“ 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)

Automated Plotting with

RHADAManTHUS

Recursively Heuristic Analysis, Display, And Manipulation: The Histogram Utility Suite

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PHENO, Pittsburgh PACC
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With: Trenton Voth, Jesse Cantu, & William Ellsworth
Sample plots from 1412.5986 (Dutta, Li, Maxin, Nanopoulos, Sinha, & JWW)
as well as work in progress with Dutta, Gao

Typical Process Flow

- **MadGraph:** Matrix Element Generation
- **MadEvent:** Hard Scattering Simulation
- **Pythia:** Showering and Hadronization
- **Delphes/PGS:** Detector Simulation
- **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)

Algorithmic Event Arbiter and Cut Selector

- 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)

Algorithmic Event Arbiter and Cut Selector

- 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, α_T, Razor & α_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

```
        # 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
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

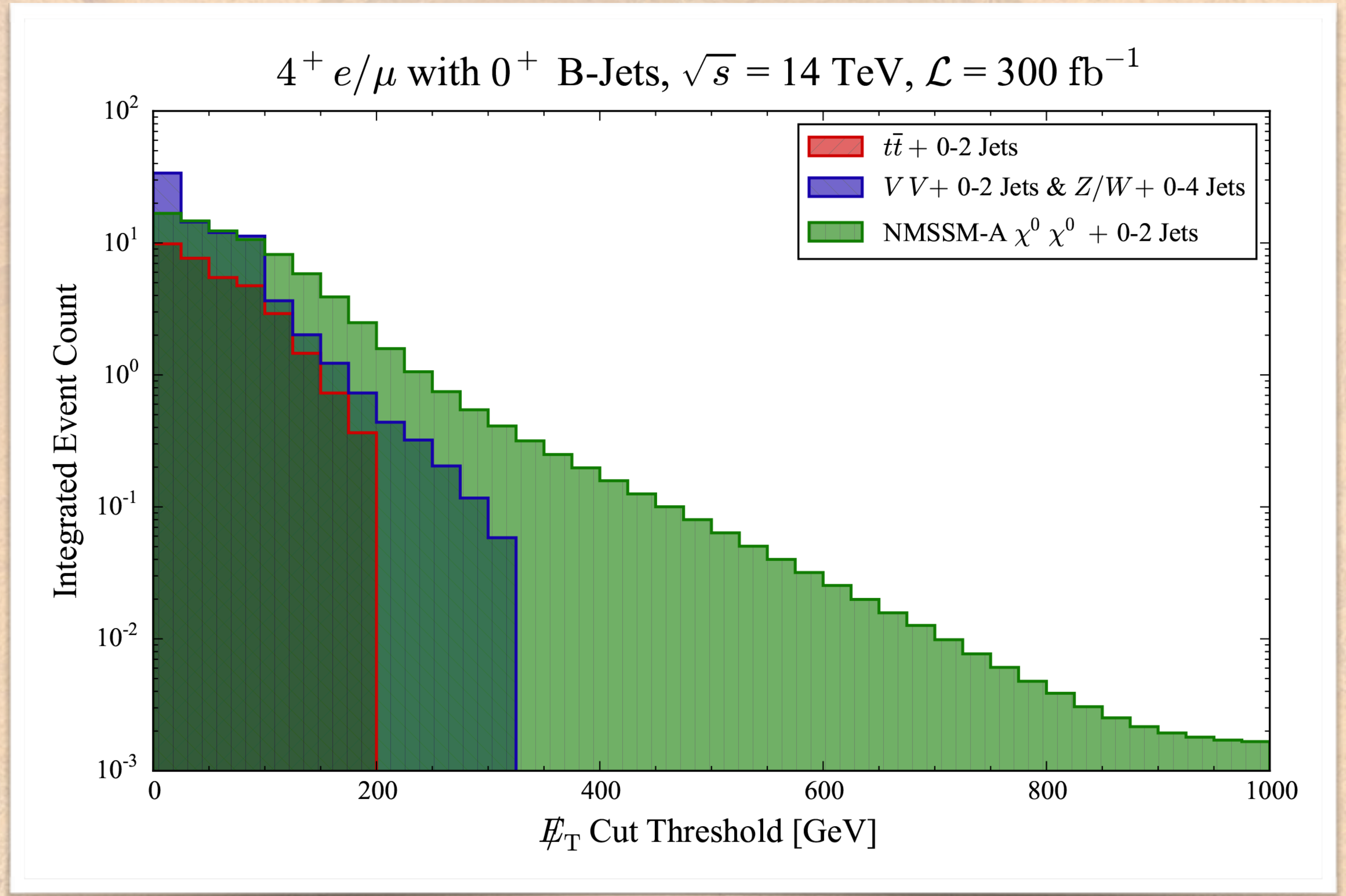
```
PLT_DAT_001 = DIR:"./M3/0b_4l", FIL:"BG:MEG:TTBAR*"
```

- 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



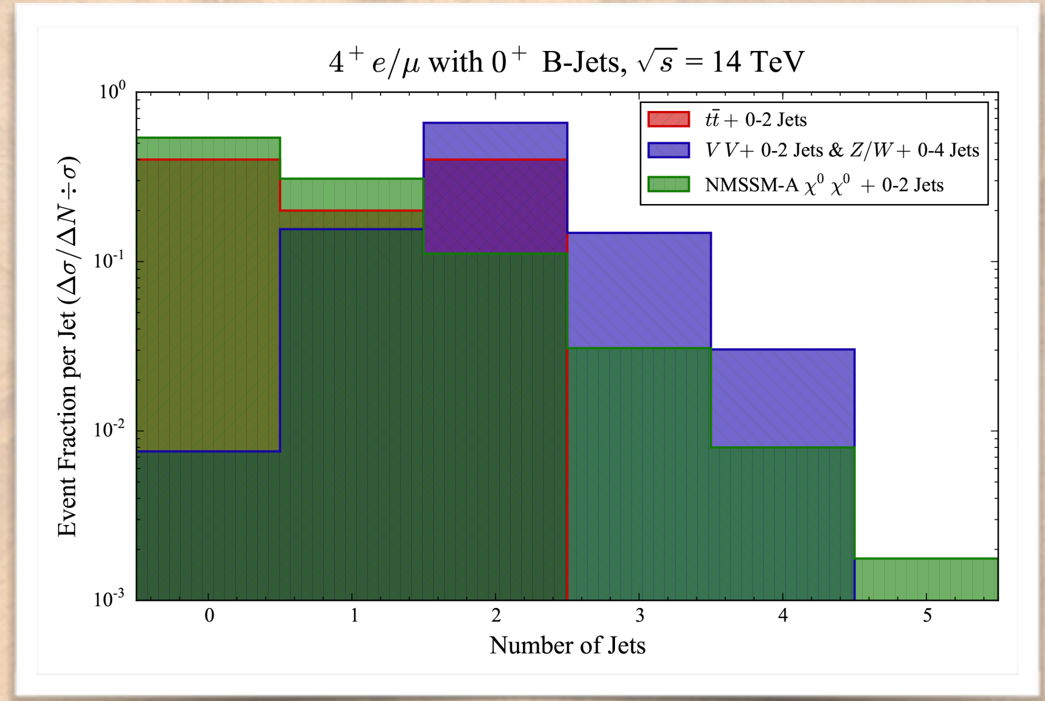
4^+ e/μ with 0^+ B-Jets, $\sqrt{s}$ = 14 TeV, $\mathcal{L}$ = 300 fb^{-1}
