Early SUSY Discovery in Jets+MET with Low Jet Multiplicities

Alex Richards, Claire Gwenlan

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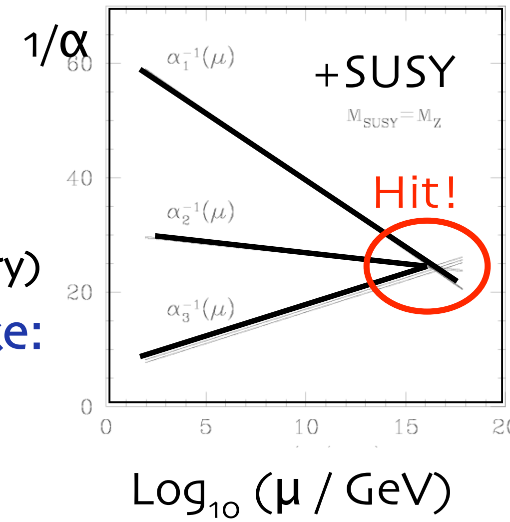
UCL ATLAS Physics Meeting

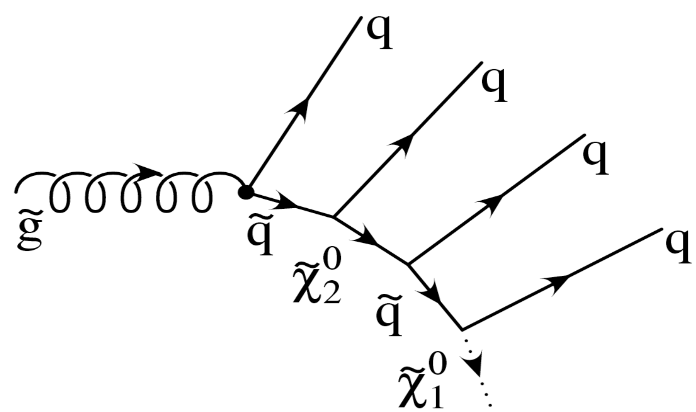
SUSY (in a nutshell)

SUperSYmmetry (SUSY)

- Postulates symmetry between bosons and fermions
  - → each SM particle has SUSY (s)partner: spin differs by ½
  - (but SUSY particles not yet observed → heavy → broken symmetry)
- SUSY at TeV scale provides solutions to problems like:
  - hierarchy (disparity between m_H and m_{Pl})?
  - nature of dark matter?
  - Gauge-unification (step towards GUT)?

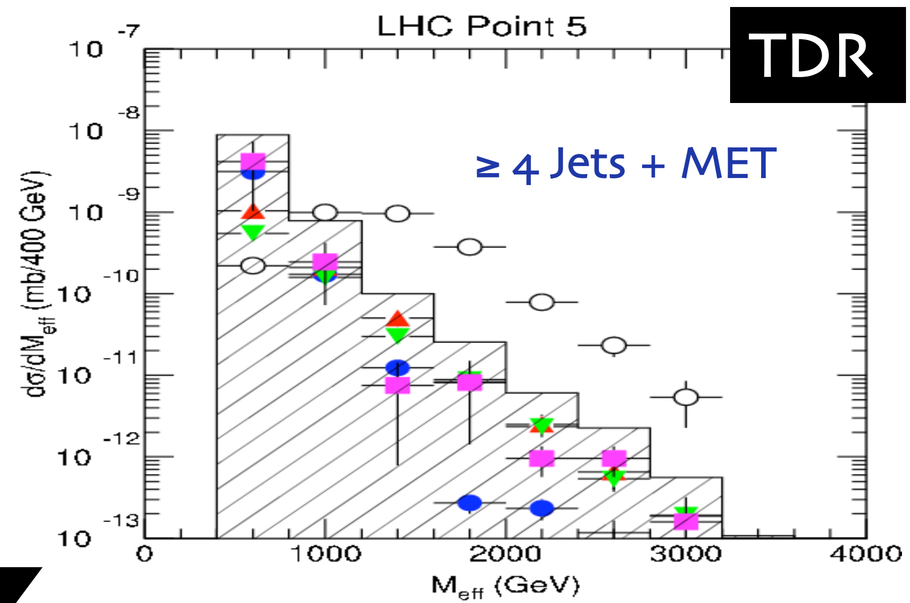


At LHC, sparticles may be copiously produced:
Cascade decays end in quarks, gluons (Jets),
Leptons and (in R-Parity conserving models)
Missing Energy (LSP escapes undetected)



SUSY Searches in Jets+MET

- Signatures with LEPTONS:
  - generally smaller cross sections
    (but also tend to have lower backgrounds)
  - rely on multiple cascade decays
    (model dependent)
- Hadronic-only (i.e. JETS) channels tend to have higher cross sections and less model dependence BUT:



To date, most effort has been concentrated on large jet multiplicities i.e. ≥ 4 jets - the assumption being that this is required to reduce the large QCD background (e.g. TDR plot and ALL studies since then)

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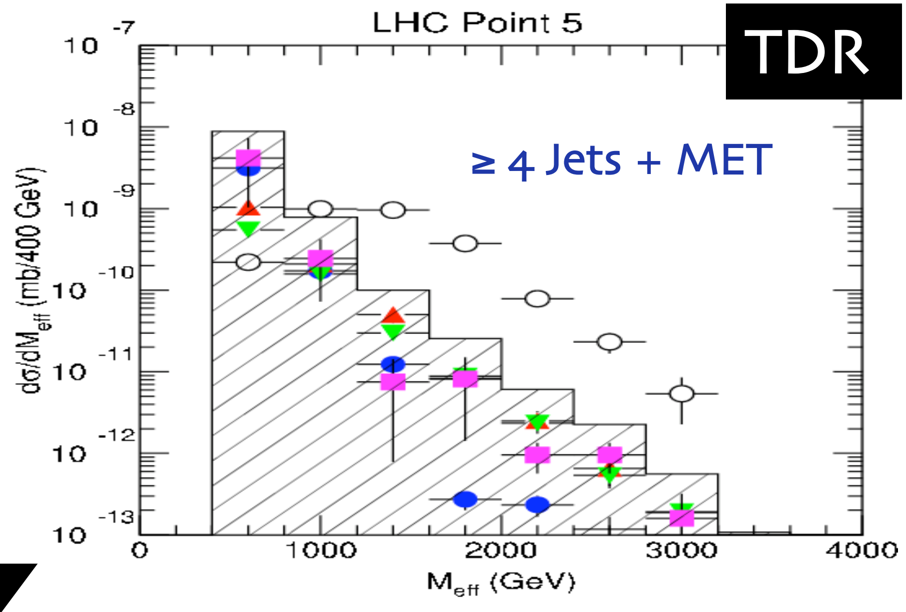


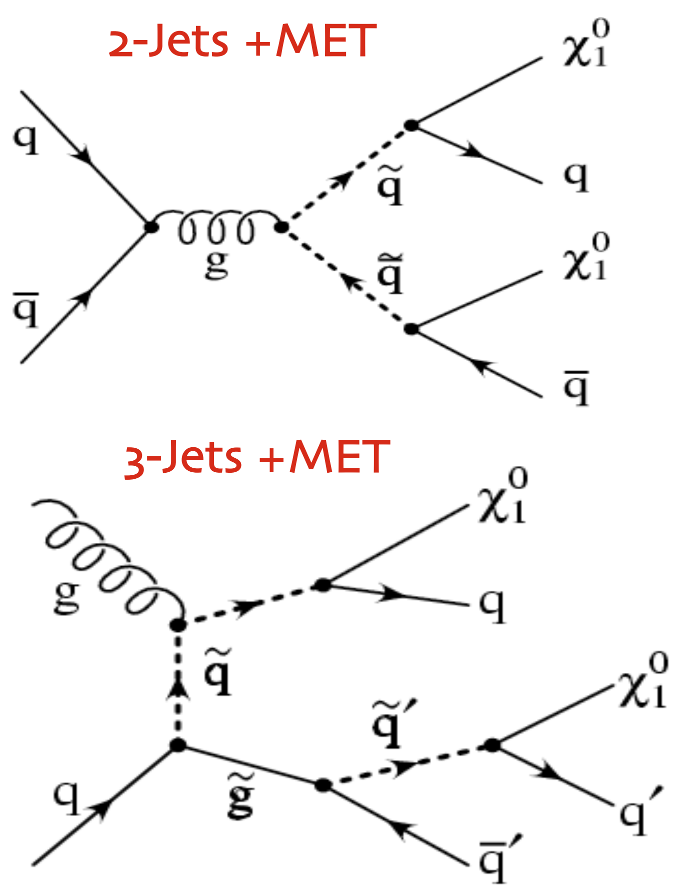
To date, most effort has been concentrated on large jet multiplicities i.e. ≥ 4 jets - the assumption being that this is required to reduce the large QCD background (e.g. TDR plot and ALL studies since then)

OK but cf. lower jet multiplicities:

1) smaller cross sections
2) calculations less reliable
3) more complicated in detector
4) more model dependent (i.e. like leptonic channels, they depend on cascade decays)

SUSY Searches with Small nJets

EG: RPC 2-Jet and 3-Jet SUSY processes



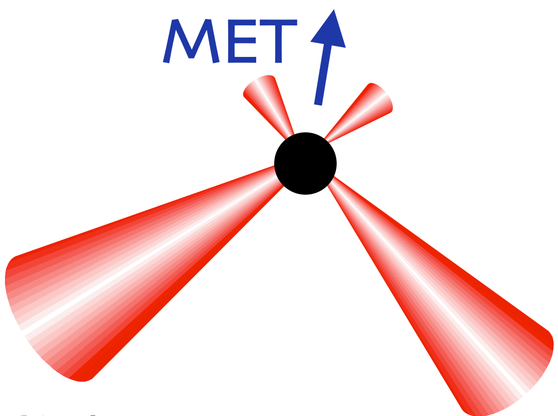
Concentrate on smaller numbers of high-pT jets (2,3):

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

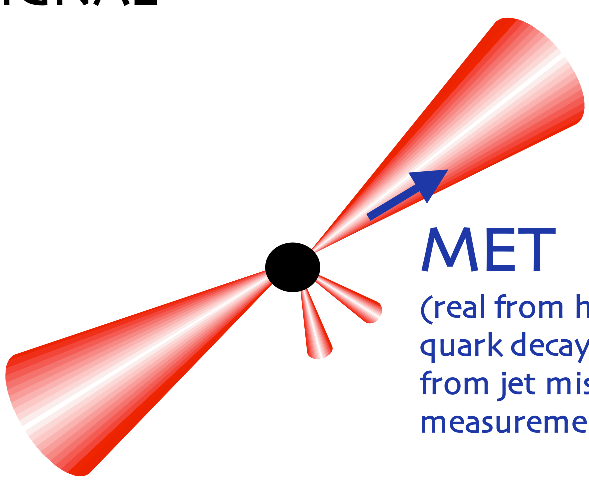
Use kinematics, rather than "business of event" to pick out SUSY

