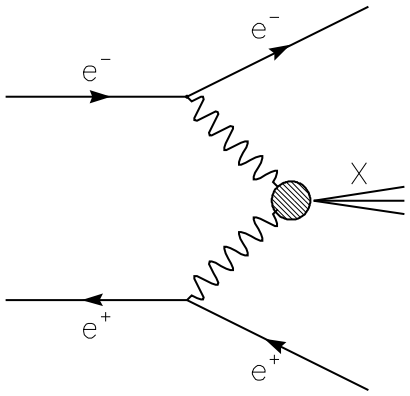
Introduction

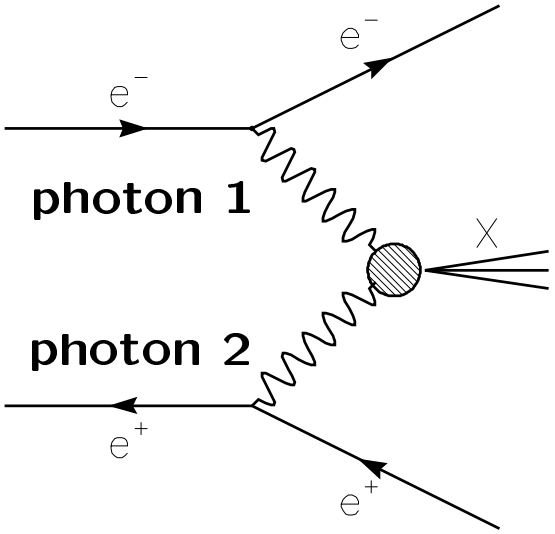
Four new ALEPH results in $\gamma\gamma$ physics, all of which test QCD.

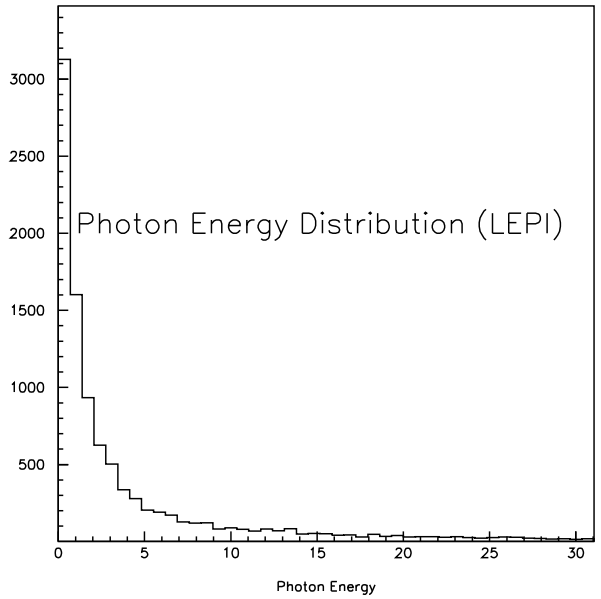
- Hadronic Photon Structure Function $F_2^\gamma(x, Q2)$
- Inclusive $D*^{\pm}$ production
- Hadronic cross section of double tagged events.
- Exclusive π and K pairs



LEP	L	$\sigma^{tot}(W > 4)$	Events
I	$200pb^{-1}$	9nb	1.8 Million
II	$660pb^{-1}$	16nb	11 Million

Two Photon Physics - General Features





Q^2 = -(4 momentum transfer)^2 of photon 1

P^2 = -(4 momentum transfer)^2 of photon 2

$Q^2 > P^2$

W = Invariant mass of final state X

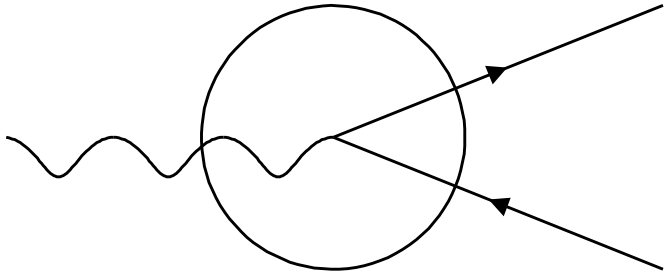
$W_{vis} \leq W_{true} \leq \sqrt{s}$

Longitudinal momentum along beam > 0

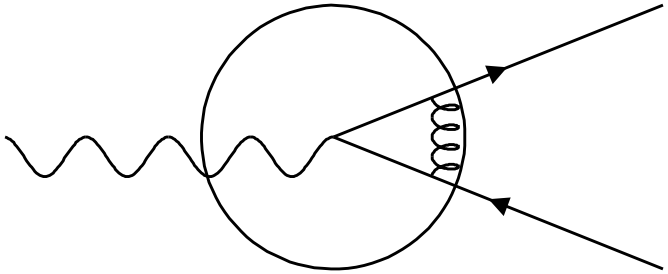
$\sigma(e^+e^- \rightarrow e^+e^-X) \sim \log(\sqrt{s})$

Hadronic Nature of Photon at different scales

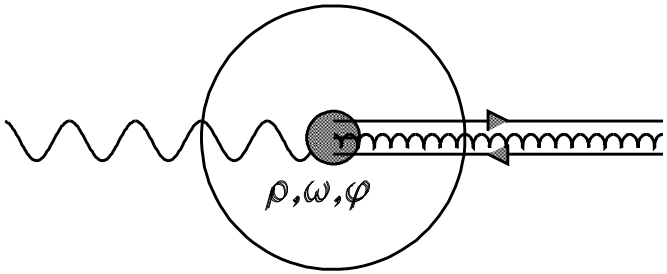
Large Scale, Bare or 'Direct' Photon



Intermediate Scale, QCD corrections calculable



Low Scale, incalculable, $\gamma \sim$Vector Meson ...'VDM'



Testing Pertubative QCD with Two Photons

$\alpha_s(Q^2)$ small $\Rightarrow$ Q^2 large
(Q^2 is some scale in the process)

4 possibilities:

Q^2 The Photon Structure Function
Double tagged cross section

P_t^2 Transverse Momentum of Jets/particles

M_Q Heavy Flavour production

W_{pair} Meson/Baryon Pair production

The Photon Structure Function

Applicable to tagged events, where one electron is seen in the detector.

Assume $P^2 = 0$. Express cross section in terms of structure functions $F_1(x, Q^2)$ and $F_2(x, Q^2)$.

$$\frac{d\sigma}{dxdy} = \frac{4\pi\alpha^2 s(e\gamma)}{Q^4}[(1-y)F_2(x,Q^2) + xy^2 F_1(x,Q^2)$$

with

$$Q^2 = 2EE_{tag}(1-\cos\theta_{tag}) \qquad x = \frac{Q^2}{Q^2+W^2} \qquad y = 1 - \frac{E_{tag}}{E}\cos^2(\frac{\theta_{tag}}{2})$$

Calculating $F_2^\gamma(x,Q^2)$

$$F_2(x,Q^2) = F_2^{PL}(x,Q^2) + F_2^{HAD}(x,Q^2)$$

F_2^{PL}
- Calculable exactly in QCD.
- Depends only on λ_{QCD}.
- Rises logarithmically with Q^2.

F_2^{HAD}
- is approximated by VDM.

At finite Q^2 - Various approaches - :

- Similar answers.
- Require extra parameter (t_0,Q_0,p_t^0).
- Different definitions of 'hadronic' and 'pointlike' part.

Many fits/models (DG,LAC,GRV,SAS,GS,WHIT,...)

