Top quark mass measurement @ LHC
&
going beyond for a new physics search.

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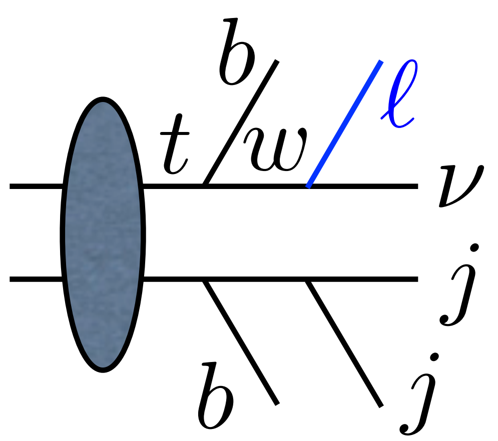
PHENO 2013

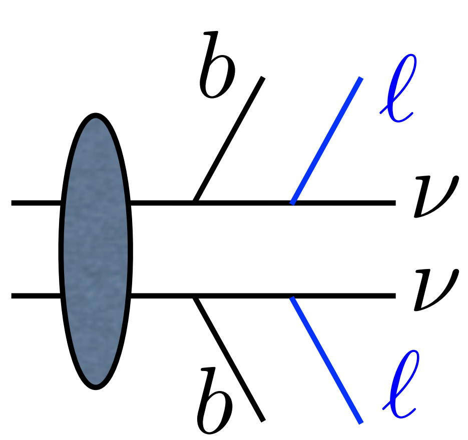
Talk will be based on
“Re-interpreting the Oxbridge stransverse mass variable MT2 in general cases”
arxiv:1212.1720 **(with Rakhi Mahbubani, Konstantin Matchev)**

CMS result quoted from CMS-TOP-11-027

Prelude

- With 5.0fb^{-1} statistics at 7TeV LHC, CMS reported a top-quark mass:





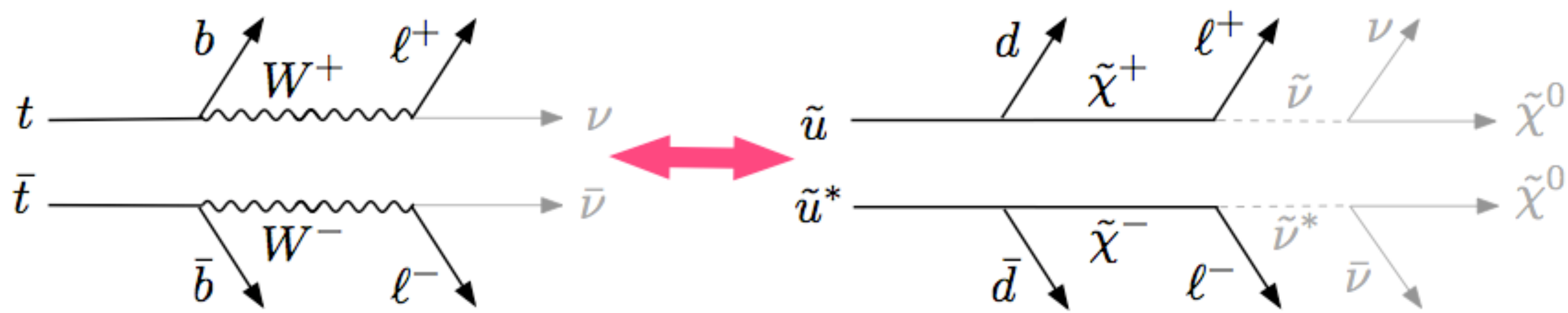
semi lepton +jets channel	Kinematic fit (TOP-11-015)	173.49±0.43(stat)±0.98(sys) [GeV]	with assumptions on W and neutrino's mass
di-leptons +jets channel	$\|M\|^2$ (AMWT) (TOP-11-016)	172.5±0.4(stat)±1.5(sys) [GeV]	Full assumptions on interactions, masses of W and neutrino
	kinematic endpoints (TOP-11-027)	173.9±0.9(stat)$_{-2.0}^{+1.6}$(sys) [GeV]	with/**WITHOUT** assumptions on W and neutrino's mass

- CMS "Kinematic endpoints method" is based on two papers;
  1. 1D projection: arxiv:0910.1584 (K.Matchev, MP), arxiv:0910.3679(P. Konar, K.Kong, K. Matchev, MP)
  2. Subsystem concept: arxiv:0903.4371 (M. Burns, K. Matchev, MP)

- In this talk, I will explain the basic concept of TOP-11-027 as an introduction.
  - No detailed explanation on specific variables, but I will focus on the core concepts.

- There have been many new techniques to measure the properties of the new physics at the LHC.
- CMS applied one of these new techniques to measure top-quark mass and demonstrated it's robustness.

figure from CMS-TOP-11-027

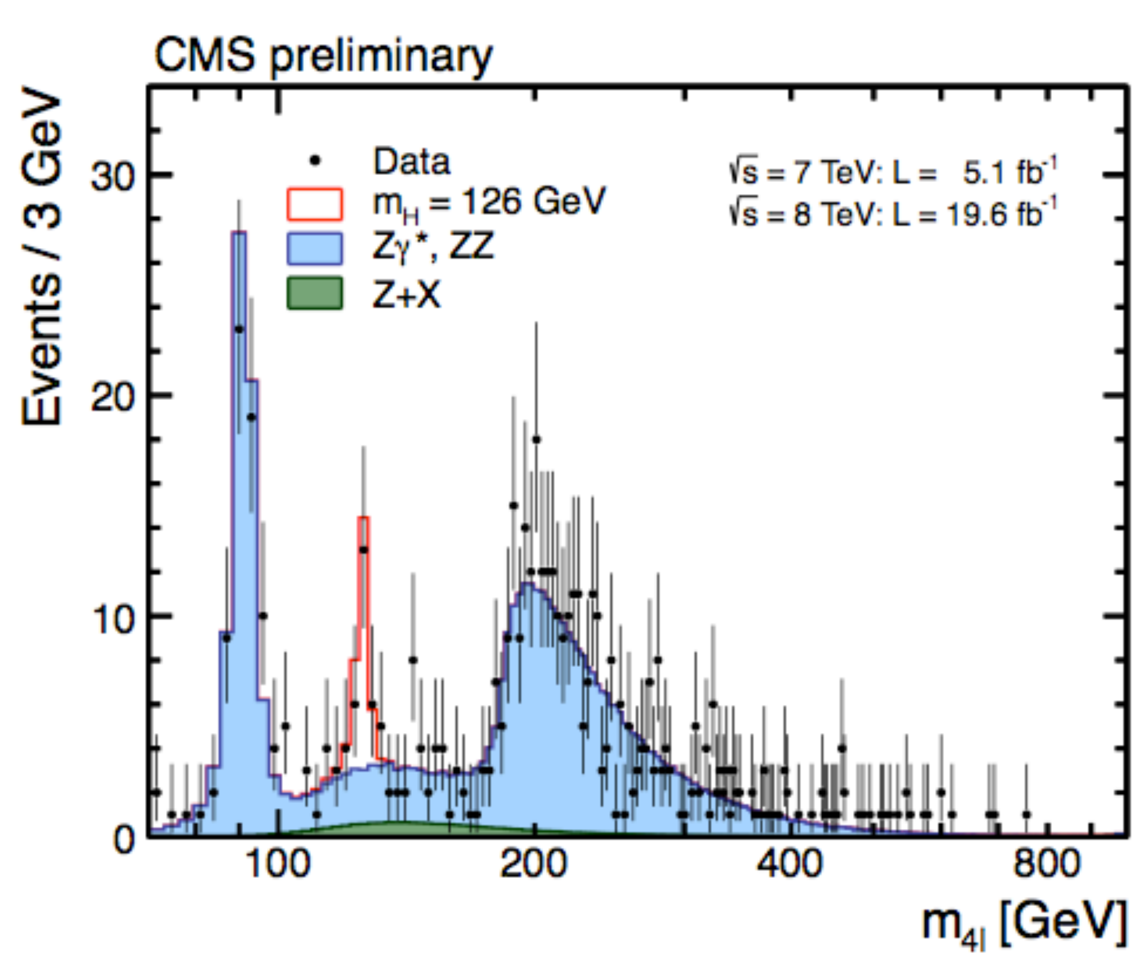


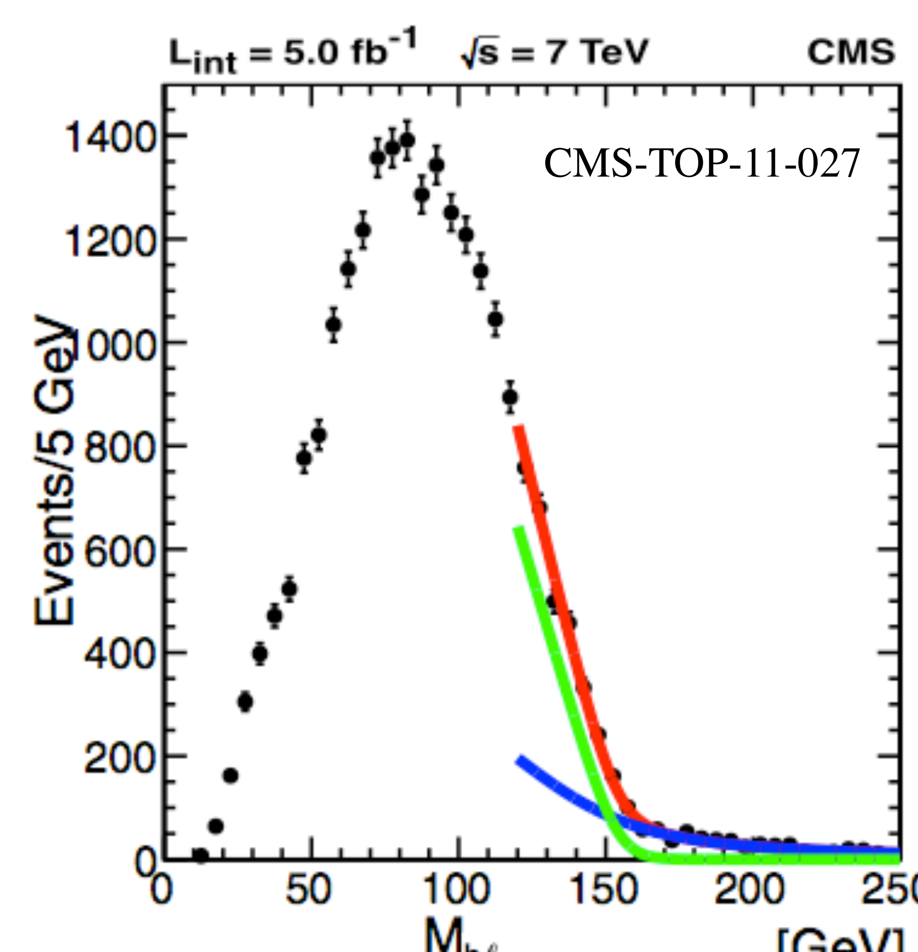
- A ttbar production has been one of major backgrounds for the Beyond the standard model (BSM) searches, but it serves as a testing ground for the BSM search tools.
- It is important to notice that CMS did not assume anything on W and neutrino's mass spectrum or their properties. (for example, spin, interaction vertices)

