PHOTOS for bremsstrahlung in W and Z decays: status and perspectives: slides for discussion.

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- **(1)** Detector response to bremsstrahlung in leptonic W and Z decays depend of lepton flavour; strength is proportional to logarithm of lepton mass.

- **(2)** MC (correlated) samples with and without bremsstrahlung are useful. Without bremsstrahlung: lepton universality. Unfold detector together with FSR.

- **(3)** *Is PHOTOS Monte Carlo suuficiently precise to be useful for QED FSR?* POINTS: phase space, single emission, double emisssion, multiple emission. Tests and decay channel dependent matrix elements: first order, second order.

- **(4)** *What are technical constraints:* event record HEPEVT, HepMC: intermediate W, Z explicit or not, installation numerical tests.

- **(5)** *At which precision QED FSR can not be anymore separated from the rest?* POINTS: genuine weak corrections, ISR, ISR$\times$PS, ISR-FSR interference.

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.
- Full events combining complicated tree structure of production and subsequent decays have to be fed into PHOTOS, usually with the help of HEPEVT event record of F77 (beta version working with HepMC event record of C++ exist).
- At every event decay branching, PHOTOS intervene. With certain probability extra photon may be added and kinematics of other particles adjusted.
- In particular bremsstrahlung can be added in W and Z decays.

PHOTOS MC: QED FSR only

Main References

- E. Barberio, B. van Eijk and Z. Was, Comput. Phys. Commun. **66**, 115 (1991): single emission
- E. Barberio and Z. Was, Comput. Phys. Commun. **79**, 291 (1994). double emission introduced, tests with second order matrix elements
- P. Golonka and Z. Was, EPJC 45 (2006) 97 multiple photon emisson introduced, tests with precioson second order exponentiation MC.
- P. Golonka and Z. Was, EPJC 50 (2007) 53 complete matrix element for Z decay, and further tests
- G. Nanava, Z. Was, Eur.Phys.J.C51:569-583,2007, best description of phase space
- G. Nanava, Z. Was, Q. Xu, arXiv:0906.4052. EPJC in print complete matrix element for W decay
- N. Davidson, T. Przedzinski, Z. Was http://www.ph.unimelb.edu.au/˜ndavidson/photos/doxygen/index.html HepMC interface

Phase Space: exact

Orthodox exact Lorentz-invariant phase space (*Lips*) is in use in PHOTOS!

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

Integration variables, the four-vector p, compensated with $\delta^4\big(p - \sum_1^n k_i\big)$, and another integration variable M_1 compensated with $\delta\big(p^2 - M_1^2\big)$ are introduced.

PHOTOS MC: QED FSR only

Phase Space Formula of Photos

$$dLips_{n+1}(P \to k_1...k_n, k_{n+1}) = dLips_n^{+1\ tangent} \times W_n^{n+1},$$

$$dLips_n^{+1\ tangent} = dk_\gamma d\cos\theta d\phi \times dLips_n(P \to \bar{k}_1...\bar{k}_n),$$
$$\{k_1, \dots, k_{n+1}\} = \mathbf{T}\big(k_\gamma, \theta, \phi, \{\bar{k}_1, \dots, \bar{k}_n\}\big). \quad (1)$$

1. One can verify that if $dLips_n(P)$ was exact, then this formula lead to exact parametrization of $dLips_{n+1}(P)$
2. Practical implementation: Take the configurations from n-body phase space.
3. Turn it back into some coordinate variables.
4. construct new kinematical configuration from all variables.
5. **Forget about temporary** $k_\gamma\theta\phi$. **From now on, only weight and four vectors count.**
6. A lot depend on $\mathbf{T}$. Options depend on matrix element: must tangent at singularities. Simultaneous use of several $\mathbf{T}$ is possible and necessary/convenient if more than one charge is present in final state.

Phase Space: (main formula)

If we choose

$$G_n \;:\; M^2_{2\ldots n}, \theta_1, \phi_1, M^2_{3\ldots n}, \theta_2, \phi_2, \ldots, \theta_{n-1}, \phi_{n-1} \;\longrightarrow\; \bar{k}_1 \ldots \bar{k}_n \tag{2}$$

and

$$G_{n+1} \;:\; k_\gamma, \theta, \phi, M^2_{2\ldots n}, \theta_1, \phi_1, M^2_{3\ldots n}, \theta_2, \phi_2, \ldots, \theta_{n-1}, \phi_{n-1} \;\longrightarrow\; k_1 \ldots k_n, k_{n+1} \tag{3}$$

then

$$\mathbf{T} = G_{n+1}(k_\gamma, \theta, \phi, G_n^{-1}(\bar{k}_1, \ldots, \bar{k}_n)). \tag{4}$$

The ratio of the Jacobians form the phase space weight W_n^{n+1} for the transformation. Such solution is universal and valid for any choice of G's. However, G_{n+1} and G_n has to match matrix element, otherwise algorithm will be inefficient (factor 10^{10} ...).

In case of PHOTOS G_n's

$$W_n^{n+1} = k_\gamma \frac{1}{2(2\pi)^3} \times \frac{\lambda^{1/2}(1, m_1^2/M^2_{1\ldots n}, M^2_{2\ldots n}/M^2_{1\ldots n})}{\lambda^{1/2}(1, m_1^2/M^2, M^2_{2\ldots n}/M^2)}, \tag{5}$$

Phase Space: (multiply iterated)

By iteration, we can generalize formula (1) and add l particles:

$$dLips_{n+l}(P \to k_1 ... k_n, k_{n+1} ... k_{n+l}) = \frac{1}{l!} \prod_{i=1}^{l} \Big[dk_{\gamma_i} d\cos\theta_{\gamma_i} d\phi_{\gamma_i} W_{n+i-1}^{n+i} \Big]$$

$$\times dLips_n(P \to \bar{k}_1 ... \bar{k}_n), \quad (6)$$

$$\{k_1, \dots, k_{n+l}\} = \mathbf{T}\big(k_{\gamma_l}, \theta_{\gamma_l}, \phi_{\gamma_l}, \mathbf{T}\big(\dots, \mathbf{T}\big(k_{\gamma_1}, \theta_{\gamma_1}, \phi_{\gamma_1}, \{\bar{k}_1, \dots, \bar{k}_n\}\big) \dots \big).$$

Note that variables $k_{\gamma_m}, \theta_{\gamma_m}, \phi_{\gamma_m}$ are used at a time of the $m-$th step of iteration only, and are not needed elsewhere in construction of the physical phase space; the same is true for invariants and angles $M^2_{2\dots n}, \theta_1, \phi_1, \dots, \theta_{n-1}, \phi_{n-1} \;\; \to \;\; \bar{k}_1 \dots \bar{k}_n$ of (2,3), which are also redefined at each step of the iteration. Also intermediate steps require explicit construction of temporary $\bar{k}'_1 \dots \bar{k}'_n \dots \bar{k}'_{n+m}$, statistical factor $\frac{1}{l!}$ added.

We have **exact distribution** of **weighted** events over l and $n+l$ body phase spaces.

