SUSY Point 5

Chargino / Neutralino Analysis in Fully Hadronic Final State

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General Things:
Processes & Technicalities

What Are We Looking For?

The SUSY signal processes:

$$e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow W \tilde{\chi}_1^0 \, W \tilde{\chi}_1^0 \rightarrow q\bar{q}' \, \tilde{\chi}_1^0 \, q\bar{q}' \, \tilde{\chi}_1^0$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0 \, Z \tilde{\chi}_1^0 \rightarrow q\bar{q} \, \tilde{\chi}_1^0 \, q\bar{q} \, \tilde{\chi}_1^0$$

What do we want with these signals?

- separate signal(s) sufficiently from backgrounds (SM & SUSY alike)
- measure the cross section → need good $\varepsilon \times \pi$!
- extract SUSY-masses: $m(\tilde{\chi}_1^\pm)$, $m(\tilde{\chi}_2^0)$ and m_{LSP}

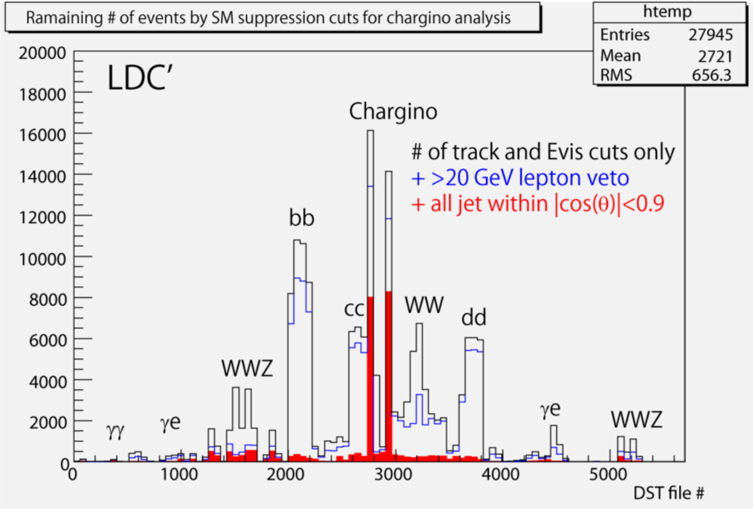
SUSY p5: Params, Samples & Software

Input Parameters		m_{bosino} [GeV]		Decays
m_0:	206.0 GeV	$\widetilde{\chi}_1^0$	115.7	–
$m_{1/2}$:	293.0 GeV	$\widetilde{\chi}_2^0$	216.7	$\widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0 Z$: 96.4 %
$\tan(\beta)$:	10	$\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$	413, 430	not relevant
Sgn(μ):	1	$\widetilde{\chi}_1^\pm$	216.5	$\widetilde{\chi}_1^\pm \rightarrow \widetilde{\chi}_1^0 W$: 99.4 %
A_0:	0	$\widetilde{\chi}_2^\pm$	430.7	2-body: $\approx$ 87.0 %

- DESY mass produced Monte Carlo samples; that have been generated at SLAC using WHIZARD
- So far only for $\sqrt{s}$ = 500 GeV and with $\mathcal{P}_{e^+} = +1$, $\mathcal{P}_{e^-} = -1$
- Software: ILCsoft v01-04, detector model: LDC$'$:
  DST01-*_ch1ch1_????_500_LDCPrime_02Sc*_ep+1.0_em-1.0_Desy_point5_00??.slcio
  DST01-*_ne2ne2_????_500_LDCPrime_02Sc*_ep+1.0_em-1.0_Desy_point5_00??.slcio
  DST01-*_ch1ch1_????_500_LDCPrime_02Sc*_ep+1.0_em-1.0_Desy_point5_00??.slcio

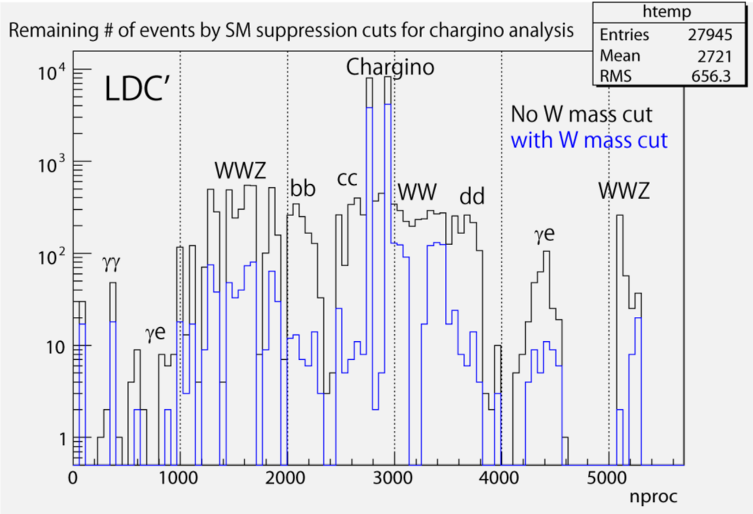
How to separate Charginos/Neutralinos?

Scanning the SM-Background



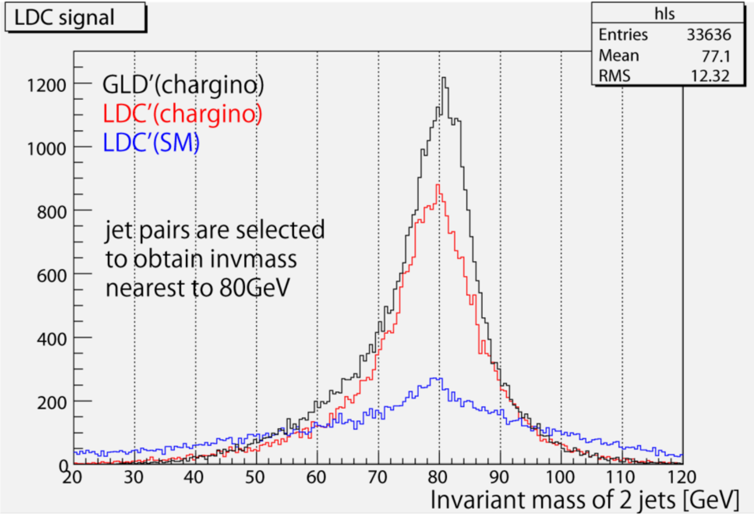
Luminosity is NOT normalized: SUSY-signals = 500 fb^{-1},
but for backgrounds only: $\gamma\gamma \,/\, \gamma e = 1$ fb^{-1}, $qq \,/\, qqqq$ = 20-50 fb^{-1}

