PHOTOS
as “pocket” parton shower

HERA-LHC workshop WG week

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Program available from: `http://wasm.home.cern.ch/wasm/goodies.html`

Presented (and additional) tests available from: `http://cern.ch/Piotr.Golonka/MC/PHOTOS-MCTESTER`

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What is this presentation about:

- PHOTOS - a software project
- PHOTOS - an algorithm for QED radiative corrections in particle decays
- PHOTOS - a "meta-algorithm" for transforming exact first-order QED calculations into fixed-number photon-generation and multiple-photon generator, Example for QCD (?)
- PHOTOS in practical applications

Plan of the talk:

1. Software project: tests of numerical stability and kinematic-repair algorithms
2. Analysis of first-order QED calculations (in form of numerical tests)
3. Merging two independent emissions (tests with two-photon ME)
4. Implementation of shower-like procedure: tests with KKMC and WINHAC

$\mathcal{F}$ocus points

- *presentation of basic elements in the algorithm*
- *tests of these parts*
- *tests of the complete algorithm in case of W and Z decays*
- $\mathcal{Q}$: *Why Parton Shower?*
- $\mathcal{A}$: *Takes $X \rightarrow Y^+ Z^- U$,*
  makes $X \rightarrow Y^+ Z^- U\gamma$, $X \rightarrow Y^+ Z^- U\gamma\gamma$, ...
- *Full phase-space coverage for photons!*

$\mathcal{W}$hat this presentation is NOT about:

- *we do not discuss formal proofs*
- *this talk is rather a "salesman's presentation"*

PHOTOS: a software project

- over 20 years of development: MUSTRAAL(1982), PHOTOS (1991, Single emission), PHOTOS 2.0 (1994, double emission, threshold terms)
- functional C++ prototype (1999) (my first contact with the project)
- evolving: improvements and extensions (currently part of the TAUOLA-PHOTOS-F: numerical stability, W decay, interference)
- recent achievement: multiple emission, k_0 problem resolved
- interesting “toy-MC example” : compact code, exercises on event records (searching, modifications, adding particles), and functional blocks (iteration of single-emission kernel, dedicated weights)
- “dark side of the project”: numerical stability (resolved to large degree)

Numerical Stability

- Before any improvements could be done, better control of numerical stability needed.
- Sources of problems:
  - accumulation of rounding-errors due to iteration
  - traps in the algorithms induced by rounding errors
  - "standard" problem of k_0
- testing procedure

Rounding errors:

- PHOTOS works on 4-vectors (event records)
- kinematic-modifications (particularly: boosts) may cause severe rounding errors
- iterative nature of the algorithm aggreviates the situation: accumulation of errors
- Need for a transformation (”kinematic-correction”) that is
  - called after every iteration
  - suitable to physical context (various options): light particles, heavy particles, off-shell, ...
  - SUBROUTINE PHCORK (1999, 2004)

