"Hands on"
Transverse variables

References

[1] A. J. Barr, T. J. Khoo, P. Konar, K. Kong, C. G. Lester, K. T. Matchev, and M. Park, "Guide to transverse projections and mass-constraining variables," *Phys. Rev. D* **84** no. 9, (Nov., 2011) 095031, `arXiv:1105.2977 [hep-ph]`.

[2] A. Barr, C. Lester, and P. Stephens, "A variable for measuring masses at hadron colliders when missing energy is expected m_{T2}: the truth behind the glamour," *Journal of Physics G Nuclear Physics* **29** (Oct., 2003) 2343–2363, `arXiv:hep-ph/0304226`.

[3] J. Smith, W. van Neerven, and J. Vermaseren, "The transverse mass and width of the W boson," *Phys.Rev.Lett.* **50** (1983) 1738.

[4] K. Agashe, D. Kim, D. G. E. Walker, and L. Zhu, "Using M_{T2} to distinguish dark matter stabilization symmetries," *Phys. Rev. D* **84** no. 5, (Sept., 2011) 055020, `arXiv:1012.4460 [hep-ph]`.

[5] G. F. Giudice, B. Gripaios, and R. Mahbubani, "Counting dark matter particles in LHC events," *Phys. Rev. D* **85** no. 7, (Apr., 2012) 075019, `arXiv:1108.1800 [hep-ph]`.

An old friend

$$p_\mu = \{E, p_x, p_y, p_z\}$$

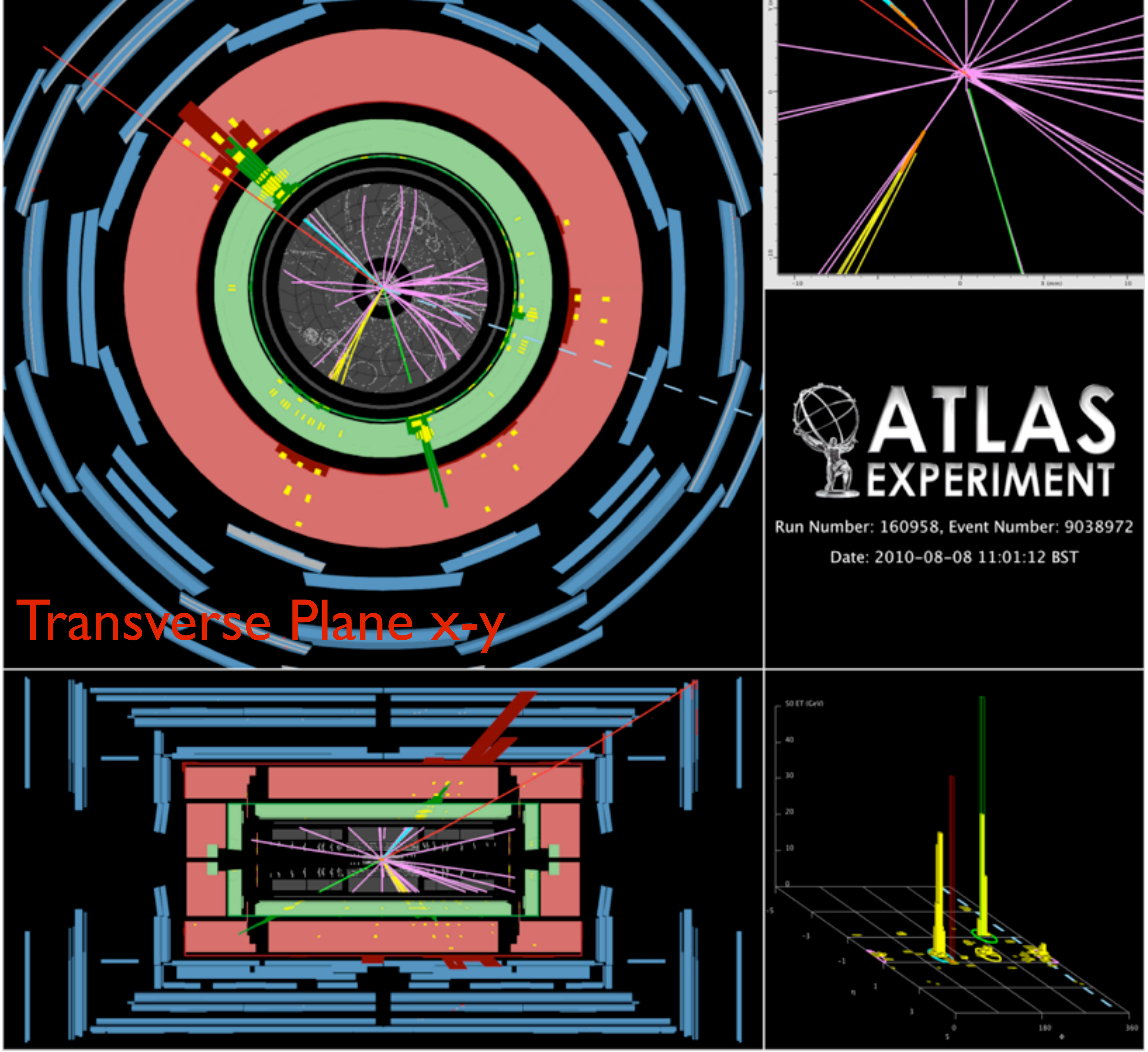
$$= \{E,\ p\sin\theta\sin\phi,\ p\sin\theta\cos\phi,\ p\cos\theta\}$$

