

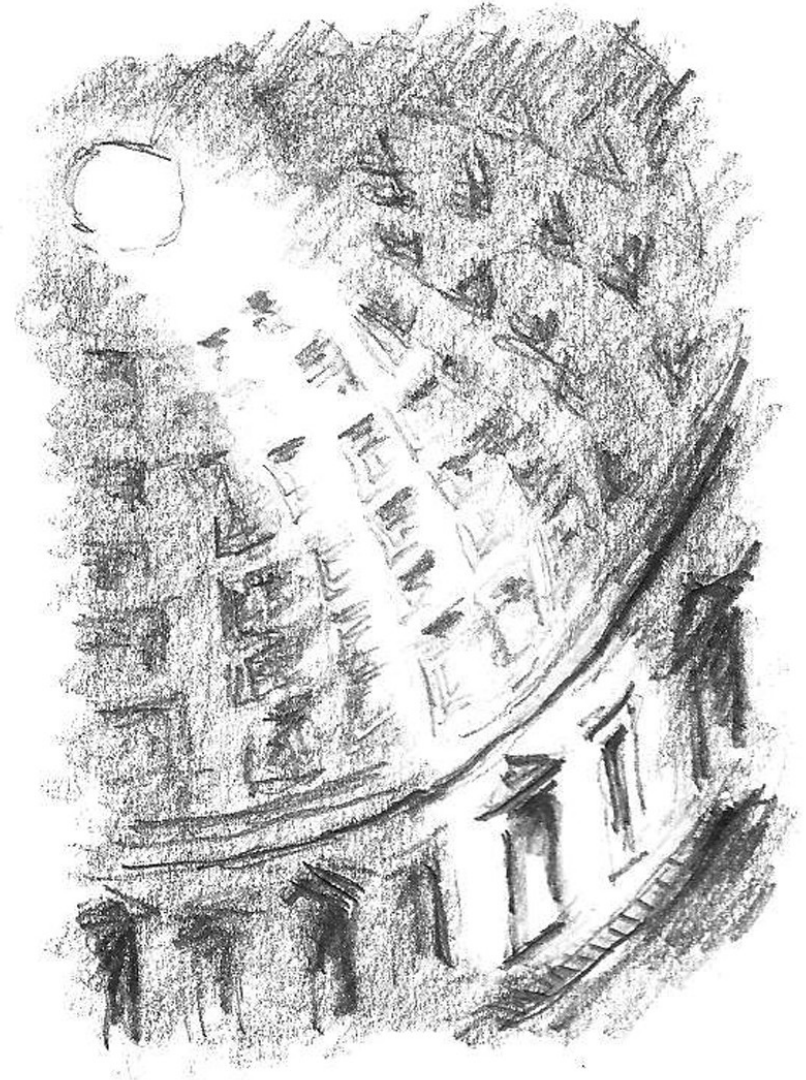


“Light meson spectroscopy at KLOE/KLOE-2”

Matteo Mascolo
(on behalf of the KLOE-2 coll.)

PHI 13
PSI

Rome, 9 – 12 September 2013



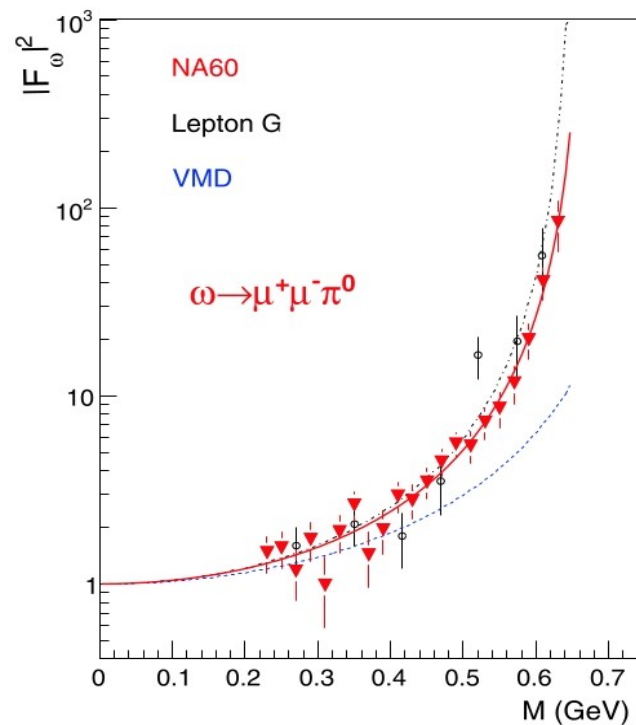
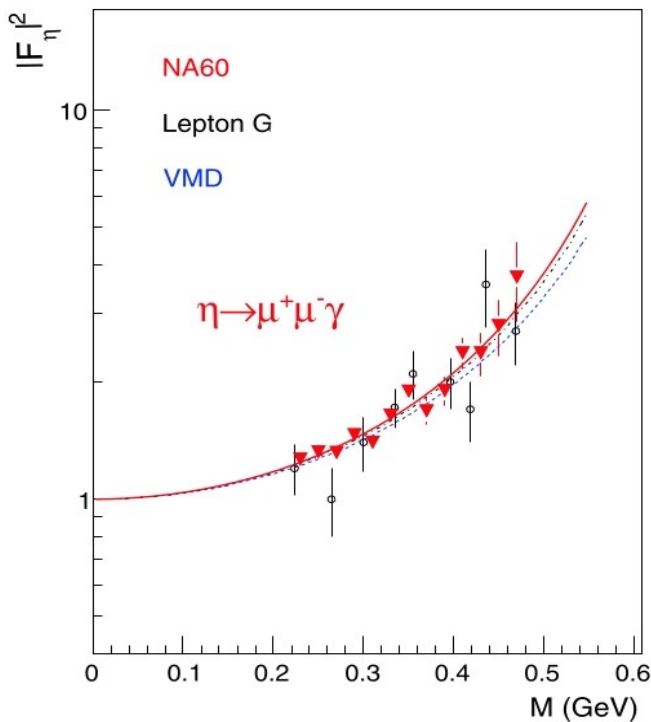


Talk Outline

- ✓ Physics motivation for the investigation of light mesons (η and π^0) at KLOE/KLOE-2
- ✓ Recent results on $\phi \rightarrow \eta e^+ e^-$ analyses
 - $\eta \rightarrow \pi^0 \pi^0 \pi^0$
 - $\eta \rightarrow \pi^+ \pi^- \pi^0$
- ✓ The analysis of $\phi \rightarrow \pi^0 e^+ e^-$
- ✓ The Dalitz Plot analysis of $\eta \rightarrow \pi^+ \pi^- \pi^0$
- ✓ Conclusions

Physics motivation (1/2)

- ✓ Test the modelings of the TFF (the naïve VMD approach is satisfactory in the description of $\eta \rightarrow \gamma \mu^+ \mu^-$ but fails in the $\omega \rightarrow \pi^0 \mu^+ \mu^-$ case)



Data

NA60 coll, Phys. Lett. B 677 260-266 (2009)

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)

Physics motivation (2/2)

SND @ VEPP-2M
[Achasov et al. Phys. Lett. B 504 275-281 (2001)]

