

White Box Analysis

Box C : Signal + Background

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Data Boxes :

- Signal + Background Box » Accelerator Data
- Background Box » Monte Carlo of SM Background

Terminology :

- Identified Object = Jet, b-Jet, Electron, Muon, Tau, Photon
- All Energies are Transverse
- $H_T = \sum$ Transverse Energies of Given Object(s)
- MET = Missing Transverse Energy
- $m^2_{\text{Objects}} = (\sum_{\text{Objects}} p^{\mu}_i)^2$

Signal + Background

SMbox: [Box10fb-1a.lhco.gz](#) through [Box10fb-1d.lhco.gz](#) Aug 9

* BoxC: [BoxC10fb-1.lhco.gz](#) Aug 16

Signal Only

Scott or ScottCut: [scott1-612.lhco](#) 10 fb-1 June 13 (Slightly Different Cuts)
BoxB 150 fb-1

Background

* BGbox: [Background5fb-1a.lhco.gz](#) and [Background5fb-1b.lhco.gz](#) Aug 9

(Resource !)

* White Box Analysis

PGS4 and ChRoot from UPenn Group

Signal :

Variation of (Standard) SUSY ([pythia](#))

- (Very) Easy to See and Separate from Background
- Opportunities for Interesting Analysis

[Leptons + Jets + MET](#)

Background :

Standard Model Physics ([pythia](#))

Detector / Fakes - Mis-identification / Overlaps

Event Selection Triggers + Cuts

Trigger Name	L1	L2
1) Inclusive isolated lepton (muon/electron)	30 GeV	180 GeV
2) Lepton (muon/electron) plus jet	(20 GeV, 100 GeV)	(130 GeV, 200 GeV) (lepton, jet)
3) Isolated dileptons (mumu/ee)	15 GeV	60 GeV
4) Dileptons (mumu/ee) plus jet	(10 GeV, 100 GeV)	(45 GeV, 150 GeV) (ll, jet)
5) Isolated dileptons (emu)	10 GeV	30 GeV
6) Isolated lepton (mu/ e) plus isolated tau	(15 GeV, 45 GeV)	(45 GeV, 60 GeV) (lepton, tau)
7) Isolated ditau	60 GeV	60 GeV
8) Inclusive isolated photon	80 GeV	80 GeV
9) Isolated diphoton	25 GeV	40 GeV
10) Inclusive MET	90 GeV	200 GeV
11) Inclusive single-jet	400 GeV	1000 GeV
12) Jet plus MET	(180 GeV, 80 GeV)	(300 GeV, 125 GeV) (jet, MET)
13) Acoplanar jet and MET (1 < Dphi < 2)	(100 GeV, 80 GeV)	(150 GeV, 80 GeV) (jet, MET)
14) Acoplanar dijets (Dphi < 2)	200 GeV	400 GeV

***Selection Cuts:**

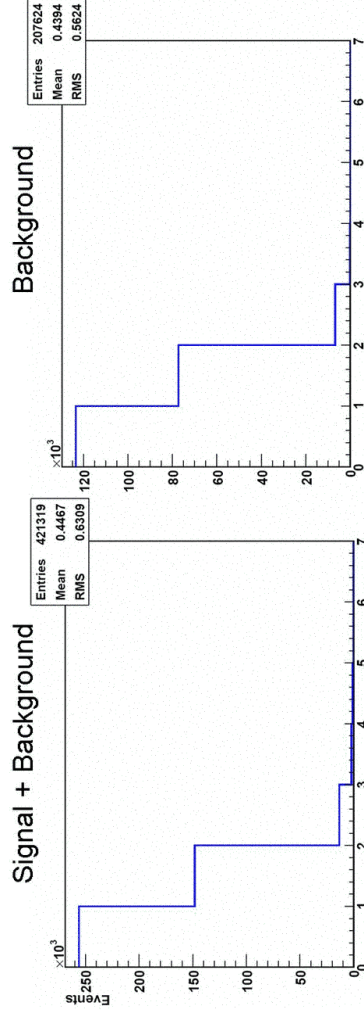
L2 Trigger(i)
 AND MET > 150 GeV
 AND (($H_T > 600$ GeV if 0 Leptons) $H_T = \sum \text{Jet} + \text{MET}$
 OR ($H_T > 500$ GeV if 1 Lepton)
 OR ($H_T > 400$ GeV if 2 Leptons)
 OR ($H_T > 0$ GeV if >3 Leptons))
 * Must be applied to Signal Boxes

	Signal + Background	Background
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)
		S/B ' 0

Signal / Background Cuts

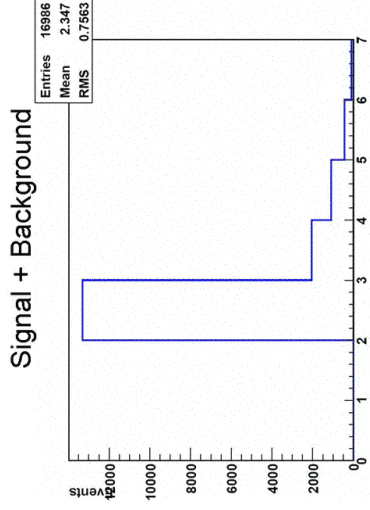
- Apply Cuts to Both Signal + Background Sample and Background Sample to Improve S/B
- Cuts Optimized - Depending on Signal Search
- Here Focus on General Lepton + Jets + MET Signature (Standard SUSY)

Leptons :

