Measurements of the Photon and Electron Structure Functions using SW Detectors
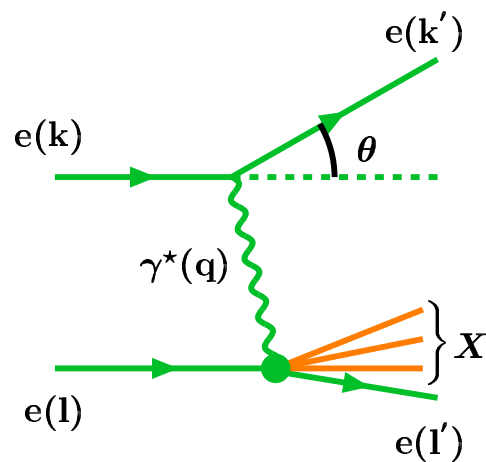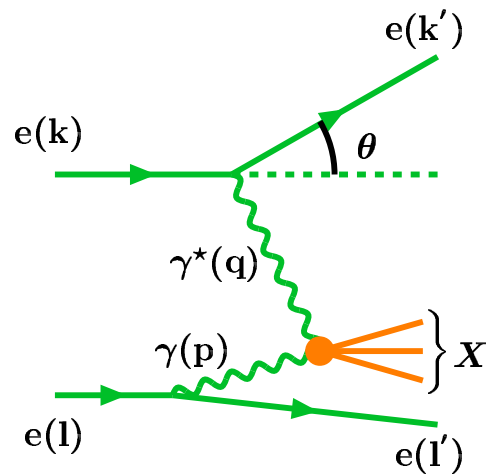
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&

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- Introduction.
- Selection of single tagged events.
- Properties of single tagged events.
- Radiative corrections and the P^2 effect.
- Extraction of structure functions.
- Conclusions.

Kinematics of $e^+e^- \to e^+e^-\gamma^\star\gamma \to e^+e^-X$

$$Q^2 \equiv -q^2 = -(k - k^{'})^2 > 0,$$
$$P^2 \equiv -p^2 = -(l - l^{'})^2 \approx 0.$$

$$s = (k + l)^2 \quad W^2 = (q + p)^2$$

$$y_e = \frac{l \cdot q}{l \cdot k} \quad x = \frac{Q^2}{2q \cdot p} \quad z = \frac{Q^2}{2q \cdot l}$$

$$Q^2 = 2E_b(1 - \cos\theta)$$
$$y_e = 1 - \frac{E}{E_b}\cos^2(\theta/2)$$

$$z = \frac{Q^2}{y_e s} \qquad x = \frac{Q^2}{Q^2 + W^2 + P^2}$$

Cross section for $e^+e^- \to e^+e^-\gamma^\star\gamma \to e^+e^-X$

Cross section in terms of photon structure functions:

$$\frac{\mathrm{d}^4\sigma_{ee}}{\mathrm{d}x\mathrm{d}Q^2\mathrm{d}z\mathrm{d}P^2} = \frac{2\pi\alpha^2}{x^2Q^4}\left[\left(1 + (1-y_e)^2\right)F_2^\gamma(x,Q^2,P^2) - \right.$$
$$\left. - y_e^2 F_L^\gamma(x,Q^2,P^2)\right]\hat{f}_\gamma^e(z/x,P^2)$$

Cross section in terms of electron structure functions:

$$\frac{\mathrm{d}^2\sigma_{ee}}{\mathrm{d}z\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{zQ^4}\left[\left(1 + (1-y_e)^2\right)F_2^e(z,Q^2) - y_e^2 F_L^e(z,Q^2)\right]$$

Relation between photon and electron structure functions:

$$F_2^e(z,Q^2) \equiv \int_z^1 dx \int_{P_{\min}^2(z/x)}^{P_{\max}^2} dP^2 \frac{z}{x^2}F_2^\gamma(x,Q^2,P^2)\hat{f}_\gamma^e(z/x,P^2)$$

Selection of single tagged $\gamma^\star\gamma$ events

Cuts applied in order to select single tagged $\gamma^\star\gamma$ events:

- $E_e > 0.75 \cdot E_b$, $E_{atag} < 0.25 \cdot E_b$,
- 34 mrad $< \theta_e < 55$ mrad,
- 2.5 GeV $< W_{had} < 0.33 \cdot \sqrt{s_{ee}}$,
- number of tracks $N_{ch} > 2$,
- $|\langle z_0 \rangle| < 4$ cm,
- $|\langle d_0 \rangle| < 0.5$ cm,
- energy of the most energetic object in all detectors (the scattered beam electrons are excluded) must be below $0.25 \cdot E_b$.

The total luminosity used in this analysis equals to 592.7 pb^{-1}: 168.5 pb^{-1} (1998) + 208.3 pb^{-1} (1999) + 215.9 pb^{-1} (2000).

Luminosity weighted centre-of-mass energy: $\sqrt{s_e e} = 198$ GeV.

Stability of single tag selection

Stability of single tagged selection (L/R) - integrated
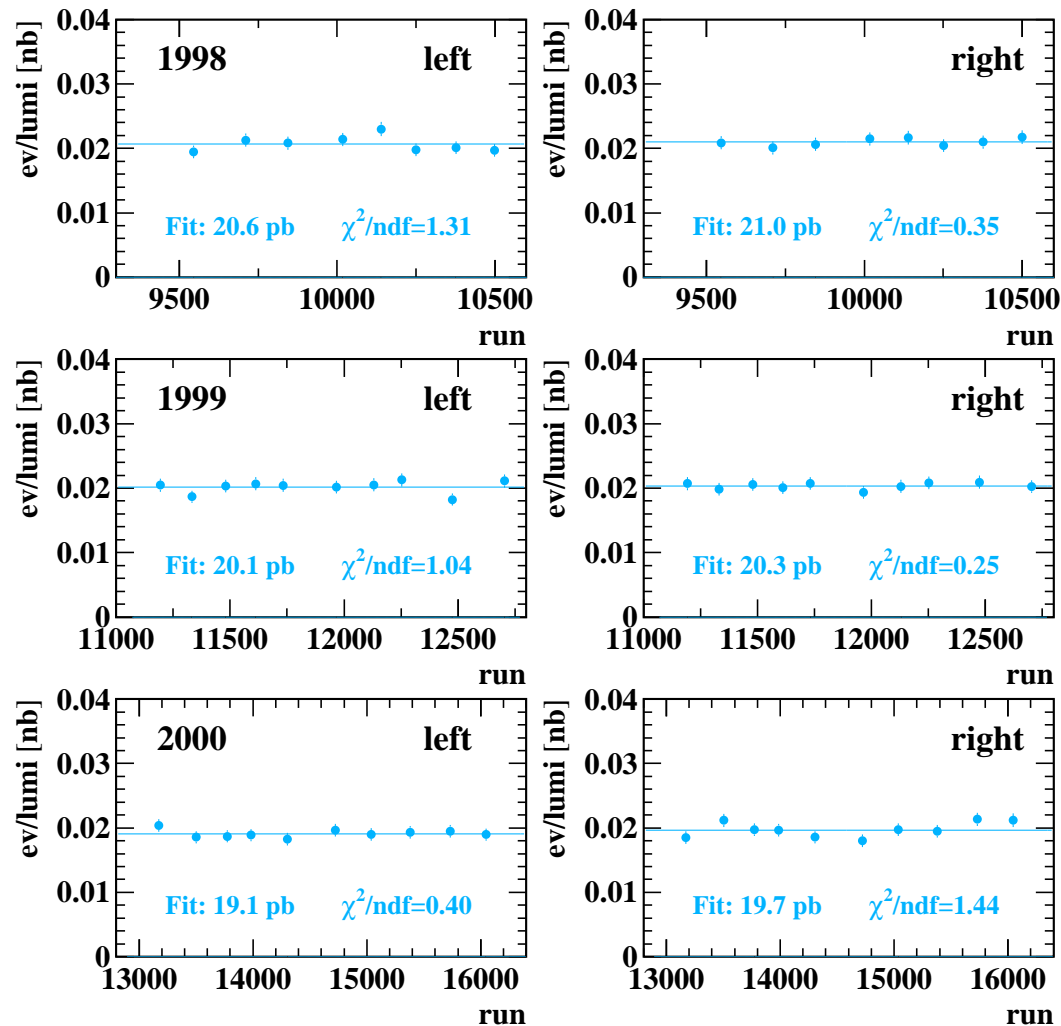
The events are equaly distributed on each side of the detector and the tagging efficiency is stable in time.

