PHOTOS

as pocket parton shower – recent developments.

”HERA-LHC” workshop DESY, 22 March 2005

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Web pages for transparencies and progam(s):

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

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

Motivation (2004/2005)

- CKM matrix elements and new physics discovery potential of B-factories are related to Branching Fractions and shapes of distributions in decay processes
- Processes of particular interest:
  $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$
  $B^0 \to \pi^+ l^-\nu$, $B^0 \to K l^+ l^-$, $K \to \pi l\nu$
- 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.
- Physics of these resonances, will be of some interest at LHC as well.

Motivation 2003/2004

- For similar purposes radiative corrections need to be included in case of simulations for measurements of W mass and couplings in TEVATRON/LHC experiments;
- Main interest: decays of W's and Z's, but also t, H

Algorithmic side

- Iterative solution like in parton shower
- Relation to Matrix elements (virtual+real) and exact phase space
- Organization of solution from 1-dim to full phase space
- Organization from sophisticated multi dim. kernels to simple (integrable) ones.

Motivation

- PHOTOS (by E.Barberio, B. van Eijk, Z. W., P.Golonka) is used to calculate the effect of radiatiative corrections
- but we need to discuss its systematic error
- PHOTOS has not been tested for B, K decays. No works on matrix elements.
- See our transparencies for CKM workshop last week in La Jolla CA,
- However a lot was done recently in context of Z and W decays, precision of 0.1% was established!
- Technical and algorithmic developments as well: multiple photon mode, plays at different level of crude distr ..
- The purpose of my talk is nonetheless mainly presentation of 'numerical proofs'.

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, quatric 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 $K \to l^{\pm}\nu\pi^{\mp}$. 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 (like always) PHOTOS was expected to be used at LL precision level, that is for the purpose acceptance-simulations only and NOT for shape corrections. Precision was supposed to come from other programs.
PHOTOS was for easy use. Just add photons here and there in HEPEVT – favorite event record of 90’s.

Technical developments:

- **PART 1: Rounding error traps**
  - classified and those found removed
  - HEPEVT living object. Action of PHOTOS depends on its content
  - Increased physics sophistication brought additional numerical pressure
- **PART 2: Single photon emission**
  - Plays with intereference and underlying crude for angular singularities around each charge !!!
  - From 4-vectors to angular parametrization of phase space and back! Shwinger-Dyson type relations
- **PART 3: Iteration**
  - double, triple, quatric, multiple-photon emission. Reshuffling
- **I am just listing elements in game, they may give hints for QCD.**

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
- **Motto: Guilty until proven otherwise.**

PART 1:

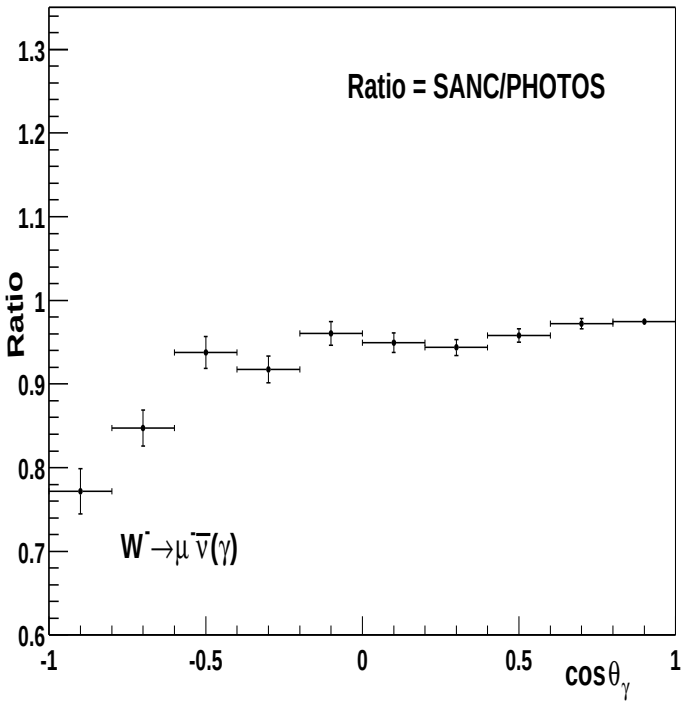
Completed scenario for improvements in W and Z decays.

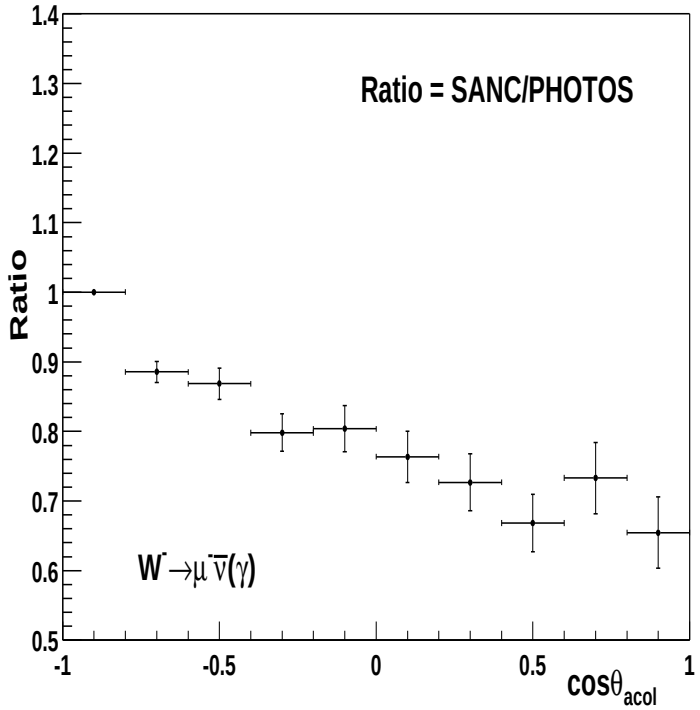
project performed for Tevatron and LHC applications

(measurement of the W mass)

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

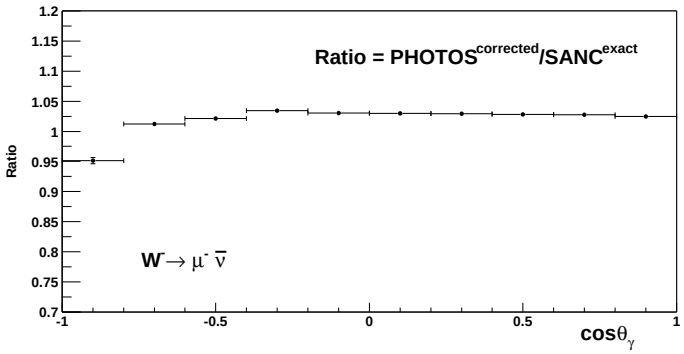
$W \to l\nu$ PHOTOS vs. ME, interference terms missing:

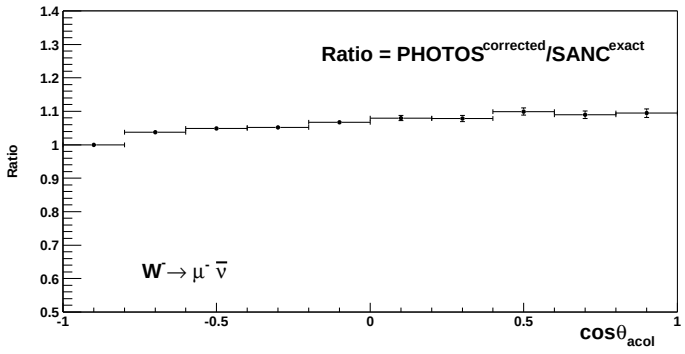


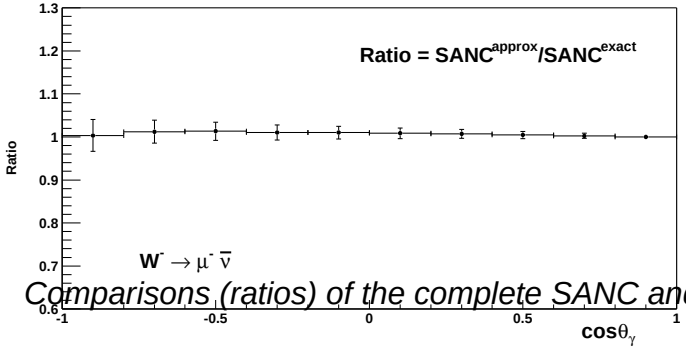


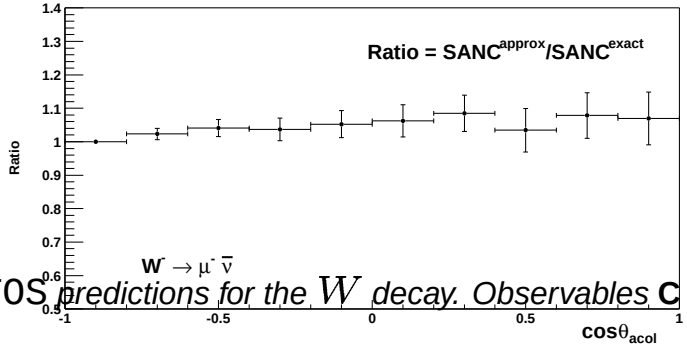
Status as of 2002/2003 (from paper by D. Bardin at al.), program works as expected but not good enough for Tevatron 2004.

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









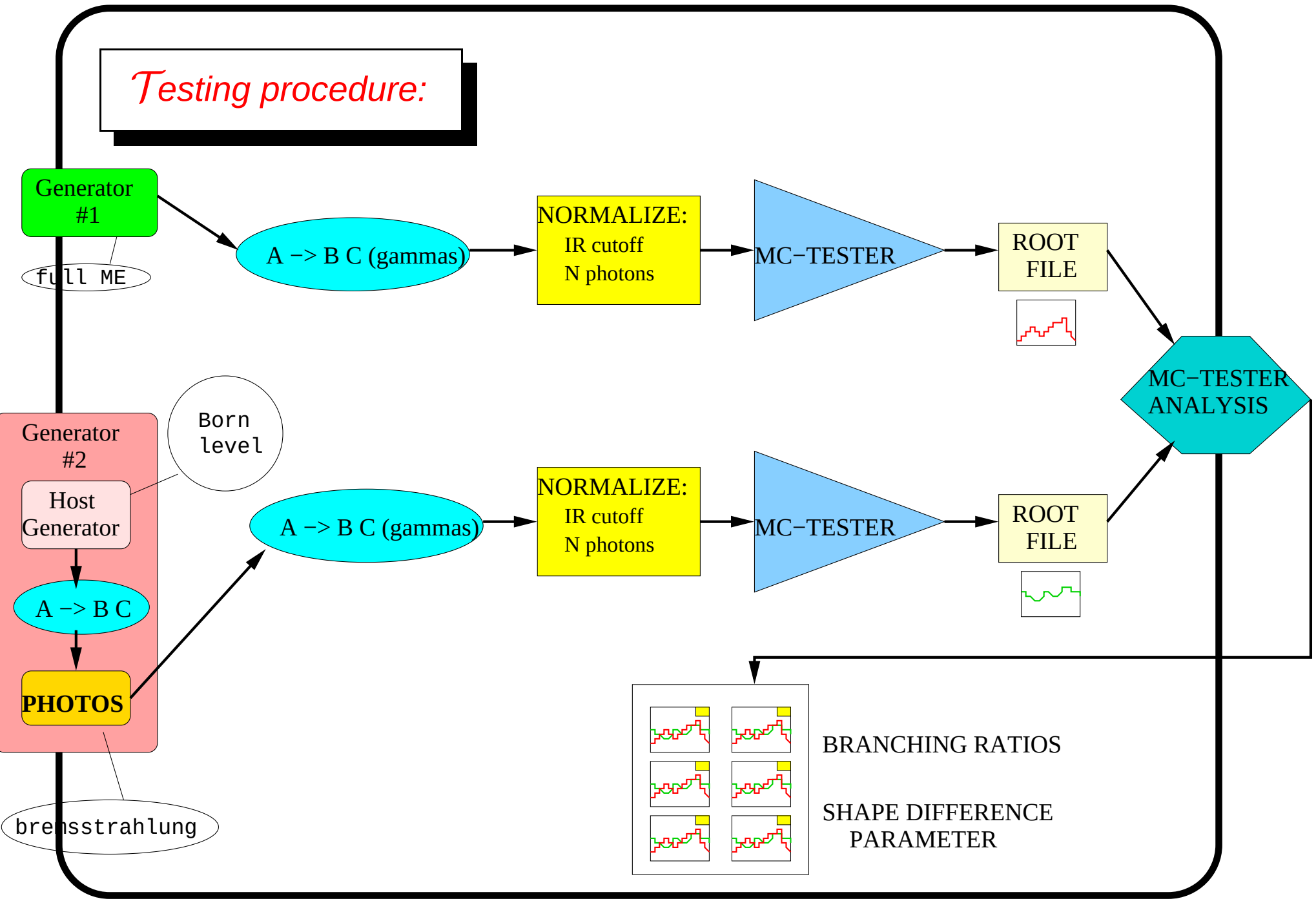
Comparisons (ratios) of the complete SANC and corrected PHOTOS *predictions for the W decay. Observables* **C** *and* **D***: ratios of the photon angle with respect to μ^- (left-hand side) and $\mu^- \bar{\nu}$ acollinearity (right-hand side) distributions from the two programs. The dominant contribution 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: comparsions 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 need 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


Testing procedure:
Generator #1
full ME
A −> B C (gammas)
NORMALIZE:
IR cutoff
N photons
MC−TESTER
ROOT FILE
MC−TESTER ANALYSIS
Generator #2
Born level
Host Generator
A −> B C
PHOTOS
bremsstrahlung
A −> B C (gammas)
NORMALIZE:
IR cutoff
N photons
MC−TESTER
ROOT FILE
BRANCHING RATIOS
SHAPE DIFFERENCE PARAMETER

