

Low Jet Multiplicities and m_{T2} for early SUSY discovery

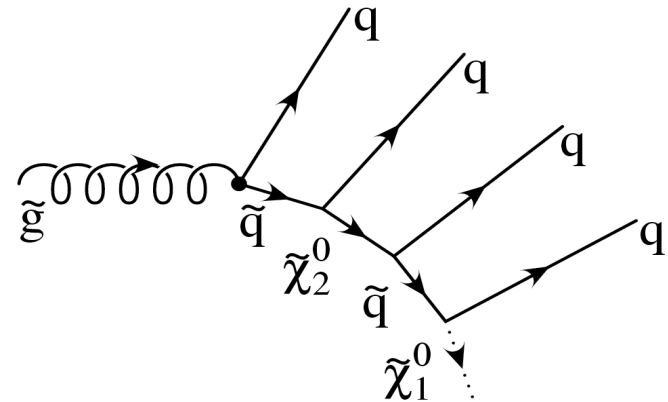
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31 January 2008

Oxford SUSY Working Group

Searching for SUSY

At LHC, sparticles may be copiously produced:
Cascade decays end in quarks, gluons (**Jets**),
Leptons and (in R-Parity conserving models)
Missing Energy (LSP escapes undetected)

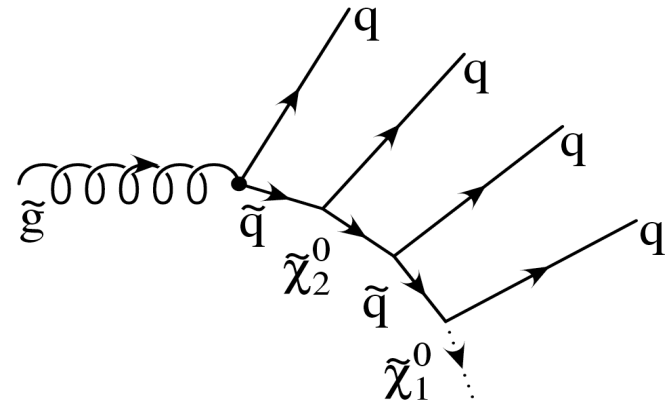


Look for events with lots of high transverse-momentum **Jets** and/or **Leptons** and (in RPC) **Missing-Transverse-Energy (MET)**

- Signatures with LEPTONS:
 - generally **smaller cross sections** (but also tend to have lower Backgrounds)
 - **rely on multiple cascade decays** (model dependent)
- **JETS-only** channels tend to have **higher cross sections** and **less model dependence** → **good early search strategy** **BUT...**

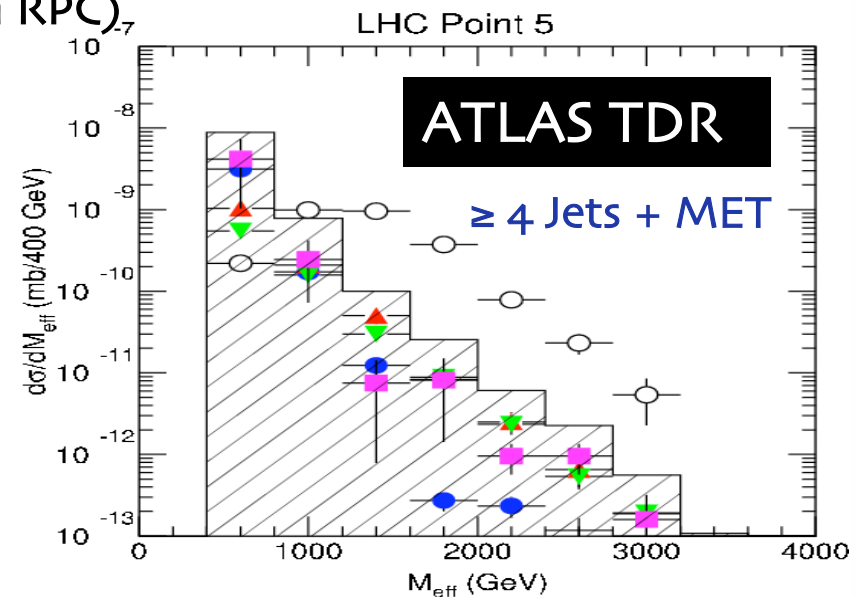
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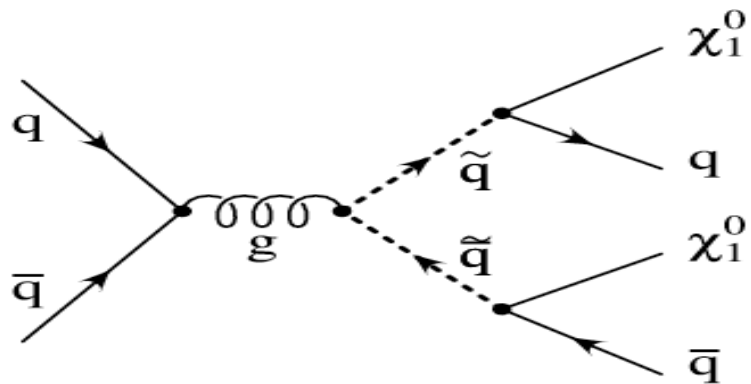


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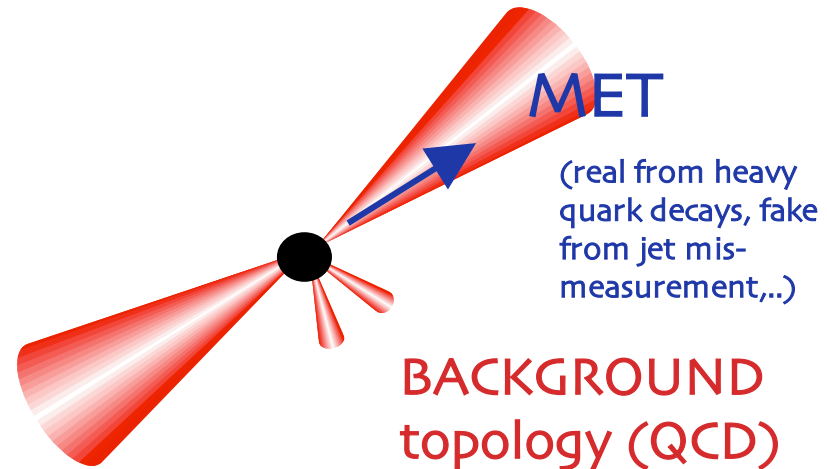
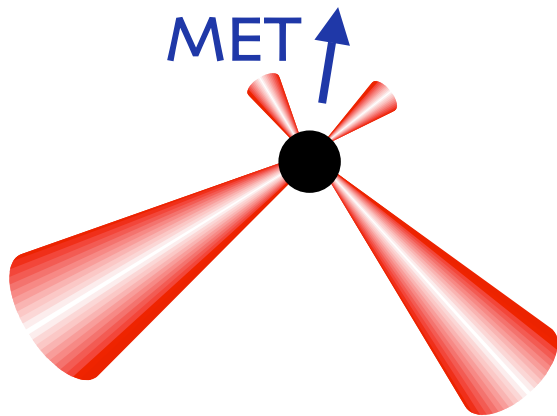
To date, most effort concentrated
 on **large jet multiplicities i.e. ≥ 4 jets**
 - assumption being that this is
required to reduce large QCD BG
 (e.g. ATLAS TDR (1999) and ALL studies since then)



SUSY searches with small nJets



and similar ...