Monte Carlo samples

Signal MC: HERWIG 5.9+k_T(dyn) and PHOJET 1.05

Dominant background processes:

- $e^+e^- \to e^+e^- \tau^+ \tau^- (e^+e^-)$ − Vermaseren MC
- $Z_0 \to q\bar{q}$ − Pythia 5.7
- $\gamma^\star \gamma^\star \to$ hadrons − Phojet 1.10
- $e^+e^- \to e^+e^- q\bar{q}$ (non-multiperipheral) − GRC4F

**Radiative corrections -** TWOGAM 2.04

Selected events in data and MC

year / luminosity	1998/186 pb^{-1}	1999/203 pb^{-1}	2000/215.9 pb^{-1}
Data selected	7003	8414	8384
Data signal	6447 $\pm$ 84	7745 $\pm$ 92	7657 $\pm$ 92
HERWIG signal	6538 $\pm$ 16	7738 $\pm$ 19	8010 $\pm$ 20
Backgrounds			
$\gamma^{\star}\gamma \rightarrow \tau^{+}\tau^{-}$	349 $\pm$ 7.7	416 $\pm$ 9.3	446 $\pm$ 9.7
$\gamma^{\star}\gamma \rightarrow e^{+}e^{-}$	146 $\pm$ 5.0	174 $\pm$ 6.0	200 $\pm$ 6.7
$\gamma^{\star}\gamma^{\star} \rightarrow$ hadrons	27 $\pm$ 0.6	32 $\pm$ 0.7	32 $\pm$ 0.7
$Z_0/\gamma^{\star} \rightarrow$ hadrons	25 $\pm$ 0.9	36 $\pm$ 1.6	38 $\pm$ 2.0
4–fermion eeqq	6 $\pm$ 0.5	7 $\pm$ 0.6	8 $\pm$ 0.6

The numbers of selected events and signal events (selected events corrected for background) in the data compared to the signal predictions from the HERWIG program.

The expected numbers of background events for the dominant sources according to Monte Carlo are also listed.
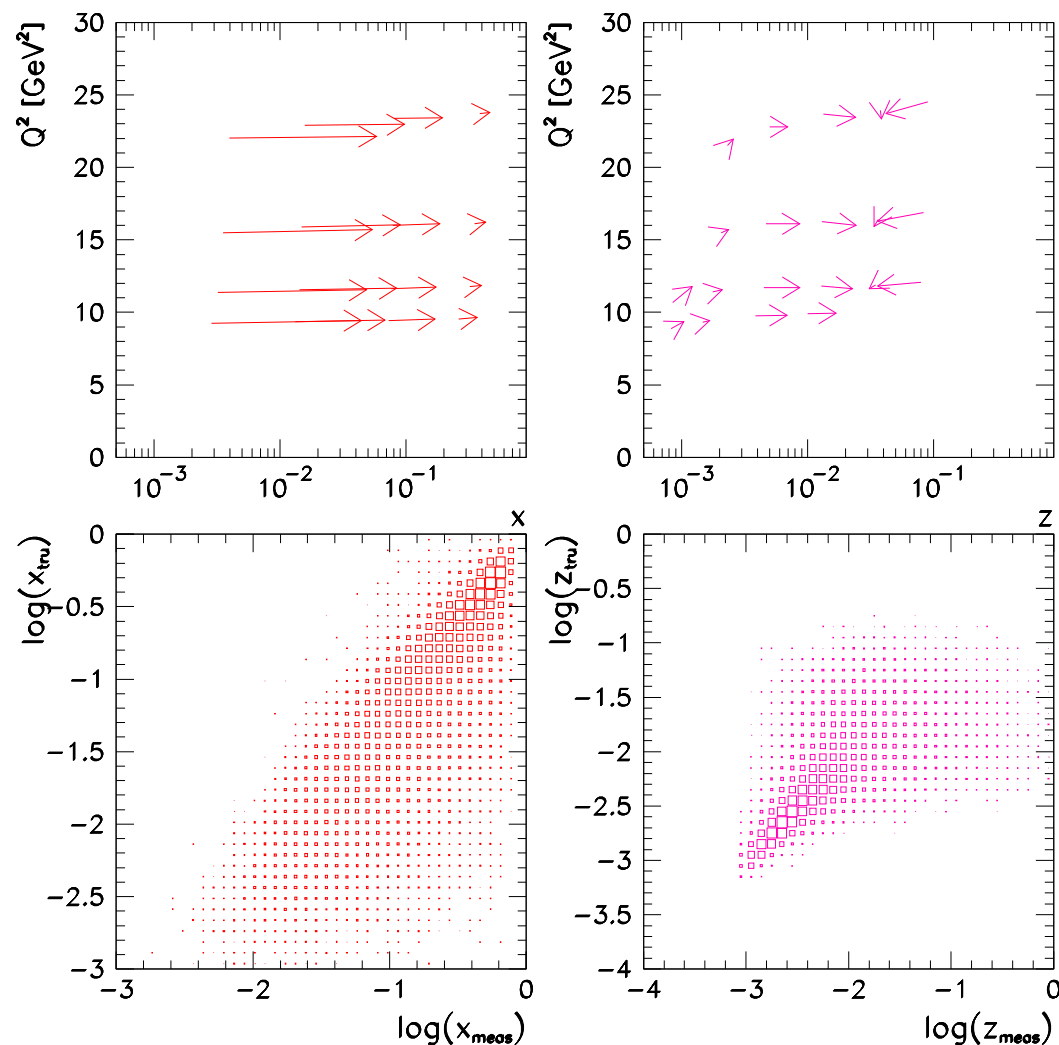
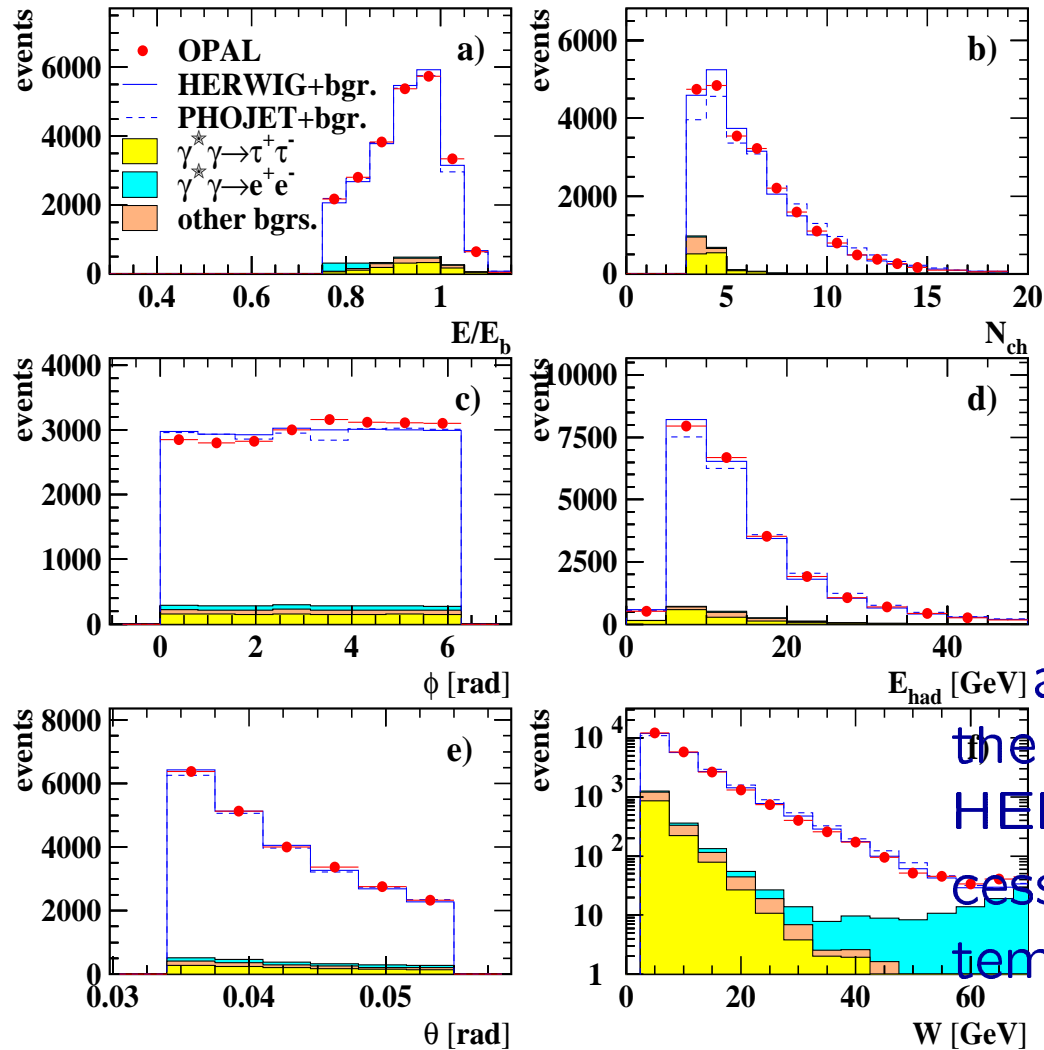The errors given are only statistical.

