“Point 5“: LOI – DBD comparison

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Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

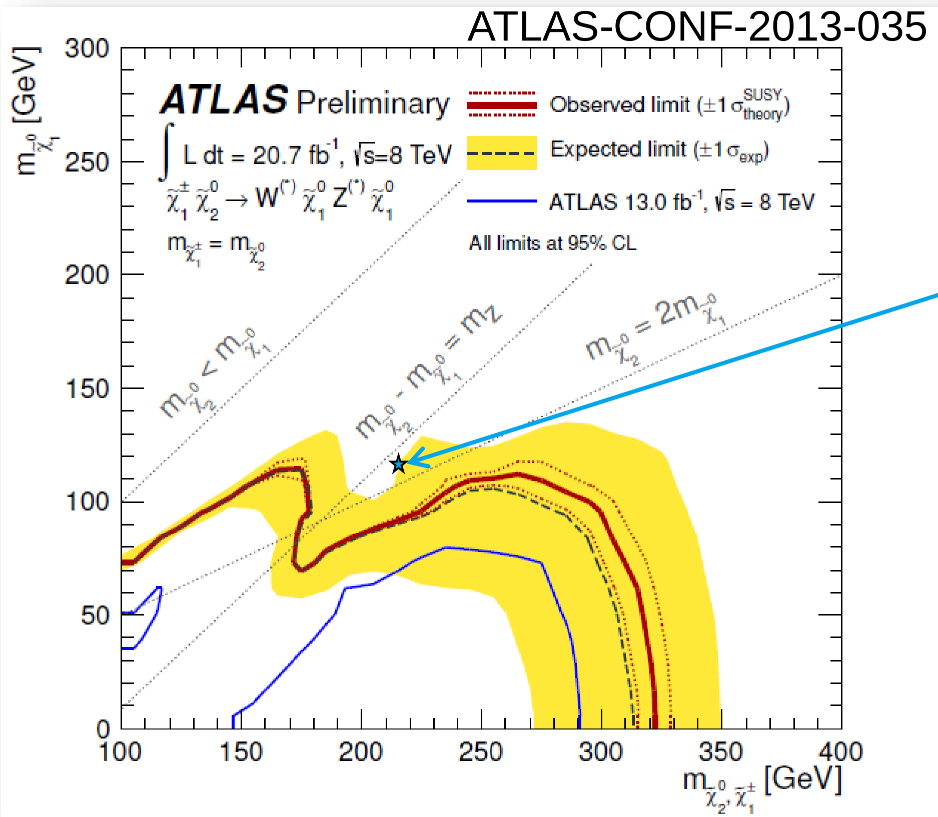
Particles, Strings, and the Early Universe
Collaborative Research Center SFB 676

DESY

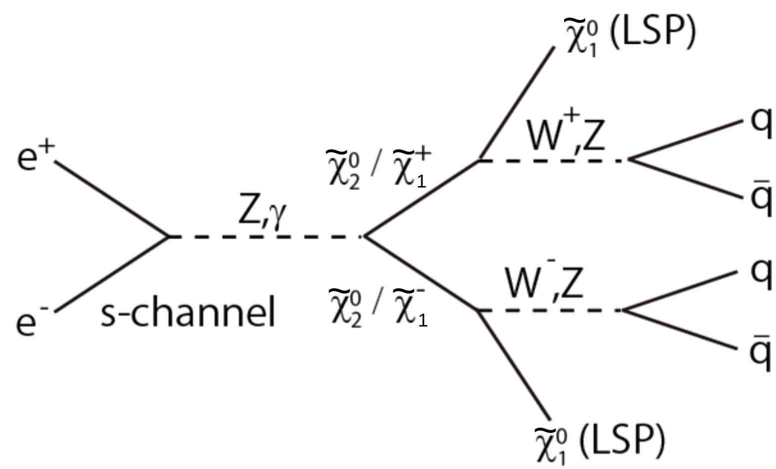
Point 5: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ Pair Production at the ILC

"Point 5" benchmark : gaugino pair production at ILC

http://arxiv.org/pdf/1006.3396.pdf (ILD LoI)
http://arxiv.org/pdf/0911.0006v1.pdf (SiD LoI)



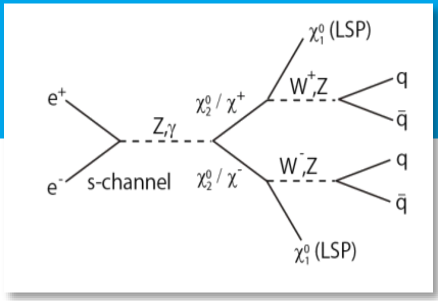
Particle	Mass [GeV]
$\tilde{\chi}_1^0$	115.7
$\tilde{\chi}_1^{\pm}$	216.5
$\tilde{\chi}_2^0$	216.7
$\tilde{\chi}_3^0$	380



$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 W^{\pm} \qquad BR = 99.4\%$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^0 \qquad BR = 96.4\%$$

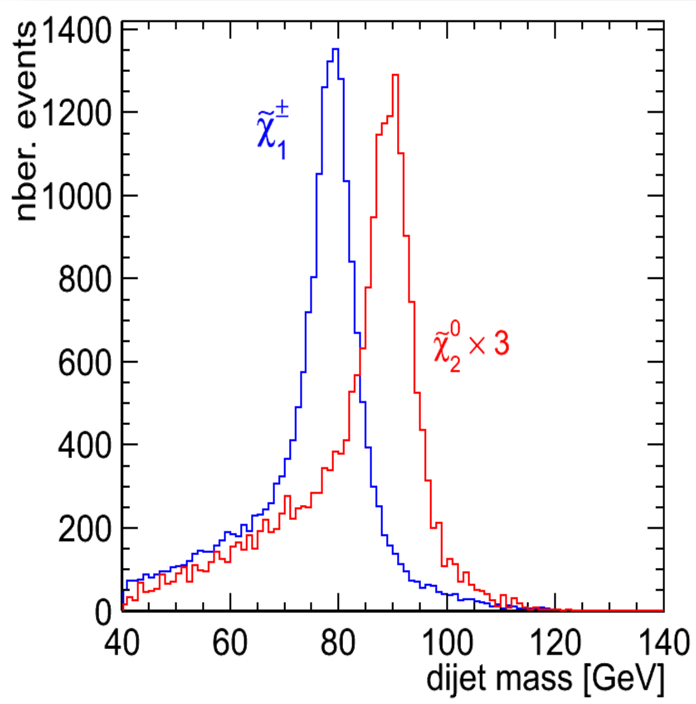
Study case - motivation



- Signal topology:
  - Four jets and missing energy (due to LSP)
  - Hadronic decay modes of gauge bosons chosen as signal
  - Both decay channels treated as signal in turn

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 W^{\pm} \quad \text{and} \quad \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^0$$

- $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ sample separation: essentially distinguish between W and Z pair events
- Good case for studying the detector and particle flow performance



Data Samples:

> Signal: 40000 $\tilde{\chi}_1^{\pm}$ events and 9000 $\tilde{\chi}_2^0$ events

> **LOI sample:**	> **DBD sample:**
▪ Signal generated with `Whizard1.51` Background generated with `Whizard1.40`	▪ Signal (as well as SM background) generated with `Whizard 1.95`
▪ The RDR beam spectrum was used	▪ The TDR beam spectrum was used

▪ **Note:** in the signal samples, the M_W was inadvertently lowered by Whizard to M_W = 79.8 GeV

▪ Signal + background were simulated and reconstructed with `ilcsoft v01-06`	▪ Signal + background were simulated and reconstructed with `ilcsoft v01-16-02`
▪ The jet energy scale was increased by 1%	▪ The jet energy scale was **not** increased
▪ No $\gamma\gamma$ background overlay	▪ The **$\gamma\gamma$ background overlay** was taken into account
▪ The analysis was re-run on existing data samples	▪ The analysis was re-run

Analysis Strategy

- Remove $\gamma\gamma \rightarrow \mathrm{hadrons}$ background — only for DBD
- Cluster event into 4 jets (Durham)
- Run kinematic fit (equal mass constraint)
- Run isolated lepton finder (Junping) — only for DBD
- Perform SUSY preselection
- Separate $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ samples
- Perform mass measurement

(Cluster event into 4 jets through Run kinematic fit, and Perform SUSY preselection through Perform mass measurement: **common to both LOI and DBD**)

Analysis Strategy

- Remove $\gamma\gamma \to \text{hadrons}$ background — **only for DBD**
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common to both LOI and DBD (Cluster event into 4 jets; Run kinematic fit; Perform SUSY preselection; Separate samples; Perform mass measurement)

Removing the γγ Background II

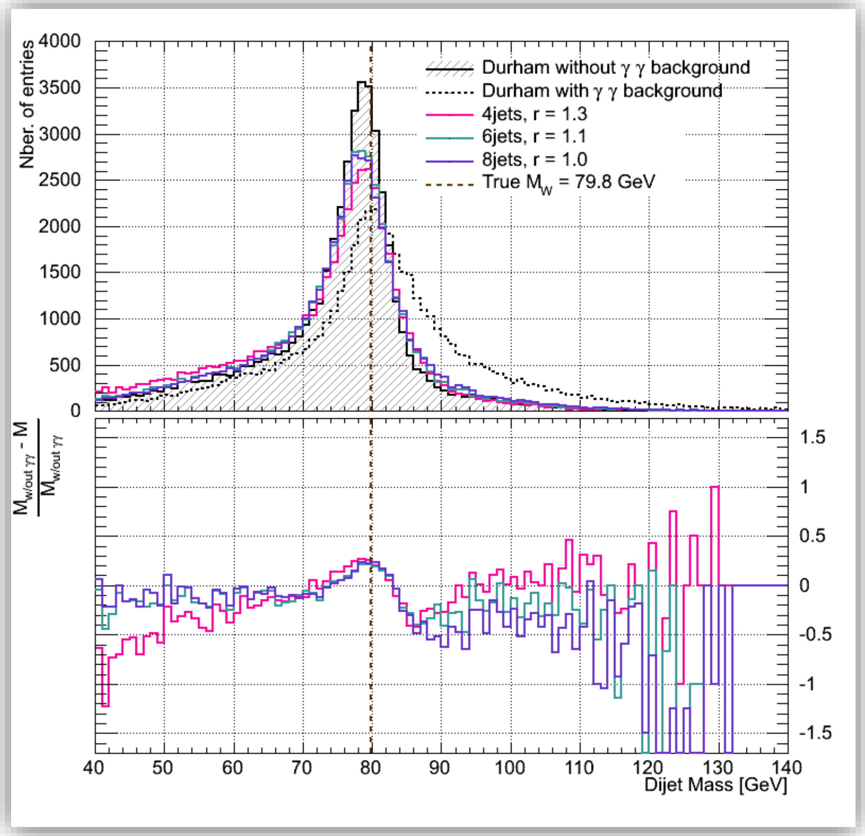
- Tested configurations:

Jets #	4 jets	6 jets	8 jets
	1.1	0.9	0.8
R value	**1.3**	**1.1**	**1.0**
	1.5	1.3	1.2

- Find the configuration most similar to the Durham distribution → χ^2 test :

Jets #	R val.	χ^2/ndf W	χ^2/ndf Z
4 jets	1.3	13.4	11.6
6 jets	**1.1**	**6.9**	**4.7**
8 jets	1.0	9.3	6.8

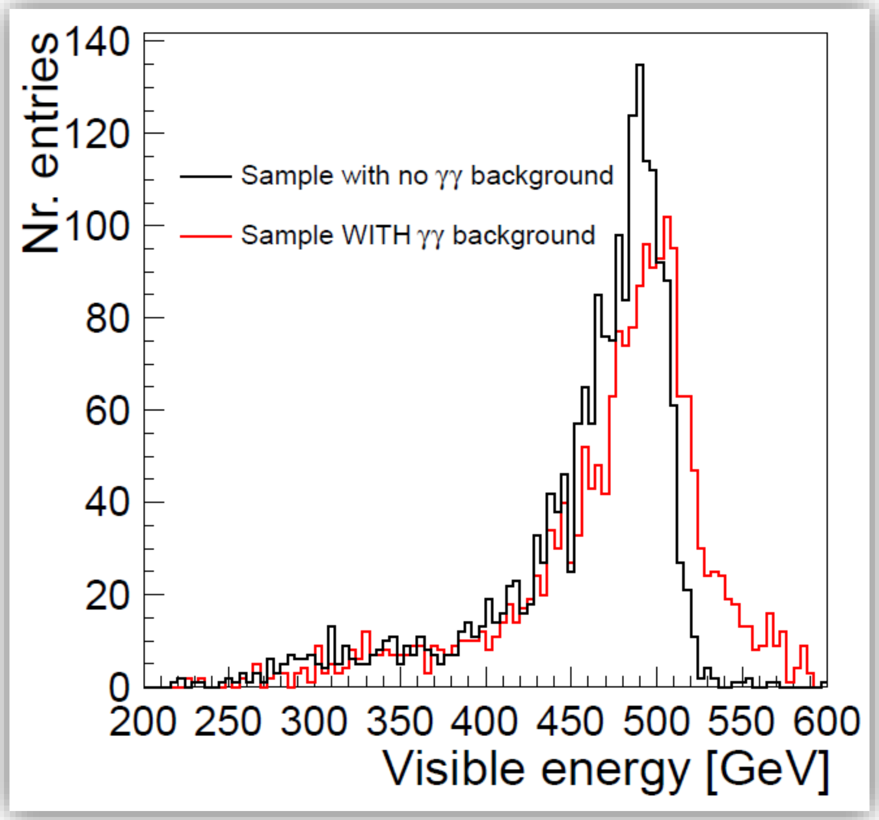
Used: **exclusive longitudinal k_T algorithm**

