Reconstructing new physics models at the LHC

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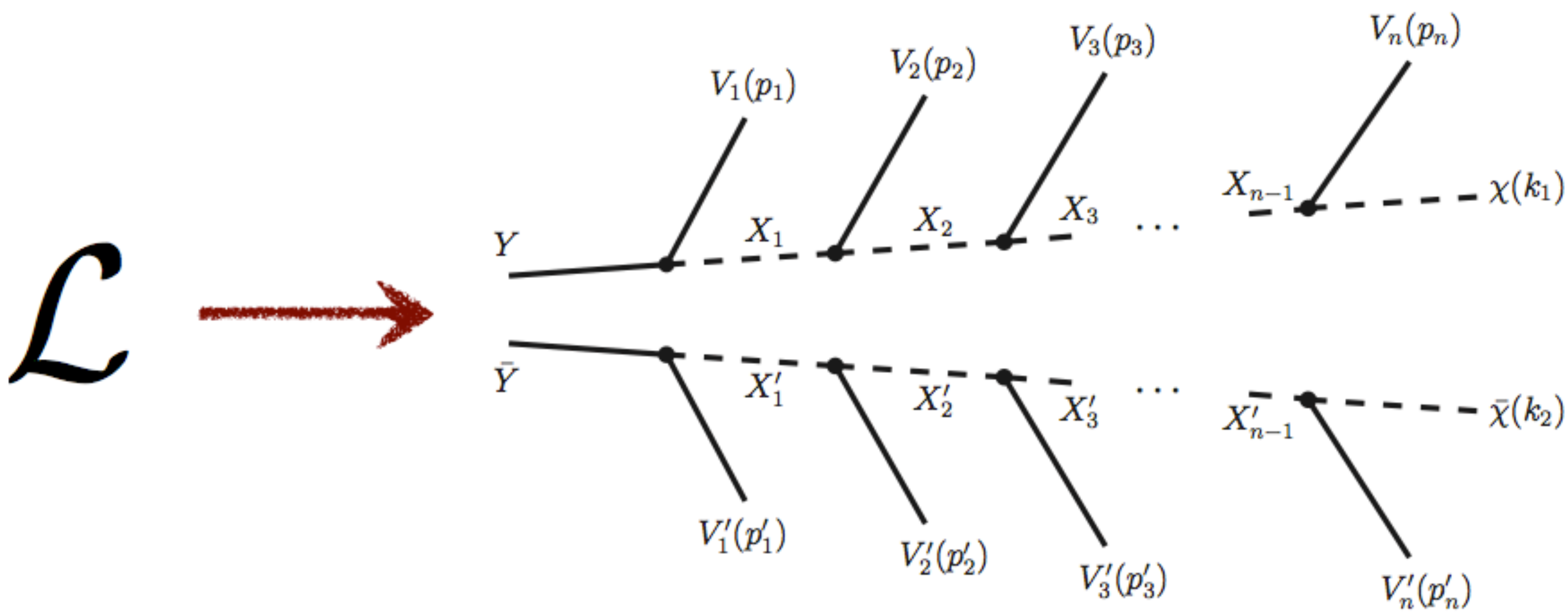
CERN Theory Group Retreat

