# Theoretical and practical aspects of simulations for $\tau$-lepton decay

**Z. Was**

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**talk include presentation of work necessary to match high precision data of today, some work was recently done thanks to effort by:**

*P. Golonka, G. Nanava, Qingjun Xu, A. Kalinowski, O. Shekhovtsova, V. Cherepanov, T. Przedzinski, N. Davidson*

I have extended my subject from $\gamma \to \pi^+\pi^-(\gamma)$ to more general one of complete predictions $\longrightarrow$ pressure from Graziano and Olga. I have somehow missed the point that I give two talks ...

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

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

## $\mathcal{M}$ ain topics

**Production of $\tau$ leptons, spin correlations.** OK at 0.2-0.5 % precision level. Topic will not be covered now. Progress to obtain 0.1 % precision level as at LEP is in principle easy, but in practice not. Issue of devoted qualified people. Long term effort. Is it really needed ??

**Decay matrix element separation into leptonic and hadronic current**. OK at 0.2 % precision level. Plans of validation by A. Korchin?

**Phase space**: easy and exact

**Bremsstrahlung in decays**

**Models of $\tau$ decays** and how they survive confrontation with data.

**Models confronting data** high precision regime requires options and options

**Projection operators** case of 3 scalars final states

**Events with multitude of weights** simulation allowing model tuning and model choice, when full detector effects are on.

## Purpose of the talk

**To prepare simulation chain for the given physics goal one has to define physics precision target on the basis of experimental requirements.**

**Once this is done, one has to check if it is possible to obtain appropriate precision from theoretical side too.**

**One can negotiate what is to to be taken from theory and what can/must be measured.**

**List of the points was meant to help sorting the aspects prepared for that purpose.**

-1- **I want to start from point which are better controlled**

-2- **and end where difficulties are present** Simon was showing earlier today how far TAUOLA results are from precison of experimental data.

-3- **I want to say few words about solutions**, and how/if things are moving.

# Production of $\tau$ leptons, spin correlations. OK at 0.5 %

- This is by far the most complex point. I will ignore it today nearly completely.
- Precision for simulations at LEP energies is of the order of 0.1 %, thanks to effort concentrated around KKMC Monte Carlo for example.
- At lower energies precision is lower, of the order of **0.5 %** see my recent paper with S. Banerjee B. Pietrzyk and M. Roney. Precision can be improved in a rather standard way to LEP 1 standards (0.1%) but it require effort to be counted in large no of qualified man-months of work.
- good thing is that production and decay can be separated, thanks to relatively long tau lepton lifetime.
- Production of n-pions instead of $\tau$ pair is next story.
- also how long one can trust scalar QED.

# Formalism for $\tau^+\tau^-$

- Because narrow $\tau$ width approximation can be obviously used for phase space , cross section for the process $f\bar{f} \to \tau^+\tau^- Y; \tau^+ \to X^+\bar{\nu}; \tau^- \to \nu\nu$ reads:

$$d\sigma = \sum_{spin} |\mathcal{M}|^2 d\Omega = \sum_{spin} |\mathcal{M}|^2 d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- This formalism is fine, but because of over 20 $\tau$ decay channels we have over 400 distinct processes. Also picture of production and decay are mixed.

- but (only $\tau$ spin indices are explicitly written):

$$\mathcal{M} = \sum_{\lambda_1\lambda_2=1}^{2} \mathcal{M}^{prod}_{\lambda_1\lambda_2}\; \mathcal{M}^{\tau^+}_{\lambda_1} \mathcal{M}^{\tau^-}_{\lambda_2}$$

- Formula for the cross section can be re-written

$$d\sigma = \Big(\sum_{spin} |\mathcal{M}^{prod}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^+}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^-}|^2\Big) wt\; d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- where

$$wt = \Big( \sum_{i,j=0,3} R_{ij} h^i h^j \Big)$$

$$R_{00} = 1, \quad < wt >= 1, \quad 0 \leq wt \leq 4.$$

$R_{ij}$ can be calculated from $\mathcal{M}_{\lambda_1 \lambda_2}$
and $h^i$, $h^j$ respectively from $\mathcal{M}^{\tau^+}$ and $\mathcal{M}^{\tau^-}$.

- Bell inequalities tell us that it is impossible to re-write $wt$ in the following form

$$wt \neq \Big( \sum_{i,j=0,3} R^A_i h^i \Big) \Big( \sum_{i,j=0,3} R^B_j h^j \Big)$$

that means it is impossible to generate first $\tau^+$ and $\tau^-$ first in some given ‘ quantum state’ and later perform separatelly decays of $\tau^+$ and $\tau^-$

- It can be done only if approximations are used !!!

- May be often reasonable, nonetheless approximations can/must be avoided.

- The point require study of relation between QED genuine electroweak and corrections to hadronic final state interactions.
- There is some interest in this point. A. Korchin was suggesting that he may be interested
- This is probably OK down to 0.2 % precision level

## General formalism for semileptonic decays

- Matrix element used in TAUOLA for semileptonic decay

$$\tau(P,s) \to \nu_\tau(N) X$$
$$\mathcal{M} = \frac{G}{\sqrt{2}} \bar{u}(N)\gamma^\mu(v + a\gamma_5)u(P)J_\mu$$

- $J_\mu$ the current depends on the momenta of all hadrons.
- I can provide only prototypes for $J_\mu$.

$$|\mathcal{M}|^2 = G^2 \frac{v^2+a^2}{2}(\omega + H_\mu s^\mu)$$
$$\omega = P^\mu(\Pi_\mu - \gamma_{va}\Pi^5_\mu), \qquad H_\mu = \frac{1}{M}(M^2\delta^\nu_\mu - P_\mu P^\nu)(\Pi^5_\nu - \gamma_{va}\Pi_\nu)$$
$$\Pi_\mu = 2[(J^* \cdot N)J_\mu + (J \cdot N)J^*_\mu - (J^* \cdot J)N_\mu]$$
$$\Pi^{5\mu} = 2\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma} J^*_\nu J_\rho N_\sigma, \qquad \gamma_{va} = -\frac{2va}{v^2+a^2}$$

- If $\tau$ coupling $v + a\gamma_5$ and $m_{\nu_\tau} \neq 0$ is allowed, one has to add to $\omega$ and $H_\mu$:

$$\hat{\omega} = 2\frac{v^2-a^2}{v^2+a^2} m_\nu M(J^* \cdot J)$$
$$\hat{H}^\mu = -2\frac{v^2-a^2}{v^2+a^2} m_\nu\, \mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma} J^*_\nu J_\rho P_\sigma$$

**Semileptonic decays: Phase-space $\times$ weak-current $\times$ hadronic-current**

- The differential partial width for the channel under consideration reads

$$d\Gamma_X = G^2 \frac{v^2+a^2}{4M} d\mathrm{Lips}(P; q_i, N)(\omega + \hat{\omega} + (H_\mu + \hat{H}_\mu)s^\mu)$$

- The phase space distribution is given by the following expression where a compact notation with $q_5 = N$ and $q_i^2 = m_i^2$ is used

$$d\mathrm{Lips}(P; q_1, q_2, q_3, q_4, q_5) = \frac{1}{2^{23}\pi^{11}} \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{Q^2_{3,min}}^{Q^2_{3,max}} dQ_3^2$$

$$\int_{Q^2_{2,min}}^{Q^2_{2,max}} dQ_2^2 \quad \times \quad \int d\Omega_5 \frac{\sqrt{\lambda(M^2, Q^2, m_5^2)}}{M^2} \int d\Omega_4 \frac{\sqrt{\lambda(Q^2, Q_3^2, m_4^2)}}{Q^2}$$

$$\times \quad \int d\Omega_3 \frac{\sqrt{\lambda(Q_3^2, Q_2^2, m_3^2)}}{Q_3^2} \int d\Omega_2 \frac{\sqrt{\lambda(Q_2^2, m_2^2, m_1^2)}}{Q_2^2}$$

$$Q^2 = (q_1 + q_2 + q_3 + q_4)^2, \quad Q_3^2 = (q_1 + q_2 + q_3)^2, \quad Q_2^2 = (q_1 + q_2)^2$$

$$Q_{min} = m_1 + m_2 + m_3 + m_4, \quad Q_{max} = M - m_5$$

$$Q_{3,min} = m_1 + m_2 + m_3, \qquad Q_{3,max} = Q - m_4 \; Q_{2,min} = m_1 + m_2, \qquad Q_{2,max} = Q_3 - m_3$$

- These formulas are inefficient if sharp peaks due to resonances in the intermediate states are present. The changes (change of variables multichannel generation) improve program efficiency, but the density remains intact. No approximations.

## PHOTOS for bremsstrahlung in decays

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

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

P. Golonka and Z. Was hep-ph/0604232, G. Nanava and Z. Was hep-ph/0607019

- It was developed as single photon emission. starting from MUSTRAAL (F. Berends, R. Kleiss, S. Jadach, Comput. Phys. Commun. (1982)) option for final state bremsstrahlung in $Z$ decay only.
- Factorization of phase space for photonic variables and two-body decay phase space was studied. Similarily for matrix element: process independent kernel was found. Phase space is exact.
- Interference between emission from $\mu^+$ and $\mu^-$ is dropped and re-introduced later. Exact matrix element can be used if available.
- Because of breath-taking precision, I am investing in more mathematical language.
- I will drop these aspects and will show some numerical tests instead.
- At certain precision level modelling bemsstrahlung must rely on data. Eg. scalar QED is valid in chiral limit only ...

## Phase Space: (trivialities)

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

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

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

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

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

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 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 (factors $\lambda^{1/2}$ etc.) form simple factor $W_n^{n+1}$ in our case,

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

- All details depend on definition of $G_n$. Important NLO detail: if we need single emission in $X \to Y^+ Z^-$ thus presample for collinear singularity along two directions resulting parametrizations have identical Jacobian (6). This must be compromised for multiple emissions, unless exact second order matrix element is used! Otherwise precision loss.

## Phase Space: (multiply iterated)

By iteration, we can generalize formula (1) to the case of $l$ particles added and obtain:

$$dLips_{n+l}(P \to k_1...k_n, k_{n+1}...k_{n+l}) = \frac{1}{l!}\prod_{i=1}^{l}\Big[dk_{\gamma_i} d\cos\theta_{\gamma_i} d\phi_{\gamma_i} W^{n+i}_{n+i-1}\Big]$$
$$\times dLips_n(P \to \bar{k}_1...\bar{k}_n), \tag{6}$$
$$\{k_1,\dots,k_{n+l}\} = \mathbf{T}\big(k_{\gamma_l},\theta_{\gamma_l},\phi_{\gamma_l},\mathbf{T}\big(\dots,\mathbf{T}\big(k_{\gamma_1},\theta_{\gamma_1},\phi_{\gamma_1},\{\bar{k}_1,\dots,\bar{k}_n\}\big)\dots\big).$$

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 $\bar{k}'_1 \dots \bar{k}'_n \dots \bar{k}'_{n+m}$

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

## Crude Ddistribution

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

$$\sum_{l=0} \exp(-F)\frac{1}{l!}\prod_{i=1}^{l} f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i}) dLips_{n+l}(P\to k_1...k_n,k_{n+1}...k_{n+l}) =$$
$$\sum_{l=0} \exp(-F)\frac{1}{l!}\prod_{i=1}^{l}\Big[f(k_{\gamma_i},\theta_{\gamma_i},\phi_{\gamma_i}) dk_{\gamma_i} d\cos\theta_{\gamma_i} d\phi_{\gamma_i} W^{n+i}_{n+i-1}\Big]\times$$
$$dLips_n(P\to\bar{k}_1...\bar{k}_n), \qquad (7)$$
$$\{k_1,\ldots,k_{n+l}\} = \mathbf{T}\Big(k_{\gamma_l},\theta_{\gamma_l},\phi_{\gamma_l},\mathbf{T}\Big(\ldots,\mathbf{T}\Big(k_{\gamma_1},\theta_{\gamma_1},\phi_{\gamma_1},\{\bar{k}_1,\ldots,\bar{k}_n\}\Big)\ldots\Big),$$
$$F=\int_{k_{min}}^{k_{max}} dk_\gamma d\cos\theta_\gamma d\phi_\gamma f(k_\gamma,\theta_\gamma,\phi_\gamma).$$

- The Green parts of rhs. alone, give crude distribution over tangent space (orthogonal set of variables $k_i,\theta_i,\phi_i$).

