BEST: Bi-Event Subtraction Technique and Mass Reconstruction at the LHC

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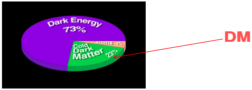
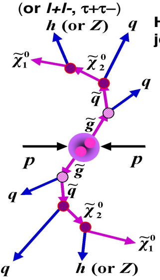
PHENO 2012

Supersymmetry at the LHC





High PT jet

[mass difference is large]

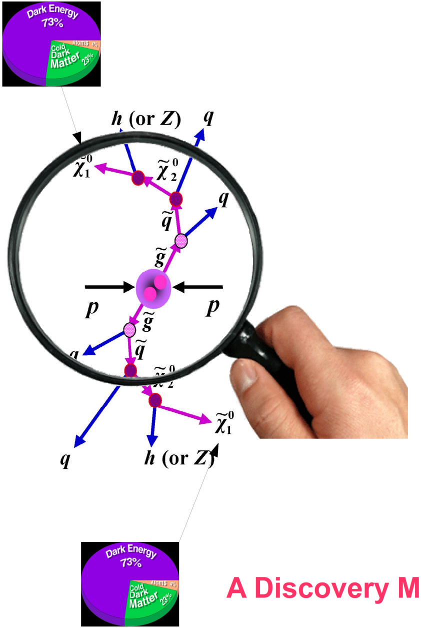
The pT of jets and leptons depend on the sparticle masses which are given by models

Colored particles are produced and they decay finally into the weakly interacting stable particle

R-parity conserving

The signal :

jets + leptons+ t's +W's+Z's+H's + missing ET



Signal:

Jets + leptons + t's + W's + Z's + H's + MET

Different approaches/observables

alpha_T, Razor, MT2

Many different data-driven techniques to derive backgrounds CMS PAS SUS-10-001

BUT

Reconstruction of chains hard

Mass measurements hard

Establishing a model hard

A Discovery Machine or a Model Machine?

- This talk will mainly focus on the reconstruction of masses of superpartners from decay chains

- At a theoretical level, we will investigate to what extent mass reconstruction can tell us about supersymmetry breaking mediation schemes

- We will reconstruct masses of W, t and $\tilde{g}$, two lightest neutralinos, $\tilde{t}$, $\tilde{b}$

BEST

Bi-Event Subtraction Technique

- A technique to model combinatoric background
- Reconstruct a variety of masses in SM and BSM models

Apply BEST in Supersymmetry, W, t mass

Papers by TAMU theory+experiment group

arXiv:1112.3966, arXiv:1104.2508[PLB], arXiv:1008.3380[PRD], arXiv:0808.1372[PRD], arXiv:0802.2968[PRL],

hep-ph/0701053, hep-ph/0611089, hep-ph/0608193, hep-ph/0603128[PLB]

Richard Arnowitt, Bhaskar Dutta, Teruki Kamon, Abram Krislock, KS, Kechen Wang

Specific models are hard to pin down

Can mass reconstruction say anything intelligent about things like mediation schemes?

Good bet: gaugino sector

- mSUGRA pattern: GUT scale unification.

  $m_1 : m_2 : m_3 \ \sim \ 1 : 2 : 6 \ \sim \ g_1^2 : g_2^2 : g_3^2$

- Anomaly pattern: determined by β functions.

  $m_1 : m_2 : m_3 \ \sim \ 3.3 : 1 : 9$

- Mirage pattern: Mixed boundary conditions at GUT scale parametrized by α

  $m_1 : m_2 : m_3 \ \sim \ 1 : 1.3 : 2.5 \ (\alpha \sim 1)$

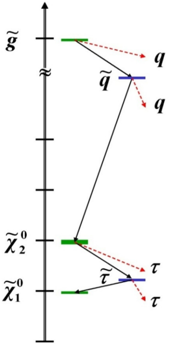
Theoretical Challenges:

- Gaugino unification scale may not necessarily tell you the mediation scheme, let alone the UV construction
- The observables that we measure give neutralino masses. Gaugino ⇒ specific regions of parameter space
- Need to verify that we are in those regions ⇒ more mass reconstruction

We will take a UV model which allows a full realization of our program and a spectrum in a part of parameter space where lightest neutralinos are mainly gauginos.

KKLT with *D7* branes, in stop/stau coannihilation parts of parameter space.

Roadmap

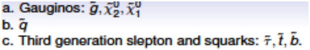


Construct and measure kinematical variables in a benchmark model (KKLT with D7 branes).

