international linear collider

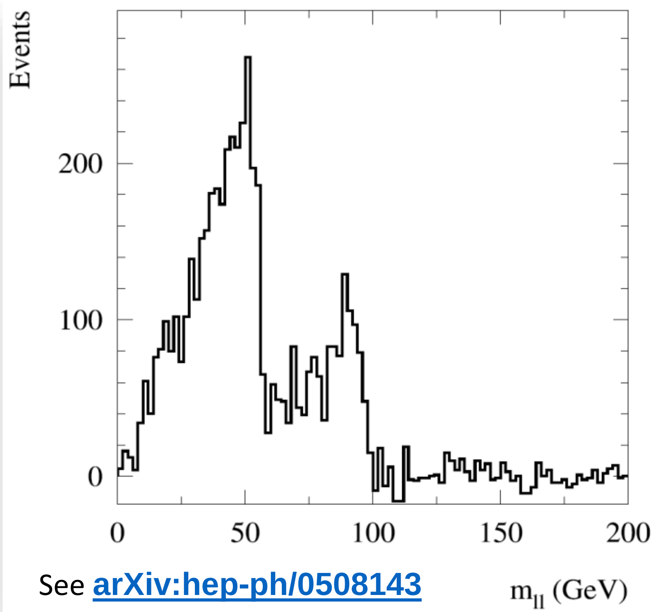
Universität Hamburg

# Computational edge detection on ILC SUSY measurements

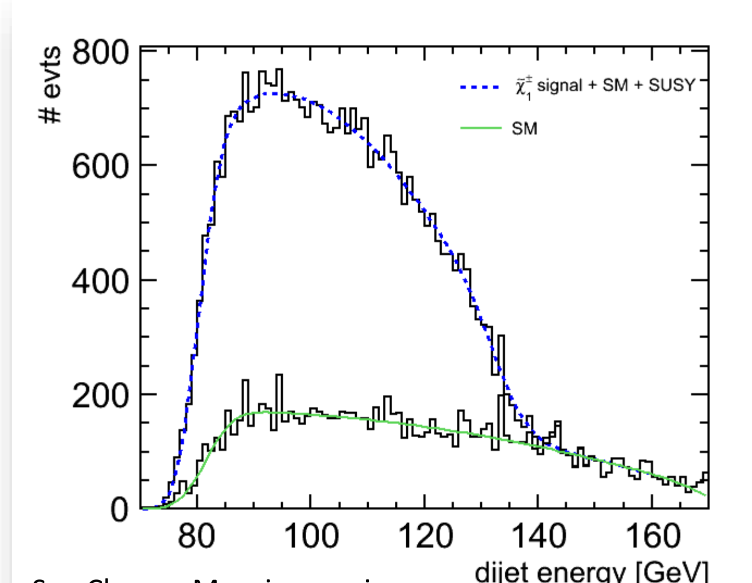

<u>Sabato Stefano Caiazza</u>,
J. List, M. Berggren


29 May 2013, ECFA 2013

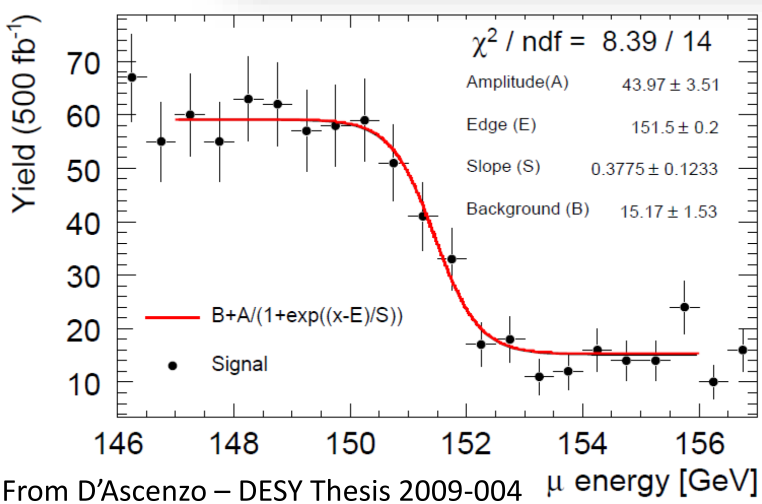
# EDGES IN HEP




See [arXiv:hep-ph/0508143]




See Chera – Morning session




From D'Ascenzo – DESY Thesis 2009-004

## Often defining feature of a distribution

- Edge position due to a kinematic constraint

## Common in SUSY

- Decay Cascades
- S-fermions decays
- Neutralino/Chargino decays

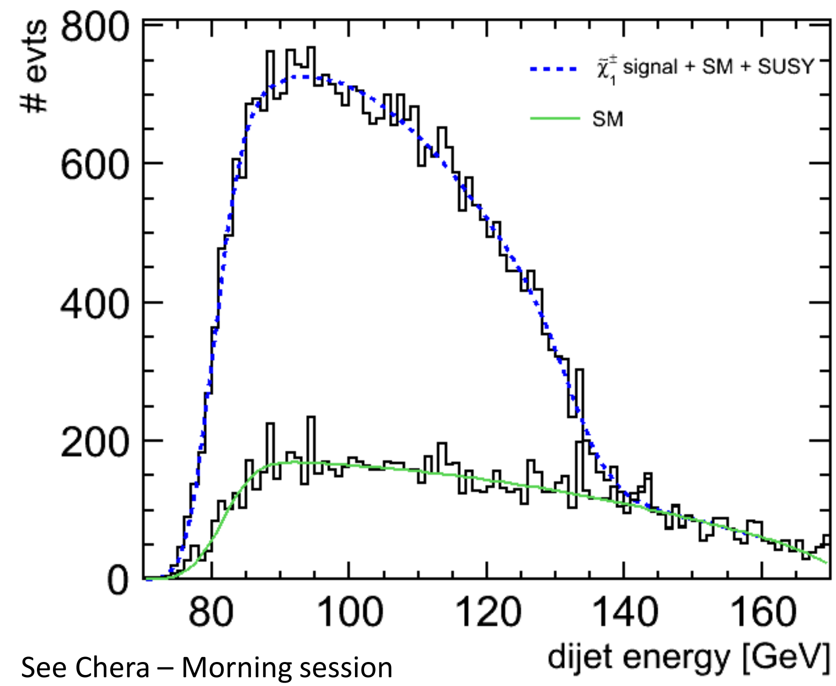
# GLOBAL FIT EDGE FUNDING

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

One function describes the whole distribution

Fit the data with a background correction

Find the edges from the fit parameters




See Chera – Morning session

Use whole data set

Implies a strong expectation on the signal features

Requires a strong understanding of background and systematics

Roughly detect the edge location → Define an ad-hoc function → Fit only in the area around the edge

