Some remarks on « PHOTOS » and « Structure function » methods in pbar-p annihilation to a lepton pair including QED radiative corrections

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Introduction to Photos Monte Carlo

« PHOTOS » is the Monte Carlo generator for radiative corrections in decays

The algorithm is designed to include (if necessary) the exact process-dependent matrix subgenerator

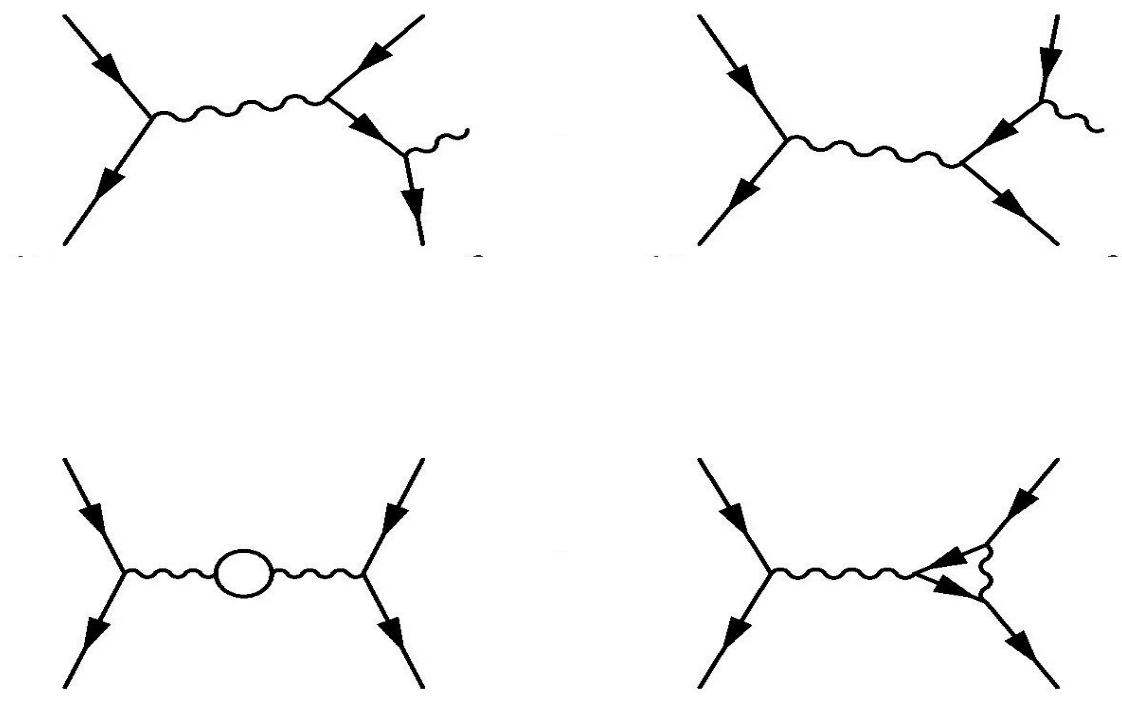
The program is universal : It allows for interface with any program generating decays of any particle

First Remark

In our subgenerator for electromagnetic form factors measurements, the effect of vacuum polarization is still missing and should be incorporated in the code

For PHOTOS, the bulk of these effects is usually incorporated into the overall normalization of the branching ratio

Feynman diagrams including radiative corrections at leading order for pbar p ------- e+ e-



Internal radiative corrections

$$\frac{d\sigma}{d\cos\theta} = \frac{d\sigma_0}{d\cos\theta}(1+\delta) + \iiint \frac{d^4\sigma}{d\cos\theta\, d\omega\, d\Omega_\gamma}\, d\omega\, d\Omega_\gamma$$

δ contains the vaccum polarisation, the vertex part and soft photons contributions.

The second term is the hard photons contribution

ω is the energy of the hard photon

A cut-off parameter on the energy of the photon, namely « XPHCUT » in the « Photos » code, is introduced for the distinction between the soft and hard photon

Although the distinction between the soft and hard photon is somewhat arbitrary

One can split the integral for photon emission into two parts, one by integrating up to a small value of the photon energy (cut-off) where the soft photon approximation holds and a second starting from this cut-off up to the energy where one performs the experimental cut in the spectrum

This second integral is finite and can be performed numerically ; this is the radiative tail contribution

Second Remark

We need to control the infrared cut-off parameter, namely « XPHCUT » in the « PHOTOS » Code

The real photon correction alone lead to infrared singularities. These singularities are cancelled order by order by virtual corrections, which are infinite as well but of opposite sign

In « PHOTOS », instead of calculating virtual corrections analytically, they reconstruct them numerically up to the leading logs (comparison with our calculation should be done)

