New particle mass spectrometry at the LHC : M_{CT2} for boosted decay systems

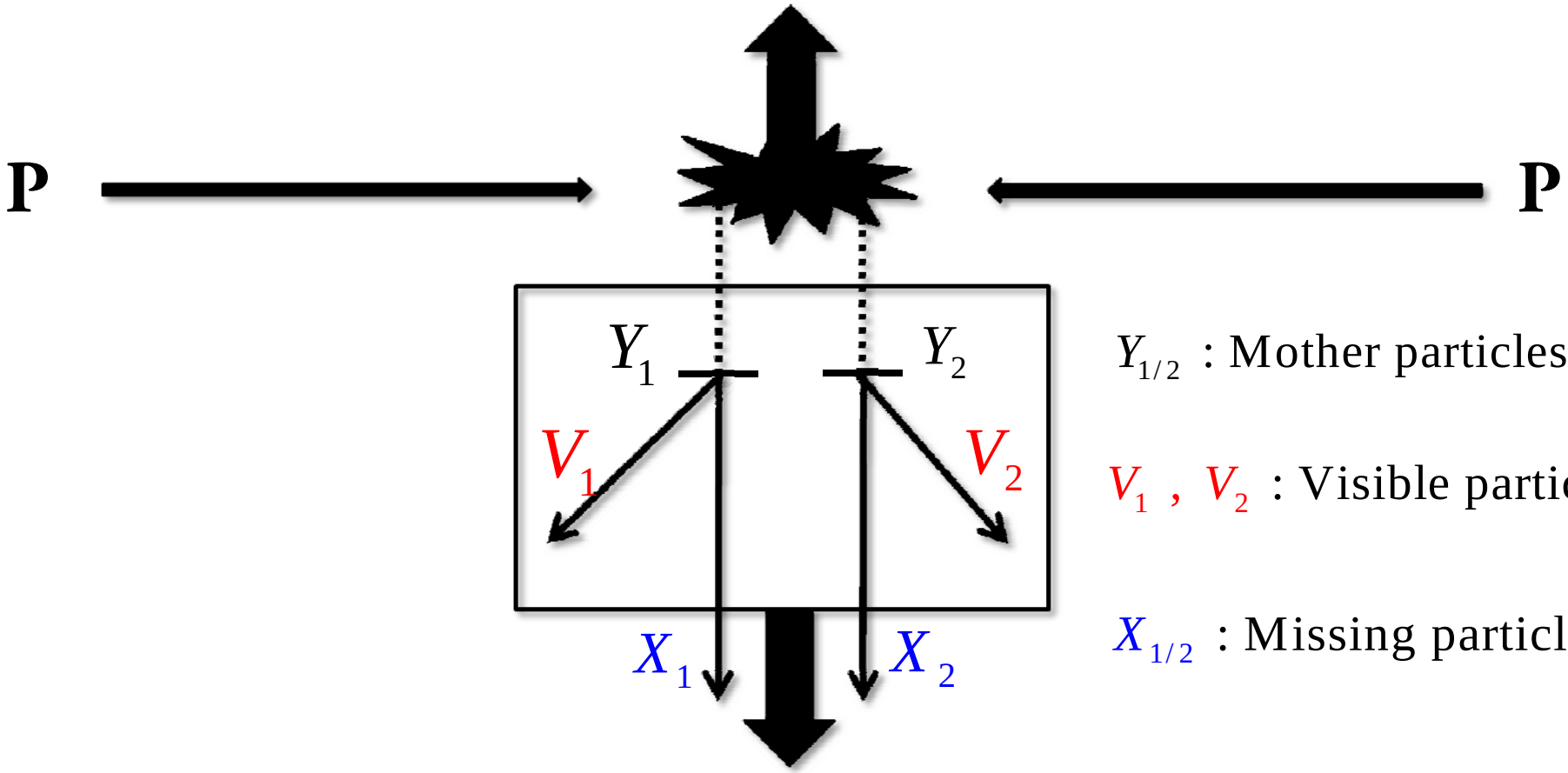
Won Sang Cho (IPMU)

In collaboration with W. Klemm and M. M. Nojiri
Ref) arXiv:1008.0391

SUSY 2010
Physikalisches Institut, Bonn, Germany
2010. 08. 23

Mass Measurement in Boosted Decay System with Missing Particle(s)

$\vec{\delta}_T$: Transverse momentum from ISR or initial decays of $Y_{1,2}$



$Y_{1/2}$: Mother particles

V_1 , V_2 : Visible particles

$X_{1/2}$: Missing particles

$-\vec{\delta}_T$ of boosted $Y_{1,2}$ system with single step decay

In the Standard Model …

- M_T (Transverse mass) for M_W measurement in $p\bar{p} \rightarrow \delta_T + W(\rightarrow \ell + \nu)$: Single Y/X

V. Barger, A. Martin and R. Phillips Z. Phys. C 21,99 (1983),
J. Smith, W. van Neerven and J. Vermaseren Phys. Rev. Lett 50, 1738 (1983)

- $M_T^2 = m_\ell^2 + m_\nu^2 + 2\,(E_T^\ell E_T^\nu - p_T^\ell p_T^\nu) = 2p_T^\ell p_T^\nu\,(1 - \cos\varphi) \leq M_W$

