Determining Masses and Spins of New Particles (with missing energy)

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KEK seminar
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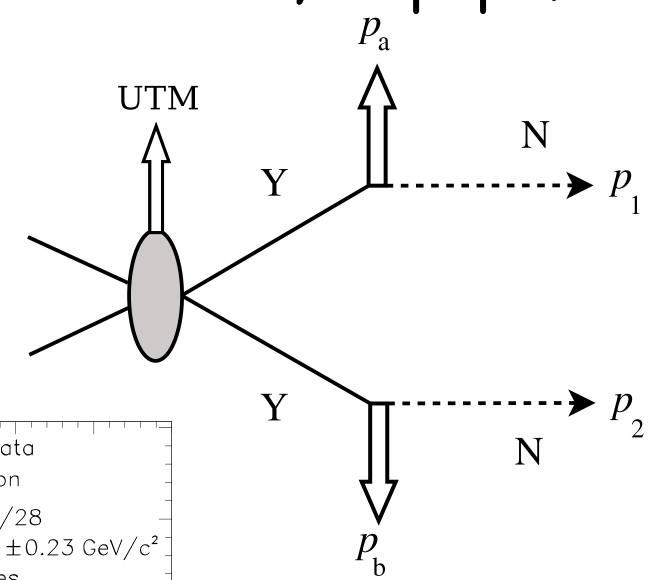
Outline

- Mass determination
  - M_{T2} variable
  - Jet contamination
  - Solving decay chains
  - 'Inclusive' observables
- Spin determination
  - Decay chains
  - Dileptons
  - Three-body decays
  - Cross sections

Mass determination with M_{T2}

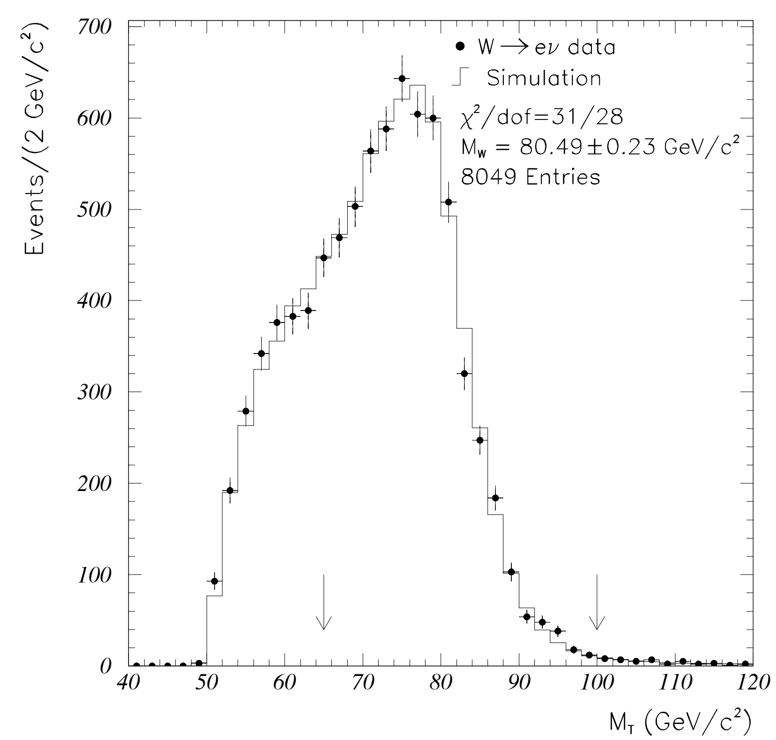
M_{T2} variable

Lester & Summers, hep-ph/9906349



- pp → YYX, Y → aN, Y → bN
- a,b visible, N invisible
- Transverse mass:

$$m_T^2(\mathbf{p}_T^1, \mathbf{p}_T^a; \mu_N) = \mu_N^2 + m_a^2 \\ +2\left(E_T^1 E_T^a - \mathbf{p}_T^1 \cdot \mathbf{p}_T^a\right)$$

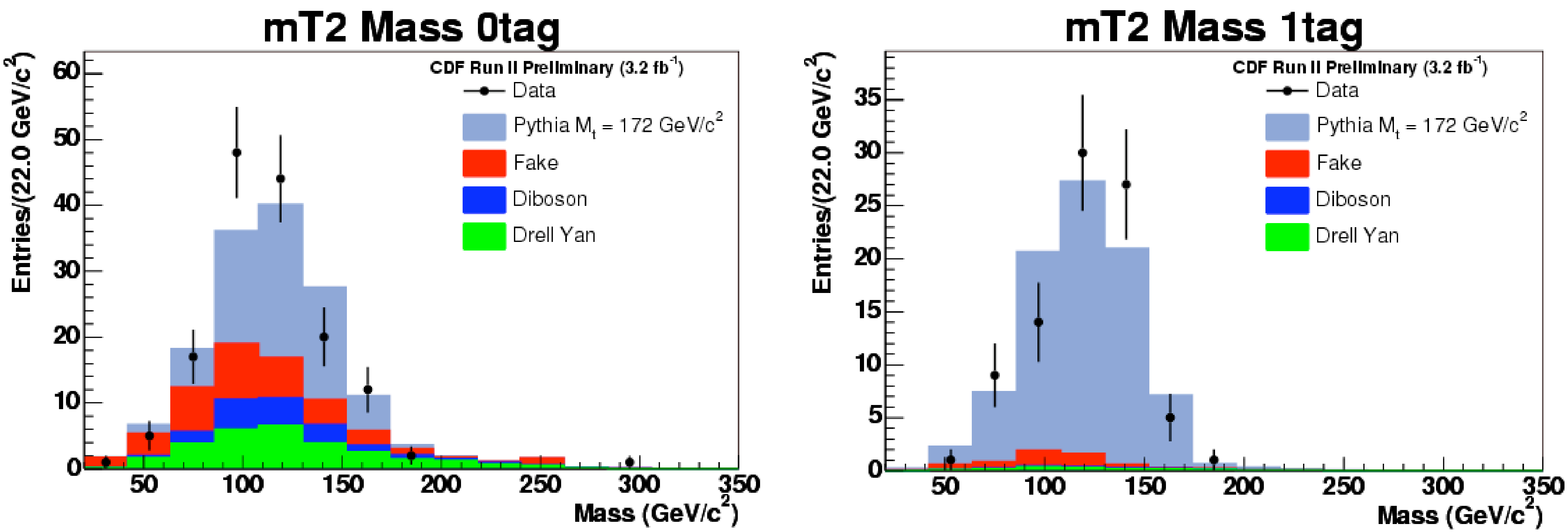


$$m_{T2}^2(\mu_N) \equiv \min_{\mathbf{p}_T^1 + \mathbf{p}_T^2 = \not{p}_T} \left[\max\{m_T^2(\mathbf{p}_T^1, \mathbf{p}_T^a; \mu_N), m_T^2(\mathbf{p}_T^2, \mathbf{p}_T^b; \mu_N)\}\right]$$

$$\leq m_Y^2 \text{ when } \mu_N = m_N$$

CDF top mass from M_{T2}

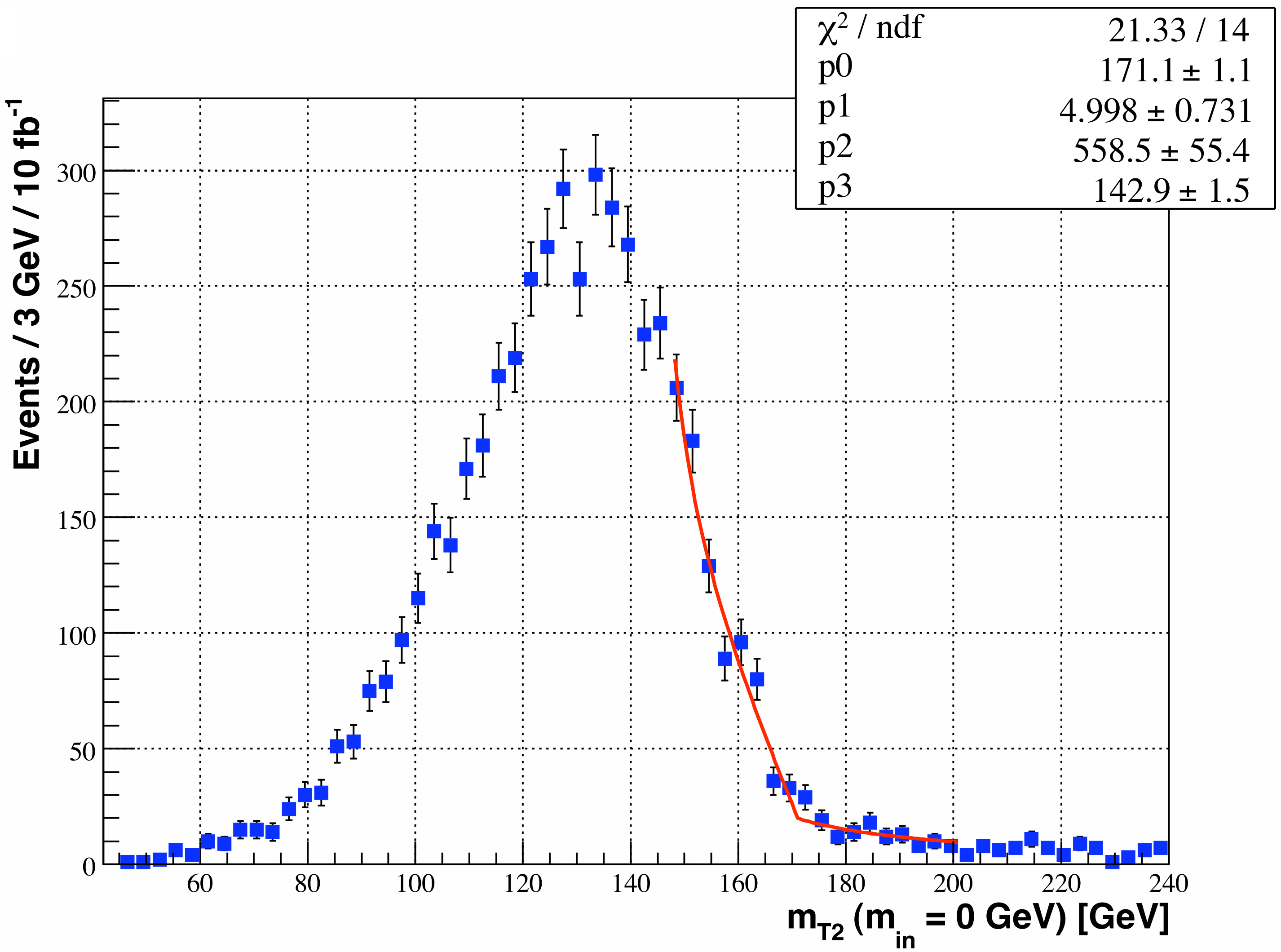
CDF note 9679



- $0.2\ fb^{-1}$ => m_t = 168.0 +5.6/-5.0 GeV (prelim.)

Top mass from M_{T2} at LHC

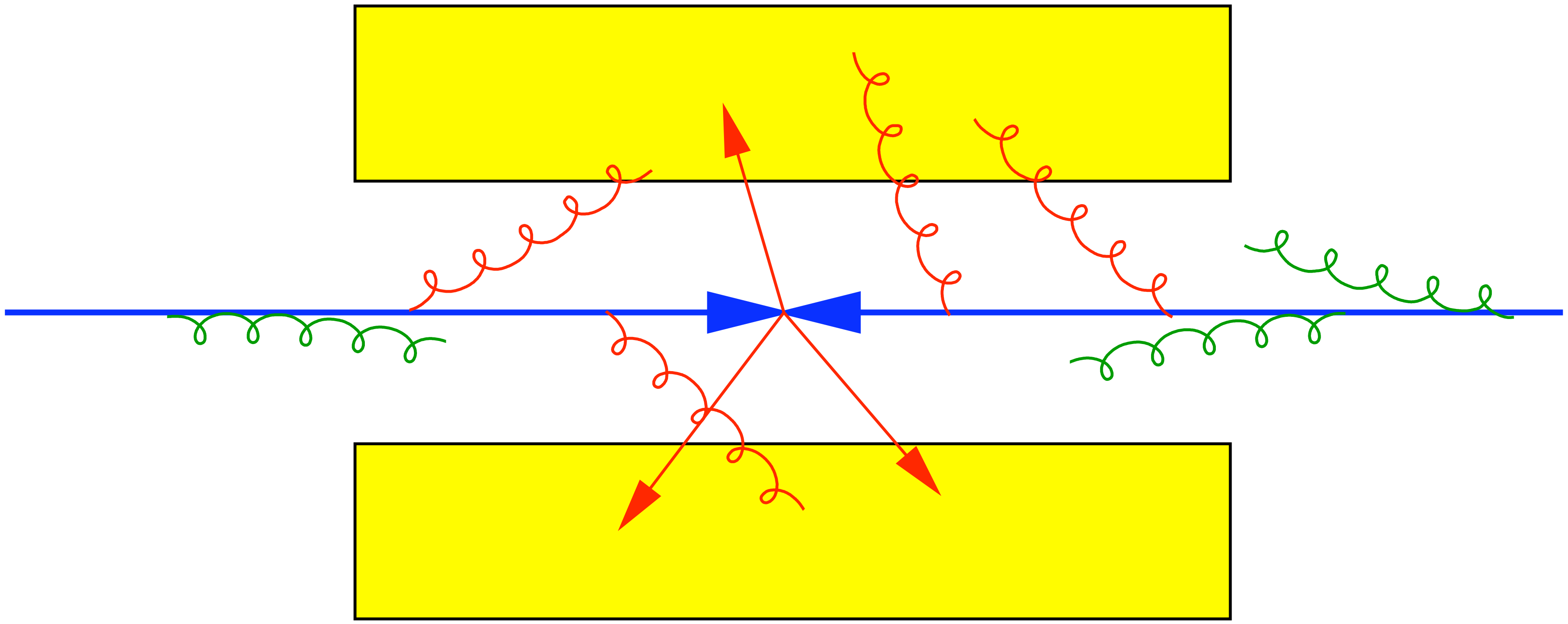
Cho, Choi, Kim & Park, 0804.2185



- Input mass 170.9 GeV; PYTHIA+PGS; b-tagging 50%

- 10 fb^{-1} @ LHC (14 TeV) => m_t = 171.1 +/- 1.1 GeV

Initial-state QCD radiation



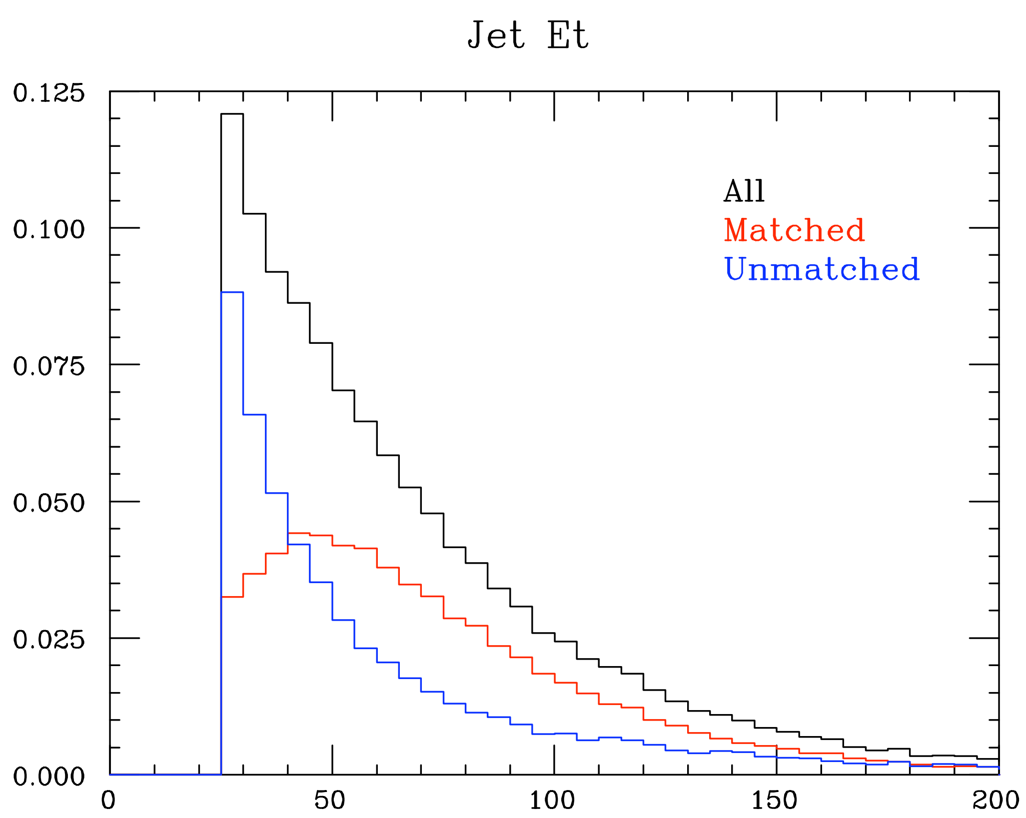
- Irreducible source of "jet contamination"

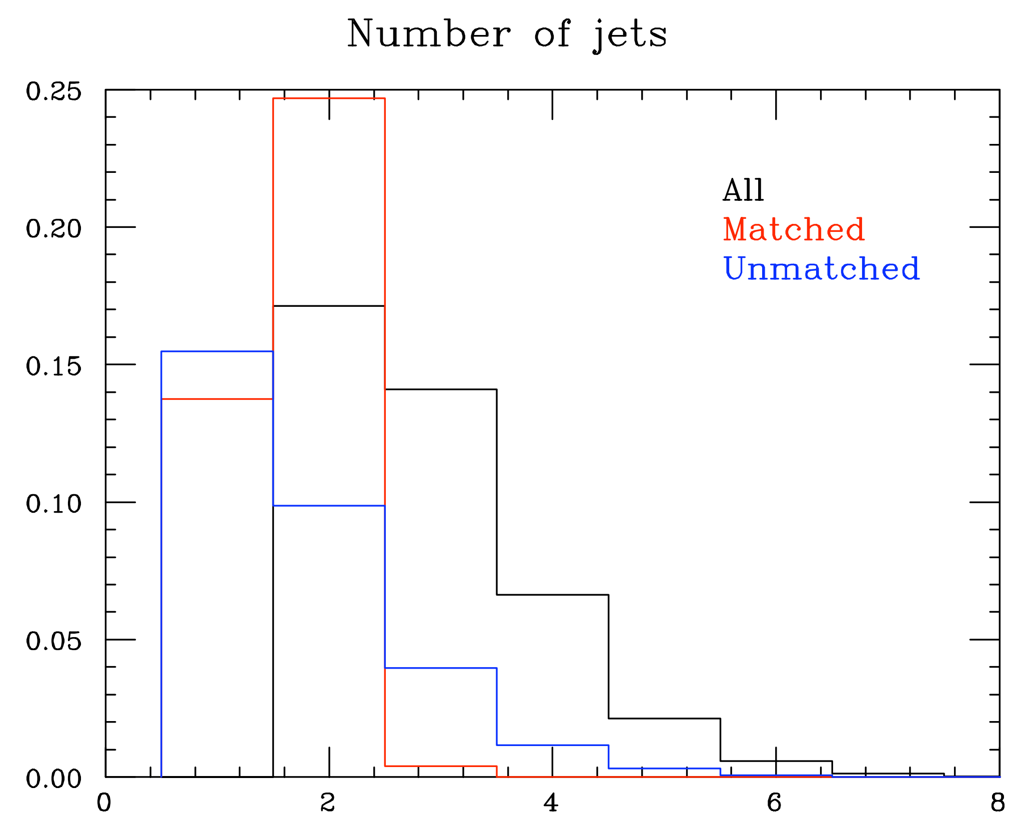
➡ Misidentification of processes

➡ Combinatorial ambiguities

Jet contamination

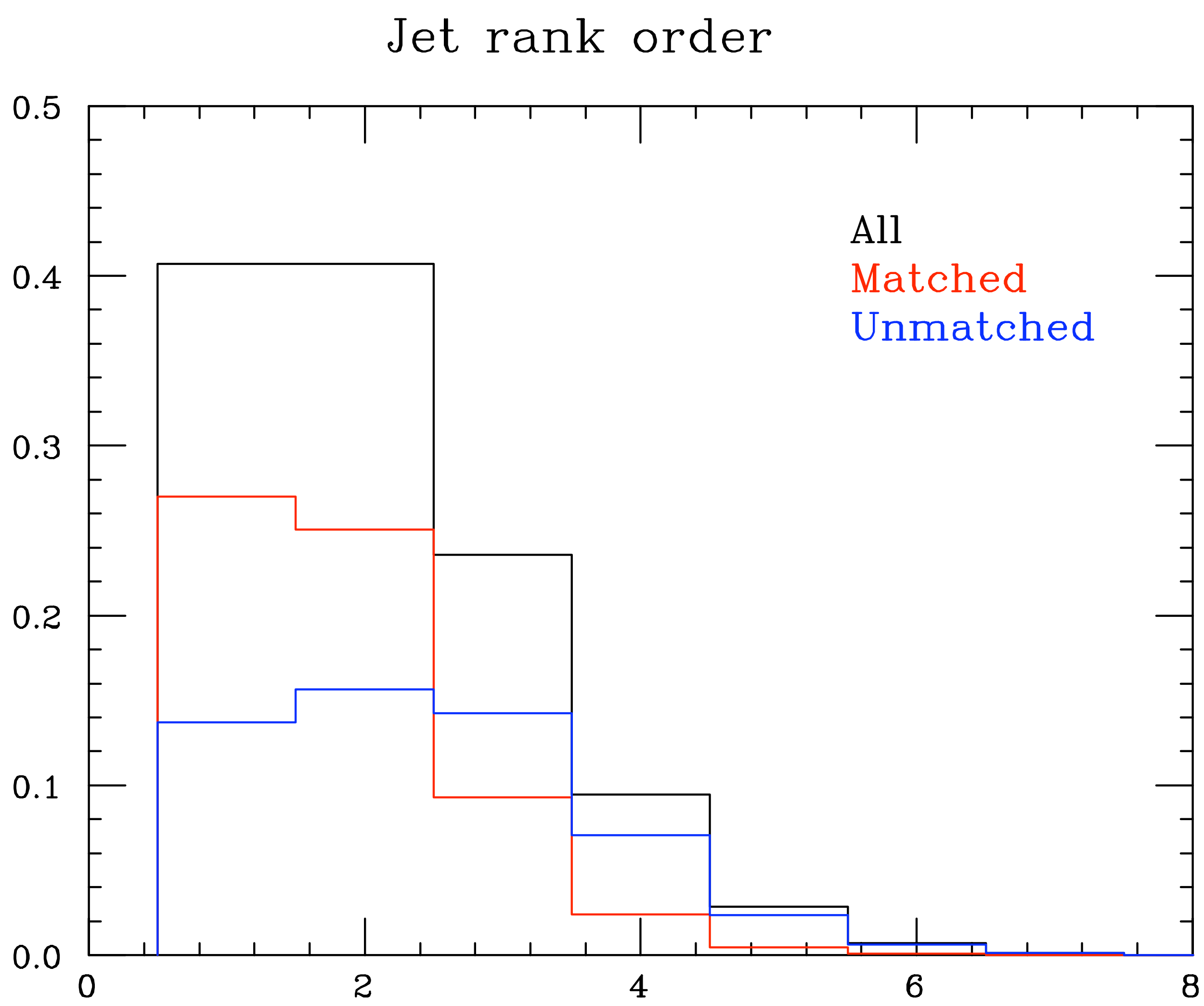
- Fully leptonic $t\bar{t}$: 2 jets (+2 leptons + MET)
- Matched = top decay parton within ΔR=0.5 and $\Delta E/E$=0.3
- Generated with MC@NLO (no underlying event)





➡ Half of events have an extra jet

E_T ordering of jets



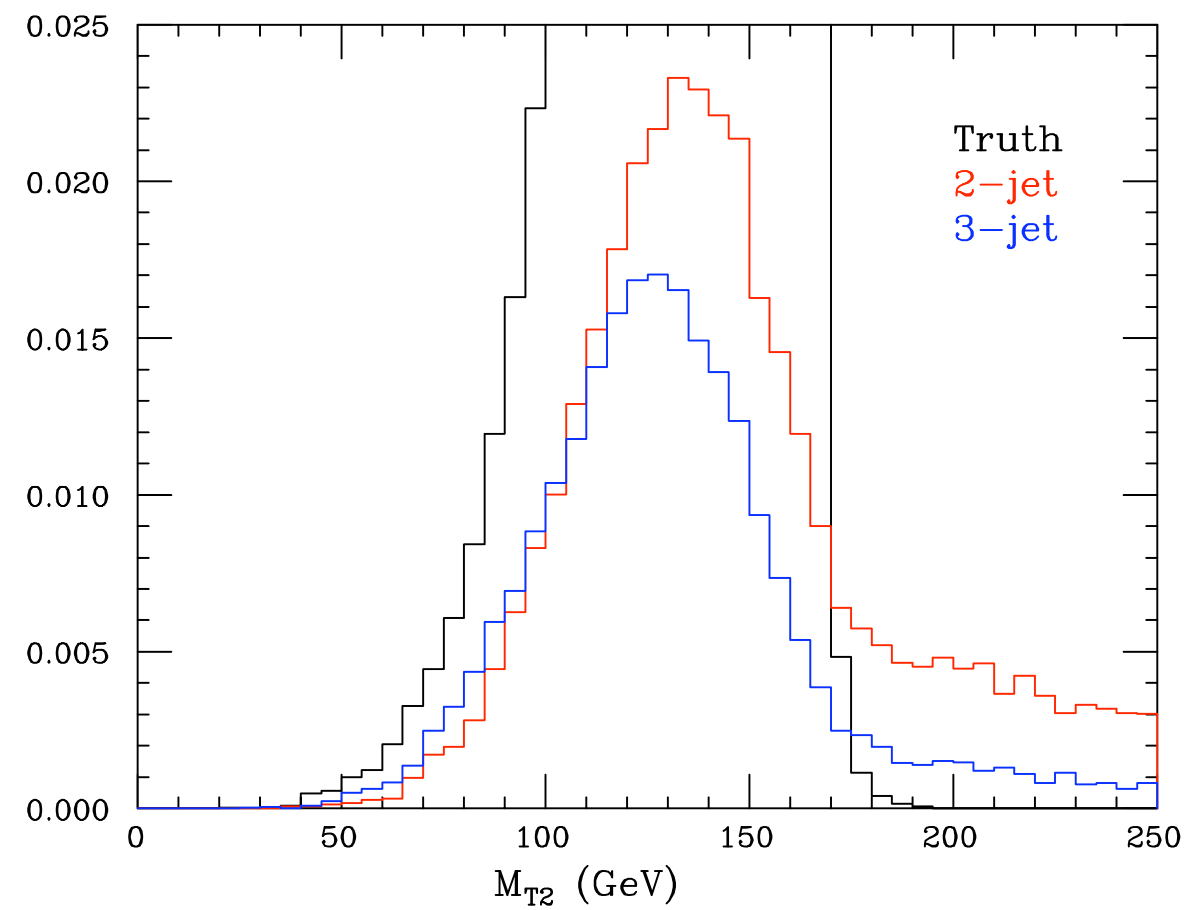
- P(1 or both leading jets unmatched) > 50%

