# *Focus Point Phenomenology*

## "LCC2" Benchmark studies

## Linear Collider Cosmology Connection


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Dan Hertz

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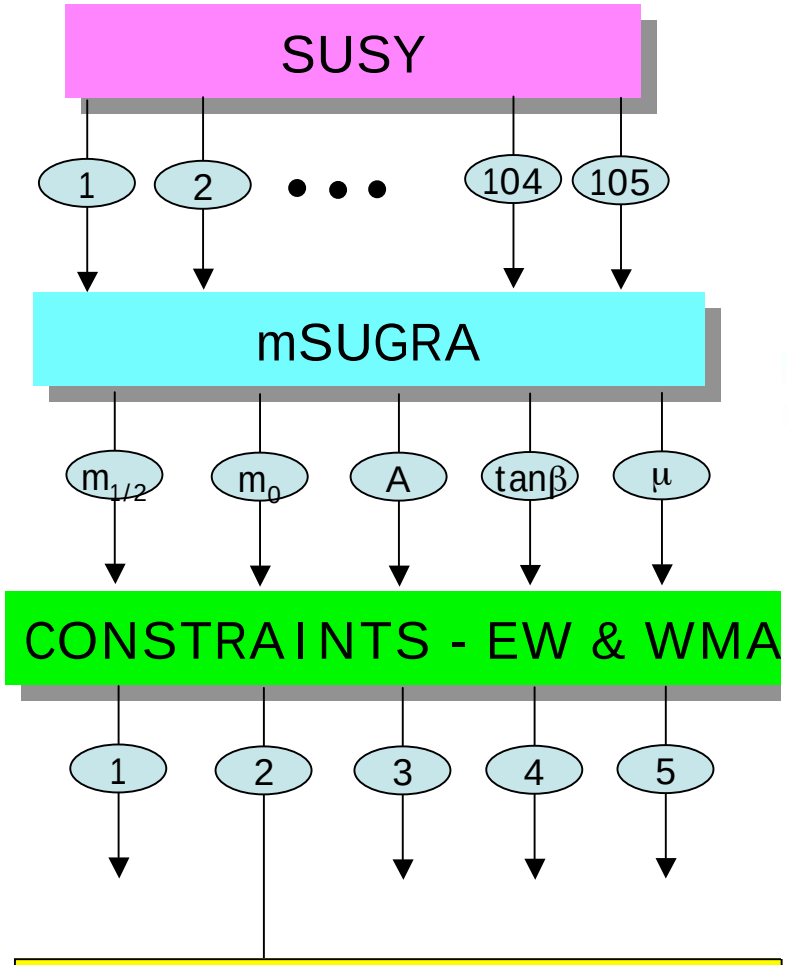
Jim Alexander

