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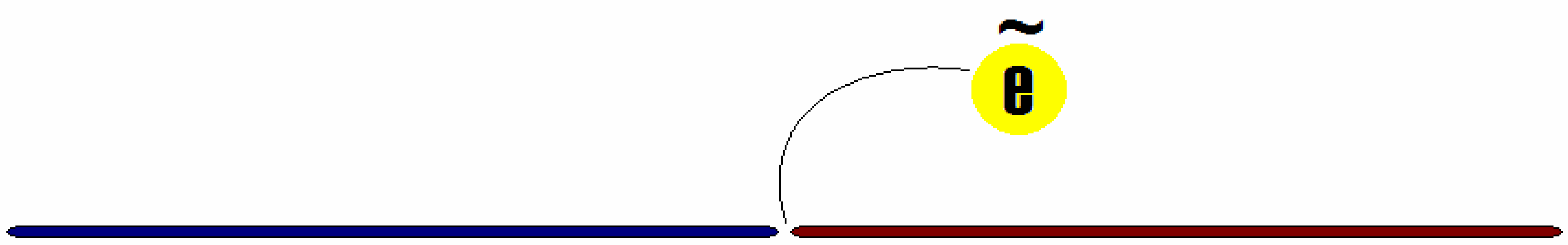
The Selectron Mass Resolution at the 1 TeV Linear Collider

Troy Lau
UC Santa Cruz

April 14 2005

SLAC



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THE UC SANTA CRUZ GROUP

Bruce Schumm

Past

Sharon Gerbode (now at Cornell)
Heath Holguin (now a UCSC grad student)
Paul Mooser
Adam Pearlstein (now at Colorado State)

Present

Troy Lau (will be at U of Michigan)
Ayelet Lorberbaum
Joe Rose

Tools of the trade

LCDIsajet – SUSY event generation/simulation

Java Analysis Studio – event analysis, cuts

MATLAB – statistical analysis

Excel – in depth energy distribution investigation, graphing

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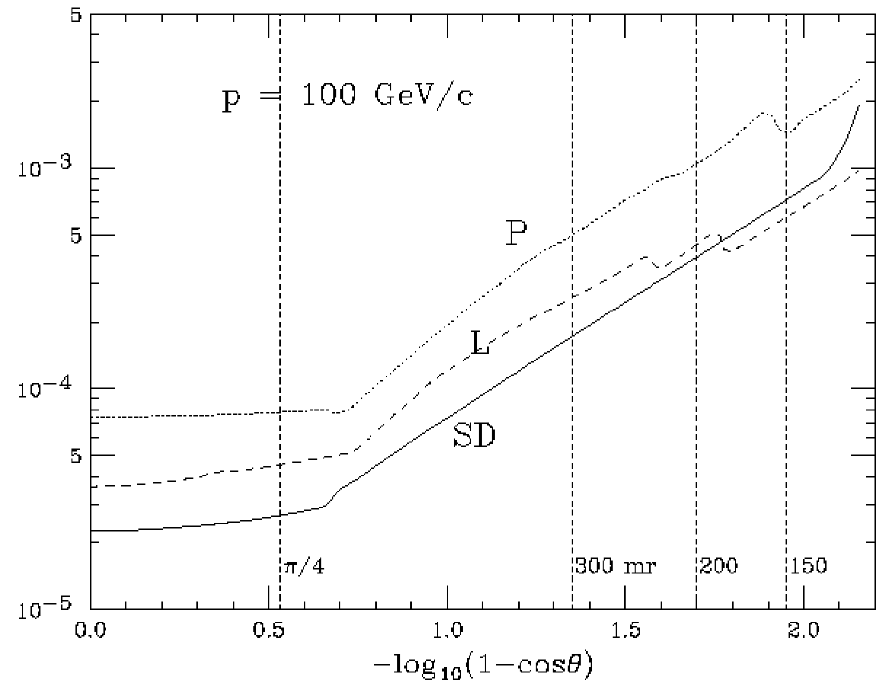
Motivation

To explore the effects of limited detector resolution on our ability to measure SUSY parameters in the **forward** ($\cos(\theta) > .8$)and central regions of the detector.



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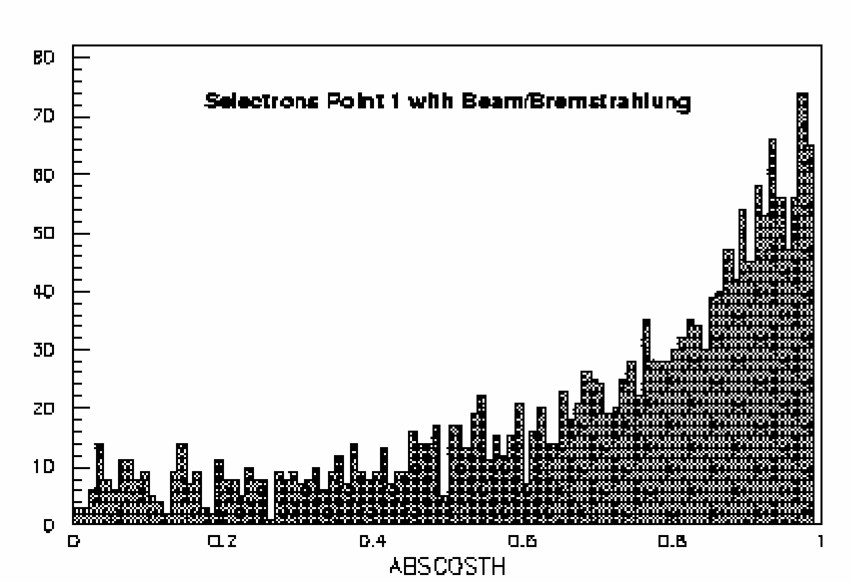
Why at 1 TeV ?

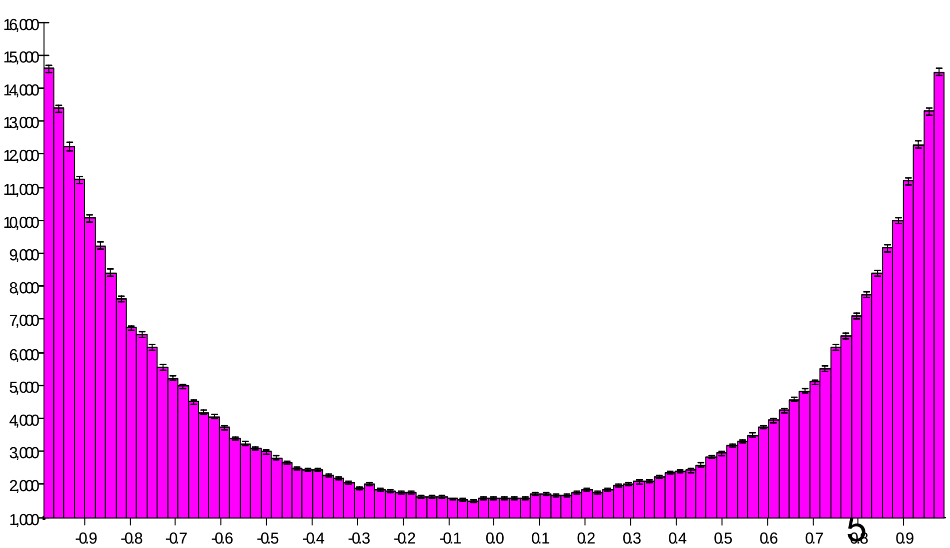
Selectron/electron production is peaked in the forward direction at 1 TeV for "low" mass selectrons.

right handed selectrons

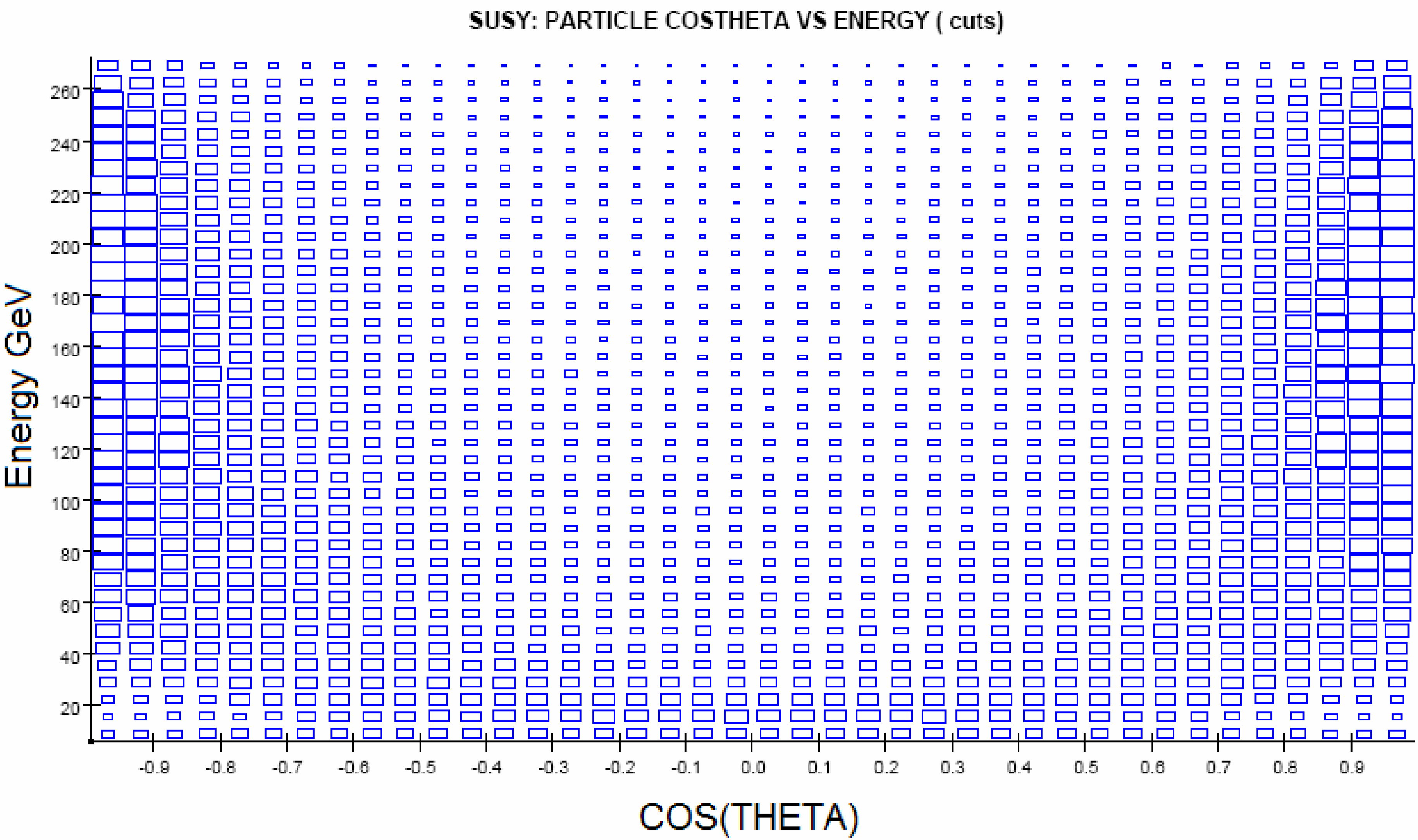


electrons

SUSY: Particle cos(theta) (no cuts)



Electron production is peaked in the forward region for higher energies.



LC-TH-2001-079
hep-ph/0201233
January 18, 2002

Compilation of SUSY particle spectra from Snowmass 2001 benchmark models

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[†] DESY, Hamburg, Germany, [*] I. Physikalisches Institut der RWTH, Aachen, Germany

Abstract

A comparative study of supersymmetric particle spectra calculated by the programs ISAJET, SUSYGEN and PYTHIA is presented for various SUSY scenarios defined at the Snowmass 2001 workshop.

At the Snowmass 2001 *'Summer Study on the Future of Particle Physics'* a concensus was reached to define a list of SUSY models as benchmarks to be investigated in future collider studies. Various scenarios, so-called 'Snowmass Points and Slopes' (SPS), were proposed[1,2] in terms of a few parameters describing 'typical' to 'extreme' R_p conserving supersymmetry breaking mechanisms of mSUGRA, GMSB and AMSB. All benchmark points respect currently existing experimental constraints.

	mSUGRA scenario	m_0	$m_{1/2}$	A_0	$\tan\beta$	sign μ
SPS 1	typical point	100	250	-100	10	+
SPS 2	focus point region	1450	300	0	10	+
SPS 3	model line into coannihilation region	90	400	0	10	+
SPS 4	large $\tan\beta$	400	300	0	50	+
SPS 5	light stop	150	300	-1000	5	+
SPS 6	non-unified gaugino masses $M_1 = 480,\ M_2 = M_3 = 300$	150	300	0	10	+
	GMSB scenario	Λ	M_{mess}	N_{mess}	$\tan\beta$	sign μ
SPS 7	NLSP $= \tilde{\tau}_1$	40,000	80,000	3	15	+
SPS 8	NLSP $= \tilde{\chi}^0_1$	100,000	200,000	1	15	+
	AMSB scenario	m_0	$m_{3/2}$		$\tan\beta$	sign μ
SPS 9	small $\Delta m(\tilde{\chi}^+_1 - \tilde{\chi}^0_1)$	400	60,000		10	+

masses and scales in GeV

However, at Snowmass it was recommended to take the SUSY particle spectrum as generated by the program ISAJET[3] as the reference for benchmark models, instead of the few high energy

[1] *'SUSY benchmark discussion'* at Snowmass 2001, http://lotus.phys.nwu.edu~schmittm/snowmass
[2] M Battaglia et al, *'The Snowmass points and slopes: benchmarks for SUSY searches'*, Snowmass proceedings, in preparation
[3] H Baer et al, hep-ph/0001086, ISAJET, http://paige.home.cern.ch/paige

Physics parameters

mSUGRA Parameters M_0 = 100 GeV (Universal Scale mass)

SPS1A $m_{1/2}$ = 250 GeV (Universal Gaugino Mass)

A_0 = -100 GeV (Trilinear coupling in Higgs sector)

$\tan\beta$ =10 (Ratio of two VEV)

signμ =1 (Higgsino mixing parameter)