9 November 2012

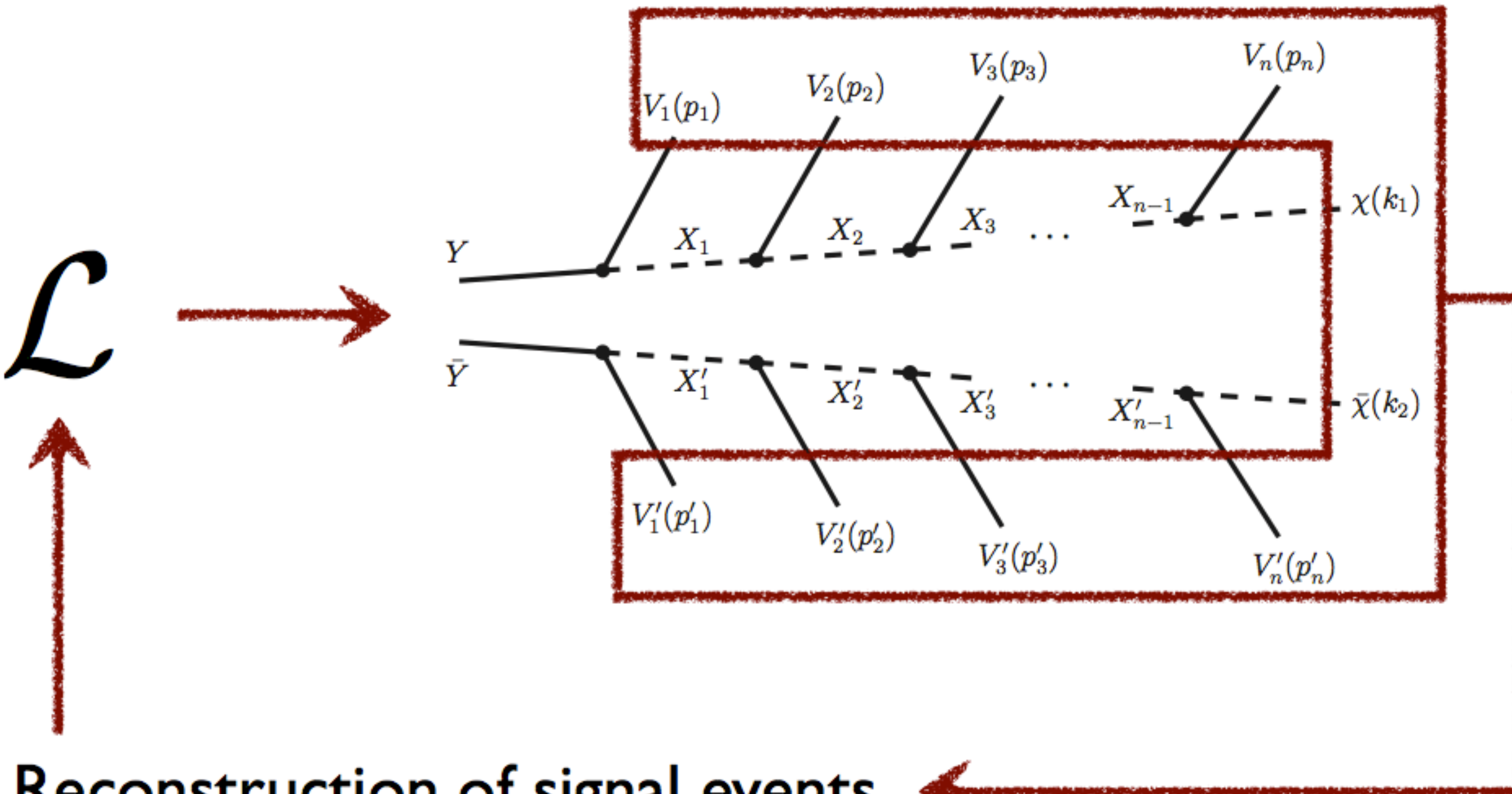
Off topic: Personal info

- Ph.D. at KAIST, Daejeon, South Korea (2010)
- Postdoc at IFT UAM/CSIC, Madrid, Spain (2010 – 2012)
- Main research topics:
  - SUSY phenomenology (currently working on NMSSM-type models)
  - Collider physics (mass and spin measure)

Reconstruction of theory from collider



Reconstruction of theory from collider



Reconstruction of signal events
(mass, spin, ...)

Once new physics signals are discovered, the next step should be to figure out what it is.

- particle contents, EM charges, SU(3) rep.,
- dominant decay channel, mass,
- spin, lifetime, branching fraction, polarization, ..

Problem of hadron collider:

- when more than one undetectable particles in the event, the CM frame of parton collision is unknown.

$$\sum \mathbf{k}_{\mathrm{T}}(\mathrm{invisible}) = -\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} = \sum \mathbf{p}_{\mathrm{T}}(\mathrm{measured})$$

→ difficult to reconstruct the kinematic structure of the event from the measured decay products.

Reconstruction of theory from hadron collider

- Cutting out the ignorance
  - M_{eff}, M_T, M_{T2}, M_{TGen}, M_{CT}, M_{CT2}, ...
  (see for review, Barr et al, arXiv:1004.2732)

- Utilizing an approximation scheme for the ignorance
  - collinear approx., neutrino weighting method, on-shell reconstruction, ...

M_{T2} (stransverse mass)

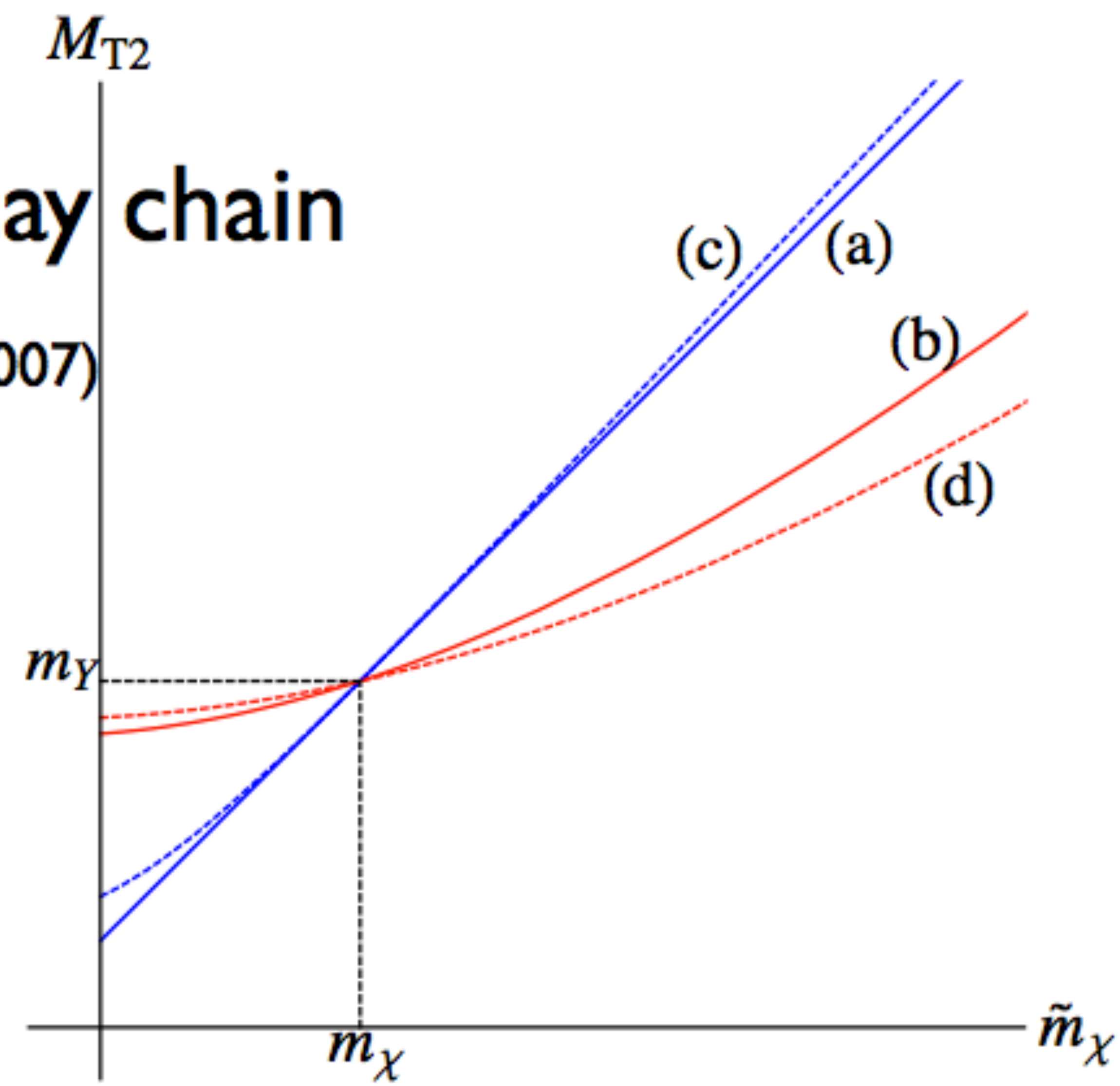
(Lester,Summers,1999, Barr,Lester,Stephens,2003)