Kinematical plane ('98 data)
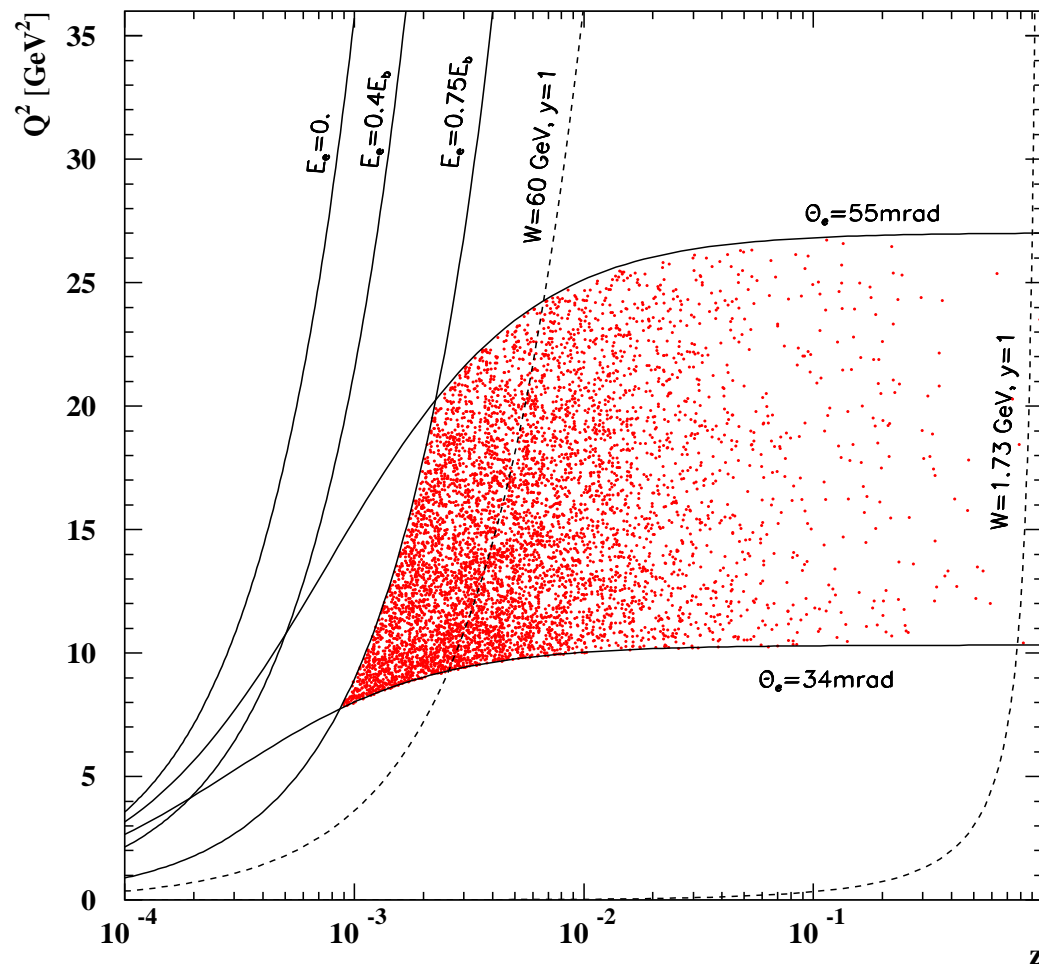
Distribution of OPAL '98 data on the (z, Q^2) plane. Several lines of constant valueas of different kinematical variables are also shown.

Migrations in x, z and Q^2

Huge migrations in x are observed and only small in z. In case of F_2^γ measurement an unfolding is necesary.

Properties of single tagged events

The electron and hadron variables are well described by the sum of signal predicted by HERWIG and background processes. PHOJET gives systematically description.