Reconstruct SM particles: top, W

Reconstruct SUSY masses from kinematic observables

Bi-Event Subtraction Technique(BEST)

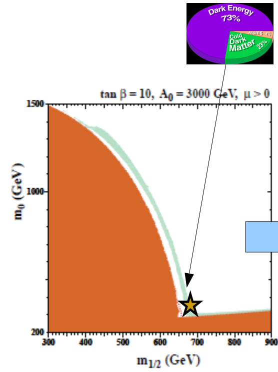


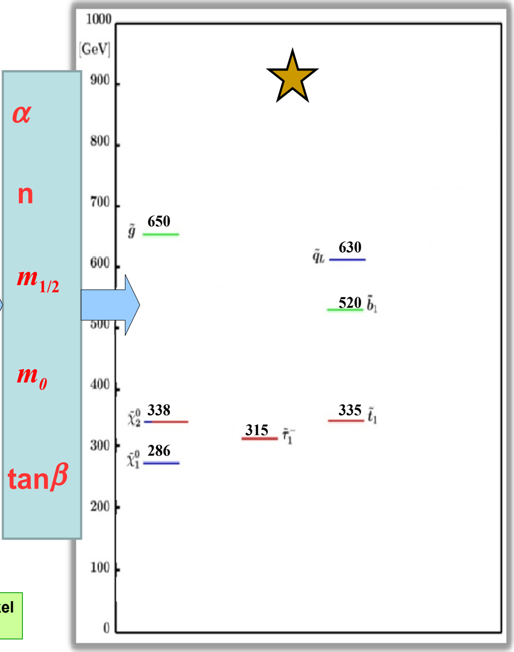
a. Gauginos: $\tilde{g}, \tilde{\chi}_2^0, \tilde{\chi}_1^0$
b. $\tilde{q}$
c. Third generation slepton and squarks: $\tilde{\tau}, \tilde{t}, \tilde{b}$.

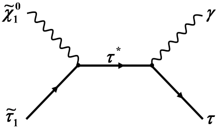
Mediation Scheme

Relic Density

Stop-Neutralino Coannihilation

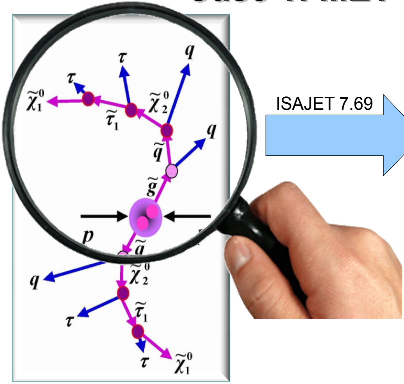




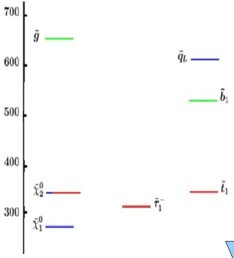


Co-annihilation (CA) Process (Griest, Seckel '91)

Case 1: MET + Jets + Taus



ISAJET 7.69



PYTHIA 6.411
PGS4

CUTS

(i) Missing transverse energy $\not{E}_T \geq 180$ GeV

(ii) $p_{T,jet1} + p_{T,jet2} + \not{E}_T \geqslant 600$ GeV

(iii) Leading jet cuts: At least two jets should be present, each with $p_T \geq 200$ GeV in $|\eta| \leq 2.5$. The jets are both required to be non b-tagged jets, and the event is discarded when either of them is tagged as a b jet

(iv) Soft jet cuts: Any jet with $p_T \geq 30$ GeV in $|\eta| \leq 2.5$ is accepted in the analysis

(v) τ cuts: At least two τ leptons, with visible $p_T \geq 15$ GeV in $|\eta| \leq 2.5$

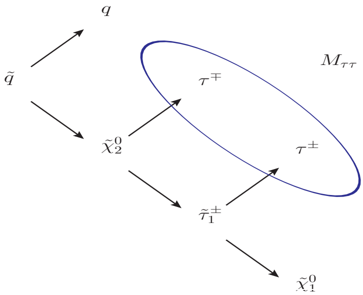
CMS Physics Analysis Summary CMS-PAS-SUS-11-007 (2011)

Observables:

$M_{\tau\tau}$
$M_{j\tau\tau}$
M_{eff}

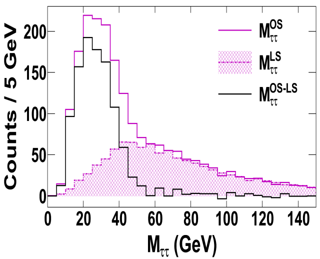
We will construct a combination of p_T information of τ pair

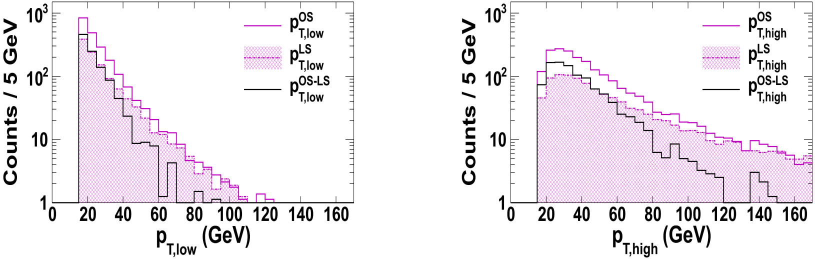
$M_{\tau\tau}, p_{T\tau_1}, p_{T\tau_2}$ observables:



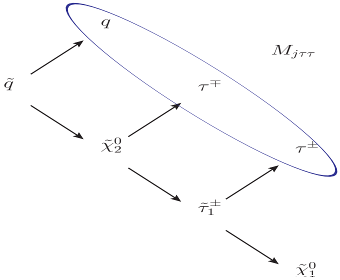
Scourge: combinatoric background

Solution: Opposite Sign - Like Sign (OS-LS) technique


Counts / 5 GeV
0
50
100
150
200
$M_{\tau\tau}^{OS}$
$M_{\tau\tau}^{LS}$
$M_{\tau\tau}^{OS-LS}$
0
20
40
60
80
100
120
140
$M_{\tau\tau}$ (GeV)

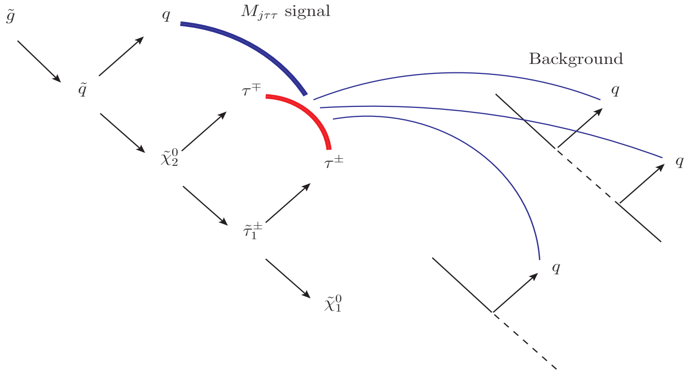

Counts / 5 GeV
1
10
10^2
10^3
$p_{T,low}^{OS}$
$p_{T,low}^{LS}$
$p_{T,low}^{OS-LS}$
0
20
40
60
80
100
120
140
160
$p_{T,low}$ (GeV)
Counts / 5 GeV
1
10
10^2
10^3
$p_{T,high}^{OS}$
$p_{T,high}^{LS}$
$p_{T,high}^{OS-LS}$
0
20
40
60
80
100
120
140
160
$p_{T,high}$ (GeV)

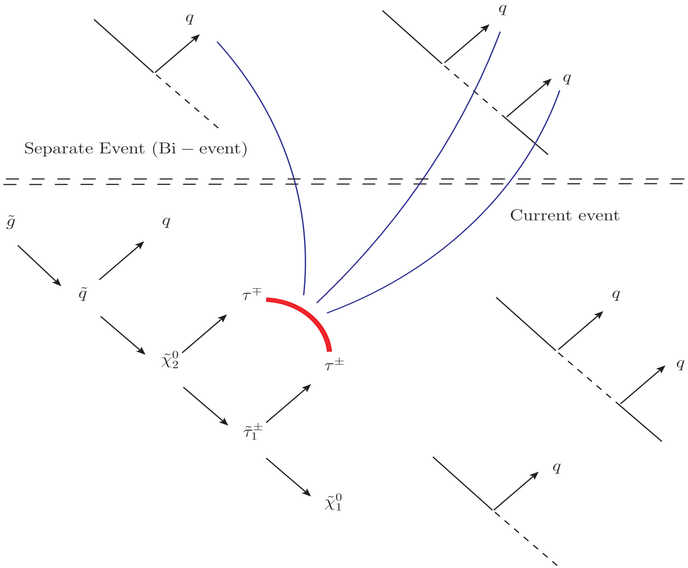
$M_{j\tau\tau}$ observable

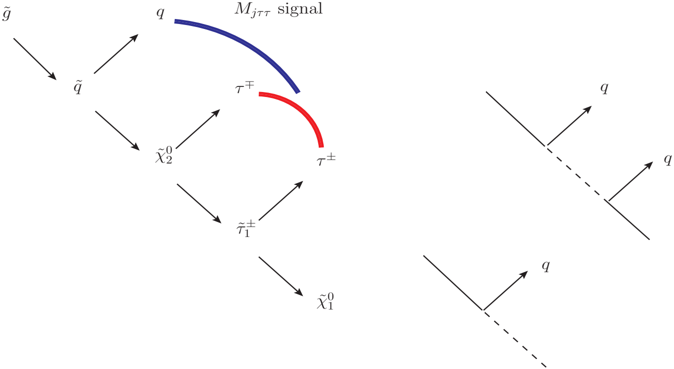


Scourge: combinatoric background

Solution: Bi-Event Subtraction Technique (BEST) Dutta, Kamon, et. al. (2010)