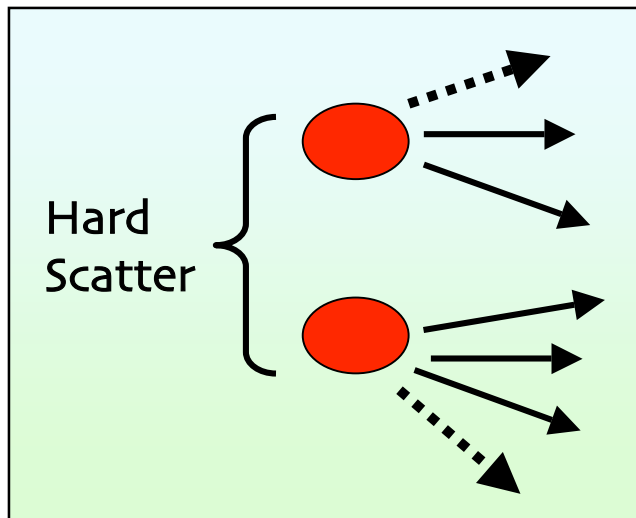
Concentrate on small nos. of high-pT jets :

- 1) Large signal cross section (provided at least 1 strongly int. particle @ TeV scale)
- 2) Large control statistics
- 3) Relatively well known SM backgrounds
- 4) Relatively model independent
 - do not rely on leptonic cascades
 - do not rely on hadronic cascades

Use kinematics, rather than "business of event" to pick out SUSY

mT2 (sTransverse Mass)

mT2: a reminder



mT2 useful in events where 2 identical particles decay semi-invisibly (e.g. 2-Jets + MET)

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

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

"Try all possible directions for the neutralinos and find the minimum heavy sparticle mass"

mT2 designed to provide information on mass of sparticles for "simple" SUSY topologies such as 2-Jet+MET or 2-lepton+MET (or for more complicated cases but in which one can unambiguously know which particles originated from which side of the decay)

mT2 for discovery?

BUT mT2 also has nice properties which make it useful for discovery!!!

i.e. it is a property of the variable that $mT2(m_{LSP}=0) \rightarrow 0$ if:

- $p_T^{\text{Jet}} \rightarrow 0$
- $MET \rightarrow 0$
- MET parallel to either jet

Naturally very nice features!
This is why mT2 is a useful discriminator for discovery

→ expect small mT2 values for backgrounds from:

- decays of “light” semi-invisible particles (W,top)
- events with small MET
- mis-measurement of a single jet energy (MET along jet axis)

(includes WW, ttbar, QCD fakes, neutrinos in jets,...)

NOTE: no *a priori* reason to expect small mT2 for $Z \rightarrow \nu\nu + \text{Jets}$ → may expect this to be dominant background at larger mT2

“Simple” analysis

mT2 already “does the job” of traditional cuts

- MET cut (small if MET → 0)
- $\delta\phi$ cut (small if MET parallel to either jet)
- transverse sphericity cut (small if 2 jets are back-to-back)

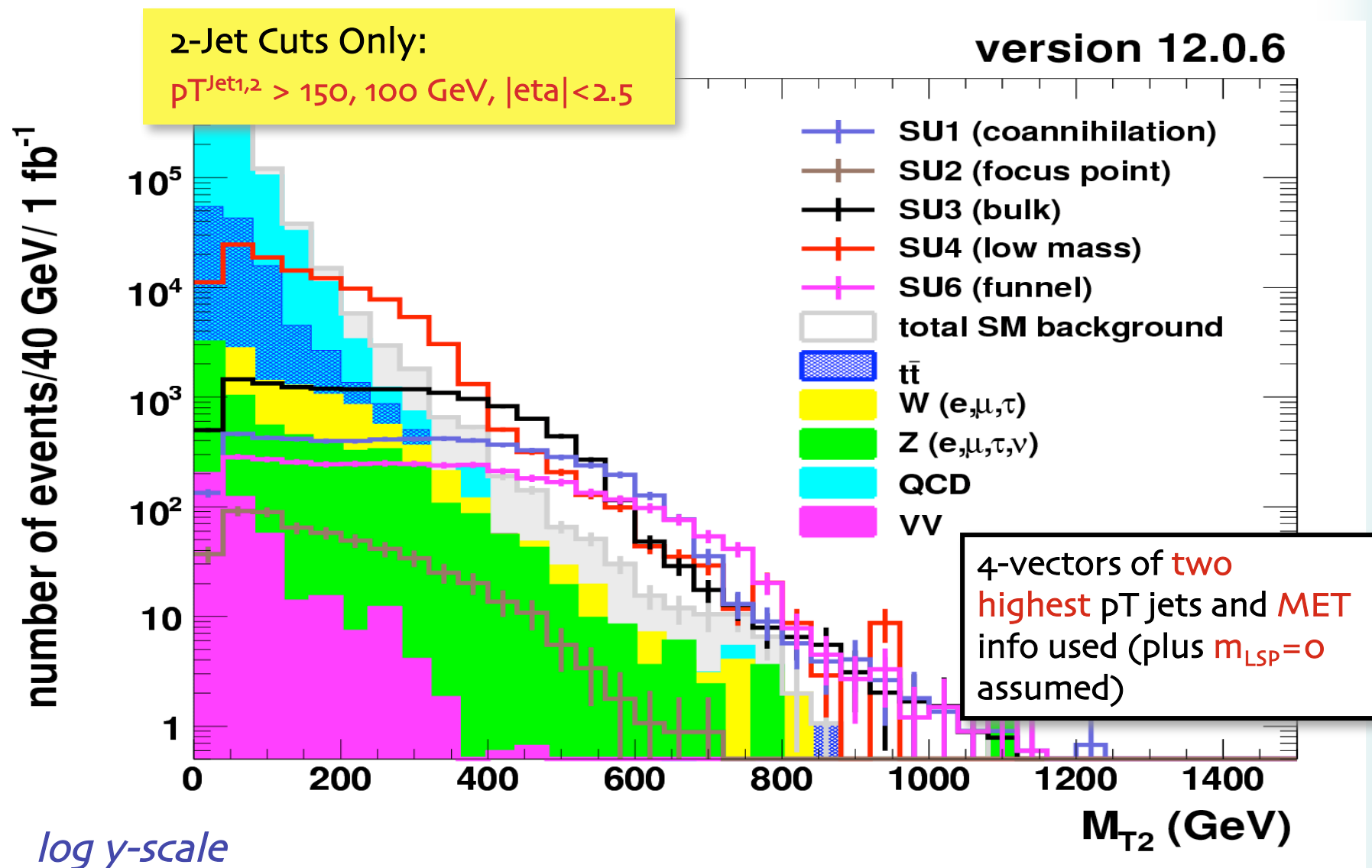
Go for “simple approach” (2-Jet selection only):

CUTS:

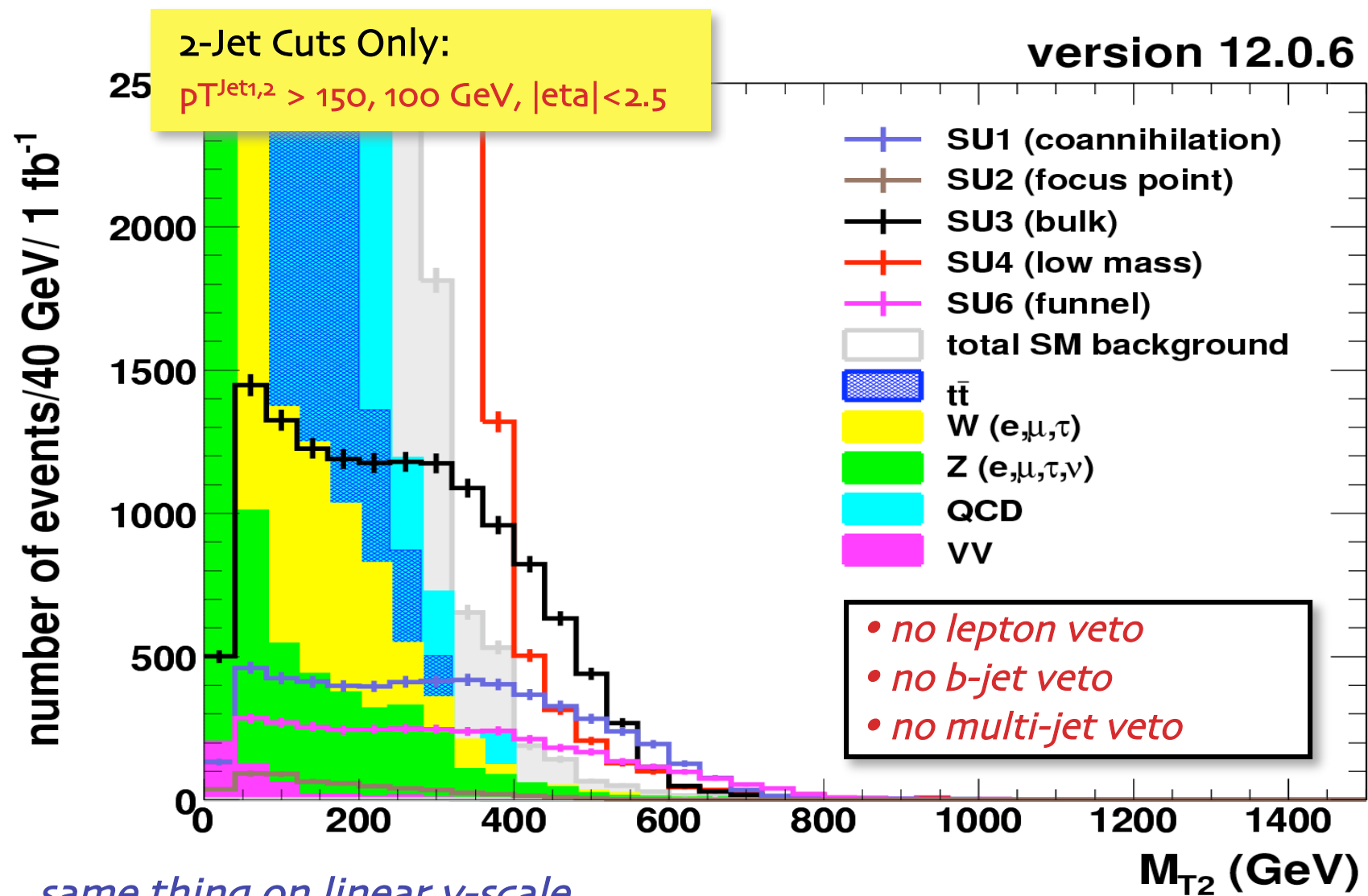
- at least 2 Jets with $p_T^{\text{Jet}1,2} > 150, 100 \text{ GeV}$, $|\eta| < 2.5$ → plot mT2
(simple 2-Jet cuts only)

NOTE: We don't claim you would just plot M_{T2} and publish(!) BUT a simple selection may make it easier to (for example) understand systematics and backgrounds, and so could speed up the whole process