- Factors $f$ must be integrable over tangent space. Regulators of singularities necessary.
- If we request that

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

and that sum rules originating from perturbative approach will not change an overall normalization of the cross section, 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
- PHOTOS can be used as prototype.

## Scalar QED for matrix elements in B decays

- 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:

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

## Scalar QED for $\gamma^* \to \pi^+\pi^-\gamma$

- This case is different, because of spin structure. One can not make spin of initial state out of internal spin of outgoing particles.

$$H^\mu = \frac{e^2 F_{2\pi}(p^2)}{p^2} \left\{ (q_1 + k - q_2)^\mu \frac{q_1 \cdot \epsilon^*}{q_1 \cdot k} + (q_2 + k - q_1)^\mu \frac{q_2 \cdot \epsilon^*}{q_2 \cdot k} - 2\epsilon^{*\mu} \right\}$$

- As in case of $Z$ decay one can separate spin amplitude into gauge invariant parts ($C = \frac{e^2 F_{2\pi}(p^2)}{p^2}$):

$$H_I^\mu = C\ (q_1 - q_2)^\mu \left( \frac{q_1 \cdot \epsilon^*}{q_1 \cdot k} - \frac{q_2 \cdot \epsilon^*}{q_2 \cdot k} \right), H_{II}^\mu = C\ \left( k^\mu \left( \frac{q_1 \cdot \epsilon^*}{q_1 \cdot k} + \frac{q_2 \cdot \epsilon^*}{q_2 \cdot k} \right) - 2\epsilon^{*\mu} \right), \tag{8}$$

- This can be improved with the following change:

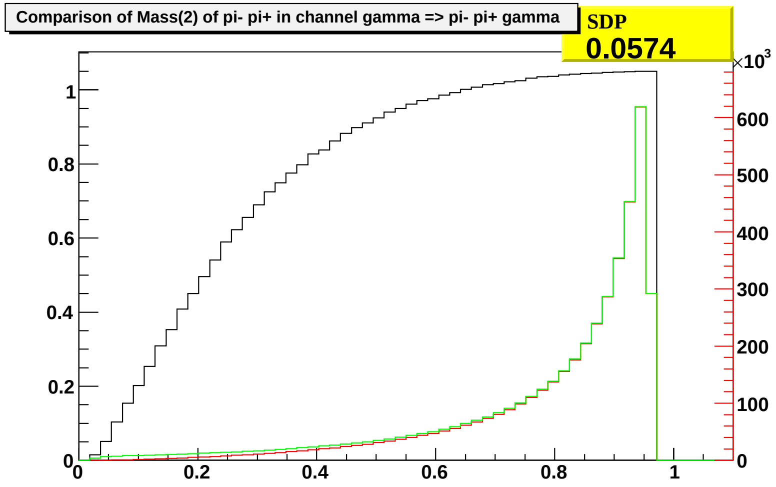
$$H_{I'}^\mu = C\ \left( (q_1 - q_2)^\mu + k^\mu \frac{q_2 \cdot k - q_1 \cdot k}{q_2 \cdot k + q_1 \cdot k} \right) \left( \frac{q_1 \cdot \epsilon^*}{q_1 \cdot k} - \frac{q_2 \cdot \epsilon^*}{q_2 \cdot k} \right), \tag{9}$$

$$H_{II'}^\mu = C\ \left( \frac{k^\mu}{q_2 \cdot k + q_1 \cdot k} (q_1 \cdot \epsilon^* + q_2 \cdot \epsilon^*) - \epsilon^{*\mu} \right). \tag{10}$$

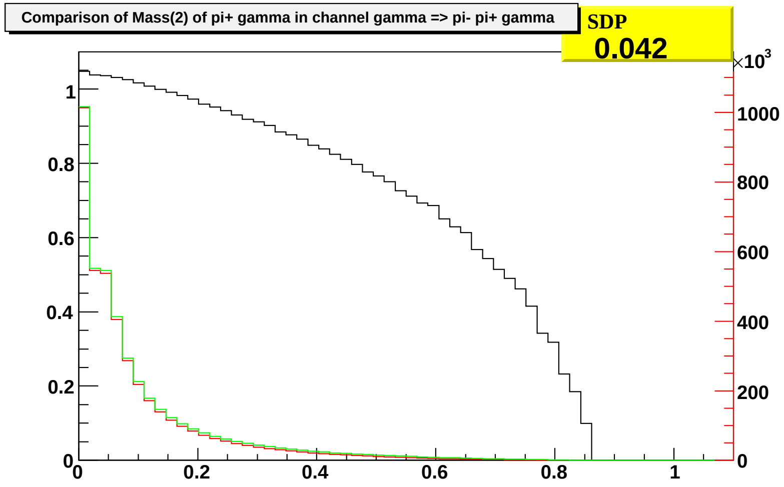
- In the second case non-eikonal term is free of collinear logarithm, but is non trivial and contributes 0.2 % to total rate, thus can be numerically studied!

Figure 1: *Distributions for* $e^+e^- \to \pi^+\pi^-(\gamma)$ *at 2 GeV center of mass energy. Results from PHOTOS with matrix element taken from transparency 17 are given in red colour. If complete matrix element is used results given in green colour shoule be taken. Fraction of events with photons above 50 MeV is respectively 4.2279* $\pm$ *0.0021 % and 4.4320* $\pm$ *0.0021%*

*Agreement is good, differences are in 'empty' bins!*




(a) Square of $\pi^+\pi^-$ invariant mass. The variable is normalized to virtality of decaying photon. Variable is lorentz invariant, and eqivalent to photon energy in the reaction frame.




(b) *Square of* $\pi^+\gamma$ *invariant mass. The distribution variable is also normalized to virtality of decaying photon.*

## Matrix Element

- We have seen again nice properties of matrix element which dominant part factorize into Born-like distribution and photon emission factor.
- Such expression can be used all over the phase space.
- Full phase space coverage of PHOTOS remain assured.
- Exact matrix element can be installed with process dependent weight.
- This time resulting weight is not well behaved, it has large tail.
- Not all of this photon emission process is just bremstrahlung. Resulting effect is present in this region of phase space where scalar QED is not expected to be reliable anyway.
- This effect is small of 0.2 % in size (G. Nanava Q. Xu, ZW in preparation).
- as always multiphoton generation can be activated.

## Hadronic Current; 3 scalars

Using Lorentz invariance the hadronic current can be cast into the following form

$$J^\mu = N \quad \Big\{ T^\mu_\nu \big[ c_1 (p_2 - p_3)^\nu F_1 + c_2 (p_3 - p_1)^\nu F_2 + c_3 (p_1 - p_2)^\nu F_3 \big] + c_4 q^\mu F_4 - \frac{i}{4\pi^2 f_\pi^2} c_5 \epsilon^\mu_{.\ \nu\rho\sigma} p_1^\nu p_2^\rho p_3^\sigma F_5 \Big\},$$

- $T_{\mu\nu} = g_{\mu\nu} - q_\mu q_\nu / q^2$ is the transverse projector,
- $q = p_1 + p_2 + p_3$ and $p_1, p_2, p_3$ are four momenta of the consecutive scalars.
- Functions $F_i$ can be in principle of 3 variables $q^2 = (p_1 + p_2 + p_3)^2$ and two of the following ones $s_1 = (p_2 + p_3)^2$, $s_2 = (p_1 + p_3)^2$, $s_3 = (p_2 + p_3)^2$
- Fortunately, for 3 scalar final states we have only 4 scalar functions contributing to the current.
- That is equal (it is not more than)/to the phase-space dimension.
- So the projection operators can be defined, for 2 and 3 scalar final states.

$$
\begin{aligned}
J^{\mu} &= N \quad \Big\{ T^{\mu}_{\nu} \big[ c_1 (p_2 - p_3)^{\nu} F_1 + c_2 (p_3 - p_1)^{\nu} F_2 + c_3 (p_1 - p_2)^{\nu} F_3 \big] \\
&\quad + c_4 q^{\mu} F_4 - \frac{i}{4\pi^2 f_{\pi}^2} c_5 \epsilon^{\mu}_{.\ \nu\rho\sigma} p_1^{\nu} p_2^{\rho} p_3^{\sigma} F_5 \Big\},
\end{aligned}
$$

Recall how current enters matrix element squared:

$$
\begin{gathered}
|\mathcal{M}|^2 = G^2 \frac{v^2 + a^2}{2} (\omega + H_{\mu} s^{\mu}) \\
\omega = P^{\mu} (\Pi_{\mu} - \gamma_{va} \Pi^5_{\mu}), \qquad H_{\mu} = \frac{1}{M} (M^2 \delta^{\nu}_{\mu} - P_{\mu} P^{\nu}) (\Pi^5_{\nu} - \gamma_{va} \Pi_{\nu}) \\
\Pi_{\mu} = 2 [(J^* \cdot N) J_{\mu} + (J \cdot N) J^*_{\mu} - (J^* \cdot J) N_{\mu}] \\
\Pi^{5\mu} = 2 \,\mathrm{Im}\, \epsilon^{\mu\nu\rho\sigma} J^*_{\nu} J_{\rho} N_{\sigma}, \qquad \gamma_{va} = - \frac{2va}{v^2 + a^2}
\end{gathered}
$$

- Indeed one can construct up to 16=4·4 such operators and with their help get $F_i$ directly from the data including their phases.
- The operators were coded/checked together with TAUOLA as benchmarks.
- Artur and Olga are trying to revive the method described in J. H. Kuhn, E. Mirkes, Z.Phys.C56:661-672,1992, Erratum-ibid.C67:364,1995. Widely used (CLEO), but how it will cope with detector acceptance and precision?

## *Multitude Weight samples*

The method described in previous transparency is OK, but ...

- It can be used in 2 or 3 scalar final states.
- Requires full phase space **and** perfect backgrund subtraction.
- Can not be applied if more than 3 scalars are produced.
- $\longrightarrow$ Another method is prepared bu T. Przedzinski, V. Cherepanov.
- Generated sample is weight one, but alternative weights for different models can be obtained.
- With linear extrapolation between the weights one can fit the best model.
- This, with full detector effects and cross contamination between channels.
- But will Tomasz and Vladimir stay with us long enoug?

