F_2^γ at the ILC, CLIC and FCC-ee

On behalf of the FCAL Collaboration

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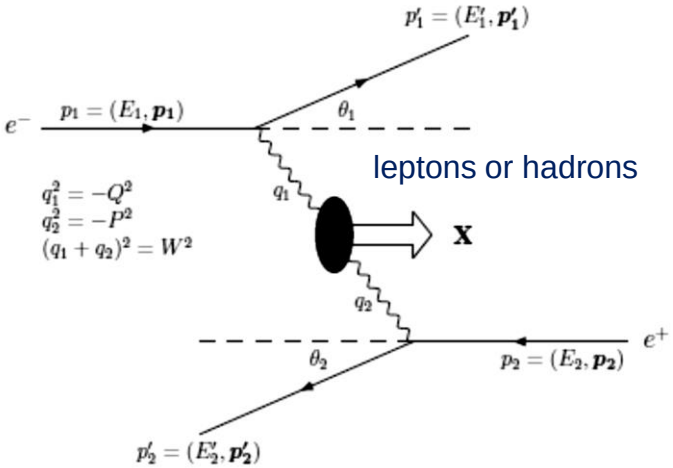
PHOTON 2017
22 – 26 May, CERN

Is the study of photon structure important?

In spite of many studies of the photon structure done in the past, it is still needed to bring our understanding of the photon to the same level as HERA has achieved for the proton. This will allow us to further test the QCD predictions.

- At the ILC/CLIC the measurements of the Q^2 evolution of the photon structure function will be in the range much wider than for LEP.
- FCC-ee will offer large statistics – one can expect valuable results on many issues related to the photon structure function (PSF).
- By tagging both electrons one can measure W^2 independently of the hadronic final state. The interaction of two virtual photons is a ‚golden' process to study the parton dynamics: DGLAP and/or BFKL.
- It will be possible to investigate the spin-dependent photon structure functions using polarized beams in the future colliders. They have not been measured so far.
- The contributions from Z^0 exchange in eγ DIS and the charged-current process eγ → νX become accessible, allowing to study the weak photon structure.

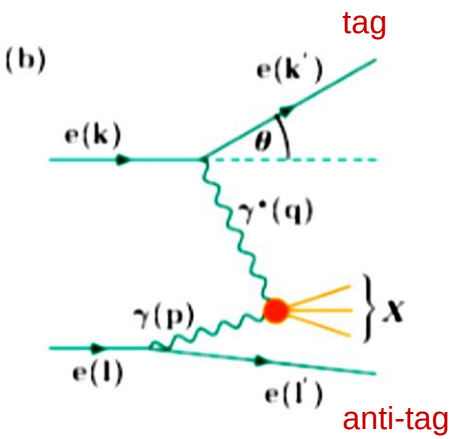


Two-photon processes are the background for physical analyses in which New Physics signals are being searched for, therefore the knowledge of their nature is important.

Photon structure function & its measurement

The single-tag process

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



Deep inelastic eγ scattering (DIS)

$$\frac{d\sigma(e\gamma \to eX)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \cdot \left[\{1+(1-y)^2\}F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

$$Q^2 = 4E_b E' sin^2(\theta/2)$$

$$y = 1 - \frac{E'}{E_b} cos^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{Q^2 + W^2 + P^2}$$

$$W^2 = \left(\sum E_h\right)^2 - \left(\sum \vec{p}_h\right)^2$$

x – fraction of parton momentum with respect to the target photon

y – energy lost by the inelastically scattered electrons

E_b (E') – energy of the beam electrons (the scattered electrons)

E_h $(\vec{p}_h)$ – energies (momenta) of final state particles

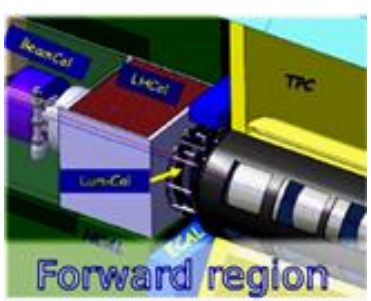
DIS events were obtained using Monte Carlo programs : PYTHIA 6.4, HERWIG 6.5, TWOGAM 2.04,
possible others: WHIZARD, PYTHIA 8.2
if their desciption of γγ physics will be at the level of PYTHIA 6.4 or better

Expected measurement capabilities

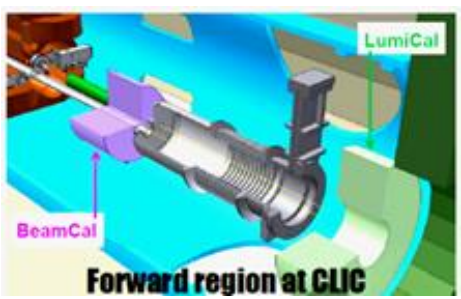
Estimated numbers of events per 10 months of work – tagging at LumiCal

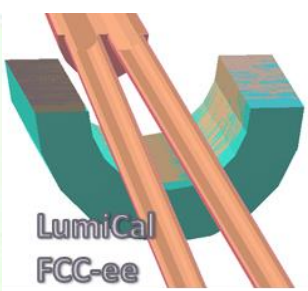
	sqrt(s) [GeV]	Luminosity [$10^{34}cm^{-2}s^{-1}$]	$\sigma(e^+e^-\to e^+e^-\gamma\gamma\to e^+e^-hadrons)$ [pb]	Acceptance	N(events)
FCC-ee	90	68.0	287.8	0.170	8.6×10^8
	160	19.0	419.4	0.076	1.6×10^8
	240	4.9	540.8	0.042	2.9×10^7
	350	1.3	674.1	0.024	5.4×10^6
ILC	500	1.8	823.5	0.040	15.4×10^6
	1000	3.6	1035.5	0.040	38.8×10^6
CLIC	1500	3.7	1212.6	0.015	4.6×10^6
	3000	5.7	1425.1	0.015	8.7×10^7