Reducing jet contamination

- Idea: demand more jets, select lowest M_{T2}
  As long as one is correct, this cannot raise edge

Alwall, Hiramatsu, Nojiri & Shimizu, 0905.1201

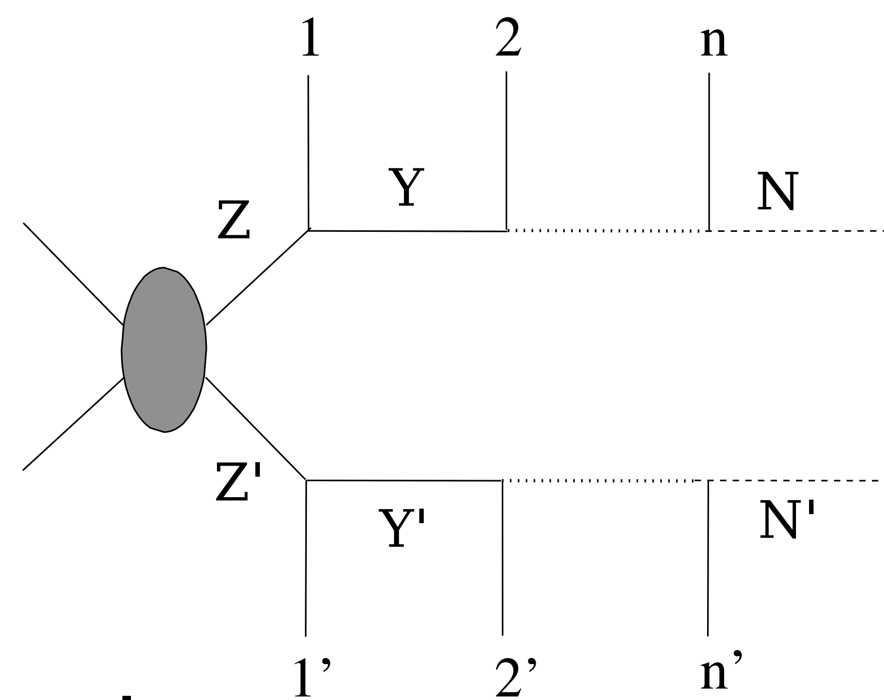
- 7 fb^{-1} MC@NLO, no b-tagging
- > 50% events have extra jets
- Hardest 2 jets (red) => ISR contaminates edge
- Smallest M_{T2} from 3 hardest (blue) => less contamination



Solving decay chains

- Measure visible momenta 1...n, 1'...n' and missing p_T
  - 6 unknown momentum components per event
  - n+n'+2 on-mass-shell constraints per event
  - N_m unknown masses → we need

    $N_{ev}(n+n'-4) \geqslant N_m$ to solve for masses



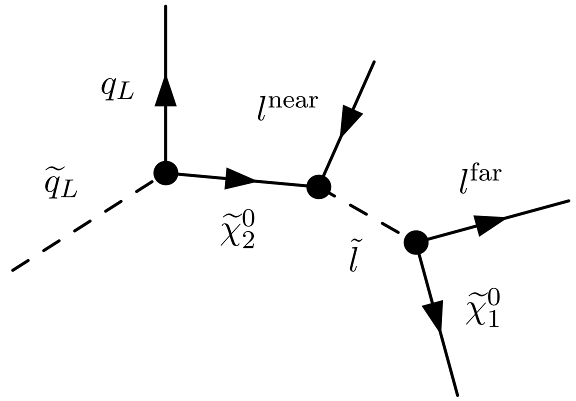
- Identical chains: $n=n'$, $N_m = n+1$ → need $N_{ev} = 2$ for n=3,4

Non-identical (N=N'): $N_m = n+n'+1$ → need $N_{ev} = 6$ for n+n'=5

Solving pairs of events

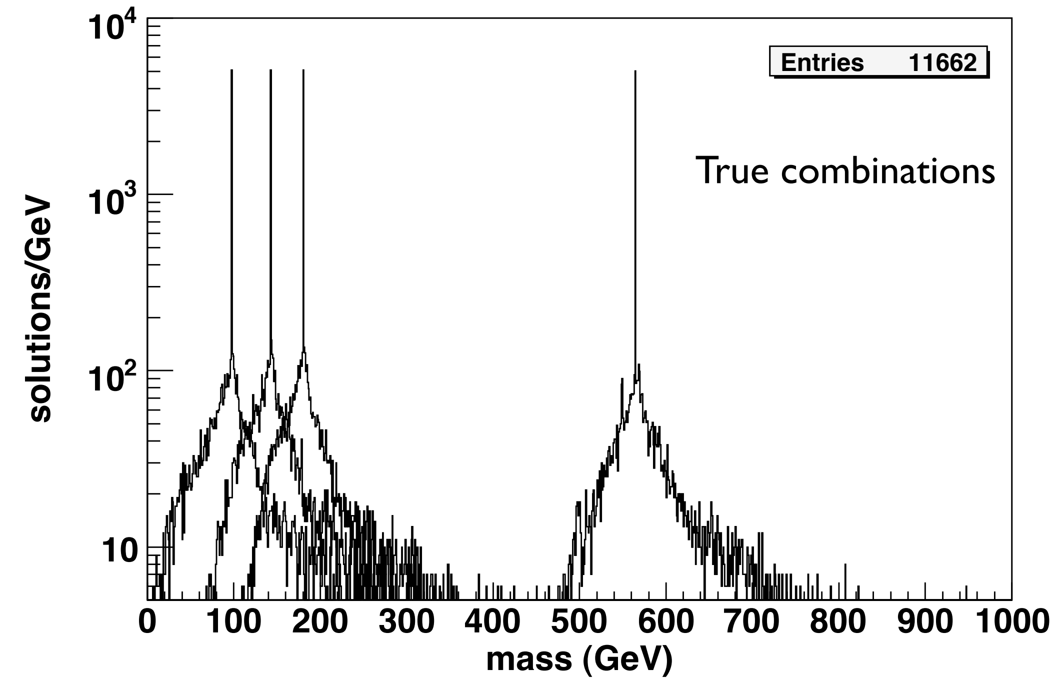
Chen, Gunion, Han, McElrath 0905.1344

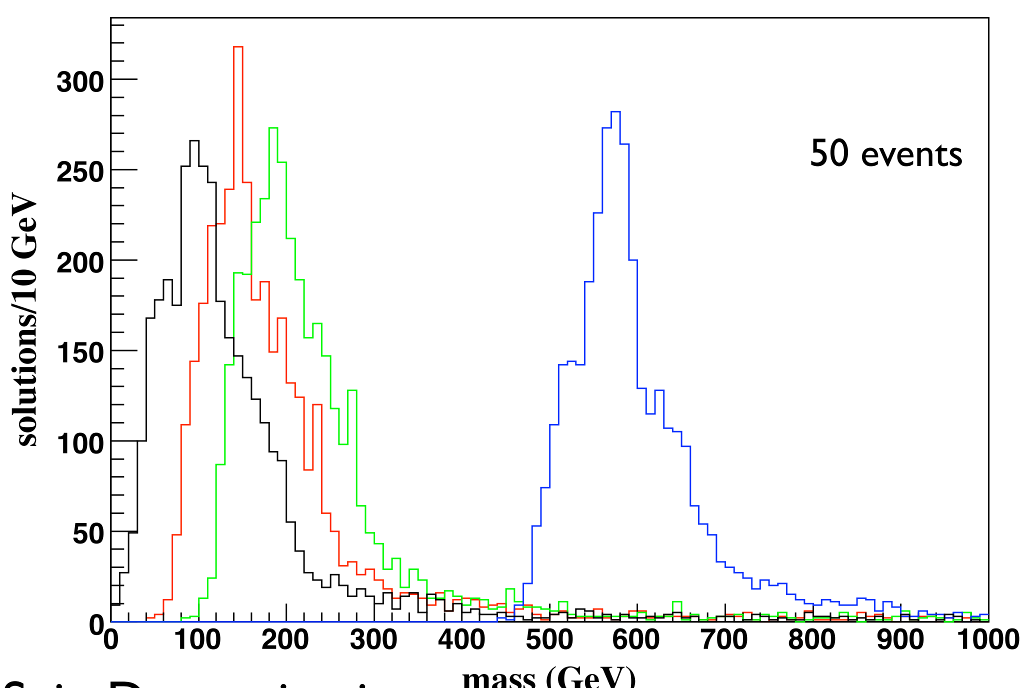
- Two identical chains

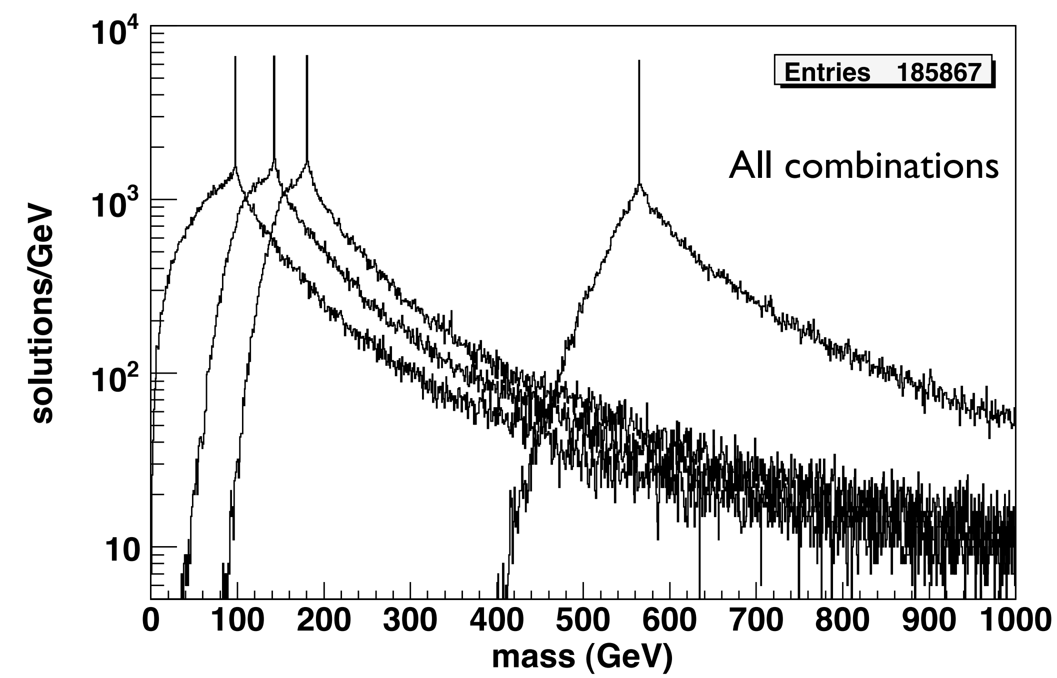


- SPS 1a masses

$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{u}_L$	$\tilde{e}_R$
96	177	537	143







Fitting decay chains

Kawagoe, Nojiri, Polesello, hep-ph/0410160

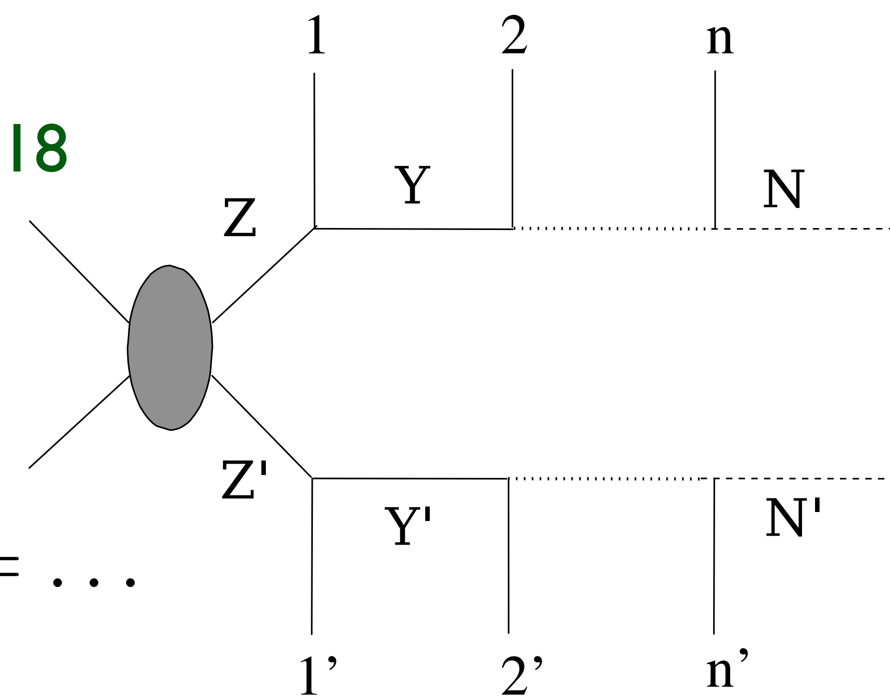
BW 0905.1344

- Assume a mass hypothesis: if n+n’ > 4 then each event is over-constrained
- E.g. if n, n’=3, can solve for p_N, $p_{N'}$

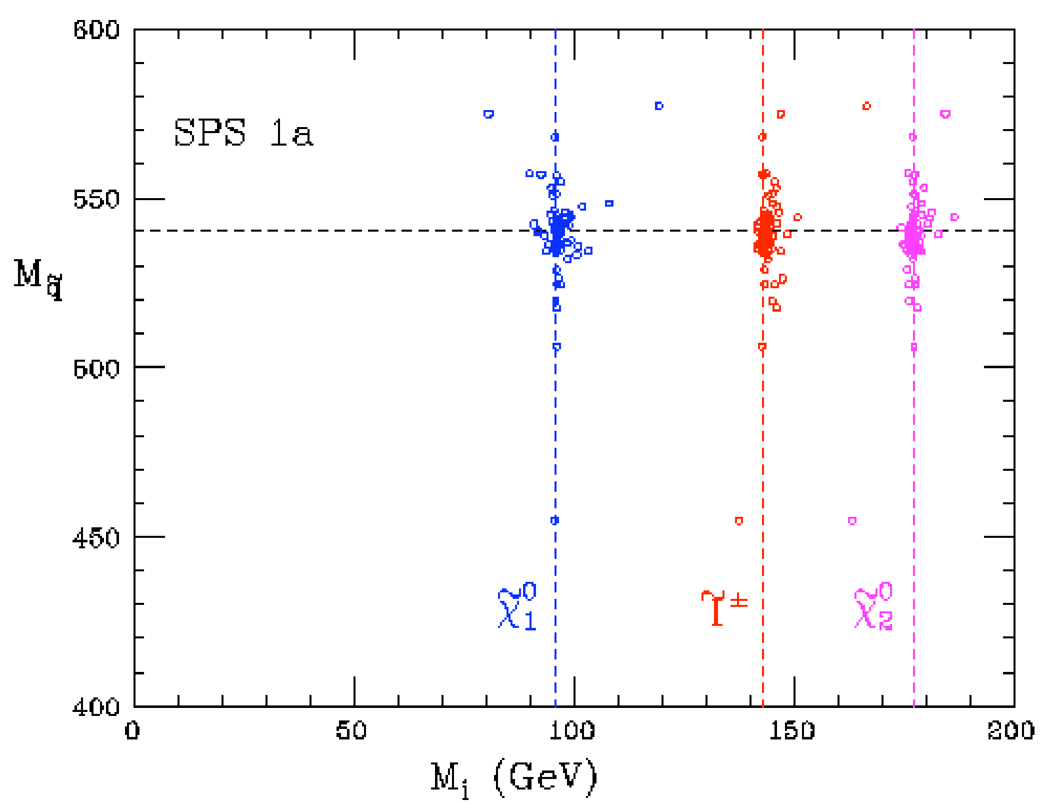
Nojiri, Polesello, Tovey 0712.2718

- Measure goodness of fit by

$$\xi^2 = (p_N^2 - M_N^2)^2 + (p_{N'}^2 - M_{N'}^2)^2$$



  - N.B. $p_N^2 - M_N^2 = p_Z^2 - M_Z^2 = p_Y^2 - M_Y^2 = \ldots$



Best-fit points for 100 samples of 25 events (all combinations)

- Effects of jet contamination and background under study

Global Inclusive Observables

Inclusive observables

- How can jets from hard subprocess be distinguished from ISR jets?
- In principle, there is no way! So let's look at "global inclusive" observables
- Consider e.g. the total invariant mass M visible in the detector:

$$M = \sqrt{E^2 - P_z^2 - \not{E}_T^2}$$

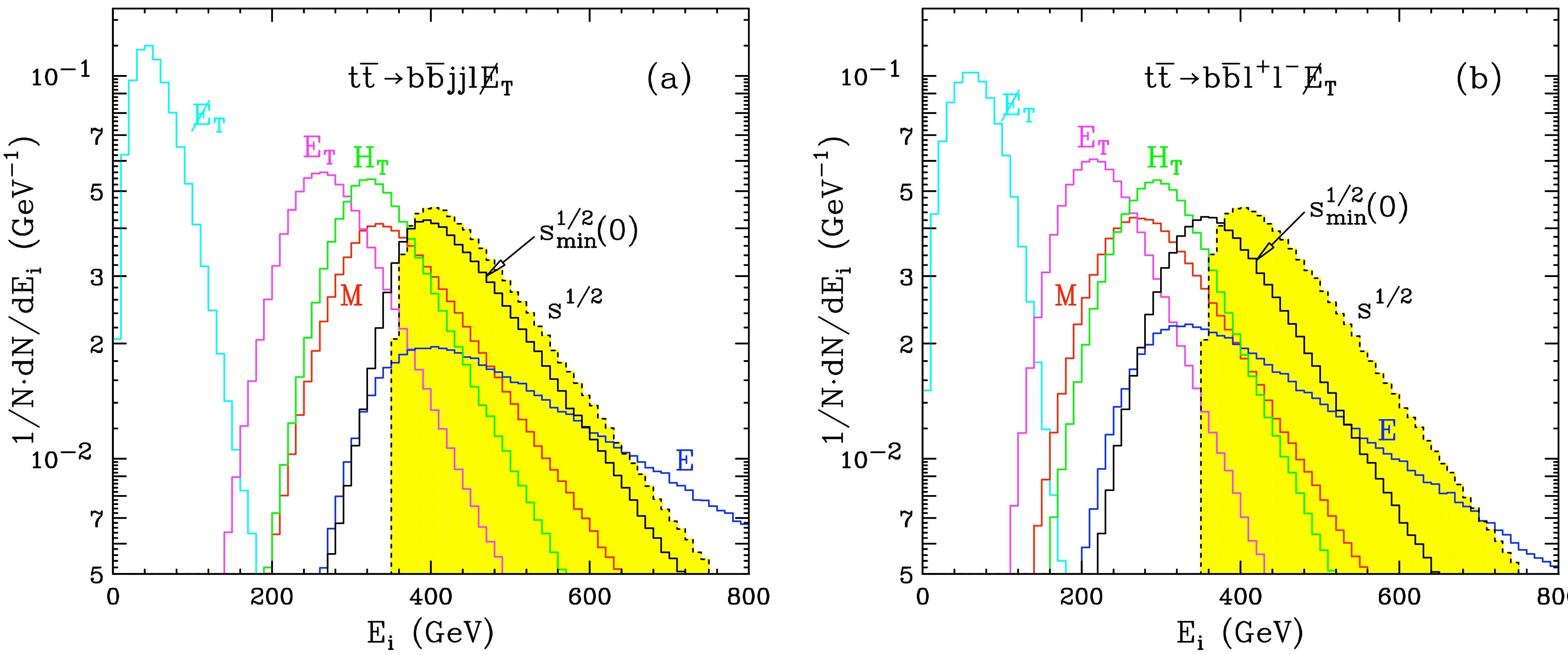
or (Konar, Kong & Matchev, 0812.1042)

$$\hat{s}_{\min}^{1/2}(M_{\mathrm{inv}}) = \sqrt{M^2 + \not{E}_T^2} + \sqrt{M_{\mathrm{inv}}^2 + \not{E}_T^2}$$

Inclusive observables: MC results

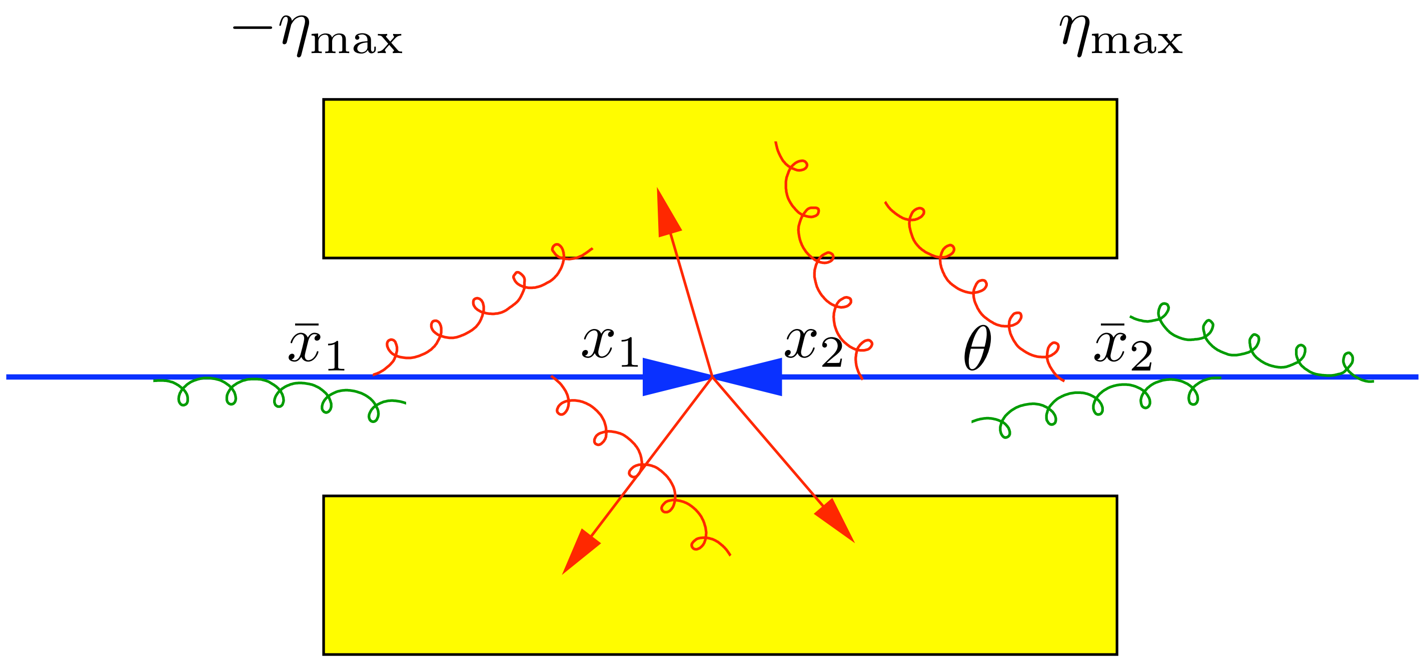
$$\hat{s}^{1/2}_{\min}(M_{\rm inv}) = \sqrt{M^2 + \not{E}_T^2} + \sqrt{M_{\rm inv}^2 + \not{E}_T^2}$$

$$M = \sqrt{E^2 - P_z^2 - \not{E}_T^2} \qquad H_T = E_T + \not{E}_T$$



Konar, Kong, Matchev, 0812.1042

ISR effects on inclusive observables



$$\frac{d\sigma}{dM^2} = \int \frac{d\bar{x}_1}{\bar{x}_1}\frac{d\bar{x}_2}{\bar{x}_2} dx_1\, dx_2 f(\bar{x}_1, Q_c) f(\bar{x}_2, Q_c) K\left(\frac{x_1}{\bar{x}_1}; Q_c, Q\right) K\left(\frac{x_2}{\bar{x}_2}; Q_c, Q\right) \hat{\sigma}(x_1 x_2 S)\delta(M^2 - \bar{x}_1\bar{x}_2 S)$$

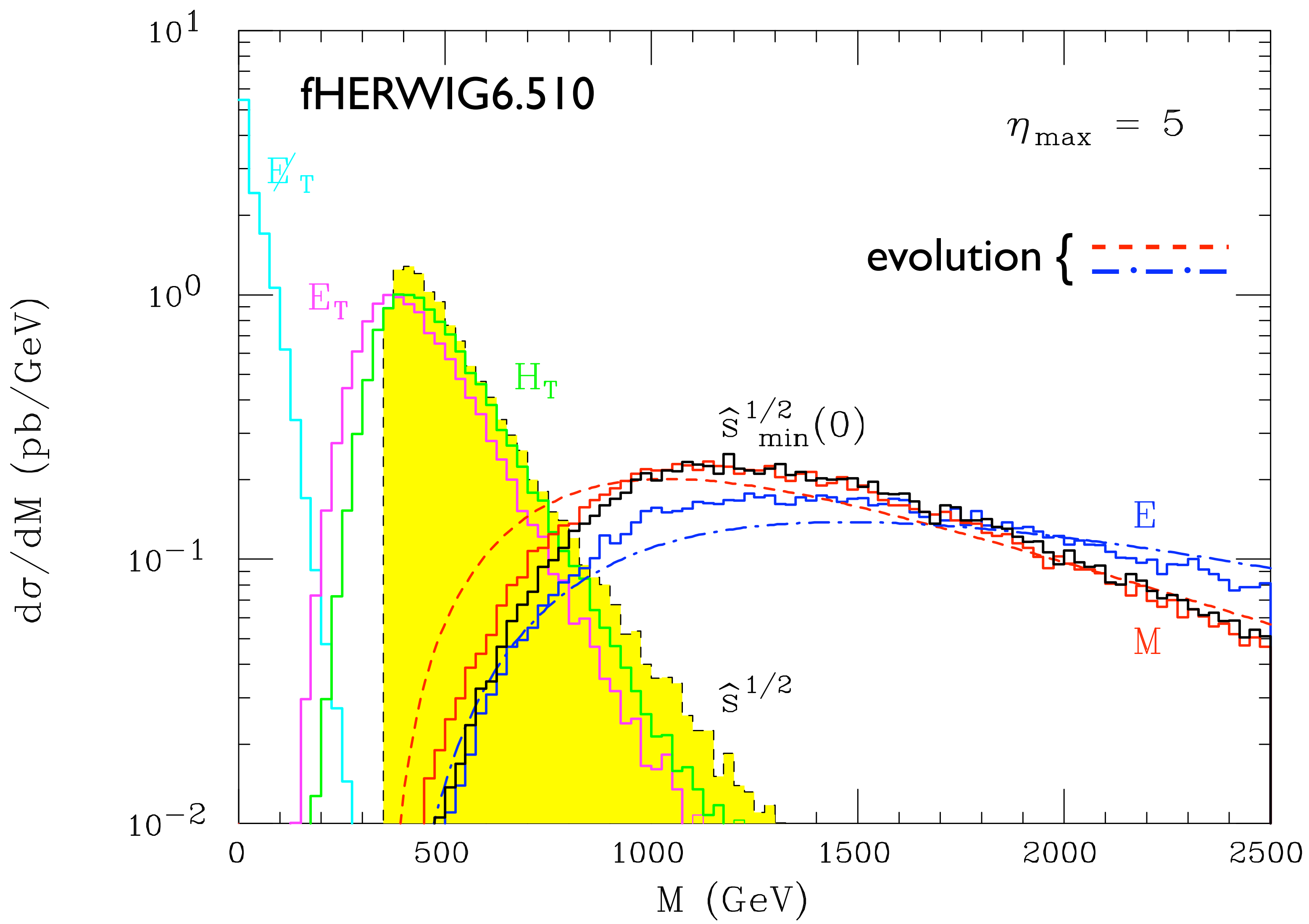
- ISR at $\theta > \theta_c \sim \exp(-\eta_{\max})$ enters detector
- Hard scale $Q^2 \sim \hat{s} = x_1 x_2 S$ but $M^2 = \bar{x}_1\bar{x}_2 S$
- PDFs sampled at $Q_c \sim \theta_c Q$

