MC tools for extracting luminosity spectra What do we need?

S. Jadach

Institute of Nuclear Physics, Kraków, Poland

OUTLINE:

- **Future experiment as an ultimate guide**
- **Pre-experimental MC Studies on extraction of luminosity spectra**
- **Desirable features of the MC tools (event generators)**

Work supported by EU 5-th Framework grant HPRN-CT-2000-00149, “Physics at Colliders”.

These and related slides on http://home.cern.ch/jadach

INTRODUCTION

Luminosity measurement error in CLIC will be dominated by theoretical uncertainty (TU) that is Standard Model higher orders, as in LEP.

Low angle Bhabha at CLIC is like wide angle angle Bhabha at LEP ($\sqrt{|t|} \sim$ 70GeV).
TU for wide angle angle Bhabha at LEP was $\sim 1\%$.

Can we reach TU of 0.07% as in LEP?

Also, at CLIC and other LC's luminosity is not a number – it is a distribution.

Conclusions of my previous talk in June (see also Snowmas note)

Conclusions from numerical results:

- Pure QED photonic probably only 30% bigger than at LEP1 (due to dominance of the t-channel exchange)
- EW corrections can be important; at 3TeV EW uncertainty $< 0.1\%$
- Error due to hadronic vacuum polarization $\sim 0.1\%$ seems to dominate
- Exponentiation unavoidable

QUESTION: Do we expect problems with theory error at the level of 0.1% in the luminosity measurement using double-tagged Bhabha within 25-100mrads, at 1-3 TeV?

ANSWER: Total error $< 0.1\%$ looks feasible

LabMC Monte Carlo is our 1-st step towards combined analysis of QED and beamstrahlung – needed more input on the detector resolution, lumin. spectra, etc.

Past studies on extraction of beamsstrahlung spectra

For TESLA there is a study by Klauss Moenig:

LC note LC-PHSM-2000-60-TESLA, December 2000,

which describes extraction of the beamstrahlung spectrum

using $d\sigma/d\theta_1 d\theta_2$ of the low angle Bhabha.

Similar study was done by Marco Battaglia for CLIC energy 1.5TeV

contributed to Snowmass 2001 (article together with D. Bardin and S.J.)

The above studies are based on BHLUMI or BHWIDE Monte Carlo's supplemented

with the "pre-generation" of the beam energy loss due to beamstrahlung.

NB. Does variation of the CMS energy destroy the MC algorithm of BHLUMI?

Probably not much or (with a litle bit of luck not at all).

Questions:

Can one do do better? What one could actually do?

What MC tools one would need?

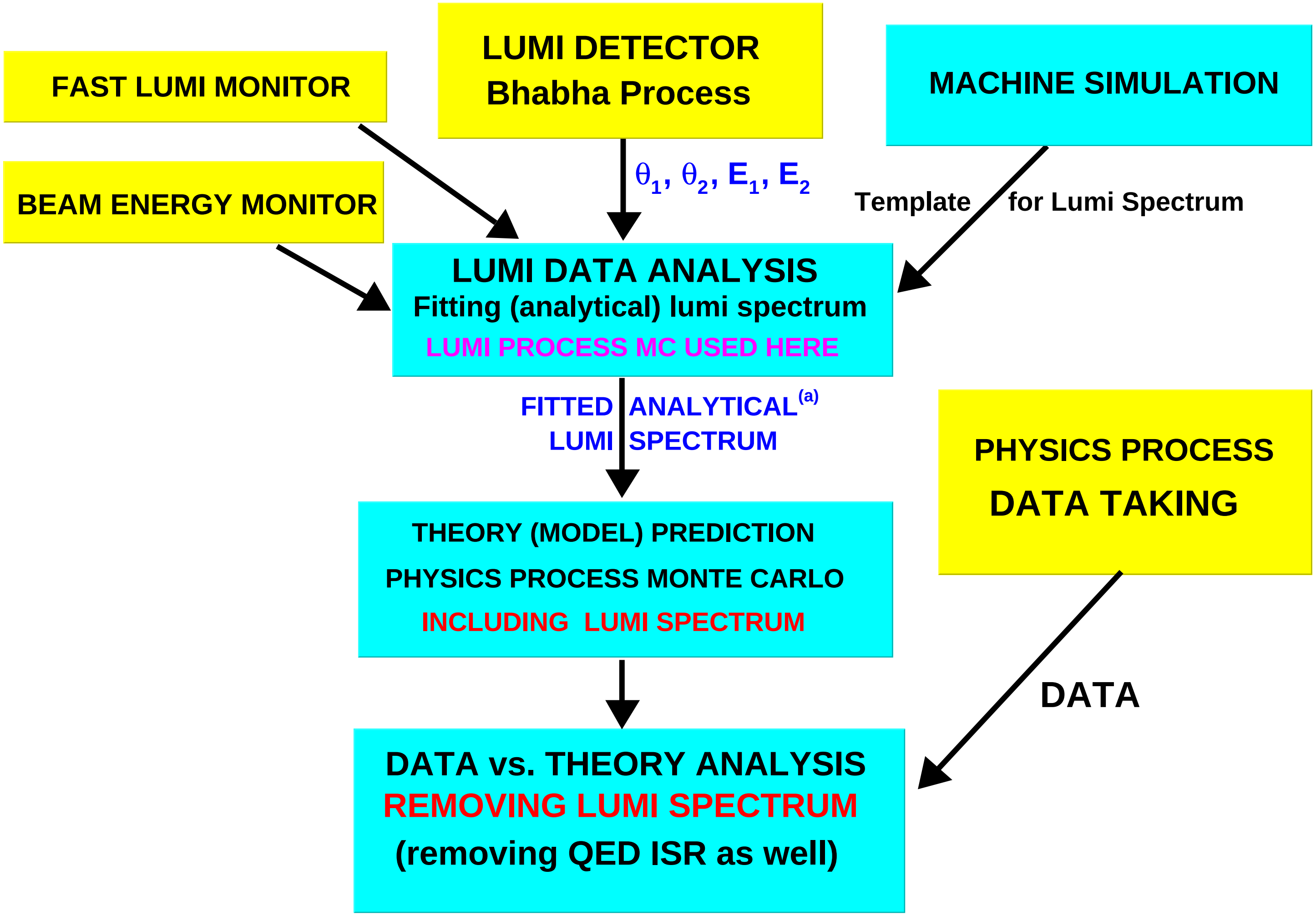
Future real experiment as an ultimate guide