Third remark

To introduce the discussions on this subject,

Let me show you some results from Alaa and Egle presentations

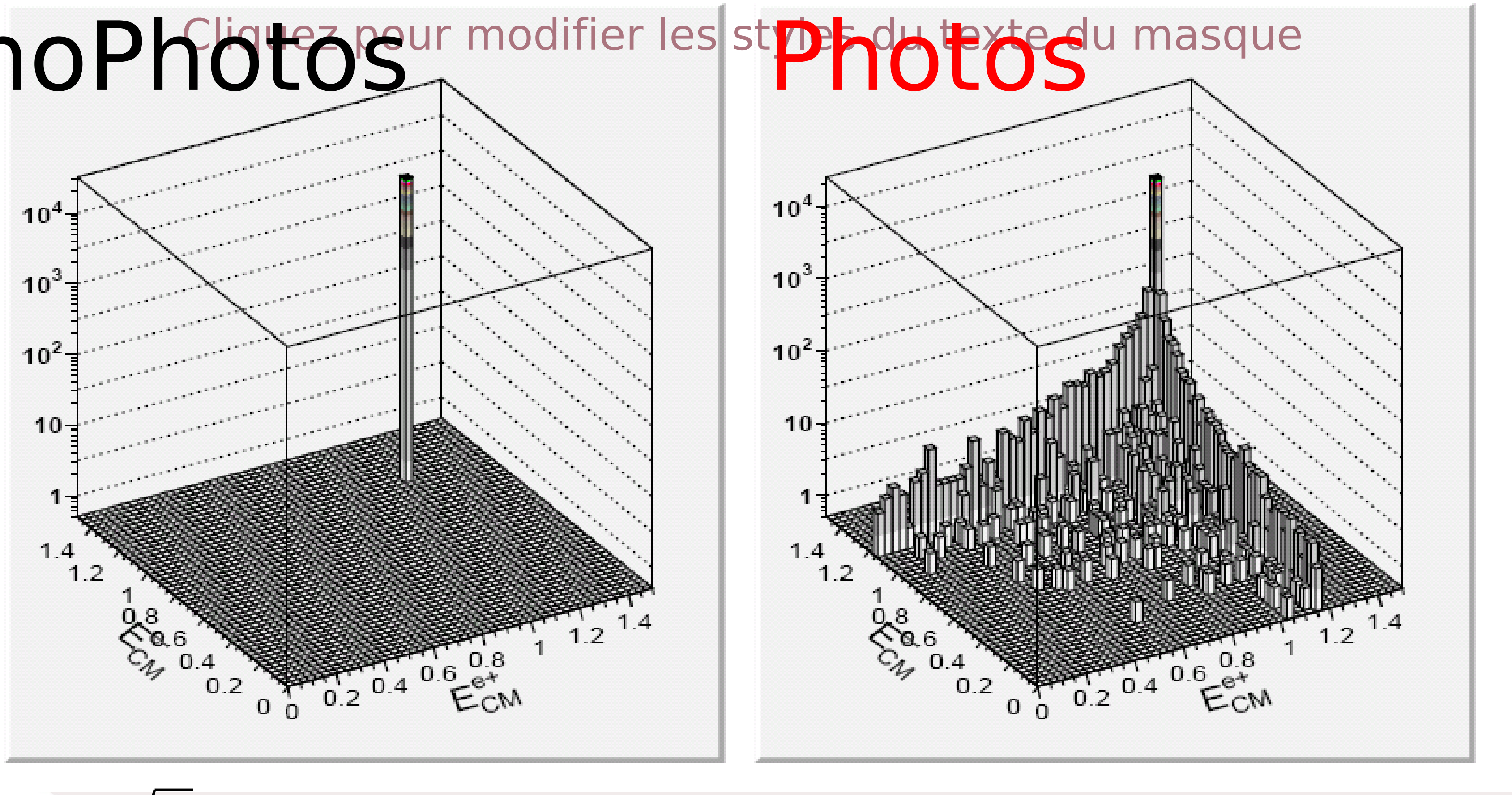
In the GDR Meeting (Orsay , May 2011)