J. Smith et. al. Phys. Rev. Lett 50, 1738 (1983)

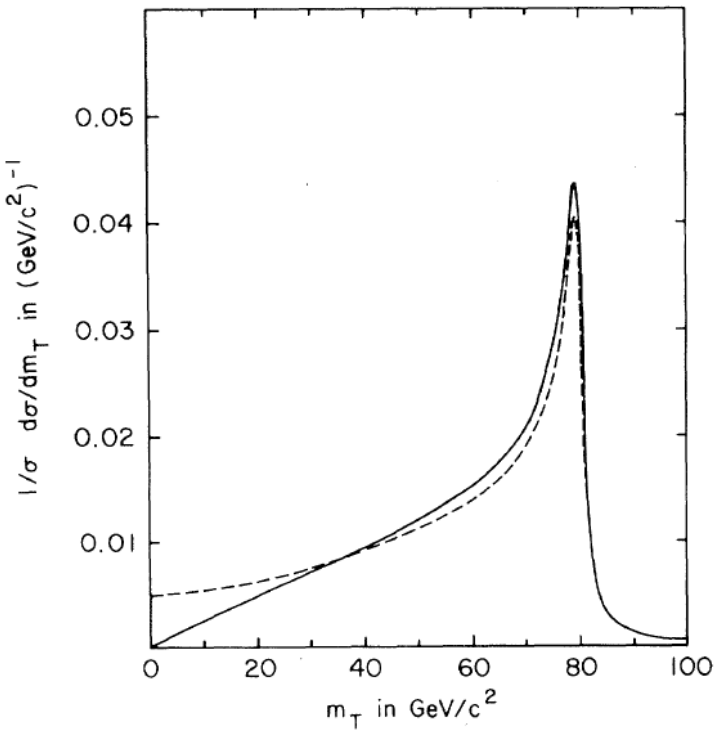
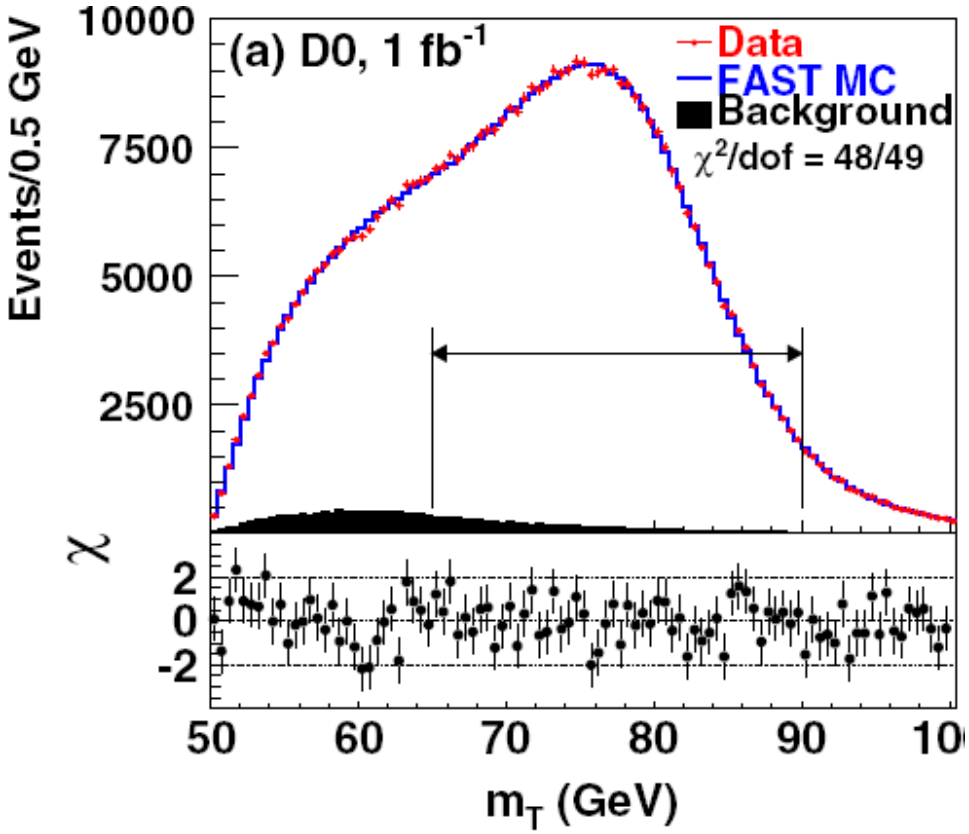


FIG. 1. $\sigma^{-1}d\sigma/dm_T$ for $M = 80$ GeV/c^2 and $\Gamma = 2.5$ GeV/c^2. The solid line is for $p_T{}^W = 0$ GeV/c, while the dashed line is for $p_T{}^W = 50$ GeV/c.

D0 Collaboration, Phys. Rev. Lett 103, 141801 (2009)



$\Rightarrow M_W = 80.401 \pm 0.021(\text{stat}) \pm 0.038(\text{sys})$ GeV

Questions for New Physics at the LHC

1) What if we don't know M_X as well as M_Y?

⇒ The endpoint relation $M_T^{max} = M_Y$ is not conserved anymore for trial missing particle mass, $\chi \neq M_X$.

2) What if there exist multiple missing particles in the boosted decay system ?? (DM candidates in Z_2-parity conserving NP models)

⇒ Only the sum of Tr. momenta is known.

