MC tools for extracting luminosity spectra
What do we need?

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OUTLINE:

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

Partly based on work with D.Y. Bardin and M. Battaglia, help of W. Płaczek is acknowledged.

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

Past studies on extraction of beamstrahlung spectra

For TESLA there is a study by Klaus 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 for CLIC energy 1.5TeV,

SNOWMASS-2001-E3015 by M. Battaglia, S. J. and D. Bardin.

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 little bit of luck not at all).

Questions:

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

What MC tools one would need?

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.

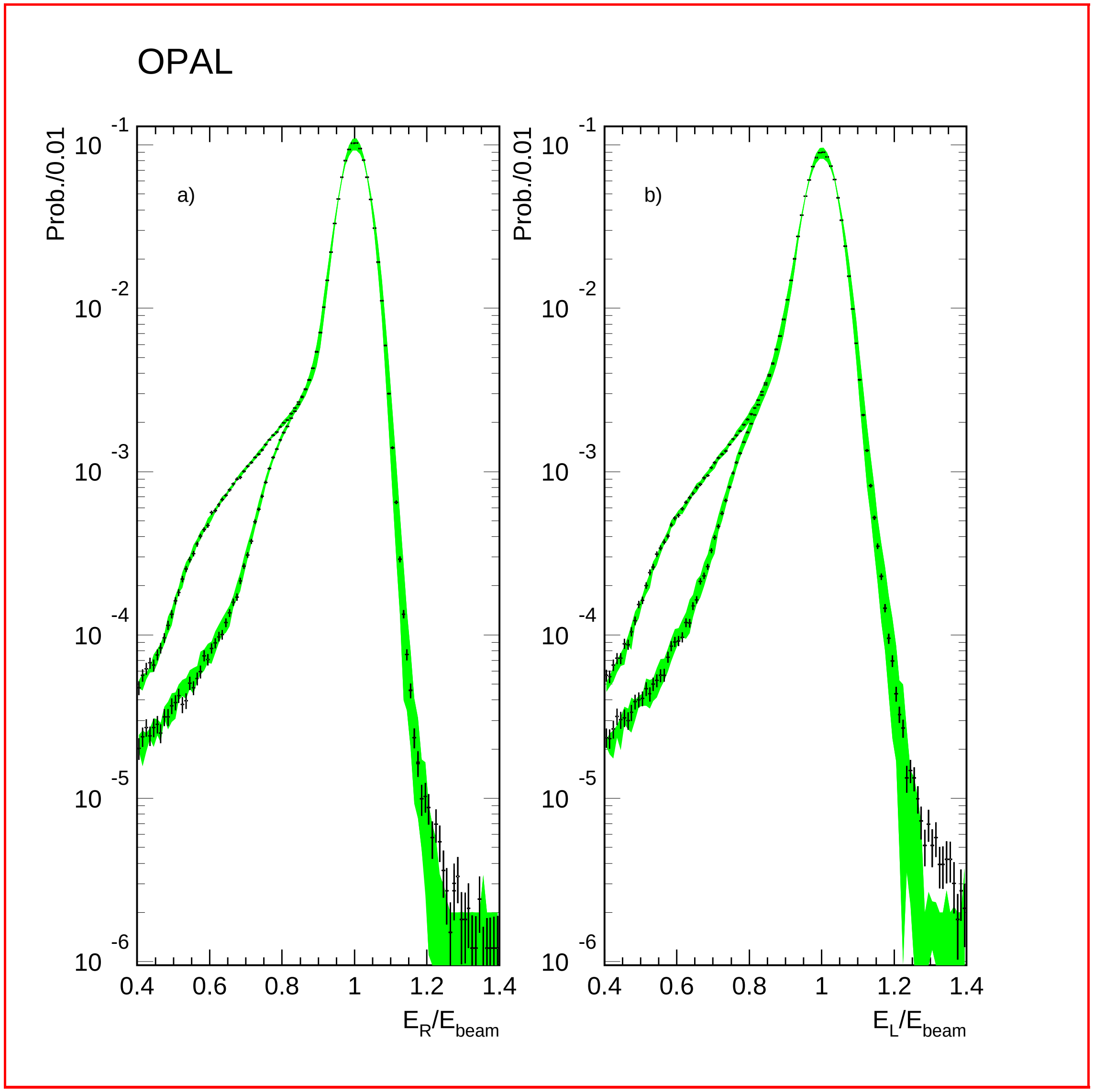
At LC's situation will be dramatically different: the difference between distributions for experiment and MC will be exploited to measure beamstrahlung spectra! Experimentalist will have to have much more "blind confidence" in the lumi MC.

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).

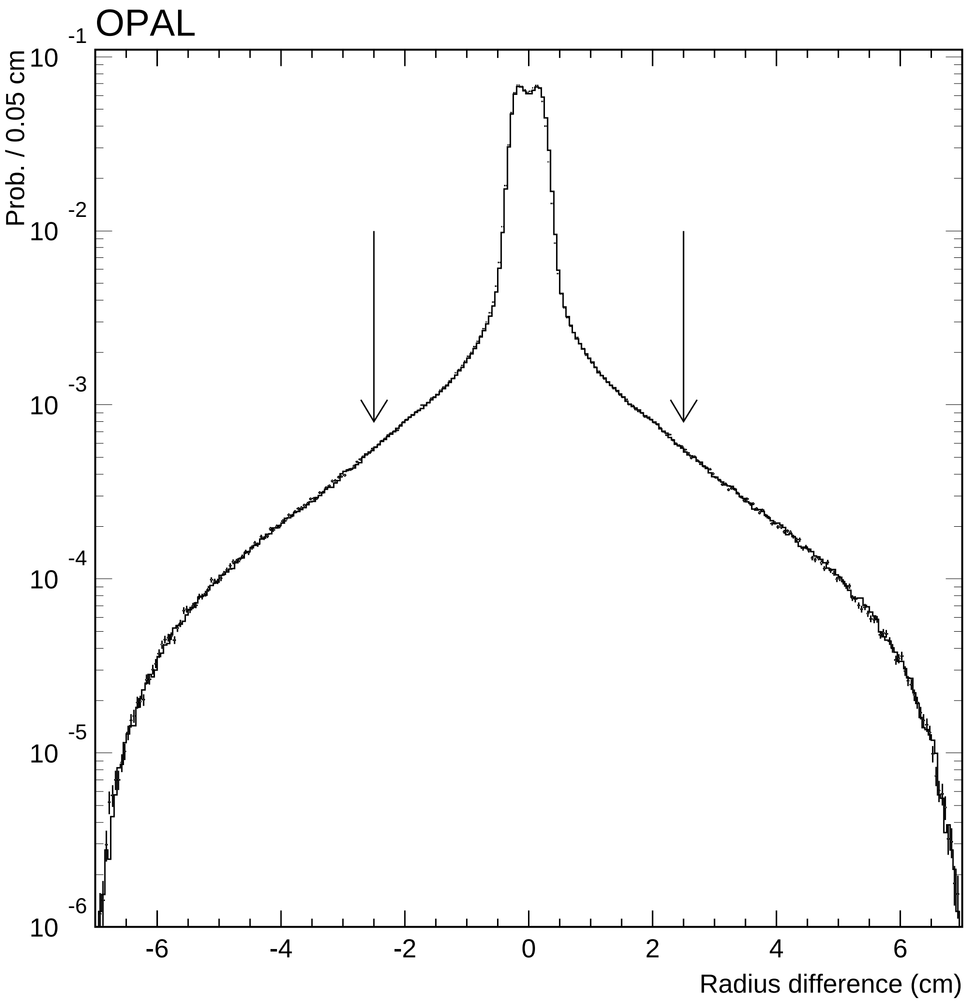
Any further improvement on lumi MC for ELC's beyond BHLUMI will require TWO independently developed MC's which agree perfectly for normalization and for all distributions.