PHOTOS MC: QED FSR only

- Fully differential single photon emission formula in Z decay reads:

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

- Variables in use:

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

- 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.

- Factorization of first order matrix element and fully differential distribution breaks at the level $\frac{\alpha^2}{\pi^2} \simeq 10^{-4}$

PHOTOS MC: QED FSR only

- after trivial manipulation it can be written as:

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

- In PHOTOS the following kernel is used (decay channel, decay particle orientation, independent):

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

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

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

PHOTOS MC: QED FSR only

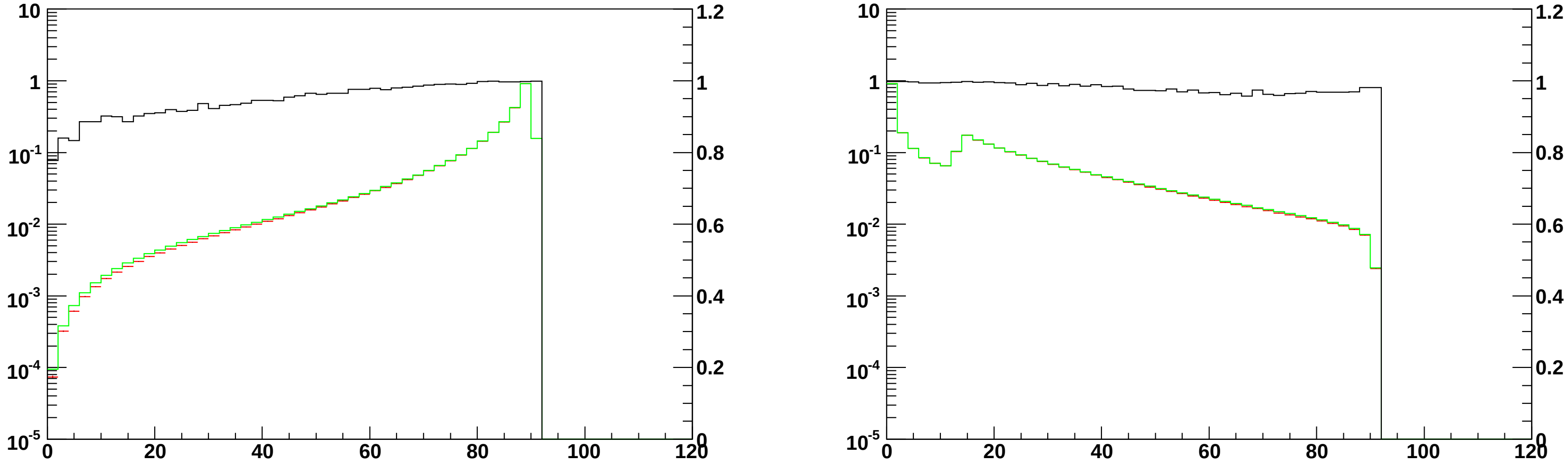


Figure 1: Comparison of standard PHOTOS and KORALZ for single photon emission. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.00534. In the right frame the invariant mass of $\mu^-\gamma$; SDP=0.00296. The histograms produced by the two programs (logarithmic scale) and their ratio (linear scale, black line) are plotted in both frames. The fraction of events with hard photon was 17.4863 $\pm$ 0.0042% for KORALZ and 17.6378 $\pm$ 0.0042% for PHOTOS.

Matrix Element for Z decay:

- Our discussion of double emission amplitudes was started from the single photon one
- The same is true for amplitudes of other processes. We have to check if they are similar to this for Z decay.
- In particular only if they structure match we can expect that our discussion of multiemission may apply as well.
- $$I = I^A \qquad\qquad + I^B \qquad\qquad + I^C$$
- $$I = \not{J}\left[\left(\frac{p\cdot e_1}{p\cdot k_1} - \frac{q\cdot e_1}{q\cdot k_1}\right)\right] - \left[\frac{1}{2}\frac{\not{e}_1\not{k}_1}{p\cdot k_1}\right]\not{J} + \not{J}\left[\frac{1}{2}\frac{\not{e}_1\not{k}_1}{q\cdot k_1}\right]$$

three gauge invariant parts, I^A is eikonal; I^B, I^C carry collinear contrib from p and q

QED for $W \to l\nu_l\gamma$: I^A, I^B and non-leading

$$
\begin{aligned}
M^{\sigma}_{\lambda,\lambda_\nu,\lambda_l}(k,Q,p_\nu,p_l) \quad = \quad & \left[\frac{Q_l}{2\,k\cdot p_l} b_\sigma(k,p_l) - \frac{Q_W}{2\,k\cdot Q}\left(b_\sigma(k,p_l)+b_\sigma(k,p_\nu)\right)\right] B^{\lambda}_{\lambda_l,\lambda_\nu}(p_l,Q,p_\nu) \\
& + \frac{Q_l}{2\,k\cdot p_l}\sum_{\rho=\pm} U^{\sigma}_{\lambda_l,\rho}(p_l,m_l,k,0,k,0) B^{\lambda}_{\rho,-\lambda_\nu}(k,Q,p_\nu) \\
& - \frac{Q_W}{2\,k\cdot Q}\sum_{\rho=\pm}\Big(B^{\lambda}_{\lambda_l,-\rho}(p_l,Q,k) U^{\sigma}_{-\rho,-\lambda_\nu}(k,0,k,0,p_\nu,0) \\
& \qquad + U^{\sigma}_{\lambda_l,\rho}(p_l,m_l,k,0,k,0) B^{\lambda}_{\rho,-\lambda_\nu}(k,Q,p_\nu)\Big)\,, \qquad (7)
\end{aligned}
$$

$$
\begin{aligned}
B^{\lambda}_{\lambda_1,\lambda_2}(p_1,Q,p_2) \quad &\equiv \quad \frac{g}{2\sqrt{2}}\bar{u}(p_1,\lambda_1)\,\widehat{\epsilon}^{\lambda}_W(Q)(1+\gamma_5)\,v(p_2,\lambda_2)\,, \\
U^{\sigma}_{\lambda_1,\lambda_2}(p_1,m_1,k,0,p_2,m_2) \quad &\equiv \quad \bar{u}(p_1,\lambda_1)\,\widehat{\epsilon}^{\sigma}_\gamma(k)\,u(p_2,\lambda_2)\,, \qquad (8) \\
\delta_{\lambda_1\lambda_2} b_\sigma(k,p) \quad &\equiv \quad U^{\sigma}_{\lambda_1,\lambda_2}(p,m,k,0,p,m)\,,
\end{aligned}
$$

Q_l and Q_W are the electric charges of the fermion l and the W boson, respectively, in units of the positron charge, $\epsilon^{\sigma}_{\gamma}(k)$ and $\epsilon^{\lambda}_{W}(Q)$ denote respectively the polarization vectors of the photon and the W boson. An expression of the function $U^{\sigma}_{\lambda_1,\lambda_2}$ in terms of the massels spinors.

PHOTOS MC: QED FSR only

Agreement is again good even if W spin orientation is ignored in correcting wt!

