Event-shape of dileptons plus missing energy at a linear collider as a SUSY/ADD discriminant

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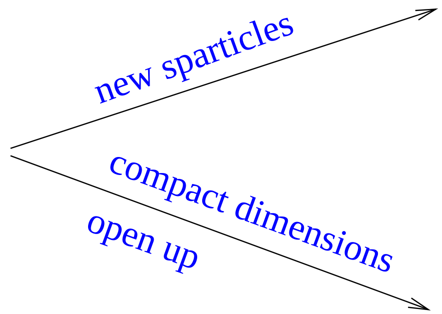
Based on work with Partha Konar, hep-ph/0509161, Phys. Lett. B634 (2006) 295

- Proposal
- Signal
- SM background and chosen cuts
- Cross-sections and event-shape variables
- Results
- Discussion

Proposal

New TeV scale physics predicted on the basis of naturalness, gauge hierarchy and dark matter wimp considerations



SUSY

Theory and Phenomenology of Sparticles
Drees, Godbole, Roy
(World Scientific 2004)

ADD

Antoniadis (1990)
Arkani−Hamed, Dimopoulos, Dvali (1998)
Perez−Lorenzana (2005)

Importance of SUSY/ADD discrimination.
Focus on lepton sector where LHC is not a powerful probe, e.g. $m_{\tilde{e}} \sim 250$ GeV will be hard.
Consider event shapes in $e^+e^- \to \ell^+\ell^- \not{E}$ at both ILC ($\sqrt{s} = 500$ GeV) and CLIC ($\sqrt{s} = 3$ TeV).

Signal

SUSY

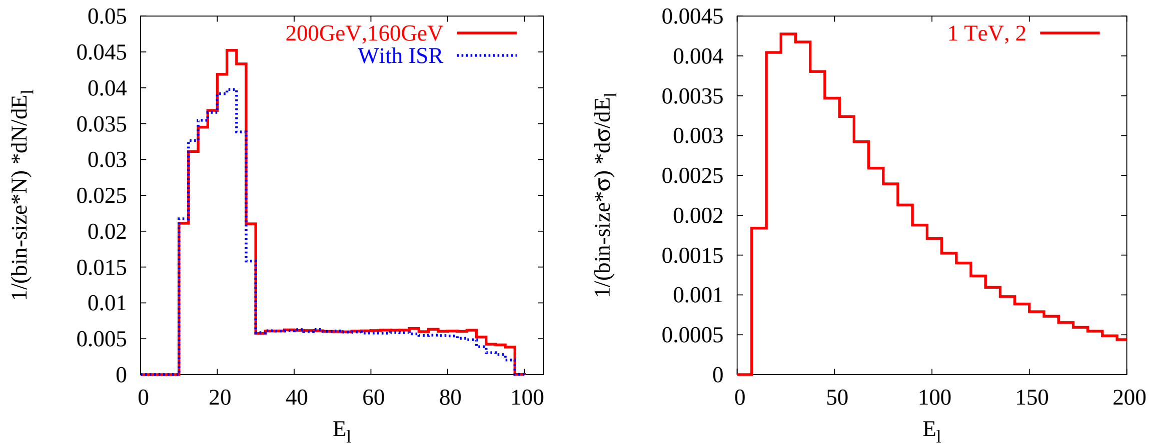
MSSM: free parameters $\overbrace{m_{\tilde{e}_{L,R}}, M_1, M_2, \mu}^{\mathcal{O}(10^2\ \text{GeV})}, \tan\beta$
(only gauge coupling unification assumed at $2 + 10^{16}$ GeV)

ADD

- All extra dims compactified on a d-torus with radius R_c for each
- SM fields on 3-brane, gravity in the bulk
- $(M_s)^{2+d} = (4\pi)^{d/2}\Gamma(d/2)G_N^{-1}(R_c)^{-d}$. only 2-parameters M_s, d.