EG: Suppressing QCD Background

Part of Alex's work



SIGNAL



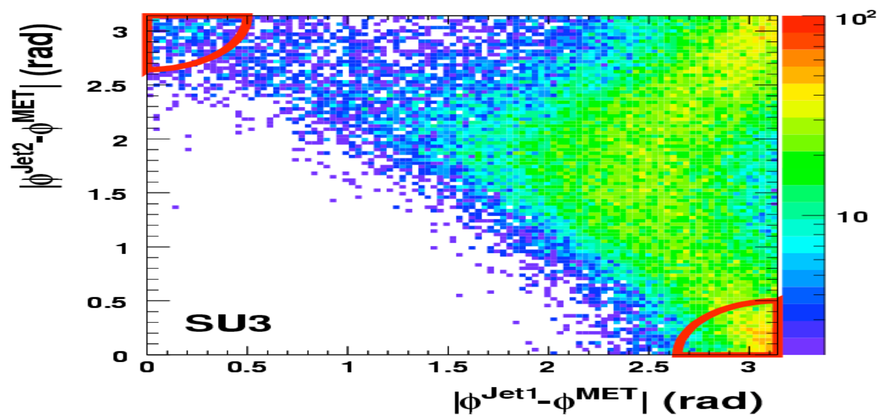
QCD background

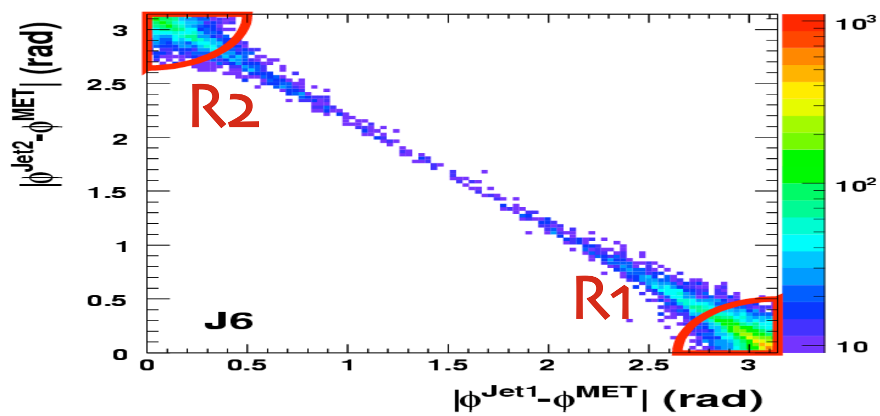
Remove events with jets close to MET direction:

dphi(i) = |phi(Jet,i)-phi(MET)| > CUT

R1 = sqrt(dphi(2)**2+ (π-dphi(1))**2) > CUT

R2 = sqrt(dphi(1)**2 + (π-dphi(2))**2) > CUT





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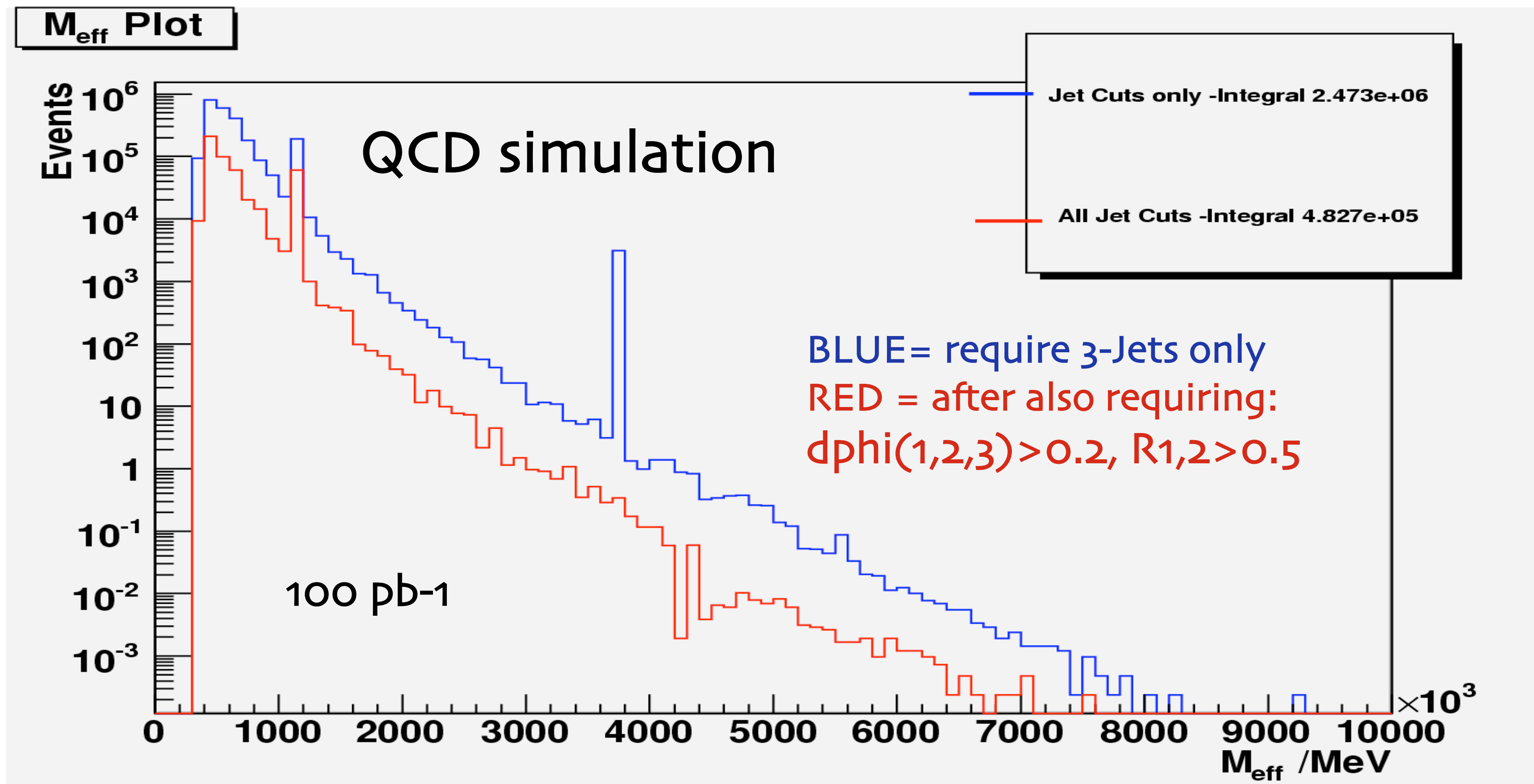


Imposing cuts on dphi and R1,2 removes > 80% of QCD background (according to this MC simulation!) - can suppress further by cuts on e.g. MET

Contribution to CSC Note

Our 2- and 3-Jet analyses will be contributions to CSC5 (inclusive SUSY search)

Cuts	3-Jet	2-Jet
Cut1	$pT^{Jet1,3}$ > 150,100 GeV, |eta| < 2.5	$pT^{Jet1,2}$ > 150,100 GeV, |eta| < 2.5
Cut2	MET > max(100,0.25*m_{eff}) GeV	MET > max(100,0.3*m_{eff}) GeV
Cut3	dphi(1,2,3) > 0.2	dphi(1,2) > 0.2
Cut4*	R1,2 > 0.5	R1,2 > 0.5
Cut5**	no isolated lepton	no isolated lepton

* not yet a standard cut for all CSC5 contributors

** isolated lepton definition as prescribe by CSC5 group (see BACKUPS)

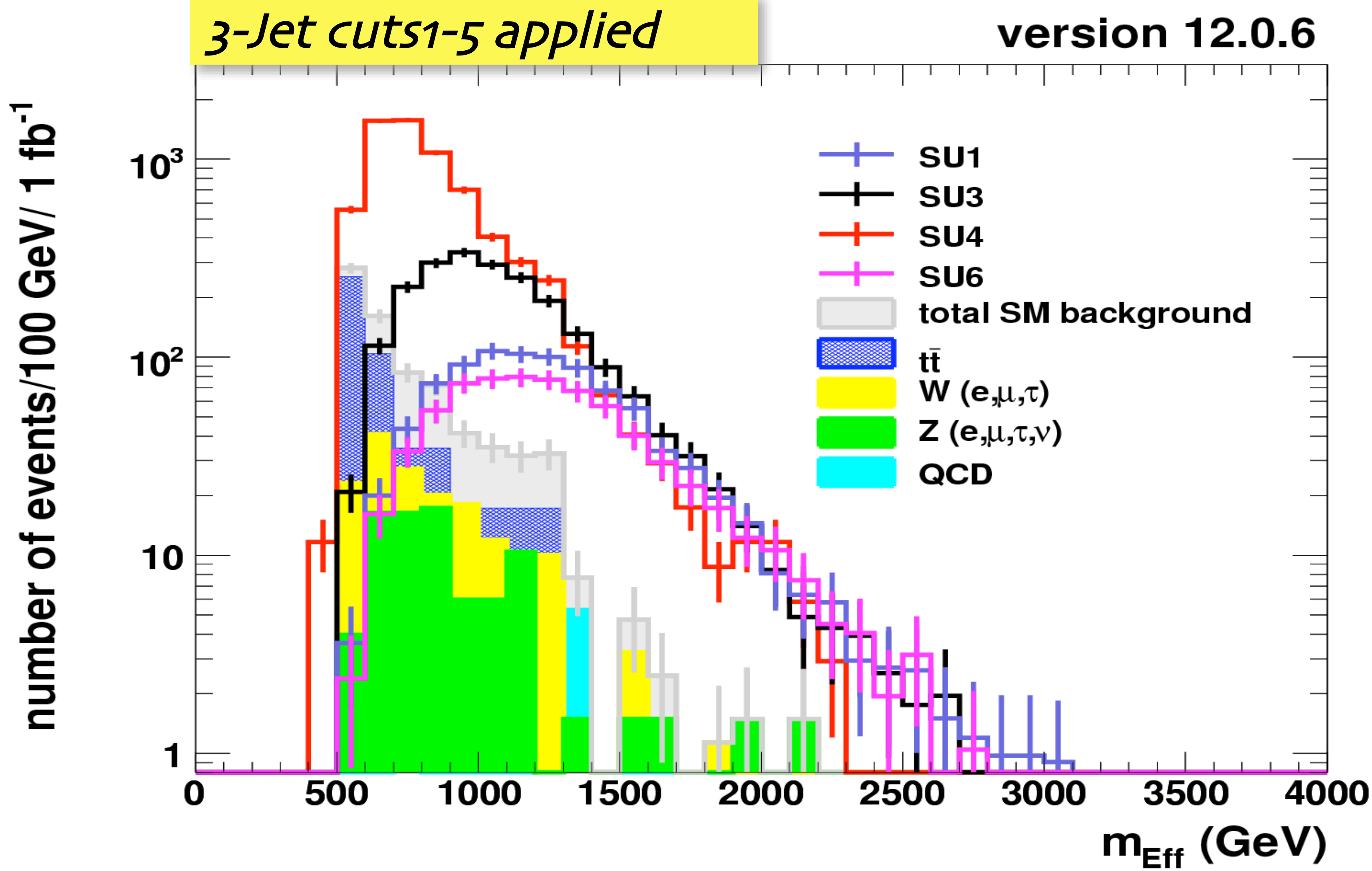
where $m_{eff} = \Sigma_i pT^{Jet,i}$ + MET (sum runs from i=1-3 for 3-Jet and i=1-2 for 2-Jet)

NOTE: most CSC5 contributors are using SUSYView – we are not!!!

- means having to implement default SUSYView pre-selection and overlap removal for consistency (probably not the most sensible thing) – see BACKUPS if interested in what SUSYView does!

3-Jet Results (for CSC5)

