Hadron Physics Studies at KLOE/KLOE-2

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on behalf of the KLOE-2 Collaboration

Light Meson Dynamics
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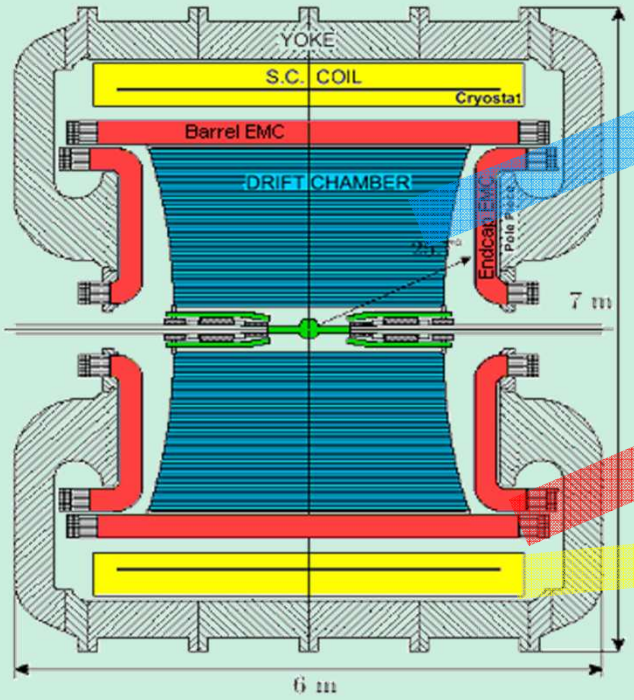
Outline

- KLOE and the KLOE-2 upgrade
- Recent results on hadron physics with KLOE data:
  - Dynamics of the $\eta \to \pi^+\pi^-\gamma$ decay
  - Dynamics of the $\eta \to \pi^+\pi^-\pi^0$ decay
  - Transition form factor for $\phi \to \eta/\pi^0 e^+e^-$
  - Search for dark force mediator
  - Cross section of $e^+e^- \to e^+e^-\eta$ @ 1 GeV and $\Gamma(\eta \to \gamma\gamma)$
- Perspectives on KLOE-2
- Conclusions

The KLOE experiment



Drift chamber

- Gas mixture: **90% He + 10% C_4H_{10}**
- **$\delta p_t / p_t < 0.4\%$ ($\theta > 45^\circ$)**
- **$\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm**

Electromagnetic calorimeter

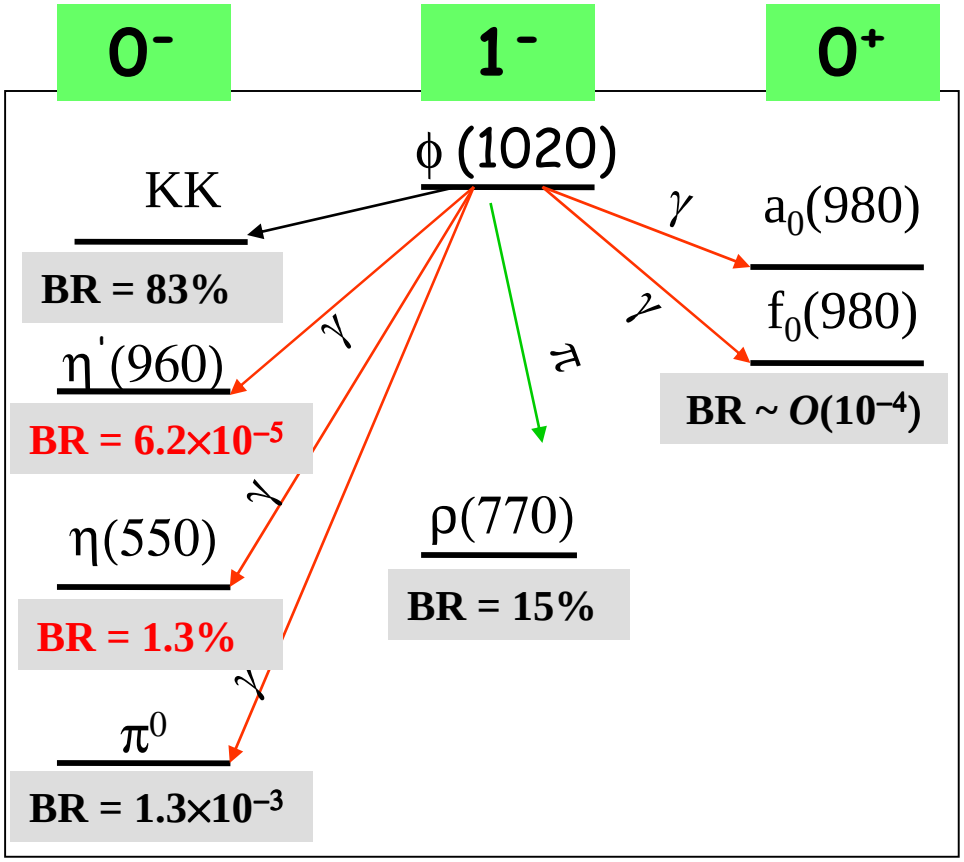
- lead/scintillating fibers
- 98% solid angle coverage
- **$\sigma_E / E = 5.7\% / \sqrt{(E(GeV))}$**
- **$\sigma_t = 57$ ps $/ \sqrt{(E(GeV))} \oplus 100$ ps**
- **PID capabilities**

Magnetic field: 0.52 T

- The KLOE experiment at the DAΦNE ϕ-factory took data in 2001-2006
- 2.5 fb^{-1} integrated @ 1.02 GeV, 250 pb^{-1} @ 1 GeV
- Excellent quality data set for precision measurement on:
  - ✓ Kaon physics
  - ✓ Light meson spectroscopy
  - ✓ Hadron production in $\gamma\gamma$ collisions
  - ✓ Search for dark force mediator
  - ✓ $\pi^+\pi^-$contribution to $(g-2)_\mu$

- KLOE-2 upgrade completed
- Expected 5 fb^{-1} in three years running [Eur. Phys. J. C 68 (2010), 619]

Physics at a ϕ-factory

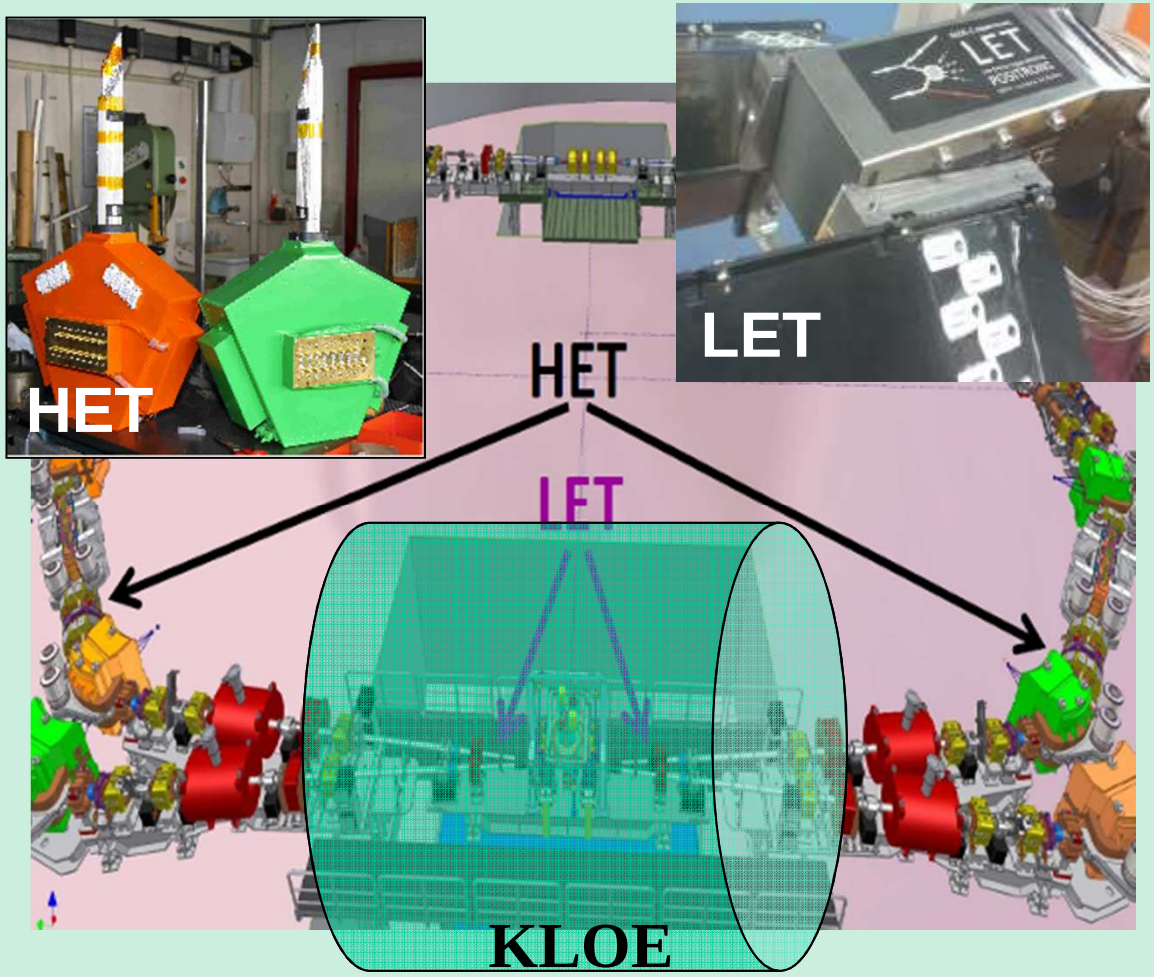


ϕ decay	Produced ev/fb^{-1}
K^+K^-	1.5×10^9
K_LK_S	1.0×10^9
η	5×10^7
η'	2×10^5

η/η' tagged with recoil monochromatic photon (363 and 60 MeV respectively)

The KLOE-2 upgrade: $\gamma\gamma$ taggers

2+2 $\gamma\gamma$ taggers installed and ready for the KLOE-2 run
Measurement of lepton momenta in $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$



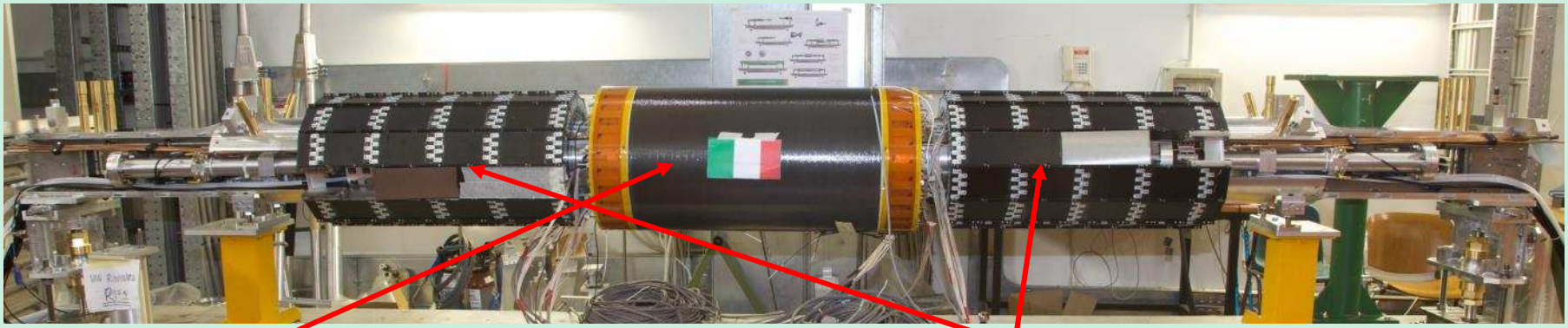
LET : E=160 – 230 MeV

- Inside KLOE detector
- LYSO+SiPM
- σ_E<10% for E>150 MeV

HET : E > 400 MeV

- 11 m from IP
- Scintillator hodoscopes
- $\sigma_E \sim 2.5$ MeV
- $\sigma_T \sim 200$ ps

The KLOE-2 upgrade: IR region



INNER TRACKER

- 4 layers of cylindrical triple GEM
- Better vertex reconstruction near IP
- Larger acceptance for low p_t tracks

QCALT

- W + scintillator tiles + WLS/SiPM
- QUADS coverage for K_L decays

CCALT

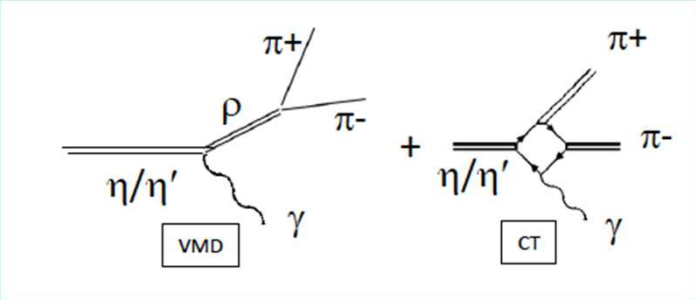
- LYSO + SiPM
- Increase acceptance for γ's from IP ($21^o \rightarrow 10^o$)

Installation of the upgrades and the new DAΦNE IR completed in July 2013

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

- Study of the **box anomaly**: test of ChPT and its unitarized extensions

[Benayoun et al. EPJC31(2003)525; Holstein, Phys. Scripta, T99(2002)55; Borasoy, Nissler, NPA740(2004)362, Picciotto PRD45(1992)1569]



Sizeable effect of the Contact Term expected both in $\Gamma(\eta \to \pi^+\pi^-\gamma)$ and in $M_{\pi\pi}$ distribution

Decay	PDG 2010	Prediction with Box Anomaly (HLS)	Prediction without Box Anomaly
$\eta \to \pi^+\pi^-\gamma$	60±4 eV	56.3±1.7 eV	100.9±2.8 eV
$\eta' \to \pi^+\pi^-\gamma$	60±5 keV	48.9±3.9 keV	57.5±4.0 keV

HLS: Benayoun, Eur. Phys. J. C31 (2003) 525

- CLEO result (2007)

~ 3 σ's lower than previous measurements

$\Gamma_{CLEO}(\eta \to \pi^+\pi^-\gamma) = (52 \pm 4)$ **eV**

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

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

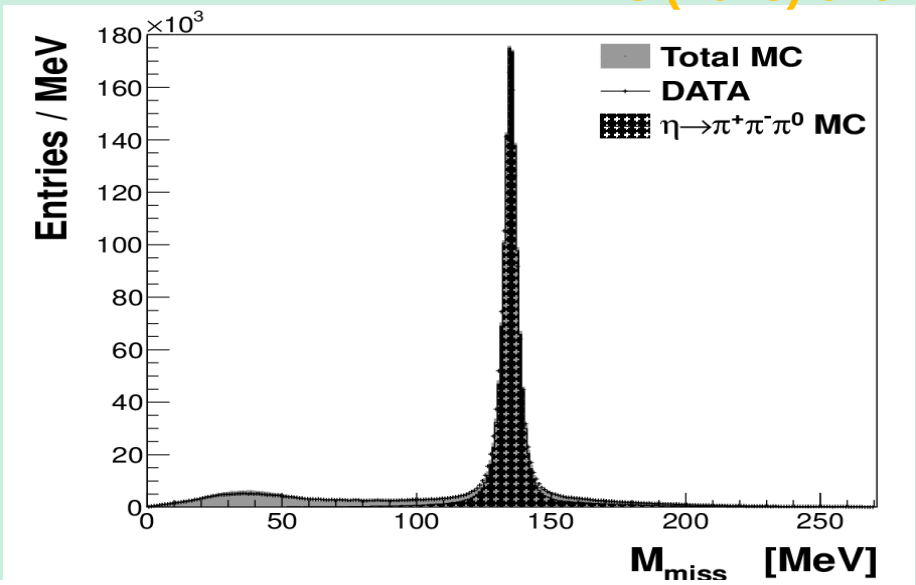
$\eta\to\pi^+\pi^-\gamma$: $\eta\to\pi^+\pi^-\pi^0$ normalization sample

