A Historical Retrospect of Two-Photon Physics in the 1980ies at DORIS, SPEAR, PETRA and PEP

A Prosperous Era of γγ Physics

Hermann Kolanoski
Humboldt-Universität zu Berlin and DESY

Novosibirsk 30 Years Ago

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Telefax
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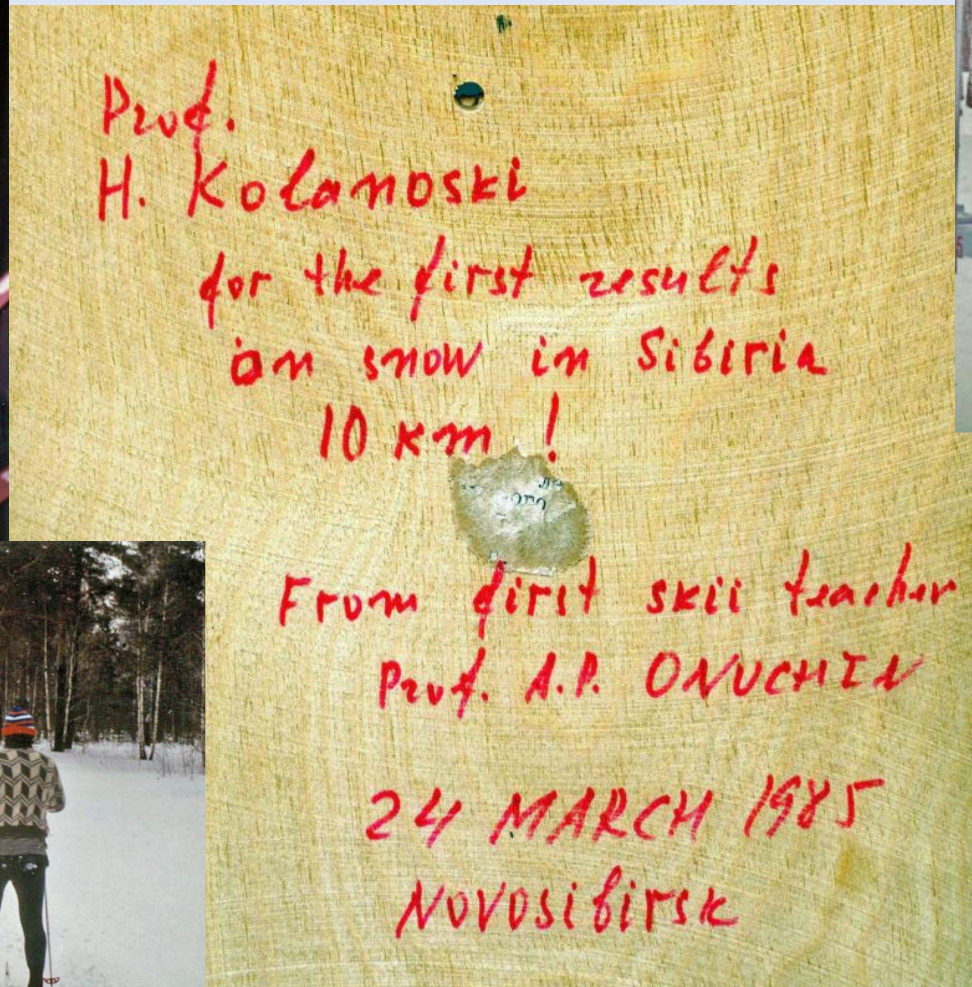
prof h kolanoski d-5300 cmnn
phys inst univ bonn nussallee 12
republique federale d'allemagne

xlad to wnvioe
you to visit the ussr.for two 1
pnfll in novosibirsk
in march 1985 stop we shall covar all expenses for
your stay in ussr including transportation inside
our country stop best regards

director nuclear physics institute novosibirsk
a n skrinsky

How to become сибиря́к – Siberian?



9th Intern. Workshop on Photon-Photon Collisions: San Diego 1992

An Experimentalists View of Two-Photon Physics

H. Kolanoski, Univ. Dortmund

4 years ago, the $\gamma\gamma$-Workshop in Shoresh summarized the PETRA and PEP era.

Purpose of this talk is to build a bridge from the $\gamma\gamma$-Workshops of the 70-80ties by recalling for the newcomers the

status of two-photon experiments

as of the Shoresh Workshop.

Reviews

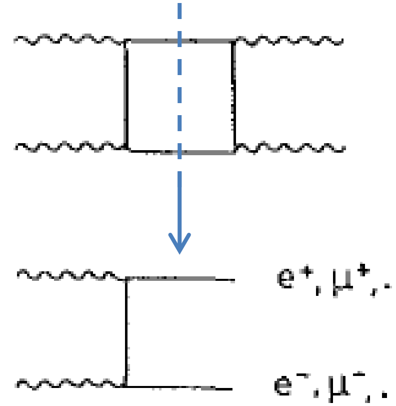
Proceedings of the International Workshops on Photon-Photon Collisions

- Sheffield, 1995
- San Diego, 1992
- Jerusalem, 1988
- Paris, 1986
- Lake Tahoe, 1984
- Aachen, 1983
- Paris, 1981
- Amiens, 1980
- Lake Tahoe, 1979
- Paris, 1973

- H. Kolanoski, Two-Photon Physics at e^+e^- Storage Rings, Springer Tracts in Mod. Phys. 105 (1984).
- Ch. Berger and W. Wagner, Photon Photon Reactions, Physics Reports 146 (1987)
- H. Kolanoski and Zerwas, Two Photon Physics, in Ali, A., Soeding, P. (Ed.): High Energy Electron-positron Physics, World Scientific (1988).

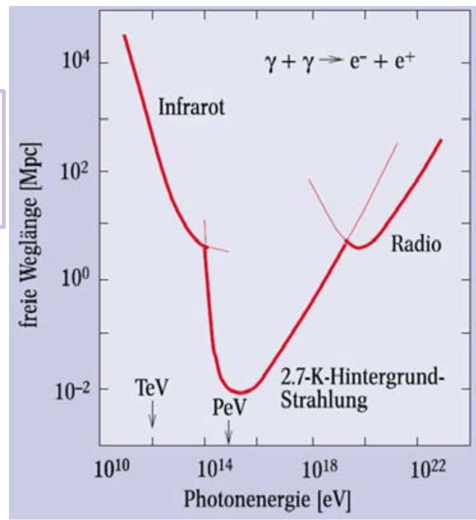
Pioneering Times of Two-Photon Physics

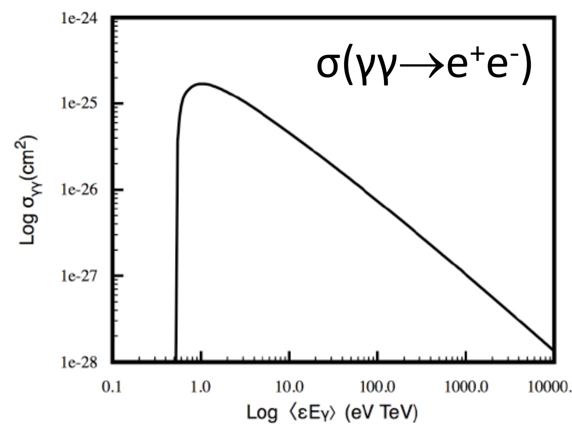
light-light scattering calculated in the 1930ies by Heisenberg's student Euler



first photon-photon reactions measured: beginning of 70ties

problem for VHE gamma astronomy:

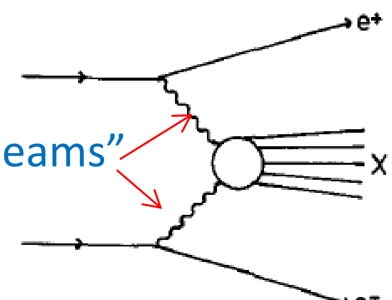




..... and on earth:

possible because of advent of e^+e^- storage rings

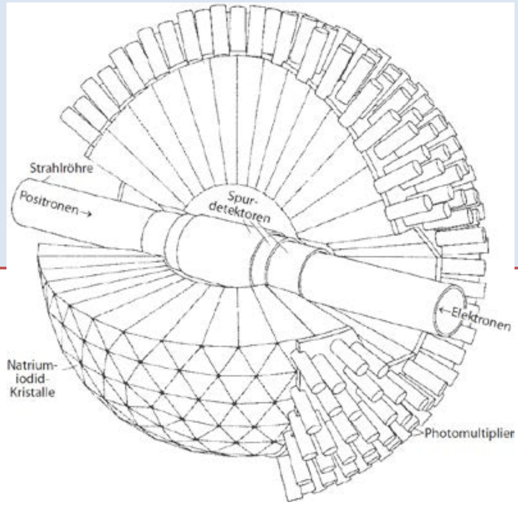
photon "beams"

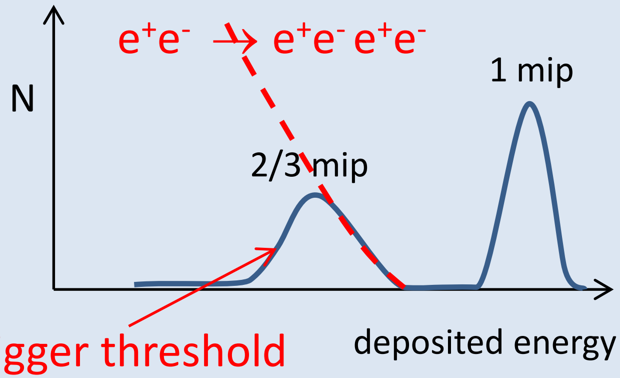


My First Encounter with Two Photon Physics

My first encounter with two photon reactions:

Quark Trigger in Crystal Ball experiment





... and the second encounter:
the Bonn group at the
TASSO experiment at the
storage ring PETRA in Hamburg

The PETRA/PEP Era of Two-Photon Physics

Machine	Running	Location	E_{beam} [GeV]	E_{cm} [GeV]
SPEAR	1972-1990	Stanford (USA)	4 + 4	8
DORIS	1973-1993	DESY (Hamburg)	5.6 + 5.6	11.2
CESR	1979-2002	Cornell (USA)	6 + 6	12
VEPP-4M	1994-	Novosibirsk	6 + 6	12
PETRA	1978-1986	DESY (Hamburg)	20 + 20	40
PEP	1980-1990	Stanford (USA)	15 + 15	30
TRISTAN	1987-1995	KEK (Japan)	32 + 32	74

- QED: γγ → lepton pairs
- C=+ meson resonances
- total cross section γγ → hadrons
- inclusive particle spectra
- hard scattering, high-p_T, jets
- structure of the photon

THE TWO-PHOTON PARTICLE PRODUCTION MECHANISM. PHYSICAL PROBLEMS. APPLICATIONS. EQUIVALENT PHOTON APPROXIMATION

our Bible

PHYSICS REPORTS 15, no. 4 (1975)

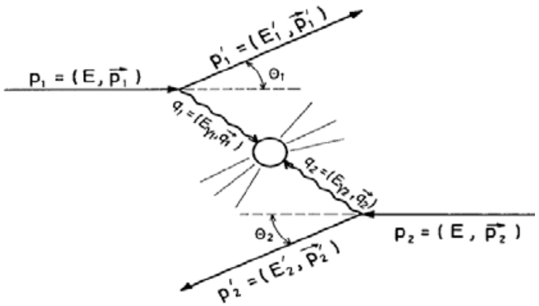
V.M. BUDNEV, I.F. GINZBURG, G.V. MELEDIN and V.G. SERBO

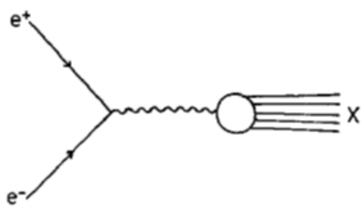
USSR Academy of Science, Siberian Division, Institute for Mathematics, Novosibirsk, USSR