Right selectron mass = 143.112 GeV

Neutralino mass = 95.473 GeV

1 SPS 1 – mSUGRA scenario

m_0	100 GeV
$m_{1/2}$	250 GeV
A_0	-100 GeV
$\tan\beta$	10
sign μ	+

'typical' scenario
$m_0 = 0.4\, m_{1/2} = -A_0$

1.1 Spectrum & parameters of ISAJET 7.58

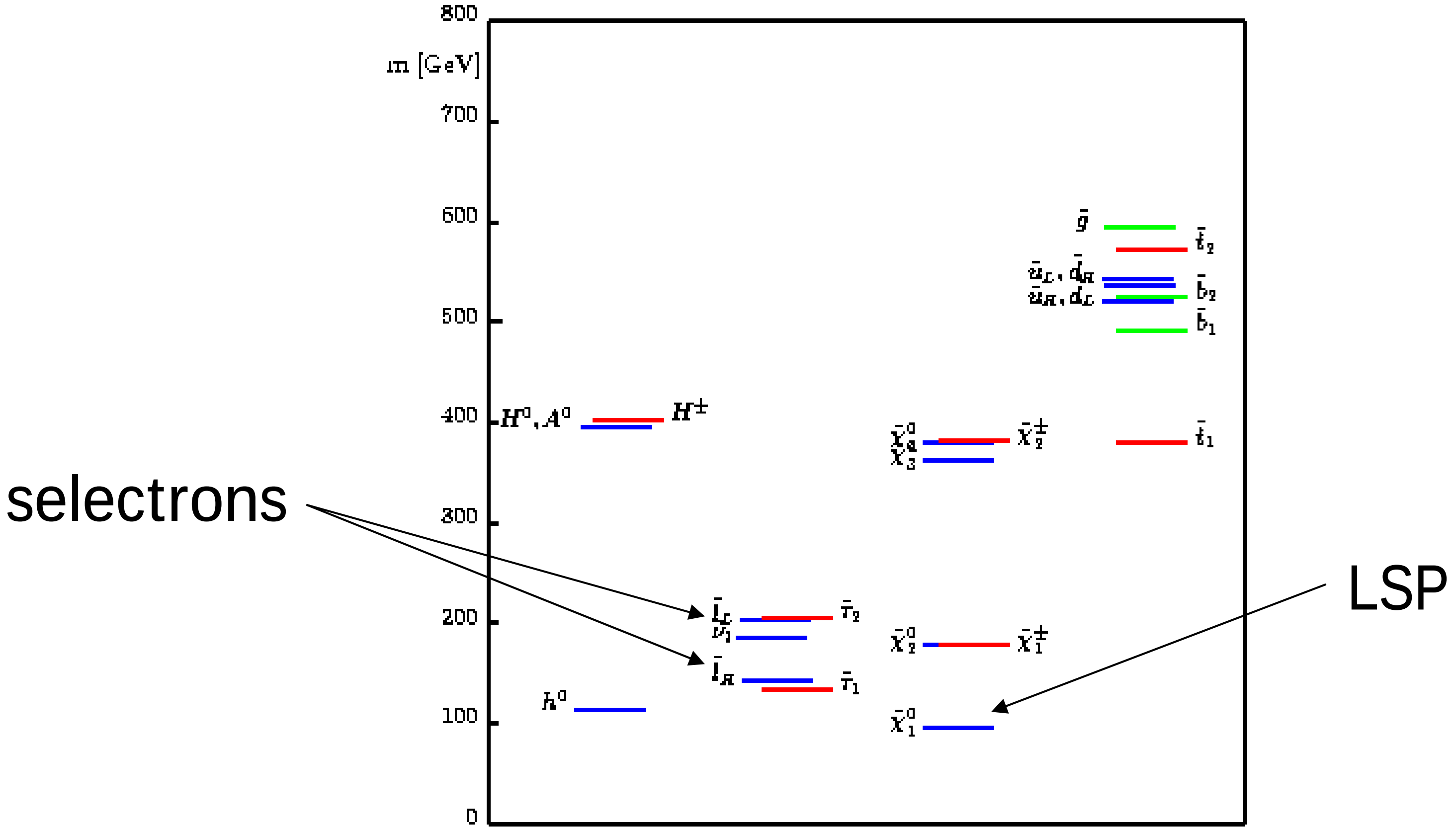
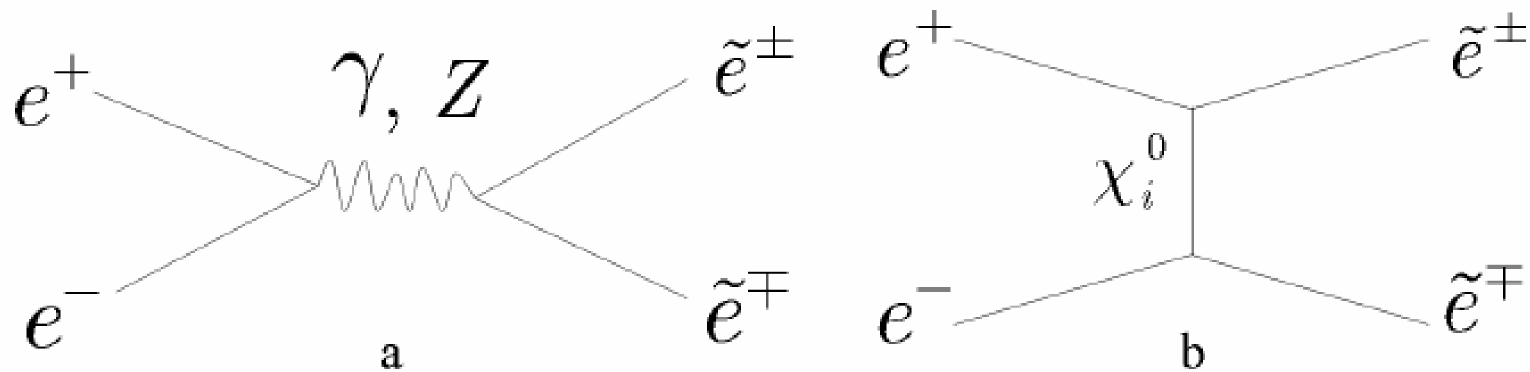


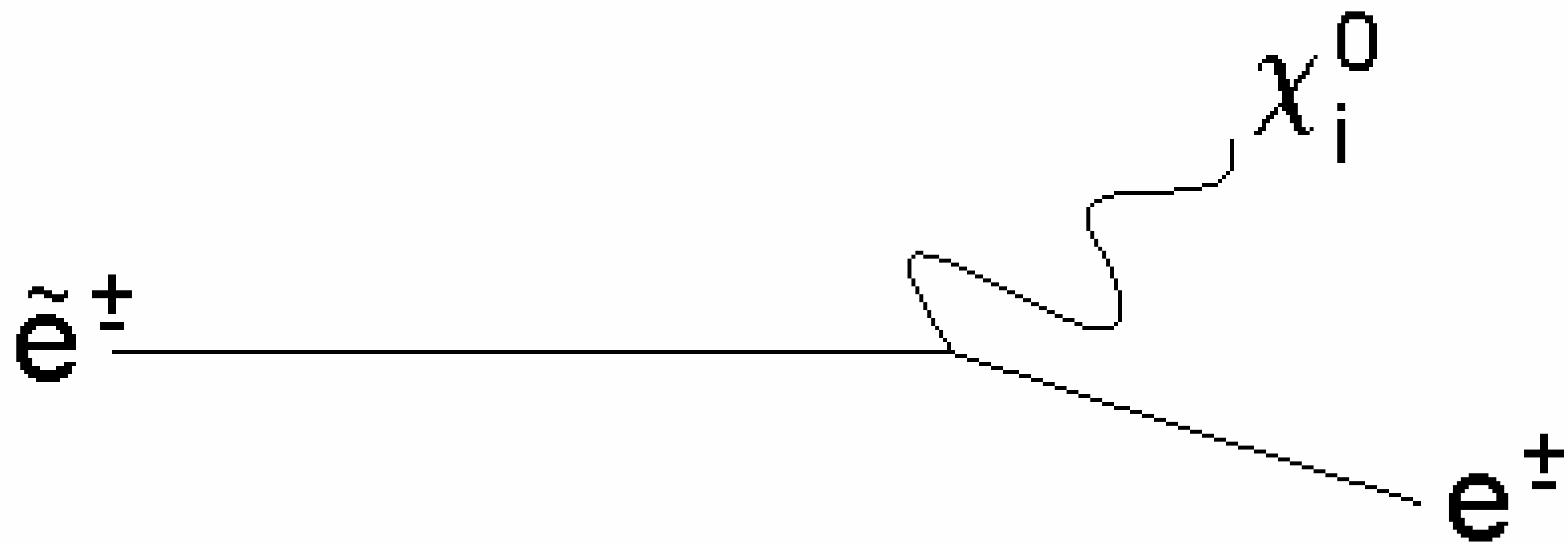
Figure 1: SPS 1 mass spectrum of ISAJET



Selectron production channels

a) s-channel (central region)

b) t-channel (dominates the forward region when lightest selectron and neutralino masses are small... SPS1A satisfies these conditions)



- selectron decay → electron + neutralino

Theory

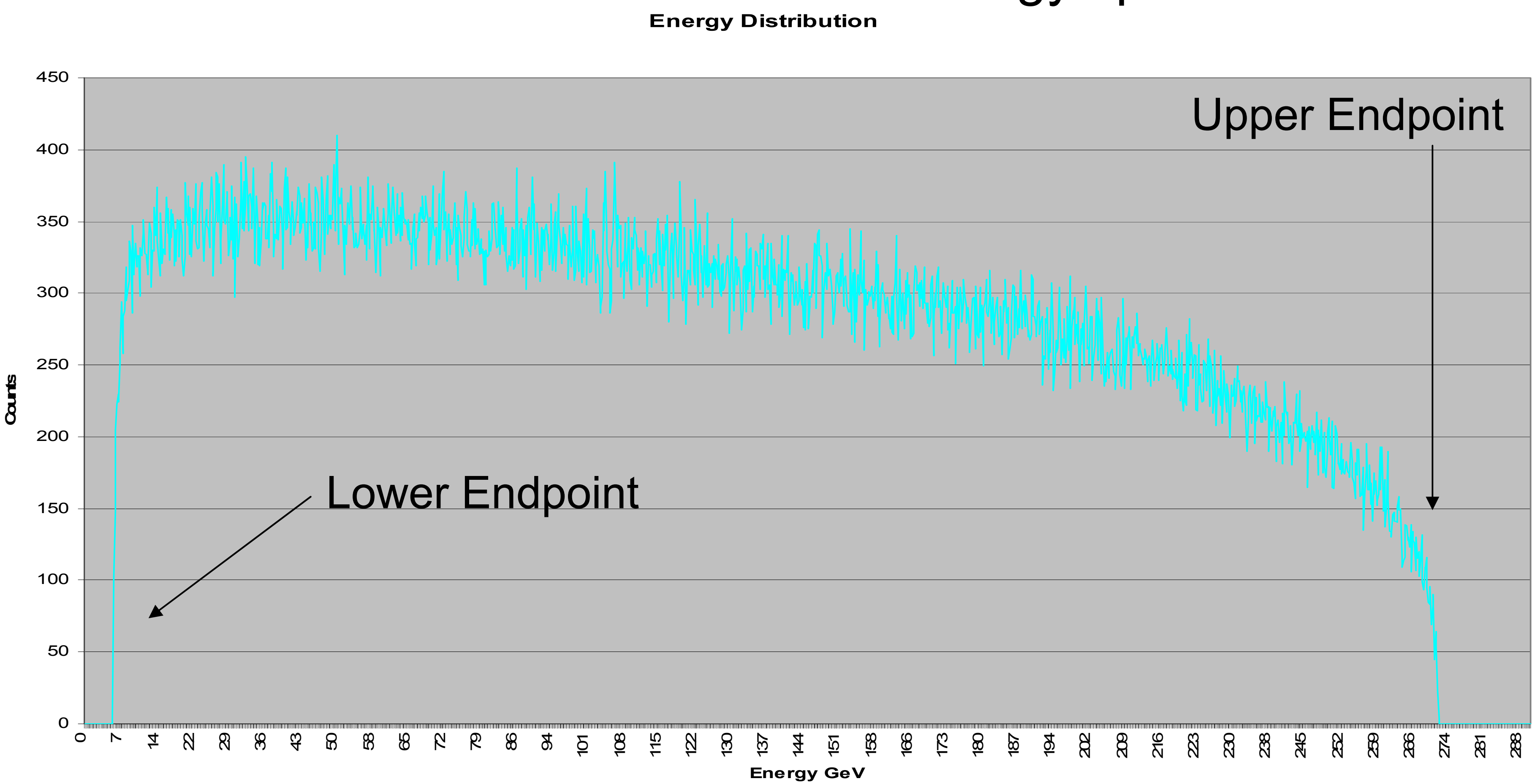
Every χ^0_1 / selectron mass combination has a distinctive electron energy distribution.

The electron energy spectrum endpoint (EEEP) reveals the mass of the selectron and χ^0_1 LSP.

Measurement can be difficult in the presence of ISR, bremsstrahlung, and beamsstrahlung. How do we do it ?

What effects, if any, do beamspread and the detectors' resolution have on determining the EEEP?

Electron energy distribution with beam/bremm/ISR. No detector effects or beam energy spread.



- sample electron energy distribution $M_{selectron}$ = 143.112 (SPS1A)

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Collider parameters

1 TeV (500 GeV each beam)

100% right-handed electron polarization (0% left)
0% positron polarization (50% right, 50% left)

Beam/Bremm - $\sqrt{s}_{min}$ **=1** γ **= .29**
$\sqrt{s}_{max}$ **=1000** σ_z **= .11 (mm)**

Beamspread =.16% (also 0% and 1%)
(both electrons and positrons; oops… typo… should have been .14% or less?)

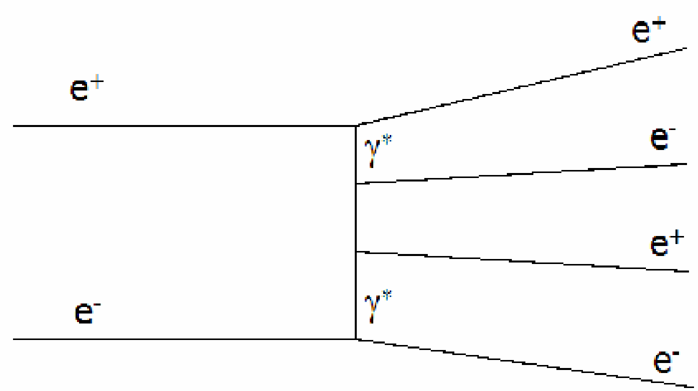
Gerbode, Mooser, Holguin

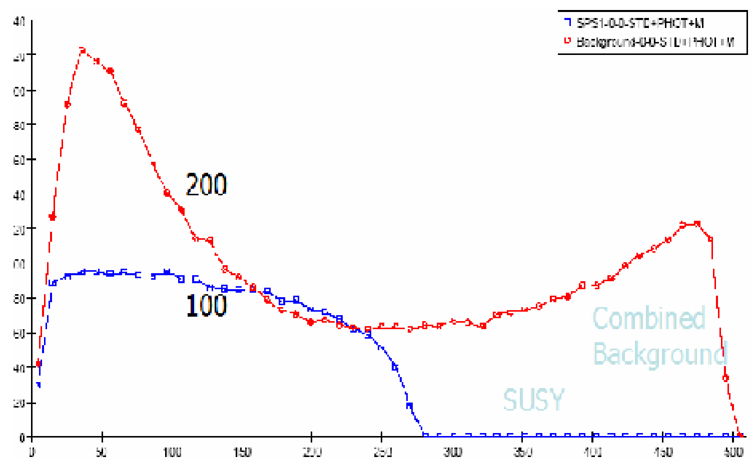
Standard Model Cuts

Previous work done in 2003-2004 developed cuts to remove standard model, SUSY like, events.

Explored forward region

Explored *eeee* backgrounds in central region





The Cuts

• **Fiducial Cut:** Exactly one final state positron/electron pair is observed, and each of the
pairs has a transverse momentum of at least 5GeV. Otherwise the event is discarded.

• **Tagging Cut:** If a final state fermion is found in the tagging
region, the event is discarded.

• **Transverse Momentum Cut:** Cuts events where vector sum of transverse
momentum for + - e e pair is less than 2 * 250GeV * sin (20 mrads).

• **Photon Cut:** Cuts events if there is a photon in the tagging region with energy
of 20GeV or more, and cuts events with photon in forward or central
region with energy of 5GeV or more.

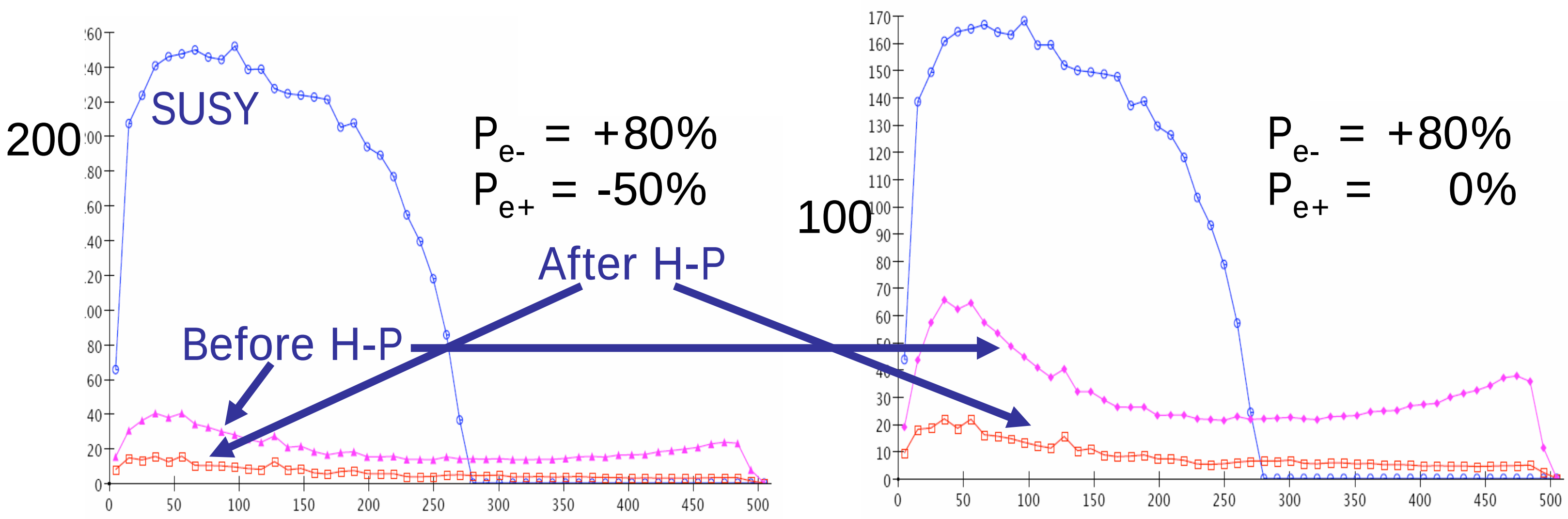
$$| \vec{p}_{e-} + \vec{p}_{e+} | < 225$$

• **HP Cut:** Removes low-mass, t-channel-dominated eeνν backgrounds while preserving high-mass SUSY signal

Use of Beam Polarization

Also: can extinguish main background (eeνν) with RH electron and LH positron polarization

For fixed integrated luminosity, the signal is higher and the background lower with positron polarization.



Electron Energy (GeV)

Results of Event Selection Study

<u>Selectron production can be detected over the full tracking volume</u>

Developed two additional helpful cuts: looking for photons radiated in eeee processes and cutting on momentum imbalance (`H-P').

