Mass-constraining variables to confront dark matter production at the LHC

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SUSY 2016, Melbourne

July 5, 2016

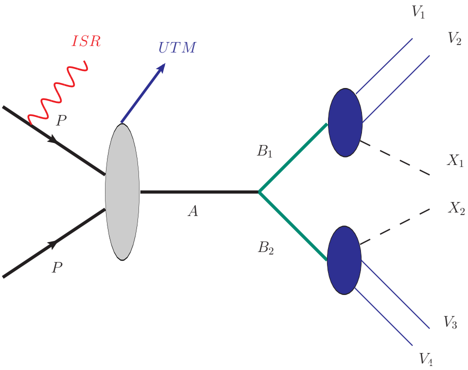
Outline

- Objective
- Part-I:
  - Constrained $\hat{s}$ variables
  - Mass determination using $\hat{s}^{cons}_{min/max}$
  - Event reconstruction using $\hat{s}^{cons}_{min/max}$
  - summary
- Part-II:
  - M_{2Cons}
  - Mass measurement using M_{2Cons}
  - Event reconstruction using M_{2Cons}
  - summary

Objective

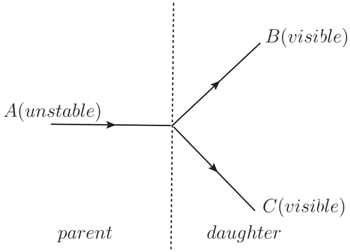
- Determine/constrain: Unknown masses $\{M_A, M_B, M_\chi\}$.

- Event reconstruction $\Rightarrow$ determination of q_i.



Two body visible: A simple case study

⋆ Mass measurement is very easy if there are no invisible particles in the final state.



Example:

- $h \to \gamma\gamma$
- $Z \to \ell\ell$

Why it is challenging?

Problems with hadron collider:

- Incoming parton momenta unknown.
- CM energy of collision unknown.
- Boost along the beam direction unknown.

Problems introduced by DM motivated theories:

- Two invisible particles escape detection.
- Masses of the invisible particles are unknown.
- Masses of their parent are also unknown.

Part-I: Presence of invisible particles in final state

Example: $h \to \tau\tau \to \tau_h \nu_\tau \tau_h \nu_\tau$

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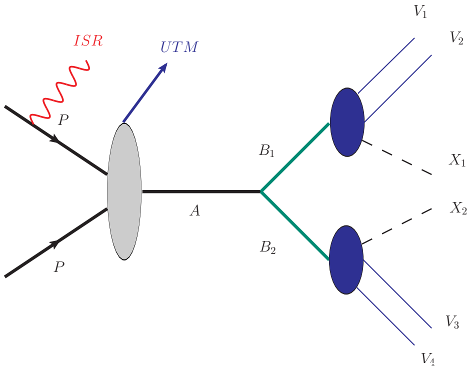
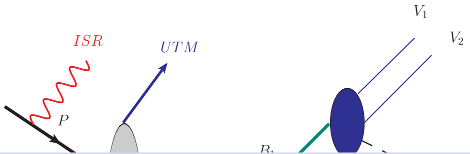


Part-I: Presence of invisible particles in final state

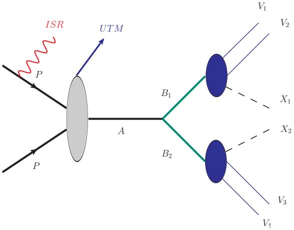
Example: $h \to \tau\tau \to \tau_h \nu_\tau \tau_h \nu_\tau$



examples: where we know B and X mass.

- $h \to WW^* \to l\nu l\nu$
- Heavy H/Z': $H/Z' \to t\bar{t} \to b\bar{b}w^+w^- \to b\bar{b}\ell^+\nu_\ell\ell^-\bar{\nu}_\ell$
- Exotic scalar: $\phi^{++} \to w^+w^+ \to \ell^+\nu_\ell\ell^+\nu_\ell$

$\hat{S}_{min}$: An inclusive variable



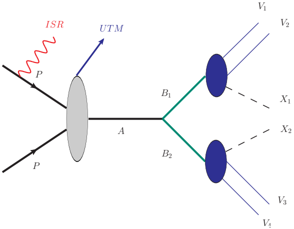
- Parton level Mandelstam variable:

$$\hat{s}(\vec{q}_i, m_\chi) = (E + \sum_{i=1}^{2} \sqrt{{m_\chi}^2 + {\vec{q}_i}^2})^2 - (\vec{P} + \sum_{i=1}^{2} \vec{q}_i)^2$$