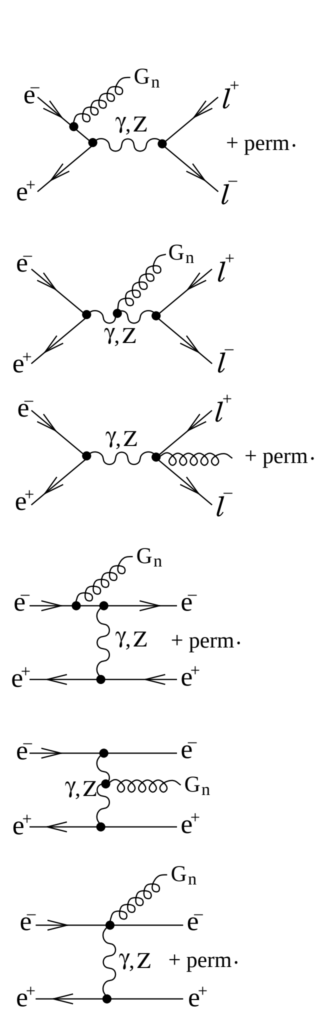
Motivation for event shape analysis of $e^+e^- \rightarrow \ell^+\ell^-\not{E}$.

- **Lepton energy spectrum parameter – and ISR-sensitive, Battaglia et al JHEP 0507 (2005) 033, hep-ph/0507284.**

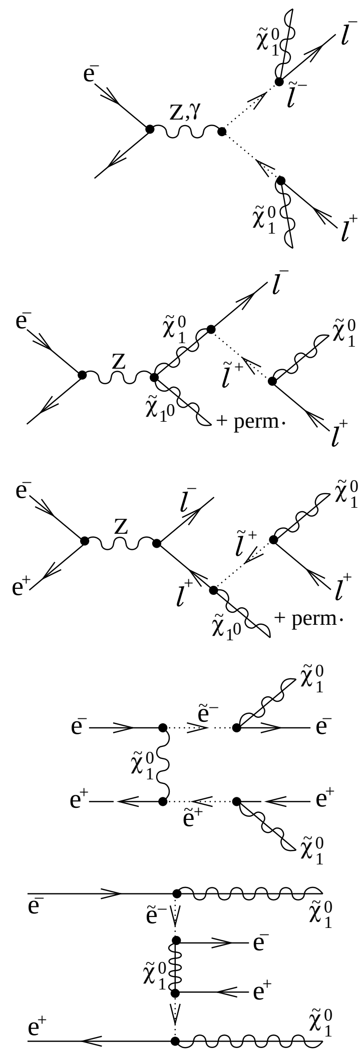


- **Angular distributions also tend to be flat over most of the range and somewhat similar.**

ADD



SUSY



Method of helicity amplitudes CompHEP: Freitas, von Manteuffel, Zerwas (2004)

(obey ward identities) HELAS PYTHIA: Choudhury, Datta, Huitu, Konar, Moretti (2003)

$$\sigma(e^+e^- \to \ell^+\ell^- \not{E}) = \sum_n \sigma(e^+e^- \to \ell^+ e^- G_N)$$
$$\simeq \int_0^{\sqrt{s}} dm \rho(m) \sigma(m),$$
$$\rho(m) = \frac{2R_c^d m^{d-1}}{(4\pi)^{d/2}\Gamma(d/2)}$$

Leading contribution

$\sigma(e^+e^- \to \tilde{\ell}^+_{L,R}\tilde{\ell}^-_{L,R}) BR(\tilde{\ell}^+_{L,R} \to \ell^+_{L,R}\tilde{\chi}^0_1) BR(\tilde{\ell}^-_{L,R} \to \ell^-_{L,R}\tilde{\chi}^0_1)$

$\mathrm{off-shell}$ $\tilde{\ell}$ contribution insignificant; so are

$e^+e^- \to \tilde{\ell}^+_{L,R}\tilde{\ell}^-_{L,R} \to \tilde{\chi}^+\tilde{\chi}^-\nu_\ell\nu_\ell \to \ell^+\ell^-\tilde{\chi}^0_1\tilde{\chi}^0_1\nu_e\nu_e\bar{\nu}_\ell\bar{\nu}_\ell$

BR's controlled by (1) LSP composition (2) channel access for $m_{\tilde{\ell}} > M_{\tilde{\chi}^\pm}$.

SM background and cuts

$e^+e^- \longrightarrow \ell^+\ell^-\nu_e\bar{\nu}_e$ from

$\nearrow$ $\ell^+\ell^- Z$: eliminated by missing mass cut

$\searrow$ W^+W^-: reconstructible modulo 2-fold ambiguity. Subtract!

