Study of the Top reconstruction in top partner event at the LHC

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Collaboration with Mihoko Nojiri (KEK)

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.

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

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

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

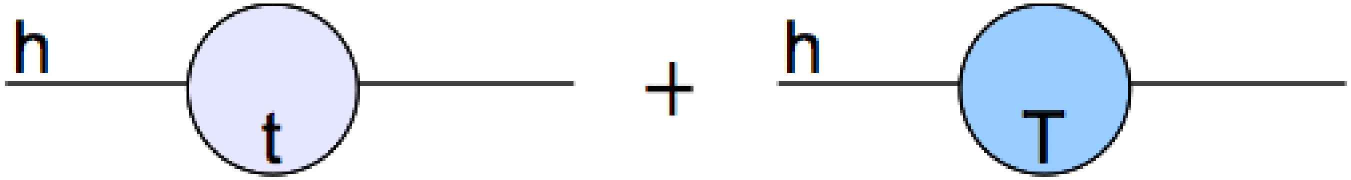
Jets events reconstruction is important toward the LHC.

Focus on Top sector

- Top decays into 3 jet final state.

$$t \to bW \to bjj$$

- Strongly coupled with Higgs sector.
  (Strong relation with fine tuning problem)



- It is plausible Top partner exists.
  And it decays into top and DM in many models.

$$T \to tA_H, \quad \tilde{t} \to t\tilde{\chi}_1^0$$ and so on..

Plan of talk

1. Introduction (Focus on Top jets)
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

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

Missing momentum

- 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 which is implemented in FastJET.

BG $t\bar{t} \to b\bar{b} W^+ W^- \to b\bar{b} jjjj$ 463pb ALPGEN
$(t\bar{t}j, t\bar{t}jj)$

We set mass spectrum as

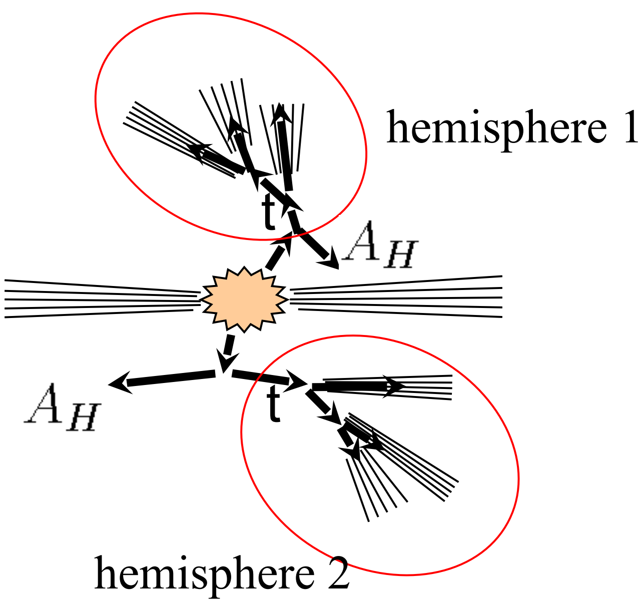
	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00

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 $\mathbf{p}_i$).

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

Collinear objects are grouped in the same hemisphere

Tops from top partner is highly boosted.

	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00

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, the efficiency is lower.

Event selection

Mass spectrum

	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00

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

Summary of Cuts

to drop ttbar contributions

$\not{E} > 200\mathrm{GeV}$ and $\not{E} \geq 0.2 M_{\mathrm{eff}}$. — Cut the SM events

$n_{\mathrm{lepton}} = 0$ — Forbid semi-leptonic decay of tops

$p_{T,H_1}, p_{T,H_2} > 200\mathrm{GeV}$. $(p_{H_j} \equiv \sum_{i \in H_j} p_i)$ — Require boosted tops (from top partner decay)

$n_{\mathrm{jet},H} \leq 3$ — Drop the events with other QCD jets or with 2 tops in 1 hemisphere.

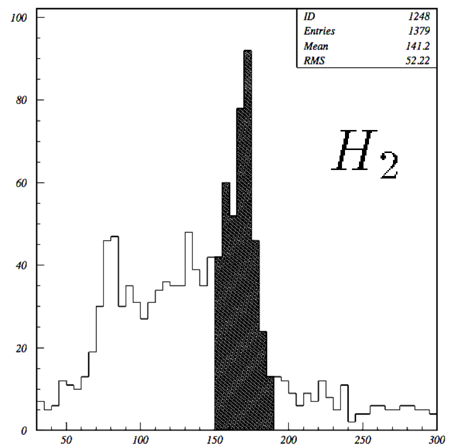
	generated	$\not{E}, M_{\mathrm{eff}}$ cut	$n_{\mathrm{lep}} = 0$	$p_{T,H}$ cut	$n_{\mathrm{jet},H} \leq 3$	$m_{P_{H_1}}$	$m_{P_{H_2}}$	both m_{P_H}	relaxed m_{P_H}	$m_{T2} > 500$
$T_-\bar{T}_-$	8,550	6,670	4,174	2,117	1,379	434	407	142	496	263
$t\bar{t}$	23,150,000	201,202	74,118	15,710	9,778	2,515	1,334	386	1666	2

