Workshop on "Particle Physics Opportunities at IRIDE"

24-25 June 2013 *INFN - LNF*
Europe/Rome timezone

$\gamma\gamma$ particle production at IRIDE

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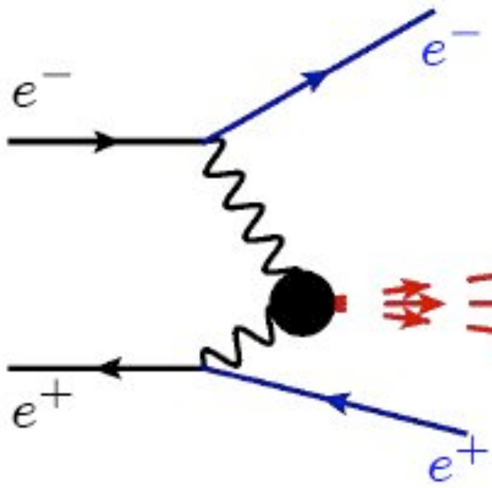
June, 25th 2013

An outline (from experience at low energy)

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

- pseudoscalar mesons



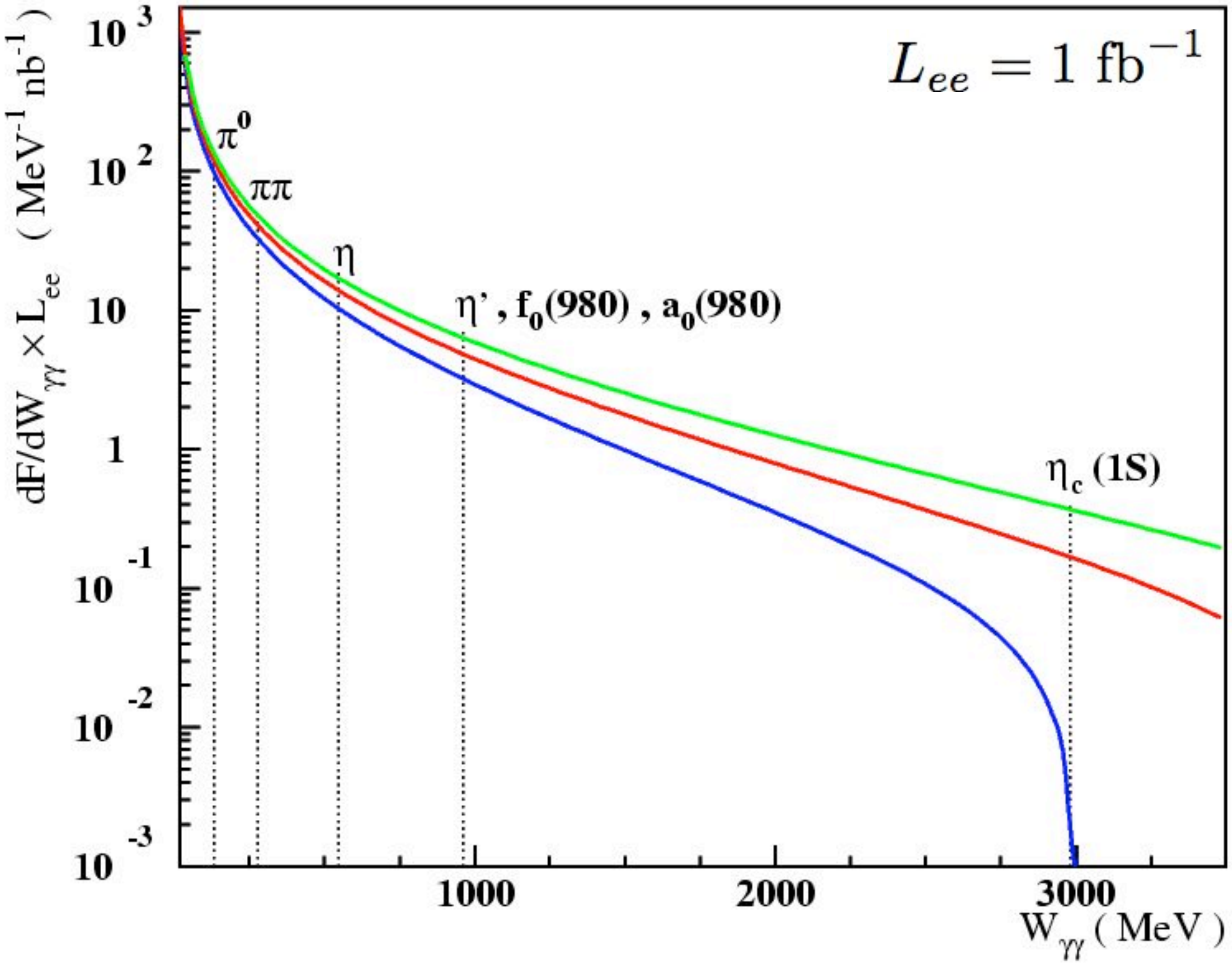
- scalar mesons

- QED tests

- an outlook

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

Gamma-gamma flux @ Iride



$$N_{e^+e^- \to e^+e^- X} =$$

$$L_{ee} \int \frac{\mathrm{dF}}{\mathrm{dW}_{\gamma\gamma}} \sigma_{\gamma\gamma\to X}(\mathrm{W}_{\gamma\gamma}) \mathrm{dW}_{\gamma\gamma}$$

– $\sqrt{s}$ = 5 GeV

– $\sqrt{s}$ = 4 GeV

– $\sqrt{s}$ = 3 GeV

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

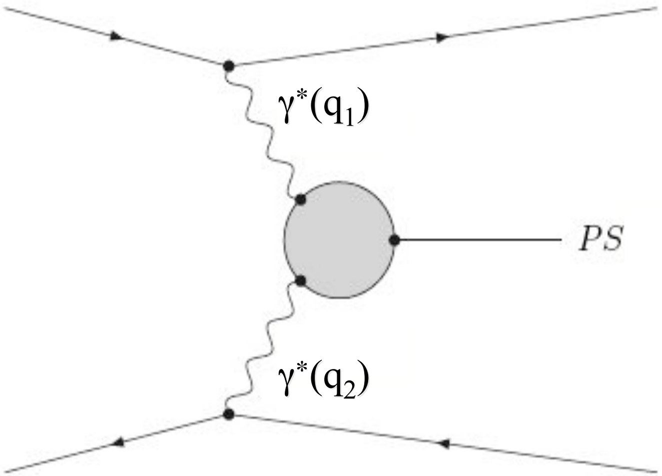
PseudoScalar mesons: $\gamma\gamma$ widths

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

for narrow pseudoscalar [see C. Di Donato] mesons (e.g. π^0, η, η', $\eta_c(1S)$,…):

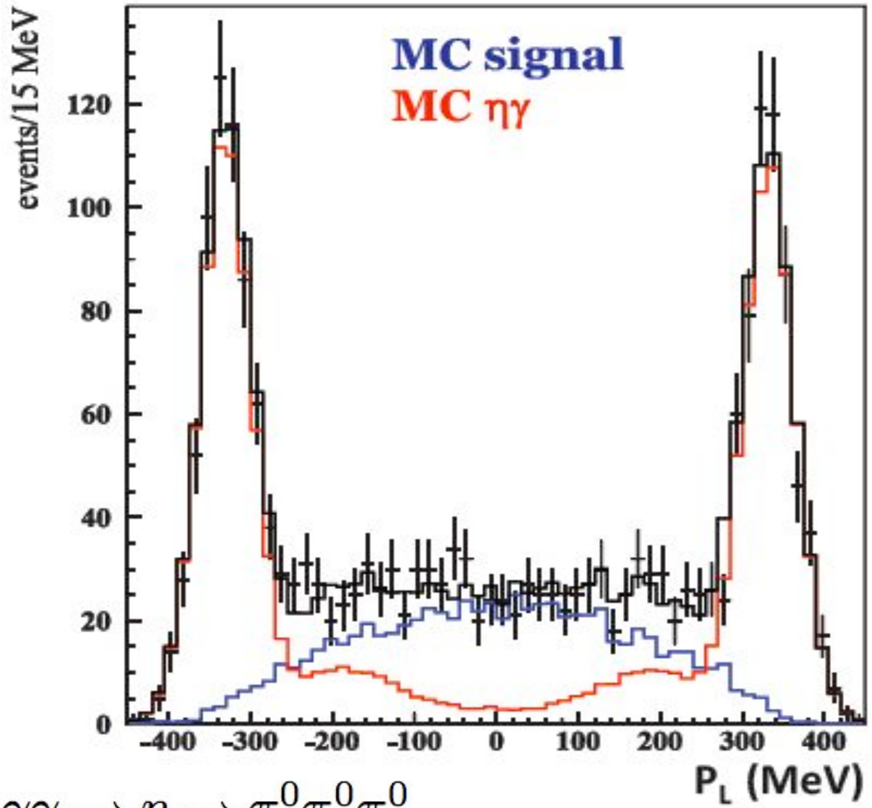
$$\sigma_{\gamma\gamma\to X}(q_1,q_2) \propto \boxed{\Gamma_{X\to\gamma\gamma}}\frac{8\pi^2}{M_X}\delta((q_1+q_2)^2 - M_X^2)\boxed{\left|F(q_1^2,q_2^2)\right|^2}$$

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



spectrum measurement, as a function of a single momentum transfer, fixing or integrating over the other one, 2-dim PDF not yet measured