$$M_{T2} \equiv \min_{\mathbf{k}_{1T}+\mathbf{k}_{2T}=\mathbf{p}_T^{\text{miss}}} \left[\max \left\{ M_T^{(1)},\, M_T^{(2)} \right\} \right]$$

$$M_T^{(i)}(m_V,\, m_\chi,\, \mathbf{p}_T^V,\, \mathbf{k}_T^\chi)$$

transverse mass in each decay chain

(Cho,Choi,Kim,CBP,2007, Barr,Gripaios,Lester,2007)



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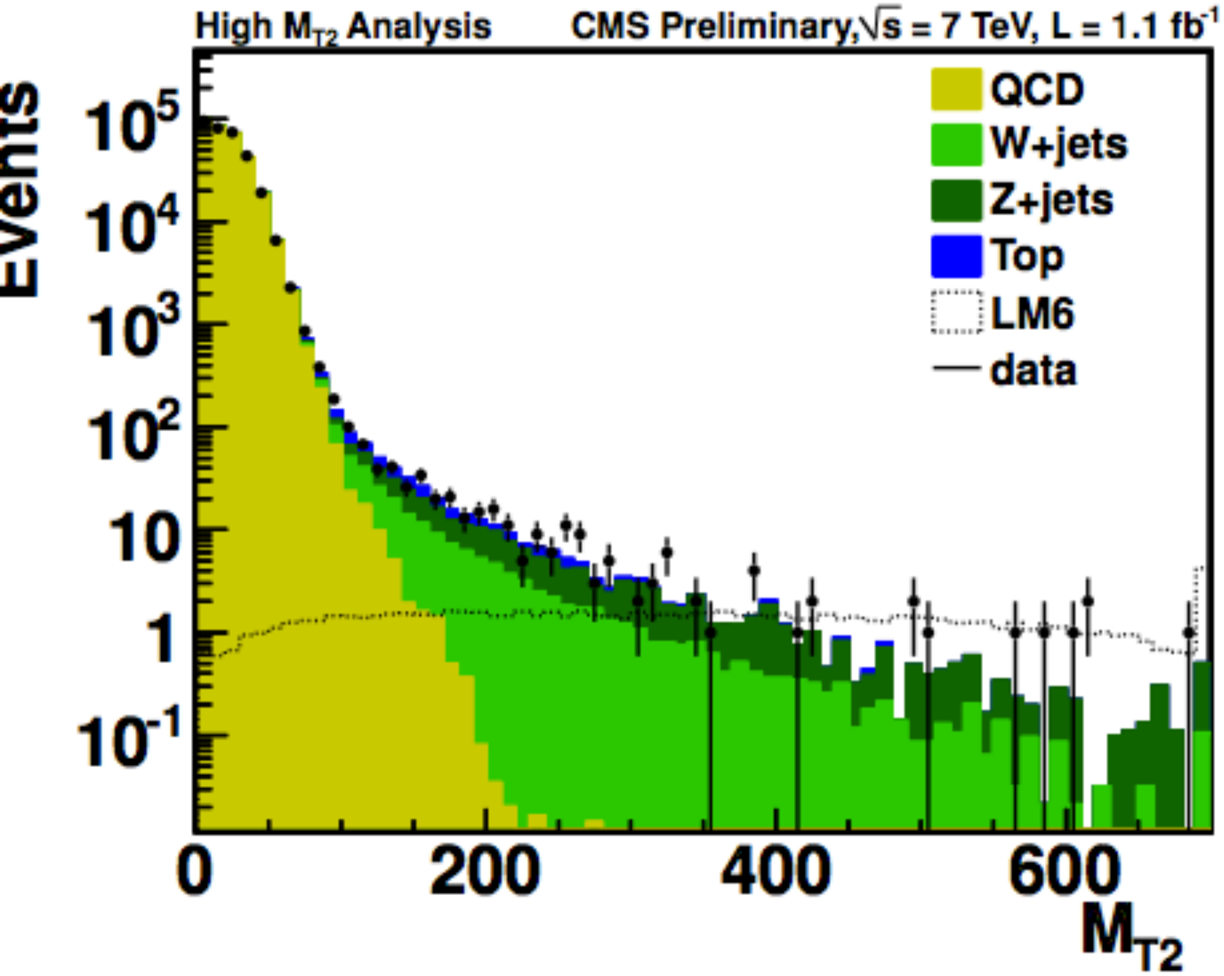
transverse mass in each decay chain

- generalized transverse mass for SUSY-like event type (two invisible LSPs stabilized by R-parity).

