OPTIMAL INVARIANT MASS VARIABLES FOR SUSY-LIKE MISSING ENERGY EVENTS

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D. Kim, KM, F. Moortgat, L. Pape 1703.06887
W. S. Cho, J. Gainer, D. Kim, KM, F. Moortgat, L. Pape, M. Park JHEP (2014)

N

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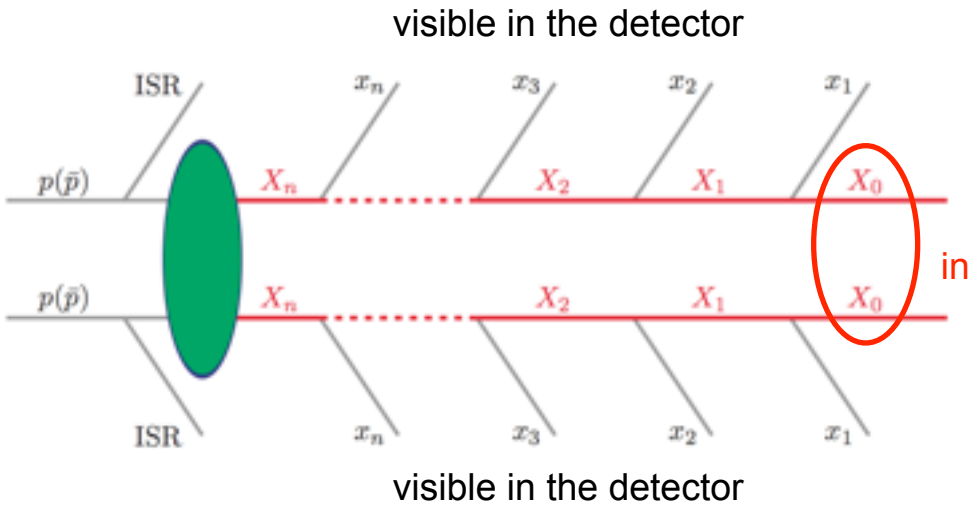
Pheno Symposium, Pittsburgh, May 9, 2017

The basic problem with missing energy events



invisible in the detector

What to do about the unknown LSP momenta?
We have three options:

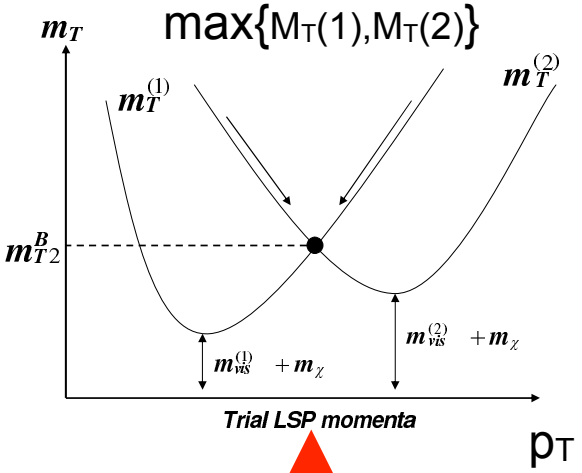
A. Ignore
B. Compute
C. Guess

- A. Study the invariant mass distributions of the visible particles
  - Kinematic endpoint methods Hinchliffe et al. 1997 see talk by D. Debnath
  - Suboptimal? (do not use all available information, bumps easier to see than endpoints)
- B. Use on-shell relations and the MET constraint to compute exactly
  - Polynomial methods Kawagoe,Nojiri,Polesello 2004 Cheng et al. 2008 see talk by P. Shyamsundar
  - only applicable to (symmetric) events with long decay chains, extraneous solutions
- C. Use an ansatz which optimizes (min/max) a suitable function of the momenta
  - M_{T2}-Assisted On-Shell (MAOS) method determines p_T and p_z Cho,Choi,Kim,Park 2008
  - M_2-Assisted (MA?) method finds p_T and p_z simultaneously Cho,Gainer,Kim,KM,Moortgat,Pape,Park 2014