The $\Gamma_{\eta\gamma\gamma}$ KLOE measurement



$\gamma\gamma \rightarrow \eta \rightarrow \pi^0\pi^0\pi^0$

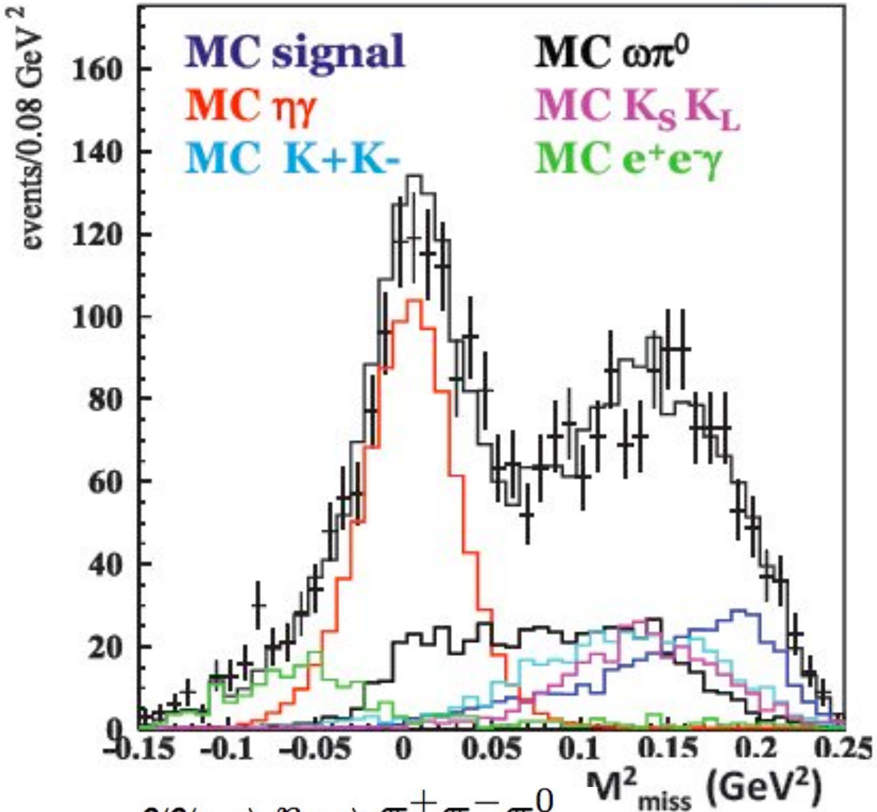
2166 events in the final sample

from the fit: 722 signal events

$\sigma_{e^+e^-\rightarrow e^+e^-\eta} =$

$32.0(1.5)_{\mathrm{stat}}(0.9)_{\mathrm{syst}}$ pb

[JHEP01(2013)119]



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

2720 events in the final sample

from the fit: 394 signal events

$\sigma_{e^+e^-\rightarrow e^+e^-\eta} =$

$34.5(2.5)_{\mathrm{stat}}(1.3)_{\mathrm{syst}}$ pb

The $\Gamma_{\eta\gamma\gamma}$ KLOE measurement

from 240 pb^{-1} of data taken at DAΦNE, combining the two measurements:

$$\sigma(e^+e^- \to e^+e^-\eta) = (32.7 \pm 1.3 \pm 0.7)\ \text{pb}$$

$$\sigma_{\gamma\gamma\to\eta} = \frac{8\pi^2}{m_\eta}\Gamma(\eta\to\gamma\gamma)\delta(w^2 - m_\eta^2)|F(q_1^2, q_2^2)|^2$$

and assuming:

$$F(q_1^2, q_2^2) = \frac{1}{1-bq_1^2}\frac{1}{1-bq_2^2} \quad \text{with } b = 1.94\ \text{GeV}^{-2}$$

$$\Rightarrow \Gamma(\eta\to\gamma\gamma) = (520 \pm 20 \pm 13)\ \text{eV}$$

most precise measurement to date

[JHEP01(2013)119]

PDG average: $\Gamma(\eta\to\gamma\gamma) = (510 \pm 26)\ \text{eV}$

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$$\sigma_{\gamma\gamma\to\eta} = \frac{8\pi^2}{m} \ldots \Gamma(q_1^2, q_2^2)|^2$$

and assuming:

$$F(q_1^2, q_2^2) \ldots 1.94\ \text{GeV}^{-2}$$

$$\Rightarrow \Gamma(\eta \to \ldots \ldots 20 \pm 20 \pm 13)\ \text{eV}$$

how to improve?

1) **larger statistics**
2) **switch off annihilations**

1 fb^{-1} @ Iride in e^-e^- mode

most precise measurement to date

[JHEP01(2013)119]

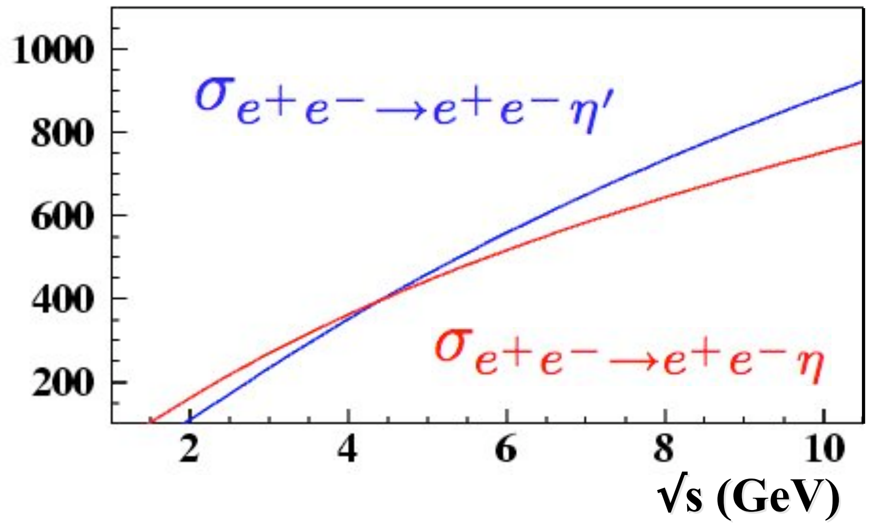
PDG average: $\Gamma(\eta \to \gamma\gamma) = (510 \pm 26)\ \text{eV}$

PS meson production: Iride vs. flavour factories

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

$\sigma_{e^+e^-\to e^+e^-PS}$ [pb]			
$\sqrt{s}$	ϕ	J/ψ	4 GeV
π^0	261	638	752
η	45	279	362
η'	8	245	351
$\eta_c(1S)$	–	0.2	2.1

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



Iride vs. BESIII: same yield, but in the e^-e^- collider configuration

no annihilation background

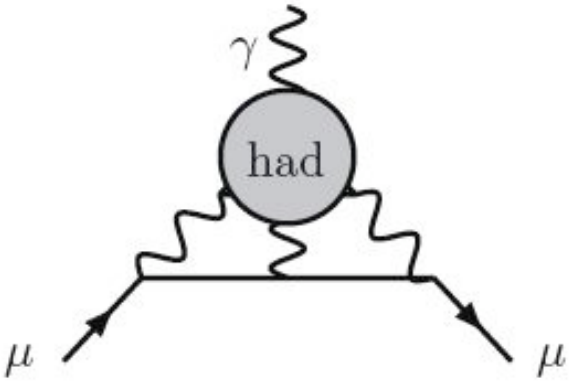
The $\eta'(958)$ width @ Iride: a tentative strategy

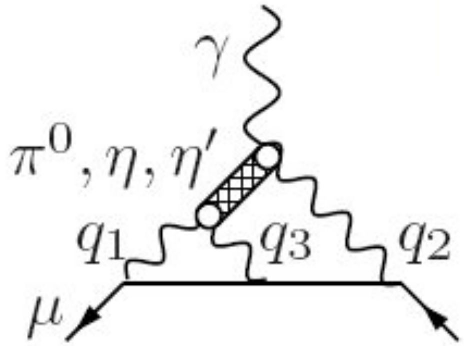
- ✓ final states with charged tracks are preferable
- ✓ each F channel provides $\sigma \propto \Gamma(\eta' \to F) \times \Gamma(\eta' \to \gamma\gamma)$
- ✓ measure directly $\sigma(e^-e^- \to e^-e^-\eta' \to e^-e^-\gamma\gamma) \propto [\Gamma(\eta' \to \gamma\gamma)]^2$
- ✓ also measure η' cross sections in dominant final states, close them
  to a combined fit → extract precise $\Gamma(\eta' \to \gamma\gamma)$

Iride: 1 fb^{-1} @ 4 GeV

final state F	$BR(\eta' \to F)$ (%)	preferable chain	BR_{eff} (%)	events
$\pi^+\pi^-\eta$	44.6 ± 1.4	$\pi^+\pi^-\eta(\to 2\gamma) \leftrightarrow \pi^+\pi^-2\gamma$	17.5	60 000
$\pi^+\pi^-\gamma$	29.4 ± 0.9			100 000
$\pi^0\pi^0\eta$	20.7 ± 1.2	$\pi^0\pi^0\eta(\to \pi^+\pi^-\pi^0) \leftrightarrow \pi^+\pi^-6\gamma$	4.7	16 000
$\omega\gamma$	3.02 ± 0.31	$\omega(\to \pi^+\pi^-\pi^0)\gamma \leftrightarrow \pi^+\pi^-3\gamma$	2.7	9 500
$\gamma\gamma$	2.10 ± 0.12			7 300

PS transition form factors: L-by-L





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

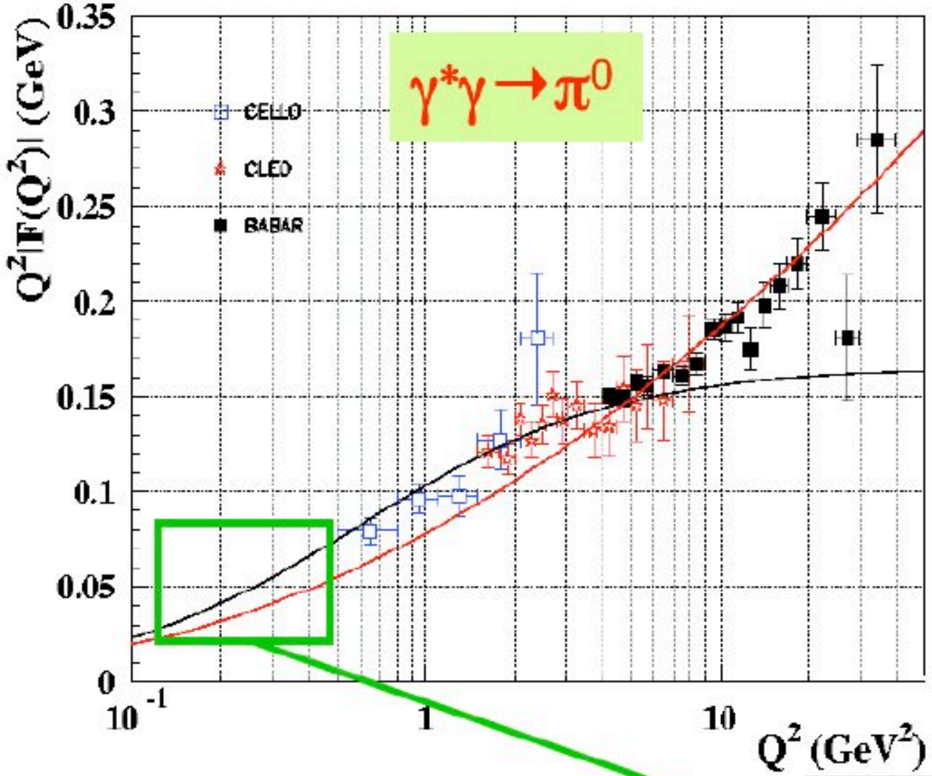
Contribution	N/JN
π^0, η, η'	99±16
π, K loops	−19±13
π, K loops + other subleading in N_c	–
axial vectors	22± 5
scalars	−7± 2
quark loops	21± 3
total	116±39

