PHOTOS Monte Carlo and its theoretical accuracy

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- PHOTOS Monte Carlo was at first simple utility to get crude simulation of QED radiative corrections in decays.
- It had to be universal; first aid tool. Precision came years later.
- PHOTOS may be of interest for you: supplementary tool.

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

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

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Purpose of the talk

RADCOR-1998 summary talk, R. Peccei said: talks on "all these experimental codes"were also given.

One may not like the truth, BUT: phenomenology Monte Carlo programs are indeed at first for practical applications.

Theoretical aspects are essential for discussion of theoretical uncertainties of experimental papers: that is complex affair, even for PHOTOS; nonetheless let me try ...

-1- **Iteration properties** for phase space: LL and exact: TAUOLA, PHOTOS, KKMC.

-2- **Iteration properties** of matrix elements, and matrix elements themselves.

-3- **Note, mathematical beauty in Monte Carlo design**: tangent spaces, induced measures. Triangulation and structure of singularities, CW complexes.

-4- At the end I will show numerical examples.

PHOTOS: short presentation

Main References

- E. Barberio and Z. Was, Comput. Phys. Commun. **79**, 291 (1994).

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- Z. Was, Eur. Phys. J. C **44** (2005) 489
- P. Golonka and Z. Was, Eur. Phys. J. C **45** (2006) 97, ibid, C50:53-62,2007
- G. Nanava, Z. Was, Eur.Phys.J.C51:569-583,2007

Main References for other projects.

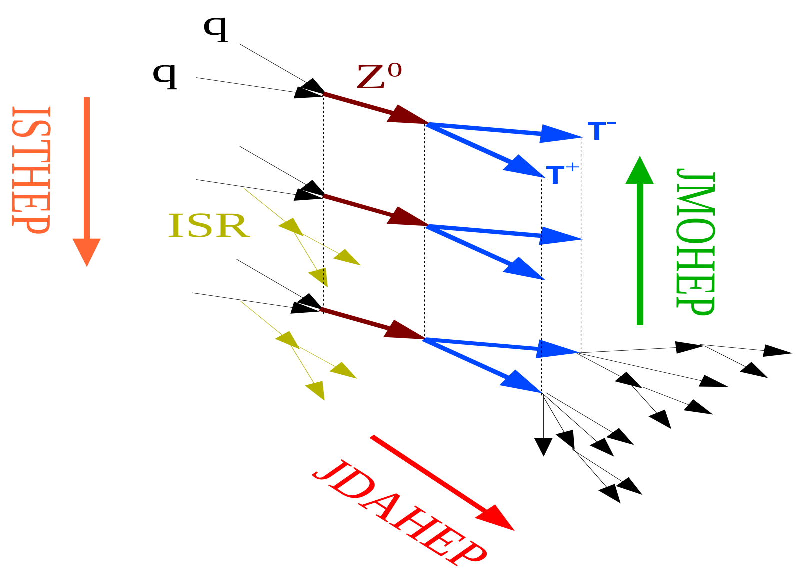
- S. Jadach, Yennie-Frautschi-Suura soft photons in Monte Carlo event generators, MPI-PAE/PTh 6/87,
- E. Richter-Was and J. Szwed, Z. Phys. C **31**, 253 (1986)
- F. Berends, S. Jadach, R. Kleiss, Nucl. Phys. **B202** (1982) 63
- S. Jadach, M. Jezabek, J. H. Kuhn, ZW CPC 64 (1990); 70 (1992); 76 (1993)

PHOTOS: main properties of methodology

Presentation

- Since 1989 PHOTOS (by E.Barberio, B. van Eijk, Z. W., P. Golonka) is used to simulate the **trivial parts** of radiative corrections in decays.
- Full events combining complicated tree structure of production and subsequent decays are fed from other generators through *event records*.
- At every event tree branching, PHOTOS intervene. With probability extra photon(s) may be added and kinematics of other particles adjusted.
- PHOTOS works on four-momenta provided from other programs.
- Precision of the simulation at the pre-PHOTOS level is thus essential for PHOTOS performace!
- Phase space is a keystone in construction. It is necessary for program universality and precision as well.

Problems With Event Record (we skip today)



1. Hard process
2. with shower
3. after hadronization
4. Event record overloaded with physics beyond design $\longrightarrow$ gramar problems.
5. Here we have basically LL phenomenology only.

This Is Physics Not F77!

Similar problems are in any use of full scale Monte Carlos, lots of complaints at MC4LHC workshop, `HEPEVTrepair` utility (C. Biscarat and ZW) being probed in D0.

Design of event structure WITH some grammar requirements AND WITHOUT neglecting possible physics is needed NOW to avoid large problems later.

Phase Space: (trivialities)

Let us recall the element of Lorentz-invariant phase space (*Lips*):

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

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.

Pase Space Formula of the talk

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

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

1. One can verify that if $dLips_n(P)$ is exact, this formula lead to exact parametrization of $dLips_{n+1}(P)$ as well
2. Practical use: Take the confi gurations from n-body phase space.
3. Turn it back into some coordinate variables.
4. construct new kinematic confi guration 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 fi nal state.

Phase Space: (main formula)

If we choose

$$G_n \ : \ M^2_{2\dots n}, \theta_1, \phi_1, M^2_{3\dots n}, \theta_2, \phi_2, \dots, \theta_{n-1}, \phi_{n-1} \ \rightarrow \ \bar{k}_1 \dots \bar{k}_n \qquad (2)$$

and

$$G_{n+1} \ : \ k_\gamma, \theta, \phi, M^2_{2\dots n}, \theta_1, \phi_1, M^2_{3\dots n}, \theta_2, \phi_2, \dots, \theta_{n-1}, \phi_{n-1} \ \rightarrow \ k_1 \dots k_n, k_{n+1} \qquad (3)$$

then

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

The ratio of the Jacobian's (factors $\lambda^{1/2}$ etc.) form the factor W_n^{n+1}, which in our case is rather simple,

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

- All details depend on definition of G_n.

- The fully differential distribution from MUSTRAAL (1982):

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

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

- after trivial manipulation it can be written as:

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

$$+ \frac{1}{(k'_+ + k'_-)} \frac{1}{k'_+} \Big[\frac{\mathrm{d}\sigma_B}{\mathrm{d}\Omega}(s,t,u') + \frac{\mathrm{d}\sigma_B}{\mathrm{d}\Omega}(s,t',u) \Big] \Bigg\}$$

- In PHOTOS, algebraically simpler, expression is used at crude level:

$$X_f^{PHOTOS} = \frac{Q'^2\alpha(1-\Delta)}{4\pi^2 s} s^2 \Bigg\{$$

$$\frac{1}{k'_+ + k'_-} \frac{1}{k'_-} \quad \Big[(1+(1-x_k)^2) \frac{d\sigma_B}{d\Omega}\Big(s, \frac{s(1-\cos\Theta_+)}{2}, \frac{s(1+\cos\Theta_+)}{2}\Big)\Big] \frac{(1+\beta\cos\Theta_\gamma)}{2}$$

$$+ \frac{1}{k'_+ + k'_-} \frac{1}{k'_+} \quad \Big[(1+(1-x_k)^2) \frac{d\sigma_B}{d\Omega}\Big(s, \frac{s(1-\cos\Theta_-)}{2}, \frac{s(1+\cos\Theta_-)}{2}\Big)\Big] \frac{(1-\beta\cos\Theta_\gamma)}{2} \Bigg\}$$

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

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

- also factor $\Gamma^{total}/\Gamma^{Born} = 1 + 3/4\alpha/\pi$ defines first order (NLO) weight.

The differences are important

- The two expressions define weight to make out of PHOTOS complete first order.
- The PHOTOS expression separates (i) Final state bremsstrahlung (ii) electroweak parameters of the Born Cross section (iii) Initial state bremsstrahlung that is orientation of the spin quantization axis for Z.
- Process dependent weight would be heavy burden for most of PHOTOS users. Special weights are becoming available for the ones who need it.
- Of course all this has to be understood in context of Leading Pole approximation. For example initial-fi nal state interference breaks the simplifi cation. Limitations need to be controlled: Phys. Lett. B219:103,1989.

Scalar QED for matrix elements in B decays tests of 2007 by G. Nanava

- The one-loop QED correction to the decay width can be represented as the sum of the Born contribution with the contributions due to virtual loop diagrams and soft and hard photon emissions.

$$d\Gamma^{\rm Total} = d\Gamma^{\rm Born}\left\{1+\frac{\alpha}{\pi}\left[\delta^{\rm Soft}(m_\gamma,\omega)+\delta^{\rm Virt}(m_\gamma,\mu_{UV})\right]\right\}+d\Gamma^{\rm Hard}(\omega)$$

- where for **Neutral meson decay channels**, hard photon contribution:

$$d\Gamma^{\rm Hard} = |A^{\rm Born}|^2 4\pi\alpha\left(q_1\frac{k_1.\epsilon}{k_1.k_\gamma}-q_2\frac{k_2.\epsilon}{k_2.k_\gamma}\right)^2 dLips_3(P\to k_1,k_2,k_\gamma)$$

- for **Charged meson decay channels**, hard photon contribution:

$$d\Gamma^{\rm Hard} = |A^{\rm Born}|^2 4\pi\alpha\left(q_1\frac{k_1.\epsilon}{k_1.k_\gamma}-q\frac{P.\epsilon}{P.k_\gamma}\right)^2 dLips_3(P\to k_1,k_2,k_\gamma)$$

Status of 1991

- Extensions from $Z \to l\bar{l}$ decays was done without much of theoretical work.
- In particular no much work to explain interference implementation was done.
- Sole purpose was to have any QED bremsstrahlung in all channels of τ decays

Steps toward version of 1994

- Similar phase-space as in PHOTOS is in exact, QED first order, ME for $\tau \to l\nu_\tau\bar{\nu}_l(\gamma)$ decays of TAUOLA; S. Jadach, M. Jeżabek, J. Kühn, Z. W. 1994
- Interference between emissions from different charged lines, still treated badly!
- But many new tests, of mixed technical sophistication for W, B, K decays.
- Double bremsstrahlung enabled, extensions to higher orders, prepared, but blocked by rounding error trap and lack of interest from users.

Iteration

- 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.
- Technology was at hand: papers by J. Szwed and E. Richter-Was (1984-86) and Jadach Skrzypek (1991-92).
- Formal solution of evolution equation reads

$$D(x,\beta_{ch}) = \delta(1-x)+\beta_{ch}P(x)+\frac{1}{2!}\beta_{ch}^2\{P\times P\}(x)+\frac{1}{3!}\beta_{ch}^3\{P\times P\times P\}(x)+\dots \tag{6}$$

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) and lead directly to this solution. In 1994 it was truncated to second order.

