What LHC may need from theory – LEP lesson:

private opinions, quesses possible analogies by

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To start discussion I will concentrate on:

- How it was at LEP, theory, detector, MC ...
- How precision requirements of LEP scale to LHC cases.
- Do we need precision calculations? What does it mean for LHC? Can we neglect them now in feasibility studies, but may be not in 201x
- Technical point on language: event records. In this case I know what I will be talking about ...

Thanks to:

H. Burkhardt, M. Dittmar, S. Jadach, E. Richter-Was

for many remarks, in particular those underlying the state of my confusion.

Theoretical calculations as tools

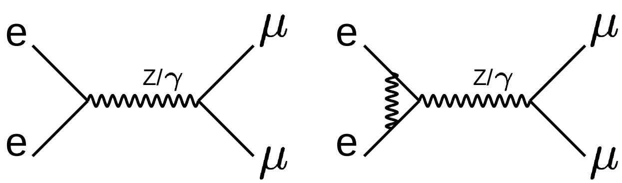
To be able to interpret results of the HEP measurements either as a signature of new physics or as a confirmation of some prediction from Standard Model one has to control background and not-interesting part of cross sections calculated first.

- It is relatively easy, and theoretically appealing, to perform calculations for inclusive quantities, such as total cross sections. Lots of theoretical machinery can be seen if it is performed.
- On the other side detectors have holes, resolutions, backgrounds from other processes etc.

Let me start with presentations how it was in LEP and even earlier ...

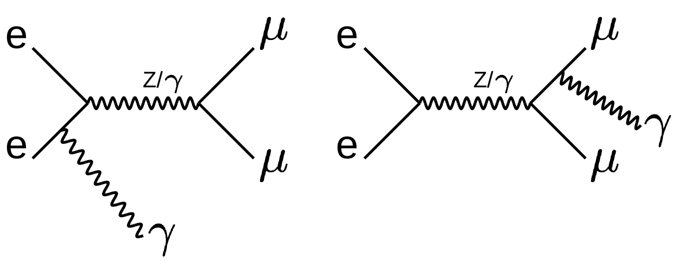
A_{FB} and σ_{tot}

For early LEP and even earlier PETRA phenomenology, one was starting from Born predictions and then one loop virtual corrections were added ...



Real bremsstrahlung had to be added:

- People started from *integrated* to some E_{cut} (or full phase space) real photon contribution



This was valid logic till 1982-84 when PETRA (KORALB) and LEP (MUSTRAAL) were prepared.

- Monte Carlo technique for theoretical predictions was slowly catching up as necessary in some cases, but was considered to be inferior tool, may be helpful in some doubtful applications, but not necessary if somebody was doing correct work. Definitelly not main stream.
- I remember how painful for me it was, to work on MC of first order when everybody was saying that 'superior' analytic calculations are completed since long ...
- With approaching LEP first order (single bremsstrahlung) Monte Carlo programs became available and first experimental PhD dissetrations on phenomenology became completed.

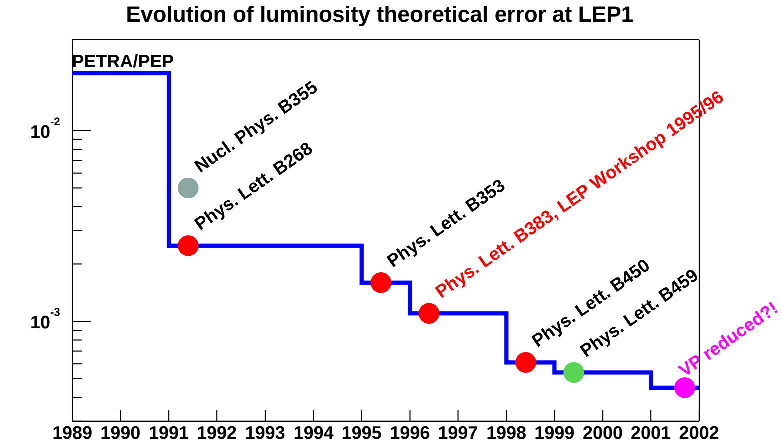
A_{FB} and σ_{tot}

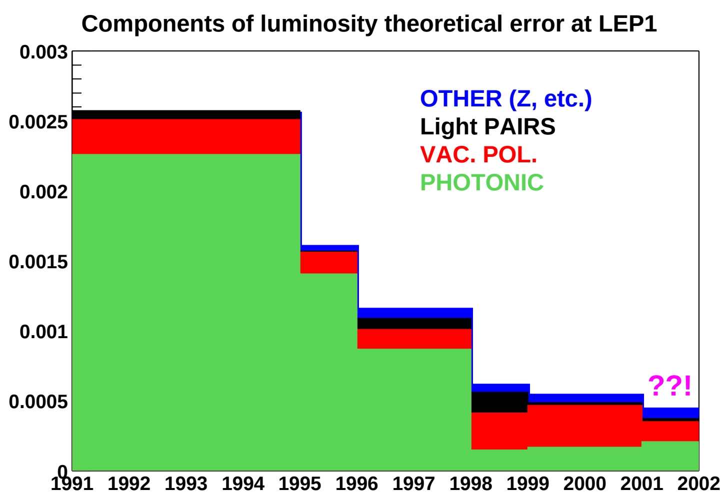
- Famous k_0 crisis started to appear, one wanted to shift k_0 to lower and lower values. (k_0 is the upper limit of energy of photon phase space to be integrated and added to Born configuration).
- This was of course related to improved (understanding) of detector granularity
- Things like FSR correction to A_{pol} is zero, but not to A_{pol}-related observable.
- In parellel higher orders, techniques of inclusive exponentiations were used.
- Analytic calculations were used as well and hybrid MC-analytic calculations started, like KORALZ (still first order only) +CALASY for τ (μ) pair.
- Structure function based algorithms were evolving as well.
- All this turned out to be either not sufficient or extremely complicated in use
- Many runs with the same detector cuts, but different physics effects switched on and off had to be combined. Negative weight had to be used as well ...
- The exclusive exponentiation turned out to be sufficient solution, first in YFS2/3 and KORALZ for LEP1 and later KKMC for LEP2.
- It required however basic re-organization of perturbative expansion. Monte Carlo scheme following expnentiation of Yennie Frautchi Suura with complete generation of all multiple photon configurations was possible.

