CIRCE2: From Guinea-Pig to WHIZARD

Thorsten Ohl

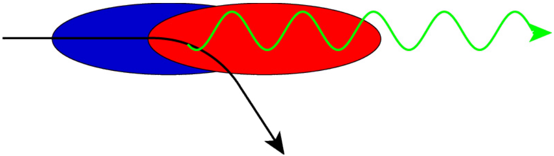
http://physik.uni-wuerzburg.de/ohl

Institute for Theoretical Physics and Astrophysics
Würzburg University

Second International WHIZARD Forum
Würzburg, March 16-18, 2015

Contents

- TeV-scale e^+e^--colliders must provide very high luminosity approaching ab^{-1} per year
$$L \approx \frac{N}{4\pi\sigma_x\sigma_y}\frac{\eta P_{AC}}{E_{CM}}$$
- Linear colliders are limited by total AC power P_{AC}) and must produce bunches with extremely high charge N and small cross section $\sigma_{x,y}$
- these dense beams will produce strong electromagnetic fields that deflect the charged particles in the opposing bunch
- these will emit bremsstrahlung, which is known as beamstrahlung in this case:



- these non-trivial non-linear electrodynamical effects must be simulated microscopically: Guinea-Pig [Schulte 1996ff]

- luminosity of beamstrahlung-photons large enough to provide significant background
- typical energy loss of $e^{\pm}$-beams large enough to require inclusion in physics simulations for future $e^{+}e^{-}$-colliders
- physics event generators need energy distribution functions or a stream of random numbers distributed accordingly
- problem: each run of Guinea-Pig will produce a set of events of fixed, but a priori unknown size (depending nonlinearly on simulation grids, macro particle size, &c.)
- wanted: parametrization of Guinea-Pig output that allows efficient generation of random numbers with the same distribution
- "back in the TESLA glory days", distributions were simple enough to allow to guess well behaved family of distribution functions:

CIRCE [Ohl, 1997]:
"seven real numbers to rule them all"

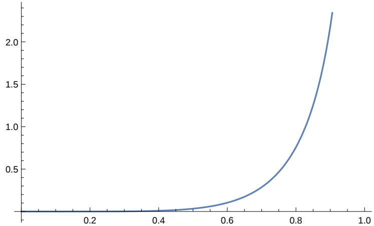
- Factorized 6-parameter ansatz (where $p_i \in \{e^\pm, \gamma\}$)

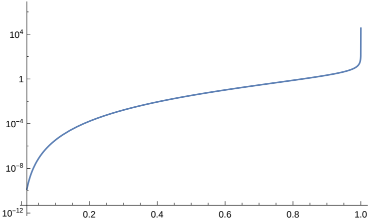
$$D_{p_1p_2}(x_1, x_2) = d_{p_1}(x_1)d_{p_2}(x_2)$$

with δ-peaks for unaffected electrons/positrons and β-distributions for the integrable singularities at $x \to 1$ and $x \to 0$, as suggested by theory

$$d_{e^\pm}(x) = a_0\delta(1-x) + a_1x^{a_2}(1-x)^{a_3}$$
$$d_\gamma(x) = a_4x^{a_5}(1-x)^{a_6}$$

- e.g. $x^{5.5}(1-x)^{-0.59}$ ($e^\pm$ @ TESLA 1 TeV)

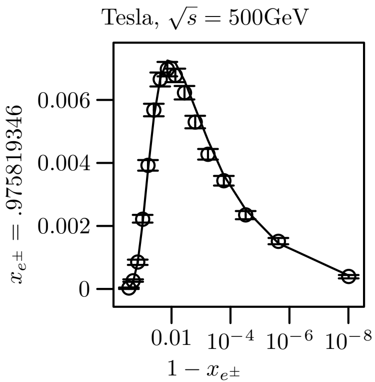


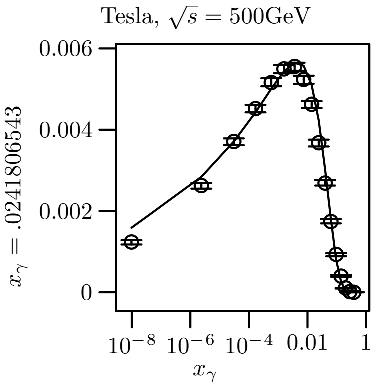


- Parameters change significantly among collider designs:

	TESLA 500 GeV	TESLA 1 TeV
$\mathcal{L}/\mathrm{fb}^{-1}\upsilon^{-1}$	$106.25^{+0.71}_{-0.71}$	214.33^{+0***}_{-0***}
$\int d_{e^\pm}$	$0.5723^{+0.0046}_{-0.0045}$	$0.6686^{+0.0040}_{-0.0040}$
$x_{e^\pm}^\alpha$	$15.2837^{+0.0923}_{-0.0914}$	$5.5438^{+0.0241}_{-0.0239}$
$(1-x_{e^\pm})^\alpha$	$-0.6166^{+0.0011}_{-0.0011}$	$-0.5847^{+0.0011}_{-0.0011}$
$\int d_\gamma$	$0.7381^{+0.0036}_{-0.0036}$	$1.0112^{+0.0033}_{-0.0033}$
x_γ^α	$-0.6921^{+0.0006}_{-0.0006}$	$-0.6908^{+0.0004}_{-0.0004}$
$(1-x_\gamma)^\alpha$	$24.1647^{+0.1124}_{-0.1116}$	$9.9992^{+0.0342}_{-0.0340}$

- fits are reasonably good





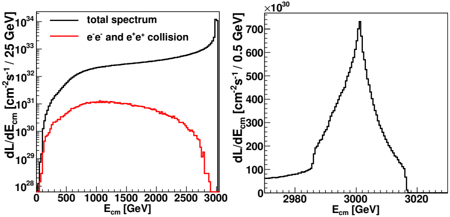
- NB: for fitting and plotting, the integrable singularity in the $e^\pm$-distribution at $x \to 1$ is handled by a map

$$x \to t = (1 - x)^{1/\eta}$$

$$\int_0^1 dx\, f(x) = \int_0^1 dt\, \eta t^{\eta-1} f(1 - t^\eta)$$

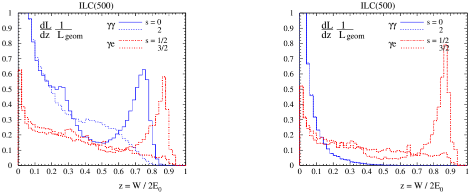
with $\eta \approx 5$. Analogously for the γ-distribution at $x \to 0$.

- while the low energy tail can still be described by power laws, the peak looks much more complicated at CLIC (wakefields &c):



[Dalena, Esberg, Schulte @LCWS11]

- CIRCE1 parameterizations are no longer adequate
- NB: even worse for $\gamma\gamma$ and $e^-\gamma$ collisions at a photon collider



[Telnov 2006]

- we have to give up
  - factorization:

$$D_{p_1p_2}(x_1,x_2) \neq d_{p_1}(x_1)d_{p_2}(x_2)$$

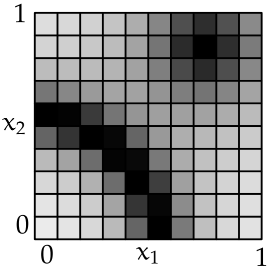
  - simple power laws:

$$D_{p_1p_2}(x_1,x_2) \not\propto x_1^{\alpha_1}(1-x_1)^{\beta_1}x_2^{\alpha_2}(1-x_2)^{\beta_2}$$

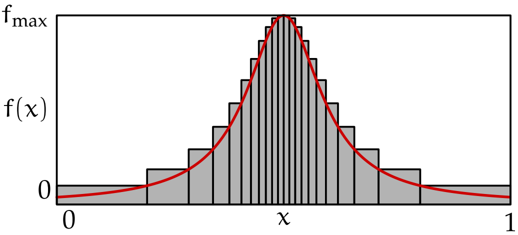
- instead: adapted 2-dimensional histograms

  CIRCE2 [Ohl, 2002ff]
- two parts
  - API for (x_1,x_2) efficient event generation
  - `circe2_tool` as a documented end-user tool for processing Guinea-Pig output (CIRCE1 was a bit obscure . . .)
- Why not port the unadapted 2D histograms of Lumilinker [Barklow, 2005?] from WHIZARD-1.9x? to WHIZARD-2.x?
  - distributions very steep, varying over many orders of magnitude
  - many almost empty cells with large fluctuations

