Mass measurement in boosted decay system at the LHC : M_{CT2} , complementary to M_{T2}

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Ref) arXiv:0912.2354, 1008.0391
+ work in progress

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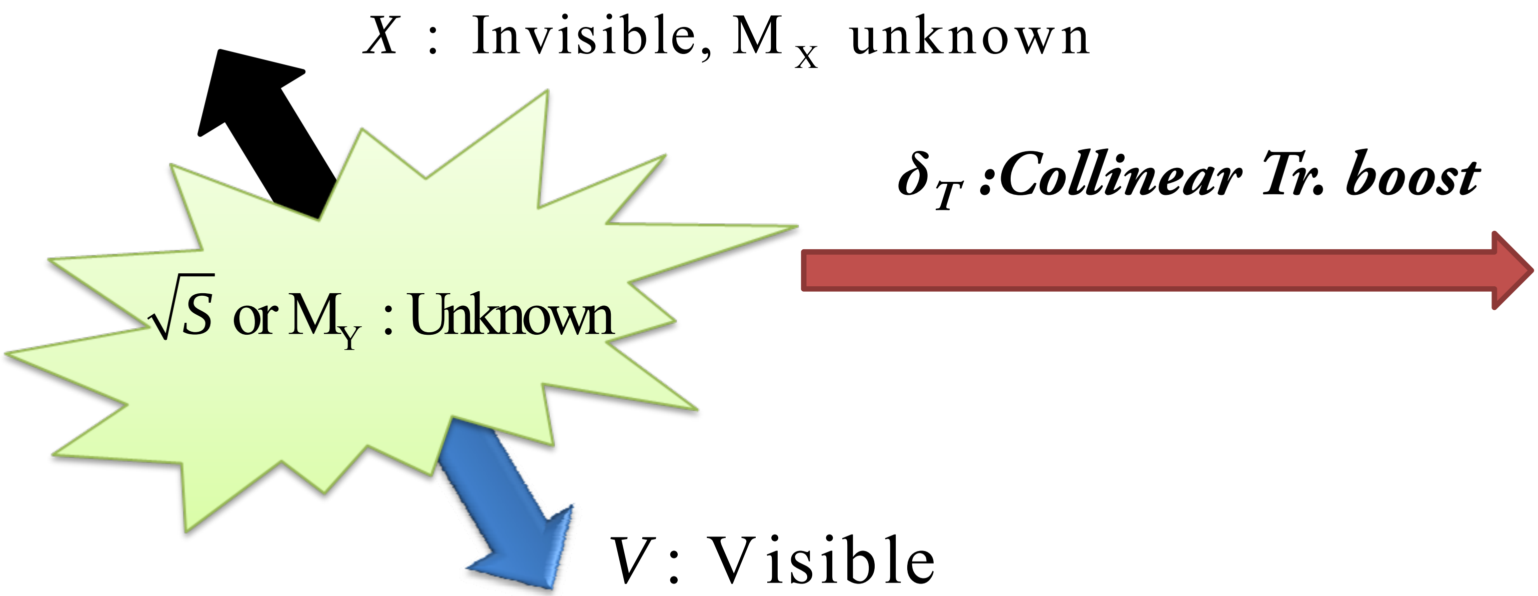
Reconstruction of Semi-invisible Boosted Decay System

$$Y \rightarrow X\,(inv) + V\,(vis)$$

- **SIMPLEST event topology for BSM at hadron collider**



- **NON-RECONSTRUCTABLE**
- **DISTORTED KINEMATIC BOUNDARIES of visible Tr. momenta by Tr. Boost effects → Important information for both M_Y and M_X**

