XVII SuperB Workshop and Kick Off Meeting

γγ Physics: on-going activities and Super-B

Federico Nguyen - *INFN Roma TRE*

La Biodola (LI) - May, 30th 2011

An outline (from experience at low energy…)

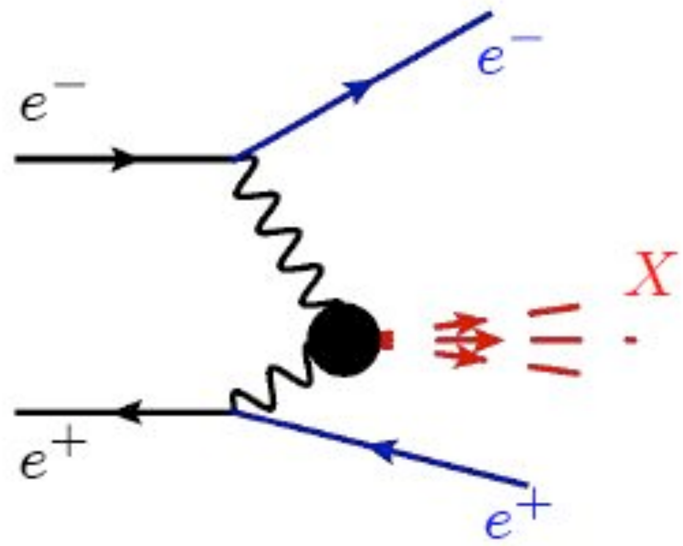
- main motivations and recent results:

where to improve…

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

- current activities: KLOE

as an example



- opportunities @ Super-B

- conclusions

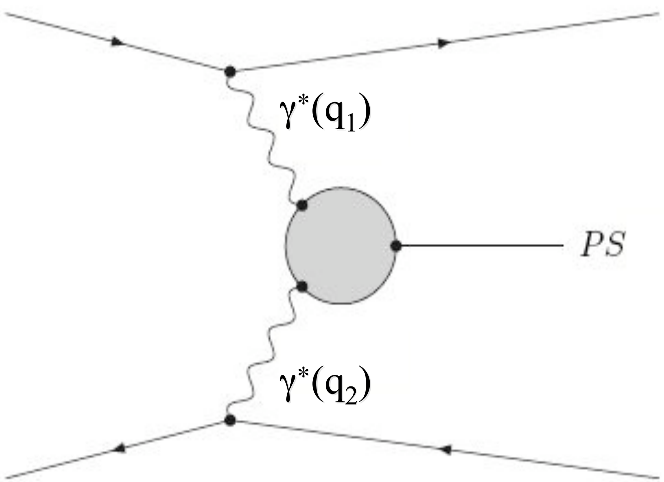
Recent results
with PS mesons

PseudoScalar mesons: γγ widths

$$N_{e^+e^- \to e^+e^- X} = L_{ee} \int \frac{dF}{dW_{\gamma\gamma}} \sigma_{\gamma\gamma\to X}(W_{\gamma\gamma}) dW_{\gamma\gamma}$$

for narrow pseudoscalar mesons (e.g. π^0, η, η', $\eta_c(1S)$, etc…):

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



absolute measurement: either your decay channel is X → γγ or must know BR(X→f)… often the limiting factor

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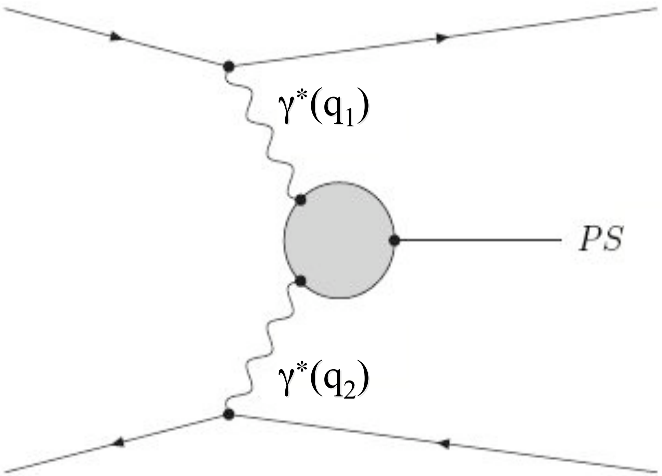


spectrum measurement, as a function of a single momentum transfer, fixing or integrating over the other one

2-dim PDF not yet measured

PS mixing angle and the gluonium in η'

$$\frac{\Gamma(\eta\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)} = \left(\frac{m_\eta}{m_{\pi^0}}\right)^3 \frac{1}{9}\left(5\cos\varphi_P - \sqrt{2}\frac{f_n}{f_s}\sin\varphi_P\right)^2$$

$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)} = \left(\frac{m'_\eta}{m_{\pi^0}}\right)^3 \frac{1}{9}\left(5\sin\varphi_P + \sqrt{2}\frac{f_n}{f_s}\cos\varphi_P\right)^2 \cos^2\phi_G$$

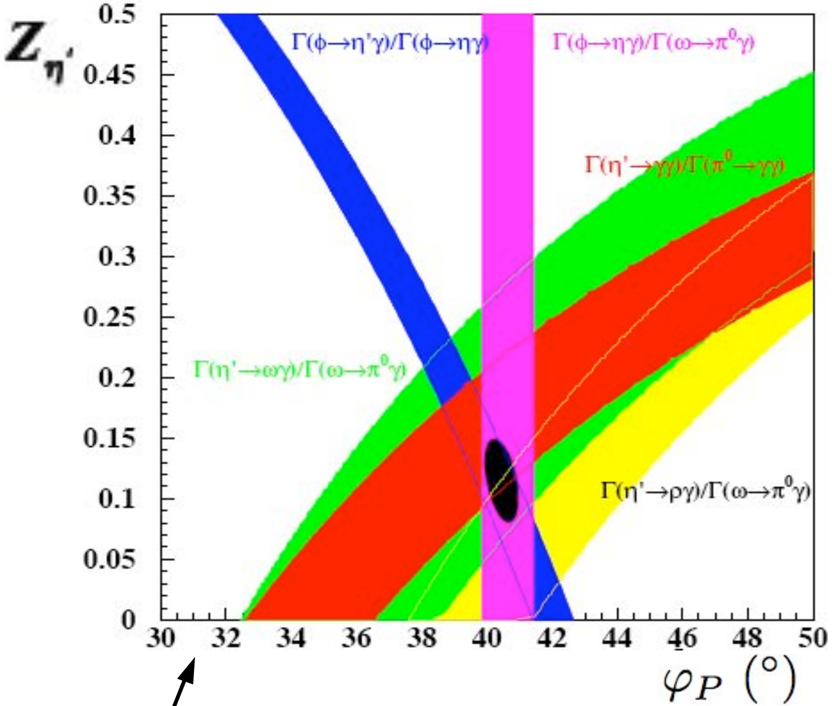
$$|\eta'\rangle = X_{\eta'}\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|glue\rangle$$

$$|\eta\rangle = \cos\varphi_P\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle - \sin\varphi_P|s\bar{s}\rangle$$

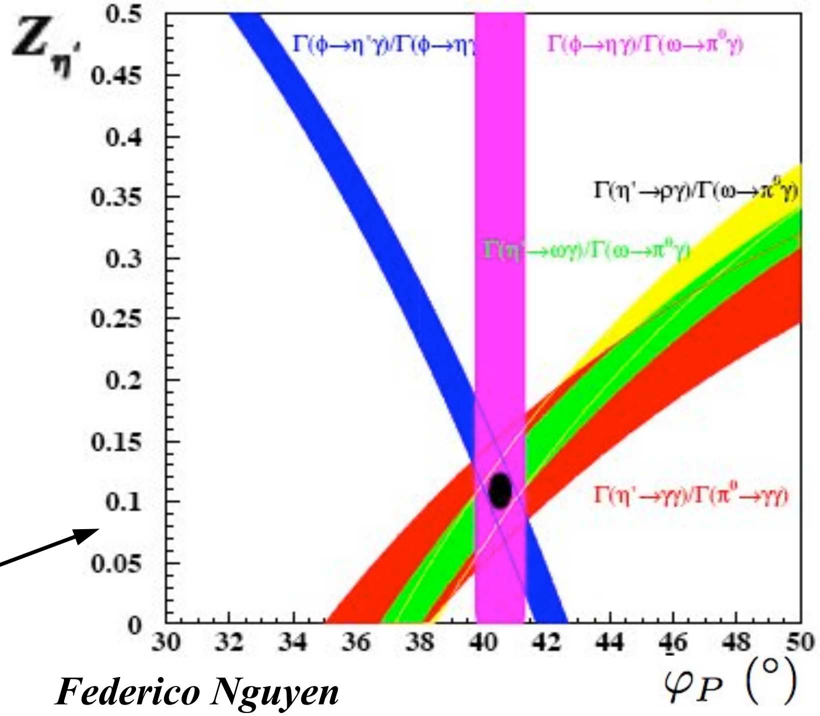
$$X_{\eta'} = \cos\phi_G\sin\varphi_P$$

$$Y_{\eta'} = \cos\phi_G\cos\varphi_P$$

$$Z_{\eta'} = \sin\phi_G$$



present status



with dominant η' BR's to 1%

PS form factors: from models to the $(g\text{-}2)_\mu$ saga

important to test phenomenological models, more or less QCD/ChPT inspired…, but impacts also the $(g\text{-}2)_\mu$

e.g.

$$F(k_1^2, k_2^2) = \frac{m_\rho^2}{(m_\rho^2 - k_1^2 - k_2^2)}$$

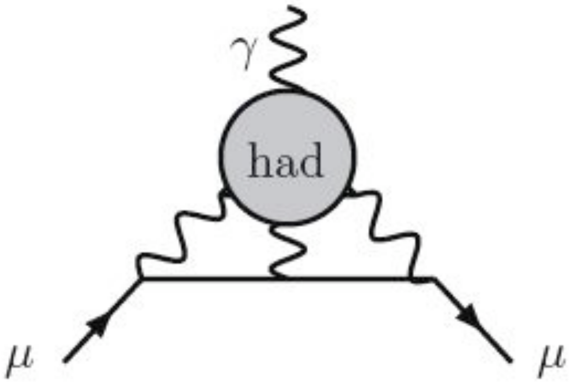
$$F(k_1^2, k_2^2) = \frac{m_\rho^4 - \frac{4\pi^2\ F_\pi^2}{N_c}\ (k_1^2 + k_2^2)}{(m_\rho^2 - k_1^2)(m_\rho^2 - k_2^2)}$$

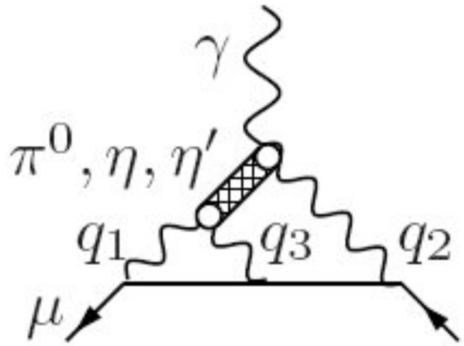
from F.Jegerlehner & A.Nyffeler, Phys. Rept,477(2009)1

Standard model theory and experiment comparison [in units 10^{-11}].

Contribution	Value	Error
QED incl. 4-loops + LO 5-loops	116584718.1	0.2
Leading hadronic vacuum polarization	6903.0	52.6
Subleading hadronic vacuum polarization	−100.3	1.1
Hadronic light-by-light	116.0	39.0
Weak incl. 2-loops	153.2	1.8
Theory	116591790.0	64.6
Experiment	116592080.0	63.0
Exp. - The. 3.2 standard deviations	290.0	90.3

PS transition form factors: L-by-L





$$\mathcal{F}_{\pi^{0*}\gamma^*\gamma^*}\left((q_1+q_2)^2, q_1^2, q_2^2\right)$$

Contribution	N/JN
π^0, η, η'	99±16
π, K loops	−19±13
π, K loops + other subleading in N_c	–
axial vectors	22±5
scalars	−7±2
quark loops	21±3
total	116±39

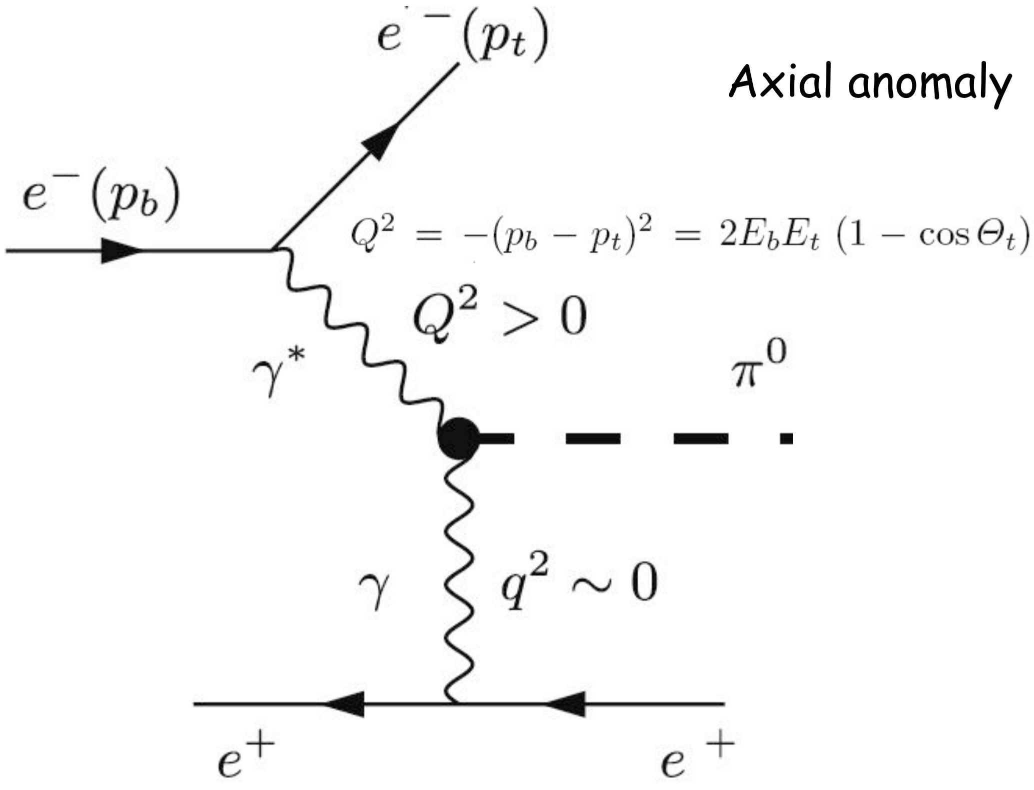
$a_\mu^{\mathrm{LbL;had}} \times 10^{11}$

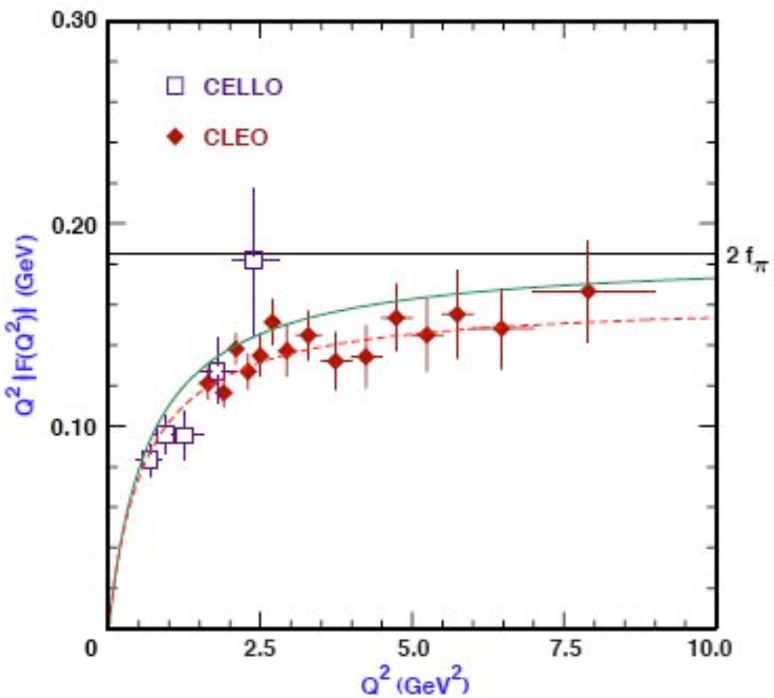
- not clear how to constrain contributions from data
- pseudoscalar pole contribution dominates, many theory approaches, perhaps a cleaner case w/ only 2 independent scales, $F(m_{PS}^2, q_1^2, q_2^2)$

An example: π^0 transition form factor

Brodsky-Lepage $\lim_{Q^2\to\infty} \mathcal{F}_{\pi^0\gamma^*\gamma}(m_\pi^2, -Q^2, 0) \sim \frac{2F_\pi}{Q^2}$

Axial anomaly $\lim_{Q^2\to 0} \mathcal{F}_{\pi^0\gamma^*\gamma}(m_\pi^2, -Q^2, 0) = \frac{1}{4\pi^2 F_\pi}$





well known asymptotic limits from 1st principles,
how to interpolate? what about η, η' ?