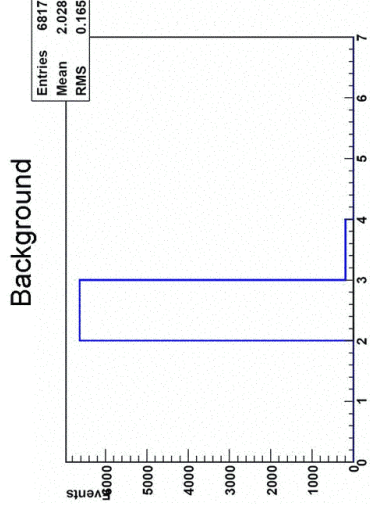


Most of SM Background comes with 0 or 1 Lepton

$N_{\text{Lepton}} \geq 2$



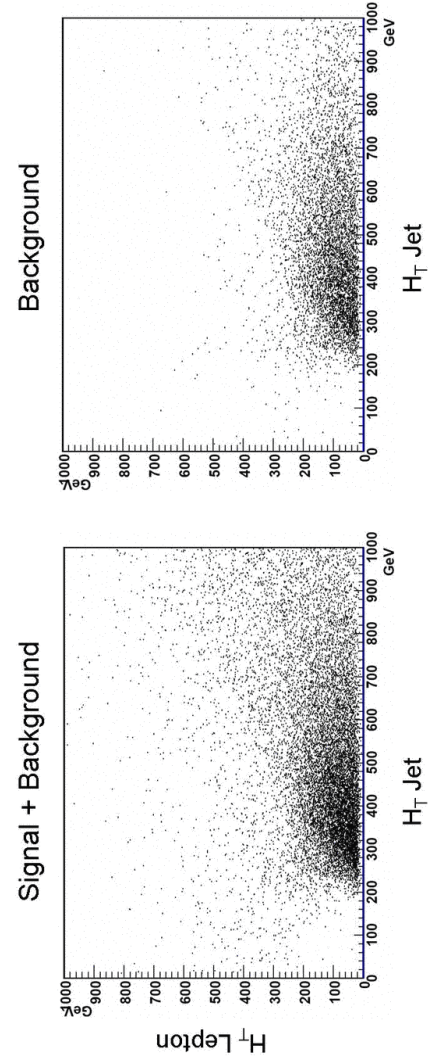
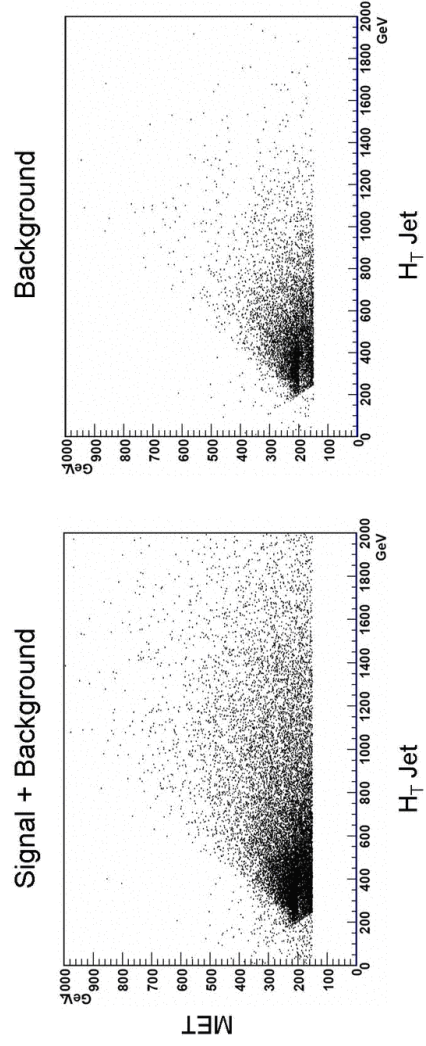
Can already see excess in $N_{\text{Lepton}} \geq 3$



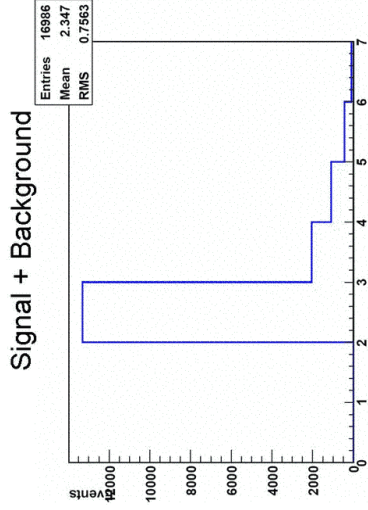
» Leptonic $t\bar{t}$! $ll\text{ } b\bar{b}$ + MET

	Signal + Background	Background
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)
AND ≥ 2 Leptons	16986 (0.040)	6817 (0.033)
AND ≥ 2 Jets	16799 (0.040)	6716 (0.032)

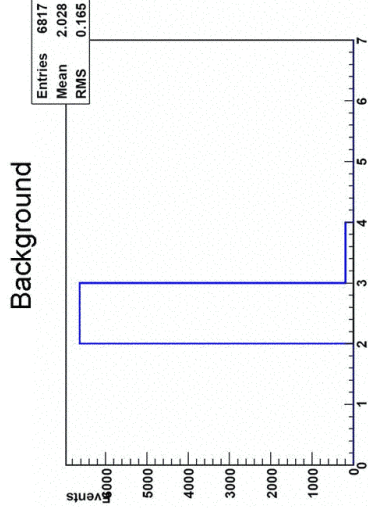
S/B ' 1/5



$N_{\text{Lepton}} \geq 2$



Can already see excess in $N_{\text{Lepton}} \geq 3$
 Apply Cut



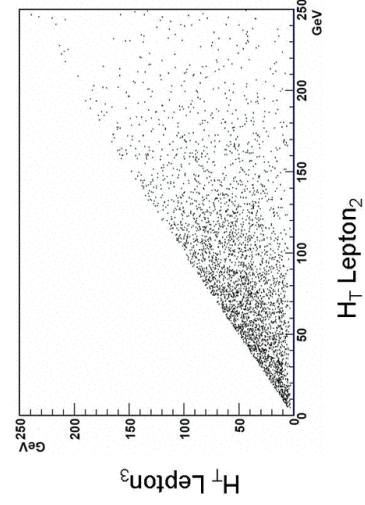
» Leptonic $t\bar{t}$! ll bb + MET

	Signal + Background	Background
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)
AND ≥ 2 Leptons	16986 (0.040)	6817 (0.033)
AND ≥ 2 Jets	16799 (0.040)	6716 (0.032)
AND ≥ 3 Lepton	3656 (8.7 $\times 10^{-3}$)	189 (9.1 $\times 10^{-4}$)
		S/B ' 8

- For Background with N Physics Objects –
N+1 th Object Typically Soft
- For Signal with > N Physics Objects –
N+1 th Object Typically Harder