## *Multitude Weight samples*

The method described in previous two transparencies is OK, but ...

- Sometimes we have no access to all phase space variables.
- Some directions can be well distinguished some other not, or systematics is bad.
- Example on how to work in such case was sumarized in
- A. E. Bondar, S. I. Eidelman, A. I. Milstein, T. Pierzchala, N. I. Root, Z. Was and M. Worek, “Novosibirsk hadronic currents for tau $\longrightarrow$ 4pi channels of tau decay library TAUOLA,” Comput. Phys. Commun. **146**, 139 (2002)
- Parametrization was using data for $d\Gamma/dQ^2$ but in case where data for relative position of pions in 4-scala final state was not so good. Models and other measurements were used instead.
- It points to necessity to adopt projection operators to detector properties too.

- Lots of experimental/theoretical work needed.
- What is more important, chiral symmetry or unitarity constraints.
- What was first chicken or egg...
- How to use theoretical constraints simultaneously with experimental data.
- What (who??) is more important.

## *Summary* thoretical aspects

- **We have presented list of topic necessary for high precision phenomenology of $\tau$ decays.**
- **Most of the points are ok down to precision level of 0.2 %**
- **TAUOLA predictions based on formfactors of 1997 (CLEO ALEPH).**
- **Major efort on new currents and how to confront them with precision experiments is needed. Otherwise no sense for other work.**
- **Methods to improve fits are gradually being installed into TAUOLA env. thanks to effort of A. Kalinowski, V. Cherepanov, O. Shekhovtsova, T. Przedzinski.**
- **But it is the beginnng of the long road. Is it needed? Can it acumulate enough momentum?**

## Extra transparencies

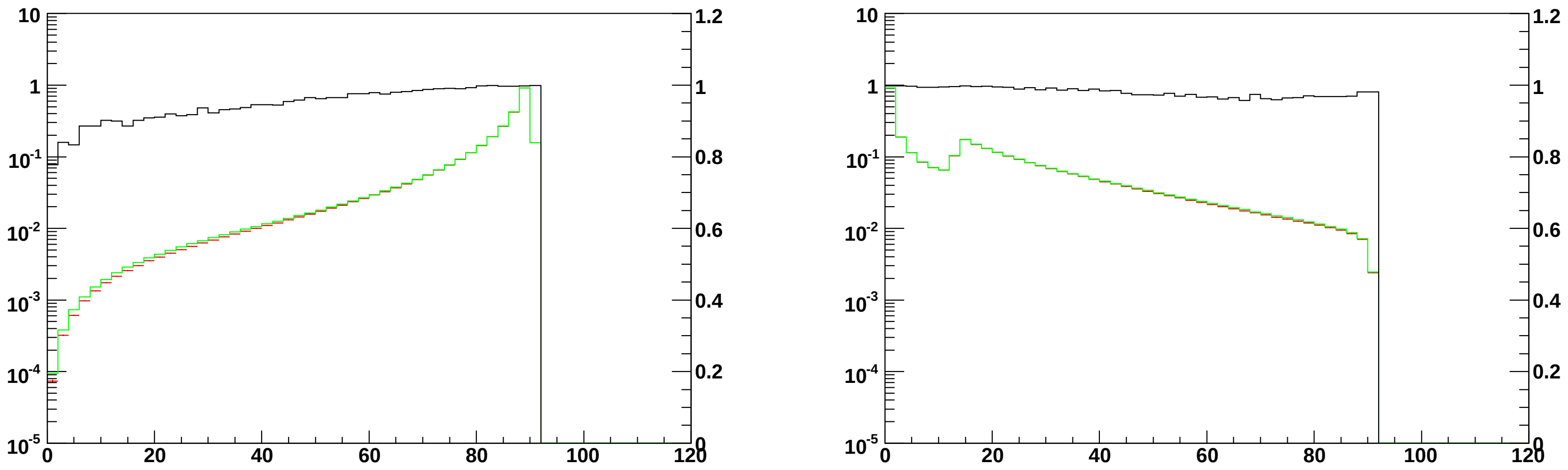



*Figure 1: Comparison of standard PHOTOS and KORALZ for single photon emission. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.00534. In the right frame the invariant mass of $\mu^-\gamma$; SDP=0.00296. The histograms produced by the two programs (logarithmic scale) and their ratio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

# Numerical results showing that for QED method works

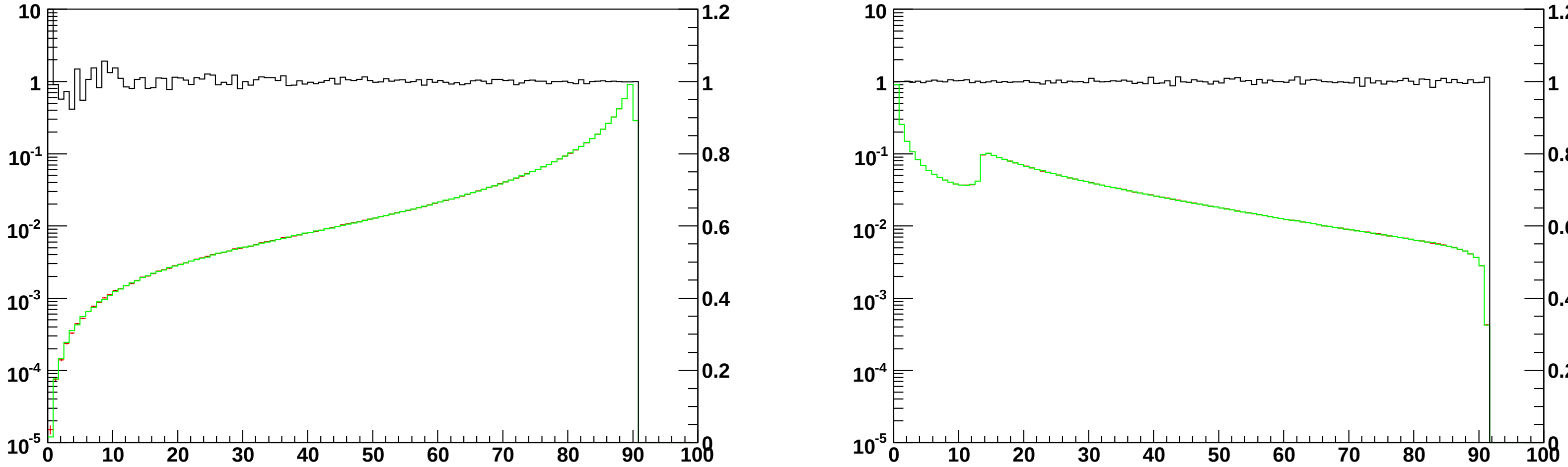
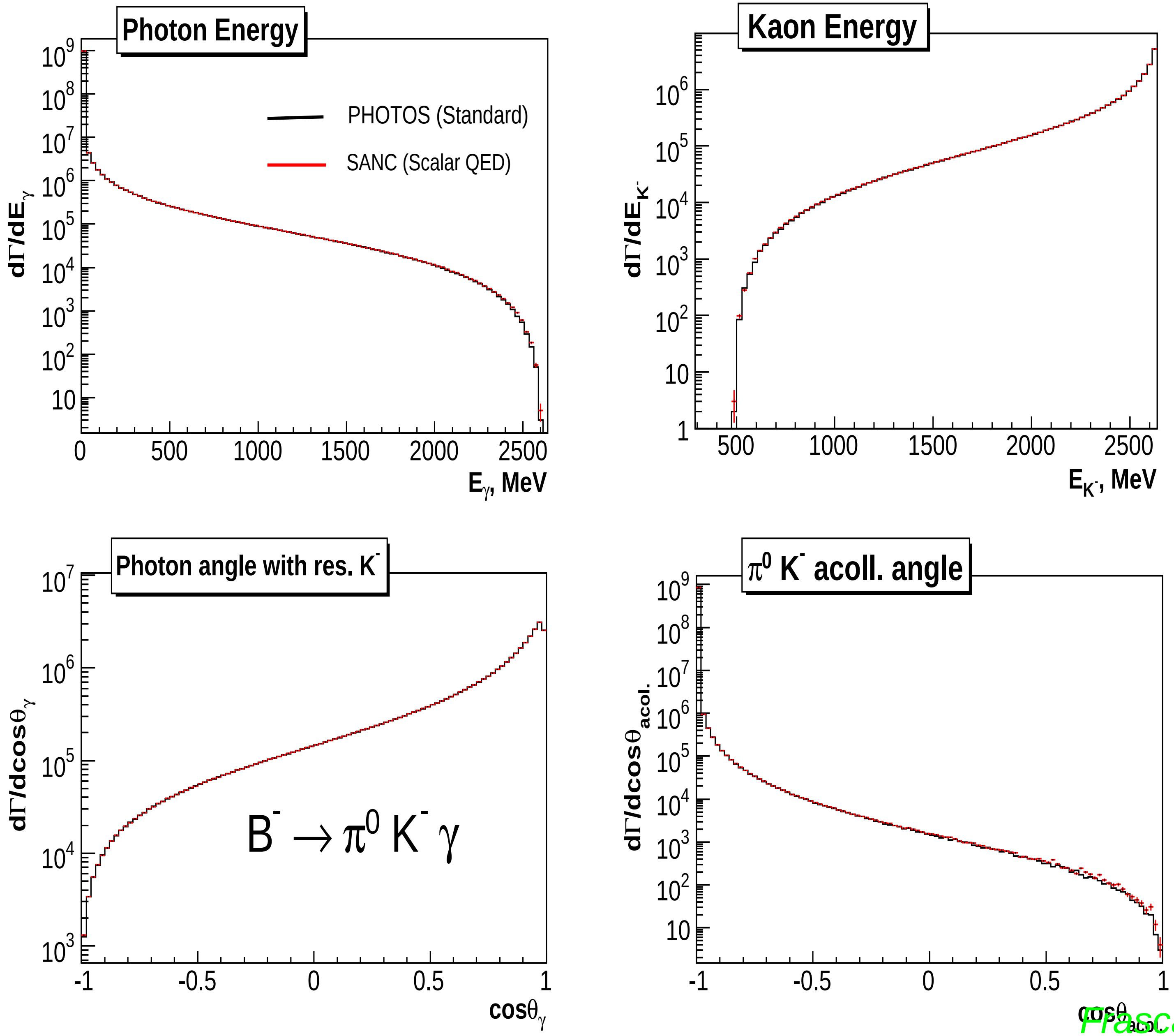
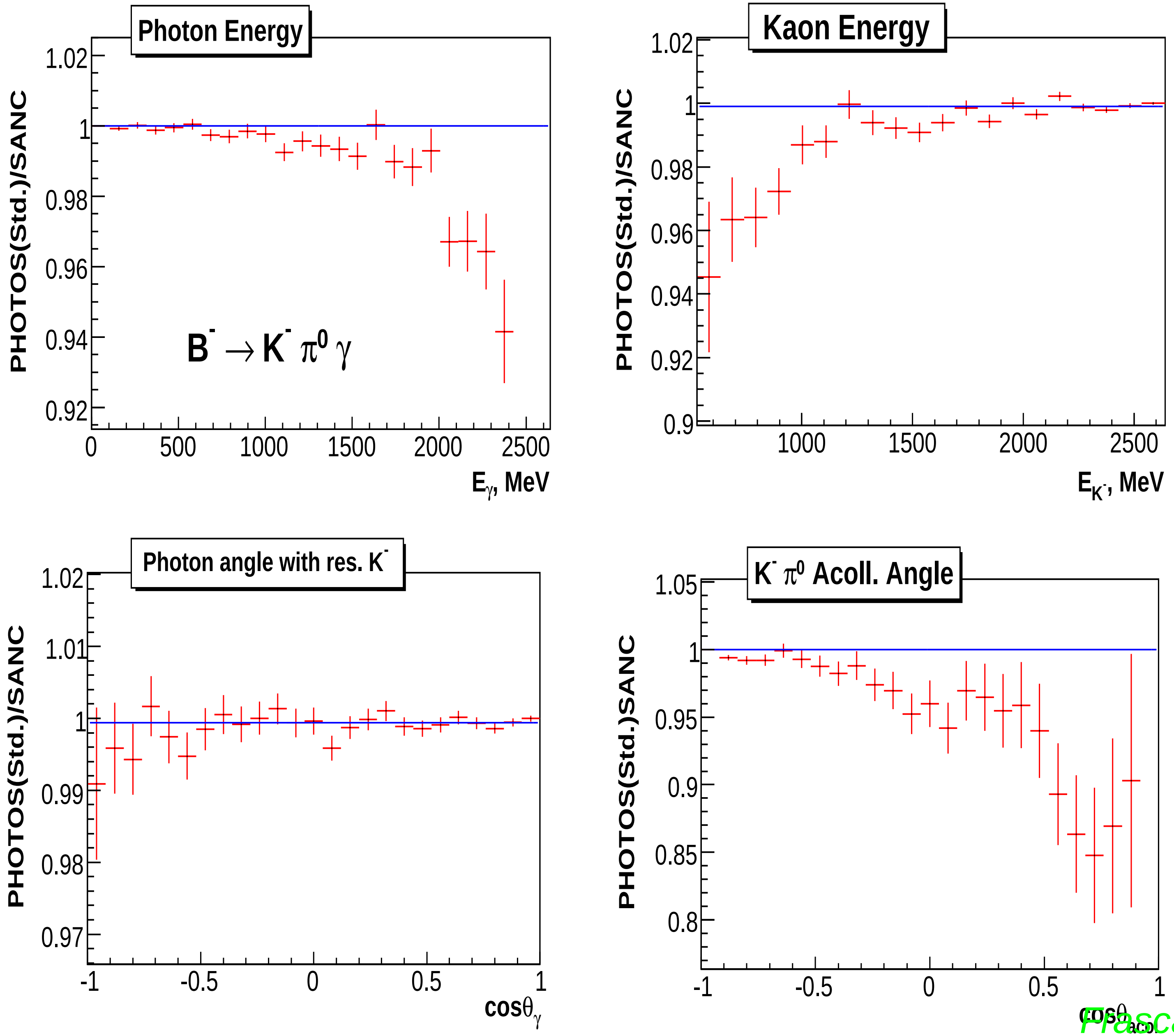