✓ $F_{\phi \eta \gamma^*}$ slope, $b_{\phi \eta} = \Lambda^{-2} = dF(q^2)/dq^2 |_{q^2=0}$

$$b_{\text{exp}} = (3.8 \pm 1.8) \text{ GeV}^{-2}$$

$$b_{\text{VMD}} \approx 1.0 \text{ GeV}^{-2}$$

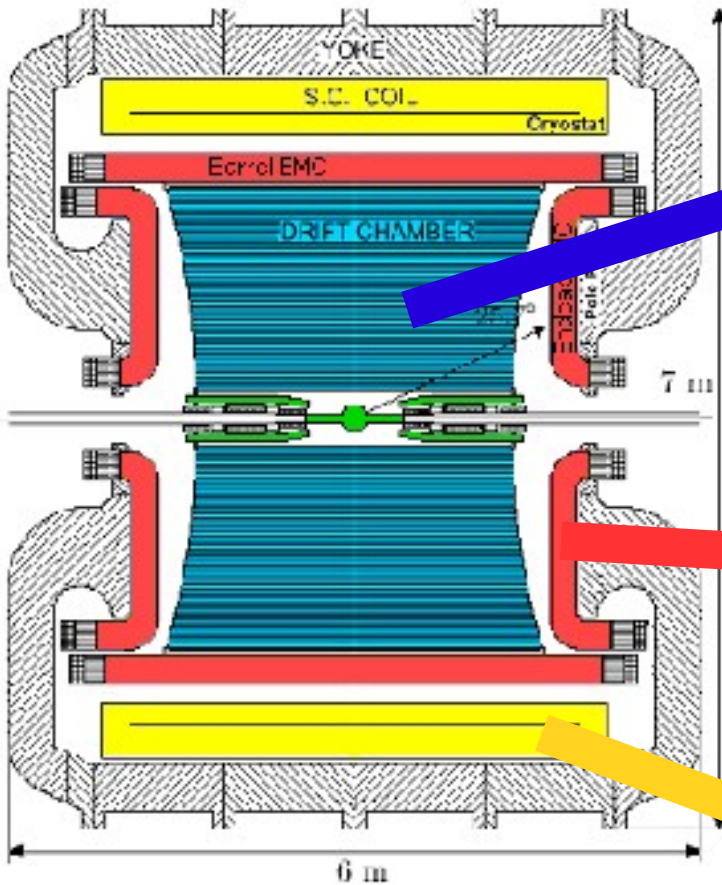
✓ NO DATA available for $F_{\phi \pi^0 \gamma^*}$ TFF (an enhancement due to ρ resonance is expected)

✓ Improve the measurement of the BRs ($\phi \rightarrow \pi^0 e^+ e^-$ is OZI suppressed)

BR decay	SND	CMD-2	PDG av.	Tot err.
$\phi \rightarrow \eta e^+ e^- (10^{-4})$	$(1.19 \pm 0.19 \pm 0.12)$	$(1.14 \pm 0.10 \pm 0.06)$	(1.15 ± 0.10)	~ 8.7 %
$\phi \rightarrow \pi^0 e^+ e^- (10^{-5})$	$(1.01 \pm 0.28 \pm 0.29)$	$(1.22 \pm 0.34 \pm 0.21)$	(1.12 ± 0.28)	~ 25 %

[J. Beringer et al. Phys. Rev. D 86 (2012)]

The KLOE experiment



Drift chamber

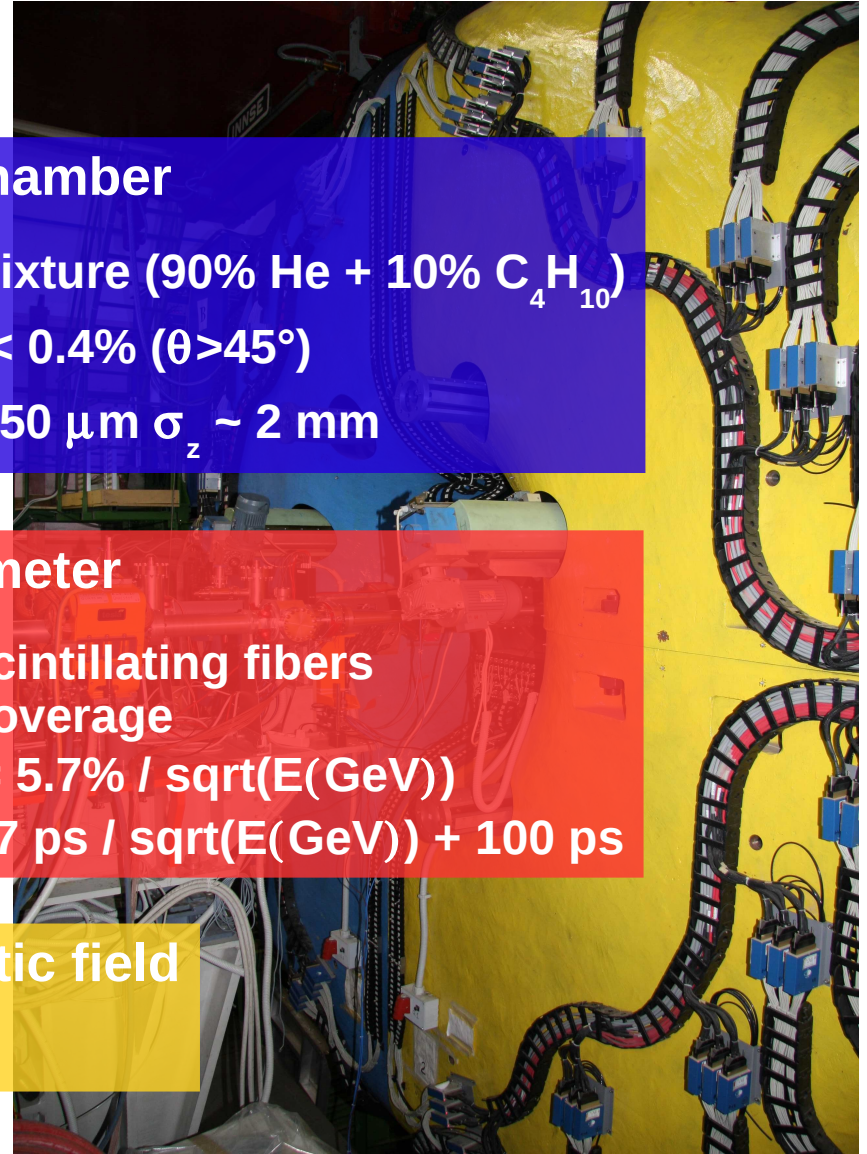
- Gas mixture (90% He + 10% C₄H₁₀)
- $\delta p_t/p_t < 0.4\%$ ($\theta > 45^\circ$)
- $\sigma_{xy} \sim 150 \mu\text{m}$ $\sigma_z \sim 2 \text{ mm}$

Calorimeter

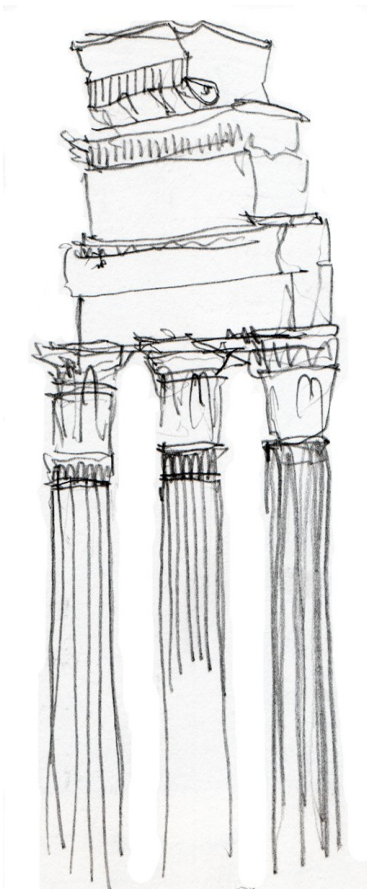
- lead/scintillating fibers
- 98% coverage
- $\delta E/E = 5.7\% / \sqrt{E(\text{GeV})}$
- $\delta t = 57 \text{ ps} / \sqrt{E(\text{GeV})} + 100 \text{ ps}$