Scanning the SM-Background



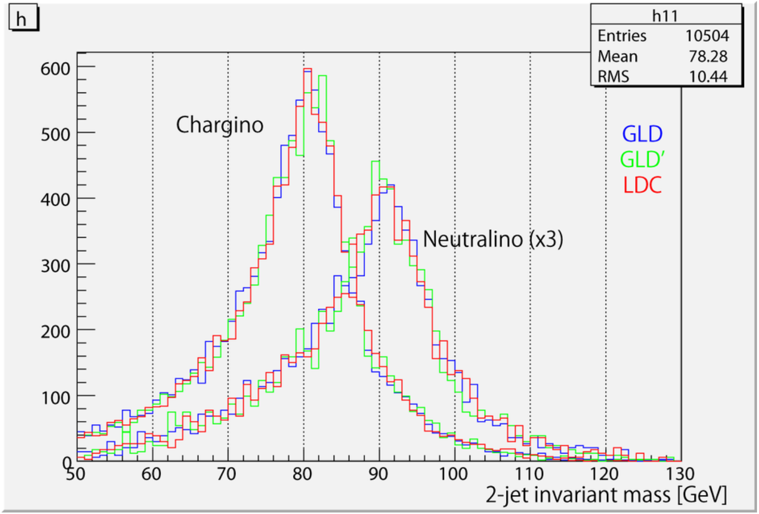
After W-mass cut: WW & WWZ are the dominant background.

Di-Jet Invariant Mass



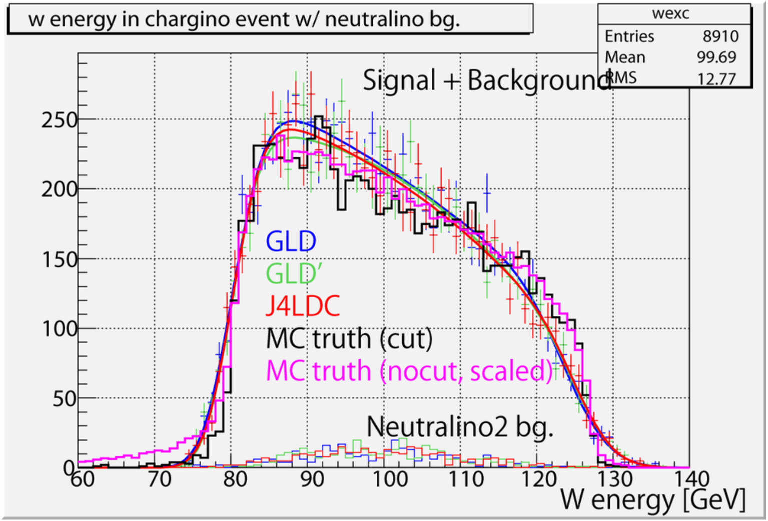
SUSY-signals & SM-processes simulated using diff. detector models.
(Ratio 4j/2j decays from Charginos might differ between GLD and LDC′.)

Chargino/Neutralino Di-Jet Mass-Spectra



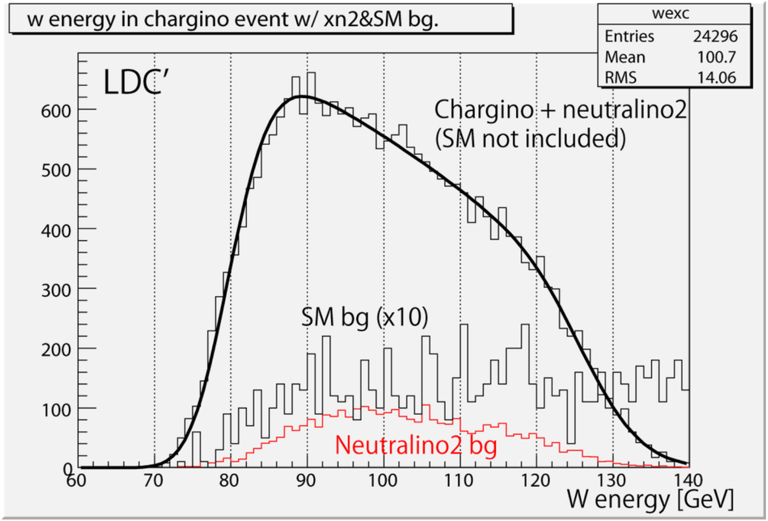
Jet pairs are selected such that the invariant di-jet mass is closest to either the W-mass (Charginos) or the Z-mass (Neutralinos).

Gauge Boson Energy Spectrum (Chargino Analysis)



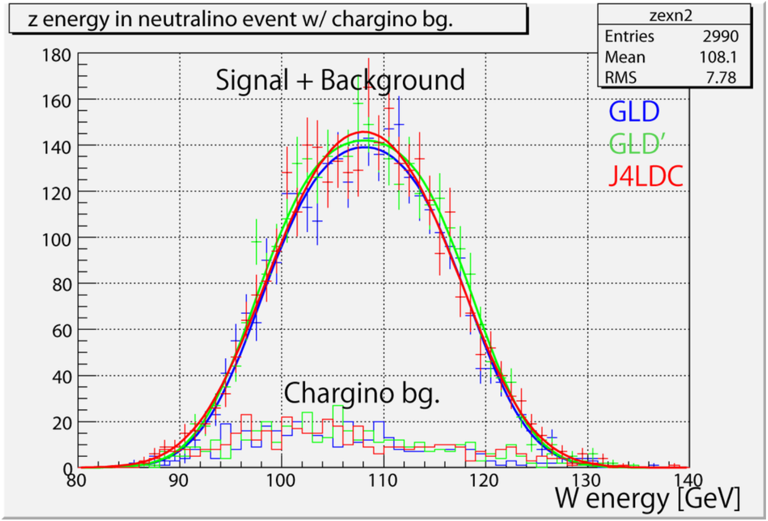
Charginos: W-Boson Energy including Neutralino background.

Gauge Boson Energy Spectrum (Chargino Analysis)



Charginos: W-Boson Energy including Neutralino & SM background.