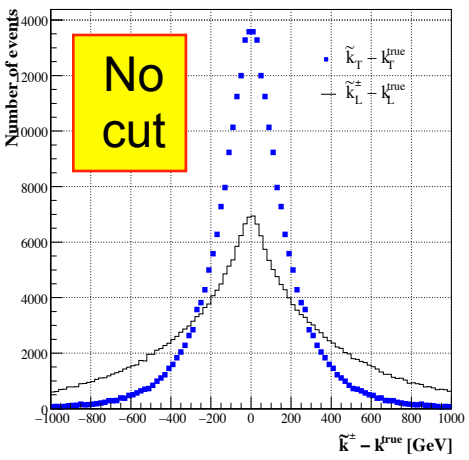
MAOS momentum reconstruction

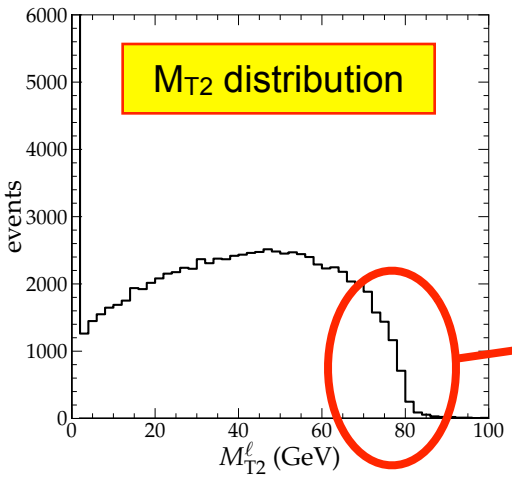
Cho,Choi,Kim,Park 2008

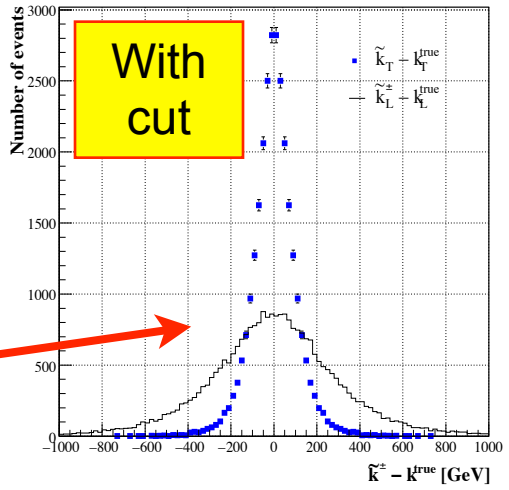
- Step 0: Adopt a test value for the LSP mass
- Step 1: fix the transverse invisible momenta
  - obtained during the M_{T2} minimization
- Step 2: fix the longitudinal momenta from an additional kinematic constraint. 3 options:
  - MAOS1: the known mass of the parent particle
  - MAOS2: the event-wise value of M_{T2}
  - MAOS3: the event-wise values of $M_T(1)$ and $M_T(2)$
- The accuracy can be improved by a preselection cut on M_{T2}



The MAOS p_T value

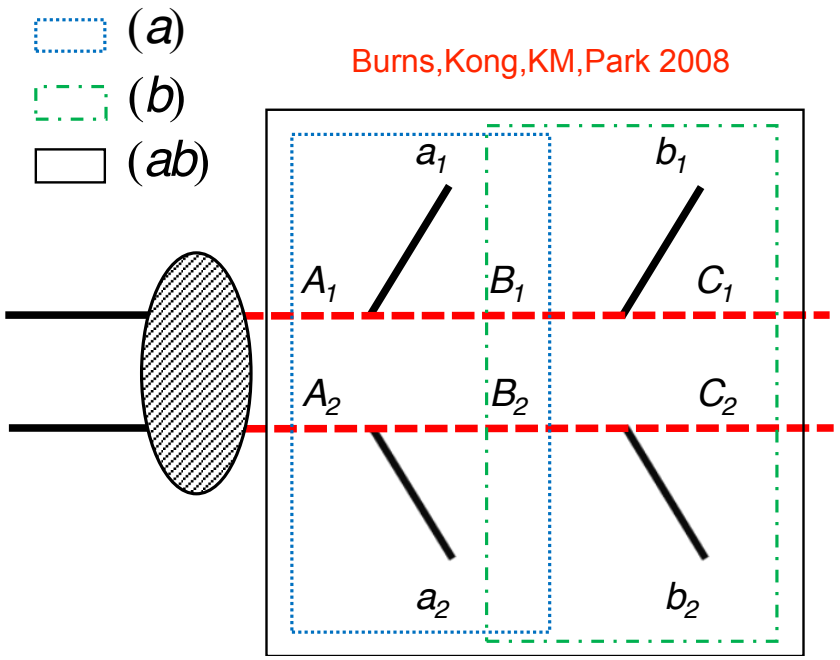






The many faces of MAOS

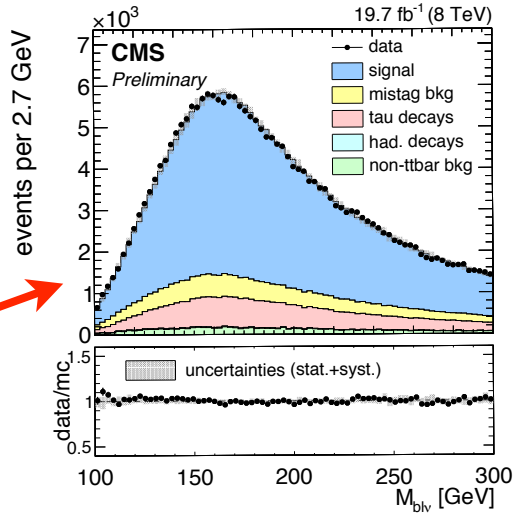
Kim,KM,Moortgat,Pape 2017



Method	required inputs	Ansatz for the invisible momenta		
		longitudinal components	No of solutions	transverse components
MAOS1(ab)	m_A, m_C	eq. (3.6)	up to 4	$M_{T2}(ab)$
MAOS2(ab)	m_C	eq. (3.9)	up to 2	
MAOS3(ab)	m_C	eq. (3.12)	unique	
MAOS4(ab)	m_B, m_C	eq. (3.15)	up to 4	
MAOS1(b)	m_B, m_C	eq. (3.7)	up to 4	$M_{T2}(b)$
MAOS2(b)	m_C	eq. (3.10)	unique	
MAOS3(b)		eq. (3.13)		
MAOS4(b)	m_A, m_C	eq. (3.16)	up to 4	
MAOS1(a)	m_A, m_B	eq. (3.8)	up to 4	$M_{T2}(a)$
MAOS2(a)	m_B	eq. (3.11)	unique	
MAOS3(a)		eq. (3.14)		
MAOS4(a)	m_C, m_B	eq. (3.17)	up to 4	