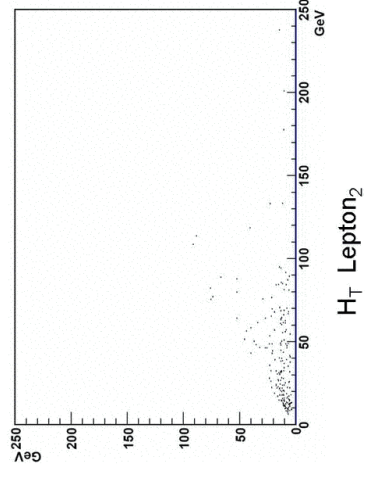
$$N_{\text{Lepton}} \geq 3$$

Signal + Background



Indicates Hard ≥ 3 Lepton process

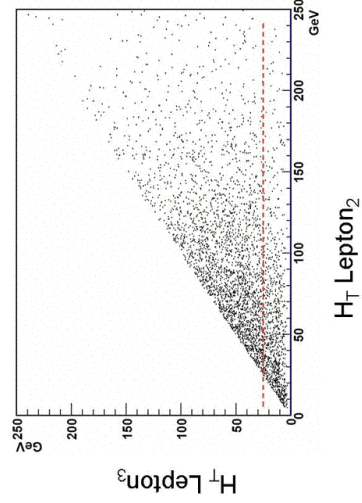
Background



e.g. Leptonic $t\bar{t}$! || $b\bar{b}$ + MET
with b ! ! X and l escapes b-jet

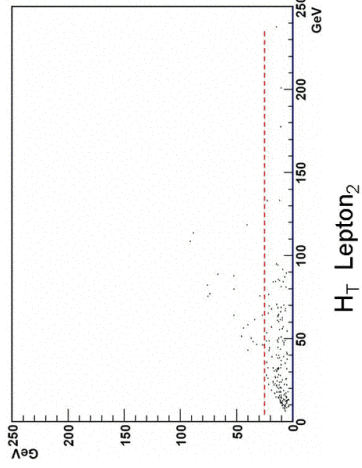
$N_{\text{Lepton}} \geq 3$

Signal + Background



Indicates Hard ≥ 3 Lepton process

Background



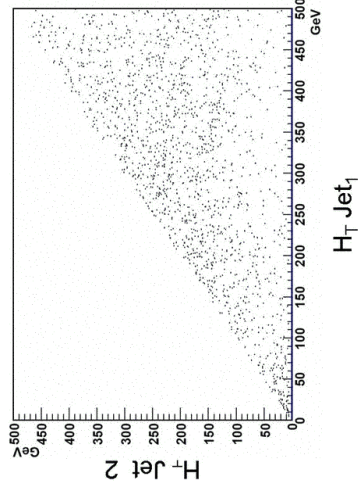
e.g. Leptonic $t\bar{t}$! $bb + MET$
with $b \rightarrow X$ and l escapes b -jet

Apply Cut

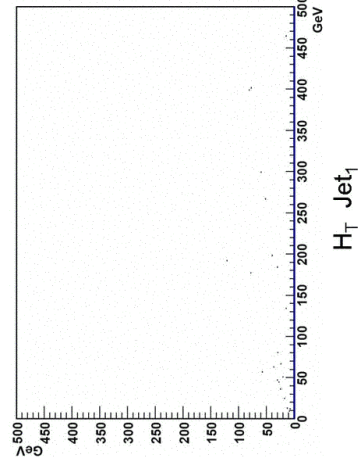
	Signal + Background	Background
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)
AND ≥ 2 Leptons	16986 (0.040)	6817 (0.033)
AND ≥ 2 Jets	16799 (0.040)	6716 (0.032)
AND ≥ 3 Lepton	3656 (8.7 $\times 10^{-3}$)	189 (9.1 $\times 10^{-4}$)
AND 3 rd Lepton > 25 GeV	2746 (6.5 $\times 10^{-3}$)	22 (1.1 $\times 10^{-4}$)
		S/B '60

$N_{\text{Lepton}} \geq 3$
3rd Lepton > 25 GeV

Signal + Background



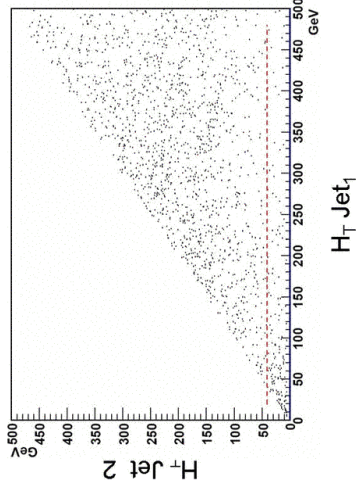
Background



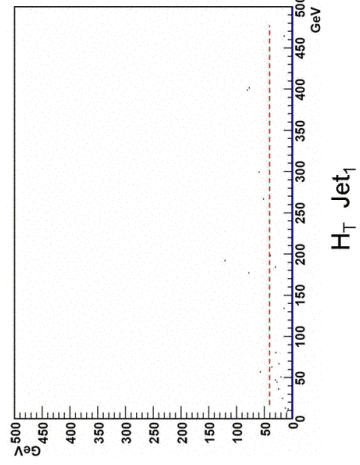
Indicates Hard (≥ 3 Lepton and
 ≥ 2 Jet) Process

$N_{\text{Lepton}} \geq 3$
3rd Lepton > 25 GeV

Signal + Background



Background



Indicates Hard (≥ 3 Lepton and
 ≥ 2 Jet) Process

Apply Cut

	Signal + Background	Background
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)
AND >= 2 Leptons	16986 (0.040)	6817 (0.033)
AND >= 2 Jets	16799 (0.040)	6716 (0.032)
AND >= 3 Lepton	3656 (8.7 £ 10 ⁻³)	189 (9.1 £ 10 ⁻⁴)
AND 3 rd Lepton > 25 GeV	2746 (6.5 £ 10 ⁻³)	22 (1.1 £ 10 ⁻⁴)
AND 2 nd Jet > 40 GeV	2571 (6.1 £ 10 ⁻³)	7 (3.4 £ 10 ⁻⁵)
		S/B ' 180