ALEPH Photon Structure Function Analysis

- **DATA:** $548 pb^{-1}$ $\sqrt{s}$= **189 - 107 GeV (1998, 1999, 2000)**
- **Single tag - electron detected in lumi calorimeters**
  $E > 70$ **GeV,**
  $\theta > 34$**mrad**
- **At least 3 charged particles**
- $W_{\gamma\gamma} > 3.5 GeV$
- **Unfold** x_{true} **distribution from** x_{vis} **using Tikhonov unfolding.**
- **Two bins of** $< Q^2 >$ **= 16.4 and 64.1** GeV^2

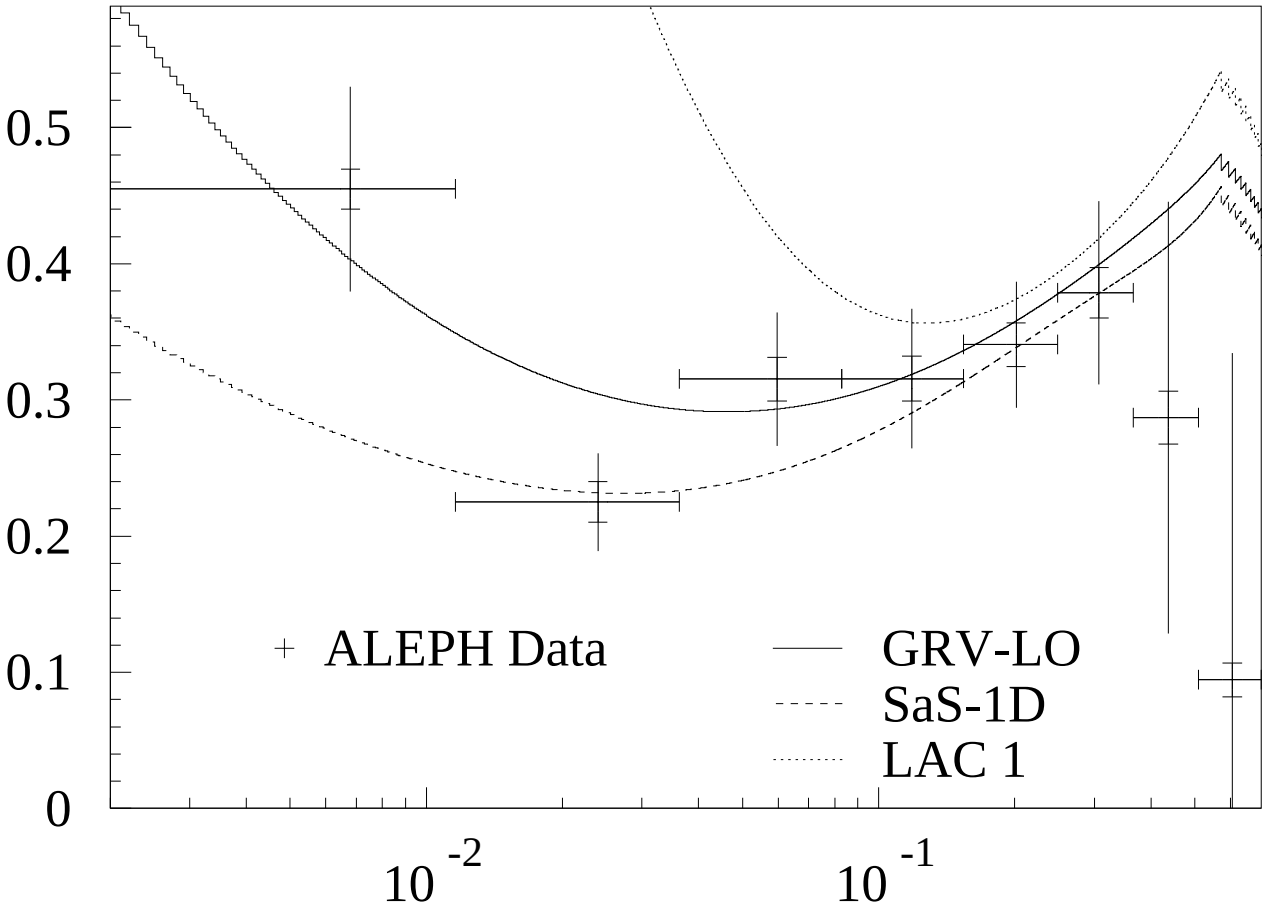
Correlations in F_2^γ measurements

Table 2: Correlation coefficients for the results of the F_2^γ measurement.

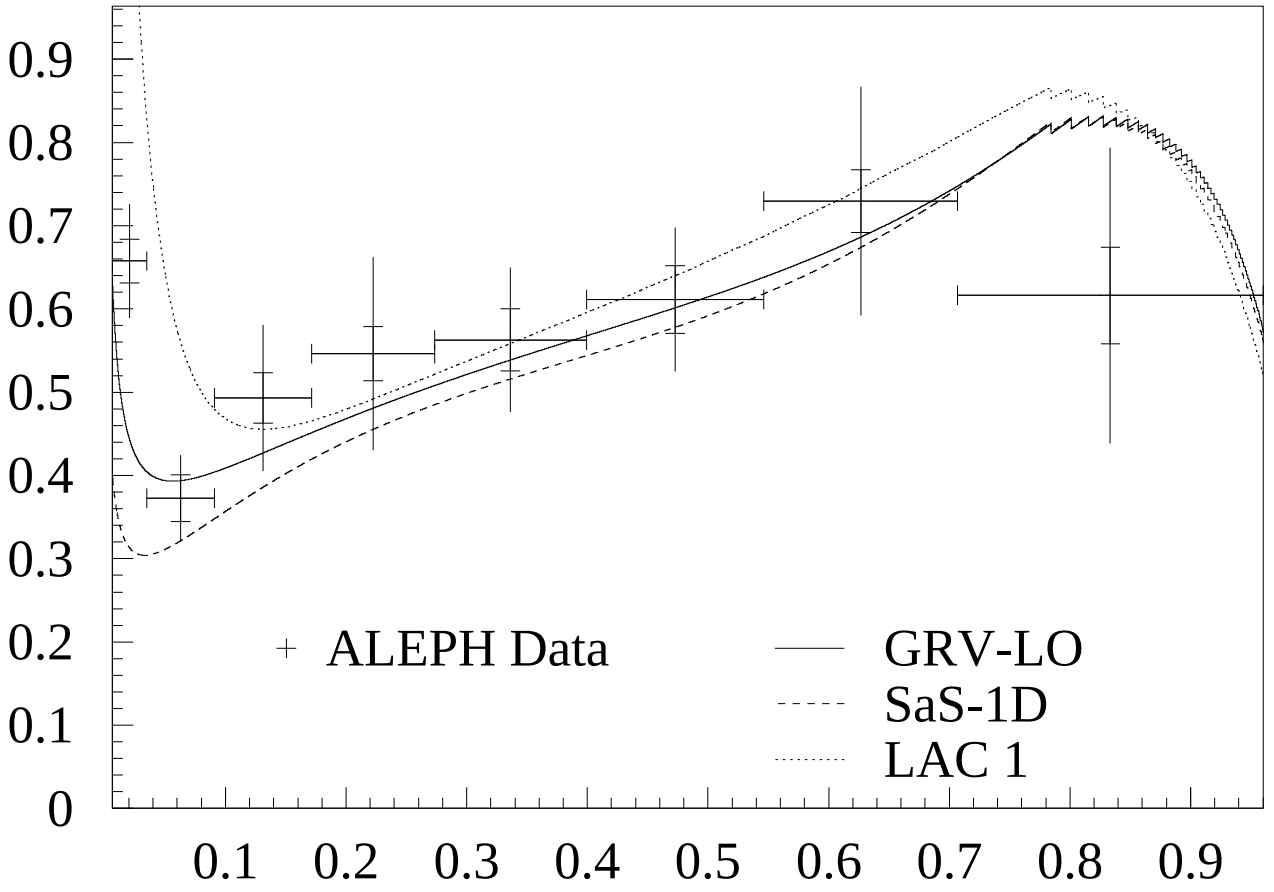
$\langle Q^2 \rangle = 16.4\,\mathrm{GeV}^2$								
x-Bin	1	2	3	4	5	6	7	8
1	1.00	-0.56	0.16	0.08	-0.09	-0.02	0.03	0.02
2		1.00	-0.60	0.01	0.24	-0.04	-0.07	-0.02
3			1.00	-0.45	-0.32	0.27	0.10	-0.02
4				1.00	-0.22	-0.60	0.10	0.18
5					1.00	0.02	-0.69	-0.24
6						1.00	0.37	-0.34
7							1.00	0.51
8								1.00

