News on PHOTOS Monte Carlo: issue of systematic errors .

Z. Was

Institute of Nuclear Physics, Krakow *and* CERN-PH, Geneva

talk include contributions from:

P. Golonka CERN IT/CO-BE , Geneva, Institute of Nuclear Physics, Krakow

G. Nanava JINR, Dubna, Russia, Institute of Nuclear Physics, Krakow

E. Barberio Melbourne University, Australia

and:

Other members of BELLE and NA48 Collab.

Web pages: http://wasm.home.cern.ch/wasm/goodies.html

http://piters.home.cern.ch/piters/MC/PHOTOS-MCTESTER/

Plan

- PHOTOS Monte Carlo is widely used by eg. Belle/Babar TEVATRON/LHC.
- Its basic design remained nearly unchanged since 1994, however:
- Last summer tests of its precison and flexibility of its algorithm became public: hep-ph/0508015 and Eur.Phys.J.C45:97-107,2006. Precision level 0.1%.
- Complete NLO corrections in Z decays were introduced into PHOTOS and appropriate tests were completed.
- PHOTOS results were compared with respect to prediction of scalar QED for the first time.
- Formal aspects of PHOTOS algorithm I have forwarded to March 2nd seminar in CERN-TH.
- I may recall some results on PHOTOS for the B-meson decays into final states with leptons.

PHOTOS: short presentation

Presentation

- PHOTOS (by E.Barberio, B. van Eijk, Z. W., P.Golonka) is used to simulate the effect of radiatiative corrections in decays, since 1989.
- Events of complicated tree structure: production and subsequent decays fed into PHOTOS, usually though HEPEVT event record of F77.
- This is often source of technical difficulties as standard is often overruled.
- At every event decay branching, PHOTOS intervene. With certain probability extra photon may be added and kinematics of other particles adjusted.
- PHOTOS works on four-momenta four-vectors. Fun with numerical stability.
- I will not talk about those time consuming aspects but about relation of PHOTOS with explicit field theory calculations, n-body phase space, and expansions with respect to leadin-log truncation and eikonal-truncation.
- See my March 2nd talk:

PHOTOS: short presentation

- for many years PHOTOS was exploited as low precision tool.
- Nonetheless it can provide extremely precise and fast simulations.
- This fact may be worth publicising ! PHOTOS soultion is unique!
- It has no free hidden parameters
- Unless QED lagrangian is replaced with effective one (for hadrons).

Main References

- E. Barberio, B. van Eijk and Z. Was, Comput. Phys. Commun. **66**, 115 (1991).
- E. Barberio and Z. Was, Comput. Phys. Commun. **79**, 291 (1994).
- P. Golonka, B. Kersevan, T. Pierzchala, E. Richter-Was, Z. Was and M. Worek, arXiv:hep-ph/0312240, Comput. Phys. Commun.in print.
- P. Golonka, T. Pierzchala and Z. Was, Comput. Phys. Commun. **157** (2004) 39
- Z. Was, Eur. Phys. J. C **44** (2005) 489
- P. Golonka and Z. Was, arXiv:hep-ph/0506026, Eur. Phys. J. C **45** (2006) 97 and arXiv:hep-ph/0508015

Why worry about QED?

Before going into details let me show an example where PHOTOS was used.

Most of you probably know it better than be.

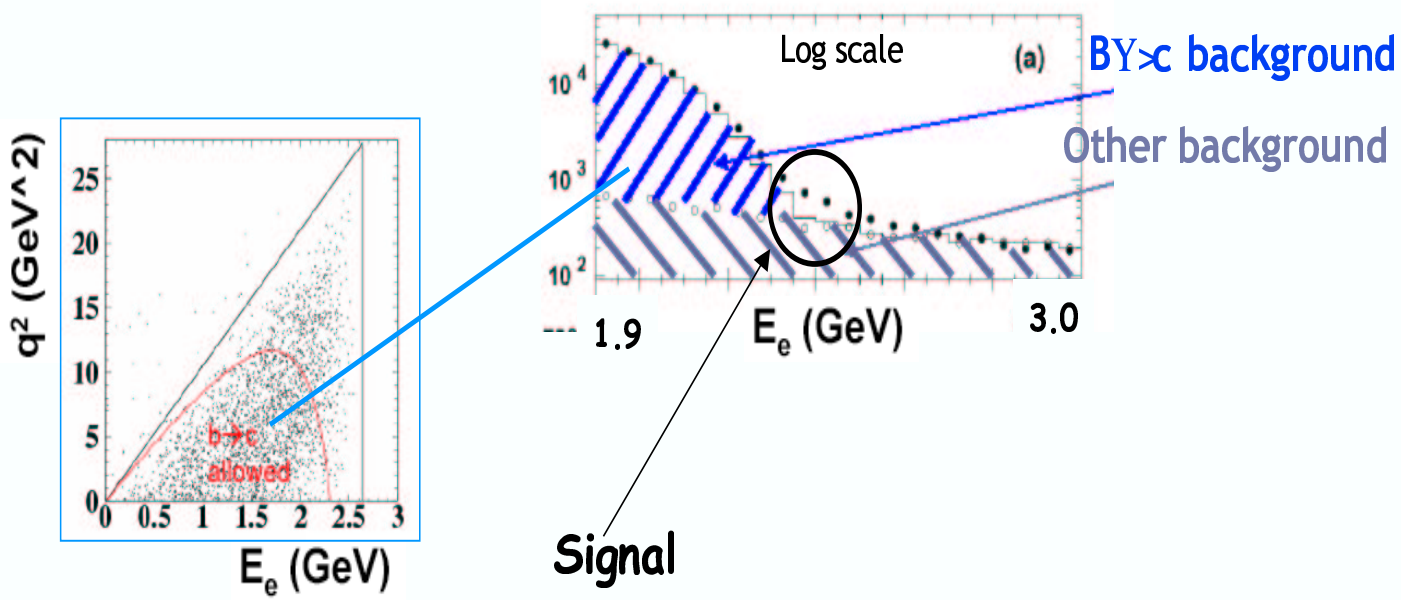
It should illustrate the complex nature of interplay between: (i) QED (ii) experimental cuts (iii) signal-backgound separation

For me it is just an example to illustrate how QED can produce 10% correction to the rate ...

At the end of my talk I may return to the point of PHOTOS systematic error for this type of processes.

I did something wrong with encapsulating PDF's some characters are corrupted.

electron endpoint



Systematic uncertainty:
Model dependent signal efficiencies
B_Xcℓ Y background estimation

Phys. Lett. B 621, 28 (2005)

$$\Delta Br(X_u l \nu) = \frac{N(X_u l \nu)}{2 N_{BB}\, \varepsilon_{MC}}$$

$$|V_{ub}| = \sqrt{\frac{(1+\delta_{rad}) \times \Delta Br(X_u l \nu)}{\tau_B} \frac{1}{R}}$$

Transparency of E. Barberio

QED radiative corrections: bΥ u endpoint

Lepton momentum region (GeV) In the Υ(4s) frame	PHOTOS correction to partial branching fraction measurement of bΥ uℓΥ
1.9-2.6	1.060±0.007
2.2-2.6	1.086±0.010
2.3-2.6	1.096±0.011
2.4-2.6	1.107±0.014

Transparency of E. Barberio

My Talk

- For 15 years PHOTOS was developped as ‘cheap tool’ and its theoretical foundations were left ‘in dark’.
- I apologize.
- Recently its use entered the field of high responsability: precision CKM, W mass, W coupling etc
- My old approach to rely mainly on comparisons with matrix element calculations to justify PHOTOS with comparisons is succesful, but not anymore sufficient.
- Nonetheless today I will present mainly numerical results:
  – comparisons of PHOTOS running at fixed first order with first order QED matrix element calculations
  – comparisons of PHOTOS running with multiple radiation with precision Monte Carlo KKMC for Z decay, based on second order matrix element and exclusive exponentiation.

Kernel

- An essential Building Block is single emission kernel
- In 1991 universal emission kernel was defined for PHOTOS, thanks to approximation for explicit Matrix El. ($Z \to \mu^+\mu^-(\gamma)$).
- Without approximation, kernel is valid only for $Z \to \mu^+\mu^-$
- Define transformation from n-body phase space (no bremsstrahlung) to (n+1)-body phase space with photon present. Also no emission probablity.
- For the phase space parametrisation like in FOWL of F. James (70's). I used variant of that in TAUOLA too, see references for details.
- Exact kernel differs from decay channel to channel. Has to be obtained from orthodox first order calculation.
- Let us present new results of tests for Kernel performance; case of scalar charged products in B meson decays (scalar QED used).

Comparison of SANC with PHOTOS for non-leptonic B Meson Decays Work Report

Nanava Gizo

Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Dubna, Russia
(On leave from IHEP, TSU, Tbilisi, Georgia)

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- Exercise
- SANC
- Scalar QED Lagrangian
- Radiative Corrections
- Comparison with PHOTOS
- Conclusion