	Signal + Background	Background	Signal
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)	177118 (1)
AND >= 2 Leptons	16986 (0.040)	6817 (0.033)	88951 (0.50)
AND >= 2 Jets	16799 (0.040)	6716 (0.032)	88546 (0.50)
AND >= 3 Lepton	3656 (8.7 £ 10 ⁻³)	189 (9.1 £ 10 ⁻⁴)	59090 (0.34)
AND 3 rd Lepton > 25 GeV	2746 (6.5 £ 10 ⁻³)	22 (1.1 £ 10 ⁻⁴)	46826 (0.26)
AND 2 nd Jet > 40 GeV	2571 (6.1 £ 10 ⁻³)	7 (3.4 £ 10 ⁻⁵)	43910 (0.25)

S/B ' 180 (pythia) *

High Signal Efficiency



* Increasing Lepton and Jet Energy Cuts won't Hurt Signal Much

Mis-Identification Backgrounds :

25 GeV Jet ! Electron » 10^{-4}

	Signal + Background	Background	Signal
L2 Trigger + Selection Cuts	421319 (1)	207634 (1)	177118 (1)
AND >= 2 Leptons	16986 (0.040)	6817 (0.033)	88951 (0.50)
AND >= 2 Jets	16799 (0.040)	6716 (0.032)	88546 (0.50)
AND >= 3 Lepton	3656 (8.7 £ 10 ⁻³)	189 (9.1 £ 10 ⁻⁴)	59090 (0.34)
AND 3 rd Lepton > 25 GeV	2746 (6.5 £ 10 ⁻³)	22 (1.1 £ 10 ⁻⁴)	46826 (0.26)
AND 2 nd Jet > 40 GeV	2571 (6.1 £ 10 ⁻³)	7 (3.4 £ 10 ⁻⁵)	43910 (0.25)
OR >= 2 Leptons >=3 Jets		3641	
2 nd Jet > 40 GeV		(1.7 £ 10 ⁻²)	
3 rd Jet > 25 GeV			

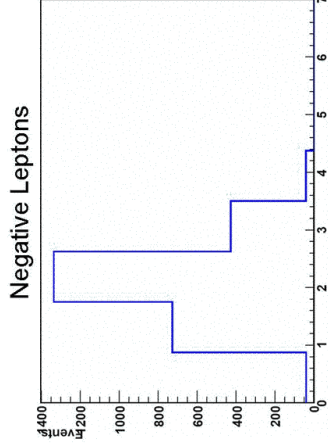
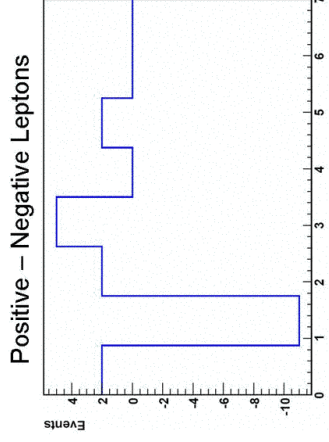
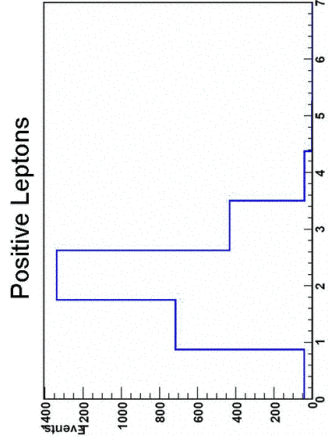
Physics Analysis of Signal + Background

- Integrated Luminosity of 10 fb^{-1}
 - L2 Trigger + Selection + S/B Cuts ! **2571** Signal + Background Events .
 - With an Estimated **15** Background Events (pythia)

Charge Asymmetry :

Strong SUSY production

- $pp \rightarrow gq_{L,R}, q_{L,R} q_{L,R}$ (t-channel) $q=u,d$ charge asymmetry
 - q_L NC+CC Decays - transfer charge asymmetry to leptons ! | X
 - q_R NC Decays - No lepton asymmetry from SUSY decays
- Lepton Charge Asymmetry) Some gq_L, q_L (t-channel)
- Lepton Charge Symmetry) Consistent with gg, gq_R (t-channel) or $q_{L,R}q_{L,R}$ (s-channel)

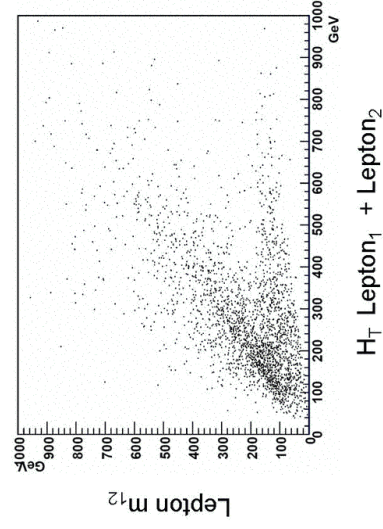


Consistent with Vanishing
Lepton Charge Asymmetry

No Indication for $g_{\bar{L}} \text{ or } q_{\bar{L}} q_L$
(t-channel) production

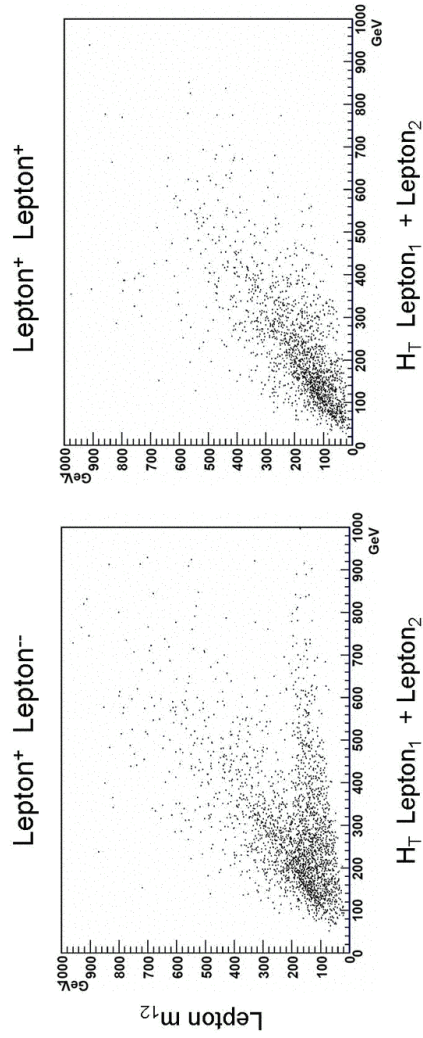
Kinematic Features : Signal + Background