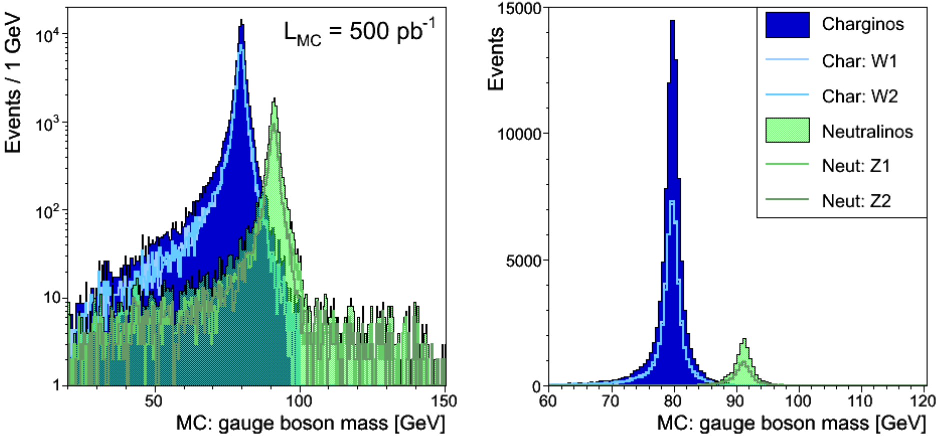
Gauge Boson Energy Spectrum (Neutralino Analysis)



Neutralinos: Z-Boson Energy including Chargino background.

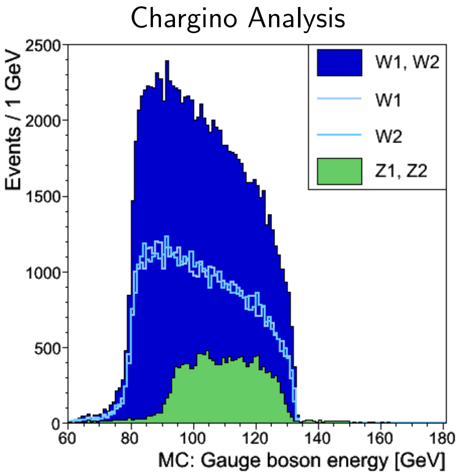
Charginos/Neutralinos Using Kinematic Fits

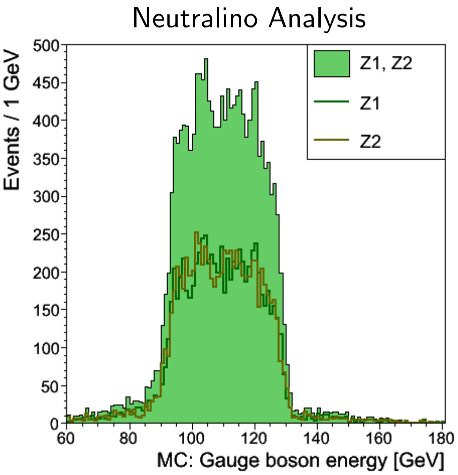
Generator Level Distributions



Gauge boson masses from Chargino/Neutralino decays (just for fun).

Generator Level Distributions





incl. Neutralino background

w/o Chargino background

These allow to extract masses precisely: $m(\tilde{\chi}_1^\pm)\,/\,m(\tilde{\chi}_2^0)$ and m_{LSP}.

Kinematic Fits: W/Z mass constraints

What for?

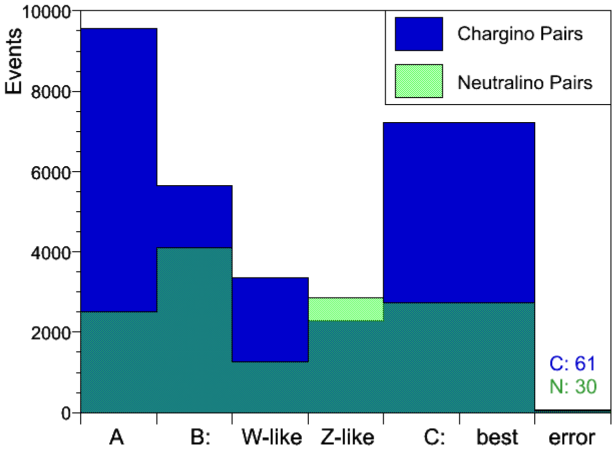
- Find the "correct" jet-pairing
- Improve mass and energy resolution

How is it done?

- Use all three permutations of di-jet pairs and save those with the best fit probability and those, where the di-jet invariant mass lies closest to the "W" or "Z" hypothesis.
- Software is based on Kinfit (ILCsoft v01-04), using JES: $+1\%$ and assuming Gaussian errors for all parameters.

1C-fit: making use of: $m(j1, j2) = m(j3, j4)$

Different Cases of the Kinematic Fit

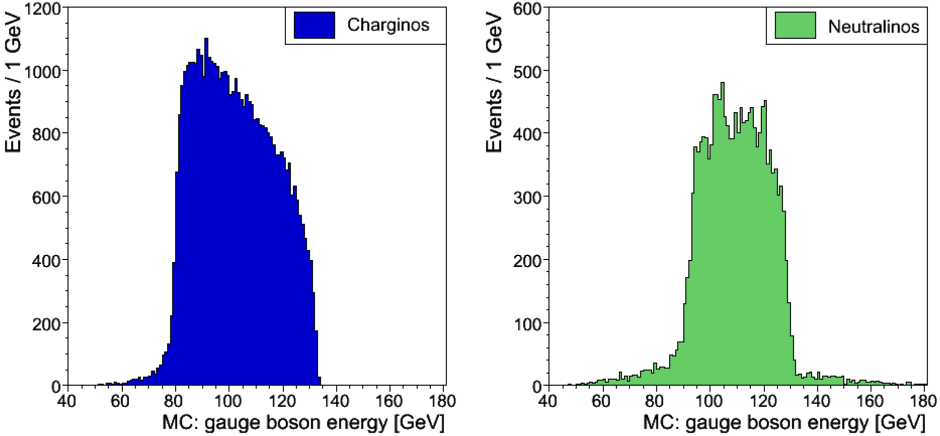


A: best fit prob = W fit prob = Z fit prob (best permutation)