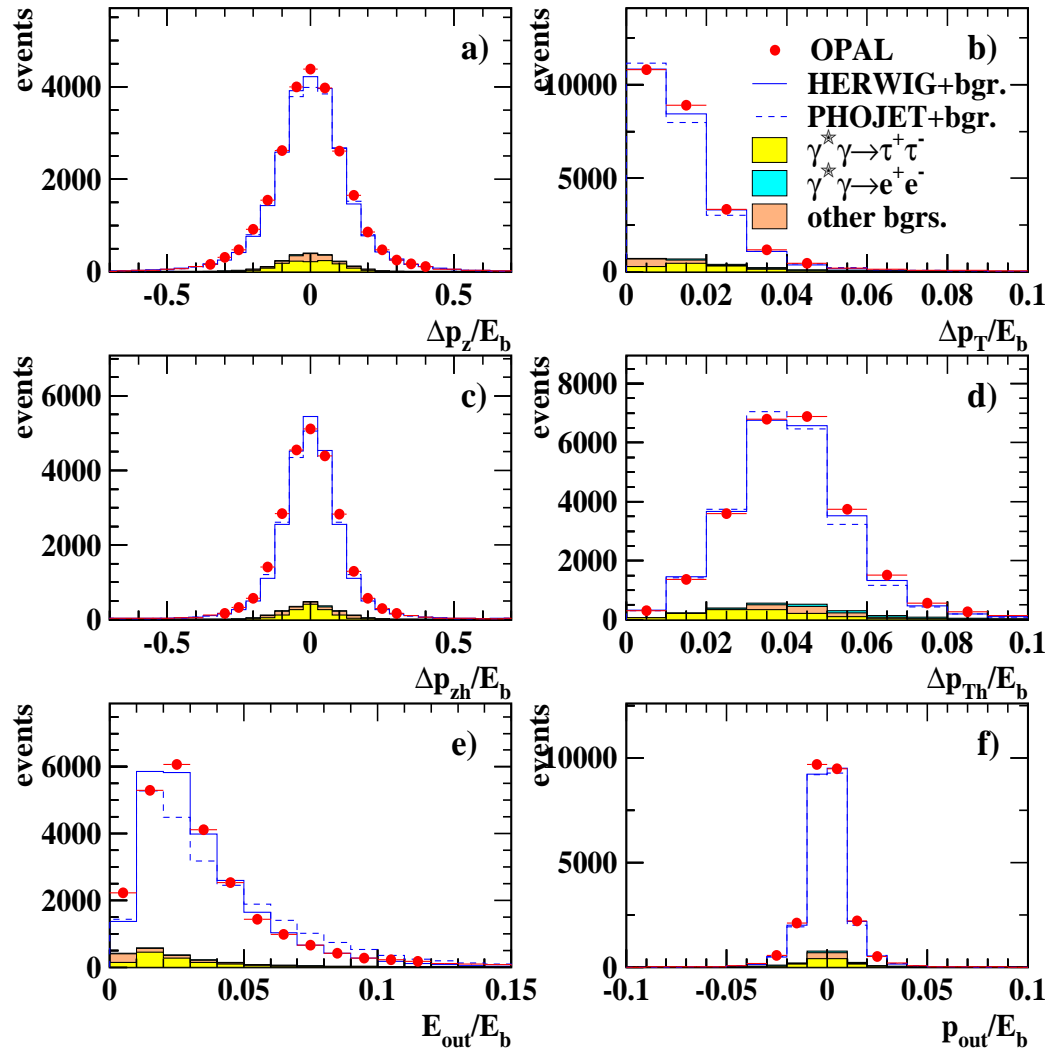# Properties of single tagged events (W_{mix})
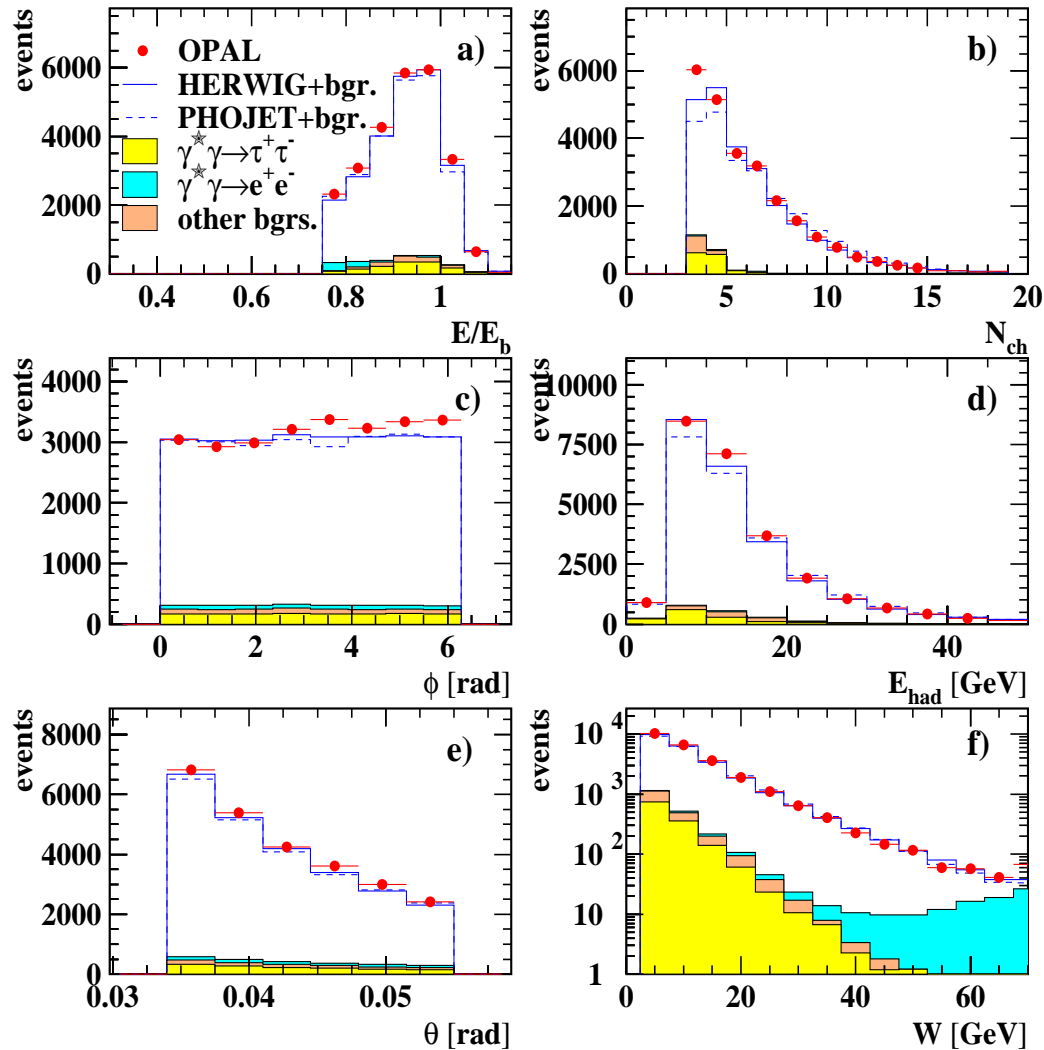
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Properties of single tagged events
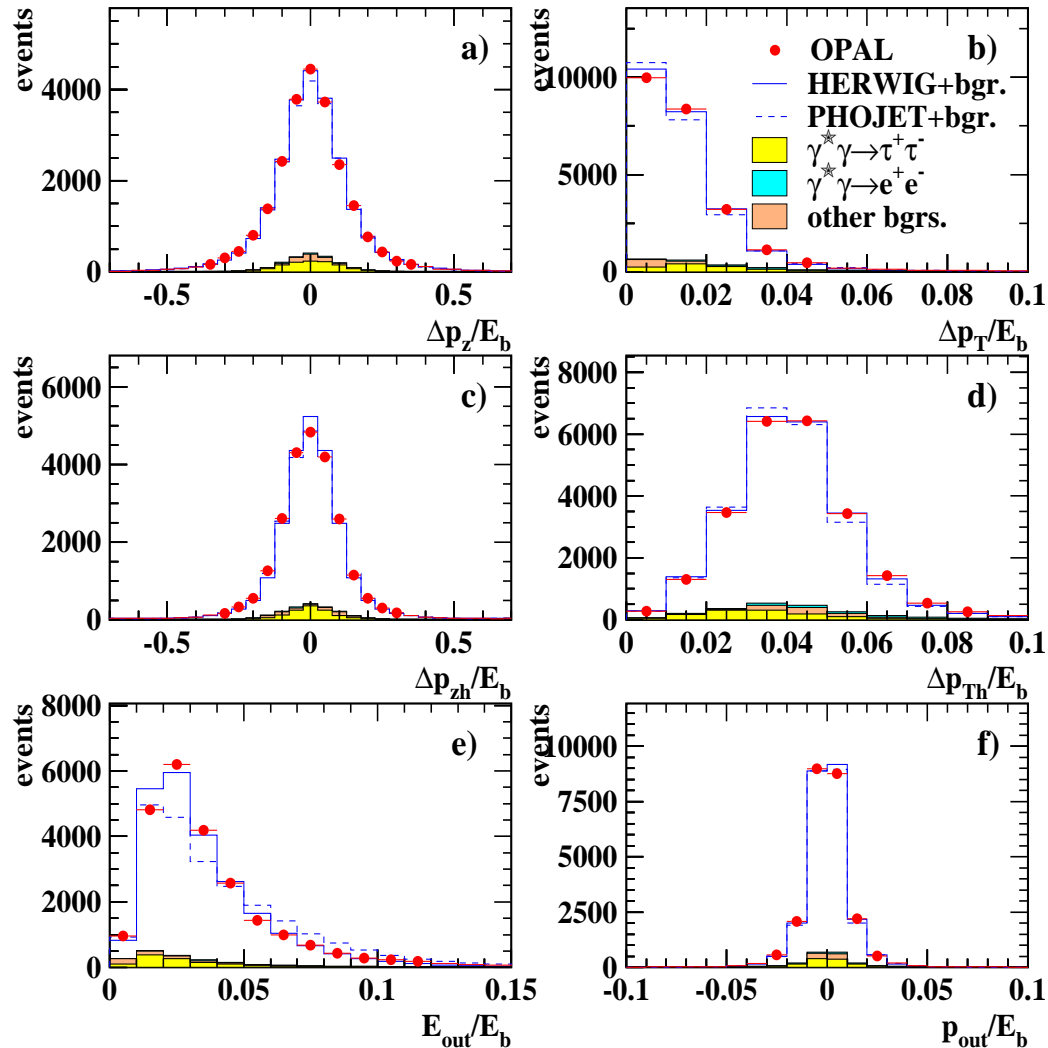
Missing longitudunal and transverse momenta as well as transverse energy out of the tag plane are well described by the sum of HERWIG and background processes.