Multiple charge final states

- No problems of principle with multiple charge final states.
- Not only LL and soft regions remain OK, but some non leading corrections are automatically installed, see tests.
- Full phase space for all photon(s) covered.
- Nice observation: For mutiple charges. phase space Jacobians need to be approximated. Otherwise problems with precision: **One has to be consistent with approximations for matrix element.**
- Refinements supported with tests using second order matrix elements from papers by E. Richter-Was (years 1994-1996).

kernels for other than $\frac{1}{2}$ spin were taken from papers by Szwed and Richter-Was on supersymetic QCD (1990)

What happen if we multiply iterate $\mathcal{P}$hase $\mathcal{S}$pace transformation

...we generalize formula (1) to the case of l particles added and obtain:

$$dLips_{n+l}(P \to k_1...k_n, k_{n+1}...k_{n+l}) = \frac{1}{l!} \prod_{i=1}^{l} \Big[dk_{\gamma_i} d\cos\theta_{\gamma_i} d\phi_{\gamma_i} W^{n+i}_{n+i-1} \Big]$$
$$\times dLips_n(P \to \bar{k}_1...\bar{k}_n), \qquad (7)$$
$$\{k_1, \ldots, k_{n+l}\} = \mathbf{T}\big(k_{\gamma_l}, \theta_{\gamma_l}, \phi_{\gamma_l}, \mathbf{T}\big(\ldots, \mathbf{T}\big(k_{\gamma_1}, \theta_{\gamma_1}, \phi_{\gamma_1}, \{\bar{k}_1, \ldots, \bar{k}_n\}\big) \ldots\big).$$

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 $M^2_{2\ldots n}, \theta_1, \phi_1, \ldots, \theta_{n-1}, \phi_{n-1} \;\; \longrightarrow \;\; \bar{k}_1 \ldots \bar{k}_n$ of (2,3), which are also redefi ned at each step of the iteration. Also intermediate steps require explicit construction of temporary $\bar{k}'_1 \ldots \bar{k}'_n \ldots \bar{k}'_{n+m}$

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

Crude Distribution for multiple emission

If we add arbitrary factors $f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i})$ and sum over l we obtain:

$$\sum_{l=0} \exp(-F)\frac{1}{l!}\prod_{i=1}^{l} f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i}) dLips_{n+l}(P \to k_1...k_n,k_{n+1}...k_{n+l}) =$$
$$\sum_{l=0} \exp(-F)\frac{1}{l!}\prod_{i=1}^{l}\Big[f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i}) dk_{\gamma_i} d\cos\theta_{\gamma_i} d\phi_{\gamma_i} W^{n+i}_{n+i-1}\Big] \times$$
$$dLips_n(P \to \bar{k}_1...\bar{k}_n), \tag{8}$$
$$\{k_1,\dots,k_{n+l}\} = \mathbf{T}\Big(k_{\gamma_l},\theta_{\gamma_l},\phi_{\gamma_l},\mathbf{T}\Big(\dots,\mathbf{T}\Big(k_{\gamma_1},\theta_{\gamma_1},\phi_{\gamma_1},\{\bar{k}_1,\dots,\bar{k}_n\}\Big)\dots\Big),$$
$$F = \int_{k_{min}}^{k_{max}} dk_\gamma d\cos\theta_\gamma d\phi_\gamma f(k_\gamma,\theta_\gamma,\phi_\gamma).$$

- The Green parts of rhs. alone, give crude distribution over tangent space (orthogonal set of variables k_i,θ_i,ϕ_i).

• Factors f must be integrable over tangent space. Regulators of singularities necessary.

• If we request that

$$\sigma_{tangent} = 1 =$$

$$\sum_{l=0} \exp(-F)\frac{1}{l!}\prod_{i=1}^{l}\Big[f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i})dk_{\gamma_i}d\cos\theta_{\gamma_i}d\phi_{\gamma_i}\Big]$$

and that sum rules originating from perturbative approach can be used to get virtual corrections, we will get Monte Carlo solution of PHOTOS type.

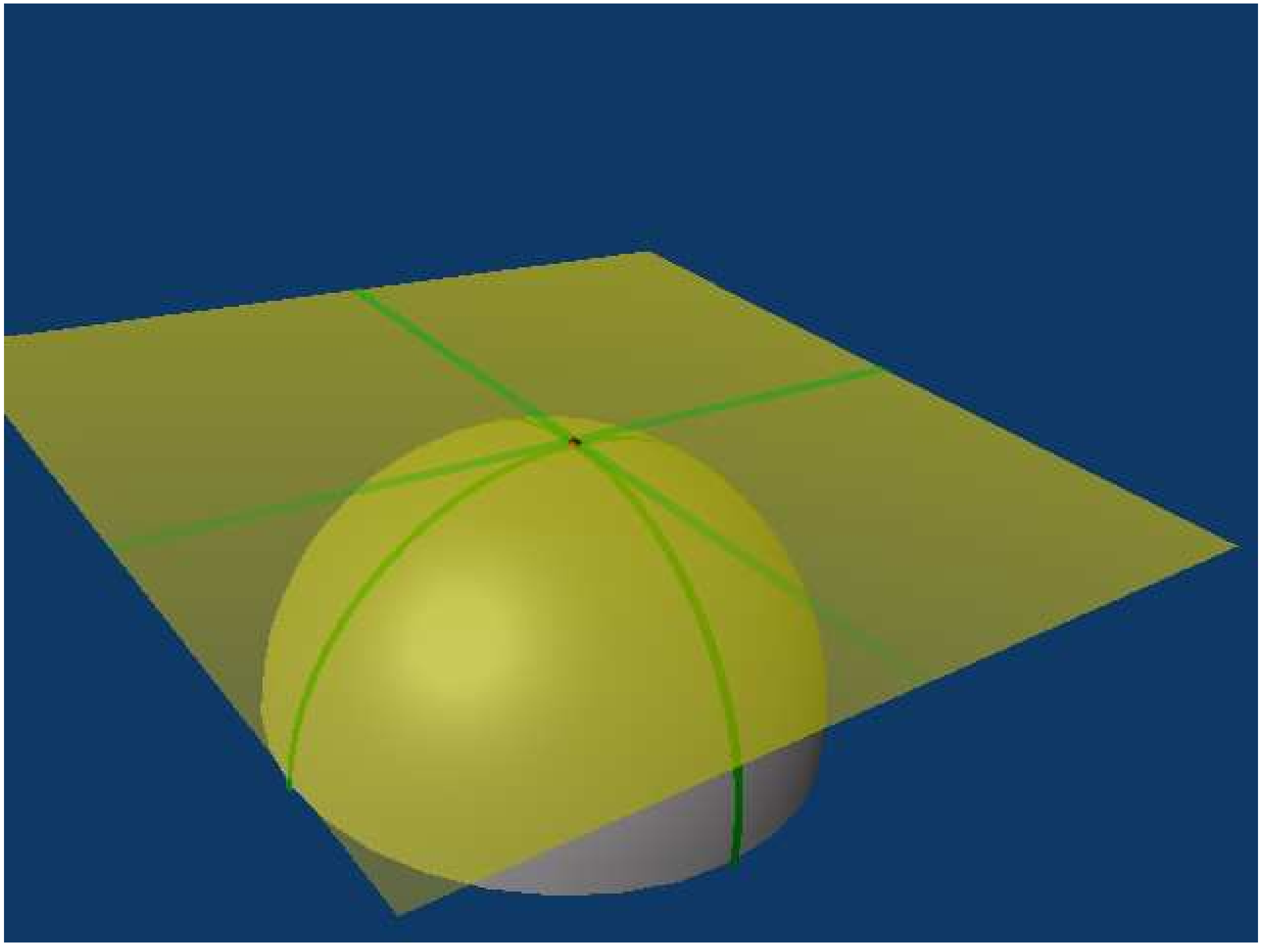
• For that to work, real emission and virtual corrections need to be calculated and their factorization properties analyzed.

• Choice of f must be synchronized with those results.

• If such conditions are fulfilled construction of Monte Carlo algorithm is possible

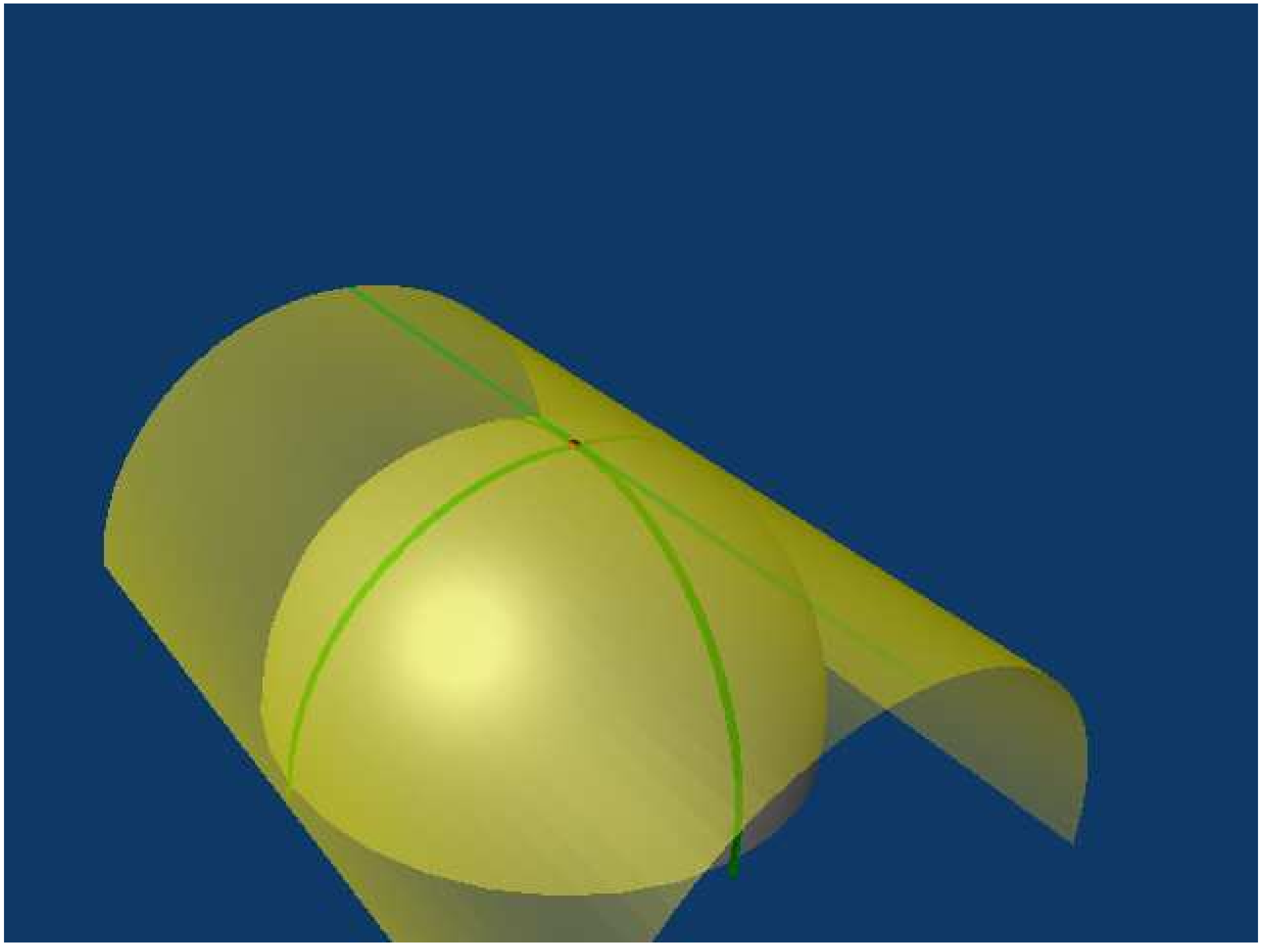
Heuristic CW complexes

We define our crude distribution over yellow space (surface=1) (represented by sum of: red point, green lines and flat yellow square)