3-Jet cuts1-5 applied



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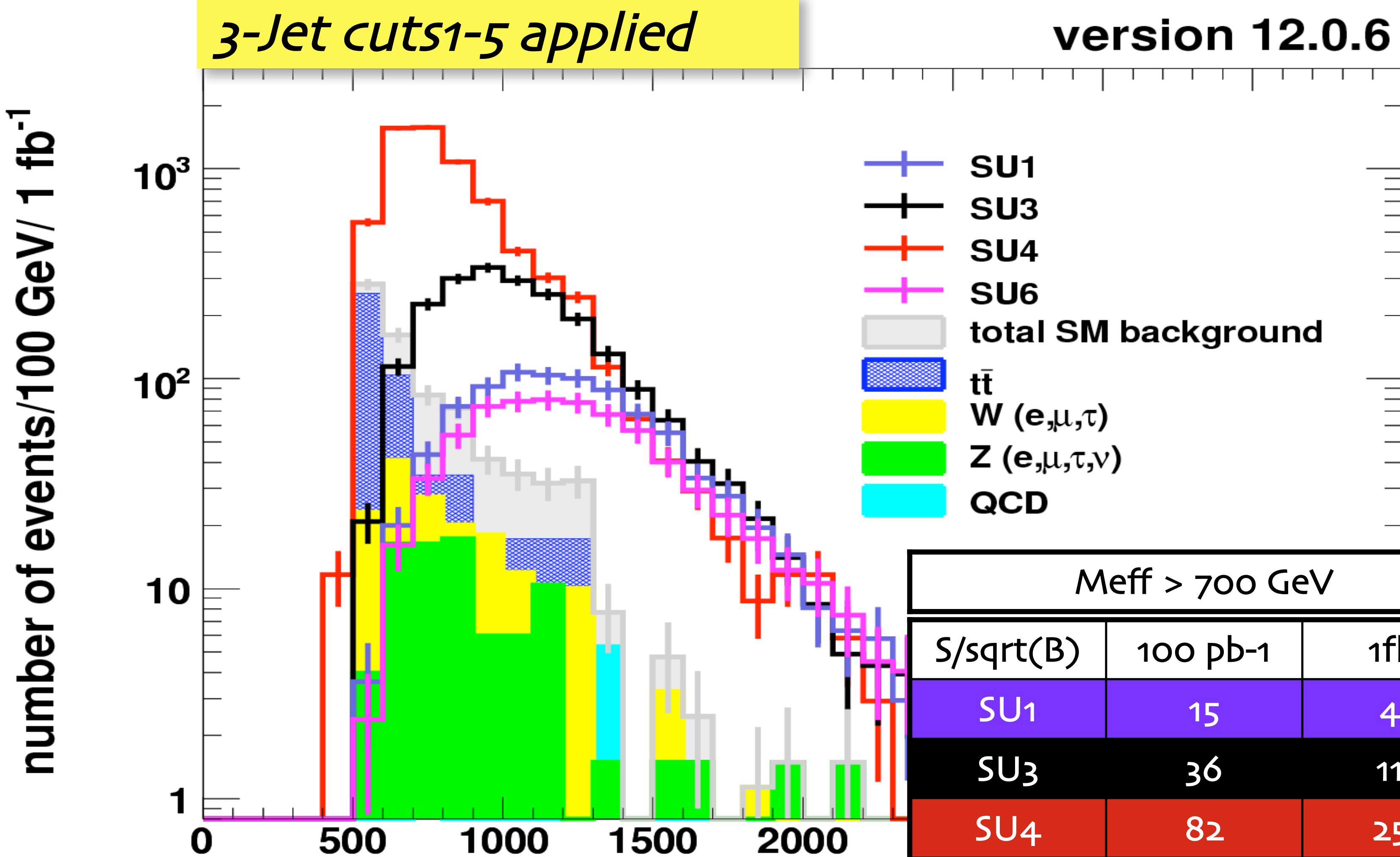
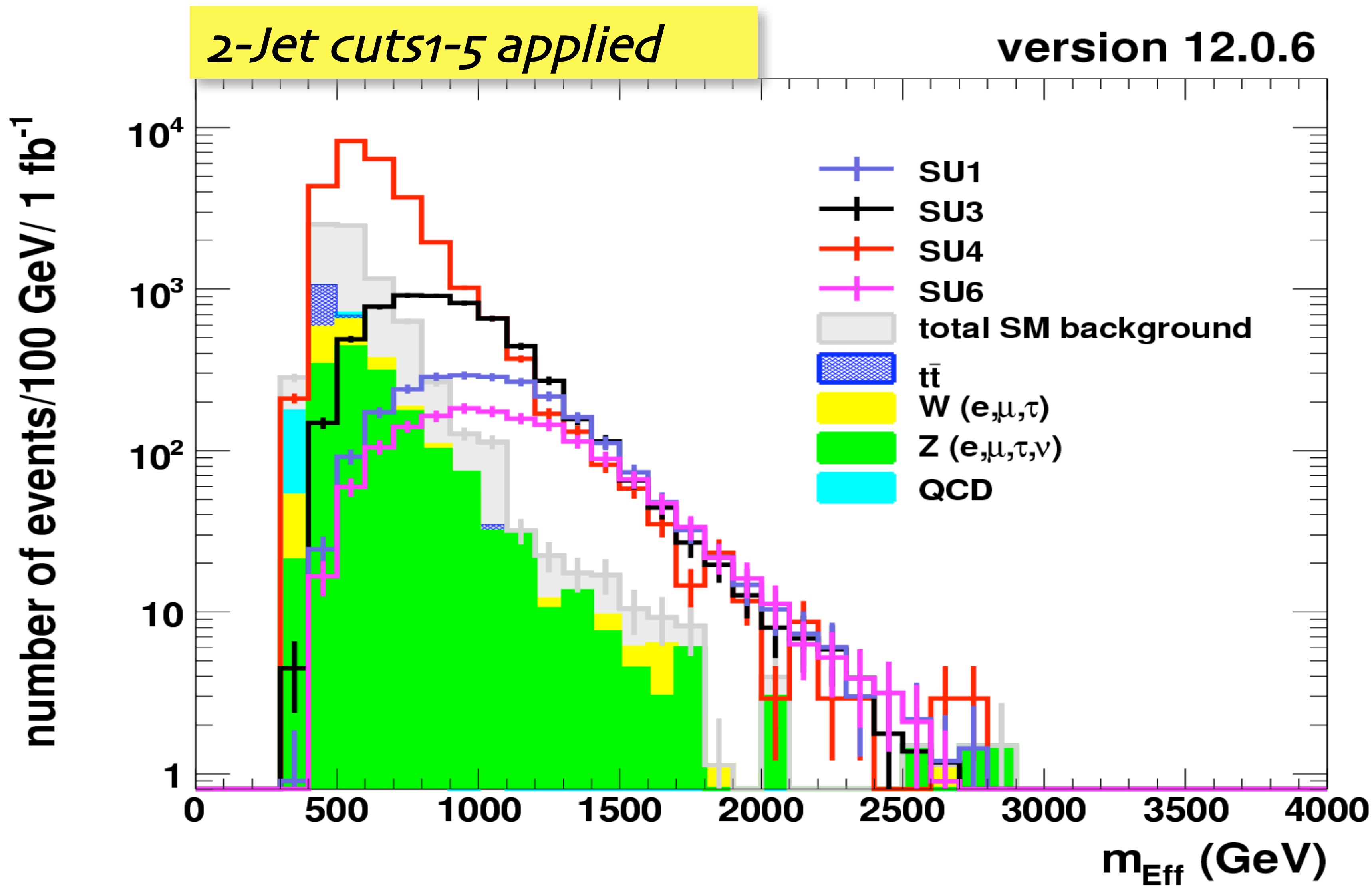


Meff > 700 GeV		
S/sqrt(B)	100 pb-1	1fb-1
SU1	15	49
SU3	36	114
SU4	82	259
SU6	12	38

c.f. S/sqrt(B) ~ 35 (1 fb-1) for SU3 model in current 4-jet analyses

2-Jet Results (for CSC5)



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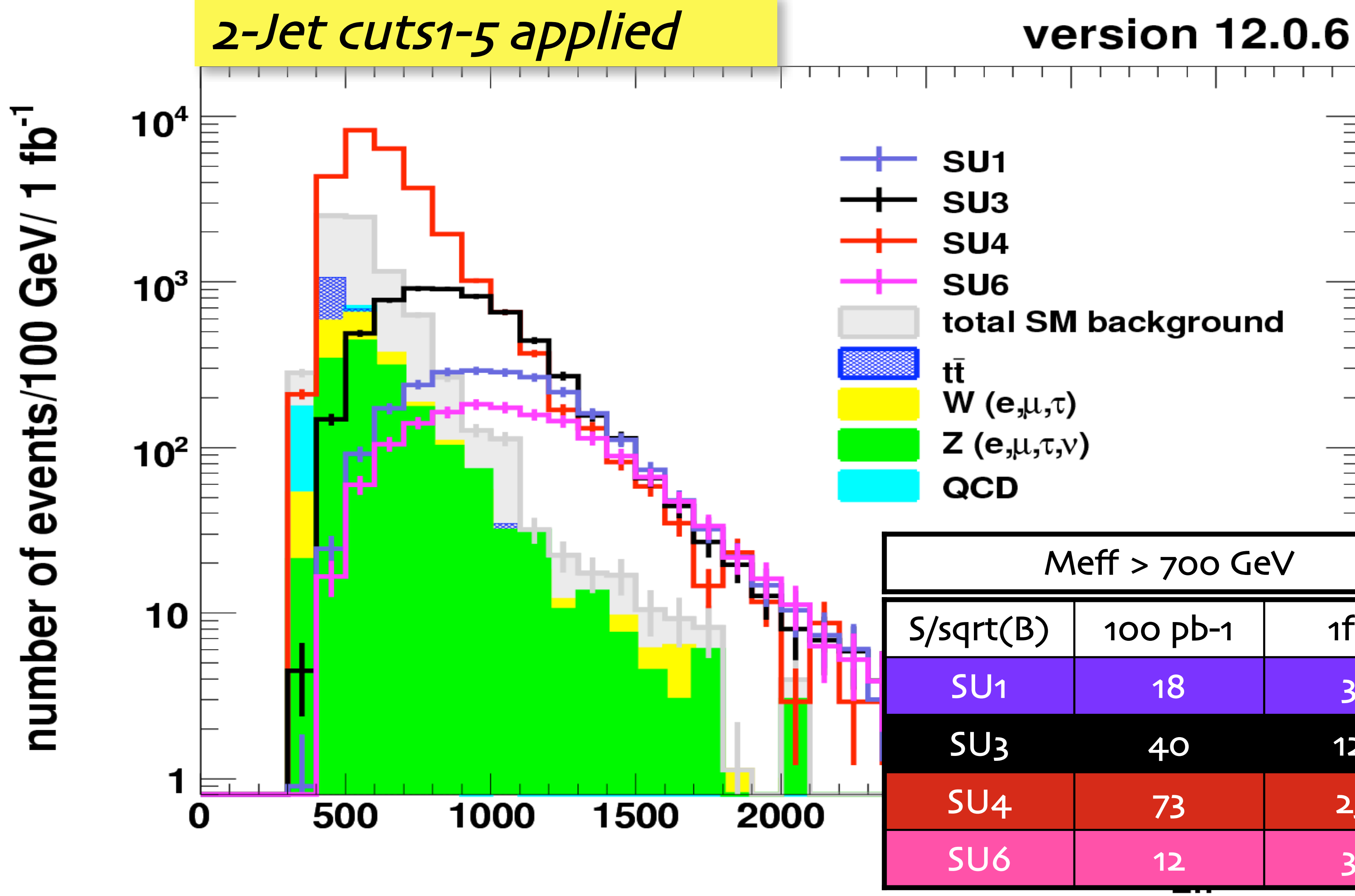


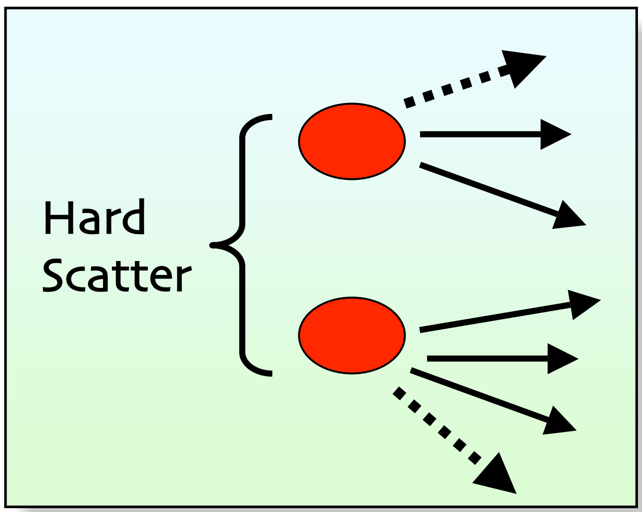
Meff > 700 GeV		
S/sqrt(B)	100 pb-1	1fb-1
SU1	18	36
SU3	40	126
SU4	73	231
SU6	12	39

c.f. S/sqrt(B) ~ 35 (1 fb-1) for SU3 model in current 4-jet analyses

mT2 (sTransverse Mass)

Already seen that "TDR-like" analyses (i.e. using a number of cuts to reduce backgrounds and Meff as discriminating variable) show promise for 2- and 3-jets as well as ≥ 4 jets → CSC note 5 will be first time that 2- and 3-jet results considered seriously in ATLAS

Alternative Strategy: mT2 (analysis running in parallel to previous ones)



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

$$M_{T2} \equiv \min_{\not{p}^{(1)}+\not{p}^{(2)}=\not{p}_T} \left[\max\left\{ m_T\left(\mathbf{p}_T^{j(1)}, \not{p}^{(1)}\right), m_T\left(\mathbf{p}_T^{j(2)}, \not{p}^{(2)}\right) \right\} \right]$$

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 for Discovery?

mT2 designed to provide information on mass of sparticles
(for "simple" SUSY topologies such as 2-Jet+MET or 2-lepton+MET)

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) → 0 if:

- $P_T^{Jet} \to 0$
- MET → 0
- MET parallel to either jet (i.e. small dphi values)

→ 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: there is no *a priori* reason to expect small mT2 for Z → νν + Jets → this background may dominate at large mT2?