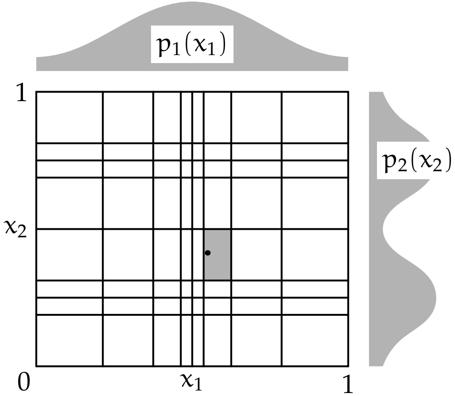
- A fixed grid with variable weights can not adapt to singular integrands:



- In one dimension, a variable grid with fixed weights can adapt well to singular integrands.



- factorizable singularities can also be described by a variable grid with fixed weights



- the remaining nonsingular nonfactorizable contributions can be handled by a variable weights on top of variable grid

- read TDR.circe and generate 1000000 (x_1, x_2) pairs for unpolarized electron-positron pairs

```
program girce2
  type(circe2_state) :: c2s
  type(rng_t) :: rng
  integer :: i, ierror
  real(kind=default), dimension(2) :: x
  call circe2_load (c2s, "TDR.circe", "ILC", 500.0_default, ierror)
  do i = 1, 1000000
     call circe2_generate (c2s, rng, x, [11, -11], [0, 0])
     print *, x, 1.0_default
  end do
end program girce2
```

- even simpler: use it from inside WHIZARD as

```
sqrts = 500
beams = "e-", "e+" => circe2
$circe2_file = "TDR.circe"
$circe2_design = "ILC"
?circe2_polarized = false
```

- basic example of CIRCE2 input

```
{ file = "TDR.circe"     # name of the output file
  { design = "ILC"       # there can be more than one design per file
     roots = 500         #                             energy
     scale = 250         # map [0,250] → [0,1]
     bins = 100          # use 100 bins in each direction
    { pid/1 = electron   # first and second particle
      pid/2 = positron
      pol = 0            # both particles unpolarized
      events = "guinea_pig/out/ILC_500_unpolarized.data"
      columns = 2        # read only the first two columns
      lumi = 8.008e33
      min = 0
      max = 1.05         # allow 5% energy spread at the upper end
} } }
```

will generate a fixed width histogram with weights according to Guinea-Pig output:

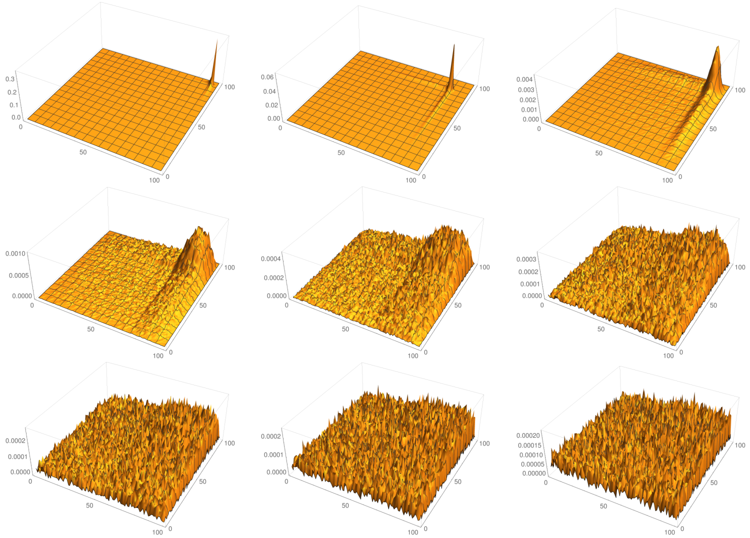
```
  $ head guinea_pig/out/ILC_500_unpolarized.data
249.435 250.16 405.499 -0.67215 32.2081 193 2.31349e-05 ...
249.791 250.109 -406.506 5.4995 61.3885 267 7.91127e-06 ...
...
```

