

PHOTOS Monte Carlo

as a high-precision tool for B-physics

"Radiative Corrections in B , D and K meson decays" workshop
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Motivation

- CKM matrix elements and new physics discovery potential are related to Branching Fractions and shapes of distributions in decay processes

- Processes of particular interest:

$$B^0 \rightarrow \pi^+ \pi^- , \quad B^0 \rightarrow K^+ \pi^-$$

$$B^0 \rightarrow \pi^+ l^- \nu , \quad B^0 \rightarrow K l^+ l^-$$

$$K \rightarrow \pi l \nu$$

- For example, the branching fraction for B decays are $BF = \frac{N}{\epsilon} \sim 10^{-5}$
- Impact of the radiative correction comes through efficiency (ϵ): it is around 5%
- If we want to measure with precision of 1% then shape corrections due to bremsstrahlung have to be known with precision (0.3%) for related systematics to be negligible.

Motivation

- PHOTOS (by E.Barberio, B. van Eijk, Z. Was, P.G.) is used to calculate the effect of radiative corrections
- but we need to discuss its systematic error
- PHOTOS has not been tested for B , K decays. No study of matrix elements.
- However a lot was done recently in context of Z and W decays, precision of 0.1% was established!
- Could the same be done for B decays ? How quickly? What is necessary to do?
- That is the purpose of my talk.

PHOTOS recent changes

E. Barberio, B. van Eijk, Z. Was, Comput. Phys. Commun.(1991) ibid. (1994)

See also: P. Golonka et al. hep-ph/0312240

- Until 2002 option for single- and double- photon emissions were available, no precision tests were performed, no work with W decays matrix elements, no related weights in PHOTOS!
- Year 2003: improvements in W decays, for 30 MeV-precision in Tevatron.
- Summer 2004: precision tests for W and Z decays, hundreds of histograms and benchmark numbers available at cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER
- Summer 2004: new options for triple, quatic and multiple-photon emission
- January 2005: thanks to input from NA48 improvements in meson decays. Precision improved from about factor of two to 20% for decays like $K \rightarrow l^\pm \nu \pi^\mp$. Middle of the work!
- I assume here that there is no need for presentation of PHOTOS. It is a Monte Carlo of “after-burner” type which reads in event record for decay chains without radiative corrections and, sometimes, adds bremsstrahlung photons. It is weight=1 algorithm, very convenient for use with full detector acceptance simulations.

PHOTOS may work in three regimes:

1. as a universal crude tool in decays of "any" particle
2. as a precision tool in dedicated channels: Z and W decays - precision better than per-mile level, **this was never assured for B , K , etc decays!**
3. with explicit process-dependent ME included (never needed so far)

In B meson decays PHOTOS was expected to be used at LL precision level, that is for the purpose acceptance-simulations only and **NOT** for shape corrections.

Main lines of development and underlying tests:

- **PART 1: W and Z decays: field theory input available in full**
 - correction weights for W decays
 - universal test
 - results of comparison with ME Monte Carlo and (indirectly) LEP data
- **PART 2: Semileptonic B decays**
 - some Monte Carlo (weighted events) and semi-analytical energy spectra available for tests
 - comparisons with data also useful and partly performed
- **PART 3: Non-leptonic B decays**
 - only comparisons with data are possible

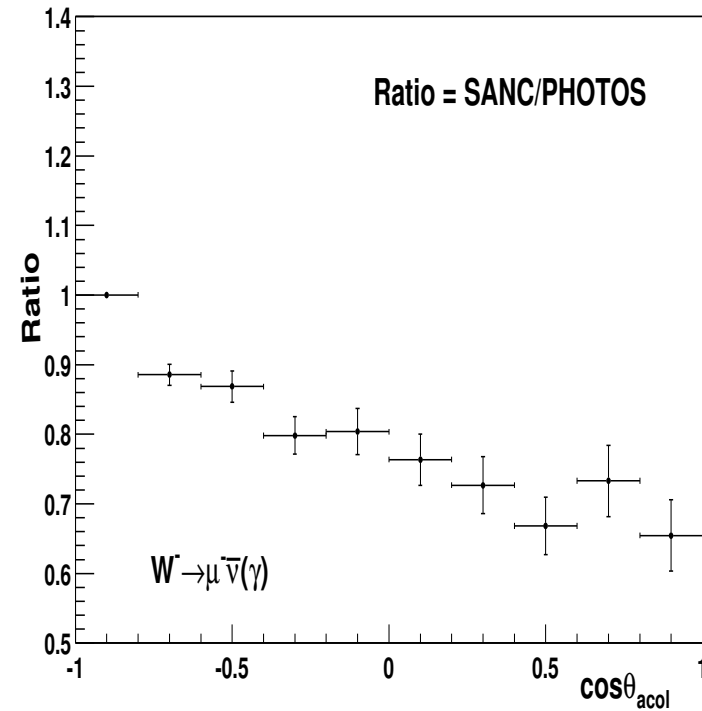
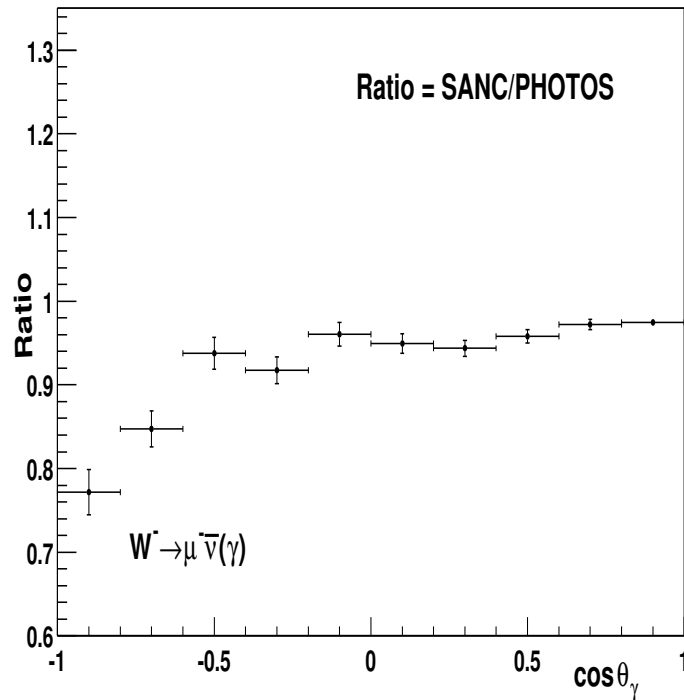
PART 1:

Completed scenario for improvements
in W and Z decays.

project performed for Tevatron and LHC applications
(measurement of the W mass)

