ChRoot Tools and Preliminary Analysis of Black Box B

Penn LHC Olympics Team:

- Presentation: Mike Ambroso, Michael Schulz
- Analysis: Mike Ambroso, Volker Braun, Brent Nelson, Michael Schulz
- Additional Support: V. Balasubramanian, E. Thomson, H. Williams

- Special Thanks: L. Rastelli, J. Thaler, S. Thomas, H. Verlinde

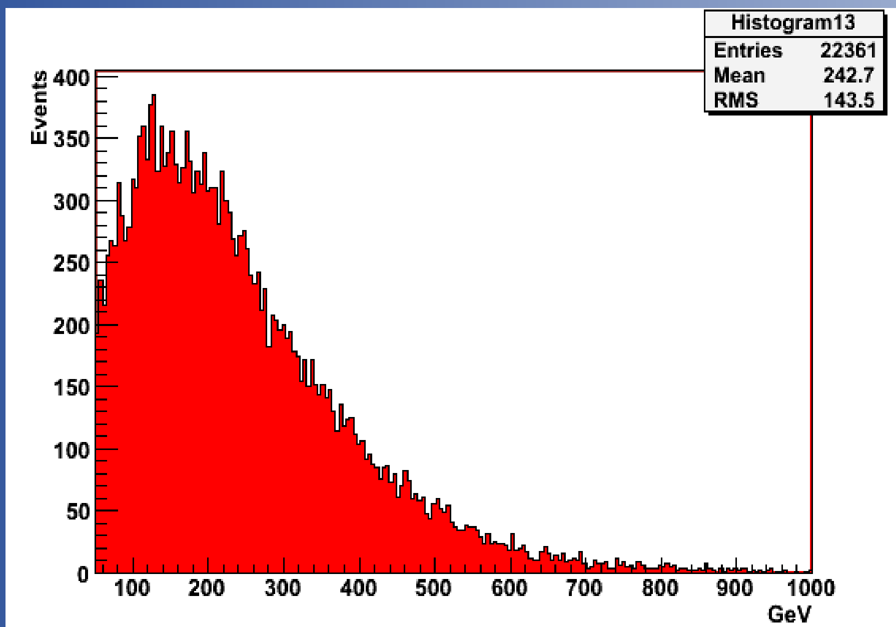
Plan of Talk: Two Parts

- Part I
  - Preliminary Analysis of Black Box B
    - Michael Schulz
- Part II
  - Description of ChRoot
    - Mike Ambroso
- (See Wiki for more details.)

Black Box B: First Look

- Level three trigger
  - We chose to implement cuts on the data by setting a “level three” trigger to remove certain detector objects;
  - used the default settings from the last version of Chameleon:
    - **`PTCUT = 25;`**
    - **`ETACUT = 2;`**
    - **`PTCUTJET = 50;`**
    - **`ETACUTJET = 3;`**
    - **`MISSINGPTCUT=50;`**
    - **`EFFMASSCUT=0;`**
- Total event rate
  - 22,366 signal events
  - integrated luminosity 20 fb^{-1}
  - σ x ε = 1.1183 pb
    - For comparison, Snowmass point SPS1A gives total SUSY production σ of 40pb, with gluino-gluino and squark-squark 3-5pb range — but this point has light superpartners!
    - Pair production of electroweak gauginos is down an order of magnitude from this.
  - If Box B is SUSY, $\sigma \approx 1$ pb means heavier gluinos & squarks, roughly TeV.

Missing Transverse Energy



`ScottCut.Histogram( EffMass(), 0, 5000, 100)`

- There is a substantial amount of MET in the sample.
- 82.3% of the events have MET > 100 GeV.
- Half have MET > 200 GeV.
- The distribution is the same across many different types of events
  - e.g., jets only (no leptons), or leptons only (no jets).

“Lightest New Particle” (LNP)

- We conclude that MET is carried by a neutral particle without SU(3) charge, stable on the time scale of the detector.
- Since the likelihood of getting 100s of GeV worth of MET from neutrinos is small:
- We assume that the **MET is due to a new stable particle**, and that it’s the lightest such particle: the LNP.
- The peak above suggests that if there are two LNPs per event, then the **mass of the LNP is approximately 120 GeV.**

Inclusive Counts

Number	0	1	2	3	4	5
	Events with Number of outgoing tracks					
Photons	21325	1007	28	1	0	0
Jets	868	1271	2323	3978	4833	4089
BJets	14297	5926	1796	294	42	6
Lepton	1478	4702	7083	5481	2634	785
e-	12910	7827	1478	141	5	0
e+	12882	7750	1596	128	5	0
mu-	11421	8605	2129	200	6	0
mu+	11279	8682	2211	184	5	0
tau-	21748	601	12	0	0	0
tau+	21737	617	7	0	0	0

- Lots of leptons!
- Few prompt photons ⇒ **probably not a world with gravitino/higgs-like LNP.**
- Looks "b-rich": lots of events were b-tagged, many more than in previous SUSY black boxes. Significance?

Trigger Menu

Trigger	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Percent	48.4	60.1	55	59	55.3	3.2	0	1.9	0	50.6	6.8	60	37.2	6.4

- Where are all the (hadronically decaying) taus?!
  - Definitely not "tau-rich."
  - No events captured on the isolated di-tau trigger, and very few on the isolated lepton plus tau trigger.