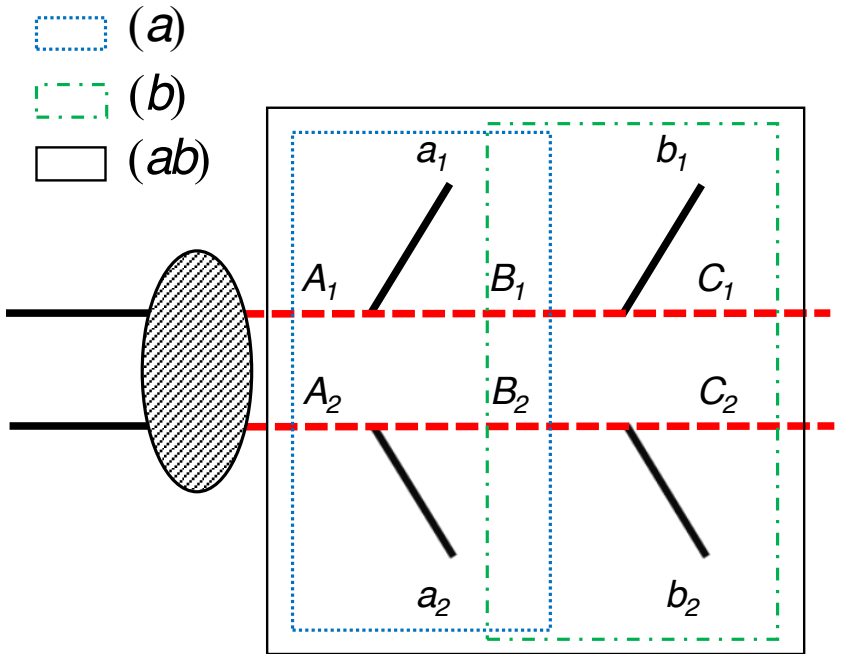
- For the dilepton ttbar event topology, there are up to 12 different MAOS schemes
  - p_T calculation: there are 3 possible M_{T2} subsystems
  - p_z calculation: there are actually 4 possibilities.
- Beware: different number of inputs
  - 1/0 in addition to the LSP mass
- Beware: different number of solutions (up to 4)
  - MAOS3 is always unique

MAOS1(b)



M_2-assisted invisible momentum reconstruction

Kim,KM,Moortgat,Pape 2017



Variable	Subsystem type	Mass inputs	Applied constraints for parents	Applied constraints for relatives
$M_{2XX}(ab)$	(ab)	m_C	—	—
$M_{2XC}(ab)$	(ab)	m_C	—	$m_{B_1} = m_{B_2}$
$M_{2CX}(ab)$	(ab)	m_C	$m_{A_1} = m_{A_2}$	—
$M_{2CC}(ab)$	(ab)	m_C	$m_{A_1} = m_{A_2}$	$m_{B_1} = m_{B_2}$
$M_{2XR}(ab)$	(ab)	m_B, m_C	—	$m_{B_1} = m_{B_2} = m_B$
$M_{2CR}(ab)$	(ab)	m_B, m_C	$m_{A_1} = m_{A_2}$	$m_{B_1} = m_{B_2} = m_B$
$M_{2XX}(b)$	(b)	m_C	—	—
$M_{2XC}(b)$	(b)	m_C	—	$m_{A_1} = m_{A_2}$
$M_{2CX}(b)$	(b)	m_C	$m_{B_1} = m_{B_2}$	—
$M_{2CC}(b)$	(b)	m_C	$m_{B_1} = m_{B_2}$	$m_{A_1} = m_{A_2}$
$M_{2XR}(b)$	(b)	m_A, m_C	—	$m_{A_1} = m_{A_2} = m_A$
$M_{2CR}(b)$	(b)	m_A, m_C	$m_{B_1} = m_{B_2}$	$m_{A_1} = m_{A_2} = m_A$
$M_{2XX}(a)$	(a)	m_B	—	—
$M_{2XC}(a)$	(a)	m_B	—	$m_{C_1} = m_{C_2}$
$M_{2CX}(a)$	(a)	m_B	$m_{A_1} = m_{A_2}$	—
$M_{2CC}(a)$	(a)	m_B	$m_{A_1} = m_{A_2}$	$m_{C_1} = m_{C_2}$
$M_{2XR}(a)$	(a)	m_B, m_C	—	$m_{C_1} = m_{C_2} = m_C$
$M_{2CR}(a)$	(a)	m_B, m_C	$m_{A_1} = m_{A_2}$	$m_{C_1} = m_{C_2} = m_C$

- The M_{T2} idea can be applied to the (3+1)-dimensional parent masses
  - it is straightforward to enforce the kinematic constraints

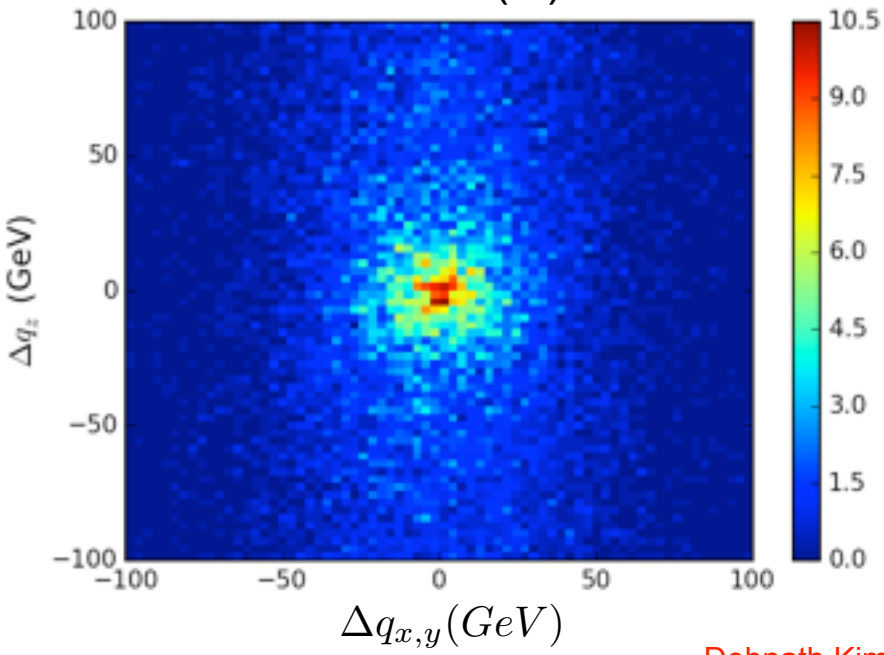
  Cho,Gainer,Kim,KM,Moortgat,Pape,Park 2014
- The constraints are applied during the minimization
  - an improved guess for the invisible momenta
  - the global minimum is unique -> unique ansatz for the invisible momenta
- Publicly available software OPTIMASS