*Figure 2: Comparisons of improved PHOTOS and KORALZ for single photon emission. In the left frame the invariant mass of the $\mu^+\mu^-$ pair. In the right frame the invariant mass of $\mu^-\gamma$ pair is shown. In both cases differences between PHOTOS and KORALZ are below statistical error. The fraction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

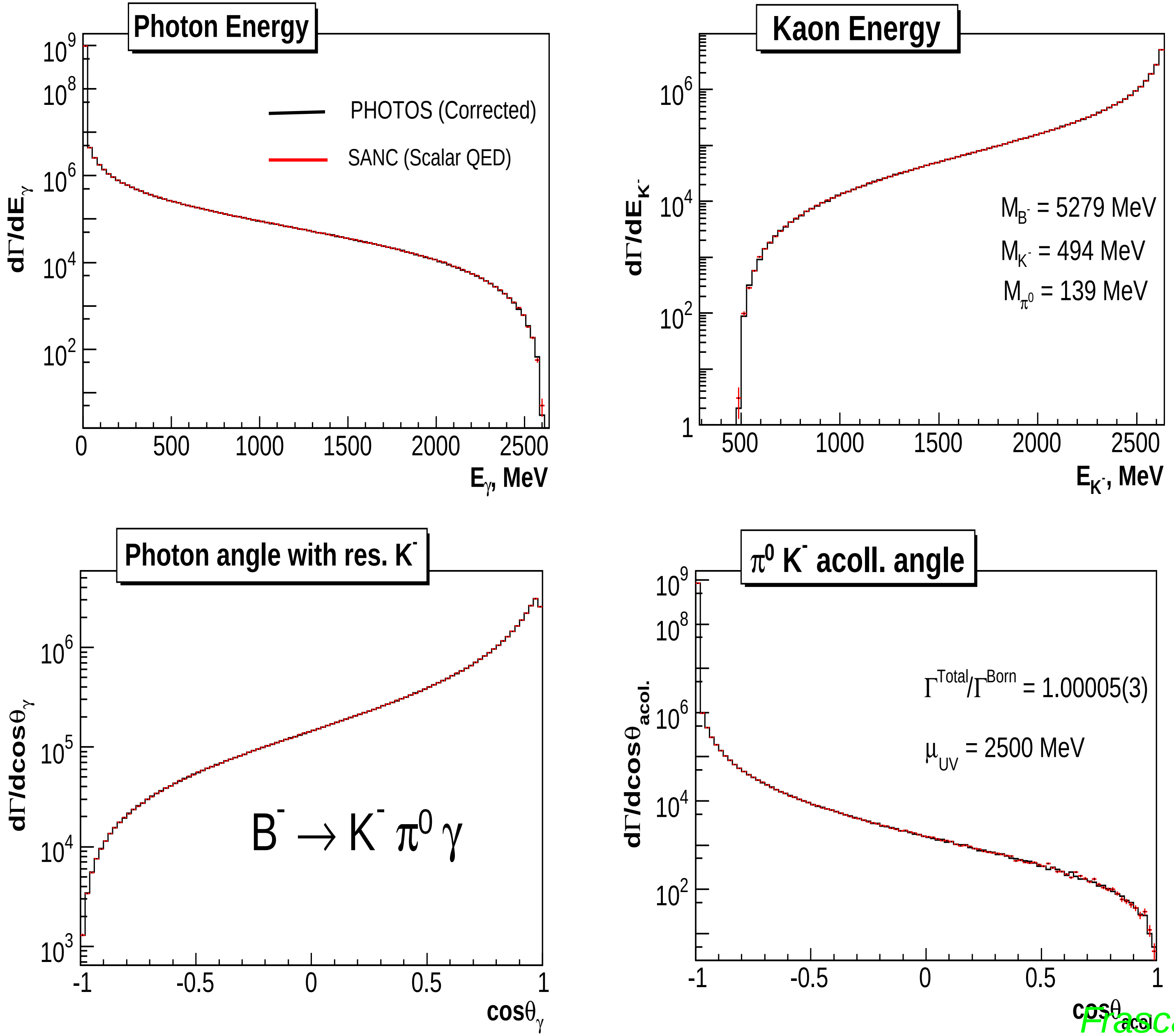
$B^- \to \pi^0 K^-$: *standard PHOTOS* looks good, but ...



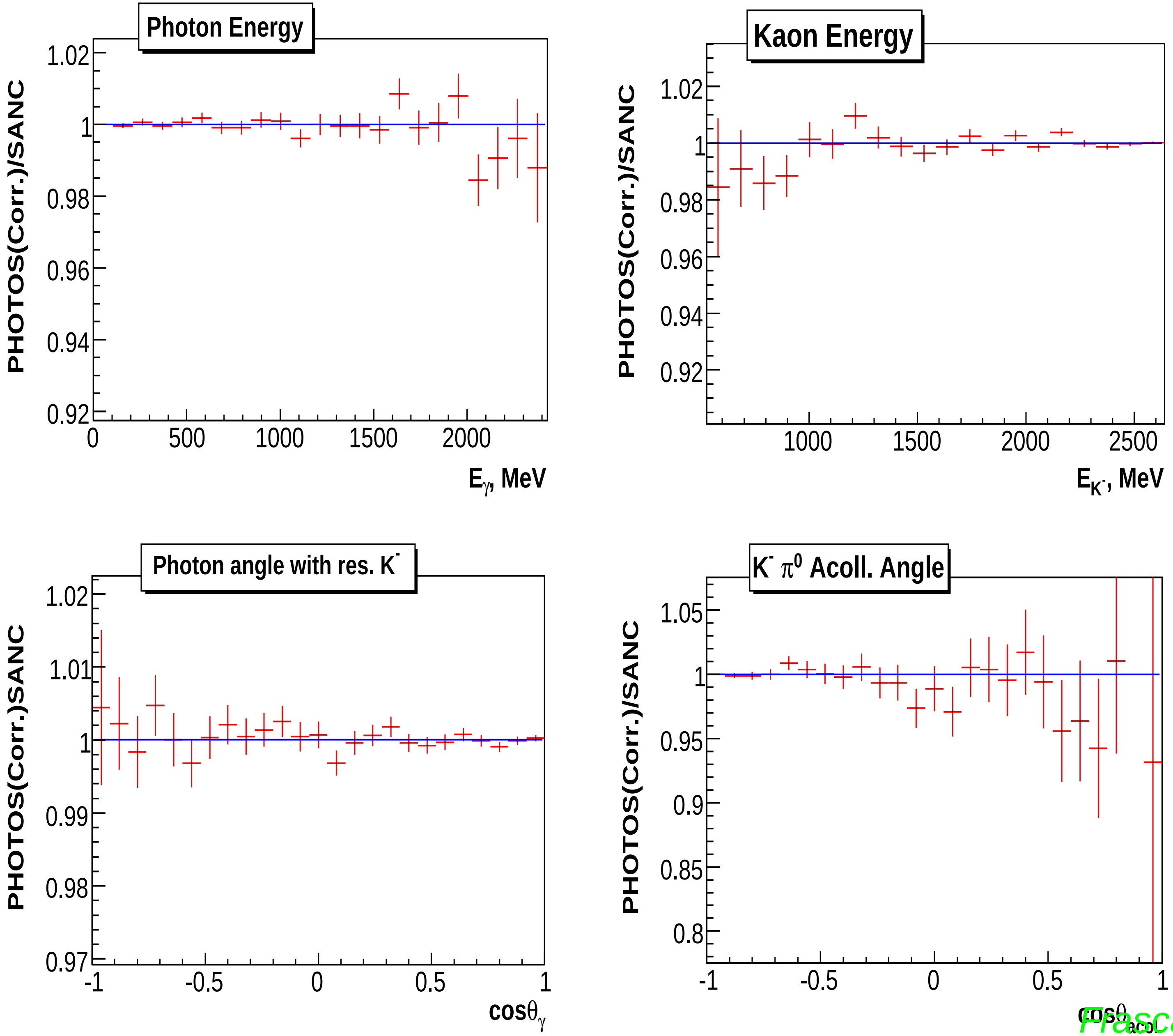
$B^- \rightarrow \pi^0 K^-$: standard PHOTOS not perfect