Lepton Counts

Single-lepton counts for all events

Lepton	e-	mu-	tau-	e+	mu+	tau+
count	994	1287	42	1060	1269	50

Dilepton counts for all events

count	e-	mu-	tau-	e+	mu+	tau+
e-	201	581	23	988	1064	35
mu-	*	353	34	975	1455	68
tau-	*	*	1	32	63	0
e+	*	*	*	217	570	17
mu+	*	*	*	*	377	27
tau+	*	*	*	*	*	2

Single-lepton counts for events without jets

Lepton	e-	mu-	tau-	e+	mu+	tau+
count	25	49	0	20	37	2

Dilepton counts for events without jets

count	e-	mu-	tau-	e+	mu+	tau+
e-	1	9	0	55	77	0
mu-	*	5	0	78	112	6
tau-	*	*	0	1	4	0
e+	*	*	*	4	13	0
mu+	*	*	*	*	5	1
tau+	*	*	*	*	*	0

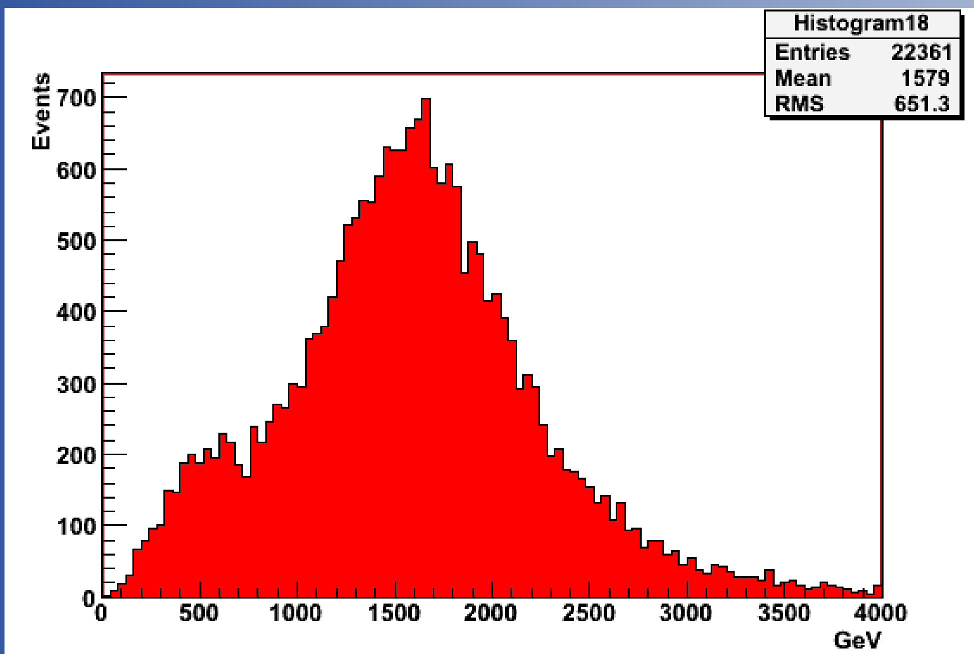
- Lots of same-sign dileptons (SSDL)
  - Most come from jets (few "clean" cases, probably just where jets failed the p_T cut).
- 5481 trilepton events!
- SUSY?

Trilepton-counts (lepton content {l+,l-,l'})
for all events

{l+,l-} \ l'	e+	e-	mu+	mu-	tau+	tau-
{e+, e-}	297	258	530	520	32	19
{mu+, mu-}	564	591	446	475	33	36
{tau+, tau-}	0	1	2	1	0	0

Effective Mass Distribution

Effective mass distribution of all objects, all events:



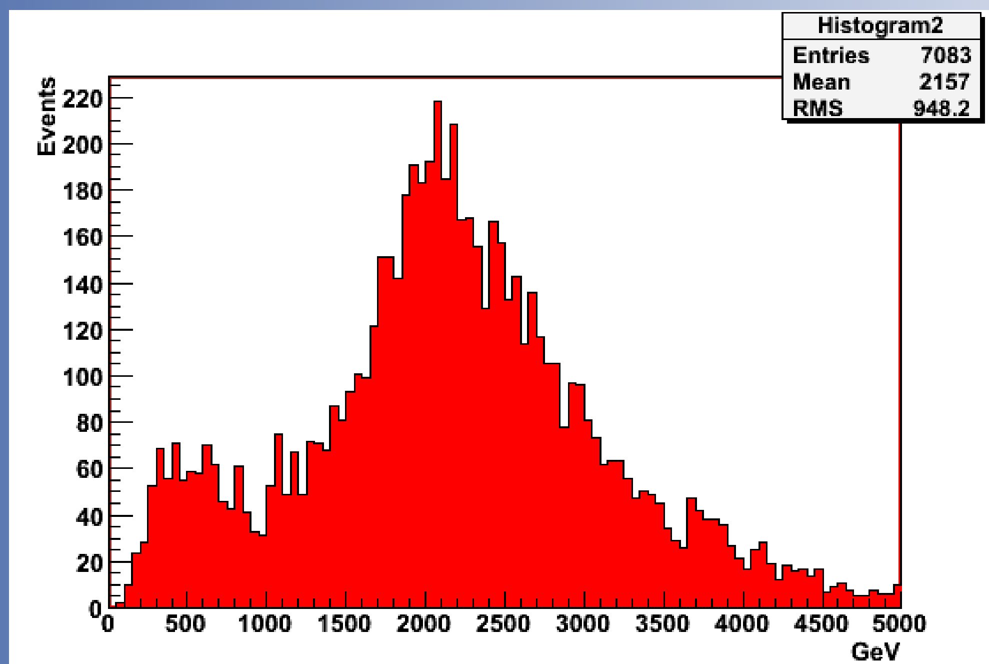

```
ScottCut.Histogram( EffMass(), 0, 5000, 100)
```

- Two peaks: around 600 GeV and 1600 GeV.
- Assume **pair production of two new particles:**
- **Particle B ($m_B \approx$ 300 GeV)**
  Particle C ($m_C \approx$ 800 GeV).
- # counts in each region ($\approx$ 2356 &17359, respectively) implies production cross-sections of **$\sigma_B \approx$100 fb and $\sigma_C \approx$900 fb**.
- Former is consistent with electroweak gaugino production at that mass range.
- Latter is roughly consistent with strong production of fermions at that mass range.