1st and 2nd Leptons

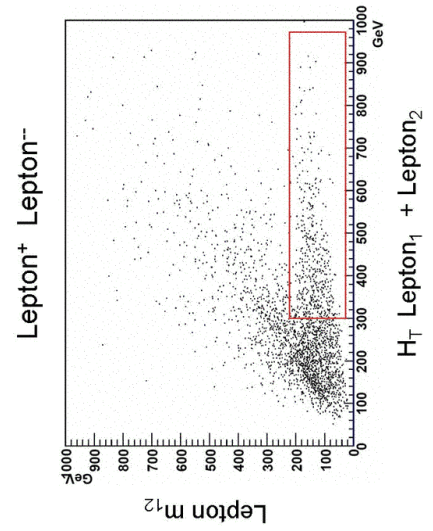


Two populations of events – Horizontal and Diagonal Branches

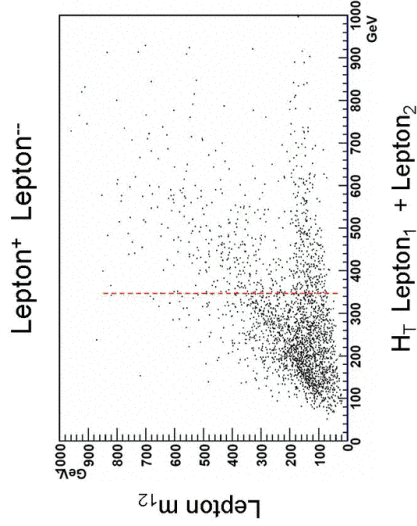
Shaping Along Bottom Due to Isolation Requirement



Horizontal Branch Present Only in Opposite Sign



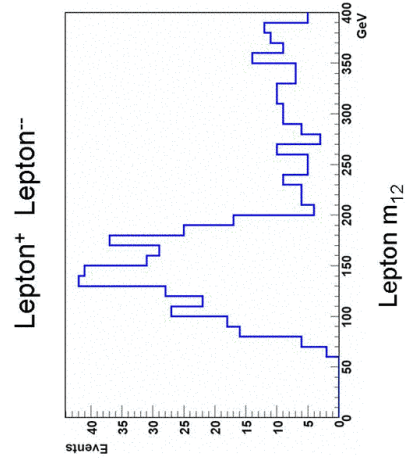
- Highly Boosted, Small ΔR) Lepton Pair Recoiling Against Something Hard
- Upper Edge in m_{12}) Originates from Decay of Light State With MET
- Opposite Sign Lepton Pair Only) Light State is Neutral if Decays by $X^0 \rightarrow l^+ l^- + MET$



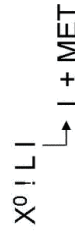
- Horizontal Branch Lepton m_{12} Edge
- Apply Cut : Separate Horizontal and Diagonal Branches
- H_T Lepton₁ + Lepton₂ > 350 GeV

- Highly Boosted, Small ΔR) Lepton Pair Recoiling Against Something Hard
- Upper Edge in m_{12}) Leptons Originate from Decay of Light State With MET
- Opposite Sign Lepton Pair Only) Light State is Neutral if Decays by $X^0 ! l^+ l^- + MET$

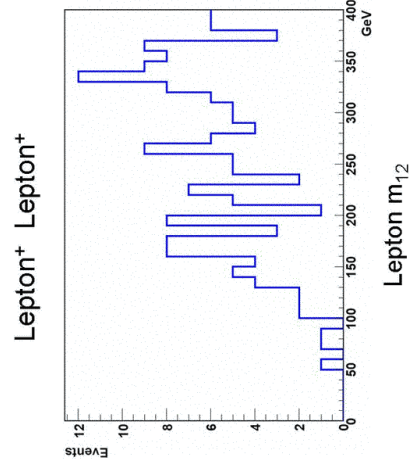
L2 Trigger + Selection + S/B Cuts + H_T (Lepton₁ + Lepton₂) > 350 GeV



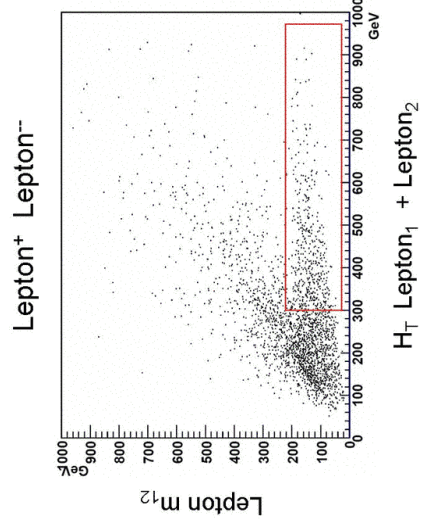
Edge) Intermediate Resonance



$$m_{12,max} = f(m_{X^0}, m_l, m_{MET})$$



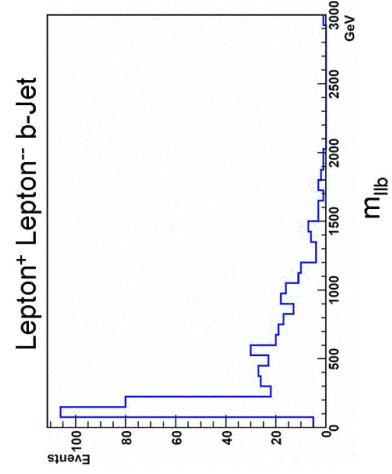
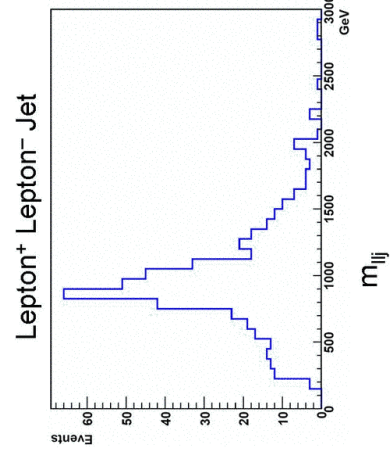
Note: $l^+ l^-$ Roughly Same in Magnitude in Tail along Diagonal Branch – Consistent with Mis-match