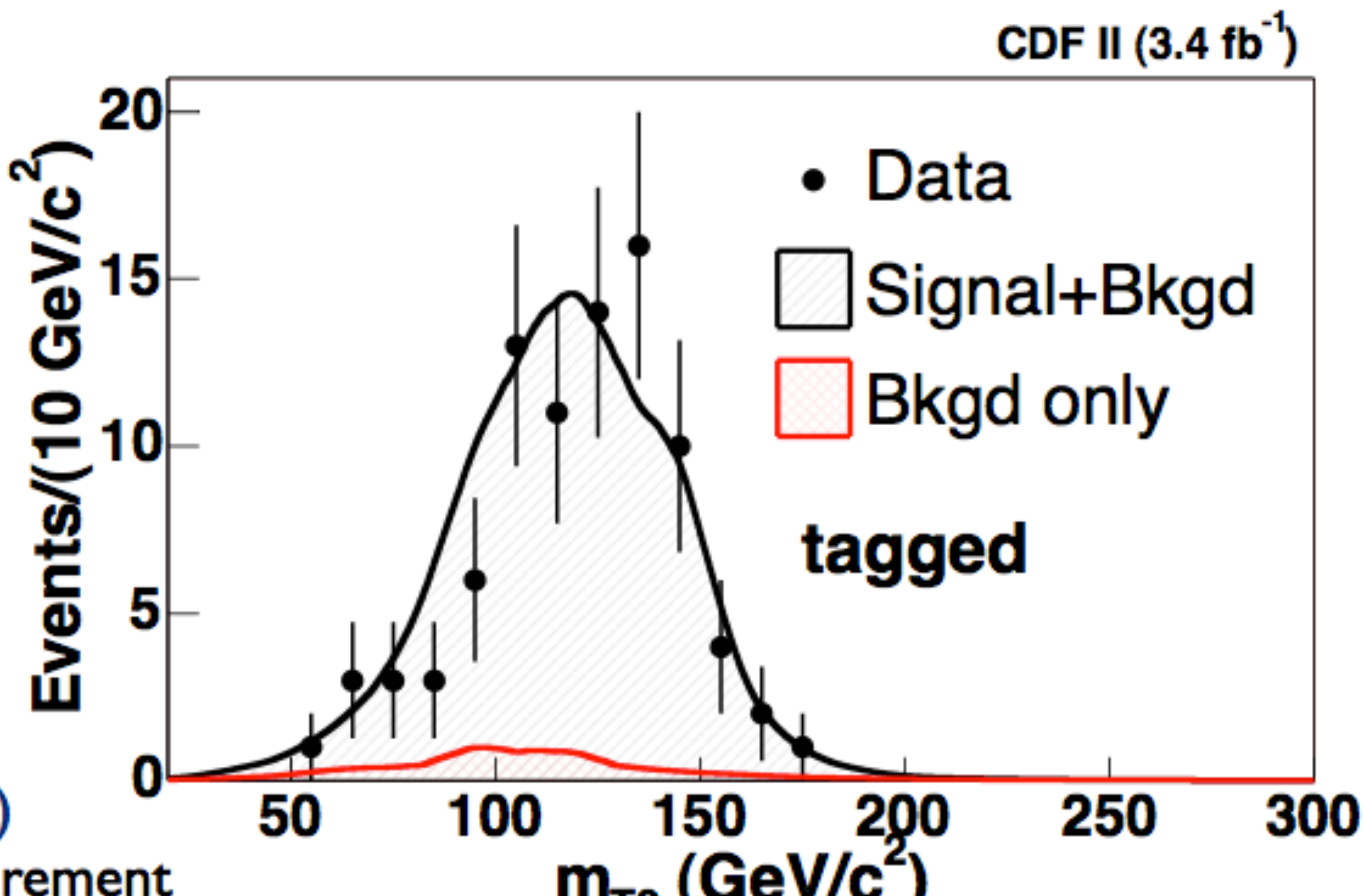
- useful for discovery as well as mass measurement

(Cho,Choi,Kim,CBP,2007, Barr,Gripaios,Lester,2007, Burns,Matchev,Kong,Park,2008).