- more sophisticated CIRCE2 input

```
{ file = "TDR.circe"
  { design = "ILC"
     roots = 500
     scale = 250
     bins = 100
    { pid/1 = electron
      pid/2 = positron
      pol = 0
      events = "guinea_pig/out/ILC_500_unpolarized.data"
      columns = 2
      lumi = 8.008e33
      min = 0
      max = 1.05
      iterations = 10
} } }
```

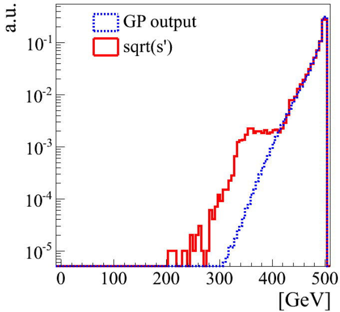
will generate a variable width histogram with weights according to Guinea-Pig output performing 10 iterations of adapting the bin widths to minimize the variance of the weights

- iterations $= 0, 1, 2, 3, 4, 5, 6, 7, 8$:



(171.306 Guinea-Pig events in 10.000 bins)

- CAVEAT: too many iterations (e.g. 10) can produce a too coarse description of regions with low luminosity



[Moritz Habermehl]

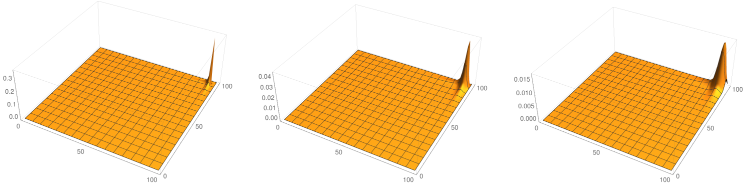
- `iterations = 2` appears to be safe

- more sophisticated CIRCE2 input

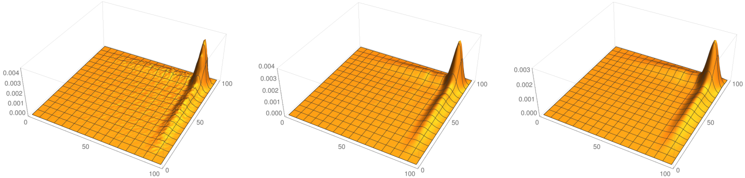
```
{ file = "TDR.circe"
  { design = "ILC"
     roots = 500
     scale = 250
     bins = 100
    { pid/1 = electron
      pid/2 = positron
      pol = 0
      events = "guinea_pig/out/ILC_500_unpolarized.data"
      columns = 2
      lumi = 8.008e33
      min = 0
      max = 1.05
      iterations = 4
      smooth = 5 [0.00,1.05] [0.00,1.05]
} } }
```

applies a Gaussian smearing

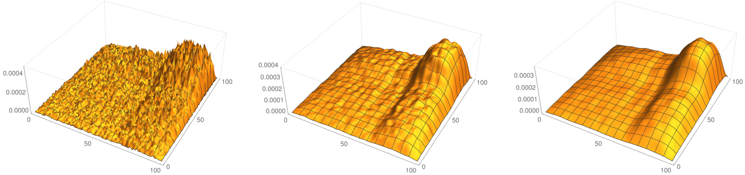
- `iterations` = 0 and `smooth` = 0, 3, 5:



- `iterations` = 2 and `smooth` = 0, 3, 5:



- `iterations` = 4 and `smooth` = 0, 3, 5:



- the densities are now normalized individually and no longer relative to a master e^+e^- distribution.
- the special treatment of δ-distributions at the endpoints has been retired. The corresponding contributions have been included in small bins close to the endpoints. For small enough bins, this approach is sufficiently accurate and avoids the pitfalls of the approach of CIRCE1.

- CIRCE2 as a powerful, yet convenient, bridge between beam and event generation
- allows to produce application specific parametrizations
  - precise and smooth high energy peaks for threshold scans (e.g. $t\bar{t}$)
  - more uniform bins for background studies
- a better quality control tool for endusers will be made available
- is available from `http://whizard.hepforge.org/`
  - as part of WHIZARD
  - also as standalone package