“Simple” Analysis

mT2 already “does the job” of traditional cuts (dphi, MET,…)

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

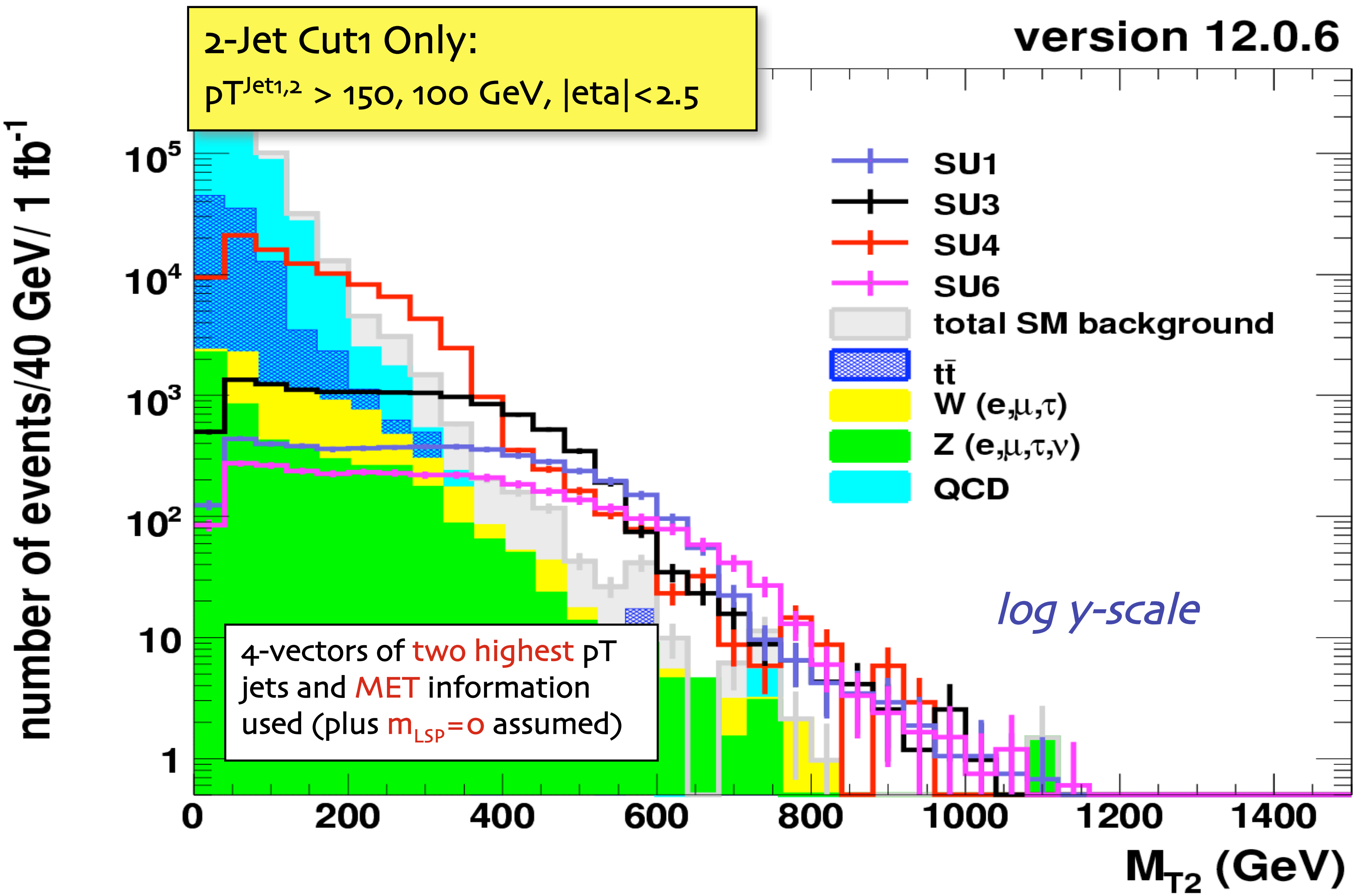
CUTS:

- ≥ 2 Jets with $pT^{Jet1,2}$>150,100GeV, |eta|<2.5 → plot mT2

(this is just FIRST cut of 2-Jet Meff analysis)

NB: Not claiming you would just plot M_{T2} and publish(!) BUT a simple selection <u>may</u> make it easier to (for example) understand systematics and backgrounds, and so could speed up the whole process

mT2 Results (for CSC5)



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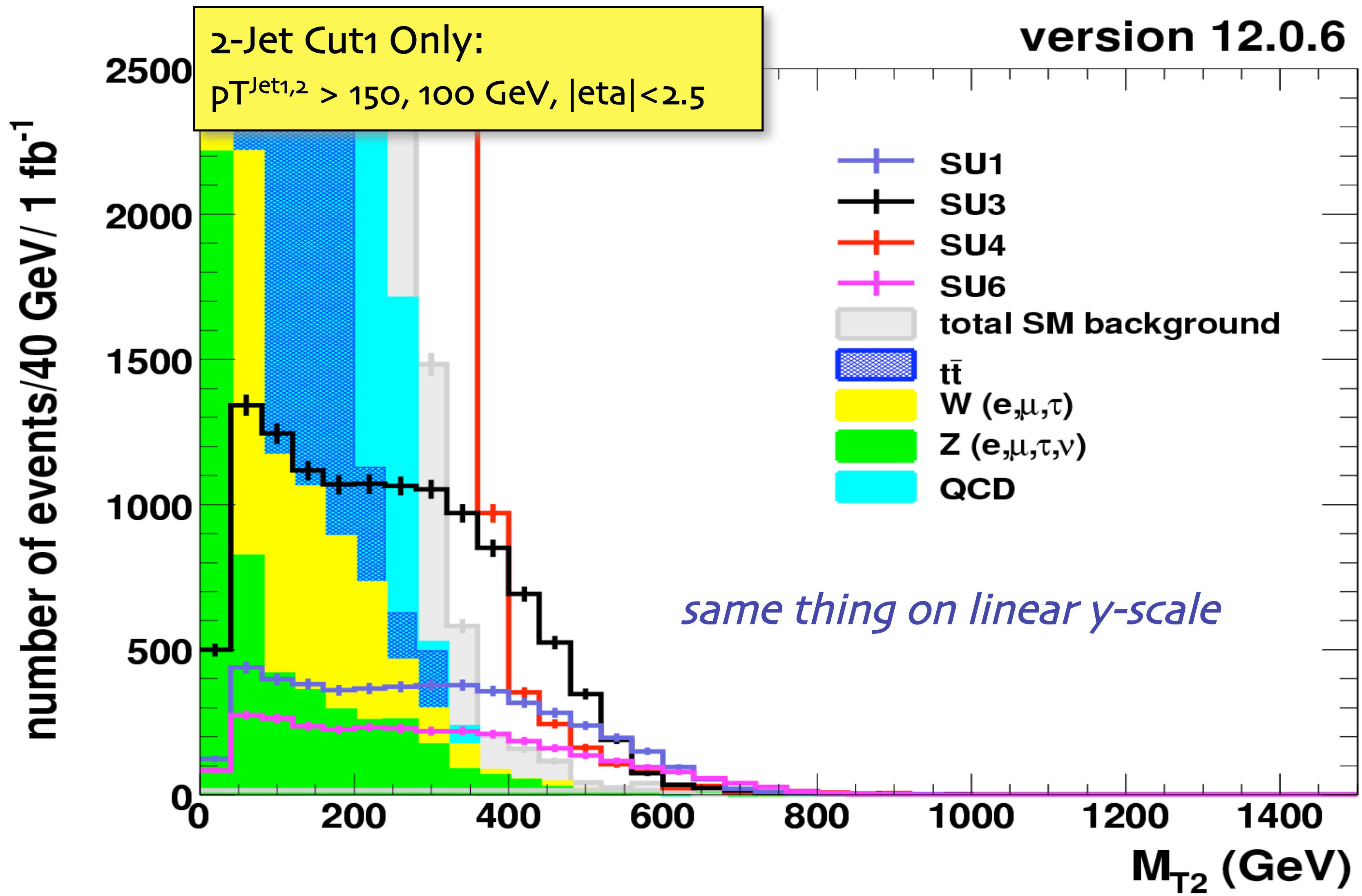
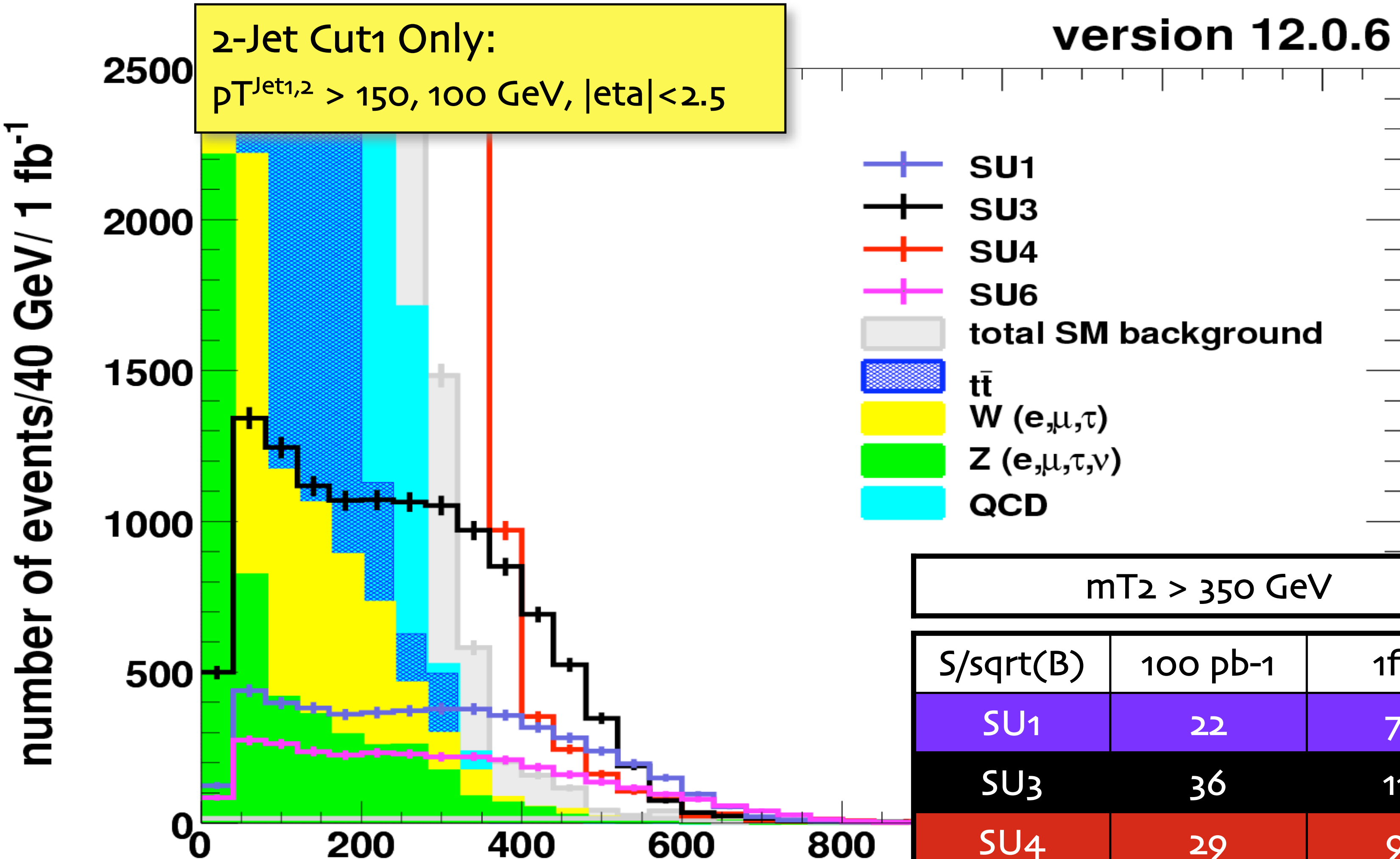


mT2 Results (for CSC5)

2-Jet Cut1 Only:

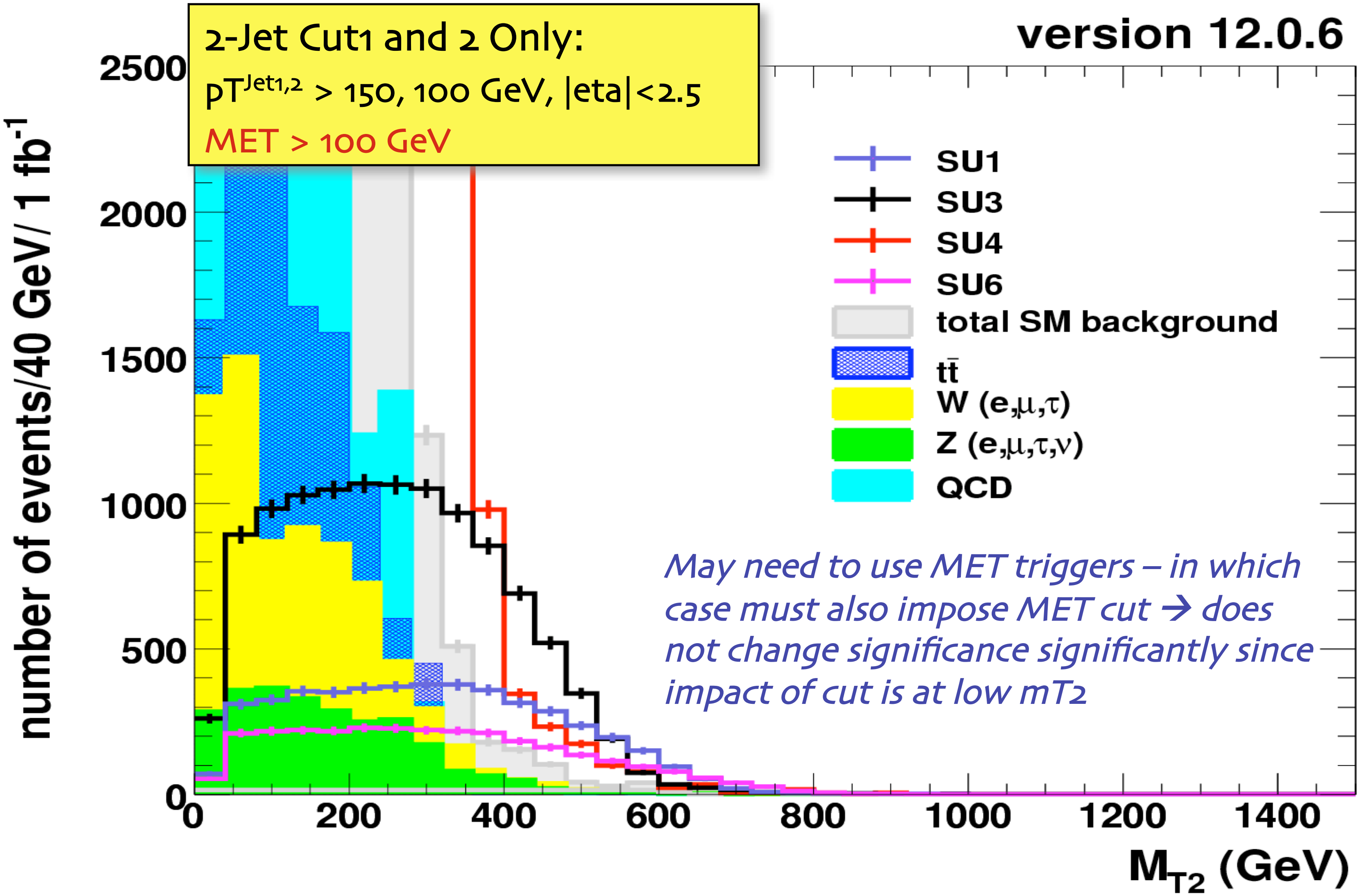
$pT^{Jet1,2}$ > 150, 100 GeV, |eta|<2.5



mT2 > 350 GeV		
S/sqrt(B)	100 pb-1	1fb-1
SU1	22	70
SU3	36	113
SU4	29	92
SU6	14	45

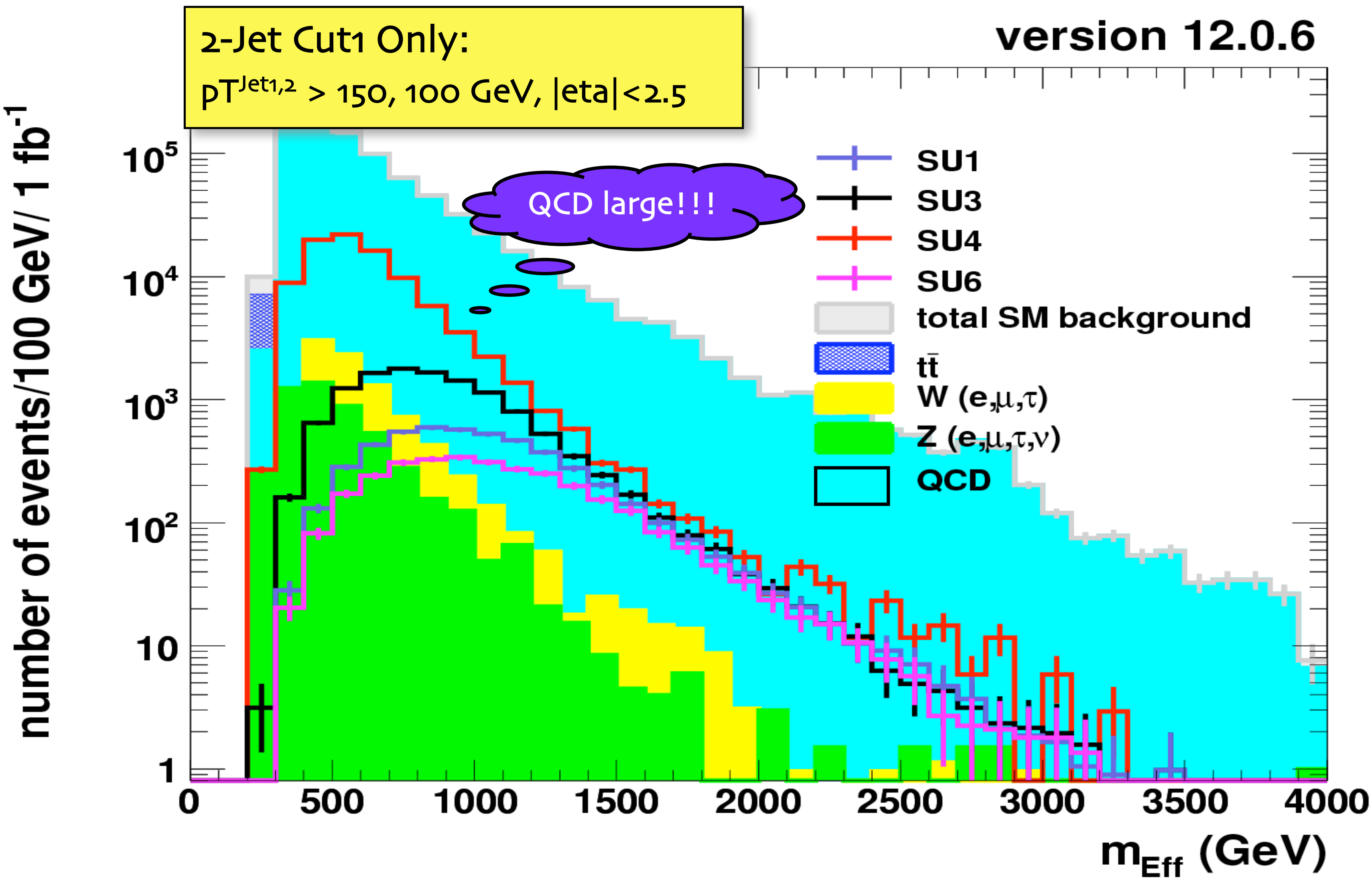
mT2 Results (for CSC5)

2-Jet Cut1 and 2 Only:
$pT^{Jet1,2}$ > 150, 100 GeV, |eta|<2.5
MET > 100 GeV



May need to use MET triggers – in which case must also impose MET cut → does not change significance significantly since impact of cut is at low mT2

Just for Comparison: Meff



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 $Z \to \nu\nu$ from $Z \to \mu\mu$
- 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

Need to quantify above statements

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

SUSY Mass Scale: mTgen

mT2 originally developed to give information on SUSY mass scale
(but only for "simple" topologies)

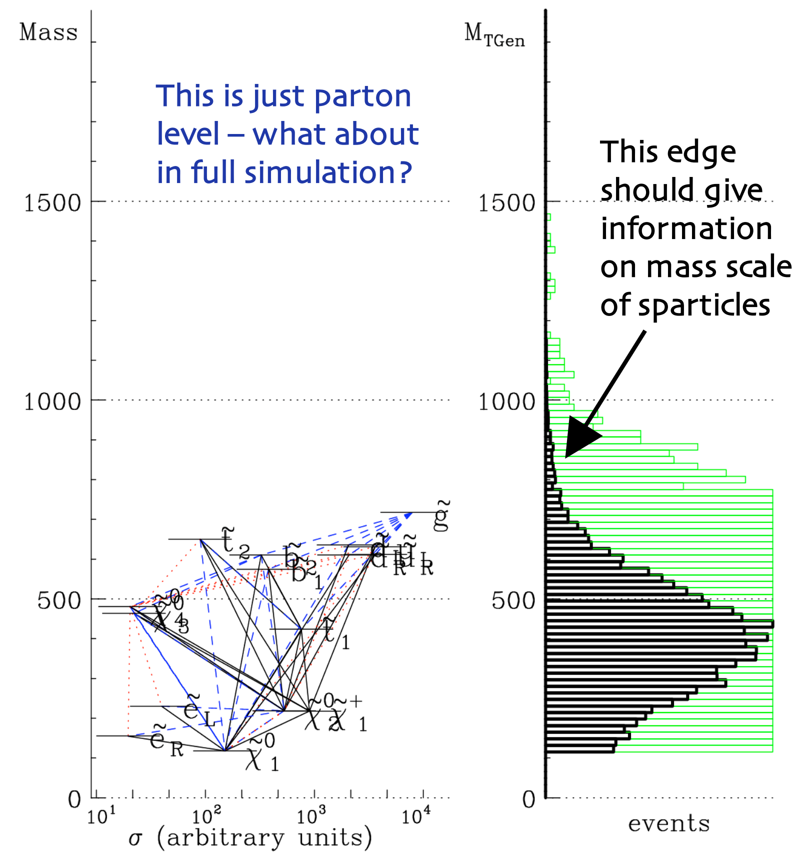
$$M_{T2} \equiv \min_{\mathbf{p}^{(1)}+\mathbf{p}^{(2)}=\mathbf{p}_T} \left[\max \left\{ m_T\left(\mathbf{p}_T^{j(1)}, \mathbf{p}^{(1)}\right), m_T\left(\mathbf{p}_T^{j(2)}, \mathbf{p}^{(2)}\right) \right\} \right]$$