A Papaefstathiou & BW, 0903.2013

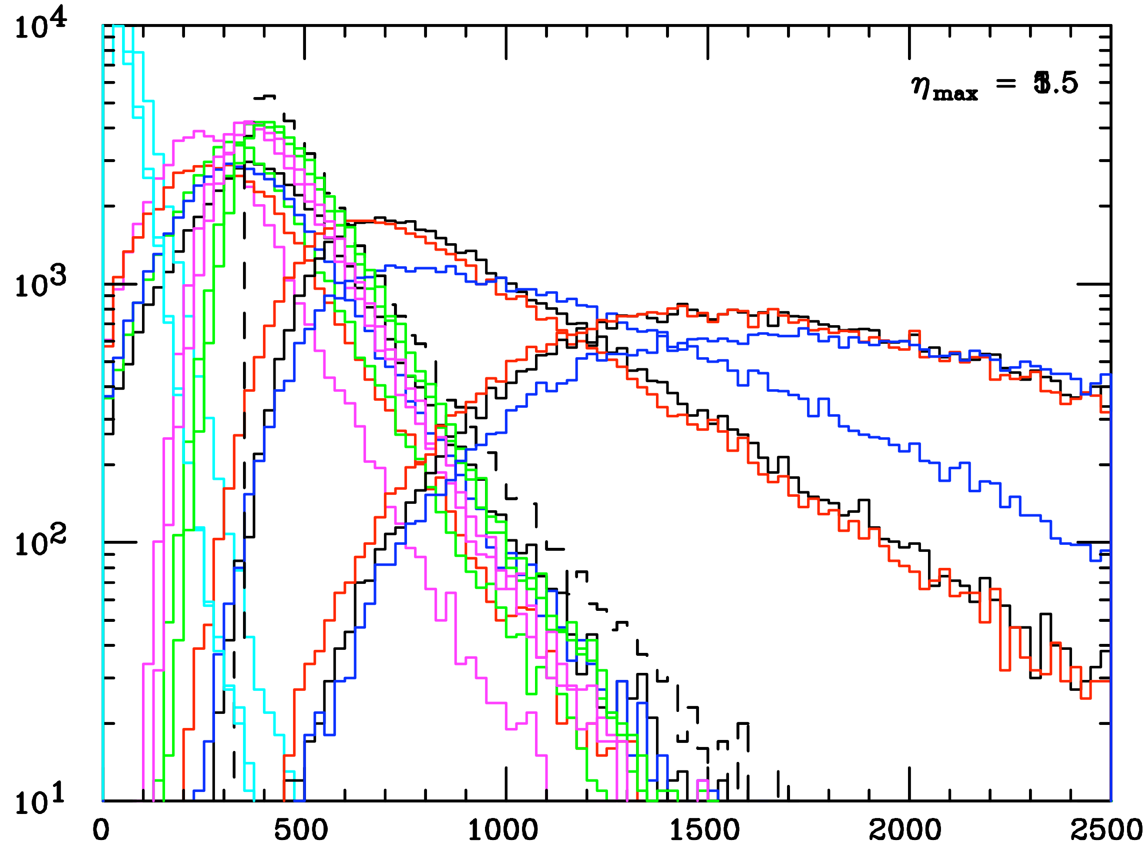
ISR Effects: MC Results

$$\hat{s}^{1/2}_{\min}(M_{\rm inv}) = \sqrt{M^2 + \not{E}_T^2} + \sqrt{M^2_{\rm inv} + \not{E}_T^2}$$

$$M = \sqrt{E^2 - P_z^2 - \not{E}_T^2} \qquad H_T = E_T + \not{E}_T$$



Dependence on $\eta_{\max}$



- E, M, $\hat{s}_{min}$ strongly dependent; $\not{E}_T$, E_T, H_T not

Conclusions on Masses

- M_{T2} will be an important observable
  - New ideas on reducing ISR jet contamination
- Decay chains: solving vs fitting
  - Which is more robust w.r.t. ISR & background?
- Global inclusive observables
  - Only transverse observables are robust
  - Scale information from others?

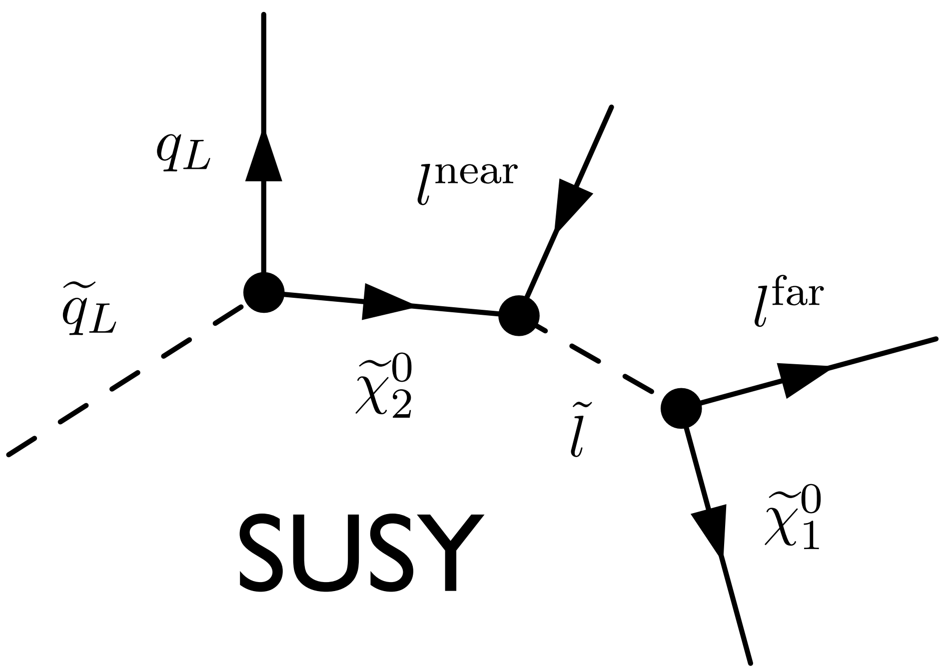
Spin Determination with ...

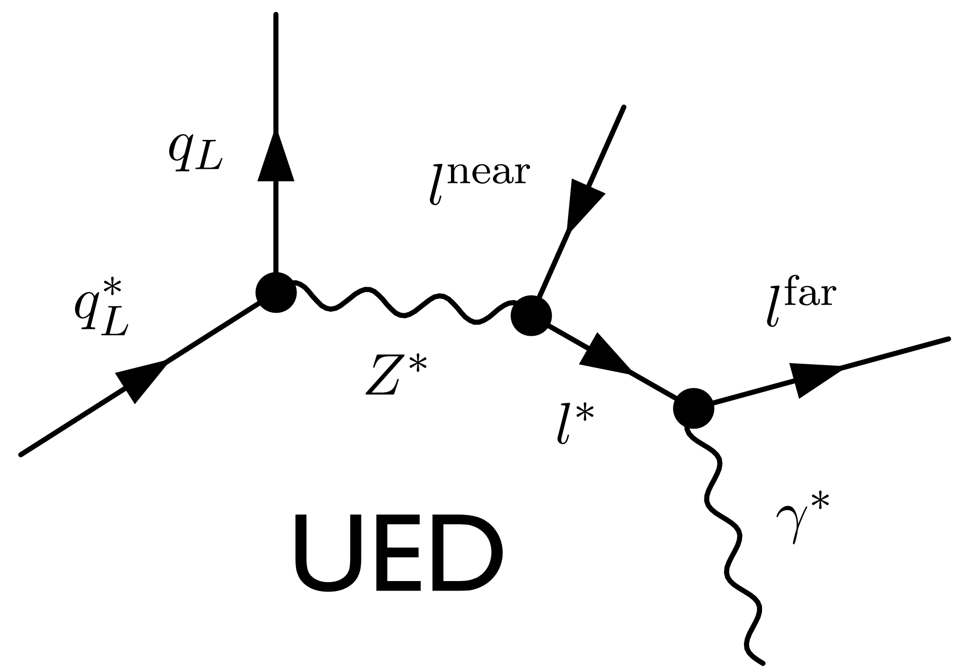
- Sequential decay chains
- Dileptons
- Three-body decays
- Cross sections

See also: review by Wang & Yavin, 0802.2726

Decay chains

"Classic" decay chain again

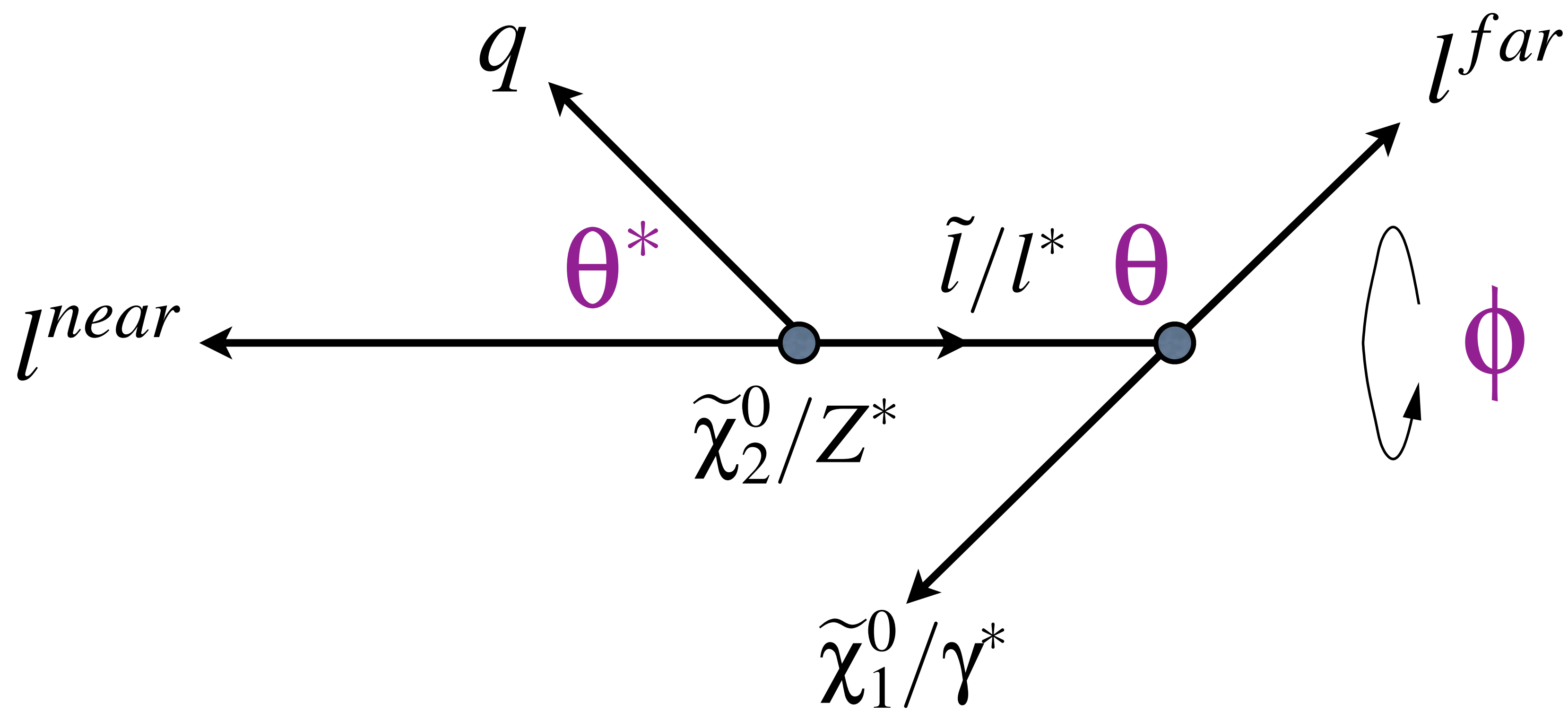




- Two distinct helicity structures, with different spin correlations:
  - Process 1: $\{q, l^{\text{near}}, l^{\text{far}}\} = \{q_L, l_L^-, l_L^+\}$ or $\{\bar{q}_L, l_L^+, l_L^-\}$ or $\{q_L, l_R^+, l_R^-\}$ or $\{\bar{q}_L, l_R^-, l_R^+\}$;
  - Process 2: $\{q, l^{\text{near}}, l^{\text{far}}\} = \{q_L, l_L^+, l_L^-\}$ or $\{\bar{q}_L, l_L^-, l_L^+\}$ or $\{q_L, l_R^-, l_R^+\}$ or $\{\bar{q}_L, l_R^+, l_R^-\}$.

Smillie, Webber, hep-ph/0507170
Datta, Kong, Matchev hep-ph/0509246

Angular variables



- θ^* defined in $\tilde{\chi}_2^0/Z^*$ rest frame
- θ, ϕ defined in $\tilde{l}/l^*$ rest frame

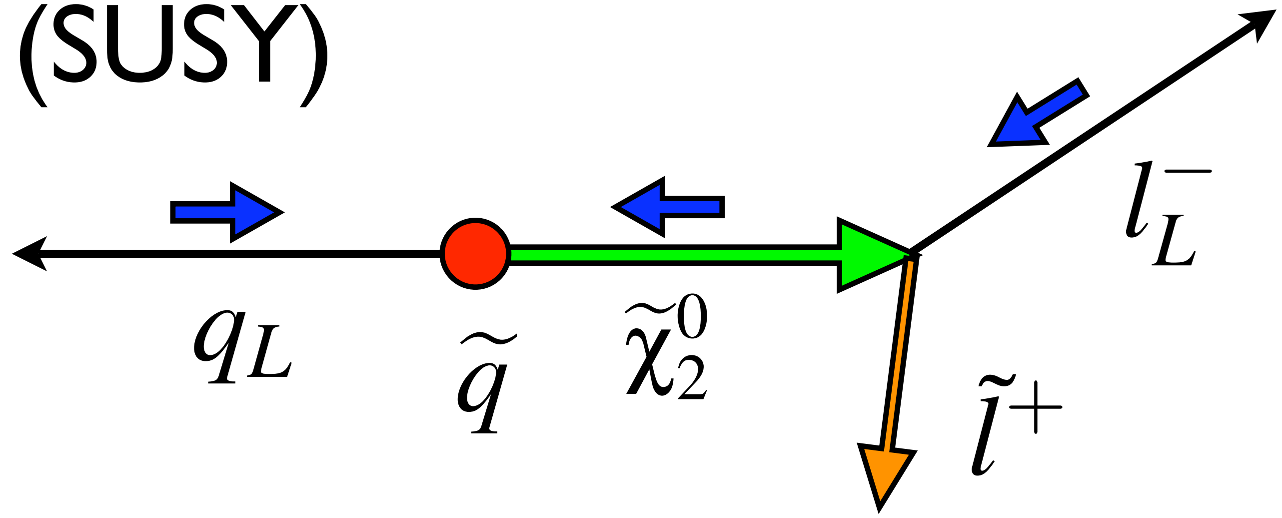
Invariant masses

- ql^{near}: $m_{ql}/(m_{ql})_{max} = \sin(\theta^*/2)$
- $l^{near}l^{far}$: $m_{ll}/(m_{ll})_{max} = \sin(\theta/2)$
- ql^{far}: $$m_{ql}/(m_{ql})_{max} = \frac{1}{2}\Big[(1-y)(1-\cos\theta^*\cos\theta)+ \\ +(1-y)(\cos\theta^*-\cos\theta)-2\sqrt{y}\sin\theta^*\sin\theta\cos\phi\Big]^{\frac{1}{2}}$$

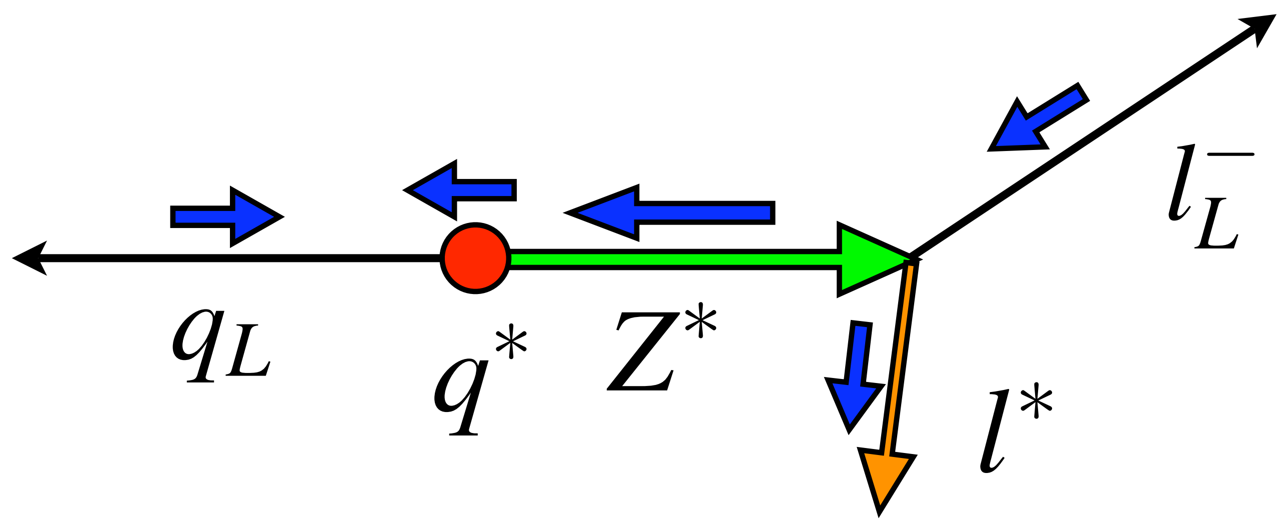
where $x = m_{Z^*}^2/m_{q^*}^2,\ y = m_{l^*}^2/m_{Z^*}^2,\ z = m_{\gamma^*}^2/m_{l^*}^2$

Helicity dependence

- Process I (SUSY)



- Process I (UED, transverse Z*: $P_T/P_L = 2x$)



➡ Both prefer high $(ql^-)^{near}$ invariant mass

UED and SUSY mass spectra

- UED models tend to have quasi-degenerate spectra

γ^*	Z^*	q_L^*	l_R^*	l_L^*
501	536	598	505	515

Table 1: UED masses in GeV, for $R^{-1} = 500\text{GeV}$, $\Lambda R = 20$, $m_h = 120\text{GeV}$, $\overline{m}_h^2 = 0$ and vanishing boundary terms at cut-off scale Λ.

($M_n \sim n/R$
broken by boundary terms and loops, with low cutoff)

- SUSY spectra typically more hierarchical

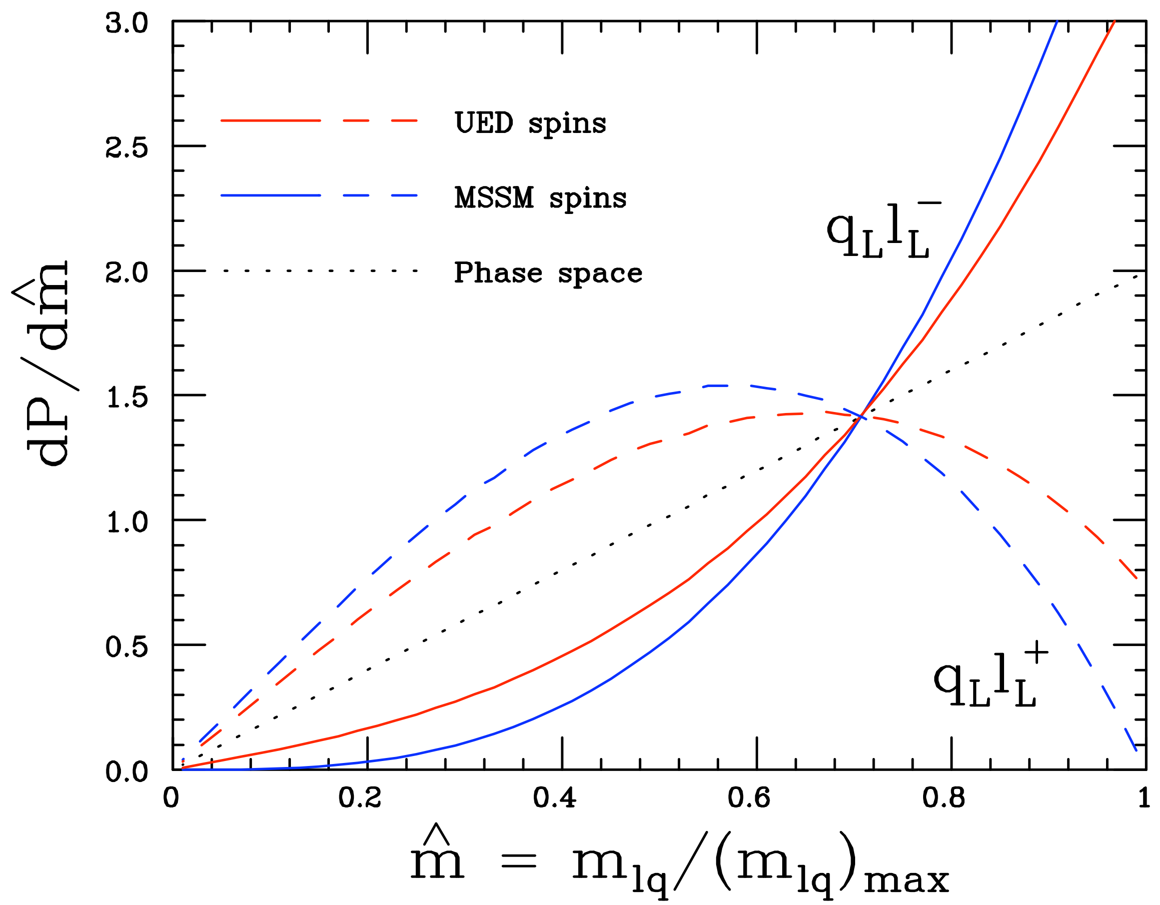
$\widetilde{\chi}_1^0$	$\widetilde{\chi}_2^0$	$\widetilde{u}_L$	$\widetilde{e}_R$	$\widetilde{e}_L$
96	177	537	143	202

Table 2: SUSY masses in GeV, for SPS point 1a.

