

# Decays and transition form factors of $\pi^0$ , and $\eta'$ mesons: status at KLOE/KLOE-2 and other experiments



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Uppsala University

for the KLOE/KLOE-2

and for the WASA-at-COSY

Collaborations



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Amherst, March 7th, 2014

# Outline

- $\eta, \eta'$  factories/data samples (pd, pp,  $e^+e^-$ )
- Selected results KLOE/WASA:

## Transition Form Factors / Anomalous processes

- $\gamma^*\gamma \rightarrow \eta$  ( $\Gamma_{\gamma\gamma}$ )
- $e^+e^- \rightarrow \eta\gamma$
- $\eta \rightarrow e^+e^-e^+e^-$  /  $e^+e^- \rightarrow \phi \rightarrow \eta/\pi^0 e^+e^-$  (TFF)
- $\eta \rightarrow \pi^+\pi^-\gamma$

## Even P processes

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



Juliet Lee-Franzini

**KLOE**



Ben Nefkens

Saclay  
pd

**CBall**  
 $\pi$ -p,  $\gamma$ p

Sven Kullander

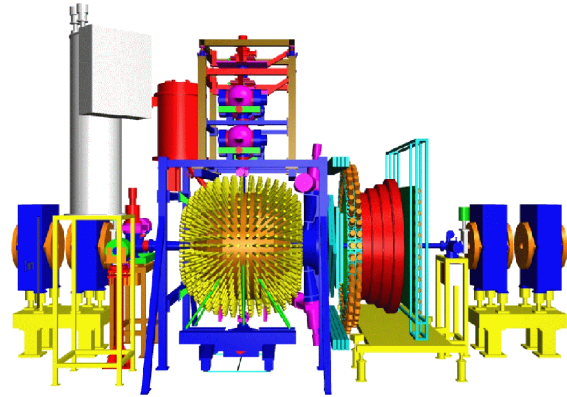


**WASA**  
pd, pp

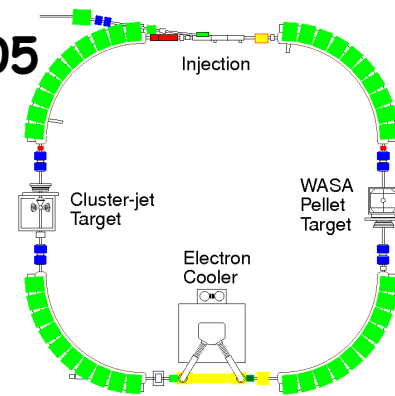


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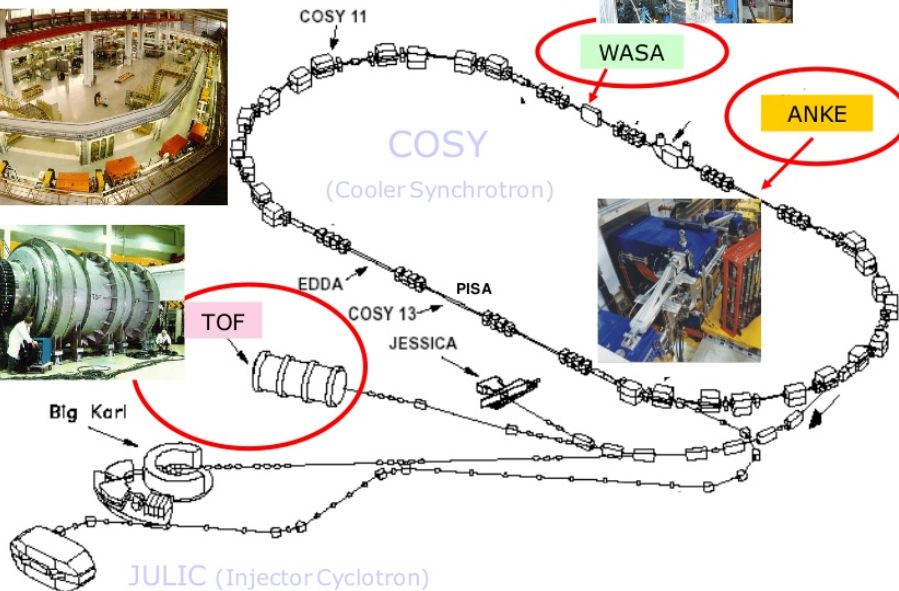
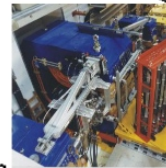
# WASA Proposal 1987: key experiments: $\pi^0, \eta \rightarrow e^+e^-$



## CELSIUS < 2005

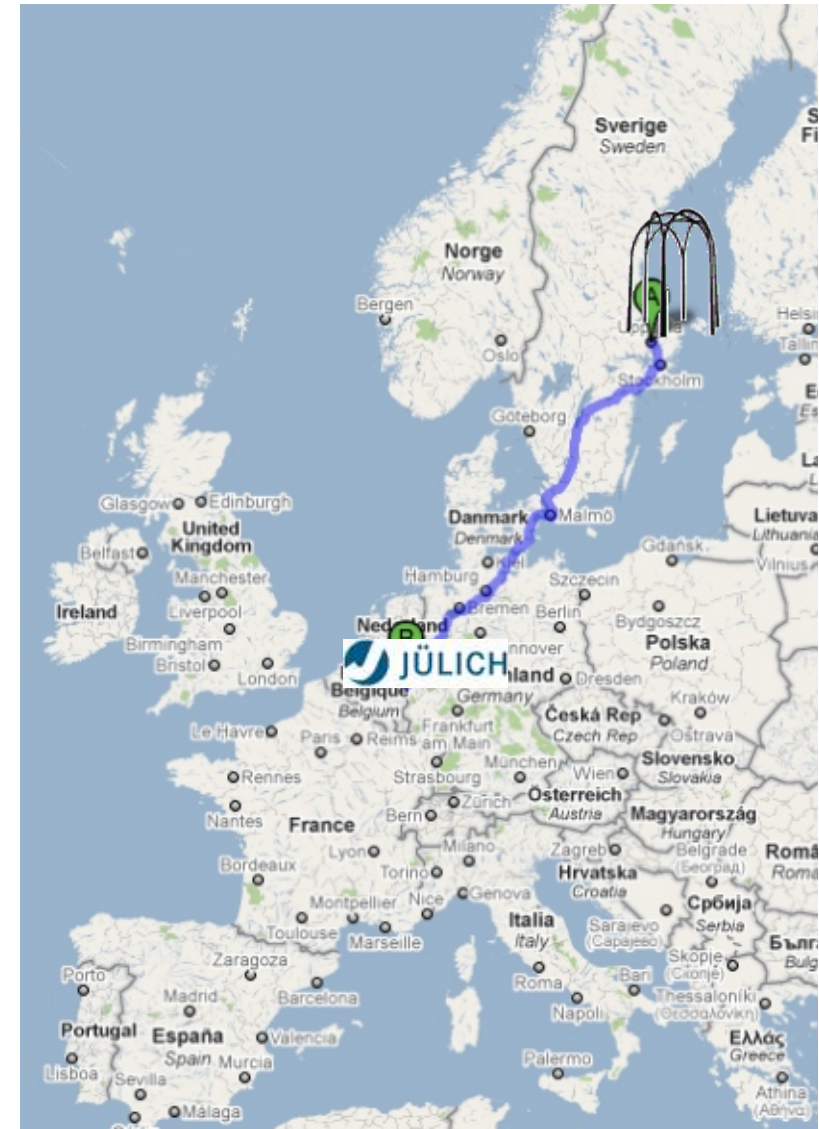


## COSY 2007 - 2014



Schematic overview COSY Facility (FZ-Jülich)

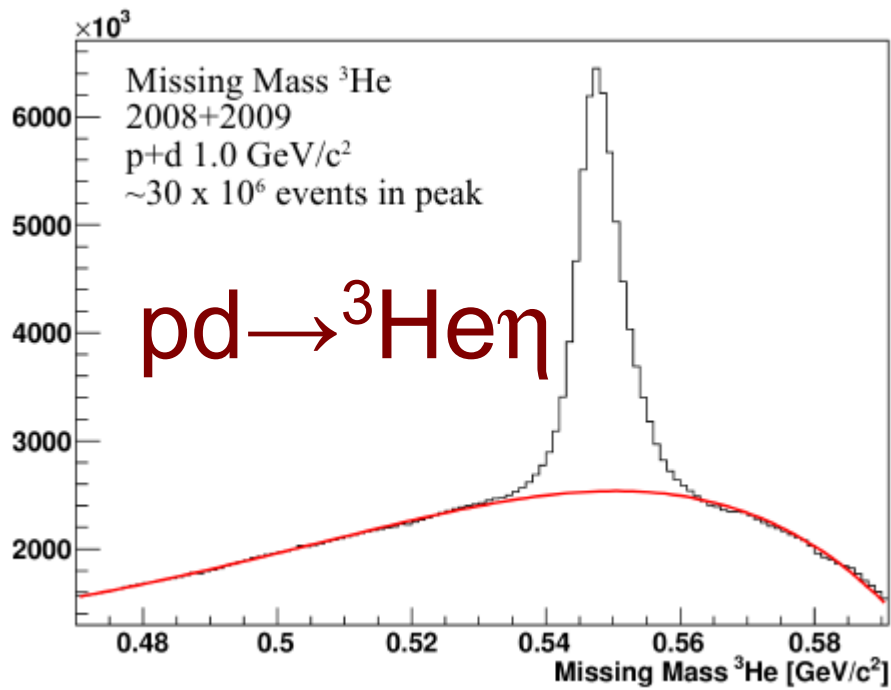
Recent results from Experiments at COSY, HADRON2009, 4/12/09



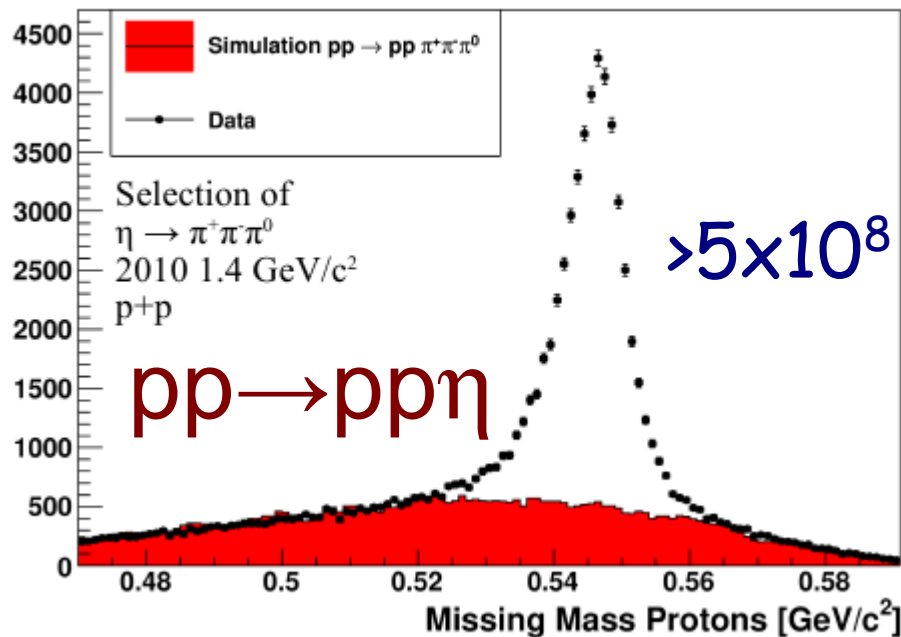




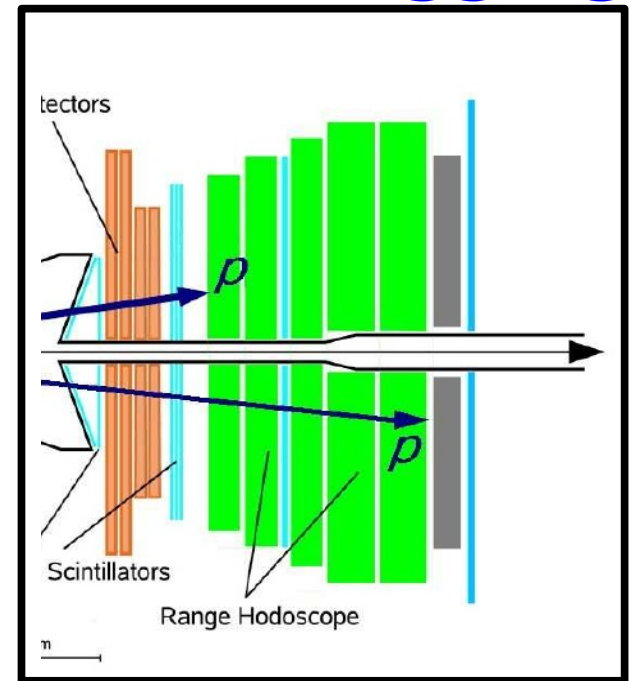
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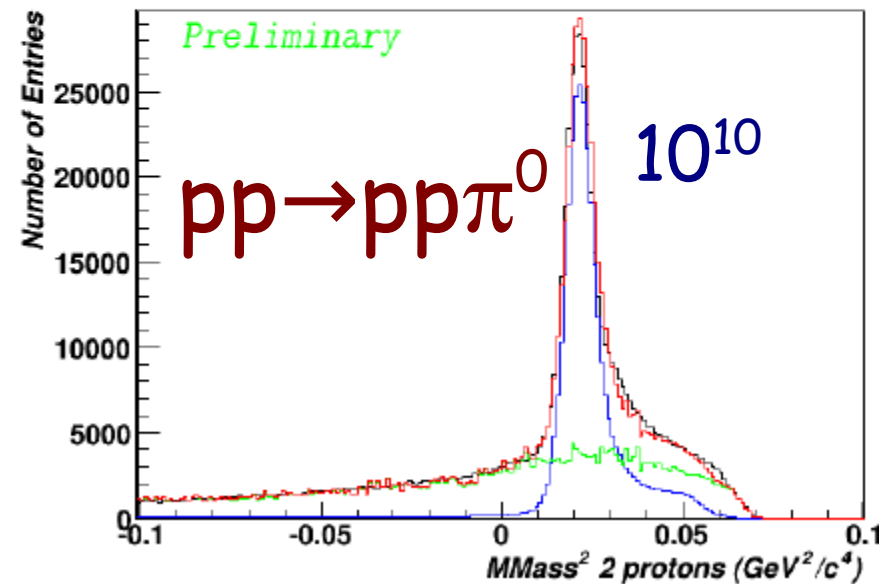
$$\text{Missing Mass} = \sqrt{(E_{in} - E_{out})^2 - (P_{in} - P_{out})^2}$$



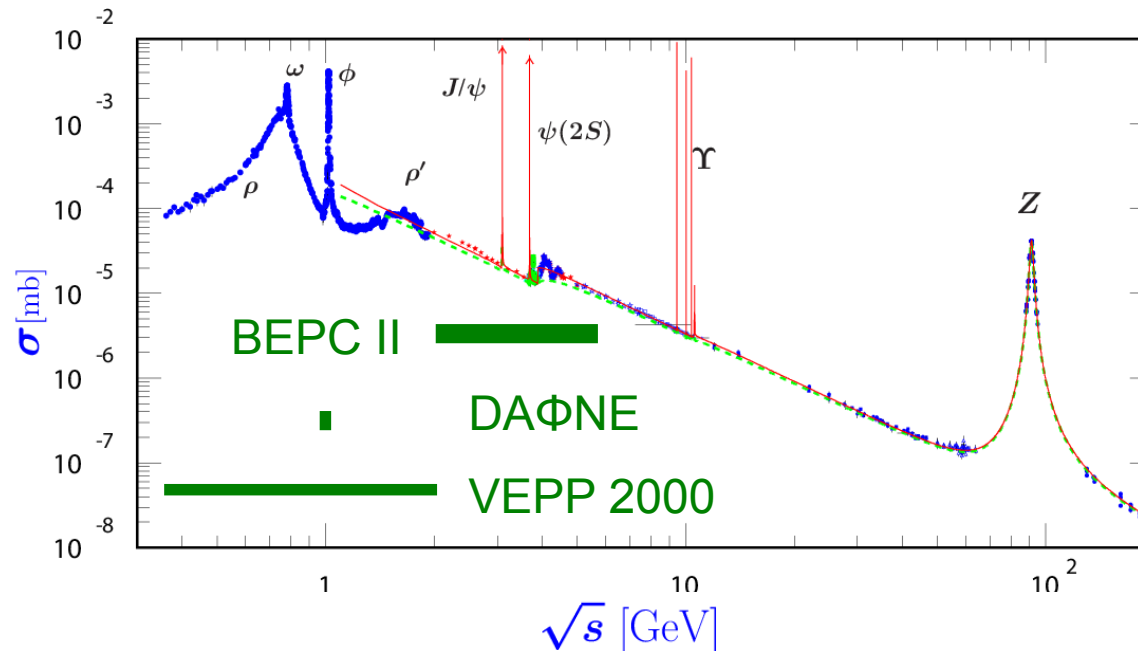
# Meson tagging



2 FD protons



# $e^+e^-$ colliders



BEPCII  $L=6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  at  $J/\psi$

BESIII

DAΦNE  $L= 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  at  $\phi$

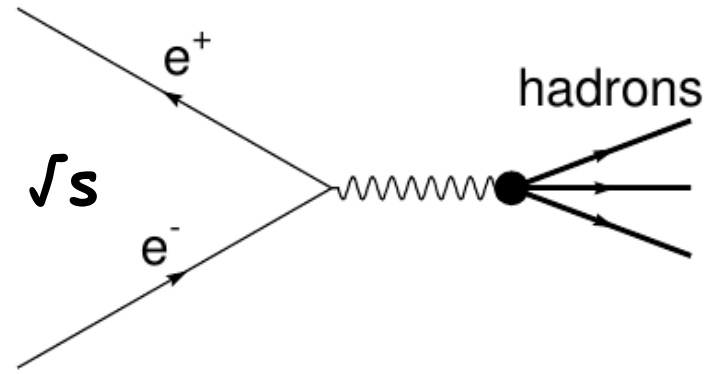
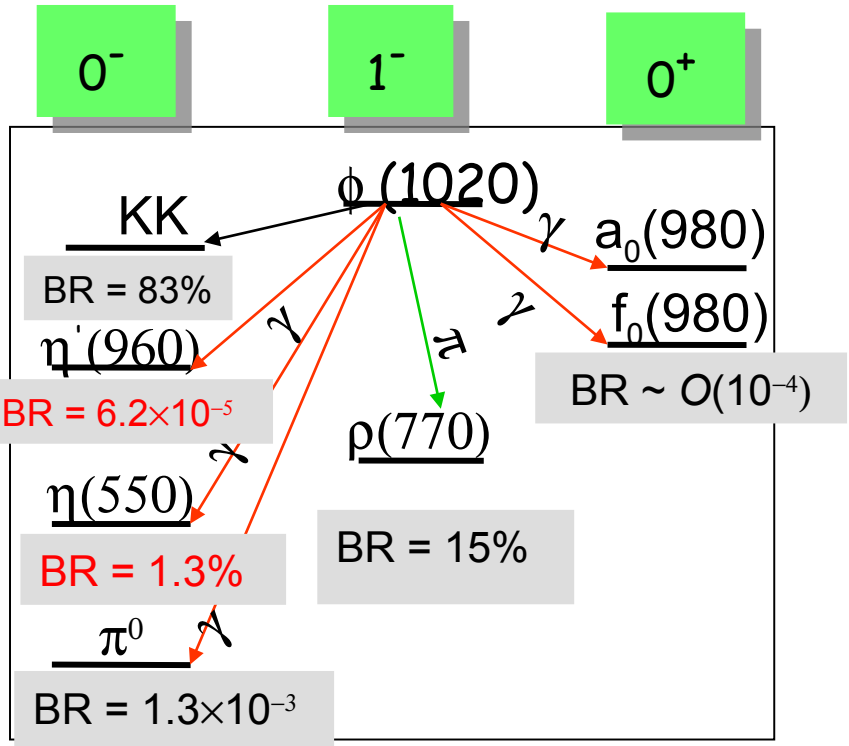
KLOE/KLOE-2

VEPP2000  $L= 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  at 2GeV

CMD-3, SND



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



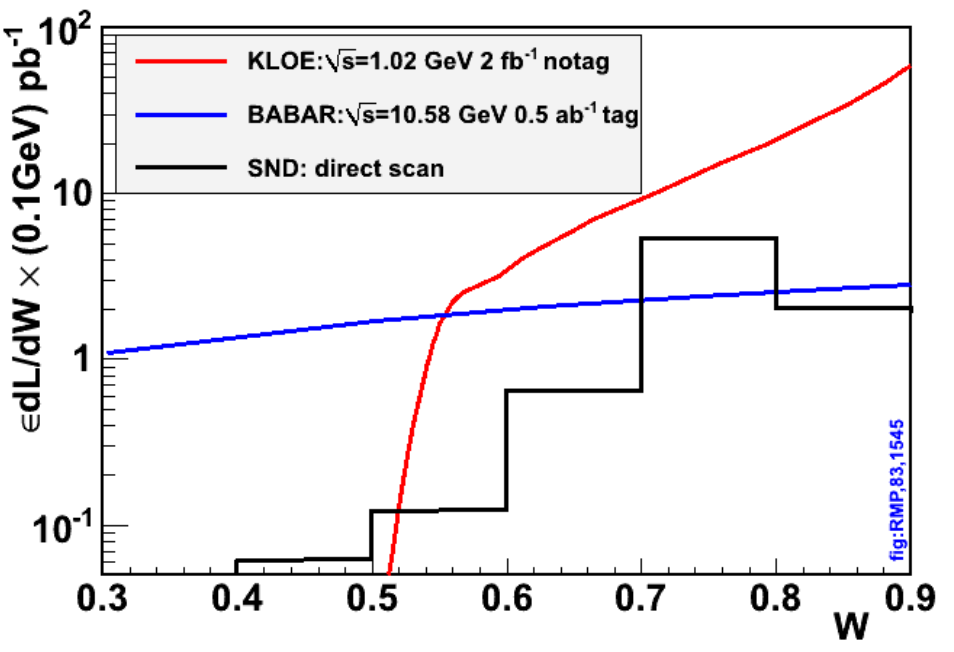
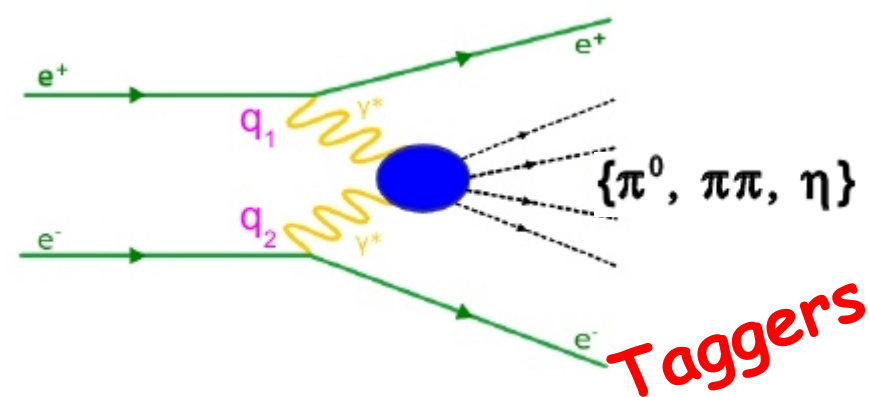
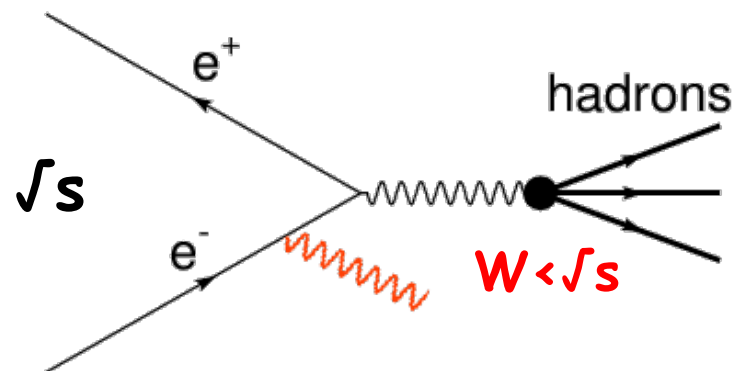
**$1 \times 10^8 \eta$**   
 **$0.5 \times 10^6 \eta'$**