An example: π^0 transition form factor

Brodsky-Lepage $$\lim_{Q^2\to\infty} \mathcal{F}_{\pi^0\gamma^*\gamma}(m_\pi^2, -Q^2, 0) \sim \frac{2F_\pi}{Q^2}$$

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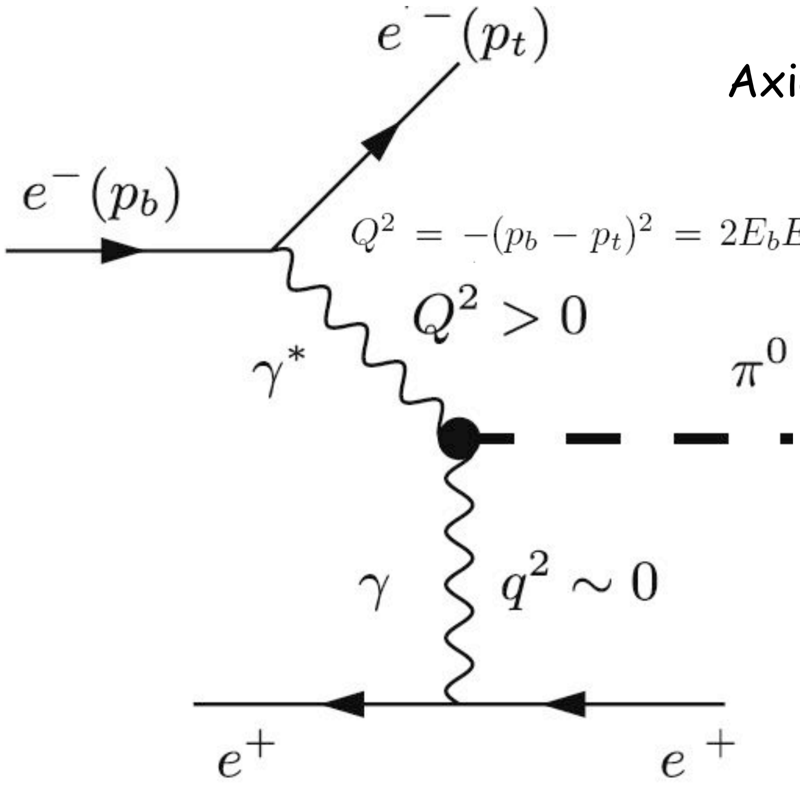
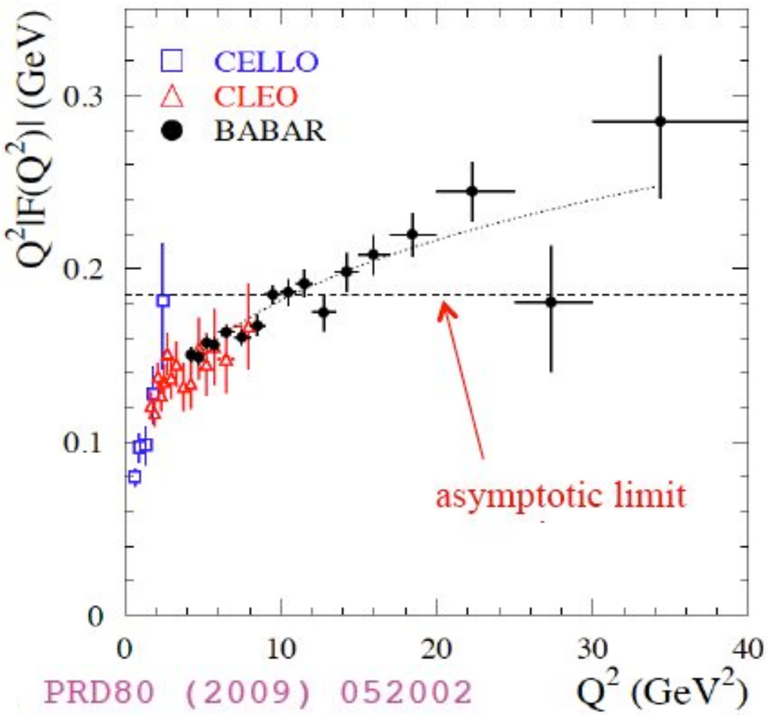


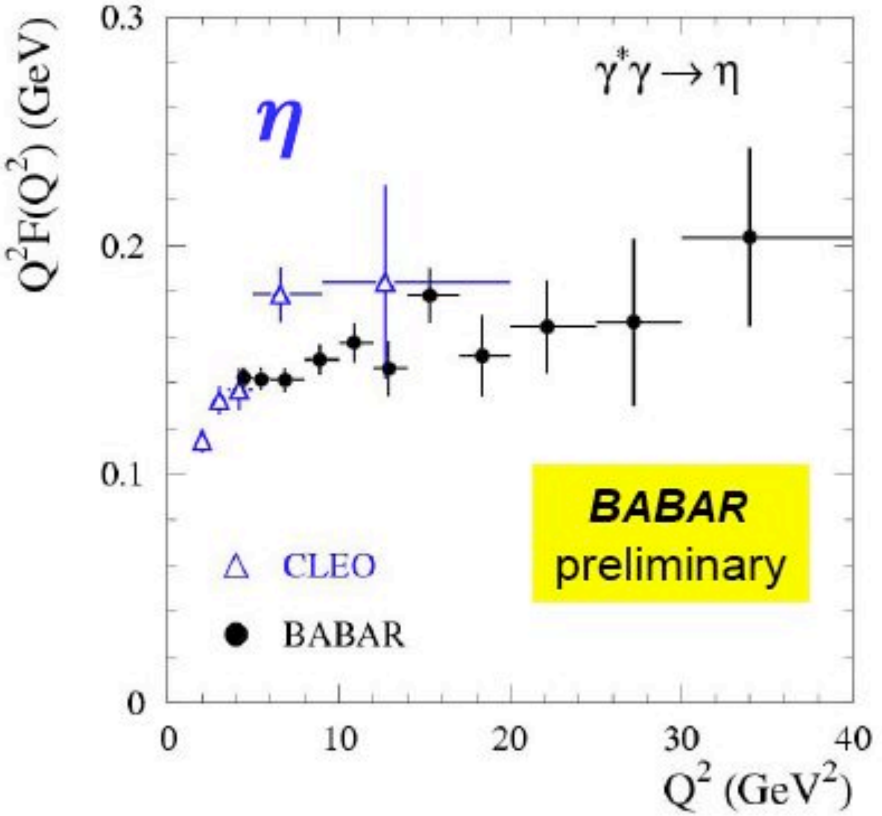
$$Q^2 = -(p_b - p_t)^2 = 2E_bE_t\,(1 - \cos\Theta_t)$$

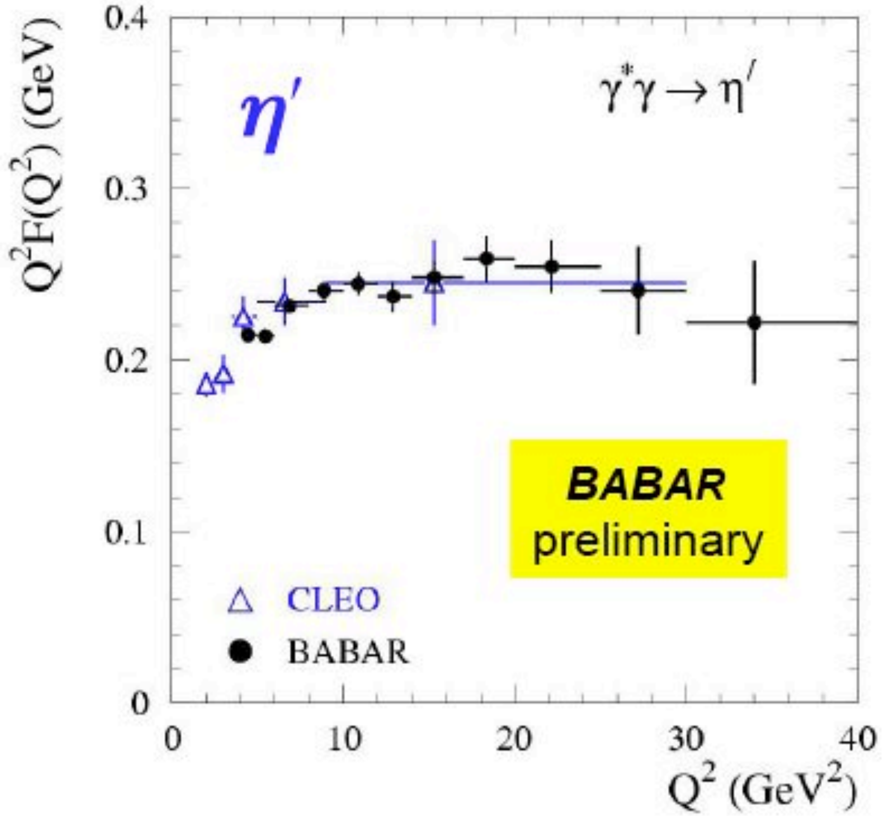


PRD80 (2009) 052002

<u>no longer known</u> asymptotic limits? anything missing? what about η, η' ?

Measuring η and η' does not clarify

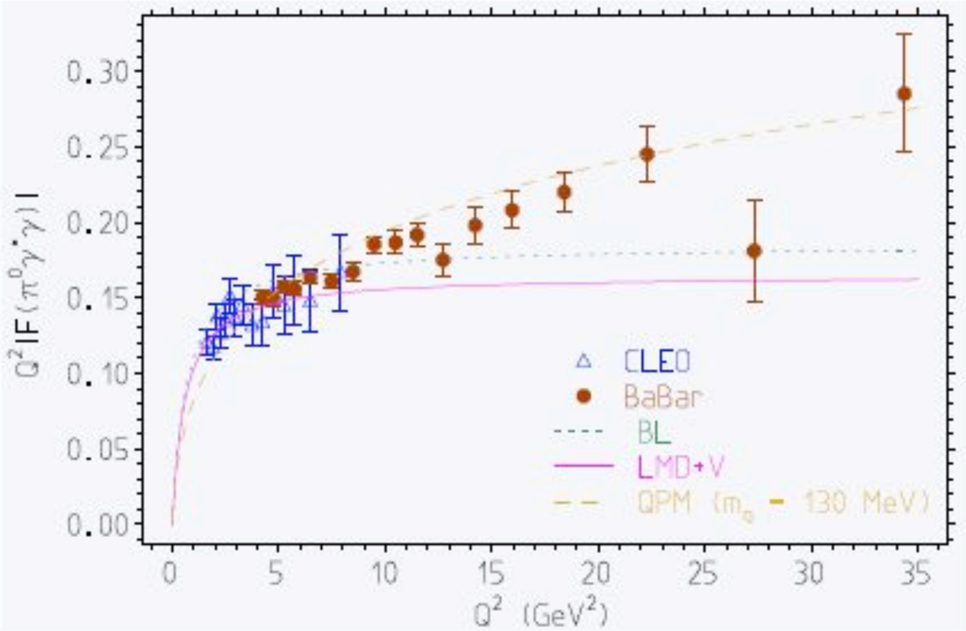




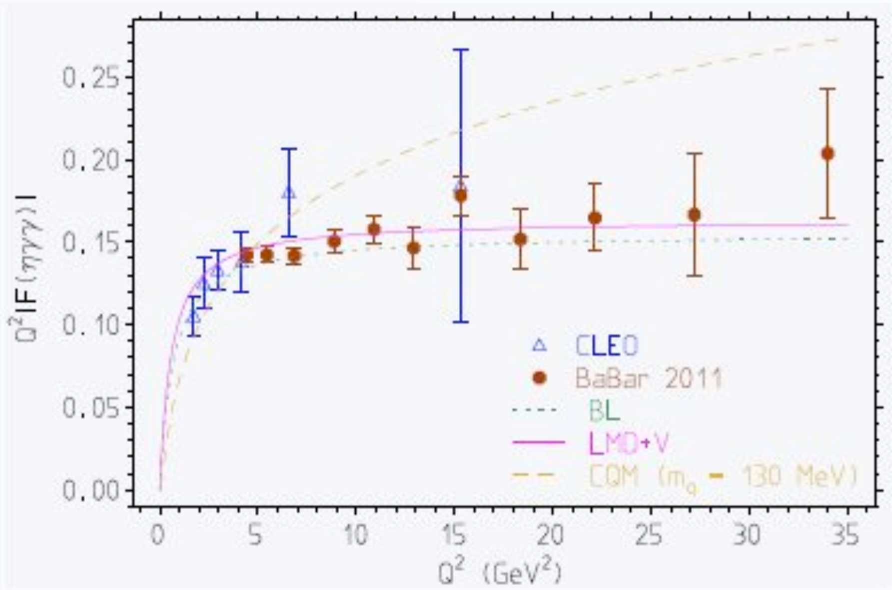
good agreement with CLEO in the overlapping regions, but…