Magnetic field

- 0.52 T

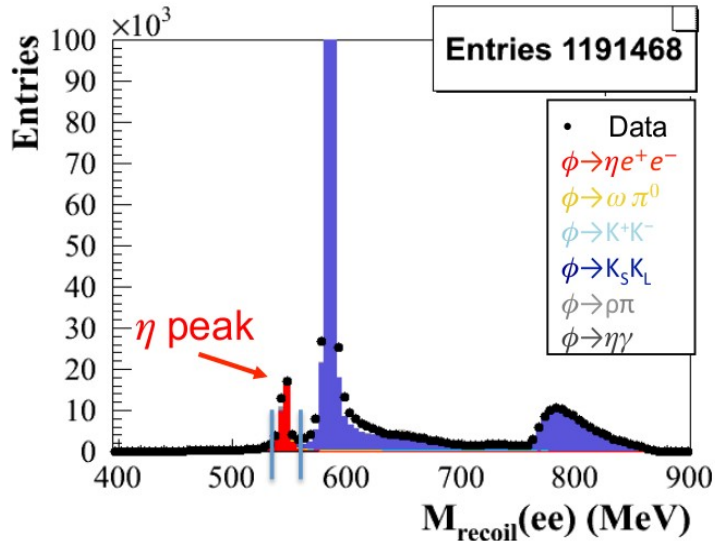


DAΦNE → e⁺e⁻ collider $\sqrt{s} = M\phi = 1.02 \text{ GeV}$
 KLOE → 2.5 fb⁻¹ collected on peak



The $\phi \rightarrow \eta e^+e^-$ analyses

The analysis of $\phi \rightarrow \eta e^+e^-$ ($\eta \rightarrow \pi^0\pi^0\pi^0$)



✓ The analysis is performed on 1.7 fb^{-1} collected at $\sqrt{s} = M_\phi \approx 1.02 \text{ GeV}$

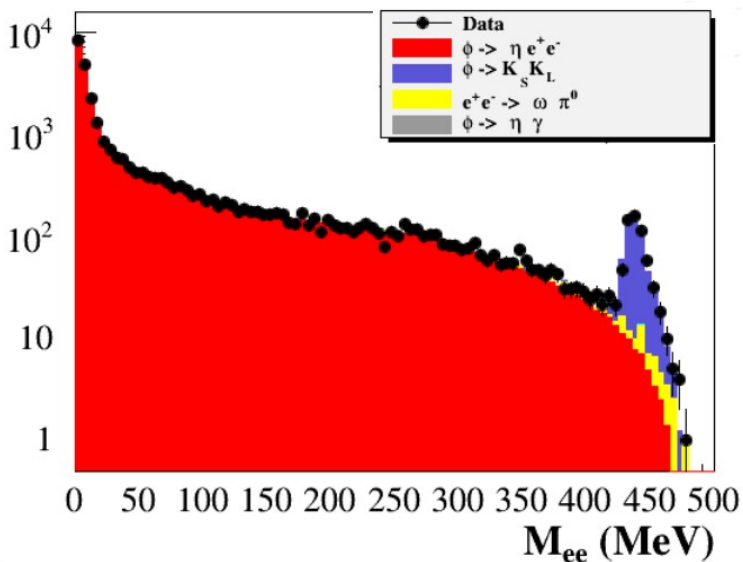
✓ Pre-selection:

- 2 tracks of opposite charge from IP
- 6 photon-clusters candidates from IP

✓ Selection:

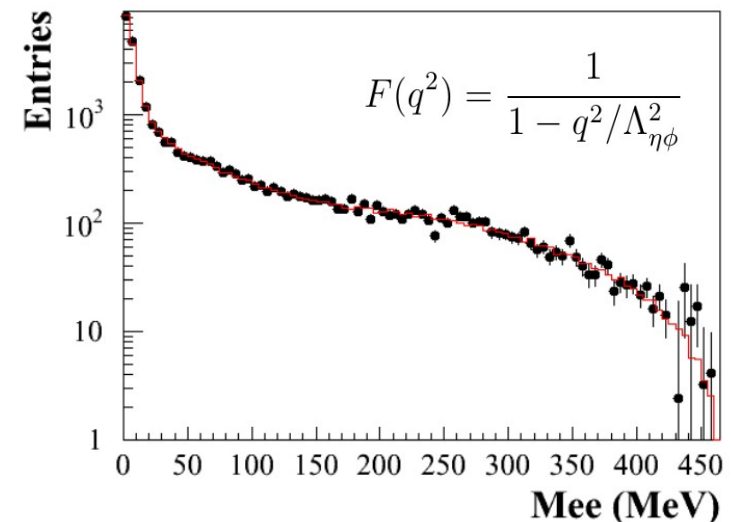
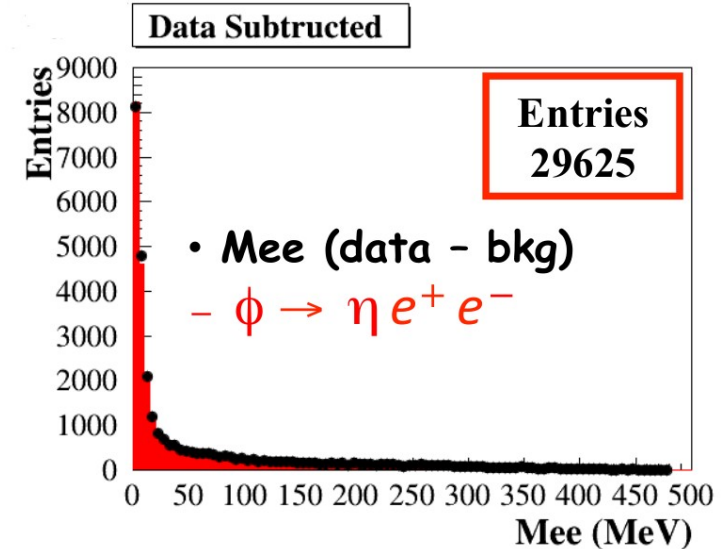
- $400 < M_{6\gamma} < 700 \text{ MeV}$
- Cut to reject γ conversion on BP and DC walls
- TOF cut for e^+e^- selection

✓ $\sim 3 \times 10^4$ evts selected, $\sim 15\%$ global efficiency
 $< 3\%$ residual bkg contamination



Preliminary TFF $\phi \rightarrow \eta e^+e^-$ ($\eta \rightarrow \pi^0\pi^0\pi^0$)

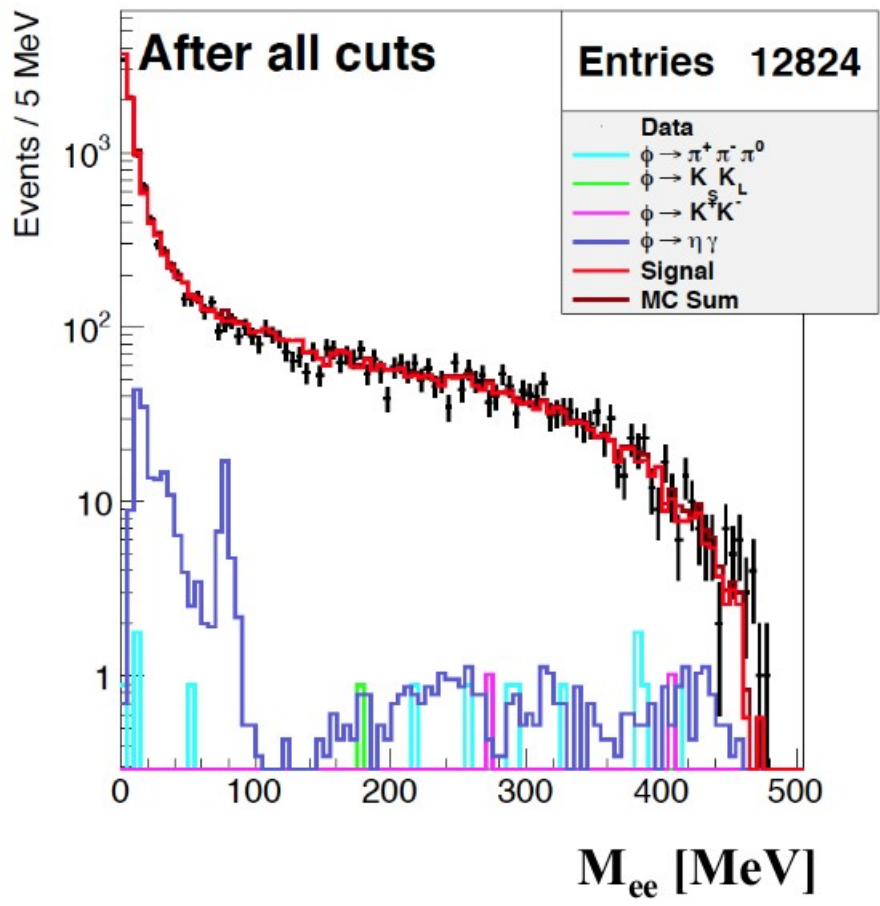
- ✓ Good MC-Data agreement after bkg subtraction
- ✓ $F_{\phi\eta\gamma^*}$ is extracted by the fit of the invariant-mass spectrum of the e^+e^- pair to the Landsberg formula [L.G. Landsberg Phys. Rep. 128 301 (1985)]