$\phi$ decay	Produced $\text{ev}/\text{fb}^{-1}$
$K^+K^-$	$1.5 \times 10^9$
$K_L K_S$	$1.0 \times 10^9$
$\eta$	$5 \times 10^7$
$\eta'$	$2 \times 10^5$

$\sigma_{\text{peak}} \sim 3.1 \mu\text{b}$   
**KLOE:  $2.5 \text{ fb}^{-1}$  @  $\sqrt{s} = M_\phi$  ( $\sim 8 \times 10^9 \phi$  produced)**  
**+  $250 \text{ pb}^{-1}$  @  $1000 \text{ MeV}$  (off-peak data)**

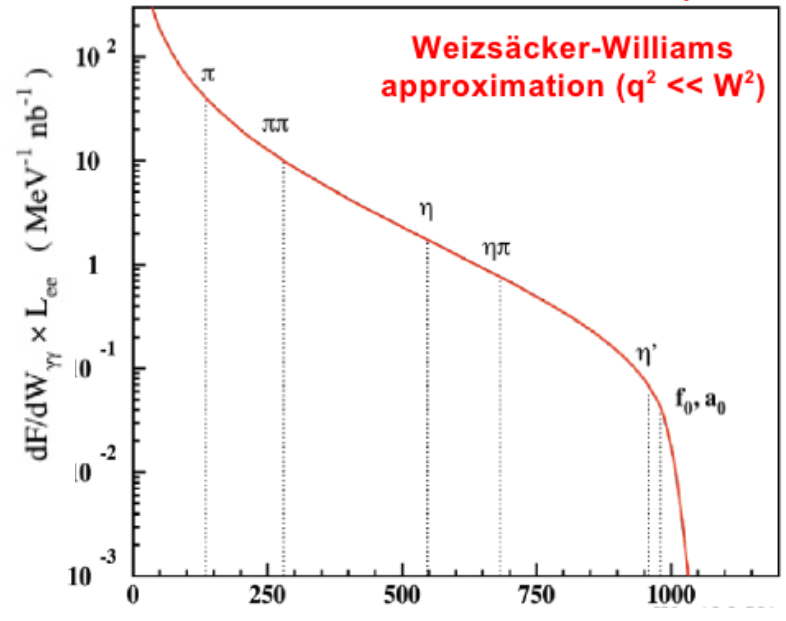
$\sigma_T$  (1GeV) **80 nb**  
**+ scan  $\pm 20 \text{ MeV} \sim O(10 \text{ pb}^{-1})$**

KLOE 2001-2005 data



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



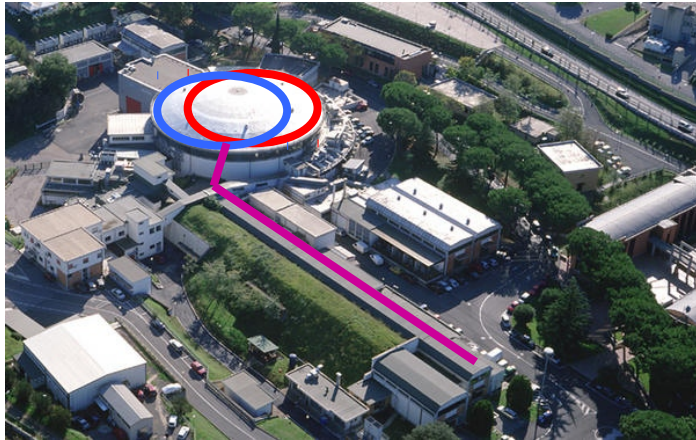


# DAΦNE luminosity upgrade



## Frascati $\phi$ -factory

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

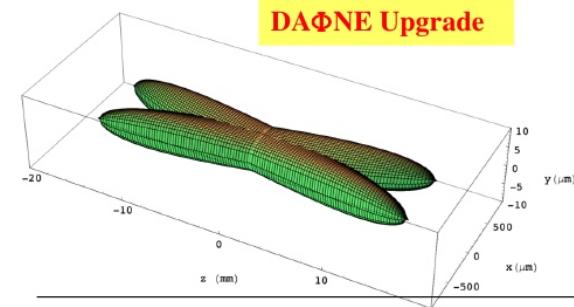
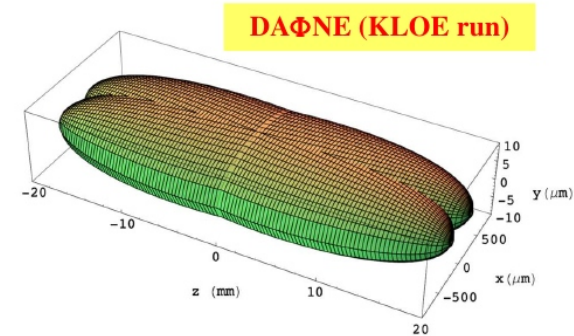
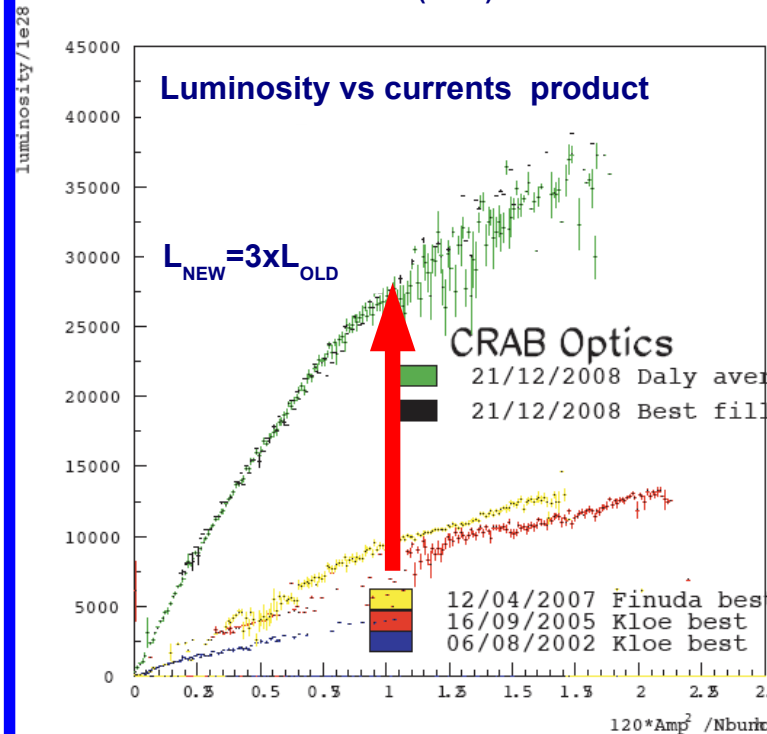


**KLOE-2 IP collisions:**  
from 2010  
Commissioning for KLOE-2

Status:  $L = 1.5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$   
with 1.3 A + 700/800 mA,  
7pb<sup>-1</sup>/day

Novel interaction scheme:  
large angle beam crossing  
+ crabbed waist sextupoles

PRL104 (2010) 174801



**KLOE-2:**

Extension of the KLOE physics program at upgraded DAΦNE

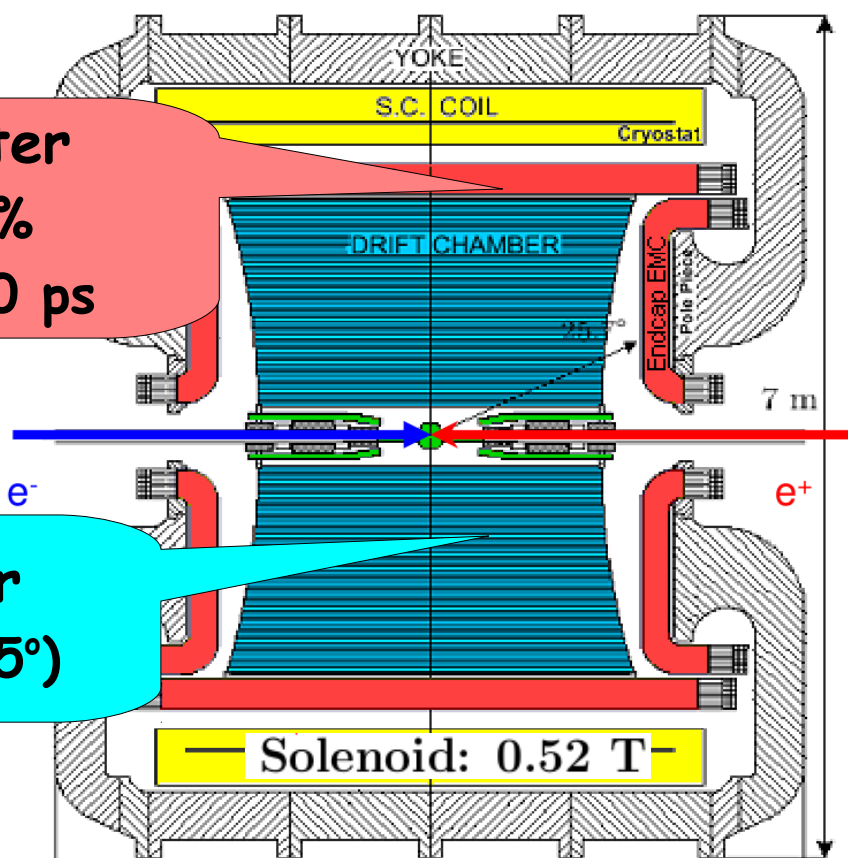


# KLOE → KLOE-2

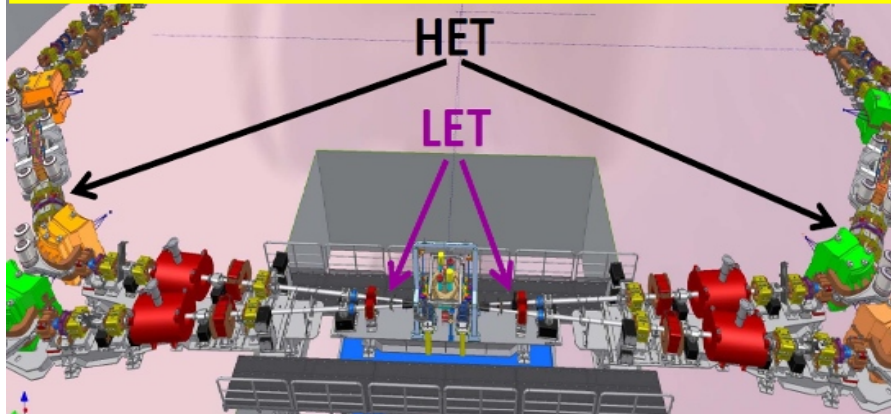


**EM Calorimeter**  
 $\delta E/E = 5.7/\sqrt{E} \%$   
 $\delta t = 57/\sqrt{E} \oplus 100 \text{ ps}$

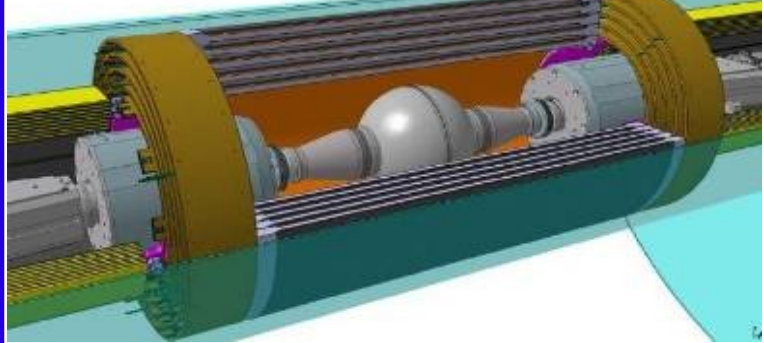
**Drift Chamber**  
 $\delta p_T \sim 0.4\% (\theta < 45^\circ)$



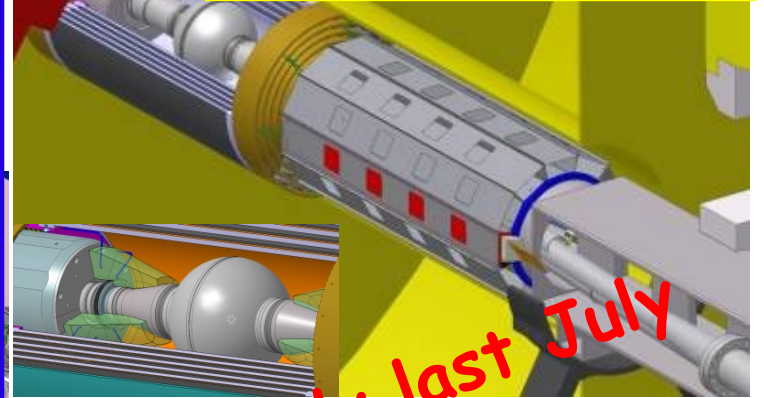
**2+2 taggers for:**  
 $e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^- X$



**Upgrades**  
**Inner Tracker: cyl. GEM**

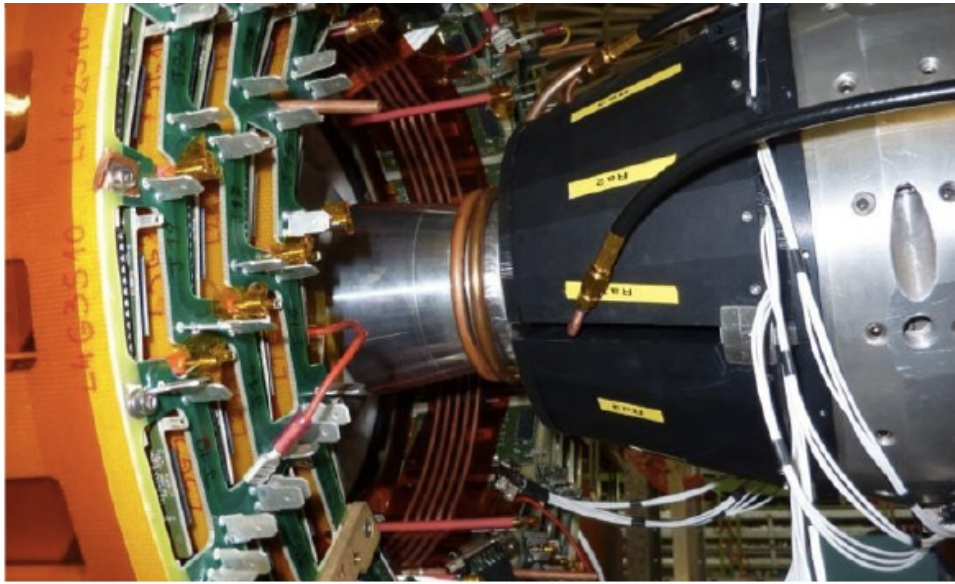


**Small angle EMC**

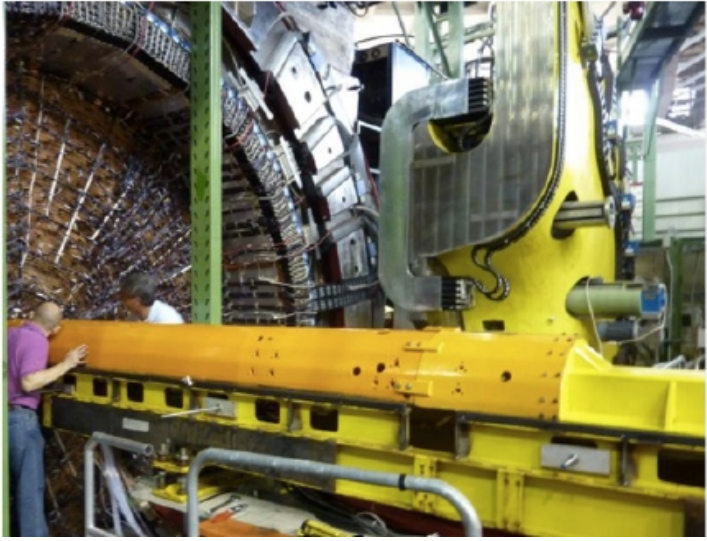


**Ready last July**





IT front-end  
and CCALT

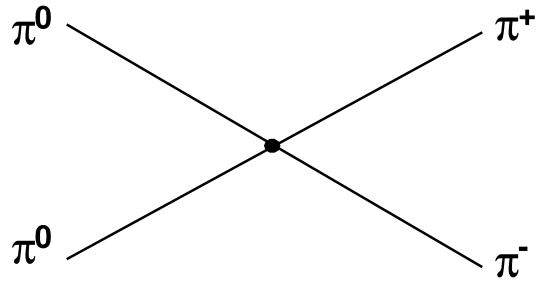


IR insertion in  
DAFNE

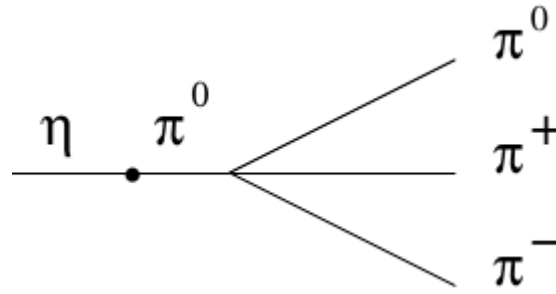
➔ Installation of the  
upgrades and the IR in  
DAFNE completed on  
July, 12th

# Low Energy QCD processes

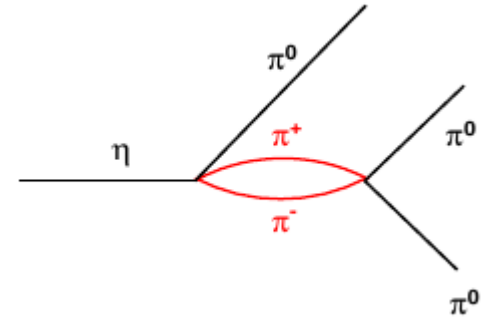
## Even # pseudoscalars PPPP



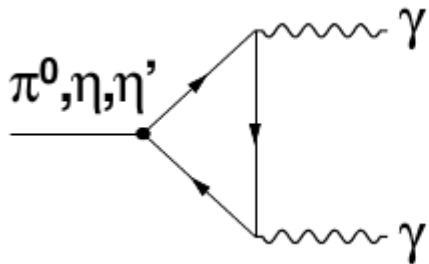
u-d quark masses



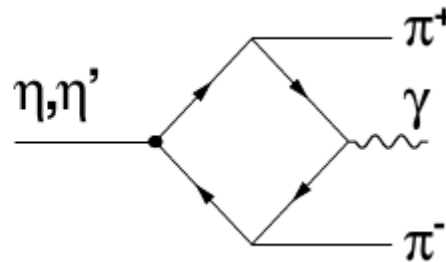
$\pi$ - $\pi$ ,  $\pi$ - $\eta$  scattering



## Anomalous: odd # pseudoscalars: PVV(P $\gamma\gamma$ ), PPPV



$V \rightarrow PV$



Vector Meson Dominance:  
 $V^0 \leftrightarrow \gamma$

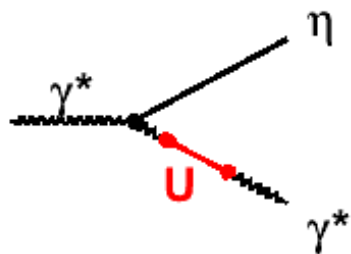
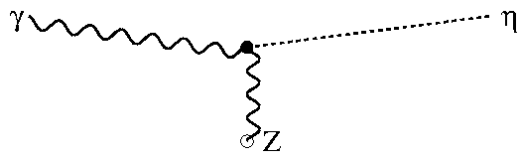
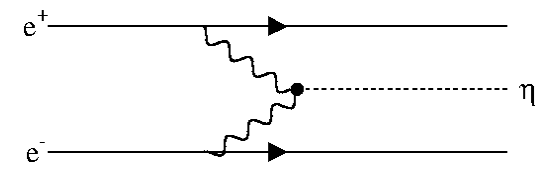
# Pseudoscalar Transition Form Factors (TFF)