3) Can we determine both of the masses, simultaneously, in such a non-reconstructable event with short decay chains ???

⇒ Yes.

M_{T2}-kink Methods

$$M_{T2} \text{ for } pp \to \delta_T + Y_1\ Y_2(\to V_1 X_1 + V_2 X_2)$$

$$M_{T2} \equiv \min[\max\{M_T(Y_1), M_T(Y_2)\}],$$

C. Lester and D. Summers, Phys. Lett. B463:99-103(1999)

$$M_T(Y_i)^2 \equiv \chi^2 + m_{Vi}{}^2 + 2\sqrt{m_{Vi}{}^2 + |V_{iT}|^2}\sqrt{\chi^2 + |X_{iT}|^2} - 2V_{iT}\cdot X_{iT}$$

χ = Trial mass of m_X. min and max over $X_{1T} + X_{2T} = \not{E}_T$

- Using $M_{T2}{}^{max}(\chi)$ / kink position at true masses, (M_Y, M_X)
- The kink is from the variety of kinematic configurations for $M_{T2}{}^{max}(\chi)$

1. ``Mass Kink" from M_{Vis} variation (i.e. only for $N_{V1\&V2} \geq 2$) :

W. Cho, (K. Choi, Y. Kim, C. Park), 0709.0288, 0711.4526, (1005.0618);
M. Nojiri et al. 0802.2412, 0808.1094, 0905.1201

2. ``Boosted Kink" from various recoiling configurations by δ_T:

: A. Barr, (B. Gripaios), C. Lester, (0709.2740), 0711.4009;
M. Burns, K. Kong, K. Matchev, F. Moortgat, L. Pape, M. Park, 0810.5576, 0909.4309;

- *However, the BK structure may not be easy to identify as it requires very large δ_T.*
  (See T. Roben's talk)
  → ``M_{T2}-bowl" (Statistical approach to pinpoint BK)
  P. Konar, K. Kong, K. Matchev, M. Park, 0910.3679;
  T. Cohen, E. Kuflik, K. Zurek, 0905.1201

Magnifying the boost effect on the system ?
M_{CT2} (Constransverse mass)

W.S.Cho, J.E.Kim and J.H.Kim, Phys.Rev.D81,095010(2010)

$$M_{CT2} \text{ for } pp \to \delta_T + Y_1\ Y_2(\to V_1 X_1 + V_2 X_2)$$

$$M_{CT2} \equiv \min[\max\{M_{CT}(Y_1), M_{CT}(Y_2)\}],$$

$$M_{CT}(Y_i)^2 \equiv \chi^2 + 2|V_{iT}|\sqrt{\chi^2 + |X_{iT}|^2} + 2V_{iT}\cdot X_{iT}$$

- χ = Trial missing particle mass, massless visible assumed.
- min & max over all possible missing Tr. Momentum,