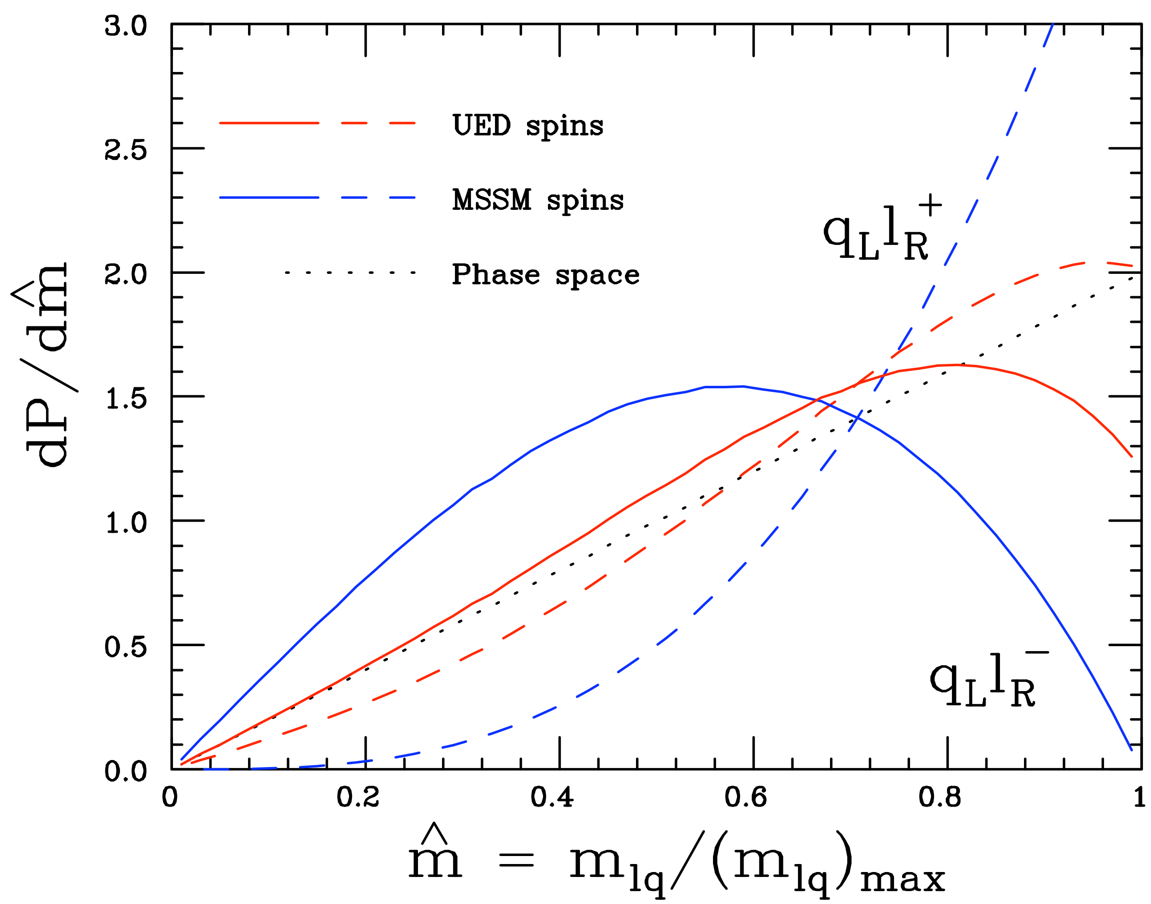
(high-scale universality)

ql^{near} mass distribution

UED masses

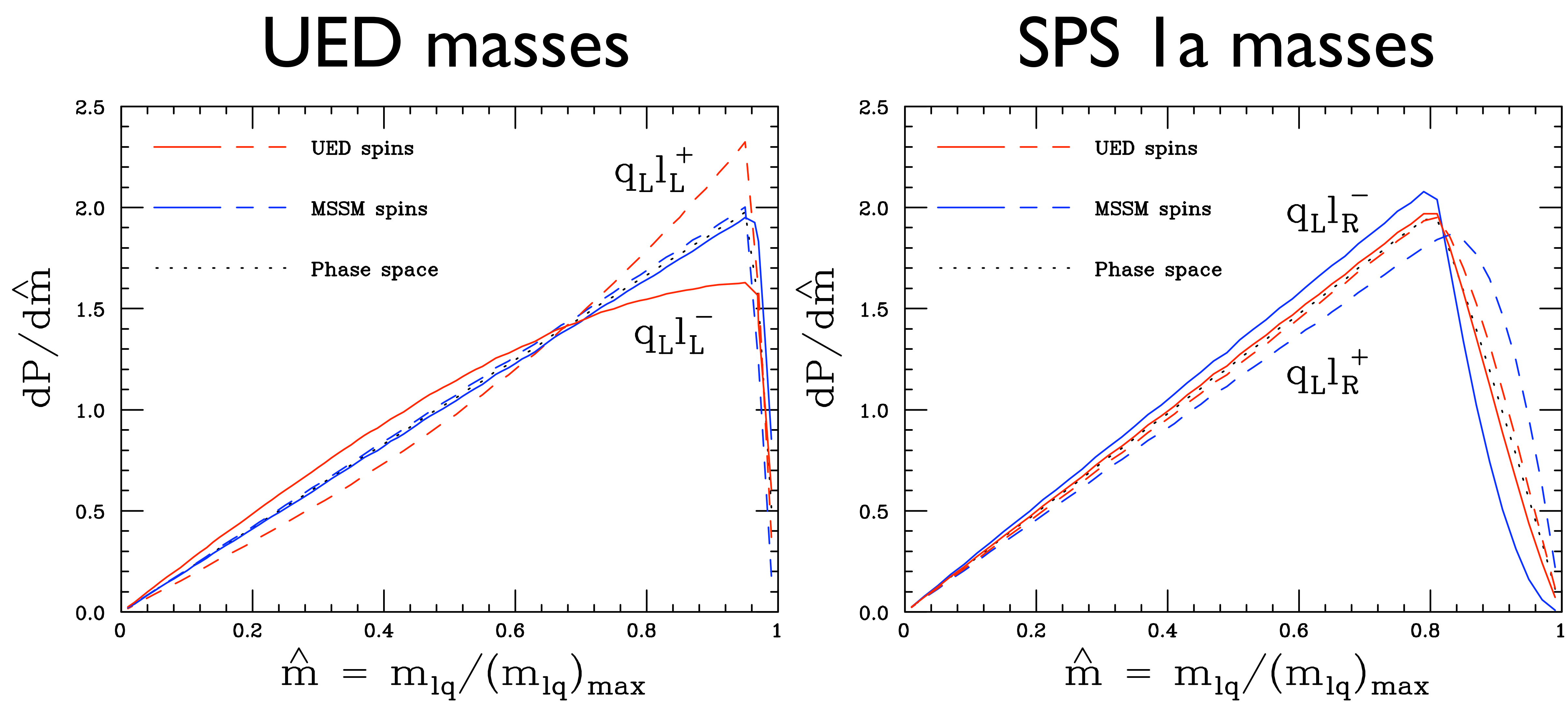


SPS 1a masses



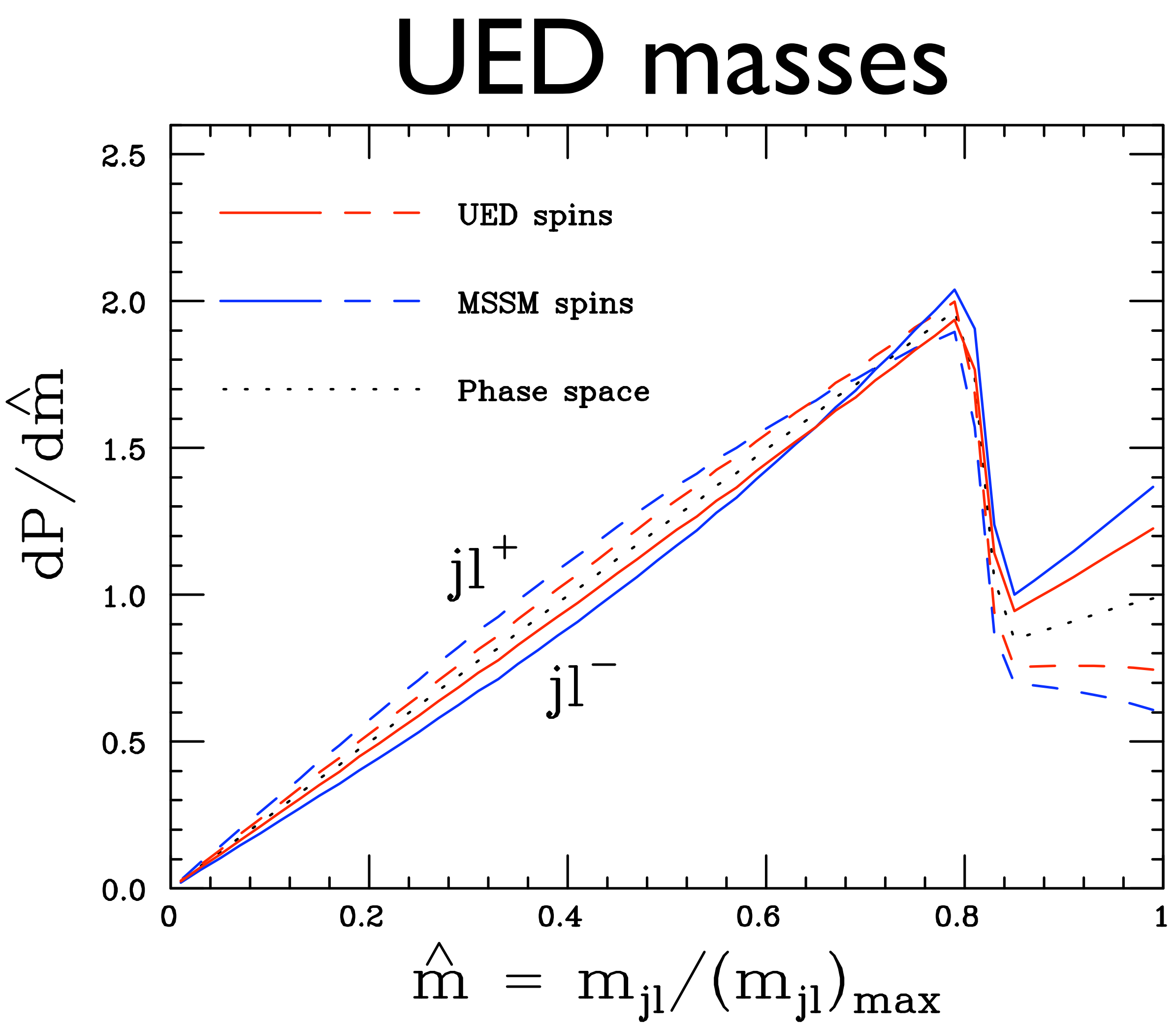
➡ UED and SUSY not distinguishable for UED masses

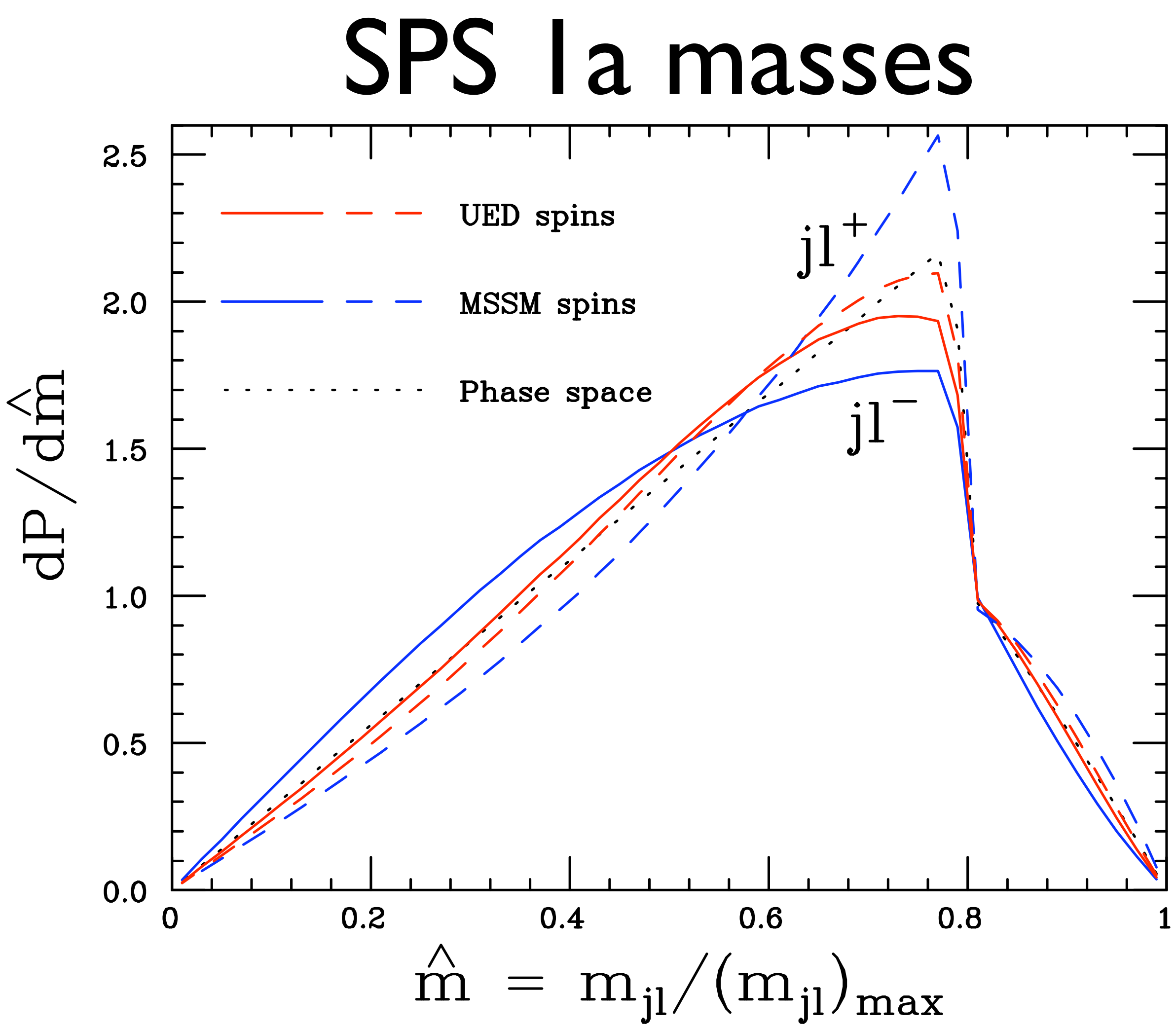
ql^{far} mass distribution



Correlation weak but slightly enhances UED-SUSY difference

Jet + lepton mass distribution





- Not resolvable for UED masses, maybe for SUSY masses
- Charge asymmetry due to quark vs antiquark excess

Production cross sections (pb)

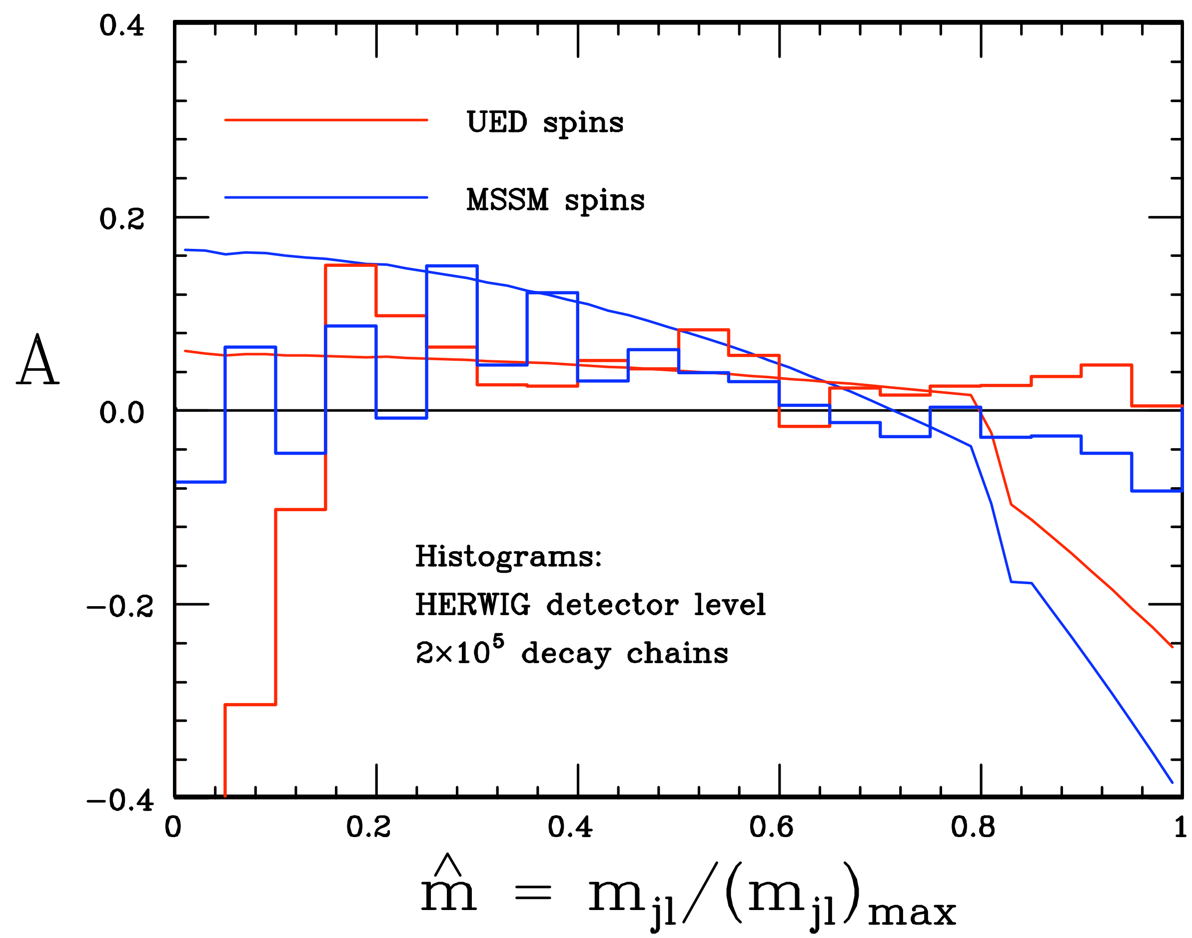
Masses	Model	$\sigma_{\rm all}$	σ_{q^*}	$\sigma_{\bar{q}^*}$	f_q
UED	UED	253	163	84	0.66
UED	SUSY	28	18	9	0.65
SPS 1a	UED	433	224	80	0.74
SPS 1a	SUSY	55	26	11	0.70

- $\sigma_{\rm UED} \gg \sigma_{\rm SUSY}$ for same masses (100 pb = 1/sec)
  - $q^*/\bar{q}^* \sim 2 \;\Rightarrow\;$ charge asymmetry

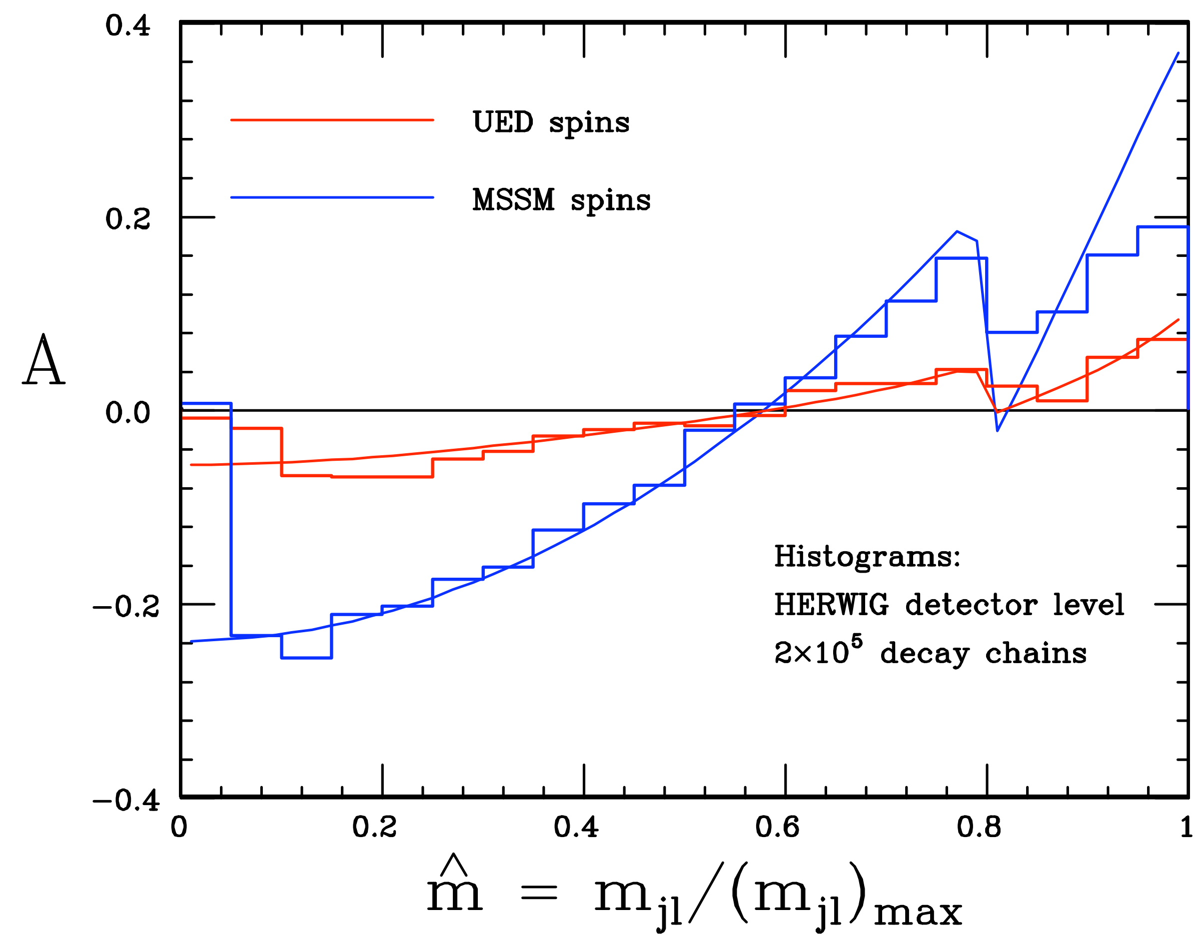
Charge asymmetry

$$A = \frac{(jl^+) - (jl^-)}{(jl^+) + (jl^-)}$$

UED masses



SPS 1a masses

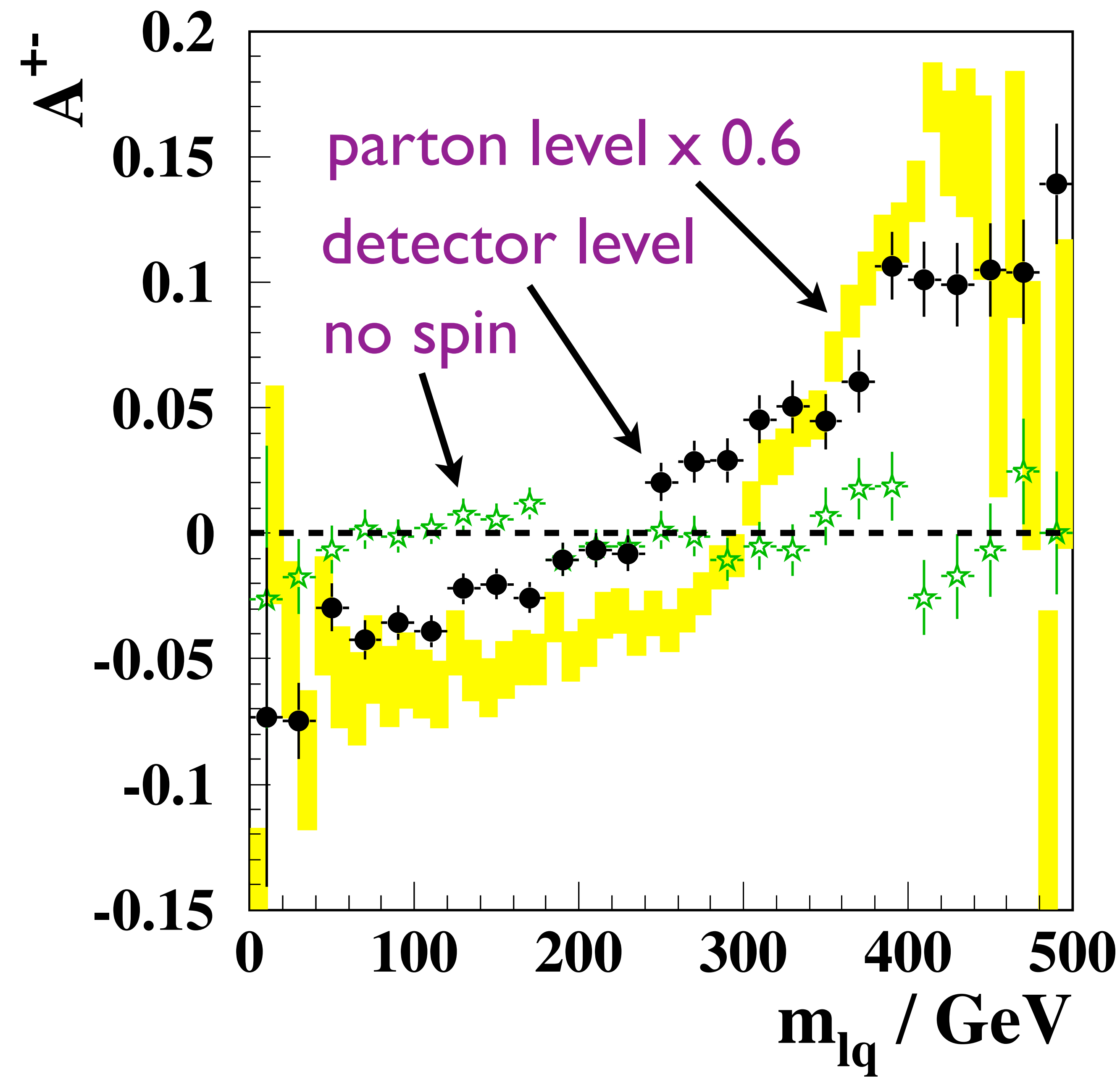


- Similar form, different magnitude
- Not detectable for UED masses

Charge asymmetry at detector level

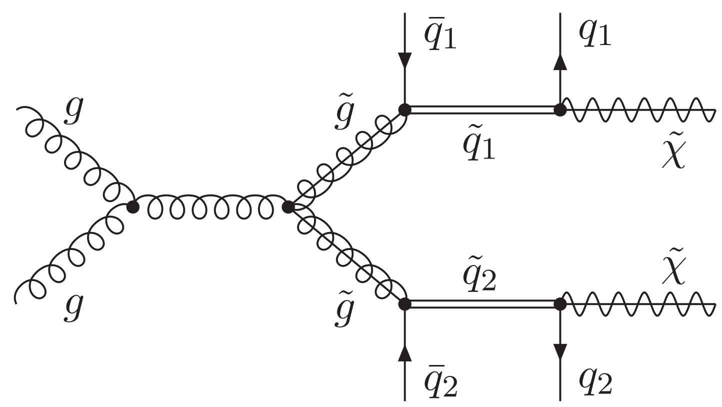
A Barr, hep-ph/0405052

- Same decay chain:
  $\tilde{q}_L \to \tilde{\chi}_2^0 q_L \to \tilde{l}_R^{\pm} l^{\mp} q_L$
- Different MSSM point (now excluded)
- Compared with no spin (i.e. phase space) only
- More careful study of back-ground and detector effects
- Points are for 500 fb^{-1}
- Used HERWIG