mT2 Results

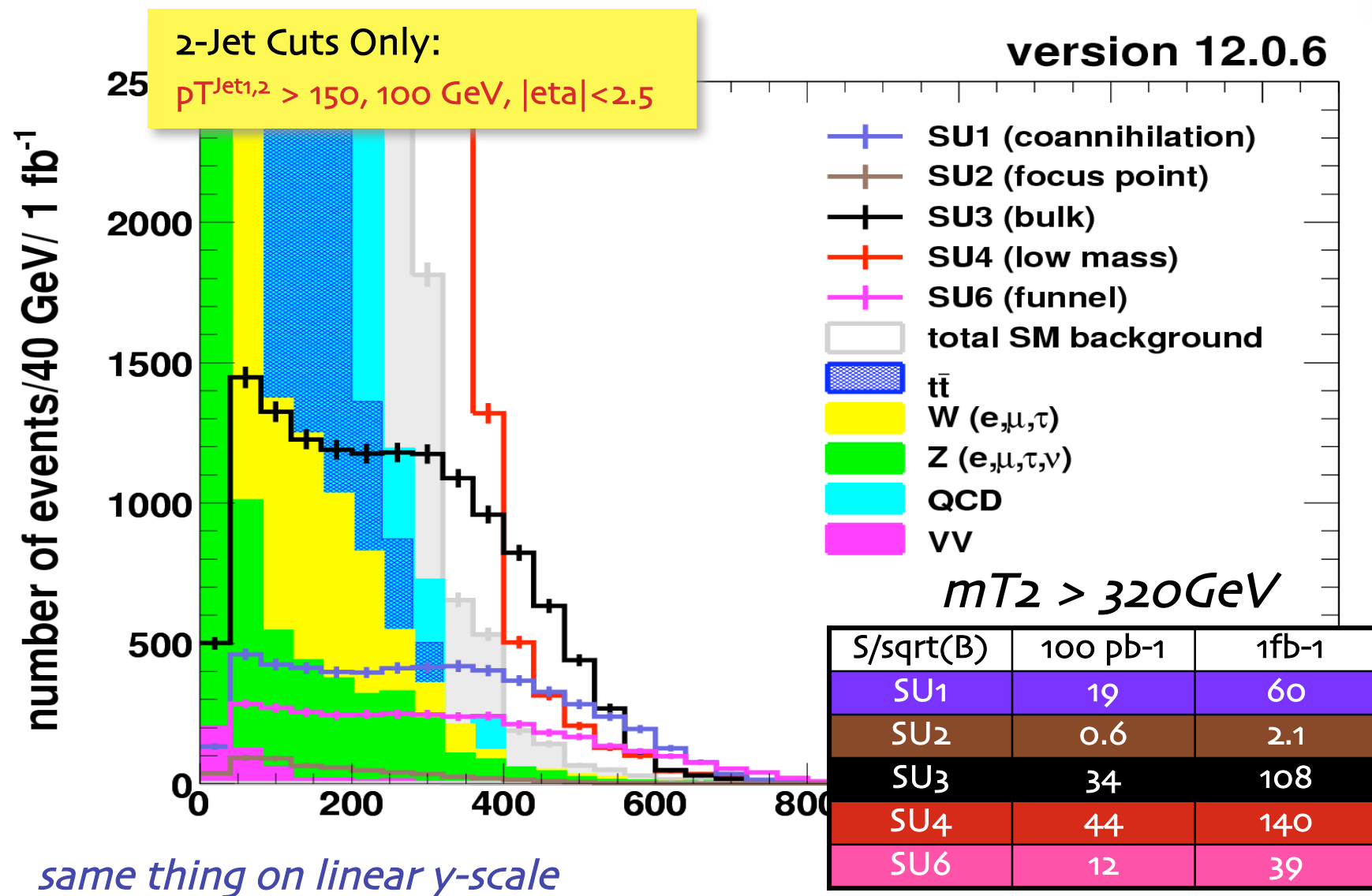


mT₂ Results

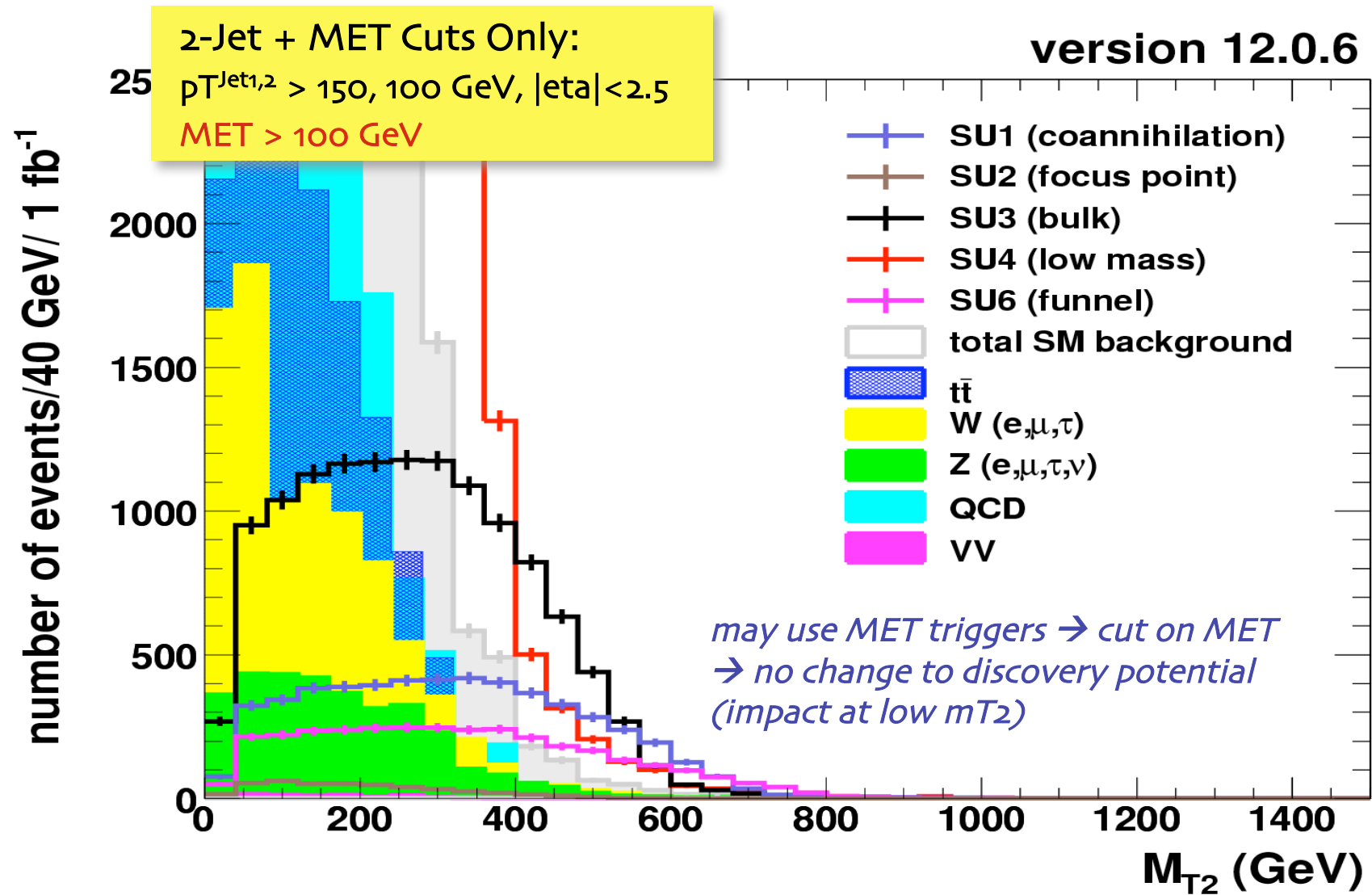


same thing on linear y-scale

mT2 Results



mT₂ after MET cut



mT₂ for early discovery?

Simple offline cuts could be sufficient - BUT what do we need to know?

NEED:

- Some understanding of MET and hadronic energy scale
 - degree needs to be determined
- Some lepton ID
 - eg. estimate $Z \rightarrow \nu\nu$ from $Z \rightarrow \mu\mu$
- Some idea of ttbar background

“DO NOT NEED”:

- B-tagging
 - only if needed to measure ttbar background
- detailed understanding of jet resolution tails
 - in limit where only 1 jet per event fluctuates
- MET tails from multi-jets (if “pure” 2-jet)

Need to quantify above statements

- need 2-/3-parton Alpgen to validate against $2 \rightarrow 2$ MC
 - QCD and Drell-Yan backgrounds
- study effect of extra jet mis-calibration/resolution
- study triggers in detail (jets+MET triggers probably sufficient)

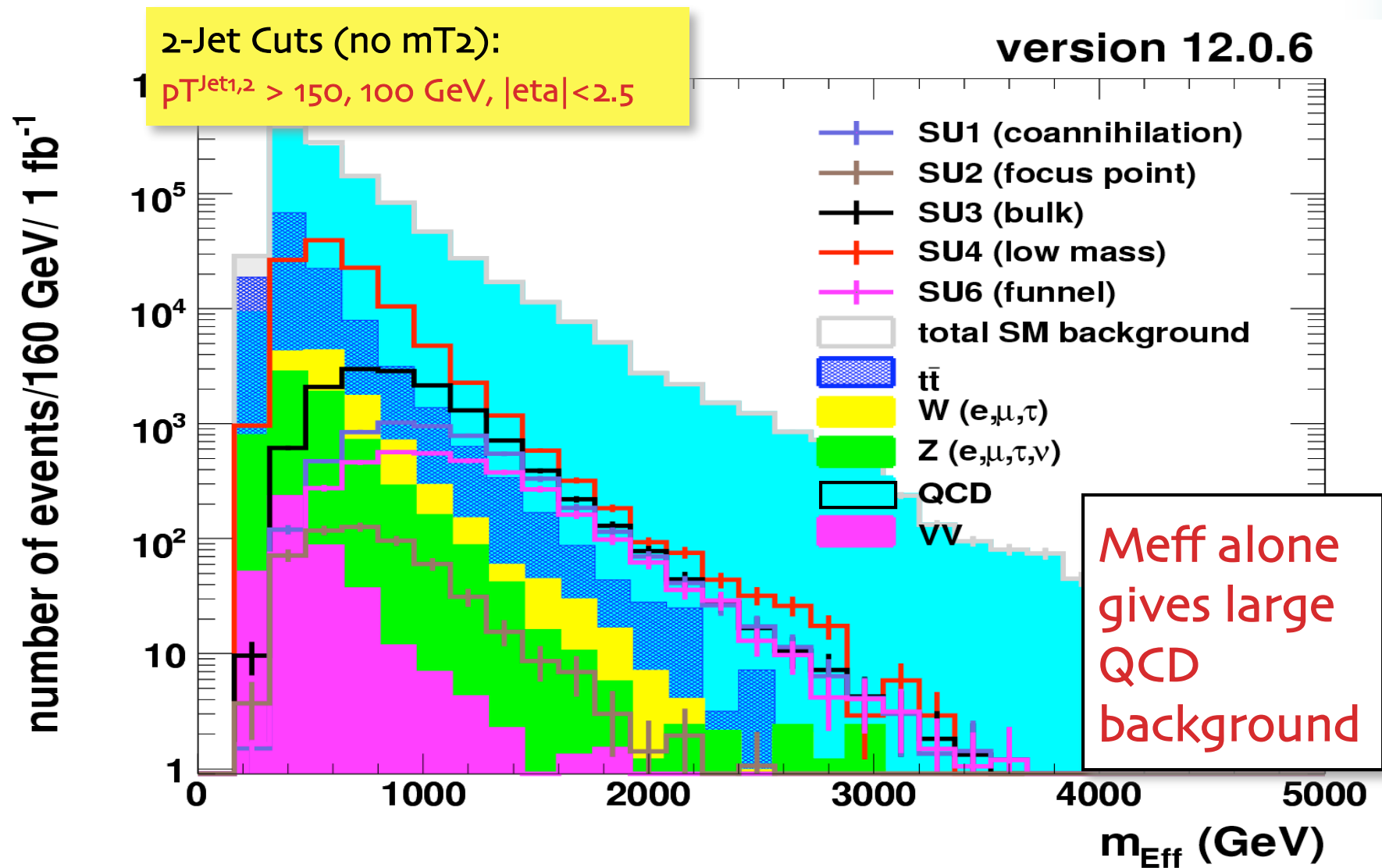
2-Jet analysis without mT_2 ?

