Measurement of the Differential Luminosity at 3 TeV CLIC

– Luminosity Spectrum Modelling –

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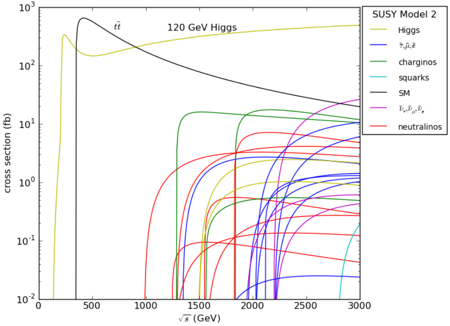
Goal and Limits of our Study

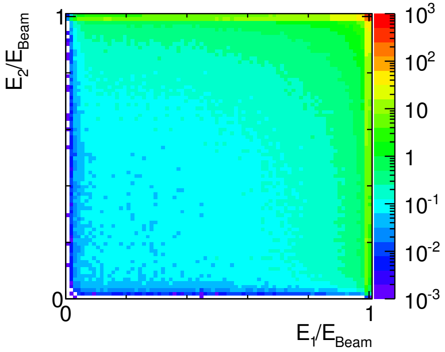
- How does the uncertainty in the luminosity spectrum affect measurements at CLIC 3 TeV?
  - Benchmark processes far above threshold, very few events with $\sqrt{s'} < 1.5$ TeV
  - Integrated Luminosity 2 ab^{-1}
- Studied lumi spectrum in light of these benchmarks
- Including relevant effects for reconstruction
- Can use a minimal model to describe the luminosity spectrum, do not need a complete and global description of the spectrum from $\sqrt{s'} = 0$ TeV – 3 TeV



What is the Goal of this Measurement?

- Goal: The distribution of the pairs of particle energies prior to initial state radiation $L(x_1, x_2)$
  - Only reconstructing the centre-of-mass energy ignores the longitudinal boost of the system
  - Strong correlation between the two particle energies
  - Account for Asymmetric beams
  - Initial state radiation depends on the specific process and centre-of-mass energy
- Note: We mostly show the c.m.s. luminosity spectrum $L(\sqrt{s'})$ because it is easier to compare and interpret

Particle Energy Spectrum from GUINEAPIG



$$L(\sqrt{s'}) = \int dx_1 \int dx_2 L(x_1, x_2) \delta\left(\frac{\sqrt{s'}}{\sqrt{s_{nom}}} - \sqrt{x_1 x_2}\right)$$

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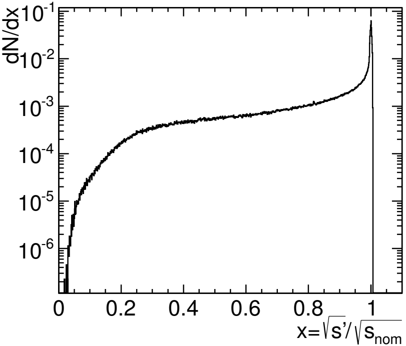

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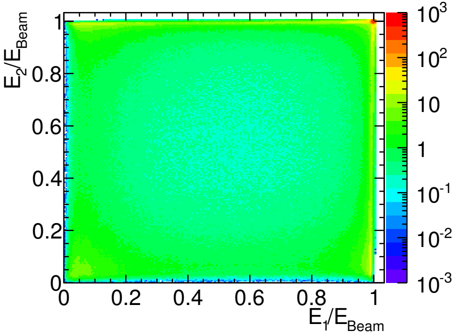
- Need large cross-section and well known process: Bhabha scattering
- In the detector we measure the final state particles affected by the cross-section (initial state radiation, final state radiation, $\sqrt{s'}$ dependence)
- There is no way, for an individual event, to know if the energy was lost from initial state radiation or Beamstrahlung
- The measured values are also affected by the resolution of the respective subdetector

Distributions after Bhabha scattering and cross-section (without detector resolutions)



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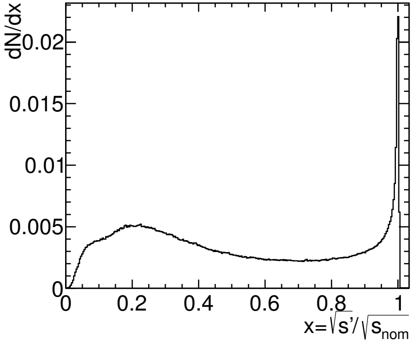