$t\bar{t}$ + 0-2 Jets
VV+ 0-2 Jets & Z/W+ 0-4 Jets
NMSSM-A χ^0 χ^0 + 0-2 Jets
Integrated Event Count
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
200
400
600
800
1000
$\not\!\!E_T$ Cut Threshold [GeV]

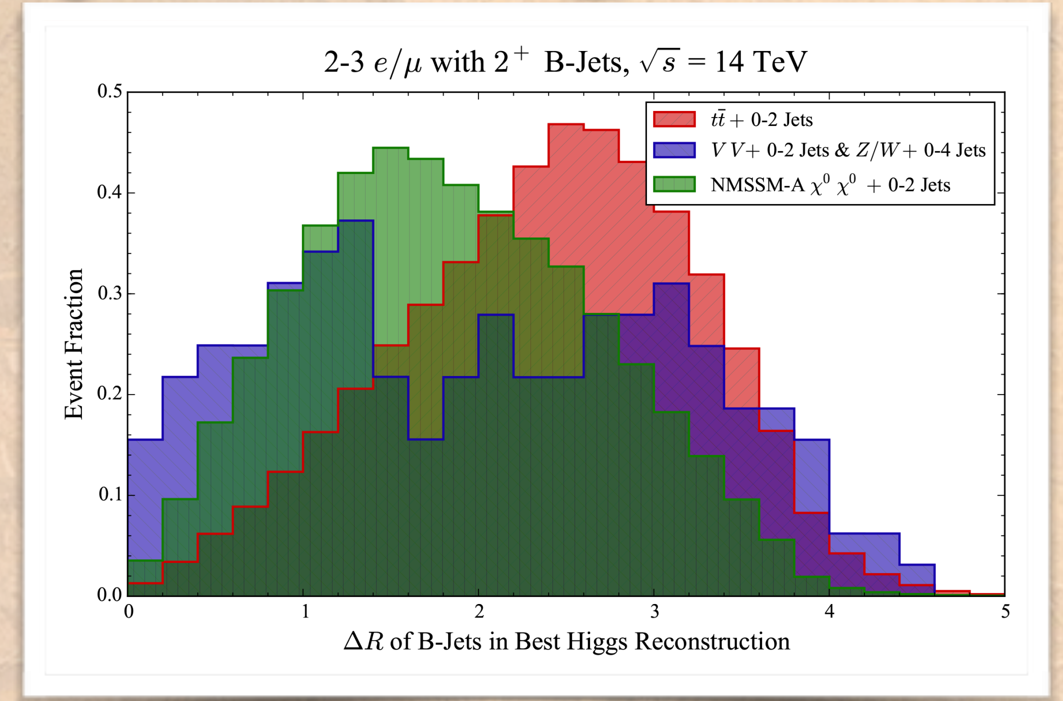
Optimize By Shape

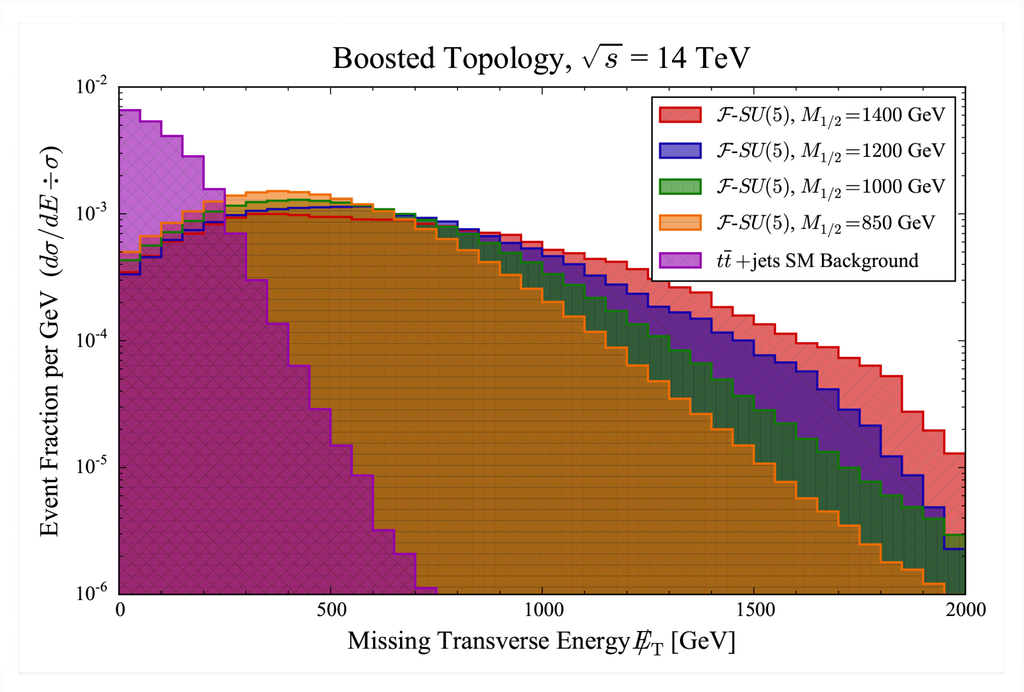
```
PLT_DAT_001 = DIR:"./Cuts", FIL:"Forward:BG:MEG:TTBAR_*"
PLT_DAT_002 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:850_*"
PLT_DAT_003 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1000_*"
PLT_DAT_004 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1200_*"
PLT_DAT_005 = DIR:"./Cuts", FIL:"Forward:FSU5_VBF_25:1400_*"