A. Dbeyssi, le 17/05/2011

$$p_{\bar{p}} = 1.7 GeV$$

Cliquez pour modifier les styles du texte du masque

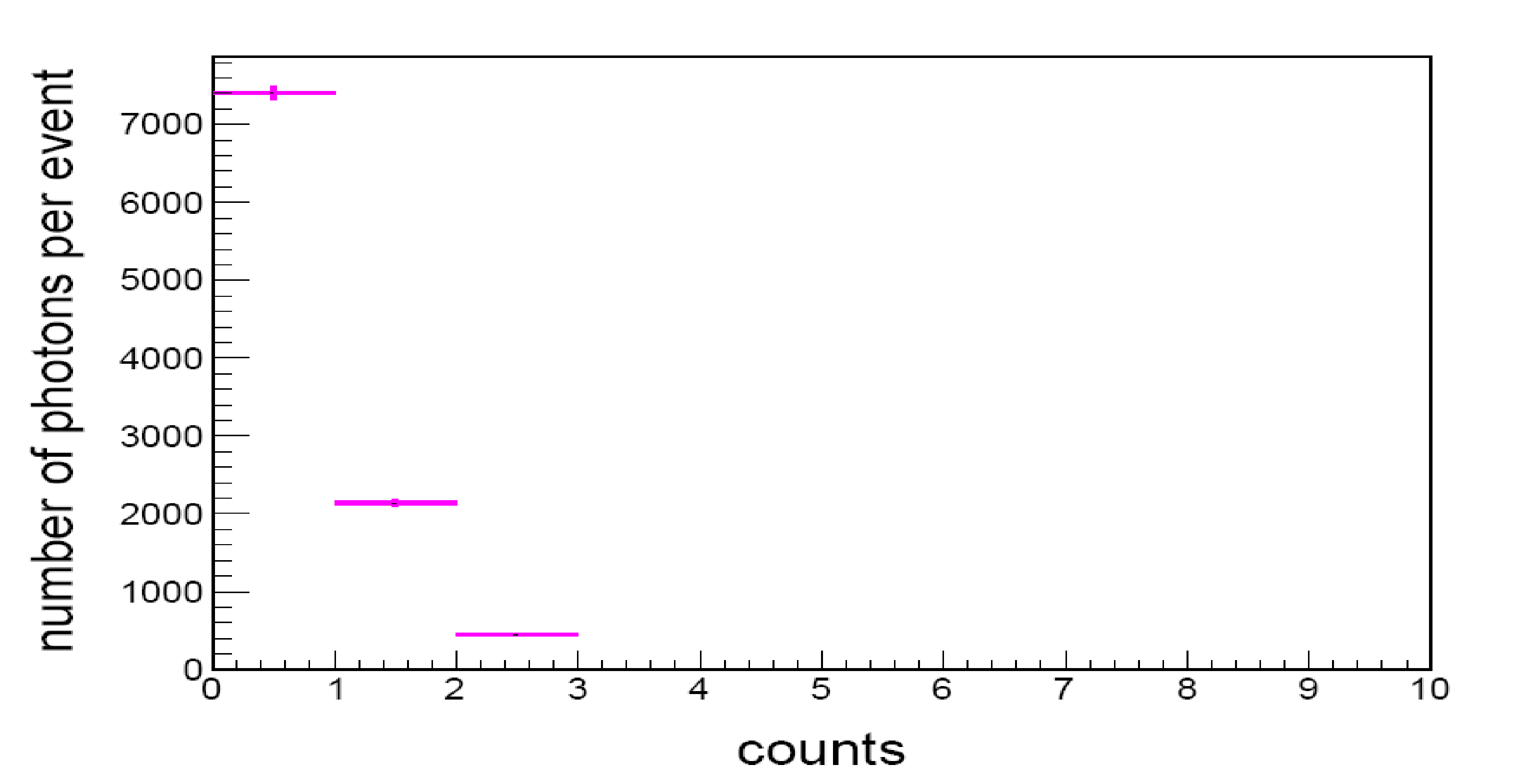
noPhotos Photos



$$\frac{\sqrt{s}}{2} = 1.16 GeV$$

$$E_{e^{\pm}} = 1.16 GeV$$

A. Dbeyssi, le 17/05/2011



Probability of photon emmision in PHOTOS

Cliquez sur l'icône pour ajouter une image

- no γ : 75 %
- 1 γ   : 21 %
- 2 γ   : 4 %

Comments in « PHOTOS »

For our analysis :

We call the event « zero photon » if there was no photon of energy larger than the parameter (cut-off)

The « one photon » event had to have one (and only one) photon of energy larger than the cut-off

If there were more than one such photon, we call it a « two photon » event

In Photos, the formula for the raw cross section reads:

$$d\sigma^{R} = d\sigma^{Born}\, f(k_\gamma, \cos(\theta_\gamma), \phi_\gamma) k_\gamma dk_\gamma d\cos(\theta_\gamma) d\phi_\gamma$$

With

$$\int\int\int_{PS} f(k_\gamma, \cos(\theta_\gamma), \phi_\gamma) k_\gamma dk_\gamma d\cos(\theta_\gamma) d\phi_\gamma = 1$$

The function f contains two terms (virtual+soft photon correction) up to the maximum energy ϵ with a Dirac distribution $\delta(k_\gamma)$ and the hard photon correction with the Heaside function $\Theta(k_\gamma - \epsilon)$

Angular distribution of the electron at 1.7 GeV :