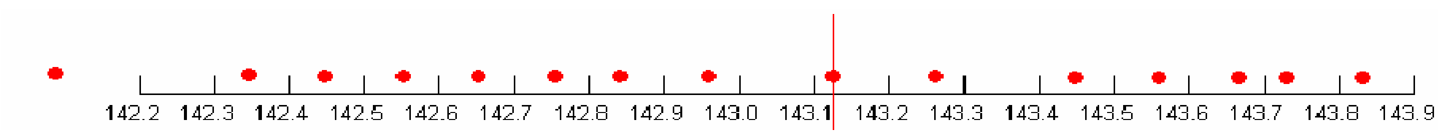
M_{min} cutoff needs to be extended down below 4 Gev for $ee\nu\nu$ generation

Now on to finding the selectron mass…

The one-dimensional **CHI-Squared Method** for determining the right-handed selectron mass

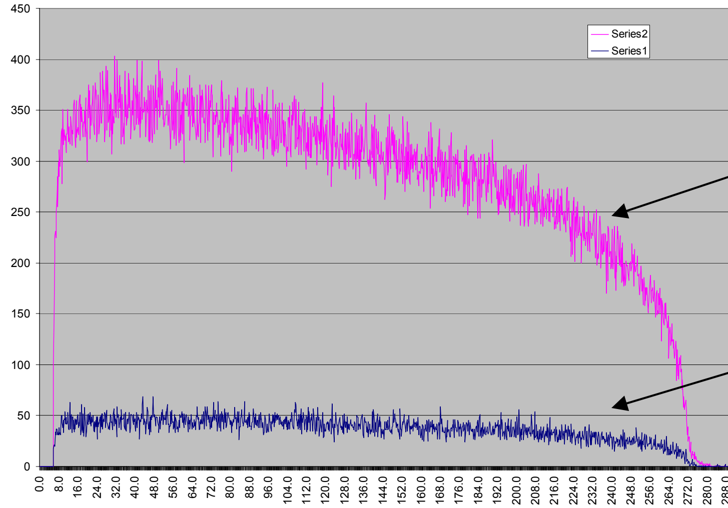
1) Keep the neutralino mass constant at 95.473 GeV

2) Vary the selectron mass and create corresponding Monte Carlo template data. Files are generated at high luminosity (800 fb-1) and simulate beam/brem and ISR.



3) Generate a data set at SPS1A with expected LC luminosity(115 fb-1).

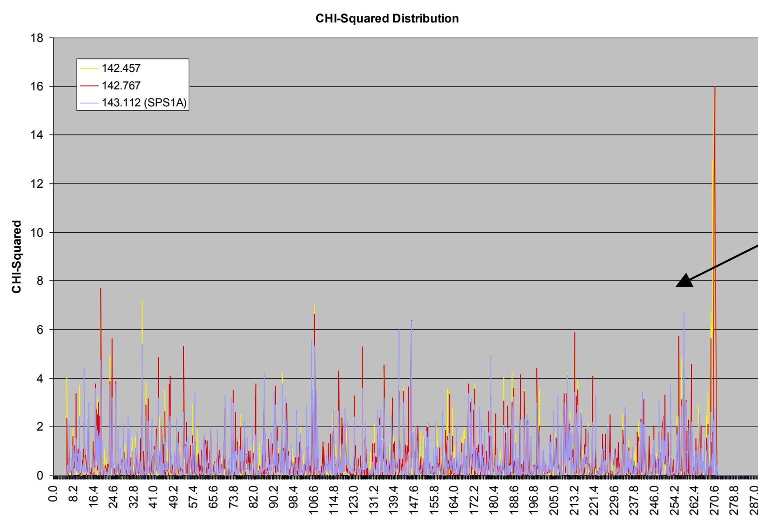
4) Run everything through JAS, perform Cuts, histogram the energy



High luminosity MC template

Realistic luminosity data

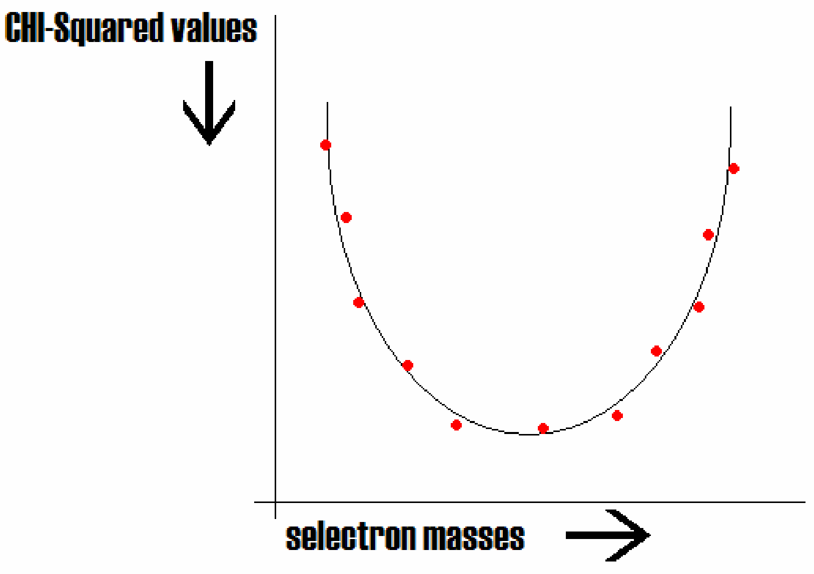
5) Perform a CHI-Squared comparison between the data set and each of the template sets' (selectron mass assumptions) histograms. Obtain a Chi-Square value for each.



MC CHI-Square spectrum for three MC templates

6) Plot CHI-Squared vs. selectron mass and fit to a parabola-like curve (quartic).

7) The minimum of the curve is the fitted selectron mass corresponding to this data set.



8) Wash, rinse and repeat the process 120

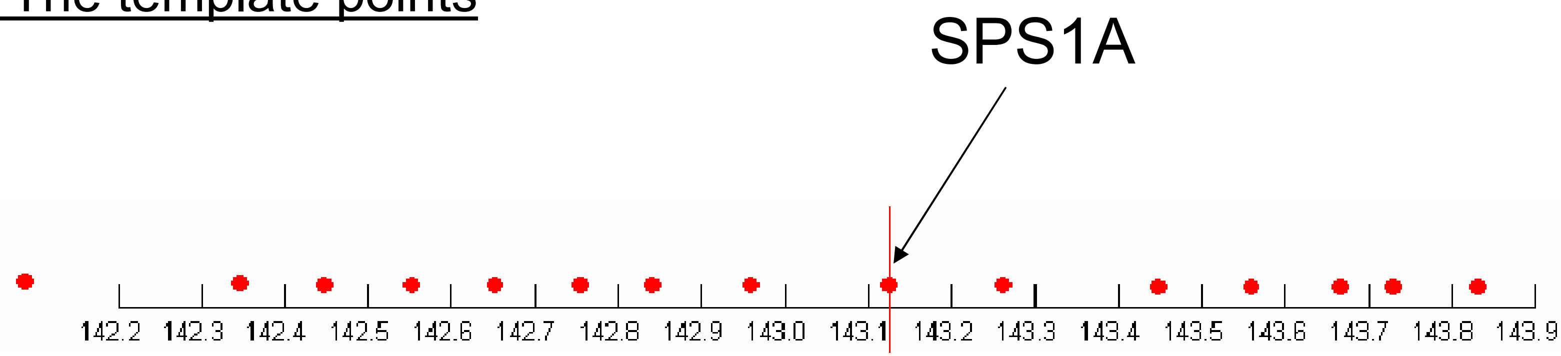
9) Calculate the average fitted mass and RMS error.

10) Bin the data, fit to Gaussian, and find the Gaussian fitted mass and Gaussian error.

* Cuts developed by Gerbode, Holguin, and Mooser remove practically all backgrounds, therefore standard model processes are not included in this study.

Step 2 - The template points

143.823
143.718
143.680
143.571
143.440
143.279
143.112
142.974
142.836
142.767
142.663
142.560
142.457
142.353
142.015

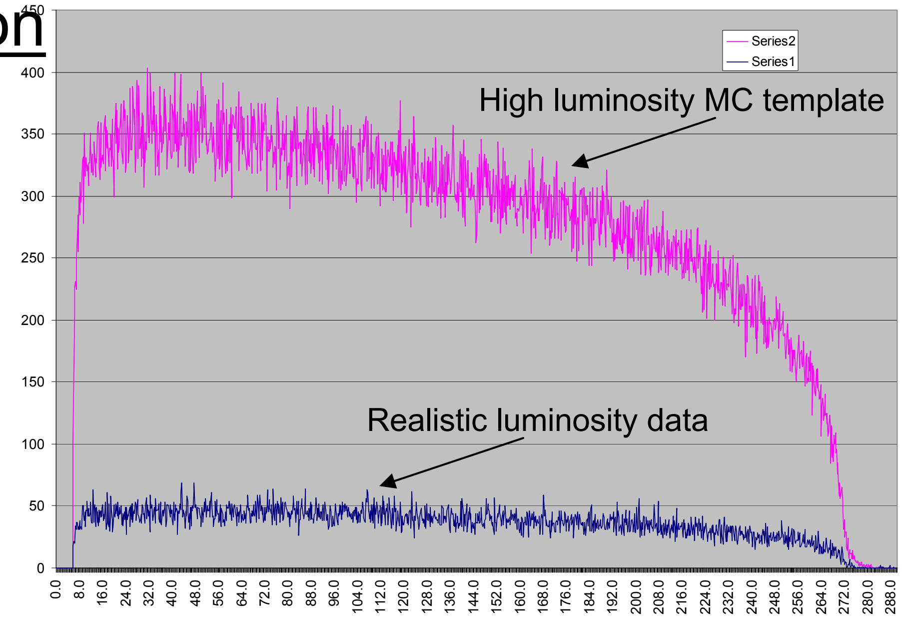


SUSY parameters are changed in a way that changes the selectron mass while holding the neutralino mass constant.

Initially 24 were created, but only the innermost 15 were necessary for quality resolution and fits.

Step 5 - CHI-Squared equation

Energy binning - .2 GeV



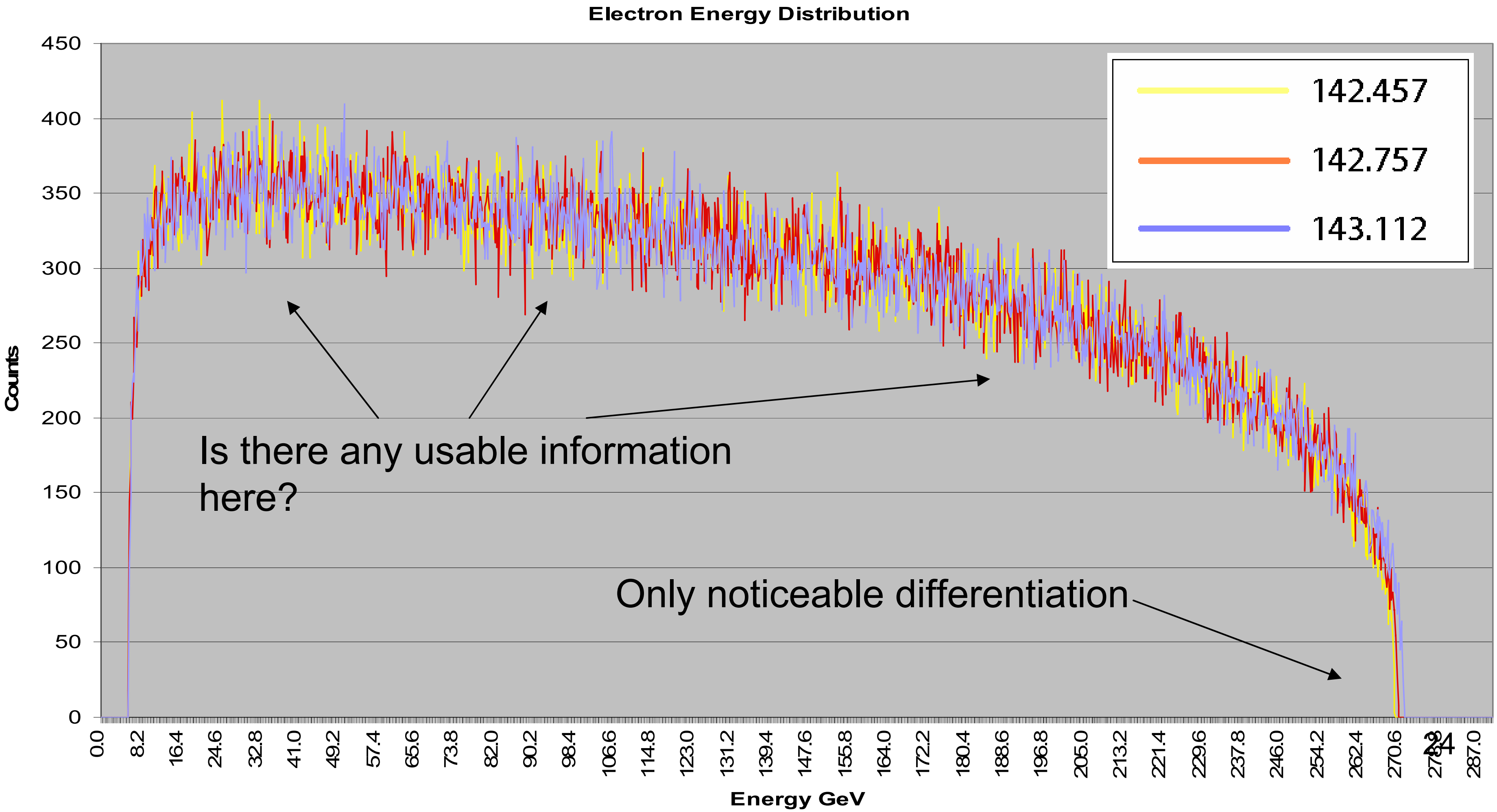
m_i = bin content of template

n_i = bin content of data

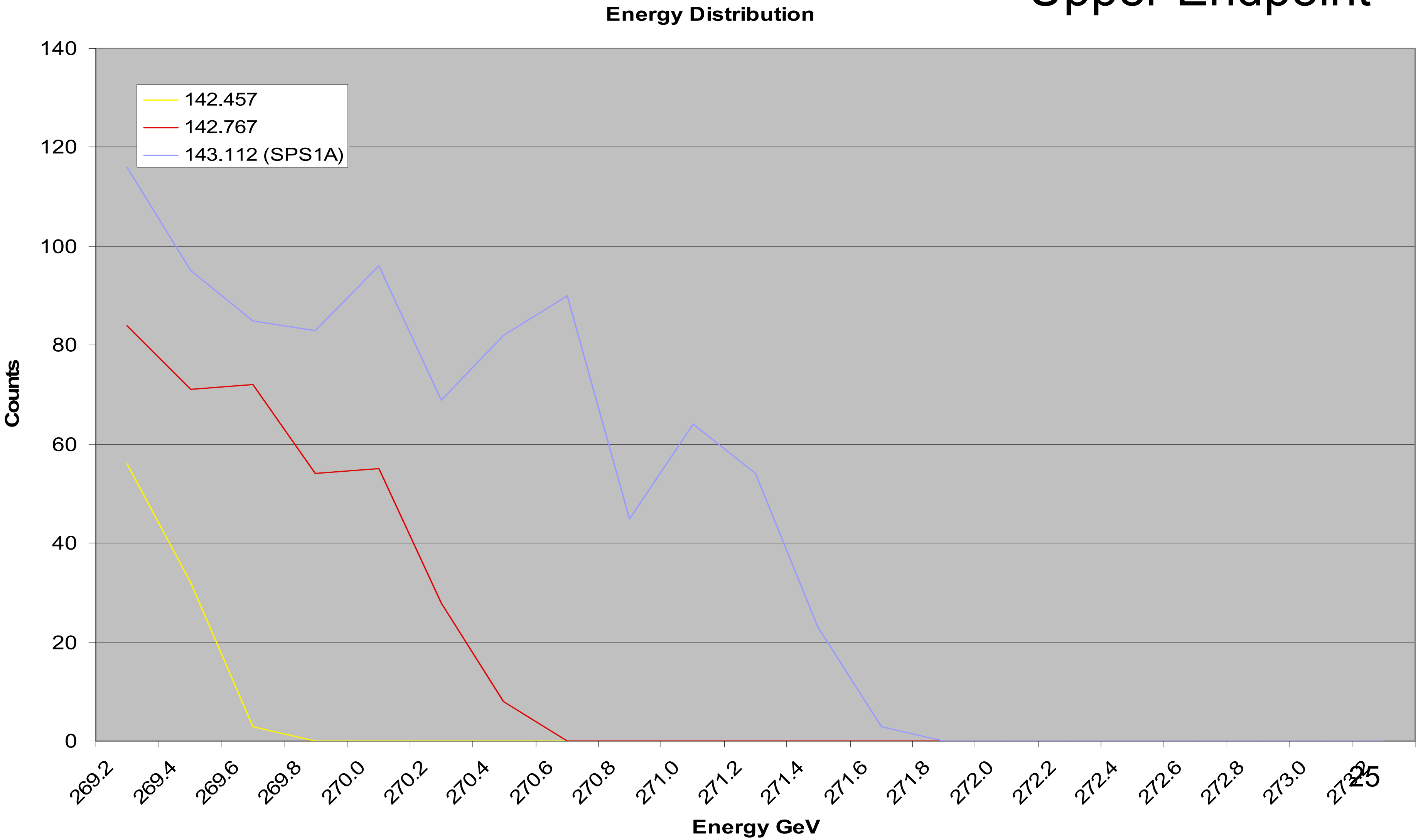
w^2 = $\sum m_i / \sum n_i$ (weighting factor)