Radiative Corrections

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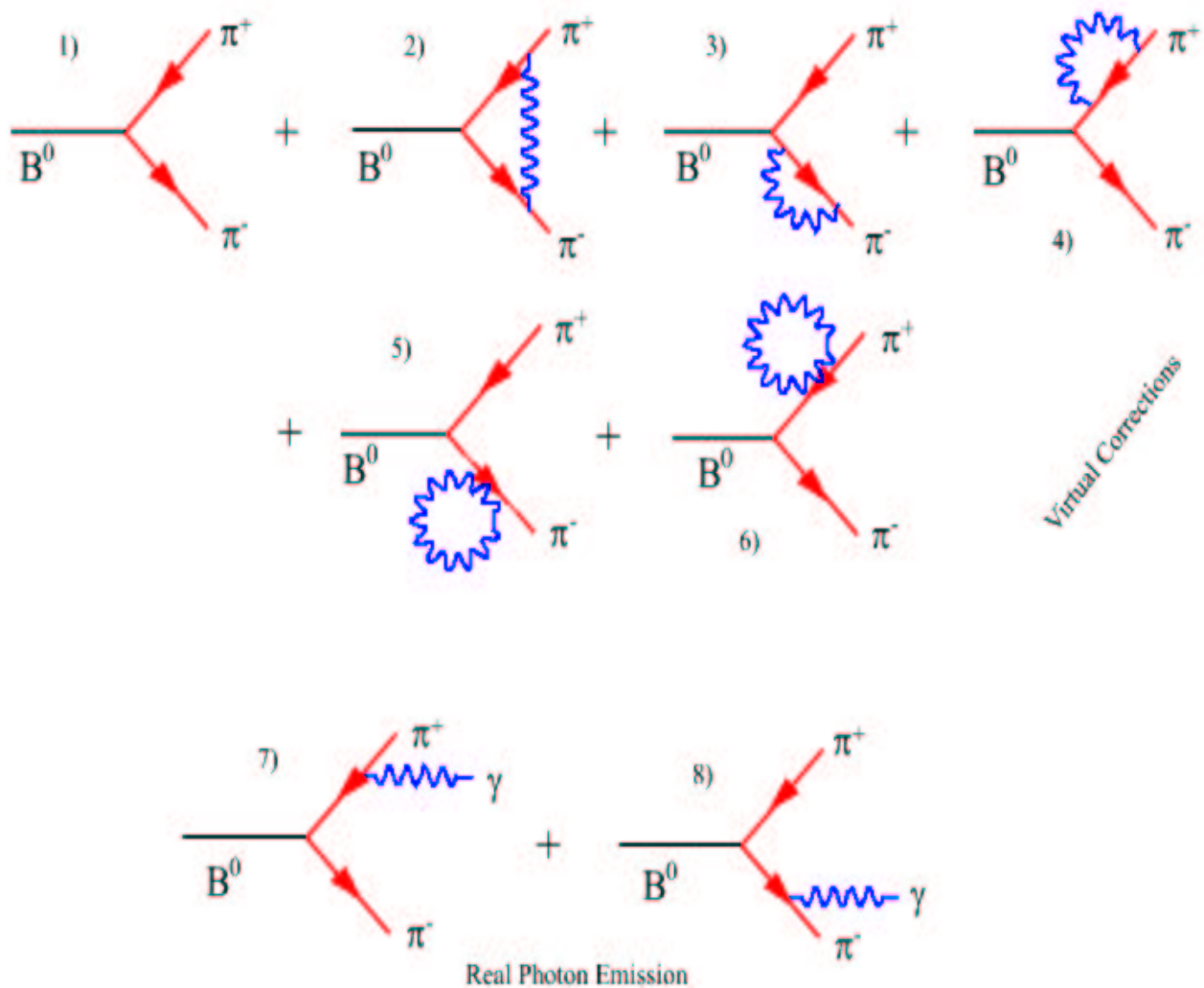
Diagrams of order $O(\alpha)$ contributing to $B^0 \to \pi^- \pi^+ \gamma$



The QED radiative corrections modify the lowest order decay rate

$$d\Gamma^{\text{One-loop}}_{B^0\to\pi^-\pi^+\gamma}(\Lambda_{QED}) = d\Gamma^{\text{Born}}_{B^0\to\pi^-\pi^+}\left[1+\delta^{\text{Virt+Soft}}(\Lambda_{QED},\omega)\right]$$

$$+\, d\Gamma^{\text{Hard}}_{B^0\to\pi^-\pi^+\gamma}(\omega)$$

$$\delta^{\text{Virt+Soft}}(\Lambda_{QED},\omega) = 2\Re\left[\delta^{\text{Virt}}(\Lambda_{QED},m_\gamma)\right] + \delta^{\text{Soft}}(m_\gamma,\omega)$$

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- IR pole, which is represented here by the photon mass, cancels in the sum
- However, dependence on the Ultraviolet Renormalization Scale remains
- SANC Monte Carlo for radiative B Meson decays is based on this formula

Comparison With PHOTOS

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- We used the same methodology as in the case of " W decay" (*Acta Phys. Pol.* B34, (2003) 4561-4569; *hep-ph*/0303260)
- To visualize the usually small differences between SANC and PHOTOS, we plot the ratios of the predictions from the two program for the certain class of (pseudo-)observables
- These observables are

List of Observables

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- Photon energy in the decaying particle rest frame – sensitive to the collinear–soft componet of the distributions
- Energy of final state charged particle – as the previous one
- Angle of photon with final-state charged particle - sensitive to the collinear componet of the distributions
- Acollinearity angle of the final-state particles - sensitive to the non-soft and non-collinear, but non-leading componet of the distributions

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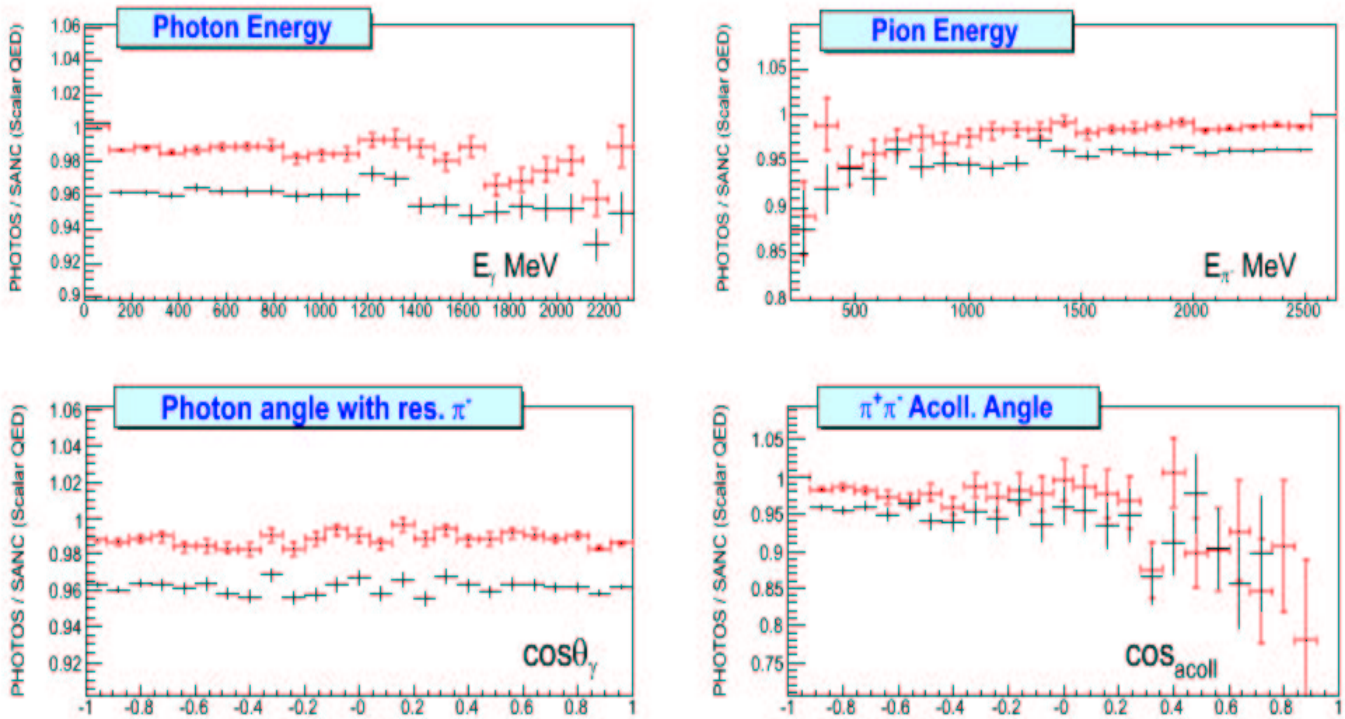

$\Lambda_{QED} = M_\pi$ $\Lambda_{QED} = M_{B^0}$

Λ_{QED} → Ultraviolet Renormalization Scale

M_π = 139.57 MeV

M_{B^0} = 5279.4 MeV

ω (soft/hard cut-off) = M_{B^0}/200 MeV

$$B^0 \to \pi^- \pi^+ \gamma$$

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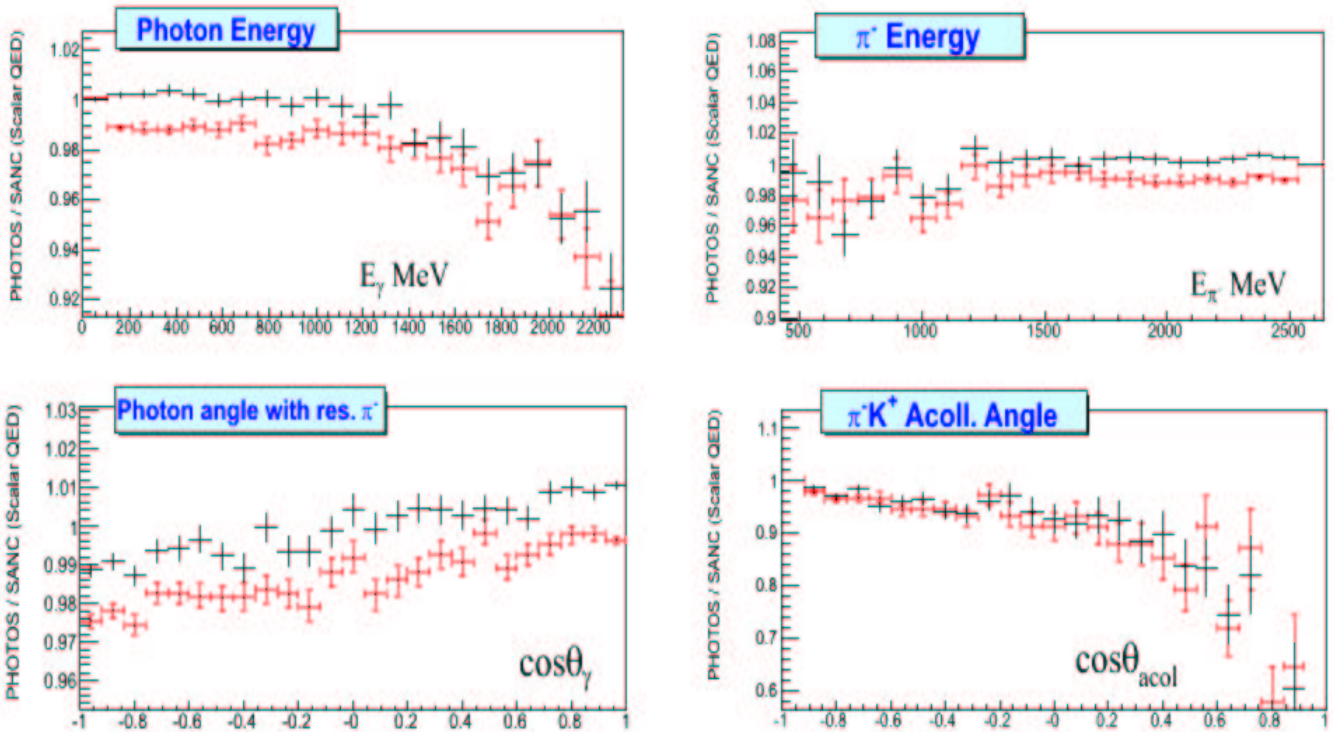

