Luminosity spectrum at CLIC (3 TeV)

Status and Outlook

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Outline

Outline

Motivations for the luminosity spectrum measurement

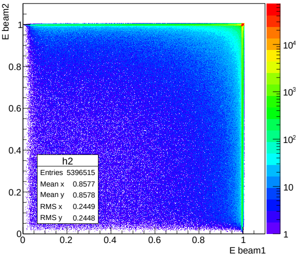
Why it's important to know it:

- *cross section* measurements: Higgs, etc.
- *mass* measurements: slepton analysis, etc.
- *threshold scans*

Spectrum is not directly measurable as it's affected by initial state radiation that escape detection.

Motivations for the luminosity spectrum measurement

What we want to “measure”: set of parameters that describes the luminosity spectrum:



- need a model, based on assumptions and existing Monte Carlo samples
- need a framework/procedure for parameter estimation

Why the need for a model? Why not use directly Guinea Pig?

- Because of the very large number of parameters in GP, input particle distributions, etc.

Outline

Introduction and Motivations

Fit Methods

The Model

Statistical Intermission

Fit Status

Fit with Bhabha Events

Conclusion

Fit methods

Parametrize beam energies and their correlations using a model which gives a set of parameters $[p]$ to estimate.

Central point of the method: compare histograms (MC vs Data) using χ^2.

For the fit itself, 2 methods:

- Brute force (Backup)
- Reweighting fit

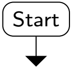
Relies on existing Data (MC at this level) set: here Guinea Pig sample with CLIC 3TeV nominal settings.

Reweighting fit

- A distribution of an observable = "probability" for an event to happen with a given observable value. Observable can be e.g. $\{E1, E2\}$ for a given event
- If said distribution is built from a set of parameters' values $[p]$, then probabilities can be computed from that set
- Changing $[p] \rightarrow [p]' \Rightarrow$ change of the probabilities. This change is accounted by the ratio $\frac{P(\{E1,E2\},[p]')}{P(\{E1,E2\},[p])}$. This weight is applied individually to every event.

Same principle applies when looking at reconstructible obervables (Bhabha events, see later)

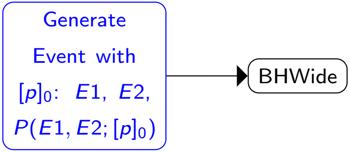
Reweighting fit



Reweighting fit

Generate
Event with
$[p]_0$: $E1$, $E2$,
$P(E1, E2; [p]_0)$

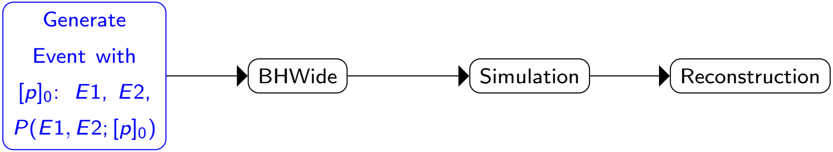
Reweighting fit



Reweighting fit

Generate Event with $[p]_0$: $E1$, $E2$, $P(E1, E2; [p]_0)$ → BHWide → Simulation

Reweighting fit



Reweighting fit

Generate
Event with
$[p]_0$: $E1$, $E2$,
$P(E1, E2; [p]_0)$

↓

Minimizer:
$[p]_N \rightarrow [p]_{N+1}$

Reconstruction

Reweighting fit

Generate

Event with

$[p]_0$: $E1$, $E2$,

$P(E1, E2; [p]_0)$

Reconstruction

Minimizer:

$[p]_N \rightarrow [p]_{N+1}$

Compute

$P(E1, E2; [p]_{N+1})$

for all events

Reweighting fit

Generate

Event with

$[p]_0$: $E1$, $E2$,

$P(E1, E2; [p]_0)$

Reconstruction

Minimizer:

$[p]_N \rightarrow [p]_{N+1}$

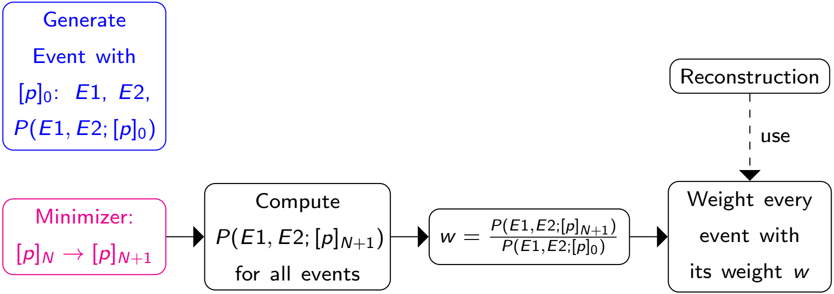
Compute

$P(E1, E2; [p]_{N+1})$

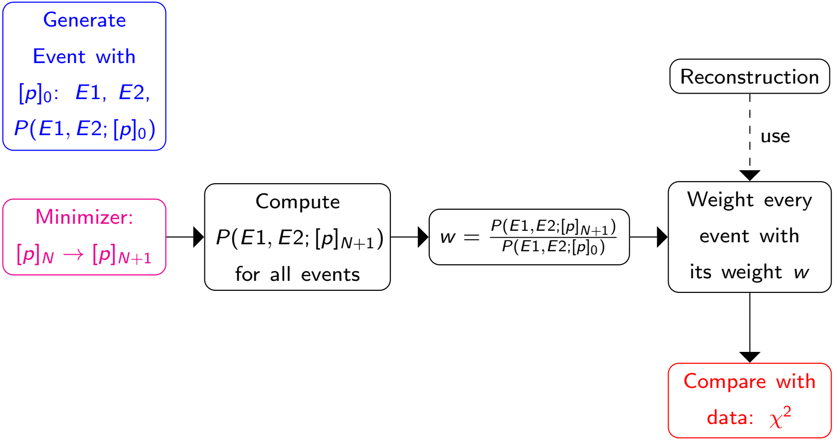
for all events

$$w = \frac{P(E1,E2;[p]_{N+1})}{P(E1,E2;[p]_0)}$$

Reweighting fit



Reweighting fit



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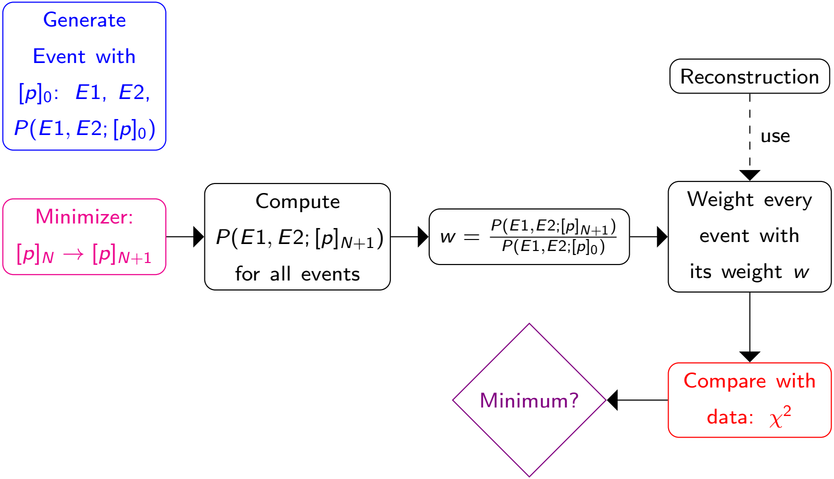
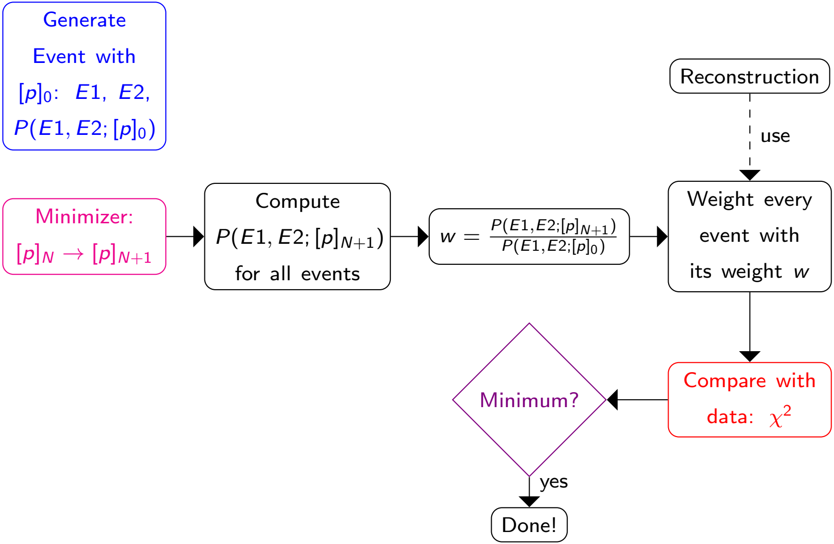


Reweighting fit



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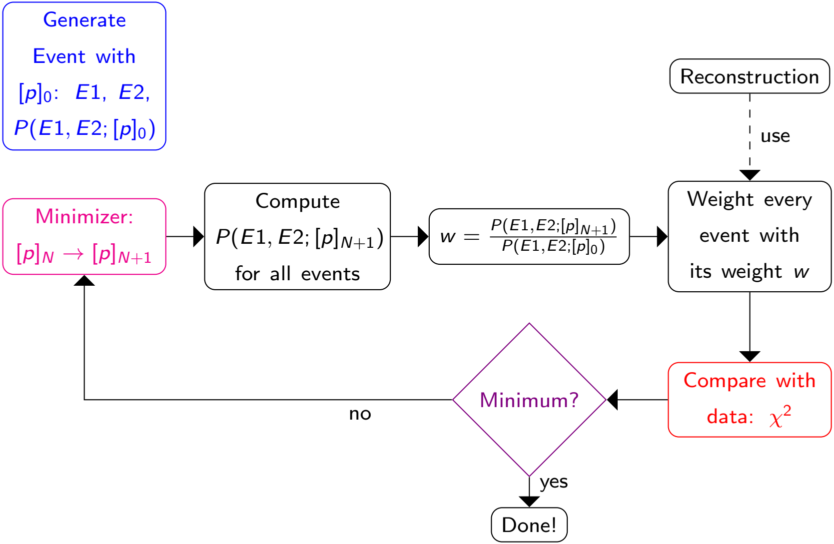

Reweighting fit

Generate
Event with
$[p]_0$: $E1$, $E2$,
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Reconstruction

Minimizer:
$[p]_N \rightarrow [p]_{N+1}$

Reweighting fit

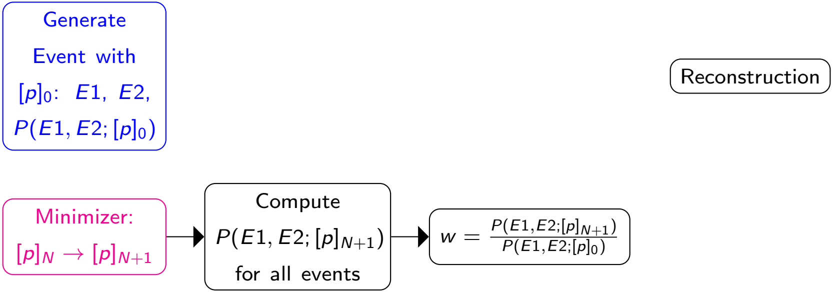
Generate Event with $[p]_0$: $E1$, $E2$, $P(E1, E2; [p]_0)$

Reconstruction

Minimizer: $[p]_N \rightarrow [p]_{N+1}$

Compute $P(E1, E2; [p]_{N+1})$ for all events

Reweighting fit



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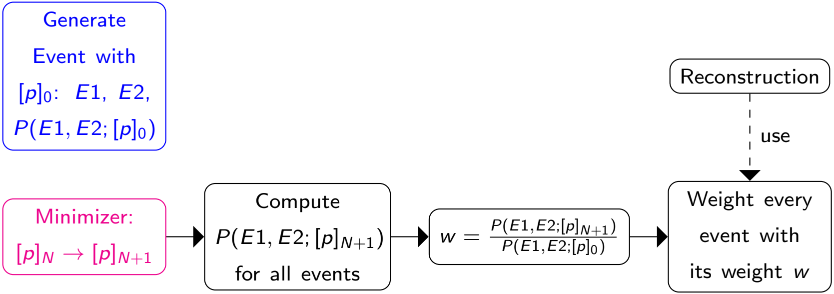