B: best fit prob = W fit prob or best fit prob = Z fit prob

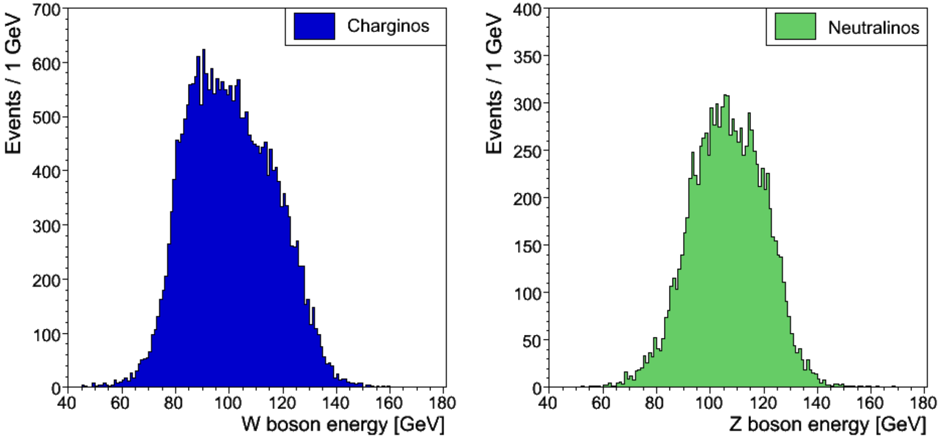
C: best fit prob != W fit prob and != Z fit prob ⇒ unclear events!

W/Z Energy Spectra



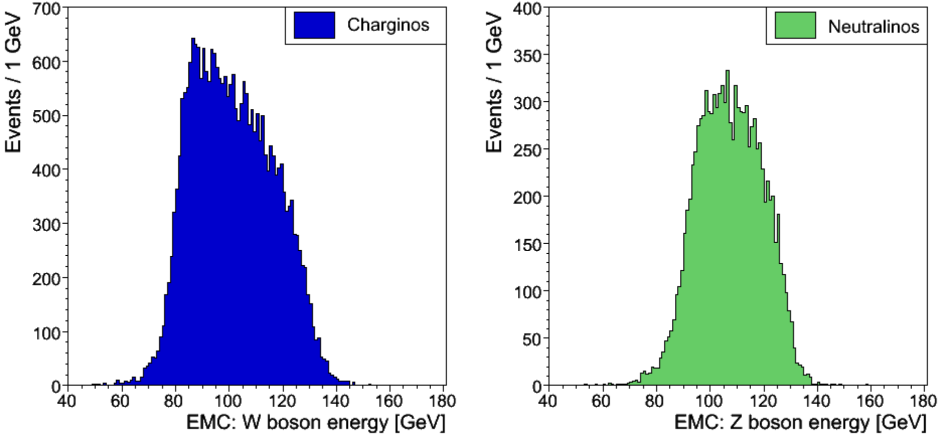
Energy spectra at generator level (pure MC).

W/Z Energy Spectra



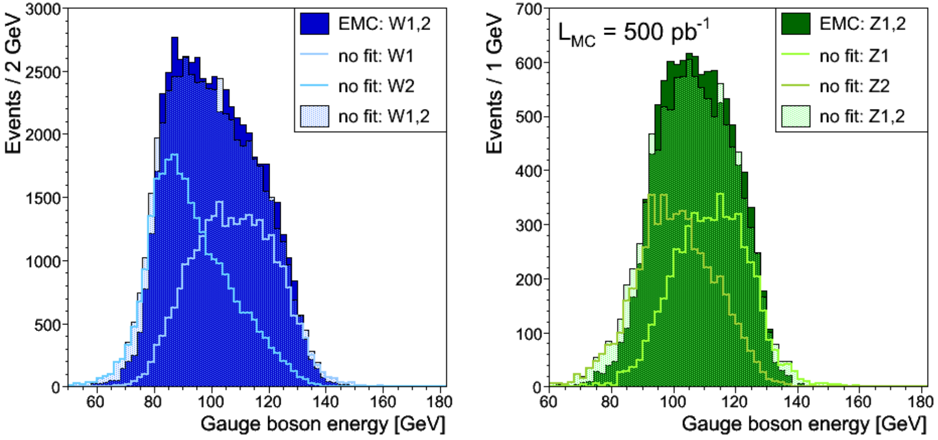
Energy spectra after reconstruction, but without kinematic fit. (nof)

W/Z Energy Spectra



Energy spectra after reconstruction and with kinematic fit. (EMC)

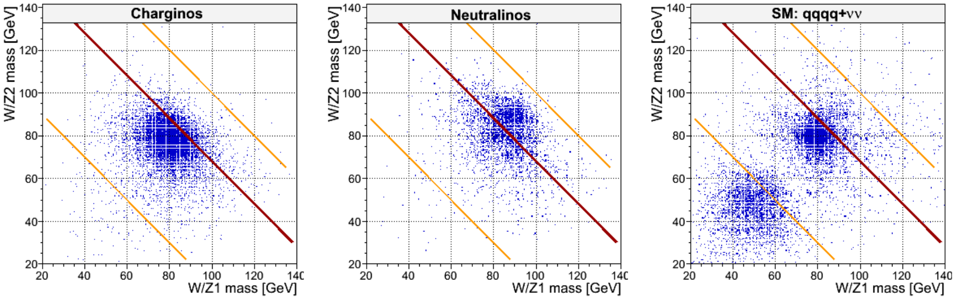
W/Z Energy Spectra



Energy spectra after reconstruction and with kinematic fit. (EMC)
(Comparison between unfitted and fitted distributions.)

Selection Cuts in (V1,V2)-Mass Plane

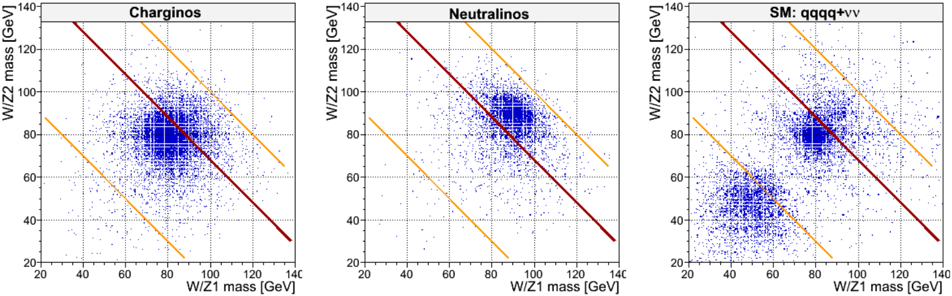
W-like events: kinematic fit (equal mass constr.) closer to "W" mass.



