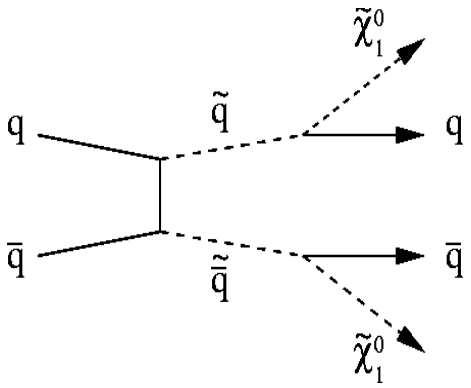


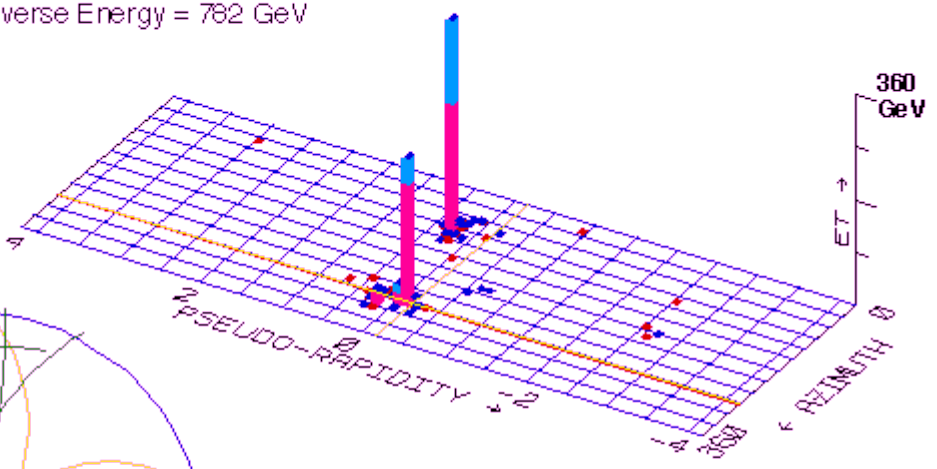
SUSY searches in a dijet channel

Contents:

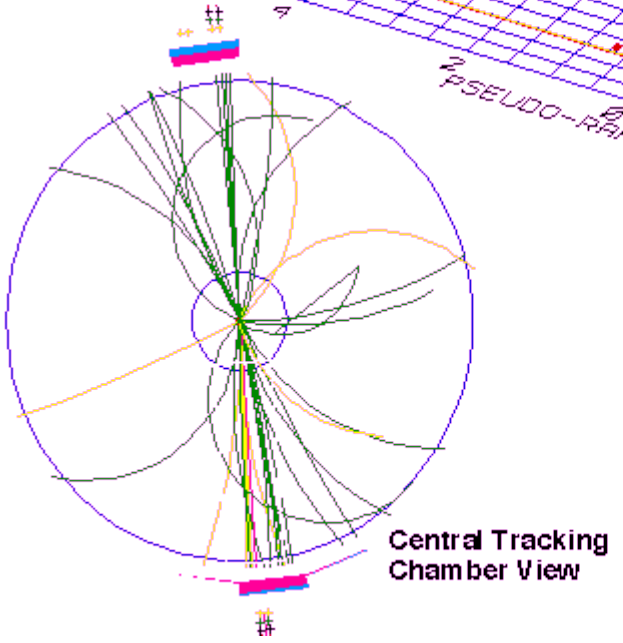
- SUSY
- The dijet channel
- EtMiss/Meff analysis
- Mt2
- Analysis with Mt2

CDF: Highest Transverse Energy Event from the 1988-89 Collider Run

Sum of Transverse Energy = 782 GeV



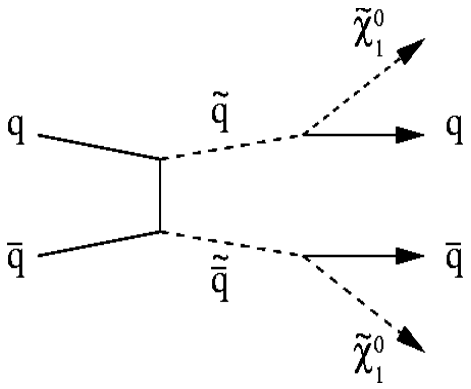
Calorimeter lego plot
Two Jets, 424 GeV and 371 GeV



Central Tracking Chamber View

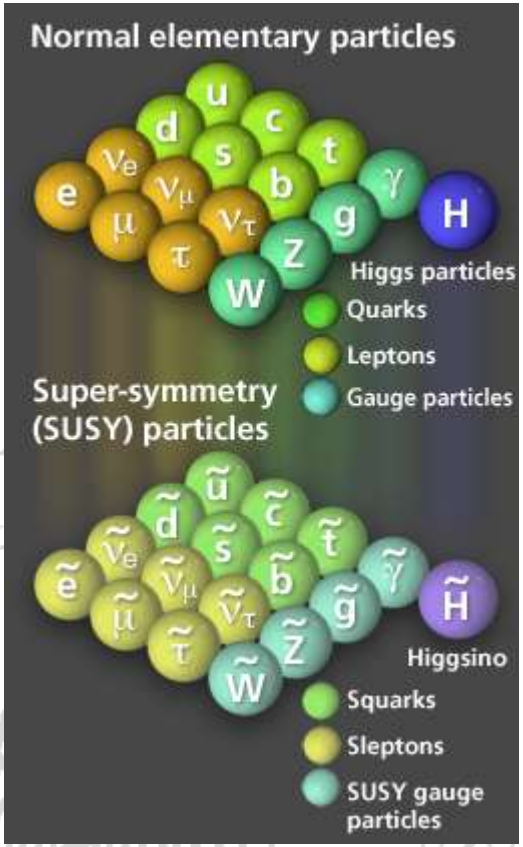
Bjørn Samset

EPF seminar, 20.06.07



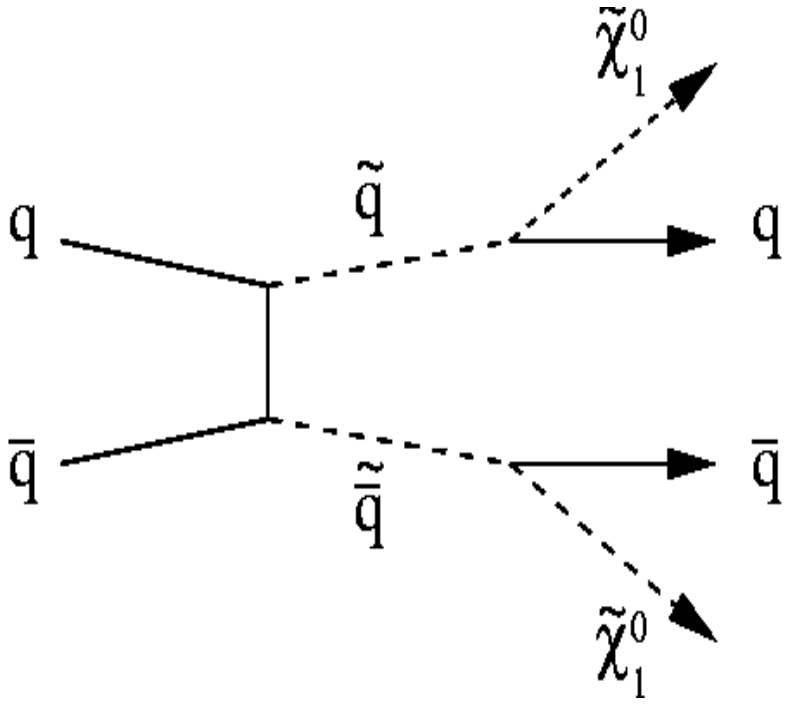
SUSY and mSUGRA

- For every SM particle, there is a SUSY partner
- We want to find them, and measure their properties
- We assume R-parity conservation – i.e. there is an LSP which will escape our events undetected
- There must be at least two such LSPs per SUSY event
- We «detect» missing transverse energy



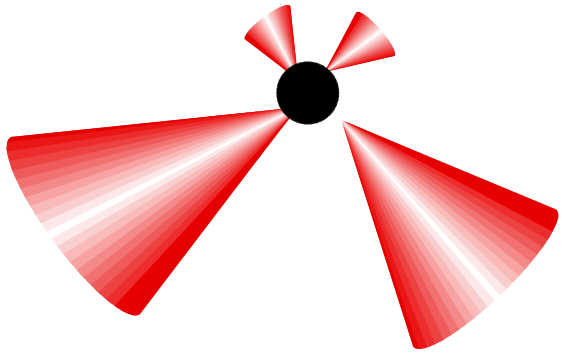
https://twiki.cern.ch/twiki/bin/view/Atlas/SusyEventFilesInfo

Point	m_0 (GeV)	m1/2 (GeV)	A0(GeV)	tan(β)	sgn(μ)	x-sec (pb)	DC1	Rome	CSC
Coannihilation (SU1)	70	350	0	10	+	7.43 (a)		Y	Y
Focus Point (SU2)	3550	300	0	10	+	4.86 (a)		Y	Y
Bulk (SU3)	100	300	-300	6	+	18.59 (a)	Y	Y	Y
Low Mass (SU4)	200	160	-400	10	+	262 (b)		Y	
Scan (SU5.1)	130	600	0	10	+	0.44 (b)		Y	
Scan (SU5.2)	250	600	0	10	+	0.40 (b)		Y	
Scan (SU5.3)	500	600	0	10	+	0.31 (b)		Y	
Funnel (SU6)	320	375	0	50	+			Y	Y
Coannihilation (SU8.1)	210	360	0	40	+	6.44 (a)			Y
Coannihilation (SU8.2)	215	360	0	40	+	6.40 (a)			Y
Coannihilation (SU8.3)	225	360	0	40	+	6.32 (a)			Y



The dijet topology

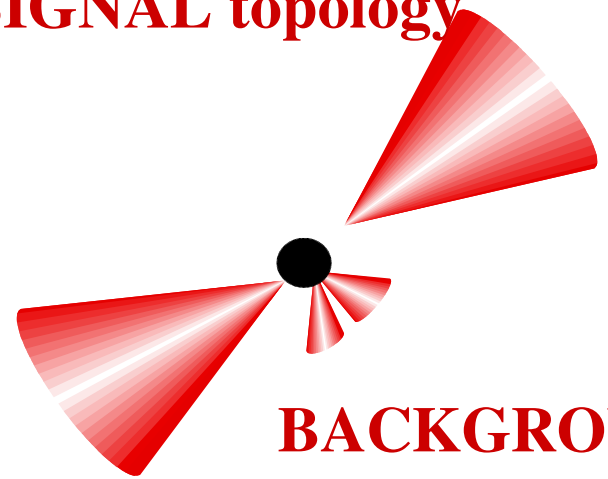
(You don't really study «a SUSY channel» - you study an event topology that will hopefully contain interesting information.)



