Identifying the production process of new physics at colliders; symmetric or asymmetric?

Lim, Sung Hak

KAIST & IBS-CTPU (PTC)

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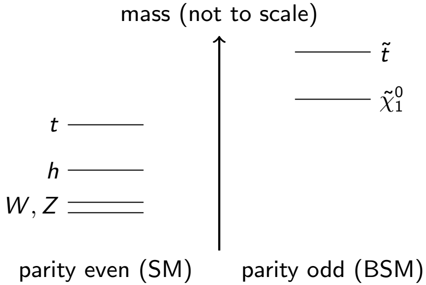
based on **S. H. Lim**, JHEP **1606**, 105 (2016), [arXiv:1603.01981 [hep-ph]].

Models with parity symmetry and dark matter candidate

- Models with a dark matter candidate often have a parity symmetry to make dark matter stable
  - R-parity in SUSY models, KK-parity in extra-dimensional models



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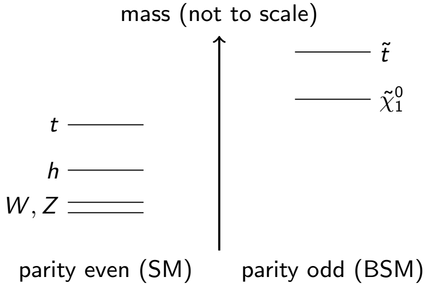

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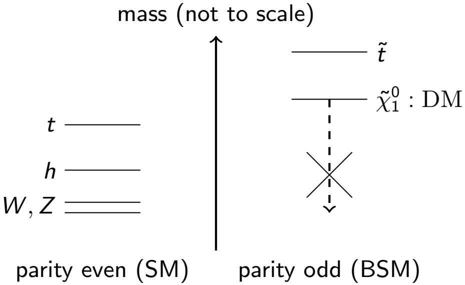


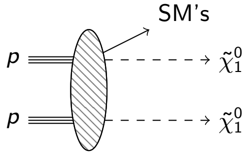
- The parity symmetry separates particle spectrum into two sectors: SM sector and BSM sector
- The lightest particle in BSM sector is stable because the parity prohibits decay. $\rightarrow$ a dark matter candidate!

Collider signature of the dark matter candidate

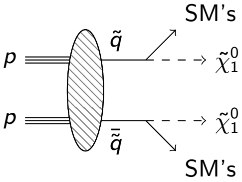
- Particles in BSM sector should be pair-produced in *pp* collision to make parity even state.

$$\langle BSM, SM \cdots |S|pp\rangle \xrightarrow{R-\text{parity}} -\langle BSM, SM \cdots |S|pp\rangle = 0$$
$$\langle BSM, BSM, SM \cdots |S|pp\rangle \xrightarrow{R-\text{parity}} \langle BSM, BSM, SM \cdots |S|pp\rangle \neq 0$$

- Possible relevant collider signatures:



mono-X searches



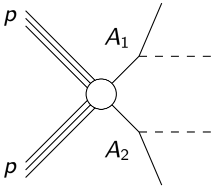
semi-invisibly decaying pair production

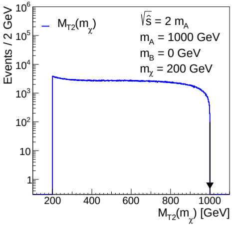
- Semi-invisibly decaying pair production is interesting because this channel is not only capable of determining the mass of the intermediate resonance, but also the mass of the dark matter. → M_{T2} analysis

A min-max strategy

- Stransverse mass, M_{T2},

$$M_{T2} = \min_{\substack{\vec{q}_{\chi_1}, \vec{q}_{\chi_2} \\ \vec{q}_{T,\chi_1} + \vec{q}_{T,\chi_2} = \not{\vec{p}}_T}} \max(M_{A_1}, M_{A_2})$$





- M_{T2} distribution is bounded above

$$M_{T2} \leq \max[m_{A_1}, m_{A_2}] = m_A \quad \text{if } m_{A_1} = m_{A_2} \tag{1}$$

- M_{T2} is a very successful mass-bounding variable for
  - Mass measurement of top quark (CDF, CMS)
  - Supressing SM background from new physics signals (QCD, $WW \to 2\ell + \not{E}_T$, $t\bar{t} \to 2b2\ell + \not{E}_T$, $\cdots$)
- However, M_{T2} has an intrinsic prejudice...