A new (much better) friend

$$p_\mu(y,\phi,p_T,m) = \left\{\cosh(y)\sqrt{m^2+p_T^2}, p_T\sin(\phi), p_T\cos(\phi), \sinh(y)\sqrt{m^2+p_T^2}\right\}$$

$$y = \frac{1}{2}\log\frac{E+p_z}{E-p_z} = \frac{1}{2}\log\frac{E+p\cos\theta}{E-p\cos\theta}\,,$$

$$y \to y + y_{boost}, \text{ where } \cosh y_{boost} = \gamma, \, \sinh y_{boost} = \gamma\beta.$$


ATLAS
EXPERIMENT
Run Number: 160958, Event Number: 9038972
Date: 2010-08-08 11:01:12 BST
Transverse Plane x-y

A decay

$$a \to bc$$

$$p_\mu^{(a)} = p_\mu^{(b)} + p_\mu^{(c)}$$

$$\begin{aligned} m_a^2 &= p^{(a)} \cdot p^{(a)} = \left(p_\mu^{(b)} + p_\mu^{(c)}\right)^2 \\ &= 2 \cosh \Delta\mathrm{y} \sqrt{p_{T,b}^2 + m_b^2} \sqrt{p_{T,c}^2 + m_c^2} - 2 \cos \Delta\phi \, p_{T,b} p_{T,c} + m_b^2 + m_c^2 \,. \end{aligned}$$

in presence of invisible particles

no complete longitudinal momentum information
(partonic center of mass is not know)

zero transverse momentum for the initial state
is still it is a good approximation

Mass-preserving transverse projection

$$\{p_x, p_y, p_z\} \to \{p_x, p_y\} \, .$$

$$E = \sqrt{m^2 + p_x^2 + p_y^2 + p_z^2} \to E_T = \sqrt{m^2 + p_x^2 + p_y^2}$$

(1+2)-vector

$$\tilde{p}_\alpha(\phi, p_T, m) = \left\{ \sqrt{m^2 + p_T^2}, p_T \sin(\phi), p_T \cos(\phi) \right\}$$

