MT2

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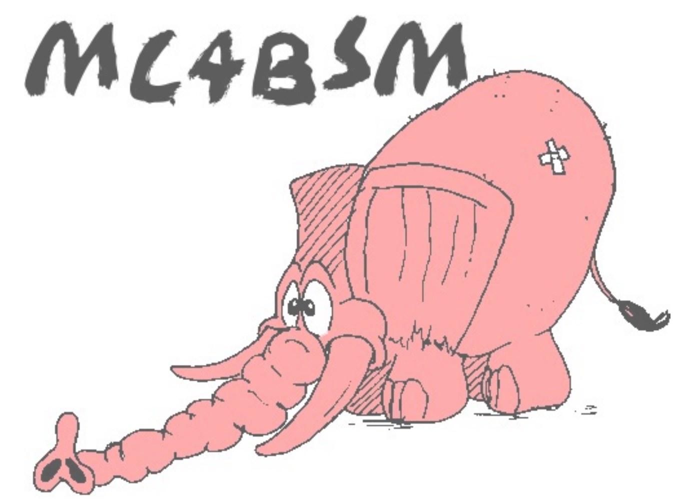
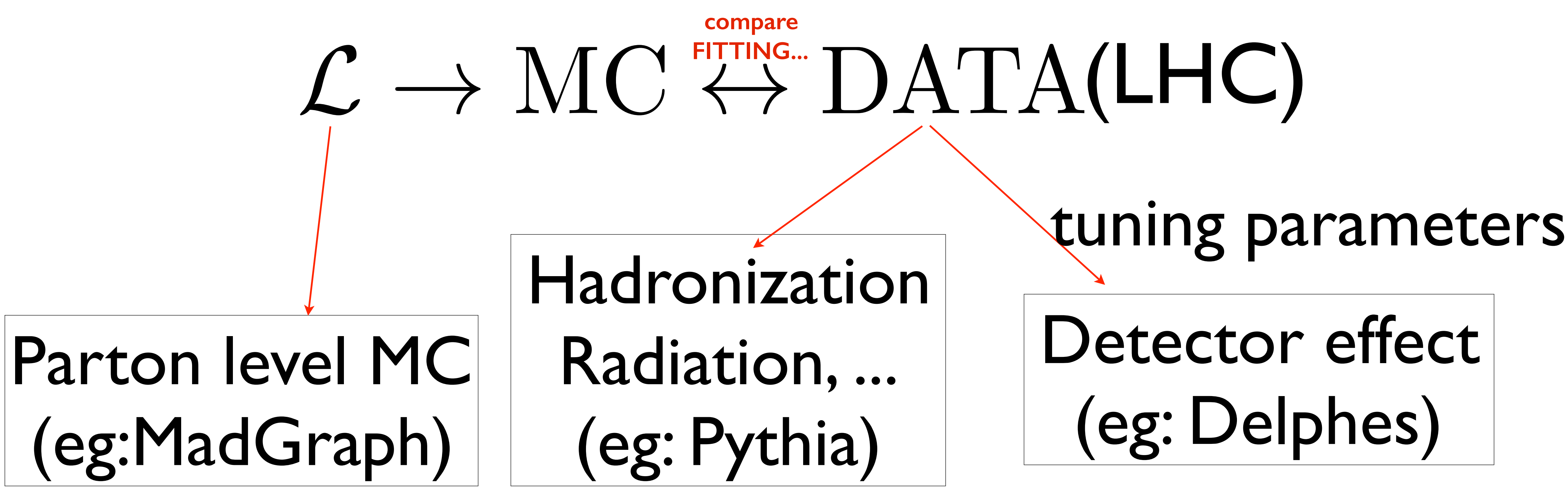
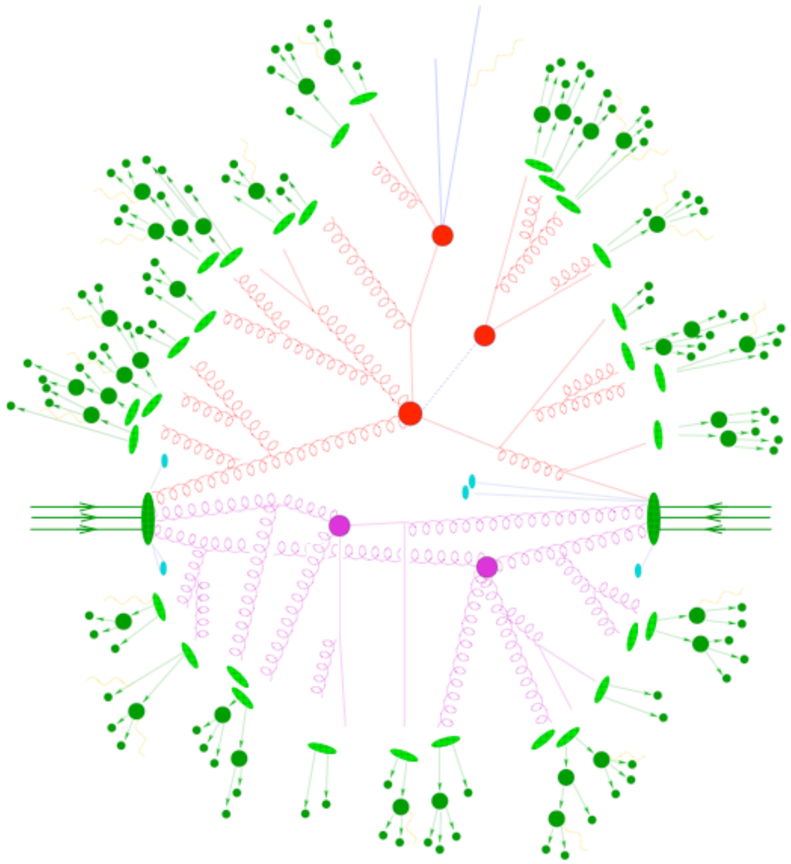


MC4BSM 2016 Beijing

Understanding physics@LHC

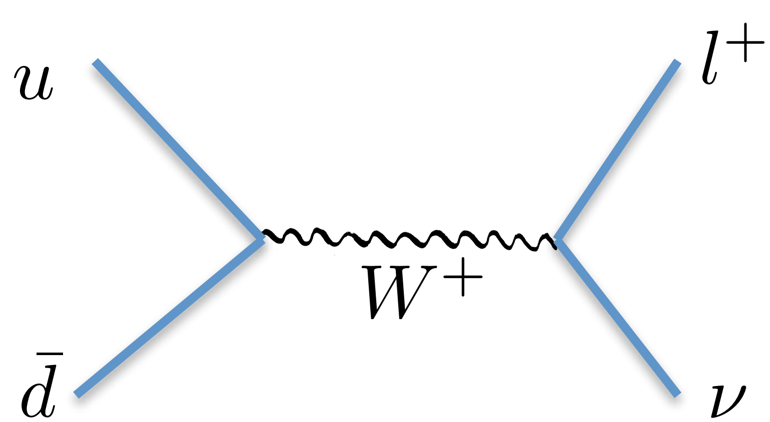
- If we know the physics model (theory [=Lagrangian]) and want to determine parameters, we can directly compare Monte Carlo (MC) simulations to data





Sherpa (Tanju Gleisberg, et.al.)
JHEP 0402 (2004) 056

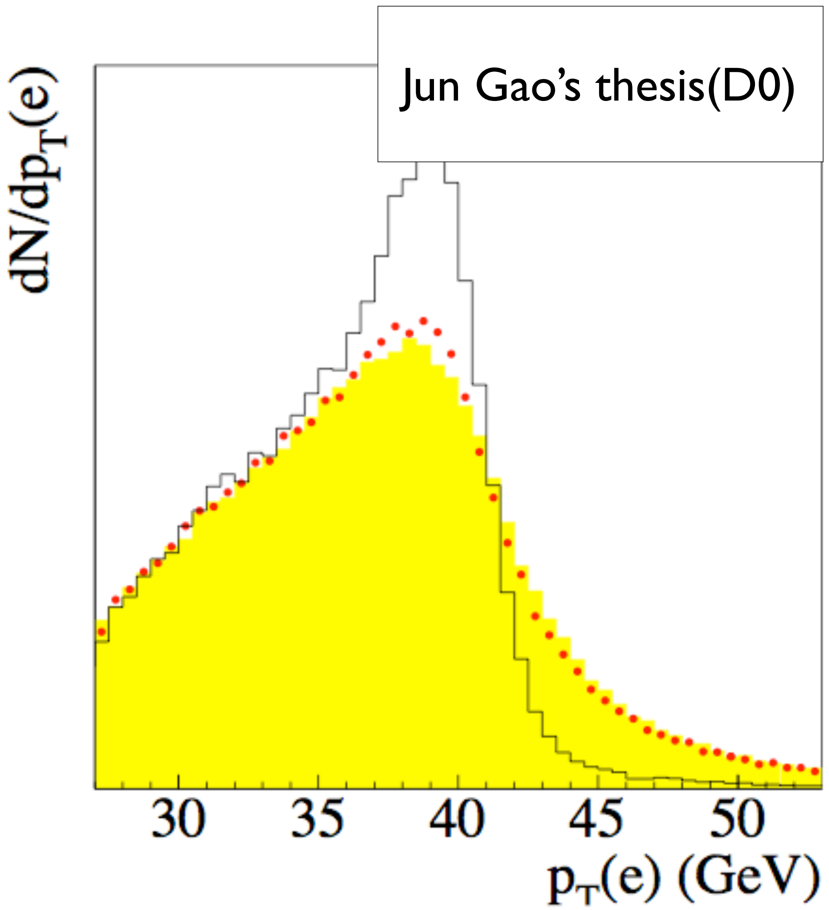
- Huge amount of community's efforts have been focused on MC to describe physics more precisely. (to remove systematic uncertainties from **MC**, DATA comparison)
- We need observables(histograms) to compare MC outputs with data.
- One example: W-boson mass measurement@Tevatron



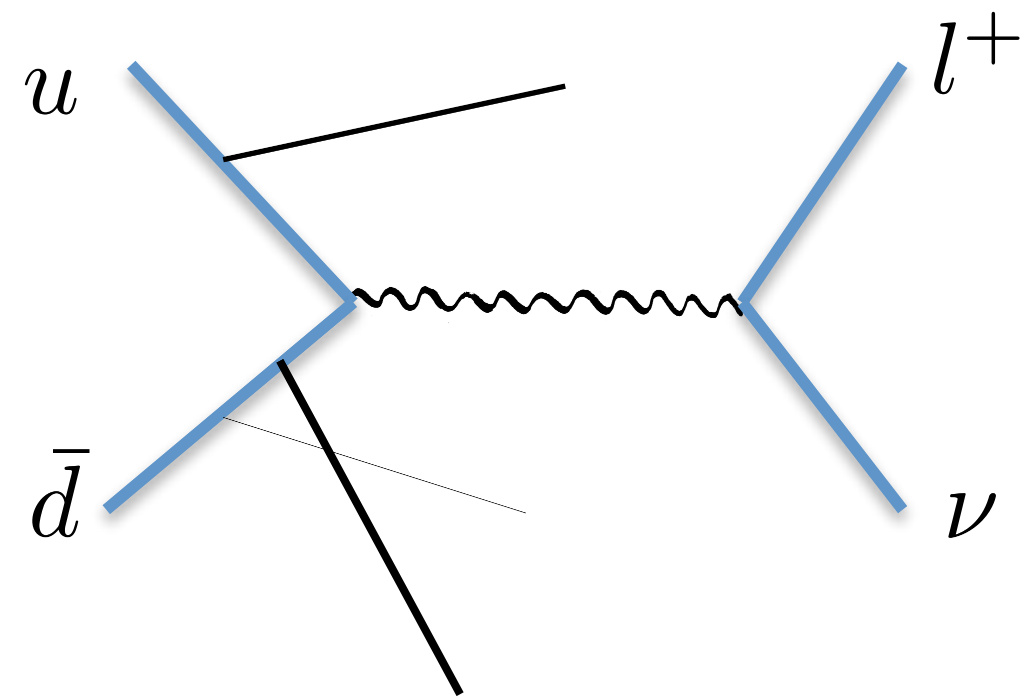
- At LO, W boson's transverse momentum (orthogonal to beam direction) ~ 0.
- Using the change of variable, we have a well-known Jacobian peak in leptons' PT distribution.

$$\frac{d\sigma}{dp_\perp} = \frac{d\cos\hat{\theta}}{dp_\perp}\frac{d\sigma}{d\cos\hat{\theta}} = \frac{p_\perp}{\sqrt{\left(\frac{M_W}{2}\right)^2 - p_\perp^2}}\frac{d\sigma}{d\cos\hat{\theta}}$$

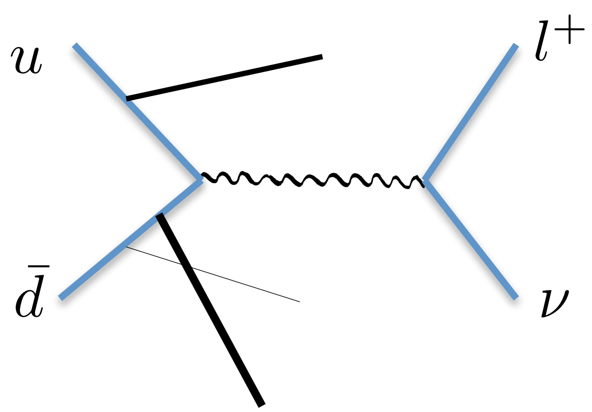
- In reality, W boson will be kicked off by extra jets!
- Thus, precise measurement will be highly dependent on the goodness of MC tools.
- Option: We can make some special variable to remove effects from this effect.



Black: Parton level [PT(W)=0]
RED: Parton level [PT(W) !=0]
Yellow: Detector level



Like as invariant mass is boost-invariant, a "**transverse mass**" will be invariant under the boost along transverse direction.

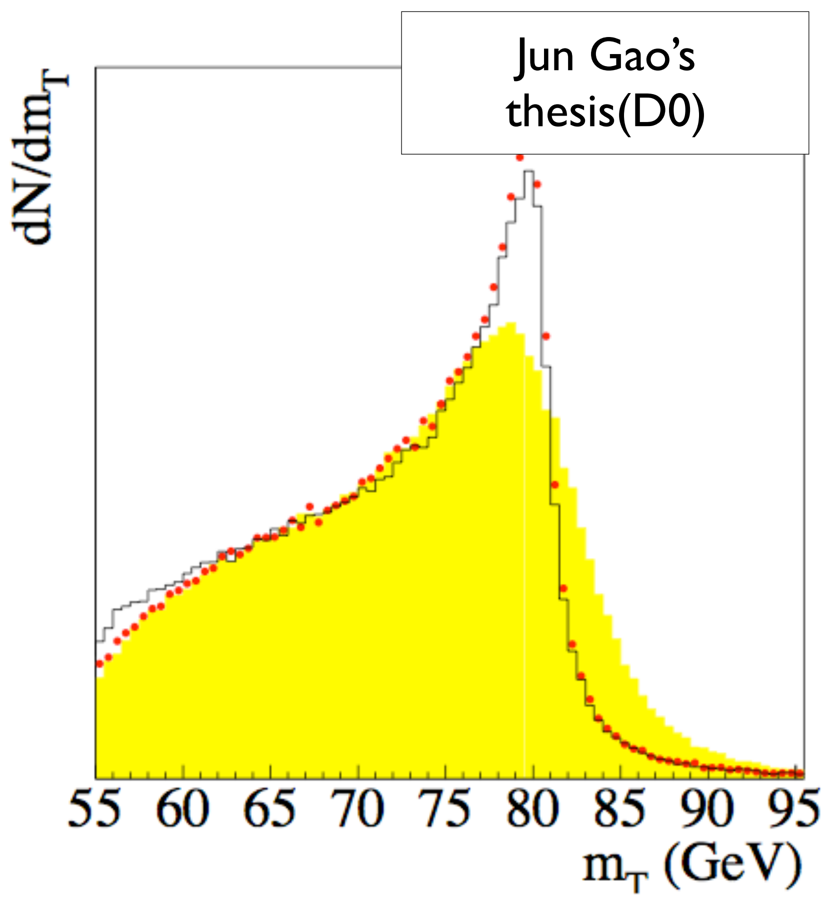


$$m_T^2 = (|\mathbf{p}_\perp^\nu| + |\mathbf{p}_\perp^\ell|)^2 - (\mathbf{p}_\perp^\nu + \mathbf{p}_\perp^\ell)^2$$

This variable is bounded by the mass of W boson, and have Jacobian peak just like lepton's PT distribution.

What we learned from old days:

It is important to **design observables** that are **strong** under (complicated, uncontrolled) **effects.**



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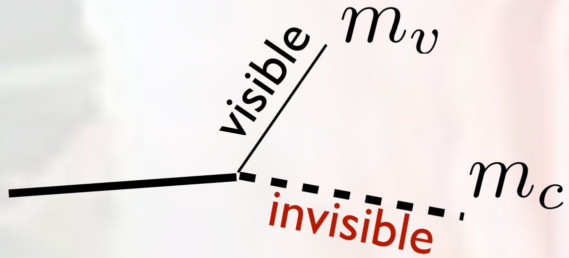
D0(arxiv:0908.0766)

TABLE II: Systematic uncertainties of the M_W measurement.

Source	ΔM_W (MeV) m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron shower modeling	4	6	7
Electron energy loss model	4	4	4
Hadronic recoil model	6	12	20
Electron efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	10	11	11
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	14
Total	37	40	43

Variable in Rosy dream before July. 2012

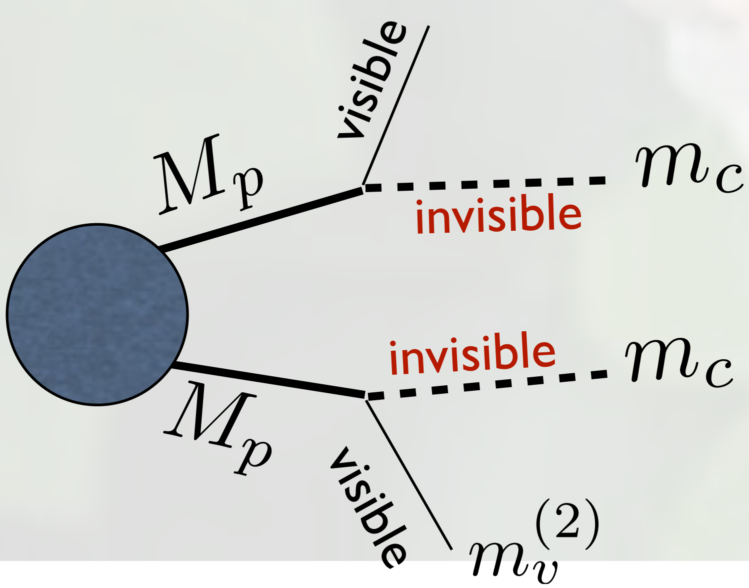
- A transverse mass M_T: $$M_T\left(m_c\right)=\sqrt{m_v^2+m_c^2+2\left(e_v e_c-\vec{p}_T^{\,v}\cdot\vec{p}_T^{\,(c)}\right)}$$



with a transverse energy, $e_c=\sqrt{\vec{p}_T^{\,(c)}\cdot\vec{p}_T^{\,(c)}+m_c^2}$

- For double decay chain event: Let's use M_T twice.