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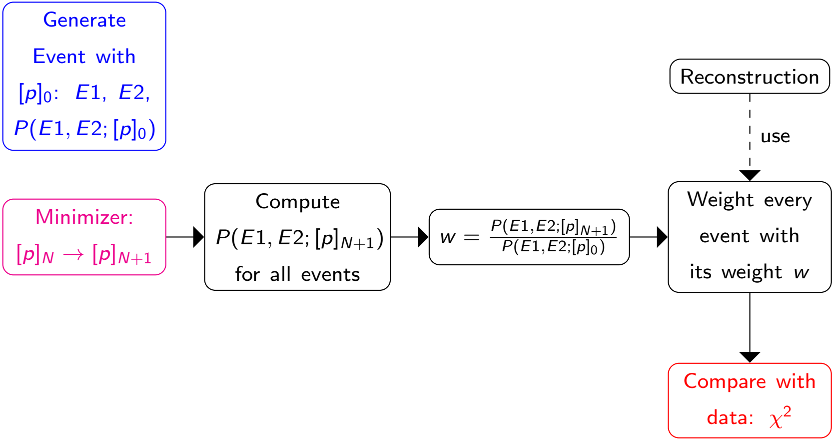

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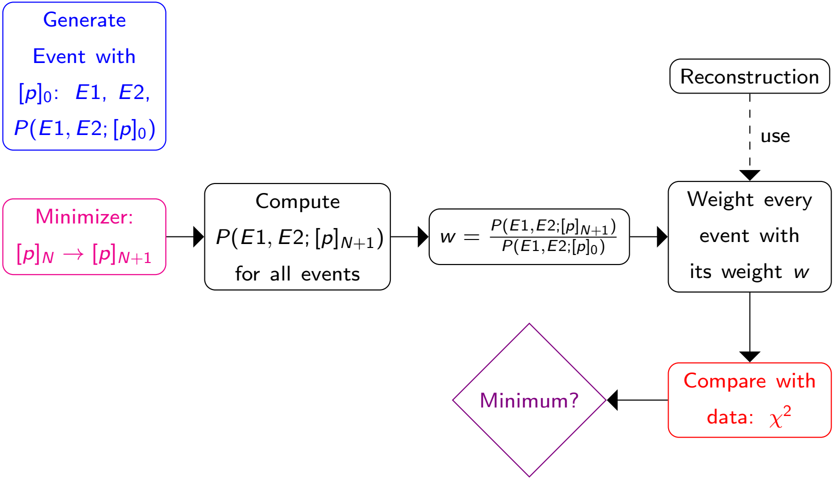

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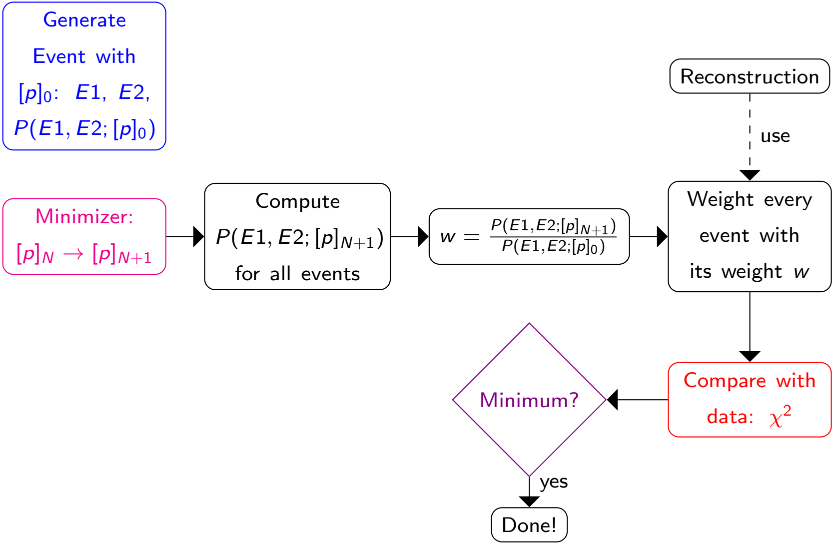

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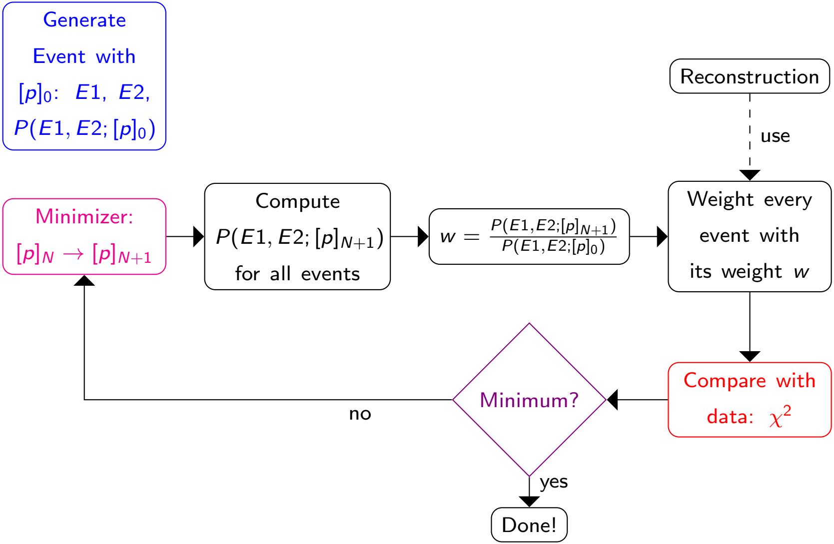

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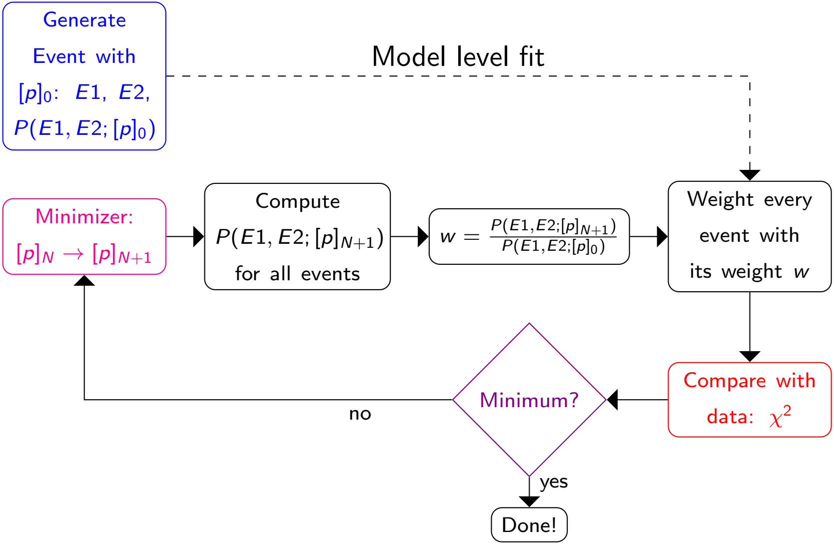


Fit timing

- 4 000 function calls (loop in slide 9) for the minimization: $\sim$ 12h
- 2 weeks for the simulation/reconstruction of 5 000 000 events

That's the way to go!