$\tilde{g}$
q
$M_{j\tau\tau}$ signal
$\tilde{q}$
$\tau^{\mp}$
Background
q
$\tilde{\chi}_2^0$
$\tau^{\pm}$
q
$\tilde{\tau}_1^{\pm}$
q
$\tilde{\chi}_1^0$


q
q
q
Separate Event (Bi – event)
Current event
$\tilde{g}$
q
$\tilde{q}$
$\tau^{\mp}$
q
$\tilde{\chi}_2^0$
$\tau^{\pm}$
q
$\tilde{\tau}_1^{\pm}$
q
$\tilde{\chi}_1^0$


$\tilde{g}$
q
$M_{j\tau\tau}$ signal
$\tilde{q}$
$\tau^{\mp}$
$\tilde{\chi}_2^0$
$\tau^{\pm}$
$\tilde{\tau}_1^{\pm}$
$\tilde{\chi}_1^0$
q
q
q

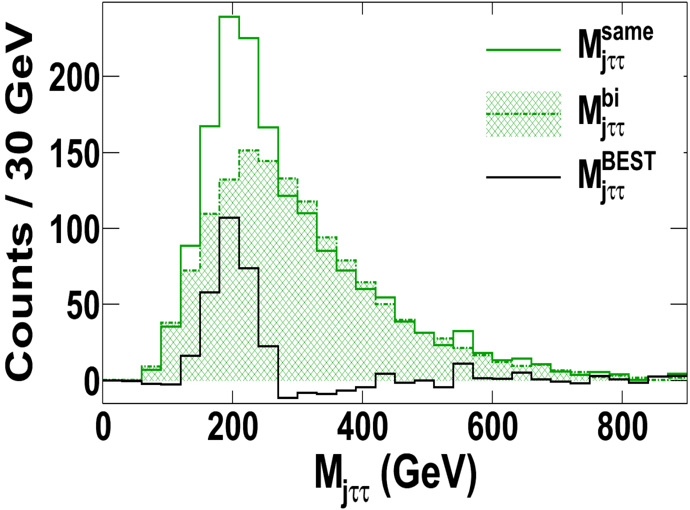


Figure: The result for the endpoint is $269.09 \pm 3.18(\text{Stat.})$ GeV.

4 jets + $\not{E}_T$

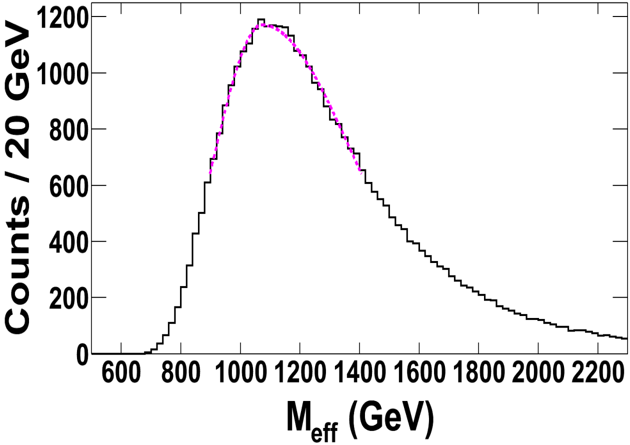
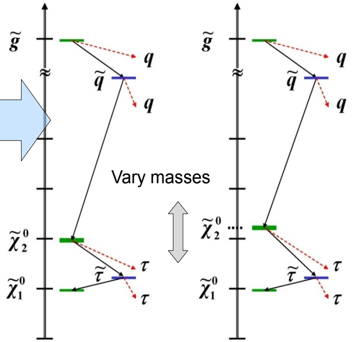


Figure: Distribution of M_{eff} at a stop coannihilation benchmark point. The distribution is fitted with a Gaussian function to find the peak. The value of the $M_{\mathrm{eff}}^{\mathrm{peak}}$ observable is $1073.01 \pm 8.72(\mathrm{Stat.})$ GeV.

All observables solved.

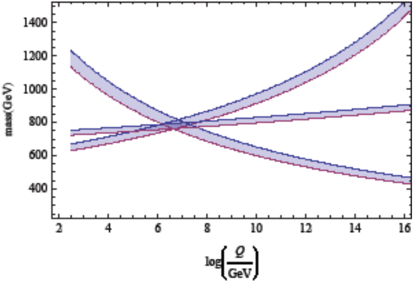
$$
\begin{aligned}
M^{\mathrm{end}}_{\tau\tau} &= M^{\mathrm{end}}_{\tau\tau}(m_{\tilde{\chi}^0_2}, m_{\tilde{\tau}}, m_{\tilde{\chi}^0_1}) \\
M^{\mathrm{end}}_{j\tau\tau} &= M^{\mathrm{end}}_{j\tau\tau}(m_{\tilde{q}_L}, m_{\tilde{\chi}^0_2}, m_{\tilde{\chi}^0_1}) \\
slope(p_{T,\mathrm{AM}}) &= p_{T,\mathrm{AM}}(m_{\tilde{\chi}^0_2}, m_{\tilde{\chi}^0_1}) \\
slope(p_{T,\mathrm{diff}}) &= p_{T,\mathrm{diff}}(m_{\tilde{\tau}}, m_{\tilde{\chi}^0_2}, m_{\tilde{\chi}^0_1}) \\
M^{\mathrm{peak}}_{\mathrm{eff}} &= M^{\mathrm{peak}}_{\mathrm{eff}}(m_{\tilde{q}_L}, m_{\tilde{g}})
\end{aligned}
$$