C.Lester, D. Summers (hep-ph/9906349)



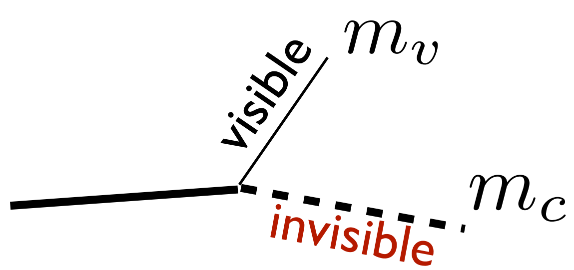
Assumptions:

I. Decaying particle in both chain has a common mass : M_p

II. Invisible particle in both chain has a common mass : m_c

III. No invisible particles except LSP

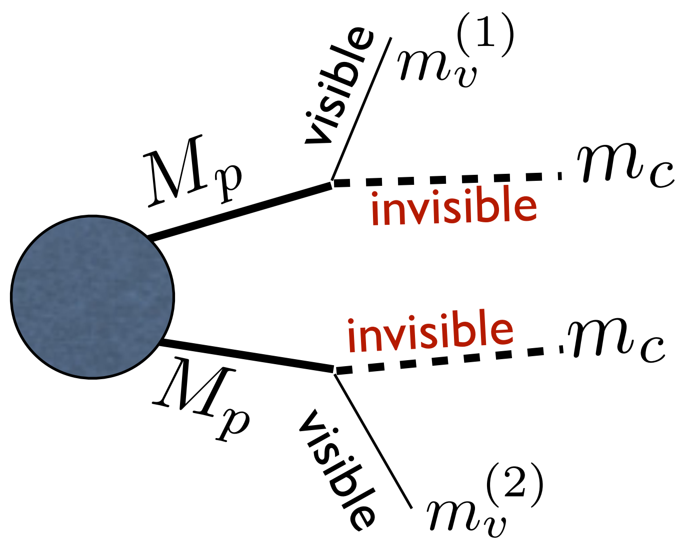
- A transverse mass M_T:

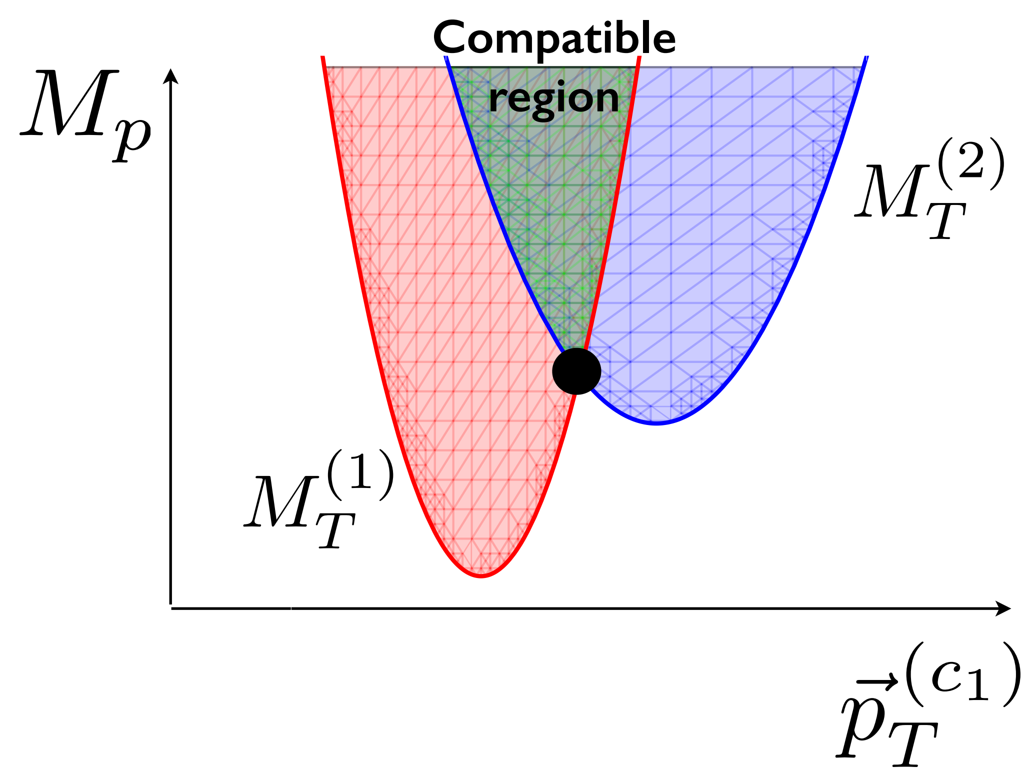


$$M_T\,(m_c) = \sqrt{m_v^2 + m_c^2 + 2\left(e_v e_c - \vec{p}_T^{\,v} \cdot \vec{p}_T^{\,(c)}\right)}$$

with a transverse energy, $e_c = \sqrt{\vec{p}_T^{\,(c)} \cdot \vec{p}_T^{\,(c)} + m_c^2}$

- For double decay chain event: Let's use M_T twice





- Minimum possible Mp with above kinematics constraints= M_{T2}

$$M_T^{(1)} \leq M_p \;\&\; M_T^{(2)} \leq M_p$$

(Transverse mass is less than the actual mass.)

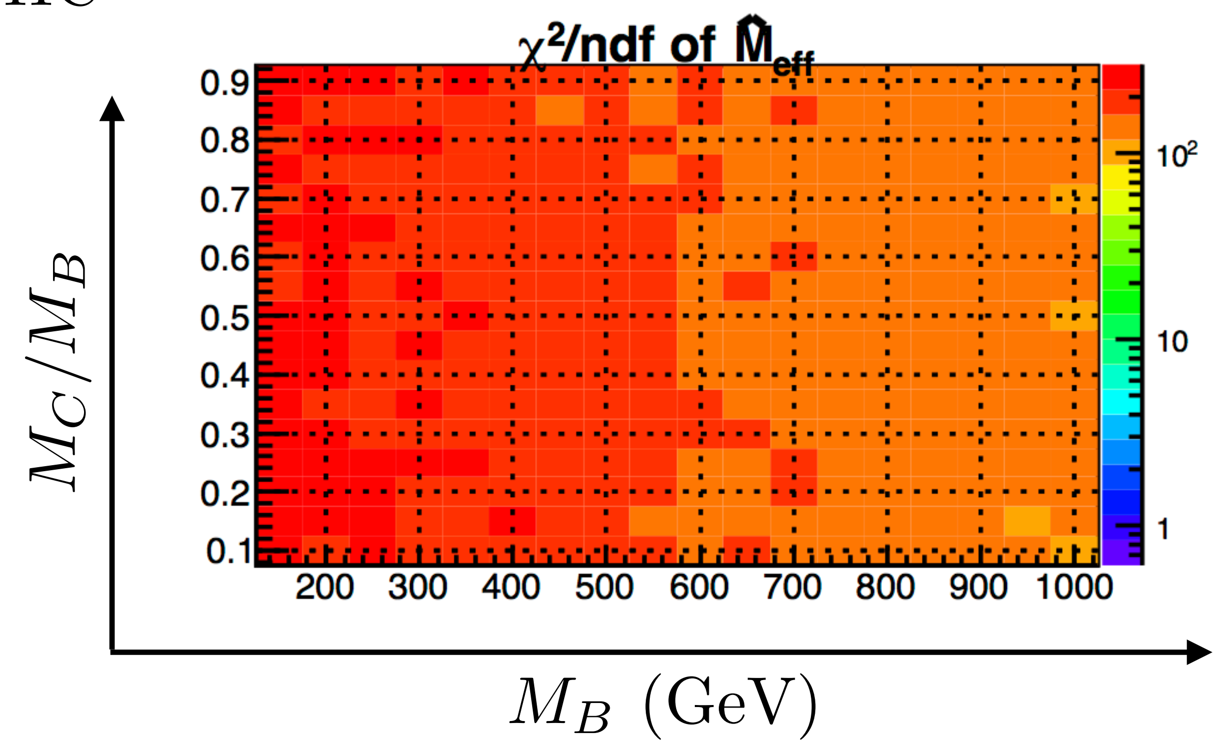
by H.-C. Cheng and Z. Han (hep-ph:0810.5178)

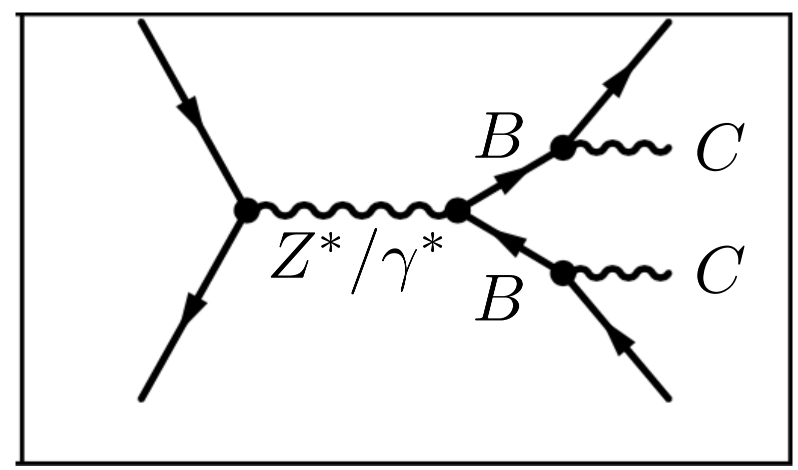
$$M_{T2}(m_c) = \min\left(\max[M_T^{(1)}(m_c), M_T^{(2)}(m_c)]\right)$$

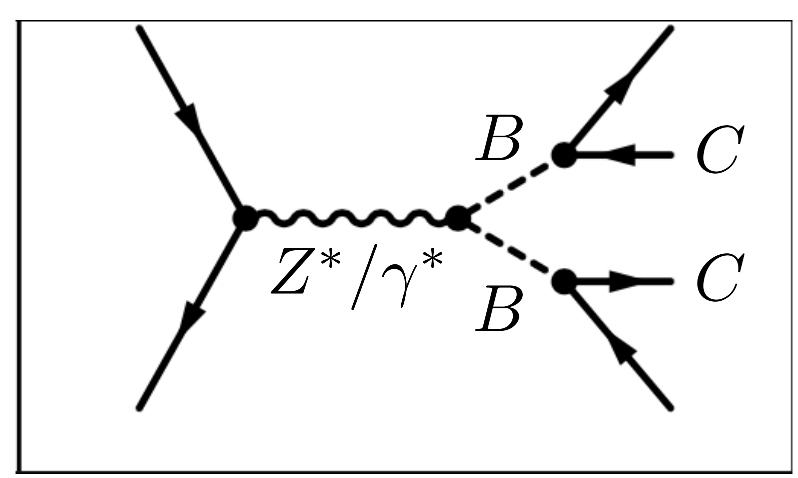
Goodness of MT2

- It is insensitive to helicity structures:
  - Your analyses are **independent** to BSM scenarios
  - Easy to recast analysis in specific BSM to others.
  - Only depends on the kinematical structure.

8Tev LHC







$$M_{\text{eff}} = P_{1T} + P_{2T} + \not{E}_T$$

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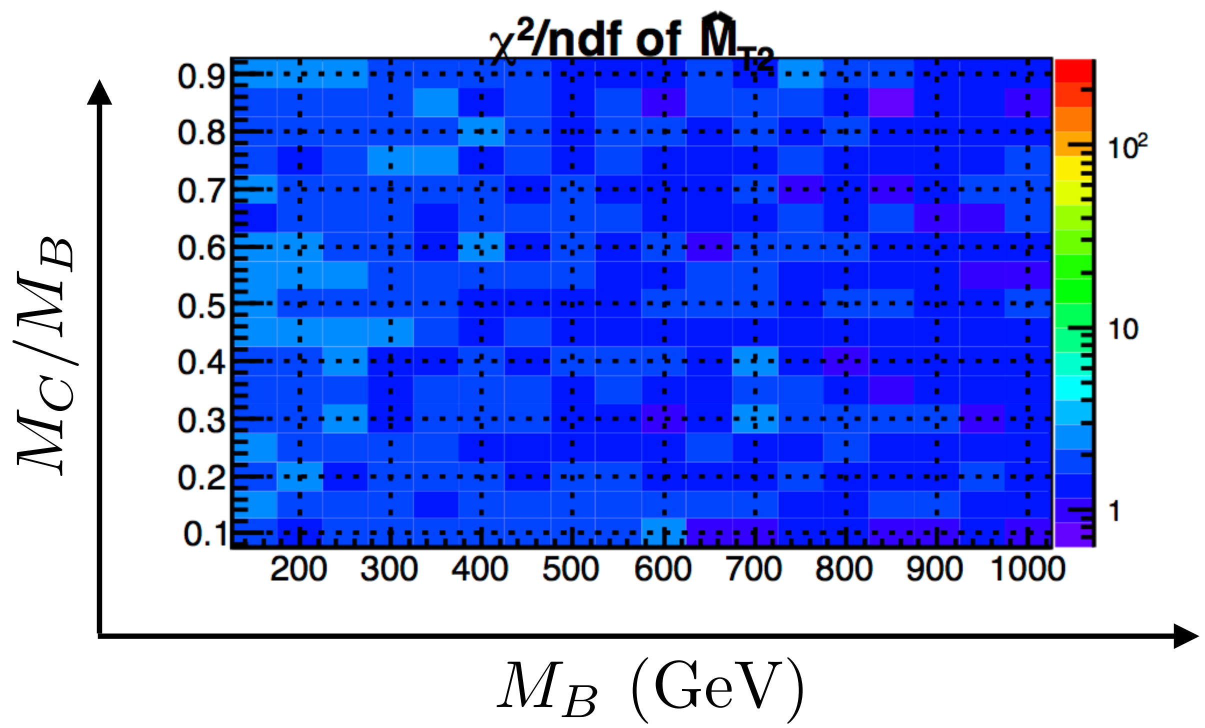
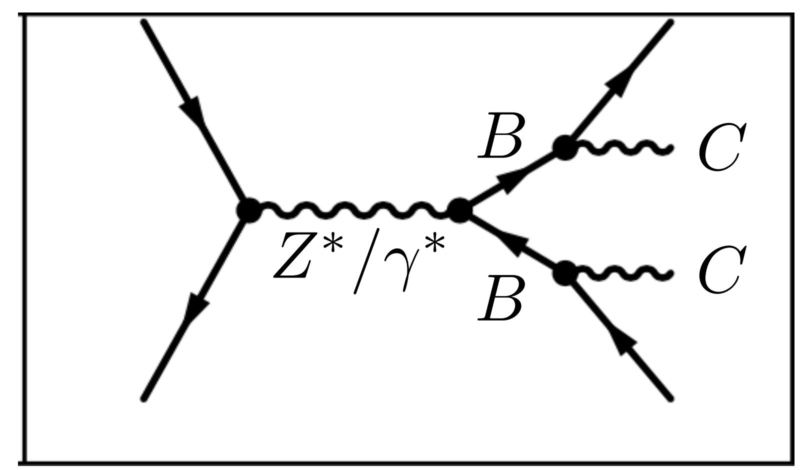
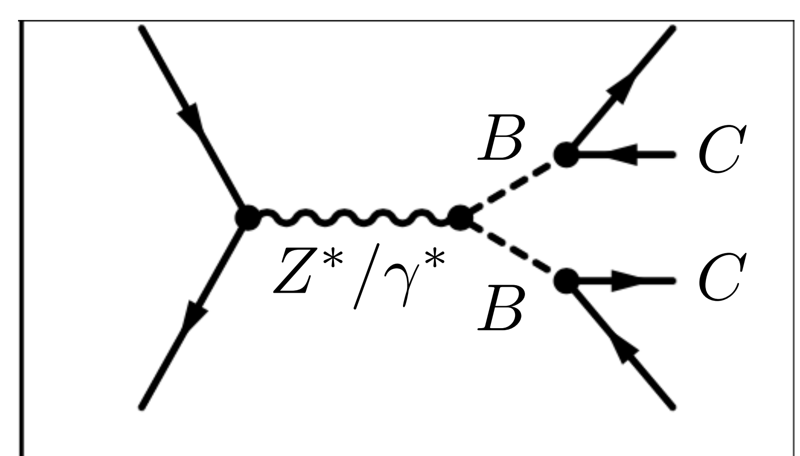
8Tev LHC



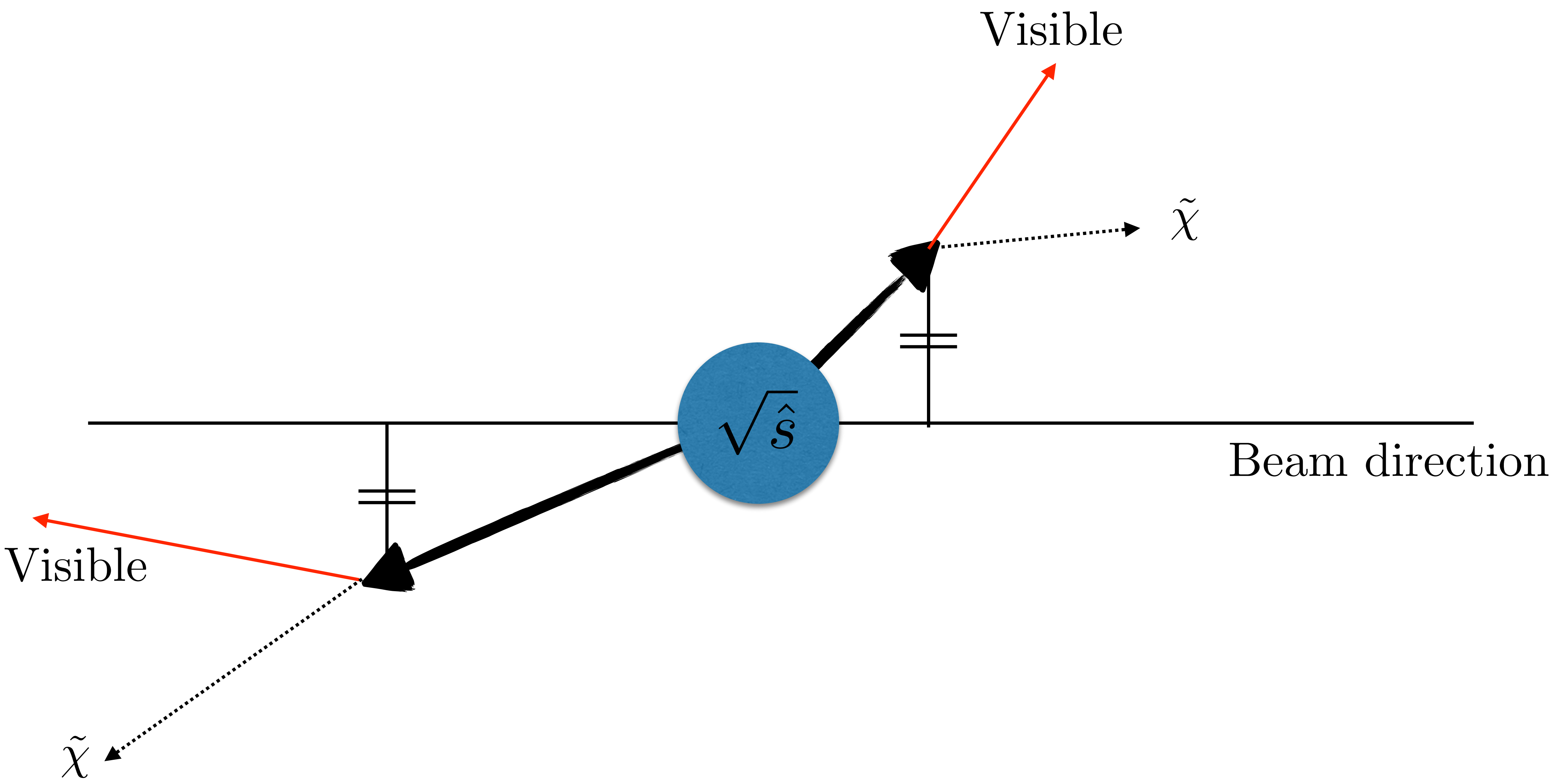




MT2 has a **Back to back boost Invariance**

Back to back "Transverse" BOOST INV

- Just like MT variable



Back to back
“Transverse” BOOST INV

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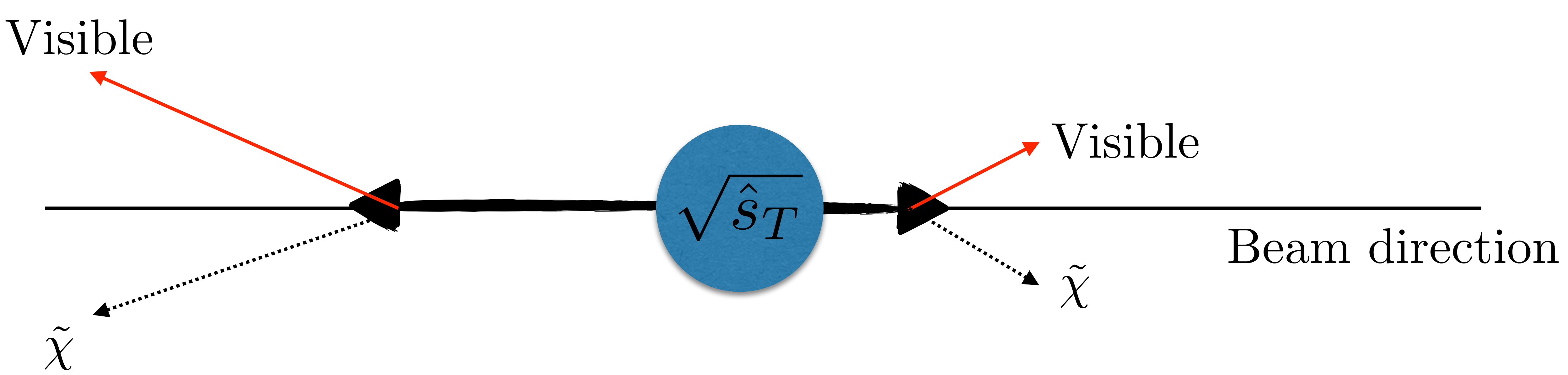