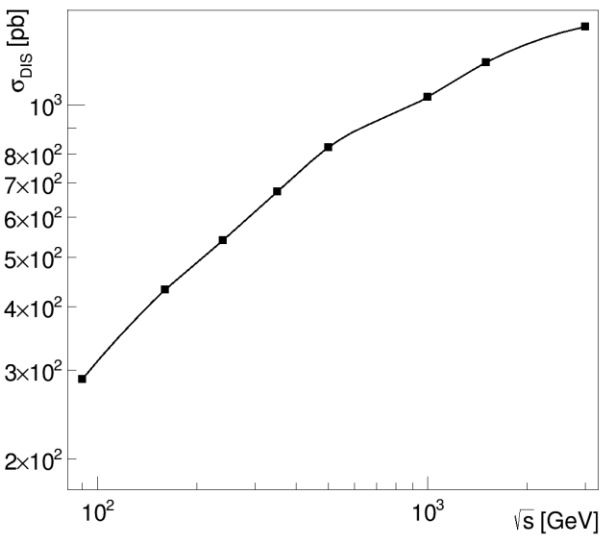
ILC	31 – 78 mrad
CLIC	38 – 110 mrad
FCC-ee	51 – 85 mrad



ILC

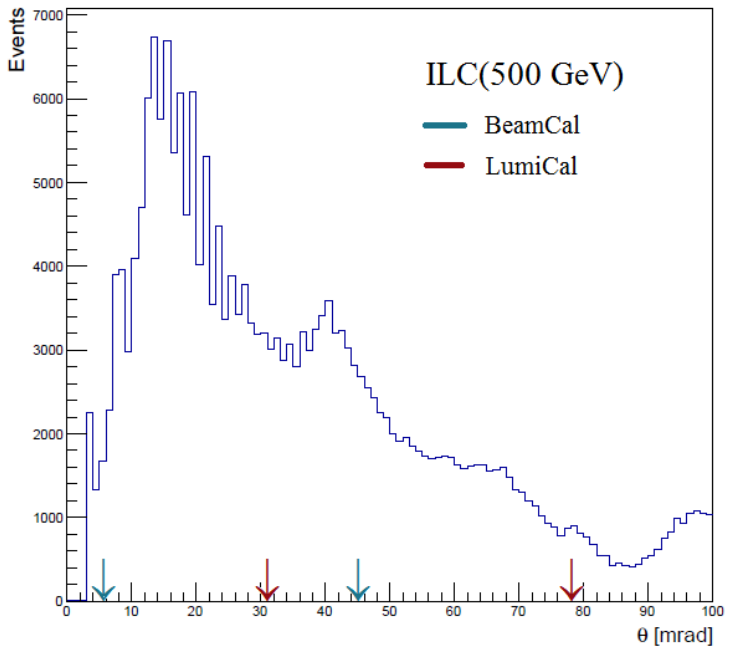


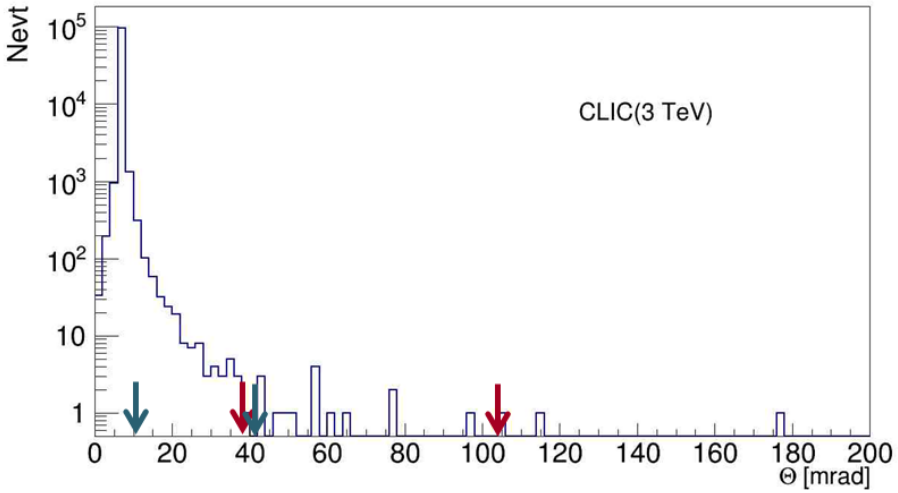


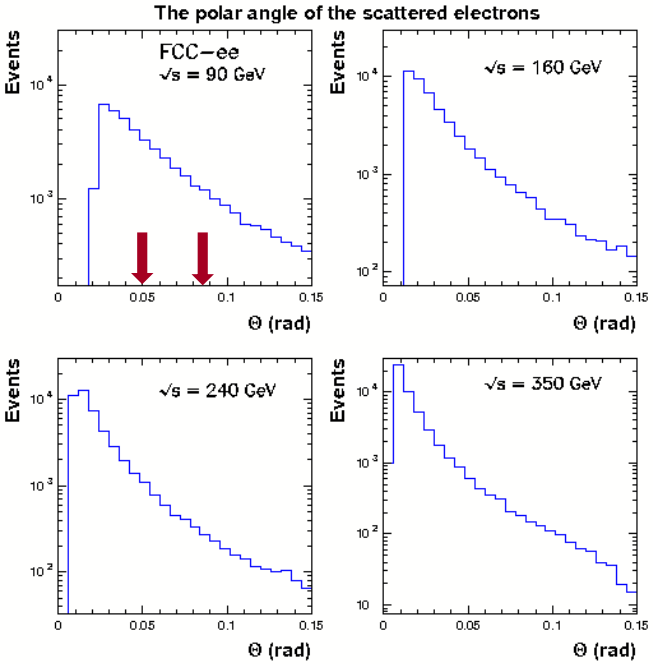


A. Abada et al., The International Linear Collider, Technical Design Report, 2013
P. N. Burrows et al., Updated baseline for a staged Compact Linear Collider, CERN, 2016
P. Azzi, The FCC-ee project, presented at Higgs – Maxwell PPWS, Feb. 2016