- For CLIC and other LC's are and will be for long in the "workshop mode", however, we should keep in mind how extracting and using luminosity spectra will look like in the future real experiment, see next slide.
- The most important is to remember that the luminosity spectrum $\mathcal{L}(z_1, z_2)$ will be deduced from the luminometer process (Bhabha for e^+e^-), using analytical function with several parameters, to be fed into "physics Monte Carlo".
- Finally aim is to remove any effect of (beamstrahlung) luminosity spectrum from the observables – certain bias will always remain as a trace of it.
- For example: fitting physics parameters (masses, couplings in the Lagrangian) can be done (as for W mass in LEP2) by fitting the data using large n-tuple produced by the "physics Monte Carlo" and "corrections MC weights" due to change of the physics parameters – then any effect of luminosity spectrum (measured by luminometer) will be automatically removed.

Future real experiment as an ultimate guide, cont.

- Final uncertainty left in the physics results due to imperfect luminosity control:
  (a) angular and energy resolution of the lumi detector (statistics looks infinite!)
  (b) theoretical incomplete control over luminometer process (h.o. corrs.)
  (c) inefficient parametrization of the lumi spectra (new!)
- Machine simulation will have limited role in the determination of the luminosity spectra and removing their effects from the data, due to high precision requrements. (Contrary to pre-experimental studies.)

Handling Lumi spectra in the future Real Experiment



FAST LUMI MONITOR

LUMI DETECTOR
Bhabha Process

MACHINE SIMULATION

BEAM ENERGY MONITOR

θ_1, θ_2, E_1, E_2

Template for Lumi Spectrum

LUMI DATA ANALYSIS
Fitting (analytical) lumi spectrum
LUMI PROCESS MC USED HERE

FITTED ANALYTICAL$^{(a)}$
LUMI SPECTRUM

PHYSICS PROCESS
DATA TAKING

THEORY (MODEL) PREDICTION
PHYSICS PROCESS MONTE CARLO
INCLUDING LUMI SPECTRUM

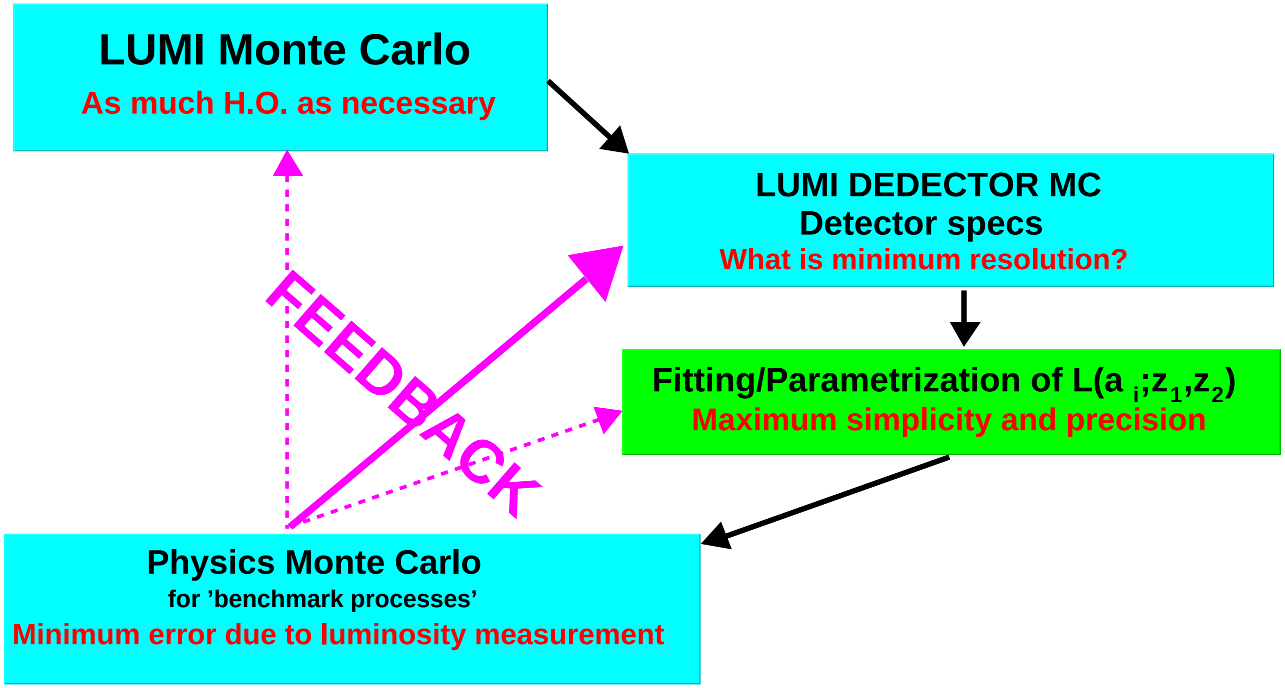
DATA

DATA vs. THEORY ANALYSIS
REMOVING LUMI SPECTRUM
(removing QED ISR as well)