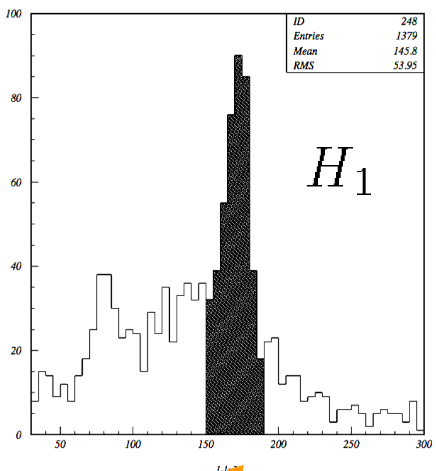
Top reconstruction

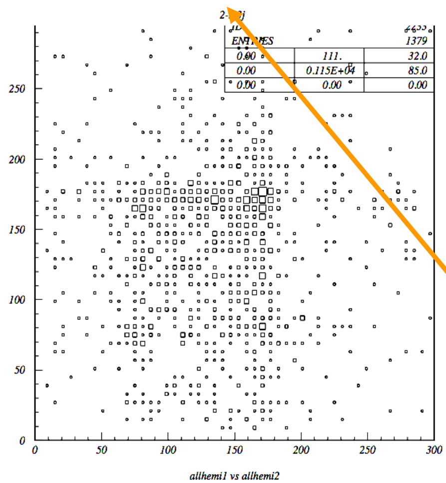
Distribution of hemisphere's mass

$T\_\bar{T}\_$

150<m<190GeV





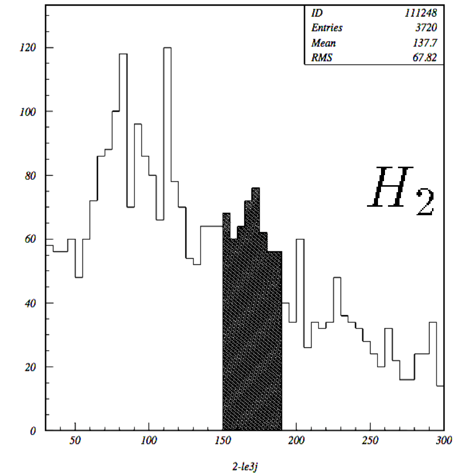


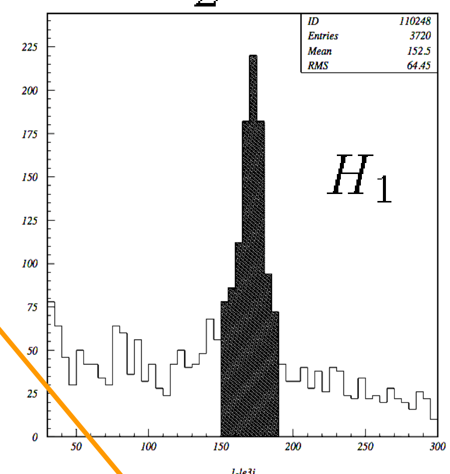
$t\bar{t}$

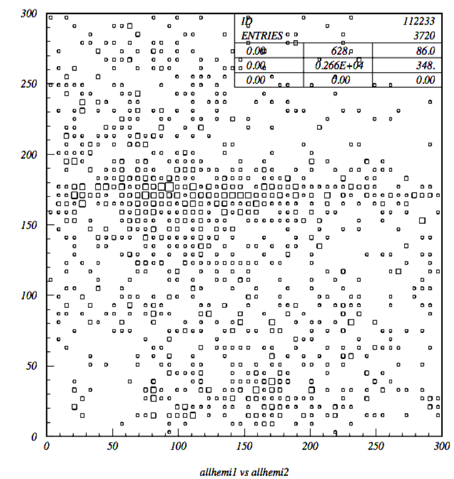
To produce large $\not{E}_T$,

at least one top decays leptonically.

Difficult to reconstruct in H_2







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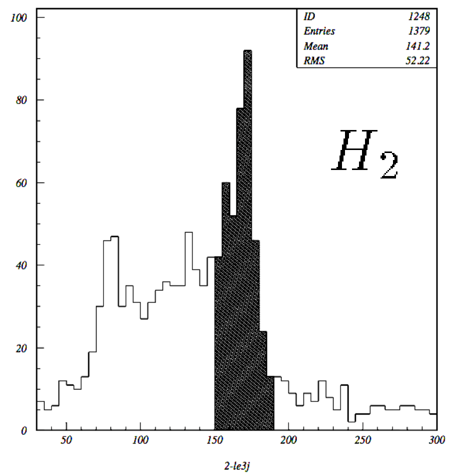