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"
```

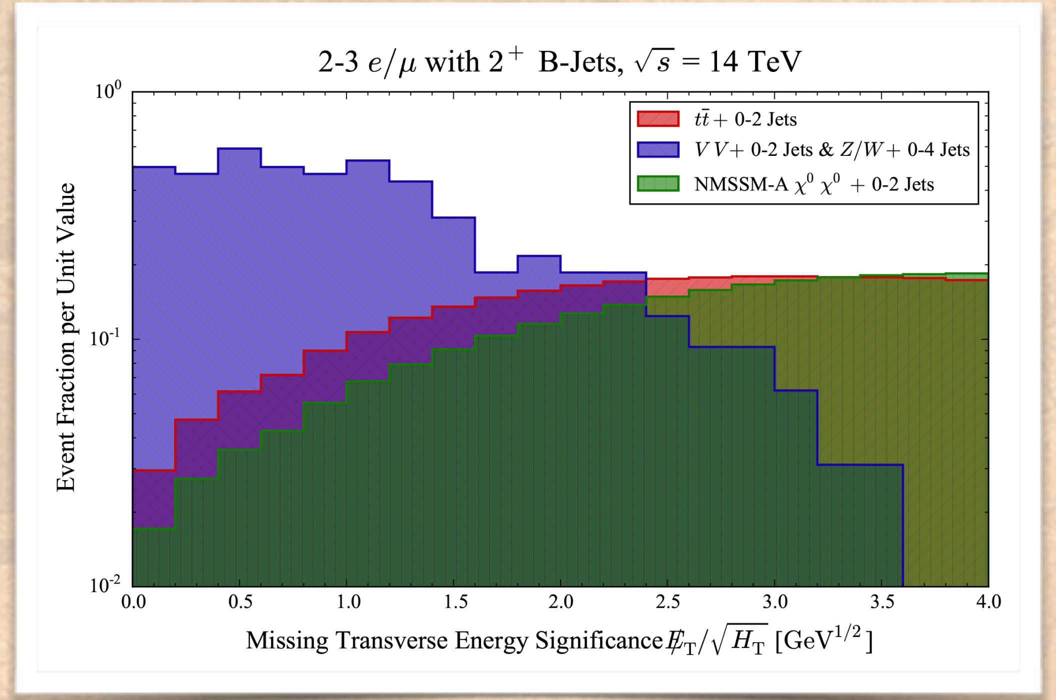
- Shape plots are unit normalized
- Bins are not left/right compounded

Optimize By Shape









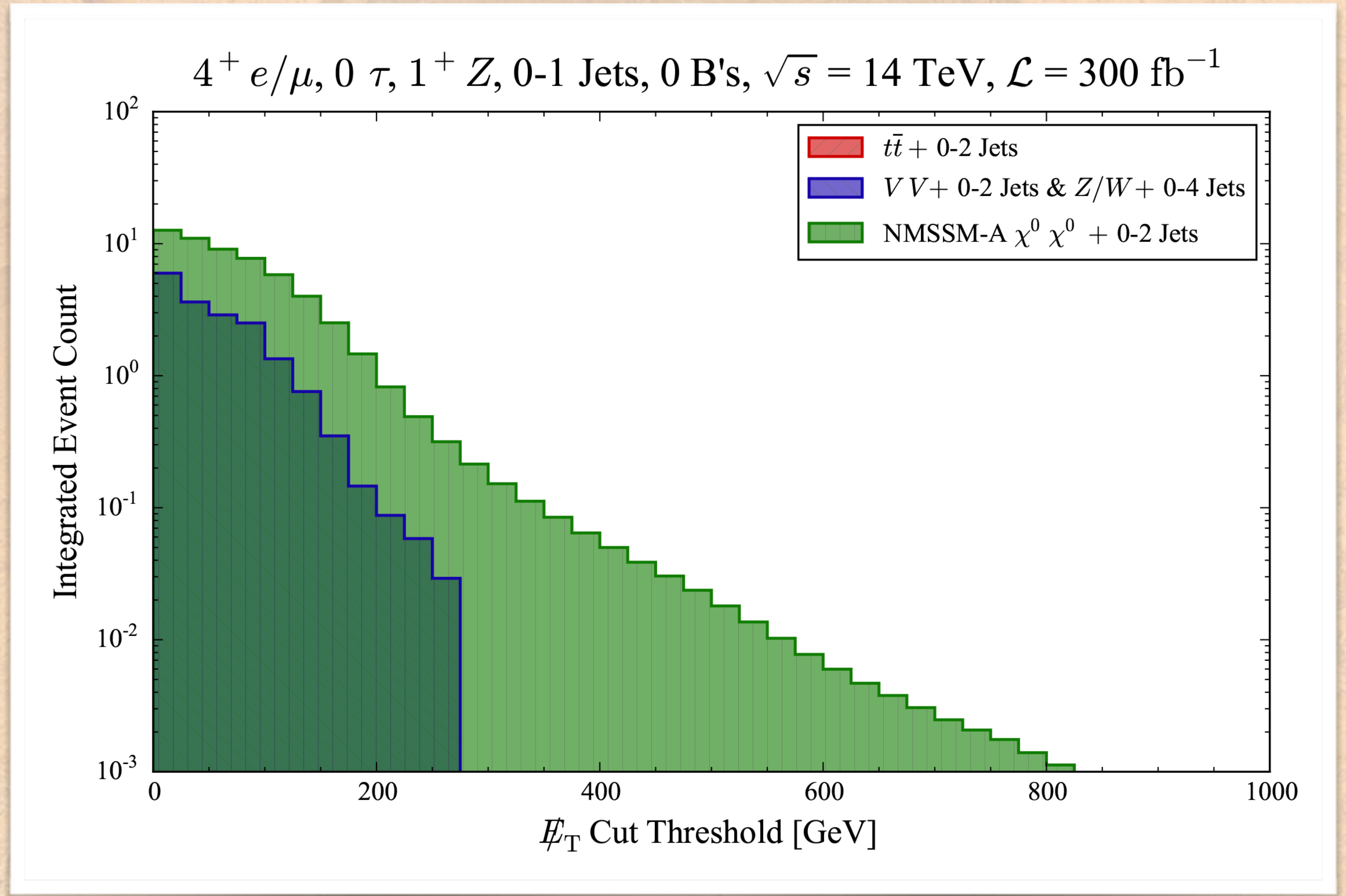
Apply Selection Cuts