Improvement with longitudinally polarized beam

Chosen cuts

- Direction of each $\ell > 10^\circ$ from beam pipe (control collinear singularities from t-channel γ and beamstrahlung)

- $p_T^{\ell} > 10$ **GeV (20 GeV)**

- $p_T^{\text{miss}} > 15$ **GeV (25 GeV)**

- $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 02$

- $5^\circ < \theta_{\ell^+\ell^-} < 175^\circ$

- $\mathbf{E}_{\text{miss}} >$ **150 GeV (450 GeV)**

Cross-sections and event-shape variables

$\sigma_{\rm SUSY}$[fb] ILC							$\sigma_{\rm ADD}$[fb] ILC				
$\tan\beta = 10$		$m_{\tilde{\ell}}$[GeV]				|	M_S[TeV]				
M_2, M_1[GeV]	μ[GeV]	155	205	225	245	|	.75	1.0	1.5	2.0	d
200, 100	−400	427	164	59	7.8	|	1090	345	68	22	2
300, 150	−400	144	137	75	19	|	455	108	14	3.3	3
400, 200	−150	92	40	13	0.6	|	202	36	3.2	0.6	4
400, 200	−100	79	32	6.9	0.3	|	97	13	0.8	0.1	5

$\sigma_{\rm SUSY}$[fb] CLIC							$\sigma_{\rm ADD}$[fb] CLIC				
$\tan\beta = 10$		$m_{\tilde{\ell}}$[GeV]				|	M_S[TeV]				
M_2, M_1[GeV]	μ[GeV]	700	800	900	1000	|	4.5	5.0	5.5	6.0	d
200, 100	−500	24	19	15	11	|	124	81	56	39	2
400, 190	−500	22	18	15	11	|	58	34	21	14	3
600, 290	−500	21	16	13	10	|	31	16	9.2	5.5	4
800, 380	−500	21	18	12	8	|	17	8.3	4.2	2.3	5

SM bkgd $\sim$ 36 fb (72 fb)

S/$\sqrt{B}$ would be desirably $\simeq 3$ **for** $\int dt\pounds = 100$ fb^{-1}(1000 fb^{-1}) **if min** $\sigma_{\text{signal}} = 1.8$ fb (0.8 fb)**.**

SUSY decay products of sleptons (not far from production thresholds) more isotropic
ADD heavier graviton modes, which contribute significantly, prefer more spiked configurations

$$\text{Sphericity tensor } S^{ij} = \frac{\sum_a p_a^i p_a^j}{\sum_a \vec{p}_a{}^{i2}}; \quad i,j = 1,2,3.$$

Eigenvalues $\lambda_{1,2,3}$ **:** $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq 0$ **and** $\lambda_1 + \lambda_2 + \lambda_3 = 1$
Event sphericity

$$S = \frac{3}{2}(\lambda_2 + \lambda_3), \qquad 0 < S < 1$$

(0 ↑ linear; 1 ↑ spherical)

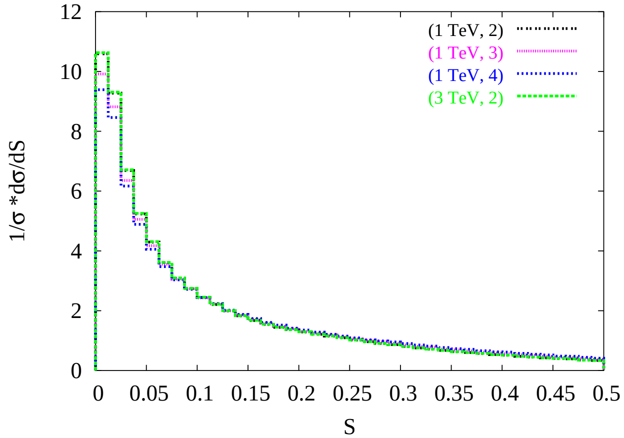
Thrust $T = \max \frac{\Sigma_a |\hat{n} - \vec{p}_a|}{\Sigma_a |\vec{p}_a|}$; $\frac{1}{2} \leq T \leq 1$

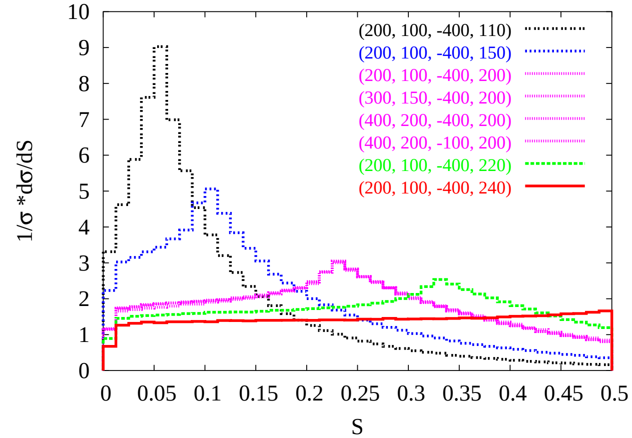
$\uparrow$ choice of $\hat{n}$ $\uparrow$ isotropic $\uparrow$ spiked