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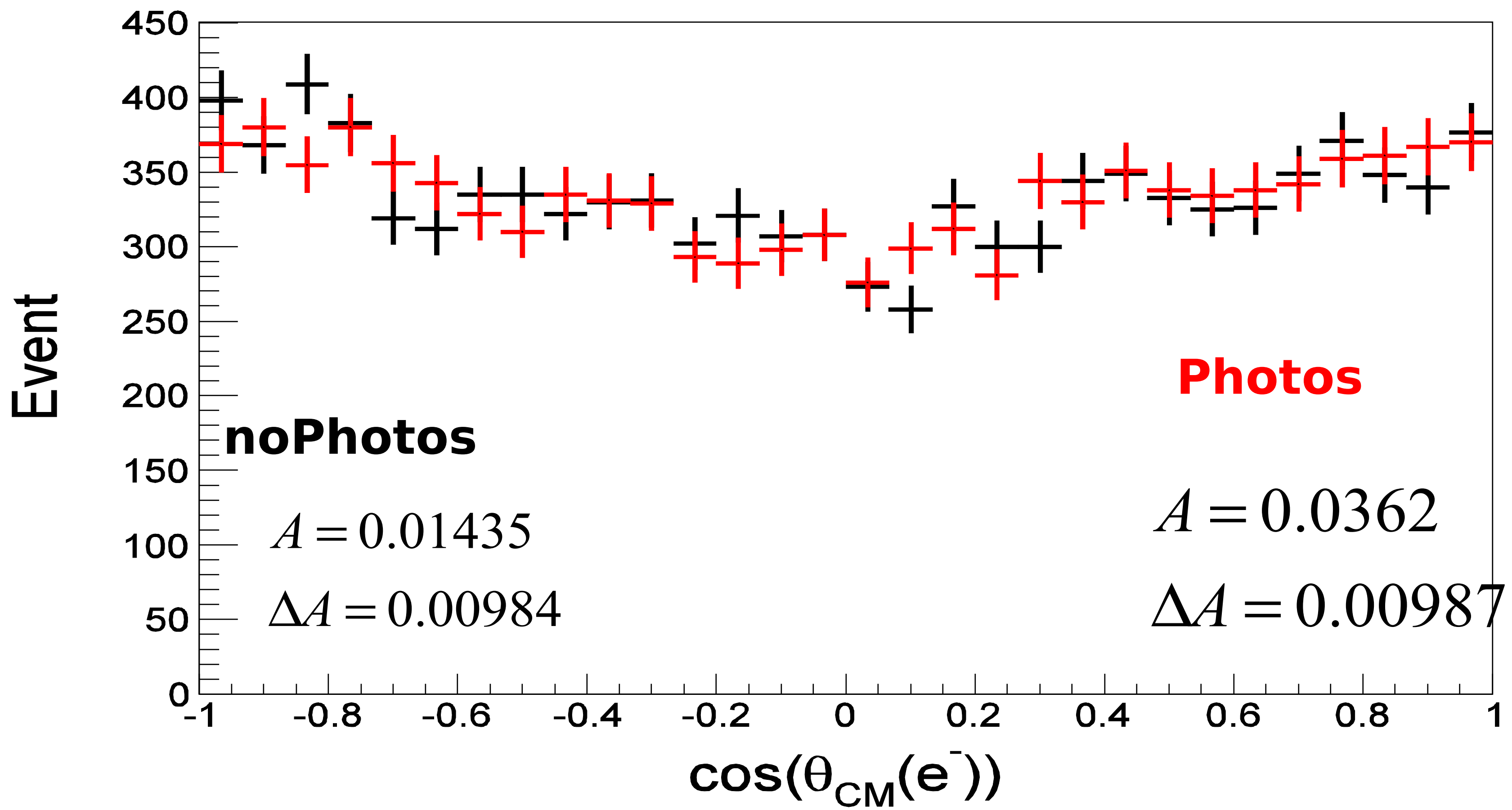
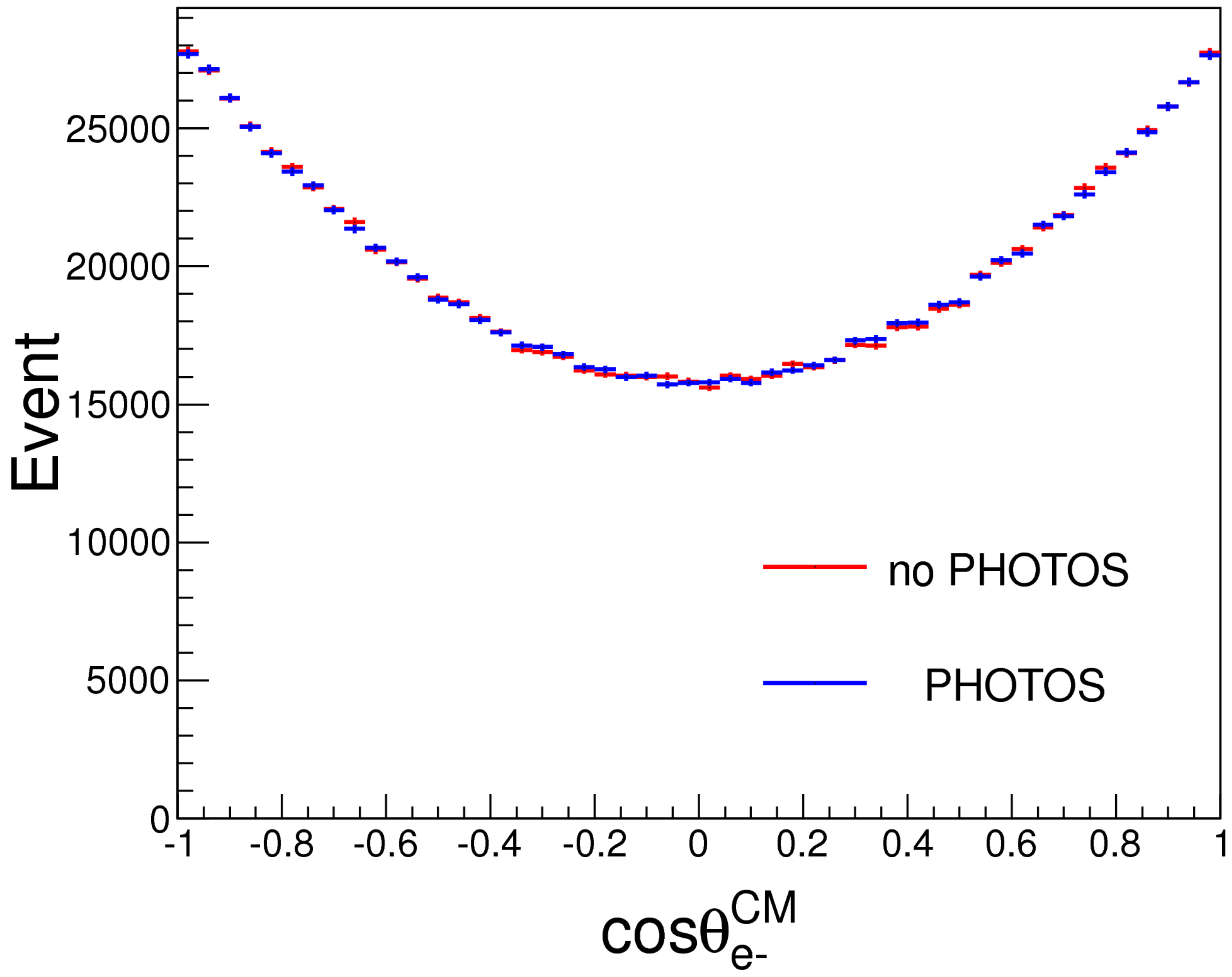
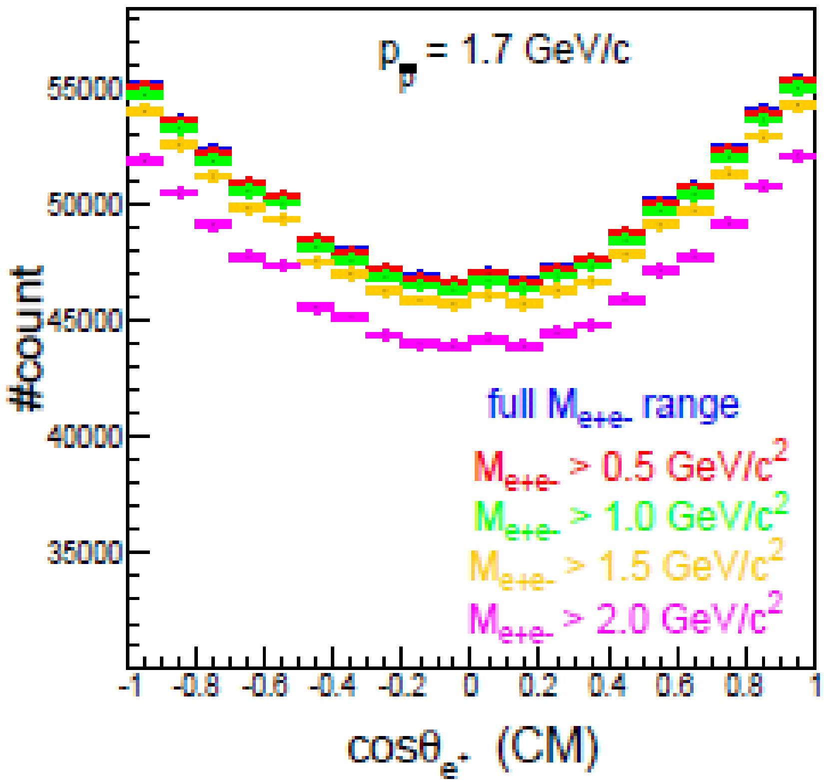