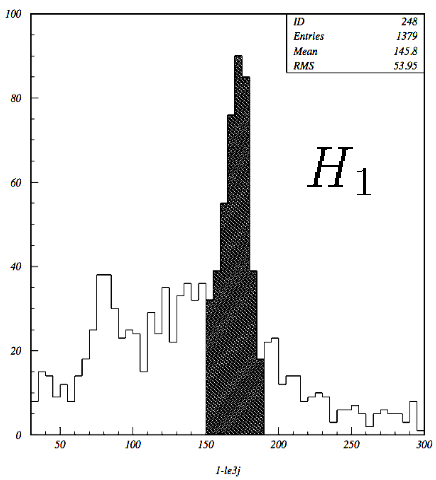

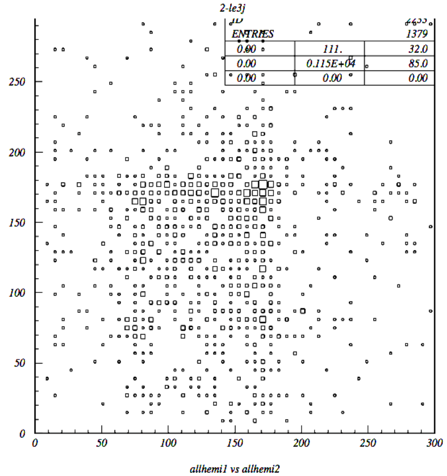

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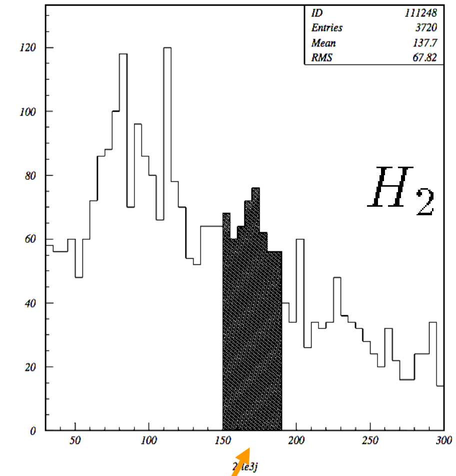

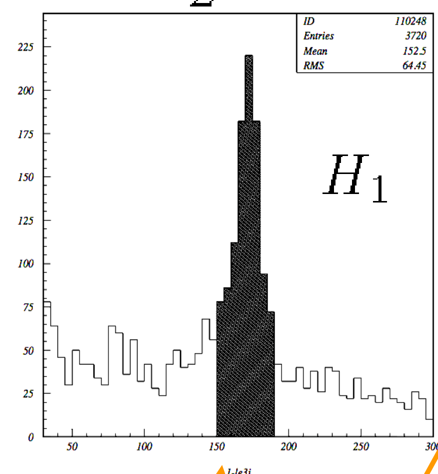

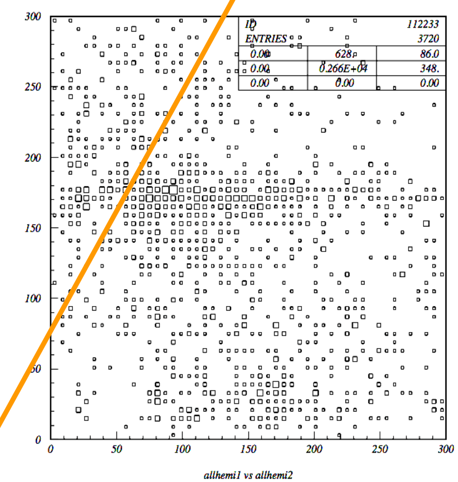

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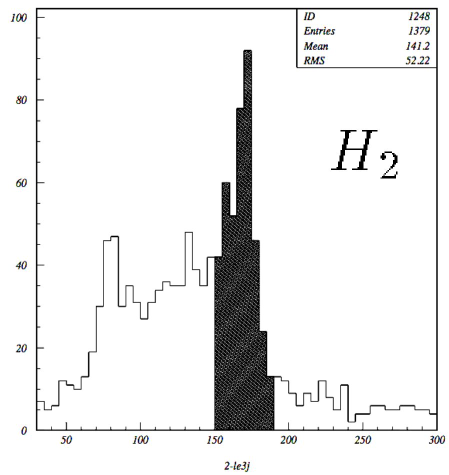