Fit Procedure

For an efficient extraction of the parameters a reweighting fit is used

- Create 'real' spectrum, taken from GuineaPig (GP-Sample)
- Create a luminosity spectrum according to Model (Model-Sample)

Fit Level a) Use the particle energy spectra directly

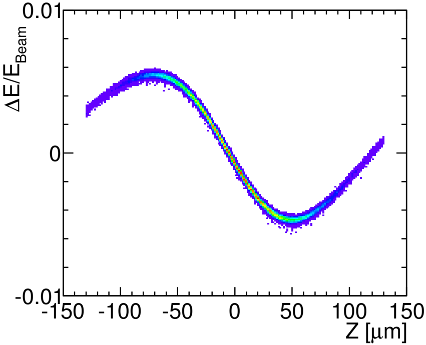
Fit Level b) Simulate Bhabha events, add detector effects, use observables for fit (see presentation by Stéphane)

- Fill GP-Sample and Model-Sample in different histograms
- Let `Minuit` vary the parameters and change the weight of every single event of the Model to minimize the χ^2 between GP-Sample and Model-Sample

Beam-Energy Spread

- Energy distribution mostly due to intra-bunch wakefields and RF phase offset
- Front of bunch gains more energy and wakefields reduce effective gradient for the tail

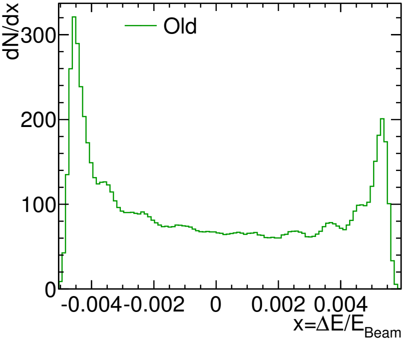
Particle energy vs. longitudinal position from the accelerator simulation



Bunch travelling towards the left

Better Beam Particle Files

- Beam Particle files used as input to GUINEAPIG showed *wiggles* in the energy spectrum
- Also visible in 2D lumi-spectrum
- Wiggles due to number of slices used in accelerator simulation
- B. Dalena reran simulation with more (50) slices
- Wiggles disappear



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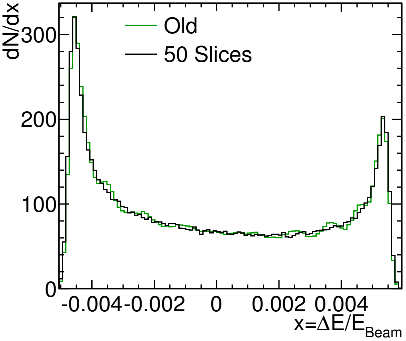


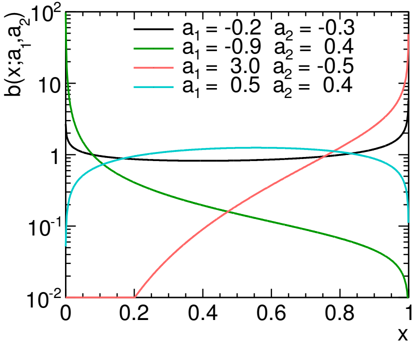
Beta-Distributions

- Mostly using Beta-Distributions for the description of the luminosity spectrum

$$b(x) = \frac{1}{N} x^{a_1} (1-x)^{a_2}$$

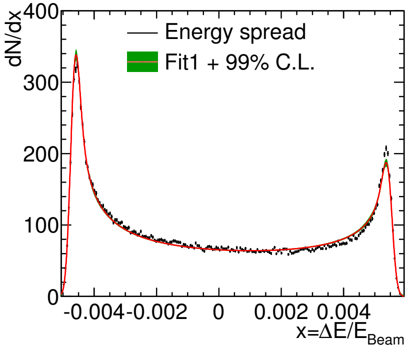
with different parameter bounds

- Range: $0 < x < 1$



Beam-Energy Spread Function

Particle energy distribution from accelerator simulation



- Tried several different functions to fit, settled on beta-distribution convoluted with Gauss

