BEST
Bi-Event Subtraction Technique

Teruki Kamon

Mitchell Institute for Fundamental Physics and Astronomy
Texas A&M University
&
Department of Physics
Kyungpook National University

SFB/HEP Seminar
University of Hamburg / DESY
August 5, 2011
Introduction
Why am I here?

Supersymmetry at the Large Hadron Collider

Project Leaders
Peter Schleper (e-mail | group homepage)

Abstract
The project focuses on the interconnection between models for Supersymmetry breaking and corresponding experimental signatures at the LHC. The key ingredient is the investigation of experimental observables which are inherently sensitive to supersymmetric parameters, but which at the same time have a predictable background from QCD and other Standard Model processes. Likelihood techniques are employed making use of kinematic fits and matrix element methods to identify decay chains and combinatoric hypotheses with the aim to determine masses and decay properties of supersymmetric particles.

Researchers
Christian Autermann
Jochen Bartels
Isabelle Meier-Palmmann

Publications
List of publications (also available as biblatex-file)

Texas-style hunting
TAMU Phenomenology Projects

http://faculty.physics.tamu.edu/kamon/research/TEVpheno/
http://faculty.physics.tamu.edu/kamon/research/ILCpheno/
http://faculty.physics.tamu.edu/kamon/research/LHCpheno/


“Supersymmetry Parameter Analysis: SPA Convention and Project”

hep-ph/1104.2508 (“BEST” at LHC),
conditionally accepted for publication by PLB.
Texas A&M Univ. (TAMU)

Mitchell Institute for Fundamental Physics and Astronomy

WCU Program

SFB Program

Teruki Kamon

BEST
I feel like a Backpacker ...

Mitchell Institute for Fundamental Physics and Astronomy

Teruki Kamon

WCU Program

SFB Program

BEST

De-evolution
# Dept. of Physics and Astronomy

93 Faculty, Adjunct Faculty, Emeritus & Lecturers

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
<th>Phone</th>
<th>Email</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teruki Kamon</td>
<td><a href="mailto:tkamon@physics.tamu.edu">tkamon@physics.tamu.edu</a></td>
<td>409-7740</td>
<td><a href="mailto:tkamon@physics.tamu.edu">tkamon@physics.tamu.edu</a></td>
<td>409-7740</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BEST**

- Teruki Kamon
- BEST

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**For more information:**

- Dept. of Physics and Astronomy
- 93 Faculty, Adjunct Faculty, Emeritus & Lecturers
- Email: tkamon@physics.tamu.edu
- Phone: 409-7740

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**Notes:**

- This is a contact list for the Dept. of Physics and Astronomy.
- It includes 93 faculty members, adjunct faculty, emeritus, and lecturers.
- The list provides their names, email addresses, and phone numbers.
- Contact information is available for each entry.

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**Additional Information:**

- This list is likely used for academic and professional communication within the department.
- It may be used for scheduling meetings, sending newsletters, or disseminating departmental updates.

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**Sample Entry:**

- **Name:** Teruki Kamon
- **Email:** tkamon@physics.tamu.edu
- **Phone:** 409-7740
- **Email:** tkamon@physics.tamu.edu
- **Phone:** 409-7740

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**Use Case:**

- This list can be used by faculty, students, and staff to contact their counterparts within the department.
- It facilitates interdisciplinary collaboration and communication.

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**Further Actions:**

- Review the contact list periodically for any updates.
- Use the listed contact information for various departmental activities.
- Ensure the accuracy and currency of the contact information.

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**Technical Details:**

- The contact list is formatted in a table for easy reading and navigation.
- Each entry includes essential contact information for efficient communication.
- The list is presented in a logical and organized manner.

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**Questions:**

- How often is this contact list updated?
- How can one request to be added to or removed from the list?
Mitchell Institute for Fundamental Physics and Astronomy

Department of Physics and Astronomy

Mitchell Institute for Fundamental Physics and Astronomy
Interconnection

<table>
<thead>
<tr>
<th>LHC</th>
<th>SuperCDMS</th>
<th>AMS-2</th>
<th>GMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>USA</td>
<td>ISS</td>
<td>Chile</td>
</tr>
<tr>
<td>pp collisions</td>
<td>DM-proton elastic collisions</td>
<td>DM annihilation</td>
<td>Dark matter &amp; Dark energy, Black hole, Galaxy formation</td>
</tr>
<tr>
<td>7 TeV → 14 TeV</td>
<td></td>
<td></td>
<td>24.5-meter primary mirror</td>
</tr>
</tbody>
</table>

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BEST
Interconnection between Particle Physics and Cosmology

About “PPC” Cube

PPC 2011 at CERN, June 14-18
PPC 2012 at ???
[Seminar]
Why am I here?