Get dependence around benchmark



Solves

$\tilde{g}, \tilde{\chi}^0_2, \tilde{\chi}^0_1, \tilde{\tau}_1, \tilde{q}$



Having solved the masses, can you track back to the UV parameters α, $m_{3/2}$, etc.?

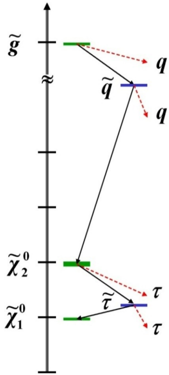
Clearly, the map back to a specific model is not unique

Can do fitting studies - scan over parameter space until you reproduce the spectrum you solved.

We used the Nelder Mead method, a nonlinear optimization technique

Determined the parameters, statistical uncertainties $5-15\%$.

Where we are



Construct and measure kinematical variables in a α – ***NonUniversal*** benchmark model.

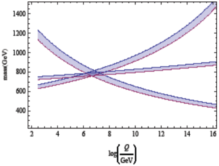
Reconstruct SM particles: top, W

Reconstruct SUSY masses from kinematic observables

Bi-Event Subtraction Technique(BEST)

a. Gauginos: $\tilde{g}, \tilde{\chi}_2^0, \tilde{\chi}_1^0$
b. $\tilde{q}$
c. Third generation slepton and squarks: $\tilde{\tau}, \tilde{t}, \tilde{b}$.

Mediation Scheme



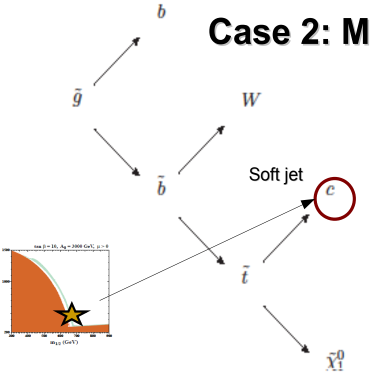
Mirage Mediation Established

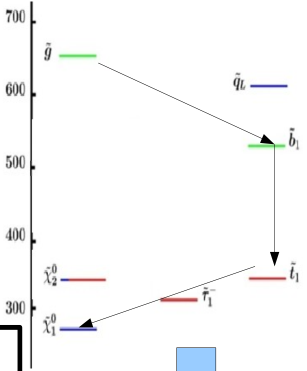
Relic Density

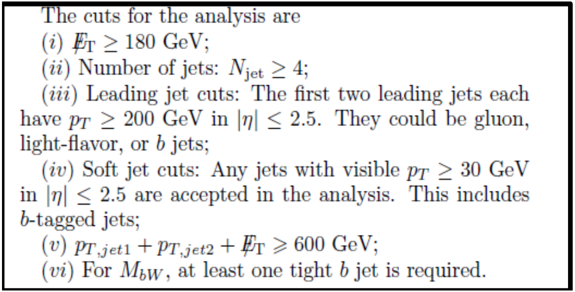
Satisfied to 31% accuracy

Next

Case 2: MET + Jets + b + W







The cuts for the analysis are

(*i*) $\not{E}_T \geq 180$ GeV;

(*ii*) Number of jets: $N_{\text{jet}} \geq 4$;

(*iii*) Leading jet cuts: The first two leading jets each have $p_T \geq 200$ GeV in $|\eta| \leq 2.5$. They could be gluon, light-flavor, or b jets;

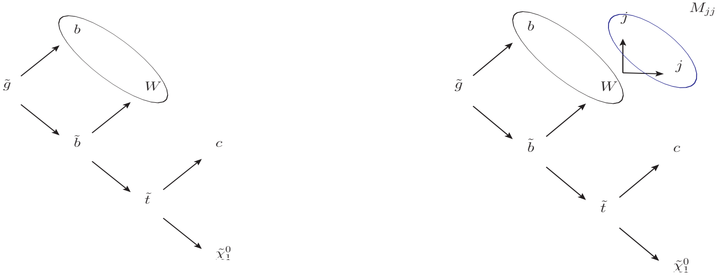
(*iv*) Soft jet cuts: Any jets with visible $p_T \geq 30$ GeV in $|\eta| \leq 2.5$ are accepted in the analysis. This includes b-tagged jets;

(*v*) $p_{T,jet1} + p_{T,jet2} + \not{E}_T \geqslant 600$ GeV;

(*vi*) For M_{bW}, at least one tight b jet is required.

