# Gaugino Mass Measurement as Benchmark for a Particle Flow Detector at the ILC

Mikael Berggren, Jenny List,
**Madalina Chera**

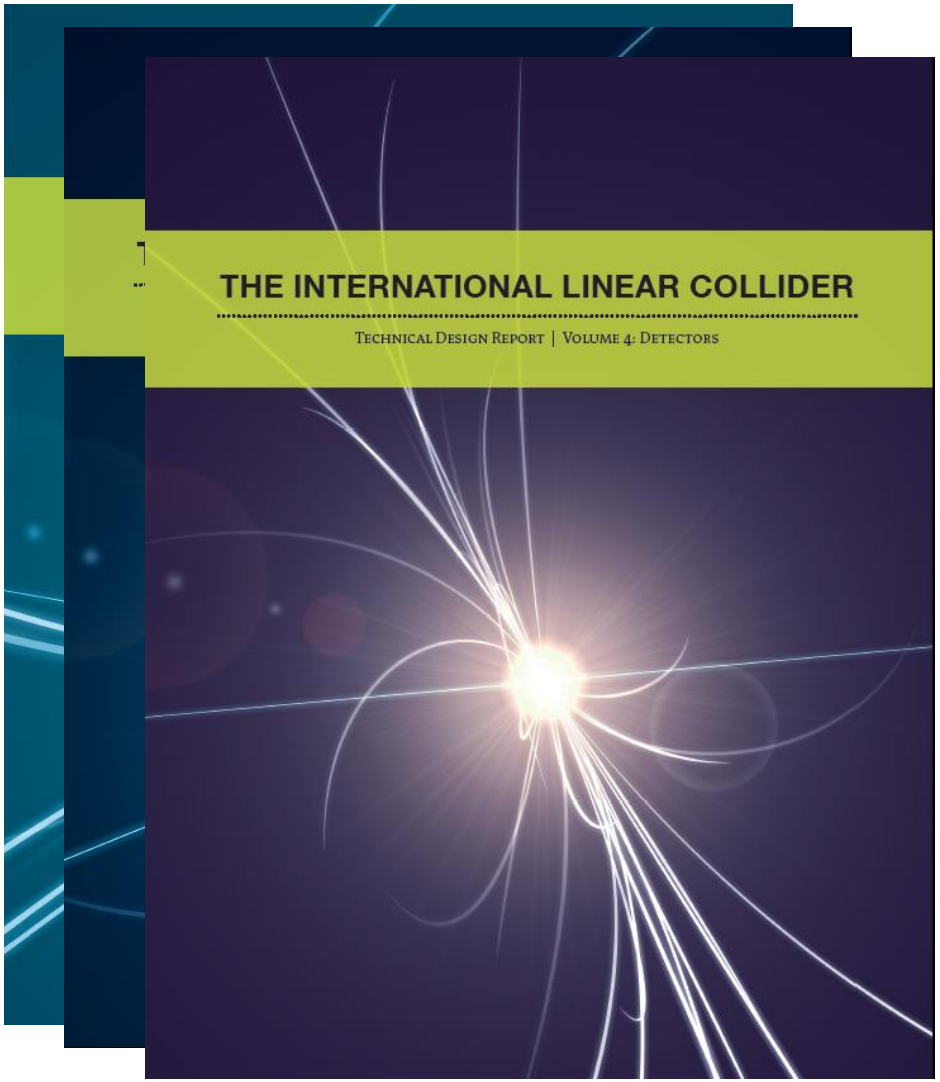
LC Forum, DESY, 9-11 October 2013

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

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

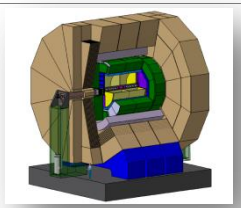
# Motivation

- The ILC detector design optimisation & the physics studies are carried out with a detector simulation.
- The Particle Flow concept is very important for achieving the desired precision at the ILC.
- The PFlow is a crucial part of the reconstruction software.
- Due to the inherent changes and development of the software it is worthwhile to:
  - Quantify (parametrise) its performance
  - Study, compare and document the simulation and reconstruction performance of the available ILC simulations
  - Understand what could be improved in the detector design and reconstruction



# Current Detector Simulations

## > Full Sim – „LOI“



EVENT GENERATOR
WHIZARD

↓

DETECTOR SIMULATION
MOKKA
- based on GEANT4

↓

RECONSTRUCTION
MARLINRECO
- track finding and fitting
- particle flow – PandoraPFA
- flavour tagging

↓

OUTPUT
DST

## > Full Sim – „DBD“

EVENT GENERATOR
WHIZARD

↓

DETECTOR SIMULATION
MOKKA
- **Increased realism**

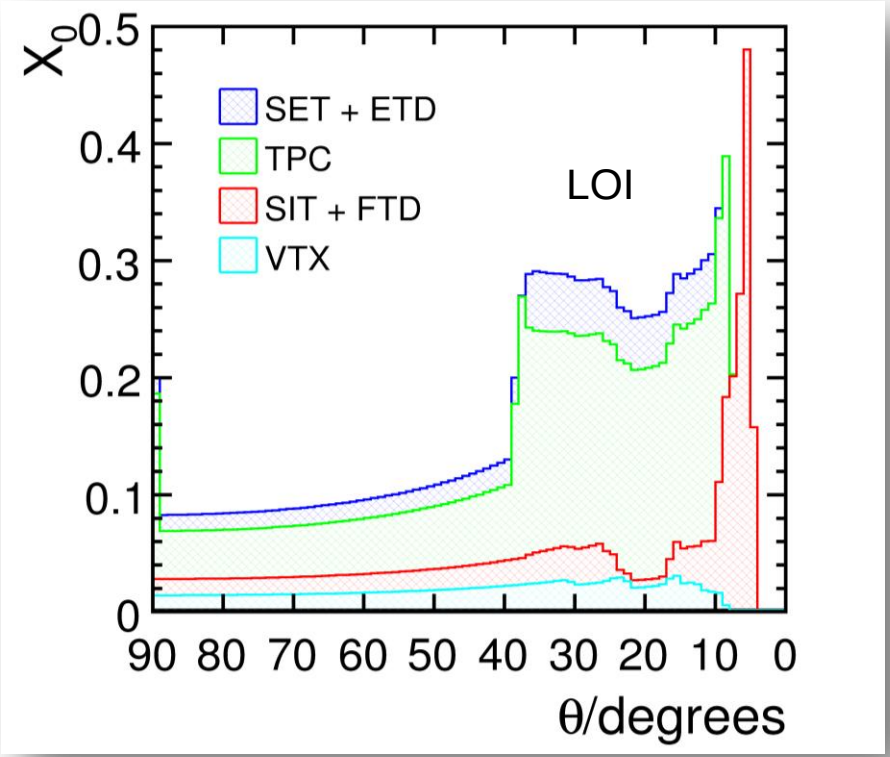
↓

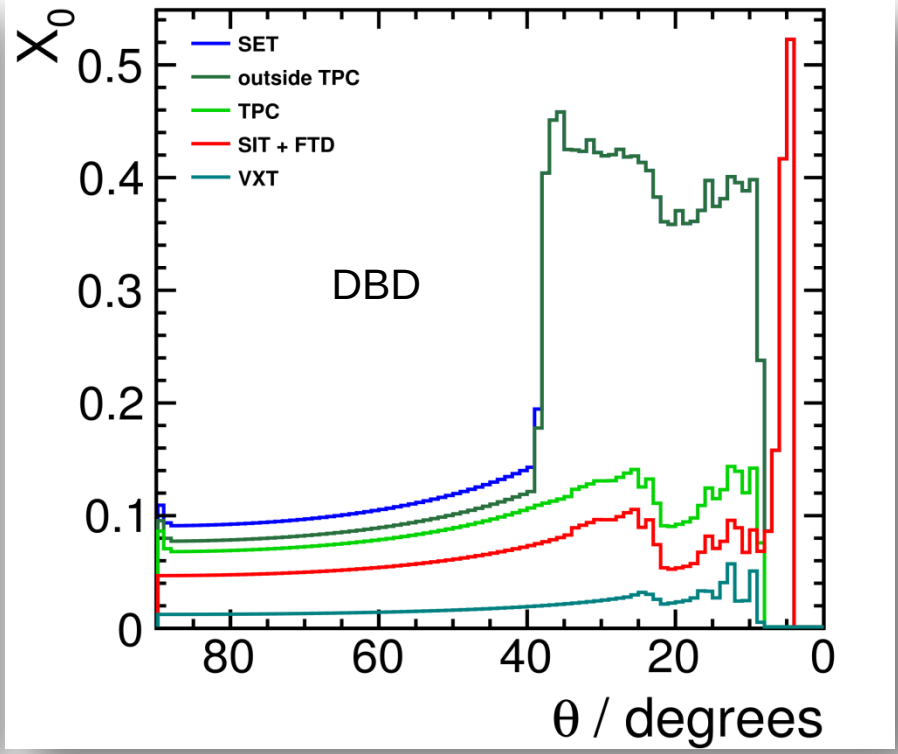
RECONSTRUCTION
MARLINRECO
- track finding and fitting
- **PandoraPFA - rewritten**
- flavour tagging

↓

OUTPUT
DST

# Changes Between LOI and DBD




> The new simulation → **improved detector realism:**

- the vertexing
- the tracker (TPC)
- the calorimeter

} **now include electronics and service materials.**

# Changes Between LOI and DBD

- New forward tracking pattern recognition
- New TPC pattern recognition
- Pandora PFANew has been developed and rewritten

For |cos(θ)| < 0.7:

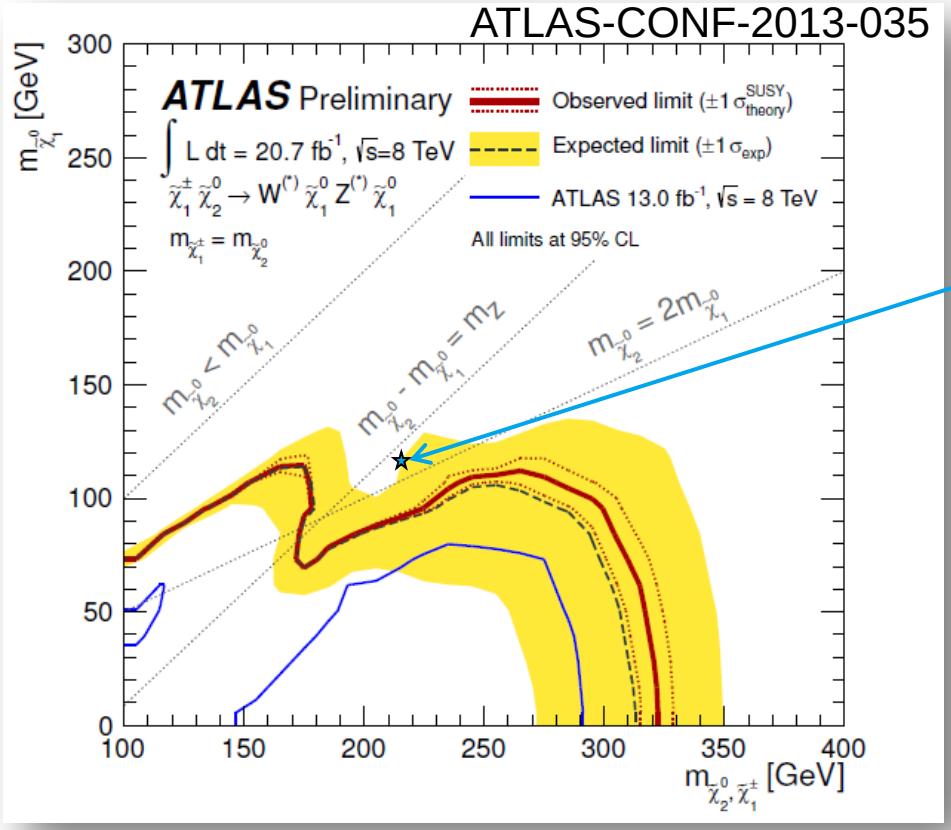
| Jet Energy [GeV] | $\sigma_{Ej}/E_j$ [LOI] | $\sigma_{Ej}/E_j$ [DBD] |
|---|---|---|
| 45 | 3.71±0.05 % | 3.66±0.05 % |
| 100 | 2.95±0.04 % | 2.83±0.04 % |
| 180 | 2.99±0.04 % | 2.86±0.04 % |
| 250 | 3.17±0.05 % | 2.95±0.04 % |

