Low Jet Multiplicities and mT2 for early SUSY discovery

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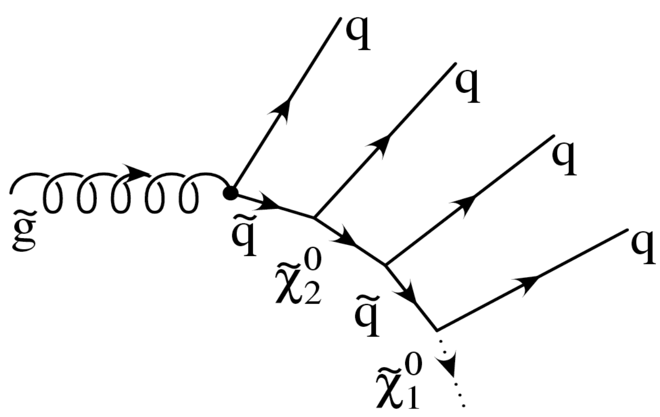
Searching for SUSY

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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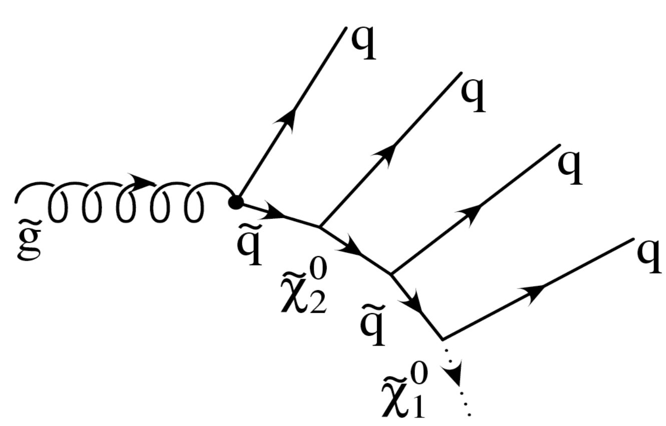

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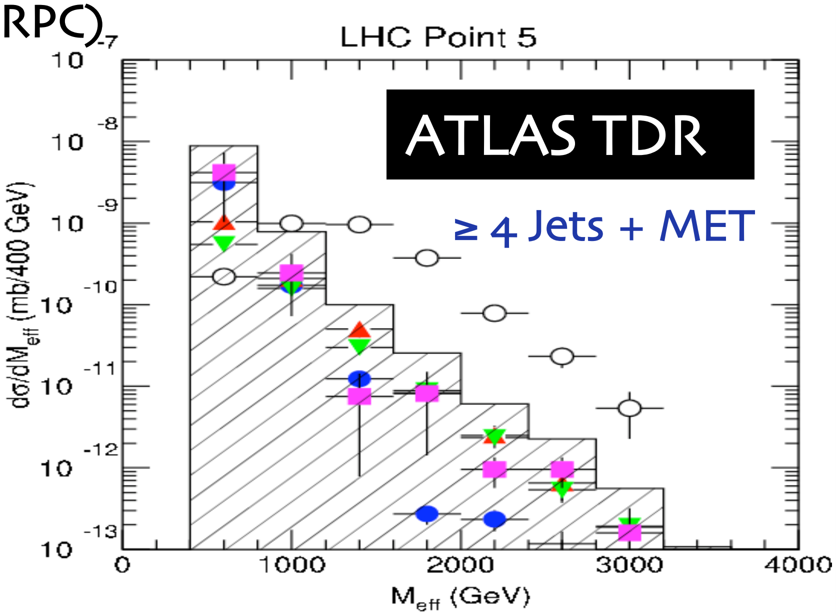
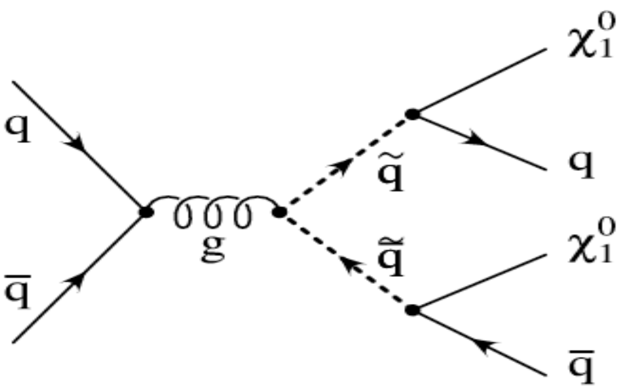
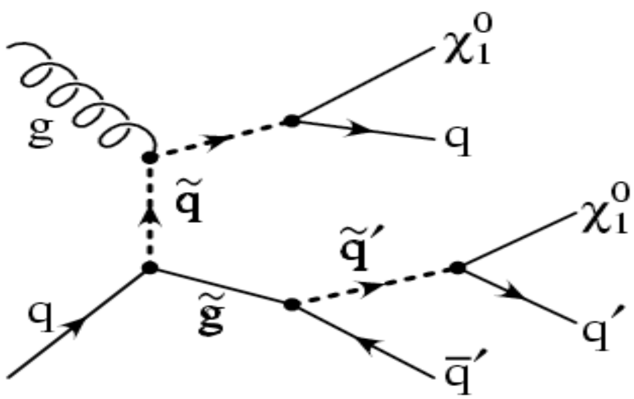


To date, most effort concentrated on large jet multiplicities i.e. ≥ 4 jets - assumption being that this is required to reduce large QCD BG
(e.g. ATLAS TDR (1999) and ALL studies since then)

SUSY searches with small nJets





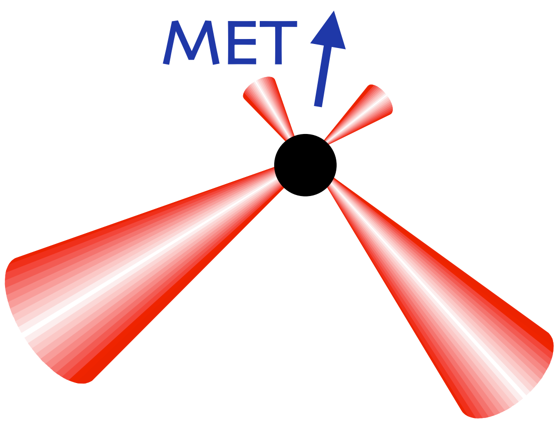
and similar …

Concentrate on <u>small</u> nos. of high-pT jets :

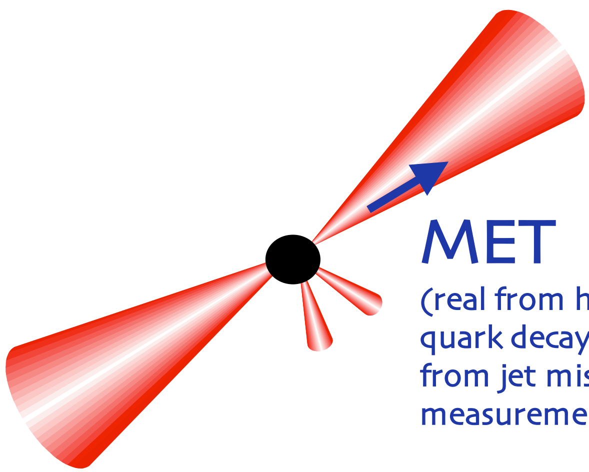
1) Large signal cross section (provided at least 1 strongly int. particle @ TeV scale)
2) Large control statistics
3) Relatively well known SM backgrounds
4) Relatively model independent
   - do not rely on leptonic cascades
   - do not rely on hadronic cascades