Back to back "Transverse" BOOST INV

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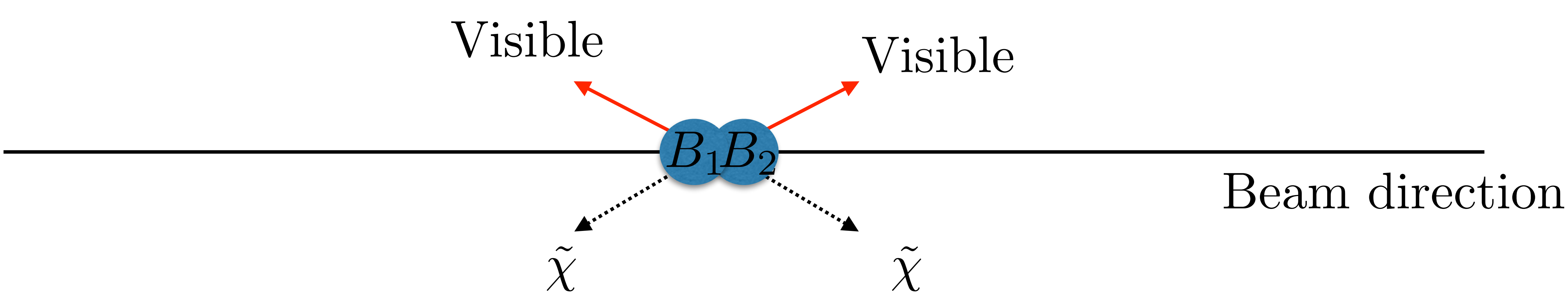
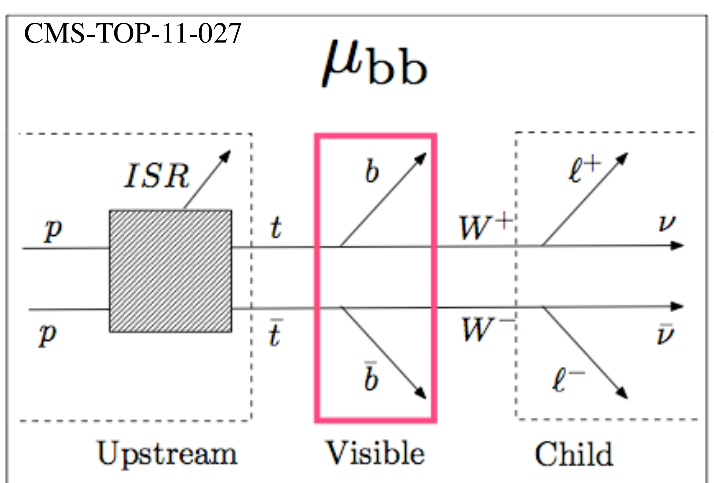


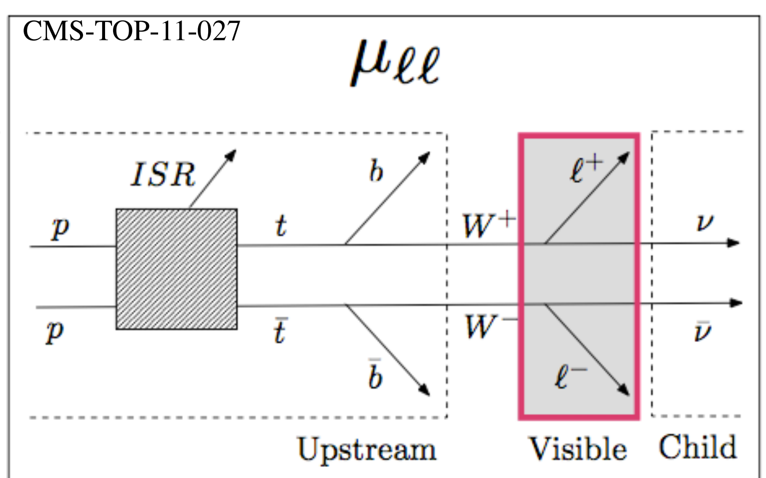
Very easy to **estimate** MT2 behavior for **Know kinematics** (Standard Model Back grounds)

MT2 as a CUT variable

- M_{T2} inherits the good property of M_T: Transverse boost invariance!
  (<u>But only when you put the the right value for m_c</u>)
- Since we don't know the true mass of LSP, we only can get the constraint of decayed particle in terms of LSP mass.
- But we know what will be missing particles of background (Standard Model) : neutrino
  - Thus, experimentalists started to use this variable as one of cuts.
  (by Alan Barr, Claire Gwenlan : arxiv:0907.2713)

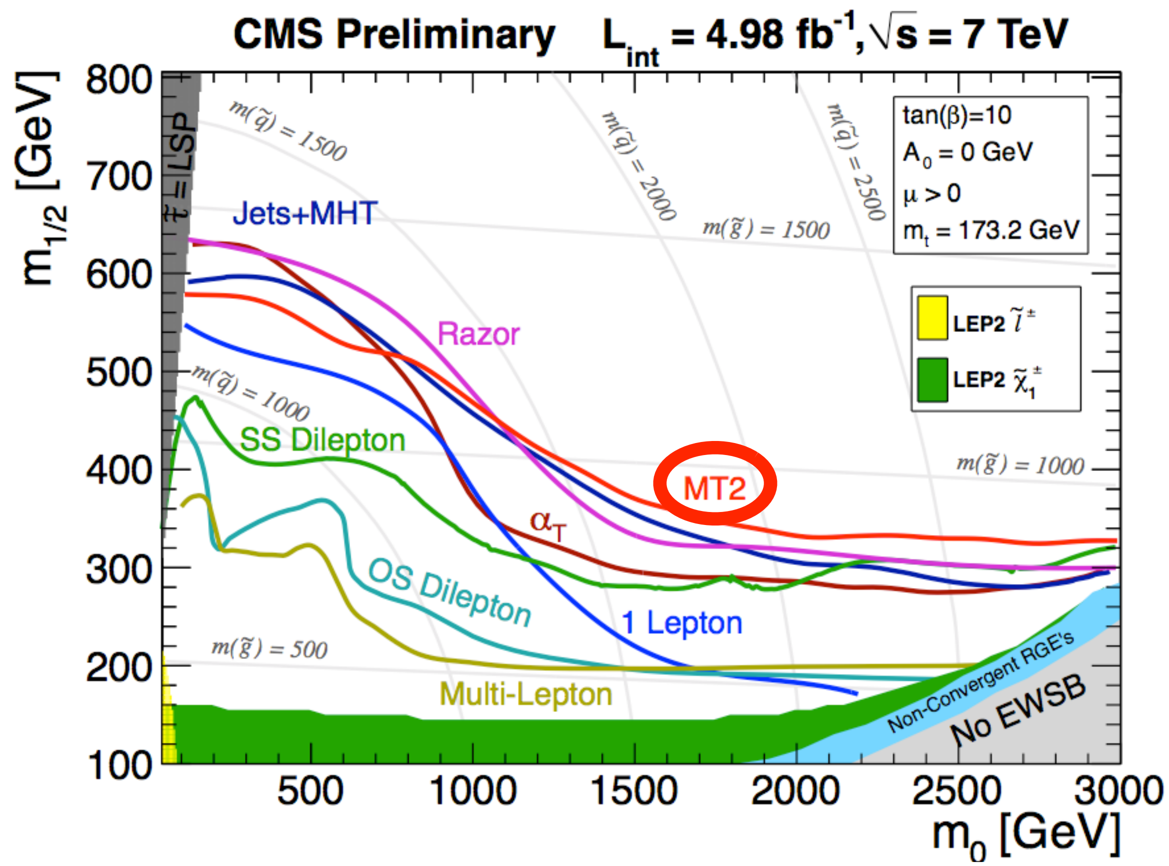
<u>example cartoon to describe MT2 in ttbar events</u>





Process	$m_{T2}(v_1, v_2, \not{p}_T, 0, 0)$	Comments
QCD di-jet → hadrons	$= \max m_j$ by Lemmas 1,4	
QCD multi jets → hadrons	$= \max m_j$ by Lemma 4	
$t\bar{t}$ production	$= \max m_j$ by Lemma 4	fully hadronic decays
	$\leq m_t$ by Lemmas 1,7	any leptonic decays
Single top / tW	$= \max m_j$ by Lemma 4	fully hadronic decays
	$\leq m_t$ by Lemmas 2,7	any leptonic decays
Multi jets: "fake" $\not{p}_T$	$= \max m_j$ by Lemma 5	single mismeasured jet[a]
	$= \max m_j$ by Lemma 6	two mismeasured jets[a]
Multi jets: "real" $\not{p}_T$	$= \max m_j$ by Lemma 5	single jet with leptonic b decay[a]
	$= \max m_j$ by Lemma 6	two jets with leptonic b decays[a]
$Z \to \nu\bar{\nu}$	$= 0$ by Lemma 3	
$Z\,j \to \nu\bar{\nu}\,j$	$= m_j$ by Lemma 3	one ISR jet[a]
$W \to \ell\nu$ [b]	$= m_\ell$ by Lemma 3	
$W\,j \to \ell\nu\,j$ [b]	$\leq m_W$ by Lemma 2	one ISR jet[a]
$WW \to \ell\nu\ell\nu$ [b]	$\leq m_W$ by Lemma 1	
$ZZ \to \nu\bar{\nu}\nu\bar{\nu}$	$= 0$ by Lemma 3	also $= m_j$ for one ISR jet[a]
$LQ\,\overline{LQ} \to q\nu\bar{q}\bar{\nu}$	$\leq m_{LQ}$	} i.e. can take large values
$\tilde{q}\,\bar{\tilde{q}} \to q\tilde{\chi}_1^0\,\bar{q}\tilde{\chi}_1^0$	$\leq m_{\tilde{q}}$	
$q_1, \bar{q}_1 \to q\gamma_1, \bar{q}\gamma_1$	$\leq m_{q_1}$	

MT2 as a CUT variable



$$H_T = \sum E_T,$$

$$HET = |-\sum \vec{P_T}|,$$

$$\alpha_T = \frac{E_J^{2nd}}{\sqrt{H_T^2 - HET^2}} = \frac{E_J^{2nd}}{M_T},$$

$$R = \frac{M_T^R}{M_R},$$

$$M_{T2} = \min\left(\max\{M_{T_1}, M_{T_2}\}\right).$$

- alphaT and Razor are good to suppress QCD multi jets corruptions to MET events. (No finite endpoint structure, Some characteristic # to cut backgrounds.)
- MT2 has a finite endpoint for SM backgrounds. (A.Barr arXiv:0907.2713)

- Various contributions from all over the world.
  - Cambridge: Parents of MT2
  - Oxford: In detail study of MT2
  - ATLAS: Analyses
  - KAIST : Realization of “kink” feature of MT2, MAOS
  - KEK: Various in-depth phenomenological studies of MT2
  - U.C.Davis : New interpretation of MT2 as kinematical bound
  - U.Florida : Generalizations, link to CMS
  - CMS: Analyses
  - Cornell : TTbar di-leptonic analysis@LHC
  - ETHZ : CMS MT2 analysis
  - CDF : Top quark measurement@Tevatron
  - D0
  - Even more vivid contributions so far

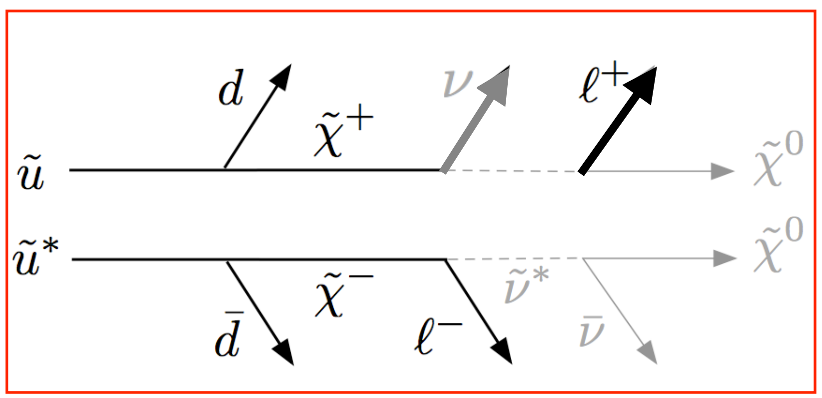
- Now, MT2 is the one of the **standard** variables in MET channels.

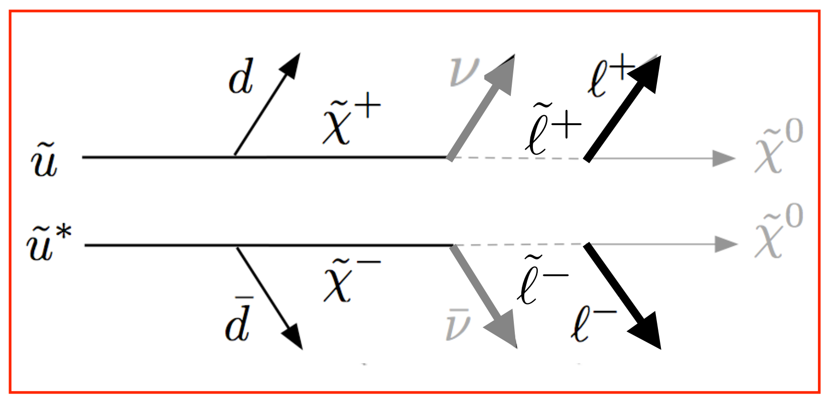
MT2 under BIG assumptions

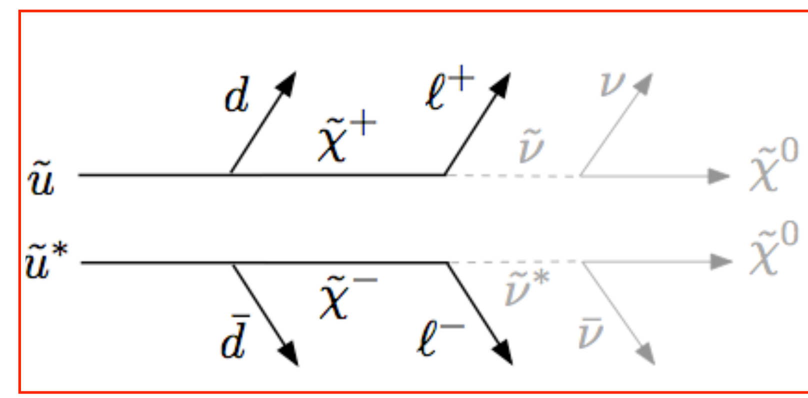
- I would like to remind you that
  M_{T2} was based on three big assumptions.
- Thus if most of signals (the new physics) violate
  at least one of these assumptions,
  is there any chance for signals **can hide behind Backgrounds**?
- I would like to study the behavior of M_{T2}
  when signals break some (all) of these assumptions.

