Neutralino Mass Measurement in Dilepton Final States

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Outline

- Dilepton edges in SUSY
  - Chosen benchmark points
  - Different decay modes of the neutralinos
- Standard model backgrounds
  - Event selection
- Fit of the mass edge
  - Fit method
  - Calibration of the estimator
- Expected results for 1 fb^{-1}
  - Including statistical and systematical uncertainty

Supersymmetry

- SUSY solves many problems of the SM
  - Unification of the 3 forces
  - Dark matter candidate
- Symmetry between fermions and bosons
- Each standard model particle gets its superpartner
  - Spin differs by 1/2
- Up to now: no sparticles found
  - Symmetry is broken
- Mass eigenstates are measured
- R-Parity (Matter-Parity)
  - P_R = +1 SM particle
  - P_R = -1 SUSY particle

$$P_R = (-1)^{3\cdot(B-L)+2s}$$

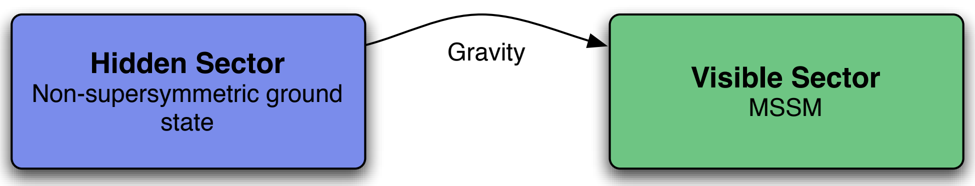
SM particle		spin	MSSM partner		spin
quark	q	$\frac{1}{2}$	squark	$\tilde{q}$	0
lepton	l	$\frac{1}{2}$	slepton	$\tilde{l}$	0
gluon	g	1	gluino	$\tilde{g}$	$\frac{1}{2}$
W bosons	$W^\pm,\ W^0$	1	winos	$\tilde{W}^\pm,\ \tilde{W}^0$	$\frac{1}{2}$
B boson	B^0	1	bino	$\tilde{B}^0$	$\frac{1}{2}$
Higgs boson	H	0	higgsinos	$\tilde{H}$	$\frac{1}{2}$
graviton	G	2	gravitino	$\tilde{G}$	$\frac{3}{2}$

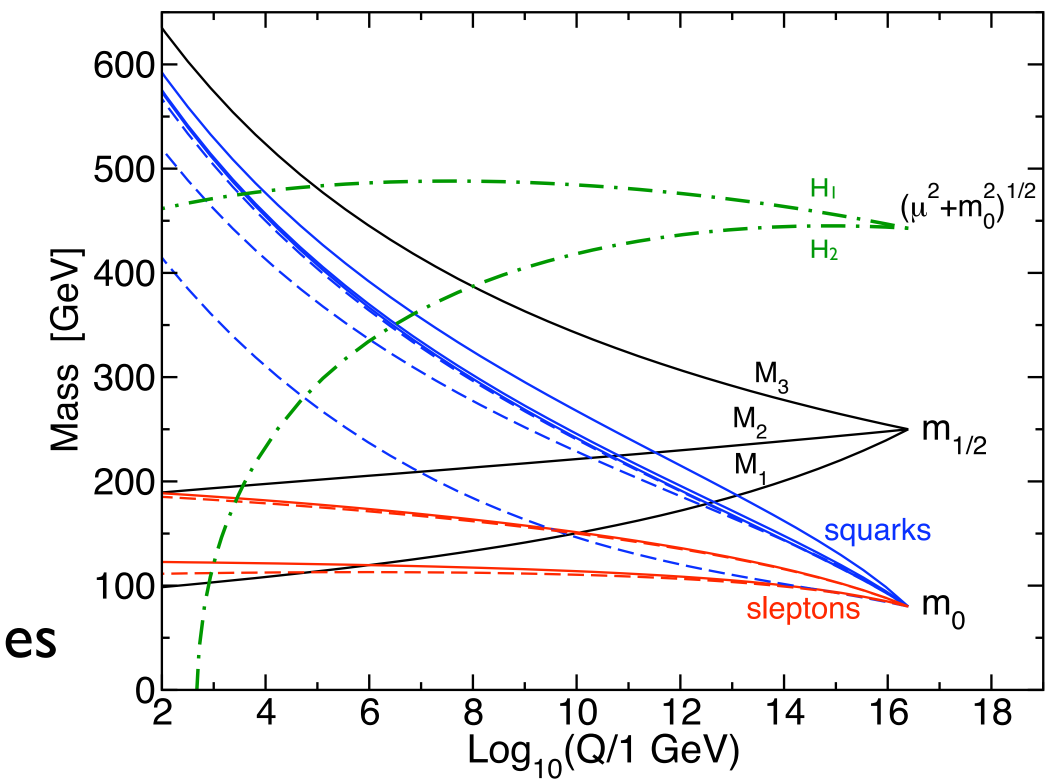
Particle	spin	P_R	gauge eigenstates	mass eigenstates
Higgs bosons	0	+1	$H_1^0,\ H_2^0,\ H_1^+,\ H_2^-$	$h^0,\ A^0,\ H^0,\ H^\pm$
squarks	0	−1	$\tilde{q}$	$\tilde{q}$
sleptons	0	−1	$\tilde{l}$	$\tilde{l}$
neutralinos	$\frac{1}{2}$	−1	$\tilde{B}^0,\ \tilde{W}^0,\ \tilde{H}_1^0,\ \tilde{H}_2^0$	$\tilde{\chi}_1^0,\ \tilde{\chi}_2^0,\ \tilde{\chi}_3^0,\ \tilde{\chi}_4^0$
charginos	$\frac{1}{2}$	−1	$\tilde{W}^\pm,\ \tilde{H}_1^-,\ \tilde{H}_2^+$	$\tilde{\chi}_1^\pm,\ \tilde{\chi}_2^\pm$
gluino	$\frac{1}{2}$	−1	$\tilde{g}$	$\tilde{g}$
gravitino	$\frac{3}{2}$	−1	$\tilde{G}$	$\tilde{G}$