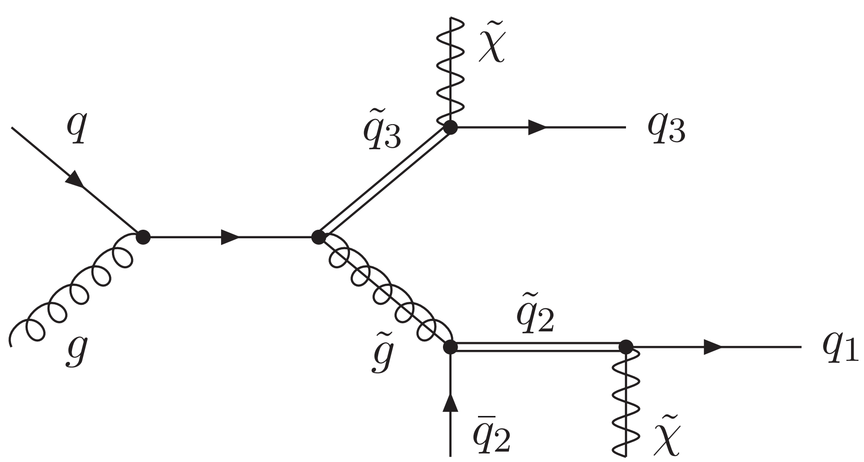


See also: Goto, Kawagoe, Nojiri, hep-ph/0406317

Gluino spin correlations

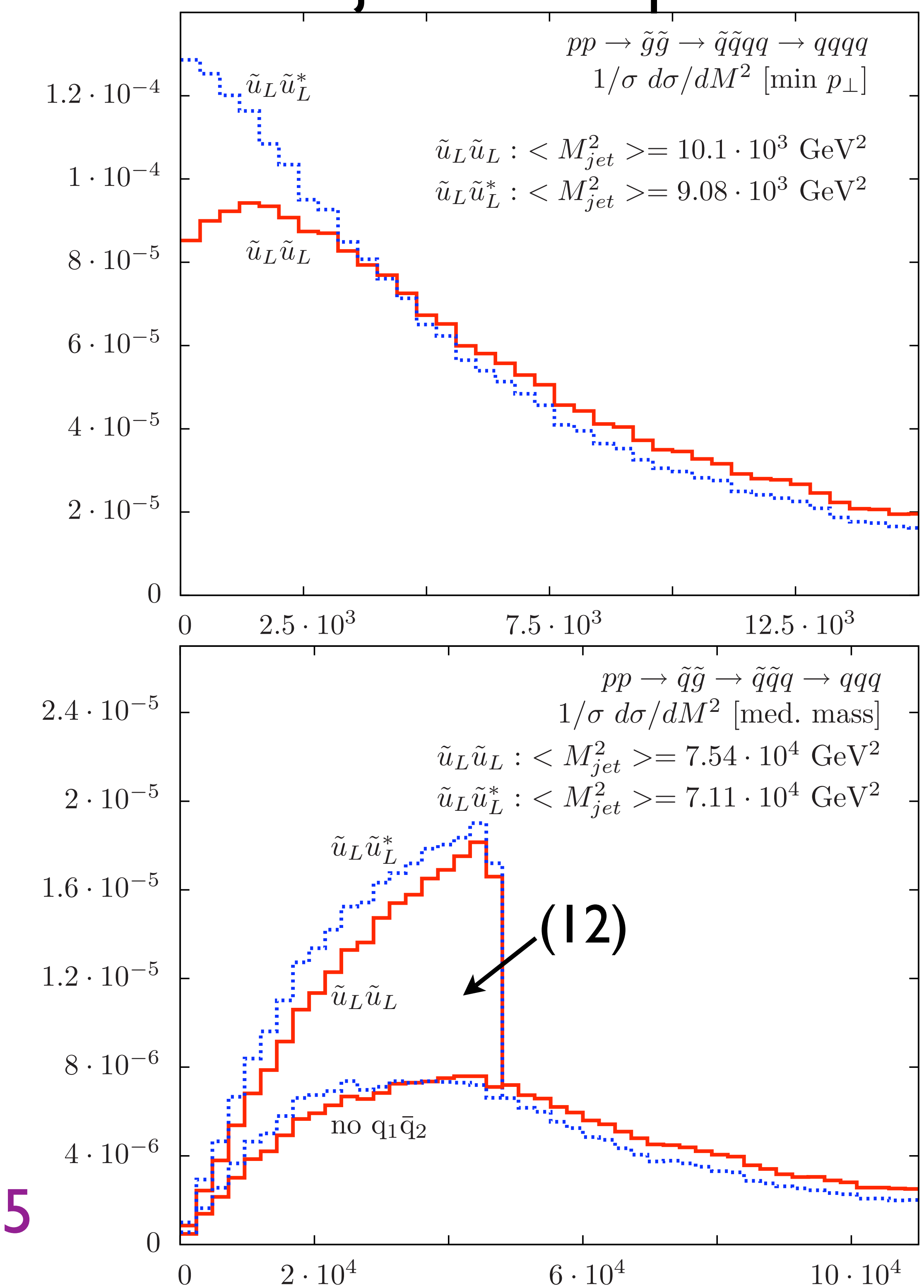


- Lowest mass dijet ~ (12)



- Medium mass dijet ~ (23)

Dijet mass-squared

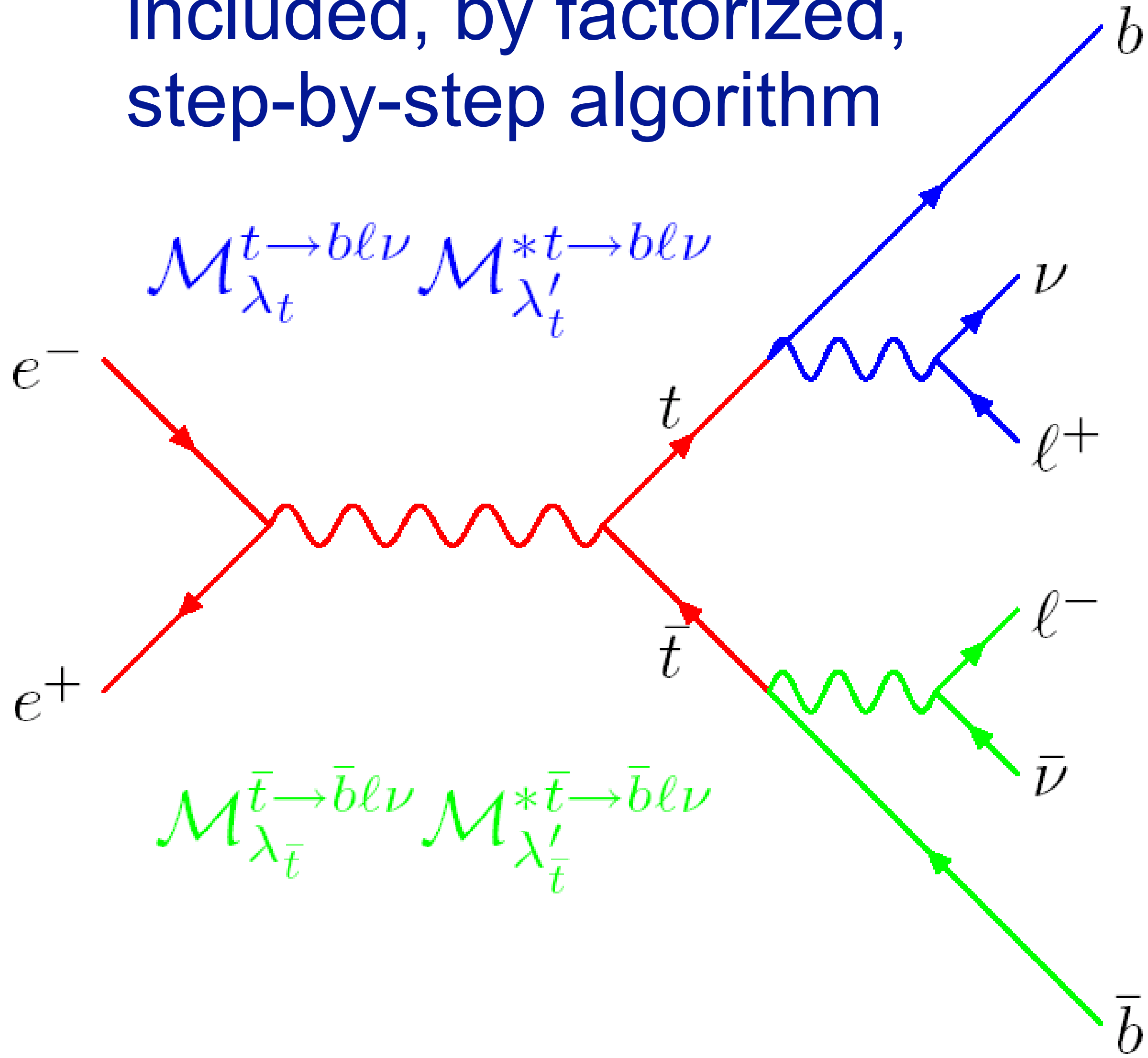


Krämer, Popenda, Spira, Zerwas, 0902.3795

Production/Decay Spin Correlations in Herwig

- Example: top quark pairs in e+e- annihilation:

Full spin correlations included, by factorized, step-by-step algorithm



$$\rho_{\mathrm{prod}}^{\lambda_c\lambda'_c\lambda_d\lambda'_d} = \mathcal{M}_{ab\to cd}^{\lambda_c\lambda_d}\mathcal{M}_{ab\to cd}^{*\lambda'_c\lambda'_d},$$

$$D_c^{\lambda_c\lambda'_c} = \mathcal{M}_{c\ \mathrm{decay}}^{\lambda_c}\mathcal{M}_{c\ \mathrm{decay}}^{*\lambda'_c},$$

$$|\mathcal{M}|^2 = \rho_{\mathrm{prod}}^{\lambda_c\lambda'_c\lambda_d\lambda'_d} D_c^{\lambda_c\lambda'_c} D_d^{\lambda_d\lambda'_d}$$

$$= \rho_{\mathrm{prod}}^{\lambda_c\lambda_c\lambda_d\lambda_d}\left(\frac{\rho_{\mathrm{prod}}^{\lambda_c\lambda'_c\lambda_d\lambda_d} D_c^{\lambda_c\lambda'_c}}{\rho_{\mathrm{prod}}^{\lambda_c\lambda_c\lambda_d\lambda_d}}\right)$$

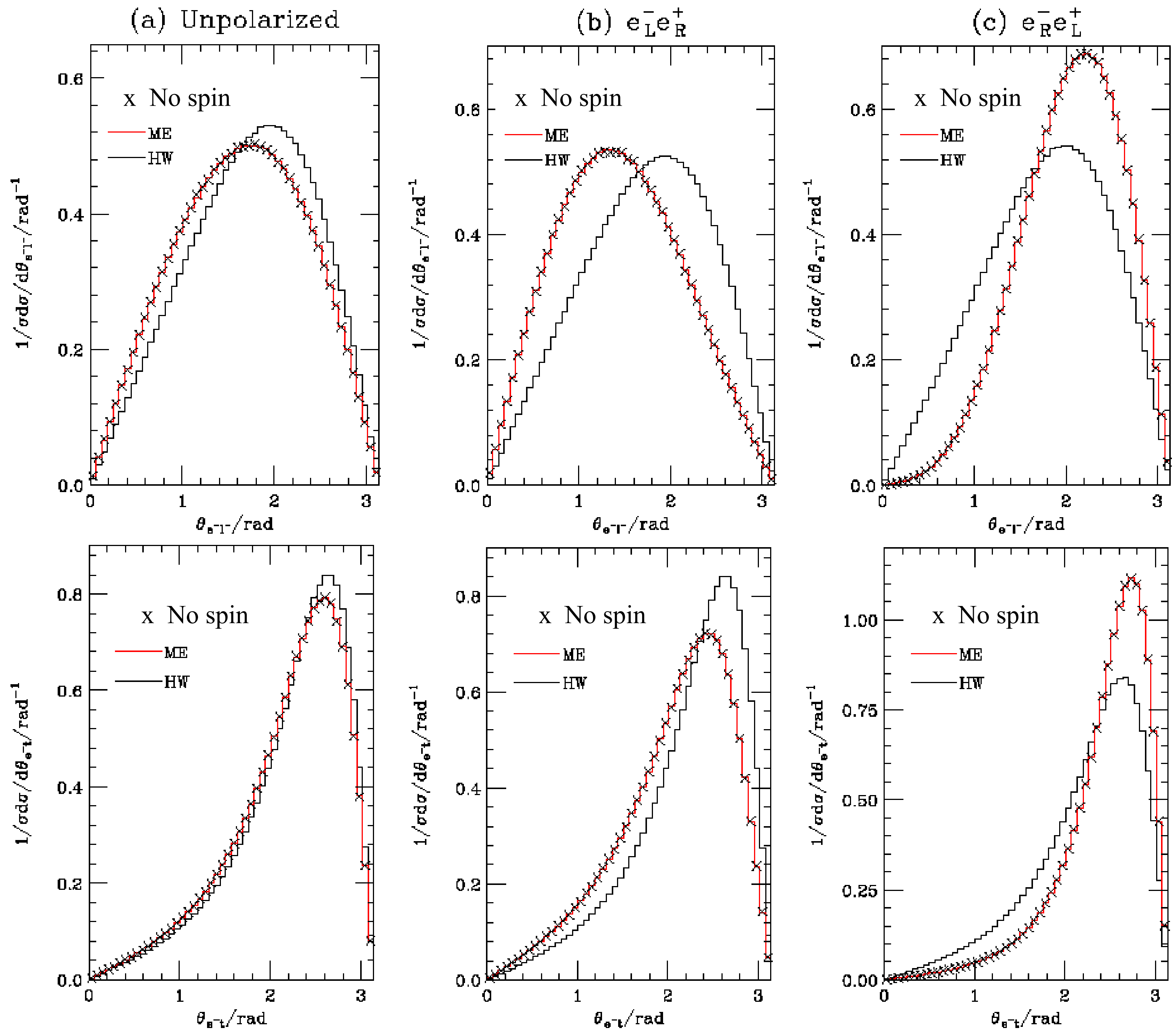
$$\times\left(\frac{\rho_{\mathrm{prod}}^{\lambda_c\lambda'_c\lambda_d\lambda'_d} D_c^{\lambda_c\lambda'_c} D_d^{\lambda_d\lambda'_d}}{\rho_{\mathrm{prod}}^{\lambda_c\lambda'_c\lambda_d\lambda_d} D_c^{\lambda_c\lambda'_c}}\right)$$

Richardson, hep-ph/0110108

Top spin correlations in Herwig

Lepton-beam correlation

Top-beam correlation

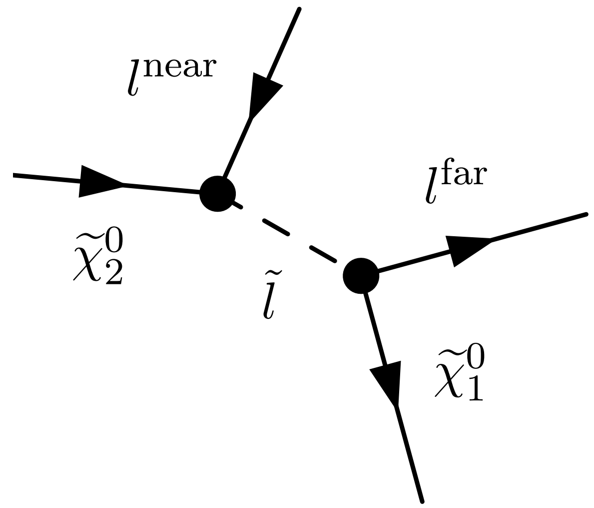


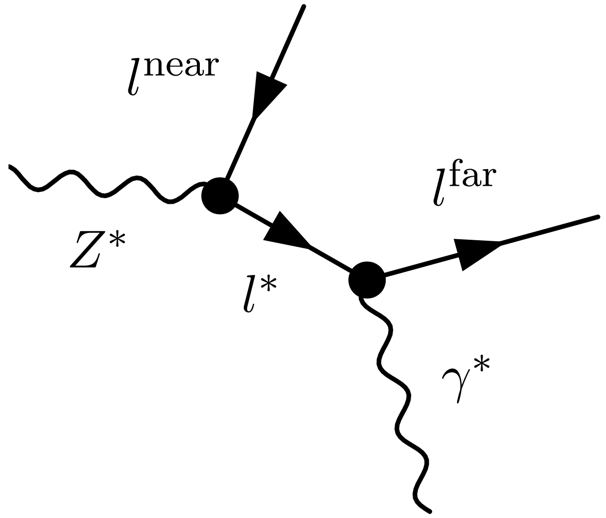
- SM, SUSY & UED in Herwig++

Hw++ manual: Bähr et al., 0803.0883

Dileptons

Dileptons in "classic" chain



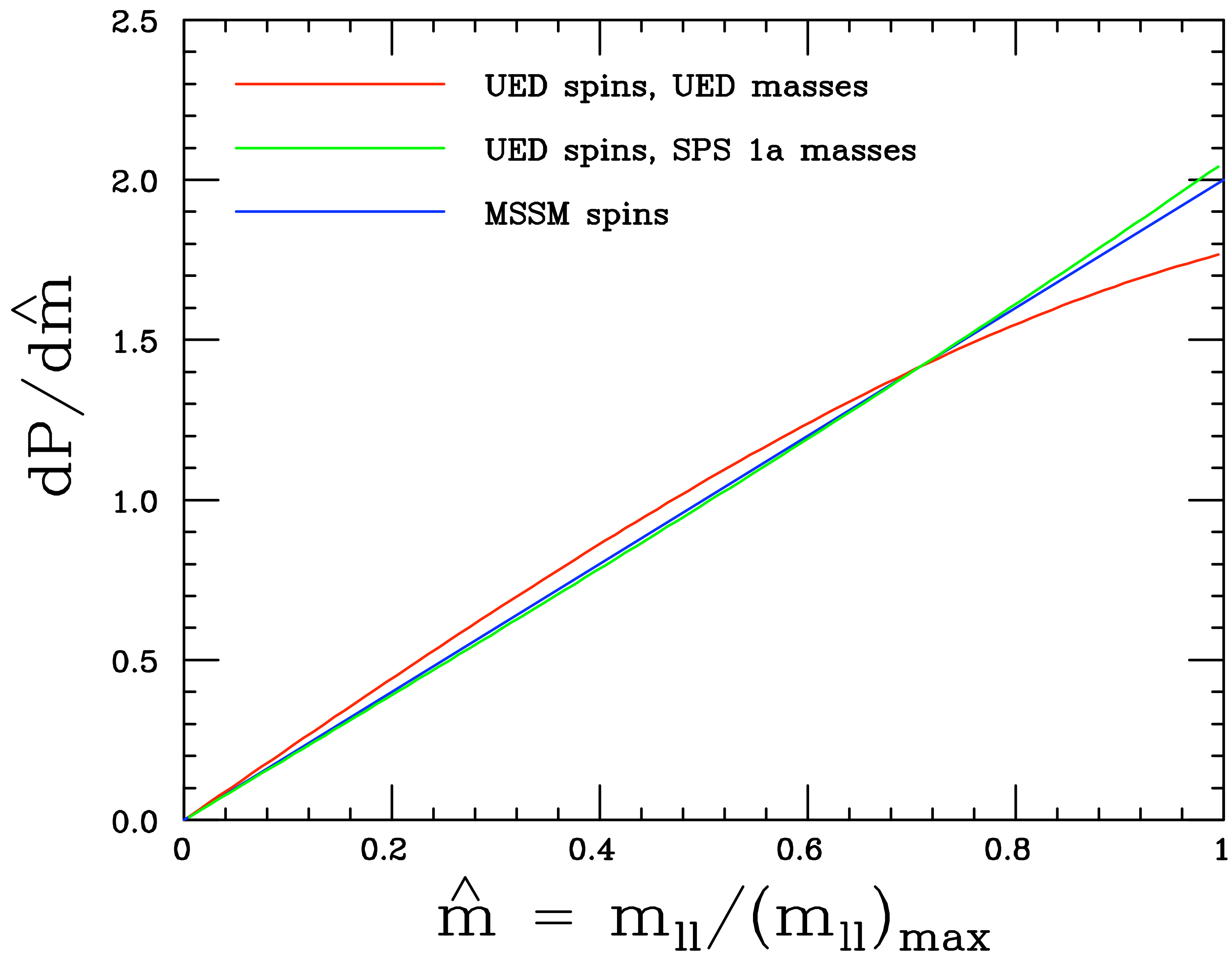


$$\frac{dP^{UED}}{d\widehat{m}_{ll}} = \frac{4\widehat{m}_{ll}}{(2+y)(1+2z)}\left[y+4z+(2-y)(1-2z)\widehat{m}_{ll}^2\right]$$

- $y = m_{l^*}^2/m_{Z^*}^2$ and $z = m_{\gamma^*}^2/m_{l^*}^2$
- UED: $y = 0.92 \quad z = 0.95$
- SPS 1a: $y = 0.65 \quad z = 0.45$

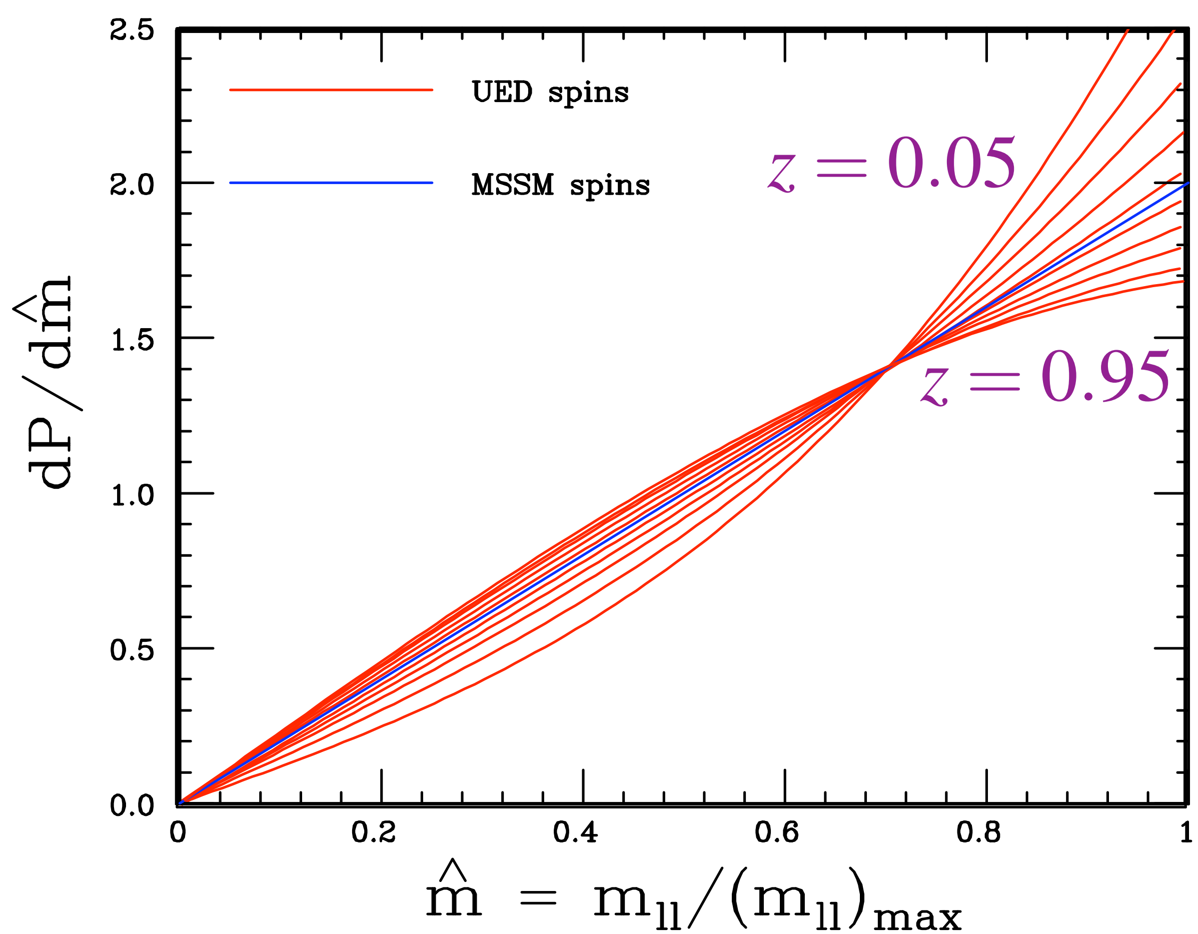
➡ Sensitivity greatest at small y and z

Dilepton mass distribution



➡ No sensitivity for these masses!

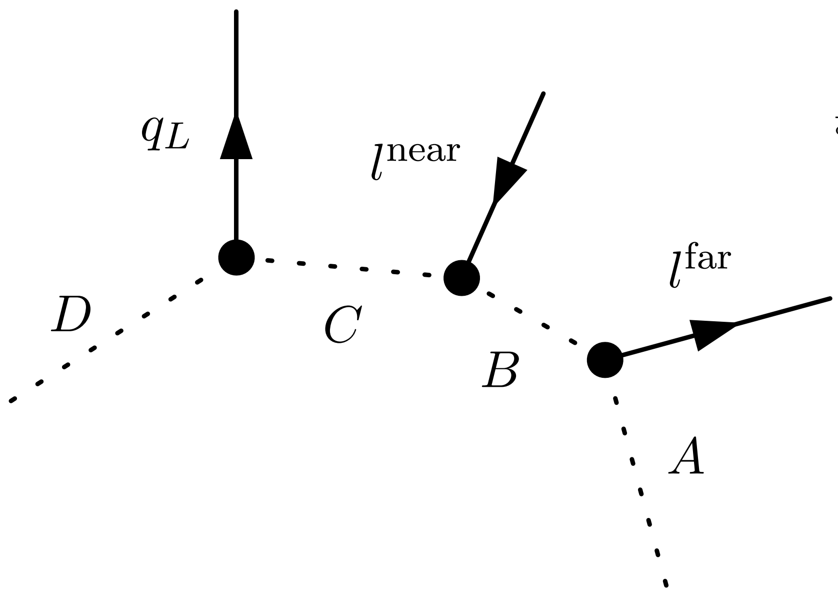
Dilepton mass distribution (2)



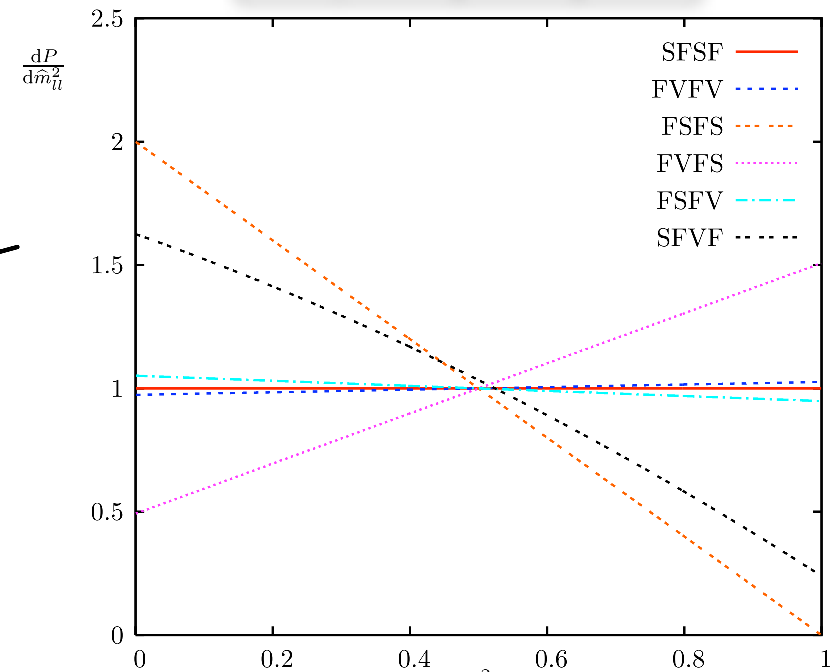
$$y = m_{l^*}^2/m_{Z^*}^2 = 0.65\,,\ \ z = m_{\gamma^*}^2/m_{l^*}^2 = 0.95 - 0.05$$

➡ Independent of masses and spins at $\widehat{m} = 1/\sqrt{2}$ $(\theta = \pi/2)$

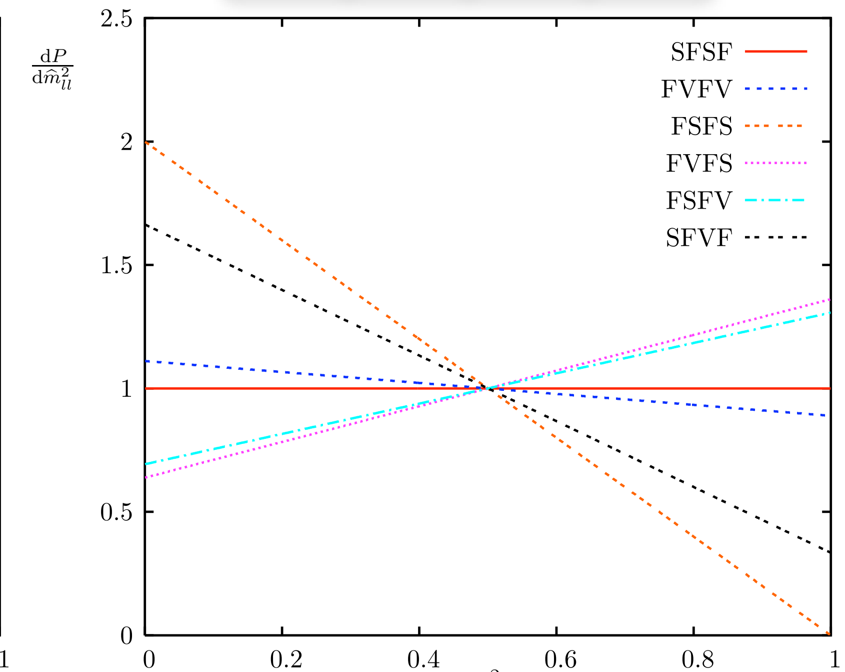
All possible spin assignments



A	B	C	D
$\tilde{\chi}_1^0$	$\tilde{e}_R$	$\tilde{\chi}_2^0$	$\tilde{u}_L$
96	143	177	537



A	B	C	D
γ^*	l_L^*	Z^*	q_L^*
800	824	851	956



Dilepton invariant mass-squared

D	C	B	A
Scalar	Fermion	Scalar	Fermion
Fermion	Vector	Fermion	Vector
Fermion	Scalar	Fermion	Scalar
Fermion	Vector	Fermion	Scalar
Fermion	Scalar	Fermion	Vector
Scalar	Fermion	Vector	Fermion

SUSY
UED } not distinguishable

... but some others are.