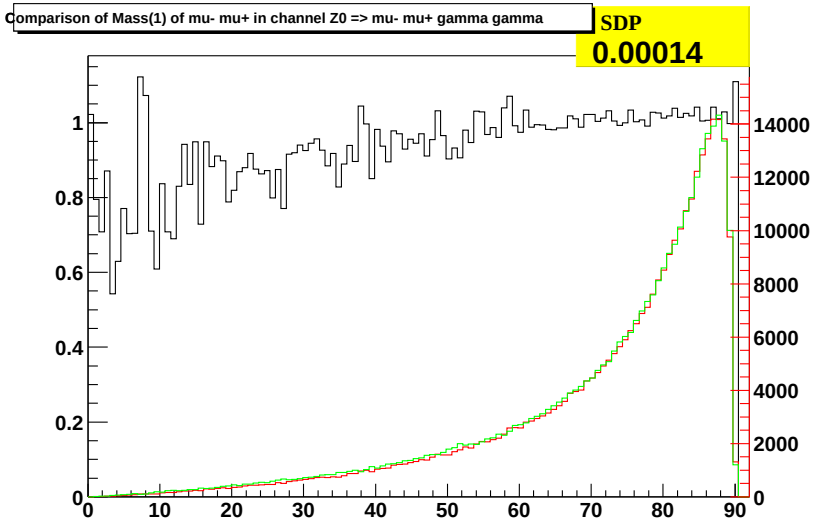
A lot of tests for W and Z decays with radiative corrrections are available at:

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

Hard bremsstrahlung in KK and PHOTOS - results

Comparison of KK and PHOTOS.
in Z->mu mu + 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	0.00208	0	0.00123	0.00124	0.133	0.133	0.033	0.019		
KORAL-Z O(1)	82.514	17.486				0	0.037				2.807		0.621			
PHOTOS O(1)	82.362	17.638				0	0.0314				3.111		0.528			
PHOTOS O(2)	83.925	16.075	83.925	14.630	1.445	0	0.0067	0	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	0.0038	0	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	0.0040	0	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	0.0041	0	0.0023	0.0092	0.161	0.161	0.066	0.044		
This is to be compared with WINHAC tests:																
KoralZ ME O(1) Exp			83.931	14.899	1.170			0	0.0009	0.0678		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.

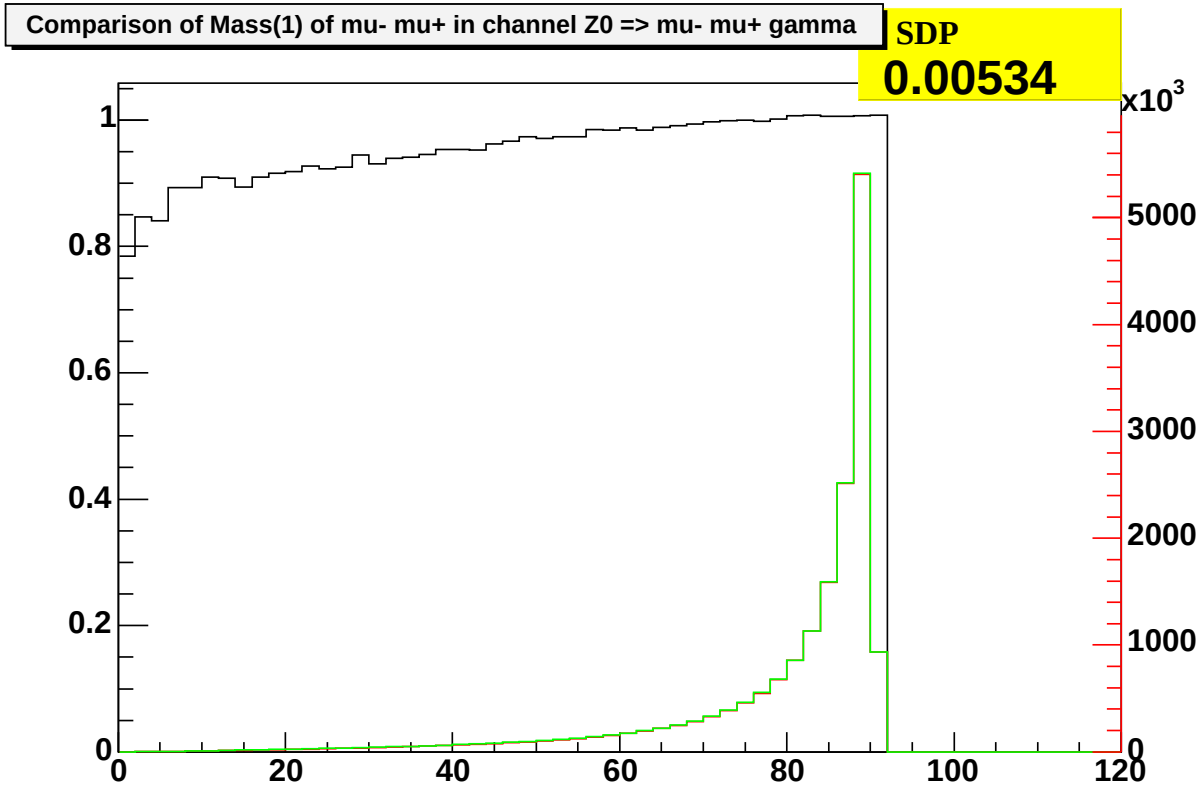
Further tests

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

- Z^0 leptonic decays (comparisons with KORALZ and KKMC) good agreement, options for PHOTOS: single-, double-, triple-, quatric- 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