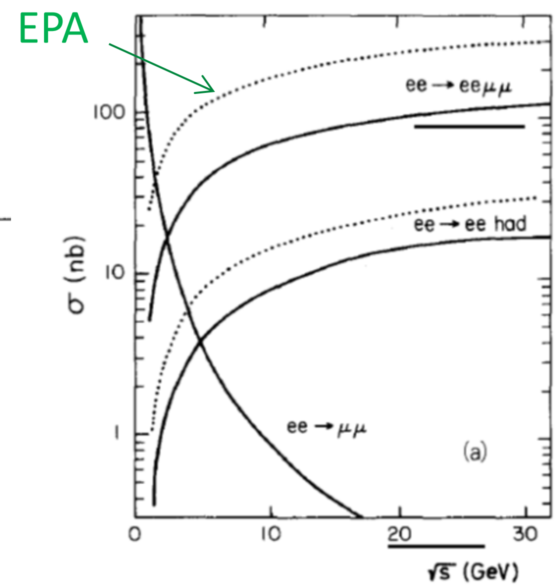
Basic and detailed theory in the 1970ies:

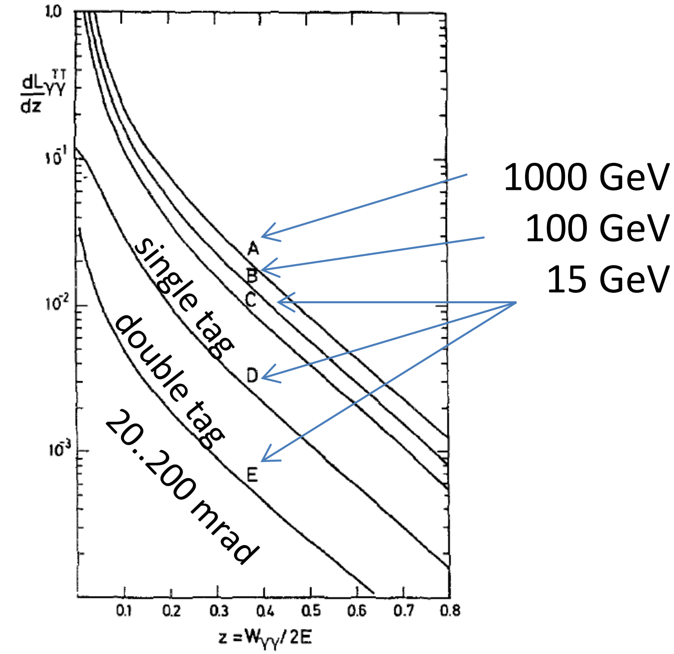
Kessler, Budnev et al., Walsh and Zerwas, Witten, Brodsky-Lepage, Bardeen&Buras . . .

Kinematics and Cross Sections









$$d\sigma(e^+e^-\to e^+e^-X) = \frac{\alpha^2\sqrt{(q_1q_2)^2-q_1^2q_2^2}}{32\pi^4\ E^2\ q_1^2q_2^2} \times \frac{d^3p'_1\ d^3p'_2}{E_1'\cdot E_2'} \times \qquad (2.14)$$

$$\times\left[\ 4\ \rho_1^{++}\rho_2^{++}\ \sigma_{TT} + 2\ \rho_1^{++}\rho_2^{00}\ \sigma_{TL} + 2\ \rho_1^{00}\rho_2^{++}\ \sigma_{LT} + \rho_1^{00}\rho_2^{00}\ \sigma_{LL}\right.$$

$$\left. + 2\ |\rho_1^{+-}\rho_2^{+-}|\ \tau_{TT}\ \cos2\tilde{\varphi} - 8\ |\rho_1^{+0}\rho_2^{+0}|\ \tau_{TL}\ \cos2\tilde{\varphi} + A\cdot\tau_{TT}^{a} + B\cdot\tau_{TL}^{a}\ \right].$$

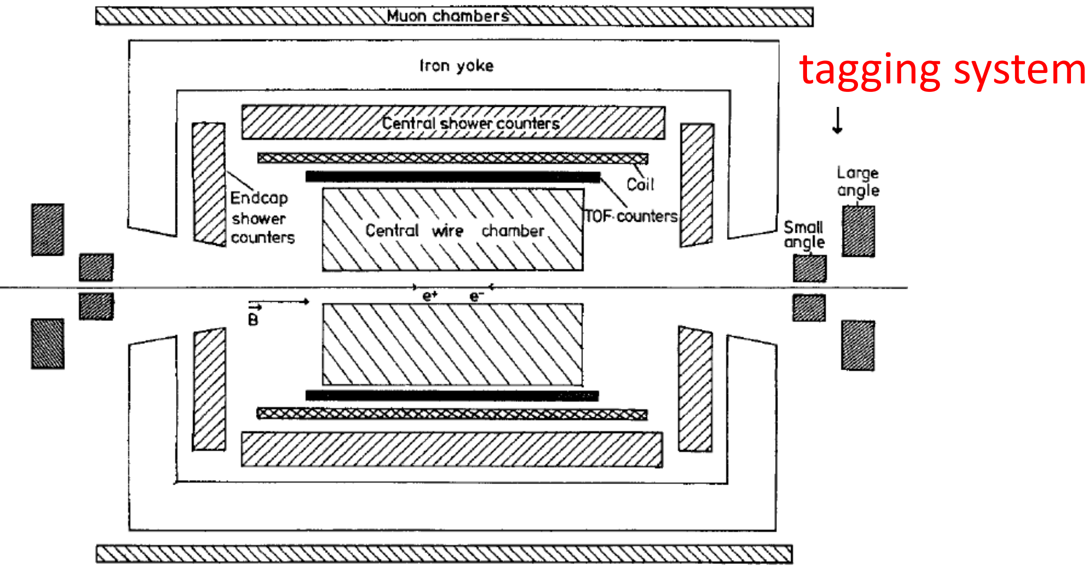
Only TT terms remain ≠0 at Q_i^2=0 (i=1,2)

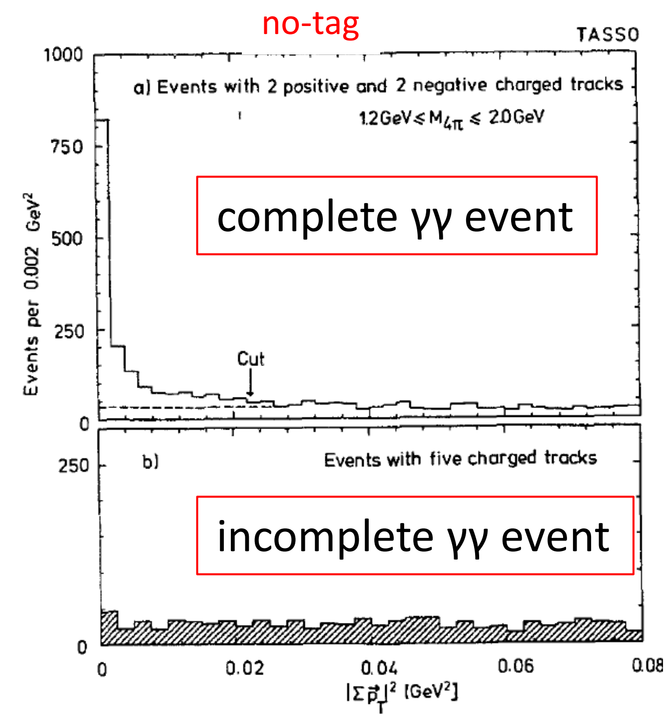
EPA (real photons):

$$\frac{d^2L_{\gamma\gamma}}{d\omega_1 d\omega_2} = \frac{dN_\gamma(\omega_1)}{d\omega_1}\ \frac{dN_\gamma(\omega_2)}{d\omega_2}$$

with the strengthening of computers the `**equivalent photon approximation**‘ (EPA) became less important for the actual analyses

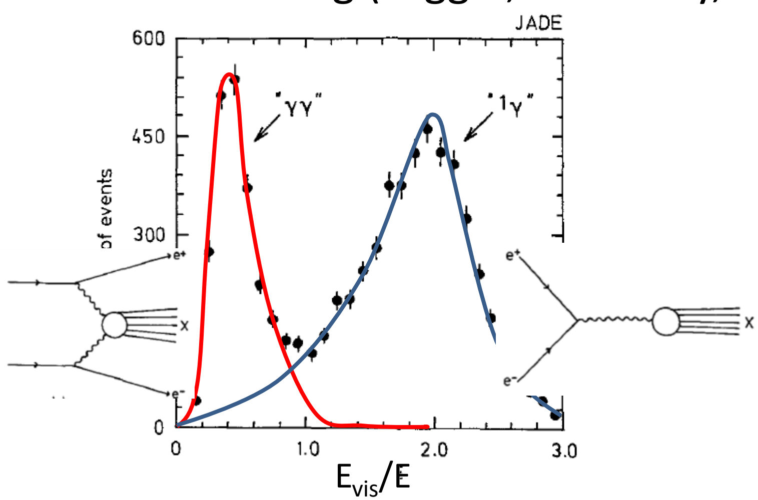
Experimental Characteristics

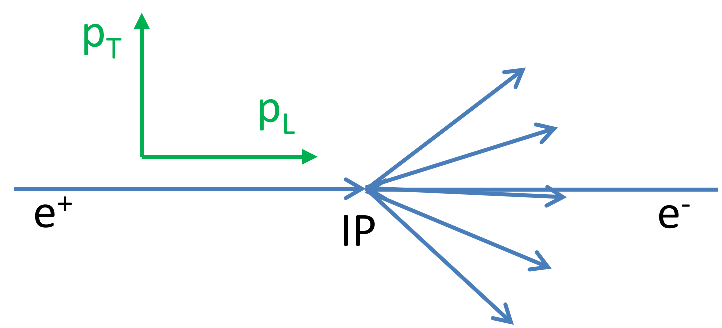




γγ versus 1γ:

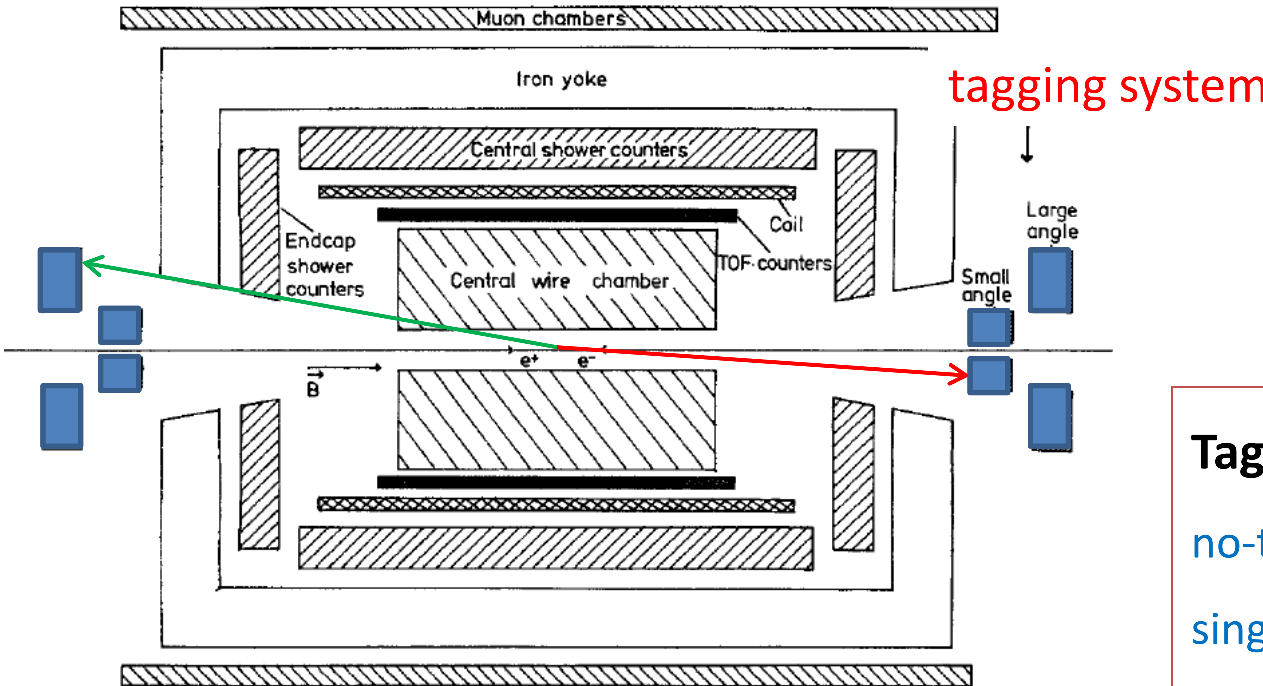
γγ more demanding (trigger, efficiency, …)





in general boosted with flat rapidity distribution

Experimental Characteristics: (No-)Tagging



- Selecting γγ events
- fixing Q^2

Tagging conditions:

no-tag: mostly 2 real photons

single tag: 1 real/1virtual photon

double tag: 2 virtual photons

0° tagging: real photons

double tag allows in principle determination of kinematics of γγ system e.g. for σ_{tot} measurements (usually not sufficient resolution)

