TAOLA the τ lepton decay library

KKMC/KORALB/KORALZ/...

Status report

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Main Topics:

- **Introduction.**
- **TAUOLA itself, software upgades.**
- **External versions.**
- **KORALB/KORALZ/KKMC.**
- **Universal interface.**
- **summary and outlook.**

TAUOLA and related projects were developped by: R. Decker, S. Jadach, M. Jeżabek, J.H. Kühn, Z.W. (production of τ's also B.F.L. Ward E. Richter-Was), contributions from ALEPH, CLEO, Delphi, Opal, L3 collabs, Karlsruhe theory grup, and others.

Slides are on http://home.cern.ch/wasm

Motivation

I hope that we can agree, that at least in simplified way:

Physics of the τ lepton developpes fast

Precision of the measurements is already high and improving,

Different τ decay modes form background to each other

Measurements often require sophisticated cuts.

Monte Carlo solution is a must:

Due to the long τ lepton lifetime,

generation can be separated into production and decay as completely independent projects.

all spin effects of the Einstein-Rosen-Podolsky type can be handled this way

τ decay generation consist of:

Bookkeeping and library for phase space generation.

Easy to replace matrix elements or hadronic currents

Main references:

1. R. Decker, S.Jadach, M.Ježabek, J.H.Kuhn, Z. Was, Comput. Phys. Commun. 76 (1993) 361, ibid. 70 (1992) 69, ibid. 64 (1990) 275
2. P. Golonka, Z. Was, TPJU 10/2000, technical stuff only.

Also:

1. Alain Weinstein www home page: http://www.cithep.caltech.edu/˜ajw/korb_doc.html#files
2. B. Bloch, private communications.
3. R. Decker, M. Finkemeier, P. Heiliger and H.H. Jonsson, Hep-ph/9410260, now standard 4π formfactors.
4. P. Abreu et al., Phys. Lett. B426 (1998) 411 (alternative 3π formfactors)
5. Sherry Towers aternative formfactors in K$\pi\pi$ modes, hep-ex/9908013

And as usual, references therein

I am nearly sure, I have forgotten something.

The complete distribution directory can be found on: http://home.cern.ch/wasm

Tauola itself

Not much progress on our side:

Elements of standard description:

Tere are (at least) 22 decay modes included,

Program is ogranized on the basis of full phase-space – matrix-element separation,

Modifications to matrix elements (hadronic currents) are easy and localized in well defined functions.

Interface for complete spin treatment is prepared.

Recent progress:

Technical fix ups (essential for linux)

Pre-coding for versions using cpp pre-compiler

Choices available

Dimensionality of HEPEVT common block

Type of physic initialization standard CPC, CLEO, ALEPH

Type of application: stand-alone, like in KKMC, universal interface based on searching through HEPEVT common block

utilities to replace: random number generators and (centrally) input parameters

PHOTOS versions are also included in this environment

HEPEVT common block

The work was motivated and started by member of LHC collaboration

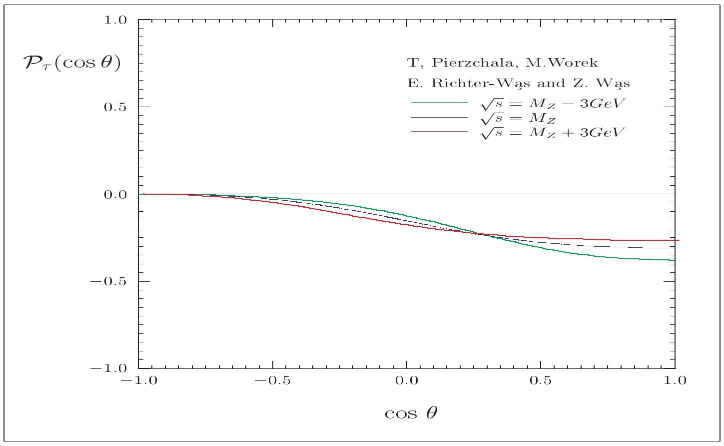
It is often convenient to decay τ leptons easy and quickly. We do exactly like that. Once event is generated and HEPEVT common block is filled it is enough to CALL TAUOLA(0,IDUM) and all undecayed τ leptons will be decayed and stored into HEPEVT.