Structure of light mesons

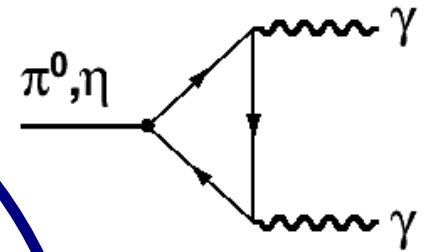
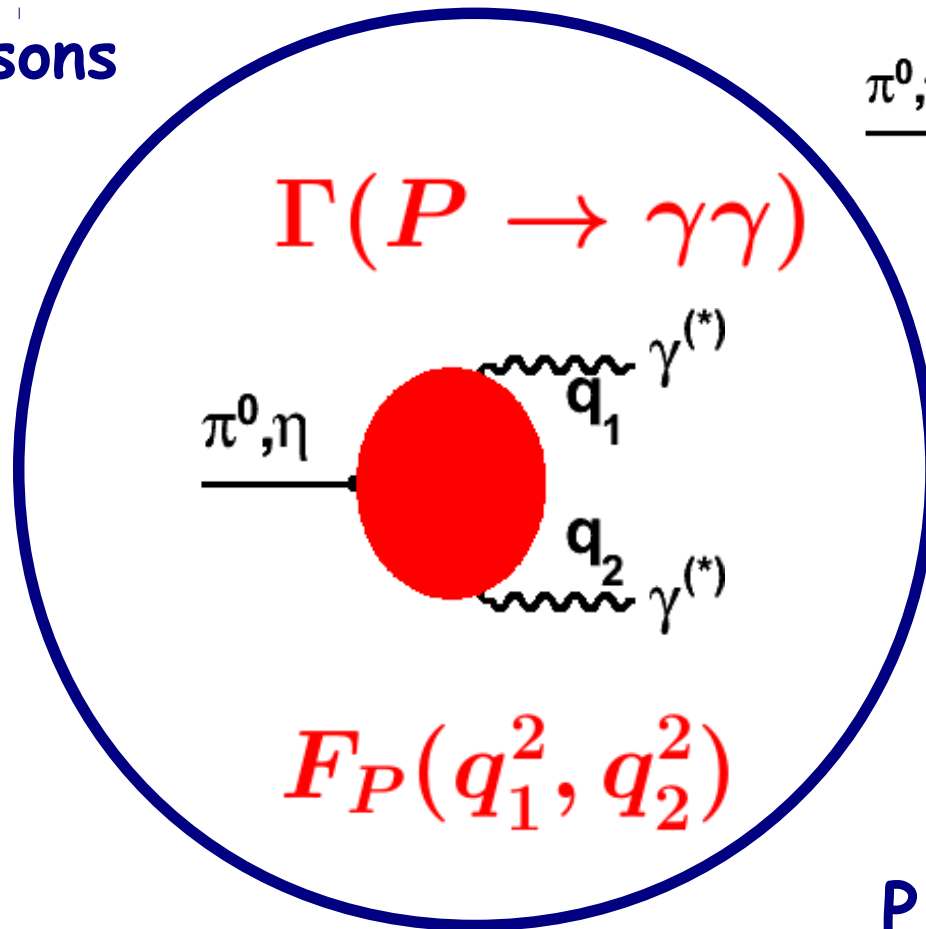
L/H energy QDC LAB

$l^+l^-$  spectra in HIon

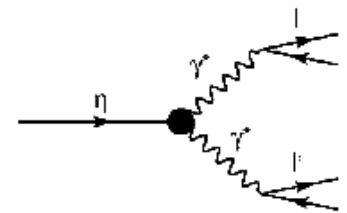
$F_{\pi^0} q^2 \rightarrow \infty$  puzzle



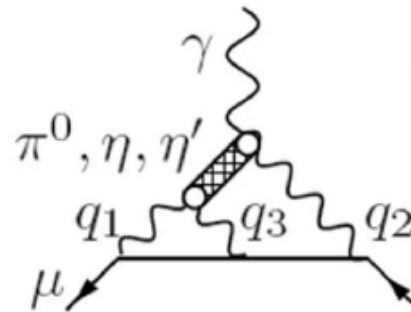
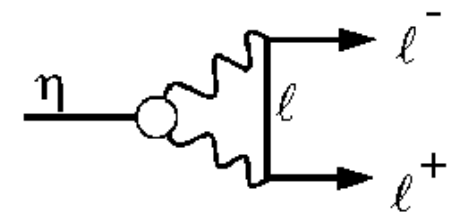
Dark photon



$\eta: \Gamma_{\gamma\gamma}$   
 $m_u/m_d$



$P \rightarrow l^+l^-$



$g-2$  LbL

# Radiative widths of $\eta, \pi^0$

$\eta, \pi^0$  : narrow and short lived

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

$$\eta: 5 \times 10^{-19} \text{ s}; \Gamma = 1.3 \text{ keV} \quad \eta \rightarrow \gamma\gamma$$

$$\pi^0: 8 \times 10^{-17} \text{ s}; c\tau = 25 \text{ nm} \quad \pi^0 \rightarrow \gamma\gamma$$

Two exp. techniques:

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

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

PrimEx PRL 106,162303(2011)

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

KLOE-2, Taggers

$$5\text{fb}^{-1} \Rightarrow \delta\Gamma(\pi^0 \rightarrow \gamma\gamma) \sim 1\%$$

Details: [EPJC 72, 1917 (2012)]

VALUE (keV)	EVTS	DOCUMENT ID	TECN	COMMENT
0.510 ± 0.026	OUR FIT	$\delta\Gamma(\eta \rightarrow \gamma\gamma) \sim 5\%$		
0.510 ± 0.026	OUR AVERAGE			
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		<sup>1</sup> 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		<sup>2</sup> BEMPORAD	67 CNTR	Primakoff effect

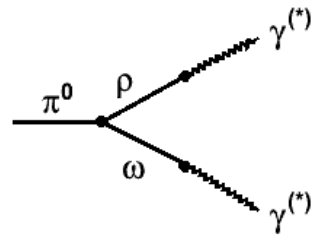
$$\sigma(e^+e^- \rightarrow e^+e^-\eta, \sqrt{s}=1\text{GeV})$$

$$\Gamma_{\gamma\gamma} = 520 \pm 20_{\text{stat}} \pm 13_{\text{syst}} \text{ eV}$$

[KLOE JHEP1301 (2013) 119]

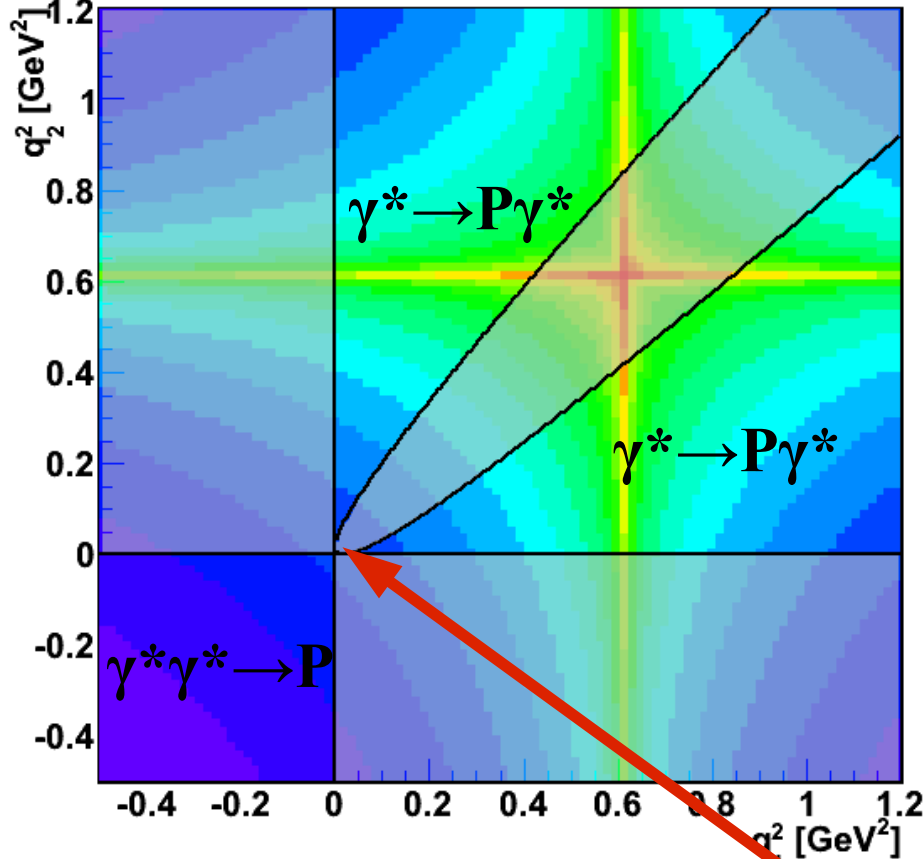


# TFF kinematic regions: $\pi^0, \eta$

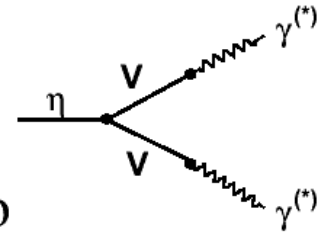


$$|F_{\pi^0}(q_1^2, q_2^2)|^2$$

$\pi^0$

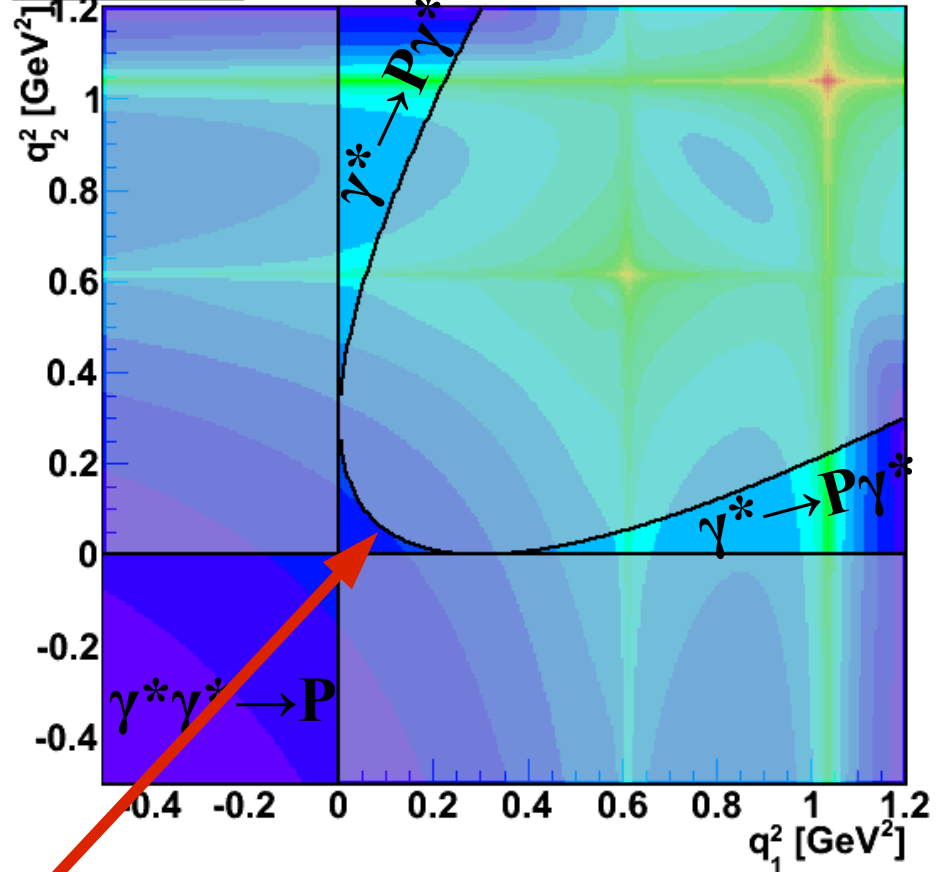


$$\sum_{V=\rho, \omega, \phi}$$



$$|F_{\eta}(q_1^2, q_2^2)|^2$$

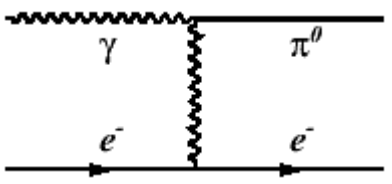
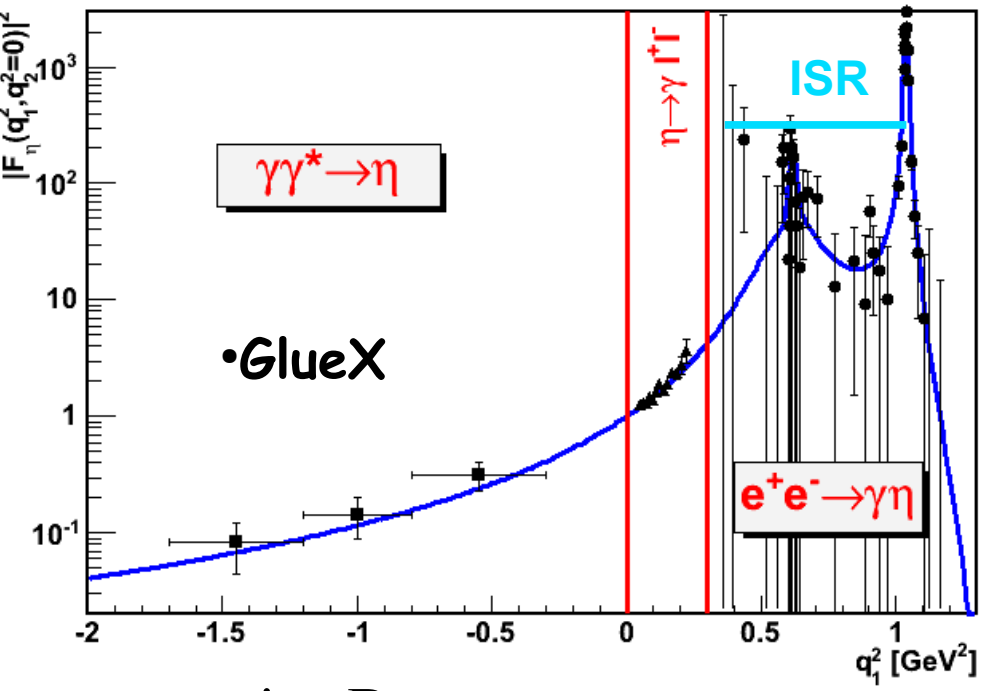
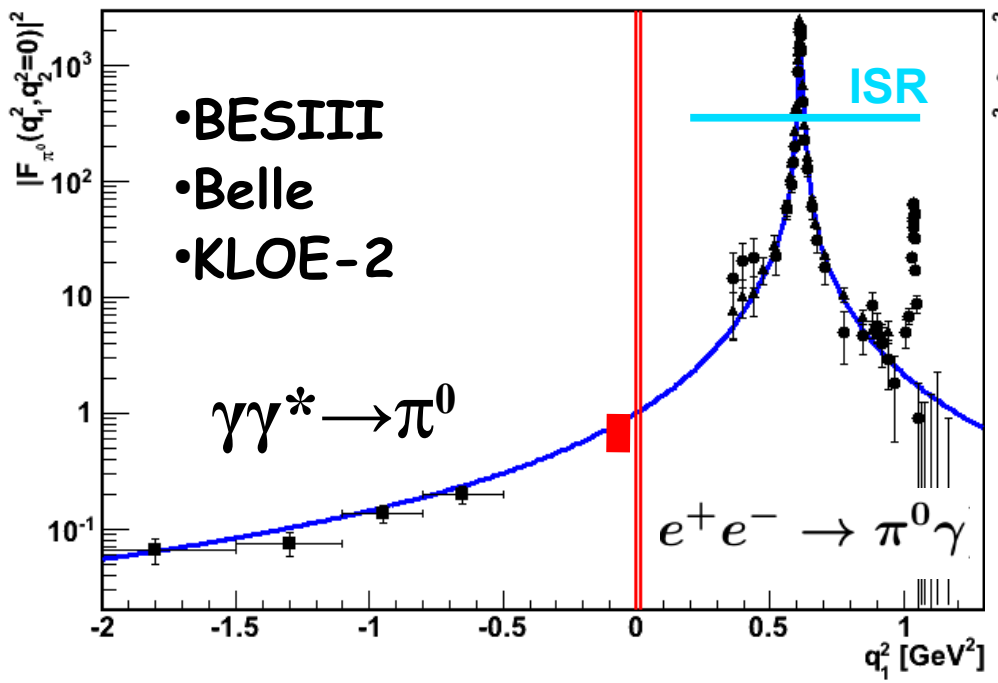
$\eta$



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



# $\eta, \pi^0$ single off shell TFF

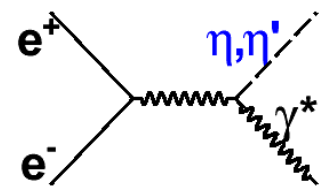


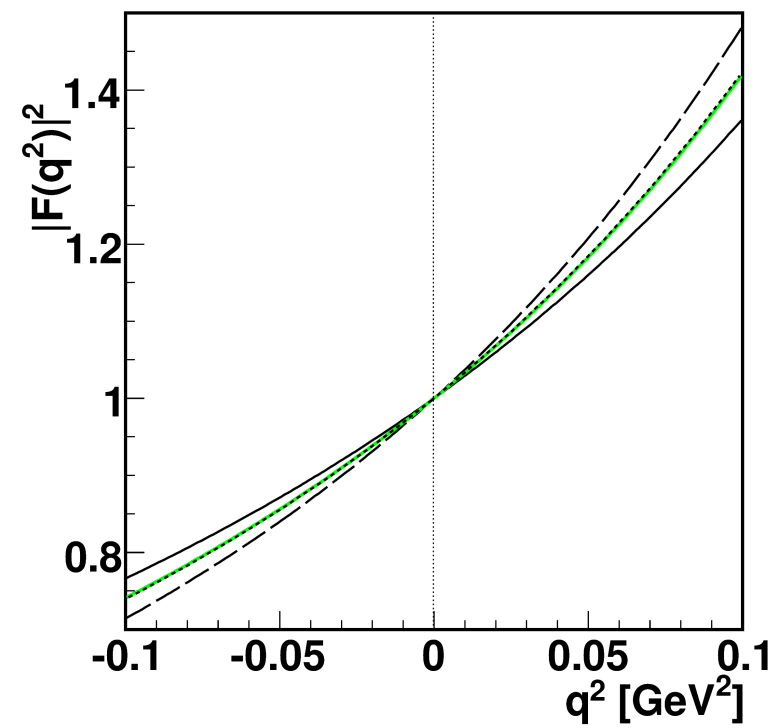
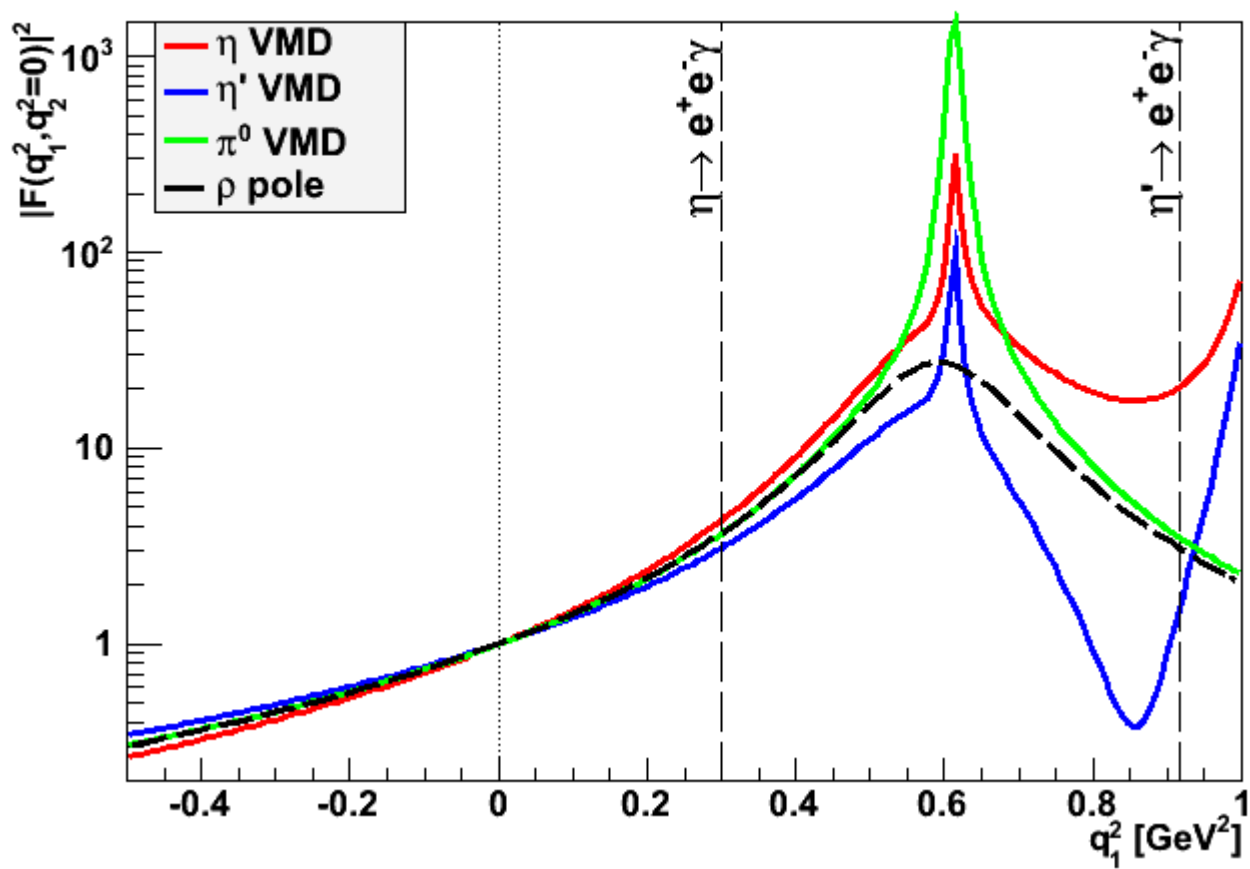
$$\frac{d\sigma}{dt}(e^- \gamma \rightarrow e^- P) = \frac{16 \pi \alpha}{3 s m_P^3} \Gamma_{\gamma\gamma} |F_P(t, 0)|^2 \frac{s - m_P^2 + t}{t}$$

$\gamma^* \rightarrow P\gamma$   
 VEPP 2000 0.3-2GeV  
 KLOE-2 ISR, BESIII

$$\sigma(e^+e^- \rightarrow P\gamma) = \frac{8}{3} \pi \alpha \Gamma_{\gamma\gamma} |F_P(s, 0)|^2 \left( \frac{s - m_P^2}{s m_P} \right)^3$$

