AEACUS & RHADAMANTHUS • MC4BSM • FNAL • May 18-20, 2015 • Joel W. Walker • SHSU

“ Then spake Zeus: … ‘The cases are now indeed judged ill and it is because … many … who have wicked souls are clad in fair bodies and ancestry and wealth, and … the judges are confounded …, having their own soul muffled in the veil of eyes and ears and the whole body. …They must be stripped bare of all those things …, beholding with very soul the very soul of each immediately. … [I] have appointed sons of my own to be judges; two from Asia, **Minos** and **Rhadamanthus**, and one from Europe, **Aeacus**. These … shall give judgement in the meadow at the dividing of the road, whence are the two ways leading, one to the Isles of the Blest …, and the other to Tartaros.’ ”

– Plato, *Gorgias* (trans. Lamb)

Cutting with

# AEACuS

(Algorithmic Event Arbiter and CUt Selector)

and Plotting with

# RHADAMANTHUS

(Recursively Heuristic Analysis, Display, And MANipulation: The Histogram Utility Suite)

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Sample plots from 1412.5986 (Dutta, Li, Maxin, Nanopoulos, Sinha, & JWW)
as well as work in progress with Dutta, Gao

# Typical Process Flow

- **MadGraph (+ Others):** Matrix Element Generation
- **MadEvent (+ Others):** Hard Scattering Simulation
- **Pythia (+ Others):** Showering and Hadronization
- **DELPHES/PGS:** Detector Simulation
  (DEtector Level PHysics Emulation Software)
- **AEACUS:** Statistics Computation & Cut Selection
- **RHADAMANTHUS:** Graphical Event Analysis

# Package Notes

- AEACuS and RHADAMANTHUS are written in Perl
- All Perl scripts are self contained - no libraries or installation
- RHADAMANTHUS calls the public Python MatPlotLib library
- Control is provided by simple reusable card files
- Directory structure is: "./Events" for input .lhco event files, "./Cards" for input cards, "./Cuts" & "./Plots" for output
- Cut with AEACuS: "`./aeacus.pl card_name event_name cross_section`"
- Plot with RHADAMANTHUS: "`./rhadamanthus.pl card_name`"

# AEACuS (Goals)

- Automate model comparison against LHC data
- Replicate most current search strategies for new physics
- Embody lightweight, consumer-level, standalone design
- Decouple specific usage from general functionality
- Render event cut strategies compactly & unambiguously
- Merge power & flexibility with uniformity & simplicity
- Decouple phenomenology from software maintenance

# AEACUS (Function)

- Reads from standardized LHCO format input
- Filters kinematics, geometry, isolation, charge & flavor
- Dilepton pair assembly (by like/unlike charge & flavor)
- Jet clustering (KT, C/A, Anti-KT) & Hemispheres (Lund, etc.)
- Missing $E_T$, scalar $H_T$, effective & invariant mass, ratios & products
- Transverse mass, 1- & 2-step asymmetric $M_{T2}$ (with combinatorics), Tri-jet mass, $\alpha_T$, Razor & $\alpha_R$, Dilepton Z-balance, Lepton W-projection, $\Delta\phi$ (& biased $\Delta\phi^*$), Shape Variables (thrust & minor, spheri[o]city, F)

# Cut Card Example

```
*** Object Reconstruction ****
        # ALL Jets
OBJ_JET_000 = PTM:30, PRM:[0.0,5.0], CUT:0
        # LEAD Jet
OBJ_JET_001 = SRC:+000, PRM:[0.0,2.5],
        CUT:[1,UNDEF,-1], OUT:PTM_001, ANY:0
        # SECOND Jet
OBJ_JET_002 = SRC:[+000,-001], PRM:[0.0,2.5],
        CUT:[1,UNDEF,-1], OUT:PTM_002, ANY:0
        # B-Tagged Jets
OBJ_JET_003 = SRC:+000, PRM:[0.0,2.5], HFT:0.5, CUT:0
        # Non-B Jets
OBJ_JET_004 = SRC:[+000,-003], PRM:[0.0,2.5], CUT:0
        # B-TAGS in Jets 1,2
OBJ_JET_005 = SRC:[+001,+002], HFT:0.5, CUT:0
        # Non-B Sub-Leading Jets
OBJ_JET_006 = SRC:[+000,-001,-002,-003],
        PRM:[0.0,2.5], CUT:0
        # 1 B-Tags in Z/Higgs Window
OBJ_JET_007 = SRC:+003, EFF:[WIN,92,20,126,20,1], CUT:0
        # 2 B-Tags in Z/Higgs Window
OBJ_JET_008 = SRC:+003, EFF:[WIN,92,20,126,20,2], CUT:0
        # 2 B-Tags in Higgs Window
OBJ_JET_009 = SRC:+003, EFF:[WIN,126,20,2], CUT:0
        # Single Track Jets
OBJ_JET_010 = SRC:+000, TRK:[1,1], CUT:0
        # Leading or B-Tagged Jets (No Output)
OBJ_JET_011 = SRC:[+001,+002,+003]
        # Nearest B-Tag Object Pair to Higgs Window
OBJ_JET_012 = SRC:+003, EFF:[OIM,126,UNDEF,-1]
        # Further B-Tag Object Pair from Higgs Window
OBJ_JET_013 = SRC:[+003,-012], EFF:[OIM,126,UNDEF,-1]
        # ALL Leptons
OBJ_LEP_000 = PTM:10, PRM:[0.0,2.5]
        # Light Soft Leptons
OBJ_LEP_001 = SRC:+000, EMT:-3, SDR:[0.3,UNDEF,1], CUT:0
        # Soft Taus
OBJ_LEP_002 = SRC:+000, EMT:+3, CUT:0
        # Light Hard Leptons
OBJ_LEP_003 = SRC:+001, PTM:20, CUT:0
        # Hard Taus
OBJ_LEP_004 = SRC:+002, PTM:20, CUT:0
        # 1 Lepton in Z Window
OBJ_LEP_005 = SRC:+001, EFF:[WIN,92,5], CUT:0
```

```
****** Event Selection *******
        # MET-Jet Delta Phi (Leading+B-Tags)
EVT_MDP_001 = MET:000, JET:011, OUT:1
        # MET Significance MET / sqrt( HT )
EVT_RHR_001 = NUM:000, DEN:000, OUT:1
        # Invariant Mass of Nearest Higgs Window Pair
EVT_OIM_001 = JET:012, OUT:1
        # Invariant Mass of Further Higgs Window Pair
EVT_OIM_002 = JET:013, OUT:1
        # Delta-R Separation of Nearest Higgs Window Pair
EVT_ODR_001 = JET:012, OUT:1
        # Delta-R Separation of Further Higgs Window Pair
EVT_ODR_002 = JET:013, OUT:1
****** Event Filtering *******
        # Category I: 4 Leptons, 0+ B-Jets
SRT_ESC_001 = KEY:LEP_001, CUT:4
SRT_ESC_002 = KEY:JET_003, CUT:0
SRT_CHN_001 = ESC:[+001,+002], OUT:"./Cuts/0b_4l"
        # Category II: 2-3 Leptons, 2+ B-Jets
SRT_ESC_003 = KEY:LEP_001, CUT:[2,3]
SRT_ESC_004 = KEY:JET_003, CUT:2
SRT_CHN_002 = ESC:[+003,+004], OUT:"./Cuts/2b_2l"
        # Category III: 0-1 Leptons, 4+ B-Jets
SRT_ESC_005 = KEY:LEP_001, CUT:[0,1]
SRT_ESC_006 = KEY:JET_003, CUT:4
SRT_CHN_003 = ESC:[+005,+006], OUT:"./Cuts/4b_0l"
```