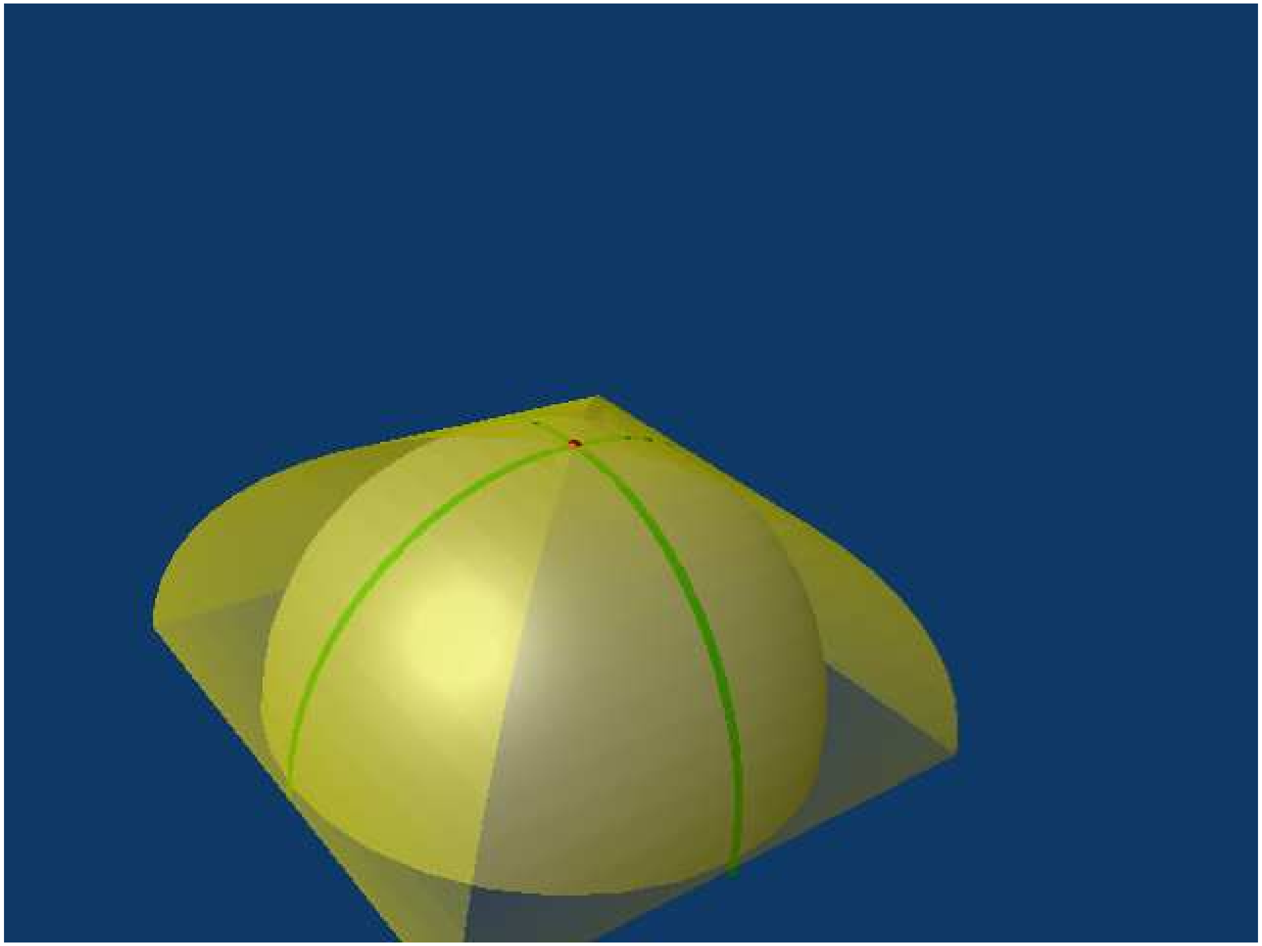
Heuristic CW complexes projection step 1

We project in steps, relative measure of point and lines on cylinder is larger than in previous step, overall measure remain 1.



Heuristic CW complexes projection step 2

Final distribution does not match the exact one, solely because approximation in matrix elements, phase space is exact.



Why it could work?

- because we could use our phase space parametrization, no obstacles of topological nature
- ‘distance’ between points from n- and $(n + l)$-body configurations defined
- we could construct triangulation(s) (better to say CW-complexes) matching structures of singularities.
- such CW-complexes for exact space and tangent space were identical
- to achieve that we could use properties of factorization
- infrared singularity being within perturbative domain was a bonus.
- We studied spin amplitudes a lot, and by naked eye!
- this is also a ‘to do’ list if extension to QCD are attempted

Analogies/inspirations

- Any Field Theory calculation, MC or not, relies Feynman diagrams and mathematical techniques. must be similar.
- Formula (3.1) from 1987 paper by S. Jadach is basically as tangent space of multi-photon PHOTOS (and not much different from $D(x, \beta_{ch})$):

$$\sigma(K) = exp\Big(\frac{2\alpha}{\pi}(\ln\frac{s}{m^2}-1)\ln\frac{k_s}{E}+\frac{\alpha}{\pi}\ln\frac{s}{m^2}\Big) \sum_{n=0}\frac{1}{n!}\prod_{m=1}^{n}\int_{k_s<k_m<K}\frac{d^3k_m}{k_m}\tilde{S}(k_1)\ldots\tilde{S}(k_n)\tilde{\beta}_0 \qquad (9)$$

- The difference appear in projection from this tangent space:
- Classical solution use conformal symmetry, one step projection from eikonal to real space is performed.
- In PHOTOS eikonal symmetry is not used. Iterative projection is used, somewhat similar as in TAUOLA.
- Two methods have advantages; provide exact phase space.

Phase Space is not everything

Elements of the picture we have formed:

- points, lines and surfaces on heuristic plots represented consecutive manifolds of phase spacers for n, n+2, n+3 dimensions, counted in number of Lorentz group representations multiplied and later divided by another one (energy-momentum constraints).

- For QED no worry of topological structure. It is trivial to assure that projection from tangent space to real one cover it all.

Matrix Element (small comments):

- We have seen nice properties of matrix element squared which were factorizing into Born-like distribution and photon factor.
- It was shown many years ago by Ronald Kleiss that such property does not hold beyond first order!
- Dead end? We have shifted to spin amplitudes and projections.
- Spin amplitudes can be divided into **gauge invariant segments**; some parts represent complete results of other processes other theories (eg. scalar QED)
- How deeply all this relates to MHV? Probably quite a bit, but ...
- ... theory of walking is not the best recipe of a baby to start walking after all.
- we need to worry about numerical stability too !

Iteration Exponentiation:

- Algorithm for single bremsstrahlung form important element in PHOTOS construction
- That is also explicit manifestation of perturbative calculation.
- Such building block is used for multiple emissions as well.
- In case of fixed order extensions directly, for exponentiation bit less.
- Formal expansion of Poissonian distribution into sum of binomial ones give example of one set of special function expansion into other one ($p = \lambda$, $q = 1 - p$).

$$\exp(-\lambda)\sum_{n=0}\frac{1}{n!}\lambda^n\mid_1 = \quad 1\cdot(p+q)^1$$

$$\exp(-\lambda)\sum_{n=0}\frac{1}{n!}\lambda^n\mid_2 = \quad \tfrac{1}{2}\cdot(p+q)^0+\tfrac{1}{2}\cdot(p+q)^2$$

$$\exp(-\lambda)\sum_{n=0}\frac{1}{n!}\lambda^n\mid_3 = \quad \tfrac{2}{6}\cdot(p+q)^0+\tfrac{3}{6}\cdot(p+q)^1+\tfrac{1}{6}\cdot(p+q)^3$$

$$\exp(-\lambda)\sum_{n=0}\frac{1}{n!}\lambda^n\mid_4 = \quad \tfrac{9}{24}\cdot(p+q)^0+\tfrac{8}{24}\cdot(p+q)^1+\tfrac{6}{24}\cdot(p+q)^2+\tfrac{1}{24}\cdot(p+q)^4$$

Nice, example of expansion coefficients, just ratios of integers.

Summary

Summary theoretical aspects

- **We have presented some elements of PHOTOS Monte Carlo construction.**
- **We have concentrated on phase space and its iterative description, to demonstrate that it is complete and that there are no approximations.**
- **Work on matrix elements was only marginally mentioned.**
- **But hopefully it was enough to show that process dependent weights can be installed whenever matrix elements are available.**
- **In particular, technical framework for discussion of electromagnetic form-factors is now ready.**
- **But hard work was only started, and simple cases were covered only ...**
- **let us now show, with some numerical results, how program perform:**

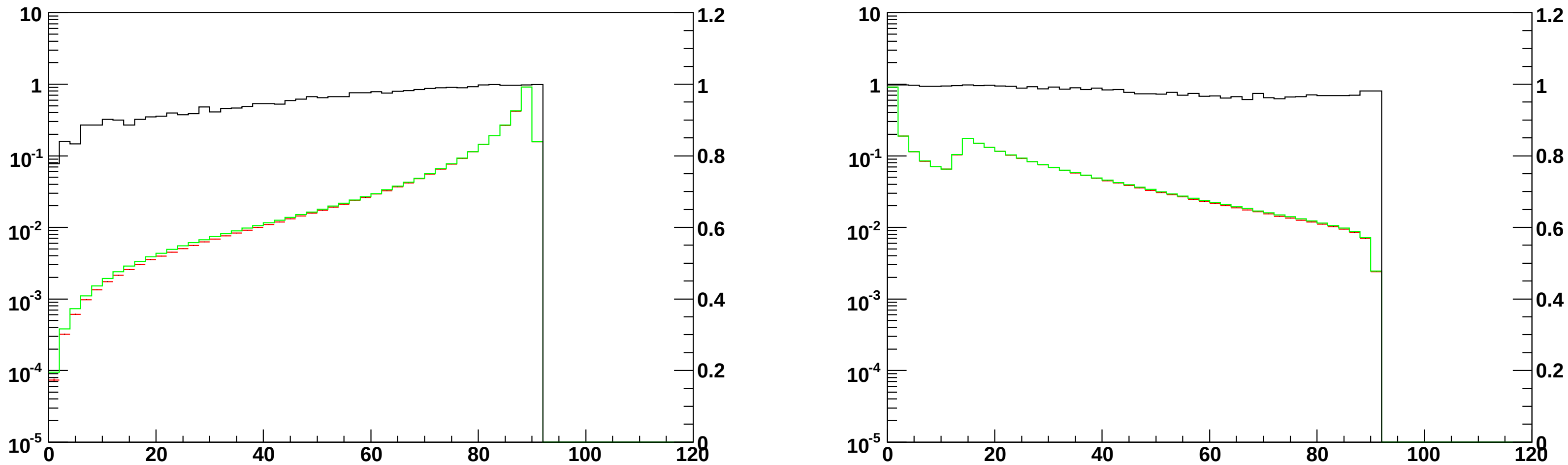


Figure 1: Comparison of standard PHOTOS and KORALZ for single photon emission. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.00534. In the right frame the invariant mass of $\mu^-\gamma$; SDP=0.00296. The histograms produced by the two programs (logarithmic scale) and their ratio (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.