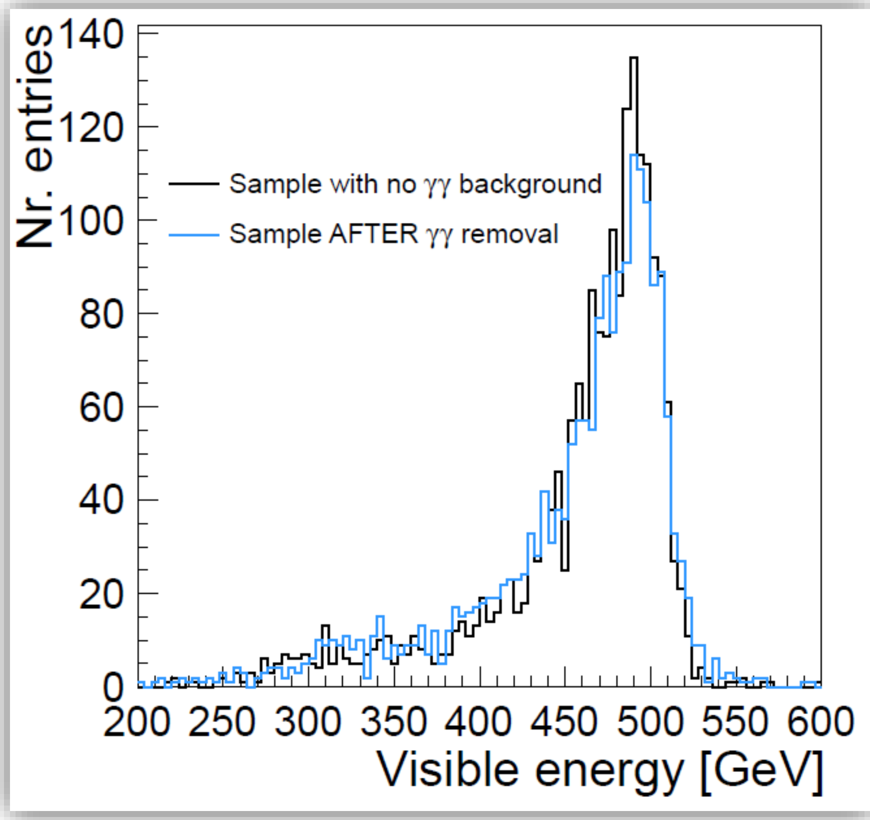


- **The 6 jets configuration with an R-value of 1.1 is best for γγ background removal !**

Removing the γγ Background III

- Checking the γγ background removal for the chosen configuration:





- After running the longitudinal exclusive k_T algorithm the visible energy is very similar to the no background case.

Analysis Strategy

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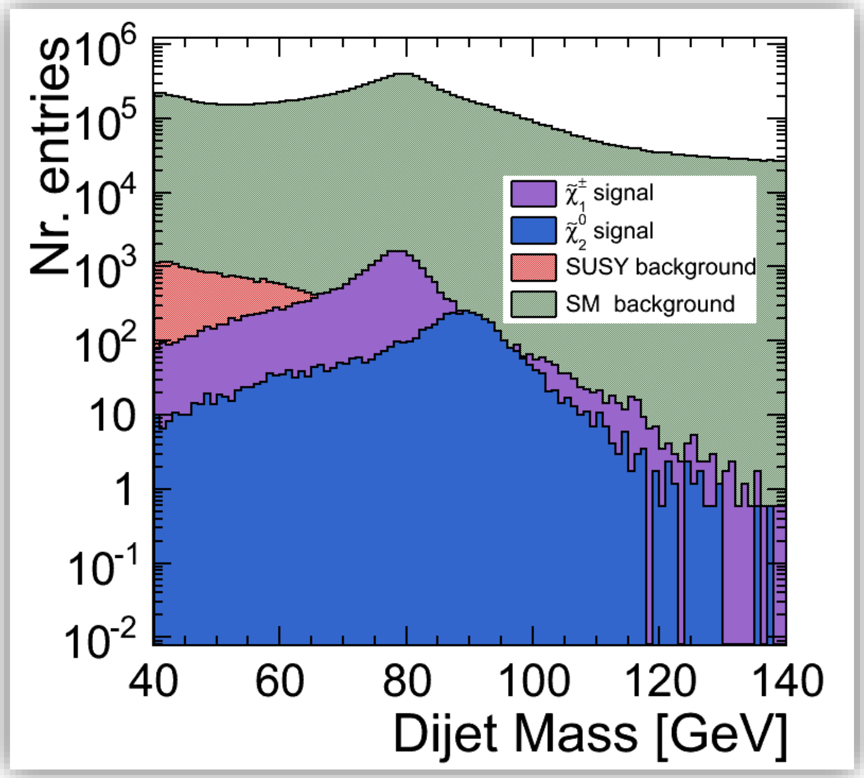
- Separate $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ samples
- Perform mass measurement

common to both LOI and DBD (Cluster event into 4 jets, Run kinematic fit, Perform SUSY preselection, Separate samples, Perform mass measurement)

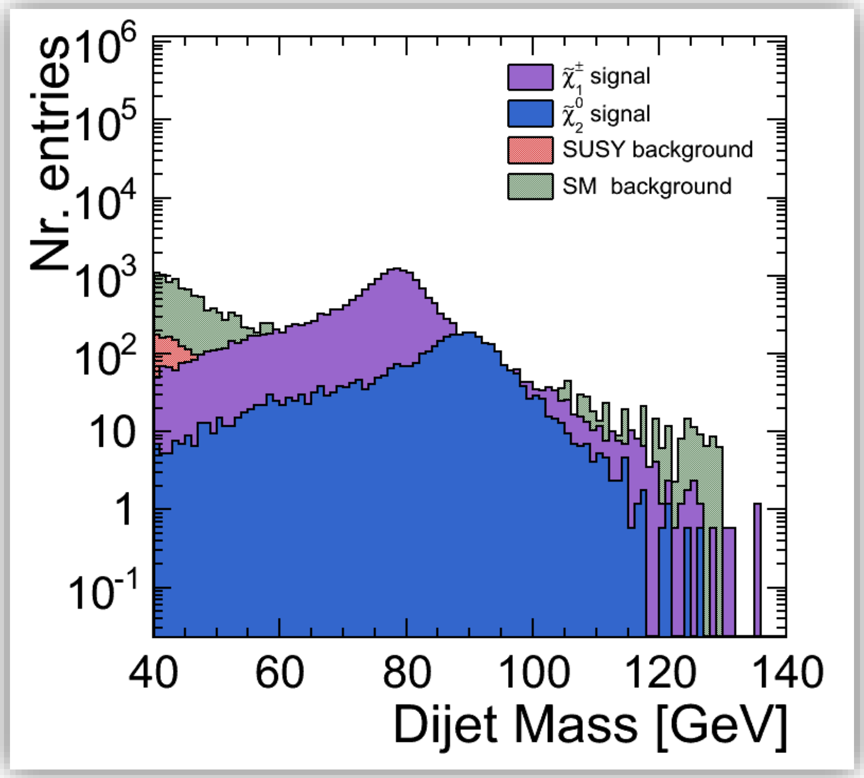
Preselection Outcome

Example: the DBD sample [LOI sample very similar]

Before preselection



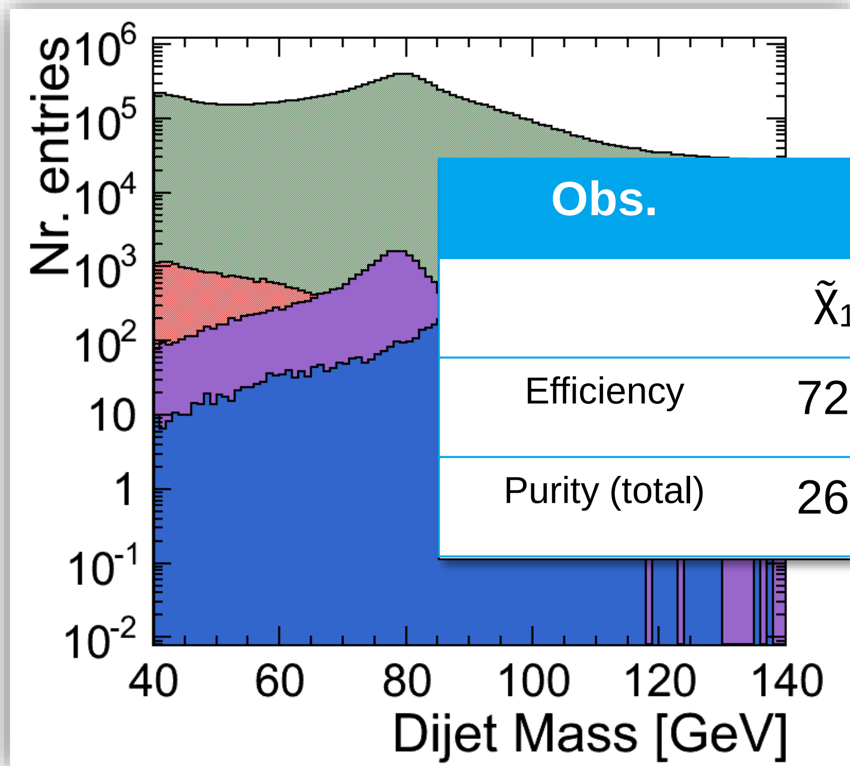
After preselection



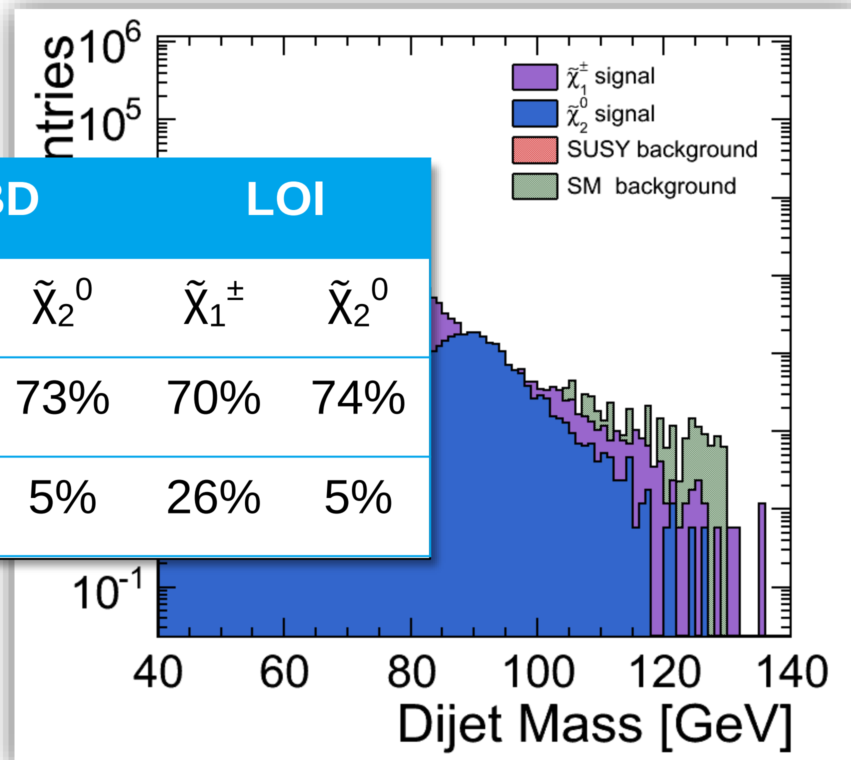
Preselection Outcome

Example: the DBD sample [LOI sample very similar]