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

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

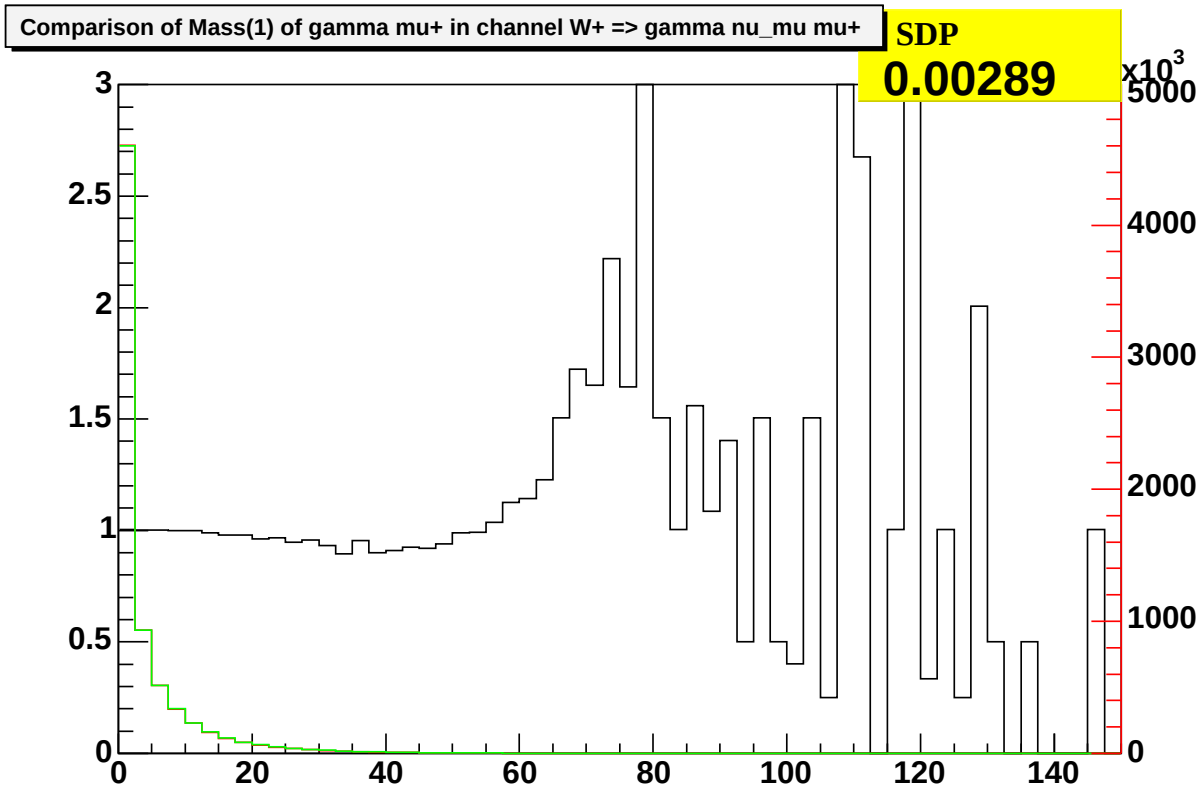


The difference in branching ratios are at fraction of permile level; BR * SDP$<$0.1%.

The differences due to approximations in PHOTOS kernel (restorable with process dep. wt. if needed).

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

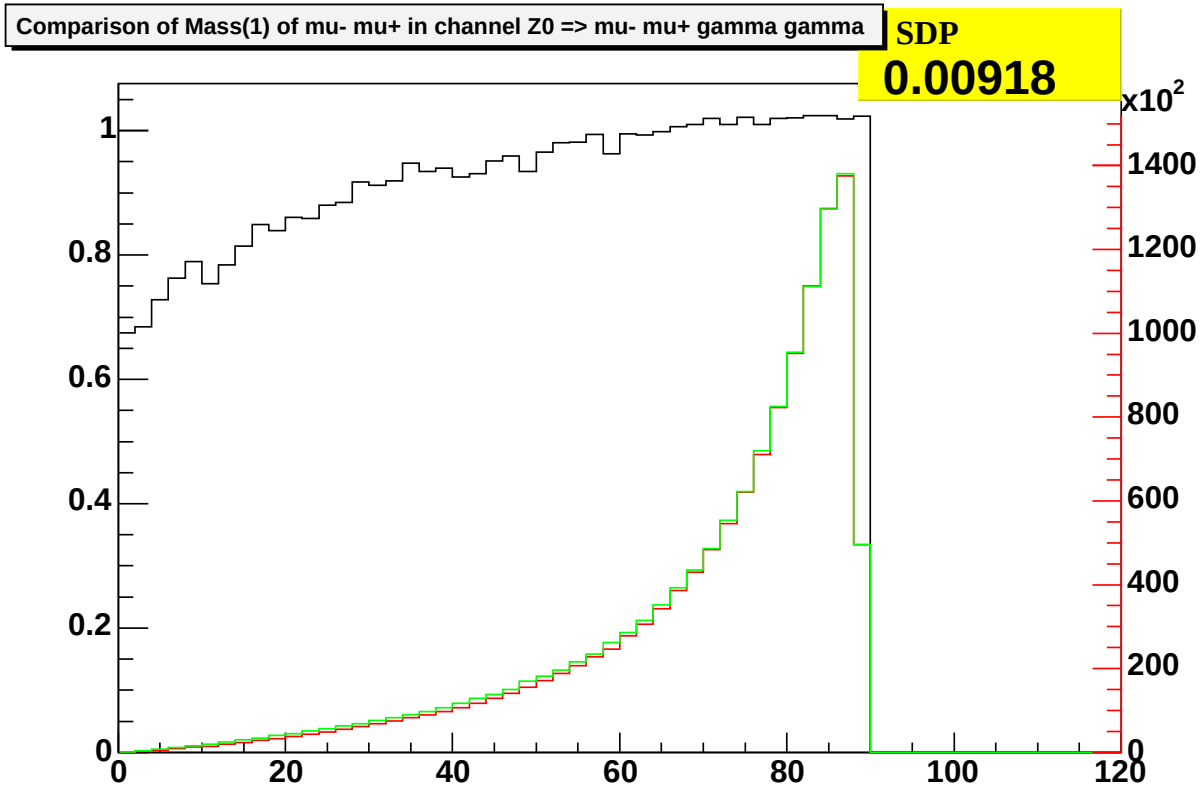
Plot of largest difference:



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

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

Plot of largest difference:

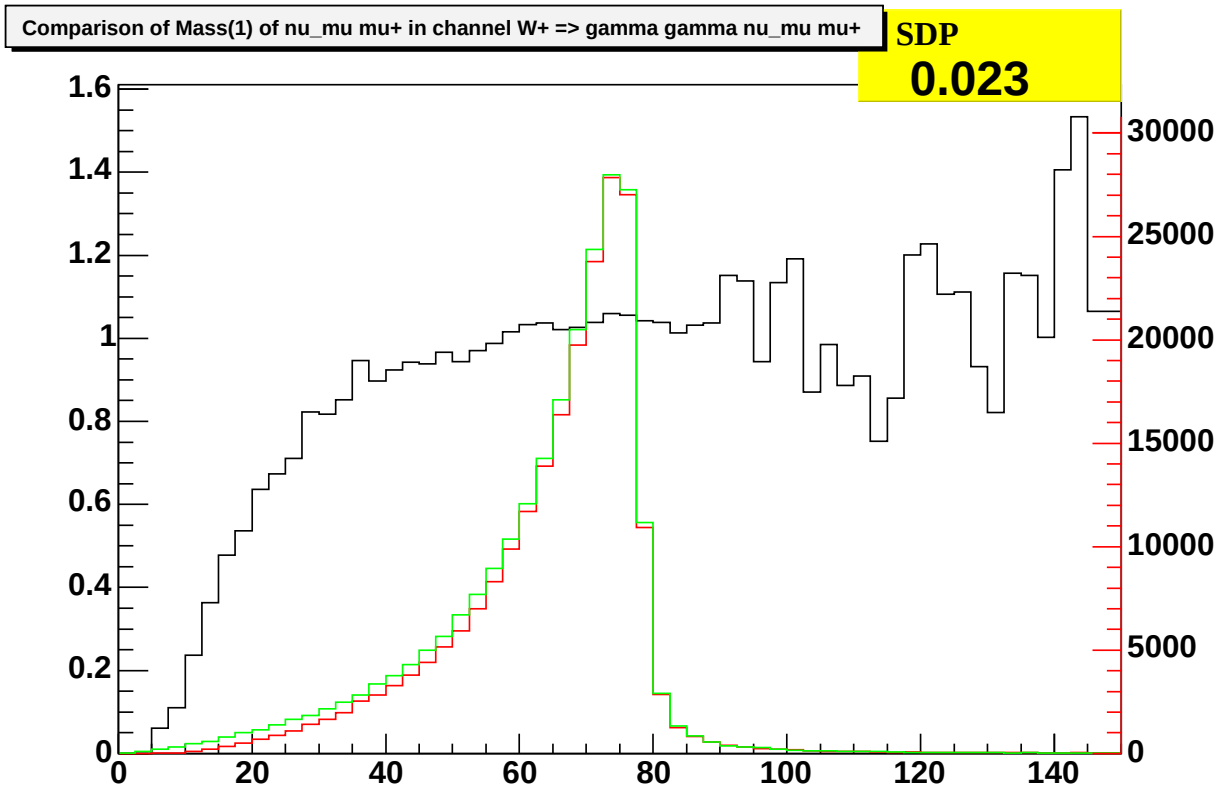


The difference in branching ratios are at permile level and BR * SDP$<$0.1%.