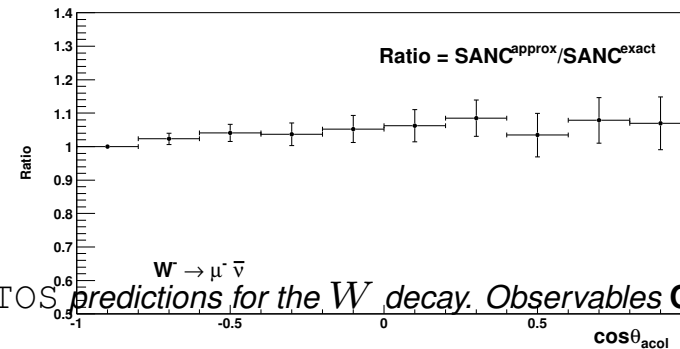
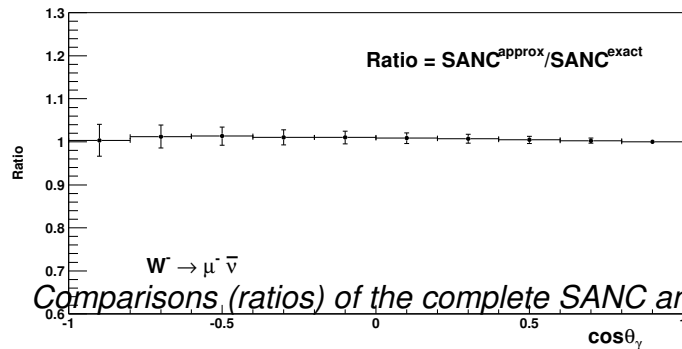
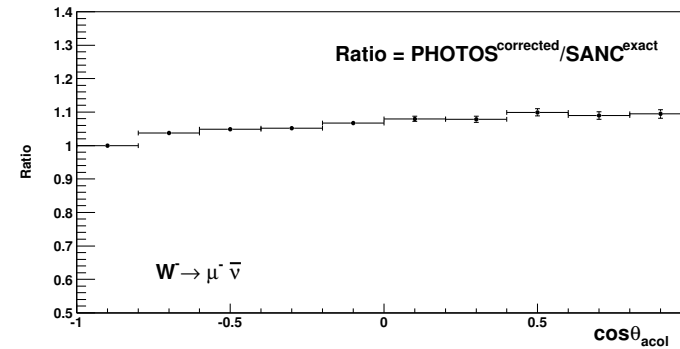
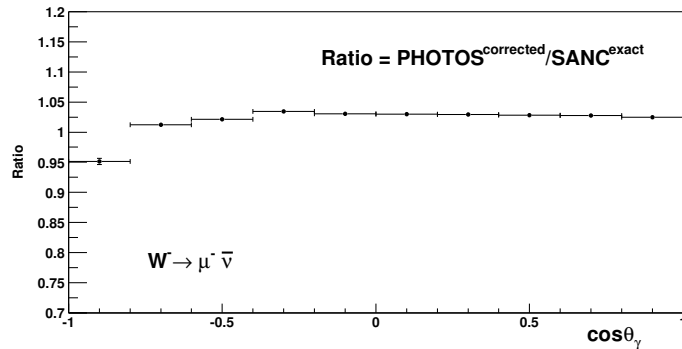
Will serve as example of the work which is done (nearly).

$W \rightarrow l\nu$ PHOTOS vs. ME, interference terms missing:



Status as of 2002/2003 (from paper by D. Bardin et al.), program works as expected but not good enough for Tevatron 2004.

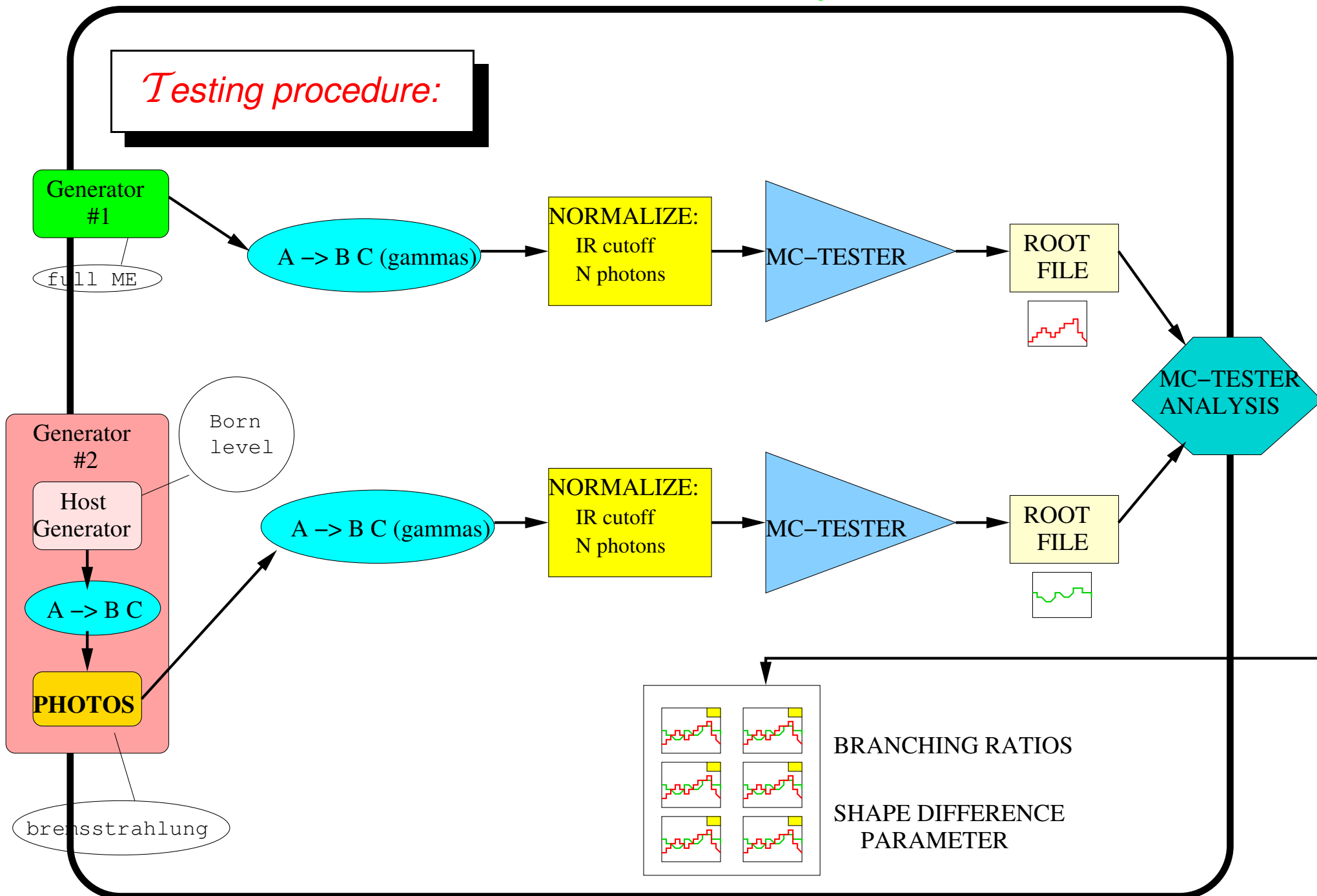
$W \rightarrow l\nu$ PHOTOS with correcting weight vs. ME, 2003



Comparisons (ratios) of the complete SANC and corrected PHOTOS predictions for the W decay. Observables **C** and **D**: ratios of the photon angle with respect to μ^- (left-hand side) and $\mu^- \bar{\nu}$ acollinearity (right-hand side) distributions from the two programs. The dominant contribution is of infrared non-leading-log nature for the left-hand side plot, and non-infrared non-leading-log nature for the right-hand side one. In the lower part of the plots similar comparisons for the complete and truncated-corrected with δ predictions are given. From paper by G. Nanawa and Z. Was.