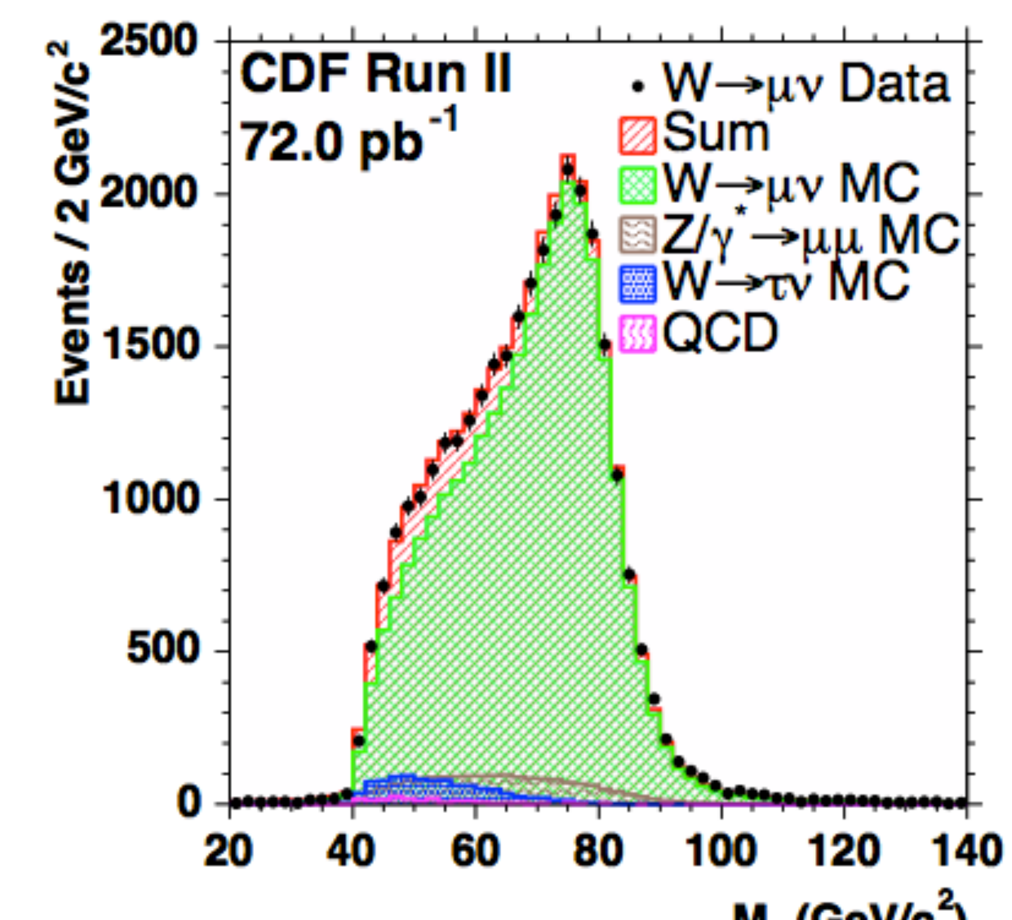
- LHC has an intrinsic uncertainty along the beam direction as a pp collider if we can not reconstruct the event.

- Thus, when we study channels with MET (the case in which we can not reconstruct an event due to lack of informations), we try to use
  - Lorentz invariant observables: Invariant mass, $\Delta\eta$ (longitudinal boost inv) ,...
  - observables independent on longitudinal information
    : transverse variables, for example, HT, MET, MT2, MCT,
    CMS-Razor, ...

- We try to get information from the features (bump, endpoint, jacobian peak,...) in observables' distributions.

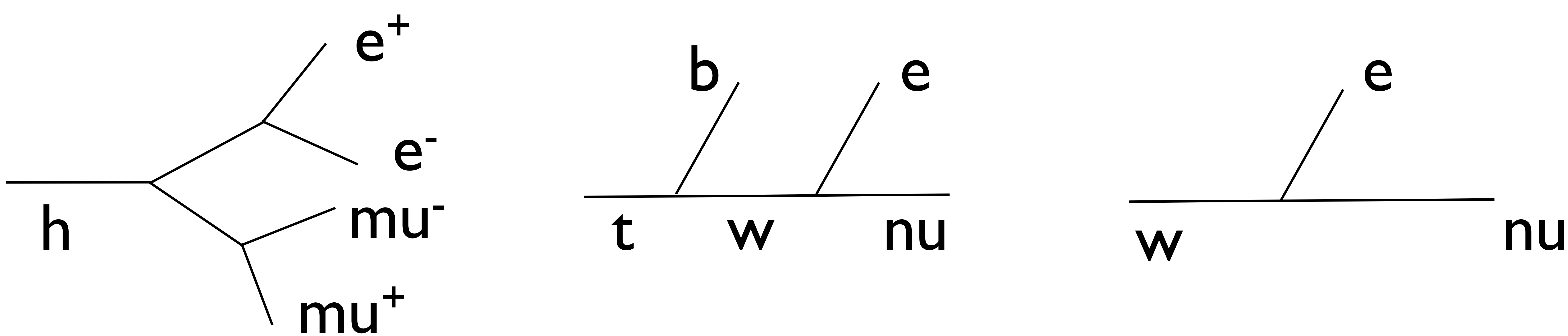






- These bump, endpoint or jacobian peak are independent of $|M|^2$, only depend on the kinematical information; mass spectra and an event-topology.

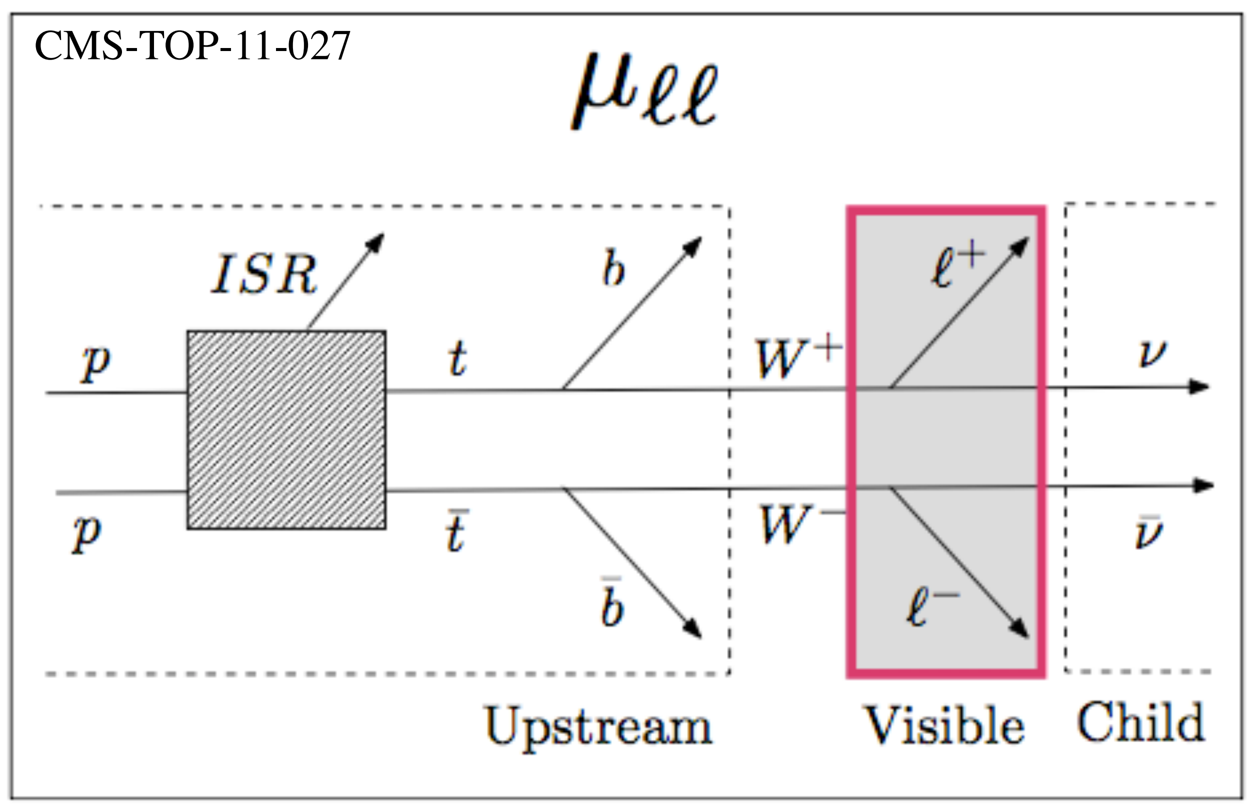
even-topology: How particles are created and decayed into other particles.

