Gaugino Properties Determination in the Fully Hadronic Decay Mode at the ILC

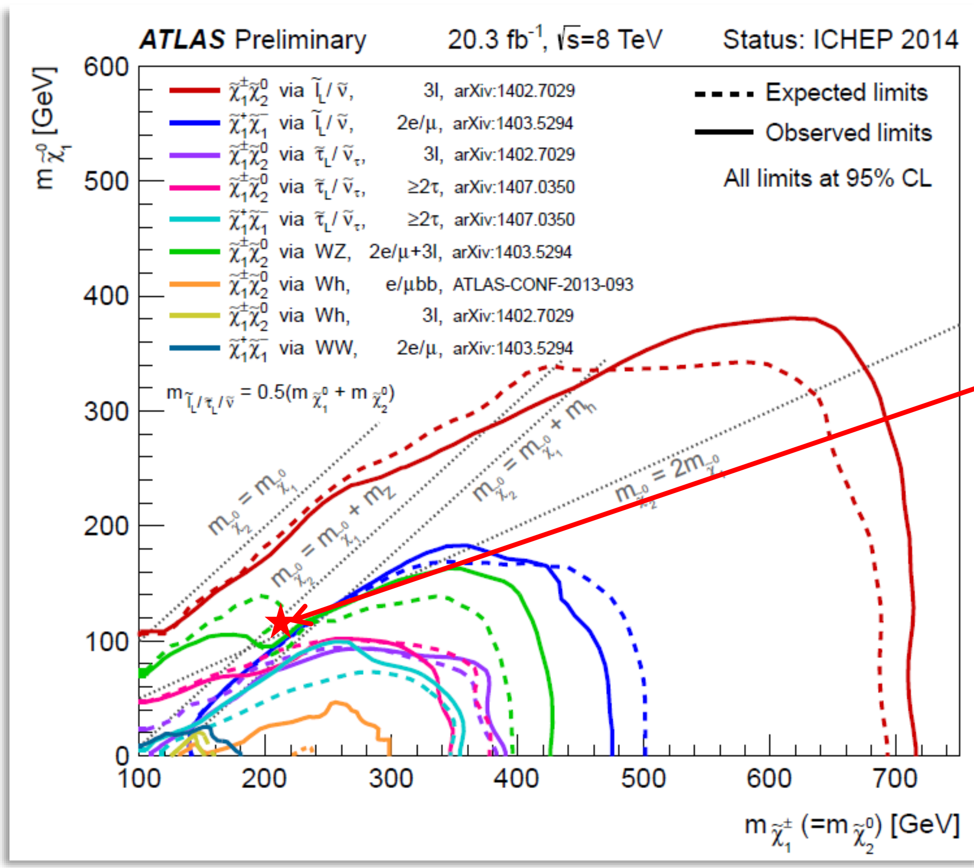
Jenny List, Mikael Berggren, Madalina Chera
LC Forum, DESY, 17 November 2015

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG
Particles, Strings, and the Early Universe
Collaborative Research Center SFB 676
DESY

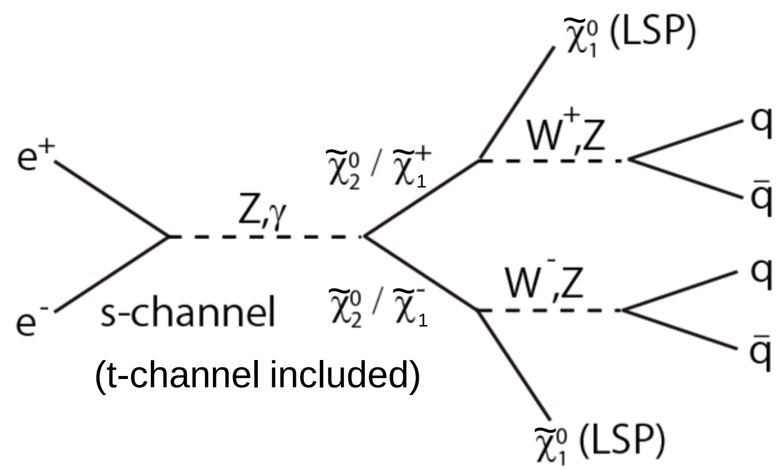
Study case: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ Pair Production at the ILC

"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



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

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

Analysis Strategy

- Remove $\gamma\gamma \rightarrow \text{hadrons}$ background: applied k_T exclusive algorithm ↔ 6 jets, R=1.1 (FastJet)
- Cluster event into 4 jets (Durham)
- Run kinematic fit (equal mass constraint: $M_{jj1} = M_{jj2}$)
  - → choose jet pairing with best fit probability
- Run isolated lepton finder (J. Tian and C. Dürig)
- Perform SUSY selection (12/16 cuts → see back-up slide)

	Sample	$\tilde{\chi}_1^{\pm}$ hadronic	$\tilde{\chi}_2^{0}$ hadronic
Selection for mass	Efficiency	90.8% → 53%	91% → 30%
	Purity	14.7% → 63%	2.6% → 38%
Selection for x-section	Efficiency	72%	73%
	Purity	27%	5%

Mass Measurements

Gaugino Mass Measurement

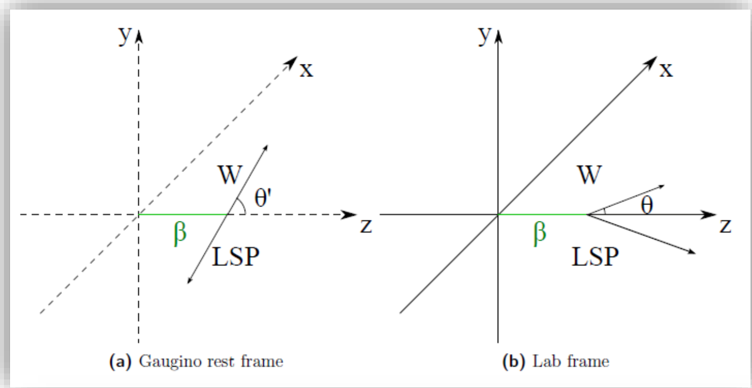
- Mass difference to LSP ($\tilde{\chi}_1^0$) is **larger** than M_Z → decays of real gauge bosons
- This is a **two-body decay** (well known kinematics!)
- In the gaugino C.M frame: *(E, p conservation)*

$$\boldsymbol{P}_\chi = \boldsymbol{P}_V + \boldsymbol{P}_{LSP} \Rightarrow \boldsymbol{P}_{LSP} = \boldsymbol{P}_\chi - \boldsymbol{P}_V$$

where $\boldsymbol{P}_\chi = (M_\chi, \vec{0})$

$$M_{LSP}^2 = M_\chi^2 + M_V^2 - (2E_\chi E_V - \vec{p}_V \vec{p}_\chi)$$

$$\boldsymbol{E_V = (M_\chi^2 + M_V^2 - M_{LSP}^2)/2M_\chi}$$ ***(boson energy)***

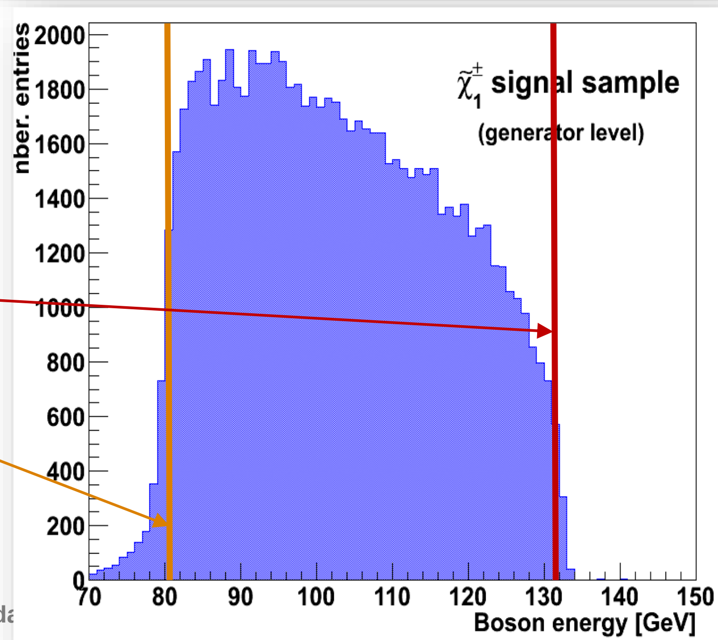


- Boosting into the lab frame:

$$E_V^{lab} = \gamma E_V + \beta\gamma \vec{p}_{V,\parallel}$$
$$= \gamma E_V + \beta\gamma |\vec{p}_V| \cos\theta'$$

$$\theta' = 0 \rightarrow E_V^{lab} = \gamma E_V + \beta\gamma\sqrt{E_V^2 - M_V^2}$$

$$\theta' = \pi \rightarrow E_V^{lab} = \gamma E_V - \beta\gamma\sqrt{E_V^2 - M_V^2}$$



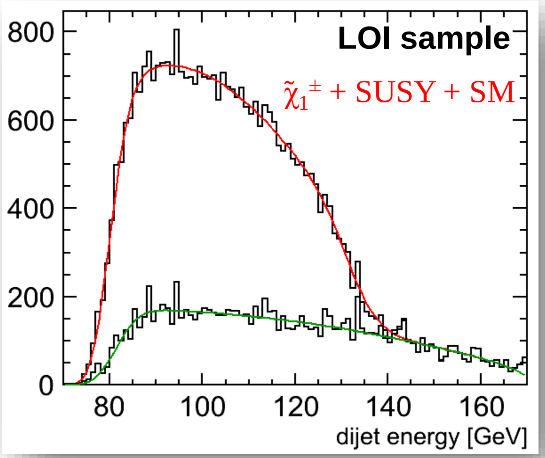
- **Use edge values to calculate gaugino masses!**
- **Two** different **strategies** for edge detection

LOI Strategy: Fit the Boson Energy Spectrum

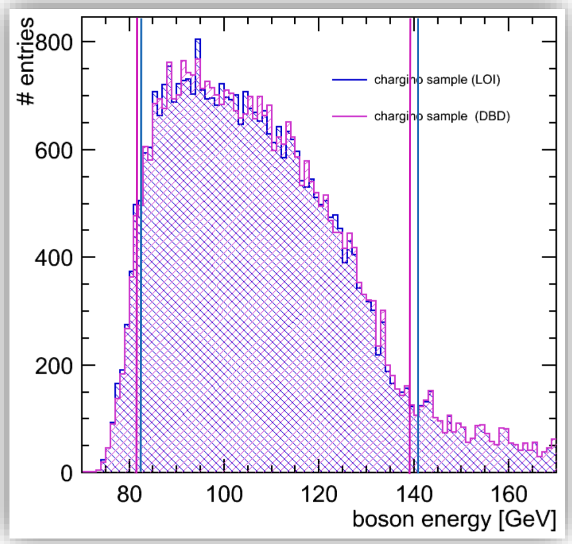
> Fit dijet energy spectrum and obtain edge positions:

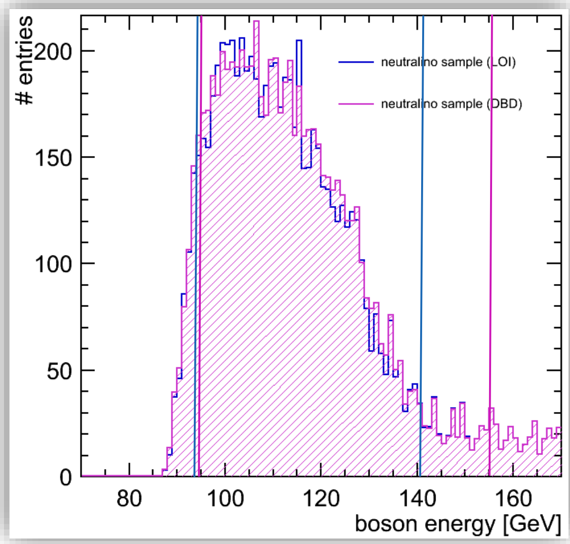
$$f(x; t_{0\_1}, b_{0\_2}, \sigma_{1\_2}, \gamma) = f_{SM} + \int_{t_0}^{t_1} (b_2 t^2 + b_1 t + b_0) V(x - t, \sigma(t), \gamma)\, dt$$

- The only free fit parameters: the edge positions t_0 and t_1
- Polynomial → Spectrum slope
- Voigt function → detector resolution and gauge boson width



> Issues with the LOI method:





Fit method highly sensitive to small fluctuations in energy distribution.

