Experimental Status of $\gamma\gamma \longrightarrow$ Baryon Antibaryon Pairs

PEP-N Workshop May 2, 2001 , SLAC T. Barillari, Univ. of Colorado

- Introduction
- Theory
  - $\gamma\gamma$ physics
  - QCD and quark-diquark model predictions
- The $\gamma\gamma \rightarrow$ Baryon Antibaryon processes
  - The $\gamma\gamma \longrightarrow p\overline{p}$ process
  - The $\gamma\gamma \longrightarrow \Lambda\overline{\Lambda}$ process
- PEP-N expectations
- Conclusion

Introduction

The work here presented has been motivated by the quark-diquark model predictions [a] for the

$\gamma\gamma \rightarrow B\overline{B}$ processes (B =Baryons, e.g. p, Λ, Ξ^- etc.)

- The $\gamma\gamma \rightarrow p\overline{p}$ process has been studied by different experiments at the e^+e^- colliders
  - ***OPAL*** $\gamma\gamma \rightarrow p\overline{p}$ cross section measurements
- CLEO has studied the exclusive $\Lambda\overline{\Lambda}$ production in $\gamma\gamma$ interactions
- L3 has studied the reaction $e^+e^- \rightarrow e^+e^-\Lambda\overline{\Lambda}X$ at LEP
- At PEP-N the $\gamma\gamma \rightarrow p\overline{p}$ reaction can be investigated in an interesting range of low invariant mass

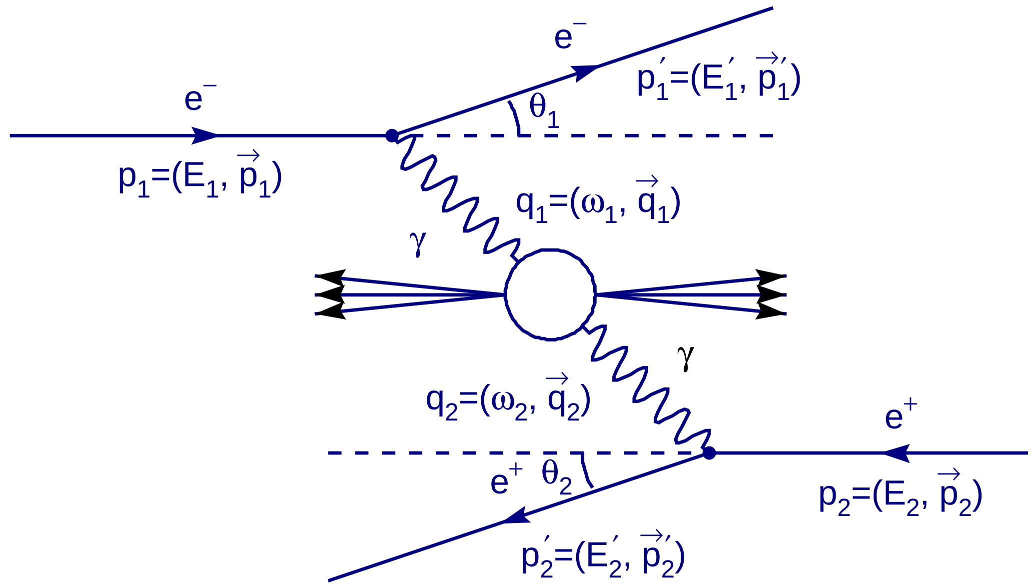
[a] C. F. Berger,Exclusive two-photon reactions in the few GeV region, Diploma thesis, Tech. Univ. Graz 1997; M. Anselmino et al., Int. J. Mod. Phys. A4 1989

Kinematics

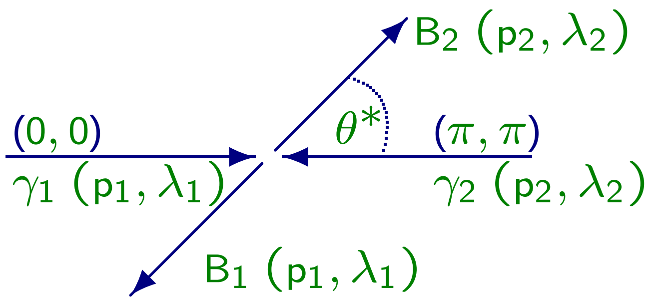
$$e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-X \qquad X = p\bar{p}, \Lambda\bar{\Lambda}, \ldots$$

$$Q_i^2 \approx 2E_iE_i'(1-\cos\theta_i)$$

$$Q_i^2 = (q_i^2 - w_i^2)$$



$\gamma\gamma$ center-of-mass system (CMS)



$W_{\gamma\gamma}$, invariant mass in the $\gamma\gamma$ CMS

θ^*, polar angle in the $\gamma\gamma$ CMS

Untagged $\gamma\gamma$ events

In the two-photon events it is possible to distinguish:

- Double-tag $\gamma\gamma$ events:

  Both scattered electrons are detected

- Single-tag $\gamma\gamma$ events:

  One scattered electrons is detected

- No-tag $\gamma\gamma$ events:

  No electron is detected

Hard scattering picture (HSP)

In pQCD (or HSP) an exclusive process: $A + B \to C + D$
is described by the exclusive hadronic amplitude [a]

$$\mathcal{M} = \int_0^1 T_H(x_j, p_\perp) \prod_{H_i} \left(\phi_{H_i}(x_j, \tilde{p}_\perp) \delta(1 - \sum_{k=1}^{n_i} x_k) \prod_{j=1}^{n_i} d\,x_j\right)$$

$\mathcal{M}$ separates: "short-range" from "long-range" phenomena

- ϕ_{H_i}: Parton distribution amplitude (DA) for each hadron in the process
- T_H: Hard scattering amplitude
- $\tilde{p}_\perp \approx min(x, 1-x)\sqrt{s}|\sin\theta|$
- x_j: Longitudinal momentum fraction carried by the valence partons in the hadron

$\mathcal{M}$ has "two" phenomenological consequences

[a] Brodsky et al., Phys. Rev. D24, 1981; Brodsky et al., ECFA 87/108, 1987

Spin Problem and diquark solution

1) The dimensional counting rules: $\mathcal{M} \approx \frac{1}{(p_\perp^2)^{(n-4)/2}} f(\theta_{c.m.})$

- Valid for wide scattering angle and $p_\perp^2 \to \infty$
- n = num. of scattered quanta

2) The hadron helicity conservation rules: $\lambda_A + \lambda_B = \lambda_C + \lambda_D$

- λ is the spin component in the direction of the motion
- Valid for exclusive reaction $A + B \to C + D$