Testing procedure: comparisons of predictions of two Monte Carlo runs

- Numerical comparison tests: we heavily rely on other generators (KKMC, KORALZ, MUSTRAAL, WINHAC, TAUOLA) and work of other people: E. Baberio, F. Berends, R. Decker, B. van Eijk, S. Jadach, M. Jezabek, J. Kuhn, R. Kleiss, W. Placzek, B. Ward and, indirectly, on LEP data. No miracles: precision requires work with matrix elements and/or data (on top of defining algorithm).
- Testing procedure need to be infrared-safe, see <http://cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER> for details.
- Test parameter: E_{test} threshold for soft photons
- Test parameter: maximum number of photons (1 or 2);
- The softer photons' momenta added to fermions momenta (number of photons reduced to 1 or 2)
- We use MC-TESTER to perform systematic study of large number of distributions of invariant masses of decay products



A lot of tests for W and Z decays with radiative corrections are available at:

<http://cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER>

Hard bremsstrahlung in KK and PHOTOS - results

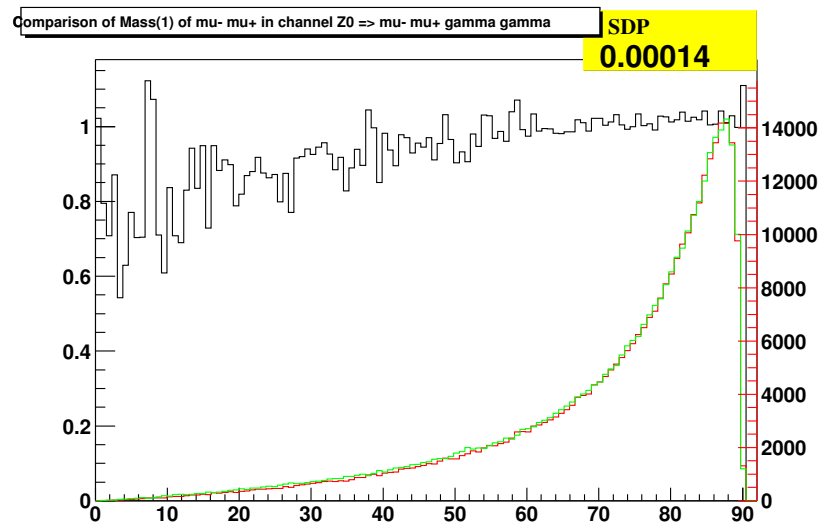
Comparison of KK and PHOTOS.
in $Z \rightarrow \mu\mu + \text{bremsstrahlung}$ process at Z mass

GENERATOR	Branching ratio					Maximum SDP					T1		T2		Booklet	
	test1		test2			test1		test2			test1	test2	test1	test2	test1	test2
(n photons) ->	0	1	0	1	2	0	1	0	1	2						
E_test=1.0																
KK	83.918	16.082	83.918	14.816	1.266											
KORAL-Z	83.984	16.016	83.984	14.771	1.244	0.00208	0.00123	0.00124	0.133	0.133	0.033	0.019				
KORAL-Z O(1)	82.514	17.486				0.0037			2.807		0.621					
PHOTOS O(1)	82.362	17.638				0.00314			3.111		0.528					
PHOTOS O(2)	83.925	16.075	83.925	14.630	1.445	0.0067	0.0035	0.0122	0.016	0.373	0.107	0.065				
PHOTOS O(3)	83.832	16.168	83.832	14.889	1.280	0.0038	0.0025	0.0080	0.172	0.172	0.061	0.046				
PHOTOS O(4)	83.836	16.164	83.836	14.871	1.293	0.0040	0.0027	0.0058	0.163	0.163	0.0635	0.045				
PHOTOS EXP	83.837	16.163	83.837	14.868	1.295	0.0041	0.0023	0.0092	0.161	0.161	0.066	0.044				
This is to be compared with WNHAC tests:																
KoralZ ME O(1)Exp			83.981	14.889	1.170	0.0009	0.0078		0.191		0.086					

A summary table points to booklets with thousands of detailed plots.

This one presents the invariant of **largest** (SDP < 0.1% !) discrepancy between PHOTOS EXP and KKMC in Z decays.

Events are referred to as 0, 1 or 2 photon configurations, when 0 1 or at least 2 photons with energy above E_{test} are present.



Further tests

Numerical comparison tests of the single photon emission kernel have been performed for:

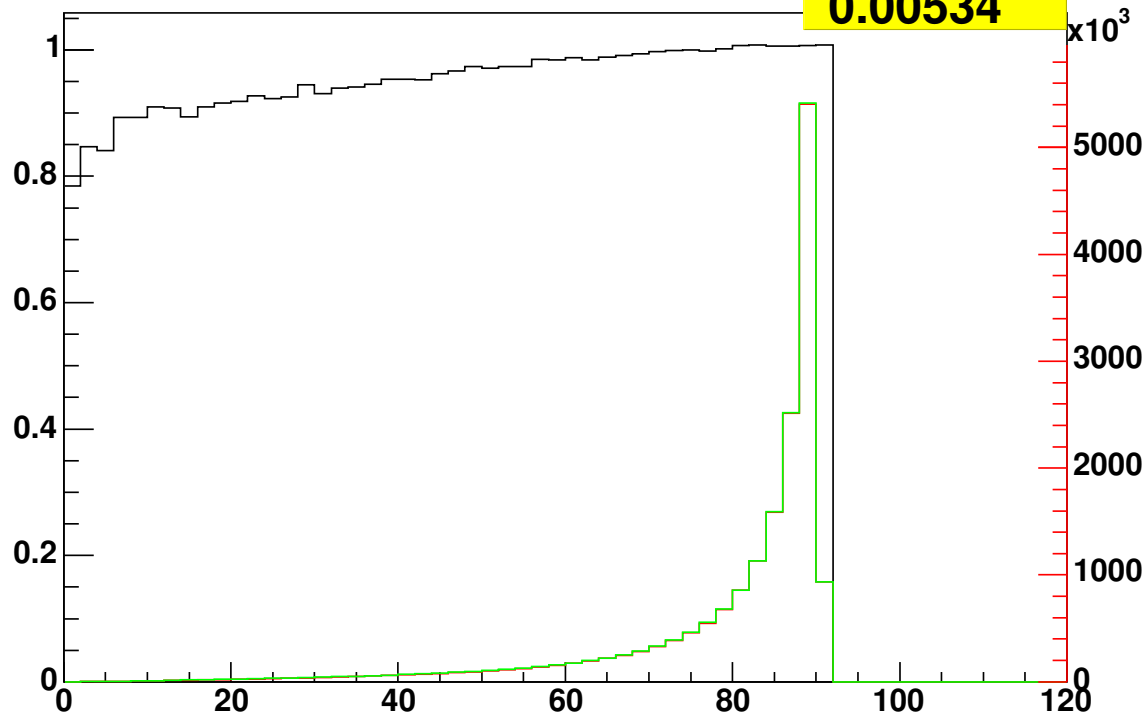
- Z^0 leptonic decays (comparisons with KORALZ and KKMC) good agreement, options for PHOTOS: single-, double-, triple-, quatic- and multiple-photon emission
options for KKMC: $O(\alpha^2)$ exponentiated, $O(\alpha)$ exponentiated
options for KoralZ $O(\alpha^2)$ exponentiated, $O(\alpha)$ exponentiated and fixed first-order (no exp).
- W leptonic decays:
WINHAC: first-order, SANC first-order and WINHAC exponentiated,
PHOTOS: first order and exponentiated

$Z \rightarrow \mu^+ \mu^-$ PHOTOS vs KORALZ, fixed first-order

Plot of largest difference (quantifies approx. in PHOTOS necessary to iterate)