Some minimum care of the spin is taken at the longitudinal approximation:

1. Cases of τ produced from: W (virtual), Z/γ, Higgs, Charged Higgs are distinguished in spin correlations.
2. For Z/γ case τ polarization as a function of effective $\cos\theta$, s and initial state flavour is used.
3. Lots of tests need to be done, Now we have done only most elementary ones, full spin option for Z/γ is thus not yet included in the distribution file instead, polarization as from pure γ production is used.

τ-polarization in $e^+e^- \to \tau^+\tau^-$

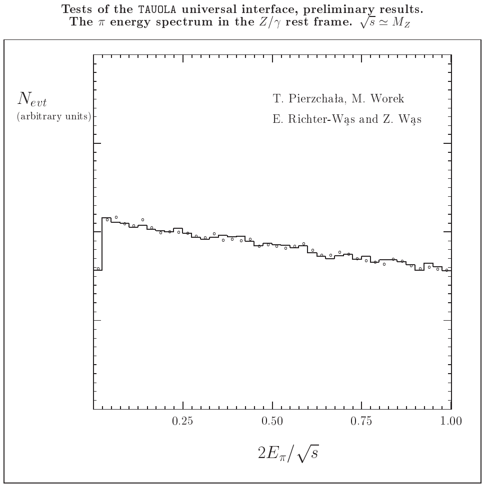
Tests of the TAUOLA universal interface, preliminary results.
The τ lepton polarization as a function od $\cos\theta$ for the $e^+e^- \to \tau^+\tau^-$ process.

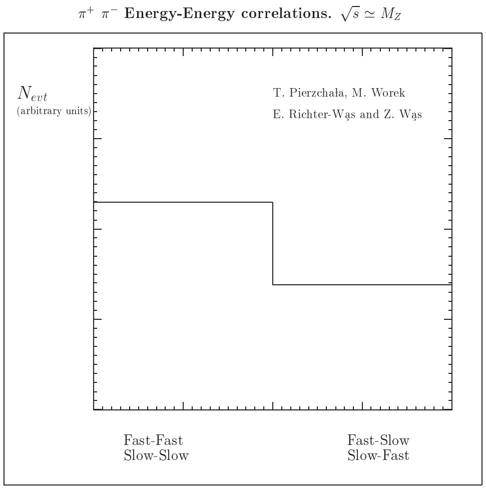


The function used in the interface is taken form KORALZ.

It looks after implementation (equally) OK.

Test at τ decay products level





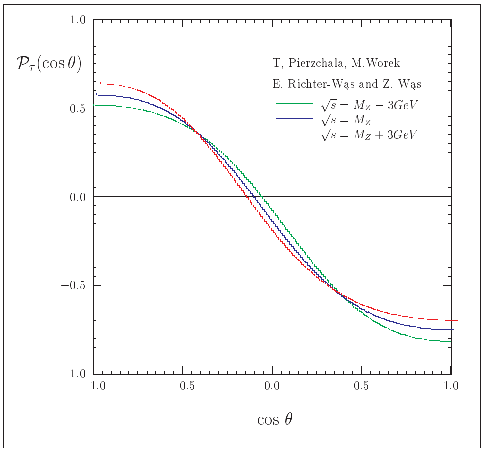
To make spin effects large, we take sample of both τ' decaying into $\pi\nu$. Standard tests are getting reproduced qualitativelly.

We will continue with the more sophisticated tests in future. In particular we need to test the algorithm for matching bremsstrahlung.

τ-polarization in $q\bar{q} \to \tau^+\tau^-$

Now let us use the same functions for quarks:

Tests of the TAUOLA universal interface, preliminary results
The τ lepton polarization as a function od $\cos\theta$ for the $u\bar{u} \to \tau^+\tau^-$ process.