A Bit of History of Events

Experim. highlights in $\gamma\gamma$ physics

- 1971 Novosibirsk + Frascati : 1st observation of $\gamma\gamma$-QED : $ee \to ee\ \ell^+\ell^-$
- 1979 Mark II (SPEAR) : $\gamma\gamma \to \eta'$
- 1980 PLUTO (PETRA) : $\gamma\gamma \to f_2(1270)$
- 1980 TASSO (PETRA) : $\gamma\gamma \to \rho^0\rho^0$ $(qq\bar{q}\bar{q}?)$
- 1981 PLUTO (PETRA) : $\sigma_{TOT}(\gamma\gamma \to hadrons)$
- 1981 TASSO + JADE : $\gamma\gamma \to jets$
- 1981 PLUTO : F_2^{γ}

⋮ (phase of detailed work)

- 1986 TPC/$\gamma\gamma$ (PEP) : $\gamma^*\gamma \to f_1(1420)$

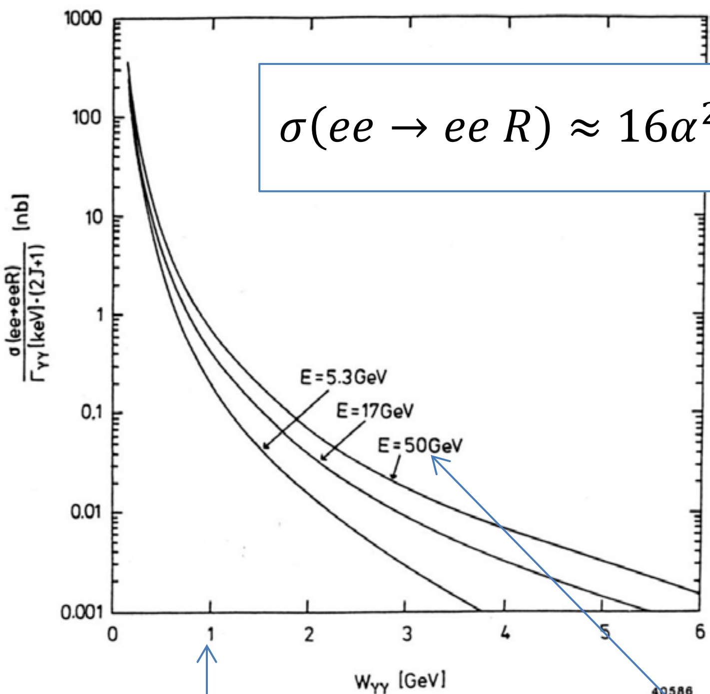
From

QED

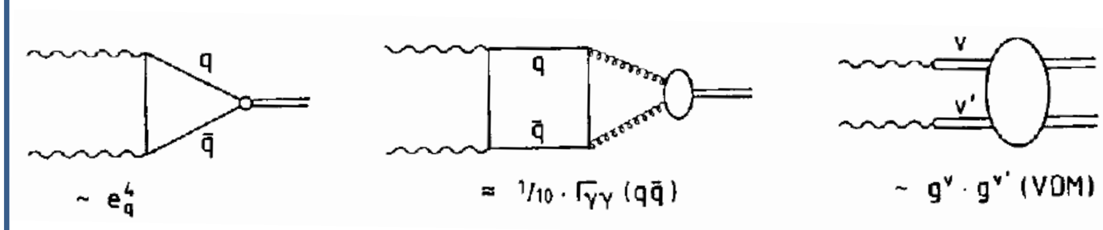
to

QCD

Gamma-Gamma Couplings to Resonances



$$\sigma(ee \to ee\ R) \approx 16\alpha^2 \left(\log \frac{E}{m_e}\right)^2 \mathrm{f}\left(\frac{M_R}{2E}\right) \frac{(2J+1)\Gamma_{\gamma\gamma}}{{M_R}^2}$$



quark states glueballs 4-quark states

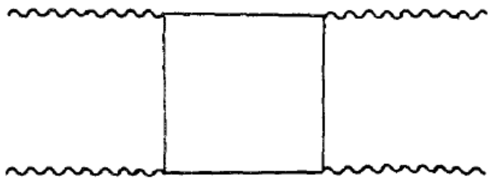
in the resonance range not much dependence on machine energy

at higher energies more boosted energy

Goal: clarify meson systematics

- quark (or other) content
- singlet-octet mixing
- glueballs?
- 4-quark states?
- . . . .

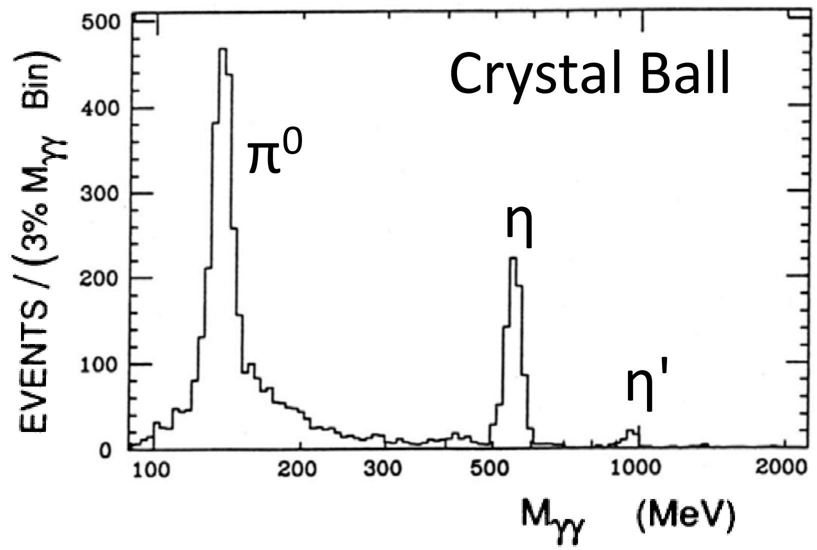
Resonances in $\gamma\gamma \to \gamma\gamma$



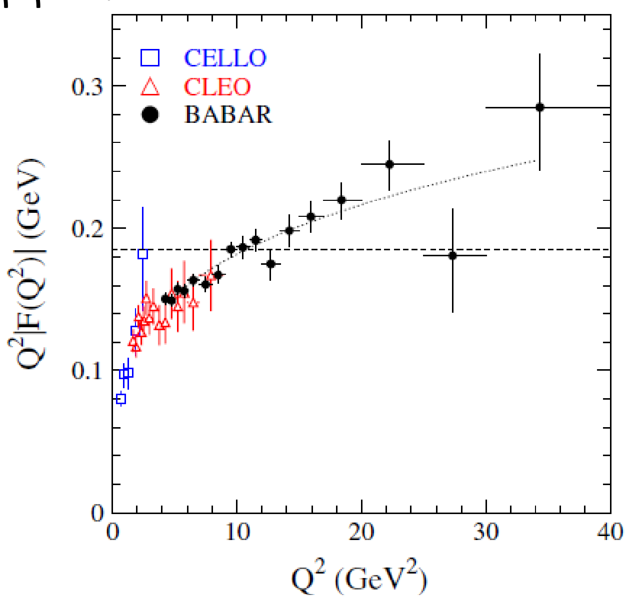
$$\Gamma_{\pi^\circ\to\gamma\gamma} = 7.7 \pm 0.5 \pm 0.5 \text{ eV}$$

$$\Gamma_{\eta\to\gamma\gamma} = 0.514 \pm 0.017 \pm 0.035 \text{ keV}$$

$$\Gamma_{\eta'\to\gamma\gamma} = 4.7 \pm 0.5 \pm 0.5 \text{ keV}$$

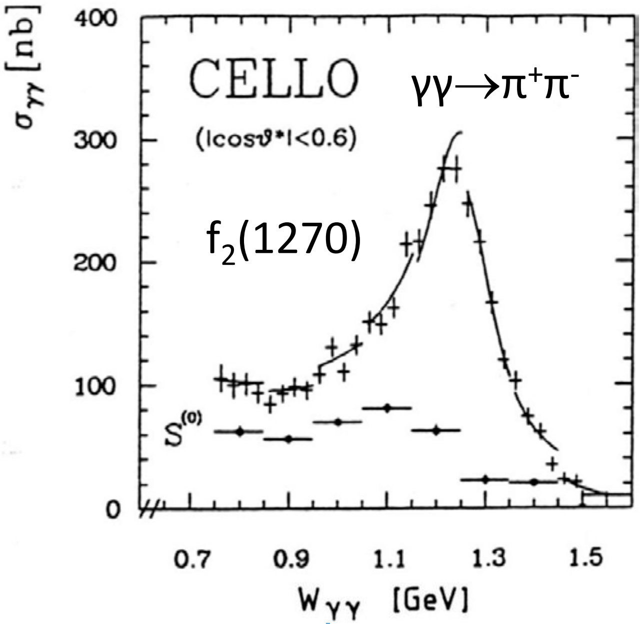


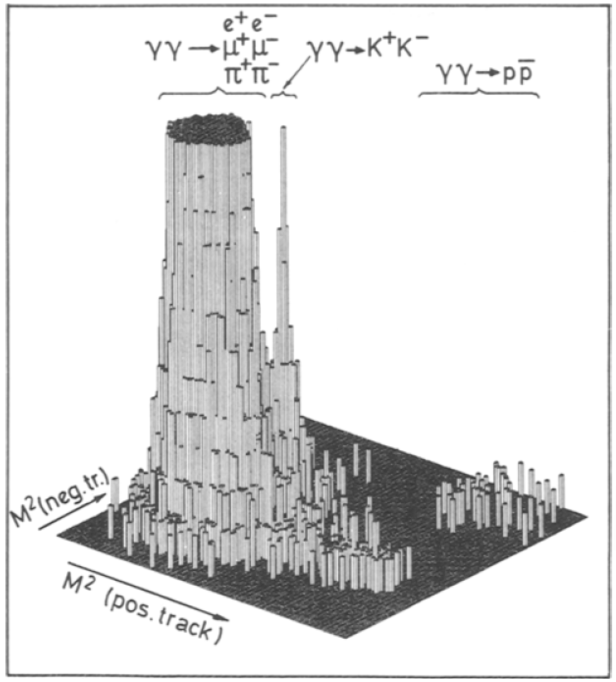
$\gamma\,\gamma^* \to \pi^0$ transition form factor

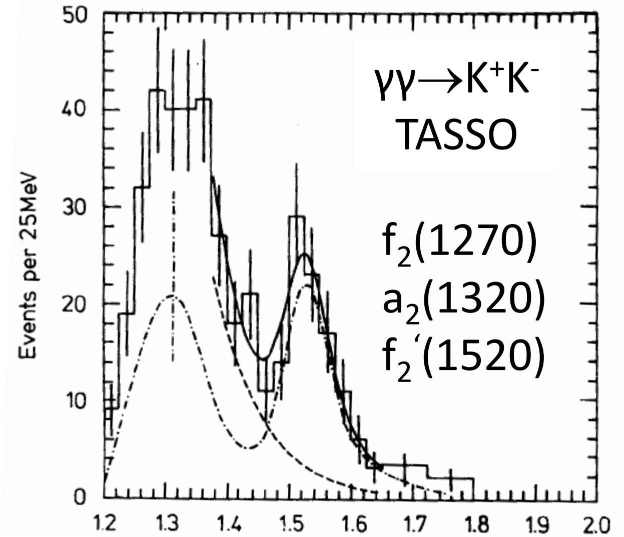


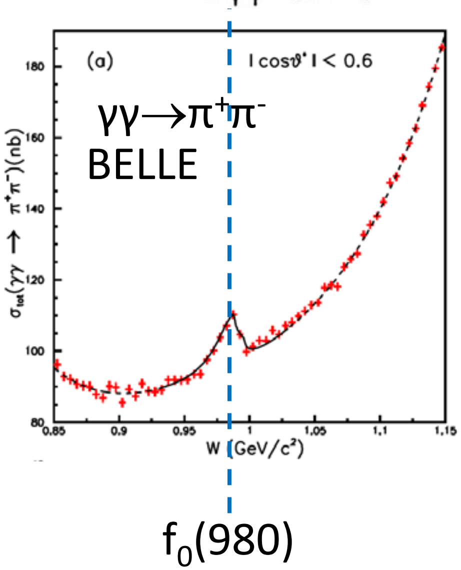
- quark content
- singlet-octet mixing
- $\Gamma(\gamma\gamma\to\eta')$ excludes Han-Nambu model of integer quark charges