  Cho,Gainer,Kim,Lim,KM,Moortgat,Pape,Park 2015

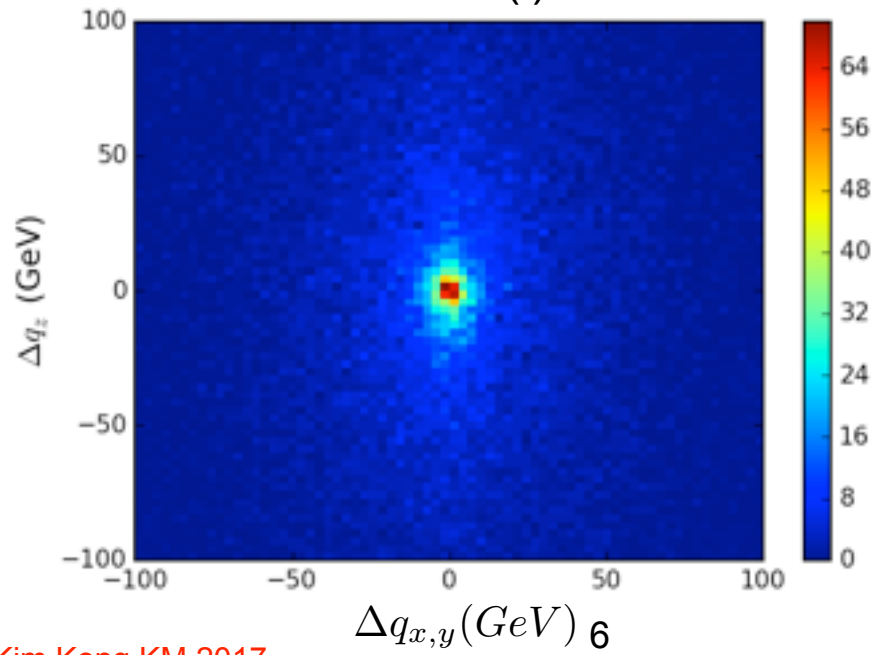
Comparison of ansatze for the invisible momenta

- Which of the two methods gives a better approximation for the invisible momenta?
- For fairness, make the same set of assumptions
  - in the example below, use the known value of the top mass
- Both methods seem to work well
  - The transverse components are determined slightly more accurately
  - The M2 method seems to work better

MAOS1(bl)



M_{2Ct}(l)

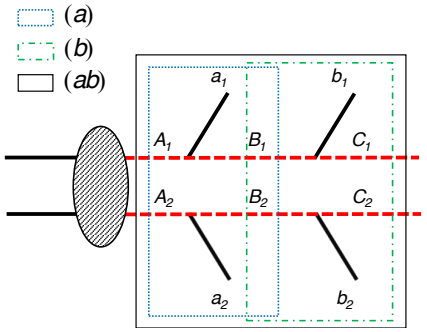


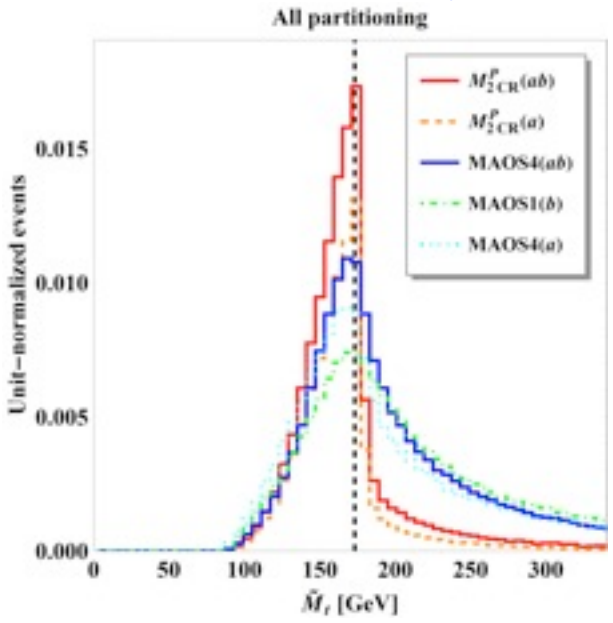
Debnath,Kim,Kim,Kong,KM 2017

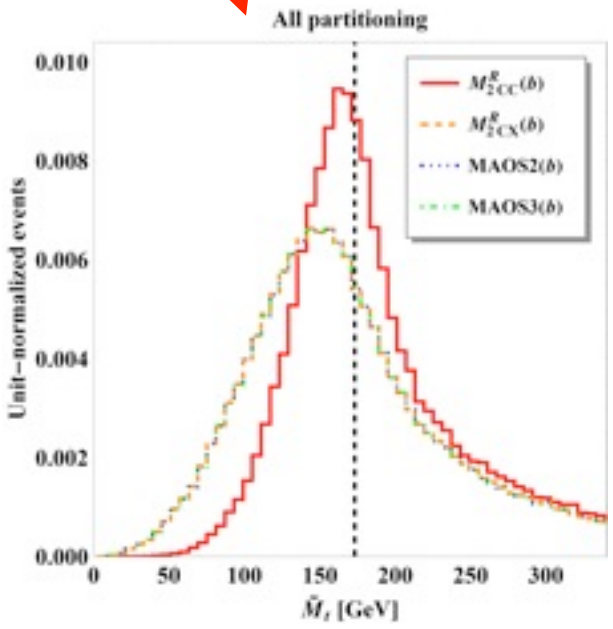
The sharpness of reconstructed peaks: top