Comparison of Mass(1) of mu- mu+ in channel Z0 => mu- mu+ gamma

SDP
0.00534



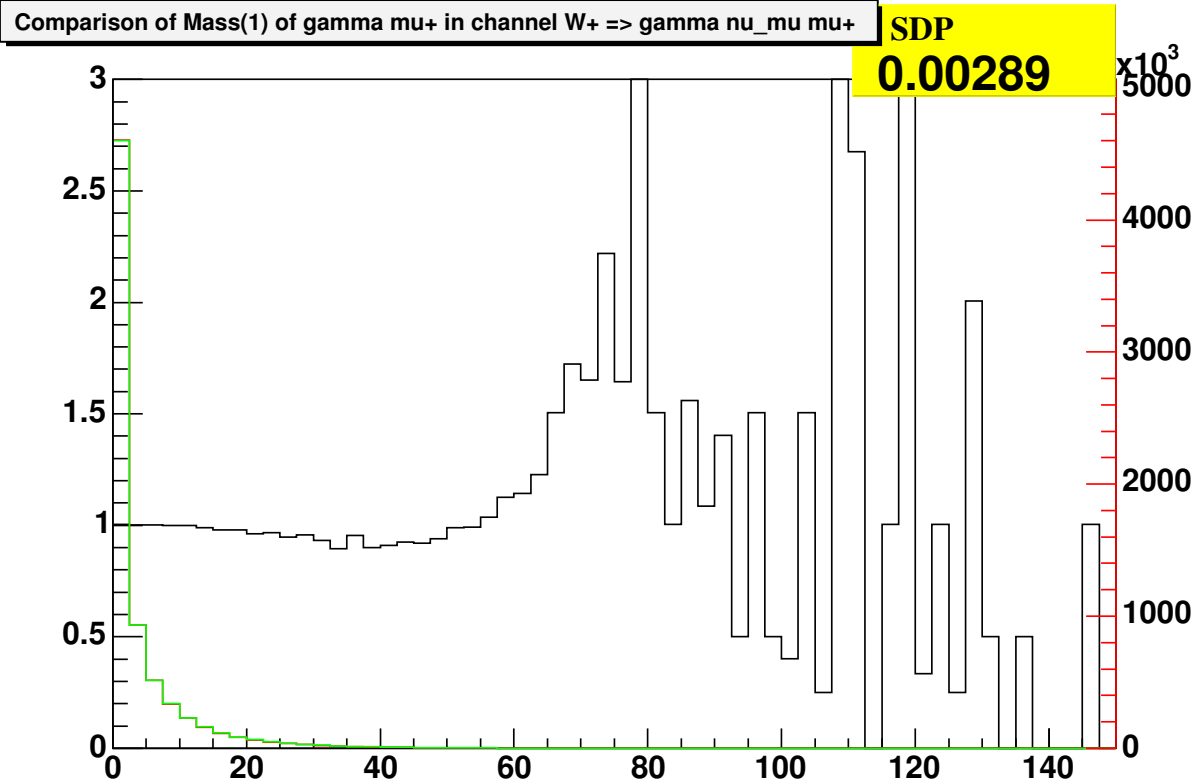
The difference in branching ratios are at fraction of permille level; $BR * SDP < 0.1\%$.

The differences due to approximations in PHOTOS kernel

(restorable with process-dependent weight if needed).

$W \rightarrow l\nu$ PHOTOS vs. WINHAC, fixed first order

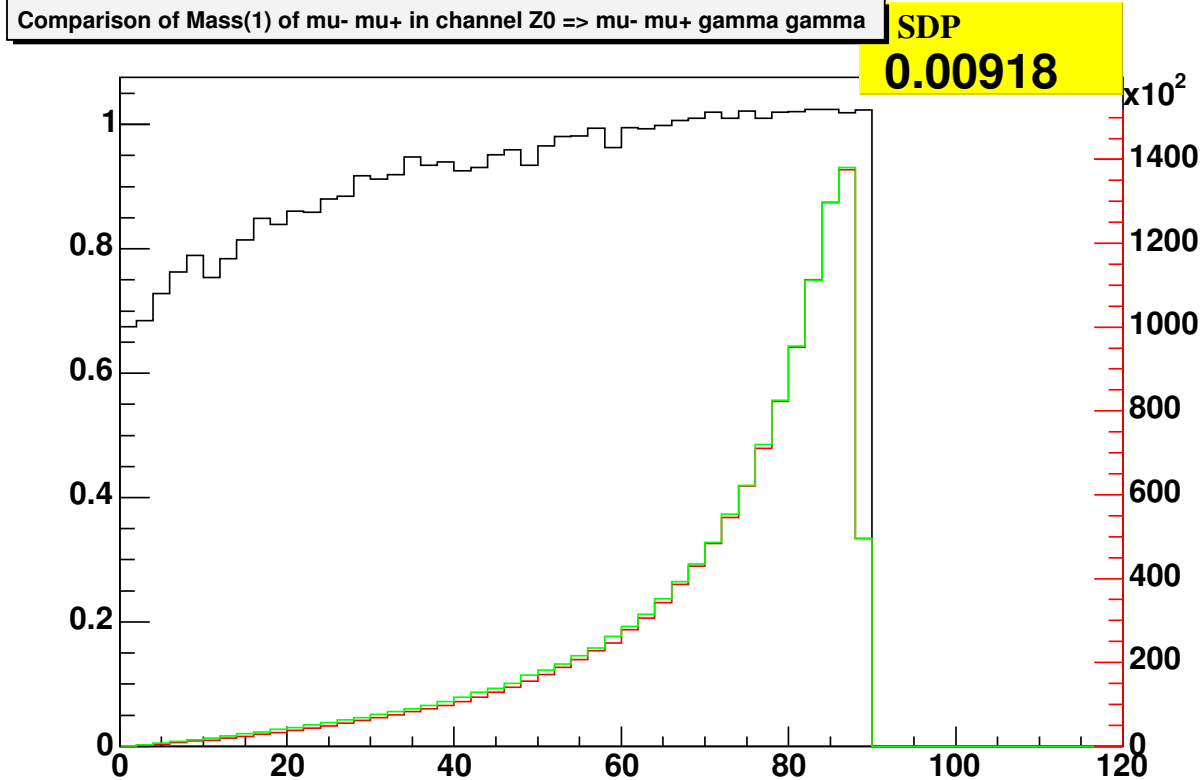
Plot of largest difference:



The difference in branching ratios are at fraction of permille level,
also $BR * SDP < 0.1\%$.

$Z \rightarrow \mu^+ \mu^-$ PHOTOS (EXP) vs. KKMC $O(\alpha^2)$

Plot of largest difference:

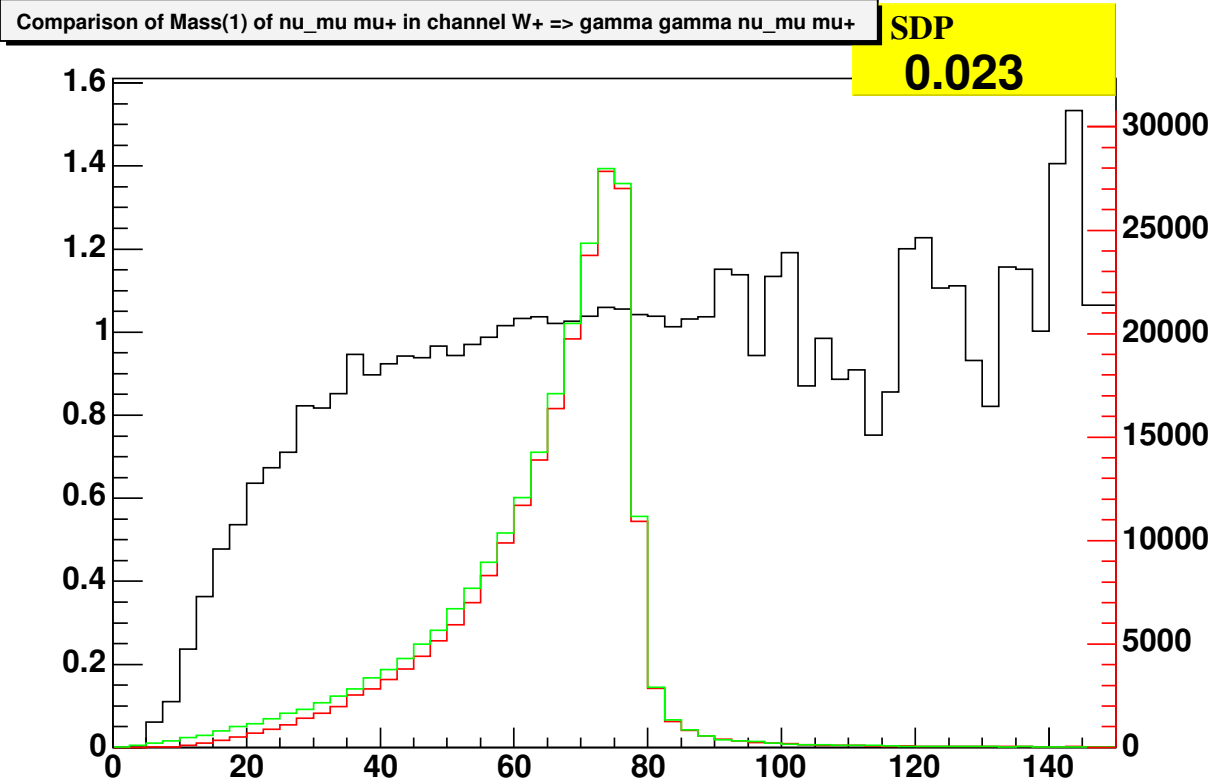


The difference in branching ratios are at permille level and $BR * SDP < 0.1\%$.

The agreement was good only if complete $O(\alpha^2)$ ME used in KKMC!

$W \rightarrow l\nu$ PHOTOS (EXP) vs. WINHAC $O(\alpha)$ exp

Plot of largest difference:



The difference in branching ratios are at permille level and $BR * SDP < 0.1\%$.

The source of residual difference not investigated; too small to bother.

WINHAC is full $O(\alpha)$ ME only; PHOTOS single-emission kernel not perfect as well

PART 2:
Semileptonic and leptonic decays

some theoretical predictions available:

Ginsberg, Marciano, Richter-Was, Andre, FFS (NA48)

We need to test single-emission kernel.

General properties of algorithm for higher-orders have been checked before.

We will profit from Z , W tests in B -decays as well.

Work in progress

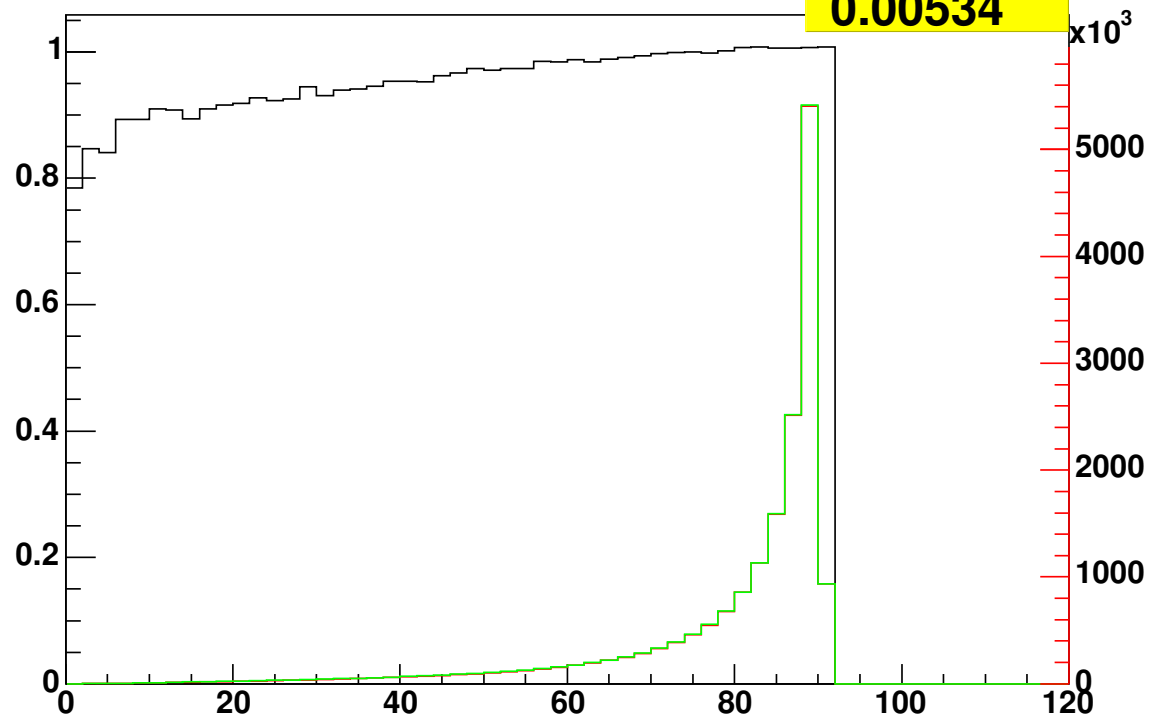
$Z \rightarrow \mu^+ \mu^-$ PHOTOS vs KORALZ, fixed first-order

Plot of largest difference (quantifies approx. in PHOTOS necessary to iterate)

Comparison of Mass(1) of $\mu^- \mu^+$ in channel $Z0 \Rightarrow \mu^- \mu^+ \gamma$

SDP

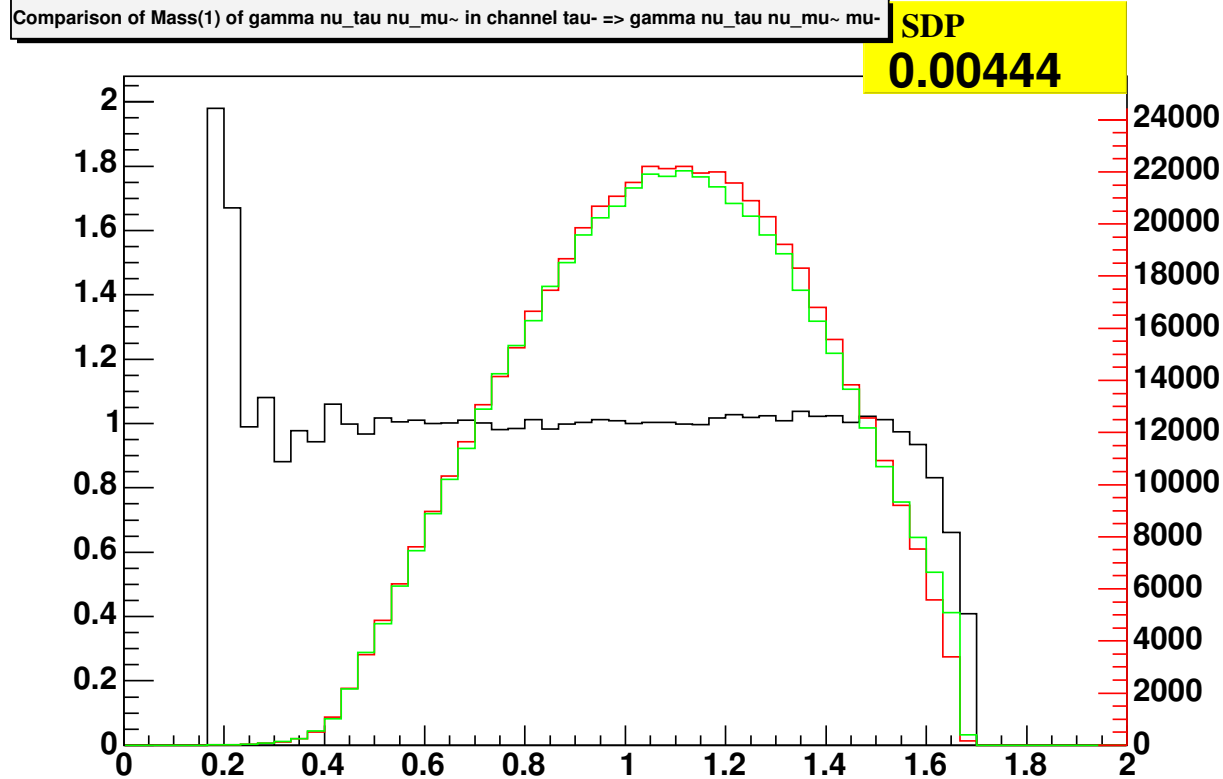
0.00534



We need to find a counterpart for this result, but in case of B , K decays.

