Predictions for $\nu\bar{\nu}\gamma$ production at LEP

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The aim is to summarize briefly on:

- status of KKMC for $\nu\bar{\nu}\gamma$ predictions
- numerical comparisons of KKMC KORALZ and data
- KKMC and anomalous triple- (quatric-) gauge boson couplings

Related papers:

S. Jadach, B.F.L. Ward and Z. Wąs, Comput.Phys.Commun.**130** (2000) 260

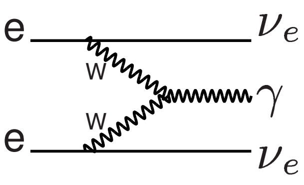
D. Bardin, S. Jadach, T. Riemann and Z. Wąs, Eur.Phys.J.**C24** (2002) 373; hep-ph/0110371

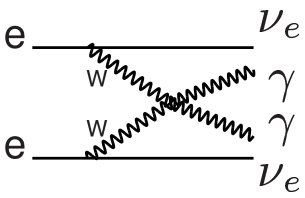
A. Jacholkowska, J. Kalinowski and Z. Wąs Comput. Phys. Commun.**124** (2000) 238

These and related slides/programs can be found from http://home.cern.ch/wasm

Physics Point

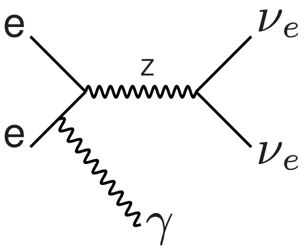
It is possible to measure 3-boson (4-boson), interaction at LEP with the help of:

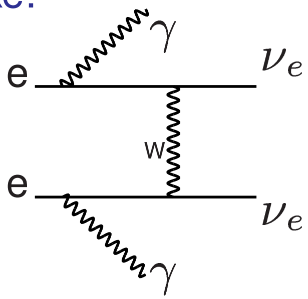




But:

- All diagrams contributing to $e^+e^- \to \nu_e\bar{\nu}_e\gamma$ ($e^+e^- \to \nu_e\bar{\nu}_e\gamma$) processes, like:





have to be taken into account as well.

- Luminosity and beams momenta are well known at LEP, but ...
- of final state particles only photon momentum is observable.
- 'Background' from $e^+e^- \to \nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}\gamma$ ($e^+e^- \to \nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}\gamma$) must be included into signal as well
- Radiative corrections virtual and real affect measurable distributions a lot.

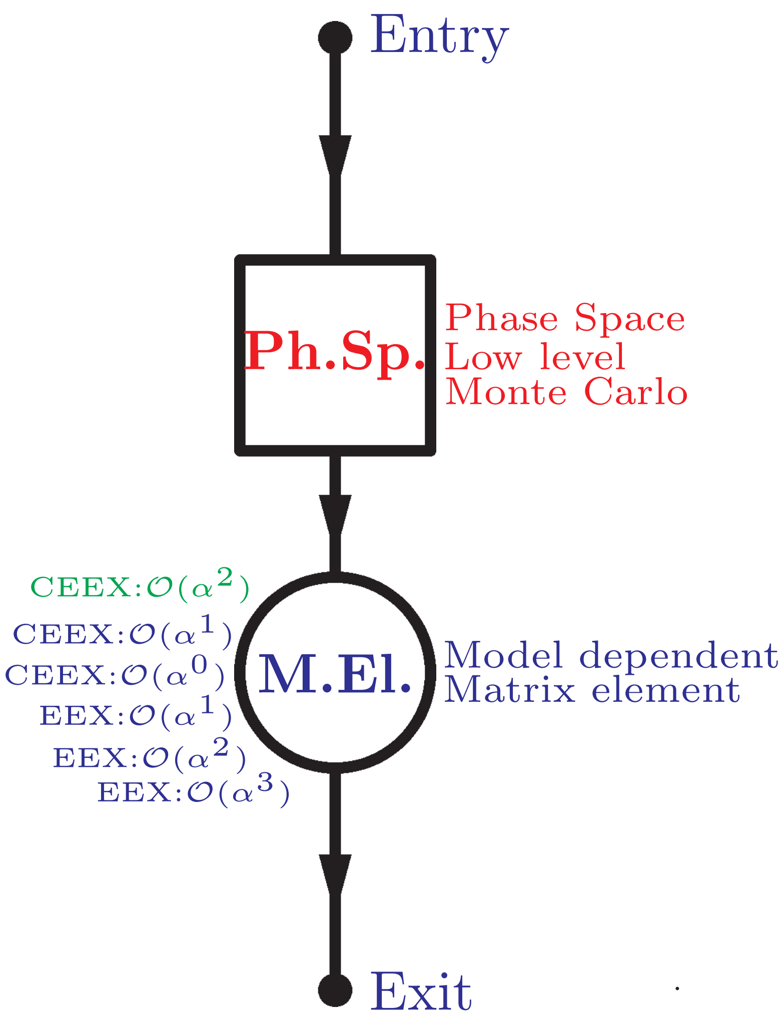
Physics Point

Any theoretical scheme to be helpful in interpretation of experimental data must:

- Provide distributions for $e^+e^- \to \nu\bar{\nu}\gamma(\gamma...)$ calculated from Standard Model with sufficiently high precision.
- Provide techniques to calculate variation of these distributions with respect to anomalous couplings.