Kim,KM,Moortgat,Pape 2017

- Use the ansatz for invisible momenta to reconstruct a mass peak, e.g. top
- Two-fold combinatorial problem: use both combinations on the plots
- Consider separately the methods which
  - do NOT rely on a known value of some particle's mass
  - rely on the known value of some particle's mass







The sharpness of reconstructed peaks: W

Kim,KM,Moortgat,Pape 2017

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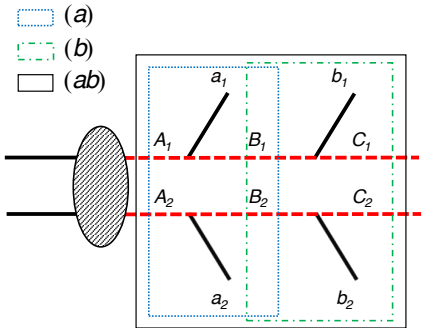
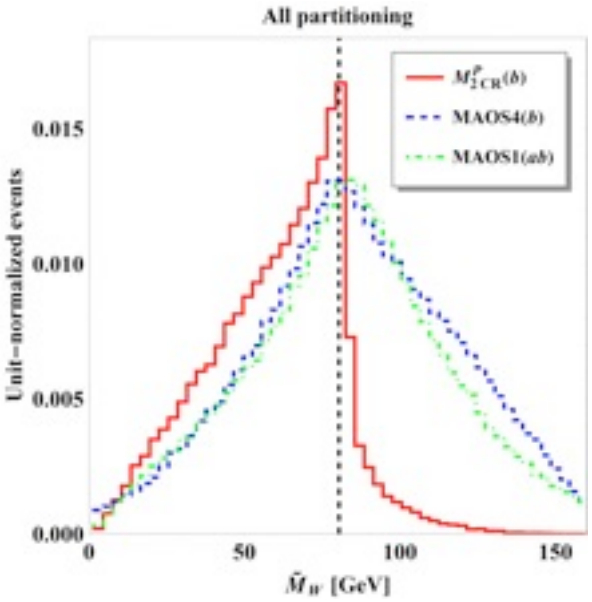
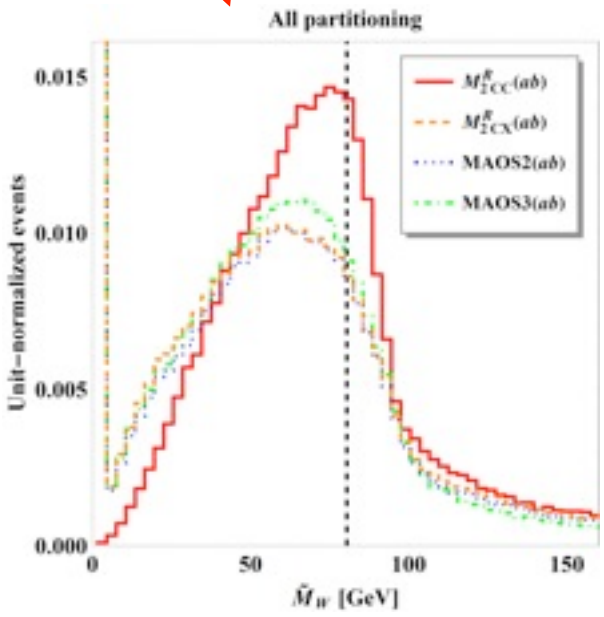
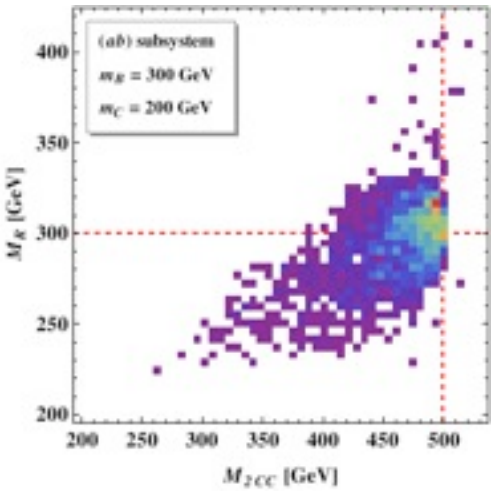


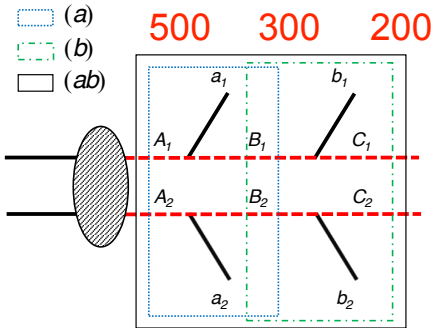




BSM applications: a “good” study point

- Consider the general mass parameter space of “top”, “W”, “neutrino”
- Do we always get the reconstructed peak in the right place?
  - most of the time, especially if (approximately) $M_A*M_C=M_B*M_B$





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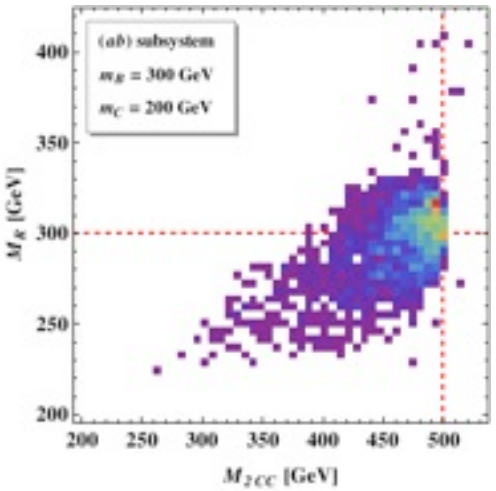