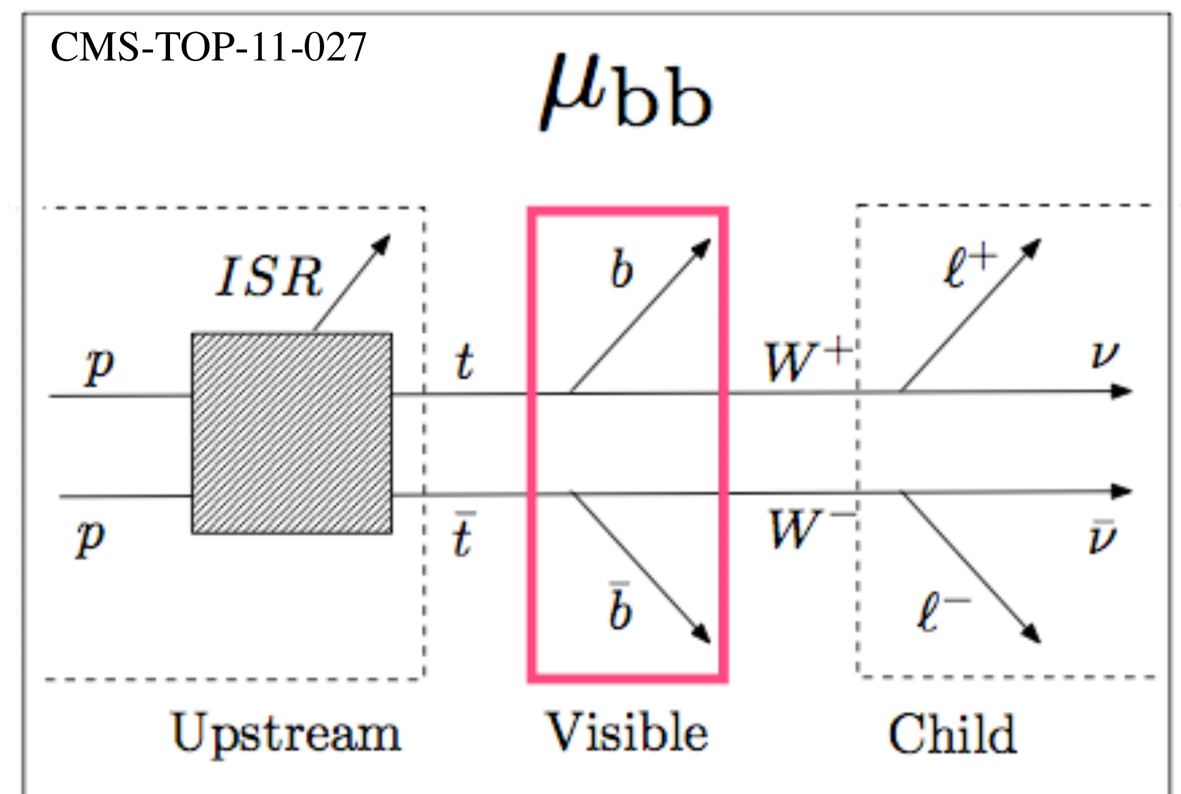


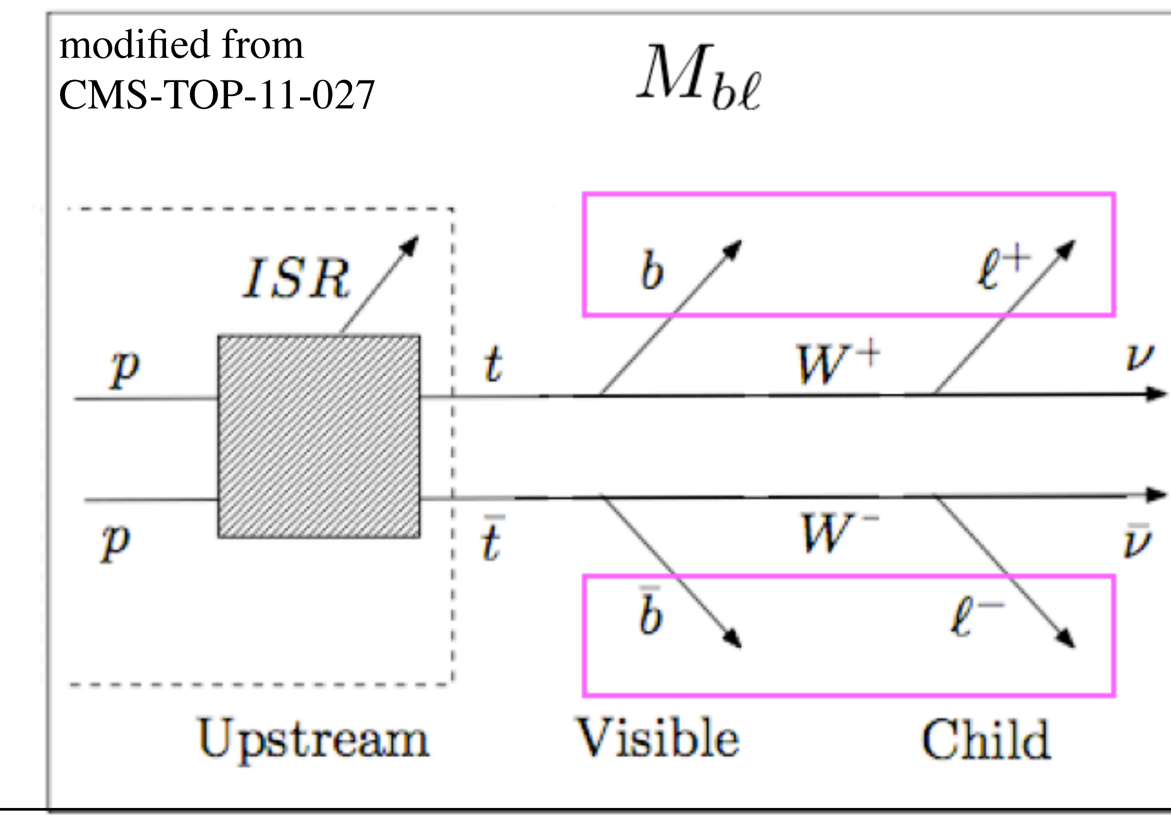
- Thus studies based on the minimal assumptions will be the first step of measurements of a new physics.

CMS measurement

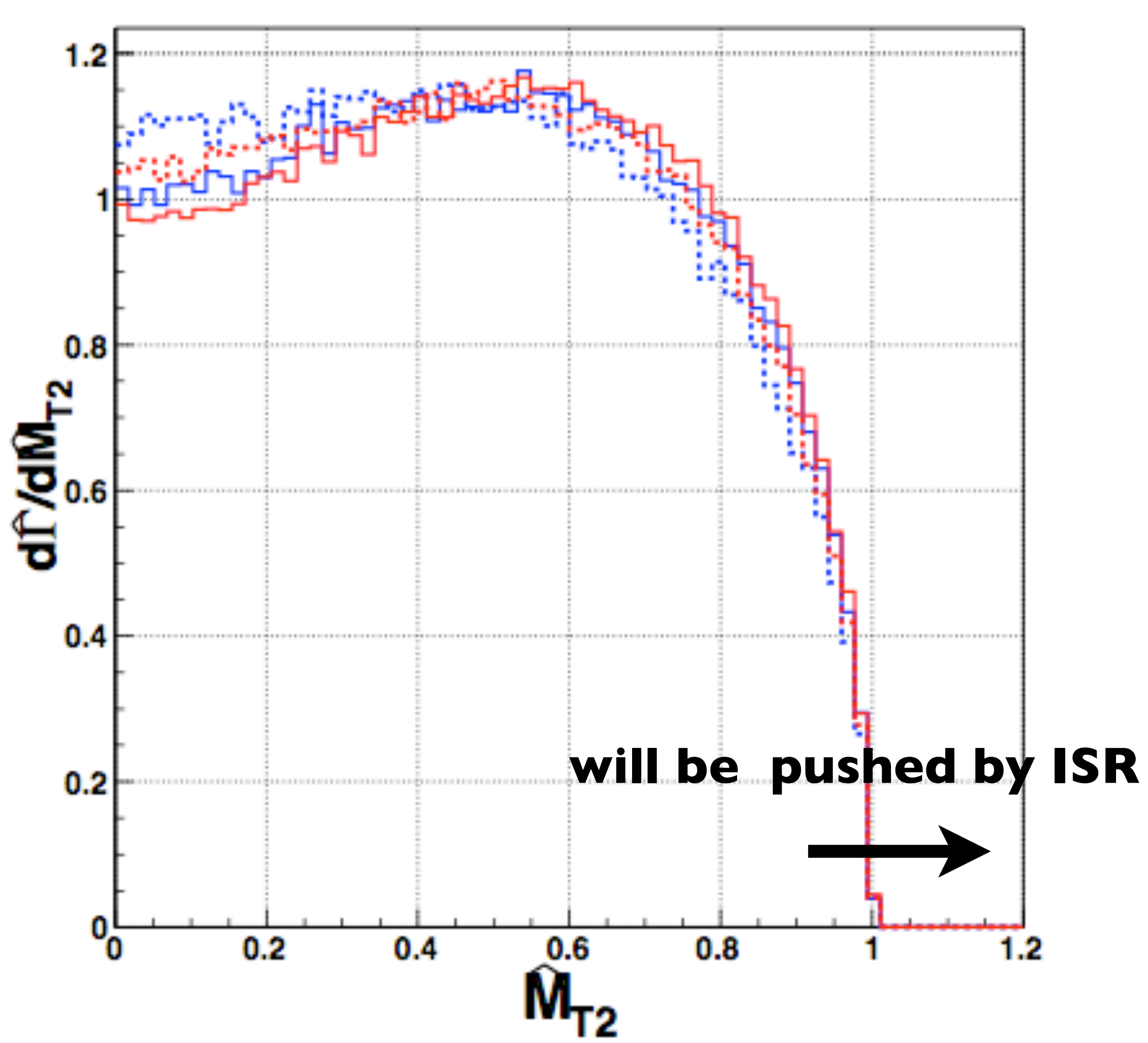
- With three unknowns, we need to have three independent measurements.







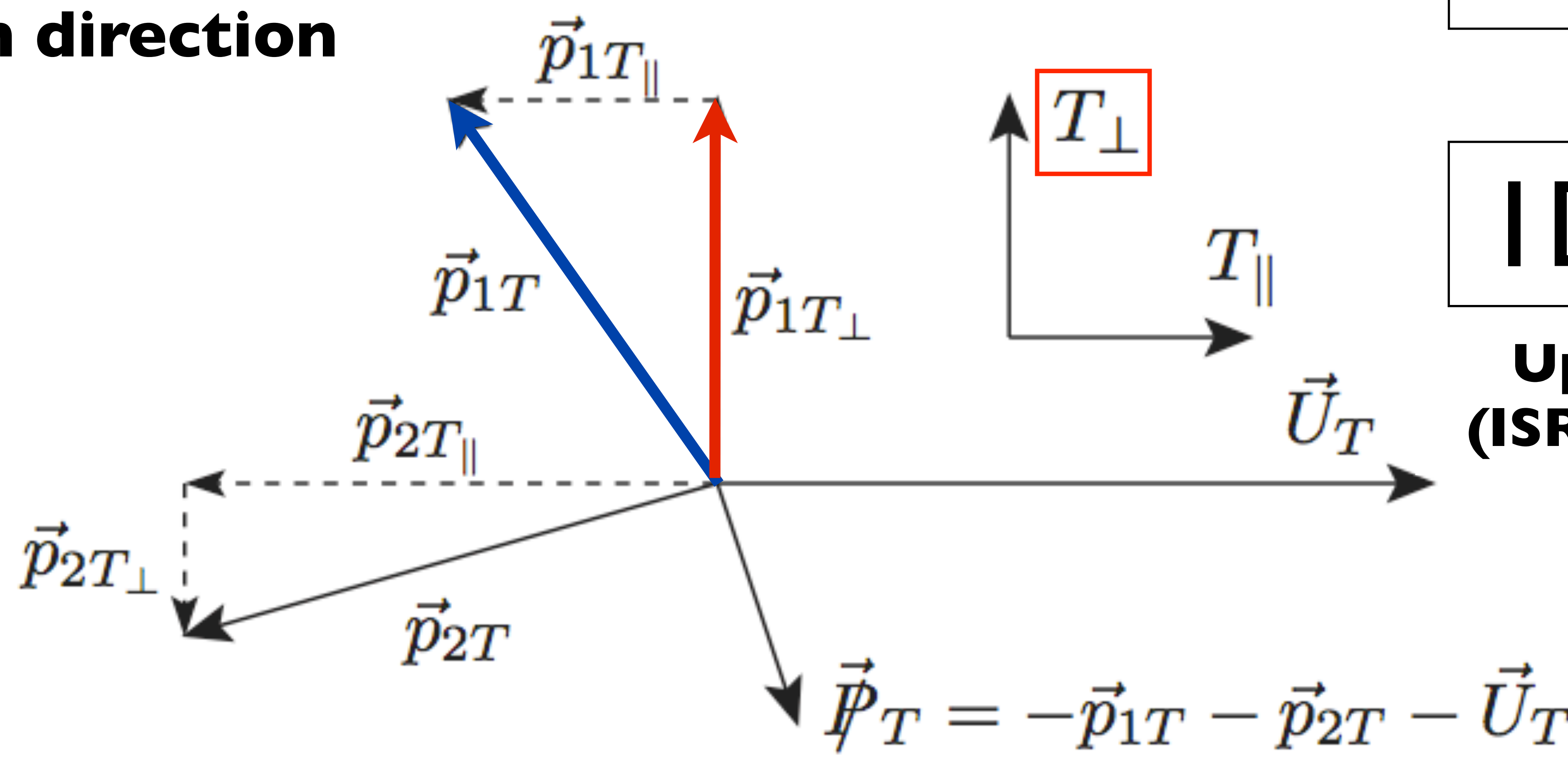
arxiv:0903.4371 (M. Burns, K. Matchev, MP)



