Top partner in Littlest Higgs model with T parity

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Collaboration with
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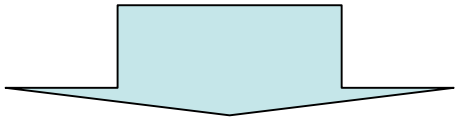
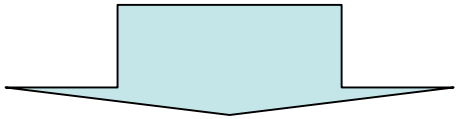
1.Introduction

There are several models beyond the SM: MSSM,LHT,UED, …
Common signal at the LHC: Many high p_T jets, leptons, Large $\not{E}_T$
Many studies are devoted, lepton channels are established.



However, the analyses of lepton channel depends on the lepton BR.

If lepton BR is small, few events can be observed at the LHC.



Even in the case, Jet BR is large, much events with only jets will be observed.

To reconstruct events by using Jets are important toward the LHC.

Plan of talk

1. Introduction (Jets are important)
2. Top reconstruction in the LHT
3. Top-partner mass measurement
4. Top polarization
5. Summary

2. Top reconstruction in the LHT

Top partner in Littlest Higgs model with T-paity

- Studied in S.Matsumoto, M.M. Nojiri, D.Nomura PRD75,(2007)
  The simplest cone algorithm (AcerDET) is used for reconstructing jets.

- Problem AcerDET treats jet masses as 0.
  Then invariant masses of jet systems are underestimated.
  (In an extreme case, top jet merged as one jet is massless)

- We have reanalysed the same process by using kt, Cambridge, SISCone.

We set mass spectrum as same as the above paper

	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00

Signal $T_-\bar{T}_- \to t\bar{t}A_HA_H \to b\bar{b}W^+W^-A_HA_H \to b\bar{b}jjjjA_HA_H$ 0.171pb

BG $t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}jjjj$ 463pb

Missing momentum

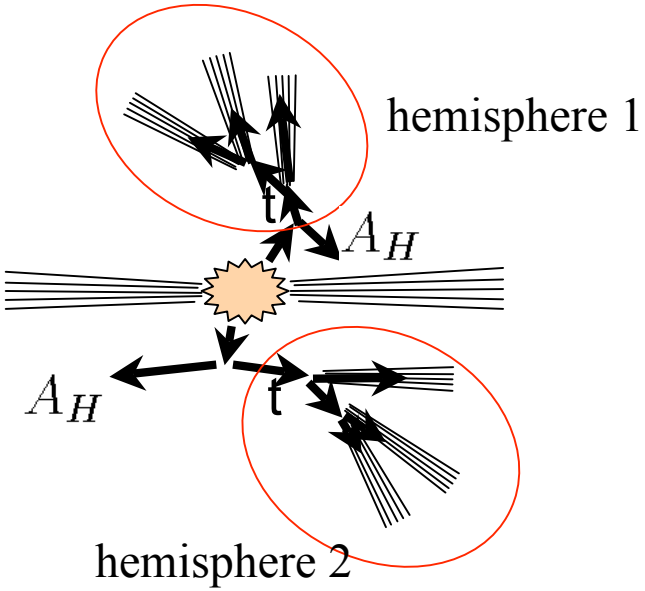
We want to drop the ttbar events.

Point:

Tops from the top-partner decays are highly boosted.

Hemisphere analysis

The method to group objects into 2 groups (hemispheres).



Any $p_{1i} \in \{p_{1k}\},\ p_{2i} \in \{p_{2k}\}$ satisfy the conditions

$$d(p_{\rm ax}, p_i) \equiv \frac{(E_{\rm ax} - |\mathbf{p}_{\rm ax}| \cos\theta_i) E_{\rm ax}}{(E_{\rm ax} + E_i)^2}$$

(θ_i is the angle between $\mathbf{p}_{\rm ax}$ and $\mathbf{p}_i$).

$$d(p_{1,\rm ax}, p_{1i}) \leq d(p_{2,\rm ax}, p_{1i}), \quad d(p_{2,\rm ax}, p_{2i}) \leq d(p_{1,\rm ax}, p_{2i}).$$

Collinear objects are grouped in the same hemisphere

	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00

Tops from top partner is highly boosted.

Decay products from a boosted top has collinear momenta then grouped in the same hemisphere.

On the other hand, tops from ttbar are not boosted, this grouping dose not work well.

Event selection

Events are generated by HERWIG for 50fb^{-1}

Mass spectrum

	$m_{T\_}$	A_H	m_t
Point	800.19	151.79	175.00

Summary of Cuts

to drop ttbar contributions

$\not{E} > 200\text{GeV}$ and $\not{E} \geq 0.2 M_{\text{eff}}$.	Cut the SM events
$n_{\text{lepton}} = 0$	Forbid semi-leptonic decay of tops
$p_{T,H_1}, p_{T,H_2} > 200\text{GeV}.$ $(p_{H_j} \equiv \sum_{i \in H_j} p_i)$	Require boosted tops (from top partner decay)
$n_{\text{jet},H} \leq 3$	Drop the events with other QCD jets or with 2 tops in 1 hemisphere.

50fb^{-1}

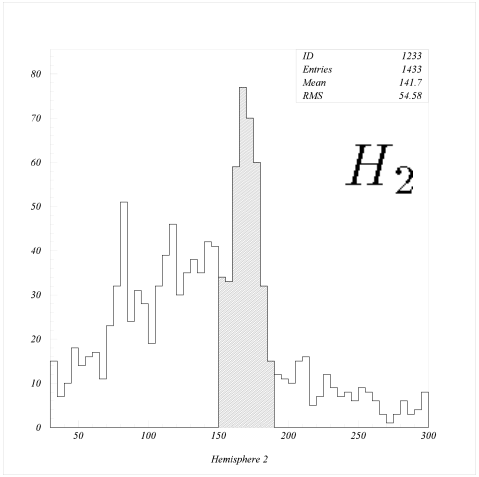
	generated	$\not{E}, M_{\text{eff}}$ cut	$n_{\text{lep}} = 0$	$p_{T,H}$ cut *	$n_{\text{jet},H} \leq 3$	m_{H_1}	m_{H_2}	$m_{H_1} \& m_{H_2}$	relaxed $m_{H_1} m_{H_2}$
$T\_\overline{T}\_$	8,550	6,590	4,384	2276	1433	437	380	118	708
$t\bar{t}$	23,150,000	199,640	88,540	9475	6835	2105	765	235	1835