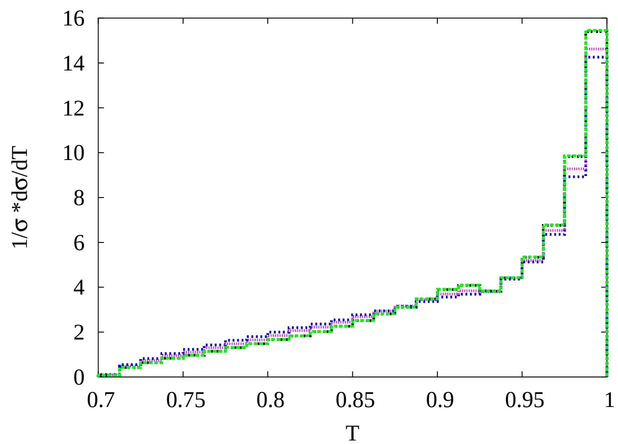
For our process, $\lambda_3 = 0$; planar events, shape circular rather than spherical for $S_{\mathrm{max}} = 3/4$

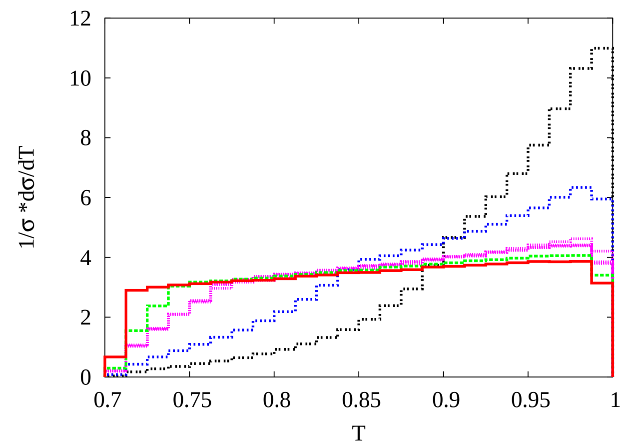
ISR/FSR effects take S_{max} beyond 3/4.

Results at $\sqrt{s} = 500$ GeV for ADD (M_s, d) and SUSY $(M_2, M_1, \mu, m_{\tilde{\ell}})$