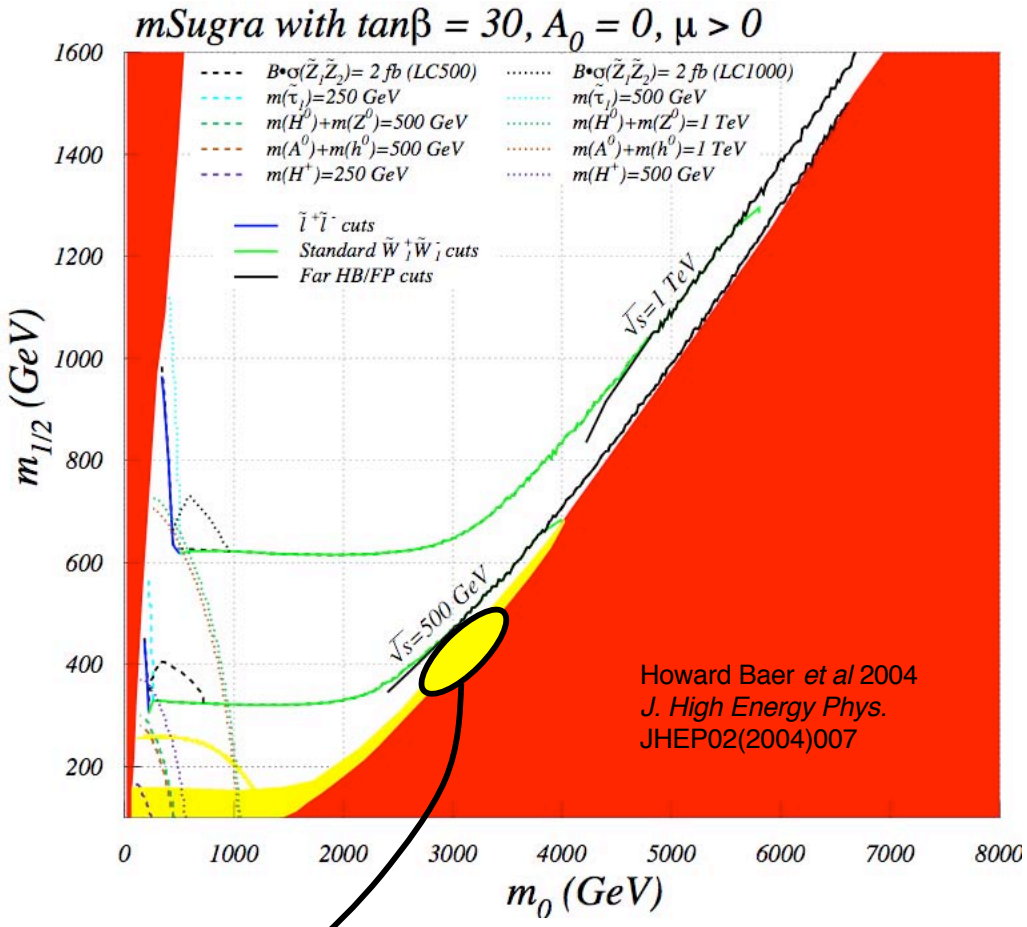
# Focus Point Benchmark LCC-2




$m_0 = 3280$ $m_{1/2} = 300$

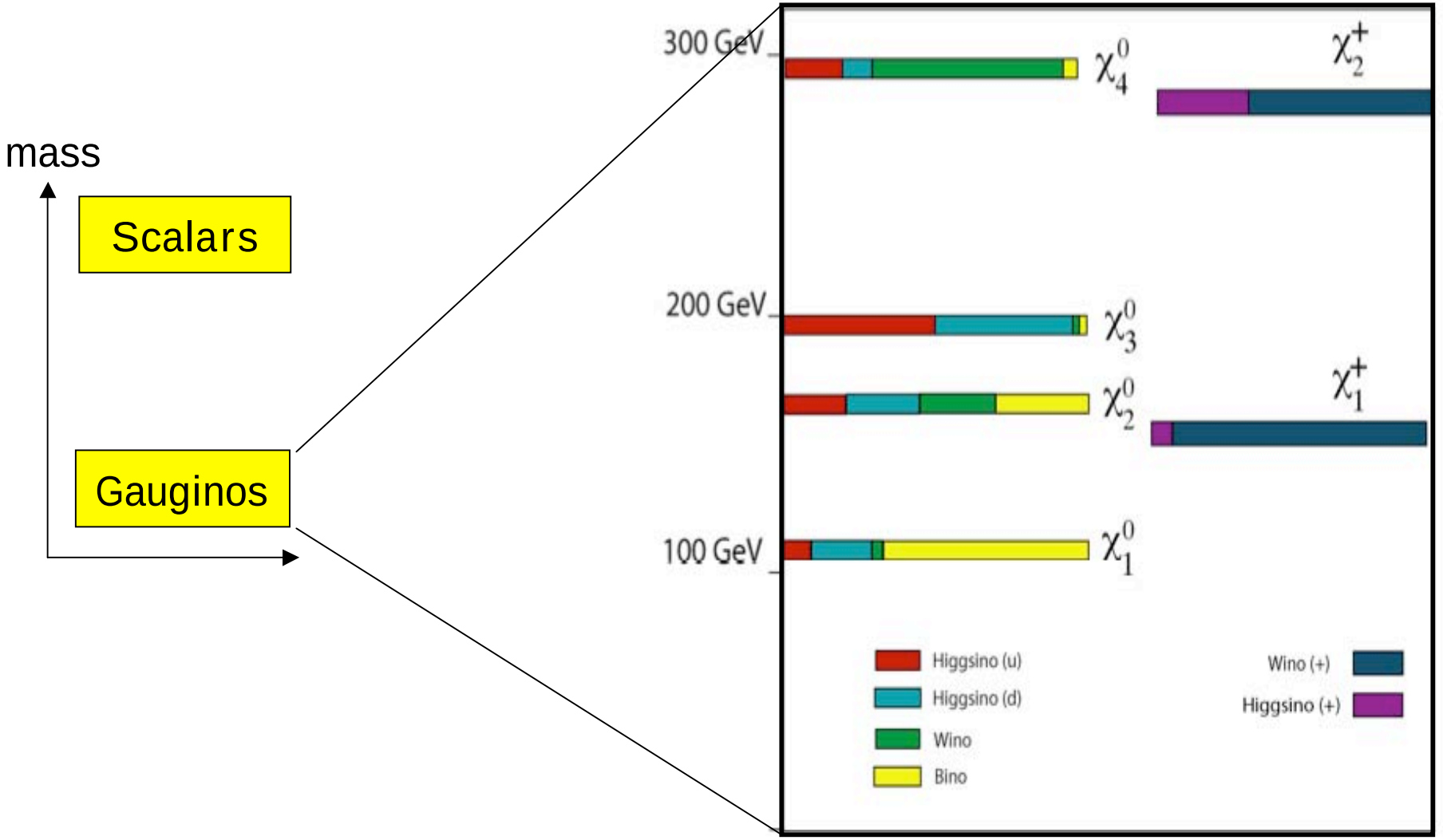
$A = 0$ $\tan\beta = 10$

$\mathrm{sgn}(\mu) = +$ $(m_t = 175)$



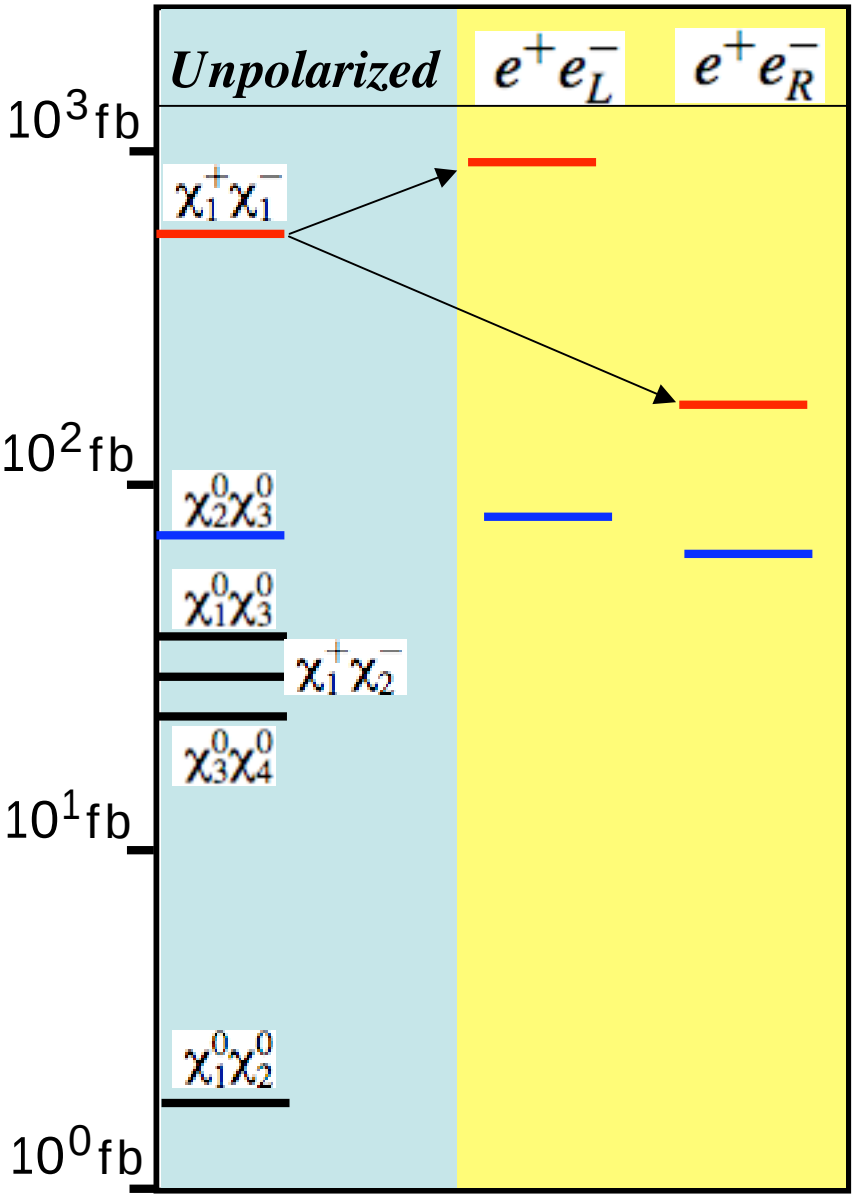

Howard Baer *et al* 2004
*J. High Energy Phys.*
JHEP02(2004)007

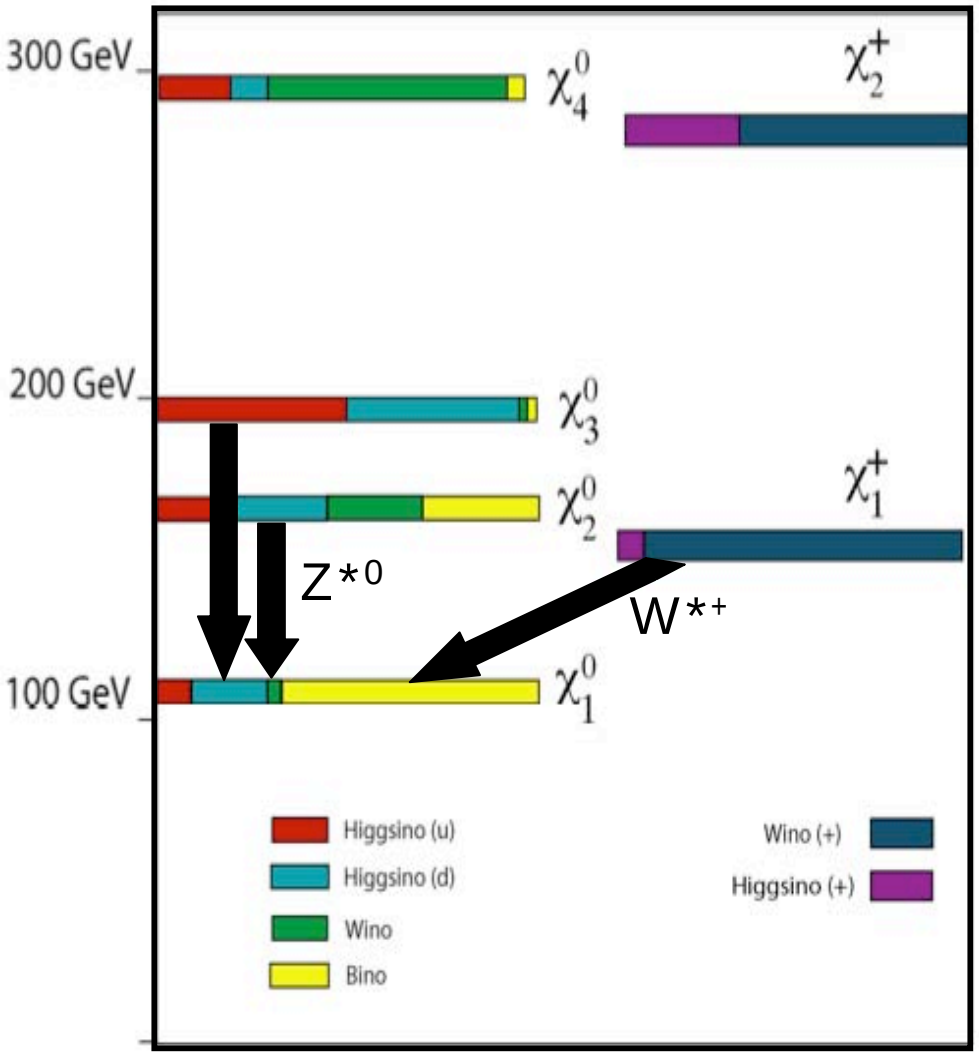
# Focus Point Spectrum




Spectrum computed by ISAJET

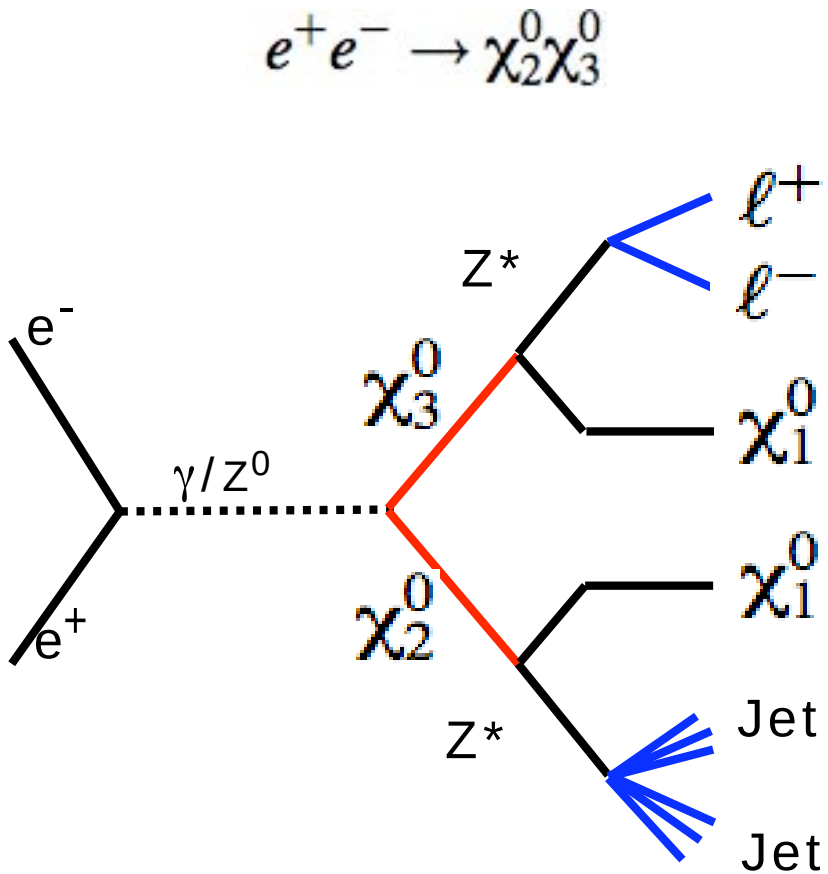
# Production and Decay




Cross sections computed by ISAJET

# Studies Presented at LCWS-05




- Talks:
  - Richard Gray
    - hep-ex/0507008
  - Andreas Birkedal
    - hep-ph/0507214
- Results (500fb$^{-1}$):

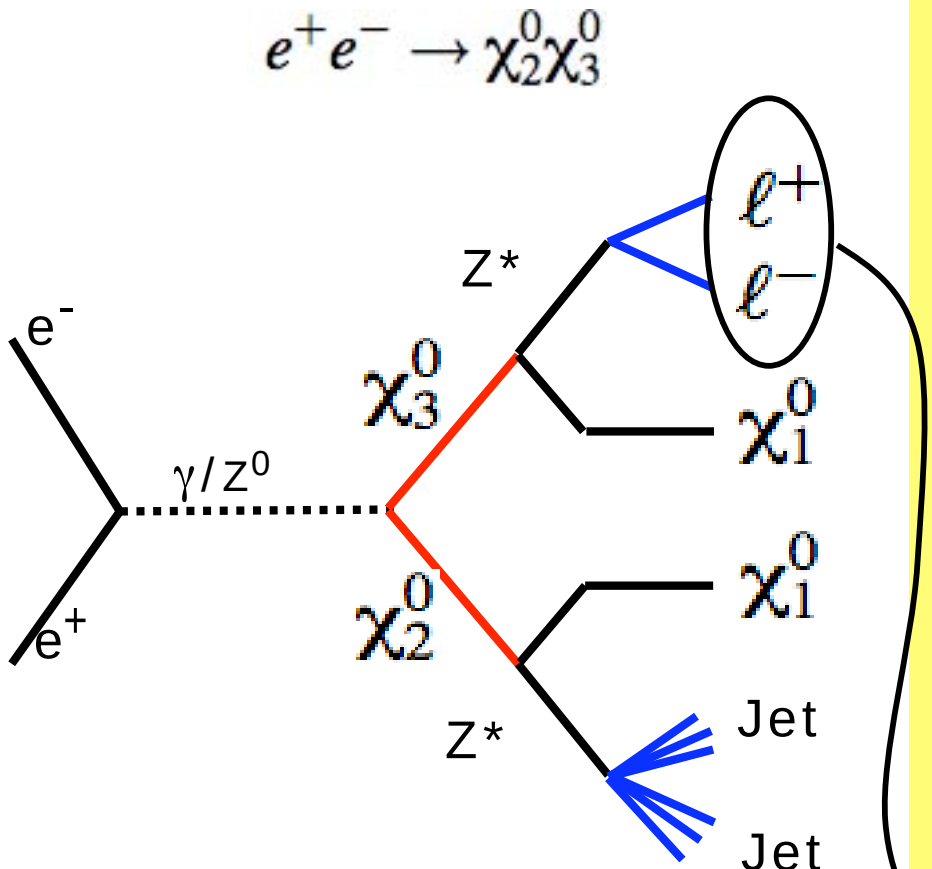
$$m(\chi_3^0) - m(\chi_1^0) = 82.3 \pm 0.2$$