$$\tilde{p} \cdot \tilde{p} = m^2$$

$$\eta_T = \{1, -1, -1\}$$

A decay

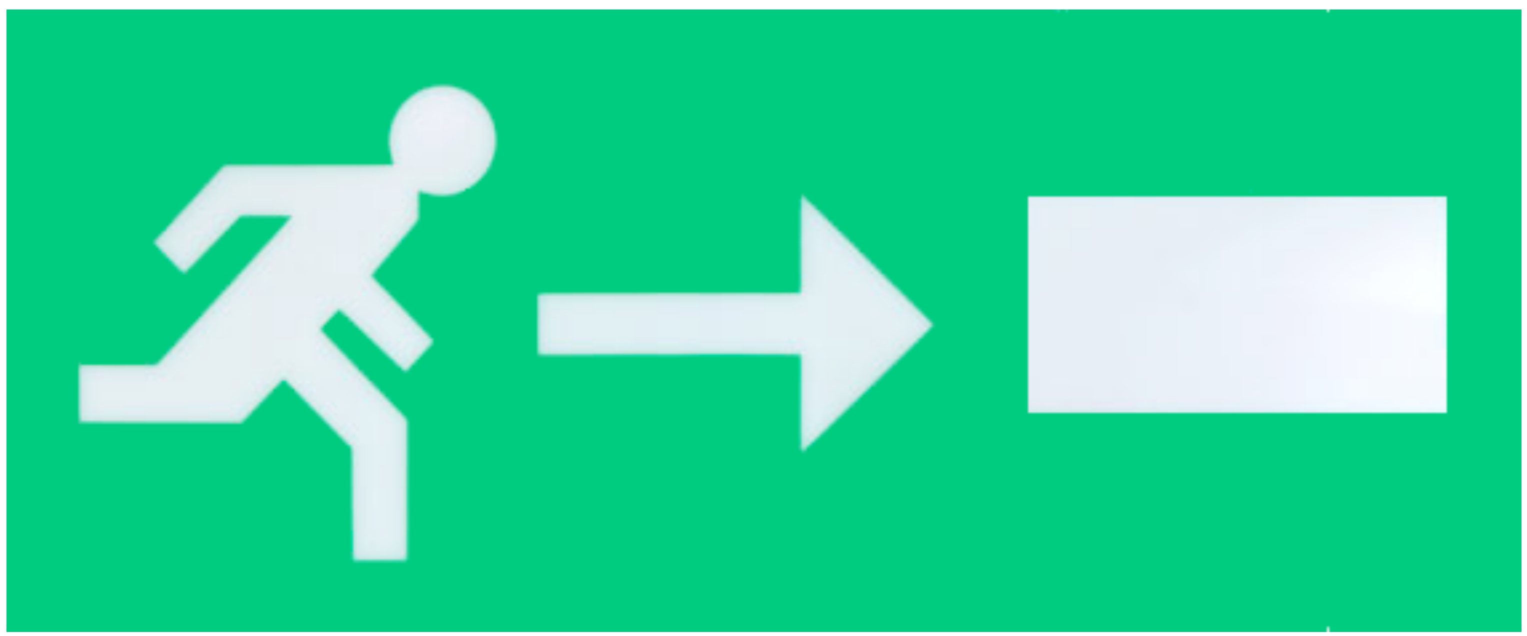
$$a \to bc$$

$$\begin{aligned}\tilde{m}_{bc}^2 &= \left(\tilde{p}_\alpha^{(b)} + \tilde{p}_\alpha^{(c)}\right)^2 \\ &= 2\sqrt{p_{T,b}^2 + m_b^2}\sqrt{p_{T,c}^2 + m_c^2} - 2\cos(\Delta\phi) p_{T,b} p_{T,c} + m_b^2 + m_c^2 \leq m_a^2\end{aligned}$$

$$\tilde{m}_{bc} = m_{bc} \quad \text{for } y_b = y_c$$

decay products have equal rapidity
"y"