Hadron helicity conservation rules not in agreement with data

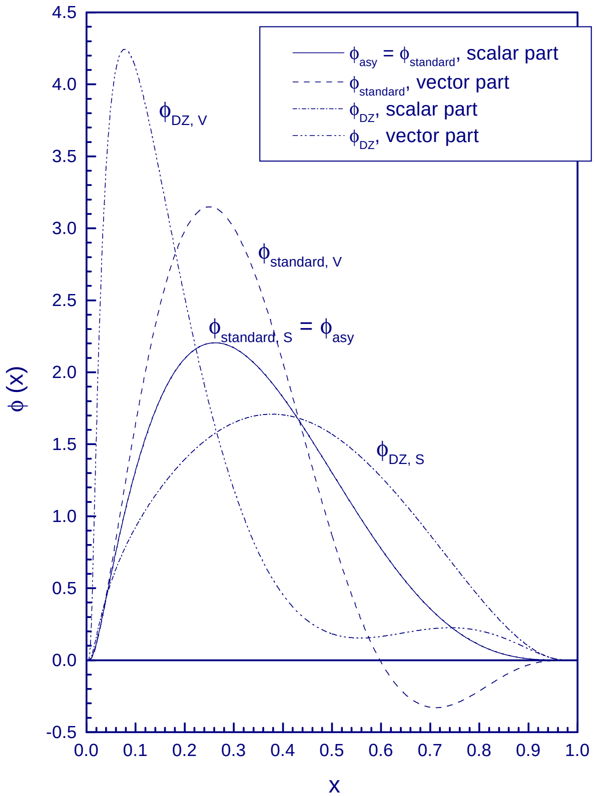
⇒ Diquark solution for the "quark model spin problem":

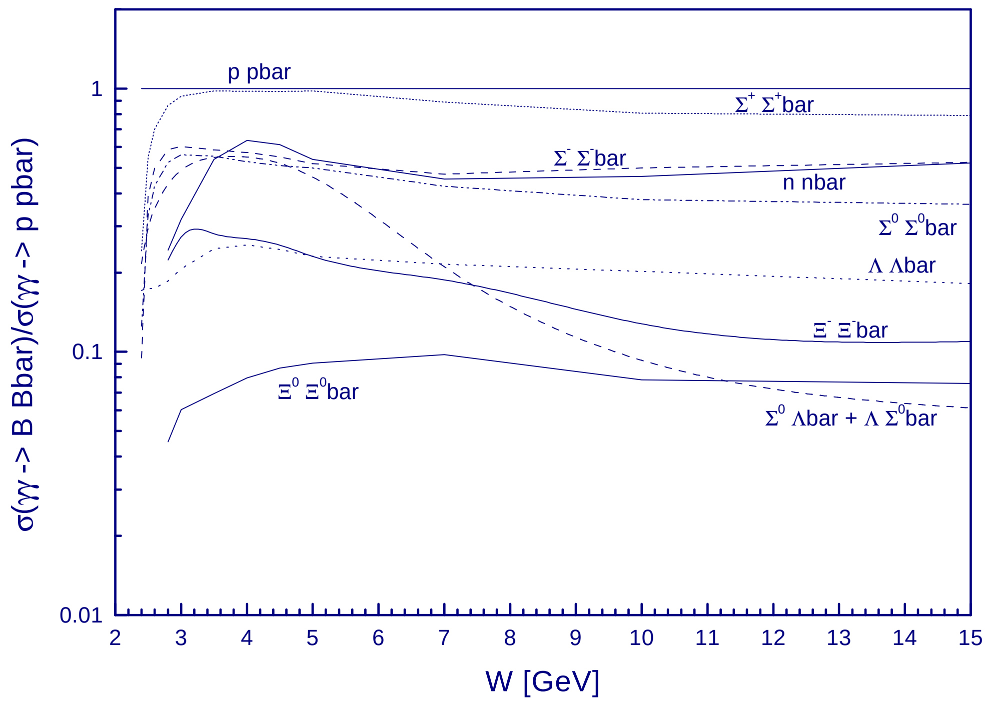
- Diquarks modify the dimensional counting rules by decreasing n
  - We have: $\frac{d\sigma(\gamma\gamma\to p\bar{p})}{dt} \sim \frac{1}{s^4}|F(g^2)|^2$ instead of $\frac{d\sigma(\gamma\gamma\to p\bar{p})}{dt} \sim s^{-6}$
- Diquarks can violate the hadron helicity conservation rules
  - Gluons can couple now with those partons that allow helicity flips: vector diquarks

Quark-diquark model

There are applications [a] and new recent calculations [b] of the quark-diquark model to the reactions: $\gamma\gamma \to B\overline{B}$ where $B = p, \Lambda, \Xi^-$, etc.

- the new calculations proposed in (b) include now vector-diquarks and baryon mass effect
- $\phi(x)$ are in (b) the distribution amplitudes (DAs) proposed for the proton





---

[a] M. Anselmino et al., Int. J. Mod. Phys. A4 1989

[b] C. F. Berger, Exclusive two-photon reactions in the few GeV region, Diploma thesis, Tech. Univ. Graz 1997

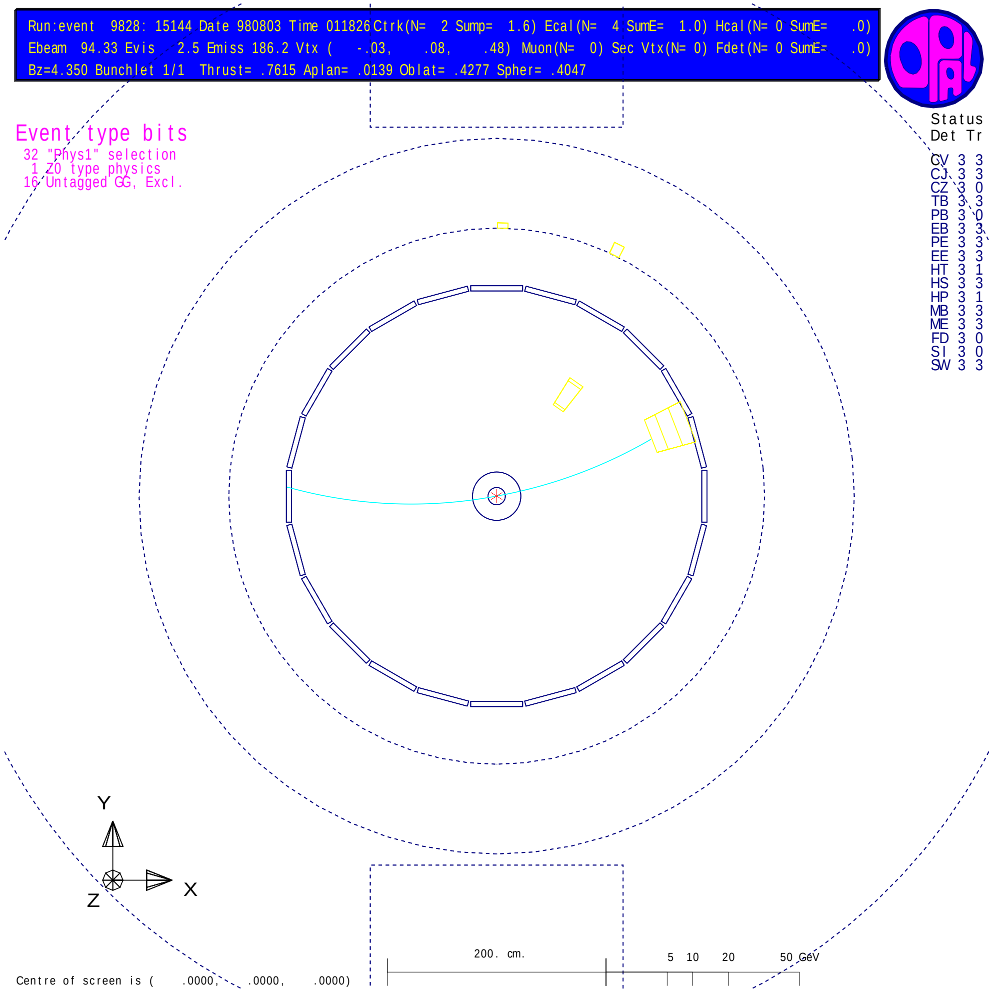
Features of the untagged $e^+e^- \to e^+e^-X$ events