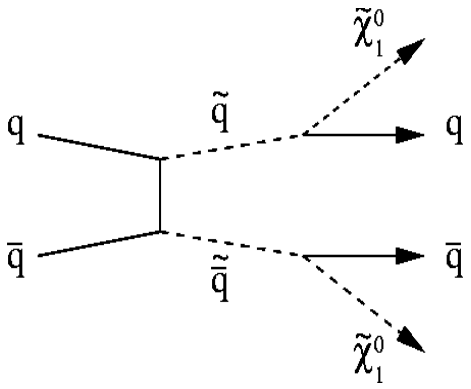
SIGNAL topology

A dijet event:

- two jets with high pt (to be defined)
- no (high energy) leptons
- cannot just cut away all bg because of underlying event, pileup, fakes etc.

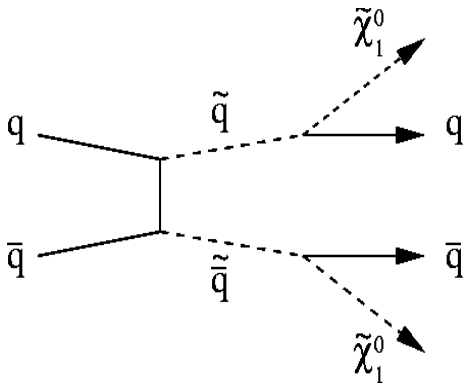


BACKGROUND topology (QCD)



A «standard» analysis

- Define a signal sample, e.g. an mSUGRA point
- Select a topology to study – in this case dijets
- Round up all background processes that may contribute to this topology
- Select a variable to plot, e.g. EtMiss or Meff
- Make a number of cuts that distinguish between signal and background events
- Plot signal and background on top of each other, see if signal>BG in any region
- Calculate the signal-to-background (S/sqrt(B)) for the appropriate region

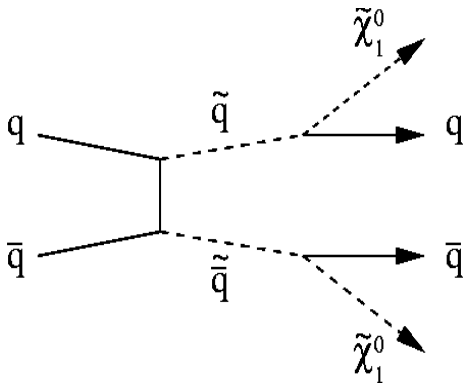


A «standard» analysis

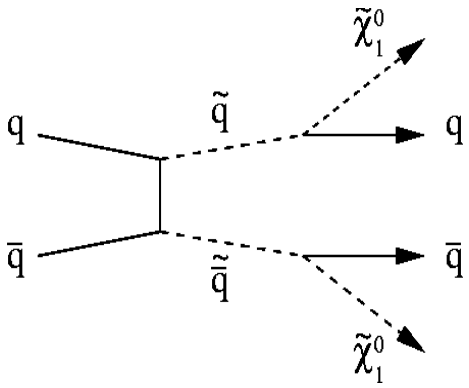
(using simulated data...)

- Define a signal sample, e.g. an mSUGRA point
- Select a topology to study – in this case dijets
- Round up all background processes that may contribute to this topology
- Select a variable to plot, e.g. EtMiss or Meff
- Make a number of cuts that distinguish between signal and background events
- Plot signal and background on top of each other, see if signal>BG in any region
- Calculate the signal-to-background (S/sqrt(B)) for the appropriate region

- Should ideally estimate the BG from part of the full combined simulation. This is on the TODO list...

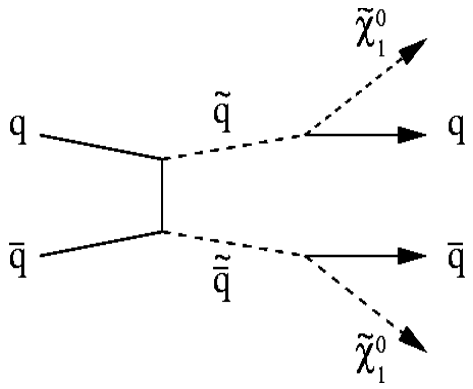


Standard EtMiss/Meff analysis



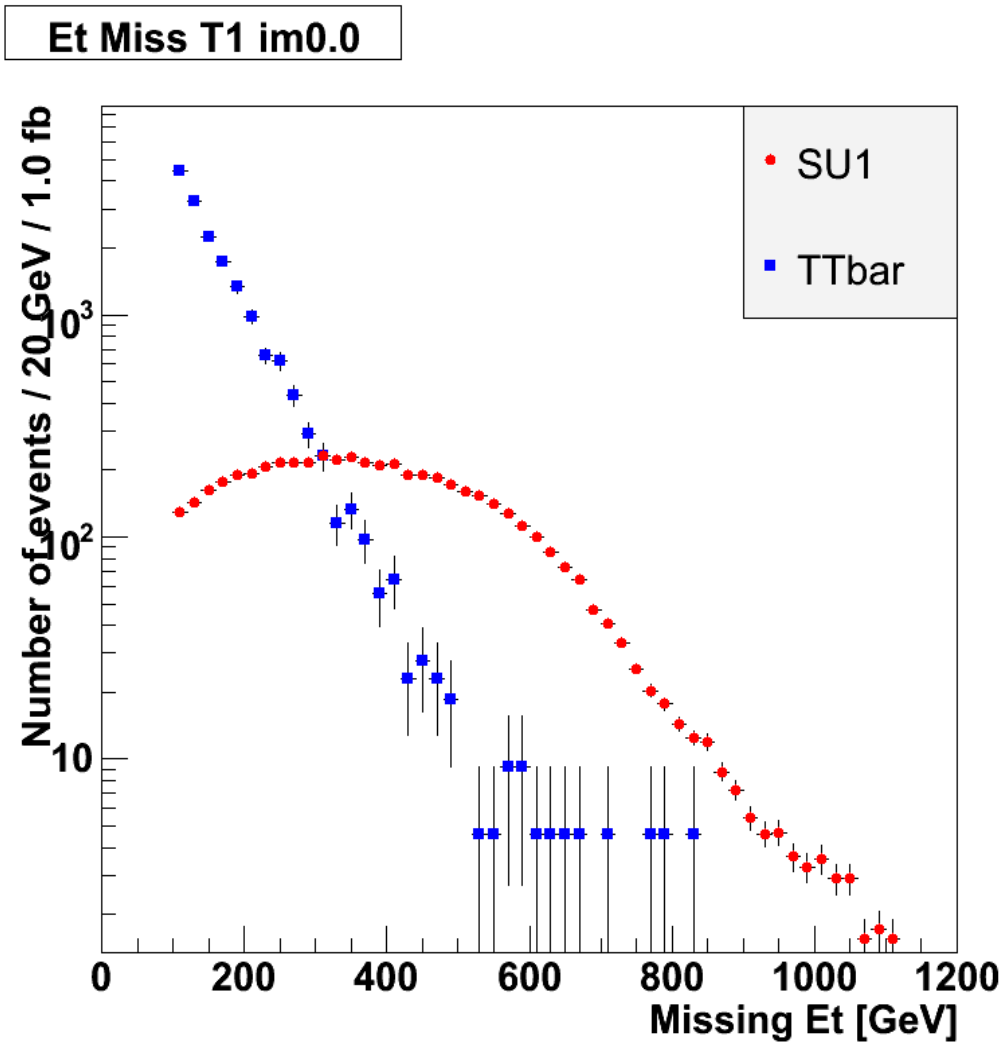
Standard: Datasets used

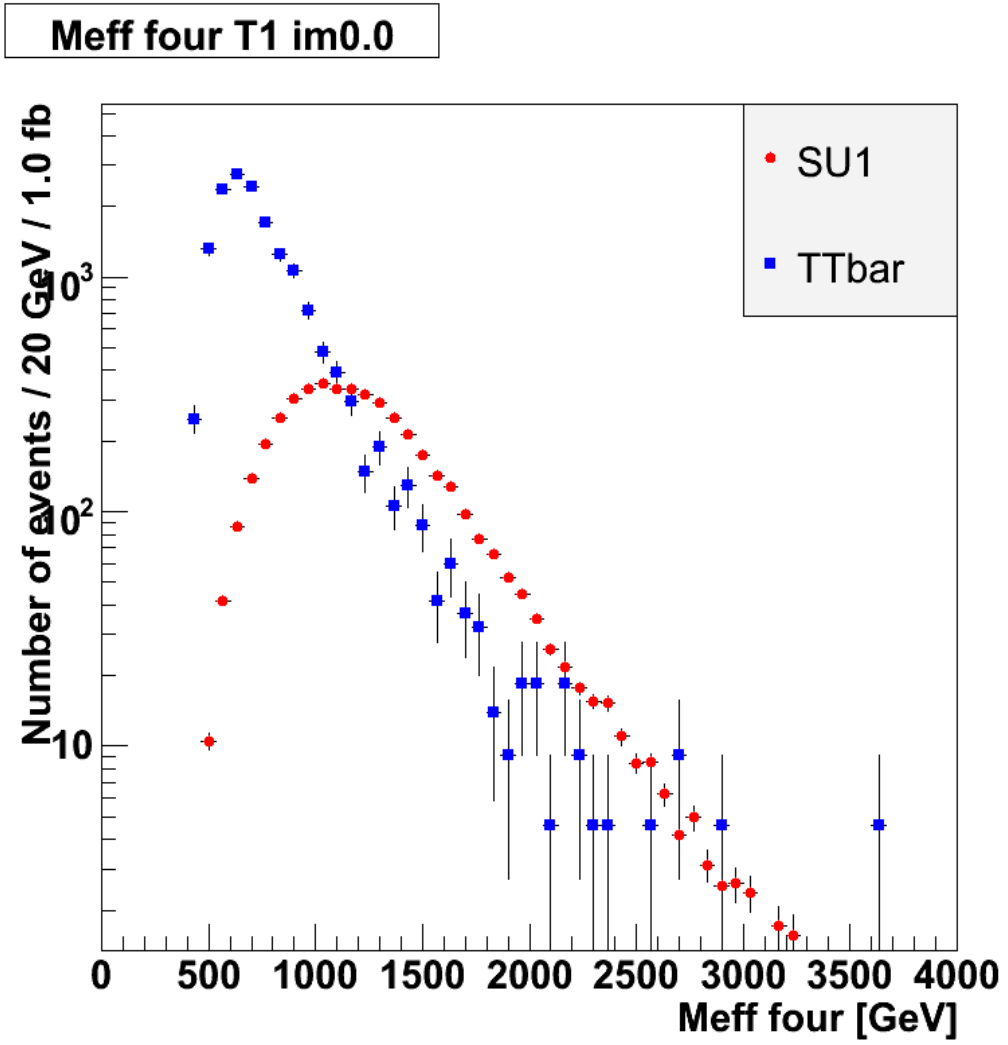
Name	Dataset	Sigma [pb]
SU1	trig1_misal1_csc11.005401.SU1_jimmy_susy.recon.AOD.v12000601_tid008573	7.43
SU2	user.MarijaMilosavljevic.SU2_jimmy_susy.HPTV.v12000601_tid005862	4.86
SU3	trig1_misal1_csc11.005403.SU3_jimmy_susy.recon.AOD.v12000601	18.59
SU4	trig1_misal1_mc12.006400.SU4_jimmy_susy.recon.AOD.v12000601_tid006724	262
SU8.1	trig1_misal1_csc11.005406.SU8_jimmy_susy1.recon.AOD.v12000601_tid006099/	6.44
J1	-	
J2	-	
J3	-	
J4	trig1_misal1_mc12.008090.pythia_J4_Nj2_FMET100.recon.AOD.v12000601_tid006101	316000
J5	trig1_misal1_mc12.008091.pythia_J5_Nj2_FMET100.recon.AOD.v12000601_tid009323	12500
J6	user.JelenaKrstic.trig1_misal1_mc12.008092.pythia_J6_Nj2_FMET100.recon.HPTV.v12000601_tid006102	344
J7	user.JelenaKrstic.trig1_misal1_mc12.008093.pythia_J7_Nj2_FMET100.recon.HPTV.v12000601_tid006103	5.3
J8	user.JelenaKrstic.trig1_misal1_mc12.008094.pythia_J8_Nj2_FMET100.recon.HPTV.v12000601_tid006104	0.02
T1	trig1_misal1_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000601_tid005997	461
Ttbar	trig1_misal1_mc12.005204.TTbar_FullHad_McAtNlo_Jimmy.recon.AOD.v12000601_tid006015	**???**
Wenu	user.MarijaMilosavljevic.pythia_Wenu_qg_ckin80_Nj2.HPTV.v12000601_tid006105	343
Wmunu	user.MarijaMilosavljevic.pythia_Wmunu_qg_ckin80_Nj2.HPTV.v12000601_tid006106	343
Wtaunu	user.MarijaMilosavljevic.pythia_Wtaunu_qg_ckin80_Nj2.HPTV.v12000601_tid006107	343
Zee	trig1_misal1_mc12.008194.pythia_Zee_qg_ckin80_Nj2.recon.AOD.v12000601_tid006109	1432
Zmumu	trig1_misal1_mc12.008195.pythia_Zmumu_qg_ckin80_Nj2.recon.AOD.v12000601_tid006110	46.4
Ztautau	user.MarijaMilosavljevic.pythia_Ztautau_qg_ckin80_Nj2.HPTV.v12000601_tid006709	46.3
Znunu	user.MarijaMilosavljevic.pythia_Znunu_qg_ckin80_Nj2.HPTV.v12000601_tid006108	246