M_{T2} (stransverse mass)



CMS PAS SUS-11-005
SUSY multijet+MET search



CDF, PRD(2010)
top mass measurement

M_{T2}-assisted on-shell (MAOS) reconstruction

If one could obtain all the information except longitudinal momenta of invisible particles,

on-shell condition: $(p+k)^2 = (q+l)^2 = m_Y^2,\ k^2 = l^2 = m_\chi^2$

$$k_L = \frac{1}{E_T^2(p)}\left[\mathcal{A}p_L \pm \sqrt{p_L^2 + E_T^2(p)}\sqrt{\mathcal{A}^2 - E_T^2(p)E_T^2(k)}\right],$$
$$l_L = \frac{1}{E_T^2(q)}\left[\mathcal{B}q_L \pm \sqrt{q_L^2 + E_T^2(q)}\sqrt{\mathcal{B}^2 - E_T^2(q)E_T^2(l)}\right],$$

where $\mathcal{A} = \frac{1}{2}\left(\tilde{m}_Y^2 - \tilde{m}_\chi^2 - m_{V_1}^2\right) + \mathbf{p}_T \cdot \mathbf{k}_T,$

$\mathcal{B} = \frac{1}{2}\left(\tilde{m}_Y^2 - \tilde{m}_\chi^2 - m_{V_2}^2\right) + \mathbf{q}_T \cdot \mathbf{l}_T,$ and

transverse energies

M_{T2}-assisted on-shell (MAOS) reconstruction

Use the transverse momenta from M_{T2} with trial masses

on-shell condition: $$(p + k^{\rm maos})^2 + (q + l^{\rm maos})^2 = \tilde{m}_Y^2,$$
$$(k^{\rm maos})^2 = (l^{\rm maos})^2 = \tilde{m}_\chi^2$$

$$k_L^{\rm maos} = \frac{1}{E_T^2(p)}\left[\mathcal{A} p_L \pm \sqrt{p_L^2 + E_T^2(p)}\sqrt{\mathcal{A}^2 - E_T^2(p) E_T^2(k)}\right],$$

$$l_L^{\rm maos} = \frac{1}{E_T^2(q)}\left[\mathcal{B} q_L \pm \sqrt{q_L^2 + E_T^2(q)}\sqrt{\mathcal{B}^2 - E_T^2(q) E_T^2(l)}\right],$$

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transverse energies

M_{T2}-assisted on-shell (MAOS) reconstruction

- In general, the MAOS solution has 4-fold ambiguity.

- The solution becomes unique for the endpoint events of M_{T2},

$$k^{\rm maos} = k^{\rm true},\ l^{\rm maos} = l^{\rm true}$$

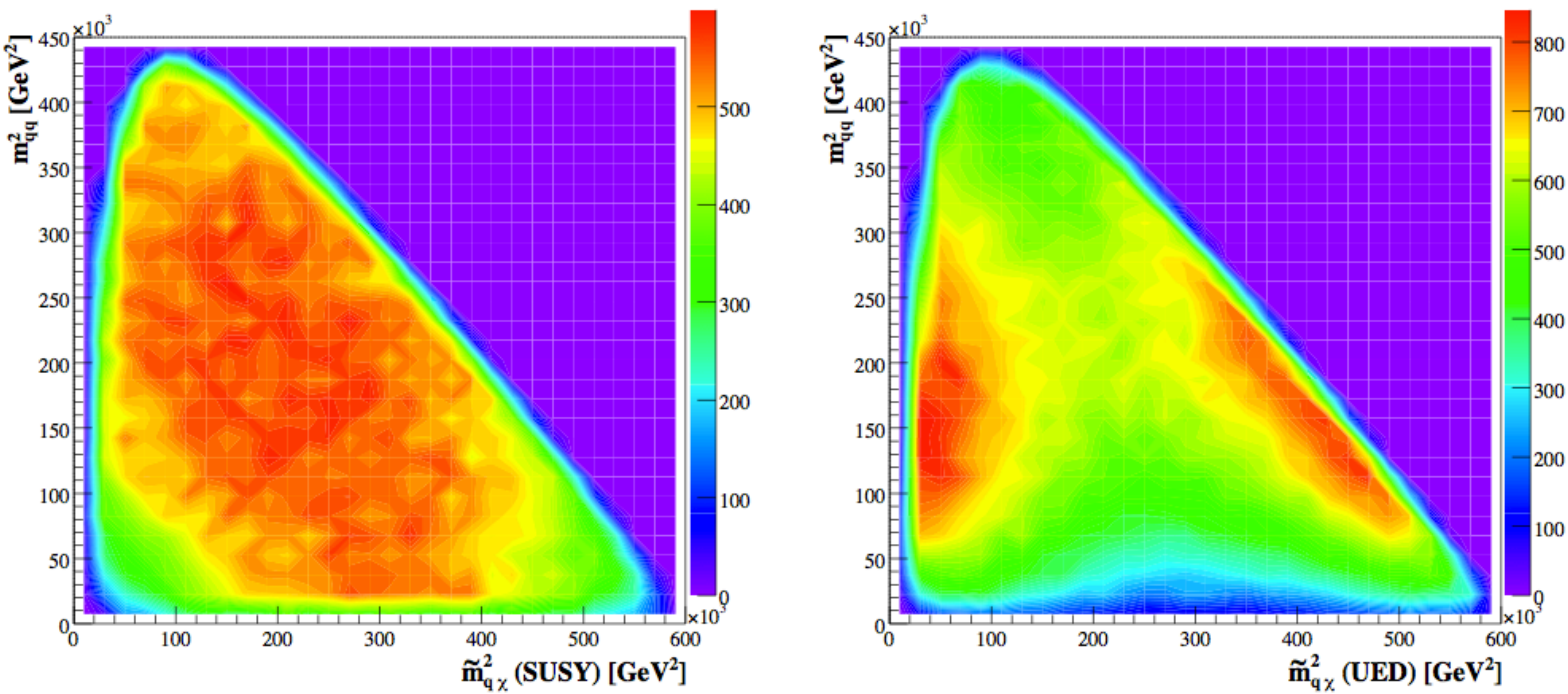
for the balanced M_{T2} events ($M_T^{(1)} = M_T^{(2)}$).