1. Isolate Horizontal Branch by
 - i) H_T Lepton₁ + Lepton₂ > 300 GeV
 - ii) Lepton m_{12} < 200 GeV
2. Look for Object Recoiling Against X^0

- Highly Boosted, Small ΔR) Lepton Pair Recoiling Against Something Hard
- Upper Edge in m_{12}) Leptons Originate from Decay of Light State With MET
- Opposite Sign Lepton Pair Only) Light State is Neutral IF Decays by $X^0 \rightarrow l^+ l^- + MET$

L2 Trigger + Selection + S/B Cuts +
 H_T (Lepton₁ + Lepton₂) > 300 GeV +
 Lepton m_{12} < 200 GeV

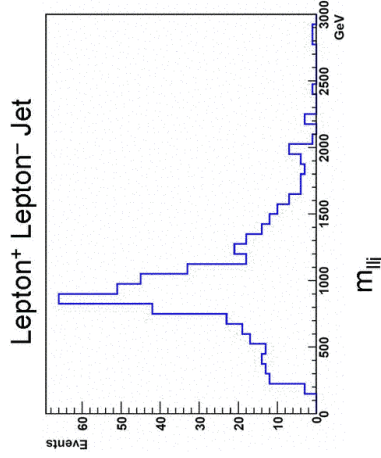


• "Resonance") X^0 Recoils Against Single Jet

$$Q \rightarrow l^+ l^- + (MET)$$

L2 Trigger + Selection + S/B Cuts +
 $H_T (\text{Lepton}_1 + \text{Lepton}_2) > 300 \text{ GeV} +$
 $\text{Lepton } m_{12} < 200 \text{ GeV}$

Notes:



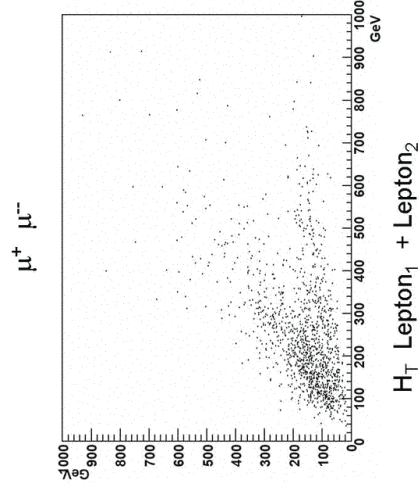
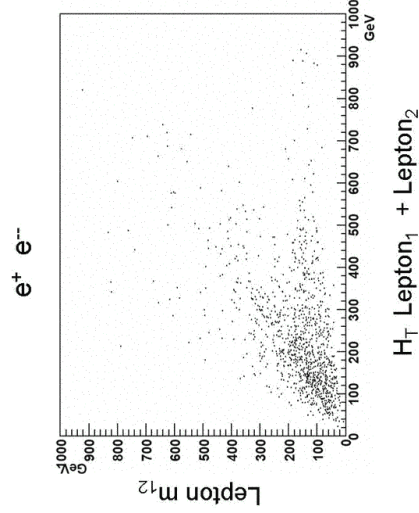
Effectively "Resonance" Even though MET in Decay - Since m_{l+l-} m_{max} MET '0 - Could probably apply Correction for non-zero MET

Tails from Jet Radiation and mismatching Leptons and Jets -
 . Could be Cleaned Up With
 . ΔR Cuts and Jet Merging

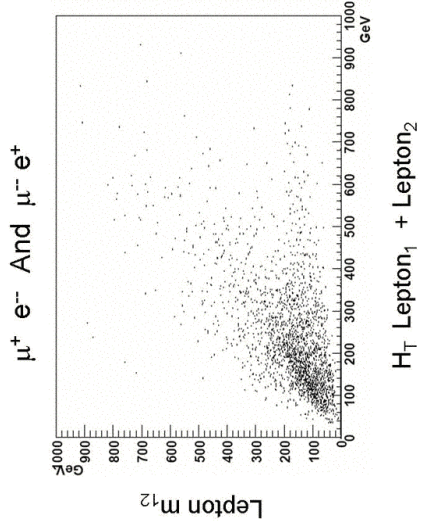
• "Resonance" X^0 Recoils Against Single Jet

$$Q \rightarrow j X^0 \rightarrow l^+ l^- + (\text{MET})$$

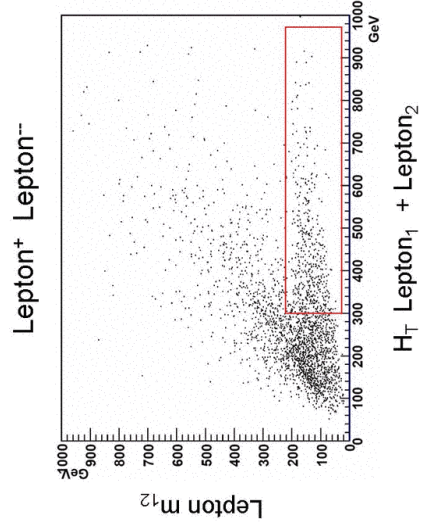
• Rate would indicate Strong Production



Horizontal Branch Present In Both $e^+ e^-$ and $\mu^+ \mu^-$

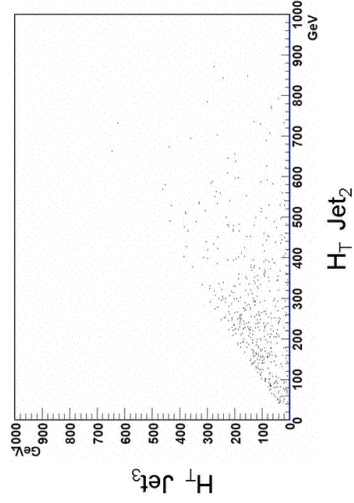


Horizontal Branch Also Present in $\mu^+ e^-$ And $\mu^- e^+$
) (Large) Lepton Flavor Violation in $X^0 \rightarrow l^+ l^- + MET$