BHLUMI: S. Jadach, E. Richter-Was, B.F.L. Ward, Z. Was; Comput.Phys.Commun. 70 (1992) 305

Energy distribution in OPAL lumi paper, MC vs. experiment



Collinearity distribution OPAL lumi paper, MC vs. experiment



Conclusions of my previous talk at TESLA and CLIC WG meetings

Conclusions from numerical results:

- Pure QED photonic probably only up 30% bigger than at LEP1
- EW corrections can be important; At 3TeV EW uncertainty $< 0.1\%$, provided all state of art $\mathcal{O}(\alpha^1)$ EW is included!
- Error due to hadronic vacuum polarization $\sim 0.1\%$ seems to dominate
- Exponentiation unavoidable, for photonic QED r.cors.

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 $\delta\sigma/\sigma < 0.1\%$ seems feasible, but...

will require serious work!

Leading TH errors of σ^{tot}_{LABH} at Linear Colliders, 25-100mrad:

The **double-tag low angle Bhabha (LABH)** process is a leading candidate for the luminometer process at Linear Colliders.

Main theoretical uncertainties of LABH luminometer σ^{tot} at TESLA/NLC/CLIC, at scat. angles 25-100mrads:

- Hadronic vacuum polarization
- QED photonic corrections
- EW corrections to Z_t
- Light fermion pairs??

Main sources of TH error of σ_{LABH}^{tot} at ELCs, 25-100mrad:

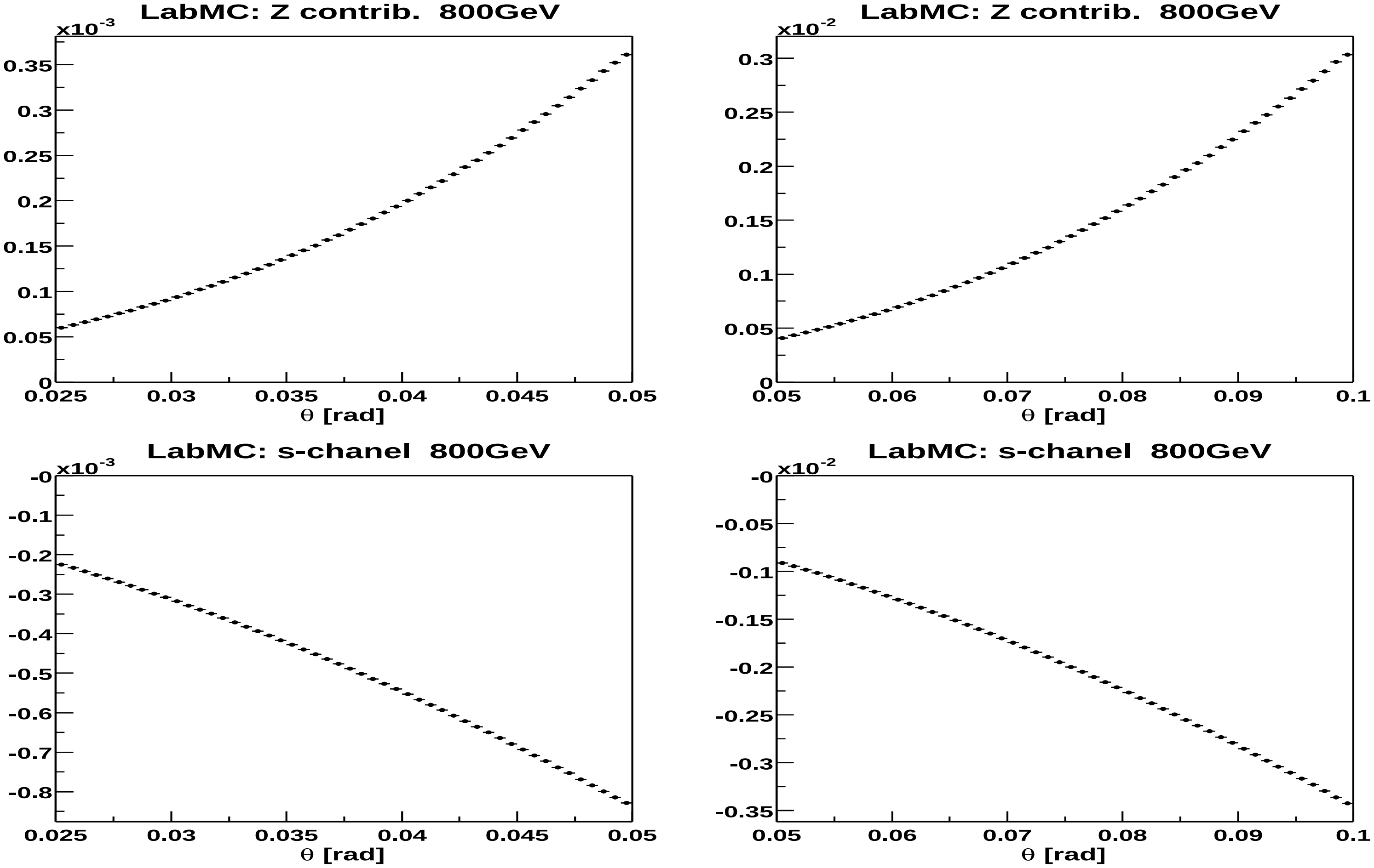
Basic difference with LEP1:

- The transfer instead of $\sqrt{|t|} \sim 2$GeV, for $\sqrt{s}$=91GeV and ϑ =45mrad, is at the same angle 10GeV at 500GeV, and 60GeV at 3TeV!
- Z (t-channel) increasingly (with $\sqrt{s}$) important!
- Hadronic vacuum polarization and its error grows strongly with $\sqrt{|t|}$, factor 2 grow from 100 to 500Gev and stabilizes > 500GeV.
- Photonic QED corrections $\sim \alpha \ln(|t|/m_e^2) \ln(\vartheta_{max}/\vartheta_{\min})$ grow mildly, and will increase by $\sim \ln(s/M_Z^2)/\ln(M_Z/m_e) \sim 15-30\%$.