Quantity	Previous exp.	Preliminary!! KLOE
$b_{\phi\eta} = \Lambda_{\phi\eta}$ [GeV ⁻²]	SND (3.8 ± 1.8) CMD-2 ---	$(1.17 \pm 0.11^{+0.09}_{-0.08})$
BR ($\phi \rightarrow \eta e^+ e^-$) (10 ⁻⁴)	SND (1.19 ± 0.22) CMD-2 (1.14 ± 0.12)	$(1.131 \pm 0.032^{+0.011}_{-0.06})$



The analysis of $\phi \rightarrow \eta e^+e^-$ ($\eta \rightarrow \pi^+\pi^-\pi^0$)



✓ The analysis is performed on 1.5 fb^{-1} collected at $\sqrt{s} = M_\phi \approx 1.02 \text{ GeV}$

✓ **Pre-selection:**

- 4 tracks from IP
- 2 photon-clusters candidates from IP

✓ **Selection:**

- $495 < M_{\gamma\gamma\pi\pi} < 600 \text{ MeV}$ / $70 < M_{\gamma\gamma} < 200 \text{ MeV}$
- $70 < M_{\text{miss-ee}} < 200 \text{ MeV}$
- Cut to reject γ conversion on BP and DC walls
- TOF cut for e^+e^- selection

✓ $\sim 1.3 \times 10^4$ evts \rightarrow fit checks and systematics evaluation in progress





U boson searches in $\phi \rightarrow \eta e^+e^-$

✓ Associated decay of ϕ meson into a PS and a U suggested by M. Reece and L.T. Wang [JHEP 0907:051 (2009)]

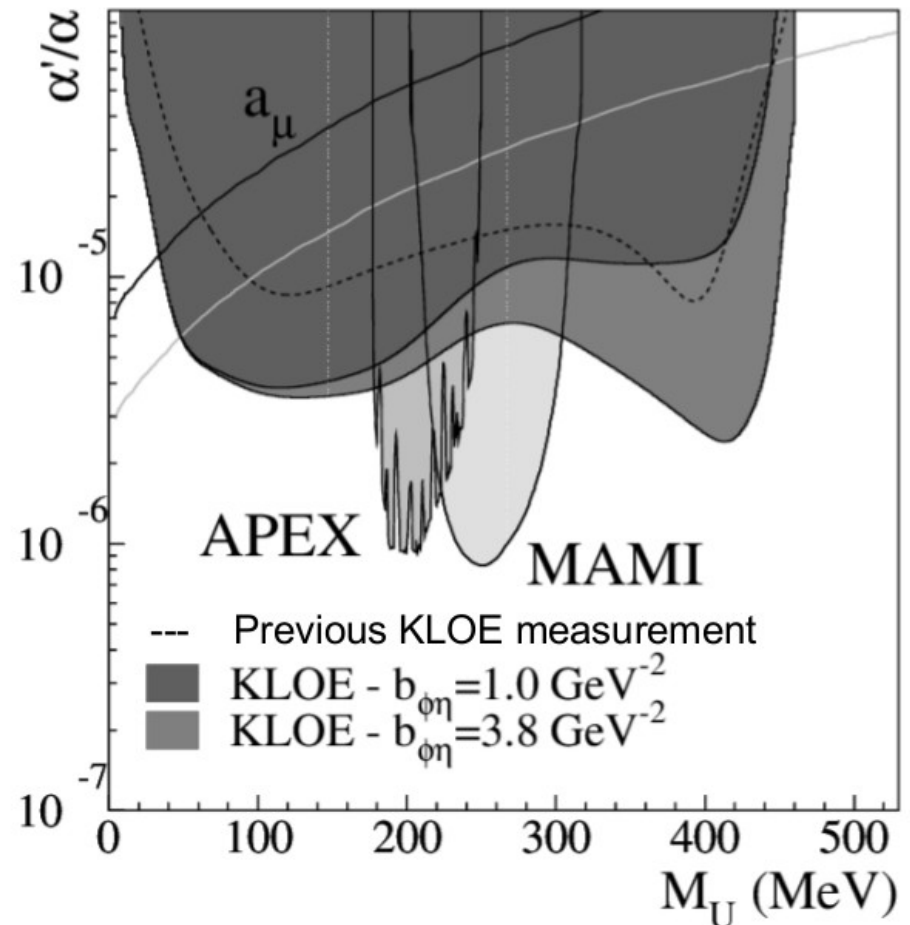
✓ Investigated decay chains:

- **OLD**: $\phi \rightarrow U\eta$ ($\eta \rightarrow \pi^+\pi^-\pi^0$ $U \rightarrow e^+e^-$)
[Phys. Lett. B706 251-255 (2012)]

- **NEW**: $\phi \rightarrow U\eta$ ($\eta \rightarrow \pi^+\pi^-\pi^0/\pi^0\pi^0\pi^0$ $U \rightarrow e^+e^-$)
[Phys. Lett. B720 111-115 (2013)]

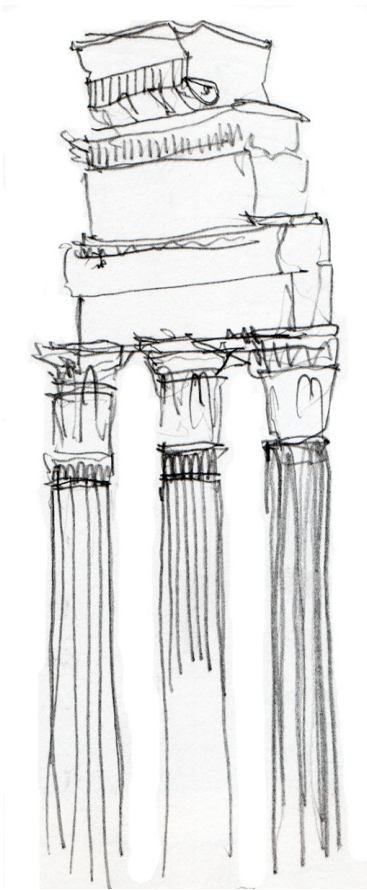
✓ Upper limit for α'/α (90% C.L.)

$$\alpha'/\alpha < 1.7 \times 10^{-5} \text{ for } 30 < M_U < 400 \text{ MeV}$$
$$(\alpha'/\alpha < 8.0 \times 10^{-6} \text{ for } 50 < M_U < 210 \text{ MeV})$$



See the talk of E. Graziani (Monday 09)