∗ The MAOS solution can be used for spin determination in some cases. (K.Choi et al, PRD (2009), M.M.Nojiri et al, arXiv:1101.2701, O.J.P.Eboli et al, arXiv:1102.3429)

M_{T2}-assisted on-shell (MAOS) reconstruction

SUSY vs UED

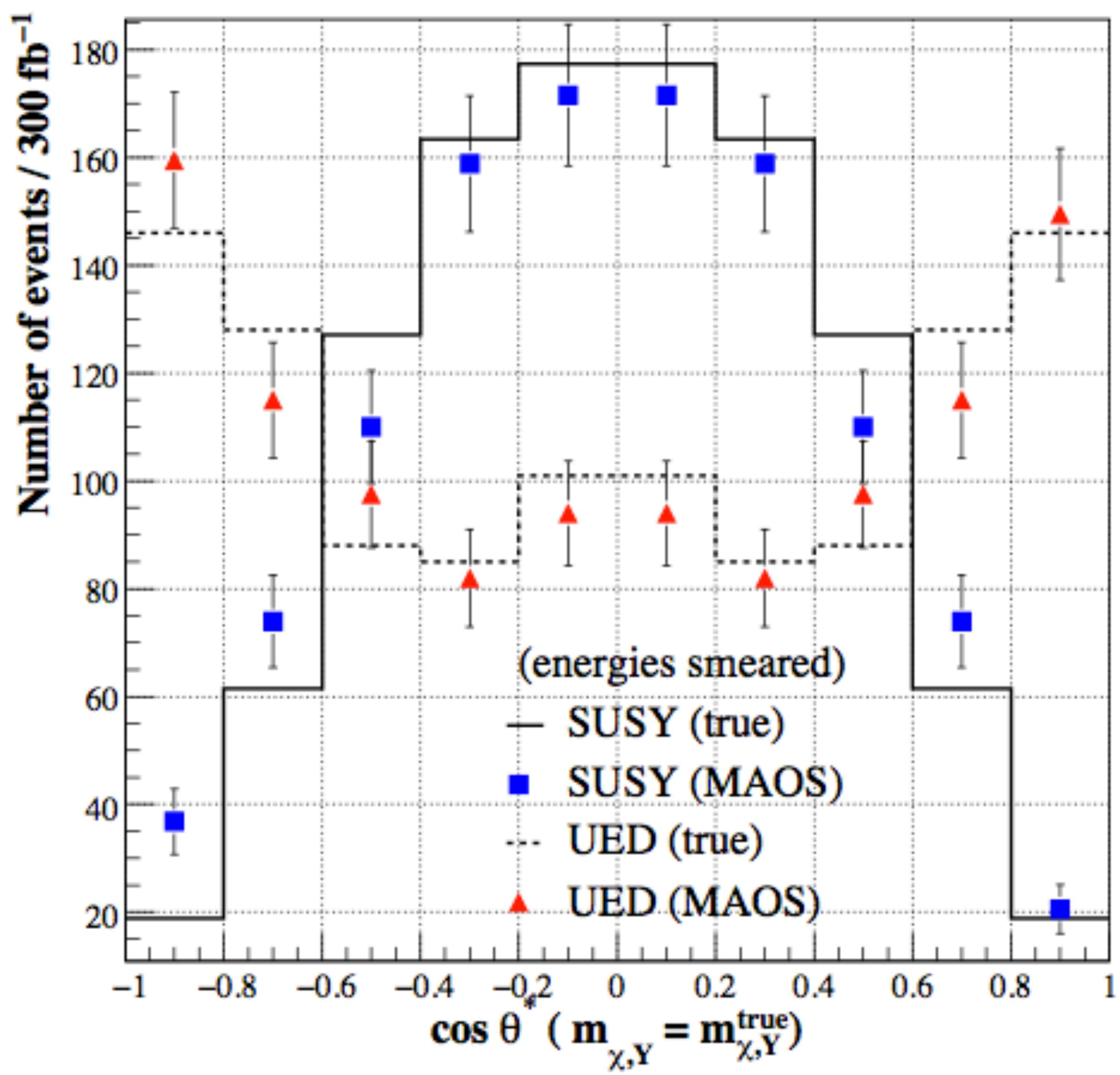
$$\tilde{g}\tilde{g} \rightarrow qq\tilde{\chi}_1^0 qq\tilde{\chi}_1^0 \qquad g_{(1)}g_{(1)} \rightarrow qq\gamma_{(1)}qq\gamma_{(1)}$$