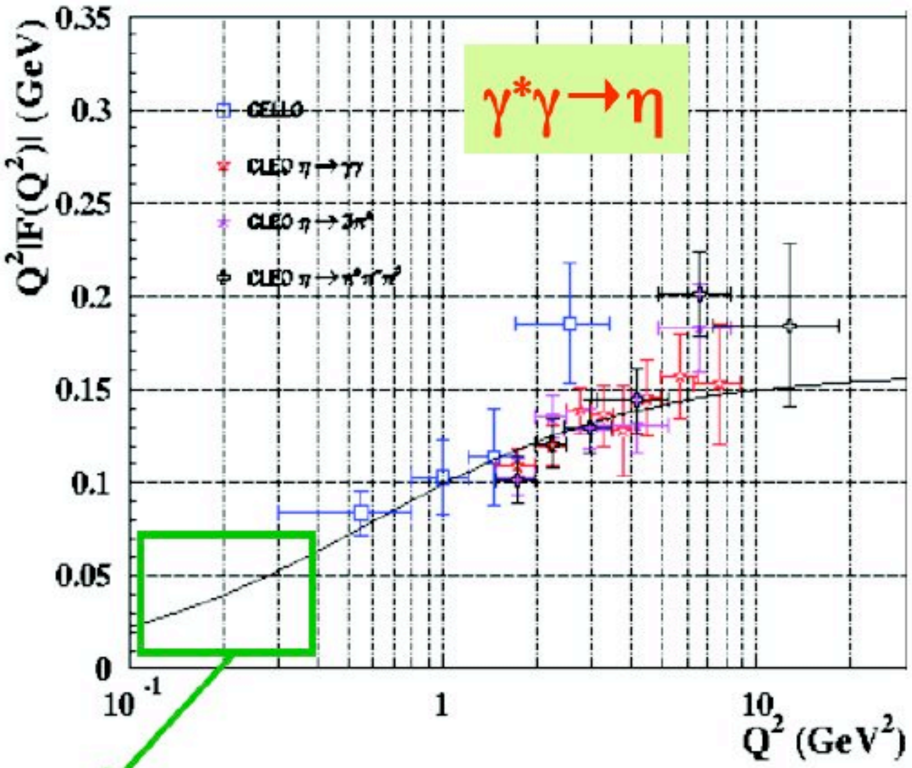
$a_\mu^{\mathrm{LbL;had}} \times 10^{11}$

- possibility to constrain contributions from data
- pseudoscalar pole contribution dominates, many theory approaches → a clean case with only 2 independent scales, $F(m_{PS}^2, q_1^2, q_2^2)$

Iride: low Q^2 region unexplored

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

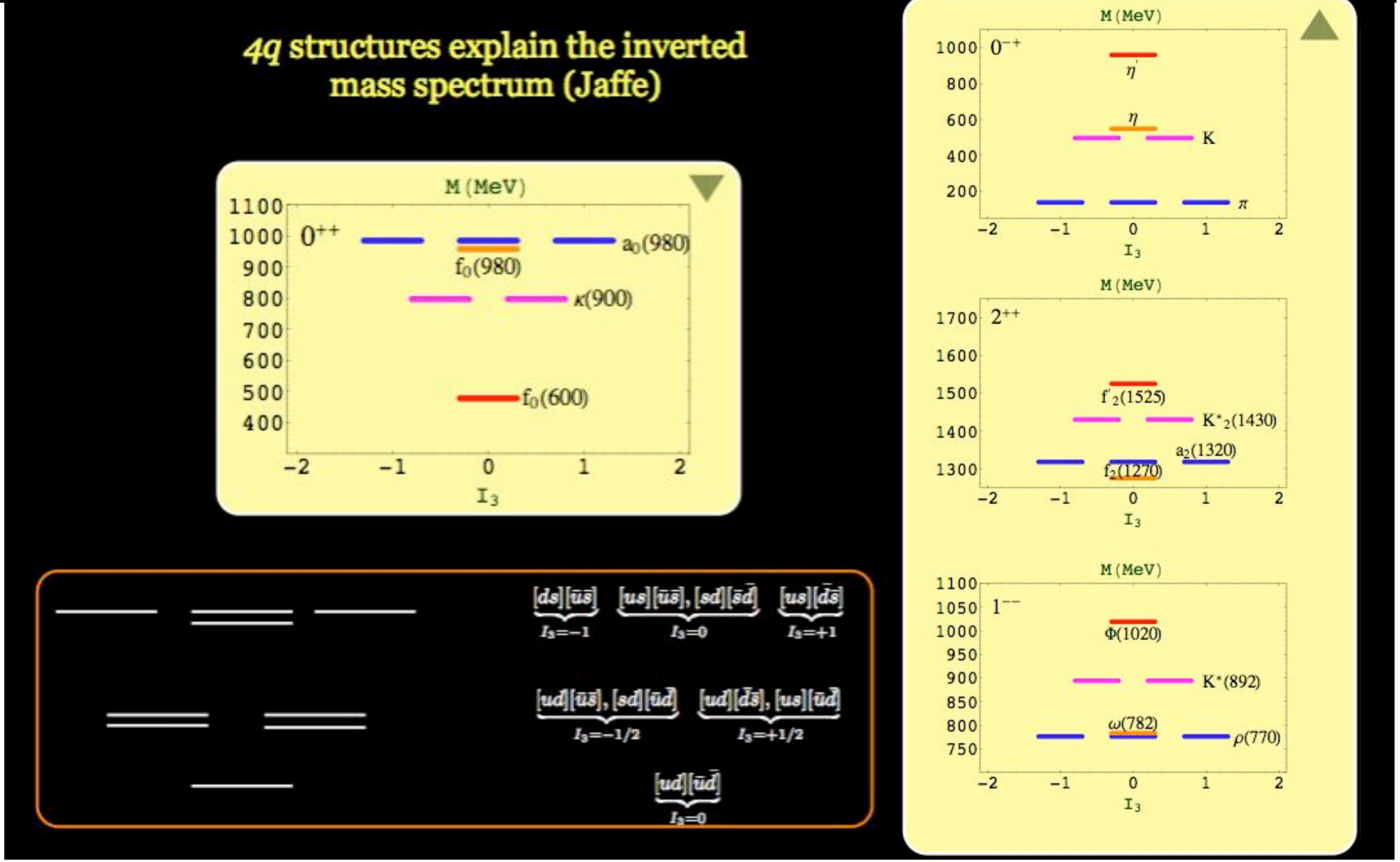




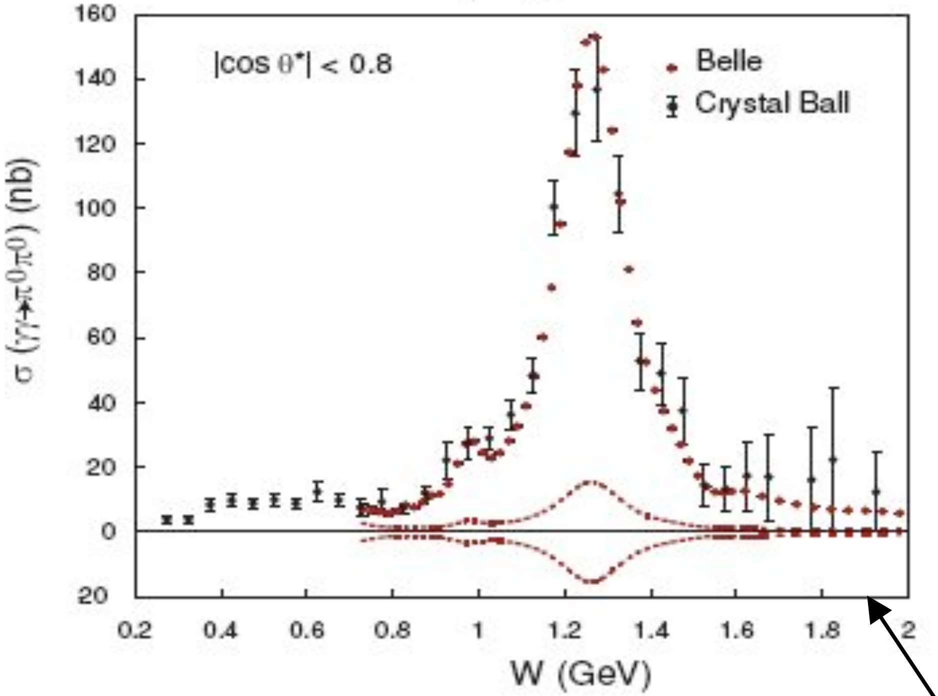
lack of
data points

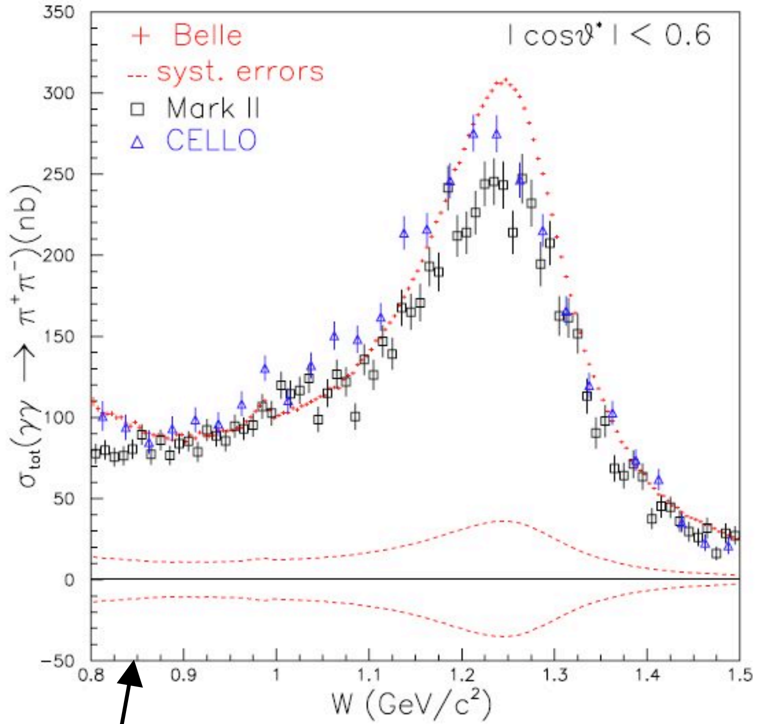
Low mass scalar mesons: puzzling since the 70's