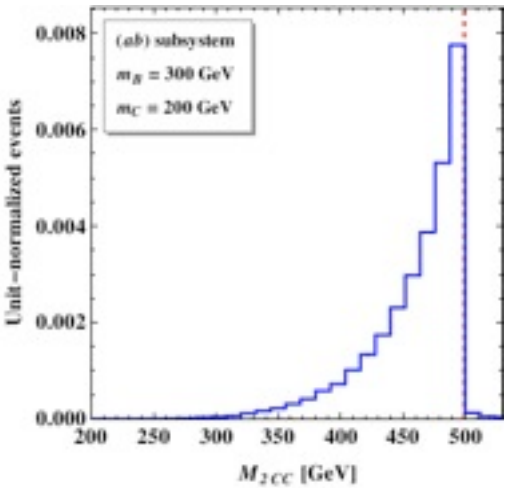

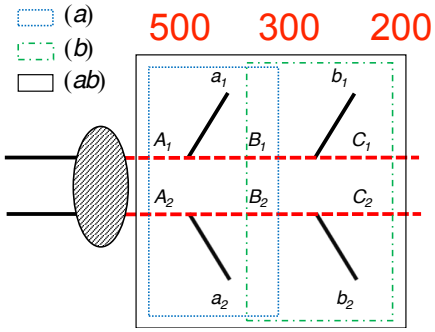

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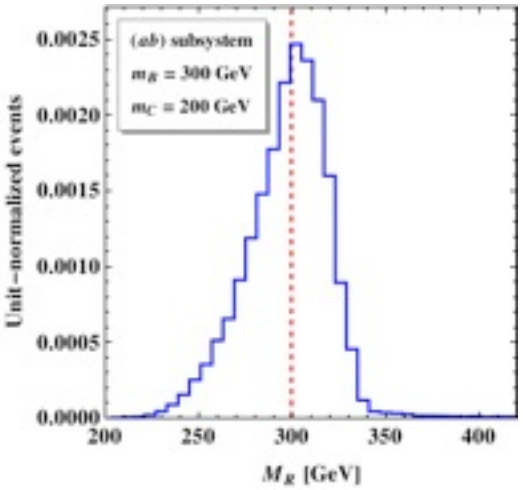