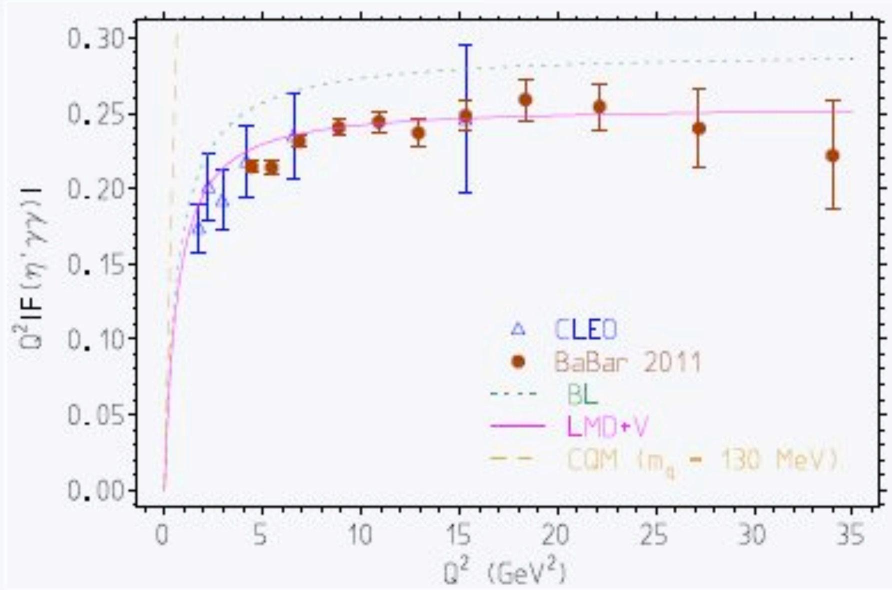
Measuring η and η' does not clarify

…with different aymptotic behaviour



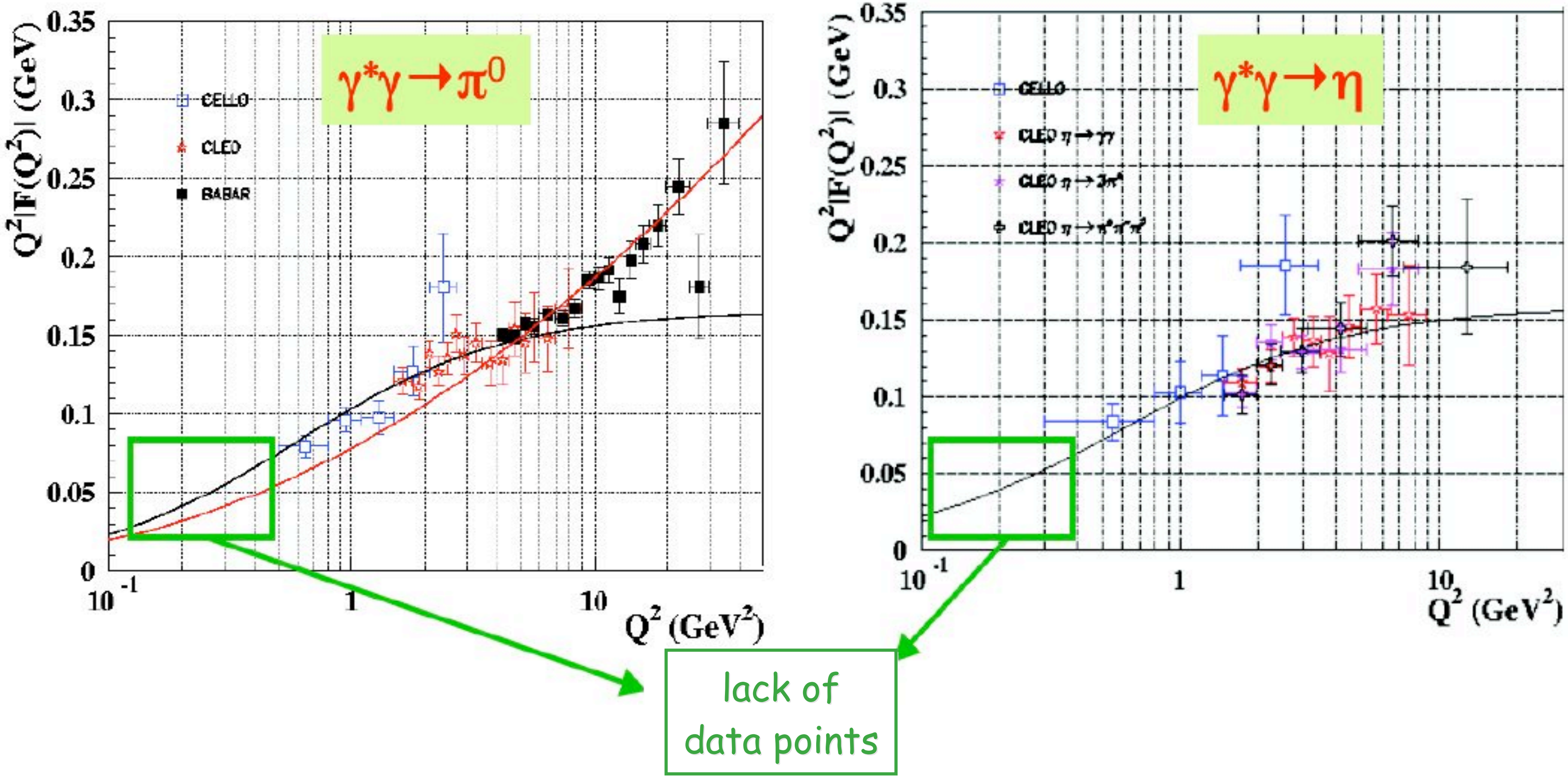
more measurements of the whole spectrum are useful





Low Q^2 region unexplored, so far

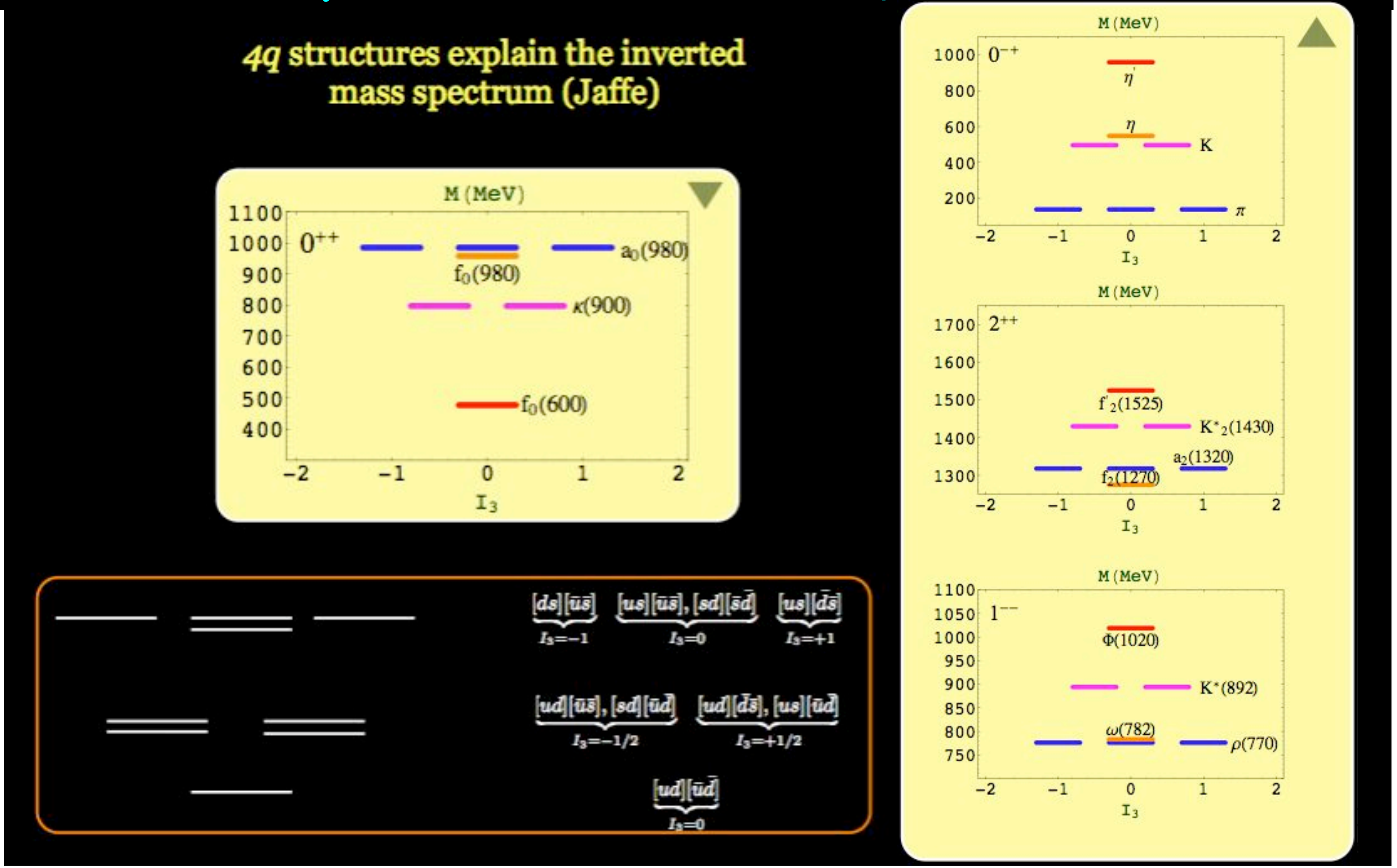
the region relevant to the g-2 is Q<1.5 GeV for the 3 lightest PS mesons



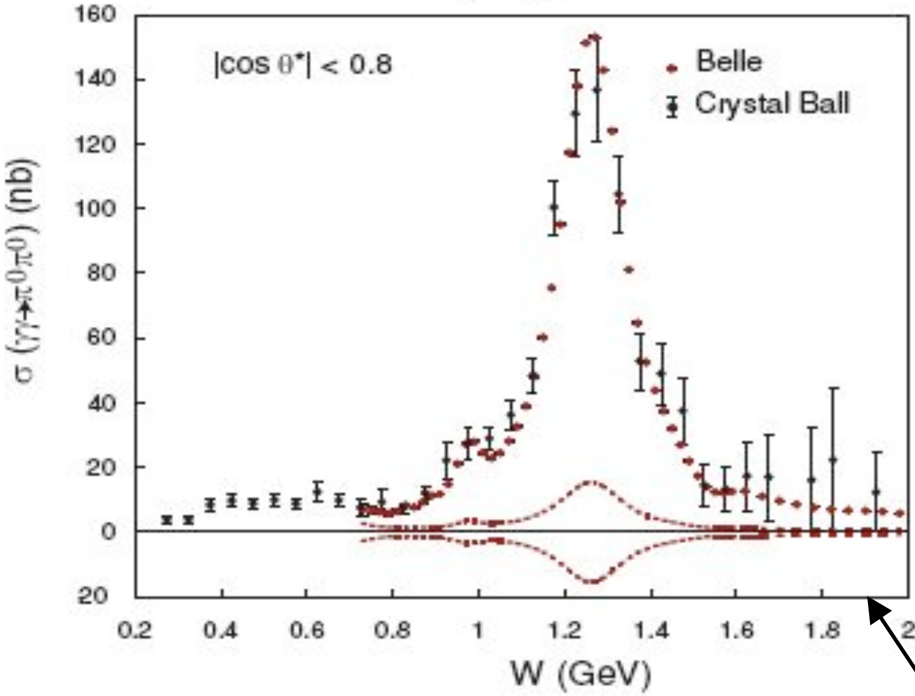
Recent results with scalar mesons

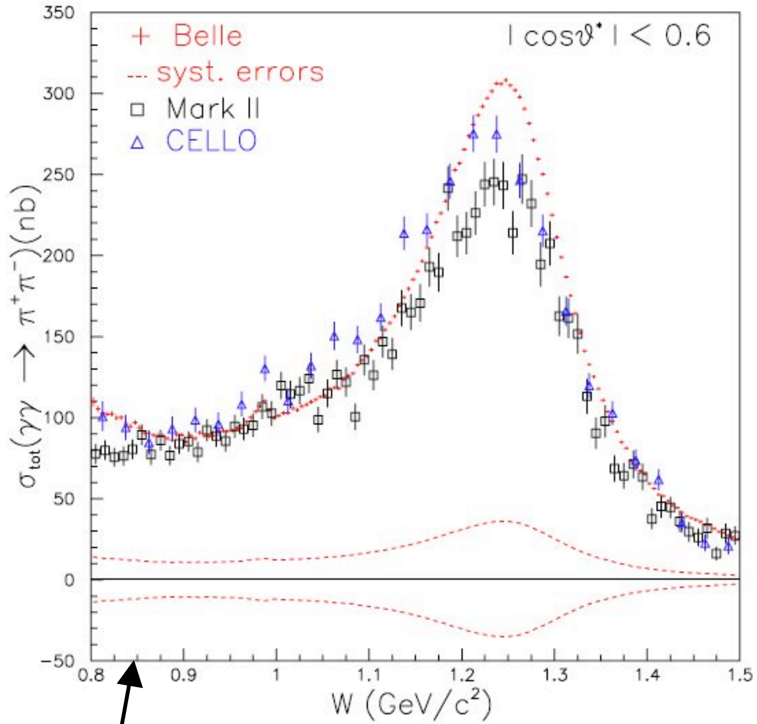
Low mass scalar mesons: puzzling since the 70's

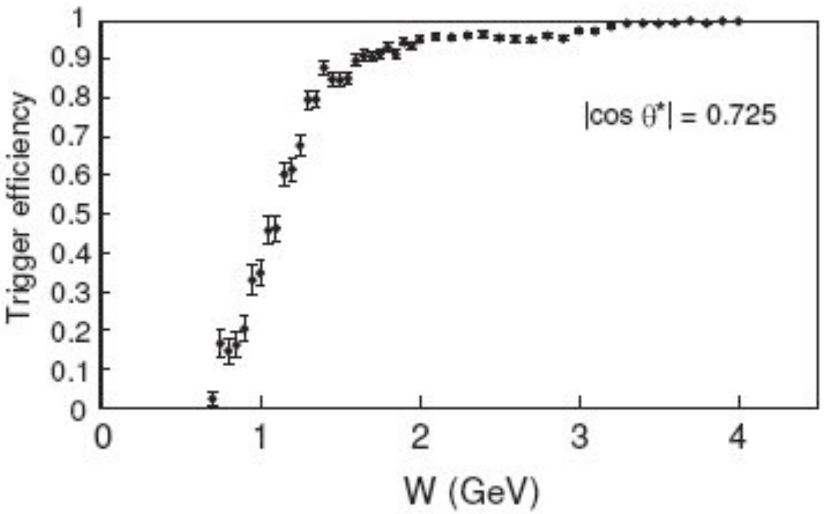
Maiani et al. :: A new look at scalar mesons as *4q* structures - PRL93(2004)212002
`t Hooft et al. :: A theory of scalar mesons - PLB662(2008)424



Recent measurements of $\gamma\gamma \to \pi\pi$







S.Uehara et al., PRD78(2008)052004

T.Mori et al., PRD75(2007)051101R

fantastic measurements that
cannot reach the low mass region
for trigger efficiency

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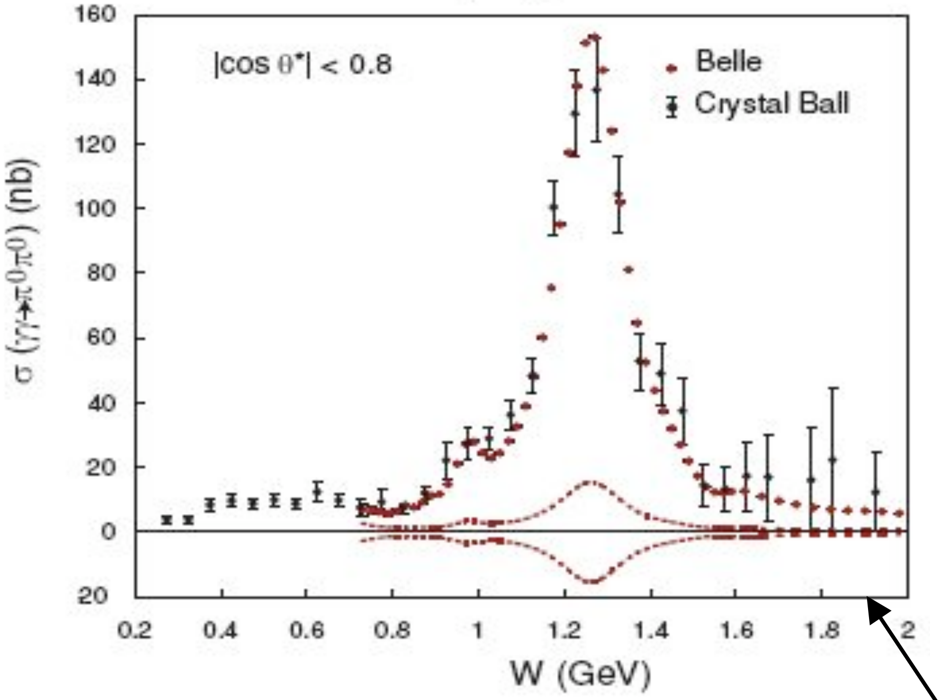