$$\text{CHI-Squared} = \sum \frac{(w * n_i - m_i / w)^2}{(n_i * w^2 + m_i)}$$

Steps 5,6 – Understanding the distribution endpoints



Upper Endpoint



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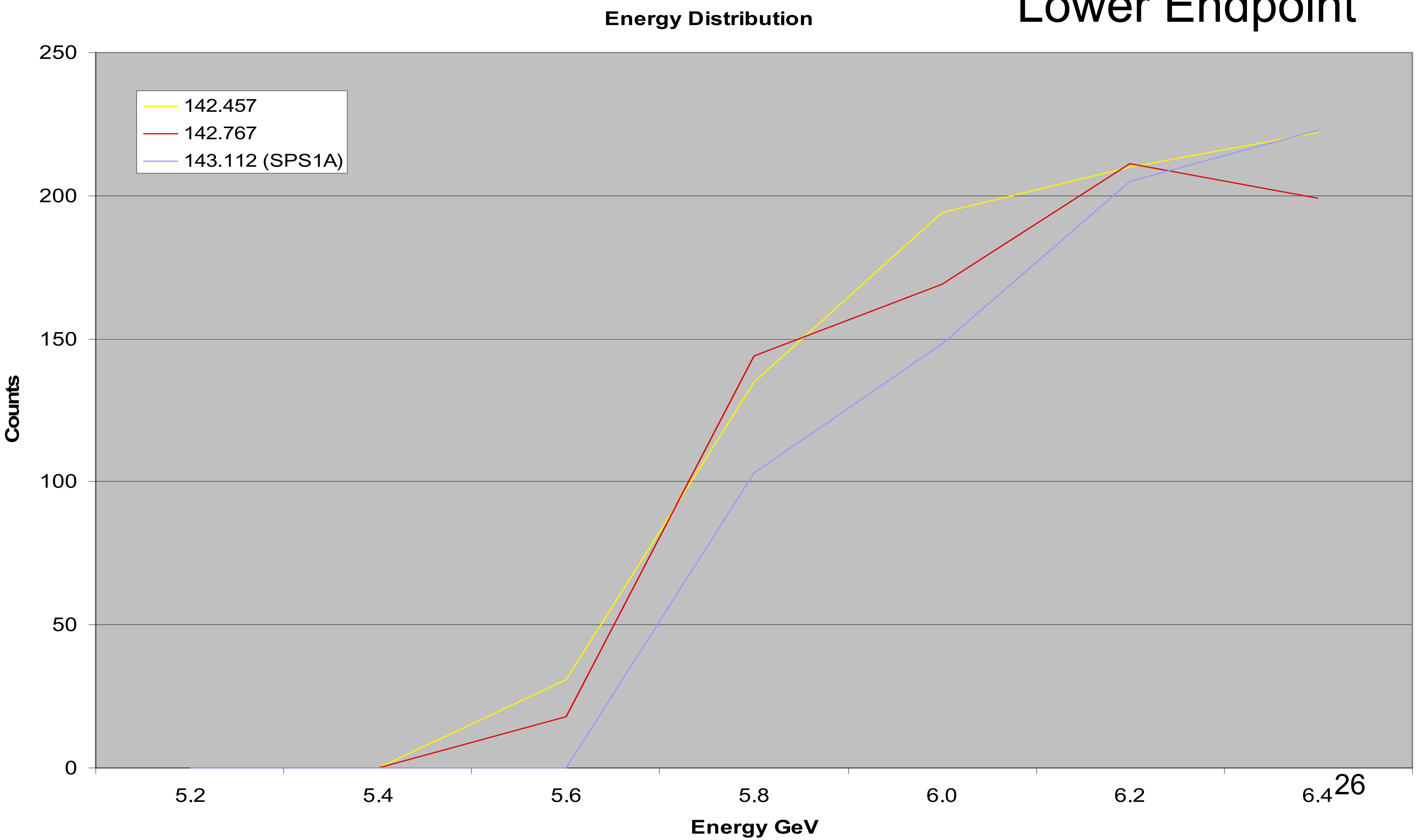
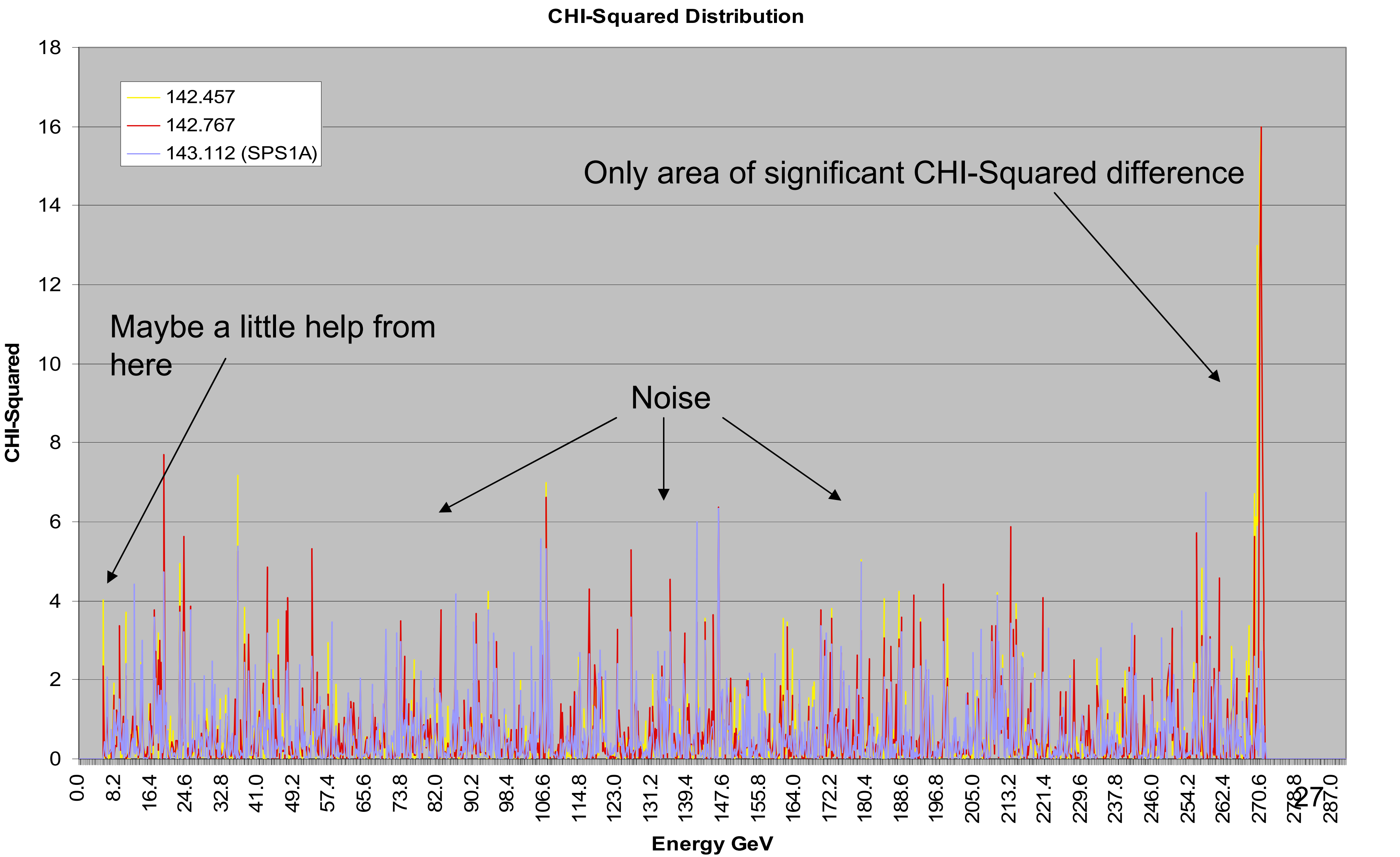
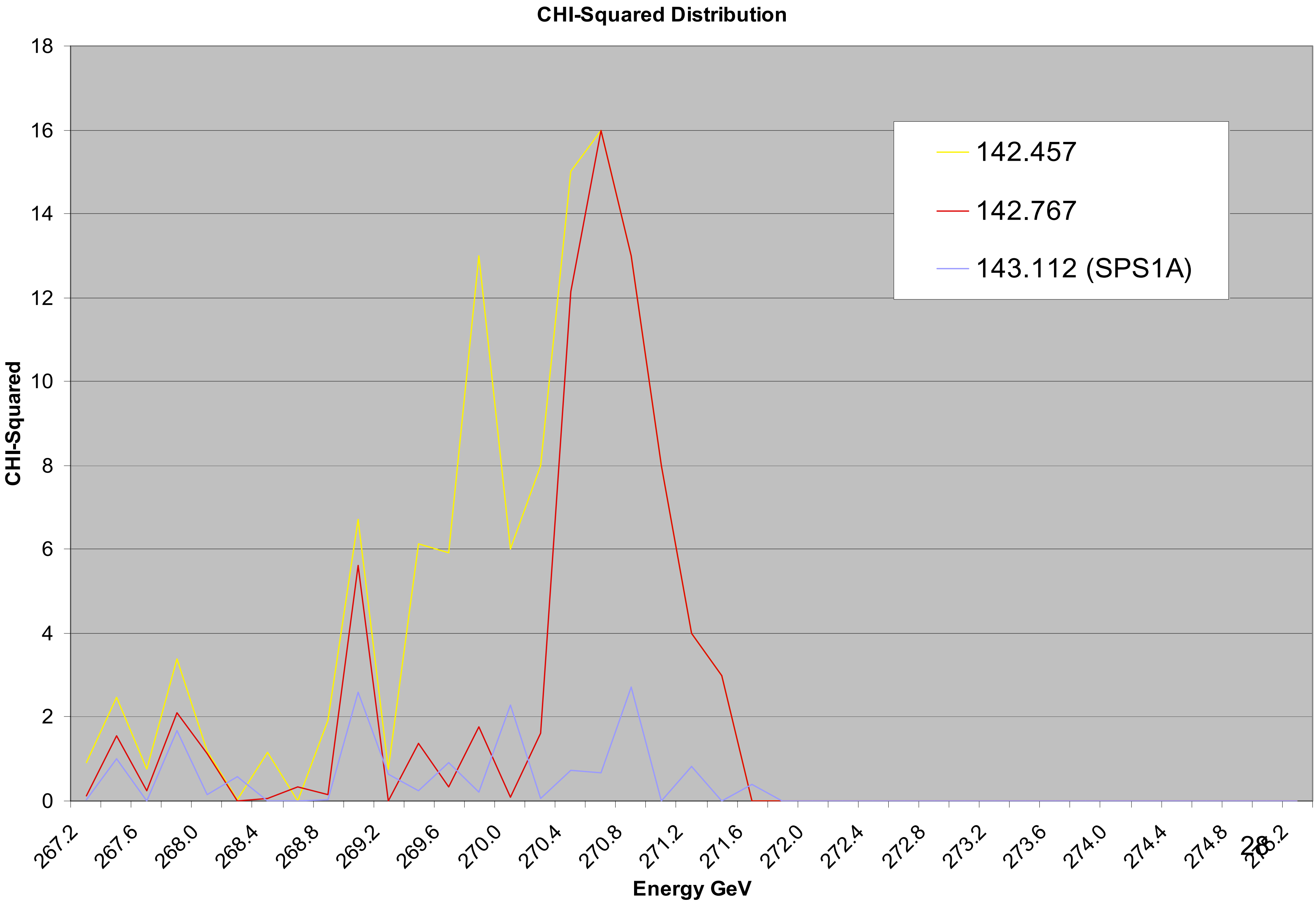
Lower Endpoint



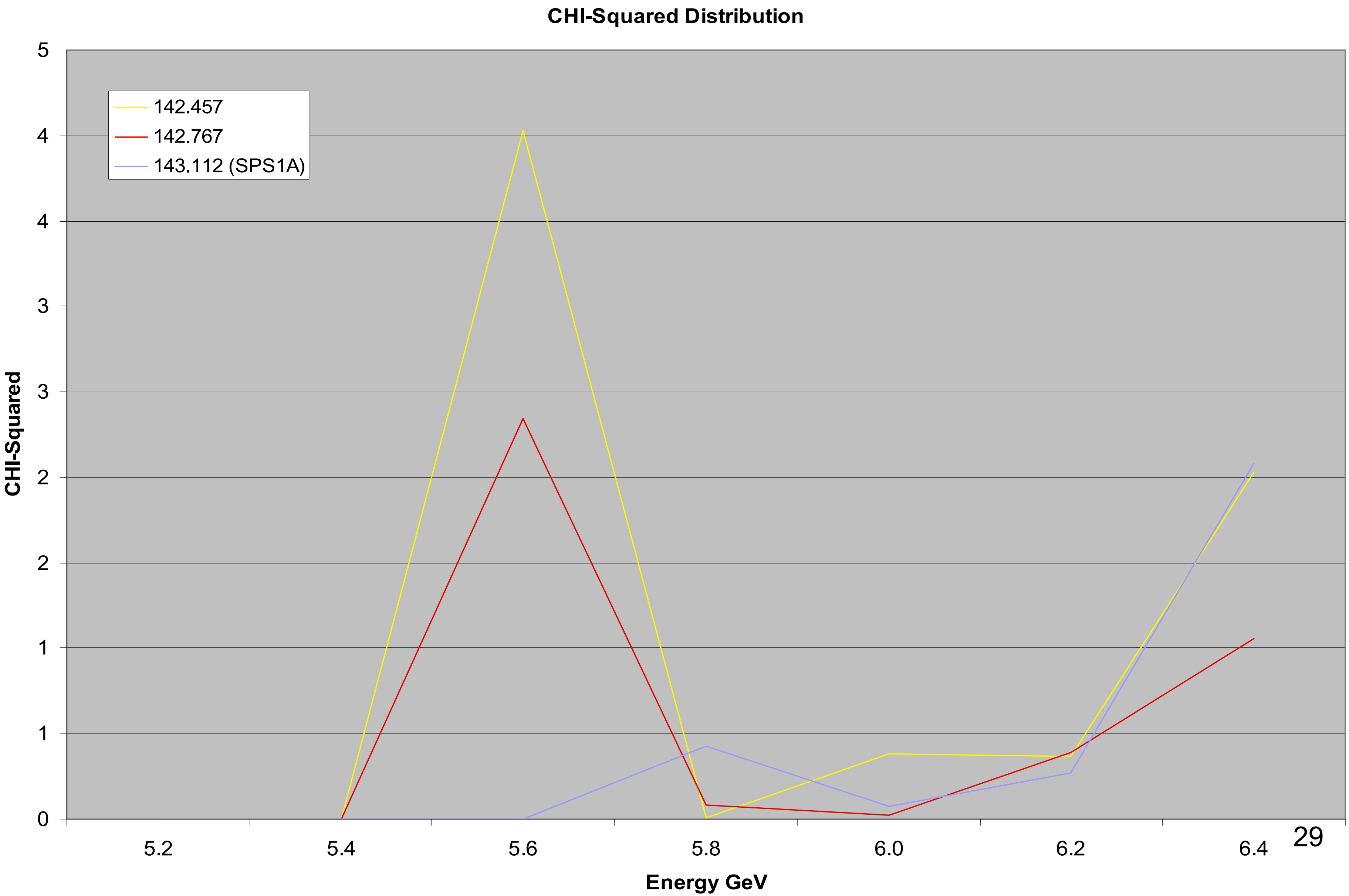
Plot CHI-Squared vs. energy spectrum and see where the differentiation comes from



Zooming into the endpoints (upper)…



Zooming into the endpoints (lower)…



Isolating the endpoint

- Differentiation is small but measurable.
- The noise "off – endpoint", is enough to compromise the differentiation.
- Ignore the middle. Carefully chose the energy range in which CHI-Squared will be calculated.
- Endpoint ranges used in this study are