$\langle Q^2 \rangle = 64.1\,\mathrm{GeV}^2$								
x-Bin	1	2	3	4	5	6	7	8
1	1.00	-0.53	0.09	0.16	-0.14	0.02	0.07	-0.04
2		1.00	-0.52	-0.15	0.30	-0.09	-0.10	0.06
3			1.00	-0.31	-0.37	0.31	0.01	-0.08
4				1.00	-0.25	-0.47	0.39	-0.05
5					1.00	-0.23	-0.77	0.44
6						1.00	0.25	-0.69
7							1.00	-0.24
8								1.00

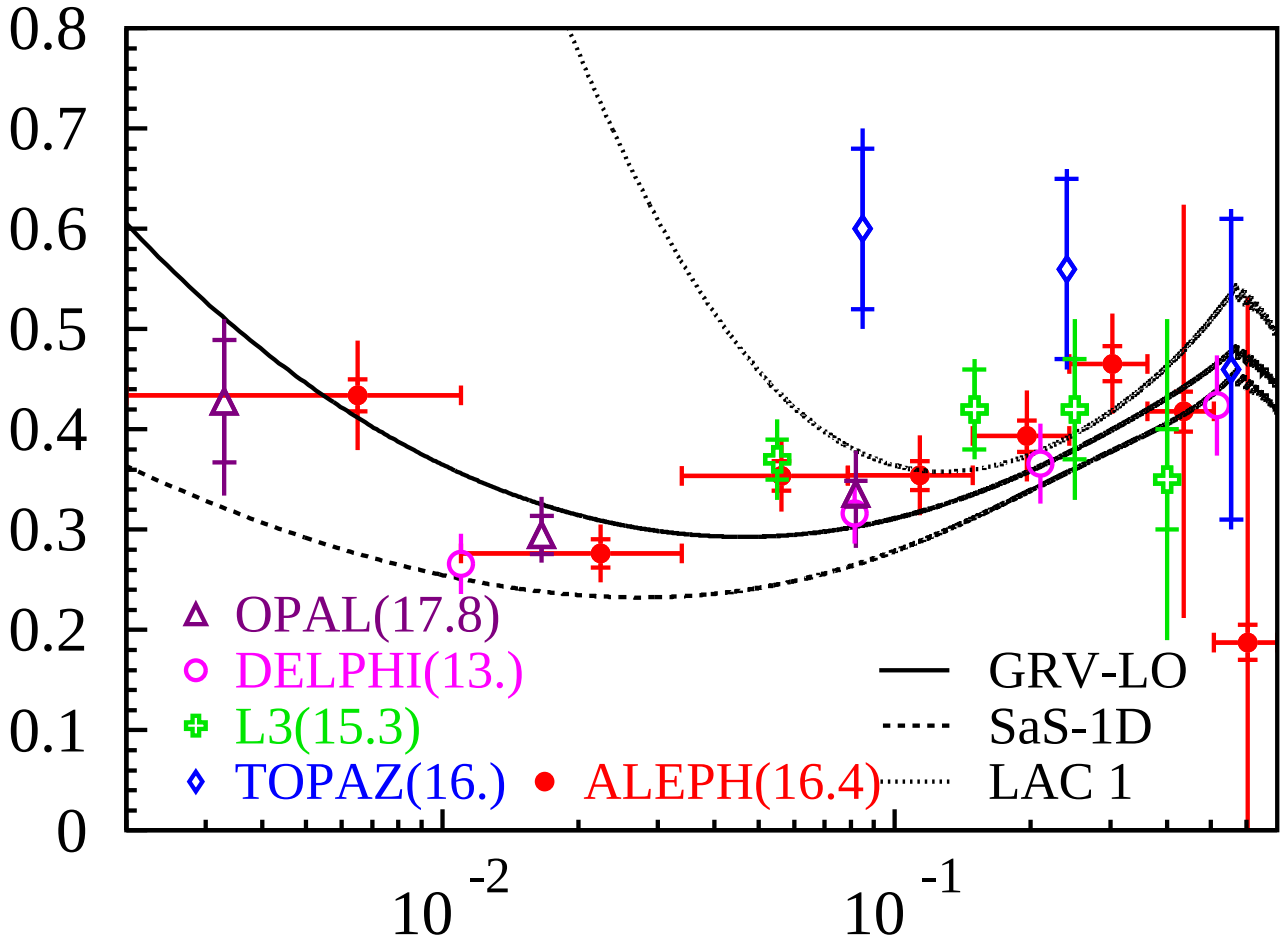
ALEPH Photon Structure Function Results
$< Q^2 > = 16.4$



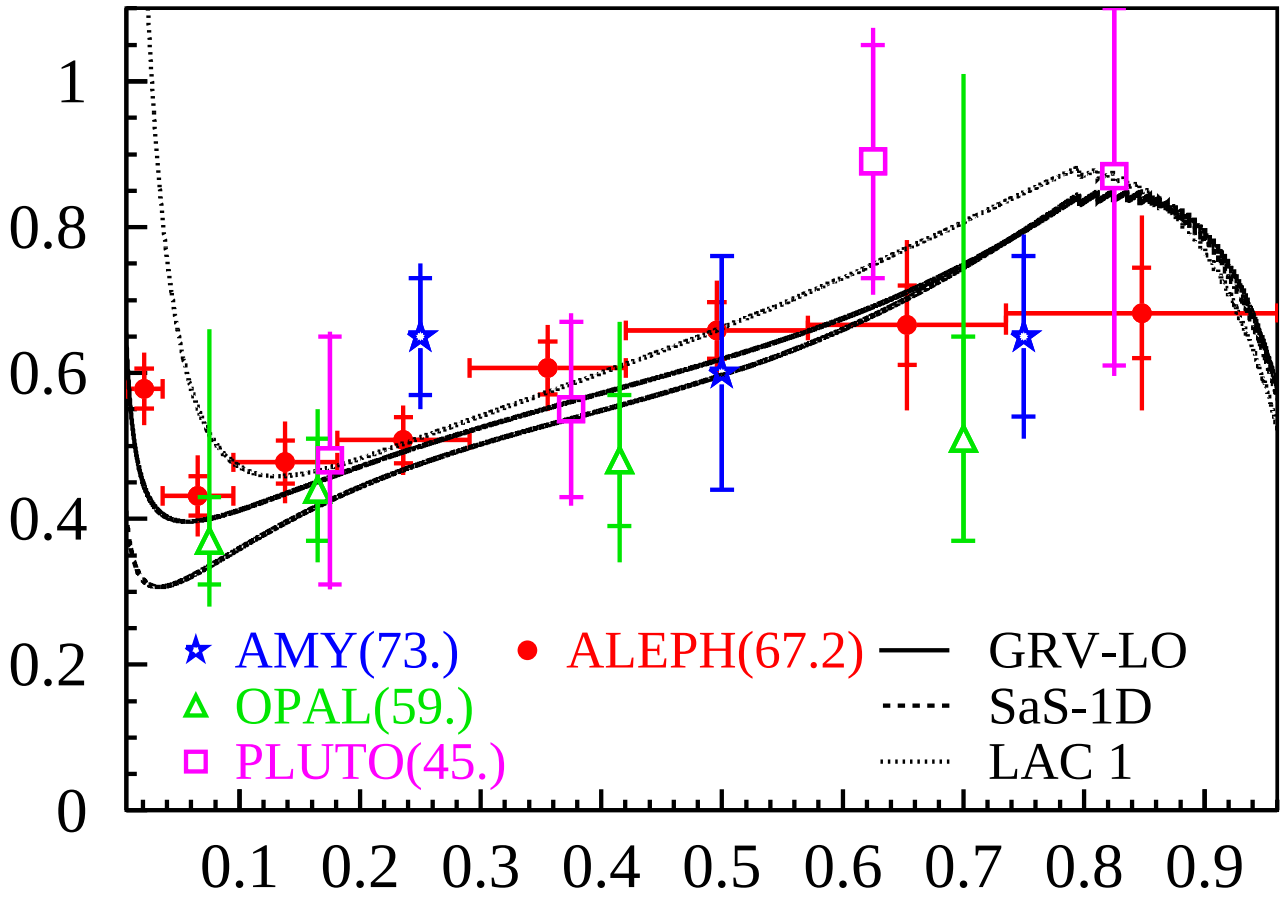
ALEPH Photon Structure Function Results
$< Q^2 > = 64.1$