$\Lambda_{QED} = M_{B^0}$ $\Lambda = 770$ MeV

$\lambda_{QED} \rightarrow$ Ultraviolet Renormalization Scale

$M_{B^0} = 35279.4$ MeV

$M_{\pi^-} = 139.57$ MeV

$M_{K^+} = 493.677$ MeV

ω (soft/hard cut-off) = M_{B^0} / 200 MeV

$$B^0 \rightarrow \pi^- K^+ \gamma$$

12/12/05 IFJ, Cracow. Nanava Gizo. 13

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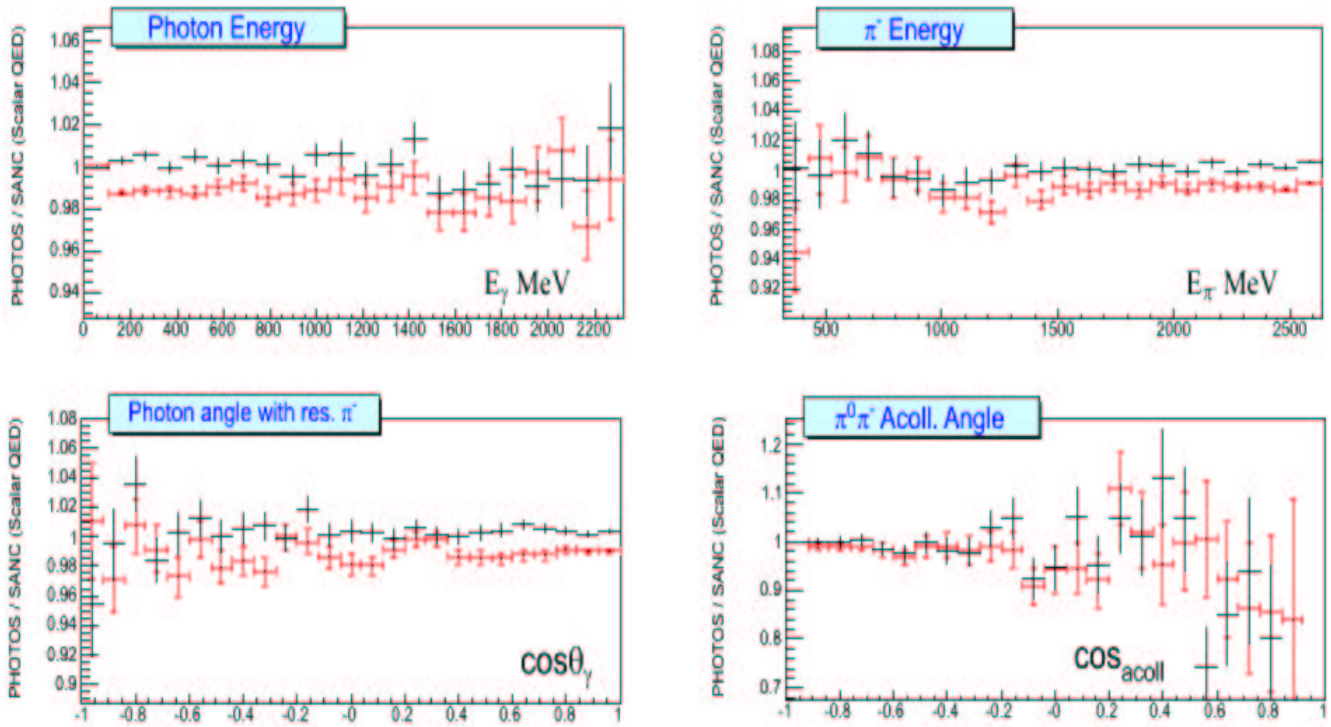

$\Lambda_{QED} = M_{B^-}$ $\Lambda_{QED} = 770$ MeV

$\Lambda_{QED} \rightarrow$ Ultraviolet Renormalization Scale

$M_{B^-} = 5279.57$ MeV

$M_{\pi^0} = 134.98$ MeV

$M_{\pi^-} = 139.57$ MeV

ω (soft/hard cut-off) = $M_B/200$ MeV

$$B^- \rightarrow \pi^- \pi^0 \gamma$$

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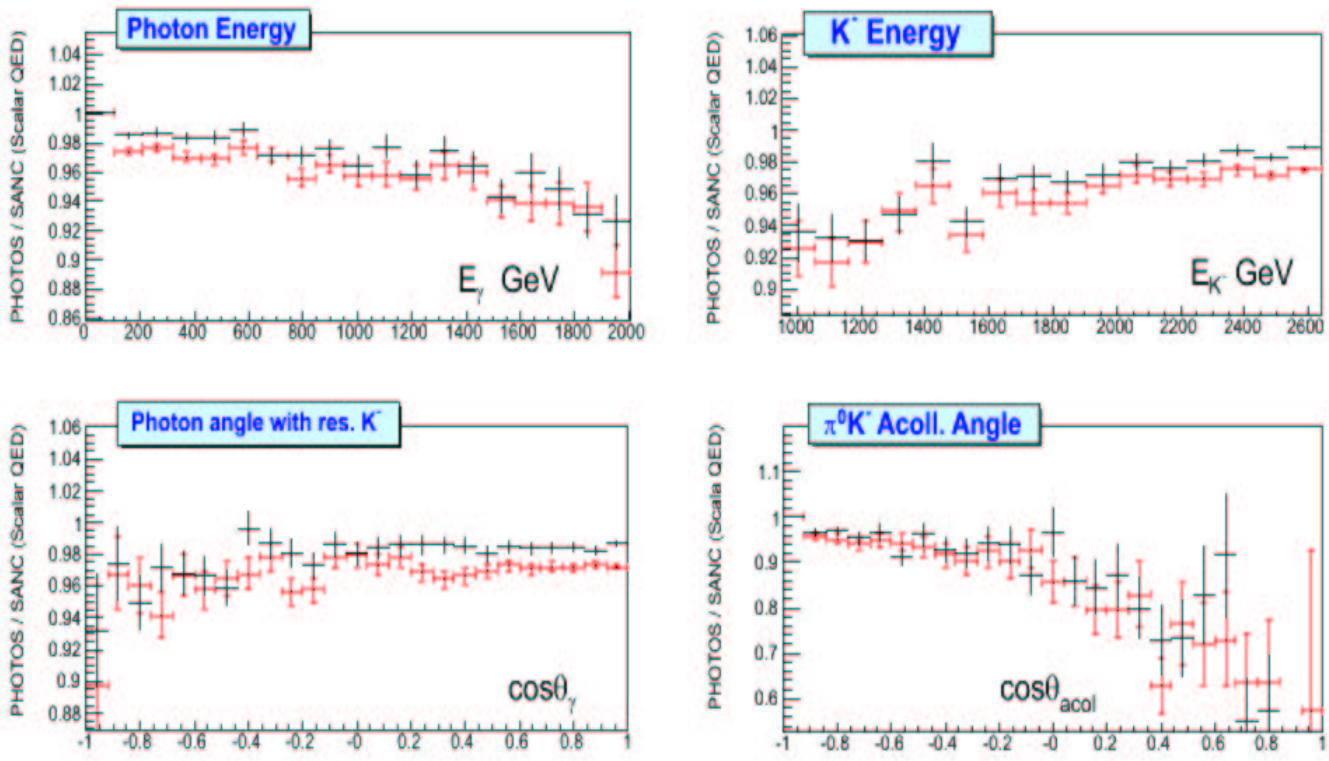

$\Lambda_{QED} = M_{B^-}$ $\Lambda_{QED} = 770$ MeV

$\Lambda \rightarrow$ Ultraviolet Renormalization Scale

$M_{B^-} = 5279.57$ MeV

$M_{\pi^0} = 134.98$ Mev

$M_{K^-} = 493.677$ MeV

ω (soft/hard cut-off) = M_{B^-} / 200 MeV

$$B^- \rightarrow K^- \pi^0 \gamma$$

12/12/05 IFJ, Cracow. Nanava Gizo. 15

Conclusion

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- Comparisons of SANC with PHOTOS Monte Caro generator were made for non-leptonic B Meson decays within the Scalar QED Lagrangian. The results from both two programs for all observables agree within the expected precision range
- In future it is possible to study other channels and more complicated Lagrangians
- Some notes about the work was done will be written (I could not do it now because of other tasks)

Kernel and data

- We could see that approximated kernel of PHOTOS performed resonably well once confronted with scalar QED.
- Does scalar QED make sense for $B \to hh$ decays?
- It is good to be able to start answering such a question having QED predictions reproduced first. No modelling !
- For many decay channels emission kernels will have to be modified with shape-factors
- These will have to be obtained from experimental data.
- PHOTOS profitted from that a lot, already now.

Kernel and exact matrix element

- From the point of view of matrix element and choice of internal angular variables in case of Z decays, PHOTOS is very close to MUSTRAAL MC by F. Berends S. Jadach and R. Kleiss, CPC 29 (1983) 185.
- The first step to re-introduce NLO terms for Z decay into PHOTOS was to check relations between 4-vectors and angles.
- For PHOTOS those angles are ill-defined in general. incoming beams (defining Z polarisations) have to be along z axis.
- To match this requirement PHOTOS has to read in events, appropriately orientined Born level events generator.
- The fully differential distribution from MUSTRAAL (used also in KORALZ for

single photon mode) reads:

$$X_f = \frac{Q'^2\alpha(1-\Delta)}{4\pi^2 s} s^2 \quad \left\{ \frac{1}{(k'_+ k'_-)} \left[\frac{\mathrm{d}\sigma_B}{\mathrm{d}\Omega}(s,t,u') + \frac{\mathrm{d}\sigma_B}{\mathrm{d}\Omega}(s,t',u) \right] \right\}$$

- Here:

$$\begin{aligned} s &= 2p_+ \cdot p_-, \quad & s' &= 2q_+ \cdot q_-, \\ t &= 2p_+ \cdot q_+, \quad & t' &= 2p_+ \cdot q_-, \\ u &= 2p_+ \cdot q_-, \quad & u' &= 2_- \cdot q_+, \\ k'_\pm &= q_\pm \cdot k, \quad & x_k &= 2E_\gamma/\sqrt{s} \end{aligned}$$

- The Δ term is responsable for final state mass dependent terms, p_+, p_-, q_+, q_-, k denote four-momenta of incoming positron, electron beams, outcoming muons and bremsstrahlung photon.