$\tau \rightarrow l\nu\bar{\nu}$ PHOTOS vs TAUOLA

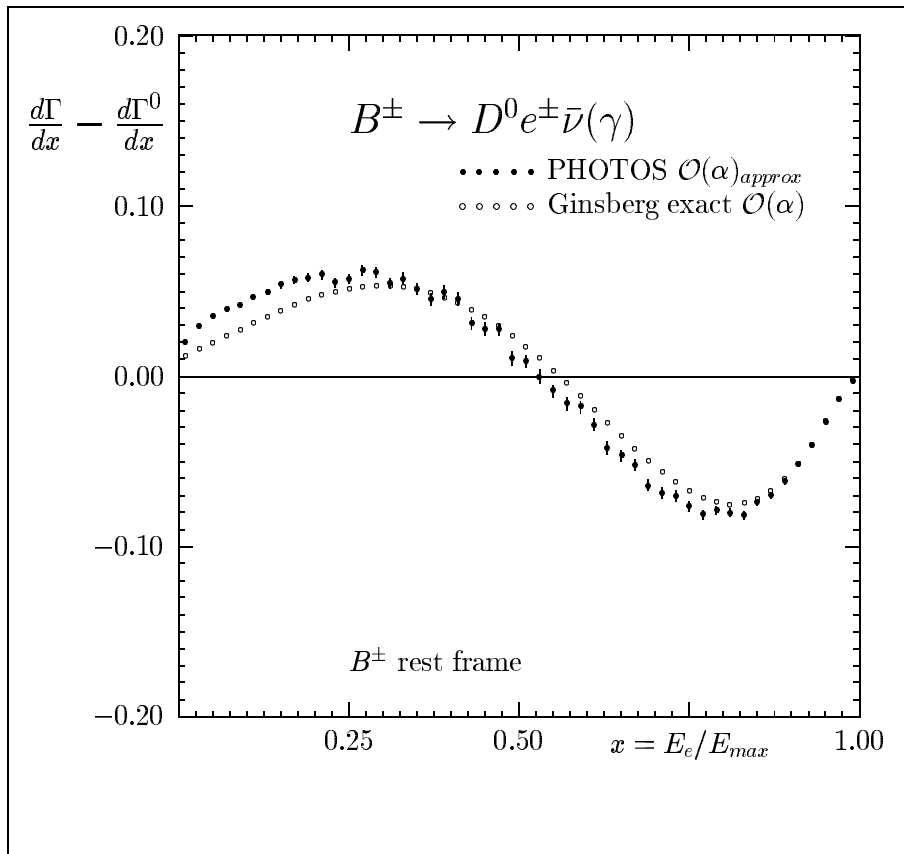
Plot of largest difference:



The difference in branching ratios are at fraction of permille level.

These are still leptonic decays, field-theory prediction available, PHOTOS works excellently.

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

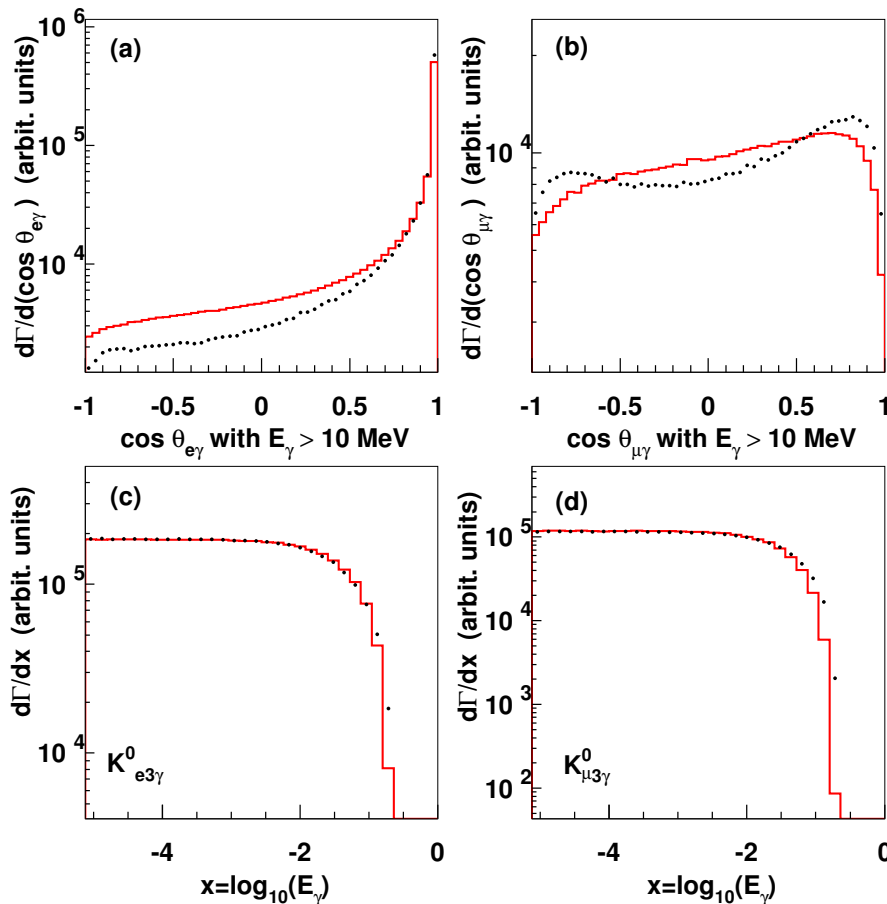


Radiative correction to the decay rate ($d\Gamma/dx - d\Gamma^0/dx$) for $B^\pm \rightarrow D^0 e^\pm \bar{\nu}(\gamma)$ in the B^\pm rest frame. Open circles are from the exact analytical formula [2], points with the marked statistical errors from PHOTOS applied to JETSET 7.3. A total of 10^7 events 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

$K \rightarrow \pi l \nu$ 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) $\cos(\Theta_{\gamma,l}) K_{e 3}$