# Cut Card Example

```
*** Object Reconstruction ****
            # ALL Jets
OBJ_JET_000 = PTM:30, PRM:[0.0,5.0], CUT:0
            # LEAD Jet
OBJ_JET_001 = SRC:+000, PRM:[0.0,2.5],
            CUT:[1,UNDEF,-1], OUT:PTM_001, ANY:0
            # SECOND Jet
OBJ_JET_002 = SRC:[+000,-001], PRM:[0.0,2.5],
            CUT:[1,UNDEF,-1], OUT:PTM_002, ANY:0
            # B-Tagged Jets
OBJ_JET_003 = SRC:+000, PRM:[0.0,2.5], HFT:0.5, CUT:0
            # Non-B Jets
OBJ_JET_004 = SRC:[+000,-003], PRM:[0.0,2.5], CUT:0
            # B-TAGS in Jets 1,2
OBJ_JET_005 = SRC:[+001,+002], HFT:0.5, CUT:0
            # Non-B Sub-Leading Jets
OBJ_JET_006 = SRC:[+000,-001,-002,-003],
            PRM:[0.0,2.5], CUT:0
            # 1 B-Tags in Z/Higgs Window
OBJ_JET_007 = SRC:+003, EFF:[WIN,92,20,126,20,1], CUT:0
            # 2 B-Tags in Z/Higgs Window
OBJ_JET_008 = SRC:+003, EFF:[WIN,92,20,126,20,2], CUT:0
            # 2 B-Tags in Higgs Window
OBJ_JET_009 = SRC:+003, EFF:[WIN,126,20,2], CUT:0
            # Single Track Jets
OBJ_JET_010 = SRC:+000, TRK:[1,1], CUT:0
            # Leading or B-Tagged Jets (No Output)
OBJ_JET_011 = SRC:[+001,+002,+003]
            # Nearest B-Tag Object Pair to Higgs Window
OBJ_JET_012 = SRC:+003, EFF:[OIM,126,UNDEF,-1]
            # Further B-Tag Object Pair from Higgs Window
OBJ_JET_013 = SRC:[+003,-012], EFF:[OIM,126,UNDEF,-1]
            # ALL Leptons
OBJ_LEP_000 = PTM:10, PRM:[0.0,2.5]
            # Light Soft Leptons
OBJ_LEP_001 = SRC:+000, EMT:-3, SDR:[0.3,UNDEF,1], CUT:0
            # Soft Taus
OBJ_LEP_002 = SRC:+000, EMT:+3, CUT:0
            # Light Hard Leptons
OBJ_LEP_003 = SRC:+001, PTM:20, CUT:0
            # Hard Taus
OBJ_LEP_004 = SRC:+002, PTM:20, CUT:0
            # 1 Lepton in Z Window
OBJ_LEP_005 = SRC:+001, EFF:[WIN,92,5], CUT:0
```

- **Define hierarchical groupings of Jets & Leptons sorted on kinematics**

```
            # Invariant Mass of Further Higgs Window Pair
EVT_OIM_002 = JET:013, OUT:1
            # Delta-R Separation of Nearest Higgs Window Pair
EVT_ODR_001 = JET:012, OUT:1
            # Delta-R Separation of Further Higgs Window Pair
EVT_ODR_002 = JET:013, OUT:1
****** Event Filtering *******
            # Category I: 4 Leptons, 0+ B-Jets
CUT_ESC_001 = KEY:LEP_001, CUT:4
CUT_ESC_002 = KEY:JET_003, CUT:0
CUT_CHN_001 = ESC:[+001,+002], OUT:"./Cuts/0b_4l"
            # Category II: 2-3 Leptons, 2+ B-Jets
CUT_ESC_003 = KEY:LEP_001, CUT:[2,3]
CUT_ESC_004 = KEY:JET_003, CUT:2
CUT_CHN_002 = ESC:[+003,+004], OUT:"./Cuts/2b_2l"
            # Category III: 0-1 Leptons, 4+ B-Jets
CUT_ESC_005 = KEY:LEP_001, CUT:[0,1]
CUT_ESC_006 = KEY:JET_003, CUT:4
CUT_CHN_003 = ESC:[+005,+006], OUT:"./Cuts/4b_0l"
```

# Cut Card Example

- Compute statistics associated with referenced groups of kinematic objects, or with the event as a whole

```
****** Event Selection *******
        # MET-Jet Delta Phi (Leading+B-Tags)
EVT_MDP_001 = MET:000, JET:011, OUT:1
        # MET Significance MET / sqrt( HT )
EVT_RHR_001 = NUM:000, DEN:000, OUT:1
        # Invariant Mass of Nearest Higgs Window Pair
EVT_OIM_001 = JET:012, OUT:1
        # Invariant Mass of Further Higgs Window Pair
EVT_OIM_002 = JET:013, OUT:1
        # Delta-R Separation of Nearest Higgs Window Pair
EVT_ODR_001 = JET:012, OUT:1
        # Delta-R Separation of Further Higgs Window Pair
EVT_ODR_002 = JET:013, OUT:1
```

```
        # B-TAGS in Jets 1,2
OBJ_JET_005 = SRC:[+001,+002], HFT:0.5, CUT:0
        # Non-B Sub-Leading Jets
OBJ_JET_006 = SRC:[+000,-001,-002,-003],
        PRM:[0.0,2.5], CUT:0
        # 1 B-Tags in Z/Higgs Window
OBJ_JET_007 = SRC:+003, EFF:[WIN,92,20,126,20,1], CUT:0
        # 2 B-Tags in Z/Higgs Window
OBJ_JET_008 = SRC:+003, EFF:[WIN,92,20,126,20,2], CUT:0
        # 2 B-Tags in Higgs Window
OBJ_JET_009 = SRC:+003, EFF:[WIN,126,20,2], CUT:0
        # Single Track Jets
OBJ_JET_010 = SRC:+000, TRK:[1,1], CUT:0
        # Leading or B-Tagged Jets (No Output)
OBJ_JET_011 = SRC:[+001,+002,+003]
        # Nearest B-Tag Object Pair to Higgs Window
OBJ_JET_012 = SRC:+003, EFF:[OIM,126,UNDEF,-1]
        # Further B-Tag Object Pair from Higgs Window
OBJ_JET_013 = SRC:[+003,-012], EFF:[OIM,126,UNDEF,-1]
        # ALL Leptons
OBJ_LEP_000 = PTM:10, PRM:[0.0,2.5]
        # Light Soft Leptons
OBJ_LEP_001 = SRC:+000, EMT:-3, SDR:[0.3,UNDEF,1], CUT:0
        # Soft Taus
OBJ_LEP_002 = SRC:+000, EMT:+3, CUT:0
        # Light Hard Leptons
OBJ_LEP_003 = SRC:+001, PTM:20, CUT:0
        # Hard Taus
OBJ_LEP_004 = SRC:+002, PTM:20, CUT:0
        # 1 Lepton in Z Window
OBJ_LEP_005 = SRC:+001, EFF:[WIN,92,5], CUT:0
```

```
****** Event Filtering *******
        # Category I: 4 Leptons, 0+ B-Jets
CUT_ESC_001 = KEY:LEP_001, CUT:4
CUT_ESC_002 = KEY:JET_003, CUT:0
CUT_CHN_001 = ESC:[+001,+002], OUT:"./Cuts/0b_4l"
        # Category II: 2-3 Leptons, 2+ B-Jets
CUT_ESC_003 = KEY:LEP_001, CUT:[2,3]
CUT_ESC_004 = KEY:JET_003, CUT:2
CUT_CHN_002 = ESC:[+003,+004], OUT:"./Cuts/2b_2l"
        # Category III: 0-1 Leptons, 4+ B-Jets
CUT_ESC_005 = KEY:LEP_001, CUT:[0,1]
CUT_ESC_006 = KEY:JET_003, CUT:4
CUT_CHN_003 = ESC:[+005,+006], OUT:"./Cuts/4b_0l"
```

# Cut Card Example

```
*** Object Reconstruction ****
          # ALL Jets
OBJ_JET_000 = PTM:30, PRM:[0.0,5.0], CUT:0
          # LEAD Jet
OBJ_JET_001 = SRC:+000, PRM:[0.0,2.5],
          CUT:[1,UNDEF,-1], OUT:PTM_001, ANY:0
          # SECOND Jet
OBJ_JET_002 = SRC:[+000,-001], PRM:[0.0,2.5],
          CUT:[1,UNDEF,-1], OUT:PTM_002, ANY:0
          # B-Tagged Jets
OBJ_JET_003 = SRC:+000, PRM:[0.0,2.5], HFT:0.5, CUT:0
          # Non-B Jets
OBJ_JET_004 = SRC:[+000,-003], PRM:[0.0,2.5], CUT:0
          # B-TAGS in Jets 1,2
OBJ_JET_005 = SRC:[+001,+002], HFT:0.5, CUT:0
```