More traditionally (since TDR), M_{eff} distribution used as discriminator

Cuts
at <u>least</u> 2 Jets: • $p_{T\text{Jet}1,2} > 150, 100 \text{ GeV}$ • $\eta_{\text{Jet}1,2} < 2.5$

$$M_{\text{eff}} = \sum_{\text{Jets}} p_T^{\text{Jet},i} + \text{MET}$$

Meff distribution



2-Jet analysis without mT2?

More traditionally (since TDR), Meff distribution used as discriminator

Cuts

at least 2 Jets:

- $p_{T, \text{Jet}1,2} > 150, 100 \text{ GeV}$
- $|\eta_{\text{Jet}1,2}| < 2.5$

BUT with further Cuts

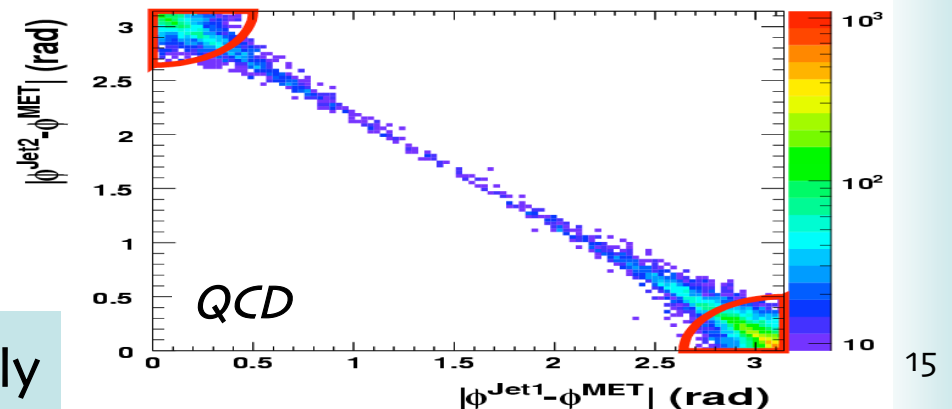
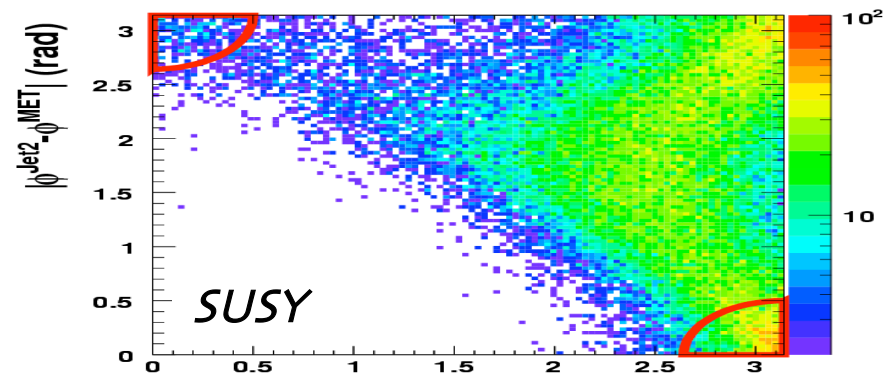
$\text{MET} > \max(100, 0.3 * \text{Meff}) \text{ GeV}$

Cuts based on: $\delta\phi_i = |\phi(\text{Jet}i) - \phi(\text{MET})|$

- $\delta\phi_{1,2} > 0.2 \text{ rad}$
- $R1 = > 0.5 \text{ rad}, R2 > 0.5 \text{ rad}$

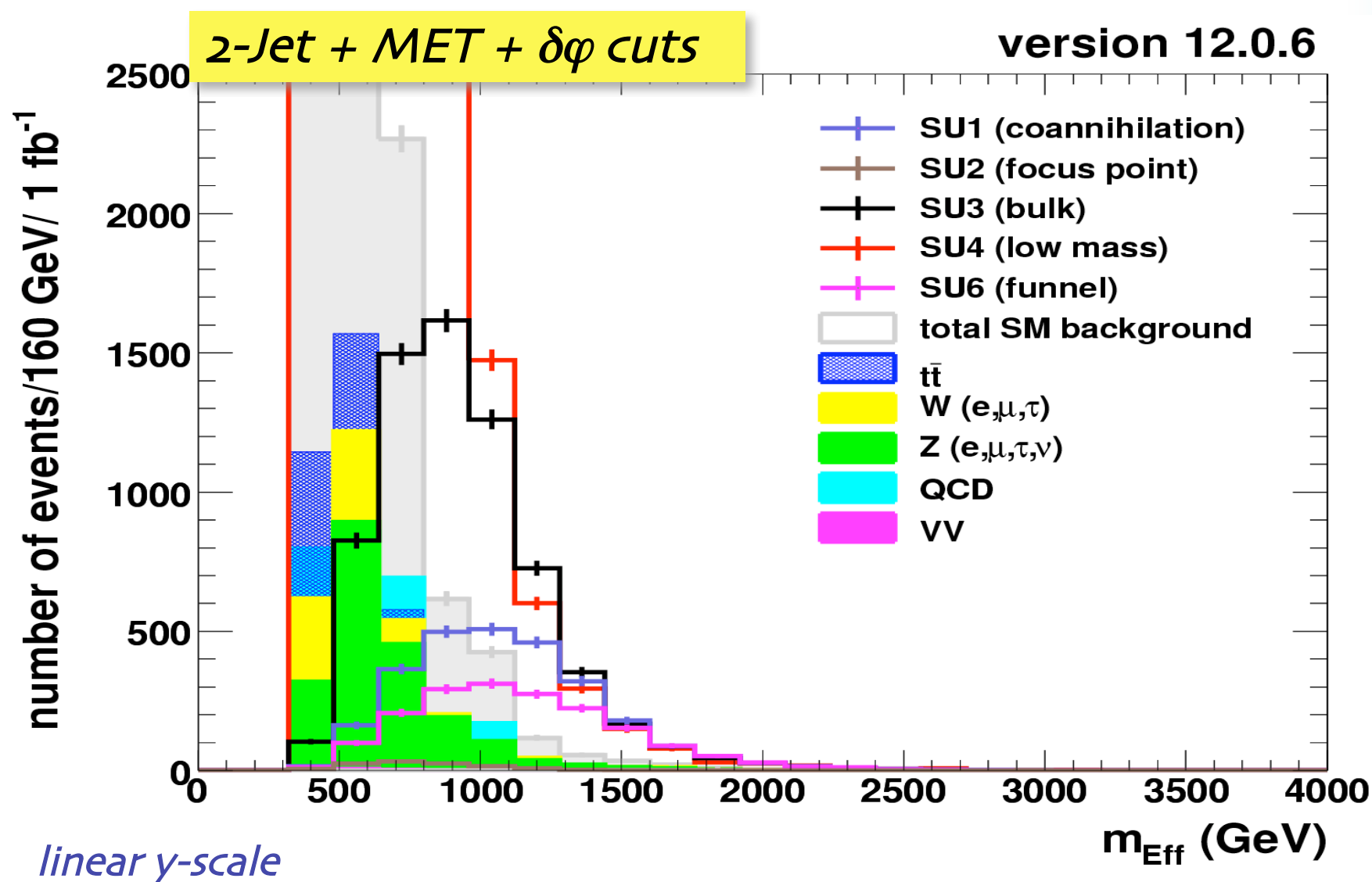
$$[R1,2 = \sqrt{(\delta\phi_{2,1})^2 + (\pi - \delta\phi_{1,2})^2}]$$