Apply a different edge extraction method!

DBD Strategy: 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.

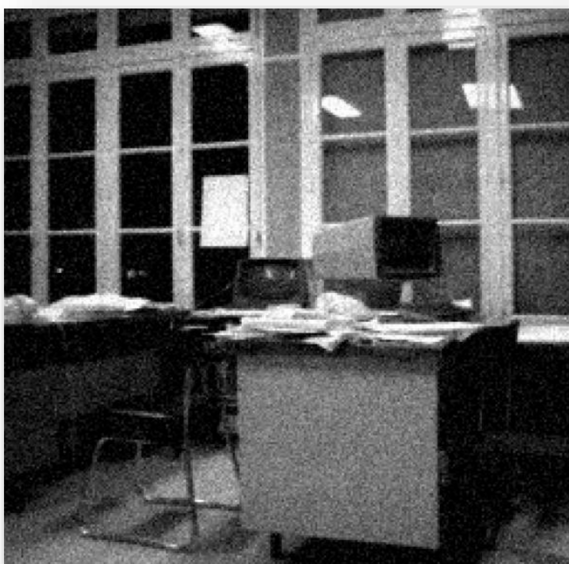
$$y[n] = \sum_{k=-M_1}^{M_2} b_k x[n-k]$$

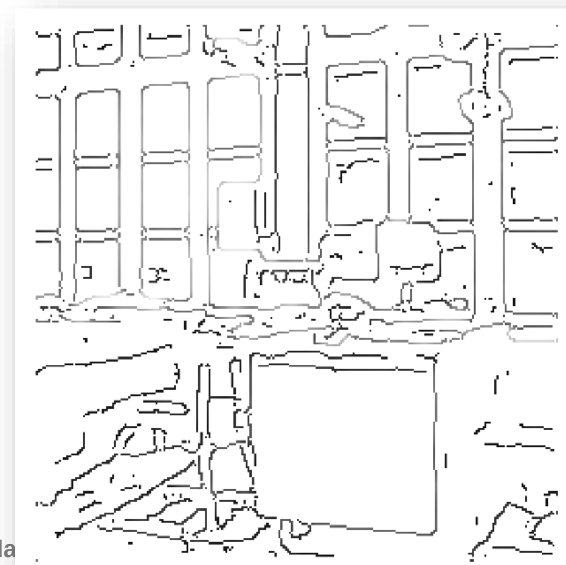
the input signal

the filter coefficients (weights)

- y is obtained by convolving the input signal with the (finite) weights

D. Demigny, T. Kamlé

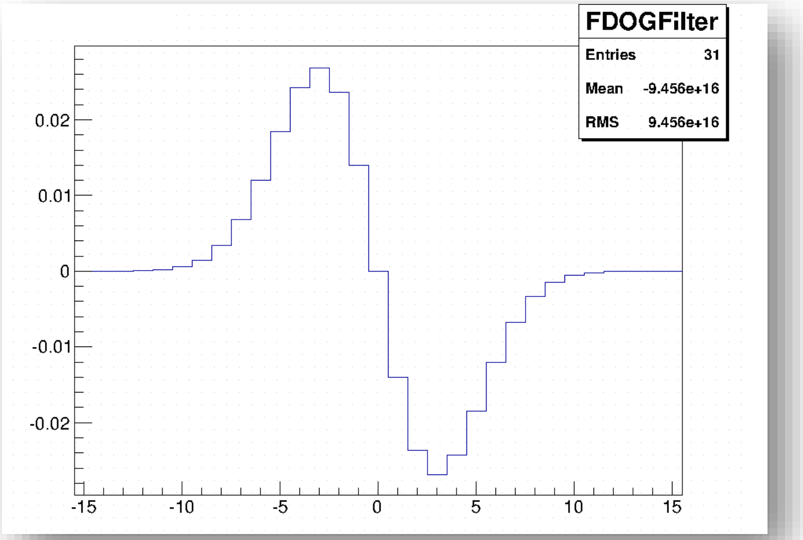




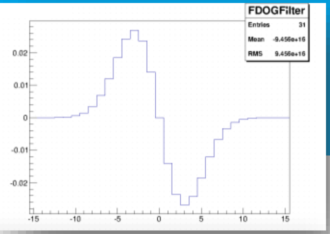
Mada

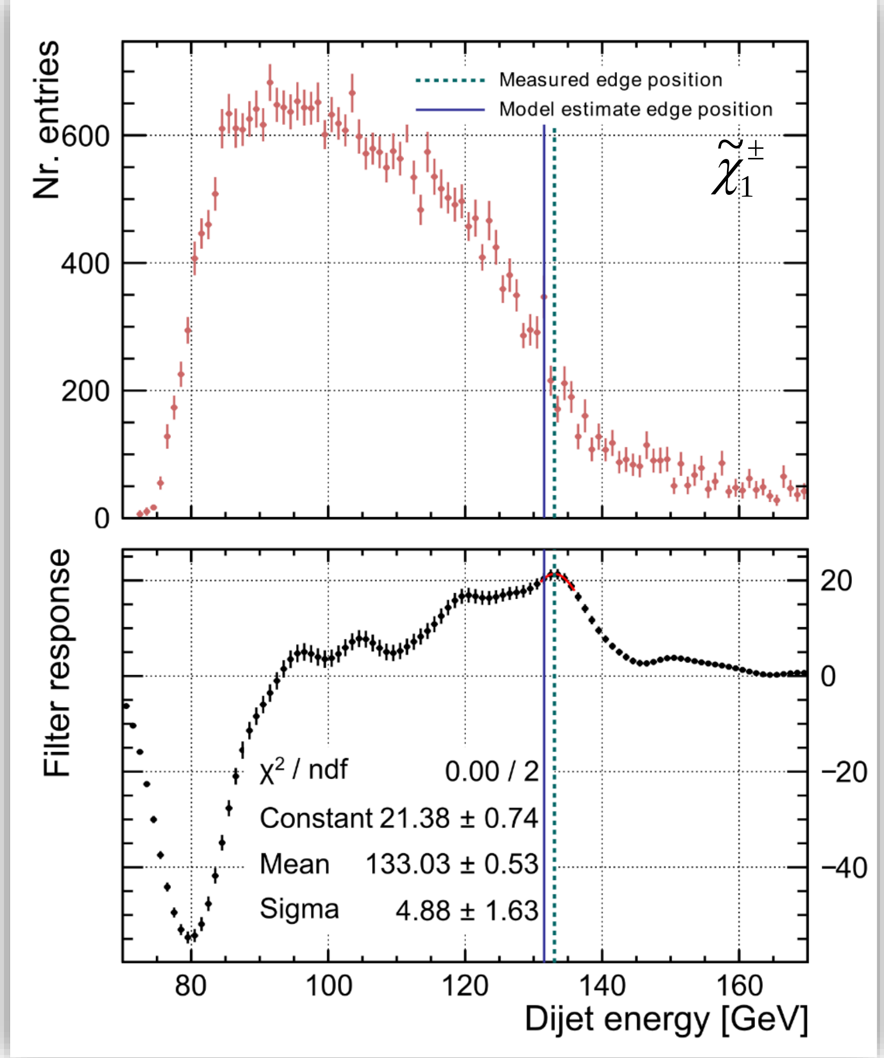
Choosing the Appropriate Filter

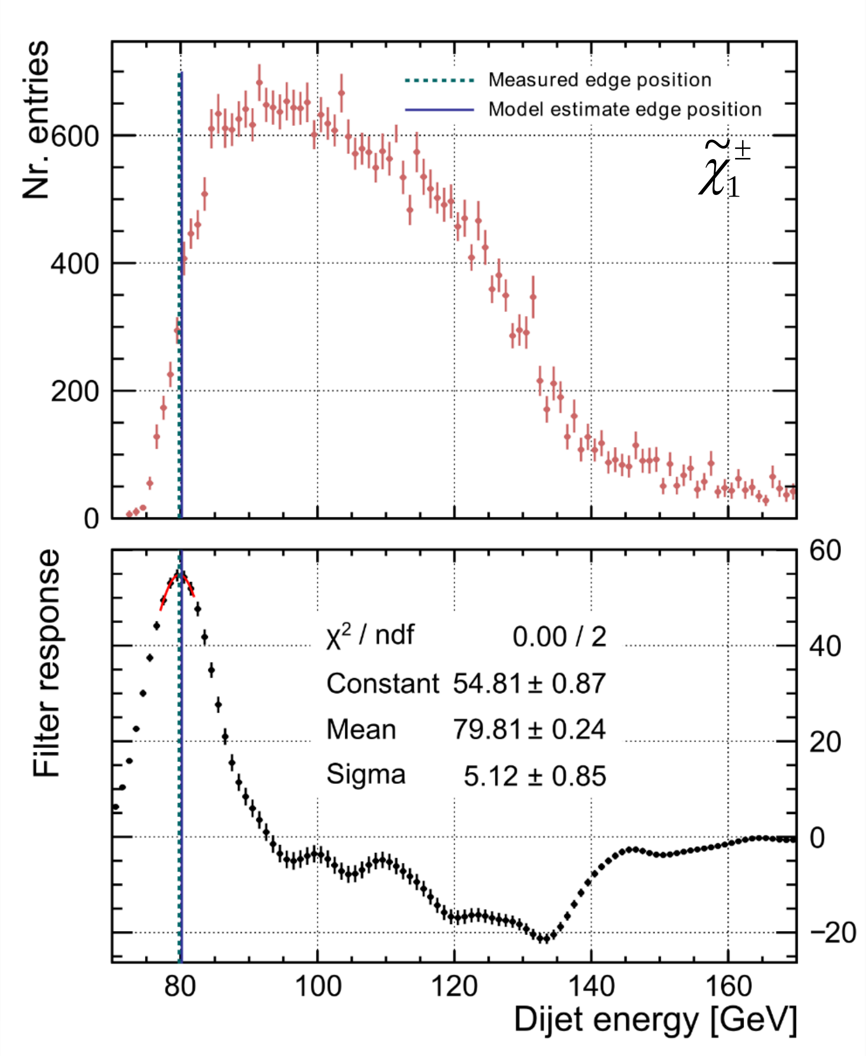
- Canny's criteria for an optimal filter:
  - *J. F. Canny*. **A computational approach to edge detection.** *IEEE Trans. Pattern Analysis and Machine Intelligence*, pages 679-698, 1986
  - **Good detection**: probability of obtaining a peak in the response must be high
  - **Localisation**: standard deviation of the peak position must be small
  - **Multiple response minimisation**: probability of false postive detection must be small
- Canny has shown that an optimal filter is very similar to the first derivative of a Gaussian



Applying the FIR Filter on DBD Data: Results







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	80.4±0.2	129.9±0.7	92.3±0.4	128.3±0.9
DBD	79.6±0.2	130.1±0.8	92.1±0.3	128.9±0.8

filter

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	216.8±3.2	220.6±1.2	118.2±0.9

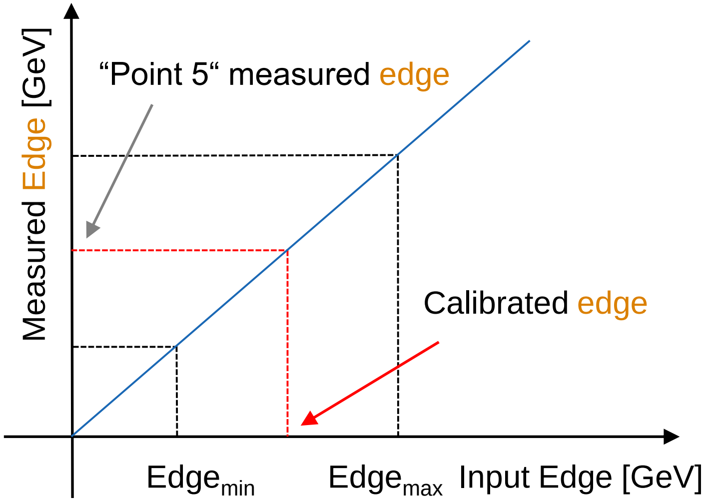
- The filter method is more stable in determining the edge position
- The mass values extracted from the LOI and DBD samples: well compatibile within their statistical errors
- The systematic errors will be addressed by a **mass calibration study**

Edge Calibration → Mass Calibration

- Performed **only** for DBD sample → account for systematics
- Calibrate the edge positions → then calculate the calibrated mass(es)
- Edge calibration procedure:
  - Vary input masses: $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ varied simultaneously, LSP mass fixed!