**Only uses a limited amount of data**

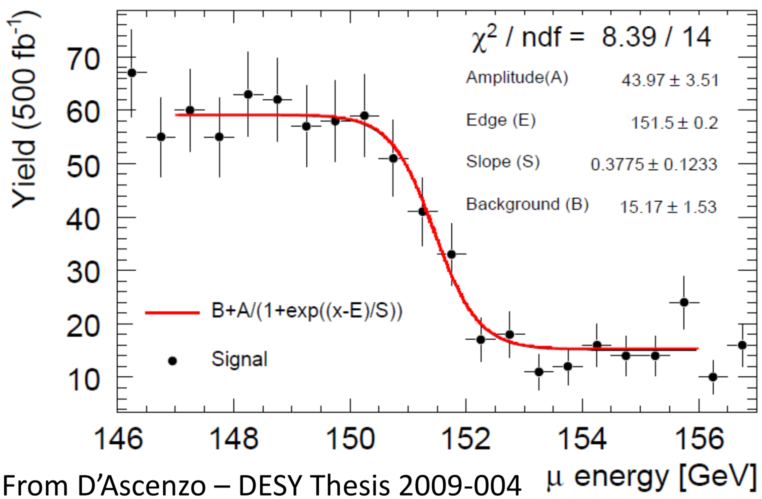
- Ignores the distribution bulk

**Requires a limited a-priori knowledge**

- Only of a limited part of the distribution

**Machine and detector effects more relevant**

- Compared to the global fit scenario
- This effects can be more difficult to evaluate




From D'Ascenzo – DESY Thesis 2009-004

# COMPUTATIONAL EDGE FINDING

## Computational detection

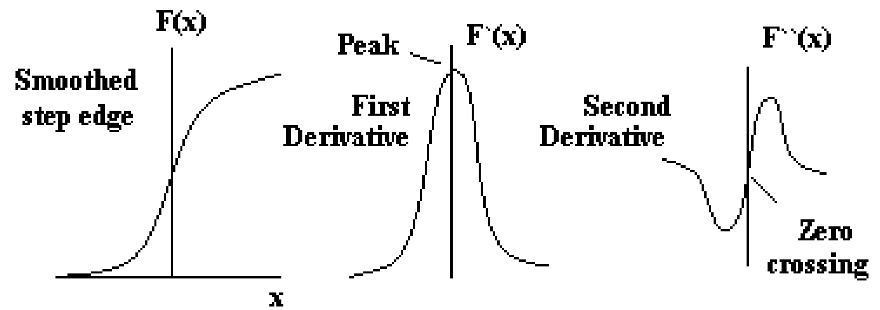
- Defining an algorithm weakly dependent from the edge shape
- Defining your measurement as a function of the algorithm response
- Eventually describe the edge parameters from the response

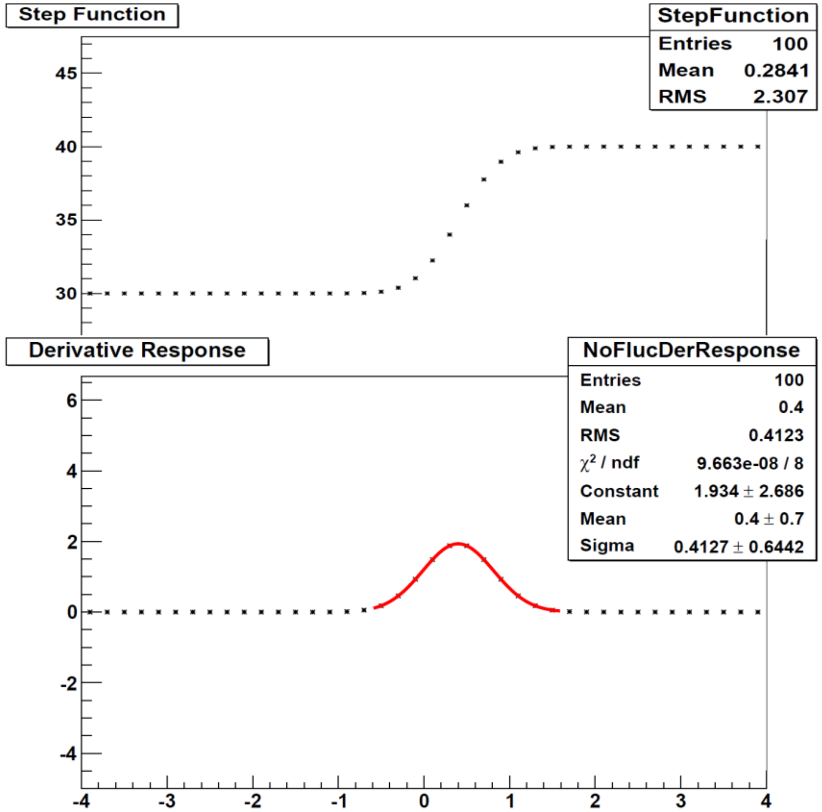
## Continuous function

- Calculate the derivative
- Take the turning point

## Discrete domain

- $F'(x) = (F(x+h) - F(x-h))/2h$
- Find the maximum



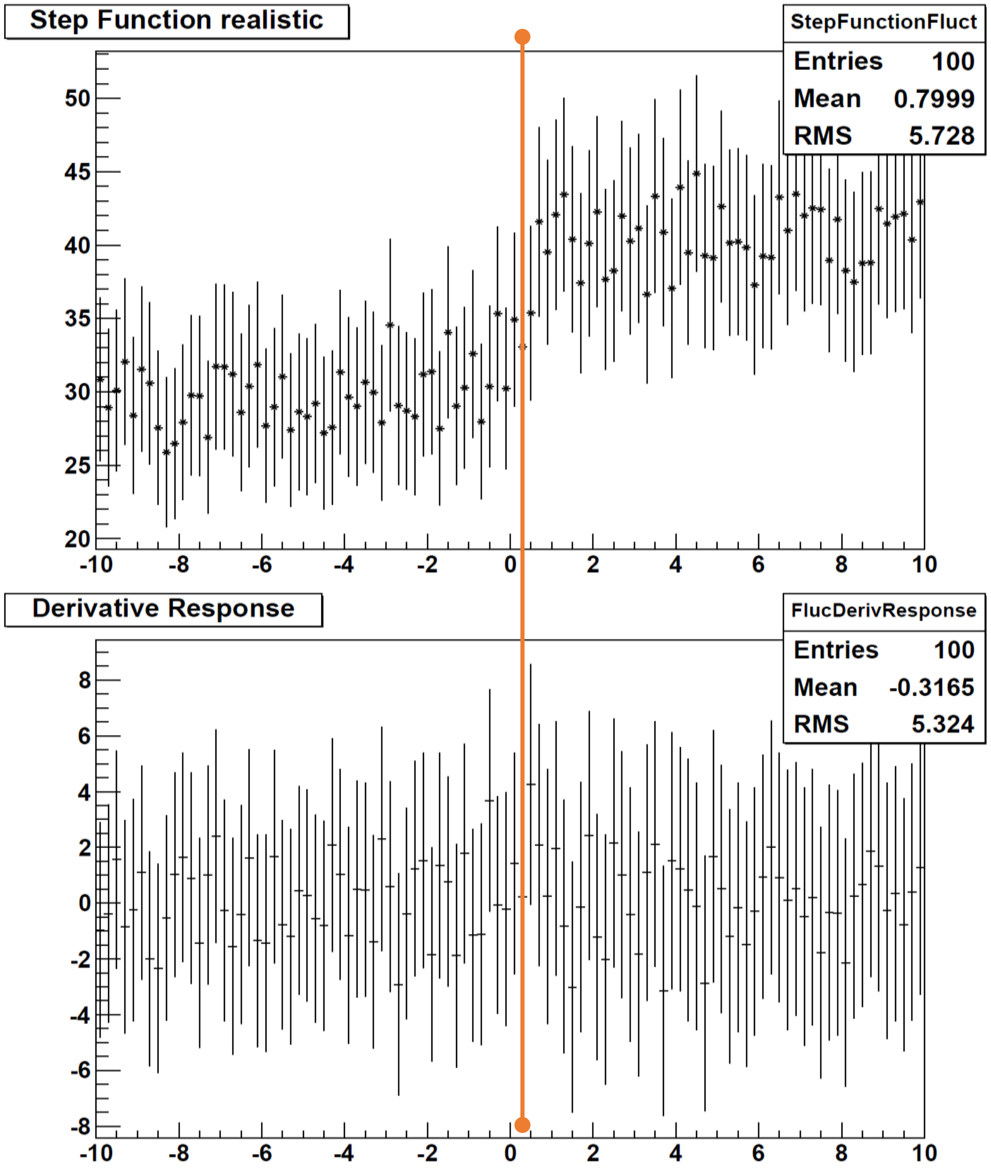
# NOISY EDGE

## Noisy smeared edge

- Edge Position at 0.37
- Gaussian smearing with $\sigma = 2$
- Poisson fluctuation on background and signal
- $\sqrt{n}$ errors