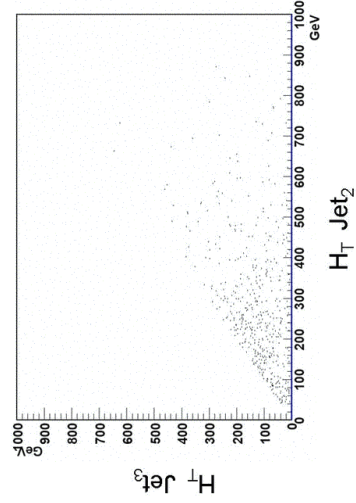


• Remainder of Event on Horizontal Branch

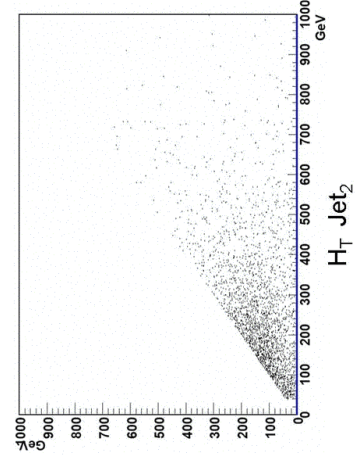
L2 Trigger + Selection + S/B Cuts +
 $H_T (\text{Lepton}_1 + \text{Lepton}_2) > 300 \text{ GeV} +$
 $\text{Lepton } m_{12} < 200 \text{ GeV}$



L2 Trigger + Selection + S/B Cuts +
 $H_T (\text{Lepton}_1 + \text{Lepton}_2) > 300 \text{ GeV} +$
 $\text{Lepton } m_{12} < 200 \text{ GeV}$



L2 Trigger + Selection + S/B Cuts

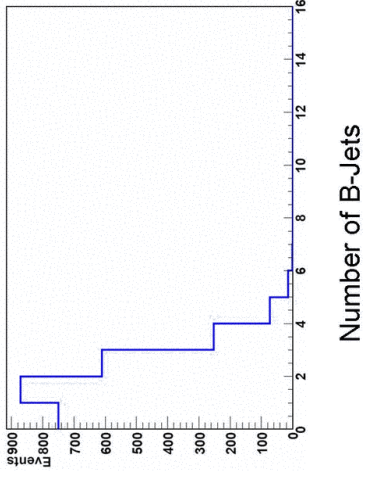
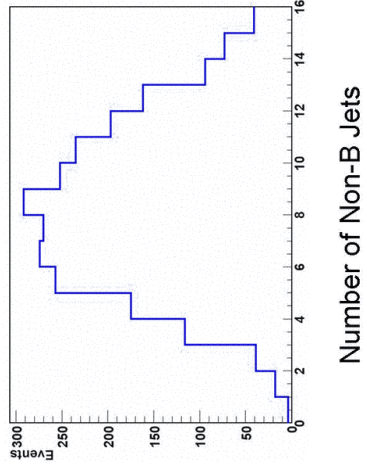


Indicates Hard ≥ 3 Jets On Both Horizontal and Diagonal Branches

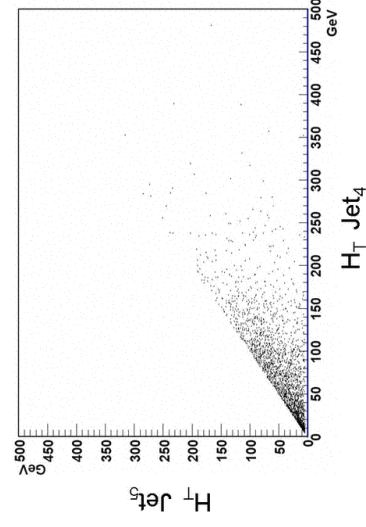
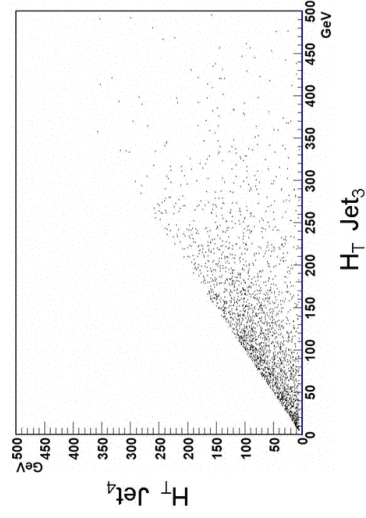
Consistent with gq_R and gg production Production