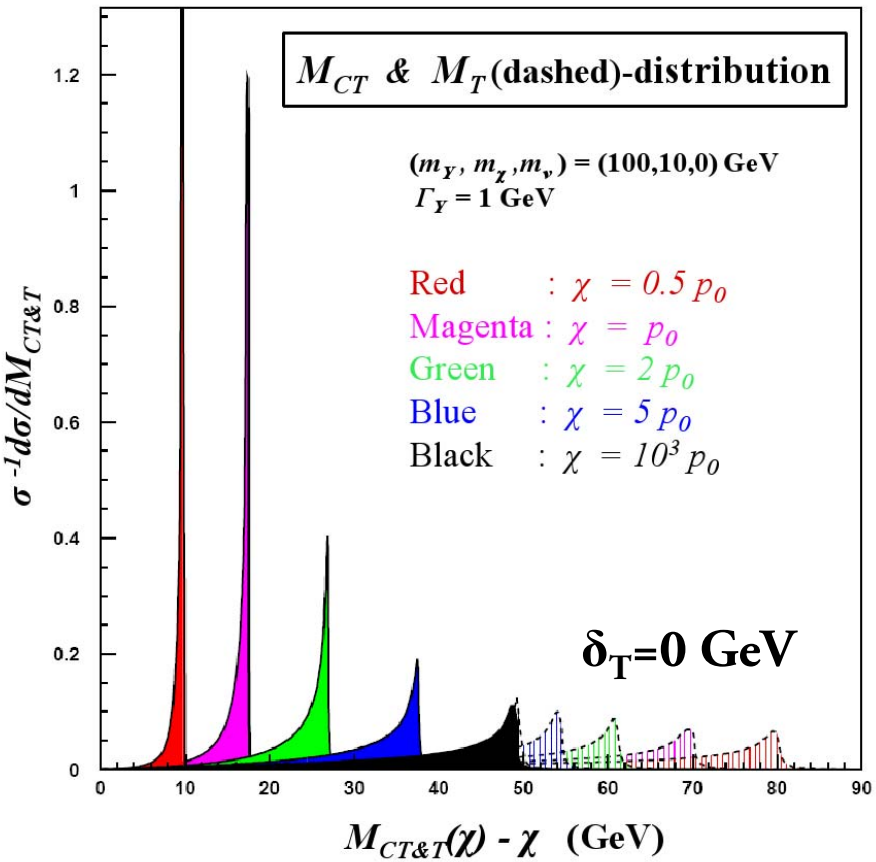
$$X_{1T} + X_{2T} = \not{E}_T$$

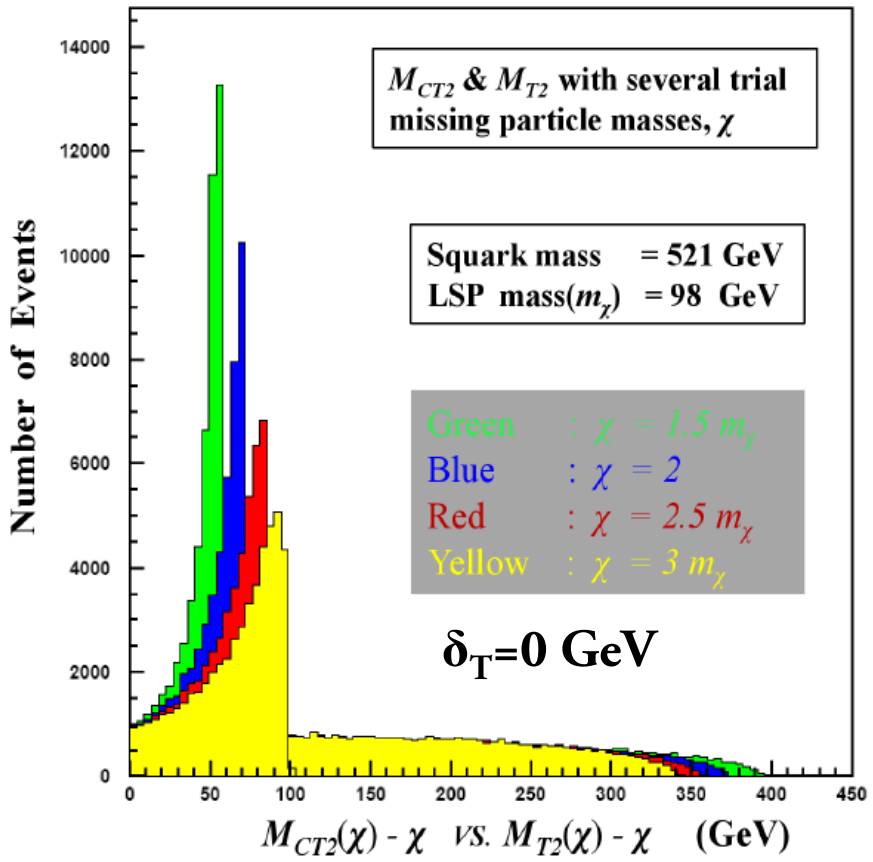
- Mixture of M_{T2} and M_{CT} [D. Tovey, JHEP0804:034(2008), using visibles crossing two decay chains]

1. Large Jacobi Factor in the Endpoint Region of $M_{CT}/M_{CT2} \Leftrightarrow M_T/M_{T2}$:

- **Compact distribution**
  for the internal momentum scale from the decay in system.
- **Controlled by trial missing particle mass, χ**
- **Accentuation of singular structure in the endpoint region**
- **Reduction of systematic error in endpoint extraction**

W.S. Cho, J.E.Kim and J.H.Kim, arXiv:0912.2354,
Phys.Rev.D81,095010(2010)





2. $M_{CT2}^{max}(\chi)$ with Non-zero Tr. Boost

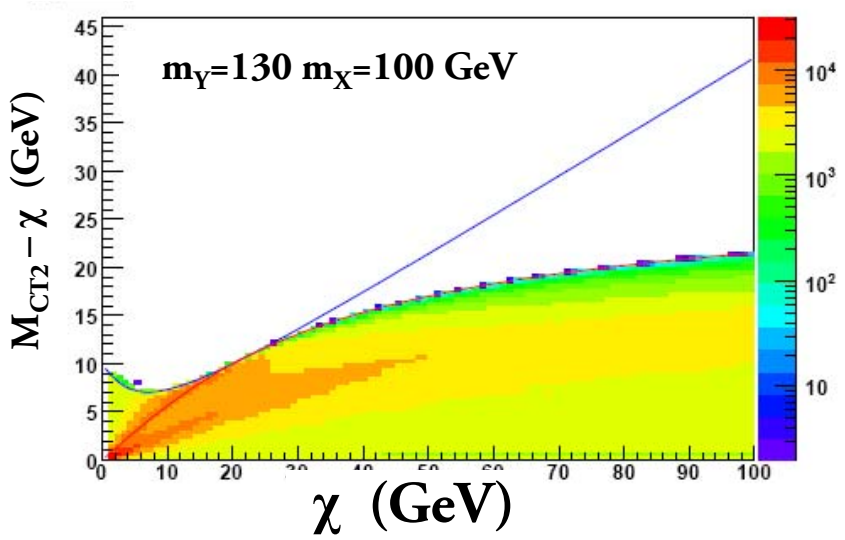
W.S. Cho, W. Klemm and M. M. Nojiri, [arXiv:1008.0391]