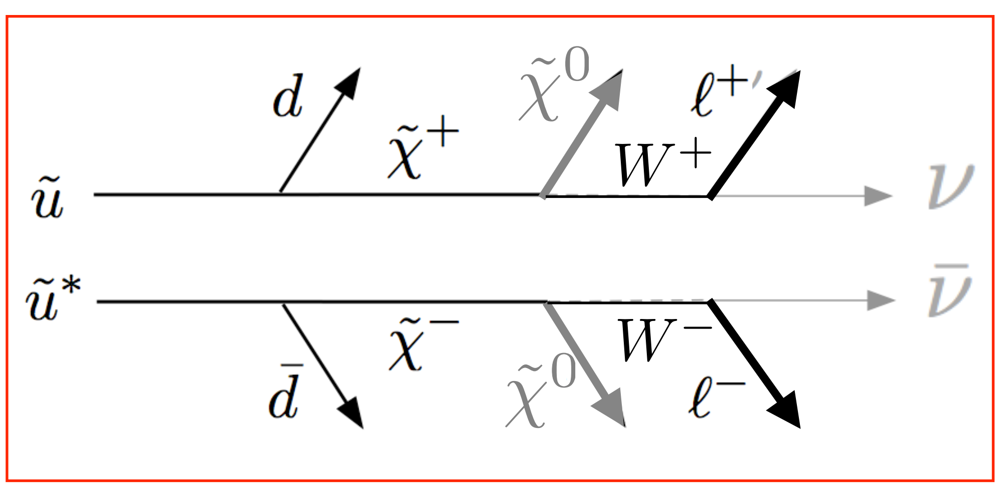
Various possibilities

- There may be more than one diagram in the BSM with the same signature. Some can violate assumptions of MT2





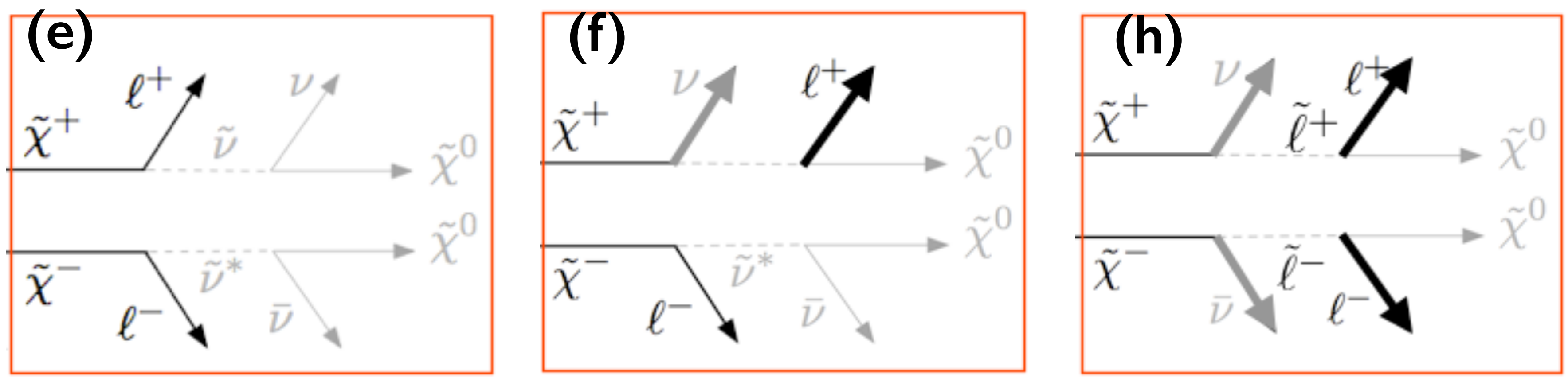




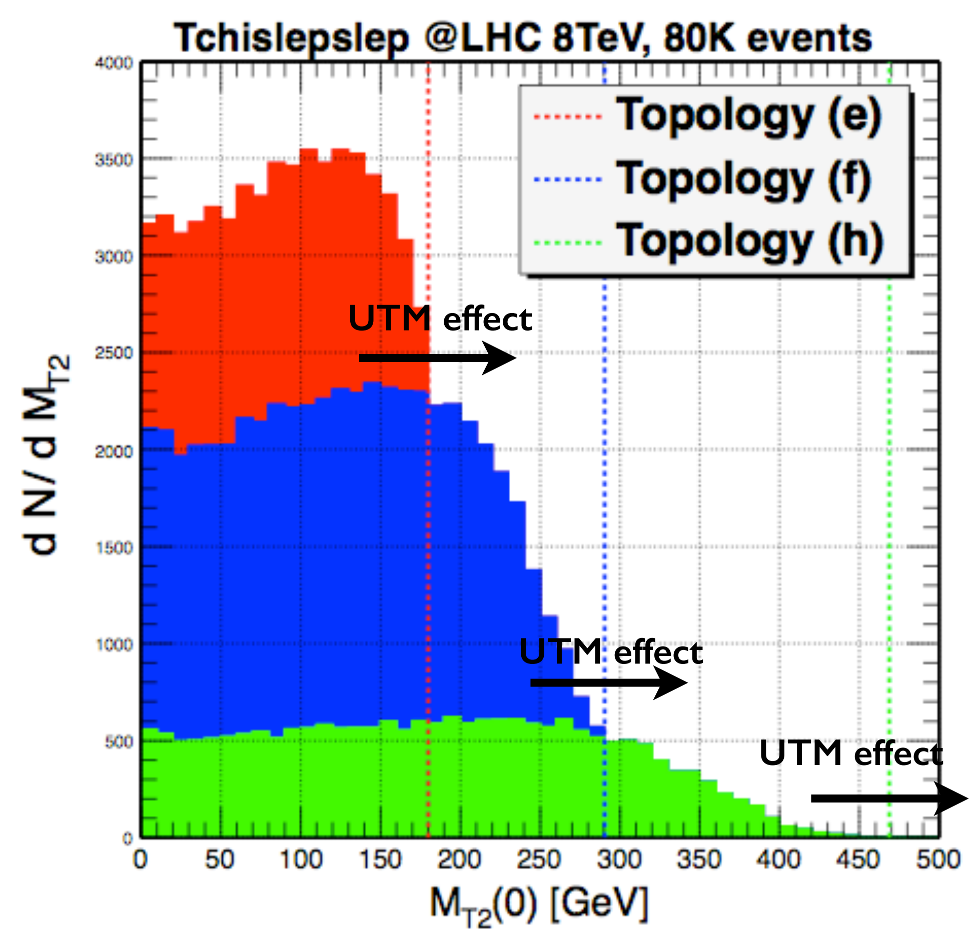
+ more if we consider different signals: squarks decays through long cascade (four leptons signals)

Various possibilities

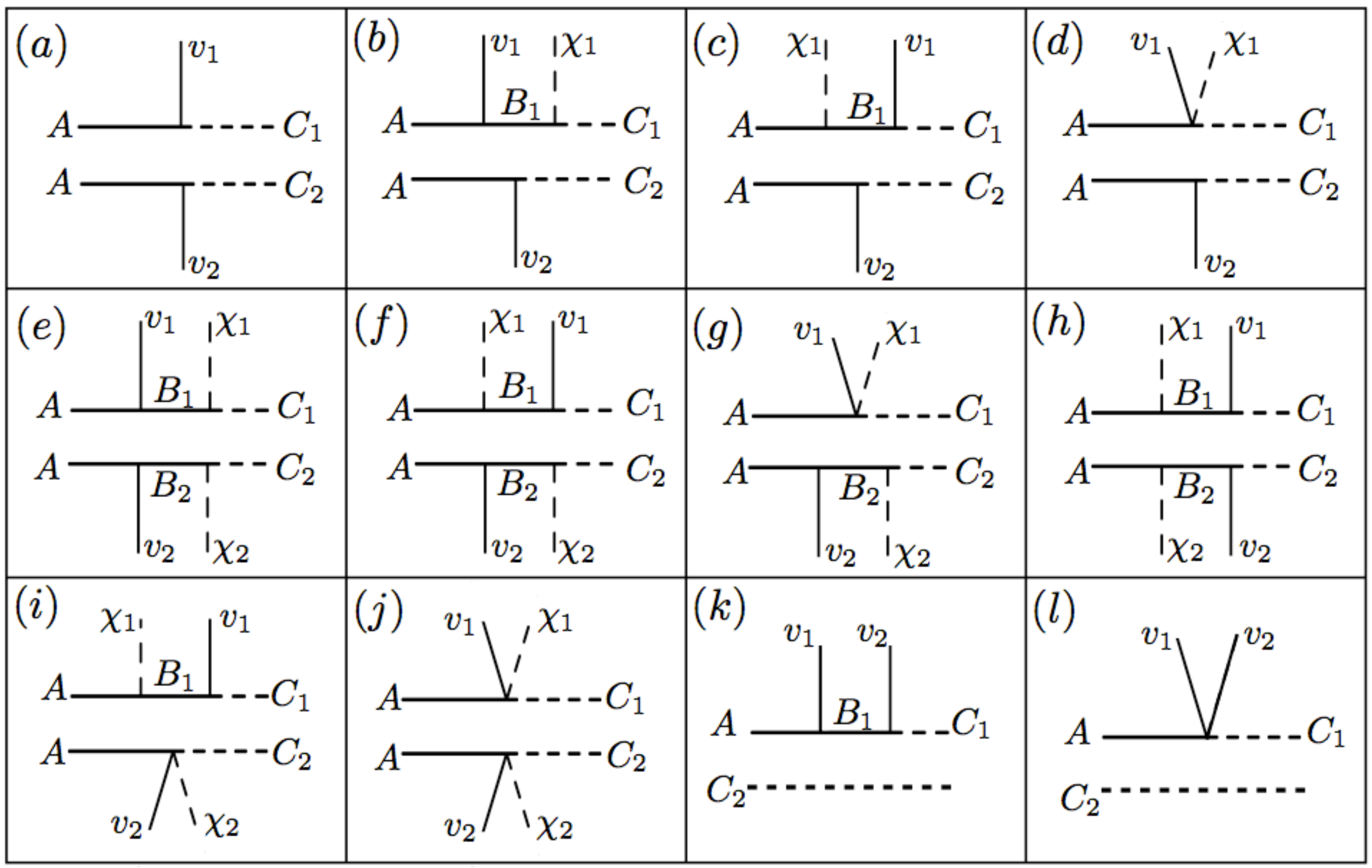
- As an example, we generated CMS Tchislepslep simplified model with $M_{\tilde{\chi}^+} > M_{\tilde{\nu}_L} \simeq M_{\tilde{\ell}_L^+} > M_{\tilde{\chi}^0}$



- Simulated[parton level] with masses:
  chargino 500GeV
  slepton(sneutrino) 400GeV
  LSP: 100GeV



Various possibilities



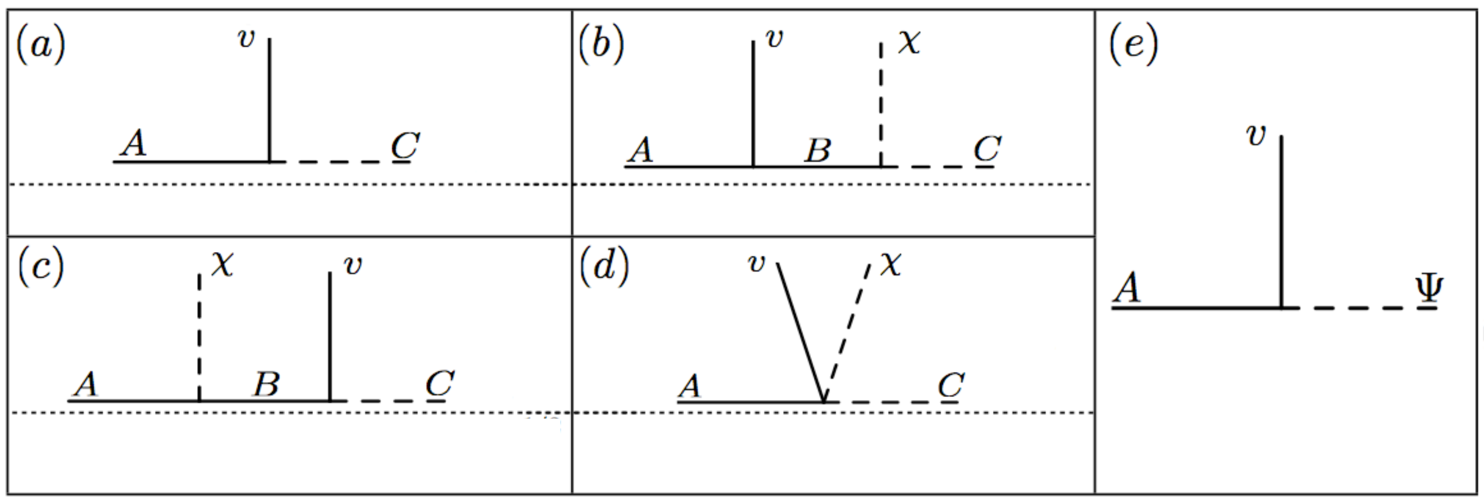
- There are 12 (sub) diagrams that have two visible particles and up to four invisible particles.
- We have options:
  1. we need to invent new observables based on each event-topology.

  2. And/Or we need to <u>understand how to interpret a result of existing observables (e.g. MT2) for each event-topology case.</u>

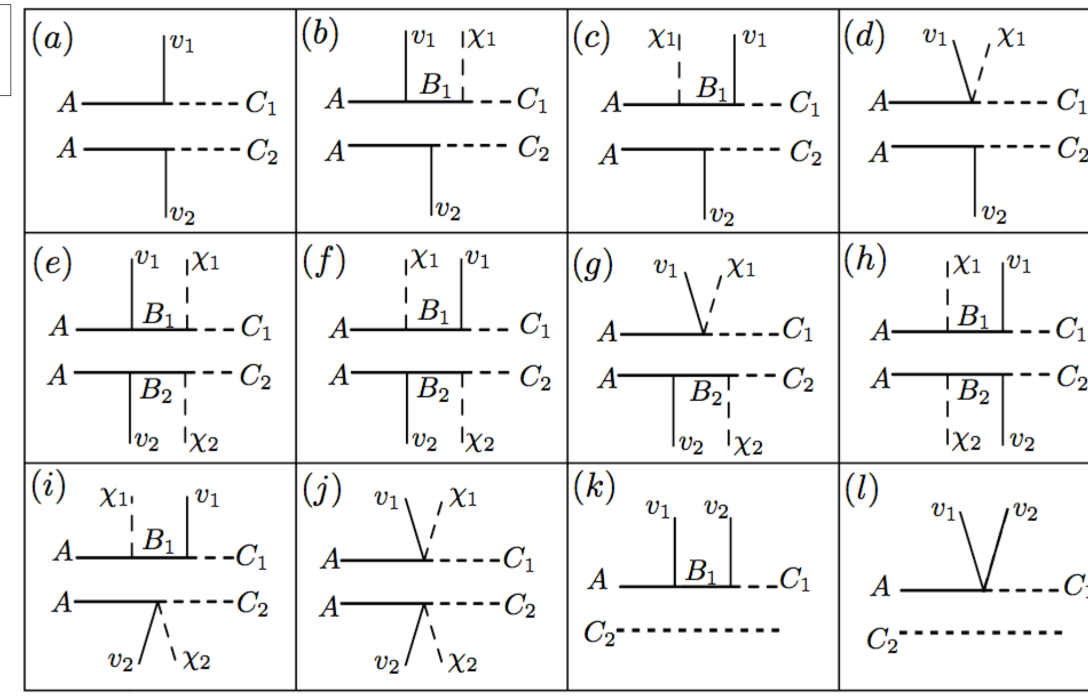
Effective event-topology

1. Number of invisible particle:
Introduce Equivalent event-topology method

I

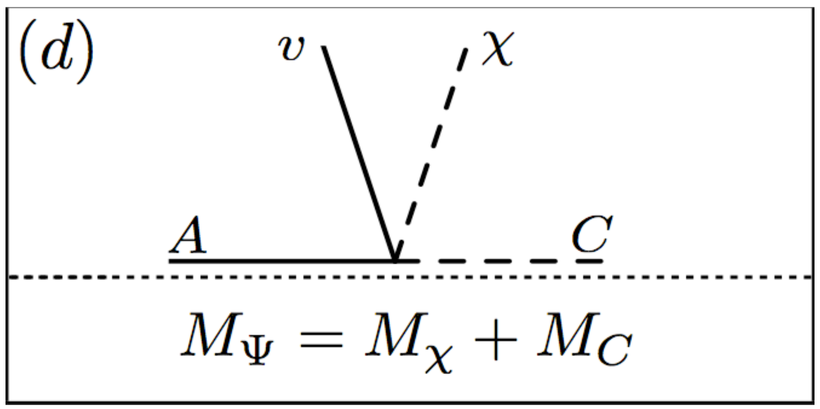


II



- 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**.) **(Back to back Boost Inv.)**

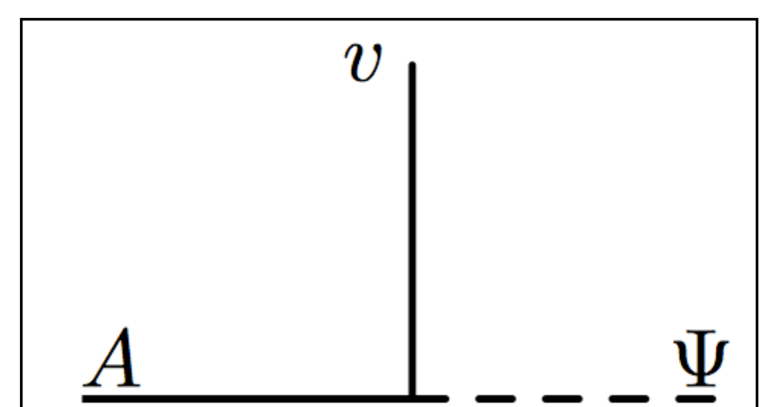


At A's rest frame, a range of transverse momentum of v

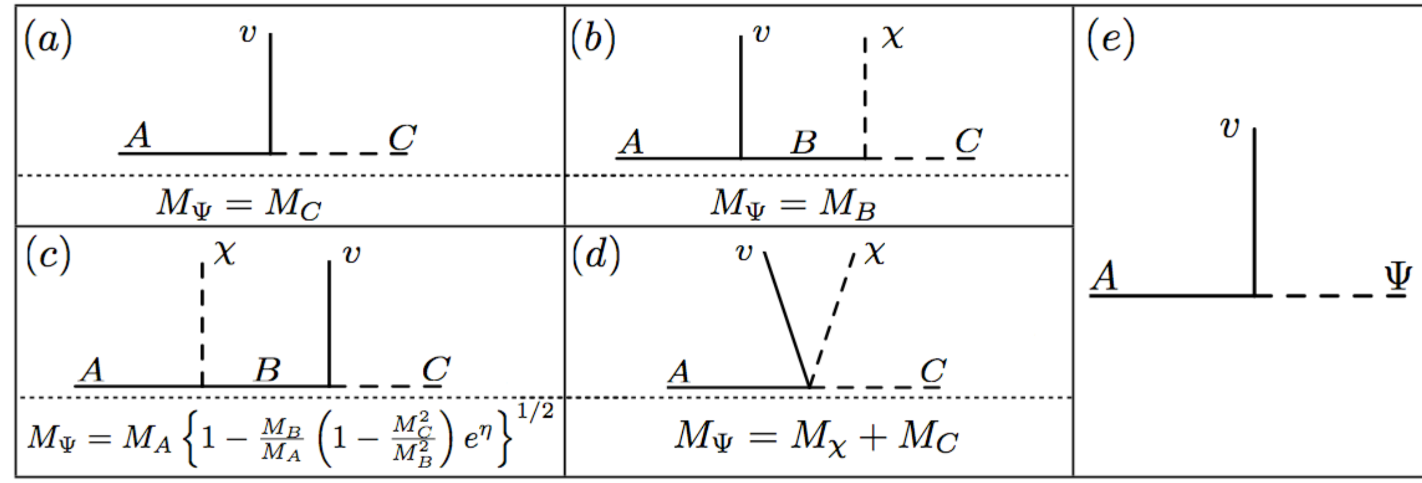
$$0 \leq P_T \leq \frac{M_A}{2}\left(1 - \frac{M_{C\chi}^2}{M_A^2}\right)$$