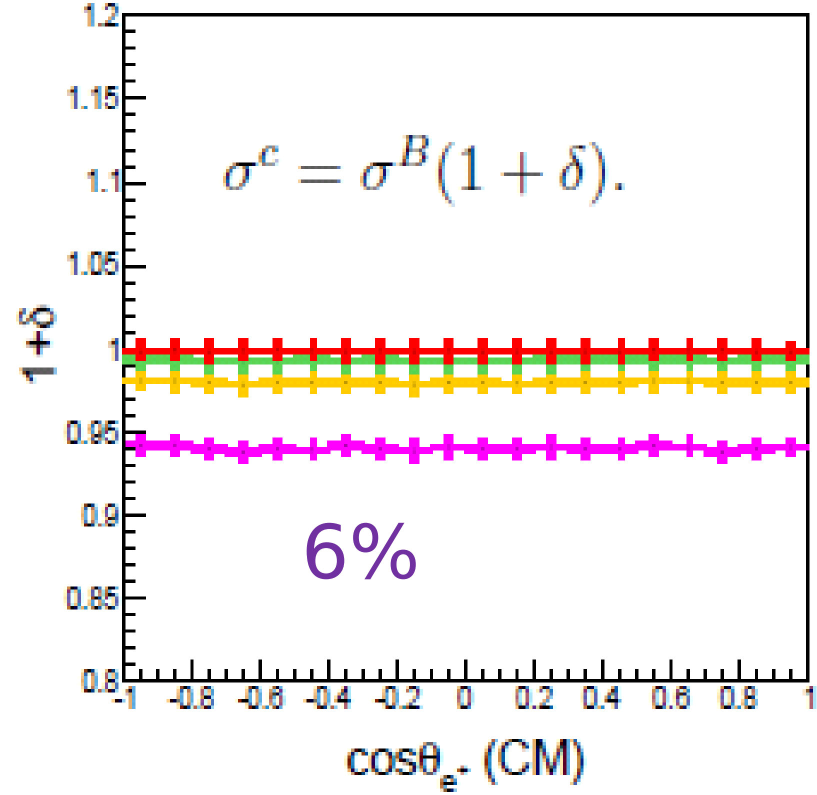
mall difference -> necessary to decrease the widh of the bi