EFFECTIVE Collider basis ??
to illuminate boosted and distorted phase space

- Two requirements

1) Should sensitive to Sqrt(S), M_X and M_V

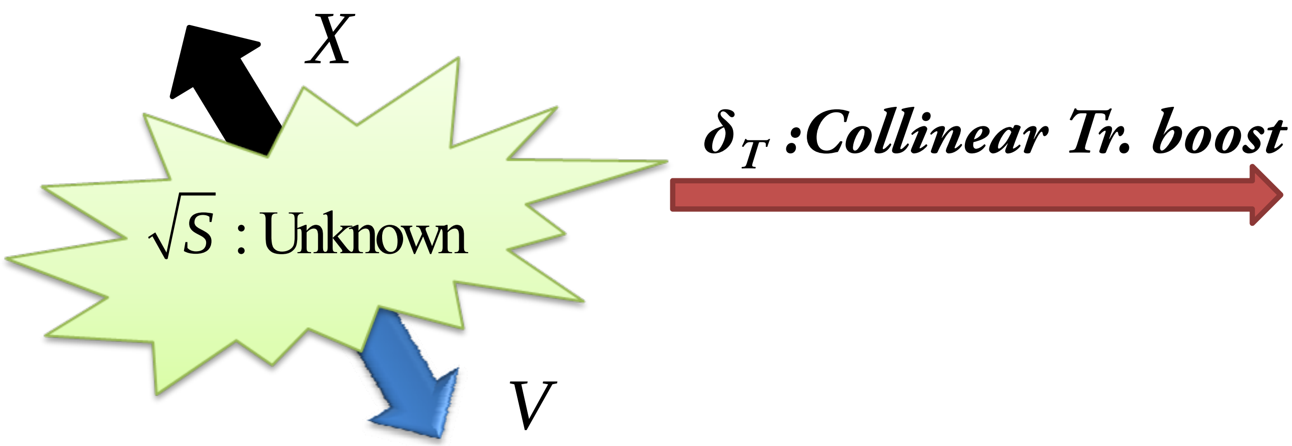
→ Overall volume of the phase space ~ P_V

2) Should sensitive to Tr. boost effect

→ To resolve the distorted PS by ~ δ_T

- However, both the 1) and 2) are hard to be satisfied simultaneously by usual transverse mass variable, because mass is boost invariant.

Suggestion : Using Complementary Variables



Example)

	$\sqrt{S}$	$Collinear-Boost(\delta_T)$
M_{CT}^{max}	Invariant	Sensitive
M_T^{max}	Sensitive	Invariant

What is the M_{CT} ?

Contra-linear boosts invariant, M_{CT}

- **Contra-linear boosts**

  ≡ Two independent back-to-back boosts of V and X

- M_{CT}

$$M_{CT}^2 \equiv m_X^2 + m_V^2 + 2(E_T^V E_T^X + V_T \cdot X_T)$$

$$\leq$$

$$M_C^2 \equiv m_X^2 + m_V^2 + 2(E^V E^X + V \cdot X)$$

- Contra-linear boosts invariant endpoint

$\Rightarrow$ $\sqrt{S}$ invariance : $M_{CT}^{max}(\sqrt{S}) = M_{CT}^{max}(\sqrt{S_{thre}})$