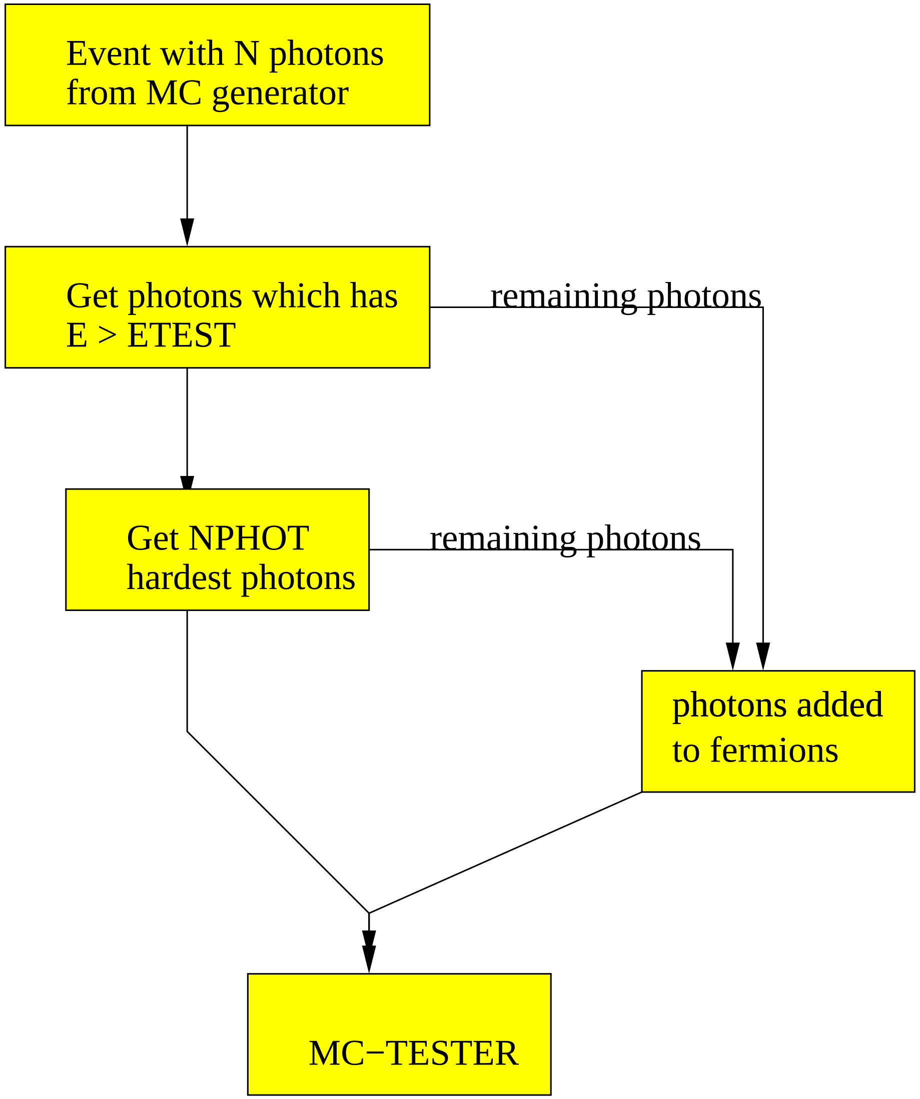
Testing procedure:

- 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

- Testing procedure need to be applicable to fixed-order and exponentiated algorithms: unified treatment of the soft-photon limit and number of particles:
- 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:



Analysis of fi rst-order calculations:

- 1991: algorithm downgraded from full $O(\alpha)$ ME for $Z \to \mu^+\mu^-$ (MUSTRAAL, F. Berends, R. Kleiss, S.Jadach) to universal kernel
- change of variables from angles to transformation of 4-vectors
- independent emission from charges implemented
- interference may be put back for some cases (in approximated way) (Decays of neutral particles into two charged particles)