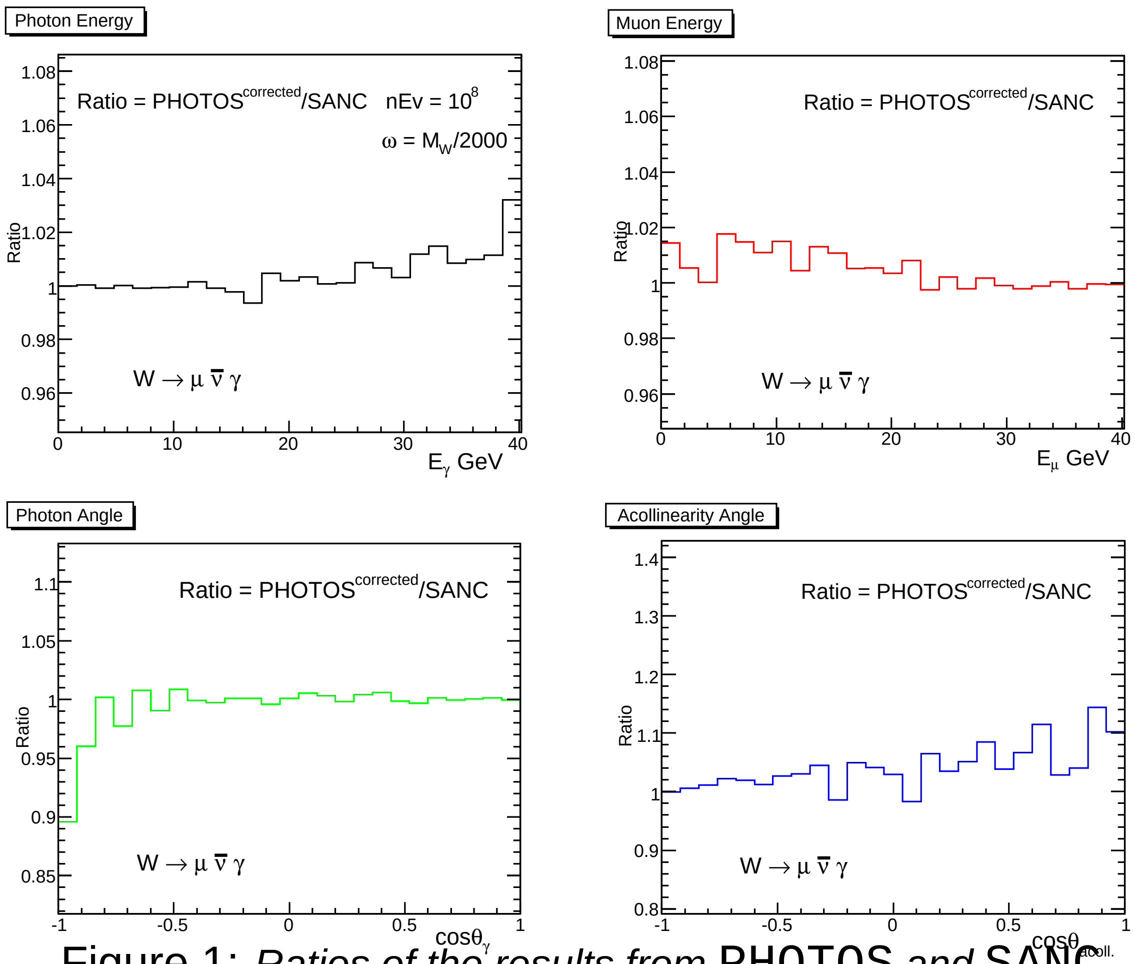


Figure 1: *Ratios of the results from* PHOTOS *and* SANC*.*

PHOTOS MC: QED FSR only

Once exact ME is installed agreement is perfect: prize orientation of W spin must be known.

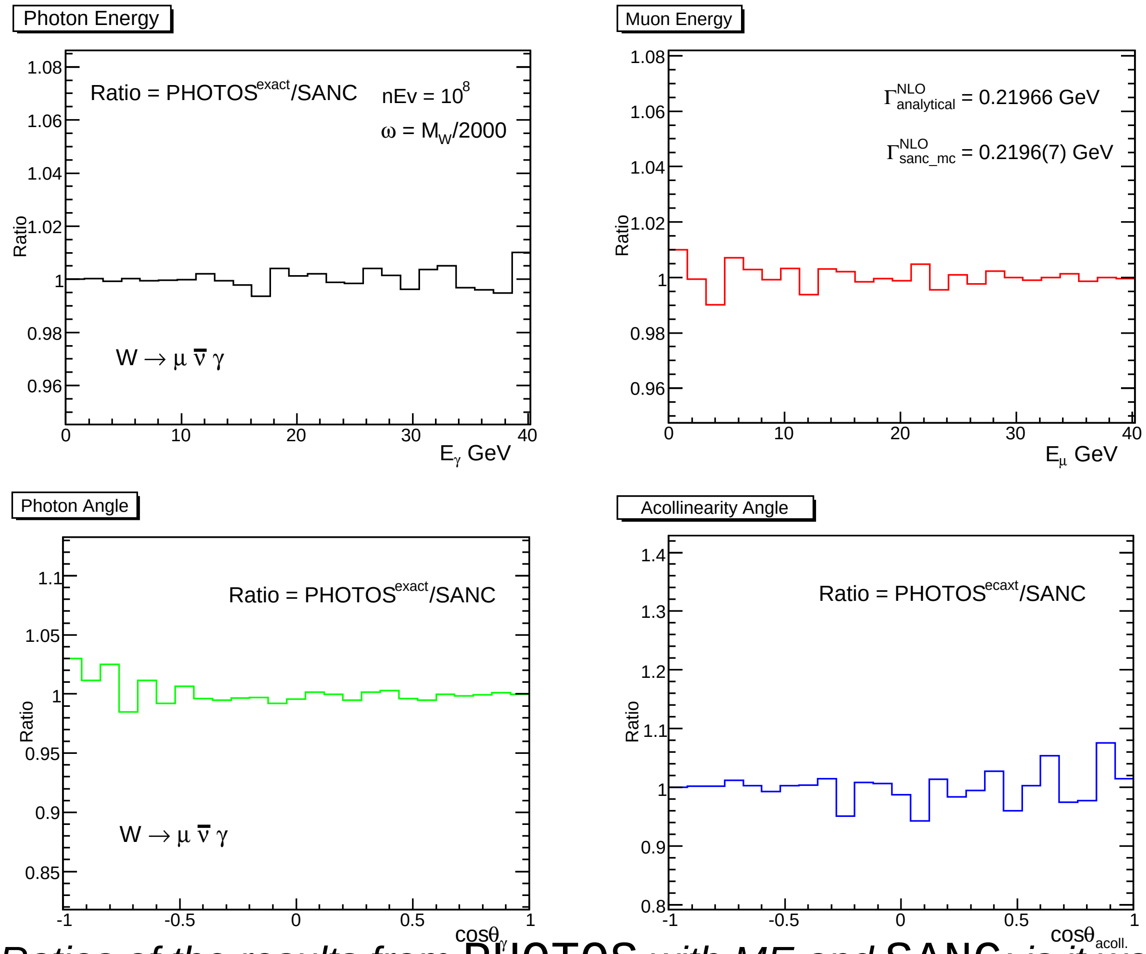


Figure 2: *Ratios of the results from* PHOTOS *with ME and* SANC*: is it worth an effort?*

Single emission

1. **Solution for single emission works perfect.**
2. **Technical precision controlled to precision better than statistical error of 100 Mevts.**
3. **Approximation to simplify work with event record under control and reversible if needed.**
4. **Web page with multitude of automated tests (RECOMENDATION: to be repeated after installation in collaboration software): http://mc-tester.web.cern.ch/MC-TESTER/**
5. **Let us go to second order and muliple photon emission now, but still pure QED FSR.**

PHOTOS MC: QED FSR only

Analytic benchmark

- One of the necessary steps was to verify, that once PHOTOS activated, the lepton spectra will be reproduced as far as the LL corrections to required order.