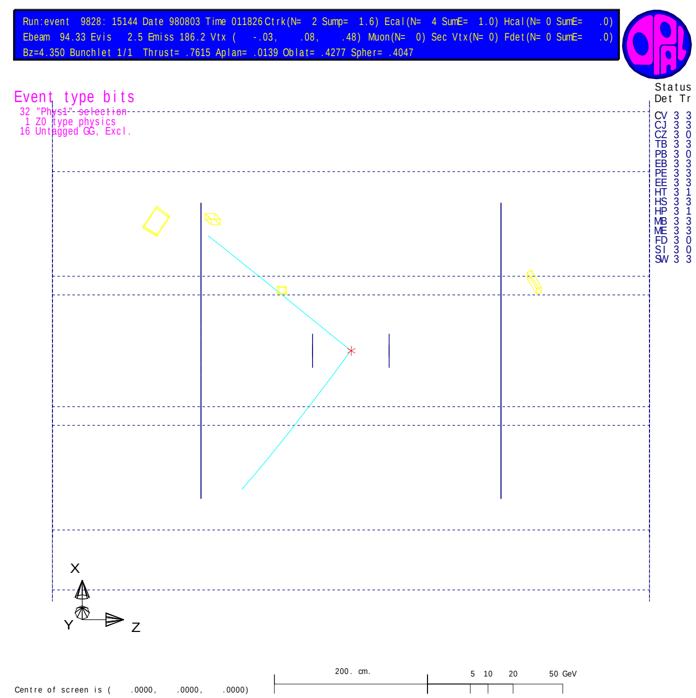
- The final state X has small $p_\perp$ and low mass
- The charged track particles coming from X are detected at small angles with respect to the beam
- They are almost back-to-back in the $x-y$ plane but not in the $x-z$ plane
- The $\gamma\gamma$ CMS is boosted along the beam axis
- The produced particles are close to the beam direction

⇒ Detection and trigger efficiencies limited

The $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-p\bar{p}$ events

A typical $\gamma\gamma \rightarrow p\bar{p}$ event selected with the ***OPAL*** detector at LEP2

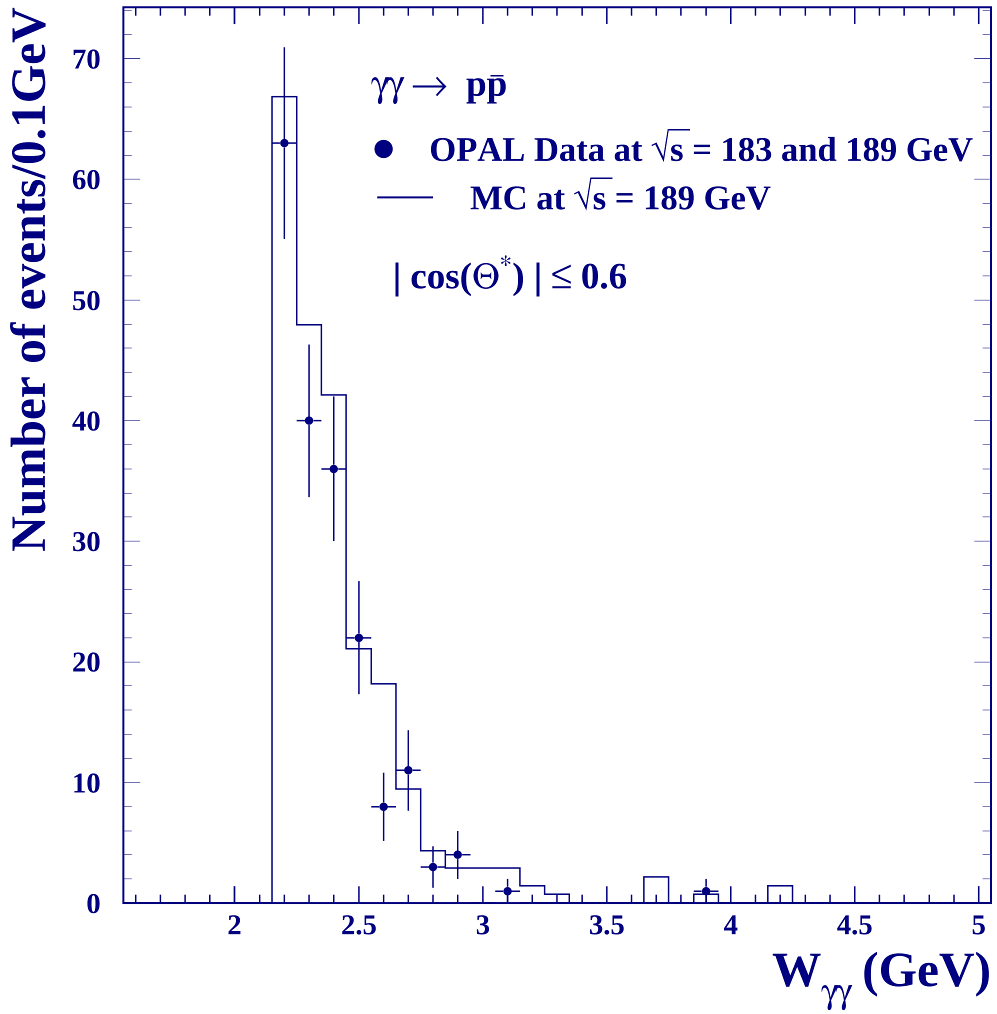




OPAL $\gamma\gamma \to p\bar{p}$ events

Applied cuts

- Number of hits in CJ> 20
- 2 tracks with $Q_{\mathrm{Tot}} = 0$
- $|d_0| < 1.0$
- $|\cos\theta| < 0.75$
- $p_\perp > 400\mathrm{MeV}$
- $|\cos\theta^*| < 0.60$
- Trigger Conditions
- $|\sum \vec{p}_\perp|^2$
- dE/dx to eliminate background
- $W_{\gamma\gamma} > 2.15\,\mathrm{GeV}$