Disadvantage: 105 new parameters (MSSM)

mSUGRA

- Unification of masses and couplings at the GUT scale
- Symmetry-breaking via gravity
- R-Parity conservation $$P_R = (-1)^{3\cdot(B-L)+2s}$$
    - Supersymmetric particles are produced in pairs
    - LSP is stable
    - Sparticles decay into the LSP
- Only 5 free parameters:
    - M_0: common scalar mass
    - $M_{1/2}$: common gaugino mass
    - $\tan(\beta)$: ratio of the Higgs vacuum expectation values
    - A_0: trilinear coupling
    - $\mathrm{sgn}(\mu)$: sign of the higgsino mass parameter

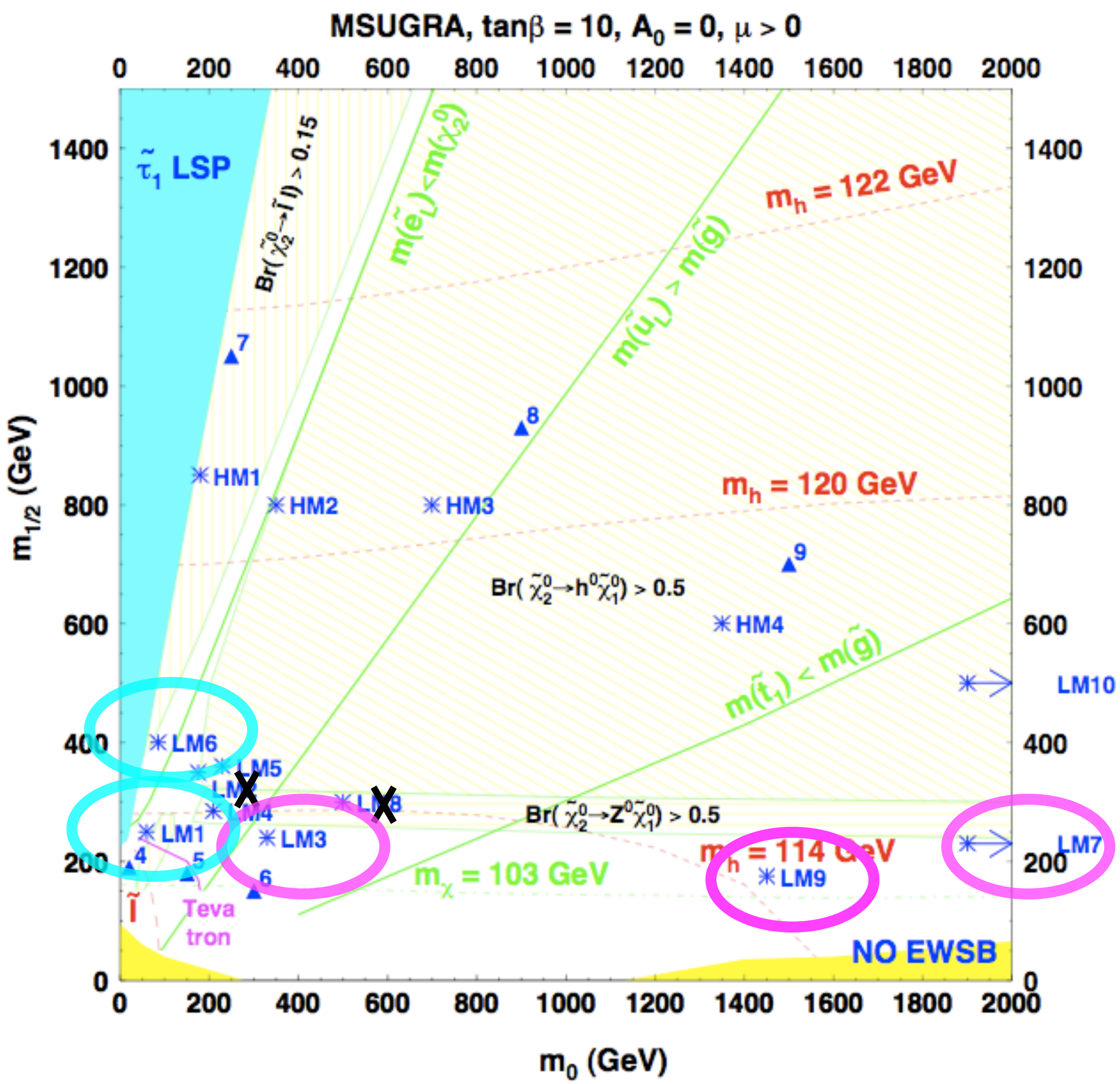




Masses are calculated via running of the renormalization group equations

CMS Benchmark points

Aim: Determination of $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$ in mSUGRA