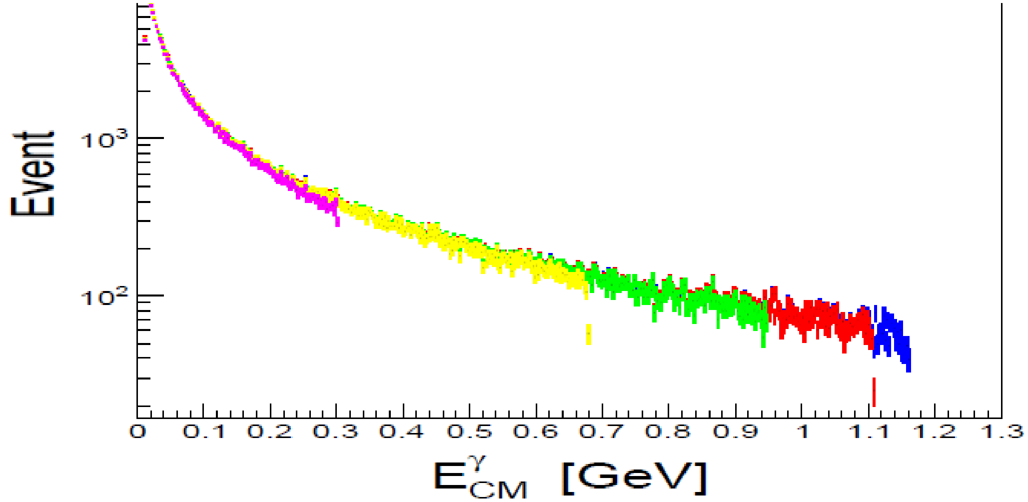


Event
25000
20000
15000
10000
5000
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
$\cos\theta_{e-}^{CM}$
no PHOTOS
PHOTOS

Angular distribution with hard photon cut-off (Dbeyssi, Sudol, Tomasi-Gustafsson)







Let me show you our first results:

For the virtual and soft photon correction,

$$\delta = \frac{2\alpha}{\pi}[(-1+2\ln(2E/m))(\ln(\Delta E/E)+13/12)-17/36+\pi^2/6]$$

m is the electron masse and ΔE is the energy resolution of the detector
G. Bonneau and F. Martin Nucl. Phys. B27 (1971) 381

In the vaccum polarization, we include the contributions from the muon and hadron loops

Peaking approximation for hard photons radiation

We need to calculate the integral with the kinematical constraints of the experiment.

So the photon is emitted in the final state. This does not affect the Q2 of the scattering and the electron and photon are moving pratically in the same direction.

The Peaking approximation is the good one for this study

Equivalent photon spectrum
Williams-Weizsacker

$$\delta_{durs} = \frac{2\alpha}{\pi} \int_{\Delta E}^{\omega_{\max}} \left(1 - \frac{\omega}{E} + \frac{\omega^2}{2E^2}\right)\left(-1 + 2\ln(2E/m_e)\right) \frac{d\omega}{\omega}$$

S=5.4 (GeV2) E_photon(cut)=50 MeV is the experimental cut on the photon spectrum	E_soft(max)= 1 MeV is the infrared cut-off (XPHCUT)	E_soft(max)= 11 MeV	E_soft(max)= 25 MeV
(virtual+soft)	-44.7 %	-27 %	-21%
Hard photon	+28.5 %	+10.9 %	+4.94 %
Total radiative correction	- 16.2 %	- 16.1 %	- 16.06 %

S=5.4 (GeV2) and E_photon(cut)= 300 MeV	E_soft(max)= 1 MeV		
(virtual+soft)	-44.7 %		
Hard photon	+40 %		
Total radiative correction	- 4.7 %		

Conclusion

The difference between our result and Photos comes probably from the vacuum polarisation effect (~1%-2%)

Photos may be used with confidence (caution) for our data analysis. The correction is obtained with an experimantal cut on the photon spectrum (or the invariant mass of e+e-)