Top reconstruction

Distribution of hemisphere's mass

$T_-\bar{T}_-$

150<m<190GeV

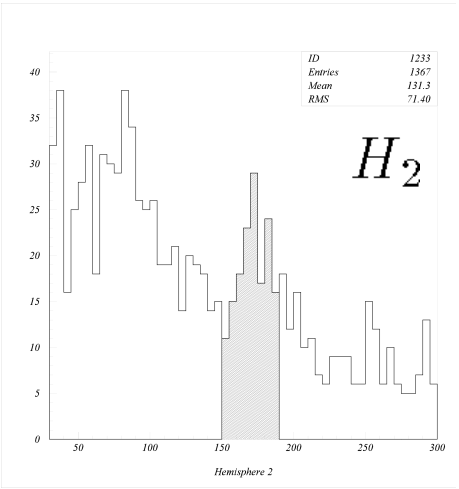


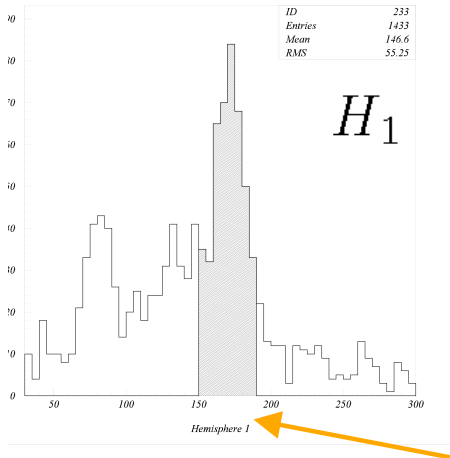
$t\bar{t}$

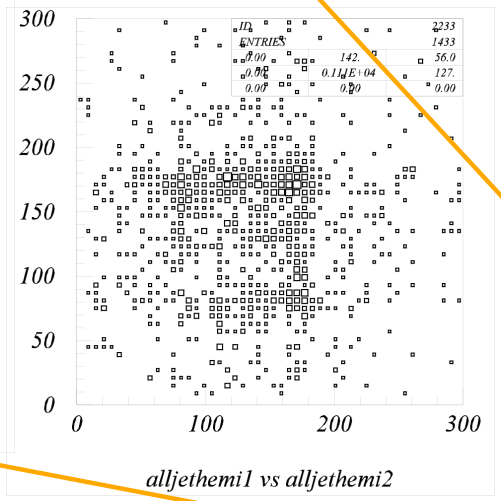
To produce large $\not{E}$,

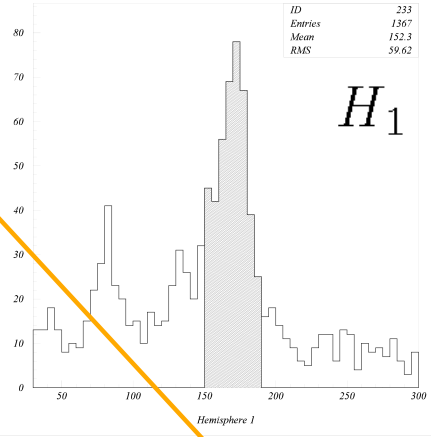
at least one top decays leptonically.

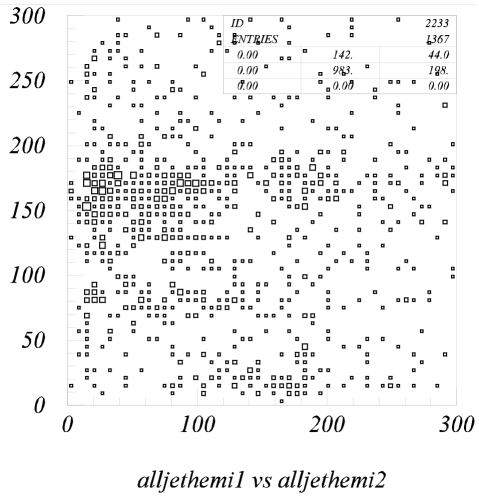
Difficult to reconstruct in H_2











50fb^{-1}

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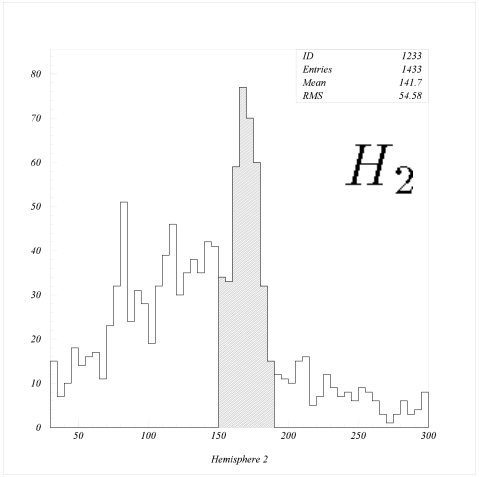

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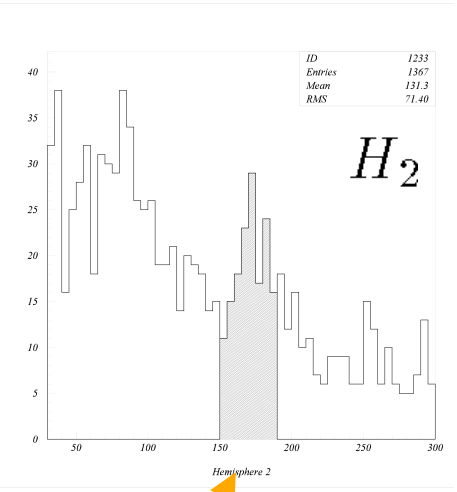