## Standard derivative fails

- The signal is flooded by the noise



# NOISY EDGE DETECTION

## Computational edge detection

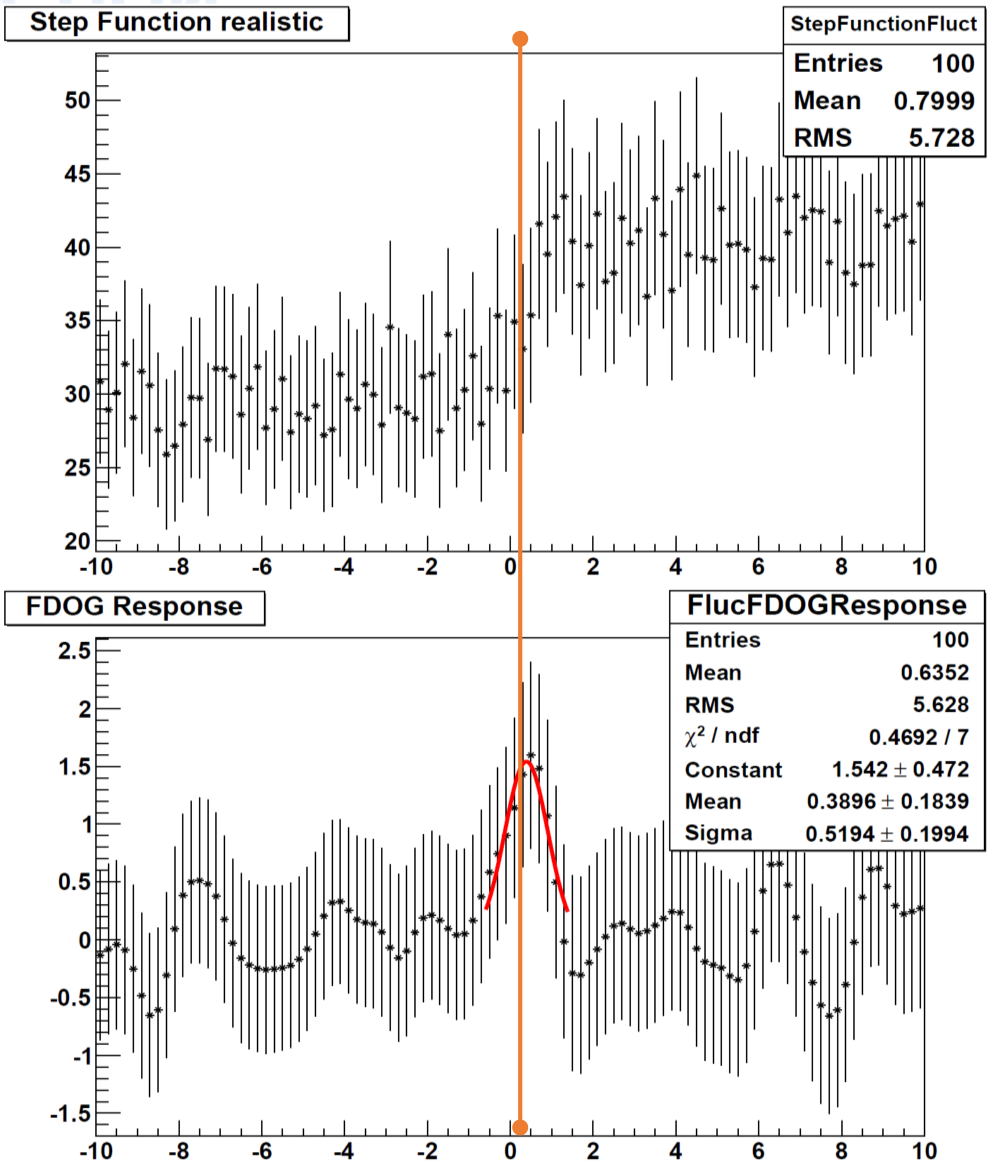
- Common problem in image processing
- Problem solution available (Canny Filter)

## How does it work

- Convolution with a specific weighting function
- Weighting function is optimized for the feature to detect (Steps, Ridges, Roofs)
- See: John Canny – A Computational approach to edge Detection (1986)

## Algorithm test

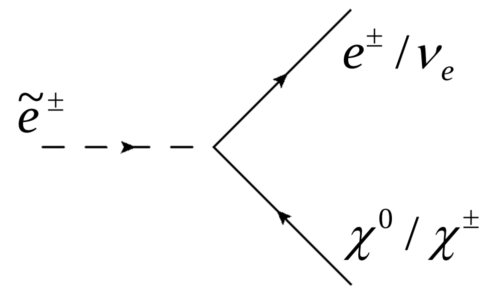
- Same test function as before
- The response shows a clear peak at the right place
- The ideal response should be gaussian
- Expected value: 0.37
- Detected value: 0.39 ± 0.18



# CASE STUDY – S-ELECTRON DECAYS

## General case

- Electron + any Neutralino
- Neutrino + any Chargino
- Start of a potentially long decay chain with many potential kinematic edges




## Special case

- Electron + LSP (TDR4 benchmark scenario)
- Very clean signature and potentially high cross section
- Two body decay of a boosted scalar particle

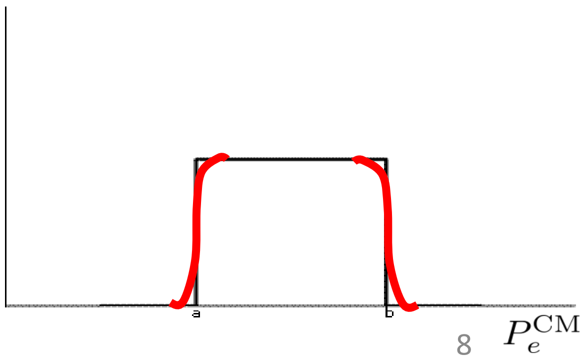
$$P_e^{\tilde{e}} = \frac{M_{\tilde{e}}^2 - M_{\chi}^2}{2M_{\tilde{e}}^2}$$