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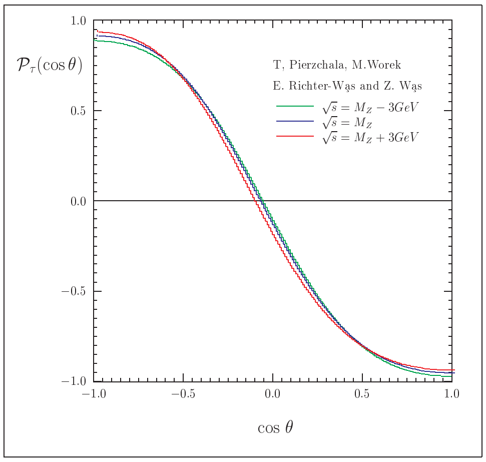
Tests of the TAUOLA universal interface, preliminary results.
The τ lepton polarization as a function od $\cos\theta$ for the $d\bar{d} \to \tau^+\tau^-$ process.



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Programs presentation

I will concentrarte on what is new that is KKMC:

references:

Papers on CEEX by S. Jadach, B.F.L. Ward and Z. Wąs:

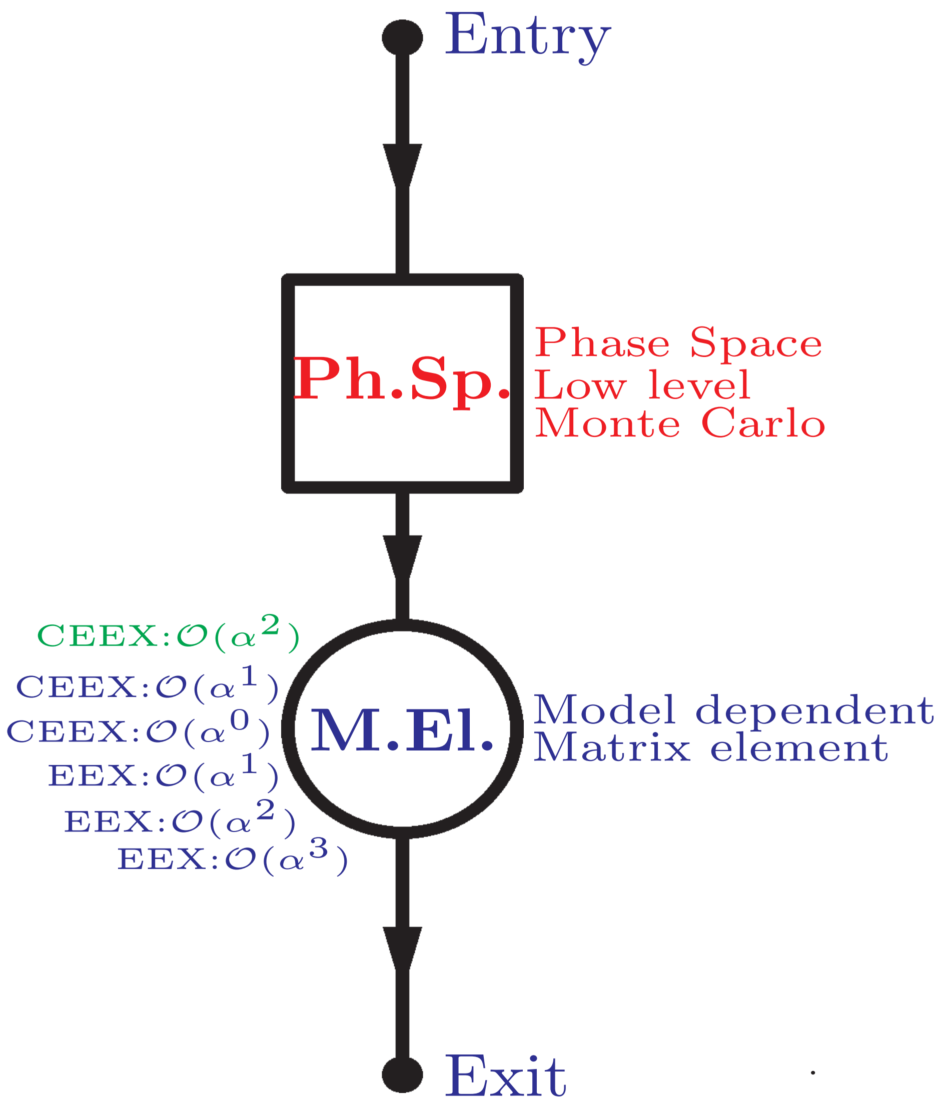
Phys. Lett. B449 (1999) 97, (CERN-TH/98-253), CERN-TH/98-235, subm. to EPJ,