Cuts in (V1,V2)-mass plane is choosen by eye, no optimisation yet.
will be optimised for $\varepsilon \times \pi$ (efficiency×purity)... + further cuts.

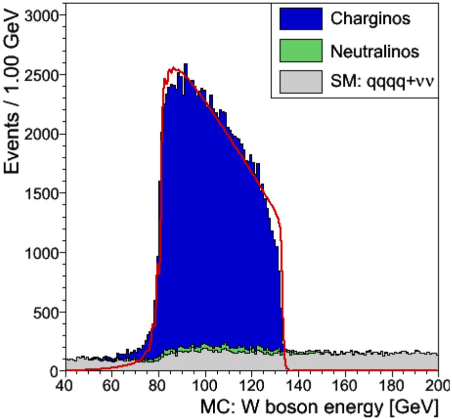
Selection Cuts in (V1,V2)-Mass Plane

Z-like events: kinematic fit (equal mass constr.) closer to "Z" mass.



Cuts in (V1,V2)-mass plane is choosen by eye, no optimisation yet.
will be optimised for $\varepsilon \times \pi$ (efficiency×purity)... + further cuts.

Extracting $m(\widetilde{\chi}_1^\pm)$, or $m(\widetilde{\chi}_2^0)$ via Fit: I



Basically, the VERY complicated fit uses the upper and lower edges of the gauge boson energy spectrum, convolutes them with the Breit-Wigner shape of the boson mass and adds a little gaussian smearing.

Assumptions (due to kinematic fit):

- $m(V1) = m(V2)$ (bosons)

$$\text{bin}_i = \frac{1 - a \cdot \text{reg}}{2} \qquad \text{(no Gaussian smearing)}$$

$$\cdot \left[\Theta\left(\frac{\text{reg}+1}{\sigma_{jes}\, b}\right) - \Theta\left(\frac{\text{reg}-1}{\sigma_{jes}\, b}\right)\right] + a \cdot \frac{b}{2\pi}\left[e^{-\frac{(\text{reg}_{-1})^2}{2\,(\sigma_{jes}\, b)^2}} - e^{-\frac{(\text{reg}_{+1})^2}{2\,(\sigma_{jes}\, b)^2}}\right]$$

Extracting $m(\widetilde{\chi}_1^{\pm})$, or $m(\widetilde{\chi}_2^0)$ via Fit: II

Perform a "bloody" complicated fit to the E_W (E_Z) Spectrum:

- express E_V and $|\vec{p}_V|$ in terms of the 3 relevant masses:

$$m_2 = m(\widetilde{\chi}_1^{\pm}, \widetilde{\chi}_2^0), \quad m_1 = m(\widetilde{\chi}_1^0) = m_{\text{LSP}}, \quad m_V = m_{W,Z}:$$

$$E_V = \frac{1}{m_2}\left(m_1^2 - m_2^2 - m_V^2\right) = \frac{1}{m_2}\lambda\left(m_1, m_2, m_V\right)$$

$$|\vec{p}_V| = \frac{1}{m_2}\sqrt{\left(m_2^2 - m_1^2 - m_V^2\right)^2 - 4\, m_1^2\, m_V^2}$$

- then find the inverse expression for either the chargino mass or the neutralino mass
- add the effect of a finite boson mass width via integrating over a Breit-Wigner distribution
- add Gaussian smearing to the boson energy spectrum . . .

Extracting $m(\widetilde{\chi}_1^{\pm})$, or $m(\widetilde{\chi}_2^0)$ via Fit: III

...finally, the fit function looks like this - allowed region: $|\text{reg}| < 1$

$$\text{bin}_i = \frac{1 \, - \, a \cdot \text{reg}}{2} \qquad \text{(no Gaussian smearing)}$$

$$\cdot \left[\Theta\left(\frac{\text{reg}+1}{\sigma_{jes}\, b}\right) - \Theta\left(\frac{\text{reg}-1}{\sigma_{jes}\, b}\right)\right] + a \cdot \frac{b}{2\pi}\left[e^{-\frac{(\text{reg}_{-1})^2}{2\,(\sigma_{jes}\,b)^2}} - e^{-\frac{(\text{reg}_{+1})^2}{2\,(\sigma_{jes}\,b)^2}} \right]$$

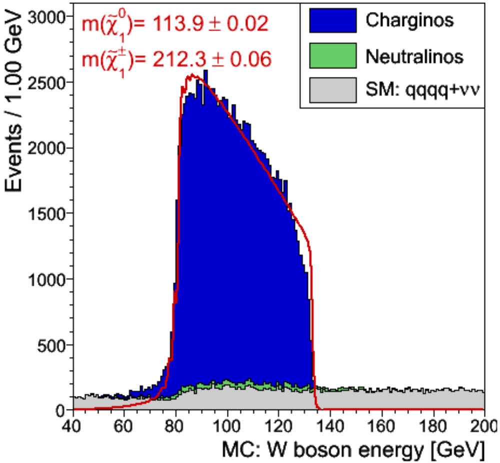
$$\text{spect} = \text{bin}_i \cdot \text{BW}\left(m_V^0,\, \gamma,\, m_V - \frac{\Delta m}{2},\, m_V + \frac{\Delta m}{2}\right) + \text{spect}$$

with the boson E_V and $|\vec{p}_W|$ in the bosino rest-frame:

$$p_V = \frac{\lambda}{2\, m_2} \qquad b = \frac{m_2}{\sqrt{E_{beam}^2 - m_2^2} \cdot p_V}$$

$$E_V = \left| \frac{m_1^2 - m_2^2 - m_V^2}{2\, m_2} \right| \qquad \text{reg} = \frac{x\, m_2 \, - \, E_{beam}\, E_V}{\sqrt{E_{beam}^2 - m_2^2} \cdot p_V}$$

Chargino Selection and Fits I

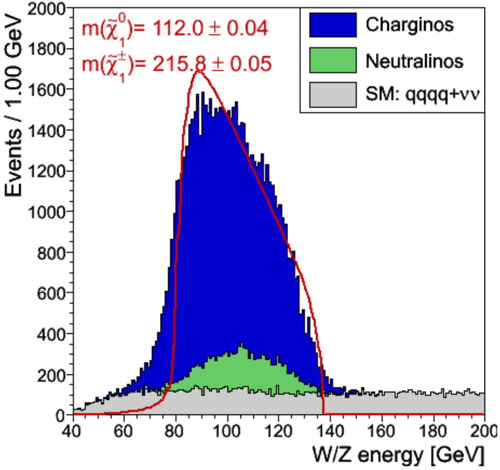


E_{boson} at generator level:

but inclunding Neutralino background and the most dangerous SM 6-fermion background from WWZ-processes: $qqqq + \nu\nu$.