- Collinear boost sensitive

- M_T

$$M_T^2 \equiv m_X^2 + m_V^2 + 2(E_T^V E_T^X - V_T \cdot X_T)$$

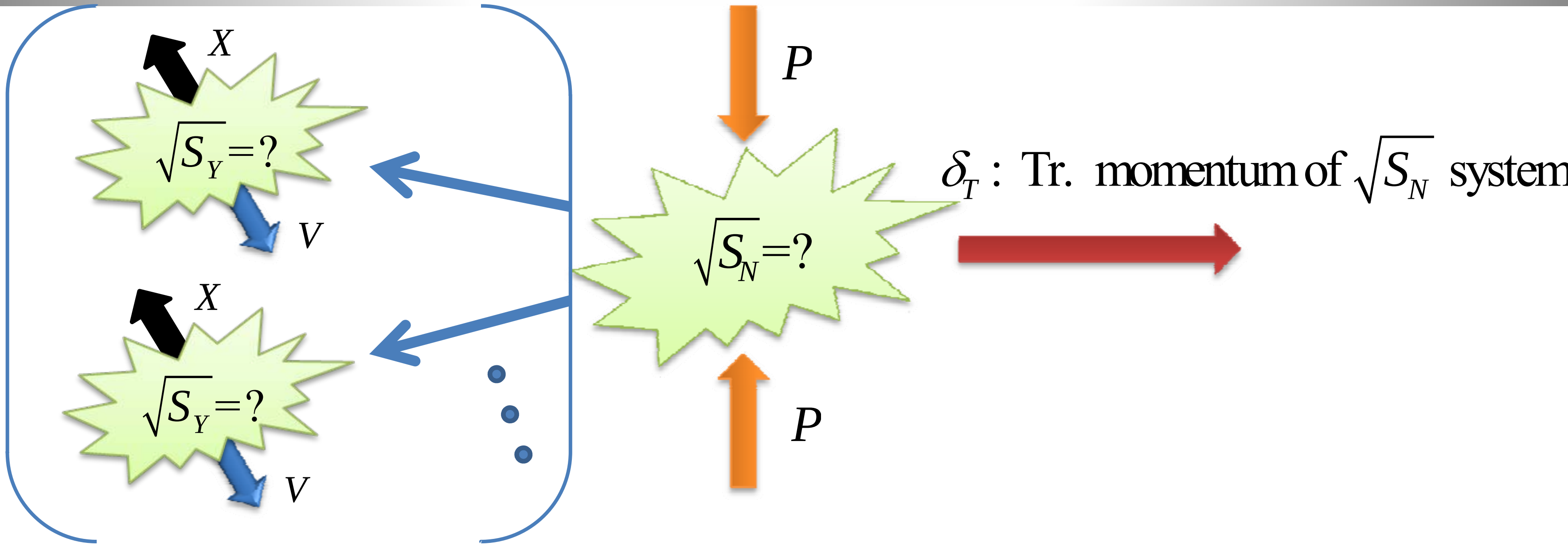
$$\leq$$

$$S \equiv m_X^2 + m_V^2 + 2(E^V E^X - V \cdot X)$$

$\Rightarrow$ $\sqrt{S}$ sensitive

$\Rightarrow$ Collinear boost invariant endpoint

Generalization for N-identical decays is possible



- **M_{CTN} using minimization subject to MET constraint as in $M_{T2/TN}$**
  → Washing out unknown effect of Sqrt(SN)

Example) N=2 with $pp \to \delta_T + Y_1\ Y_2(\to V_1 X_1\ +\ V_2 X_2)$

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

  $M_{CT}(Y_i)^2 \equiv \chi^2 + m_V{}^2 + 2(E_T^{Vi} E_T^{Xi} + \ V_{iT} \cdot X_{iT})$