$$m(\chi_2^0) - m(\chi_1^0) = 58.8 \pm 0.3$$

$$m(\chi_1^0) = 108.3 \pm 1.0$$

$$\frac{\varepsilon_2\varepsilon_3}{\varepsilon_0} = +- \ (13\sigma)$$

# Studies Presented at LCWS-05

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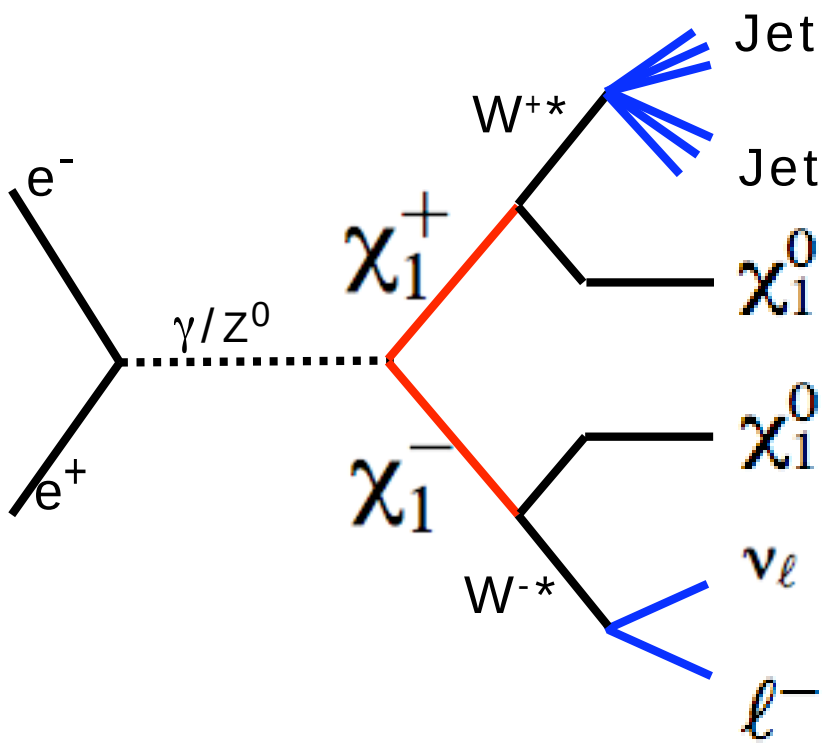
# Mode du jour: $e^+e^- \to \chi_1^+\chi_1^-$




poorer resolution

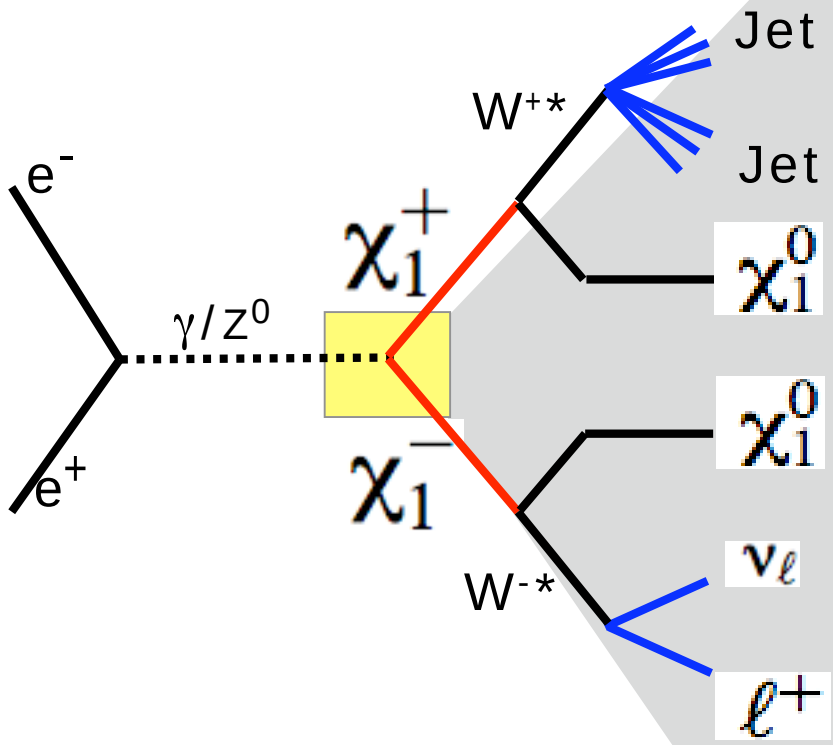
More missing energy

Fewer visible leptons

But:

- much larger cross section
- lepton sign tags chargino (maybe useful later)

# Physics: The $\chi_1^+\chi_1^-(Z^0,\gamma)$ vertex




Yield: σ

$$\frac{ig}{2\cos\theta_W}\gamma^\mu\left[O'^{L}_{11}(1-\gamma_5)+O'^{R}_{11}(1+\gamma_5)\right]$$

$M_2$, μ, tanβ

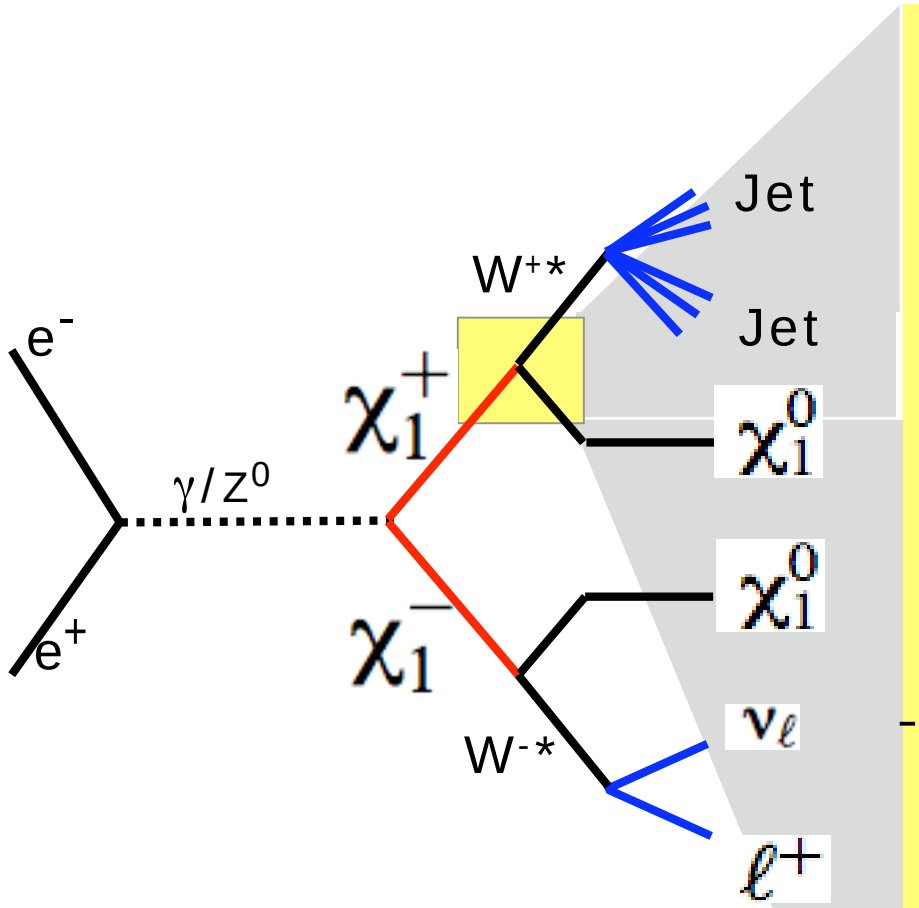
For future study:

Are the χ+- polarized?

Can we measure the polarization?

Can we find an estimator of the χ+- axis (cosθ)... → dσ/d cosθ ?

# Physics: The $\chi_1^+\chi_1^0 W^{*+}$ vertex



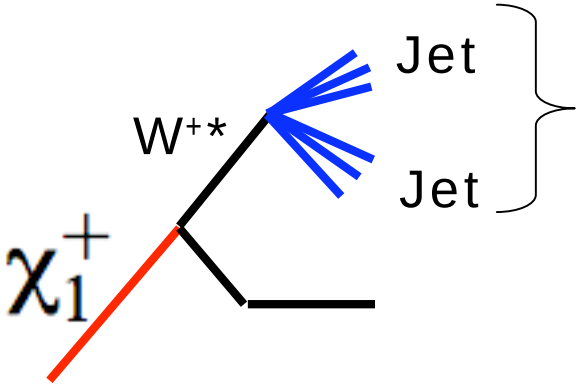

Kinematic distributions
$d\Gamma/dM$, $d\Gamma/dE$

$$\frac{ig}{2}\left[O_{11}^{L}(1-\gamma_5)+O_{11}^{R}(1+\gamma_5)\right]$$

$M_1$ , $M_2$, $\mu$, $\tan\beta$

For future study:
If the $\chi^{+-}$ is polarized, $d\Gamma/d\cos\theta^*$ could be interesting. (Use lepton tag to separate $\chi^+$ , $\chi^-$ , measure $d\Gamma/dE$.)

# Kinematics of the hadronic system




Mass: M
Energy: E

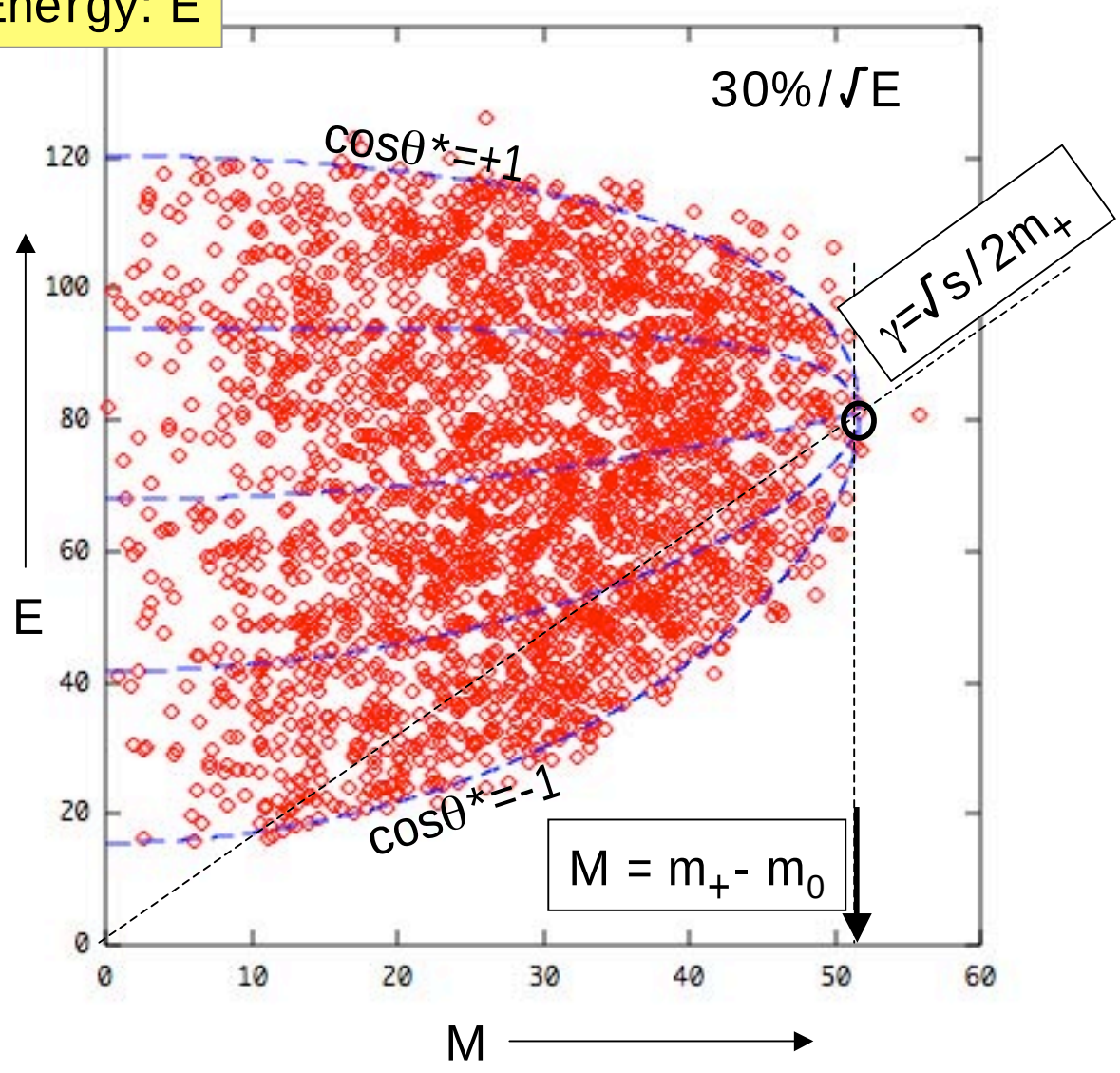
For given M, just 2-body decay:

$$\chi_1^+ \rightarrow W^* \chi_1^0$$

$$m_+ \quad M \quad m_0$$

$$E^* = \frac{M^2 + m_+^2 - m_0^2}{2m_+}$$

$$P^* = \sqrt{E^{*2} - M^2}$$



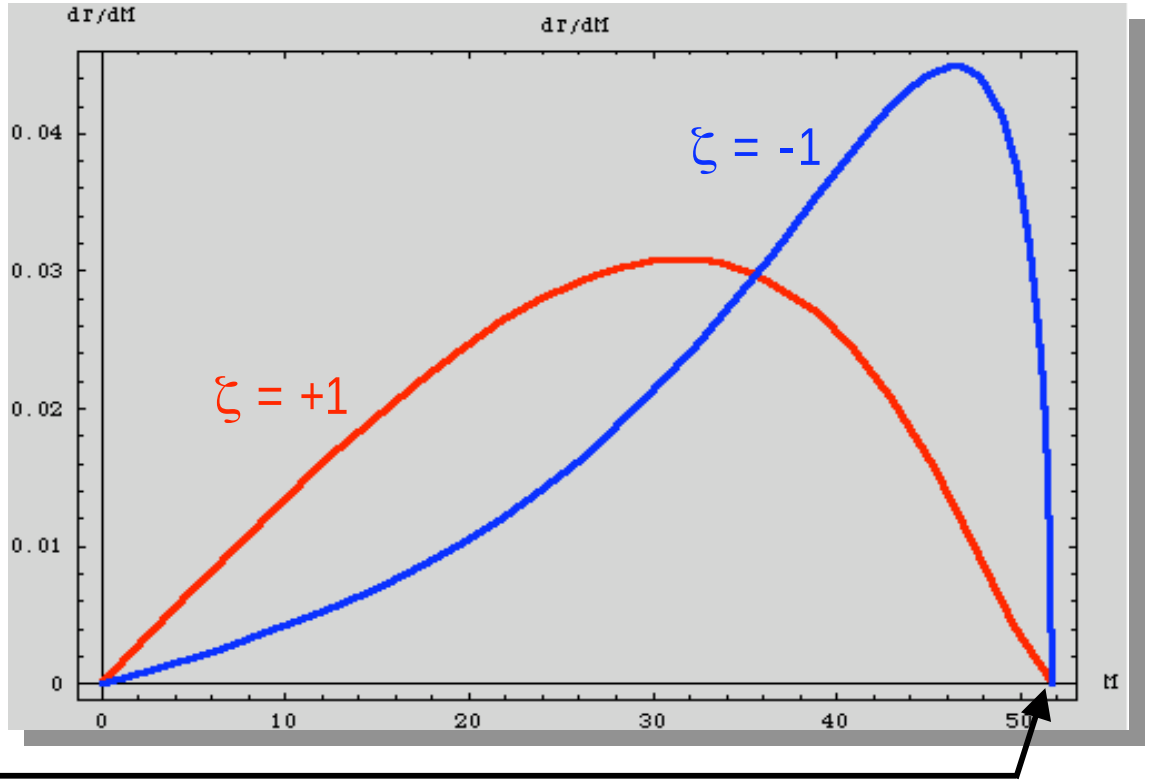
# $d\Gamma/dM$

Andreas Birkedal calculated:

$$\frac{d\Gamma}{dM} \sim \frac{MP^*}{m_+^2(M^2-m_W^2)^2} \times \left[m_0^4 + m_+^4 + M^2 m_+^2 - 2M^4 + m_0^2(M^2 - 2m_+^2) - 6\zeta M^2 m_0 m_+\right]$$

Note: $\zeta$ is asymmetry in vector & axial-vector couplings at $\chi^+ W^{*+} \chi^0$ vertex:

$$\zeta \equiv \frac{v_+^2 - a_+^2}{v_+^2 + a_+^2}$$




- Dependence:
  - Strong: $m_+ - m_0$
  - Medium: $\zeta$
  - Weak: $m_+ + m_0$

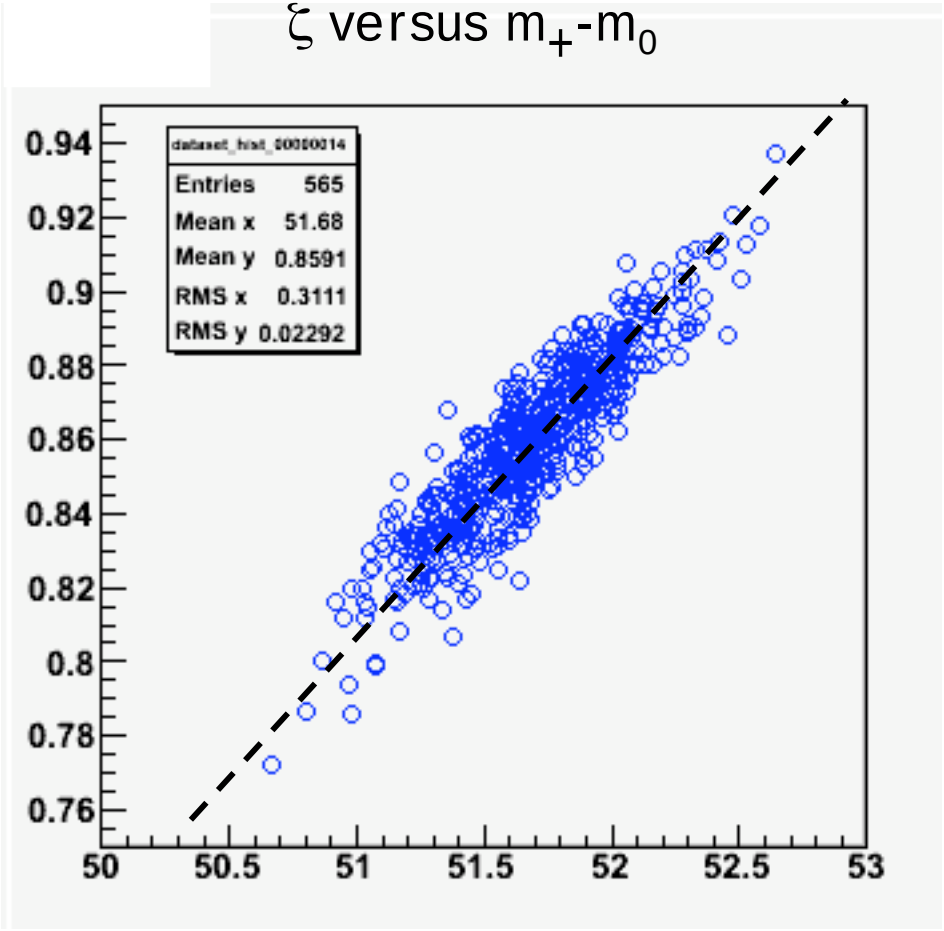
Fit yields $m_+ - m_0$ and $\zeta$

....and they are strongly (+) correlated

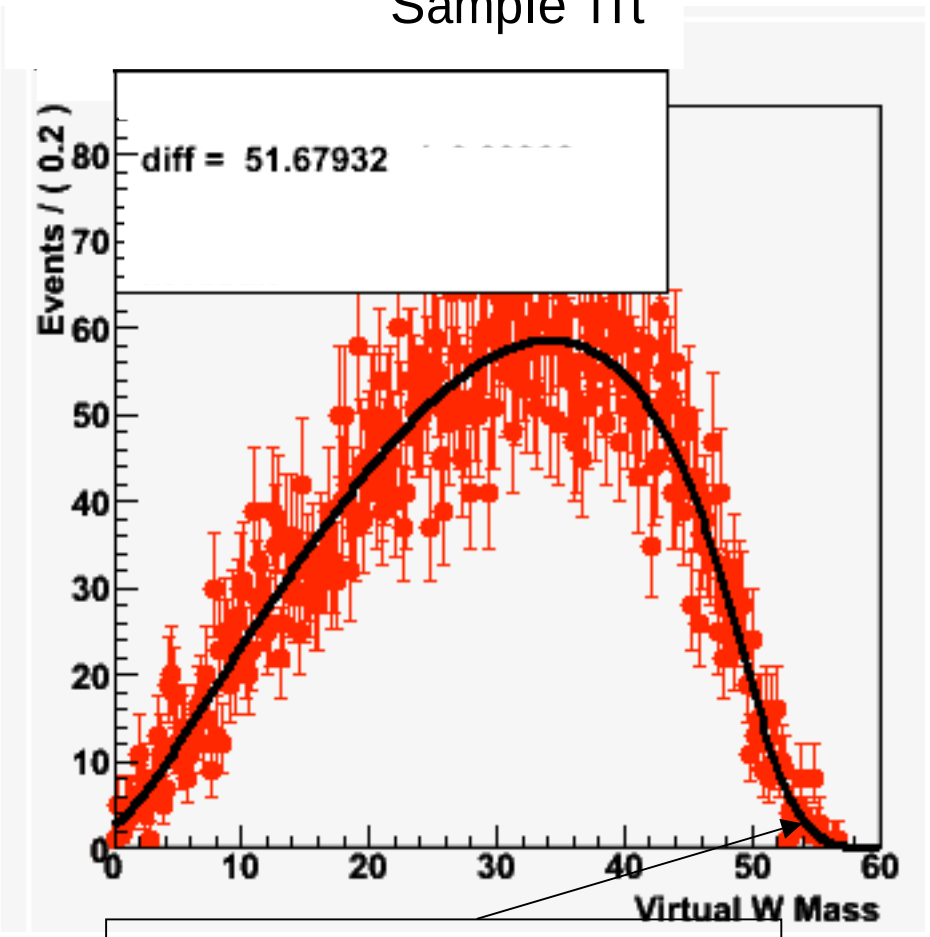
# Example: toy expts fitting to dΓ/dM

Generate ~500 toy expts, fit to formula.

ζ versus $m_+$-$m_0$



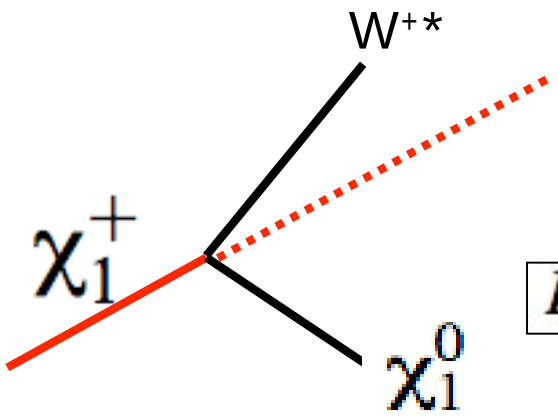

Sample fit




Shape includes resolution smearing

# $d\Gamma/dE$

Mass: M
Energy: E




E,P of W* in $\chi$+ rest frame
(functions of M,$m_+$,$m_0$)

$$E = \gamma(E^* + \beta P^* \cos\theta^*)$$

$$\frac{d\Gamma}{d\cos\theta^*} = ???$$

Lorentz boost of $\chi$+ ($\gamma = \sqrt{s}/2m_+$ )

- Thus for a given M, $d\Gamma/dE$ measures the angular distribution $d\Gamma/\cos\theta^*$.