Before preselection



After preselection



Obs.	DBD		LOI	
	$\tilde{\chi}_1^{\pm}$	$\tilde{\chi}_2^0$	$\tilde{\chi}_1^{\pm}$	$\tilde{\chi}_2^0$
Efficiency	72%	73%	70%	74%
Purity (total)	26%	5%	26%	5%

DESY

Analysis Strategy

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- Perform mass measurement

common to both LOI and DBD

$\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ Signal Sample Further Separation

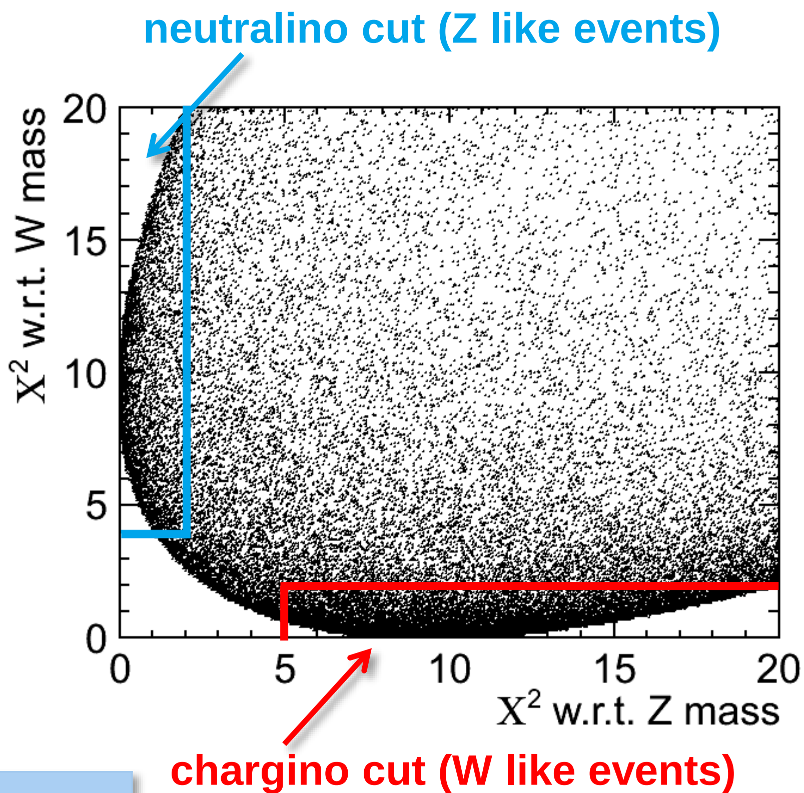
- Calculate χ^2 with respect to nominal W / Z mass

$$\chi^2(m_{j1}, m_{j2}) = \frac{(m_{j1} - m_V)^2 + (m_{j2} - m_V)^2}{\sigma^2}$$

⇩

min $\chi^2 \rightarrow \tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ separation

- Downside: lose statistics
  - Cut away 43% of $\tilde{\chi}_1^\pm$ surviving events
  - Cut away 68% of $\tilde{\chi}_2^0$ surviving events
- However, after the χ^2 cut, the separation is quite clear:



Obs.	DBD		LOI	
	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^0$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^0$
Efficiency	53%	30%	56%	34%
Purity (total)	63%	38%	62%	35%
Purity (SUSY)	94%	62%	95%	66%

$\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ Mass Measurement

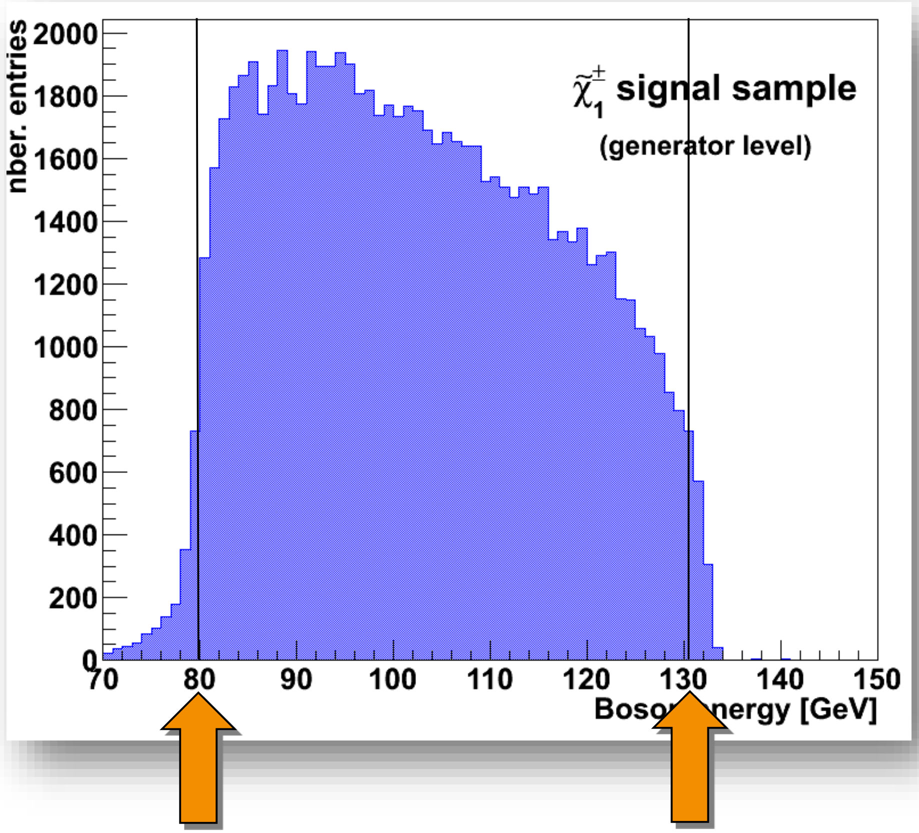
- Mass difference to LSP ($\tilde{\chi}_1^0$) is **larger** than M_Z
- Observe the decays of real gauge bosons
- 2 body decay → the edges of the energy spectrum are kinematically determined
- **Use dijet energy spectrum „end points“ in order to calculate masses**

$$\gamma = \frac{E_{beam}}{M_{\chi}}$$

$$E_{\pm} = \gamma \cdot EV^{*} \pm \gamma \cdot \beta \cdot \sqrt{E_V^{*2} - M_V^{2}}$$

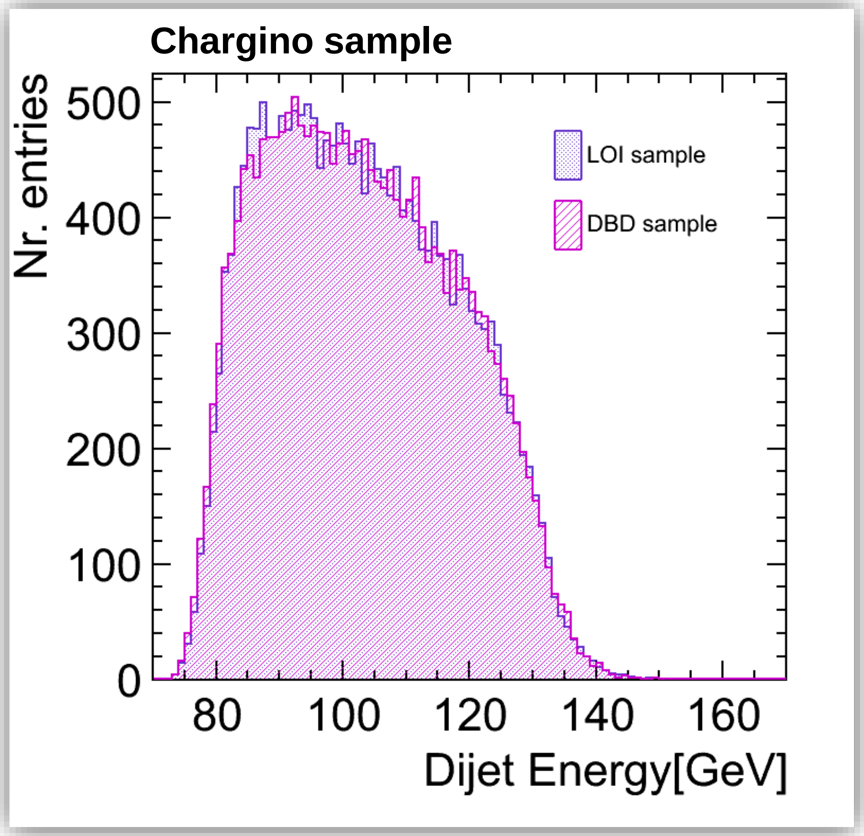
Real edge values [GeV]:

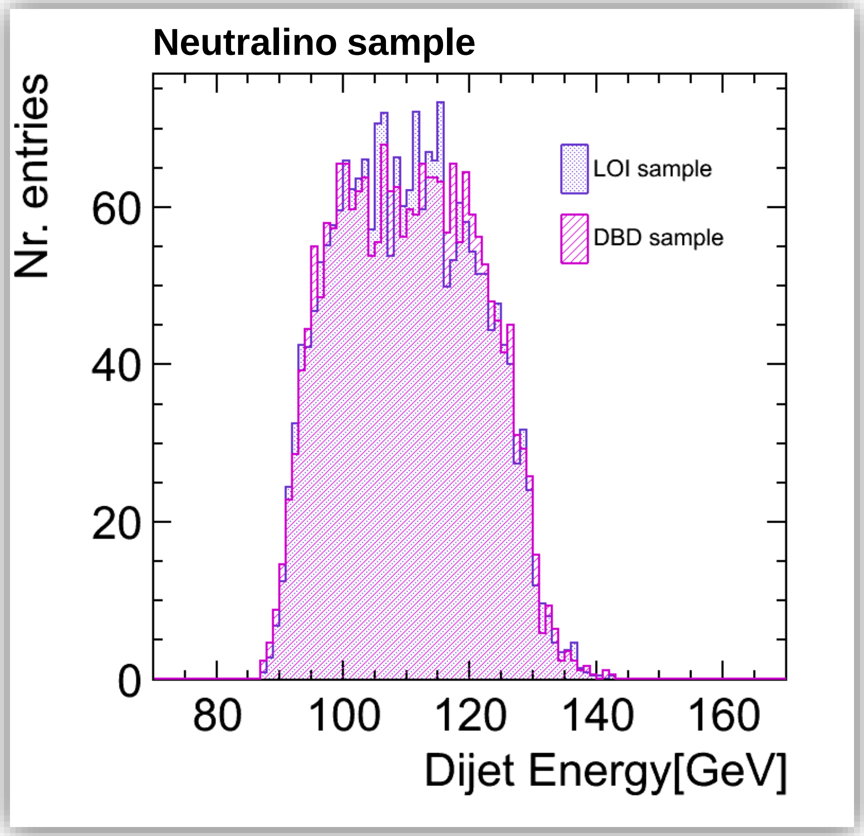
W_{low}	W_{high}	Z_{low}	Z_{high}
80.17	131.53	93.24	129.06



Dijet [Boson] Energy Comparison LOI - DBD

> Use dijet energy to measure $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ mass



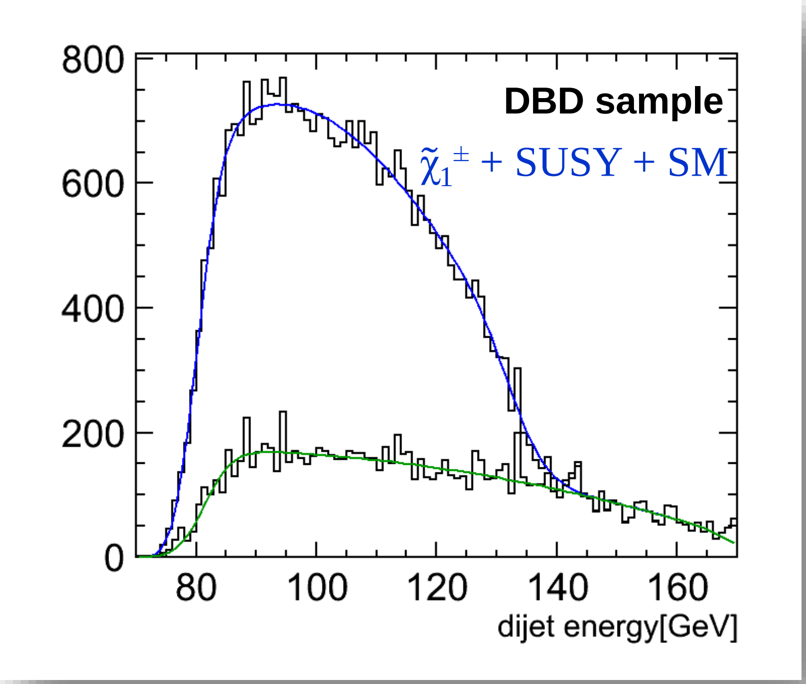


> The DBD distribution appears slightly shifted towards lower energies. Nevertheless, the two distributions agree very well.