The jet energy resolution has actually improved despite the material addition.
Goal: **study what happens in a physics scenario!**

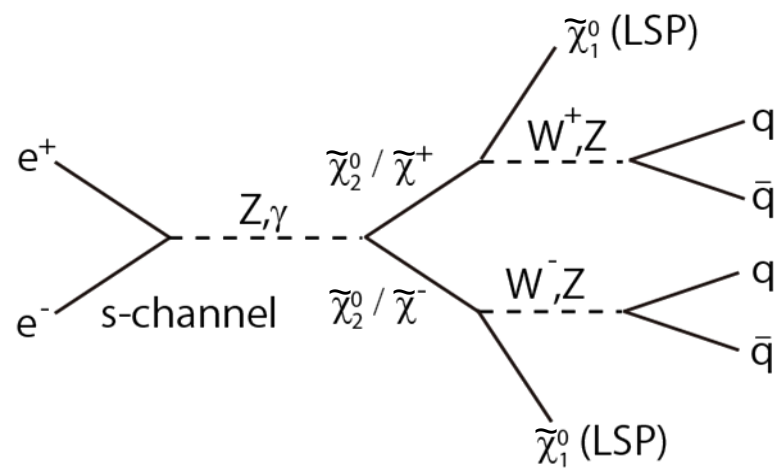
# Study case: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ Pair Production at the ILC

**"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 |

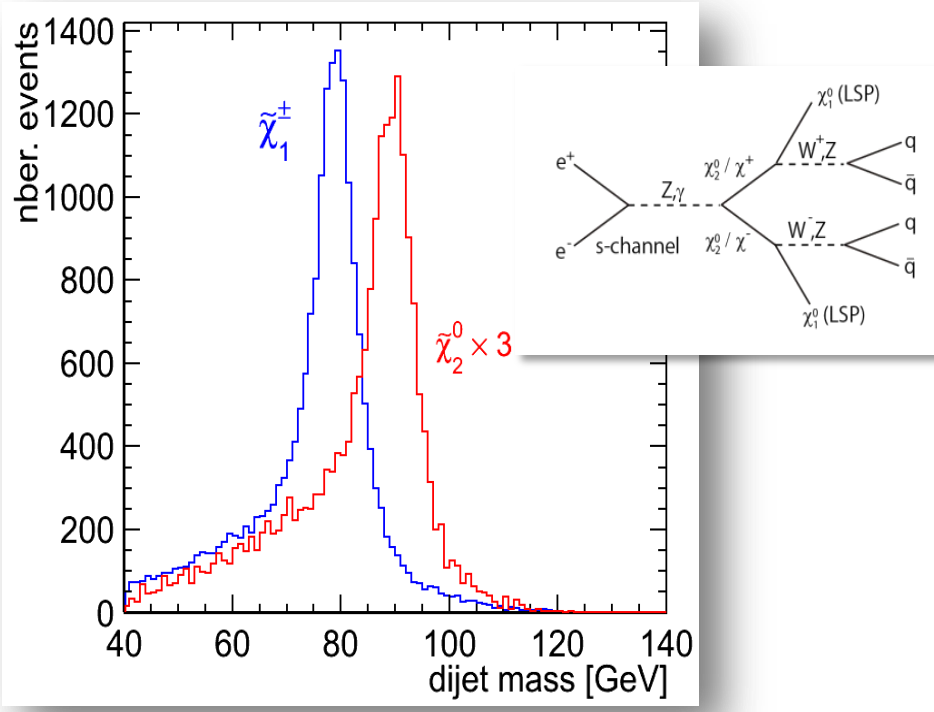


# Study case - motivation

> The „point 5“ scenario is a good case for:

> studying the detector and particle flow performance

- 2 escaping LSP’s → missing energy
- hadronic decay of gauge bosons
- goal: clearly distinguish between W and Z pair events



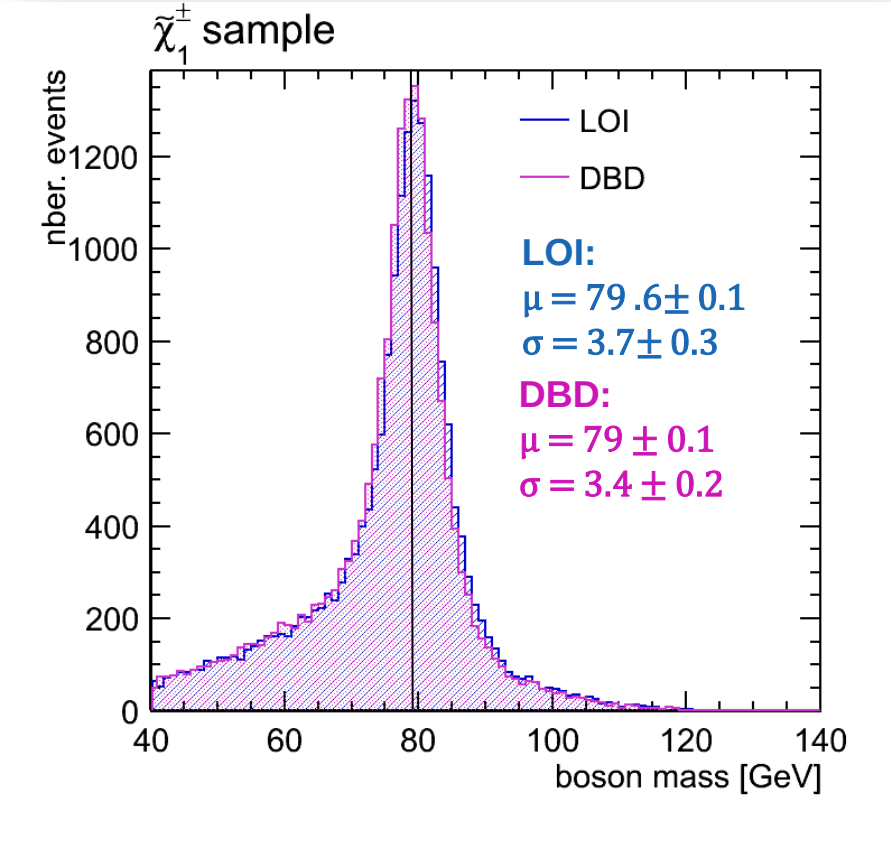

> **comparing and studying the performance of two versions of detector simulation (e.g. LOI and DBD)**

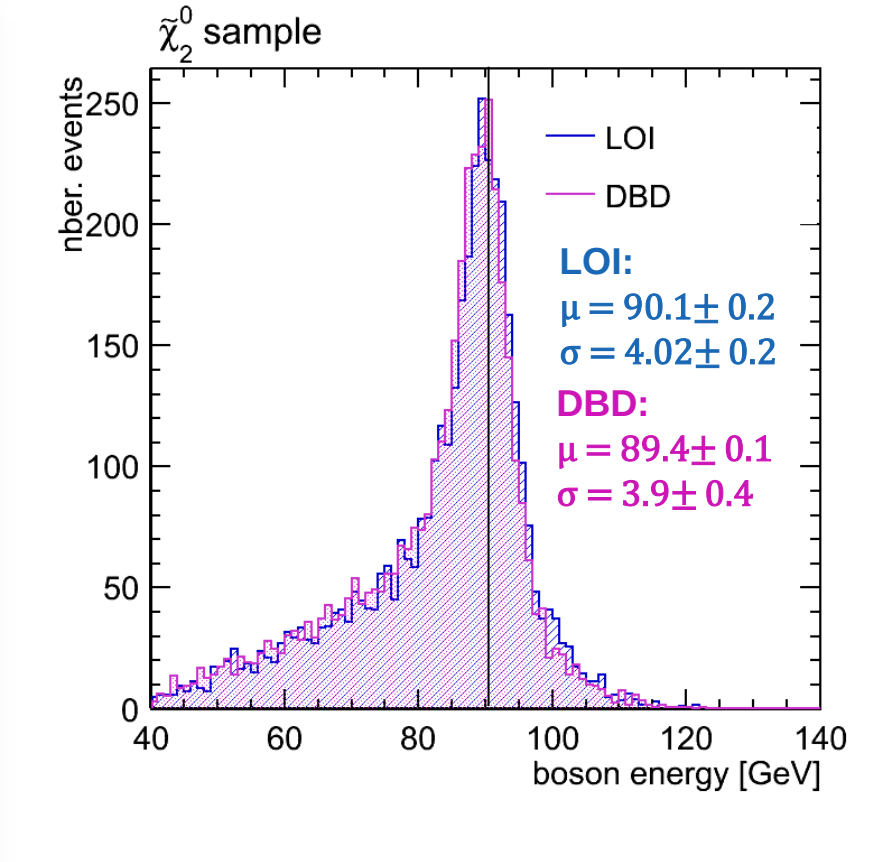
# Study case – Analysis Flow

- The **fully hadronic** decay modes of the on shell gauge bosons were chosen as **signal**
- **Signal topology**: 4 jets and missing energy
- **Background**:
  - SM 4f background is dominant
  - Each signal channel acts as background to the other!
- Event **preselection** – apply cuts on:
  - Number of tracks in event and per jet
  - Minimum number of PFOs per jet = 3
  - Minimum jet energy and $|\cos(\theta)_{jet}|$
  - $|\cos(\theta)_{pmiss}| < 0.99$
  - $100\ \text{GeV} < E_{visible} < 300\ \text{GeV}$
  - $M_{missing} > 220\ \text{GeV}$
- Perform **kinematic fit** using Marlin KinFit: equal mass constraint (determine best jet pairing)
  - Apply cut on converged kinematic fit