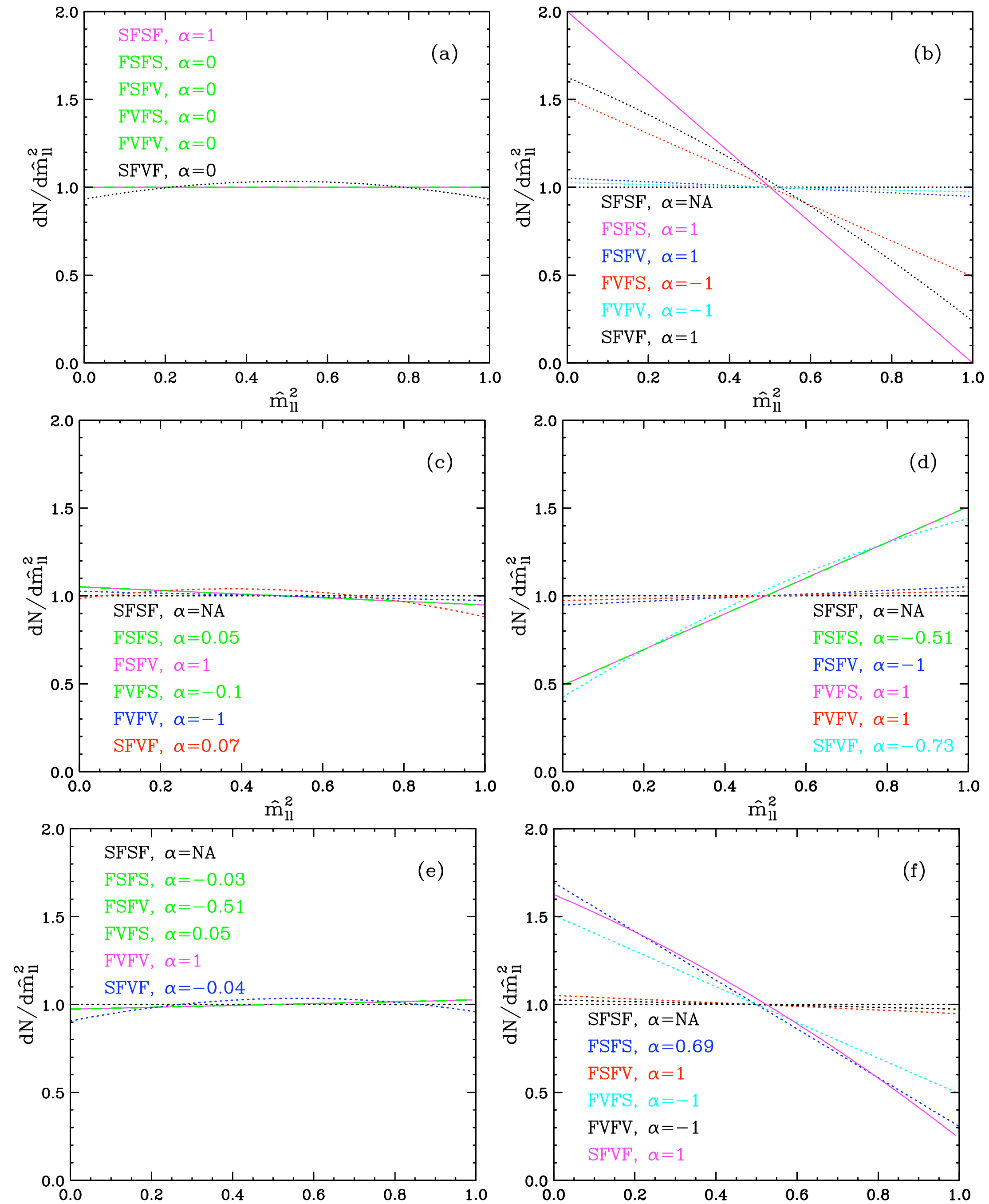
Athanasiou, Lester, Smillie, Webber, hep-ph/0605286

All possible assignments (2)

Allowing arbitrary mixtures of L and R couplings:

Processes P_{11}		Processes P_{12}	
$\{q_L, \ell_L^-, \ell_L^+\}$ $f\|c_L\|^2\|b_L\|^2\|a_L\|^2$	$\{\bar{q}_L, \ell_L^+, \ell_L^-\}$ $\bar{f}\|c_L\|^2\|b_L\|^2\|a_L\|^2$	$\{q_L, \ell_L^-, \ell_R^+\}$ $f\|c_L\|^2\|b_L\|^2\|a_R\|^2$	$\{\bar{q}_L, \ell_L^+, \ell_R^-\}$ $\bar{f}\|c_L\|^2\|b_L\|^2\|a_R\|^2$
$\{\bar{q}_L, \ell_R^-, \ell_R^+\}$ $\bar{f}\|c_L\|^2\|b_R\|^2\|a_R\|^2$	$\{q_L, \ell_R^+, \ell_R^-\}$ $f\|c_L\|^2\|b_R\|^2\|a_R\|^2$	$\{\bar{q}_L, \ell_R^-, \ell_L^+\}$ $\bar{f}\|c_L\|^2\|b_R\|^2\|a_L\|^2$	$\{q_L, \ell_R^+, \ell_L^-\}$ $f\|c_L\|^2\|b_R\|^2\|a_L\|^2$
$\{q_R, \ell_R^-, \ell_R^+\}$ $f\|c_R\|^2\|b_R\|^2\|a_R\|^2$	$\{\bar{q}_R, \ell_R^+, \ell_R^-\}$ $\bar{f}\|c_R\|^2\|b_R\|^2\|a_R\|^2$	$\{q_R, \ell_R^-, \ell_L^+\}$ $f\|c_R\|^2\|b_R\|^2\|a_L\|^2$	$\{\bar{q}_R, \ell_R^+, \ell_L^-\}$ $\bar{f}\|c_R\|^2\|b_R\|^2\|a_L\|^2$
$\{\bar{q}_R, \ell_L^-, \ell_L^+\}$ $\bar{f}\|c_R\|^2\|b_L\|^2\|a_L\|^2$	$\{q_R, \ell_L^+, \ell_L^-\}$ $f\|c_R\|^2\|b_L\|^2\|a_L\|^2$	$\{\bar{q}_R, \ell_L^-, \ell_R^+\}$ $\bar{f}\|c_R\|^2\|b_L\|^2\|a_R\|^2$	$\{q_R, \ell_L^+, \ell_R^-\}$ $f\|c_R\|^2\|b_L\|^2\|a_R\|^2$
$\{\bar{q}_L, \ell_L^-, \ell_L^+\}$ $\bar{f}\|c_L\|^2\|b_L\|^2\|a_L\|^2$	$\{q_L, \ell_L^+, \ell_L^-\}$ $f\|c_L\|^2\|b_L\|^2\|a_L\|^2$	$\{\bar{q}_L, \ell_L^-, \ell_R^+\}$ $\bar{f}\|c_L\|^2\|b_L\|^2\|a_R\|^2$	$\{q_L, \ell_L^+, \ell_R^-\}$ $f\|c_L\|^2\|b_L\|^2\|a_R\|^2$
$\{q_L, \ell_R^-, \ell_R^+\}$ $f\|c_L\|^2\|b_R\|^2\|a_R\|^2$	$\{\bar{q}_L, \ell_R^+, \ell_R^-\}$ $\bar{f}\|c_L\|^2\|b_R\|^2\|a_R\|^2$	$\{q_L, \ell_R^-, \ell_L^+\}$ $f\|c_L\|^2\|b_R\|^2\|a_L\|^2$	$\{\bar{q}_L, \ell_R^+, \ell_L^-\}$ $\bar{f}\|c_L\|^2\|b_R\|^2\|a_L\|^2$
$\{\bar{q}_R, \ell_R^-, \ell_R^+\}$ $\bar{f}\|c_R\|^2\|b_R\|^2\|a_R\|^2$	$\{q_R, \ell_R^+, \ell_R^-\}$ $f\|c_R\|^2\|b_R\|^2\|a_R\|^2$	$\{\bar{q}_R, \ell_R^-, \ell_L^+\}$ $\bar{f}\|c_R\|^2\|b_R\|^2\|a_L\|^2$	$\{q_R, \ell_R^+, \ell_L^-\}$ $f\|c_R\|^2\|b_R\|^2\|a_L\|^2$
$\{q_R, \ell_L^-, \ell_L^+\}$ $f\|c_R\|^2\|b_L\|^2\|a_L\|^2$	$\{\bar{q}_R, \ell_L^+, \ell_L^-\}$ $\bar{f}\|c_R\|^2\|b_L\|^2\|a_L\|^2$	$\{q_R, \ell_L^-, \ell_R^+\}$ $f\|c_R\|^2\|b_L\|^2\|a_R\|^2$	$\{\bar{q}_R, \ell_L^+, \ell_R^-\}$ $\bar{f}\|c_R\|^2\|b_L\|^2\|a_R\|^2$
Processes P_{21}		Processes P_{22}	

Data from	Can this data be fitted by model					
	SFSF	FSFS	FSFV	FVFS	FVFV	SFVF
SFSF	yes	no	no	no	no	no
FSFS	no	yes	maybe	no	no	no
FSFV	no	yes	yes	no	no	no
FVFS	no	no	no	yes	maybe	no
FVFV	no	no	no	yes	yes	no
SFVF	no	no	no	no	no	yes

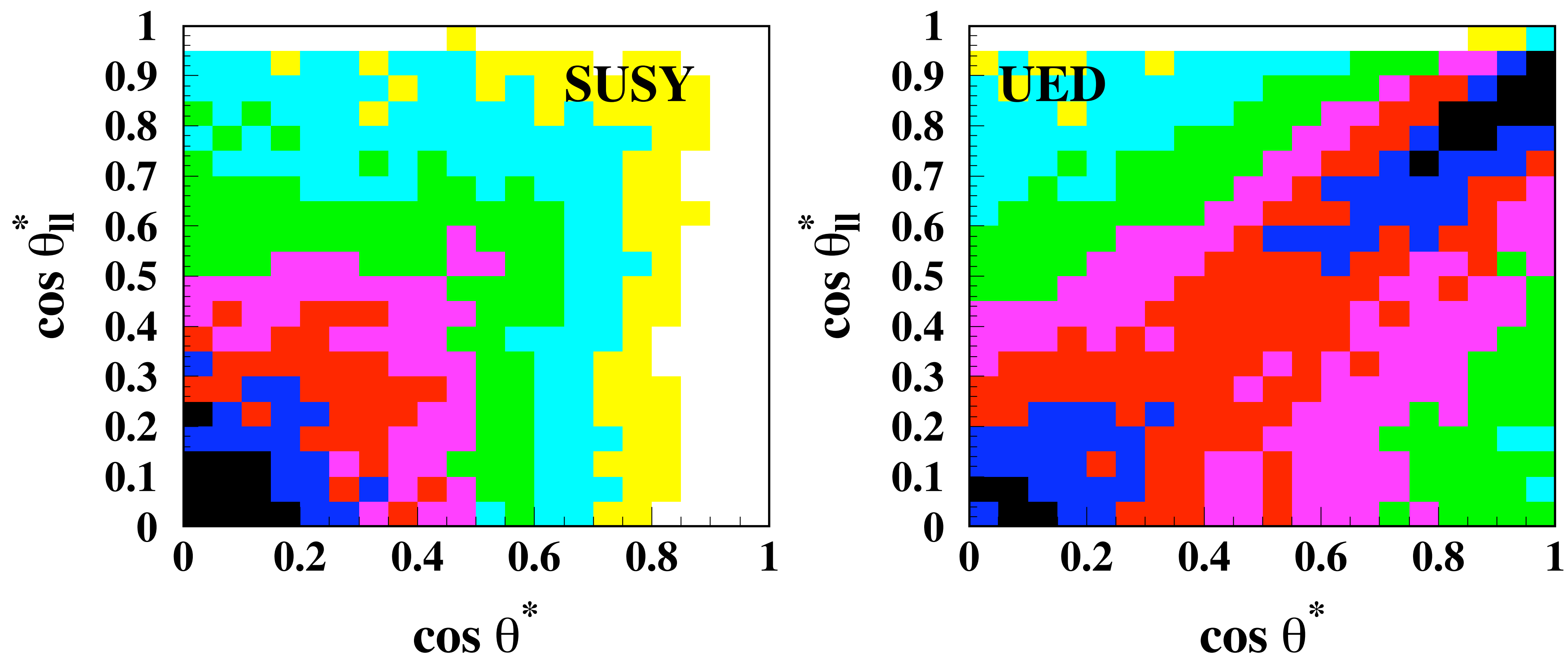


Burns, Kong, Matchev, Park, 0808.2472

Dilepton invariant mass-squared

Dislepton production

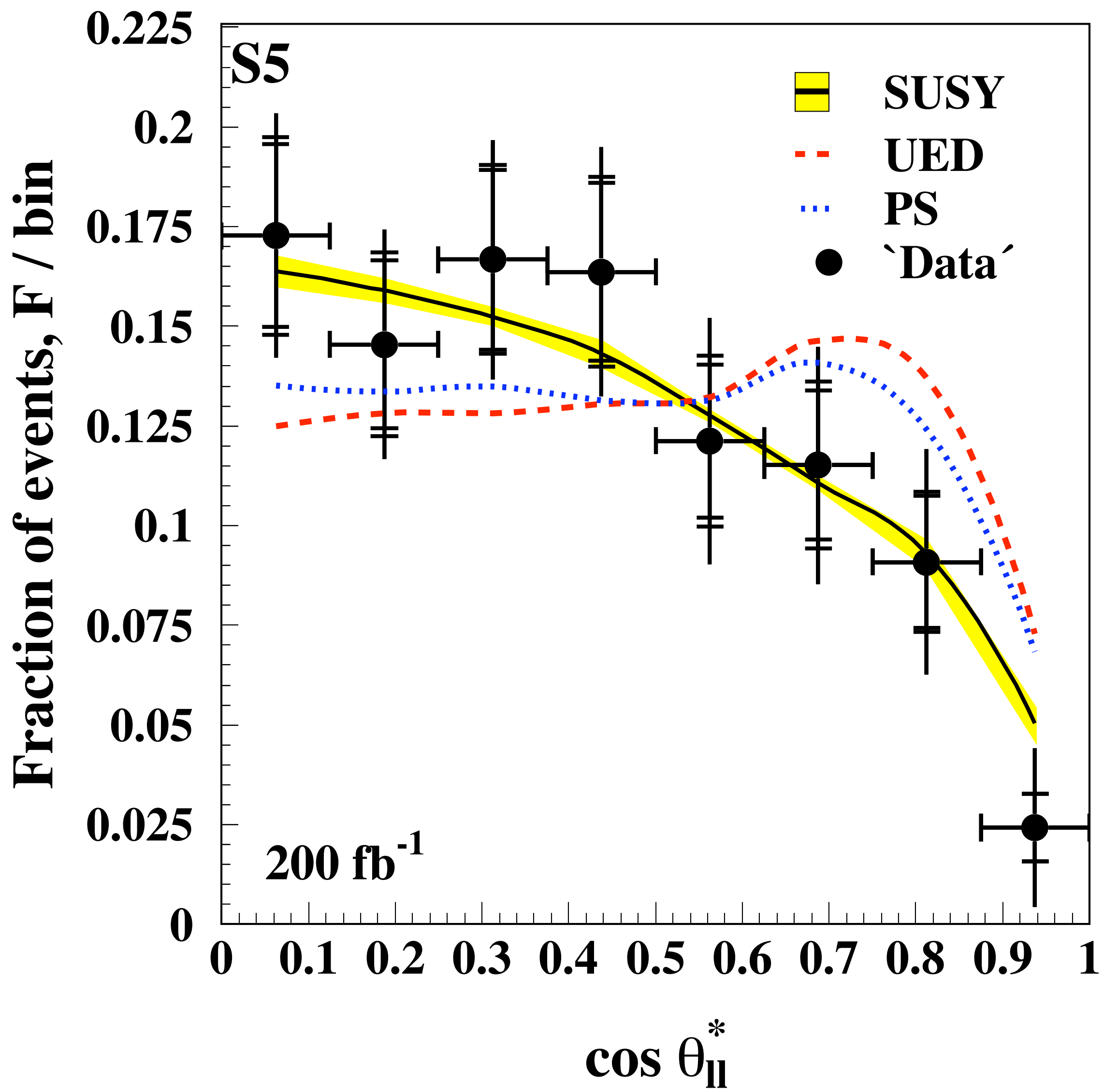
- $q\bar{q} \to Z^0/\gamma \to \tilde{\ell}^+\tilde{\ell}^- \to \tilde{\chi}_1^0\ell^+\ \tilde{\chi}_1^0\ell^-$
- Distribution of $\cos\theta_{ll}^* \equiv \tanh(\Delta\eta_{\ell^+\ell^-}/2)$ is correlated with Z^0/γ decay angle θ^*

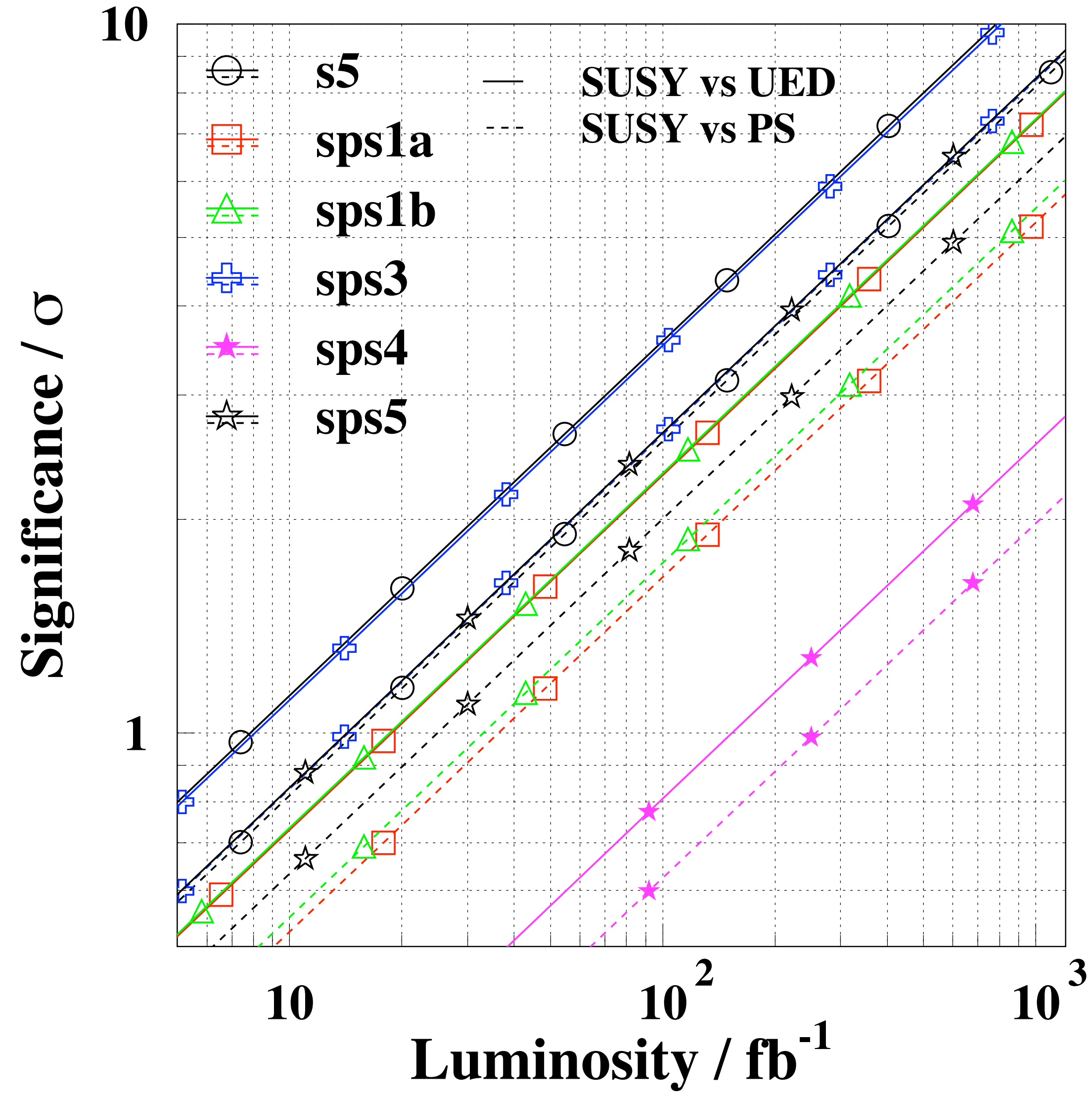


(neglects KKlepton polarisation)

A Barr, hep-ph/0511115

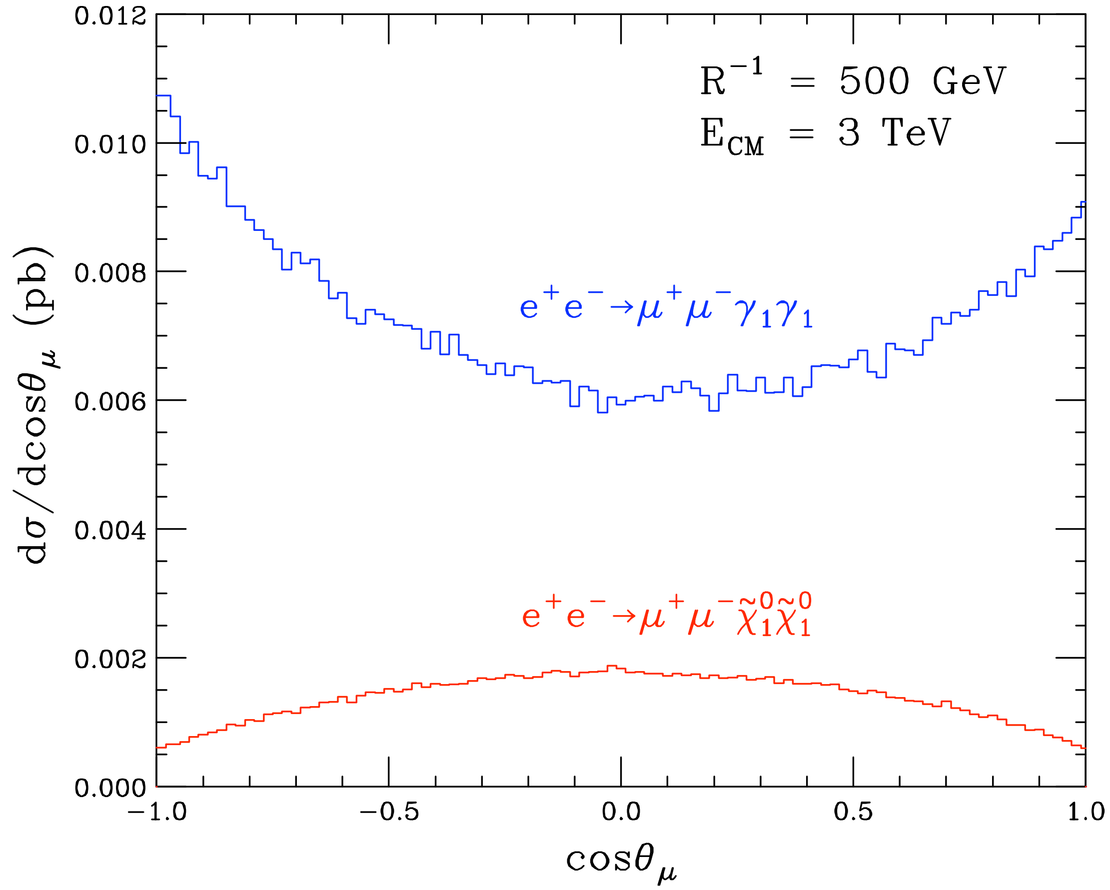
Dislepton production (2)