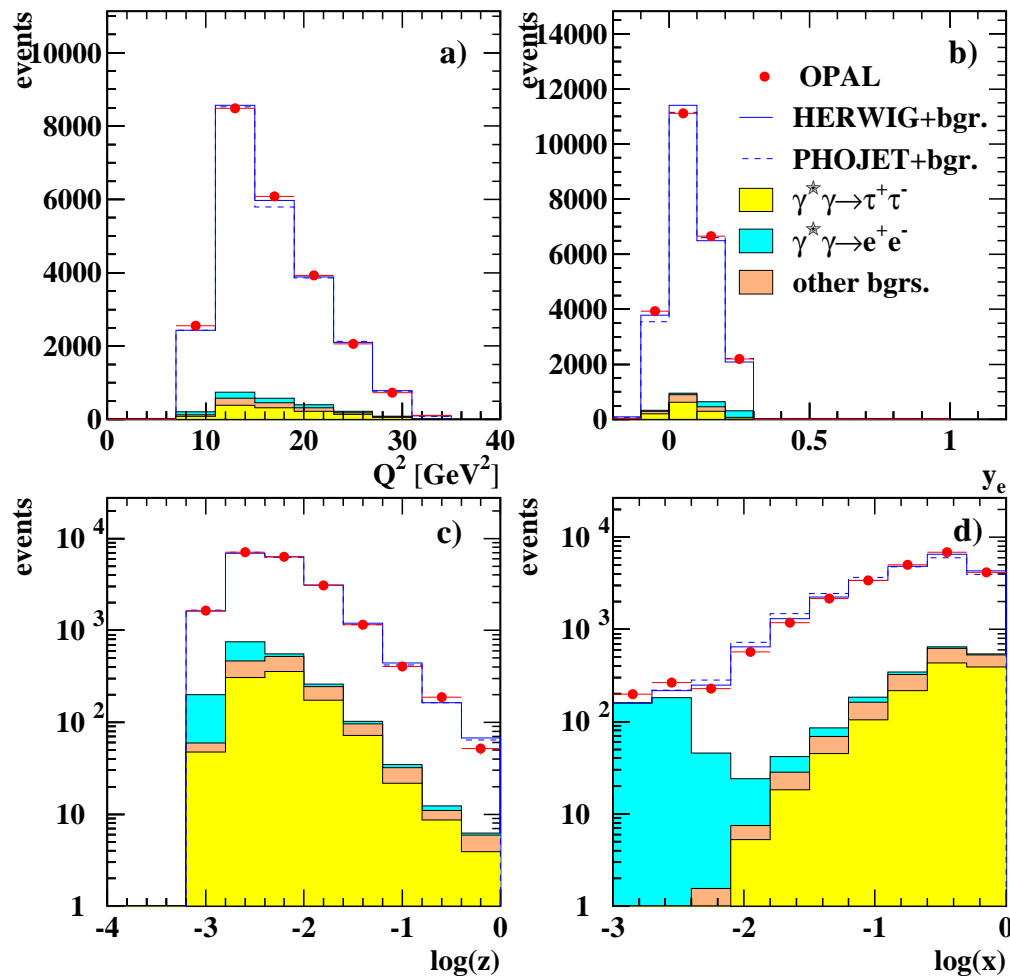# Properties of single tagged events (W_{mix})

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# Properties of single tagged events

Distributions of all important kinematical variables in data are well reproduced by the sum of HERWIG and background processes.

Properties of single tagged events (W_{mix})
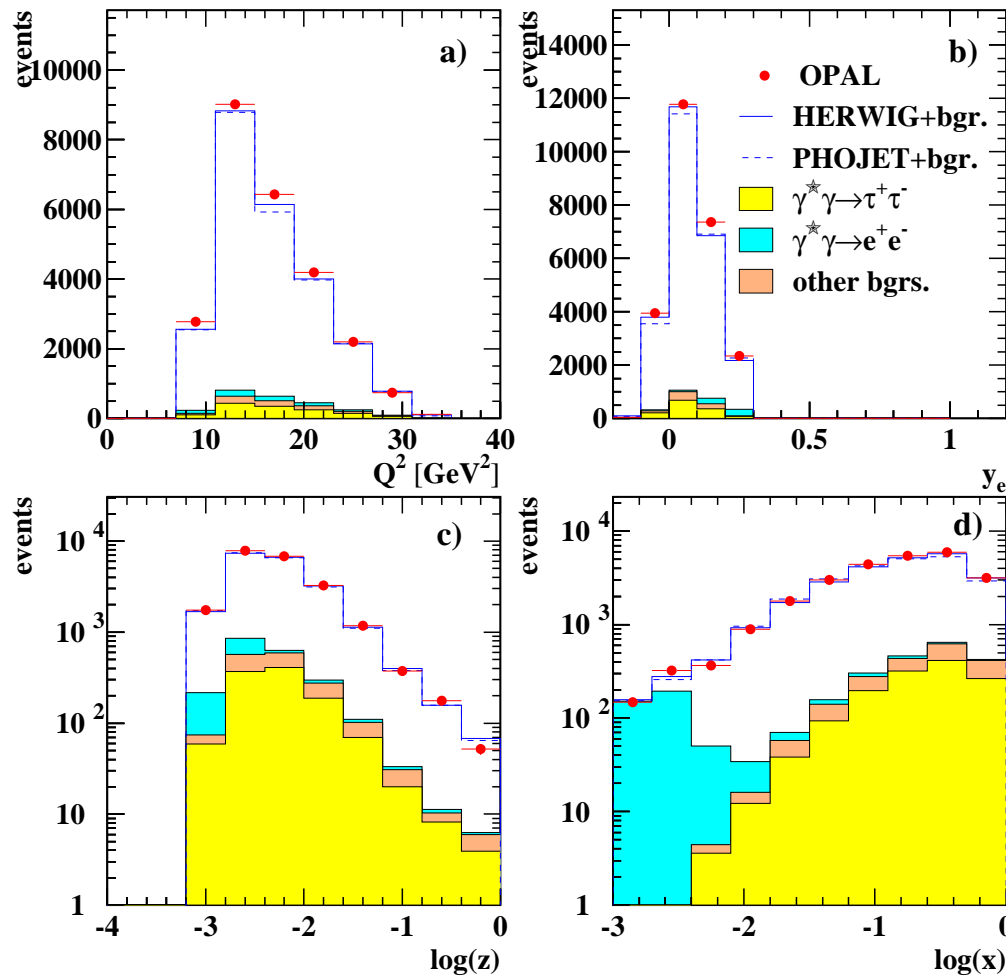

Distributions of all important kinematical variables in data are well reproduced by the sum of HERWIG and background processes.