We want to reconstruct $W \rightarrow jj$ in all hadronic mode of SUSY events ...

Why?
[Non-universality Case]

Is a cosmological measurement possible?

1) Start with over-abundance region in SSC-like mSUGRA (e.g., $m_{1/2} = 500$, $m_0 = 360$, $m_{Hu} = 360$)

2) Reduce Higgs coupling parameter, $\mu$, by increasing $m_{Hu}$ (e.g., $m_{1/2} = 500$, $m_0 = 360$, $m_{Hu} = 732$)
   → Extra contributions to $\Omega h^2$
   → More annihilation (less abundance)
   → Normal values of $\Omega h^2$

3) Find smoking gun signals

4) Technique to calculate $\Omega h^2$

\[
\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left( n^2 - n_{eq}^2 \right)
\]
$m_{1/2} = 500, \ m_0 = 360, \ tan\beta = 40, \ m_{\text{top}} = 175$

$m_{\text{Hu}} = 732, \ m_{\text{Hd}} = 732$

- $\tilde{q}_L \rightarrow q'$
- $\tilde{q}_L \rightarrow \tilde{\chi}_1^\pm \rightarrow W^\pm$
- $\tilde{t}_1 \rightarrow b$
- $\tilde{t}_1 \rightarrow \tilde{\chi}_1^\pm \rightarrow W^\pm$
- $\tilde{\chi}_2^\pm \rightarrow W^\pm$
- $\tilde{\chi}_2^0 \rightarrow \chi_{2,3} \rightarrow \tau$
- $\tilde{\tau}_1 \rightarrow \tau$
- $\tilde{\chi}_1^0$
$M(\tilde{g}, \tilde{t}_1, \tilde{b}_1) \geq 2$ with $p_T > 20$ GeV

$N(J) > 2$ with $E_T > 200$ GeV;
$E_T^{miss} + E_T^{J_1} + E_T^{J_2} > 600$ GeV

$E_T^{miss} > 180$ GeV;
$N(J) > 2$ with $E_T > 200$ GeV;
$E_T^{miss} + E_T^{J_1} + E_T^{J_2} > 600$ GeV

A clear peak at the W mass, but can we see the BG shape?
## Data-driven $M(jj)$ Extraction

<table>
<thead>
<tr>
<th>Event</th>
<th>Jets</th>
<th>$M(jj)$</th>
<th>$M(jj)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1a, 1b, 1c</td>
<td>$M(2a, 1a), M(2a, 1b), M(2a, 1c)$</td>
<td>$M(2a, 2b)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M(2b, 1a), M(2b, 1b), M(2b, 1c)$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2a, 2b</td>
<td>$M(3a, 2a), M(3a, 2b), M(3b, 2a), M(3b, 2b), M(3c, 2a), M(3c, 2b), M(3d, 2a), M(3d, 2b)$</td>
<td>$M(3a, 3b), M(3a, 3c), M(3a, 3d), M(3b, 3c), M(3b, 3d), M(3c, 3d)$</td>
</tr>
<tr>
<td>3</td>
<td>3a, 3b, 3c, 3d</td>
<td>$M(3a, 2a), M(3a, 2b), M(3b, 2a), M(3b, 2b), M(3c, 2a), M(3c, 2b), M(3d, 2a), M(3d, 2b)$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>For each $j_i$ in Event $X$, $M(j_i, j_k)$ is calculated with $j_k$ in Event $X-1$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $M(jj)$ > $nnn$ GeV for normalization

**May 5, 2009**

Extracting W’s in Jets + MET
For each $j_i$ in Event $X$, $M(j_i, j_k)$ is calculated with $j_k$ in Event $X-1$.