    M_{χ}^{min}=210 GeV ↔ M_{χ}^{max}=225 GeV, 3 GeV step
  - Measure edges for each mass sample

    → Obtain calibration curve



- Generate the **same number of signal $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ events** for all samples
- The **SM background** is the **same** for all mass samples

Edge Calibration Results I

- Three different aspects:

  1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**

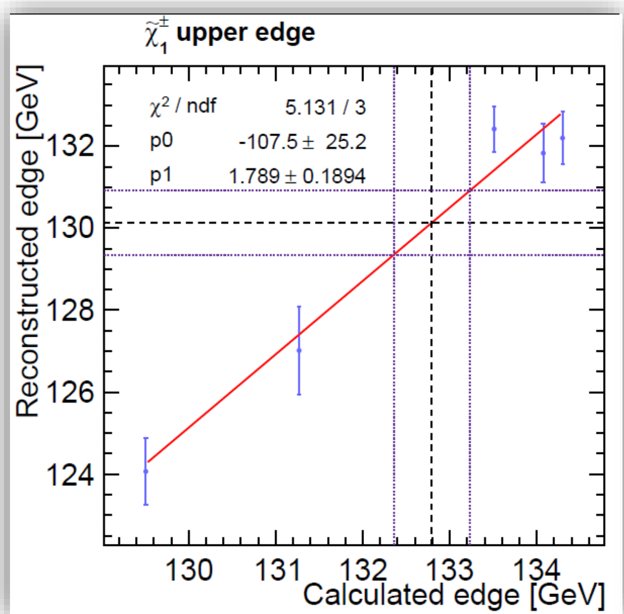
     → **study effects of ISR emission, beamstrahlung** [0.8% → 1.8%]

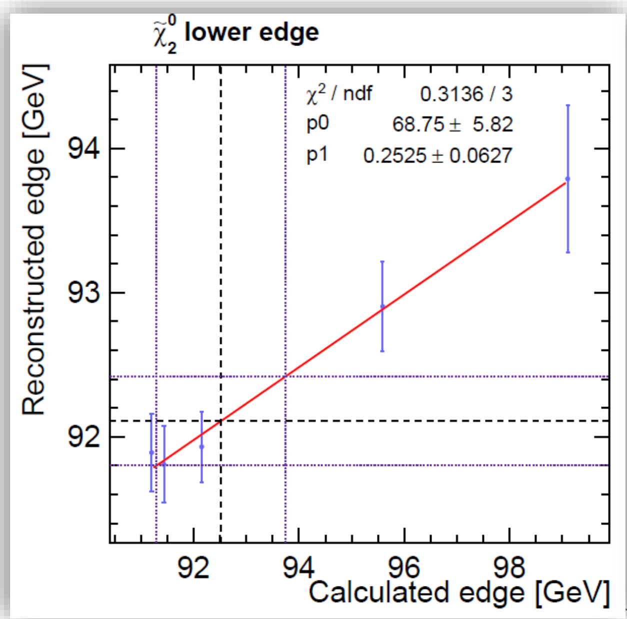
  2. Calibrate **edges** measured **on reconstruction level** w.r.t. **generator level edges**

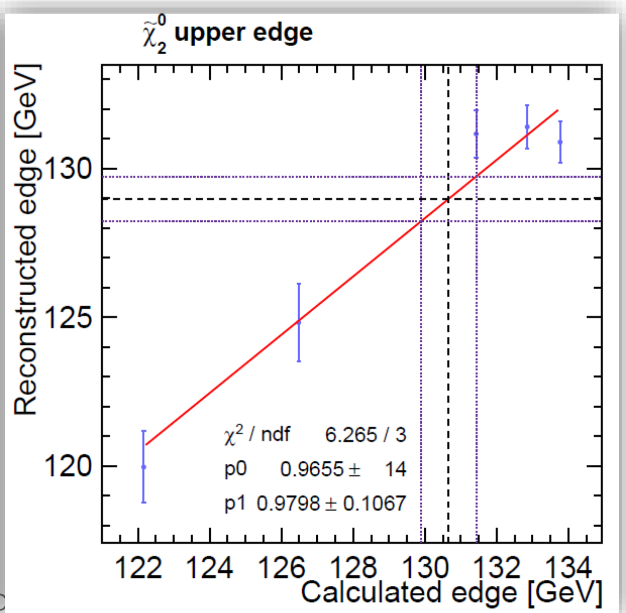
     → **study simulation and reconstruction effects** [**0.2% → 0.9%**]

  3. Calibrate **edges** measured **on reconstruction level** w.r.t **calculated edges**

     → **take all the effects into account**







Edge Calibration II

- Three different aspects:

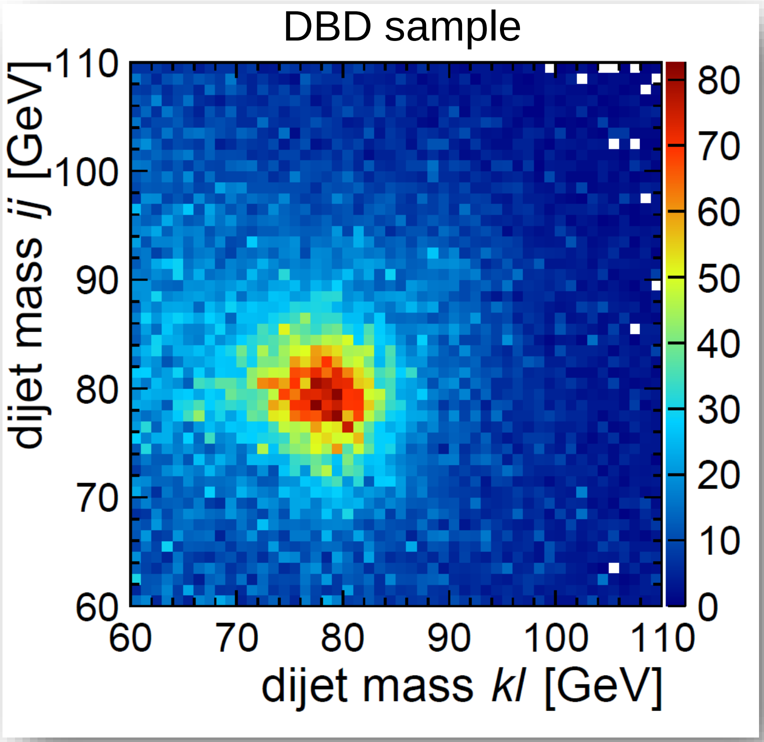
1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**
   - → **study effects of ISR emission, beamstrahlung** **[**0.8% → 1.8%**]**
2. Calibrate **edges** measured **on reconstruction level** w.r.t. **generator level edges**
   - → **study simulation and reconstruction effects** **[0.2% → 0.9%]**
3. Calibrate **edges** measured **on reconstruction level** w.r.t **calculated edges**
   - → **take all the effects into account** **[**1.1 → 2%**]**

Gaugino	Mass w/out cal.	Mass with calib.	LOI Mass	Model Mass
$\tilde{\chi}_1^{\pm}$	216.7 ± 3.1	214.1 ± 4.8	220.9 ± 2.9	216.5 [GeV]
$\tilde{\chi}_2^0$	220.4 ± 1.3	216.9 ± 3.4	220.6 ± 1.7	216.7 [GeV]
$\tilde{\chi}_1^0$	118.1 ± 0.9	115.5 ± 1.8	118.9 ± 1.0	115.7 [GeV]

Cross Section Measurement

Cross Section Determination Method

- Interested in: $\sigma(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-) \times \mathrm{BR}\,(\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-)$
  $\sigma(e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0) \times \mathrm{BR}(\tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 Z^0 Z^0)$
- Relevant observable: the reconstructed dijet [boson] mass
- Relevant distribution: the reconstructed mass of one dijet pair versus the other:
  - **AFTER** applying all selection cuts
  - Considering only those events for which the kinematic fit has converged
  - Including **all** possible dijet associations



The total distribution (SUSY + SM)

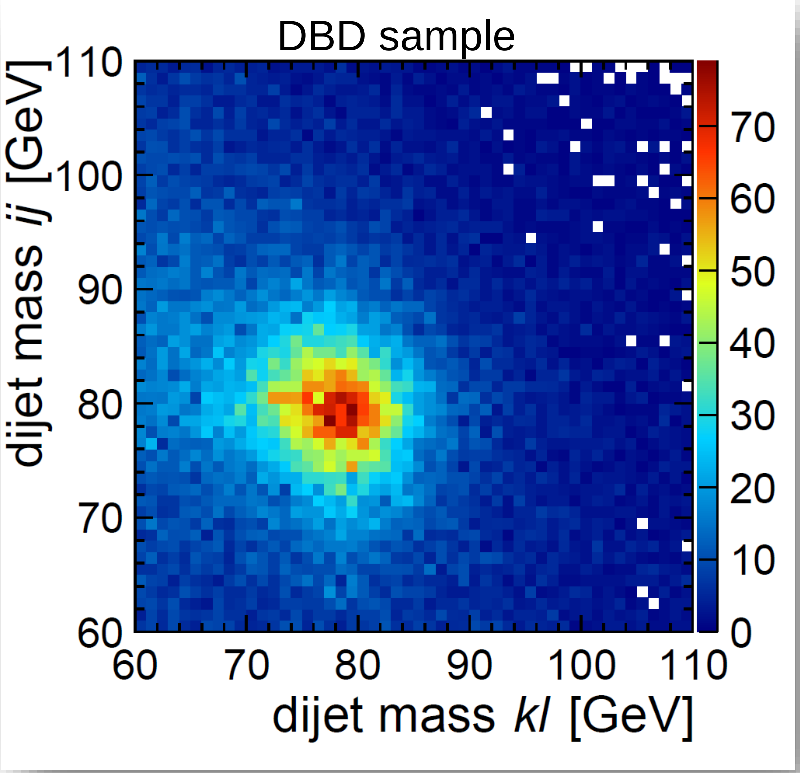
- Since $\sigma \propto \frac{Nr.events}{\varepsilon \cdot \int \mathcal{L}} \Rightarrow$ the goal is to identify the number of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ events from the total distribution

→ Perform 2D Template fit.

Cross Section: 2D Template Fit

> Use Monte Carlo data to produce:
  - the chargino template

- After preselection
- Kinematic fit converged
- All dijet permutations included

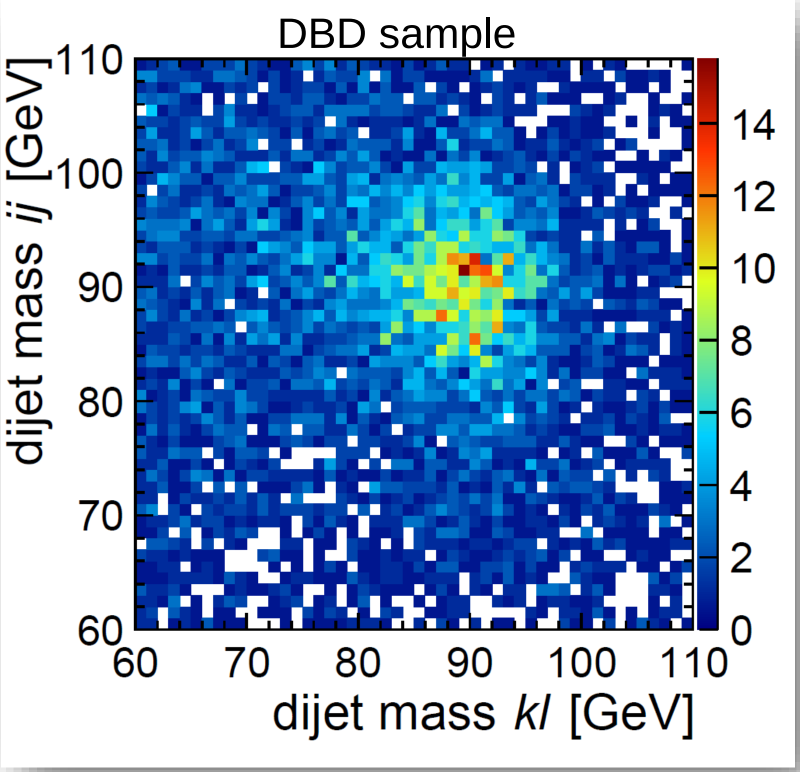


Chargino events only

Cross Section: 2D Template Fit

> Use Monte Carlo data to produce:
  - the chargino template
  - the neutralino template