$$M_{CT2} \text{ for } pp \to \delta_T + Y_1\ Y_2(\to V_1 X_1 + V_2 X_2)$$

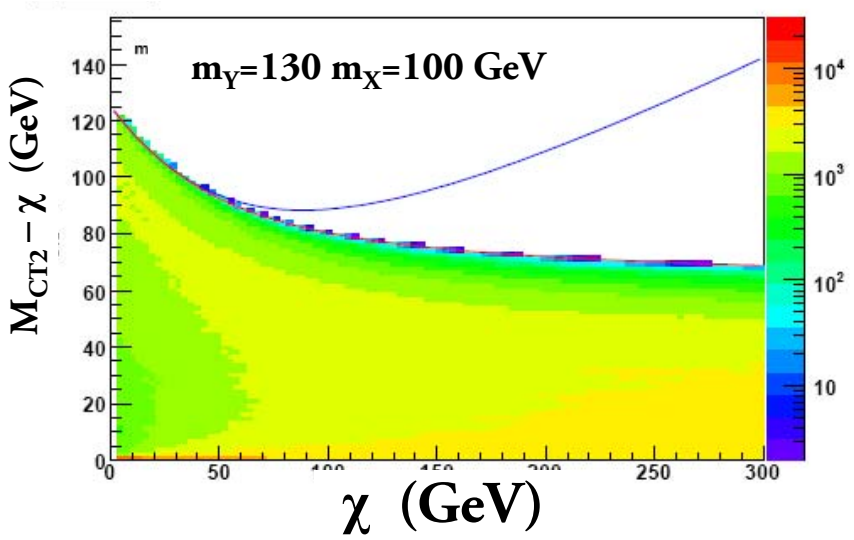
$$M_{CT2}^{\max} \equiv \begin{cases} 2\chi^2 + \dfrac{|\delta_T|^2}{4} & \text{for } \chi \le \chi_* \\ \chi^2 + 2\alpha\left(\dfrac{|\delta_T|}{2} - \alpha\right) + 2\alpha\sqrt{\chi^2 + \left(\dfrac{|\delta_T|}{2} - \alpha\right)^2} & \text{for } \chi \ge \chi_* \end{cases}$$

$$\alpha \equiv \left(\frac{m_Y^2 - m_X^2}{2m_Y}\right)\left[\frac{|\delta_T|}{2m_Y} + \sqrt{1 + \left(\frac{|\delta_T|}{2m_Y}\right)^2}\right], \quad \chi_*^2 = \frac{|\delta_T|}{2}\left(2\alpha - \frac{|\delta_T|}{2}\right)$$