$\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ Mass Measurement – "Endpoint" Method

> Fit dijet energy spectrum and obtain edge positions:

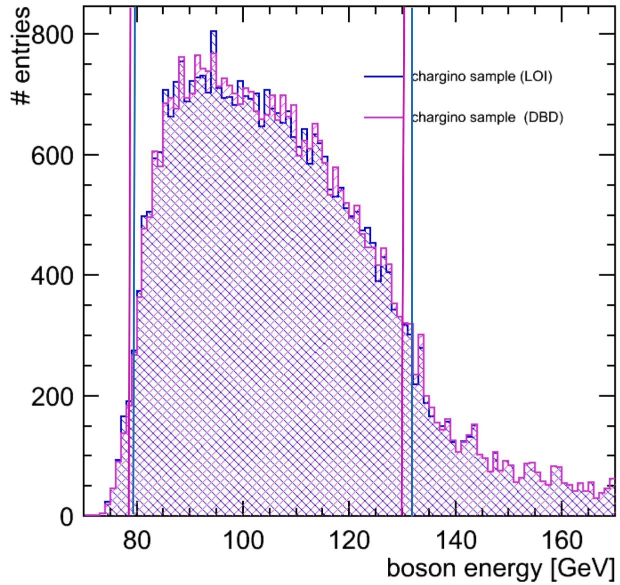
$$f(x; t_{0\_1}, b_{0\_2}, \sigma_{1\_2}, \gamma) = f_{SM} + \int_{t_0}^{t_1} (b_2 t^2 + b_1 t + b_0) V(x - t, \sigma(t), \gamma) dt$$

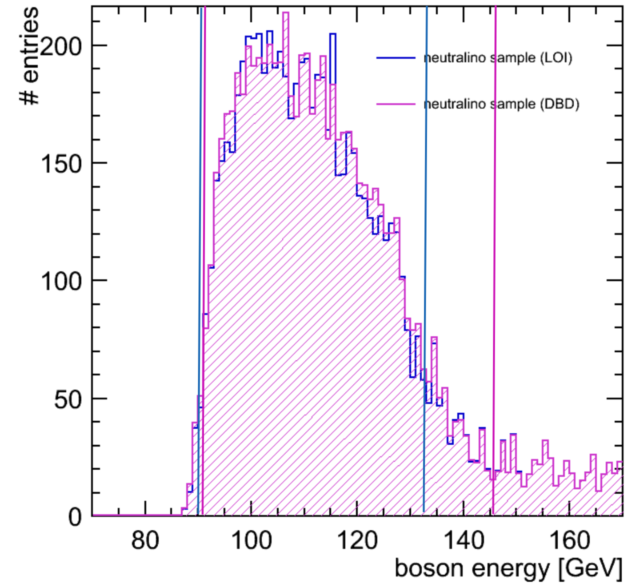


Where:

- The polynomial accounts for the slope of the initial spectrum
- The Voigt function accounts for the detector resolution and gauge boson width

Issues of the “Endpoint Method“





Sim.	Edge W_{low} [GeV]	Edge W_{high} [GeV]	Edge Z_{low} [GeV]	Edge Z_{high}[GeV]
DBD	79.5±0.5	130.2±1.1	91.3±0.6	146.1±4.8
LOI	79.7±0.3	131.9±0.9	91.0±0.7	133.6±0.5

The fitting method appears to be highly dependent on small changes in the fitted distribution → it is NOT appropriate for comparing the two samples.

We need to apply a different edge extraction method!

Endpoint Extraction using an FIR Filter

- Finite Impulse Response (FIR) filters are digital filters used in signal processing.
- FIR filters can operate both on discrete as well as continuous values.
- The concept of “finite impulse response“ ↔ **the filter output** is computed as a finite, weighted sum of a finite number of values from the filter input.

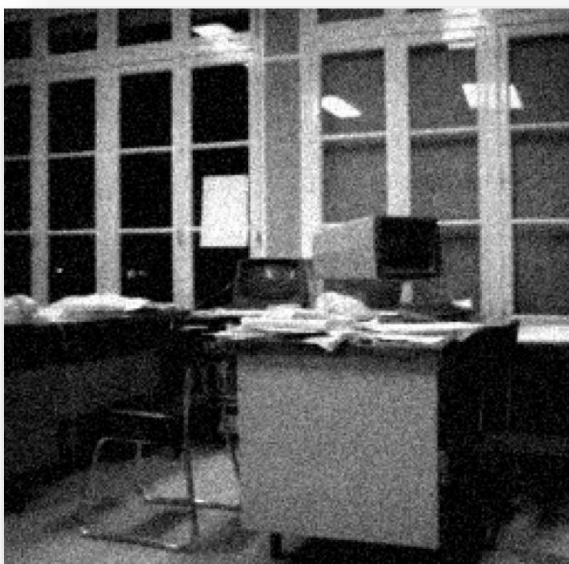
$$y[n] = \sum_{k=-M_1}^{M_2} b_k x[n-k]$$

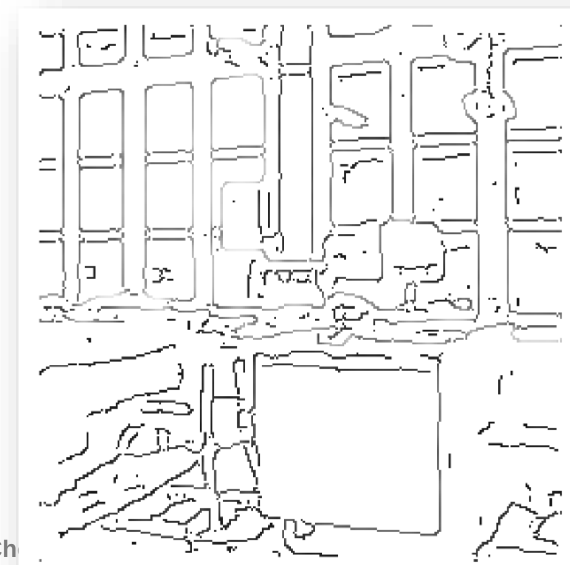
the input signal

the filter coefficients (weights)

- y is obtained by convolving the input signal with the (finite) weights
- FIR filters are used to detect edges in image processing techniques:

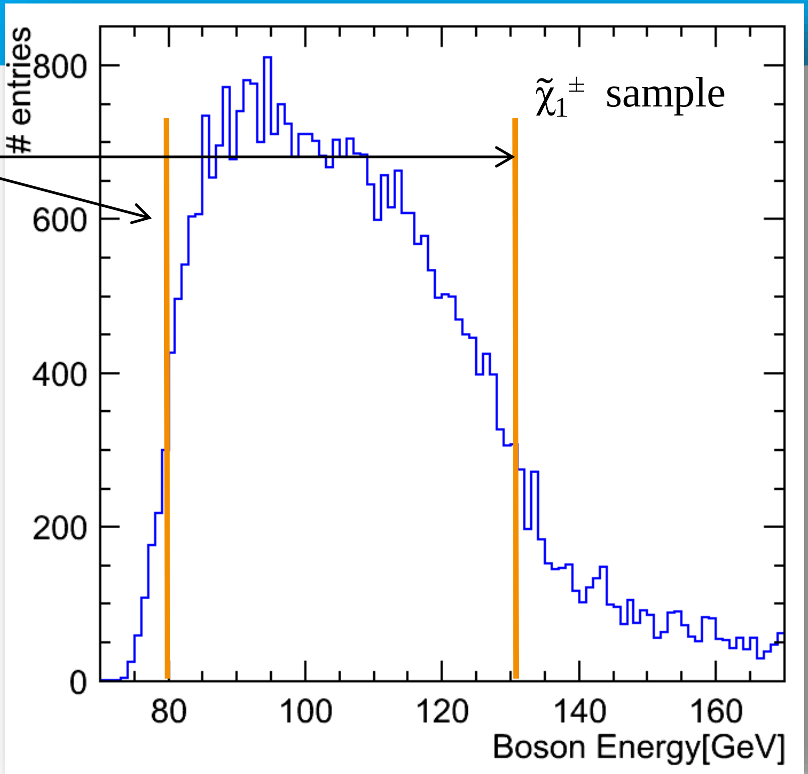
D. Demigny, T. Kamlé





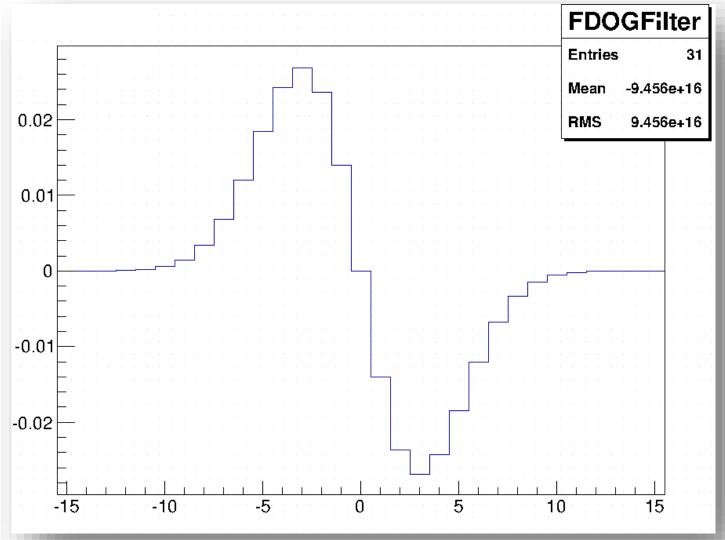
Applying an FIR Filter

- Goal: find edge positions in spectrum



Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter
  - Note: **filter length << signal histogram length**

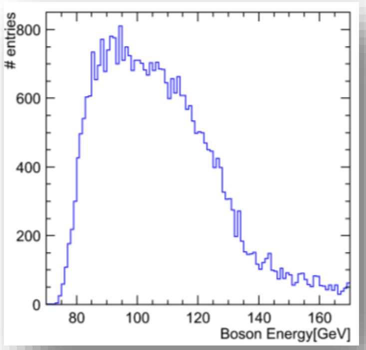


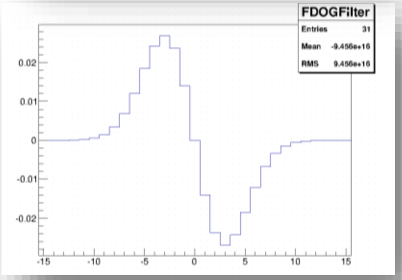
Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter
  - Note: filter length << signal histogram length
  - Treat both signal histogram as well as filter as **arrays**:

Bin #	1	2	3	...	98	99	100
Signal	0	15	28	...	34	22	4

Bin #	1	2	3	...	28	29	30
Filter	0	0.01	0.02	...	-0.02	-0.01	0





DESY

Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter
  - Note: filter length << signal histogram length
  - Treat both signal histogram as well as filter as **arrays**
  - Calculate dot product between **Signal** and **Filter → obtain one value**

Bin #	1	2	3	...	98	99	100
Signal	0	15	28	...	34	22	4

Bin #	1	2	3	...	28	29	30
Filter	0	0.01	0.02	...	-0.02	-0.01	0

$$0 \times 0 + 0.01 \times 15 + 0.02 \times 28 + \ldots = \mathrm{val1}$$

Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter
  - Note: filter length << signal histogram length
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Bin #	1	2	3	...	98	99	100
Signal	0	15	28	...	34	22	4

Bin #	1	2	3	...	28	29	30
Filter	0	0.01	0.02	...	-0.02	-0.01	0

$$0 \times 15 + 0.01 \times 28 + \ldots = \mathrm{val2}$$

  - **“Move“ Filter along the (length) of the signal → obtain more values, which will form the total filter response**