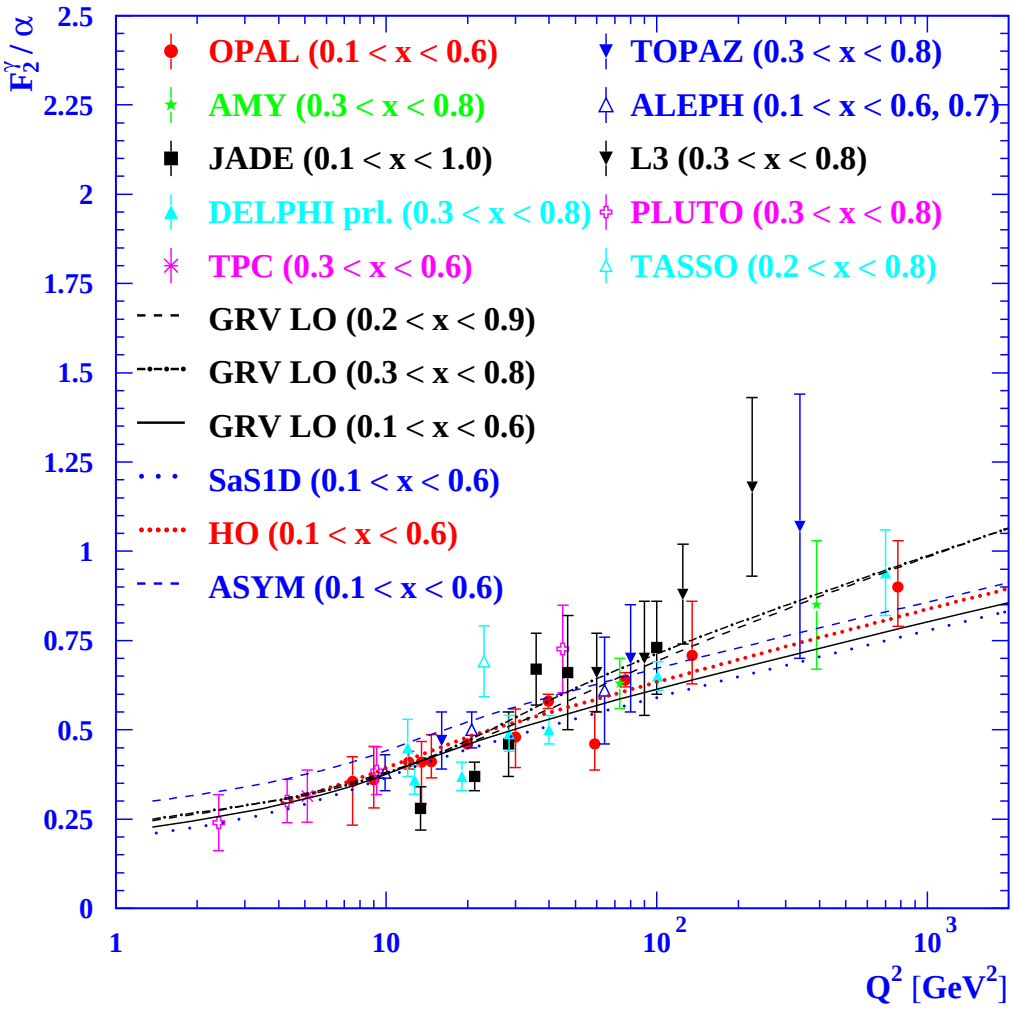
ALEPH Photon Structure Function Results
$< Q^2 > = 16.4$



ALEPH Photon Structure Function Results
$< Q^2 > = 64.1$



ALEPH Photon Structure Function Results



Heavy Flavour production $\gamma\gamma$

Theory:

- Negligible 'VDM'.
- Heavy quark mass sets scale.
- Only 'Direct' and 'Single Resolved'.
- Single Resolved part dominated by gluons.

Experiment:

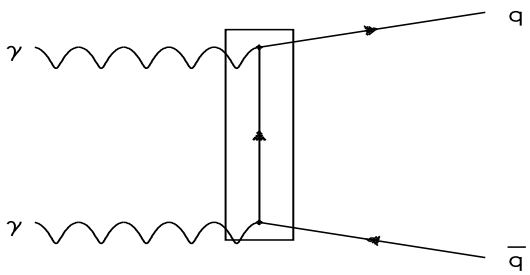
Need to tag heavy flavour... two methods used in $\gamma\gamma$:

(No vertex tagging at current energies)

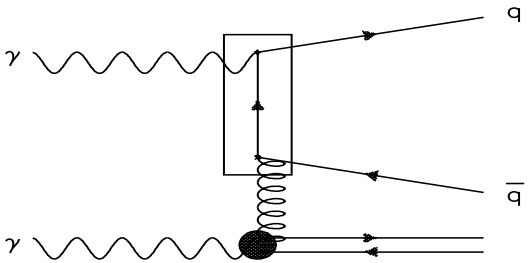
$M(D^*) - M(D^0)$	Low signal, low background
lepton	Small signal, medium background