➡ 189 $\gamma\gamma \to p\bar{p}$ events remained after the selection

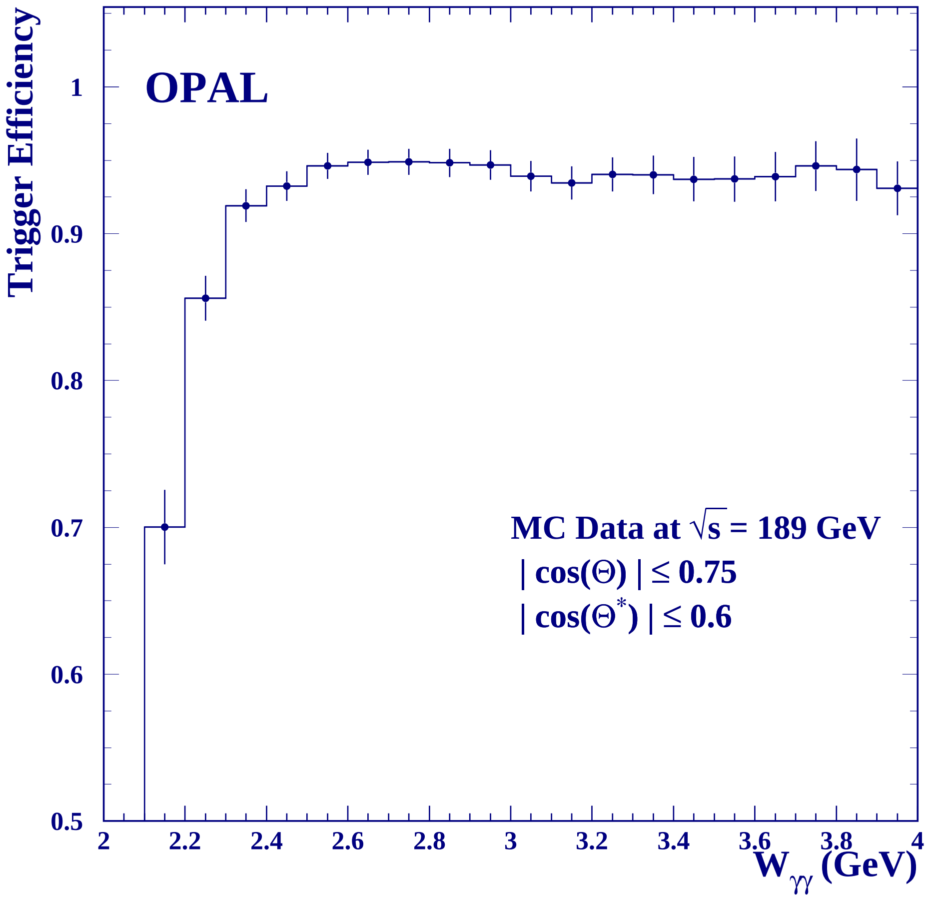
➡ $W_{\gamma\gamma} = 2.15 - 3.95\,\mathrm{GeV}$

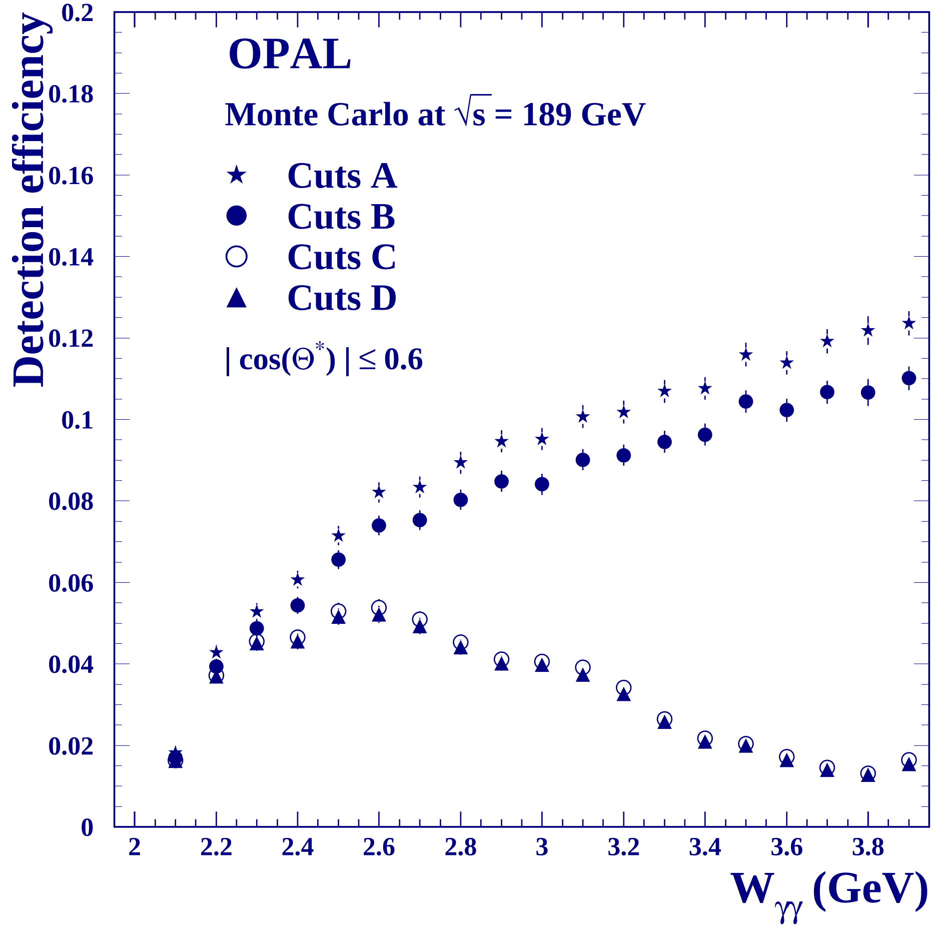
Trigger and detection efficiencies

$\varepsilon_{\mathrm{TRIG}}(\gamma\gamma \to p\bar{p}) \approx 94\%$

$\varepsilon_{\mathrm{DET}}(\gamma\gamma \to p\bar{p}) \approx 5\%$

$W \approx 2.5$ GeV





Cross section measurements

The $e^+e^- \to e^+e^- p\bar{p}$ differential cross section is given by:

$$\frac{d\sigma(e^+e^- \to e^+e^- p\bar{p})}{dW_{\gamma\gamma}\, d|\cos\theta^*|} = \frac{N_{ev}}{L_{e^+e^-}\, \varepsilon_{TRIG}\, \varepsilon_{DET}\, \Delta W_{\gamma\gamma}\, \Delta|\cos\theta^*|}$$

- N_{ev} = Number of events in each bin of $(W_{\gamma\gamma}, |\cos\theta^*|)$
- ε_{TRIG} = Trigger efficiency
- ε_{DET} = Monte Carlo detection efficiency
- $L_{e^+e^-}$ = Measured integr. luminosity = $249.10 \pm 0.22 \pm 0.43\,\text{pb}^{-1}$
- $\Delta W_{\gamma\gamma}$ and $\Delta|\cos\theta^*|$ bin widths in $W_{\gamma\gamma}$ and $|\cos\theta^*|$