- This distribution depends on m+, m0,… as well as $R_+$, $L_+$ couplings and degree of $\chi$+ polarization… potentially interesting physics in there.

- But for *now*, we finesse the $R_+$, $L_+$ couplings issue…

# $d\Gamma/dE$

If $d\Gamma/\cos\theta^*$ is symmetric, then $\langle\cos\theta^*\rangle = 0$.

- We can ensure symmetry of $d\Gamma/\cos\theta^*$ by ignoring opposite-side-lepton sign -- so we do not distinguish $\chi^+$, $\chi^-$
- Alternatively, $d\Gamma/\cos\theta^*$ may be flat (eg if $\chi^+$ is unpolarized).

Assuming $\langle\cos\theta^*\rangle = 0$, we find:

$$\langle E\rangle = \langle\gamma\rangle E^* = a + bM^2$$

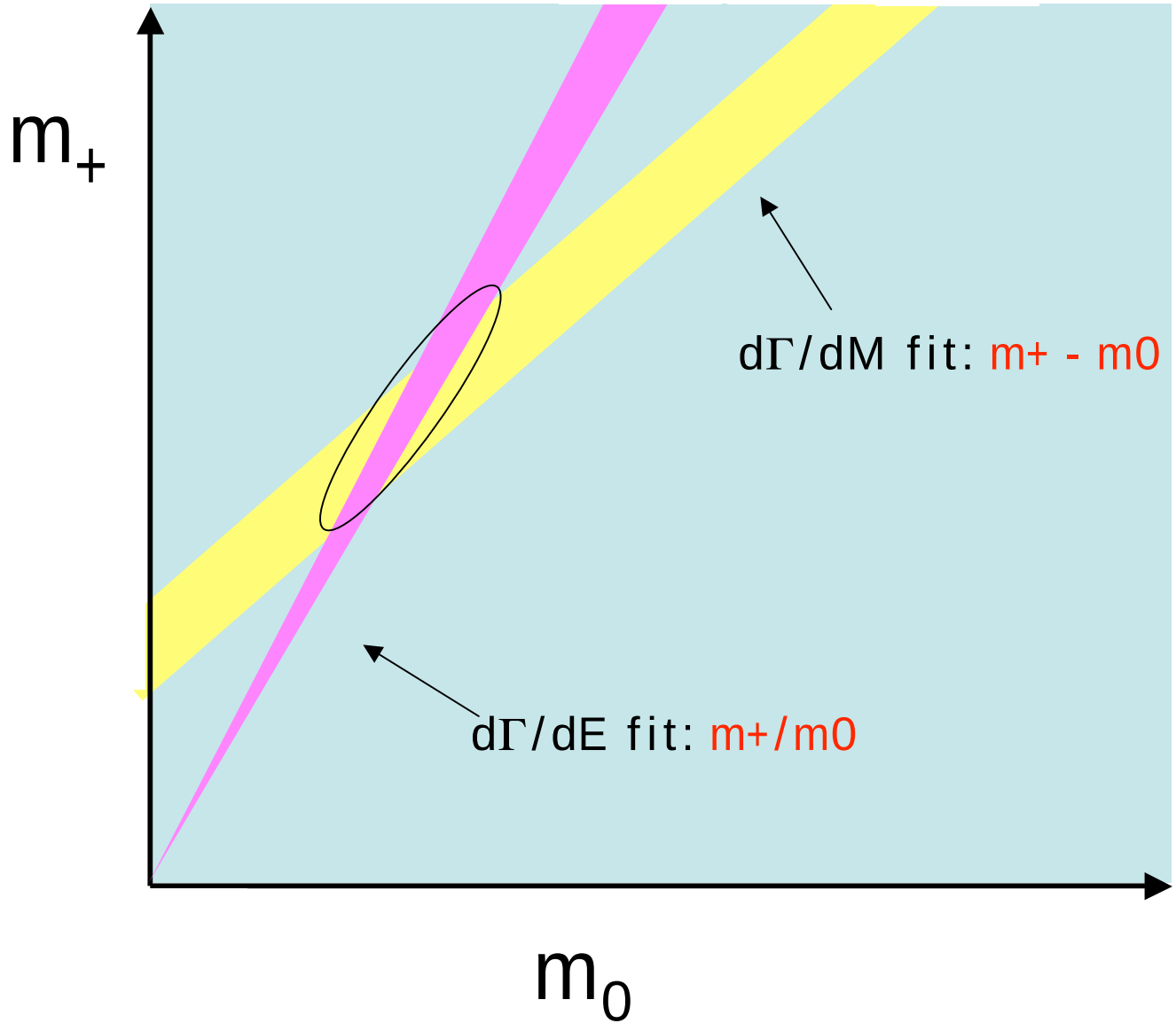
$$a = \frac{\sqrt{s}}{4}\left(1 - \left(\frac{m_0}{m_+}\right)^2\right)$$

$$b = \frac{\sqrt{s}}{4m_+^2}$$

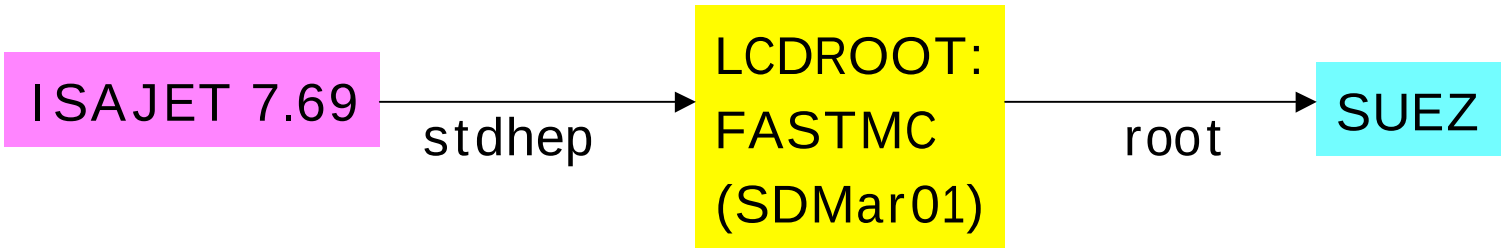
Mainly sensitive to the *ratio* $m_+/m_0$

Note: in ISAJET $d\Gamma/\cos\theta^*$ = flat.

# Simultaneous fit for dΓ/dM & dΓ/dE



# Simulation Details




Lumi = 500 $fb^{-1}$:

250$fb^{-1}$ e- pol = +95%,

250$fb^{-1}$ e- pol = -95%

Note: "95%" means $\frac{R-L}{R+L} = 0.90$

Analysis (to be described):