(c) $\log_{10}(E_\gamma) K_{\mu 3}$

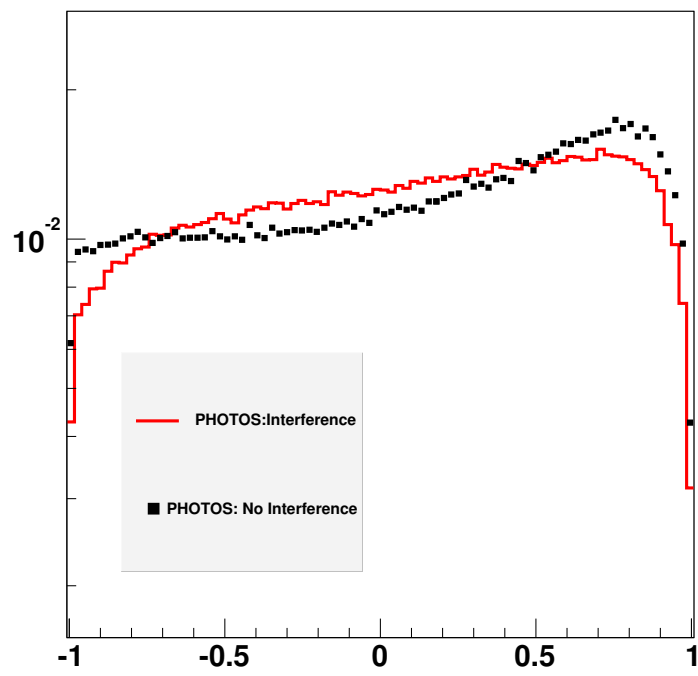
(d) $\log_{10}(E_\gamma) K_{e 3}$

in **KLOR**

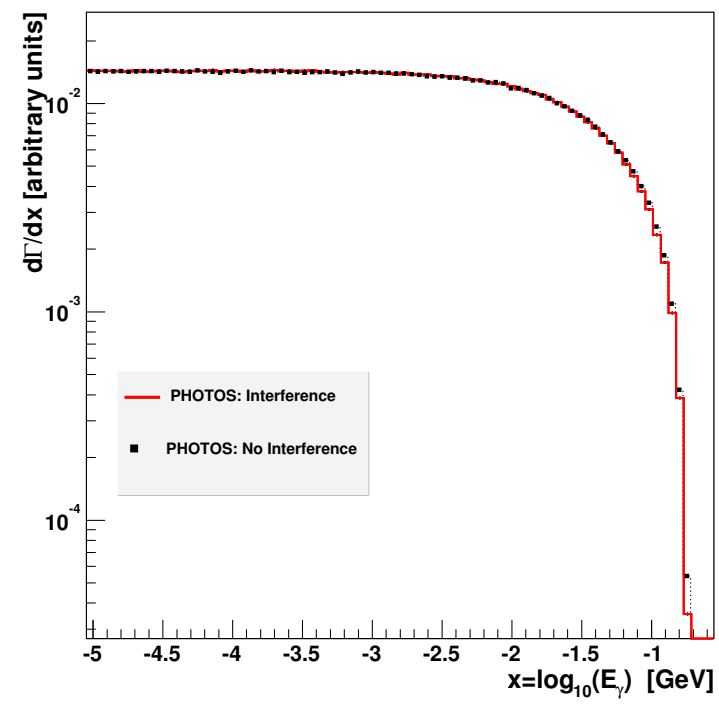
and PHOTOS

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

$\cos(\Theta_{\mu\gamma})$ in $K_L^0 \rightarrow \mu \pi \nu$, $E_\gamma > 10$ MeV

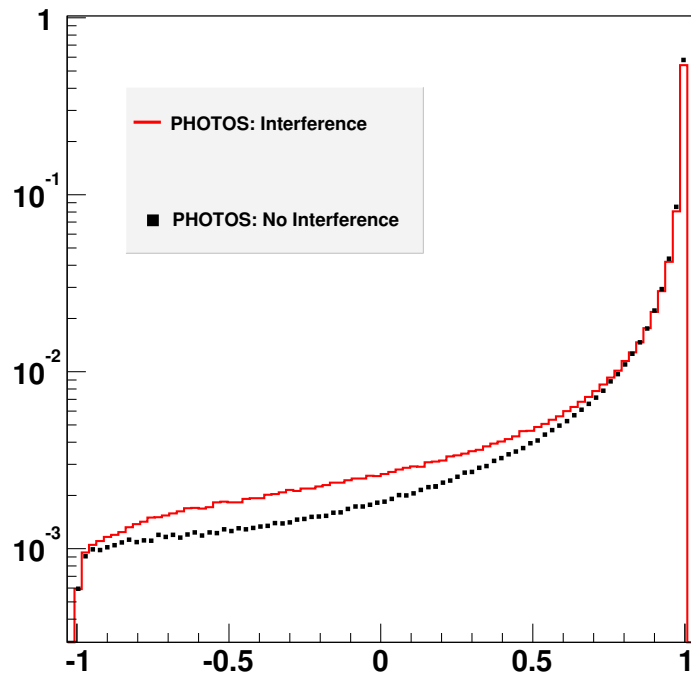


$K_L^0 \rightarrow \pi \mu \nu$

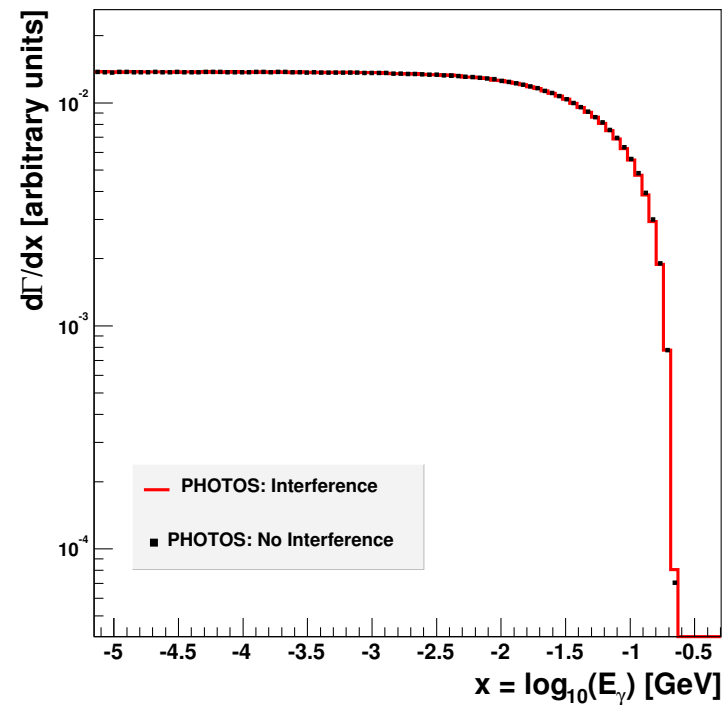


$K \rightarrow \pi e \nu$ + PHOTOS bremsstrahlung, interference on/off

$\cos(\Theta_{\gamma,e})$ in $K_L^0 \rightarrow e \pi \nu, E_\gamma > 10 \text{ MeV}$