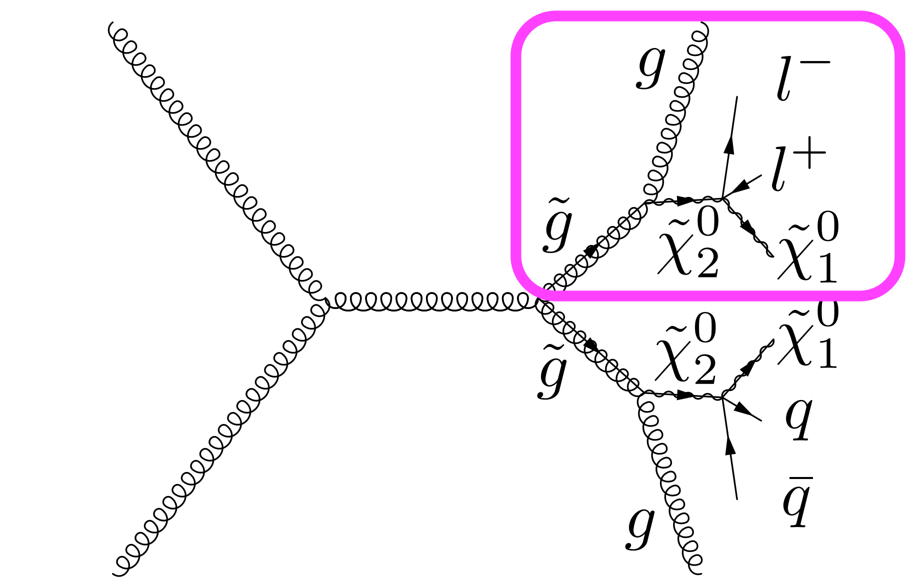


m_0	$m_{1/2}$	$\tan\beta$	A_0	sgn(μ)
1450 GeV	175 GeV	50	0	+1

LM9t175_sftsdkpyt

- High production cross section
- σ_{SUSY} = 44 pb (Prospino NLO)