- After preselection
- Kinematic fit converged
- All dijet permutations included

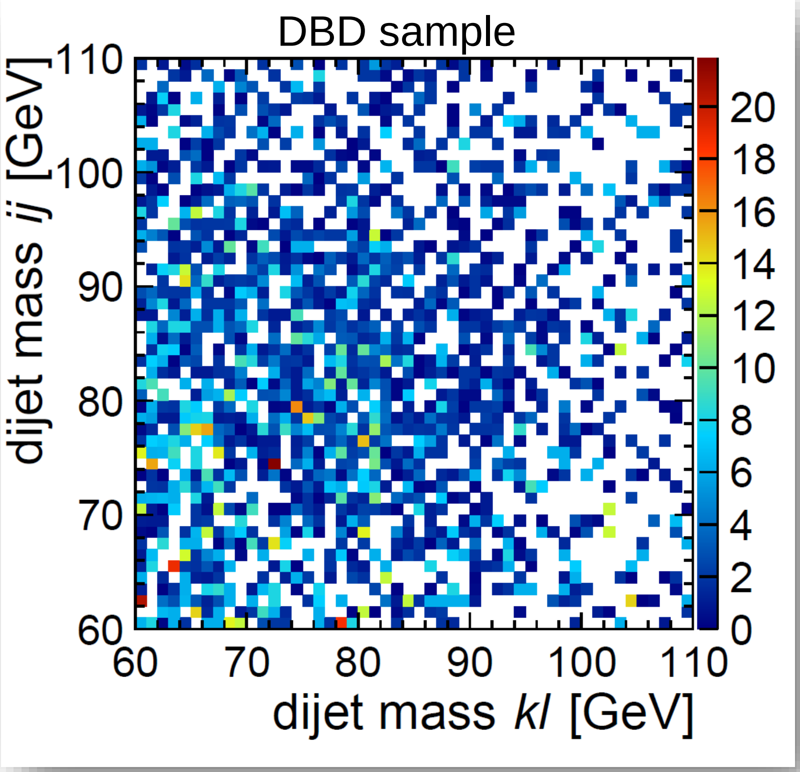


Neutralino events only

Cross Section: 2D Template Fit

> Use Monte Carlo data to produce:
  - the chargino template
  - the neutralino template
  - the SM background template

- After preselection
- Kinematic fit converged
- All dijet permutations included

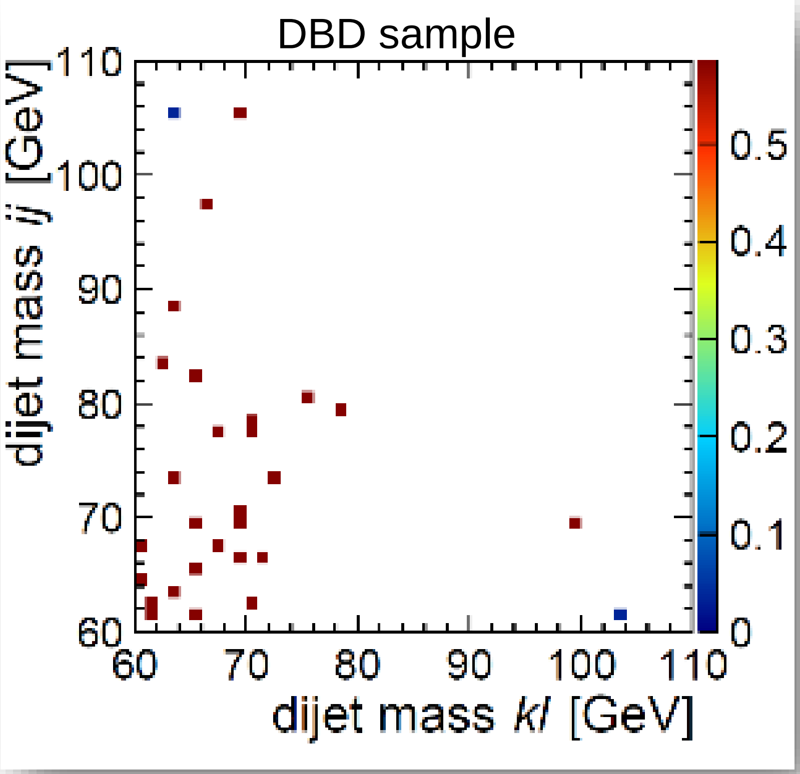


Standard Model events only

Cross Section: 2D Template Fit

- Use Monte Carlo data to produce:
  - the chargino template
  - the neutralino template
  - the SM background template
  - the SUSY background → **negligible**!

- After preselection
- Kinematic fit converged
- All dijet permutations included

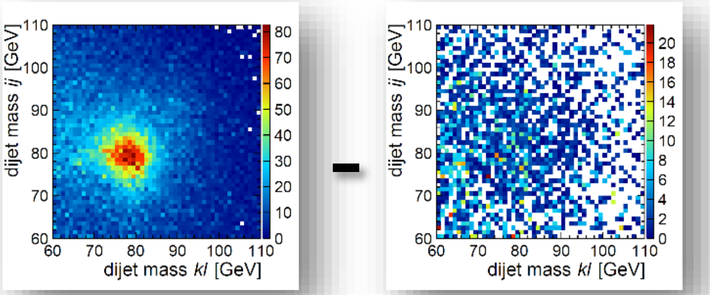


SUSY background events only

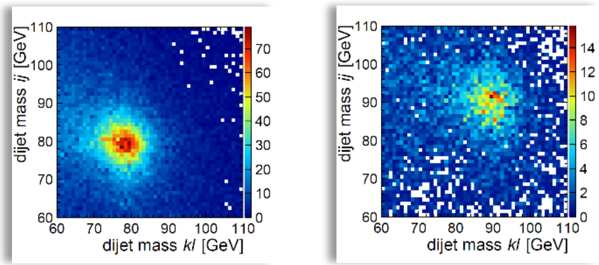
Cross Section: 2D Template Fit

- The fitting procedure:

> Subtract the SM background template from the total data distribution



> Defining the two-dimensional fitting function:



$$f_{Fit}(x,y) = a \cdot f_{\tilde{\chi}_1^{\mp}}(x,y) + b \cdot f_{\tilde{\chi}_2^0}(x,y)$$

- a and b → the only free parameters
- a and b = the fraction of template events found in the total data distribution
- in an ideal case, a = b =1

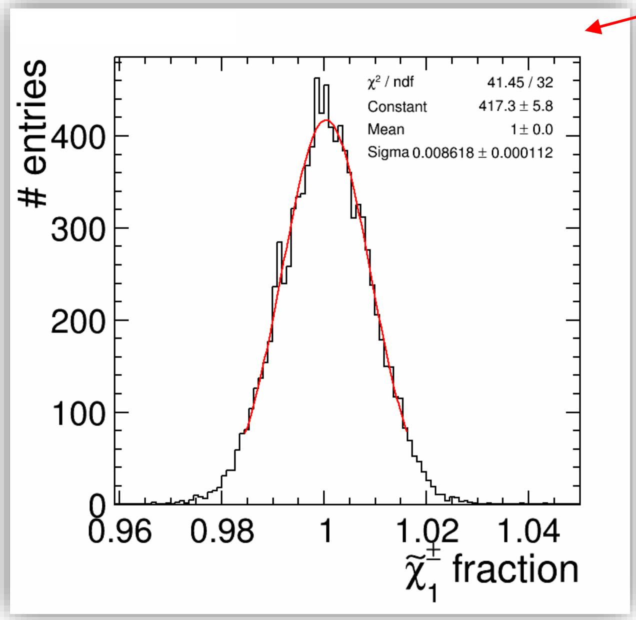
> Apply the template fit on the remaining data events

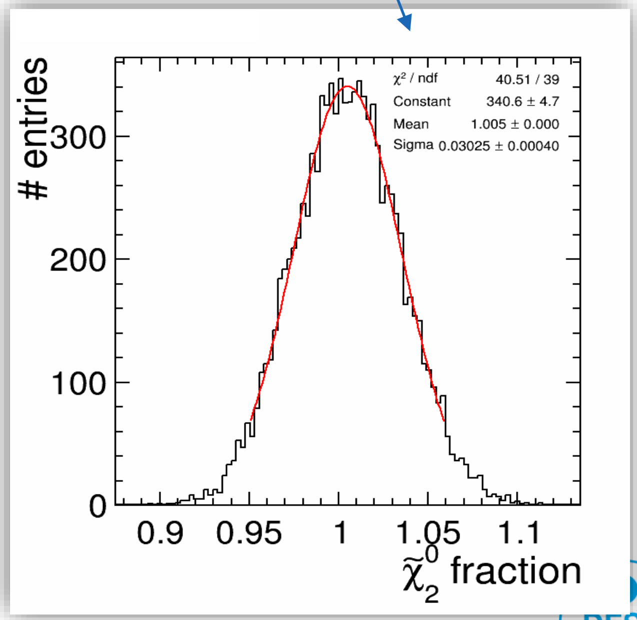
2D Template Fit Toy Monte Carlo

> **Note:** limited amount of Monte Carlo data available → **toy Monte Carlo study**

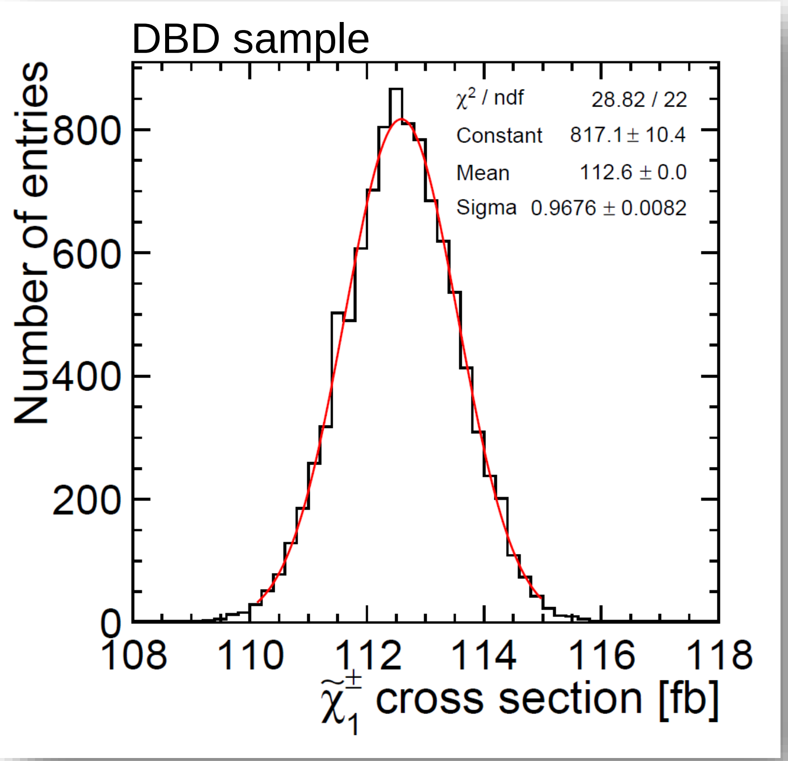
> **Running the toy MC:**

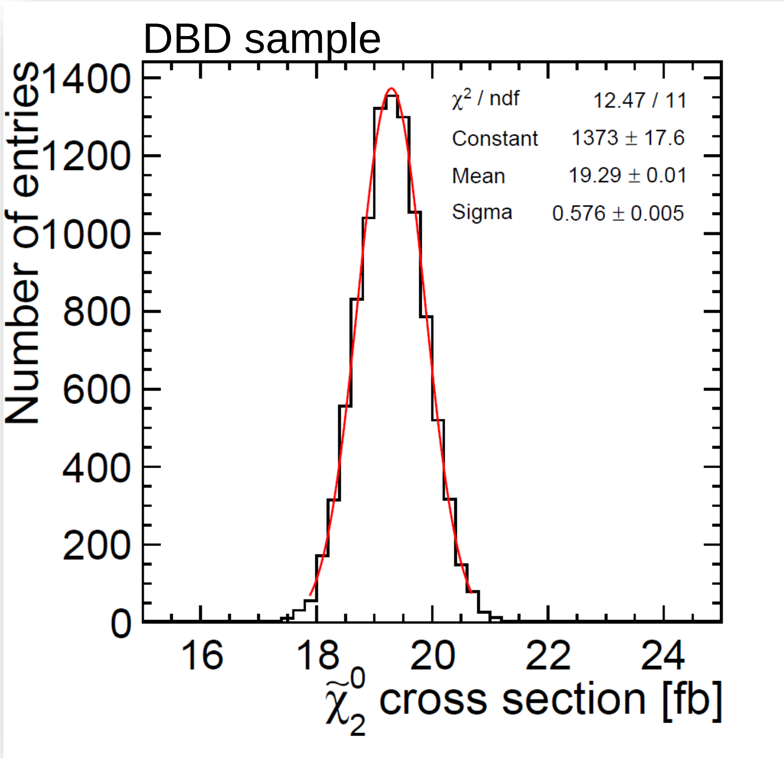
- Treat the total data distribution as a p.d.f
- Randomly sample the initial distribution N times: $N = N_{evts.}^{initial} \pm \sqrt{N_{evts.}^{initial}}$
- Subtract the SM template from the new distribution
- Apply the fitting function → obtain one value each for a and b
- Repeat procedure 10000 times