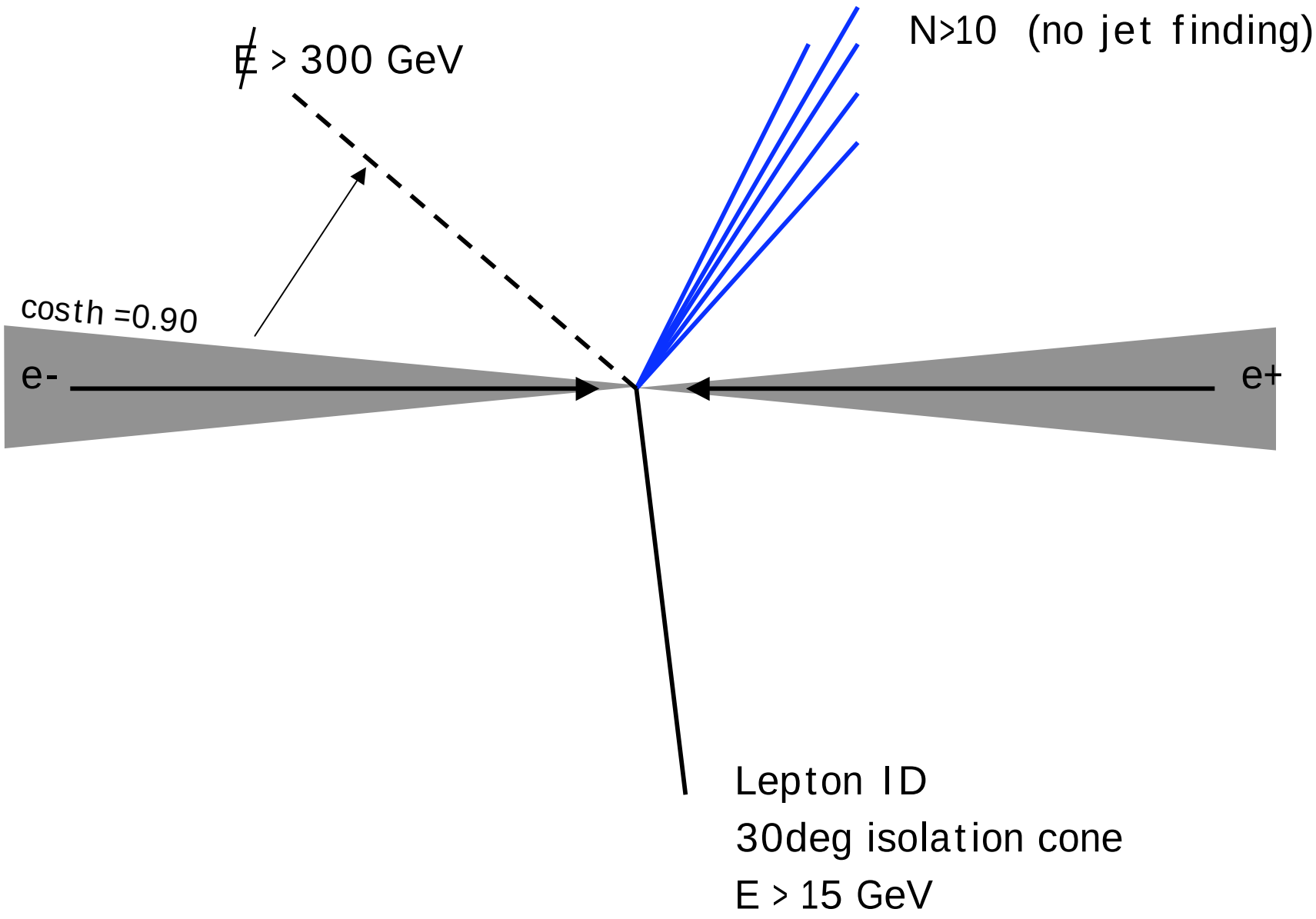
reconstruction eff = 36%

W* branching ratios = 15%

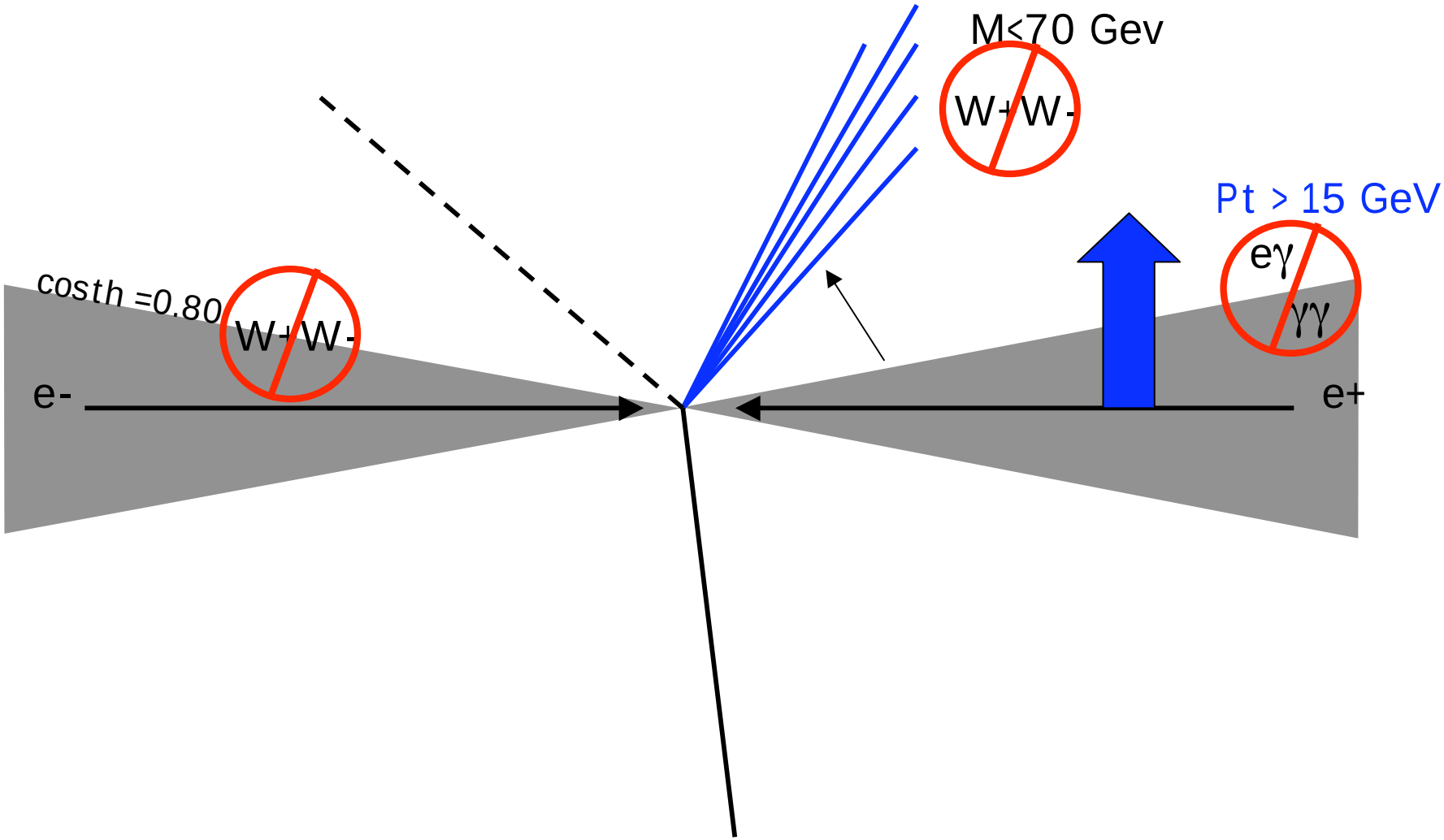
Signal yield = (500fb-1) ( $\frac{940fb}{120fb}$ ) (0.36x0.15) = $\begin{matrix} 12000 \text{ evts} & e^-_L \\ 1500 \text{ evts} & e^-_R \end{matrix}$

Backgrounds: WW, ZZ, tt + generic (1 $ab^{-1}$ from Tim Barklow)

# Signal Selection

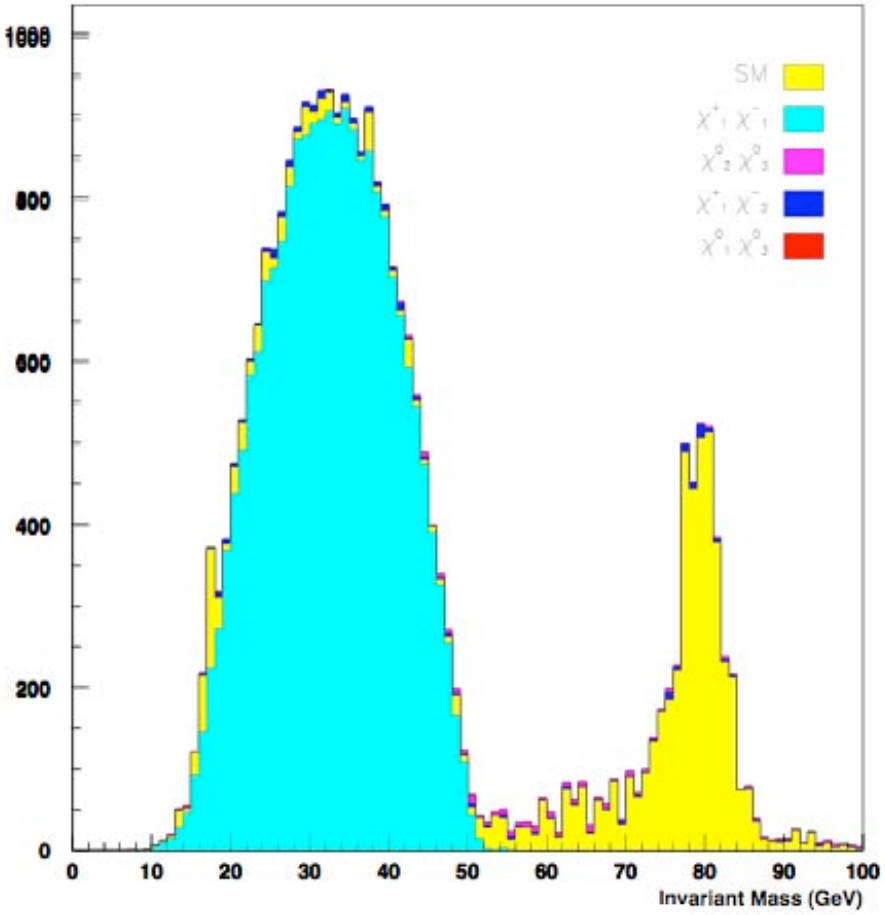


# Background Suppression



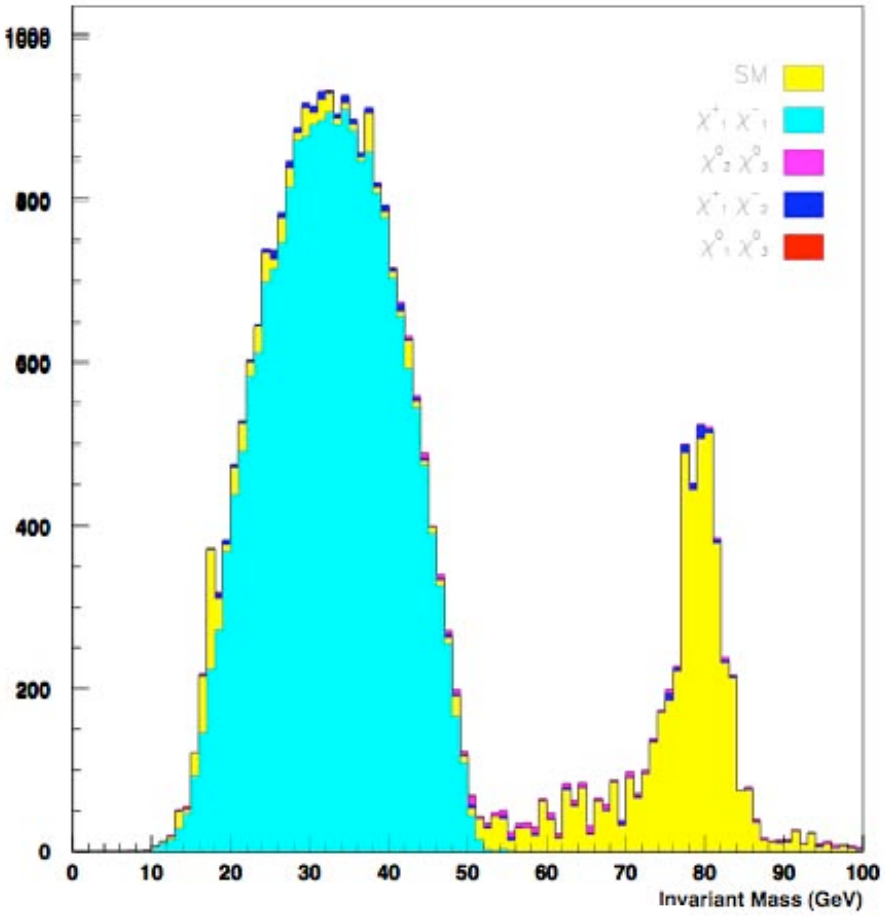
# Signal and Backgrounds

dΓ/dM, 500 fb-1



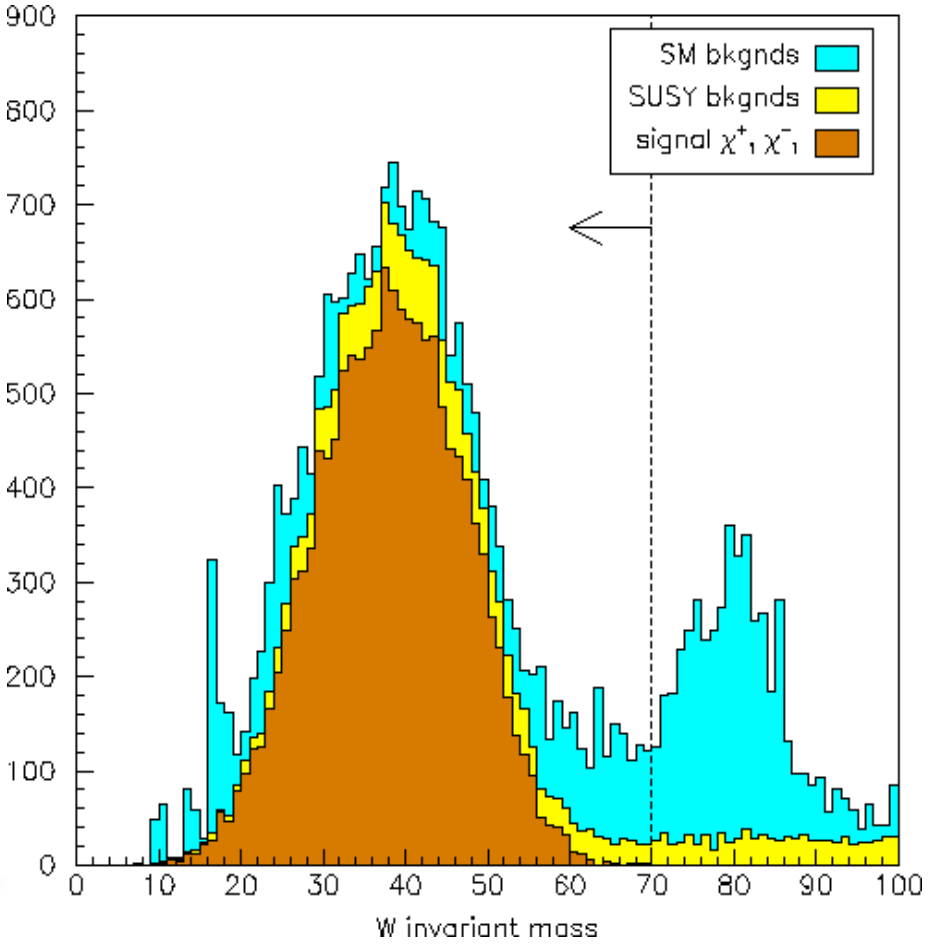
# Signal and Backgrounds

Analysis “A”




$$\frac{\sigma_E}{E} \sim \frac{0.15}{\sqrt{E}}$$

Analysis “B”




$$\frac{\sigma_E}{E} \sim \frac{0.8}{\sqrt{E}}$$

# Yields, $\sigma_L$, $\sigma_R$

Counting events in FASTMC with Analysis "B"

| | left-pol. | right-pol. |
|---|---|---|
| Signal ($\chi_1^+\chi_1^- \to e^{\pm}jj(g)$) | 12421 | 1592 |
| SUSY backgrounds (including $\chi_1^+\chi_1^-$ to other modes) | 1751 | 480 |
| Standard Model backgrounds | 3170 | 1209 |
| Cross-section measurement | $940 \pm 10$ fb | $119 \pm 4.3$ fb |