  χ : Trial X mass

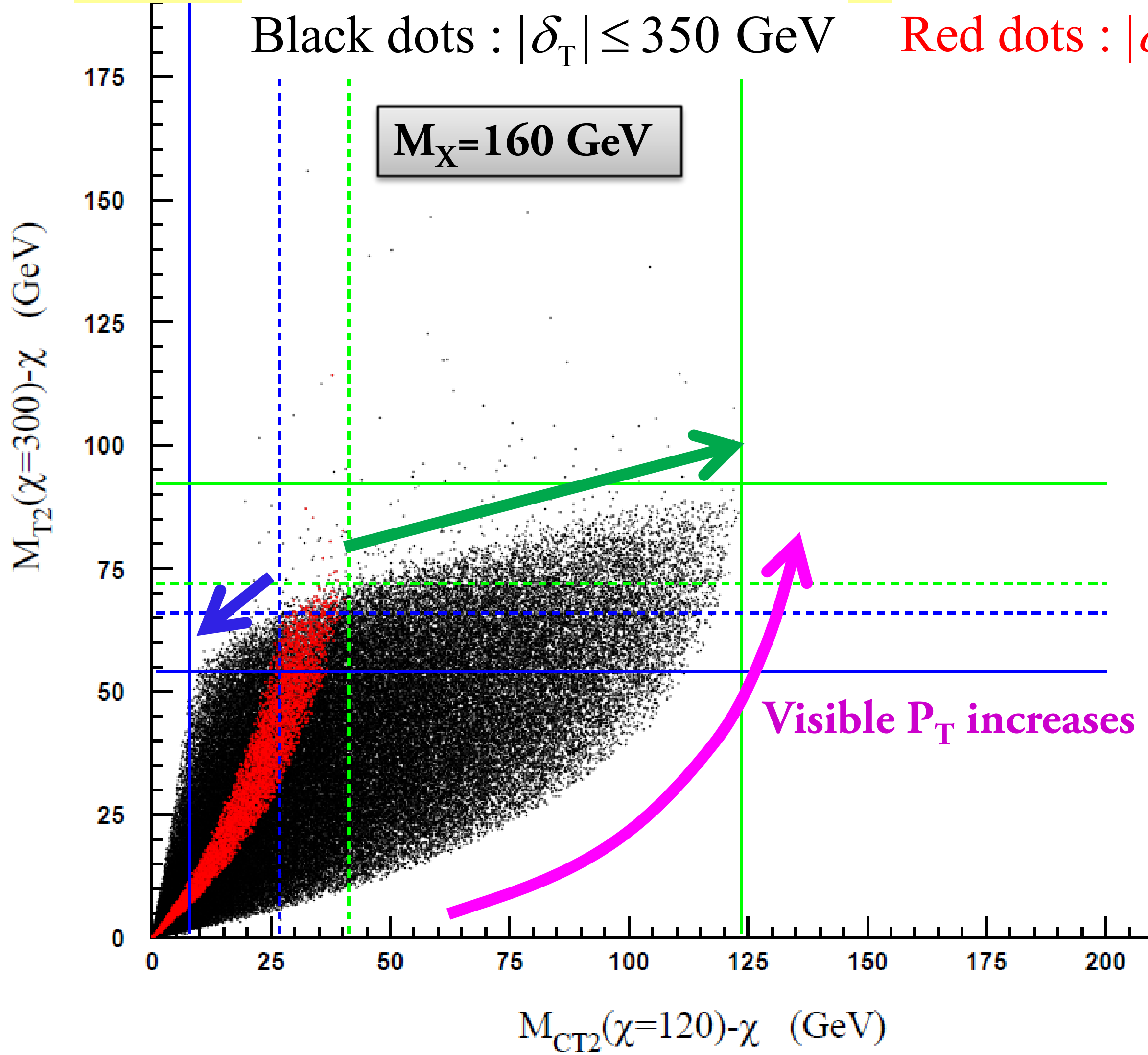
Utilizing the Complementarity

• **Complementarity - Plot (C - Plot) :**

$$M_{T2}(\xi > M_X)\text{-}\xi \;\text{ vs }\; M_{CT2}(\chi > \chi_*)\text{-}\chi \text{ with } |\delta_T| \le |\delta_T^{max}|$$