Transverse energy and energy flows
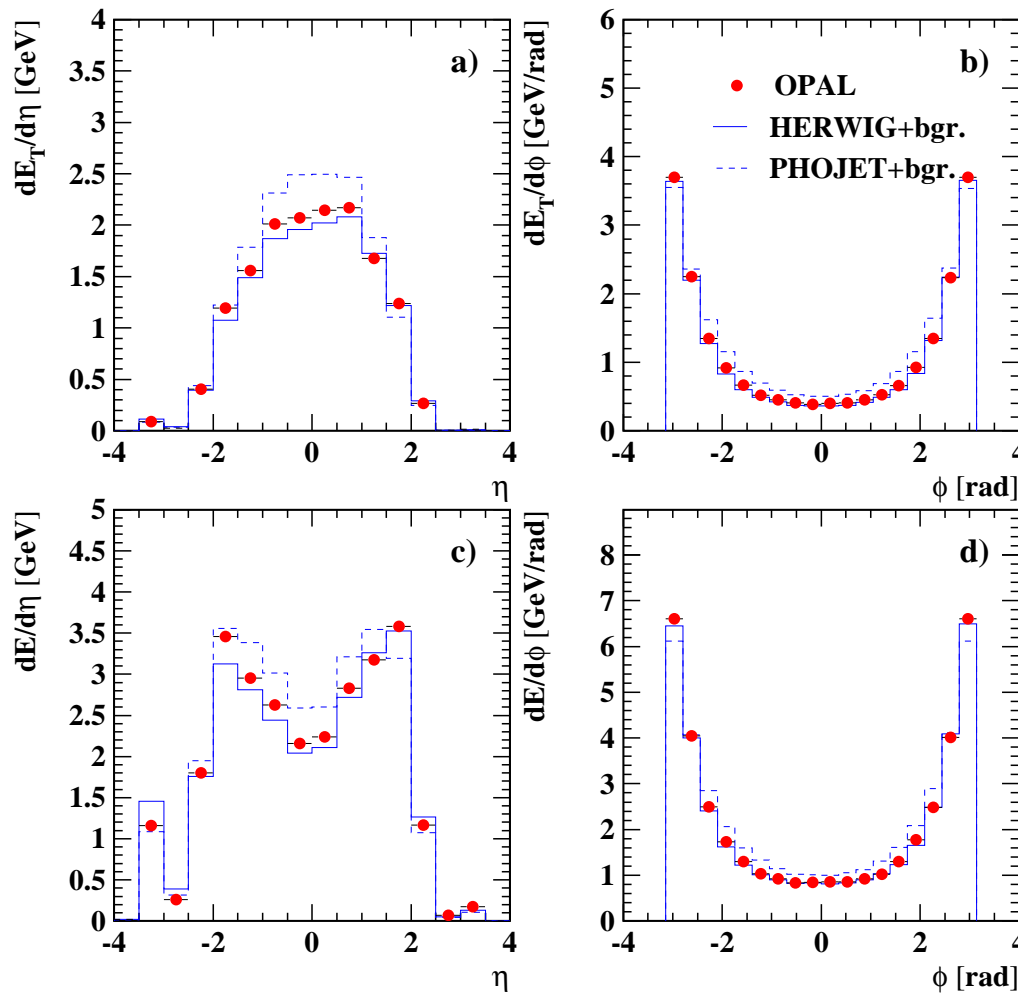
Transverse energy and energy flows of the hadronic final state are satisfactory described by the sum of the flow predicted by HERWIG and the weighted contribution from background processes. PHOJET gives significantly worse description.

Radiative corrections in function of x and z
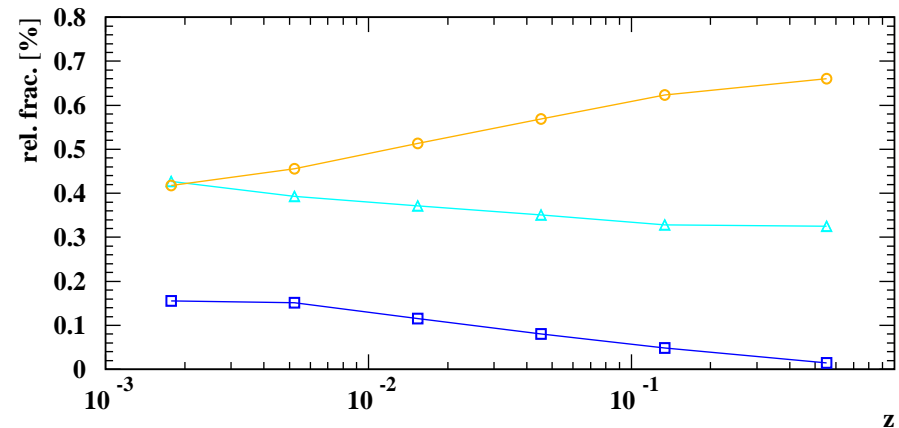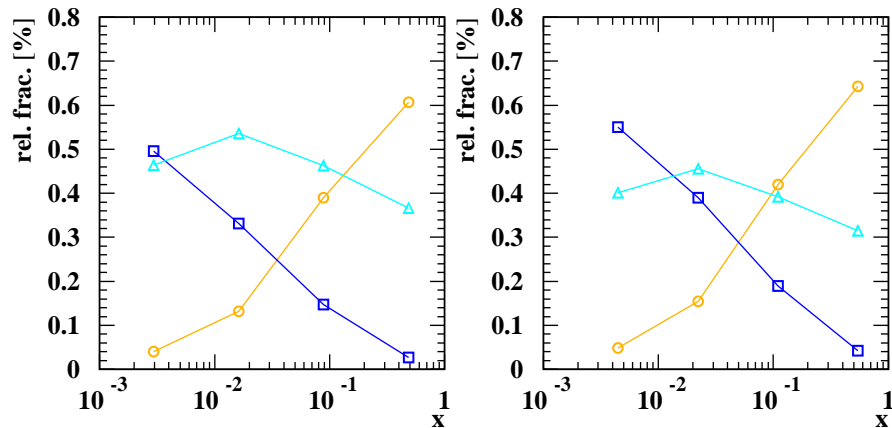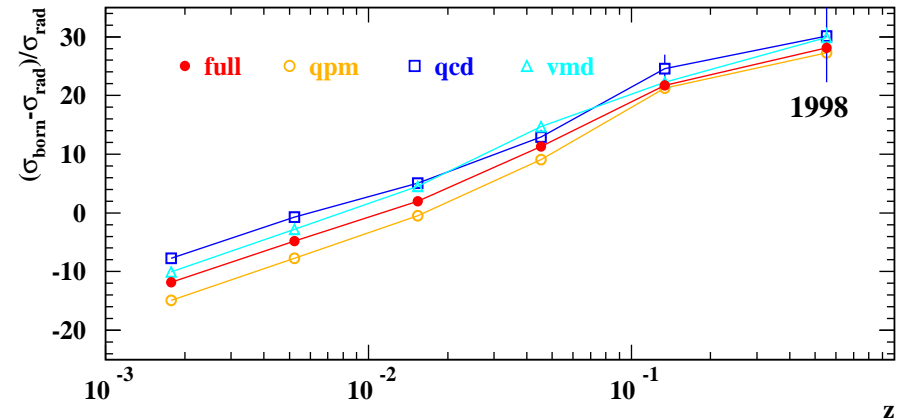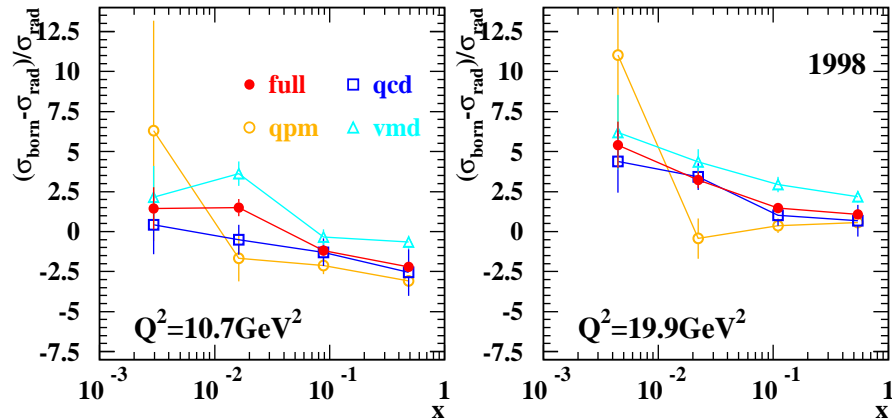
Radiative corrections in bins of x esimated using TWOGAM4. Also the average contribution of different subprocesses to the total cross section is shown.