Single emission in Z; NLO kernel

- after trivial manipulation it can be written as:

$$X_f = \frac{Q'^2\alpha(1-\Delta)}{4\pi^2 s}s^2 \quad \left\{ \frac{1}{(k'_+ + k'_-)}\frac{1}{k'_-}\left[\frac{d\sigma_B}{d\Omega}(s,t,u') + \frac{d\sigma_B}{d\Omega}(s,t',u)\right] \right.$$
$$\left. + \frac{1}{(k'_+ + k'_-)}\frac{1}{k'_+}\left[\frac{d\sigma_B}{d\Omega}(s,t,u') + \frac{d\sigma_B}{d\Omega}(s,t',u)\right] \right\}$$

- In PHOTOS the following expression is used:

$$X_f^{PHOTOS} = \frac{Q'^2\alpha(1-\Delta)}{4\pi^2 s}s^2 \left\{ \right.$$
$$\frac{1}{k'_+ + k'_-}\frac{1}{k'_-} \left[(1+(1-x_k)^2)\frac{d\sigma_B}{d\Omega}\left(s, \frac{s(1-\cos\Theta_+)}{2}, \frac{s(1+\cos\Theta_+)}{2}\right)\right]\frac{(1+\beta\cos\Theta_\gamma)}{2}$$
$$\left. + \frac{1}{k'_+ + k'_-}\frac{1}{k'_+} \left[(1+(1-x_k)^2)\frac{d\sigma_B}{d\Omega}\left(s, \frac{s(1-\cos\Theta_-)}{2}, \frac{s(1+\cos\Theta_-)}{2}\right)\right]\frac{(1-\beta\cos\Theta_\gamma)}{2} \right\}$$

where : $\Theta_+ = \angle(p_+, q_+)$, $\Theta_- = \angle(p_-, q_-)$

$\Theta_\gamma = \angle(\gamma, \mu^-)$ are defined in (μ^+, μ^-)-pair rest frame

- The two expressions define weight to make out of PHOTOS complete first order.

Standard PHOTOS, (singl em.) 100Mevts compared!

Found decay modes:

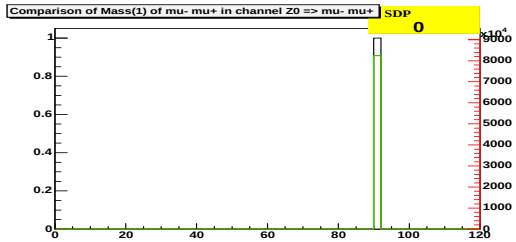
Decay channel	Branching Ratio ± Rough Errors		Max. shape dif. param.
	Generator #1	Generator #2	
$Z^0 \to \mu^- \mu^+$	82.5137 ± 0.0091%	82.3622 ± 0.0091%	0.00000
$Z^0 \to \mu^- \mu^+ \gamma$	17.4863 ± 0.0042%	17.6378 ± 0.0042%	0.00534

Similarity coefficients: T1=0.302959 %, T2=0.092415 %

Standard PHOTOS,(singl em.) 100Mevts compared!

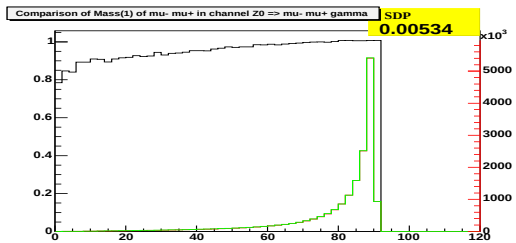
1 Decay Channel: $Z^0 \longrightarrow \mu^- \mu^+$

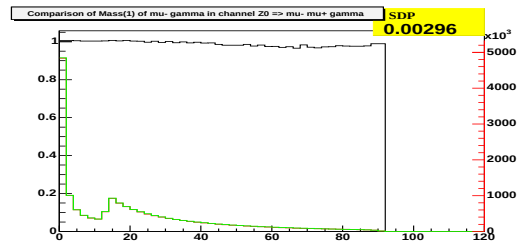
Number of events from generator 1: 82513687
Number of events from generator 2: 82362193

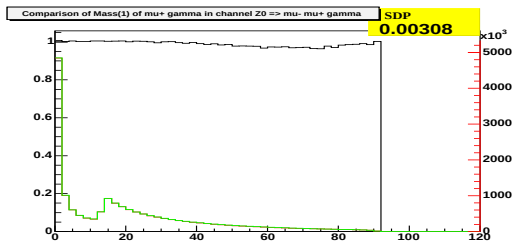


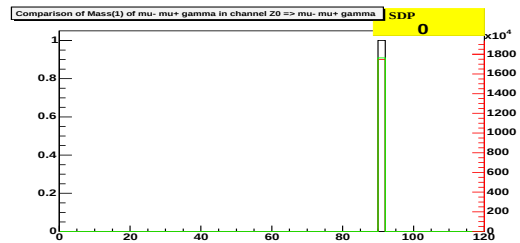
2 Decay Channel: $Z^0 \longrightarrow \mu^- \mu^+ \gamma$

Number of events from generator 1: 17486313
Number of events from generator 2: 17637807









3 User Histograms

With NLO, (singl em.) 100Mevts compared!

Discrepancy of 0.1 % has to be understood/corrected.

Found decay modes:

Decay channel	Branching Ratio ± Rough Errors		Max. shape dif. param.
	Generator #1	Generator #2	
$Z^0 \to \gamma\mu^+\mu^-$	21.9118 ± 0.0047%	22.0134 ± 0.0047%	0.00000
$Z^0 \to \mu^+\mu^-$	78.0882 ± 0.0088%	77.9866 ± 0.0088%	0.00000

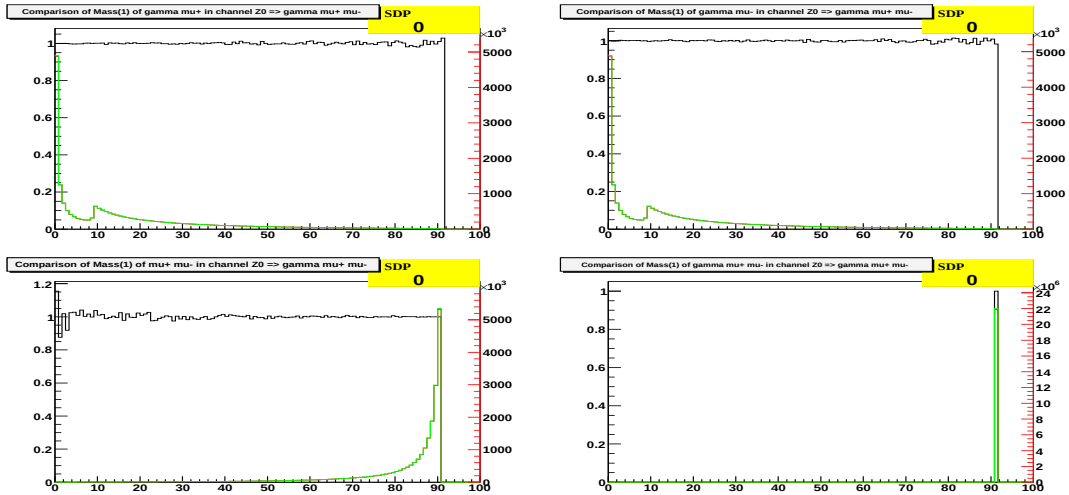
Similarity coefficients: T1=0.203241 %, T2=0.000000 %

Single emission in Z; NLO kernel

With NLO, (singl em.) 100Mevts compared!

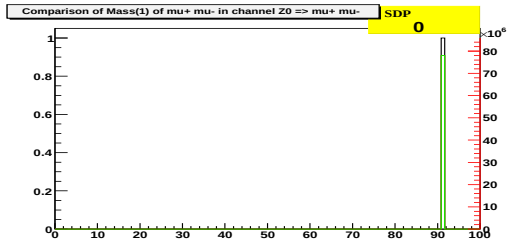
1 Decay Channel: $Z^0 \to \gamma\mu^+\mu^-$

Number of events from generator 1: 21911762
Number of events from generator 2: 22013395



2 Decay Channel: $Z^0 \to \mu^+\mu^-$

Number of events from generator 1: 78088238
Number of events from generator 2: 77986605



Also for Higgs decay agreement is to stat. err.!

- Probably PHOTOS formula from transparency 23 is accurate for Higgs
- Born Cross Section is spin blind for Higgs.
- I do not have analytical, but only numerical support for that statement.
- It suffice by now.

MC-Tester

- In the numerical tests for Z-decays and for PHOTOS at NLO.vious plots it was relatively simple to define comparison
- All invariant masses, which could be defined from 3 four-vectors were histogramed. Photon 4-momentum both in PHOTOS and KORALZ were generated starting from the same threshold
- MC-TESTER: Comput. Phys. Commun. **157** (2004) 39 could be used for automated comparison without any changes
- MC-TESTER targetting applications for decay packages, such as TAUOLA, more precisely to get a quick test if series generated by two different packages differ and where.
- Test had to be automatic and easy to use, P- CP-sensitive effects are ignored in MC-TESTER

Results with exponentiation

- Previoulsy presented and tested kernel can be used in multiple photon version of PHOTOS.
- We will use a variant of our universal test, soft photons (of energy below some threshold are ignored: merged with outgoing fermions).
- Also at most 2 (or 1) hardest photons above threshold will be preserved.
- This was necessary for the test to be free from effects of infrared singularities and its regulators.
- Let us show just one example of such a test. (i) PHOTOS working with multiple photon radiation, (ii) test is sensitive to 1 photon at most, (iii) its energy larger than 1 GeV. (iv)Comparison with second order matrix element precision generator of LEP times KKMC.
- Z decay

Standard PHOTOS (exp), 100Mevts

Found decay modes:

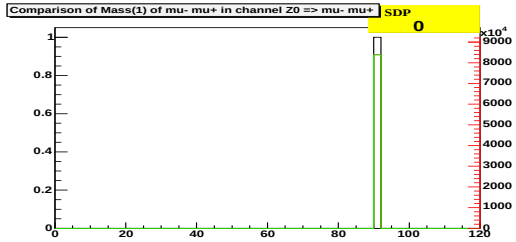
Decay channel	Branching Ratio ± Rough Errors		Max. shape dif. param.
	Generator #1	Generator #2	
$Z^0 \to \mu^- \mu^+$	83.9176 ± 0.0092%	83.8372 ± 0.0092%	0.00000
$Z^0 \to \mu^- \mu^+ \gamma$	16.0824 ± 0.0040%	16.1628 ± 0.0040%	0.00409