2D Template Fit: Results





$$a_{mean} = 1.00 \pm 0.009$$
$$b_{mean} = 1.01 \pm 0.03$$

Sample	$\tilde{\chi}_1^{\pm}$ x- section [fb]	$\tilde{\chi}_2^0$ x-section [fb]
Generator	112.54	19.2
DBD	112.6 ± 0.97	19.3 ± 0.58

Cross Section: 2D Template Fit – Comparison to LOI

> The same procedure has been applied to the LOI data:

Sample	$\tilde{\chi}_1^{\pm}$ x- section [fb]	$\tilde{\chi}_2^0$ x-section [fb]
Generator level	132.2	22.8
LOI	132.2 $\pm$1.1	23.2 $\pm$0.7
arXiv:0906.5508v2	132.9 $\pm$ 0.9	22.5 $\pm$ 0.5

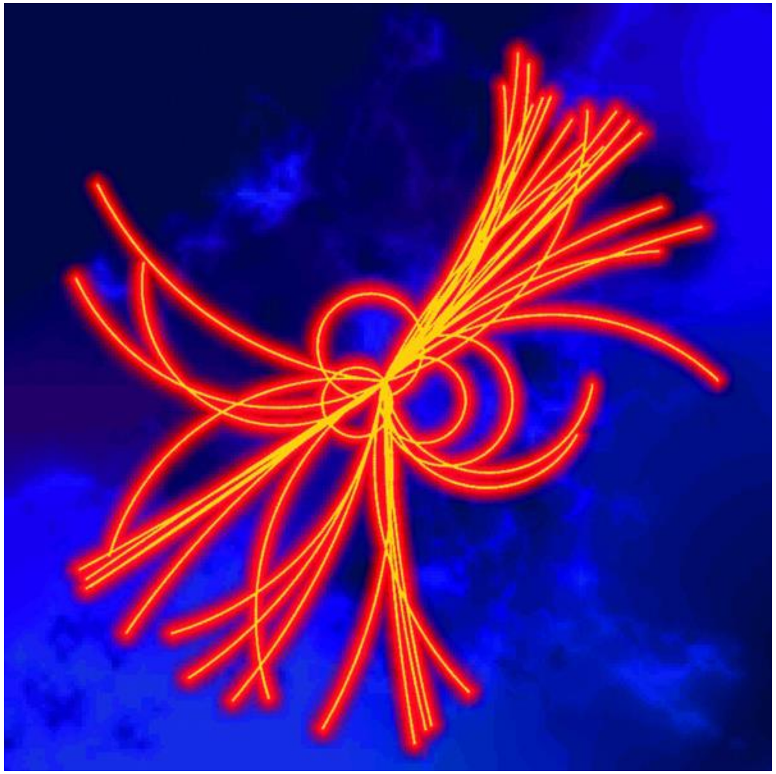
Sample	$\tilde{\chi}_1^{\pm}$ x- section [fb]	$\tilde{\chi}_2^0$ x-section [fb]
Generator level	112.5	19.2
DBD	112.6 $\pm$ 0.97	19.3 $\pm$ 0.6

- **Note** **-** the difference between cross sections at generator level
  - Difference in beam-spectrum
  - Missing processes - Whizard 1.95

Conclusions

- 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.
- **Mass measurements**:
  - LOI fitting method for edge measurement very sensitive to small changes
  - Applying a finite impulse response (FIR) filter instead: more robust (i.e., independent on distribution shape), provides just as good if not better statistical precision.
  - A mass calibration procedure was performed for the DBD sample: **beam related effects twice as large effect as sim. + reco. impact!**
- **Cross section measurements**:
  - A 2D template fitting procedure for cross-section determination was presented.
  - Due to limited amounts of available Monte Carlo data perform a toy Monte Carlo study.
  - Procedure applied both on LOI as well as on DBD data.
  - Mean cross-section values very close to the model values in both cases → cross-check for the procedure performance.
  - Despite increased detector realism and addition of $\gamma\gamma$ background statistical uncertainties are very similar for both data samples: ≈1% for $\tilde{\chi}_1^\pm$ and ≈ 3% for $\tilde{\chi}_2^0$.

Thank You!

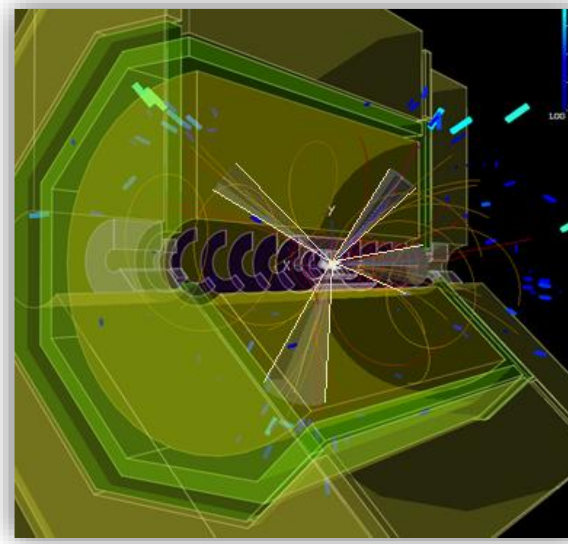


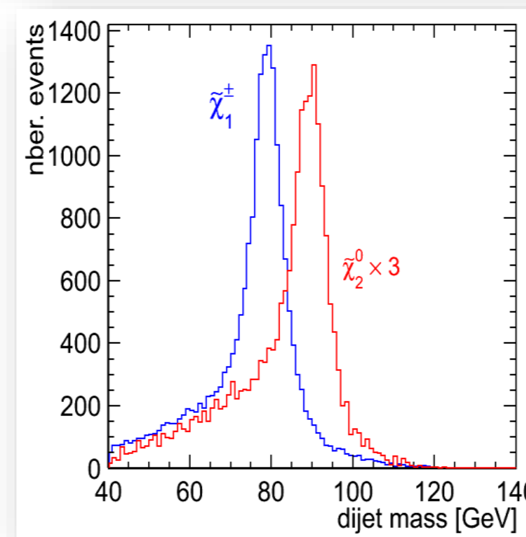
Study Case - Motivation

- 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
- **Challenge detector and particle flow performance**





Data Samples:

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

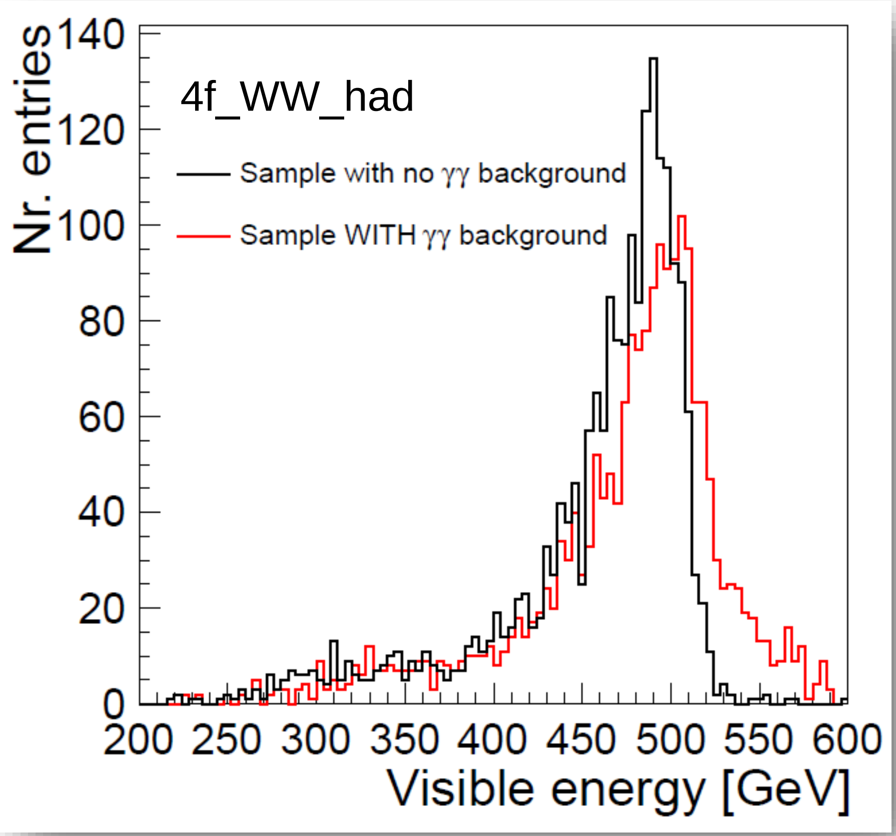
LOI sample:	**DBD sample:**
Signal generated with `Whizard1.51` Background generated with `Whizard1.40`	Signal (as well as SM background) generated with `Whizard 1.95`
The RDR beam spectrum was used	The TDR beam spectrum was used

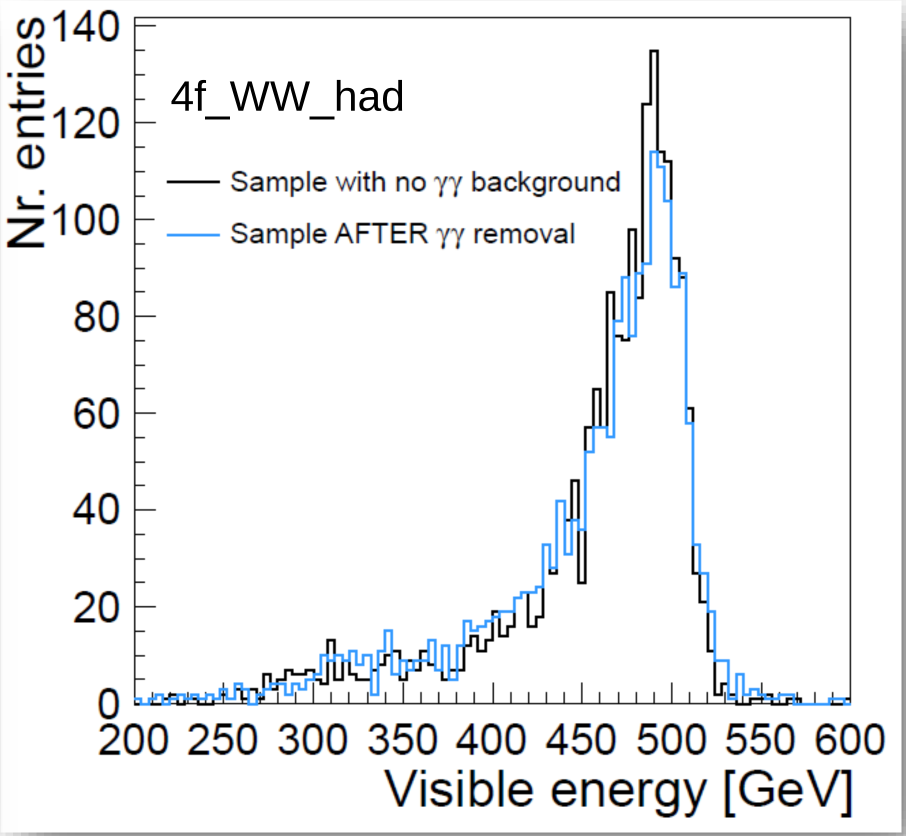
- **Note:** in the signal samples, the M_W was inadvertently lowered by Whizard to M_W = 79.8 GeV