```
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"
```

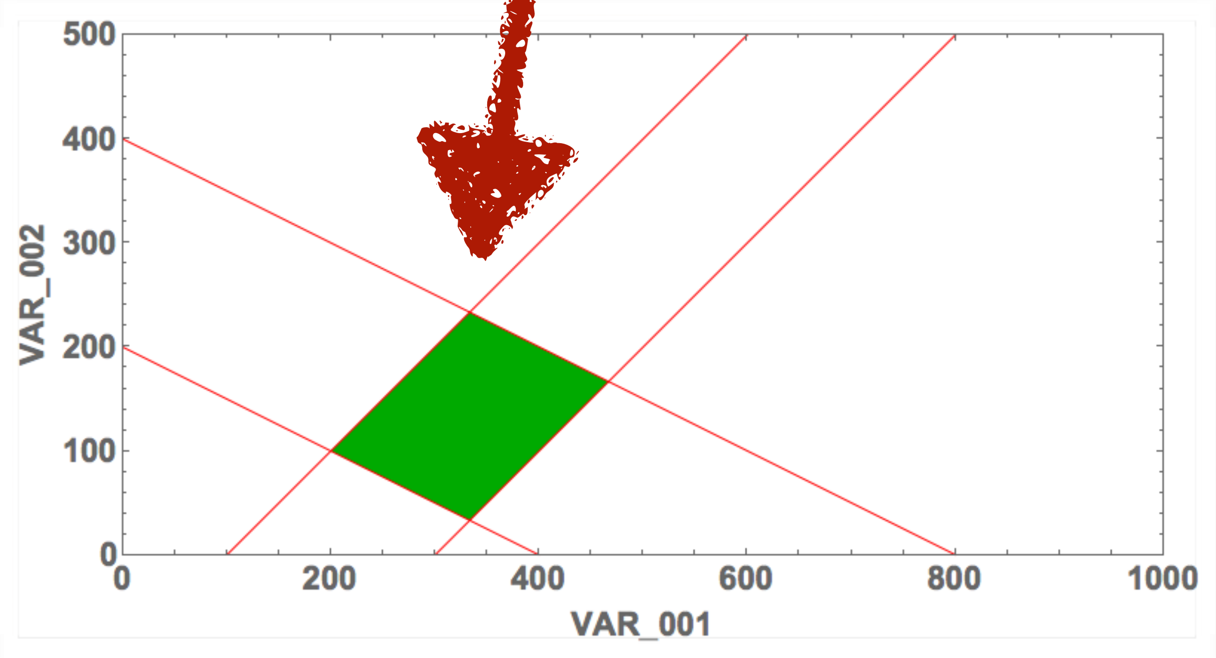
Optimized Plot Output