Similarity coefficients: T1=0.160659 %, T2=0.065801 %

Standard PHOTOS (exp), 100Mevts

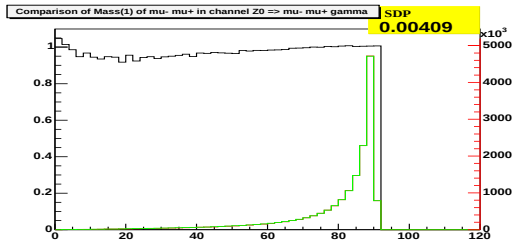
1 Decay Channel: $Z^0 \longrightarrow \mu^- \mu^+$

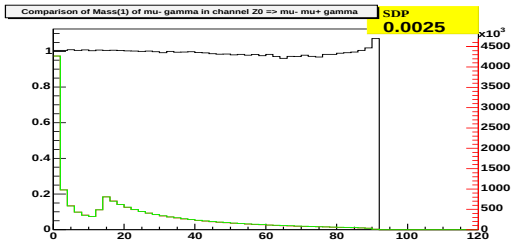
Number of events from generator 1: 83917588
Number of events from generator 2: 83837243

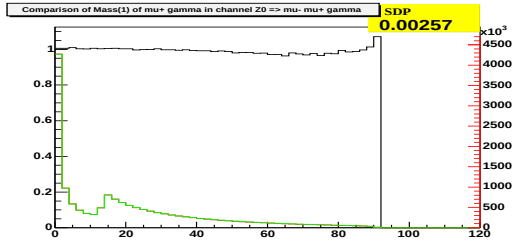


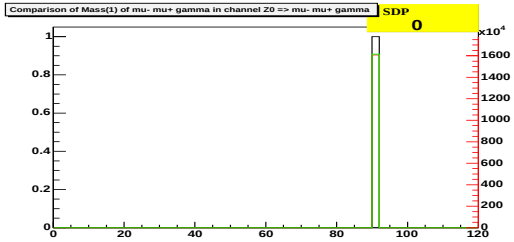
2 Decay Channel: $Z^0 \longrightarrow \mu^- \mu^+ \gamma$

Number of events from generator 1: 16082412
Number of events from generator 2: 16162757









3 User Histograms

NLO in PHOTOS (exp) included, 100Mevts

Found decay modes:

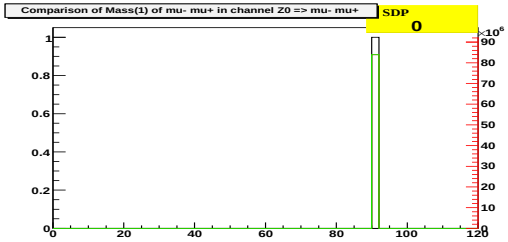
Decay channel	Branching Ratio ± Rough Errors		Max. shape dif. param.
	Generator #1	Generator #2	
$Z^0 \to \mu^- \mu^+$	83.9176 ± 0.0092%	83.9312 ± 0.0092%	0.00000
$Z^0 \to \mu^- \mu^+ \gamma$	16.0824 ± 0.0040%	16.0688 ± 0.0040%	0.00003

Similarity coefficients: T1=0.027109 %, T2=0.000482 %

NLO in PHOTOS (exp) included, 100Mevts

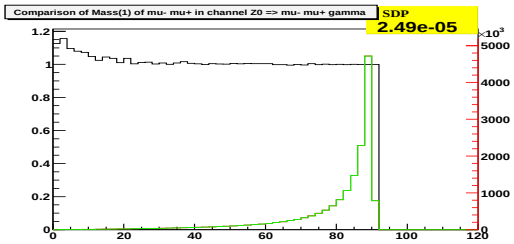
1 Decay Channel: $Z^0 \to \mu^- \mu^+$

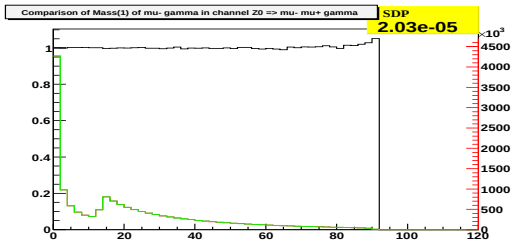
Number of events from generator 1: 83917588
Number of events from generator 2: 83931158

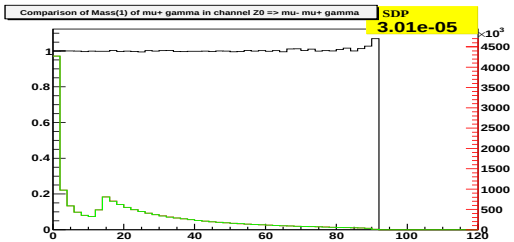


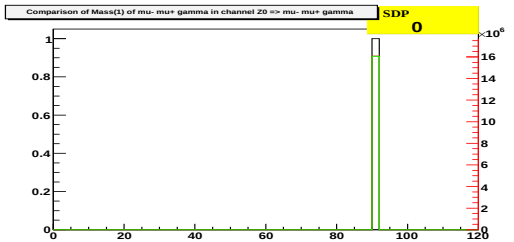
2 Decay Channel: $Z^0 \to \mu^- \mu^+ \gamma$

Number of events from generator 1: 16082412
Number of events from generator 2: 16068842









SUMMARY: Applications

- Numerical tests of the bremsstrahlung kernel with scalar QED in B-meson decays available
- Re-implementation of complete first order matrix element into PHOTOS.
- Tests with complete first order kernel in case of Z decays; cases of single photon and exponentiated modes: completed.
- Work on data for possible future form factor tuning initiated (NA48, Belle).
- **PHOTOS generates photons over all multiphoton bremsstrahlung phase space !**
- **Quality of its prediction is determined by the quality of the Kernel calculated from the matrix element**
- I have omitted intriguing aspect of how kernel iteration work.

SUMMARY: Algorithm

- Skipped to my March 2nd talk.
- Eg. I have omitted intriguing aspect of how kernel iteration work.

SUMMARY: Physics

- There is mothing like systematic error for theoretical calculation: Monte Carlo or not.
- All depends on choice of particular observable.
- PHOTOS predictions are ready for such analysis.
- It requires contributions from experiments and from people working on phenomenology of decays.
- Exactly as it was done at LEP times.

SUPPLEMENTARY TRANSPARENCIES

Phase space–near factorization

$$
\begin{aligned}
& dLips_{n+1}(P) = \\
& \frac{d^3k_1}{2k_1^0(2\pi)^3} \cdots \frac{d^3k_n}{2k_n^0(2\pi)^3} \frac{d^3q}{2q^0(2\pi)^3} (2\pi)^4 \delta^4\Big(P - \sum_1^n k_i - q\Big) \\
= \quad & d^4p\delta^4(P-p-q) \frac{d^3q}{2q^0(2\pi)^3} \frac{d^3k_1}{2k_1^0(2\pi)^3} \cdots \frac{d^3k_n}{2k_n^0(2\pi)^3} (2\pi)^4 \delta^4\Big(p - \sum_1^n k_i\Big) \\
= \quad & d^4p\delta^4(P-p-q) \frac{d^3q}{2q^0(2\pi)^3} dLips_n(p \to k_1 \ldots k_n). \qquad (1)
\end{aligned}
$$

Let us now recall the two most interesting forms of the $(n+1)$-body phase space:

$$
\begin{aligned}
& dLips_{n+1}(P) = \\
& \frac{dM_1^2}{(2\pi)} dLips_2(P \to p\,q) \times dLips_n(p \to k_1 \ldots k_n) \\
= \quad & dM_1^2 \left[d\cos\theta d\phi \frac{1}{8(2\pi)^3} \frac{\lambda^{\frac{1}{2}}(M^2, M_1^2, m^2)}{M^2} \right] \times dLips_n(p \to k_1 \ldots k_n) \qquad (2)
\end{aligned}
$$

This is basically what is underneath of FOWL, TAUOLA PHOTOS and many other generators for phase space.

The definitions of angular orientations can be quite important and non-trivial

Phase space–near factorization

$$
\begin{aligned}
& dLips_{n+1}(P) = \\
& \left[2M\,dk_\gamma \frac{2k_\gamma}{M} d\cos\theta d\phi \frac{1}{8(2\pi)^3}\right] \times dLips_n(p \to k_1 \ldots k_n) \\
= \quad & \left[k_\gamma\, dk_\gamma\, d\cos\theta d\phi \frac{1}{2(2\pi)^3}\right] \times dLips_n(p \to k_1 \ldots k_n), \qquad (3)
\end{aligned}
$$

If we have l photons accompanying n other particles, then the factor in brackets become iterated. Statistical factor $\frac{1}{l!}$ has to be introduced:

$$
dLips_{n+l}(P) = \frac{1}{l!} \prod_{i=1}^{l} \left[k_{\gamma_i}\, dk_{\gamma_i}\, d\cos\theta_i\, d\phi_i \frac{1}{2(2\pi)^3}\right] \times dLips_n(p \to k_1 \ldots k_n). \qquad (4)
$$

If we do not ask questions about phase-space limit this look like perfect term in expansion of exponent[a].

As the leading parts of the Matrix elements squared, have the same factorization property, the exponents of the YFS expansion form.

[a] In reality it can be realized relatively easy in M.C. because of the scale symmetry present in the expression.

We get:

$$\sum_{l=0} dLips_{n+l}(P) = \exp\left[k_\gamma dk_\gamma d\cos\theta d\phi \frac{1}{2(2\pi)^3}\right] \times dLips_n(p \to k_1 \ldots k_n) \times \mathcal{J}(P, p, l, \ldots) \quad (5)$$

Where $\mathcal{J}$ is:

- complicated,
- depends on everything
- but is calculable
- and $0 \leq \mathcal{J} \leq \mathcal{J}_{max}$!!!!

Here we omit in discussion lots of essential points:

- angular singularities,
- initial vs. final state radiation,
- etc.

We got functional exponent

The Exponent

Now we can obtain an exponent for the first time. If we sum the cross sections for the configurations with 0, 1, 2, ..., photons we obtain:

$$
\begin{aligned}
& d\sigma(p_1, p_2 \to q_1, \ldots, q_n, \text{ and photons}) \\
= \quad & \frac{1}{|v_1 - v_2|} \frac{1}{2p_1^0} \frac{1}{2p_2^0} |\mathcal{M}_B|^2 dLips_n(p \to q_1 \ldots q_n) \\
\times \quad & \sum_{l=0}^{\infty} \frac{1}{l!} \prod_{i=1}^{l} \Big[k_i dk_i d\cos\theta_i d\phi_i \frac{1}{2(2\pi)^3} \sum_{\varepsilon_i} e^2 \Big(\frac{\varepsilon_i p_2}{k_i p_2} - \frac{\varepsilon_i p_1}{k_i p_1} \Big)^2 \Big] \\
& \times \mathcal{J} \times (1 + higher\ oredrs) \\
= \quad & \frac{1}{|v_1 - v_2|} \frac{1}{2p_1^0} \frac{1}{2p_2^0} |\mathcal{M}_B|^2 dLips_n(p \to q_1 \ldots q_n) \\
\times \quad & \exp\Big[kdkd\cos\theta d\phi \frac{1}{2(2\pi)^3} \sum_{\varepsilon} e^2 \Big(\frac{\varepsilon p_2}{kp_2} - \frac{\varepsilon p_1}{kp_1} \Big)^2 \Big] \qquad (6) \\
= \quad & \times \mathcal{J} \times (1 + higher\ oredrs).
\end{aligned}
$$

Important is that the term $\mathcal{J} \times (1 + higher\ oredrs)$ can be made always positive, and bounded from above.