The method seems to be reasonable for SUSY ...
Start with “JW”

\[ E_T^{\text{miss}} > 180 \text{ GeV}; \]
\[ N(J) \geq 2 \text{ with } E_T > 200 \text{ GeV}; \]
\[ E_T^{\text{miss}} + E_T^{J1} + E_T^{J2} > 600 \text{ GeV} \]

&

\[ N(j) \geq 2 \text{ with } p_T > 30 \text{ GeV} \]
\[ N(b) \geq 0 \text{ with } p_T > 30 \text{ GeV} \]
\[ N(\tau) = 0 \text{ with } p_T > 20 \text{ GeV} \]

&

Jet Mix to extract W’s

Note there might be b-jets and/or \( \tau \)-jets in event, but not counted as “J” nor “j”.

\[ \tilde{q}_L \rightarrow q' \rightarrow q \rightarrow W^\pm \rightarrow \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \]

\[ \tilde{q}_L \rightarrow q' \rightarrow q \rightarrow W^\pm \rightarrow \tilde{\chi}_4^0 \rightarrow \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \]

Ture = \textcolor{red}{714 \text{ GeV} (\chi_1^{+/-})}

500-360-732

[Vetoing events with any \( \tau \)’s with \( p_T > 20 \text{ GeV} \)]

Endpoint = \textcolor{red}{774 \text{ GeV}}

Ture = \textcolor{red}{739 \text{ GeV} (\chi_4^0)}

M_{JW}

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Non-minimal SUGRA
### $M_{MW}$, shifting with $m_{Hu}$

<table>
<thead>
<tr>
<th>$m_{1/2}$-m_0-m_{Hu}</th>
<th>500-360-732</th>
<th>500-360-694</th>
<th>500-360-582</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega h^2$</td>
<td>0.110</td>
<td>0.211</td>
<td>0.462</td>
</tr>
<tr>
<td>$M_{MW}(q \rightarrow \chi_1^+ \rightarrow W + \chi_1^0)$</td>
<td>714 (Br=0.20*0.42)</td>
<td>813 (0.31*0.48)</td>
<td>867 (0.57*0.31)</td>
</tr>
<tr>
<td>$M_{MW}(q \rightarrow \chi_2^+ \rightarrow W + \chi_2^0 \rightarrow \nu/h)$</td>
<td>727 (0.46*0.92)</td>
<td>650 (0.35*0.54)</td>
<td>652 (0.087*0.30)</td>
</tr>
<tr>
<td>$M_{MW}(q \rightarrow \chi_2^+ \rightarrow W + \chi_3^0 \rightarrow Z)$</td>
<td>652 (0.46<em>0.18</em>0.46)</td>
<td>NAN (0.35*0.00)</td>
<td>NAN (0.087*0.00)</td>
</tr>
<tr>
<td>$M_{MW}(q \rightarrow \chi_4^0 \rightarrow W + \chi_1^+)$</td>
<td>739 (0.24*0.74)</td>
<td>654 (0.19*0.85)</td>
<td>650 (0.053*0.56)</td>
</tr>
</tbody>
</table>

**gluino**

- $u_L, u_R$
  - 1113, 1078
  - 1111, 1077
  - 1111, 1076

- $b_1, b_2 ; t_1, t_2$
  - 946, 989; 781, 992
  - 948, 993; 787, 996
  - 954, 1005; 787, 996

- $\chi_1^+, \chi_2^+$
  - 291, 427
  - 329, 442
  - 376, 511

- $\chi_1^0 \sim \chi_4^0$
  - 199, 293, 316, 432
  - 202, 328, 368, 445
  - 205, 375, 482, 511
BEST
Bi-Event Subtraction Technique
(hep-ph/1104.2508)
B. Dutta, T. Kamon, N. Kolev, A. Krislock

\[ pp \rightarrow t \bar{t} + j \rightarrow (W^+ b) (W^- \bar{b}) + j \]
\[ \rightarrow jj \rightarrow l^- \nu \]

BEST: "jet" mixing from two different events (TTbar, TTbar), (TTbar,W), (W,W)

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BEST in TTbar

2 fb$^{-1}$ at 7 TeV

Abram using PGS4

Without BEST

With BEST

Counts / 10 GeV

\[ m_{bW} \text{ Sideband only} \]

\[ m_{bW}^{\text{BEST + Sideband}} \]

Future BEST: SUSY with W’s

Counts / 50 GeV

Counts / 50 GeV


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[Top in CMS]
Table 1: Event yields and relative contribution of the different processes after the final selection step for an integrated luminosity of 35.9 ± 1.4 \( \text{pb}^{-1} \). The uncertainties account for the finite statistics of the simulation samples and for the uncertainty on the luminosity but not for cross-section uncertainties. The \( t\bar{t} \) and single top samples were generated using \( m_t = 172.5 \text{ GeV} \).