- Create subclassifications of events matching certain selection criteria

```
OBJ_JET_010 = SRC:+000, TRK:[1,1], CUT:0
          # Leading or B-Tagged Jets (No Output)
OBJ_JET_011 = SRC:[+001,+002,+003]
          # Nearest B-Tag Object Pair to Higgs Window
OBJ_JET_012 = SRC:+003, EFF:[OIM,126,UNDEF,-1]
          # Further B-Tag Object Pair from Higgs Window
OBJ_JET_013 = SRC:[+003,-012], EFF:[OIM,126,UNDEF,-1]
          # ALL Leptons
OBJ_LEP_000 = PTM:10, PRM:[0.0,2.5]
          # Light Soft Leptons
OBJ_LEP_001 = SRC:+000, EMT:-3, SDR:[0.3,UNDEF,1], CUT:0
          # Soft Taus
OBJ_LEP_002 = SRC:+000, EMT:+3, CUT:0
          # Light Hard Leptons
OBJ_LEP_003 = SRC:+001, PTM:20, CUT:0
          # Hard Taus
OBJ_LEP_004 = SRC:+002, PTM:20, CUT:0
          # 1 Lepton in Z Window
OBJ_LEP_005 = SRC:+001, EFF:[WIN,92,5], CUT:0
```

```
****** Event Selection *******
          # MET-Jet Delta Phi (Leading+B-Tags)
EVT_MDP_001 = MET:000, JET:011, OUT:1
          # MET Significance MET / sqrt( HT )
EVT_RHR_001 = NUM:000, DEN:000, OUT:1
          # Invariant Mass of Nearest Higgs Window Pair
EVT_OIM_001 = JET:012, OUT:1
          # Invariant Mass of Further Higgs Window Pair
EVT_OIM_002 = JET:013, OUT:1
          # Delta-R Separation of Nearest Higgs Window Pair
EVT_ODR_001 = JET:012, OUT:1
          # Delta-R Separation of Further Higgs Window Pair
EVT_ODR_002 = JET:013, OUT:1
****** Event Filtering *******
          # Category I: 4 Leptons, 0+ B-Jets
CUT_ESC_001 = KEY:LEP_001, CUT:4
CUT_ESC_002 = KEY:JET_003, CUT:0
CUT_CHN_001 = ESC:[+001,+002], OUT:"./Cuts/0b_4l"
          # Category II: 2-3 Leptons, 2+ B-Jets
CUT_ESC_003 = KEY:LEP_001, CUT:[2,3]
CUT_ESC_004 = KEY:JET_003, CUT:2
CUT_CHN_002 = ESC:[+003,+004], OUT:"./Cuts/2b_2l"
          # Category III: 0-1 Leptons, 4+ B-Jets
CUT_ESC_005 = KEY:LEP_001, CUT:[0,1]
CUT_ESC_006 = KEY:JET_003, CUT:4
CUT_CHN_003 = ESC:[+005,+006], OUT:"./Cuts/4b_0l"
```

# AEACuS Output

1000000 EVENTS PROCESSED IN TOTAL

5.316e-02 PB EVENT CROSS SECTION YIELDS 1.881e+07 PER PB LUMINOSITY

RESCALING BY 5.316e-04 TO TARGET LUMINOSITY OF 1.000e+04 PER PB

5.316e+02 SCALED EVENTS SURVIVE ALL CUTS WITH AN EFFECTIVE CROSS SECTION OF 5.316e-02 PB

000.000 % OF EVENTS CUT

| CUT ID | % CUT | % SOLO |
|---|---|---|
| LEP_001 | 000.000 | 000.000 |
| LEP_002 | 000.000 | 000.000 |
| LEP_003 | 000.000 | 000.000 |
| LEP_004 | 000.000 | 000.000 |
| LEP_005 | 000.000 | 000.000 |
| JET_000 | 000.000 | 000.000 |
| JET_001 | 000.000 | 000.000 |
| JET_002 | 000.000 | 000.000 |
| JET_003 | 000.000 | 000.000 |
| JET_004 | 000.000 | 000.000 |
| JET_005 | 000.000 | 000.000 |
| JET_006 | 000.000 | 000.000 |
| JET_007 | 000.000 | 000.000 |
| JET_008 | 000.000 | 000.000 |
| JET_009 | 000.000 | 000.000 |
| JET_010 | 000.000 | 000.000 |

INDIVIDUAL PASSING EVENT STATISTICS

| EVENT_# | LEP_001 | LEP_002 | LEP_003 | LEP_004 | LEP_005 | JET_000 | JET_001 | JET_002 | JET_003 | JET_004 | JET_005 | JET_006 | JET_007 | JET_008 | JET_009 | JET_010 | PTM_001 | PTM_002 | MET_000 | OIM_001 | OIM_002 | ODR_001 | ODR_002 | MDP_001 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0003160 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 36.6 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0005003 | 4 | 0 | 3 | 0 | 1 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 76.1 | 72.2 | 173.0 | UNDEF | UNDEF | UNDEF | UNDEF | 1.834 |
| 0005115 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 37.6 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0005211 | 4 | 0 | 3 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 94.6 | 82.0 | 77.9 | UNDEF | UNDEF | UNDEF | UNDEF | 1.425 |
| 0007055 | 4 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 31.1 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0007418 | 4 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 104.3 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0008111 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 125.0 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0008333 | 4 | 0 | 4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 36.4 | UNDEF | 27.7 | UNDEF | UNDEF | UNDEF | UNDEF | 0.175 |
| 0009493 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 111.8 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0009898 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 83.2 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0010023 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 108.3 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0010092 | 4 | 0 | 4 | 0 | 1 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 88.6 | 36.9 | 105.7 | UNDEF | UNDEF | UNDEF | UNDEF | 1.028 |
| 0010131 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 127.7 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0010219 | 4 | 0 | 4 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 79.0 | UNDEF | 46.5 | UNDEF | UNDEF | UNDEF | UNDEF | 2.291 |
| 0011575 | 4 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 93.9 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |
| 0013805 | 4 | 0 | 4 | 0 | 1 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 123.5 | 36.5 | 92.3 | UNDEF | UNDEF | UNDEF | UNDEF | 1.640 |
| 0015150 | 4 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | UNDEF | UNDEF | 60.7 | UNDEF | UNDEF | UNDEF | UNDEF | UNDEF |

- Basically, output is a spreadsheet reporting requested statistics & cut fractions
- It is often convenient to make no cuts at the lowest level, but only to compute
- Names such as "JET_001" have no invariant meaning - they are defined in a card_file

# Plot Card Example

```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
PLT_DAT_002 = DIR:"./M3/0b_4l", FIL:["BG:MEG:VVJJ*","BG:MEG:ZJJJJ*","BG:MEG:WJJJJ*"]
PLT_DAT_003 = DIR:"./M3/0b_4l", FIL:"NMSSM:A:NMSSM*"

PLT_CHN_001 = DAT:[001,002,003], KEY:MET_000

PLT_HST_001 =
        IFB:300,
        CHN:001,
        LFT:0, RGT:1000, SPN:25,
        MIN:0.001, MAX:UNDEF,
        SUM:-1, NRM:0, AVG:3,
        LOG:1, LOC:0, CLR:0,
        TTL:"$4^+e/\mu$ with $0^+$ B-Jets, <RTS> = 14 TeV, <LUM> = 300 <IFB>",
        LBL:["<MET> Cut Threshold [GeV]","Integrated Event Count"],
        LGD:[
               "$t\overline{t}+$ 0-2 Jets",
               "$V\,V+$ 0-2 Jets & $Z/W+$ 0-4 Jets",
               "NMSSM-A $\chi^0 \chi^0+$ 0-2 Jets" ],
        OUT:"./Plots", NAM:"event_count_MET_0b_4l_300", FMT:"PDF"
```

# Plot Card Example

```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
PLT_DAT_002 = DIR:"./M3/0b_4l", FIL:["BG:MEG:VVJJ*","BG:MEG:ZJJJJ*","BG:MEG:WJJJJ*"]
PLT_DAT_003 = DIR:"./M3/0b_4l", FIL:"NMSSM:A:NMSSM*"
```

- Data Sets are built out of groups of ".cut" files from AEACuS
- Wildcards "*" are allowed to match multiple files
- Cross-sections are imported automatically
- Files with common trailing digits (name_NNN.cut) are averaged
- Files with unique names are summed

```
              "$t\overline{t}+$ 0-2 Jets",
              "$V\,V+$ 0-2 Jets & $Z/W+$ 0-4 Jets",
              "NMSSM-A $\chi^0 \chi^0+$ 0-2 Jets" ],
       OUT:"./Plots", NAM:"event_count_MET_0b_4l_300", FMT:"PDF"
```

# Plot Card Example

```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
PLT_DAT_002 = DIR:"./M3/0b_4l", FIL:["BG:MEG:VVJJ*","BG:MEG:ZJJJJ*","BG:MEG:WJJJJ*"]
PLT_DAT_003 = DIR:"./M3/0b_4l", FIL:"NMSSM:A:NMSSM*"

PLT_CHN_001 = DAT:[001,002,003], KEY:MET_000
```

- Channels are built out of groups of datasets
- The plotting key refers to a statistic computed by AEACuS

```
        SUM:-1, NRM:0, AVG:3,
        LOG:1, LOC:0, CLR:0,
        TTL:"$4^+e/\mu$ with $0^+$ B-Jets, <RTS> = 14 TeV, <LUM> = 300 <IFB>",
        LBL:["<MET> Cut Threshold [GeV]","Integrated Event Count"],
        LGD:[
               "$t\overline{t}+$ 0-2 Jets",
               "$V\,V+$ 0-2 Jets & $Z/W+$ 0-4 Jets",
               "NMSSM-A $\chi^0 \chi^0+$ 0-2 Jets" ],
        OUT:"./Plots", NAM:"event_count_MET_0b_4l_300", FMT:"PDF"
```

# Plot Card Example

- Histograms are built out of groups of channels
- Line continuation is indicated simply by indentation
- The luminosity may be specified in “IPB”, “IFB”, “IAB”, etc.

```
PLT_HST_001 =
        IFB:300,
        CHN:001,
        LFT:0, RGT:1000, SPN:25,
        MIN:0.001, MAX:UNDEF,
        SUM:-1, NRM:0, AVG:3,
```