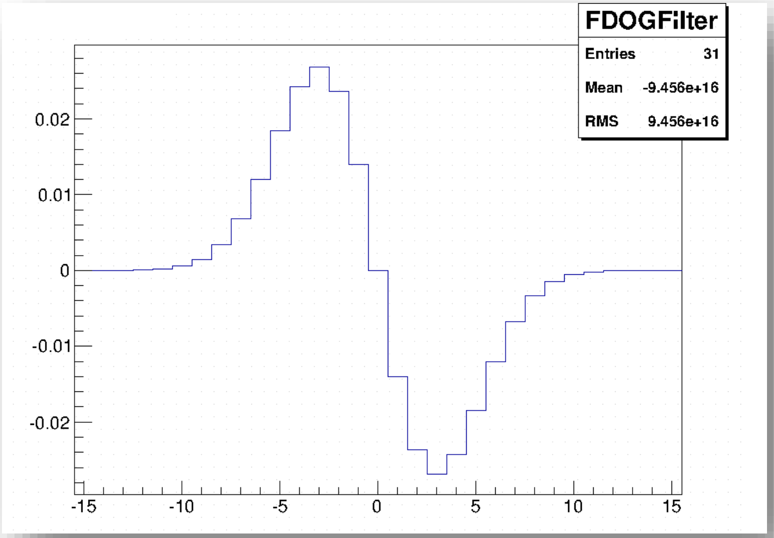
Choosing the Appropriate Filter

- In order to choose an apropriate filter one can apply the following criteria:

  Canny's criteria: [J. F. Canny. **A computational approach to edge detection.** *IEEE Trans. Pattern Analysis and Machine Intelligence*, pages 679-698, 1986]

  - Good detection: probability of obtaining a peak in the response must be high
  - Localisation: standard deviation of the peak position must be small
  - Multiple response minimisation: probability of false postive detection must be small

- Canny has suggested that an optimal filter is very similar to the first derivative of a Gaussian

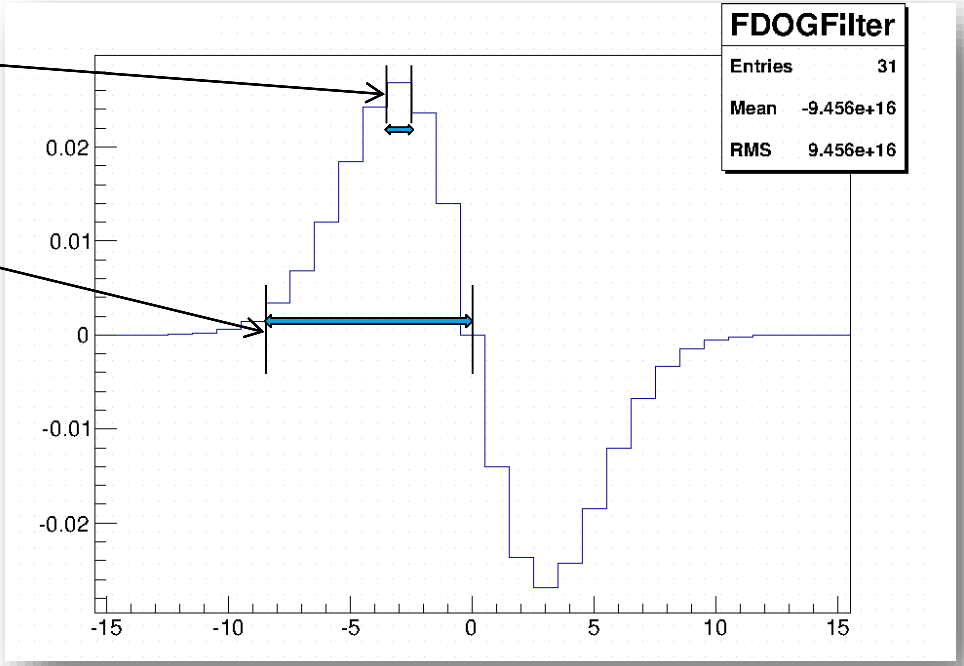


Optimising the FDOG Filter

> There are two important filter characteristics that must be optimised:

the bin size

the filter size



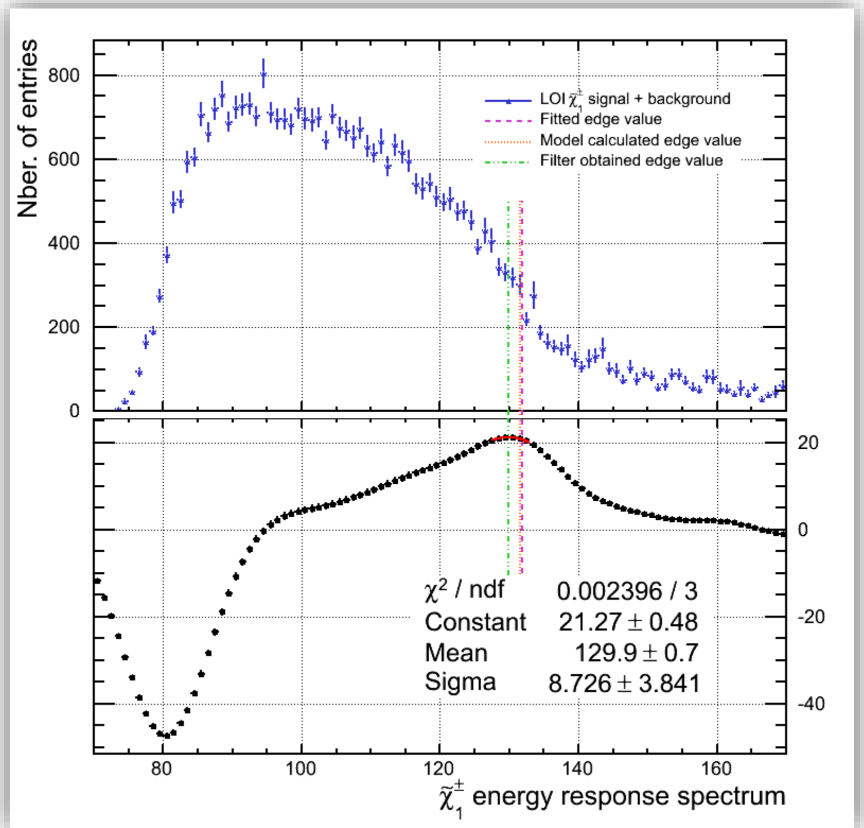
It is crucial to strike the right balance between the two:

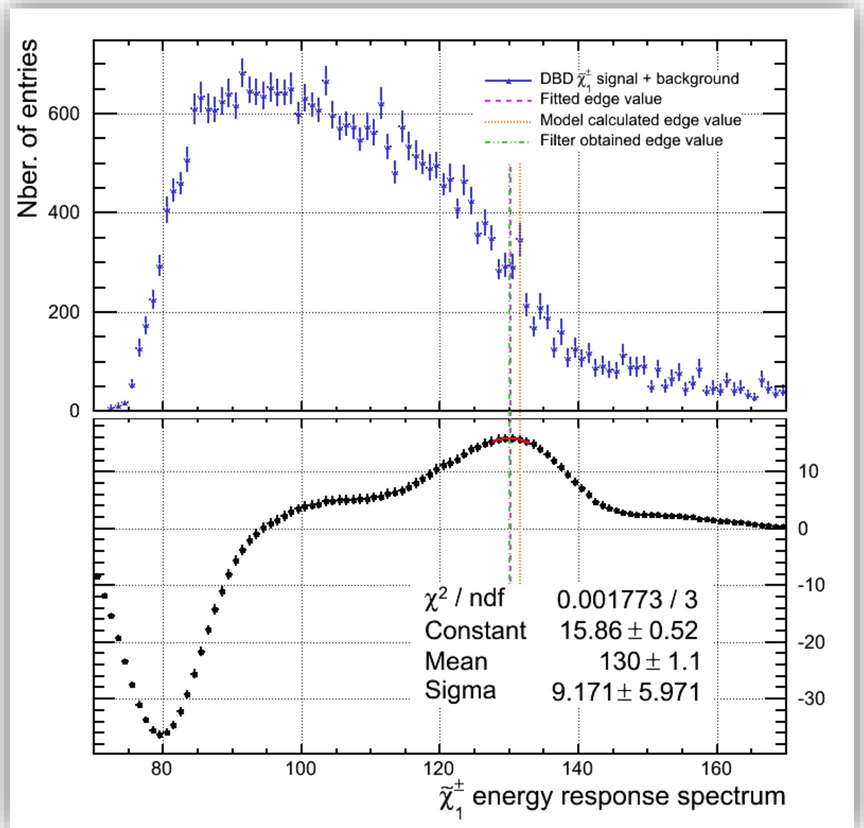
- If the bin size is too small → the filter picks up a lot of statistical fluctuations
- If the filter size is too large → the edge position cannot be localised anymore

A toy MC study has been performed to optimise the filter and bin size.

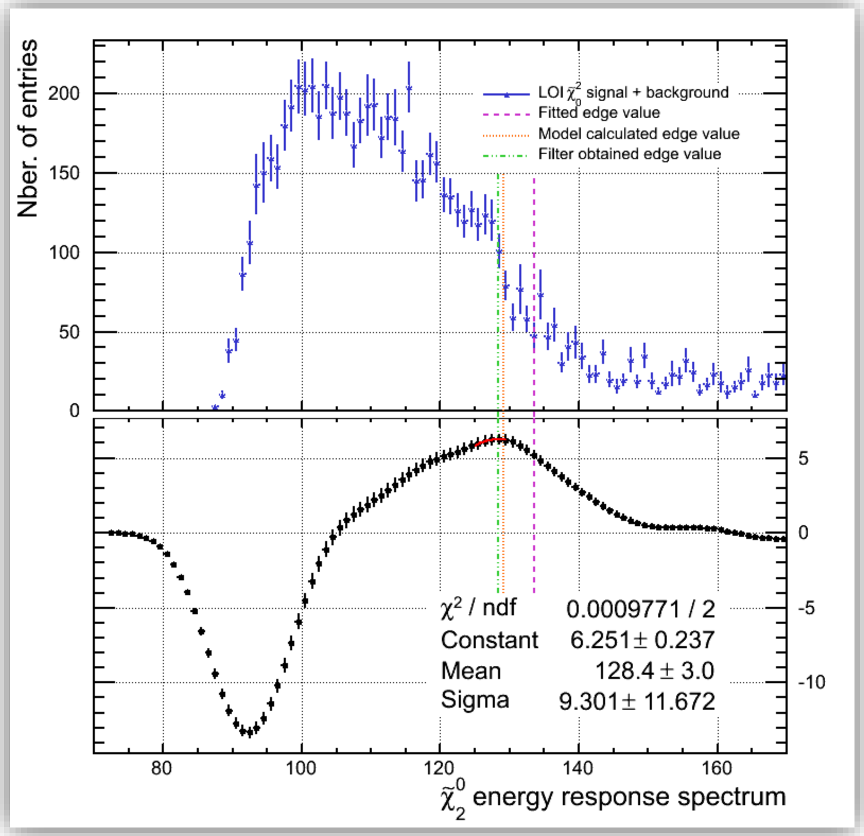
Chosen values: bin size = 1 GeV/Bin; filter size = 5 x 2 bins.

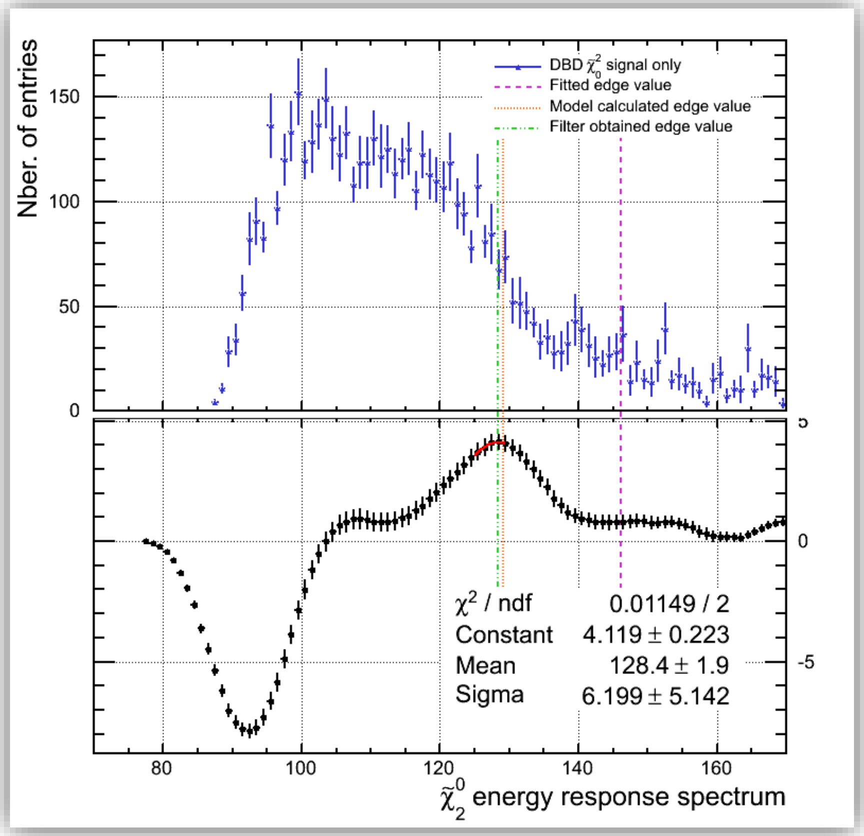
FIR Edge Extraction Comparison – LOI to DBD





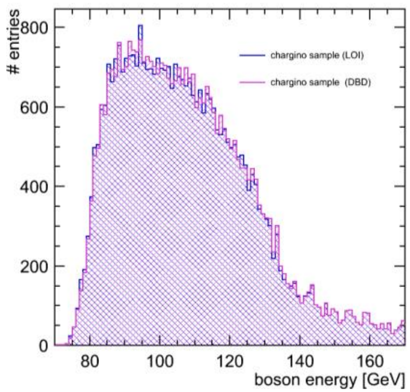
FIR Edge Extraction Comparison – LOI to DBD

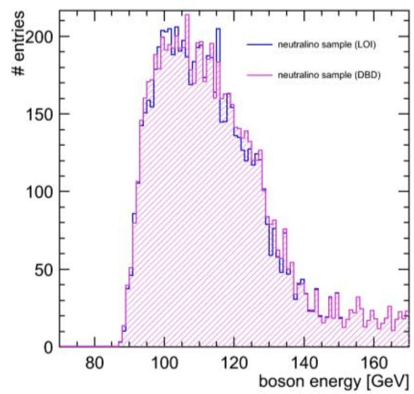




- On the chargino samples the filter appears to perform slightly worse than the fit in the LOI sample and just as well in the DBD case.
- However the filter performs considerably better in the case of the neutralino samples both for the LOI and the DBD case.