  (In contrast, 800 GeV scalar pair-production would have a cross-section of about 50-80 fb.)

Invariant Mass Distribution for DiLepton Events

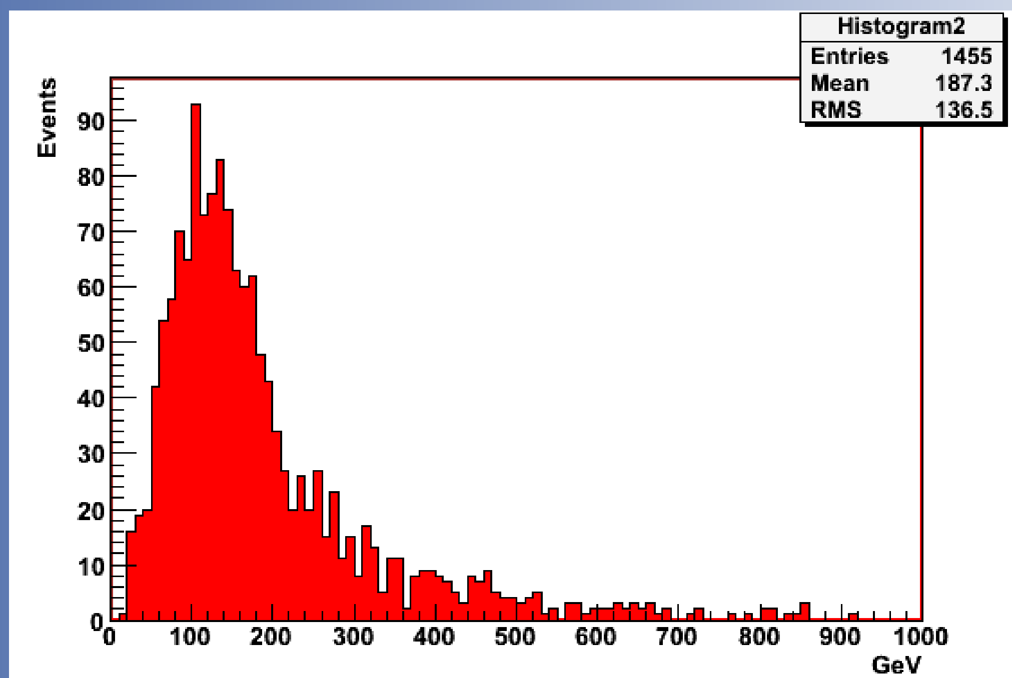
The two distinct regions are more clearly separated if we look at the invariant mass distribution of the (rather large) subset of events with two leptons:




```
ScottCut->Select( NumOf(oLepton)==2)).Histogram( InvMass(),0, 5000, 200)
```

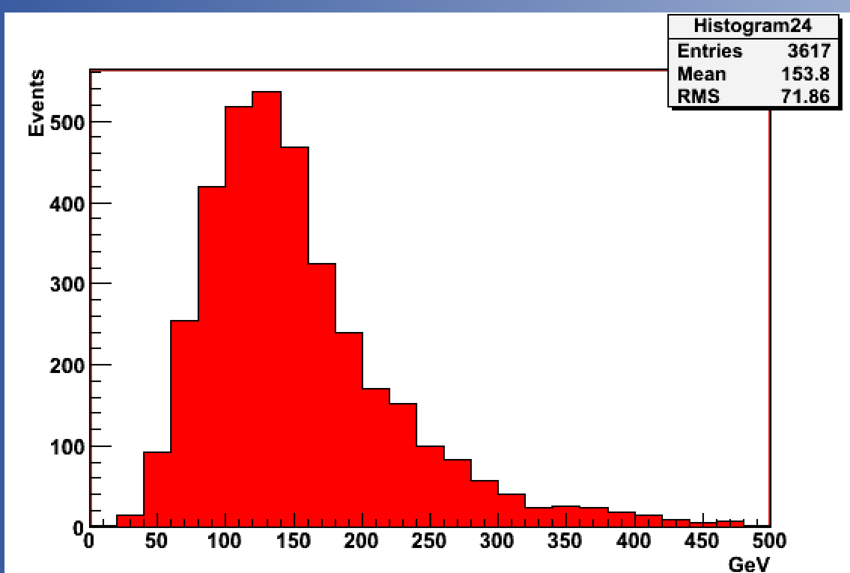
Searches for Resonances

- Lepton pairs
  - The most obvious place to begin to look for resonances is in pairs of same-flavor leptons. In the muon channel the invariant mass distribution of di-muon pairs gives:




```
ScottCut->Select( NumOf(oLepton)==2)).Histogram( InvMass(),0, 5000, 200)
```

- Four-lepton events
  - We implemented the `ReconstructTwo` algorithm:
    - For all permutations of two disjoint pairs, `ReconstructTwo` computes the invariant mass of pair one and pair two.
    - It then returns the averaged invariant mass for the two pairs that lie closest together.
      - The idea is that an intermediate (unstable) particle occurs twice in the event.
      - We don't know the mass of the intermediate, but there should be two pairs with the same invariant mass going out.
  - With this algorithm we obtain:



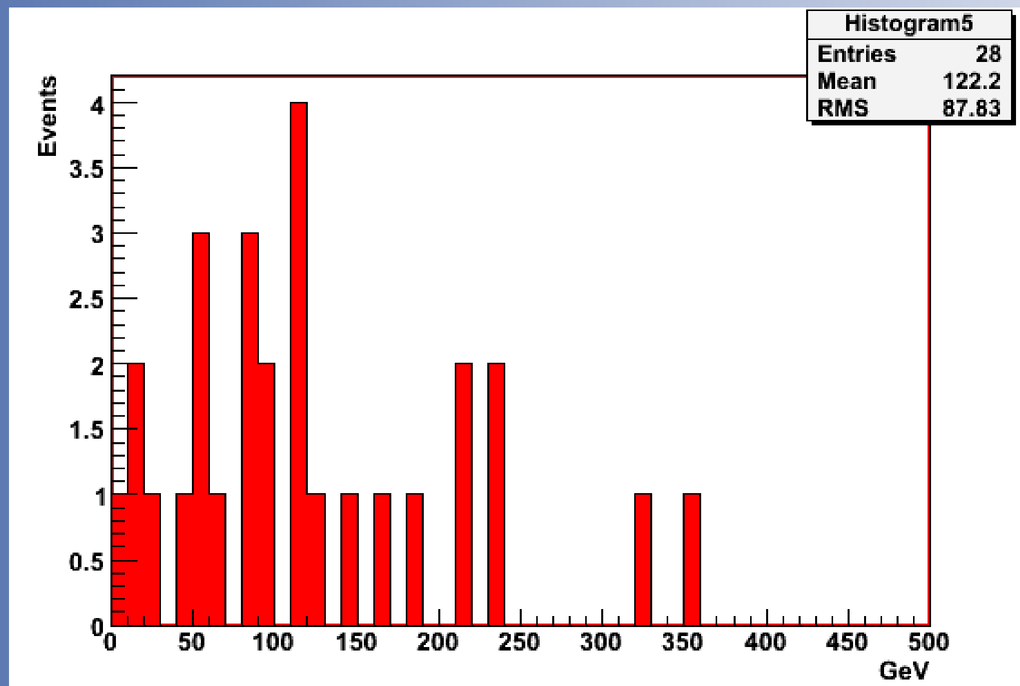
There are enough events to conclude that we are not seeing predominantly di-boson production of Zs,

but rather the **pair production of some "particle A" at**

$m_A \approx$ **120-150 GeV.**

- Photon pairs (invariant mass):

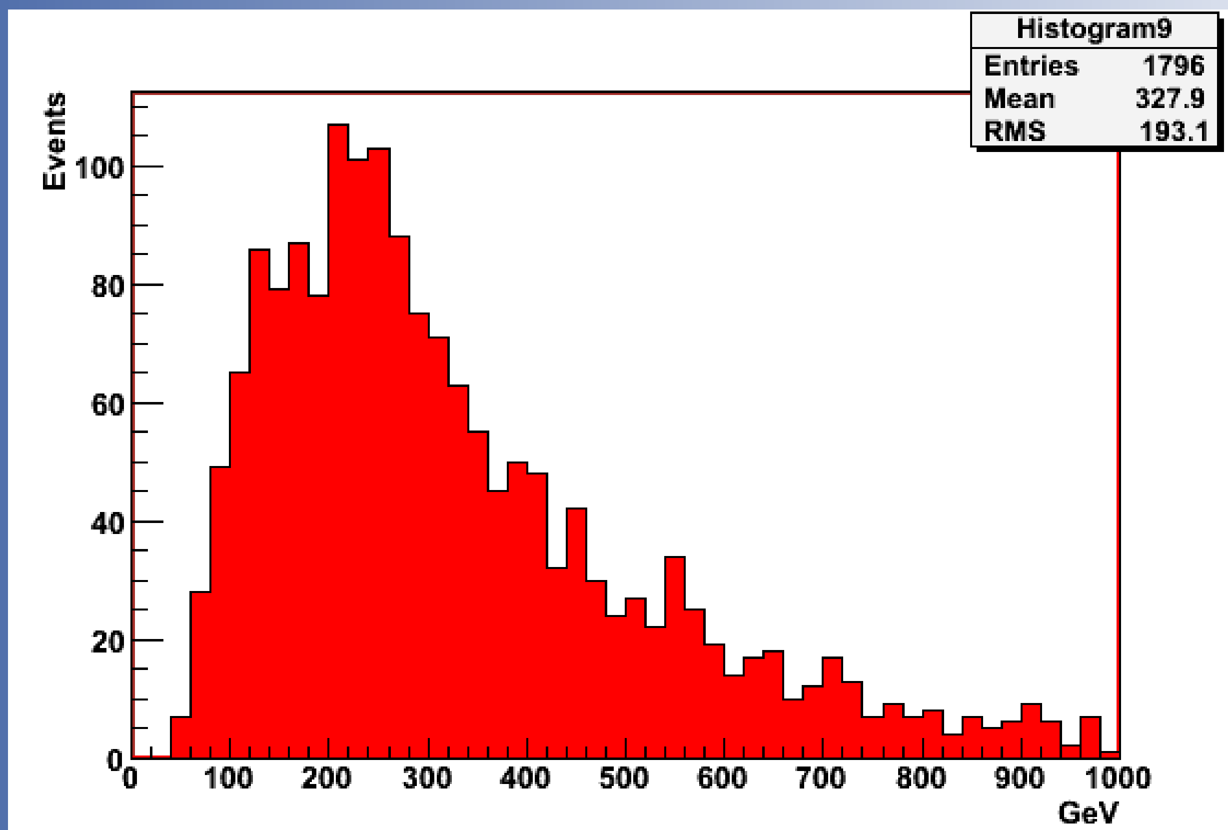
```
BlackBox Diphoton = ScottCut.Select (NumOf(oPhoton)==2)
Diphoton.Histogram( InvMass().Of( Get(oPhoton)),0, 500, 50)
```



Not a lot of statistics here. Peak at 125 GeV?