Corrections applied to data.

$\langle Q^2 \rangle$ [GeV^2]	x range	radiative cor. [%]	bin-centre cor. [%]	P^2 effect	
				$\langle P^2 \rangle$ [GeV^2]	cor. [%]
10.2	0.0009 - 0.0050	2.68 $\pm$ 1.37	3.61 $\pm$ 0.57	0.033 $\pm$ 0.005	9.81 $\pm$ 1.58
	0.0050 - 0.0273	0.74 $\pm$ 0.57	-0.23 $\pm$ 0.62	0.042 $\pm$ 0.003	11.67 $\pm$ 0.83
	0.0273 - 0.1496	-2.43 $\pm$ 0.35	-7.50 $\pm$ 0.82	0.075 $\pm$ 0.004	14.86 $\pm$ 0.18
	0.1496 - 0.8187	-3.38 $\pm$ 0.25	10.55 $\pm$ 0.62	0.095 $\pm$ 0.002	10.75 $\pm$ 0.41
20.0	0.0015 - 0.0074	4.88 $\pm$ 1.43	2.25 $\pm$ 0.35	0.033 $\pm$ 0.001	9.37 $\pm$ 0.42
	0.0074 - 0.0369	1.52 $\pm$ 0.51	-1.43 $\pm$ 0.63	0.052 $\pm$ 0.004	13.21 $\pm$ 0.38
	0.0369 - 0.1827	0.61 $\pm$ 0.30	-7.70 $\pm$ 0.87	0.092 $\pm$ 0.004	15.27 $\pm$ 0.14
	0.1827 - 0.9048	0.21 $\pm$ 0.20	6.06 $\pm$ 0.90	0.116 $\pm$ 0.002	9.24 $\pm$ 0.30

The average values of the corrections which have been applied are listed. For a given bin in Q^2 and x the correction is the difference of the corrected and non corrected cross sections as a percentage of the non corrected cross section.

Average values of P^2 in each bin are also given.

For the details of how the correction have been estimated and the meaning of the errors see text.

Systematic checks

The following possible contributions have been taken into account:

- unfolding with PHOJET instead of HERWIG,
- energy scale in SW - change by $\pm 1\%$,
- energy scale in ECAL - change by $\pm 3\%$,
- selection cuts changes reflecting resolution:
  - lower cut on θ changed by ± 0.2 mrad,
  - cut on electron energy changed by $\pm 0.02 E_b$,
  - lower cut on W changed by ± 0.2 GeV,
  - upper cut on W changed by ± 3 GeV,
  - cut on $|\langle z_0 \rangle|$ changed by ± 1 cm,
  - cut on $|\langle d_0 \rangle|$ changed by ± 0.1 cm,
  - cut on the number of tracks changed from $N_{\mathrm{ch}} > 2$ to $N_{\mathrm{ch}} > 3$ (aplied to both data and MC).
- the errors due to radiative corrections, bin-centre correction and P^2 correction were added to the total systematic error.

Extraction of the photon structure function F_2^γ

The photon structure function F_2^γ has been extracted from the differential cross section $\mathrm{d}\sigma/\mathrm{d}x\mathrm{d}Q^2$ as a function of x at two values of $\langle Q^2 \rangle = 10.2 \ \mathrm{GeV}^2$ and $20 \ \mathrm{GeV}^2$, based on the standard DIS formula. The cross section itself was measured using two dimensional unfolding (GURprogram) in bins of x and Q^2.

The cross section (and F_2^γ) was corrected for radiative effects.

The x bin center correction and the correction from the average Q^2 in a bin to the nominal $\langle Q^2 \rangle$ was calculated as the average prediction from GRV LO and SaS 1D parametrisations.

The P^2 correction was applied in order to move the measured quantities from the P^2 value accesible in the measuremento $P^2 =0$. This correction was calculated as the average prediction of the SaS 1D and GRSc parametrizations.

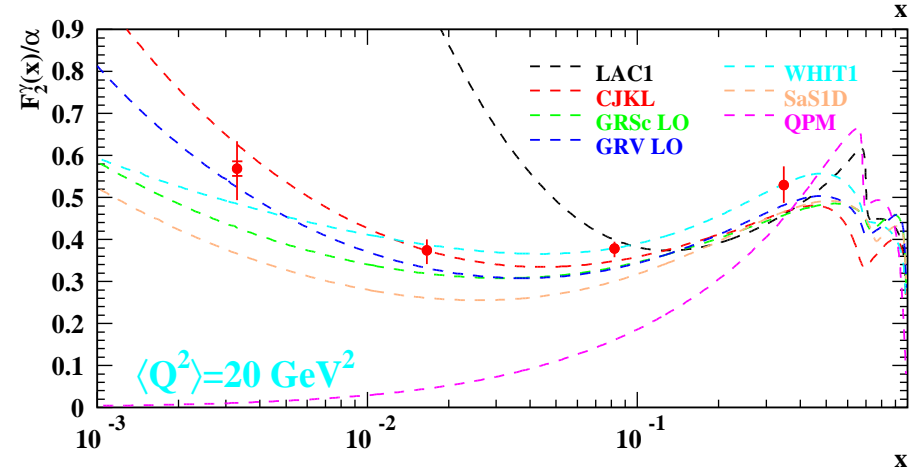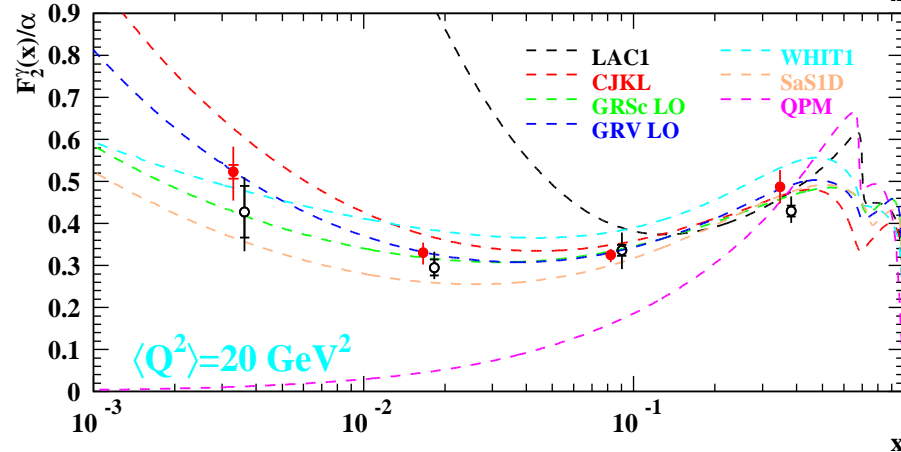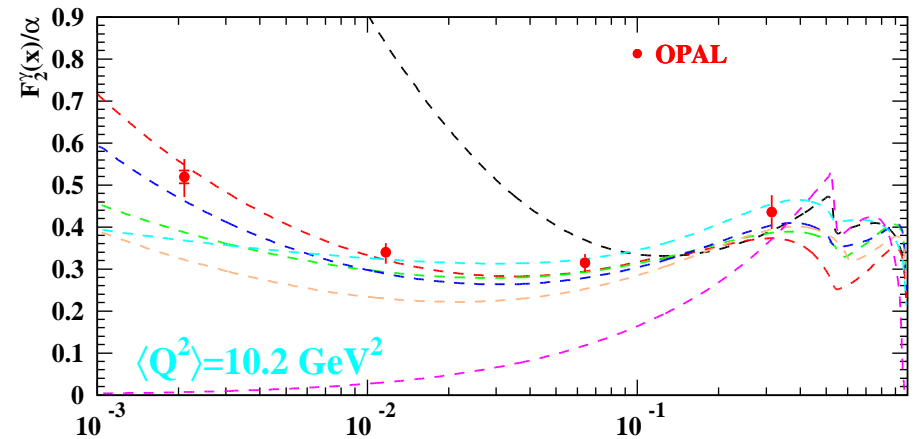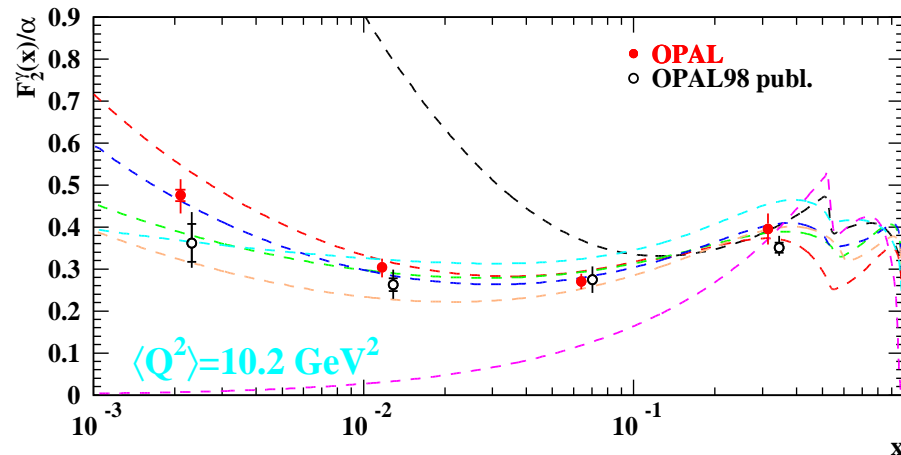# Extraction of the electron structure function F_2^e