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

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

Plot of largest difference:



The difference in branching ratios are at permile 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.

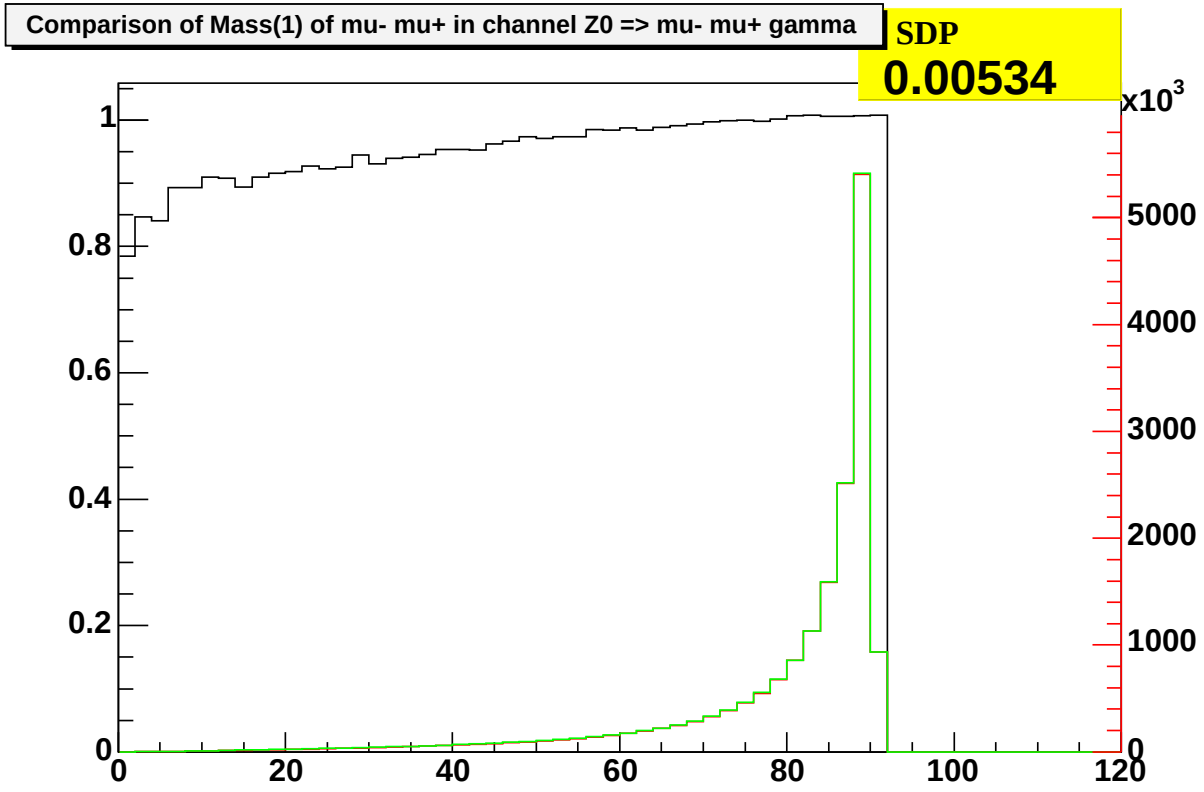
General properties of algorithm for higher-orders have been checked before.

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

Work in progress

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

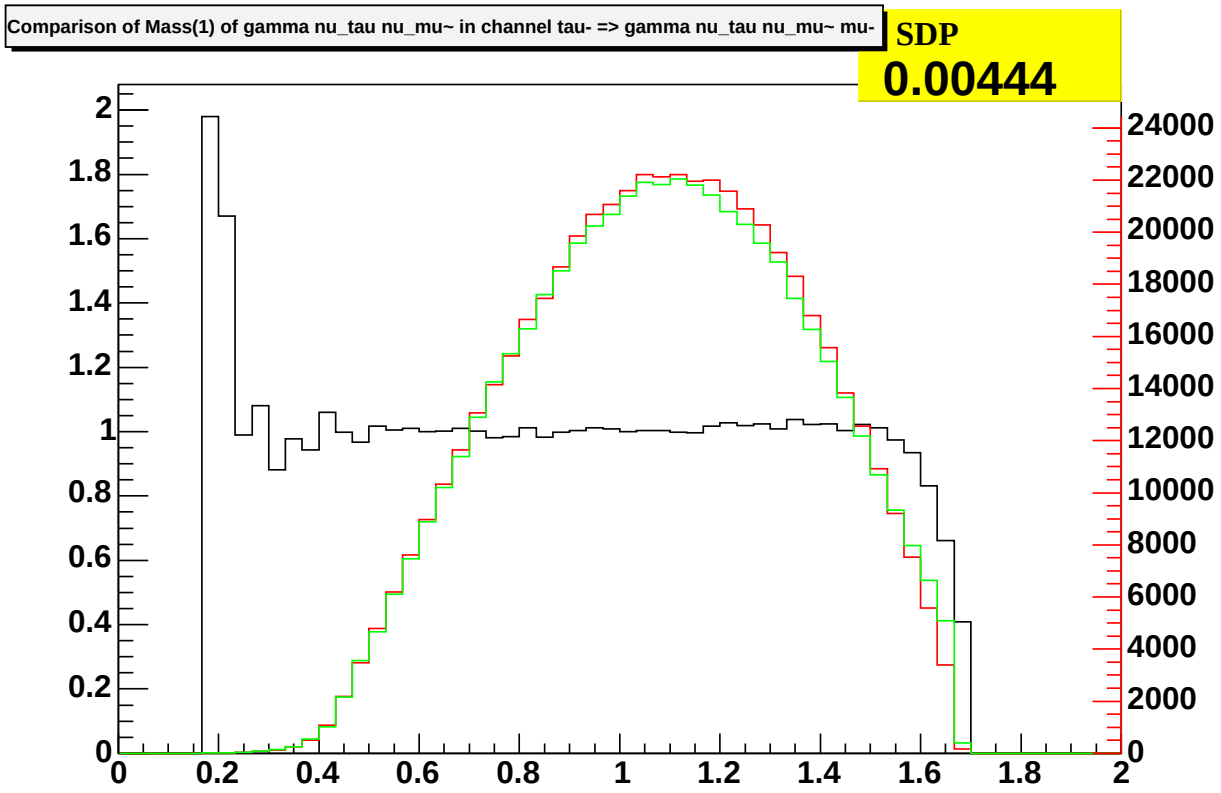
Plot of largest difference (quantifies approx. in PHOTOS necessary to iterate)