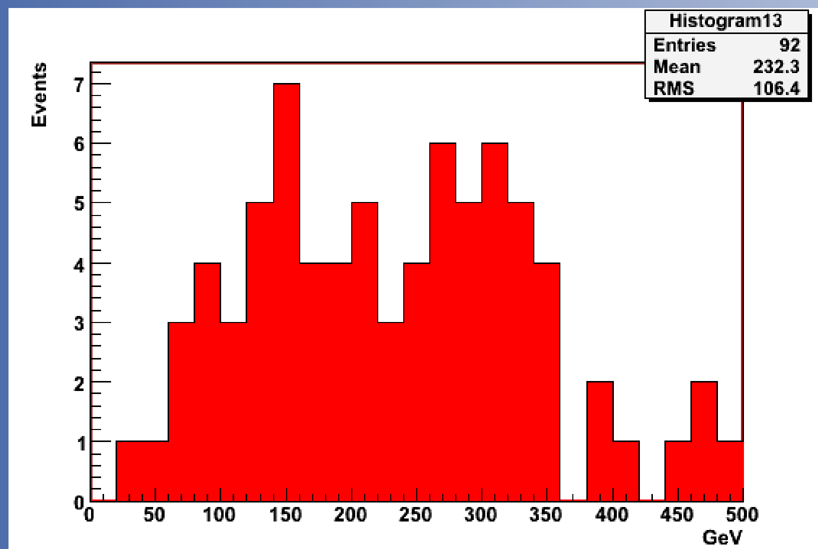
In contrast to Box A, no clear Higgs → $\gamma\gamma$ resonance.

- b-jet pairs
  - A lot of events with b-tagged jets.
  - Invariant mass distribution of the b-jets for the ≈1800 events with precisely two b-tags:




```
BlackBox Twobjets = ScottCut.Select (NumOf(oBJet)==2)
Twobjets.Histogram( InvMass().Of( Get(oBJet)),0,1000,50)
```

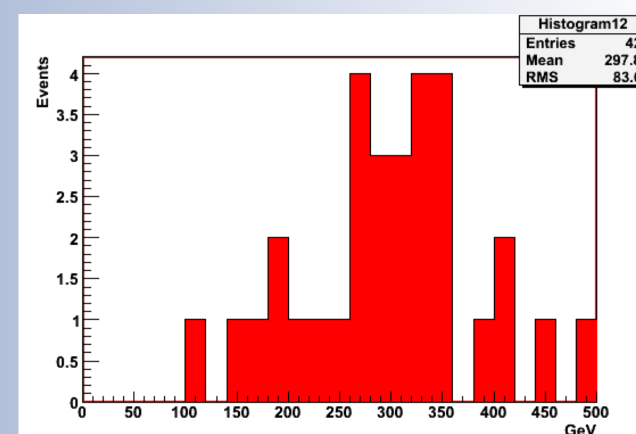
- Four b-jet events
  - For events with four b-tags (and **without** the jet-p_T cut), we can again apply `ReconstructTwo`:



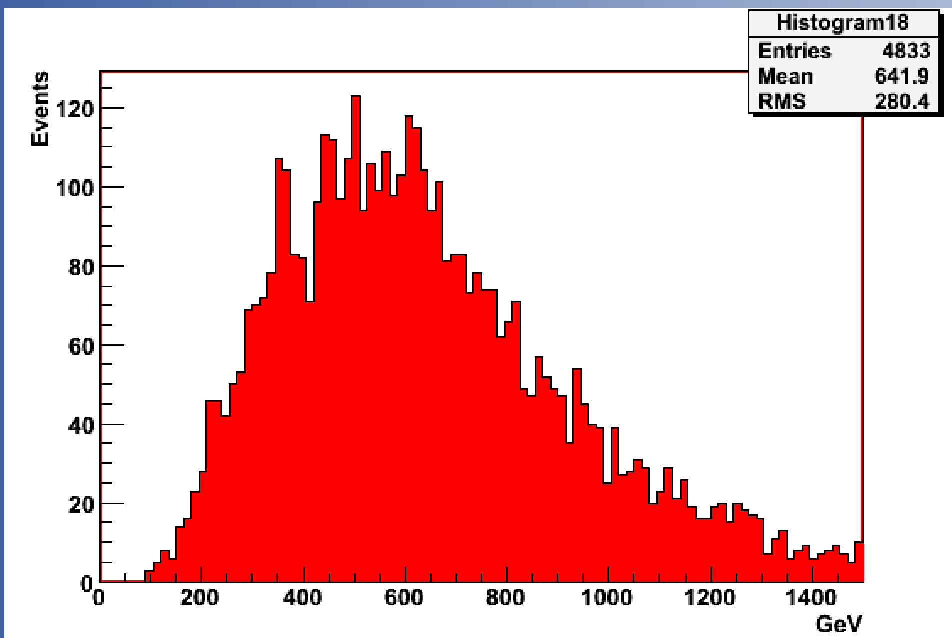
- One peak could be particle A at 125-150 GeV and the other particle B at 300 GeV.