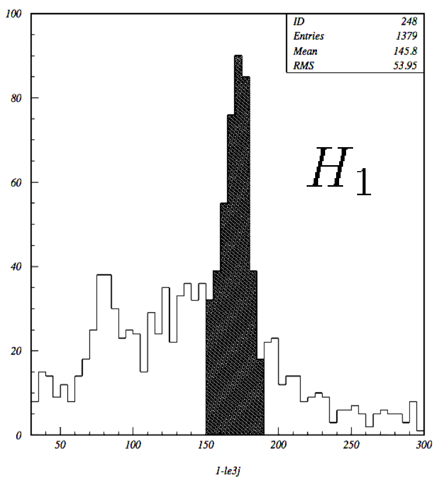

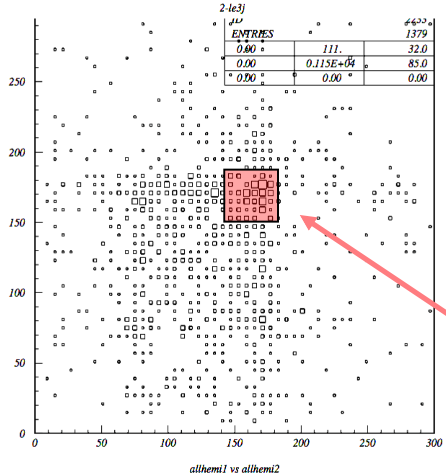

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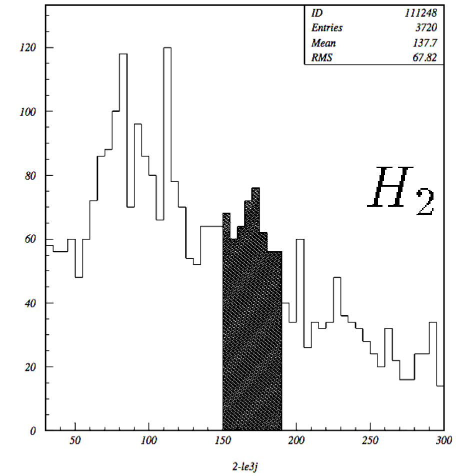

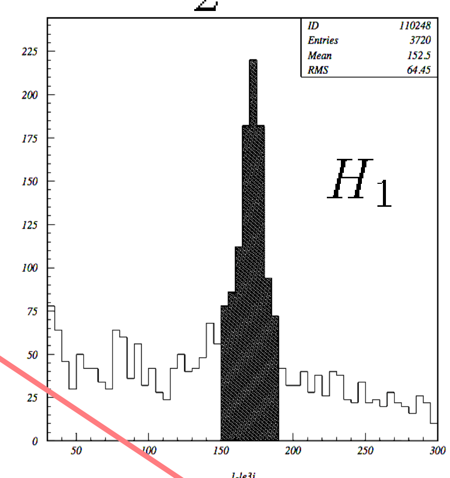

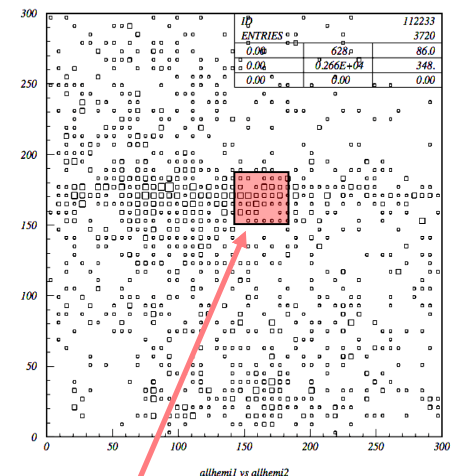

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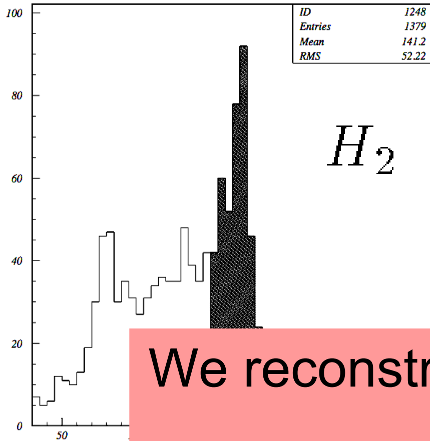