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

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

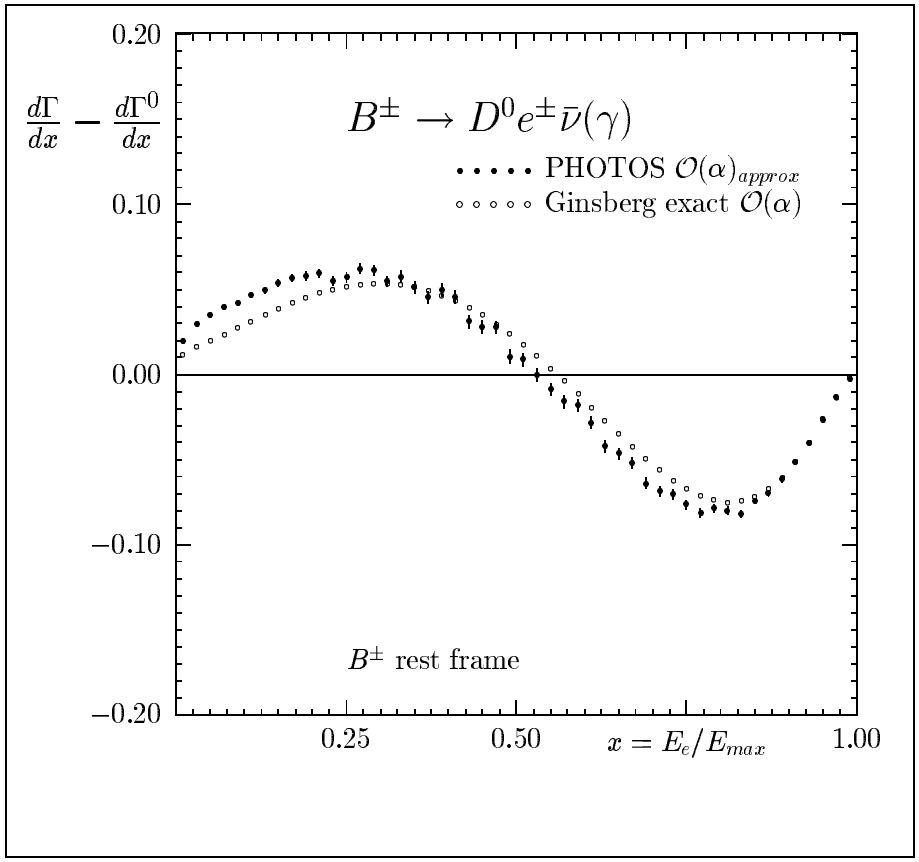
Plot of largest difference:



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

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

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

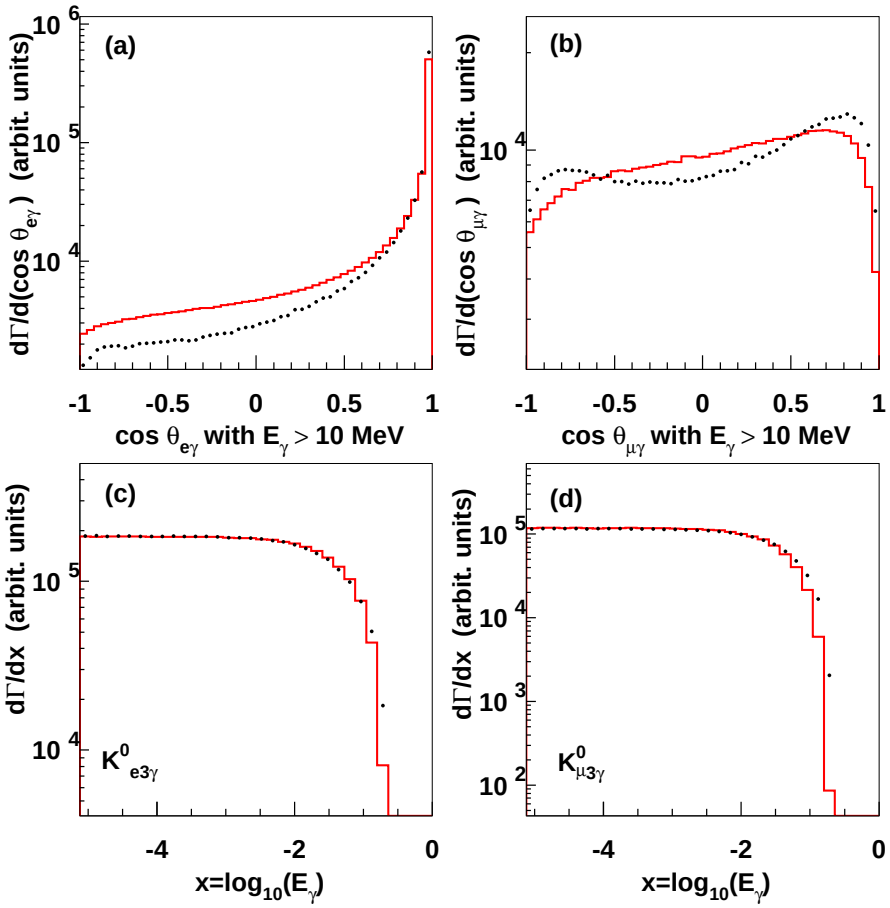


Radiative correction to the decay rate $(d\Gamma/dx - d\Gamma^0/dx)$ for $B^{\pm} \to D^0 e^{\pm} \bar{\nu}(\gamma)$ in the $B^{\pm}$ rest frame. Open circles are from the exact analytical formula [2], points with the marked statistical errors from PHOTOS applied to JETSET 7.3. A total of 10^7 events 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) $\cos(\Theta_{\gamma,l})\ K_{e3}$