- ISR will kick off the endpoint of transverse variables and we can not interpret the "spoiled" endpoint: serious systematical uncertainties in interpreting endpoints.

- We have some options;
  1. Control ISR by selecting events with negligible ISR.
     - but the kick off will come from bjets+ISR when we consider leptonic subsystem.
  2. <u>Need to develop new methods to reduce ISR effect.</u>

Transverse plane w.r.t the beam direction



2dimensional observable

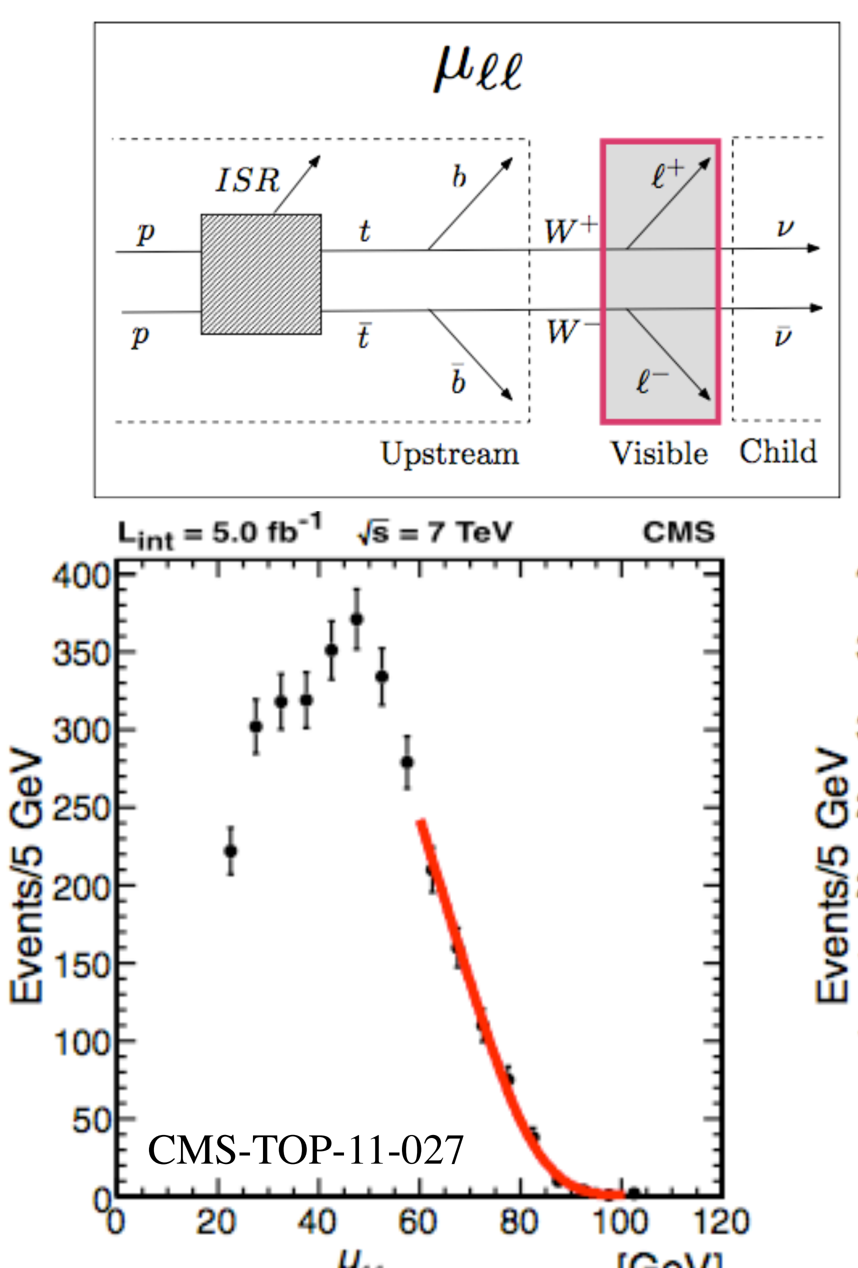
↓

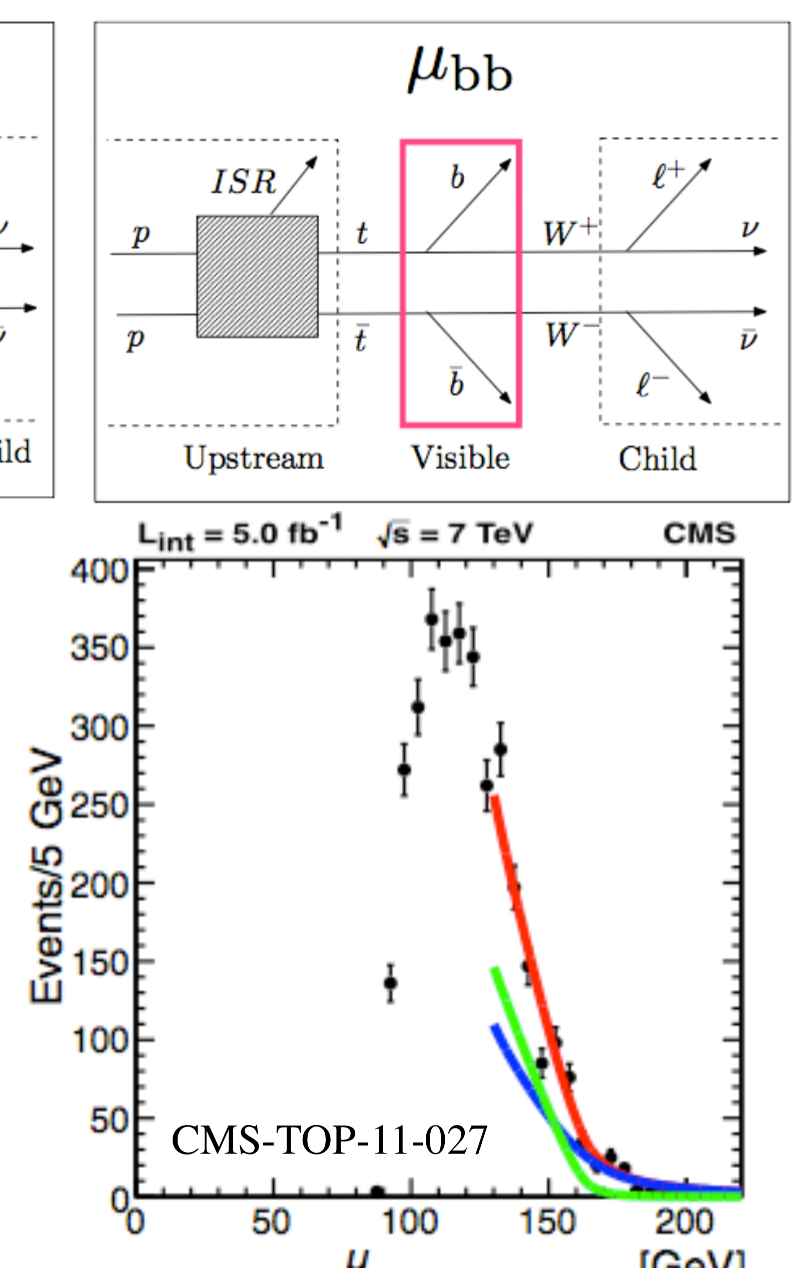
1D projected observable

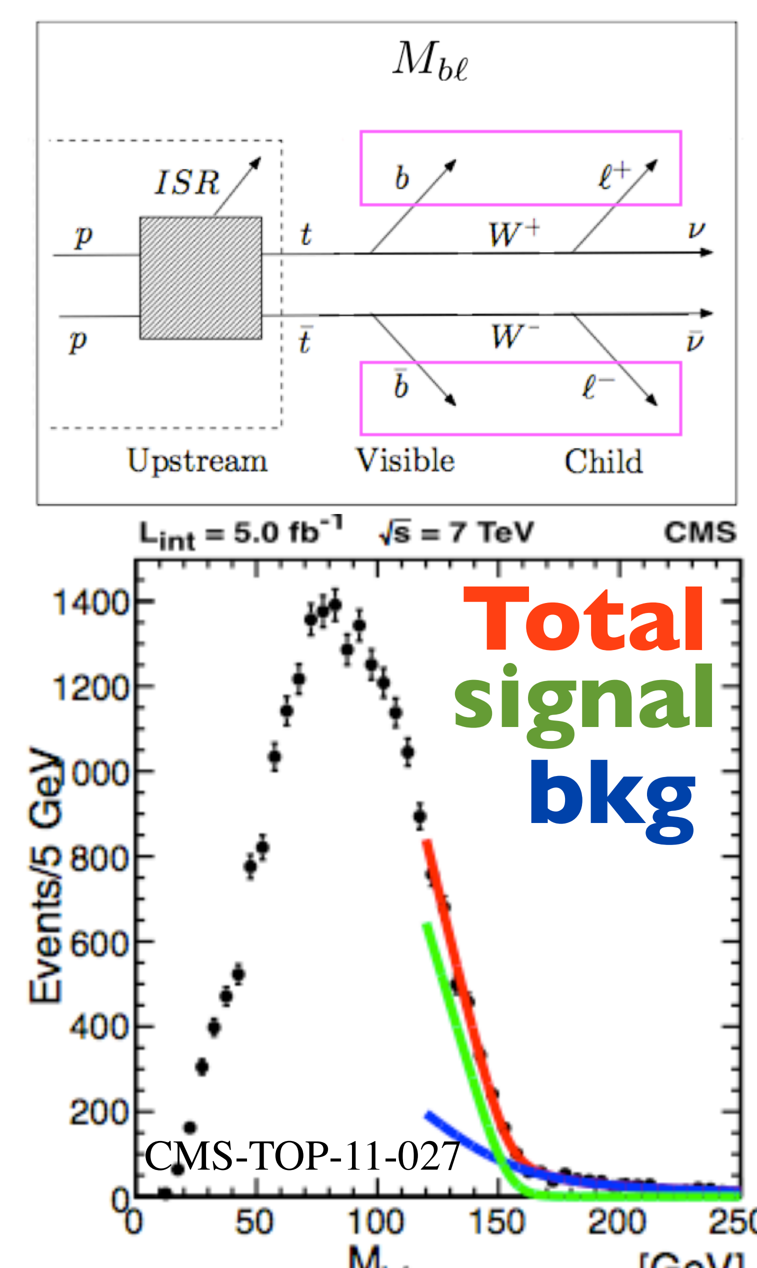
Upstream transverse momentum (ISR or bjets for leptonic subsystem)

K. Matchev, MP (arxiv:0910.1584)

- To remove the boost effect from UT (ISR or bjets), we project a transverse momentum of visible particles to the orthogonal direction of UT.