Last not least:

Due to beamstrahlung luminosity is a function $\mathcal{L}(z_1, z_2)$, not a number!

Z contribution and s-channel at 0.8TeV

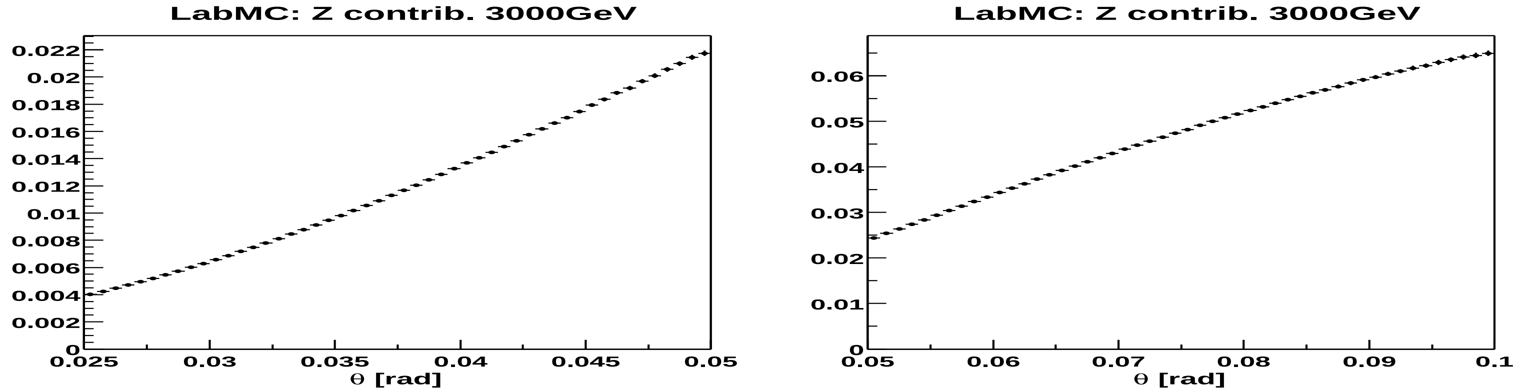


This result was x-checked with 2 Born-level calcul. using BHWIDE and DIZET.

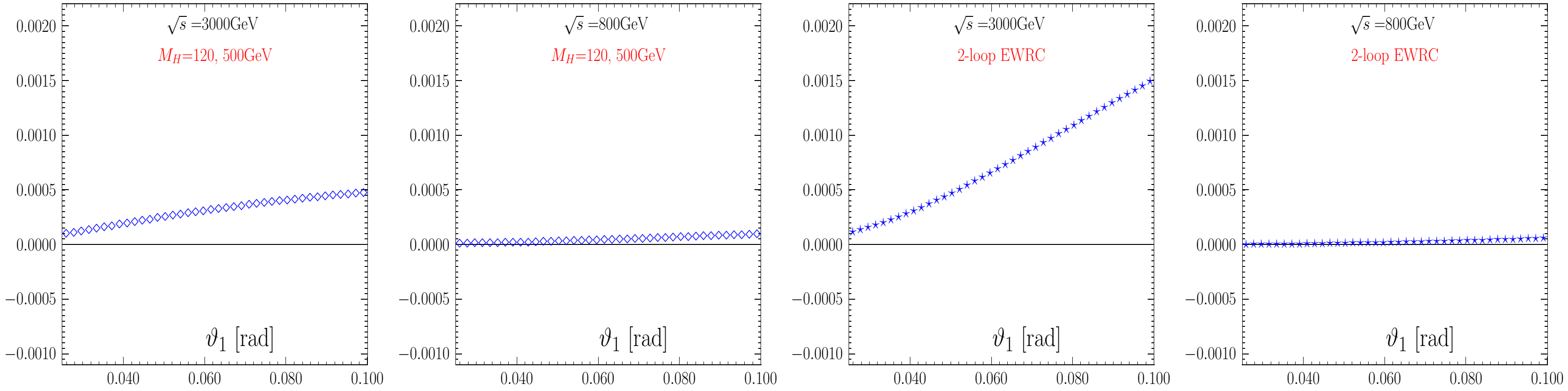
s-channel and Z contributions are negligible $< 3 \times 10^{-3}$ at 800GeV,

but Z contr. is growing see next slide...

At 3TeV Z contribution (t-channel) is sizeable, up to 6%.



How big is, therefore, uncertainty of due to EW corrections?