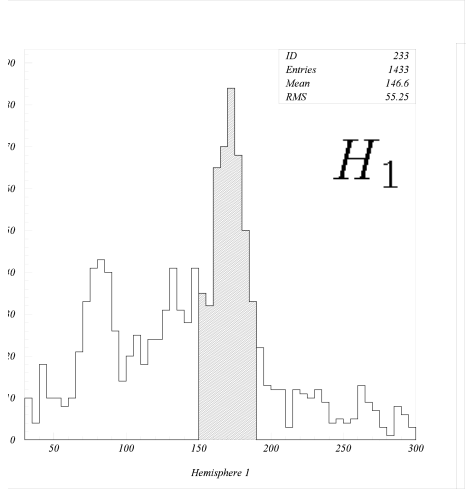

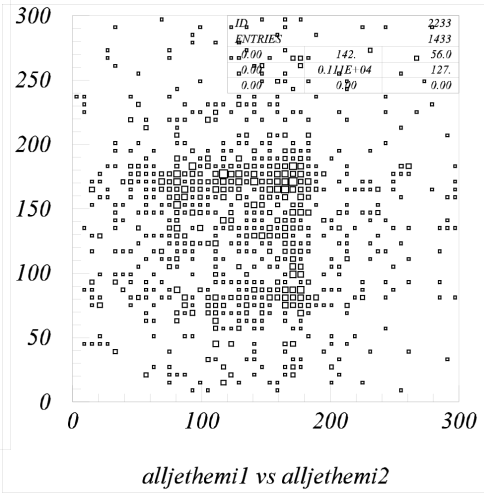

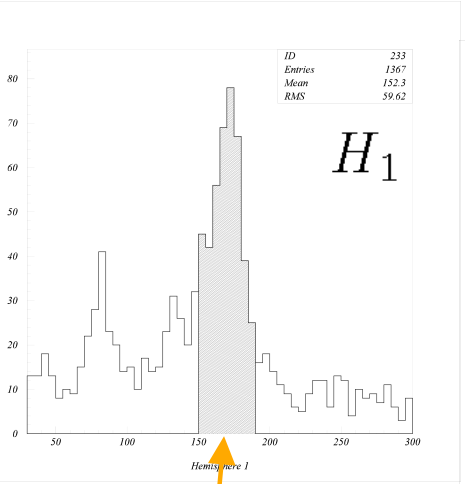

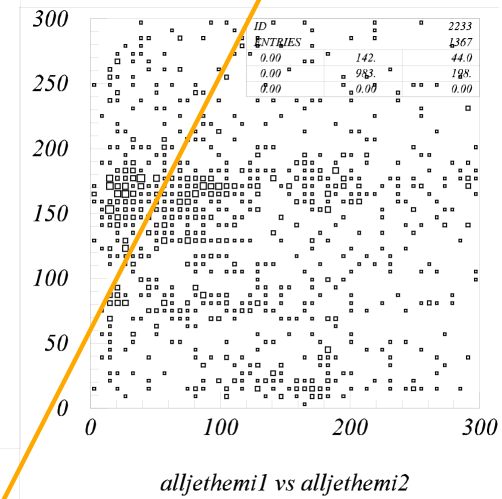

50fb^{-1}

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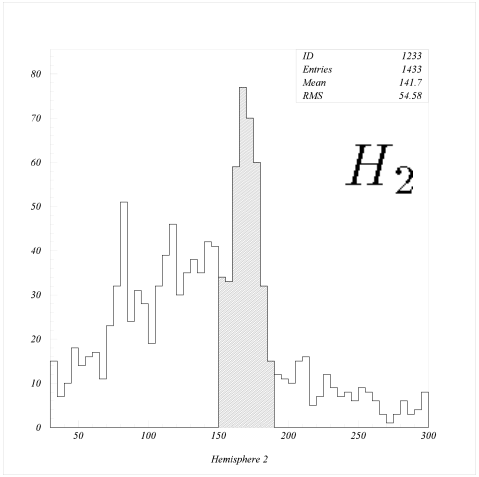

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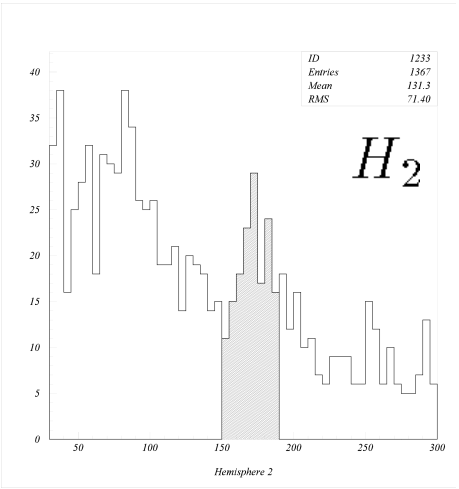