- Formal solution of QED evolution equation can be written as:

$$D(x,\beta_{ch}) = \delta(1-x)+\beta_{ch}P(x)+\frac{1}{2!}\beta_{ch}^2\{P\times P\}(x)+\frac{1}{3!}\beta_{ch}^3\{P\times P\times P\}(x)+\ldots \quad (9)$$

  where $P(x) = \delta(1-x)(\ln\varepsilon + 3/4) + \Theta(1-x-\varepsilon)\frac{1}{x}(1+x^2)/(1-x)$
  and $\{P \times P\}(x) = \int_0^1 dx_1 \int_0^1 dx_2 \delta(x - x_1x_2)P(x_1)P(x_2)$.

- In the LL contributing regions, phase space Jacobian's of PHOTOS trivialize (CPC 1994). The solution above is reproduced by PHOTOS in a straightforward manner, for each of the outcoming charged lines.

- But it is only a limit! **PHOTOS treat phase space exactly and covers all corners.**

PHOTOS MC: QED FSR only

- In a similar way (simplifying phase space Jacobians and droping parts of ME) one can get convinced that distribution of soft photons is as should be for exlusive exponentiation.
- PHOTOS has all advantages of exclusive exponentiation of first order matrix element.
- At the same time sums to all orders terms which contribute to leading logarithms of multiphoton emissions.
- This conclusion is based on numerical tests and studies of matrix elements to get optimal algorithm for iteration of photon emissions.

PHOTOS MC: QED FSR only

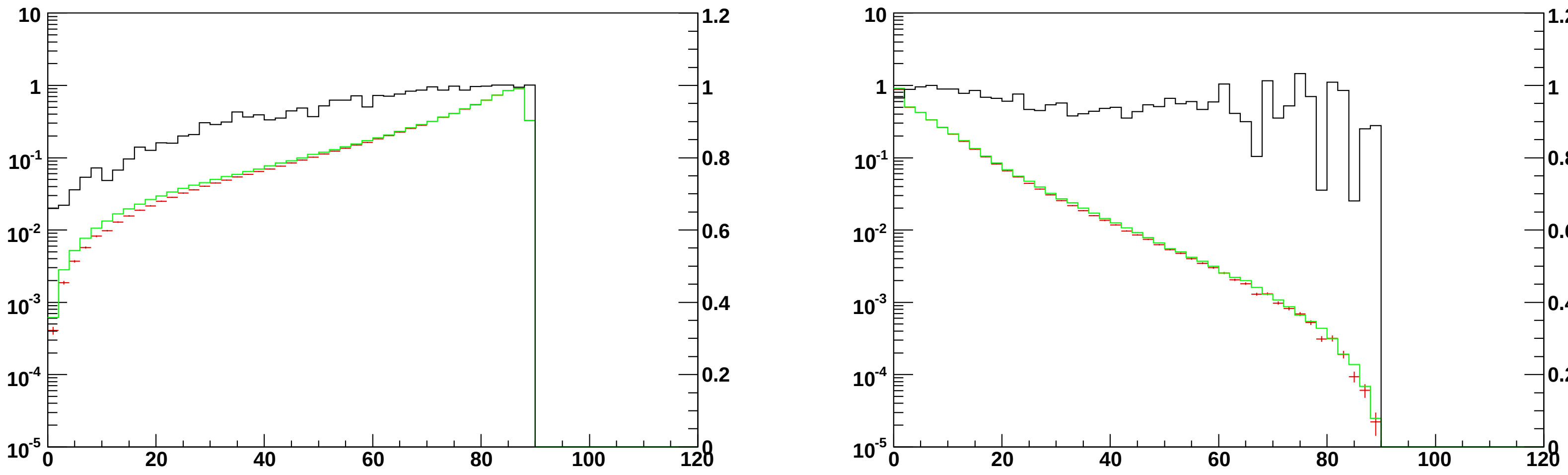


Figure 5: Comparisons of standard PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP= 0.00918 (shape difference parameter). In the right frame the invariant mass of the $\gamma\gamma$ pair; SDP=0.00268. The fraction of events with two hard photons was 1.2659 $\pm$ 0.0011% for KKMC and 1.2952 $\pm$ 0.0011% for PHOTOS.

PHOTOS MC: QED FSR only

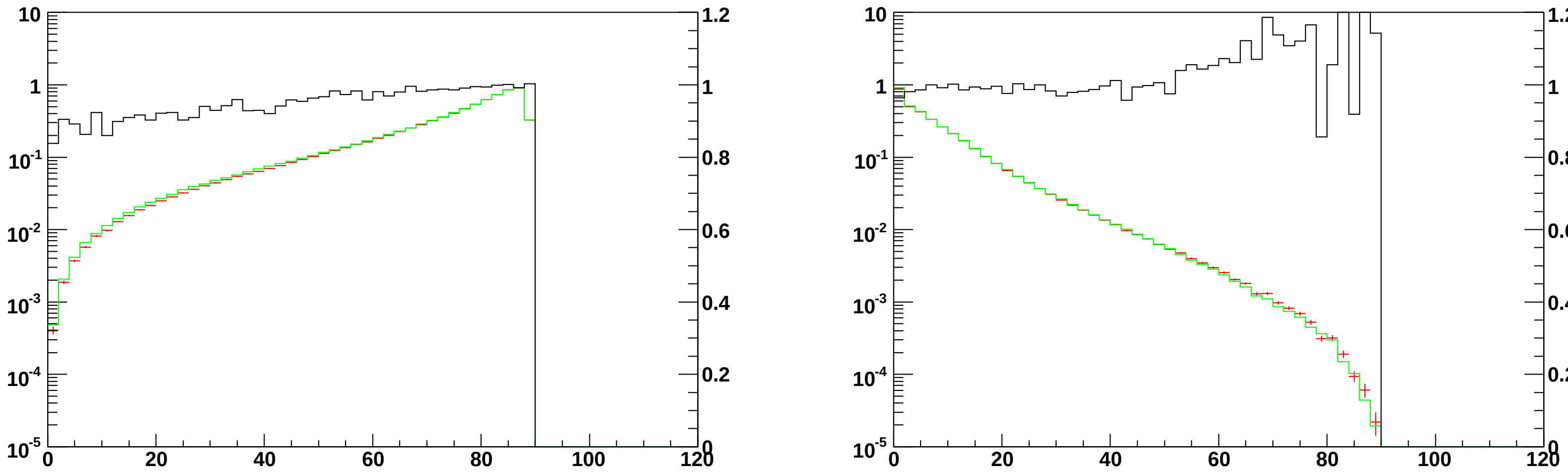


Figure 6: Comparisons of improved PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ *pair; SDP= 0.00142. In the right frame the invariant mass of the* $\gamma\gamma$*; SDP=0.00293. The fraction of events with two hard photons was 1.2659* $\pm$ *0.0011% for KKMC and 1.2868* $\pm$ *0.0011% for PHOTOS.*