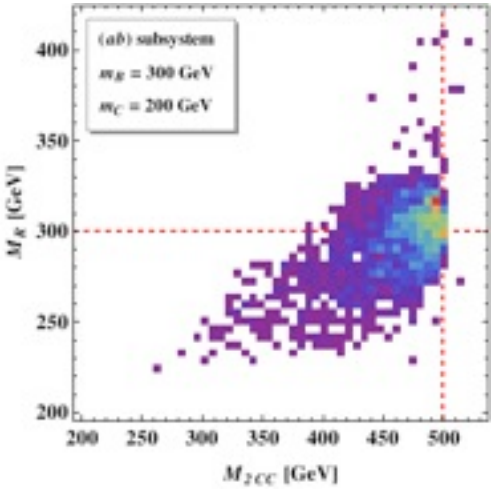

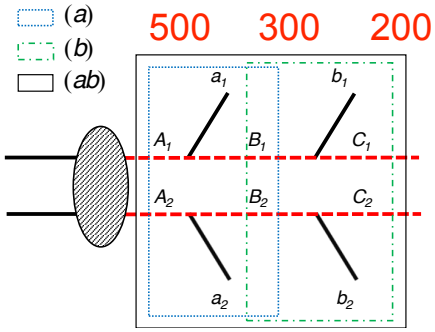

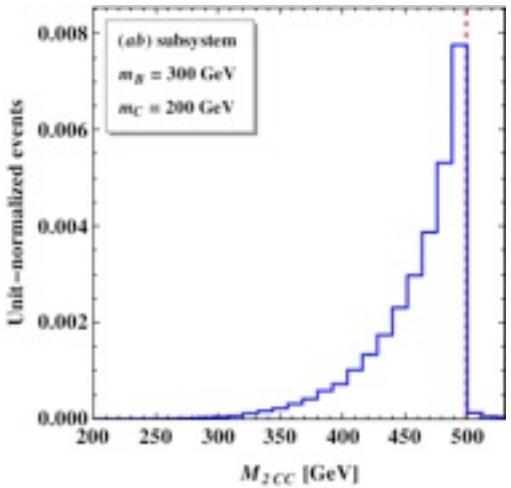

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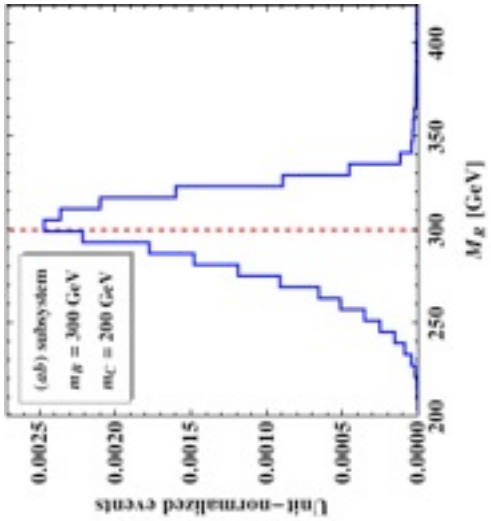
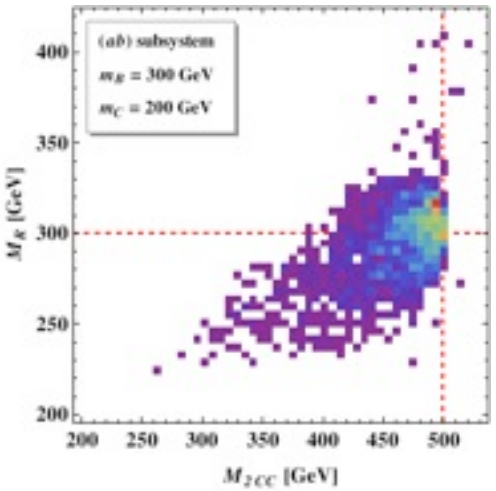
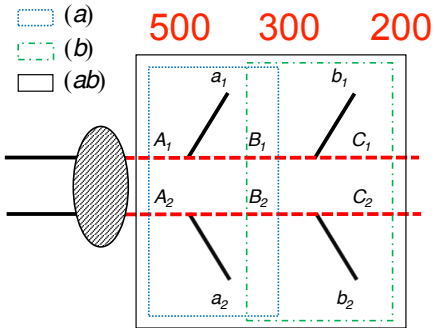
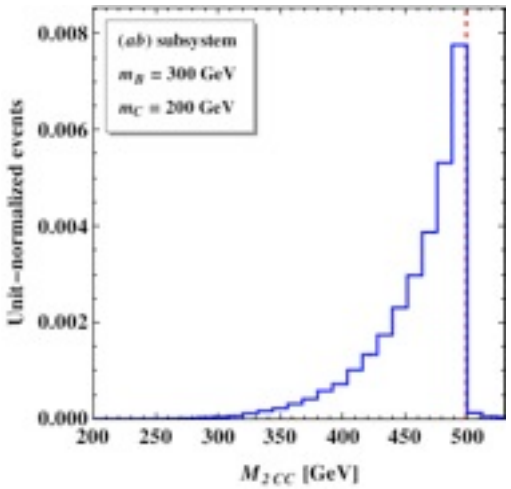


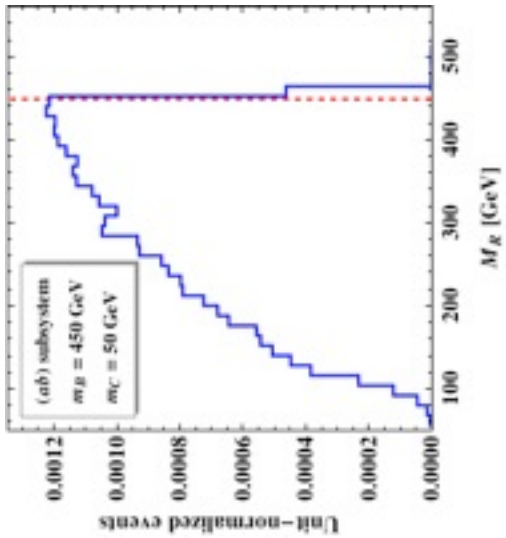


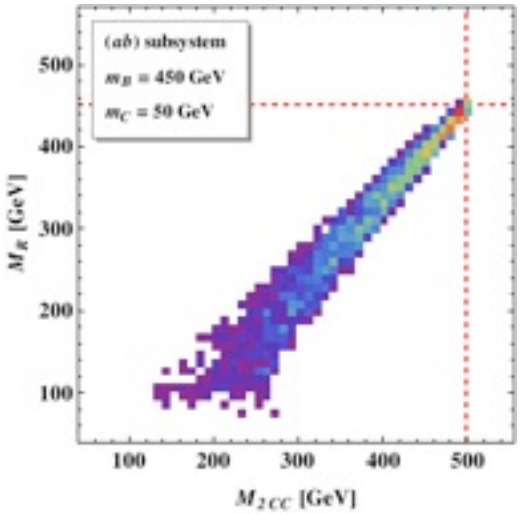


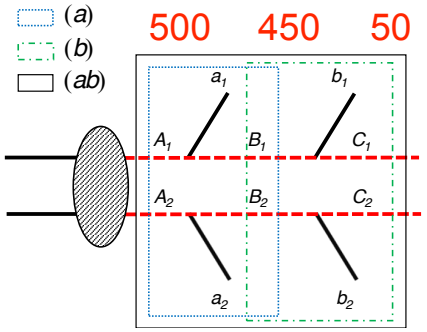


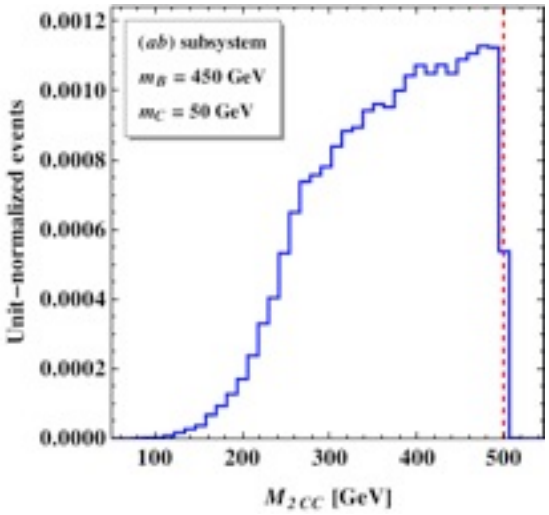
BSM applications: a “bad” study point

- Sometimes it does not work so well
  - however, recall the MAOS preselection cut trick: keep only the top 5, 10, 20, 50%