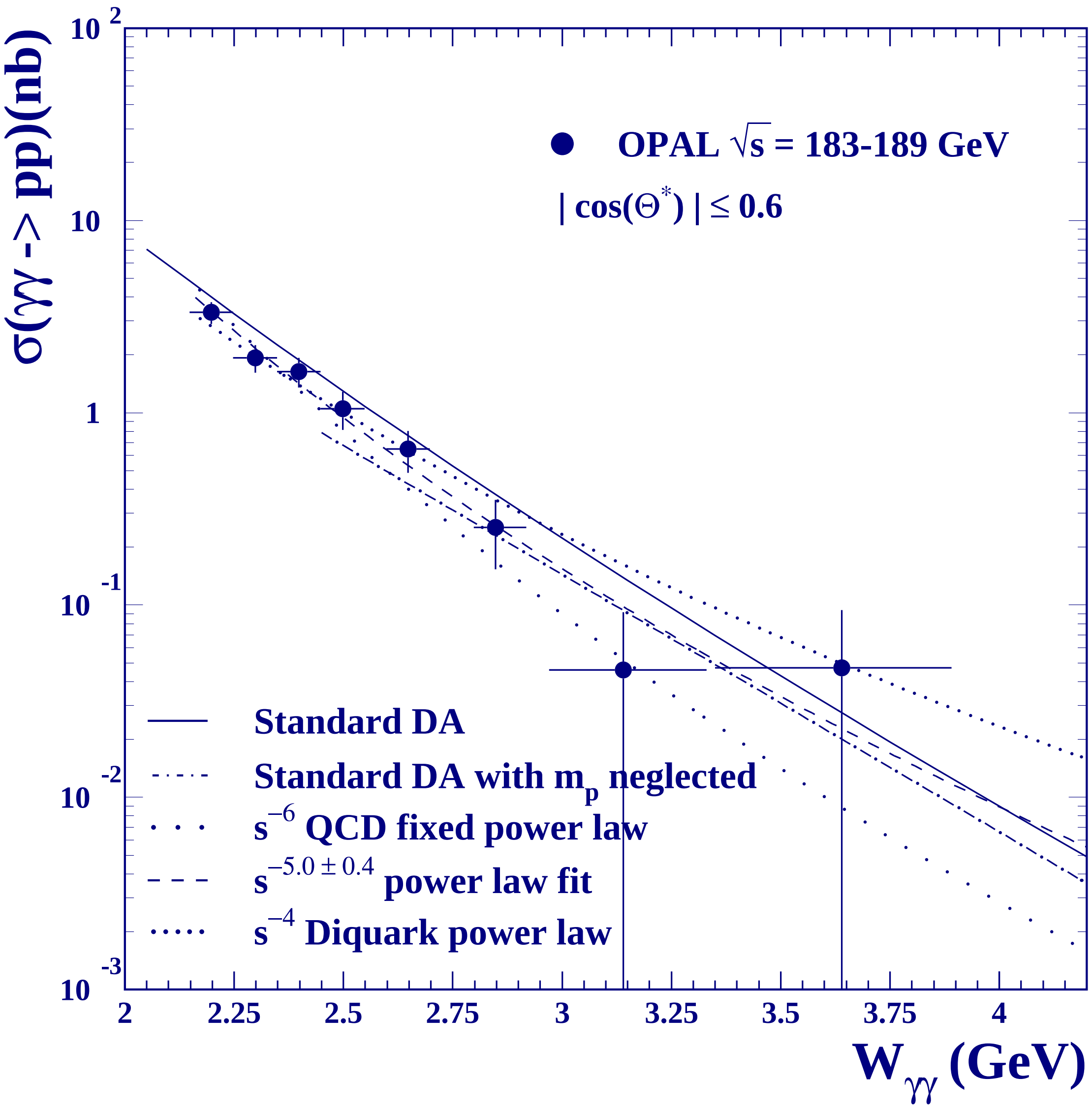
$$\frac{d\sigma(e^+e^- \to e^+e^- p\bar{p})}{dW_{\gamma\gamma}} = \frac{d\mathcal{L}_{\gamma\gamma}}{dW_{\gamma\gamma}}\, \sigma(\gamma\gamma \to p\bar{p})$$

$d\mathcal{L}_{\gamma\gamma}/dW_{\gamma\gamma}$ = GALUGA $\gamma\gamma$ luminosity function [a]

$\sigma(\gamma\gamma \to p\bar{p})$ = Total $\gamma\gamma$ cross section

[a] G. Schuler,hep-ph/9610406 (1996);G. Schuler, hep-ph/9710506 (1997)

OPAL cross section measurements

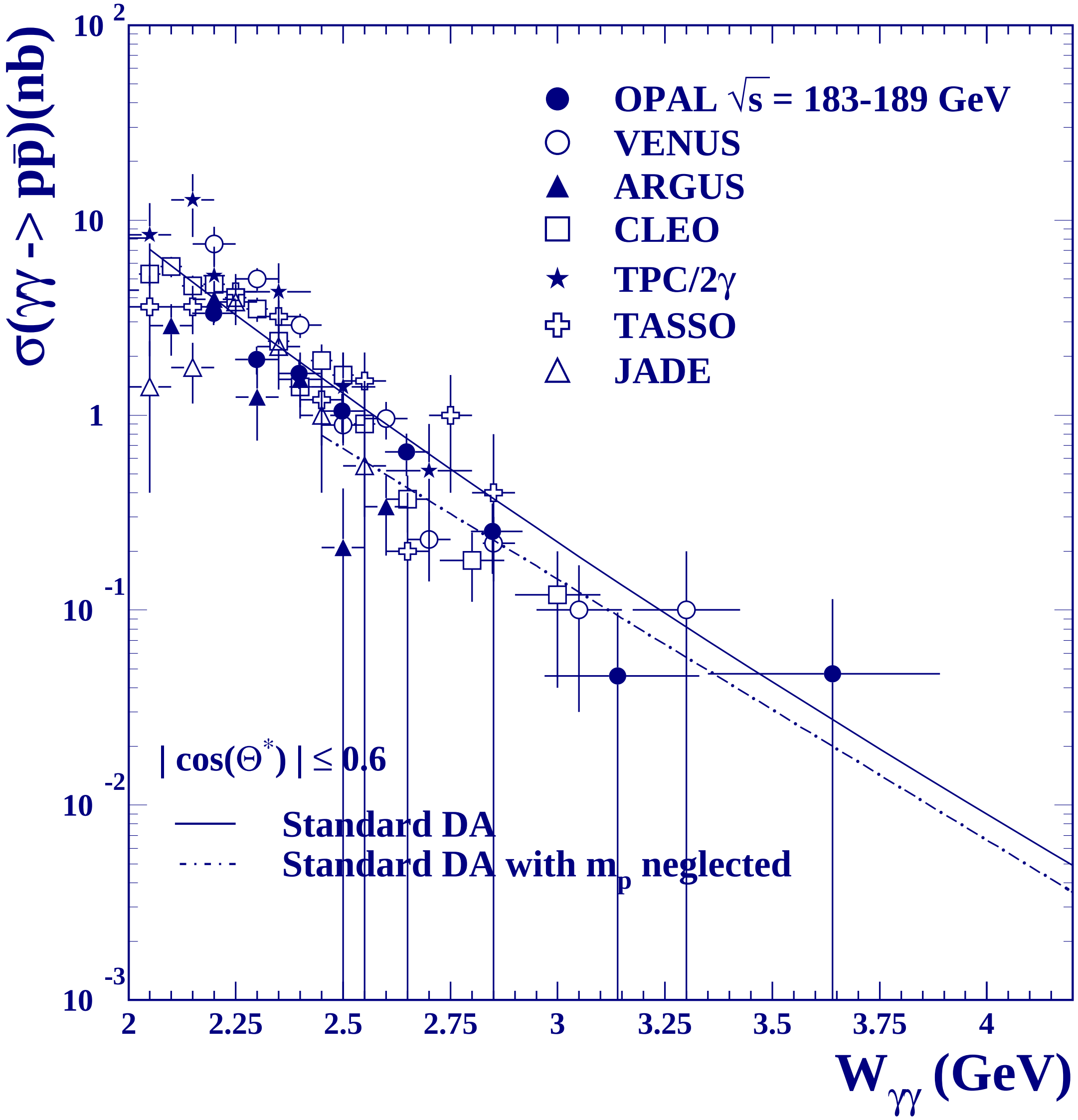


Power law predictions in agreement with data

Existing $\gamma\gamma \rightarrow p\bar{p}$ cross section measurements

e^+e^- Experiments	E_{Beam} (GeV)	Integrated Luminosity (pb^{-1})	$W_{\gamma\gamma}$ (GeV)	Number of $p\bar{p}$ events
TASSO (DESY) 1982	15 - 18.3	19.685	2.0 - 2.6	8
TASSO (DESY) 1983	17	74	2.0 - 3.1	72
JADE (DESY) 1986	17.4 - 21.9	59.3 + 24.2	2.0 - 2.6	41
TPC/2γ (SLAC) 1987	14.5	75	2.0 - 2.8	50
ARGUS (DESY) 1989	4.5 - 5.3	234	2.6 - 3.0	60
CLEO (CESR) 1994	5.29	1310	2.0 - 3.25	484
VENUS (TRISTAN) 1997	57 - 64	331	2.2 - 3.3	311
OPAL (LEP) 2000	91.5 - 94.5	249	2.15 - 3.95	189