Polar angles of scattered electrons



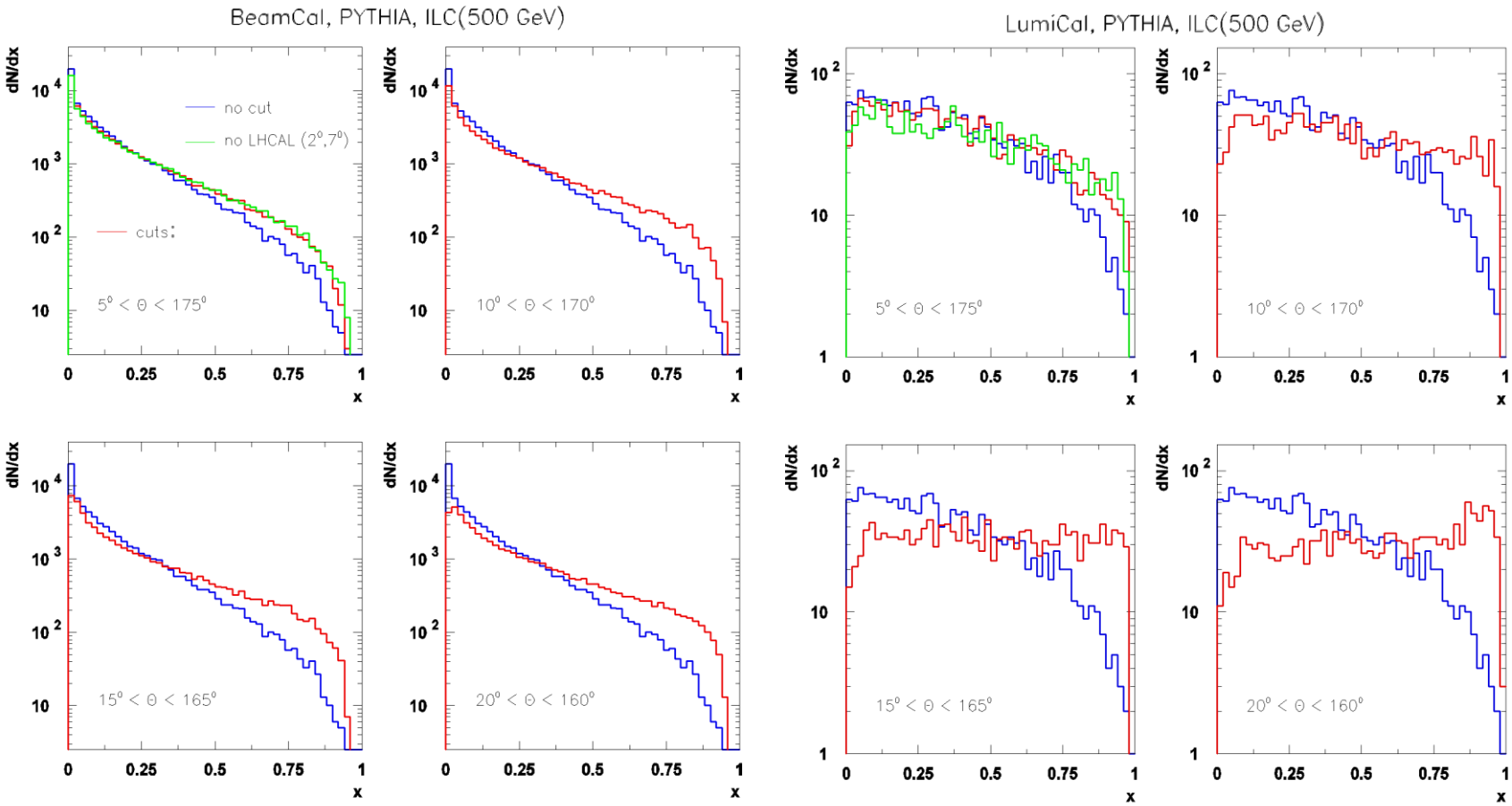




ILC	LumiCal	31 – 78 mrad
	BeamCal	5.8 – 43.5 mrad
CLIC	LumiCal	38 – 110 mrad
	BeamCal	10 – 40 mrad
FCC-ee	LumiCal	51 – 85 mrad