Some Terminology

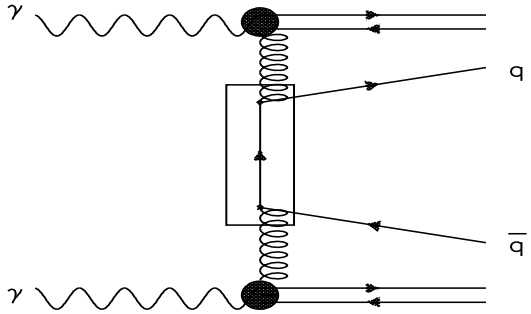
Direct Process



Single Resolved Process



Double Resolved Process

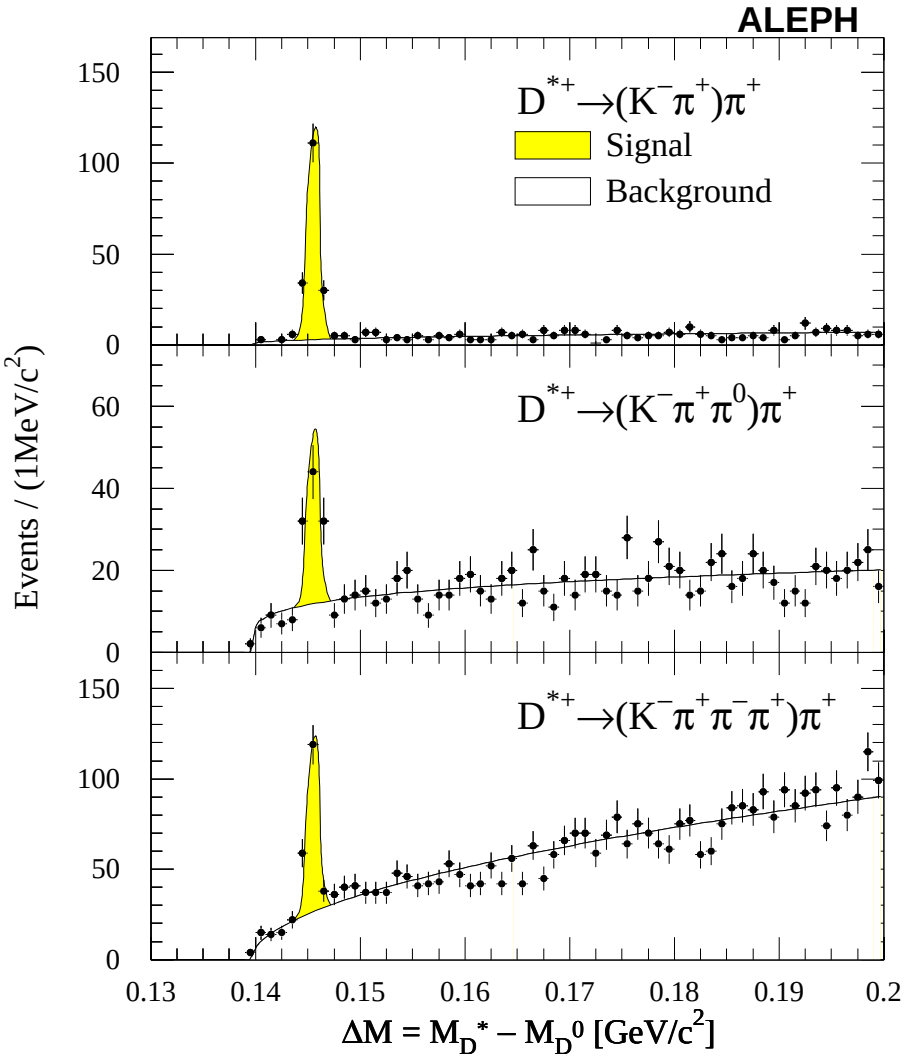


ALEPH D* Analysis

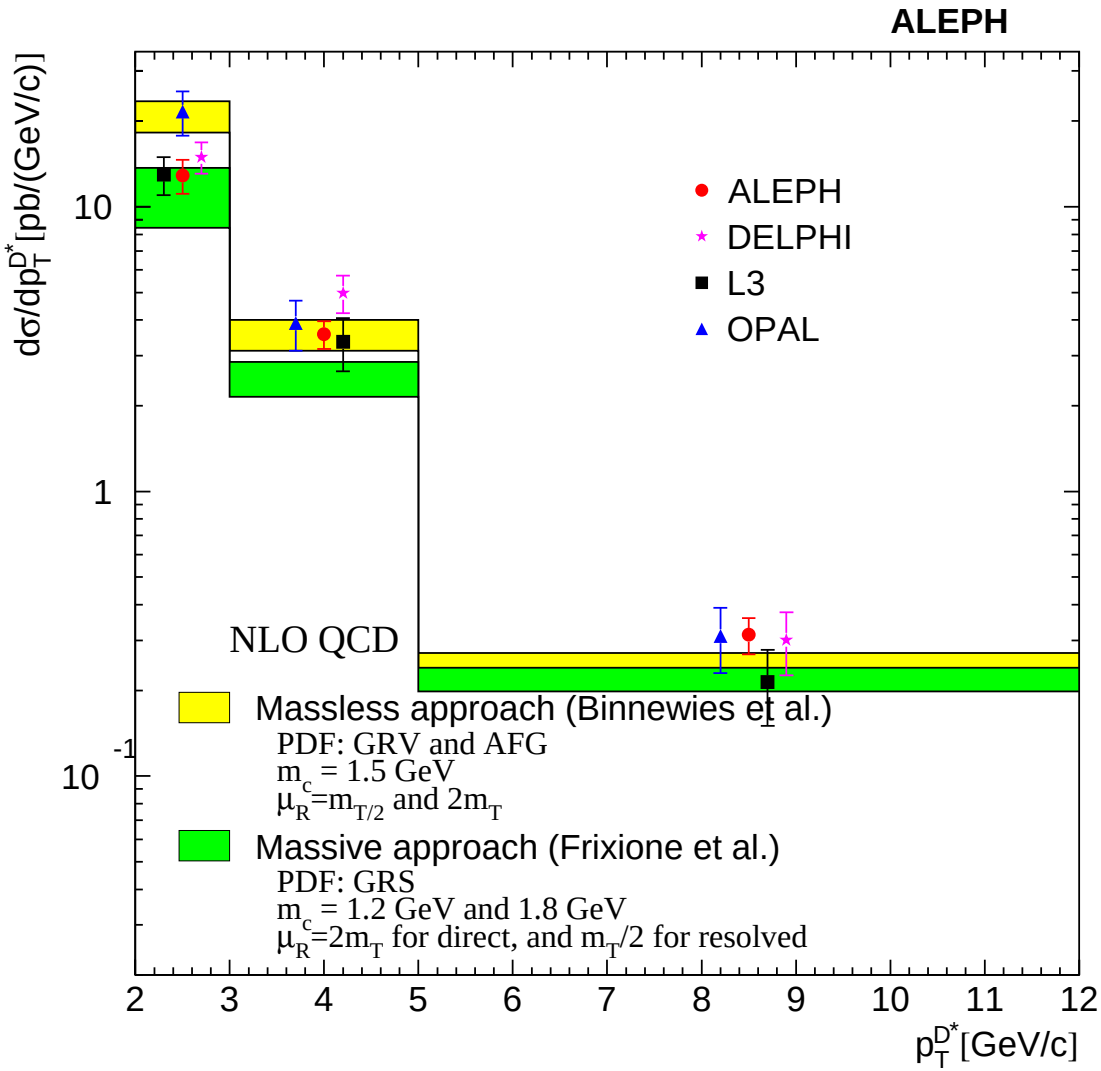
- Data sample - $699 pb^{-1}$ (All LEP 2)
- Anti-tagged hadronic $\gamma\gamma$ events
- Particle ID: $K^{\pm}$ and/or $\pi^{\pm}$ from dE/dx ;
  π^0 identified from ECAL clusters.
- Identify D^0 candidates in one of 3 decay modes:
  $K^-\pi^+$ $K^-\pi^+\pi^0$ $K^-\pi^+\pi^-\pi^+$
- Combine with additional pion to form D^{*+}.
- Plot $\Delta m = m_{D^{*+}} - m_{D^0}$
  Peak of 339.5 ± 27 events seen
- Fit fraction of direct and resolved using $p_t^{D^{*+}}/W_{vis}$
  62% direct
- Calc differential cross section in bins of p_t and η
  Compare to NLO QCD prediction
- Extrapolate to total cross section