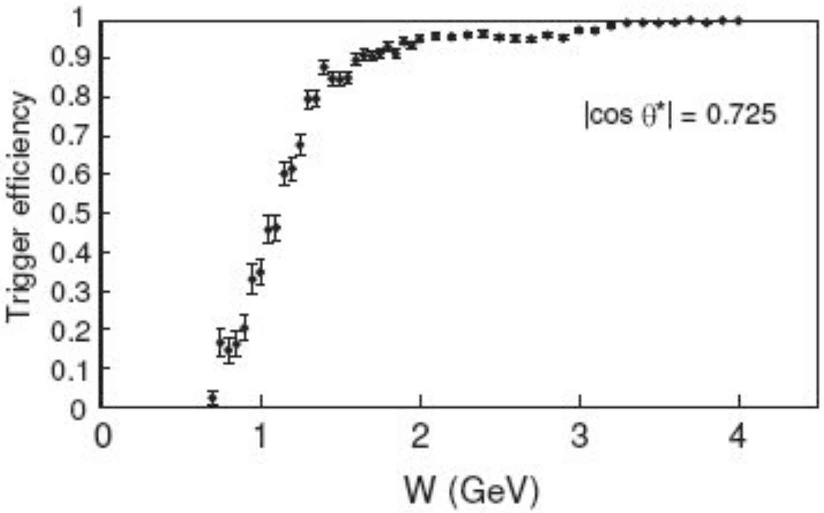
Maiani et al. :: A new look at scalar mesons as *4q* structures - PRL93(2004)212002
`t Hooft et al. :: A theory of scalar mesons - PLB662(2008)424



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

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

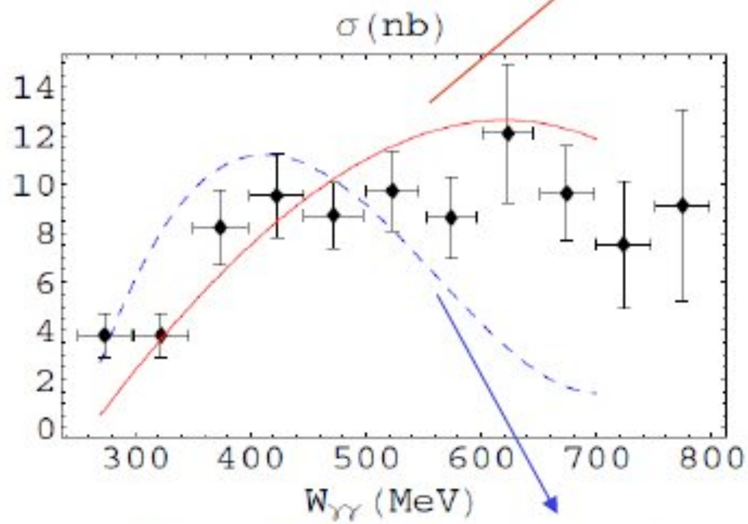
$\pi^+\pi^-$ harder than $\pi^0\pi^0$ channel:

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]
$\bar{K}K$	0.6 0.22	Barnes [76] Hanhart *et al.* [77]

- ● Crystal Ball, PRD41 (1990) 3324
- ➢ σ with BES values
- ➢ 2 loop χPT



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

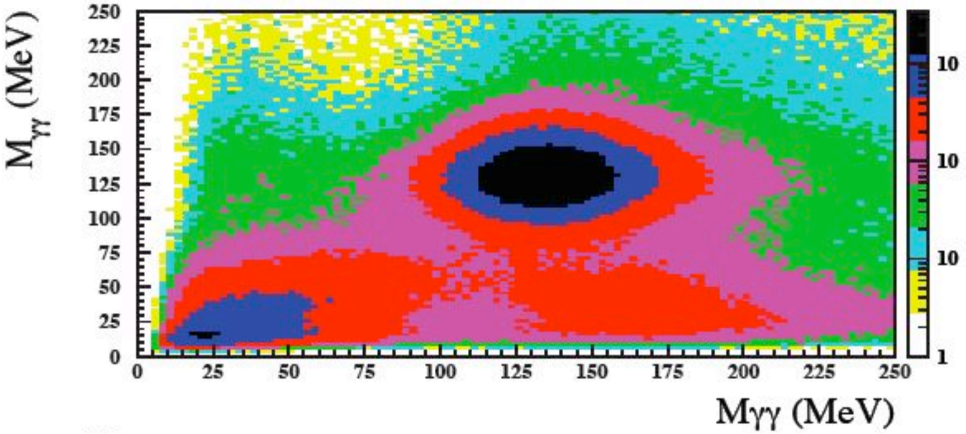
Eur. Phys. J. C 47, 65–70 (2006)
F.Nguyen, F.Piccinini & A.Polosa

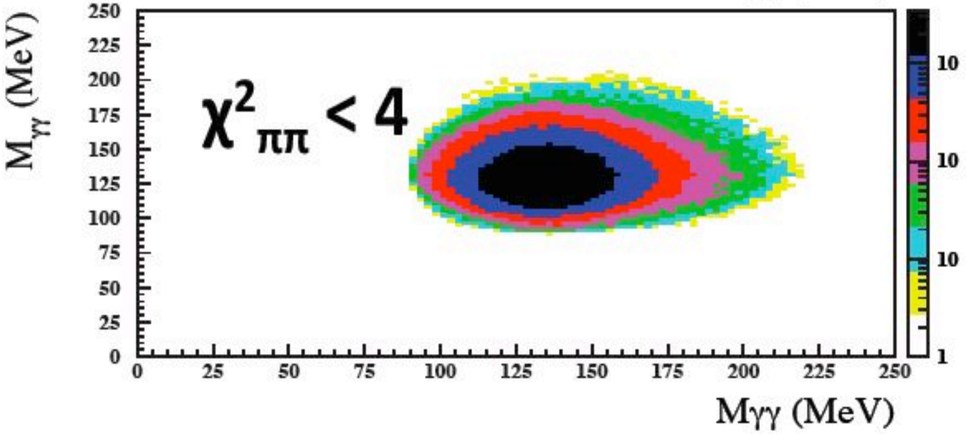
from the radiative width
→ infer the structure

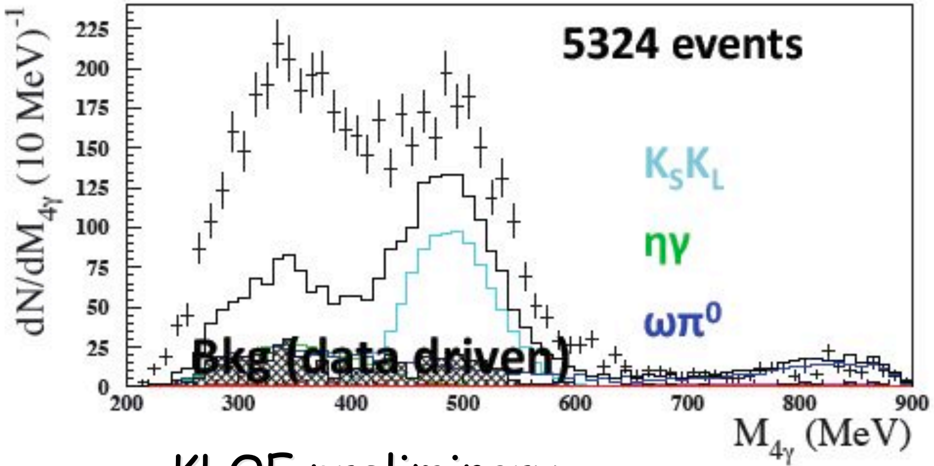
The $\gamma\gamma \to \pi^0\pi^0$ KLOE measurement

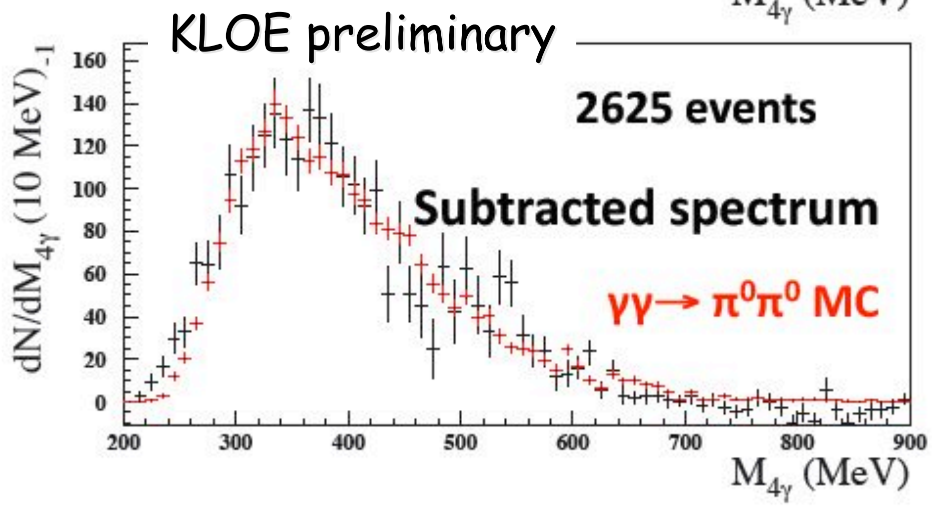
from 240 pb^{-1} @ $\sqrt{s}$ = 1 GeV

$$\chi^2_{\pi\pi} = \frac{(m_{\pi^0} - m_{ij})^2}{\sigma^2_{ij}} + \frac{(m_{\pi^0} - m_{kl})^2}{\sigma^2_{kl}}$$