$$\sigma_{\tilde{g}\tilde{g}} = 36.7 \text{ pb}$$

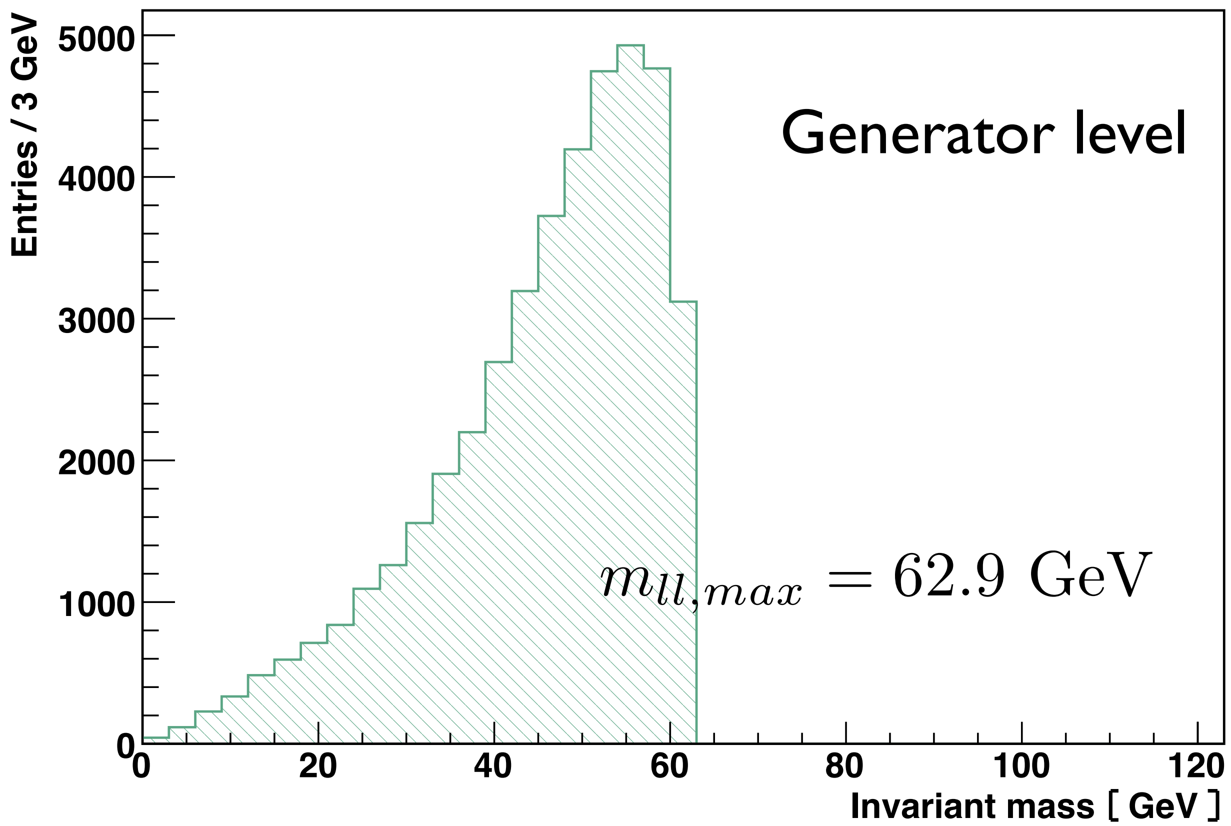


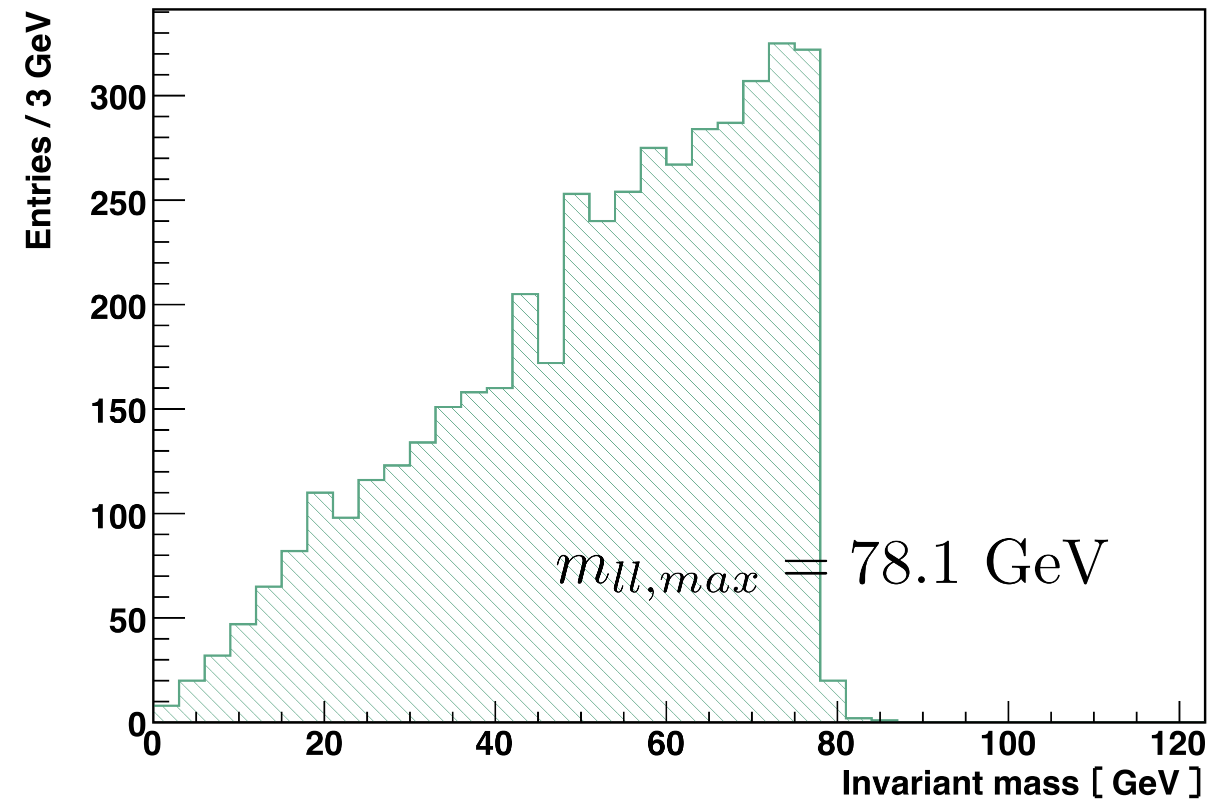
$$\tilde{g} \rightarrow q\bar{q}/g + \tilde{\chi}_2^0 \rightarrow q\bar{q}/g + \tilde{\chi}_1^0 + l^+l^-$$

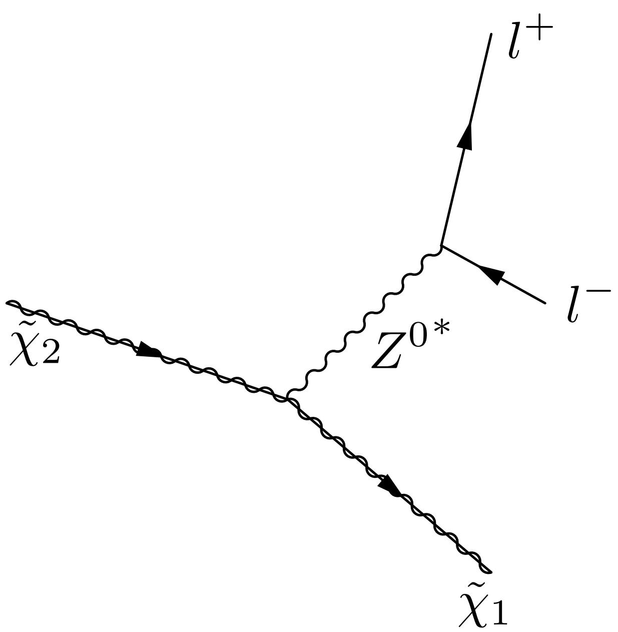
$$BR = 2.3\%$$

Edges in mSUGRA

LM9 Softsusy + Susyhit + Pythia LM1

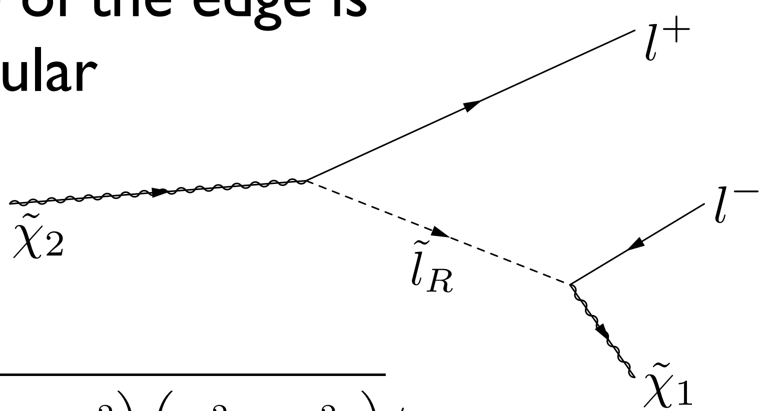






- 3-body decay
- Only numerical calculations for the shape exist (for LM9)
- Endpoint = neutralino mass difference