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

Suppressing QCD Background



SIGNAL TOPOLOGY



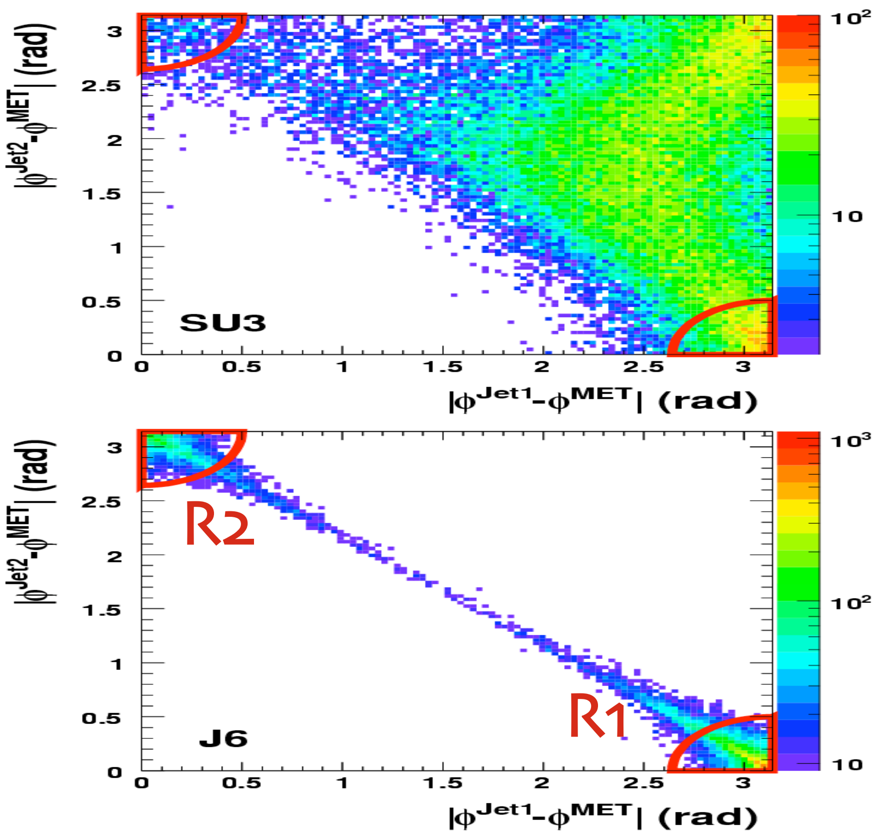
QCD background

Remove events with jets close to MET direction:

$\delta\varphi(i) = |\varphi(Jet,i) - \varphi(MET)| > CUT$

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

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



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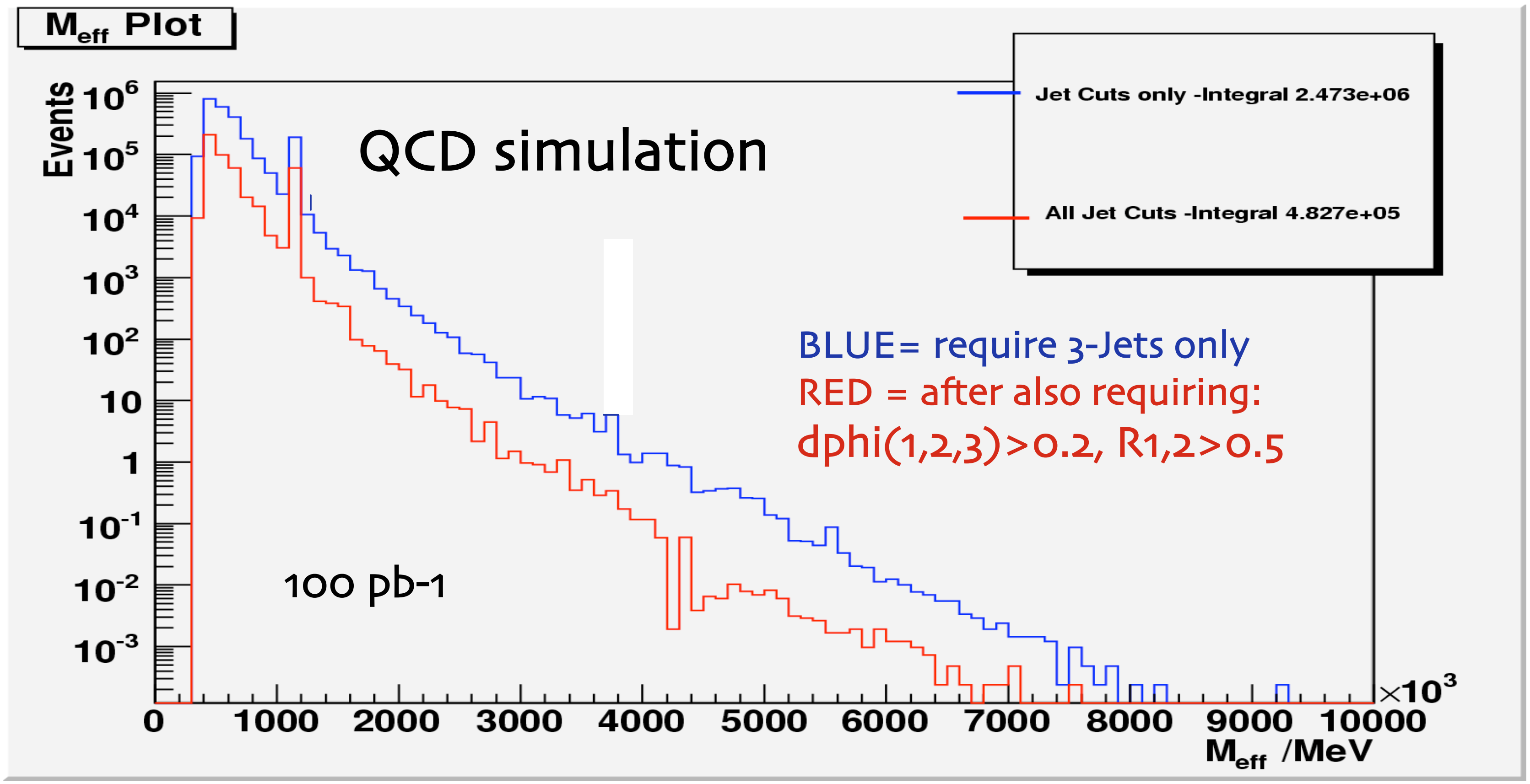


Imposing cuts on $\delta\varphi$ and R1,2 removes > 80% of QCD background (according to this MC simulation!) - can suppress further by cuts on e.g. MET

Cuts to separate signal from BG

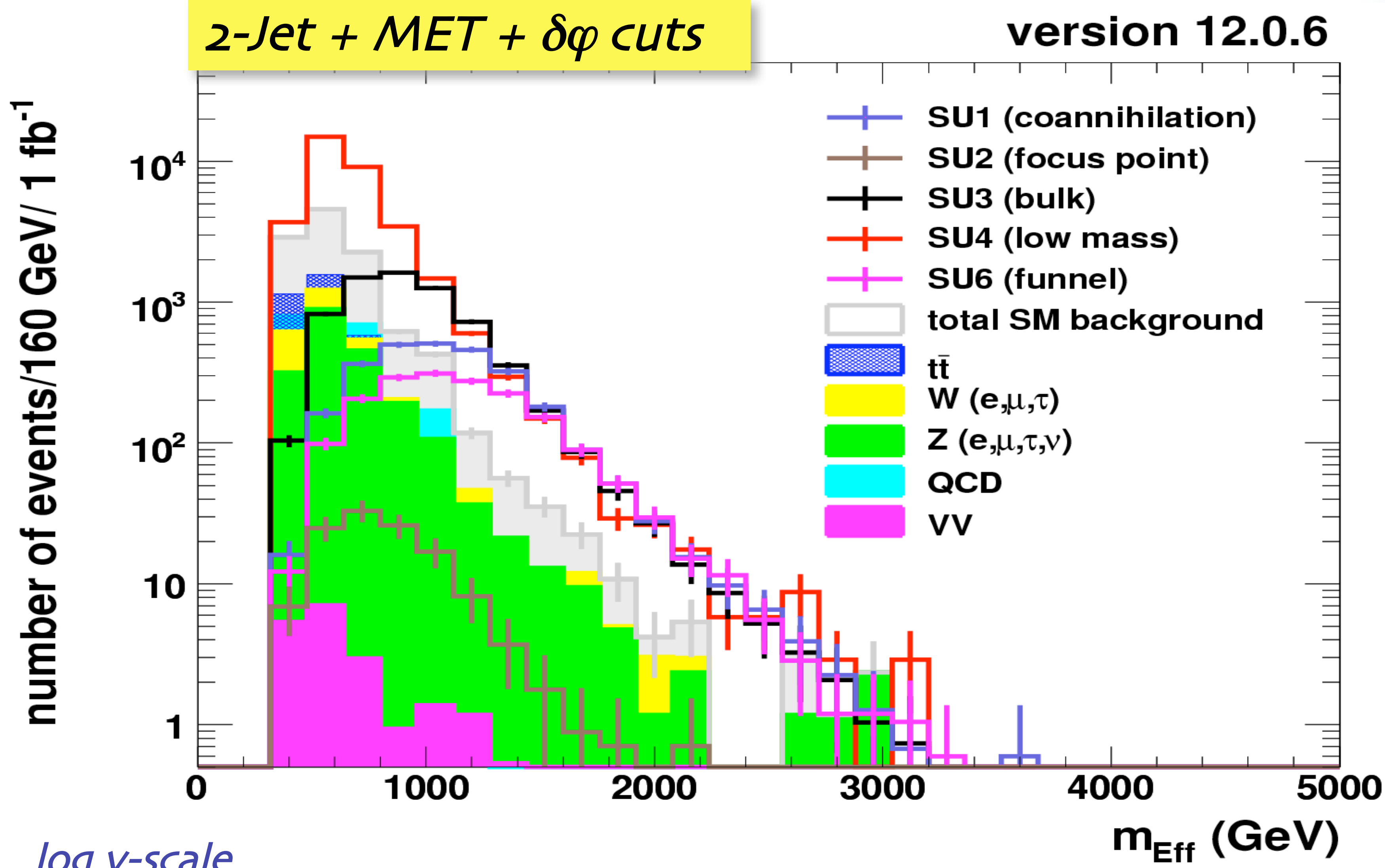
Traditionally (since TDR), Meff distribution used as discriminator