(a) The only viable VEHICLE for transferring the information about LUMI spectrum from the LUMI detector to physics MC event generator is a “parametric” representation $\mathcal{L}(a_1 ... a_n; z_1, z_2)$.

Direct use of QED+beamstrahlung SF’s deduced in Lumi data analysis unfeasible, LL scale evolution $t \longrightarrow s$ and complications in controlling NLL’s.

MC study which could/should be done before the real experiment



LUMI Monte Carlo

As much H.O. as necessary

LUMI DEDECTOR MC

Detector specs

What is minimum resolution?

Fitting/Parametrization of L(a_i;z_1,z_2)

Maximum simplicity and precision

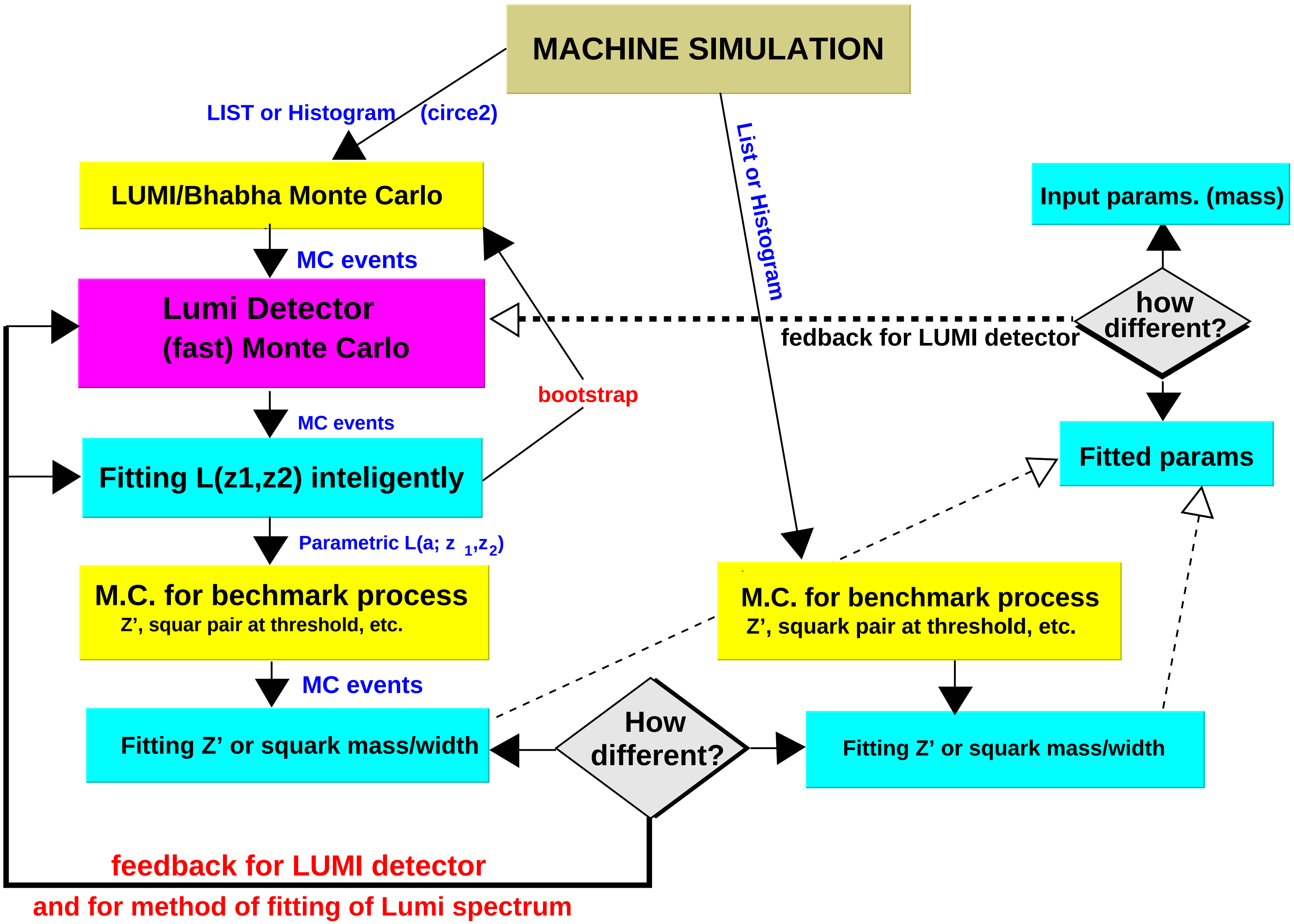
Physics Monte Carlo

for 'benchmark processes'

Minimum error due to luminosity measurement

- The minimum requirements for Lumi Detector specs are basically determined by the precision required in the physics data analysis
- The same is true for Lumi process theoretical calculation
- The method of parametrizing Lumi spectra is an obstacle in reaching the goal?
- Machine simulation is indispensable element in the game

MC study which can be done before the real experiment



MACHINE SIMULATION

LIST or Histogram (circe2)

List or Histogram

LUMI/Bhabha Monte Carlo

MC events

Lumi Detector
(fast) Monte Carlo

bootstrap

MC events

Fitting L(z1,z2) inteligently

Parametric L(a; z_1,z_2)

M.C. for bechmark process
Z', squar pair at threshold, etc.