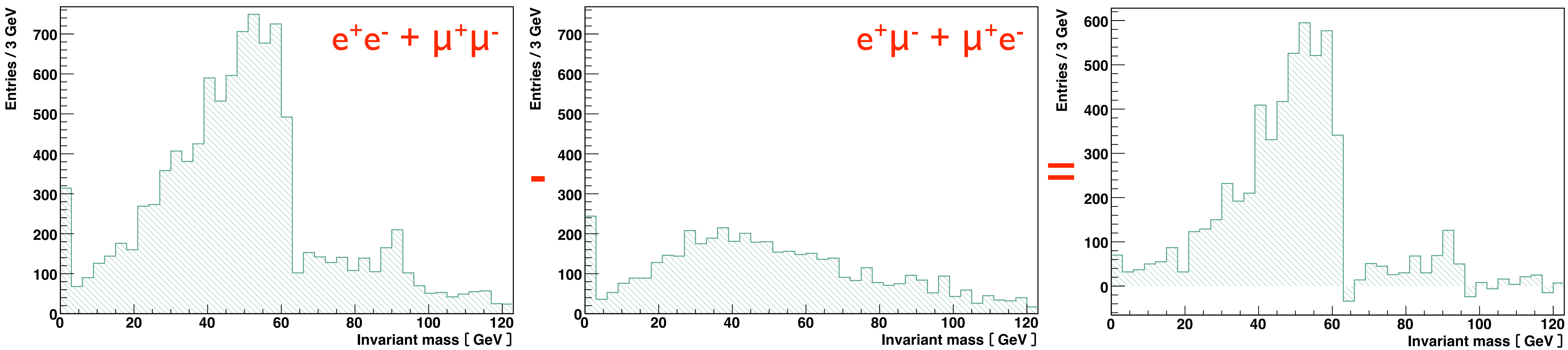
- 2-body decay
- Shape of the edge is triangular



$$m_{ll,max} = \sqrt{\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}}\right)\left(m^2_{\tilde{l}} - m^2_{\tilde{\chi}^0_1}\right)}/m_{\tilde{l}}$$