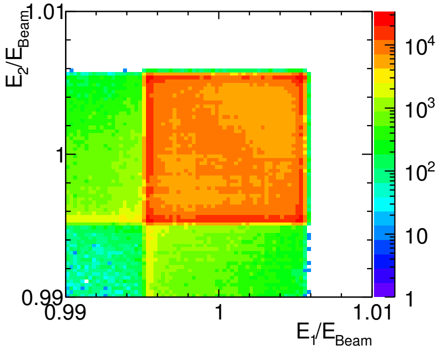
$$\mathrm{BES}(x) = \int_{x_{\min}}^{x_{\max}} b(\tau)\mathrm{Gauss}(x-\tau)\mathrm{d}\tau$$

- 5 parameters, including min. and max. of beta-distribution range
- $\chi^2/\mathrm{ndf} = 764/195$

Luminosity-weighted Beam-Energy Spread

- Due to the correlation, Beamstrahlung, and beam-beam effects two vastly different beam-energy spread distributions emerge for the luminosity spectrum
- *Peak* Region: Both particles with $E > 0.995 E_{\text{Beam}}$
- *Arms* Region: Only one of the particles with $E > 0.995 E_{\text{Beam}}$
- Both can be fit with a beta-distribution convoluted with a Gauss (keeping x_{min}, x_{max}, and σ fixed)

Peak of the luminosity spectrum



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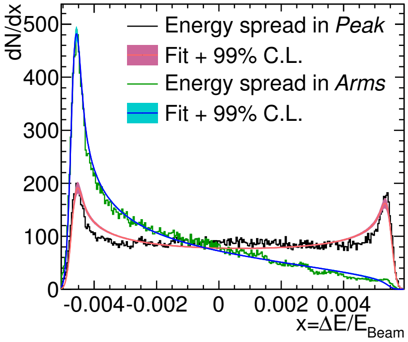
Particle energy distribution from the GUINEAPIG simulation



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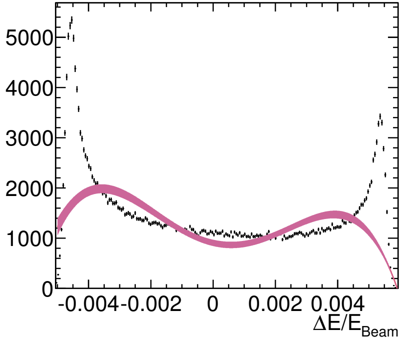

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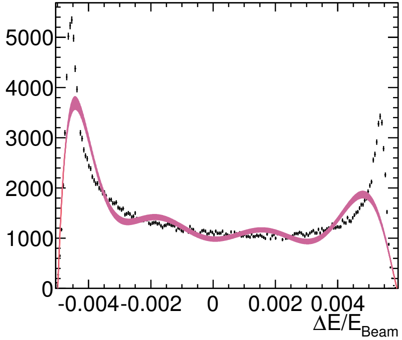

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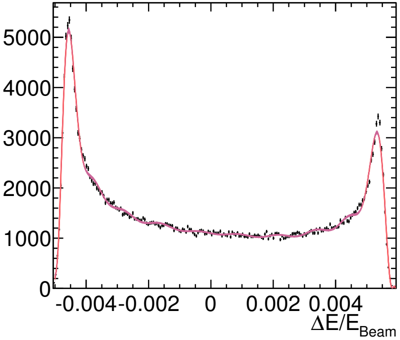

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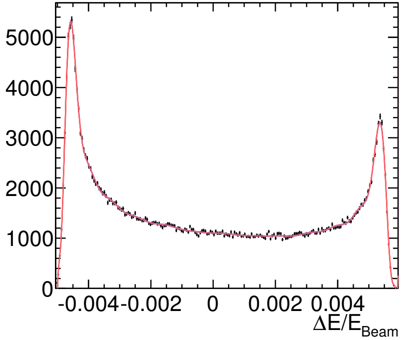

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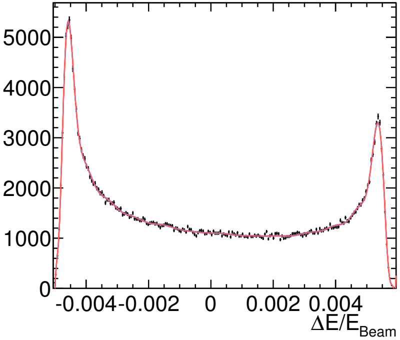
  - 26 Parameters: χ^2/ndf = 668/173
  - 35 Parameters: χ^2/ndf = 226/164
- Saves trouble of convolution, but at the cost of many parameters
- Could also fit centre only and do convolution with Gauss, but still need larger number of parameters