- There is no evidence that particle C decays predominantly into b/b-bar pairs (or lepton pairs, for that matter).

- If we perform the same exercise on Box B **with** the jet-p_T cut, the first peak disappears:
  - (Recall that the cut on jet-p_T is 50 GeV, x 4 = 200 GeV.)



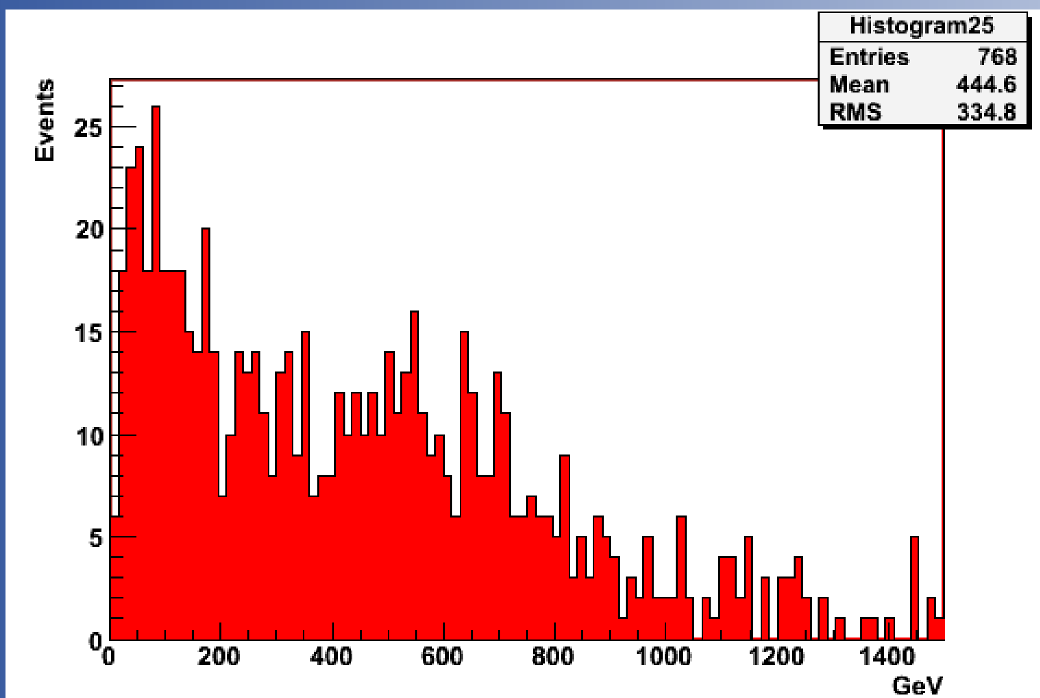
- Four light-flavor jets:
  - Clearly we're starting to get into slippery terrain: there are a lot of jets in this sample and a lot of combinatorics issues. Let's forge ahead anyway.
  - Taking all events with exactly 4 jets, and applying `ReconstructTwo` to the 4 most energetic jets, we obtain:



- Peaks at ≈ 300 GeV and ≈ 600 GeV.
  - Evidence that **particles B and C decay to jets?**

```
ScottCut.Select( NumOf(oJet)==4 ).Histogram(
  ReconstructTwo().Of(Get(oJet)), 0, 1500, 100)
```

- Four or more light-flavor jets, **no** jet-p_T cuts:
  - Removing the jet-p_T cuts, taking all events with 4+ jets and applying `ReconstructTwo` to the 4 most energetic jets, we obtain:



- Now, an additional peak at $\approx$ 125 GeV is discernable.
  - Evidence that **particle A** also **decays to jets?**

```
Scott.Select( NumOf(oJet)>=4 ).Histogram(
  ReconstructTwo().Of( Get(oJet)+1+2+3+4 ), 0, 1500, 100)
```

Black Box B: Second Look

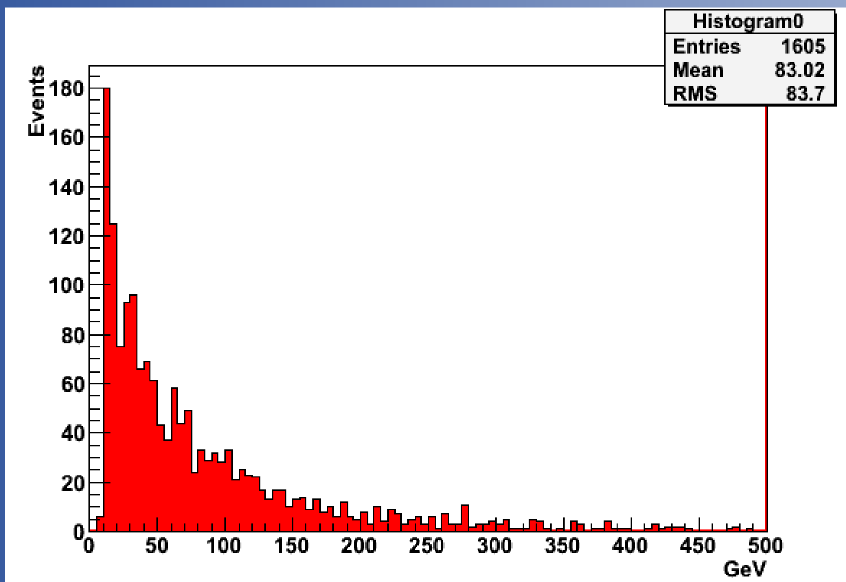
- Recap of independent states conjectured:

	Approximate Mass	Seen in Eff. Mass?	Seen in Leptons?	Seen in Photons?	Seen in b-jets?	Seen in Jets?
LNP	120 GeV	N.A.	N.A.	N.A.	N.A.	N.A.
Particle A	125-150 GeV		✔	?	✔	?
Particle B	225-300 GeV	✔	?		✔	✔
Particle C	600-900 GeV	✔				✔

- Unanswered questions:
  - What happened to the taus?
  - Where is the higgs?
  - Why so many b-jets?
  - Do the SSDL and trileptons plus MET imply SUSY?