ALEPH D* Results

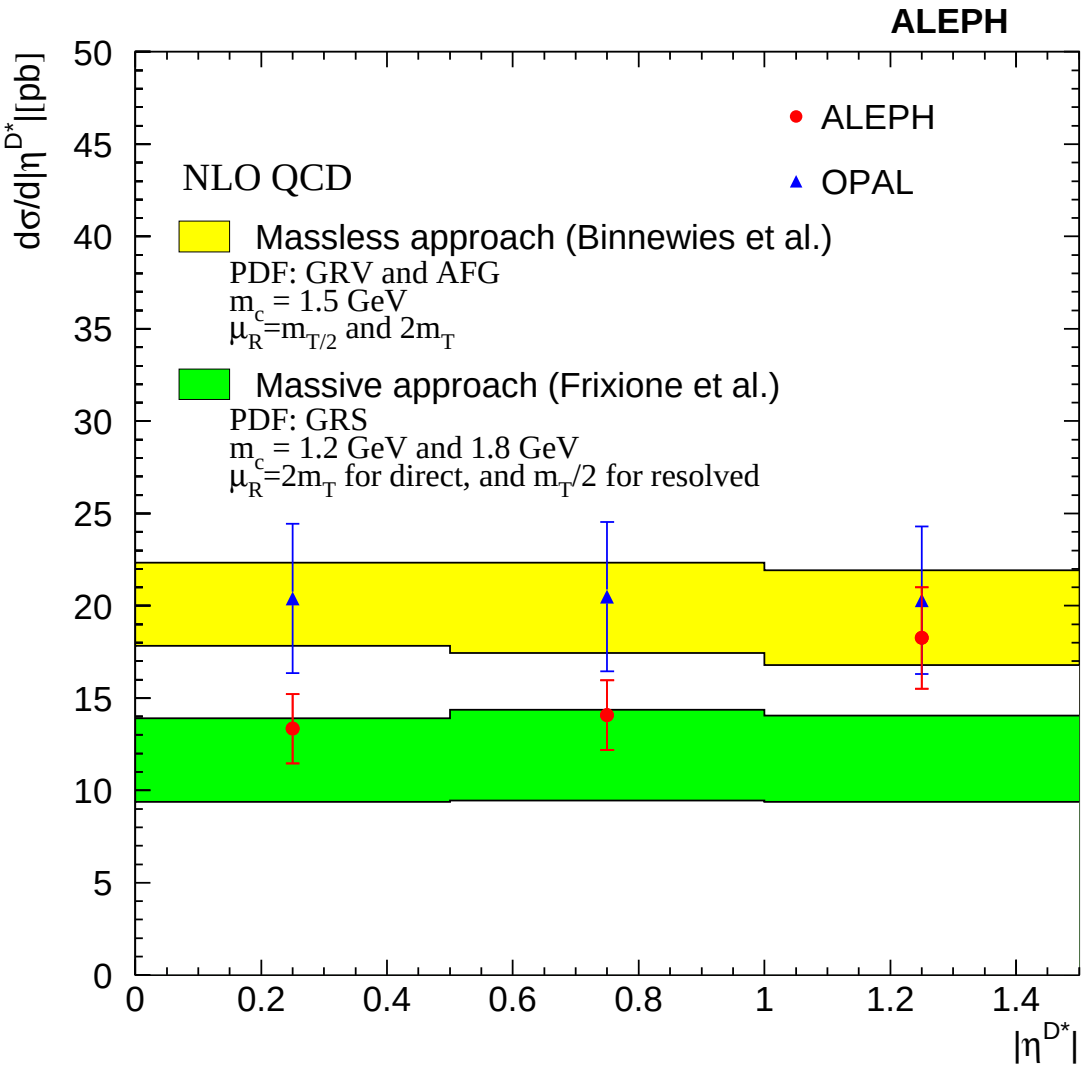
$$\begin{aligned}\gamma\gamma &\rightarrow c\bar{c} \\ &\hookrightarrow D^{*+}X \\ &\quad\hookrightarrow D^0\pi^+ \\ &\quad\quad\hookrightarrow (K^-\pi^+), \\ &\quad\quad\quad (K^-\pi^+\pi^0), \\ &\quad\quad\quad (K^-\pi^+\pi^-\pi^+)\end{aligned}$$



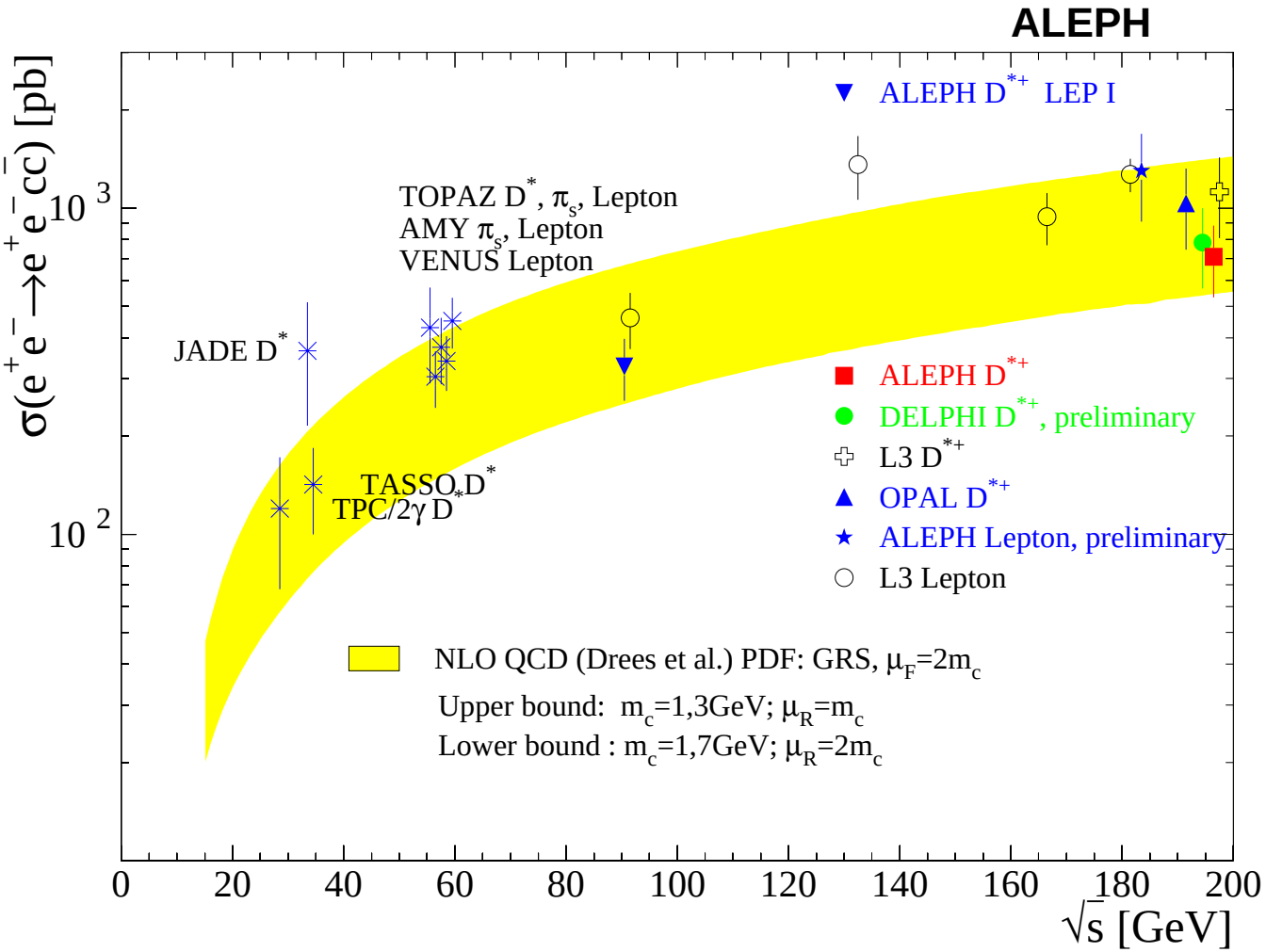
ALEPH D* Results



ALEPH D* Results



ALEPH D* Results



ALEPH D* Conclusion

Differential measurement consistent with NLO QCD.
Extrapolation to total cross section is consistent with other Experiments and NLO QCD.

Double Tagged events

Proposed as an important testing ground for BFKL calculations.

Requires two scattered electrons observed so only a few events ($\sim$500)

New variable Y defined as

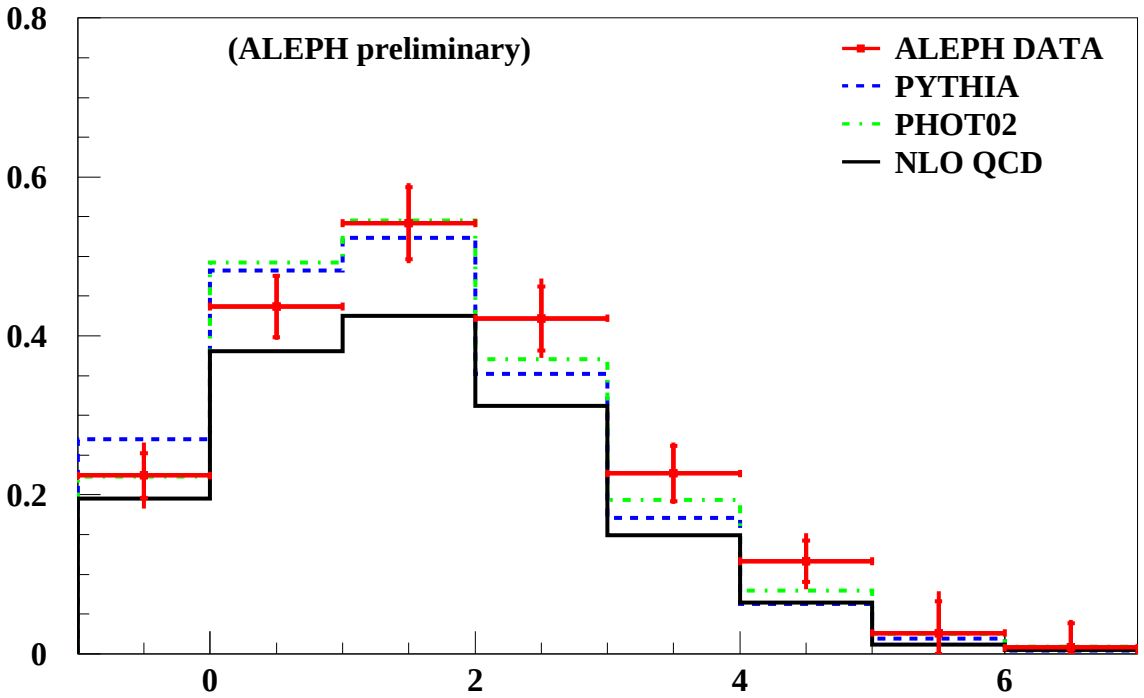
$$Y = \log W^2_{\gamma\gamma} / \sqrt{Q^2_1 Q^2_2}$$