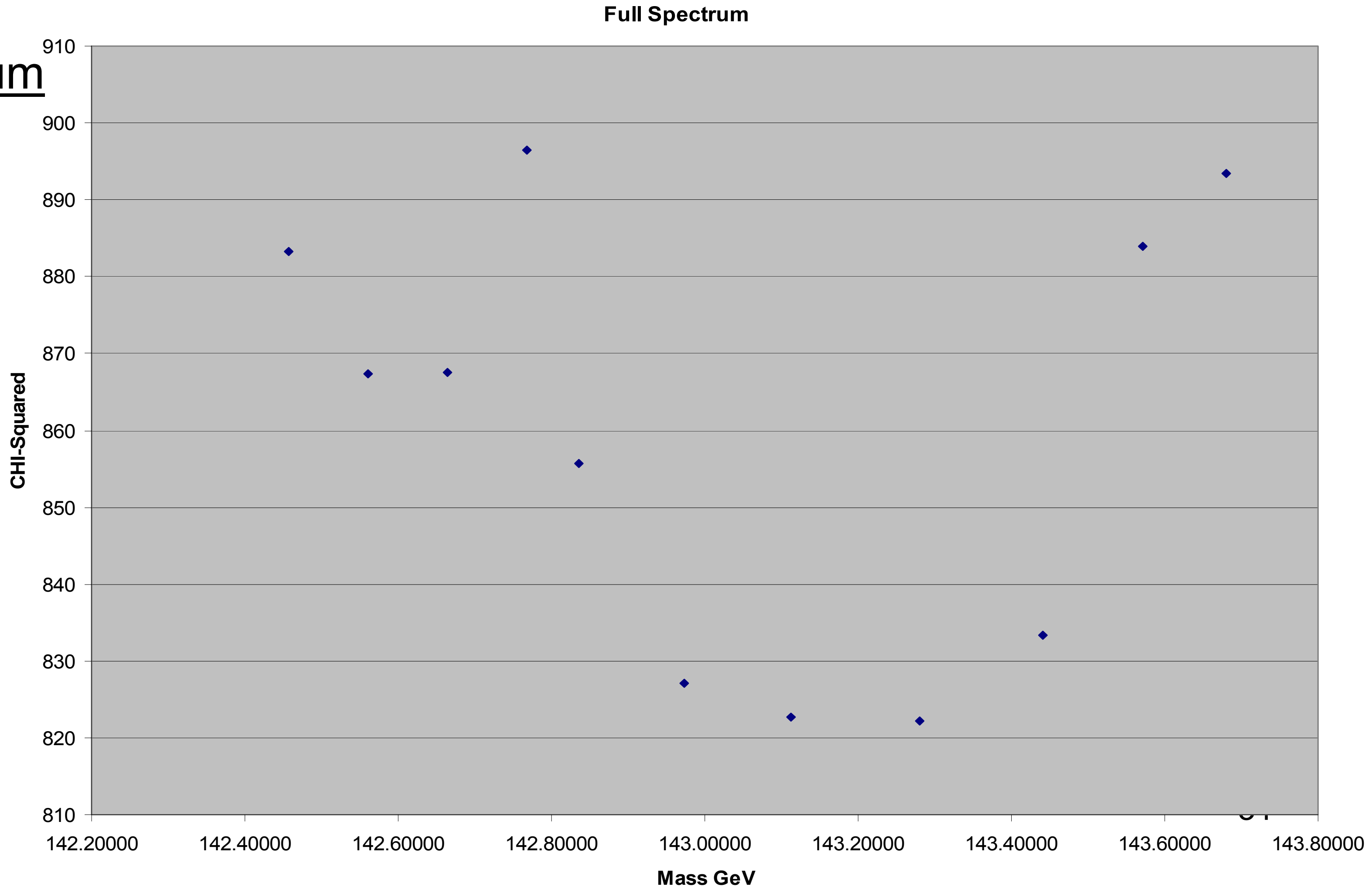
  5.2 - 6.4 GeV (lower)

  269.2 - 273.2 GeV (upper) (no detector smearing)
  267.8 - 274.6 GeV (upper) (smeared .16% beamspread)
  267.2 - 275.2 GeV (upper) (smeared 1.0% beamspread)

- A truly small part of the spectrum, 4%.
- Isolation essential to obtain the resolution that we have.

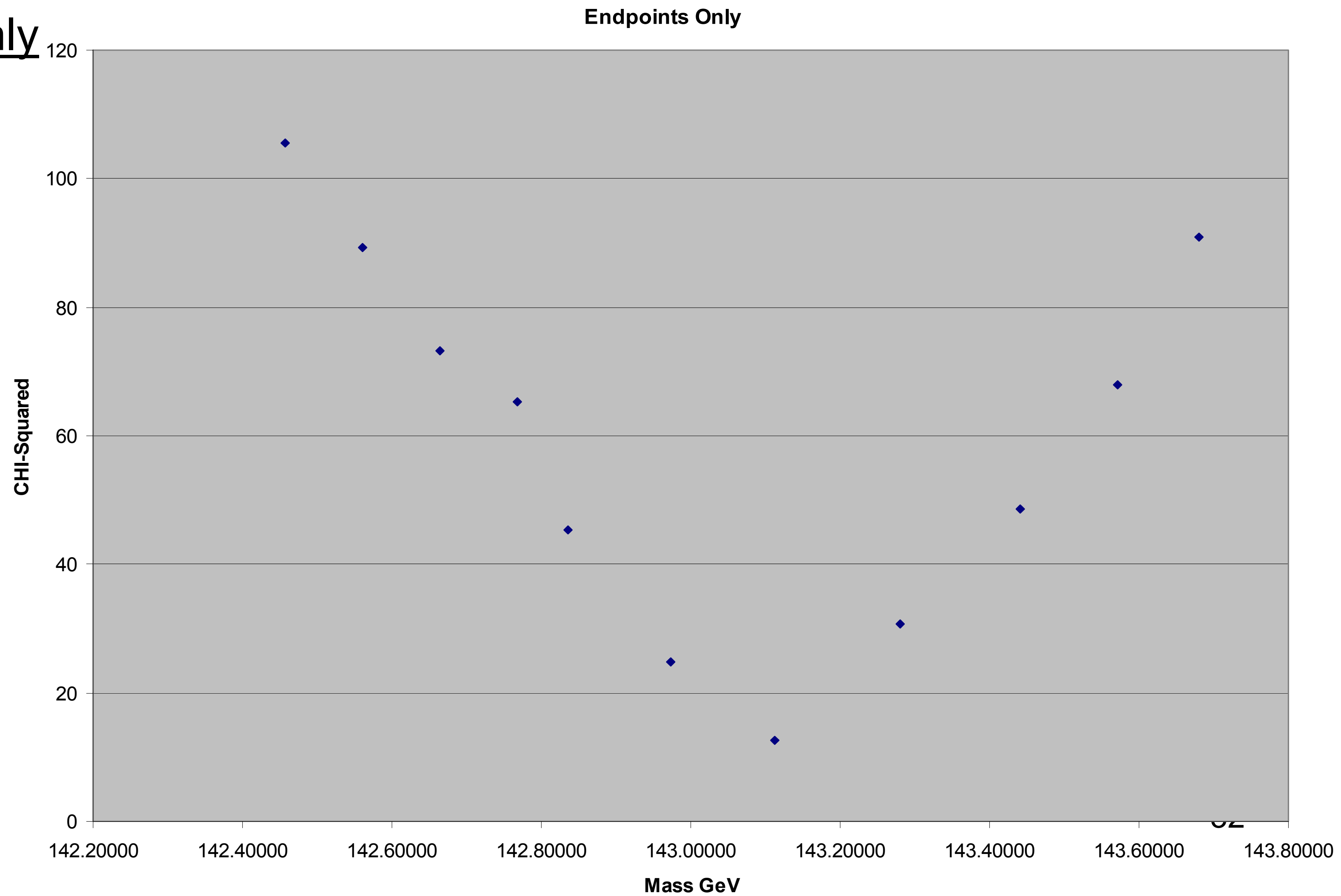
So what happens when we use the end-point only technique?

Full Spectrum

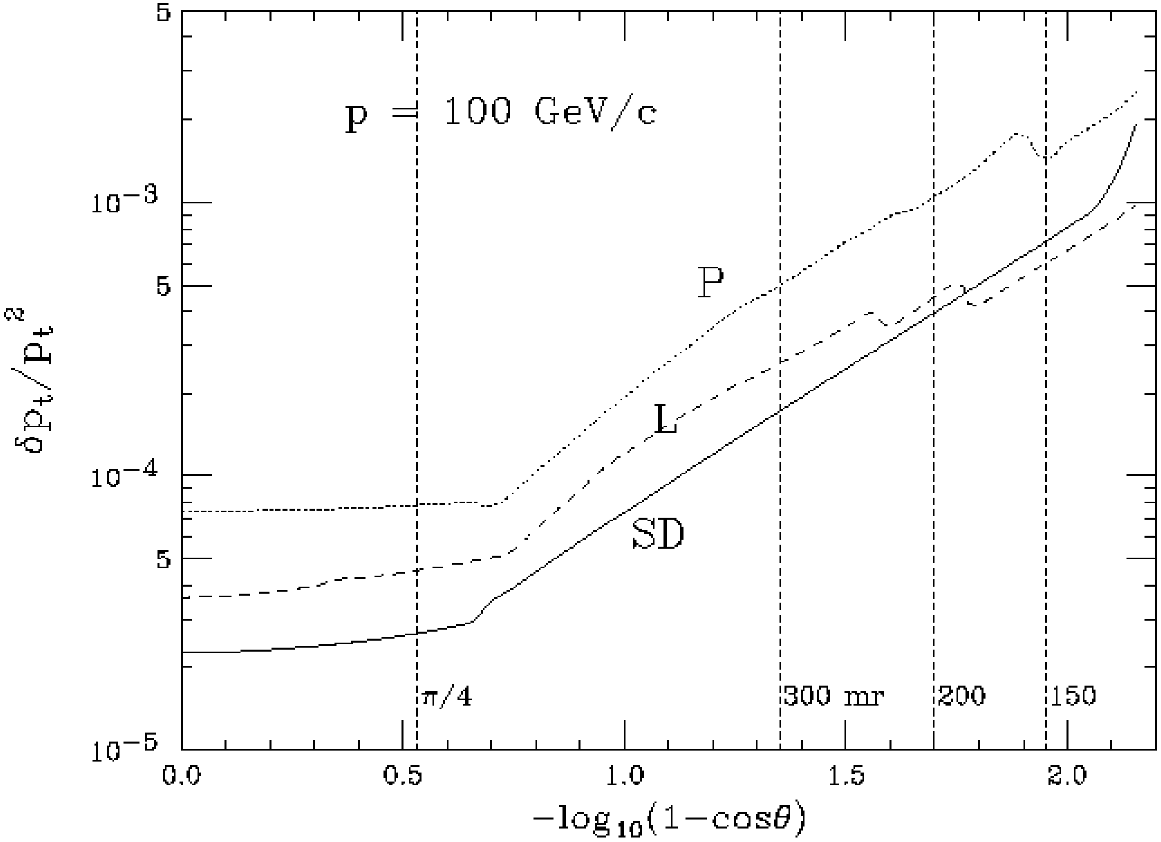


The difference is night and day !

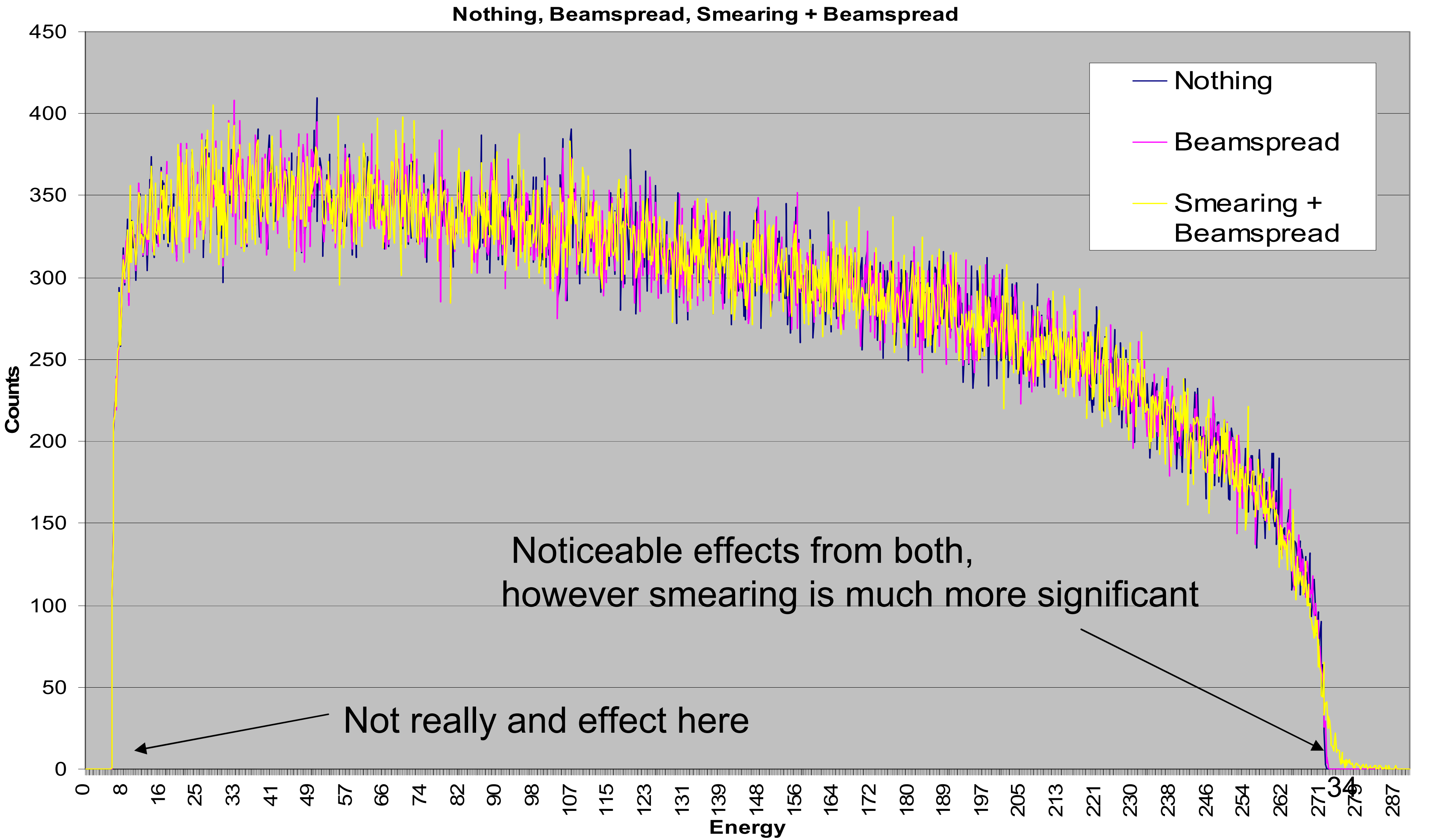
<u>Endpoint Only</u>



Okay, so now that we can deal with a perfect machine (no beamspread or smearing), what happens when we include these factors?

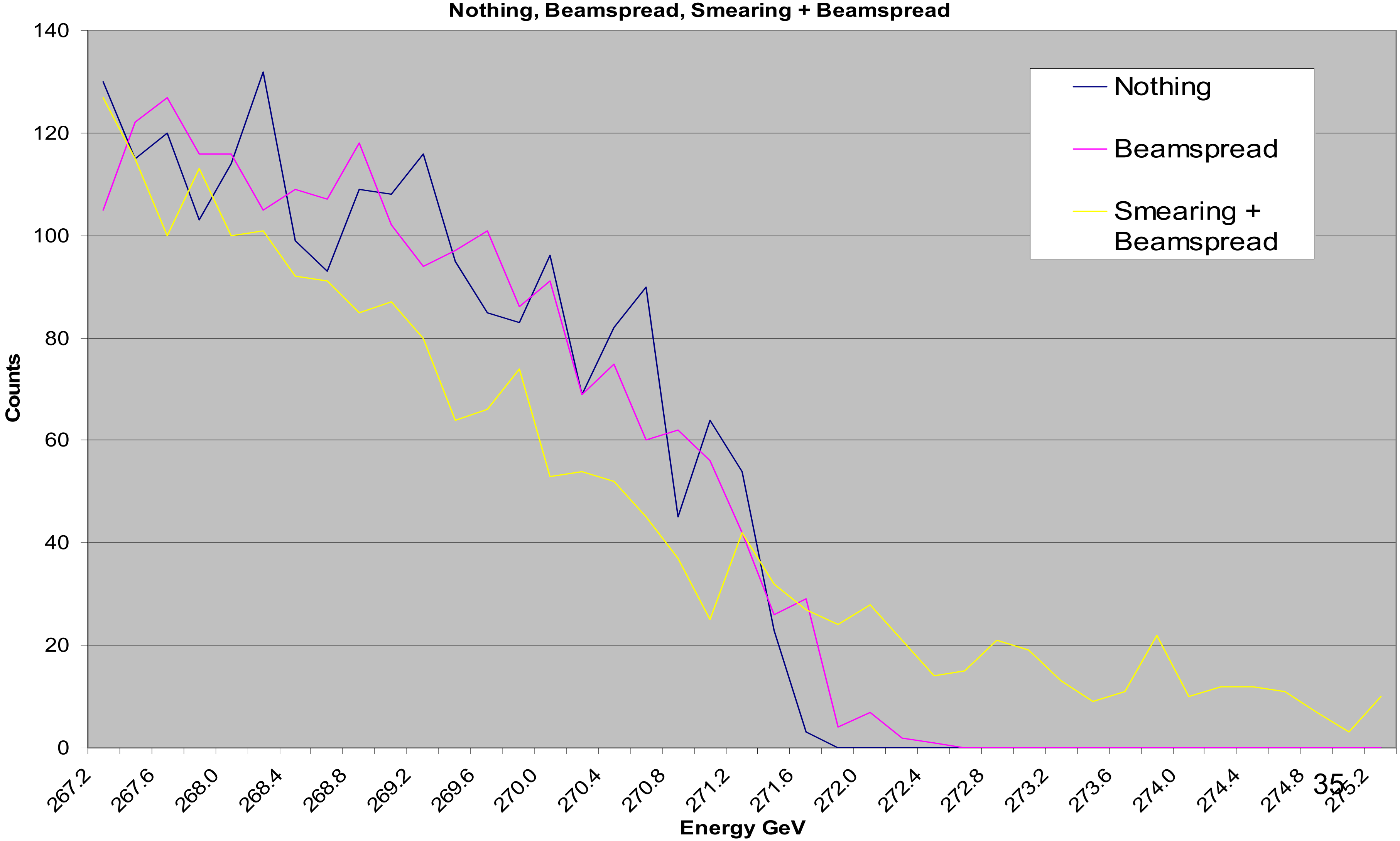


SPS1A template (high statistics) set
Mass of right selectron = 143.112
Beamspread = .16%



