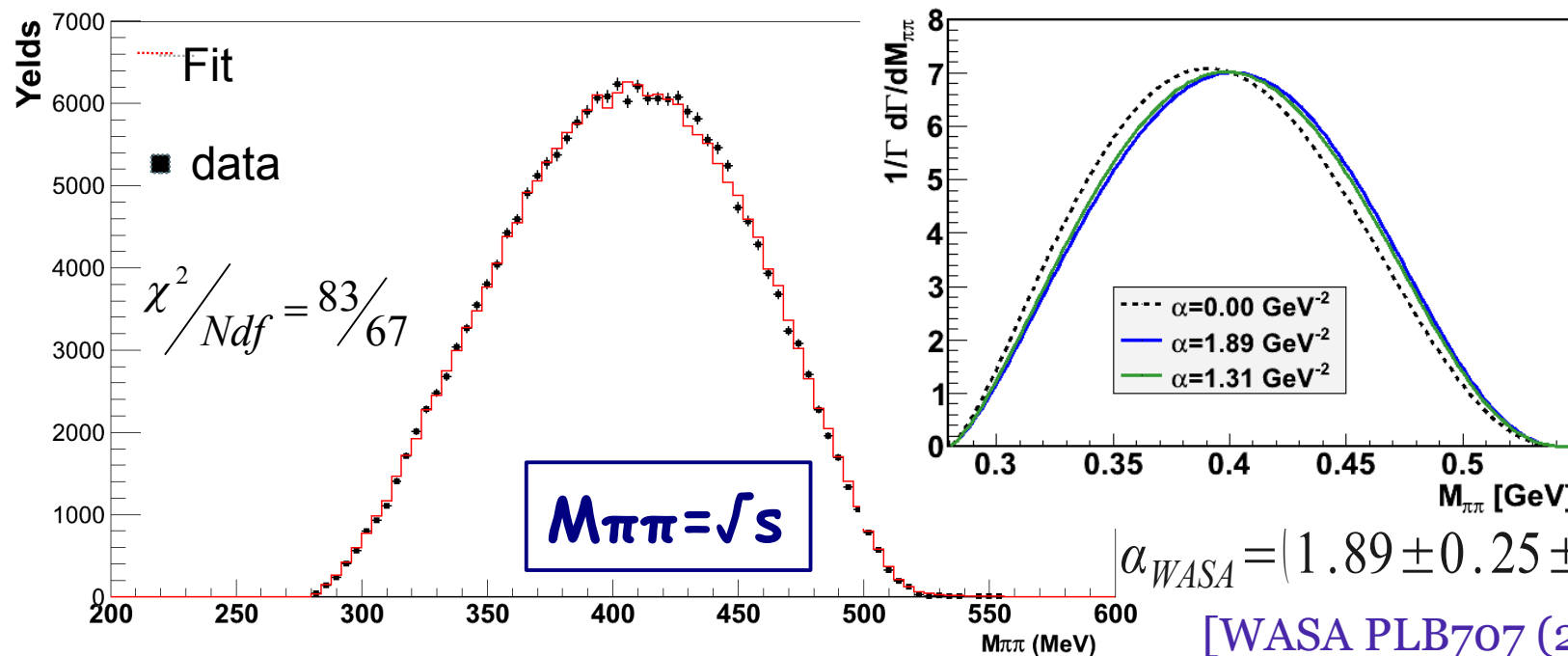
$$\frac{\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma)}{\Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)} = 0.1856 \pm 0.0005 \pm 0.0028$$

PRELIMINARY

Consistent with CLEO



$\eta \rightarrow \pi^+ \pi^- \gamma$



$$\alpha_{WASA} = (1.89 \pm 0.25 \pm 0.59 \pm 0.02) \text{ GeV}^{-2}$$

[WASA PLB707 (2012) 243]

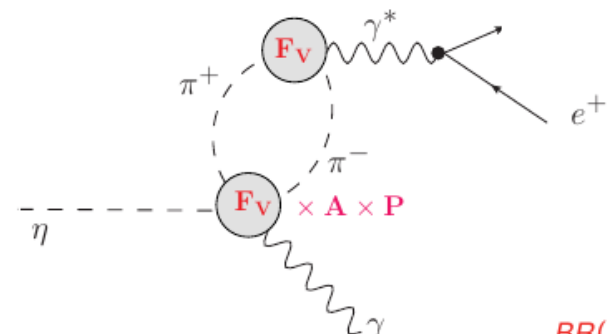
$$\frac{d\Gamma}{ds} = |A(1 + \alpha s + \dots) F_V(s)|^2 K_P(s)$$