ALEPH Double Tagged Analysis

- Data: LEP2
- Hadronic $\gamma\gamma$ selection
- Tagged in opposite luminosity calorimeters

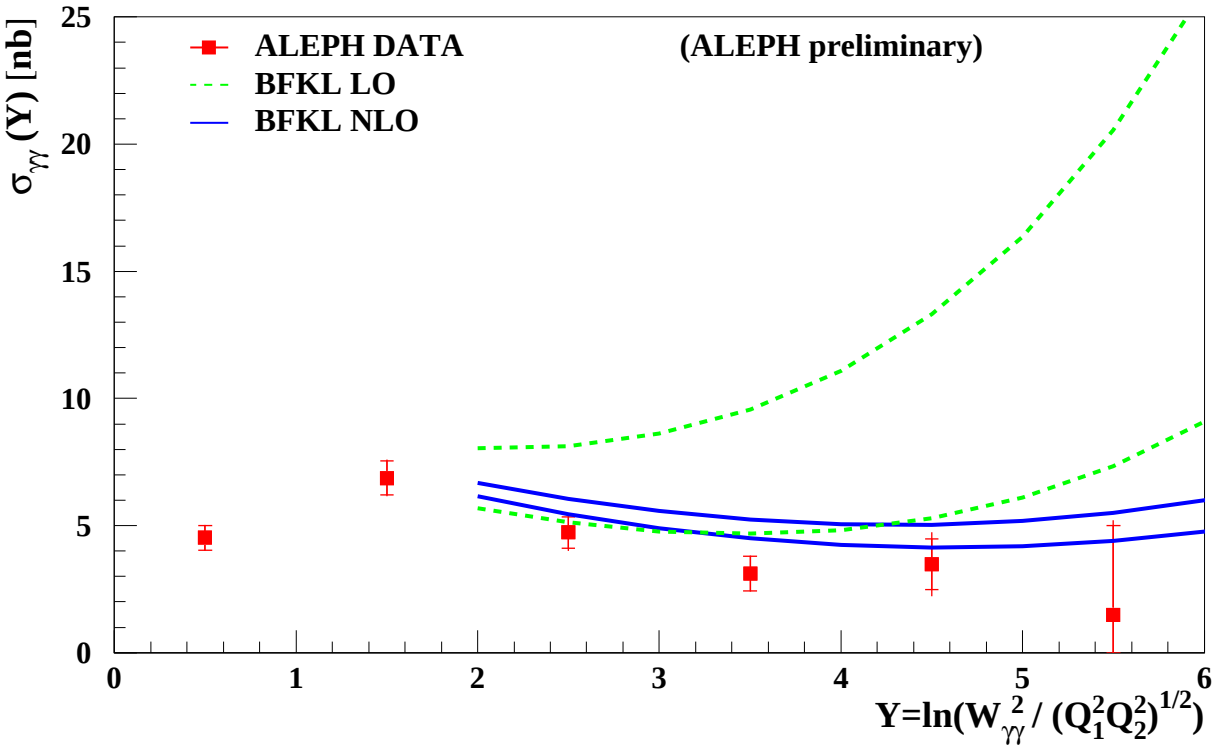
891 events with 23% background

ALEPH Double Tagged Results



Y for all events (e^+e^- differential cross section)

ALEPH Double Tagged Results



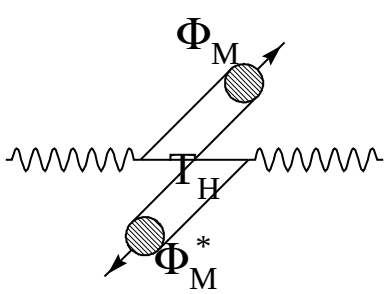
Y for events with similar Q^2 ($\gamma\gamma$ cross section)

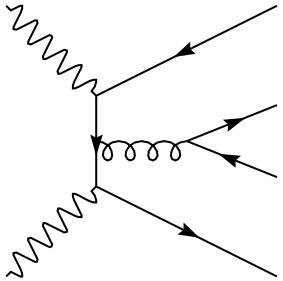
ALEPH Double Tagged Conclusion

Data consistent with NLO QCD calculation

Little room for additional (BFKL) contribution.

Exclusive Meson Pairs - QCD calculations





$$M = \int_0^1 dx \int_0^1 dy \Phi_M^*(x, p_t) T_H(x, y, p_t) \Phi_M(y, p_t)$$

T_H is the hard scattering amplitude (short range, calculable)

Φ_M is the Meson wave funtion - long range - parameterized by sum rules or lattice calculations

Results (Brodsky and Lepage):

$\gamma\gamma \to \pi^+\pi^-$ is independant of choice of Φ

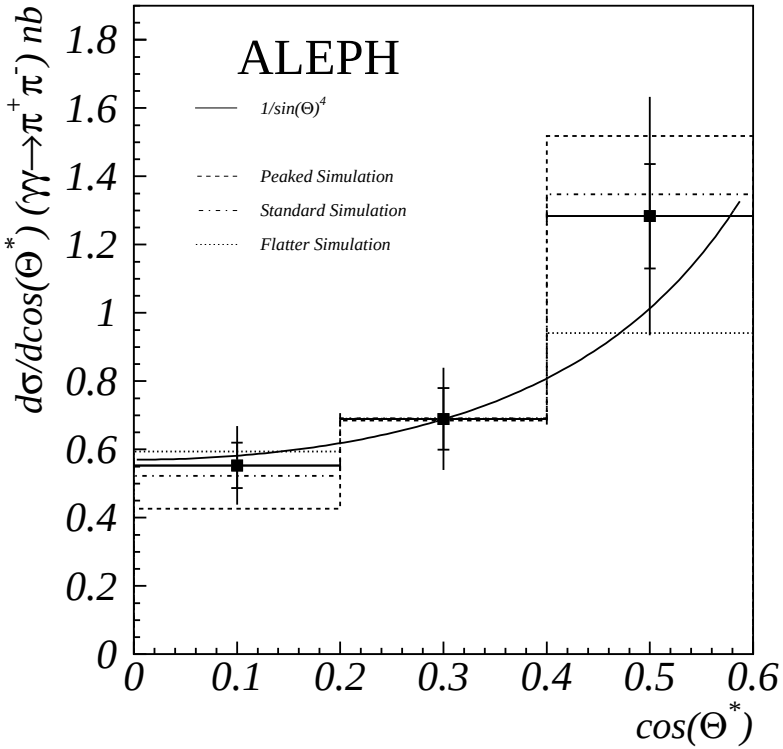
$\gamma\gamma \to \pi^0\pi^0$ is strongly dependant on choice of Φ,