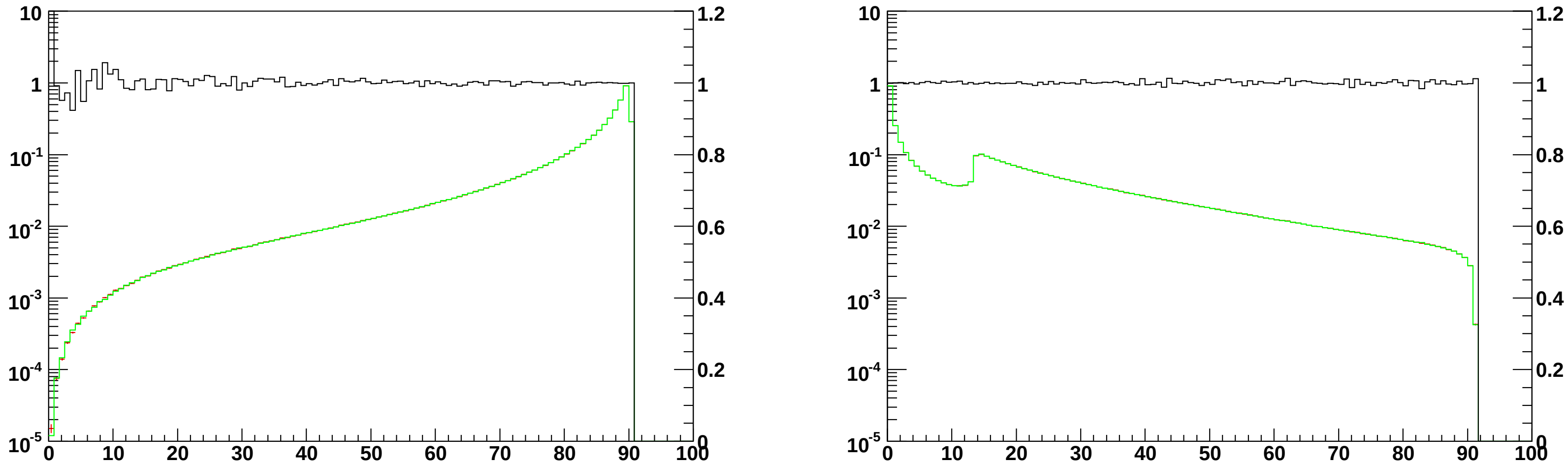
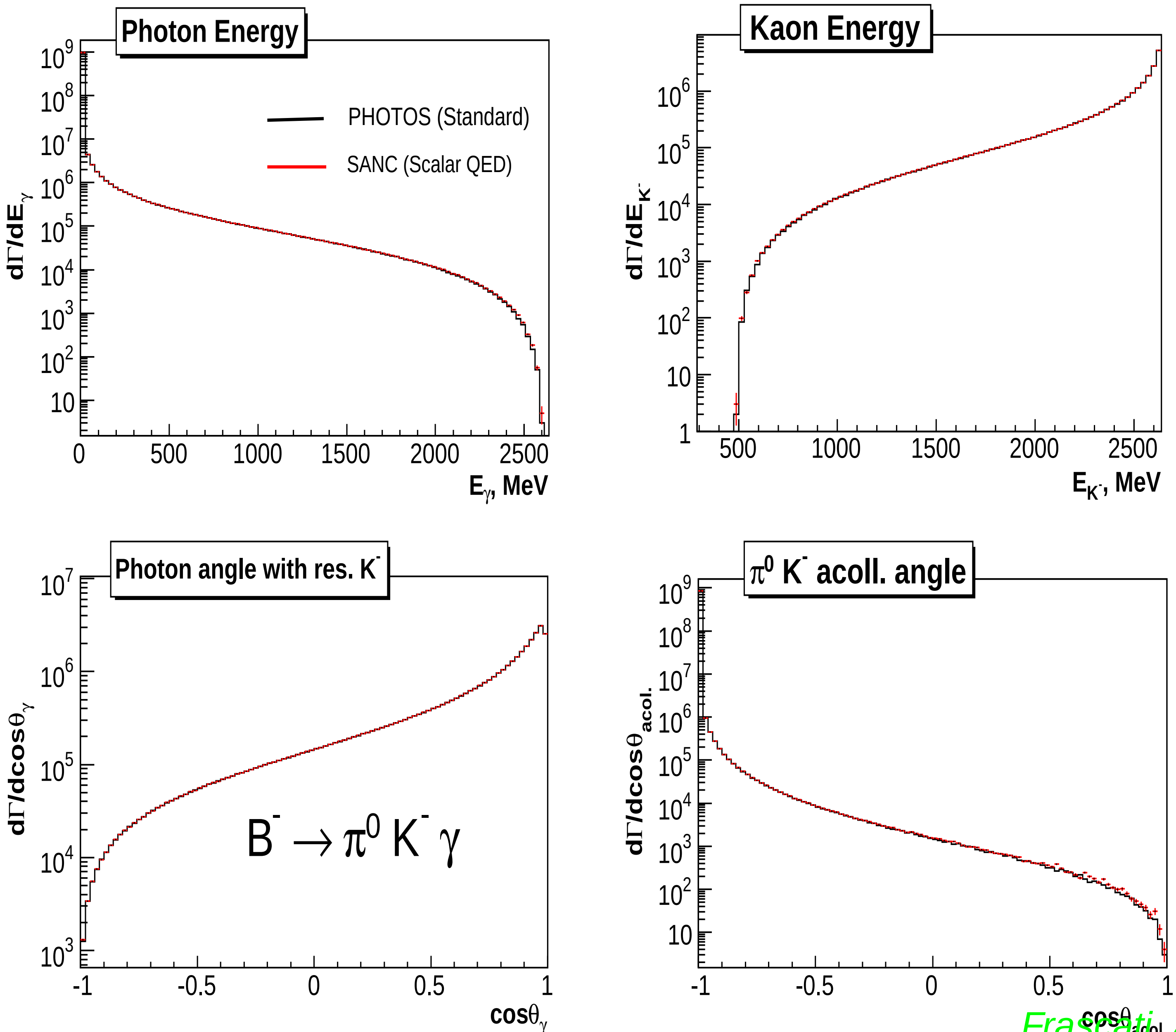
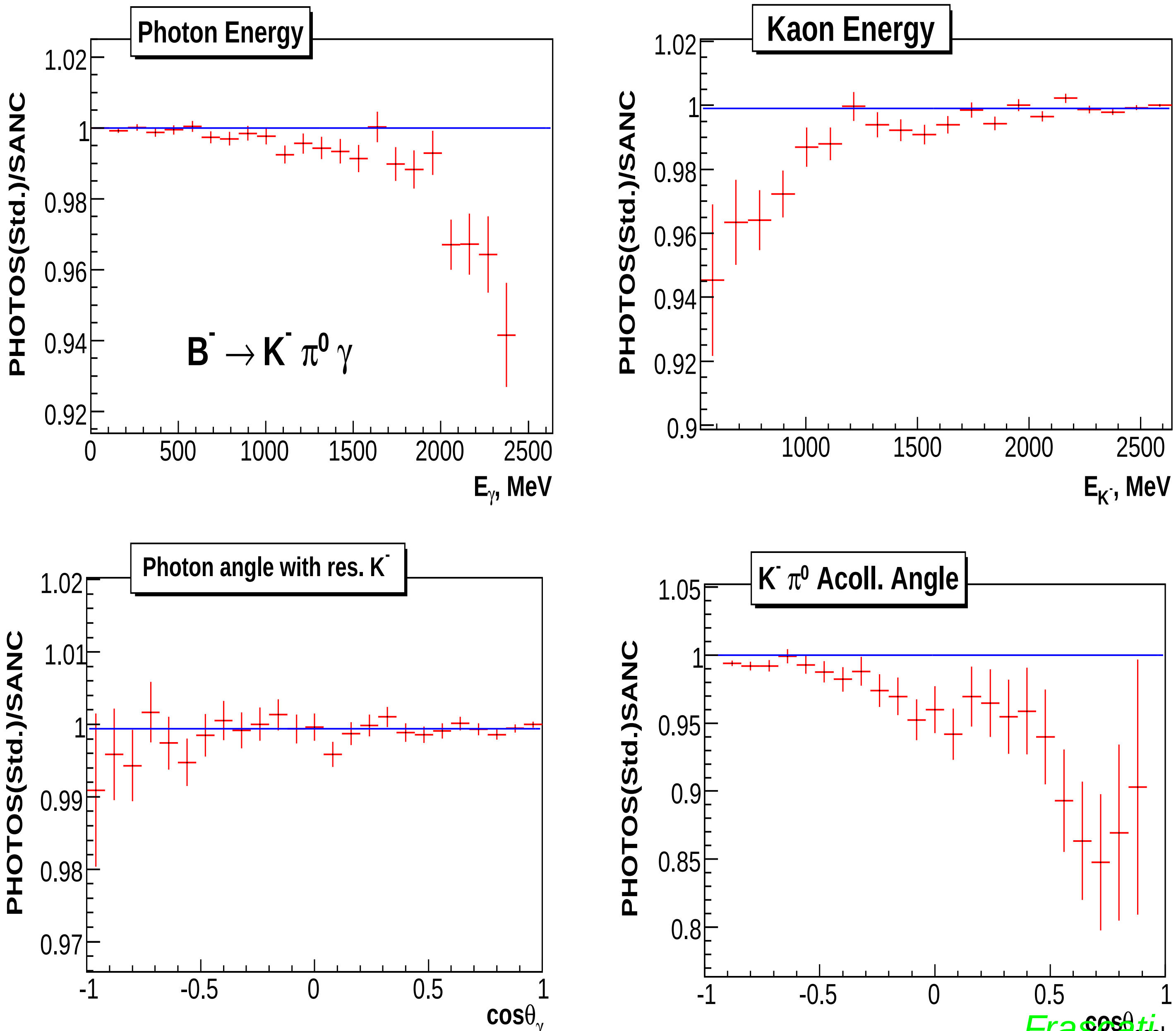


Figure 2: Comparisons of improved PHOTOS and KORALZ for single photon emission. In the left frame the invariant mass of the $\mu^+\mu^-$ pair. In the right frame the invariant mass of $\mu^-\gamma$ pair is shown. In both cases differences between PHOTOS and KORALZ are below statistical error. The fraction of events with hard photon was 17.4890 $\pm$ 0.0042% for KORALZ and 17.4926 $\pm$ 0.0042% for PHOTOS.

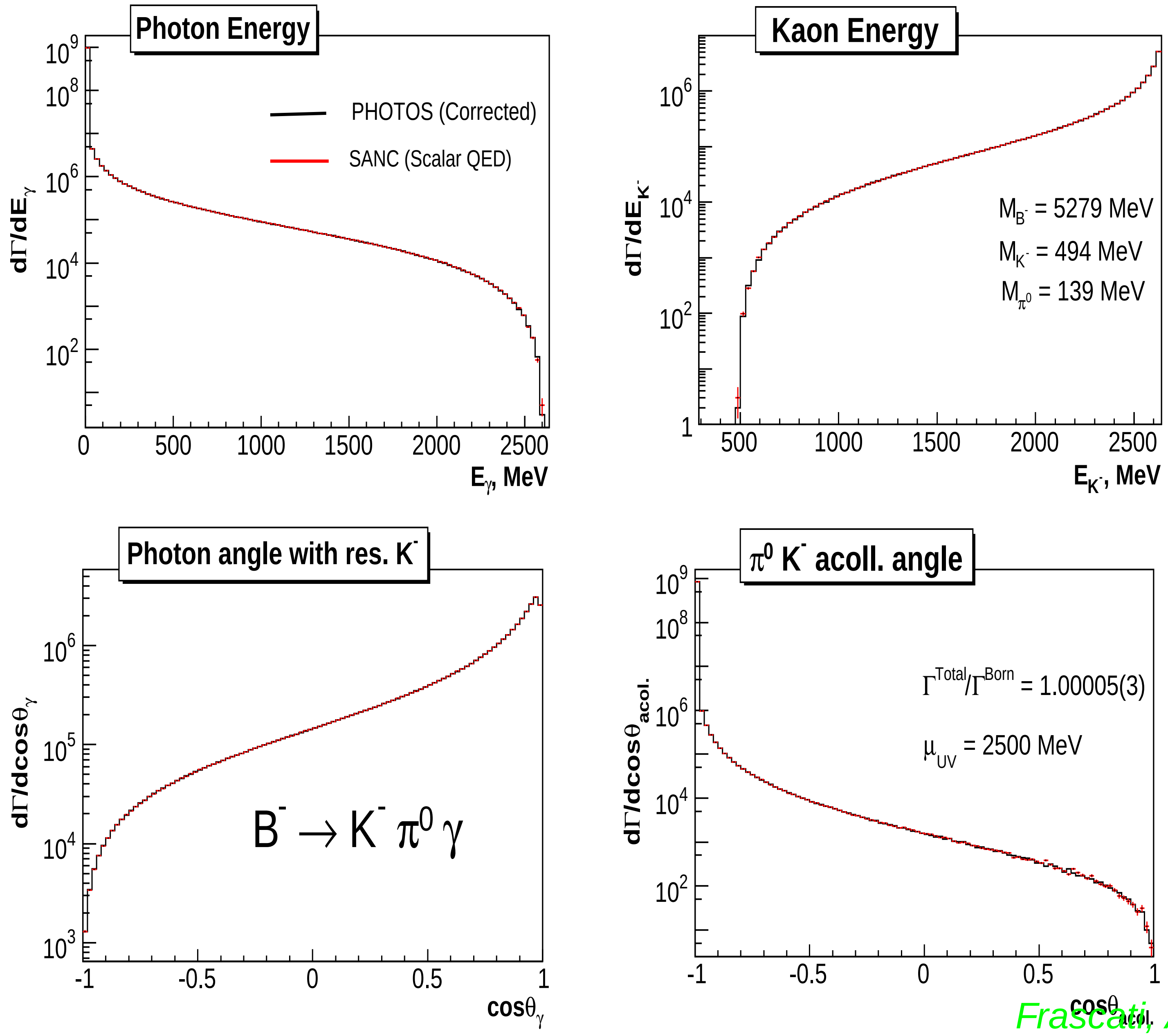
$B^- \to \pi^0 K^-$: standard PHOTOS looks good, but ...