Matrix Element: $q\bar{q} \rightarrow Jgg$ - part proportional to $T^A T^B$ fermion spinors dropped

$$I_{lr}^{(1,2)} = \left(\frac{p\cdot e_1}{p\cdot k_1} - \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{\not{e}_1 \not{k}_1}{2p\cdot k_1} \right) \not{J} \left(\frac{\not{k}_2 \not{e}_2}{2q\cdot k_2} + \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{q\cdot e_2}{q\cdot k_2} \right)$$

$$I_{ll}^{(1,2)} = \frac{p\cdot k_2}{p\cdot k_1 + p\cdot k_2 - k_1\cdot k_2} \left(\frac{p\cdot e_1}{p\cdot k_1} - \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{\not{e}_1 \not{k}_1}{2p\cdot k_1} \right) \left(\frac{p\cdot e_2}{p\cdot k_2} - \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{\not{e}_2 \not{k}_2}{2p\cdot k_2} \right) \not{J}$$

$$I_{rr}^{(1,2)} = \not{J} \frac{q\cdot k_1}{q\cdot k_1 + q\cdot k_2 - k_1\cdot k_2} \left(\frac{q\cdot e_1}{q\cdot k_1} - \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{\not{k}_1 \not{e}_1}{2q\cdot k_1} \right) \left(\frac{q\cdot e_2}{q\cdot k_2} - \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{\not{k}_2 \not{e}_2}{2q\cdot k_2} \right)$$

$$I_{e}^{(1,2)} = \not{J} \left(1 - \frac{p\cdot k_2}{p\cdot k_1 + p\cdot k_2 - k_1\cdot k_2} - \frac{q\cdot k_1}{q\cdot k_1 + q\cdot k_2 - k_1\cdot k_2} \right) \left(\frac{k_1\cdot e_2}{k_1\cdot k_2} \frac{k_2\cdot e_1}{k_1\cdot k_2} - \frac{e_1\cdot e_2}{k_1\cdot k_2} \right)$$

Remainder:

$$I_{p}^{(1,2)} = -\frac{1}{4} \frac{1}{p\cdot k_1 + p\cdot k_2 - k_1\cdot k_2} \left(\frac{\not{e}_1 \not{k}_1 \not{e}_2 \not{k}_2 - \not{e}_2 \not{k}_2 \not{e}_1 \not{k}_1}{k_1\cdot k_2} \right) \not{J}$$

$$I_{q}^{(1,2)} = -\frac{1}{4} \not{J} \frac{1}{q\cdot k_1 + q\cdot k_2 - k_1\cdot k_2} \left(\frac{\not{k}_1 \not{e}_1 \not{k}_2 \not{e}_2 - \not{k}_2 \not{e}_2 \not{k}_1 \not{e}_1}{k_1\cdot k_2} \right)$$

Matrix Element: $q\bar{q} \to Jgg$ - part proportional to $T^B T^A$ fermion spinors dropped

$$I_{lr}^{(2,1)} = \left(\frac{p\cdot e_2}{p\cdot k_2} - \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{\not e_2 \not k_2}{2p\cdot k_2} \right) \not J \left(\frac{\not k_1 \not e_1}{2q\cdot k_1} + \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{q\cdot e_1}{q\cdot k_1} \right)$$

$$I_{ll}^{(2,1)} = \frac{p\cdot k_1}{p\cdot k_2 + p\cdot k_1 - k_2\cdot k_1} \left(\frac{p\cdot e_2}{p\cdot k_2} - \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{\not e_2 \not k_2}{2p\cdot k_2} \right) \left(\frac{p\cdot e_1}{p\cdot k_1} - \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{\not e_1 \not k_1}{2p\cdot k_1} \right) \not J$$

$$I_{rr}^{(2,1)} = \not J \frac{q\cdot k_2}{q\cdot k_2 + q\cdot k_1 - k_2\cdot k_1} \left(\frac{q\cdot e_2}{q\cdot k_2} - \frac{k_1\cdot e_2}{k_1\cdot k_2} - \frac{\not k_2 \not e_2}{2q\cdot k_2} \right) \left(\frac{q\cdot e_1}{q\cdot k_1} - \frac{k_2\cdot e_1}{k_2\cdot k_1} - \frac{\not k_1 \not e_1}{2q\cdot k_1} \right)$$

$$I_{e}^{(2,1)} = \not J \left(1 - \frac{p\cdot k_1}{p\cdot k_2 + p\cdot k_1 - k_2\cdot k_1} - \frac{q\cdot k_2}{q\cdot k_2 + q\cdot k_1 - k_2\cdot k_1} \right) \left(\frac{k_2\cdot e_1}{k_2\cdot k_1} \frac{k_1\cdot e_2}{k_2\cdot k_1} - \frac{e_2\cdot e_1}{k_2\cdot k_1} \right)$$

$$I_{p}^{(2,1)} = -\frac{1}{4} \frac{1}{p\cdot k_2 + p\cdot k_1 - k_2\cdot k_1} \left(\frac{\not e_2 \not k_2 \not e_1 \not k_1 - \not e_1 \not k_1 \not e_2 \not k_2}{k_2\cdot k_1} \right) \not J$$

$$I_{q}^{(2,1)} = -\frac{1}{4} \not J \frac{1}{q\cdot k_2 + q\cdot k_1 - k_2\cdot k_1} \left(\frac{\not k_2 \not e_2 \not k_1 \not e_1 - \not k_1 \not e_1 \not k_2 \not e_2}{k_2\cdot k_1} \right)$$

HEPEVT and HepMC event records

1. Since many years interface of PHOTOS to F77 event record HEPEVT is available. It is distributed until now together with TAUOLA, as explained in Comput. Phys. Commun. 174 (2006) 818
2. At present interface to C++ HepMC event record structure is near completion www.ph.unimelb.edu.au/˜ndavidson/photos/doxygen/index.html
3. Physics quality of that HepMC interface is already the same as its FORTRAN predecessor, but tests are less profound and documentation require editorial effort.
4. Pilot users are welcome.
5. In both cases functioning of algorithm depends on actual content of event record. Program must be able to find decay vertex like $Z \to \mu^+\mu^-$ and decipher its kinematic. Energy momentum conservation must be obeyed. Final state particles should be on mass shell.
6. Exception to these rules may be sometimes accepted, but then care of possible misfunctions must be taken.