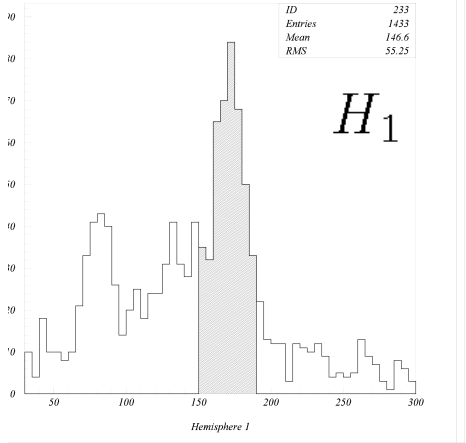

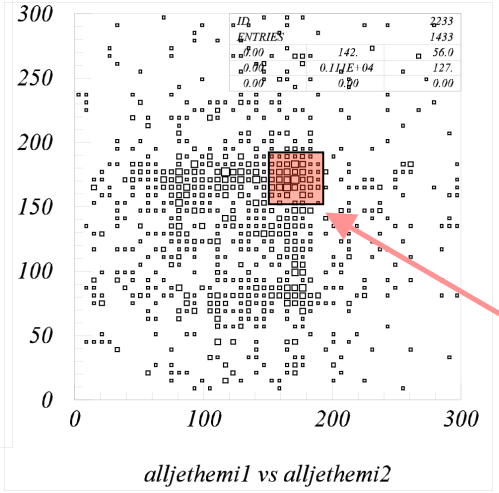

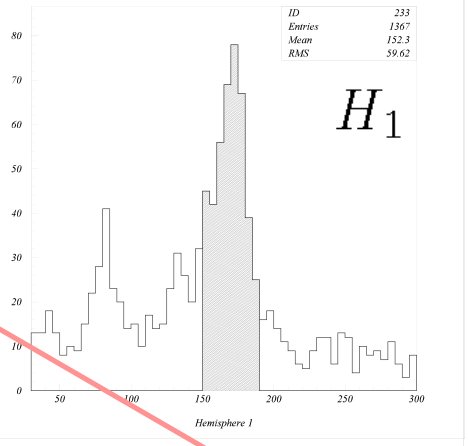

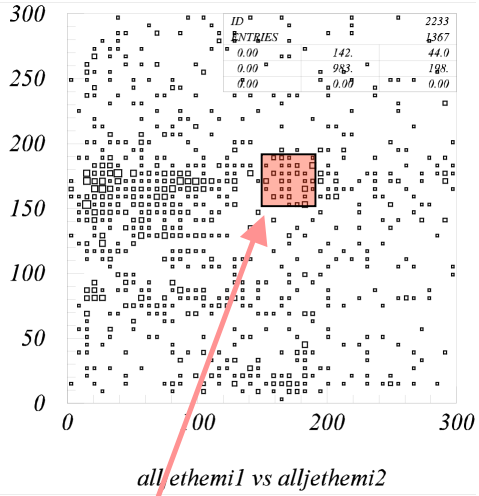

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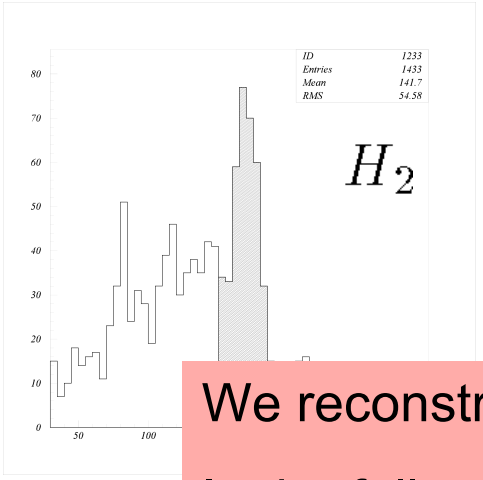

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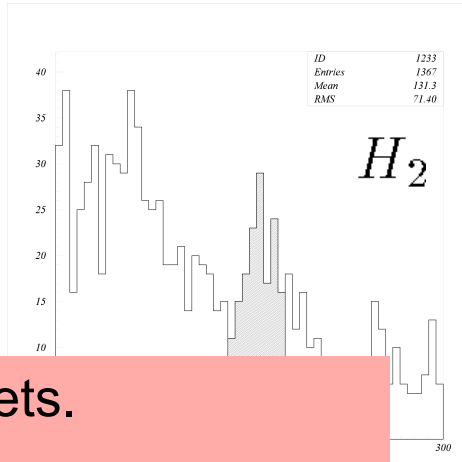
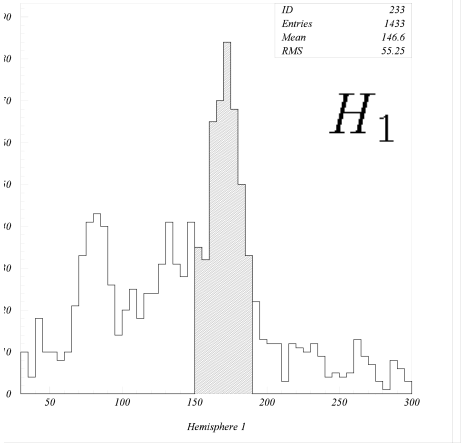
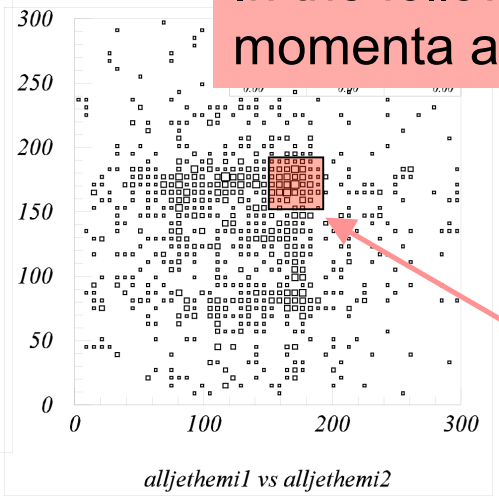
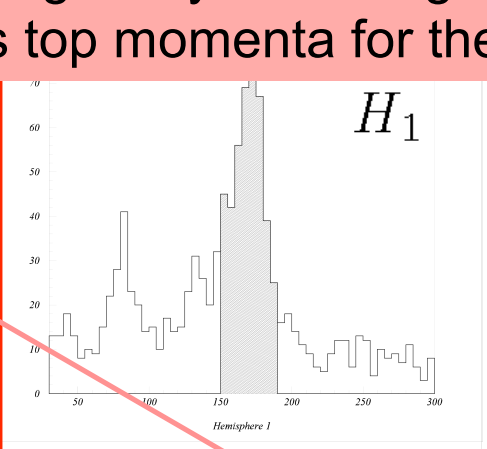


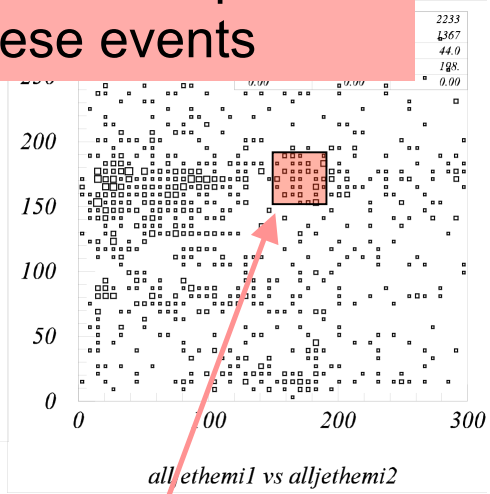
We reconstructed tops by using jets.