Cuts
at least 2(3) Jets: • $p_T^{Jet1,2(,3)}$>150,100(,100) GeV • $\|\eta^{Jet1,2(,3)}\|$ < 2.5
MET > max(100,0.3*Meff) GeV
Cuts based on: $\delta\phi i = \|\phi(Jeti)-\phi(MET)\|$ • $\delta\phi 1,2(,3)$ > 0.2 rad • R1 = > 0.5 rad, R2 > 0.5 rad
veto isolated leptons

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

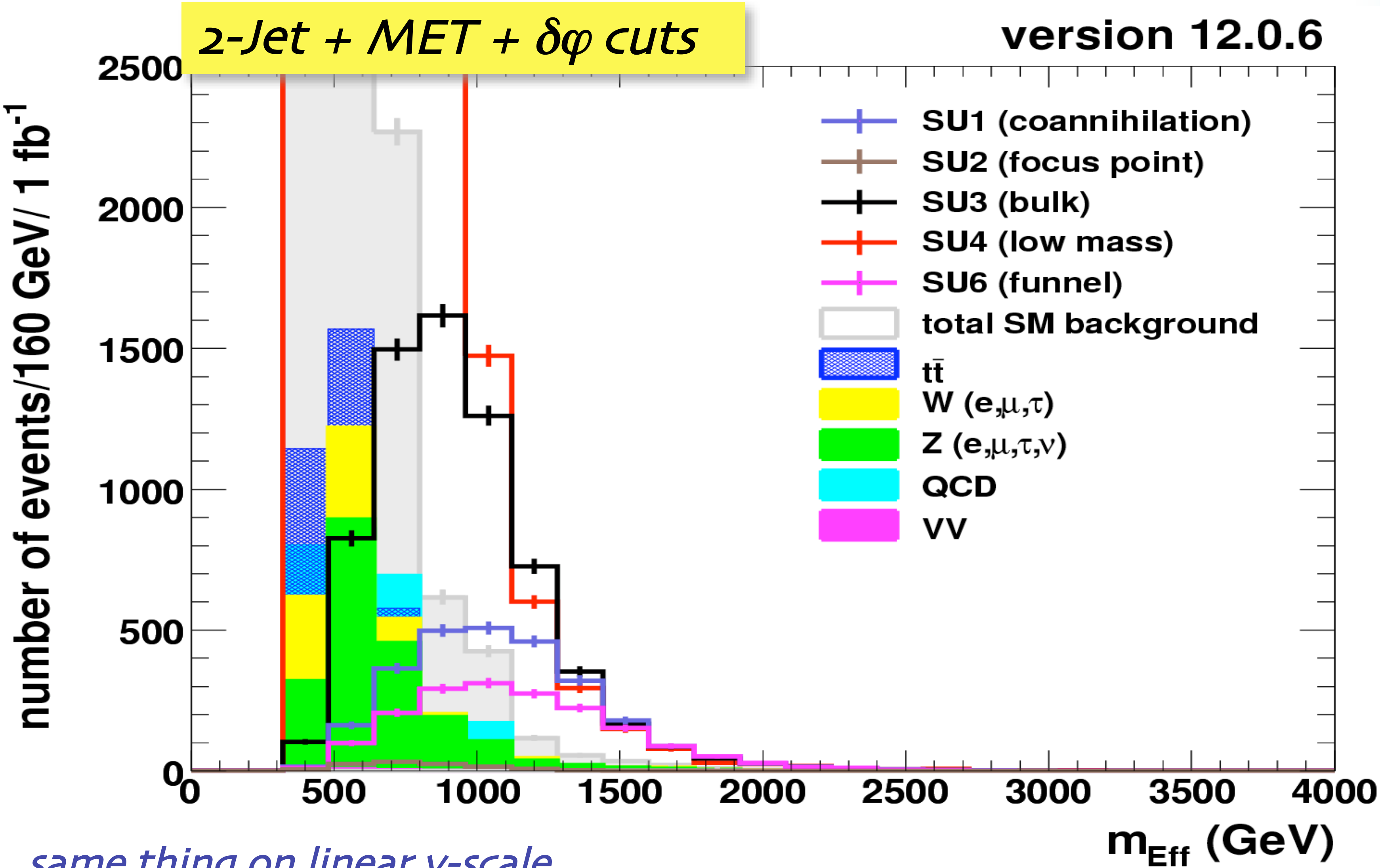
2-Jet Meff distribution

2-Jet + MET + δφ cuts



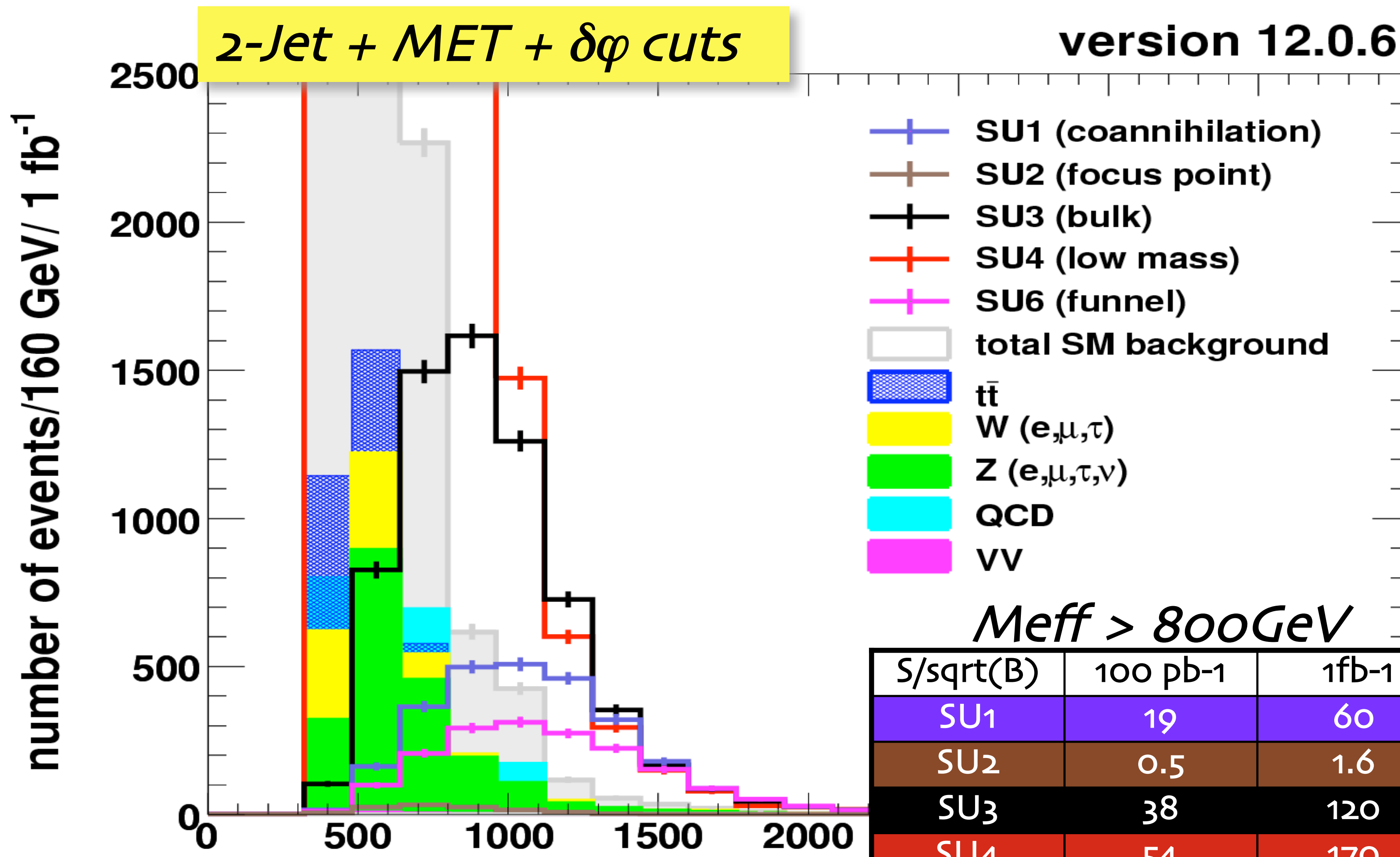
log y-scale

2-Jet Meff distribution



same thing on linear y-scale

2-Jet Meff distribution



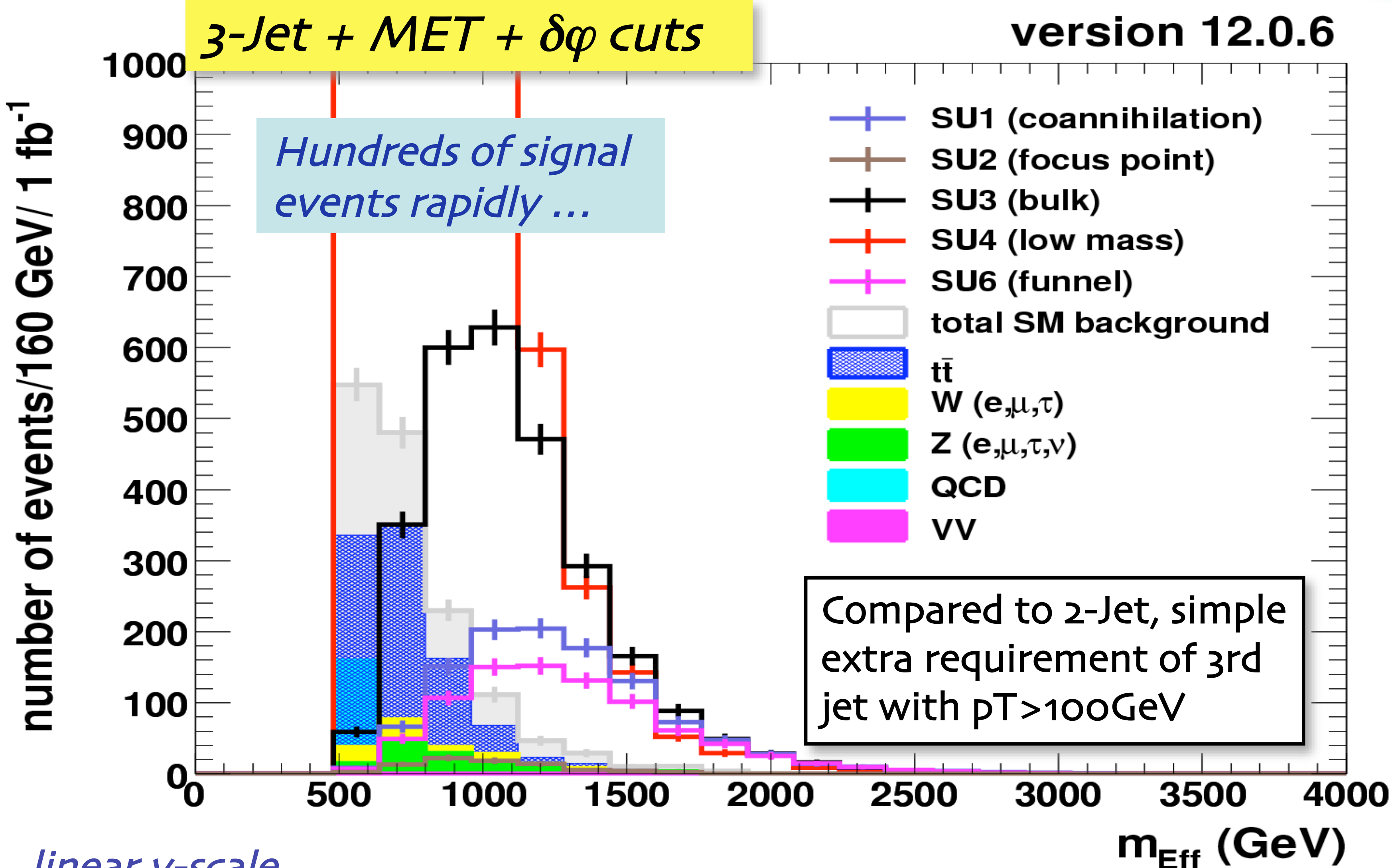
Meff > 800GeV

S/sqrt(B)	100 pb-1	1fb-1
SU1	19	60
SU2	0.5	1.6
SU3	38	120
SU4	54	170
SU6	13	41

same thing on linear y-scale

3-Jet Meff distribution

3-Jet + MET + δφ cuts