$$\text{Meff} = \sum_{\text{Jets}} p_T^{\text{Jet},i} + \text{MET}$$

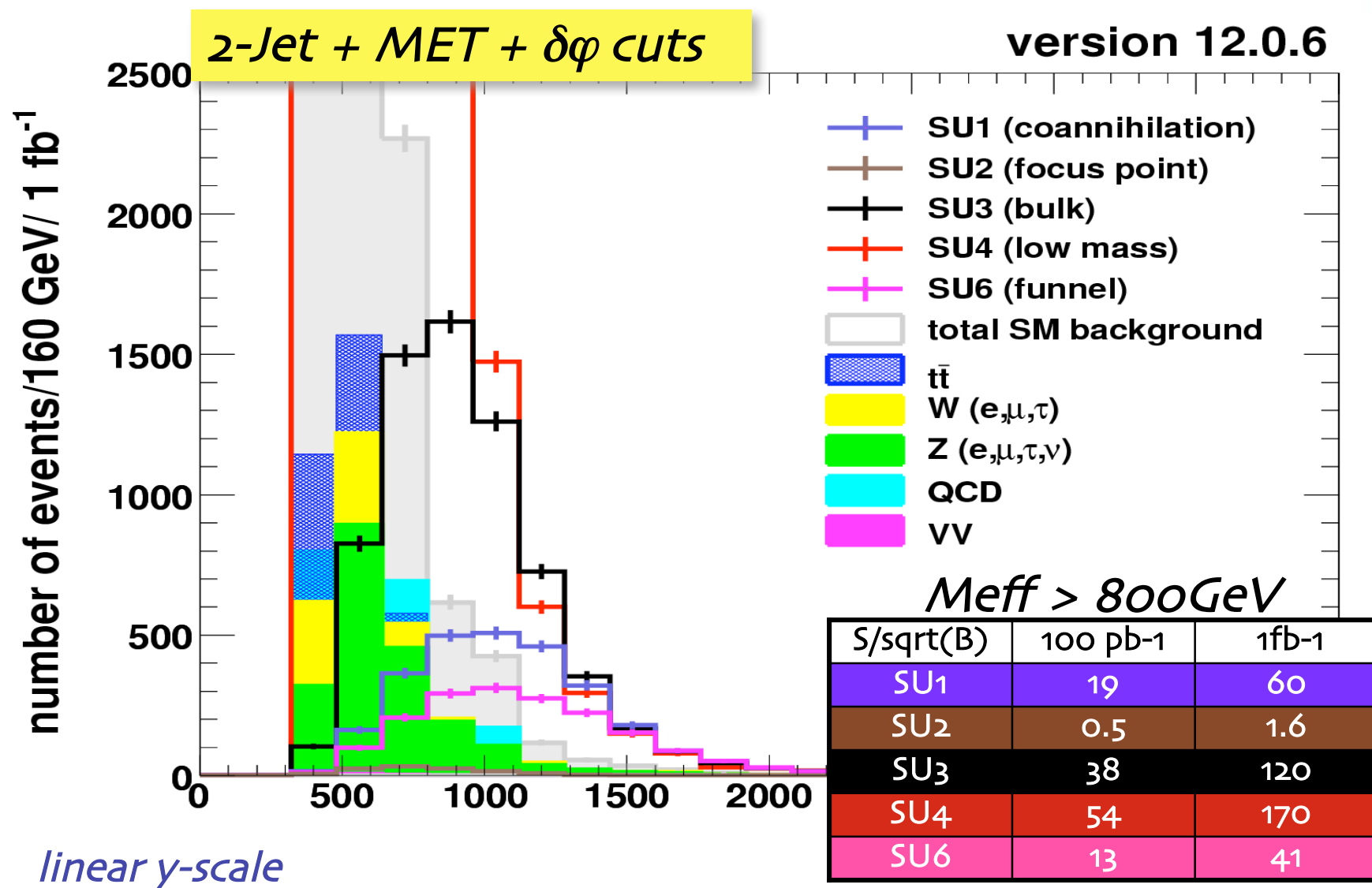


mT2 basically “does this job” implicitly

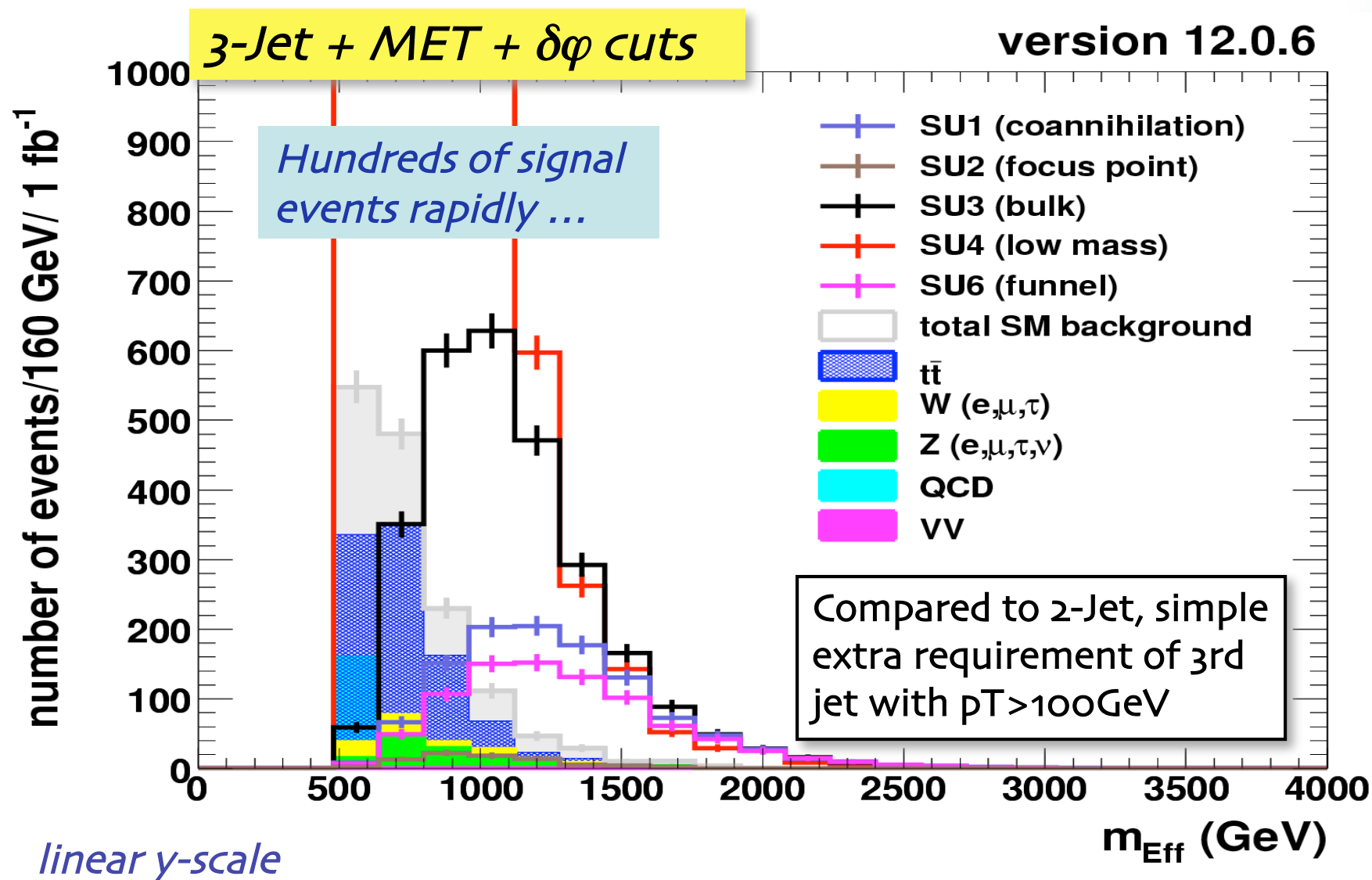
2-Jet Meff distribution



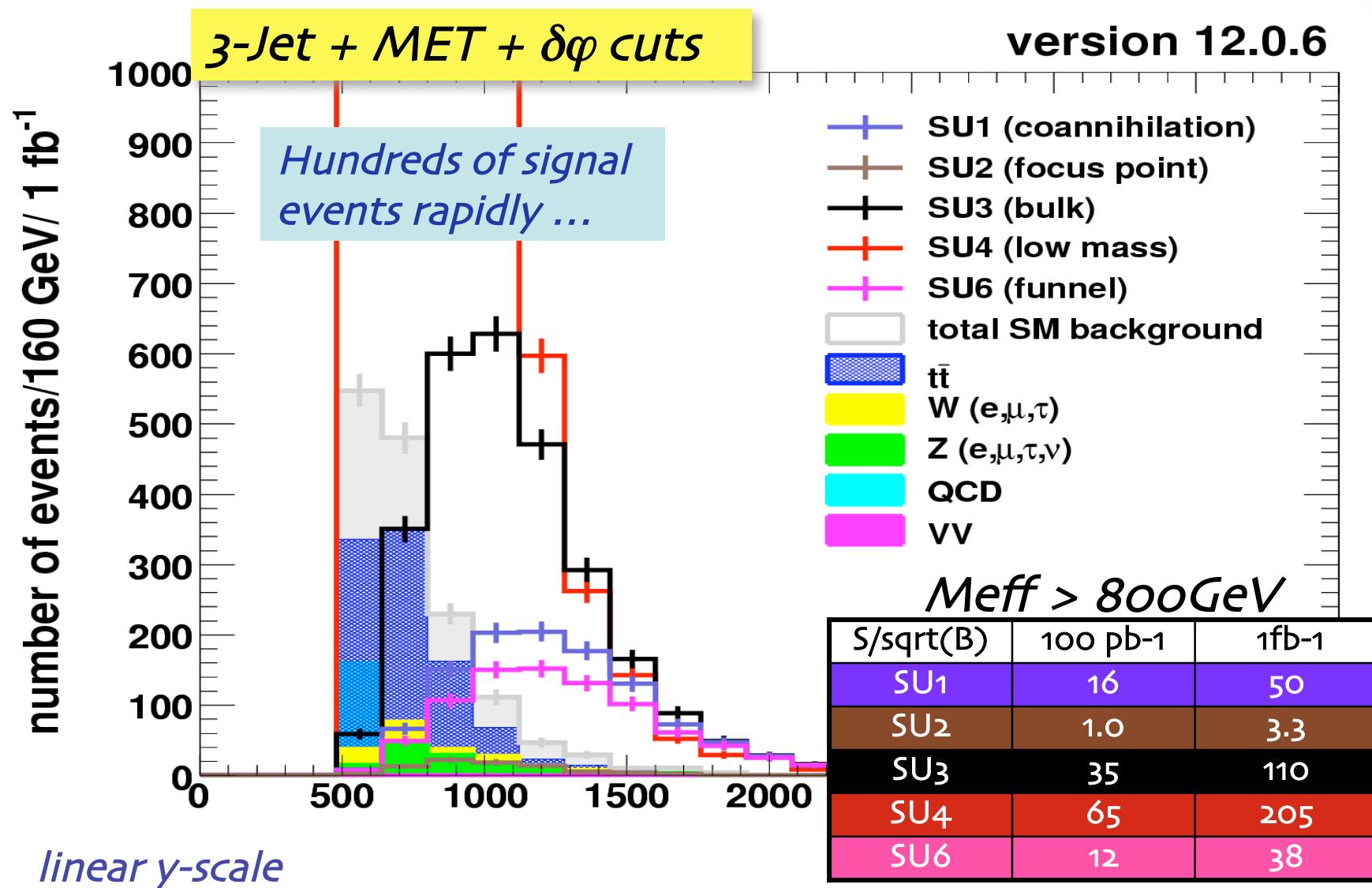
2-Jet Meff distribution



3-Jet channel (also sensitive)



3-Jet channel (also sensitive)



Summary

2-/3-Jets+MET have good SUSY sensitivity

Not just "4 or more jets"

- large cross section
- higher $S/\sqrt{B}$ than multi-jet channels at low luminosity