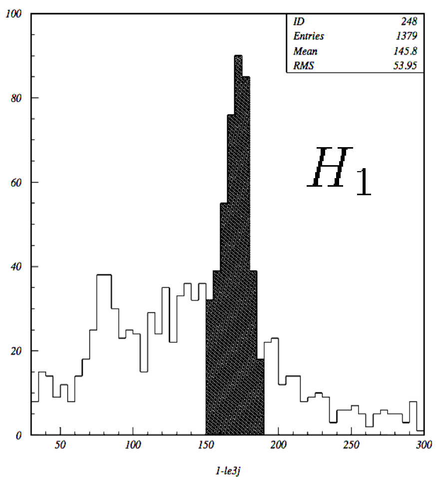

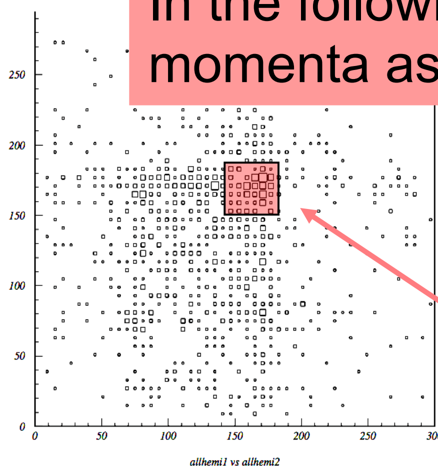

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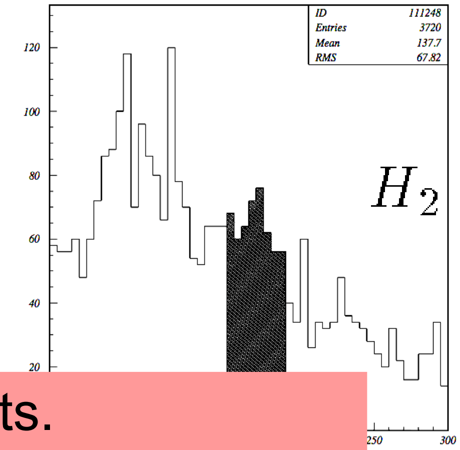
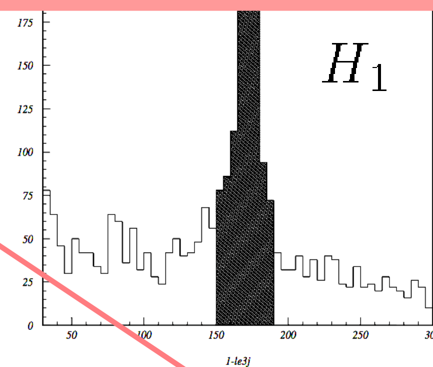
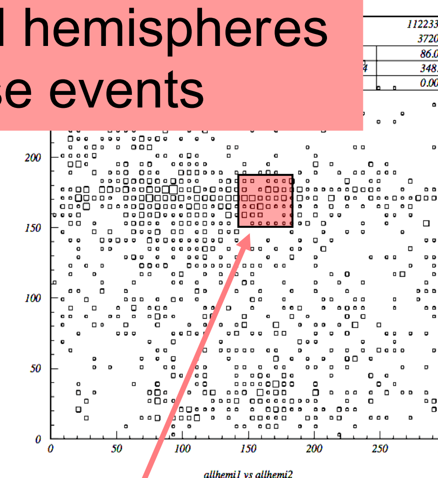


We reconstructed tops by using jets.

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





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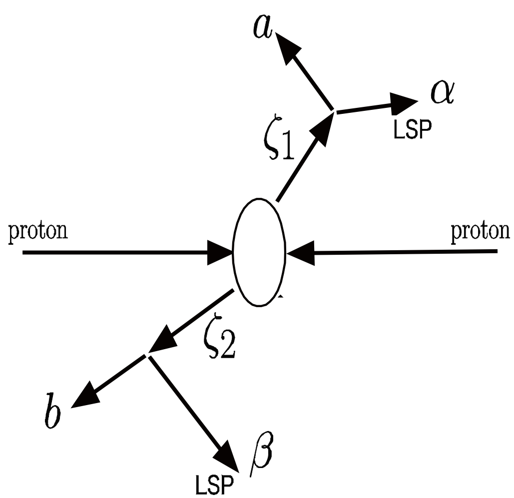
3. Top partner mass measurement

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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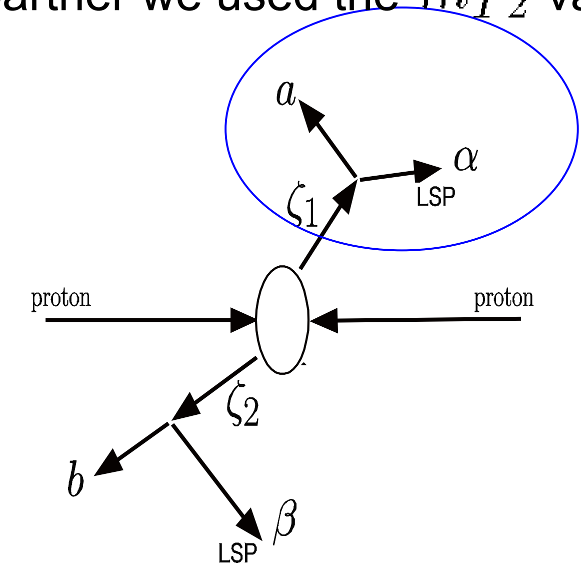
1.Let's Consider m_T

defined by two pt



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

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

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

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

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$$T_{-}\overline{T}_{-} \rightarrow (tA_H)(\bar{t}A_H)$$

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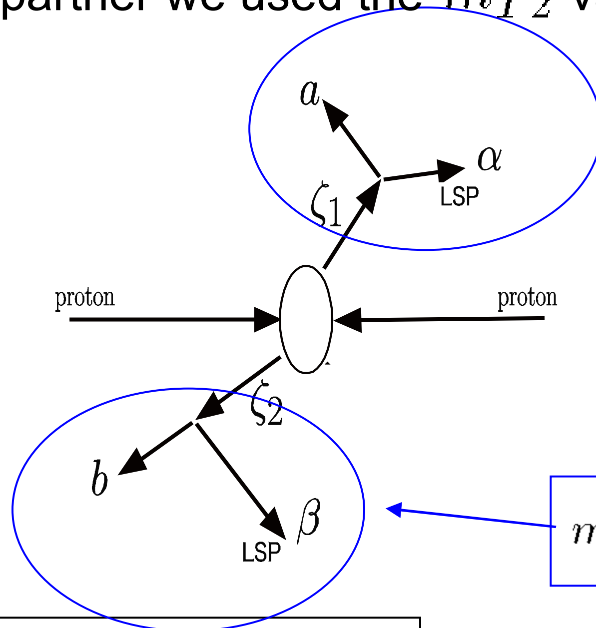

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The correct momenta are substituted