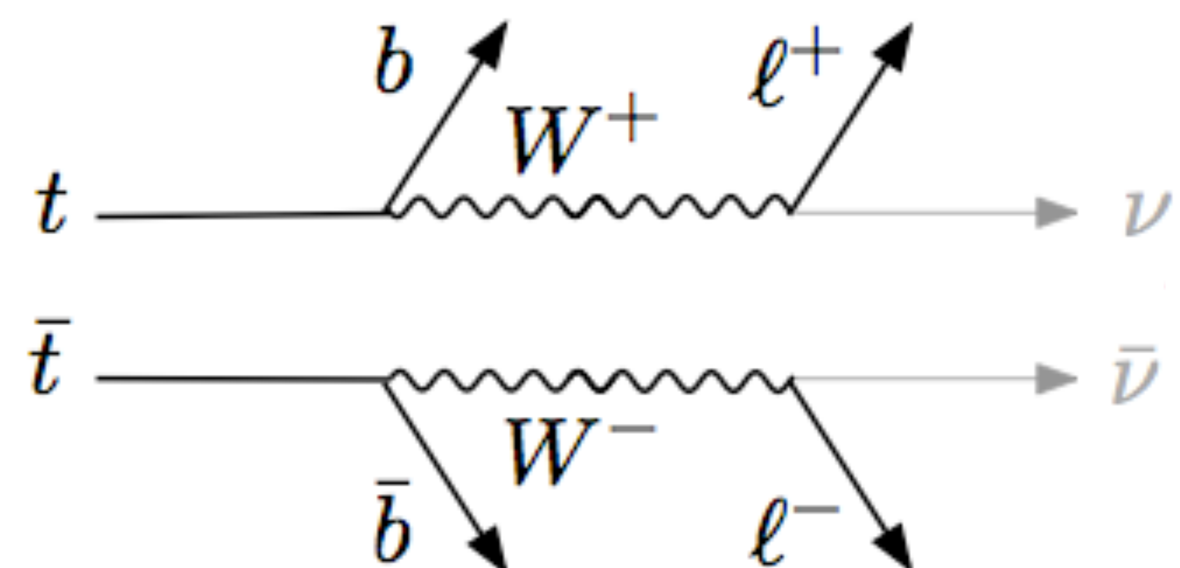


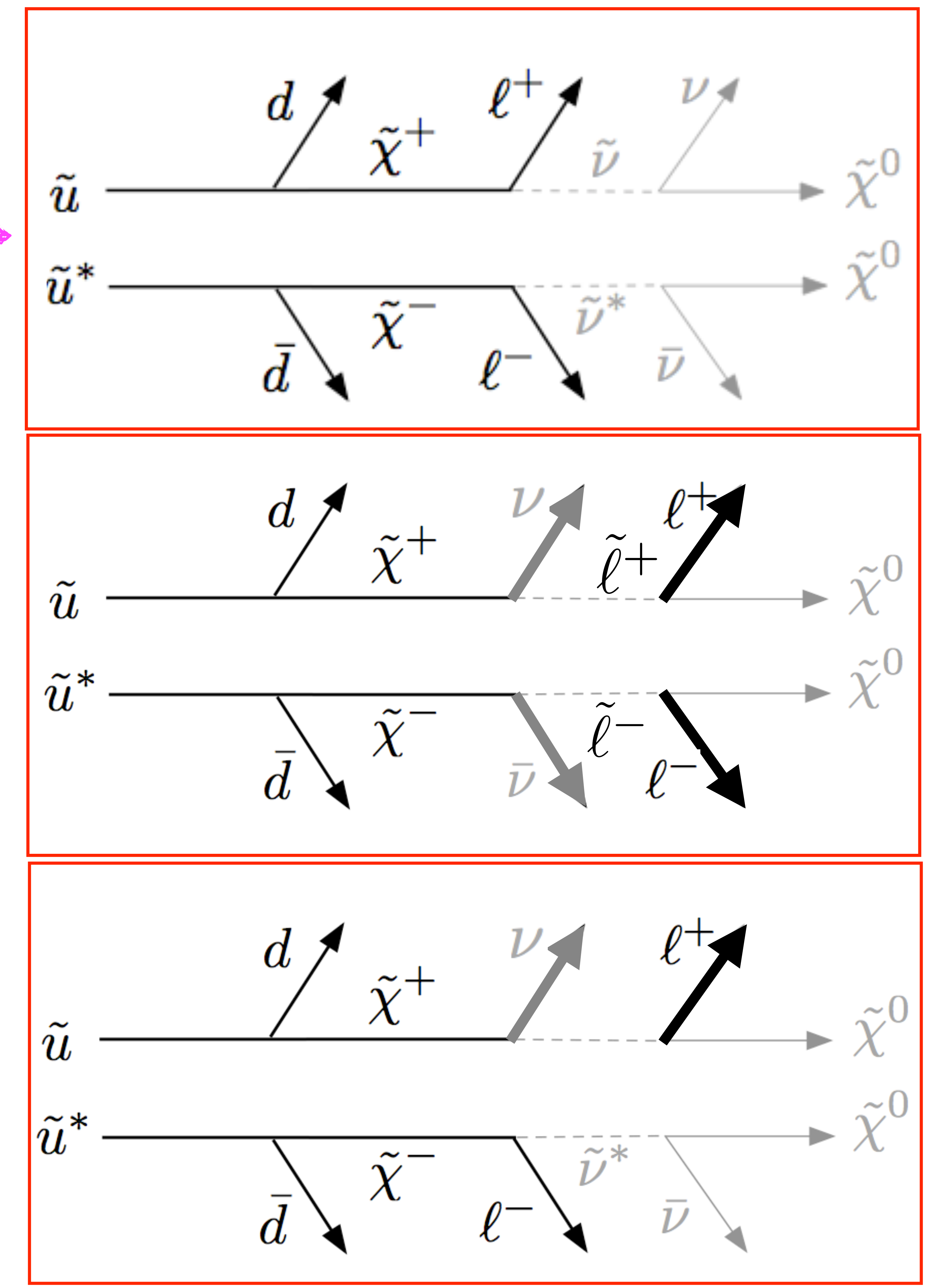
	Constraint		
Fit quantity	None	$m_\nu = 0$	$m_\nu = 0$ and $M_W = 80.4$ GeV
m_ν^2 (GeV^2)	$-556 \pm 473 \pm 622$	(0)	(0)
M_W (GeV)	$72 \pm 7 \pm 9$	$80.7 \pm 1.1 \pm 0.6$	(80.4)
M_t (GeV)	$163 \pm 10 \pm 11$	$174.0 \pm 0.9^{+1.5}_{-2.0}$	$173.9 \pm 0.9^{+1.6}_{-2.0}$

- Endpoints are function of m^2. Negative value of a neutrino comes from the solving the coupled quadratic equations of best fit endpoints.

Go beyond for a BSM search

figure from CMS-TOP-11-027

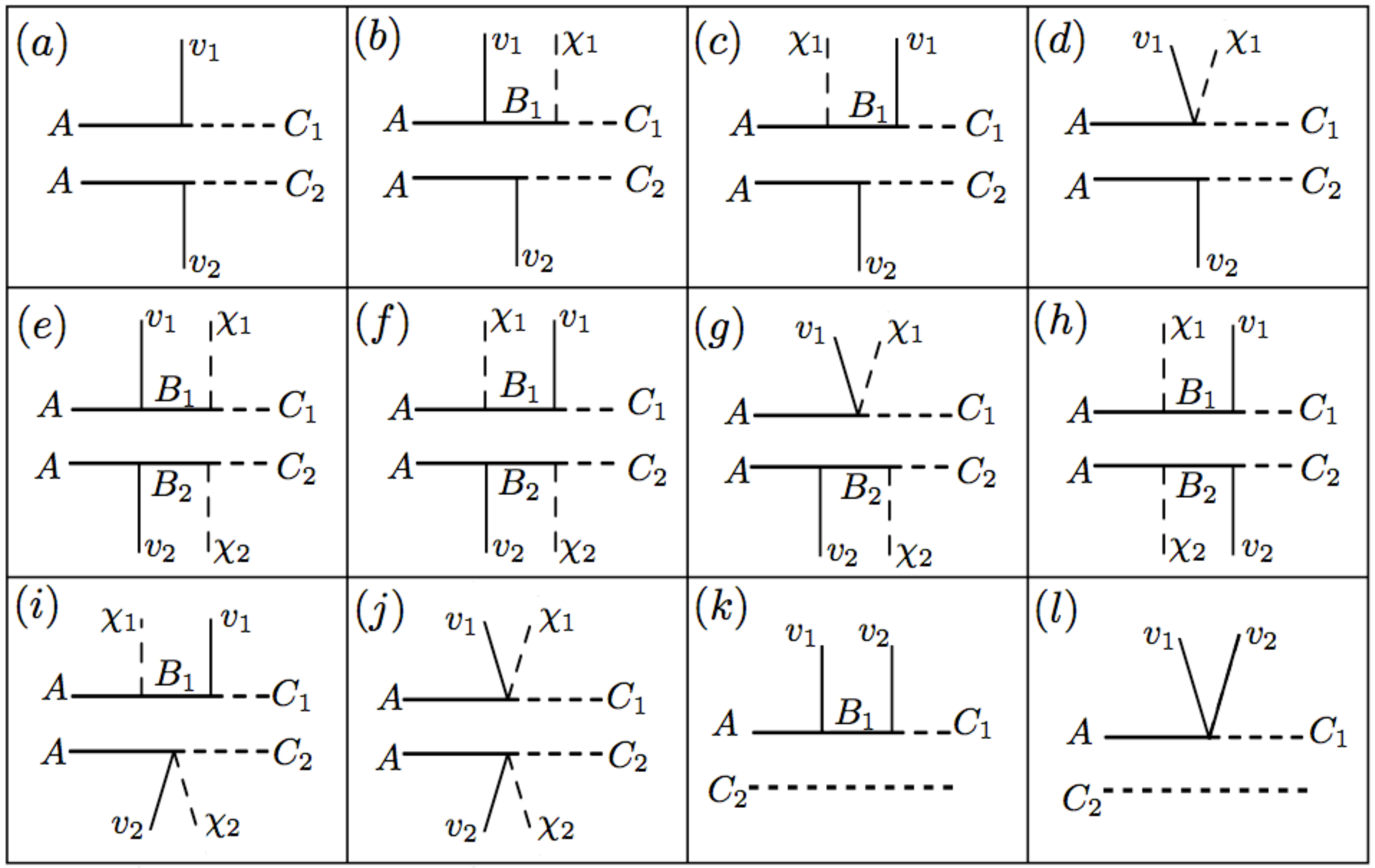




+ more...