- By default, events are oversampled and scaled down to the target luminosity
- There is a warning on scale factors < 1
- Optionally specify trim at exact luminosity “IFB:[300,-1]”
- Bins are specified by “LFT” = left, “RGT” = right, “SPN” = bin span
- Optionally “BNS” = number of bins may be used instead of one prior
- “MIN” and “MAX” provide optional manual limits on range

# Plot Card Example

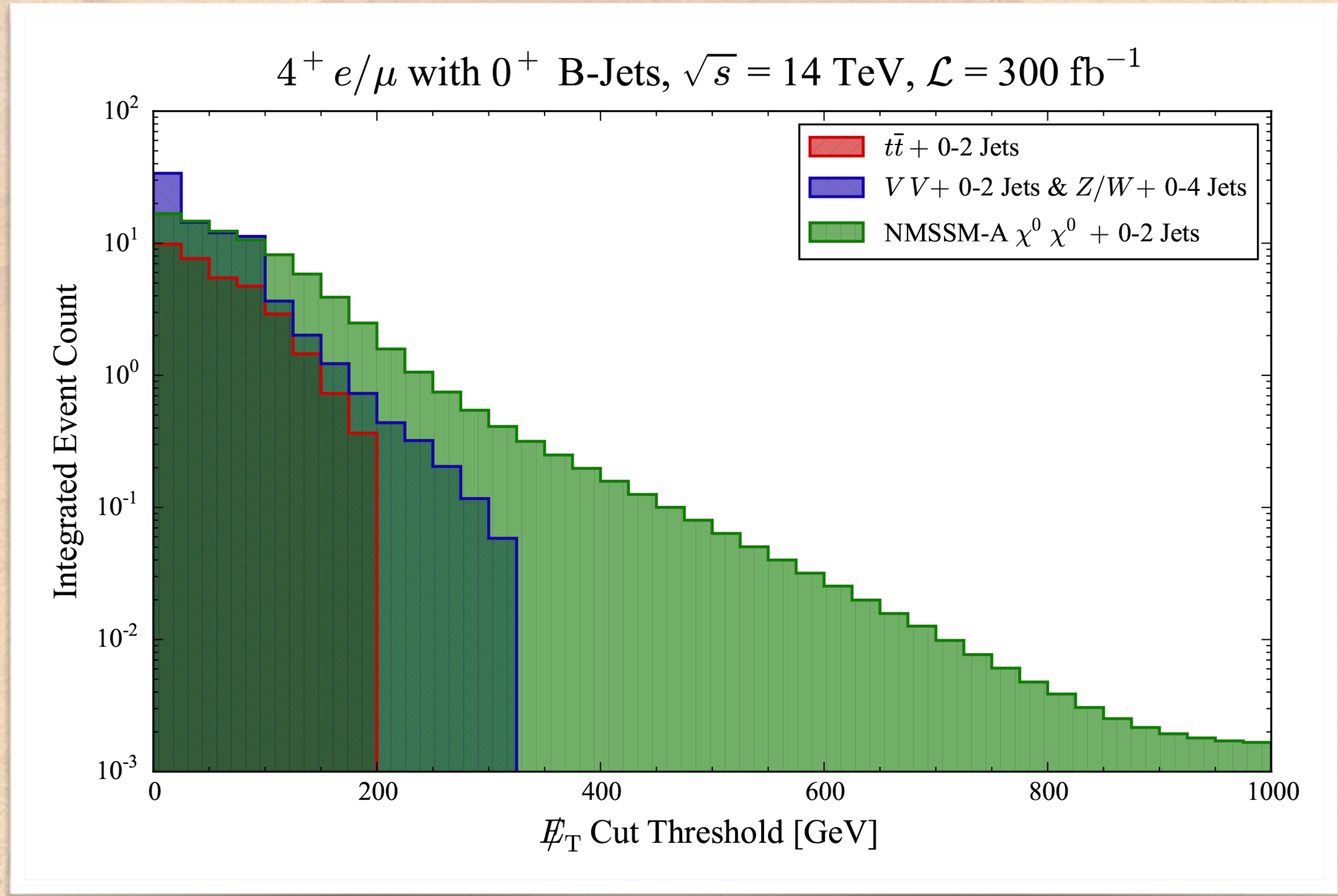
```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
```

- SUM +/- 1 compound bin counts to the right/left for threshold plots
- NRM facilitates normalization as for shape plots
- AVG engages bin smoothing with preservation of integrated counts
- LOG = 1/0 enables/disables logarithmic dependent axis

```
        SUM:-1, NRM:0, AVG:3,
        LOG:1, LOC:0, CLR:0,
        TTL:"$4^+e/\mu$ with $0^+$ B-Jets, <RTS> = 14 TeV, <LUM> = 300 <IFB>",
        LBL:["<MET> Cut Threshold [GeV]","Integrated Event Count"],
        LGD:[
                "$t\overline{t}+$ 0-2 Jets",
                "$V\,V+$ 0-2 Jets & $Z/W+$ 0-4 Jets",
                "NMSSM-A $\chi^0 \chi^0+$ 0-2 Jets" ],
        OUT:"./Plots", NAM:"event_count_MET_0b_4l_300", FMT:"PDF"
```

- Inline LaTeX is used to input formulas for title, axis labels, and legends
- Several preconfigured notations are accessible via shorthand
- Available vector output formats include publication quality “EPS” & “PDF”
- Optionally specify intermediate Python source output “FMT:[PDF,1]”

# Plot Output



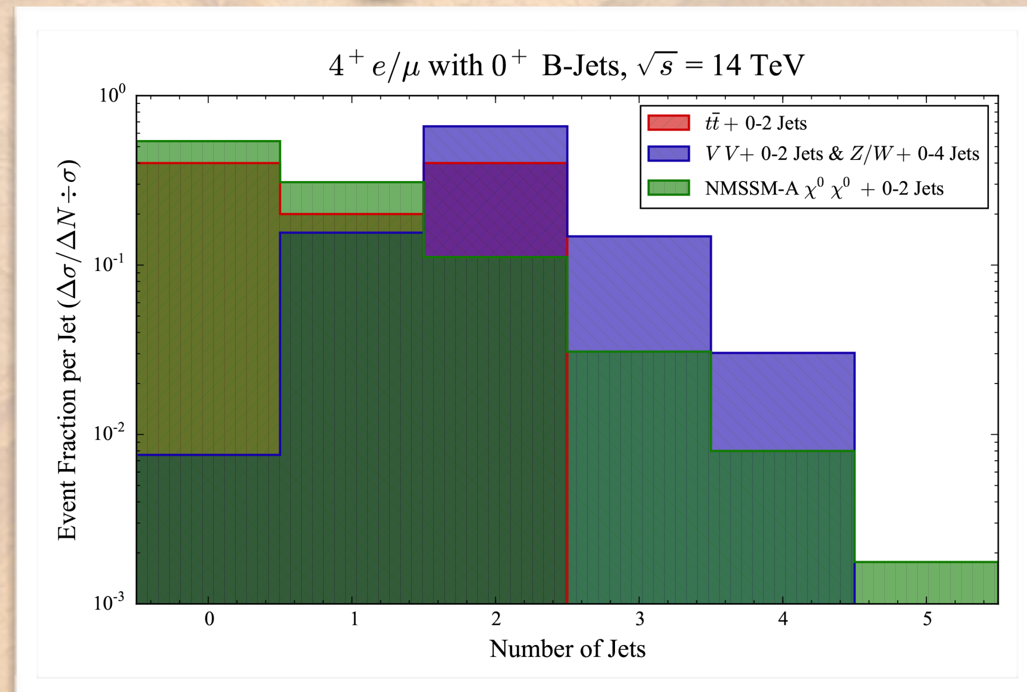
$4^+ e/\mu$ with $0^+$ B-Jets, $\sqrt{s}$ = 14 TeV, $\mathcal{L}$ = 300 fb$^{-1}$
$t\bar{t}+$ 0-2 Jets
$VV+$ 0-2 Jets & $Z/W+$ 0-4 Jets
NMSSM-A $\chi^0\ \chi^0$ + 0-2 Jets
Integrated Event Count
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
0
200
400
600
800
1000
$\not{E}_{\mathrm{T}}$ Cut Threshold [GeV]