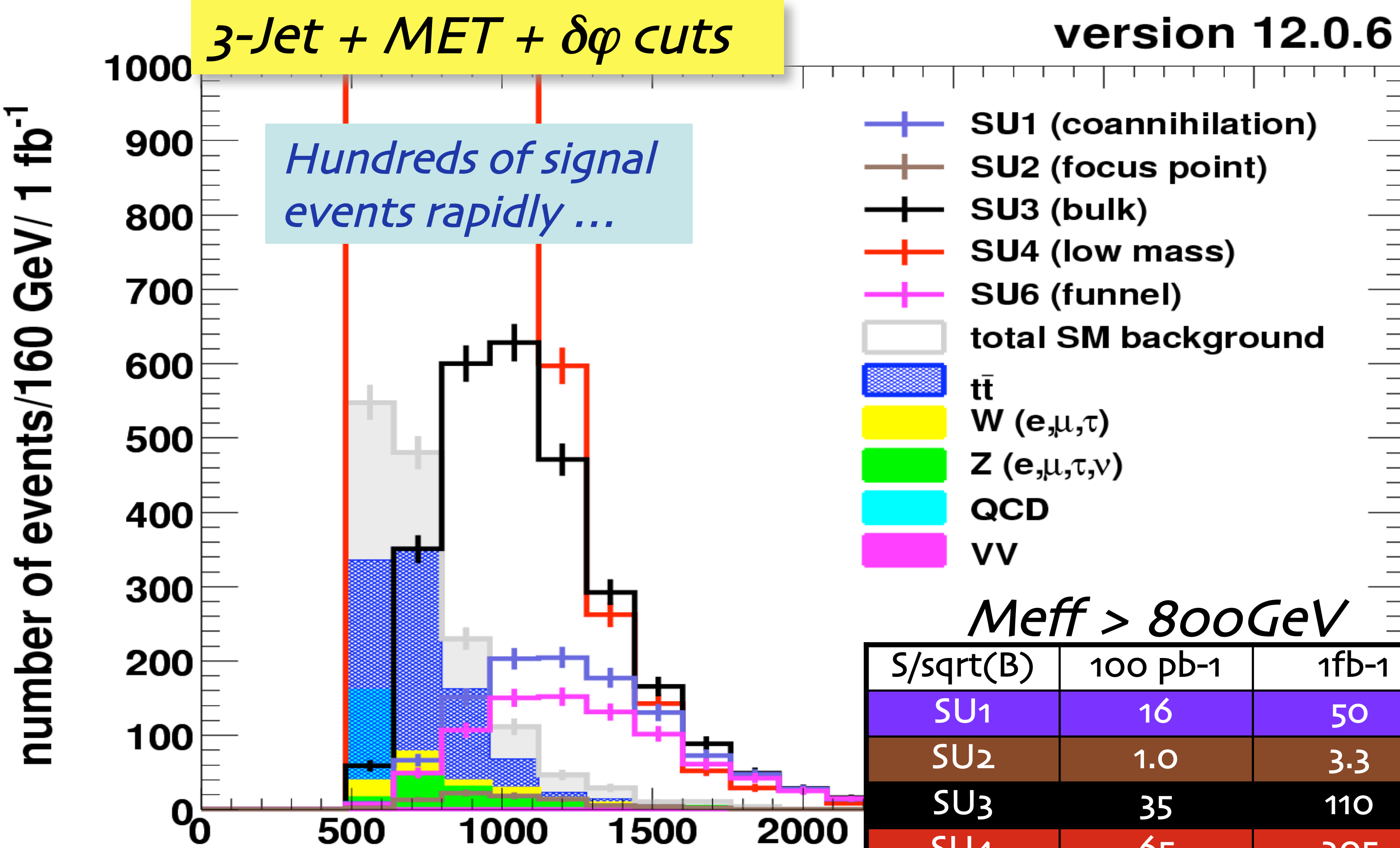


linear y-scale

3-Jet Meff distribution

3-Jet + MET + $\delta\varphi$ cuts

Hundreds of signal events rapidly …



Meff > 800GeV

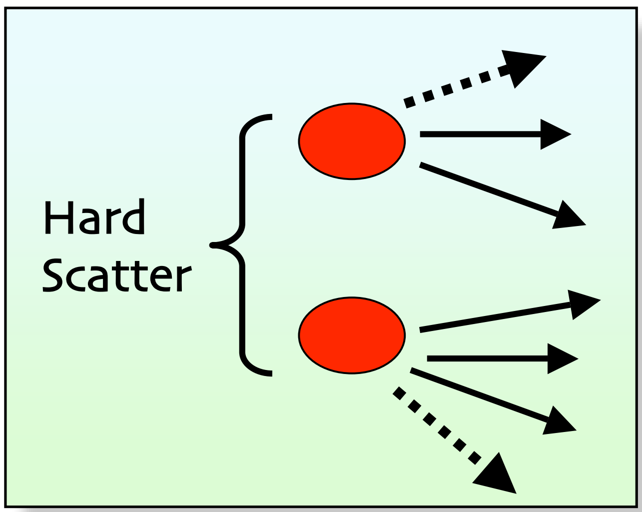
S/sqrt(B)	100 pb-1	1fb-1
SU1	16	50
SU2	1.0	3.3
SU3	35	110
SU4	65	205
SU6	12	38

linear y-scale

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

Alternative Strategy: mT2



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

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

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
(or for more complicated cases but in which one can unambiguously know which particles originated from which side of the decay)

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:

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