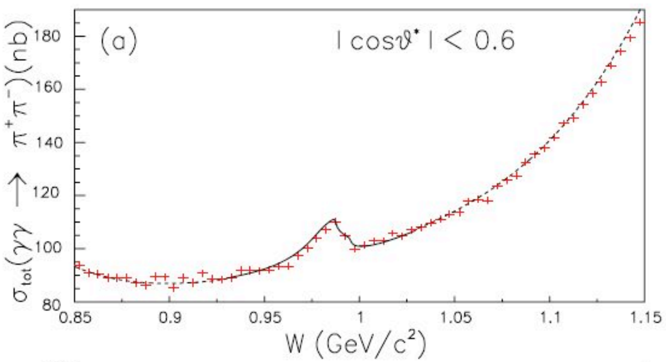

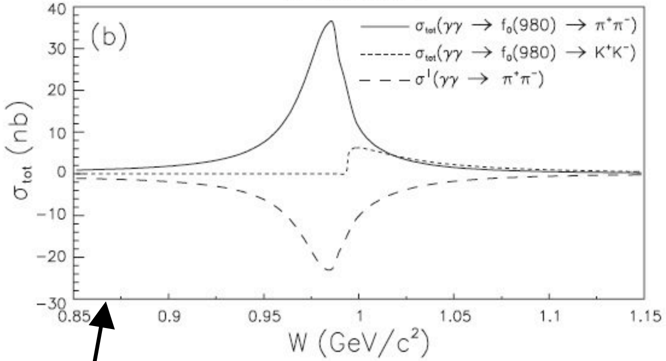

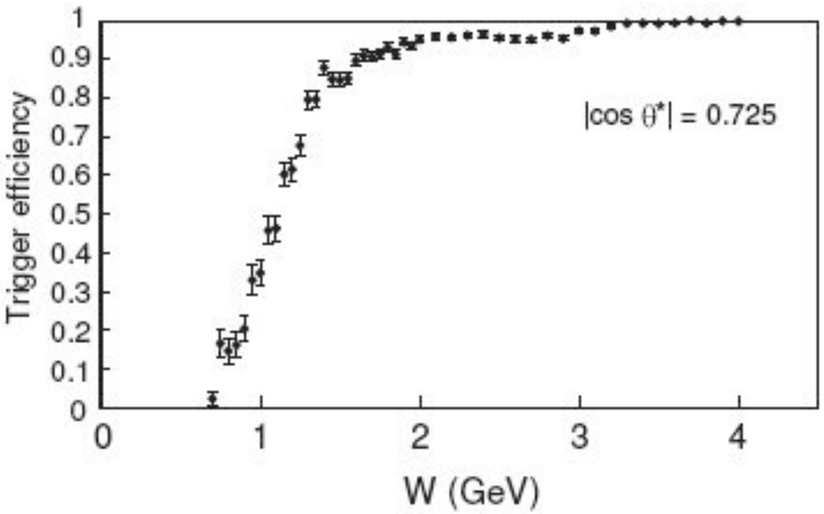

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fantastic measurements that cannot reach the low mass region for trigger efficiency

Searching for $\gamma\gamma \to \sigma(600) \to 2\pi^0$

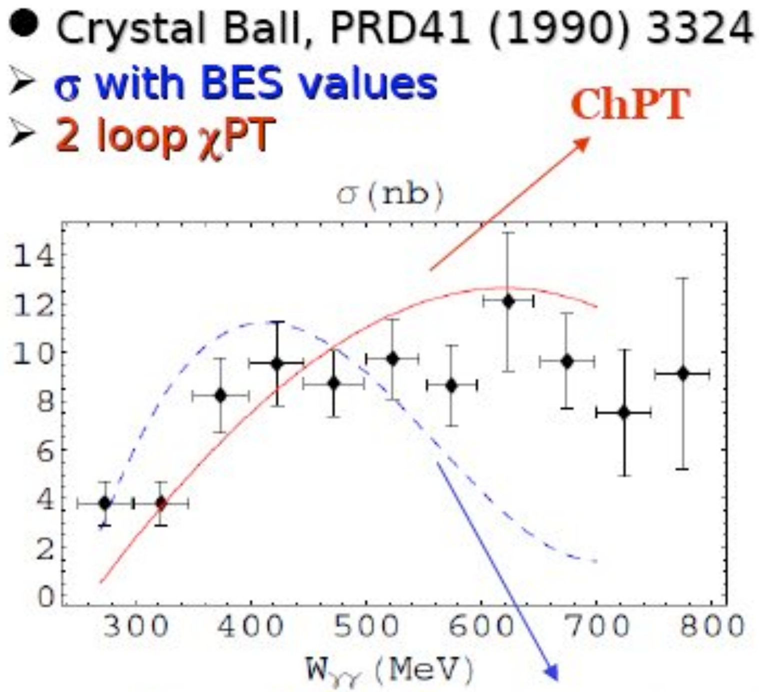
$\pi^+\pi^-$ harder than $\pi^0\pi^0$ channel:

1) $\mu^+\mu^-$ background (need robust particle ID)

2) sizeable continuum $\gamma\gamma \to \pi^+\pi^-$ at tree level in QED

$$\sigma(\gamma\gamma \to \sigma(600)) \propto \Gamma(\sigma(600) \to \gamma\gamma)$$

$\Gamma(\gamma\gamma)$ keV		
composition	predictions	author(s)
$(\bar{u}u + \bar{d}d)/\sqrt{2}$	4.0	Babcock & Rosner [73]
$\bar{s}s$	0.2	Barnes [74]
$[\overline{ns}][ns],\ n = (u, d)$	0.27	Achasov *et al.* [75]
$\overline{K}K$	0.6 0.22	Barnes [76] Hanhart *et al.* [77]



Resonant contribution $\gamma\gamma \to \sigma \to \pi^0\pi^0$

Eur. Phys. J. C 47, 65–70 (2006)
F.Nguyen, F.Piccinini & A.Polosa

from the radiative width
→ infer the structure

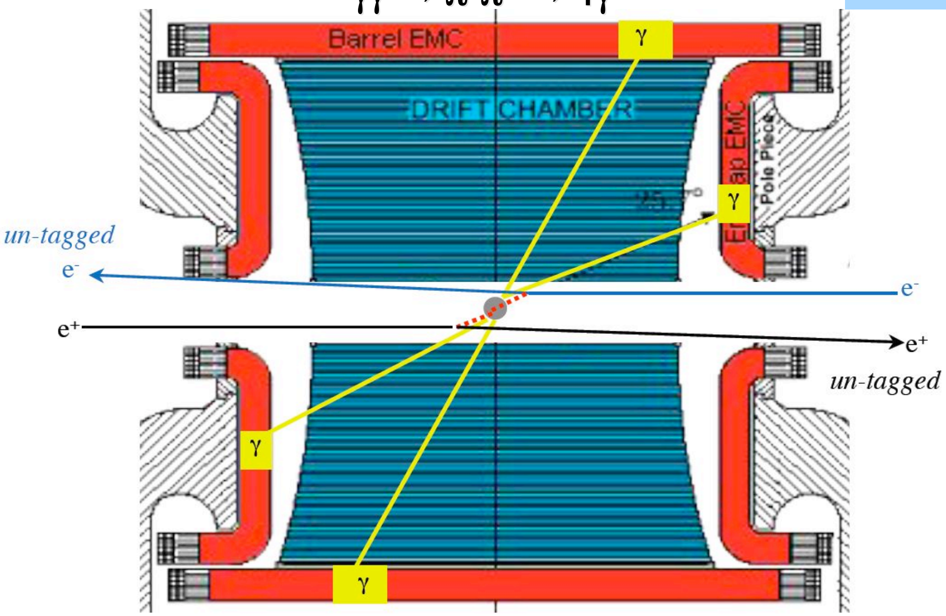
Current activities: for example KLOE/KLOE-2

Measuring γγ @ KLOE

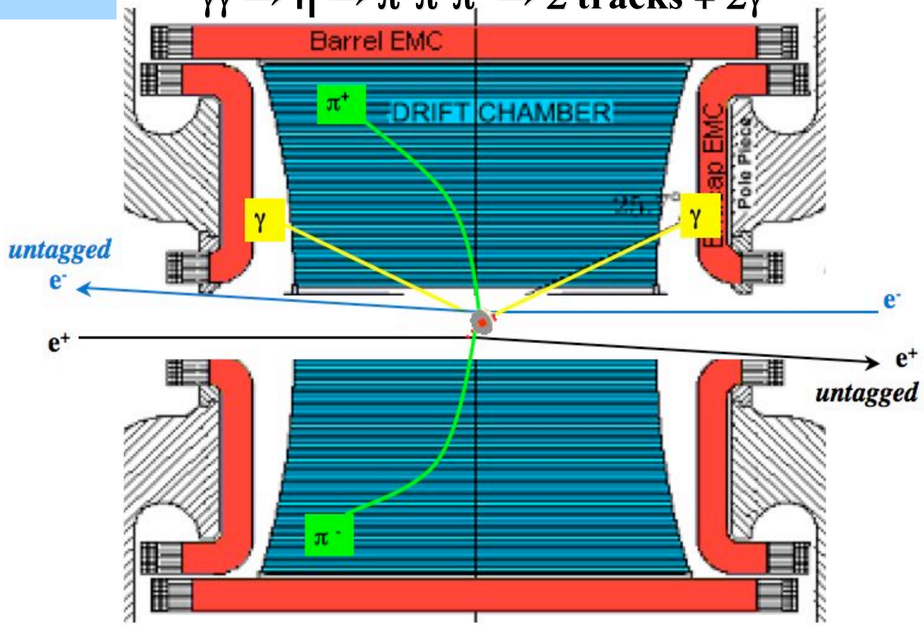
240 pb^{-1} taken @ $\sqrt{s}$ = 1 GeV, to suppress background from ϕ decays

No tag

$\gamma\gamma \to \pi^0\pi^0 \to 4\gamma$



$\gamma\gamma \to \eta \to \pi^+\pi^-\pi^0 \to$ **2 tracks + 2γ**



B=0.52 T

Calorimeter, EmC:
Pb/Scint. Fiber, 4880 PMTs
$\sigma_E/E = 0.057/\sqrt{E}$ **(GeV)**
$\sigma_t = 57$ **ps**$/\sqrt{E}$ **(GeV)** $\oplus$ **100 ps**

Drift Chamber, DC:
90% He, 10% C_4H_{10}
$\sigma_p/p = 0.4\%$ **for** $\theta > 45^\circ$
$\sigma_{r\phi} = 0.15$ **mm,** $\sigma_z = 2$ **mm**

Search for $\gamma\gamma \to \eta \to \pi^+\pi^-\pi^0$ @ KLOE

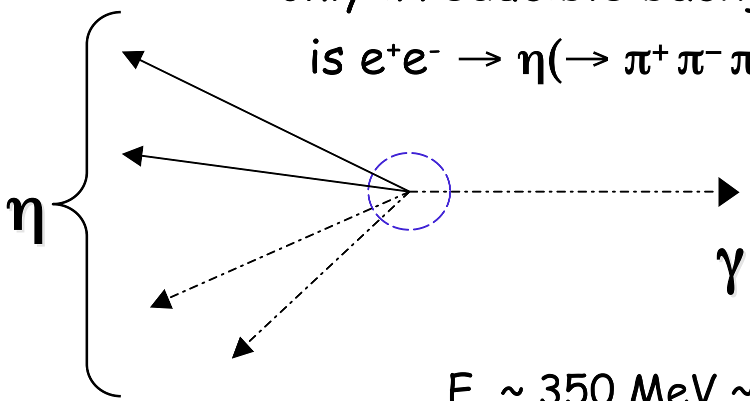
$BR(\eta \to \pi^+\pi^-\pi^0) = 22.73\%$ **2 photons + 2 tracks with opposite charge**

$$\chi^2_\eta = \sum \frac{(P_i - P_i^{meas})^2}{\sigma_i^2} + \sum \lambda_j^k C_j(P_1^k \ldots P_N^k)$$

- $\gamma\gamma$ pairing
- charged pion ID
- kinematic fit, χ_η^2
- M_{miss}^2 vs p_L fits

$$\mathbf{m^2_{\gamma\gamma} = m^2_{\pi 0}}$$
$$\mathbf{m^2_{\pi+\pi-\gamma\gamma} = m^2_\eta}$$
$$\mathbf{t_\gamma - |\underline{r}_\gamma| / c = 0 \quad \text{for } 2\gamma}$$

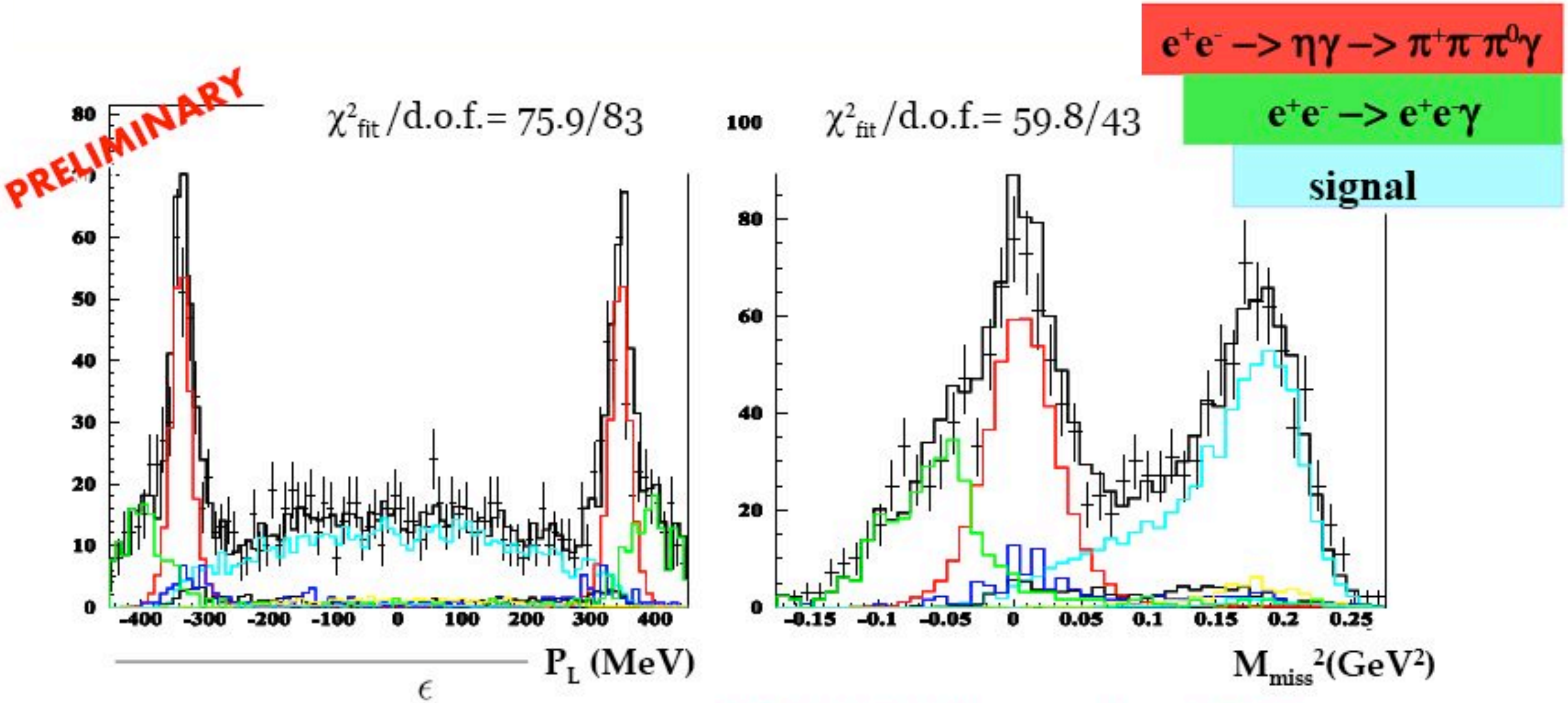
only irreducible background is $e^+e^- \to \eta(\to \pi^+\pi^-\pi^0)\,\gamma_{lost}$