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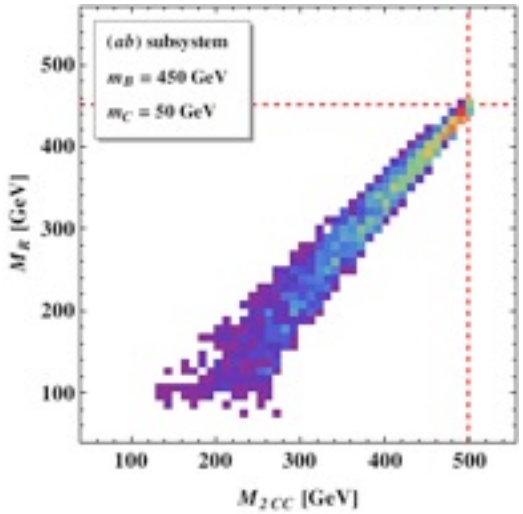
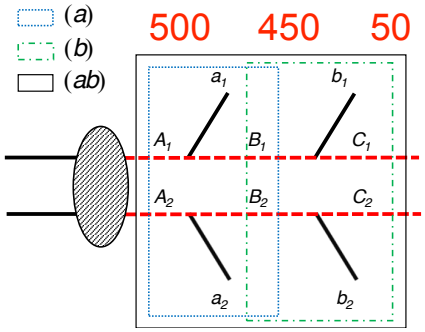
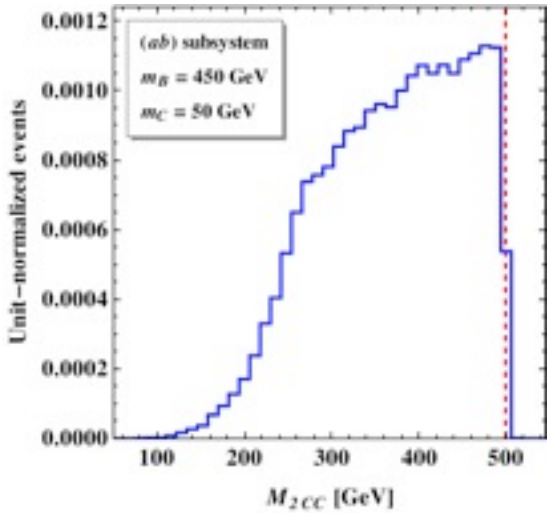
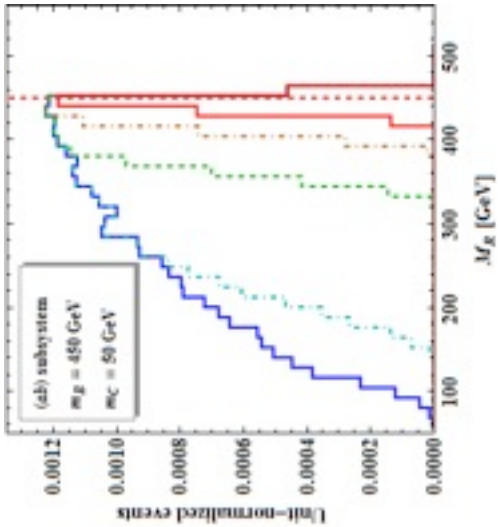


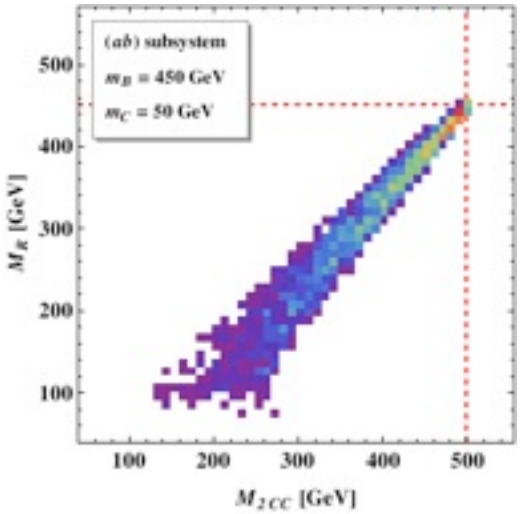


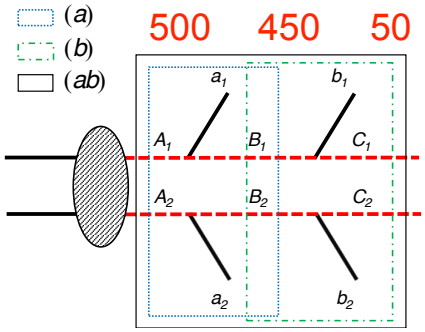


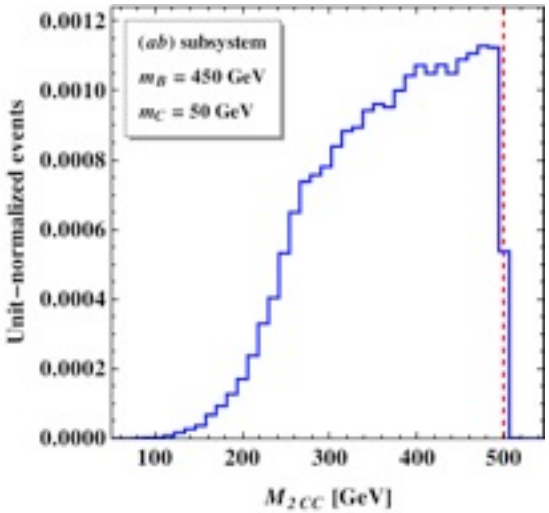
BSM applications: a “bad” study point

- Sometimes it does not work so well
  - however, recall the MAOS preselection cut trick: keep only the top 5, 10, 20, 50%









Summary and Outlook

- The momenta of the invisible particles can be obtained from an educated guess
  - Two possibilities are: MAOS and M_2-assisted reconstruction
- There are many versions of MAOS
- There are many versions of M_2-assisted reconstruction
- M_2-assisted reconstruction seems to work better
  - gives a better guess for the invisible momenta
  - leads to more narrow reconstructed invariant mass peaks
- In either case, a preselection cut helps (at the cost of decreased statistics)
- Possible future applications
  - resolving the combinatorics problem (see yesterday's talk by KC Kong)
  - spin measurements