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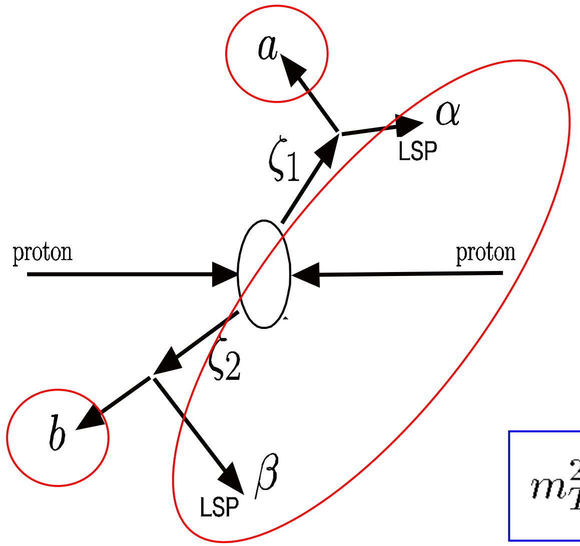
2.We can measure 3 pt



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

What we can measure is only sum of missing transverse momenta

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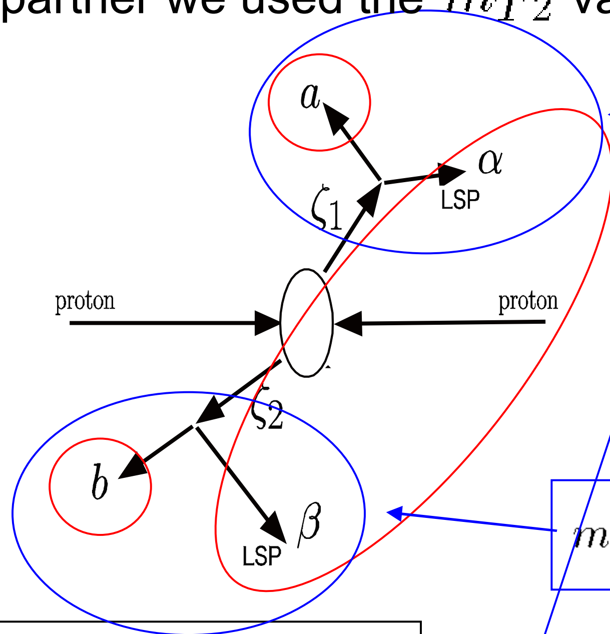
1.Consider all possible splitting of $\not{E}_T$

2.Calculate both mT for each splitting and Take larger one

3. Find minimum of them



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

Defined only by transverse momenta and masses

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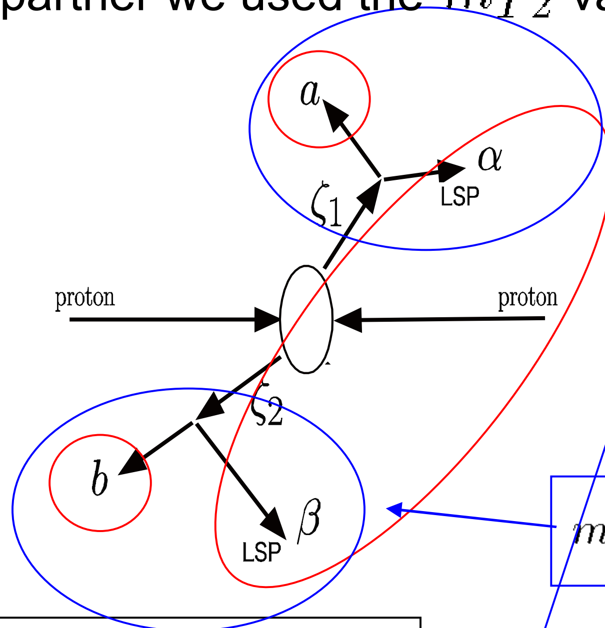

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Defined only by transverse momenta and masses

Minimum in all possible splitting of missing transverse momentum.

'all possible' includes the correct splitting

Mass measurement of Top partner

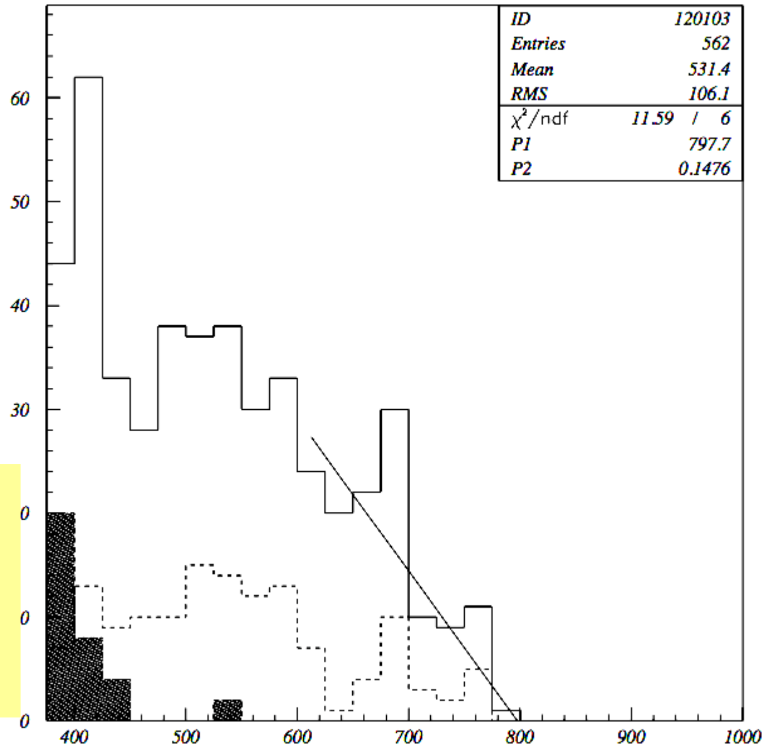
Now we have 2 top momenta from $T_- \bar{T}_-$ production events .