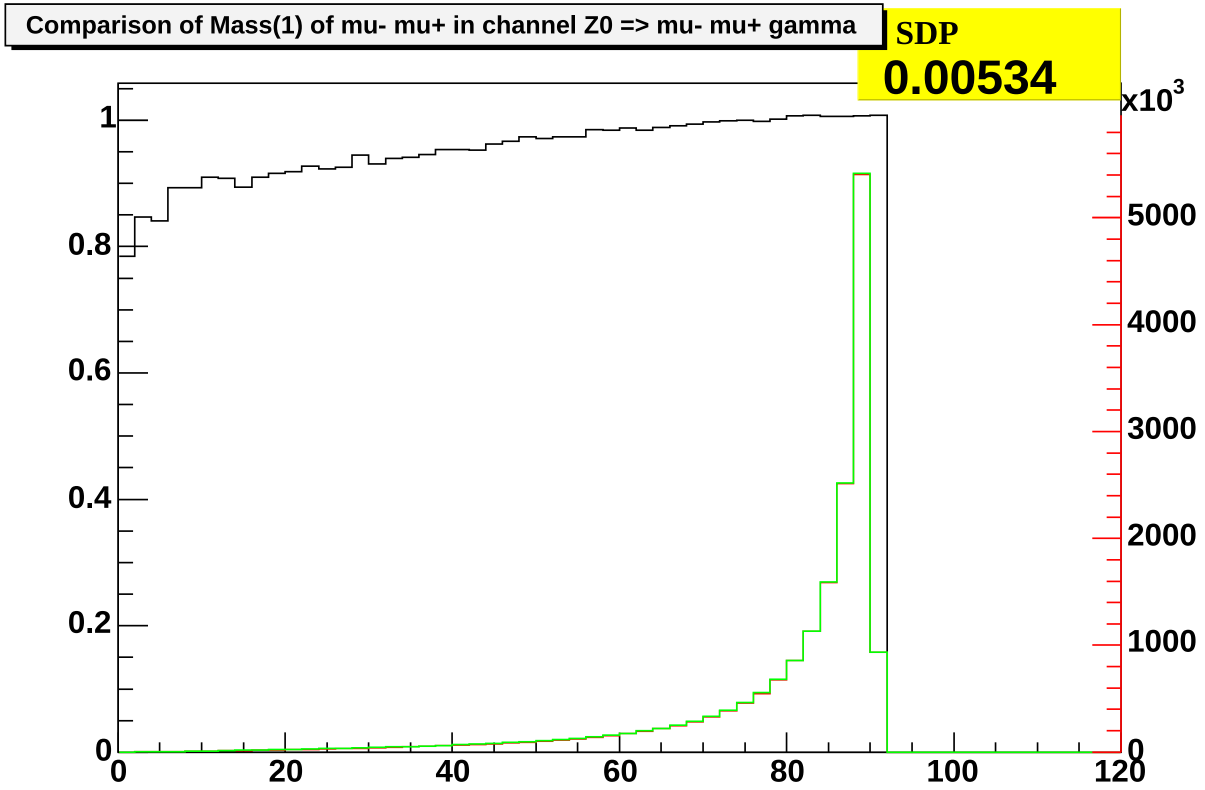
Where are we now:

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

- Z^0 leptonic decays (comparisons with KORALZ and KKMC) good agreement
- τ leptonic decays (comparisons with TAUOLA) good agreement
- W leptonic decays:
  - results were inaccurate (APP, B34 (2003), 2665) because of lack of interference terms
  - approximated weight for this channel was calculated and implemented (contains mainly terms describing the interference between emission from W and lepton) (APP, B34 (2003), 4561)
  - the results greately improved !

$Z \to \mu^+\mu^-$ PHOTOS vs KORALZ

Plot of largest difference:

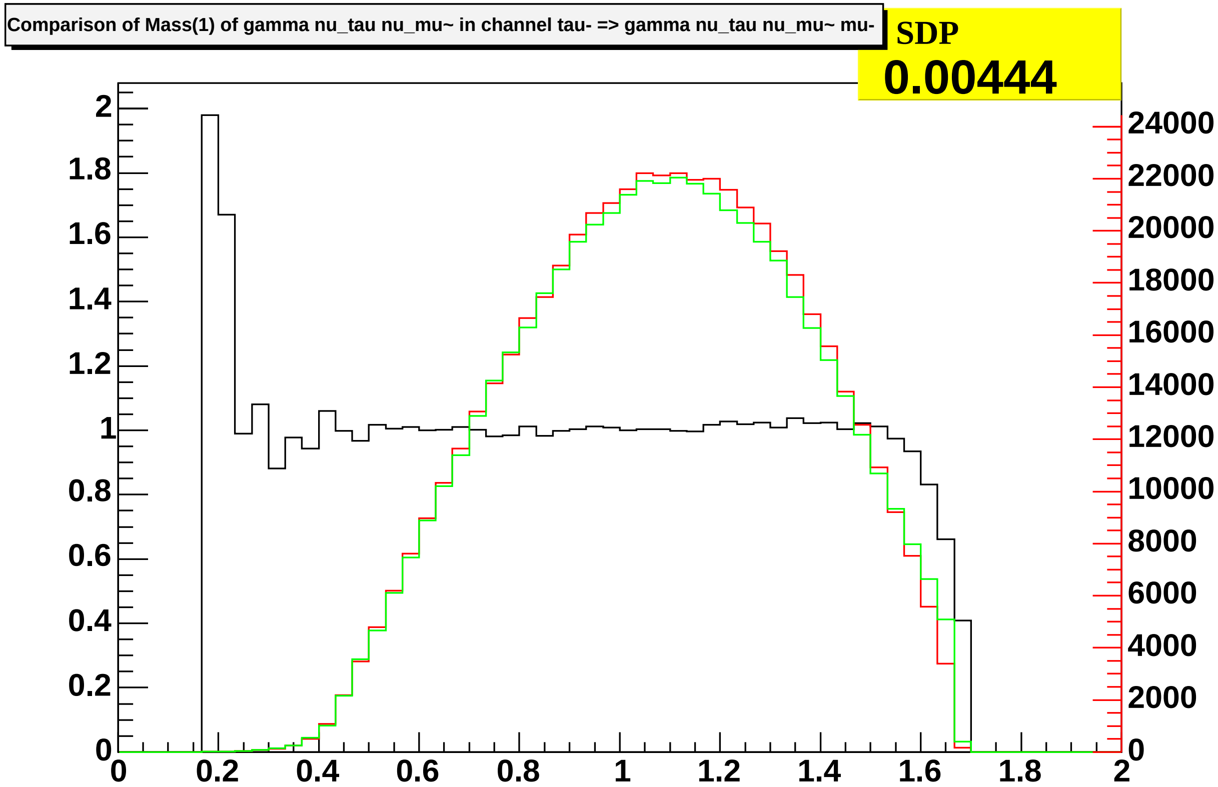


The difference in branching ratios are at fraction of permile level.

The differences are mainly due to approximations in PHOTOS kernel (this is restorable)

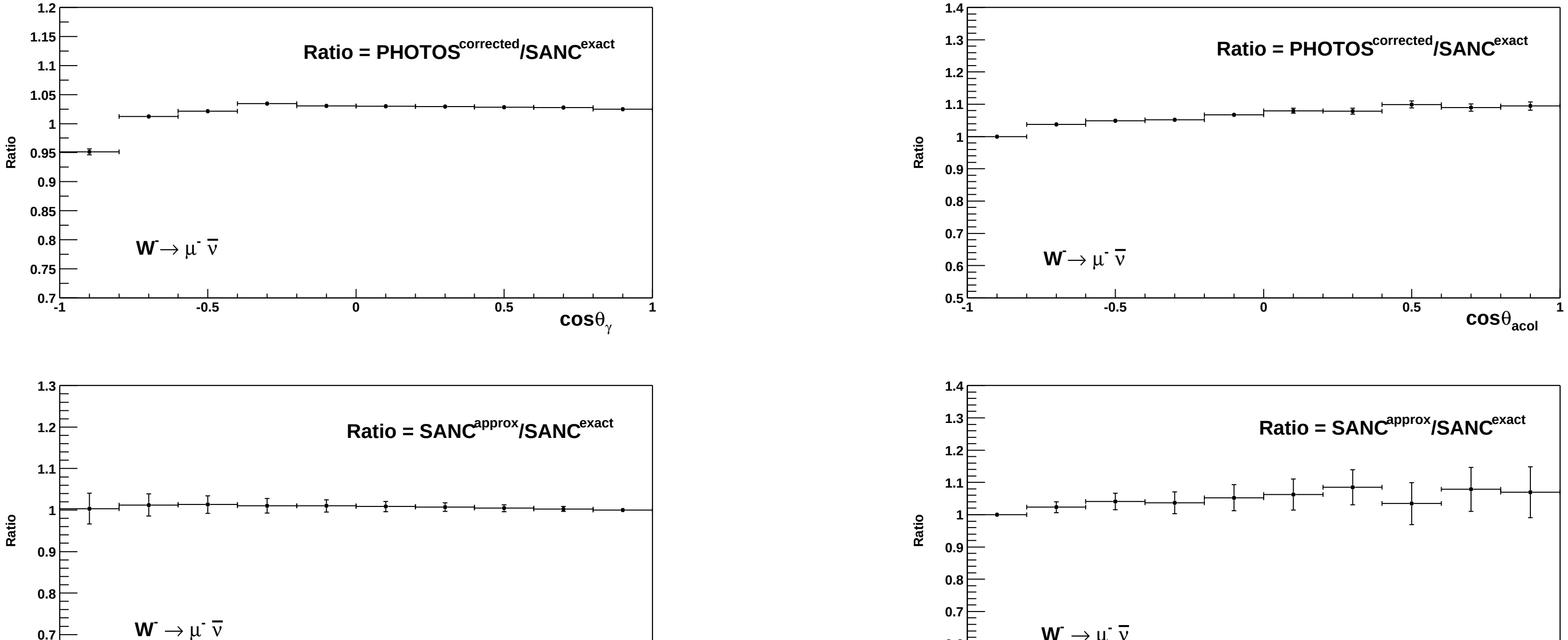
$\tau \to l\nu\bar{\nu}$ PHOTOS vs TAUOLA