$$\mathrm{Min}(P_e^{\mathrm{CM}}) = P_e^{\tilde{e}}(\gamma - \beta\gamma)$$

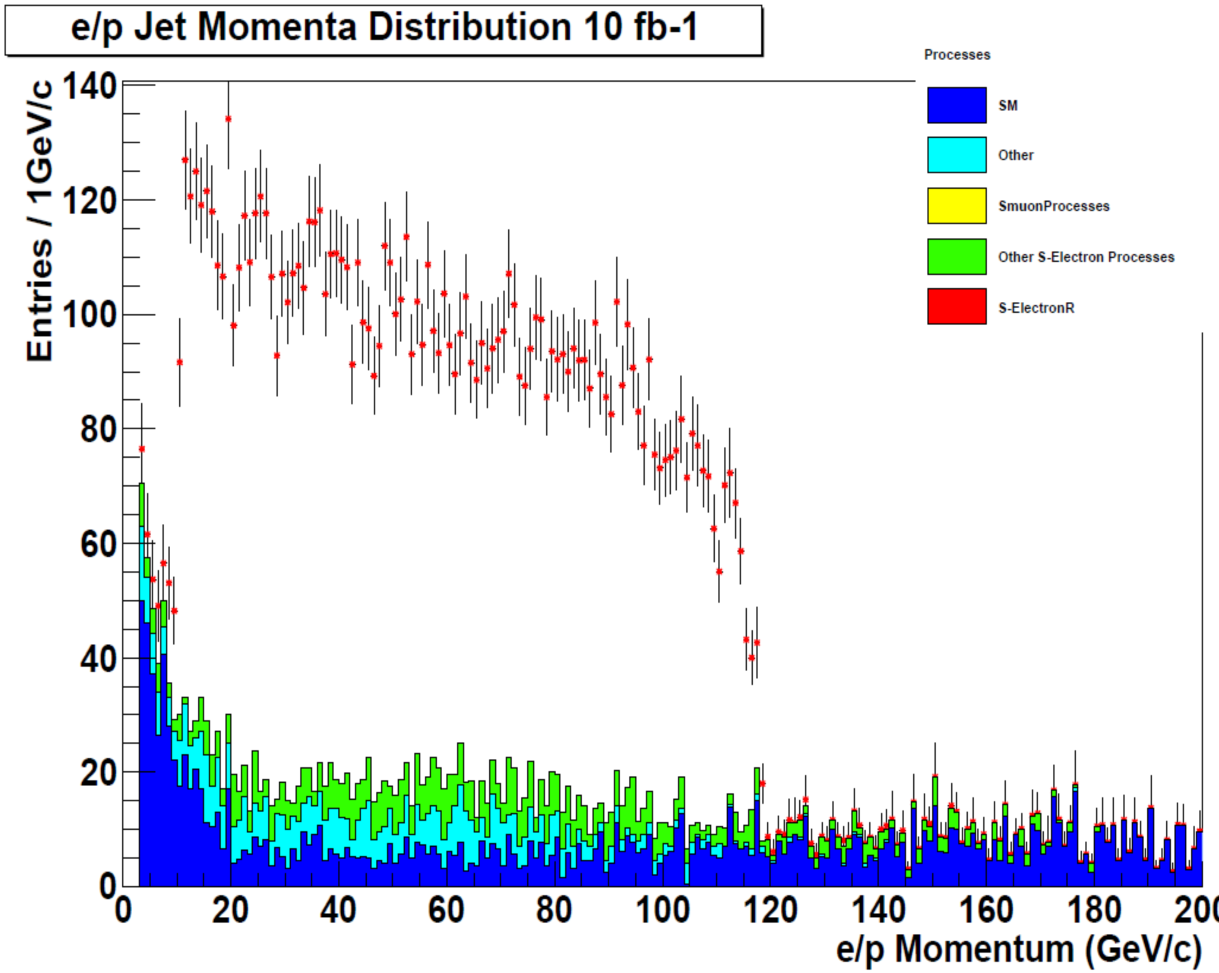
$$\mathrm{Max}(P_e^{\mathrm{CM}}) = P_e^{\tilde{e}}(\gamma + \beta\gamma)$$

## Electron momentum box distribution

- Kinematically constrained electron momentum
- Uniform distribution between two edges
- Edge smearing due to beam-strahlung and detector effects



# S-ELECTRON @ ILC IN TDR4




**10 fb$^{-1}$ ILC Data**

- Equivalent to 1 week of full luminosity

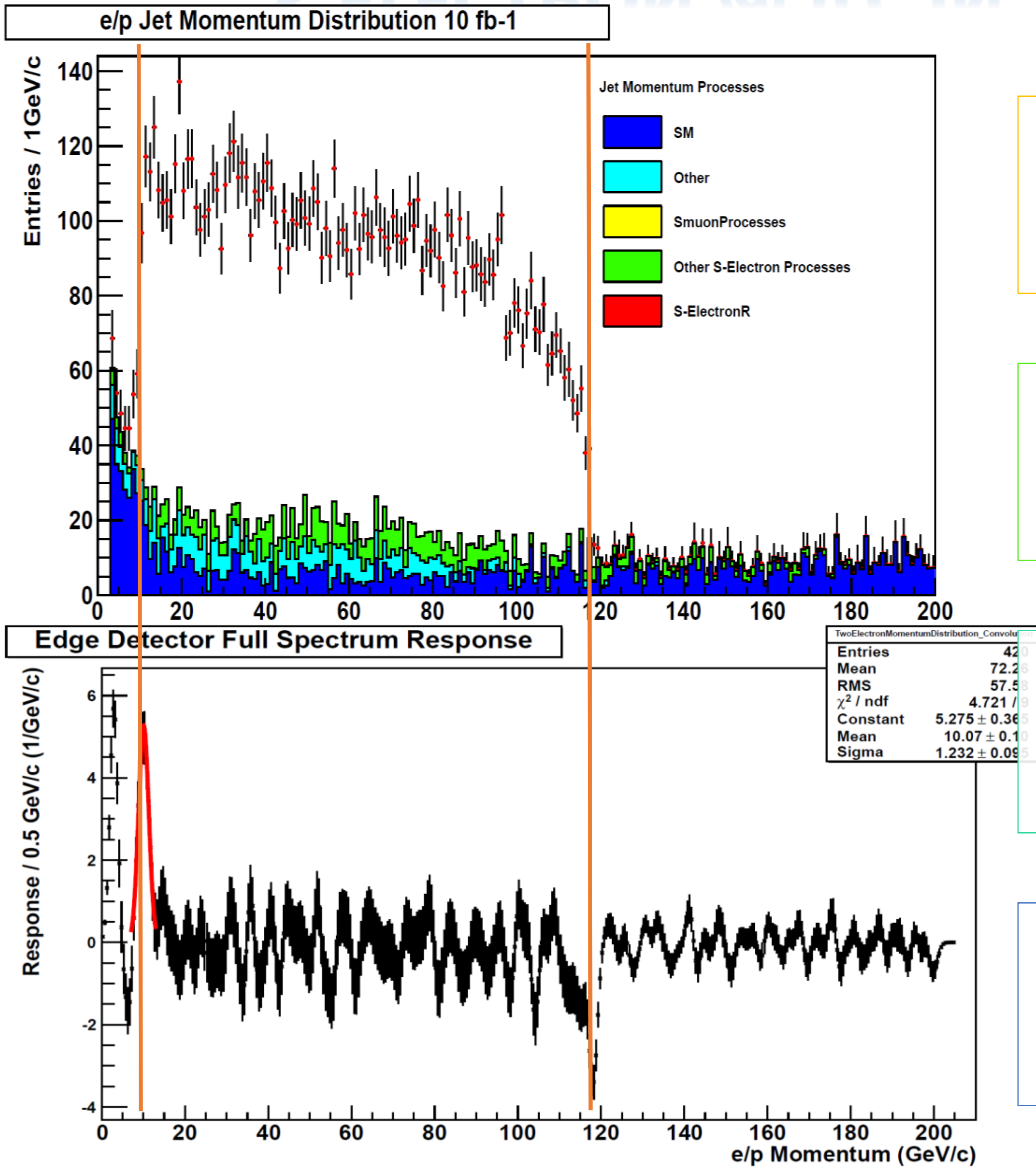
**Simple selection**

- Model independent cuts applied based on the LEP constraints
- 2 isolated high energy electrons with > 90GeV missing energy and low activity around the beam pipe