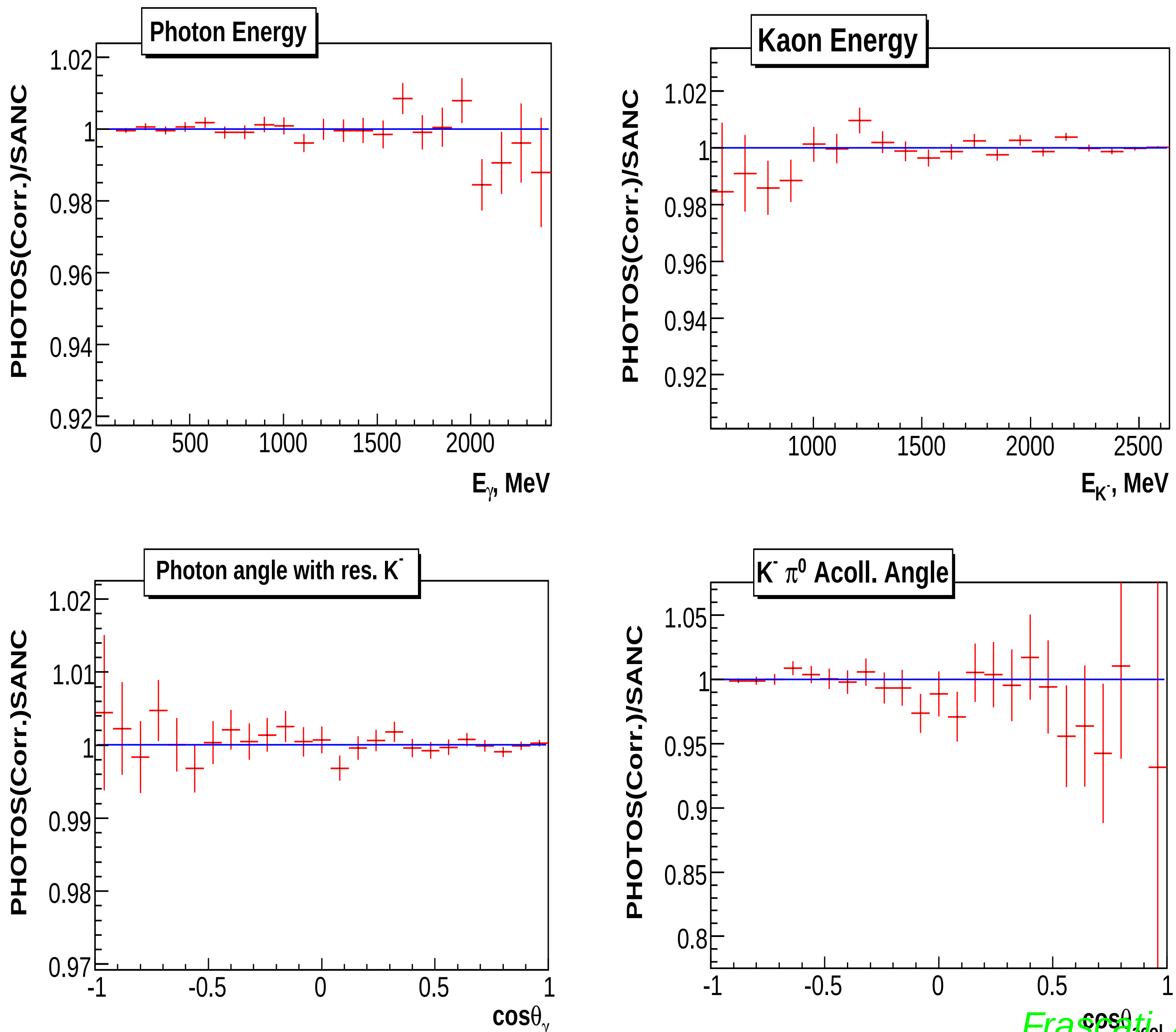
$B^- \to \pi^0 K^-$: standard PHOTOS not perfect



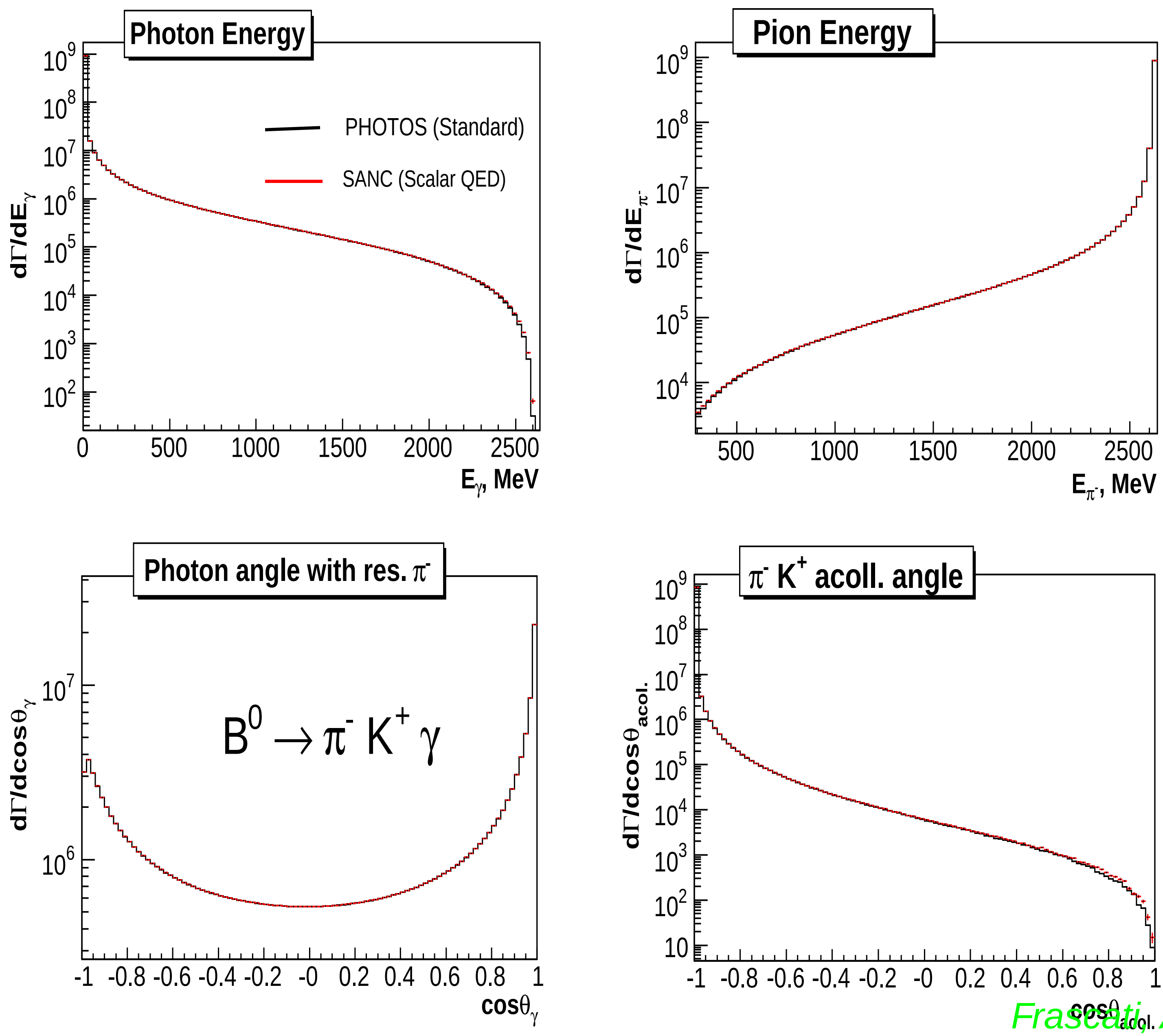
$B^- \to \pi^0 K^-$: NLO improved PHOTOS Looks good



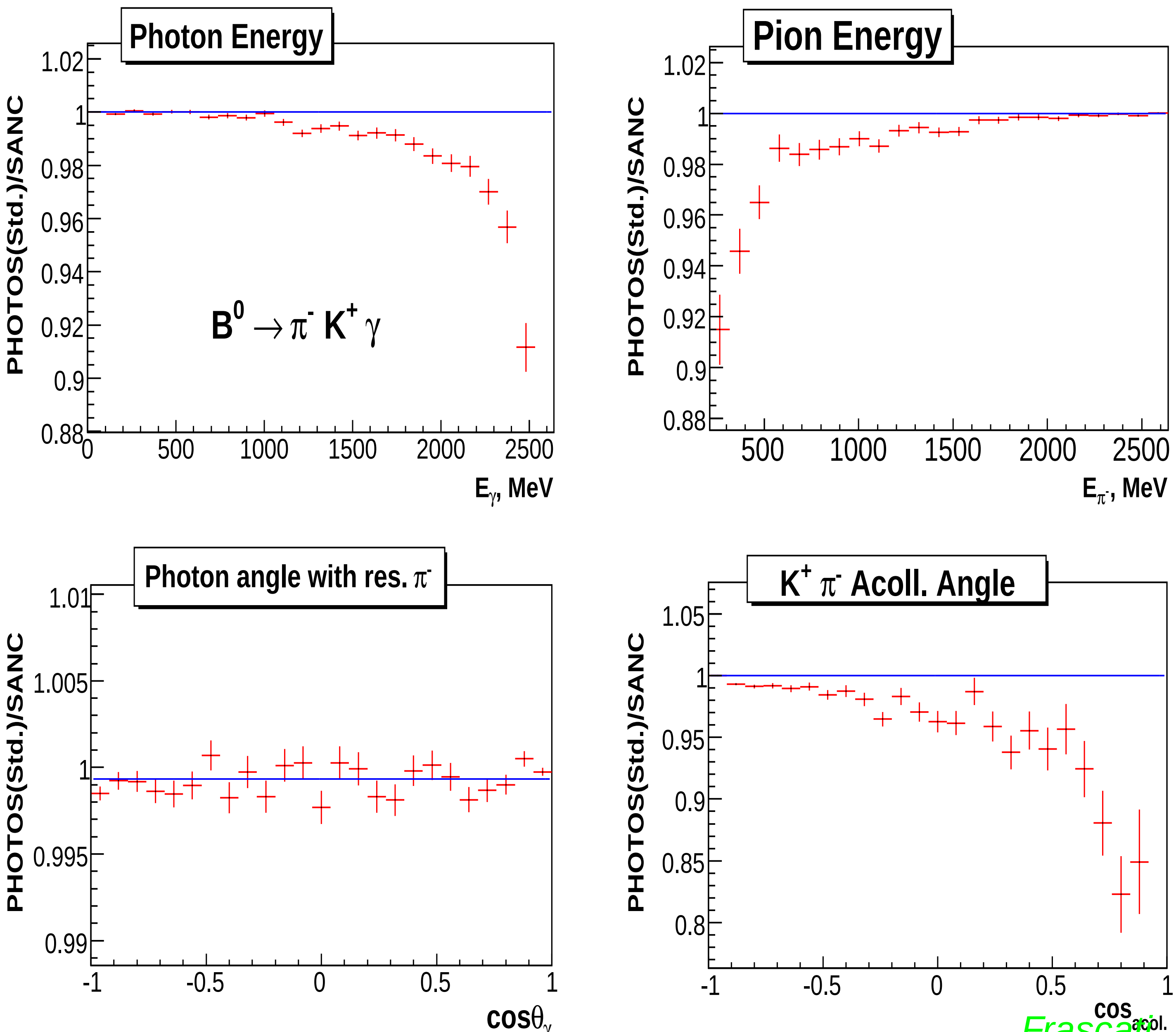
$B^- \to \pi^0 K^-$: NLO improved PHOTOS ... and is good.