In the following analysis we regard hemispheres momenta as top momenta for these events









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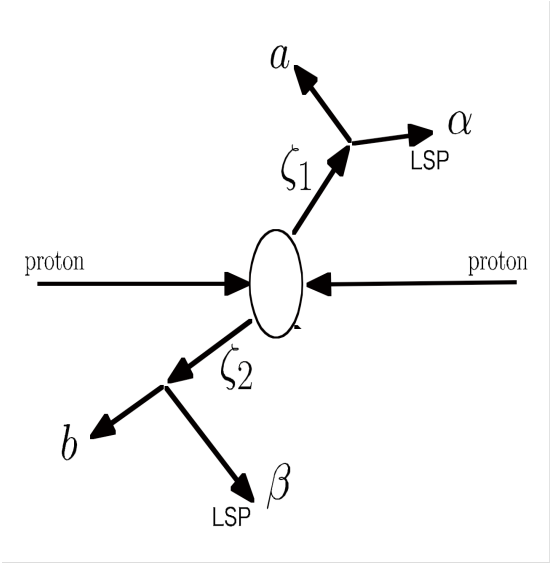
3. Top partner mass measurement

Mass measurement of Top partner

To reconstruct mass of top partner we used the m_{T2} variable.

$$\zeta\zeta \to (a\alpha)(b\beta)$$
$$T_-\overline{T}_- \to (tA_H)(\bar{t}A_H)$$



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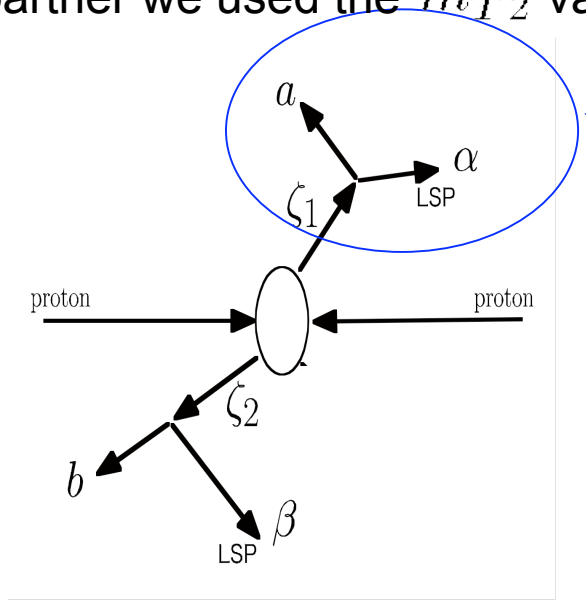
1.Let's Consider m_T

defined by two pt



$$m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^\alpha; m_{\tilde{\chi}_1^0}) \leq m_\zeta^2.$$

$$\mathbf{p}_T = (p_x, p_y, 0) \qquad E_T = \sqrt{|\mathbf{p}_T|^2 + m^2}$$

$$m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^\alpha; m_{\tilde{\chi}_1^0}) \equiv m_a^2 + m_{\tilde{\chi}_1^0}^2 + 2\left[E_T^a \not{E}_T^\alpha - \mathbf{p}_T^a \not{\mathbf{p}}_T^\alpha\right] \leq m_a^2 + m_{\tilde{\chi}_1^0}^2 + 2\left[E_T^a \not{E}_T^\alpha \cos\Delta\eta - \mathbf{p}_T^a \not{\mathbf{p}}_T^\alpha\right]$$
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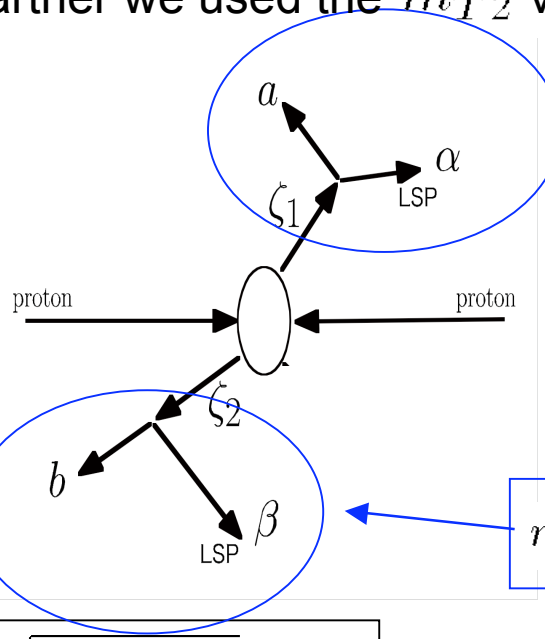

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The correct momenta are substituted

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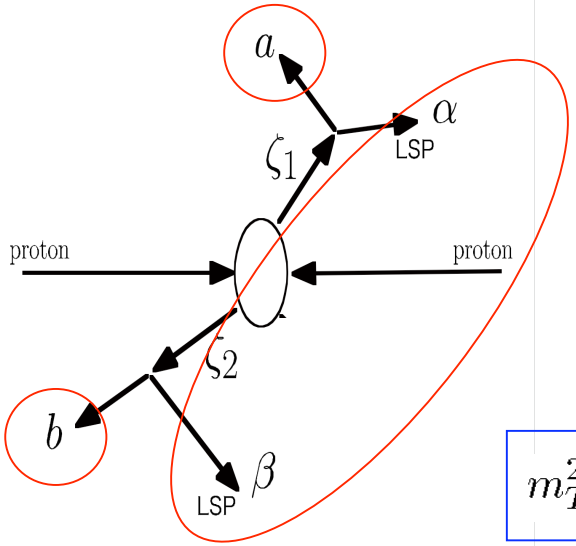
2.We can measure 3 pt



$$m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^{\alpha}; m_{\tilde{\chi}_1^0}) \leq m_\zeta^2.$$