Edge Extraction Comparison





	True	80.17	131.53	93.24	129.06
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	LOI	79.7±0.3	131.9±0.9	91.0±0.7	133.6±0.5
	DBD	79.5±0.5	130.2±1.1	91.3±0.6	146.1±4.8
filter	LOI	80.4±0.2	129.9±0.7	92.3±0.4	128.3±0.9
filter	DBD	79.8±0.3	129.9±1.0	92.2±0.4	128.3±0.6

The filter extraction method is preferable:

- it is more stable
- provides smaller uncertainties in determining the edge position.

Edge Extraction Comparison

filter

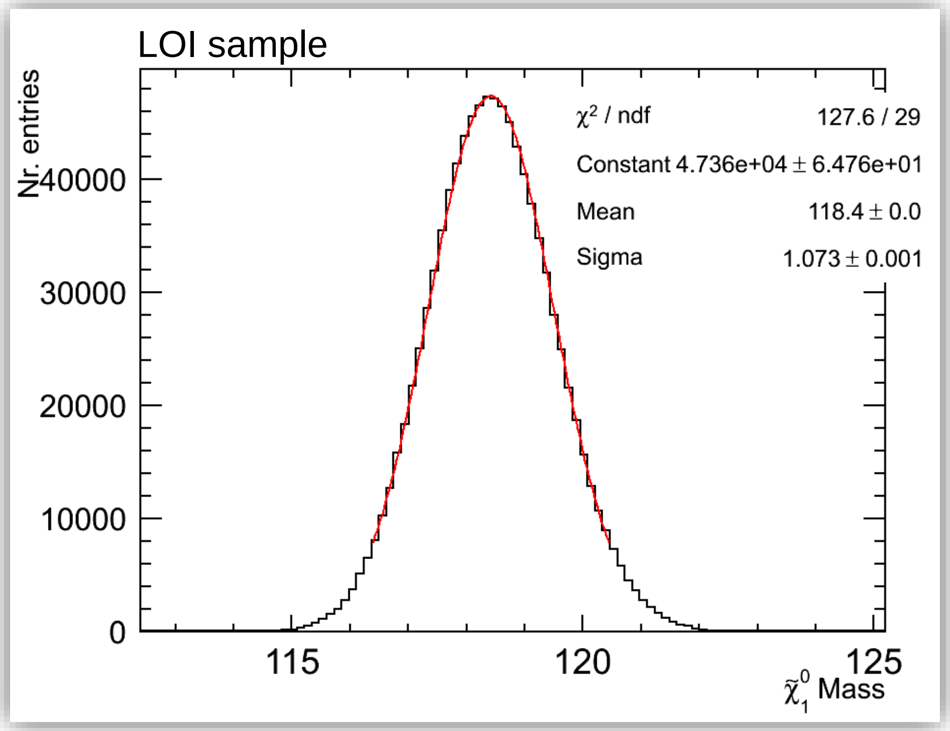
True	80.17	131.53	93.24	129.06
Sim.	Edge W_{low} [GeV]	Edge W_{high} [GeV]	Edge Z_{low} [GeV]	Edge Z_{high} [GeV]
LOI	80.4±0.2	129.9±0.7	92.3±0.4	128.3±0.9
DBD	79.8±0.3	129.9±1.0	92.2±0.4	128.3±0.6

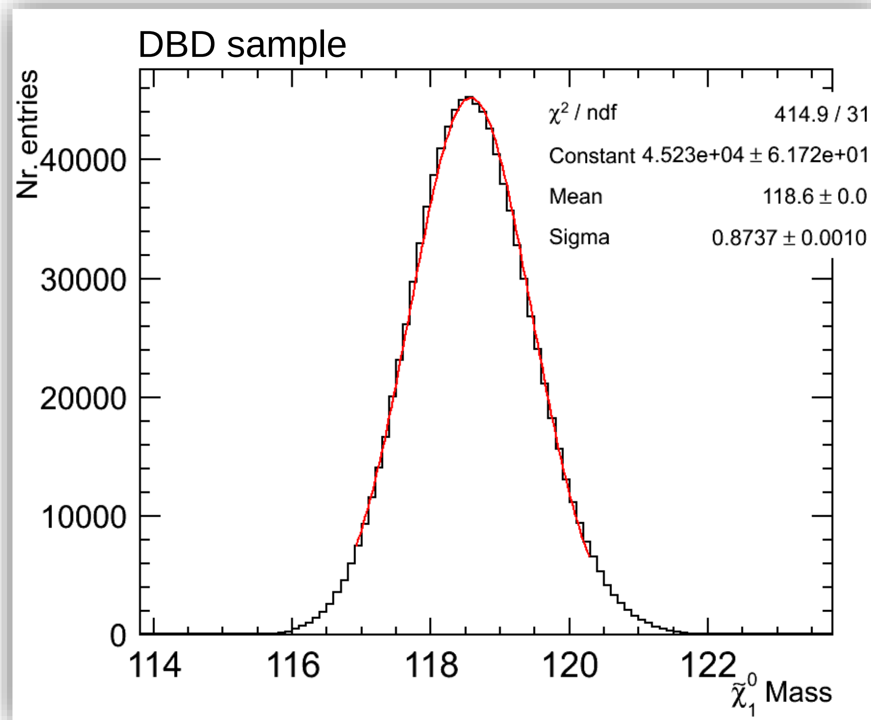
Sample	Mass $\tilde{\chi}_1^{\pm}$ [GeV]	Mass $\tilde{\chi}_2^{0}$ [GeV]	Mass $\tilde{\chi}_1^{0}$ [GeV]
TRUE	216.5	216.7	115.7
LOI	216.9±3.2	220.0±1.4	118.4±1.1
DBD	217.3±3.2	220.4±1.5	118.5±0.9

- The filter method is much more stable in determining the edge position
- The mass values extracted from the LOI and DBD samples are compatibile within their statistical errors
- The systematic errors will be addressed by a mass calibration study [ongoing]

Toy MC for the Mass Calculation

- To estimate the statistical precision of the mass measurement → toy MC
- Input: edge values + their fluctuations as obtained from the filter
- 1 000 000 values were generated within the edge fluctuations
- The mass calculations have been performed with the generated values 1 000 000 times





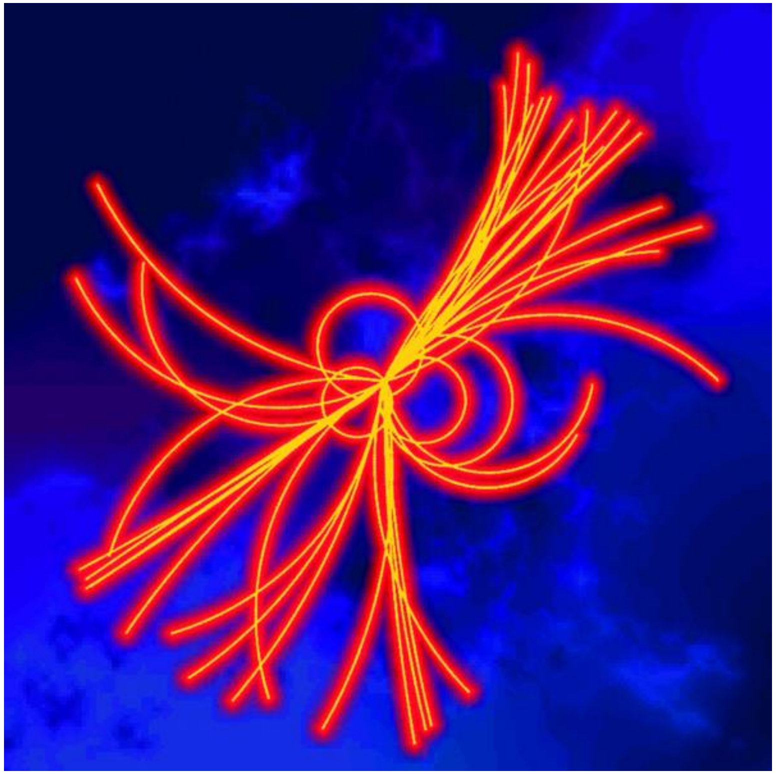
Conclusions

- A comparison between the LOI and DBD detectors has been made with "Point5":
  - The fitting method for the mass determination appears very sensitive to small changes. A more robust method is needed.
  - Applying a finite impulse response (FIR) filter in order to extract the edge information instead of the fitting method is:
    - More robust (i.e. independent on distribution shape)
    - Provides just as good if not better statistical precision
  - The $\gamma\gamma$ background in the DBD sample successfully removed

> Outlook:

- Perform mass calibration (to determine systematics).
- Perform 2D fit on dijet masses to improve the x-section measurement
- Perform full comparison LOI – DBD – SGV.

Thank You!



Preselection

- Apply the following cuts to both samples:

LOI & DBD common:

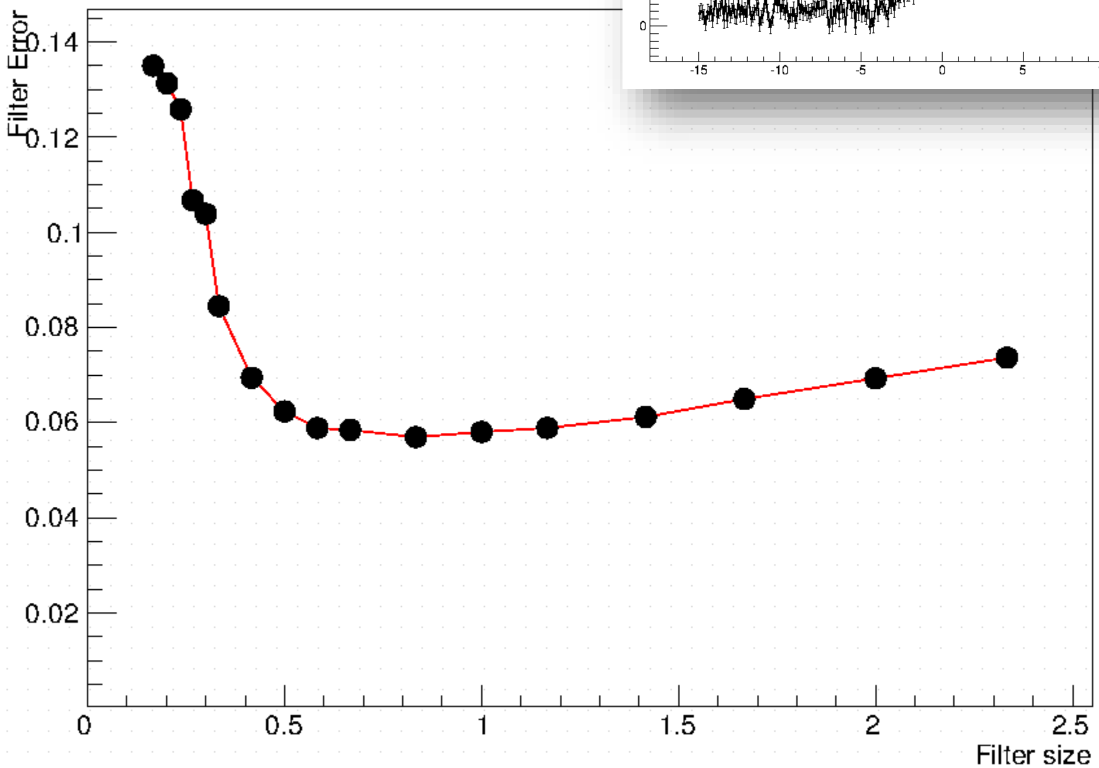
1. Number tracks in event > 20
2. 100 GeV < $E_{visible}$ < 300 GeV
3. E_{jet} > 5 GeV
4. $|\cos(\theta_{jets})| < 0.9$
5. $Y_{34} > 0.001$
6. Number tracks per jet > 2
7. $|\cos(\theta_{miss})| < 0.99$
8. E_{lepton} < 25 GeV
9. Number of PFOs per jet > 3
10. $|\cos(\theta_{miss})| < 0.8$
11. Mmiss > 220 GeV
12. Kinematic fit converged