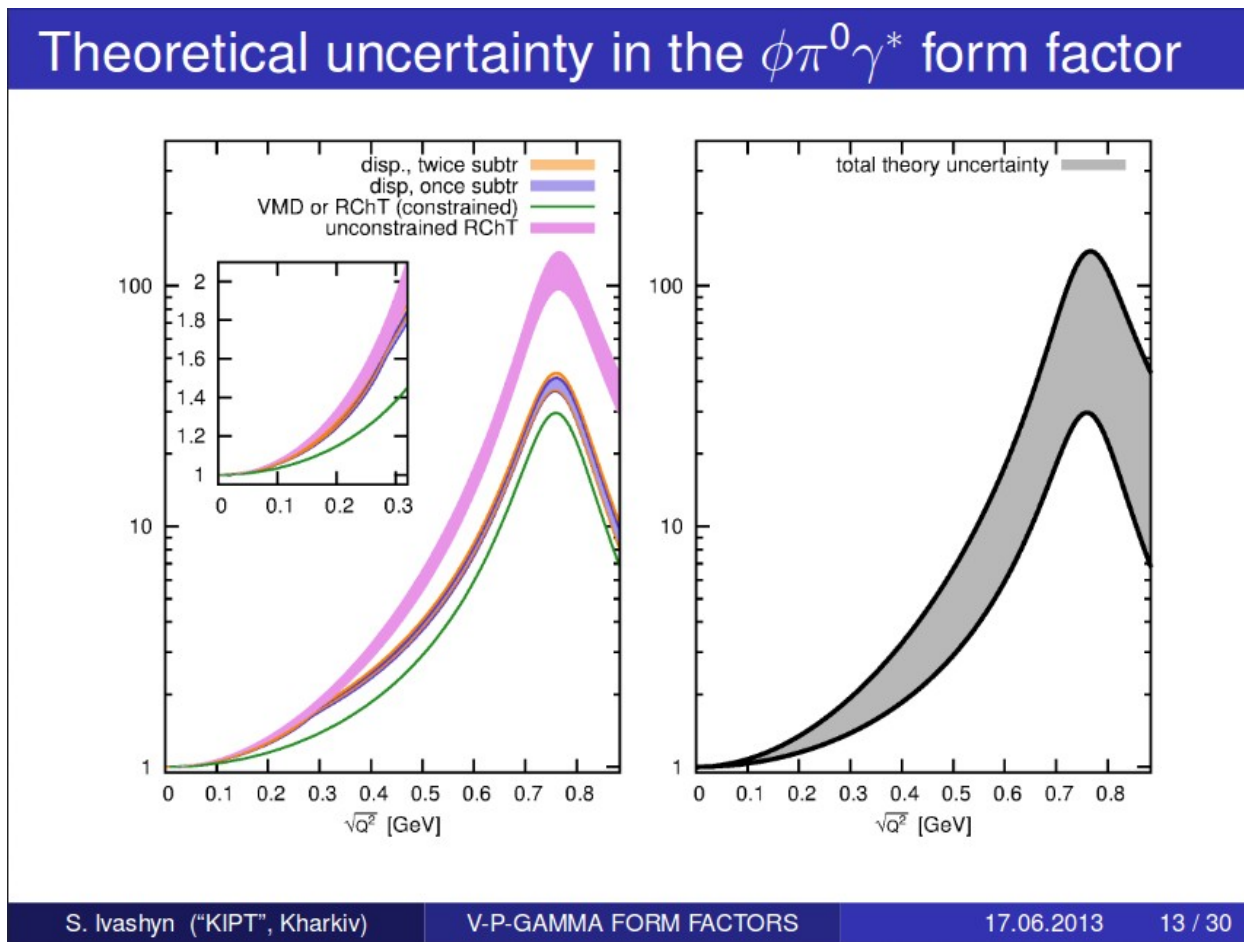
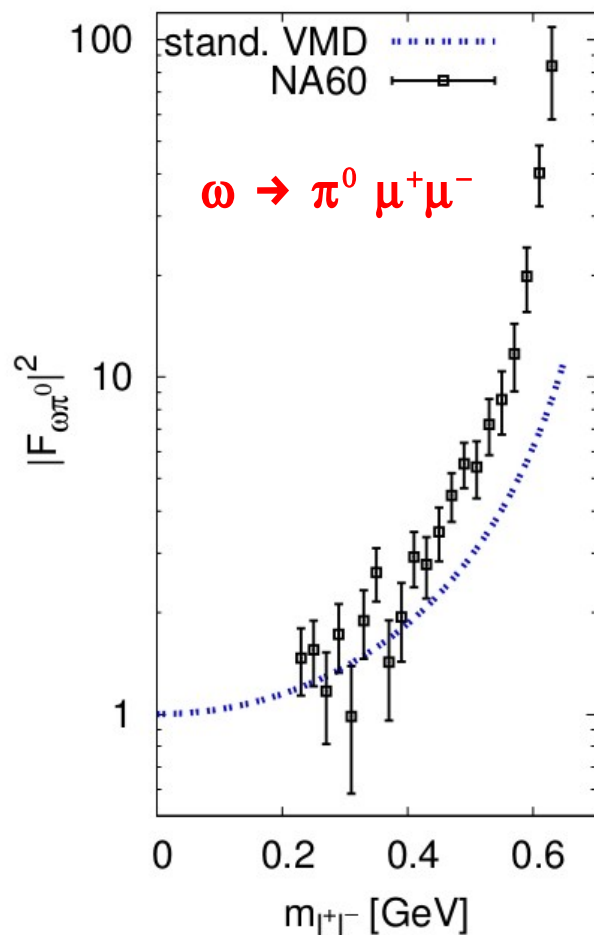


The $\phi \rightarrow \pi^0 e^+e^-$ analysis



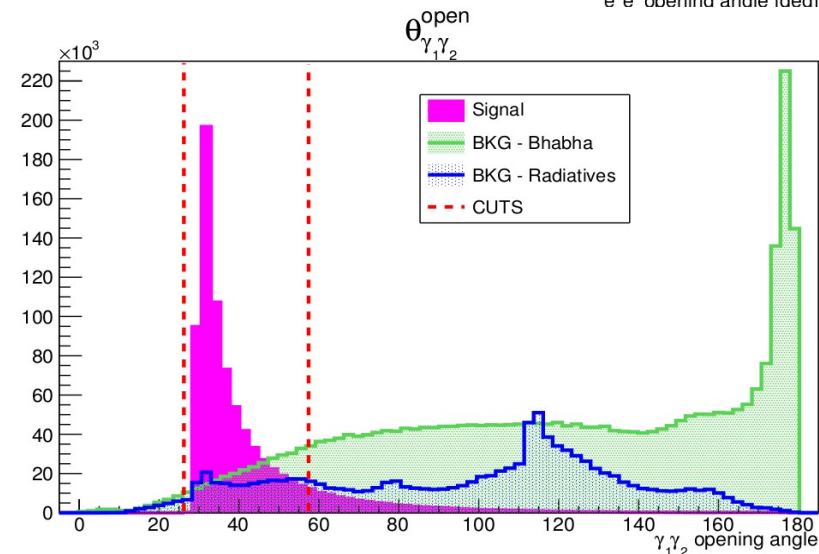
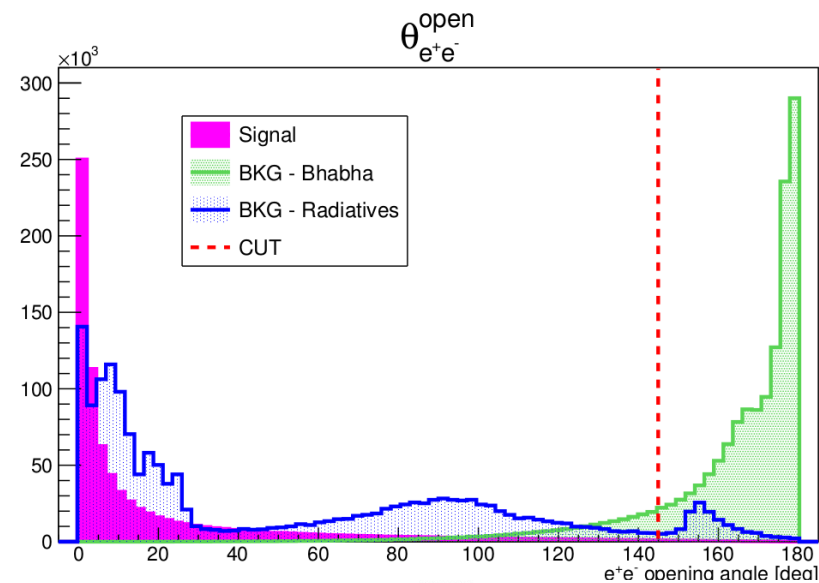
$$\phi \rightarrow \pi^0 e^+ e^-$$