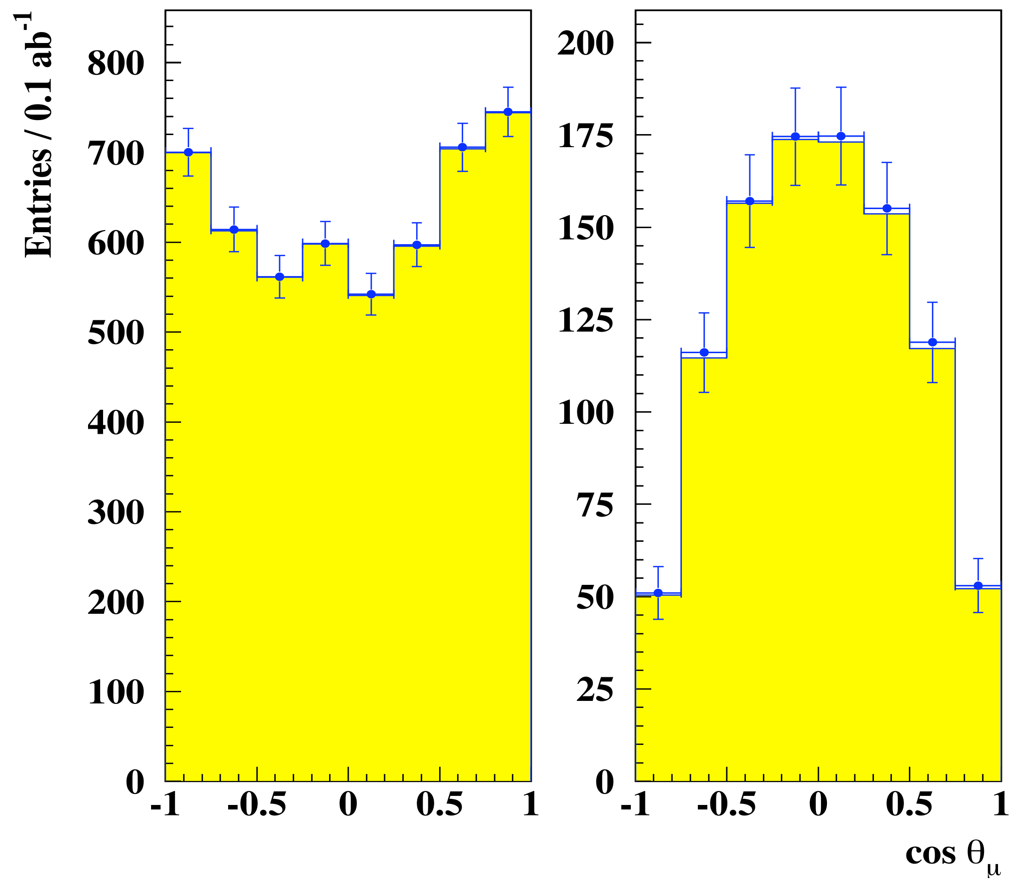




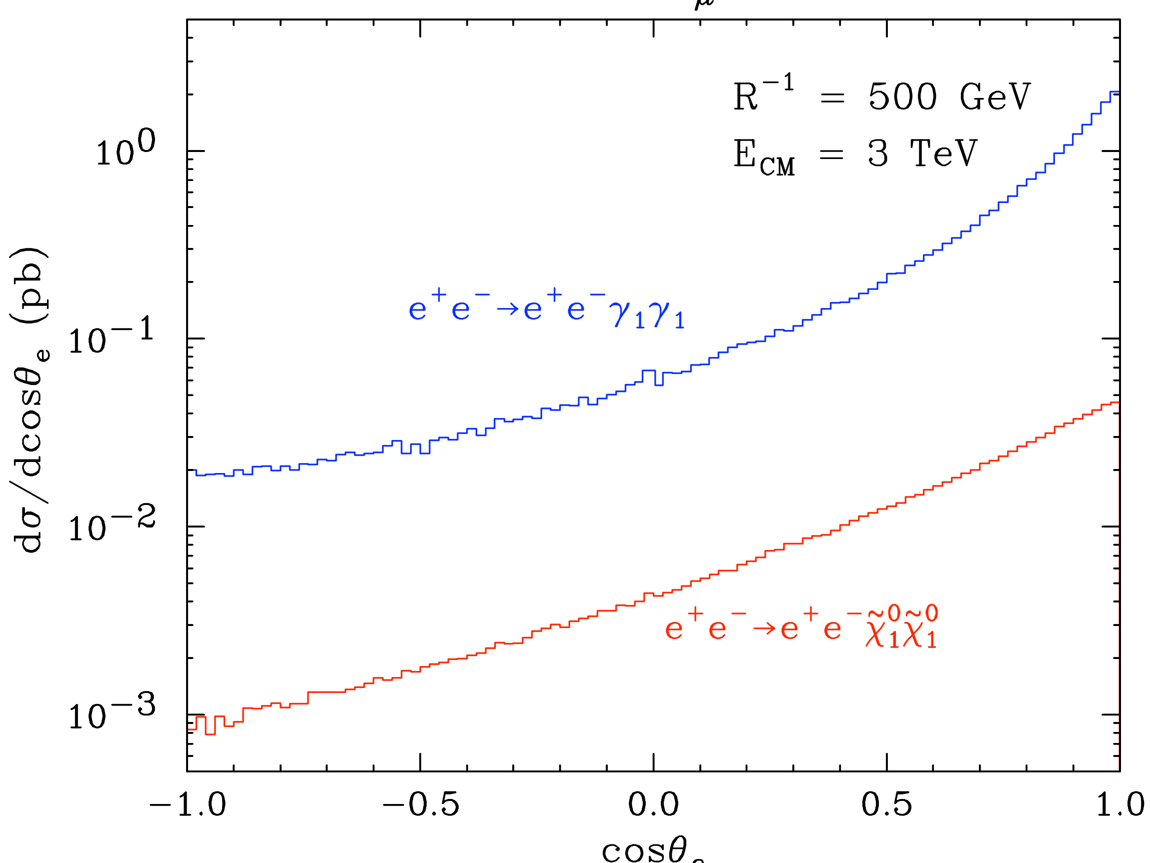
- Outer error bars: after SUSY & SM background subtraction
- Significance strongly dependent on mass spectrum

Disleptons at CLIC





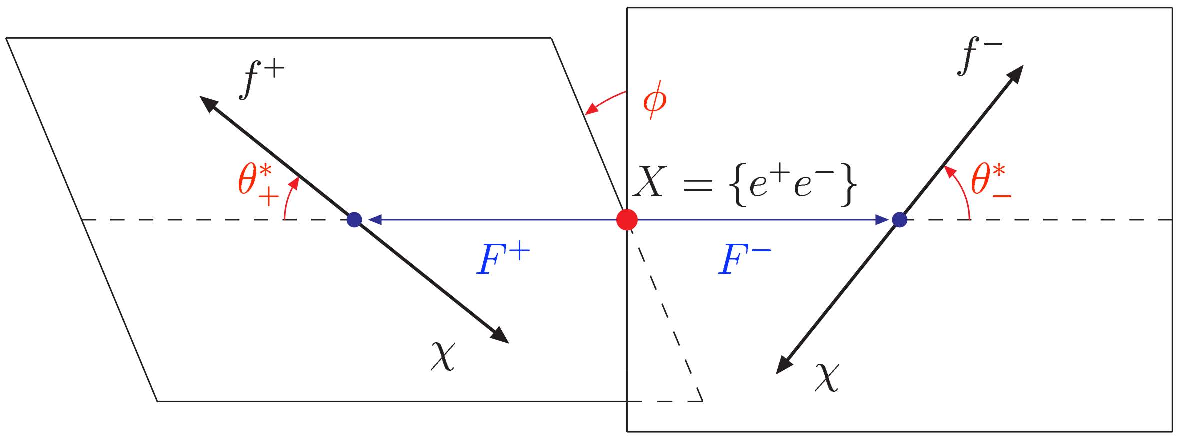
Detector level

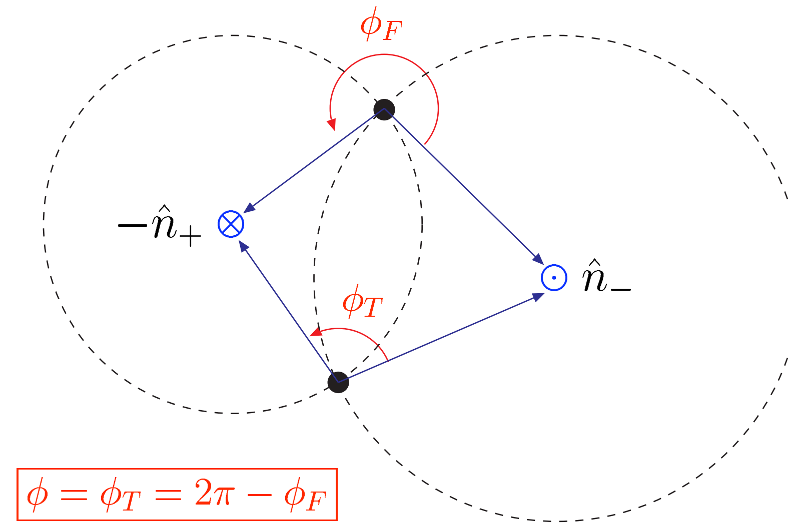


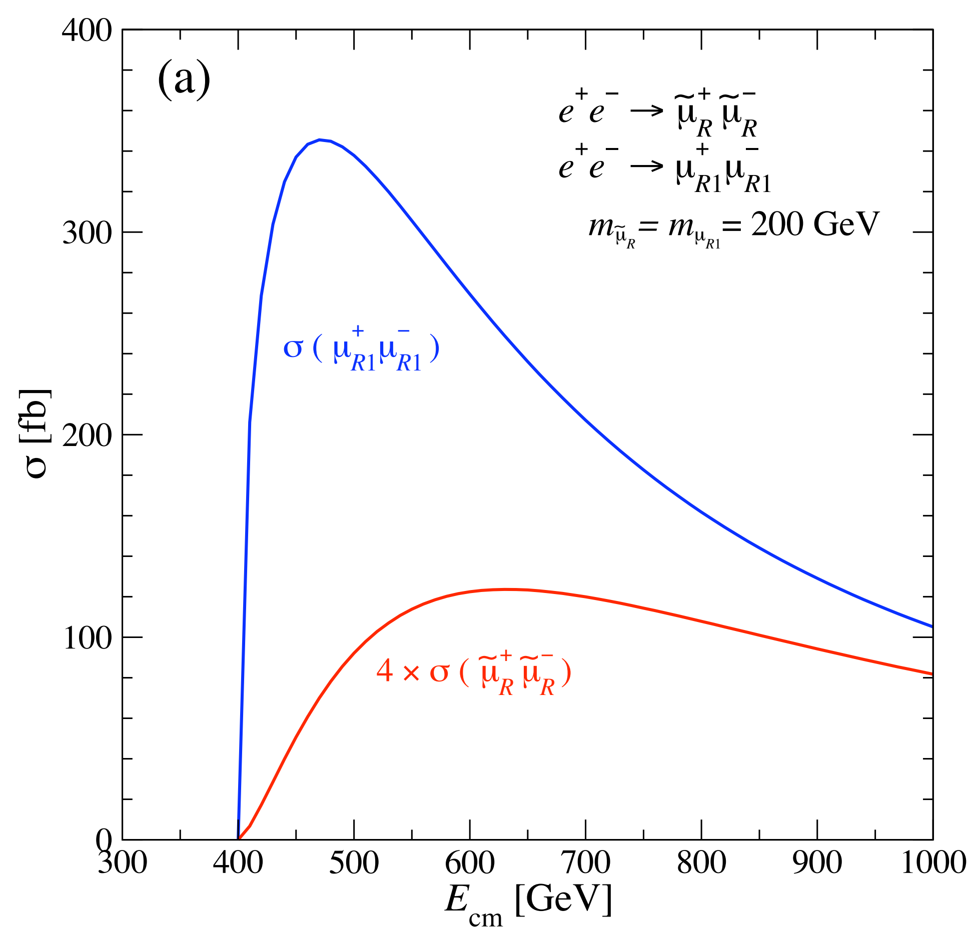
Battaglia, Datta, DeRoeck, Kong, Matchev, hep-ph/0502041, 0507084

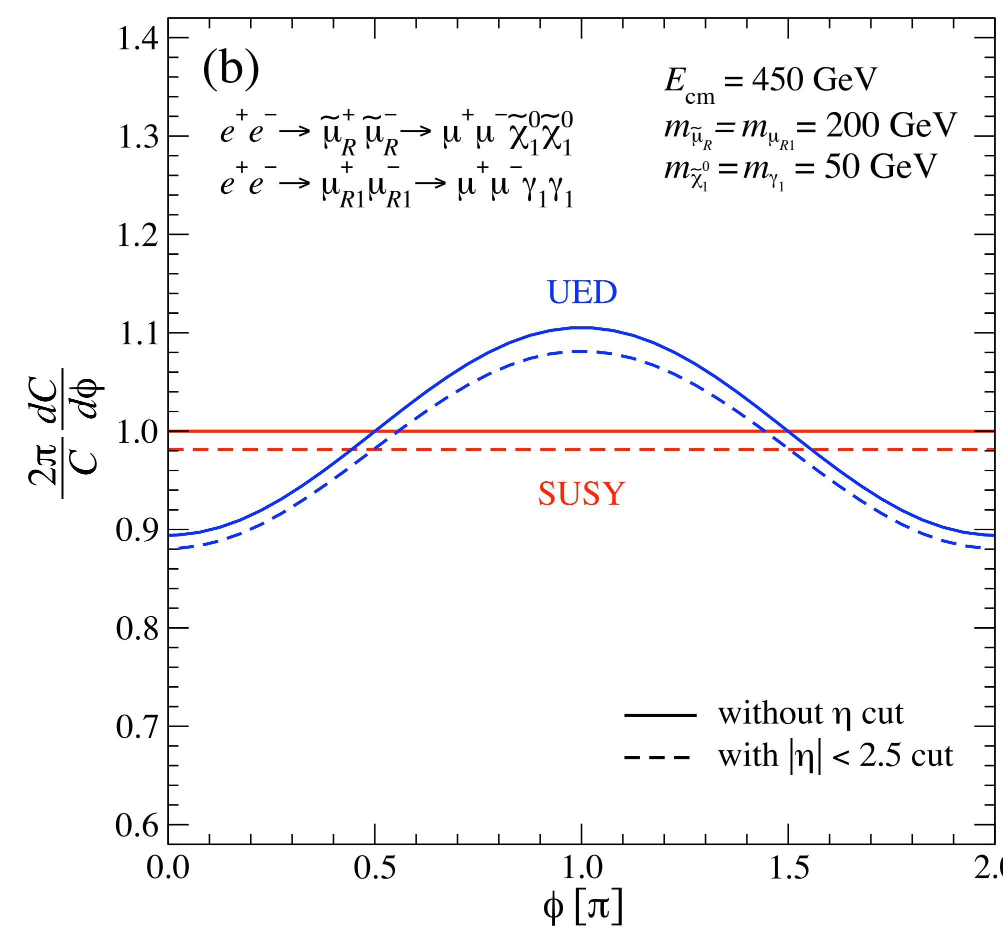
UED: Bhattacharya, Dey, Kundu, Raychaudhuri, hep-ph/0502031

Azimuthal correlations in e^+e^-





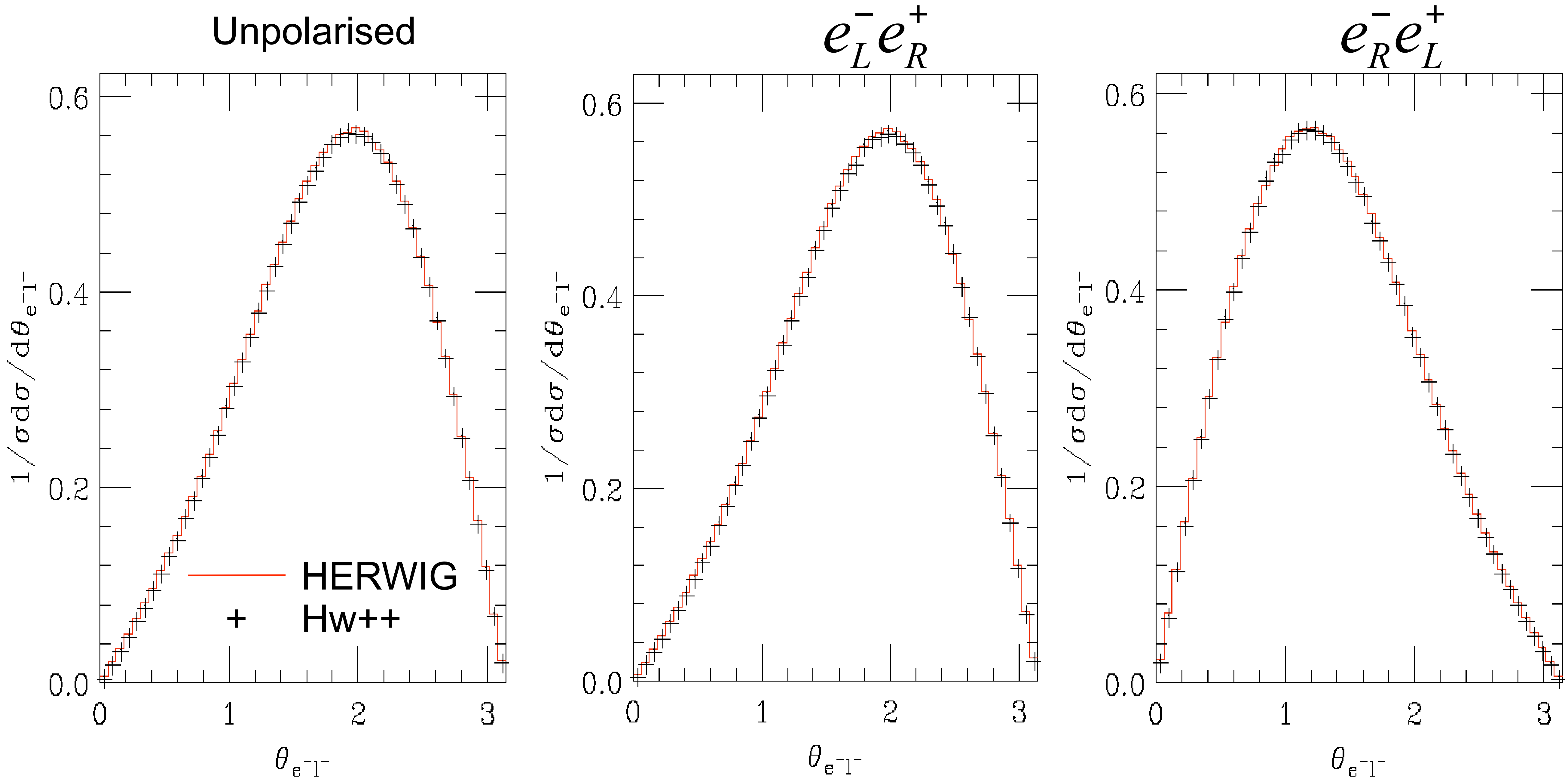




Buckley, Choi, Mawatari, Murayama, 0811.3030

Spin Correlations in HERWIG

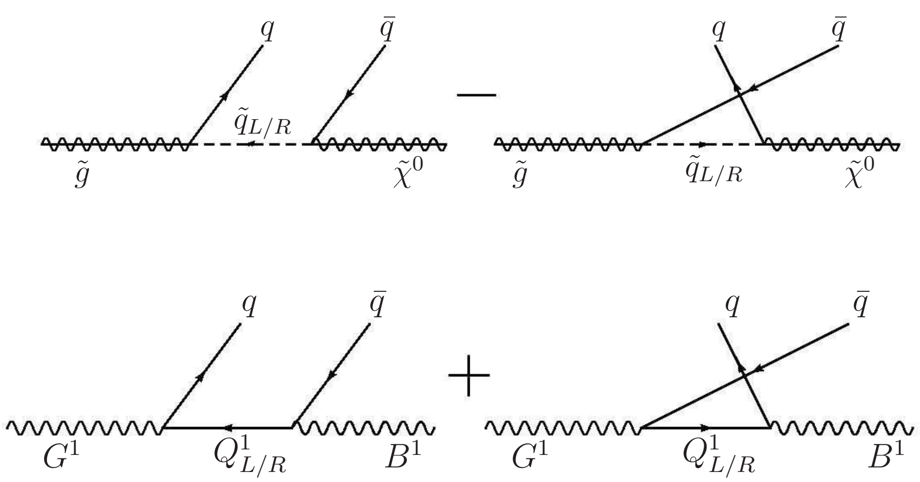
$$e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_1 \to \tilde{l}^+_R l^- \tilde{\chi}^0_1 \to l^+l^-\tilde{\chi}^0_1\tilde{\chi}^0_1$$

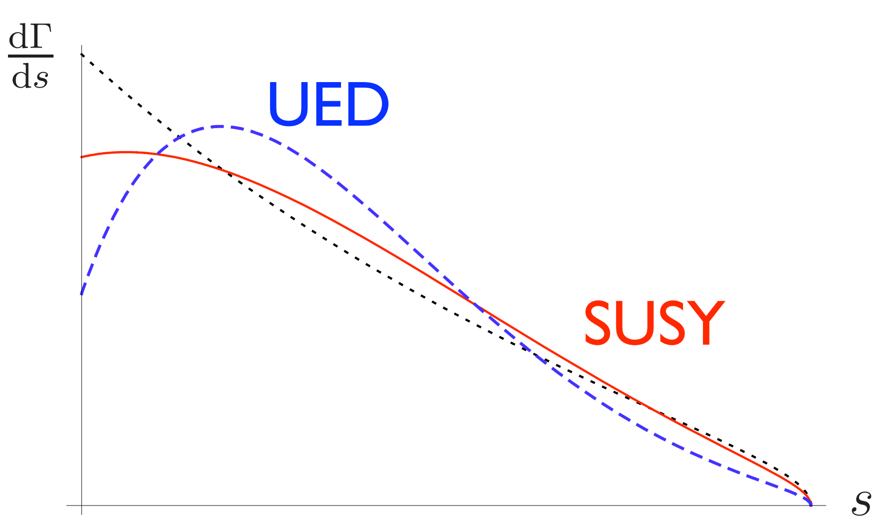


Gigg, Richardson, hep-ph/0703199

Three-body decays

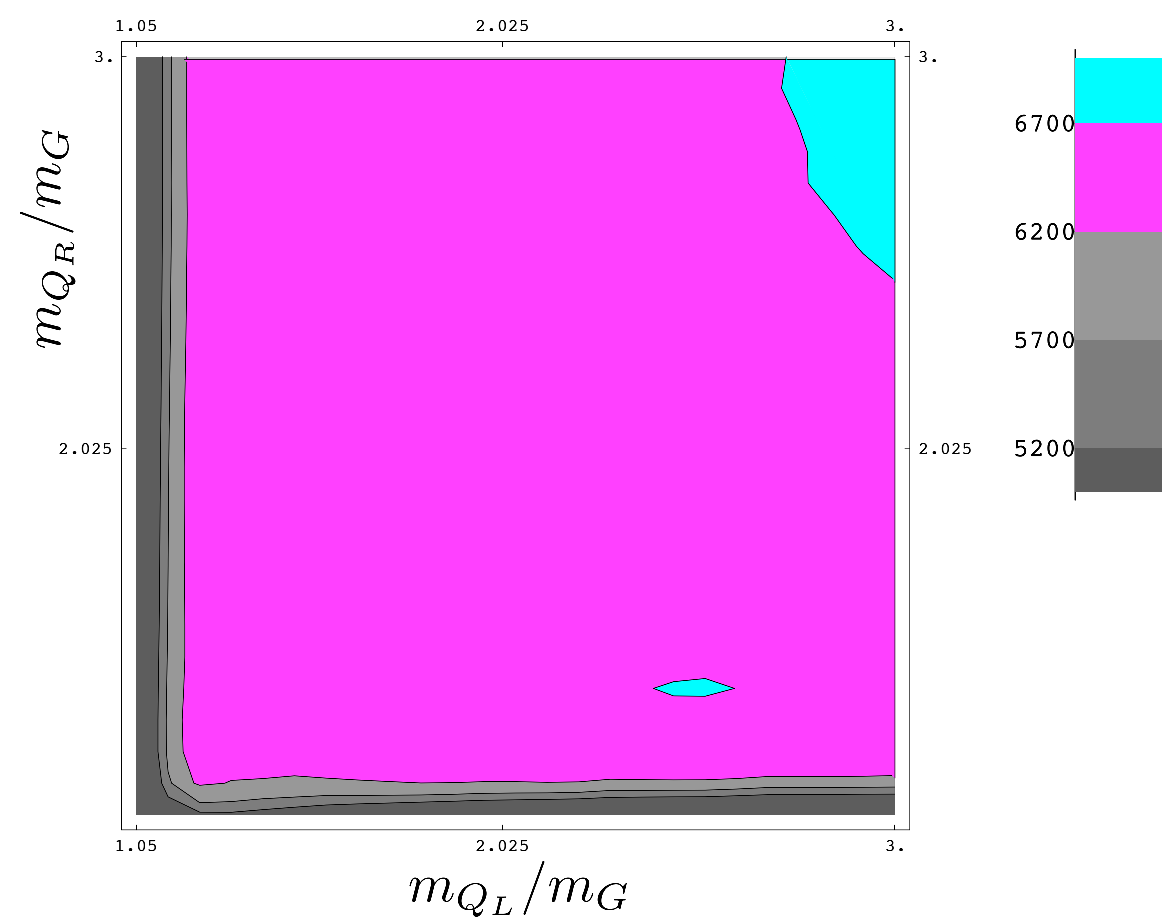
Three-body gluino decays





Dijet inv. mass-squared

Number of events needed to discriminate



Kullback-Leibler measure:

$$N \sim \log R/\mathrm{KL}(T,S)$$

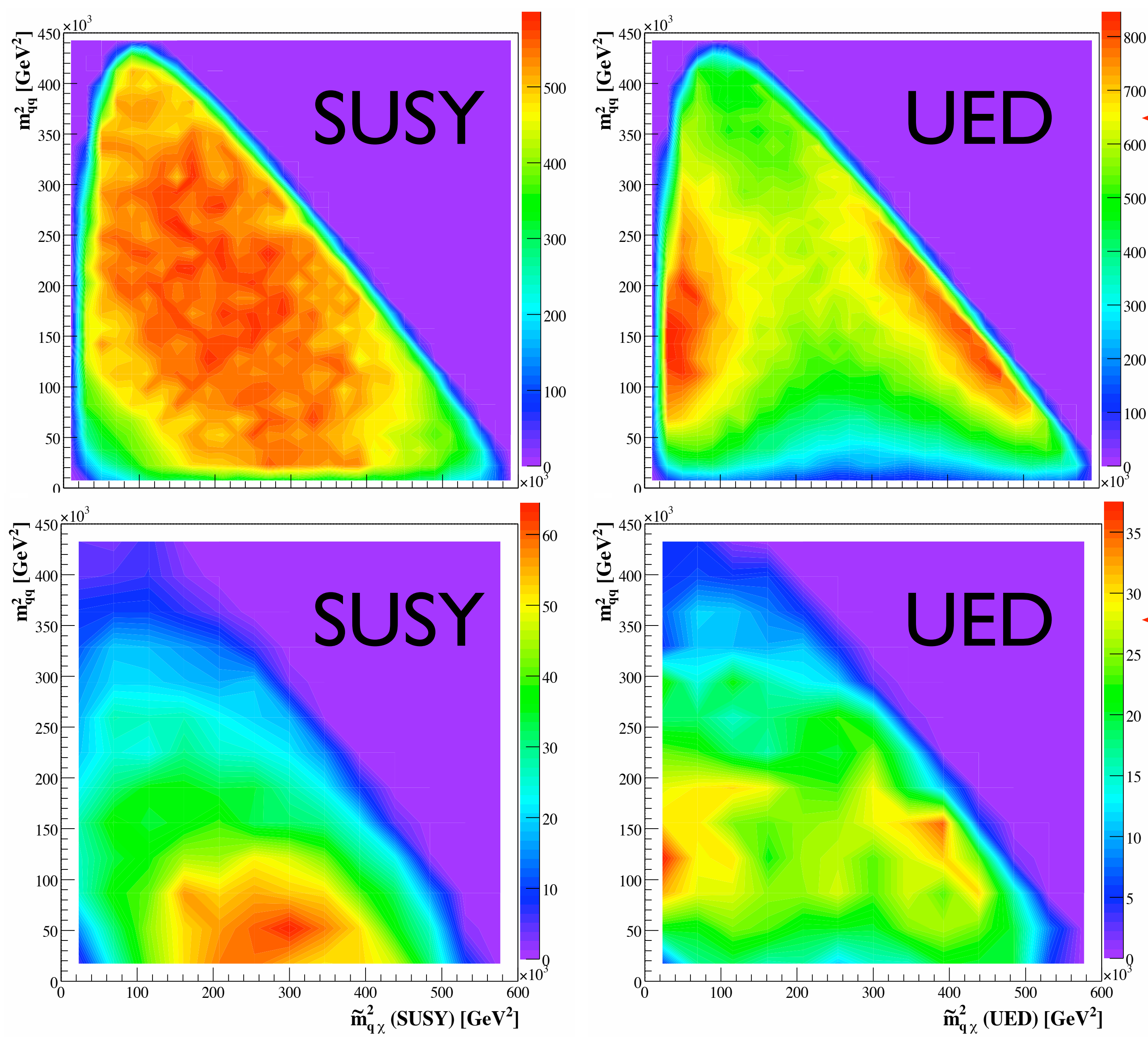
$$\mathrm{KL}(T,S) = \int_m \log\left(\frac{p(m|T)}{p(m|S)}\right) p(m|T)\, dm$$