Plot of largest difference:



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

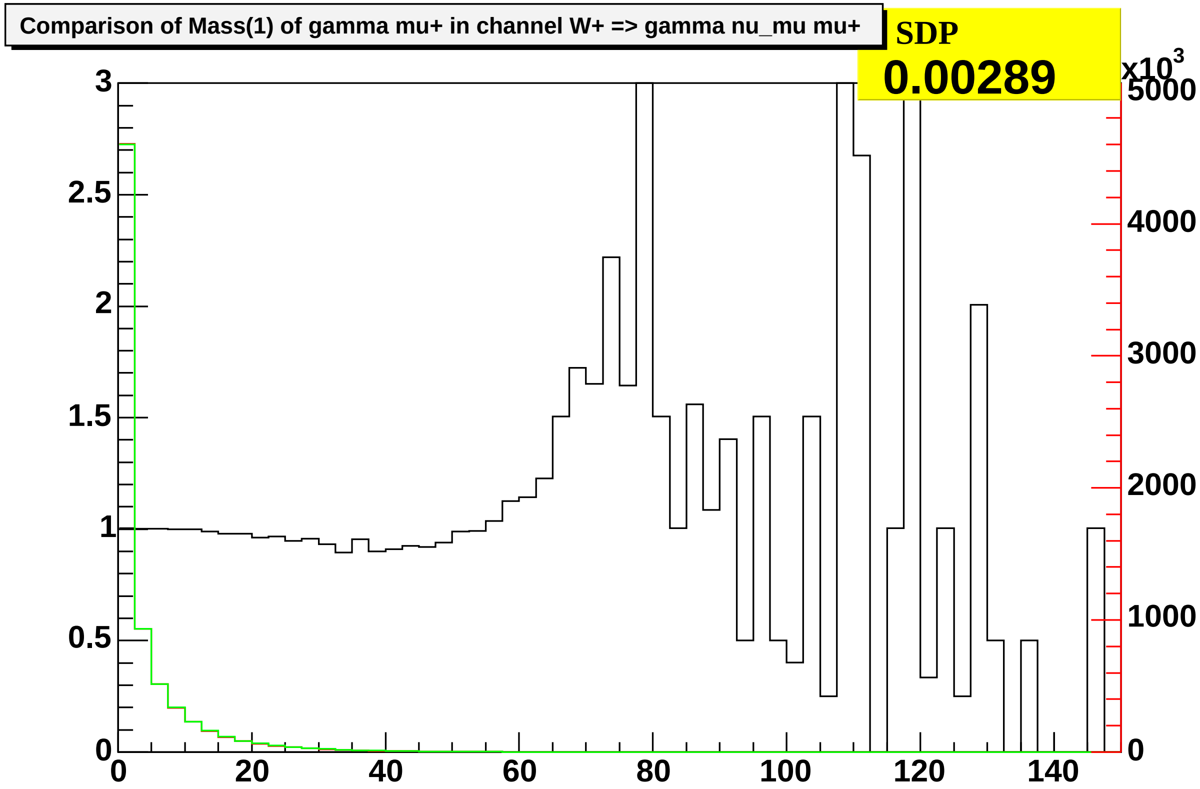
$W \to l\nu$ PHOTOS vs. Matrix Element, test and improvement