ALEPH $\gamma\gamma \to \pi^+\pi^- K^+ K^-$ Analysis

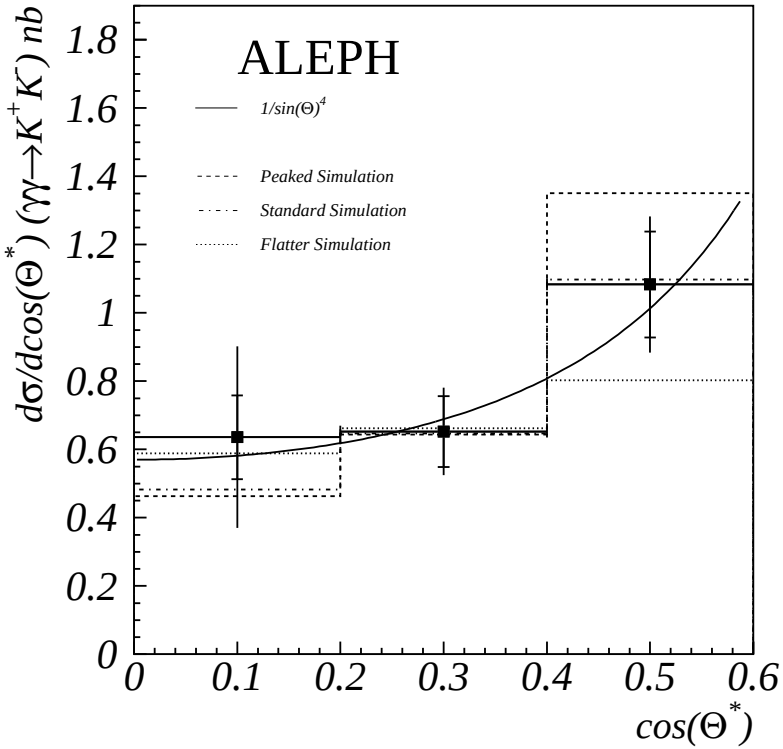
- Untagged events with just two charged tracks
- Use dE/dx to identify K or π pairs.
- Use calorimeter and muon chamber information to remove muon pair background
- Calculate cross section versus W and $\cos\theta^*$

ALEPH $\gamma\gamma \to \pi^+\pi^- K^+ K^-$ Results

$\gamma\gamma \to \pi^+\pi^-$

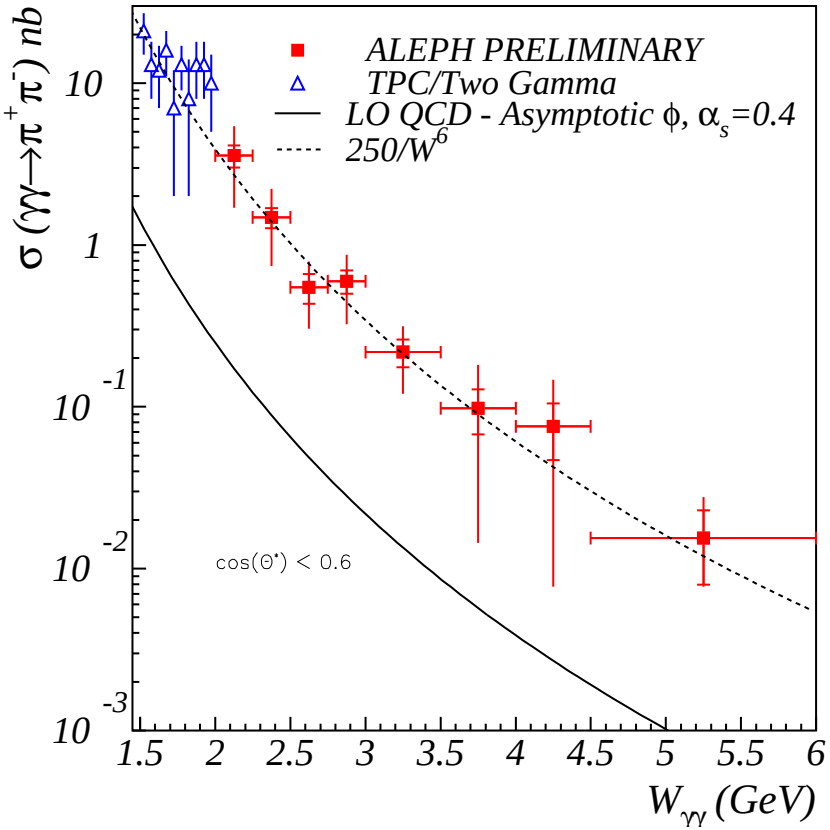


$\gamma\gamma \to K^+K^-$

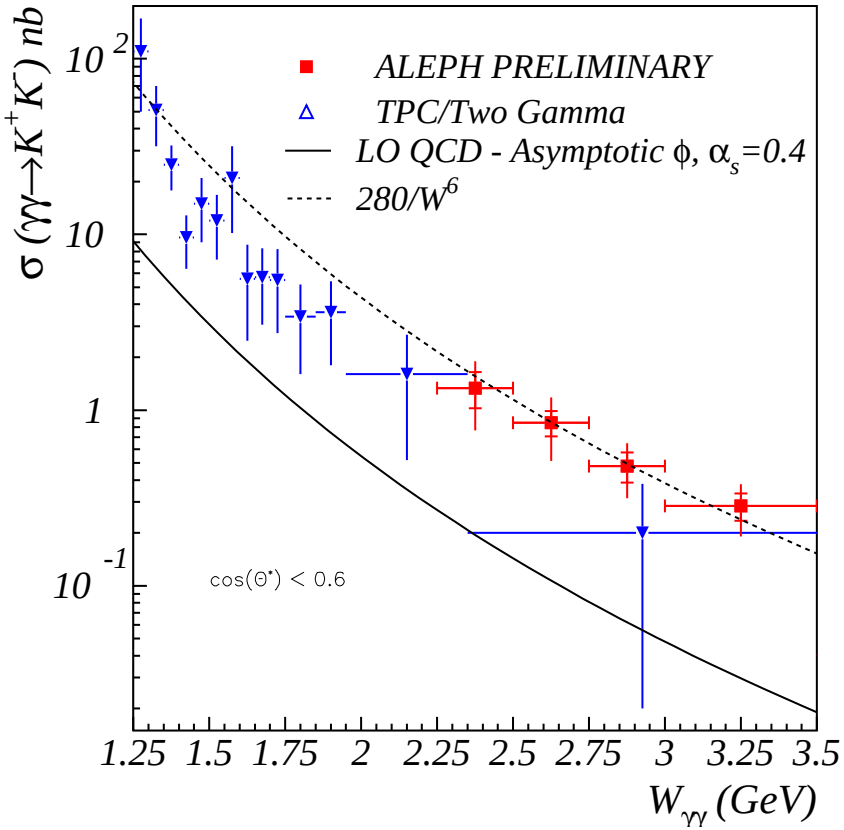


ALEPH $\gamma\gamma \to \pi^+\pi^-K^+K^-$ Results

$\gamma\gamma \to \pi^+\pi^-$



$\gamma\gamma \to K^+K^-$



ALEPH $\gamma\gamma \to \pi^+\pi^- K^+ K^-$ Conclusion

- $\gamma\gamma \to \begin{matrix}\pi^+\pi^- \\ K^+K^-\end{matrix}$ has been measured at higher masses than previously achieved.

- The shapes of the distributions in $\cos\theta^*$ and $d\sigma/dW_{\gamma\gamma}$ are in good agreement with the QCD predictions of Brodsky and Lepage.

- The normalisation of the observed signals disagrees with their prediction.

- $d\sigma/dW_{\gamma\gamma}$ fitted by A/W^6 where

  $\mathrm{A} = 250 \pm 50\,\mathrm{nb}$ for pions
  $\mathrm{A} = 280 \pm 50\,\mathrm{nb}$ for kaons.

ALEPH $\gamma\gamma$ results - Summary

Four new results in Two Photon physics at ALEPH have been presented.

New photon structure function measurements further constrain QCD fits.

NLO QCD describes charm production and double tagged cross section well.

No evidence for BFKL effects in double tagged events.

LO QCD fails to describe exclusive production of meson pairs.