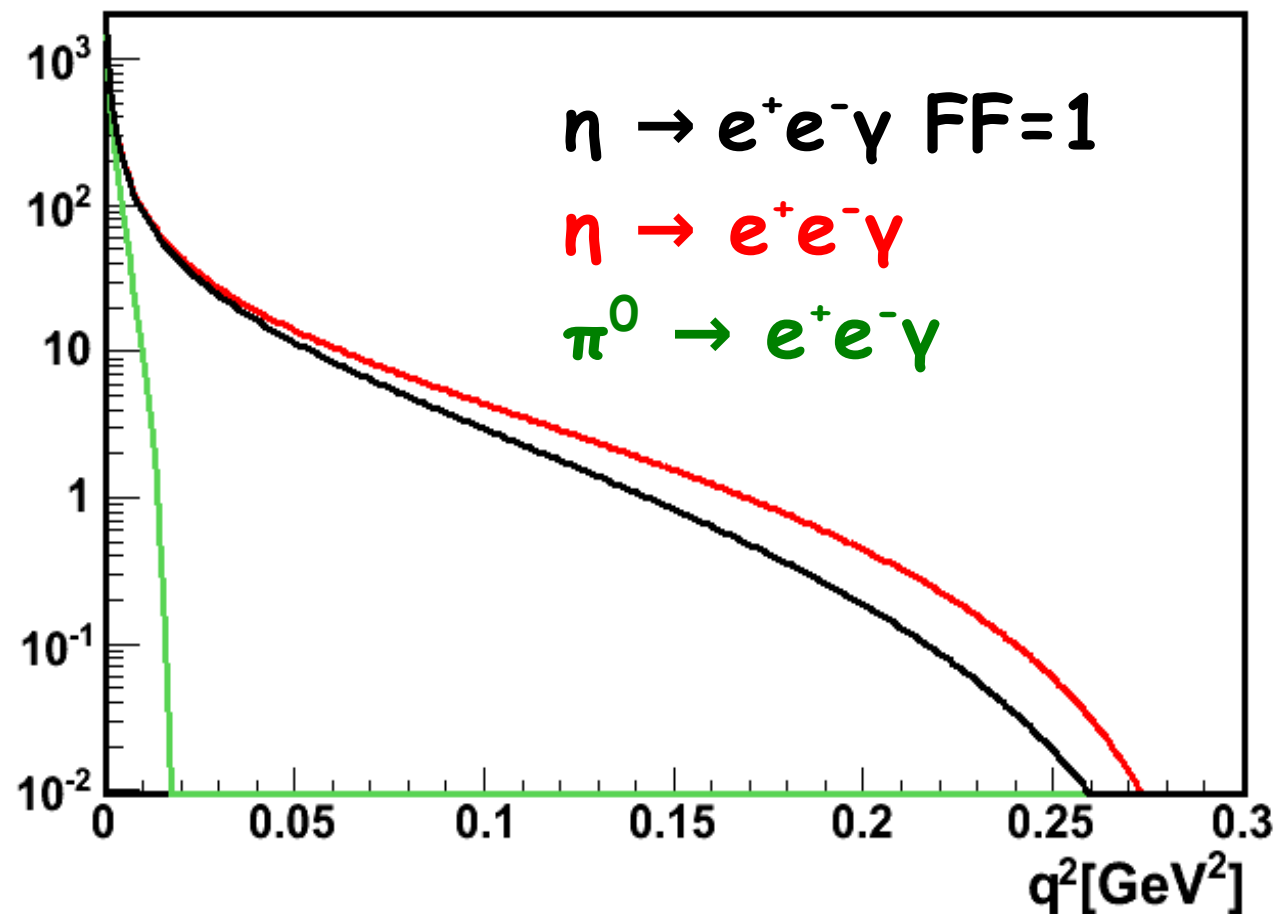
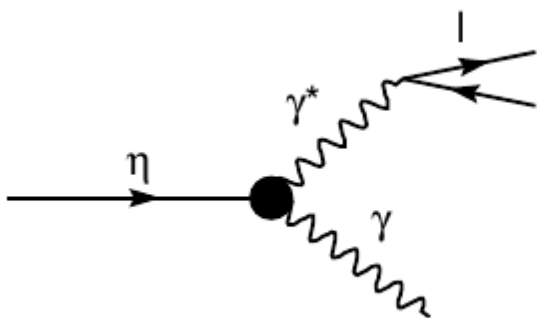
$P \rightarrow \gamma^* \gamma$   
 Dalitz decays:  
 KLOE, WASA, CBall, BESIII  
 CLAS, NA48





# Dalitz decays

$$\frac{d\Gamma(P \rightarrow \ell^+ \ell^- \gamma)}{dq^2 \Gamma_{\gamma\gamma}} = \frac{2\alpha}{3\pi} \frac{1}{q^2} \sqrt{1 - \frac{4m_\ell^2}{q^2}} \left(1 + \frac{2m_\ell^2}{q^2}\right) \left(1 - \frac{q^2}{M_P^2}\right)^3 |F_P(q^2, 0)|^2$$

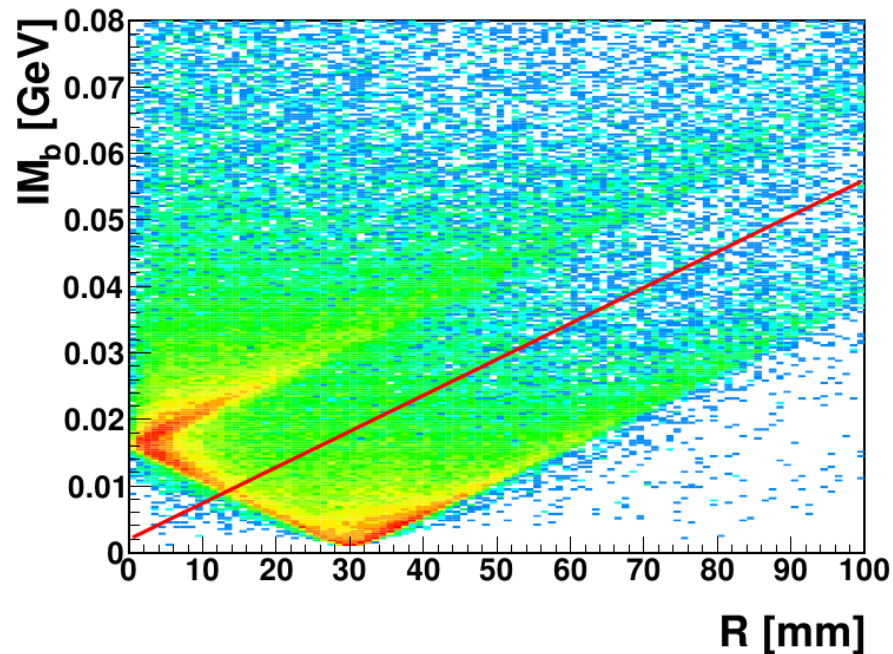
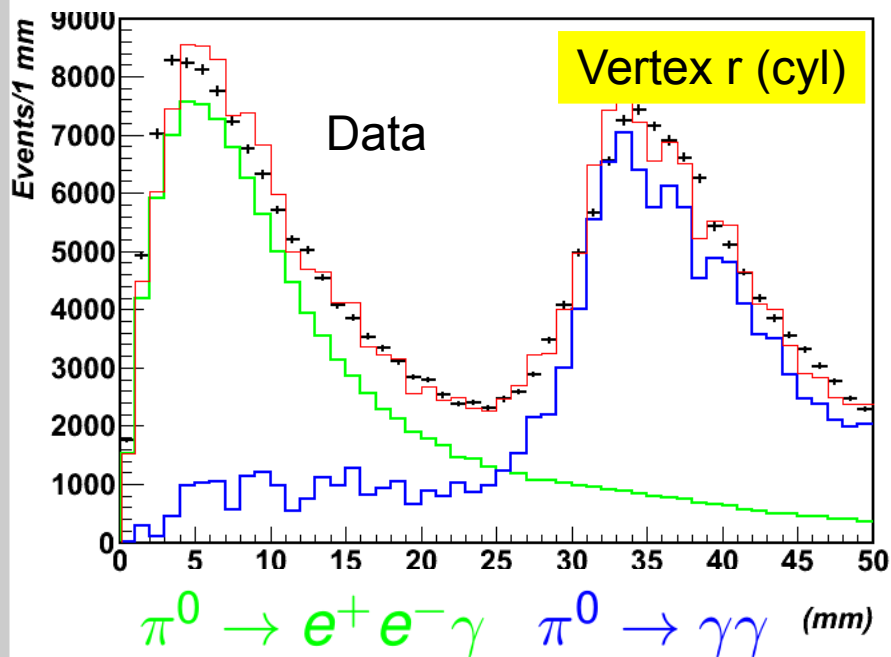
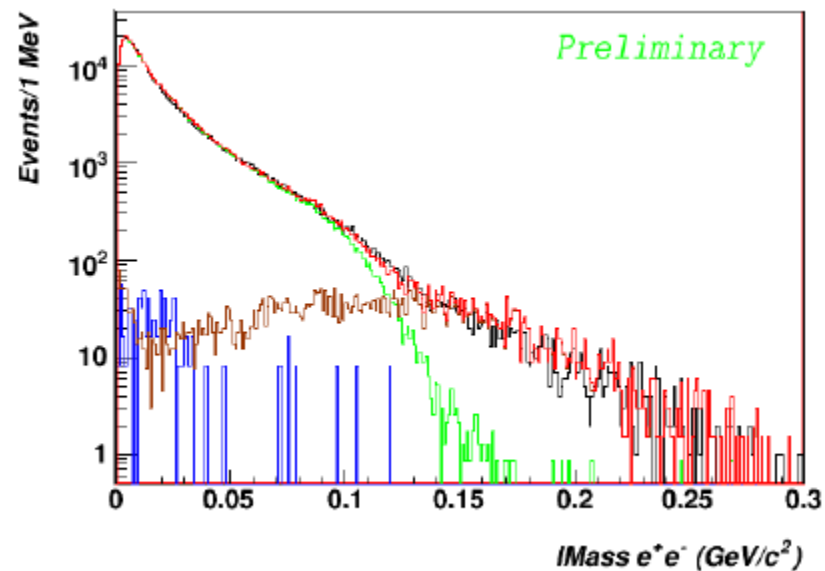
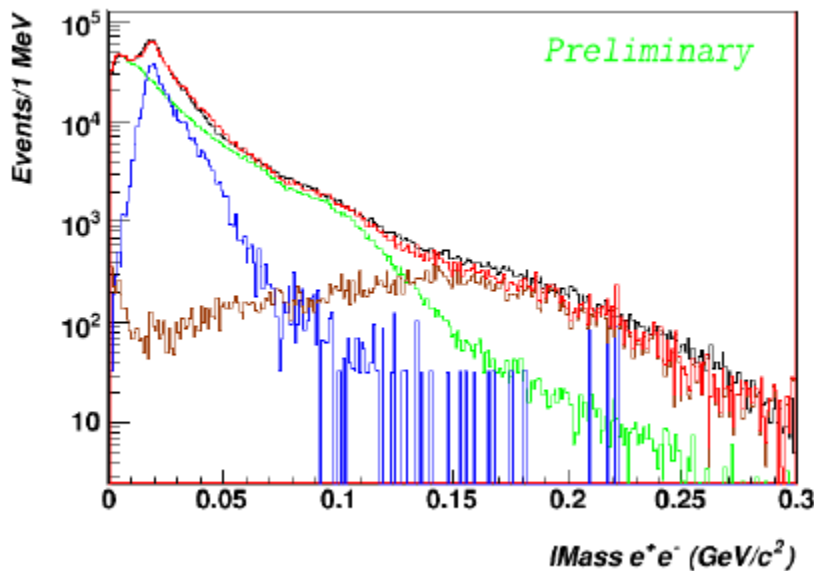




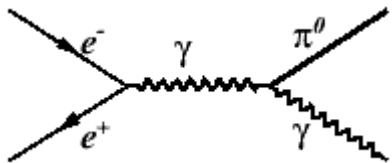
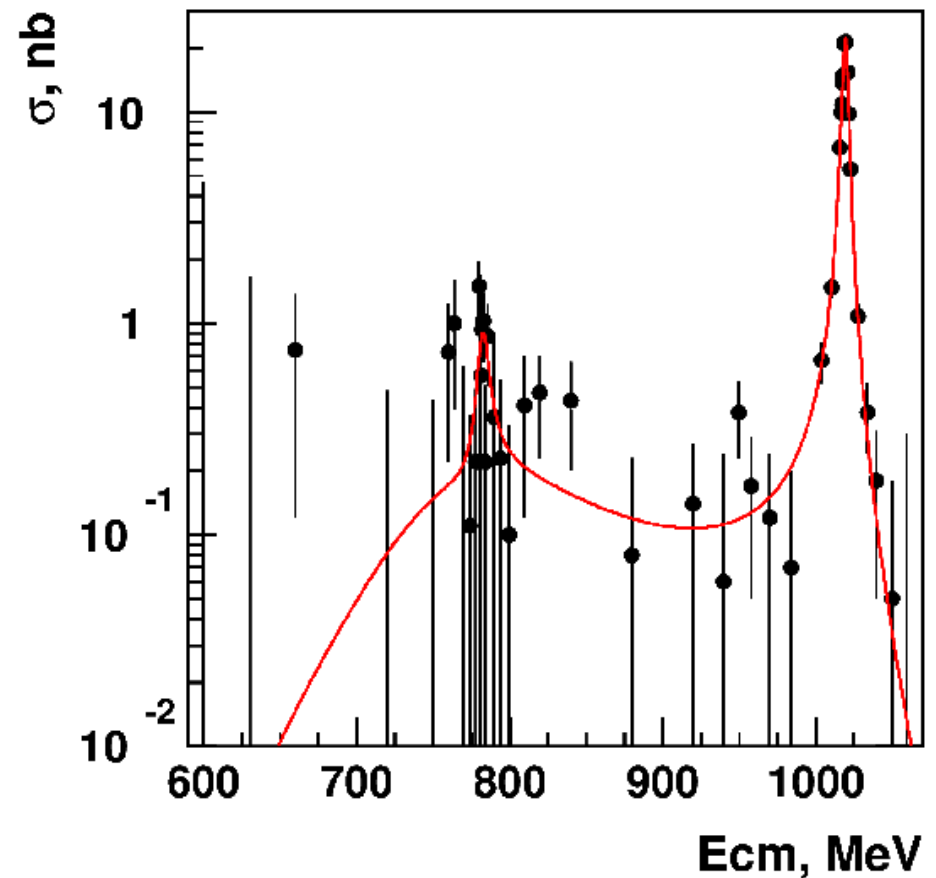
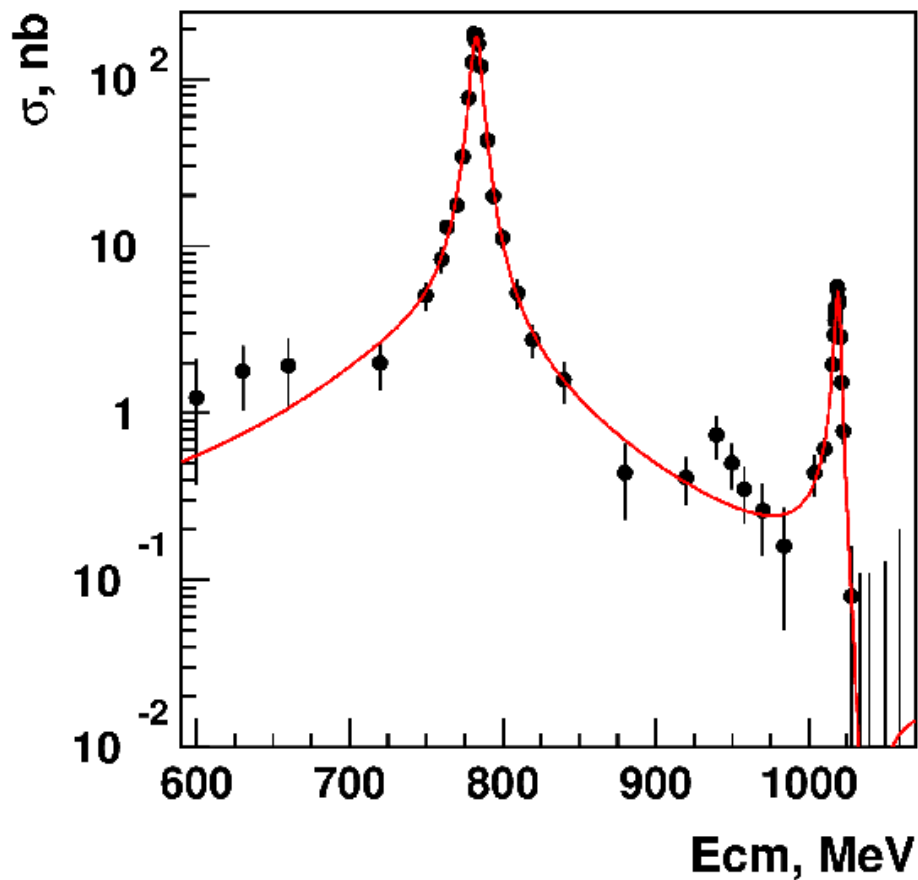
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# Analysis: $\pi^0 \rightarrow \gamma e^+ e^-$

Vertex r 20 mm + PID



# $\sigma(e^+e^- \rightarrow \pi^0\gamma, n\gamma)$



$$\sigma(e^+e^- \rightarrow P\gamma) = \frac{8}{3}\pi\alpha \Gamma_{\gamma\gamma} |F_P(s, 0)|^2 \left( \frac{s - m_P^2}{sm_P} \right)^3$$





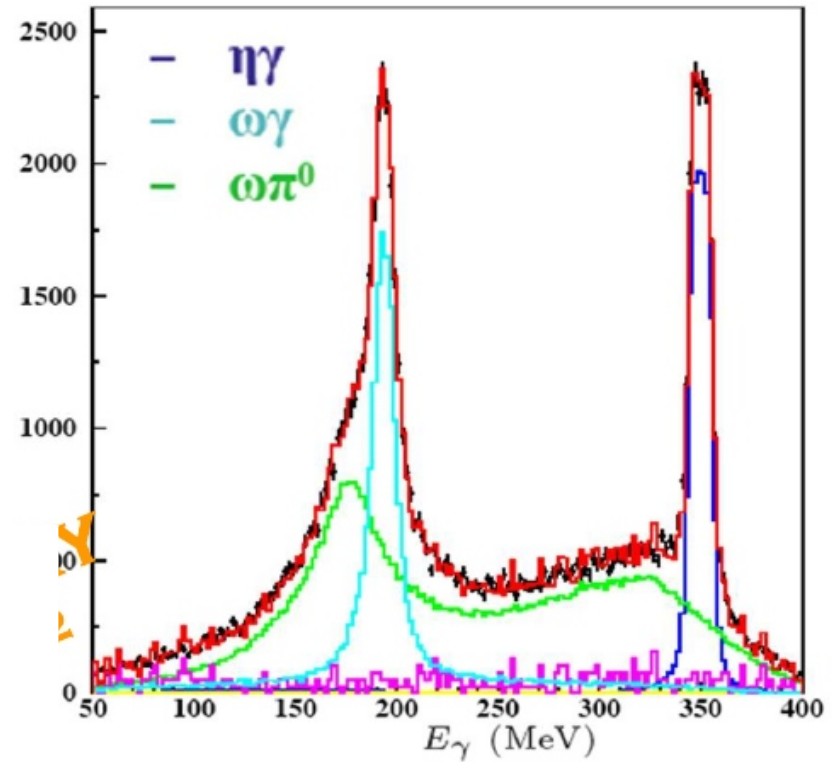
# $e^+e^- \rightarrow \eta\gamma$ at 1 GeV



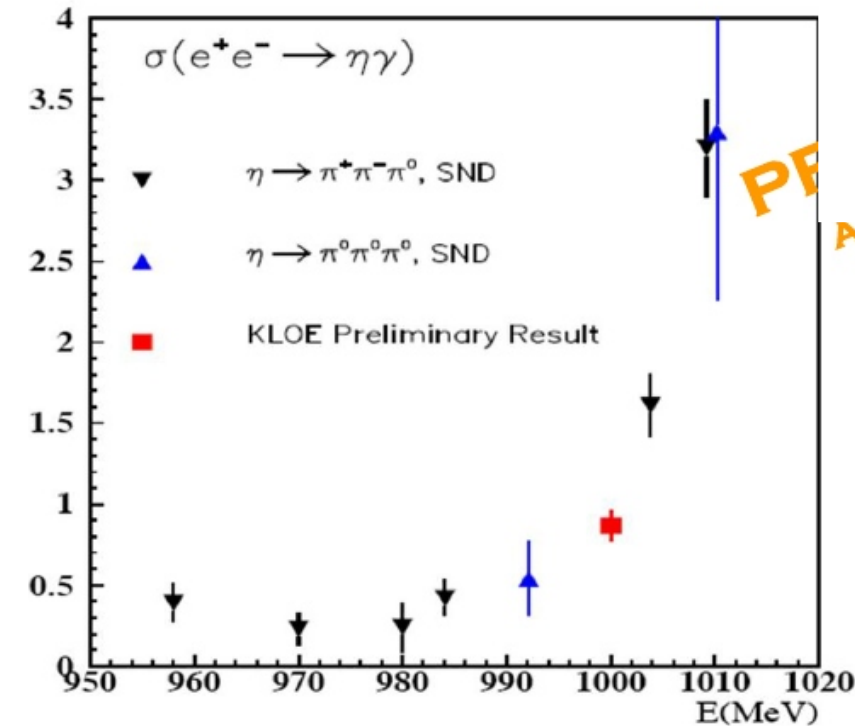
$e^+e^- \rightarrow \eta\gamma \rightarrow \pi^+\pi^-\pi^0\gamma$ : 3 photons + 2 tracks