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

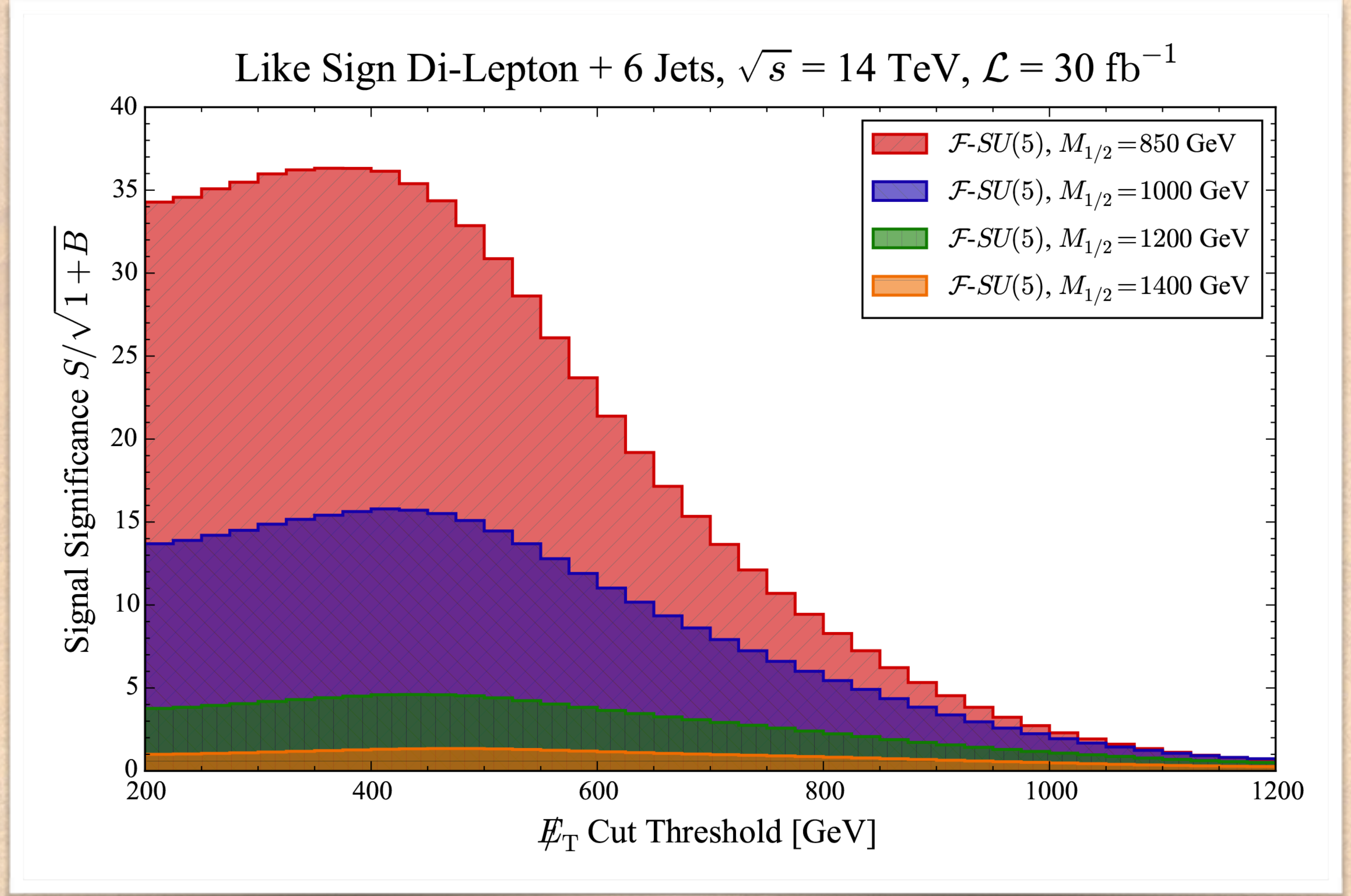
Transform Bin Channels