What we can measure is only sum of missing transverse momenta

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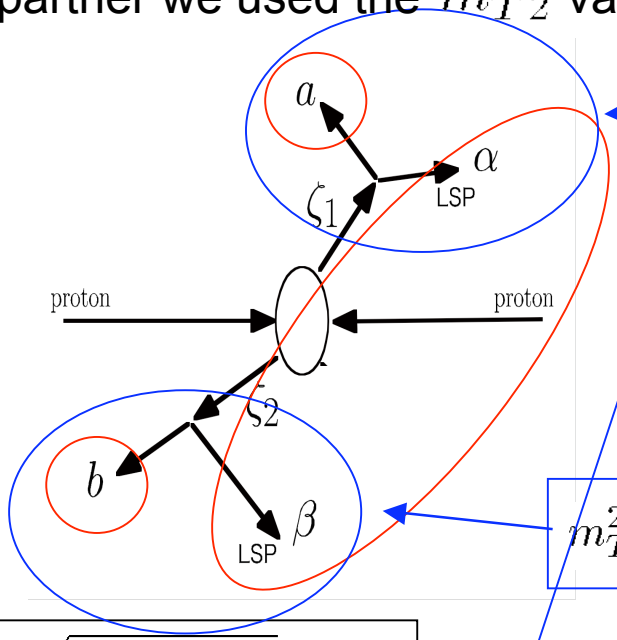
1.Consider all possible splitting of $\not{E}_T$

2.Calculate both mT for each splitting

3.Take larger one

4. Find minimum of them



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$$= (p_a + p_\alpha)^2 = m_\zeta^2$$

$$m_{T2}^2(\mathbf{p}_T^a, \mathbf{p}_T^b, \not{\mathbf{p}}_T; m_{\tilde{\chi}_1^0}) \equiv \min_{\not{\mathbf{p}}_T^{\alpha} + \not{\mathbf{p}}_T^{\beta} = \not{\mathbf{p}}_T} \left[\max\left\{m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^{\alpha}; m_{\tilde{\chi}_1^0}), m_T^2(\mathbf{p}_T^b, \not{\mathbf{p}}_T^{\beta}; m_{\tilde{\chi}_1^0})\right\}\right] \leq m_\zeta^2$$

Defined only by transverse momenta and masses

Mass measurement of Top partner

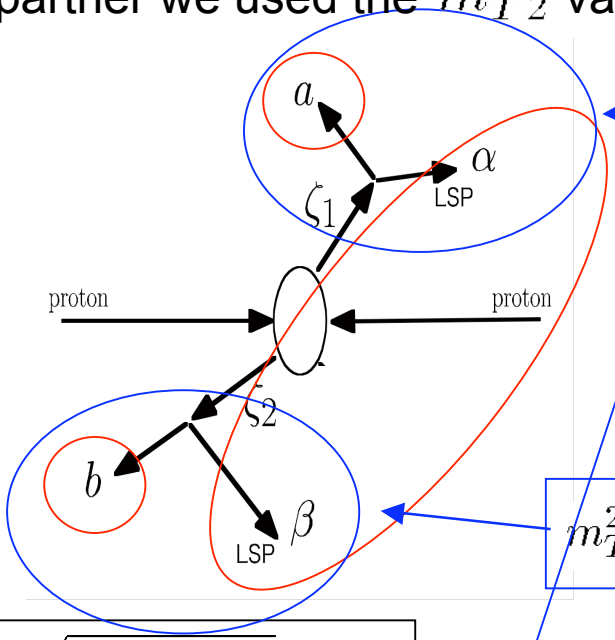
To reconstruct mass of top partner we used the m_{T2} variable.

1.Consider all possible splitting of $\not{E}_T$

2.Calculate both mT for each splitting

3.Take larger one

4. Find minimum of them



$$m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^{\alpha}; m_{\tilde{\chi}_1^0}) \leq m_\zeta^2.$$

The correct momenta are substituted

$$m_T^2(\mathbf{p}_T^b, \not{\mathbf{p}}_T^{\beta}; m_{\tilde{\chi}_1^0}) \leq m_\zeta^2.$$

$$\mathbf{p}_T = (p_x, p_y, 0) \qquad E_T = \sqrt{|\mathbf{p}_T|^2 + m^2}$$

$$m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^{\alpha}; m_{\tilde{\chi}_1^0}) \equiv m_a^2 + m_{\tilde{\chi}_1^0}^2 + 2\left[E_T^a \not{E}_T^{\alpha} - \mathbf{p}_T^a \not{\mathbf{p}}_T^{\alpha}\right] \leq m_a^2 + m_{\tilde{\chi}_1^0}^2 + 2\left[E_T^a \not{E}_T^{\alpha} \cos\Delta\eta - \mathbf{p}_T^a \not{\mathbf{p}}_T^{\alpha}\right]$$
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Defined only by transverse momenta and masses

Minimum in all possible splitting of missing transverse momentum.

'all possible' includes the correct splitting

Mass measurement of Top partner

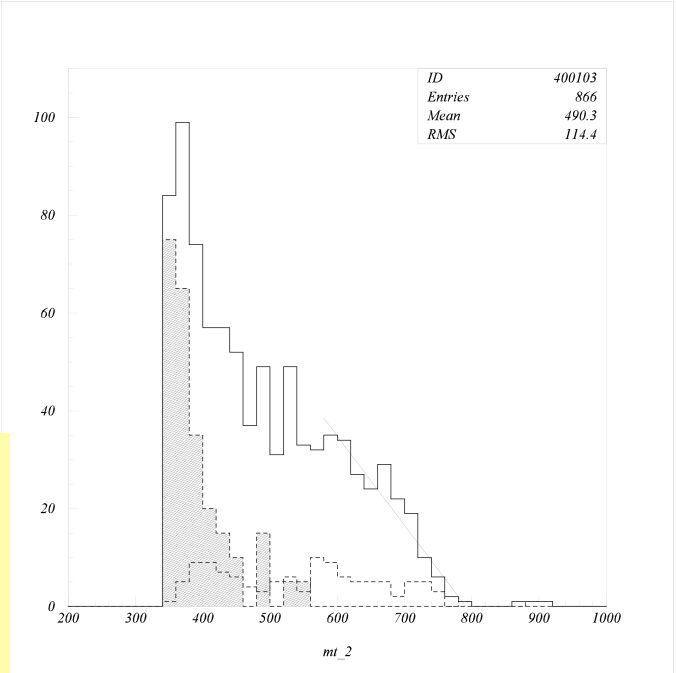
Now we have 2 top momenta from $T\_\bar{T}\_$ production events .