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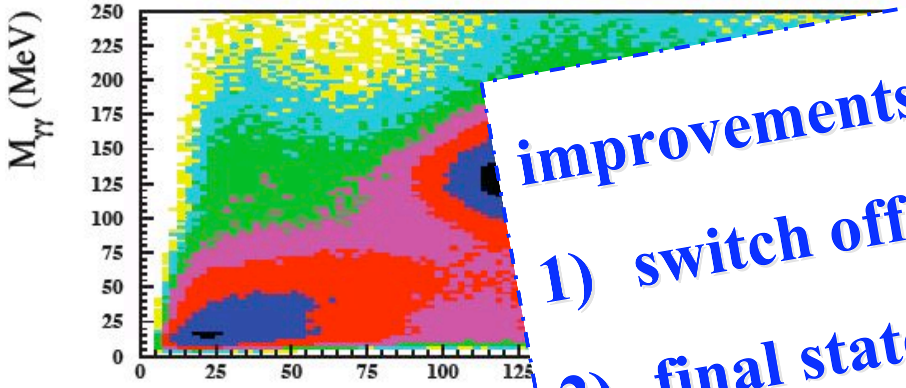
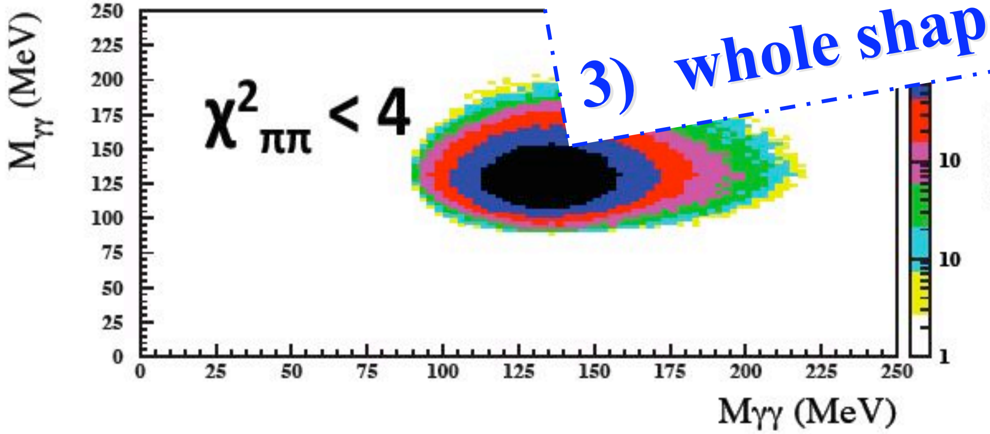
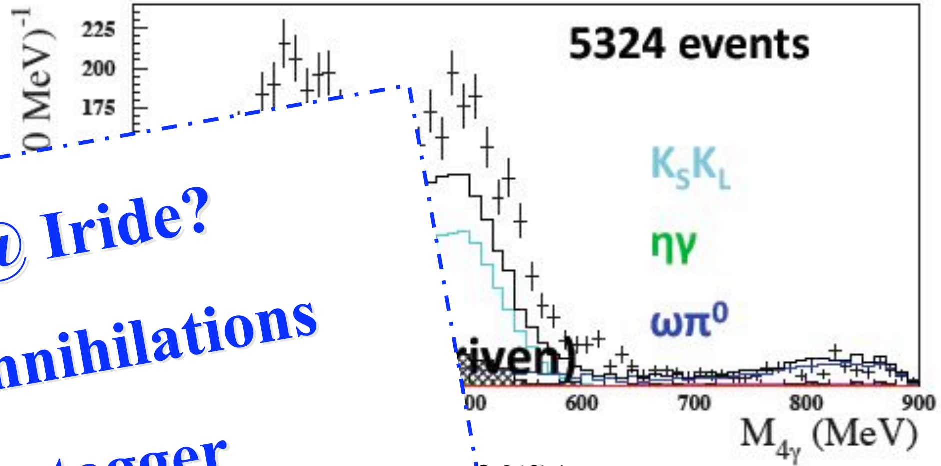
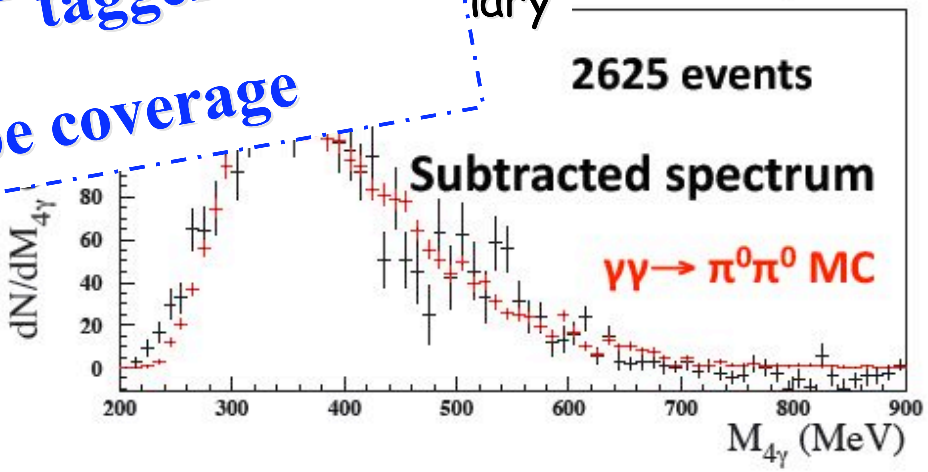




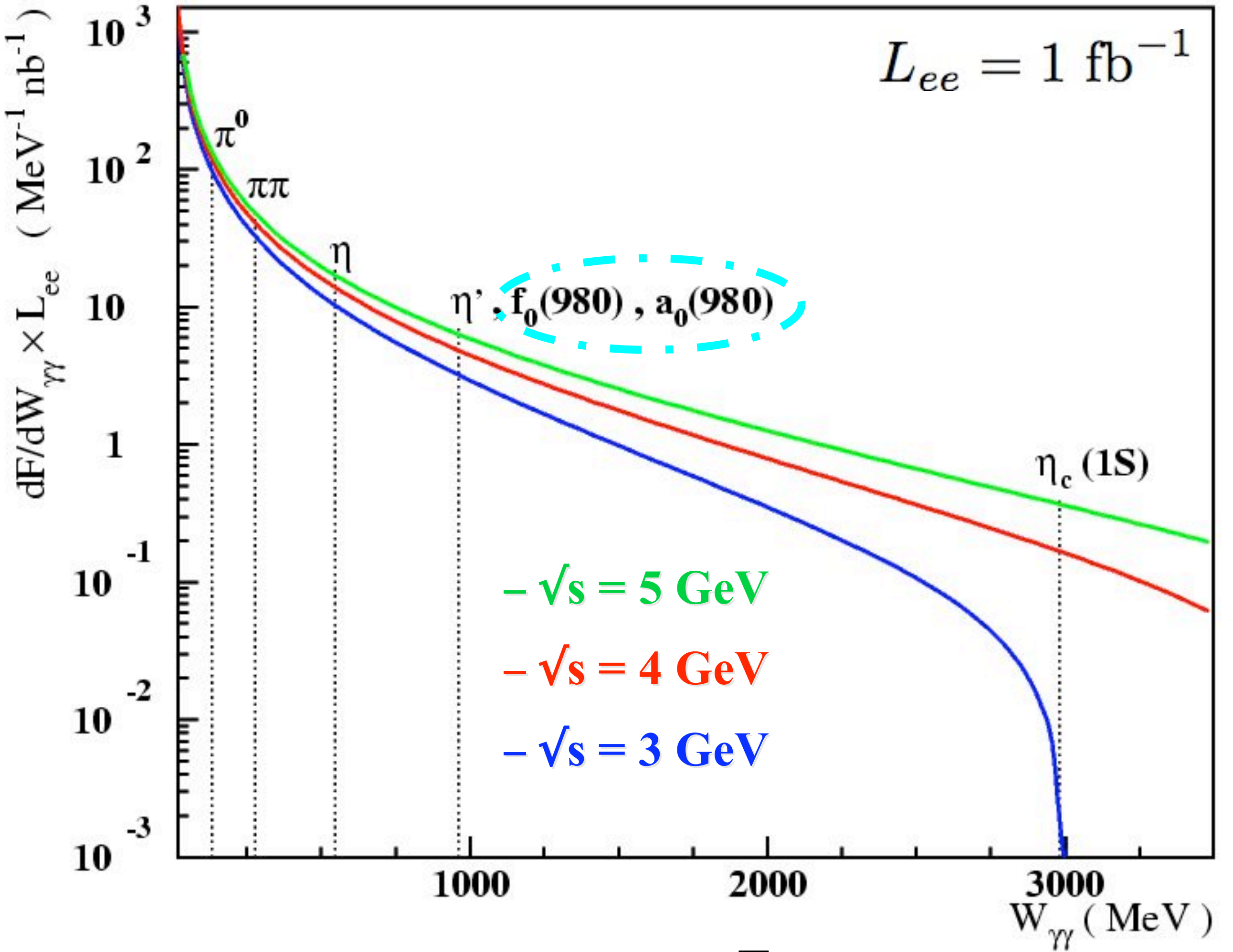




improvements @ Iride?

1) **switch off annihilations**
2) **final state e$^-$ tagger**
3) **whole shape coverage**