A prejudice of M_{T2}

- M_{T2} is a variable targeted for $m_{A_1} = m_{A_2}$ (extremum condition for minimization)
- Some symmetric pair productions (particle-antiparticle pair):
  - $t\bar{t}$ pair production
  - slepton pair production and squark pair production
  - stop pair production
- Some asymmetric pair productions:
  - squark-gluino coproduction
  - chargino-neutralino coproduction
- Problems:
  - upper bound of M_{T2} is only sensitive to the mass of the heavier resonance.

$$M_{T2} \leq \max[m_{A_1}, m_{A_2}]$$

  - Moreover, since we did not observe any of those resonances, we need to justify $m_{A_1} = m_{A_2}$ hypothesis also from experimental data.
- Is there any kinematic variable can justify $m_{A_1} = m_{A_2}$?
- We can solve above problem by generalizing M_{T2}!

Generalization of Maximum Function

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$$\min(M_{A_1}, M_{A_2}) \quad \frac{1}{2}(M_{A_1}^{-1} + M_{A_2}^{-1}) \quad \sqrt{M_{A_1} M_{A_2}} \quad \frac{1}{2}(M_{A_1} + M_{A_2}) \quad \max(M_{A_1}, M_{A_2})$$

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- Power mean

$$\hat{\mu}_p(M_{A_1}, M_{A_2}) = \left(\frac{1}{2} \left(M_{A_1}^p + M_{A_2}^p \right) \right)^{\frac{1}{p}}$$

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- By construction, this kinematic variable is bounded above by

$$\mu_{p,2} \leq \hat{\mu}(m_{A_1}, m_{A_2})$$

Mass bound comparison

- Stransverse mass

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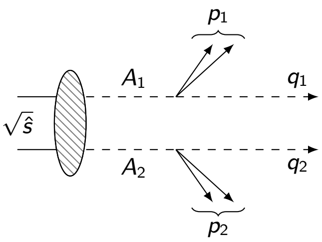
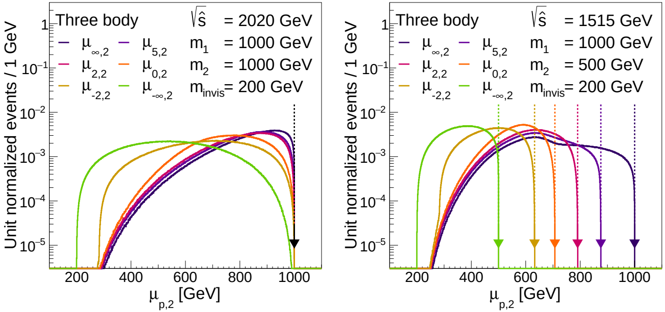
- If true mass spectrum is symmetric, $\mu_{p,2}$'s share common kinematic endpoints.
- If true mass spectrum is asymmetric, $\mu_{p,2}$'s have separated kinematic endpoints.

Power Mean Distribution



- $\mu_{p,2}$ distribution with phase-space Monte Carlo simulation only



Conclusion

- In this work, we have developed new kinematic variables $\mu_{p,2}$, which is a smooth generalization of M_{T2} variable, for measuring masses of pair-produced particles decaying semi-invisibly.
- $\mu_{p,2}$ similar properties of M_{T2}, such as mass spectrum dependent kinematic endpoints.
- We can identify mass of both masses of the resonances by $\mu_{p,2}$ without a mass spectrum assumption on production.