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

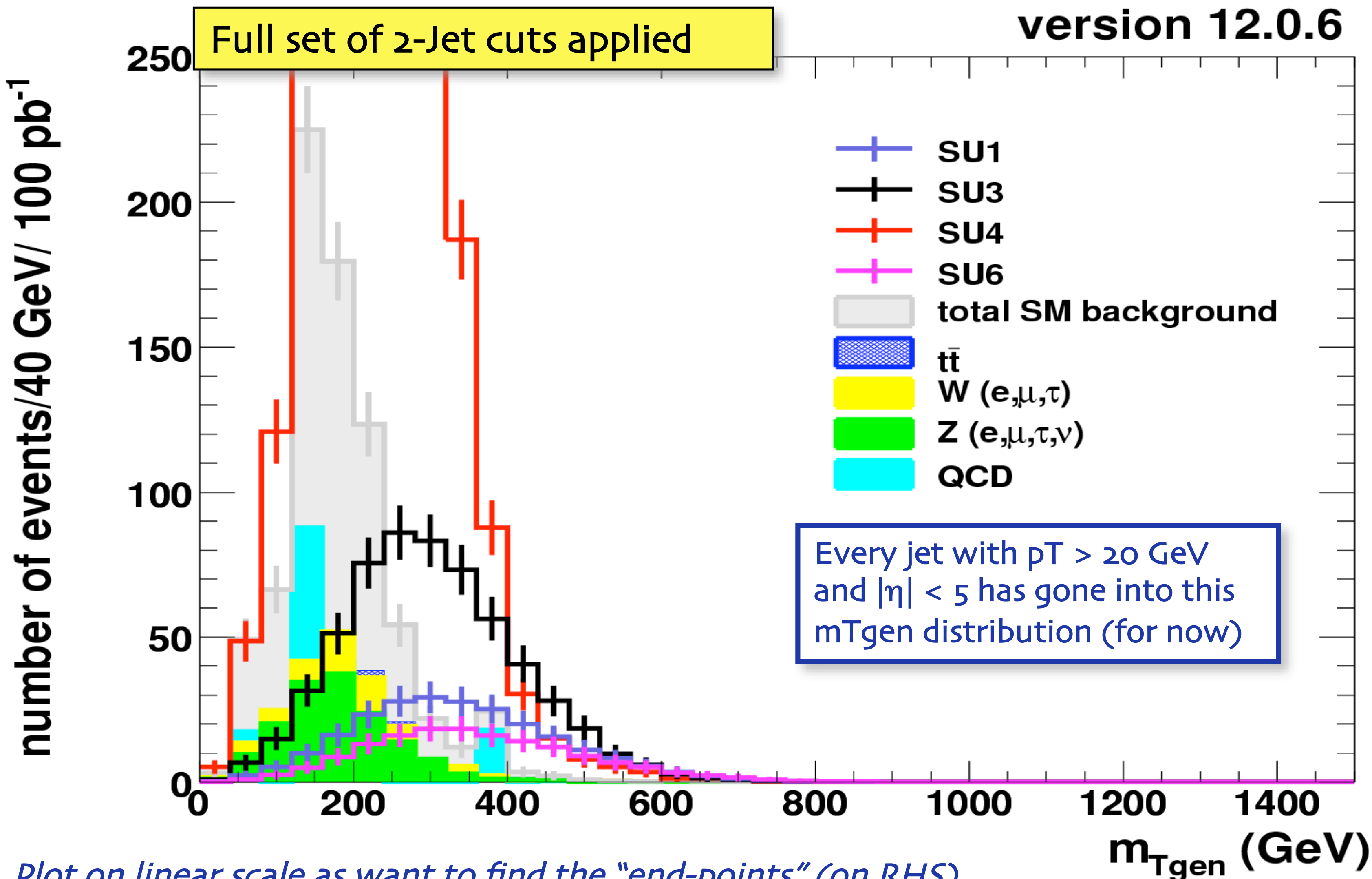
Recently, new variable m_{Tgen} developed: – generalisation of mT2 which works in more complex topologies i.e. multiple cascade decays (where it is not possible to know which particles come from which side of the decay)
arXiv:0705.0486 (C. Lester and A. Barr)

m_{Tgen} (what it does):

1) Splits all observed jets/momenta into two "sides" in all possible ways
2) Calculates mT2 for each combination
3) Takes the smallest of these mT2 values and call it m_{Tgen}



MTgen Distribution



Plot on linear scale as want to find the "end-points" (on RHS)

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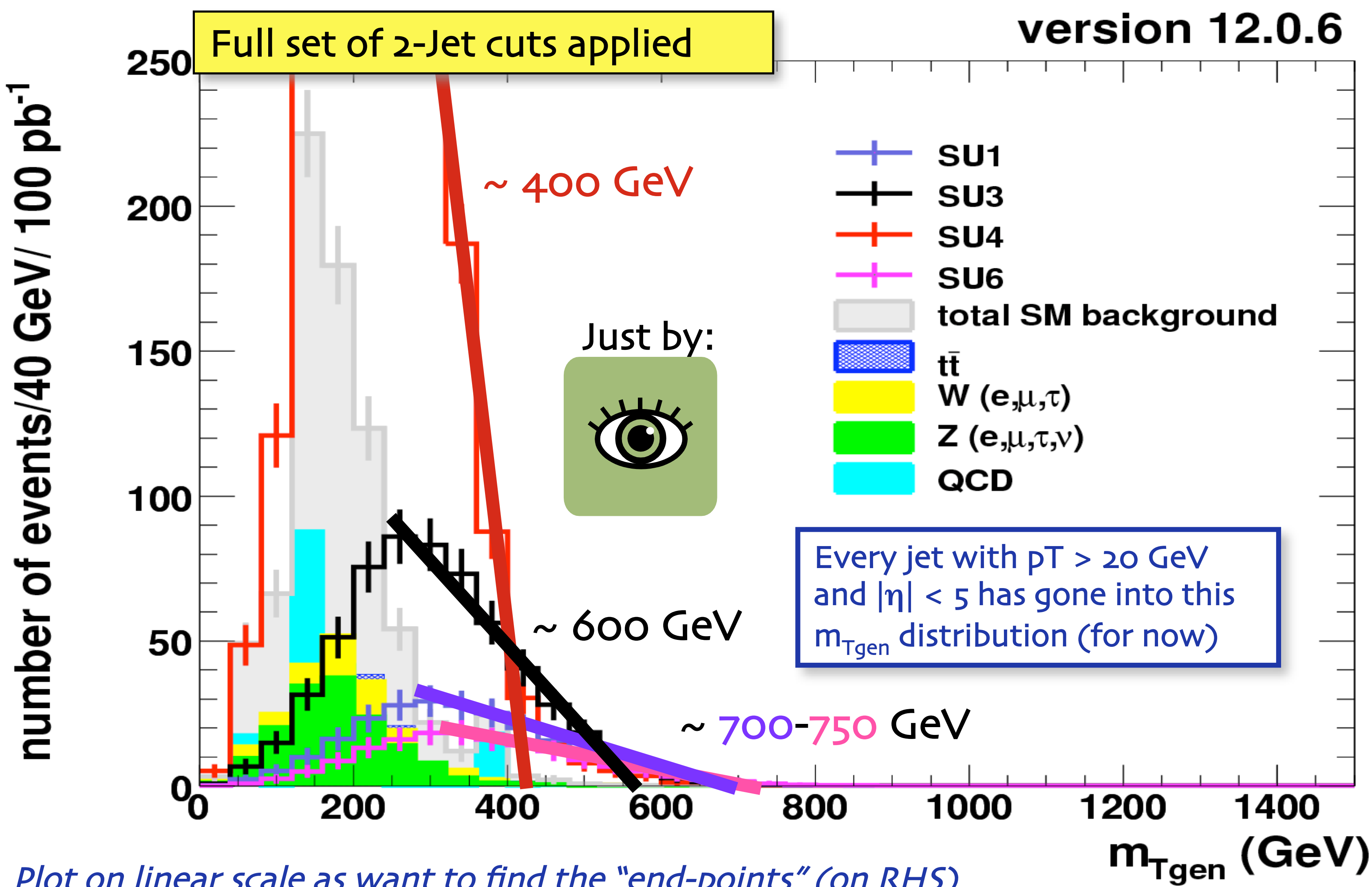


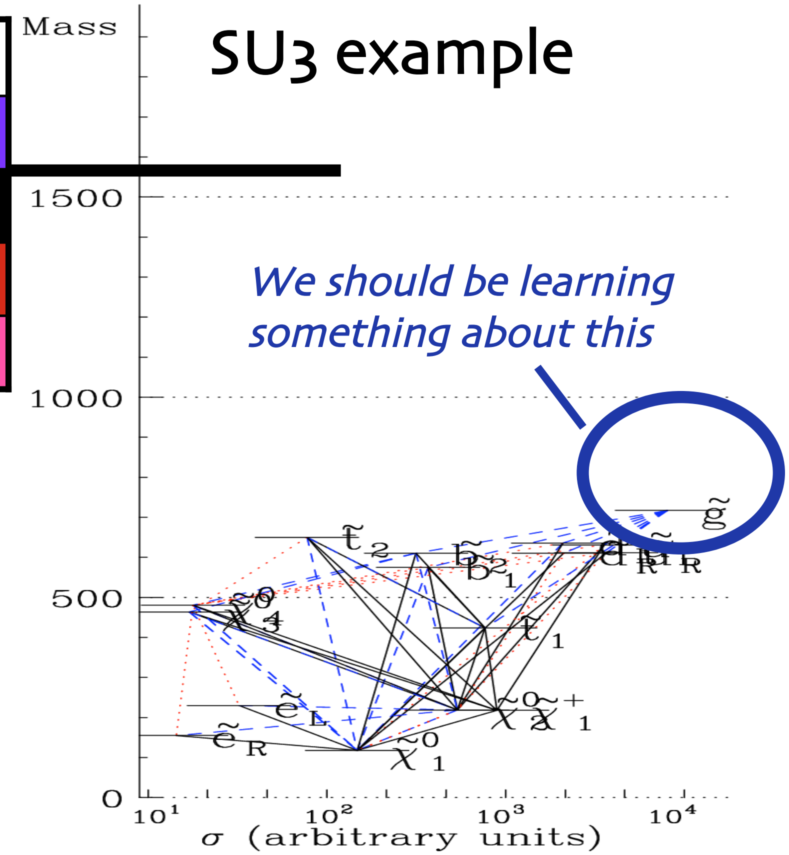
Plot on linear scale as want to find the "end-points" (on RHS)

SUSY Mass Scale Estimate

Mass Scale	My Guess	Model Input
SU1	700 GeV	830 GeV
SU3	600 GeV	720 GeV
SU4	400 GeV	413 GeV
SU6	750 GeV	895 GeV

This may not look that close BUT m_{Tgen} depends on LSP mass (it is an input). m_{LSP}=0 has been assumed here (since we don't know it!).

SU3 example



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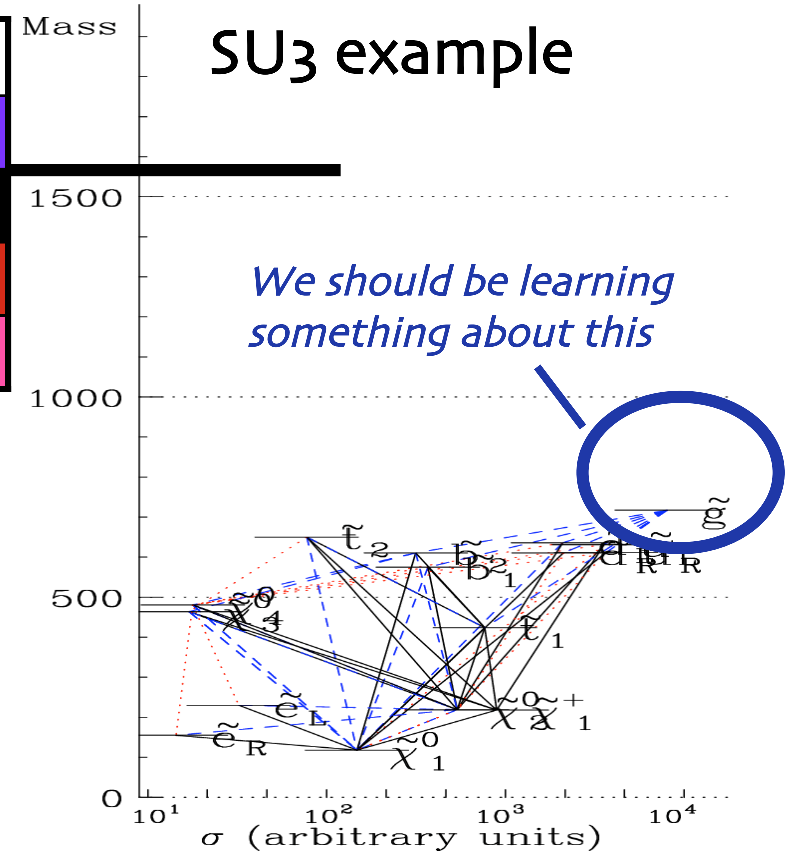

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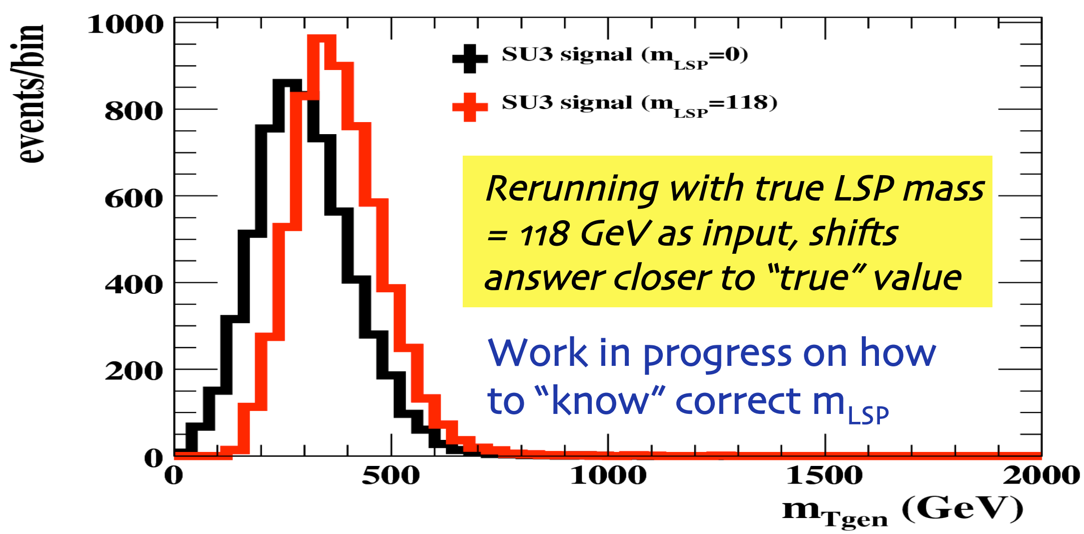