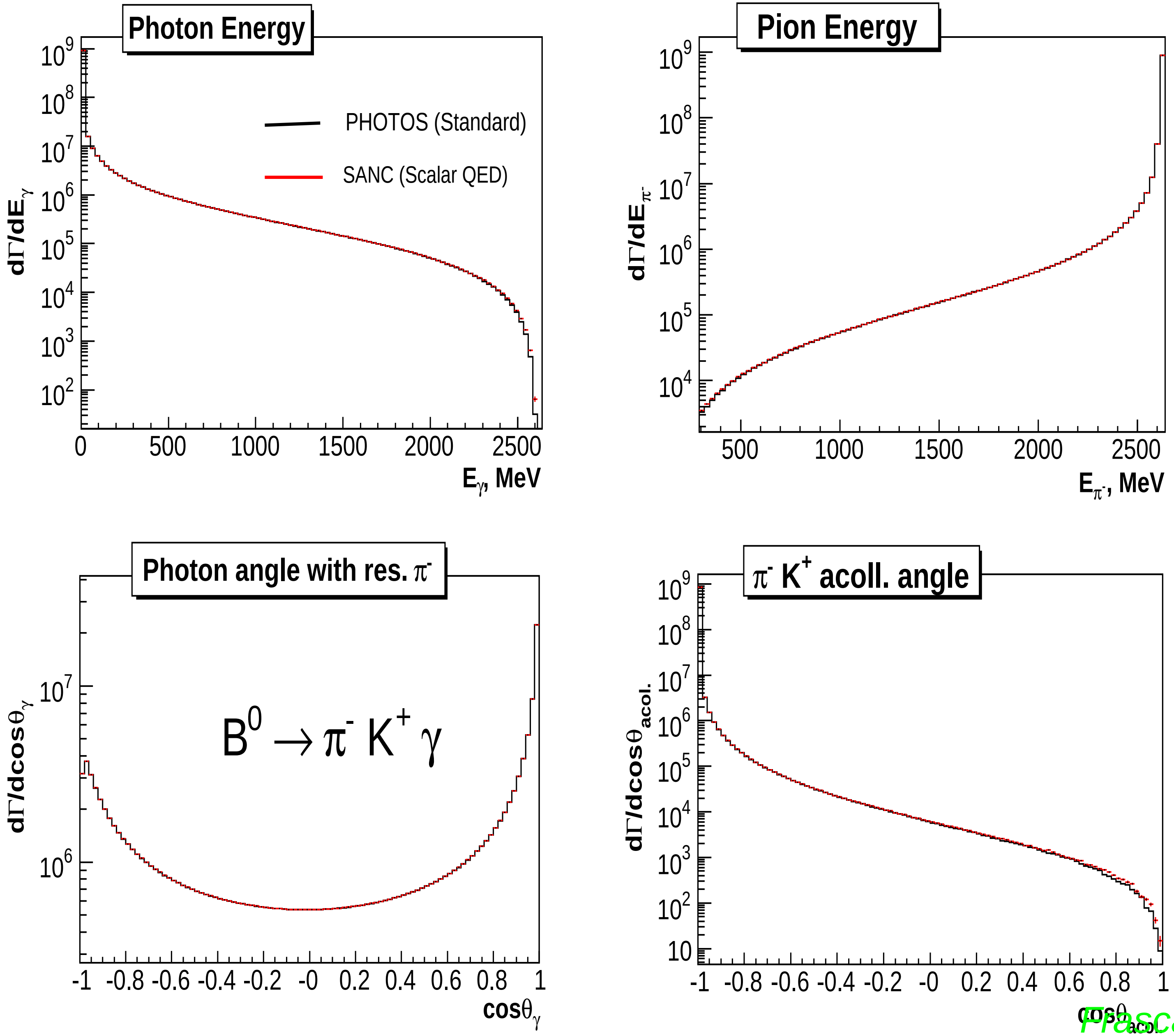
$B^- \to \pi^0 K^-$: NLO improved PHOTOS Looks good



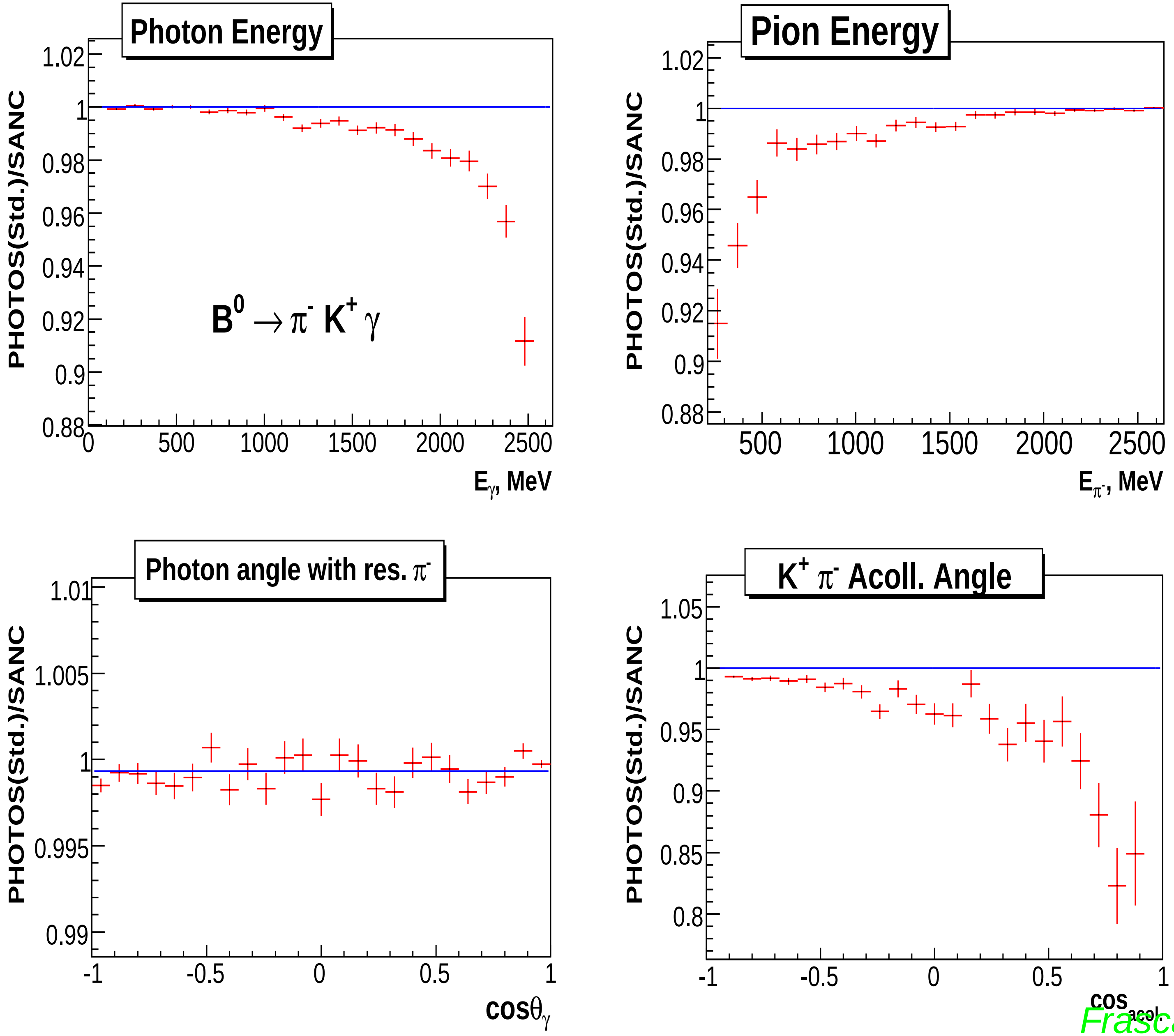
## $B^- \to \pi^0 K^-$: *NLO improved PHOTOS* ... and is good.



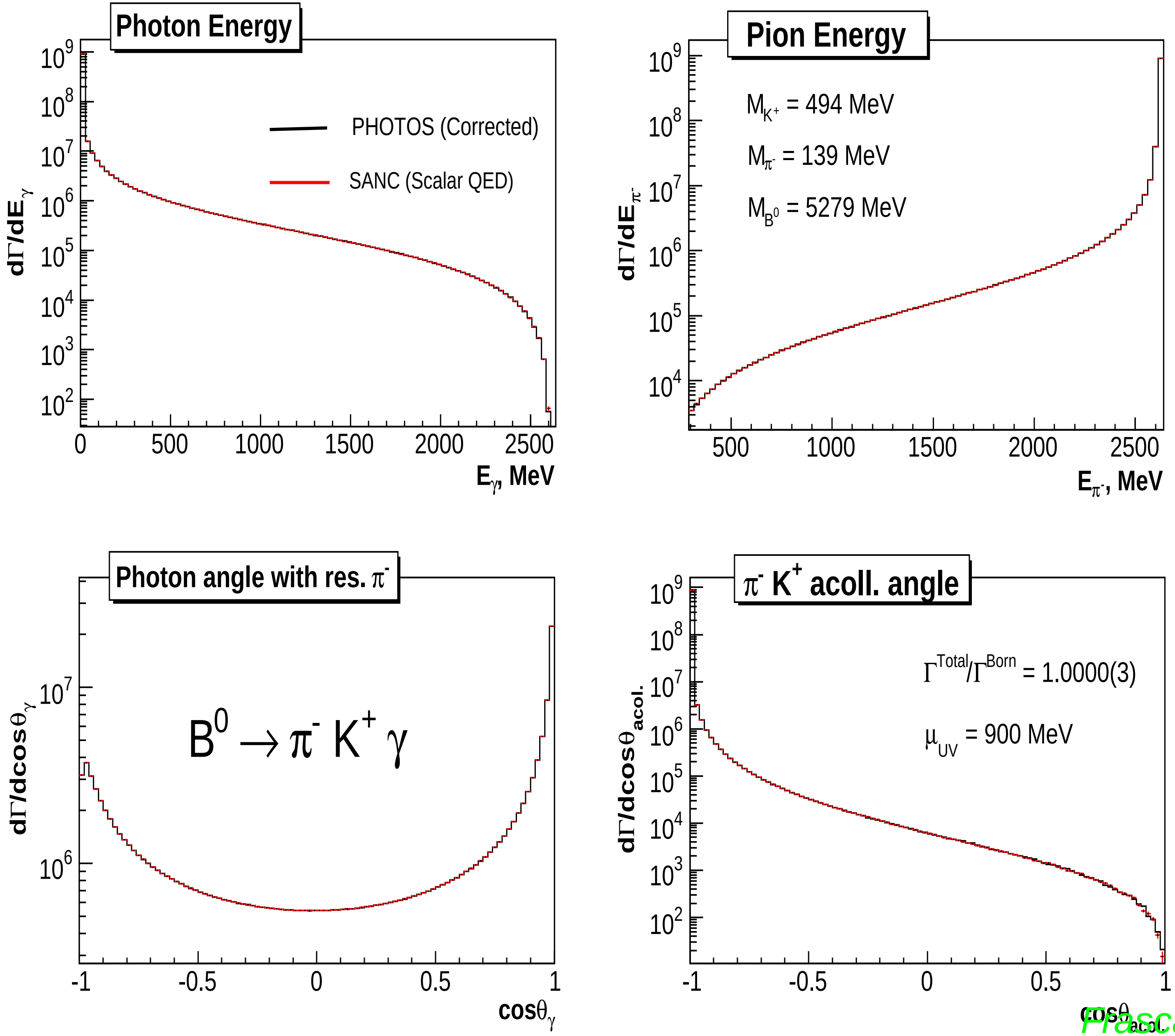
$B^0 \to \pi^- K^+$: standard PHOTOS Looks good ...