Infrared Catastrophy

It is nearly complete result of our presentation of exclusive exponentiation. However, it is infinite. Let us introduce the fictitious photon mass λ and replace the kdk factors of integration by: $k^2 dk \ / \ \sqrt{k^2 + \lambda^2}$, to *regularize* the infinity.

Back to PHOTOS

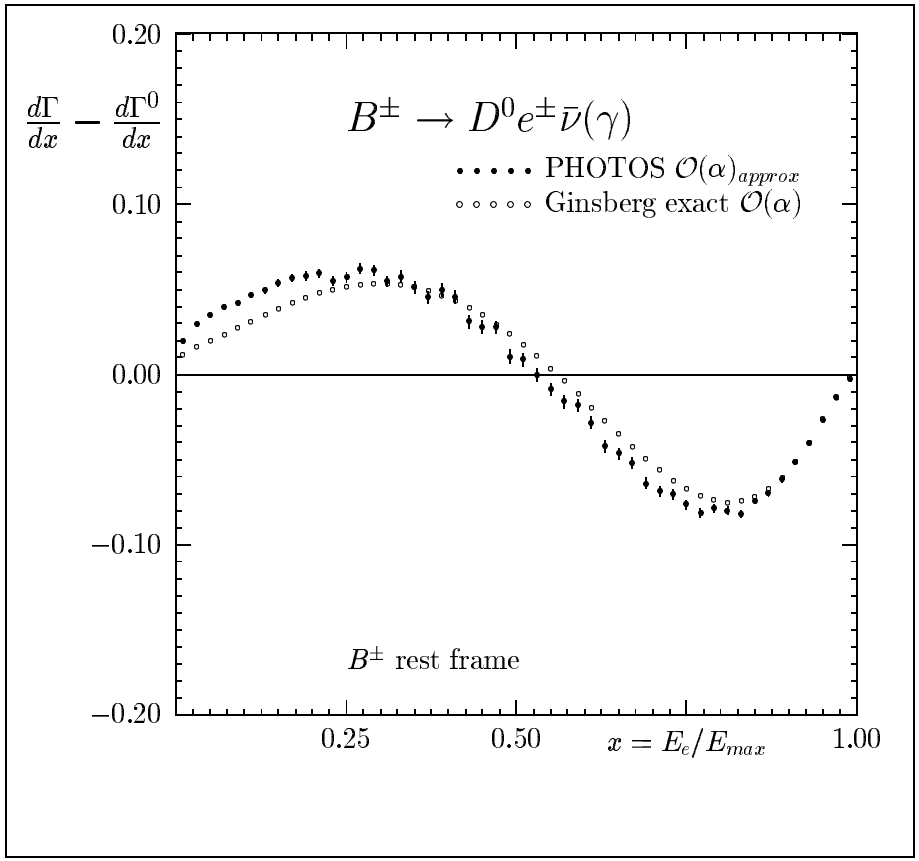
In case of PHOTOS underlying organization of the phase space is basically the same as in exponentiation.

1. The same exact treatment of all n-body phase space
2. Similar tangent space for first crude distribution

There are differences

1. In PHOTOS conformal symmetry of: tangent phase space combined with soft factors is not used to define the projection to realistic space in one step. Instead consecutive transformations are introduced
2. Organization of the non-dominant terms is different, seem to be more efficient, but not necessarily easier to describe and to calculate missing (next-to-included) terms.
3. As conformal symmetry is not used, there is thus hope to extend into application for massive particles
4. PHOTOS is also way faster than KKMC for FSR.

Phys. Lett, B 303 (1993) 163-169

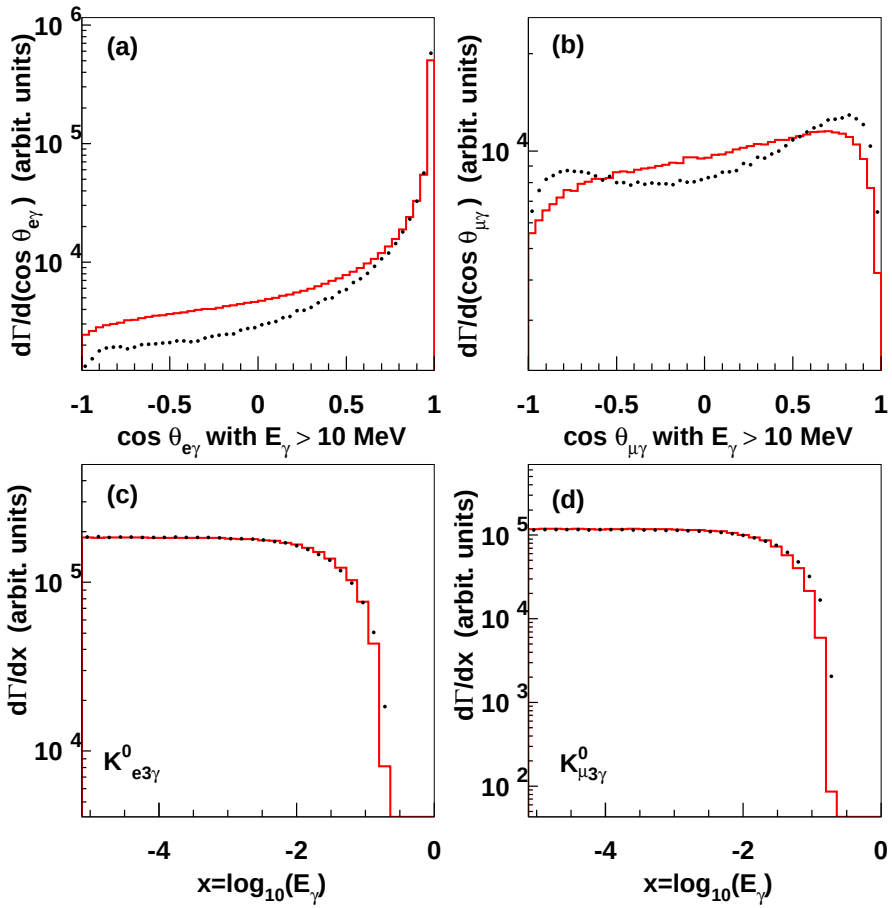


Radiative correction to the decay rate $(d\Gamma/dx - d\Gamma^0/dx)$ for $B^\pm \to D^0 e^\pm \bar{\nu}(\gamma)$ in the $B^\pm$ rest frame. Open circles are from the exact analytical formula [2], points with the marked statistical errors from PHOTOS applied to JETSET 7.3. A total of 10^7 events have been generated. The results are given in units of $(G_\mu^2 m_B^5/32\pi^3)N_\eta|V_{cb}|^2|f_+^D|^2$, where $N_\eta = \eta^5 \int_0^1 x^2(1-x)^2/(1-\eta x)dx$ and $\eta = 1 - m_D^2/m_B^2$.

- *"QED bremsstrahlung in semileptonic B and leptonic τ decays"* by E. Richter-Was.
- agreement up to 1%
- disagreement in the low-x region due to missing sub-leading terms
- study performed in 1993 - PHOTOS 1.06

$K \to \pi l \nu$ in KLOR and PHOTOS: hep-ph:0406006

only on 28 December 2004 we realized that PHOTOS is used for K decays and precision is not sufficient. Even though, program works not worse than expected.

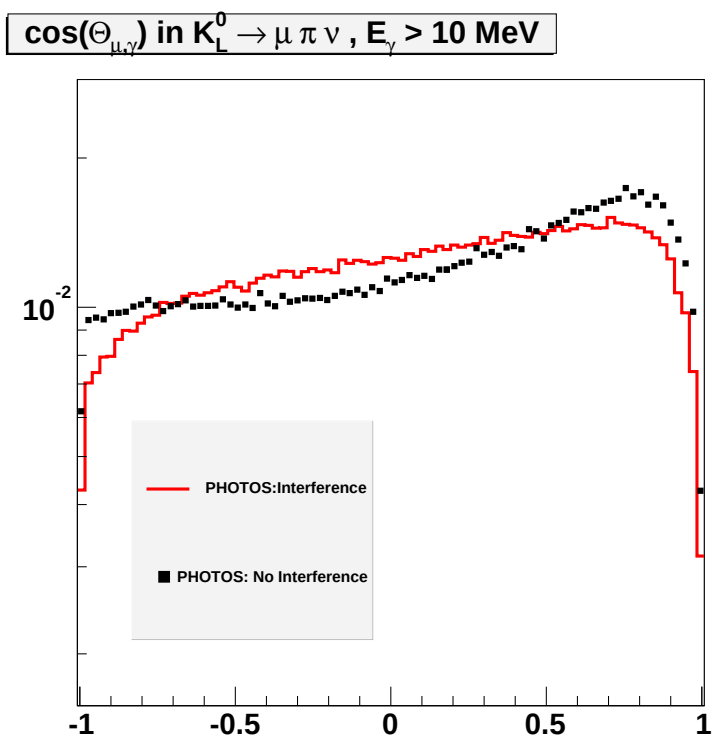


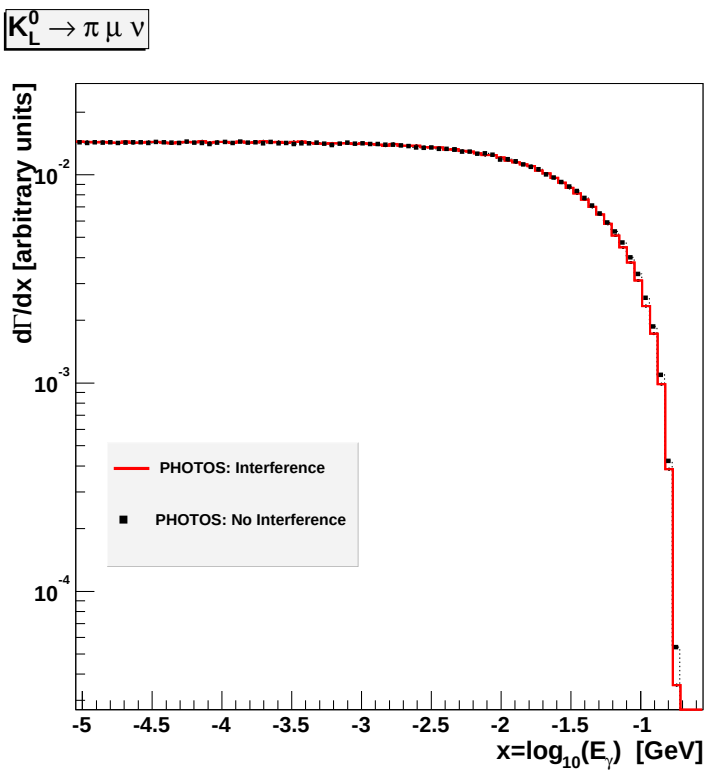
(a) $\cos(\Theta_{\gamma,l})$ $K_{\mu 3}$
(b) $\cos(\Theta_{\gamma,l})$ K_{e3}
(c) $\log_{10}(E_\gamma)$ $K_{\mu 3}$
(d) $\log_{10}(E_\gamma)$ K_{e3}