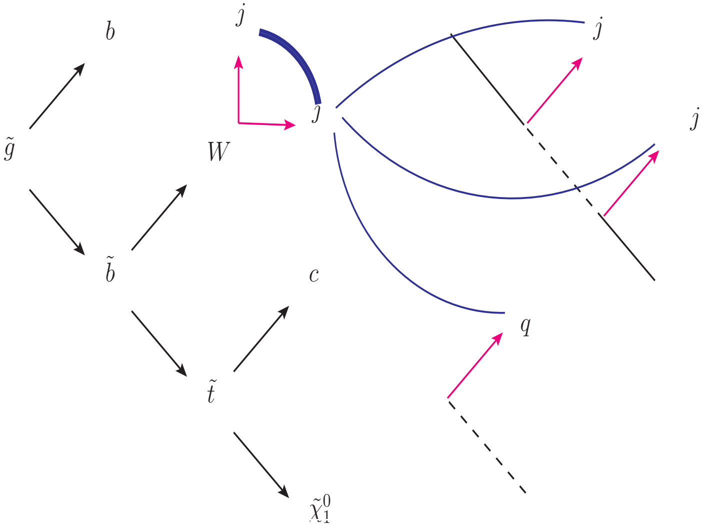
Observables

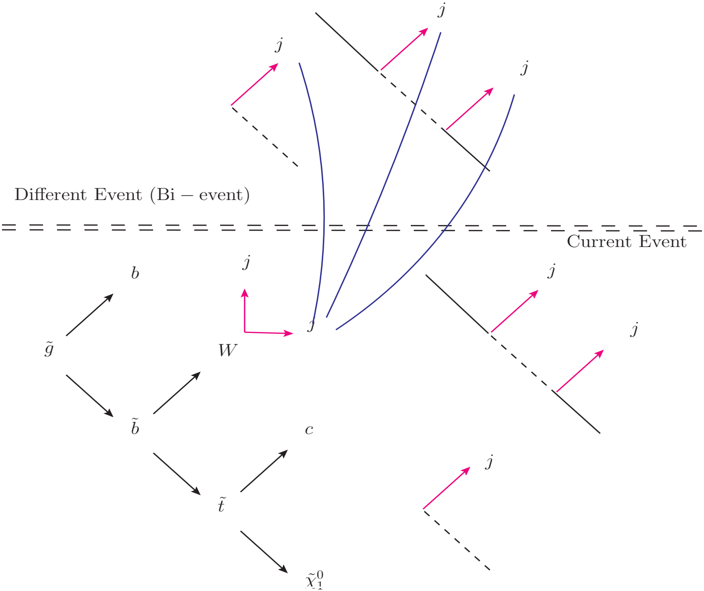
M_{jW} **M_{bW}**


$\tilde{g}$
b
W
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$
$\tilde{g}$
b
W
M_{jj}
j
j
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$

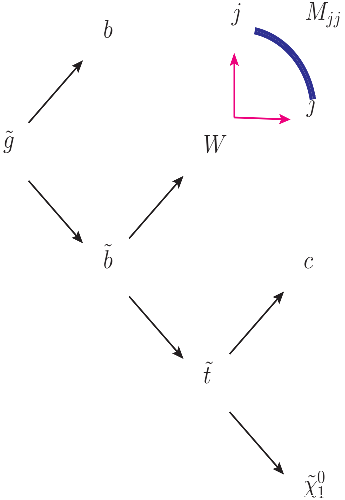
Reconstruction of W

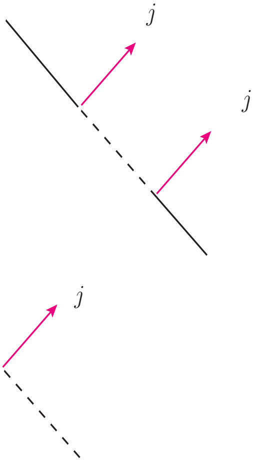
- W appears in the detector as two jets whose invariant mass falls in the W mass window (65 GeV $\leq M_{jj} \leq$ 90 GeV).
- Choose soft jet pairs (from the third leading jet and below) which are not b-tagged, with $0.4 \leq \Delta R \leq 1.5$.
- Jets put into two categories: (a) manifestly in the W window (b) fall within the sideband window (40 GeV $\leq M_{jj} \leq$ 55 GeV or 100 GeV $\leq M_{jj} \leq$ 115 GeV).
- BEST is then performed for the two categories.
- Sideband subtraction is performed to obtain the W mass.