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,…)

NB: no *a priori* reason to expect small mT2 for $Z \rightarrow \nu\nu$ + Jets → may be dominant BG at large mT2

“Simple” analysis

mT2 already “does the job” of traditional cuts

- → MET cut (small if MET→ 0)
- → δφ 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 $pT^{Jet1,2}$>150,100GeV, |eta|<2.5 → plot mT2

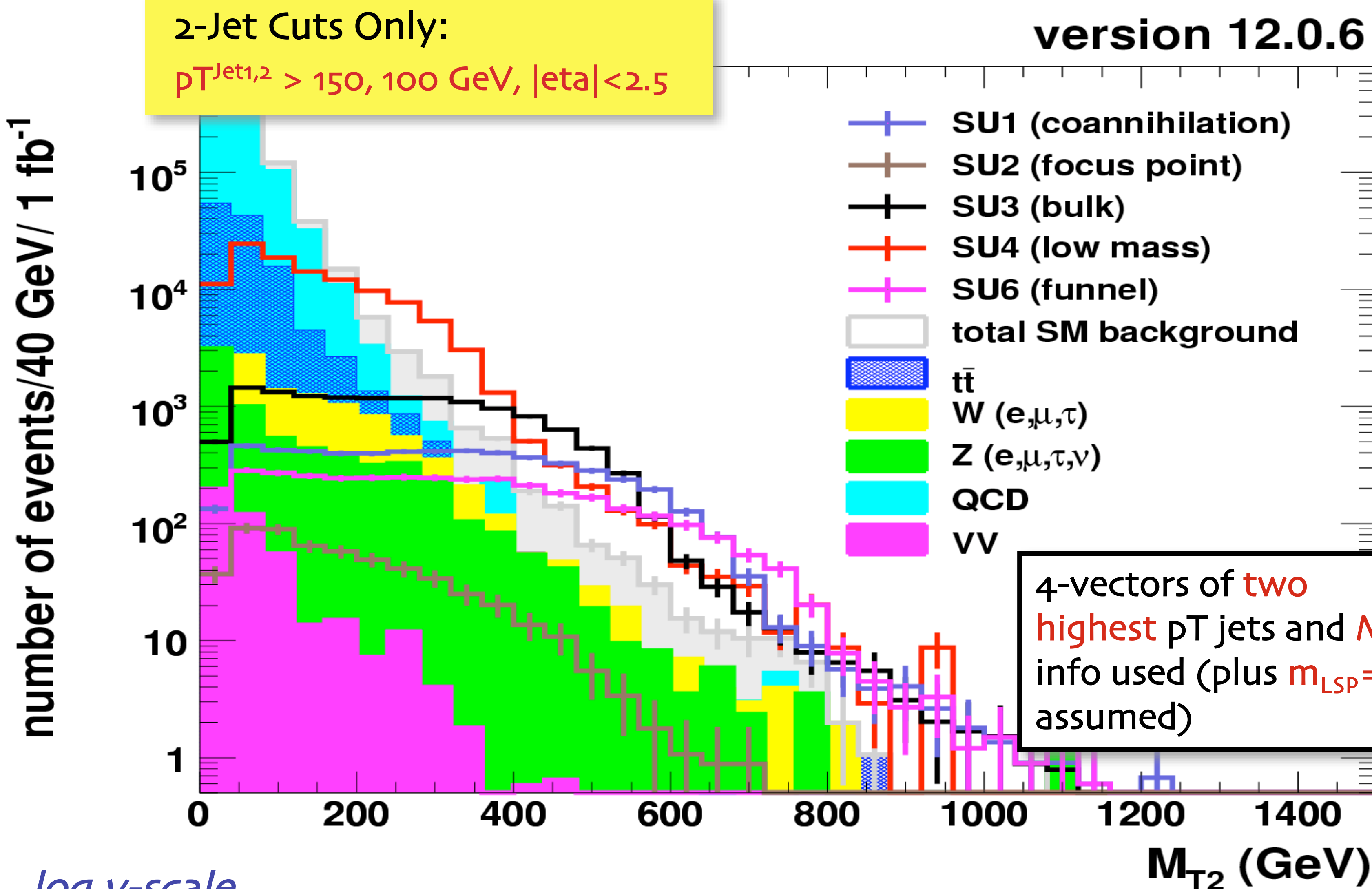
(simple 2-Jet cuts only)

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

2-Jet Cuts Only:

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



4-vectors of two highest pT jets and MET info used (plus m_{LSP}=0 assumed)

log y-scale

mT2 Results

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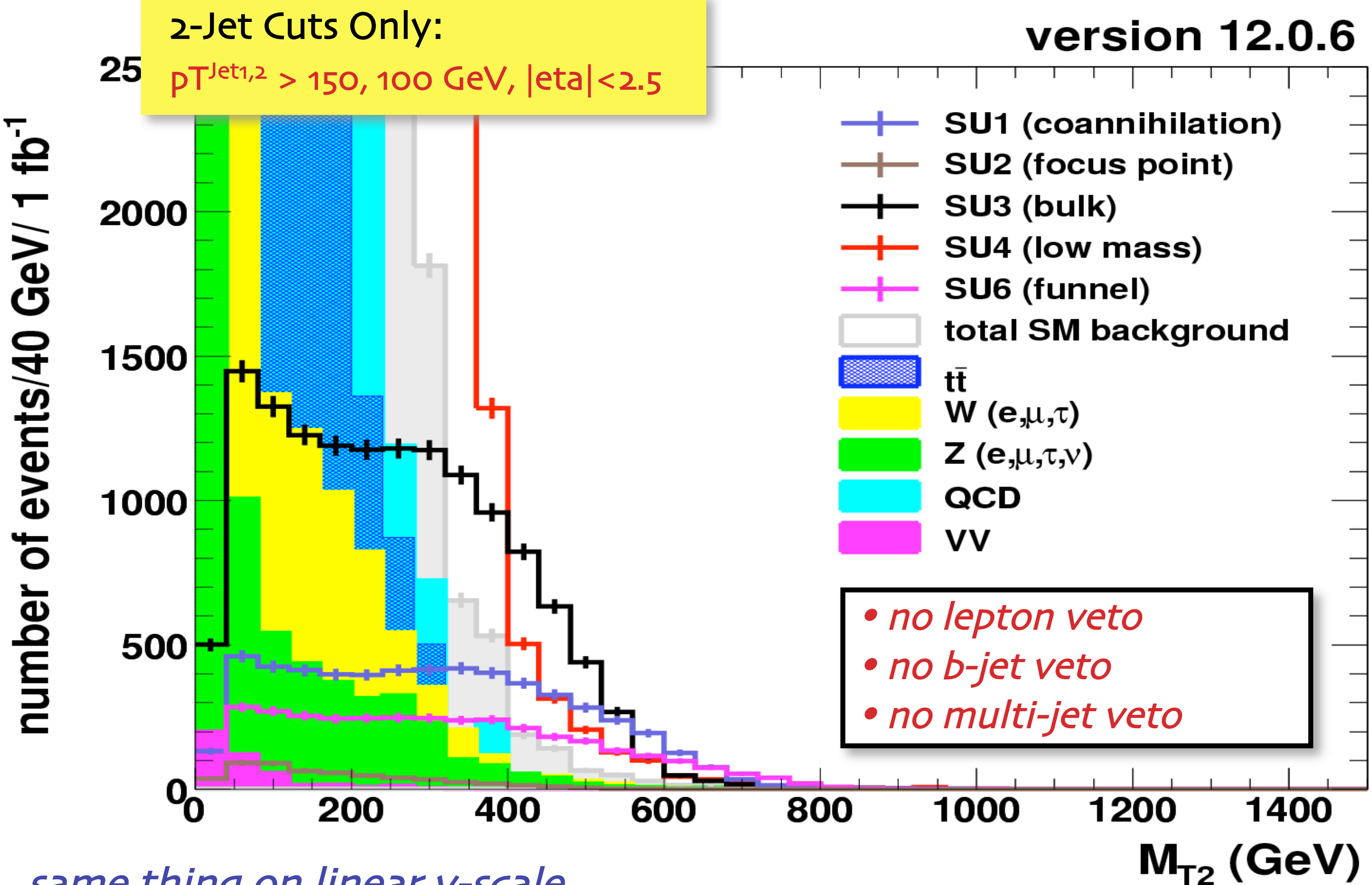