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

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



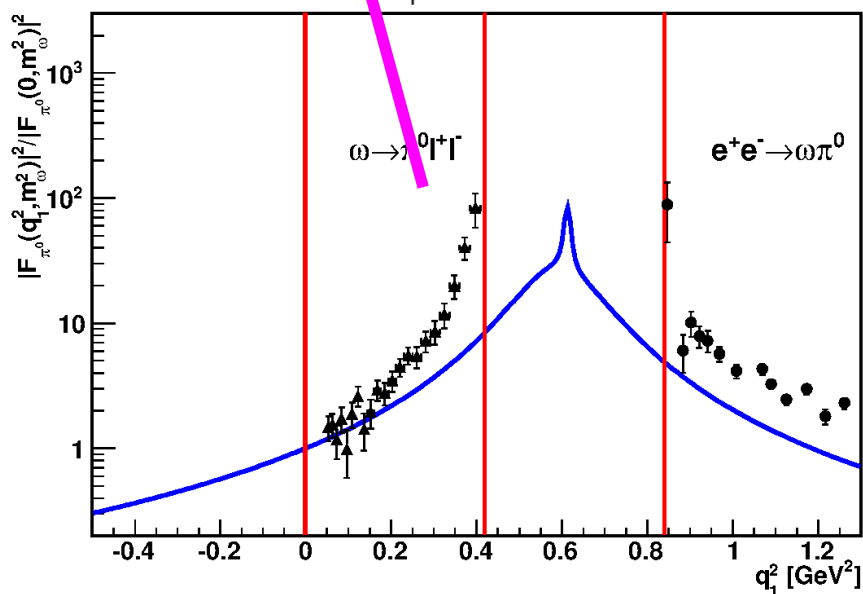
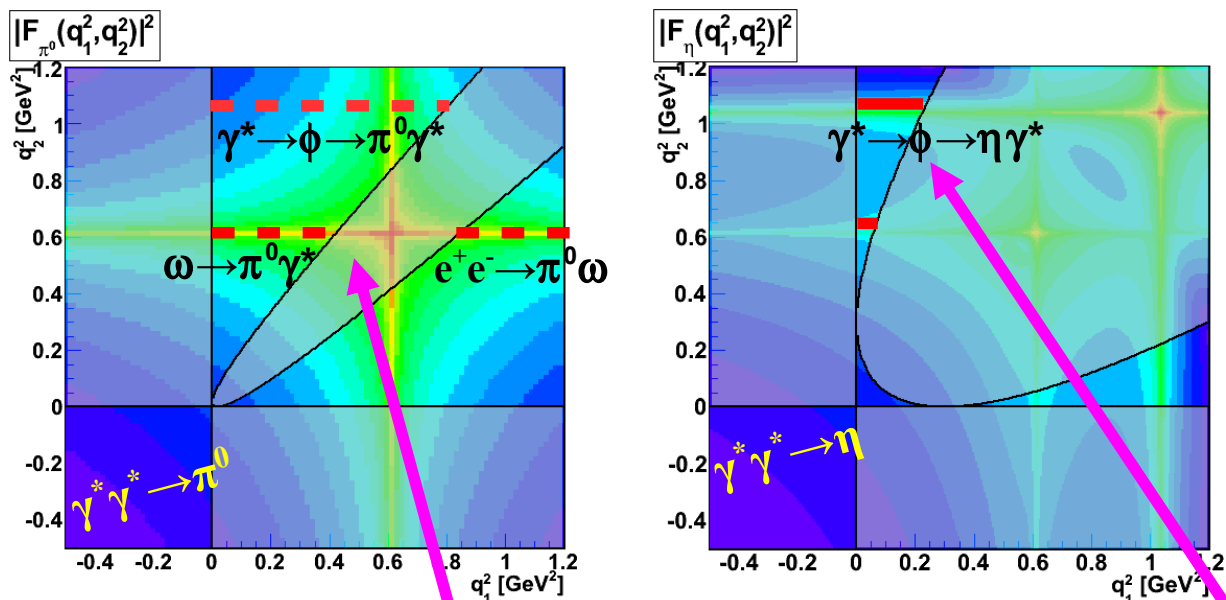
In agreement with the result from  $\eta \rightarrow \pi^0\pi^0\pi^0$   
( $\gamma$ 's with imposed  $\pi^0, \eta$  masses + miss. E)



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

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

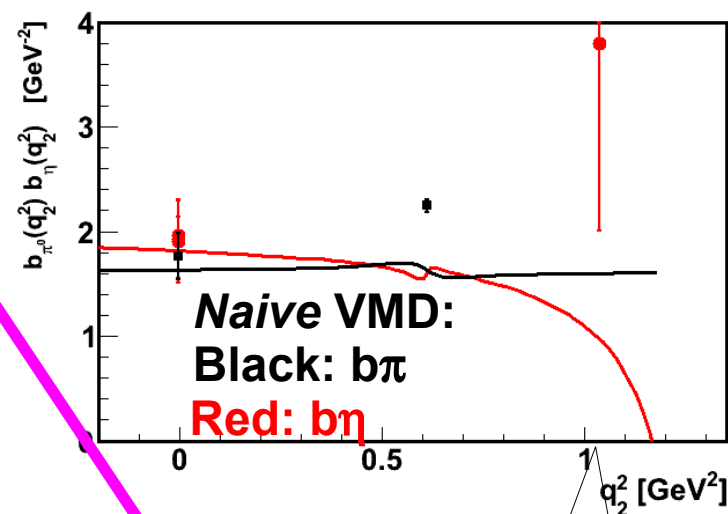


TH:  $\rightarrow$  Bastian talk

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

## slopes $b_\pi, b_\eta$

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



KLOE prel result

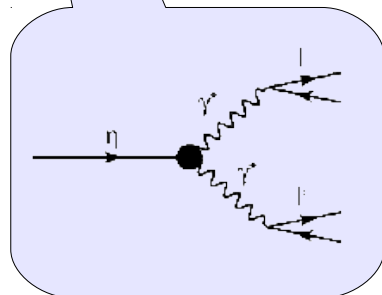
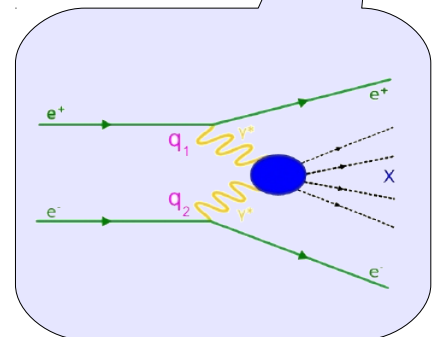
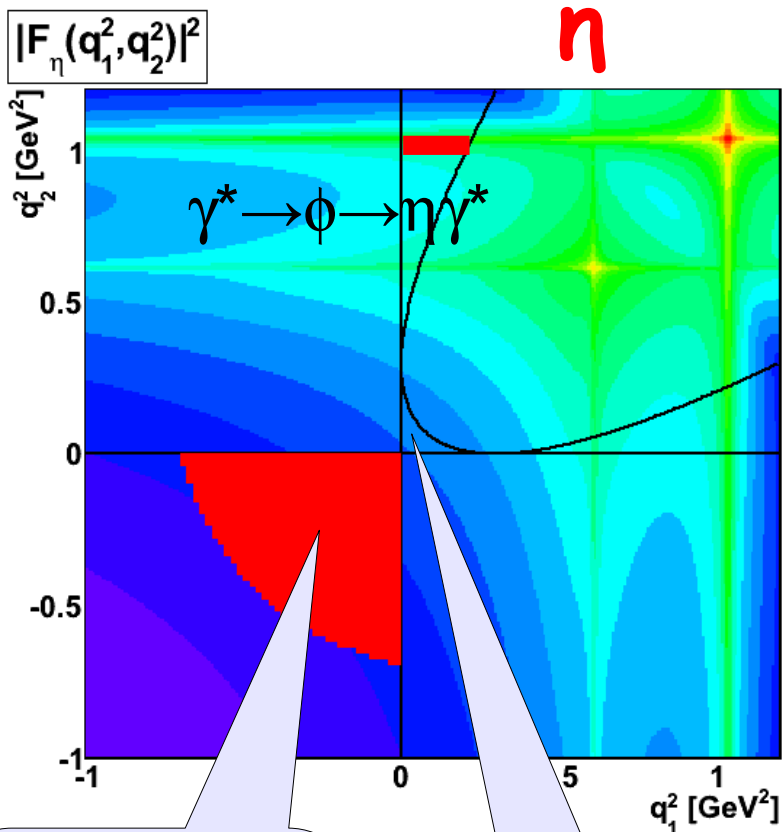
$\phi \rightarrow \eta \gamma^*$  BR  $10^{-4}$

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

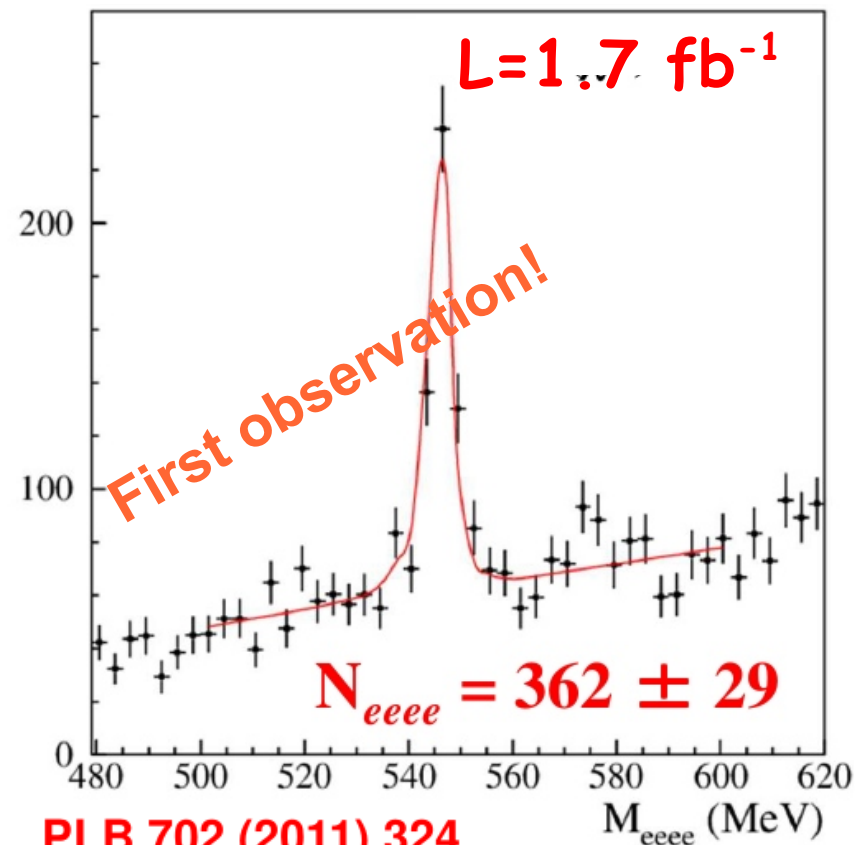
$b_\eta(m_\phi^2)$



# Double off shell TFF



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

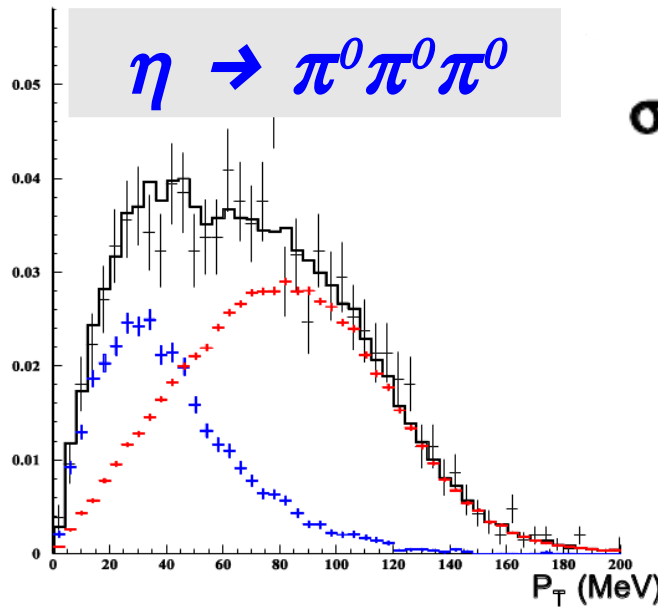
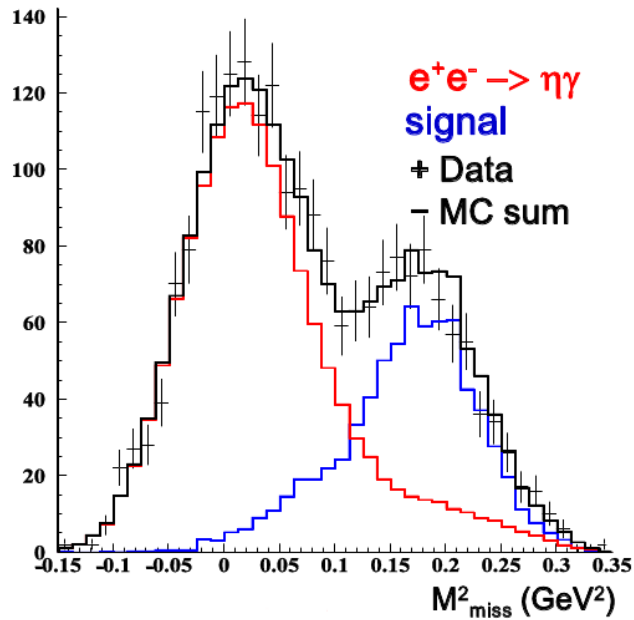


PLB 702 (2011) 324

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



# $\eta$ meson radiative decay width

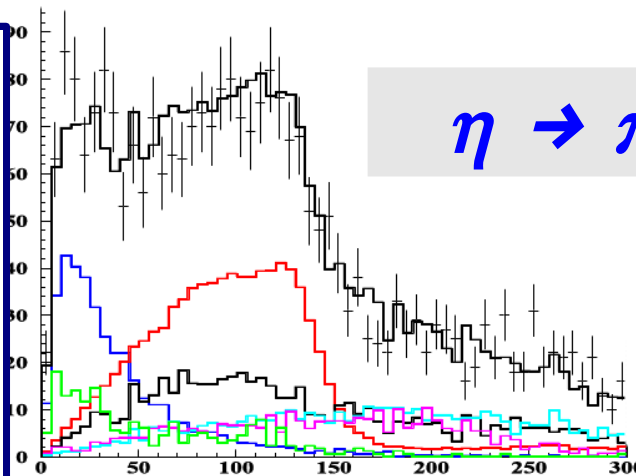
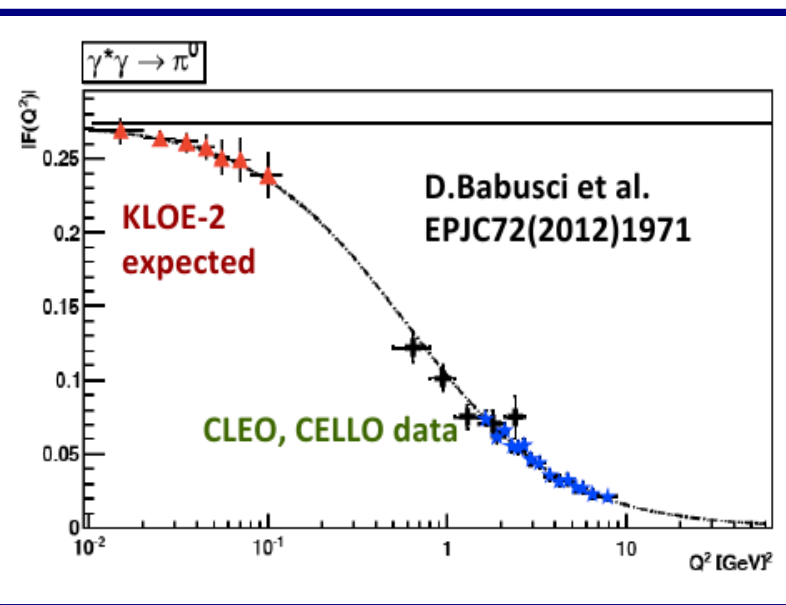


$$\sigma(e^+e^- \rightarrow e^+e^-\eta, \sqrt{s}=1\text{GeV})$$

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

$$\Gamma_{\gamma\gamma}=520 \pm 20 \pm 13 \text{ eV}$$

$$32.0 \pm 1.5 \pm 0.9 \text{ pb}$$

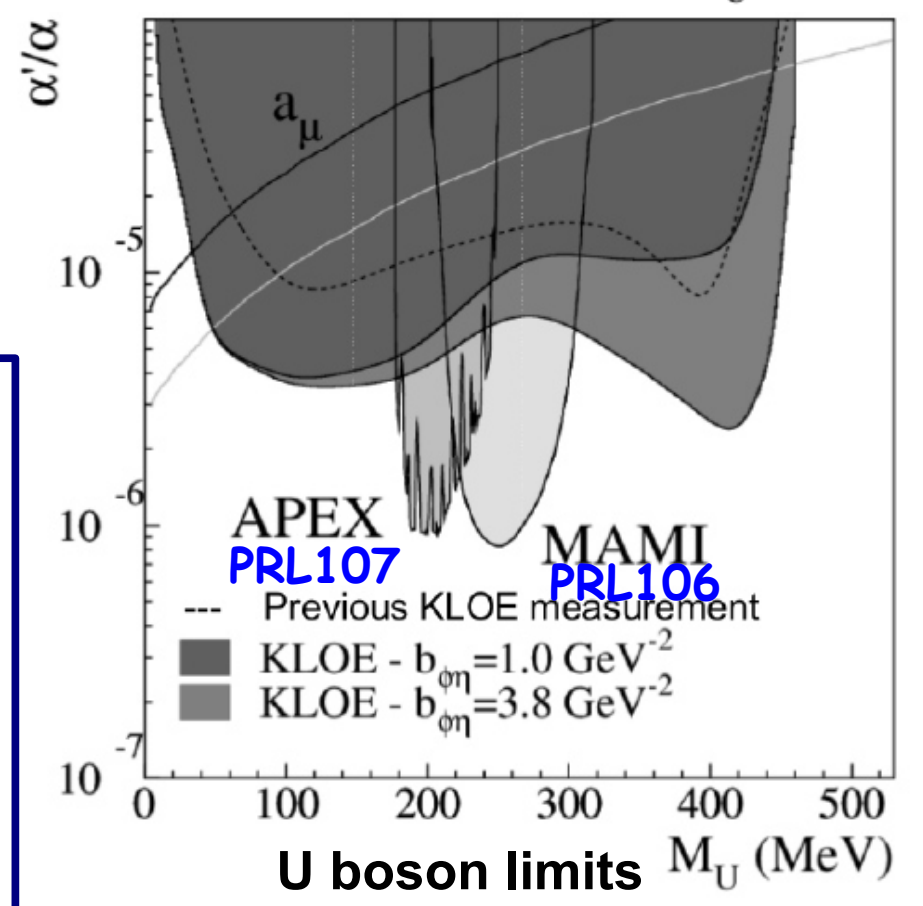
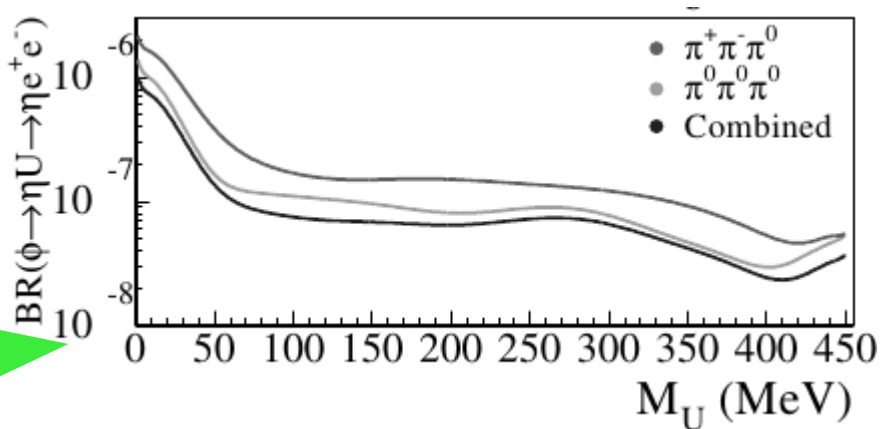
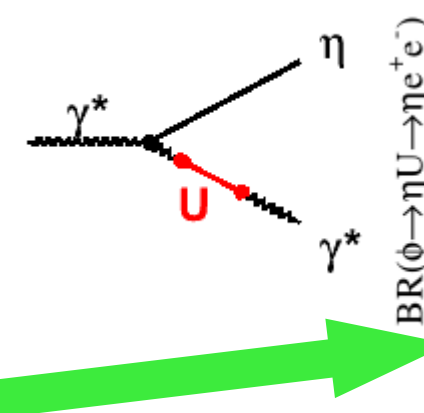
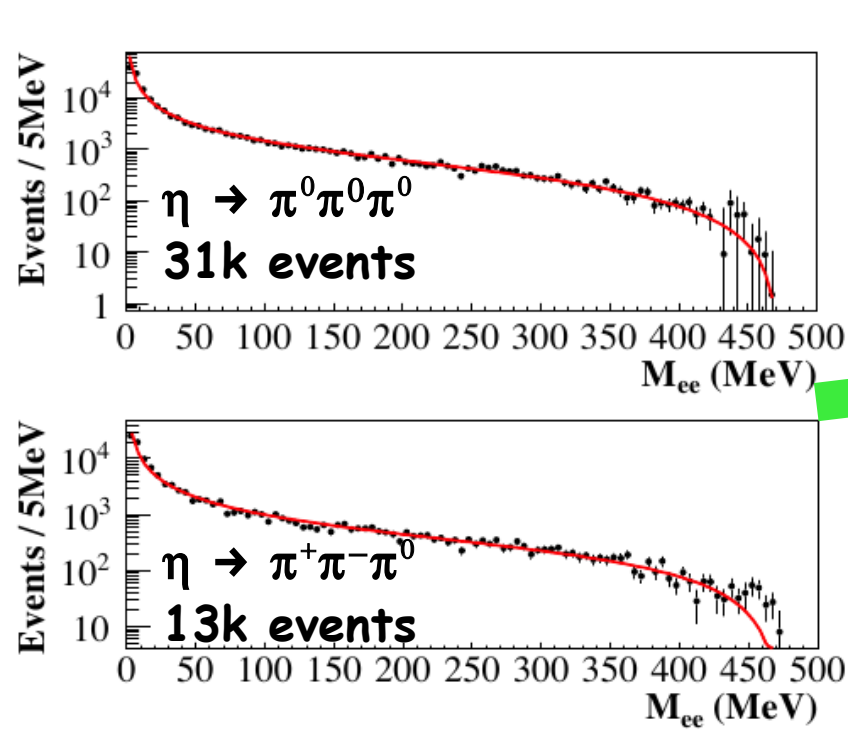