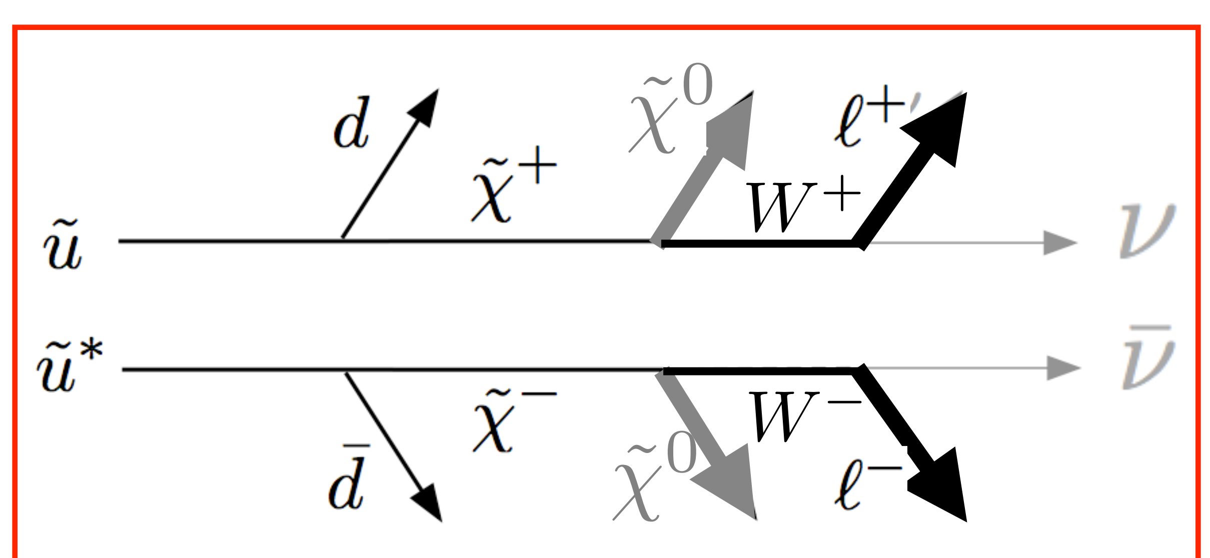
- Trained from ttbar study, we can apply the same method to the new physic search.
- But, there may be more than one diagram in the BSM to give the same signature. (For ttbar csae, there is only one.)

Various possibilities



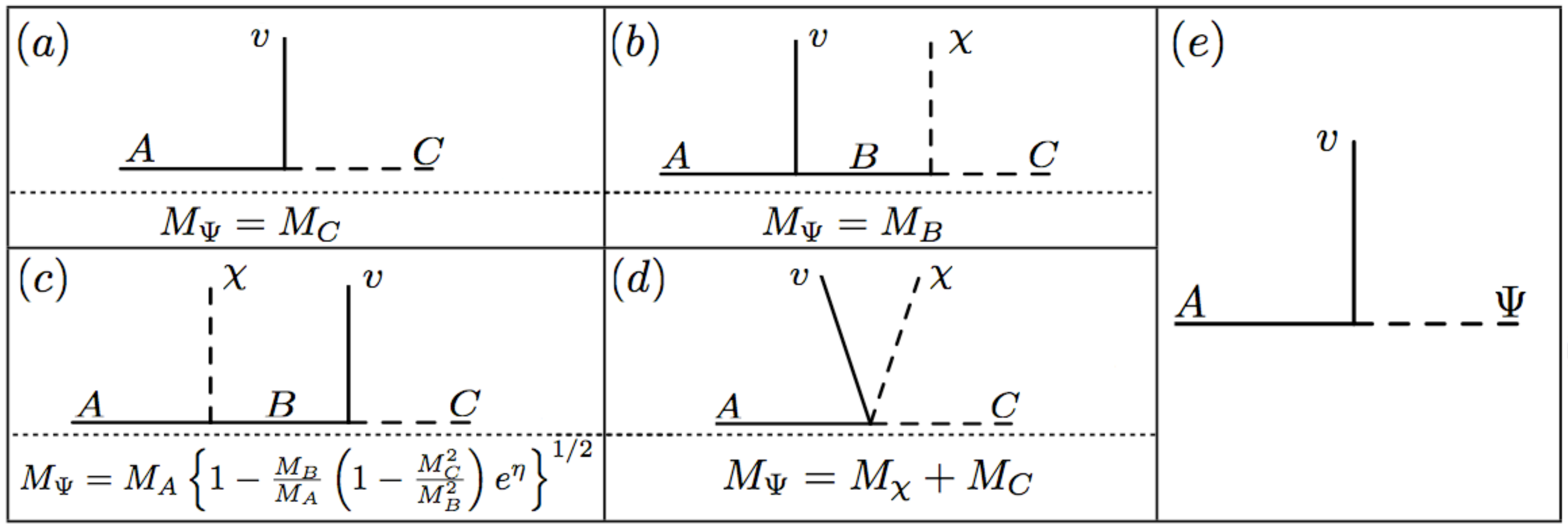
- There are 12 (sub) diagrams that have two visible particles and up to four invisible particles.
- We need to
  - invent observables based on each diagram, or/and
  - <u>understand how to interpret a result of existing observables for each diagram.</u>

+ more...