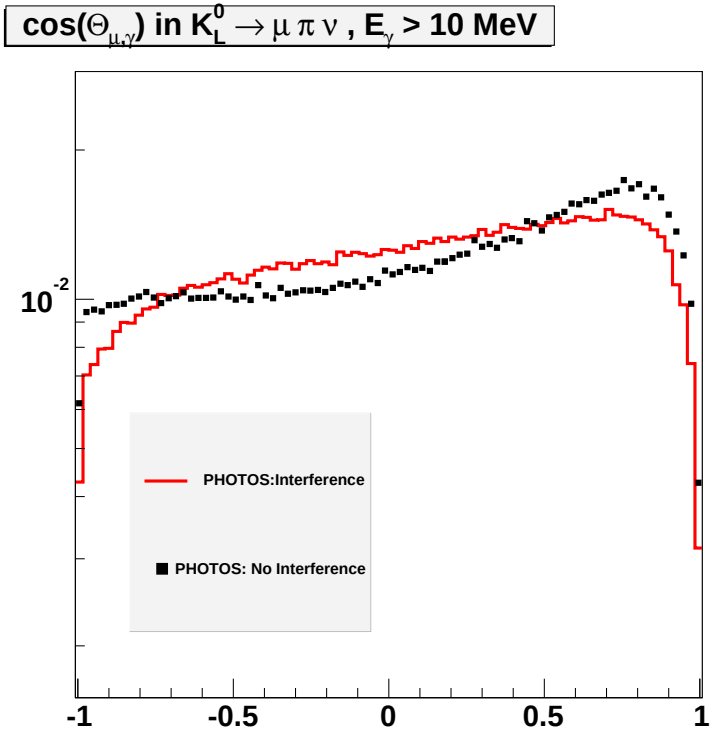
(c) $\log_{10}(E_\gamma)\ K_{\mu 3}$

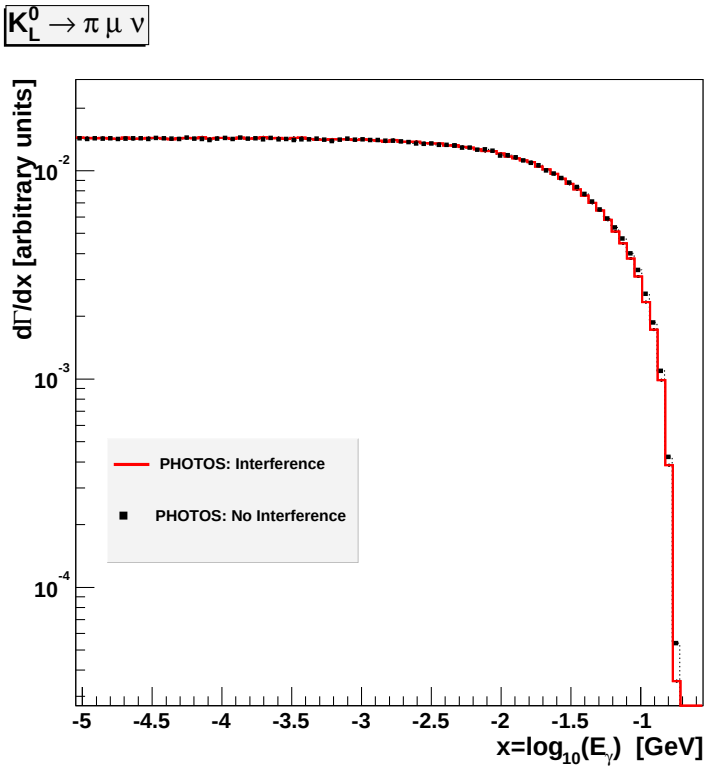
(d) $\log_{10}(E_\gamma)\ K_{e3}$

in KLOR

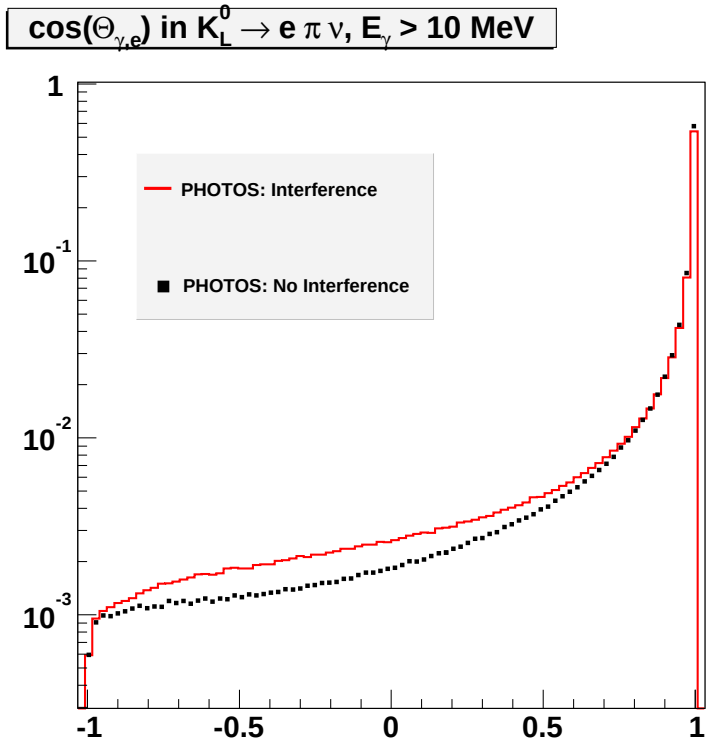
and PHOTOS

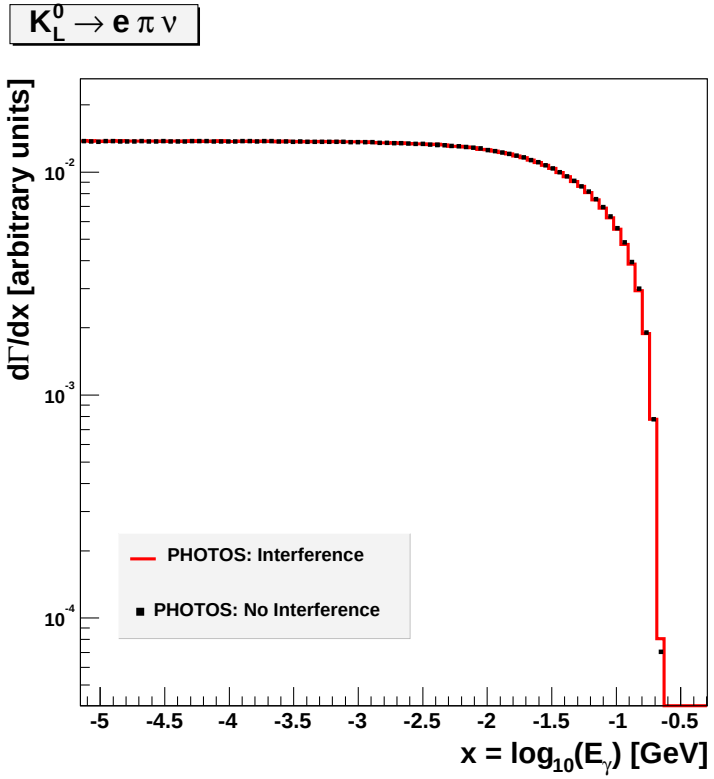
$K \to \pi \mu \nu$ + PHOTOS bremsstrahlung, interference on/off