Also need to understand effects of ISR and underlying event I.e. input momenta *should* be only those coming from SUSY cascade

Some Plans

- Finish contribution to CSC note(s) – didn't talk about it directly today but we are also contributing to CSC3 (QCD backgrounds to SUSY) as well as CSC5

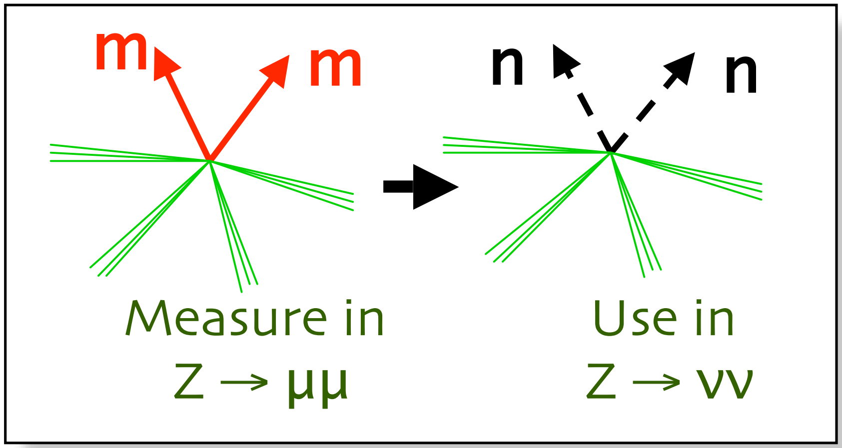
THEN start doing some proper work on how we can really make the measurement and understand the backgrounds and systematics!!!

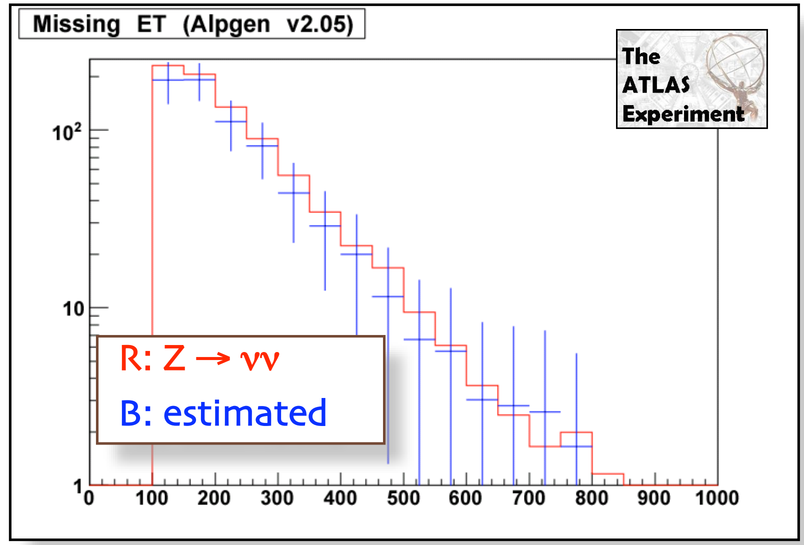
- Background determination (QCD, top, $Z \to \nu\nu$, …)
  - especially developing methods on how to measure from data

  (several people working in this area but focus so far is on ≥ 4-Jet scenarios)
- Trigger studies (doing a little bit for CSC note but not in much detail)
- Also in contact with Jets+MET people regarding contributing to determination of hadronic energy scale and MET measurement

PLUS continue working on optimising analyses (issues regarding overlap removal, object definitions,…) and study systematics associated particularly with SUSY mass determination (EG. effects of ISR and UE on m_{Tgen})

EG. Background Measurement

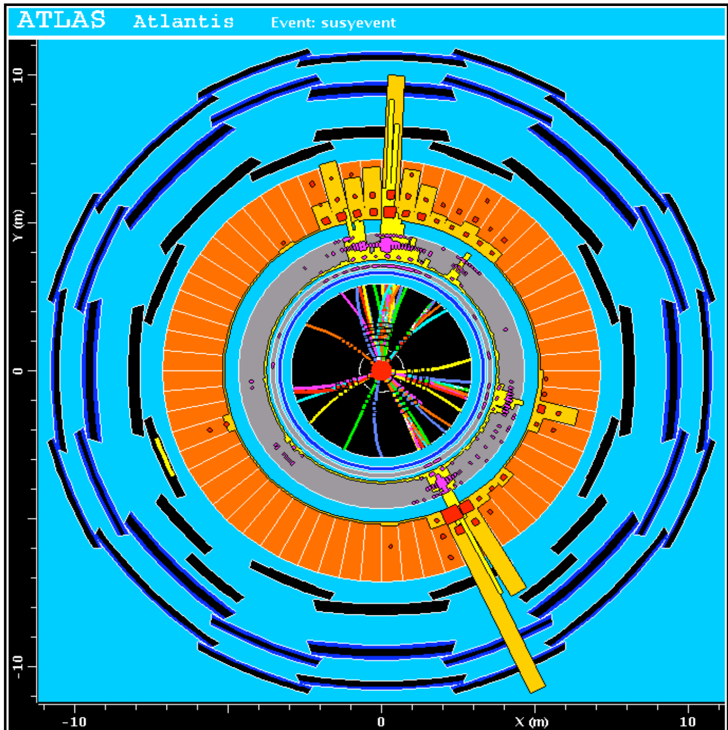


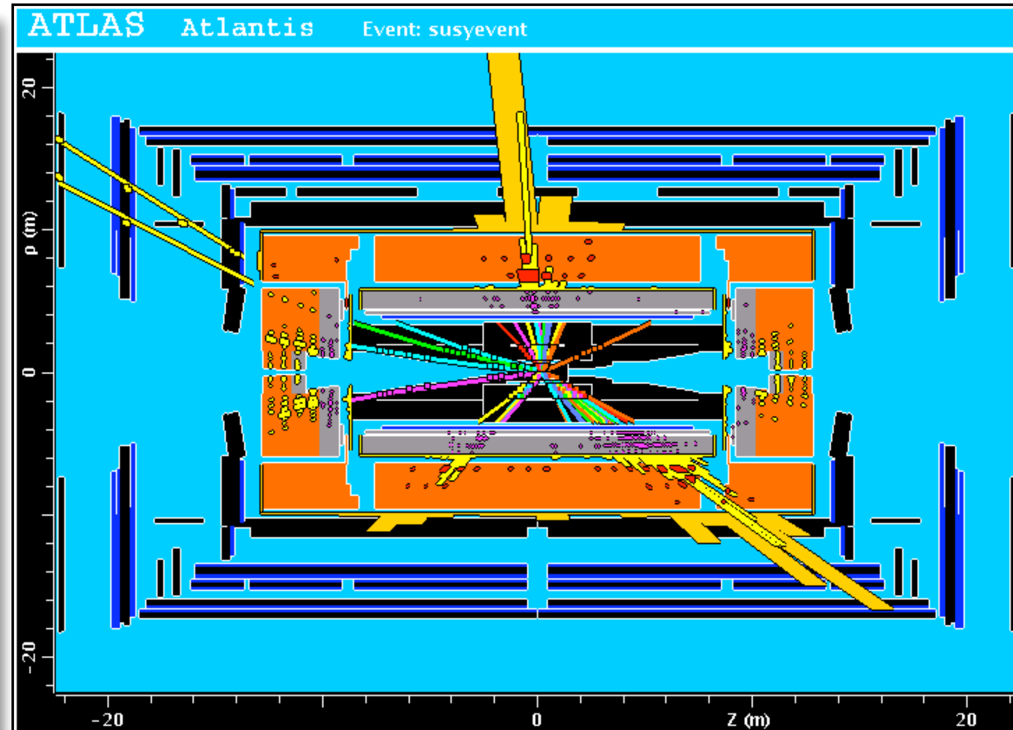


- Example: SUSY BG
  - Jets + MET from Z to neutrinos (plus ISR)
  - Measure in Z → μμ
  - Use for Z → νν
- Good match
  - Useful technique
- Statistics limited
  - Go on to use W → μν to improve

Backups

SUSY event


ATLAS Atlantis Event: susyevent
Y (m)
X (m)
10
0
-10
-10
0
10


ATLAS Atlantis Event: susyevent
ρ (m)
Z (m)
20
0
-20
-20
0
20

MC Files Used

SU1	trig1_misal1_csc11.005401.SU1_jimmy.susy.recon.AOD.v12000601
SU3	trig1_misal1_csc11.005403.SU3_jimmy.susy.recon.AOD.v12000601
SU4	trig1_misal1_csc11.006400.SU4_jimmy.susy.recon.AOD.v12000601
SU6	trig1_misal1_csc11.005404.SU6_jimmy.susy.recon.AOD.v12000601
QCD J4	trig1_misal1_mc12.008090.pythia_J4_Nj2_FMET100.recon.AOD.v12000601
QCD J5	trig1_misal1_mc12.008091.pythia_J5_Nj2_FMET100.recon.AOD.v12000601
QCD J6	trig1_misal1_mc12.008092.pythia_J6_Nj2_FMET100.recon.AOD.v12000601
QCD J7	trig1_misal1_mc12.008093.pythia_J7_Nj2_FMET100.recon.AOD.v12000601
QCD J8	trig1_misal1_mc12.008094.pythia_J8_Nj2_FMET100.recon.AOD.v12000601
Zee	trig1_misal1_mc12.008094.pythia_Zee_qg_ckin80_Nj2.recon.AOD.v12000601
Zmumu	trig1_misal1_mc12.008095.pythia_Zmumu_qg_ckin80_Nj2.recon.AOD.v12000601
Ztautau	trig1_misal1_mc12.008091.pythia_Ztautau_qg_ckin80_Nj2.recon.AOD.v12000601
Znunu	trig1_misal1_mc12.008090.pythia_Znunu_qg_ckin80_Nj2.recon.AOD.v12000601
Wenu	trig1_misal1_mc12.008270.pythia_Wenu_qg_ckin80_Nj2.recon.AOD.v12000601
Wmunu	trig1_misal1_mc12.008271.pythia_Wmunu_qg_ckin80_Nj2.merge.AOD.v12000605
Wtaunu	trig1_misal1_mc12.008271.pythia_Wtaunu_qg_ckin80_Nj2.merge.AOD.v12000605
TTbar	trig1_misal1_mc12.005204.TTbar_FullHad_McAtNlo_Jimmy.recon.AOD.v12000601
T1	trig1_misal1_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000601

SUSY Points

Point	m_0 (GeV)	m_1/2 (GeV)	A0 (GeV)	tan(β)	sign(μ)	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

SUSYView Pre-Selection

MUONS (MuidMuonCollection):

- any muon (i.e. onlyHighPt == false), pT > 15 GeV; no eta cut
- Chi2(fit)/DOF < 5 (for highPt), Chi2(match) < 20 (for highPt)
- etcone45 < 5 GeV + pT(muon)

ELECTRONS (ElectronCollection):

- electronAuthor != 0, pT > 10 GeV; no eta cut
- isEM & 0x3ff == 0 (isEMSofte & 0x3ff == 0 instead for electronAuthor == 2)

PHOTONS (PhotonCollection):

- pT > 10 GeV; no eta cut
- statusShowerShape == 15 (as defined in EVPhotonInserter.cxx)
- etcone45 < 10 GeV

OVERLAP REMOVAL: remove JETS overlapping with ELECTRONS or PHOTONS with dR < 0.3 (no JET overlap removal for MUONS or TAUS)

(CSC5) Definition of Isolated Leptons

Isolated Lepton Definition (used in Cut5: lepton veto):