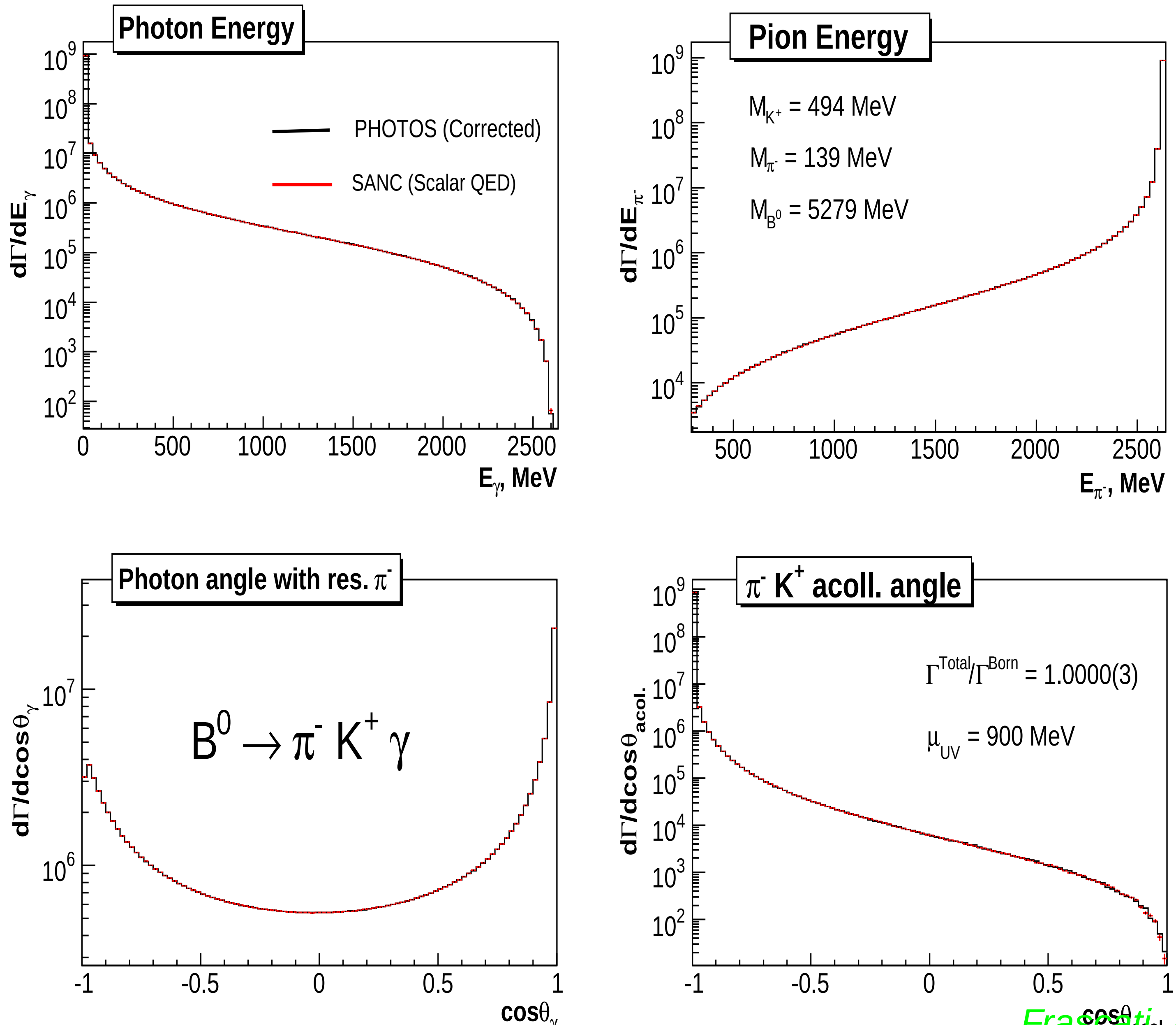
$B^0 \to \pi^- K^+$: standard PHOTOS Looks good ...



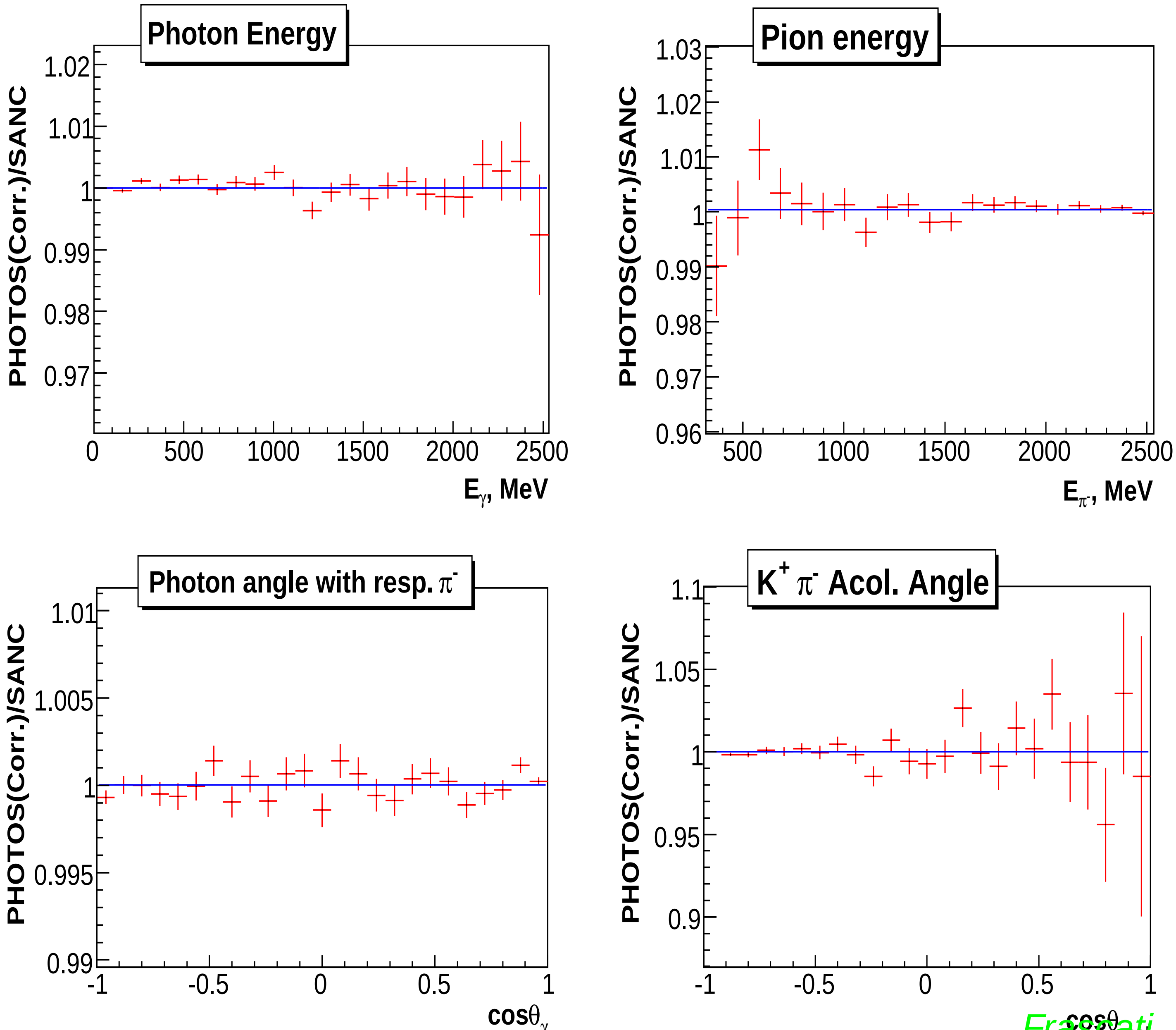
$B^0 \to \pi^- K^+$: standard PHOTOS ... but not perfect.



$B^0 \to \pi^- K^+$: NLO improved PHOTOS Looks good ...

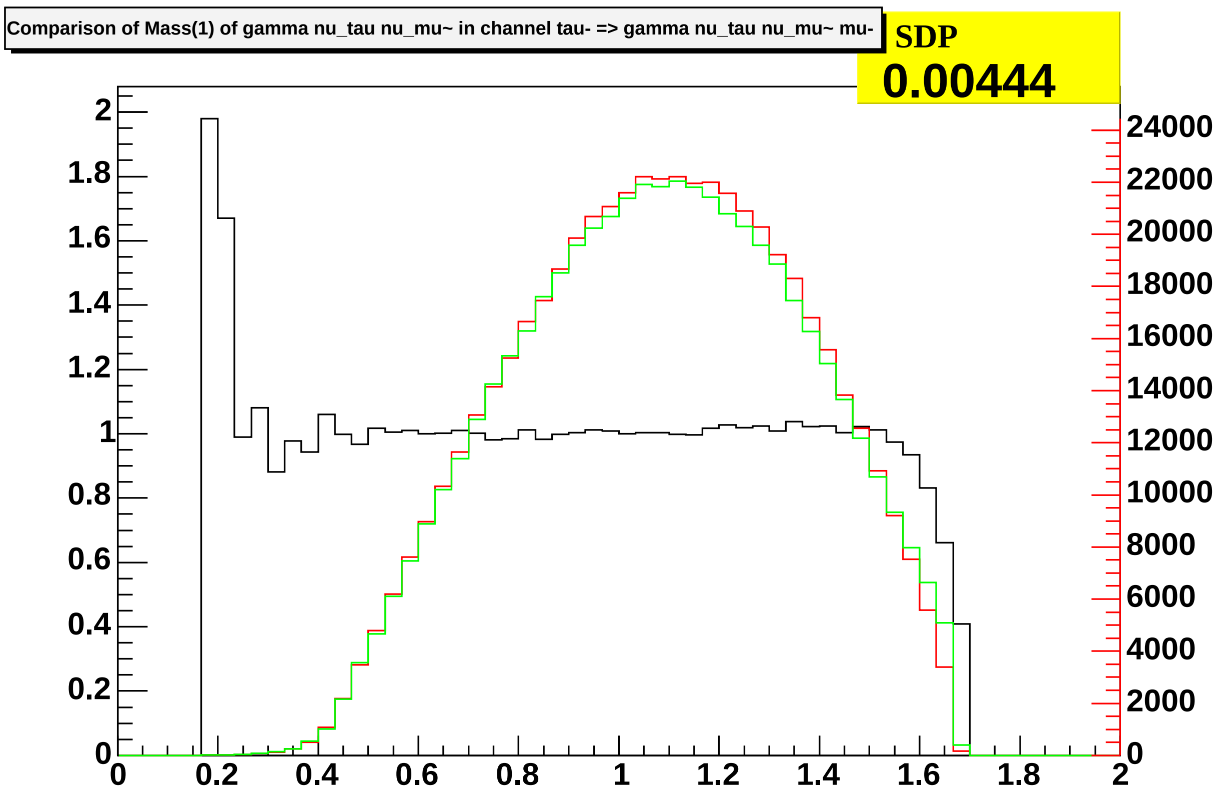


$B^0 \to \pi^- K^+$; *NLO improved PHOTOS* ... also perfect !



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

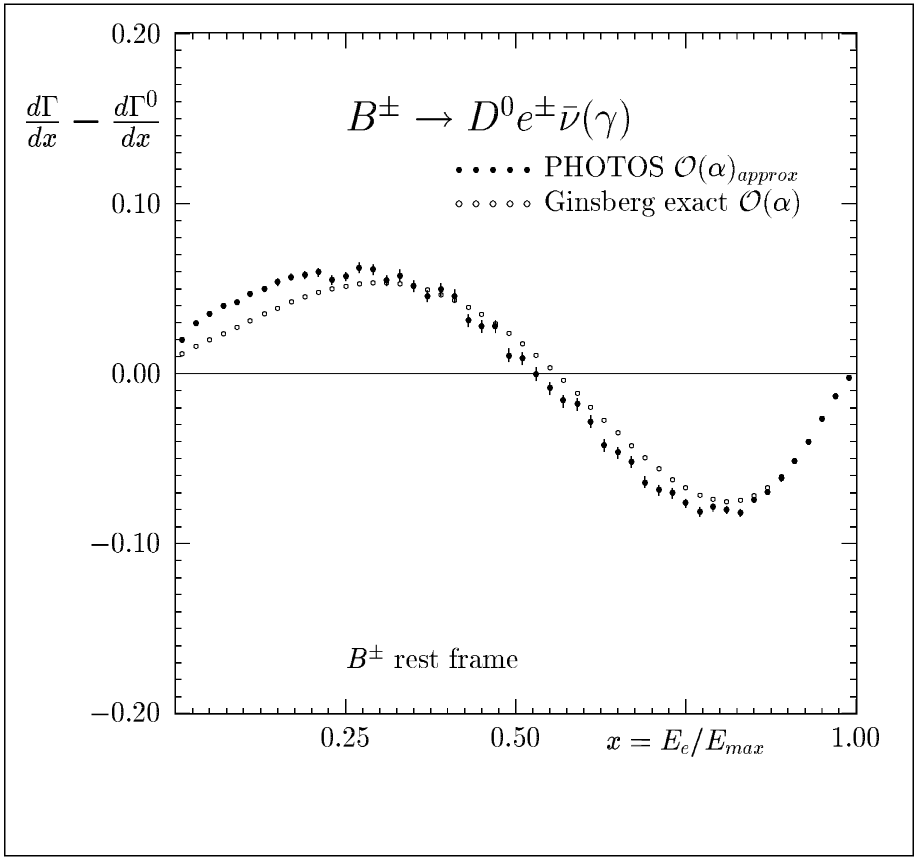
Plot of worst agreement for the channel. Distribution of $\gamma\nu_\tau\nu_\mu$ system mass is shown .