MC events

Fitting Z' or squark mass/width

How different?

M.C. for benchmark process
Z', squark pair at threshold, etc.

Fitting Z' or squark mass/width

Input params. (mass)

how different?

fedback for LUMI detector

Fitted params

feedback for LUMI detector
and for method of fitting of Lumi spectrum

MC tools that we need ...

- As seen in the above discussed schemes every Monte Carlo has to have built in method of using lumi spectra in form of (analytical/parametrical) arbitrary distribution $\mathcal{L}(z_1, z_2)$, as an external "user function".
- However, possibility of using "lists of beams" (and the "external pre-generation") is a useful/desired option for pre-experiment studies.
- The above is true for both "Lumi MC" and "Physics MC".
- Lumi process MC should feature procedure providing a "correction weight" due to change of parameters a_i in $\mathcal{L}(a_i; z_1, z_2)$, for lumi events stored on the disk (for the purpose of the fitting of a_i to the lumi data).
- As pointed out by K. Moenig the "beam spread" should be included in the MC.

MC: Is the importance sampling for $D(z_1, z_2) \times \sigma(sz_1z_2)$ necessary?

For the narrow resonances it is ABSOLUTELY NECESSARY and the "pre-generation" of (z_1, z_2) independently of the other phase space variables leads to unacceptable loss of MC statistics. Weight distribution with bad tail of large weights (see LEP1).

For "threshold process" one may perhaps survive with "pre-generation" method. Weight distribution will not have bad tail with large weights.

For other processes ($\sigma \sim 1/s$ class) the critical point is the high precision requirement. Nobody will use Pythia for large angle Bhabha (LABH). A dedicated program featuring 2-loop r.c.'s will be very slow, even with the pretabulation of the h.o. form-factors. The additional loss of factor 2-3 in CPU time due to lack of importance sampling related to beamstrahlung will be UNACCEPTABLE.

Bottom line:

Yes, the importance sampling for $D(z_1, z_2) \times \sigma(sz_1z_2)$ IS really necessary.

Legacy of BHLUMI, going beyond BHLUMI

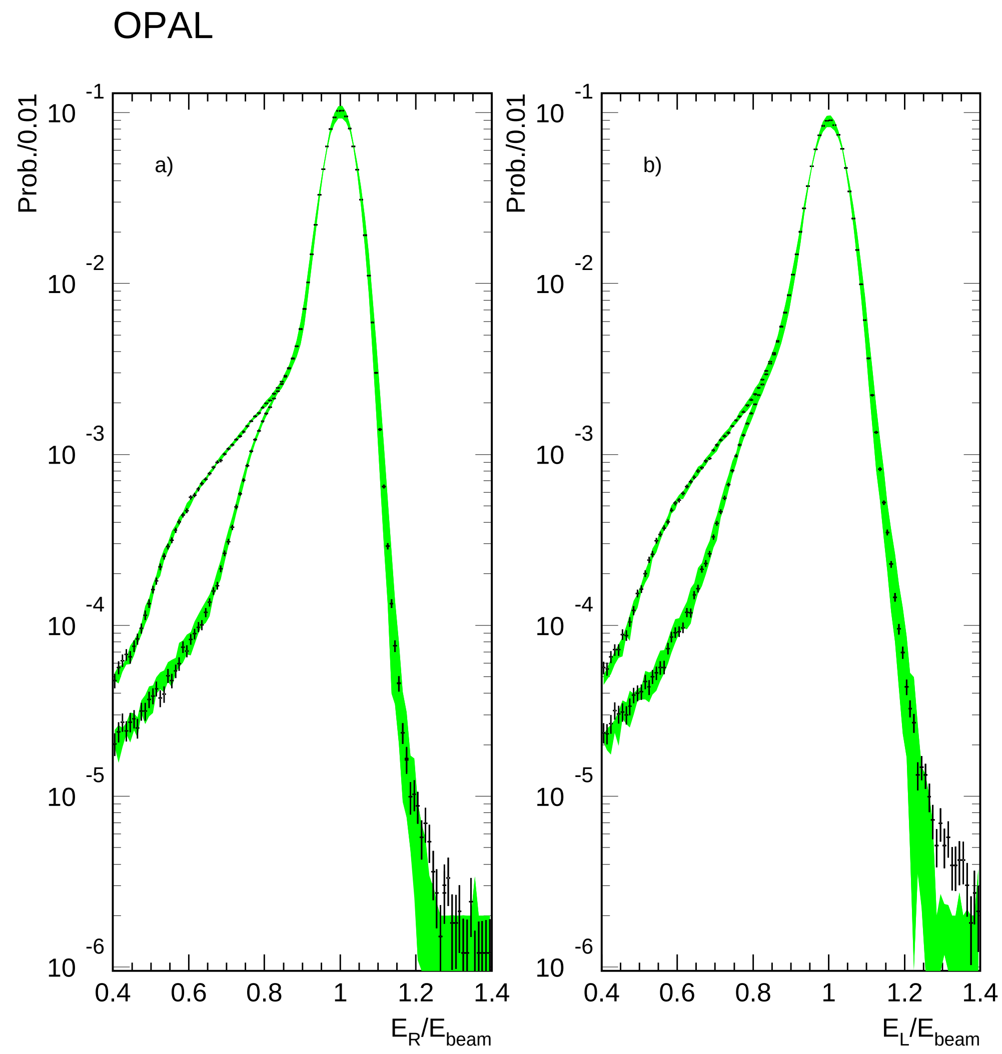
At LEP luminosity measurement perfect agreement between BHLUMI MC and the data for energy of the final (dressed) electrons and of their collinearity was a cornerstone in reducing systematics experimental errors.
See for instance OPAL measurement.