	Some processes could not be produced in Whizard 1.95
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 run on existing data samples	The analysis was run

Analysis Strategy

- Remove $\gamma\gamma \rightarrow$ hadrons background: applied k_T exclusive algorithm ↔ 6 jets, R=1.1 (FastJet)





Cutflow

Sample	$\tilde{\chi}_1^\pm$ hadronic (signal)	$\tilde{\chi}_2^0$ hadronic (signal)	SUSY background	$\gamma\gamma$ & γe (SM)	2 fermions (SM)	4 fermions (SM)	6 fermions (SM)
No cut	27427	4897	71450	173791	1.1239e+07	1.60385e+07	589188
No isolated leptons found	27281	4857	39592	51136	1.02105e+07	9.21406e+06	372419
Nber. PFOs in event	27274	4853	28936	38553	8.61602e+06	6.73891e+06	311637
Nber. tracks with P_T > 1 GeV in event	27228	4851	25530	34803	7.60753e+06	6.22246e+06	282188
Thrust	27213	4845	24996	34347	4.57776e+06	4.9343e+06	281913
Nber. tracks in event	27193	4841	23049	33647	4.27554e+06	4.81107e+06	281652
Visible energy	27159	4831	20935	21830	2.88111e+06	926895	17059
Jet energy	27141	4829	17895	21360	2.55856e+06	846448	16914
Jet cos(θ)	26530	4729	15964	17582	1.78384e+06	607998	16049
y_{34}	26372	4704	11202	16231	330943	299658	14892
Nber tracks in jet	25434	4585	8083	14666	261520	205867	12125
Miss cos(θ)	25171	4535	8020	4489	9171	117756	11656
Lepton energy	24913	4460	7749	4281	8432	109365	10121
Nber. PFOs in jet	24737	4444	7305	4148	8253	102304	9783
Miss cos(θ)	19868	3589	6135	1383	1100	53957	6955
Missing mass	19830	3584	6134	1175	931	41326	1764
Kinematic fit converged	19753	3565	5966	1152	839	40263	1749

Blue: selection for the mass measurement
Red: selection for the cross section measurement

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

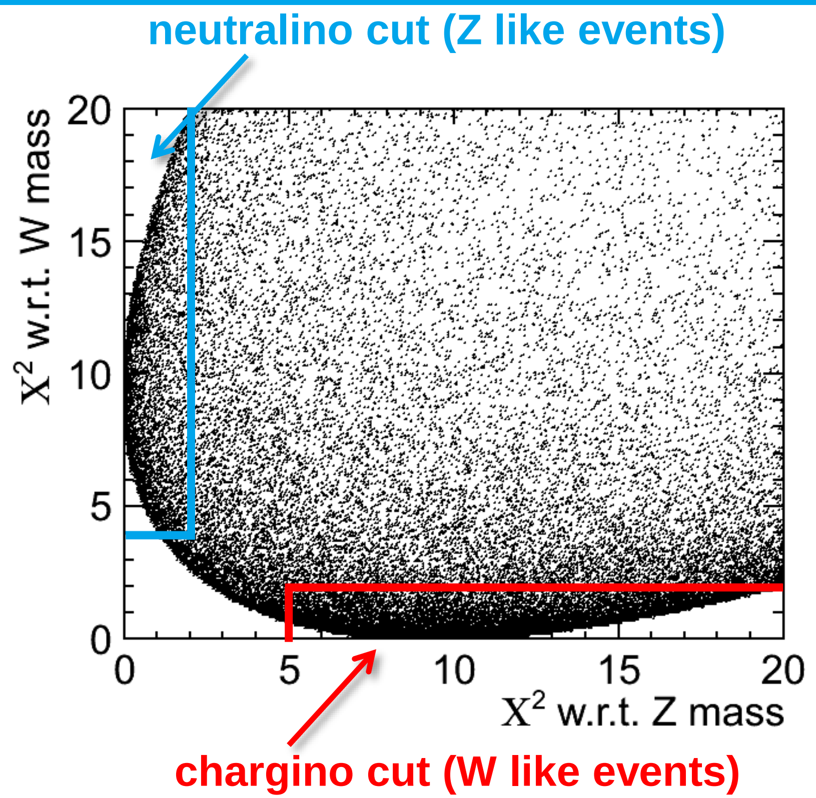
- Calculate χ^2 with respect to nominal W / Z mass

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

⇩

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

- Downside: lose statistics
  - Cut away 47% of $\tilde{\chi}_1^{\pm}$ surviving events
  - Cut away 61% of $\tilde{\chi}_2^0$ surviving events
- However, after the χ^2 cut, the separation is quite clear:

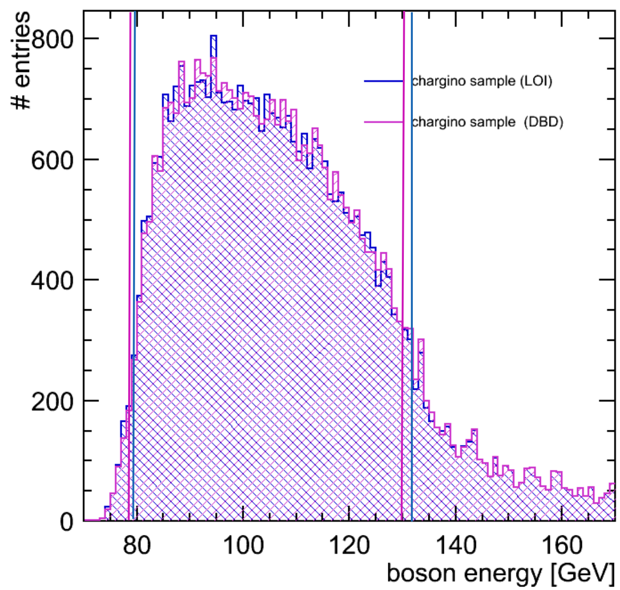


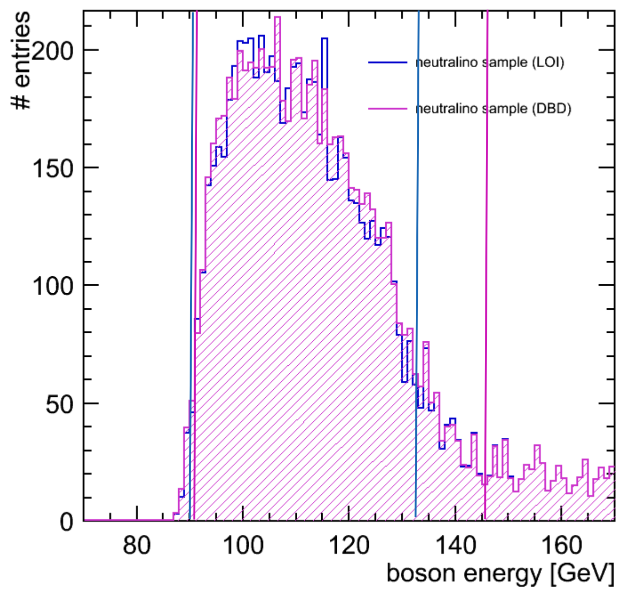
Sample	$\tilde{\chi}_1^{\pm}$ hadronic	$\tilde{\chi}_2^0$ hadronic
Efficiency	90.8%	91%
Purity	14.7%	2.6%

→

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

Issues of the LOI Strategy



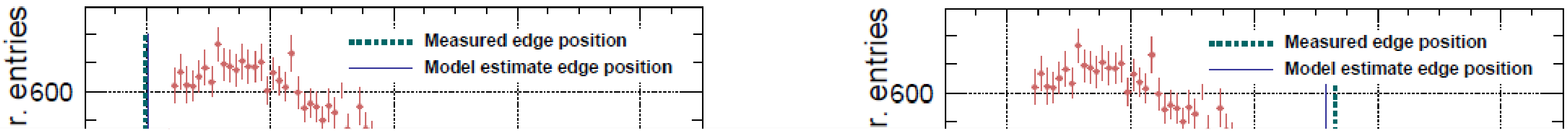


Sim.	Edge W_{low} [GeV]	Edge W_{high} [GeV]	Edge Z_{low} [GeV]	Edge Z_{high} [GeV]
DBD	79.5±0.5	130.2±1.1	91.3±0.6	146.1±4.8
LOI	79.7±0.3	131.9±0.9	91.0±0.7	133.6±0.5

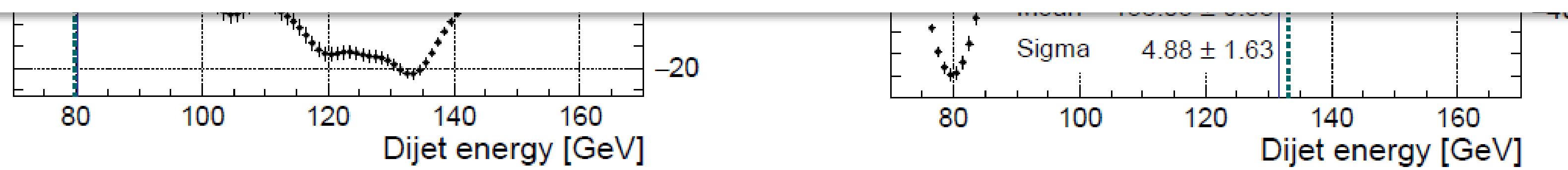
The fitting method appears to be highly dependent on small changes in the fitted distribution → it is NOT appropriate for comparing the two samples.

We need to apply a different edge extraction method!

Applying the FIR Filter on DBD Data: Results



	Calc.	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]**
fit	LOI	79.7±0.3	131.9±0.9	91.0±0.7	133.6±0.5
fit	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	79.6±0.2	130.1±0.8	92.1±0.3	128.9±0.8

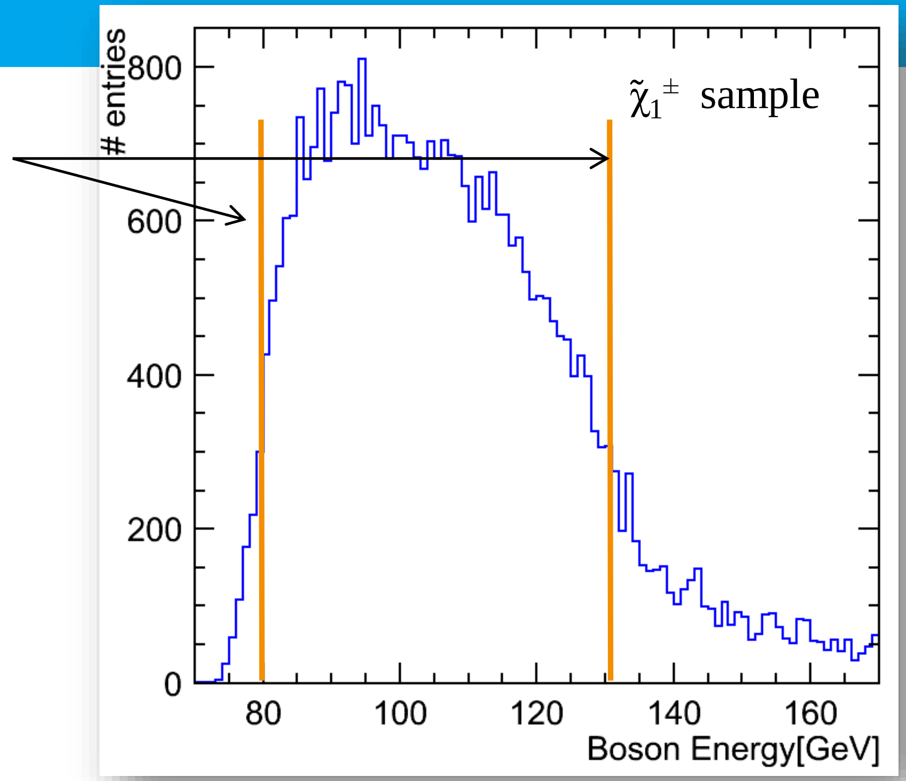


- **Statistical errors determined from toy Monte Carlo**

DESY

Applying an FIR Filter

- Goal: find edge positions in spectrum



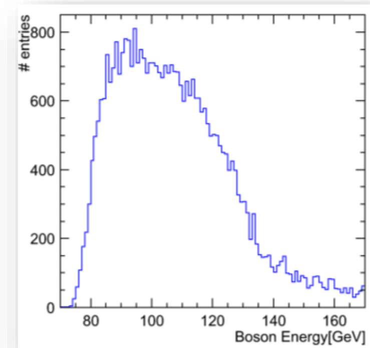
Applying an FIR Filter

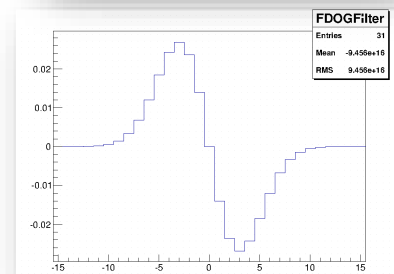
Thanks to S. Caiazza.