Resonances Decaying into π, K, p Pairs

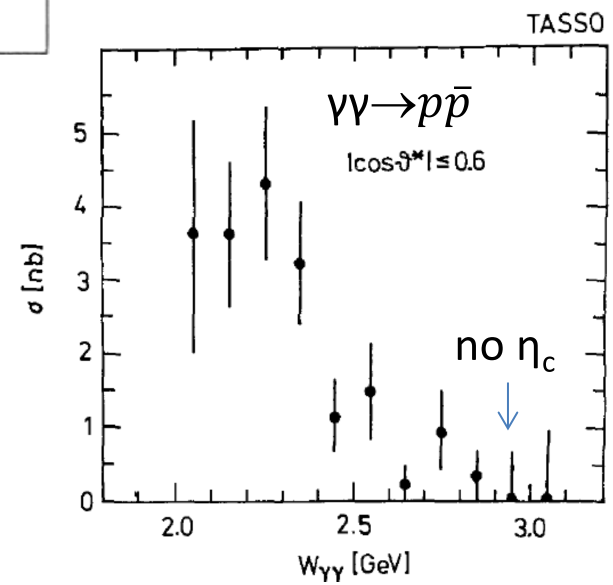








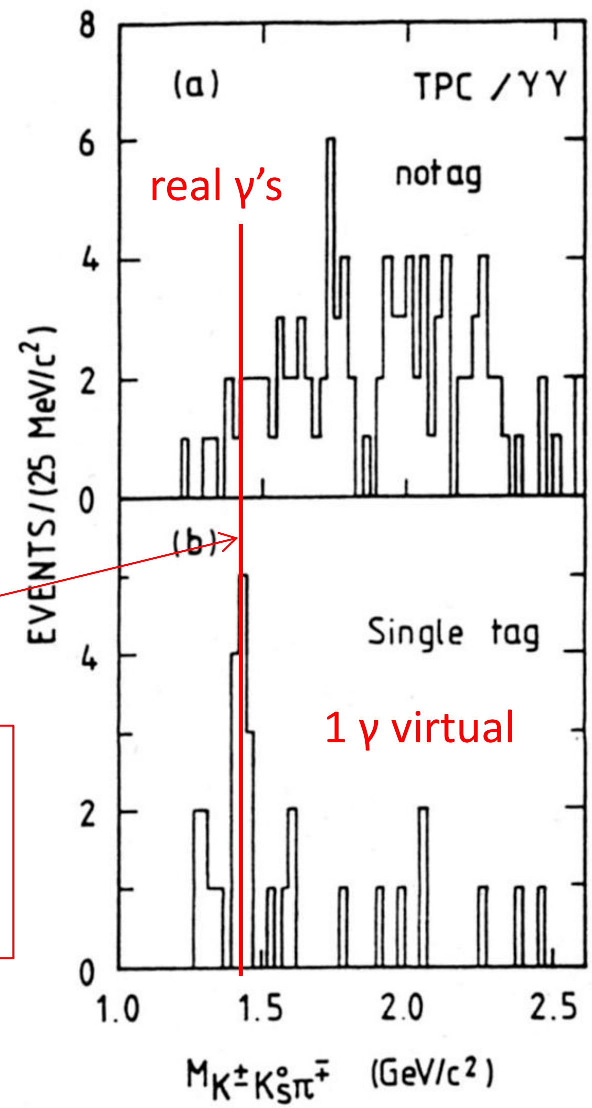
demonstrates the enormous statistics at BELLE (& BaBar)



Gamma-Gamma Couplings to Axial Vectors

Landau-Yang Theorem:

Particle (J=1) $\rightarrow \gamma\gamma$ forbidden for real photons



if qq it must be an axial vector state $J^{PC} = 1^{++}$

$f_1(1420)$ could be the mainly ss partner of the $f_1(1285)$ (seen also in tagged $\gamma\gamma^*$ by MARK II)

γγ Couplings for $J^{PC} = 0^{-+}, 0^{++}, 2^{++}$

Plenty of results……

0^{-+}

Two photon decay width of 0^{-+} states as measured in 2γ experiments

Res.	$\Gamma_{\gamma\gamma}$ [keV]		Ref.	Remark
π^0	$(7.9 \pm 1.4 \pm 1.6) \times 10^{-3}$		Crystal Ball [3.7]	prel.
η	$0.56 \pm 0.12 \pm 0.1$		Crystal Ball [3.8]	
	$0.64 \pm 0.14 \pm 0.13$		TPC/2γ [3.9]	
	$0.58 \pm 0.02 \pm 0.06$		Crystal Ball [3.10]	prel.
	$0.53 \pm 0.04 \pm 0.04$		JADE [3.11]	
	Average: 0.56 ± 0.04			
η'(958)	$5.8 \pm 1.1 \pm 1.2$		Mark II [3.12]	
	$6.2 \pm 1.1 \pm 0.8$		CELLO [3.13]	
	$5.0 \pm 0.5 \pm 0.9$		JADE [3.14]	
	$5.1 \pm 0.4 \pm 0.7$		TASSO [3.15]	
	$3.8 \pm 0.26 \pm 0.43$		PLUTO [3.16]	
	3.8 ± 0.5		Mark II [3.17]	prel.
	$4.5 \pm 0.3 \pm 0.6$		TPC/2γ [3.18]	prel.
	Average: 4.3 ± 0.27			
ι(1440)	<1.0	95% CL	TASSO [3.19]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \rho^0\rho^0)$
	<2.0	90% CL	Mark II [illegible]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K\bar{K}\pi)$
	<1.5	95% CL	TASSO [3.15]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \rho^0\gamma)$
	<2.2	95% CL	TASSO [3.20]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K\bar{K}\pi)$
	<1.5	95% CL	TPC/2γ [3.21]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K^0_s K^\pm \pi^\mp)$
η_c(2980)	$0.5^{+0.2}_{-0.1} \pm 0.1$		PLUTO [3.22]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K^0_s K^\pm \pi^\mp)$
	<0.32	95% CL	TASSO [3.23]	$\Gamma_{\gamma\gamma} \cdot BR(R \to p\bar{p})$
	<4.4	95% CL	TASSO [3.20]	$\Gamma_{\gamma\gamma} \cdot BR(R \to KK\pi)$

2^{++}

Two photon decay width of 2^{++} states as measured in 2γ reactions

Res.	$\Gamma_{\gamma\gamma}$ [keV]		Ref.	Remark
f(1270)	$2.3 \pm 0.5 \pm 0.3$		PLUTO [3.24]	
	$3.2 \pm 0.2 \pm 0.6$		TASSO [3.25]	
	$3.6 \pm 0.3 \pm 0.5$		Mark II [3.26]	
	$2.7 \pm 0.2 \pm 0.6$		Crystal Ball [3.27]	
	$2.5 \pm 0.1 \pm 0.5$		CELLO [3.28]	
	$2.52 \pm 0.13 \pm 0.38$		Mark II [3.29]	
	$2.7 \pm 0.05 \pm 0.02$		DELCO [3.30]	
	$2.85 \pm 0.25 \pm 0.5$		PLUTO [3.31]	
	$3.2 \pm 0.1 \pm 0.4$		TPC/2γ [3.32]	
	Average 2.78 ± 0.14			
A_2(1320)	$0.77 \pm 0.18 \pm 0.27$		Crystal Ball [3.27]	
	$0.81 \pm 0.19 \pm 0.27$		CELLO [3.13]	
	$1.06 \pm 0.18 \pm 0.19$		PLUTO [3.35]	
	$1.14 \pm 0.20 \pm 0.26$		Crystal Ball [3.36]	
	$0.9 \pm 0.27 \pm 0.16$		TASSO [3.37]	
	Average 0.95 ± 0.14			
f'(1525)	$0.11 \pm 0.02 \pm 0.04$		TASSSO [3.38]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K\bar{K})$
	<0.28	95% CL	TPC/2γ [3.32]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K\bar{K})$
θ(1690) (= f_2(1720))	<0.28	95% CL	TASSO [3.20]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K\bar{K})$
	<1.2	95% CL	TASSO [3.19]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \rho^0\rho^0)$
	<0.3	95% CL	Crystal Ball [3.39]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \eta\eta)$
	<0.1	95% CL	TPC/2γ [3.32]	$\Gamma_{\gamma\gamma} \cdot BR(R \to K^+K^-)$

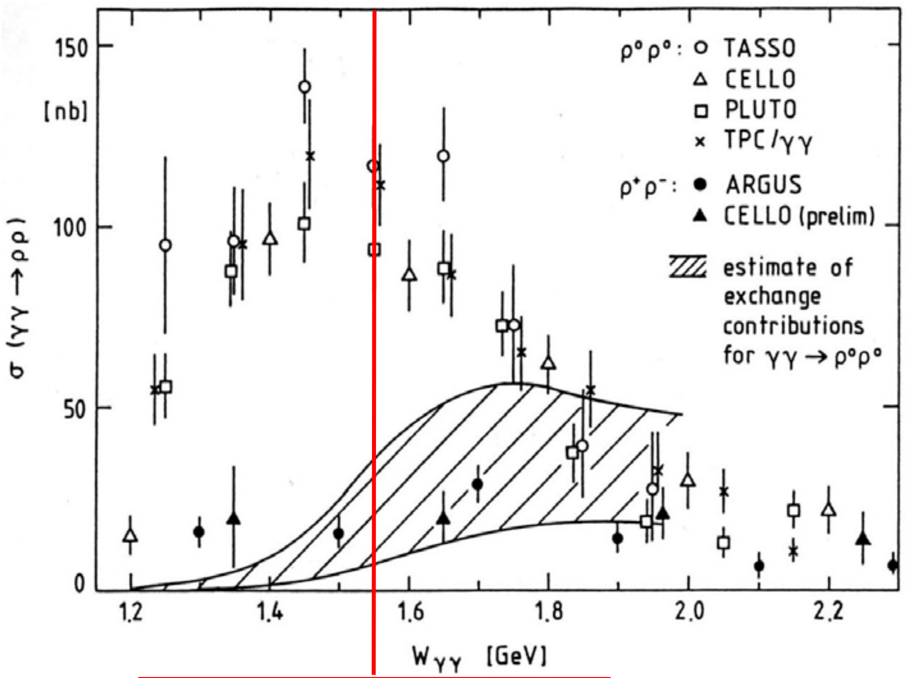
from Berger & Wagner

0^{++}

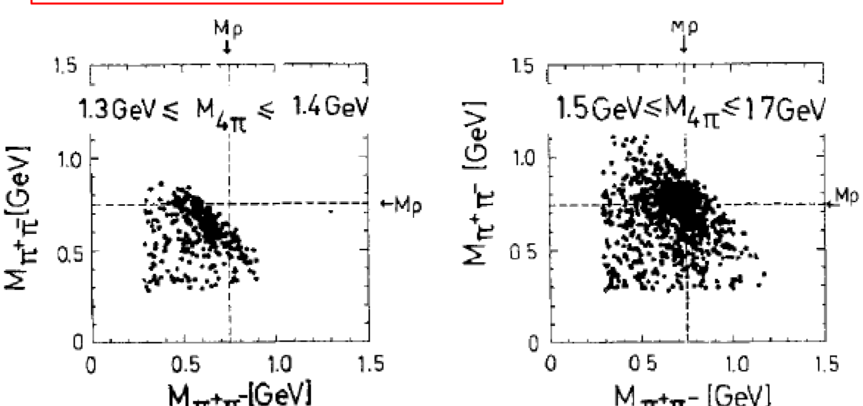
Two photon decay width of 0^{++} states as measured in 2γ reactions

Res.	$\Gamma_{\gamma\gamma}$ [keV]		Ref.	Remark	
S*(975)	<1 keV	95% CL	Crystal Ball [3.27]		f_0(975)
δ(980)	$0.19 \pm 0.07^{+0.10}_{-0.07}$		Crystal Ball [3.36]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \delta \to \eta\pi)$	a_0(980) see PDG 86 p.4
ε(1300)	<1.5 keV	95% CL	TASSO [3.25]	$\Gamma_{\gamma\gamma} \cdot BR(R \to \pi\pi)$	f_0(1300)

Vector Meson Pairs Near Threshold



nominal ρρ threshold



It looks as if there is a resonant $\rho^0\rho^0$ state below threshold.