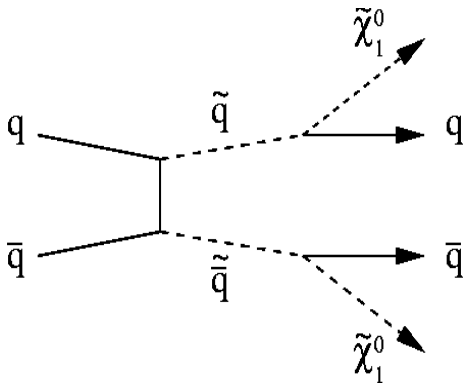


Standard: Variables

Examples for one signal and one «typical» background

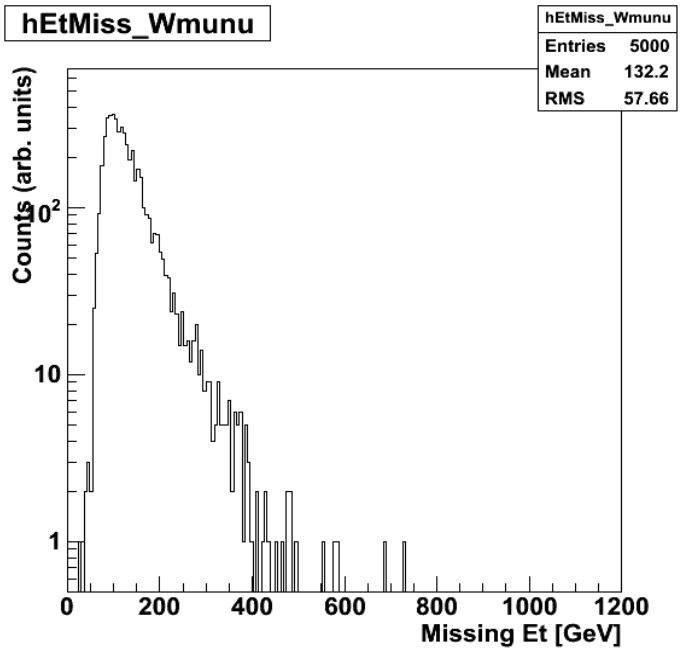


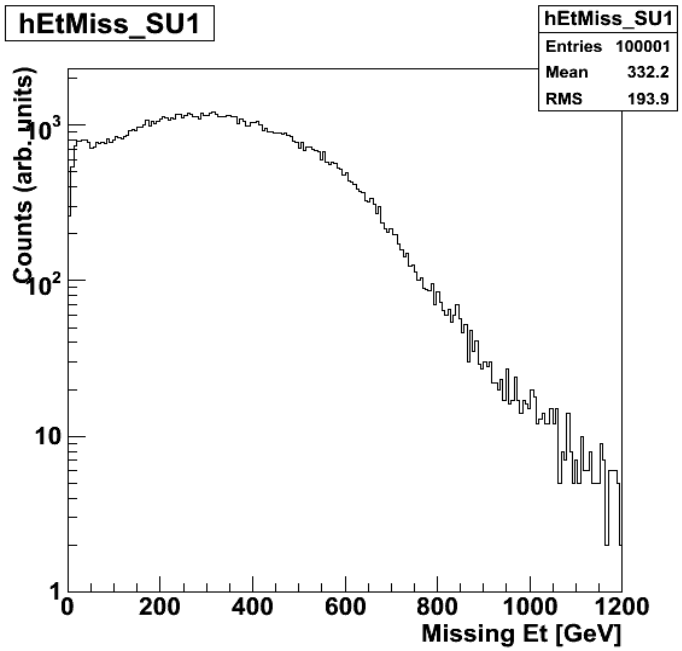




Standard: Cuts

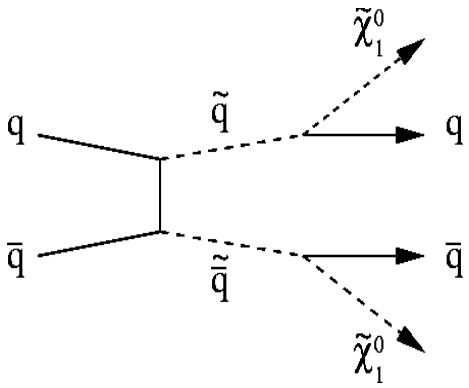
- EtMiss
- Jet pt
- Jet eta
- Lepton veto
- JetPhi difference
- JetPhi – EtMissPhi





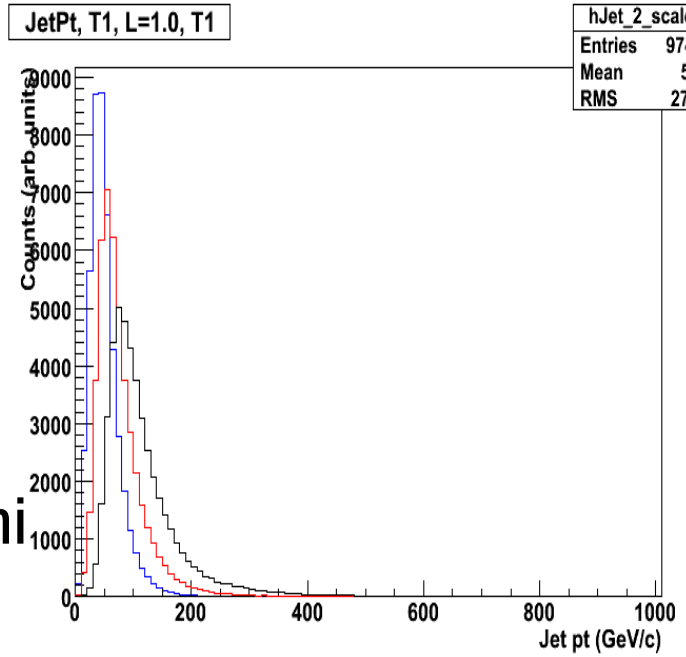
EtMiss>100GeV

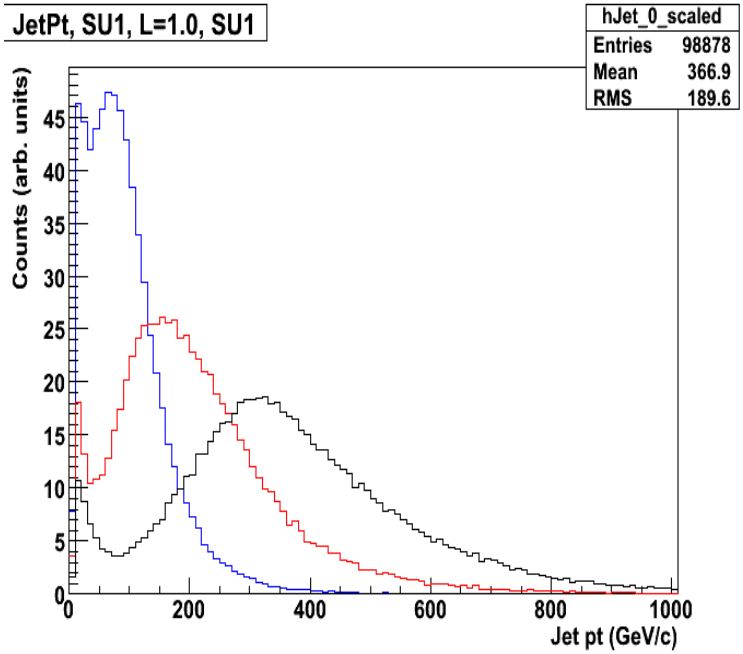
(Already included in my jet samples...)