Black dots : $|\delta_T| \le 350$ GeV

Red dots : $|\delta_T| \le 50$ GeV



• **Extreme Kinematic boost Configurations are easily accessible in the C-Plot**

EKC 1> $V_T(\rightarrow)$, $\delta_T(\rightarrow)$

→ : Shift of EKC-1 by larger Tr. Boost

EKC 2> $V_T(\leftarrow)$, $\delta_T(\rightarrow)$

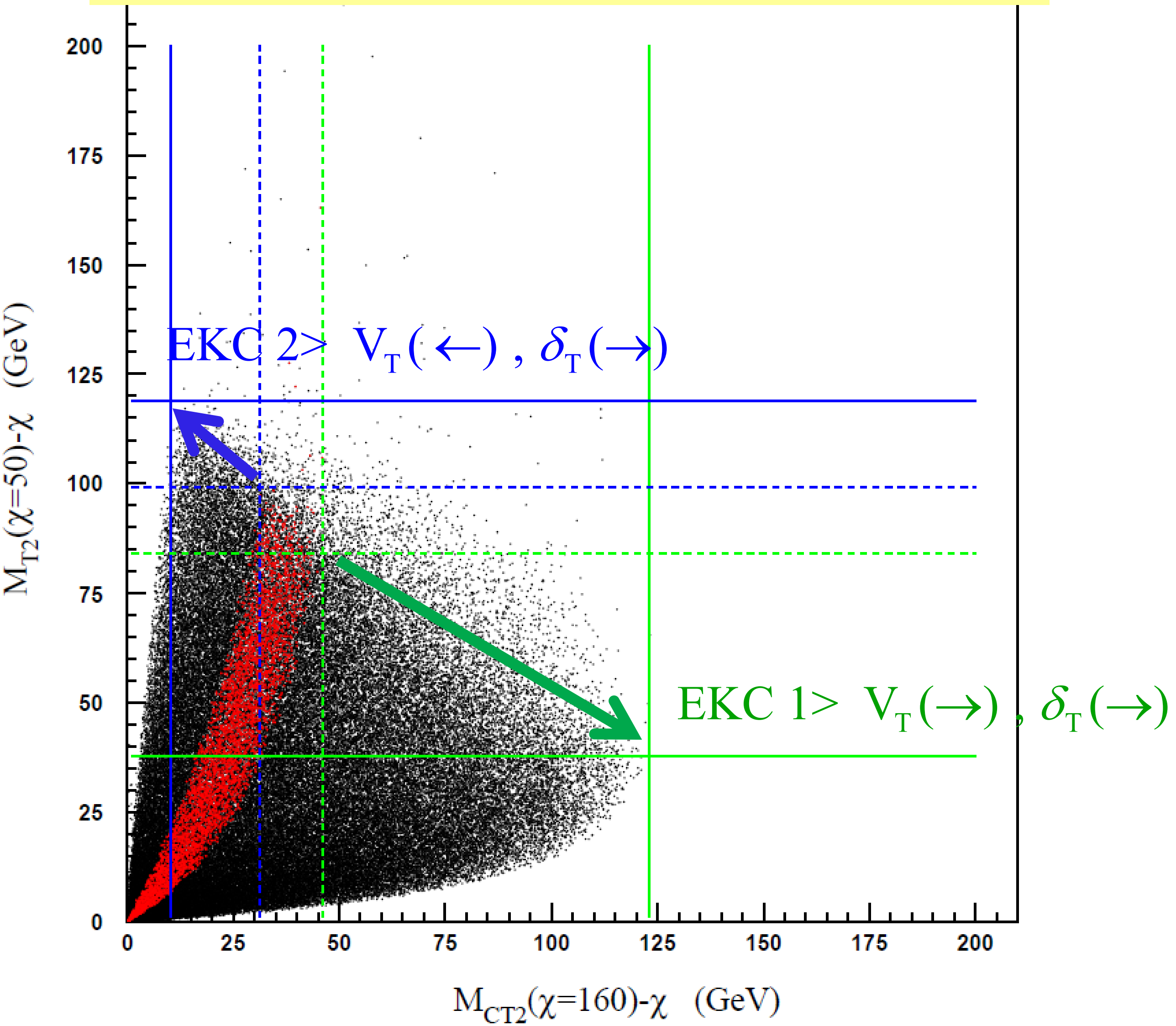
← : Shift of EKC-2

• **Sensitivity of M_{CT2} under the Tr. boost**
→ Much larger number density of shifted events in M_{CT2} projection

• **Changing the trial masses :**

Ex)