# 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**



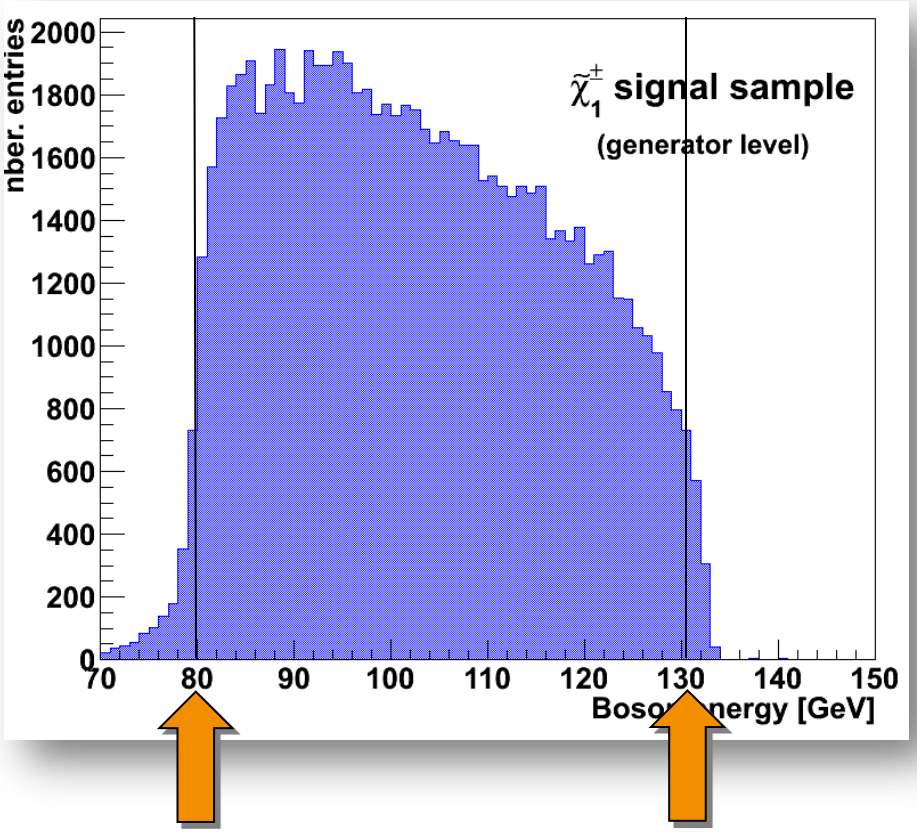

> The DBD distribution appears slightly narrower and shifted towards lower energy, however the DBD and LOI distributions are compatible with each other.

# $\tilde{\chi}_1^{\pm}$ 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**

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

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

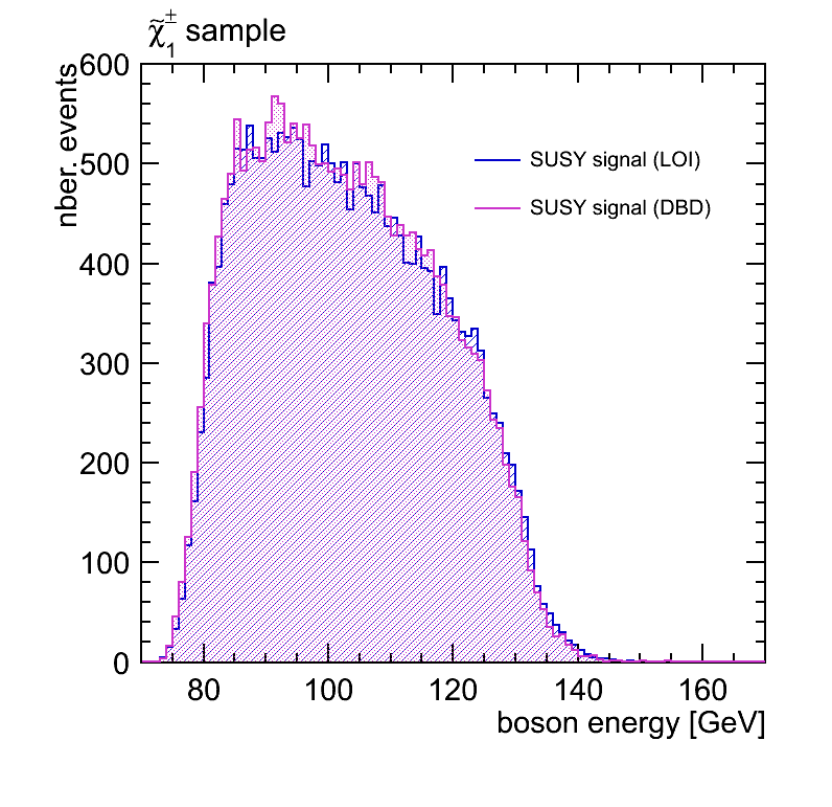


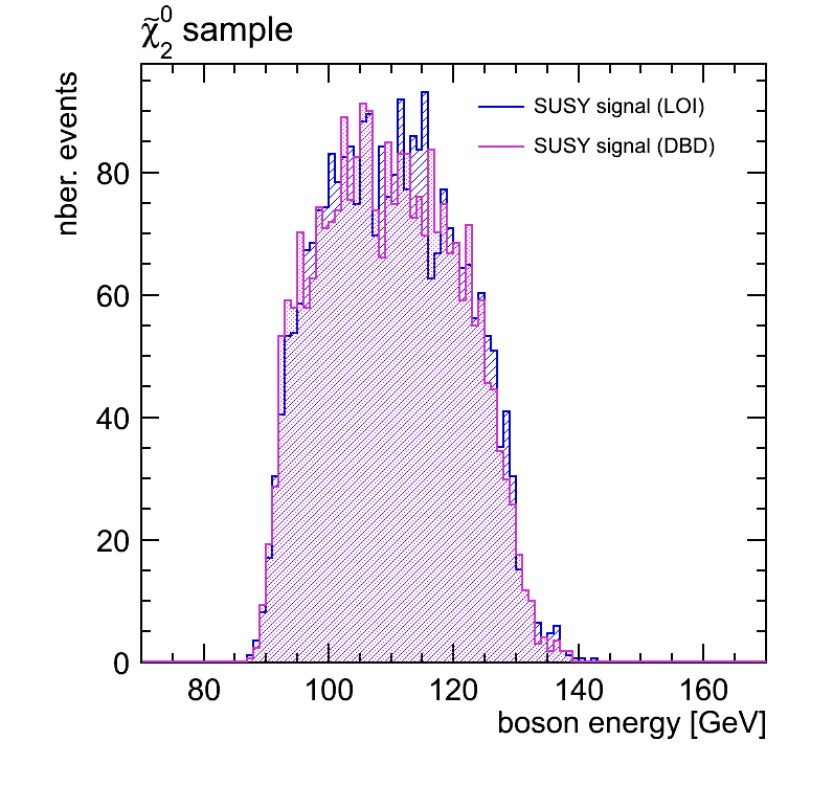

**Real edge values [GeV]:**

| $W_{low}$ | $W_{high}$ | $Z_{low}$ | $Z_{high}$ |
|---|---|---|---|
| 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 narrower and shifted towards lower energies. Nevertheless, the two distributions agree very well.

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

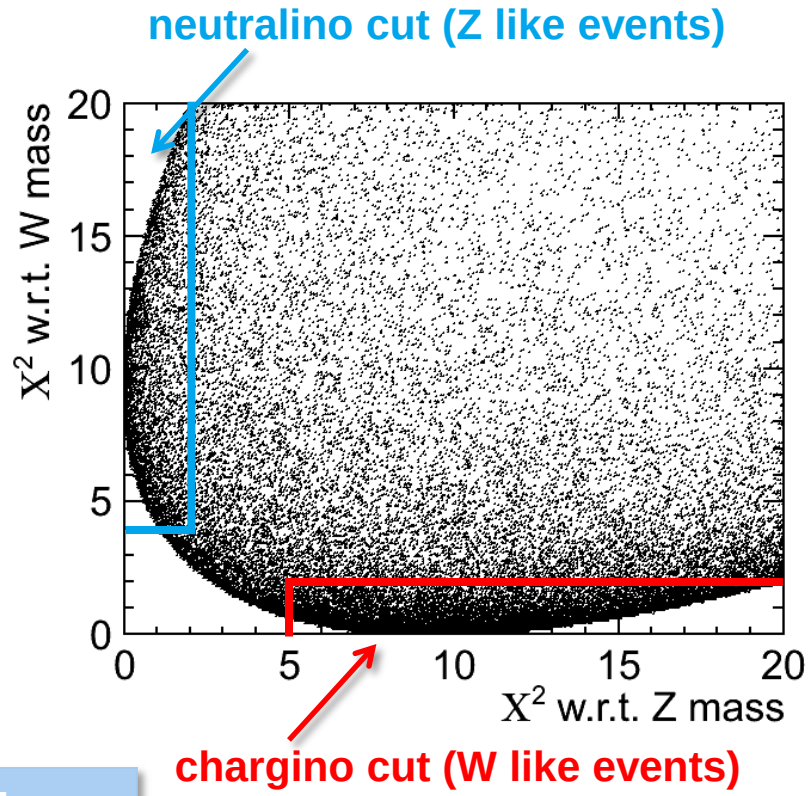
- Calculate $\chi^2$ with respect to nominal W / Z mass

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

$$\Downarrow$$

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 $\chi^2$ cut, the separation is quite clear:

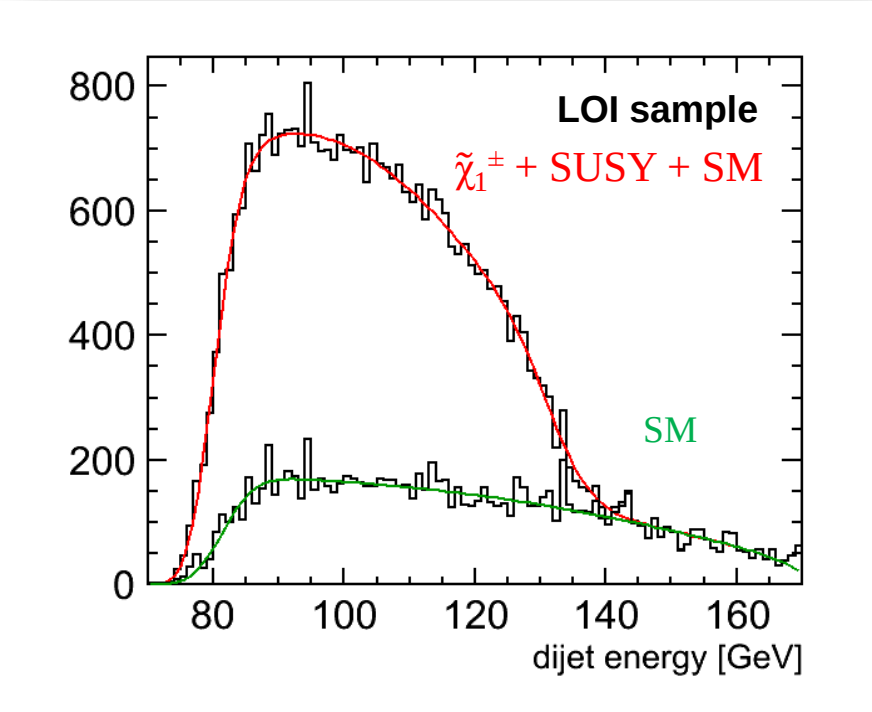



| Obs. | DBD | | LOI | |
|---|---|---|---|---|
| | $\tilde{\chi}_1^{\pm}$ | $\tilde{\chi}_2^{0}$ | $\tilde{\chi}_1^{\pm}$ | $\tilde{\chi}_2^{0}$ |
| Efficiency | 57% | 32% | 56% | 34% |
| Purity (total) | 63% | 35% | 62% | 35% |
| Purity (SUSY) | 94% | 68% | 95% | 66% |