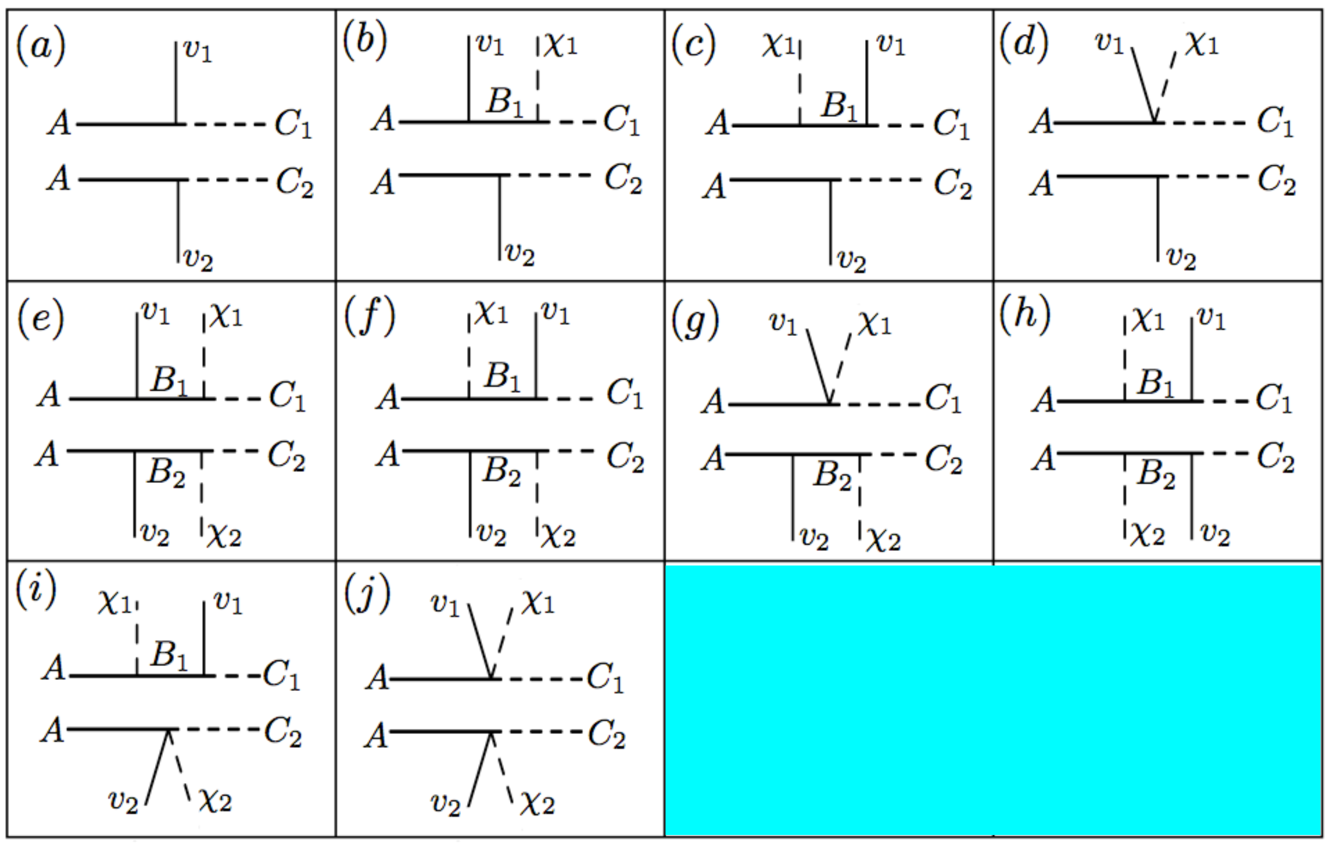
Thus, P_T will have a maximum when the invariant mass $M_{C\chi}$ (of C and chi) has a minimum value $= M_C + M_\chi$

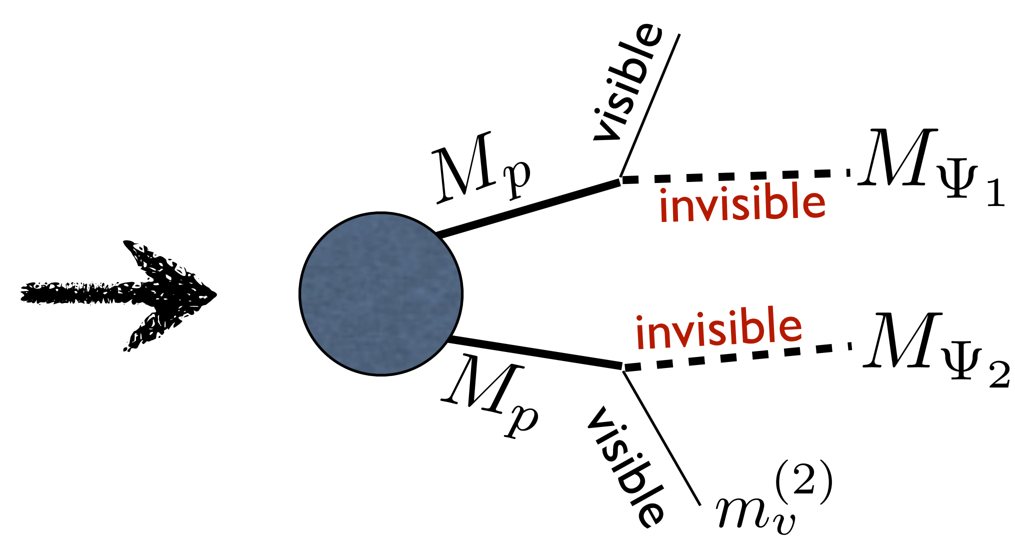
This range of P_T also come from the right diagram where a particle Ψ with a mass of $M_\Psi = M_C + M_\chi$. Thus we can replace (d) with a right diagram for the endpoint of transverse observables.



Using "Equivalent event-topology method", we can change event-topologies with multi-invisible particles into an event-topology with two invisible particle.



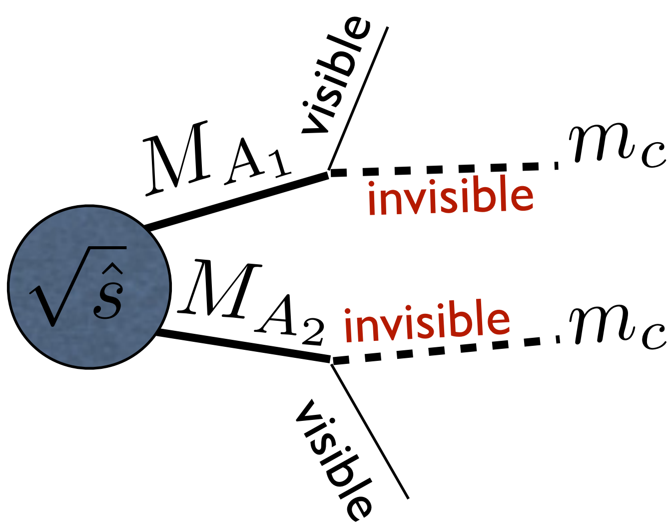




- But, now we need to deal with the case with different types of invisible particle ($M_{\Psi_1} \neq M_{\Psi_2}$): Studied by P. Konar, K.Matchev, K.Kong. MP [arxiv:0911.4126]

When decaying particles are **different**

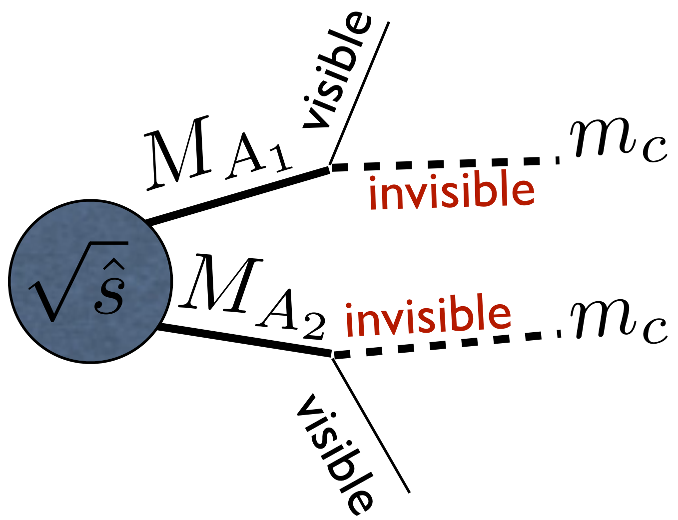
If $M_{A2} > M_{A1}$, then A_1 get the additional boost $\delta\eta\left(\sqrt{\hat{s}}\right)$ from E_{CM} ($\sqrt{\hat{s}}$) compared to A_2.



$$\eta_1(\sqrt{\hat{s}}) = \cosh^{-1}\left(\frac{\hat{s} + M_{A_1}^2 - M_{A_2}^2}{2\hat{s}\, M_{A_1}}\right) \qquad \eta_2(\sqrt{\hat{s}}) = \cosh^{-1}\left(\frac{\hat{s} + M_{A_2}^2 - M_{A_1}^2}{2\hat{s}\, M_{A_2}}\right)$$

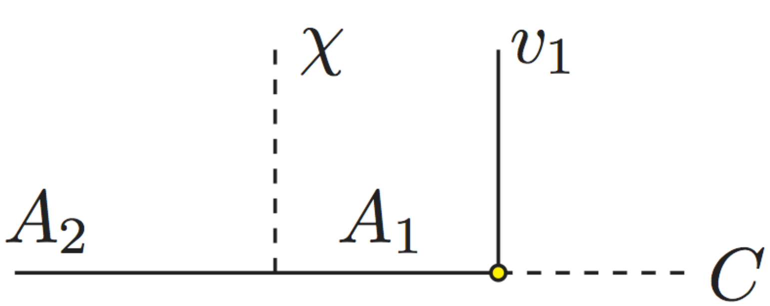
$$\delta\eta(\sqrt{\hat{s}}) \equiv \eta_1(\sqrt{\hat{s}}) - \eta_2(\sqrt{\hat{s}}) = \cosh^{-1}\left[\frac{M_{A_2}^2 + M_{A_1}^2 - \left(\frac{M_{A_2}^2 - M_{A_1}^2}{\sqrt{\hat{s}}}\right)^2}{2M_{A_2}M_{A_1}}\right]$$

This additional boost will give effect on the visible part on A_1.
We can mimic this situation by inserting "GHOST" particle in front of A_1



$$\delta\eta(\sqrt{\hat{s}}) \equiv \eta_1(\sqrt{\hat{s}}) - \eta_2(\sqrt{\hat{s}}) = \cosh^{-1}\left[\frac{M_{A_2}^2 + M_{A_1}^2 - \left(\frac{M_{A_2}^2 - M_{A_1}^2}{\sqrt{\hat{s}}}\right)^2}{2M_{A_2}M_{A_1}}\right]$$

This additional boost will give effect on the visible part on A_1.
We can mimic this situation by inserting "GHOST" particle in front of A_1

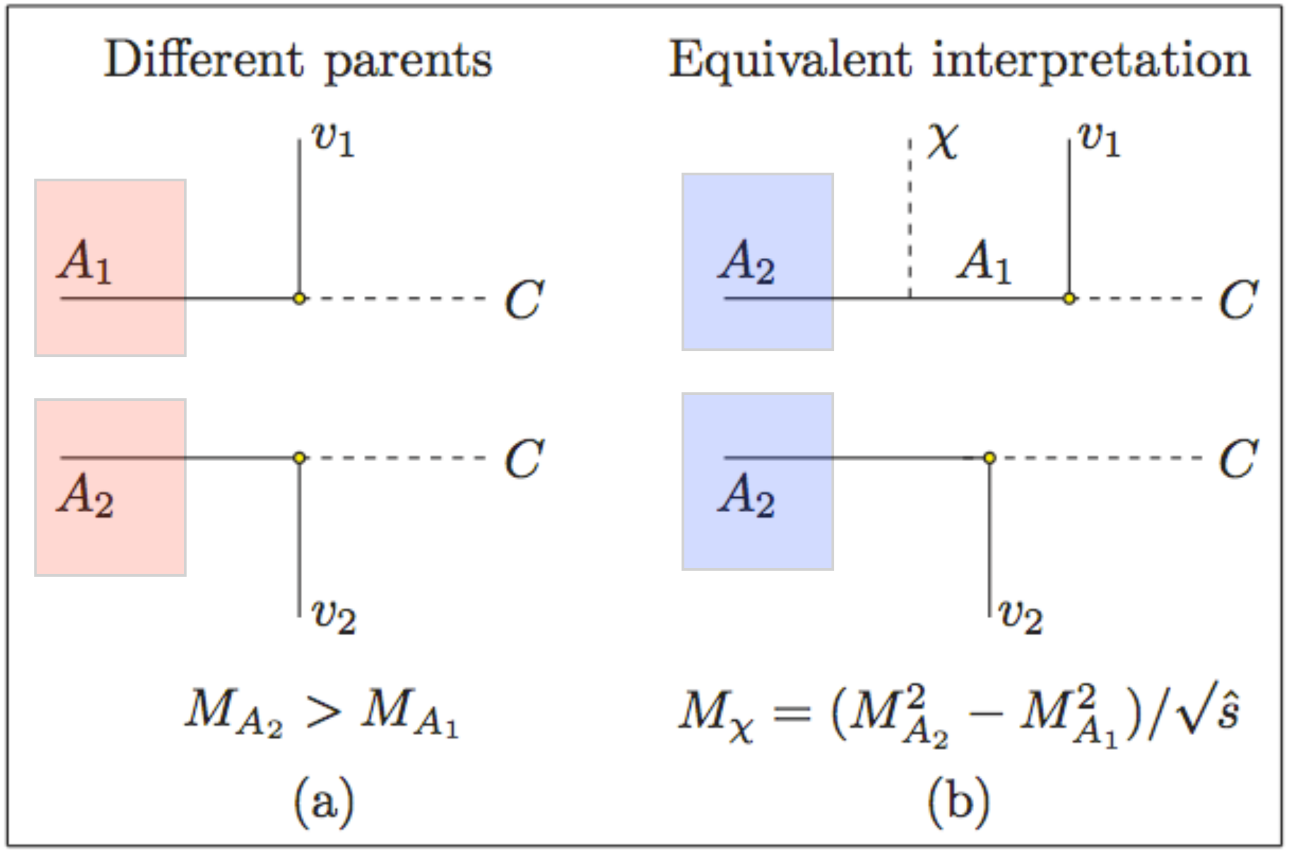


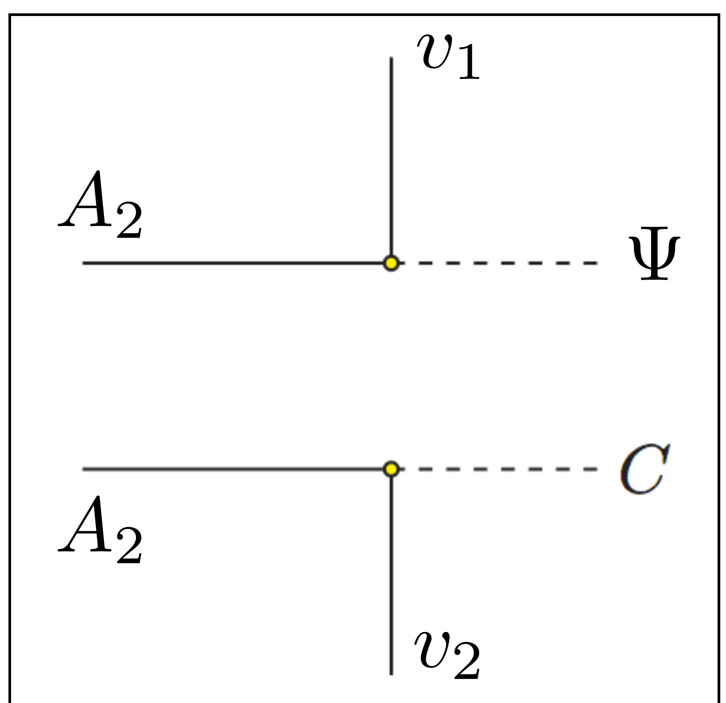
$$M_\Psi = M_{A_2}\left\{1 - \frac{M_{A_1}}{M_{A_2}}\left(1 - \frac{m_c^2}{M_{A_1}^2}\right)e^\eta\right\}^{1/2}$$

$$\eta = \cosh^{-1}\left(\frac{M_{A_2}^2 + M_{A_1}^2 - M_\chi^2}{2M_{A_2}M_{A_1}}\right)$$

Thus we can re-interpret this situation by putting invisible particle with mass

$$M_\chi(\sqrt{\hat{s}}) \equiv \frac{M_{A_2}^2 - M_{A_1}^2}{\sqrt{\hat{s}}}$$





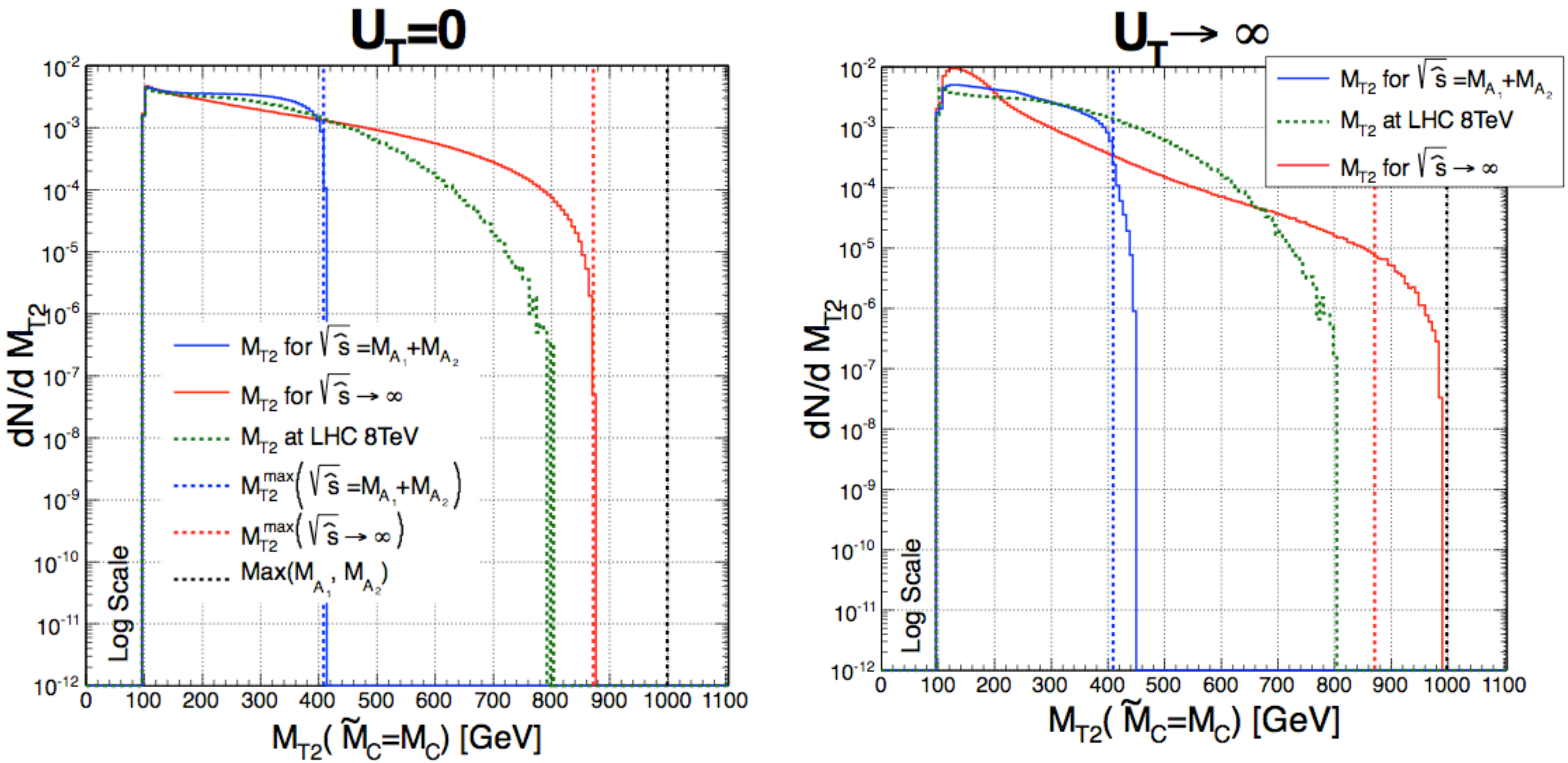
$$\eta = \cosh^{-1}\left(\frac{M_{A_2}^2 + M_{A_1}^2 - M_\chi^2}{2M_{A_2}M_{A_1}}\right)$$

$$M_\Psi = M_{A_2}\left\{1 - \frac{M_{A_1}}{M_{A_2}}\left(1 - \frac{m_c^2}{M_{A_1}^2}\right)e^\eta\right\}^{1/2}$$

$$0 \leq M_\chi(\sqrt{\hat{s}}) \leq M_{A_2} - M_{A_1}$$ **with** $$M_{A_1} + M_{A_2} \leq \sqrt{\hat{s}} < \infty$$

resulting in the effective particle Ψ's mass **dependency on the** $\sqrt{\hat{s}}$