$\tilde{g}$
b
$\tilde{b}$
W
j
j
c
$\tilde{t}$
$\tilde{\chi}_1^0$
j
j
q

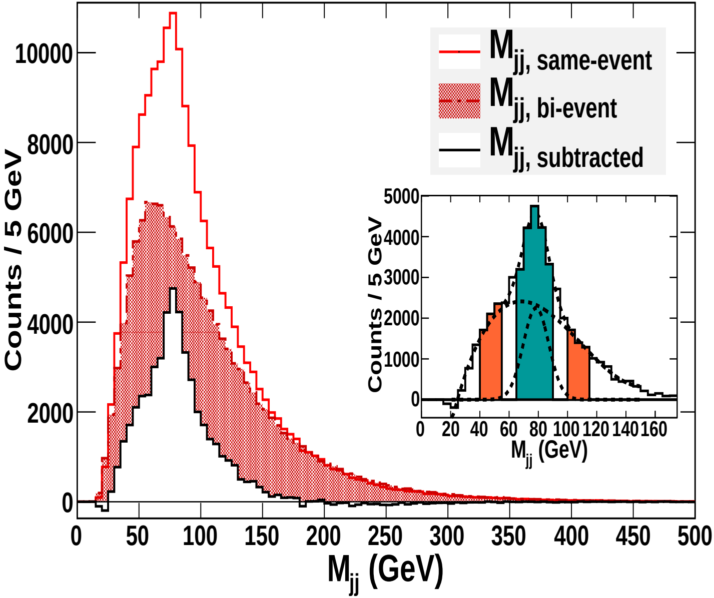


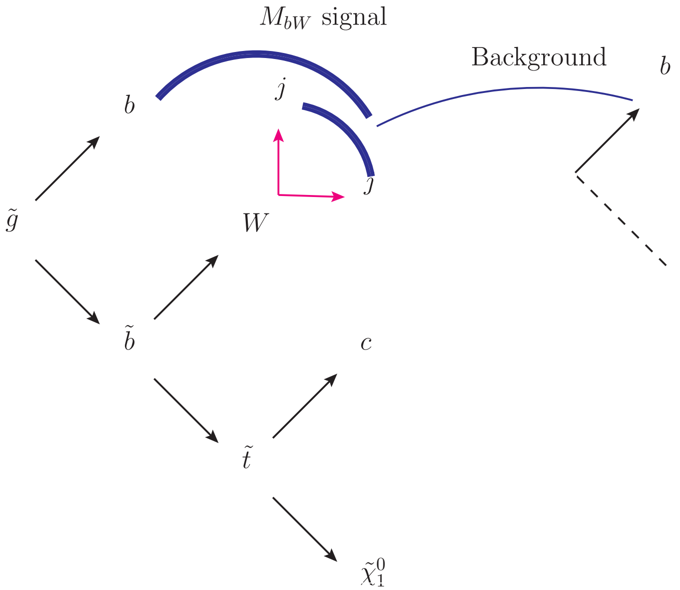
j
j
j
Different Event (Bi − event)
Current Event
b
j
j
$\tilde{g}$
W
j
j
$\tilde{b}$
c
j
$\tilde{t}$
$\tilde{\chi}_1^0$

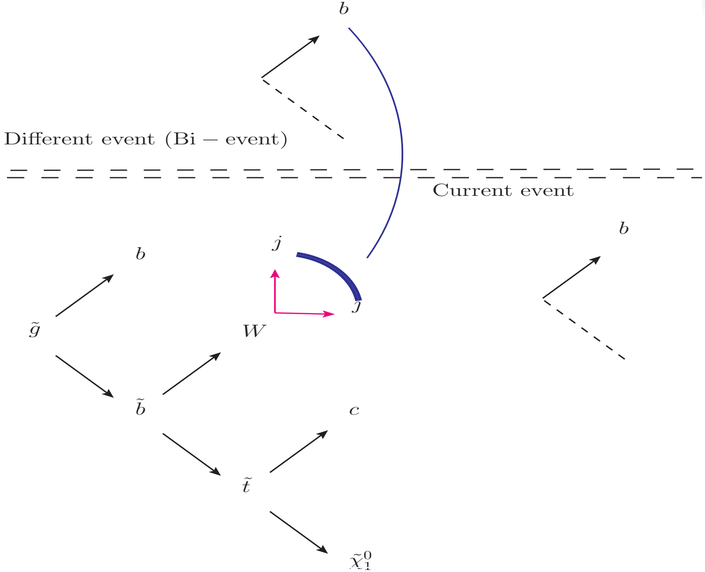

j
M_{jj}
b
j
$\tilde{g}$
W
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$