- $\phi \rightarrow \eta\gamma$
- $e^+e^- \rightarrow e^+e^-\gamma$
- $e^+e^- \rightarrow \omega\pi^0$
- Signal
- $e^+e^- \rightarrow K^+K^-$
- $e^+e^- \rightarrow K_s K_L$

$$34.5 \pm 2.5 \pm 1.0 \text{ pb}$$



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



**Form factor/BR:**

	SND/CMD-2 (2001)	KLOE – Preliminary Mode	Neutral
$b_{\phi\eta} [\text{GeV}^{-2}]$	$3.8 \pm 1.8 / --$	$1.17 \pm 0.11^{+0.09}_{-0.08}$	
BR ( $\times 10^4$ )	$1.19 \pm 0.31 / 1.14 \pm 0.16$	$1.131 \pm 0.031 \pm 0.007^{+0.011}_{-0.006}$	

$$F_\eta(q^2, m_\phi^2) \propto \frac{1}{1 - b_\eta(m_\phi^2)q^2}$$



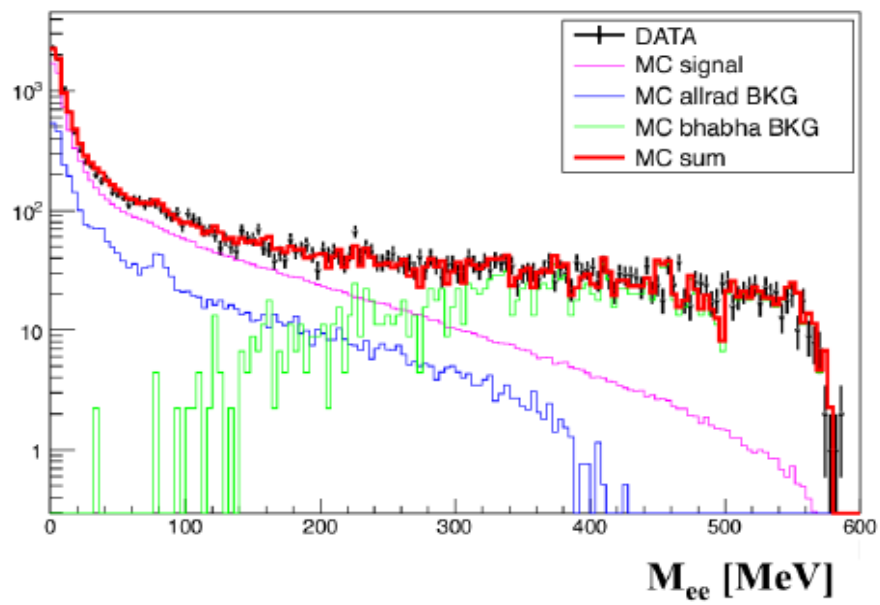
$$\psi \rightarrow e^+e^-\pi^0$$



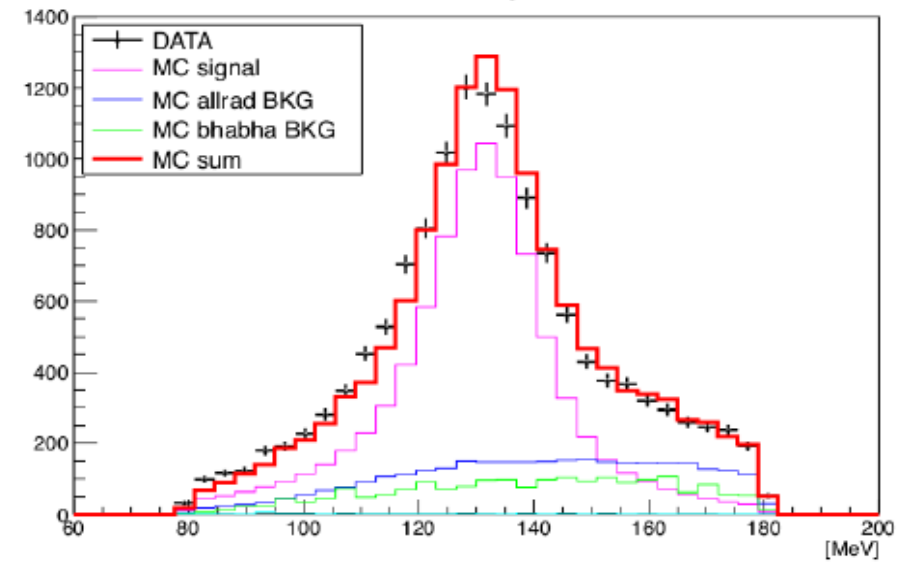
Value ( $10^{-5}$ )	CL%	EVTS	Document ID	TECN
$1.12 \pm 0.28$	<b>OUR AVERAGE</b>			
$1.01 \pm 0.28 \pm 0.29$		52	ACHASOV <sup>1</sup>	2002D SND
$1.22 \pm 0.34 \pm 0.21$		46	AKHMETSHIN <sub>2</sub>	2001C CMD2

**9k events**      **Background radiative Bhabha and  $\psi \rightarrow \pi^0\gamma$**       **efficiency: 15%  $\rightarrow$  2% low  $\rightarrow$  high  $q$**       **Analysis in progress: background subtraction + global efficiency**

e+e- mass spectrum



e e+ missing mass

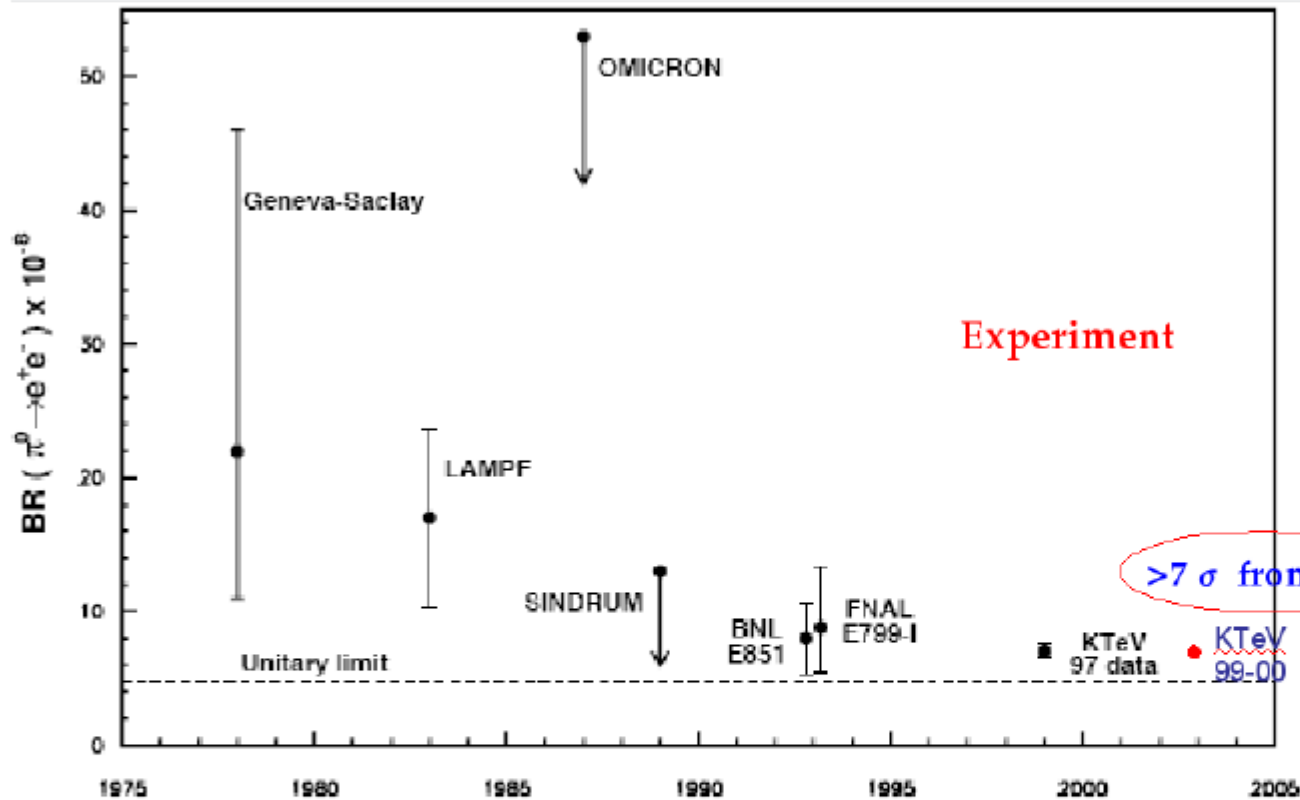




# History of $\pi^0 \rightarrow e^+ e^-$ measurements



UPPSALA  
UNIVERSITET



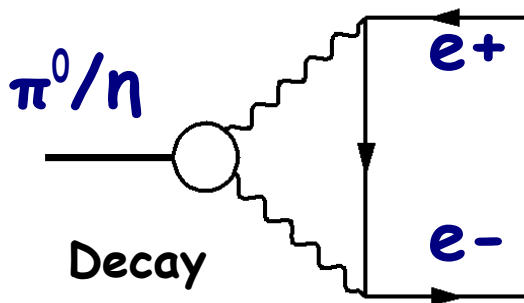
$$BR \approx \alpha^2 \left( \frac{m_e}{m_\pi} \right)^2 \approx O(10^{-8})$$

- Unitary bound (model independent)  $BR \geq 4.75 \cdot 10^{-8}$
- Experiment: KTeV (794 events from  $K_L \rightarrow 3\pi^0$ ):  

$$BR(\pi^0 \rightarrow e^+ e^-) = (6.44 \pm 0.25_{stat} \pm 0.22_{syst}) \times 10^{-8}$$

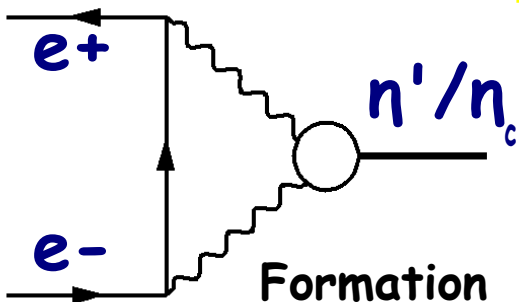
$$BR_{\text{no-rad}}(\pi^0 \rightarrow e^+ e^-) = (7.48 \pm 0.29_{stat} \pm 0.25_{syst}) \times 10^{-8}$$

PRD75:012004(07)



HADES  
WASA  
CBall  
NA48/NA62

	UB	SM $3\sigma$ diff	EXP
$\mathcal{B}(\pi^0 \rightarrow e^+e^-) \times 10^8$	$\geq 4.69$	$6.23 \pm 0.12$	$7.49 \pm 0.38$ KTeV2007
$\mathcal{B}(\eta \rightarrow e^+e^-) \times 10^9$	$\geq 1.78$	$5.2 \pm 0.3$	$\leq 5.6 \cdot 10^3$ HADES2012
$\mathcal{B}(\eta' \rightarrow e^+e^-) \times 10^{10}$	$\geq 0.36$	$1.9 \pm 0.3$	$\leq 2.1 \cdot 10^3$ ND1988
$\mathcal{B}(\eta_c \rightarrow e^+e^-) \times 10^{14}$	$\geq 4.2$	<b>Dorokhov, PLB667,145</b>	

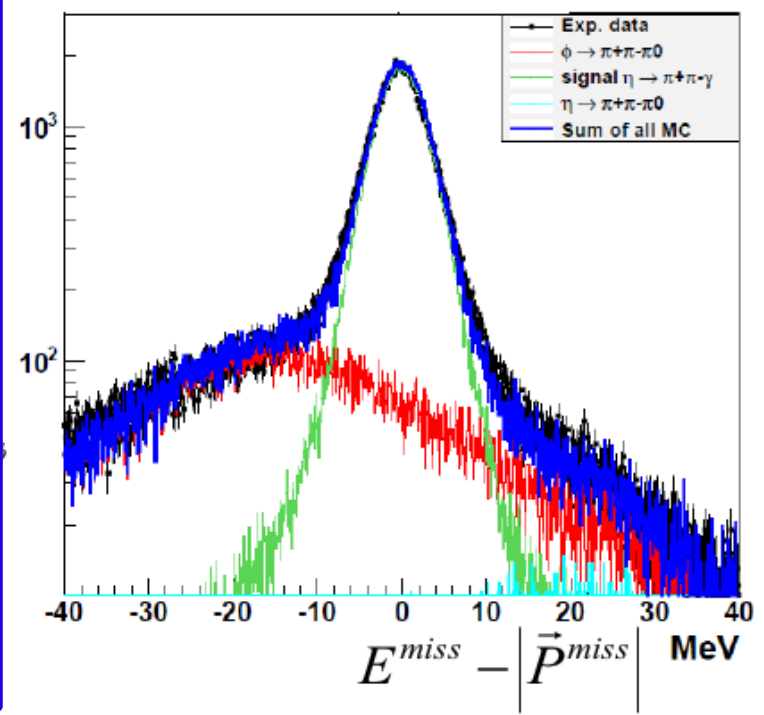
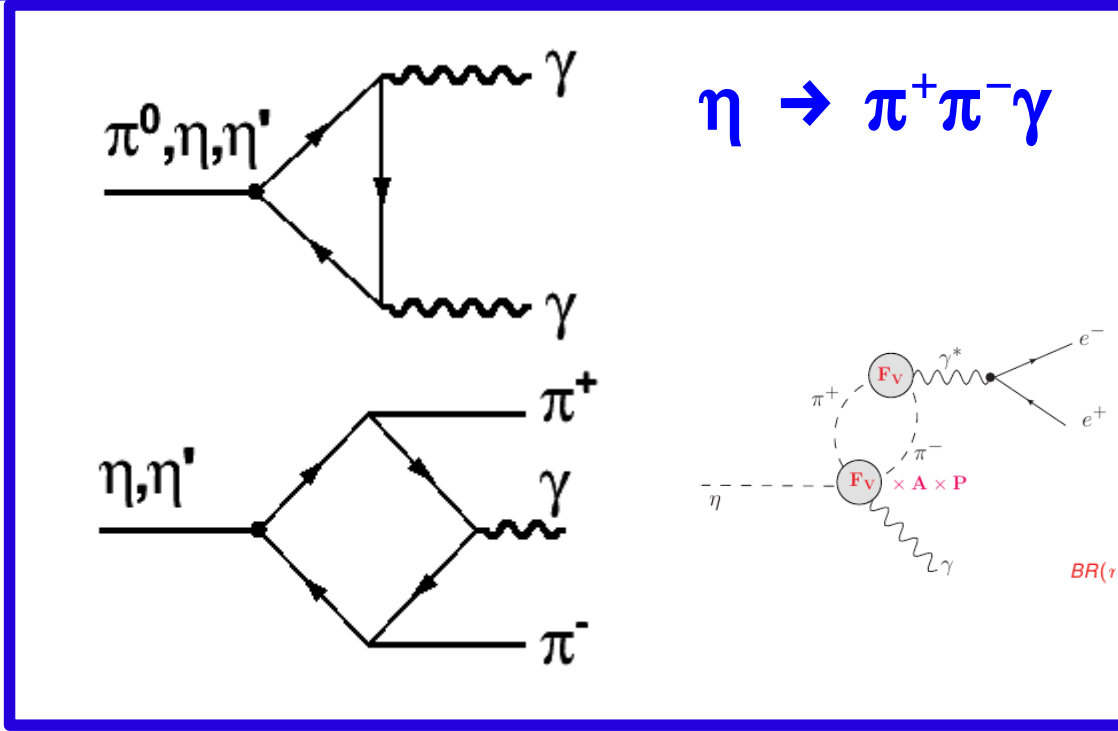


Searches using formation:  
 $e^+e^- \rightarrow \eta'$  ,  $L=0.5\text{pb}^{-1}$   
 $\Rightarrow B < 2.1 \cdot 10^{-7}$  90% CL

Vorobev SJNP 48(1988)273



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



- No kin fit: use DC resolution
- Not use EMC Energy
- $\Phi \rightarrow \eta \gamma$   $L = 558 \text{ pb}^{-1}$
- 205 k events
- eff=21%
- S/B=10

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

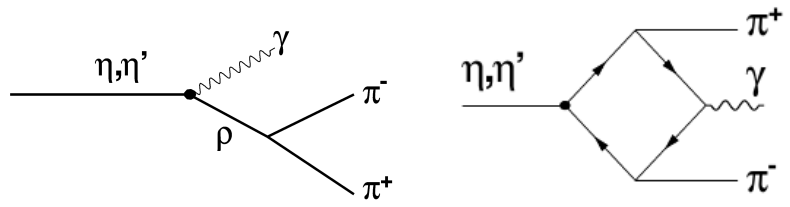
## $\Gamma(\eta \rightarrow \pi^+\pi^-\gamma) / \Gamma(\eta \rightarrow \pi^+\pi^-\pi^0)$

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

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



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

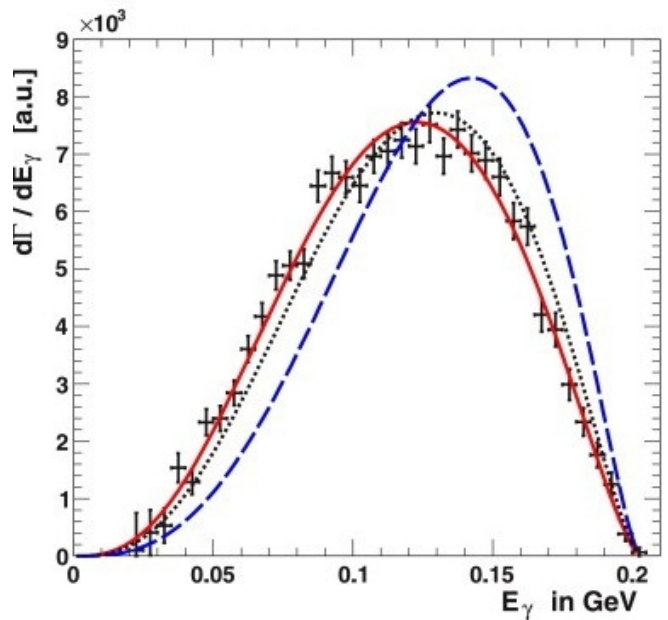


$$\frac{d\Gamma}{ds} = |A(1 + \alpha s + \dots) F_V(s)|^2 K_P(s)$$

PLB707 (2012) 184

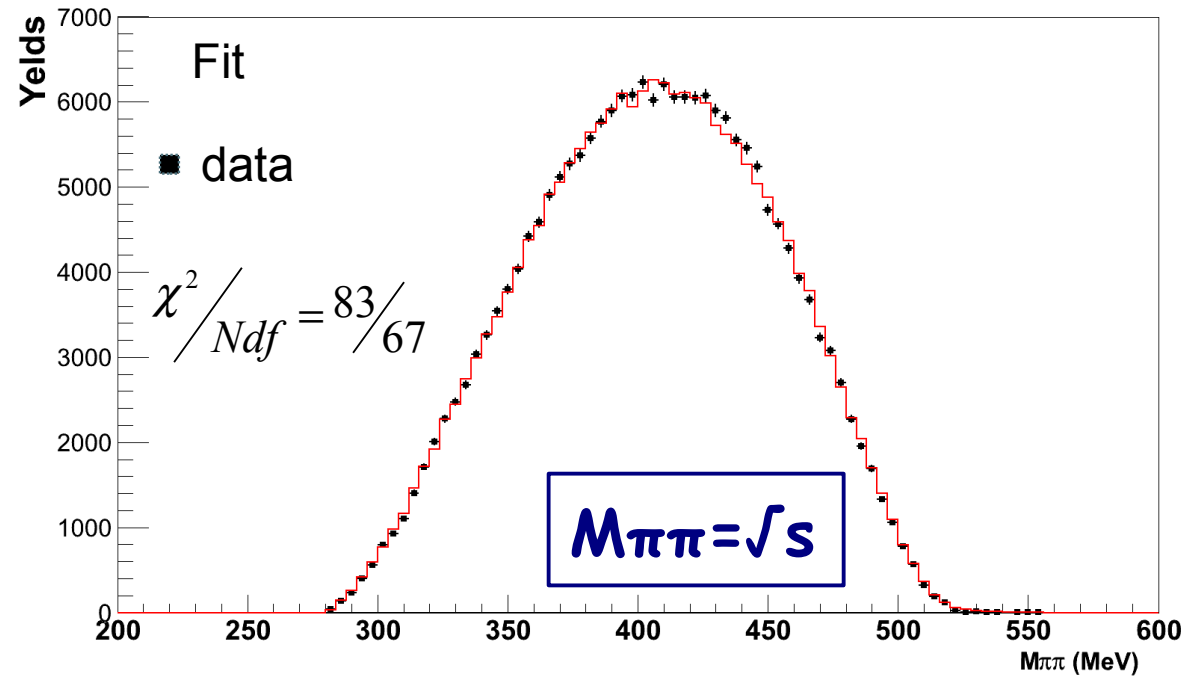
$e^+ e^- \rightarrow \pi^+ \pi^-$

$$\frac{d\Gamma_{\eta(\eta')}}{ds_{\pi\pi}} \propto \left| C + \frac{1}{s_{\pi\pi} - m_\rho^2 - im_\rho \Gamma_\rho} \right|^2$$



$$\alpha = 1.89 \pm 0.25_{\text{stat}} \pm 0.59_{\text{syst}} \text{ GeV}^{-2}$$

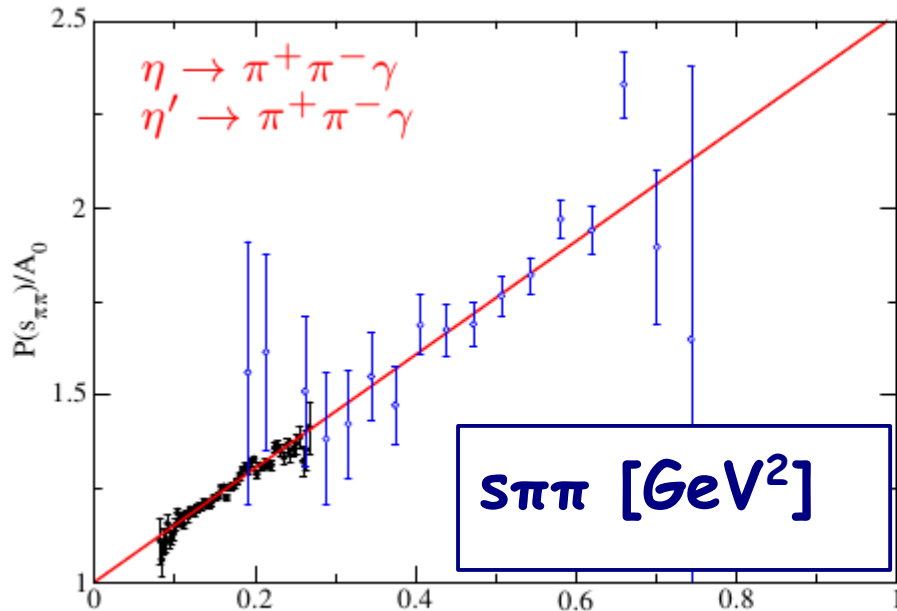
[WASA PLB707 (2012) 243]



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

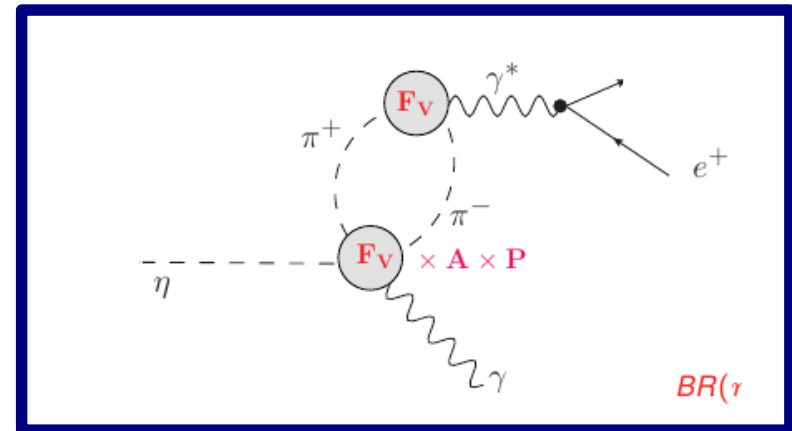
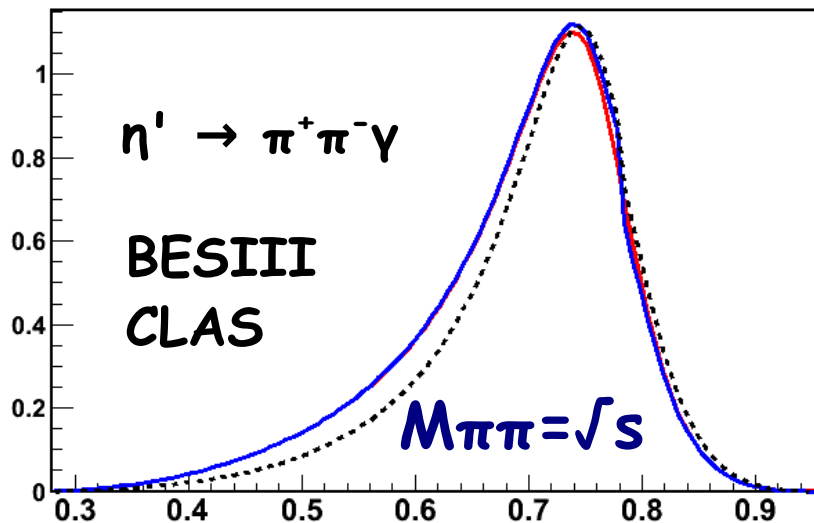
[KLOE PLB718 (2013) 910]

