Study on theoretical uncertaincies (QED) in the measurement of Z the invisible width from $e^-e^+ \to \nu + \bar{\nu} + \gamma$ using KKMC

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Z the invisible width from $e^- e^+ \to \nu + \bar{\nu} + \gamma$ at TLEP

- Z invisible width in terms of number of neutrinos from LEP
  $N_\nu = 2.984 \pm 0.008$
- According to "The TLEP Design Study...", page 29
  `http://arxiv.org/abs/arXiv:1308.6176`
  could be measured 10 times better.
- TLEP run near WW threshold 5pb would ensure 3M events with visible photon and invisible $Z \to \nu\bar{\nu}$ decay.
- No reliable estimate of the theoretical (QED) uncertaities at this precision level – only hope that this process is possibly better that Z peak cross section.
- Let us make 1st step in working out such an estimate...

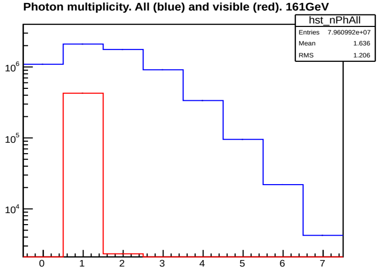
Acceptance criteria for $e^- e^+ \to \nu + \bar{\nu} + \gamma$

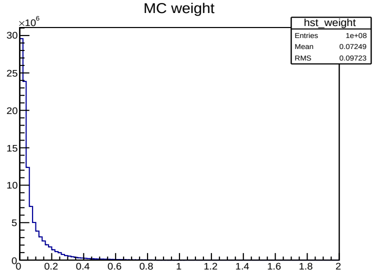
Acceptance criteria:

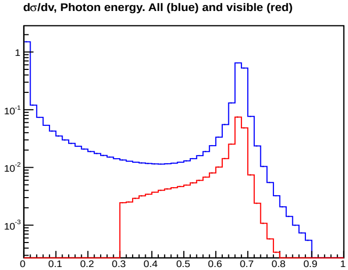
- Minimum photon angle $\Theta_{\rm min} = 15^o$,
- Minimum photon energy $x_\gamma = 0.3, \quad E_\gamma > x_\gamma E_{beam}$,
- Minimum phot. transv. mom. $x_T = 0.3, \quad k^T_\gamma > x_\gamma E_{beam}$,
- Only one photon within the above restrictions.

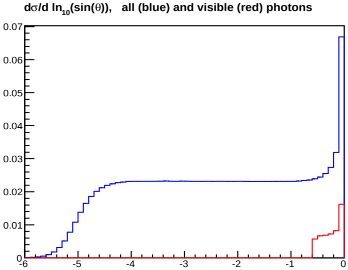
Variable $v = E_\gamma / E_{beam}$ will be used in the histograms.
MC results will come from KKMC version 4.22, see Appendix.

Acceptance criteria at work, 161GeV

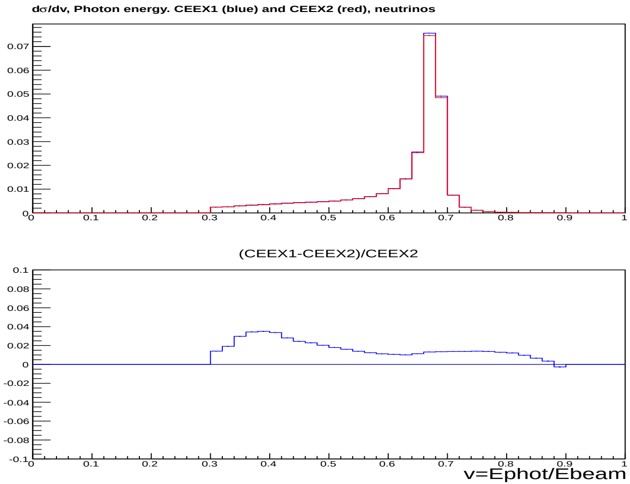








H.O. QED corrections estimate, neutrino channel.