However, one needs to control the systematic error of the Photos algorithm

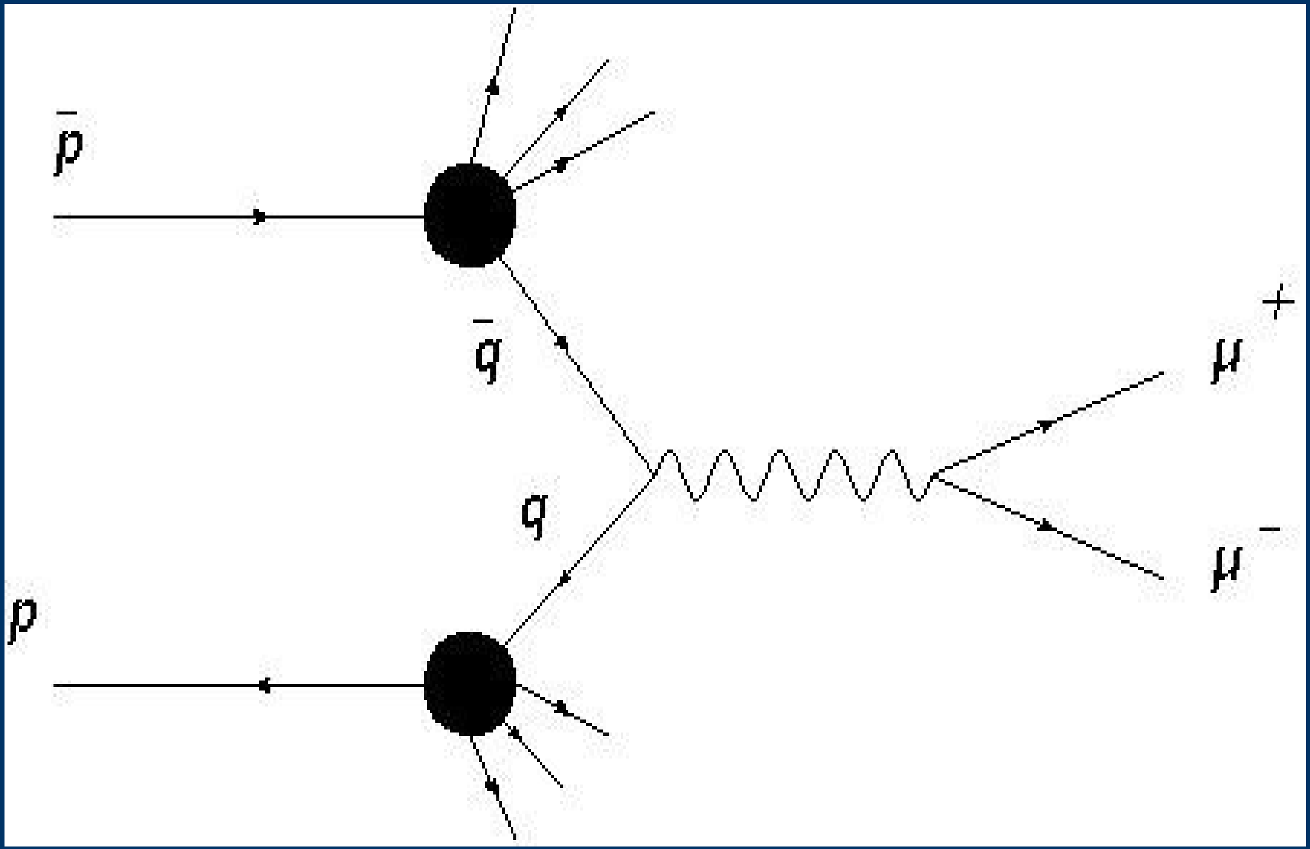
For example, for the single photon generator, the bias due to the neglect of kinematic effects of photons of energy lower than the cut-off, needs a comparison with another approach (preferably analytical one) with the same physical assumptions and inputs