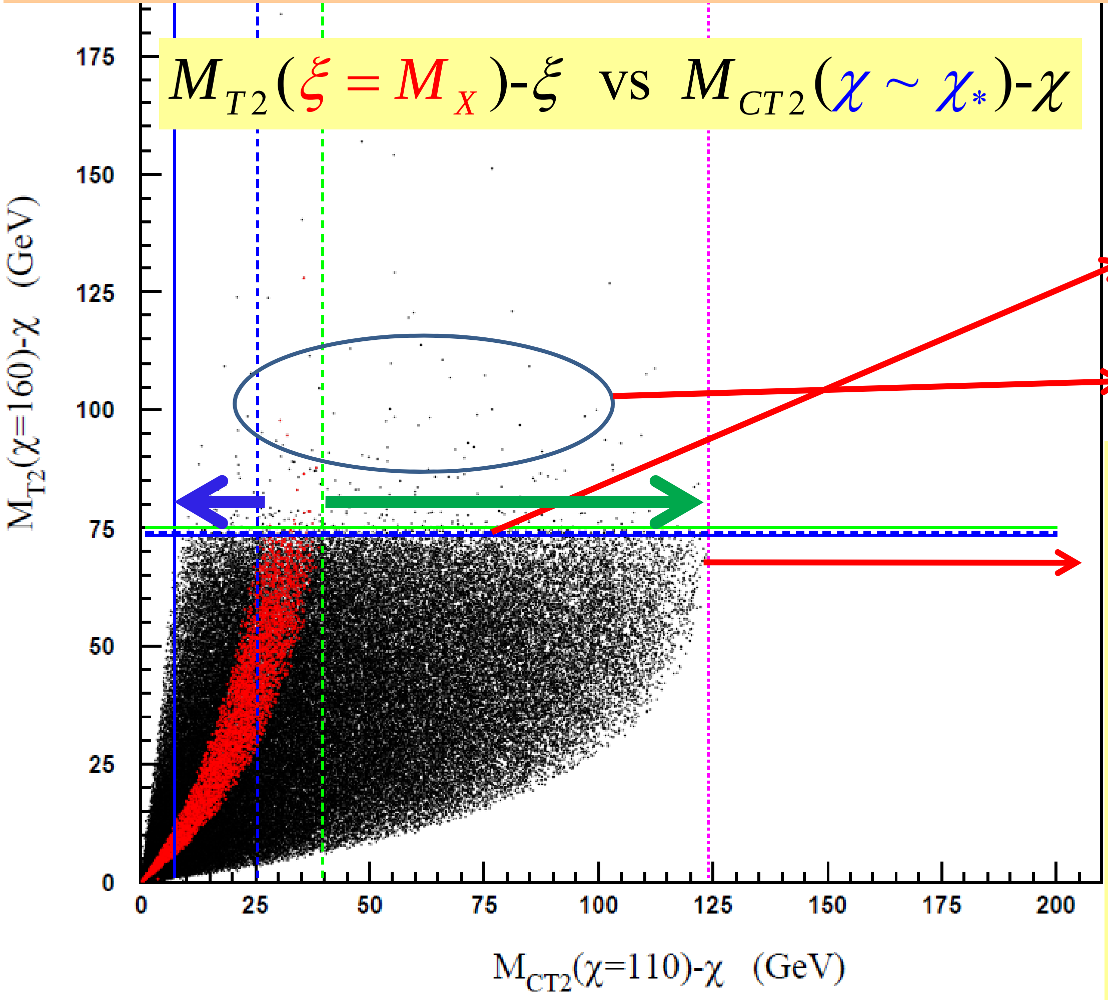
$$M_{T2}(\xi < M_X)\text{-}\xi \quad \text{vs} \quad M_{CT2}(\chi > \chi_*)\text{-}\chi$$



• Statistical interpretation of the complementarity

: The less the statistical uncertainty for ${M_{T2}}^{\max}(\xi)$ or ${M_{CT2}}^{\max}(\chi)$, the larger the number of corresponding M_{CT2} or M_{T2} values, respectively.

→ This behavior becomes maximal as $\xi \to M_X$ or $\chi \to \chi_*$



For $\xi = M_X$, any of ${M_{CT2}}^{\max}(\chi, \delta_T)$ can contribute to ${M_{T2}}^{\max} = M_Y$
→ Flat !

Width effect of M_Y on ${M_{T2}}^{\max}$

$$\left.\frac{\partial M_{T2}}{\partial M_{CT2}(\chi = \chi_*)}\right|_{M_{CT2} \to {M_{CT2}}^{\max}}$$