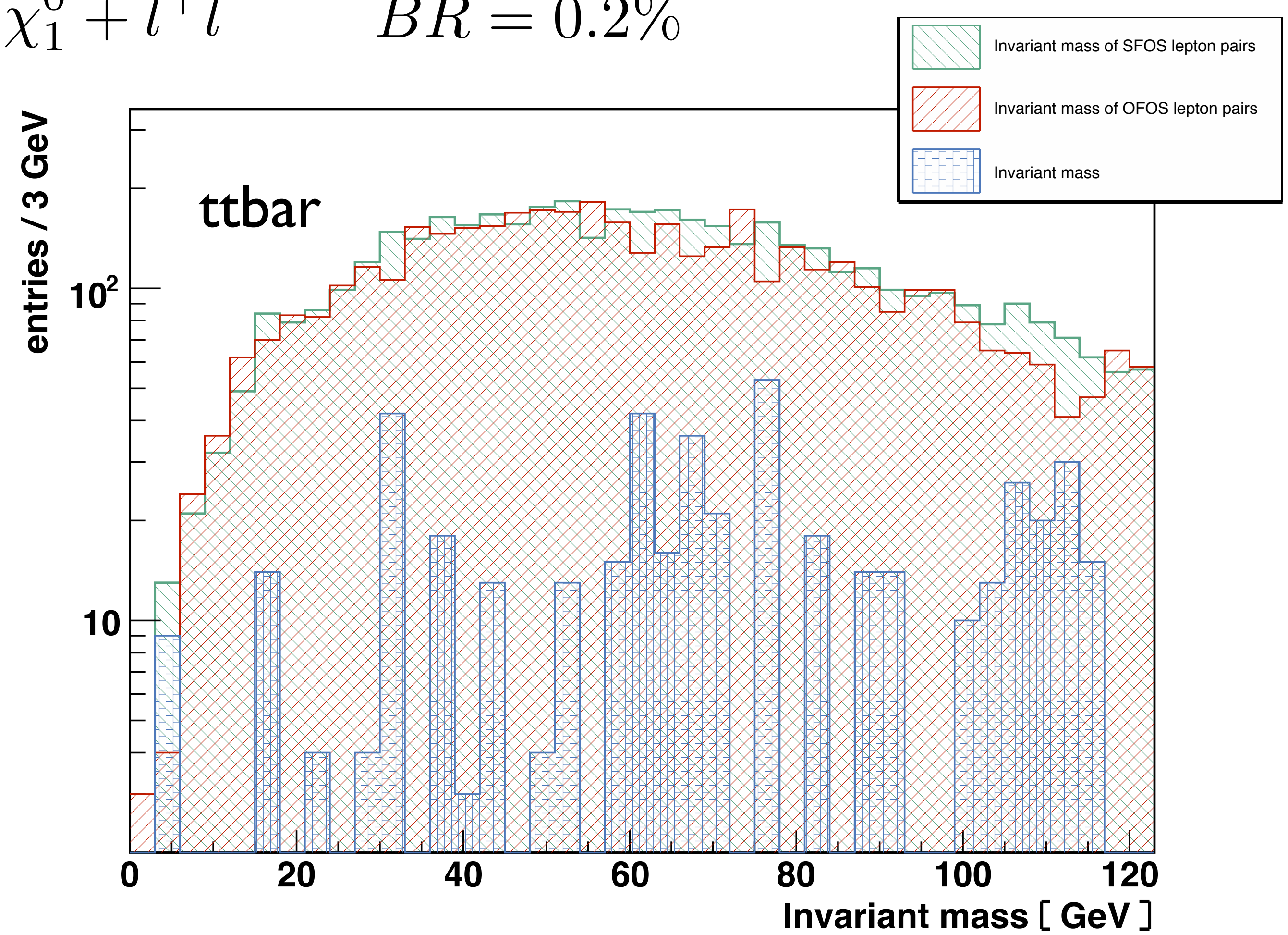
Statistical subtraction

SUSY inclusive (LM9)



$$\tilde{g} \to q\bar{q} + \tilde{\chi}_2^{\pm} \to q\bar{q} + W^{\pm} + \tilde{\chi}_2^0 \to q\bar{q} + l^{\pm}\nu + \tilde{\chi}_1^0 + l^+l^- \qquad BR = 0.2\%$$

- Reduces SUSY and SM background in events where two leptons are produced uncorrelated
- Needs high statistics
- Similar reconstruction efficiency for electrons and muons

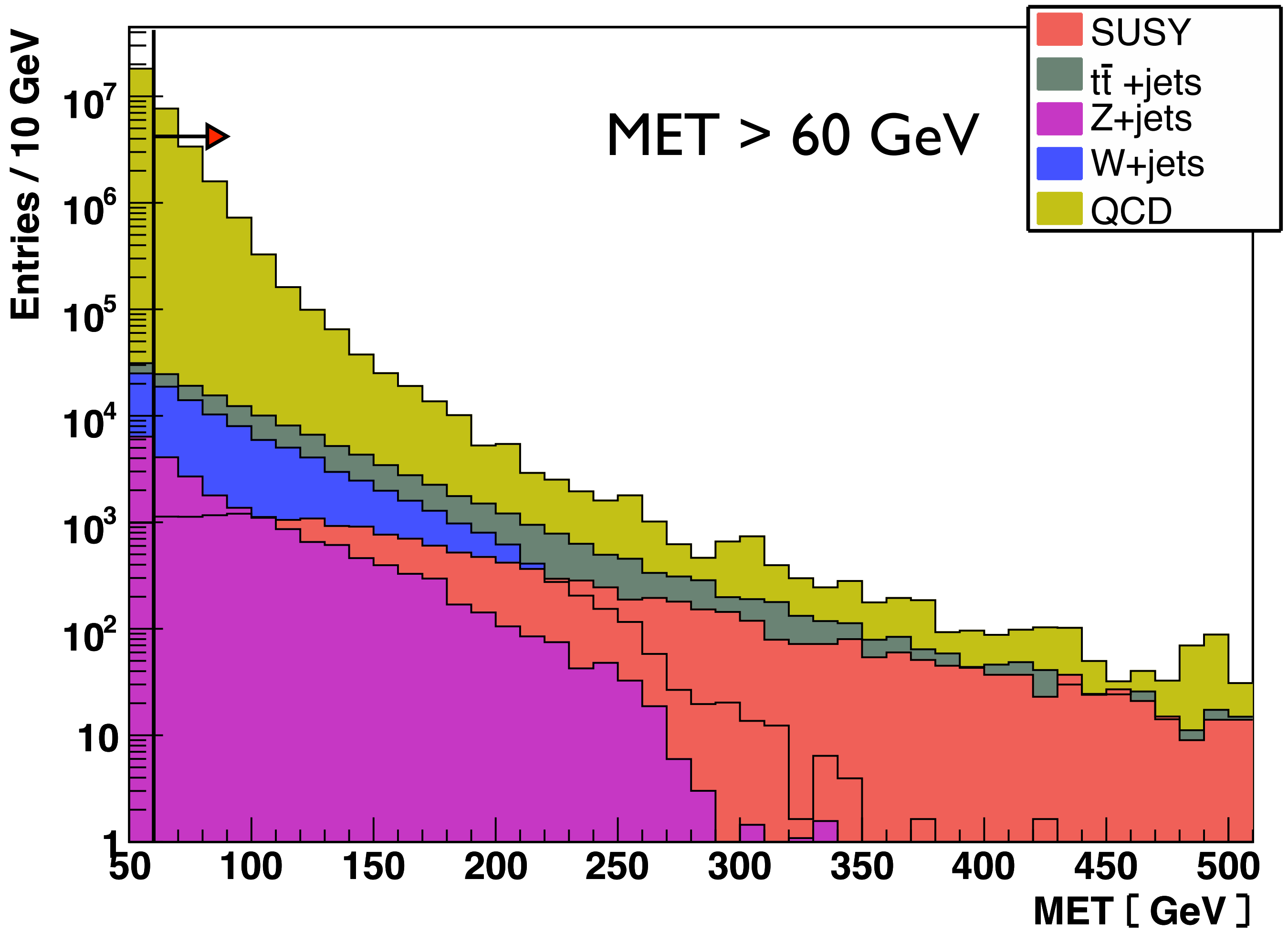


SM backgrounds

σ_{SUSY} = 44 pb

- Top pair + Jets (Alpgen)
  - σ = 830 pb
- Z+Jets (Alpgen)
  - σ = 6 nb
- W+Jets (Alpgen)
  - σ = 57 nb
- QCD (Pythia)
  - σ = 819 μb