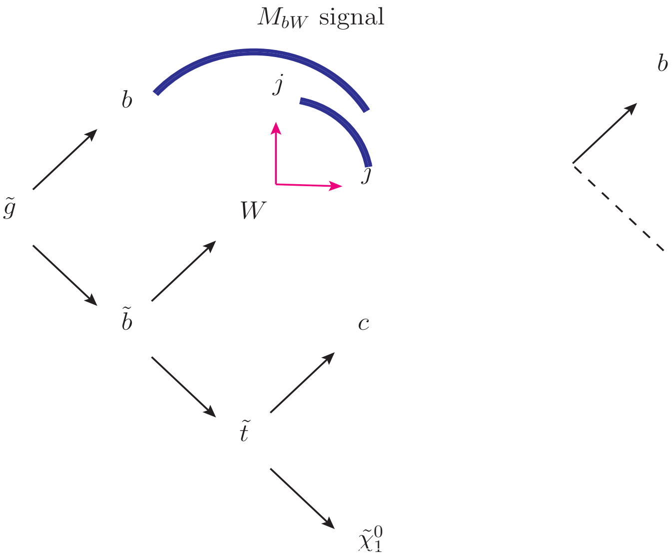

j
j
j

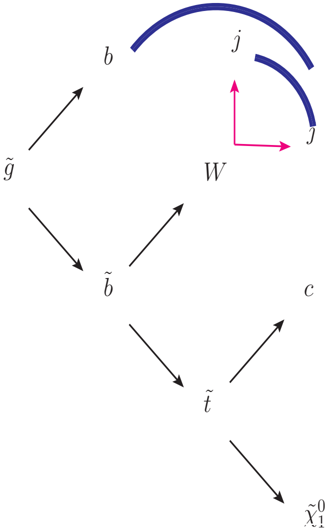
W reconstruction



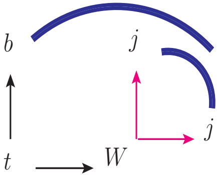
M_{bW} signal
Background
b
j
b
j
$\tilde{g}$
W
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$


b
Different event (Bi − event)
Current event
b
j
b
j
$\tilde{g}$
W
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$


M_{bW} signal
b
j
j
$\tilde{g}$
W
$\tilde{b}$
c
$\tilde{t}$
$\tilde{\chi}_1^0$
b

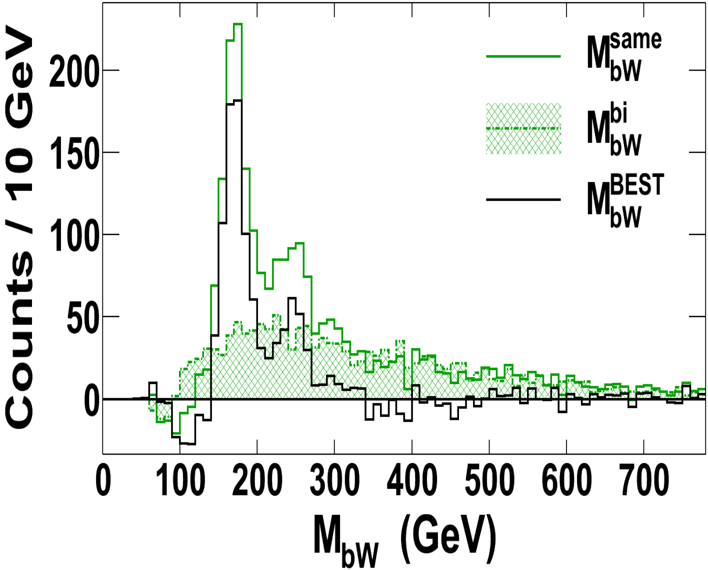


M_{bW} signal



M_{bW} signal from top

Top peak and M_{bW} endpoint



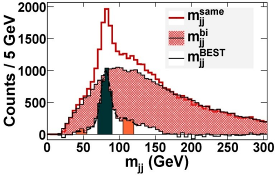
M_{jW} may be obtained similarly. Reconstructed W is paired with a non b-tagged soft jet, whose rank is three or lower. This is because we are in the stop coannihilation region.

Can use M_{bW} and M_{jW} to solve for the $\tilde{t}$ and $\tilde{b}$ masses.

M_{bW} and M_{jW}: Statistical uncertainties 0.2% – 1.4%

$\tilde{t}$ and $\tilde{b}$ masses: Statistical uncertainties 2.5% – 11.3%

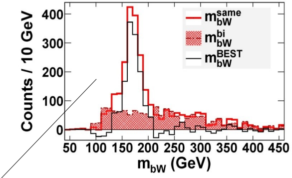
BEST



W reconstruction

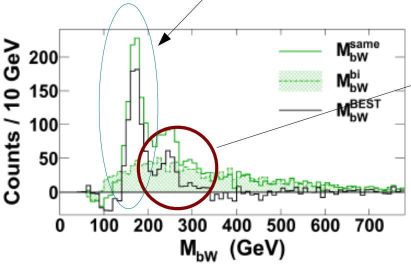
BEST in ttbar

arXiv:1104.2508, PLB



Top reconstruction

BEST in SUSY



New physics

We used it to solve third generation superpartners

Future directions

Use techniques of reconstructing third generation squark masses to study direct stop production (in progress)

Extend study of mass patterns and mediation schemes to Higgsino dominated regions

Many other applications of BEST (Abram Krislock, 6 pm)