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.*

$W \to l\nu$ PHOTOS vs. WINHAC

Plot of largest difference:



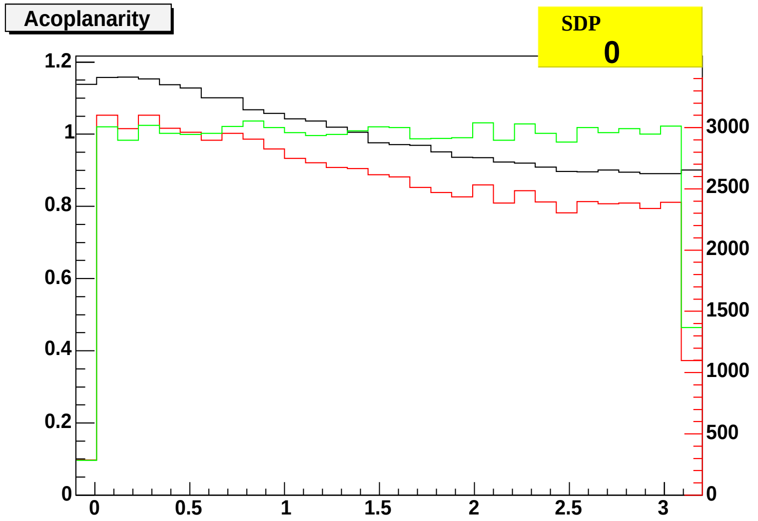
The difference in branching ratios are at fraction of permile level.

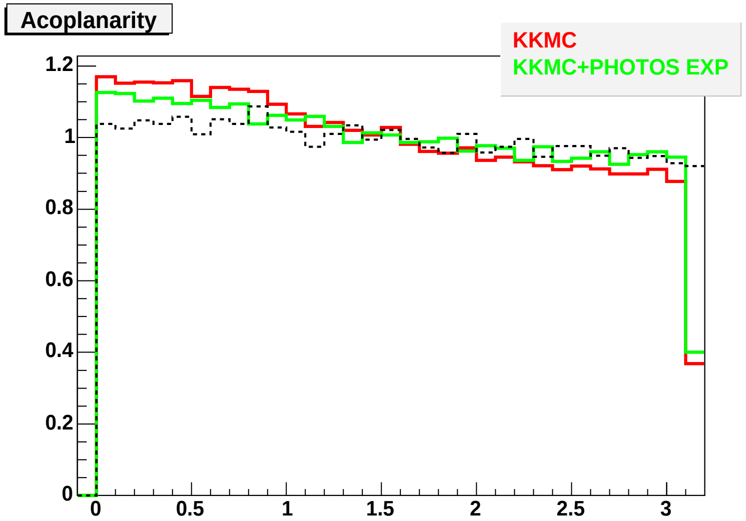
Where are we now (cont):

- Recently: interest in $K^0 \to \pi^- e^+ \nu_e$ and $K^0 \to \pi^- \mu^+ \nu_\mu$
- Interference weight in PHOTOS is missing for that channel
- Performance not excellent (as expected)
- Question to NA48: Do we need appropriate correction weight implemented ?

Merging independent emissions

- Some comparisons with exact ME generators for processes like $Z \to \mu^+\mu^-\gamma\gamma$, $gg \to t\bar{t}\gamma\gamma$, etc already performed in 1994
- Original PHOTOS was assumed to be used at LL level only
- Can PHOTOS do better (sum up to NNLL) ?
- Acoplanarity distributions never looked at...