✓ NO DATA available for $F_{\phi \pi^0 \gamma^*}$ TFF \rightarrow Needed to test the theoretical models



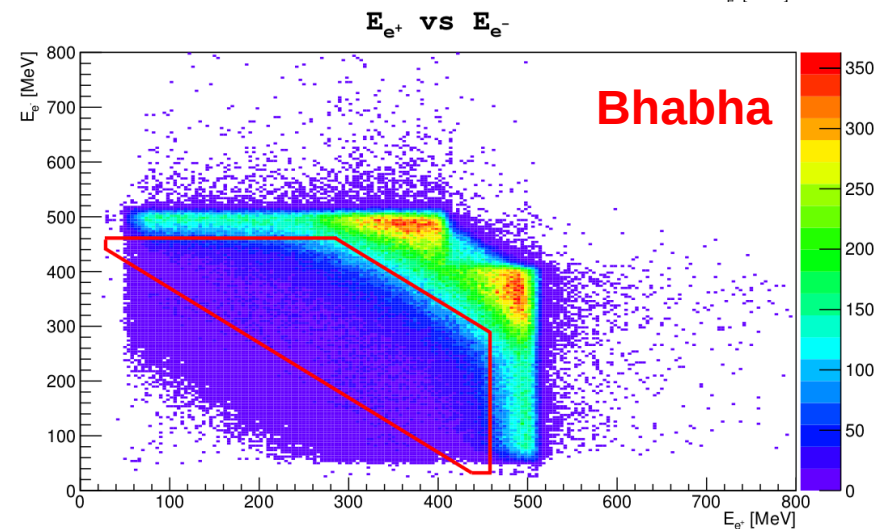
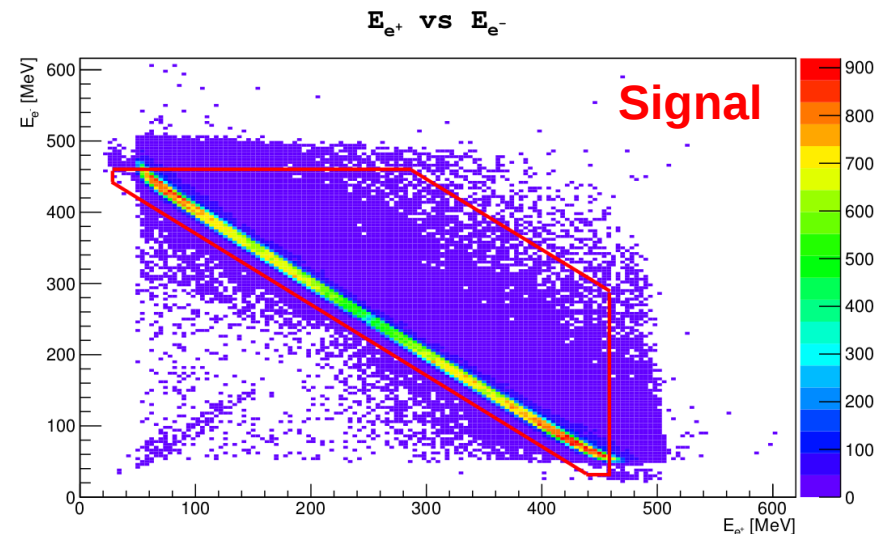
The analysis of $\phi \rightarrow \pi^0 e^+ e^-$

- ✓ The signal is “classified” as Bhabha event by the streaming algorithm
- ✓ Main bkg: $e^+ e^- \rightarrow e^+ e^- \gamma \gamma$ and $\phi \rightarrow \pi^0 \gamma$
Several orders of magnitude larger!
- ✓ Selection (main):
 - $E_e < 460$ MeV
 - $470 < E_{e^+} + E_{e^-} < 750$ MeV
 - $300 < E_{\gamma_1} + E_{\gamma_2} < 670$ MeV
 - $\theta_{\text{open}}(ee) < 145^\circ$ and $27^\circ < \theta_{\text{open}}(\gamma\gamma) < 57^\circ$
 - $90 < M_{2\gamma} < 190$ MeV and $80 < M_{\text{miss}}^{ee} < 180$ MeV
 - Cut to reject γ conv. on BP and DC walls



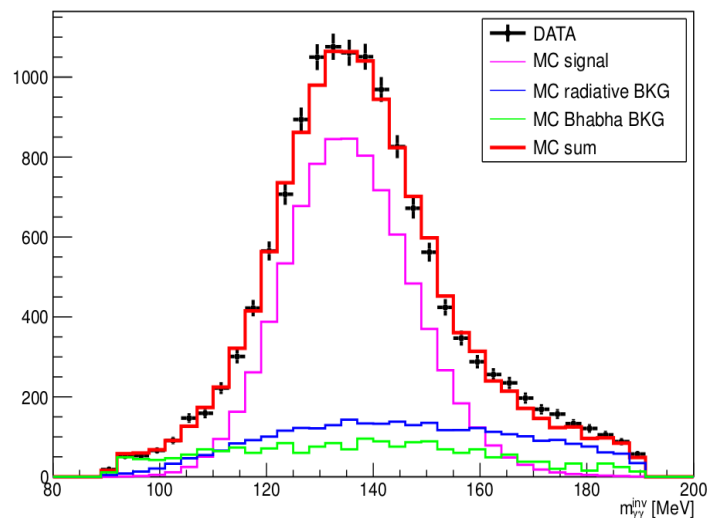
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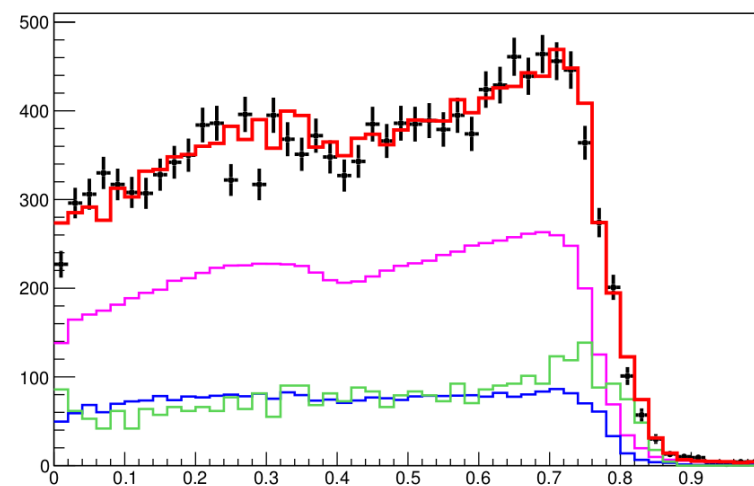