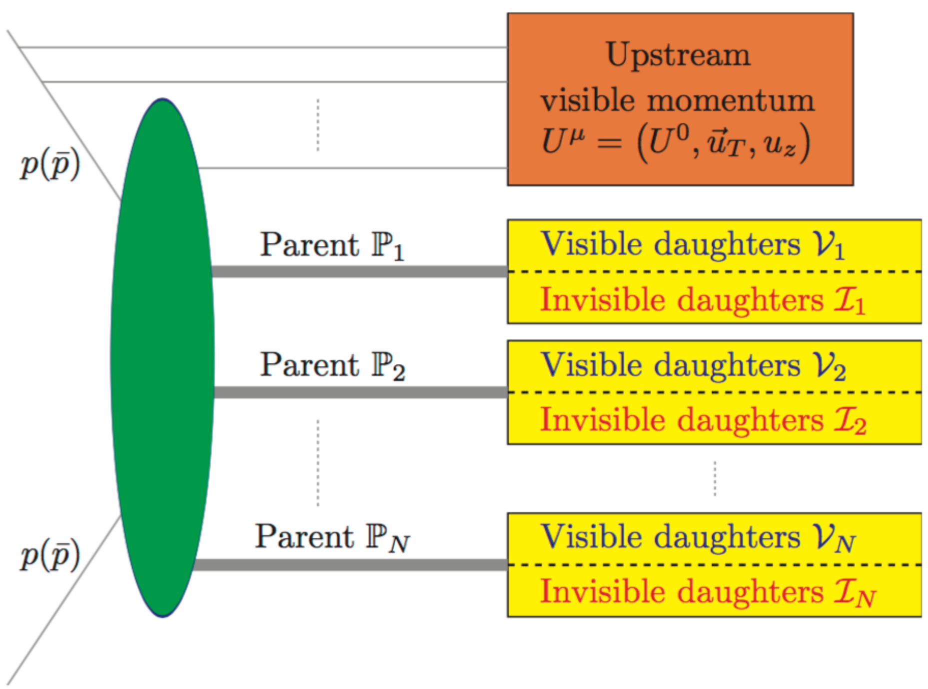
$$(M_{A_2}, M_{A_1}, m_C) = (1\text{TeV}, 200\text{GeV}, 100\text{GeV})$$

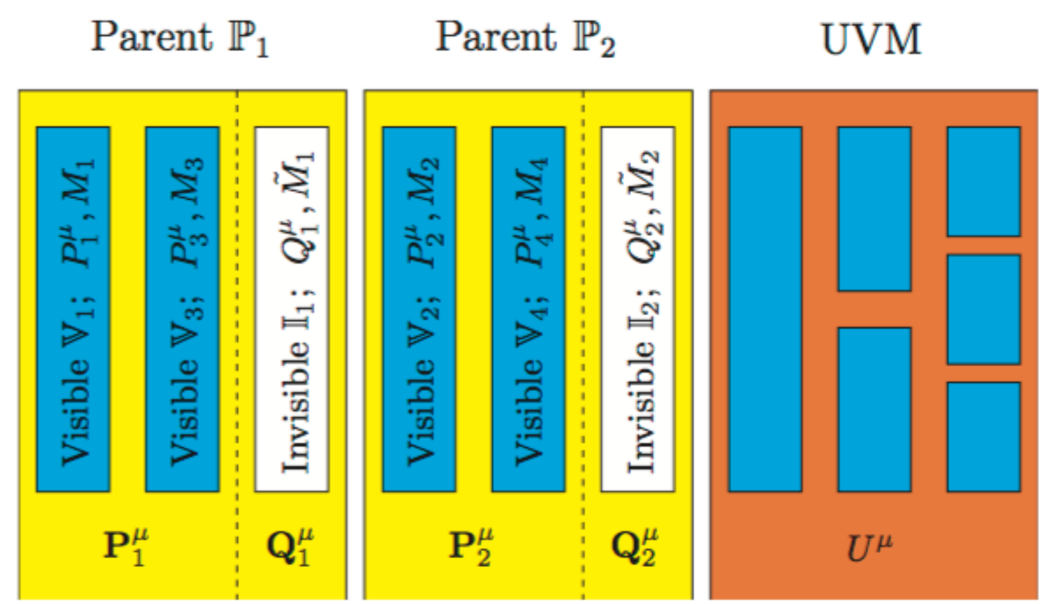


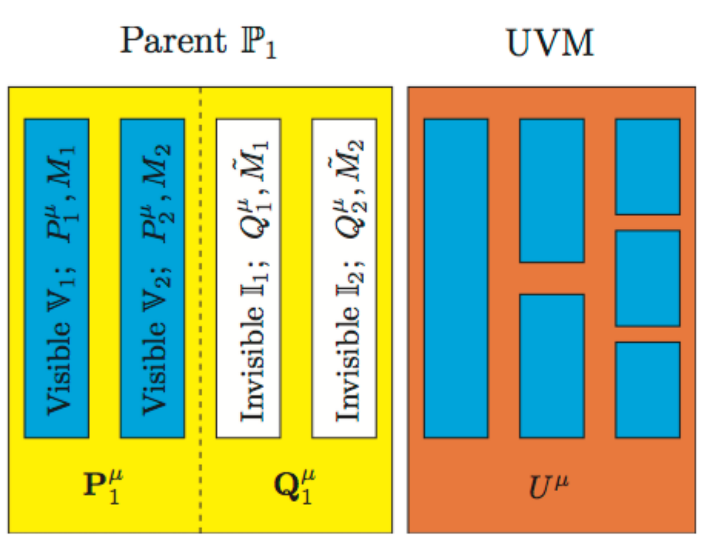
MT2 is **NOT** sensitive (good) variable to represent "kinematics" when decaying particles are **different**

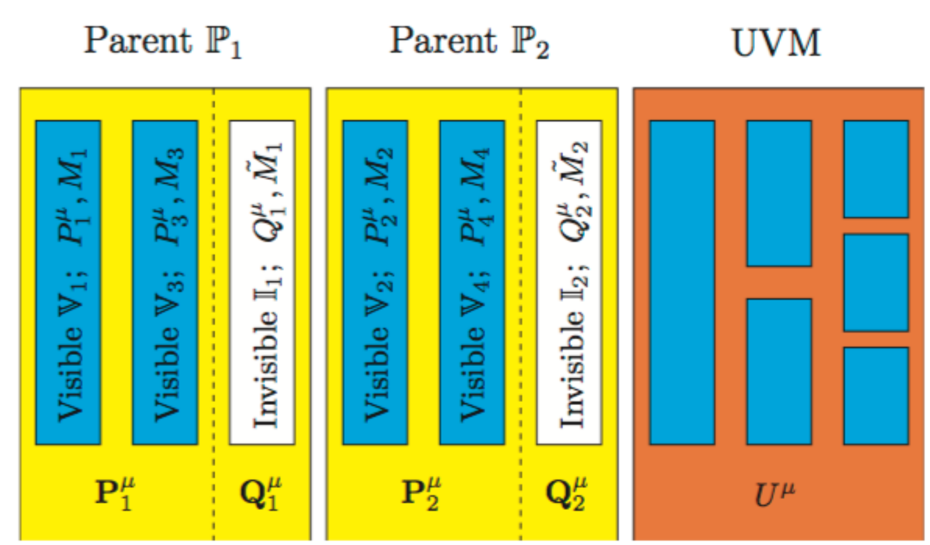
MET variables

- How to cluster visible (& invisible) particles



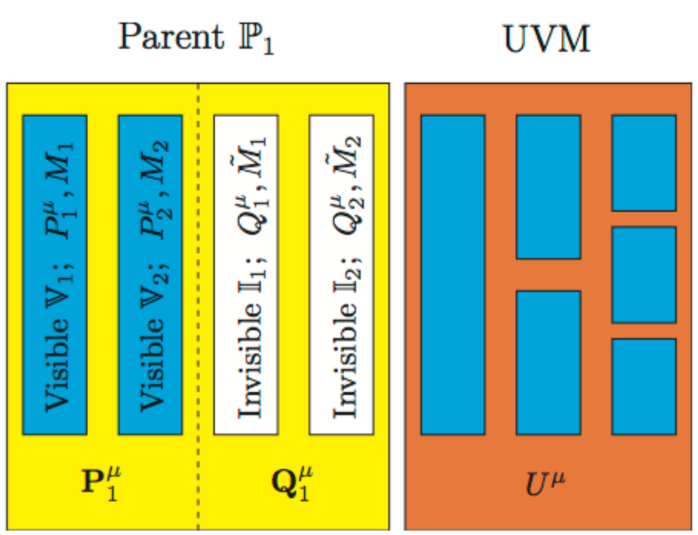






MET variables

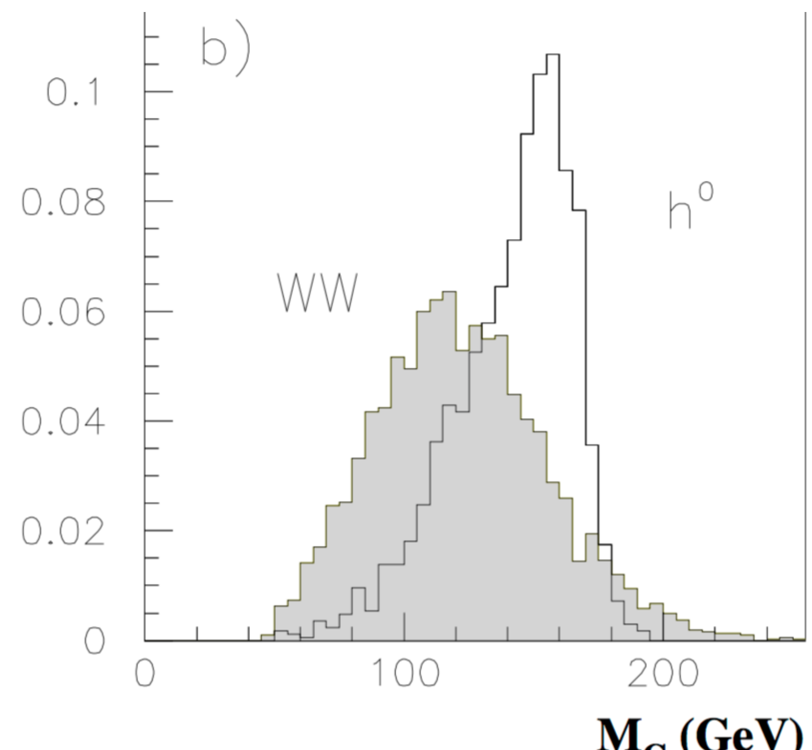
- How to cluster visible (& invisible) particles



Tao Han: hep-ph/0508097

$H \to W_1 W_2 \to \ell_1 \nu_1 \ \ell_2 \nu_2$:

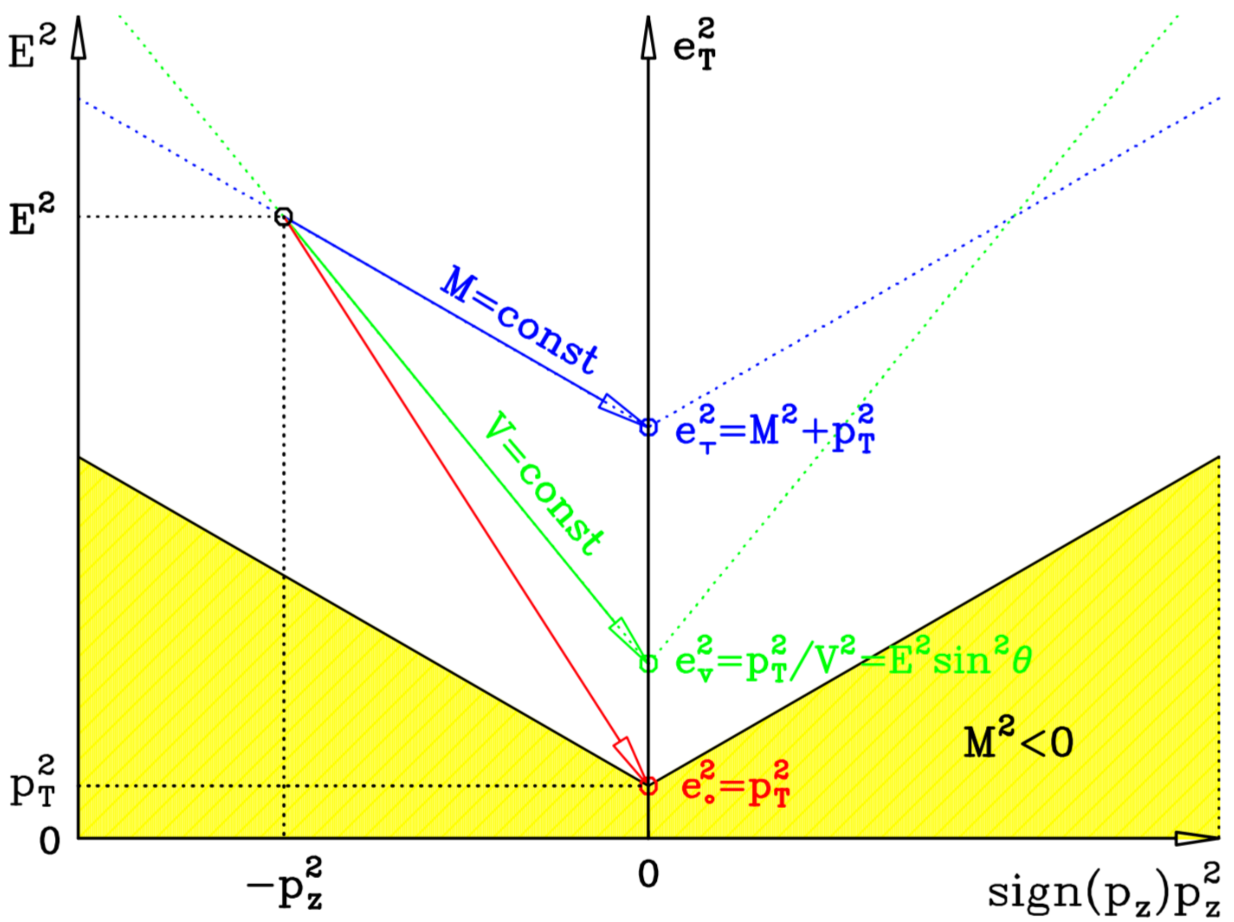
$$M_{C,WW}^2 = \left(\sqrt{p_{T,\ell\ell}^2 + M_{\ell\ell}^2} + \not{p}_T\right)^2 - (\vec{p}_{T,\ell\ell} + \vec{\not{p}}_T)^2$$

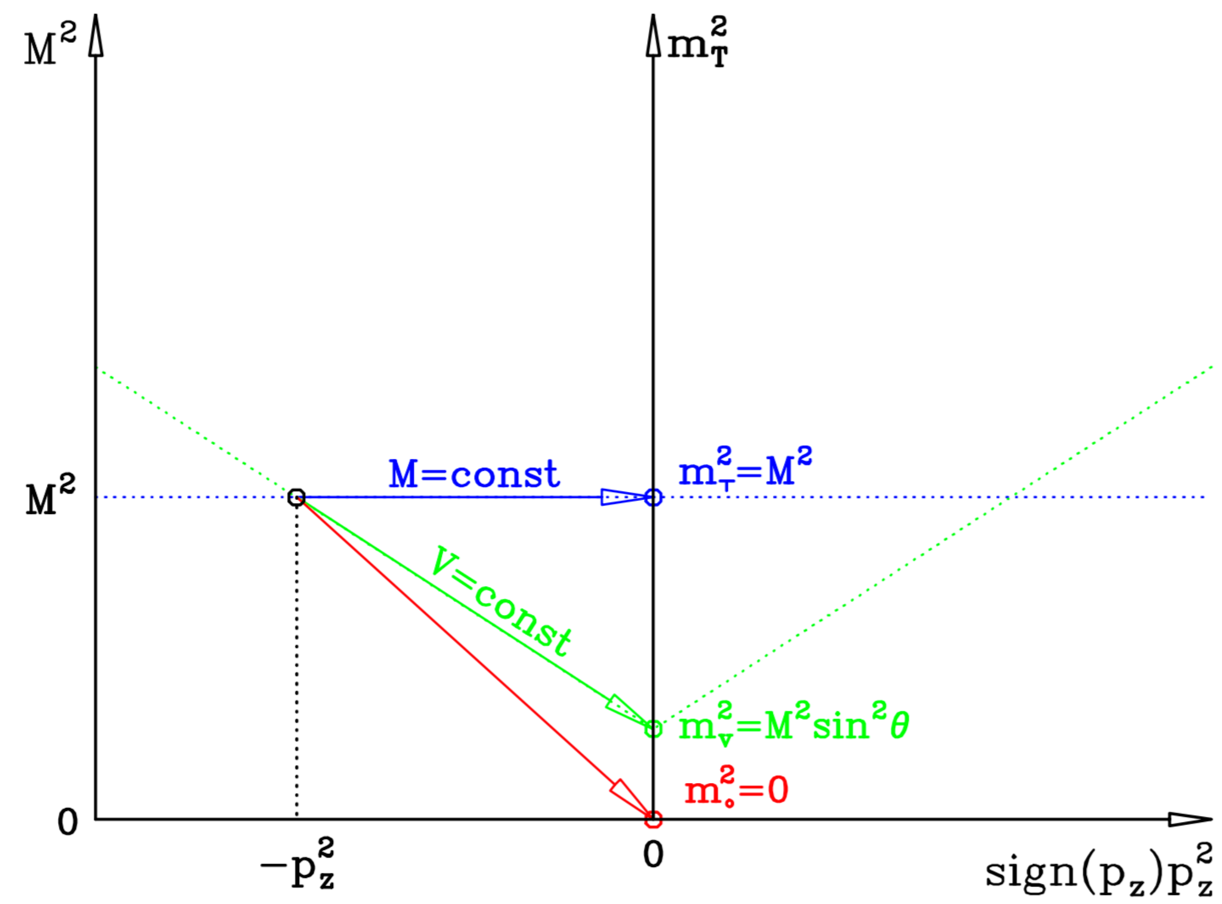


V. Barger, T. Han, and J. Ohnemus, Phys. Rev. D37, 1174 (1988)

MET variables

- How to project four-vector into transverse (to beam) plane.