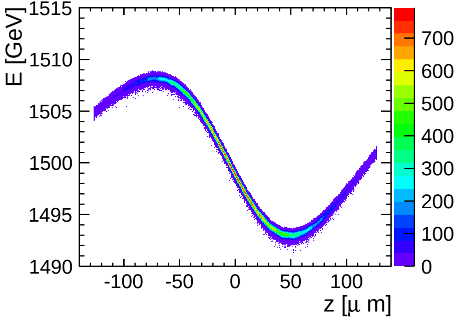
Outline

Understanding the physics

Building a model:

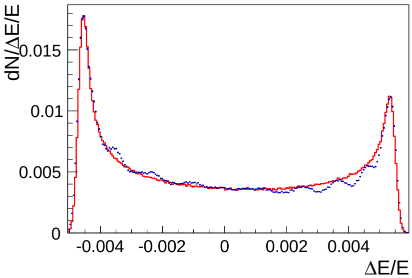
- understanding the beam-beam interactions
- accounting for the beam spread
- adding the effects of beamstrahlung

Particle distribution in a beam



beam direction

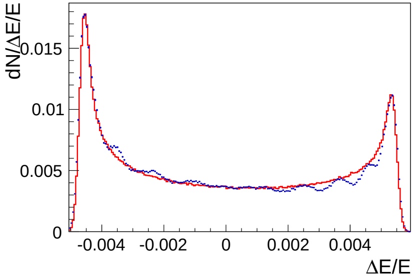
Back of the beam has less energy.

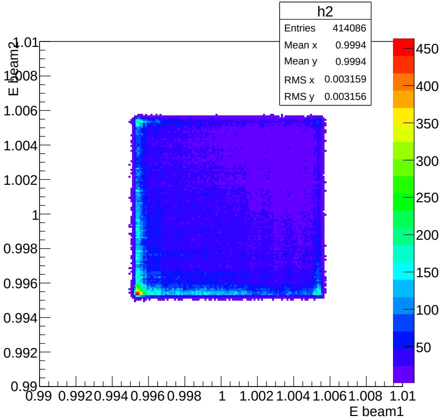


Projection on E, normalized, fitted

Beam energy spread

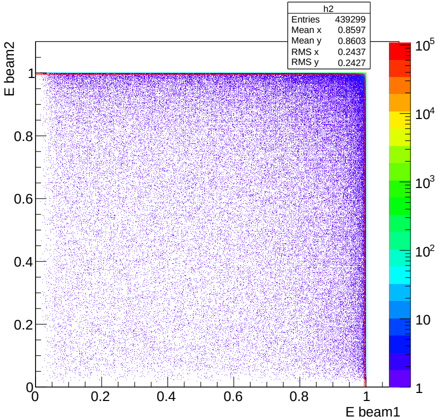
Guinea pig with beam spread and without beamstrahlung:

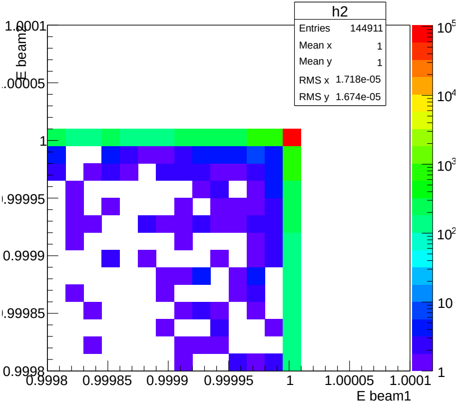




Beamstrahlung effects

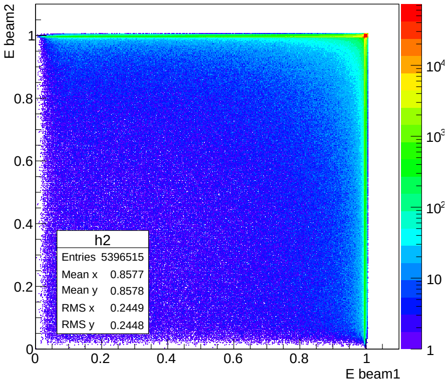
Guinea pig without beam spread but with beamstrahlung:

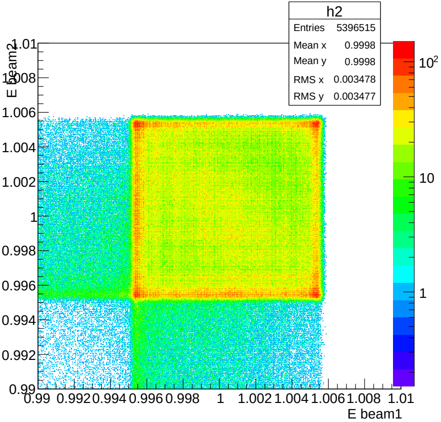




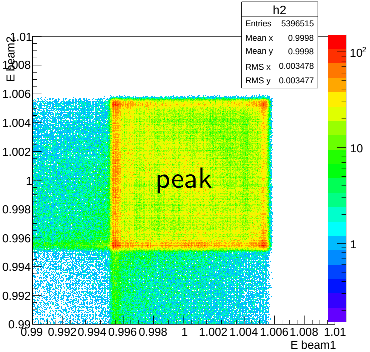
Beam-Beam interactions

Guinea pig with beam spread and with beamstrahlung:





Getting a model for the peak

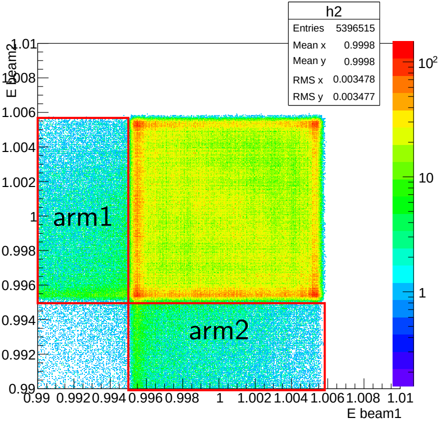


Using slide 14 and slide 15:

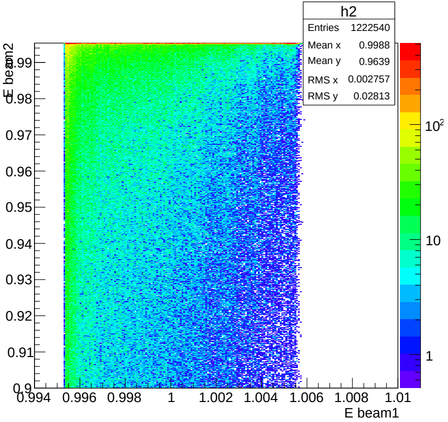
- Use 1 beta distribution for each beam for the “box” (slide 42)
- neglect the effect of beamstrahlung: events contributing mostly to the peak did not emit beamstrahlung

Same range for the beam spread shape for both beams.

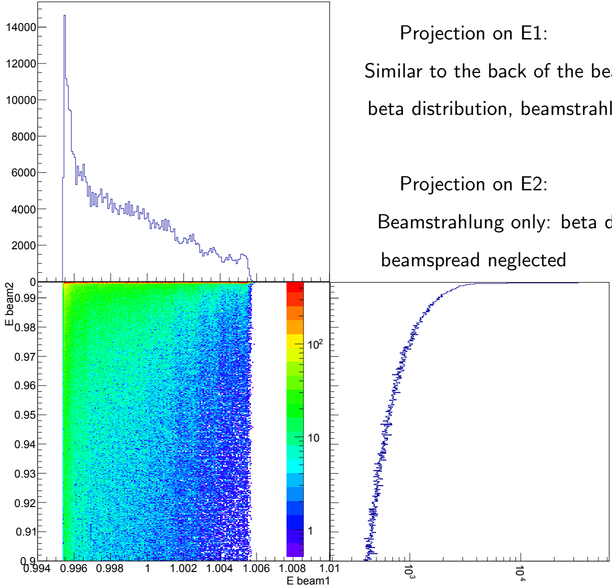
Getting a model for the arms



Arm 2:



Getting a model for the arms



Projection on E1:

Similar to the back of the beam spread (sl.44):

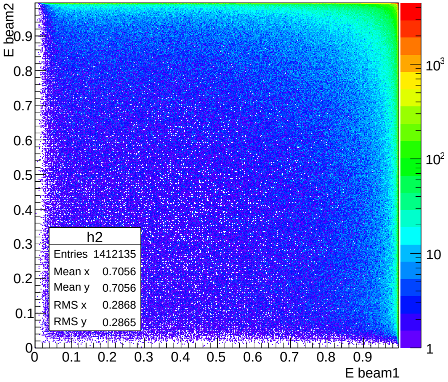
beta distribution, beamstrahlung neglected

Projection on E2:

Beamstrahlung only: beta distribution,

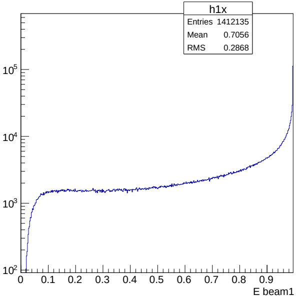
beamspread neglected

Getting a model for the body

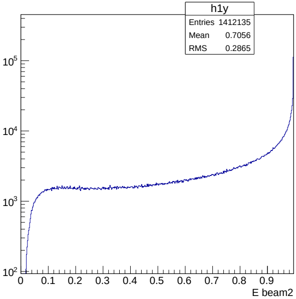


Getting a model for the body

Projection on E1:



Projection on E2:



Body is assumed to be dominated by beamstrahlung effects. The beam spread is completely neglected.

Beamstrahlung is modeled by different beta distributions for each beam (slide 41).

Final model

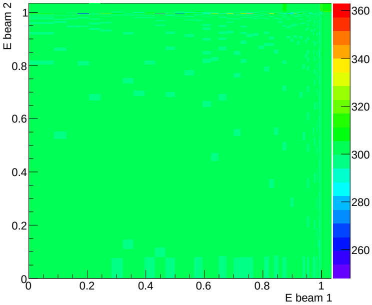
Global factor for every regions: 3 parameters
2 Beam spread beta function for the peak: 4 parameters
2 Beamstrahlung beta functions for the body: 4 parameters
1 Beam spread for each arm: 4 parameters
15 free parameters.

Outline

Statistical Methodology: the χ^2

Method relies on histogram comparison using χ^2. To be a correct estimator of the compatibility[1]:

- Number of entries per bin > 7
- Each bin should contain similar number of entries: equiprobability binning necessary (ROOT's TH2Poly only for 2D fit)



[1] Statistical Methods for Experimental Physics, F. James, p.304

Outline

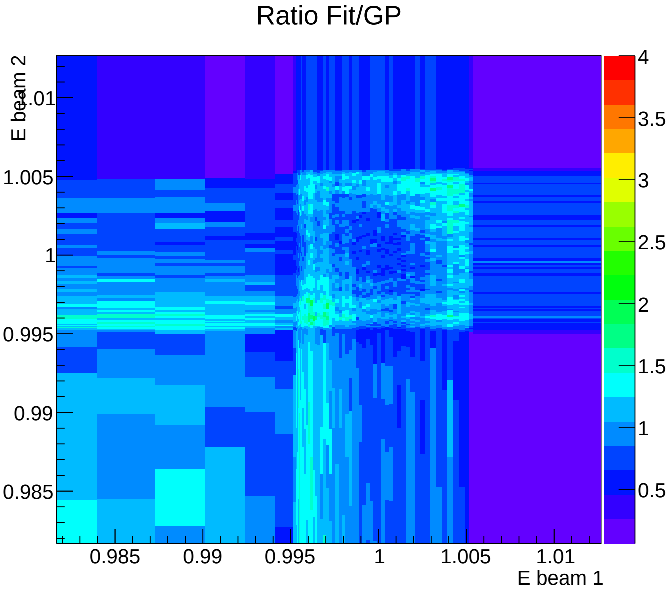
Fit Status

Model level fit: fit directly the beam energies given by our model against the Guinea Pig spectrum