M_{T2}-assisted on-shell (MAOS) reconstruction

SUSY vs UED

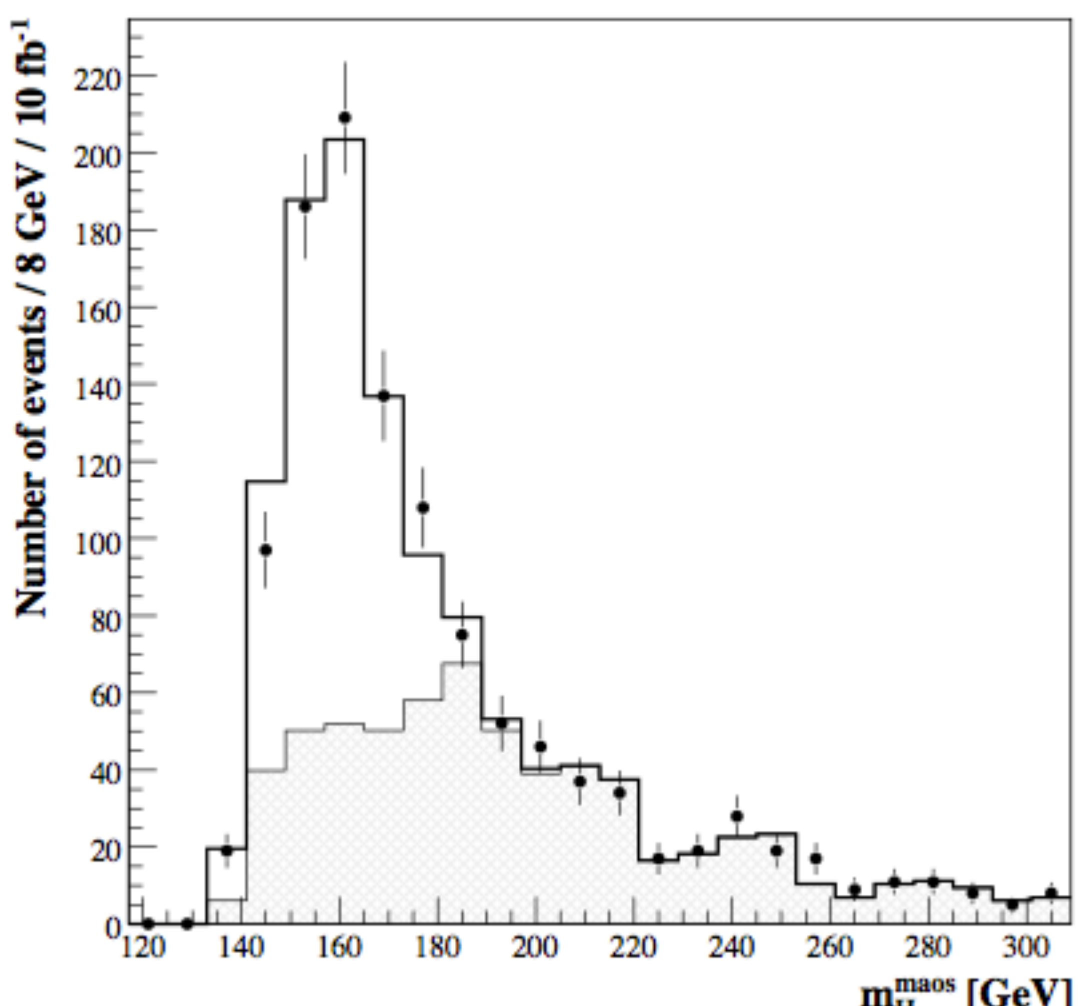
$$pp \to \widetilde{\ell}\widetilde{\ell} \to \ell\widetilde{\chi}_1^0\ell\widetilde{\chi}_1^0 \qquad pp \to \ell_{(1)}\ell_{(1)} \to \ell\gamma_{(1)}\ell\gamma_{(1)}$$