in KLOR

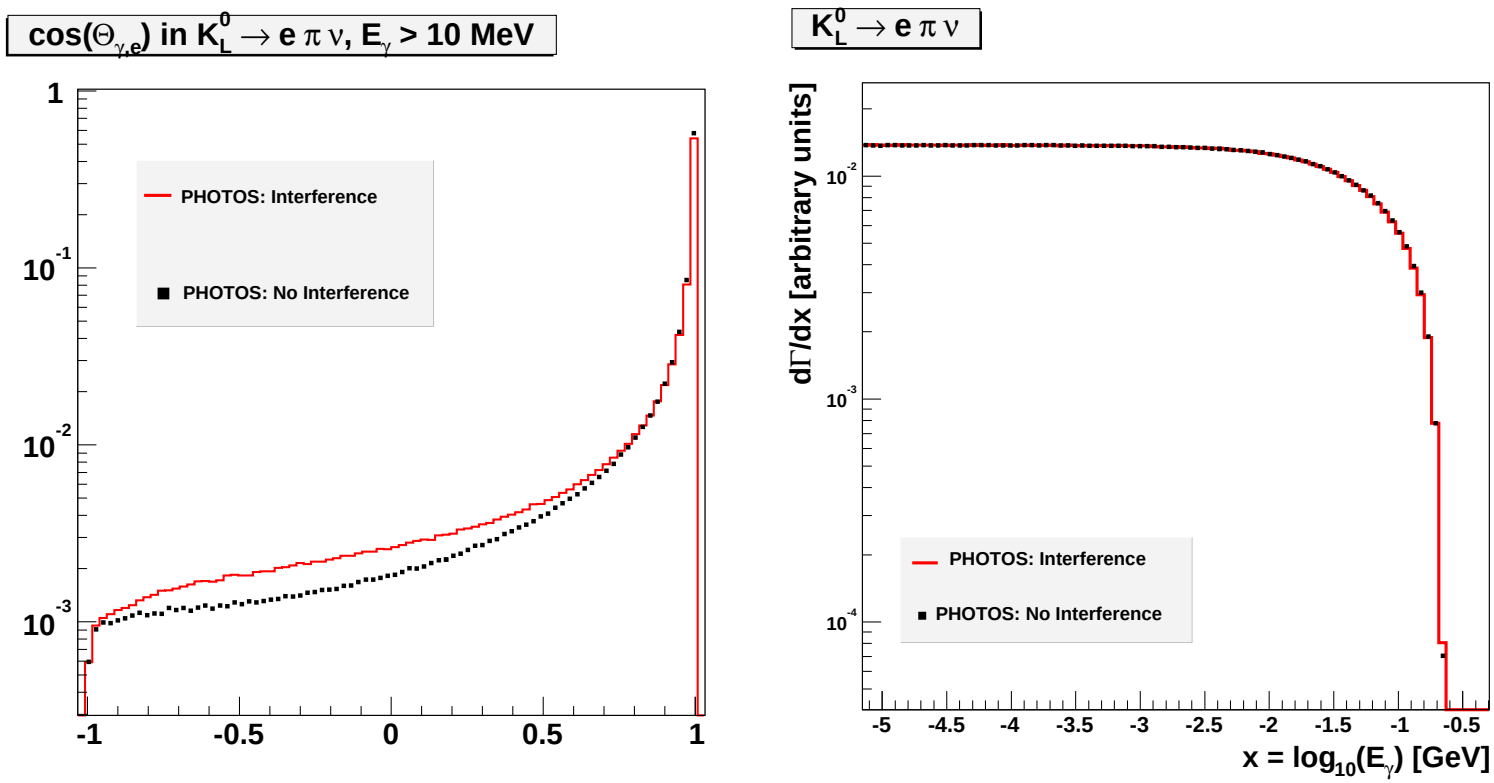
and PHOTOS

$K \to \pi\mu\nu$ + PHOTOS bremsstrahlung, interference on/off





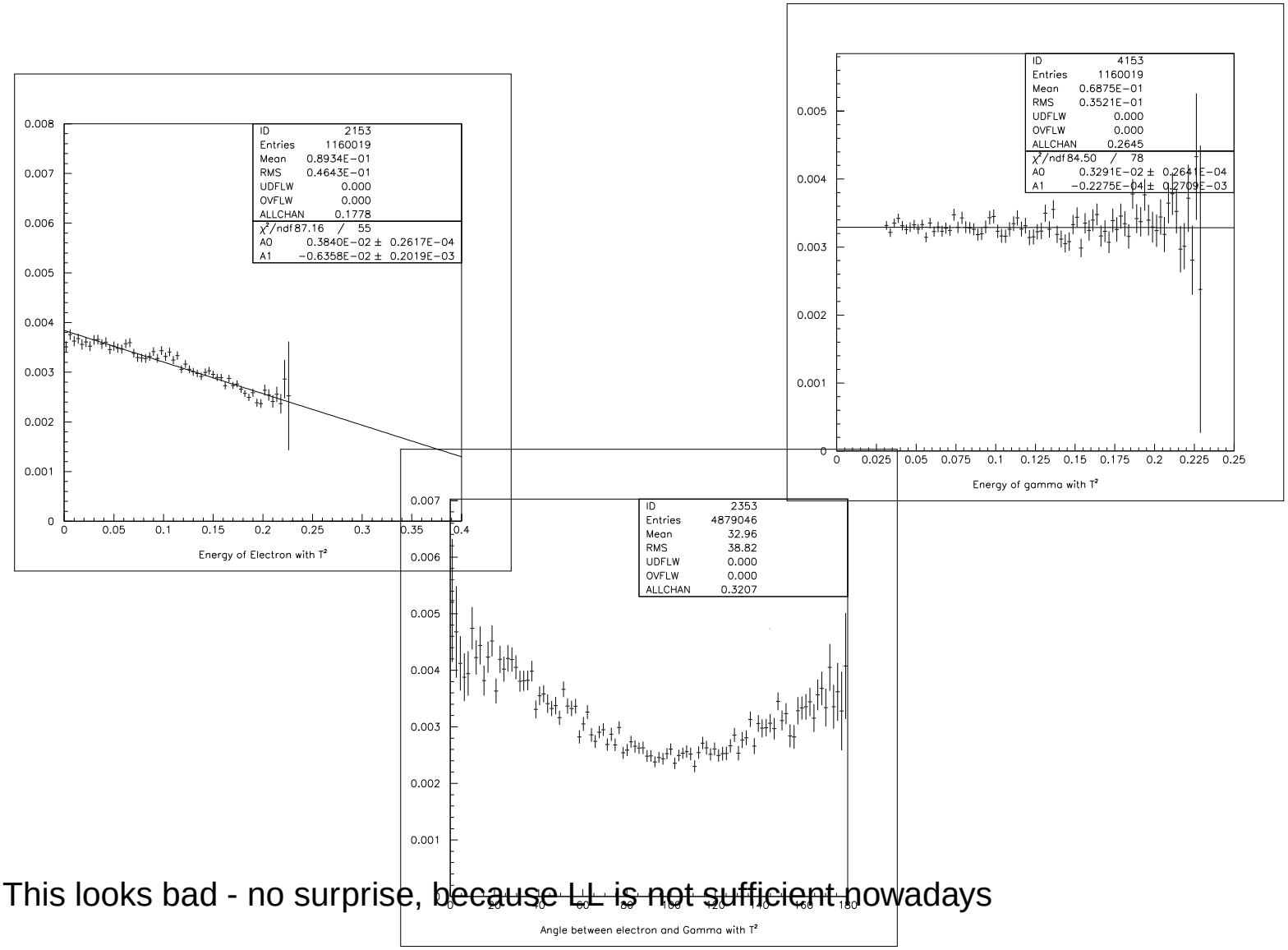
$K \to \pi e \nu$ + PHOTOS bremsstrahlung, interference on/off



Seems that the interference weight removed the difference to a large degree, but still some inconsistencies at $\cos\Theta \simeq -1$

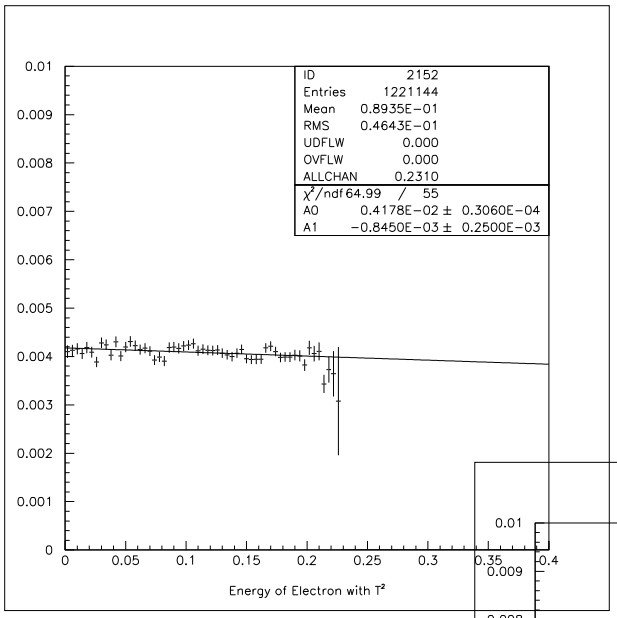
- We used published results which indicated improvements in PHOTOS were urgent.
- Fortunately thanks to work for W it was trivial to do.
- After initial success we need to worry about smaller, also possibly technical problems.
- Thanks to NA48 (L. Litov, et al) we proceed with further comparisons with Matrix-Element generators.
- channel $K \to \pi^{\pm} e^{\mp} \nu$
- channel $K \to \pi^{\pm} \mu^{\mp} \nu$