Plot mt2 distribution

(assuming correct mass of A_H is known)

	$m_{T\_}$	A_H	m_t
Point	800.19	151.79	175.00

Endpoint ～800 GeV



We can measure

top-partner mass by using jets

$$m_{T2}^2(\mathbf{p}_T^a, \mathbf{p}_T^b, \not{\mathbf{p}}_T; m_{\tilde{\chi}_1^0}) \equiv \min_{\not{\mathbf{p}}_T^\alpha + \not{\mathbf{p}}_T^\beta = \not{\mathbf{p}}_T} \left[\max \left\{ m_T^2(\mathbf{p}_T^a, \not{\mathbf{p}}_T^\alpha; m_{\tilde{\chi}_1^0}), m_T^2(\mathbf{p}_T^b, \not{\mathbf{p}}_T^\beta; m_{\tilde{\chi}_1^0}) \right\} \right] \leq m_\zeta^2$$

Defined only by transverse momenta and masses

Minimum of all possible splitting of missing transverse momentum.

'all possible' includes the correct splitting

4. Top polarization

Top polarization in the LHT

$$\mathcal{L} = i\frac{2g'}{5}\cos\theta_H \bar{T}_- \not{A}_H \left(\sin\beta P_L + \sin\alpha P_R\right) t \qquad \sin\alpha \simeq \frac{m_t v}{m_{T_-} f},\ >>\ \sin\beta \simeq \frac{m_t^2 v}{m_{T_-}^2 f}$$

- Tops from decays of top-partner T_- are polarized right-handedly.
- This situation is the same as MSSM (mSUGRA).($\tilde{t}_1 \sim \tilde{t}_R \rightarrow t_R$)
- For simplicity, It is important to see top polarization.

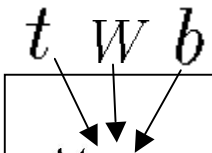
Tops are completely polarized right-handedly (helicity = +).

b is massless. (only b_L is produced)

Polarized top decay

Gordon L. Kane, G.A. Ladinsky, C.P. Yuan PRD45(1992)

$$t_R \rightarrow b_L W^+_{0,-} \rightarrow b_L (jj)_{0,-}$$



b direction

$$\mathcal{M}_{+0-} = \sqrt{2m_t E_b}\sqrt{\frac{1+\beta}{1-\beta}}\cos\frac{\theta}{2}e^{i\phi}$$ backward

$$\mathcal{M}_{+--} = -\sqrt{2m_t E_b}\sqrt{2}\sin\frac{\theta}{2}e^{2i\phi}$$ forward

$$\mathcal{M}_{-0-} = \sqrt{2m_t E_b}\sqrt{\frac{1+\beta}{1-\beta}}\sin\frac{\theta}{2}$$

$$\mathcal{M}_{---} = \sqrt{2m_t E_b}\sqrt{2}\cos\frac{\theta}{2}e^{i\phi}$$

Amplitude for each combination of helicities can be calculated.

θis W direction to the top momenta at the rest frame of the top.

Decay distribution of b-jets is obtained.

b-jet distribution

$$\beta = \frac{m_t^2 - m_W^2}{m_t^2 + m_W^2}$$

$$E_b = \frac{m_t^2 - m_W^2}{2m_t}$$

I want to show the difference between polarized and non-polarized.

b direction

$$\mathcal{M}_{+0-} = \sqrt{2m_tE_b}\sqrt{\frac{1+\beta}{1-\beta}}\cos\frac{\theta}{2}e^{i\phi} \quad \text{backward} \quad \sim 4.78$$

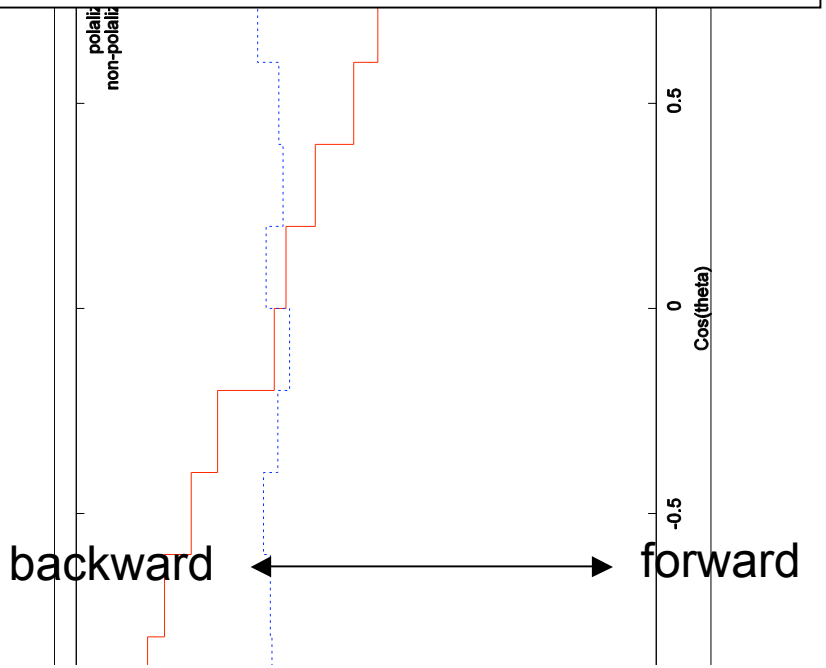
$$\mathcal{M}_{+--} = -\sqrt{2m_tE_b}\sqrt{2}\sin\frac{\theta}{2}e^{2i\phi} \quad \text{forward} \quad \sim 2$$

$$\mathcal{M}_{-0-} = \sqrt{2m_tE_b}\sqrt{\frac{1+\beta}{1-\beta}}\sin\frac{\theta}{2}$$