Let me go now to presentation of our calculation.

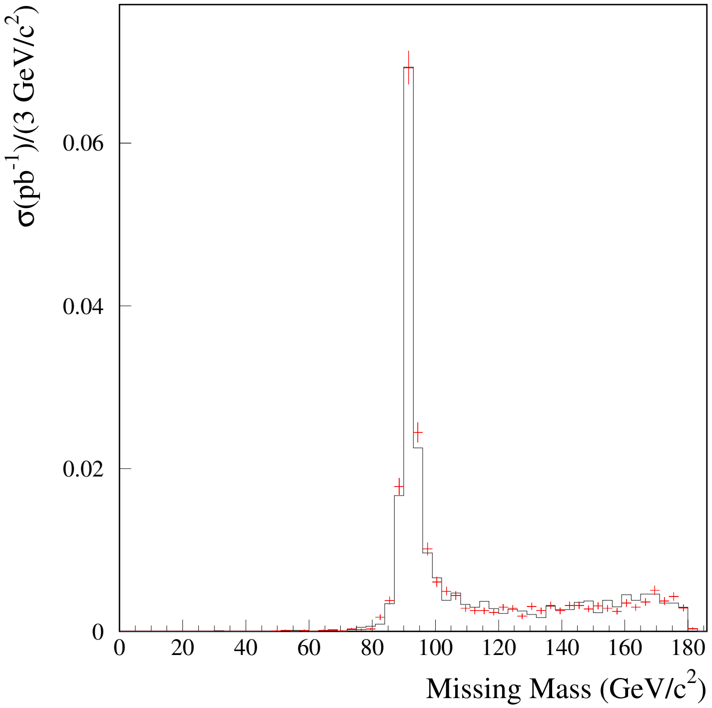
Textbook principle "matrix element $\times$ full phase space" ALWAYS ASSUMED



In the Monte Carlo realization it means that:

- Universal Phase-space Monte Carlo simulator is a separate module producing "raw events" (including importance sampling)
- Library of several types of SM/QED matrix elements provides "model weight" is another independent module
- For KKMC above is true for $\nu\bar{\nu}(\gamma)$ as well. That is big difference with respect to KORALZ, where photon emissions from W were treated in an approximate way
- Caluclation of weights involving anomalous couplings come after of course; approximations are used there.

Status at time of LEP Monte Carlo Workshop (CERN-2000-09-D, Jul 2000)



Missing mass distribution from the nunugpv Monte Carlo (histogram) and KORALZ (error bars) for Center of mass energy of 189 GeV and selection cuts as defined in CERN-2000-09-D.

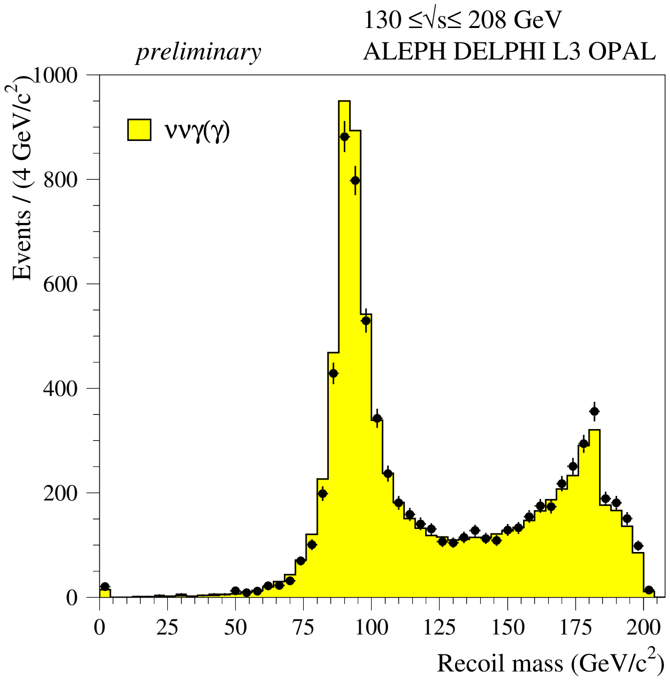
At the time of the workshop the main Monte Carlo programs available for neutrino physics were grcnunugam, KORALZ and NUNUGPV

- Systematic error of the predictions was about 4-5 %.
- Discussion of the errors was based on the overall comparisons of predictions from different codes.
- There was no o separation into cotributions from QED, pair effects, electroweak formfactors done in the systematic way for every program.
- In fact it was clear, that at least for our KORALZ, such attitude in case of $\nu_e \bar{\nu}_e \gamma$ is impracticable.