$g \rightarrow \geq 2 \text{ Jets}$

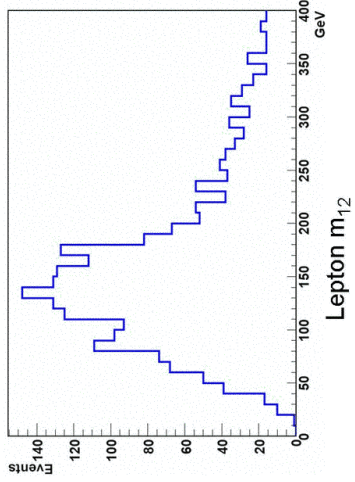
L2 Trigger + Selection + S/B Cuts



L2 Trigger + Selection + S/B Cuts



L2 Trigger + Selection + S/B Cuts



Can Subtract Combinatoric Background with assumptions

L2 Trigger + Selection + S/B Cuts

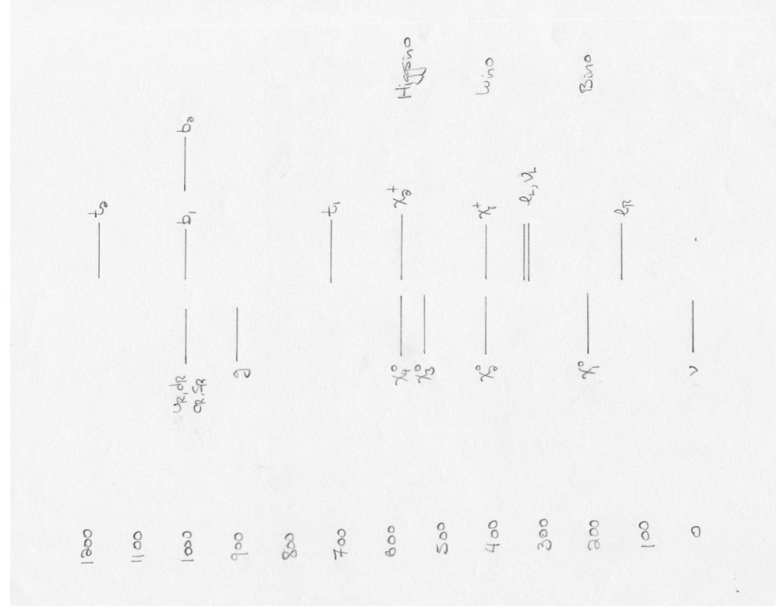
40 fb⁻¹ Signal Only

		# leptons						
# b jets	0	1	2	3	4	5	6	
0	161	1349	3353	3210	2646	975	294	
1	430	1883	3506	3557	2260	889	241	
2	513	1618	2608	2511	1469	572	151	
3	335	961	1382	1149	625	221	61	
4	146	394	490	358	190	64	16	
5	45	112	130	92	42	13	3	

Pulling Signals out of the Diagonal Branch : (Difficult)

- Additional Lepton Edges, Endpoints τ^+ , τ^+ , τ^+
- Other Edges, Endpoints lj
- Tri-Lepton Edges, Endpoints III (see UW Analysis)
- Resonances $ll, jj, bb, \gamma\gamma, jjj$ (top)

BoxC SUSY Spectrum :



BoxC SUSY Signal Features :

- LSP = Slepton η_R
- R-parity Violating Decays of Slepton η_R i) MET = ν
ii) Lepton Flavor/Number Violation
- Every Event has ≥ 4 Leptons
- Many Events have ≥ 6 Leptons
- Stop lighter than Gluino : Large L-R mixing from A_t
- Most Events have at least tt or tb
- Many Events have tttt or ttbb or ttbb
- q_L Heavy) Lepton Charge Symmetry
- $Br(q_R \rightarrow X_{1,0}^0 j)$ sizeable) Horizontal Branch
- Gluino Cascades “Difficult” to Reconstruct) Diagonal Branch
+ (Too Many Jets and Leptons) SUSY Combinatoric Confusion
+ Jet Eating)

Pythia Parameter file for Signal of Scott or BoxC BoxC10fb-1.lhco.gz
(White Box Analysis)

```

MSEL = 39 ! turn on SUSY processes
IMSS(1) = 1 ! generic SUSY scenario
IMSS(51) = 3 ! RPV
RVLAM(1,2,1) = 0.001
RVLAM(2,3,2) = 0.001
RVLAM(1,2,3) = 0.001
RMSS(1) = 210.0 ! bino
RMSS(2) = 440.0 ! wino
RMSS(4) = 530.0 ! mu
RMSS(3) = 900.0 ! gluino
RMSS(5) = 5.00 ! tan beta
RMSS(8) = 2500.0 ! left squark (1st-2nd generation)
RMSS(9) = 1000.0 ! right down squark (1st-2nd generation)
RMSS(10) = 1000.0 ! left squark (3rd generation)
RMSS(11) = 990.0 ! right down squark (3rd generation)
RMSS(12) = 910.0 ! right up squark (3rd generation)
RMSS(6) = 330.0 ! left slepton (1st-2nd generation)
RMSS(7) = 140.0 ! right slepton (1st-2nd generation)
RMSS(13) = 330.0 ! left slepton (3rd generation)
RMSS(14) = 140.0 ! right slepton (3rd generation)
RMSS(15) = 1100.0 ! bottom trilinear
RMSS(16) = 2800.0 ! top trilinear
RMSS(17) = 400.0 ! tau trilinear
RMSS(19) = 350.0 ! pseudo-scalar Higgs mass
    
```

Pythia Parameter file for Signal of SMBBox
Box10fb-1a.lhco.gz through Box10fb-1d.lhco.gz

```

MRPY( 2) = 0      ! allow a new random number seed
MRPY( 1) = 13370371 ! the new random number seed

MSEL      = 39      ! turn on SUSY processes
IMSS( 1) = 1       ! generic SUSY scenario
IMSS(51)=3        ! RPV
RVLAM(1,2,1)=0.001
RVLAM(2,3,2)=0.001
RVLAM(1,2,3)=0.001
RMSS( 1) = 210.0  ! bino
RMSS( 2) = 440.0  ! wino
RMSS( 4) = 530.0  ! mu
RMSS( 3) = 800.0  ! gluino
RMSS( 5) = 5.00   ! tan beta
RMSS( 8) = 2000.0 ! left squark (1st-2nd generation)
RMSS( 9) = 900.0  ! right down squark (1st-2nd generation)
RMSS(10) = 900.0 ! left squark (3rd generation)
RMSS(11) = 890.0  ! right down squark (3rd generation)
RMSS(12) = 810.0 ! right up squark (3rd generation)
RMSS( 6) = 330.0 ! left slepton (1st-2nd generation)
RMSS( 7) = 140.0 ! right slepton (1st-2nd generation)
RMSS(13) = 330.0 ! left slepton (3rd generation)
RMSS(14) = 140.0 ! right slepton (3rd generation)
RMSS(15) = 1100.0 ! bottom trilinear
RMSS(16) = 2800.0 ! top trilinear
RMSS(17) = 400.0  ! tau trilinear
RMSS(19) = 350.0  ! pseudo-scalar Higgs mass
    
```

Lessons / Suggestions for Future LHCO :

- Consider Future Boxes with
 - Very Challenging Signal Isolation Requirements
 - Fewer Hard Leptons
 - Signals with Smaller or no MET (too much focus on MET)
 - ALPGEN for Background
 - (Please) no “Snowmass Benchmarks”