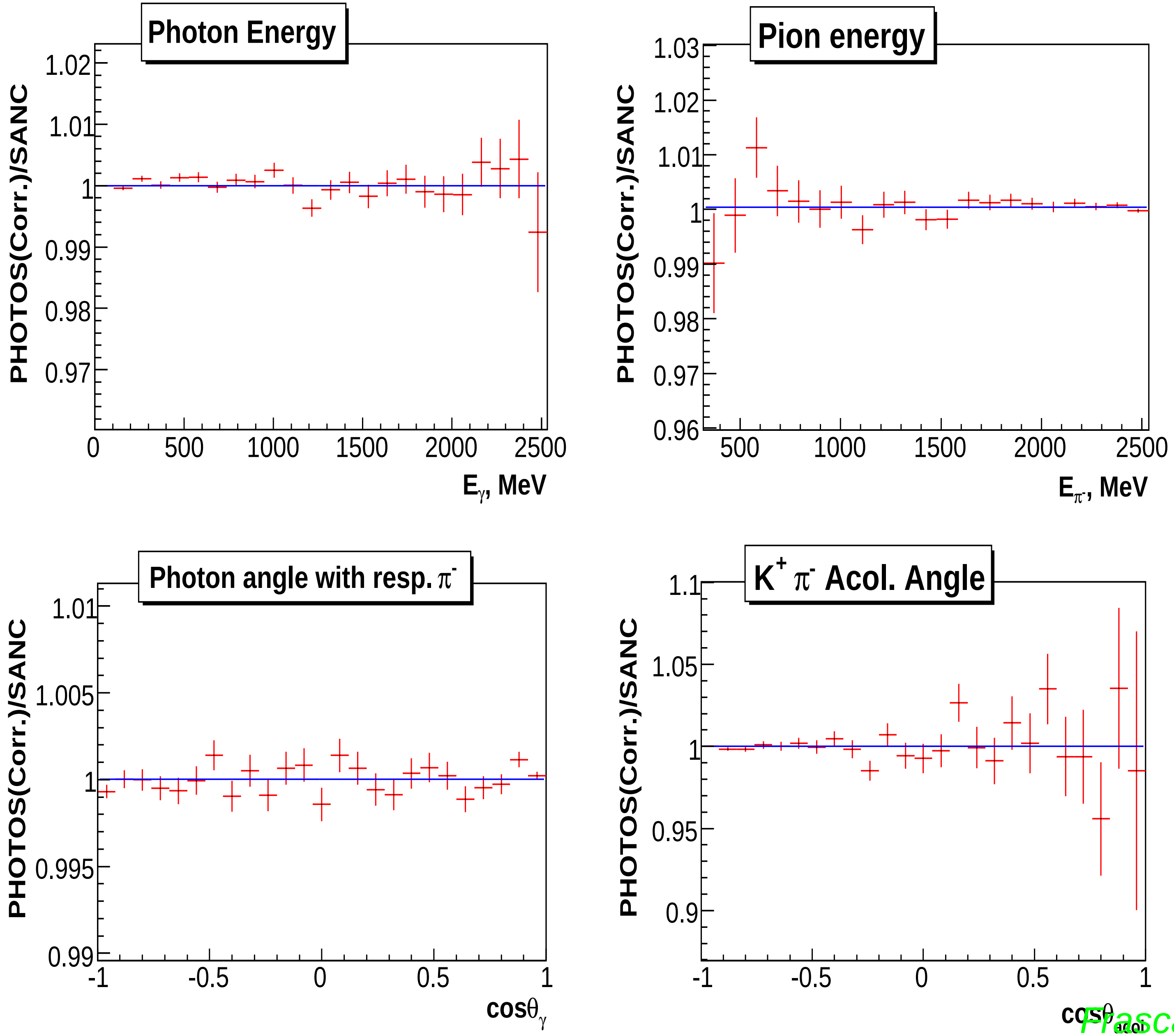
$B^0 \to \pi^- K^+$: *standard PHOTOS* ... but not perfect.



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

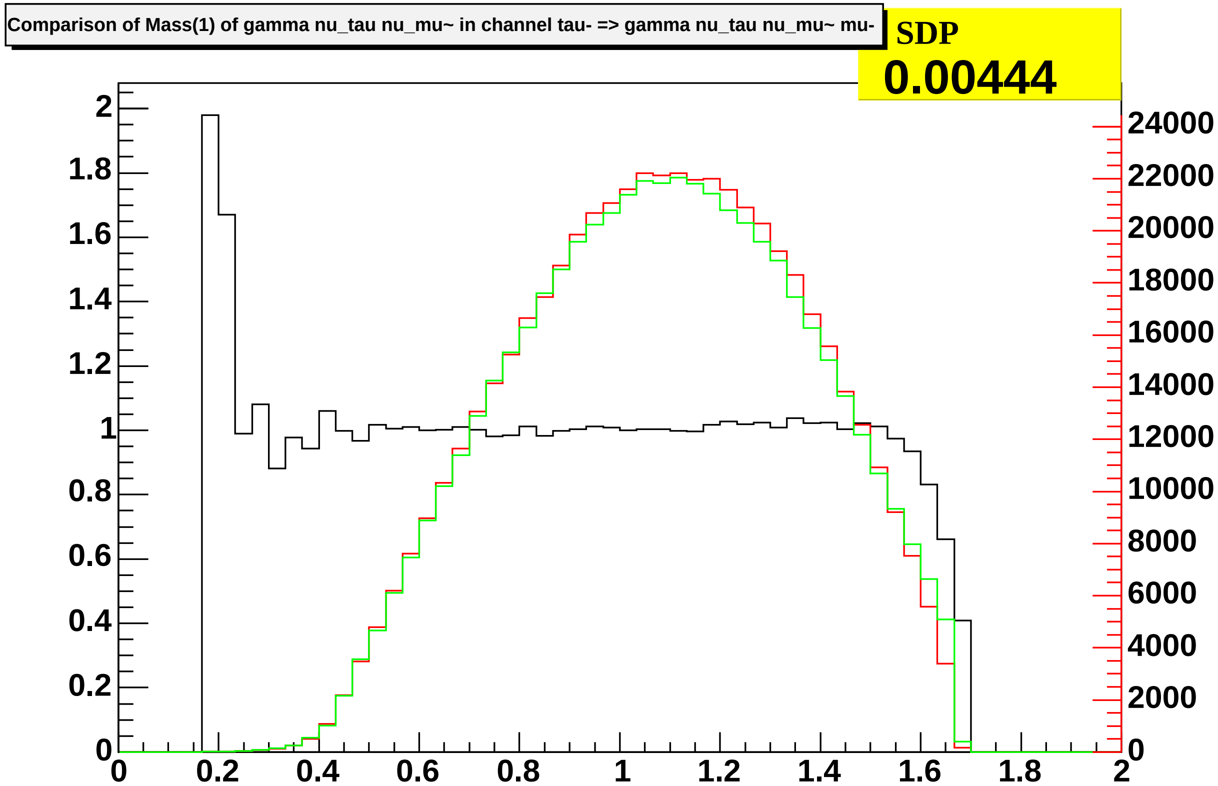


$B^0 \rightarrow \pi^- K^+$; *NLO improved PHOTOS* ... also perfect !



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

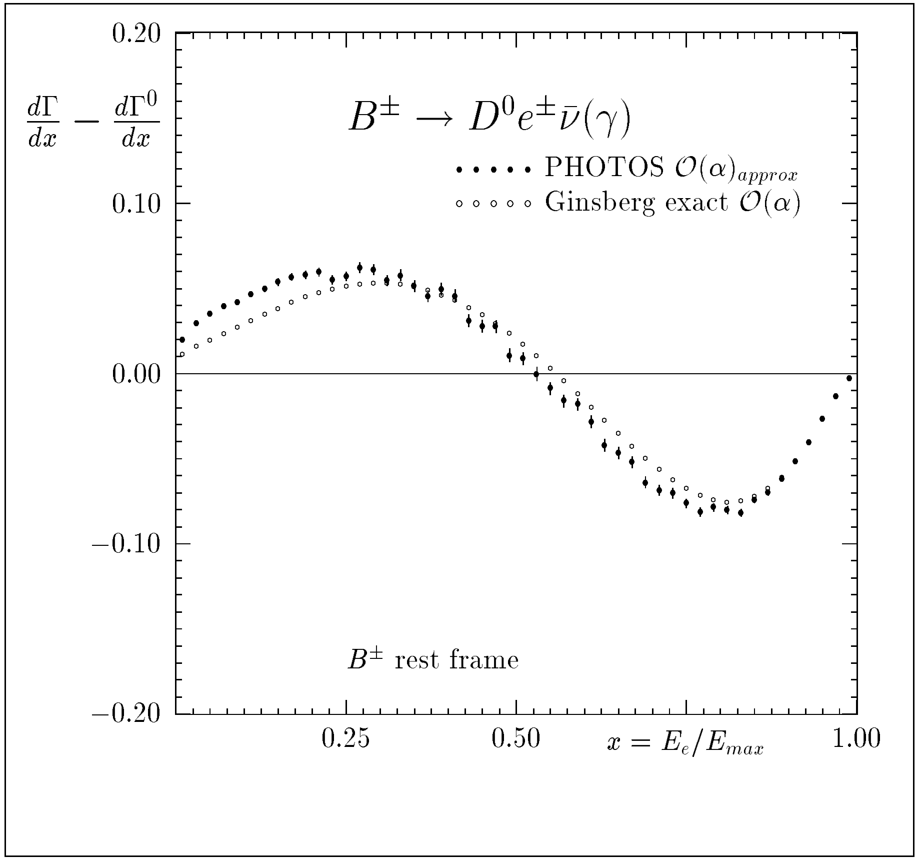
Plot of worst agreement for the channel. Distribution of $\gamma\nu_\tau\nu_\mu$ system mass is shown .




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.