Why not in $\rho^+\rho^-$?

4-quark model: I=0 & I=2 interference;

VDM same pattern but no enhancement

4-quark model predicts spin-parity and resonances in other

$\gamma\gamma \to VV'$ (V, V' = ρ, ω, ϕ)

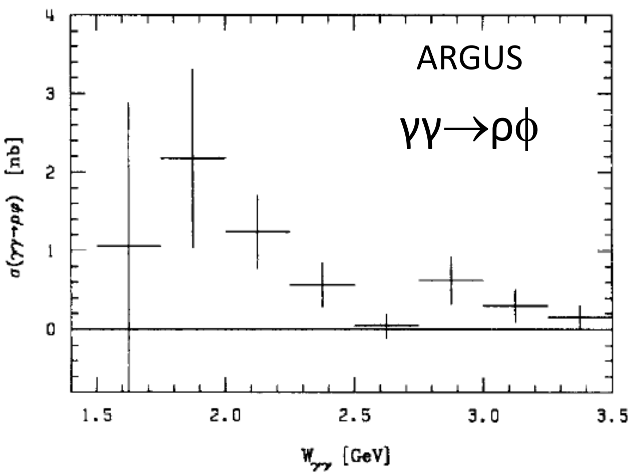
Some predictions work - others not (e.g. for $\gamma\gamma \to \rho\phi$)

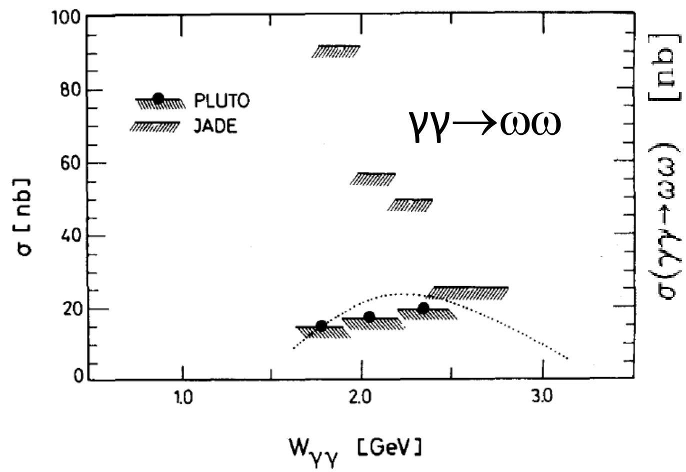
Vector Meson Pairs: 4-Quark States?

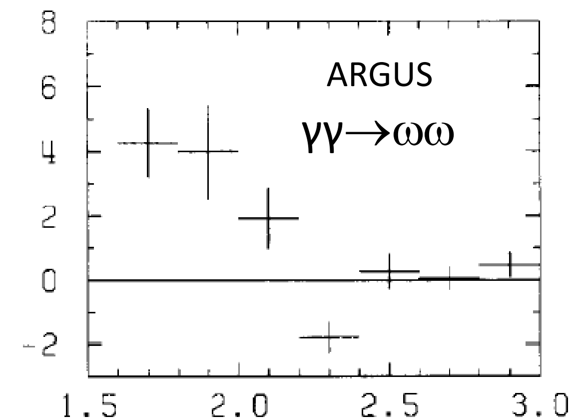
Model	Ref.	$\rho^0\rho^0$	$\rho^+\rho^-$	$\omega\omega$	$\rho^0\omega$	$\phi\phi$	$\rho\phi$
VDM (γV-coupling)		1	0	1/81	1/9	4/81	2/9
Quark model	[4.12]	1	4/25	–	–	4/25	–
Resonance ($I=0$)		1	2	–	0	–	0
$qq\bar{q}\bar{q}$	[4.10]	1	~0	~0.03	~0.6	~0.05	~0.6
$qq\bar{q}\bar{q}$	[4.11]	1	~0	~0.06	~0.03	~0.01	~0.1
t channel factorization	[4.13]	1	small	small	small	<0.01	<0.01

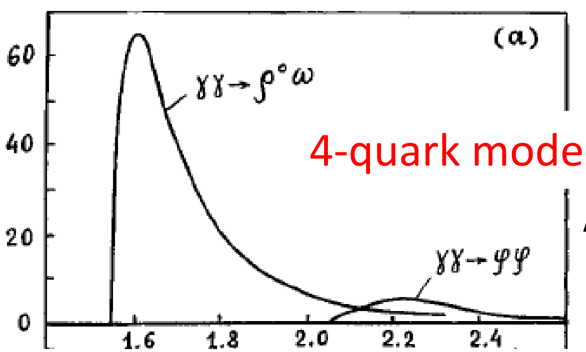
from Berger&Wagner

- all are measured
- result not conclusive





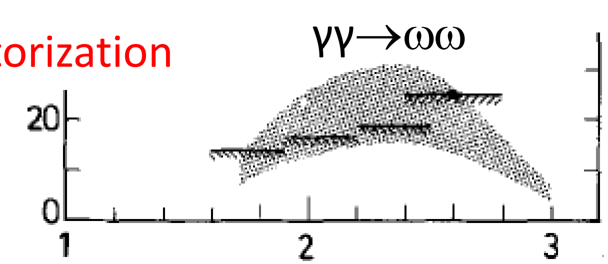




disagreement with

4-quark model

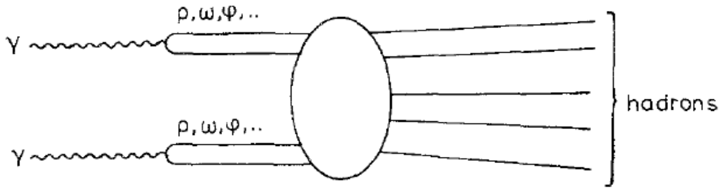
factorization



Achasov et al. 82: ~70 nb

Alexander et al.: >15 nb

Two-Photon Total Cross Section



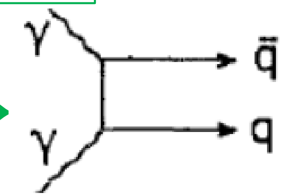
Extremely difficult to reconstruct $W_{\gamma\gamma}$ because of γγ boost and the soft phase space with

$$\boxed{d\sigma/dp_T^2 \sim \exp(-6p_T)}$$

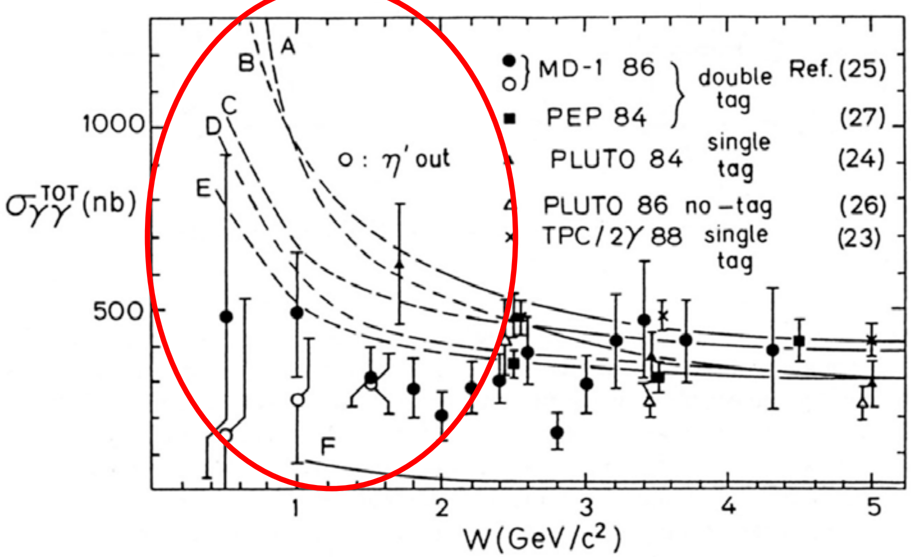
prediction from Regge theory:

$$\sigma(\gamma\gamma\rightarrow\text{hadrons}) = \sigma_0 + \sigma_1/W_{\gamma\gamma} \approx 240\text{ nb} + 270\text{ nb GeV}/W_{\gamma\gamma}$$

? →

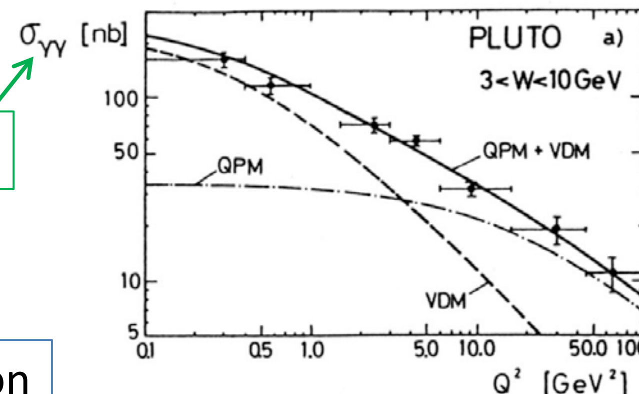


?



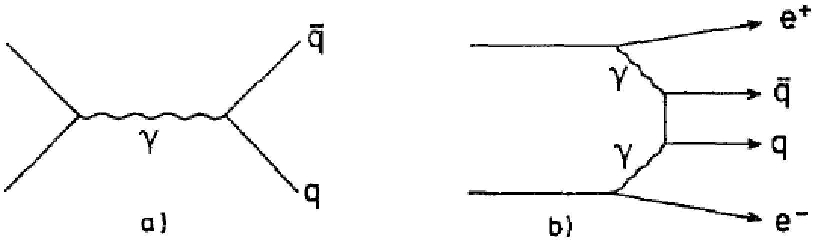
in the GeV region measurements remained inconclusive