Also the fraction of events with photon above threshold agrees better than permille level.

In TAUOLA complete matrix element, comparison test PHOTOS approximations and design.

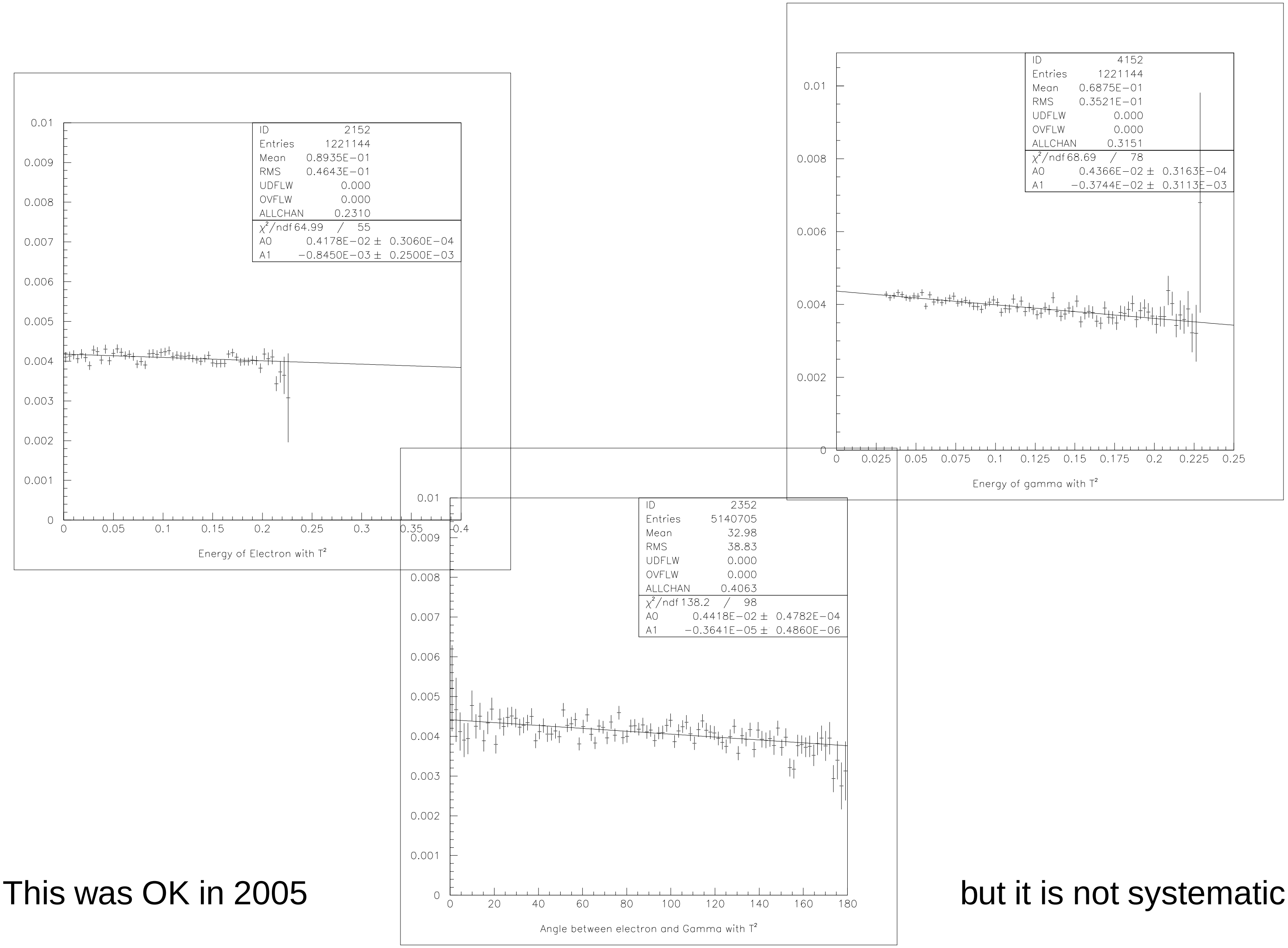
Phys. Lett, B 303 (1993) 163-169



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.

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



This was OK in 2005 but it is not systematic work.

Events with and without photon:

$R = \frac{\Gamma_{K_{e3\gamma}}}{\Gamma_{K_{e3}}}$	PHOTOS %	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

courtesy of NA48 and Prof. L.Litov

This results can be obtained starting from PHOTOS version 2.13.

Multiphoton radiation

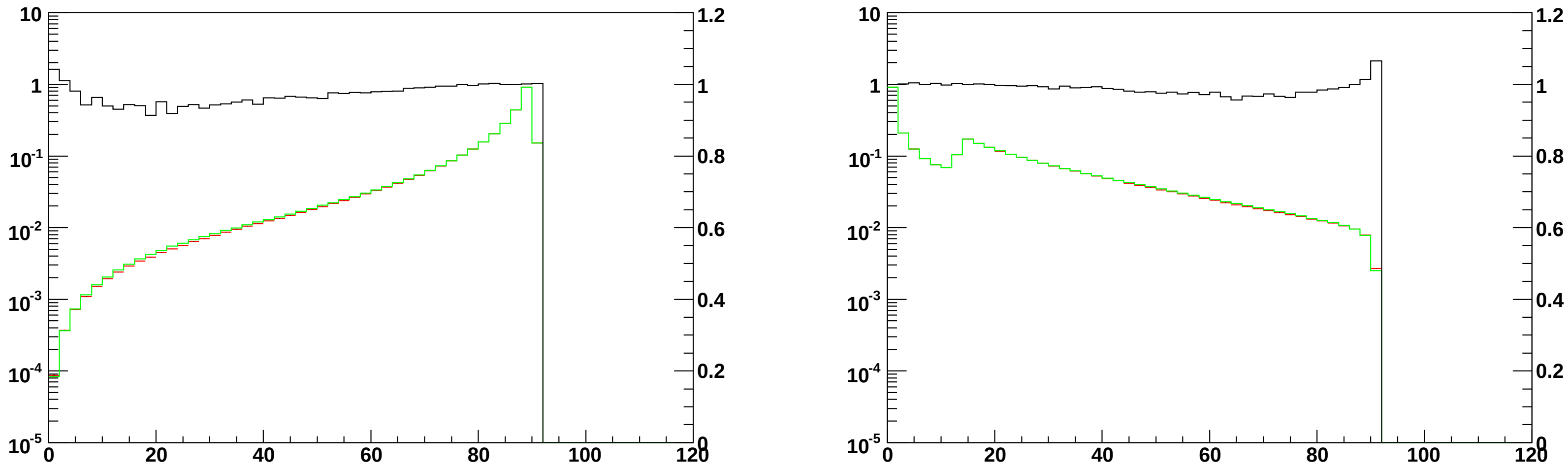
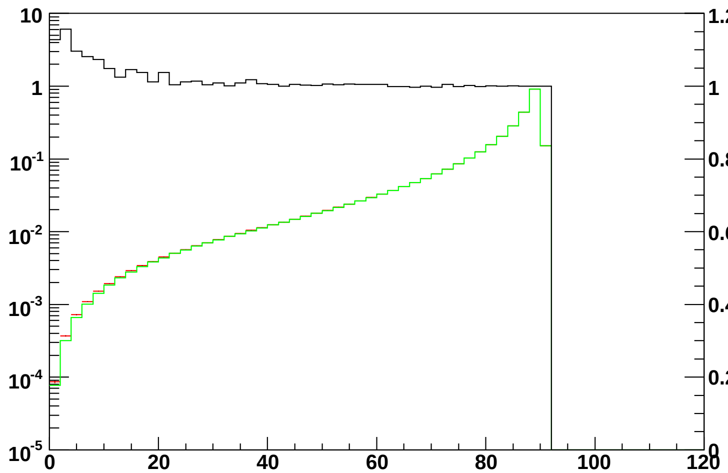


Figure 3: Comparison of standard PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.00409. In right frame the invariant mass of the $\mu^-\gamma$ pair; SDP=0.0025. The pattern of differences between PHOTOS and KKMC is similar to the one of Fig 1. The fraction of events with hard photon was 16.0824 $\pm$ 0.0040% for KKMC and 16.1628 $\pm$ 0.0040% for PHOTOS.



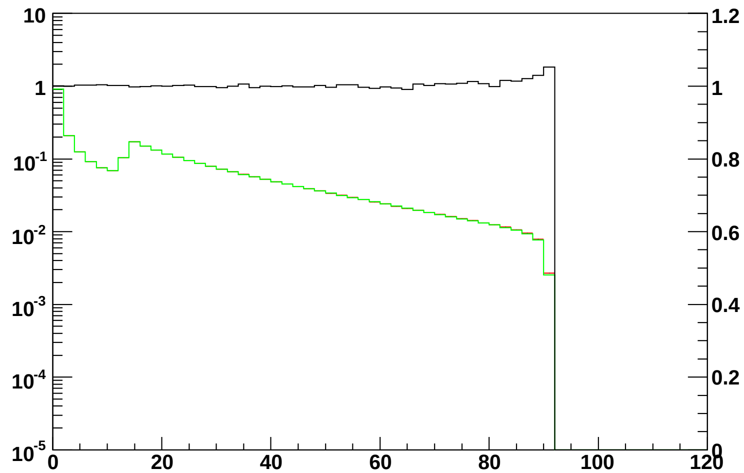


Figure 4: Comparisons of improved PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.0000249. In the right frame the invariant mass of the $\mu^-\gamma$ pair; SDP=0.0000203. The fraction of events with hard photon was 16.0824 $\pm$ 0.004% for KKMC and 16.0688 $\pm$ 0.004% for PHOTOS.

Results from: P. Golonka and Z. Was,hep-ph/0604232, EPJC 50 (2007) 53

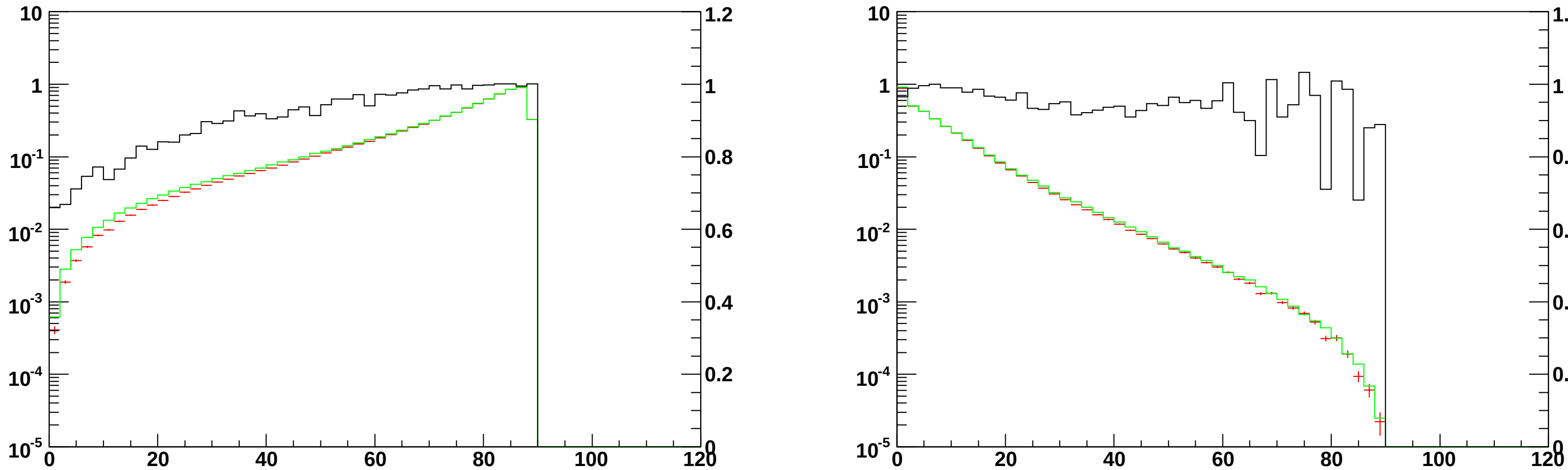


Figure 5: Comparisons of standard PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP= 0.00918. In the right frame the invariant mass of the $\gamma\gamma$ pair; SDP=0.00268. The fraction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