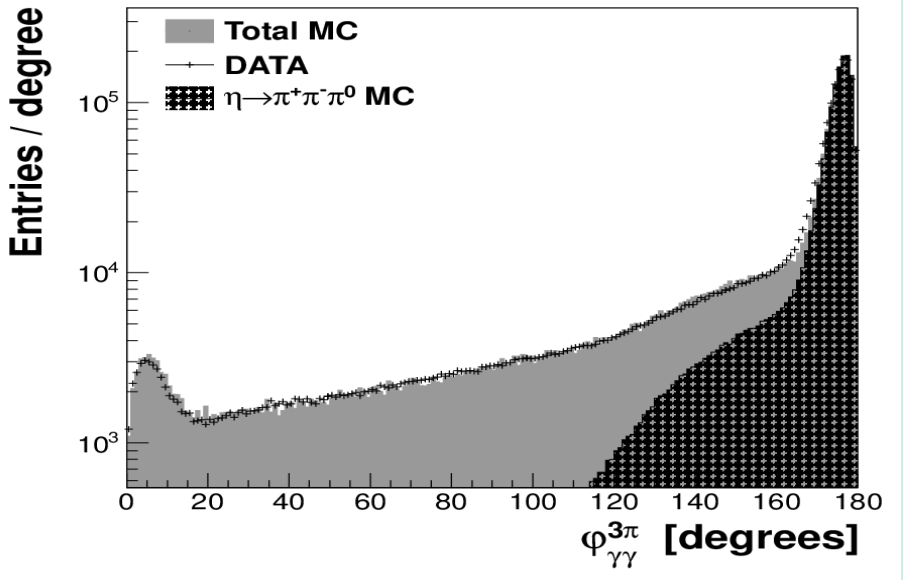
PLB 718 (2013) 910

- Data sample: **558 pb^{-1}**
- Same preselection of $\eta\to\pi^+\pi^-\gamma$ events + cuts on π^0 kinematics
- **N($\eta\to\pi^+\pi^-\pi^0$) = 1.116×10^6**
- ε = (22.76±0.02)%
- **B/S = 0.65%**
- $\sigma(e^+e^-\to\phi\to\eta\gamma)$ = (41.8 ±0.2) nb

BR($\eta\to\pi^+\pi^-\pi^0$) = (22.41 ± 0.35)%

PDG'12: BR($\eta\to\pi^+\pi^-\pi^0$) = (22.92 ± 0.28)%

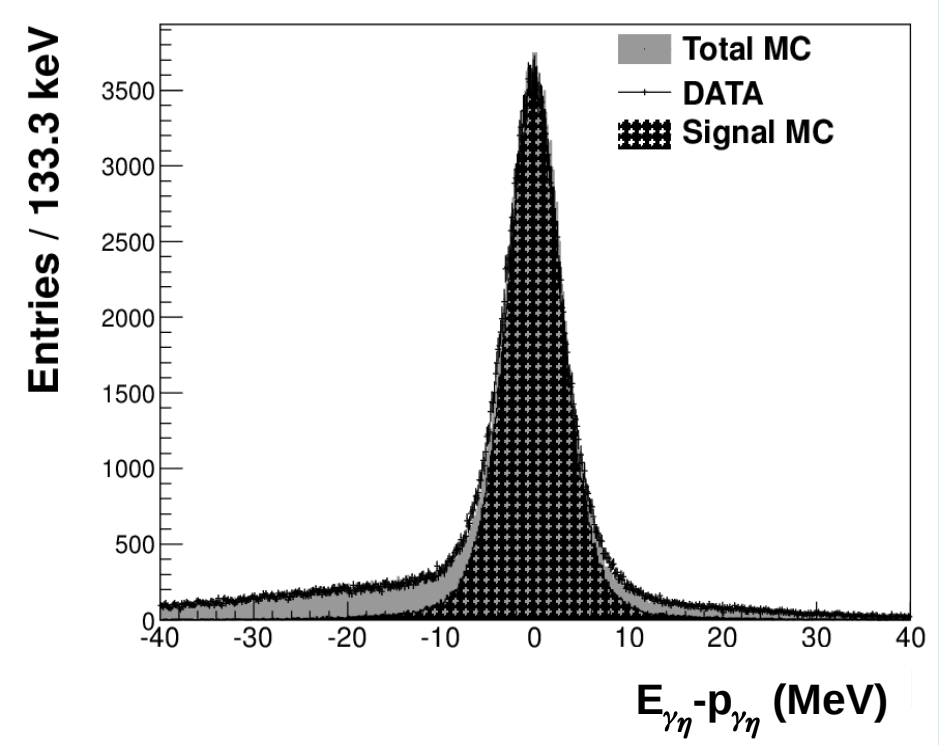




$\Gamma(\eta\to\pi^+\pi^-\gamma)/\Gamma(\eta\to\pi^+\pi^-\pi^0)$

PLB 718 (2013) 910

- Data sample: **558 pb^{-1}**
- **N($\eta\to\pi^+\pi^-\gamma$) = 204,950±450**
- ε = (21.31±0.04)%
- **B/S = 10%**
- Main background: $\phi\to\pi^+\pi^-\pi^0$
- Signal counting from fit to $E_{\gamma\eta}$-$p_{\gamma\eta}$



$$\frac{\Gamma(\eta\to\pi^+\pi^-\gamma)}{\Gamma(\eta\to\pi^+\pi^-\pi^0)} = 0.1856\pm0.0005_{stat}\pm0.0028_{syst}$$

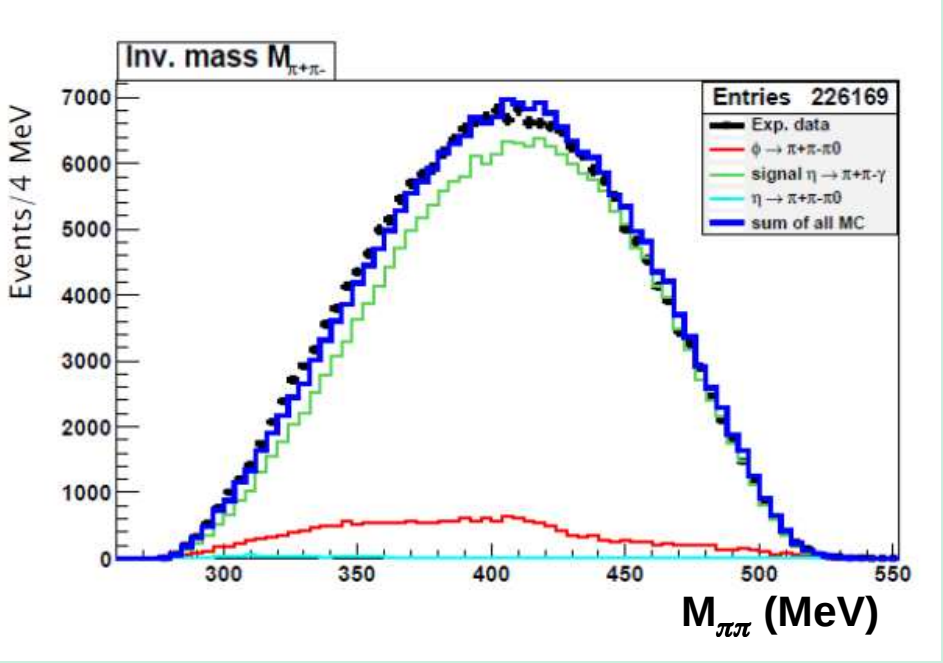
$$E_{\gamma_\eta} = \sqrt{s} - E_{\pi^+} - E_{\pi^+} - E_{\gamma_\phi}$$

$$|\vec{p}_{\gamma_\eta}| = |\vec{p}_{\pi^+} + \vec{p}_{\pi^+} + \vec{p}_{\gamma_\phi}|$$

- **Consistent with CLEO result, with a factor of three improved precision**
- **Sizeable contribution of the direct term to the total width**

$\eta \to \pi^+\pi^-\gamma$: fit to the $M_{\pi\pi}$ spectrum

PLB 718 (2013) 910

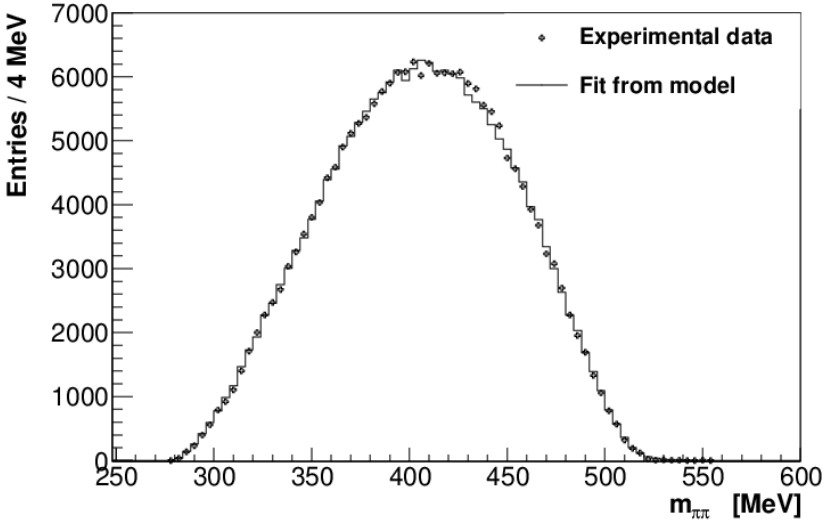


Fit with ChPT + dispersive analysis

[PLB 707 (2012) 184]

$$\mathcal{A}(\delta,\alpha) = \underbrace{A(\delta)}_{\text{fitted to BR}} \left(\underbrace{1 + \alpha\, s_{\pi\pi} + \mathcal{O}(s_{\pi\pi}^2)}_{\text{extracted from the spectrum}} \right) \underbrace{F_V(s_{\pi\pi})}_{\text{universal}}$$

Model independent description of $M_{\pi\pi}$



$$\alpha = (\, 1.32 \pm 0.08_{\text{stat}}\ ^{+0.10}_{-0.09\ \text{syst}} \pm 0.02_{\text{th}}\,)\ \text{GeV}^{-2}$$

$\alpha = (\, 1.89 \pm 0.25 \pm 0.59 \pm 0.002\,)\ \text{GeV}^{-2}$

WASA-at-COSY: PLB 707 (2012) 243

KLOE-2: box anomaly can be studied also with $\eta' \to \pi^+\pi^-\gamma$
$M_{\pi\pi}$ lineshape more sensitive to Contact Term
$O(10^5)$ selected events expected in one year running

The $\eta \to \pi^+\pi^-\pi^0$ decay

Isospin violating decay, sensitive to light quark mass difference.

From ChPT: Leutwyler,Mod.Ph.Lett.A28(2013)1360014

$$\Gamma = \left(\frac{Q_D}{Q}\right)^4 \overline{\Gamma} \quad \text{with} \quad Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

$Q_D = 24.2$

$\overline{\Gamma}$: decay width evaluated in the Dashen limit

A very accurate determination of Q can be obtained:

1. **Measure Γ** 2. **Test $\eta \to \pi\pi\pi$ dynamics** 3. **Calculate $\overline{\Gamma}$**

Largest statistics measurement: KLOE08 (450 pb^{-1}, 1.34×10^6 events)

Dalitz plot density parametrized as polynomial expansion around X=Y=0:

$$|A(X,Y)^2| \propto 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 \ldots$$

$$X = \frac{\sqrt{3}}{Q}(T_{\pi+} - T_{\pi-}), \qquad Y = \frac{3T_{\pi^0}}{Q} - 1$$

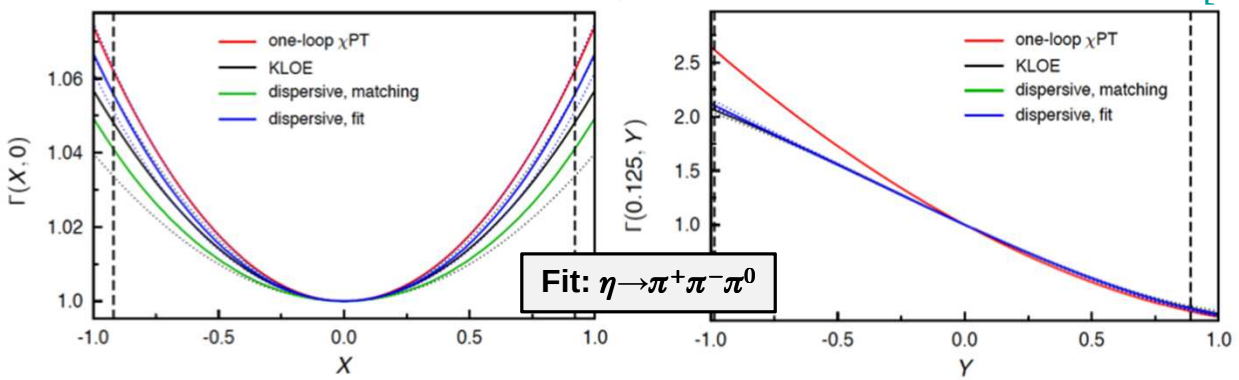
a	$-1.090 \pm 0.005\ ^{+0.008}_{-0.019}$
b	$0.124 \pm 0.006 \pm 0.010$
c	$0.002 \pm 0.003 \pm 0.001$
d	$0.057 \pm 0.006\ ^{+0.007}_{-0.016}$
e	$-0.006 \pm 0.007\ ^{+0.005}_{-0.003}$
f	$0.14 \pm 0.01 \pm 0.02$
$P(\chi^2)$	73%

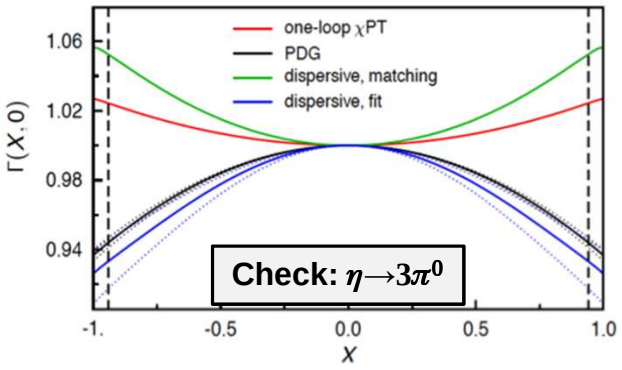
JHEP05 (2008) 006

Q mass ratio constraints from KLOE data

Dispersive analyses of $\eta \to 3\pi$ based on fits to KLOE measurement:

[Colangelo et al. PoS(EPS-HEP2011) 304]





$$Q = 21.3 \pm 0.6$$

using $\hat{m}$ and m_S from lattice QCD:

$$m_u = (2.02 \pm 0.14) MeV$$
$$m_d = (4.91 \pm 0.11) MeV$$

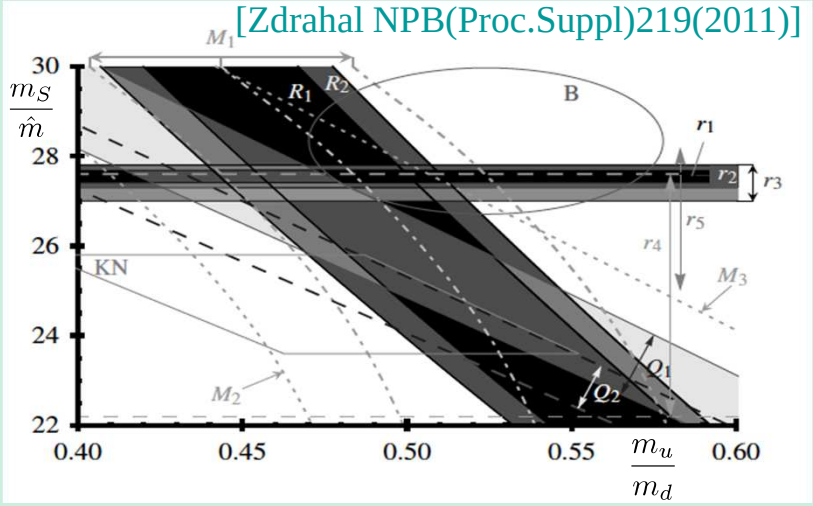
$$R = \frac{m_S - \hat{m}}{m_d - m_u} = 37.7 \pm 3.3$$

[Kampf et al., PRD84(2011)114015]

using $\hat{m}$ and m_S from lattice QCD:

$$m_u = (2.23 \pm 0.14) MeV$$
$$m_d = (4.63 \pm 0.14) MeV$$

[Zdrahal NPB(Proc.Suppl)219(2011)]



$\eta \to \pi^+\pi^-\pi^0$ with full KLOE data set

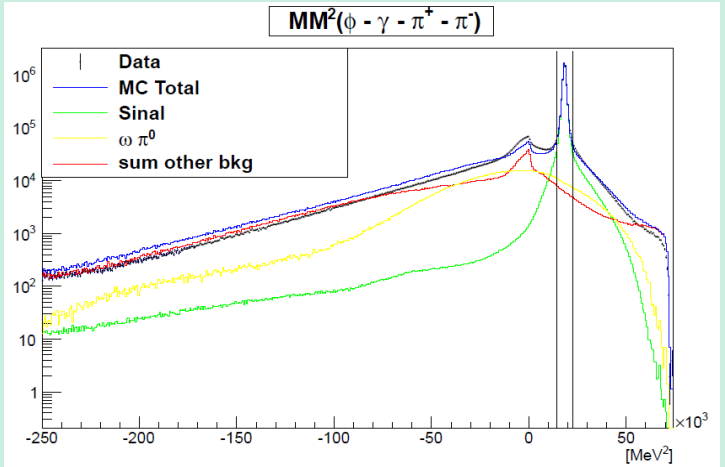
New analysis on an independent KLOE data set in progress:

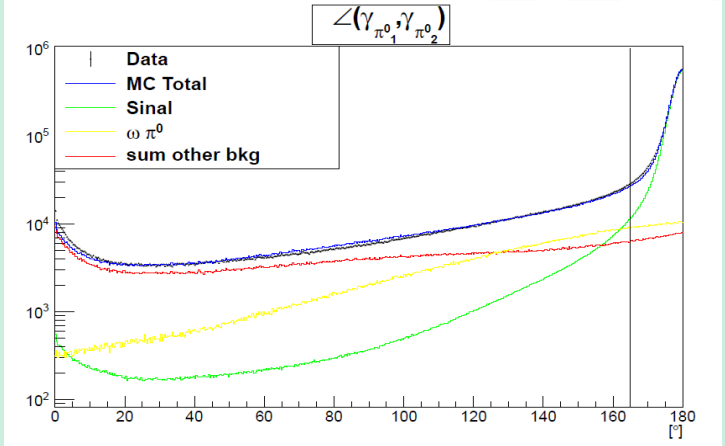
- Larger data set (1.7 fb^{-1}, ~ 4 times KLOE08)
- New analysis scheme
- Improved MC simulation

> Reduce systematics

Analysis steps:

- >= 3 prompt photons
- Most energetic photon (E>250 MeV) assumed primary
- 2 tracks selected by PCA method, assumed pions
- Primary photon energy from 2-body kinematics
- η from ϕ decay, π^0 from η decay
- Photons from π^0 decay selected by opening angle
- Bhabha events rejected with PID + kinematics
- $|MM(\phi - \gamma_{rad} - \pi^+ - \pi^-) - m(\pi^0)| < 15$ MeV
- $\gamma\gamma$ opening angle in the π^0 rest frame > 165°





- **Background scaling factors from fit**
- **Signal efficiency 37.6%**
- **Residual background contamination 0.96%**

$\eta \to \pi^+\pi^-\pi^0$ with full KLOE data set

Fit to the data-bckg ditribution with:

$$N_{theory} = \int N\left(1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y\right) dPh(X,Y)$$

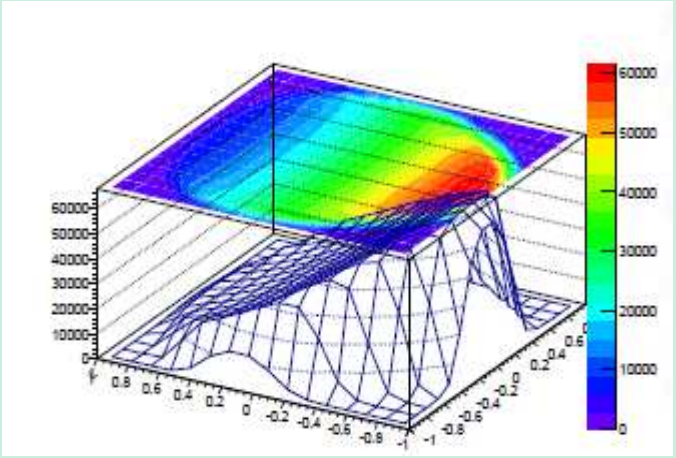
folded with smearing matrix and analysis efficiency

PRELIMINARY

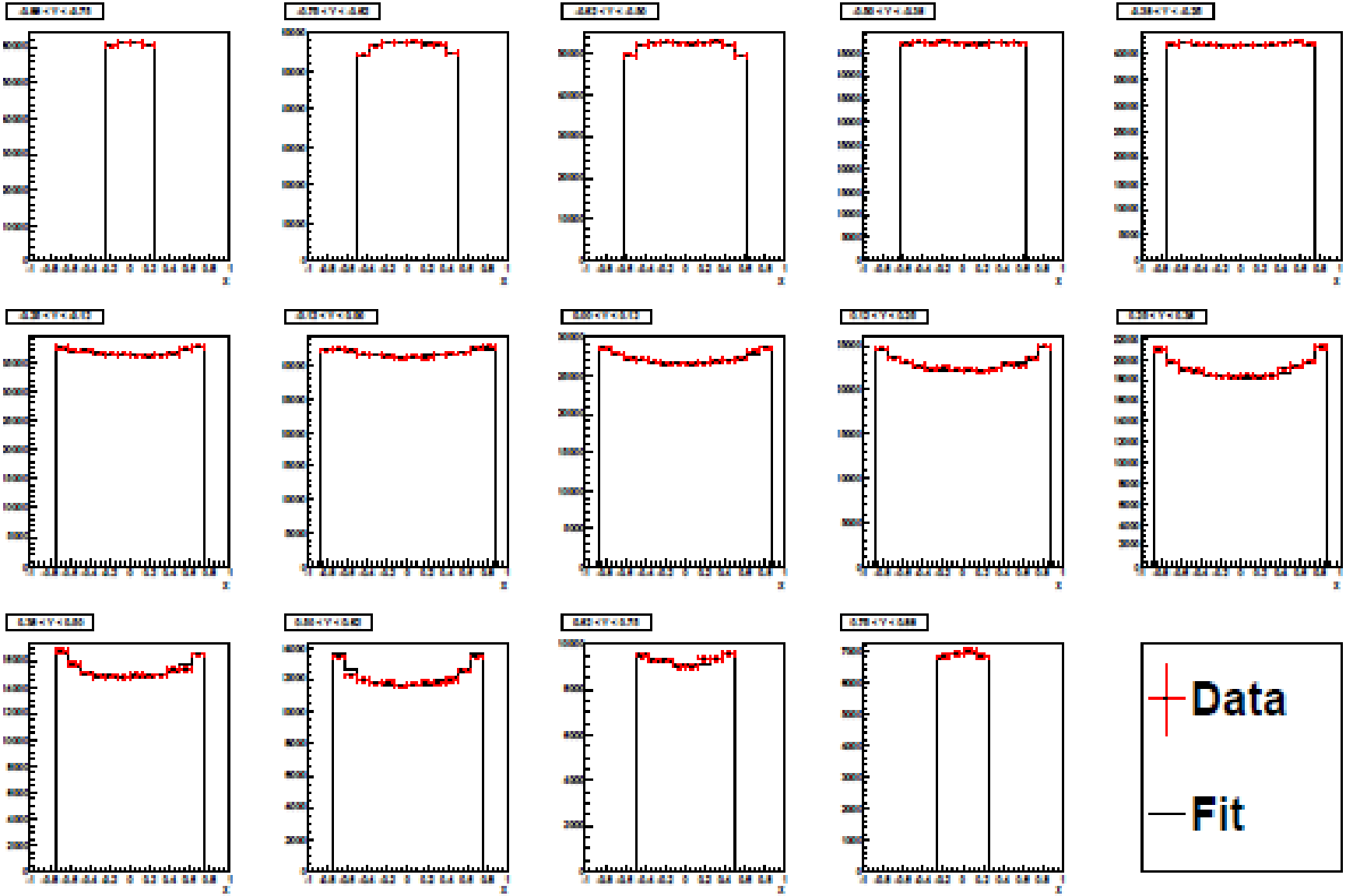
	-a	*b*	*d*	*f*
KLOE08	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
KLOE new	1.104(3)	0.144(3)	0.073(3)	0.155(6)

$\chi^2/N_{dof} = 1.15$

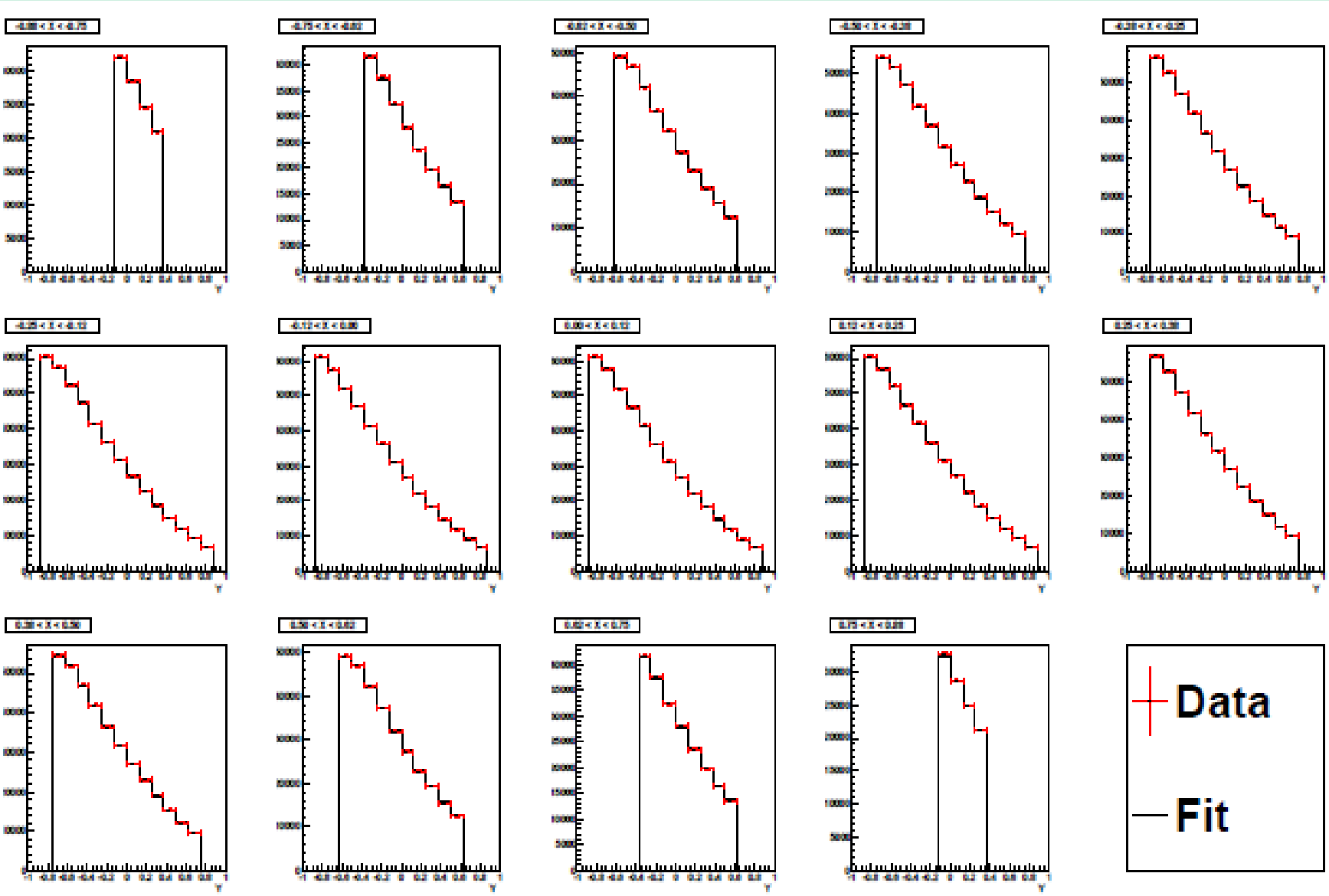
- In agreement with previous KLOE result
- *c* and *e* consistent with 0 (C-invariance condition) when used as free fit parameters
- Evaluation of systematics in progress



$\eta \to \pi^+\pi^-\pi^0$: Dalitz plot slices in Y



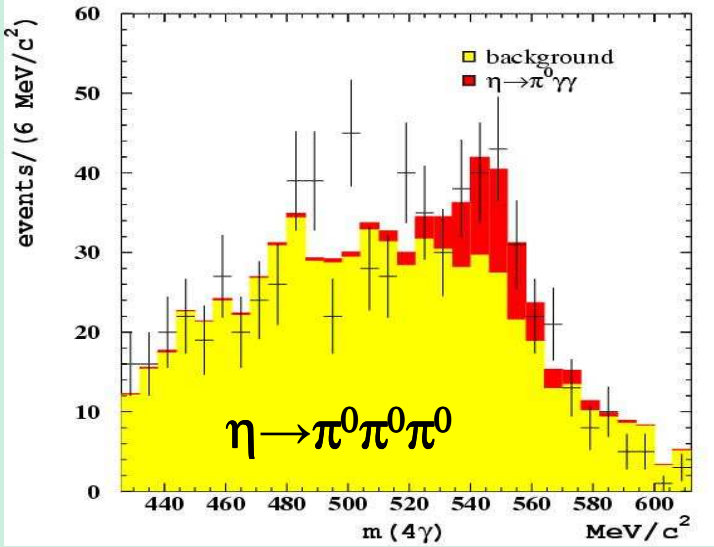
$\eta \to \pi^+\pi^-\pi^0$: Dalitz plot slices in X