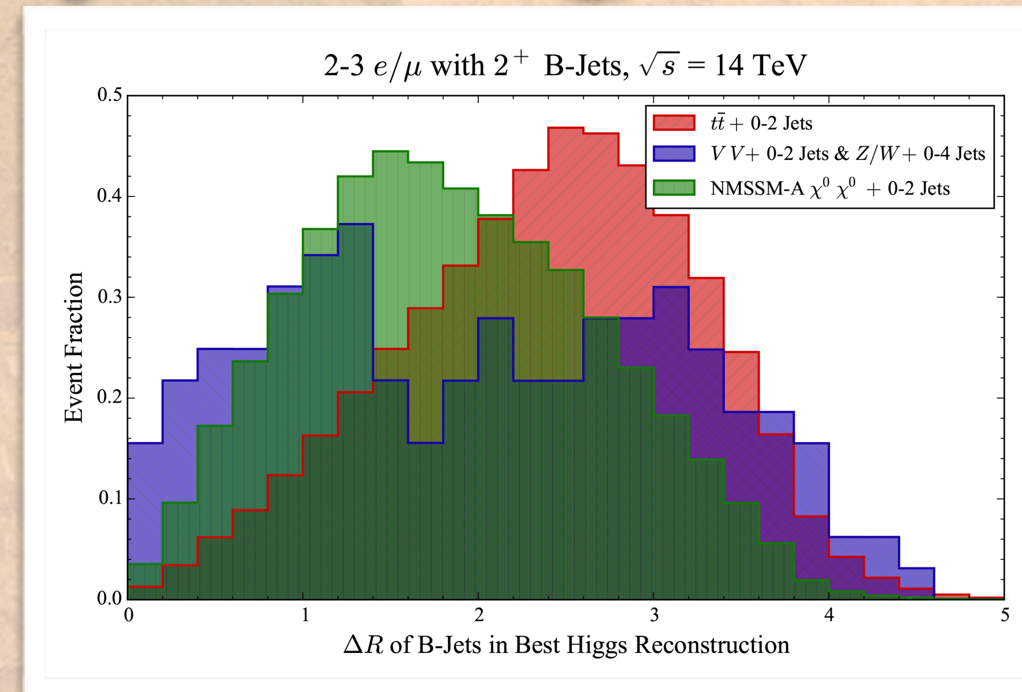
# Optimize By Shape

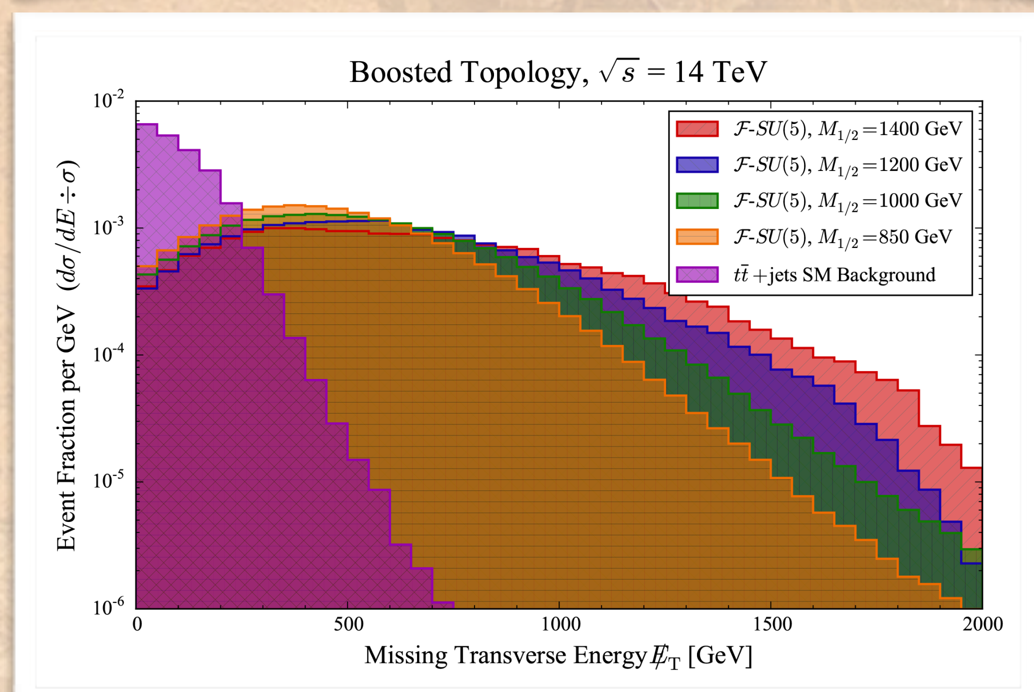
```
PLT_DAT_001 = DIR:"./Cuts", FIL:"Forward:BG:MEG:TTBAR_*"
PLT_DAT_002 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:850_*"
PLT_DAT_003 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1000_*"
PLT_DAT_004 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1200_*"
PLT_DAT_005 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1400_*"

PLT_CHN_001 = DAT:[005,004,003,002,001], KEY:MET_000

PLT_HST_
         MIN:0.000001, MAX:UNDEF,
         SUM:0, NRM:1, AVG:3,
         LOG:1, LOC:0, CLR:0,
         TTL:"Boosted Topology, <RTS> = 14 TeV",
         LBL:[   "Missing Transverse Energy <MET> [GeV]",
                 "Event Fraction per GeV  (<DEF>)" ],
         LGD:[   "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1400$ GeV",
                 "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1200$ GeV",
                 "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1000$ GeV",
                 "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 850$ GeV",
                 "$t\overline{t}+$jets SM Background" ],
         OUT:"./Plots", NAM:"met_shape_boosted_30", FMT:"PDF"
```

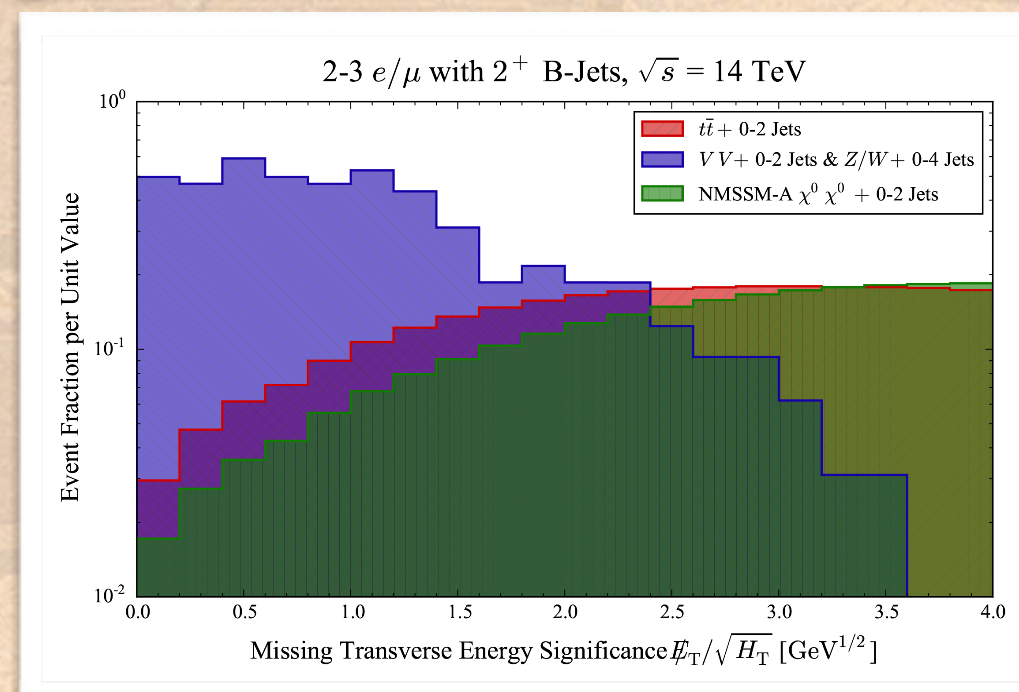
- Shape plots are unit normalized
- Bins are not left/right compounded