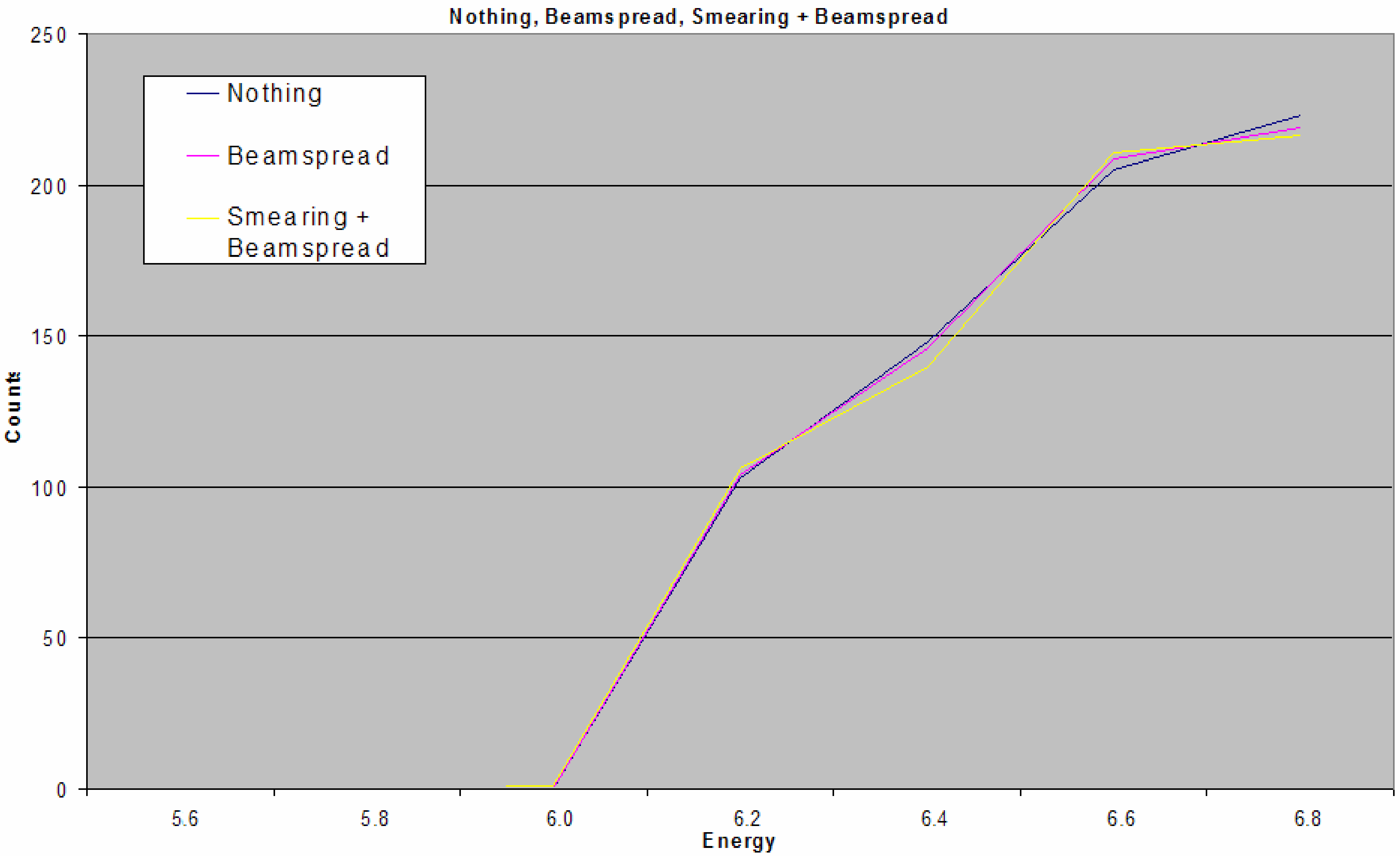
Upper endpoint

significant effects, especially with smearing



Lower endpoint

no significant effects



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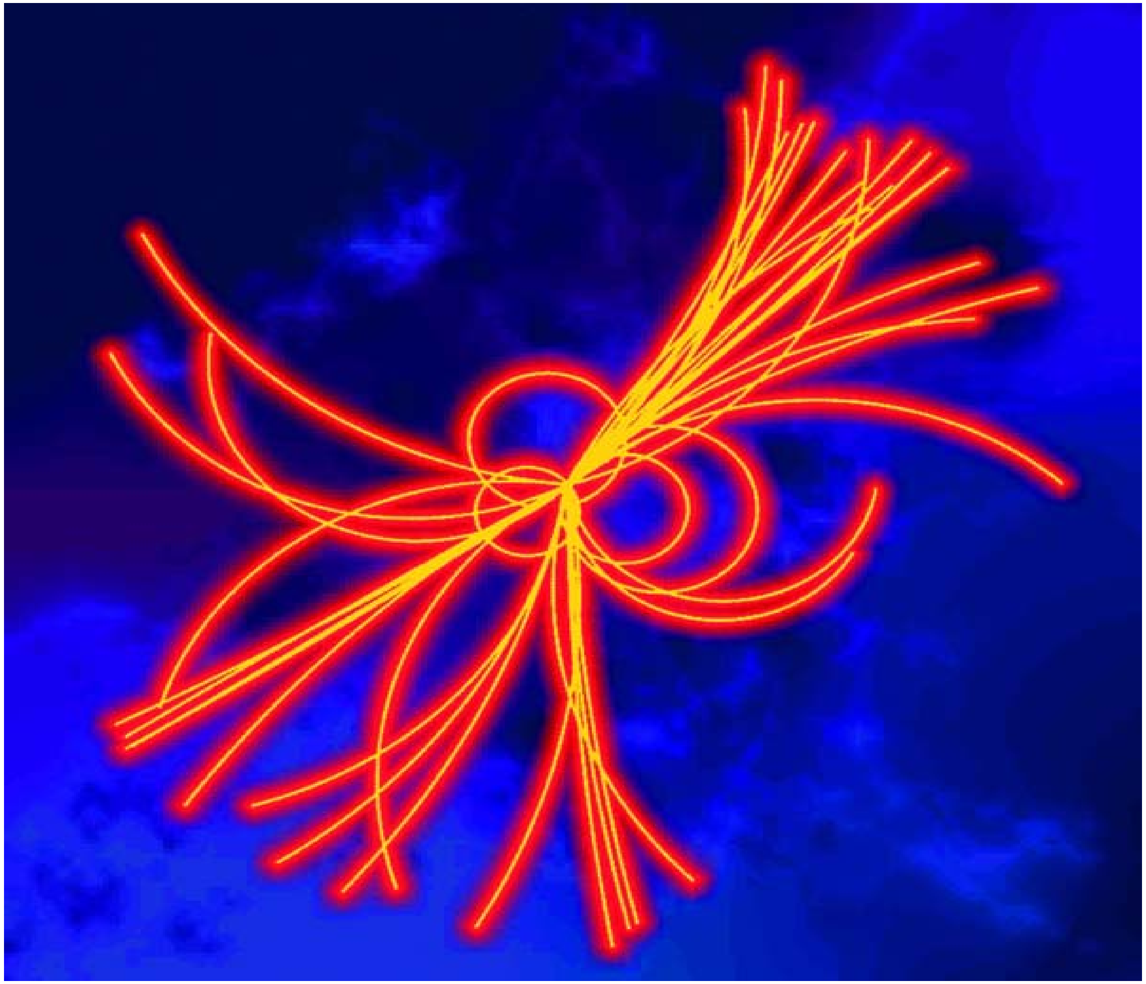
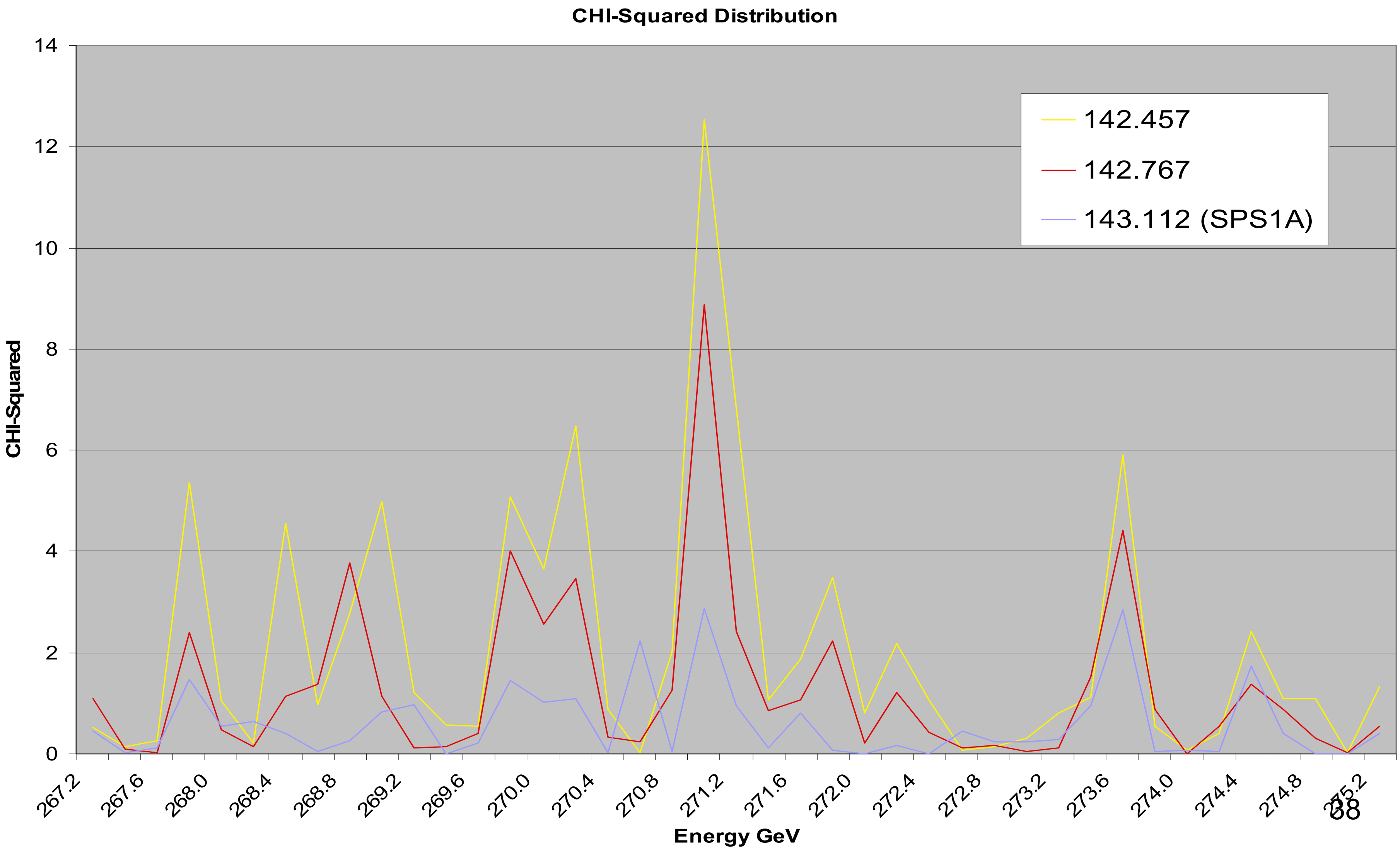
Now lets look at the CHI-Square vs. energy spectrum with detector smearing and .16% beamspread.



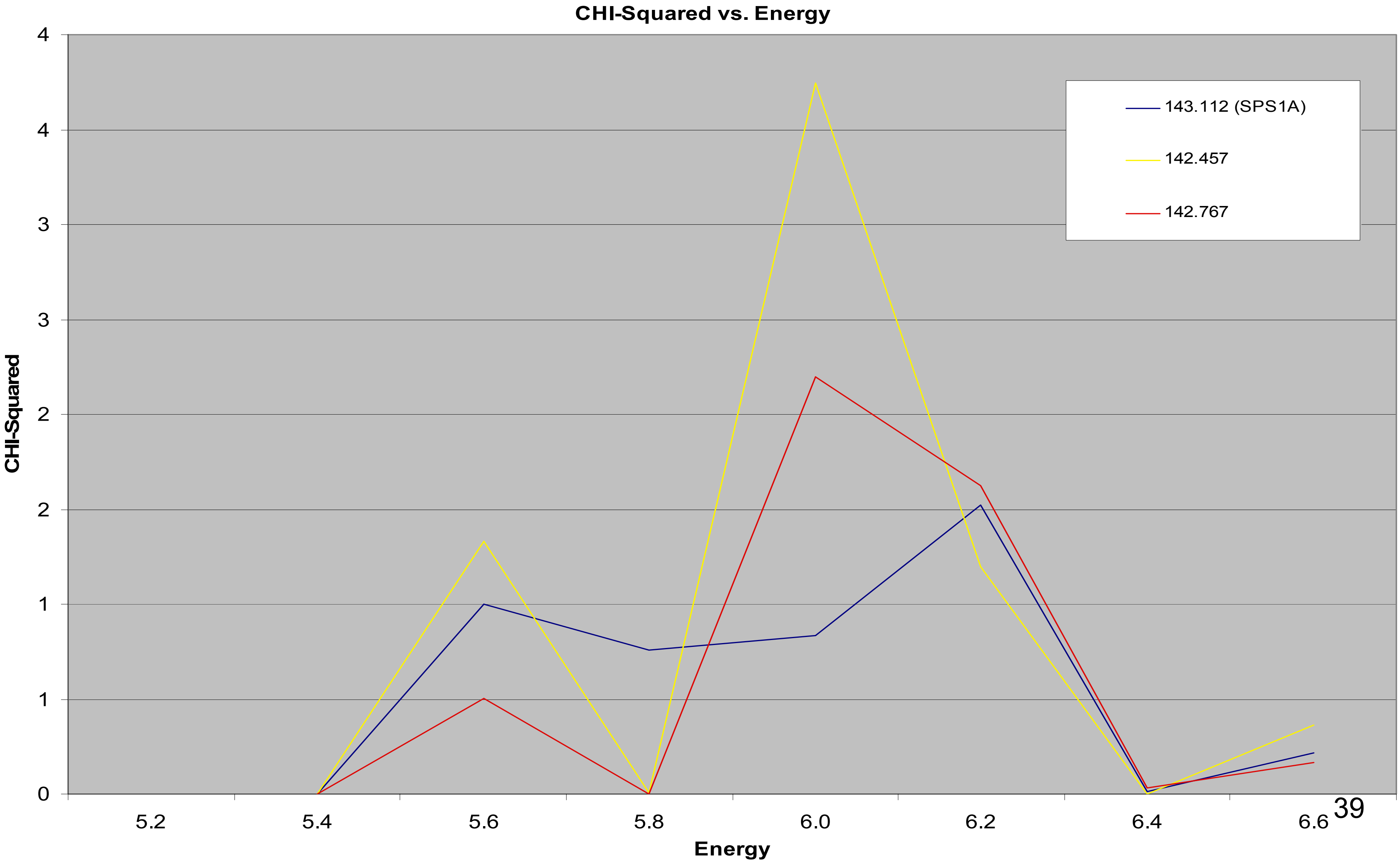
Upper endpoint

CHI-squared



Lower Endpoint

CHI-squared



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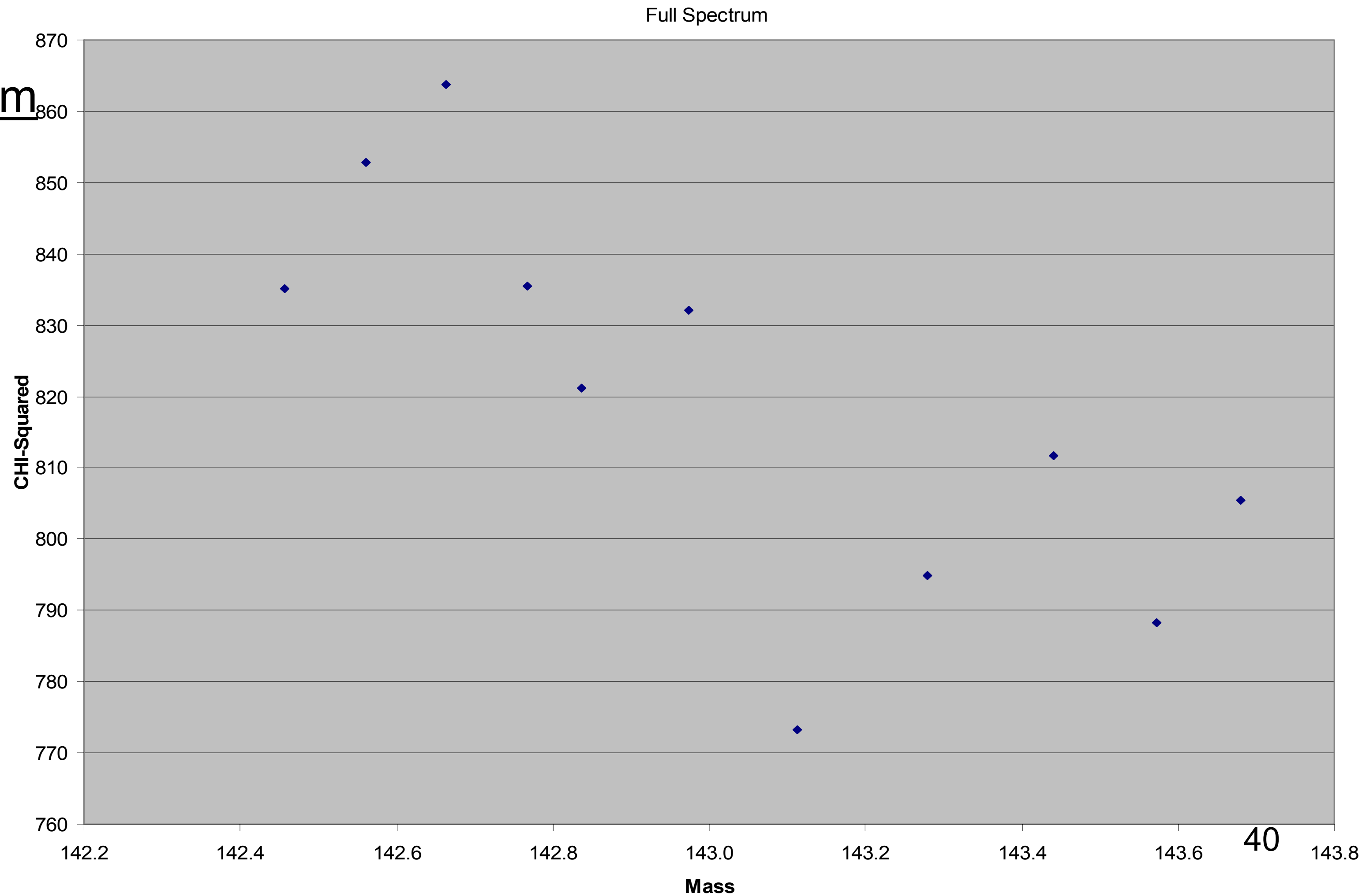
Testing the endpoint isolation technique again…. (smeared)