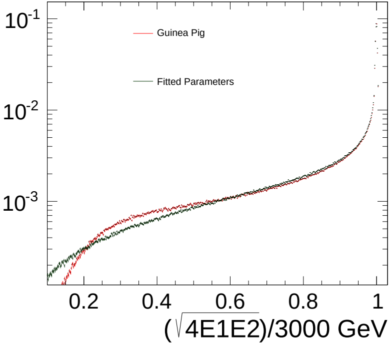
Ingredients:

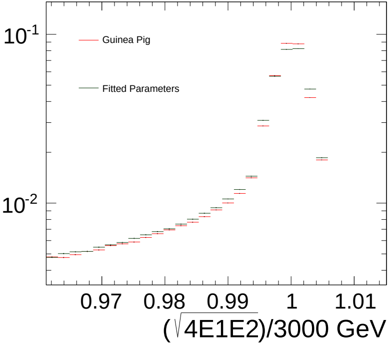
- Model: see before
- Data: 3 000 000 events of Guinea Pig (Data), 3 000 000 events of our model (Monte Carlo)

Model level fit results



Model level fit results

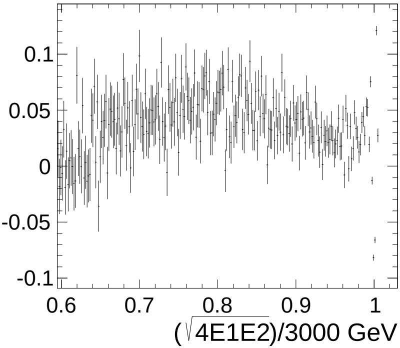


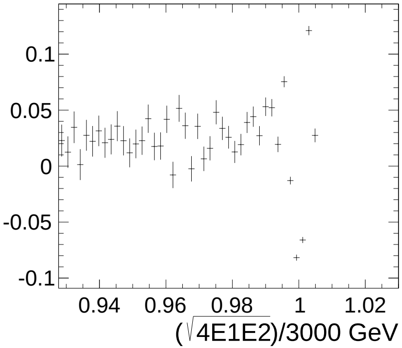


See slide 45 for linear scale plots.

Model level fit results

Relative difference between the fitted parameter set and Guinea Pig:





Partial conclusion

Fit at model level not perfect:

- Need to improve model: beta distributions for the peak and the arms not fully suitable, need higher order objects (more parameters)
- For the beamstrahlung, more beta functions may be needed

Meanwhile: can in parallel setup framework for Bhabha events.

Outline

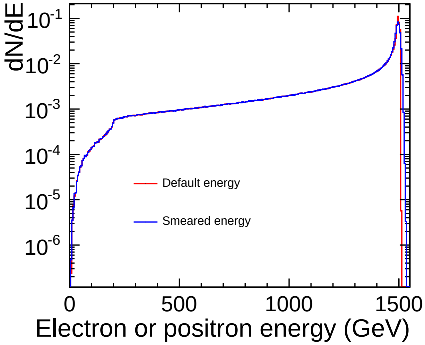
Bhabha events

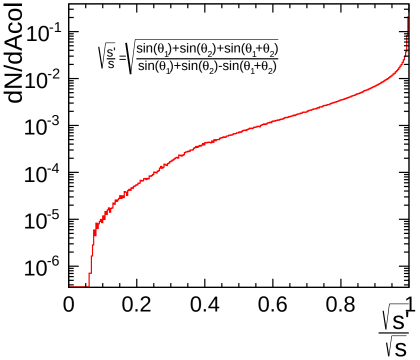
Using BHWide to obtain large angle Bhabha events:

- Input energies given either by Guinea Pig or by our model: gives 2 samples
- Keep only the particles with $\theta > 7^\circ$: visible in the tracking detector

Until we have the full chain of simulation/reconstruction running, smear the measurable energies (electron and positron) to "simulate" the energy resolution effects.

Bhabha events





Fitting the Bhabha events

Reweighting fit works as long as the input beam energies are kept in the generator level (BHWide) file:

- 1 event is then parametrized by $\{E_{beam1}, E_{beam2}, E_p, E_e, \frac{\sqrt{s'}}{\sqrt{s}}\}$
- Use $\{E_{beam1}, E_{beam2}\}$ for the weight computation
- Use $\{E_p, E_e, \frac{\sqrt{s'}}{\sqrt{s}}\}$ for Data comparison: 3D histogram needed
- Resolution effect canceled out as long as they are identical between Data and MC (systematics), but more events needed to compensate.

Issue: defining equiprobability binning in 3D

Now do not use equiprobability binning, throw away bins with less than 10 entries.

Nothing to show yet: work in progress.

Outline

Conclusion

Status:

- Model level fitting in place, need few improvements
- Framework setup
- Bhabha procedure exists, need improvement in binning

Things to add:

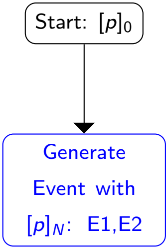
- Full simulation and reconstruction
- Background handling: pairs, $\gamma\gamma \rightarrow had$, etc.
- Propagation of the errors on our parameters to the physics measurements and impacts