same thing on linear y-scale

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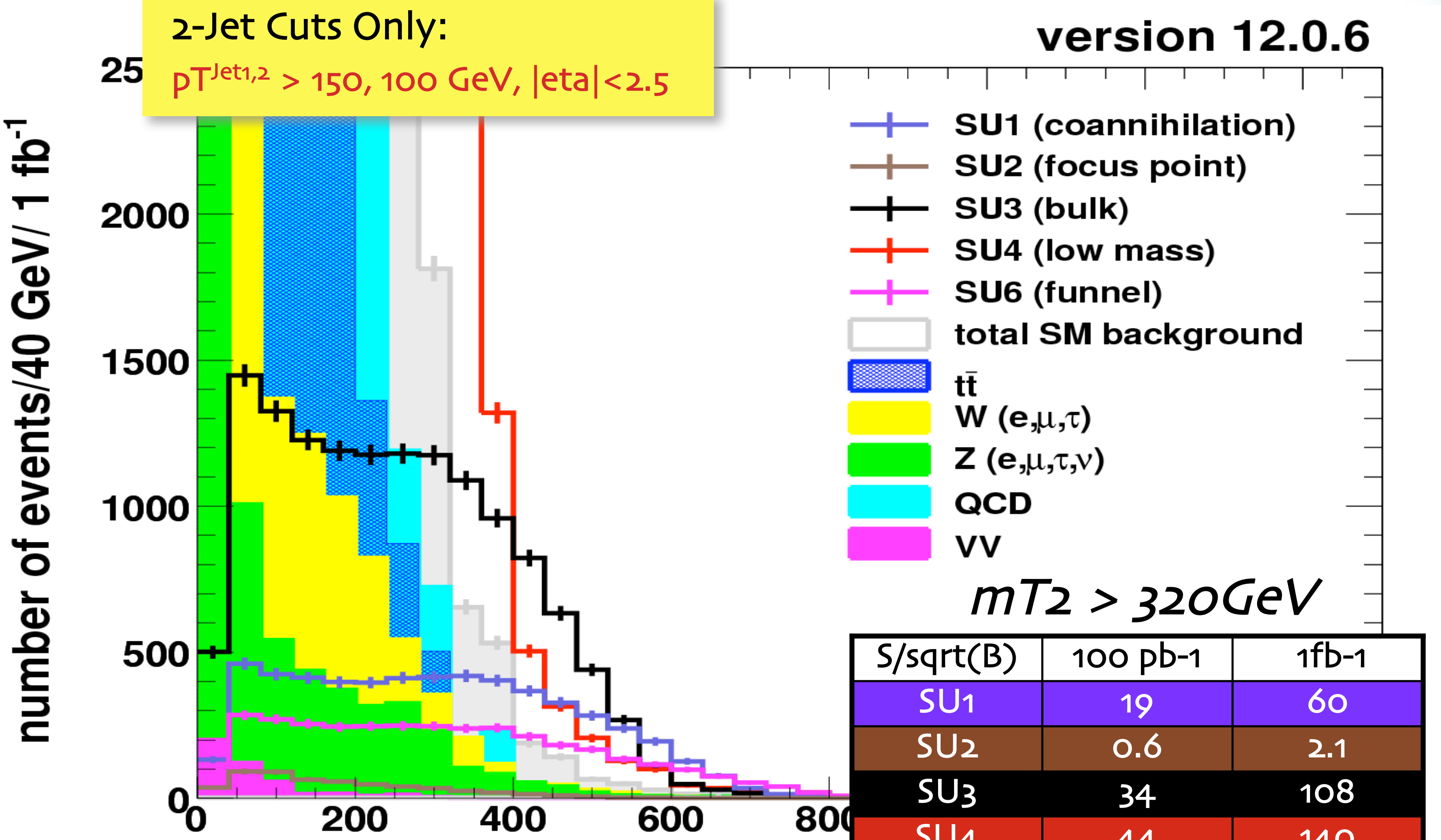