δ_T=20 GeV

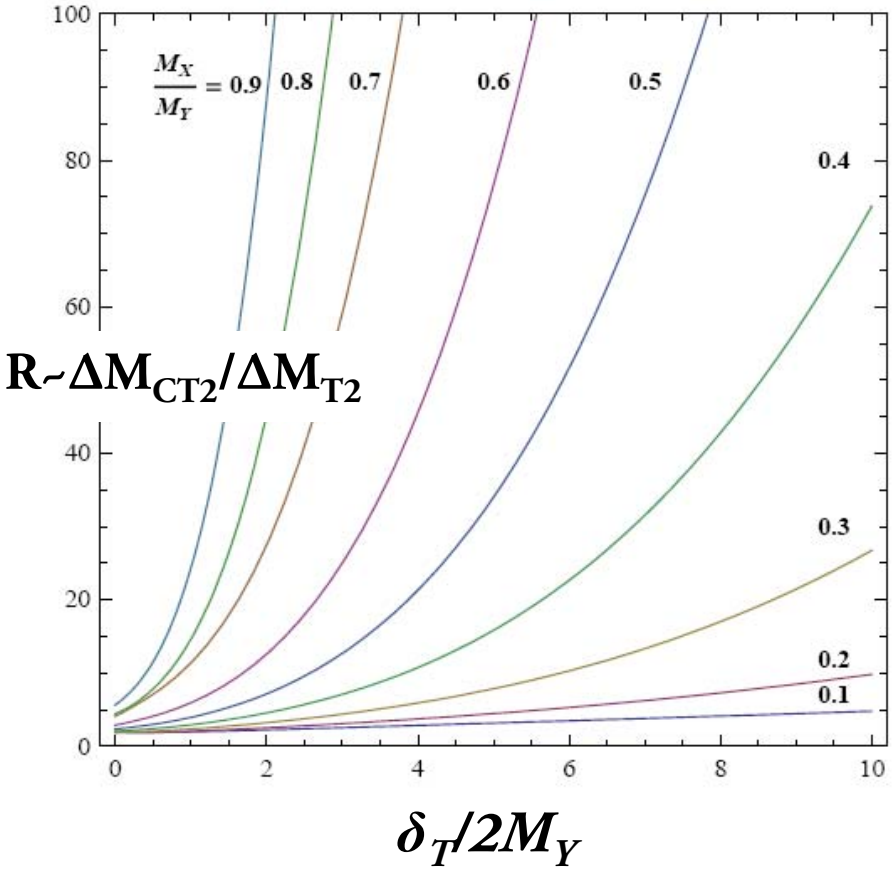


δ_T=250 GeV

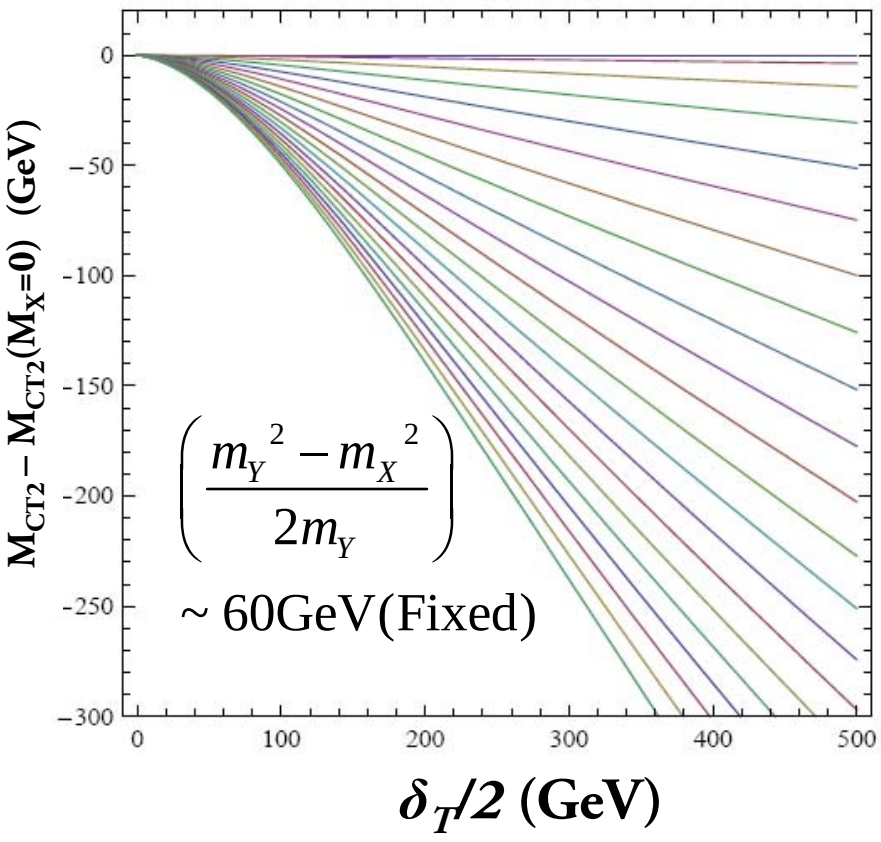


Sensitive and elastic recoiling of the endpoint with respect to external boost momentum

- Especially for near degenerate mass spectrum
- Provides enhanced experimental resolution for M_Y and M_X with moderate value of boost momentum



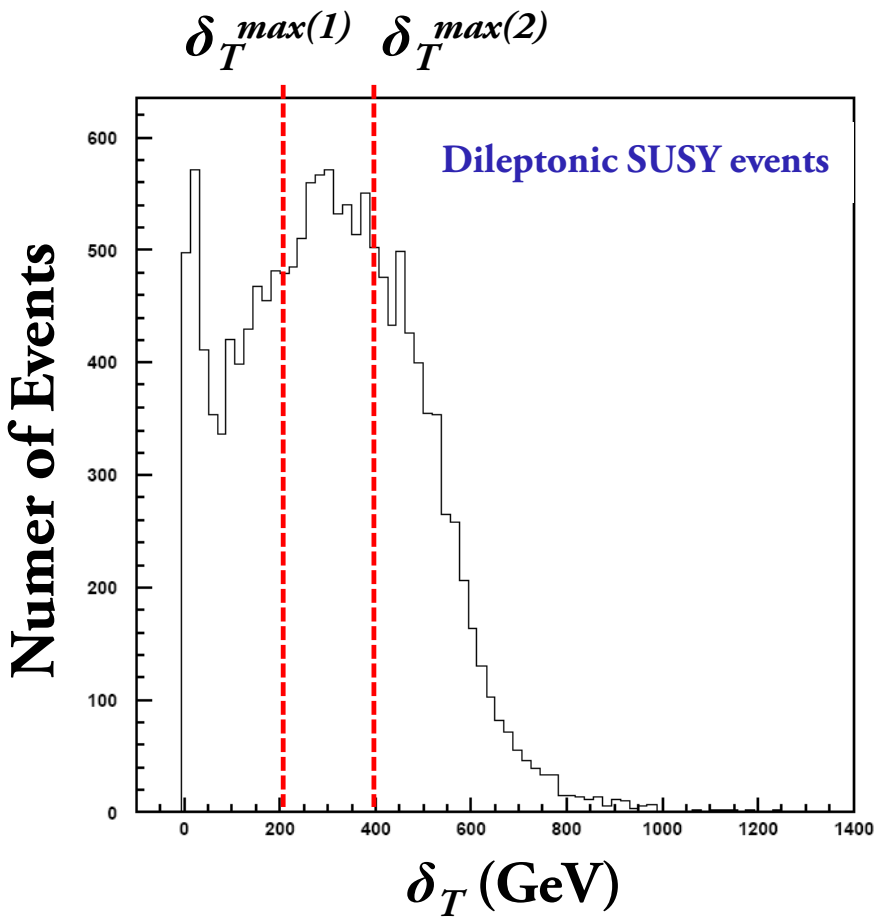
M_X =10 to 190 (GeV)



SUSY example : $m_{\tilde{\chi}_1^{\pm}}$ & $m_{\tilde{\nu}}$ measurement using same sign dileptonic events