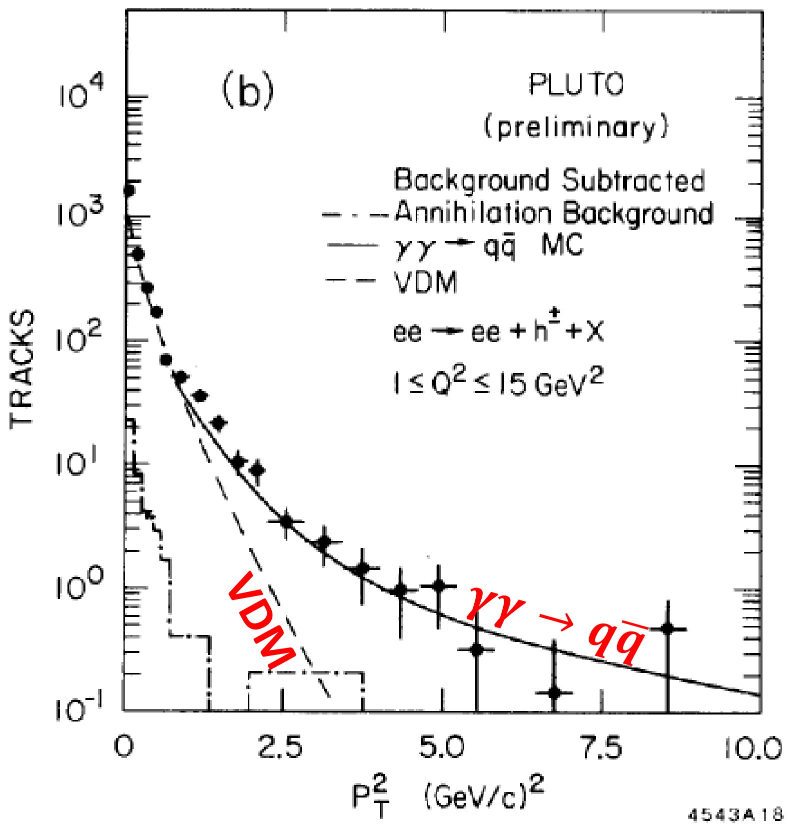
$\sim F_2^\gamma$

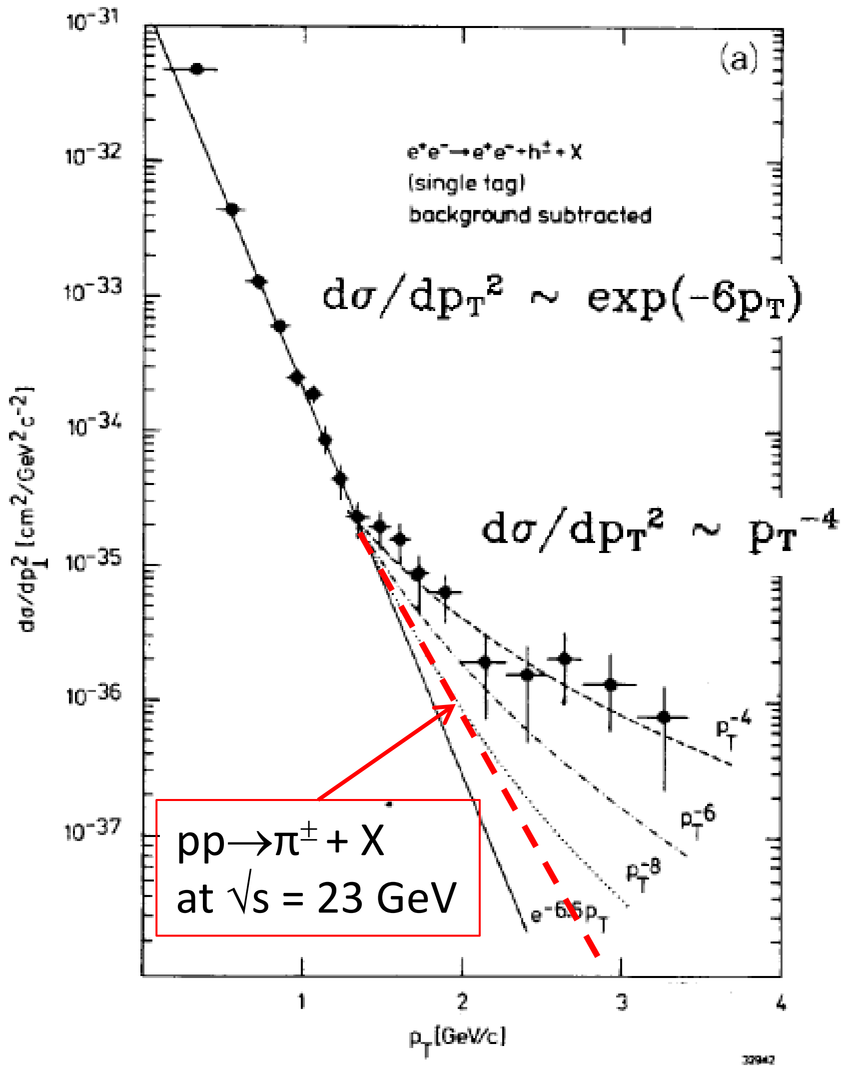


at high Q^2 hard parton interactions become more important

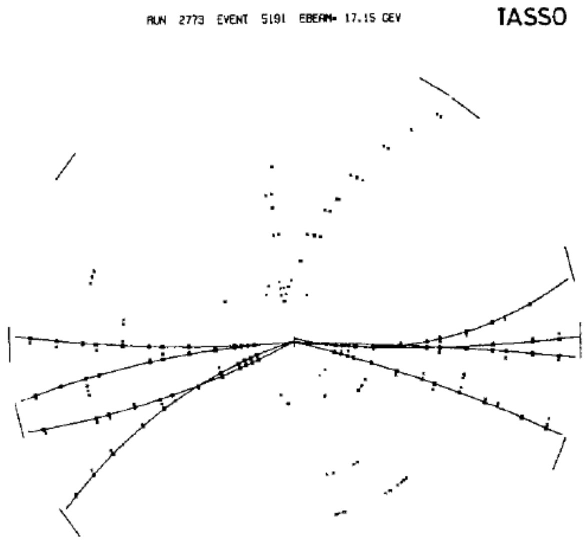
Inclusive Particle Spectra



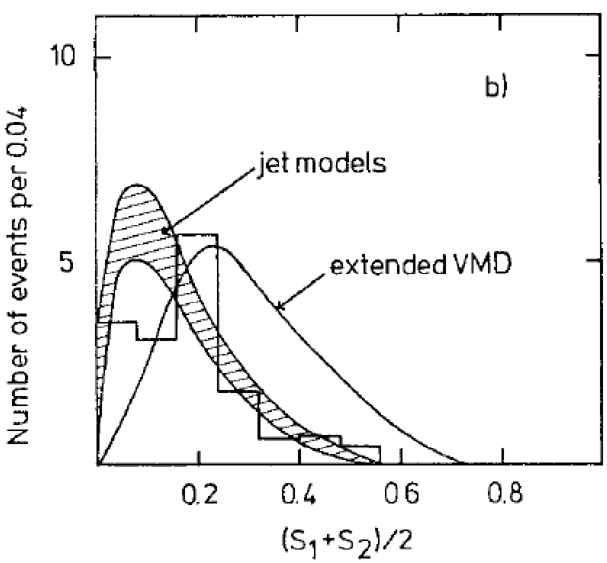




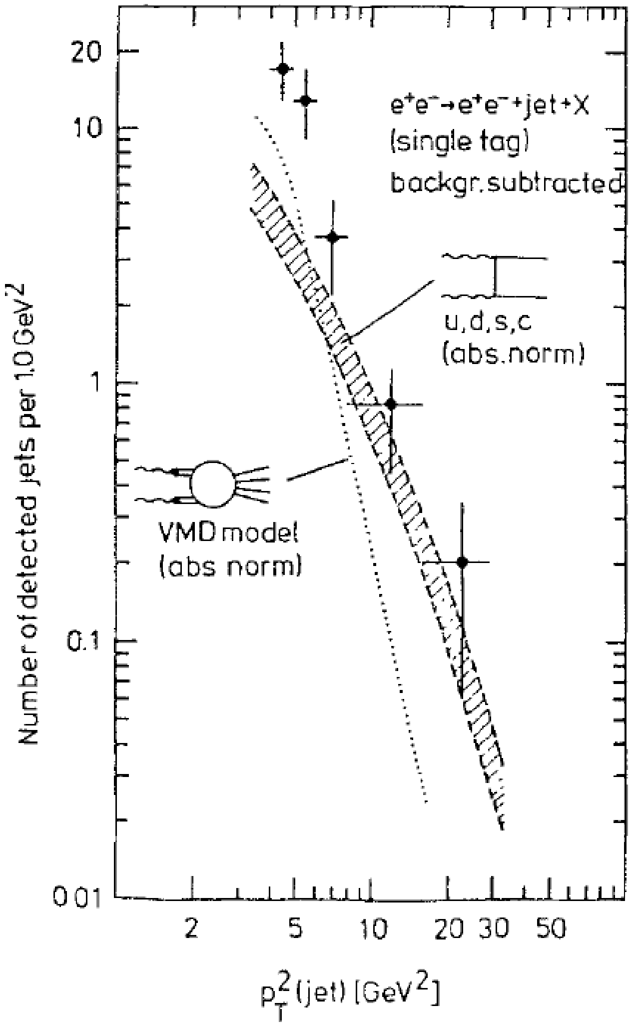
Production of High-p_T Jets



difficult to distinguish
from phase space
at low energies



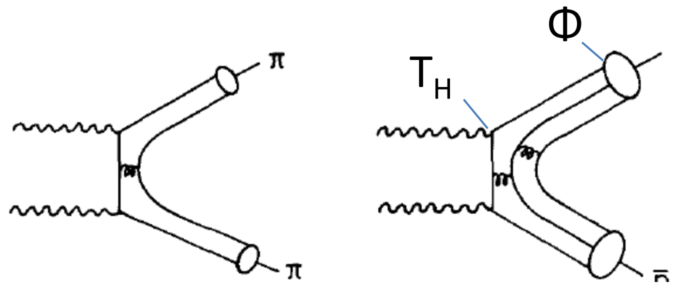
small sphericity
$\Rightarrow$ slim jets



Brodsky-Lepage: Hadron Pairs

hard-soft factorisation

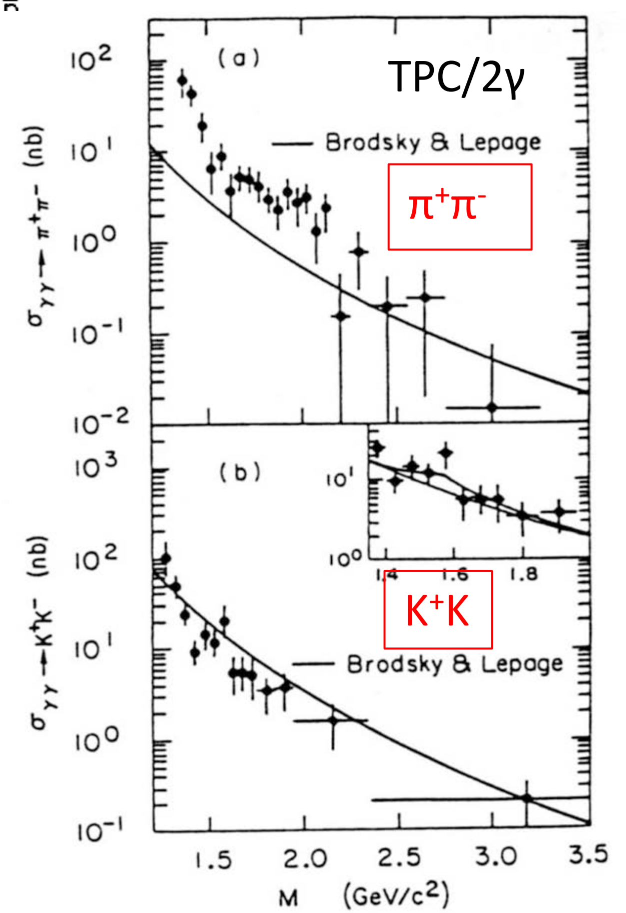
$$\boxed{ME \sim \Phi\, T_H\, \Phi^*}$$



quark counting rules

$\sim s_{\gamma\gamma}^{-4}$

$\sim s_{\gamma\gamma}^{-6}$

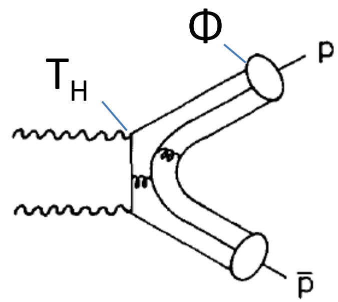


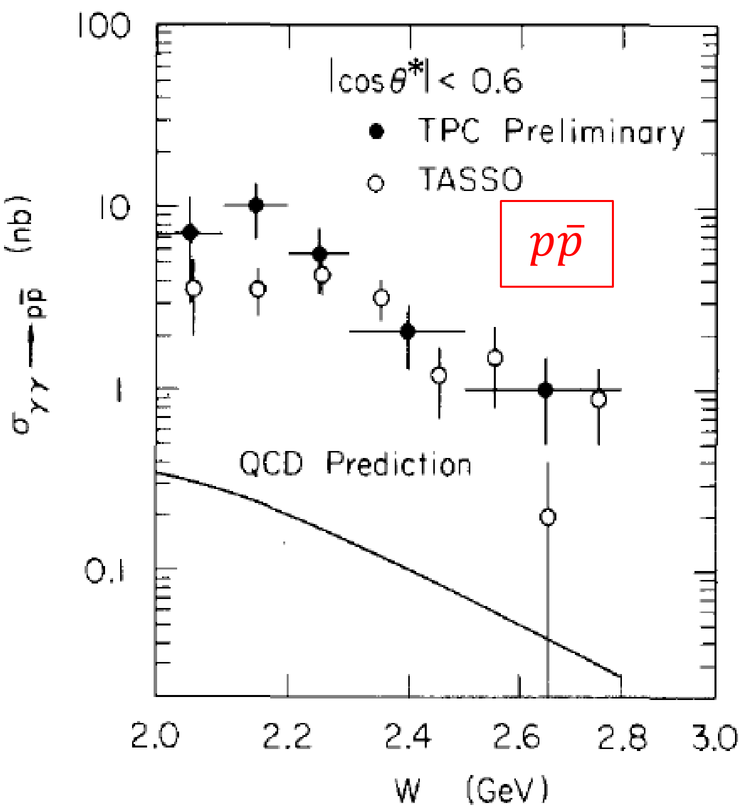
Predictions:

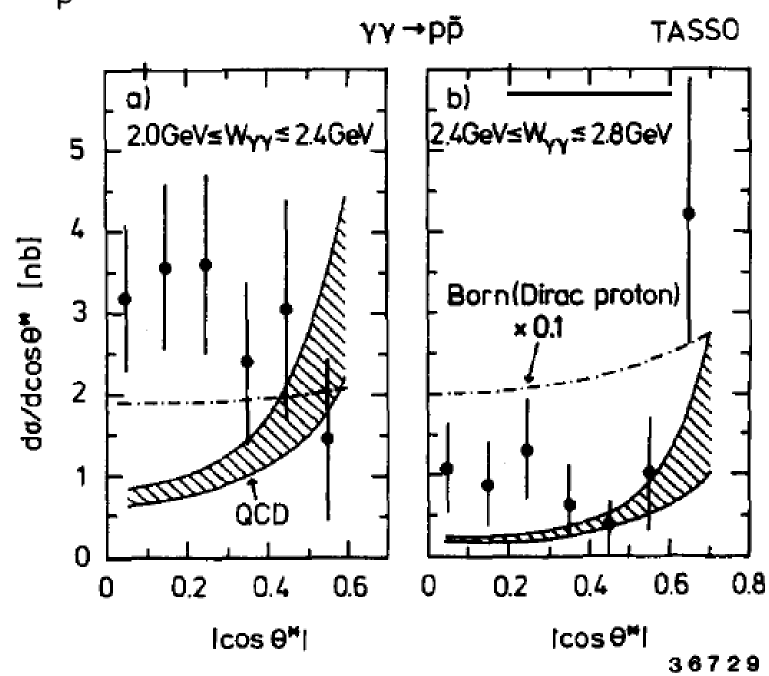
- energy dependence
- angular distribution
- absolute normalization

for meson pairs above ~2.5 GeV QCD ok

Brodsky-Lepage: Baryon Pairs



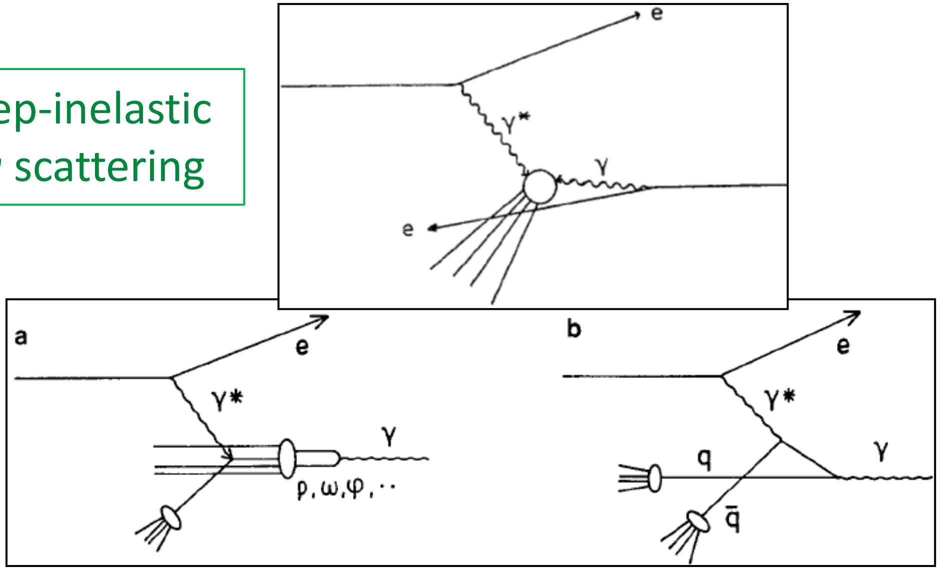


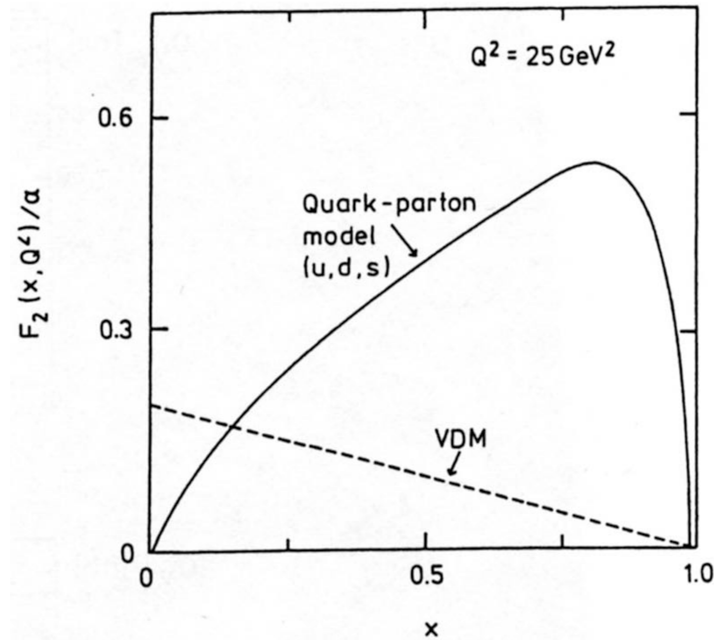


does not work for baryon pairs
at the stat. accessible energies

Hadronic Structure of the Photon

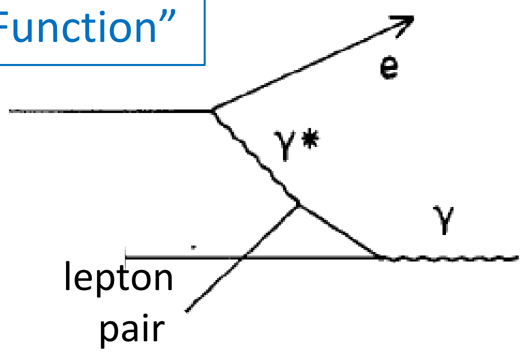
deep-inelastic eγ scattering

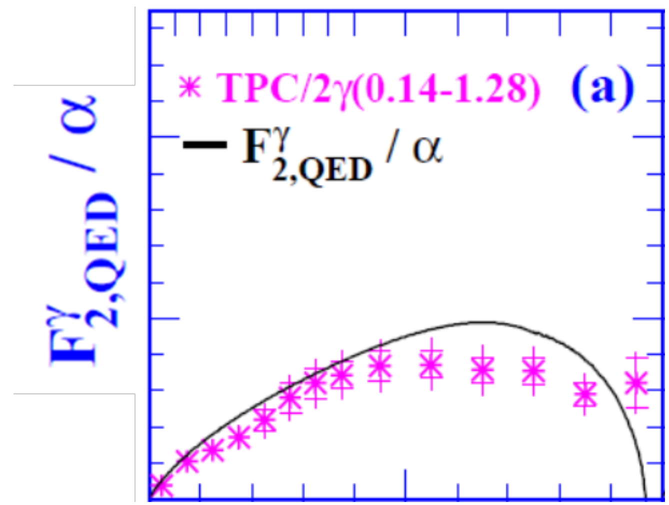




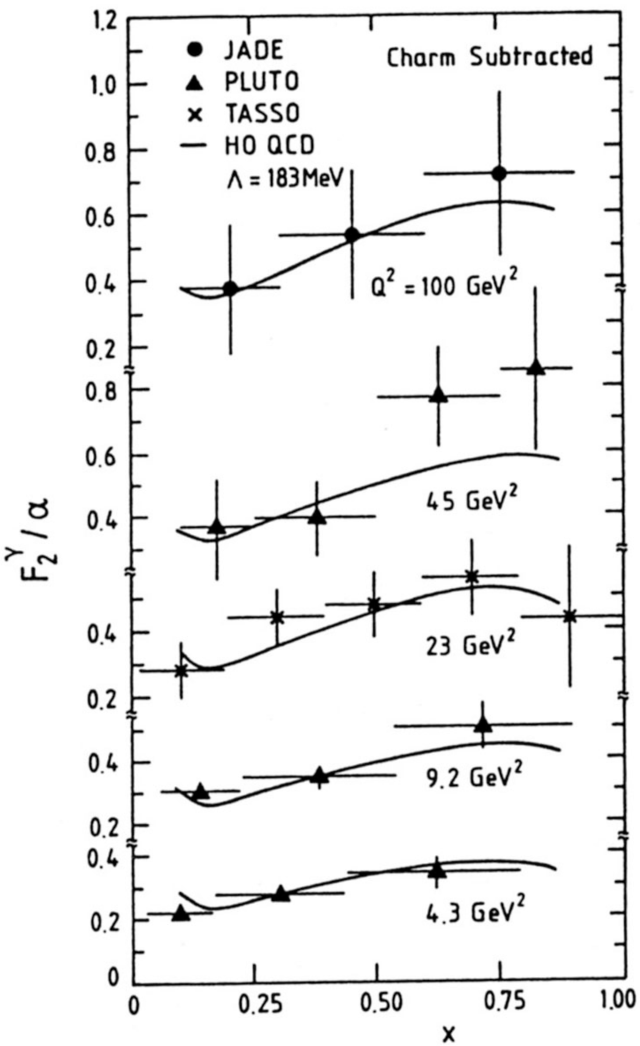
Most remarkable prediction in the early 1970ies:
point-like photon should dominate F_2^γ

compare to “QED Structure Function”