# Optimize By Shape



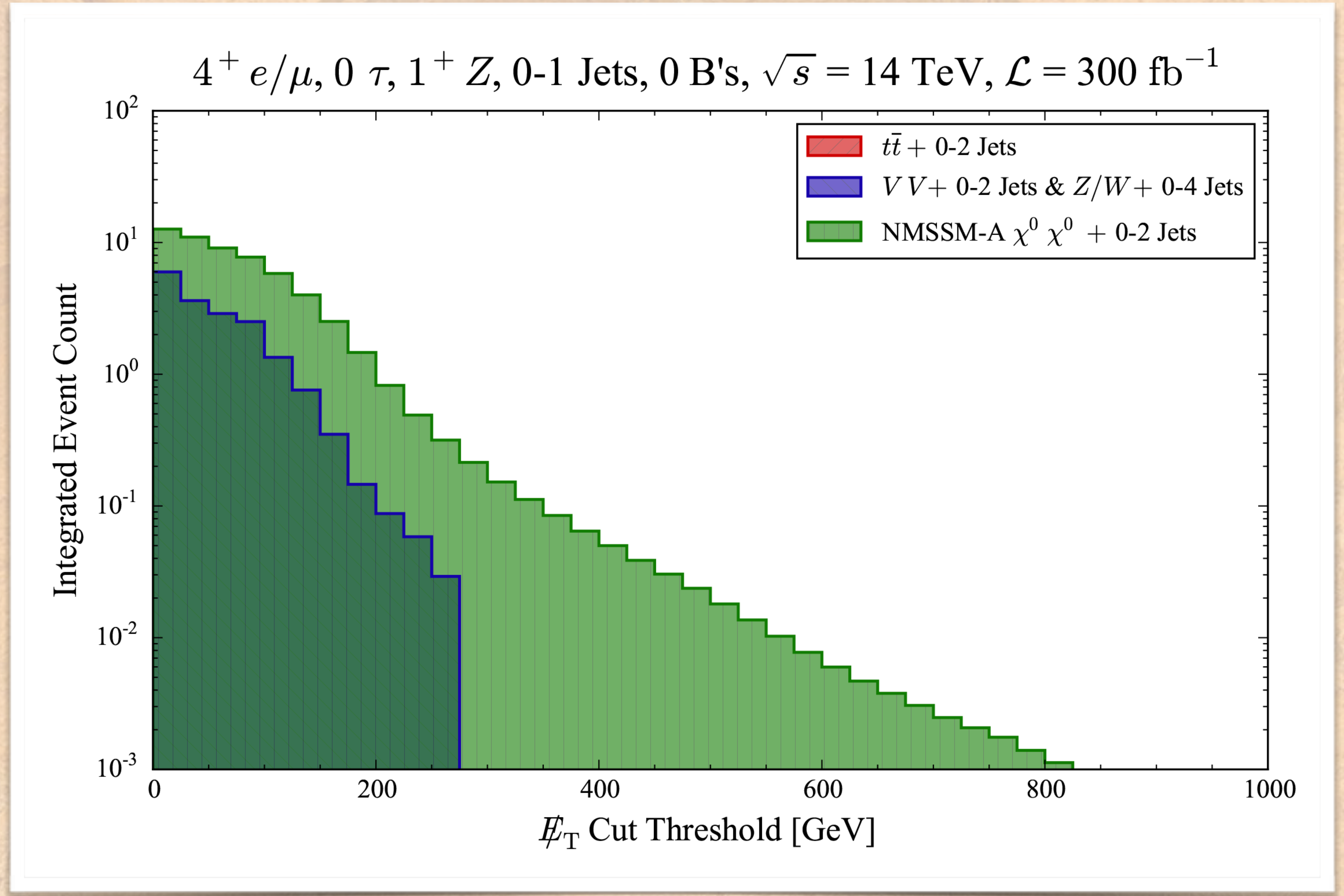
# Apply Selection Cuts

```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
PLT_DAT_002 = DIR:"./M3/0b_4l", FIL:["BG:MEG:VVJJ*","BG:MEG:ZJJJJ*","BG:MEG:WJJJJ*"]
PLT_DAT_003 = DIR:"./M3/0b_4l", FIL:"NMSSM:A:NMSSM*"

PLT_ESC_001 = KEY:LEP_002, CUT:[0,0]  # Veto Taus
PLT_ESC_002 = KEY:LEP_005, CUT:1      # Force 1 Lepton pair in Z Window
PLT_ESC_003 = KEY:JET_000, CUT:[0,1]  # Veto 2+ Jets
PLT_ESC_004 = KEY:JET_003, CUT:[0,0]  # Veto B's

PLT_CHN_003 = DAT:[001,002,003], KEY:MET_000, ESC:[+001,+002,+003,+004]
```

- Event Selection Cuts (ESC) are registered by AEACus key and range
- Channels may subscribe to any number of registered cuts

```
        SUM:-1, NRM:0, AVG:3,
        LOG:1, LOC:0, CLR:0,
        TTL:"$4^+e/\mu$, $0\,\tau$, $1^+Z$, 0-1 Jets, 0 B's, <RTS> = 14 TeV, <LUM> = 300 <IFB>",
        LBL:["<MET> Cut Threshold [GeV]","Integrated Event Count"],
        LGD:[   "$t\overline{t}+$ 0-2 Jets",
                "$V\,V+$ 0-2 Jets & $Z/W+$ 0-4 Jets",
                "NMSSM-A $\chi^0 \chi^0+$ 0-2 Jets" ],
        OUT:"./Plots", NAM:"event_count_MET_OPT_0b_4l_300", FMT:"PDF"
```

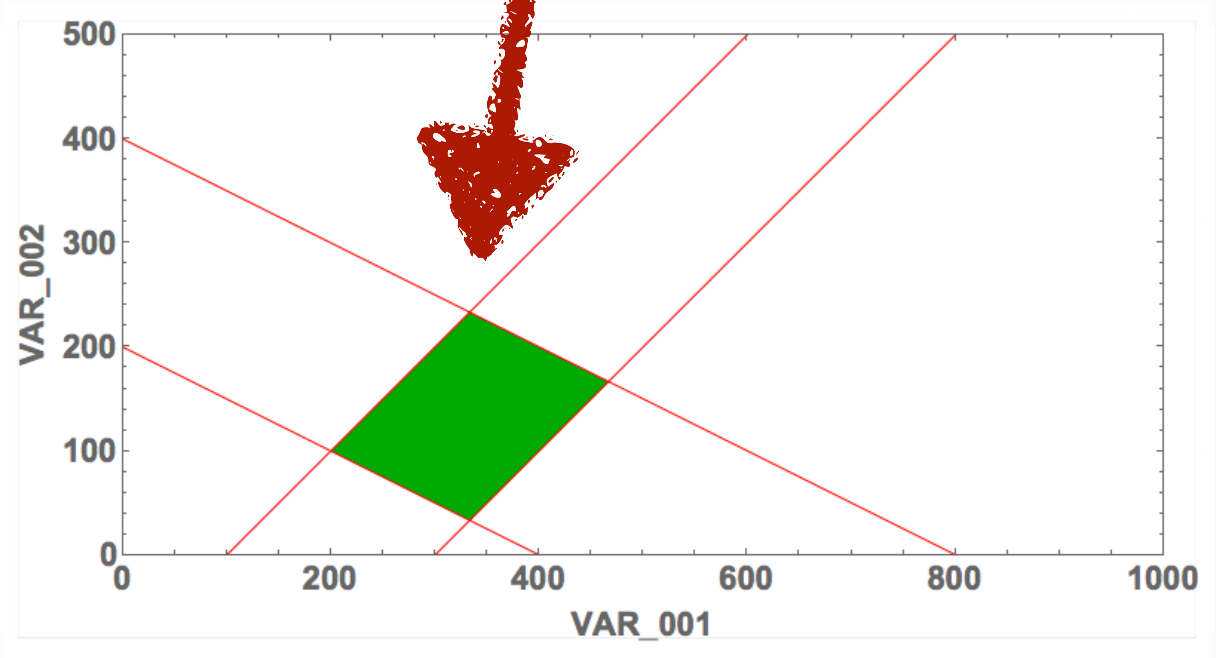
# Optimized Plot Output



# Transform Event Keys

```
        # Azimuthal Separation of two 4-vectors in range 0 to Pi
PLT_CHN_001 = DAT:[001,002,003], KEY:{PI()-ABS(PI()-ABS($2-$1)),PHI_001,PHI_002}

        # Compound rhomboid selection region in two variables
PLT_ESC_001 = KEY:{$2-$1,VAR_001,VAR_002}, CUT:[-300,-100]
PLT_ESC_002 = KEY:{$2+$1/2,VAR_001,VAR_002}, CUT:[200,400]
```

- User-defined compound functions of event keys are allowed for event selection and for specification of the independent plotting variable
- Available functions include basic arithmetic, trigonometry, roots, powers, logarithms, exponentials, min, max, integer, modulus, and average



# Transform Bin Channels

- User-defined functions of binned channels are allowed for specification of the dependent plotting variable
- Internal histogram object transparently applies the specified functional transformation bin-by-bin
- Channels with multiple data sets iterate automatically
- Single data sets expand to match large dimensionalities