Backup slides

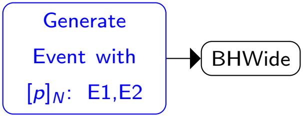
Brute force fit

Start: $[p]_0$

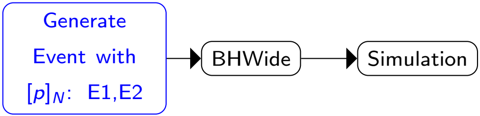
Brute force fit



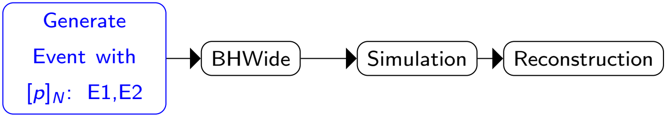
Brute force fit



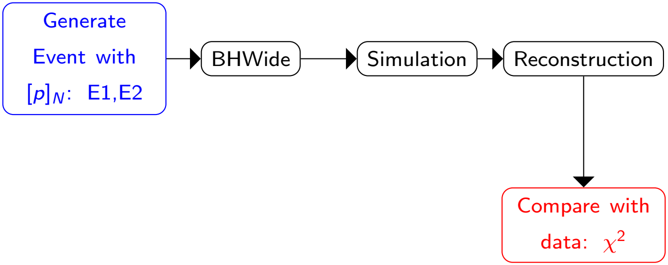
Brute force fit



Brute force fit



Brute force fit



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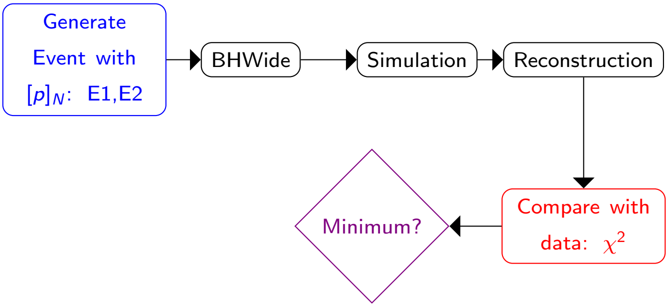

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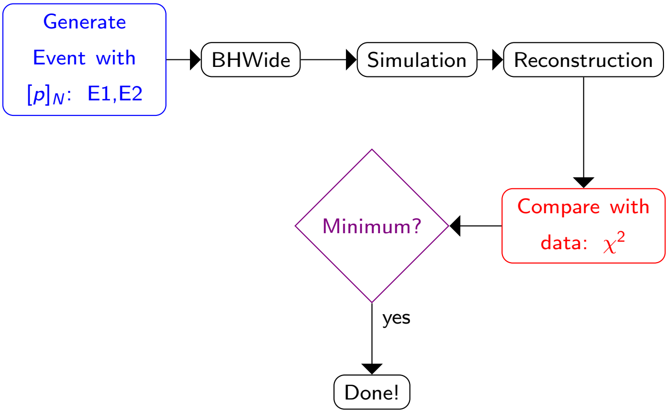

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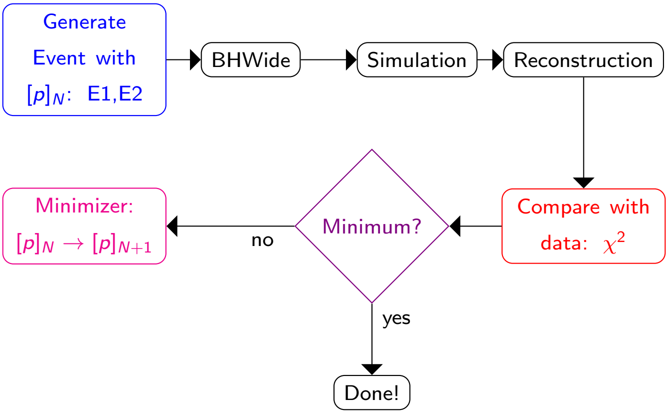

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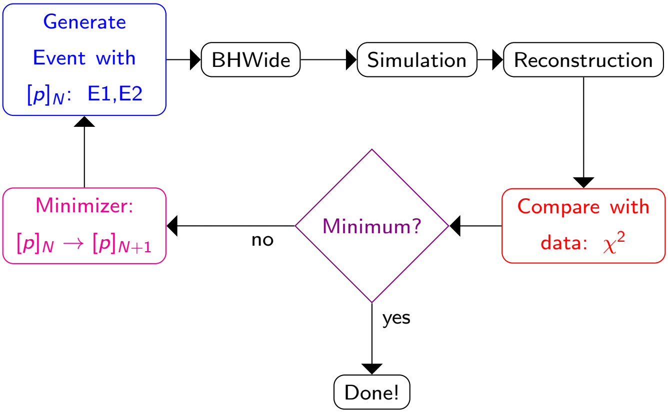

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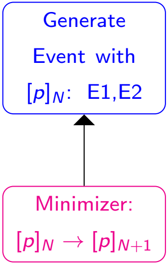

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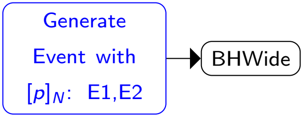

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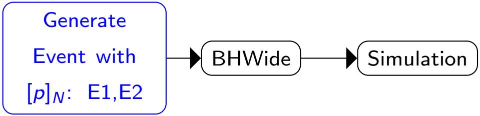

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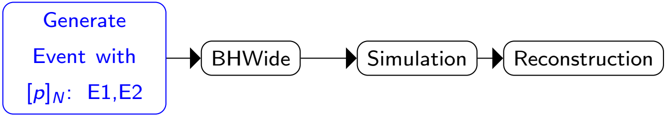

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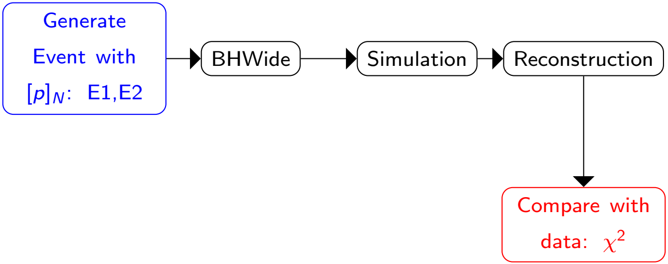

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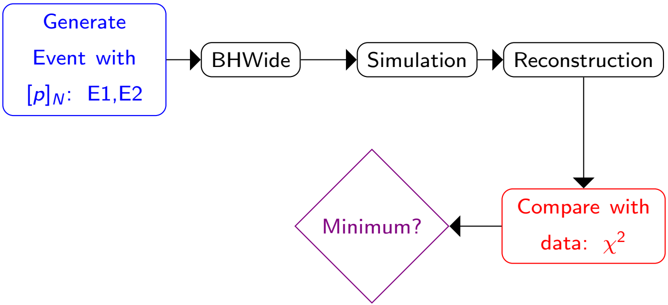