More ref) K. Matchev, et al. arXiv:0909.4300,0910.1584; P. Konar, et al. Phys. Rev. Lett 105,051802(2010)

$$M_{CT2} \text{ for } pp \to \delta_T(\text{ISR/initial decays}) + \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}(\to \ell^{\pm}\tilde{\nu}_{\ell} + \ell^{\pm}\tilde{\nu}_{\ell})$$



- **SUSY Point**

$m_{\tilde{g}},\ m_{\tilde{q}},\ m_{\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}},\ m_{\tilde{\nu}},\ m_{\tilde{\chi}_1^{0}}$

$(\sim 720, \sim 640, 231, 157, 123)$ GeV

- **Event selection cuts**

[The ATLAS Collaboration, CERN-OPEN-2008-020]

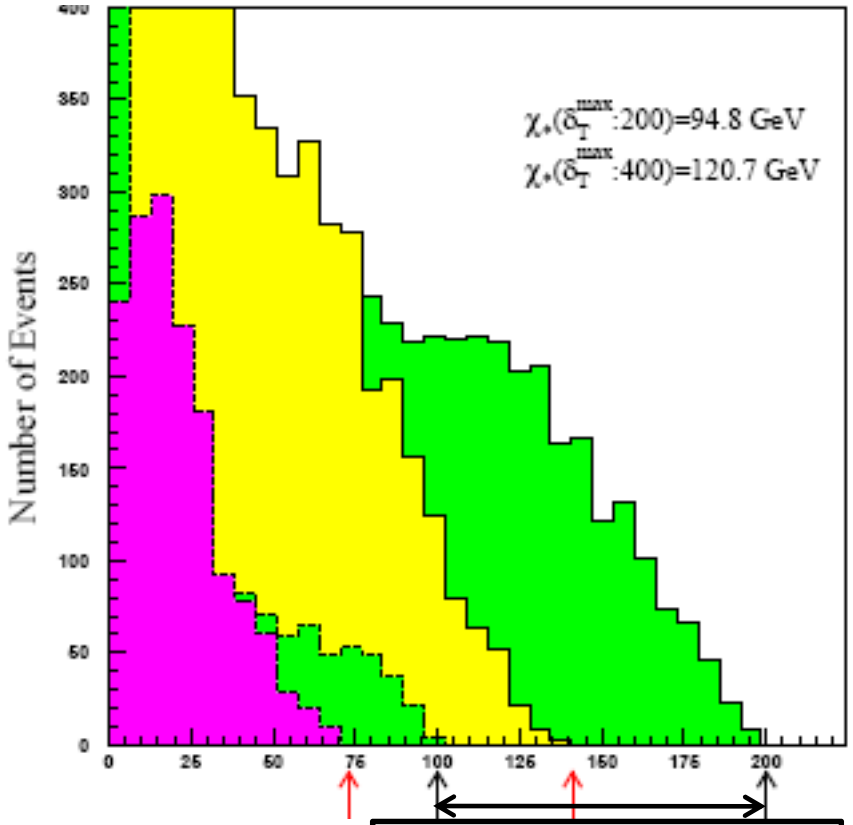
1. SS dileptonic event with $N_{jet} \geq 2$
2. $P_T(\ell_1, \ell_2) \geq 20$ GeV
3. $P_T(j_1, j_2) \geq (100,80)$ GeV
4. *Missing Tr. P* ≥ 100 GeV

Additionally,

5. $\delta_T \leq \delta_T^{max} = 200 / 400$ GeV

Result)
$M_{CT2}(\chi)$-χ distribution of SS Dileptonic events with $\delta_T \leq$ 200,400 GeV

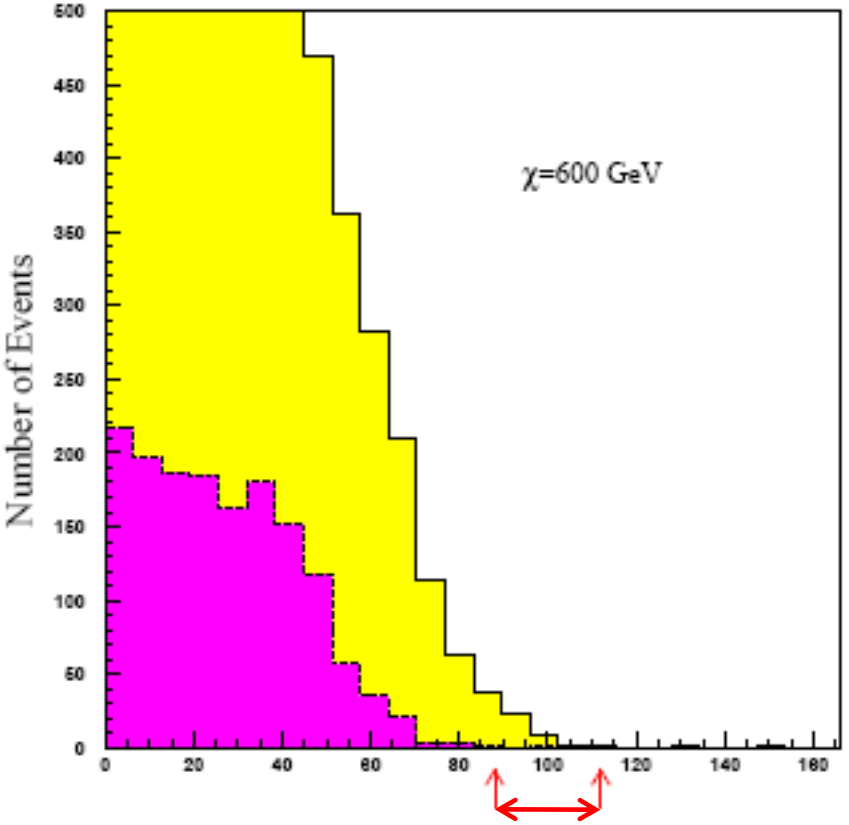
$M_{CT2}(\chi=0|\chi_*+10, \delta_T^{max}=200|400) - \chi$