- One of the properties of Matrix element calculations is coherence of consecutive photon emissions.
- Thanks to organization of consecutive iterations, PHOTOS reconstructs bulk of this coherence without inclusion of second order ME !

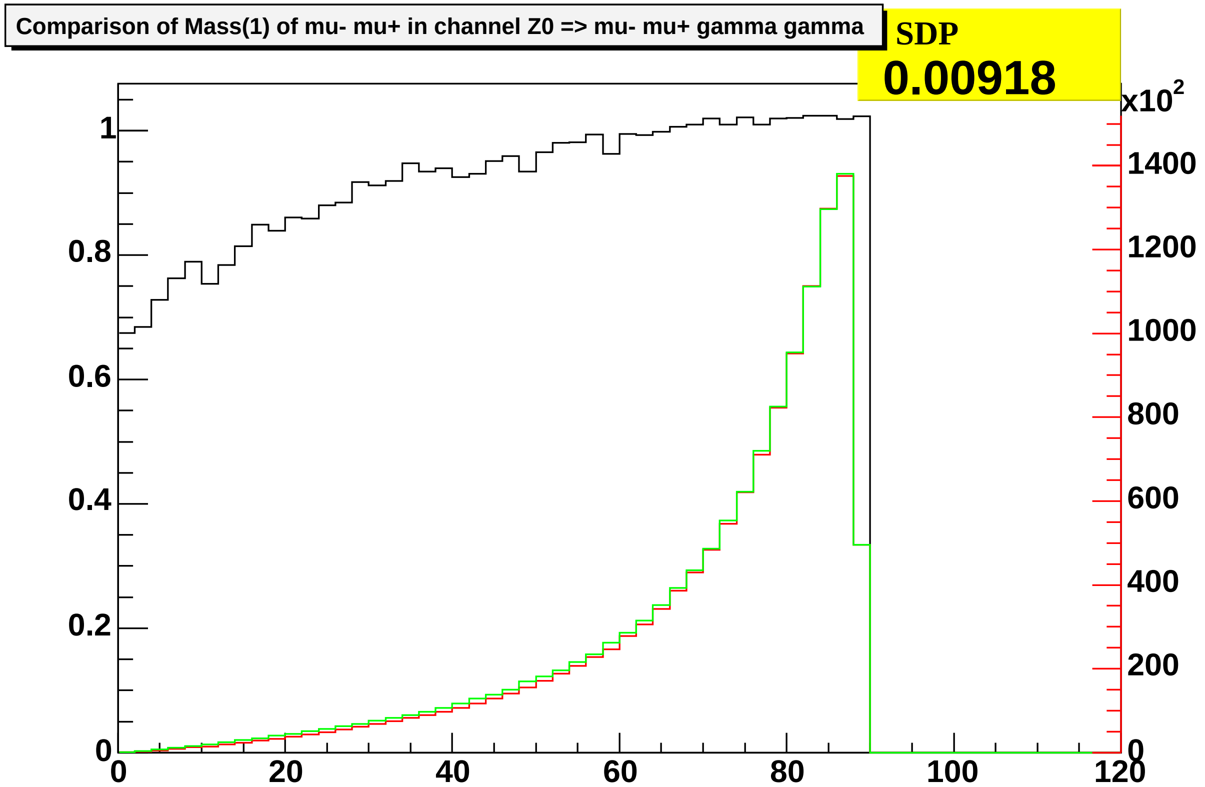
- That is potentially interesting.
- To say more careful analysis of spin amplitudes may be needed.
- Room for improvements there!

Implementation of shower-like procedure

- Encouraged by these results we can go on with improvements of the algorithm
- Options for tripple- and quadruple- emission implemented
- Exponentiated version of the algorithm implemented
- Bonus: problem with k_0 disappeared
- We performed a set of comparison tests with KKMC and WINHAC generators ...