$E_\gamma \sim 350$ MeV $\sim p_L(\eta)$

$$M^2_{miss} = s + m_\eta^2 - 2\sqrt{s}E_T\left(1 - \frac{p_L^2}{E_T^2}\right)^{1/2}$$
$$\simeq \boxed{s + m_\eta^2 - 2\sqrt{s}E_T} - \sqrt{s}\frac{p_L^2}{E_T}$$

Search for $\gamma\gamma \to \eta \to \pi^+\pi^-\pi^0$ @ KLOE



		ϵ
Signal	η	0.196
	$\eta\gamma$	9.1×10^{-3}
	$\omega\pi^0$	6.5×10^{-5}
	$\pi^+\pi^-\pi^0$	1.5×10^{-5}
	K^+K^-	1.9×10^{-5}
	K_SK_L	2.6×10^{-5}
	$e^+e^-\gamma$	$\mathcal{O}(10^{-7})$

N(data) after cuts = 1576

n_{ev} = 650

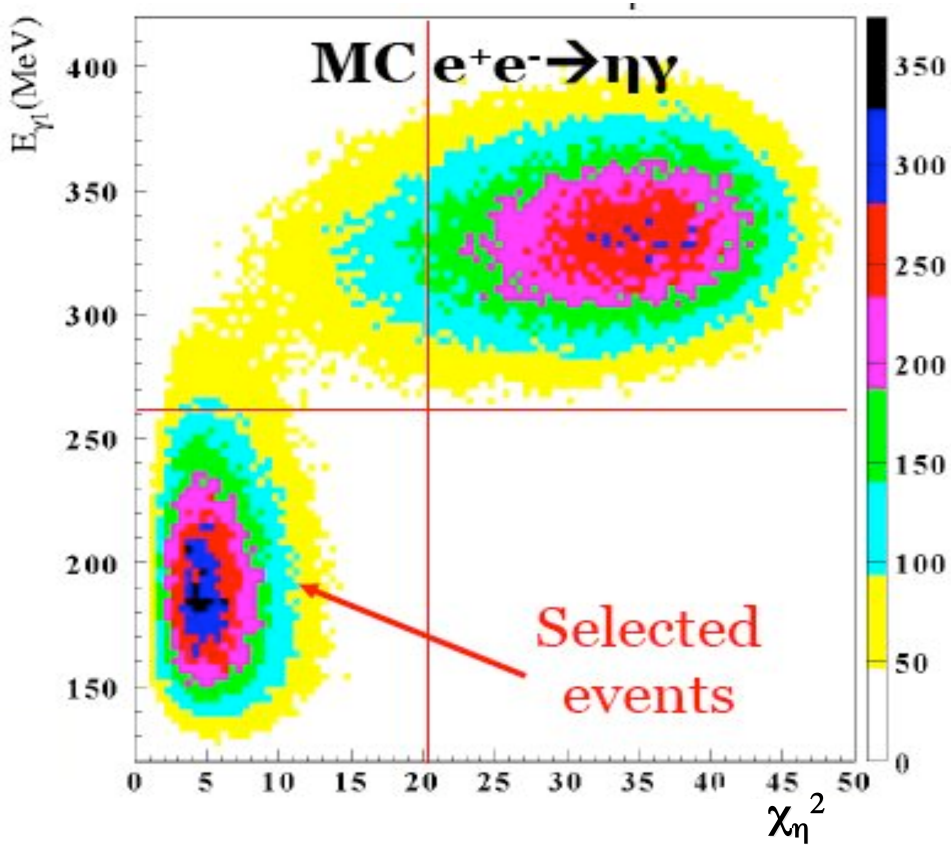
Search for $\gamma\gamma \to \eta \to 3\pi^0$ @ KLOE

$BR(\eta \to 3\pi^0) = 32.57\%$

6 photons and NO tracks

- $\gamma\gamma$ pairing to 3 pions
- kinematic fit, χ_η^2
- most energetic γ E<260 MeV

$$\chi_\eta^2 = \sum \frac{(P_i - P_i^{meas})^2}{\sigma_i^2} + \sum \lambda_j^k C_j(P_1^k \ldots P_N^k)$$



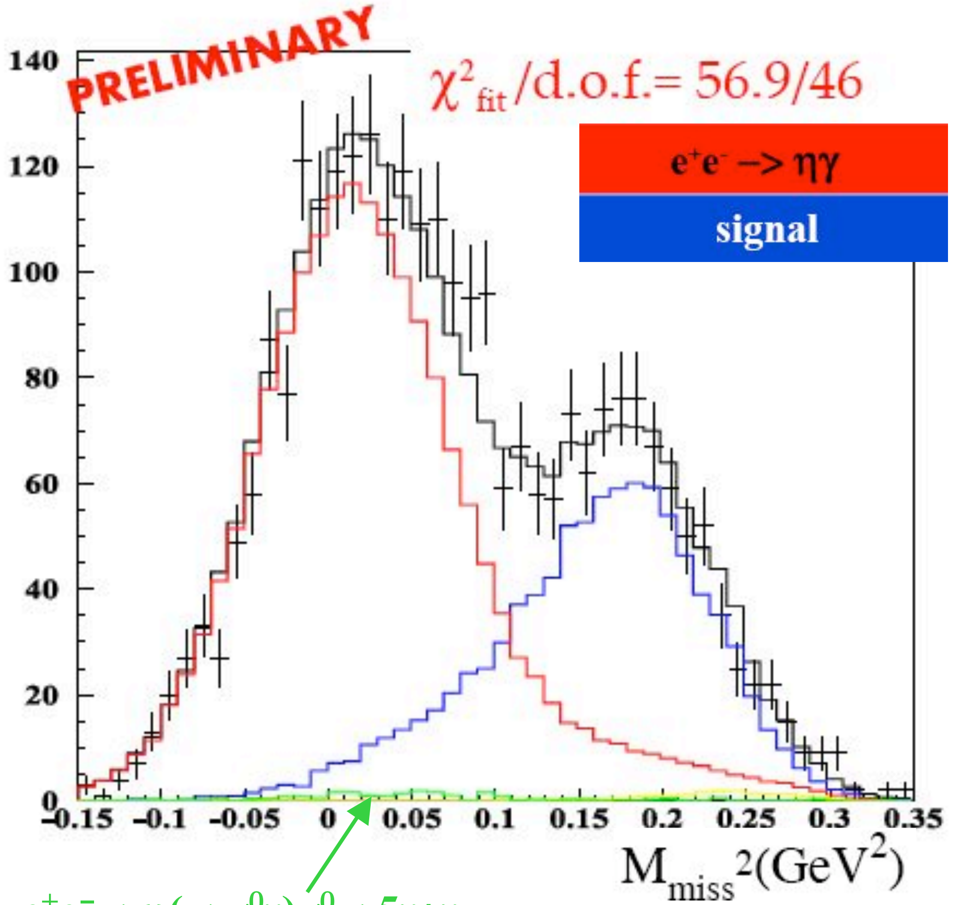
$$\boxed{\begin{array}{l} m^2_{6\gamma} = m^2_\eta \\ t_\gamma - |\underline{r}_\gamma| / c = 0 \text{ for } 6\gamma \end{array}}$$

<u>only ~~irreducible~~ background</u>

is $e^+e^- \to \eta(\to \pi^0\pi^0\pi^0)\gamma_{lost}$

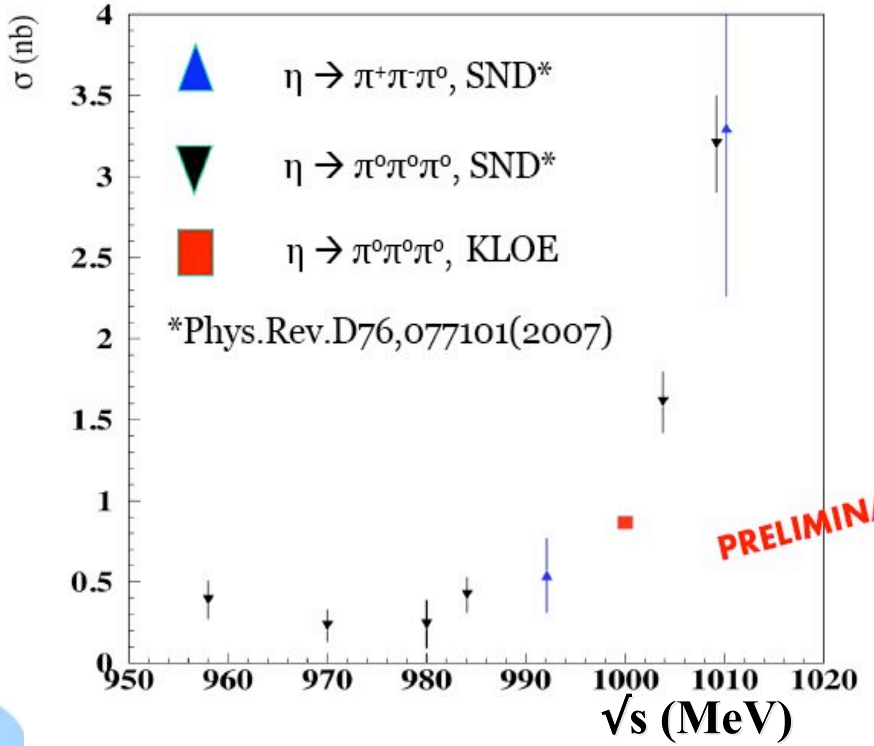
Search for $\gamma\gamma \to \eta \to 3\pi^0$ @ KLOE

2725 data events after all cuts



from the ηγ events in the fitted spectrum:

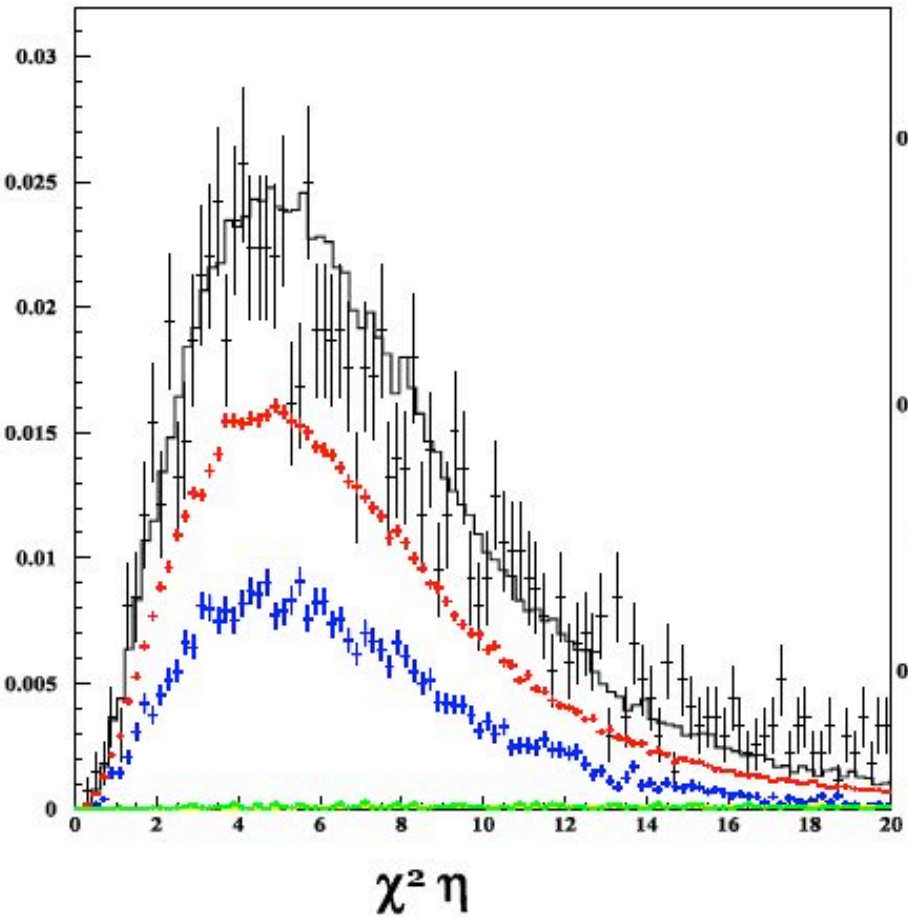
$\sigma(e^+e^- \to \eta\gamma$, 1 GeV) = 0.875 ± 0.009 nb (statistical error only)