Full CMS detector simulation

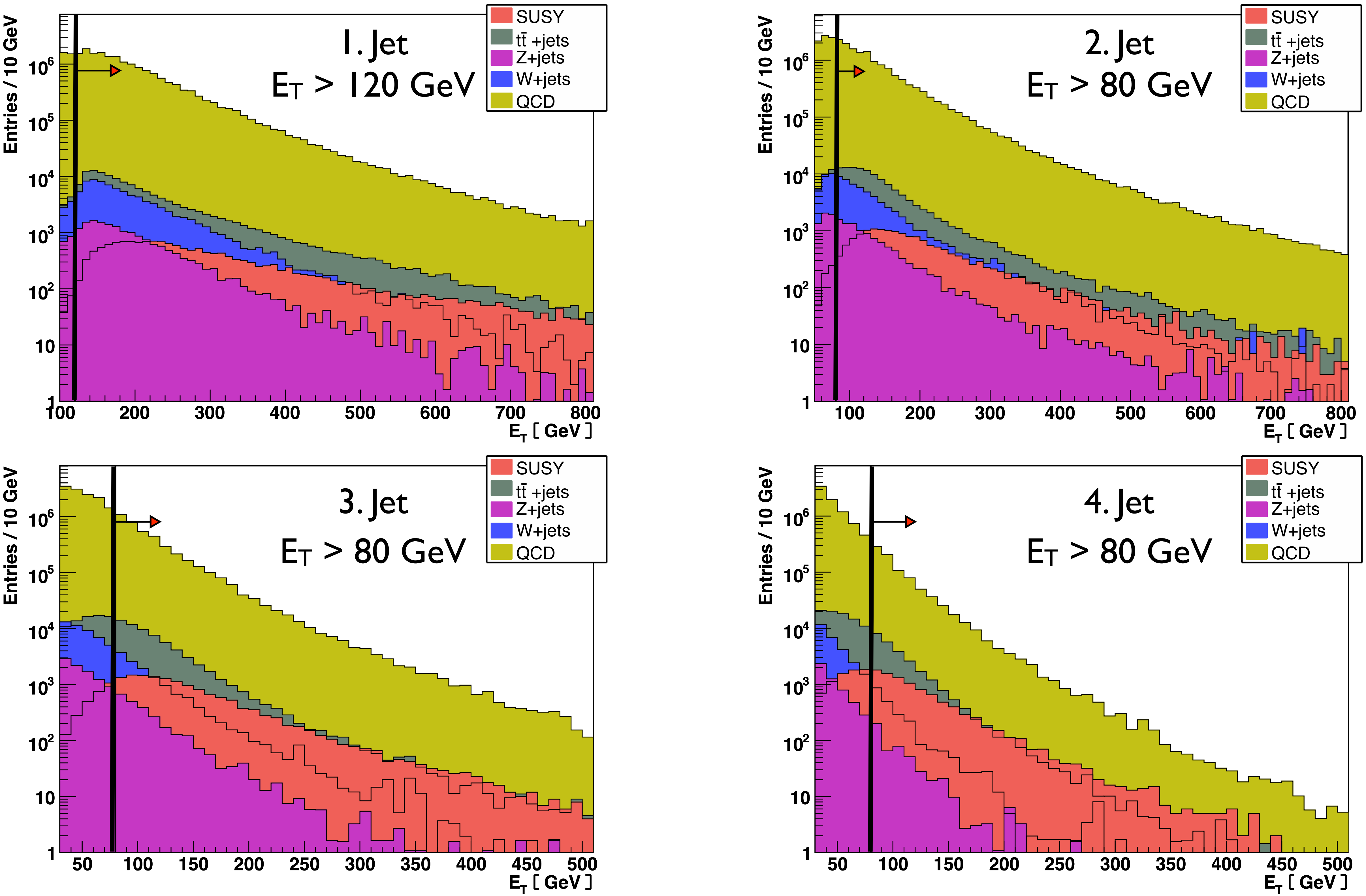


Preselection

- 2 leptons (p_T > 3 (5) GeV)
- 2 jets (80 and 30 GeV E_T)
- MET of 50 GeV

- MET distribution very comparable to the SM
- Only soft cut to preserve a high signal efficiency