**Fit Methods**

- Strong machine and detector effects distort the distribution
- Difficult to define a theoretical valid template

# S-ELECTRON @ ILC IN TDR4




## Sensitivity

- The edge is clearly identifiable in the response function

## Accuracy

- Fitting a Gaussian to the peak reveals the peak position

## High Edge Position:

- Expected: 117.64 GeV/c
- Measured 117.5 ± 0.1 GeV/c

## Low Edge Position:

- Expected: 10.11 GeV/c
- Measured: 10.07 ± 0.10 GeV/c

# MASS MEASUREMENT

Using 1 ILC-week data set

Model independent and not optimized cuts

Without calibration/corrections

## Distribution center

- Expected: 63.88 GeV/c
- Measured: 63.78 ± 0.07 GeV/c

## Distribution Width

- Expected: 107.53 GeV/c
- Measured: 107.43 ± 0.14 GeV/c

## Neutralino Mass

- Expected: 94.4 GeV/$c^2$
- Calculated: 94.3 ± 0.7 GeV/$c^2$

## S-Electron Mass

- Expected: 135.0 GeV/$c^2$
- Calculated: 134.8 ± 0.7 GeV/$c^2$

# FUTURE DEVELOPMENTS

## Refine the edge detection

- Understand better the systematics of the algorithm
- Use the response to measure the feature distortions

## Calibration around the TDR4 benchmark point

- Verify the stability of the measurement
- Improve the measurement precision on the full 250 $fb^{-1}$ data set

## Compare with a different technique

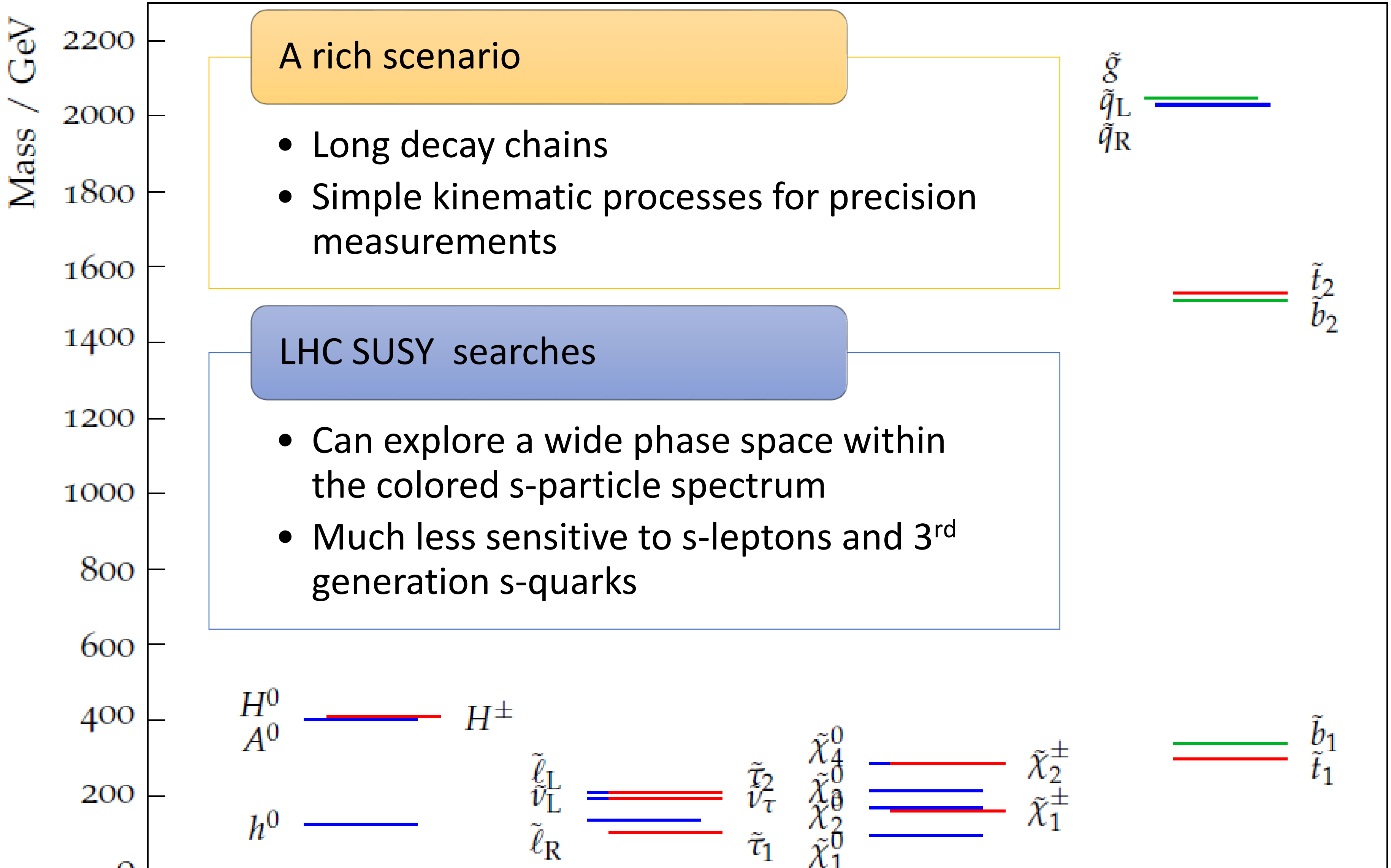
- Compare with a local fit technique

## Use the same method to detect other type of features

- For example the peak of a triangle distribution (roof detection)

# BACKUP

# LIGHT S-LEPTONS AT THE ILC




## A rich scenario

- Long decay chains
- Simple kinematic processes for precision measurements

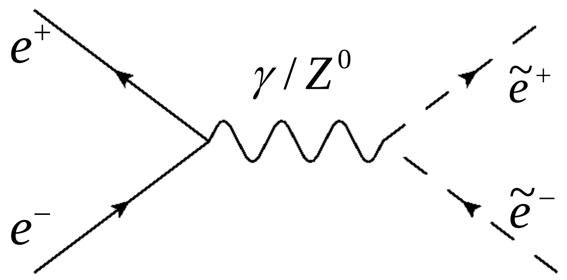
## LHC SUSY searches

- Can explore a wide phase space within the colored s-particle spectrum
- Much less sensitive to s-leptons and 3rd generation s-quarks

# S-ELECTRON PRODUCTION @ ILC

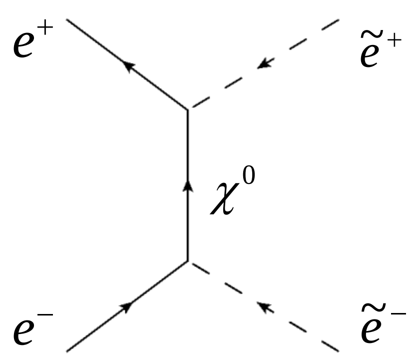
## S-Channel production

- Common to all s-fermions
- Same cross section for $\tilde{e}$ and $\tilde{\mu}$ (if mass degenerate)
- Isotropic angular distribution