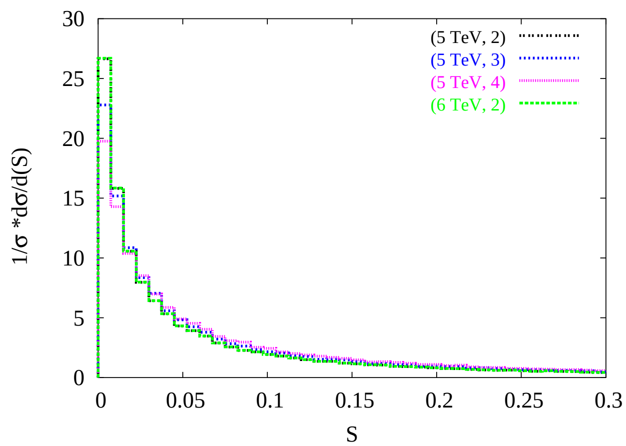


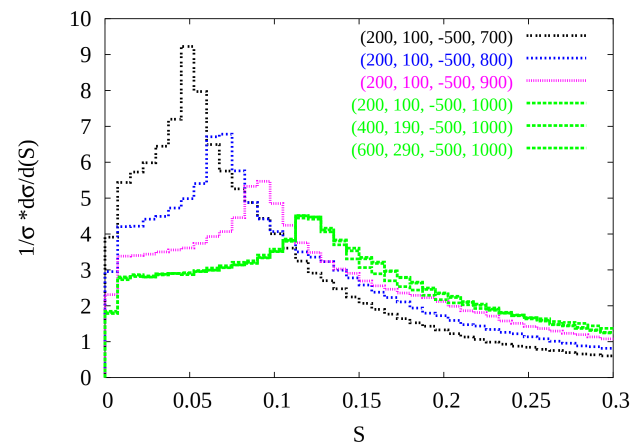


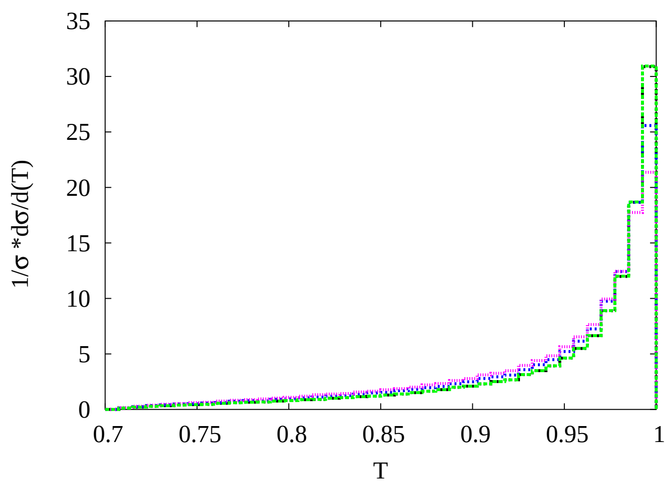


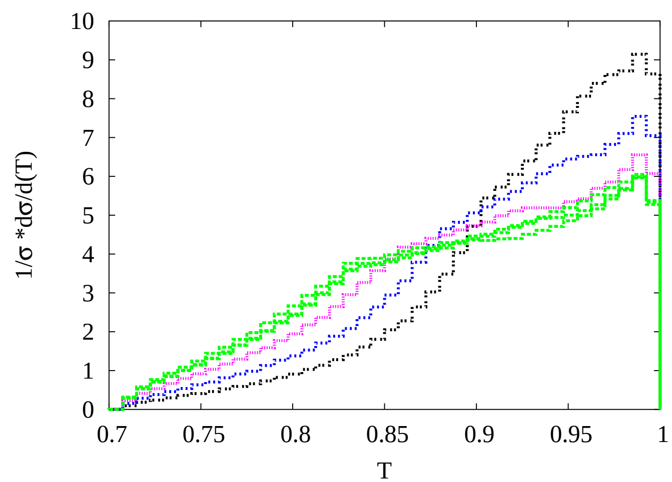


Results at $\sqrt{s} = 3$ TeV for ADD (M_s, d) and SUSY $(M_2, M_1, \mu, m_{\tilde{\ell}})$