At LC's situation will be dramatically different: the difference between distributions for experiment and MC will be exploited to measure beamstrahlung spectra!
Experimentalist will have to have much more "blind confidence" in the lumi MC.

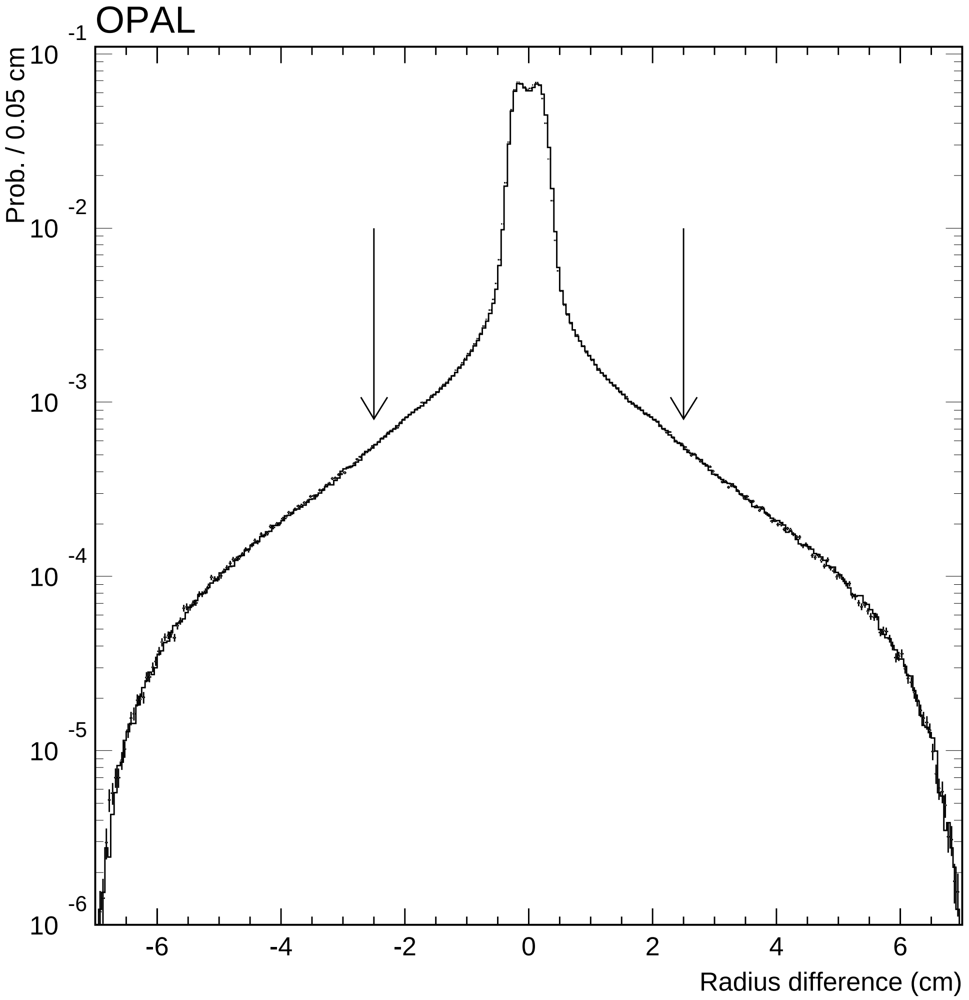
Another point: ANY new lumi MC will HAVE TO agree for the energy and angular spectra with BHLUMI at 91GeV, before it is seriously considered, because BHLUMI, effectively represents a "carbon copy" of the LEP1 experimental data (without beamstrahlung).

Any further improvement on lumi MC for ELC's beyond BHLUMI will require TWO independently developed MC's which agree perfectly for normalization and for all distributions.

Energy distribution in OPAL lumi paper, MC vs. experiment



Acollinearity distribution OPAL lumi paper, MC vs. experiment



Pre-experimental studies: Benchmark processes

The obvious candidates for benchmark processes for lumi spectra studies are those with strong s-dependence: resonance production, threshold behaviour.

For CLIC one could use Z' production and squark pair at threshold.

I would also add wide angle Bhabha (LABH), good candidate for precision physics, searches of substructure, extra-dims. etc.

(For TESLA one should add scan across $t\bar{t}$ threshold.)

What range of Lumi Spectrum is important?