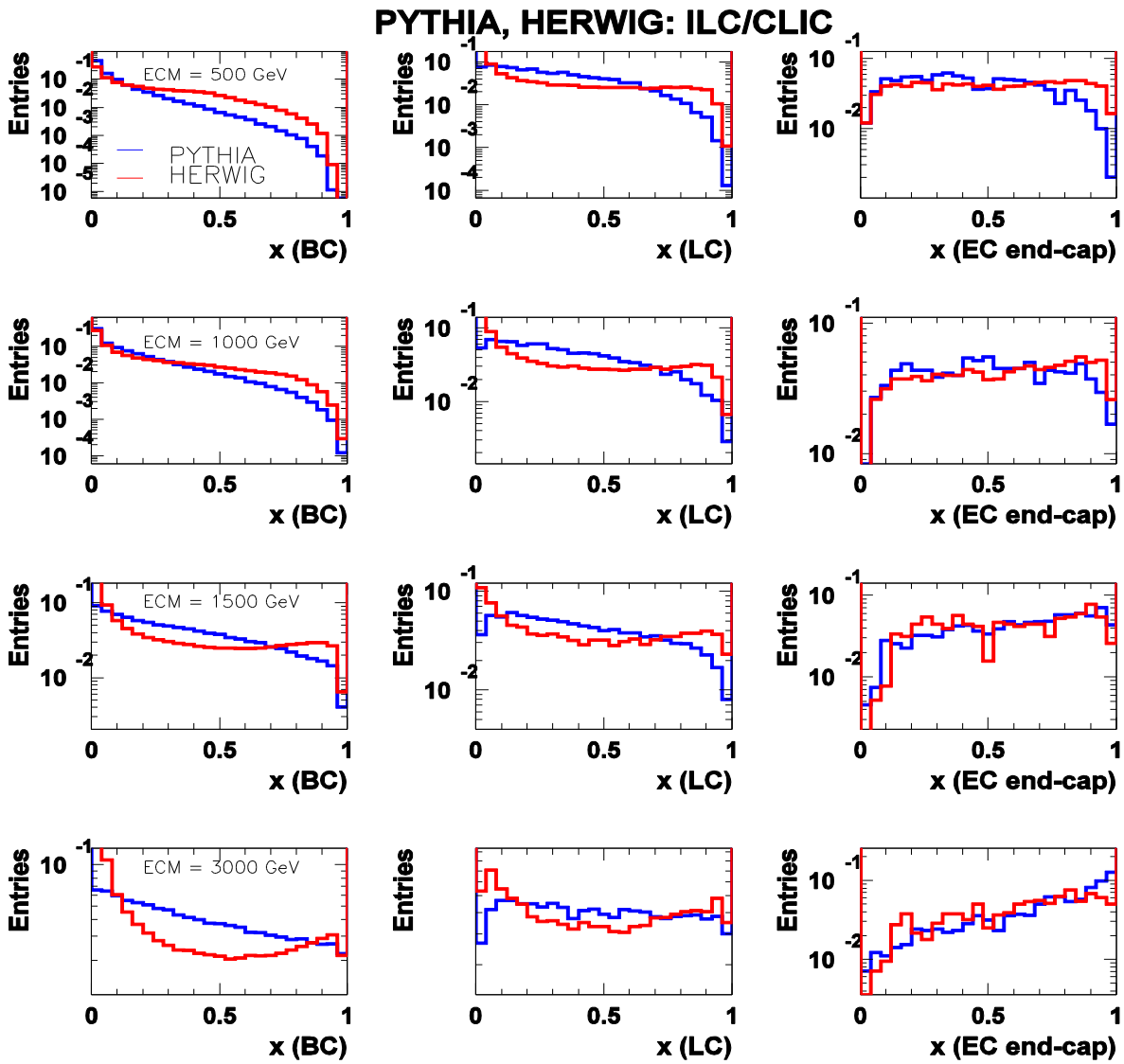
Expected values of x variables – generation level (ILC)

The values of x variables were calculated for the effective mass W of the produced hadrons found in various angular regions (for LHCAL the angular range $2^o – 7^o$ was selected).



The possibility of detecting hadrons at small polar angles (forward detector such as LHCAL) can improve the accuracy of the W measurement.

Expected values of x variables – generation level (ILC/CLIC)