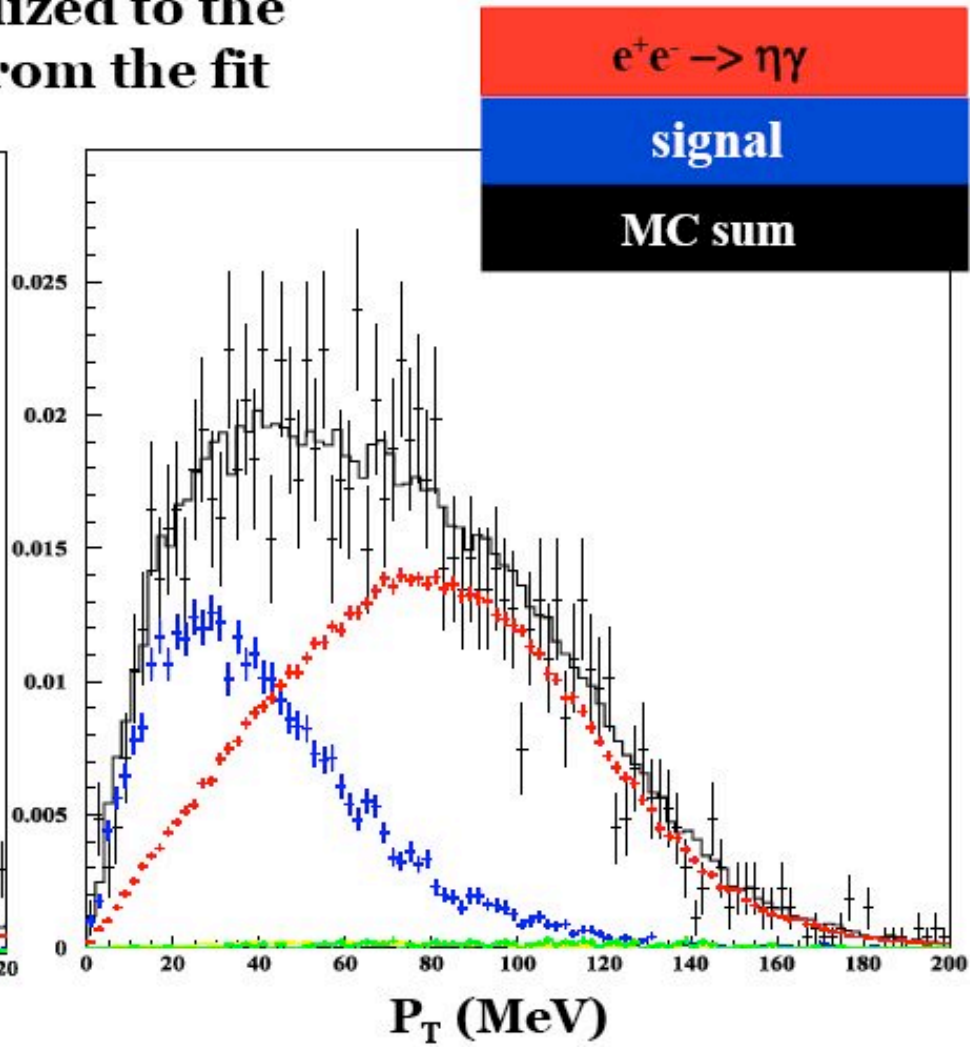


from the fit: n_{ev} = 921

Search for $\gamma\gamma \rightarrow \eta \rightarrow 3\pi^0$ @ KLOE

MC contributions normalized to the cross sections obtained from the fit

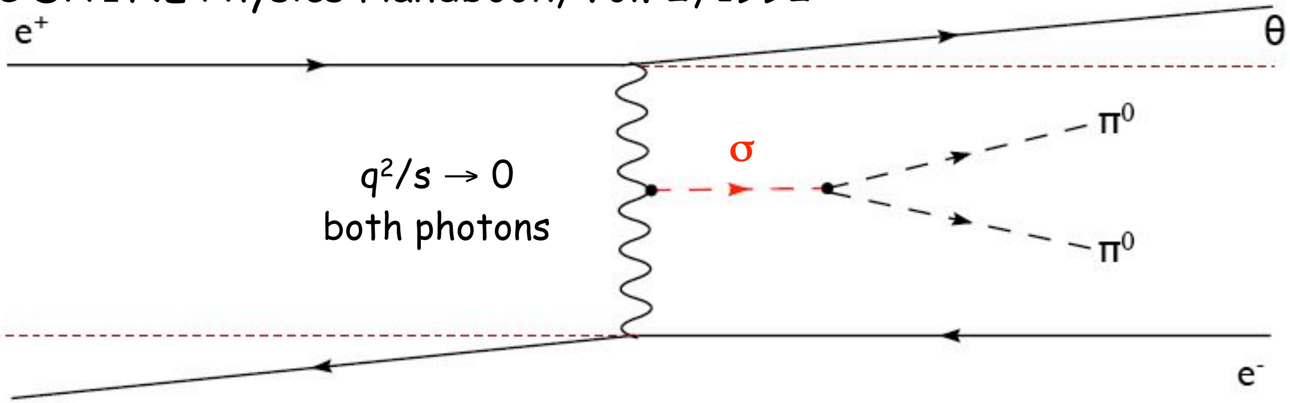




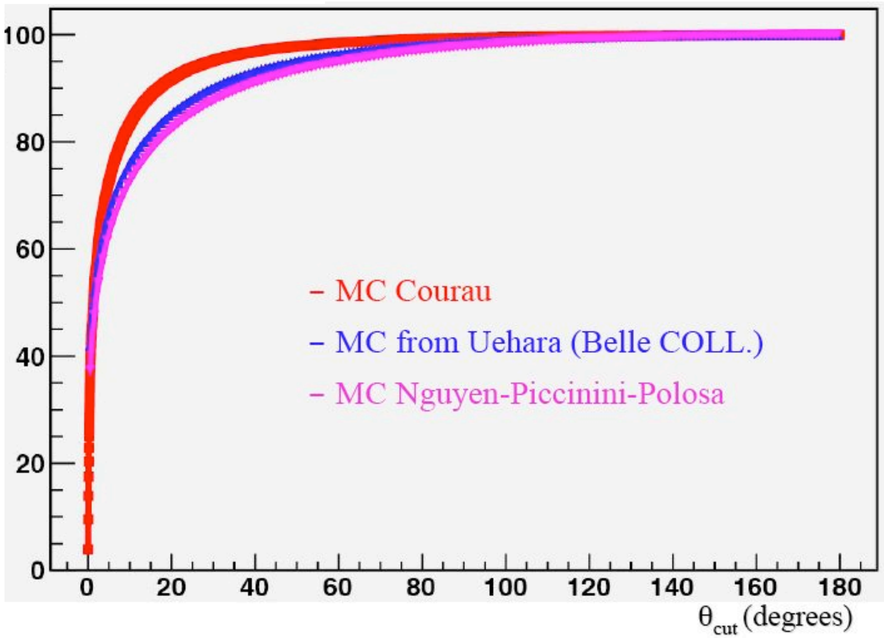
Federico Nguyen
30-05-2011

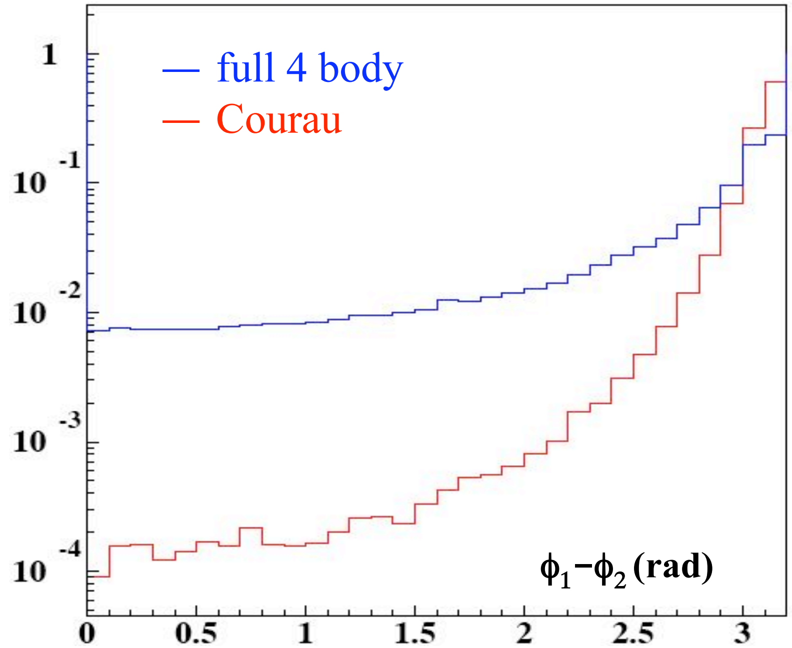
MC simulation of $\gamma\gamma \to \sigma(600) \to 2\pi^0$

the complete 4 body simulation, EPJC47 (2006) 65, is compared with
the Weizsäcker-Williams approx. (head on collision of 2 quasi-real $\gamma\gamma$)
A. Courau & G. Pancheri, The DAΦNE Physics Handbook, Vol. 2, 1992



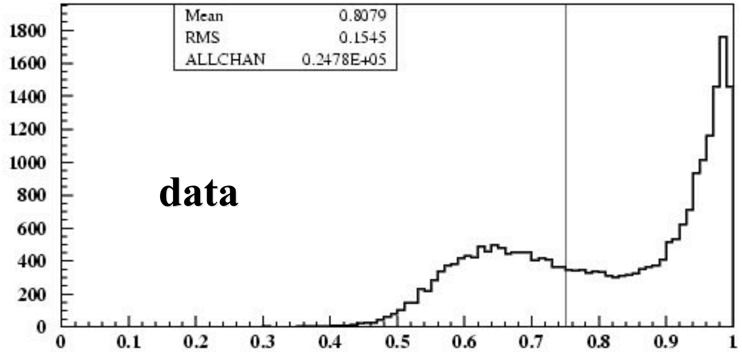
$$F(\theta_{cut}) = \int_0^{\theta_{cut}} \frac{dn}{d\theta} d\theta$$

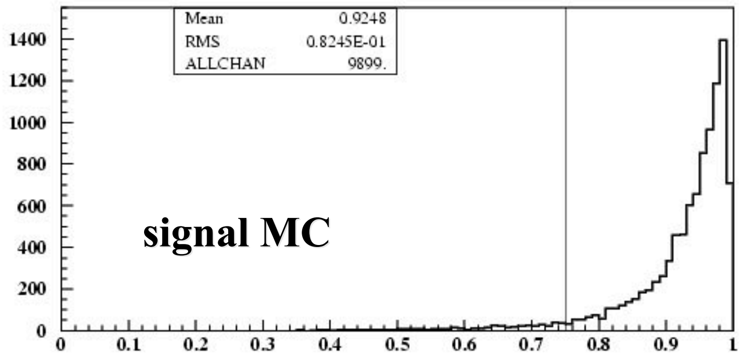


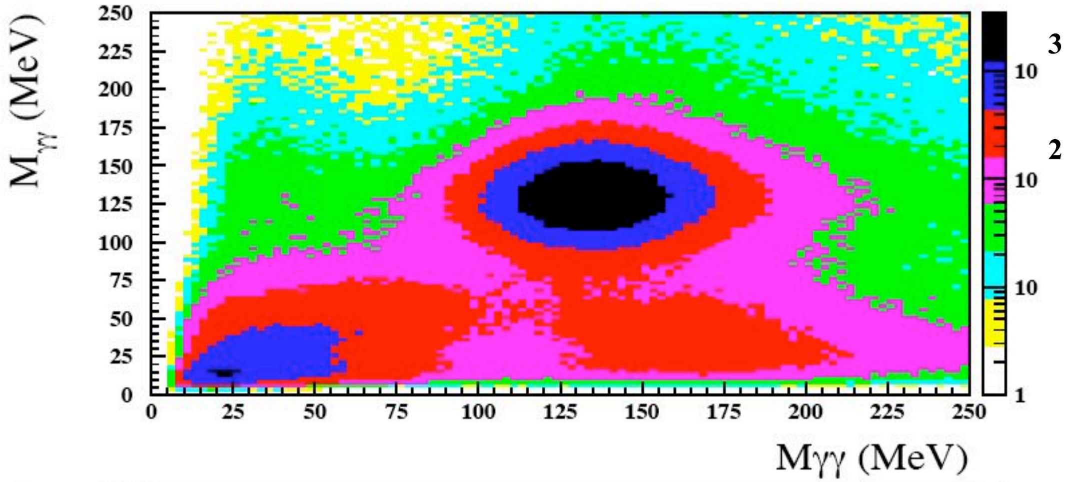


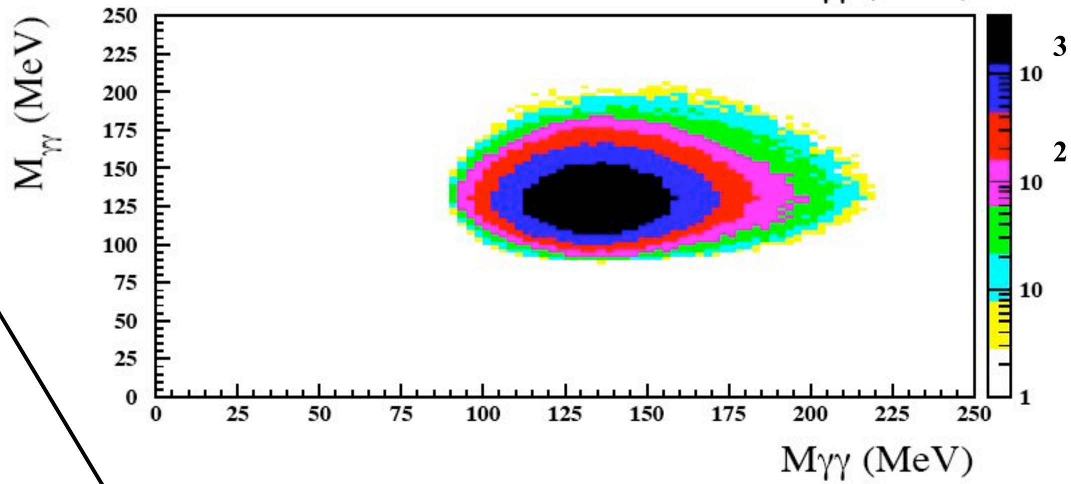
Search for $\gamma\gamma \to \sigma(600) \to 2\pi^0$ @ KLOE

- $\gamma\gamma$ pairing to 2 pions, $\chi_{\pi\pi}^2 < 4$
- 4 photons and NO tracks
- $p_T(4\gamma) < 120$ MeV
- $\Sigma_{4\gamma} / \Sigma_{CALO} > 0.75$
- promptness enforced (t_γ cuts)





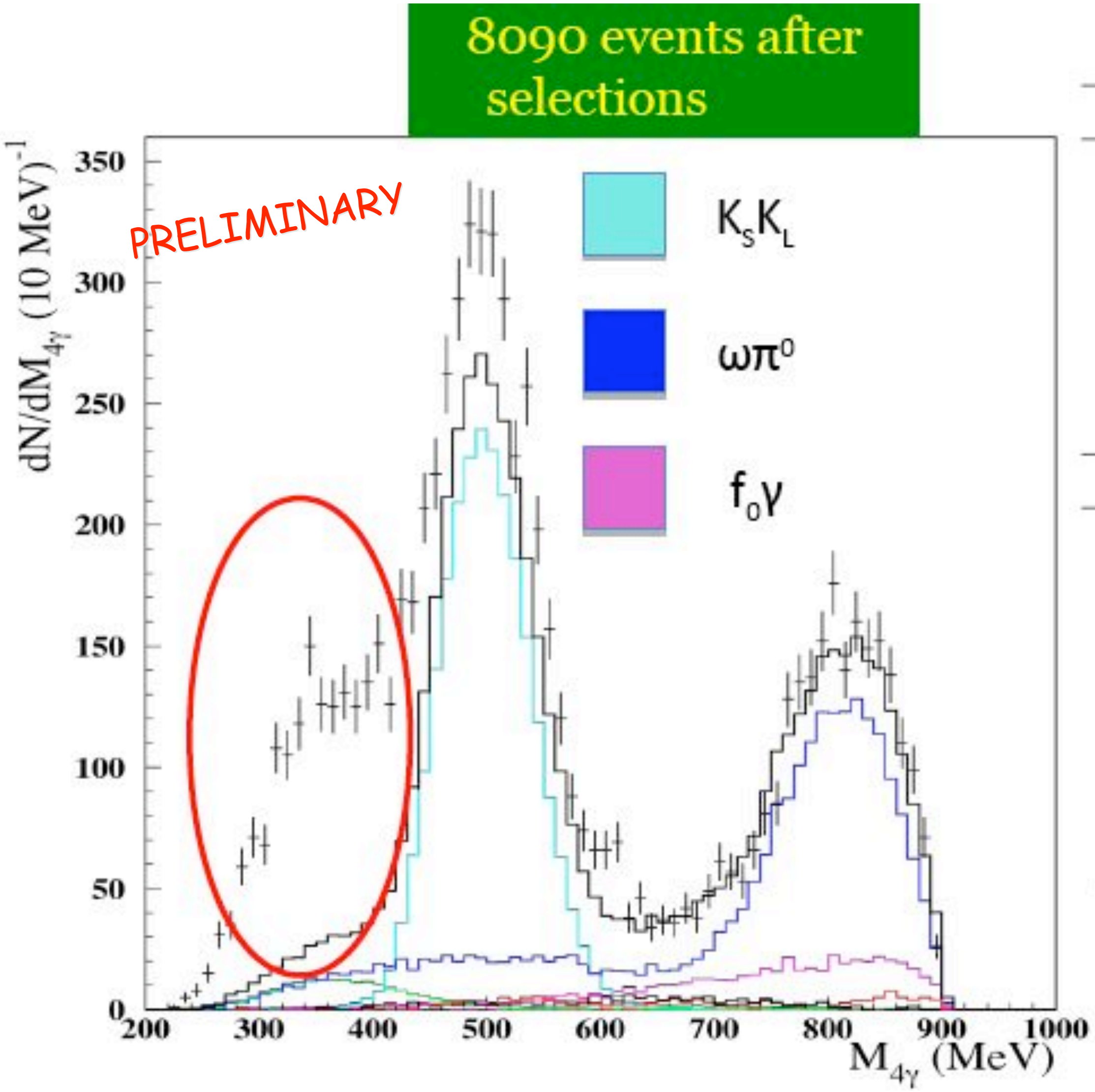




$\Sigma_{4\gamma} / \Sigma_{CALO}$

Federico Nguyen
30-05-2011

Search for $\gamma\gamma \to \sigma(600) \to 2\pi^0$ @ KLOE



	ϵ	σ (nb)	$n = \mathcal{L}\sigma\epsilon$
$K_S K_L$	7.5×10^{-3}	1.28	2328
$\eta \to 3\pi^0$	2.8×10^{-3}	0.284	193
$\omega\pi^0$	1.4×10^{-2}	0.55	1867
$f_0\gamma$	2.9×10^{-2}	0.17	1204
$a_0\gamma$	5.8×10^{-3}	0.11	155
$\gamma\gamma$	2×10^{-6}	360	175
			5922
Data			8090