DESY-99-106 (CERN-TH/99-235), 88p., Comput. Phys. Commun. 130 260 (2000) 260

UTHEP-99-09-01 (CERN-TH/2000-087, hep-ph/0006359).

web page at: **http://home.cern.ch/jadach**

General structure of $\mathcal{KK}$ MC (flowchart)

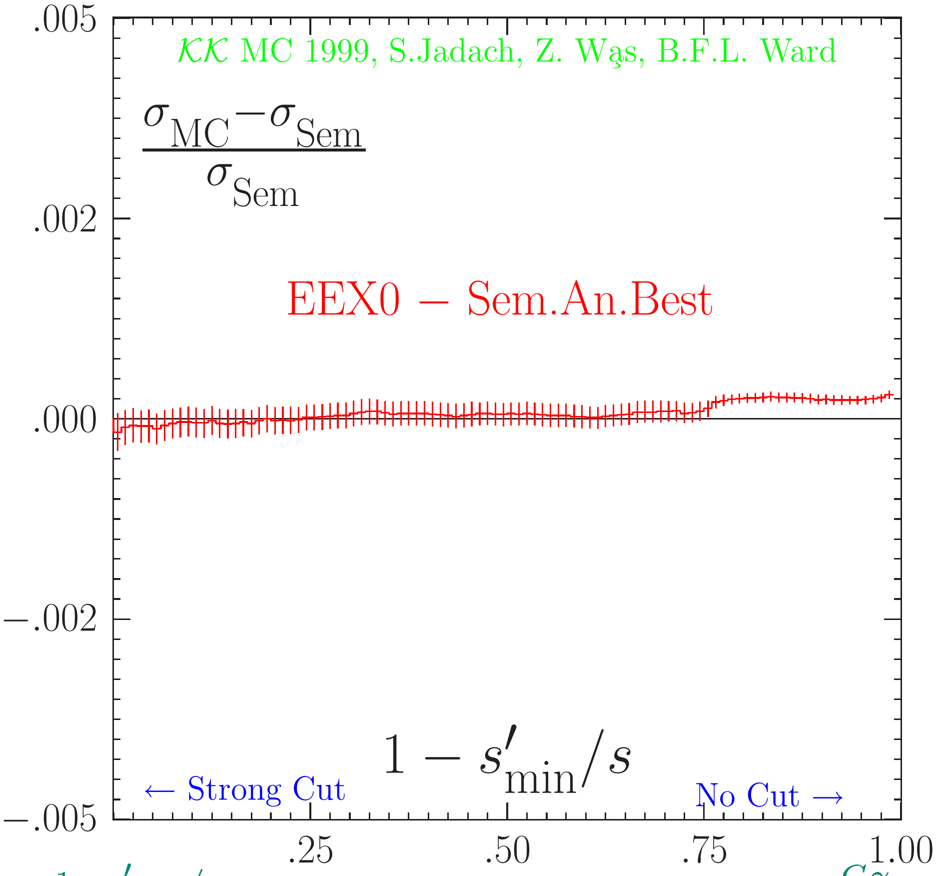


- **Universal Phase-space Monte Carlo simulator**
- **Library of several types of QED matrix elements**
- **Library of SM/QCD formf-factors**
- **Tau decays or hadronization come after**

Numerical Results: Techn. precision

Baseline test of the Low level MC

$|$ **Matrix Element** $|^2$ **= Born** $\times$ **Product of soft factors**



$$\sigma_{\mathrm{Sem.}} = \int_0^{1-s'_{\mathrm{min}}/s} dv\ \sigma^f_{\mathrm{Born}}(s(1-u)(1-v))\ \frac{e^{-C\gamma_e}}{\Gamma(1+\gamma_e)}$$

$$e^{\frac{1}{4}\gamma_e+\frac{\alpha}{\pi}\left(\frac{1}{2}+\frac{\pi^2}{3}\right)}\ \gamma_e v^{\gamma_e-1}\left[1-\frac{\gamma_e\ln(1-v)}{4}-\frac{\alpha}{\pi}\frac{\ln^2(1-v)}{2}+0\ \gamma_e^2\right]$$

$$\frac{e^{-C\gamma_f}}{\Gamma(1+\gamma_f)}e^{\frac{1}{4}\gamma_f-\frac{1}{2}\gamma_f\ln(1-u)+\frac{\alpha}{\pi}\left(\frac{1}{2}+\frac{\pi^2}{3}\right)}\gamma_f u^{\gamma_f-1}\left[1-\frac{\gamma_f\ln(1-u)}{4}\right]$$