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

PRELIMINARY

$$\alpha = 1.31 \pm 0.08_{\text{stat}} \pm 0.40_{\text{syst}} \pm 0.02_{F_V} \text{ GeV}^{-2}$$



A. Wirzba prel TFF 30/5

$BR(\gamma)$

KLOE: $A + \alpha$

$$\Rightarrow b_{\eta} = 2.19^{+0.24}_{-0.32} \text{ GeV}^{-2}$$



$$\gamma\gamma \rightarrow \sigma \rightarrow \pi^0 \pi^0$$

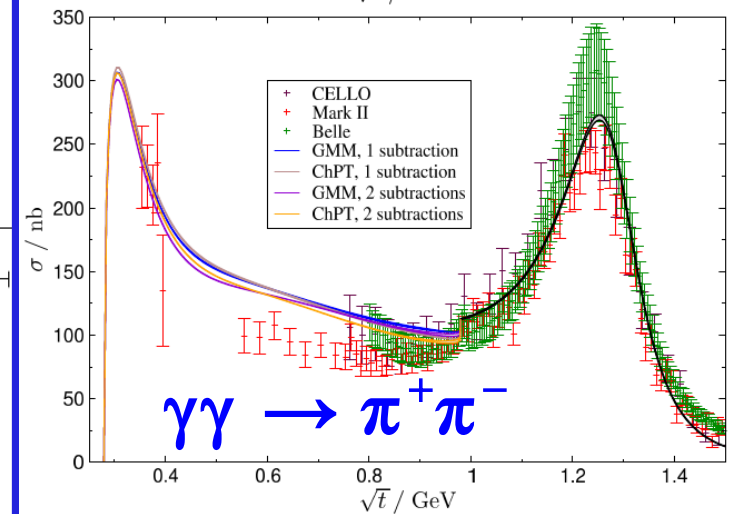
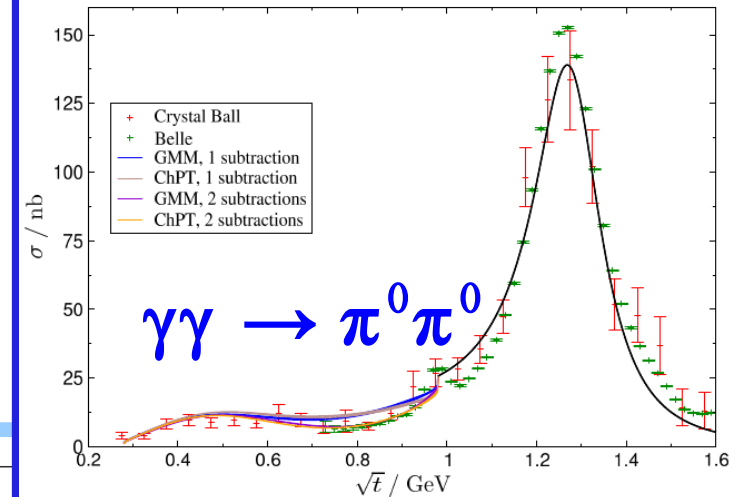
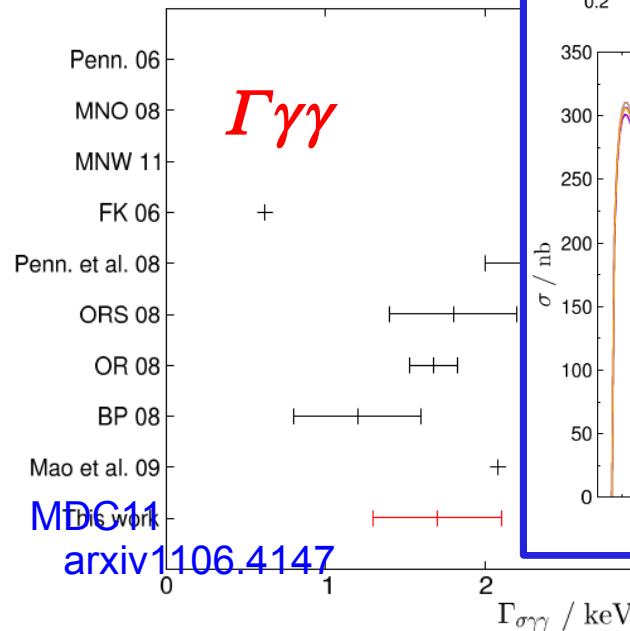
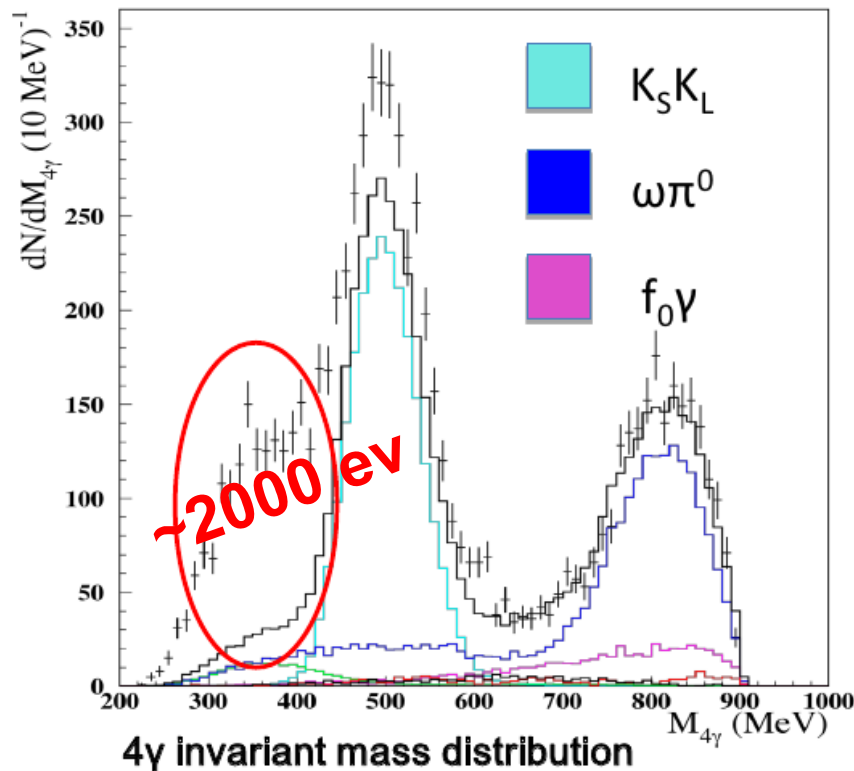