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

- Fit dijet energy spectrum and obtain edge positions:

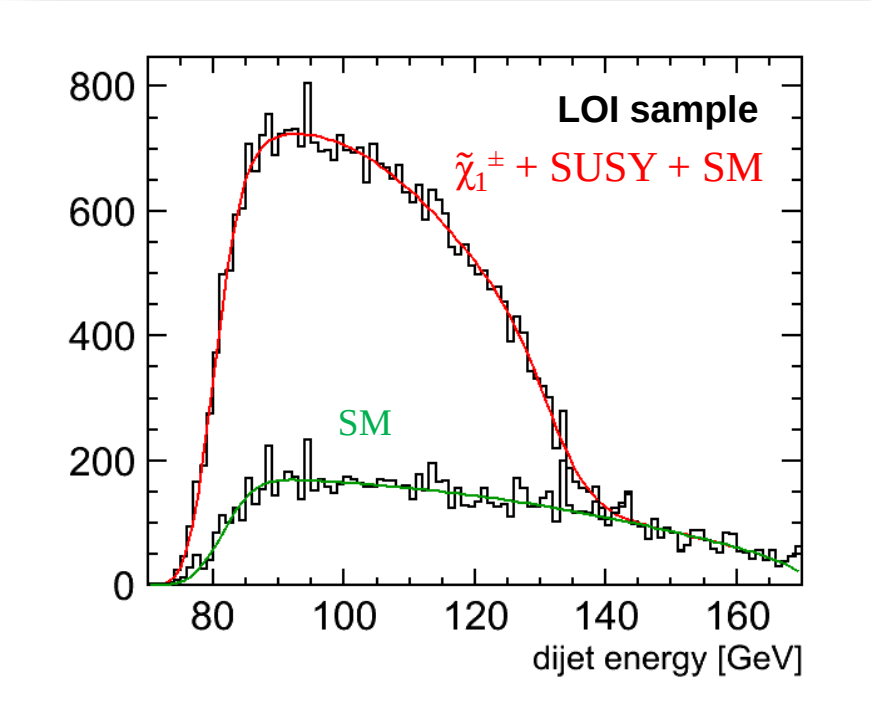
$$f(x; t_{0\_1}, b_{0\_2}, \sigma_{1\_2}, \gamma) = f_{SM} + \int_{t_0}^{t_1} (b_2 t^2 + b_1 t + b_0) V(x - t, \sigma(t), \gamma) dt$$

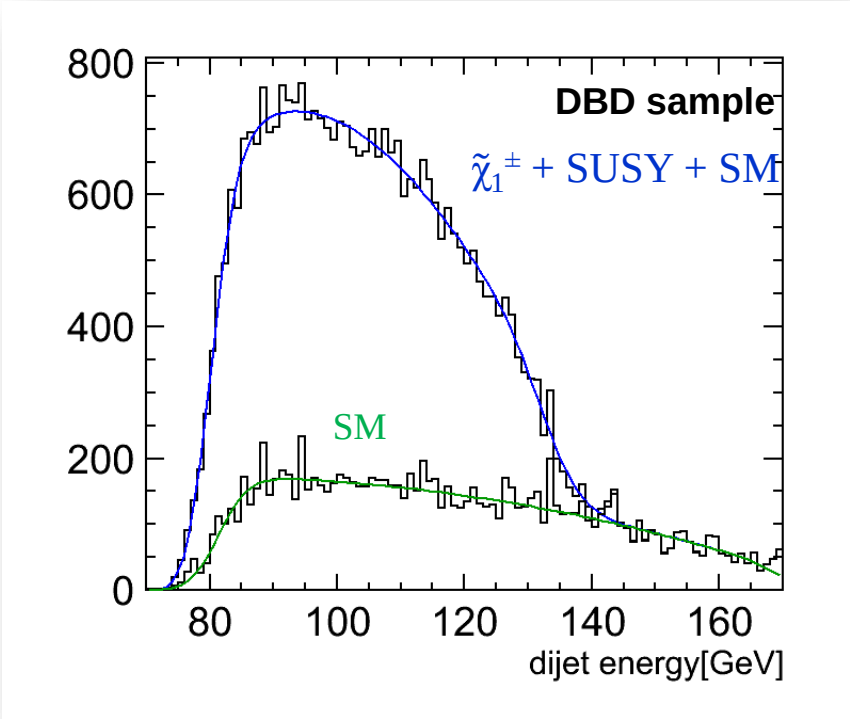



Where:

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

# Endpoint Extraction Comparison – LOI to DBD



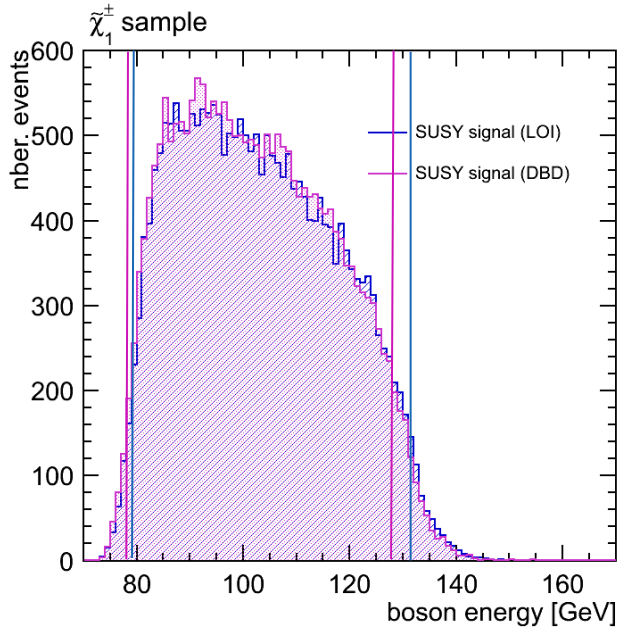



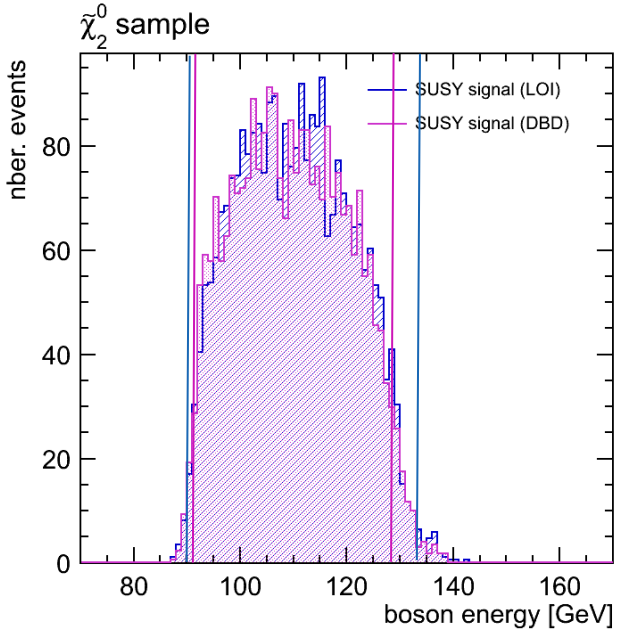

$E_{low} \simeq 79.7 \pm 0.3$ GeV
$E_{high} \simeq 131.9 \pm 0.9$ GeV

$E_{low} \simeq 79.5 \pm 1.7$ GeV
$E_{high} \simeq 128.3 \pm 1.2$ GeV

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

# 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±1.7 | 128.3±1.2 | 91.9±0.8 | 127.9±0.7 |
| 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!**

# 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.

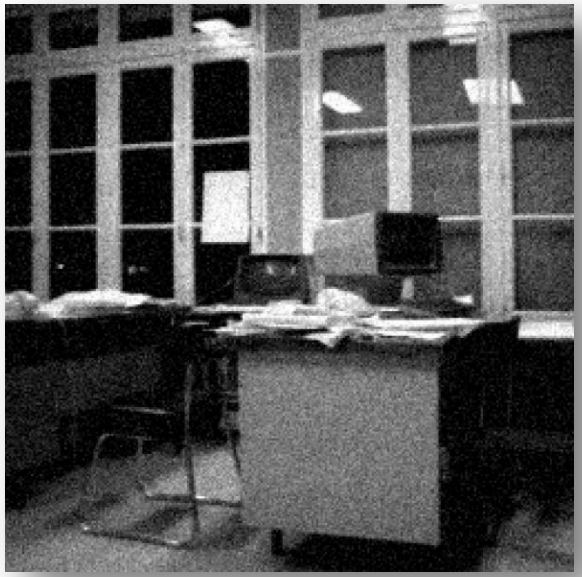
$$y[n] = \sum_{k=-M_1}^{M_2} b_k x[n-k]$$