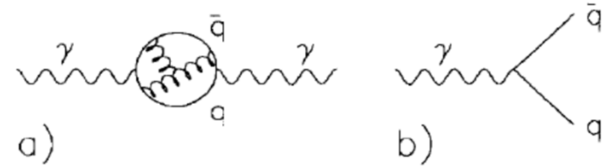


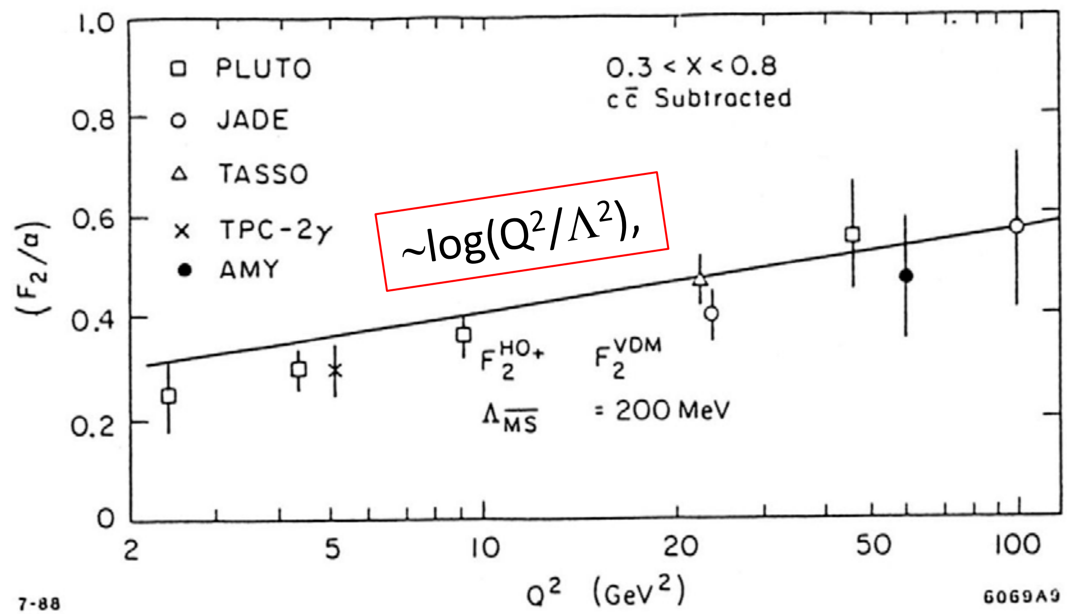


Hadronic Structure of the Photon II



At large Q^2 the photon exhibits its point-like nature

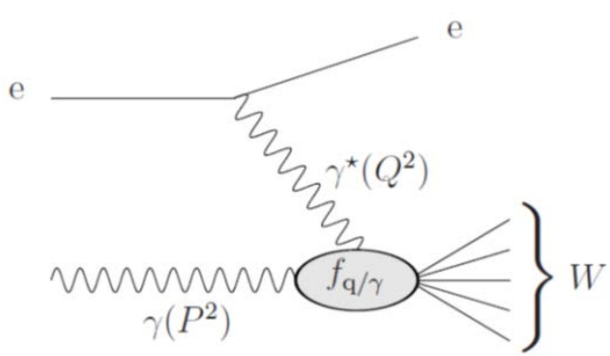


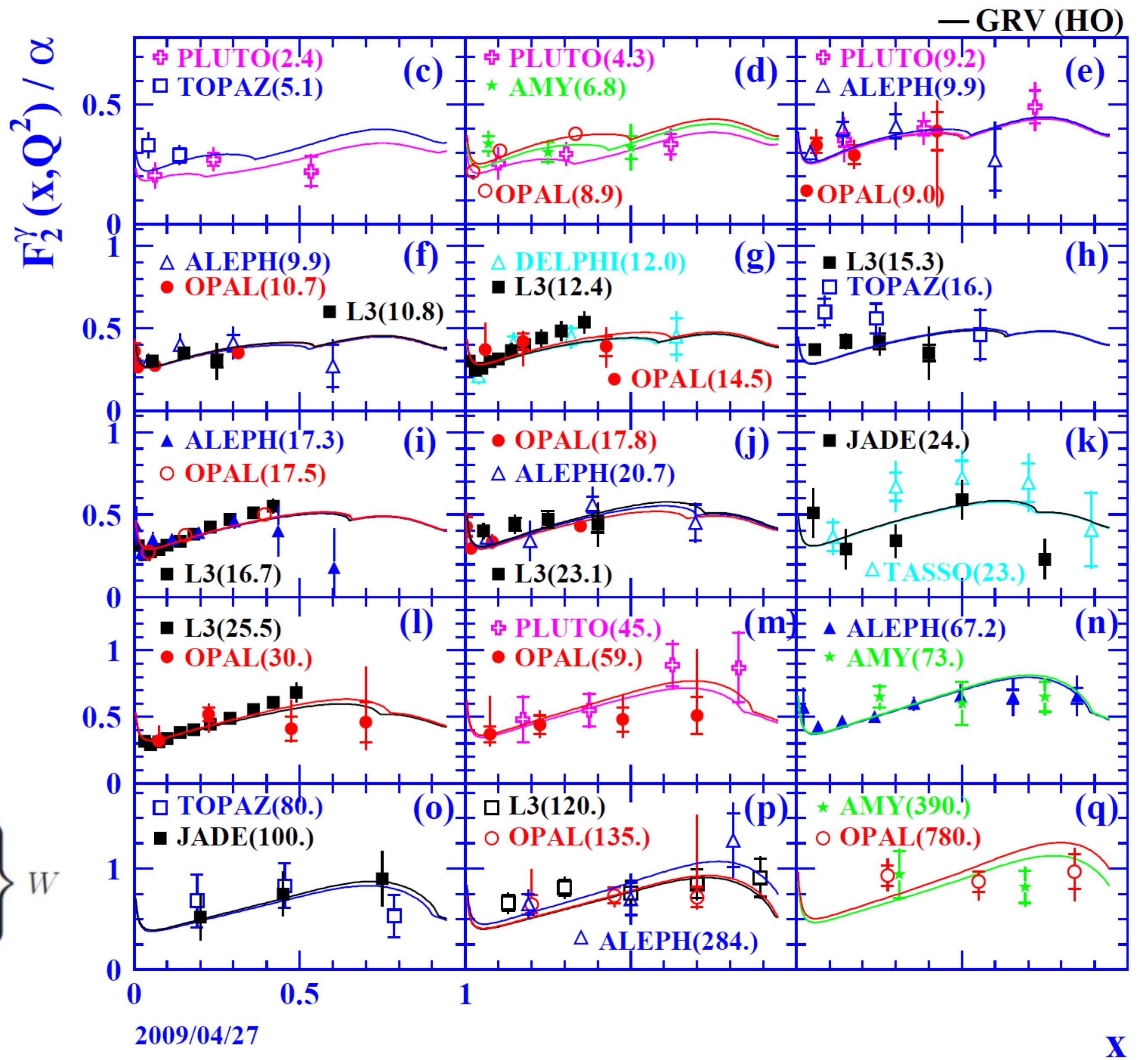


in principle Λ_{QCD} can be determined from the absolute normalisation of F_2^γ (not all theoreticians agree on that)

F_2^γ from PETRA, TRISTAN, LEP

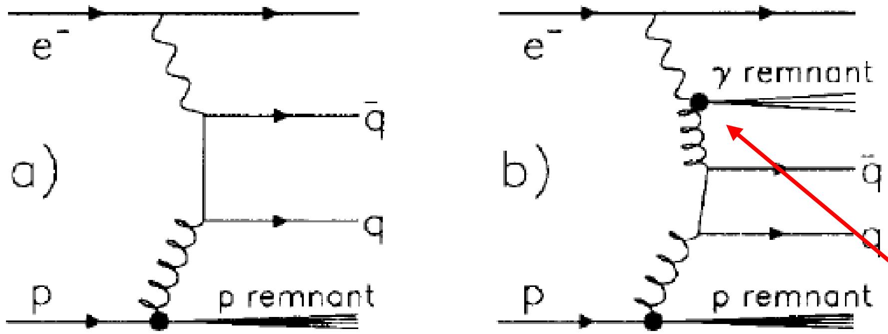
Richard Nisius @ Photon2009:





My “last encounter” of γγ physics:

HERA: the “direct” and “resolved” photon

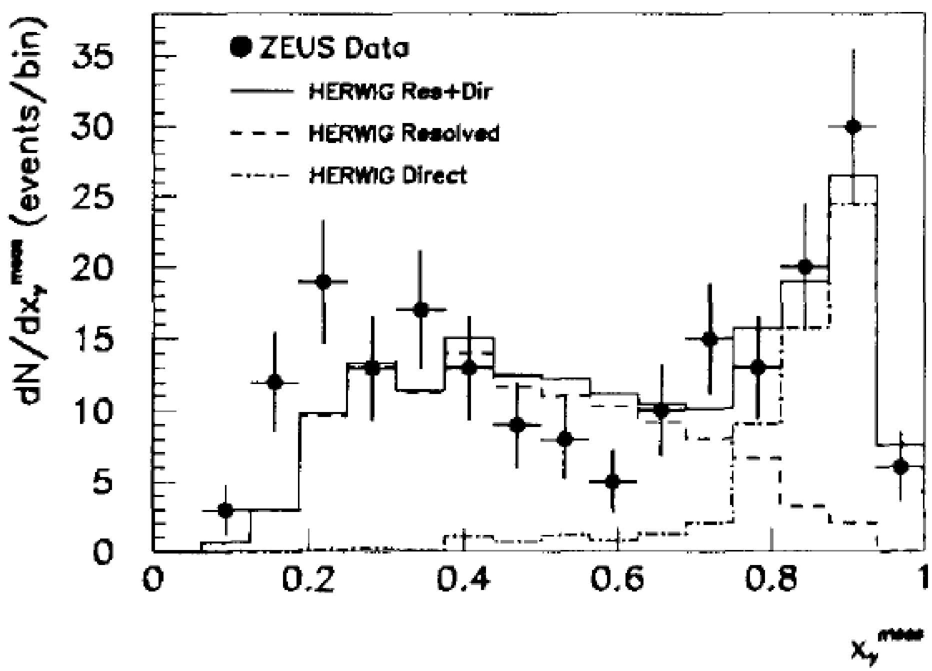


direct resolved

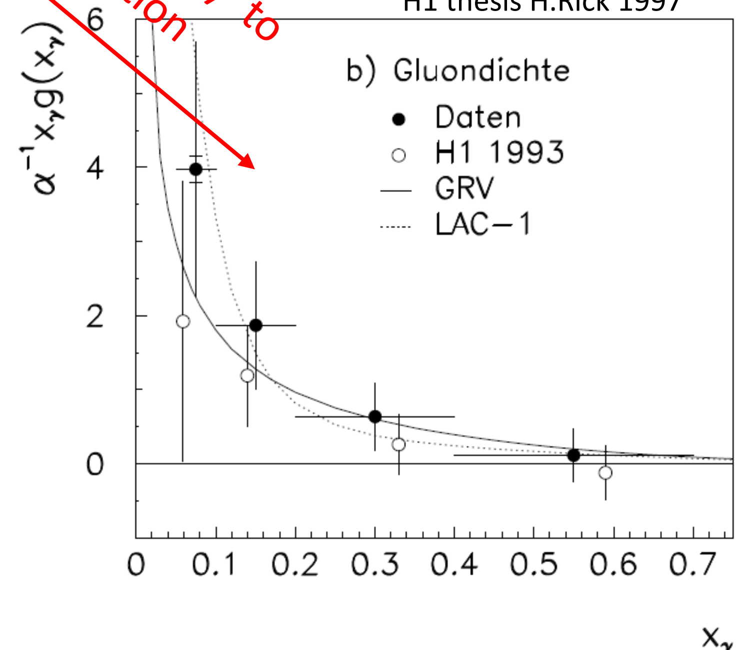
F_2^γ yields parton distributions in the photon:

Concept should be **generalizable**

@HERA sensitivity to gluon distribution



H1 thesis H.Rick 1997

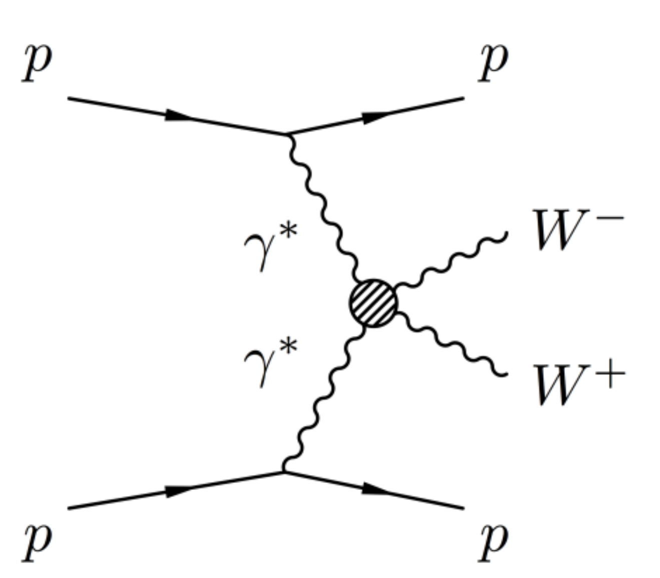


Summary, Outlook, what else?

- Basic experiments done at the e+e- colliders of the 80ies
- major improvements in statistics, in particular for meson spectroscopy, from BELLE and BaBar
- LEP opened highest Q^2

The LHC as a photon collider

http://cms.web.cern.ch/news/lhc-photon-collider



An NLC photon-photon collider?