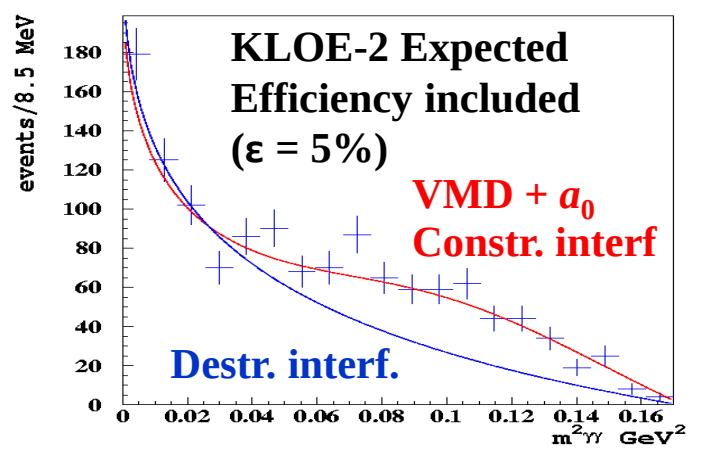


Perspectives for $\eta \to \pi^0\gamma\gamma$ @ KLOE-2

ChPT "golden mode": p^2 null, p^4 suppressed, p^6 dominates → BR & $d\Gamma/dM_{\gamma\gamma}$

KLOE Prel. 2006: 70 signal events, 3σ signal with 450 pb^{-1}, BR lower than Crystal Ball:





$$BR(\eta\to\pi^0\gamma\gamma) = (8.4 \pm 2.7_{stat} \pm 1.4_{syst}) \times 10^{-5}$$

CB@AGS: BR = (22.1 ± 2.4 ± 4.7) × 10^{-5}
PRC 78 (2008) 015206 ~ 500 signal events

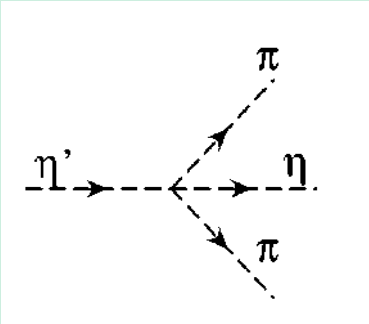
The background evaluation, from $\eta\to\pi^0\pi^0\pi^0$, is an issue: at KLOE, S/(S+B) ~ 0.13
at CB @ AGS, S/(S+B) ~ 0.17

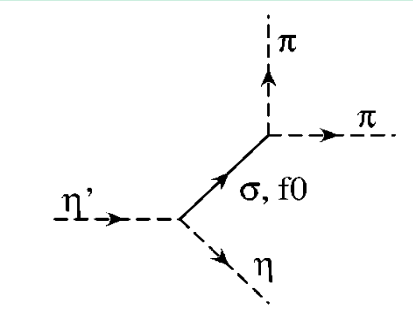
- ~1000 events expected @ KLOE-2
- The KLOE-2 calorimeter at low polar angle will substantially improves $\eta\to\pi^0\pi^0\pi^0$ background suppression: 58% of the selected events with 5 photons in the central calorimeter has 1-2 photons in CCALT acceptance

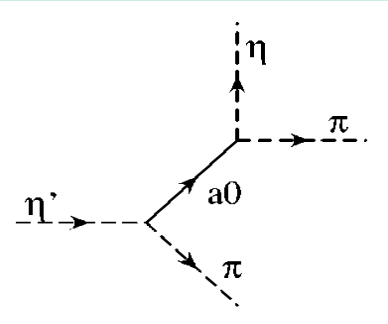
Perspectives for $\eta' \to \pi^+\pi^-\eta$ @ KLOE-2

Sensitive to the intermediate low-mass scalars: f_0, a_0, σ

[Faribortz-Schechter,PRD60(1999)034002]

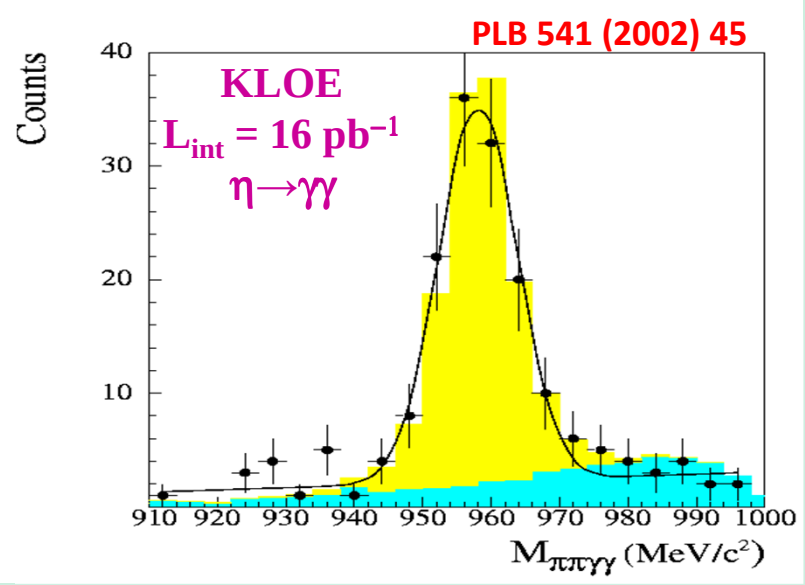






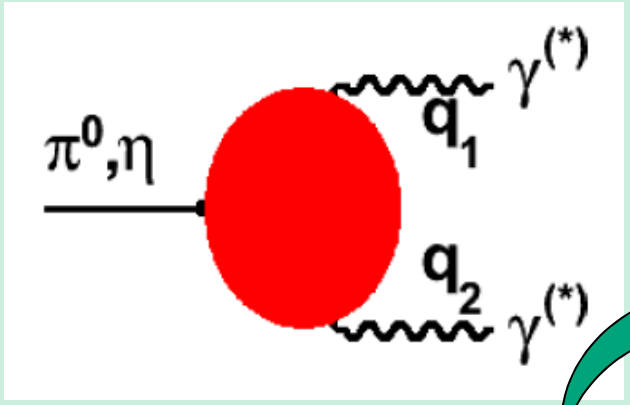
Dalitz plot (not the BR) measured by BESIII with 44000 events [PRD83(2011) 012033]

Dalitz plot fit ⇒ no evidence of scalar contributions

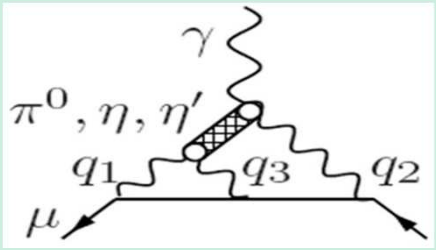


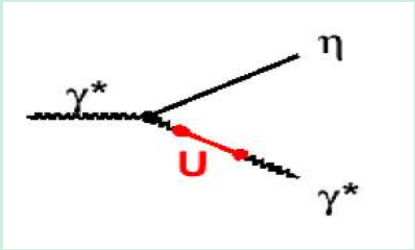
- Already measured @ KLOE with 16 pb^{-1}
- Same statistics as BESIII with ~5 fb^{-1} using $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$ decay chain
- New IR detectors will icrease acceptance both for tracks and photons
- BR measurement also possible

Meson transition form factor



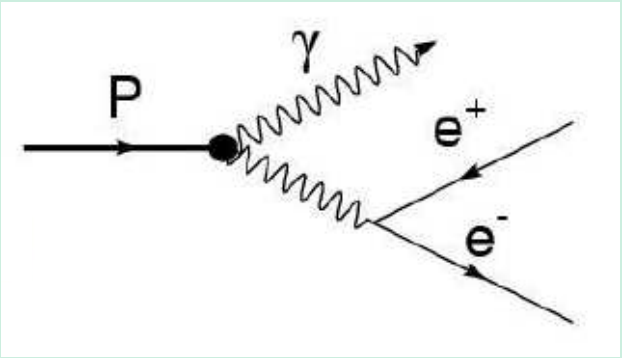
- Low energy QCD
  - Enters in th. description of QCD processes
  - Evolution with Q^2 predicted by pQCD: models can be tested using data on Q^2 dependance
- Light-by-light contribution to a_μ
- Search for light dark force mediator



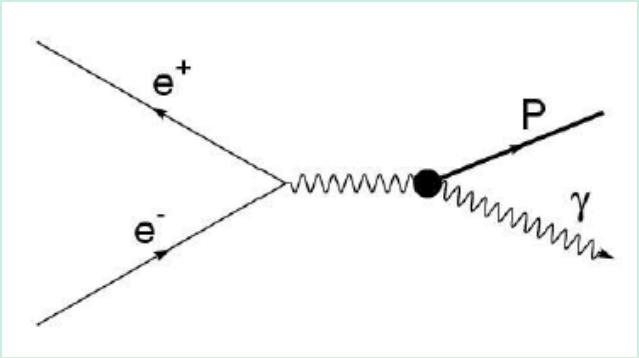


Experimentally:

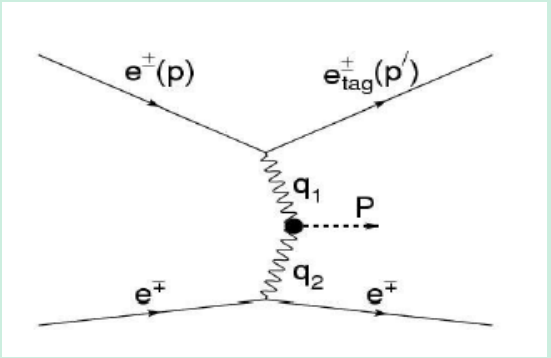
Dalitz decays



Annihilation processes



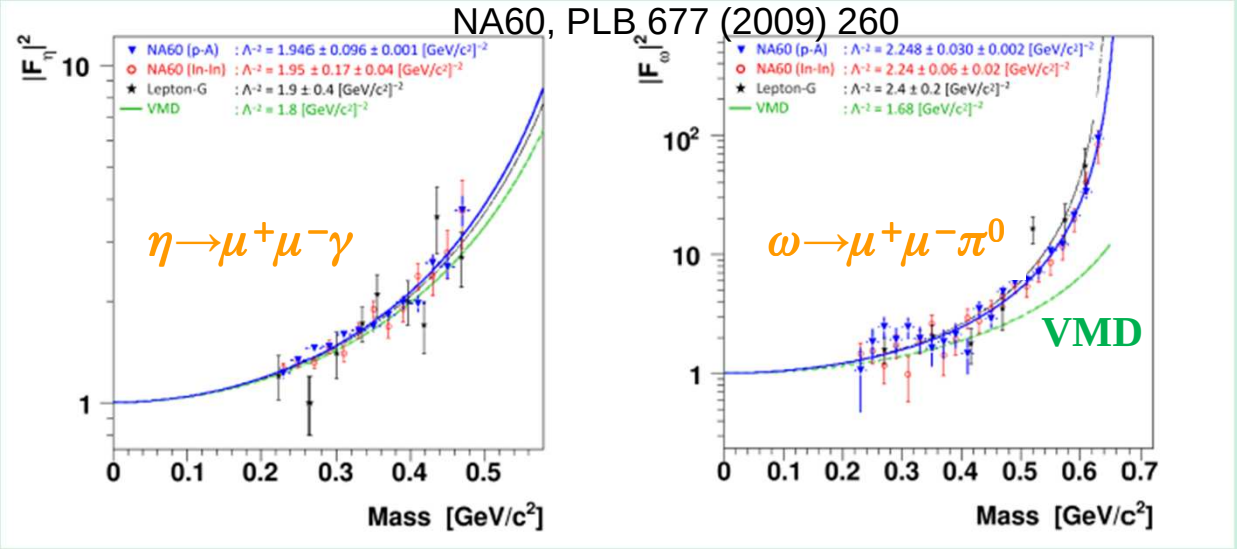
Two photon production



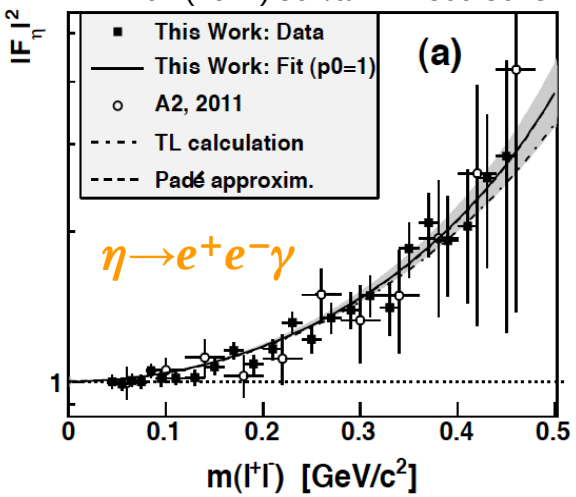
TFF from Dalitz decays

Naive VMD approach well describes $\eta \to \gamma \ell^+ \ell^-$, but fails for $\omega \to \pi^0 \ell^+ \ell^-$

NA60, PLB 677 (2009) 260



A2: PLB 701 (2011) 562/arXiv:1309.5648



Theory:

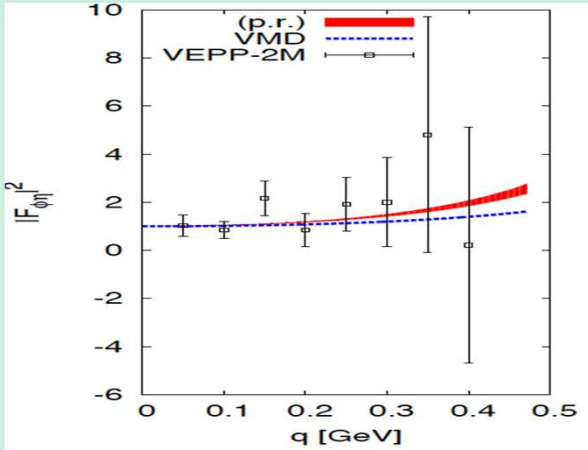
- Terschlusen and Leupold, Phys. Lett. B 691 191 (2009)
- Ivashyn, Prob. Atom. Sci. Tech. 2012N1 179 (2012)
- Schneider Kubis Nieking, Phys. Rev. D86 054013 (2012)

Experimental needs: 1. New measurement of $\omega \to \pi^0 \ell^+ \ell^-$ TFF
2. Study of other V→Pγ^* transitions

The only existing measurement is from $\phi \to \eta e^+ e^-$ (213 events):

$$b_{\phi\eta} = \Lambda_{\phi\eta}^{-2} = (3.8 \pm 1.8)\ \mathrm{GeV}^{-2}$$

[SND, PLB 504 (2001) 275]