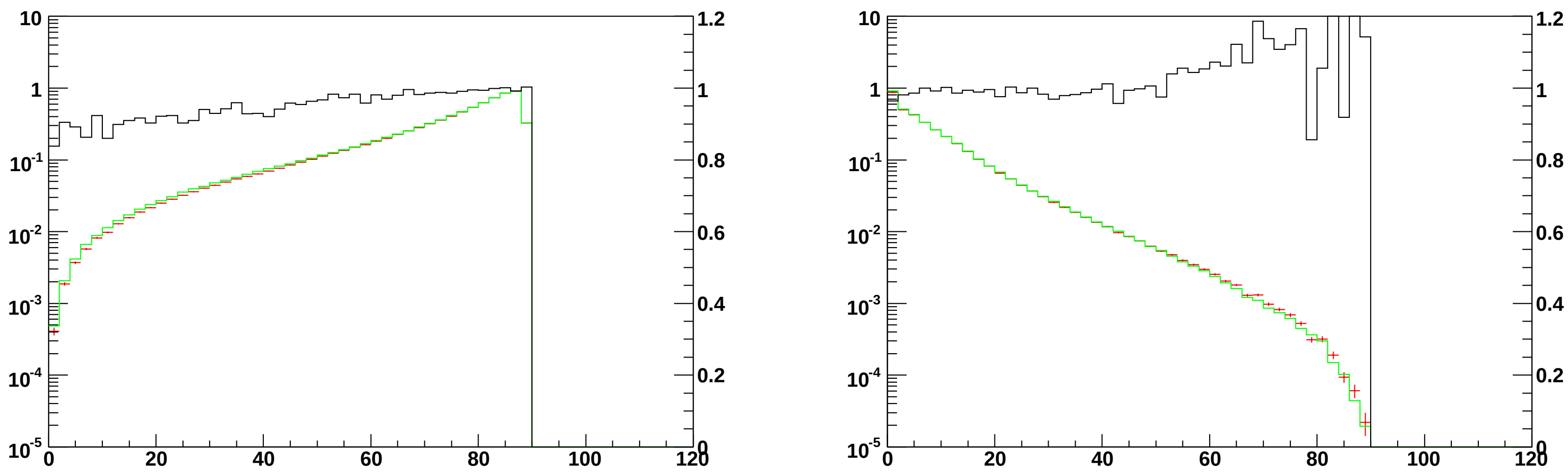
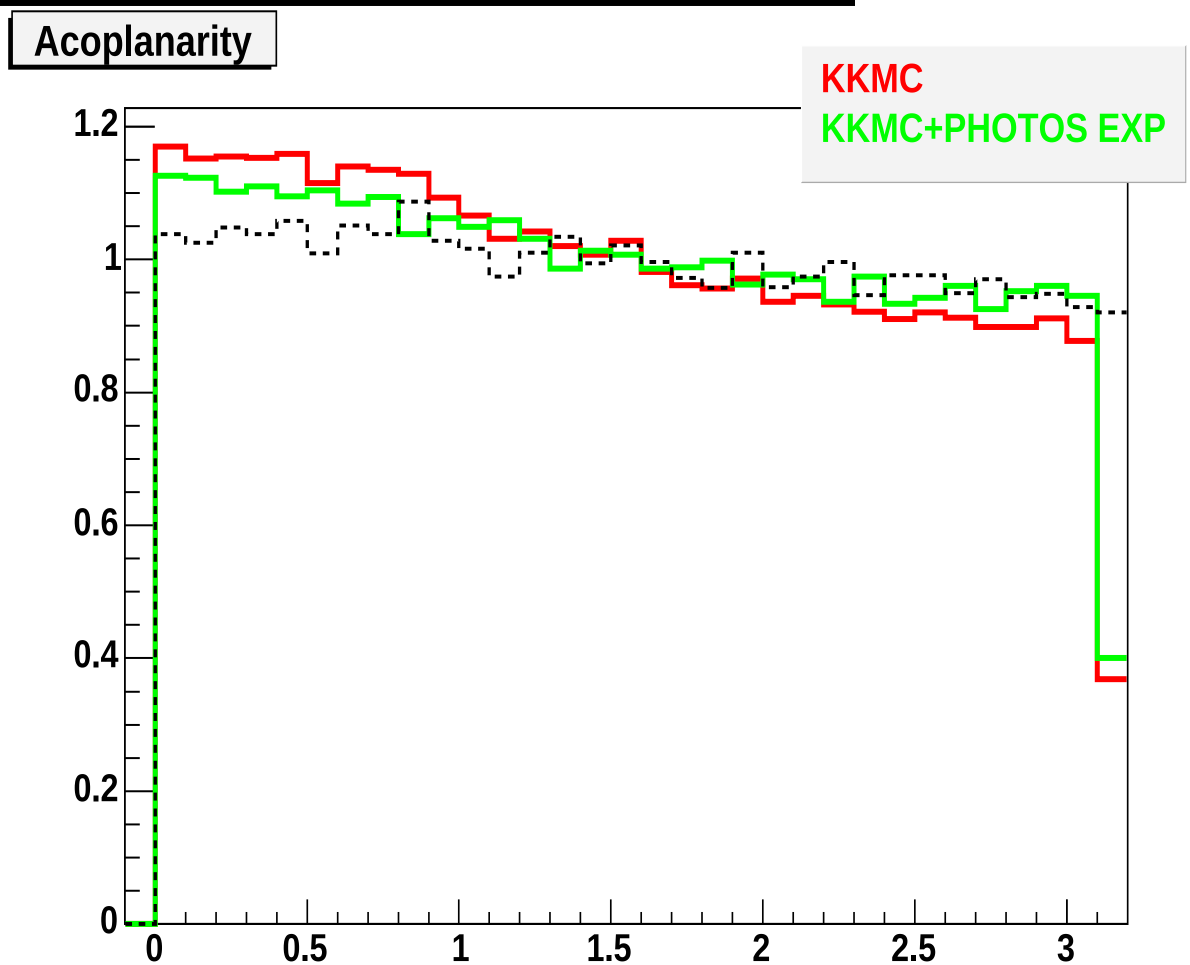


Figure 6: Comparisons of improved PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP= 0.00142. In the right frame the invariant mass of the $\gamma\gamma$; SDP=0.00293. The fraction of events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

Acoplanarity distribution – Looks good



Two plane spanned on μ^+ and respectively two hardest photons localized in the same hemisphere as μ^+. Why PHOTOS works so good?

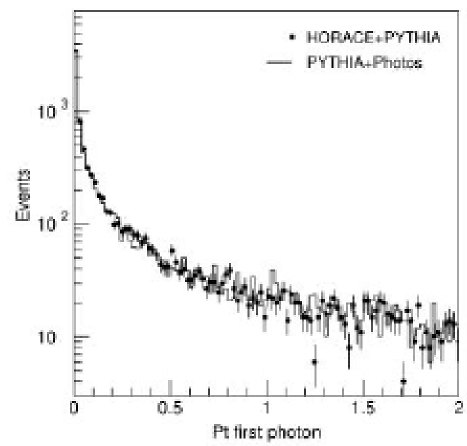
A successful validation example..

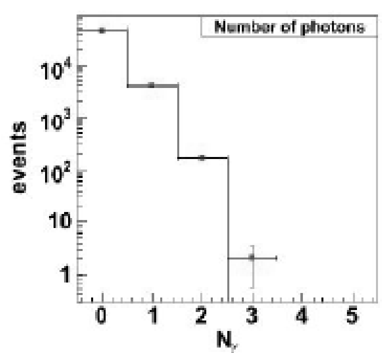
- Comparison between PHOTOS (supposed to be an approximate algorithm in principle) and HORACE (exact QED DGLAP solution):
  - Turns out that PHOTOS is doing an excellent job!

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.

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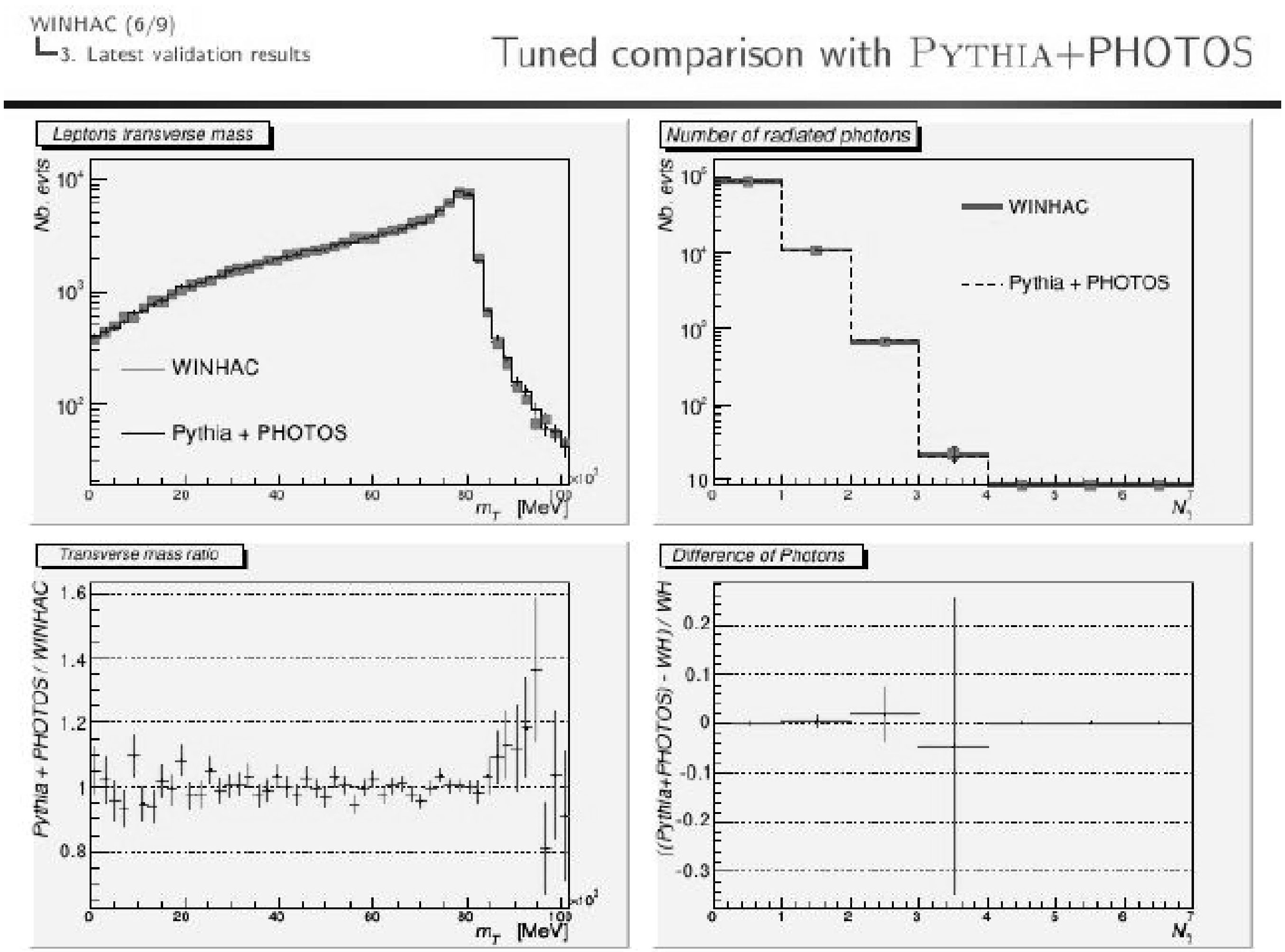
And another one.. Our Winhac effort



This is for W production at LHC.

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

Not systematic work on algorithm, but program validation for ATLAS. From one day talk at CERN main auditorium 11 am.