Recent progress on $\sigma \rightarrow f_0(500)$:

	M_σ	Γ_σ	$g_{\sigma\pi\pi}/\sqrt{2}$
CCL [161]	441_{-8}^{+16} MeV	544_{-25}^{+18} MeV	3.3 GeV
GKPRY [62]	457_{-13}^{+14} MeV	558_{-14}^{+22} MeV	$3.59_{-0.13}^{+0.11}$ GeV

KLOE:

240 pb⁻¹ @ $\sqrt{s} = 1$ GeV



KLOE analysis:

bkg subtraction

$d\sigma(\gamma\gamma \rightarrow \pi^0 \pi^0)/dM_{4\gamma}$ extraction



DAΦNE with new IP: commissioning in progress

KLOE-2 is starting a data taking campaign

- Phase 0 (old KLOE detector + taggers)
- Detector ready to take data

Physics program:

EPJC 68 (2010),619

One year at ϕ -peak $O(5 \text{ fb}^{-1})$

Run at 1 GeV of $O(1 \text{ fb}^{-1})$?

KLOE-2 + DAΦNE ideal tool for π^0, η TFF $-1 < q^2 < 1 \text{ GeV}^2$

- $\gamma\gamma$ with e^+e^- taggers in KLOE-2: $\pi^0 \Gamma_{\gamma\gamma}$ 1%
- ISR measurements

Analysis of high statistics samples produced at KLOE



$\gamma\gamma$ physics

Existence (and properties) of $\sigma/f_0(600)$

Study of $\Gamma(S/PS \rightarrow \gamma\gamma)$

PS transition form factor

Spectroscopy

Properties of scalar/vector mesons

Rare η decays

η' physics

Kaon physics

Test of CPT (and QM) in correlated kaon decays

Test of CPT in KS semileptonic decays

Test of SM (CKM unitarity, lepton universality)

Test of ChPT (KS decays)

Dark matter searches

Hadronic cross section

Light bosons @ $O(1 \text{ GeV})$

$\alpha_{\text{em}}(M_Z)$ and $(g-2)$

[Eur.Phys.J.C68\(2010\)619](#)