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

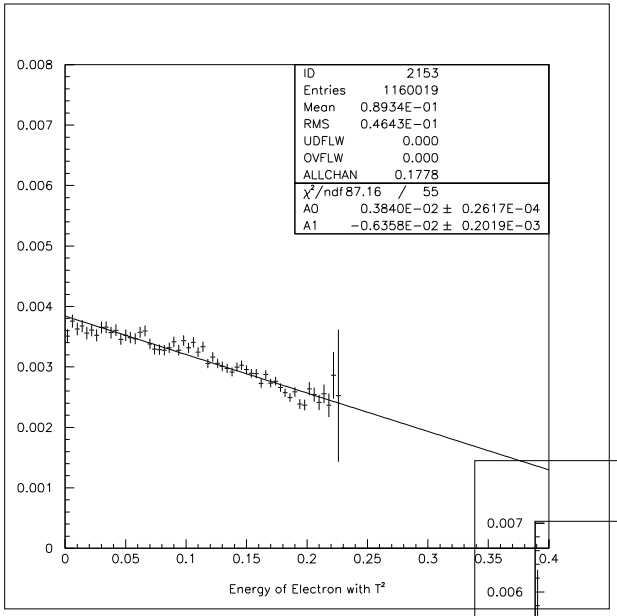


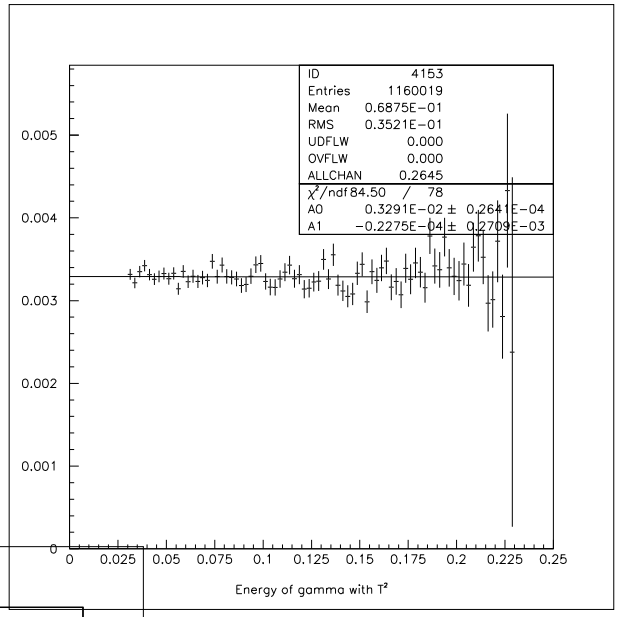


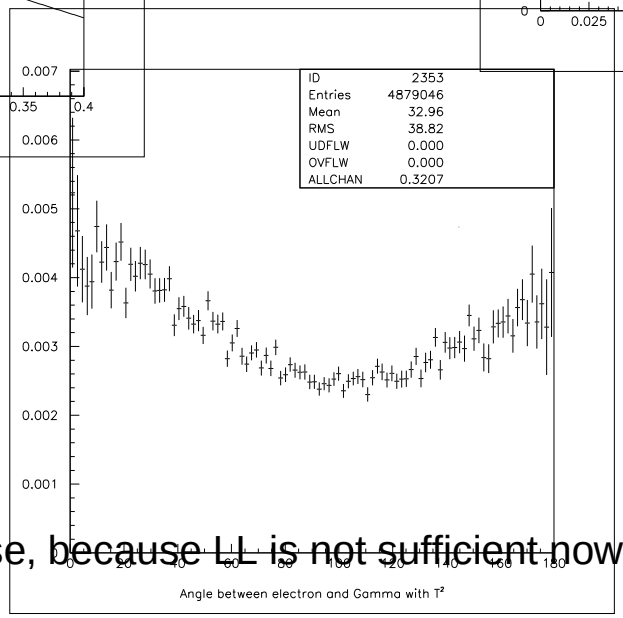
Seems that the interference weight removed the difference to a large degree, but still some inconsistencies at $\cos\Theta \simeq -1$

- 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 Matrx-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

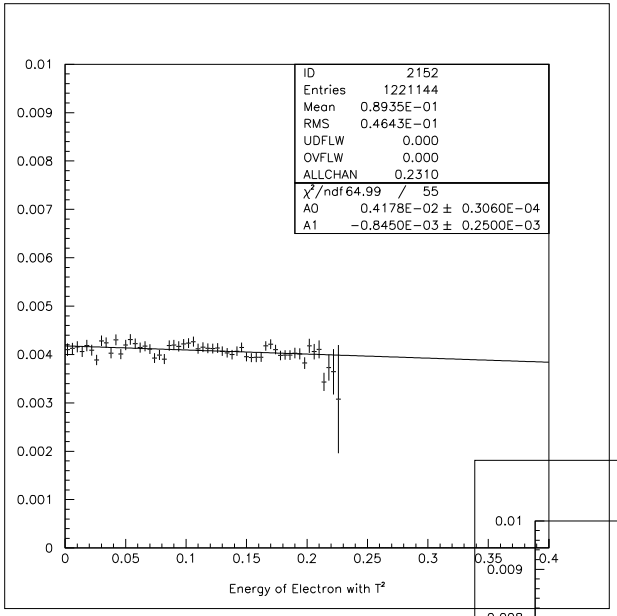


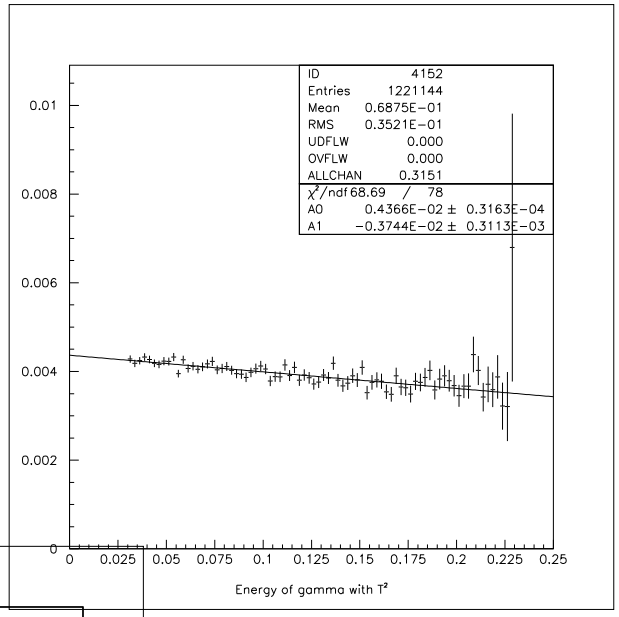


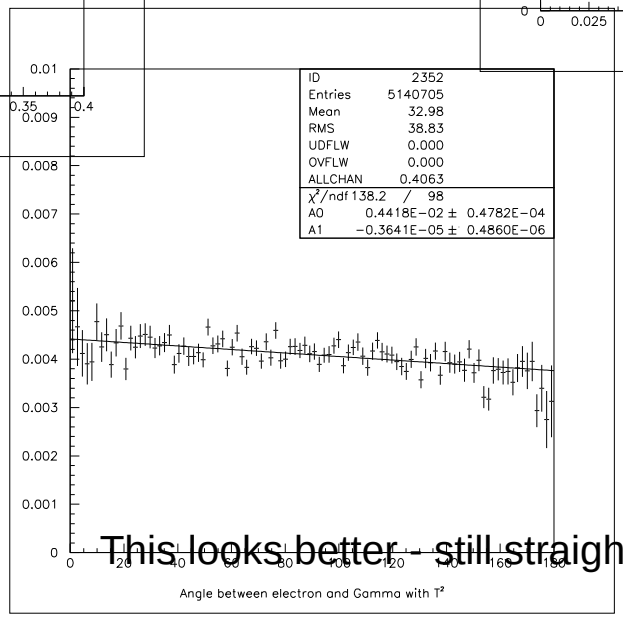


This looks bad - no surprise, because LL is not sufficient nowadays

$K \to \pi e \nu(\gamma)$ 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

PART 3:
Non-leptonic decays

- **Motto: Guilty until proven otherwise.**

Testbed

- no good field-theory predictions as in Z and W decays, also ...
- no 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...
- Present version of PHOTOS assures precision for W and Z decays, also H.
- PHOTOS is on a way from general purpose facility to precison tool in places where tests are completed.
- PHOTOS provides also interesting testbed for some parton shower-like iterative solutions.