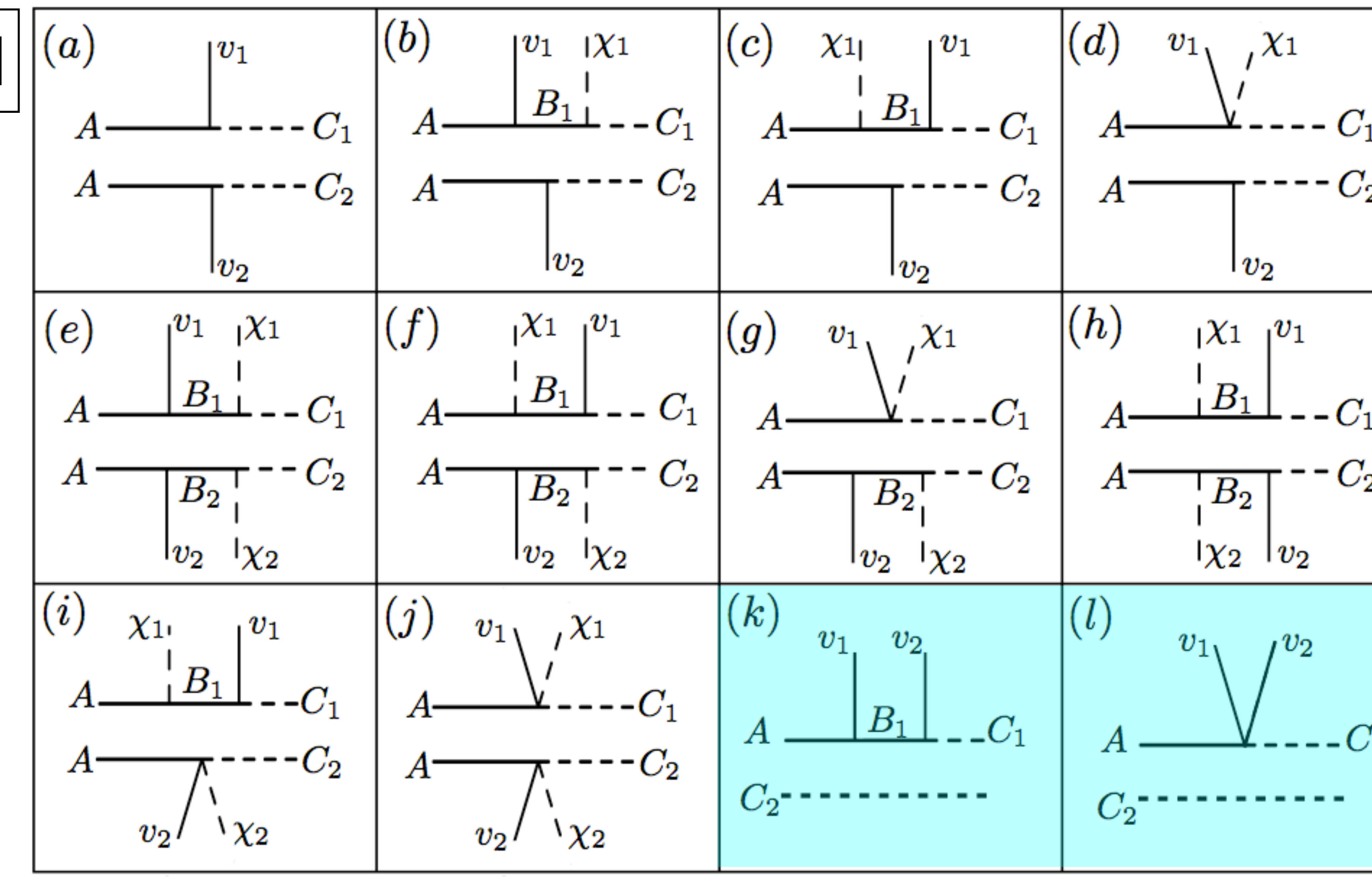


Effective diagram

I

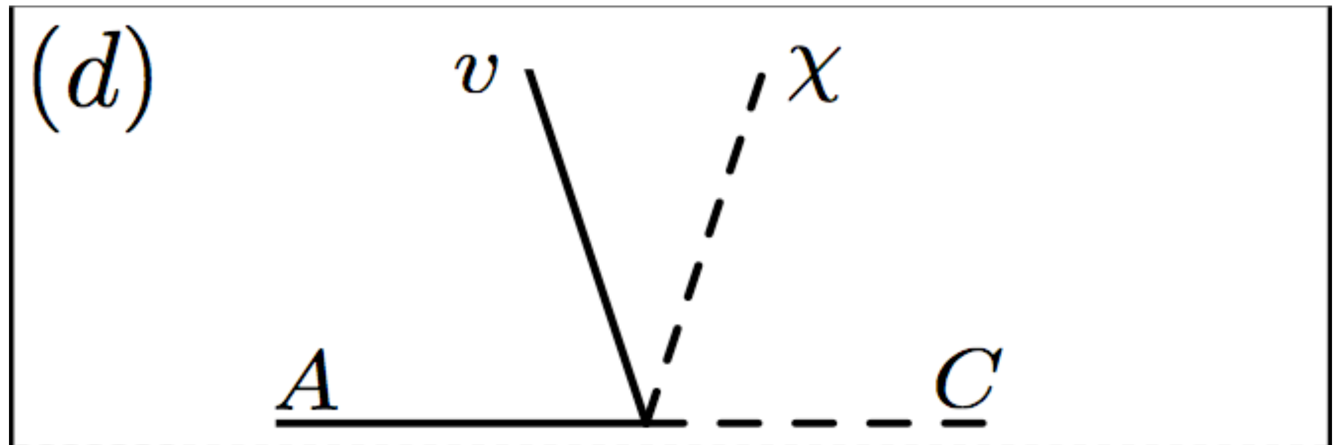


II



- We apply an observable that was motivated initially for the II (a) assumptions, and want to interpret results (endpoint of distributions) in various cases.
- Diagrams in II (except k,l) are combinations of a basic decaying leg I (a), (b), (c), and (d).
- For example, in I (b), we can treat B that decays invisibly as invisible particle.
- The only non-trivial case will be I (c).

- We are interested in the endpoint of distributions. Thus we need to focus on the range of a (transverse) momentum of visible particle v (at the rest frame of A.)



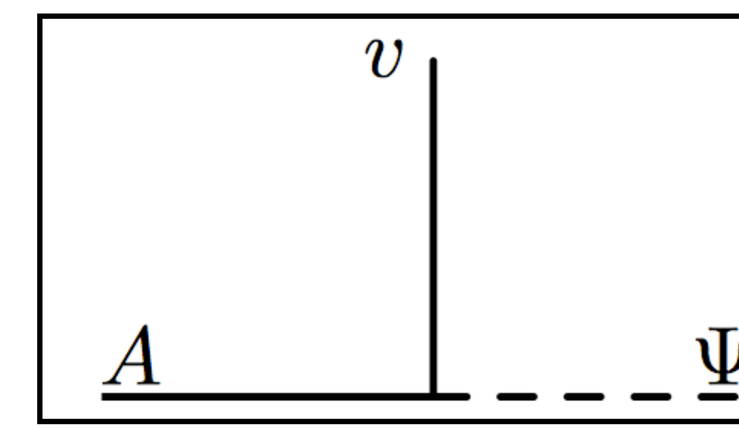
$$M_\Psi = M_\chi + M_C$$

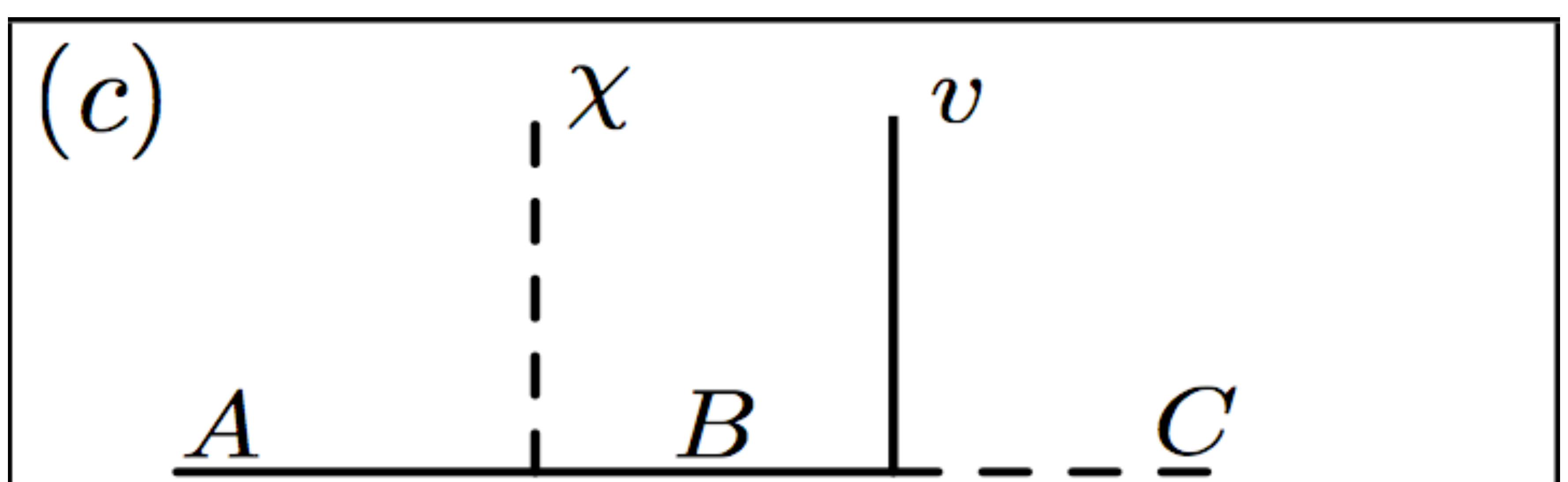
At A's rest frame, a range of transverse momentum of v

$$0 \le P_T \le \frac{M_A}{2}\left(1 - \frac{M_{C\chi}^2}{M_A^2}\right)$$

Thus, P_T will have a maximum when the invariant mass $M_{C\chi}$ of C and chi has a minimum value = $M_C + M_\chi$

This range of P_T also come from the right diagram where a particle Ψ with a mass of $M_\Psi = M_C + M_\chi$. Thus we can replace (d) with a right diagram for the endpoint of transverse observables.





$$M_\Psi = M_A\left\{1 - \frac{M_B}{M_A}\left(1 - \frac{M_C^2}{M_B^2}\right)e^\eta\right\}^{1/2}$$

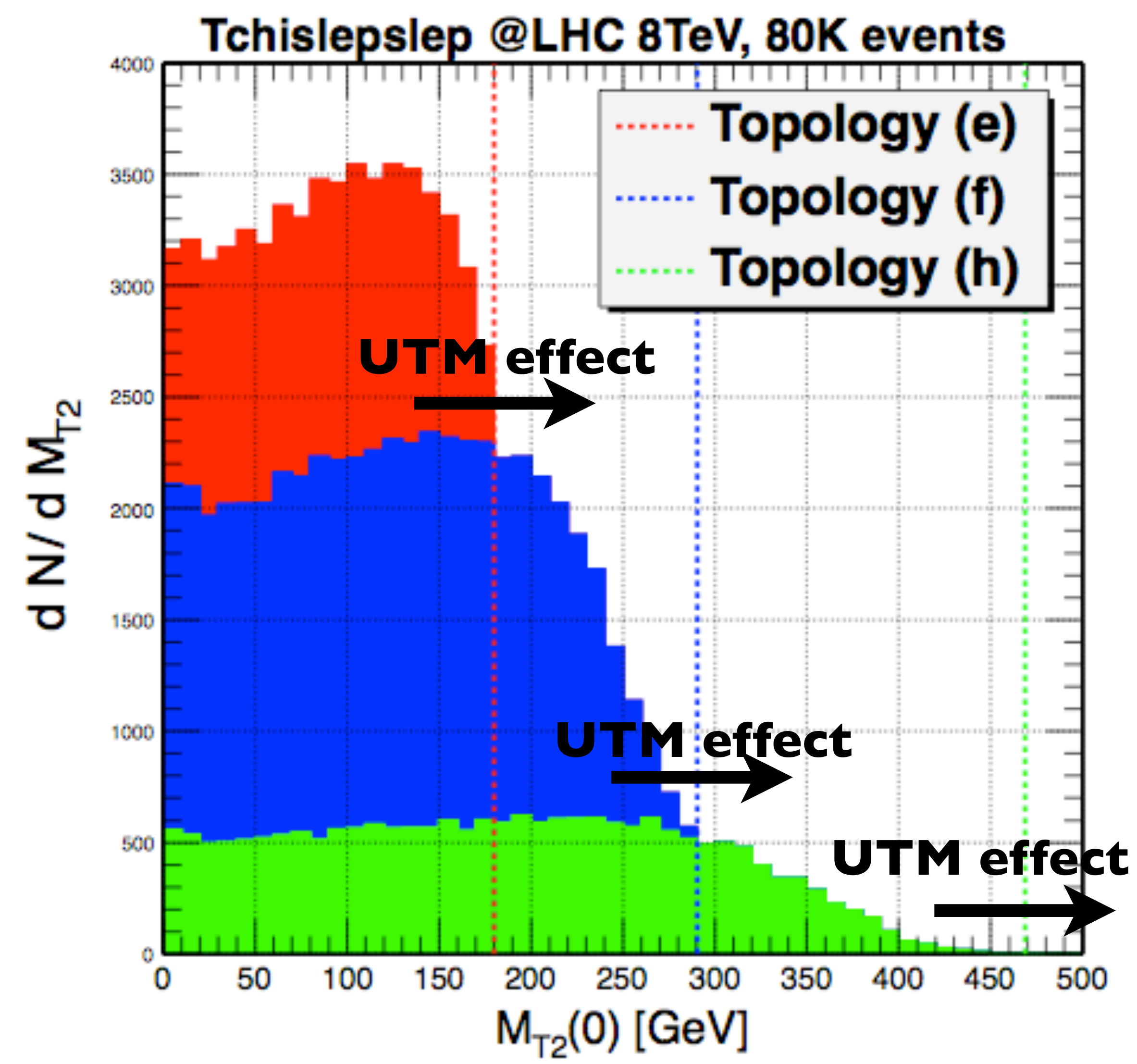
Similarly, in this case at the A's rest frame