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter (kernel)
  - 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





Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter (kernel)
  - 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

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

DESY

Applying an FIR Filter

- Goal: find edge positions in spectrum
- Strategy:
  - Choose an FIR filter (kernel)
  - 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

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

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

Applying an FIR Filter

- Goal: find edge positions in spectrum
- Procedure:
  - Choose an FIR filter (kernel)
  - 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

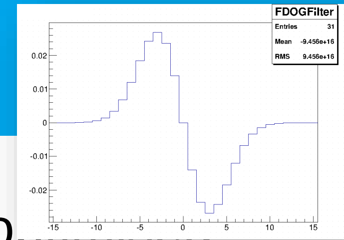
$$0 \times 15 + 0.01 \times 28 + \ldots = \mathrm{val2}$$

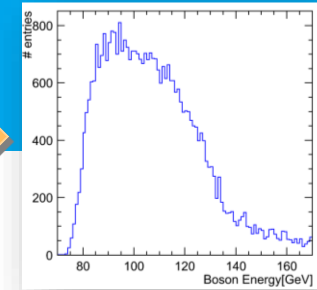
  - **“Move“ Filter along the (length) of the signal → obtain more values, which will form the total filter response**

FDOG Filter Optimisation

- There are 3 filter parameters that can be optimised
  - The width of the Gaussian (σ)
  - The kernel size (# bins of the filter histogram)
  - The binning of the input boson energy histogram

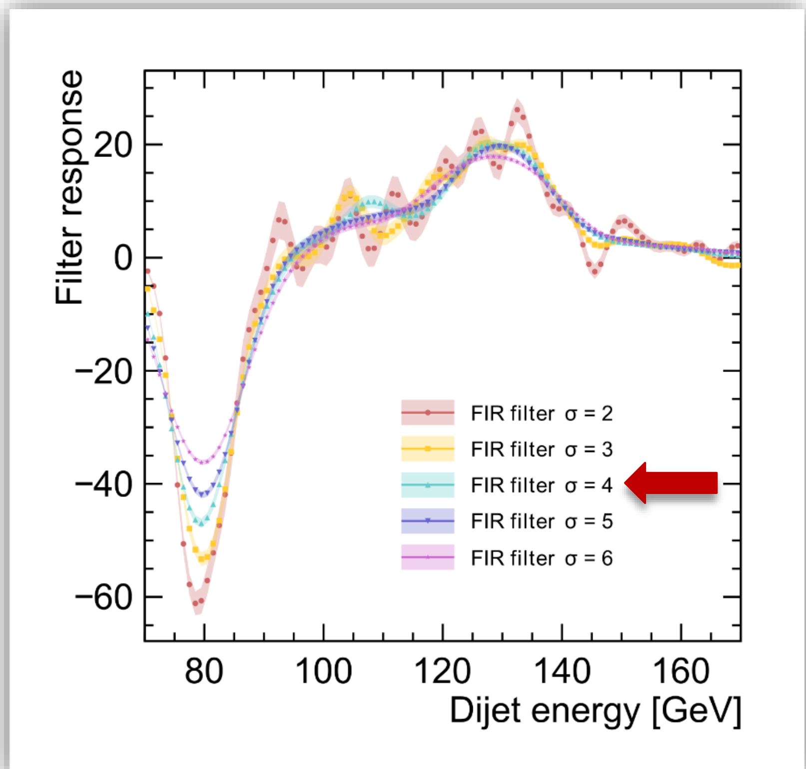
FDOG Filter Optimisation



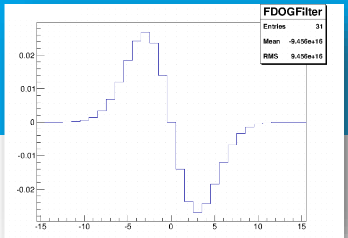


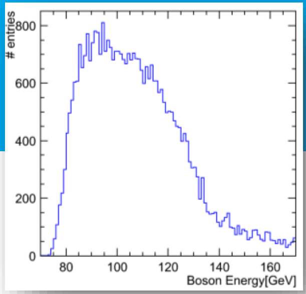
- There are 3 filter parameters that can be optimised
  - **The width of the Gaussian (σ)**
  - The kernel size (# bins of the filter histogram)
  - The binning of the input boson energy histogram

(the kernel and bin sizes were fixed)

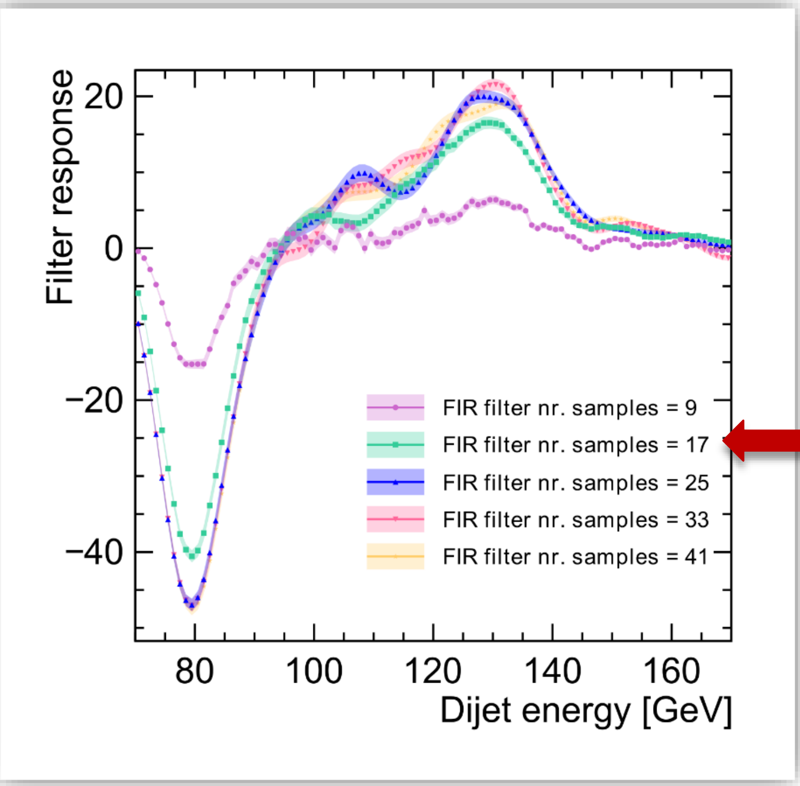


FDOG Filter Optimisation

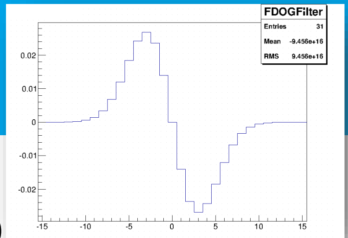


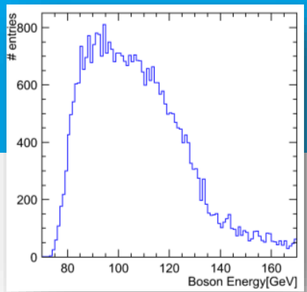


- There are 3 filter parameters that can be optimised
  - The width of the Gaussian (σ) = 4
  - **The kernel size (# bins of the filter histogram)** *(the σ and bin sizes were fixed)*
  - The binning of the input boson energy histogram

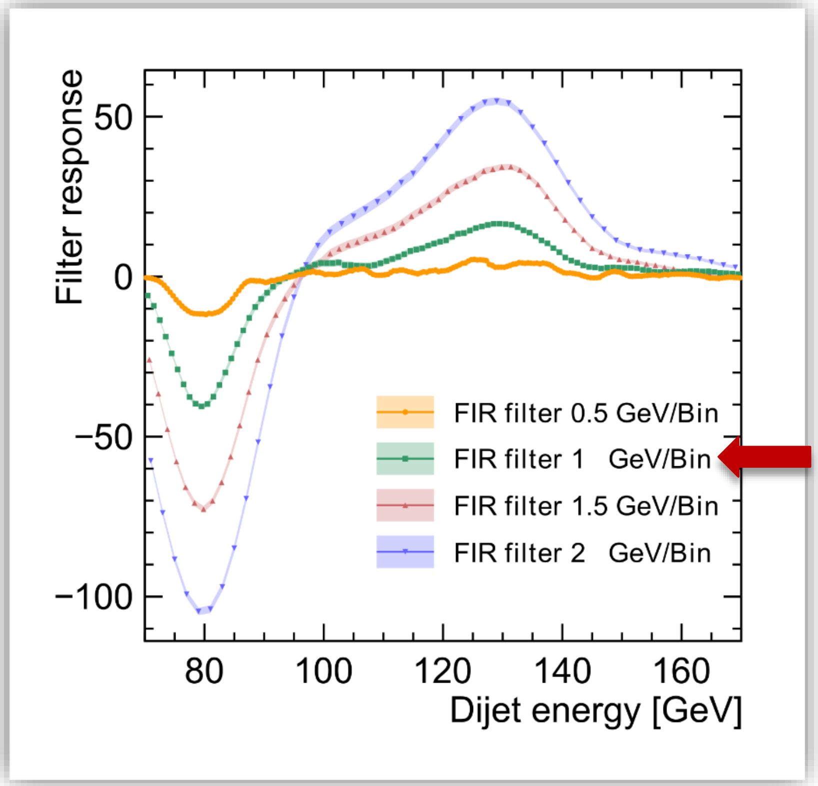


FDOG Filter Optimisation





- There are 3 filter parameters that can be optimised
  - The width of the Gaussian (σ) = 4
  - The kernel size (# bins of the filter histogram) = 17
  - **The binning of the input boson energy histogram** ***(the σ and kernel sizes were fixed)***

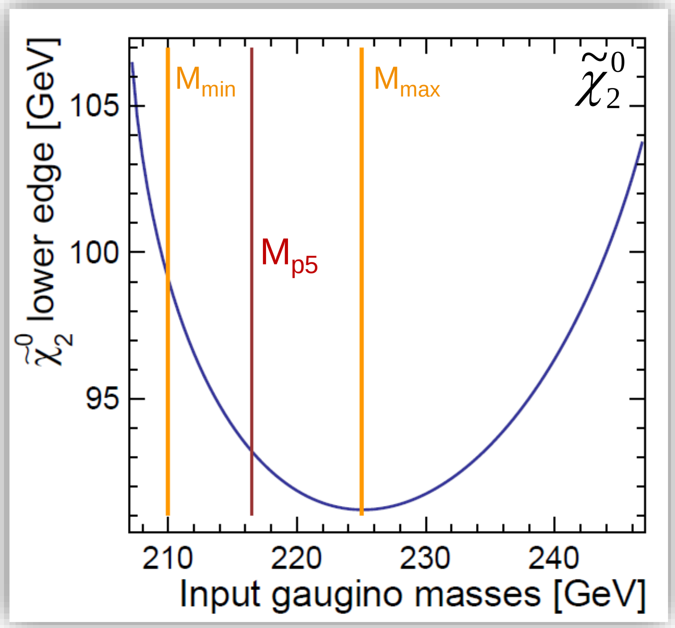


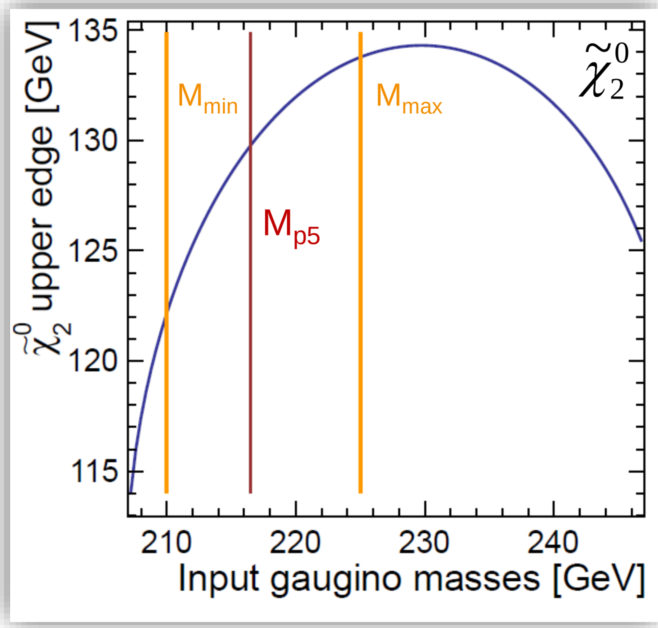
Edge Calibration

- The relation edge position ↔ input gaugino mass is given by:

$$E_V = \frac{M_\chi^2 + M_V^2 - M_{LSP}^2}{2M_\chi} \quad \text{and} \quad E_V^{lab} = \gamma E_V \pm \beta\gamma\sqrt{E_V^2 - M_V^2}$$

(NO ISR, beamstrahlung...)