Plot mt2 distribution

(assuming correct mass of A_H is known)

Endpoint ～800 GeV

	m_{T_-}	A_H	m_t
Point	800.19	151.79	175.00



We can measure top-partner mass by using jets

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

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

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

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

For simplicity

Tops are completely polarized right-handedly (helicity = +). P~0.8~0.9

b is massless. (only b_L is produced)

Polarized top decay

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

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

t W b

b direction

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

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

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

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

Amplitude for each combination of helicities can be calculated.

θ is 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

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

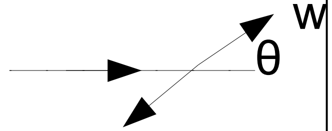
backward ~ 4.78

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

forward ~ 2

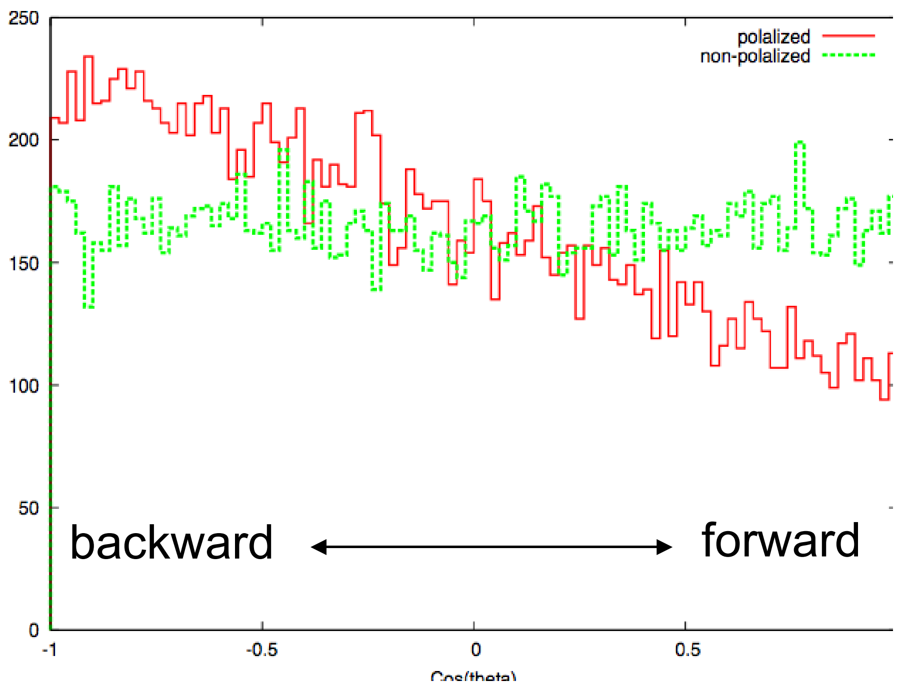
$$\mathcal{M}_{-0-} = \sqrt{2m_t E_b}\sqrt{\frac{1+\beta}{1-\beta}}\sin\frac{\theta}{2}$$

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

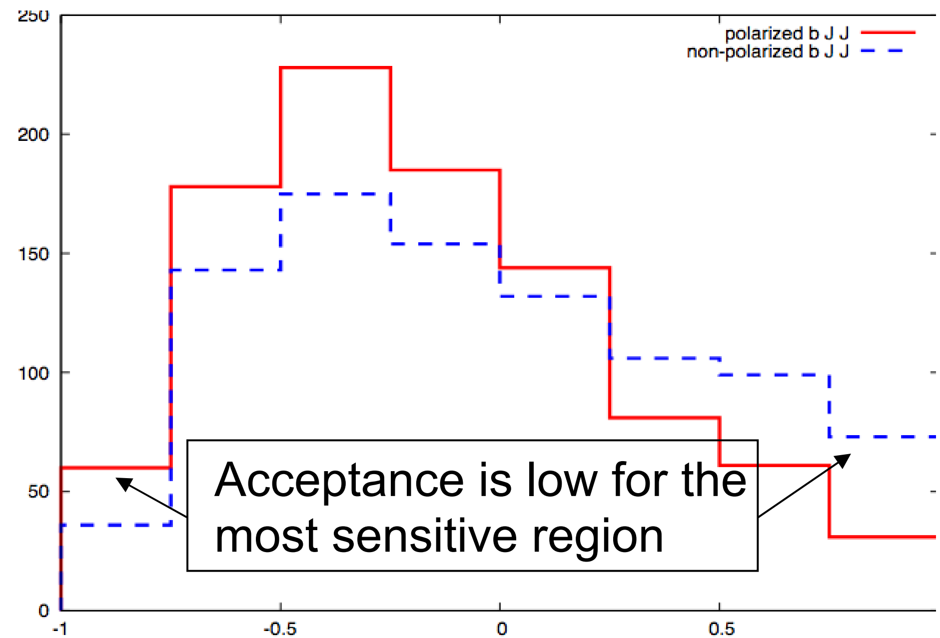


Only 3jets events in a hemisphere are analysed.