Expected values

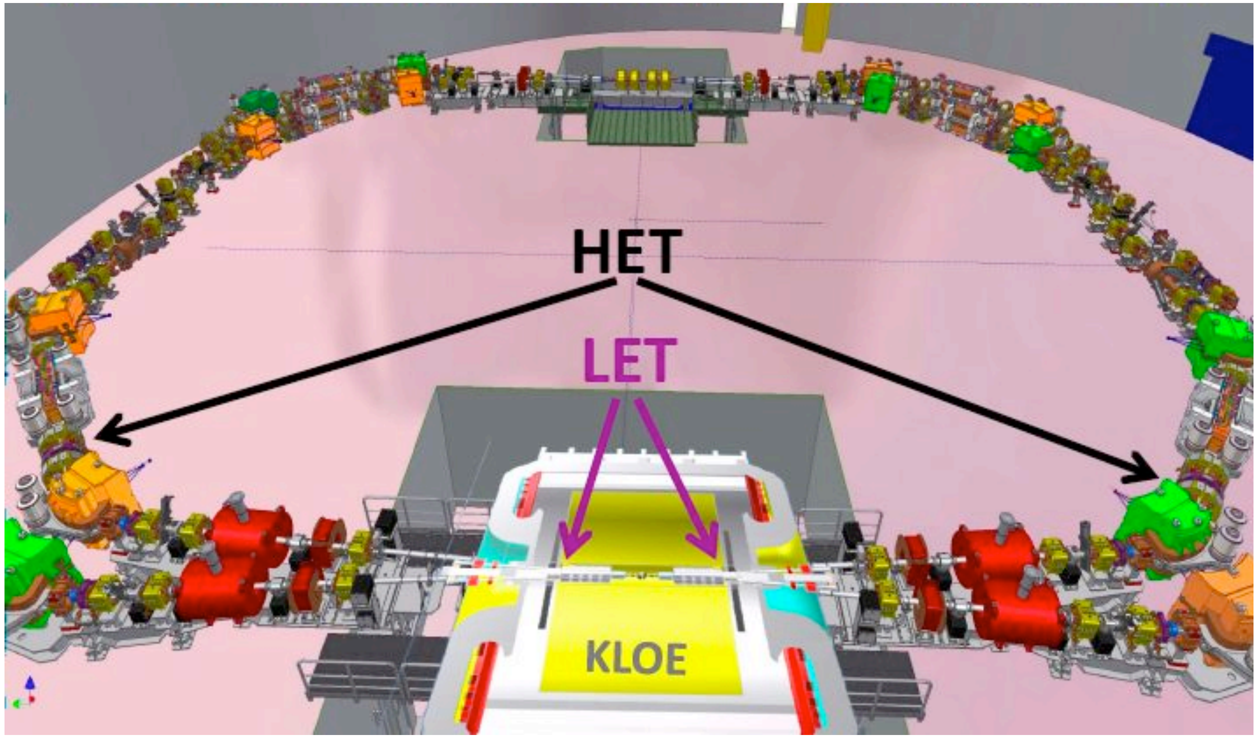
$\mathcal{O}$(2000) candidate events of $\gamma\gamma \to \pi^0\pi^0$, evaluation and interpretation of the cross section is in progress…

KLOE-2 plans

Detector upgrade for the first KLOE-2 run :
2+2 detector stations for leptons in $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$

LET (Low Energy Taggers) are LYSO calorimeters placed inside KLOE

HET (High Energy Taggers) are scintillator hodoscopes placed 11 m from the IP

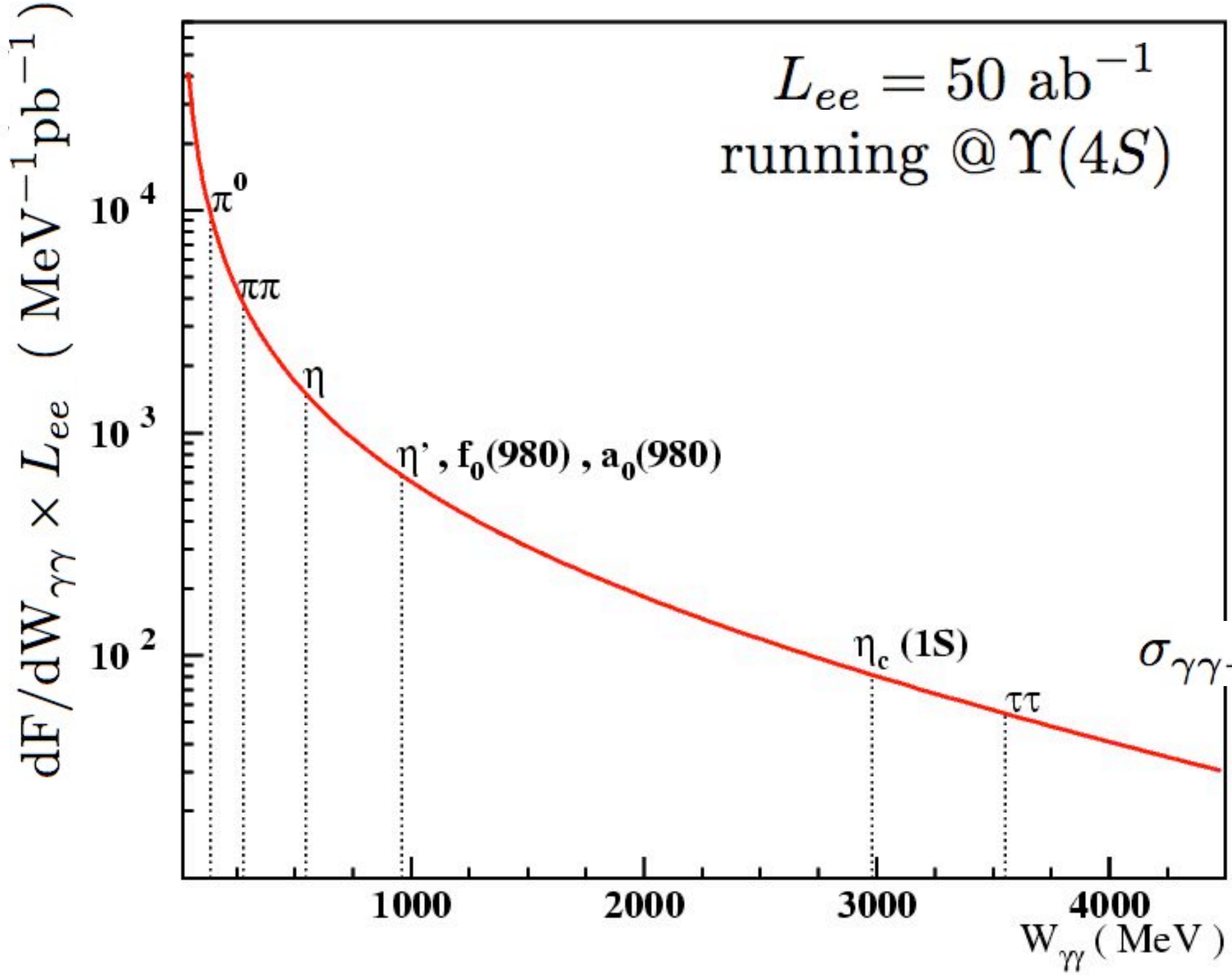


HET: $e^{\pm}$ of 425-490 MeV

LET: $e^{\pm}$ of 160-230 MeV

γγ Physics @ Super-B? so nice a product: "incredible cross section" × "incredible luminosity"

General considerations on yields @ Super-B



$$N_{e^+e^-\to e^+e^- X} = L_{ee}\int \frac{dF}{dW_{\gamma\gamma}}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})dW_{\gamma\gamma}$$

$$\sigma_{\gamma\gamma\to\tau^+\tau^-}(\Upsilon(4S)) \sim \mathcal{O}(5\ \mathrm{nb})$$

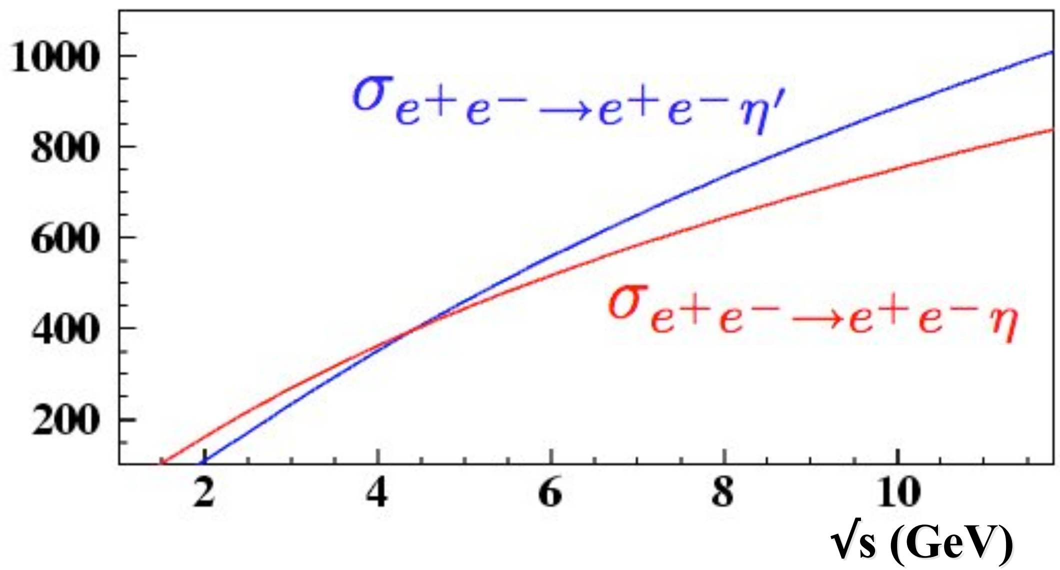
$$\frac{dF}{dW} = \frac{1}{W}\left(\frac{2\alpha}{\pi}\right)^2\left(\ln\frac{E_b}{m_e}\right)^2\left((z^2+2)^2\ \ln\frac{1}{z} - (1-z^2)\ (3+z^2)\right) \qquad z = \frac{W}{2E_b}$$

PS meson production: flavour factories comparison

$$\sigma_{e^+e^-\to e^+e^-X} = \frac{16\alpha^2\Gamma_{X\gamma\gamma}}{m_X^3}\left(\ln\frac{E_b}{m_e}\right)^2\left((y^2+2)^2\ \ln\frac{1}{y} - (1-y^2)\ (3+y^2)\right) \qquad y = m_X/(2E_b)$$

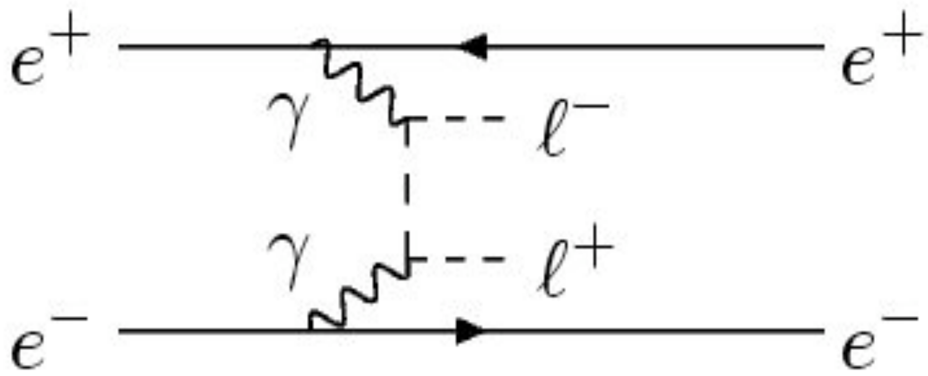
$\sigma_{e^+e^-\to e^+e^- PS}$ [pb]			
$\sqrt{s}$ (GeV)	ϕ	J/ψ	$\Upsilon(4S)$
π^0	261	638	1283
η	45	279	$\boxed{781}$
η'	8	245	$\boxed{928}$
$\eta_c(1S)$	–	0.2	3.6

even at equal luminosity… high √s matters!

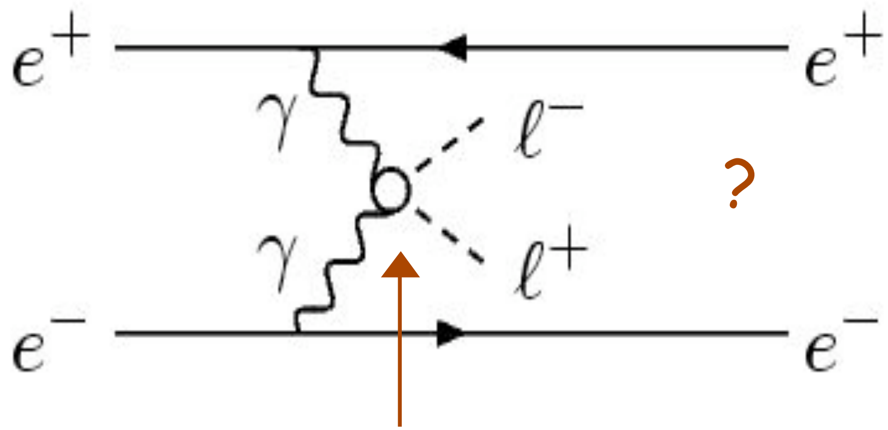


flipping of the η-η' cross sections, because phase space gets marginal wrt the partial width: $\Gamma_{\eta'\gamma\gamma} \sim 10\ \Gamma_{\eta\gamma\gamma}$

QED tests with $e^+e^- \to e^+e^-\, l^+l^-$ ($l = e, \mu, \tau$)



- ✓ $O(\alpha^2)$ tests of QED through C,P,CP-violating asymmetries
- ✓ tagger providing 4-momentum of at least 1 e+/e- is needed
- ✓ …a way to find the "unexpected"?