ILC

LumiCal
31 – 78 mrad

BeamCal
5.8 – 43.5 mrad

ECAL end-cap
100 – 700 mrad

CLIC

LumiCal
38 – 110 mrad

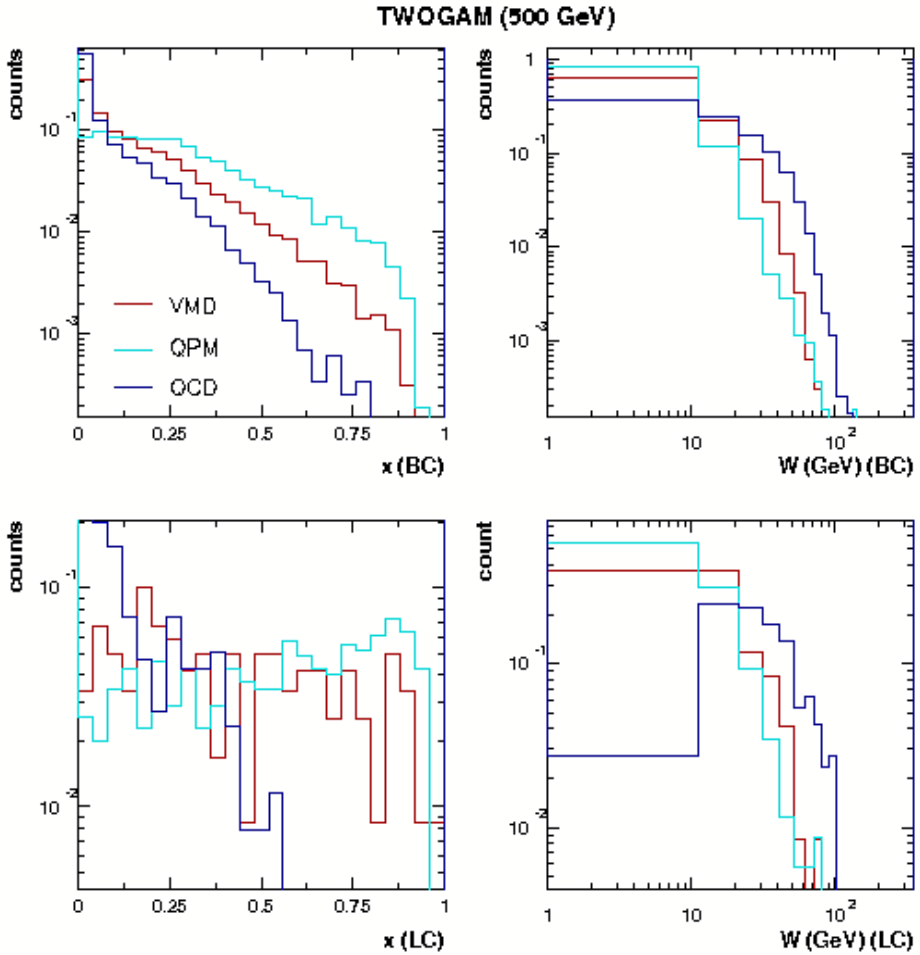
BeamCal
15 – 38 mrad

ECAL end-cap
135 – 705 mrad

PYTHIA 6.4 & HERWIG 6.5 used for generation

Expected values of x and W variables – generation level (ILC 500 GeV)

Another Monte Carlo generator



Hadron production cross section in TWOGAM is sub-divided into three parts (defined at LO):

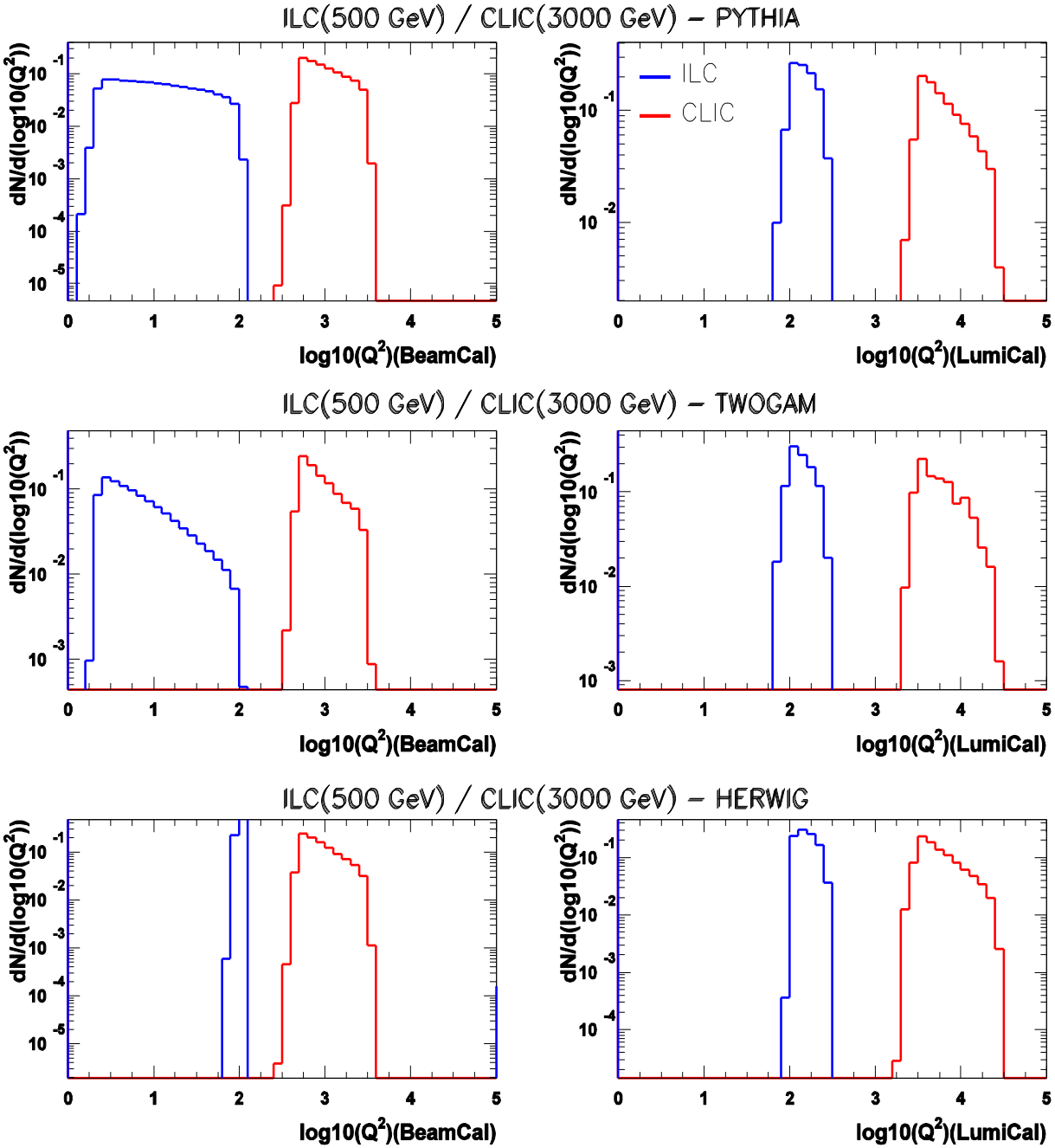
- QPM – coupling of photons to quarks
- QCD – interactions of parton constituents of resolved photons
- VMD – soft hadronic interactions according to the VMD model