Generally $z_i > 0.5$. For resonance $1 - z_i \sim \Gamma/M$.

How fine resolution in $\mathcal{L}(z_1, z_2)$ is thinkable?

From study of K. Moenig we know that $\Delta\sqrt{s'/s} \sim 5 \cdot 10^{-5}$ can be achieved.

M. Battaglia in our CLIC study has got $\Delta\sqrt{s'/s} \sim 5 - 8 \cdot 10^{-5}$

Is it good enough? Depends on the process and precision requirements.

Absolute beam energy knowledge

Luminometer (Bhabha) cross section $\sim 1/s$.

Hence to match $\delta\mathcal{L}/\mathcal{L} = 0.05\%$ will require the absolute beam energy calibration $\delta E/E = 2.5 \cdot 10^{-5}$.

Parametric representation of the lumi spectrum

Ideally it should be an analytical formula $\bar{D}(a_i; z_1, z_2)$ with several parameters $a_i, i = 1, ...N$ in it. Not too many and not to little – just right number!

The parameters a_i should be fit to the Bhabha 4-dim. distribution $d\sigma/d\theta_1 d\theta_2 dz_1 dz_2$, using Bhabha Monte Carlo.

The experimental errors in the $\theta_1, \theta_2, z_1, z_2$ will be highly correlated.

If Bhabha Monte Carlo features “correction weight” corresponding to variation of a_i then one could generate large n-tuple of Bhabha events and use it (and re-use) for fitting a_i, taking into account detector resolution and event selection.

As a starting point one could use factorizable parametrization like

$$\bar{D}(a_i; z_1, z_2) = f(z_1)f(z_2), \quad f(z) = a_0\delta(1-z) + a_1 z^{a_2}(1-z)^{a_3},$$

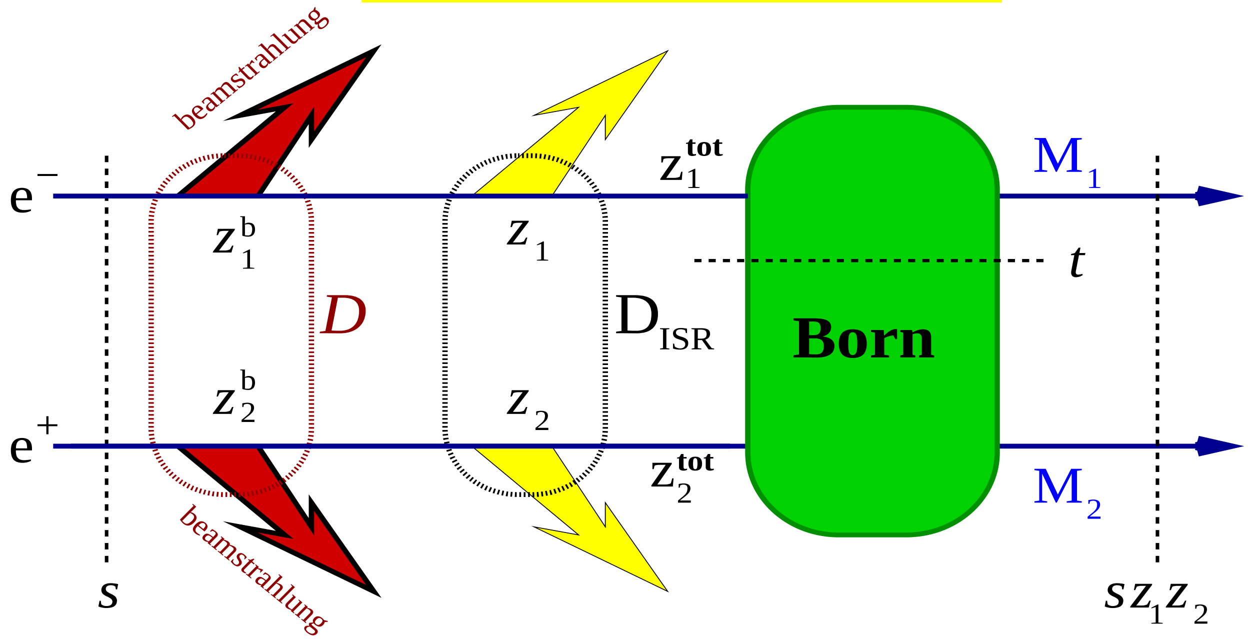
of circe1, and gradually add “small corrections” due to “non factorizability” etc.

Parametrization of circe2, employing histogram, not good for the above purpose.

LabMC: a candidate MC for the study on lumi spectra

- LabMC is not yet a replacement for BHLUMI/BHWIDE!
- 5-dimensional distrib. simulated using `Foam`, 25M events/hour; Very efficient, 95% acceptance rate (`StandardVegas` could do accept. $\sim 1\%$ only)
- Beamstrahlung SFs $\mathcal{D}(z_1^b, z_2^b)$ is an arbitrary "user provided function", presently SF's of `Circe1` of T. Ohl is used (with $\delta(1-z)$ singularities!)
- QED ISR structure function $D_{\rm ISR}^{\rm LL}(z_1, z_2)$ (Jadach, Skrzypek, Ward) is implemented: with and without exponentiation $\mathcal{O}(\alpha^i)$ $i = 0, 1, 2$ (as in LUMLOG)
- 4-momenta in CMS provided – ISR photons have all $p_T = 0$
- 17k lines in g77, 7k lines in C++, further development only in C++.
- It can also handle production of up to two instable resonances (used by G. Blair for squark threshold study).
- **Next step: inclusion of BHLUMI.**