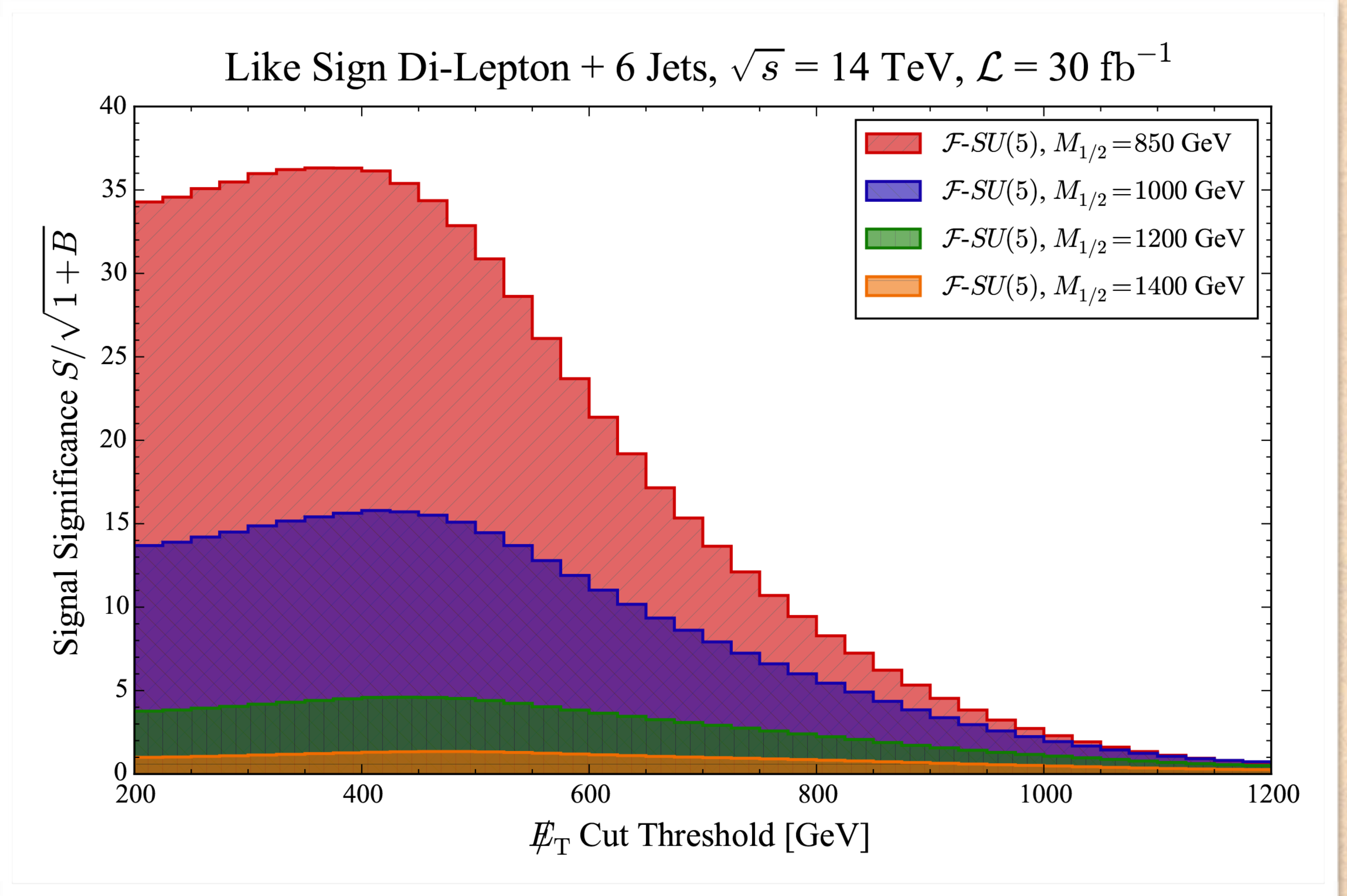
# Transform Bin Channels

```
PLT_DAT_001 = DIR:"./Cuts_LSD", FIL:"Jets:BG:MEG:TTBAR_*"
PLT_DAT_002 = DIR:"./Cuts_LSD", FIL:"Jets:FSU5_VBF_25:850_*"
PLT_DAT_003 = DIR:"./Cuts_LSD", FIL:"Jets:FSU5_VBF_25:1000_*"
PLT_DAT_004 = DIR:"./Cuts_LSD", FIL:"Jets:FSU5_VBF_25:1200_*"
PLT_DAT_005 = DIR:"./Cuts_LSD", FIL:"Jets:FSU5_VBF_25:1400_*"

PLT_ESC_001 = KEY:PTM_001, CUT:400
PLT_ESC_002 = KEY:PTM_002, CUT:200
PLT_ESC_003 = KEY:JET_003, CUT:4
PLT_ESC_004 = KEY:JET_004, CUT:2
PLT_ESC_005 = KEY:JET_001, CUT:6

        # One-dimensional background channel
PLT_CHN_001 = DAT:[001], KEY:MET_000, ESC:[+001,+002,+003,+004,+005]
        # Four-dimensional signal channel
PLT_CHN_002 = DAT:[002,003,004,005], KEY:MET_000, ESC:[+001,+002,+003,+004,+005]

PLT_HST_002 =
        IFB:30,
        CHN:{$2/SRT(1+$1),001,002},
        LFT:200, RGT:1200, SPN:25, BNS:UNDEF,
```

- Signal significance is computed here by combining Signal & BG
- Signal and BG use same key and subscribe to identical event selection cuts
- The single BG Channel is expanded to match four Signal Channels

```
                "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1200$ GeV",
                "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1400$ GeV" ],
        OUT:"./Plots", NAM:"met_sig_LSD_30", FMT:"PDF"
```

# Transform Bin Channels



# Transform Bin Channels

```
PLT_DAT_001 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_25:1000_*"
PLT_DAT_002 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_15:1000_*"
PLT_DAT_003 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_6:990_*"

PLT_ESC_001 = KEY:PTM_001, CUT:400    # Leading P_T Cut
PLT_ESC_002 = KEY:PTM_002, CUT:200    # Sub-leading P_T Cut
PLT_ESC_003 = KEY:MET_000, CUT:700    # MET Cut
PLT_ESC_004 = KEY:DIL_001, CUT:1      # Same Sign Dilepton
PLT_ESC_005 = KEY:DIL_002, CUT:1      # Opposite Sign Dilepton

PLT_CHN_001 = DAT:[001,002,003], KEY:OIM_001, ESC:[+001,+002,+003,+004]
PLT_CHN_002 = DAT:[001,002,003], KEY:OIM_001, ESC:[+001,+002,+003,+005]

PLT_HST_001 =
        IFB:UNDEF,
        CHN:{($2-$1),001,002},
        LFT:0, BCT:[100,200,300,400], SPN:[5,10,20,50]
```

- Opposite- minus Like-Sign dilepton counts are binned on invariant mass
- The signal is compared to itself, subscribing to different selection cuts
- The operation is repeated over each of three registered data sets
- There is an internal limiter ensuring positive semi-def bin values

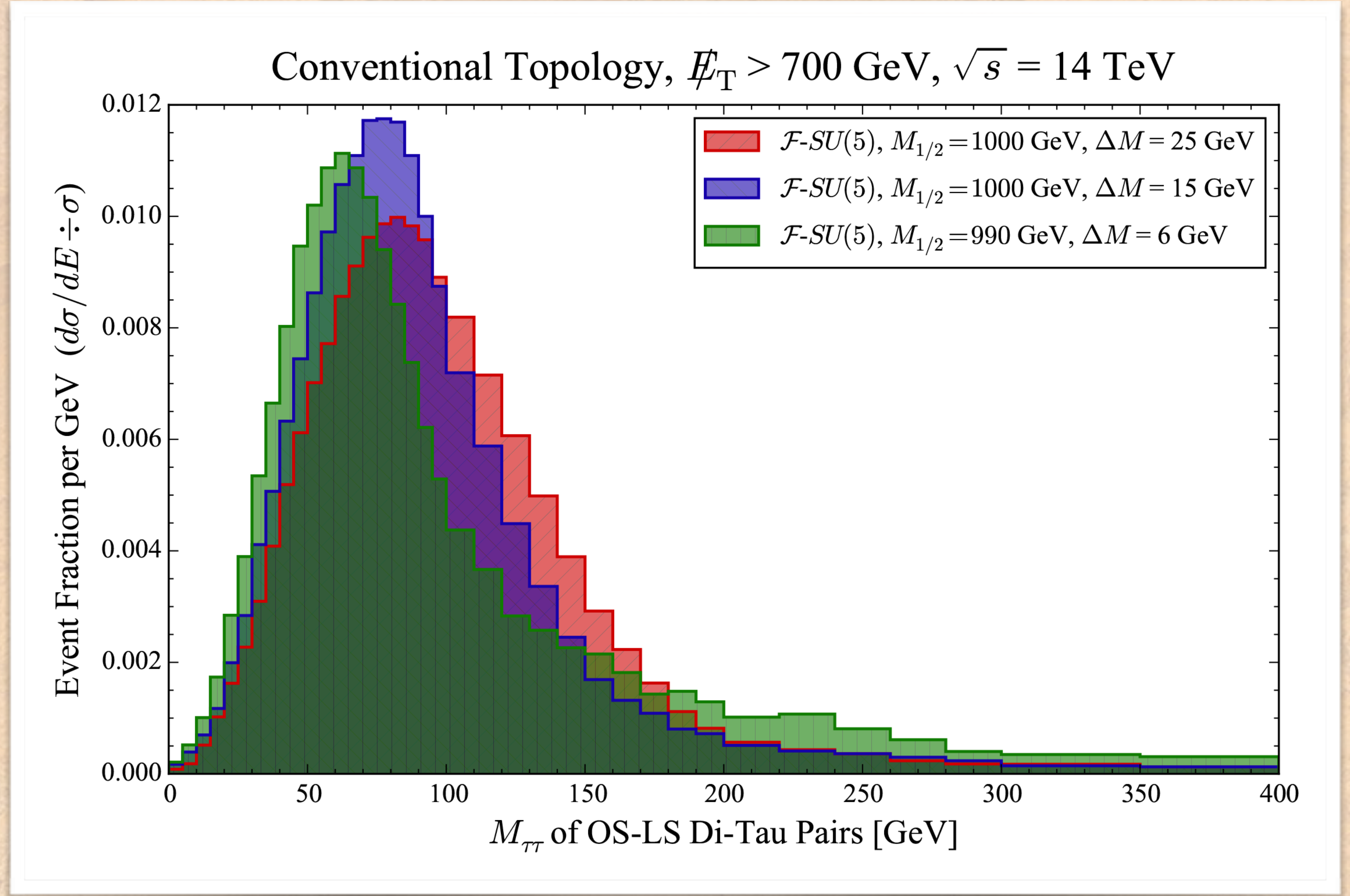
```
        OUT:"./Plots", NAM:"mtt_OS-LS_shape_DeltaM", FMT:"PDF"
```