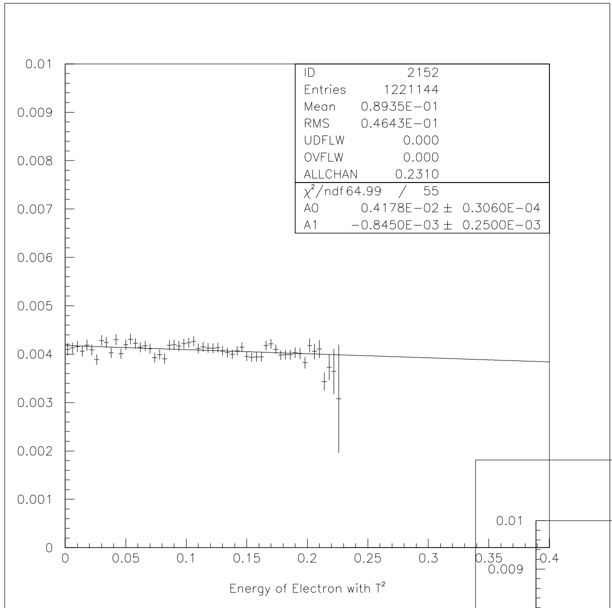
**Phys. Lett, B 303 (1993) 163-169**

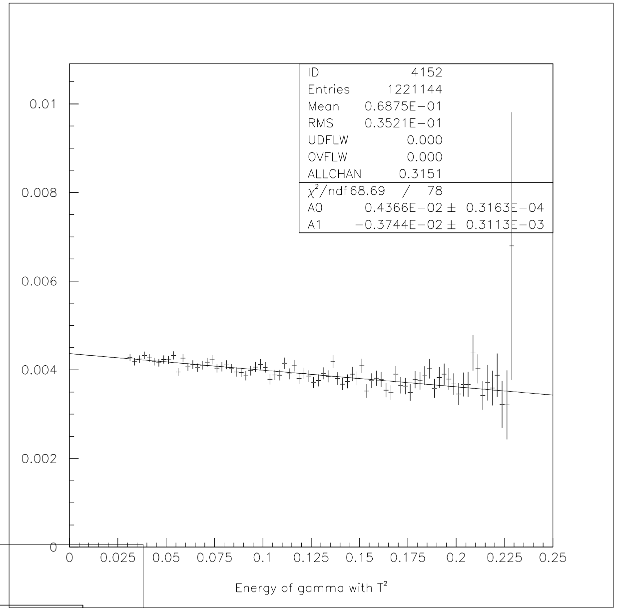


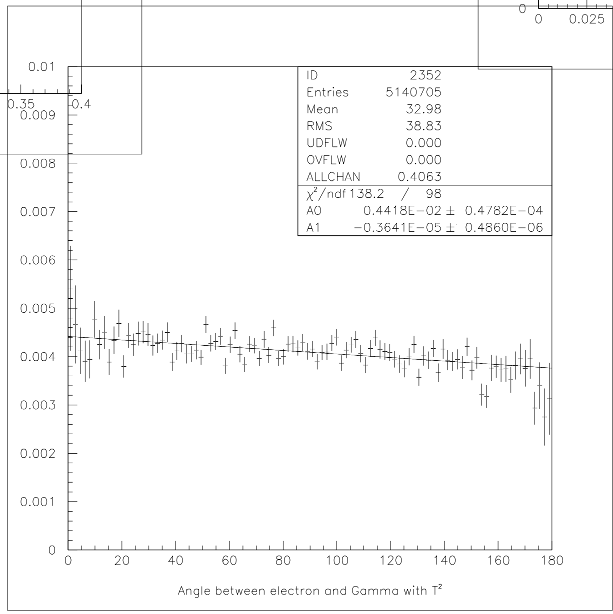

Radiative correction to the decay rate $(d\Gamma/dx - d\Gamma^0/dx)$ for $B^{\pm} \rightarrow D^0 e^{\pm} \bar{\nu}(\gamma)$ in the $B^{\pm}$ rest frame. Open circles are from the exact analytical formula [2], points with the marked statistical errors from PHOTOS applied to JETSET 7.3. A total of $10^7$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

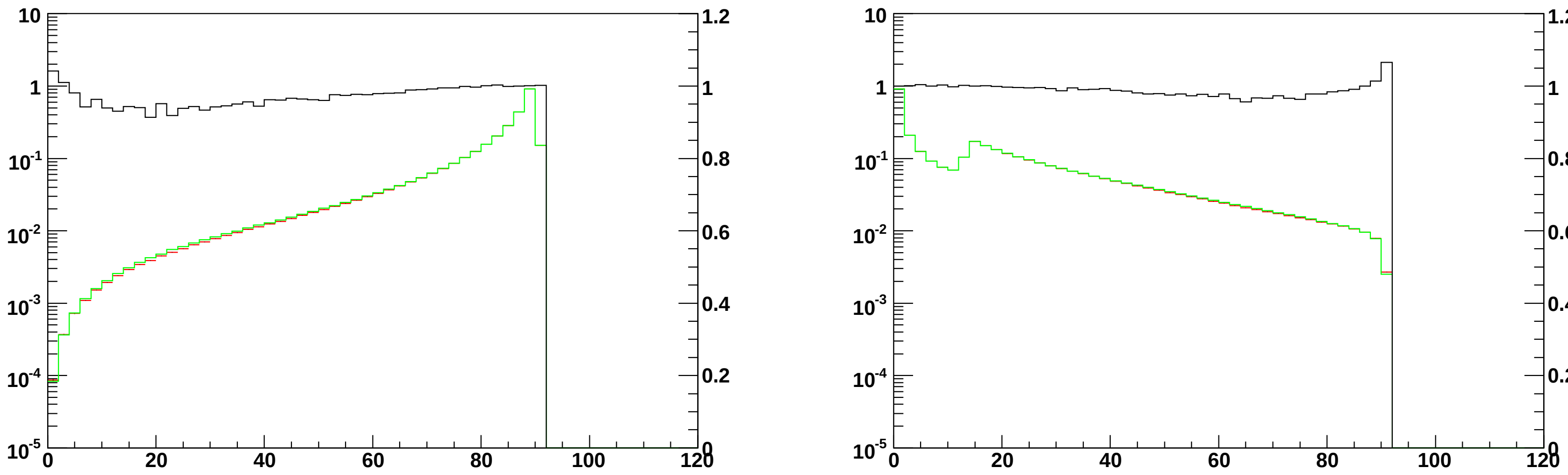



*Figure 3: Comparison of standard PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.00409. In right frame the invariant mass of the $\mu^-\gamma$ pair; SDP=0.0025. The pattern of differences 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.*

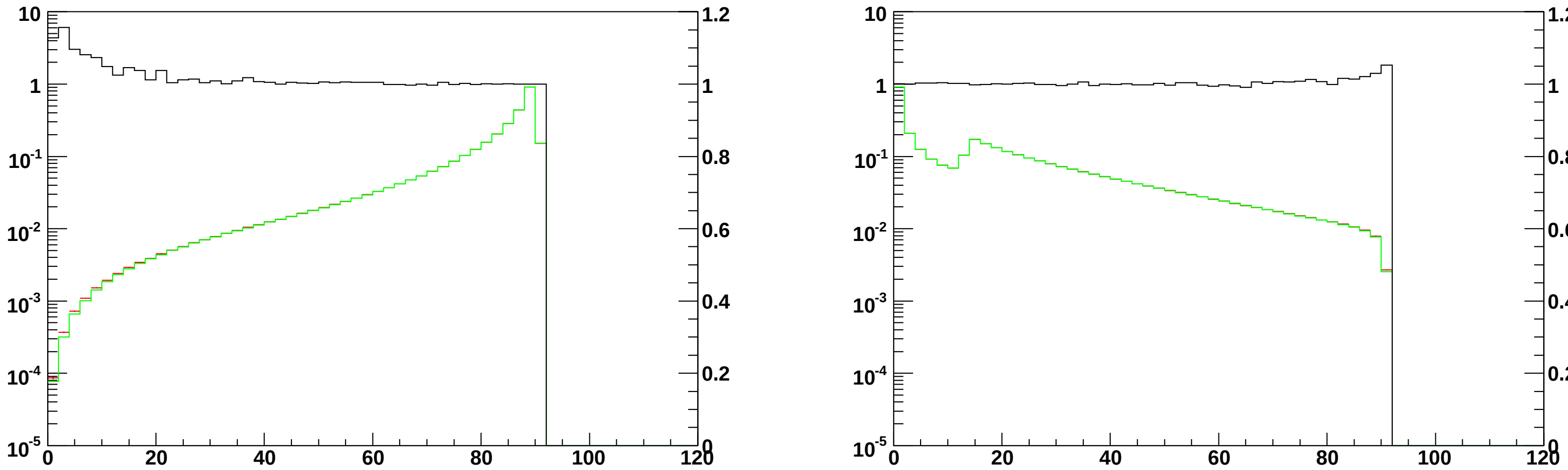



*Figure 4: Comparisons of improved PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP=0.0000249. In the right frame the invariant mass of the $\mu^-\gamma$ pair; SDP=0.0000203. The fraction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

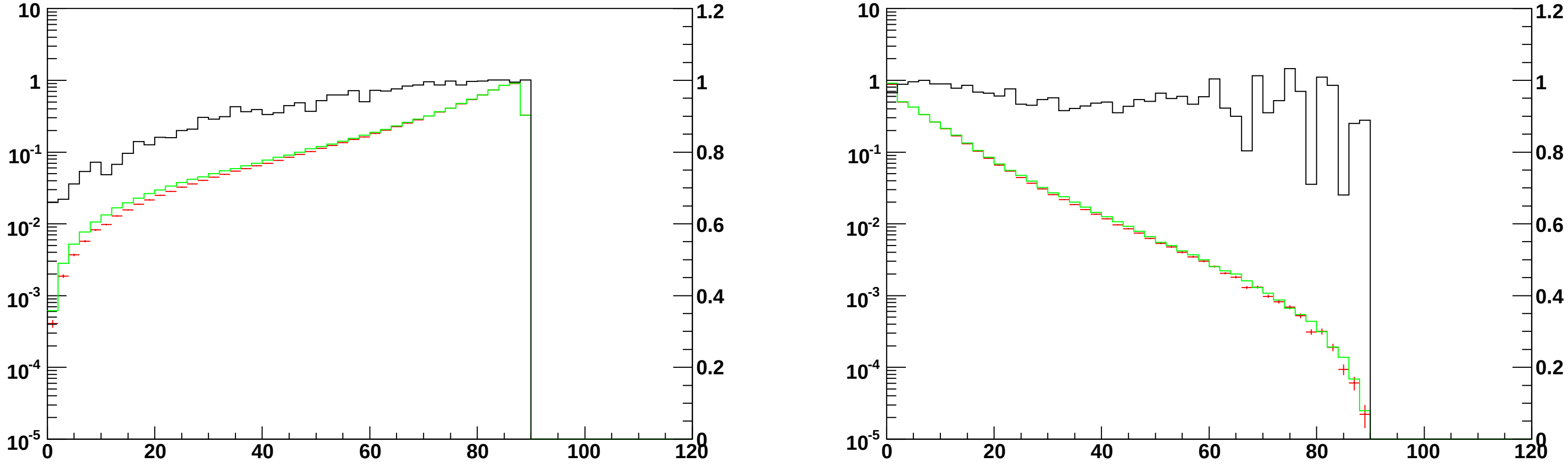



*Figure 5: Comparisons of standard PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP= 0.00918. In the right frame the invariant mass of the $\gamma\gamma$ pair; SDP=0.00268. The fraction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