~1% on total cross section (or $\sigma_L$);

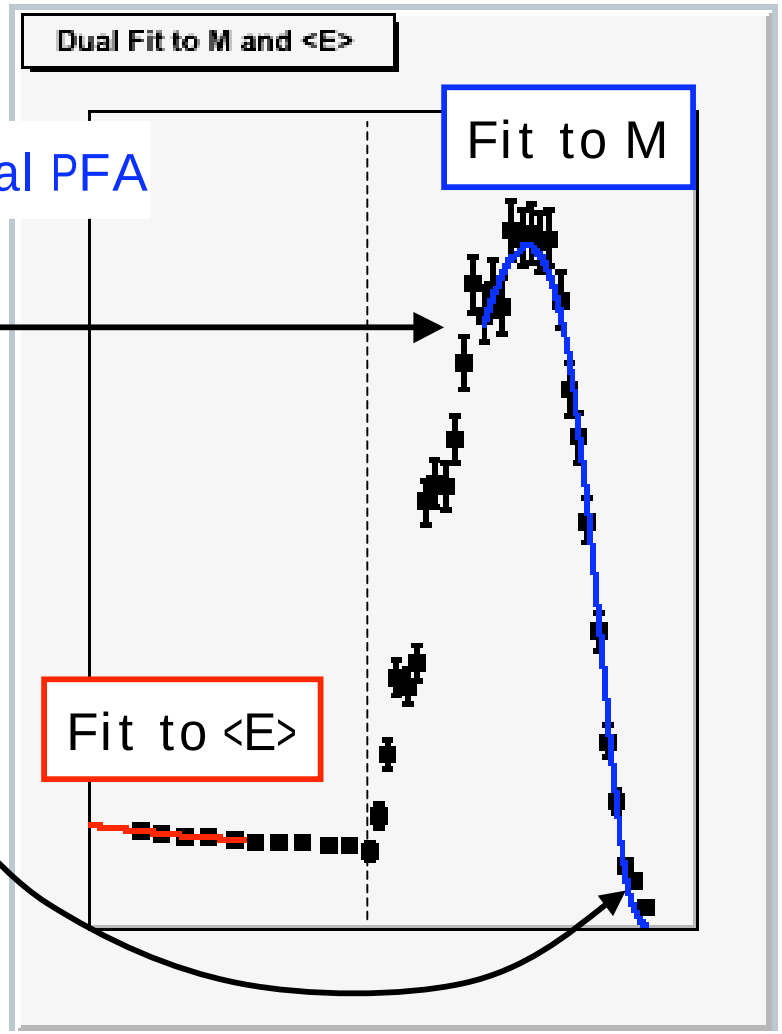
~4% on $\sigma_R$.

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = 0.78 \pm 0.01$$

# Simultaneous fit for dΓ/dM & dΓ/dE

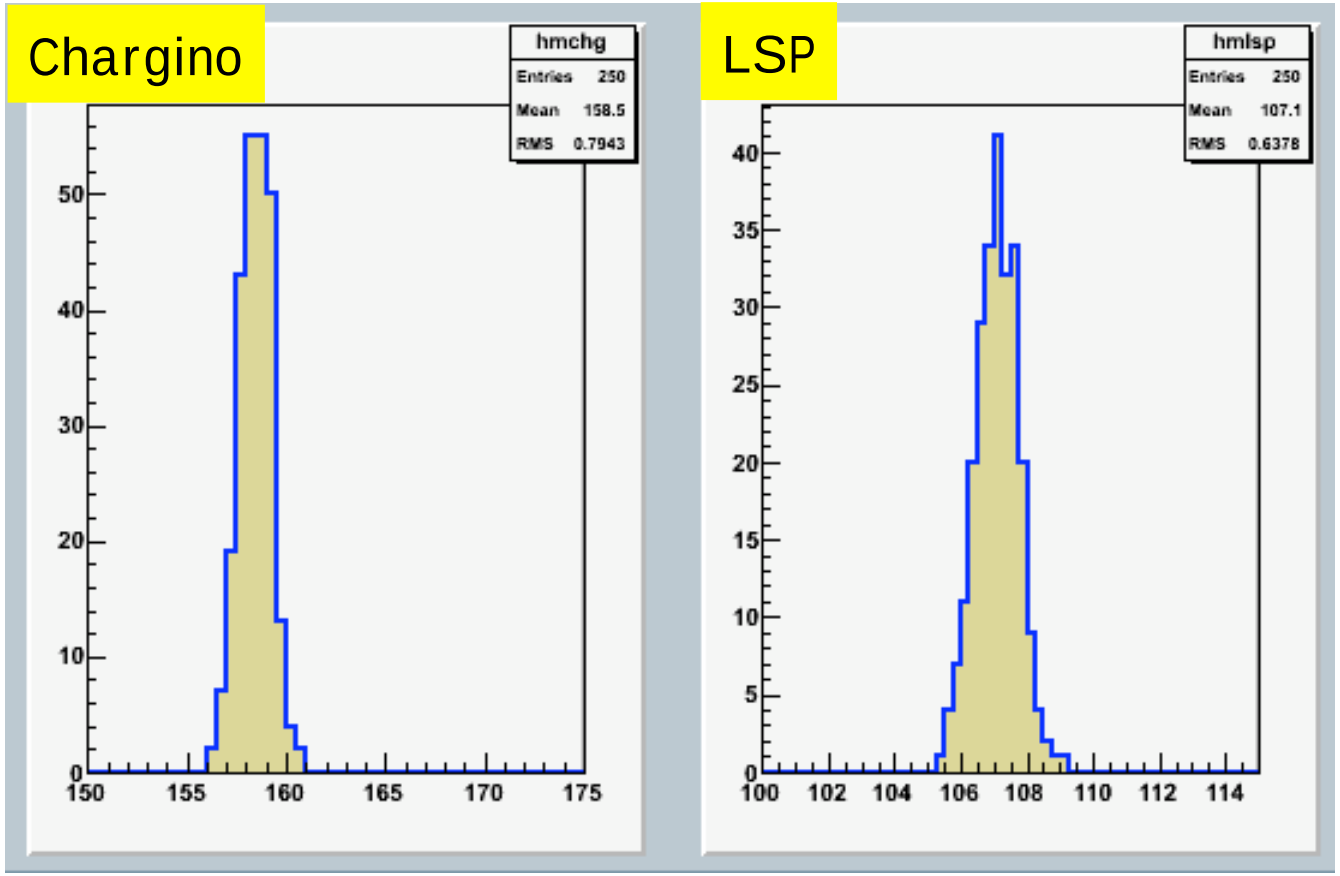
Explore further with toy MC -- flexible, fast

- 250 toy experiments
- generate 10k events in each expt:
  - dΓ/dM - Andreas' formula; ζ=0.86
  - dΓ/dE flat
- E,M smeared by $\sigma_E$=30%/√E --> optimal PFA
- Restrict fit to M>25GeV:
  - ISAJET/FASTMC:
  - low mass range is sculpted
  - not understood yet.
  - main impact on fit is reduced statistics (64%)
- -Fit includes resolution smearing
  - Sensitive - get it right!!
- No brem/beam-strahlung for now.
- -No background for now.