All processes are weighted correctly, corresponding to: $\mathcal{L}_{MC} = \mathbf{500\ fb^{-1}}$.

Chargino Selection and Fits II

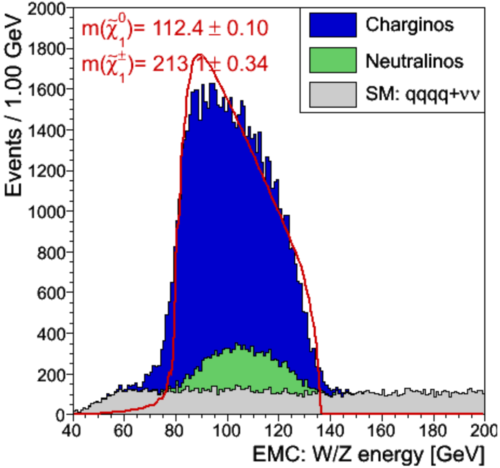


E_{boson} after reconstruction:
(but w/o kinematic fit)

but inclunding Neutralino background and the most dangerous SM 6-fermion background from WWZ-processes: $qqqq + \nu\nu$.

All processes are weighted correctly, corresponding to: $\mathcal{L}_{MC} = \mathbf{500\ fb^{-1}}$.

Chargino Selection and Fits III

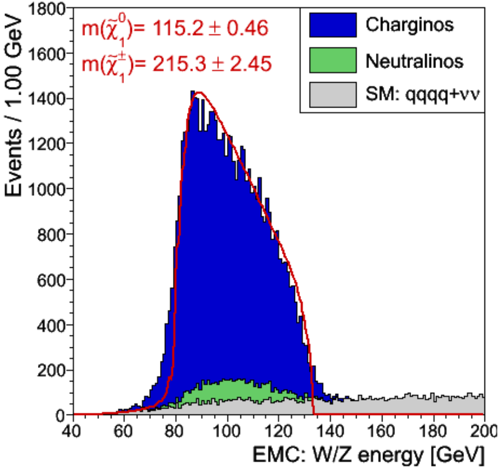


E_{boson} after reconstruction: (with kinematic fit: EMC)

but inclunding Neutralino background and the most dangerous SM 6-fermion background from WWZ-processes: $qqqq + \nu\nu$.

All processes are weighted correctly, corresponding to: $\mathcal{L}_{MC} = \mathbf{500\ fb^{-1}}$.

Chargino Selection and Fits IV



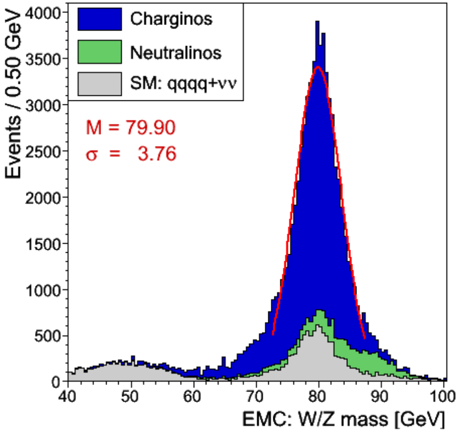
E_{boson} after reconstruction: (kinematic fit & selection)

but inclunding Neutralino background and the most dangerous SM 6-fermion background from WWZ-processes: $qqqq + \nu\nu$.

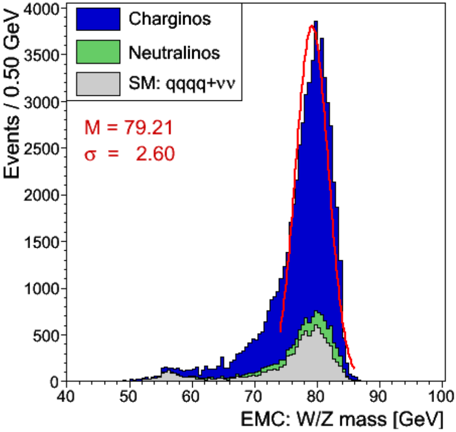
Efficiency × purity:
$\varepsilon \times \pi = 45.x\% \times 78.y\% = 0.35$

All processes are weighted correctly, corresponding to: $\mathcal{L}_{MC} = \mathbf{500\ fb^{-1}}$.

Chargino Selection: Mass Spectra

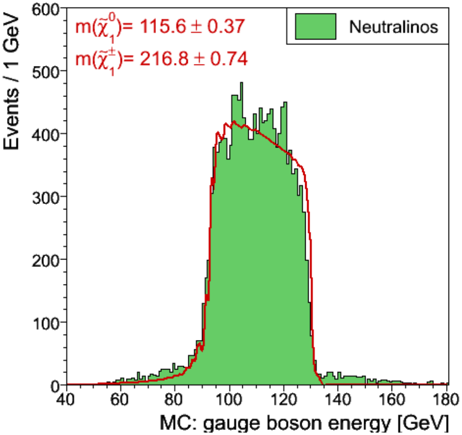


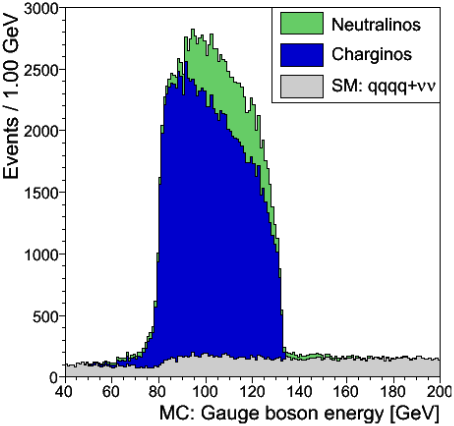
W boson mass after kinematic fit (no selection)



W boson mass after kinematic fit (2D-cut in (V1,V2)-mass plane)