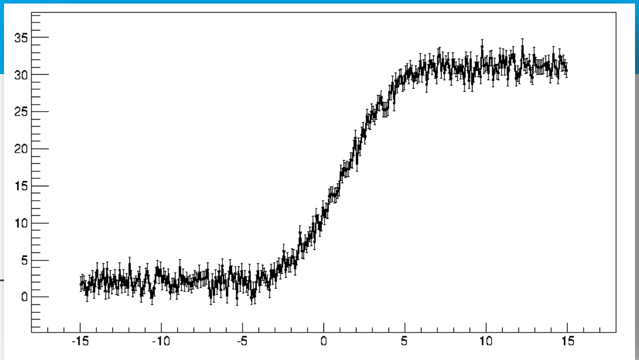
DBD:

13. No isolated lepton
14. 30 < Number PFOs in event < 150
15. 4 < Nr. Tracks with P_T > 1GeV < 50
16. Thrust < 0.98

Optimising the FDOG Filter

Studied the effect of the filter size on a smeared step edge Monte Carlo data.

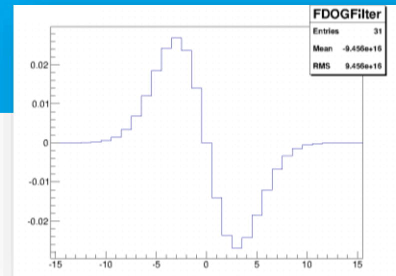


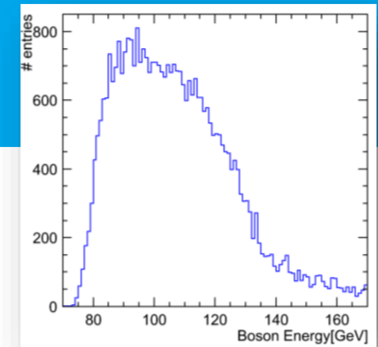


S. Caiazza

The FDOG filter does indeed perform best.
The filter size should be comparable to the size of the edge feature.
We chose $\sigma = 5$ bins.

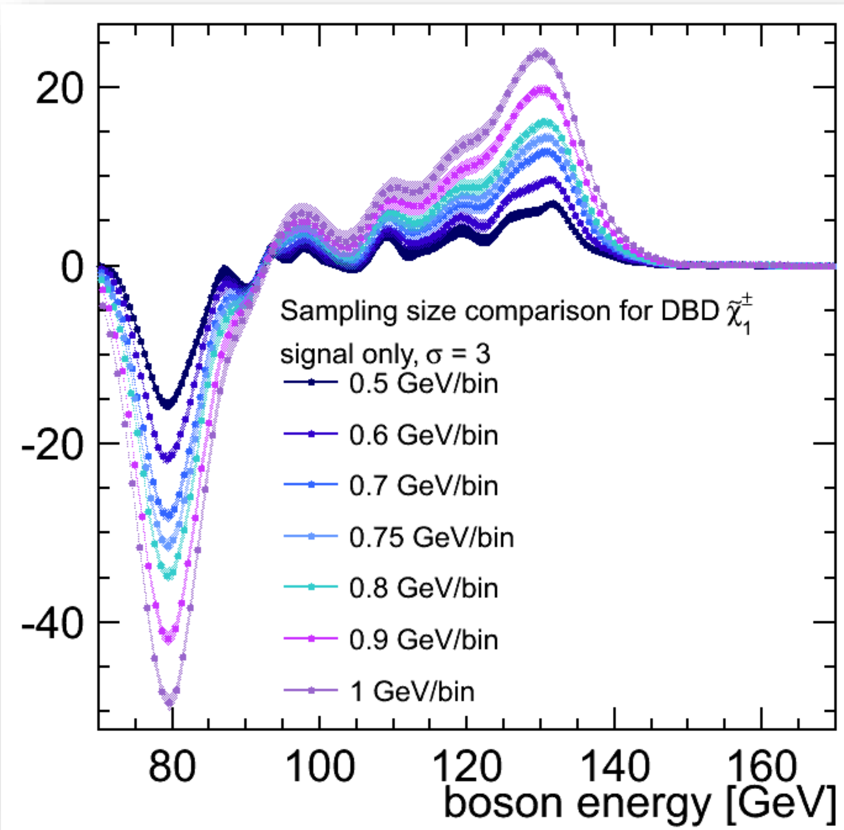
Optimising the FDOG Filter

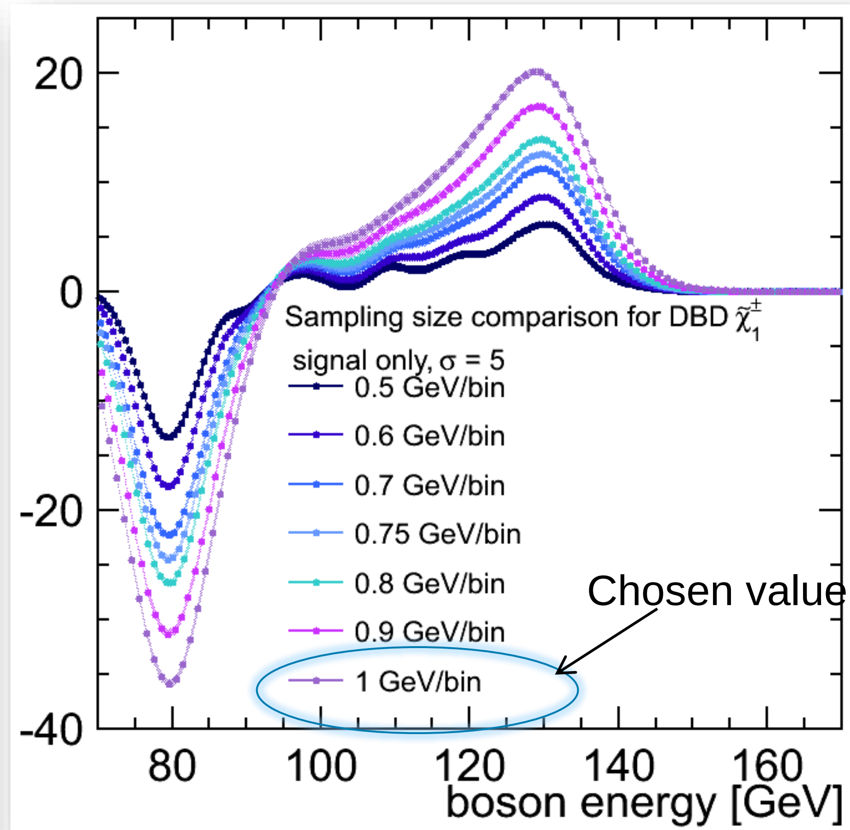




- There are two important filter characteristics that must be optimised: the bin size and the filter size.

Filter response after applying the FDOG Filter to the $\tilde{\chi}_1^{\pm}$ energy distribution:





Back up slides

Removing the $\gamma\gamma$ Background

- Use the **longitudinal exclusive k_T** jet clustering algorithm:
- It calculates:
  - The "distance" between each pair of reconstructed particles:

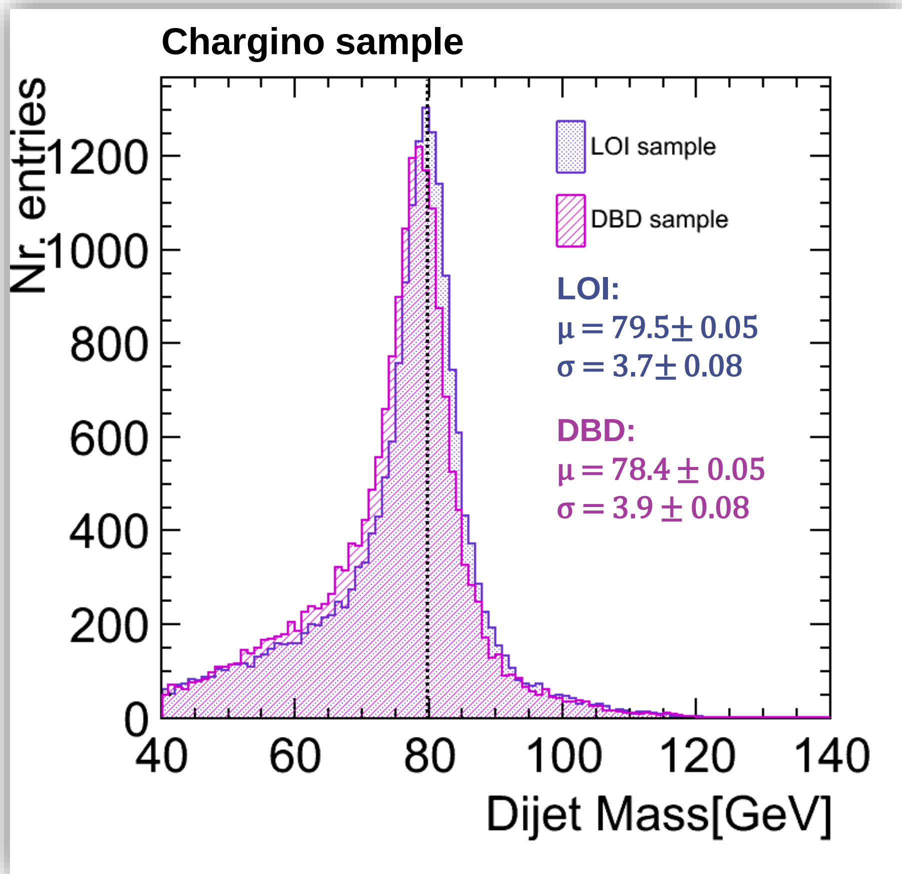
$$dist_{ij} = \frac{\min\left(p_{Ti}^2, p_{Tj}^2\right) \cdot \Delta \boldsymbol{R}_{ij}{}^2}{\boldsymbol{R}^2}$$

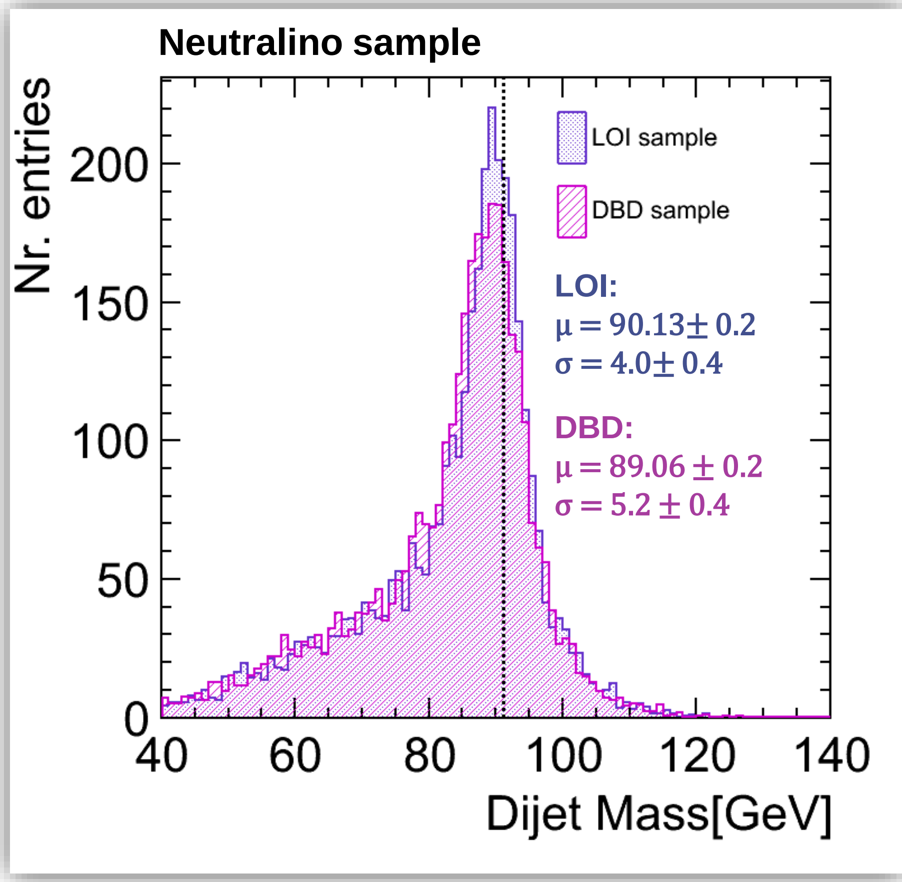
  - The distance between each reconstructed particle and the beam ($dist_{ij}^{Beam}$)
  - If the $dist_{ij}^{Beam}$ is minimum then the particle is discarded
- The number of required jets as well as the R parameter are free parameters.
- In order to increase performance:

optimise the number of requested jets and the R-value!