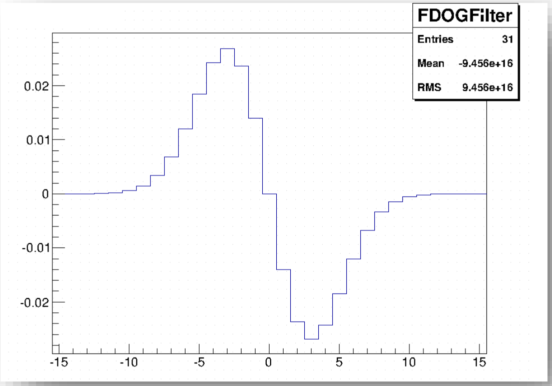




- Ignore $\tilde{\chi}_1^\pm$ low edge
- Chosen mass range: M_χ^{min}=210 GeV ↔ M_χ^{max}=225 GeV, in steps of 3 GeV
- Generate the **same number of signal $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ events** for all samples
- The **SM background** is the **same** for all mass samples

Choosing the Appropriate Filter

- Canny's criteria for an optimal filter:
  - *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 shown that an optimal filter is very similar to the first derivative of a Gaussian



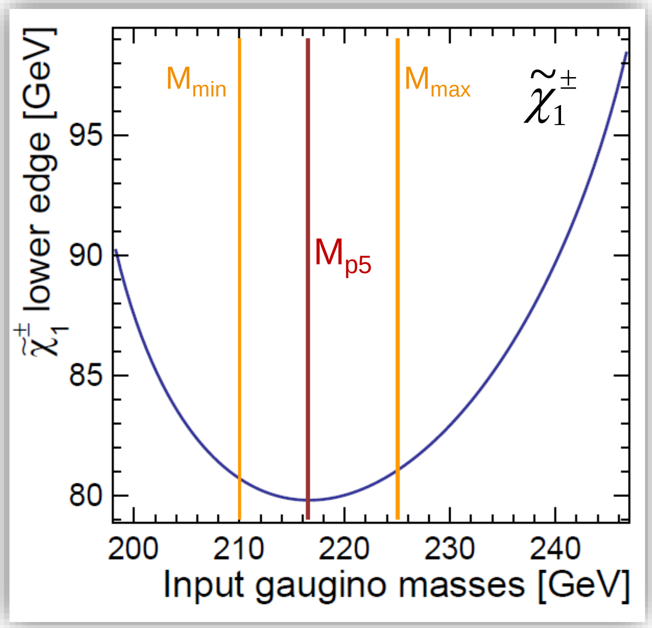
- There are 3 filter parameters that can be optimised (via toy Monte Carlo)
  - The width of the Gaussian (σ) = **4**
  - The kernel size (# bins of the filter histogram) = **17**
  - The binning of the input boson energy histogram = **1 GeV/bin**
- Edge positions stable within max.1.8% when varying filter parameters
- (Reminder: LOI edge fluctuations [from LOI vs DBD comparison]: 9.4%)

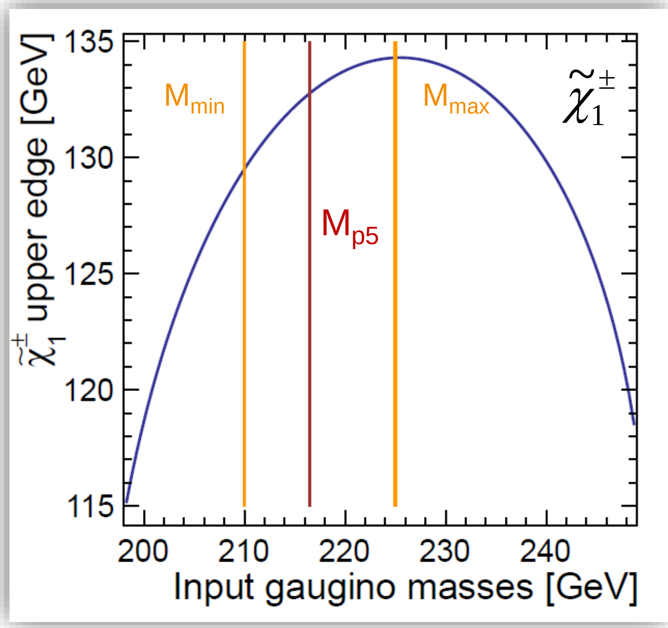
Edge Calibration

- The relation edge position ↔ input gaugino mass is given by:

$$E_V = \frac{M_\chi^2 + M_V^2 - M_{LSP}^2}{2M_\chi} \quad \text{and } E_V^{lab} = \gamma E_V \pm \beta\gamma\sqrt{E_V^2 - M_V^2}$$

(NO ISR, beamstrahlung...)



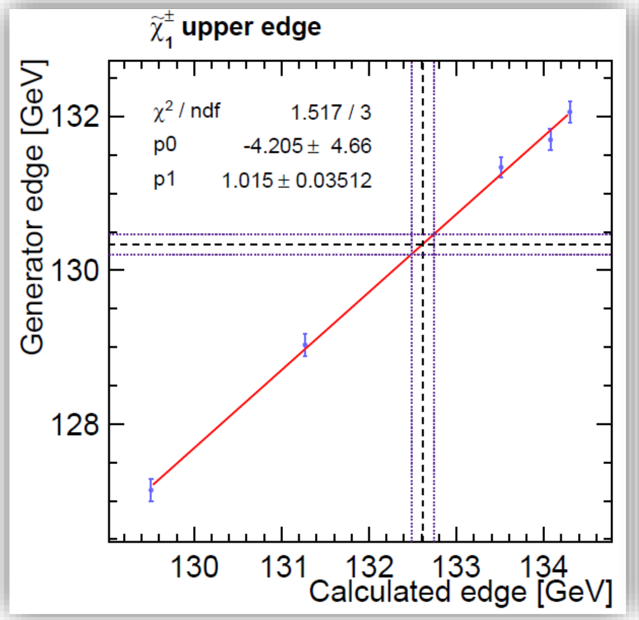


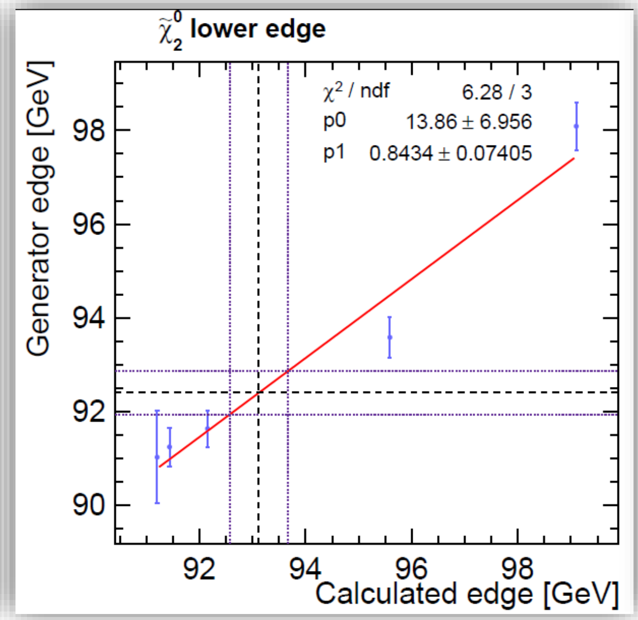
Edge Calibration II

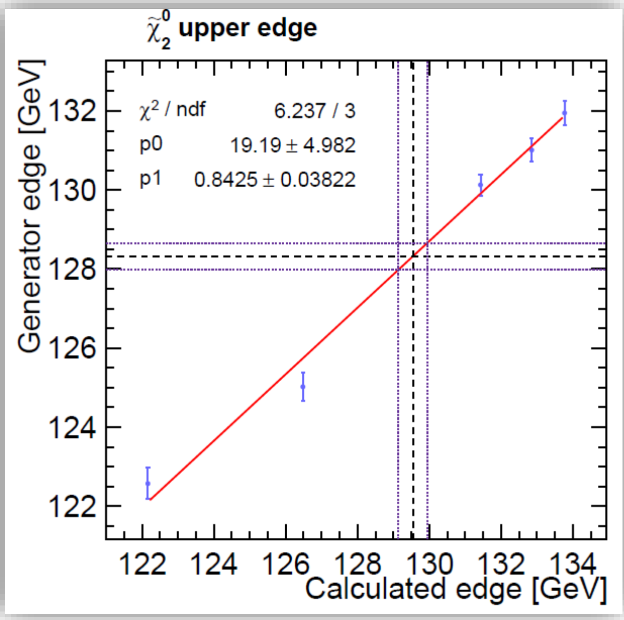
- Three different aspects:

1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**

   → **study effects of ISR emission, beamstrahlung**







Edge Calibration II

- Three different aspects:

  1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**

     → **study effects of ISR emission, beamstrahlung**

Gaugino	Generator [GeV]		Calculated [GeV]		Calibrated [GeV]	
	E_{low}	E_{high}	E_{low}	E_{high}	E_{low}	E_{high}
$\tilde{\chi}_1^{\pm}$	—	130.34±0.13	—	132.76	—	132.61±0.13
$\tilde{\chi}_2^0$	92.395±0.46	128.32±0.34	93.09	129.92	93.11±0.55	129.54±0.4

- Beam effects have an impact of 0.8% → 1.8%

Edge Calibration II

- Three different aspects:

1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**
   → **study effects of ISR emission, beamstrahlung [0.8% → 1.8%]**
2. Calibrate **edges** measured **on reconstruction level** w.r.t. **generator level edges**
   → **study simulation and reconstruction effects**

Gaugino	Reconstructed [GeV]		Generator [GeV]		Calibrated [GeV]	
	E_{low}	E_{high}	E_{low}	E_{high}	E_{low}	E_{high}
$\tilde{\chi}_1^{\pm}$	—	129.21±0.299	—	130.34±0.13	—	130.39±0.28
$\tilde{\chi}_2^0$	92.62±0.24	127.82±0.35	92.395±0.46	128.32±0.34	92.21±0.29	128.64±0.31

- **Simulation and reconstruction effects have an impact of 0.2% → 0.9% !**

Edge Calibration Results II

- Three different aspects:

  1. Calibrate **edges** measured **on generator level** w.r.t. **calculated edges**
     → **study effects of ISR emission, beamstrahlung** **[**0.8% → 1.8%**]**
  2. Calibrate **edges** measured **on reconstruction level** w.r.t. **generator level edges**
     → **study simulation and reconstruction effects** **[0.2% → 0.9%]**
  3. Calibrate **edges** measured **on reconstruction level** w.r.t **calculated edges**
     → **take all the effects into account** **[**1.1 → 2%**]**

Gaugino	Reconstructed [GeV]		Calculated [GeV]		Calibrated [GeV]	
	E_{low}	E_{high}	E_{low}	E_{high}	E_{low}	E_{high}
$\tilde{\chi}_1^{\pm}$	—	130.13±0.78	—	132.77	—	132.79±0.44
$\tilde{\chi}_2^0$	92.11±0.31	128.99±0.75	93.09	129.92	92.52±1.23	130.67±0.77

- **Cumulative effects have an impact of 1.1% → 2% !**