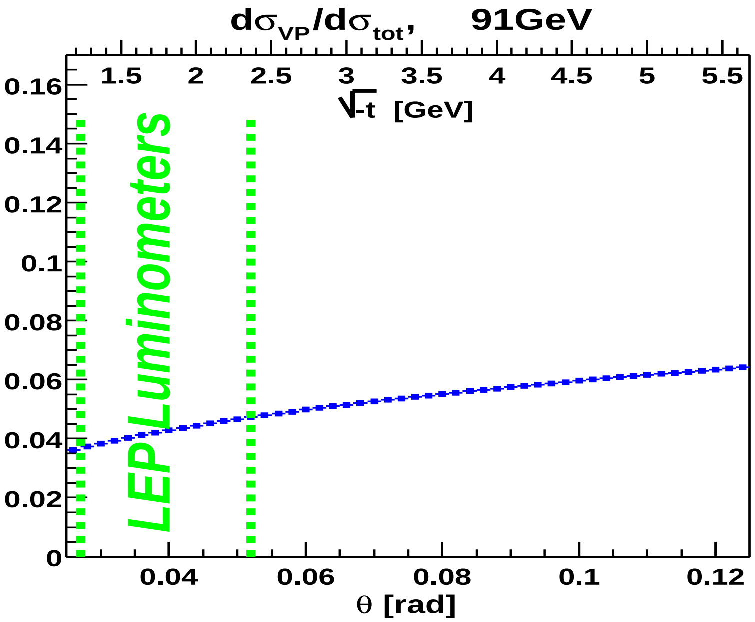


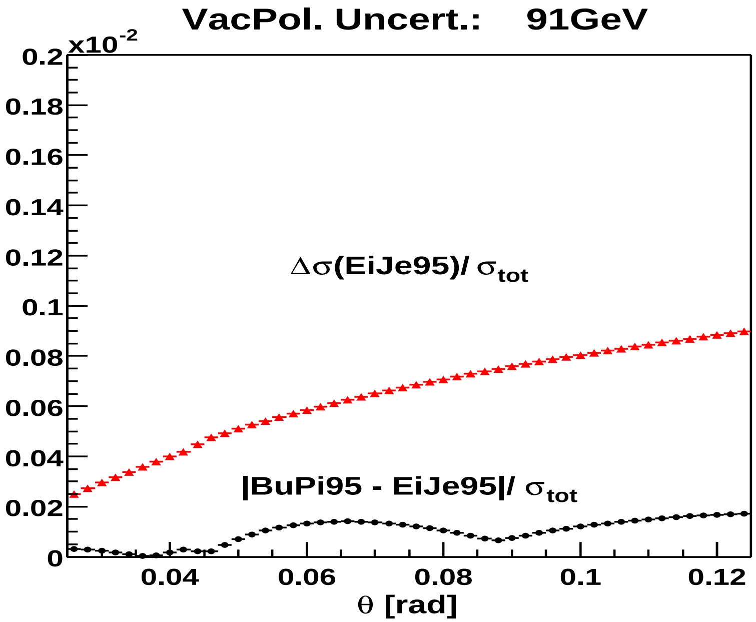
DIZET: Varied M_H =120⟶500GeV, M_t =165⟶185GeV and NPAR(2)=3⟶NPAR(2)=4 which manipulates non-leading 2-loop EW corrections $\mathcal{O}(G_F^2 M_t^2 M_Z^2)$, Degrassi et.al., keeping 2-loop EW corrections $\mathcal{O}(G_F^2 M_t^4)$.

At 3TeV (50-100mrad) we find TU of 0.09%, an estimate from NLL 2-loop EWRs.

How big is Lumi uncertainty due to hadronic vacuum polarization?

Let us recall situation at LEP1:

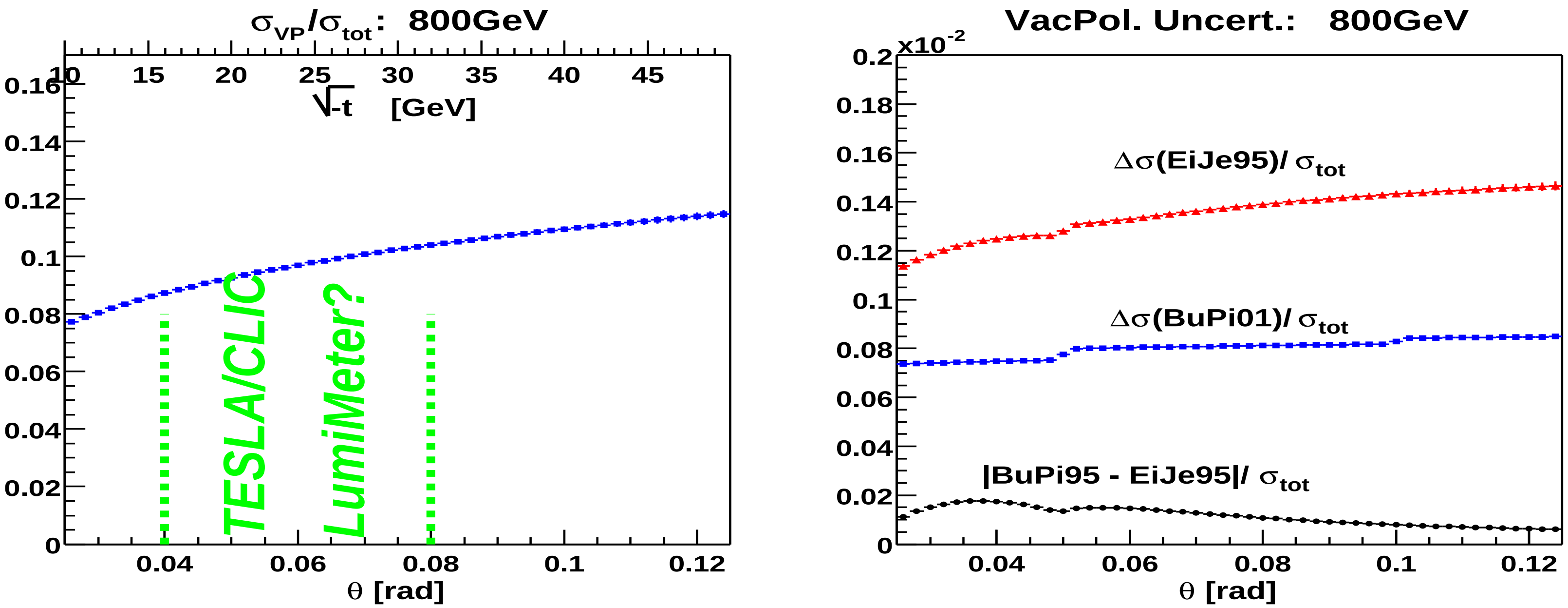




Next slide will show the case of 800GeV...

At 1-2GeV situation is almost the same.

How big is Lumi uncertainty due to hadronic vacuum polarization?



- Plots from LabMC with updated Born&VacPol of BHWIDE.
- Not all latest improvements included (to be done).
- Also x-checked with DIZET 6.35 (using Eidelman& Jegerlehner 1995).