# From $\eta \rightarrow \pi^+\pi^-\gamma$ to $\eta \rightarrow e^+e^-\gamma$



$$P(s_{\pi\pi}) = A_0(1 + \alpha s_{\pi\pi})$$

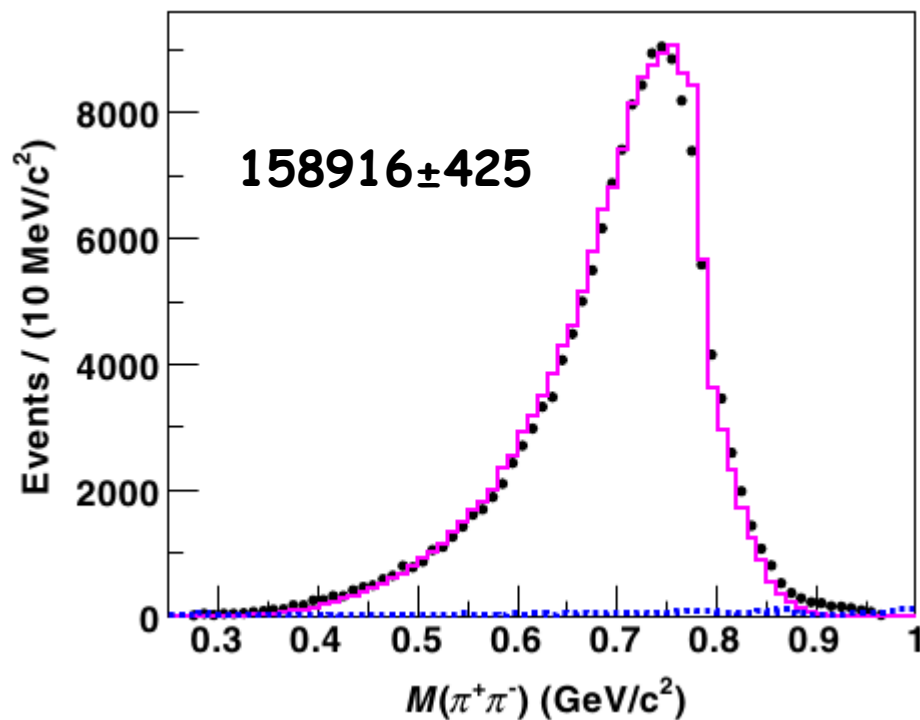
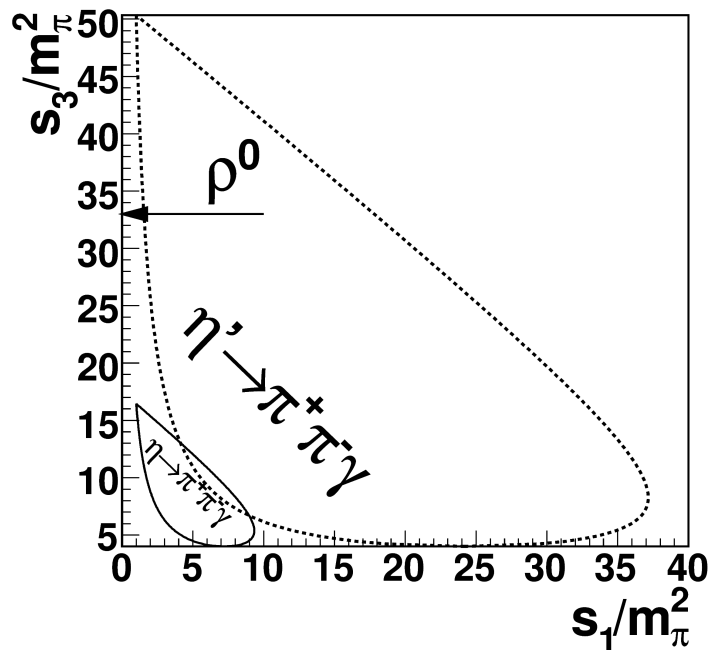
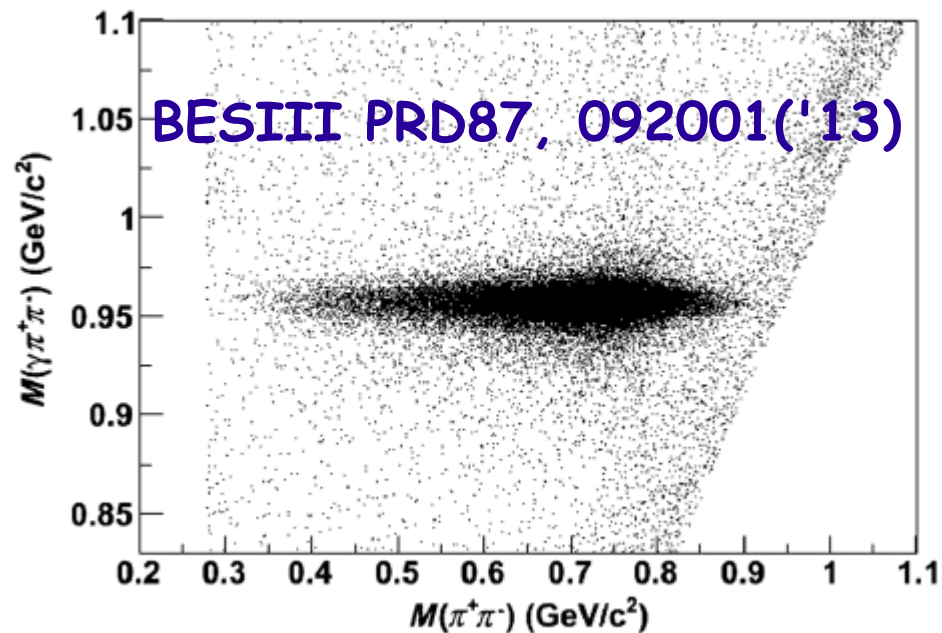
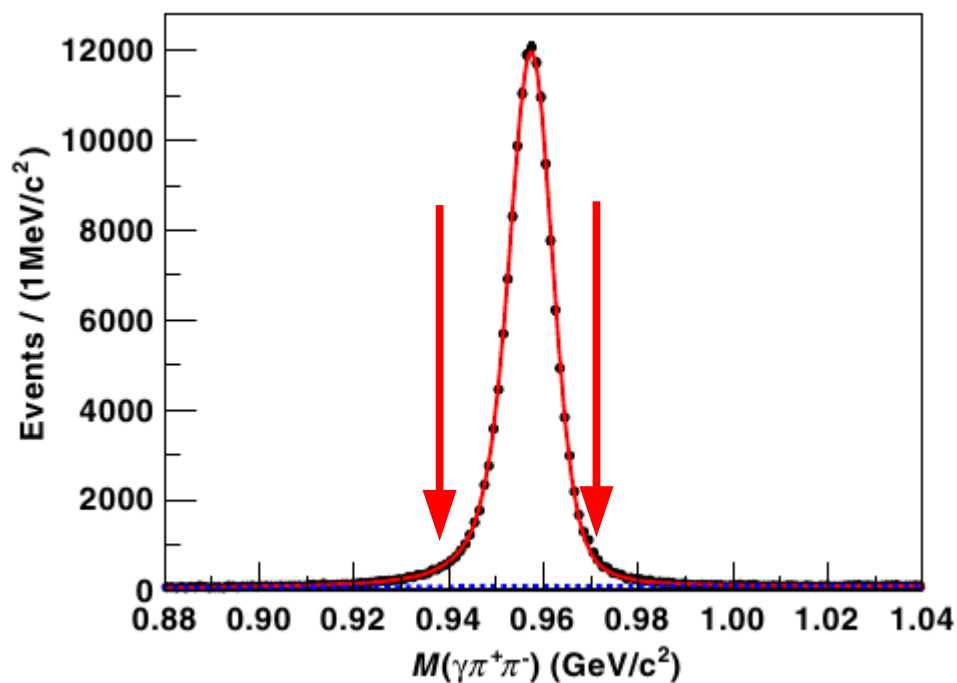
- $\alpha$  reaction specific
- $\alpha[\eta] = \alpha[\eta']$  understood  
1-loop ChPT + large  $N_c$



**KLOE:  $A + \alpha \Rightarrow b\eta(0) = 2.05^{+0.22}_{-0.10} \text{ GeV}^{-2}$**

EPJC73(13)2668

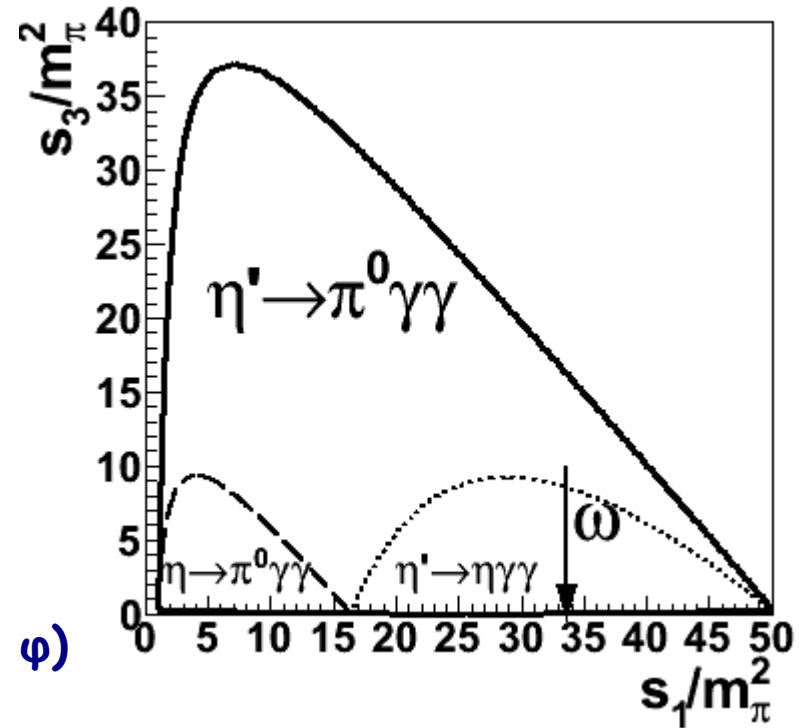
# BESIII data sample on $\eta' \rightarrow \pi^+ \pi^- \gamma$



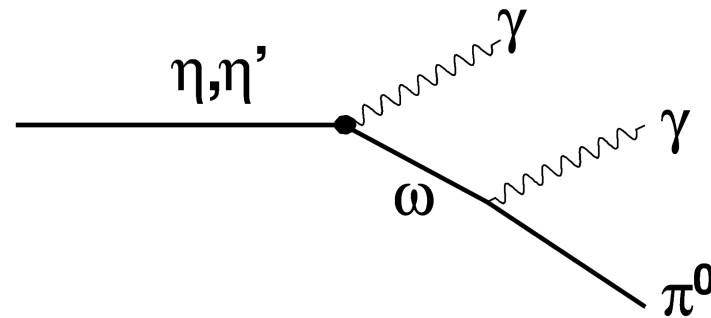


# $\eta/\eta' \rightarrow \pi^0\gamma\gamma$

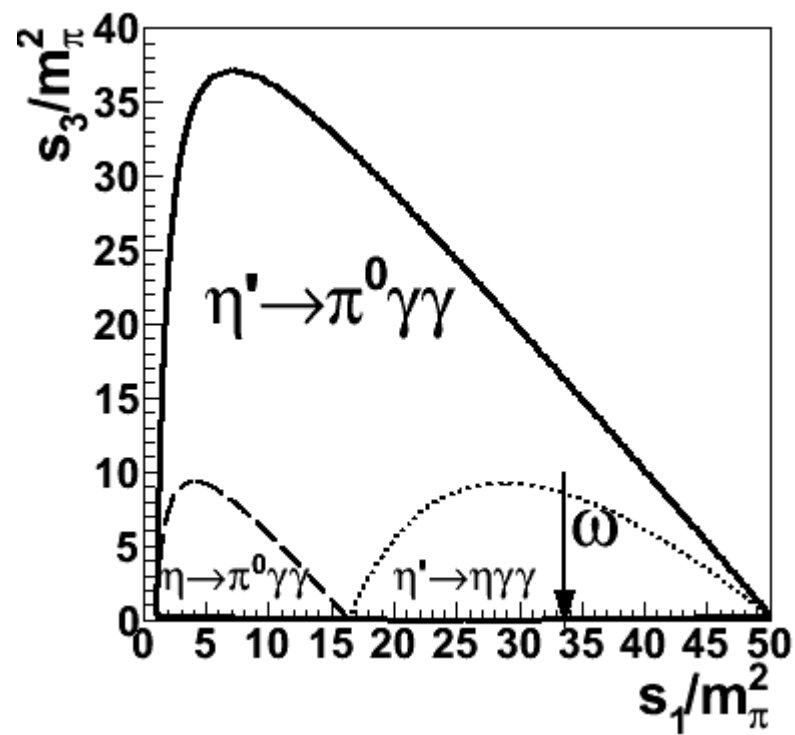
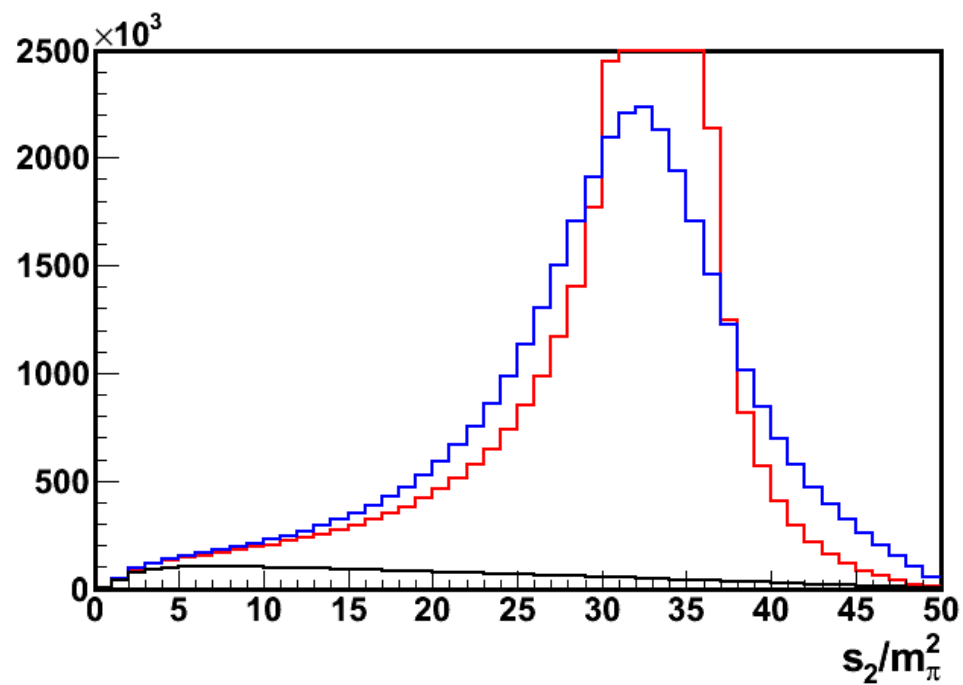
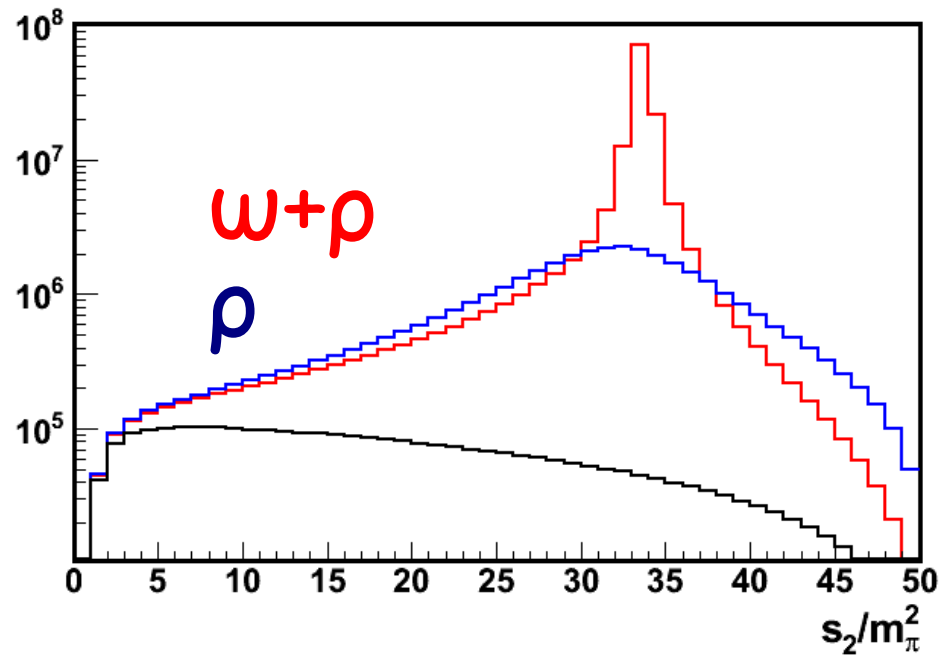
$BR \times 10^4$	VMD	Exp	
$\eta \rightarrow \pi^0\gamma\gamma$	2.1	$2.7 \pm 0.5$	PDG
$\eta' \rightarrow \omega[\pi^0\gamma]\gamma$	52		
$\eta' \rightarrow \pi^0\gamma\gamma$	3	$< 8$ (90% CL)	GAMS(87)
$\eta' \rightarrow \eta\gamma\gamma$	2.5	—	



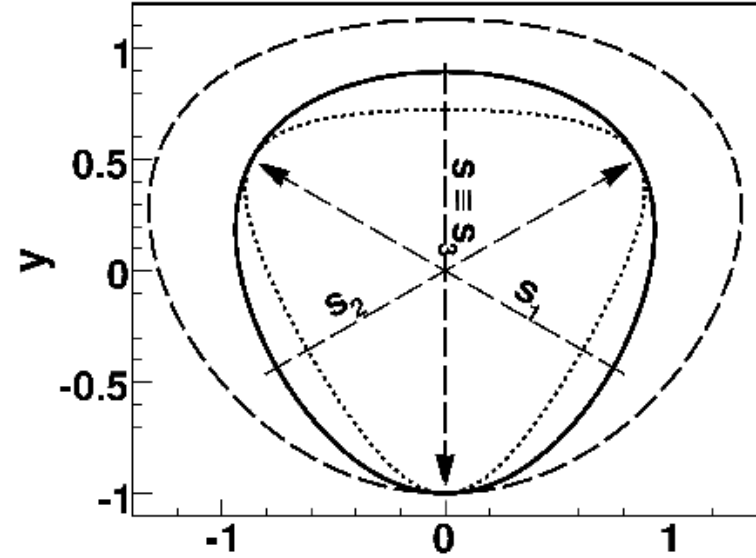
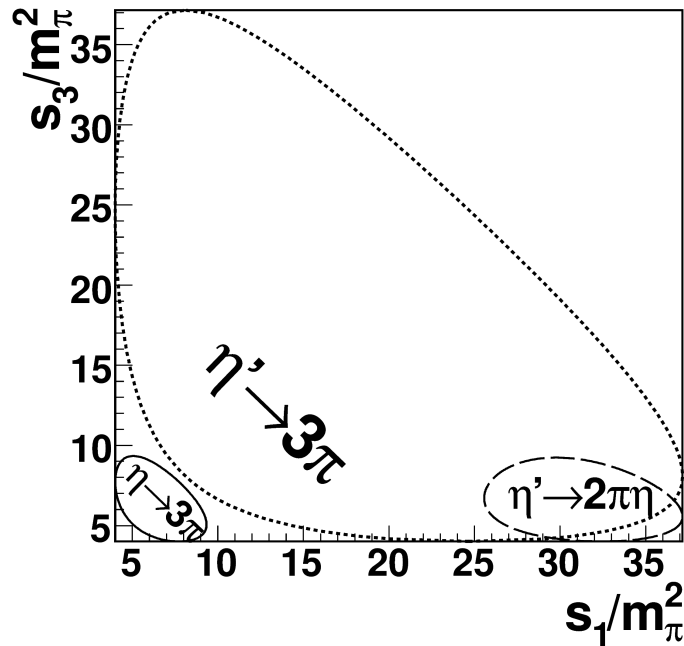
$\eta' \rightarrow \pi^0\gamma\gamma$  80%  $\omega$  4.6%  $\rho$  (+15%  $\rho\omega$  interf? and  $\varphi$ )  
 Escribano (arXiv:1207.5400)



Dominant VMD contribution



# Three body decays, Dalitz plot

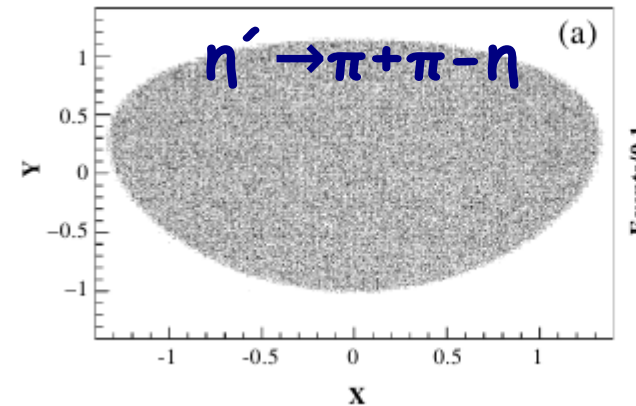
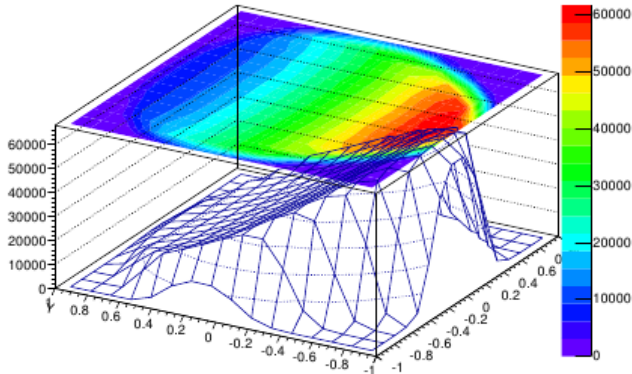