- Impossible to determine $\hat{s}$ experimentally

Partha Konar, Kyoungchul Kong, and Konstantin T. Matchev. JHEP, 0903:085, 2009, JHEP, 1106:041, 2011

$\hat{S}_{min}$: An inclusive variable



$$\hat{s}_{min} = \min_{\substack{\vec{q}_1, \vec{q}_2 \\ \{\vec{q}_{1T} + \vec{q}_{2T} = \vec{\not{P}}_T\}}} \left[\hat{s}(\vec{q}_1, \vec{q}_2) \right]$$

$$\sqrt{\hat{s}_{\rm min}(2\tilde{m}_\chi)} = \sqrt{(E^v)^2 - (P_z^v)^2} + \sqrt{|\,\vec{\not{P}}_T|^2 + (2\tilde{m}_\chi)^2}$$

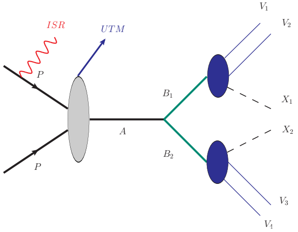
Partha Konar, Kyoungchul Kong, and Konstantin T. Matchev. JHEP, 0903:085, 2009, JHEP, 1106:041, 2011

Constrained $\hat{s}$ variables

Constrained $\hat{s}$ variables:

$$\hat{s}^{cons}_{min} = \min_{\substack{\vec{q}_1,\vec{q}_2 \\ \{constraints\}}} [\hat{s}(\vec{q}_1,\vec{q}_2)]$$

$$\hat{s}^{cons}_{max} = \max_{\substack{\vec{q}_1,\vec{q}_2 \\ \{constraints\}}} [\hat{s}(\vec{q}_1,\vec{q}_2)]$$



constraints:

Mass shell constraints of intermediate (B) and invisible particle (X)

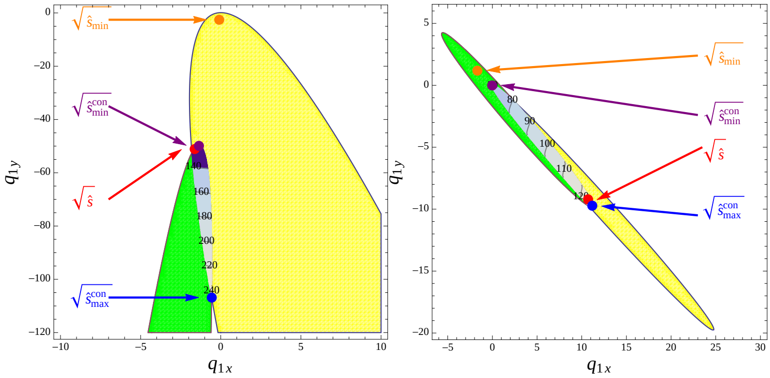
+missing transverse momenta constraints.

Assumption:Both the masses M_B and m_χ are known.

Abhaya Swain and Partha Konar, JHEP 1503 (2015) 142.

Constrained $\hat{s}$ variables

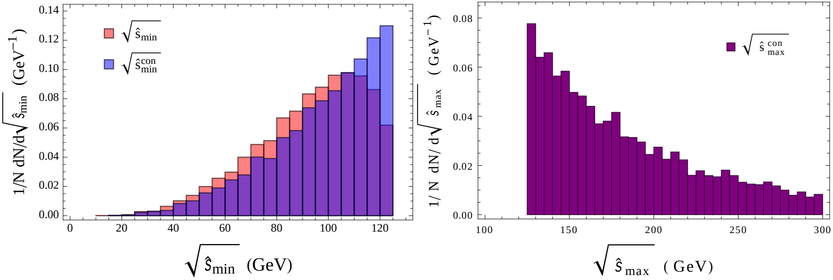
◇ Consequence of mass shell constraints.



Abhaya Swain and Partha Konar, JHEP 1503 (2015) 142.

Constrained $\hat{S}$ variables contd.