Standard: Cuts

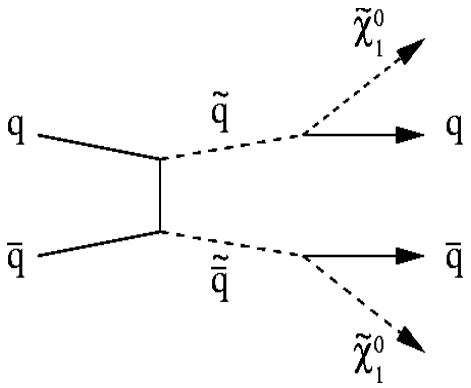
- EtMiss
- Jet pt
- Jet eta
- Lepton veto
- JetPhi difference
- JetPhi – EtMissPhi





Jet1 pt > 150GeV/c

Jet2 pt > 100GeV/c



Standard: Cuts

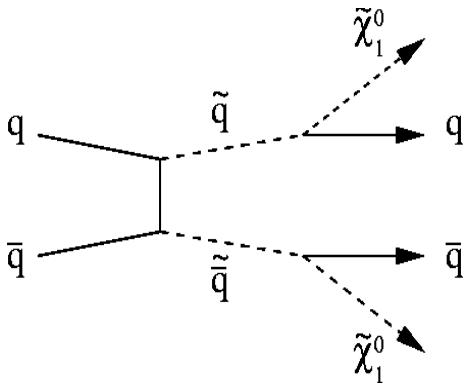
- EtMiss
- Jet pt
- Jet eta
- Lepton veto
- JetPhi difference
- JetPhi – EtMissPhi

|Jet eta| < 2.5
Stay in central barrel...

Not included yet.

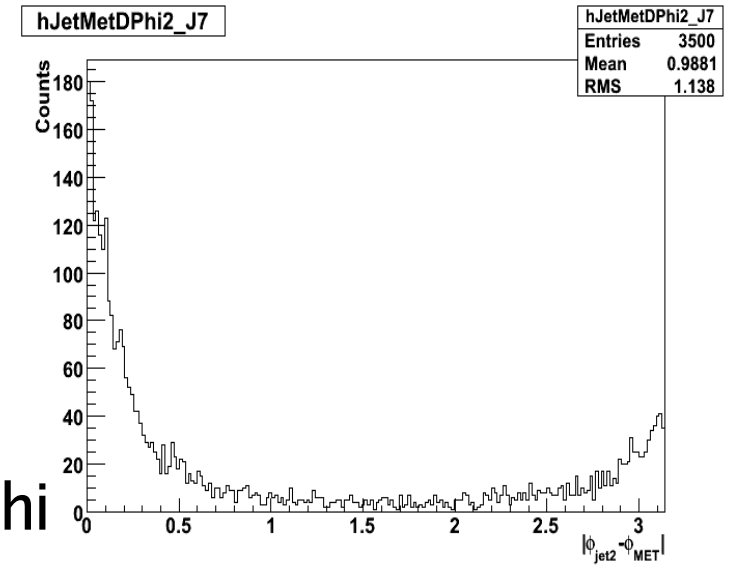
Will set

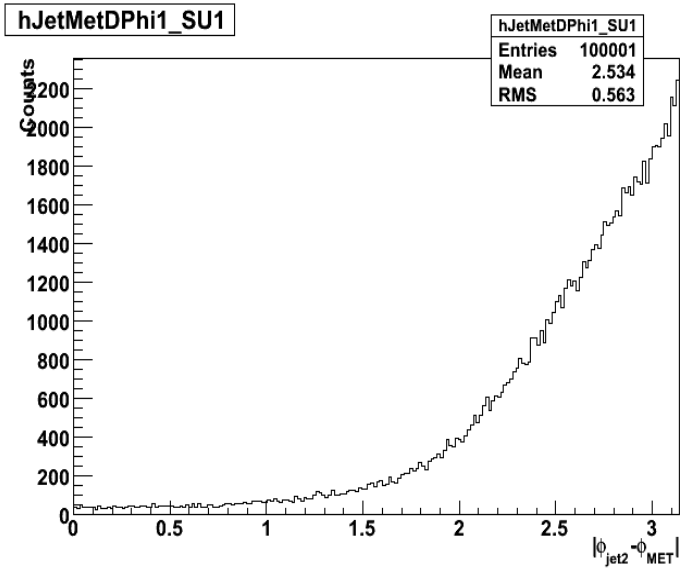
$pt_{\text{hardest lepton}} < 20\text{GeV/c}$



Standard: Cuts

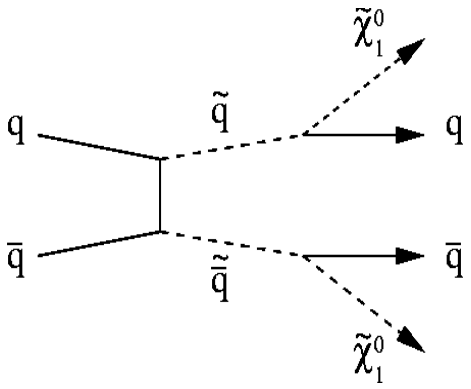
- EtMiss
- Jet pt
- Jet eta
- Lepton veto
- JetPhi difference
- JetPhi – EtMissPhi





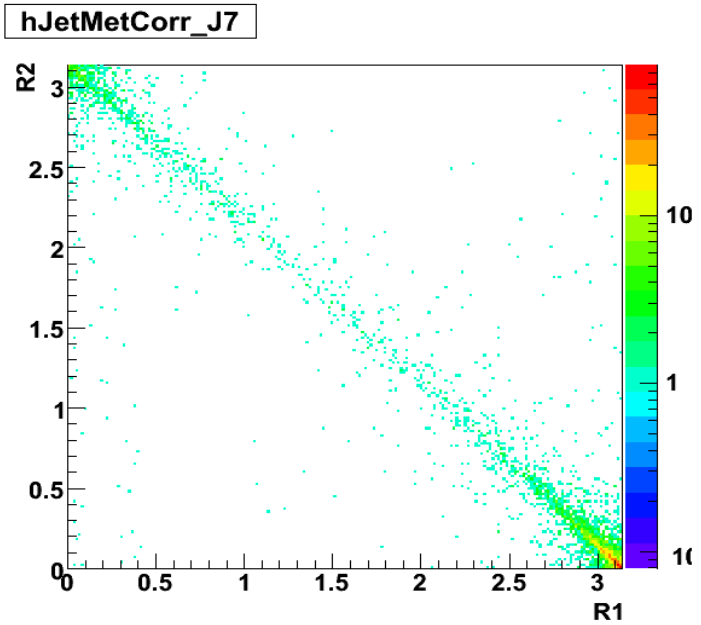
$|\phi_{jet1}-\phi_{MET}|>0.5$

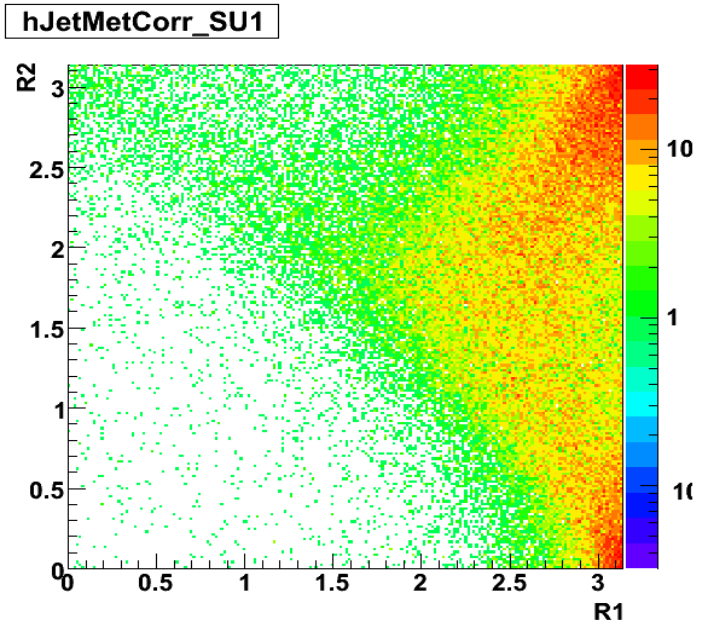
$|\phi_{jet2}-\phi_{MET}|>0.5$



Standard: Cuts

- EtMiss
- Jet pt
- Jet eta
- Lepton veto
- JetPhi difference
- JetPhi – EtMissPhi





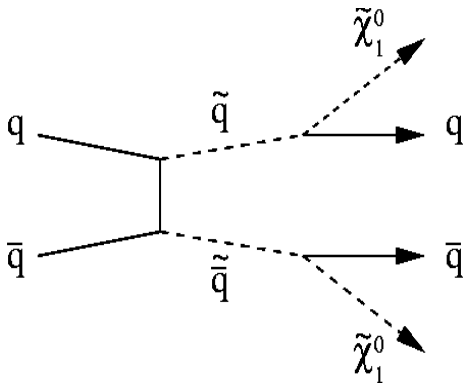
$\delta\varphi = |\varphi_{jet} - \varphi_{MET}|$