along boundary curve

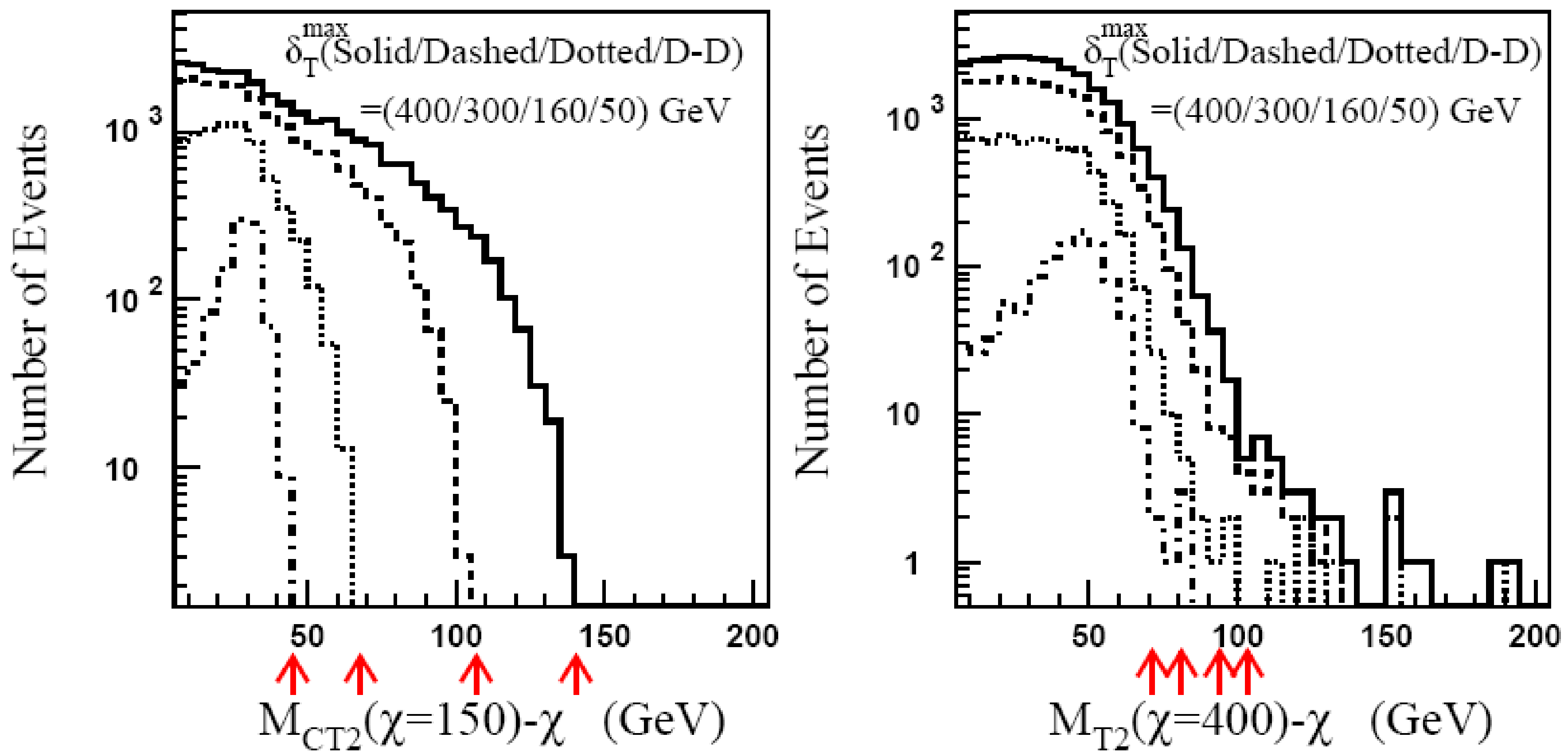
→ ∞

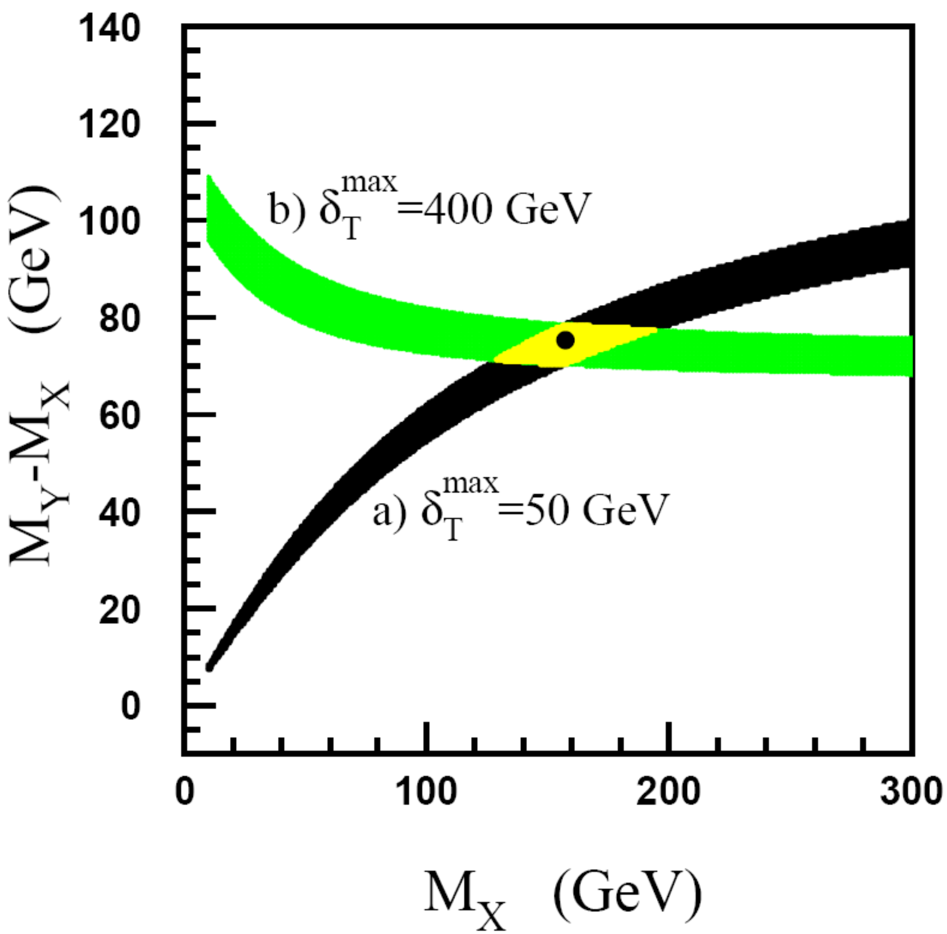
→ No width effect !