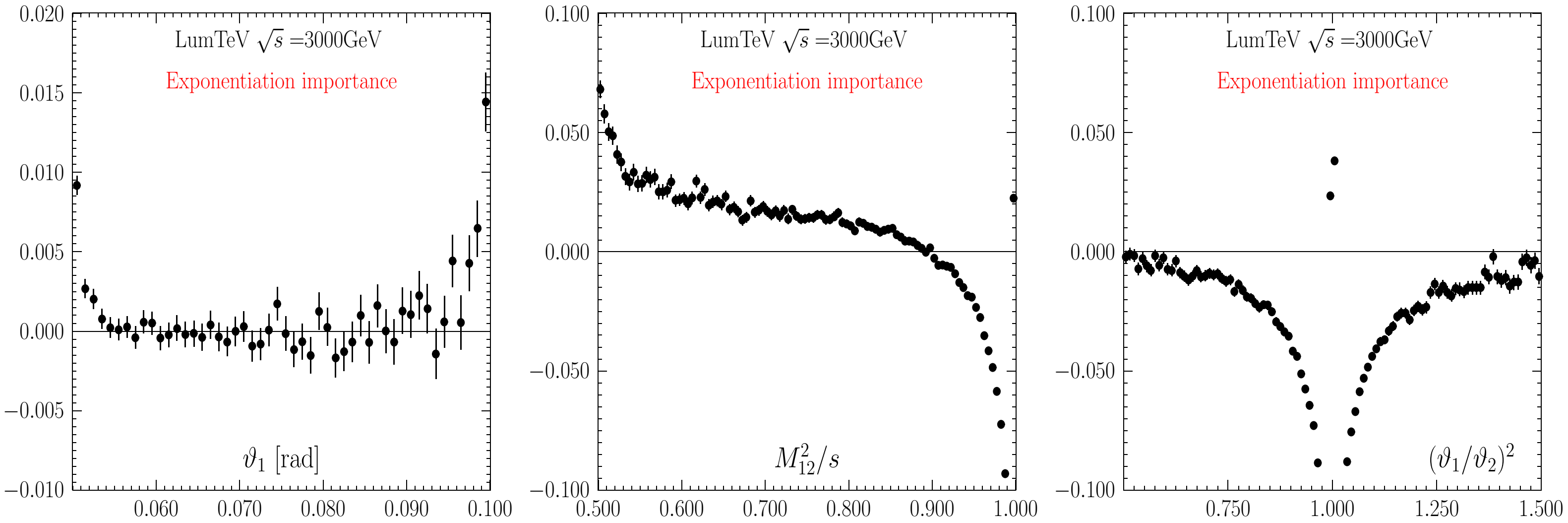
TH/Exper uncert. from Hadronic VP almost back to LEP1, thanks to recent works!

Is exponentiation important?

If someone still thinks that so-called exact complete $\mathcal{O}(\alpha^2)$ calculation without exponentiation is good for LABH precise prediction, then he should check the following slide...

Is exponentiation important for photonic QED r.c.'s?

The difference $\mathcal{O}(\alpha^3)_{exp} - \mathcal{O}(\alpha^2)$ in LL approximation (ISR only) gives us hint how bad the calculation in $\mathcal{O}(\alpha^2)$ without exponentiation actually would be:



Conclusion: Exponentiation of photonic QED is absolute necessity!

Note that $M_{12}/s = z_1 z_2$ and $\vartheta_1/\vartheta_2 \simeq z_1/z_2$ are basic variables for determination of the luminosity distribution. Effects close to ϑ-edges are due to soft ISR photons.

What next?

Looking into past studies and semi-quantitative results presented above, let's come back to our main theme:

Questions:

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

What MC tools one would need?

If yes, then the future real experiment should be used as an ultimate guide.

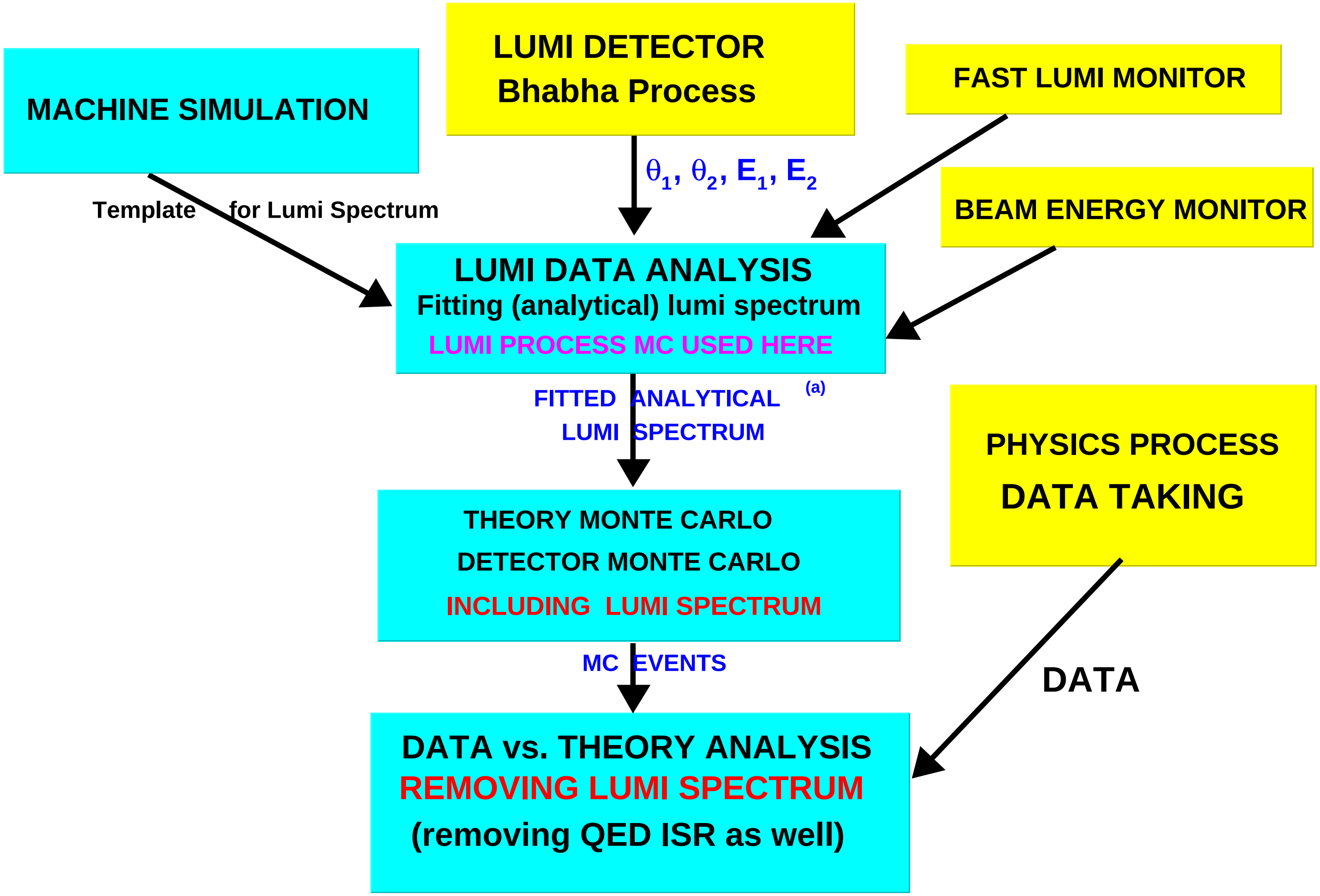
Future real experiment as an ultimate guide

- For LC's are still in the "workshop mode", however, we should have a clear idea already now 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 (LABH), using analytical function with several parameters, to be fed into "physics Monte Carlo". (Circe2 no good.)
- Final 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.

- Uncertainties 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!)
  (d) absolute measurement of the beam energy (spectrometer)
- Machine simulation will have limited role in the determination of the luminosity spectra and removing their effects from the data, due to high precision requirements. (Contrary to pre-experimental studies.)