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



Parton level analysis



Jet level analysis

Jet asymmetry of W-jets

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

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

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

jets direction

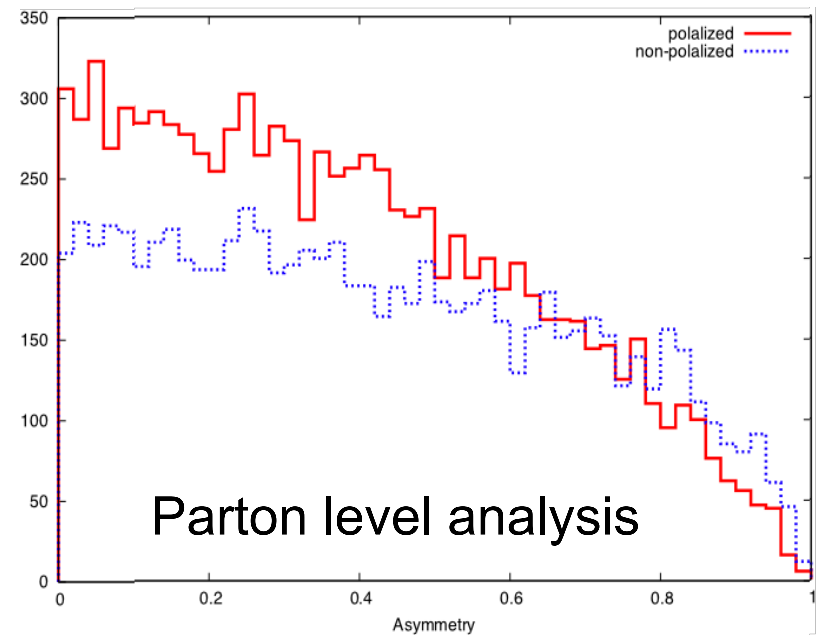
$$\mathcal{M}_0 \propto -\frac{\sin\theta^*}{\sqrt{2}}$$ transverse

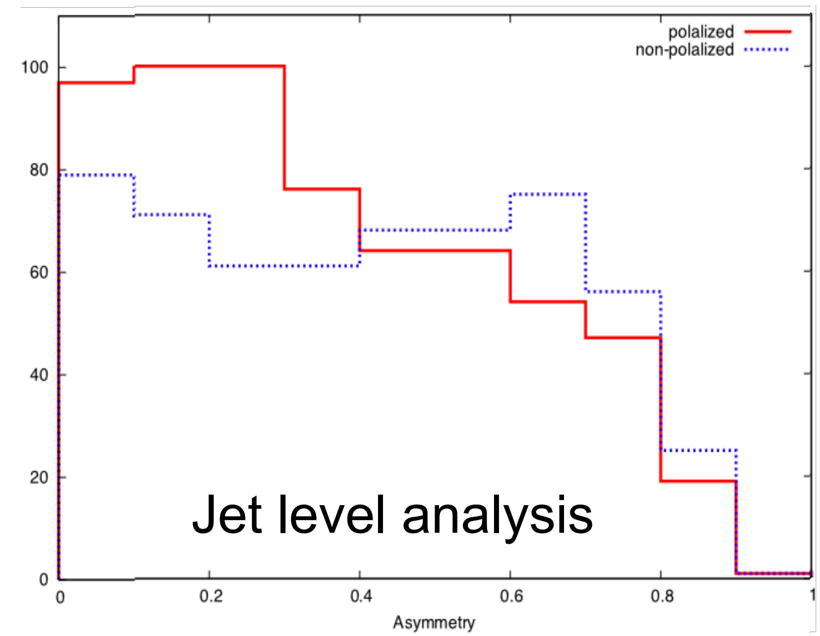
$$\mathcal{M}_- \propto -e^{-i\phi^*}\left(\frac{1-\cos\theta^*}{2}\right)$$ longitudinal

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

$$A = \frac{|p_{T1} - p_{T2}|}{p_{T1} + p_{T2}}$$

Events with backward b-jet, helicity of W from t_R is 0.
In the case, jet asymmetry prefers to be 0.





Summary

- Jets events reconstruction is important at the LHC. (Many models have Top partner.)
- We have reconstructed top momenta by using jets and measure the mass of top-partner using m_{T2}.
- Top polarization effects can be measured at Jet level analysis.
- HERWIG, Comphep, AcerDET, FastJET, ALPGEN are used for these analyses.