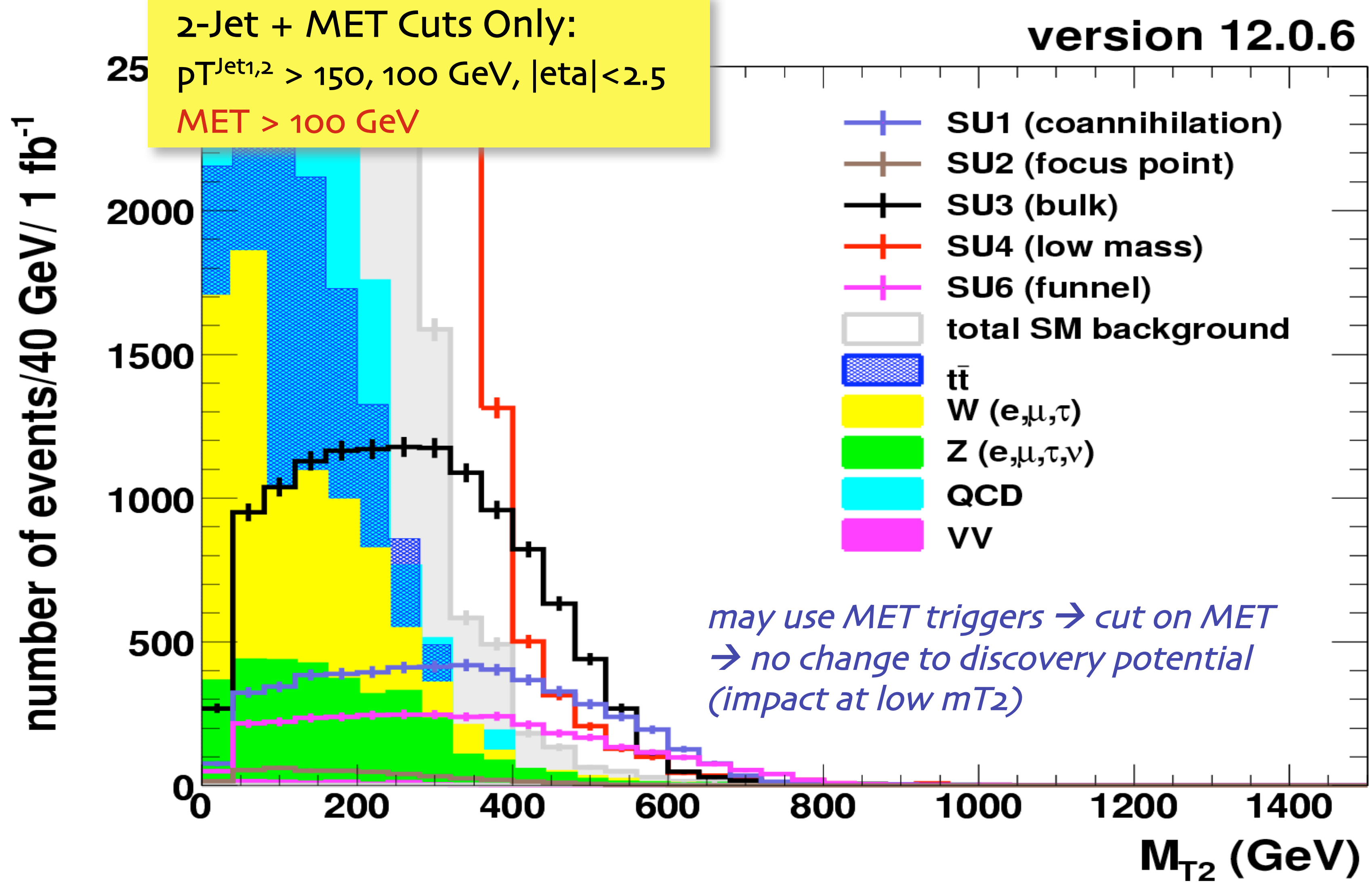
mT2 > 320GeV

S/sqrt(B)	100 pb-1	1fb-1
SU1	19	60
SU2	0.6	2.1
SU3	34	108
SU4	44	140
SU6	12	39

same thing on linear y-scale

mT2 after MET cut

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

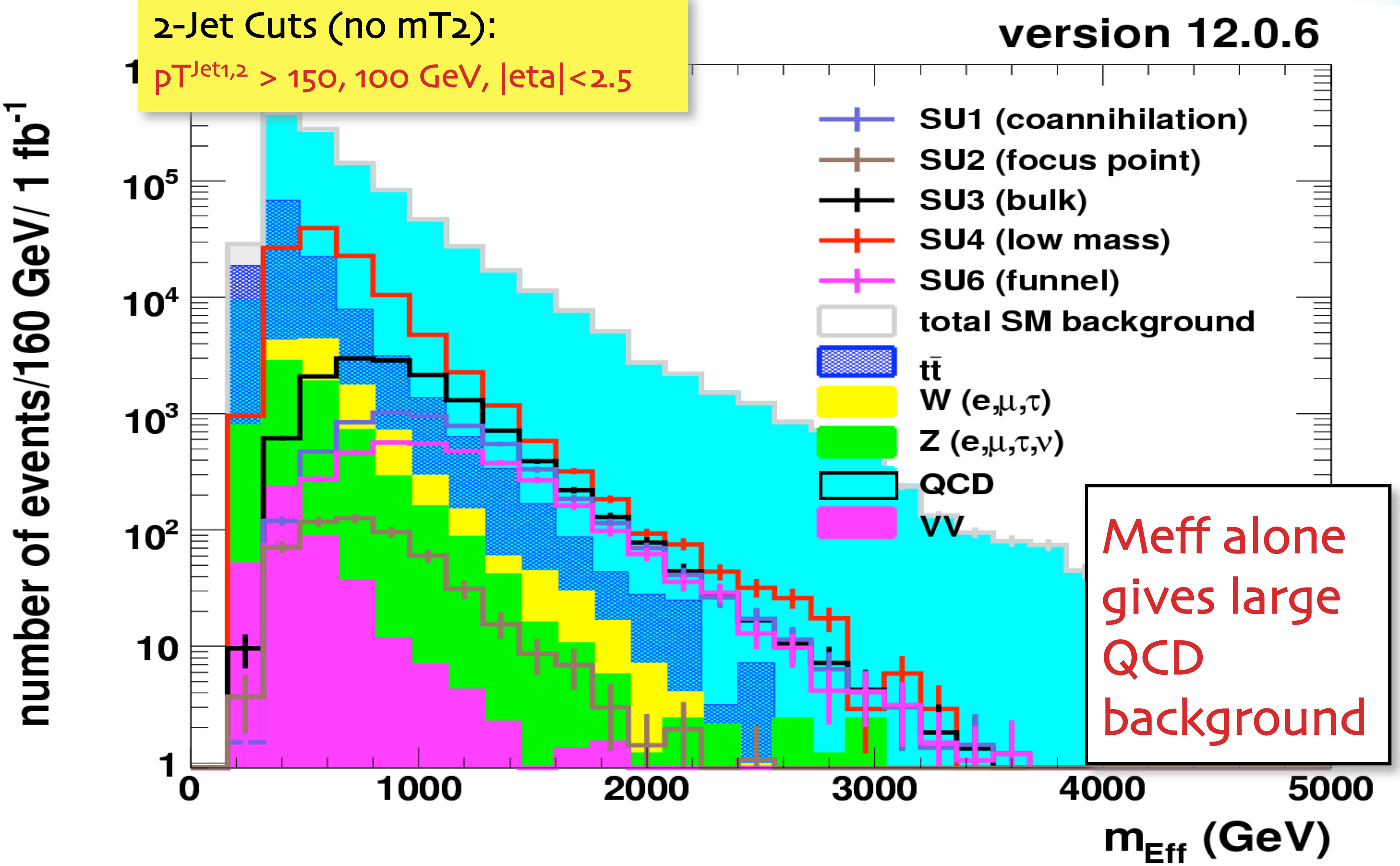


may use MET triggers → cut on MET
→ no change to discovery potential
(impact at low mT2)

Just for Comparison (Meff)

2-Jet Cuts (no mT2):

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



Meff alone gives large QCD background

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)

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?

mT2 "does the job" of several traditional cuts

- expected from its properties
- combination of {MET, sphericity, dphi}
- reduce number of explicit cuts → simplify analysis?

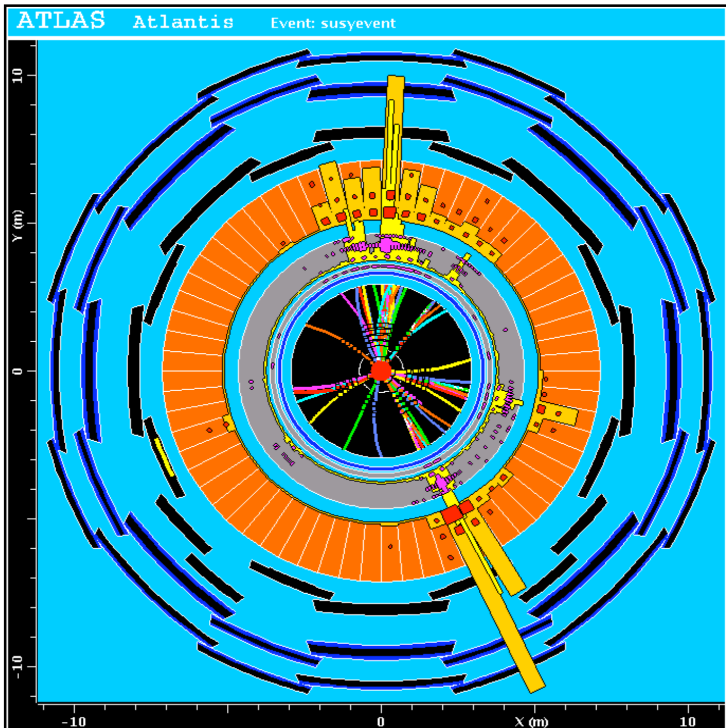
Jets+MET channels with low jet multiplicities (both "traditional" and mT2 approach) should be part of early SUSY search strategy