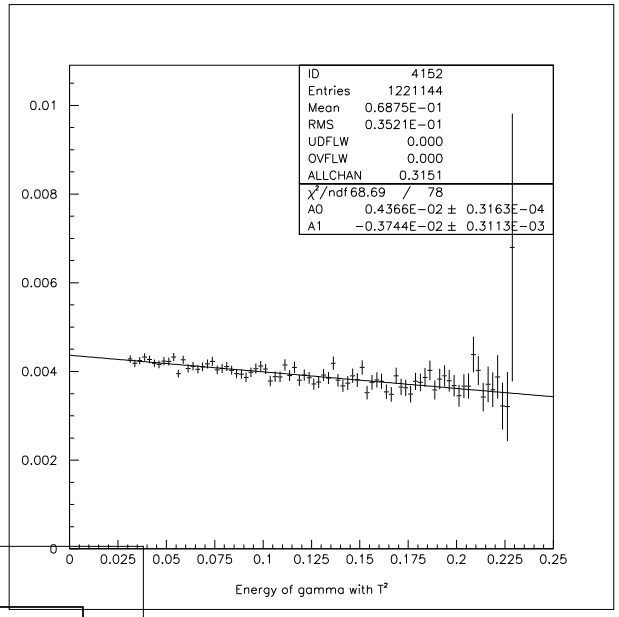
$K \to \pi e \nu(\gamma)$ PHOTOS (A.D. 2004) vs Gasser

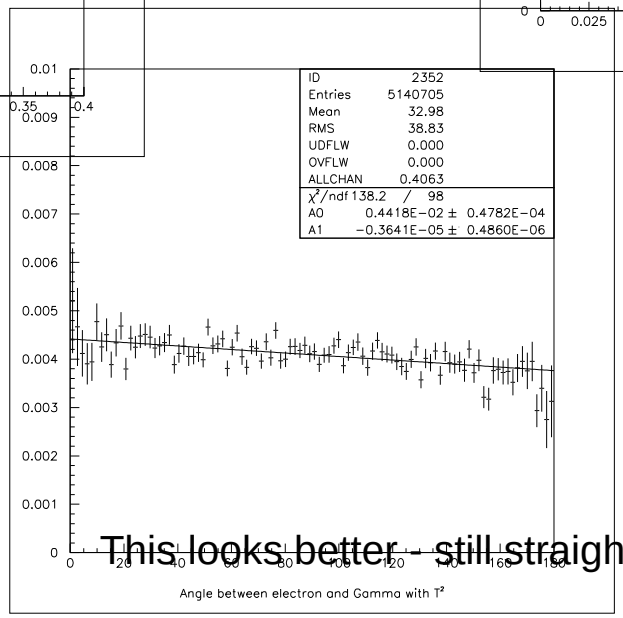


This looks bad - no surprise, because LL is not sufficient nowadays

$K \to \pi e \nu(\gamma)$ PHOTOS w/Interf vs Gasser







This looks better - still straightforward improvements possible

Events with and without photon:

$R = \frac{\Gamma_{K_{e3\gamma}}}{\Gamma_{K_{e3}}}$	PHOTOS interf	GASSER
$5 < E_\gamma < 15\,MeV$	2.38	2.42
$15 < E_\gamma < 45\,MeV$	2.03	2.07
$\Theta_{e,\gamma} > 20$	0.876	0.96

This table may indicate that residual discrepancy between new PHOTOS and KLOR for e-channel may be not real problem ...

New PHOTOS (beta version 2.13) is available (as a special patch) from http://cern.ch/wasm/goodies.html

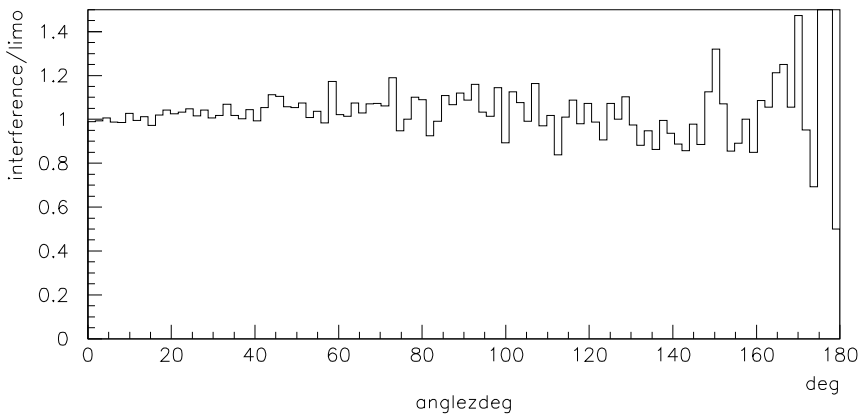
Goals:

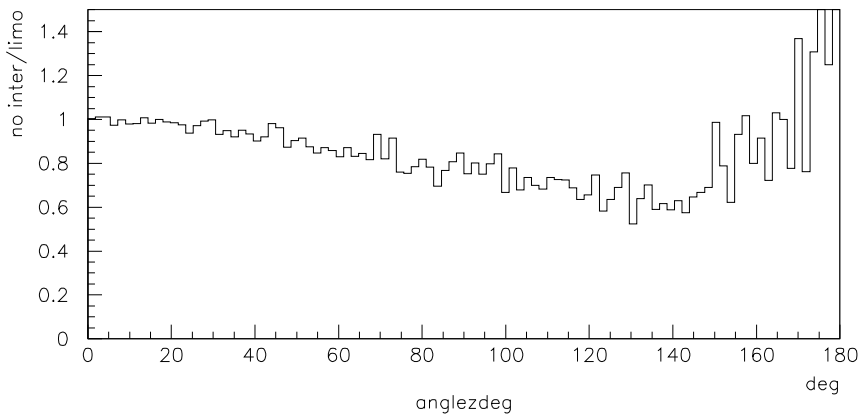
- There is an urgent need to clarify the status of radiative corrections for CKM matrix measurement at Belle
- Gradually superiority of Belle becomes evident
- That means that phenomenological solutions from Cleo and or even BaBar will become less and less adequate.
- PHOTOS is used for related simulation and discussion of its reliability has to be discussed channel by channel
- Good standard for discussion is fot the cases of Z, W and H decays.
- Some steps in direction of such work was done for NA48 needs, and reported by me 2 weeks ago, but is it enough for Belle?
- I guess YOU have to know. The famous question of Alex Bondarremains not answered.

Outcome of mine and Melbourne group activity:

- Does the work done last year for BaBar is enough?
- If not, do you have a strategy?
- Is PHOTOS part of the solution?
- We tried to convince ourselves that it is possibly part of the solution, with well defined methods how to proceed. Examples of W and Z.
- We remain convinced that such work was not completed for any channel of B decays.
- We tried in Melbourne to:
  - Prepare framework for tests: training and how to add new options.
  - execute some tests with ‘reasonable’ and ‘ad hoc’ corrections
  - Initialize internal Belle discussion on who will do the work and who will do preliminary research on: where and if it is really needed.

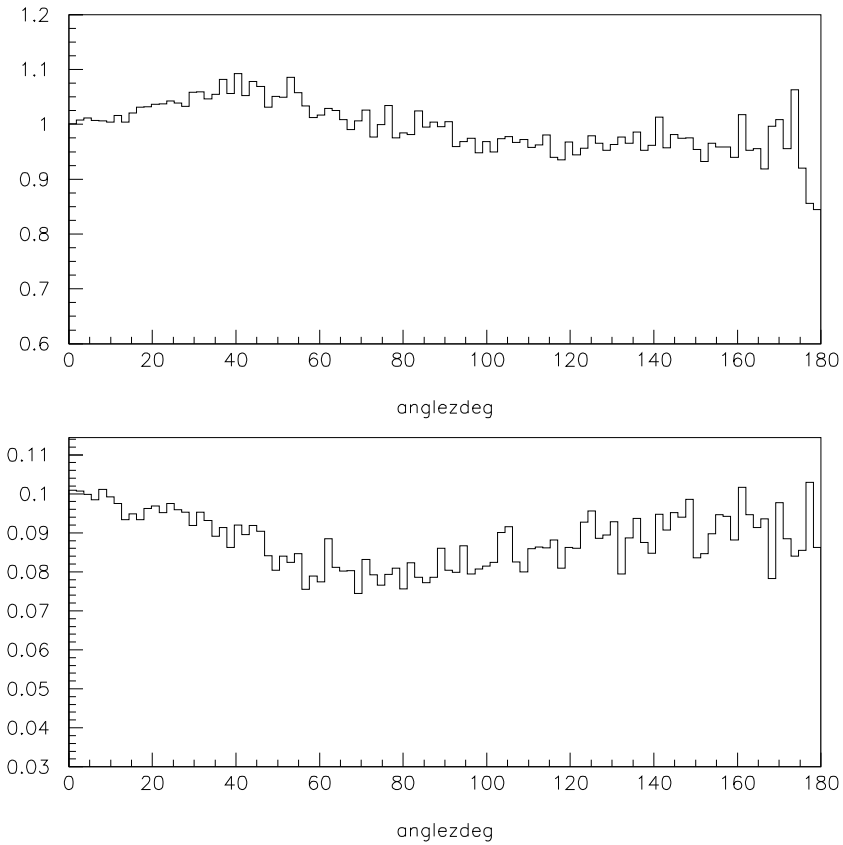
$K \to \pi e \nu(\gamma)$ PHOTOS w/Interf and no vs new interference





Similar tests but with different cuts with respect to test of Gasser, angle between photon and electron: upper plot is old interference over new interference, lower plot is no interference over new interference. May be residual effects is reduced?

$B \to \pi e \nu(\gamma)$ PHOTOS w/Interf and no vs new interference



Similar tests but with different cuts with respect to test of Gasser, angle between photon and electron: upper plot is old interference over new interference, lower plot is no interference over new interference. May be residual effects is reduced?

NO CONCLUSIONS:

- **Some ways to get preliminary numbers is in Belle hands now!**
- Still not bad having in mind that it is only 3 weeks long half time work.
- Activity started Jul 15 and ‘today’ is Aug 5.
- Note that the presented new effects are because of terms which can not be obtained from Low theorem.
- For today (Feb 7): infrastructure for non point-like sources for QED bremmstrahlung is prepared.