TWOGAM 2.04 used for generation

LumiCal acceptance
31 – 78 mrad

BeamCal acceptance
5.8 – 43.5 mrad

Expected values of Q^2 – generation level (ILC/CLIC)



ILC

LumiCal
31 – 78 mrad

BeamCal
5.8 – 43.5 mrad

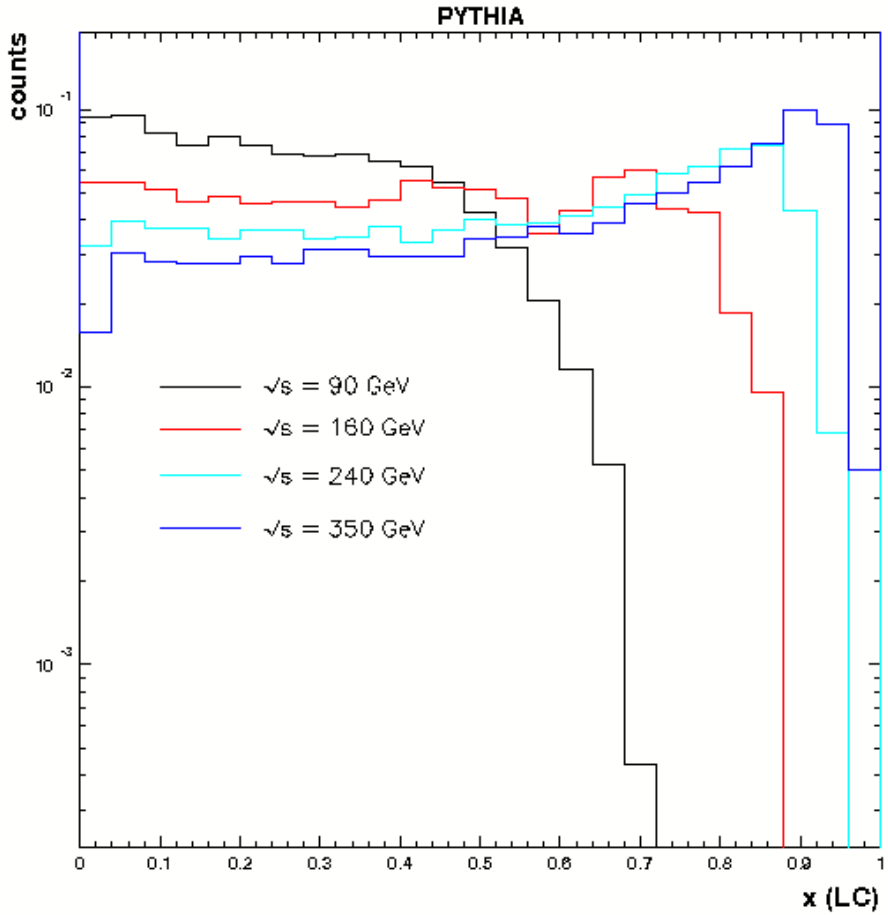
CLIC

LumiCal
38 – 110 mrad

BeamCal
10 – 40 mrad

Using PYTHIA 6.4, TWOGAM 2.04 & HERWIG 6.5

Expected values of x variables – generation level (FCC-ee)