# Simultaneous fit for $d\Gamma/dM$ & $d\Gamma/dE$

250 toy experiments: 10K evts, $\sigma_E = 30\%/\sqrt{E}$

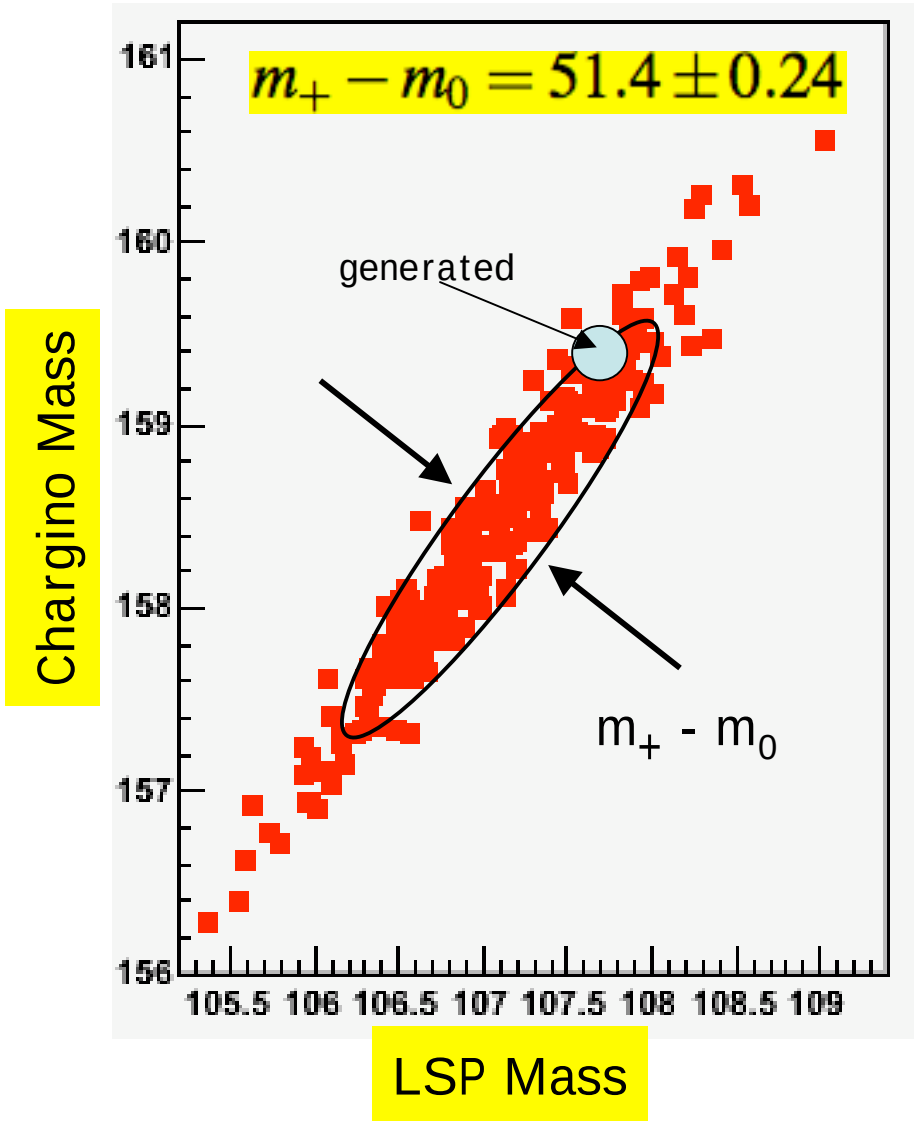


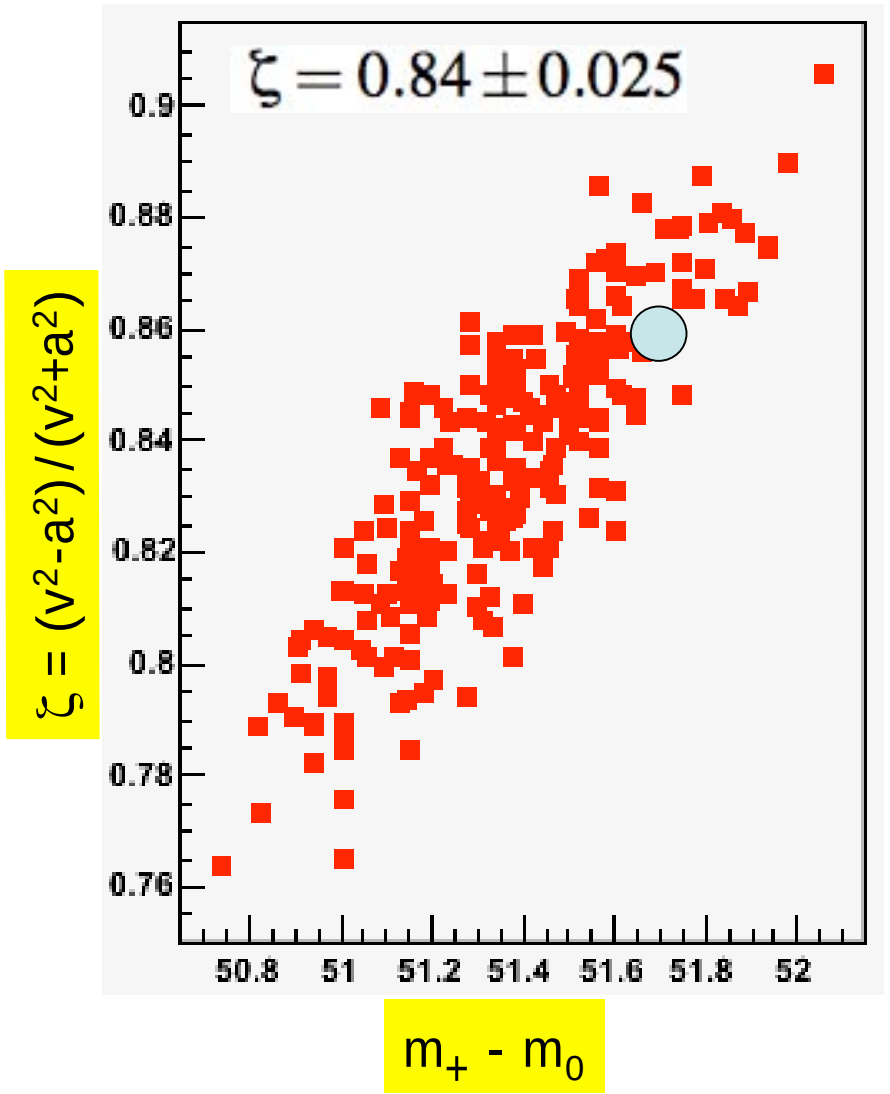

$$m_+ = 158.5 \pm 0.8 \qquad m_0 = 107.1 \pm 0.6$$

(generated value: 159.4) (generated value: 107.7)

# Simultaneous fit for dΓ/dM & dΓ/dE

250 toy experiments: 10K evts, $\sigma_E$=30%/√E



# Mass Sensitivity vs Detector Resolution

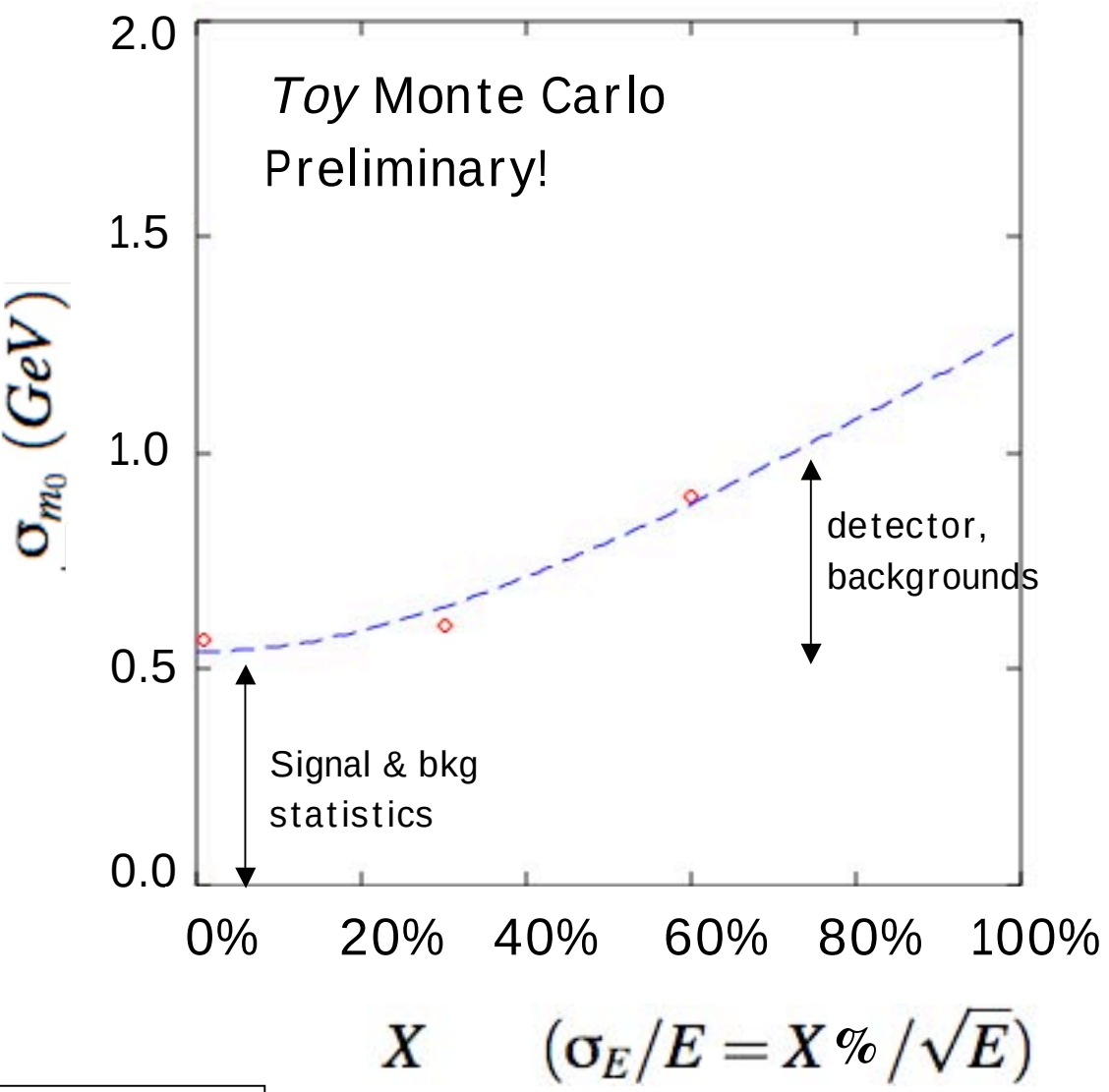
Dependence on "jet" energy resolution is somewhat mild…

CAVEATS!

1. No bkg included. Bkgs will raise the floor *and* the slope.

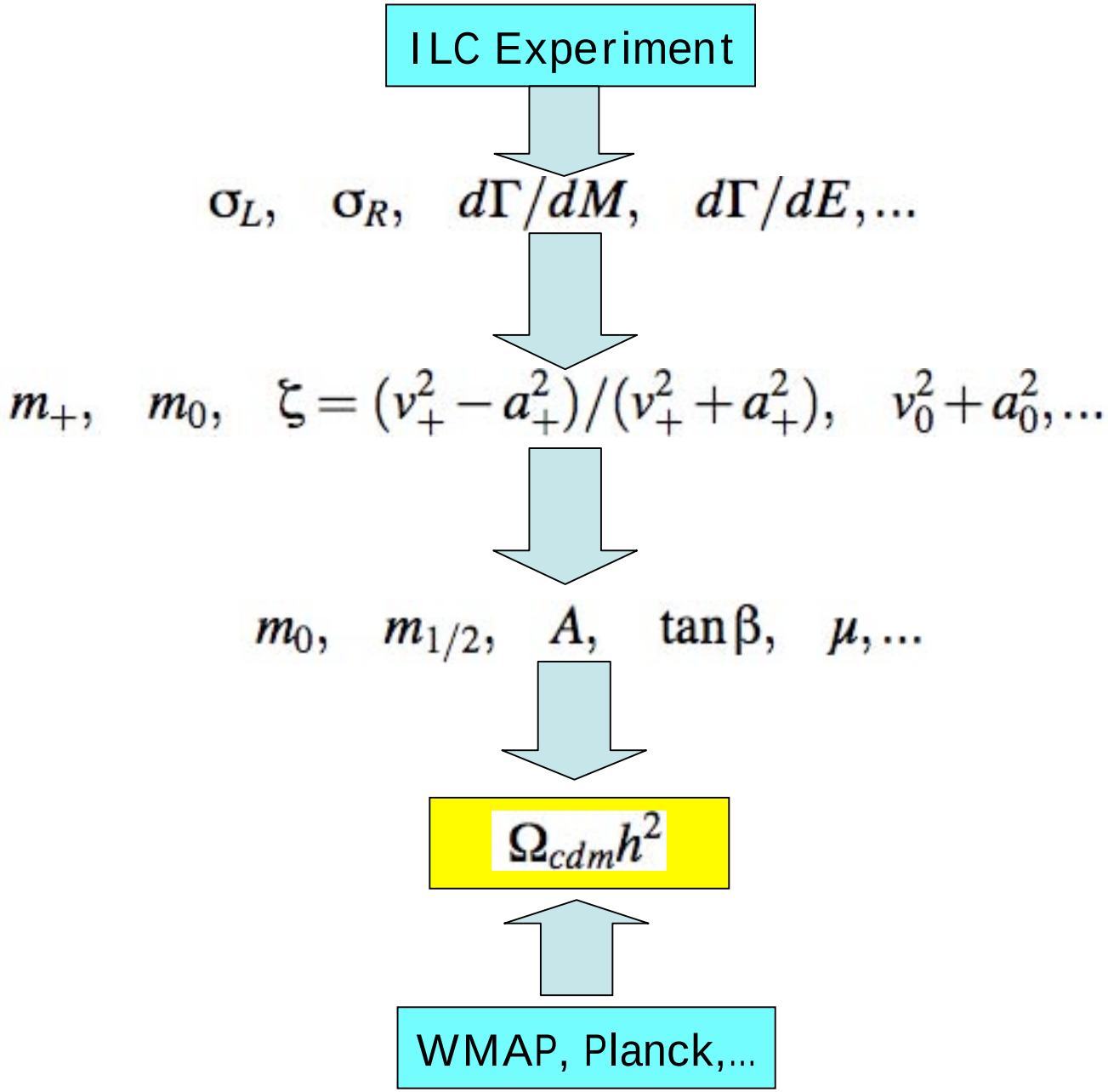
2. Toy Monte Carlo…

3. Preliminary!




| Res | mchg | mlsp | mdiff | zeta |
|---|---|---|---|---|
| 0% | +-0.66 | +-0.56 | +- 0.19 | +-0.020 |
| 30% | +- 0.8 | +- 0.6 | +- 0.25 | +-0.025 |
| 60% | +- 1.3 | +- 0.9 | +- 0.47 | +-0.039 |

# Cosmological Connections




Huron Peak, Sunday August 21