Handling Lumi spectra in the future Real Experiment



MACHINE SIMULATION

Template for Lumi Spectrum

LUMI DETECTOR
Bhabha Process

$\theta_1, \theta_2, E_1, E_2$

FAST LUMI MONITOR

BEAM ENERGY MONITOR

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

FITTED ANALYTICAL LUMI SPECTRUM (a)

THEORY MONTE CARLO
DETECTOR MONTE CARLO
INCLUDING LUMI SPECTRUM

MC EVENTS

PHYSICS PROCESS
DATA TAKING

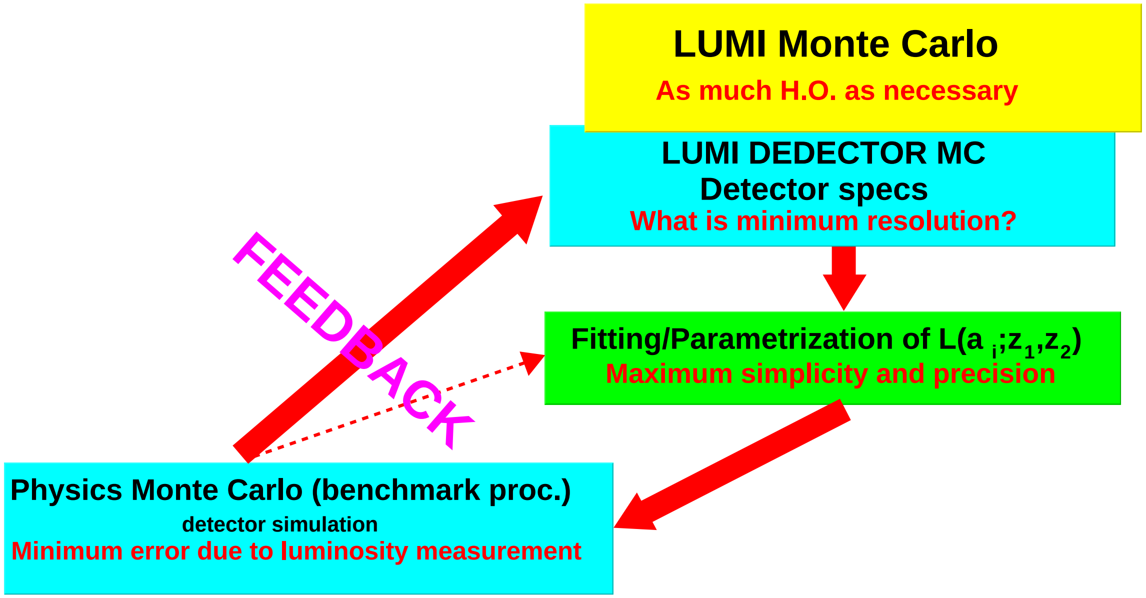
DATA

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 (benchmark proc.)

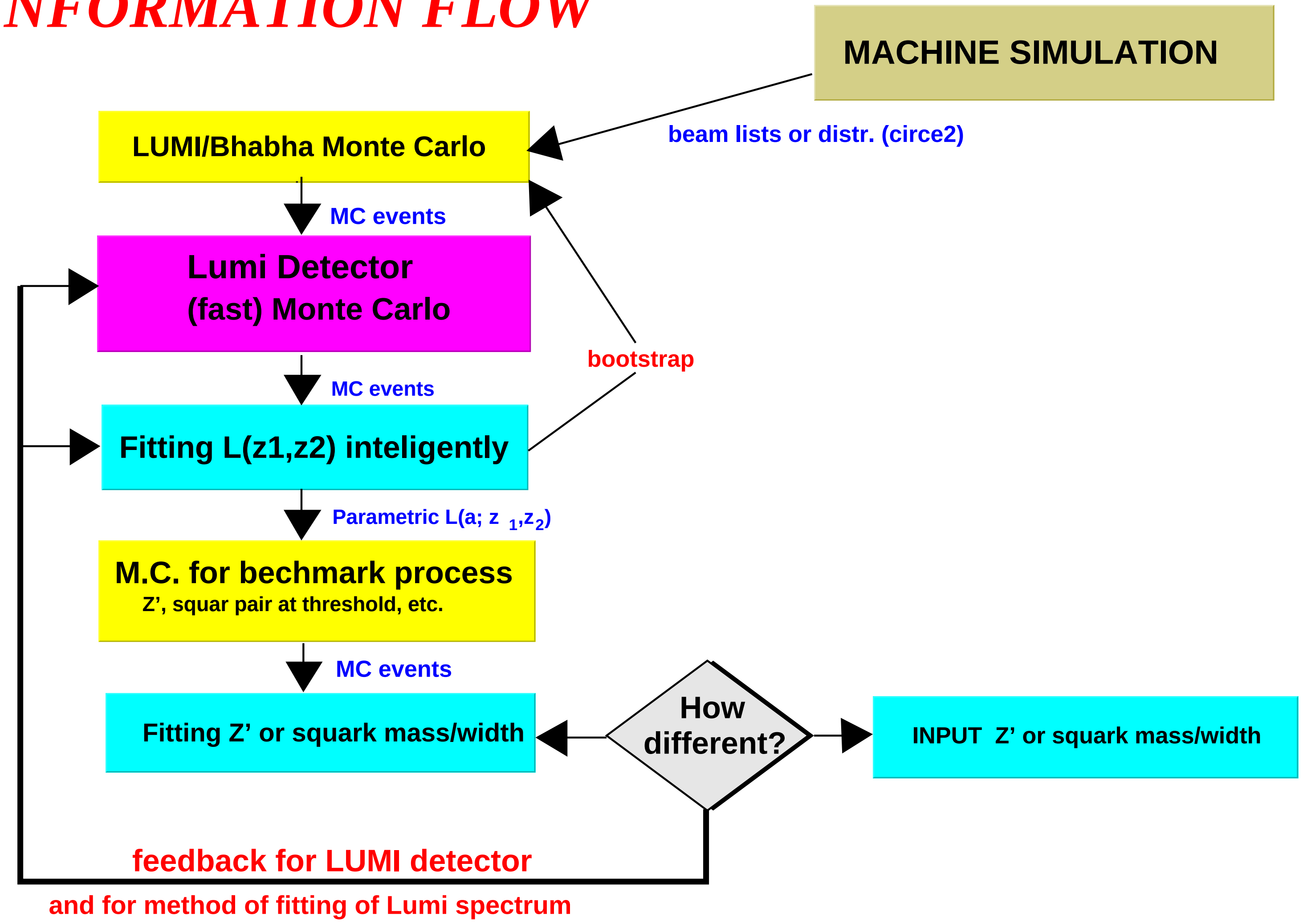
detector simulation

Minimum error due to luminosity measurement

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

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

INFORMATION FLOW



MACHINE SIMULATION

beam lists or distr. (circe2)

LUMI/Bhabha Monte Carlo

MC events

Lumi Detector (fast) Monte Carlo

MC events

bootstrap

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?