7. Program can generate bremsstrahlung with other than W,Z decays. It is extensively used for B meson cascades for example.

Summary and physics contexts

1. PHOTOS Monte Carlo can be used for precision simulation of FSR bremsstrahlung in processes mediated by Z/γ' and W's
2. Correlated samples with bremsstrahlung on/off can be obtained.
3. FSR radiation is of course not a complete set of physics effects one has to take into account.
4. QED FSR, QED ISR, QED ISR-FSR interference, genuine weak corrections: can be separated
5. **genuine weak corrections** A key element of separating electroweak corrections into parts is isolation of weak corrections. This class of correction includes also corrections to Z/γ/W propagators. A lot of work was done in that direction at LEP time. I am using results of D. Barding group. With the help of SANC library extra weight to implement these corrections can be calculated. We have functioning algorithm for that purpose available thanks to our other project TAUOLA C++ interface: arXiv:1002.0543, but at present it is only for τ-pair production.

6. **QED ISR**. Its effects should be simulated together with Parton Shower and predictions including discussion of theoretical uncertainties include QCD, may be even higher order effects. Let me quote however one sentence from abstract of recent paper on LEP data: J. Abdallah et al.[DELPHI] Study of the Dependence of Direct Soft Photon Production on the Jet Characteristics in Hadronic Z 0 Decays. EPJC 67 (2010) 343 Up to a scale factor of about four, which characterizes the overall value of the soft photon excess, a similarity of the observed soft photon behaviour to that of the inner hadronic bremsstrahlung predictions is found for the momentum, mass, and jet charged multiplicity dependences.

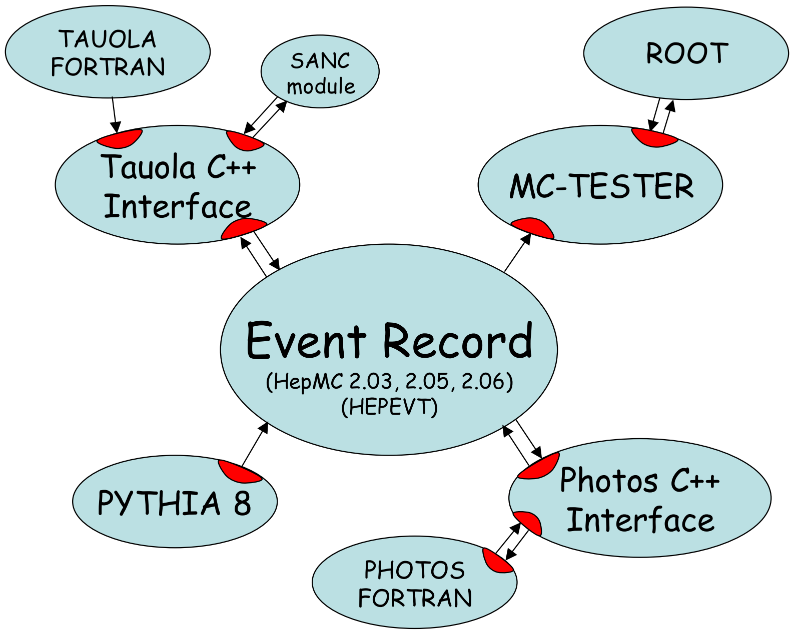
7. How relevant this message is for reversed process of lepton production from hadronic initial state? I think it may be advantageous from certain precision level to discuss ISR if possible, separately fom other electro weak corrections as well. At least for the purpose of discussion of systematic errors

8. **QED ISR-FSR interference** For semi inclusive observables size of this correction is of order $\frac{\alpha}{\pi}\frac{\Gamma}{M}$. Supression factor is easily understood. It is

because of lifetime of intermediate boson. If selection is affecting soft photons then this correction can grow to 1% level. Fixed order perturbation calculation should be enough to keep things under control.

EXTRA TRANSPARENCIES

Simulation parts communicate through event record:



- Parts:

- hard process: (Born, weak, new physics),
- parton shower,
- τ decays
- QED bremsstrahlung

- High precision achieved

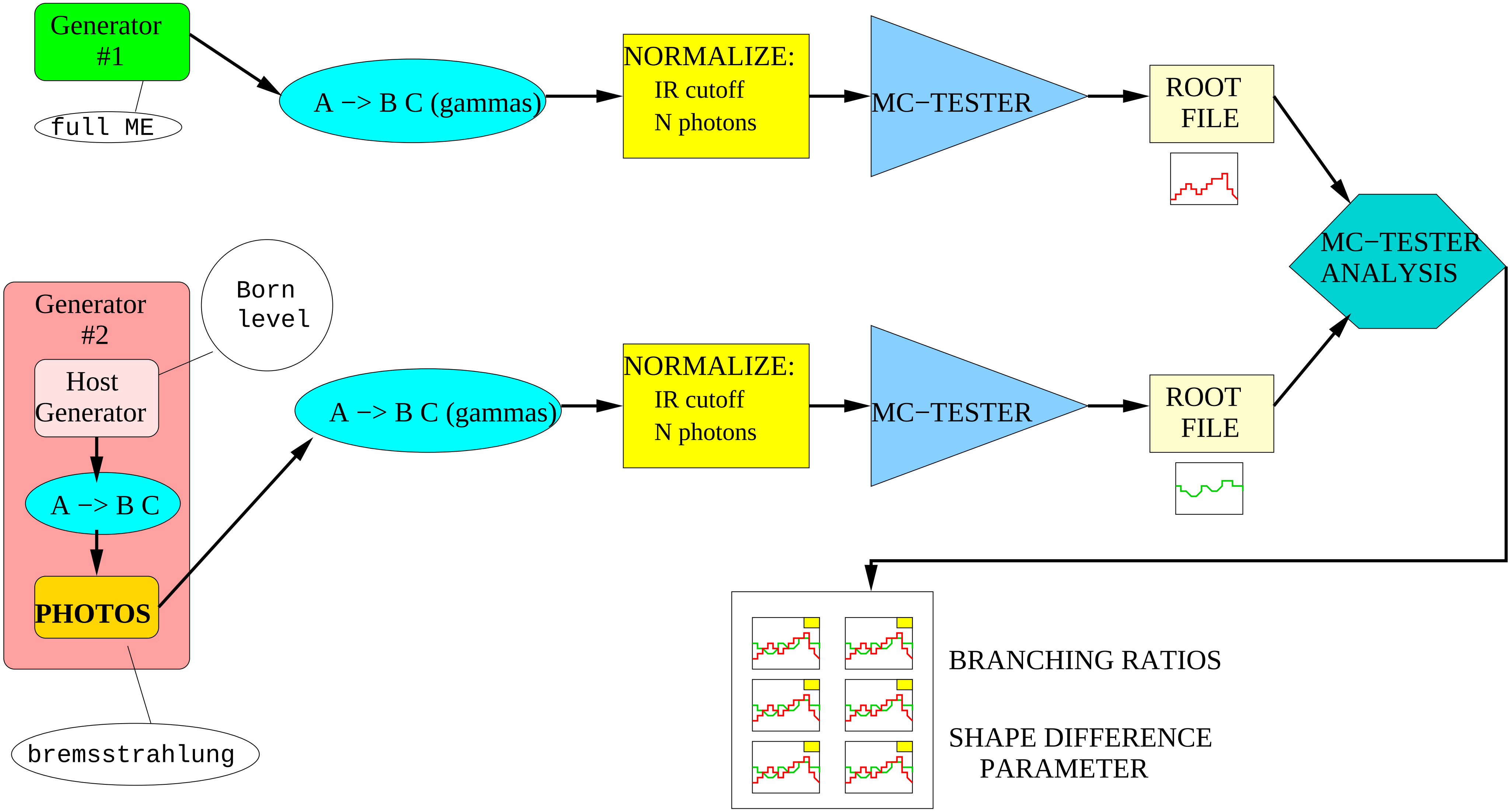
- Detector studies: acceptance, resolution lepton with or wihout photon.