The electron structure function F_2^e has been extracted from the differential cross section $\mathrm{d}\sigma/\mathrm{d}z\mathrm{d}Q^2$ as a function of z for an average Q^2 =15GeV^2.

The cross section itself has been measured in the phase space region defined by $E_e > 0.75E_b$ GeV, $34 < \theta_e < 55$ mrad and $W > 1.73$ GeV using simple bin-by-bin correction method.

The cross section (and F_2^e) was corrected for radiative effects.

The z bin center correction and the correction from the average Q^2 in a bin to the nominal $\langle Q^2 \rangle$ was calculated as the average prediction from GRV LO and SaS 1D parametrisations.

Photon structure function F_2^γ/α

Photon structure function measured at $\langle Q^2 \rangle = 10.2$ GeV^2 and 20 GeV^2.

Electron structure function F_2^e/α^2
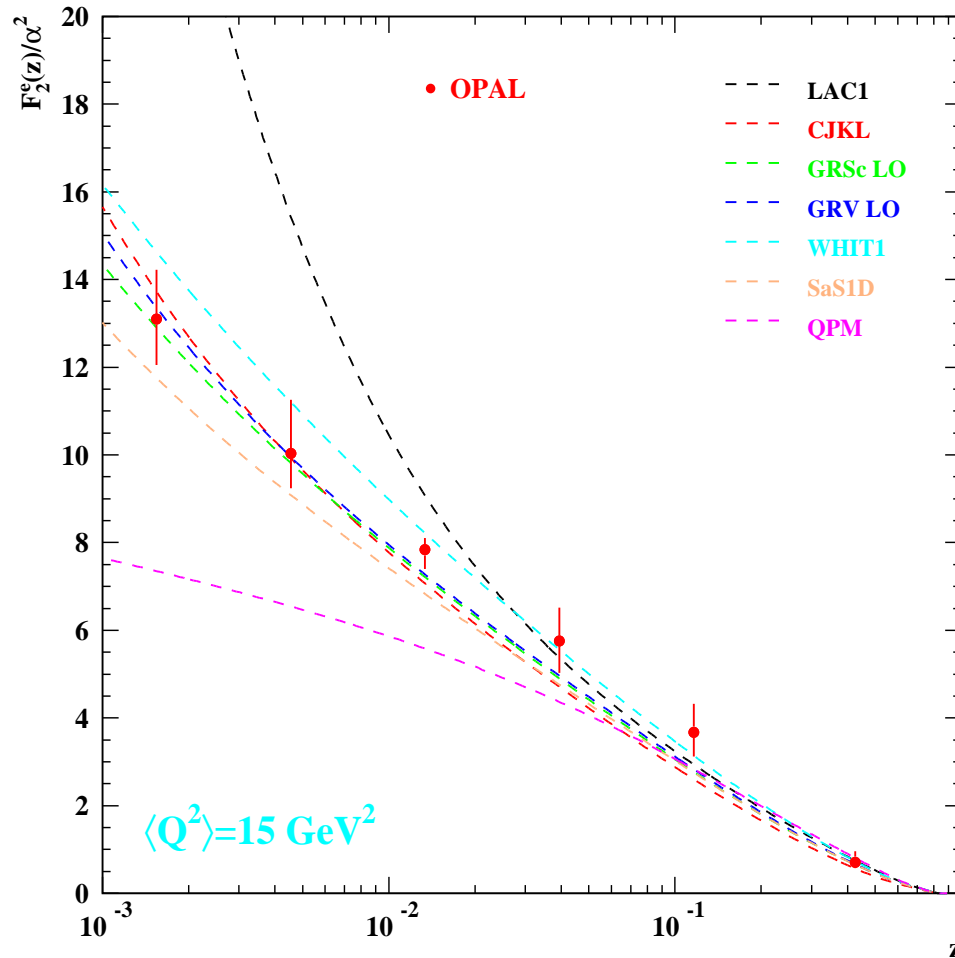
Electron structure function measured at $\langle Q^2 \rangle = 15$ GeV.

Conclusions

- The single tagged events were selected in the data taken by the OPAL experiment in years 1998-2000 at average $\sqrt{s_{e^e}} = 198$ GeVand compared to the predictions of HERWIG and PHOJET. It was found that HERWIG gives a good description of all important variables wheras PHOJET is less good.

- The differential cross section $d\sigma/dx$ and the photon structure function, F_2^{γ}, have been measured at $\langle Q^2 \rangle$ of 10.2 GeV^2 and 20 GeV^2 using a two dimensional unfolding method (GURU). The separate measurements from each year are in good agreement and were be combined.

- The differential cross section $d\sigma/dz$ has been measured in the phase space region defineby $E_e > 0.75 E_b$ GeV, $34 < \theta_e < 55$ mrad and $W > 1.73$ GeV, and the electron structure function, F_2^e, has been corrected to an average $\langle Q^2 \rangle$ of 15 GeV^2. The measured structure function is consistent with the predictions obtained from the convolution of parametrizations of F_2^{γ} with the photon flux (EPA).

- The size of radiative corrections has been estimated using TWOGAM program.