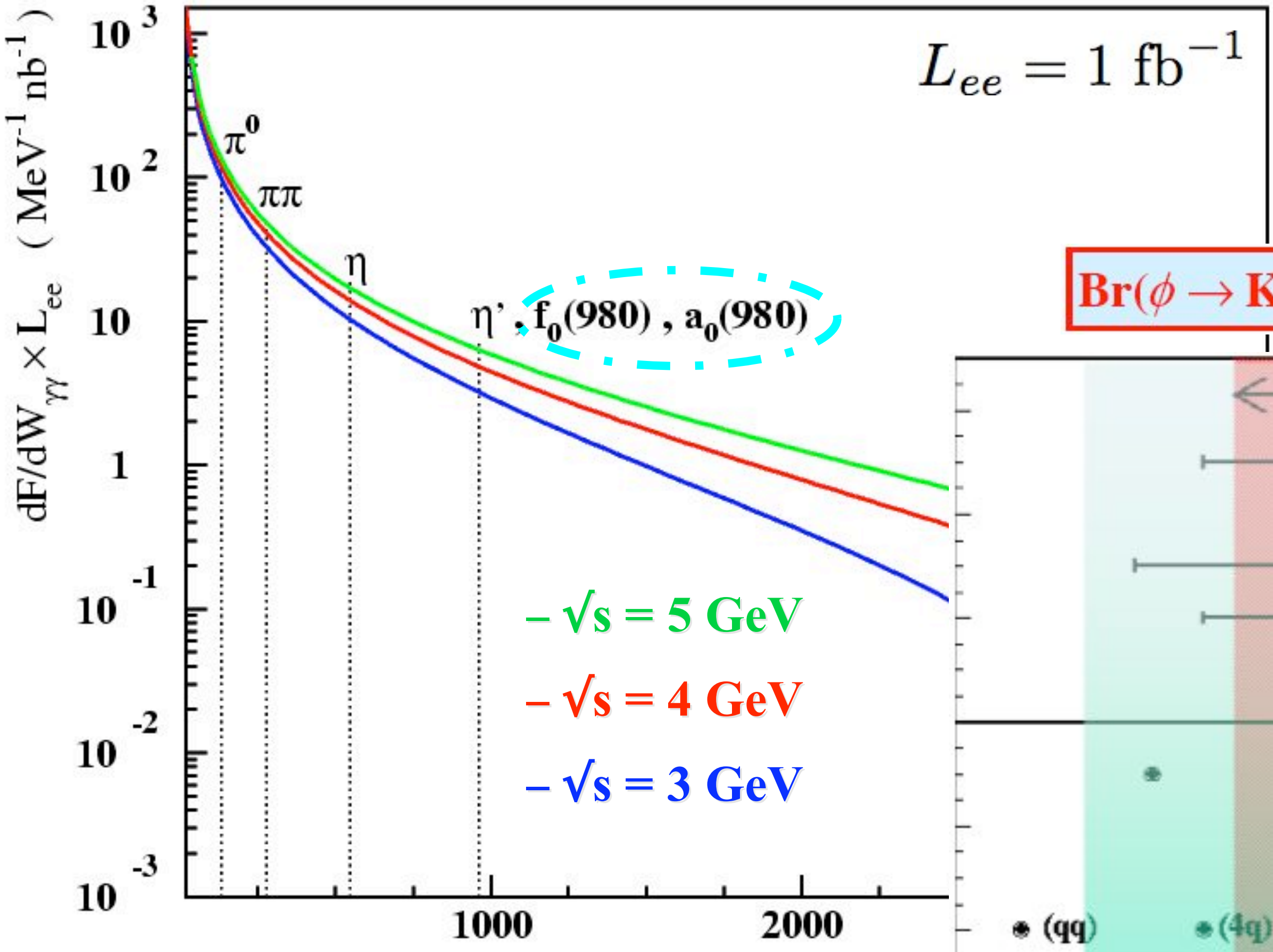
More scalar mesons produced in γγ collisions



$\gamma\gamma \rightarrow f_0(980)/a_0(980) \rightarrow K\bar{K}$

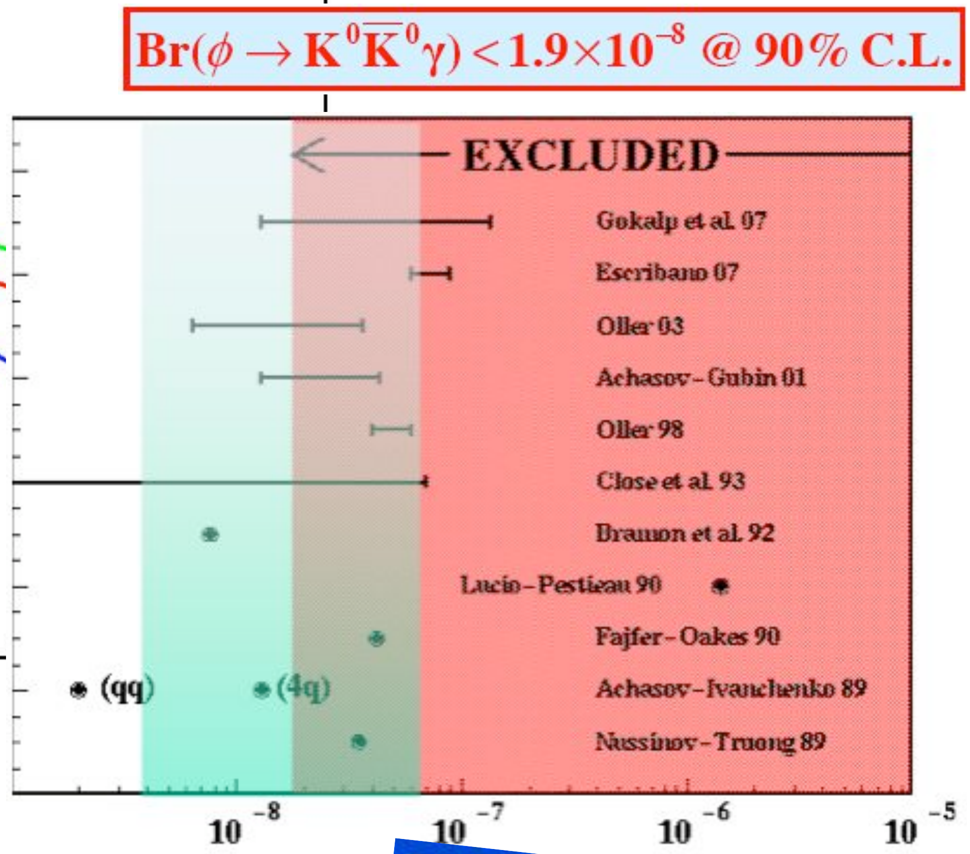
thresholds are open @ Iride

More scalar mesons produced in γγ collisions



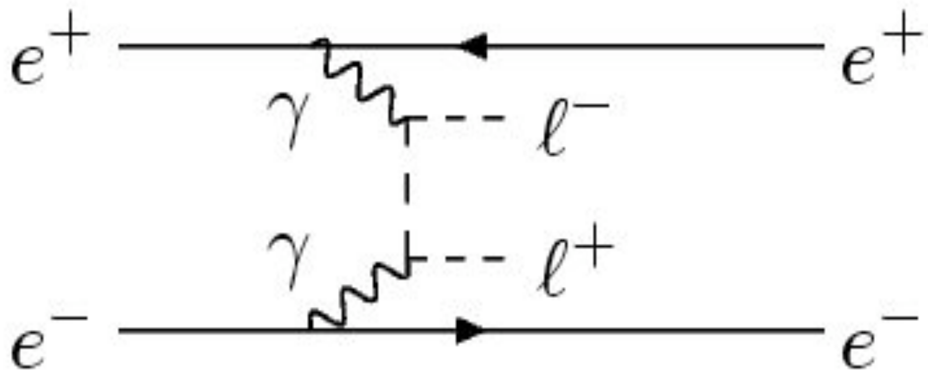
$\gamma\gamma \rightarrow f_0(980)/a_0(980) \rightarrow K\bar{K}$
thresholds are open @ Iride

a renowned $f_0(980)$
models killer

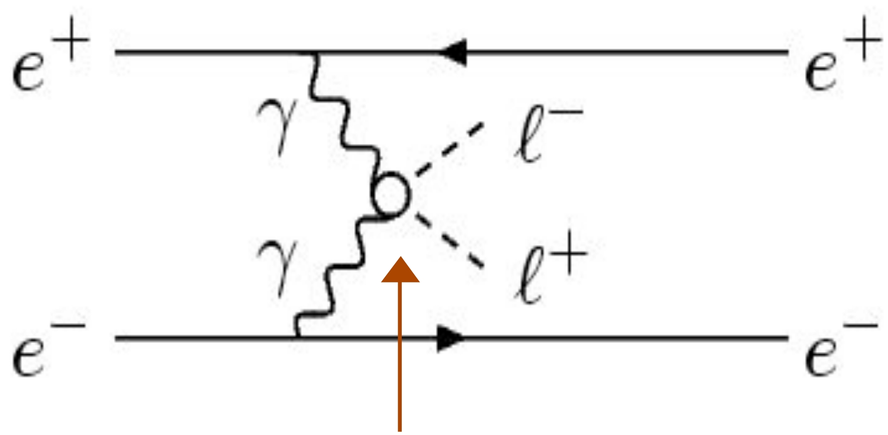


PLB 679 (2009) 10

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



a way to find the "unexpected" (*e.g.* the h' of the Dark Hidden Sector), while performing top class QED tests?



light (pseudo)scalar boson

✓ precise QED cross section tests

✓ tagger for testing differential distributions (triple products)

✓ C,P,CP-violating asymmetries would hint to new phenomena

- 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

Prospects

✓ unique $\gamma\gamma$ opportunities @ Iride, especially if also the e^-e^- collider program is carried on

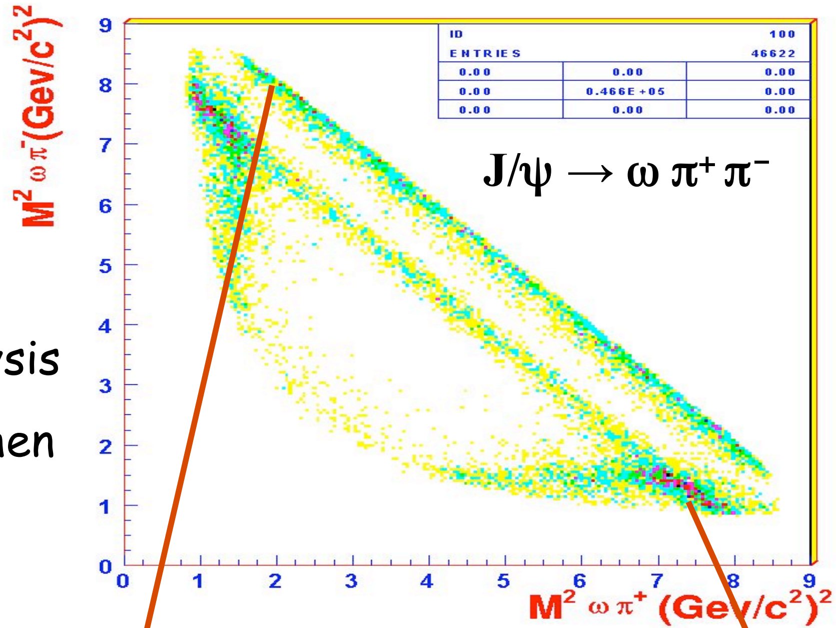
✓ legacy results on the properties of light scalar and pseudoscalar mesons through $\gamma\gamma$ production

✓ unprecedented QED tests at the GeV scale: if new particles (the U-boson with its sector) were located at that scale or below → hard escaping the scrutiny of spectra predicted with great accuracy in QED

SPARES

BES evidence (2004)