$R1 = \mathrm{sqrt}(\delta\varphi_{jet2}^2 + (\pi - \delta\varphi_{jet1}^2))$

$R2 = \mathrm{sqrt}(\delta\varphi_{jet1}^2 + (\pi - \delta\varphi_{jet1}^2))$

$R1 > 0.5$

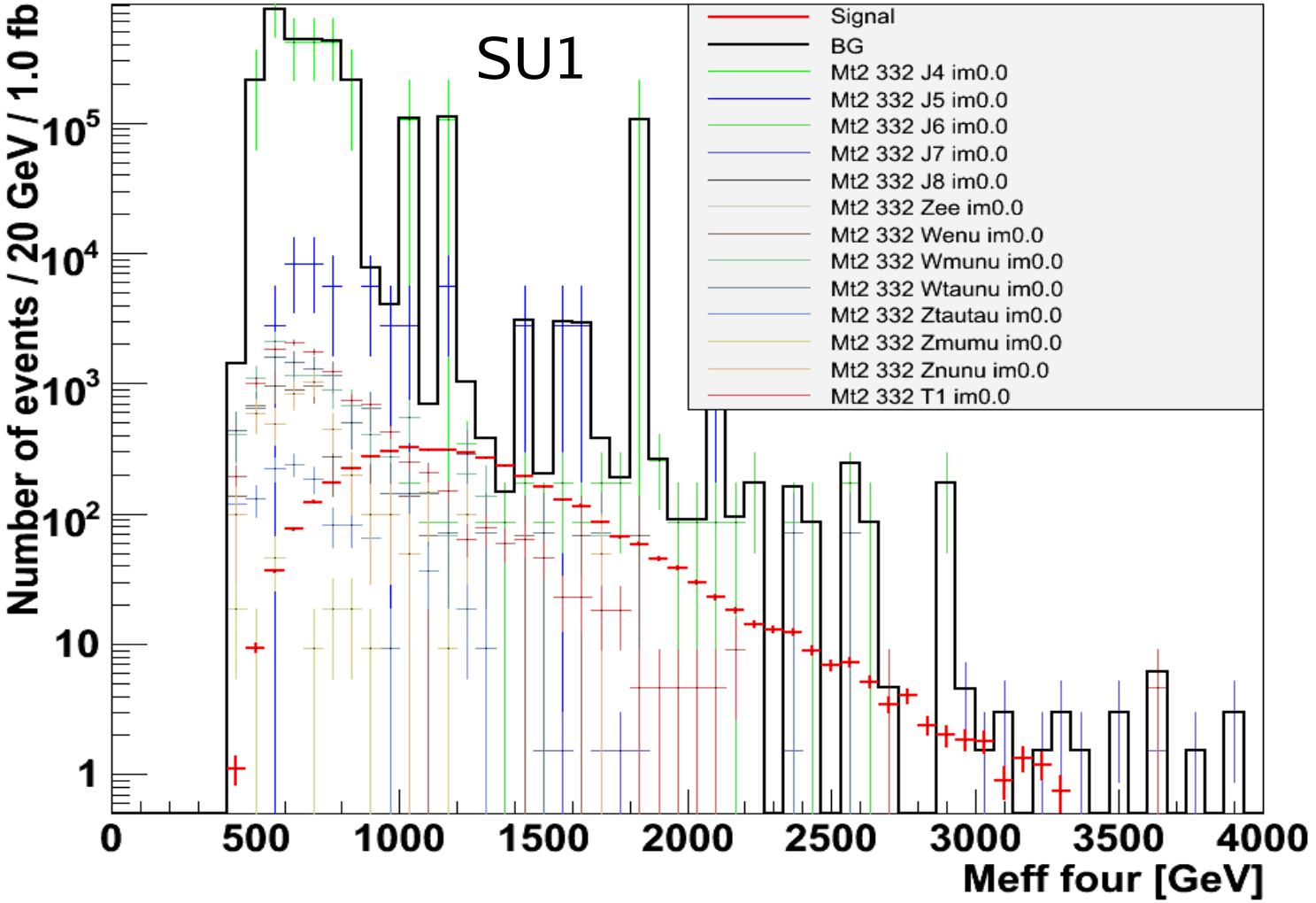
$R2 > 0.5$



Standard: Meff

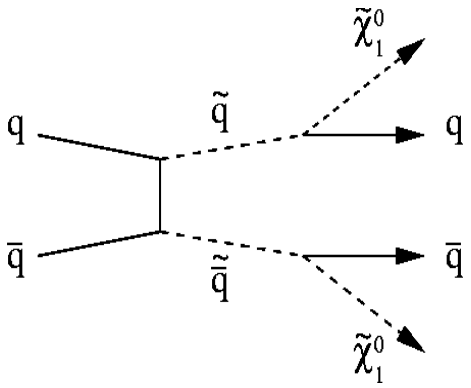
Signal and summed BG after all cuts

Meff four (C4 jets)



Haven't even calculated S/sqrt(B)...

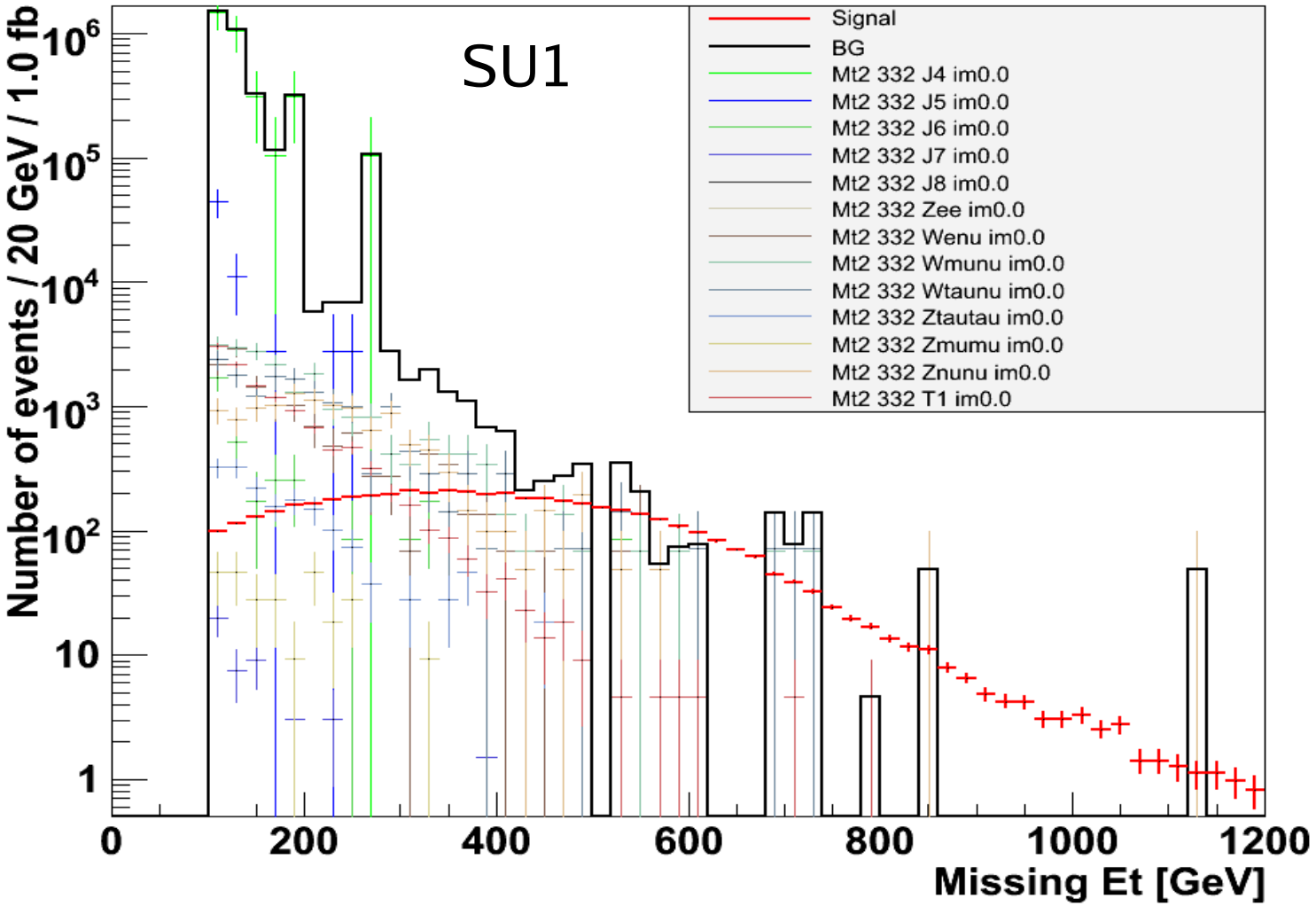
Can set additional cut on e.g. third jet pt jet_pt_3 < ?? GeV/c but haven't done this yet.



Standard: EtMiss

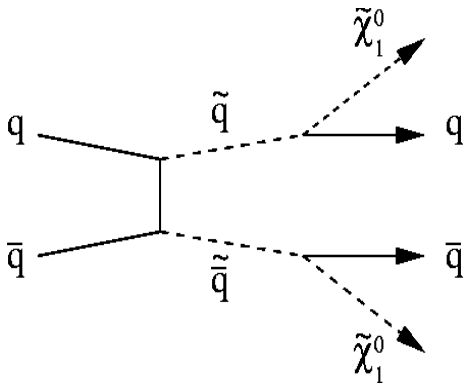
Signal and summed BG after all cuts

Missing Et

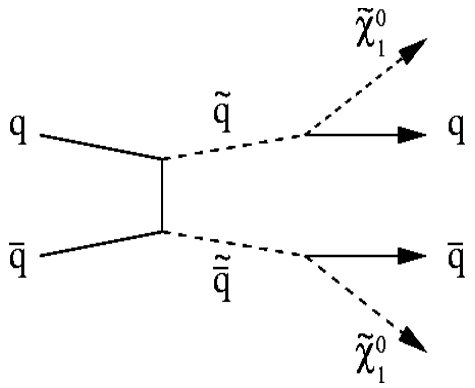


Signal	S/sqrt(B)
SU1	32
SU2	1
SU3	61
SU4	104
SU8	29

EtMiss > 300 GeV



Mt2 analysis



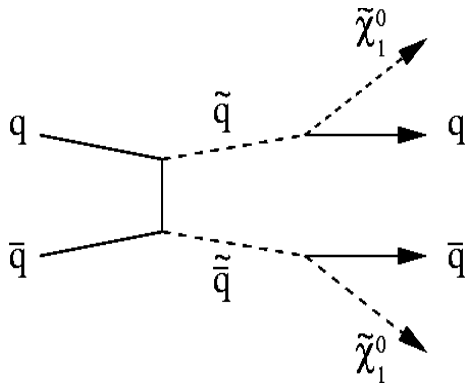
Mt2 – what is it?

Measured:

- pt, phi, eta of jet 1
- pt, phi, eta of jet 2
- EtMiss, with angle phi

Want:

- «Simple» kinematic variable that distinguishes SUSY events from SM
- Mass of invisible particle



Mt2 – what is it?

$$M_{\mathrm{T2}} \equiv \min_{p^{(1)}+p^{(2)}=p_T} \left[\max \left\{ m_T\left(p_T^{j(1)}, p^{(1)}\right), m_T\left(p_T^{j(2)}, p^{(2)}\right) \right\} \right]$$