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Total expected</th>
<th>( t\bar{t} )</th>
<th>Single-Top</th>
<th>( W \rightarrow l\nu )</th>
<th>( Z/\gamma^* \rightarrow l^+l^- )</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events</td>
<td>396</td>
<td>358 ± 37</td>
<td>209 ± 33</td>
<td>12 ± 1</td>
<td>116 ± 9</td>
<td>12 ± 1</td>
<td>9.0 ± 1.0</td>
</tr>
<tr>
<td>Fraction</td>
<td>-</td>
<td>100%</td>
<td>59%</td>
<td>3%</td>
<td>32%</td>
<td>3%</td>
<td>2%</td>
</tr>
</tbody>
</table>

|                | Events  | 345 ± 32       | 169 ± 27       | 9.5 ± 0.6   | 99 ± 7         | 16 ± 1         | 52 ± 8   |
| Fraction       | -       | 100%           | 50%            | 3%          | 28%            | 4%            | 16%   |

\[ \frac{N_S}{\sqrt{N_S + N_B}} = 13 \text{ (for } e \text{ & } \mu) \]

assumed for each of the jet-parton association energies [12].

To select events in the muon+jets channel, we require exactly one isolated muon \( (p_T > 20 \text{ GeV}, |\eta| < 2.1) \) and at least four PF jets \( (p_T > 30 \text{ GeV}, |\eta| < 2.4) \). For the electron+jets channel, we require exactly one isolated electron \( (p_T > 30 \text{ GeV}, |\eta| < 2.5) \). The jet requirements are the same as for the muon+jets channel.
Figure 2: The top quark mass before (top) and after (middle) the kinematic fit, and the estimated uncertainty on the fitted top mass (bottom), for the jet assignment that yields the lowest $\chi^2$ in the electron+jets (left) and muon+jets (right) channel. In addition to the reference event selection, we require at least one solution with $\chi^2 < 10$. The simulation is normalized to the number of events in data. The QCD contribution is modeled using events from data. Statistical uncertainties on the model prediction, while not always negligible, are not shown.

Teruki Kamon
N(isolated lepton) = 1
N(jets) ≥ 4 [N(b-jets) = 2]
No MET cut

**Fig. 2**

N(top) = 78 (e+µ)

**M(top) and M(W) using M3 and M2**

Figure 4: M3 (top left), M2 (top right) and ΔM_{32} (bottom) distributions for the muon+jets channel in data compared to the MC predictions, using the central sample with $m_t = 172.5$ GeV and JES = 1.
[Top/BEST in CMS]

Will Flanagan (TAMU)
Kalanand Mishra (FNAL)
Tai Sakuma (TAMU)
TTbar +Jets in MadGraph

Tai Sakuma

N(isolated muon, pT > 20) ≥ 1
N(jets, pT >30) ≥ 3 [N(b-jets, pT >30) ≥ 1]
MET > 20
ΔR(two jets)>0.4

3,701,947 events

M(jj) same/M(jj) bi

a) Hadronization ... simulated by Pythia6 as well as the underlying events with the tune Z2.
b) Pile-up events ... simulated comparable to the current LHC run
c) CMS detector response ... simulated by a GEANT4 based program.

W’s

bi ... underestimating combinatorial M(jj) shape

M(jj)
Phase Space Matching

\begin{equation}
W+2j
\end{equation}

Teruki Kamon
Choice of Phase Space

$p_T, \eta, \phi, \text{MET}, N_j, H_T ...$
[Wjj/BEST in CMS]

Dan Green (FNAL)
We want to reconstruct $W\rightarrow jj$ in all hadronic mode of SUSY events

... 

Can we generalize?