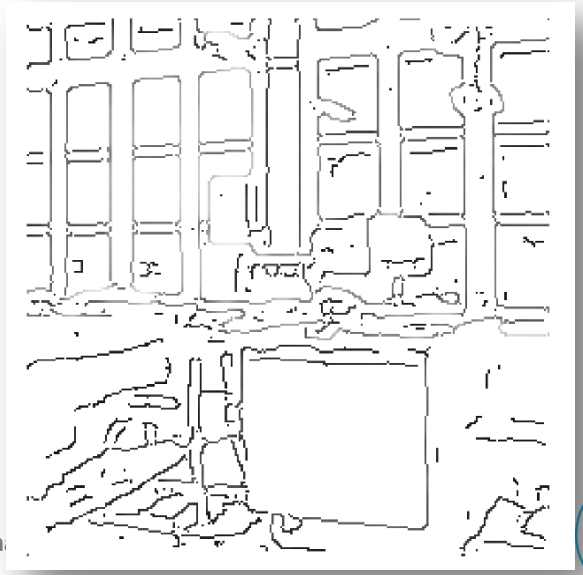
the input signal

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

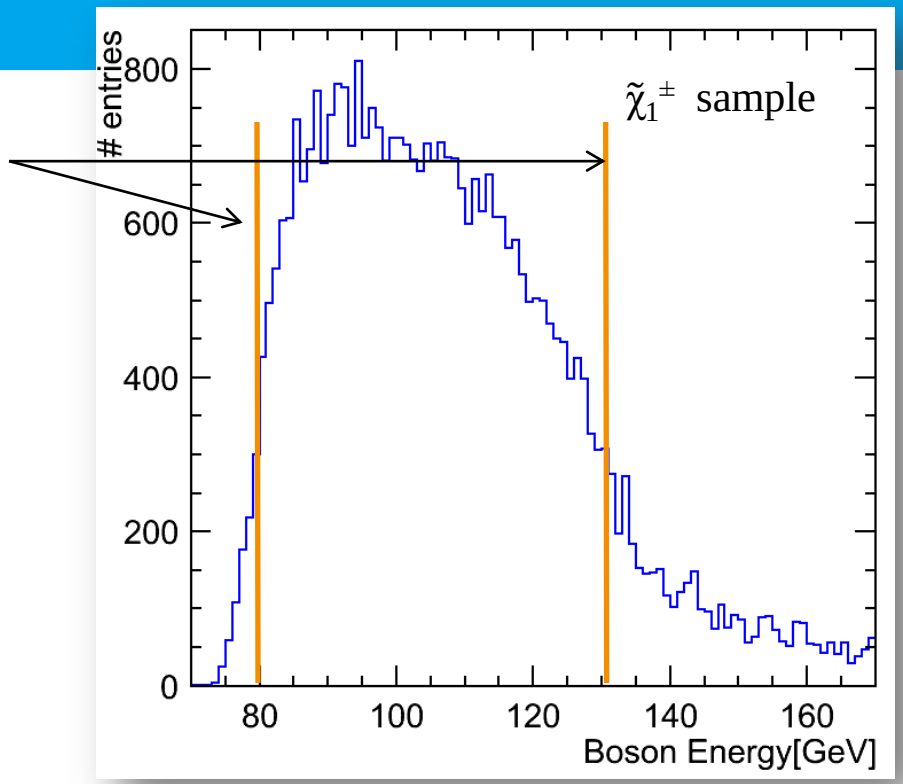




Madalin

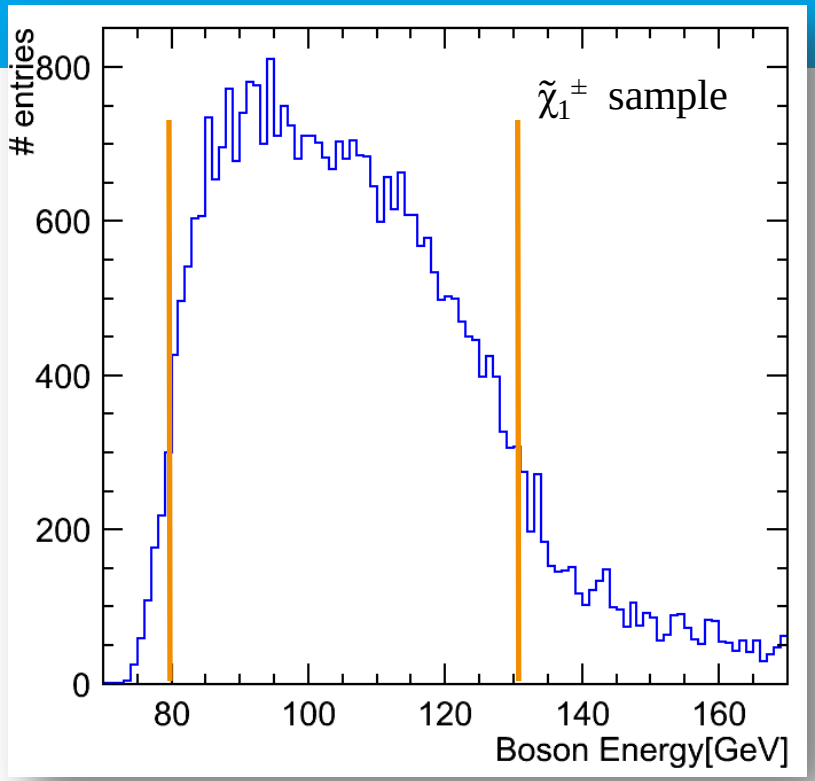
# Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy: use weighted sums of bin content values to find patterns in distribution



# Applying an FIR Filter

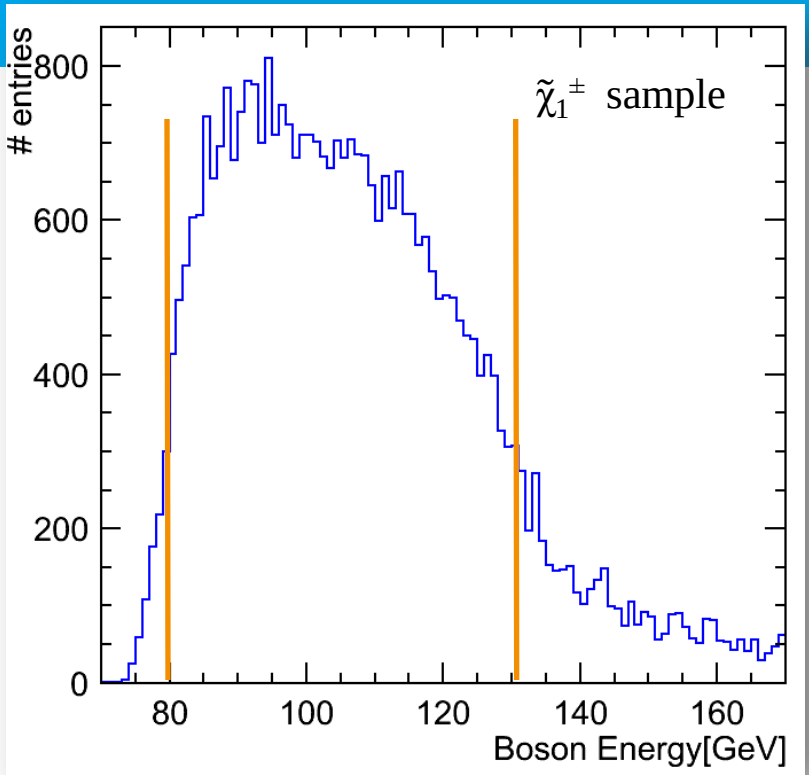
- Goal: find edge positions in spectrum
- Strategy: use weighted sums of bin content values to find patterns in distribution
- Consider the histogram as an array of bin content values




| Bin # | 1 | 2 | 3 | ... | 98 | 99 | 100 |
|---|---|---|---|---|---|---|---|
| Entries | 0 | 15 | 28 | ... | 34 | 22 | 4 |

# Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy: use weighted sums of bin content values to find patterns in distribution
- Consider the histogram as an array of bin content values
- Consider an array of chosen weights (smaller than the histogram!)
- Create new array of the same size:
  - Each entry in the new array is the weighted sum of the bin content values from the bins surrounding the corresponding bin in the original array.
  - The array is filled using the **same** (finite) weights each time.
- The value of the output depends on the pattern in the neighbourhood of the considered bin and NOT on the position of the bin
- The pattern of weights = kernel
- The filter application = convolution




| Bin # | 1 | 2 | 3 | ... | 98 | 99 | 100 |
|---|---|---|---|---|---|---|---|
| Entries | 0 | 15 | 28 | ... | 34 | 22 | 4 |

$$\underbrace{w_1 \times 0 + w_2 \times 15 + w_3 \times 28}_{} = \text{val2}$$

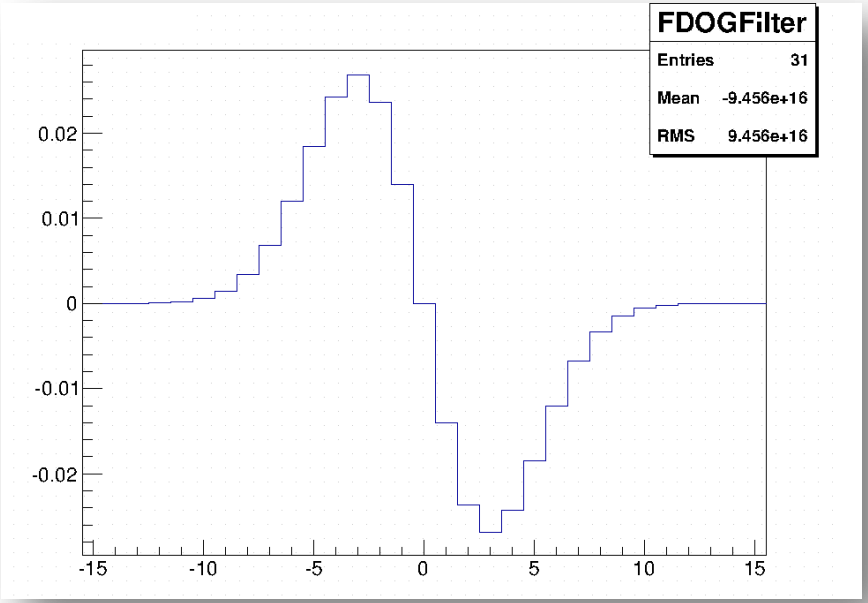
| Entries | val1 | val2 | val3 | ... | val98 | val99 | val100 |
|---|---|---|---|---|---|---|---|

# Choosing the Appropriate Filter

- Idea: first derivative as kernel → it works but may be rather noisy
- 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

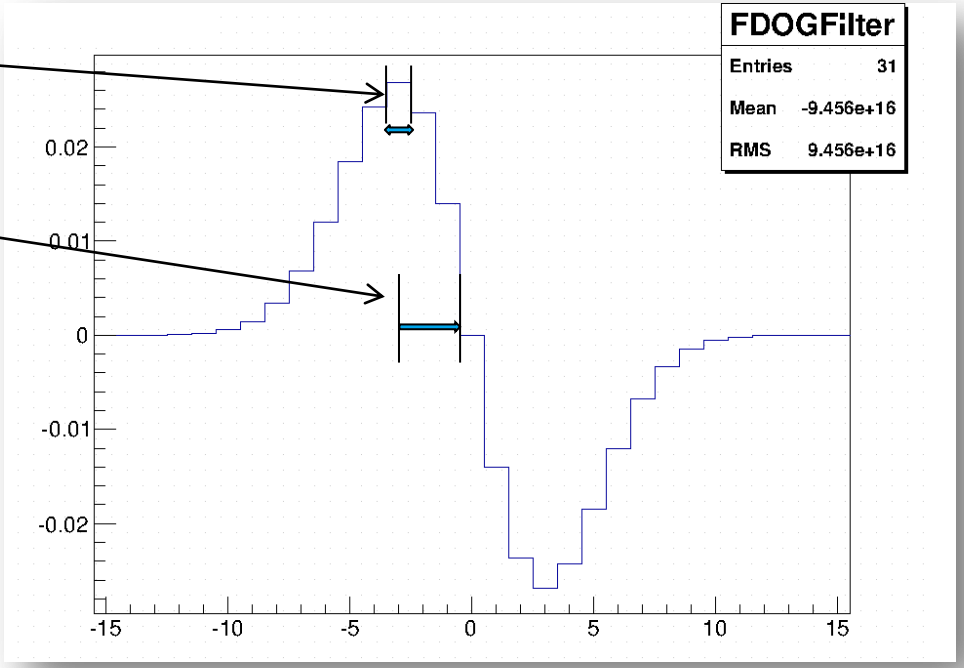


# Testing the FDOG Filter

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

the bin size

the filter size

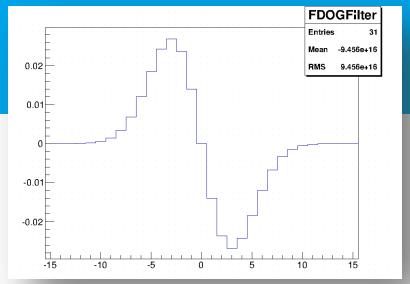


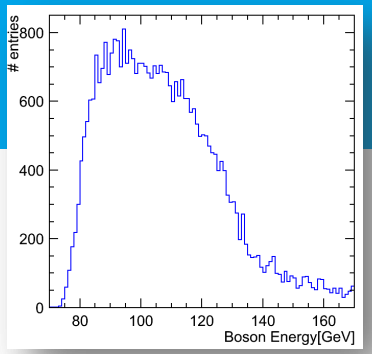

It is crucial to strike the right balance between the two:

- 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 is needed to optimise the filter and bin size!