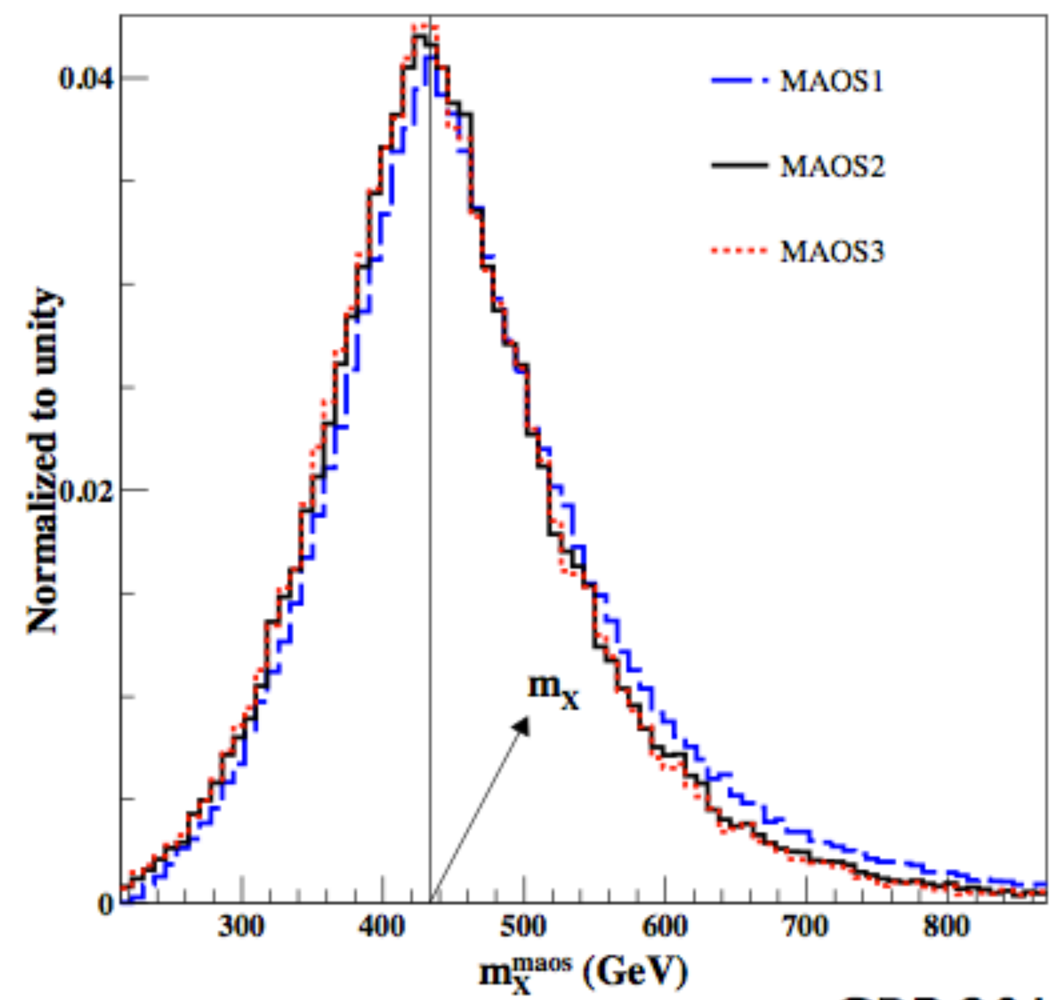


M_{T2}-assisted on-shell (MAOS) reconstruction

- Since a good approximation to the invisible momenta has been obtained, one can construct the variables that were known to be impossible.

$$H \to WW \to l\nu l\nu \qquad H/A \to \tilde{\chi}_2^0 \tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0 ll\tilde{\chi}_1^0$$





Choi et al 2009, 2010

CBP, 2011

M_{T2}-assisted on-shell (MAOS) reconstruction

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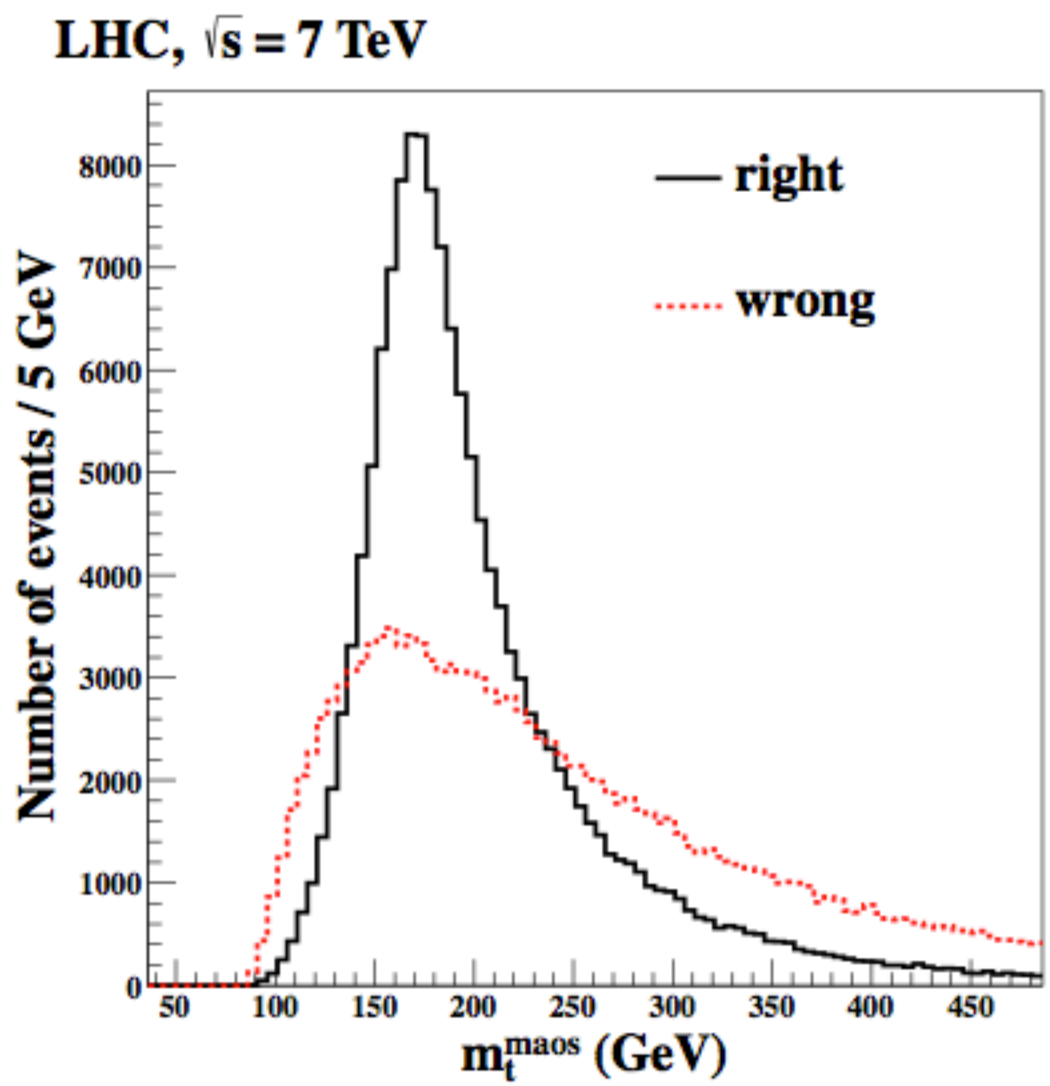
$$t\bar{t} \to bl\nu bl\nu$$



Choi, Guadagnoli, CBP, 2011

It can be useful to resolve combinatorial ambiguities.

Outlook

- The LHC is operating very well, but still we are waiting for the new physics signals.
- We should prepare for the time after the discovery and develop the methods for reconstructing the underlying theory from the data.
- The kinematical method is useful as it depends on the decay topology, not much on the detailed physics process.
- However, measuring the properties other than mass is still highly relying on the specific scenarios and the developing the useful and efficient methods for that is still ongoing.