- good statistics for signal and control regions
- same true for leptons + 2/3-Jets + MET channels?

m_{T2} "does the job" of several traditional cuts

- expected from its properties
- combination of {MET, sphericity, $d\phi$ }
- reduce number of explicit cuts $\rightarrow$ simplify analysis?

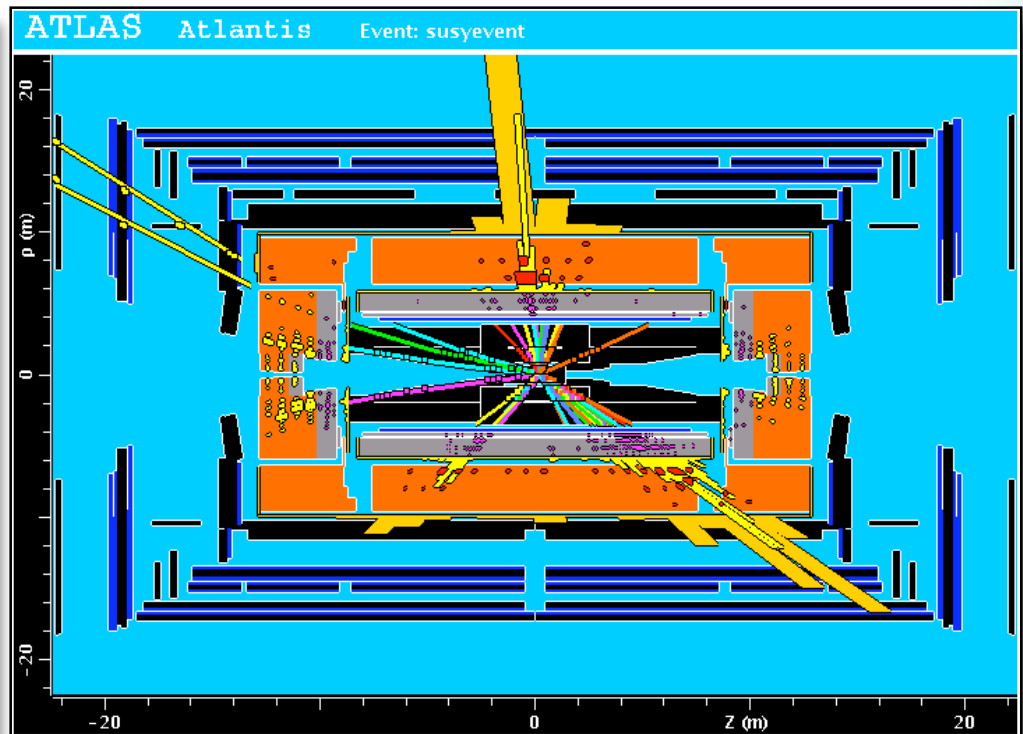
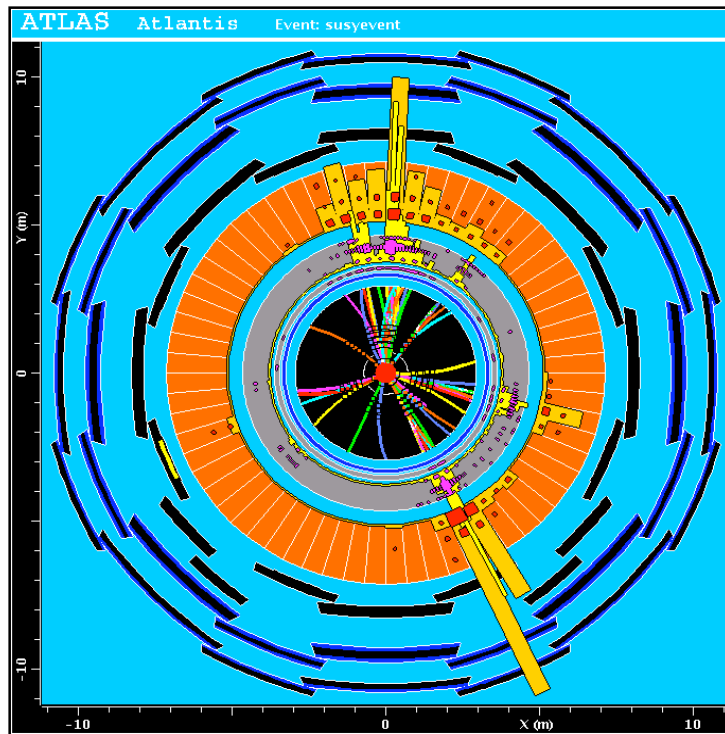
Jets+MET channels with low jet multiplicities (both "traditional" and m_{T2} approach) should be part of early SUSY search strategy