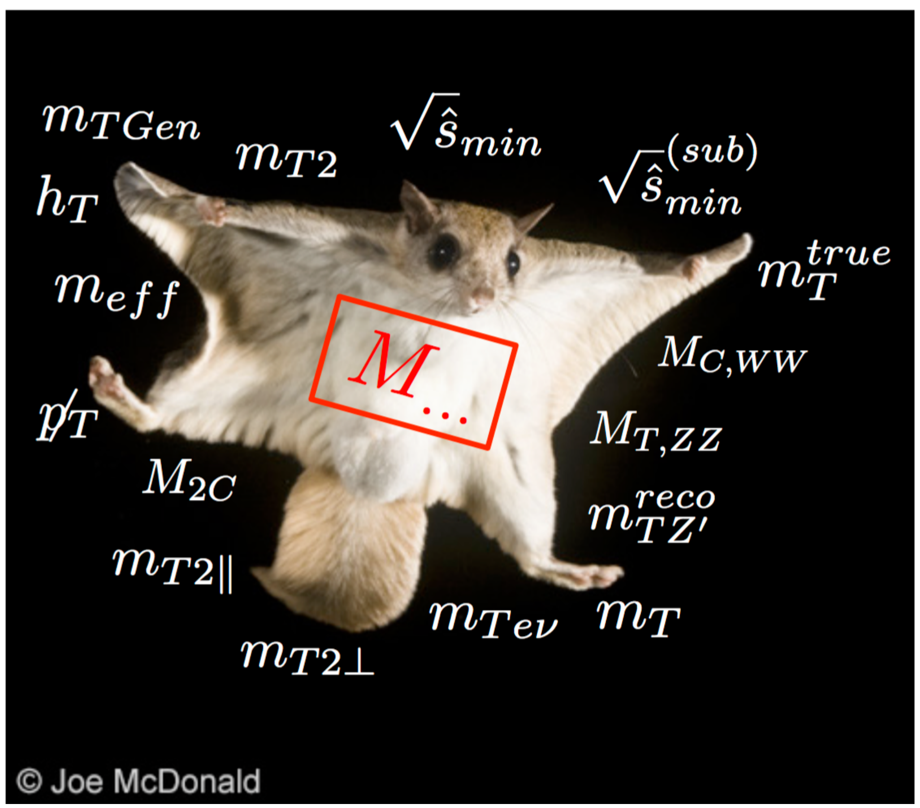
MET variables

- How to project four-vector into transverse (to beam) plane.

Type of variables	Operations			
	First	Second	Third	Notation
Unprojected	Partitioning	Minimization	—	M_N
Early partitioned (late projected) M_{NT}	Partitioning	$T = \top$ projection	Minimization	$M_{N\top}$
	Partitioning	$T = \vee$ projection	Minimization	$M_{N\vee}$
	Partitioning	$T = \circ$ projection	Minimization	$M_{N\circ}$
Late partitioned (early projected) M_{TN}	$T = \top$ projection	Partitioning	Minimization	$M_{\top N}$
	$T = \vee$ projection	Partitioning	Minimization	$M_{\vee N}$
	$T = \circ$ projection	Partitioning	Minimization	$M_{\circ N}$

MET variables

- How to cluster visible (& invisible) particles
- How to project four-vector into transverse (to beam) plane.



$$M_{1\top}^2(\not{\mathbf{M}}_1) \equiv \left(\sqrt{\mathbf{M}_1^2 + \mathbf{p}_{1T}^2} + \sqrt{\not{\mathbf{M}}_1^2 + \not{p}_T^2}\right)^2 - u_T^2$$

$$M_{1\top}^2(0) = \left(\sqrt{M_{e^+e^-}^2 + \vec{p}_{T,e^+e^-}^{\,2}} + \not{p}_T\right)^2 - \vec{u}_T^{\,2},$$

$$M_{1\top}(0) = M_{C,WW}$$

$$m_{T2} \equiv \min_{\sum \vec{q}_{iT} = \vec{\not{p}}_T} \left[\max\left[\mathcal{M}_{1\top}, \mathcal{M}_{2\top}\right]\right]$$

$$m_{T2}^{(1+3)}(\not{\mathbf{M}}) \equiv M_{2\top}(\not{\mathbf{M}}) = M_2(\not{\mathbf{M}}).$$

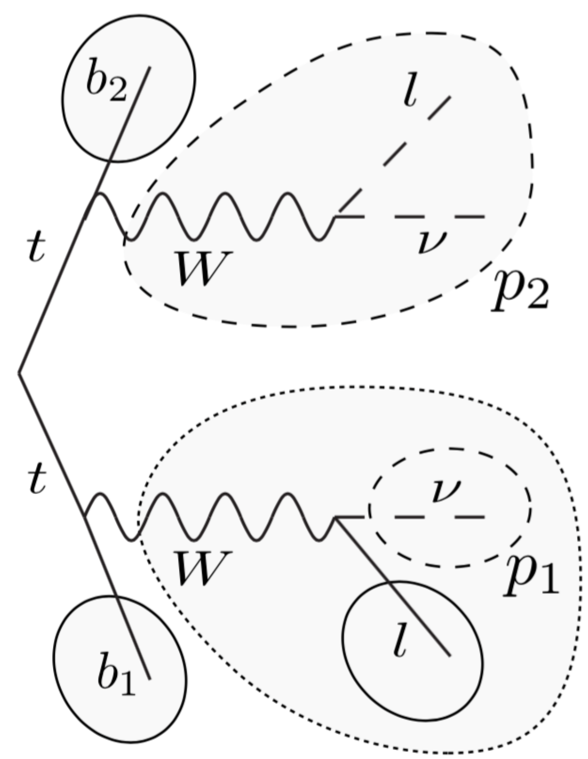
More details:

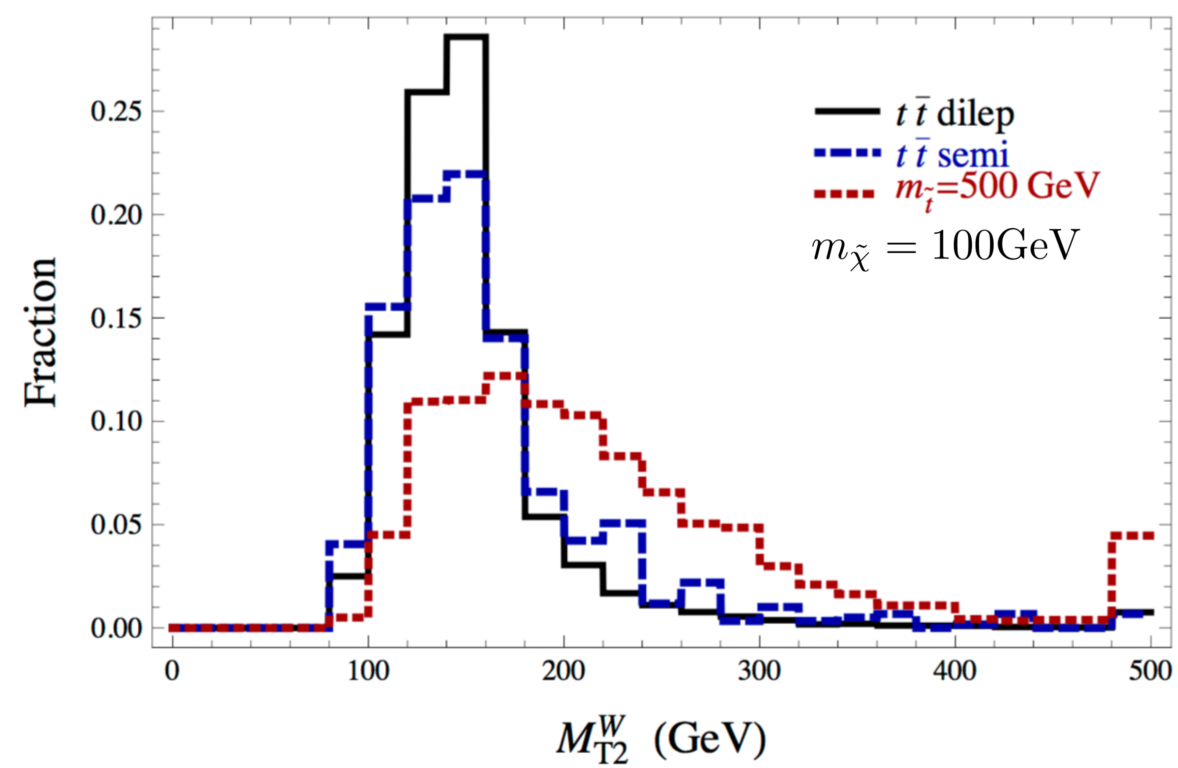
A.J.Barr, T.J.Khoo, P. Konar, K.Kong, C.G.Lester, K.T.Matchev, and MP arXiv:1105.2977

On-shell constrained
M2

Put "assumed" constraints

- One can describe SM Background more by using additional constraints



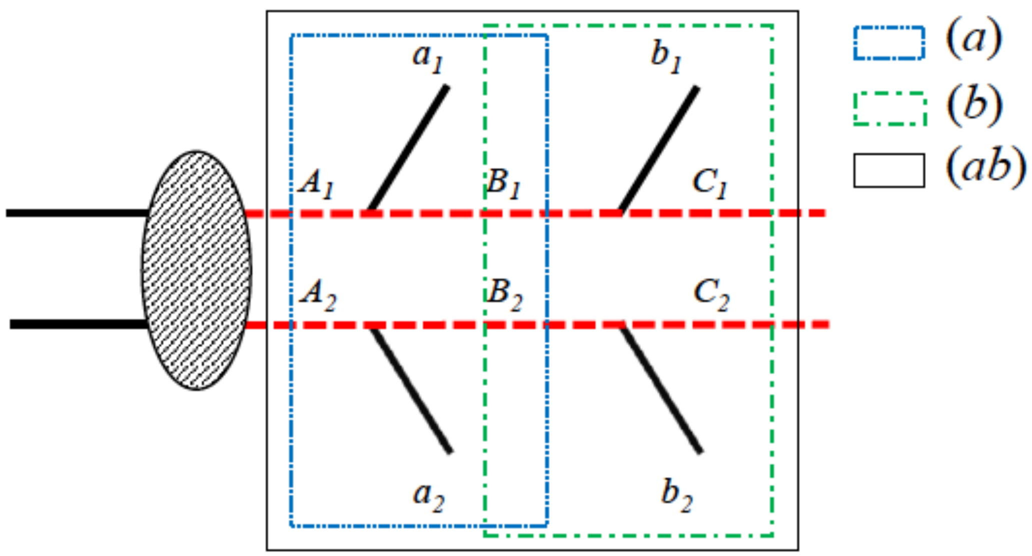


$$M_{T2}^{W} = \min\left\{ m_y \text{ consistent with: } \left[\begin{array}{r} \vec{p}_1^{\,T} + \vec{p}_2^{\,T} = \vec{E}_T^{\text{miss}}\,,\ p_1^2 = 0\,,\ (p_1 + p_\ell)^2 = p_2^2 = M_W^2\,, \\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \end{array} \right] \right\}$$

Yang Bai, Hsin-Chia Cheng, Jason Gallicchio, and Jiayin Gu (arXiv:1203.4813)

Constrained M2

- Mass on-shell constraints



Subsystem	Parents P_i	Daughters D_i	Relatives R_i
(ab)	A_i	C_i	B_i
(a)	A_i	B_i	C_i
(b)	B_i	C_i	A_i

$$M_2(\tilde{m}) \equiv \min_{\vec{q}_1,\vec{q}_2} \{\max [M_{P_1}(\vec{q}_1,\tilde{m}),\ M_{P_2}(\vec{q}_2,\tilde{m})]\}$$

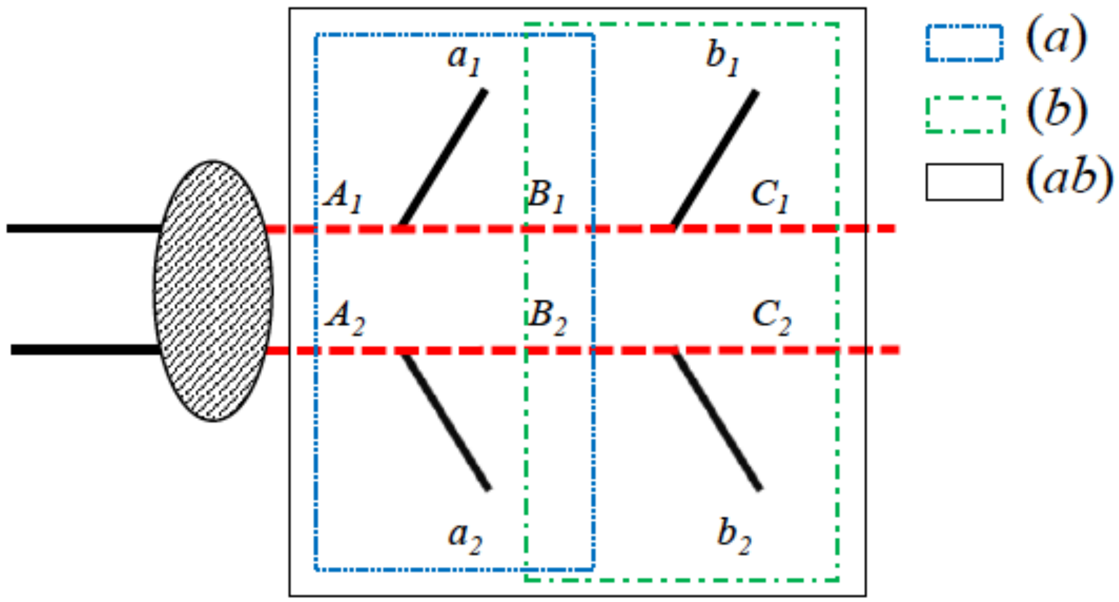
$$\vec{q}_{1T} + \vec{q}_{2T} = \vec{P}_T$$ with constraints:

Subsystem (ab)		Subsystem (a)		Subsystem (b)	
variable	constraints	variable	constraints	variable	constraints
$M_{2XX}(ab)$	—	$M_{2XX}(a)$	—	$M_{2XX}(b)$	—
$M_{2CX}(ab)$	$M^2_{A_1} = M^2_{A_2}$	$M_{2CX}(a)$	$M^2_{A_1} = M^2_{A_2}$	$M_{2CX}(b)$	$M^2_{B_1} = M^2_{B_2}$
$M_{2XC}(ab)$	$M^2_{B_1} = M^2_{B_2}$	$M_{2XC}(a)$	$M^2_{C_1} = M^2_{C_2}$	$M_{2XC}(b)$	$M^2_{A_1} = M^2_{A_2}$
$M_{2CC}(ab)$	$M^2_{A_1} = M^2_{A_2}$ $M^2_{B_1} = M^2_{B_2}$	$M_{2CC}(a)$	$M^2_{A_1} = M^2_{A_2}$ $M^2_{C_1} = M^2_{C_2}$	$M_{2CC}(b)$	$M^2_{B_1} = M^2_{B_2}$ $M^2_{A_1} = M^2_{A_2}$

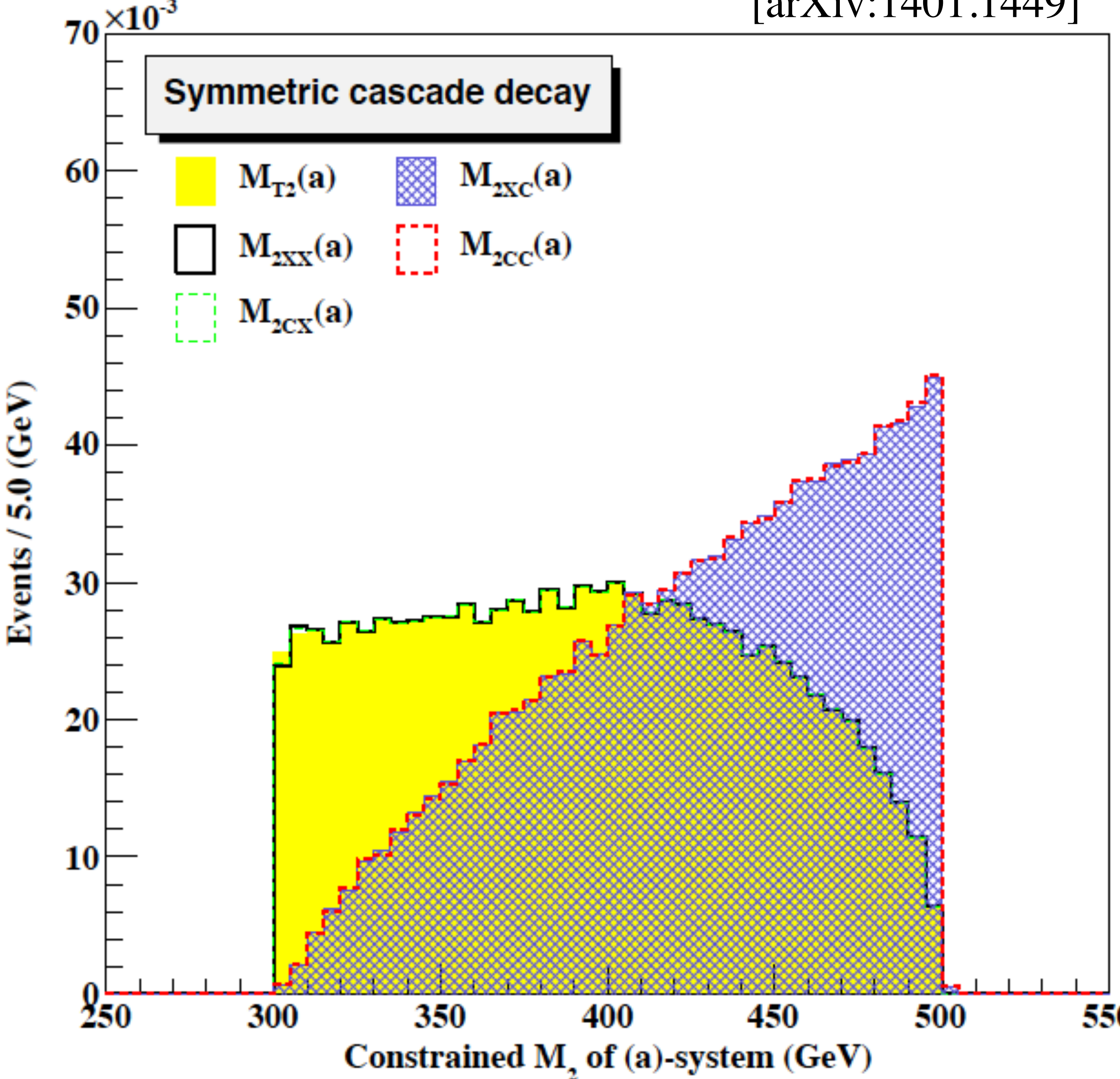
- **Power of constrained minimization (I) : enhanced event saturation to the target mass scale to be measured**

$$M_{2CC} \equiv \min_{\vec{q}_1, \vec{q}_2} \{\max [M_{P_1}(\vec{q}_1, \tilde{m}),\ M_{P_2}(\vec{q}_2, \tilde{m})]\}$$

$$\vec{q}_{1T} + \vec{q}_{2T} = \not{\vec{P}}_T$$
$$M_{P_1} = M_{P_2}$$
$$M_{R_1}^2 = M_{R_2}^2$$