ΔM_{CT2}^{max}=100 GeV

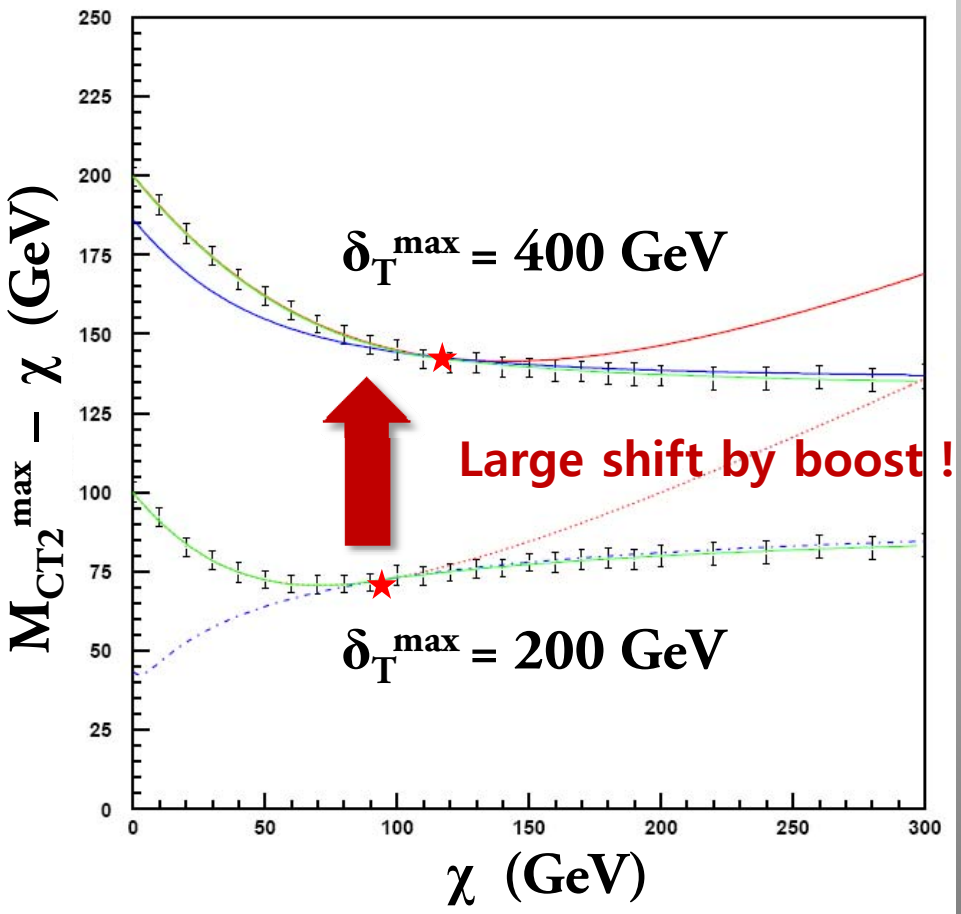
ΔM_{CT2}^{max}~ 65 GeV

$M_{T2}(\chi=600, \delta_T^{max}=200|400)-\chi$



ΔM_{T2}^{max}~ 20 GeV

Result) True/Reconstructed $M_{CT2}^{max}(\chi)$, Reconstructed Masses



★ : Position of the kink,

$$\chi_*^{\,2} = \frac{|\delta_T^{\max}|}{2}\left(2\alpha - \frac{|\delta_T^{\max}|}{2}\right)$$

$$= (94.8, 120.7)\ \text{GeV}$$

$$\alpha \equiv \left(\frac{m_Y^{\,2} - m_X^{\,2}}{2m_Y}\right)\left[\frac{|\delta_T^{\max}|}{2m_Y} + \sqrt{1 + \left(\frac{|\delta_T^{\max}|}{2m_Y}\right)^2}\right]$$

Segmented fitting with $M_{CT2}^{max}(\chi,\delta_T^{max})$ provides two α values.

$$\alpha(\delta_T^{\max} = 200 \,|\, 400)\ (GeV)$$

$$= (92.4 \pm 2.5 \,|\, 132.6 \pm 3.4)$$

$$\Rightarrow (M_{\tilde{\chi}_1^\pm}, M_{\tilde{\nu}_\ell})$$

$$= (231.2 \pm 9.9 \,|\, 159.3 \pm 5.9)$$

Conclusion

1. $M_{CT/CT2}$ distribution can have **compact endpoint structure** with respect to the internal momentum scale from decay system.

2. It shows **very sensitive endpoint recoiling** by the external boost momentum of the decay system like a flubber ball.

3. Both of the facts can be utilized in the mass measurement in **boosted single step decay systems which must be the most fundamental and general element of complex event topologies** at future hadron colliders.