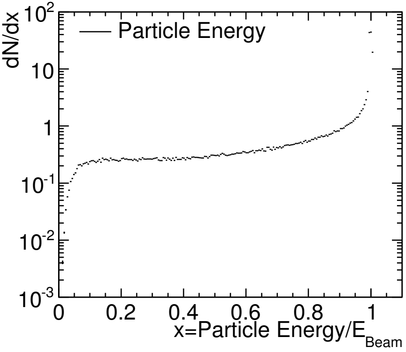


Beamstrahlung

- Second contribution to luminosity spectrum is energy loss due to Beamstrahlung
- Potentially large loss of energy for some particles, 30% in the top 1%

Fitting the particle Energy Spectrum

- Single Beta-Distribution not enough to describe full range of particle energies
- Upper bound of $0.995\sqrt{s_{\text{nom}}}$, because of impact of beam-energy spread (Particle energy is convolution of Beamstrahlung and beam-energy spread effect)
- Keep small number of parameters: Limit to $0.5\sqrt{s_{\text{nom}}}$ and a single beta-distribution (limited $a_1 \geq 0.0$), but can extend



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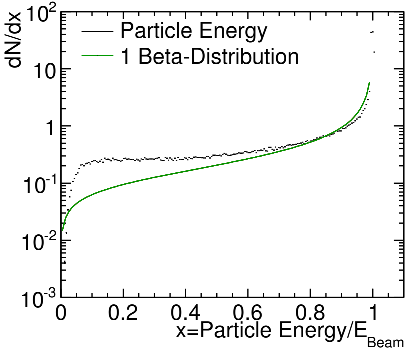

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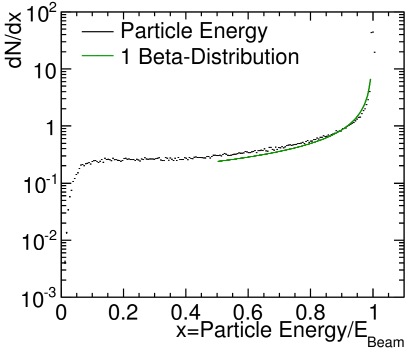

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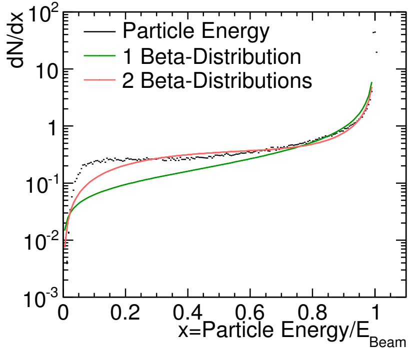

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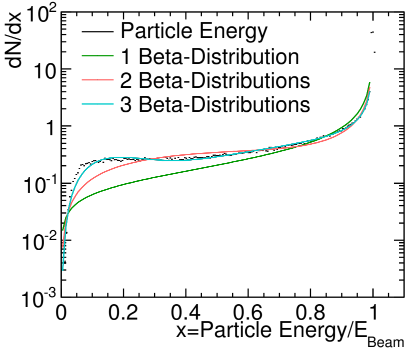
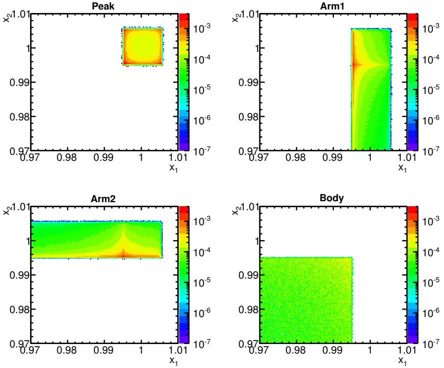


Full MODEL

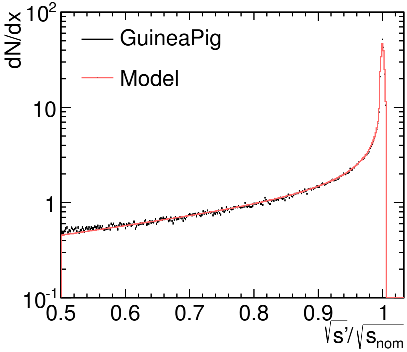
For the Function:

- Divide the luminosity spectrum in four different regions
- Individual regions described by convolutions of beam-energy spread functions and Beamstrahlung functions (or just Beamstrahlung functions)
- Created a 2D probability density function which enables the generation of the luminosity spectrum according to the MODEL
- For this model: 19 free parameters



Fitting Spectrum Directly

- Fit the 2D distribution of *Particle energies*
- 1 million GP events and 3 million according to MODEL
- No cross-section, initial state radiation, or detector effects
- Difference in the width of the peak, but averages out
- Spectrum reconstructed within 5% down to $0.6\sqrt{s_{\mathrm{nom}}}$
  - Only statistical errors from GUINEAPIG sample
  - Error due to parameters smaller
- In the topmost bin (summed): $\Delta L/L = -0.0062 \pm 0.0017(\mathrm{stat}) \pm 0.0003(\mathrm{par})$



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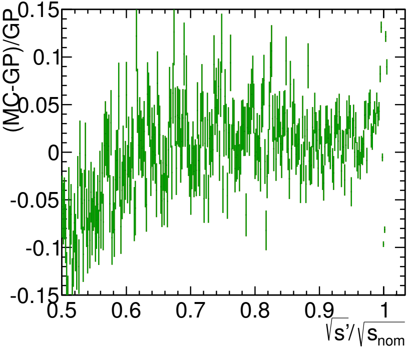

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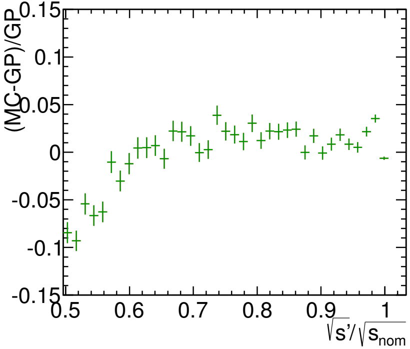

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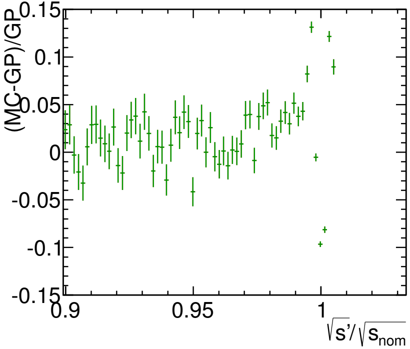

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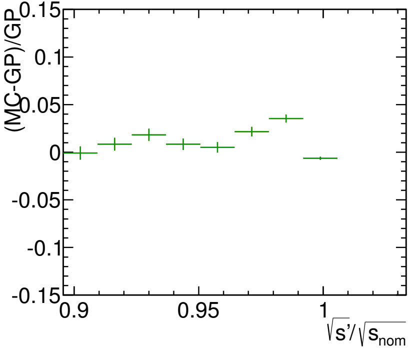

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- Cross-section read into GUINEAPIG
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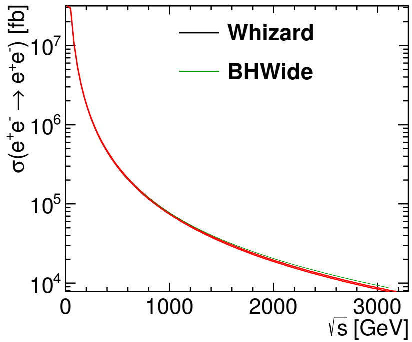

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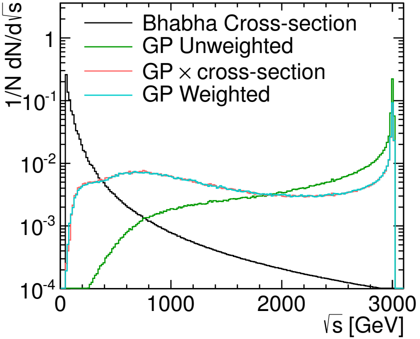

Summary and Conclusion

- The CLIC beams produce a rather peculiar luminosity spectrum
- Modelling is not as easy as for beams with Gaussian beam energy spread
- Using description with minimal number of parameters
- Model describes lumi spectrum quite well, within limits of of current model, and some differences in the peak
- Extension of the model possible
- Added luminosity spectrum scaling according to cross-section in GUINEAPIG and MODEL