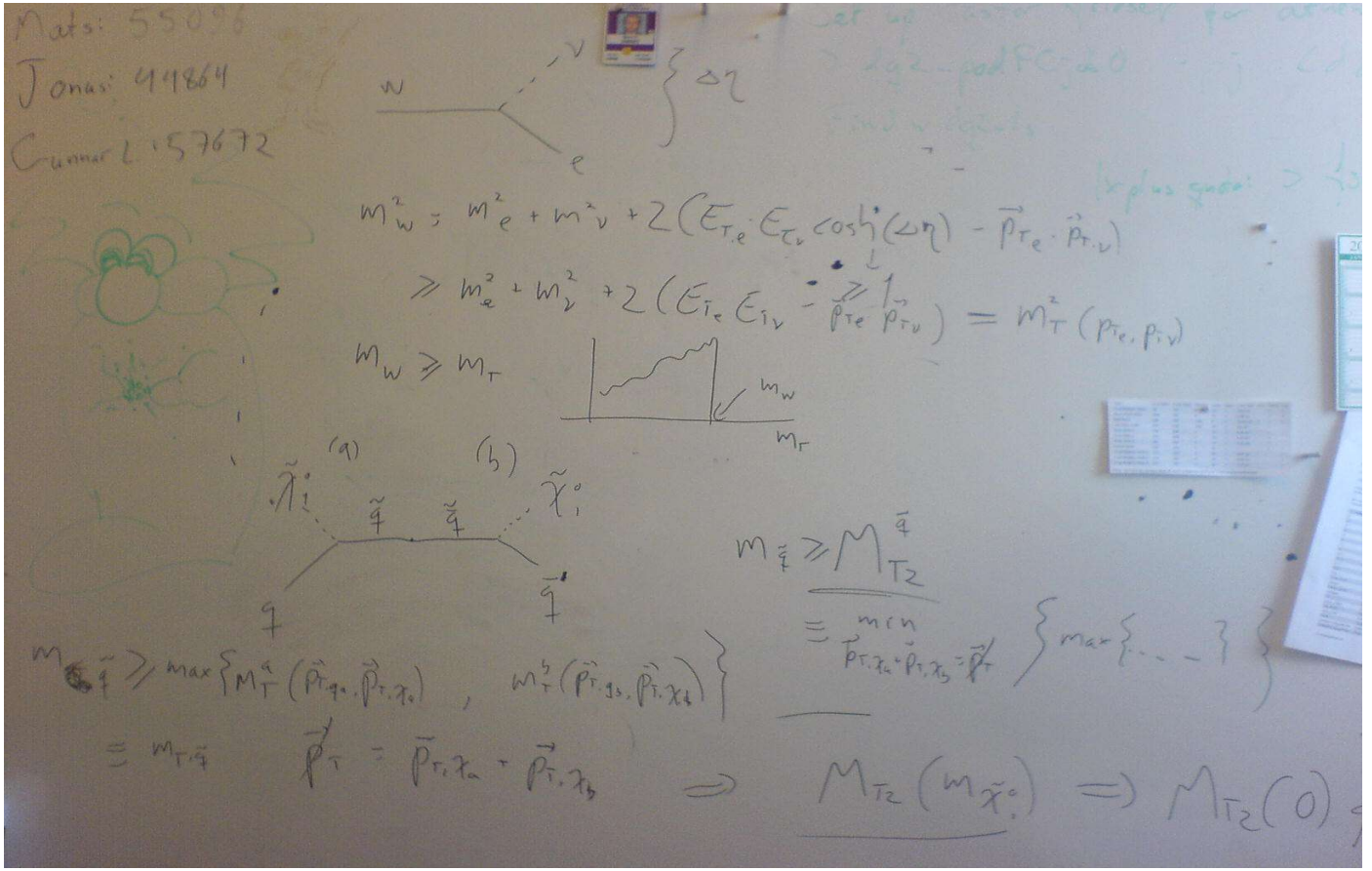
J.Phys.G29:2343-2363,2003 Phys.Lett.B463:99-103,1999

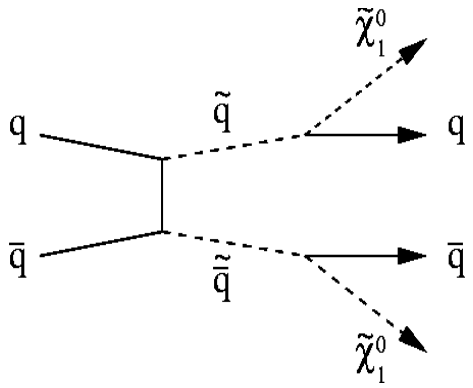
Measured:

- pt, phi, eta of jet 1
- pt, phi, eta of jet 2
- EtMiss, with angle phi

Want:

- «Simple» kinematic variable that distinguishes SUSY events from SM
- Mass of invisible particle





Mt2 – what is it?

$$M_{\mathrm{T2}} \equiv \min_{p^{(1)}+p^{(2)}=p_T} \left[\max \left\{ m_T\left(p_T^{j(1)}, p^{(1)}\right), m_T\left(p_T^{j(2)}, p^{(2)}\right) \right\} \right]$$

J.Phys.G29:2343-2363,2003 Phys.Lett.B463:99-103,1999

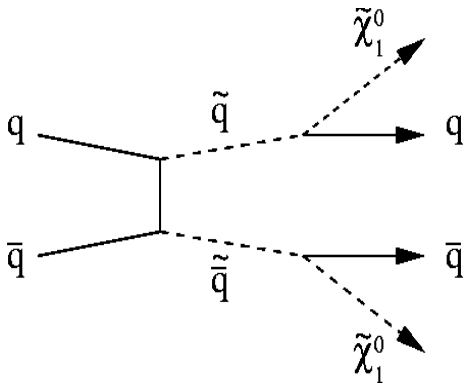
Measured:

- pt, phi, eta of jet 1
- pt, phi, eta of jet 2
- EtMiss, with angle phi

Want:

- «Simple» kinematic variable that distinguishes SUSY events from SM
- Mass of invisible particle

1) Mt of a jet and an unknown particle of mass m
2) Mt of second jet and the same unknown particle
3) Max of (1) and (2) is closest to the theoretical max point
4) Minimise over all possible combinations of p(1) and p(2), such that they make up our observed EtMiss. Minimum because we are after the max value of Mt2, and don't want fake maxima.



Mt2 analysis

- Not used to get masses (yet...)
- Just calculate Mt2(m_χ=0) for dijet events, plot it
- Does the job of may of the other cuts «automatically»

Have started to confirm this, working on it...

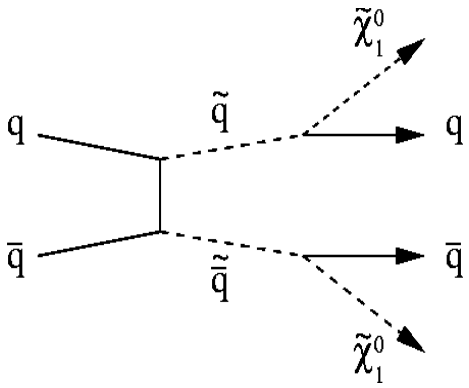
It is a property of the variable that $M_{T2}(\chi=0) \rightarrow 0$ if:

- $\not{E}_T \rightarrow 0$
- $\not{E}_T$ parallel to either jet
- Either jet $E_T \rightarrow 0$

Very nice features!
This is why M_{T2} is a useful discriminator for discovery

- Expect **small** M_{T2} for backgrounds from
  - decays of "light" semi-invisible particles
  - events with small $\not{E}_T$
  - mis-measurement of a single jet energy
- This includes: WW, ttbar, QCD fakes, neutrinos in jets, …
- **No** a-priori reason to expect M_{T2} to be small for e.g. MET coming from $Z \rightarrow \upsilon\upsilon$ + associated ISR
  - Expect this to dominate at larger M_{T2}

Barr & Gwenlan, TP week, May 2007



Mt2 public code

https://twiki.cern.ch/twiki/bin/view/Atlas/StransverseMassLibrary

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r20 - 19 Jun 2007 - 09:53:52 - ChristopherLester

The Stransverse Mass Library of the Susy Group

- Introduction
- Where is the Code for the Library?
- Do I need to build the library?
- To check out and build the library:
- Understanding the library: Examples
  - Mt2::SUSYPhys_Mt2_222_Calculator algorithm example
  - Mt2::Basic_Mt2_4441_Calculator algorithm example
  - Mt2::Basic_Mt2_332_Calculator algorithm example
- Validating/Testing the Library
- Comparison of algorithms
- Nomenclature
- Which algorithm should I use?
- External dependencies
- Notes for Maintainers

(Don't try this at home...)

Introduction

The "Cambridge MT2 Variable", sometimes also called the "Stransverse Mass", is an event variable used to bound the masses of an unseen pair of particles which are presumed to have decayed semi-invisibly into particles which were seen. MT2 is therefore a function of the momenta of two visible particles and the missing transverse momentum in an event. There is an external homepage for matters relating to MT2 here and the main references for the definition of MT2 are:

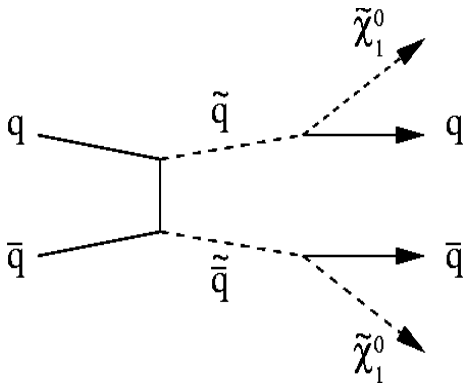
- Chris Lester, David Summers Phys.Lett.B463:99-103,1999
- Alan Barr, Christopher Lester, Phil Stephens J.Phys.G29:2343-2363,2003

A small c++ library has been created to house algorithms that can calculate MT2. The purposes of this library are:

1. to remove duplication and wasted effort from ATLAS code,
2. to make sure that the algorithms used to calculate MT2 are of high quality.
   1. (Simple implementations of MT2 can sometimes demonstrate poor performance in certain input regimes - even if they appear to work well on a few test cases. As this is not often apparent at first sight, it is hoped that central MT algorithms might be better maintained and/or have their bugs catalogued more effectively)
3. to provide a central repository for more "specialised" forms of MT2 beyond the simple "332 type" (see below) described in Phys.Lett.B463:99-103,1999 .
   1. For example, other forms (so called "4441 type" -- see below) take additional constraints from knowledge of the maximum centre-of-mass energy of the collision, and use information coming from the Z-momentum of the visible particles in the event.

Where is the Code for the Library?

The code may be found here in atlas/groups/SUSY/mT2/ in the central ATLAS CVS repository.



mT2 public code

https://twiki.cern.ch/twiki/bin/view/Atlas/StransverseMassLibrary

```
/// An exception class to indicate that the exception
/// was caused by the user's stupidity, not a failure
/// in the program:
class UserWasStupidException : public Mt2Exception {
public:
  UserWasStupidException(const std::string & reason) :
    Mt2Exception(reason) {}
};
```

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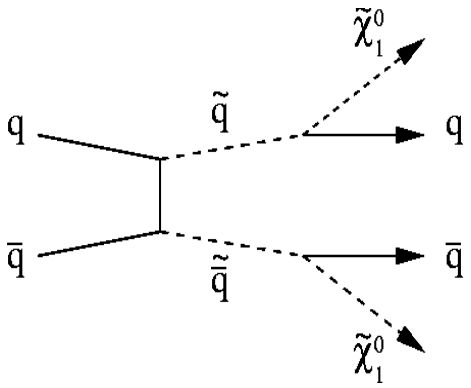
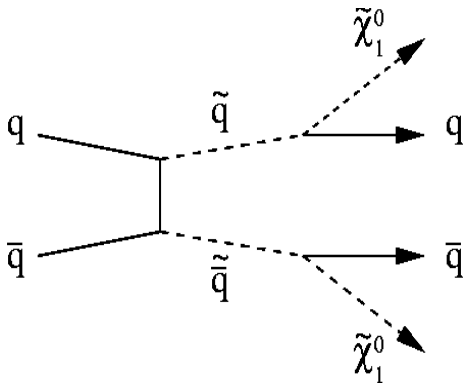