PLB598 (2004) 149



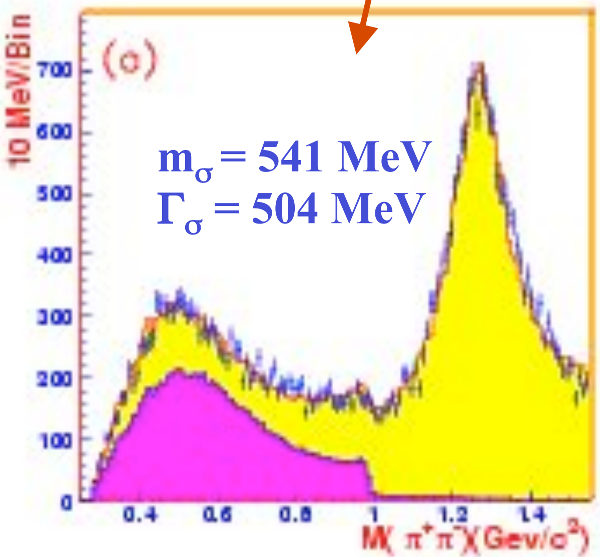
- ✓ partial wave analysis
- ✓ ΔLog*L* = 5238, when omitting the σ

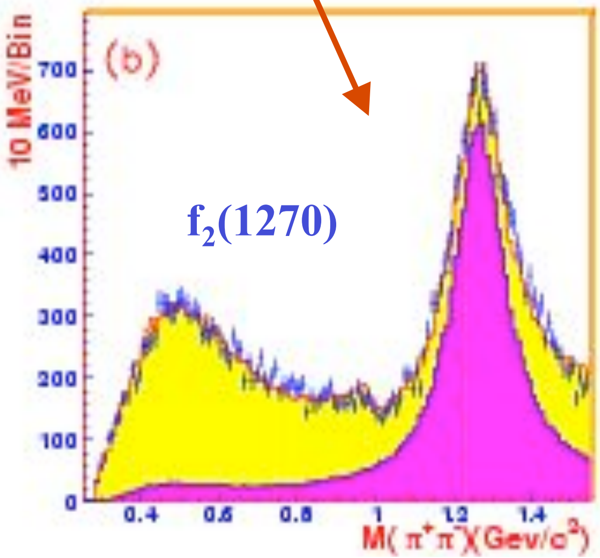
$$\begin{cases} BW_\sigma = \frac{1}{m_\sigma^2 - s - i m_\sigma \Gamma_\sigma} \\ \Gamma_\sigma \text{ is a constant} \end{cases},$$

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

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

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





$J/\psi \to \omega f_2(1270)$

$\omega\sigma$

$\omega f_0(980)$

$b_1(1235)\pi$

PS mixing angle and the gluonium in η'

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

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

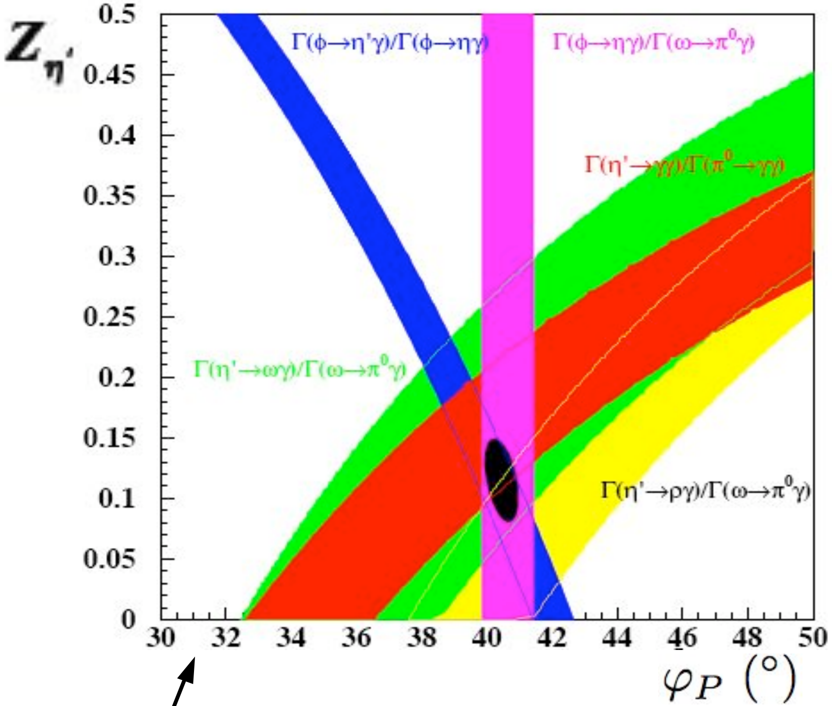
$$|\eta'\rangle = X_{\eta'}\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|glue\rangle$$

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

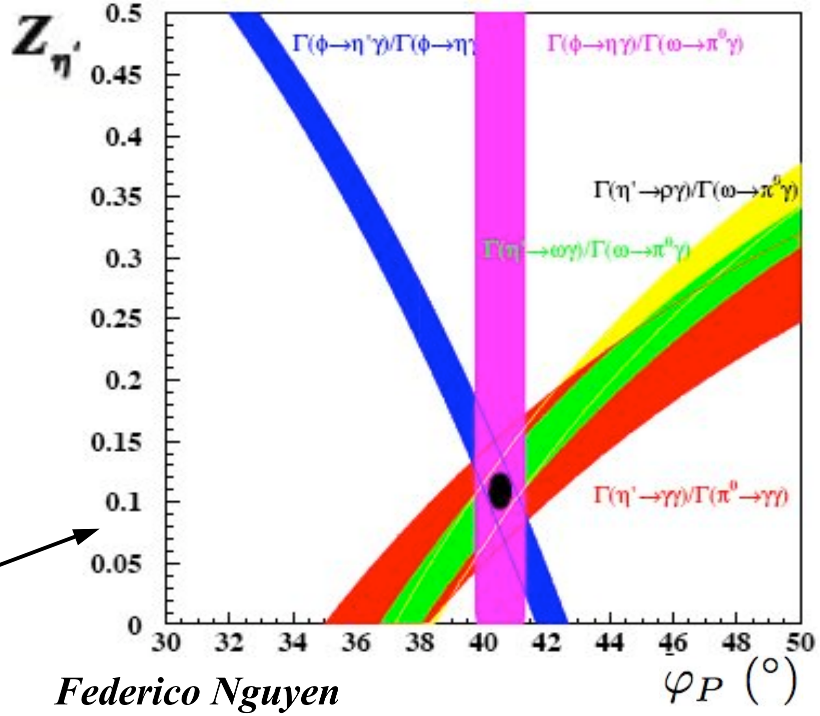
$$X_{\eta'} = \cos\phi_G\sin\varphi_P$$

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

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



present status, *JHEP 0907 (2009) 105*



with dominant η' BR's to 1%

Eur.Phys.J. C68 (2010) 619

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.

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

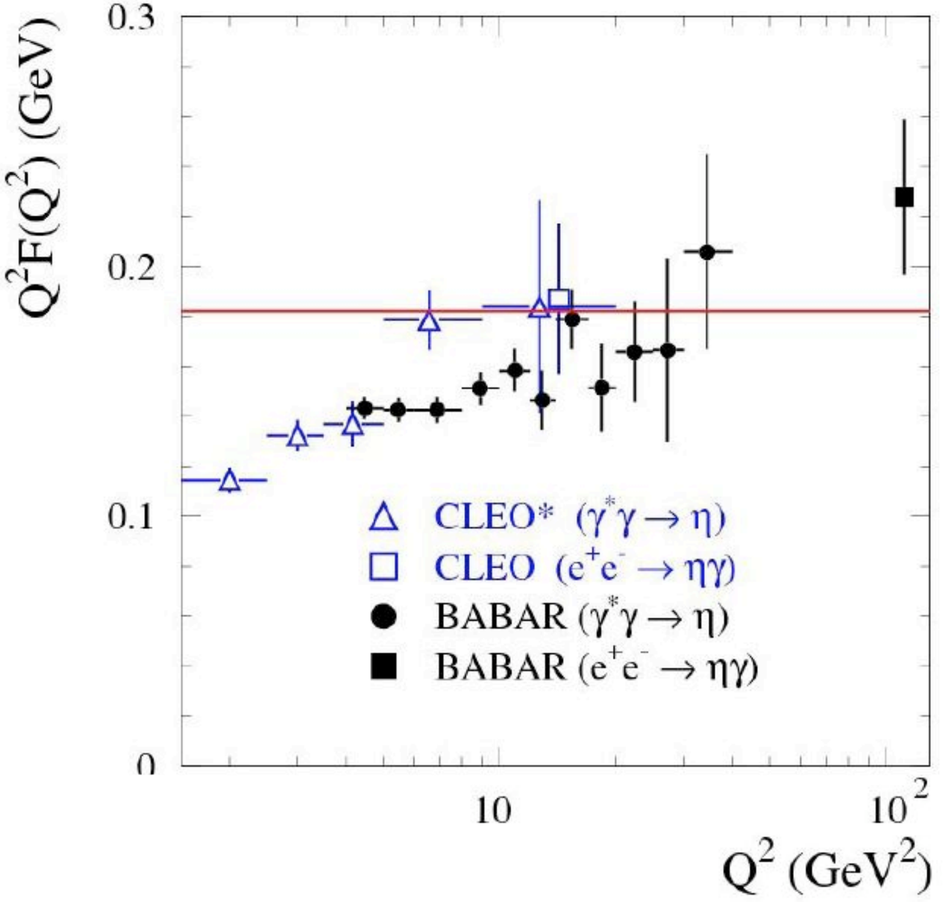
$$F(k_1^2, k_2^2) = \frac{m_\rho^4 - \frac{4\pi^2 F_\pi^2}{N_c}(k_1^2 + k_2^2)}{(m_\rho^2 - k_1^2)(m_\rho^2 - k_2^2)}$$