INPUT Z’ or squark mass/width

feedback for LUMI detector

and for method of fitting of Lumi spectrum

Issues in pre-experimental MC studies

Some features of MC tools that we need ...

- Every Monte Carlo must feature a 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.

Issues in pre-experimental MC studies

A technical issue in the MC event generator construction:

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.

For other processes ($\sigma \sim 1/s$ class) the critical point can be high precision requirement. A dedicated program featuring 2-loop r.c.'s will be rather slow, even with the pretabulations. The additional loss of factor ∼5 in CPU time due to lack of importance sampling related to beamstrahlung may be unacceptable.

Yes, it is really necessary!

Issues in pre-experimental MC studies

Choice of the benchmark processes

Good candidates for benchmark processes for lumi spectra studies are those with strong s-dependence: resonance production, threshold behaviour including $t\bar{t}$.

For 1-3 TeV studies: Z' production and squark pair at threshold.

Possibly wide angle Bhabha (LABH), as example of precision physics process, searches of substructure, extra-dims. etc.

Issues in pre-experimental MC studies

Which 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 $\delta E/E = 2.5 \cdot 10^{-4}$.

Issues in pre-experimental MC studies

More on 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 would be fit to 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.

With Bhabha Monte Carlo featuring “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 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.

Issues in pre-experimental MC studies

What could one do within the TESLA/NLC/CLIC study workshops?

Improving study of Moenig/Battaglia for several energies:

- better simulation of the “benchmark processes”, smuon/squark threshold and Z',

- add luminosity detector simulation,

- try 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 large angle Bhabha.

BHLUMI/BHWIDE$\otimes$beamstr. and beam spread can be used for small/large Bhabha at this stage. Plus “Pandora level” simulation of some “benchmark processes” in the same framework.

However, the best would be to develop simultaneously a framework of the next generation MCs for large/small angle Bhabha.

In particular: better studies of H.O. QED corrections, Z-contribution, vacuum polarization, light pairs etc.

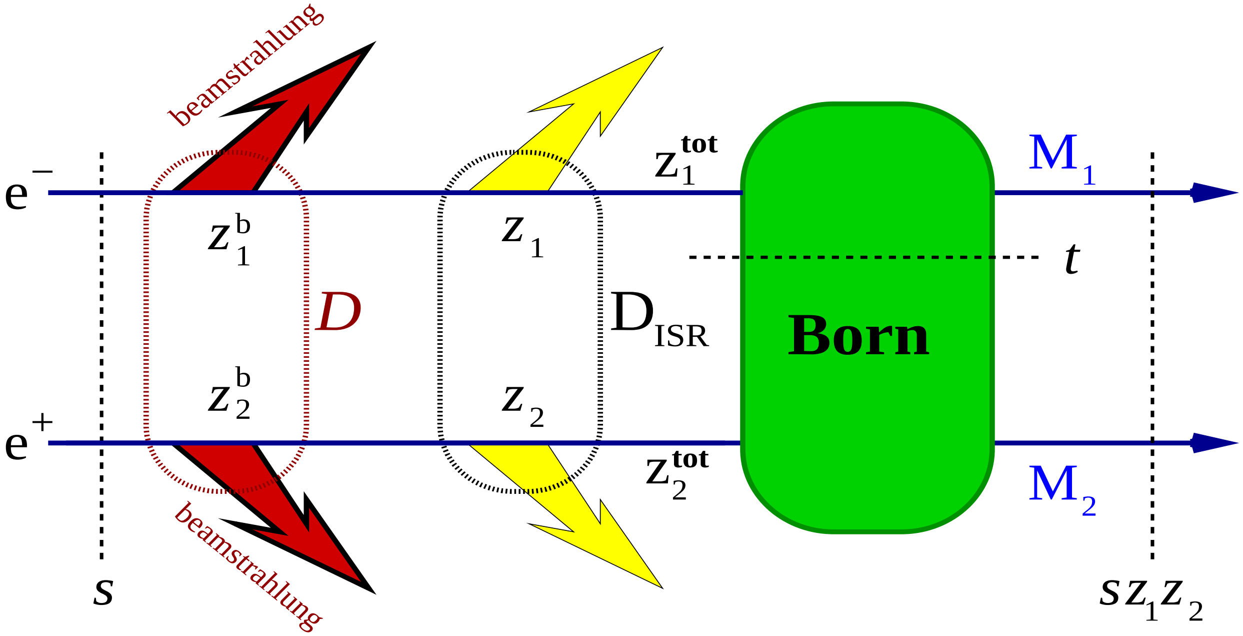
Conclusions

- **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) specified:**
  - **Inclusion of beamstrahlung,**
  - **Better QED, missing NLL $\mathcal{O}(\alpha^2)$ into MC,**
  - **Better VP hadronic,**
  - **Full $\mathcal{O}(\alpha^1)$ for Z,**
  - **Provisions for fitting beamstrahlung spectra (reweighting events).**
- **The need of "parametric representation" of the lumi spectra is underlined.**