## Massive T-Channel exchange

- Only possible for $\tilde{e}$
- Strongly enhance the $\tilde{e}$ production (from 116,7 fb to 641,9 fb in TDR4)
- Forward peaking angular distribution




## Choosing the product chirality

- $\tilde{e}_R$ and $\tilde{e}_L$ are different particles
- ILC beams can be polarized
- Allows the production of s-channel forbidden combinations ( $\tilde{e}_R$ + $\tilde{e}_L$ )

# S-ELECTRON DECAYS

## General case

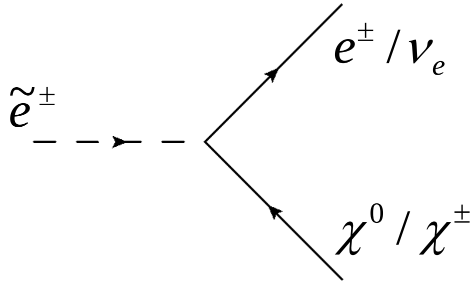
- Electron + any Neutralino
- Neutrino + any Chargino
- Start of a potentially long decay chain

## Special case

- Electron + LSP
- Very clean signature and potentially high cross section
- It can be the only available decay
- Two body decay of a boosted scalar particle

## Kinematics parameters

- Neutralino Mass
- S-Electron mass
- Center of mass energy



# TWO BODY DECAY OF A SCALAR PARTICLE

### 2-Body decay in the parent rest frame

- Daughters' momentum fixed

### Boosting the parent rest frame

- Daughters' momentum depend on the angle between the decay and the boost direction.

### Scalar parent

- The particle decay isotropically
- The momentum is distributed uniformly

### Experimental parameters

- Width and mean of the momentum distribution
- Position of the edges of the distribution
- Distribution smearing due to instability of $E_{CM}$ and other uncertainties

$$M_e = 0 \qquad \gamma = E_{CM}/2M_{\tilde{e}}$$

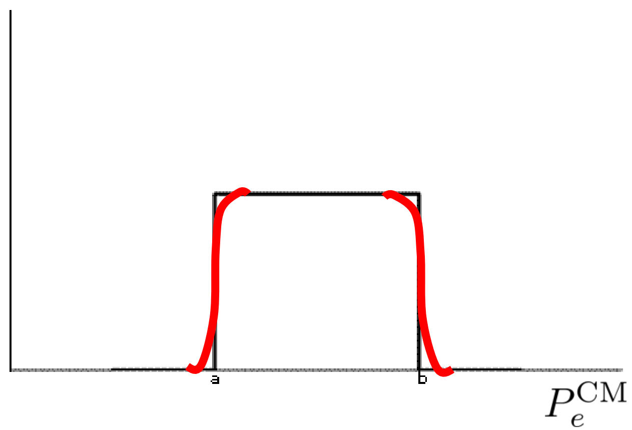
$$P_e^{\tilde{e}} = \frac{M_{\tilde{e}}^2 - M_\chi^2}{2M_{\tilde{e}}^2}$$

$$\mathrm{Min}(P_e^{\mathrm{CM}}) = P_e^{\tilde{e}}(\gamma - \beta\gamma)$$

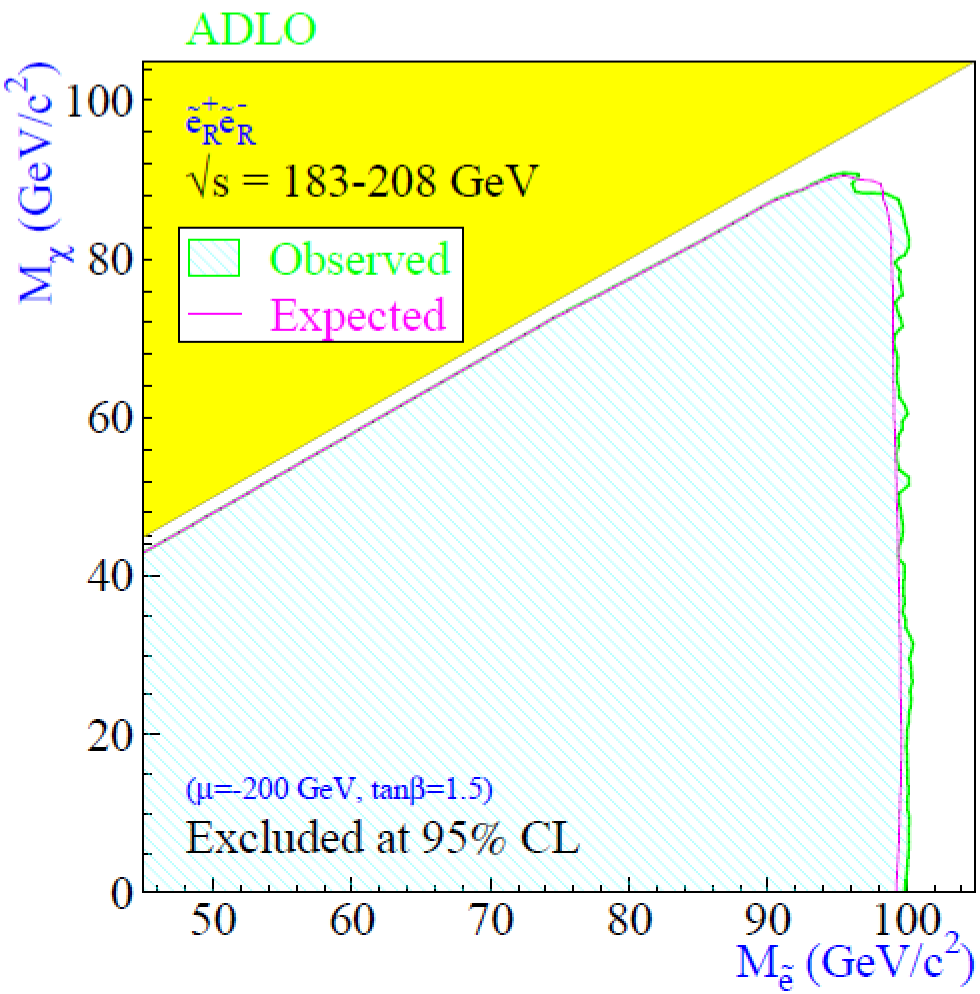
$$\mathrm{Max}(P_e^{\mathrm{CM}}) = P_e^{\tilde{e}}(\gamma + \beta\gamma)$$