VMD: $(q^2 = M^2_{\ell^+\ell^-})$ $F(q^2) = \dfrac{1}{1 - q^2/\Lambda^2}$

$b_{\phi\eta} \sim M_\phi^{-2} \sim 1\ \mathrm{GeV}^{-2}$

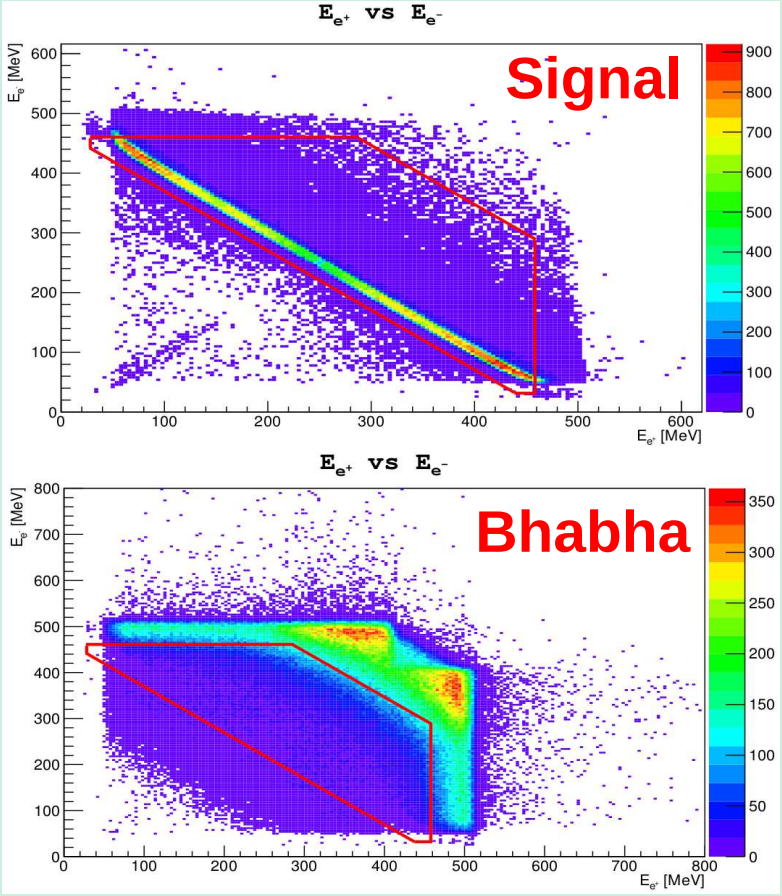
$\phi \to \pi^0 e^+ e^-$: selection cuts

- No data available for $F_{\phi\pi}(q^2)$
- 30-40% error on BR

- SND: $(1.01 \pm 0.40) \times 10^{-5}$ [JETP 75 (2002) 449]
- CMD-2: $(1.22 \pm 0.40) \times 10^{-5}$ [PLB 503 (2001) 237]

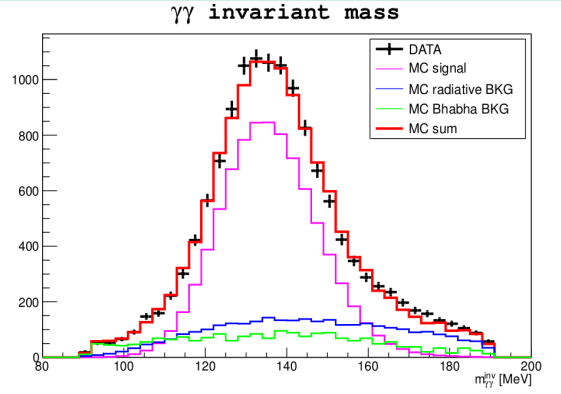
- Background from radiative Bhabha scattering events and $V \to P\gamma$: several orders of magnitude larger

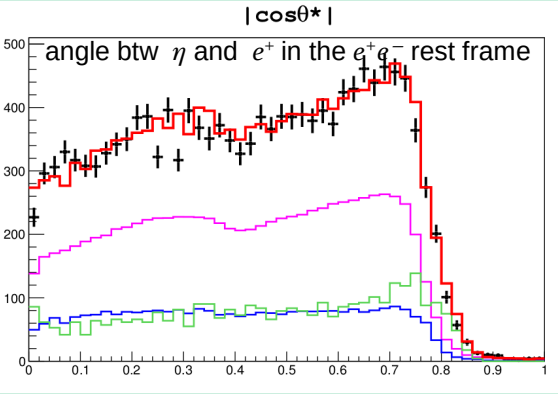
- Selection cuts:
  - $E_e < 460$ MeV
  - $470 < E_{e+} + E_{e-} < 750$ MeV
  - $300 < E_{\gamma 1} + E_{\gamma 2} < 670$ MeV
  - $\theta_{open}(ee) < 145^o$, $27^o < \theta_{open}(\gamma\gamma) < 57^o$
  - $90 < M_{2\gamma} < 190$ MeV
  - $80 < M_{miss}(ee) < 180$ MeV
  - Cut to reject γ conversions

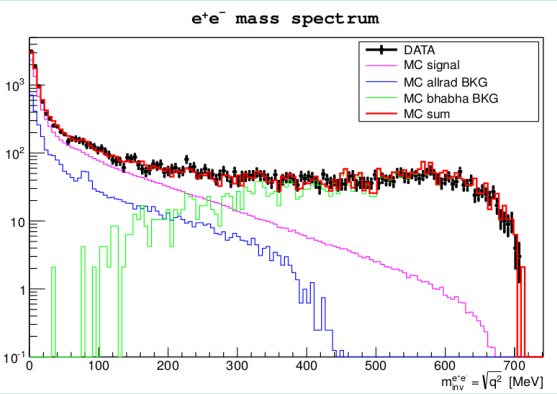


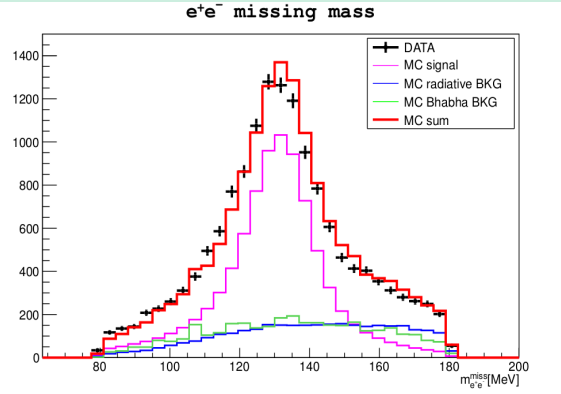
$\phi \to \pi^0 e^+ e^-$: data-MC comparison

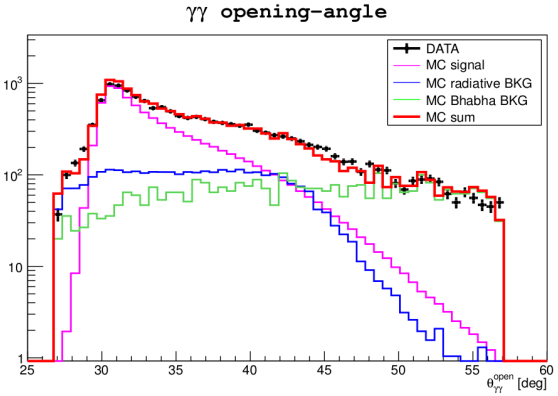
- L_{int} = 1.7 fb^{-1}
- 8777 signal events
- Global efficiency from 15% at low M_{ee} to 2% at 0.6 GeV

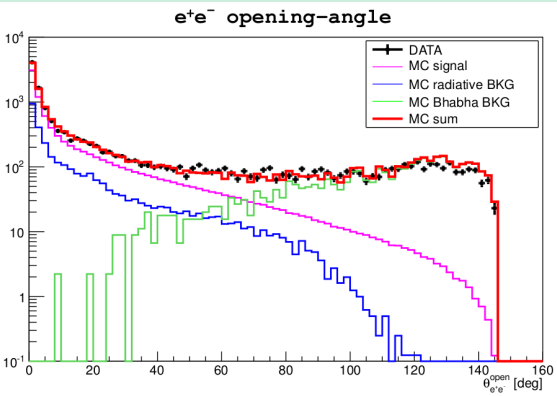








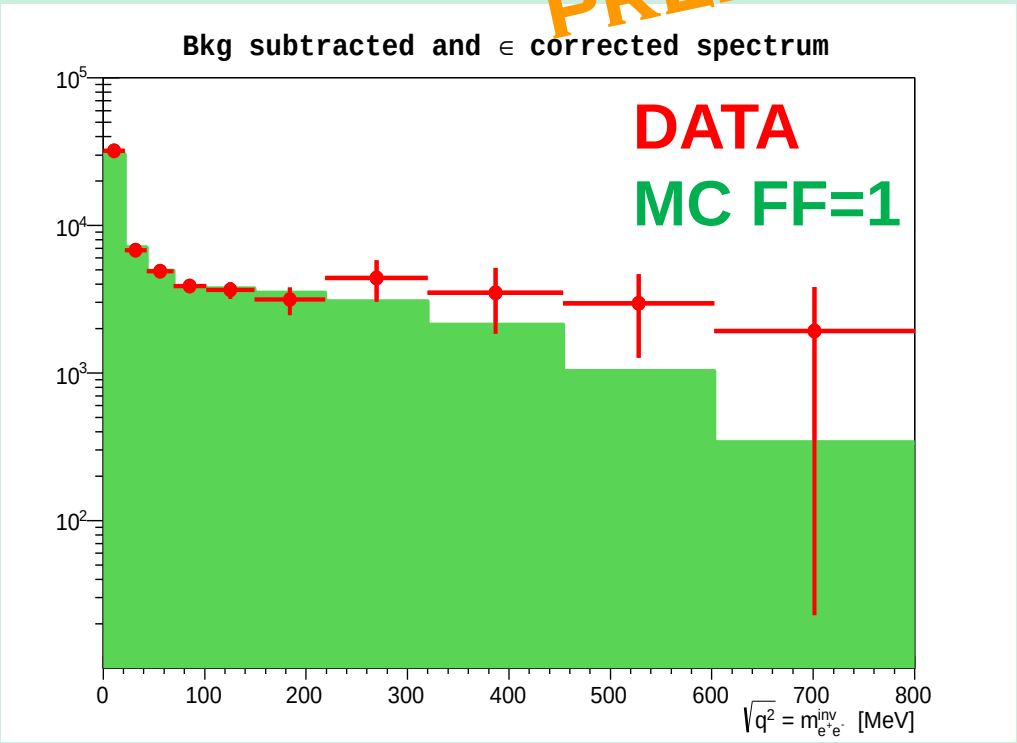


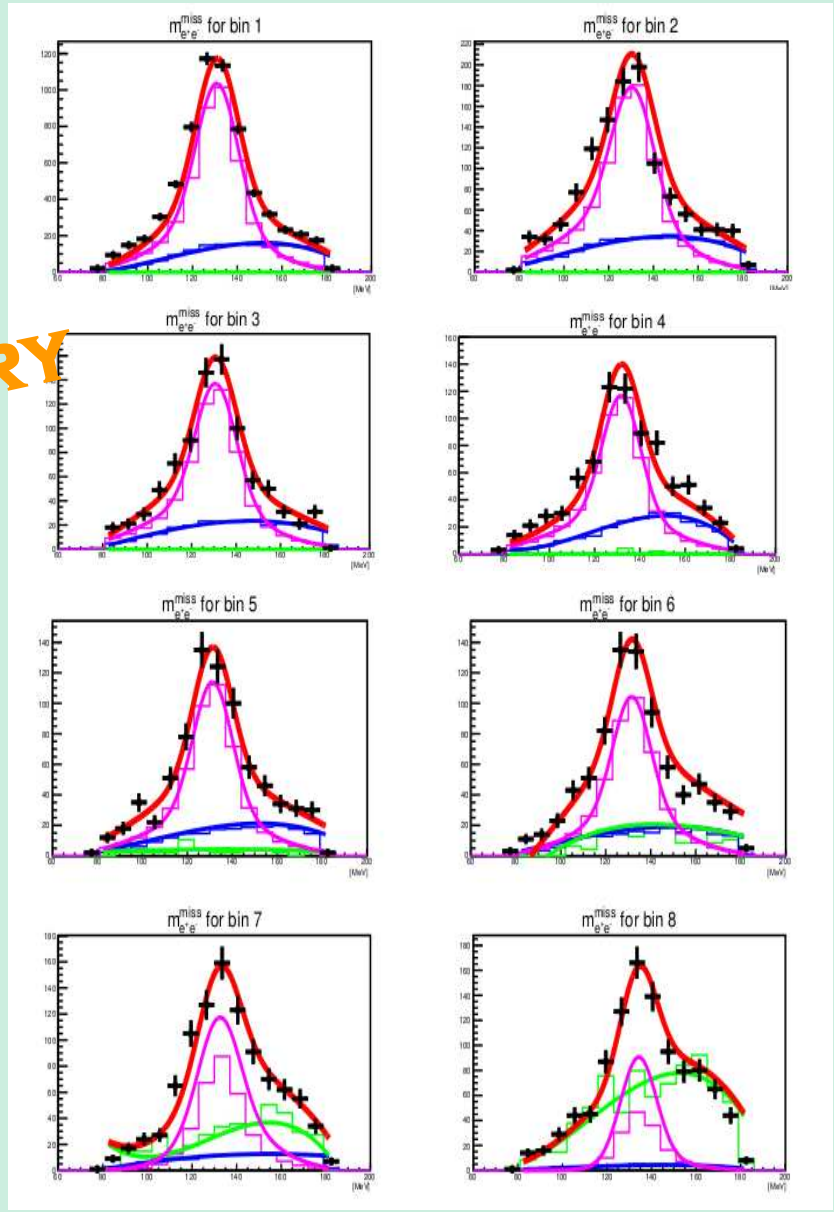


$\phi \to \pi^0 e^+ e^-$: transition form factor

- Bckg subtraction still in progress, evaluated for each M_{ee} value with a fit to the e^+e^- missing mass
- Fit systematics currently limited by Bhabha MC statistics