Main differences/similarities of KORALZ and KKMC (from 2001 on)

FEATURE:	KORALZ:	KKMC:
• Universal Phase-space Monte Carlo simulator.	• OK	• OK
• QED matrix elements "model weight", s-channel:	• Pragmatic second order within Eexclusive Exponentiation*	• Pragmatic second order within Coherent Exclusive Exponentiation* Complete two photon matrix element
• QED matrix elements "model weight", t-channel:	• Included in an approximate way, no systematic way to control theoretical errors.	• Pragmatic second order within Coherent Exclusive Exponentiation* Complete two photon matrix element, LL-approximation for one loop corrections with W exchange diagrams.
• Electroweak s-channel	• DIZET 4.6-6.05	• DIZET version 6.14
• Electroweak t-channel	• Bare W couplings only.	• DIZET version 6.14

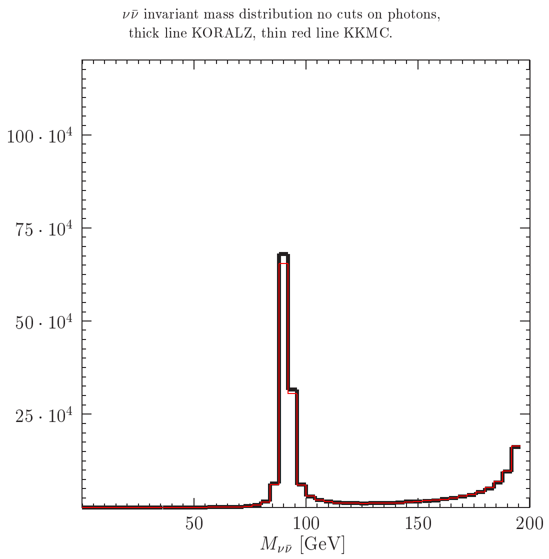
Comparisons of data with KORALZ and NUNUGPV



Taken from web-page of LEPSUSYWG/02-08.1

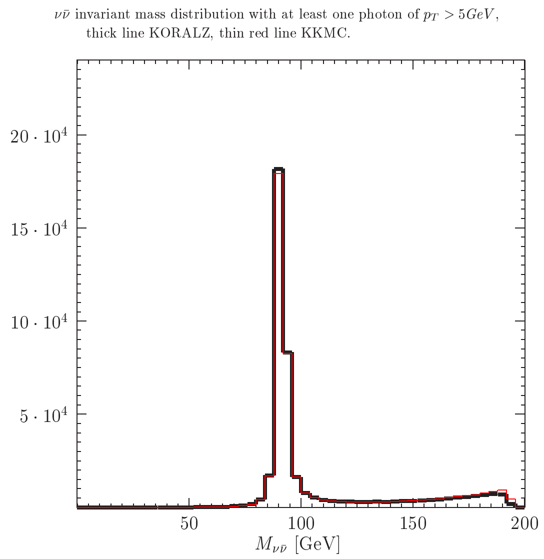
- One can seee that the data are slightly higher than KORALZ and NUNUGPV for large recoil masses,
- and slightly lower in the region of radiative return to the Z peak.
- Let us have a look at KORALZ-KKMC comparisons, for distribution of $\nu\bar{\nu}$ invariant mass, with no cuts at all, and very simple cut.

KORALZ and KKMC



- $\nu\bar{\nu}$ invariant mass distribution
- no cuts
- 200 GeV Center-of-Mass system energy
- KORALZ thick line KKMC thin red line

KORALZ and KKMC



- $\nu\bar{\nu}$ invariant mass distribution
- at least one photon with $p_T > 5GeV$
- 200 GeV Center-of-Mass system energy
- KORALZ thick line KKMC thin red line
- **It seems that KKMC should be closer to data than KORALZ, but all depends on the details of selection cuts**

Anomalous triple-(quatric-) gauge couplings

- The same algorihm for calculating weights due to additional anomalous triple gauge couplings (available in KORALZ) is installed in KKMC.
- Similar algorithm for calculating weights due to additional anomalous quatric gauge couplings was developped for KKMC.
- Simple algorithms were used for that purpose. This is OK as data favour anomalous couplings to be consistent with zero. Only SM predictions need to be precise.
- Code is available from my web-page.

These and related slides and programs can be found from http://home.cern.ch/wasm, http://home.cern.ch/jadach

Conclusions

- Yennie-Frautschi-Suura CEEX methods include built-in mechanism of cancellation of the IR singularities between real and virtual corrections. It works well in case of $\nu_e \bar{\nu}_e n\gamma$ as well. Emission of photons from W's is included pertubativelly (starting from contact interaction approximation for W interactions).
- Real photon QED corrections are included up to two photon matrix elements.
- Loop electroweak corrections are included to the first order plus leading log only. That is the main source of remaining uncertainty.
- Expected precision is of the order of 1 % for single-photon and 5 % for two-photon observables. This is some progress with respect to LEP MC workshop where precision was respectively 4 % and above 5 %.
- Algorithms to calculate additional weights for implementation of non-SM anomalous triple and quatric gauge couplings are also available.

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