Such organization requires:

- Good control of factorization (theory)
- Good understanding of tools on user side.

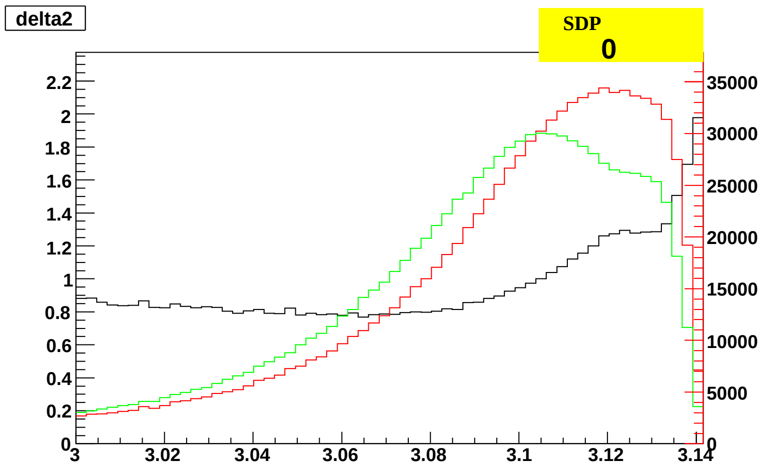
Extra transparencies: MC-TESTER

MC-TESTER to test PHOTOS/TAUOLA

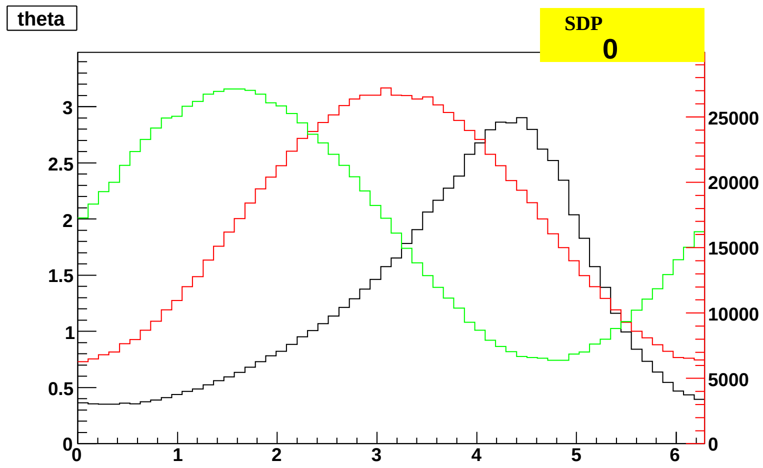


Extra transparencies: MC-TESTER

Example: Distribution for Higgs parity



(a) $\pi^+\pi^-$ acollinearity distribution ($\approx \pi$))

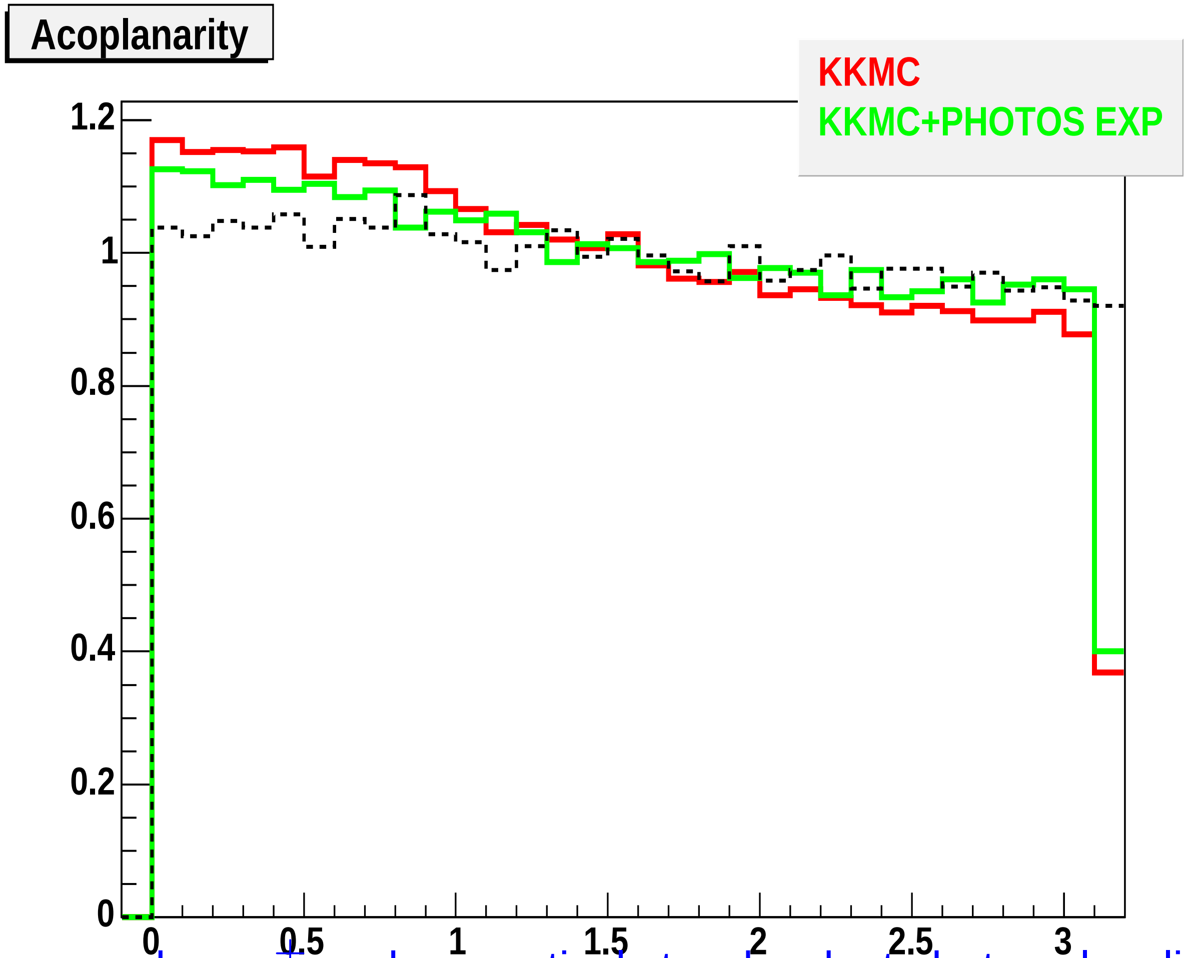


(b) $\pi^+\pi^-$ acoplanarity distribution

Figure 3: Transverse spin observables for the H boson for $\tau^\pm \to \pi^\pm \nu_\tau$. Distributions are shown for scalar higgs (red), scalar-pseudoscalar higgs with mixing angle $\frac{\pi}{4}$ (green) and the ratio between the two (black).