→ Much more cleaner endpoint near $\chi \sim \chi_*$

Utilizing the Tr. boost sensitive and clean M_{CT2} endpoints for SUSY mass measurement

$$M_{CT2/T2} \text{ for } pp \rightarrow \delta_T (\text{ISR/initial decays}) + \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}(\rightarrow \ell^{\pm}\tilde{\nu}_\ell \;+\; \ell^{\pm}\tilde{\nu}_\ell)$$





$\rightarrow \Delta M_{\tilde{\chi}_1^\pm} \sim$ O(10) GeV might be acheivable only using $M_{CT2}{}^{max}$ under Tr. boost effects

Summary

1. $M_{CT/CT2}$ as a complementary basis to $M_{T/T2}$, in representing distorted phase space of semi-invisible boosted decay systems.

   → Complementary-Plot is very useful in access to various hidden kinematic boost configurations.

2. M_{CT2} shows very sensitive recoiling on Tr. boost of the decay system, with cleaner endpoint structure.

3. All these properties can be combined and utilized for the mass measurement in complicated boosted decay chains.

M_{CT2}^{max} under transverse boost effect

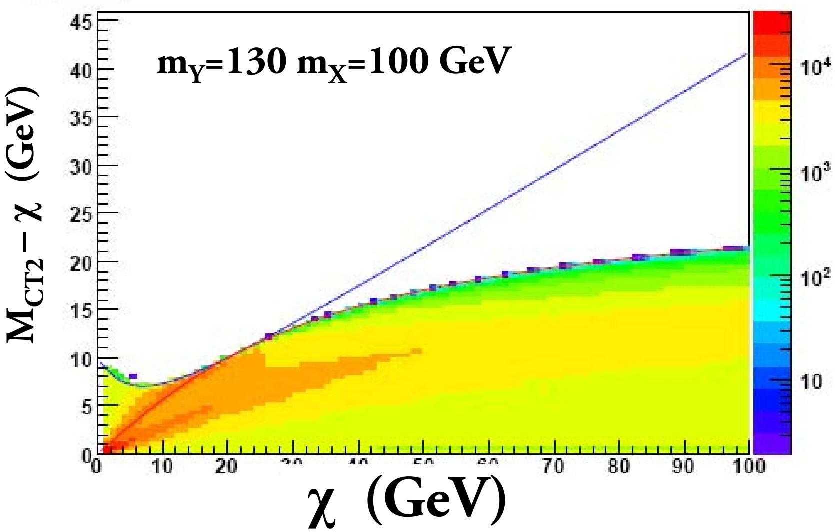
W.S. Cho, W. Klemm and M. M. Nojiri, [arXiv:1008.0391]

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

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

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

δ_T=20 GeV



δ_T=250 GeV