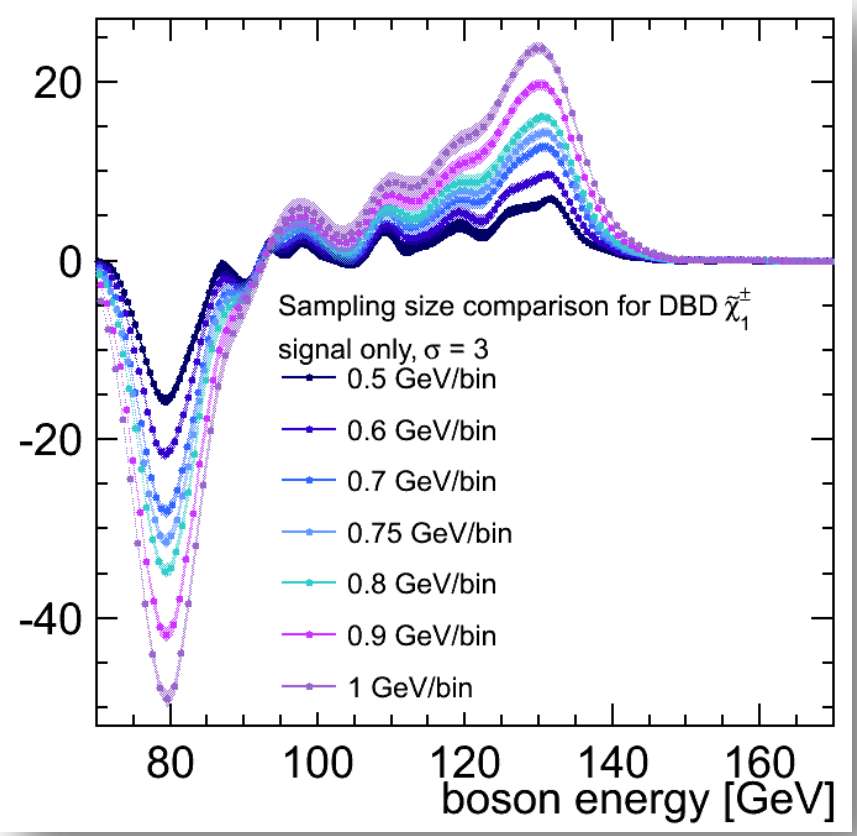
# Testing the FDOG Filter

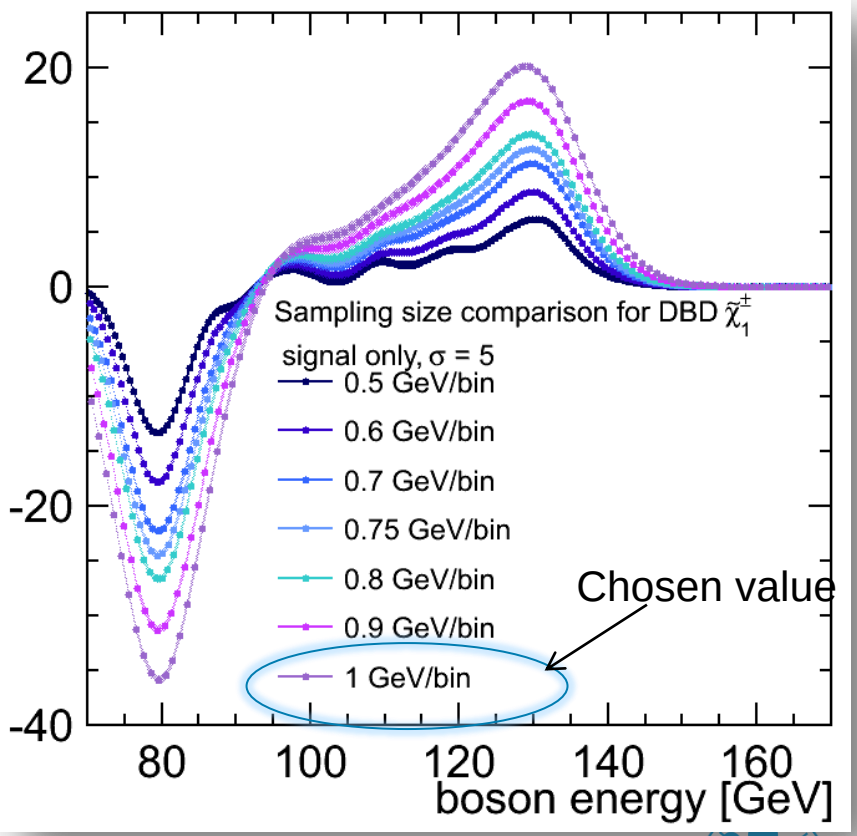



- There are two important filter characteristics that must be optimised: the bin size and the filter size.

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

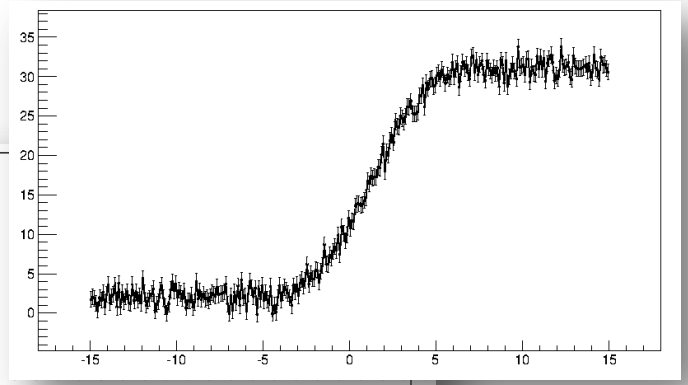


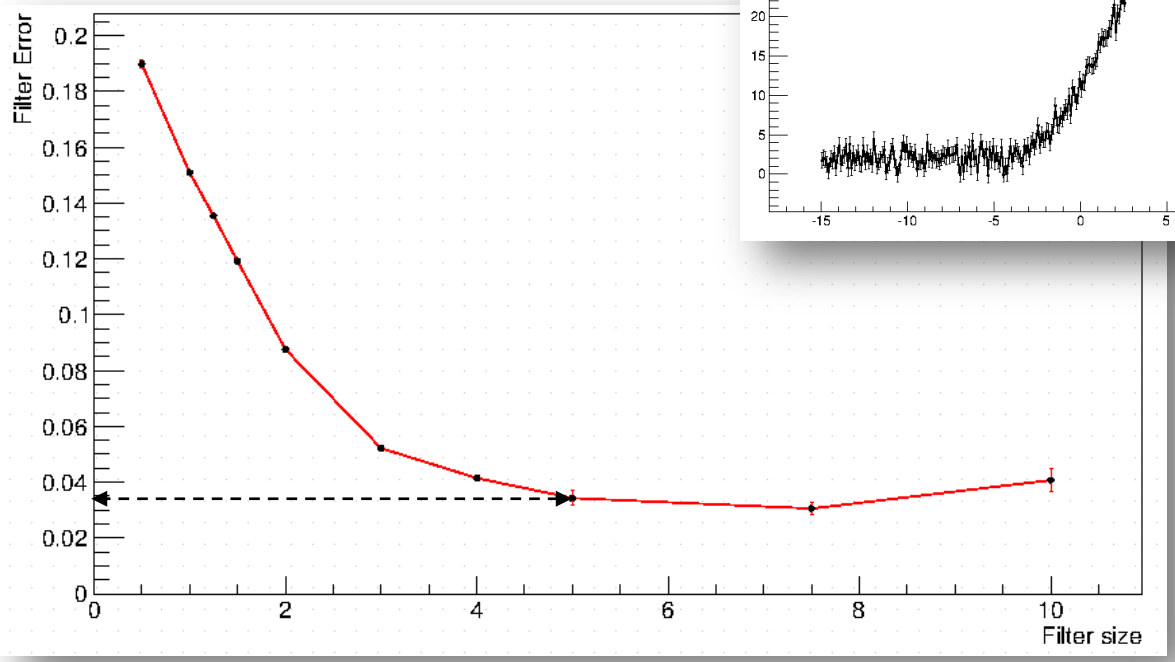



# Testing the FDOG Filter

- There are two important filter characteristics that must be optimised: the bin size and the filter size.
- Filter size ↔ σ of the FDOG kernel

Studied the effect of the filter size on a smeared step edge monte carlo data.