Neutralino Selection and Fits I

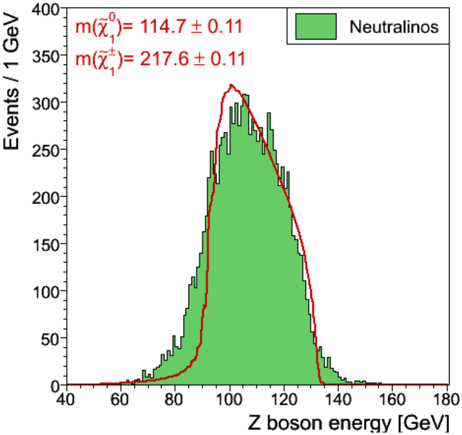


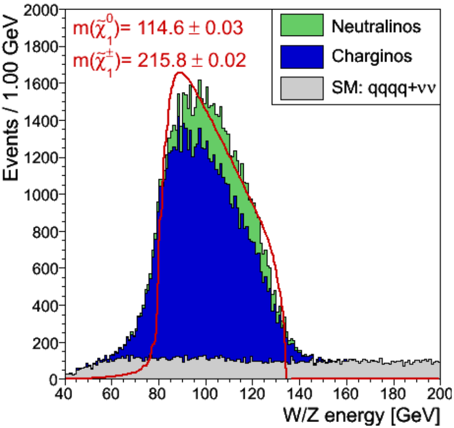


Generator level: Neutralinos
absolutely no backgrounds

Generator level: Neutralinos
Bkgd: Charginos + SM-WWZ

Neutralino Selection and Fits II

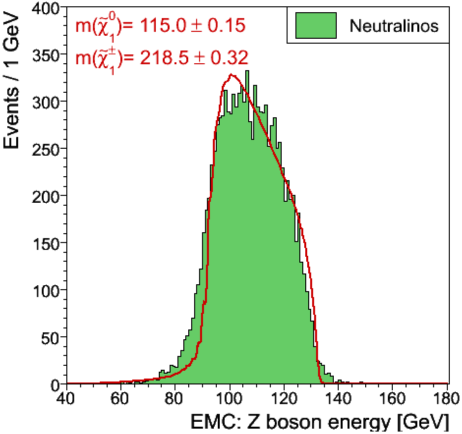


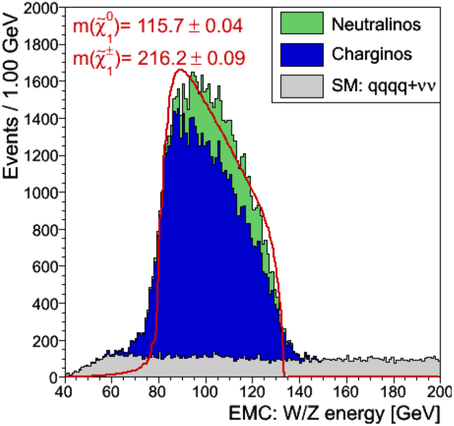


Reco', no fit: Neutralinos
absolutely no backgrounds

Reco'd no fit: Neutralinos
Bkgd: Charginos + SM-WWZ

Neutralino Selection and Fits III

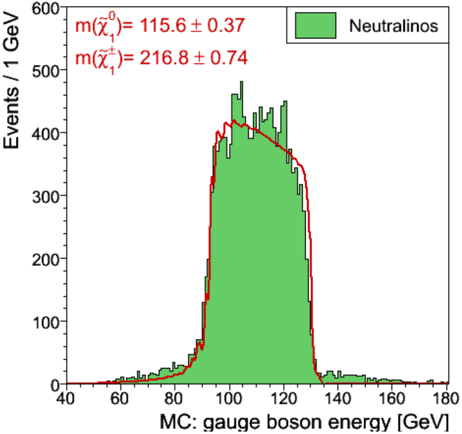


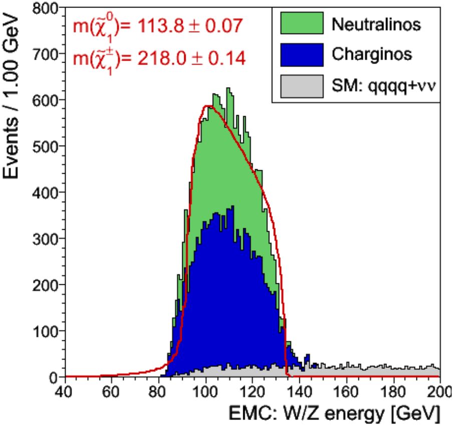


Reco'd, EMC-fit: Neutralinos
absolutely no backgrounds

Reco'd, EMC-fit: Neutralinos
Bkgd: Charginos + SM-WWZ

Neutralino Selection and Fits IV

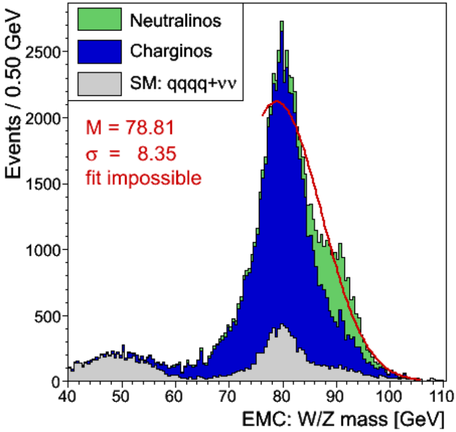




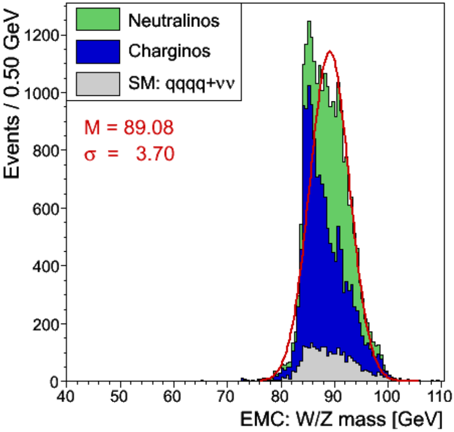
EMC-fit + Neutr.-Selection
absolutely no backgrounds

EMC-fit + Neutr.-Selection
Bkgd: Charginos + SM-WWZ

Neutralino Selection: Mass Spectra



Z boson mass after kinematic fit (no selection)



Z boson mass after kinematic fit (2D-cut in (V1,V2)-mass plane)