PRELIMINARY



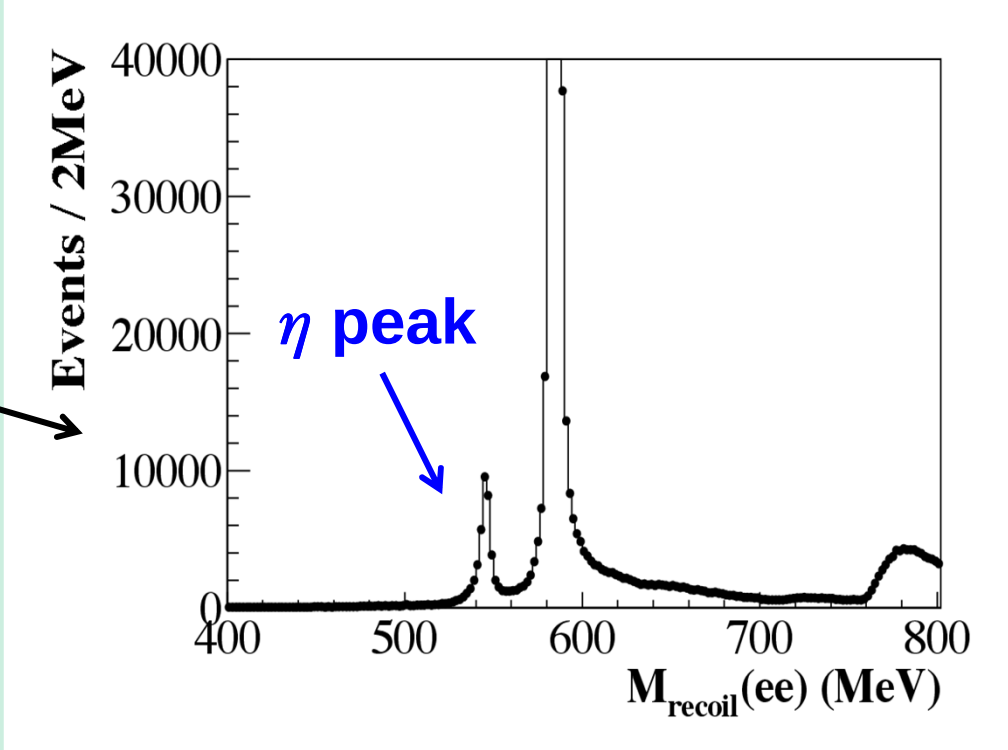


$\phi \to \eta e^+ e^-, \eta \to \pi^0\pi^0\pi^0$

Analysis performed using L_{int} = 1.7 fb^{-1}

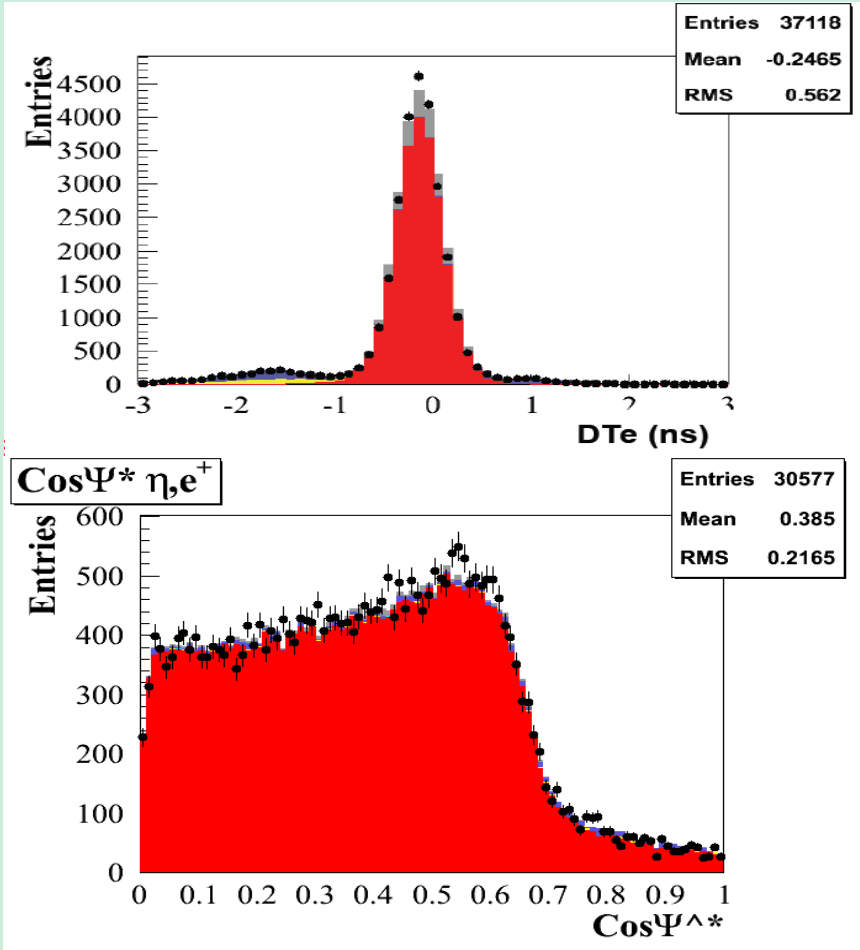
Selection:

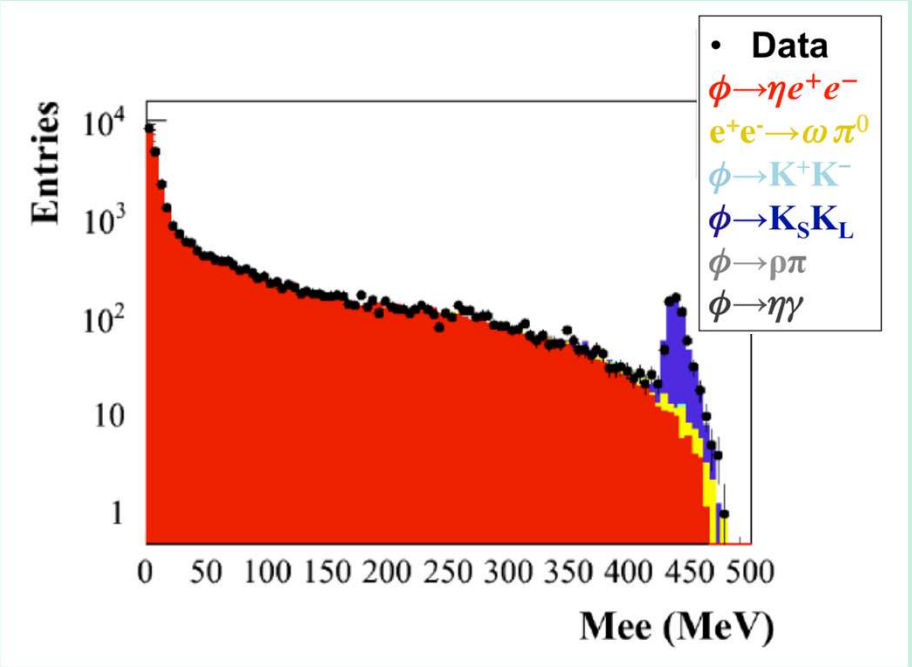
- 2 tracks in a cylinder around IP + 6 photon candidates
- $400 < M_{6\gamma} < 700$ MeV
- $536.5 < M_{recoil}(ee) < 554.5$ MeV
- Photon conversion cut
- ToF cuts to reject pions



After all analysis cuts: ~15% global efficiency
~ 30000 signal events
small background contribution (<3%)

$\phi \to \eta e^+ e^-$, $\eta \to \pi^0\pi^0\pi^0$: BR evaluation





Ψ*: angle between the η and the e^+ in the e^+e^- rest frame

PRELIMINARY

$$BR(\phi \to \eta e^+ e^-) = (1.131 \pm 0.032\ ^{+0.011}_{-0.006}) \times 10^{-4}$$

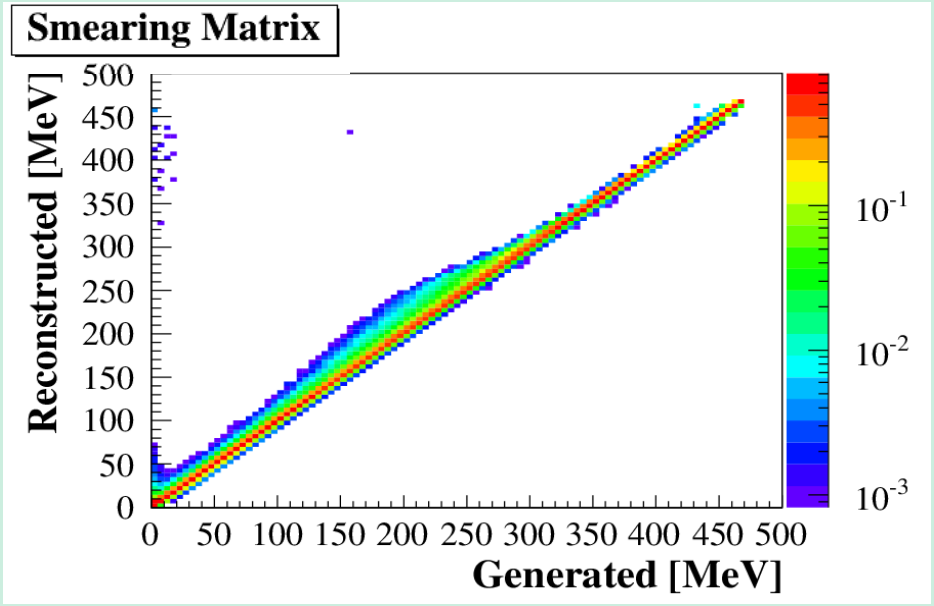
- VMD: 1.1
- SND: $(1.19 \pm 0.31) \times 10^{-4}$ [PLB 504 (2001) 275]
- CMD-2: $(1.14 \pm 0.16) \times 10^{-4}$ [PLB 501 (2001) 191]

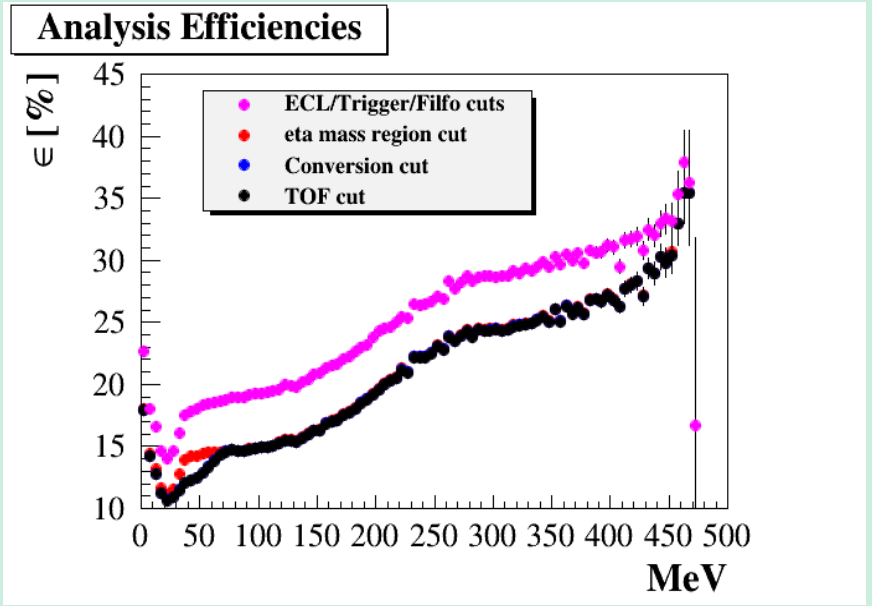
$\phi \to \eta e^+ e^-$: fit to the di-lepton inv. mass

Fit to M_{ee} distribution with decay parametrization from PR128 (1985) 301, to extract transition form factor

$$\frac{d}{dq^2}\frac{\Gamma(\phi \to \eta e^+ e^-)}{\Gamma(\phi \to \eta\gamma)} = \frac{\alpha}{3\pi}\frac{|F_{\phi\eta}(q^2)|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\times\left(1+\frac{2m^2}{q^2}\right)\times\left[\left(1+\frac{q^2}{m_\phi^2-m_\eta^2}\right)^2-\frac{4m_\phi^2 q^2}{(m_\phi^2-m_\eta^2)^2}\right]^{3/2}$$

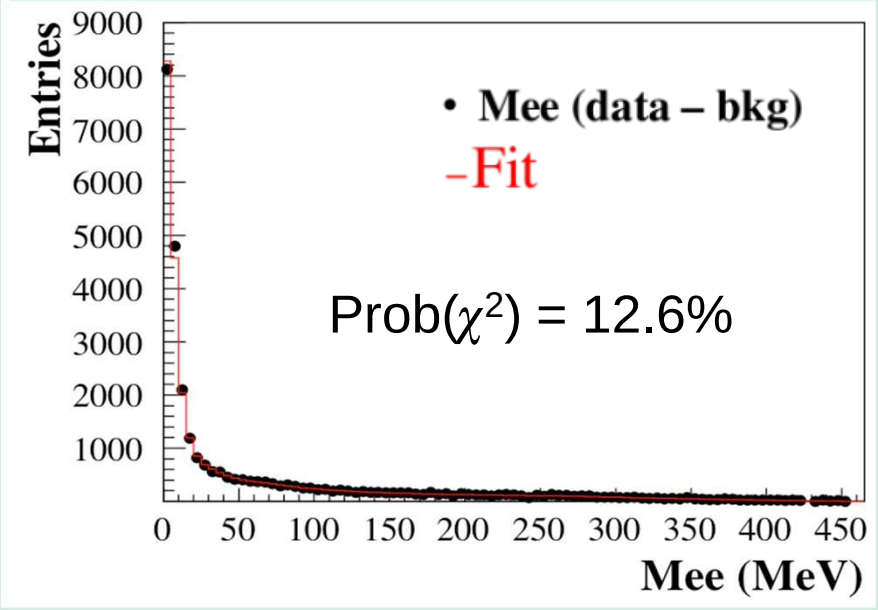
Smearing matrix, bin-by-bin analysis efficiency properly taken into account

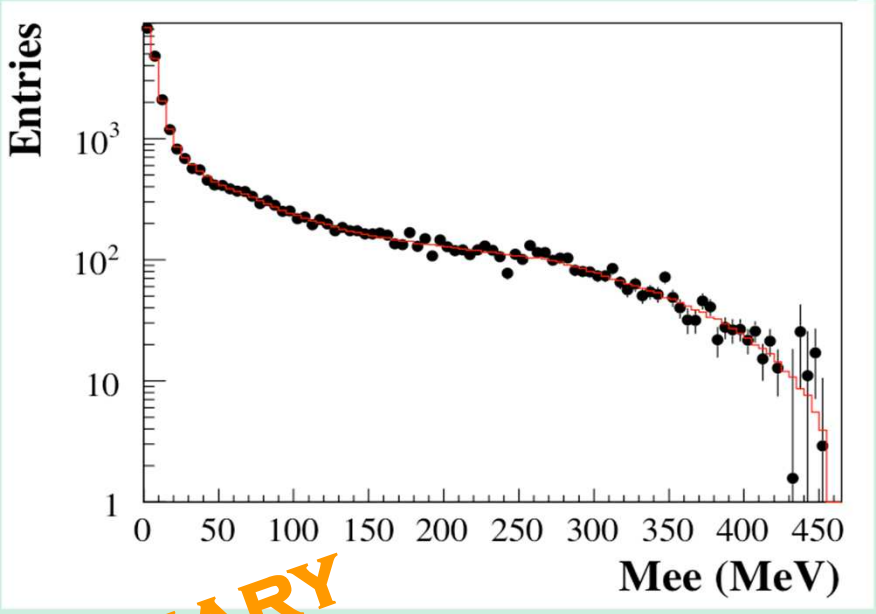




Photons from FSR included in the event generator

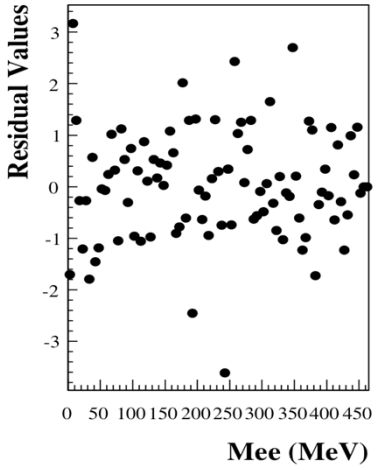
$\phi \to \eta e^+ e^-$: transition form factor