$\phi \rightarrow \pi^0 e^+ e^-$: Data-MC agreement

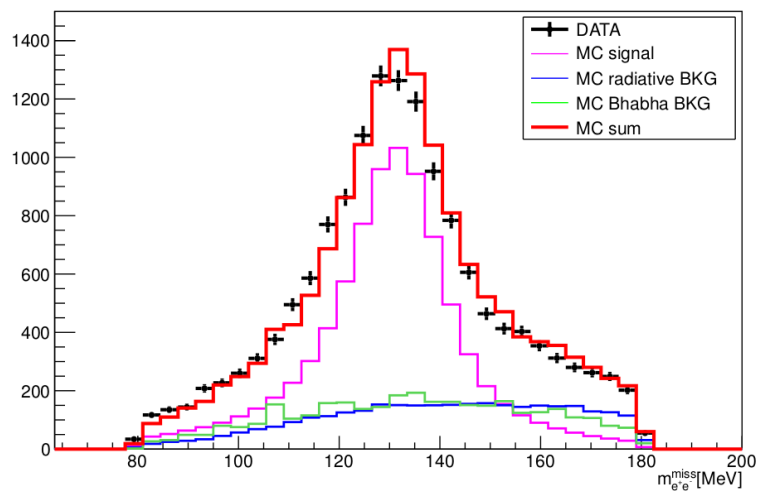
$\gamma\gamma$ invariant mass



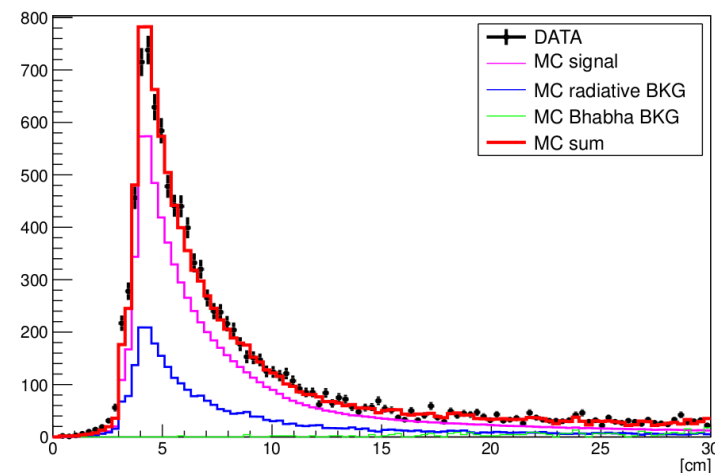
$|\cos\theta^*|$



e^+e^- missing mass



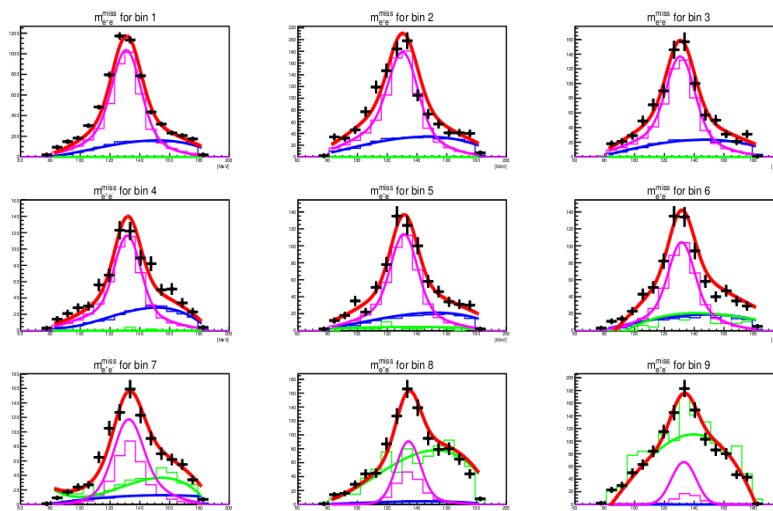
Tracks distance at DC Wall



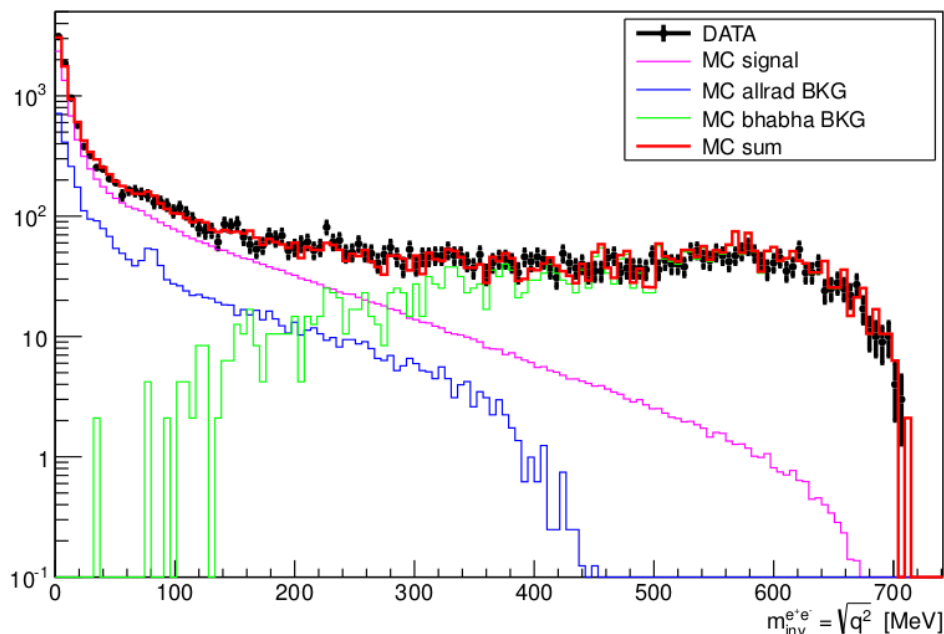
$\phi \rightarrow \pi^0 e^+e^-$: preliminary VMD comparison

- ✓ The bkg subtraction is in progress
→ fit systematics is due to the limited statistics of the Bhabha MC production

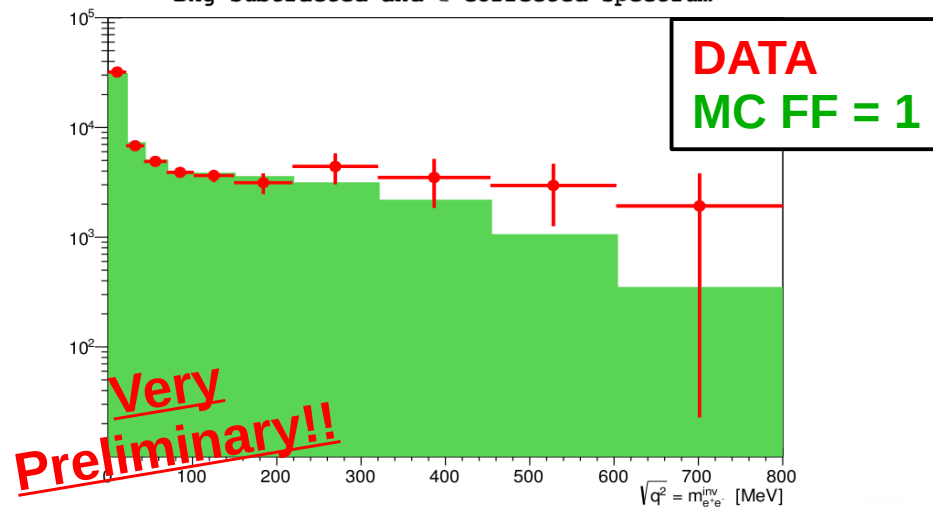
$$\langle |F(q^2)|^2 \rangle_i = \frac{1}{\mathcal{L}_{\text{int}} \times \sigma_\phi \times BR(\phi \rightarrow \pi^0 e^+e^-) \times BR(\pi^0 \rightarrow \gamma\gamma)} \frac{n_i}{\xi_i^{FF=1}}$$

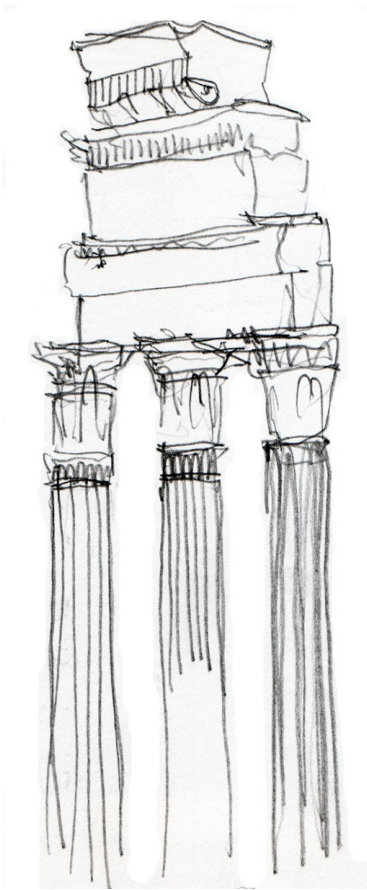


e^+e^- mass spectrum



Bkg subtracted and ϵ corrected spectrum





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

Dalitz Plot analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ (1/2)