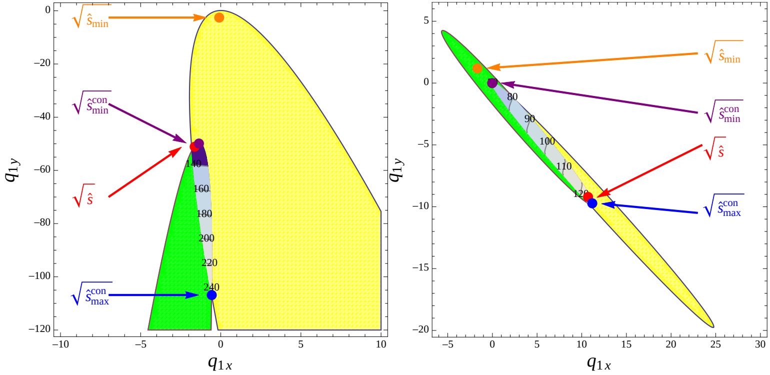
Example: $h \to \tau\tau$(SM)



Abhaya Swain and Partha Konar, JHEP 1503 (2015) 142.

Momentum reconstruction using $\hat{s}$ and its cousins

◇ Antler topology: momentum reconstruction capability.



Abhaya Swain and Partha Konar, JHEP 1503 (2015) 142.

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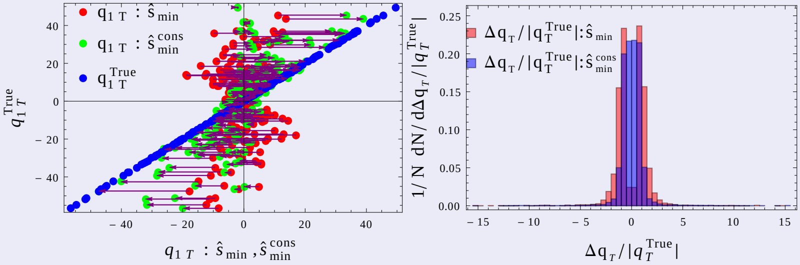
Reconstructed momenta correlated with true momenta



Abhaya Swain and Partha Konar, JHEP 1503 (2015) 142.

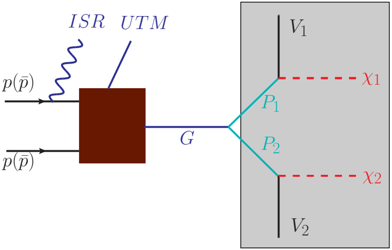
Summary of part-I

- $\hat{S}_{min}$ being global and inclusive can be used for determining mass scale of new physics without the knowledge of topology.
- $\hat{S}^{cons}_{min}$ and $\hat{S}^{cons}_{max}$ both are very useful for mass determination as well as event reconstruction.
- The events near endpoint or threshold of constrained $\hat{S}$ variables gives better momentum reconstruction.

Part-II: Unknown intermediate and invisible particle masses.

Examples:

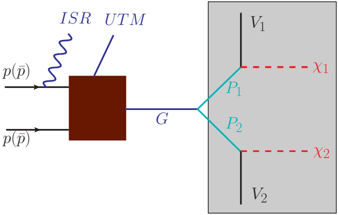
- SUSY:
  $H \to \tilde{\chi}_2^0 \tilde{\chi}_2^0 \to Z \tilde{\chi}_1^0 Z \tilde{\chi}_1^0$
- Z' SUSY:
  $Z' \to \tilde{\ell}^+ \tilde{\ell}^- \to \ell^- \tilde{\chi}_1^0 \ell^+ \tilde{\chi}_1^0$
- UED: $Z^{(2)} \to L^{(1)} L^{(1)} \to \ell^- \gamma^{(1)} \ell^+ \gamma^{(1)}$