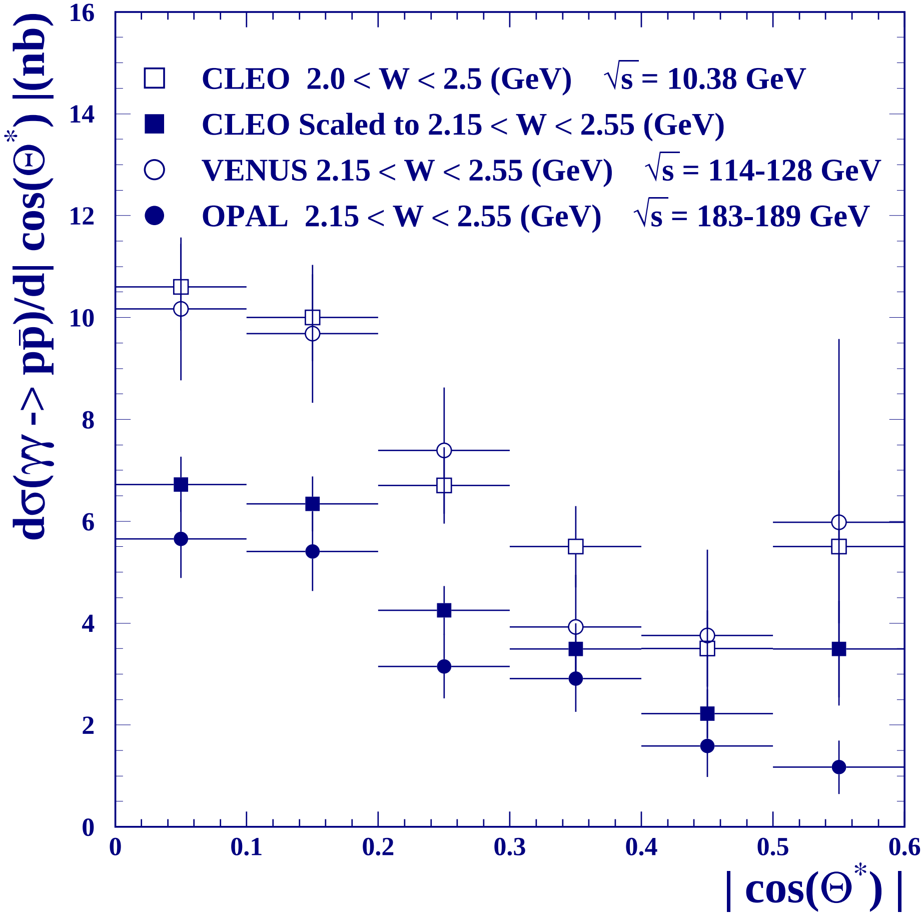
Comparison with other experiments



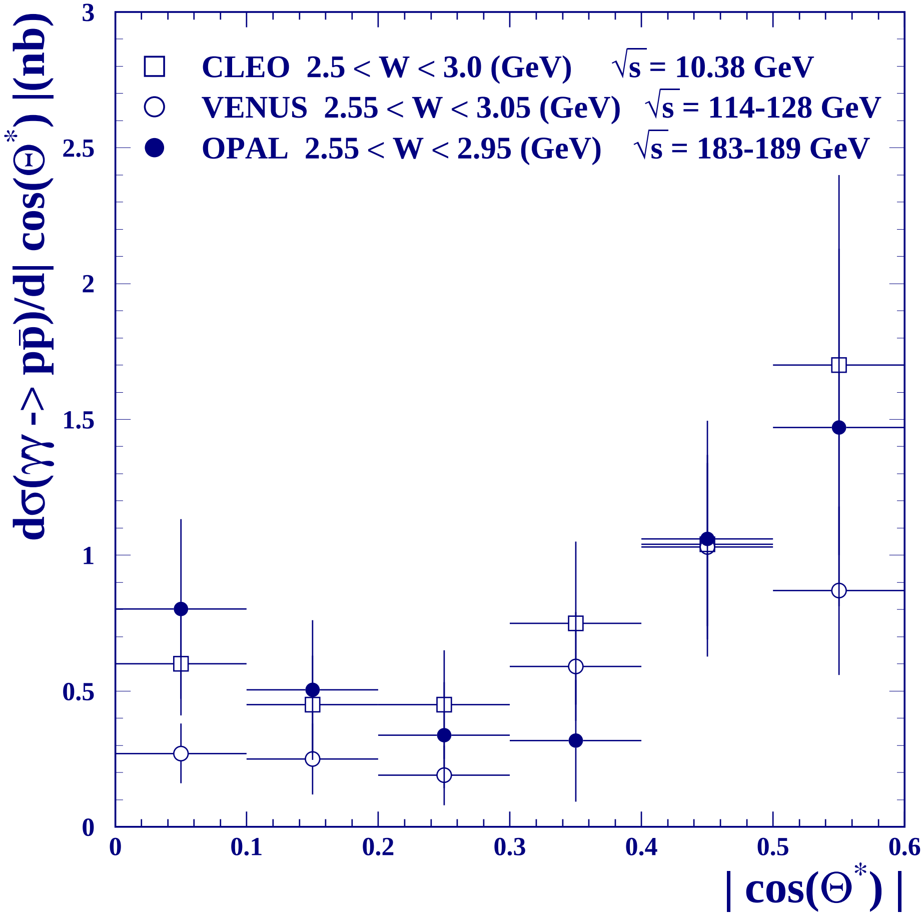
Agreement between different experiments

Differential cross section

$2.15 < W_{\gamma\gamma}(\text{GeV}) < 2.55$



$2.55 < W_{\gamma\gamma}(\text{GeV}) < 2.95$

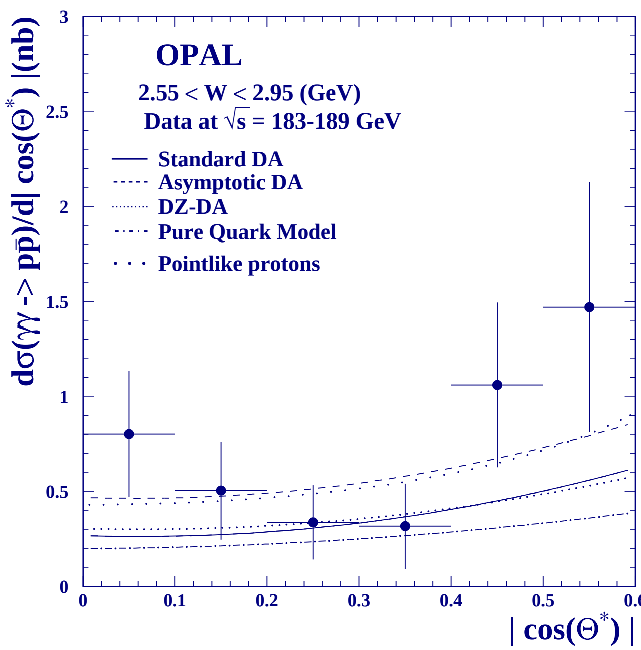


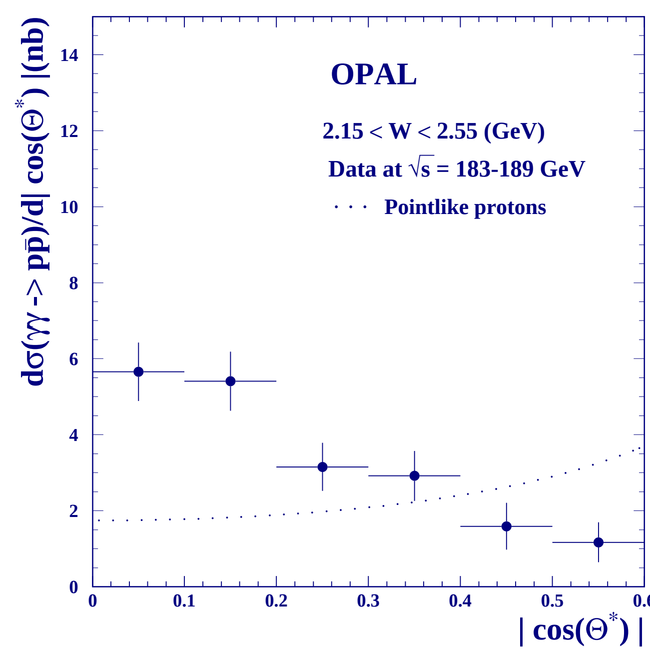
There is good agreement between the OPAL and CLEO measurements

Angular dependence of the cross section

In the limit of scalar diquark (spin 0), point-like p ($\bar{p}$) with no mass, QED says:

$$\frac{d\sigma(\gamma\gamma \to p\bar{p})}{d|\cos\theta|} \propto \frac{(1+\cos^2\theta)}{(1-\cos^2\theta)}$$