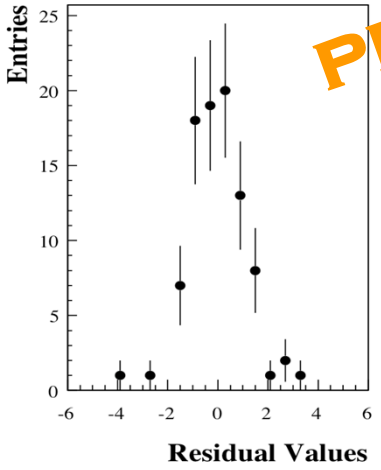




PRELIMINARY

Fit residuals





$$b_{\phi\eta} = (1.17 \pm 0.11\ ^{+0.09}_{-0.08})\ \text{GeV}^{-2}$$

- VMD: ~ 1.0 GeV^{-2}
- SND: (3.8 ± 1.8) GeV^{-2} [PLB 504 (2001) 275]

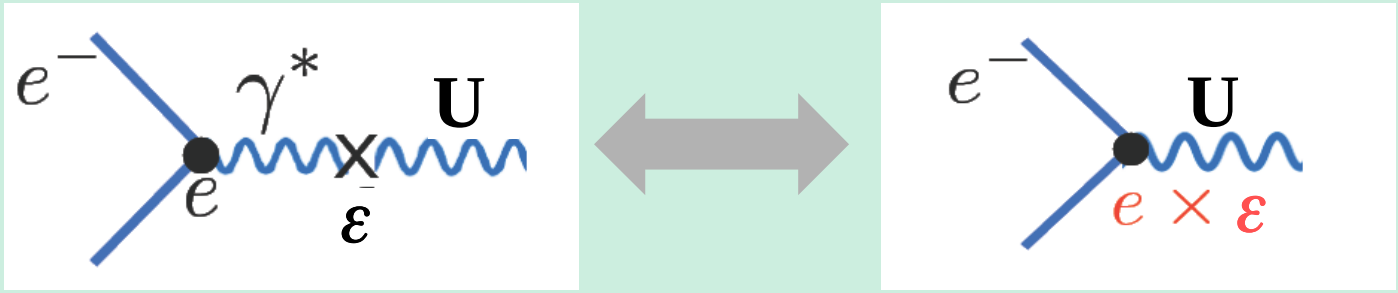
FF extraction in progress

Search for dark forces @ KLOE

PLB 720 (2013) 111

Several unexpected astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA/LIBRA, CoGent…) could be explained with the existence of a hidden gauge sector weakly coupled with SM through a mixing mechanism of a new **gauge boson (U, A', V…)** with the photon:

[Arkani-Hamed et al. PRD79 015014 (2009)]
[Essig et al., PRD80 015003 (2009)]



$$\varepsilon^2 = \frac{\alpha'}{\alpha_{em}}$$

- ✓ U mass range: **1 MeV – few GeV**
- ✓ Coupling constant of electric charge to U: $\varepsilon \leq 10^{-3}$
- ✓ U production/decay through photon mixing

Observable @ KLOE:

- ➢ ϕ Dalitz decays
- ➢ $e^+e^- \rightarrow U\gamma \rightarrow \ell^+\ell^-\gamma$
- ➢ $e^+e^- \rightarrow Uh' \rightarrow \ell^+\ell^-$ + missing energy

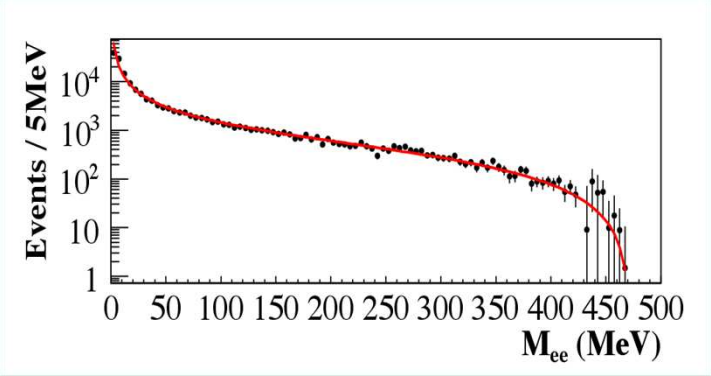
$\phi \to \eta e^+ e^-$: search for dark forces @ KLOE

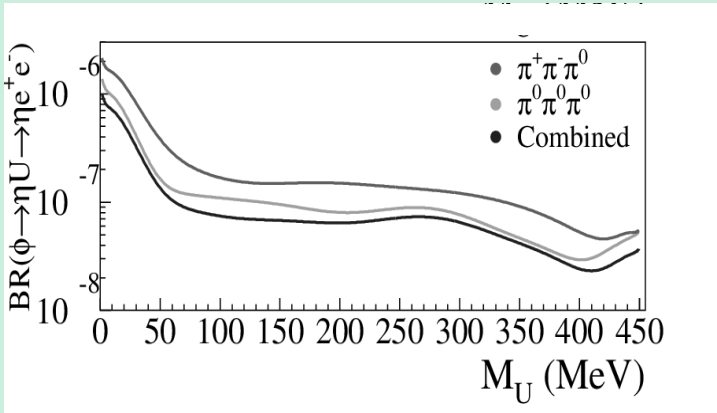
Meson having radiative decay to one photon can decay to a U boson
with $\mathrm{BR}(X \to YU) \sim \varepsilon^2 \times |FF_{XY\gamma}|^2 \times \mathrm{BR}(X \to Y\gamma)$ [M.Reece and L.T.Wang, JHEP 0907:051 (2009)]

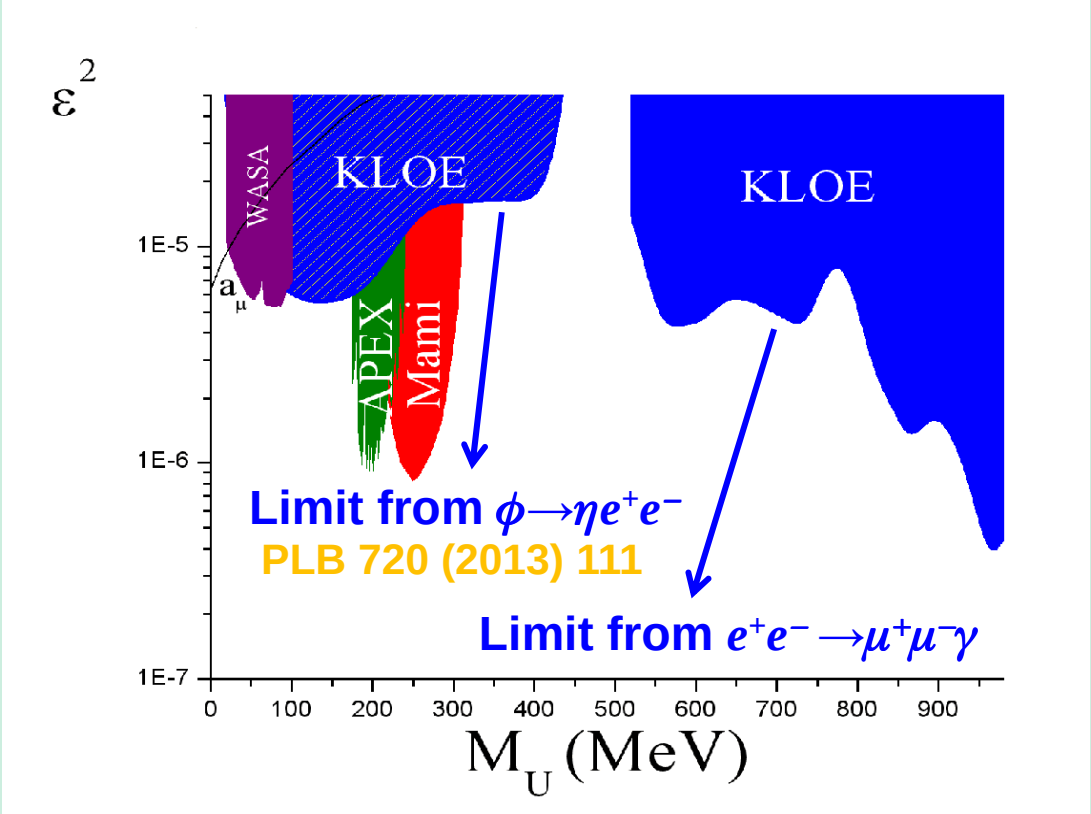
Selected decay chain: $\phi \to \eta U$, $U \to e^+e^-$ + $\eta \to \pi\pi\pi$

Irreducible background:
ϕ Dalitz decay $\phi \to \eta\gamma^* \to \eta l^+ l^-$

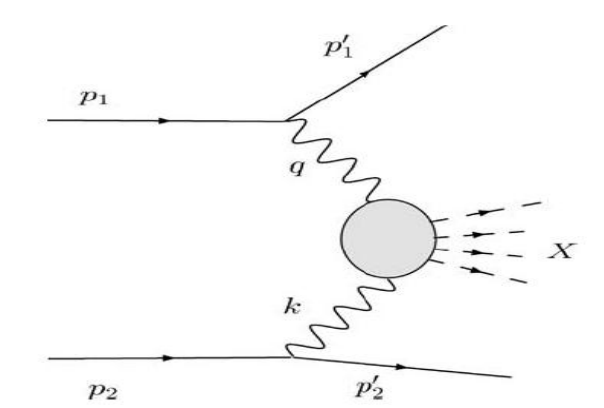
Same analysis of TFF. Bckg shape fitting sidebands of the M_{ee} distribution





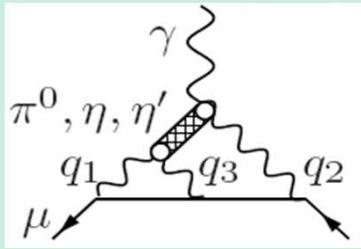


TFF from $\gamma\gamma$ interactions



$$\sigma_{\gamma\gamma\to R}(q_1,q_2) \propto \Gamma_{R\to\gamma\gamma}\frac{8\pi^2}{M_R}\delta((q_1+q_2)^2-M_R^2)\left|F(q_1^2,q_2^2)\right|^2$$

- Transition form factors crucial for hadronic light-by-light contributions to g-2
- $\Gamma_{\gamma\gamma}$ should be known precisely



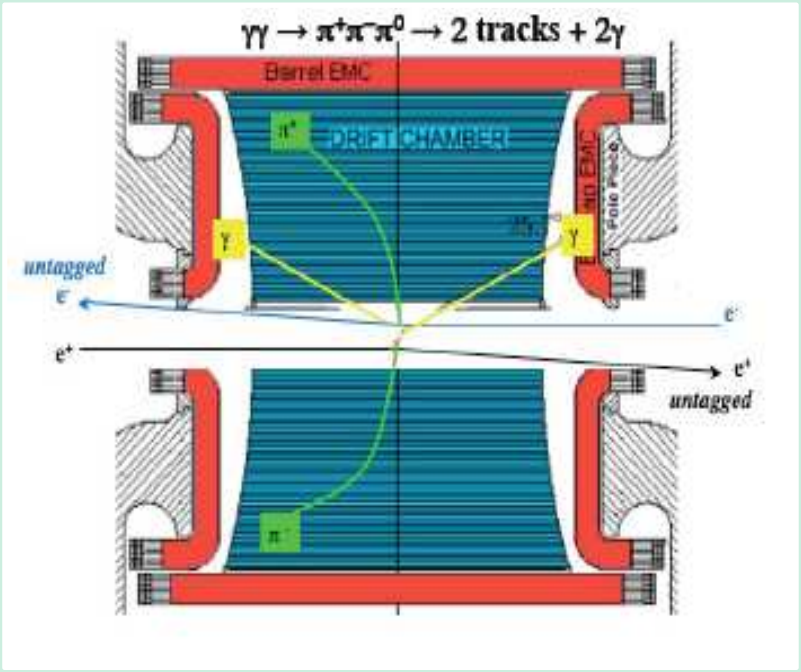
$\gamma\gamma$ physics @ KLOE/KLOE-2:

KLOE: no $e^{\pm}$ tagging

→ $\sqrt{s}$ = 1 GeV

KLOE-2: tagger to reduce background from ϕ and to close kinematics

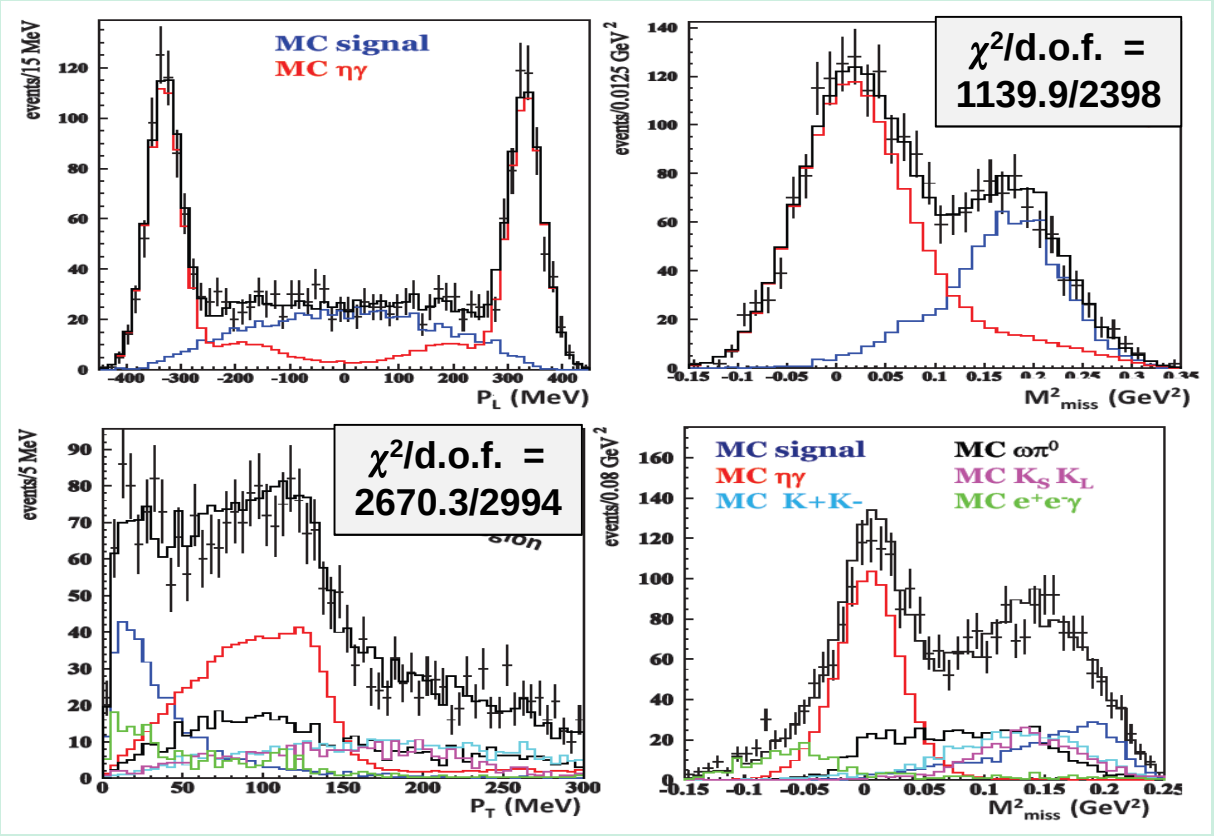
→ $\sqrt{s} = M_\phi$



$\Gamma(\eta\to\gamma\gamma)$ @ KLOE

JHEP 01 (2013) 119

- From $\gamma\gamma\to\eta$ events. No $e^{\pm}$ tagging
- Data sample: **240 pb^{-1} @ $\sqrt{s}$ = 1 GeV** (reduced background from ϕ)
- Selected channels: $\eta\to\pi^+\pi^-\pi^0/\pi^0\pi^0\pi^0$
- Main background: $\phi\to\eta\gamma$ with undetected recoil photon
- 2D fit to $M_{miss}^2 - p_{L/T}$ plane with signal and background MC shapes