Full Spectrum



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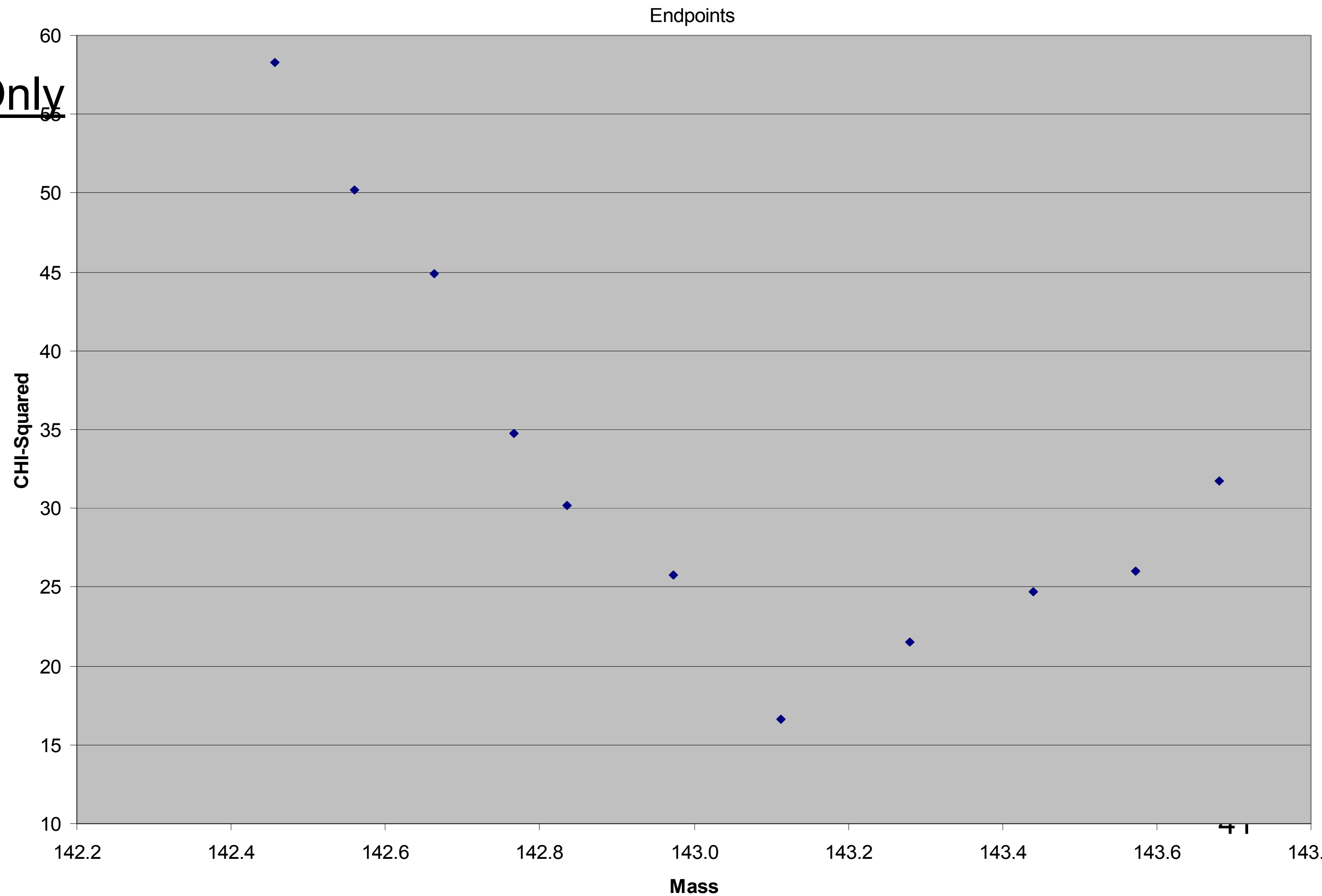
Holy COW !!!!!!!!!!!!!!

Endpoints Only



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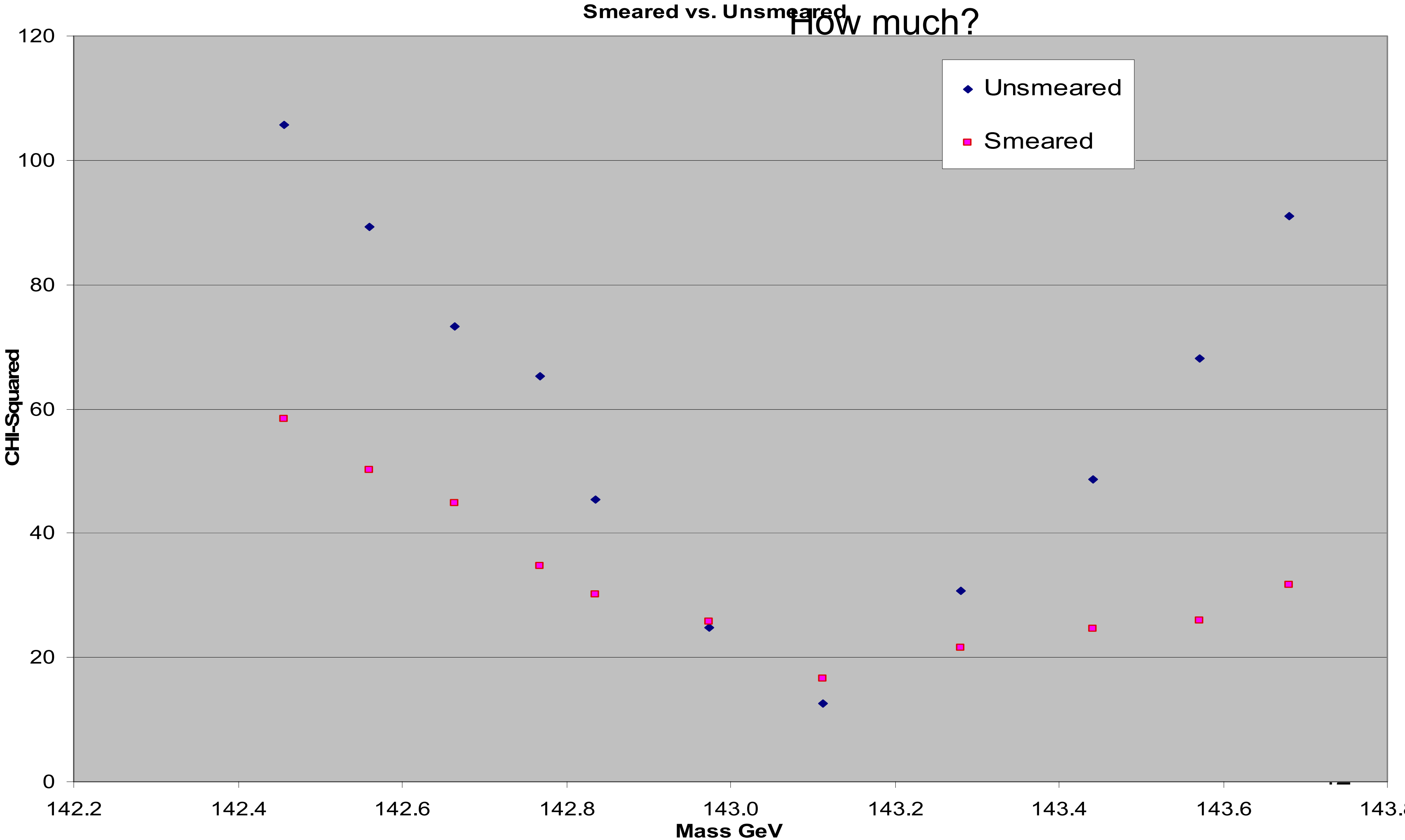
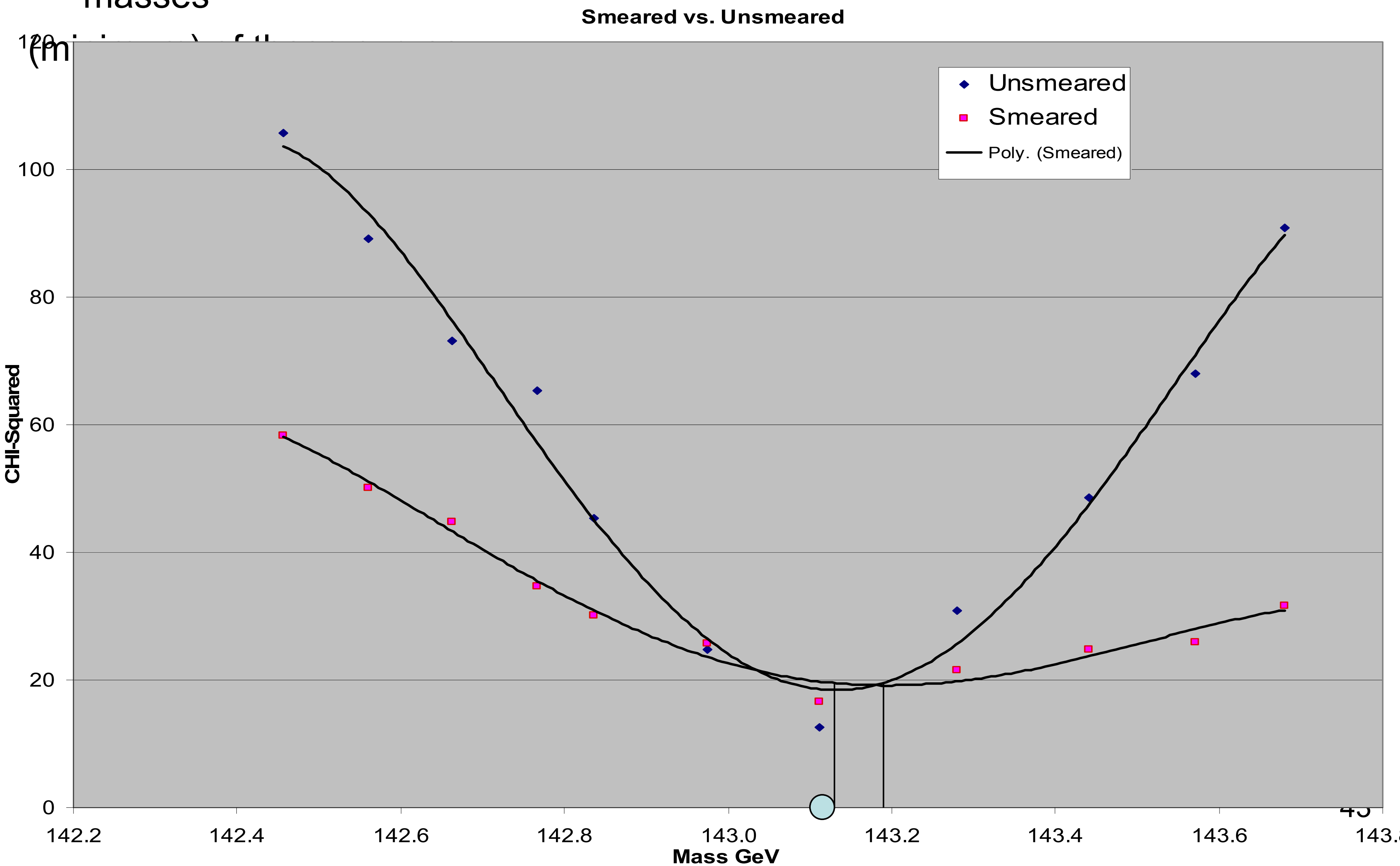
Clearly smearing has some negative effects on the CHI -Squared resolution.

How much?



Comparing steepness of CHI-Square curves is a comparison of resolution. If a curve is shallow, it is an indicator that resolution will not be as good as one that is steep. We can fit a quartic to this distribution and compare the fitted masses

(m



Calculating the resolution/error

This CHI-Squared fitting process is repeated 120 times and the fitted mass is the minimum of these curves. The resolution/error is the RMS of these masses.

Results are cross checked by binning and fitting to a

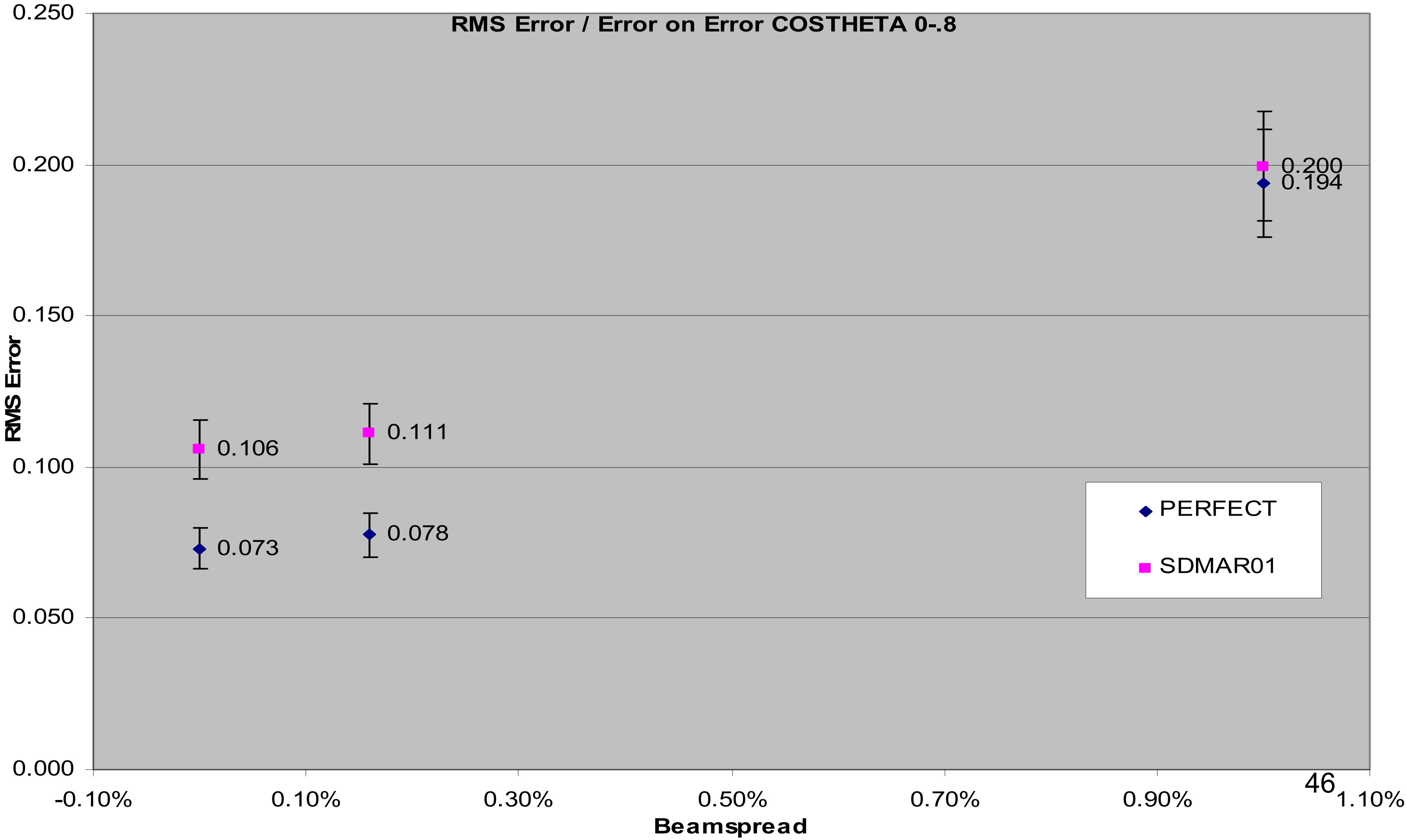
Gaussian. The error is the width, and is in agreement with the RMS.