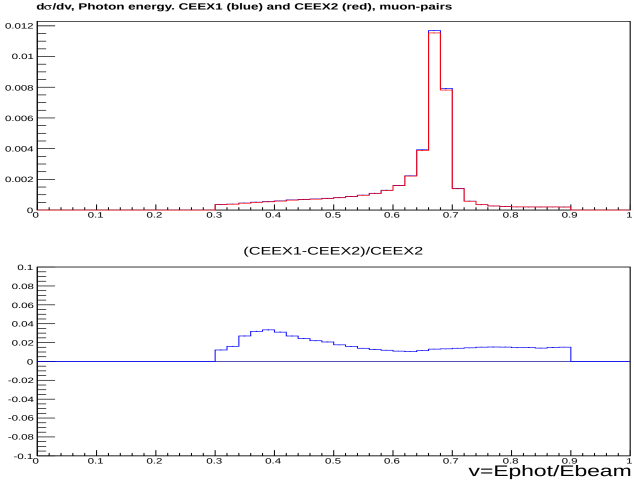
Defining $e^- e^+ \to \nu + \bar{\nu} + \gamma$ as Born, CEEX1 is Born with soft photon resummation and CEEX2 is 1st order soft photon resummation.

QED uncertainty $\sim 1 - 2\%$.

Normalization from muon channel?

- For calculating invisible width from $e^- e^+ \to \nu\bar{\nu}\gamma$ process we need to get normalization from somewhere.
- One possibility is to use similar SM process $e^- e^+ \to \mu^-\mu^+\gamma$ with the muonic decay of Z.
- We require only angular cut on both muons: $\cos\theta_\mu < 0.95$.
- Selection of single radiative photon exactly as for neutrinos.
- We examine QED corrections in the same way.

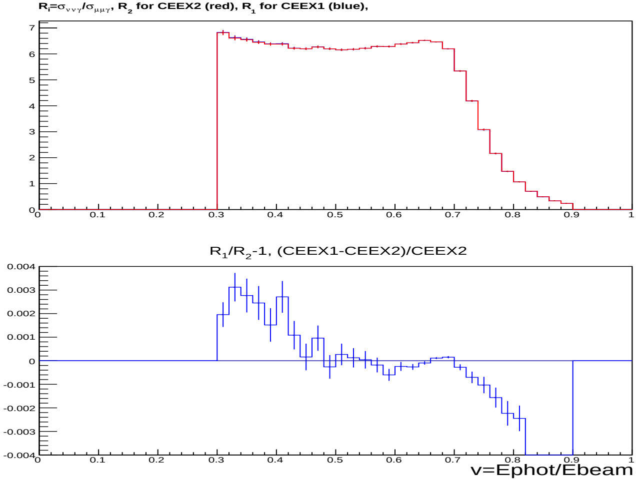
H.O. QED corrections estimate, muon channel.



Defining $e^- e^+ \to \mu^- \mu^+ \gamma$ as Born, CEEX1 is Born with soft photon resummation and CEEX2 is 1st order soft photon resummation.

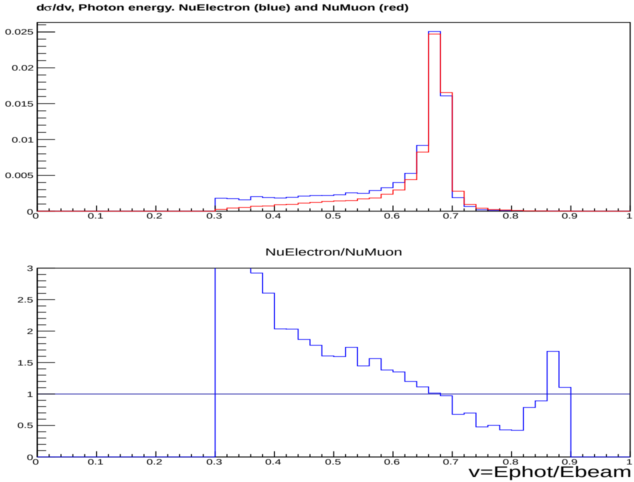
QED uncertainty again $\sim 1-2\%$.

QED corr. estimate in $\sigma(\nu\bar{\nu}\gamma)/\sigma(\mu^-\mu^+\gamma)$



QED corrections seems to cancell dramaticaly in the ratio $\sigma(\nu\bar{\nu}\gamma)/\sigma(\mu^-\mu^+\gamma)$. They drop to $\sim$ 0.03% !!!.
This is PRELIMINARY result requiring further tests.