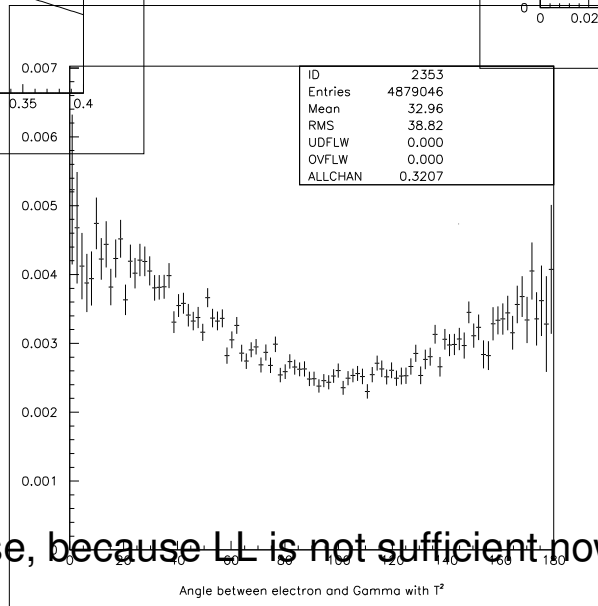
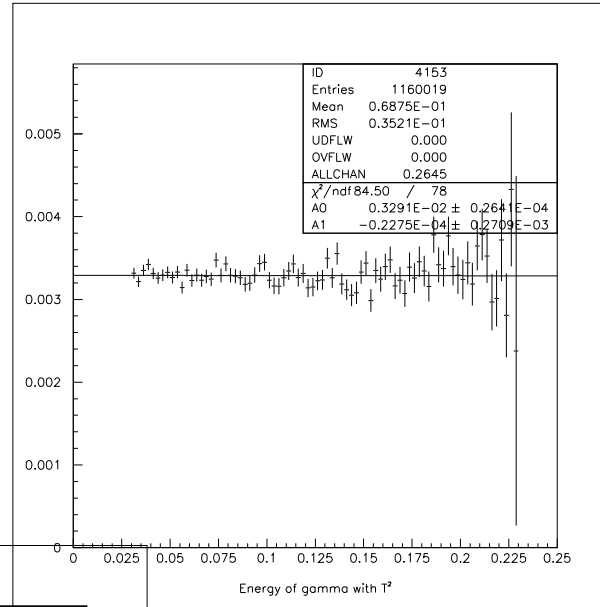
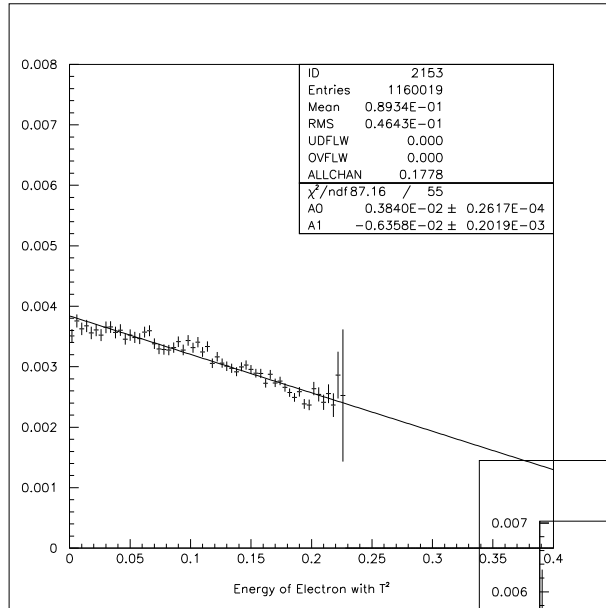
$K_L^0 \rightarrow e \pi \nu$



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

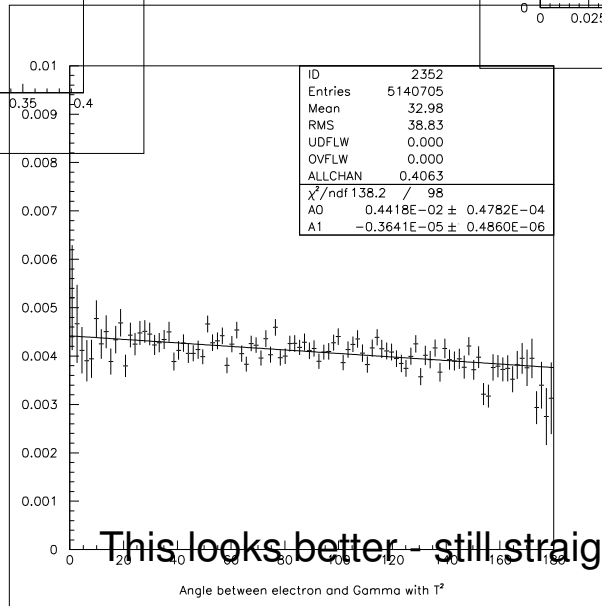
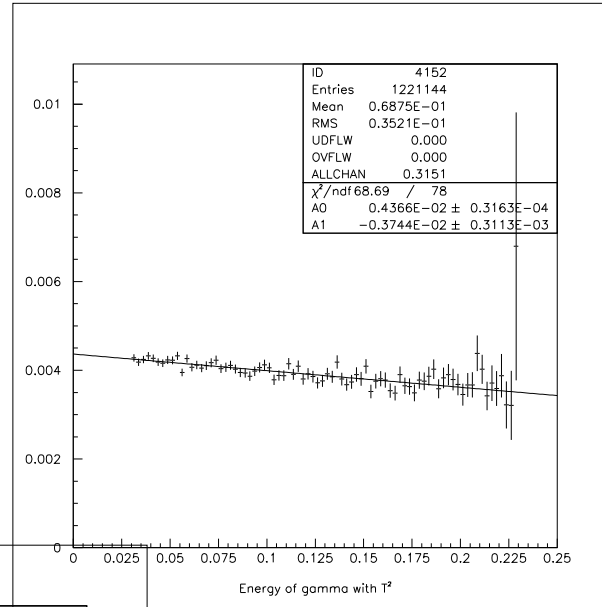
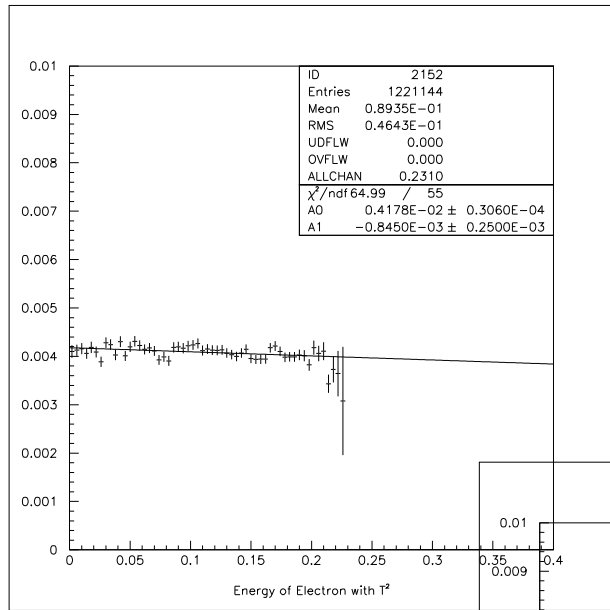
- Published results indicated improvements in PHOTOS were urgent.
- Fortunately thanks to work for W it was trivial to do.
- After initial success we need to worry about smaller, also possibly technical problems.
- Thanks to NA48 (L. Litov, et al) we proceed with further comparisons with Matrix-Element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

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



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

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



This looks better - still straightforward improvements possible

Events with and without photon:

$R = \frac{\Gamma_{Ke3\gamma}}{\Gamma_{Ke3}}$	PHOTOS interf	GASSER
$5 < E_\gamma < 15 \text{ MeV}$	2.38	2.42
$15 < E_\gamma < 45 \text{ MeV}$	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>

PART 3:
Non-leptonic decays

Testbed

- neither good field-theory predictions as in Z and W decays,
- nor semianalytical formulas, no Monte Carlo (neither weighted nor unweighted events) ...
- fortunately there is a possibility to compare with data
- collaboration effort is critically needed

Summary:

- B-physics requirements were not satisfied with PHOTOS version available in 2004.
- we improved significantly, but probably we are still half-way through only...
- for improvements to be completed, important contribution from collaborations is vital
- we have already profitted a lot from input provided by NA48 experts, for Kaon decays. Improvements work elsewhere to some degree, but no straightforward answers on precision.
- Serious man-power issues.