Points of Interest

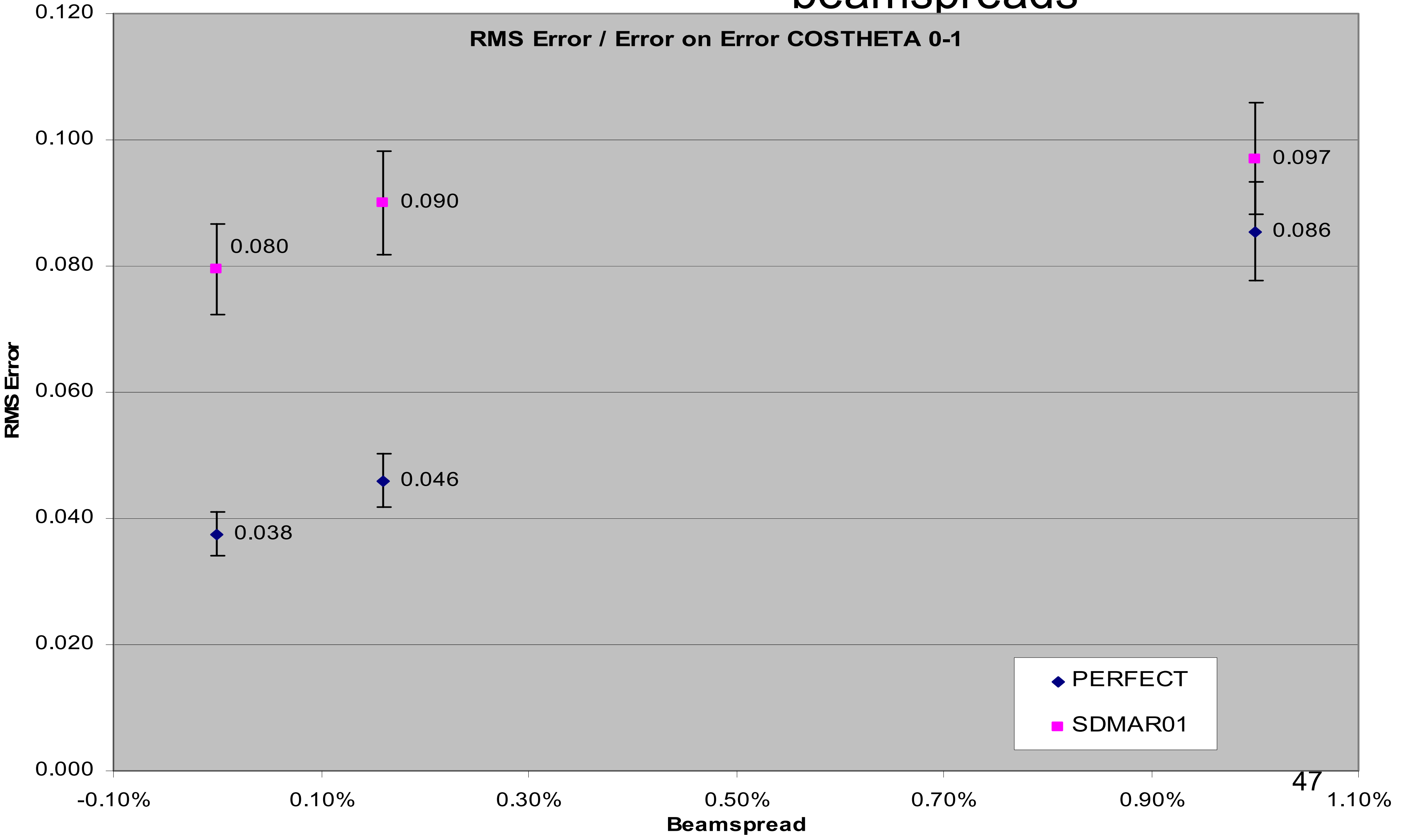
12 Scenarios are investigated.

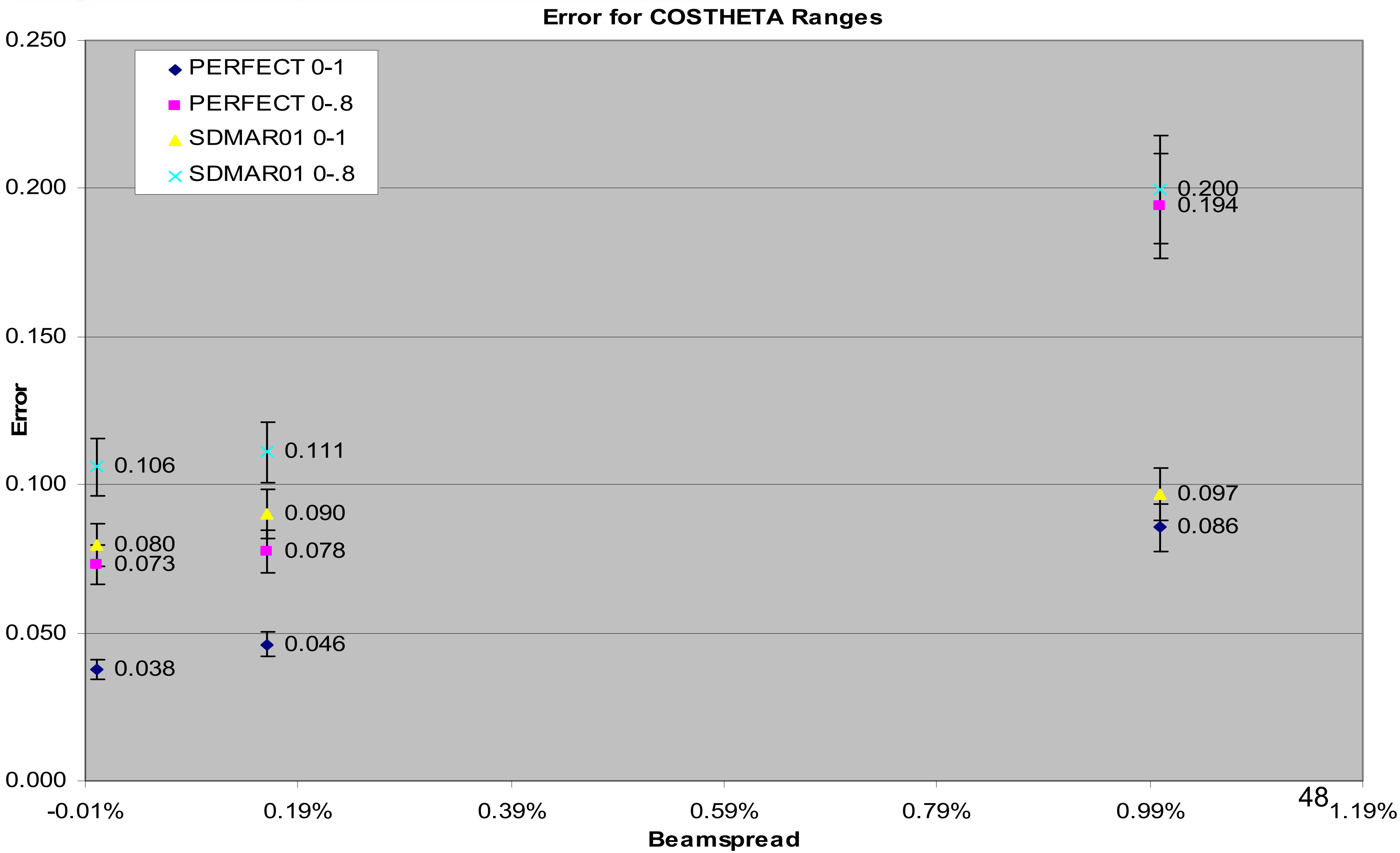
- a perfect detector (unsmeared) and sdmar01
- cos(θ) $0 - 1$ (full region) , $0 - .8$ (only central region)
- beamspreads of 0% , .16% , 1%

Fit error degrades when investigating only the central region.

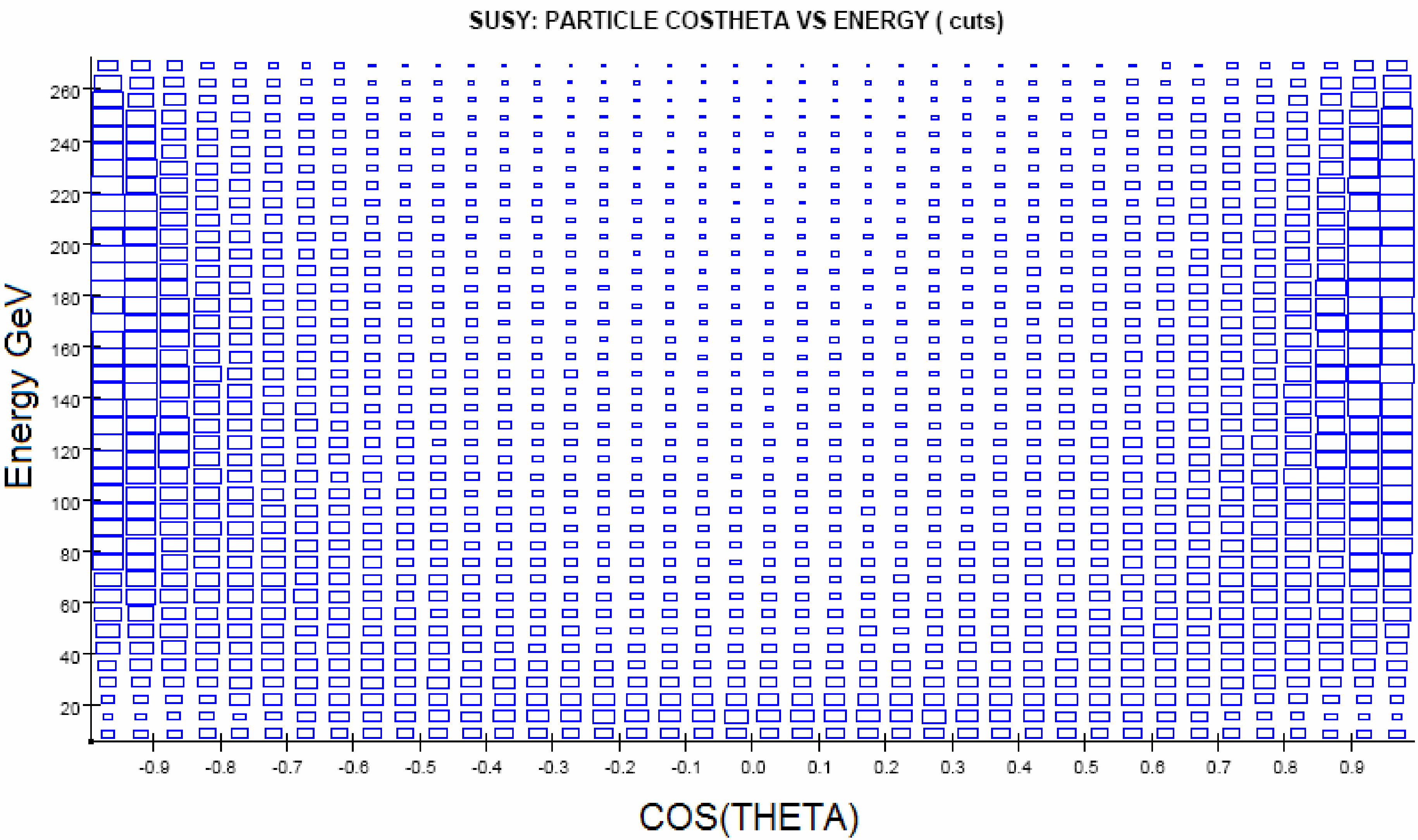


Fit error improves nearly 2* from SDMAR01 to PERFECT for realistic beamspreads




Error for COSTHETA Ranges
0.250
0.200
0.150
0.100
0.050
0.000
Error
PERFECT 0-1
PERFECT 0-.8
SDMAR01 0-1
SDMAR01 0-.8
0.200
0.194
0.106
0.111
0.097
0.090
0.086
0.080
0.073
0.078
0.046
0.038
-0.01%
0.19%
0.39%
0.59%
0.79%
0.99%
1.19%
Beamspread

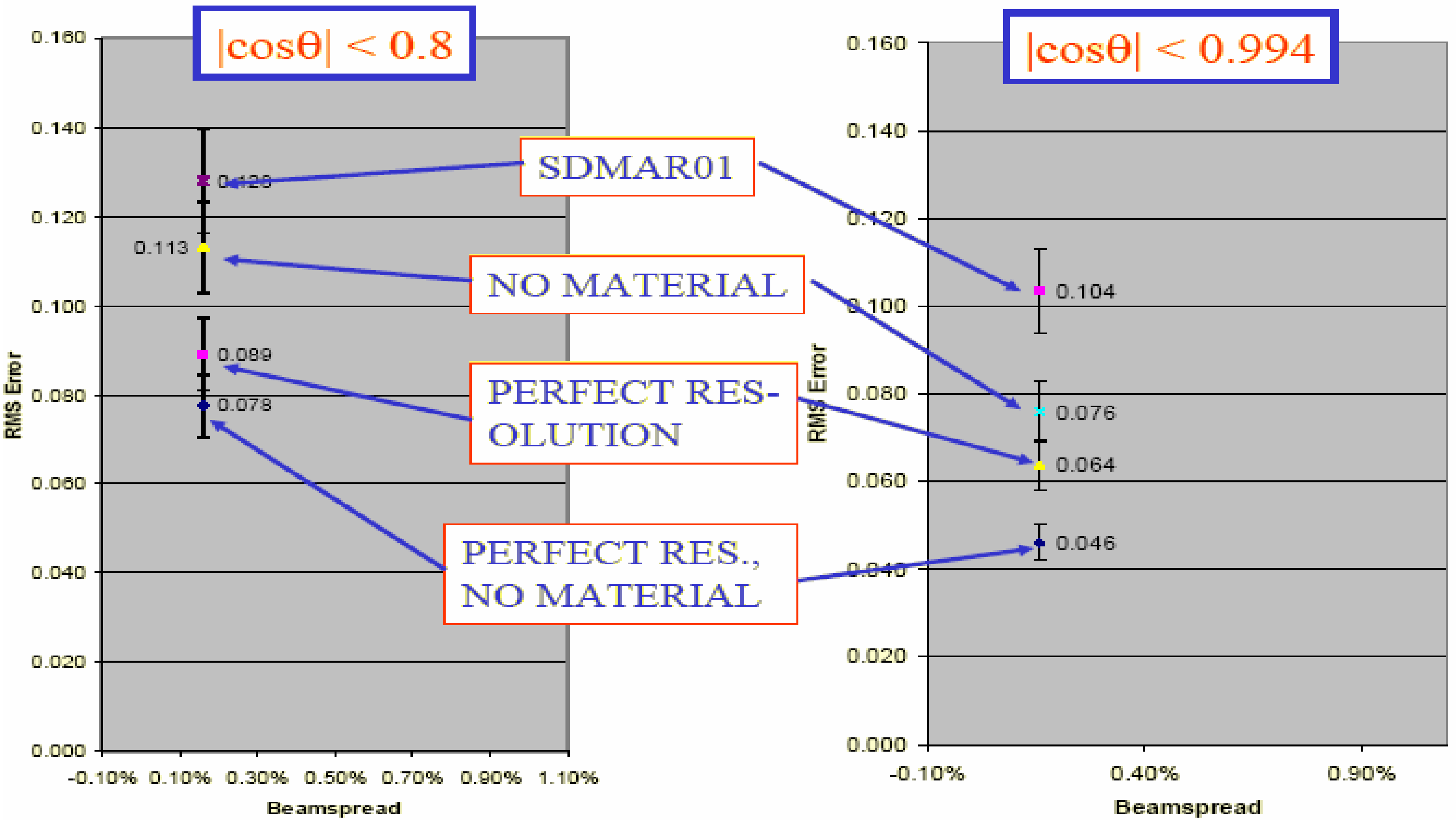
The significant resolution improvement in the full-region over just central is explained by the significant amount of statistics to be gained from using the forward direction at the upper endpoint.



BREAKING NEWS

(Recent results)

Is it the point resolution, or the material?



Conclusions

- For cold detector technology (.14 % beamspread), SDMAR01 has not reached the point of diminishing returns.
- Due to stiffening of the spectrum in the forward region, there is a surprising amount of information there.
- Detector resolution is even further from ideal in this region. If there is forward SUSY production to be measured, there is much to be gained by improving the detector.
- In the central region point resolution is dominant. In the forward region, material also comes into play.

Outlook

- Need to explore these conclusions further, and use studies to develop reasonable goals for forward tracking.
- A study soon to be completed will investigate the resolution of the selectron and neutralino simultaneously. The method will be slightly different, but employ many/all of the techniques developed in this process.
- We will also be looking at some 500 GeV stuff.