Backups

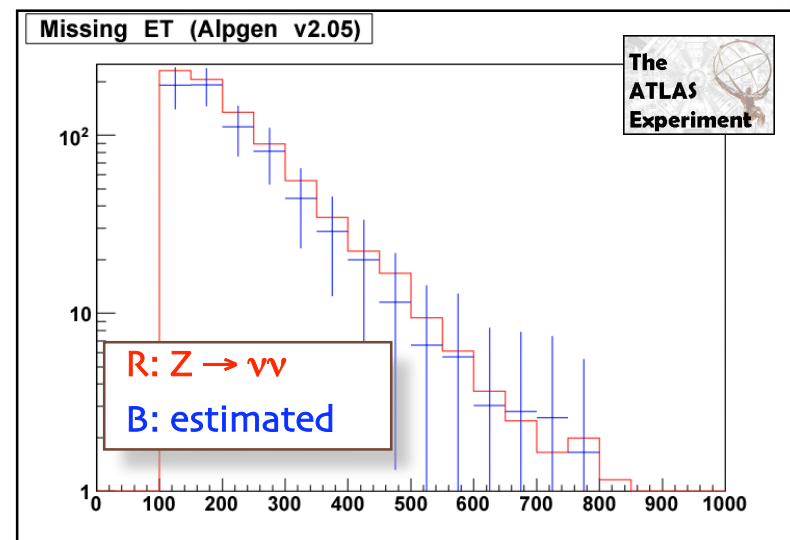
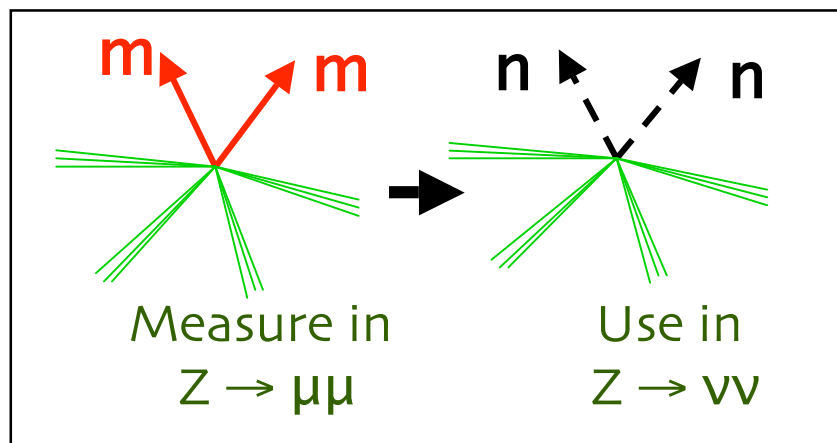
example SUSY points

Point	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0 (GeV)	$\tan(\beta)$	$\text{sign}(\mu)$	σ (pb)
Coannihilation (SU1)	70	350	0	10	+	7.43
Focus Point (SU2)	3550	300	0	10	+	4.86
Bulk (SU3)	100	300	-300	6	+	18.59
Low Mass (SU4)	200	160	-400	10	+	262
Funnel (SU6)	320	375	0	50	+	4.48
Coannihilation (SU8.1)	210	360	0	40	+	6.44
Coannihilation (SU8.2)	215	360	0	40	+	6.40
Coannihilation (SU8.3)	225	360	0	40	+	6.32

Simulated SUSY event



EG. Background Measurement



- Example: SUSY BG
 - Jets + MET from Z to neutrinos (plus ISR)
 - Measure in $Z \rightarrow \mu\mu$
 - Use for $Z \rightarrow \nu\nu$
- Good match
 - Useful technique
- Statistics limited
 - Go on to use $W \rightarrow \mu\nu$ to improve

MC samples

J4	trig1_misalh_mc12.008090.pythia_J4_Nj2_FMET100.recon.AOD.v12000601*
J5	trig1_misalh_mc12.008091.pythia_J5_Nj2_FMET100.recon.AOD.v12000601*
J6	trig1_misalh_mc12.008092.pythia_J6_Nj2_FMET100.recon.AOD.v12000601*
J7	trig1_misalh_mc12.008093.pythia_J7_Nj2_FMET100.recon.AOD.v12000601*
J8	trig1_misalh_mc12.008094.pythia_J4_Nj2_FMET100.recon.AOD.v12000601*
T1	trig1_misalh_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000604*
TTbar	trig1_misalh_mc12.005204.TTbar_FullHad_McAtNlo_Jimmy.recon.AOD.v12000601*
Zee	trig1_misalh_mc12.008194.pythia_Zee_qg_Nj2_ckin80.recon.AOD.v12000601
Zmumu	trig1_misalh_mc12.008195.pythia_Zmumu_qg_Nj2_ckin80.recon.AOD.v12000601
Ztautau	trig1_misalh_mc12.008191.pythia_Ztautau_qg_Nj2_ckin80.recon.AOD.v12000601
Znunu	trig1_misalh_mc12.008190.pythia_Znunu_qg_Nj2_ckin80.recon.AOD.v12000601*
Wenu	trig1_misalh_mc12.008270.pythia_Wenu_qg_ckin80_Nj2.recon.AOD.v12000601*
Wmumu	trig1_misalh_mc12.008271.pythia_Wmumu_qg_ckin80_Nj2.recon.AOD.v12000601*
Wtaunu	trig1_misalh_mc12.008270.pythia_Wtaunu_qg_ckin80_Nj2.recon.AOD.v12000601*
WW	trig1_misalh_csc11.005985.WW_Herwig.recon.AOD.v12000601*
WZ	trig1_misalh_csc11.005987.WZ_Herwig.recon.AOD.v12000601*
ZZ	trig1_misalh_csc11.005986.ZZ_Herwig.recon.AOD.v12000601*