PYTHIA 6.4 used for generation

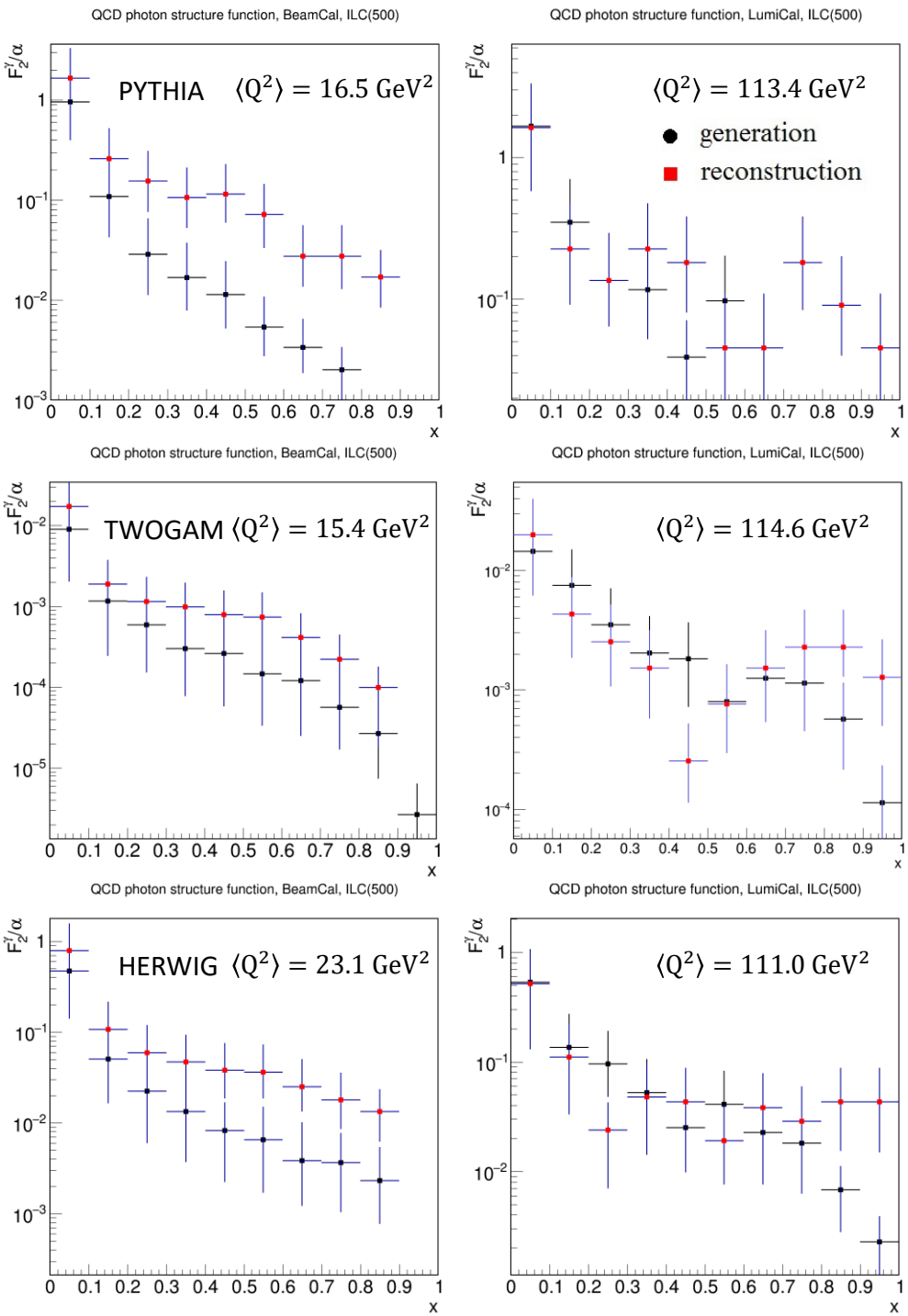
Scattered electrons tagged at LumiCal

LumiCal angular acceptance

51 – 85 mrad

Histograms are normalized to the numbers of events.

Photon structure function ILC (500 GeV)



Examples of results for generation and reconstruction level – ILC (500 GeV)

For generating events various generators were used : PYTHIA 6.4, TWOGAM 2.04 and HERWIG 6.5

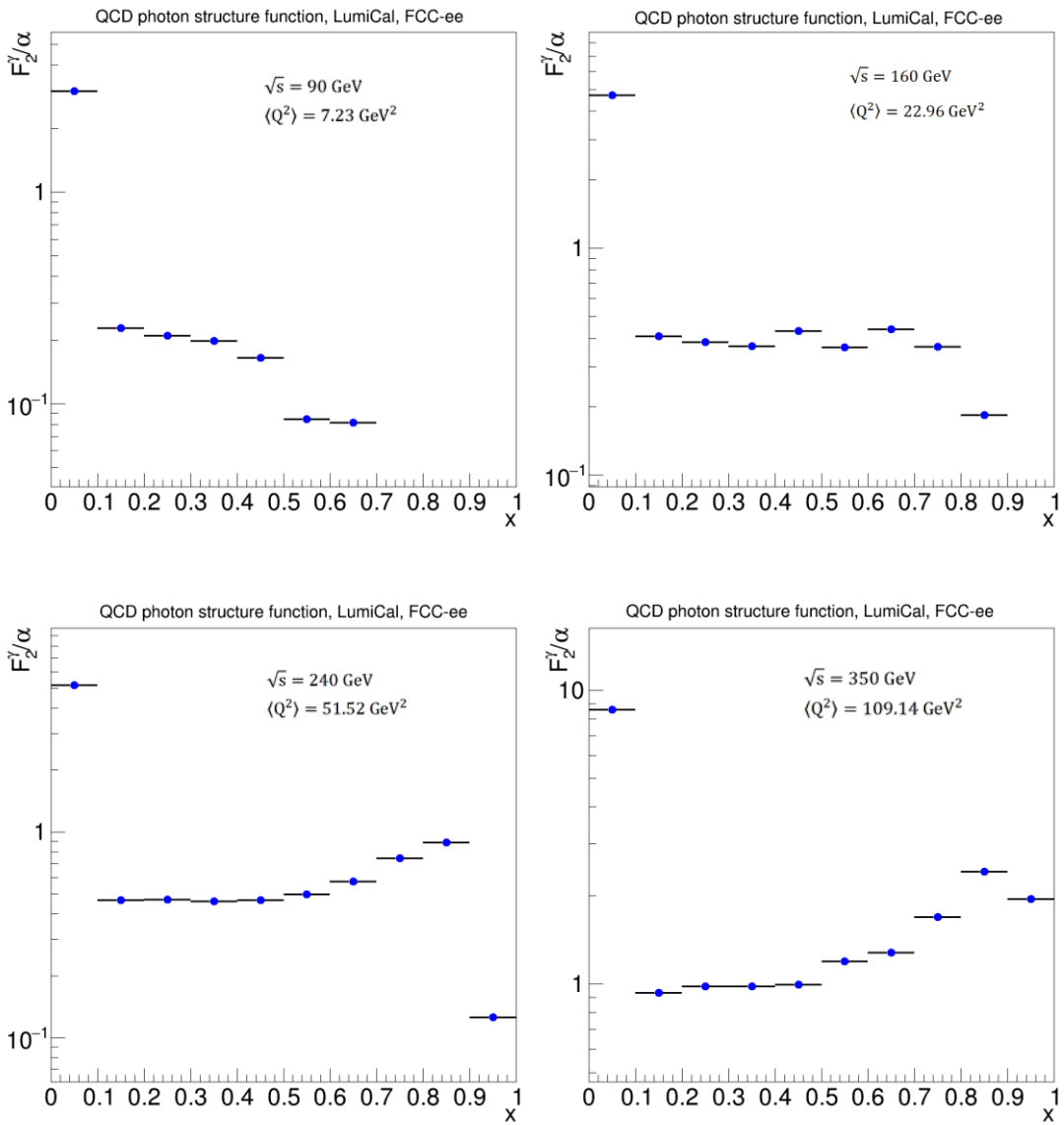
Scattered electrons tagged at the LumiCal and BeamCal

Only statistical uncertainties

The correction due to the detector effects is needed

Results are sensitive to changes in generator parameters, in particular they depend on determining the contribution of hard collisions of partons in the processes leading to hadrons in the final state.