W decay



rapidity alignment

rapidity is shifted under boosts

$$y \rightarrow y + y_{boost}$$

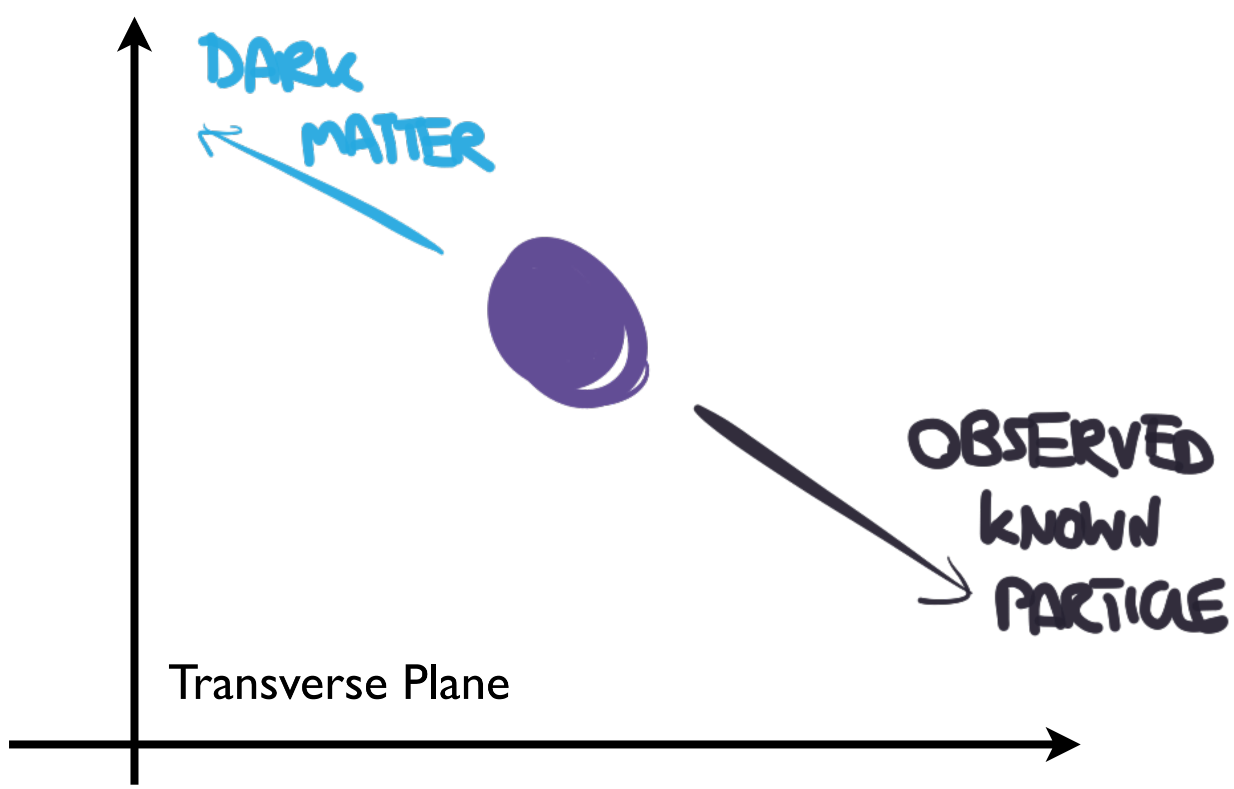
a boost along z brings the two particles to a frame where