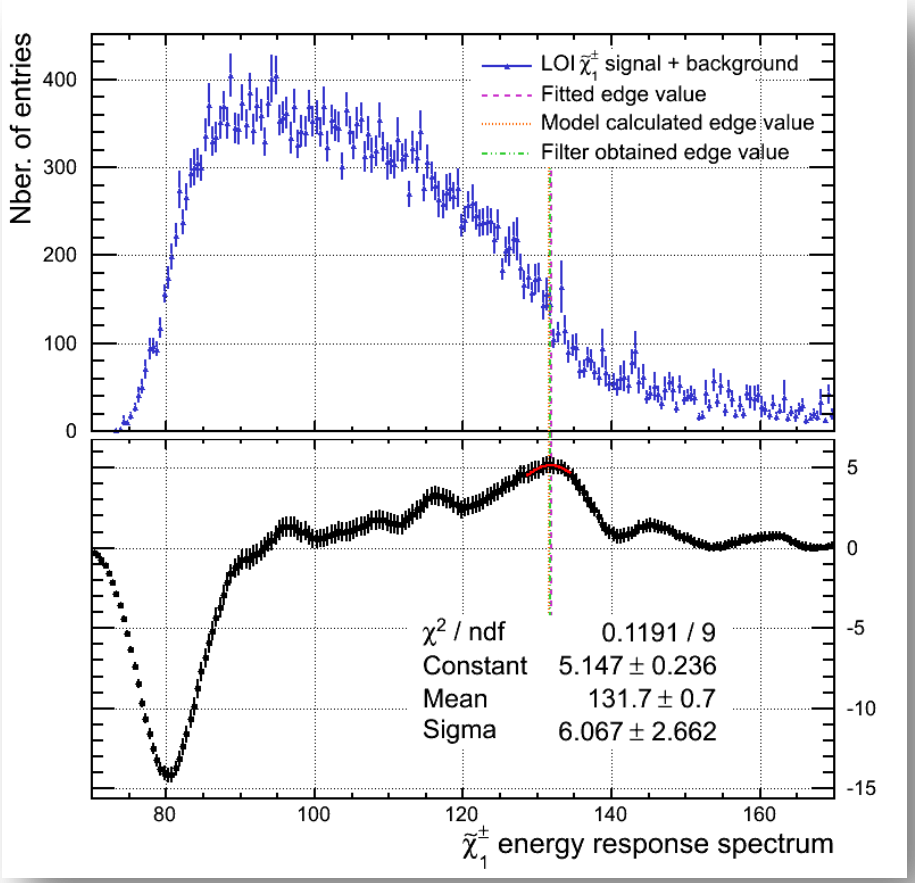


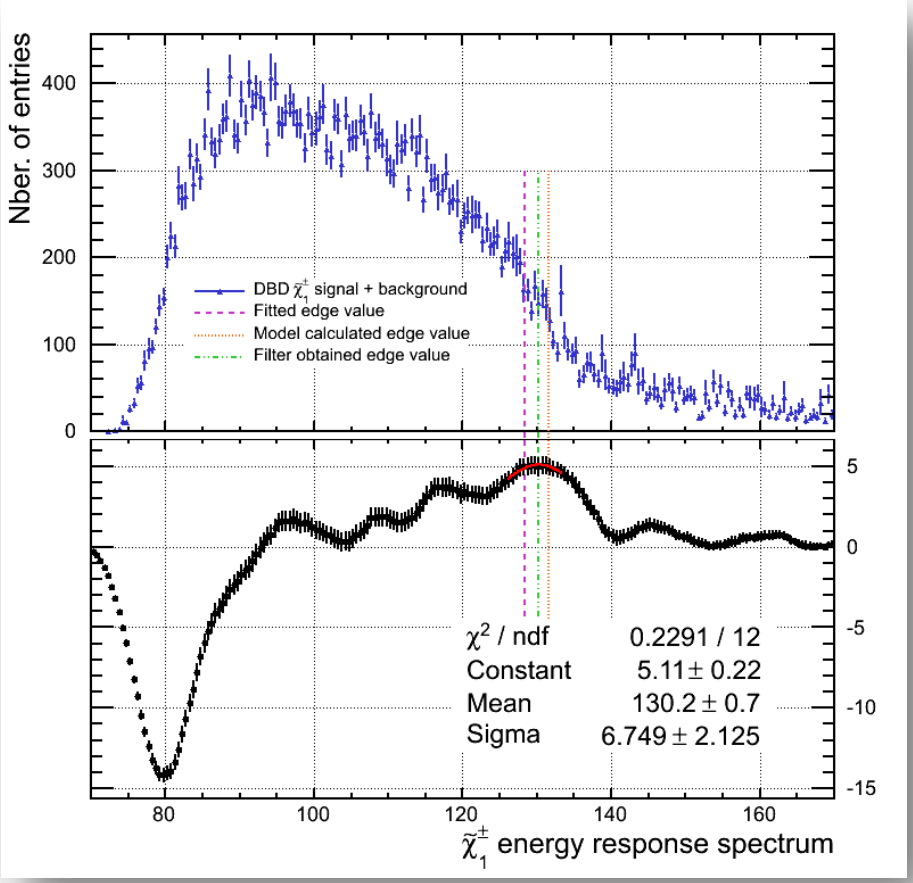




S. Caiazza

The σ = 5 value filter size is very close to the minimum range of the error curve.

# FIR Edge Extraction Comparison – LOI to DBD

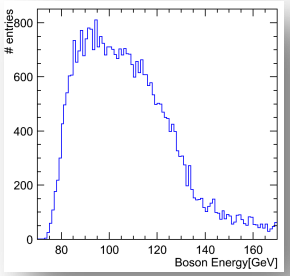


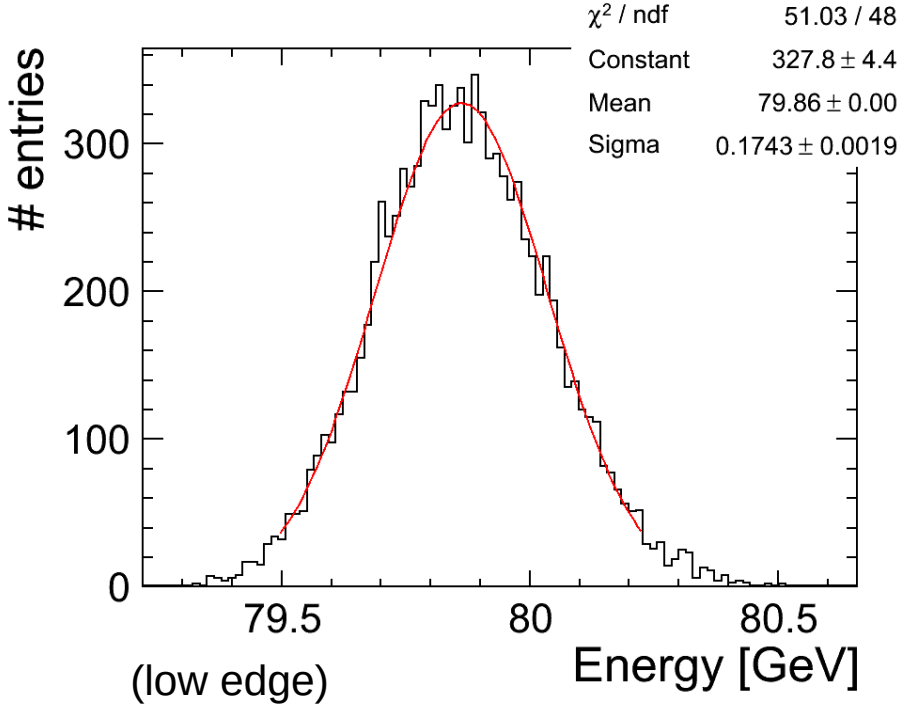



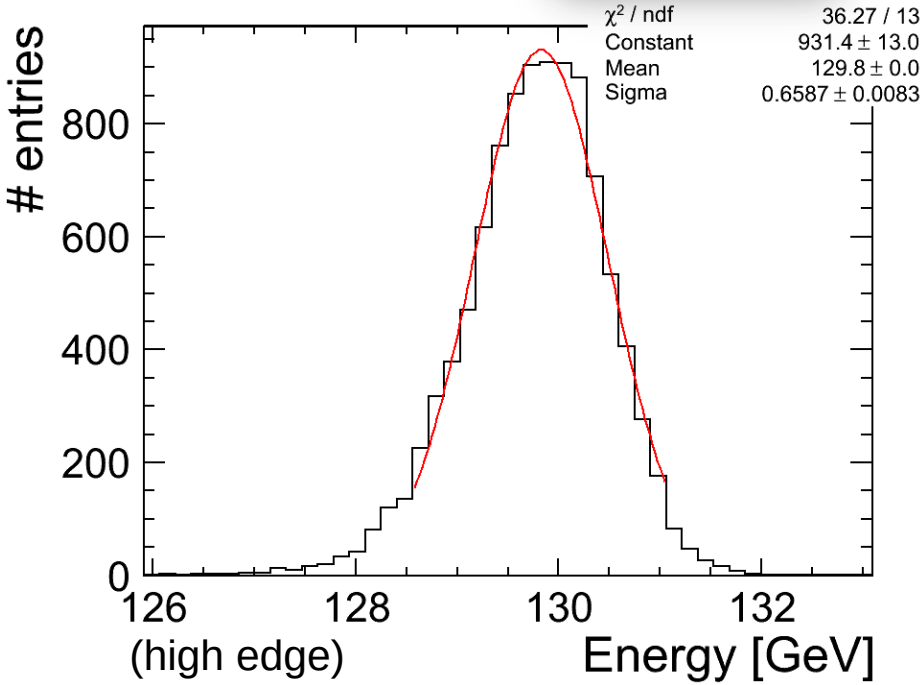

In the **LOI** case: the fitted and filter values are extremely close to the real model value.
In the **DBD** case: the filter value is much closer to the model one than the fitted edge.

# Toy MC for the Filter Edge Extraction

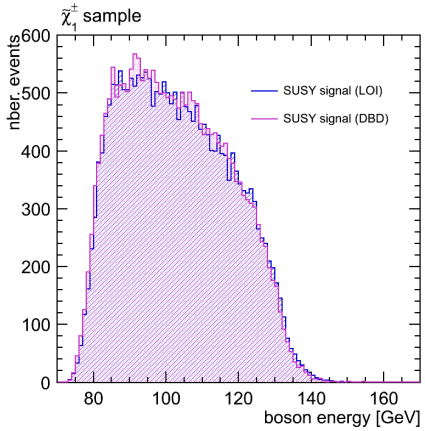
- To estimate the statistical precision of the edge extraction → toy MC
- 10000 $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ energy spectra have been produced
- The FDOG filter was then applied 10000 times
- Example: for the $\tilde{\chi}_1^{\pm}$ case:

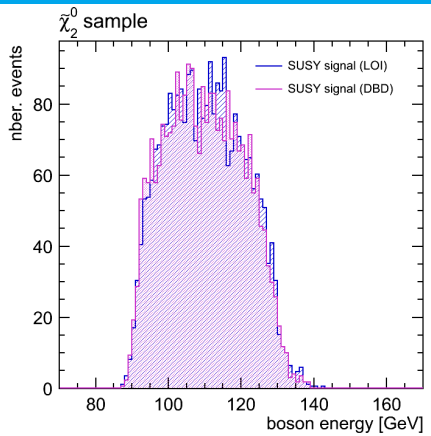


# Edge Extraction Comparison




| 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 | 79.7±0.3 | 131.9±0.9 | 91.0±0.7 | 133.6±0.5 |
| DBD | 79.5±1.7 | 128.3±1.2 | 91.9±0.8 | 127.9±0.7 |
| DBD filter | 80.1±0.2 | 129.1±0.7 | 91.9±0.2 | 127.2±0.7 |

The filter extraction method is preferable:

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

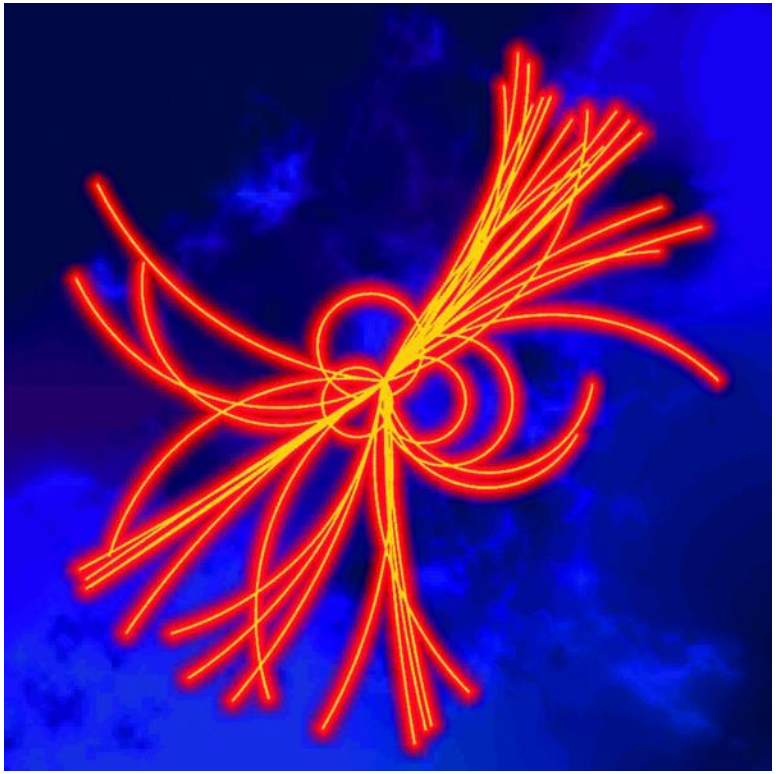
# Conclusions

- It is important to study and compare the performance of our detector simulation and reconstruction software.
- The comparison should also be done within a physics scenario.
- The $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ pair production in the framework of the “Point 5” benchmark has been presented as study case.
- A preliminary comparison between the LOI and DBD simulation and reconstruction has been made;
  - The dijet mass reconstruction from the DBD is compatible to the LOI analysis.
  - The DBD reconstructed boson energy spectrum is very similar to the LOI one
  - However 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