Where Are All the Taus?

- If we remove the 25 GeV cut on leptons and plot the Tau effective mass for all Tau events, we find:



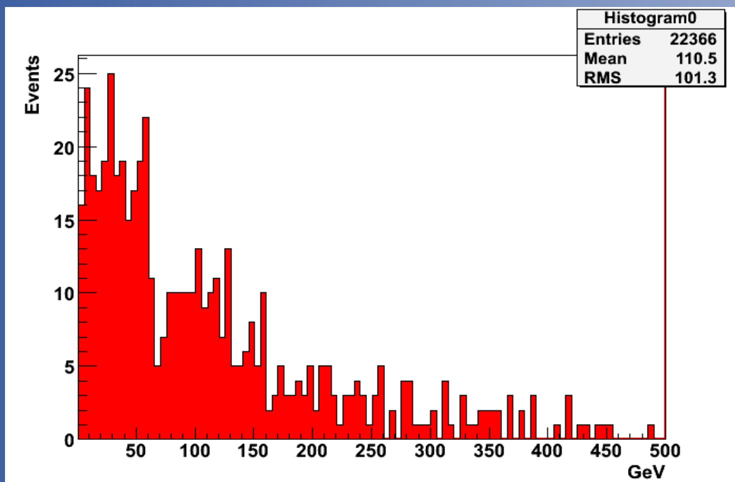

```
BlackBox Tau = ScottCut.Select( NumOf(oTau) > 0 )
Tau.Histogram(EffMass().Of(Get(oTau)),0, 500,100)
```

- The taus peak in the lowest possible bin at 10-15 GeV.
  - PGS: hadronically decaying taus,
  - E_T(cluster) > 10 GeV, p_T(track) > 3 GeV.
- We conclude that the **taus are being generated in decays of New Physics, but are extremely soft.**
- Possible interpretations:
  - They arise after very long decay chains.
  - The particle that decays into the tau + *X* lies very close in mass to particle *X*.

Flavor Subtracted Dileptons

- We implemented the m_{ll} observable.
  - It picks the hardest e^+, e^-, μ^+, μ^- and forms

$$m_{ll} = m_{\text{inv}}(e^+,e^-) + m_{\text{inv}}(\mu^+,\mu^-) - m_{\text{inv}}(e^+,\mu^-) - m_{\text{inv}}(\mu^+,e^-).$$



- Looks like a hard edge at 60 GeV (and a second edge at 160 GeV?)
- Integrated luminosity is 100^{-1} fb.
- Compare to Fig. 1 of hep-ph/0508143:

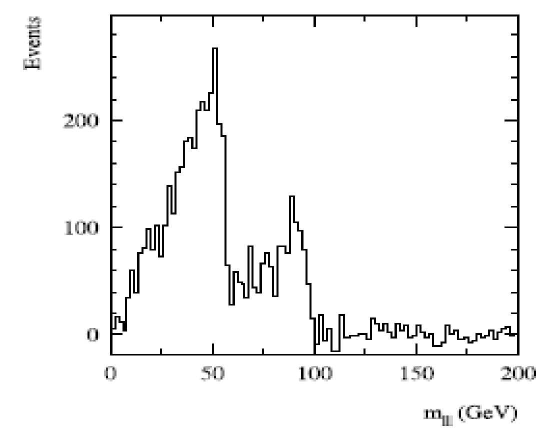
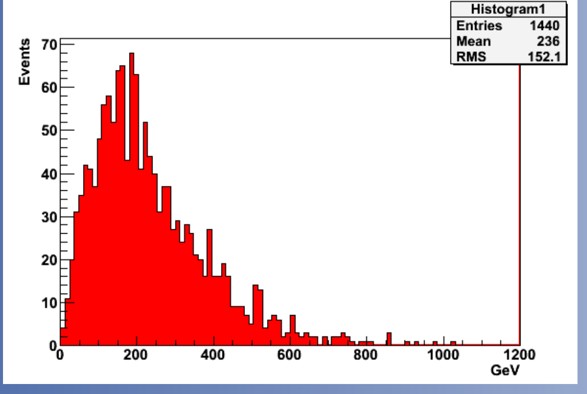


Figure 1: The flavour-subtracted dilepton invariant mass plotted with the cuts described in the text.

- First edge compatible with SUSY decay:
- $\tilde{N}_2 \to l\,\tilde{l}_L \to l^+ l^- \tilde{N}_1$
- $M_{edge} = m_{\tilde{N}_2}(1 - m^2_{\tilde{l}_L}/m^2_{\tilde{N}_2})^{1/2}(1 - m^2_{\tilde{N}_1}/m^2_{\tilde{l}_L})^{1/2}$
- $m_{\tilde{N}_2} \approx$ 60 GeV or larger.
- Second edge from $\tilde{N}_2 \to l\,\tilde{l}_R$ decay chain?

Trileptons and beyond...