Photon structure function – FCC-ee



Results for generation level

PYTHIA 6.4 used for generation

Scattered electrons tagged at LumiCal

Only statistical uncertainties (very small)

Summary and Outlook

- The forward detectors will allow the photon structure function in eγ DIS processes to be measured. Available angular ranges will make it possible to obtain the functions in a wide range of Q^2.

- It is possible to obtain a higher precision of the F_2^γ measurement than it was at LEP after a few years of data collection.

- A large statistics and higher precision of the measurement of the photon structure function, which are expected on future accelerators, will allow us to further tests of the QCD.

- The determined kinematical variables should be corrected due to the detector effects.

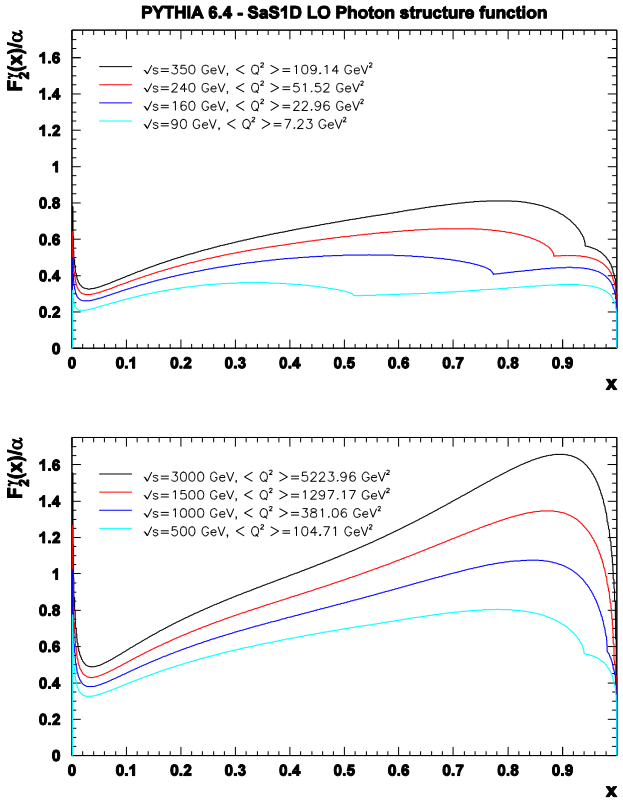
- Work to estimate the systematic effects is ongoing.

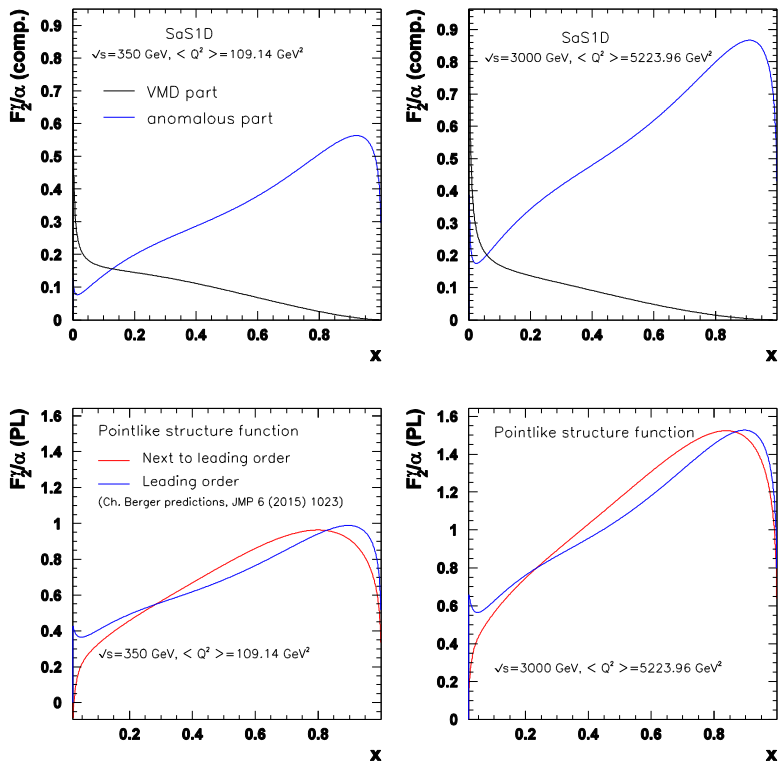
BACKUP

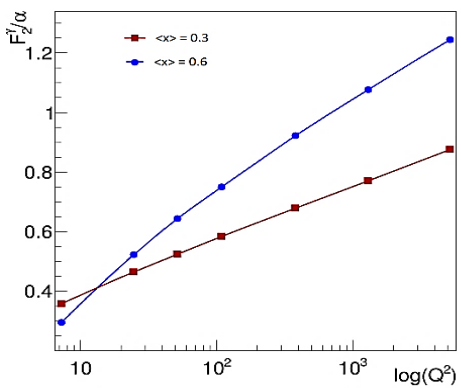
Theoretical predictions for F_2^γ

The SAS parametrisation for photon was used in PYTHIA 6.4 (available in PDFLIB 8.04)

An example: parts of PSF







Assumption: scattered electrons tagged at the LumiCal

ILC	31 – 78 mrad
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