ELECTRONS:

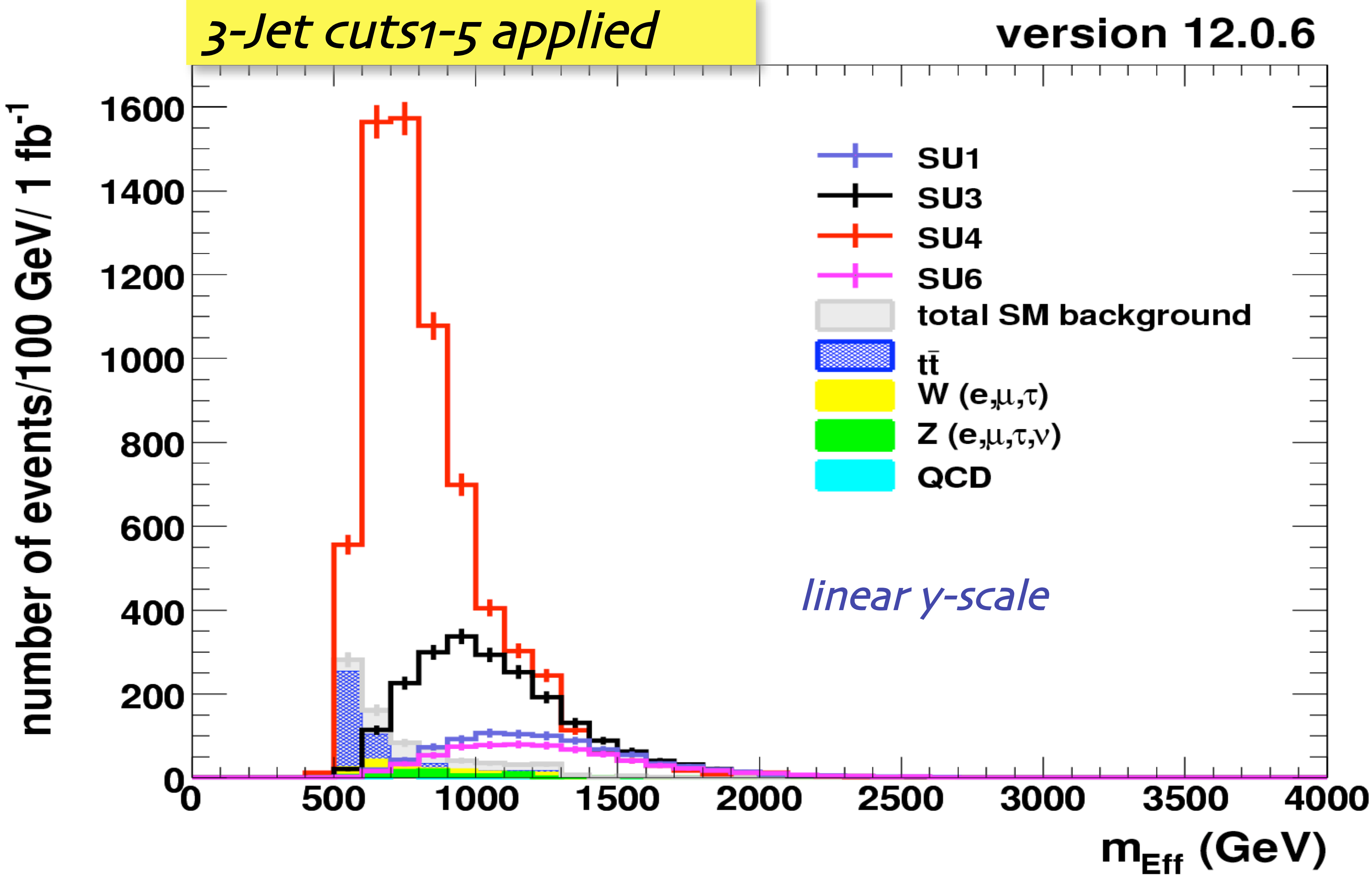
- ElectronCollection
- (author ==1 || author == 3), isEM & 0x3ff== 0
- pT > 20 GeV, |eta| < 2.5
- etcone20 < 10 GeV

MUONS:

- MuidMuonCollection
- bestMatch ==1 && isCombined ==1
- 0<fitChi2/DOF<5, 0<matchChi2<20,
- pT > 20 GeV, |eta| < 2.5,
- etcone20 < 10 GeV

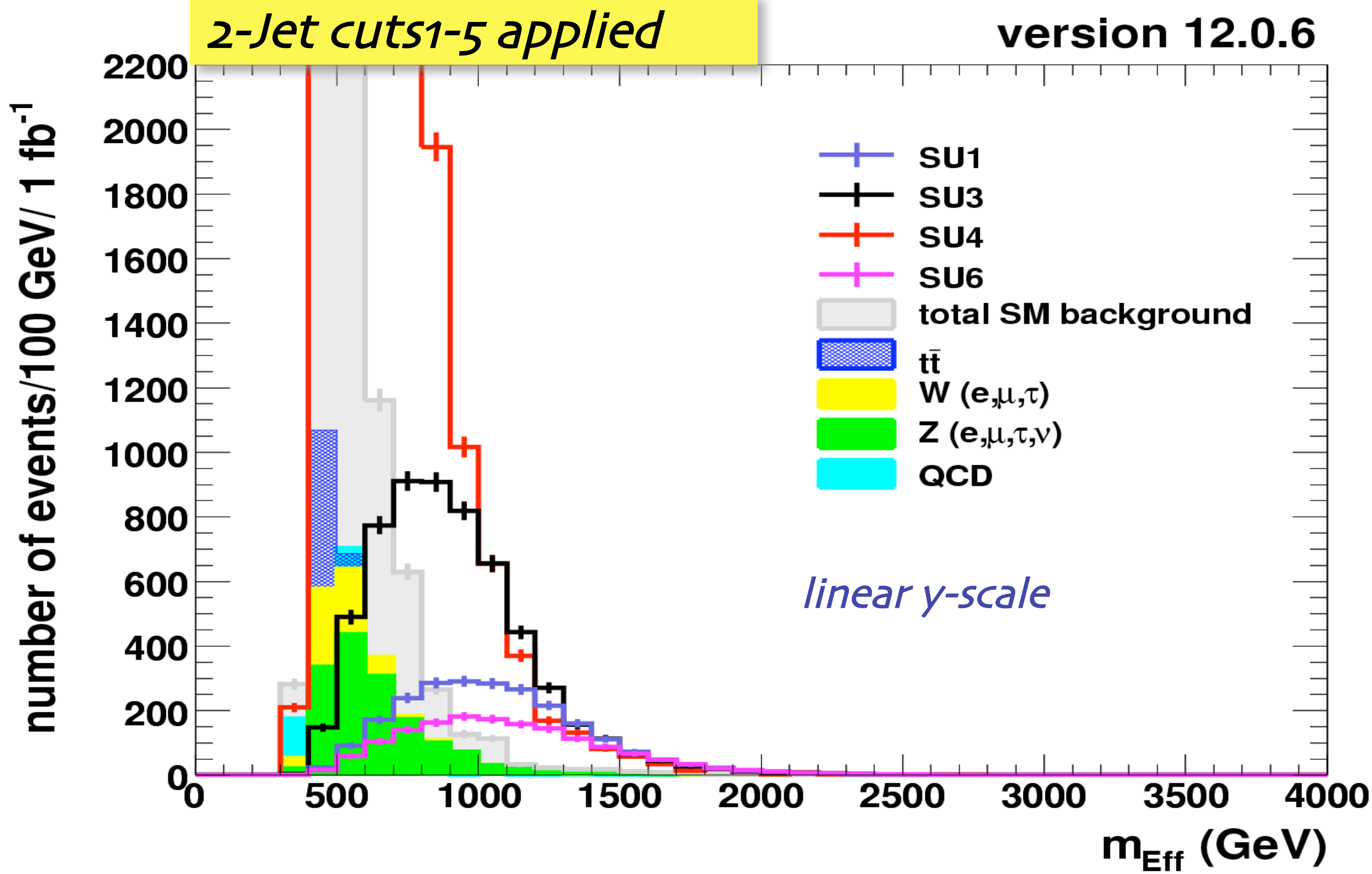
3-Jet Results (for CSC5)

3-Jet cuts1-5 applied



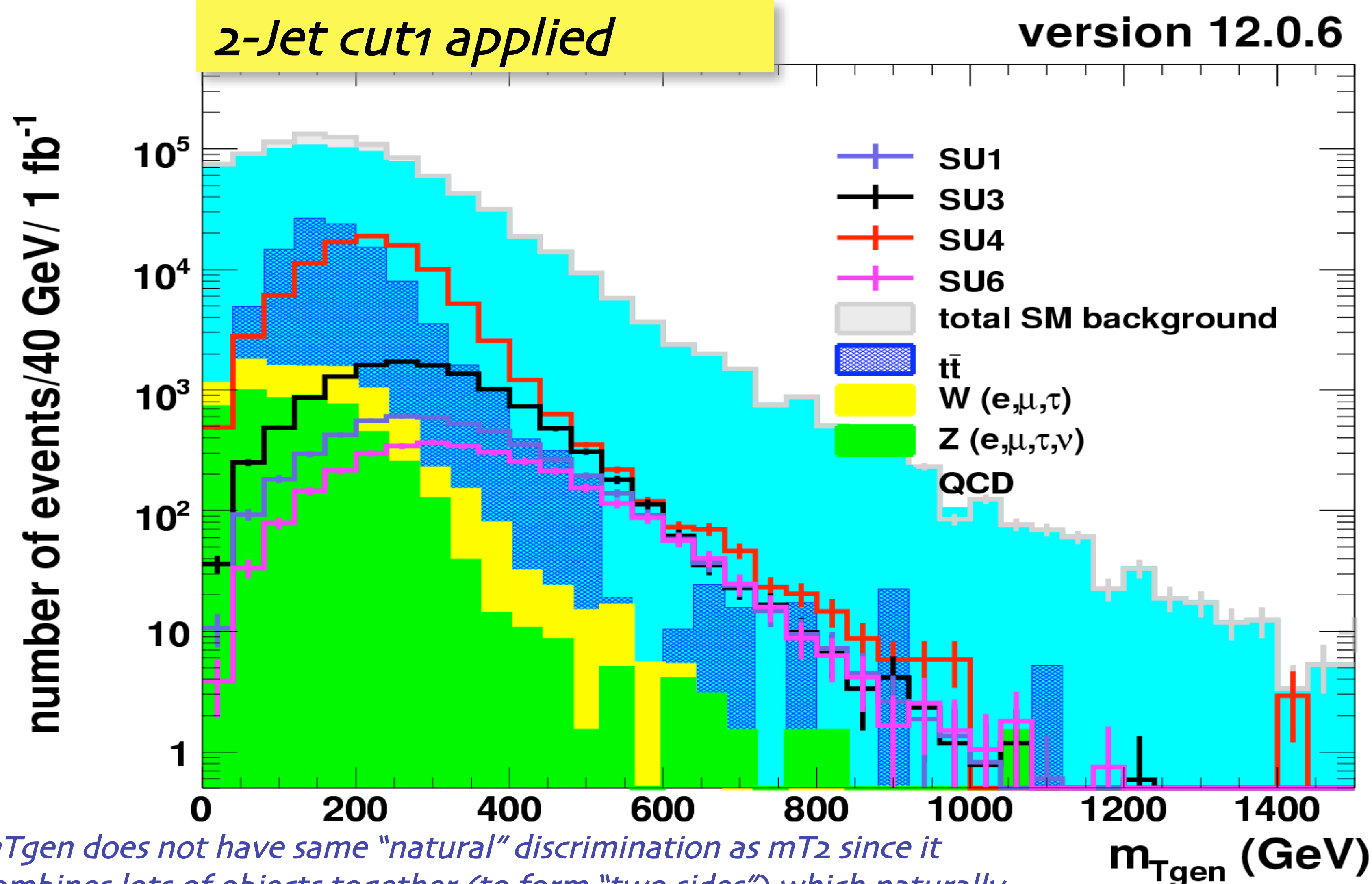
2-Jet Results (for CSC5)

2-Jet cuts1-5 applied



mTgen

2-Jet cut1 applied



mTgen does not have same "natural" discrimination as mT2 since it combines lots of objects together (to form "two sides") which naturally have large invariant masses already, before feeding into mT2 calculation