Importance of t-channel exchange



The t-channel exchange is present in electron neutrino channel.
It is of order of 10% It cannot be easily minimized by cutoffs, it has to be reliably calculated and subtracted!

Conclusions

From this limited study using KKMC at 161GeV we conclude that:

- QED corrections are sizeable, their uncertainty in $\sigma(\nu\bar{\nu}\gamma)$ is estimated $\sim$ 2%
- QED uncertainty seems to drop dramaticaly in the ratio $\sigma(\nu\bar{\nu}\gamma)/\sigma(\mu^- \mu^+ \gamma)$, down to $3 \cdot 10^{-4}$!
- *t*-channel contrubution is $\sim$ 10% near Z peak in photon energy. Possibly the bigest source of theoretical uncertainty in N_ν measurement from ratiative return.

To be studied further most urgently:

- The dependence on $\sqrt{s}$
- The dependence on θ_{min} and other cutoffs
- Dont give up on N_ν from Z-peak cross section!

Appendix

What is KKMC?

KKMC is the MC event generator for the process:

$$\boxed{e^- e^+ \rightarrow f\bar{f} + n\gamma}$$

$f = \mu, \tau, \nu, u, d, s, c, b, \quad n = 0, 1, 2 ... \infty.$

Interfaced with TAUOLA+PHOTOS
and with electroweak library DIZET.
Published version 4.13 (to be cited):

- Comput.Phys.Commun. 130(2000) 360, hep-ph/9912214, F77 code description and user guide (manual).
- Phys. Rev. D63 (2001) 113009, hep-ph/0006359 physics content, CEEX exponentiation of QED corrs.

"Workhorse" in data analysis of all four LEP collaborations.

(Replacement of earlier MC's KORALZ and KORALB.)
(Not aplicable for $e^- e^+ \rightarrow e^- e^+$)

More KKMC versions available since 2000

http://jadach.web.cern.ch/jadach/KKindex.html

- Production Version 4.16, Oct. 2001, (KKMC-v.4.16d-export.tar.gz). Improved $\nu\bar{\nu}$ matrix elm. RRes module for $\gamma^* \to$ *narrow resonances* at LEP.
- Developement Version 4.19, Sept. 2002, (KKMC-v.4.19.b-export.tar.gz). C++ wrapper. Improved $\nu\bar{\nu}$ matrix element and RRes for low energy colliders. ISR with complete NLO corrs, as in Phys.Rev. D65(2002) 073030 by S.J., M.Mells, B.F.L.Ward and S.A. Yost. Collinear beamstrahlung for NLC/ILC.
- Developement Version 4.22, June 2013, (KKMC_v4_22.tgz). Tested $\mu^-\mu+$ and $q\bar{q}$ beams (instead of e^-e^+) at fixed energy. Optionaly, collinear PDFs for $q\bar{q}$ beams instead of beamstrahlung, as a patch in the source code (temp. solution).
- The complete "algebraic" description of the NNLO formulas has been published in Phys.Rev. D73 (2006) 073001 (an extension of the work in Phys.Rev. D65 (2002) 073030), the code still not public. PHOKHARA MC is an alternative here for low energy colliders.

KKMC is special because:

- Resummed (exponentiated) multiphoton effects at the AMPLITUDE level (CEEX). $\sim$10 man-years of work in QED.
- QED rad. corrections up to third LO and NLO, both in the initial and final state plus (exponentiated) initial-final interference.
- Complete spin effects, including transverse correlations, for incoming beams and outgoing femions (needed for taus).

KKMC can be useful in the LHC data analysis,
without major developments beyond the existing code:

- Testing/calibrating PHOTOS for FSR in leptonic decays of Z/W. An obvious thing and Zbyszek Was is doing this all the time...
- Studies/estimations of ISR-FSR interferences in $q\bar{q} \to Z \to l + \bar{l}$ data
- Electroweak+QCD corrections in the for Z production.cross section
- Spin correlations in $Z \to \tau^- \tau^+$, already being done by Zbyszek
- What else???? Any new ideas????