Techn.Error= $|$**MC**$-$**Sem.Anl.**$|\ \leq 2\cdot 10^{-4}$

CEEX practical considerations

Practical problems

Deficiencies of YFS **Exclusive Exponentiation** (EEX) technique, as implemented in KORALZ/YFS3, BHLUMI, BHWIDE, KORALW:

- Lack of the ISR/FSR or Up/Down interferences (except BHWIDE, but difficult to upgrade...)
- Simplified treatment of spin, neglected transverse polarization (except KORALB, but no exponentiation...)
- Approximate matrix element for 2 and 3 hard large p_T photons. (Multiphotons are important for searches.)

The CEEX solution

New Coherent Exclusive Exponentiation CEEX solves many (all?):

- ISR$\otimes$FSR interferences are included in a natural way. Spin amplitudes for ISR and FSR summed squared numerically. (The BHWIDE approach gets cumbersome beyond first order)
- Exact treatment of fermion spin polarizations (transv.&longitudinal). Numerical Wigner rotations of spin density matrices available. (Necessary for interfacing with decay M.C. simulating fermion decays).
- Exact matrix element for 2 and 3 and more photons using Kleiss-Stirling (KS) spinor technique.

CEEX schematically

$$\sigma = \sum_{n=0}^{\infty} \int_{m_\gamma} d\Phi_{n+2} \sum_{\lambda,\sigma_1,\dots,\sigma_n} \left| e^{B(m_\gamma)} \mathcal{M}^{\lambda}_{n,\sigma_1,\dots,\sigma_n}(k_1,\dots,k_n) \right|^2$$

$\mathcal{O}(\alpha^1)$ Example:

$\mathcal{M}^{\lambda}_0 = \hat{\beta}^{\lambda}_0$, λ=fermion helicities,

$$\mathcal{M}^{\lambda}_{1,\sigma_1}(k_1) = \hat{\beta}^{\lambda}_0 \mathfrak{s}_{\sigma_1}(k_1) + \hat{\beta}^{\lambda}_{1,\sigma_1}(k_1)$$

$$\mathcal{M}^{\lambda}_{2,\sigma_1,\sigma_2}(k_1,k_2) = \hat{\beta}^{\lambda}_0 \mathfrak{s}_{\sigma_1}(k_1)\mathfrak{s}_{\sigma_2}(k_2) + \hat{\beta}^{\lambda}_{1,\sigma_1}(k_1)\mathfrak{s}_{\sigma_2}(k_2) + \hat{\beta}^{\lambda}_{1,\sigma_2}(k_2)\mathfrak{s}_{\sigma_1}(k_1)$$

IR-finite building blocks:

$$\hat{\beta}^{\lambda}_0 = \left(e^{-B} \mathcal{M}^{\text{Born+Virt.}}_{\lambda} \right)\Big|_{\mathcal{O}(\alpha^1)},$$

$$\hat{\beta}^{\lambda}_{1,\sigma}(k) = \mathcal{M}^{\lambda}_{1,\sigma}(k) - \hat{\beta}^{\lambda}_0 \mathfrak{s}_{\sigma}(k)$$

Everything in terms of $\mathcal{M}$-spin-amplitudes !!!!

Full Scale CEEX $\mathcal{O}(\alpha^r)$, r=1,2, master formula

Polarized total x-section:

$$\sigma^{(r)} = \sum_{n=0}^{\infty} \frac{1}{n!} \int d\tau_n(p_a+p_b; p_c, p_d, k_1, \dots, k_n)\; e^{2\alpha \Re B_4} \sum_{\sigma_i, \lambda, \bar\lambda} \sum_{i,j,l,m=0}^{3}$$
$$\hat\varepsilon_a^i \hat\varepsilon_b^j \sigma^i_{\lambda_a \bar\lambda_a} \sigma^j_{\lambda_b \bar\lambda_b} \mathfrak{M}_n^{(r)} \begin{pmatrix} p & k_1 & k_2 & \dots & k_n \\ \lambda & \sigma_1 & \sigma_2 & \dots & \sigma_n \end{pmatrix} \left[\mathfrak{M}_n^{(r)} \begin{pmatrix} p & k_1 & k_2 & \dots & k_n \\ \bar\lambda & \sigma_1 & \sigma_2 & \dots & \sigma_n \end{pmatrix} \right]^\star \sigma^l_{\bar\lambda_c \lambda_c} \sigma^m_{\bar\lambda_d \lambda_d} \hat h_c^l \hat h_c^m$$

CEEX amplitudes:

$$\mathfrak{M}_n^{(1)} \begin{pmatrix} p & k_1 & \dots & k_n \\ \lambda & \sigma_1 & \dots & \sigma_n \end{pmatrix} = \sum_{\wp \in \mathcal{P}} \prod_{i=1}^{n} \mathfrak{s}_{[i]}^{\{\wp_i\}} \left\{ \beta_0^{(1)} \begin{pmatrix} p \\ \lambda \end{pmatrix}; X_\wp \right) + \sum_{j=1}^{n} \frac{\beta^{(1)}_{1\{\wp_j\}} \left(\begin{smallmatrix} p & k_j \\ \lambda & \sigma_j \end{smallmatrix}; X_\wp \right)}{\mathfrak{s}_{[j]}^{\{\wp_j\}}} \right\}$$

$$\mathfrak{M}_n^{(2)} \begin{pmatrix} p & k_1 & \dots & k_n \\ \lambda & \sigma_1 & \dots & \sigma_n \end{pmatrix} = \sum_{\wp \in \mathcal{P}} \prod_{i=1}^{n} \mathfrak{s}_{[i]}^{\{\wp_i\}}$$
$$\times \left\{ \beta_0^{(2)} \left(\begin{smallmatrix} p \\ \lambda \end{smallmatrix}; X_\wp \right) + \sum_{j=1}^{n} \frac{\beta^{(1)}_{2\{\wp_j\}} \left(\begin{smallmatrix} p & k_j \\ \lambda & \sigma_j \end{smallmatrix}; X_\wp \right)}{\mathfrak{s}_{[j]}^{\{\wp_j\}}} + \sum_{1 \le j < l \le n} \frac{\beta^{(2)}_{2\{\wp_j, \wp_l\}} \left(\begin{smallmatrix} p & k_j & k_l \\ \lambda & \sigma_j & \sigma_l \end{smallmatrix}; X_\wp \right)}{\mathfrak{s}_{[j]}^{\{\wp_j\}} \mathfrak{s}_{[l]}^{\{\wp_l\}}} \right\}$$

For details see next slides, and for true details our papers.

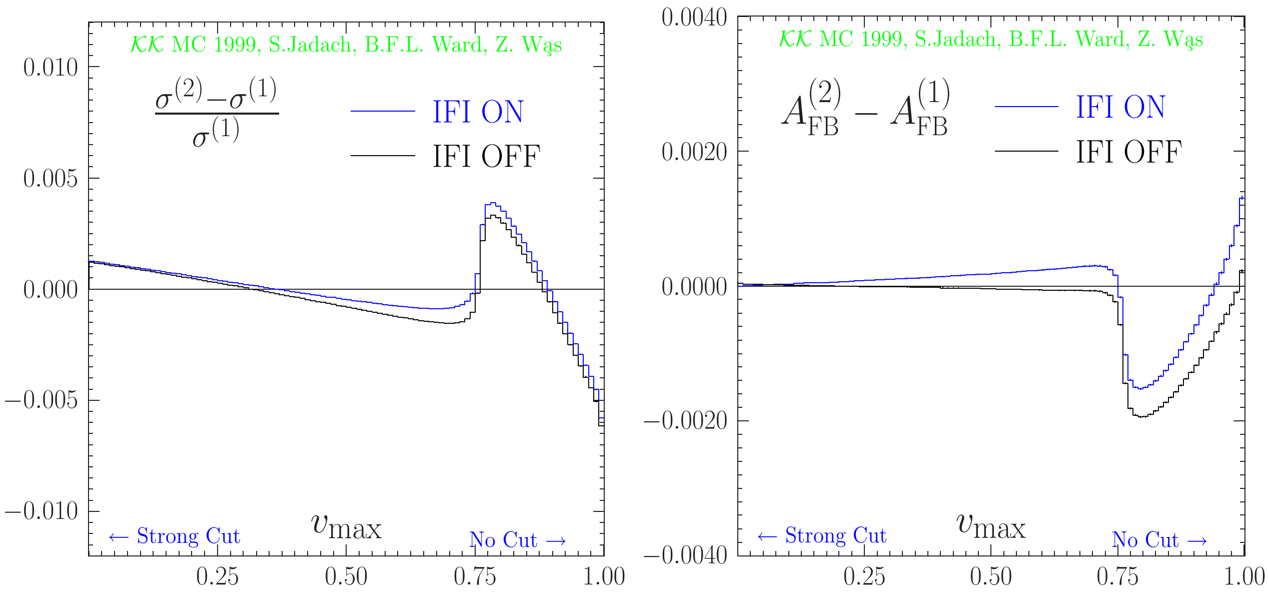
PP = neglected higher orders and subleadings