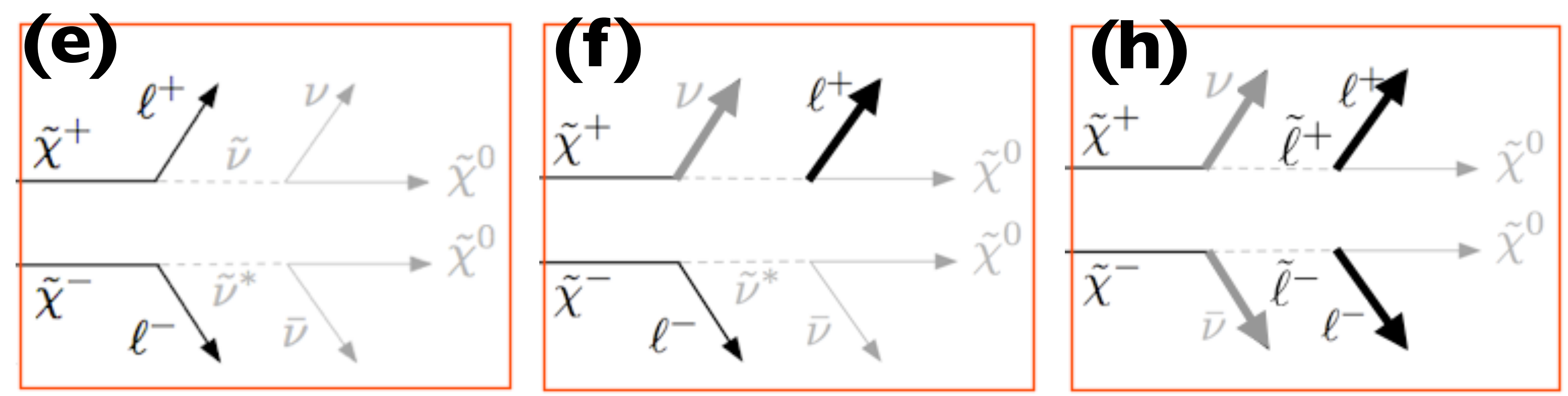
$$0 \le P_{vT}^{(A)} \le \frac{M_B}{2}\left(1 - \frac{M_C^2}{M_B^2}\right)(\cosh\eta + \sinh\eta) = \frac{M_B}{2}\left(1 - \frac{M_C^2}{M_B^2}\right)e^\eta$$

Identify as $= \frac{M_A}{2}\left(1 - \frac{M_\Psi^2}{M_A^2}\right)$

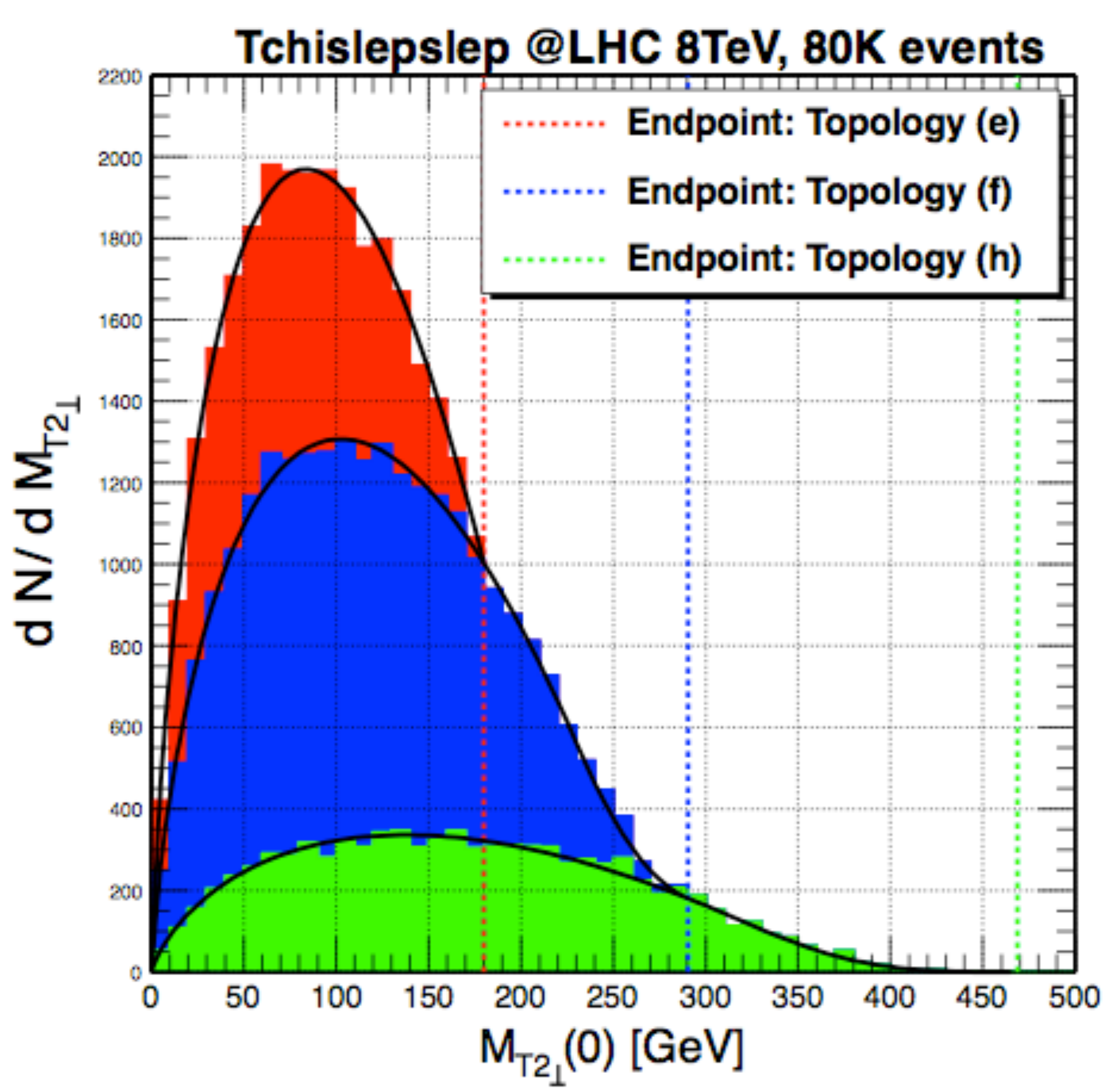
where η is a Lorentz boost factor from a rest frame of B to the rest frame of A. $\begin{pmatrix}\cosh\eta & \sinh\eta\\ \sinh\eta & \cosh\eta\end{pmatrix}\begin{pmatrix}M_B\\ 0\end{pmatrix} = \begin{pmatrix}E_B^{(A)}\\ P_B^{(A)}\end{pmatrix}$

- As an example, we generated CMS Tchislepslep simplified model with $M_{\tilde{\chi}^+} > M_{\tilde{\nu}_L} \simeq M_{\tilde{\ell}^+_L} > M_{\tilde{\chi}^0}$





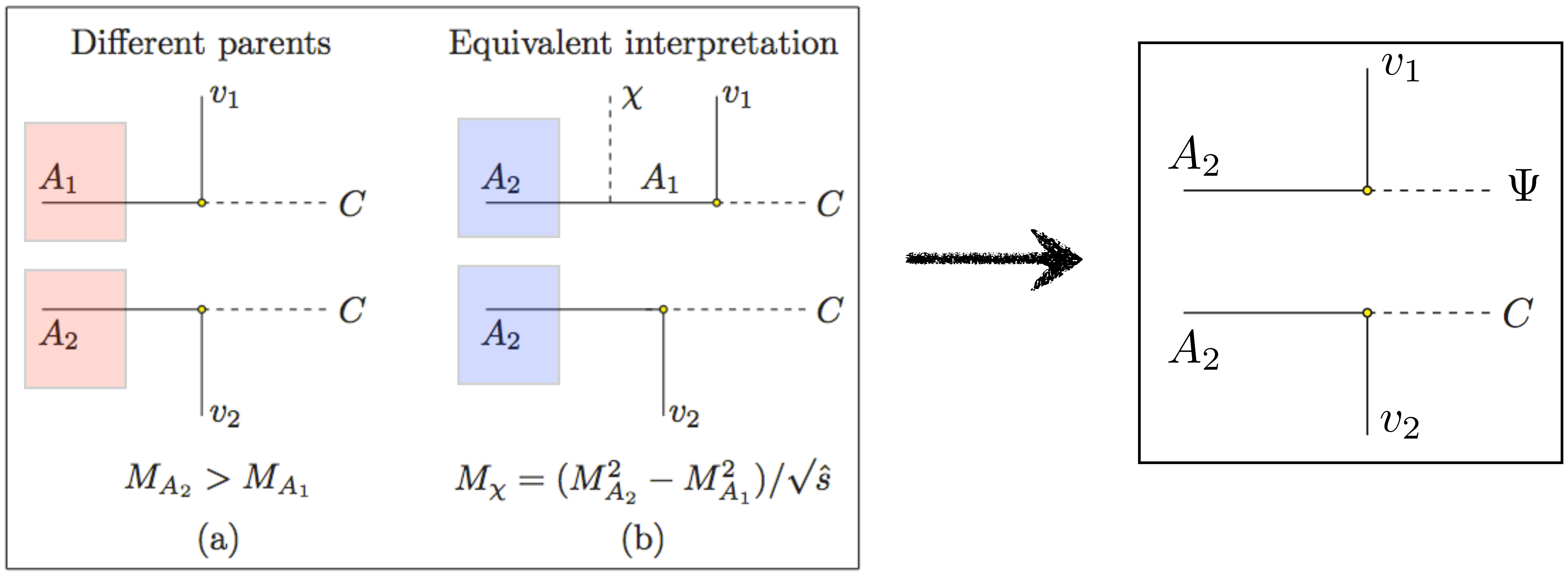
This is chargino direct productions. We predict endpoint as dashed line. But mostly chargino will be produced via squark/gluino decays or with ISR, endpoints will be smeared from UTM boost effect.



Thus we use 1D projected observables to preserve the endpoint. In this 1D observables, we predict not only the **endpoints** but the **shape of distributions**. Shape of 1D observables are **NOT** sensitive to the $|M|^2$. (Lisa, MP, Matchev, arxiv:1205.2504): Universal and depends only on the event-topology.

- The analytic formulae of distributions are useful to understand the "tail (fall-off)" behavior of distributions.

Application of effective topology



- By now, many transverse variables assume the pair produced particles to be the same. We expand our effective diagram concept to the case where pair produced particles are different.
- But in this case, inserted missing particle χ's mass depends on the invariant mass of A1 and A2 $(\sqrt{\hat{s}})$, resulting in the effective particle Ψ's mass dependency on the invariant mass of A1 and A2.

Conclusions

- Our study is rather mathematical point of view (as a framework for BSM search). But two main ideas of our methods were realized / tested in CMS top quark mass measurement and we hope that our methods keep contributing BSM searches.
- We generalized the "effective diagram" concept to cover various possibilities of the BSM physics.
  - to consider various missing energy sources (LSP and/or neutrino) and arbitrary number of missing particles.
  - to consider asymmetric productions (for example, gluino-squark co-production)
  - We provide endpoints and the shapes of distributions for 1D projected observables: This will help to understand the behavior of observables in various event-topologies.