Luminosity at LEP

- The line of development I was participating, started from OLDBAB first order Monte Carlo by Berends and Kleiss. Technically it was similar to first order Monte Carlo discussed before.
- Fixed first order solution turned out to be insufficient, higher order terms were needed.
- Solution with running OLDBAB to get complete first order results and LUMLOG to get higher order leading logs was developed. It improved precision, because higher order leading logs were included, but it was not so easy to use. Effectively it required of 3 runs with the same cuts and one of the runs was with (only) negative weights ...
- Also, configurations with more than one detected photon were present in detectors, but not in simulation. It was rather difficult to find out how much of systematic error was originating from that ...
- Second photon was needed (at least). Second order Monte Carlo turned out to be difficult, but exclusive exponentiation turned out to do the job.
- Later effects due to vacuum polarization became hot for systematic errors.
- All this was not so trivial and took years of work time ...

What were the technical steps which made this work possible





To progress seemingly independent technical developments were necessary:

- Mastering of first order generator
- Mastering of first order generator + parallel LL MC + semi-analytical benchmarks.
- Mastering of exponentiation
- Mastering of vacuum polarization and s-channel Z contribution.
- Many of this things were developed for other purposes, adaptation was non-trivial, but nonetheless possible

Mini summary

- Technology steps were developed often elsewhere.
- Fixed order solutions turned out to be insufficient, because higher order terms were needed.
- Solution with running OLDBAB to get complete first order results and LUMLOG to get higher order leading logs was developed. It improved precision, because higher order leading logs were included, but it was not so easy to use. Effectively it required of 3 runs with the same cuts and one of the runs was with (only) negative weights ...
- Matching things was sometimes very painful, like complete loop electroweak corrections and KORALZ. It took long months of work, once done it is difficult to imagine where the technical problems were sitting ...
- Matching spin amplitude techniques, separation of infrared singular terms, and MC is one of the basic element of KKMC
- All this was not so trivial and took years of work time: first multipe particle generator was written by S. Jadach in 1974 ...

Size of photonic corrections, Bhabha at LEP

Canonical coefficients in PHOTONIC corrections, $L = \ln(-t_{\min}/m_e^2)$					
		$\theta_{min} = 30$ mrad		$\theta_{min} = 60$ mrad	
		LEP1	LEP2	LEP1	LEP2
$\mathcal{O}(\alpha L)$	$\frac{\alpha}{\pi} 4L$	137×10^{-3}	152×10^{-3}	150×10^{-3}	165×10^{-3}
$\mathcal{O}(\alpha)$	$2\frac{1}{2}\frac{\alpha}{\pi}$	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
$\mathcal{O}(\alpha^2 L^2)$	$\frac{1}{2}\left(\frac{\alpha}{\pi} 4L\right)^2$	9.4×10^{-3}	11×10^{-3}	11×10^{-3}	14×10^{-3}
$\mathcal{O}(\alpha^2 L)$	$\frac{\alpha}{\pi}\left(\frac{\alpha}{\pi} 4L\right)$	0.31×10^{-3}	0.35×10^{-3}	0.35×10^{-3}	0.38×10^{-3}
$\mathcal{O}(\alpha^3 L^3)$	$\frac{1}{3!}\left(\frac{\alpha}{\pi} 4L\right)^3$	0.42×10^{-3}	0.58×10^{-3}	0.57×10^{-3}	0.74×10^{-3}

Anticipated size of QED photonic corrections in small angle Bhabha at LEP.

Already in 1992 we have anticipated MISSING photonic $\mathcal{O}(\alpha^2 L)$ and $\mathcal{O}(\alpha^3 L^3)$ in BHLUMI 4.x to be 0.1% or less. It took some time to prove it.

What does it mean for LHC

However:

All this permilles ... who would care at LHC

However:

- $\alpha_{QCD} \simeq 10\alpha_{QED}$, $\alpha_{QCD}^2 \simeq 100\alpha_{QED}^2$

- Collinear logarithm which may enhance some terms (absent for inclusive quantities but not always in real life) $L_{collinear} \leq \log(\frac{1}{14TeV} \cdot 1, 5, 15GeV) = 10, 8, 7$ for electrons, photons and jets. $L_{collinear}$ is only factor of 2 smaller at LHC than at LEP
- Extra infrared big logs can be ≤ 5.
- Quickly, these higher orders become larger than Born !!
- When experimental env. will allow to use theoretically clever approaches?
- What if detector/selections etc will take ALL of our forces?

This tiny effects of LEP translate into ...

... larger ones at LHC. How much larger?

Should we care? In which cases?

Can one do something in the first place?

Necessary techniques? How to put them together?

Hopeless items?

Hadronization combined with higher orders and for exclusive quanities?

Higher precision $\rightarrow$ Higher granularity

in TH and EP

Technical point I hit my head on

Event record, formal grammar

- How to code events into event record, Note that C++ or FORTRAN does not matter
- To make it easy to use
- To put all necessary information in
- To fulfil requirements (and provide comfort) of different models and approximations
- But to allow 'full' physisc if necessary as well.
- See talk by B. Kersevan at MC4LHC http://agenda.cern.ch/fullAgenda.php?ida=a031540