Mt2: Datasets

Name	Dataset	Sigma [pb]
SU1	trig1_misal1_csc11.005401.SU1_jimmy_susy.recon.AOD.v12000601_tid008573	7.43
SU2	user.MarijaMilosavljevic.SU2_jimmy_susy.HPTV.v12000601_tid005862	4.86
SU3	trig1_misal1_csc11.005403.SU3_jimmy_susy.recon.AOD.v12000601	18.59
SU4	trig1_misal1_mc12.006400.SU4_jimmy_susy.recon.AOD.v12000601_tid006724	262
SU8.1	trig1_misal1_csc11.005406.SU8_jimmy_susy1.recon.AOD.v12000601_tid006099/	6.44
J1	-	
J2	-	
J3	-	
J4	trig1_misal1_mc12.008090.pythia_J4_Nj2_FMET100.recon.AOD.v12000601_tid006101	316000
J5	trig1_misal1_mc12.008091.pythia_J5_Nj2_FMET100.recon.AOD.v12000601_tid009323	12500
J6	user.JelenaKrstic.trig1_misal1_mc12.008092.pythia_J6_Nj2_FMET100.recon.HPTV.v12000601_tid006102	344
J7	user.JelenaKrstic.trig1_misal1_mc12.008093.pythia_J7_Nj2_FMET100.recon.HPTV.v12000601_tid006103	5.3
J8	user.JelenaKrstic.trig1_misal1_mc12.008094.pythia_J8_Nj2_FMET100.recon.HPTV.v12000601_tid006104	0.02
T1	trig1_misal1_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000601_tid005997	461
Ttbar	trig1_misal1_mc12.005204.TTbar_FullHad_McAtNlo_Jimmy.recon.AOD.v12000601_tid006015	**???**
Wenu	user.MarijaMilosavljevic.pythia_Wenu_qg_ckin80_Nj2.HPTV.v12000601_tid006105	343
Wmunu	user.MarijaMilosavljevic.pythia_Wmunu_qg_ckin80_Nj2.HPTV.v12000601_tid006106	343
Wtaunu	user.MarijaMilosavljevic.pythia_Wtaunu_qg_ckin80_Nj2.HPTV.v12000601_tid006107	343
Zee	trig1_misal1_mc12.008194.pythia_Zee_qg_ckin80_Nj2.recon.AOD.v12000601_tid006109	1432
Zmumu	trig1_misal1_mc12.008195.pythia_Zmumu_qg_ckin80_Nj2.recon.AOD.v12000601_tid006110	46.4
Ztautau	user.MarijaMilosavljevic.pythia_Ztautau_qg_ckin80_Nj2.HPTV.v12000601_tid006709	46.3
Znunu	user.MarijaMilosavljevic.pythia_Znunu_qg_ckin80_Nj2.HPTV.v12000601_tid006108	246



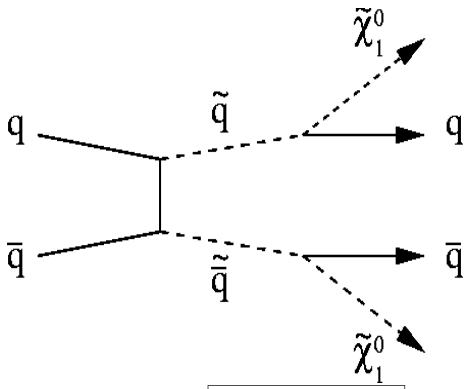
Mt2: Cuts

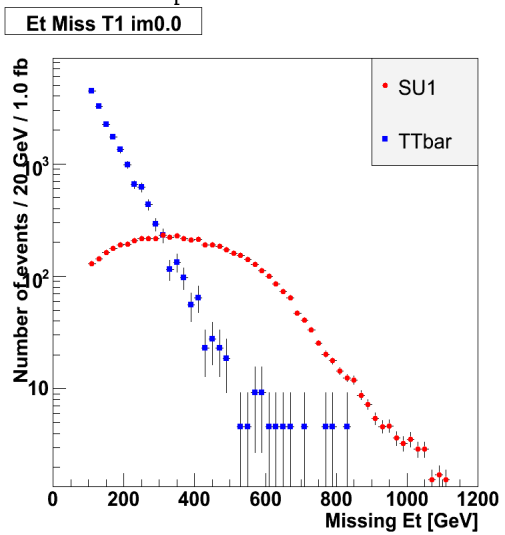
- Jet_pt_1 > 150 GeV/c
- Jet_pt_2 > 100 GeV/c «Dijet» cuts
- |Jet_eta_1,2| < 2.5
- EtMiss>100 GeV (because of my datasets)

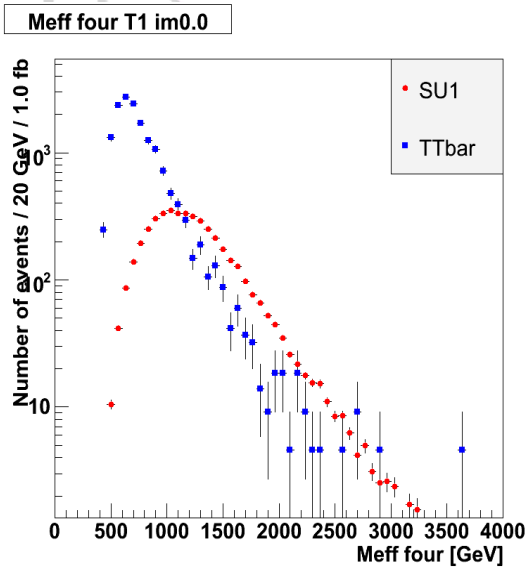
- That's it.

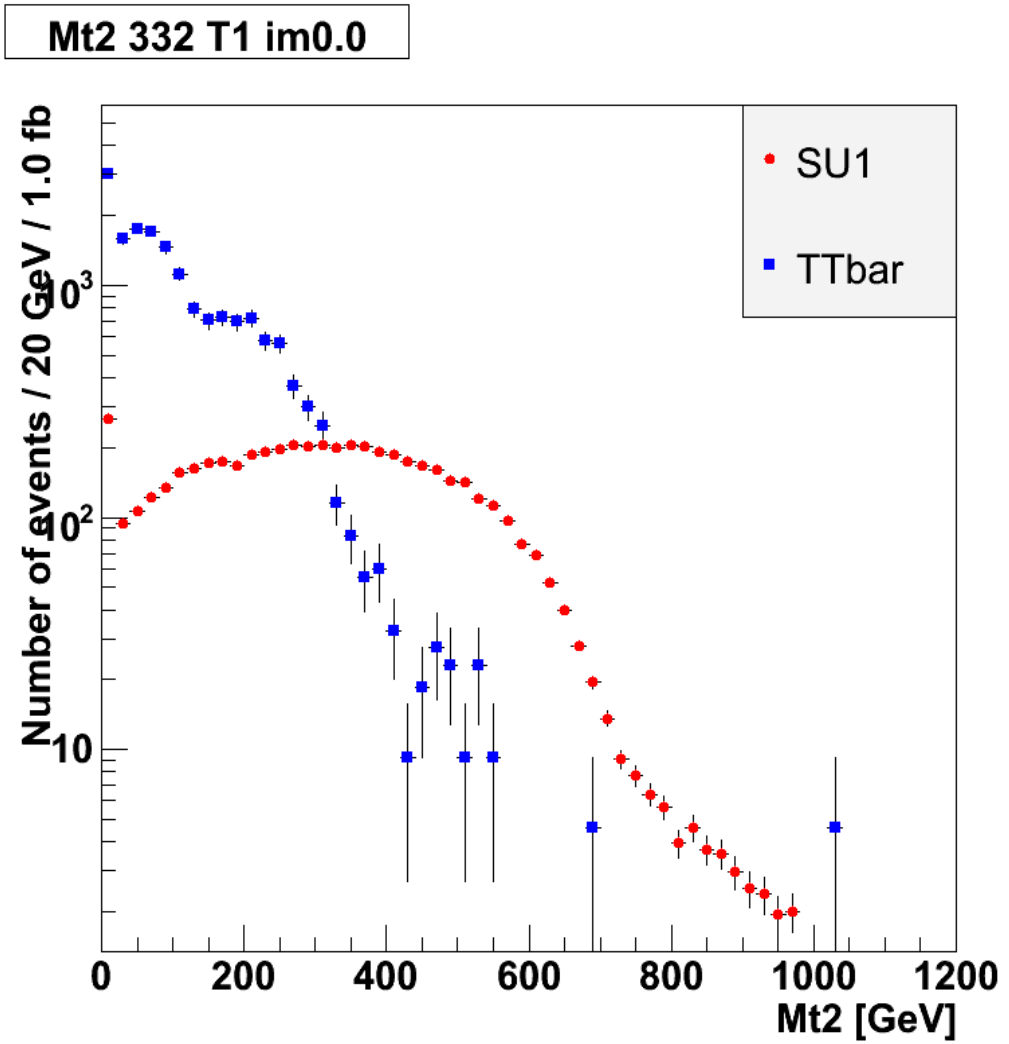
Mt2: Variable

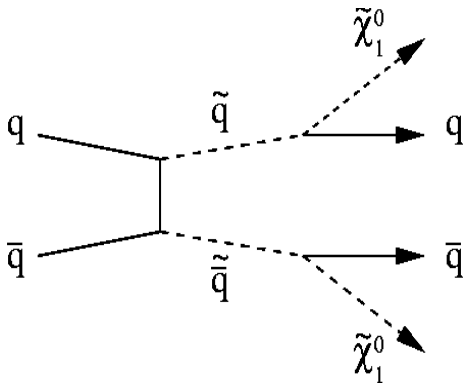
Examples for one signal and one «typical» background