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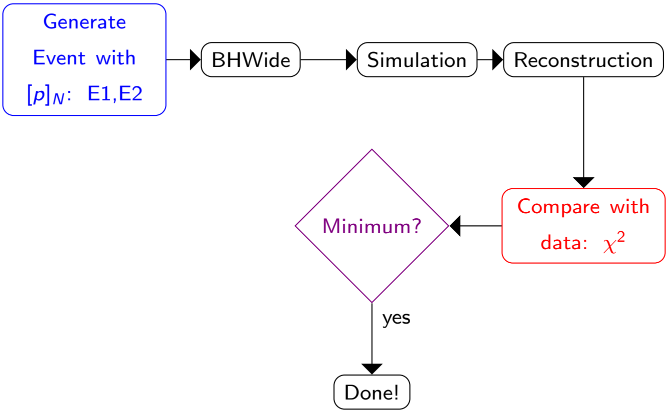
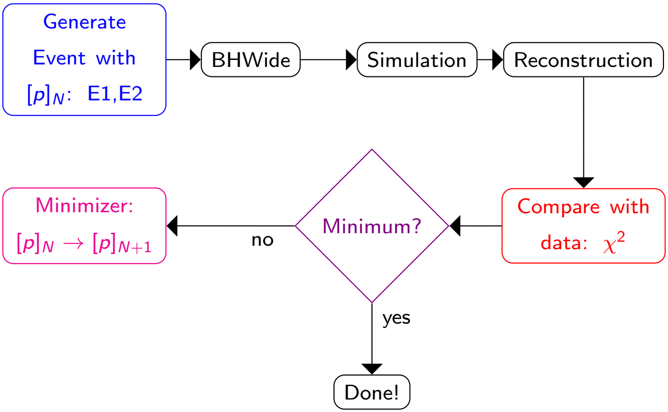
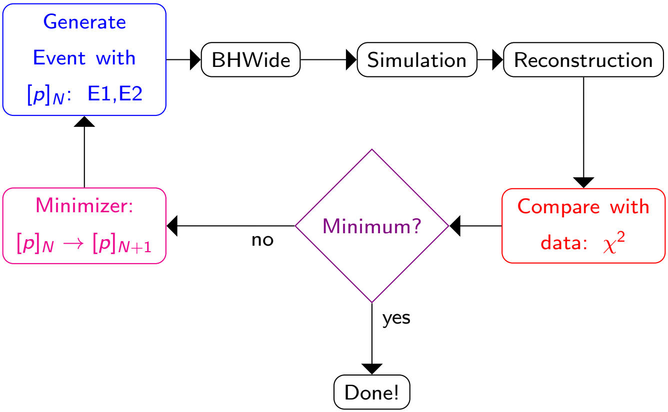


Brute force fit



Brute force fit



This procedure would take $\sim$ 200 years (see slide 39).

Why does it take so long?

- 5 000 000 events, to generate, simulate, and reconstruct
- 4 000 function calls (loop) in the minimization
- 5 minutes per event in the simulation, 30 seconds for the reconstruction
- 1 000 jobs on the grid in parallel

Accounting for the correlations

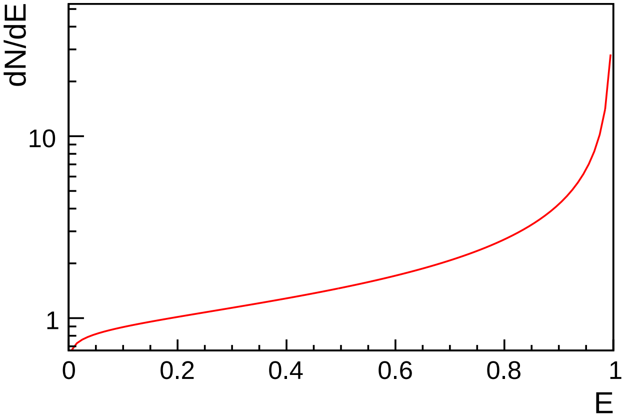
- Correlations $\Rightarrow$ convolution
- Too complex to do numerically, let alone analytically

How we do it:

- Generate values from each of the functions, and the corresponding probability to obtain such values
- Add the values for each beam to obtain the total beam energy
- Multiply the probabilities to have the event probability

Beta distributions: beamstrahlung

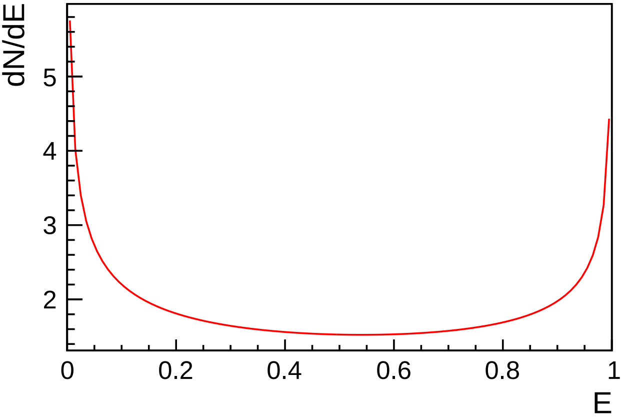
Beta distribution : $x^a(1-x)^b$



$a \sim 0.08, b \sim -0.6$

Beta distributions: beam spread in the peak

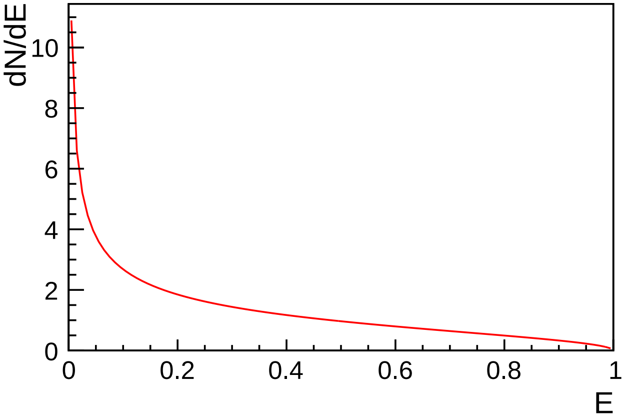
Beta distribution : $x^a(1-x)^b$



$a \sim -0.3, b \sim -0.3$

Beta distributions: beam spread in the arms

Beta distribution : $x^a(1-x)^b$



$a \sim -0.4, b \sim 0.4$

Why does the beam spread in the arms have this shape?

From slide 14, lower side of beam spread corresponds to back of the beams

For a particle in the back of the beam e.g. beam1 to interact with a particle from beam2, the particle in beam2 has to cross the front of beam1, therefore be subject to coulomb forces: higher chance to emit beamstrahlung.

Model fit results