$$\Delta E = E_{\max} - E_{\min} = 2P_e^{\tilde{e}}\beta\gamma$$

$$C = \frac{E_{\max} + E_{\min}}{2} = P_e^{\tilde{e}}\gamma$$



# LEP CONSTRAINTS




## LEP constraints

- Neutralino heavier than 45 GeV
- S-Electron / S-muon heavier than 95 GeV

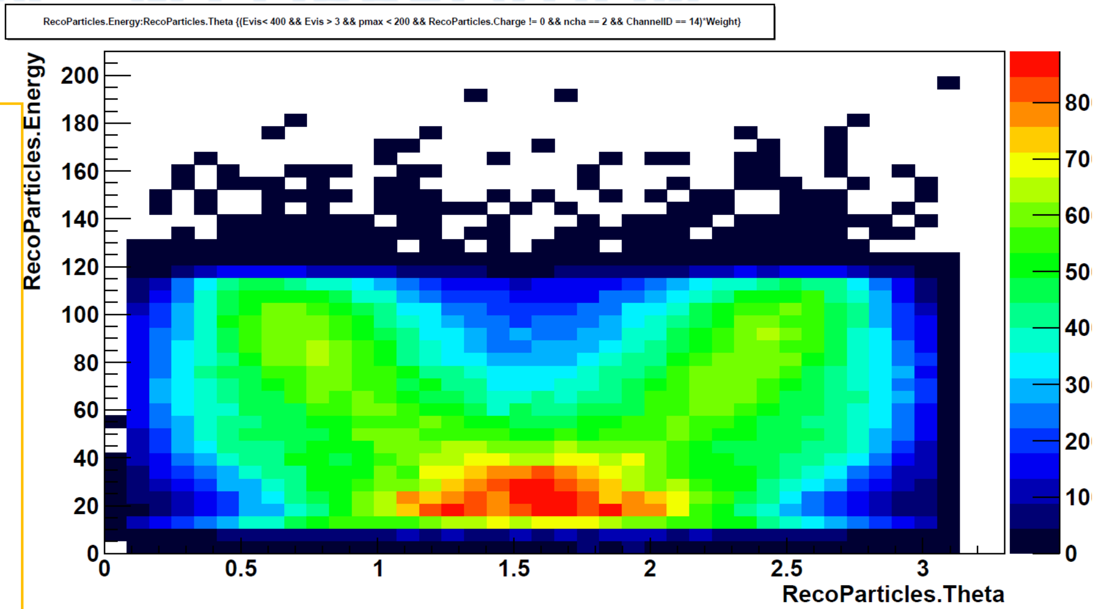
# MOMENTUM – Θ CORRELATION

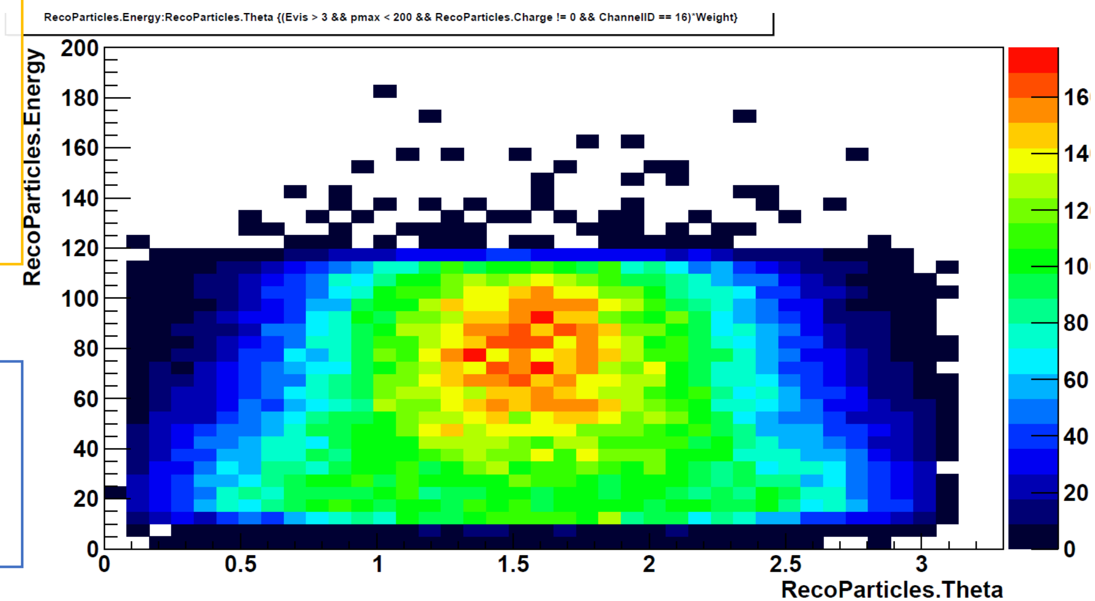
## S-Electrons

- Momentum transfer limited by Neutralino mass (in T-channel)
- Forward peaking with a minimum emission angle (0.465 rad for TDR4)
- Maximum electron energy at that angle

## Other scalars

- Isotropic production

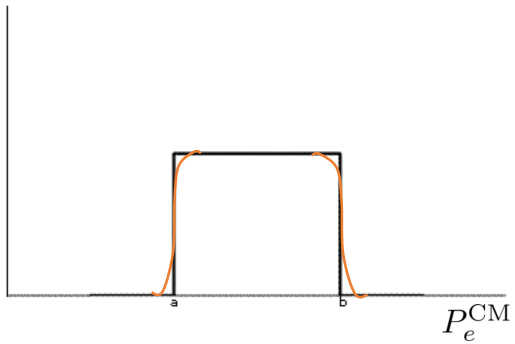


# ALTERNATIVE CHARACTERIZATION

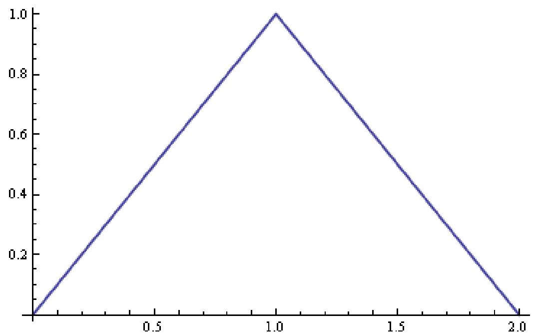
## Using all data available

- Edge detection techniques only use a limited amount of data near the feature



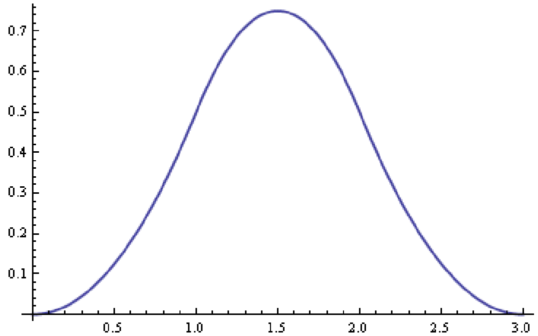

## Central Limit Theorem

- The mean of a sufficiently large number of independent random variables, each with a well-defined mean and well-defined variance, will be approximately normally distributed
- The momentum of each selected electron is an independent random variable sampled from a box like distribution




## Parameter determination

- Average a random sample of electron momenta and fit the results with a gaussian
- Derive the mean and the width of the initial distribution
- Quite effective with large amounts of data



# MODEL INDEPENDENT CONSTRAINTS

## LEP Limits

- S-Electron mass > 95 GeV
- Neutralino mass > 45 GeV

## ILC Parameters

- CM energy 500 GeV
- Max electron polarization 80%
- Max positron polarization 30%

## Model Independent signature

- Missing energy > 90 GeV
- 1 electron and 1 positron only in the final state
- Each e/p momentum < 200 GeV
- Low activity around the beam pipe