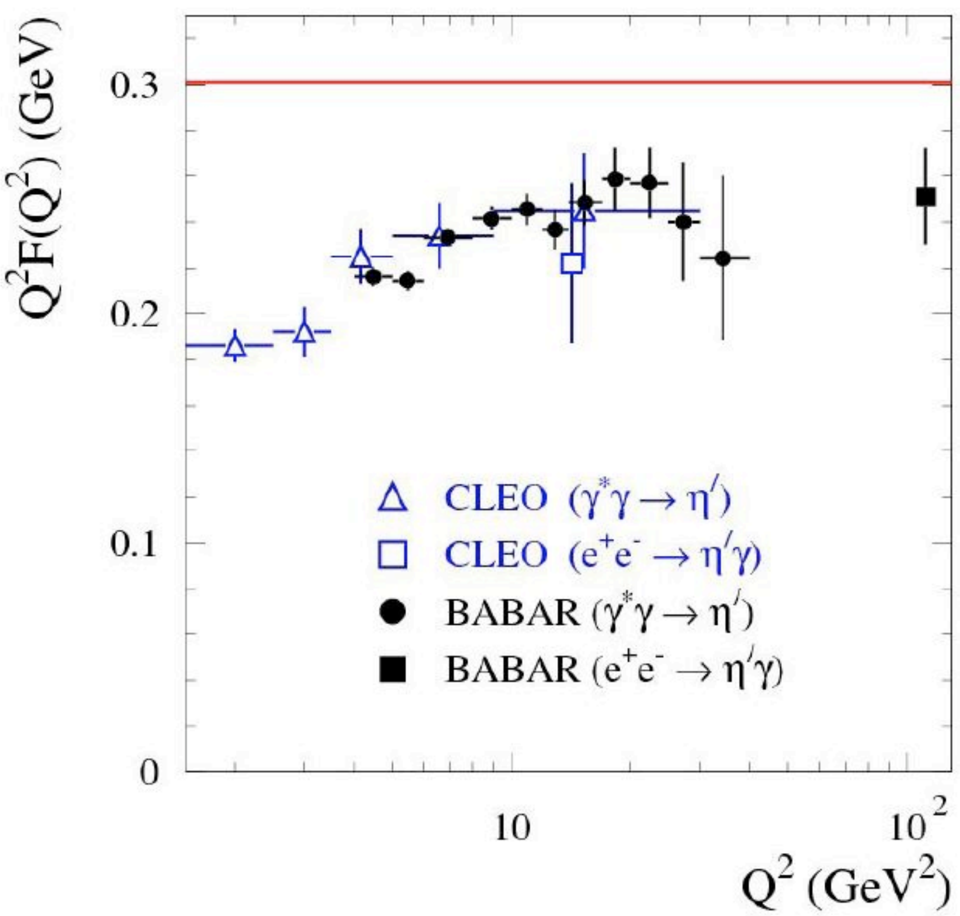
from F.Jegerlehner & A.Nyffeler, Phys. Rept,477(2009)1

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

Measuring η and η' did not clarify





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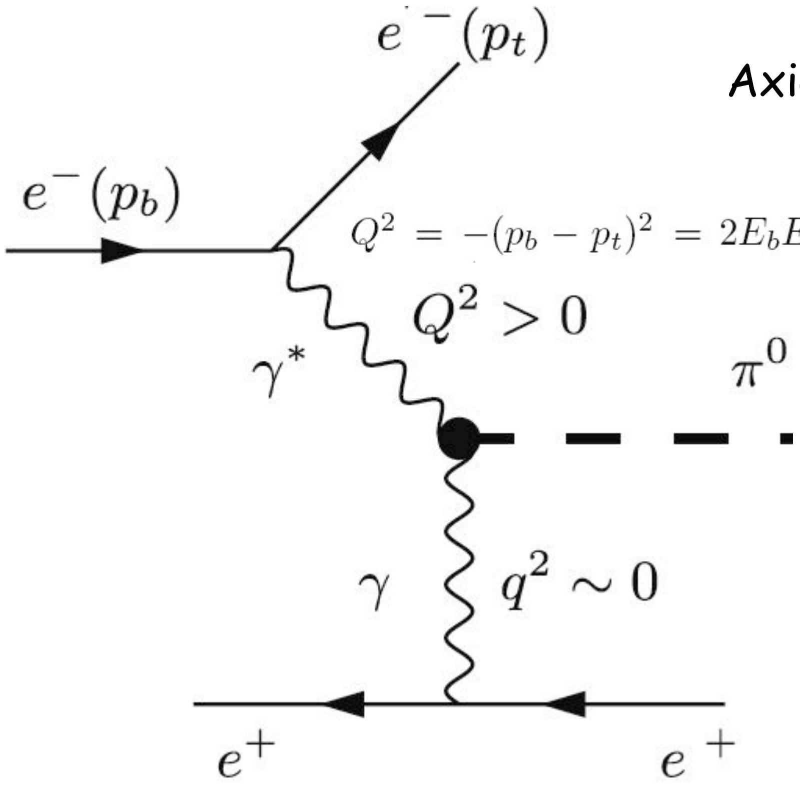
good agreement with CLEO in the overlapping regions

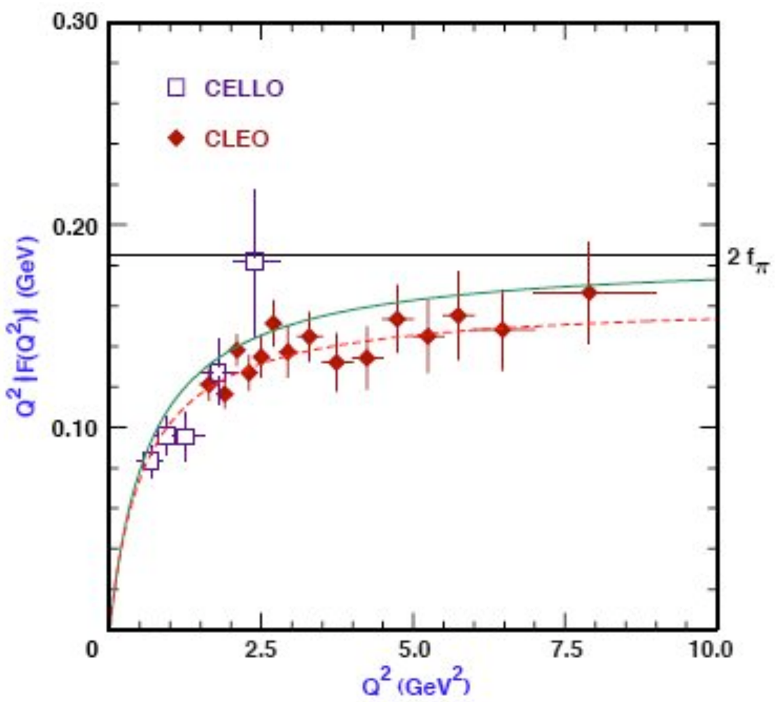
An example: π^0 transition form factor



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

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

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

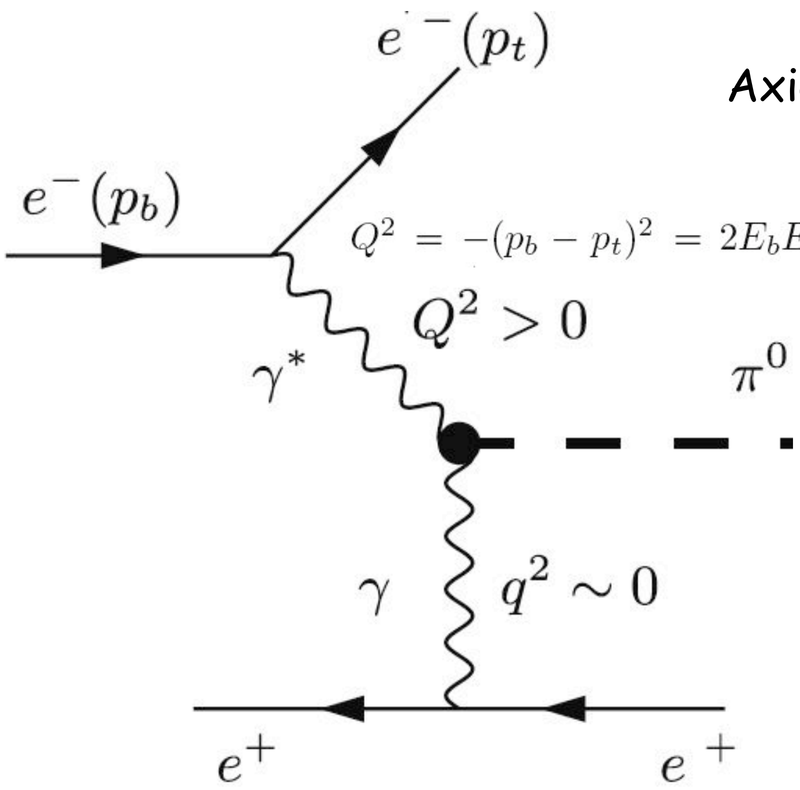


well known asymptotic limits from 1st principles,
how to interpolate? what about η, η' ?

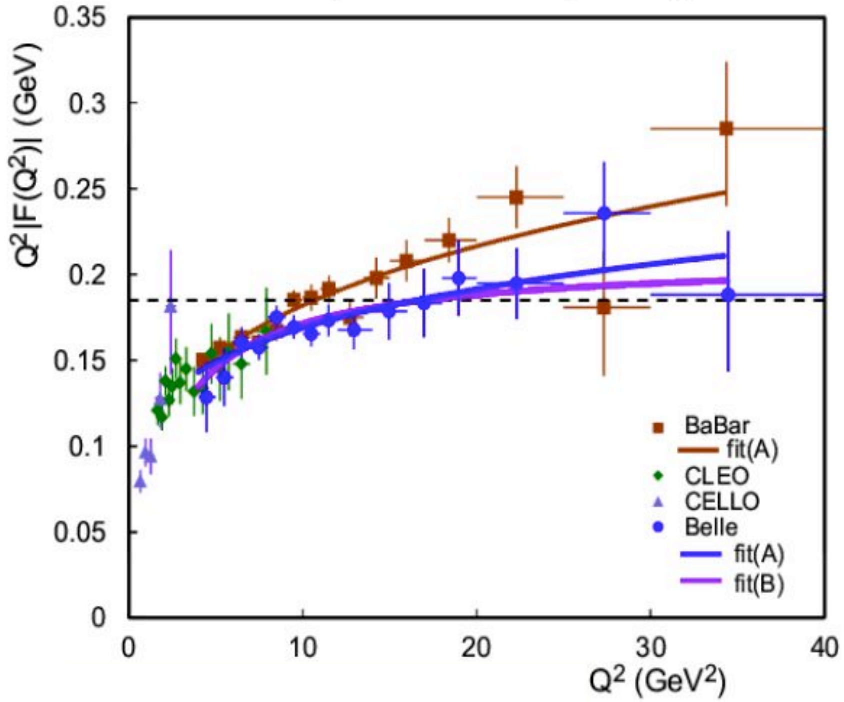
An example: π^0 transition form factor

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

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



Belle: Phys.Rev.D86 (2012) 092007



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