Extra transparencies: MC-TESTER

Acoplanarity distribution – Looks good



Two plane spanned on μ^+ and respectively two hardest photons localized in the same hemisphere as μ^+. In exlusive exponentiation this asymmetry appears with second order matrix element only.

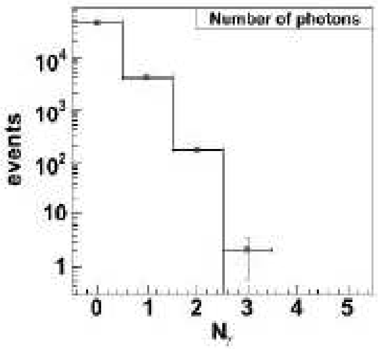
A successful validation example..

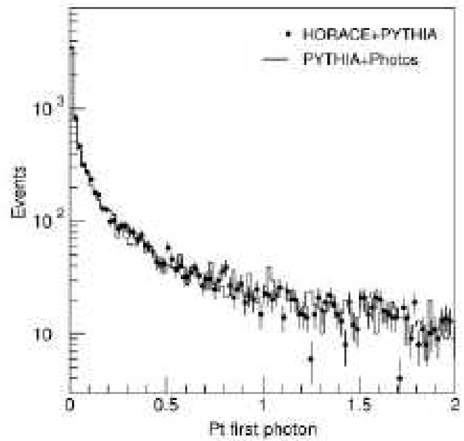
- Comparison between PHOTOS (supposed to be an approximate algorithm in principle) and HORACE (exact QED DGLAP solution):
  - Turns out that PHOTOS is doing an excellent job!

HORACE vs Photos (3)

- Photon multiplicity and transverse momentum spectrum done with standalone generators (outside Athena)

perfect agreement for all p_T range





with cut $p_T(\gamma) > 500$ MeV perfect agreement also in Athena iterfaced version to third hard photon

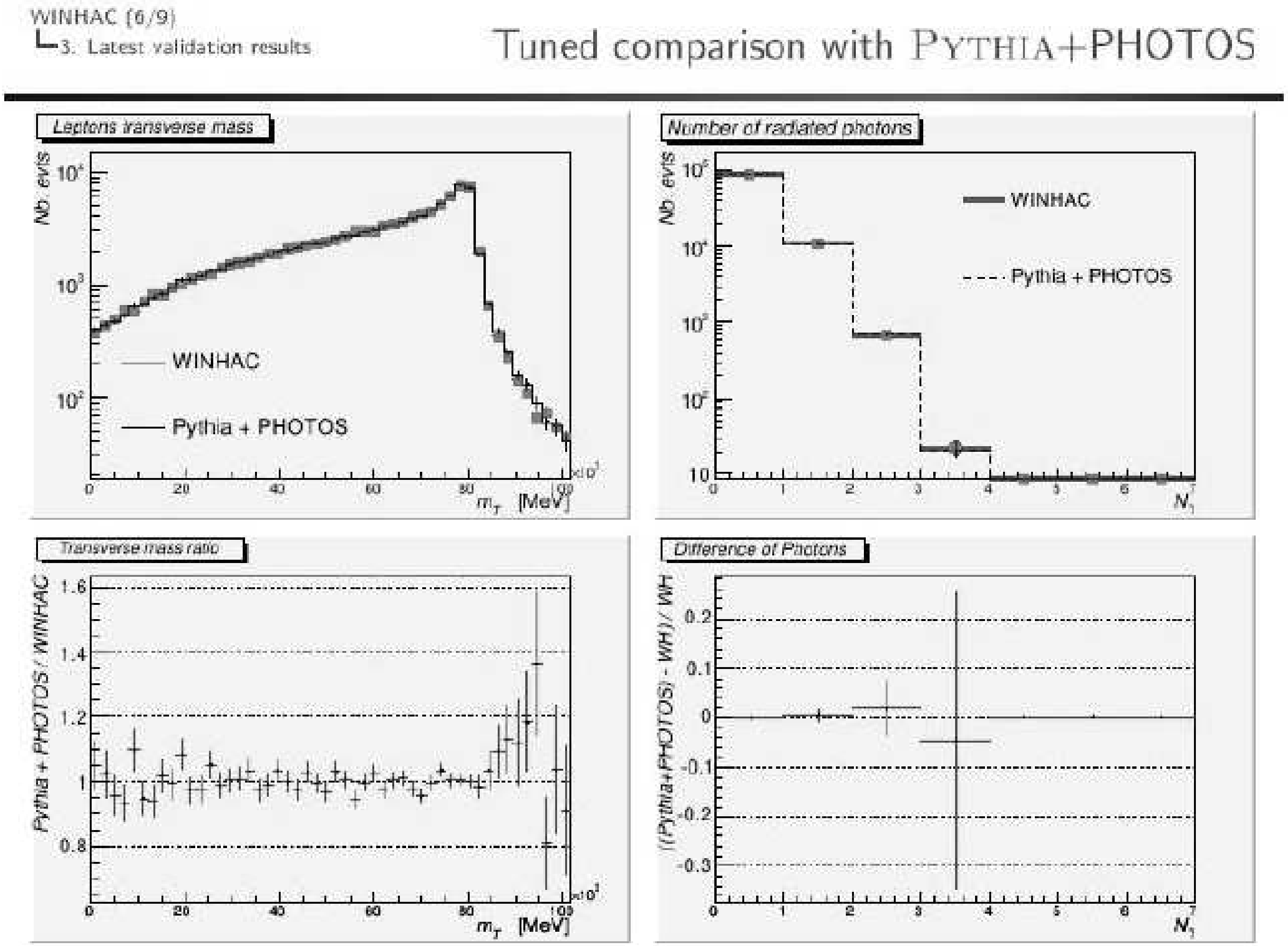
Pythia + HORACE

Pythia + Photos

29/05/06 M. Bellomo - ATLAS Monte Carlo 15

This is for Z production at LHC. Feb. 2007

And another one.. Our Winhac effort



This is for W production at LHC. Feb. 2007

MC Generators for LHC at ATLAS

ATLAS Overview Week (February 2007)

Borut Kersevan
Jozef Stefan Inst.
Univ. of Ljubljana

ATLAS experience:

- Generators used
- Validation procedures
- Interesting examples

I hope that I have convinced you that PHOTOS is beyond ‘approximate algoritm’ class, thus excellent agreement was not accidental. Programs validation for ATLAS. From talk in CERN main auditorium February 2007. These distributions are not sensitive to second order matrix elements (two hard photons).