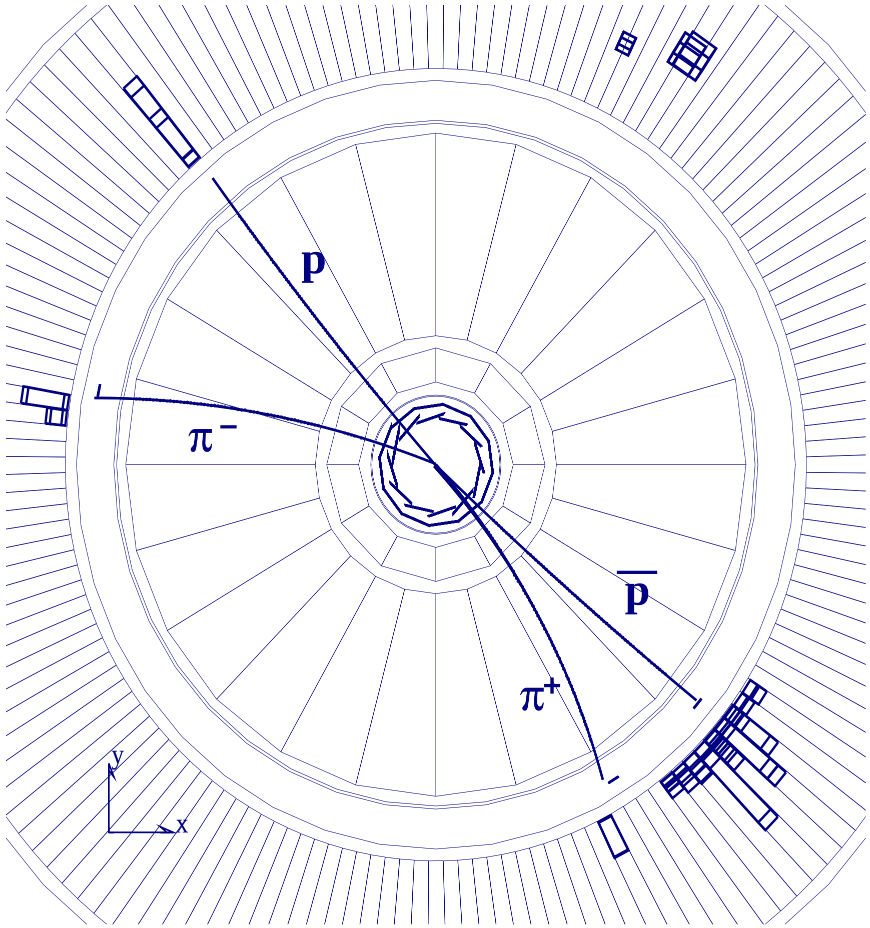


- At high $W_{\gamma\gamma}$, the p point-like approximation agrees with the data, the diquark and pure quark model curves. Helicity sum rule conserved
- At low $W_{\gamma\gamma}$, p point-like approximation not valid anymore. More experimental investigation needed

The $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-\Lambda\bar{\Lambda}$ events

A $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ event selected with the L3 detector at LEP2

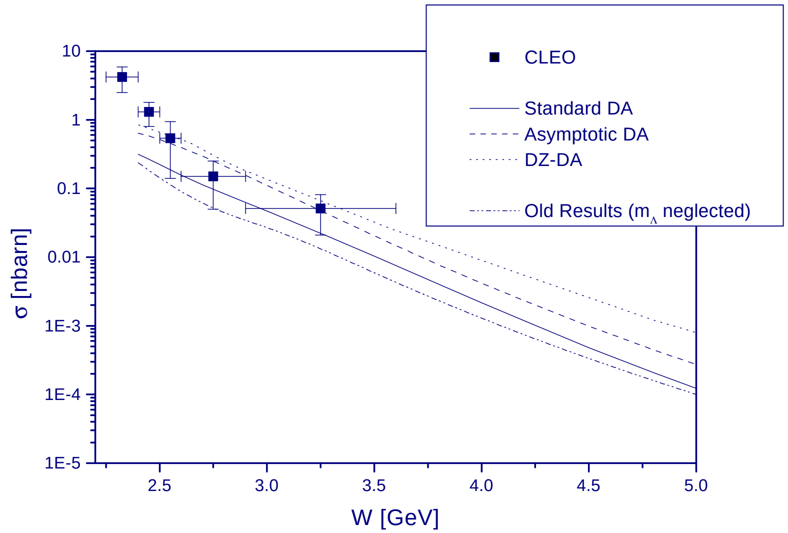
Run # **624405** **Event #** **4760** Total Energy : 2.89 GeV