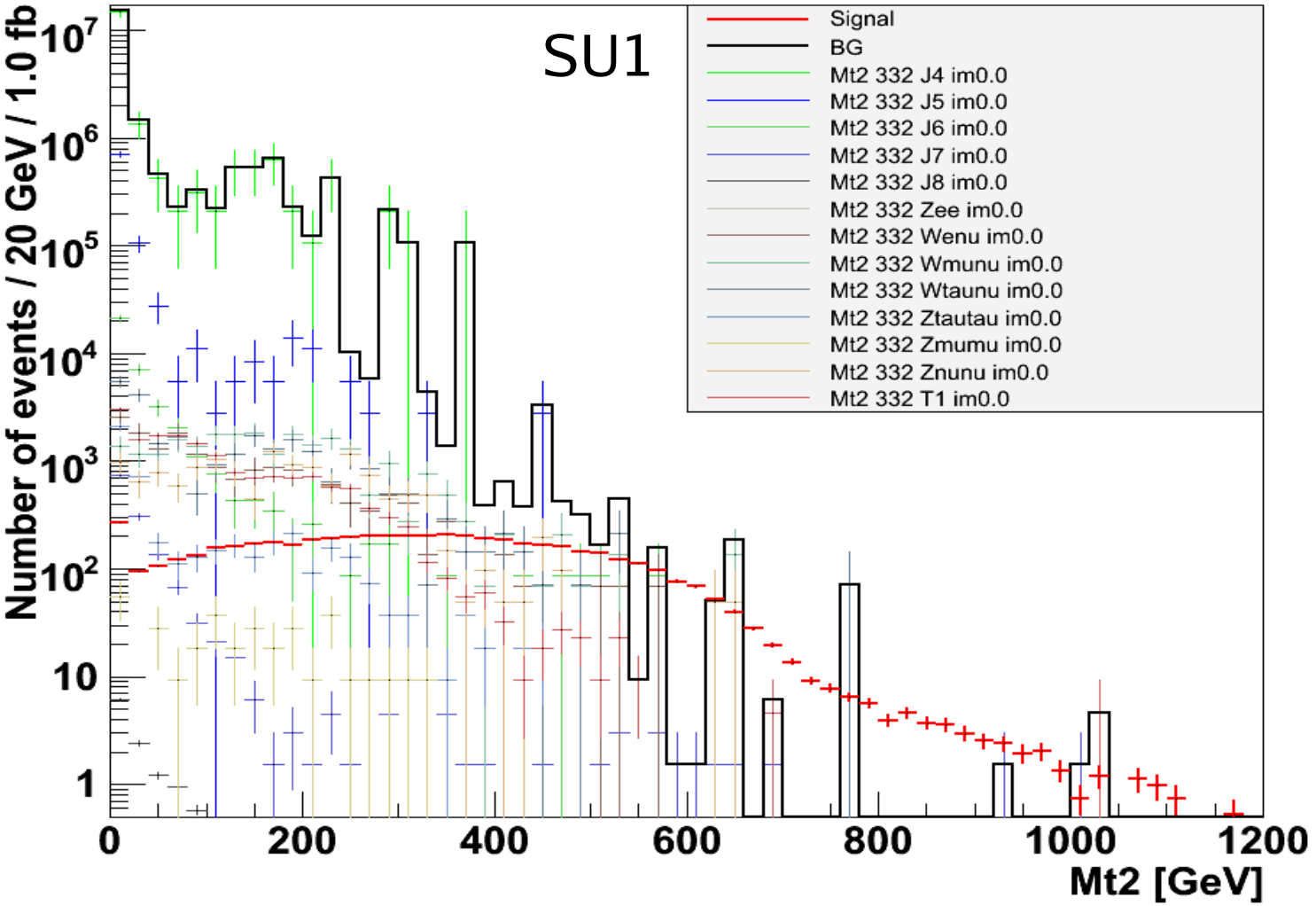




Mt2: Summary

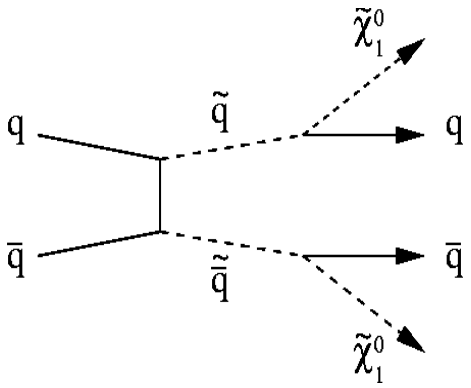
Signal and summed BG after all cuts

Mt2



Signal	S/sqrt(B)
SU1	26
SU2	0.4
SU3	20
SU4	17
SU8	26

Mt2 > 550 GeV



Standard

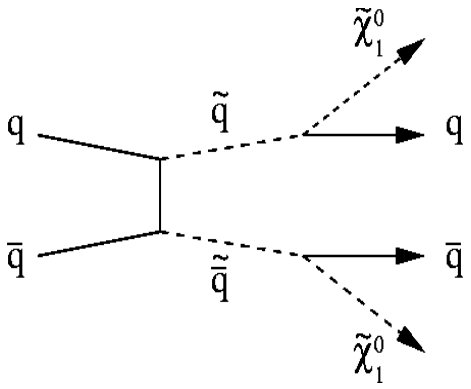
Signal	S/sqrt(B)
SU1	32
SU2	1
SU3	61
SU4	104
SU8	29

Mt2

Signal	S/sqrt(B)
SU1	26
SU2	0.4
SU3	20
SU4	17
SU8	26

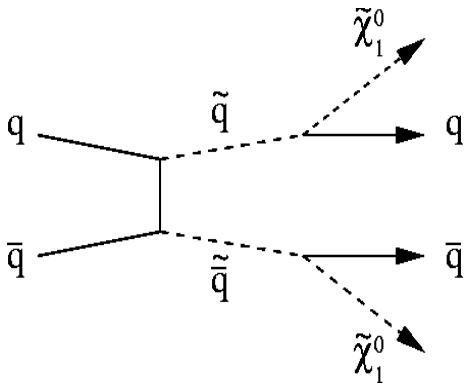
Conclusions

- It is possible to see deviations from SM physics in a dijet channel, for 1fm^{-1} of collected data. At least if the new physics is «SUSY-like».
- Mt2 does a nice job of distinguishing between SUSY and SM events, without a lot of cut tuning.
- Mt2 may have light enough correllation with other measured variables to be used for «data-driven» bg estimation.

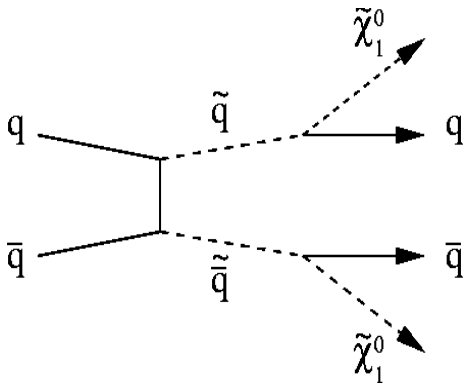


Future plans

- Get better statistics for a number of bgs!
- «Data-driven» bg estimation
- Trigger studies
- Correlate Mt2 with other measured properties, see if we can combine cuts to make robust «SUSY filter» or «non-SM filter»
- Other model assumptions – what can we get from Mt2?
- Can we get a mass measurement from Mt2? Have to assume the LSP mass, but the «correct» assumption might give best chi2 for an edge fit. Probably not year-1 measurement...
- ...



Backup slides



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Wmunu	user.MarijaMilosavljevic.pythia_Wmunu_qg_ckin80_Nj2.HPTV.v12000601_tid006106	343
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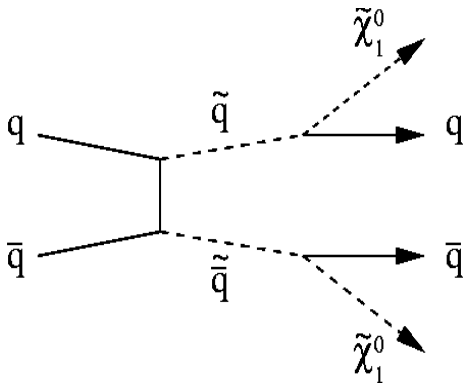
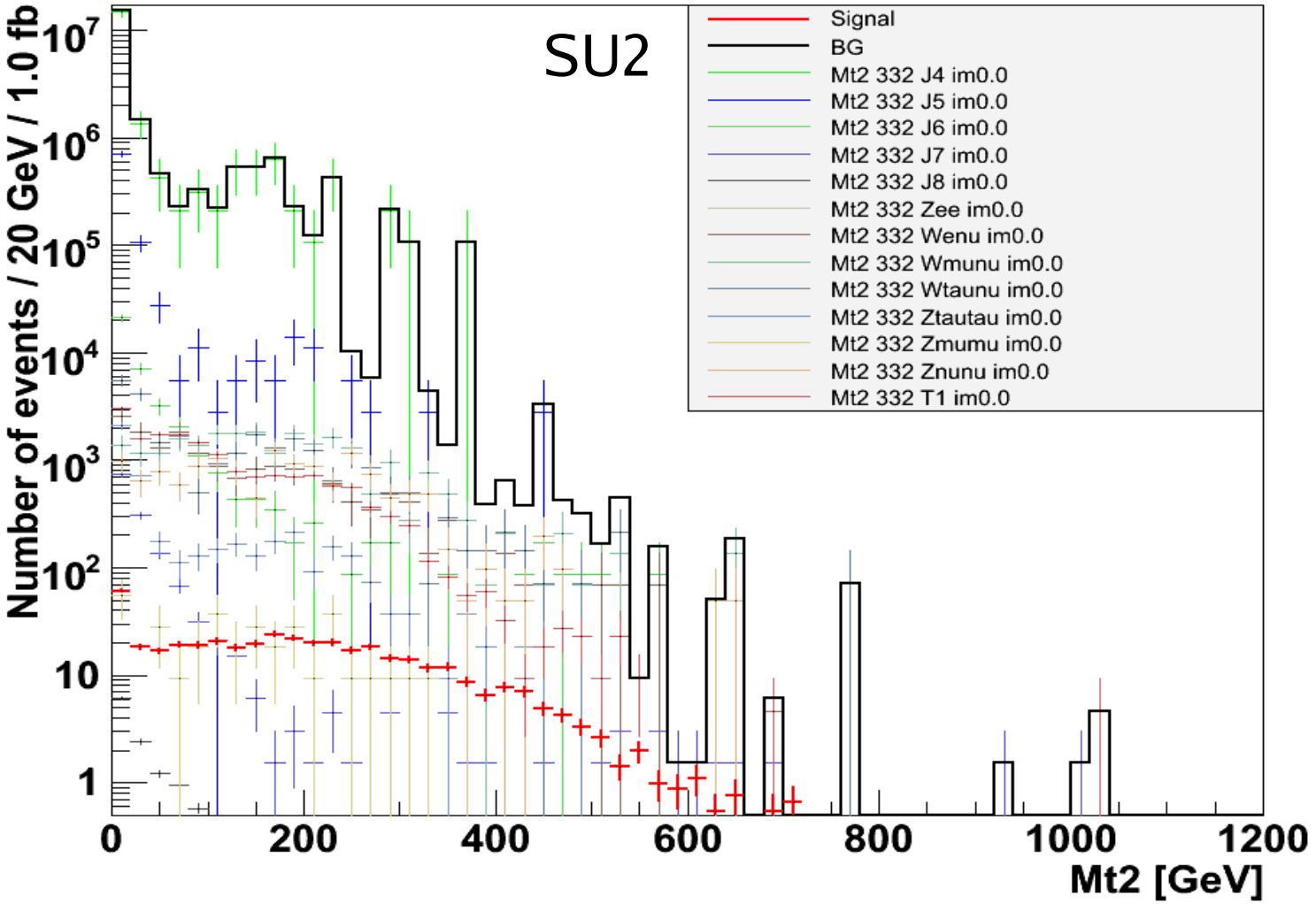


mT2 summary

Mt2



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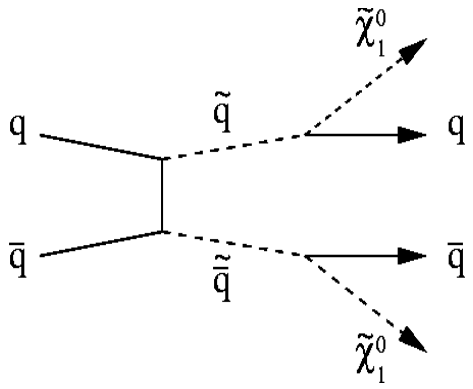

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