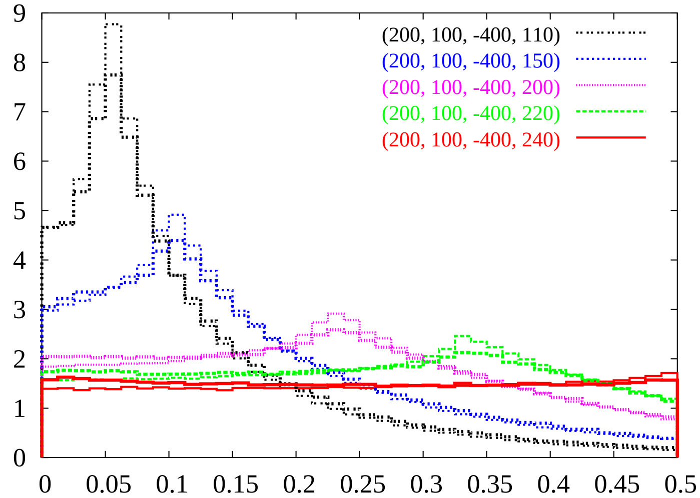


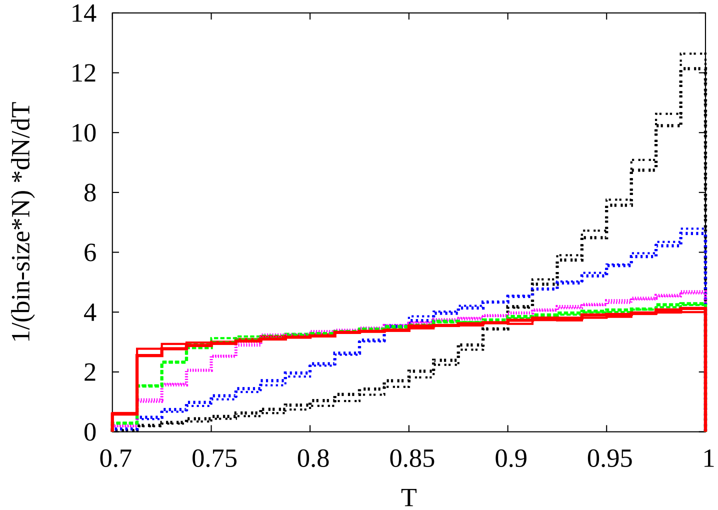




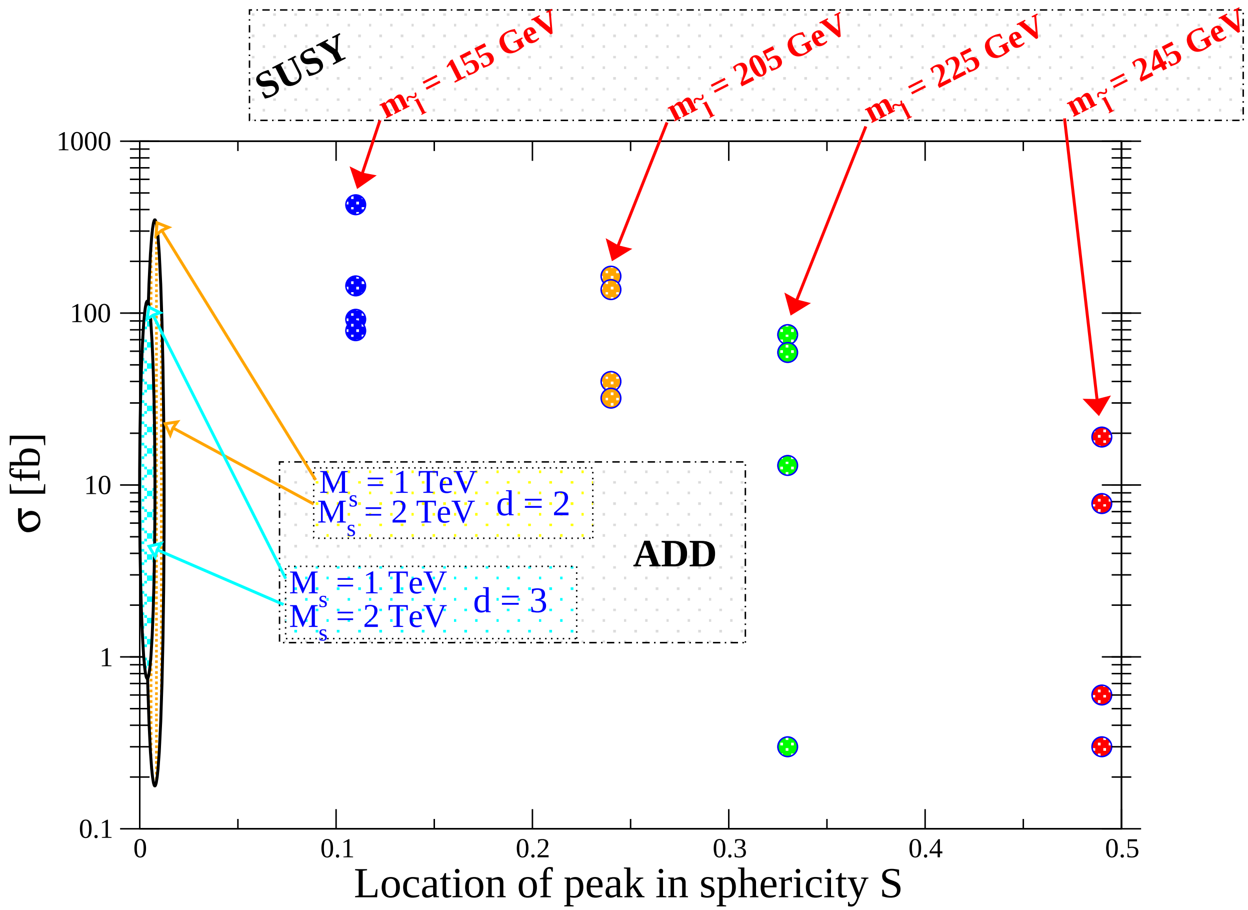


Results at $\sqrt{s} = 500$ GeV with PYTHIA for SUSY $(M_2, M_1, \mu, m_{\tilde{\ell}})$





ADD/SUSY discrimination via sphericity maximum at ILC



Discussion

- Event-shape not ISR/FSR sensitive.

- Sphericity better than thrust in SUSY/ADD discrimination.

- Structure in sphericity distribution for SUSY, structureless monotonic fall-off for ADD.

- Location of sphericity peak a robust measure of $m_{\tilde{\ell}}$; ISR/FSR insensitive; not much variation with $\sqrt{s}$.