APPENDIX: 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



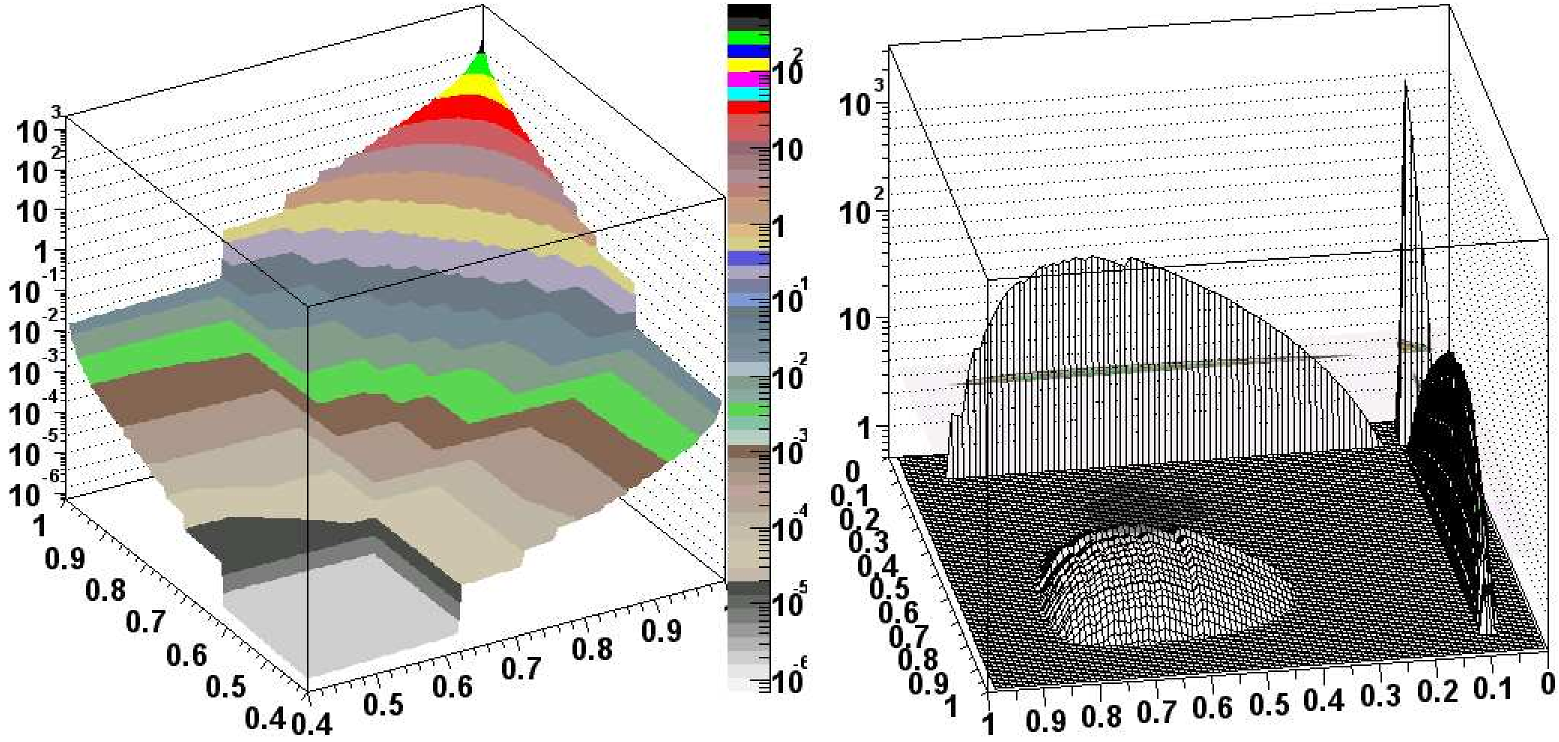
$$\sigma(s) = \int dM_1^2 \int dM_2^2 \int_0^1 dz_1^b dz_2^b \mathcal{D}(z_1^b, z_2^b)$$
$$\int_0^1 dz_1 dz_2 D_{\rm ISR}^{\rm LL}(z_1, z_2) \int dt\, \frac{d\sigma}{dt}(s z_1^{tot} z_2^{tot}, t)\Theta(\vartheta_1, \vartheta_2).$$

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

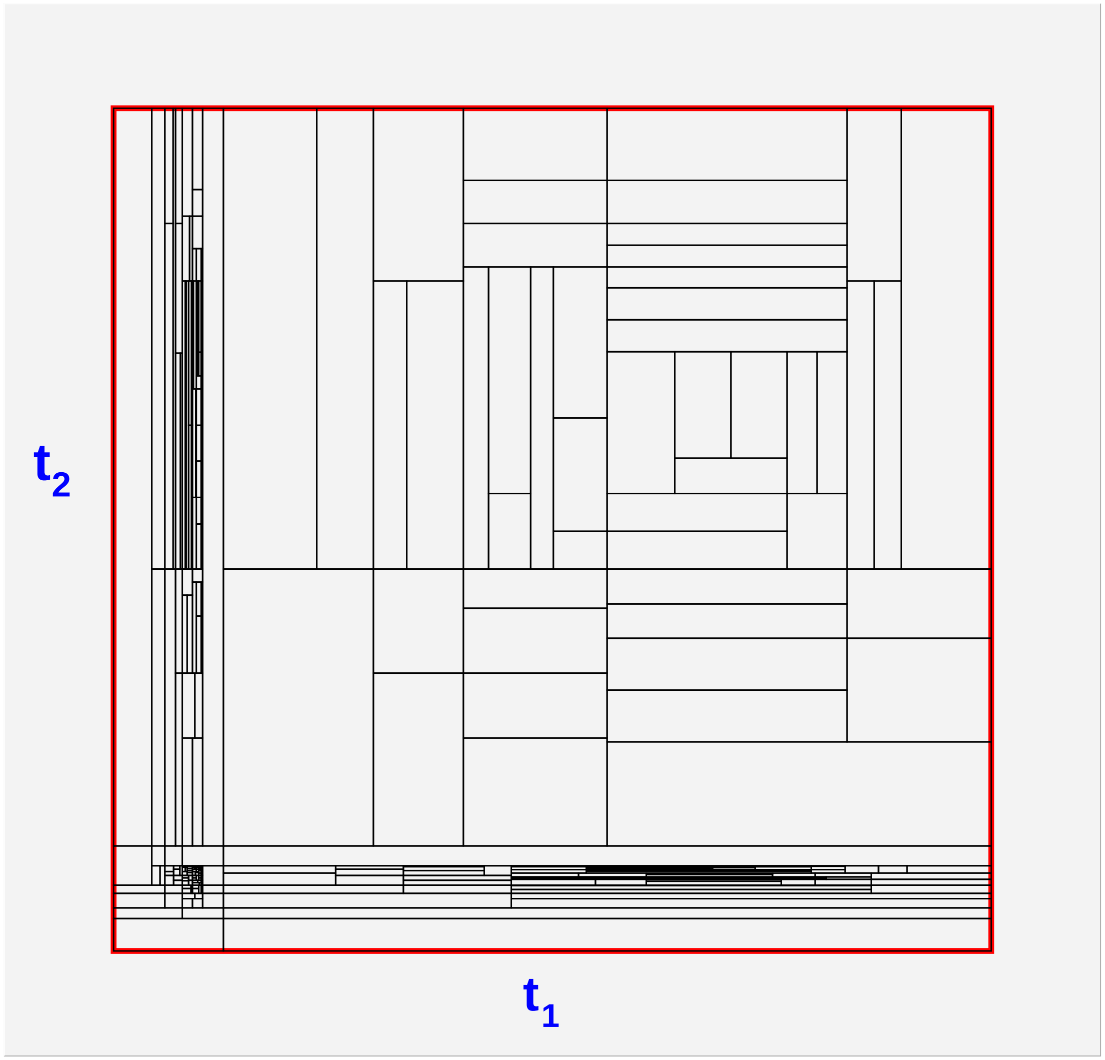


This is circe2 lumi spectrum for e^+e^- at 500GeV (no δ's!).

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.