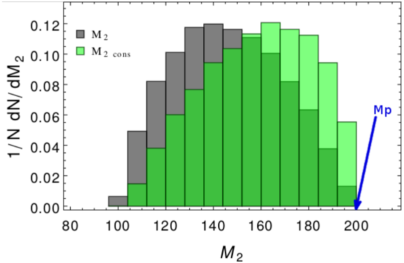


M_2 and its improvement

$$M_2(\tilde{m}_\chi) = \min_{\substack{\vec{q}_1,\vec{q}_2 \\ \{\vec{q}_{1T}+\vec{q}_{2T}=\vec{\not{P}}_T\}}} \left[\max\{M^{(1)}(\tilde{m}_\chi), M^{(2)}(\tilde{m}_\chi)\}\right]$$

$$M_{2Cons}(\tilde{m}_\chi) = M_2(\tilde{m}_\chi);\ Cons = \begin{cases} (p_{v_1} + p_{v_2} + q_1 + q_2)^2 = m_G^2 \\ M^{(1)} = M^{(2)} \end{cases} \quad (1)$$

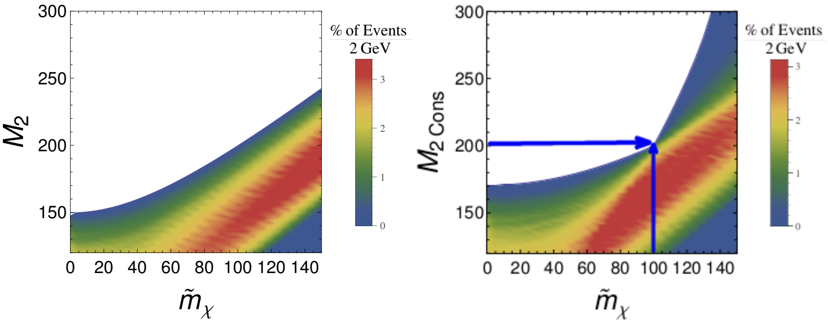




Partha Konar and Abhaya Swain, Phys. Rev., D93:015021, 2016

Mass measurement from kink

◇ The presence of kink and its population with number of events.

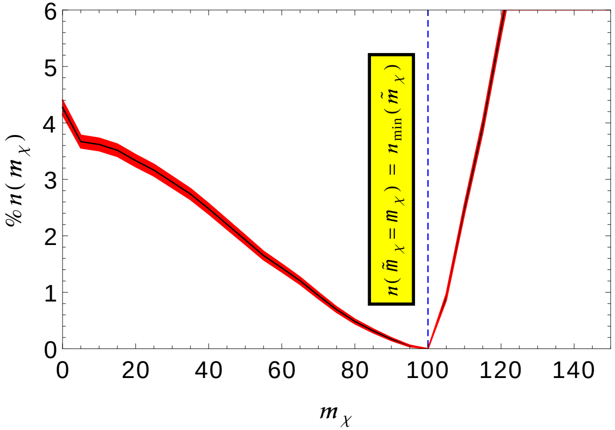


Partha Konar and Abhaya Swain, Phys. Rev., D93:015021, 2016

kink reconstruction

⋆ A way of determining m_χ optimally.

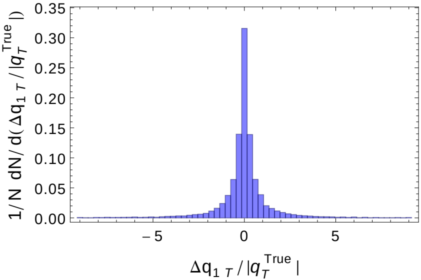
$$n(\tilde{m}_\chi) = \frac{\sum \mathcal{H}(M_{2Cons} - M_2^{max})}{N}$$

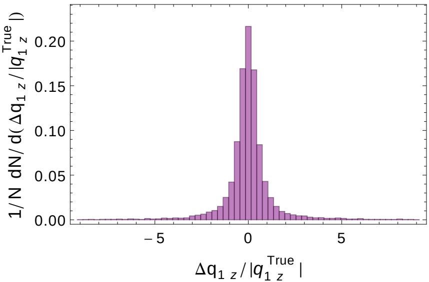


Partha Konar and Abhaya Swain, Phys. Rev., D93:015021, 2016

Event reconstruction using M_{2Cons}

◇ We reconstruct momenta from the minimization of M_{2Cons}.





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Summary of part-II

- We discuss the new variable M_{2Cons} which can be used for simultaneous determination of both intermediate and invisible particle mass.

- We demonstrate that kink appears when one uses heavy resonance mass shell constraint.

- An optimal way for reconstruction of position of kink is also discussed using Heaviside step function.

- M_{2Cons} can be used for event reconstruction and it turns out that the reconstructed momenta are well correlated with true momenta.

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Thank You