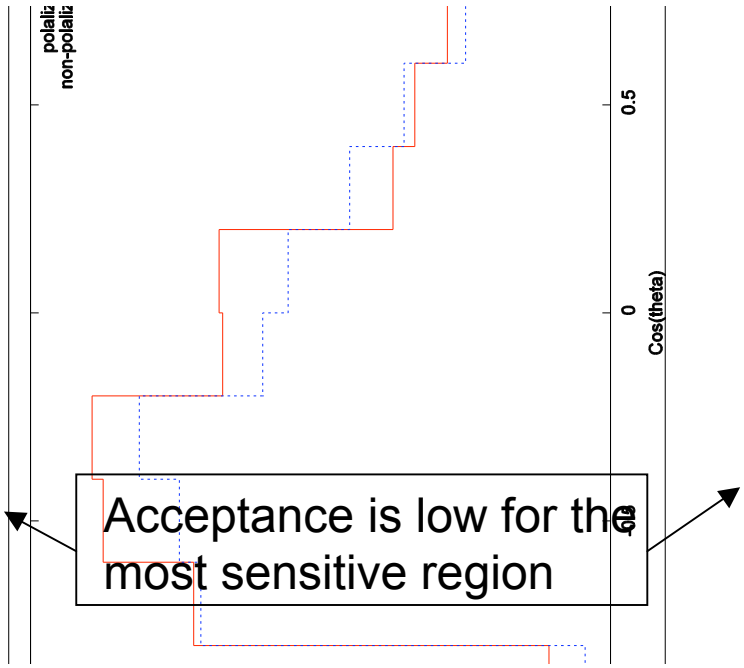
$$\mathcal{M}_{---} = \sqrt{2m_tE_b}\sqrt{2}\cos\frac{\theta}{2}e^{i\phi}$$

Only 3jets events in a hemisphere are analysed.

b-jet is selected as a jet not involved in the pair consistent with m_W.



Parton level analysis



Jet level analysis

Top polarization in LHT

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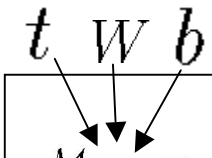

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t W b

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$$\mathcal{M}_{---} = \sqrt{2m_t E_b}\sqrt{2}\cos\frac{\theta}{2}e^{i\phi}$$

jets direction

$$\mathcal{M}_0 \propto -\frac{\sin\theta^*}{\sqrt{2}}$$ transverse

$$\mathcal{M}_- \propto -e^{-i\phi^*}\left(\frac{1-\cos\theta^*}{2}\right)$$ longitudinal

W

θ^* is a jet direction to the W momenta at the rest frame of the W.

Jet asymmetry of W-jets

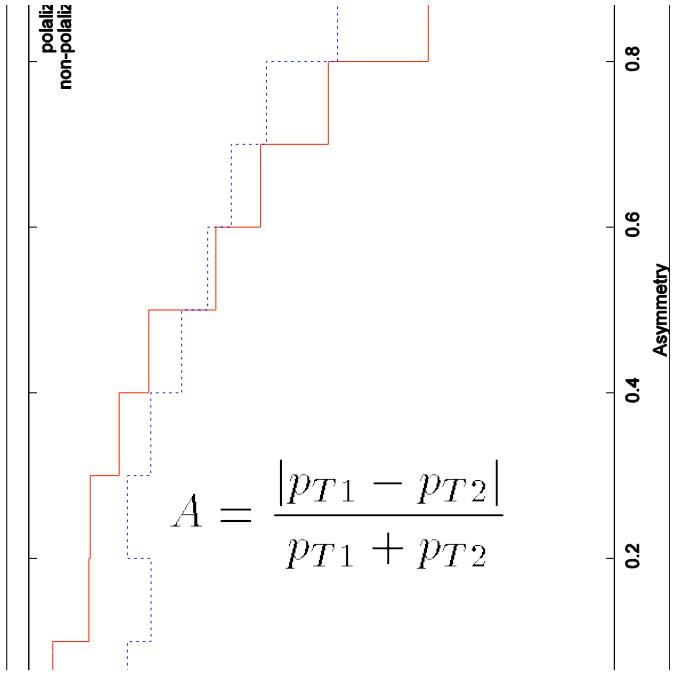
jets direction	b direction	W direction
transverse	backward	forward
longitudinal	forward	backward

$$\mathcal{M}_0 \propto -\frac{\sin\theta^*}{\sqrt{2}}$$

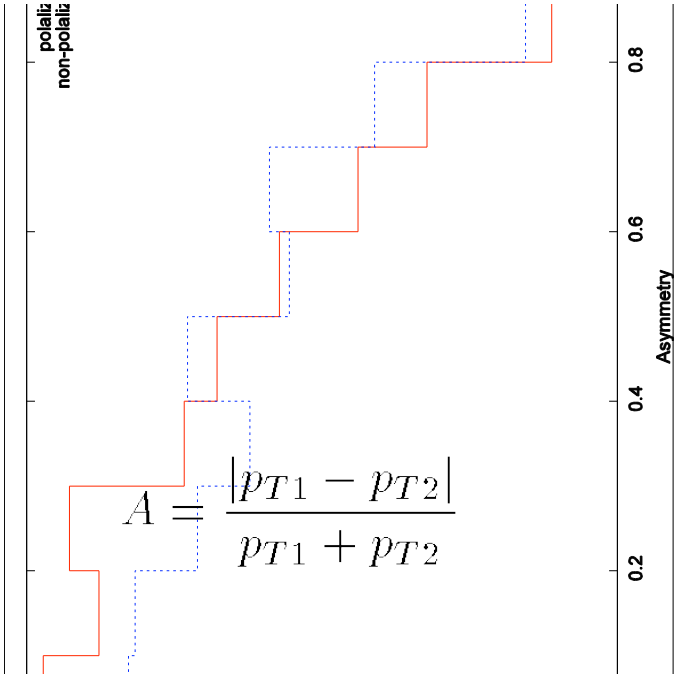
$$\mathcal{M}_- \propto -e^{-i\phi^*}\left(\frac{1-\cos\theta^*}{2}\right)$$

W

W-jets are selected as a jet pair consistent with m_W.



Parton level analysis



Jet level analysis

Summary

- To Use Jets is important at the LHC.

- We have reconstructed top momenta by using jets and measure the mass of top-partner using m_{T2} .

- To see the top polarization effects is important. Jet level analysis should be needed.