```
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},
```

- 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"
```

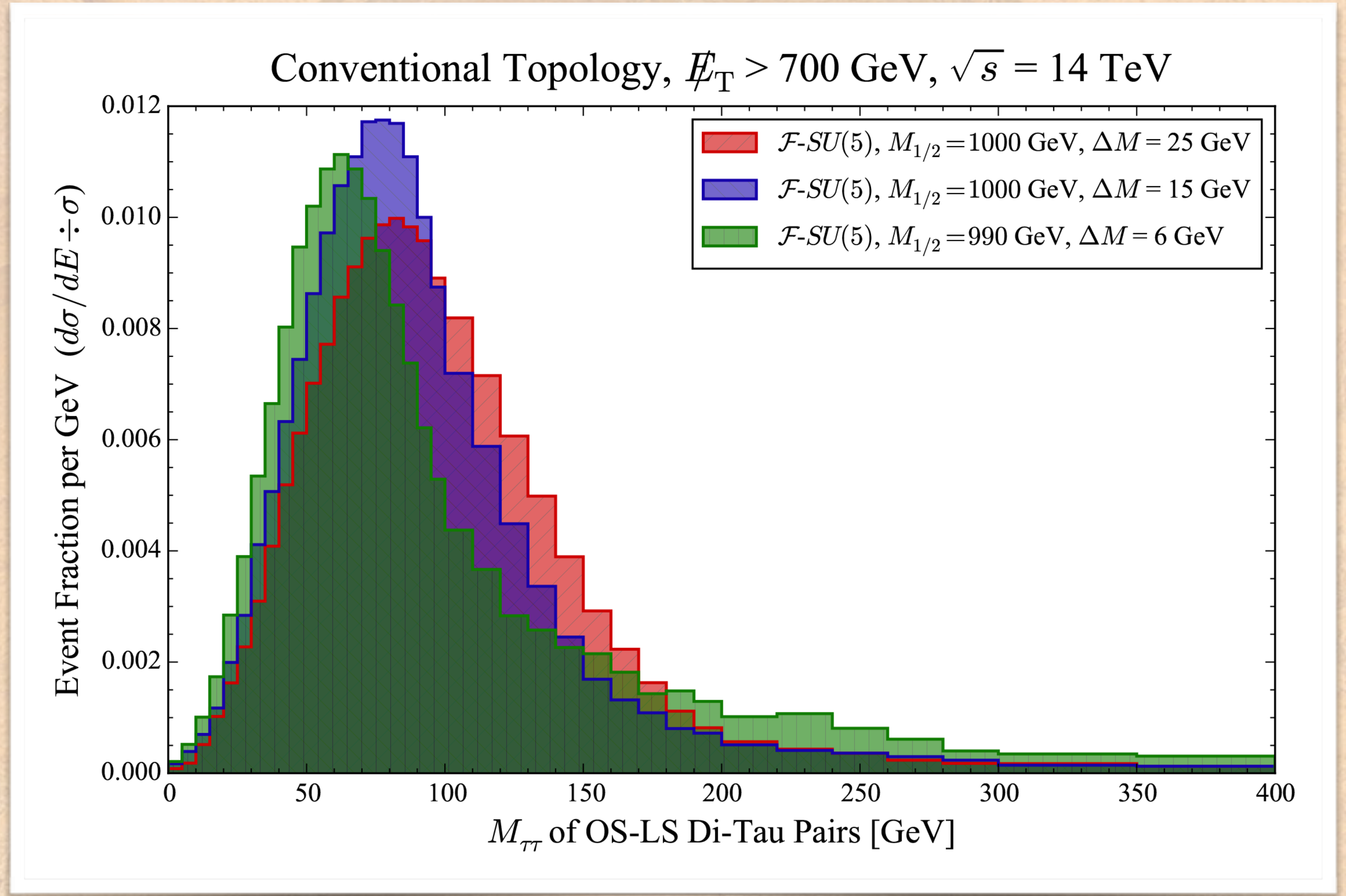
Transform Bin Channels

```
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
```