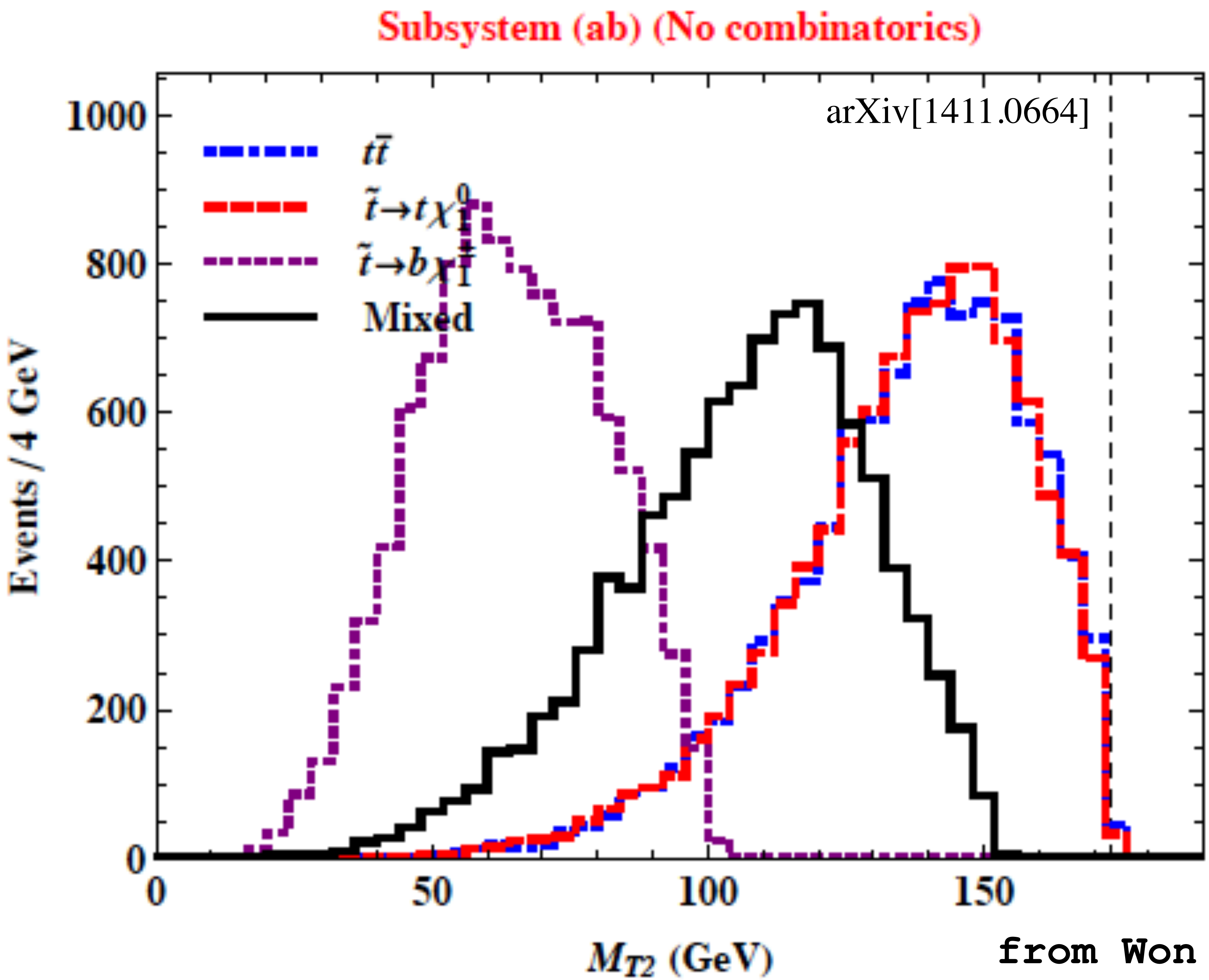


[arXiv:1401.1449]



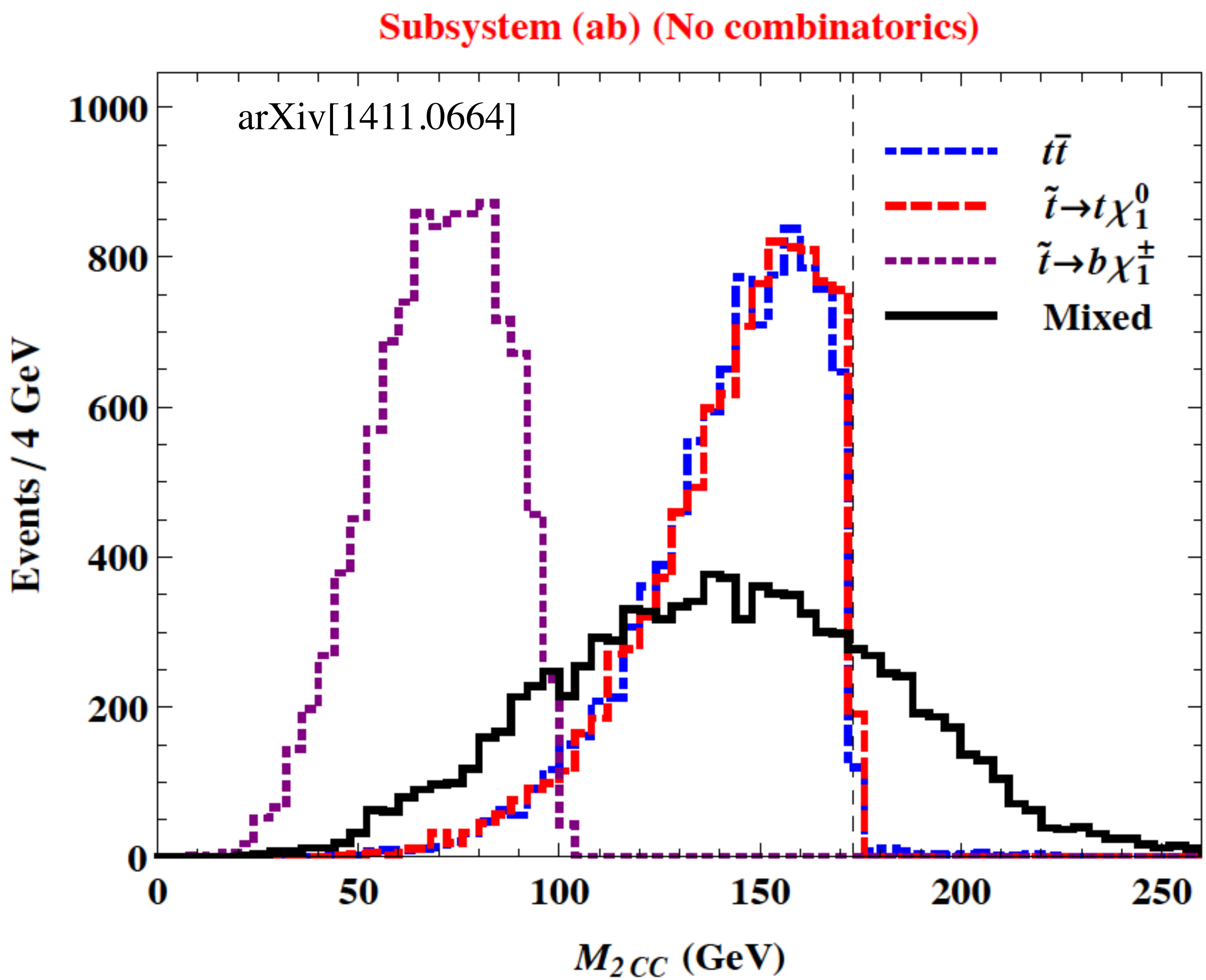
from Won Sang Cho

- **Power of constrained minimization for signal discovery (ex: MT2 vs M2CC)**



from Won Sang Cho

- **Power of constrained minimisation for signal discovery (ex: MT2 vs M2CC)**



from Won Sang Cho

Constrained Minimization

- 1) of **mass functions** of mother particle masses :

$$\tilde{M}(p,q) \quad /. \quad \text{p: visible, q: invisible four momenta}$$

- 2) **over invisible momentum d.o.f** : q
- 3) **subject to constraint functions** : $c_i(p,q)$
  involved with on-shell / endpoint relations

$$\bar{M} = \min_{q \in R^n} \tilde{M}(p,q) \quad \text{subject to} \quad c_{i=1..m}(p,q) = 0$$

- **For example) MT2**
  - => $\tilde{M}^2 \equiv \max\left[(p_1+q_1)^2, (p_2+q_2)^2\right]$
  - => subject to **minimal constraints with PT conservation**.

from Won Sang Cho

Numerical Algorithm

- **Augmented Lagrangian Method**
  - Modify the problem
  - Constrained Minimisation (in x, lambda)

TO

  - A series of Unconstrained Minimisation (in x)

  - while the constraint conditions are satisfied by the convexification by penalty-terms
  - simultaneously, the Lagrange multipliers get updated and evolved, iteration by iteration !!

from Won Sang Cho

Numerical Algorithm

- Augmented Lagrangian with ..

  1) penalty parameter (mu)

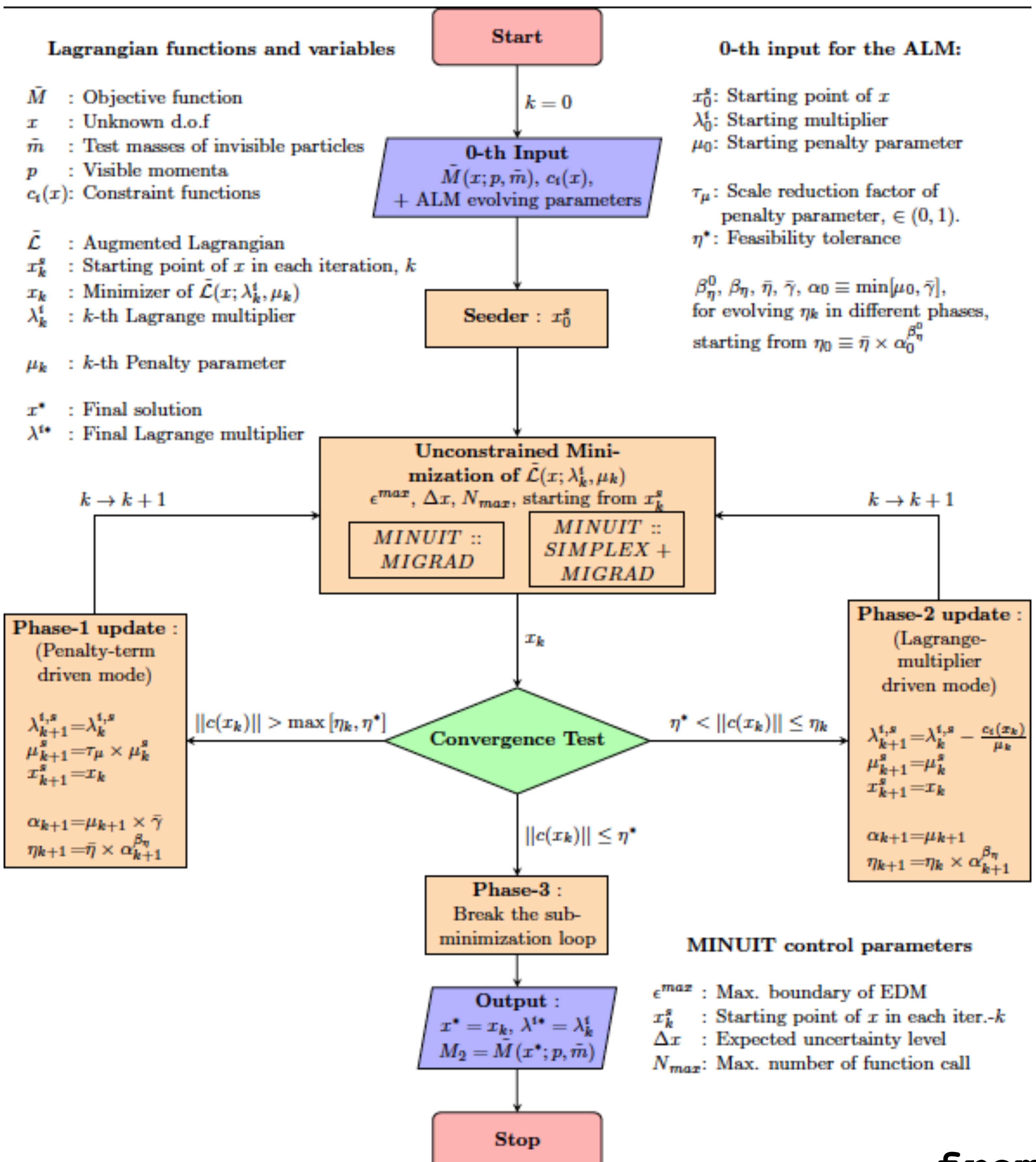
  2) augmented Lagrange parameter (lambda):

$$\tilde{\mathcal{L}}(\vec{x}\,;\boldsymbol{\lambda},\,\mu) \equiv f(\vec{x}) - \sum_a \lambda_a c_a(\vec{x}) + \frac{1}{2\mu}\sum_a c_a^2(\vec{x})$$

$$\lambda_a^{k+1} = \lambda_a^k - \frac{c_a(\vec{x}_k)}{\mu_k}$$

from Won Sang Cho

Flowchart



from Won Sang Cho

Validation

- **Example) M2CC of ttbar dileptonic decay**

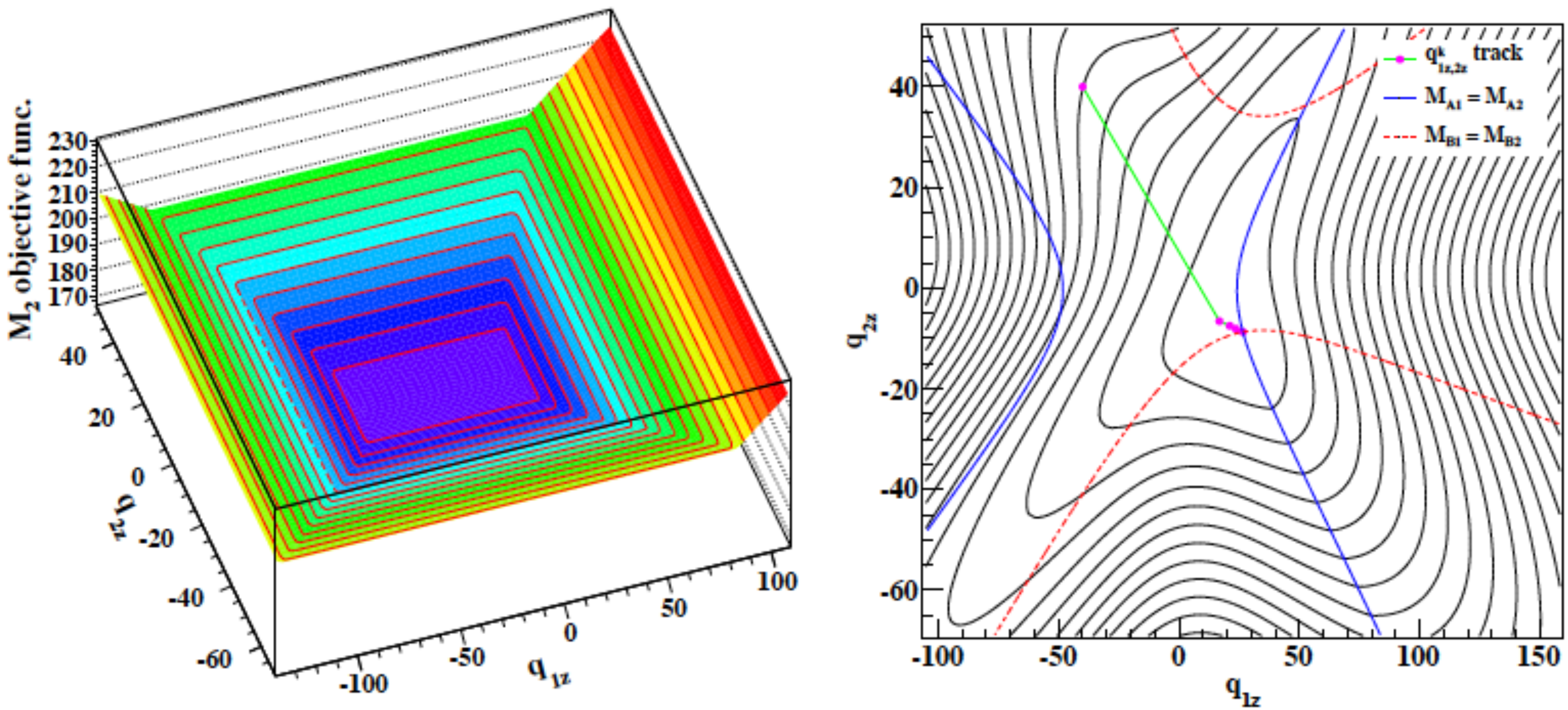


Figure 10. The same as figures 2 and 4, but for the single event considered in section 4.3. Since the objective function has four independent arguments, in order to visualize the evolution of the minimizer, we plot q_{1z} and q_{2z}, having fixed the other two variables, q_{1x} and q_{1y}, to the values which minimize the objective function for the given choice of q_{1z} and q_{2z}.

from Won Sang Cho

OPTIMASS-v1 Released!

- Language : C++, Python
- Requirements : gcc(>4.4), Python(>2.6), ROOT with MINUIT2
- Webpage (for download and installation guide):
  - http://hep-pulgrim.ibs.re.kr/optimass

from Won Sang Cho

List of Collaborators

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- Pape, Luc (luc.pape@cern.ch)
- Park, Myeonghun (parc.ctpu@gmail.com)

CMS

Main code developers

OPTIMASS interface for user's complicated decay topology

- [Full Decay System] Define any number of decay chains, and any type of decay vertices using user's own labelling scheme!

Listing 1: Cards/ttbar-ab.xml

```
# XML
---
<?xml version='1.0' encoding='utf-8'?>
<ProcessCard classname="TTbar_AB" debug="false" version="1.0">
    <!-- ==================== -->
    <!-- Define event decay chain -->
    <!-- ==================== -->
    <DecayChains>
        <DecayChain>
                t1 - b1 w1 , w1 - e1 v1
        </DecayChain>
        <DecayChain>
                t2 - b2 w2 , w2 - e2 v2
        </DecayChain>
    </DecayChains>
```

from Won Sang Cho

- **[Subsystem-Mothers]** Define your subsystem's head nodes easily just by **listing the names of (intermediate) mother particles** defined in the full decay system!

```
<!-- ============================================================ -->
<!-- Mother node particle in each decay chain to define objective function -->
<!-- ============================================================ -->
<ParticleMassFunction>
    <ParticleGroup mass_function="M2" group_function="max">
            <Particle label="t1" />
            <Particle label="t2" />
    </ParticleGroup>
</ParticleMassFunction>
```

- **[Subsystem-Effective Invisibles]** Define the **effective invisible nodes by simply tagging** it in the full decay system!

```
<ParticleProperties>
    <Particle name="top" mass="173." />
    <Particle name="bottom" mass="4.18"  />
    <Particle name="wboson" mass="80.419" optimize_target="True" />
    <Particle name="electron" />
    <Particle name="neutrino" invisible="True" />
</ParticleProperties>
```

from Won Sang Cho

- **[Kinematic Constraint Functions]** Using the particle names in the full decay chains, **their Lorentz 4 momentum d.o.f.(ROOT::TLorentaVector)** can freely be used to define constraint functions.

```
<!-- ALM Constraints Configuration -->
<!-- ========================== -->
<Constraints penalty_init="1.">
    <Constraint multiplier_init="0" type="equal">
            w1.M() - w2.M()
    </Constraint>
    <Constraint multiplier_init="0" type="equal">
            t1.M() - t2.M()
    </Constraint>
</Constraints>
```

- **[Combined-Events System Support]** Define **multiple PT conservation systems** using the full system

```
<!-- ================================ -->
<!-- Subchains for MET conditions -->
<!-- ================================ -->
<ParticleInvisibleSubsystem>
    <Subsystem set_value="manual" >
            <Particle label="t1" />
            <Particle label="t2" />
    </Subsystem>
</ParticleInvisibleSubsystem>
```

from Won Sang Cho

OPTIMASS as a mass and event reconstructor for hypothetical event topologies.

DATA: [i,j]⟹{??}⟹[visibles]+{invisibles}

OPTIMASS with (general hypothesis -'model_card.xml' for {??})

Physical / Unphysically reconstructed **{invisibles}** & **{node masses}**

⟹ **Better discrimination power!**

from Won Sang Cho

Summary

- We have studied kinematics systematically
  - Understanding relations among various variables
  - Understanding properties of variables if "assumed" assumptions are not correct

- One can add additional constraints to describe given kinematics more precisely.

- Dr. Wonsang Cho will provide a tutorial for OPTIMASS today.