Comments on Structure function methods

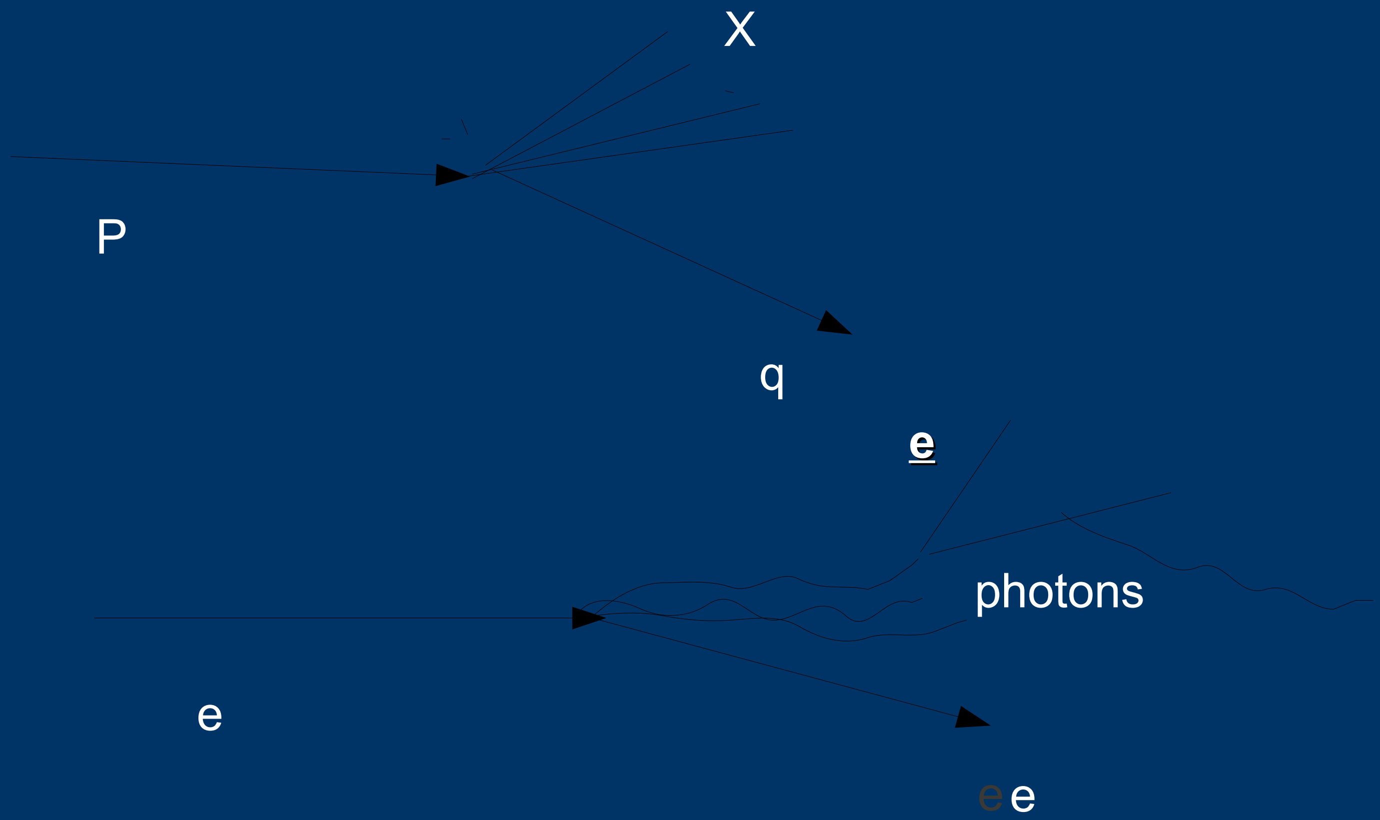
-Structure function (SF) method for radiative corrections looks like the Drell-Yan process in QCD. It represents the probability to find a quark with a longitudinal fraction momentum « x » inside the proton. Total cross section can be written as a convolution of the two structure functions for two beams.

-In QCD, one is not able to calculate these (SF). It is only possible to evoluate them from one « Q2 » to another.

-In QED, the electron (positron) structure function is calculated from the first principle. One may solve the evolution equation for the SF, the so called Lipatov equation. The SF(e+-) is the probability of finding a quasi real electron carrying a fraction « x » of the initial on-shell electron



$\bar{p}$
$\bar{q}$
q
p
μ^+
μ^-


X
P
q
e
photons
e
e e

4. M. Skrzypek, S. Jadach, Z. Phys. C 49 (1991) 577

- It is of vital importance to reproduce the well know soft photon limit « $x \rightarrow 1$ » in the structure function

- In the leading logarithmic approximation founded on the factorization theorem of the collinear singularities, the non singlet structure function D-e(x,s) with the Kuraev/Fadin (KF) exponentiation procedure or the Yennie-Fraautschi-Suura (YFS) can be found in ref. 4 and references therein

5. A.I. Ahmadov et al., Phys. Rev. D 82 (2010) 094016

I try to understand the structure function method in Ref. 5 on the Radiative proton-antiproton annihilation to a lepton pair

Many interesting formula are giving in the paper and in particular the formula (50) in the Ref. 5

Our preliminary results (assuming only the final state radiation) suggest a « delta » independent of the \cos(theta) in the CMS frame.

For the structure function methods

Advantages : - No need a separation between the hard and soft photons

-Structure function is a generalization of the well-known Williams-Weizsacker spectrum

-The summation of higher order QED effects in the exponentiation type (Kuraev-Fadin or Yennie-Frautschi-Suura) wa performed in the framework of leading logarithmic approximation

Cautions : -Numerical Instability in the soft photon region (x ~ 1)

-Combinaison of the « standard and the structure function methods should be a firm starting point for further work

References

1. E. Barberio, B. Van Eijk and Z. Was, Comput. Phys. Commun. 66 (1991)115

2. E. Barberio, Z. Was, CERN-TH 7033/93 and Comput. Phys. Commun. 79 (1994) 291

3. P. Golonka, Z. Was, Eur. Phys. J. C 45 (2006) 97

4. M. Skrzypek, S. Jadach, Z. Phys. C 49 (1991) 577

5. A.I. Ahmadov et al., Phys. Rev. D 82 (2010) 094016