# Transform Bin Channels

- This example also demonstrates variable width binning
- Counts in wide bins are automatically scaled to preserve axis units
- The bin smoothing width “AVG” is set independent for each data set

```
PLT_DAT_001 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_25:1000_*"
PLT_DAT_002 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_15:1000_*"
PLT_DAT_003 = DIR:"./Cuts_MT2", FIL:"Central:FSU5_VBF_6:990_*"

PLT_ESC_001 = KEY:PTM_001, CUT:400    # Leading P_T Cut

PLT_HST_001 =
        IFB:UNDEF,
        CHN:{($2-$1),001,002},
        LFT:0, RGT:[100,200,300,400], SPN:[5,10,20,50]
        MIN:0.0, MAX:UNDEF,
        SUM:0, NRM:1, AVG:[3,3,4],
        LOG:0, LOC:0, CLR:0,
        TTL:"Conventional Topology,  <MET> > 700 GeV, <RTS> = 14 TeV",
        LBL:[    "$M_{\tau \tau}$ of OS-LS Di-Tau Pairs [GeV]",
                 "Event Fraction per GeV  (<DEF>)" ],
        LGD:[    "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1000$ GeV, $\Delta M$ = 25 GeV",
                 "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 1000$ GeV, $\Delta M$ = 15 GeV",
                 "$\mathcal{F}$-$SU(5)$, $M_{1/2} = 990$ GeV, $\Delta M$ = 6 GeV" ],
        OUT:"./Plots", NAM:"mtt_OS-LS_shape_DeltaM", FMT:"PDF"
```

# Transform Bin Channels



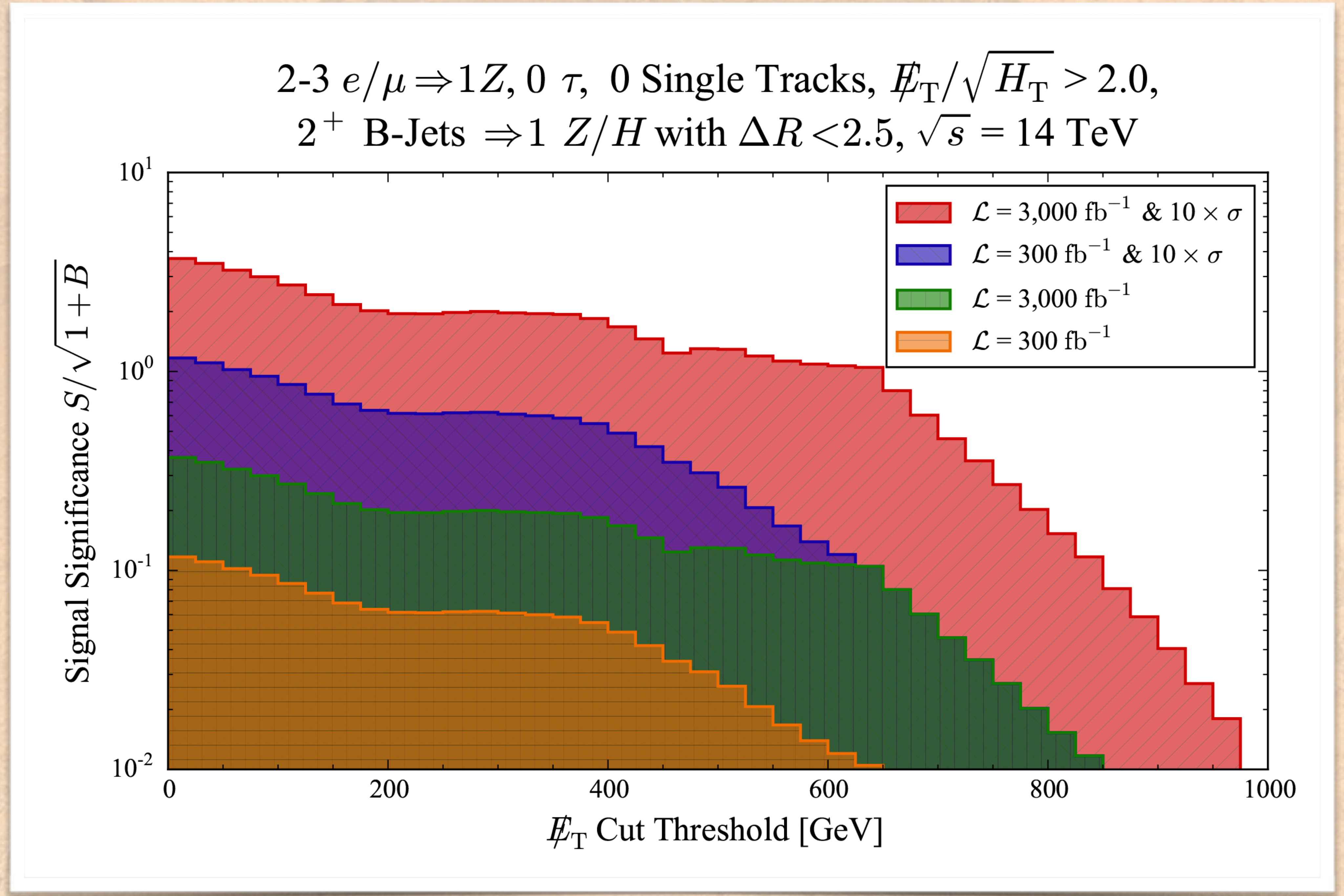
# Transform Bin Channels

```
PLT_DAT_001 = DIR:"./M3/2b_2l",
        FIL:["BG:MEG:TTBAR*","BG:MEG:VVJJ*","BG:MEG:ZJJJJ*","BG:MEG:WJJJJ*"]
PLT_DAT_002 = DIR:"./M3/2b_2l", FIL:"NMSSM:A:NMSSM*"

PLT_ESC_001 = KEY:LEP_002, CUT:[0,0] # Veto Taus
PLT_ESC_002 = KEY:JET_007, CUT:1 # Force 1 B-Jet pair in Z/H Window
PLT_ESC_003 = KEY:LEP_005, CUT:1 # Force 1 Lepton pair in Z Window
PLT_ESC_004 = KEY:JET_010, CUT:[0,0] # Veto Single Track Jets
PLT_ESC_005 = KEY:ODR_001, CUT:[0,2.5] # Best Higgs Delta R < 2.5
PLT_ESC_006 = KEY:RHR_001, CUT:[2.0] # Met/root(HT) > 2

PLT_CHN_001 = DAT:001, KEY:MET_000, ESC:[+001,+002,+003,+004,+005,+006]
PLT_CHN_002 = DAT:002, KEY:MET_000, ESC:[+001,+002,+003,+004,+005,+006]

PLT_HST_001 =
        IFB:300,
        CHN:[   {100*$2/SRT(1+10*$1),001,002},
                {10*$2/SRT(1+$1),001,002},
                {10*$2/SRT(1+10*$1),001,002},
                {$2/SRT(1+$1),001,002} ],
        LFT:0, RGT:1000, SPN:25,
```

- **Signal significance is again computed by combining Signal & BG Channels**
- **In this case the same channel is compared at two luminosity scale factors (1x,10x) and two cross section scale factors (1x,10x)**

```
                "<LUM> = 3,000 <IFB>",
                "<LUM> = 300 <IFB>" ],
        OUT:"./Plots", NAM:"event_count_MET_OPT_sig_2b_2l_300", FMT:"PDF"
```

# Transform Bin Channels



# RHADAMANTHUS

## (Recursively Heuristic Analysis, Display, And MANipulation: The Histogram Utility Suite)

- Heuristic *adjective* \ hyu̇-ˈris-tik \ (www.merriam-webster.com)

  : using experience to learn and improve :

  involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods <*heuristic* techniques> <a *heuristic* assumption>; *also* : of or relating to exploratory problem-solving techniques that utilize self-educating techniques (as the evaluation of feedback) to improve performance <a *heuristic* computer program>

- The package is now ready to use
- `http://joelwalker.net/code/aeacus.tar.gz`
- Please contact author directly: jwalker@shsu.edu
- Full documentation and availability via web are pending

# MINOS ?

(Maximally INdependent Optimization of Statistics)

- Analyze sequential cut flows
- Compute correlation metric of high dimension cut space
- Iteratively optimize on specified significance measure
- Automatically converge on event selection with maximal discrimination and minimal covariance
- Stay Tuned …