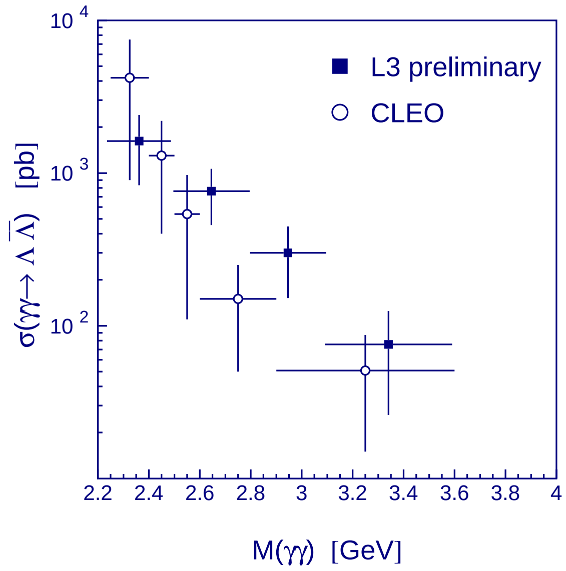
Transverse Imbalance :	.3103		**Longitudinal Imbalance :**	.1273	
Thrust :	.7656	**Major :**	.4285	**Minor :**	.1385
Event DAQ Time :	*941112 200904*				

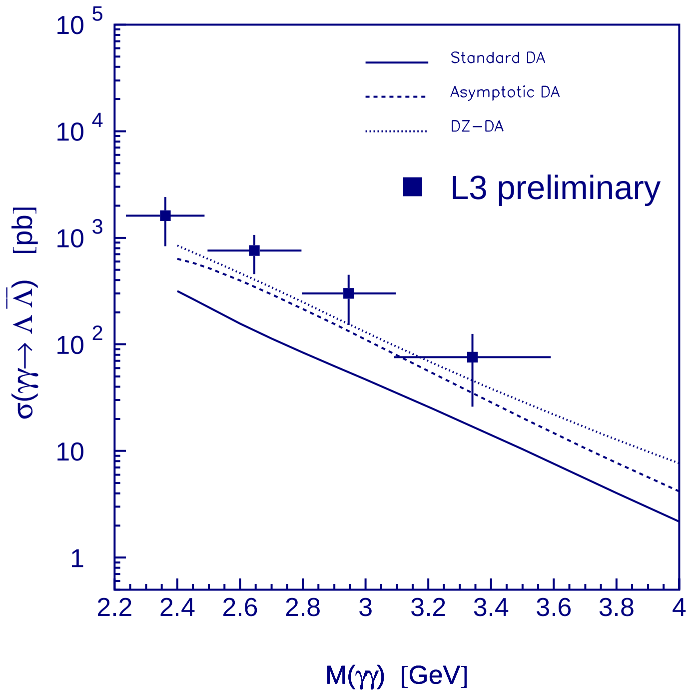
CLEO and L3 cross section measurements

CLEO $\sigma(\gamma\gamma \to \Lambda\overline{\Lambda})$ results



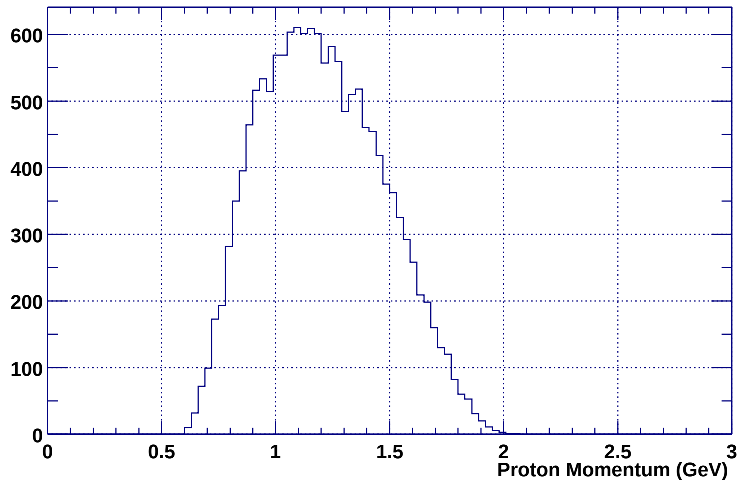
L3 $\sigma(\gamma\gamma \to (\Lambda/\Sigma^0)(\overline{\Lambda}/\overline{\Sigma^0}))$ results

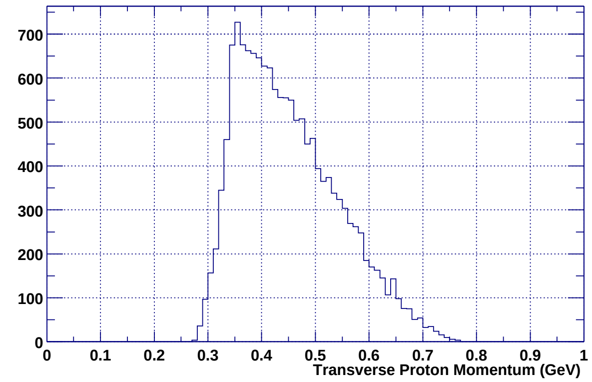


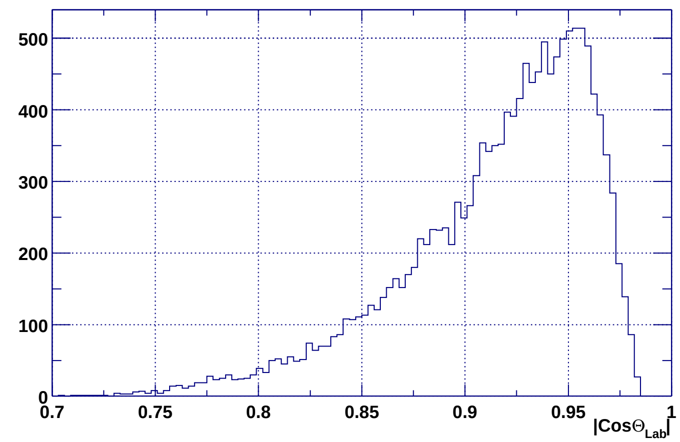


PEP-N expectations

MC $\gamma\gamma \to p\bar{p}$ events at $\sqrt{s} = 2.5$ GeV $|\cos\theta^*| < 0.6$







Better experimental conditions:

No problems with detection and trigger efficiencies

e^+e^- Exp.	E_{Beam} (GeV)	Integrated Lumi (pb^{-1})	$W_{\gamma\gamma}$ (GeV)	Number of $p\bar{p}$ expected
PEP-N (SLAC)	0.5 (VLER), 3.1 (LER)	200	1.9 - 2.6	$\sim$ 60

Conclusions

- The $\gamma\gamma \to p\bar{p}$ and $\gamma\gamma \to \Lambda\bar{\Lambda}$ (exclusive and inclusive) cross sections have been measured in untagged events at e^+e^- colliders
  - The measurements are in agreement with quark-diquark model predictions
  - The power law predictions for $W_{\gamma\gamma}^2 = s$ for a fixed exponent -6, -4, and for a fitted exponent of -5 ± 0.4 are in agreement with the data
  - Within the approximation used the helicity sum rule is conserved for the high $W_{\gamma\gamma}$ region.
  - At low $W_{\gamma\gamma}$ values, still a lot need to be investigated and understood

PEP-N: an ideal machine to study the low invarinat mass region