$\eta\to\pi^0\pi^0\pi^0$:

- ✓ $e^+e^-\to\phi\to\eta\gamma$ contribution free

$\eta\to\pi^+\pi^-\pi^0$:

- ✓ $e^+e^-\to\phi\to\eta\gamma$ constrained
- ✓ Background weights checked in control regions

$\Gamma(\eta\to\gamma\gamma)$ @ KLOE

JHEP 01 (2013) 119

Neutral channel: (723 ± 32) signal events

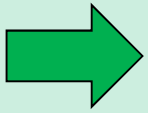
$$\sigma(e^+e^-\to e^+e^-\eta,\sqrt{s}=1\ \text{GeV}) = (\ 32.0\pm1.5_{\text{stat}}\pm0.9_{\text{syst}}\pm0.2_{\text{FF}}\pm0.2_{\text{BR}(\eta\to3\pi)}\ )\ \text{pb}$$

Charged channel: (394 ± 29) signal events

$$\sigma(e^+e^-\to e^+e^-\eta,\sqrt{s}=1\ \text{GeV}) = (\ 34.5\pm2.5_{\text{stat}}\pm1.0_{\text{syst}}\pm0.7_{\text{FF}}\pm0.4_{\text{BR}(\eta\to3\pi)}\ )\ \text{pb}$$

Combined:

$$\sigma(e^+e^-\to e^+e^-\eta,\sqrt{s}=1\ \text{GeV}) = (\ 32.7\pm1.3_{\text{stat}}\pm0.7_{\text{syst}}\ )\ \text{pb}$$



$$\Gamma(\eta\to\gamma\gamma) = (\ 520\pm20\pm13\ )\ \text{eV}$$

most precise measurement to date

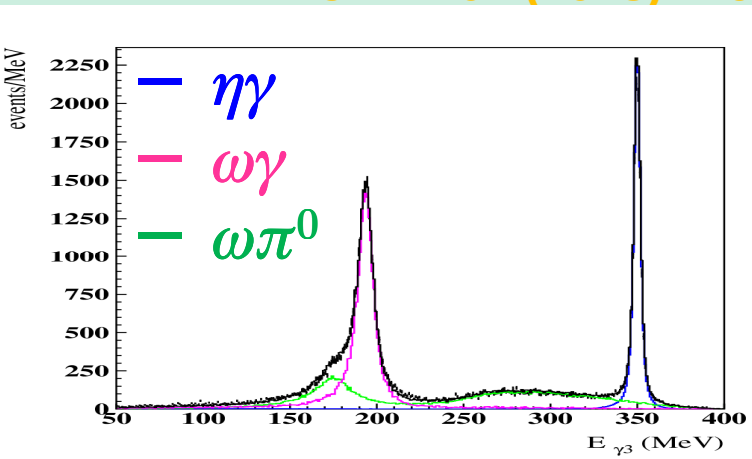
Measurement of $\sigma(e^+e^-\to\eta\gamma)$ @ 1 GeV

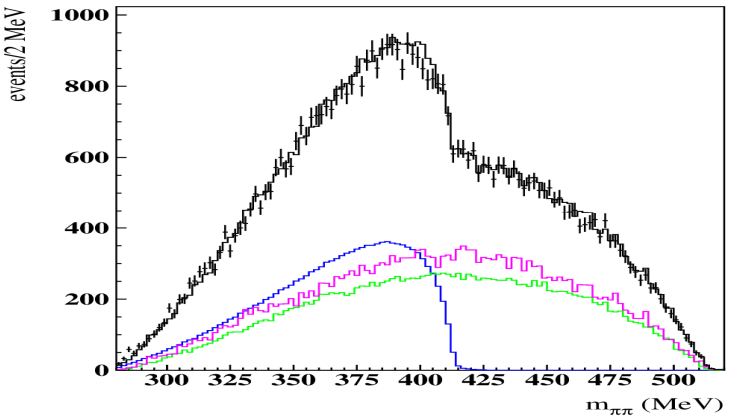
JHEP 01 (2013) 119

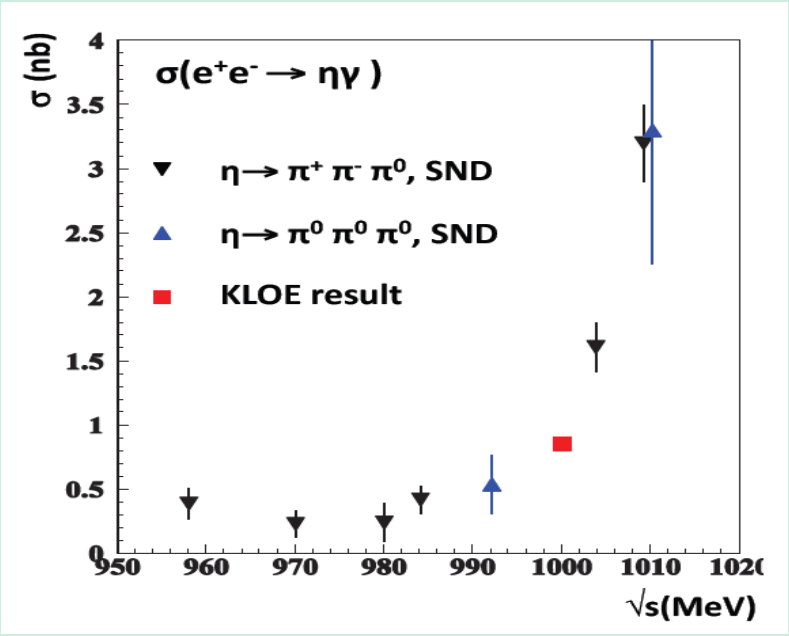
$e^+e^- \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$:

- 3 photons + 2 tracks
- π^0 ID
- Kin. cuts to suppress bckg from kaons
- kinematic fit
- Signal events from 2D-fit to $E_{\gamma 3}$--$M_{\pi\pi}$

$$\sigma(e^+e^-\to\eta\gamma) = (856 \pm 8_{stat} \pm 12_{syst} \pm 11_{BR})\ pb$$







In agreement with the result from $\eta\to\pi^0\pi^0\pi^0$

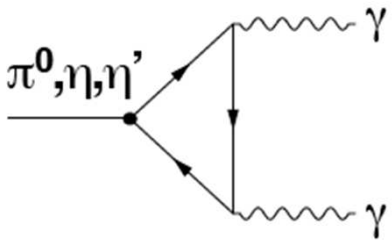
$$\sigma(e^+e^-\to\eta\gamma) = (853 \pm 25_{stat} \pm 5_{syst} \pm 6_{BR})\ pb$$

Perspectives for $\gamma\gamma \to \pi^0$ @ KLOE-2

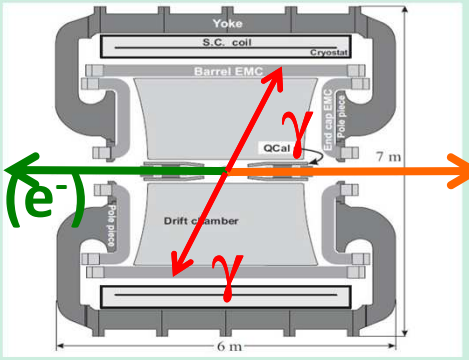
EPJC (2012) 72:1927

$\Gamma(\pi^0 \to \gamma\gamma)$ width

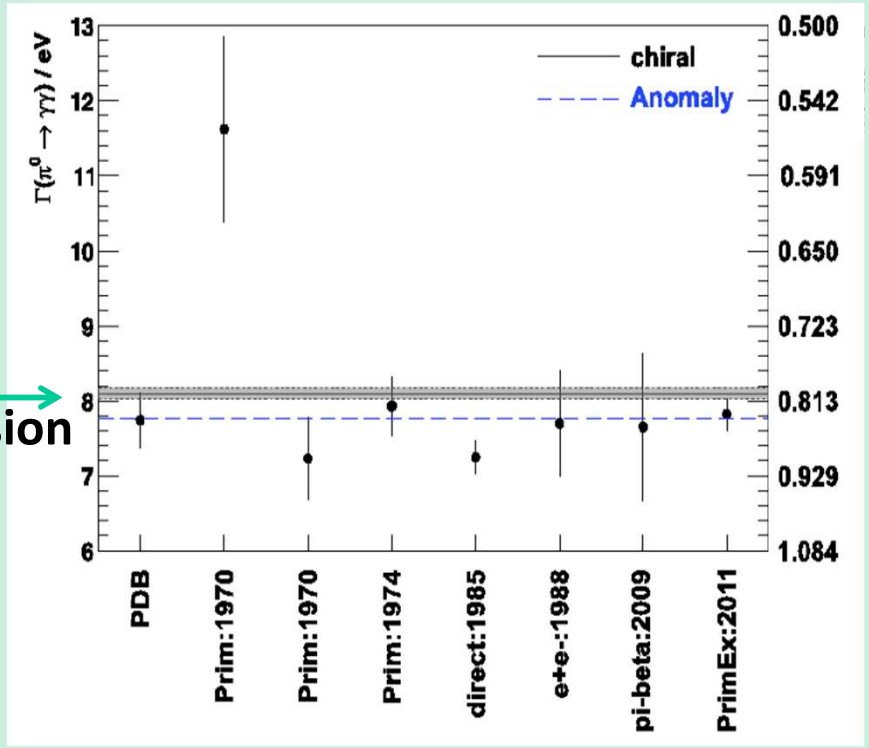
$\Gamma(\pi^0 \to \gamma\gamma)$: best measurement from Primakoff-process, PrimEX @ Jlab, at 2.8%: PRL 106(2011)162303



$\Gamma(\pi^0 \to \gamma\gamma)$ at 1% feasible at KLOE-2 with 5-6 fb^{-1}
The coincidences between KLOE central detector and HET taggers SELECT a very clean sample of ~ 1900 events per fb^{-1}
(σ_{eff} = 3.4 pb)
The radiative Bhabha-scattering events fully cut out by KLOE-HET coincidence



Theory and KLOE-2 precision



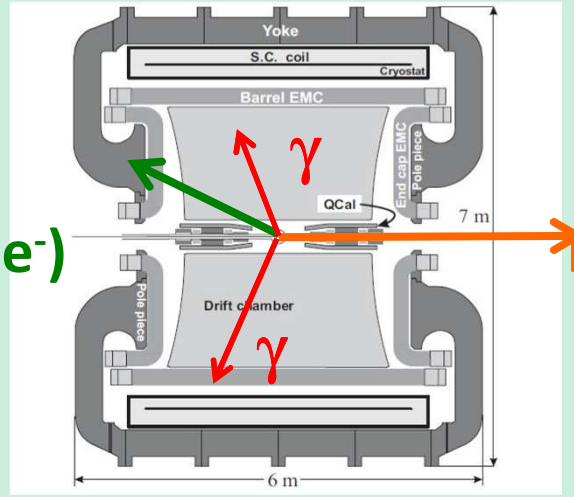
Perspectives for $\gamma\gamma \to \pi^0$ @ KLOE-2

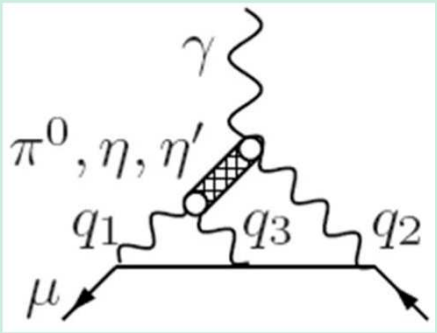
EPJC (2012) 72:1927

$\pi^0 \to \gamma\gamma^*$ transition form factor in the space-like region at low Q^2

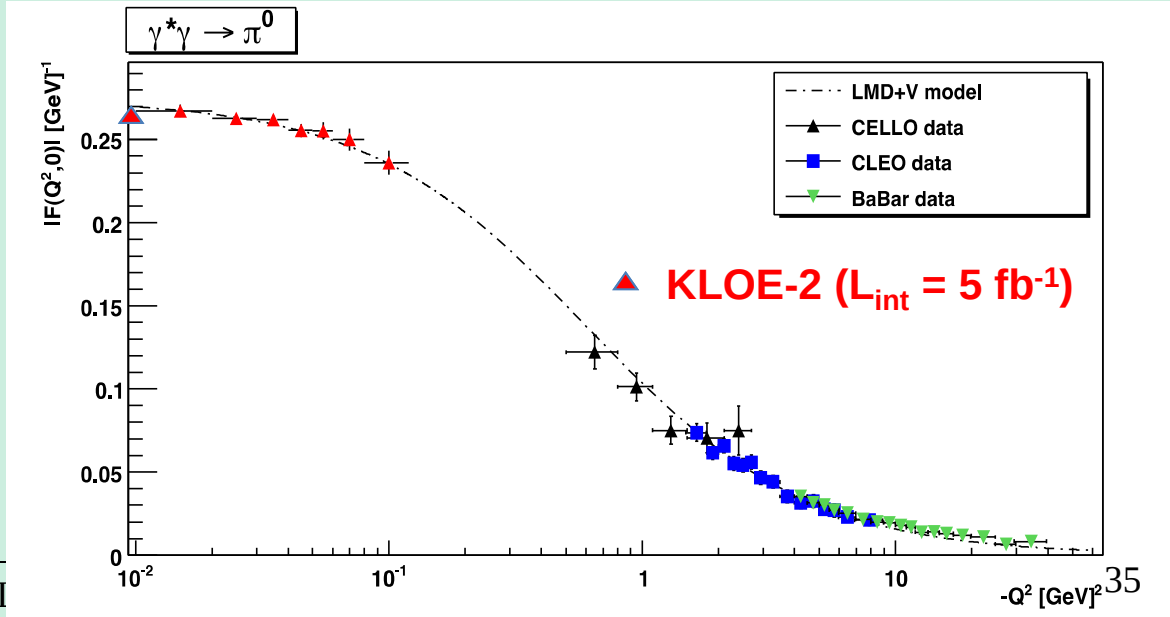
$F_{\pi^0 \gamma\gamma^*}$ at 5-6% feasible at KLOE-2 with 5 fb^{-1}

The coincidences between KLOE central detector and one of the HET stations are used





Light-by-light term to muon anomaly : both measurements, width and $F_{\pi^0 \gamma\gamma^*}$ contribute to a factor of ~2 reduction in the theoretical error, dominated by pseudoscalar (π^0) contribution



Conclusion

- Light meson spectroscopy provides a unique opportunity for:
  - fundamental tests of low energy QCD
  - search for new physics beyond SM

- Large data sample of light mesons available at KLOE provides important results on decay dynamics and transition form factor, together with tighter limits on new physics, giving the most precise measurements for:
  - $\eta \to \pi^+\pi^-\pi^0$, $\eta \to \pi^+\pi^-\gamma$
  - TFF in $\phi \to \eta/\pi^0 e^+e^-$
  - η radiative width

- New improvements will come in the near future with KLOE-2