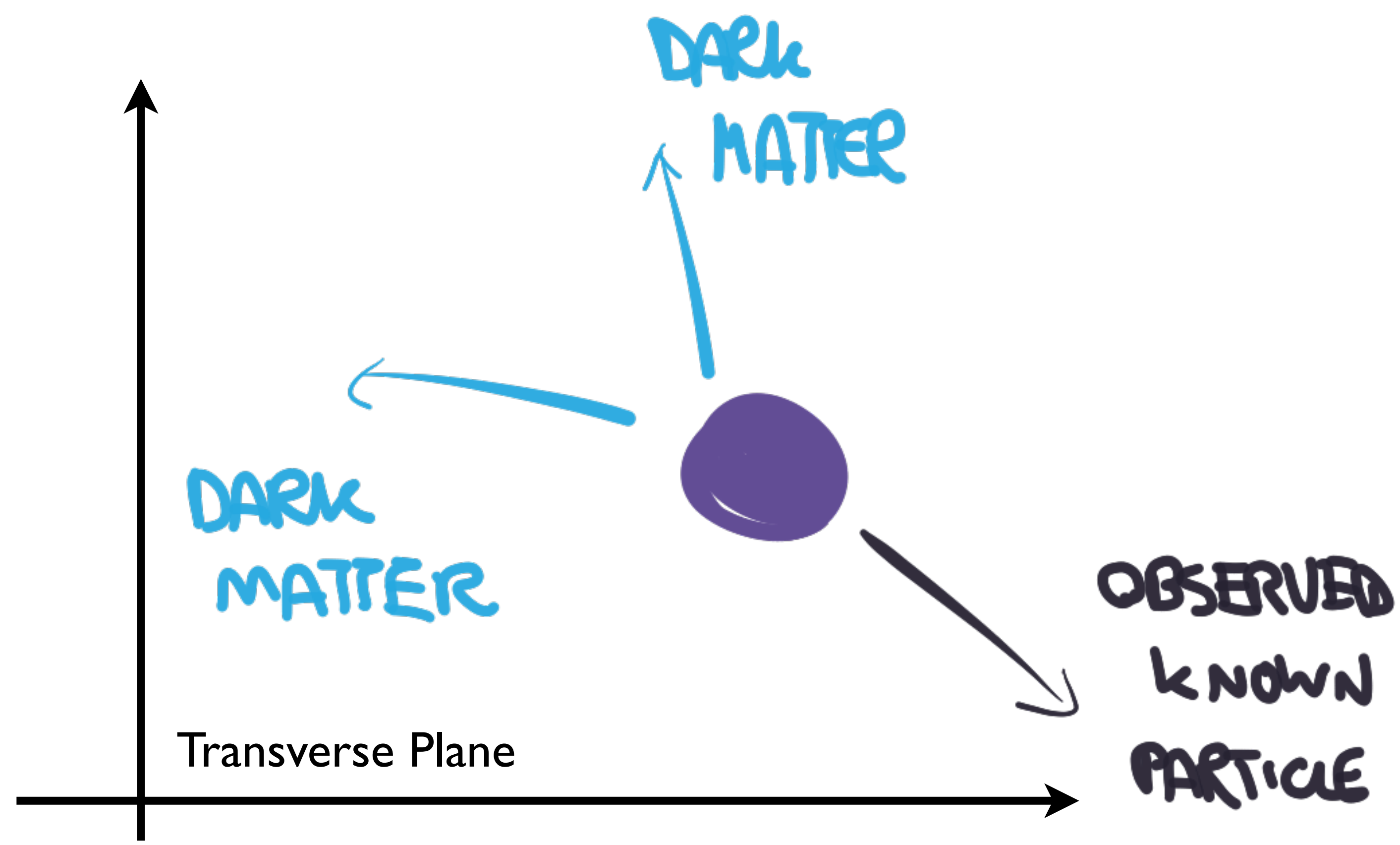
$$p_z = 0$$

i.e. they have momentum only along the transverse plane

this is clearly the case where the full invariant mass can be computed using only transverse quantities

two invisible particles ... many troubles





$$\bar{i}_T = \sum_{i=invisibles} \bar{p}_{T,i} = -\sum_{v=visibles} \bar{p}_{T,v}$$

only the sum of the invisibles can be measured by the recoiling observable system