3 body decay:  $0 \rightarrow 1 + 2 + 3$

$$s_i \equiv (p_0 - p_i)^2 = (m_0 - m_i)^2 - 2T_i m_0$$

$$x \equiv \frac{1}{\sqrt{3}} \frac{T_1 - T_2}{\langle T \rangle}; \quad y \equiv \frac{1}{3} \left( \sum_{i=1}^3 \frac{m_i}{m} \right) \frac{T_3}{\langle T \rangle} - 1$$

$$|A(X, Y)|^2 = N(1 + aY + bY^2 + dX^2 + fY^3 + gX^2Y)$$



BESIII PRD83, 012003('11)



KLOE2008 analysis (JHEP 0805,006)

$0.45 \text{ fb}^{-1} \Rightarrow 1.34 \cdot 10^6$  events in DP

large syst. uncertainty due to Event classification

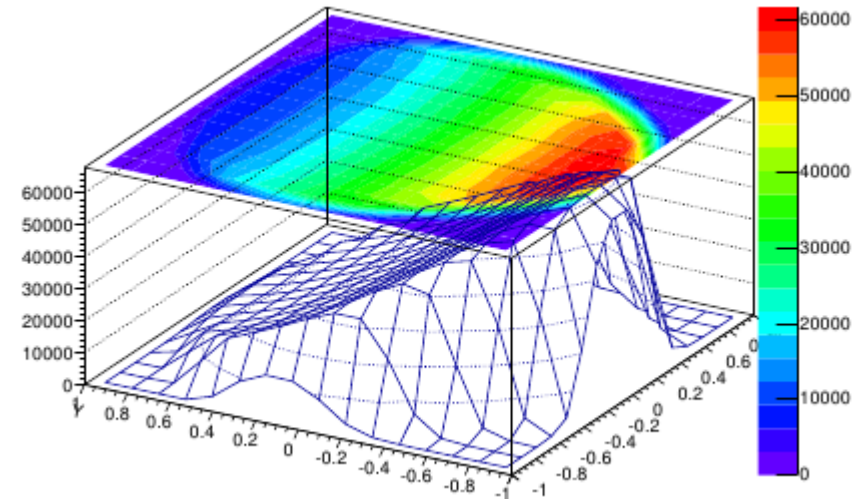
New analysis:

$1.7 \text{ fb}^{-1} \Rightarrow 4.48 \cdot 10^6$  events in DP

new analysis scheme

improved MC

new cross checks

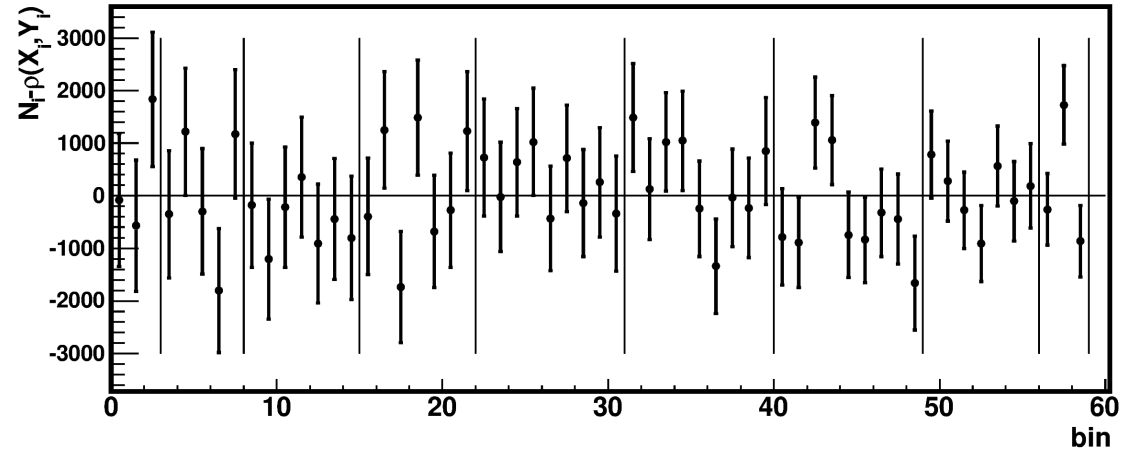
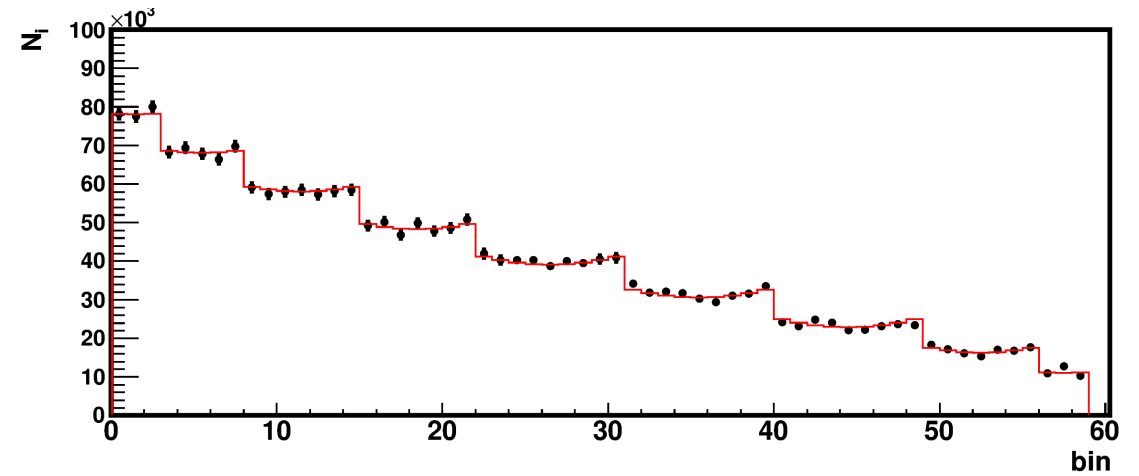
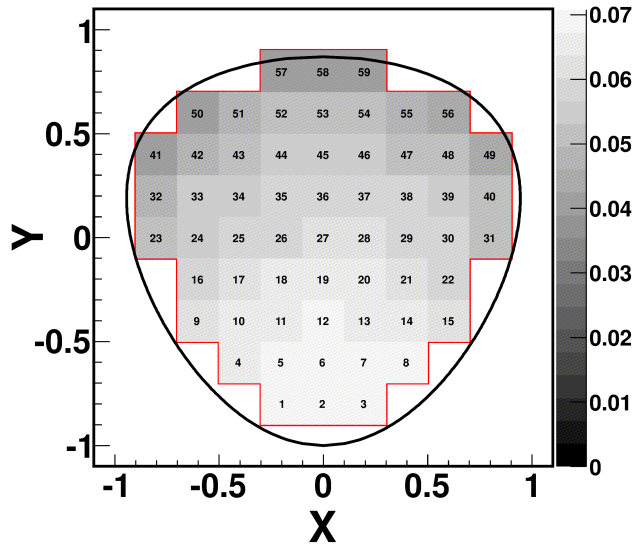


	a	b	d	f
JHEP0805,006	-1.090(5)( <sup>+8</sup> <sub>-19</sub> )	0.124(6)(10)	0.057(6)( <sup>+7</sup> <sub>-16</sub> )	0.140(10)(20)
preliminary,	-1.103(3)(?)	0.142(3)(?)	0.073(3)(?)	0.154( 6)(?)
2013				

New analysis PRELIMINARY  
(no syst. ):  $f \neq 0$  confirmed  
fits with  $g...$

$$|A(X, Y)|^2 = N(1 + aY + bY^2 + dX^2 + fY^3 + gX^2Y)$$

# WASA-at-COSY new prel. DP $\eta \rightarrow \pi^+\pi^-\pi^0$



$1.5 \cdot 10^5$  events

preliminary,  
2013

a

-1.144(18)

b

0.219(19)(37)

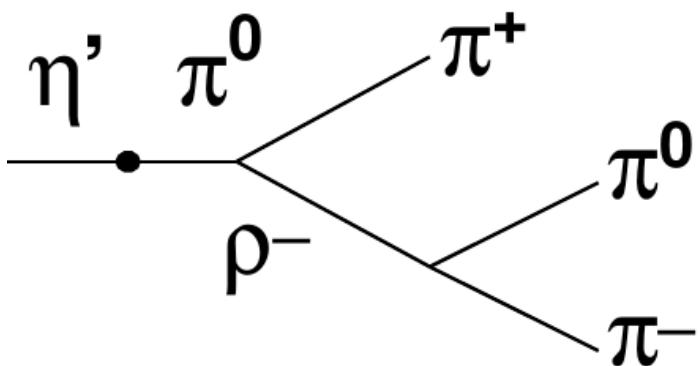
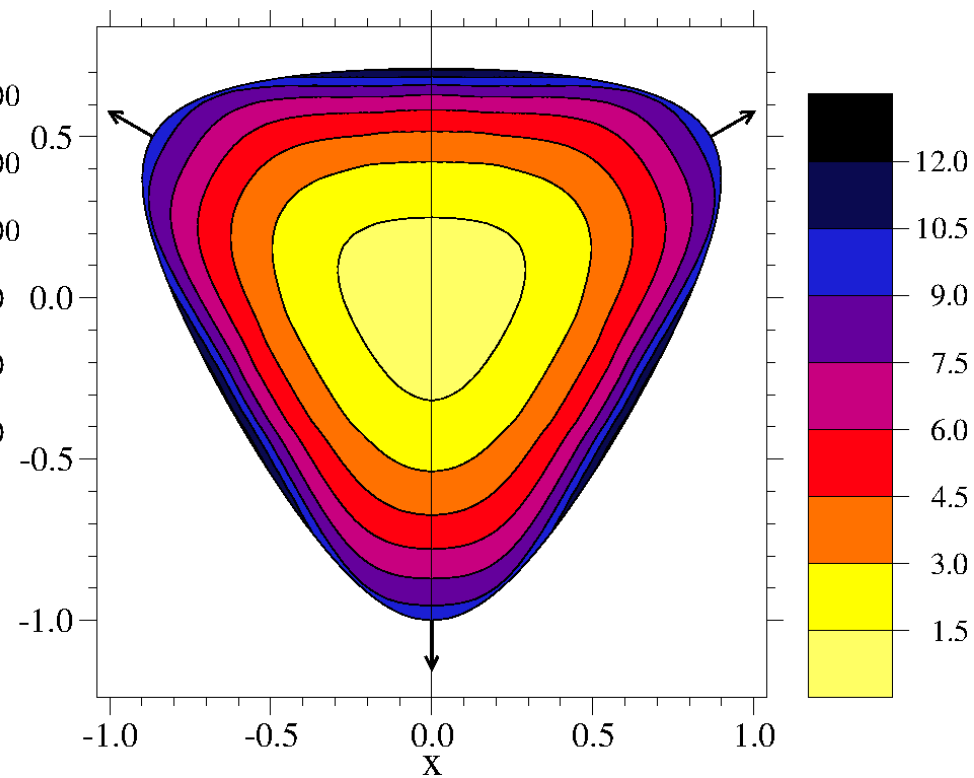
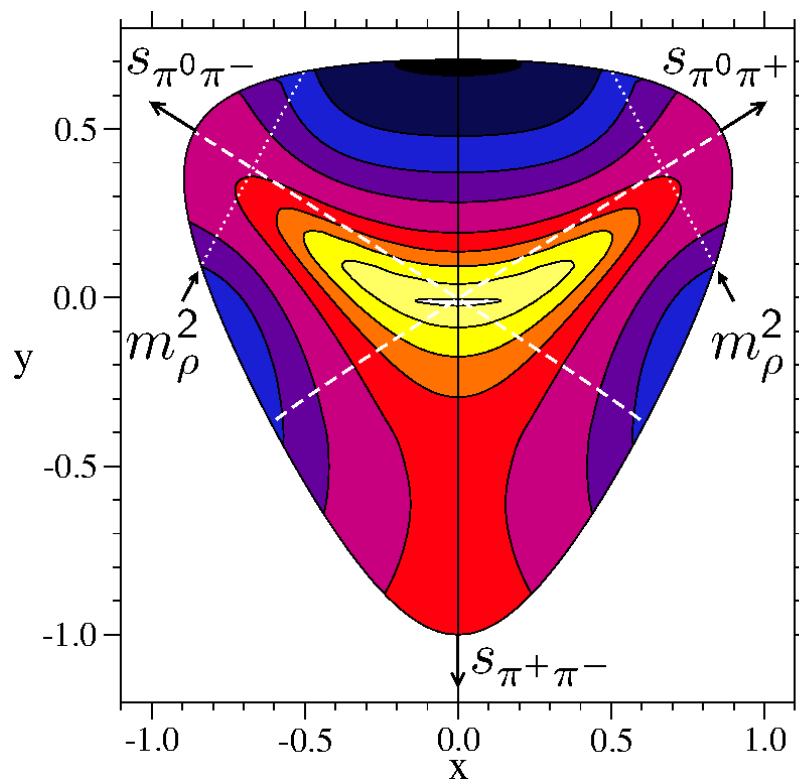
d

0.086(18)(18)

f

0.115(37)

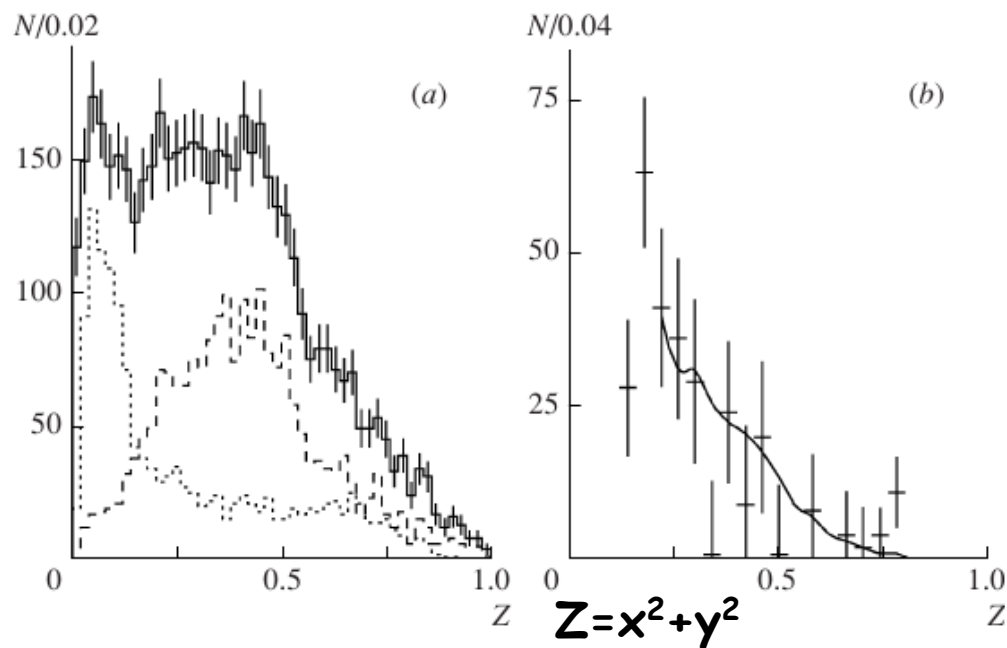
# $\eta' \rightarrow \pi\pi\pi$



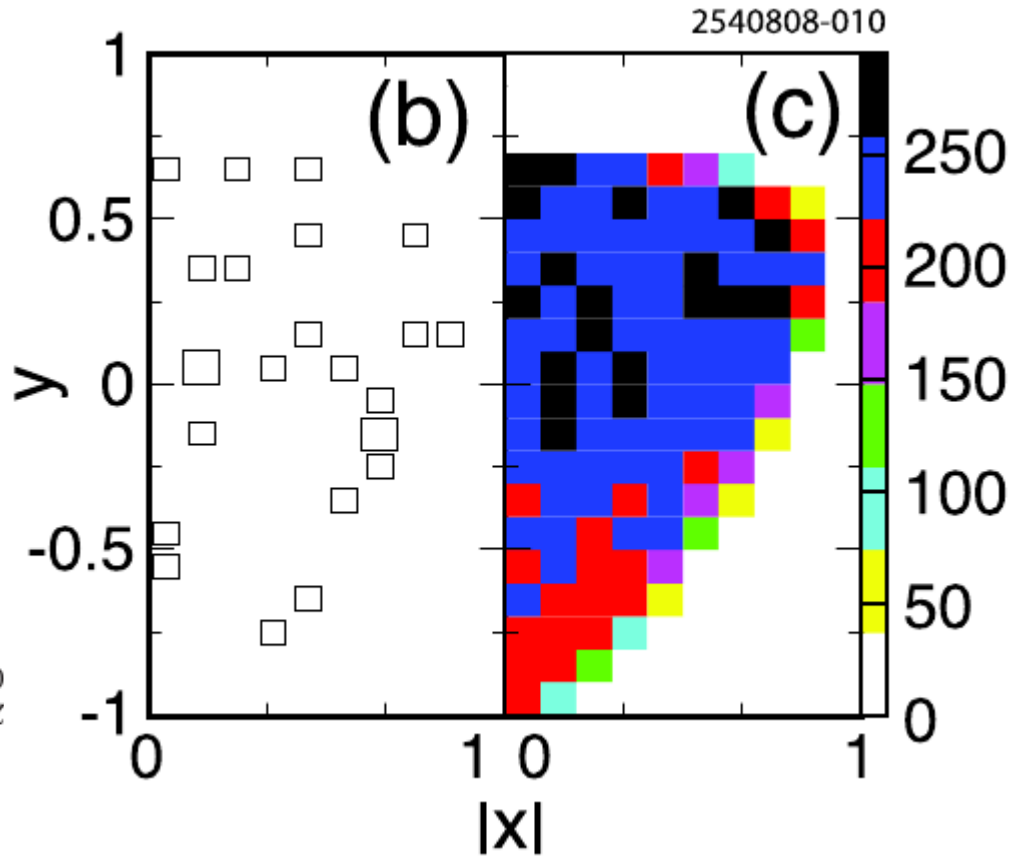
U(3) CHPT, Borasoy, Nißler 2005:  
 $BR(\eta \rightarrow \pi^+\pi^-\pi^0) \approx 1.8\%$  large  $\rho^\pm\pi^0$



# $\eta' \rightarrow \pi\pi\pi$



$Z = x^2 + y^2$   
**GAMS PAN71, 2124('08)  $235 \pm 45$**   
 **$(1.8 \pm 0.4) \times 10^{-3}$**



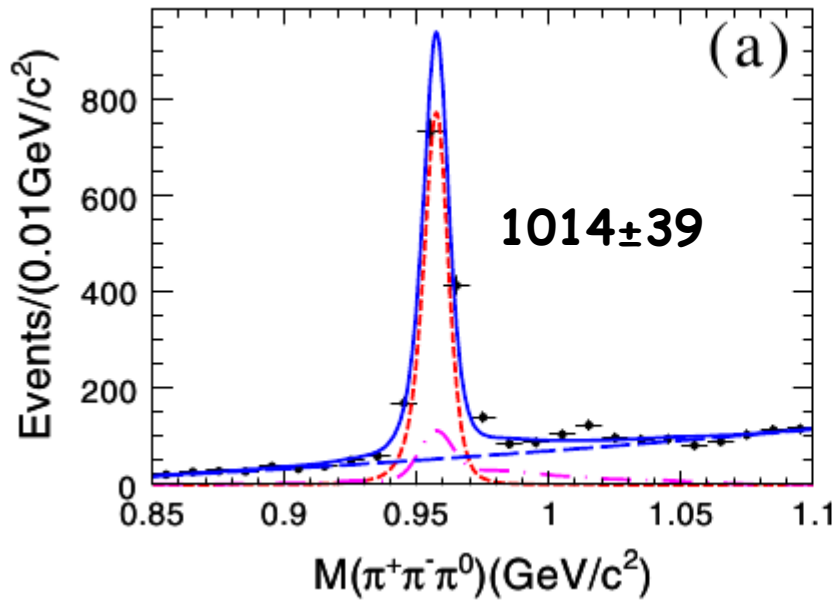
The data  $20 \pm 5$  ev.  
**BR =  $3.7 \pm 1.0 \times 10^{-3}$**

**CLEO: PRL 102, 061801 (2009)**

# BESIII $\eta' \rightarrow \pi\pi\pi$

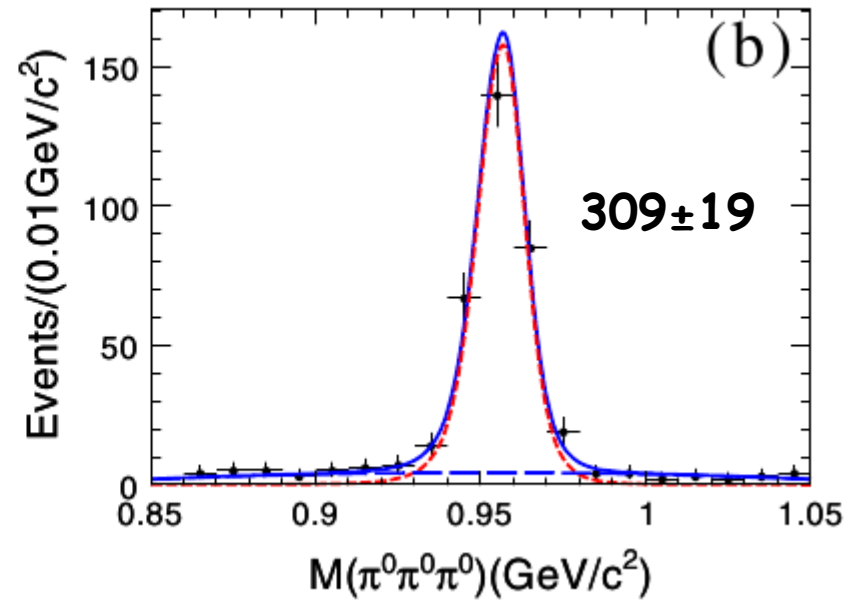
BESIII, PRL 108,182001 (2012)

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



$$\text{BR}=(3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$$

$\eta' \rightarrow \pi^0\pi^0\pi^0$



$$\text{BR}=(3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$$