Schematic picture of LabMC



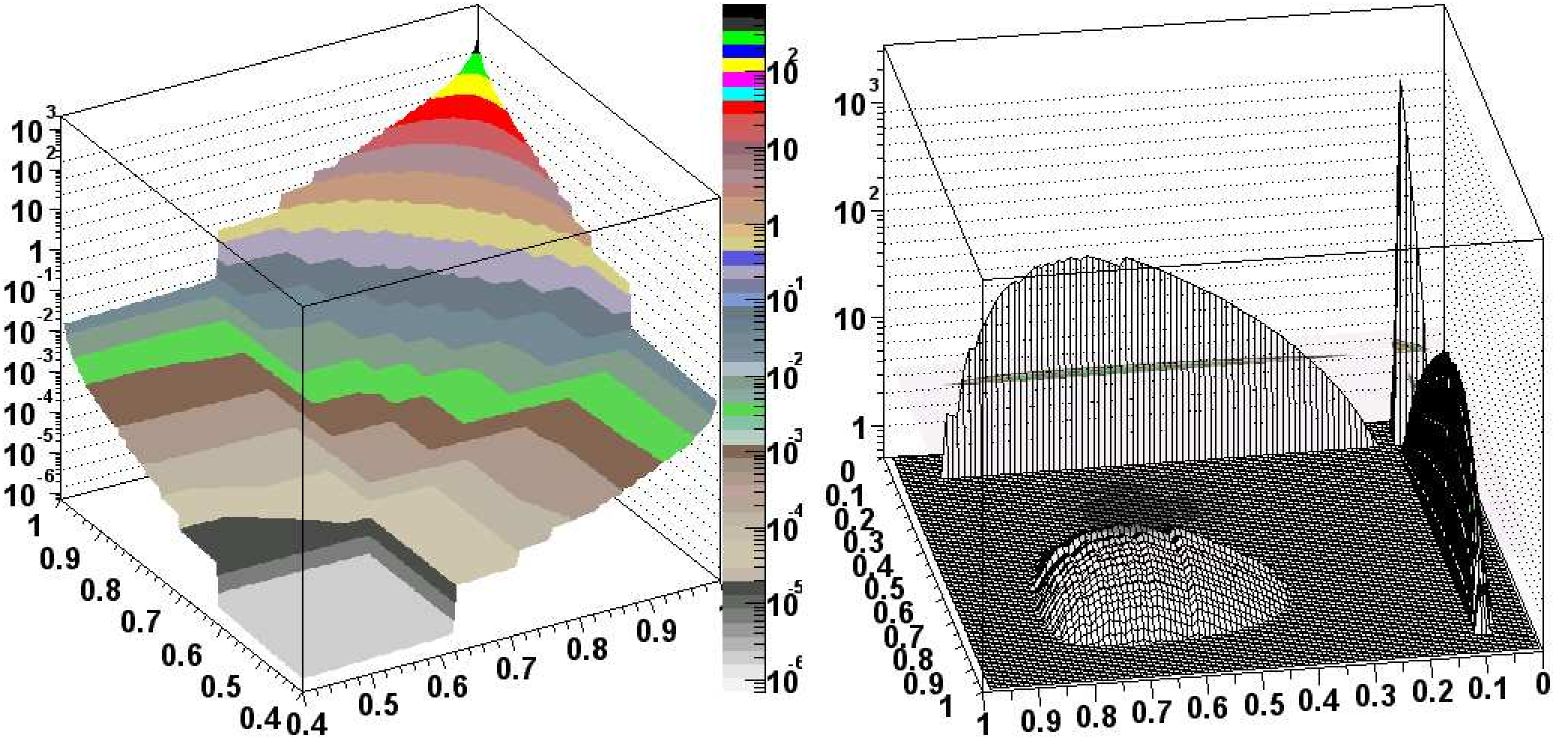
$$\sigma(s) = \int dM_1^2 \int dM_2^2 \int_0^1 dz_1^b dz_2^b \mathcal{D}(z_1^b, z_2^b)$$
$$\int_0^1 dz_1 dz_2 D_{\rm ISR}^{\rm LL}(z_1, z_2) \int dt\ \frac{d\sigma}{dt}(s z_1^{tot} z_2^{tot}, t)\Theta(\vartheta_1, \vartheta_2).$$

where $\mathcal{D}(z_1^b, z_2^b)$ is beamstrahlung function normalized to one,

$D_{\rm ISR}^{\rm LL}(z_1, z_2)$ is the QED leading-Log (LL) ISR structure function (Jadach, Skrzypek, Ward).

Acceptance $\Theta(\vartheta_1, \vartheta_2) = 1$ only if $\vartheta_{\rm min} < \vartheta_i < \vartheta_{\rm max}$ for both ϑ_i in CMS.