- HyperCP excess, for events $\Sigma^+ \to p\mu^+\mu^-$

  http://arxiv.org/abs/hep-ex/0501014

- interpretation as sgoldstino S and possible search in events

  $e^+e^- \to Se^+e^- \to \mu^+\mu^-e^+e^-$,

  $e^+e^- \to Se^+e^- \to \gamma\gamma e^+e^-$

  http://arxiv.org/abs/hep-ph/0509147

Conclusions and prospects

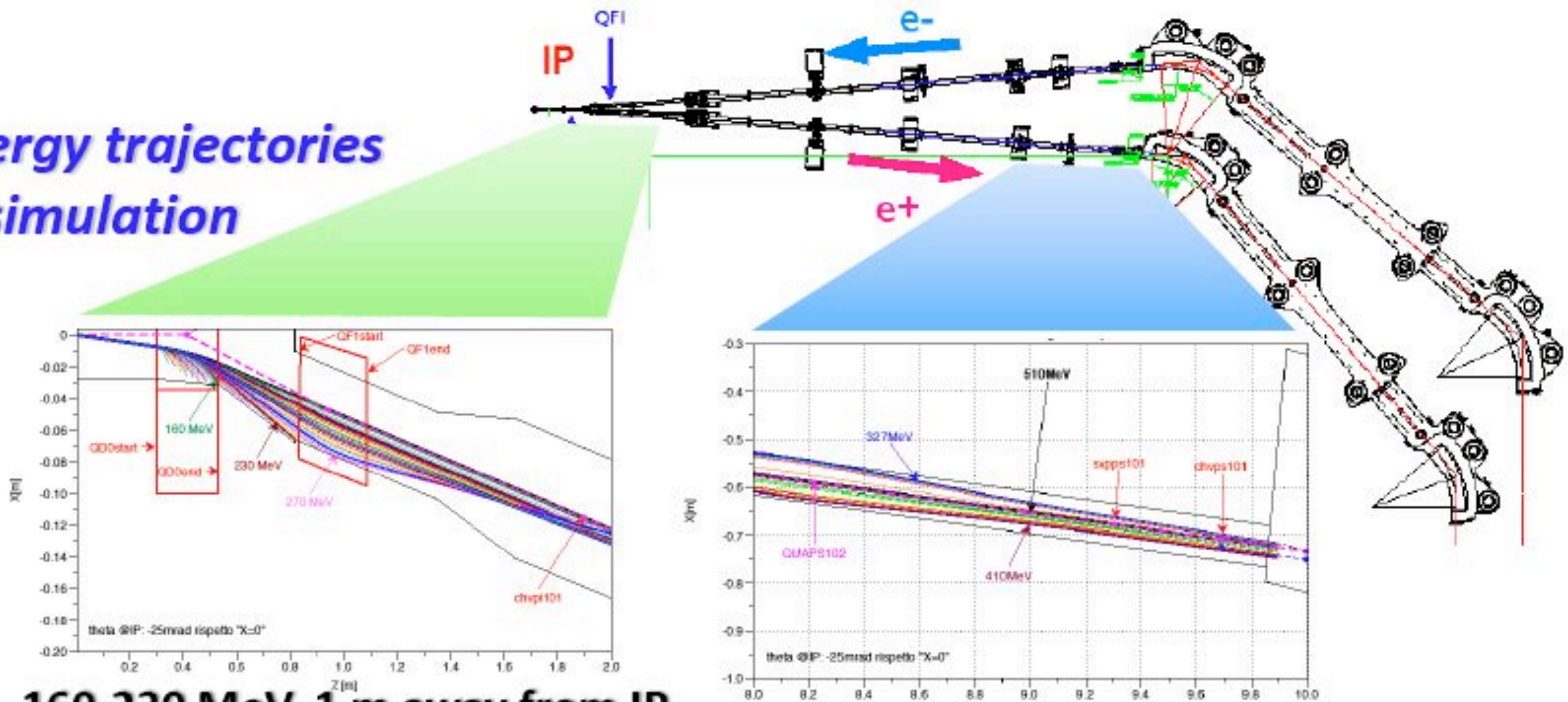
✓ important $\gamma\gamma$ measurements from the B-factories, only limit is the trigger efficiency for reaching lower momenta

✓ KLOE complementarity: first evidence of $\underline{\gamma\gamma \to \eta \text{ @ 1 GeV}}$ in 2 different channels, $\mathcal{O}(2000)$ candidate events of $\gamma\gamma \to 2\pi^0$ at threshold

✓ thanks to the high luminosity, Super-B may probe the low mass region: final state $e^{\pm}$ taggers with trigger decision?

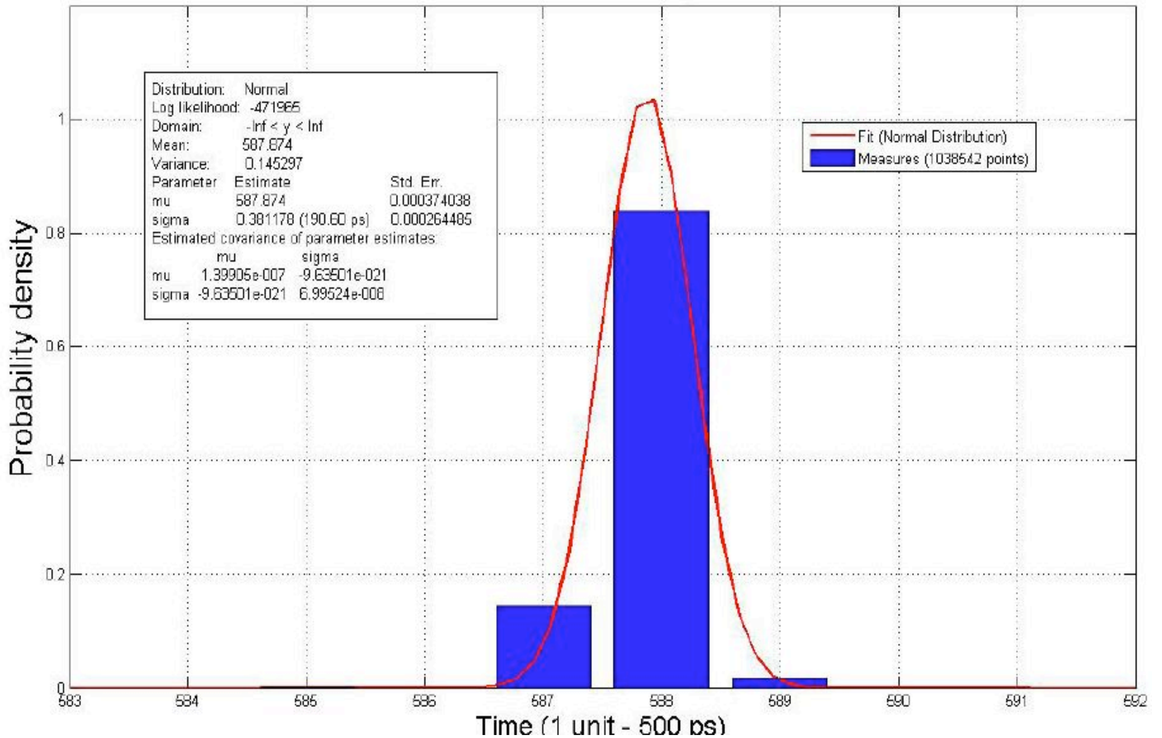
✓ unique opportunities @ Super-B: rare phenomena in $\gamma\gamma$ processes!

off-energy trajectories simulation



160-230 MeV, 1 m away from IP

425-490 MeV, 10 m away from IP



- Front End
- Discriminator
- TDC con DAQ a 368 MHz with ~ 250 ps resolution

resolution which allow clear separation between consecutive bunches.

PS meson production: flavour factories comparison

$$\sigma_{e^+e^-\to e^+e^-X} = \frac{16\alpha^2\Gamma_{X\gamma\gamma}}{m_X^3}\left(\ln\frac{E_b}{m_e}\right)^2\left((y^2+2)^2\ \ln\frac{1}{y} - (1-y^2)\ (3+y^2)\right) \qquad y = m_X/(2E_b)$$

$\sigma_{e^+e^-\to e^+e^-PS}$ [pb]			
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even at equal luminosity… high √s matters!

for example 4×10^{10} η′ produced

final state F	BR($\eta'\to F$) (%)	preferable chain	BR$_{eff}$ (%)
$\pi^+\pi^-\eta$	44.6 ± 1.4	$\pi^+\pi^-\eta(\to 2\gamma)\leftrightarrow\pi^+\pi^-2\gamma$	17.5
$\pi^+\pi^-\gamma$	29.4 ± 0.9		
$\pi^0\pi^0\eta$	20.7 ± 1.2	$\pi^0\pi^0\eta(\to\pi^+\pi^-\pi^0)\leftrightarrow\pi^+\pi^-6\gamma$	4.7
$\omega\gamma$	3.02 ± 0.31	$\omega(\to\pi^+\pi^-\pi^0)\gamma\leftrightarrow\pi^+\pi^-3\gamma$	2.7
$\gamma\gamma$	2.10 ± 0.12		

flipping of the η-η′ cross sections, because phase space gets marginal wrt the partial width: $\Gamma_{\eta'\gamma\gamma}\sim 10\,\Gamma_{\eta\gamma\gamma}$

BES evidence (2004)

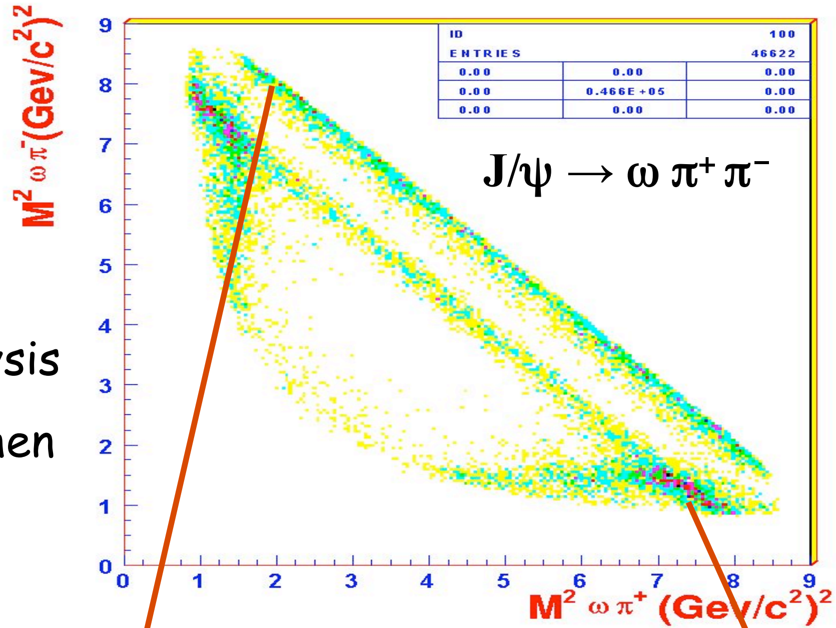
PLB598 (2004) 149

$$\begin{cases} BW_\sigma = \frac{1}{m_\sigma^2 - s - i m_\sigma \Gamma_\sigma} \\ \Gamma_\sigma \text{ is a constant} \end{cases},$$

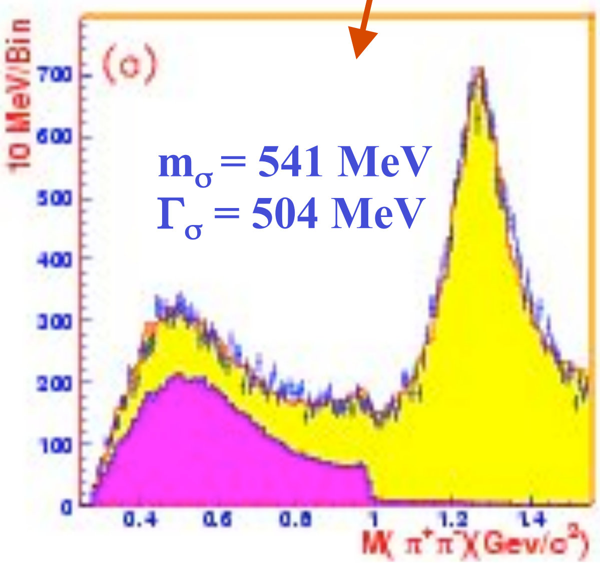
$$\begin{cases} BW_\sigma = \frac{1}{m_\sigma^2 - s - i\sqrt{s}\,\Gamma_\sigma(s)} \\ \Gamma_\sigma(s) = \frac{g_\sigma^2 \sqrt{\frac{s}{4} - m_\pi^2}}{8\pi s} \end{cases},$$

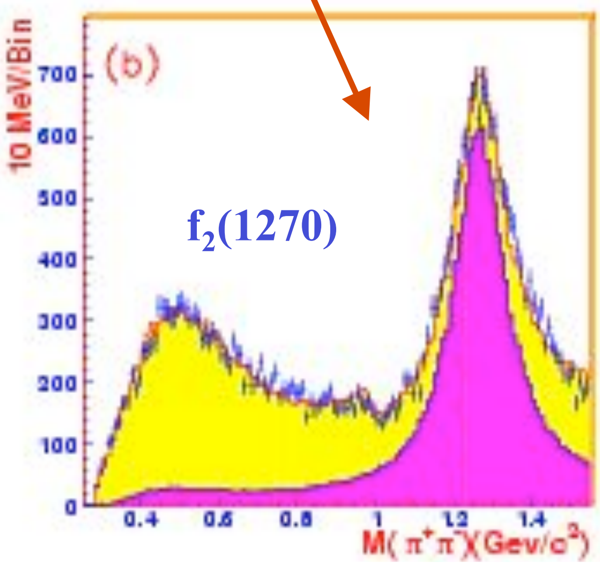
$$\begin{cases} BW_\sigma = \frac{1}{m_\sigma^2 - s - i\sqrt{s}\,\Gamma_\sigma(s)} \\ \Gamma_\sigma(s) = \alpha\sqrt{\frac{s}{4} - m_\pi^2} \end{cases},$$

$$\begin{cases} BW_\sigma = \frac{1}{m_\sigma^2 - s - i m_\sigma(\Gamma_1(s) + \Gamma_2(s))}, \\ \Gamma_1(s) = G_1 \frac{\sqrt{1 - 4m_\pi^2/s}}{\sqrt{1 - 4m_\pi^2/m_\sigma^2}} \cdot \frac{s - m_\pi^2/2}{m_\sigma^2 - m_\pi^2/2} e^{-(s - m_\sigma^2)/4\beta^2}, \\ \Gamma_2(s) = G_2 \frac{\sqrt{1 - 16m_\pi^2/s}}{\sqrt{1 - 16m_\pi^2/m_\sigma^2}} \frac{1 + e^{\Lambda(s_0 - m_\sigma^2)}}{1 + e^{\Lambda(s_0 - s)}}. \end{cases}$$



- ✓ partial wave analysis
- ✓ $\Delta \mathrm{Log}L$ = 5238, when omitting the σ





$J/\psi \to \omega f_2(1270)$
$\omega\sigma$
$\omega f_0(980)$
$b_1(1235)\pi$