Csaki, Heinonen, Perelstein, 0707.0014

M_{T2}-assisted spin determination

$$pp \to Y(1) + \bar{Y}(2) \to V(p_1)\chi(k_1) + V(p_2)\chi(k_2), \quad Y \to q(p_q)\bar{q}(p_{\bar{q}})\chi(k)$$

$$M_{T2}(p_i, m_\chi) \equiv \min_{\mathbf{k}_{1T}+\mathbf{k}_{2T}=\mathbf{p}_T^{\rm miss}} \left[\max\{M_T^{(1)}, M_T^{(2)}\}\right] \rightarrow$$ **assign 4-momenta**



$\leftarrow$ $m_{\chi,Y} = m_{\chi,Y}^{\rm true}$

$\mathcal{L} = \infty$

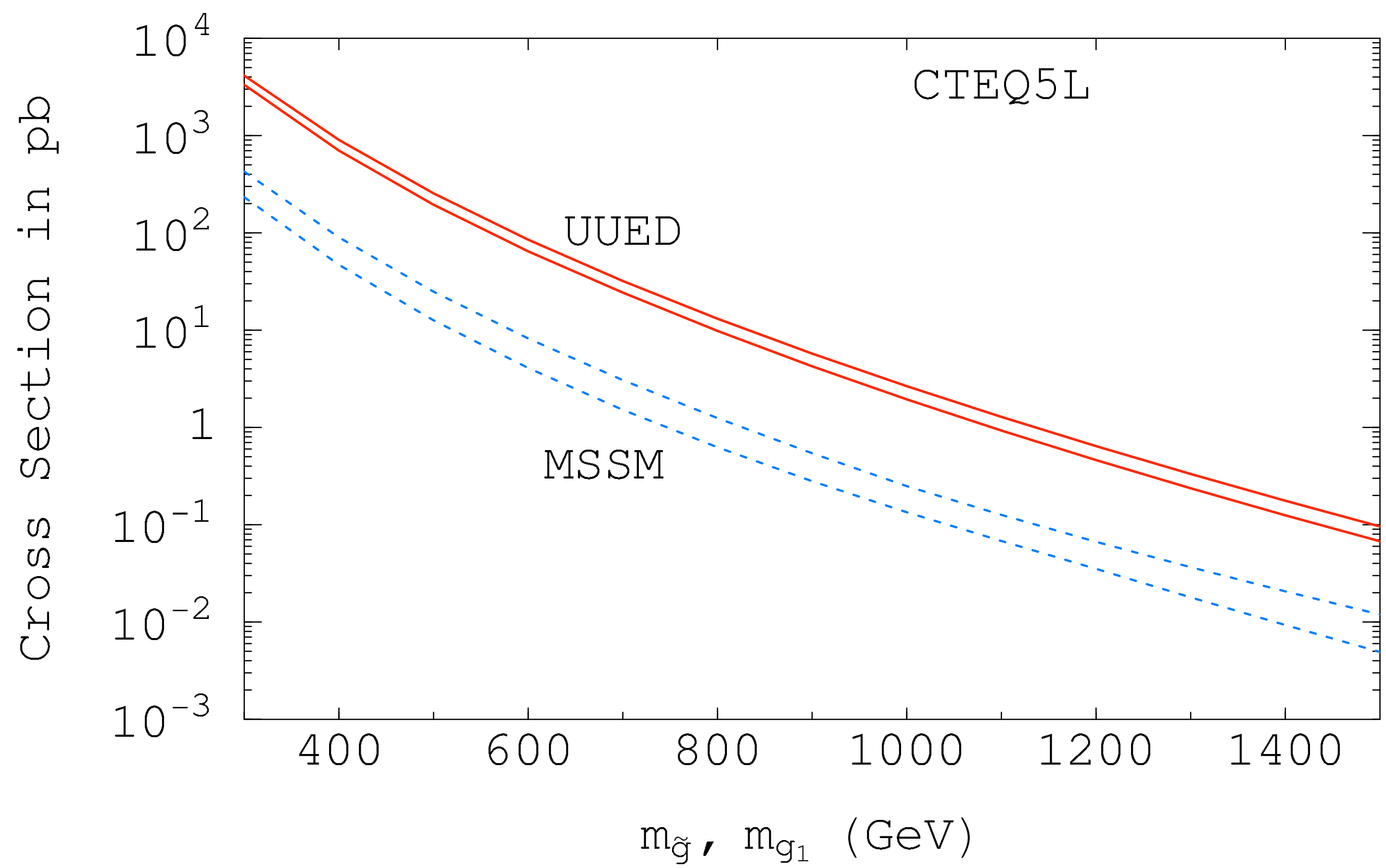
$\leftarrow$ $m_\chi = 0,\ m_Y = M_{T2}^{\max}(m_\chi = 0)$

$\mathcal{L} = 300\,\mathrm{fb}^{-1}$

Cho, Choi,Kim,Park, 0810.4853

Cross sections

Cross sections imply spins

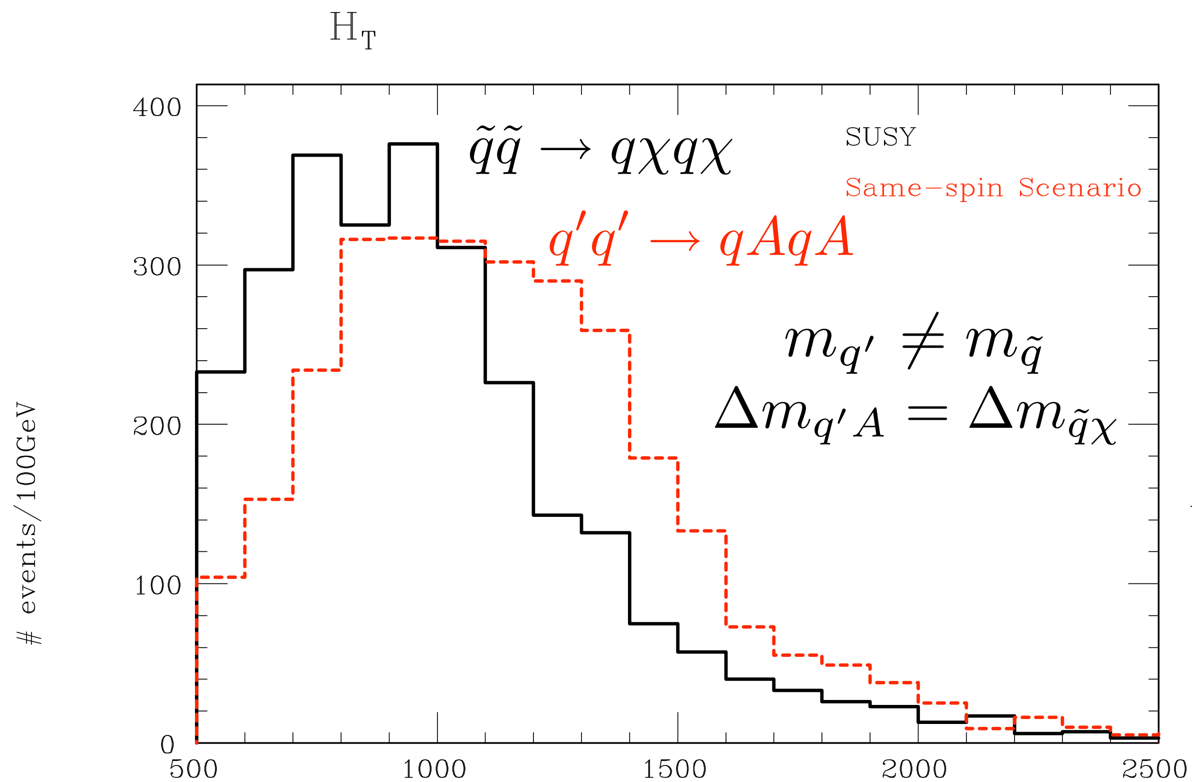


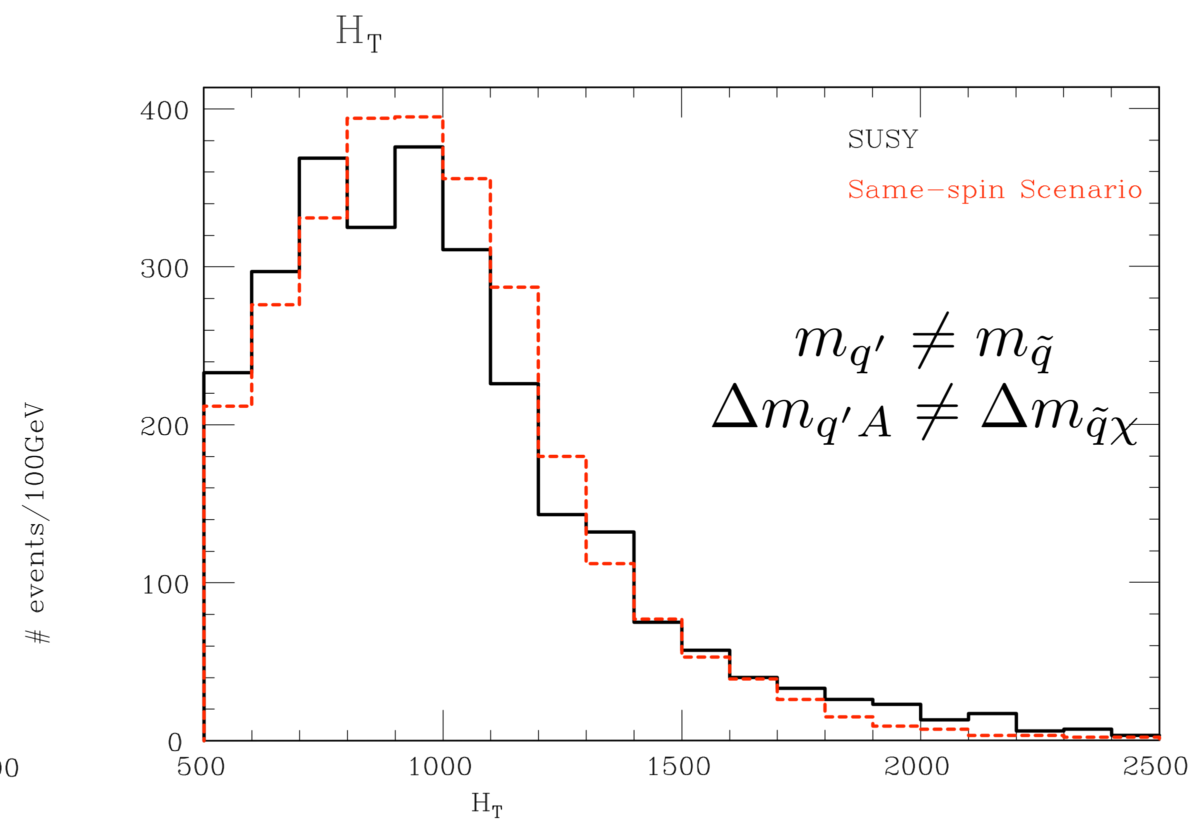
	MSSM	**U-UED**
Production Cross sections	$\sigma_{\tilde{g}\tilde{g}} = 4.51$ pb	$\sigma_{g_1 g_1} = 65.95$ pb
Branching Fractions	$\tilde{g} \to q\bar{q}'\chi_1^\pm = 0.45$ $\tilde{g} \to q\bar{q}\chi_2^0 = 0.28$ $\tilde{g} \to q\bar{q}\chi_1^0 = 0.27$	$g_1 \to q\bar{q}'W_1^\pm = 0.45$ $g_1 \to q\bar{q}'Z_1 = 0.28$ $g_1 \to q\bar{q}'B_1 = 0.27$
	$\chi_1^\pm \to q\bar{q}'\chi_1^0 = 0.67$ $\chi_1^\pm \to \ell\nu\chi_1^0 = 0.33$ $\chi_2^0 \to q\bar{q}\chi_1^0 = 0.94$ $\chi_2^0 \to \ell\bar{\ell}\chi_1^0 = 0.04$ $\chi_2^0 \to \nu\bar{\nu}\chi_1^0 = 0.01$	$W_1^\pm \to q\bar{q}'B_1 = 0.18$ $W_1^\pm \to \ell\nu B_1 = 0.82$ $Z_1^\pm \to q\bar{q}B_1 = 0.22$ $Z_1^\pm \to \ell\bar{\ell}B_1 = 0.39$ $Z_1^\pm \to \nu\bar{\nu}B_1 = 0.39$
Cascade Fractions		
1-lepton	0.248	0.385
OS 2-lepton	0.030	0.183
SS 2-lepton	0.011	0.068
3-lepton	0.003	0.081
Cascade Rates		
1-lepton	1.12 pb	25.39 pb
OS 2-lepton	0.13 pb	12.06 pb
SS 2-lepton	0.05 pb	4.48 pb
3-lepton	0.014 pb	5.34 pb

Higher spins mean higher cross sections (for given masses)

Datta, Kane, Toharia hep-ph/0510204

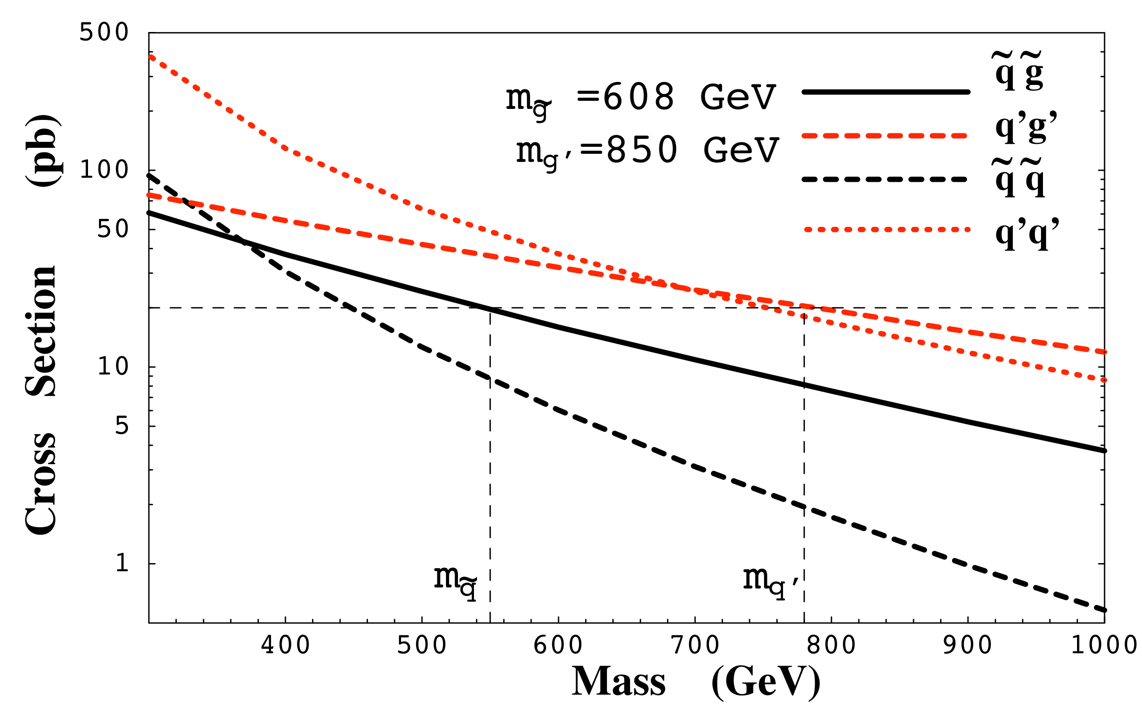
Cross sections imply spins (2)





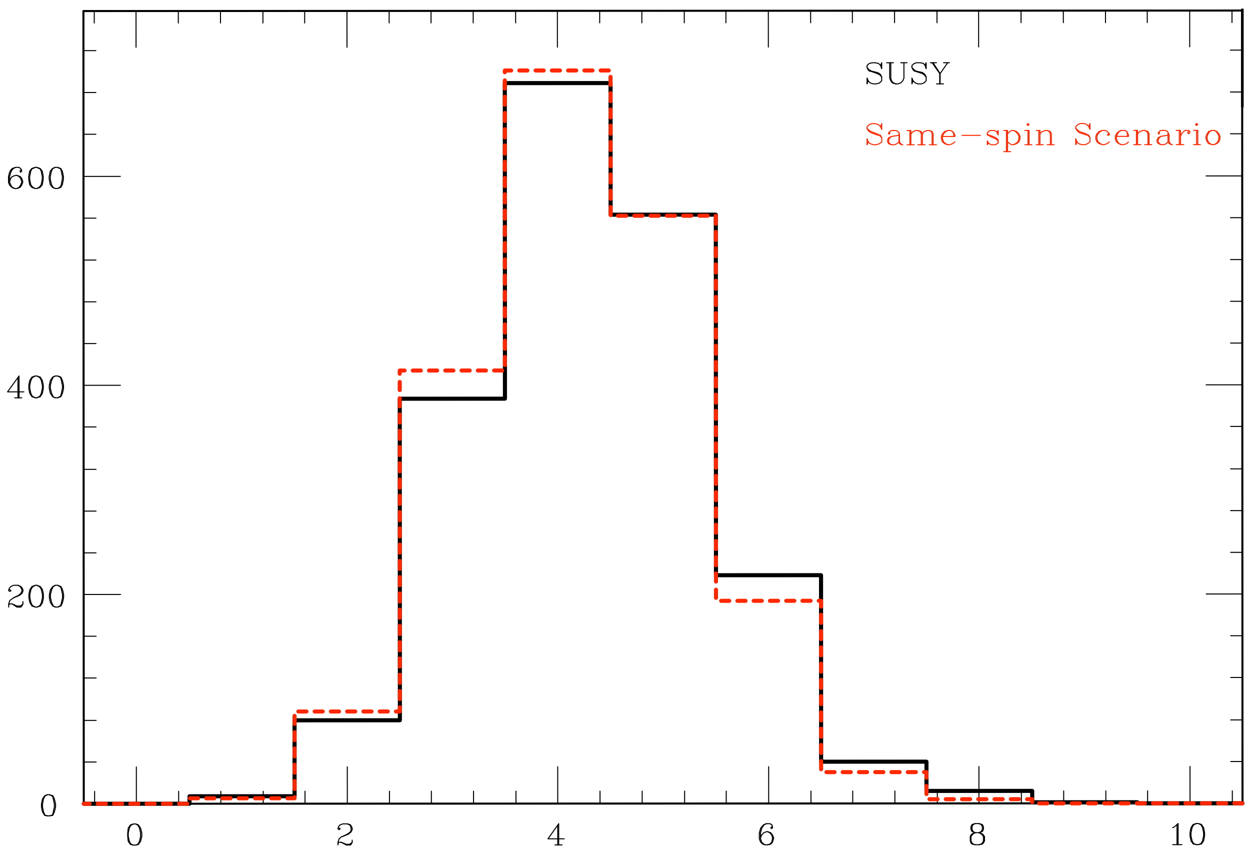
$$H_T = \sum E_T + \not{E}_T$$

- Can match cross section and one distribution by adjusting masses
- Cannot match several cross sections or distributions ...

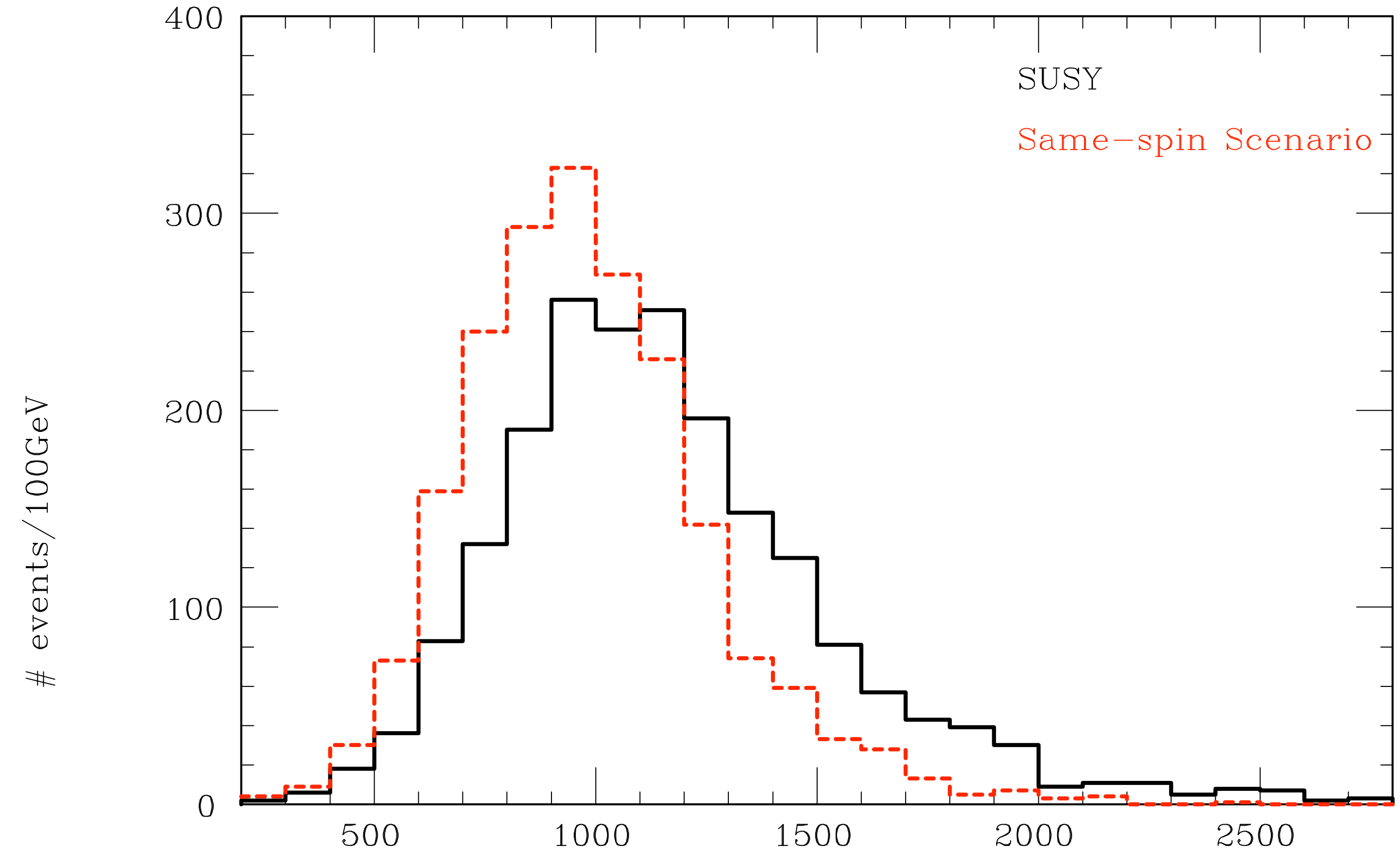


Kane, Petrov, Shao, Wang, 0805.1397

Cross sections imply spins (3)



Jet multiplicity



H_T

- Can vary masses to fit cross section and one distribution
- E.g. match jet counts → H_T doesn't match → ambiguity resolved

Conclusions on Spins

- Sequential decay chains
  - Possibilities -- but difficult for degenerate masses
  - Gluino spin -- some ideas, just starting
- Dileptons
  - SUSY vs UED difficult at LHC -- other cases possible
- Three-body decays
  - M_{T2} assistance looks useful here (and elsewhere?)
- Cross sections
  - Should be included

→ Full simulations (and data) needed!