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

Plot of largest difference:

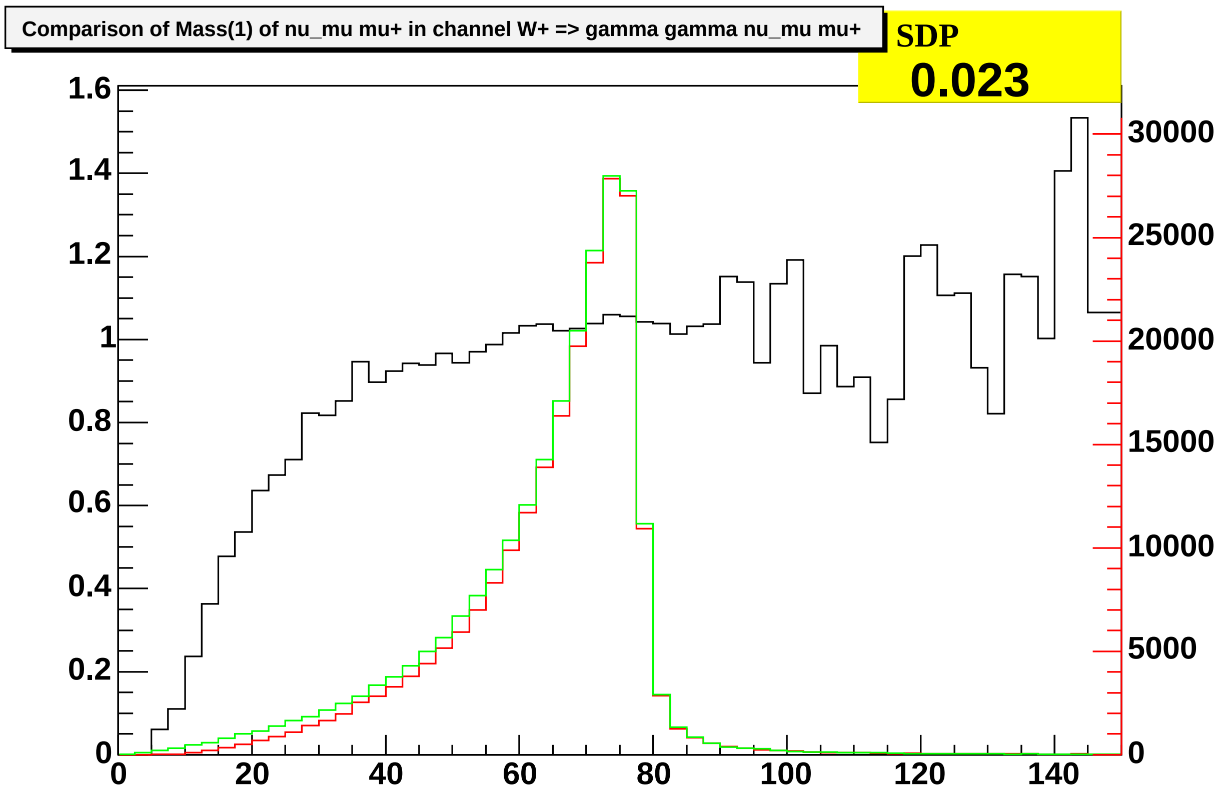


The difference in branching ratios are at permile level.

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

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

Plot of largest difference:



The difference in branching ratios are at permile level.

The source of residual difference not investigated;

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

Summary

- We tested the performance of PHOTOS with different options: $O(\alpha)$, $O(\alpha^2)$, $O(\alpha^3)$, $O(\alpha^4)$ and $O(exp)$ for Z and W decays
- With the new option: $O(exp)$ problems related to k_0 disappear. PHOTOS reproduces well KKMC $O(\alpha^2)$; in this case a precision tool
- this is good news, as it shows the power of the algorithm
- this is bad news: no testbench to investigate the missing NLO terms in PHOTOS
- this limits the understading of meta-algorithm for PHOTOS creation.
- nevertheless, some tricks may be useful for QCD

Summary

- PHOTOS seems to be complete NLL generator once the trivial missing terms installed
- formal proof missing ...
- for some decay-modes PHOTOS remains LL-only tool; example K_0 decays (NA48)
- Rules for improvements are fully defined.