Our basic estimate: PP = $\frac{1}{2}\left\{\mathcal{O}(\alpha^2)_{\rm CEEX} - \mathcal{O}(\alpha^1)_{\rm CEEX}\right\}$

$\mathcal{KK}$ **MC results for** $e^+e^- \to \mu^+\mu^-$ **at 189GeV**

Photon Energy Cut: $v = 1 - s'/s < v_{\max}$; $s' = m^2_{f\bar{f}}$

Angular Cut: $|\cos\theta| < 1$



The above result imply for Physical Precision:

$\frac{\delta\sigma}{\sigma} \leq 0.2\%$, $\delta A_{FB} \leq 0.1\%$,

even including radiative-return on-shell Z.

This is confirmed by more tests, skipped from this talk.

MC Implementation of CEEX

Comparison of $\mathcal{KK}$ MC with its predecessors

Feature	KORALB	KORALZ	$\mathcal{KK}$ 4.13	$\mathcal{KK}$ 2000+?
QED type	$\mathcal{O}(\alpha)$	EEX	CEEX, EEX	CEEX, EEX
CEEX(ISR+FSR)	none	none	$\{\alpha, \alpha L; \alpha^2 L^2, \alpha^2 L^1\}$	$\{...\alpha^2 L^1; \alpha^3 L^3\}$
EEX(ISR*FSR)	none	$\{\alpha, \alpha L, \alpha^2 L^2\}$	$\{\alpha, \alpha L, \alpha^2 L^2, \alpha^3 L^3\}$	$\{...\alpha^2 L^2, \alpha^3 L^3\}$
ISR-FSR int.	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha)$	$\{\alpha, \alpha L\}_{\rm CEEX}$	$\{\alpha, \alpha L\}_{\rm CEEX}$
Exact bremss.	1 γ	1, 2coll. γ	1, 2, 3coll. γ	up to 3 γ
Electroweak	No Z-res.	DIZET 6.x	DIZET 6.x	New version?
Beam polar.	long+trans.	longit.	long+trans.	long+trans.
τ polar.	long+trans.	longit.	long+trans.	long+trans.
Hadronization	—	JETSET	JETSET	PYTHIA
τ decay	TAUOLA	TAUOLA	TAUOLA	TAUOLA
Inclusive mode	—	No	Yes	Yes
Beamstrahlung	—	No	Yes	Yes
Beam spread	—	No	Yes	Yes
$\nu\nu$ channel	—	Yes	No	Yes
ee channel	—	No	No	Yes
tt channel	—	No	No	yes?
WW channel	—	No	No	yes?

Summary and Outlook

There was not much progress in the physics content of the program as far as authors are concerned but:

- Physics initializations prepared collaborations is now available.
- Automatization of versions is done.
- This can be good starting point for future developments. Decays
- Universal interface, including some spin effects, of TAUOLA to any generator for τ production is available.
- High precision generator KKMC for $e^+e^- \to \tau^+\tau^-$ is available
- Good starting point for future developments was prepared, production.
- Even some steps toward C++ are done, e.g. PHOTOS C++ is available.