New: Small exercise with circe2 and Foam

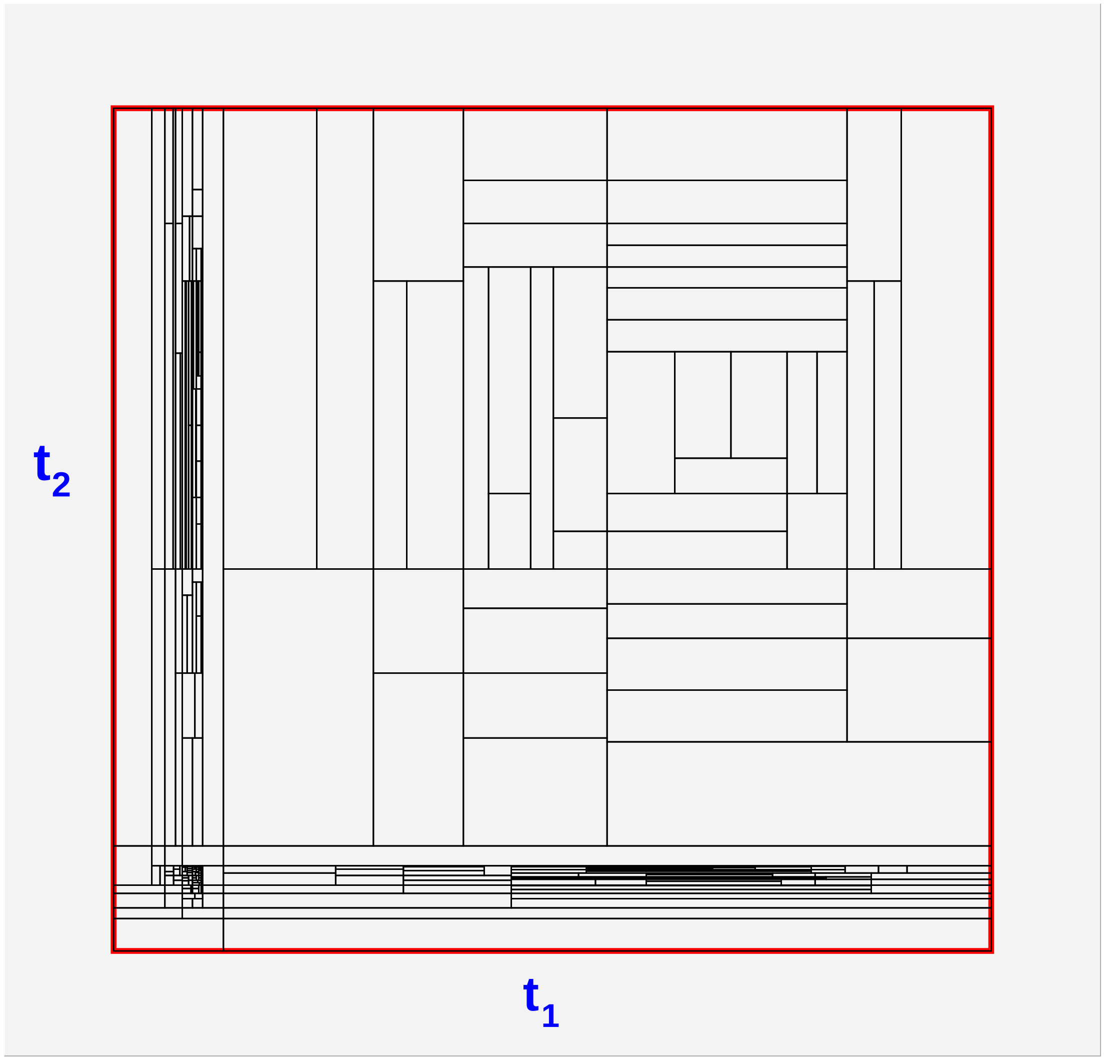


This is circe2 lumi spectrum for e^+e^- at 500GeV (no δ's!).

Shown is also LUMI density expressed in $t_i = (1 - z_i)^\gamma$ variables, $\gamma = 0.1$.

(No infinite singularities – better suited for MC generation).

New: Small exercise with circe2 and Foam



MC sampler Foam of LabMC can handle new circe2 distribution very easily.

What could we do within the CLIC study workshop?

Improving study of M. Battaglia for several energies using BHLUMI$\otimes$beamstrahlung:

- adding simulation of the "benchmark processeses", smuon/squark threshold and Z',

- adding luminosity detector simulation,

- trying to see what are the ultimate limits in the game of extracting $\mathcal{L}(z_1, z_2)$ using entire $d\sigma/d\theta_1 d\theta_2 dz_1 dz_2$ of low angle Bhabha,

- look at one example of the high statistics "precision measurement", for instance wide angle Bhabha, where one could do factor 20 better than at LEP2!

I could provide BHLUMI$\otimes$beamstrahlung and beam spread as an extension of LabMC. Plus "Pythia quality" simulation of some "benchmark processes" (if necessary) in the same framework.

My other aim would be to use the same MC framework for the next generation (full second order) MC for wide angle Bhabha, and to develop MC basic tools in c++. Otherwise it is not worth an effort and one may rely on "cut-and-paste" of BHLUMI and `circe` within f77, as was already done.

Further study of H.O. QED corrections, Z-contribution and vacuum polarization, in order to assure resonable theoretical uncertainty, should continue in parallel.

Conclusions

- **I tried to defined a template for the MC study on the realistic method of the lumi spectrum extraction, with the “feedback loop” for (a) luminometer specs, (b) lumi spectrum fitting/parametrization.**
- **Requirements for the MC tools (event generators) for such a study are specified.**
- **The need of “parametric representation” of the lumi spectrum is underlined.**
- **Attempt of some planning is made.**