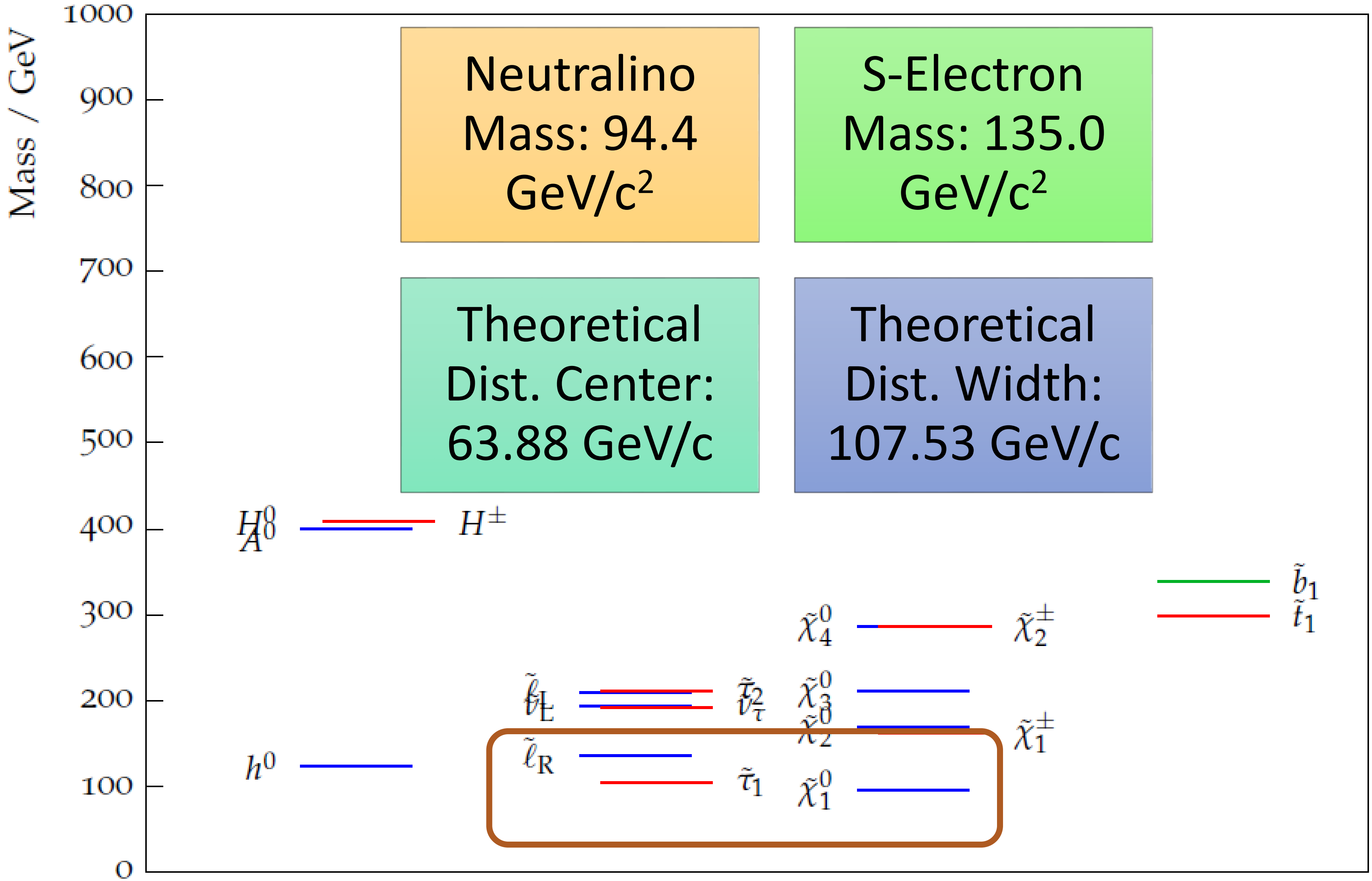
# S-LEPTONS SPECTRUM IN TDR4

Neutralino Mass: 94.4 GeV/c²

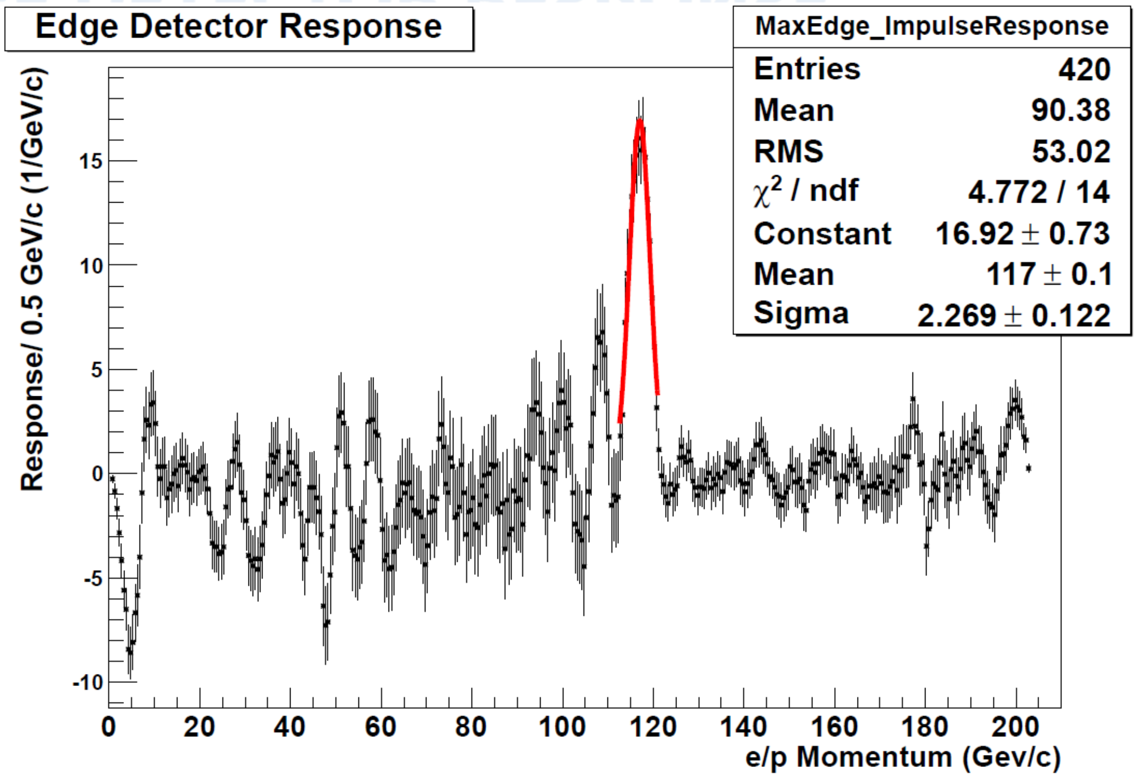
S-Electron Mass: 135.0 GeV/c²

Theoretical Dist. Center: 63.88 GeV/c

Theoretical Dist. Width: 107.53 GeV/c



# EDGE DETECTOR RESPONSE




**High Edge Position:**

- Expected: 117.64 GeV/c
- Measured 117 ± 0.1 GeV/c

**Low Edge Position:**

- Expected: 10.11 GeV/c
- Measured: 10.22 ± 0.07 GeV/c

# EDGE DETECTION ACCURACY

| High Edge Position | Low Edge Position |
|---|---|
| • Expected: 117.64 GeV/c<br>• Measured 117.5 ± 0.1 GeV/c | • Expected: 10.11 GeV/c<br>• Measured: 10.07 ± 0.10 GeV/c |

## Symmetric offset

- Some systematics yet to understand
- It could be calibrated

## Distribution center

- Expected: 63.88 GeV/c
- Measured: 63.78 ± 0.07 GeV/c