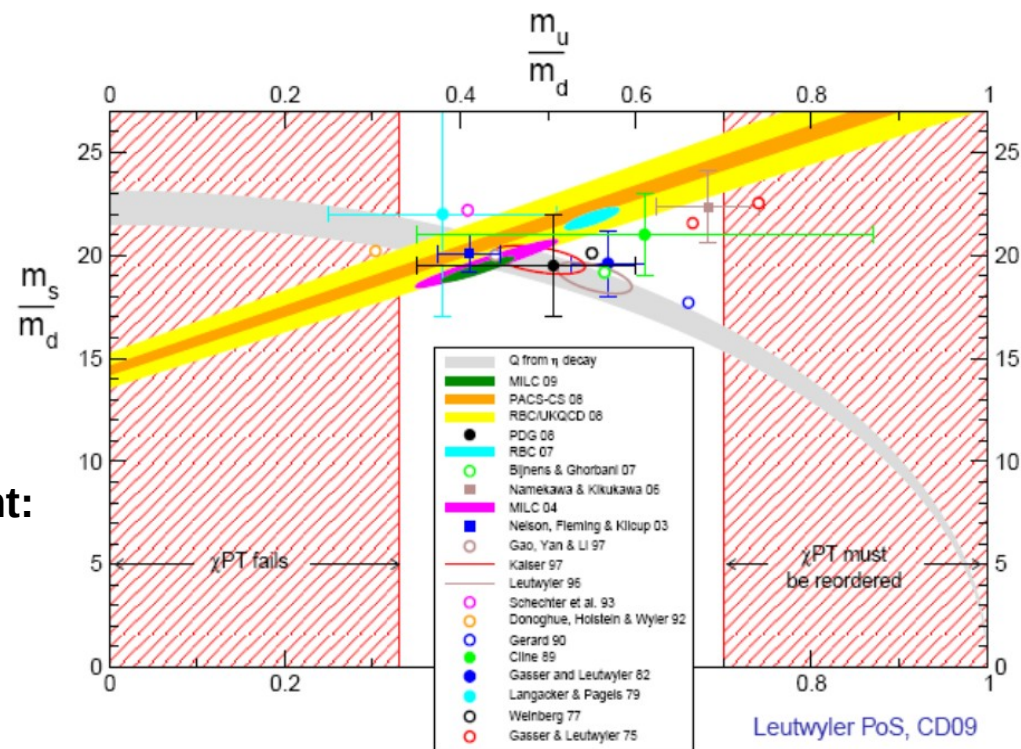
- ✓ Experimental decay width of $\eta \rightarrow \pi^+\pi^-\pi^0$ ($\Gamma_{\text{exp}} = 296 \pm 16$ eV) not well described by ($\Gamma_{\text{LO}} = 70$ eV) and ($\Gamma_{\text{NLO}} = 170 \pm 50$ eV) Chiral Perturbation Theory
- ✓ The decay is sensitive to the *light quark mass ratio*, Q , which could constrain the quark masses

$$\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0) \propto Q^{-4}$$

$$Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2} \quad \hat{m} = \frac{1}{2}(m_d + m_u)$$

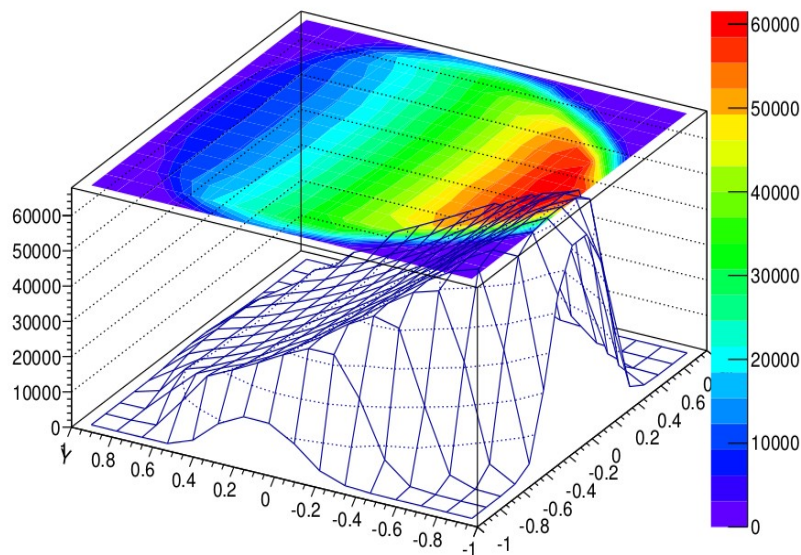
- ✓ New analysis of KLOE data on a larger (factor ~ 3.3), independent data set. OLD measurement: [Ambrosino et al. JHEP 5, 006 (2008)]

- New selection scheme (with improved systematics. \rightarrow pre-sel. ϵ)
- Improved MC simulation



Dalitz Plot analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ (2/2)

- ✓ The Dalitz Plot of X and Y is fit with a polynomial expansion around (X=0, Y=0)



In η -rest frame

$$X = \sqrt{3} \frac{T_+ - T_-}{Q_\eta}$$

$$Y = \frac{3T_0}{Q_\eta} - 1 = \frac{\sqrt{3}}{2m_\eta Q_\eta}$$

$$(Q_\eta = T_+ + T_- + T_0)$$

$$\chi^2 / \text{dof} = 1.148$$

$$N_{\text{theory}} = \int |A(X, Y)|^2 d\text{Ph}(X, Y)$$

$$\sim \int N(1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y) d\text{Ph}(X, Y)$$

- ✓ c and e consistent with 0 (C-invariance condition) → both fixed to 0

Preliminary!!

Experiment	-a	b	d	f
KLOE 08[4]	1.090(5) $^{+8}_{-19}$	0.124(6)(10)	0.057(6) $^{+7}_{-16}$	0.14(1)(2)
New KLOE, prel.	1.104(3)	0.144(3)	0.073(3)	0.155(6)

Preliminary!!

Conclusions

- ✓ $\phi \rightarrow \eta e^+ e^-$ decay is under study in the two channels:

- Neutral channel ($\eta \rightarrow \pi^0 \pi^0 \pi^0$):

$$\text{TFF slope } b_{\phi\eta} = (1.17 \pm 0.11^{+0.09}_{-0.08}) \text{ [GeV}^{-2}\text{]} \quad (\text{in agreement with VMD})$$

$$\text{B.R.}(\phi \rightarrow \eta e^+ e^-) = (1.131 \pm 0.032^{+0.011}_{-0.06}) \times 10^{-4} \quad (\text{in agreement with VMD})$$

- Charged channel ($\eta \rightarrow \pi^+ \pi^- \pi^0$) \rightarrow is going to be finalized...

- ✓ The exclusion plot for $\phi \rightarrow \eta U$ was updated combining the two channels:

$$\alpha'/\alpha < 1.7 \times 10^{-5} \text{ for } 30 < M_U < 400 \text{ MeV}$$

$$(\alpha'/\alpha < 8.0 \times 10^{-6} \text{ for } 50 < M_U < 210 \text{ MeV})$$

- ✓ The $\phi \rightarrow \pi^0 e^+ e^-$ analysis is ongoing: BR and TFF will be soon provided
- ✓ New Dalitz Plot analysis of the $\eta \rightarrow \pi^+ \pi^- \pi^0$ decay, on a larger independent data set. Systematic errors in progress...



**Thank you for your
attention.**