Dijet [Boson] Mass Comparison – LOI to DBD

> Use dijet mass to separate $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ events → measure cross section





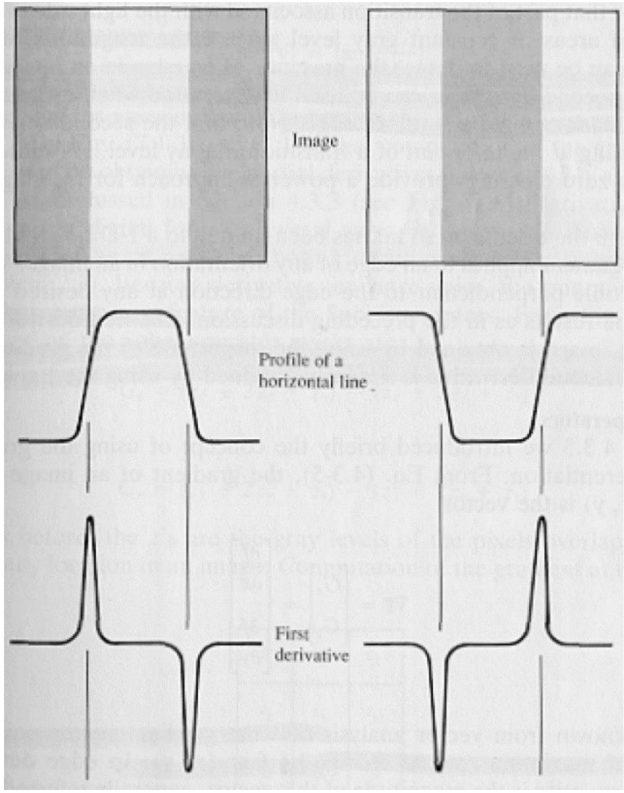
> The DBD distribution appears slightly narrower and shifted towards lower energy, however the DBD and LOI distributions are compatible with each other.

Applying an FIR Filter – Example: the box function

- The changes of a function can be described by the derivative → interpret the histogram as a 1D function
- The points that lie on the edge of the distribution → detected by local maxima and minima of the first derivative

$$f'(x) = \lim_{h \to 0} \frac{f(x+h) - f(x)}{h} \approx f(x+1) - f(x) \quad (h = 1)$$

- The first derivative is approximated by using the **kernel [-1, 0, 1]**



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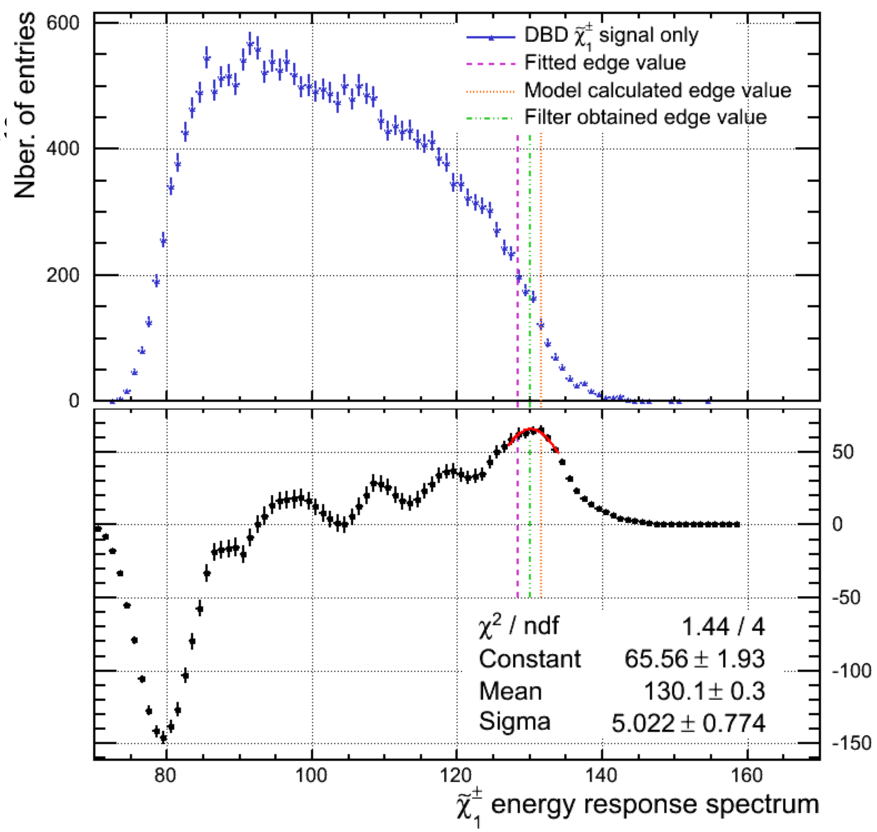
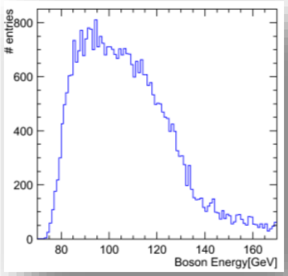
- The first derivative is approximated by using the **kernel [-1, 0, 1]**
- The kernel is convoluted with the histogram:

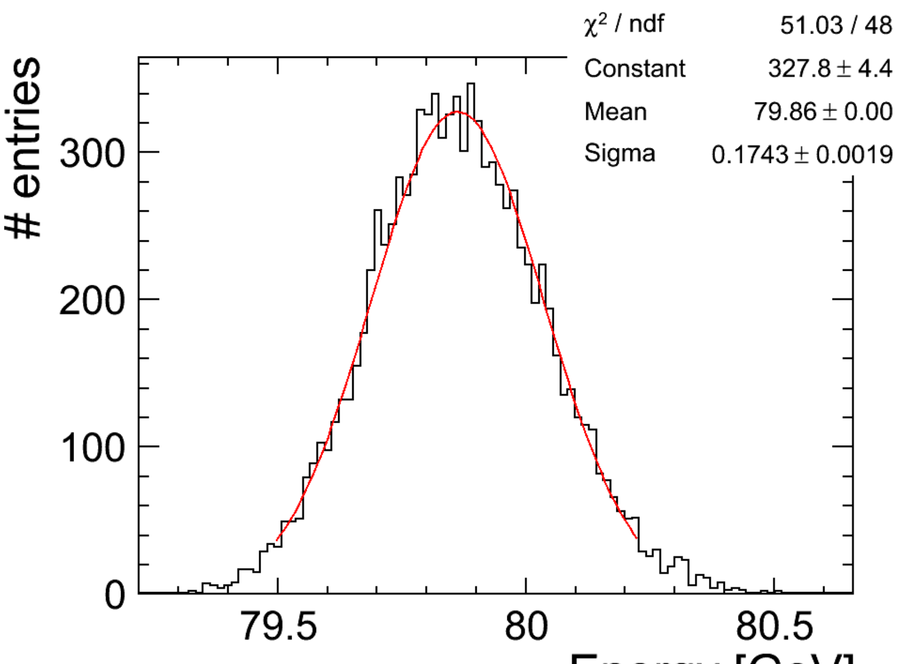
$$response_i = -1 \times bin_{i-1} + 0 \times bin_i + 1 \times bin_{i+1}$$



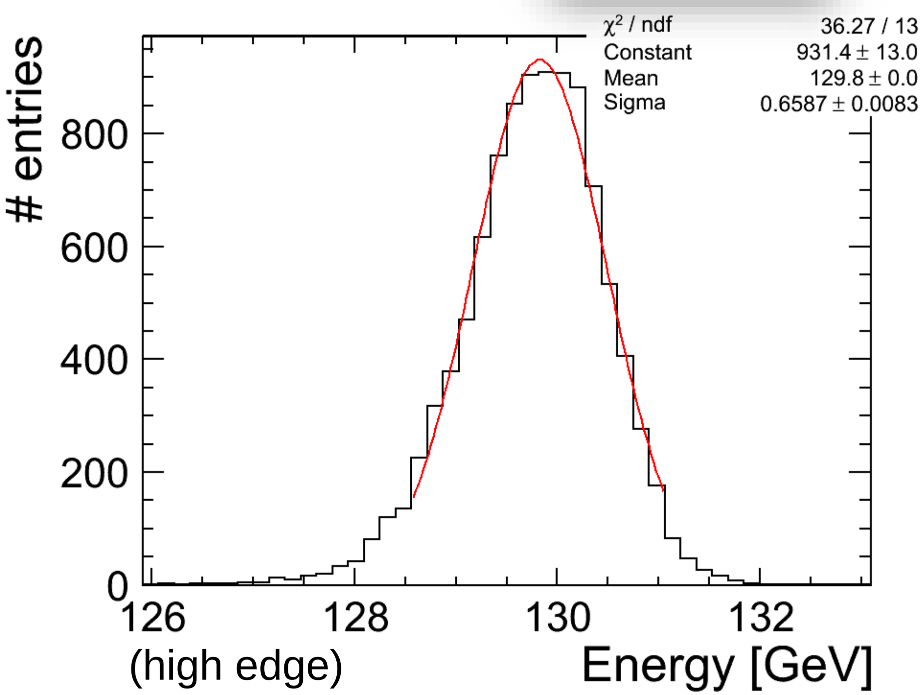
Toy MC for the Filter Edge Extraction

- To estimate the statistical precision of the edge extraction → toy MC
- 10000 $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ energy spectra have been produced
- The FDOG filter was then applied 10000 times
- Example: for the $\tilde{\chi}_1^{\pm}$ case:





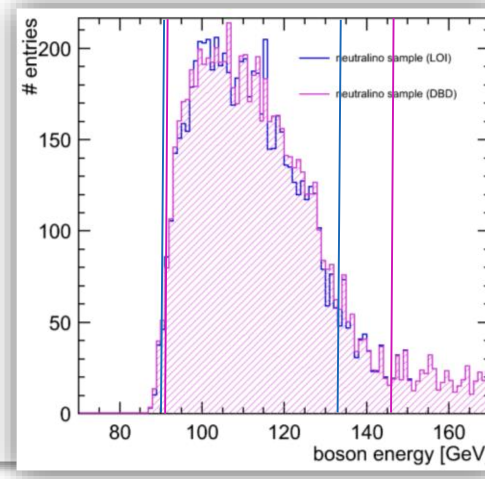
(low edge)



(high edge)

Issues of the „Endpoint Method“

```
FCN=59.9958 FROM MIGRAD    STATUS=CONVERGED     813 CALLS       815 TOTAL
                     EDM=2.74963e-05    STRATEGY= 1  ERROR MATRIX UNCERTAINTY   1.5 per cent
 EXT PARAMETER                  PARABOLIC        MINOS ERRORS
NO.   NAME      VALUE            ERROR      NEGATIVE      POSITIVE
1  p0        7.25426e+01   2.24546e+01
2  p1        2.13268e+01   1.04688e+01
3  p2        0.00000e+00     fixed
4  p3       -1.06699e+00   2.46836e-01
5  p4        9.12861e+01   6.03729e-01
6  p5        1.46148e+02   4.78189e+00
7  p6        3.49626e-01   1.53170e+00
8  p7        8.51573e+00   2.24546e+00
9  p8        3.41940e-01   1.25555e+00
10  p9        9.12000e+01     fixed
```



Sim.	Edge W_{low} [GeV]	Edge W_{high} [GeV]	Edge Z_{low} [GeV]	Edge Z_{high}[GeV]
DBD	79.5±0.5	130.2±1.1	91.3±0.6	146.1±4.8
LOI	79.7±0.3	131.9±0.9	91.0±0.7	133.6±0.5

The fitting method appears to be highly dependent on small changes in the fitted distribution → it is clearly NOT appropriate for a comparing the simulation and reconstruction performance.

We need to apply a different edge extraction method!