- The trilepton events are also consistent with SUSY.
  - E.g., from di-gluino production:
    - one $\tilde{g}$ decaying through $\tilde{N}_2 \to l\,\tilde{l} \to l^+ l^- \tilde{N}_1$
    - the other through $\tilde{C}_2^{\pm} \to l'^{\pm} \tilde{\nu}_{l'} \to l'^{\pm} \nu_{l'} \tilde{N}_1$
  - MET from $\mu^+\mu^- e^\pm$ trilepton channel has the same distribution as that from all events:

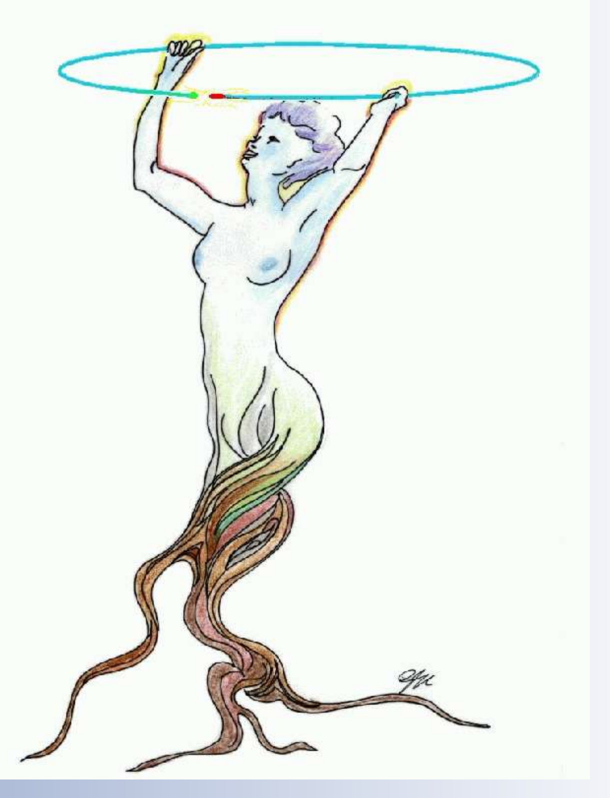


  - consistent with LNP = LSP = $\tilde{N}_1$, $m_{\tilde{N}_1}$ = 120 GeV.

- **Clearly this is work in progress:**
- Much analysis still lies ahead to unravel the secrets of Black Box B!!

ChRoot

Our greatest LHCO achievement at Penn!



What is ChRoot?

- It is an analysis package built to look at data sets produced by PGS.
- It currently has a command line interface utilizing the CINT feature of ROOT.
- ROOT is already tailored to handle collider data.

Why use ChRoot — I thought we already had Chameleon?

- ChRoot is much faster and far more memory efficient.
  - Example: Black Box B in Chameleon takes appx. 400MB to load, in ChRoot the same takes 75MB.
  - It may take minutes to load boxes in Chameleon, while mere seconds in ChRoot.
  - Histograms and other outputs are very quick.

Why use ChRoot — I thought we already had Chameleon?

- More Flexible and Universal
  - It is based in C++, easy to modify and widely known.
  - Special attention was made to create a foundation for more advanced tools to be built.
  - ROOT is firmly established in the HEP community and brings Exp and Theory closer.
  - It's free! No need to bug group manager for a license.

How to use ChRoot

An excellent start is the Quick Start Guide on the LHCO wiki.

- This site has many examples and gives basic description to the structure.
- A basic commands.txt included in the ChRoot tar outlines some of these.

How to use ChRoot

- Effort was made to make the move from Chameleon to ChRoot easy:
  - In many cases, Chameleon-style alternatives to native ChRoot C++ syntax are available.

Example:

```
CriterionCount(EasyBB, NumOf(oElectron) >= 1 && NumOf(oJet) == 1 )
EasyBB.Select( NumOf(oElectron) >= 1 && NumOf(oJet) == 1 ).size()
```

Demos

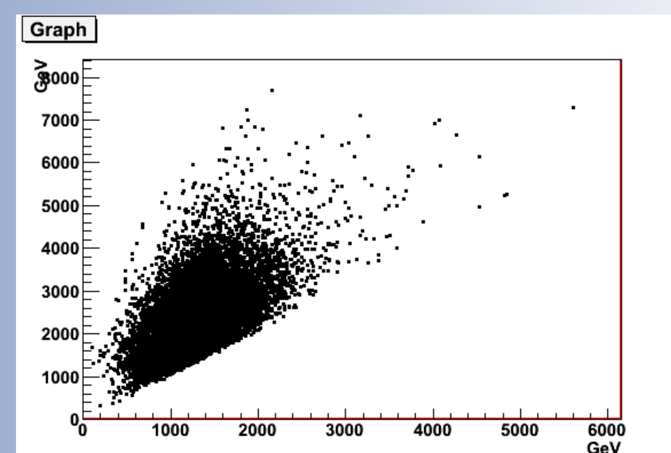
- Invariant mass of all jets except for the two jets with the largest jmas, again among events with at least 4 jets:

```
BlackBox fourjets = EasyBB.Select( NumOf(oJet) >= 4 )
fourjets.Histogram( InvMass().Of( Get(oJet).SortBy(TrackPT())-1-2 ), 0, 1000, 100)
```

- Number of events with exactly two photons that passed trigger 1 and 3 (trigger word 20+22):

```
EasyBB.Select( NumOf(oPhoton)==2 && TriggerWord(1+4) ).size()
```

- Others:
  - Scatter Plots
  - Other variables
  - Scripts, e.g. **`ReconstructZ`**



Feedback

- This is a work in progress that is growing rapidly (almost daily).
- Please send us suggestions and any problems with ChRoot to
  - Volker Braun <vbraun@physics.upenn.edu>, Mike Ambroso <mambroso@sas.upenn.edu>.