- 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_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

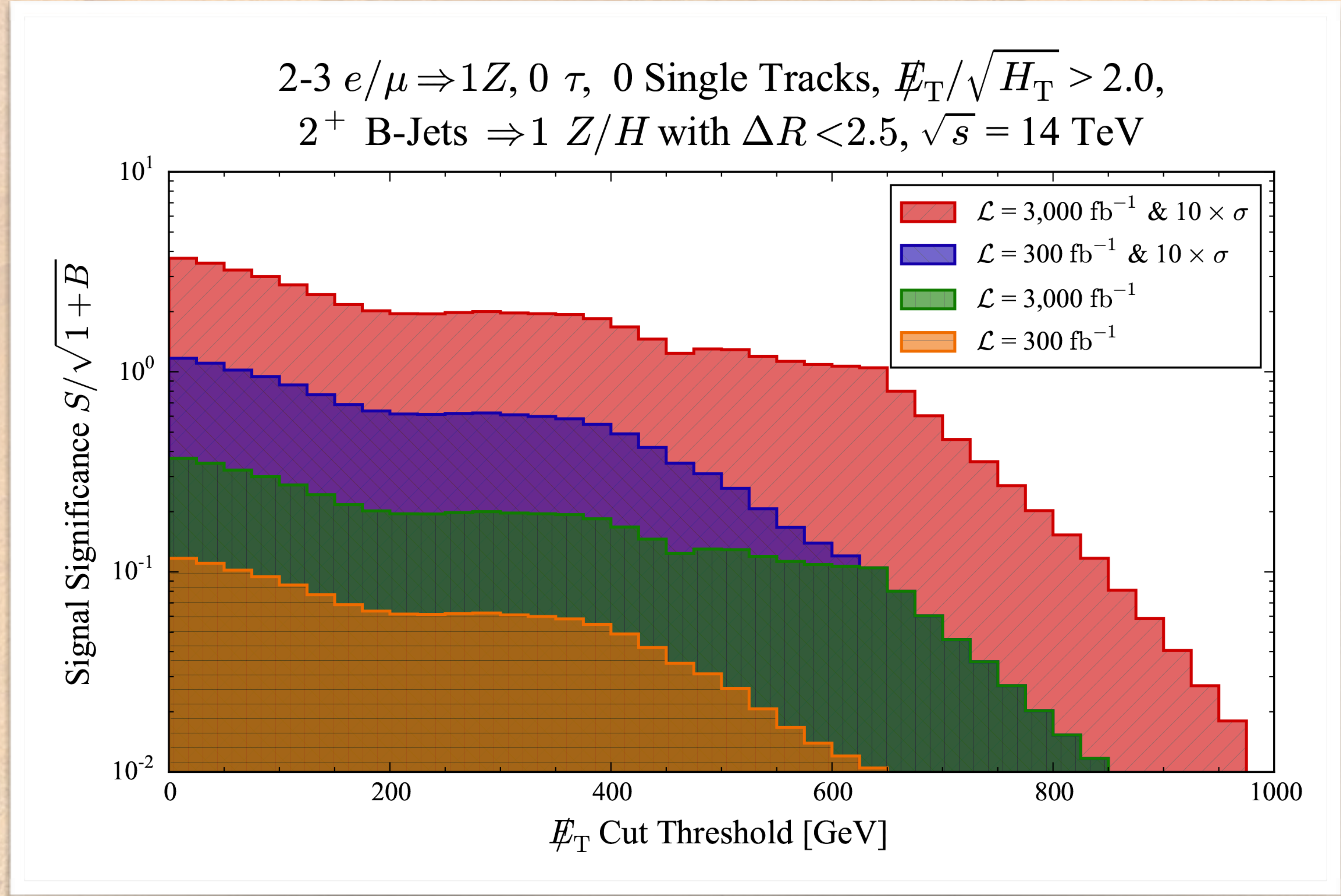


Transform Bin Channels

```
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} ],

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

- **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)**

Transform Bin Channels



RHADAManTHUS

Recursively Heuristic Analysis, Display, And Manipulation: The Histogram Utility Suite

- Heuristic *adjective* \hyü-'ris-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
- 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 …