$$pp \to XX \to Y\chi Y\chi$$

guess

what you cannot measure

$$\bar{p}_{T,\chi_1} + \bar{p}_{T,\chi_2} = \bar{i}_T$$

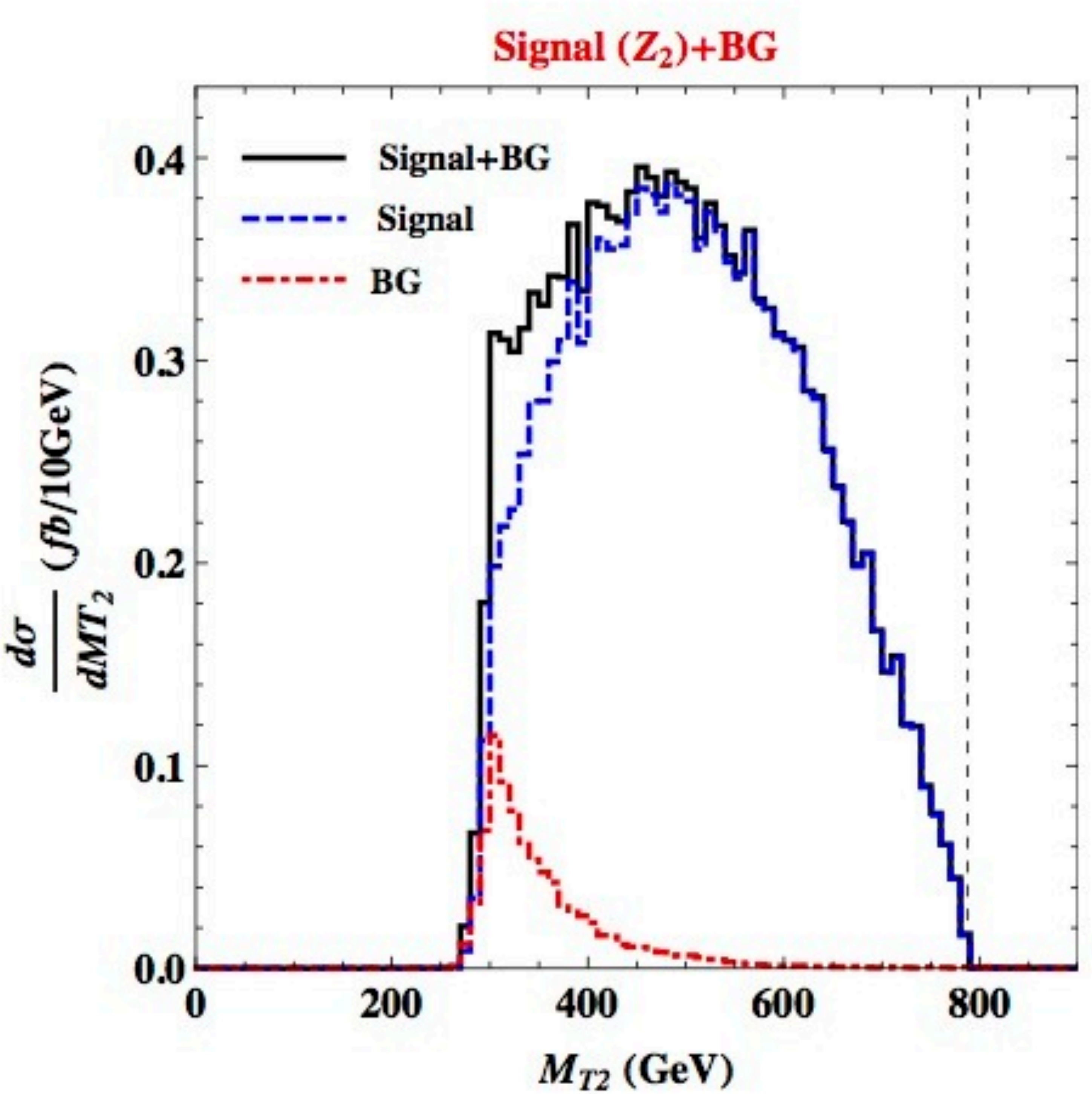
compute

2 transverse masses per each event

$$\max\left(\tilde{m}_{Y_1\chi_1},\, \tilde{m}_{Y_2\chi_2}\right) < m_X$$

make the guess safe

$$m_{T2} \equiv \min_{ansatz\, on\, p_{T,\chi}} \left(\max\left(\tilde{m}_{Y_1\chi_1},\, \tilde{m}_{Y_2\chi_2}\right)\right)$$



$$m_{T2}^{(max)} = \max_{events} m_{T2}$$

To compute transverse mass you need to know the mass of the DM ... make a guess

$$m_{\chi,trial}$$

$$m_{T2}^{(max)}(m_{\chi,trial}) = C + \sqrt{C^2 + m_{\chi,trial}^2}$$

cluster the invisibles

N invisible particles can always be thought as a single invisible object

$$P_{\mu,inv} = \sum_{i=invisibles} p_{\mu,i}$$

$$M_{cluster,inv} \geq \sum_{i=invisibles} m_i \qquad \text{and} \qquad M_{cluster,inv} < m_X$$

the minimal mass is attained for invisible particles at rest, hence they have the same rapidity in a boosted frame

$$m_{T2}^{(max)}(m_{\chi,trial}) = C + \sqrt{C^2 + m_{\chi,trial}^2}$$

the "C" parametrization holds for one as well as for many invisibles, though the meaning of "C" is different