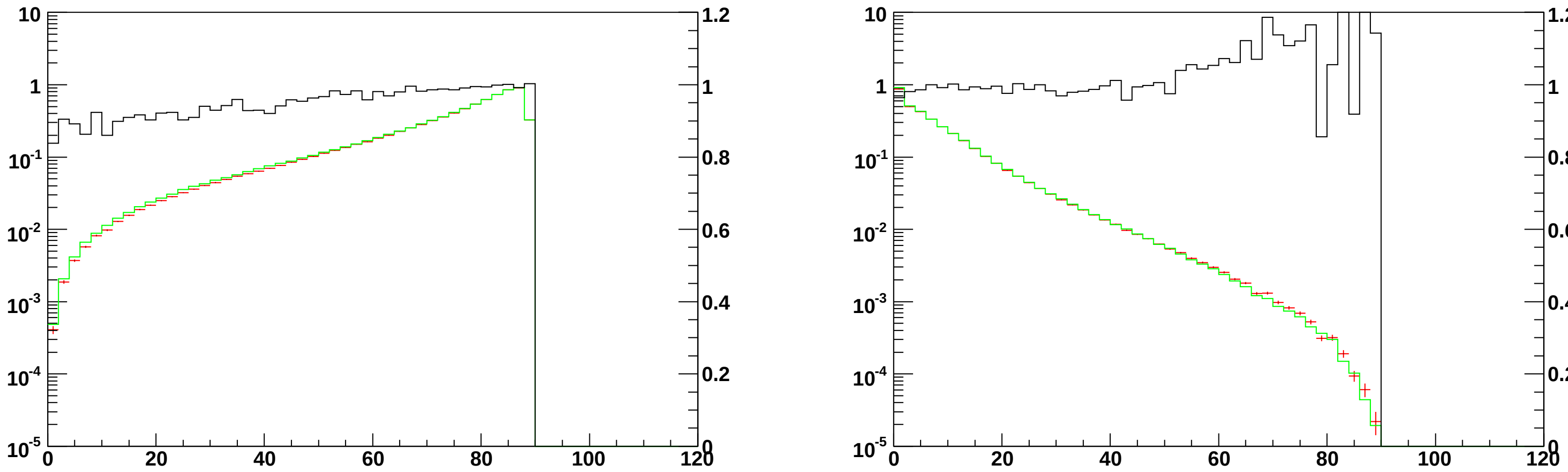
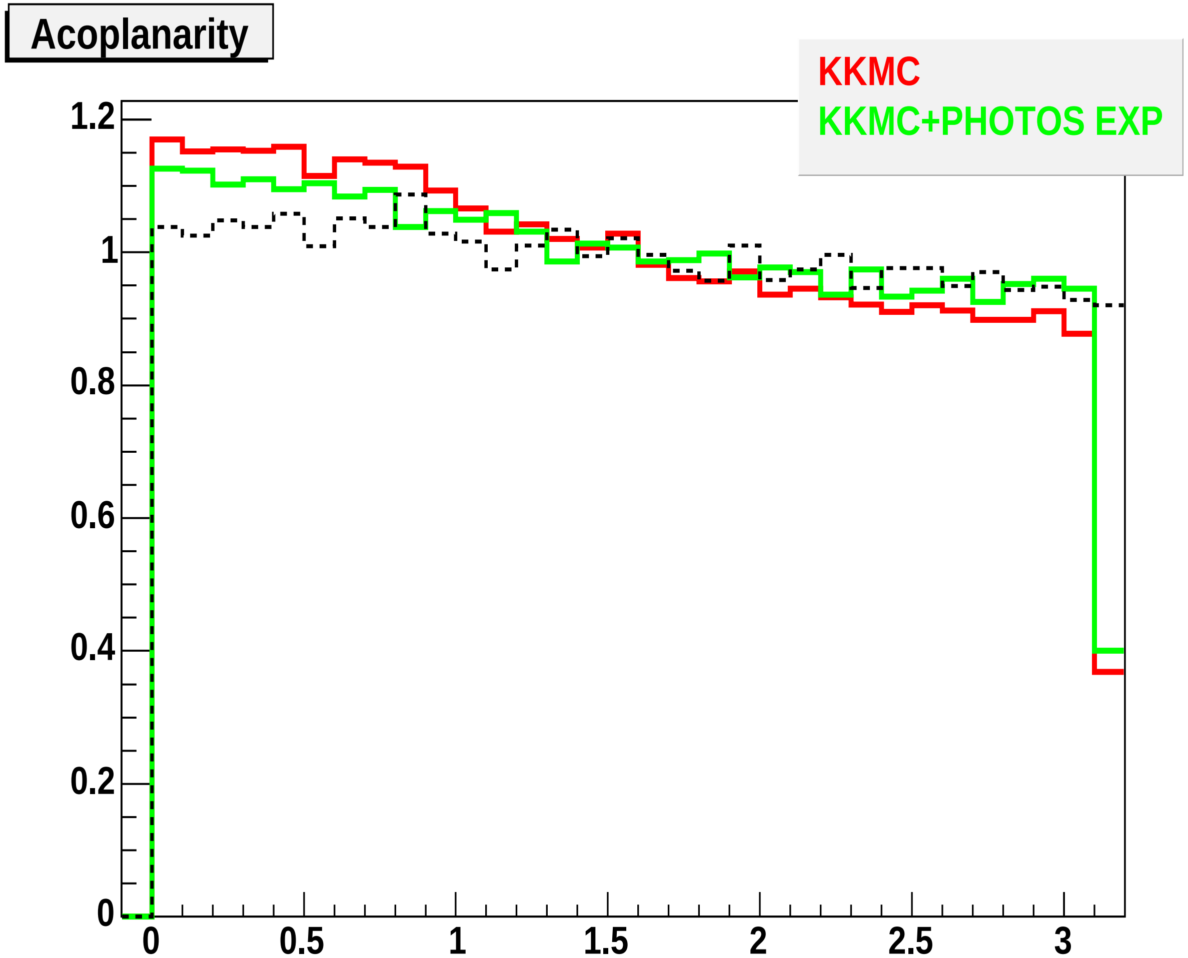



*Figure 6: Comparisons of improved PHOTOS with multiple photon emission and KKMC with second order matrix element and exponentiation. In the left frame the invariant mass of the $\mu^+\mu^-$ pair; SDP= 0.00142. In the right frame the invariant mass of the $\gamma\gamma$; SDP=0.00293. The fraction of 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 $\mu^+$ and respectively two hardest photons localized in the same hemisphere as $\mu^+$. Why PHOTOS works so good?

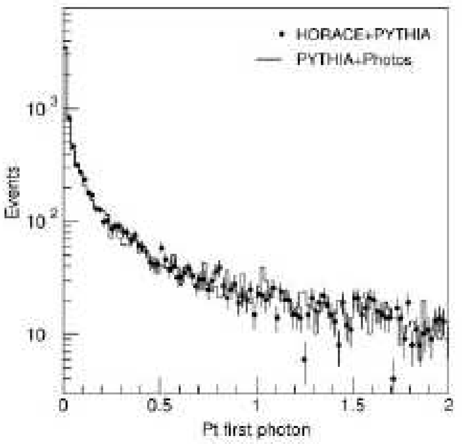
# A successful validation example..

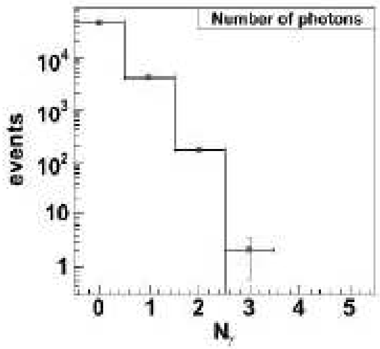
- Comparison between PHOTOS (supposed to be an approximate algorithm in principle) and HORACE (exact QED DGLAP solution):
  - Turns out that PHOTOS is doing an excellent job!

## 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

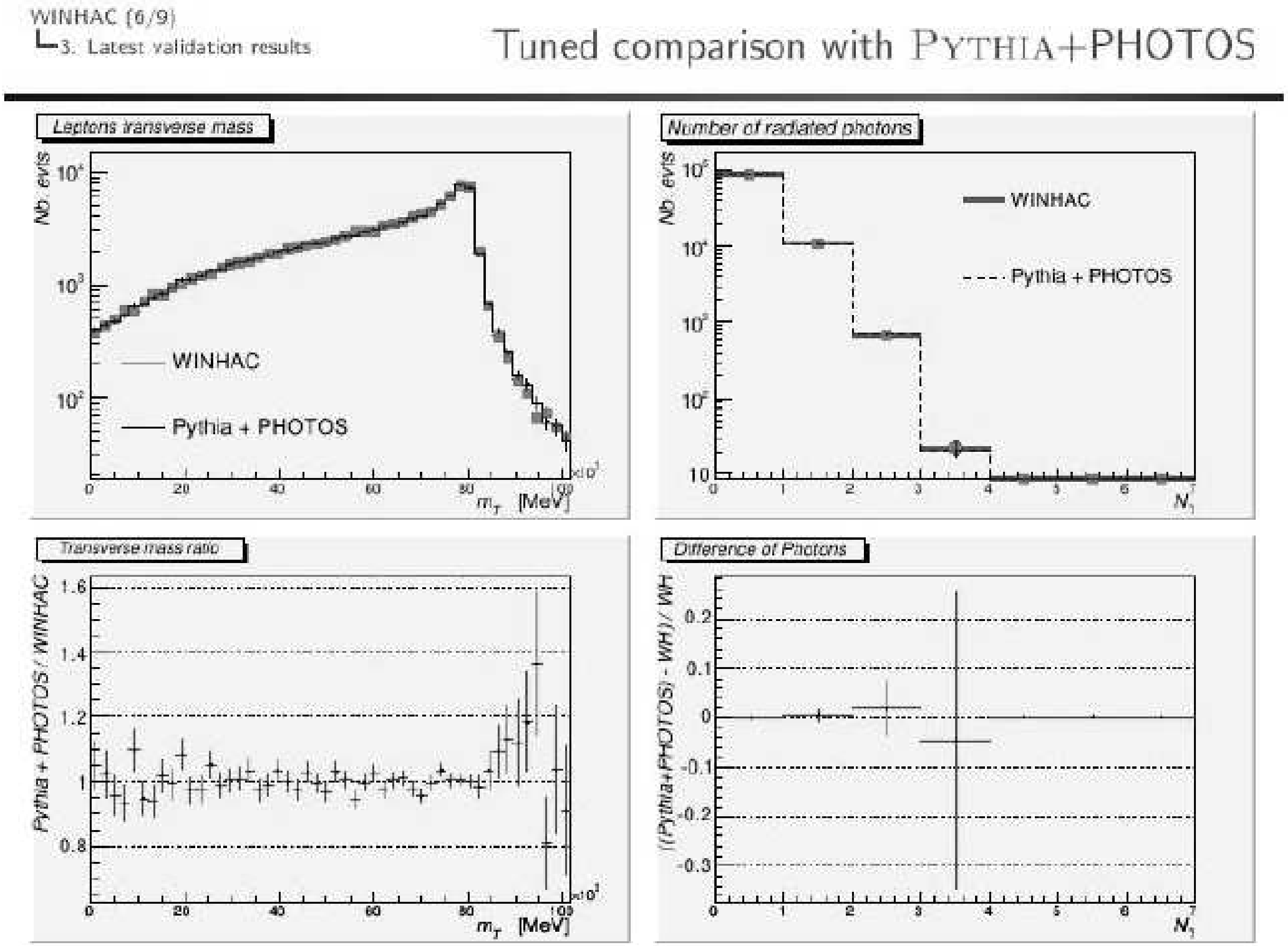
Pythia + Photos





This is for Z production at LHC.

# 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.