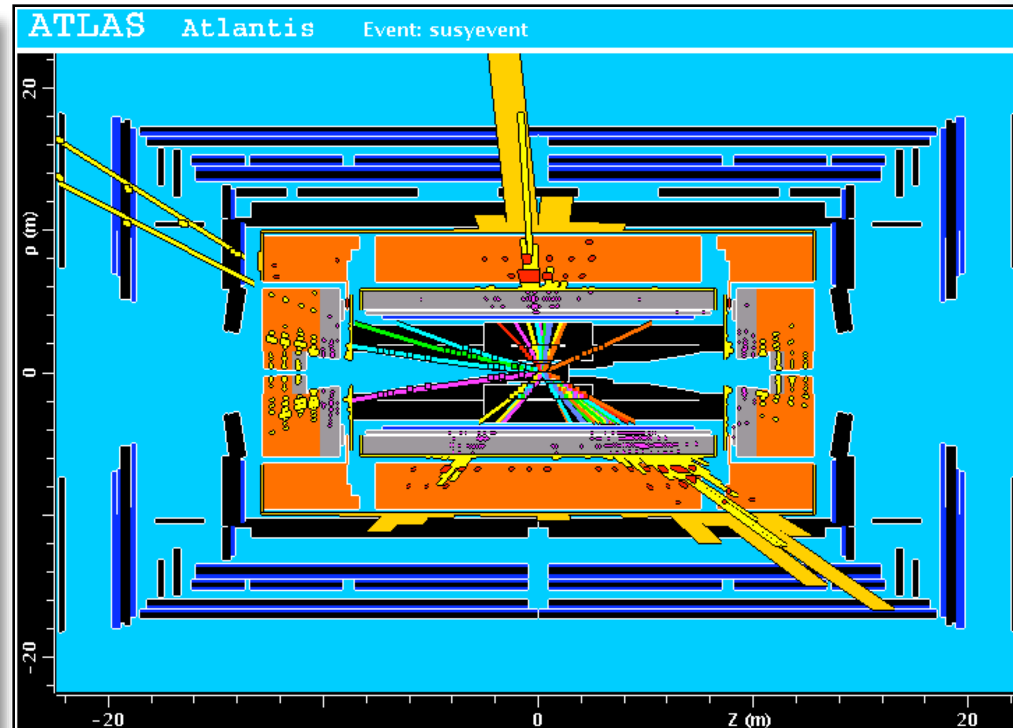
Backups

example SUSY points

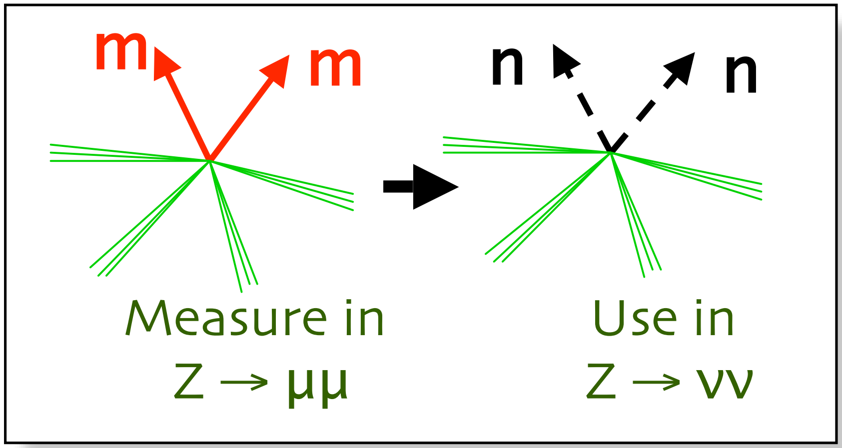
Point	m_0 (GeV)	m_1/2 (GeV)	A0 (GeV)	tan(β)	sign(μ)	σ (pb)
Coannihilation (SU1)	70	350	0	10	+	7.43
Focus Point (SU2)	3550	300	0	10	+	4.86
Bulk (SU3)	100	300	-300	6	+	18.59
Low Mass (SU4)	200	160	-400	10	+	262
Funnel (SU6)	320	375	0	50	+	4.48
Coannihilation (SU8.1)	210	360	0	40	+	6.44
Coannihilation (SU8.2)	215	360	0	40	+	6.40
Coannihilation (SU8.3)	225	360	0	40	+	6.32

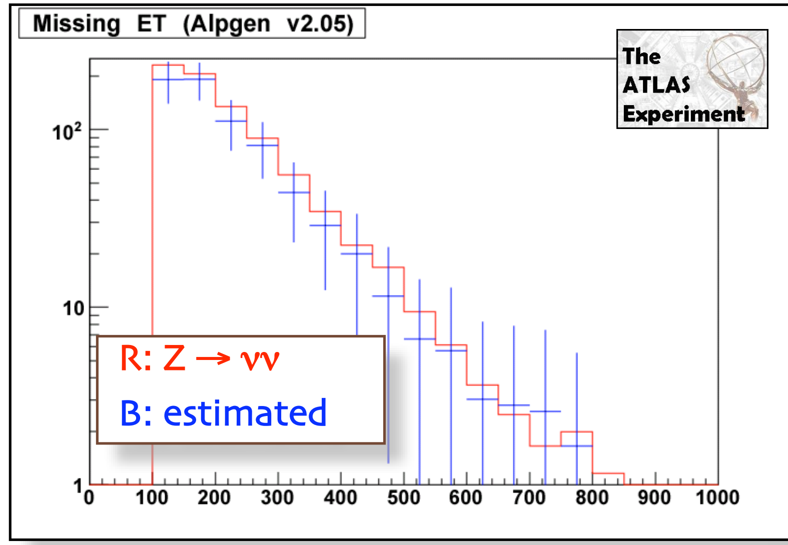
Simulated SUSY event





EG. Background Measurement





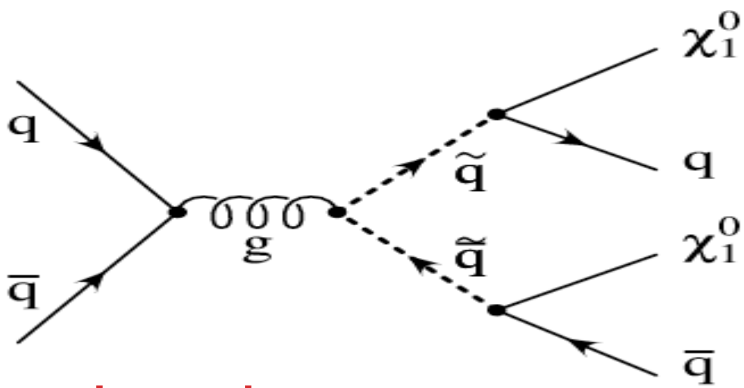
- Example: SUSY BG
  - Jets + MET from Z to neutrinos (plus ISR)
  - Measure in Z → μμ
  - Use for Z → νν

- Good match
  - Useful technique
- Statistics limited
  - Go on to use W → μν to improve

MC samples

J4	trig1_misal1_mc12.008090.pythia_J4_Nj2_FMET100.recon.AOD.v12000601*
J5	trig1_misal1_mc12.008091.pythia_J5_Nj2_FMET100.recon.AOD.v12000601*
J6	trig1_misal1_mc12.008092.pythia_J6_Nj2_FMET100.recon.AOD.v12000601*
J7	trig1_misal1_mc12.008093.pythia_J7_Nj2_FMET100.recon.AOD.v12000601*
J8	trig1_misal1_mc12.008094.pythia_J4_Nj2_FMET100.recon.AOD.v12000601*
T1	trig1_misal1_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000604*
TTbar	trig1_misal1_mc12.005204.TTbar_FullHad_McAtNlo_Jimmy.recon.AOD.v12000601*
Zee	trig1_misal1_mc12.008194.pythia_Zee_qg_Nj2_ckin80.recon.AOD.v12000601
Zmumu	trig1_misal1_mc12.008195.pythia_Zmumu_qg_Nj2_ckin80.recon.AOD.v12000601
Ztautau	trig1_misal1_mc12.008191.pythia_Ztautau_qg_Nj2_ckin80.recon.AOD.v12000601
Znunu	trig1_misal1_mc12.008190.pythia_Znunu_qg_Nj2_ckin80.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.recon.AOD.v12000601*
Wtaunu	trig1_misal1_mc12.008270.pythia_Wtaunu_qg_ckin80_Nj2.recon.AOD.v12000601*
WW	trig1_misal1_csc11.005985.WW_Herwig.recon.AOD.v12000601*
WZ	trig1_misal1_csc11.005987.WZ_Herwig.recon.AOD.v12000601*
ZZ	trig1_misal1_csc11.005986.ZZ_Herwig.recon.AOD.v12000601*

SUSY searches with small nJets



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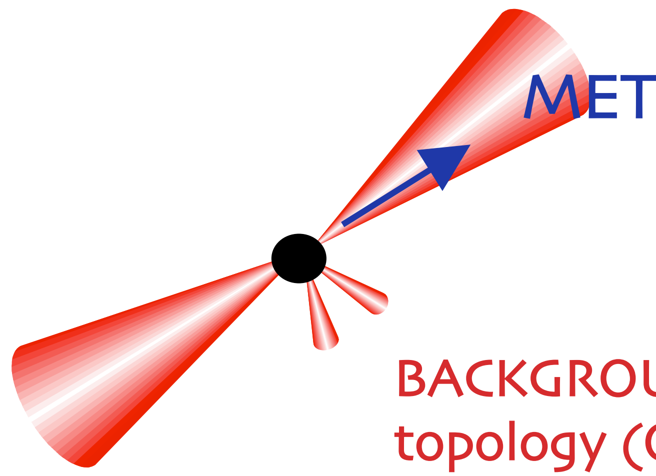
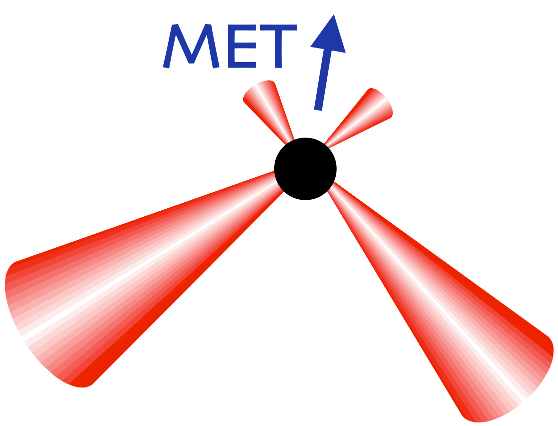


BACKGROUND
topology (QCD)



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