> Outlook:

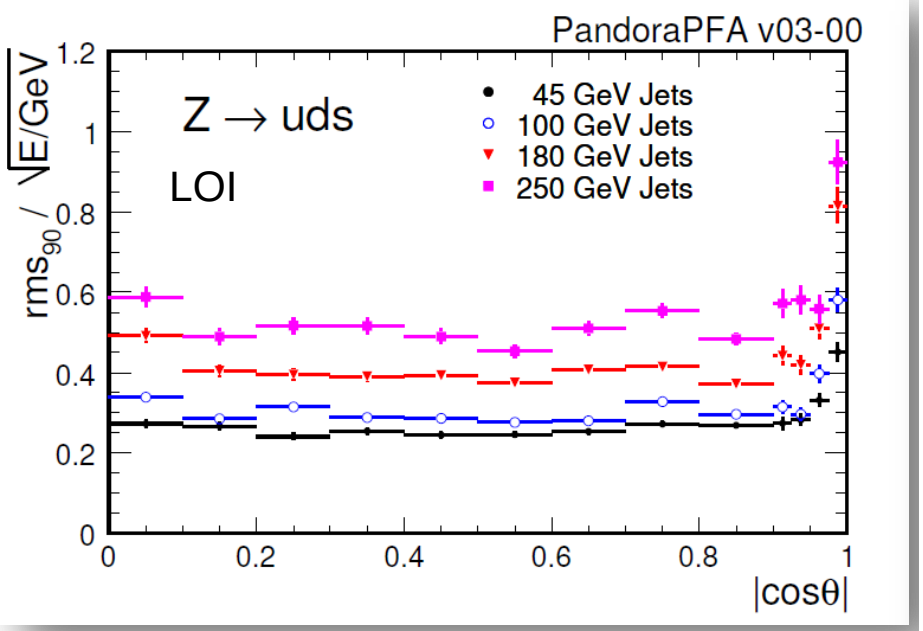
- A mass calibration will be performed for the mass measurement.

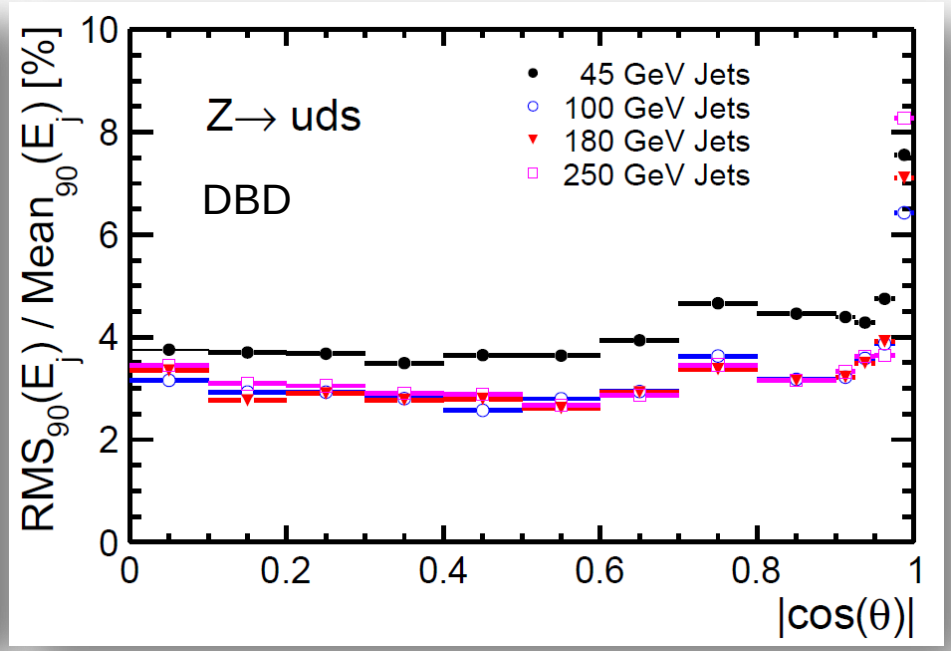
# Thank You!



# Back up

# Changes Between LOI and DBD

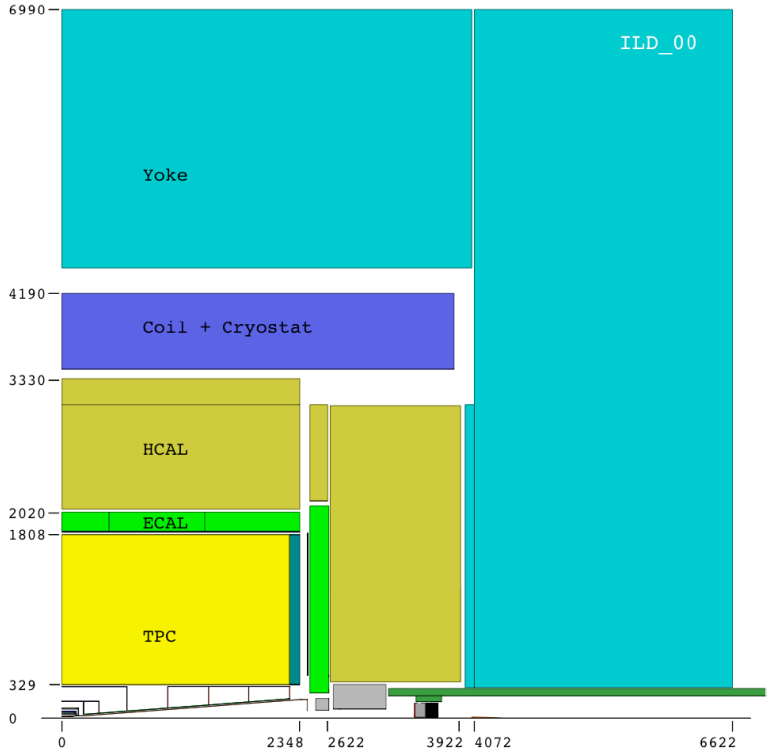


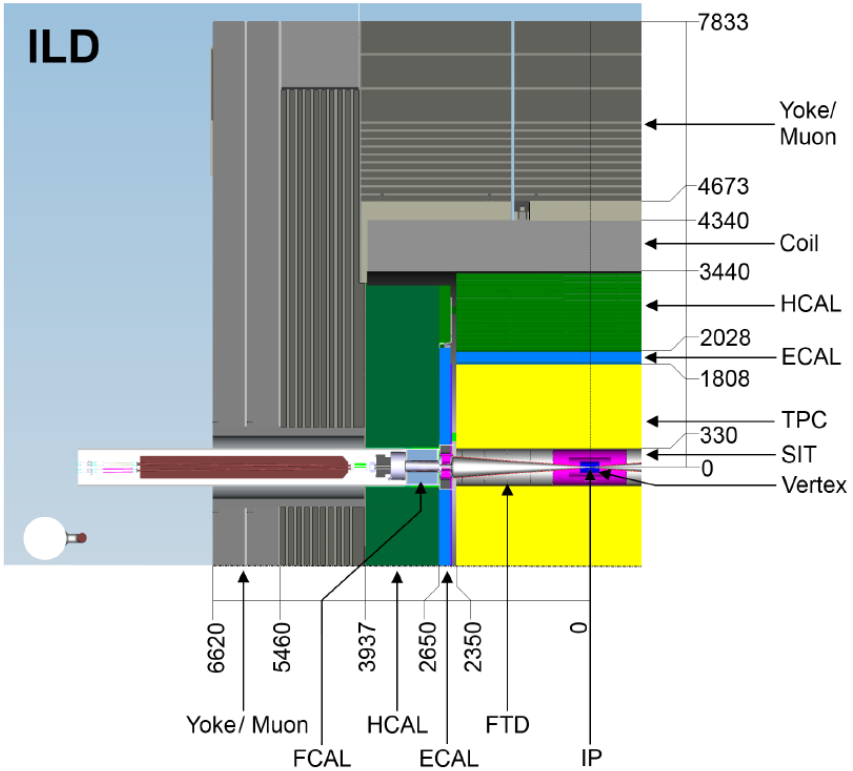




- For |cos(θ)| < 0.7:

| Jet Energy [GeV] | $\sigma_{Ej}/E_j$ [LOI] | $\sigma_{Ej}/E_j$ [DBD] |
|---|---|---|
| 45 | 3.71±0.05 % | 3.66±0.05 % |
| 100 | 2.95±0.04 % | 2.83±0.04 % |
| 180 | 2.99±0.04 % | 2.86±0.04 % |
| 250 | 3.17±0.05 % | 2.95±0.04 % |

# Changes Between LOI and DBD




> The new simulation → **improved detector realism:**

- the vertexing
- the tracker (TPC)
- the calorimeter

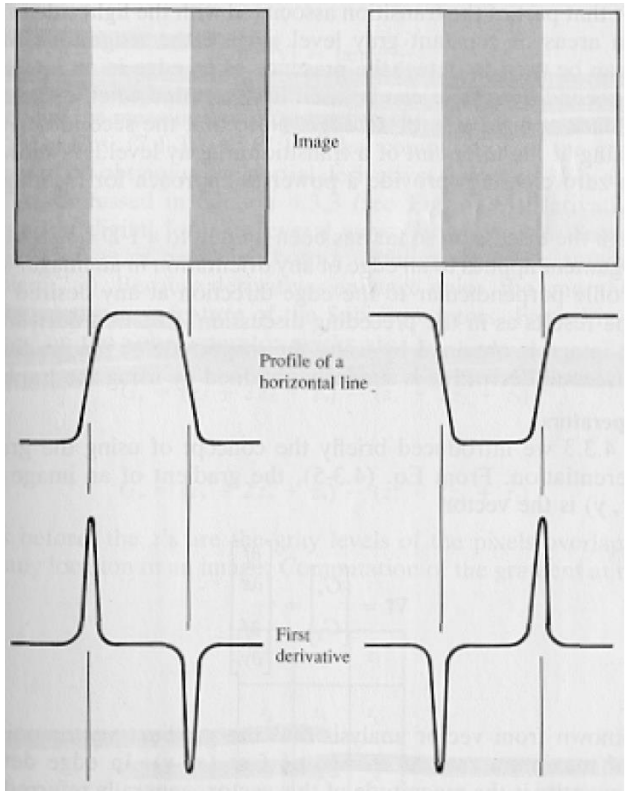
} **now include electronics and service materials.**

# 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:

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