Summary & Outlook

Summary & Outlook

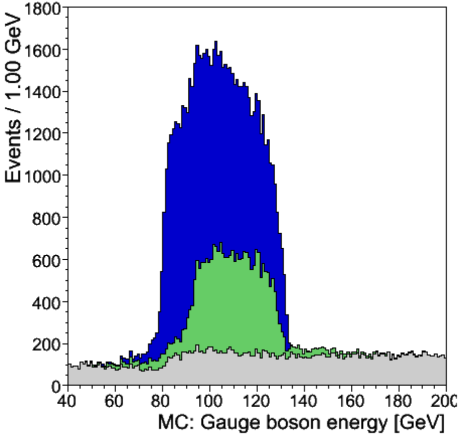
- Chargino & Neutralino pair production can be separated from the SM-background and from each other, respectively.
- Masses, $m(\widetilde{\chi}_1^\pm)$, $m(\widetilde{\chi}_2^0)$ and m_{LSP} can be extracted via fits. Although the errors are rather small, the mean values are too far away from the nominal values.
  $\Rightarrow$ need to improve selection efficiency and purity!

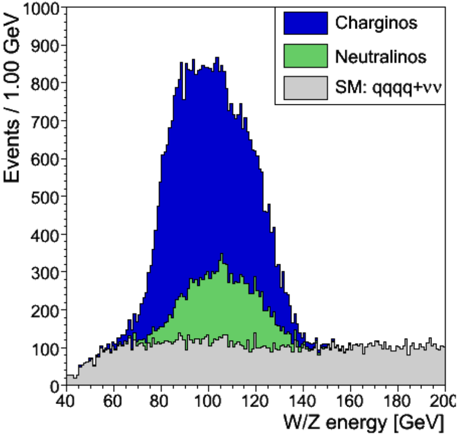
Next steps:

- Include all SM and relevant SUSY-backgrounds.
- Improve the kinematic fit to better find the correct jet-pairings and thus help improve mass and energy resolution.
- Improve on the mutual selection (Chargino vs Neutralino) and on the rejection of SM- and other SUSY-backgrounds.

THANK YOU !

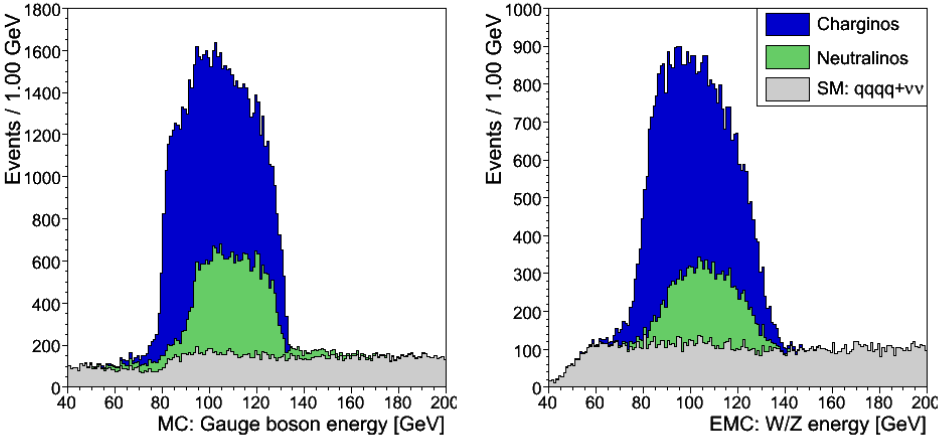
BACKUP





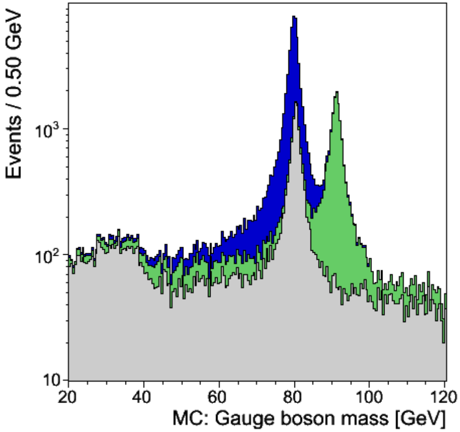
Energy spectra at generator level

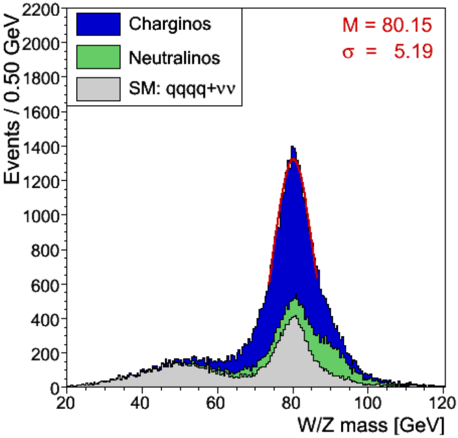
reco'd: no kinematic fit !



Energy spectra at generator level

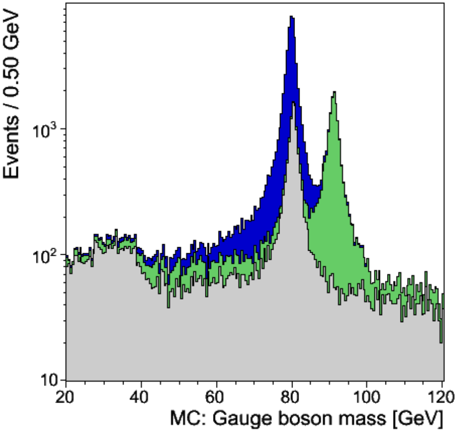
reco'd: with kinematic fit !

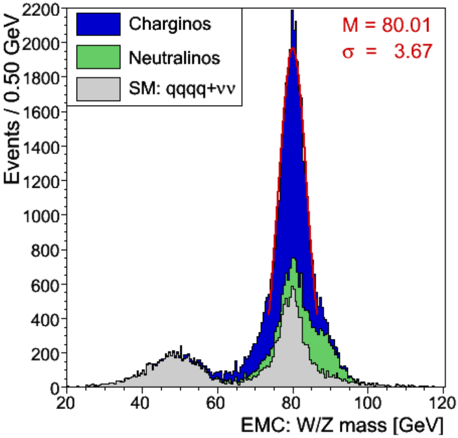




Mass spectra at generator level

reco'd: no kinematic fit !





Mass spectra at generator level

reco'd: with kinematic fit !