Cuts on four leading jets



Selection for 1 fb^{-1}

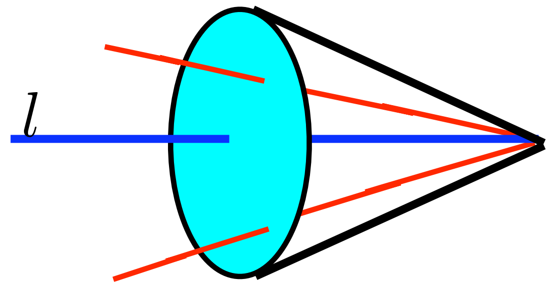
	σ [pb]	Dilepton skim	MET cut	4 jets	2 isolated leptons
LM9t175_sftsdkpyt	25,86	11392	10794	6131	330
LM9_sftsdkpyt	29,49	13189	12449	6927	447
LM1_sftsdkpyt	43,48	18755	18447	4708	379
$t\bar{t}$+jets (NLO)	836	93718	74969	12074	306
Z+jets ($0<p_T<300$)	5777	13210	9351	235	57
W+jets ($0<p_T<300$)	58155	63419	48294	1085	1
QCD	-	$1{,}9 \cdot 10^7$	$8{,}7 \cdot 10^6$	390895	2

Lepton isolation

- Reduction of the QCD background
- Energy in a cone around the lepton is required to be smaller than 30%

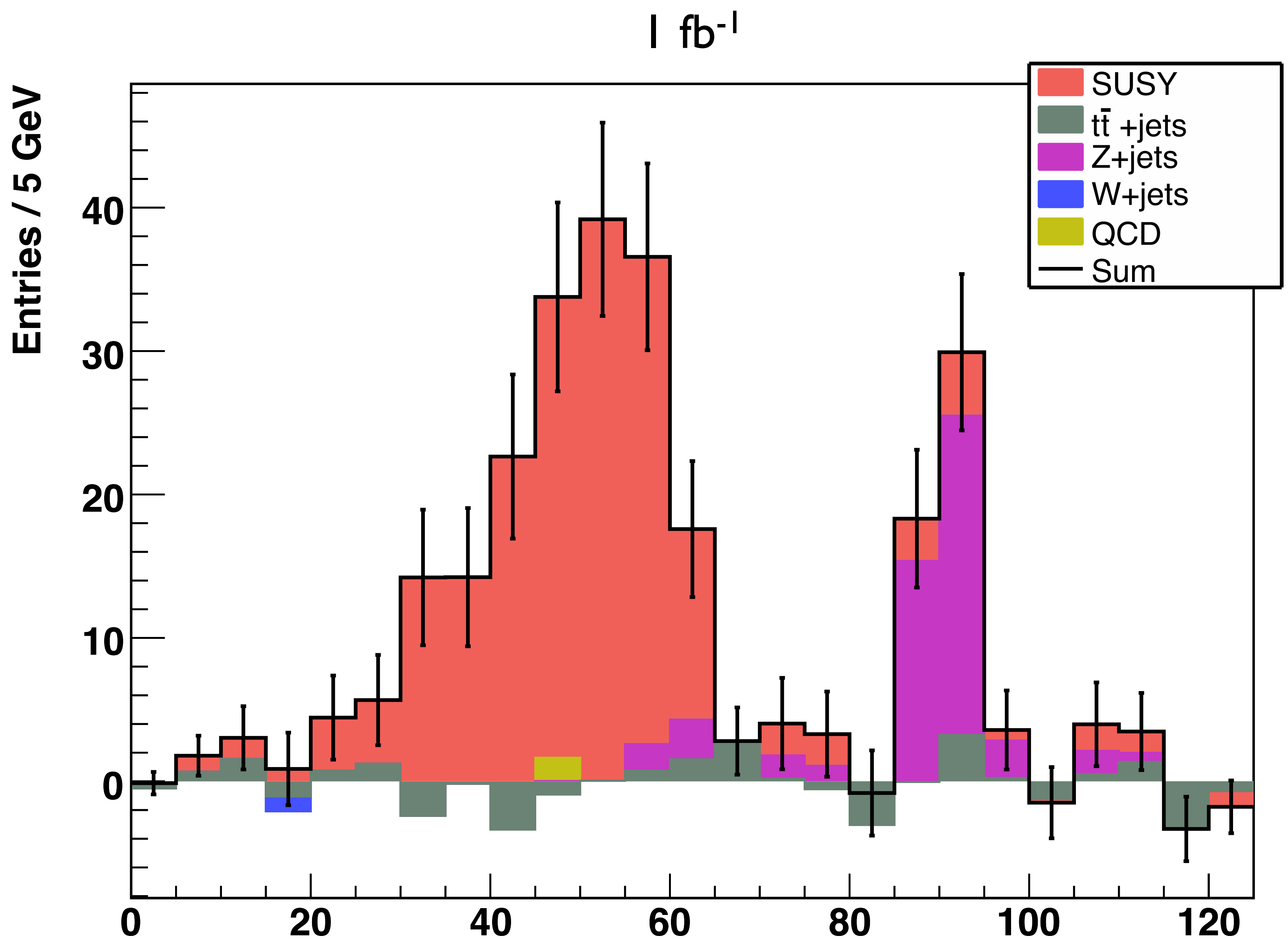
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

$$\frac{E_{cone} - E_{lept}}{E_{lept}} < 0.3$$



$\Delta R_{cone} < 0.2$

Invariant mass distribution



$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^+ l^-$

- 100% trigger efficiency
- Endpoint is clearly visible
- High significance of the signal
- Negative entries due to statistical subtraction

Entries 0-80 GeV	all cuts
SUSY	192
tt+jets	-2,4
Z+jets	13,6
W+jets	-1,0
QCD	1,6

Aim: Determination of the endpoint

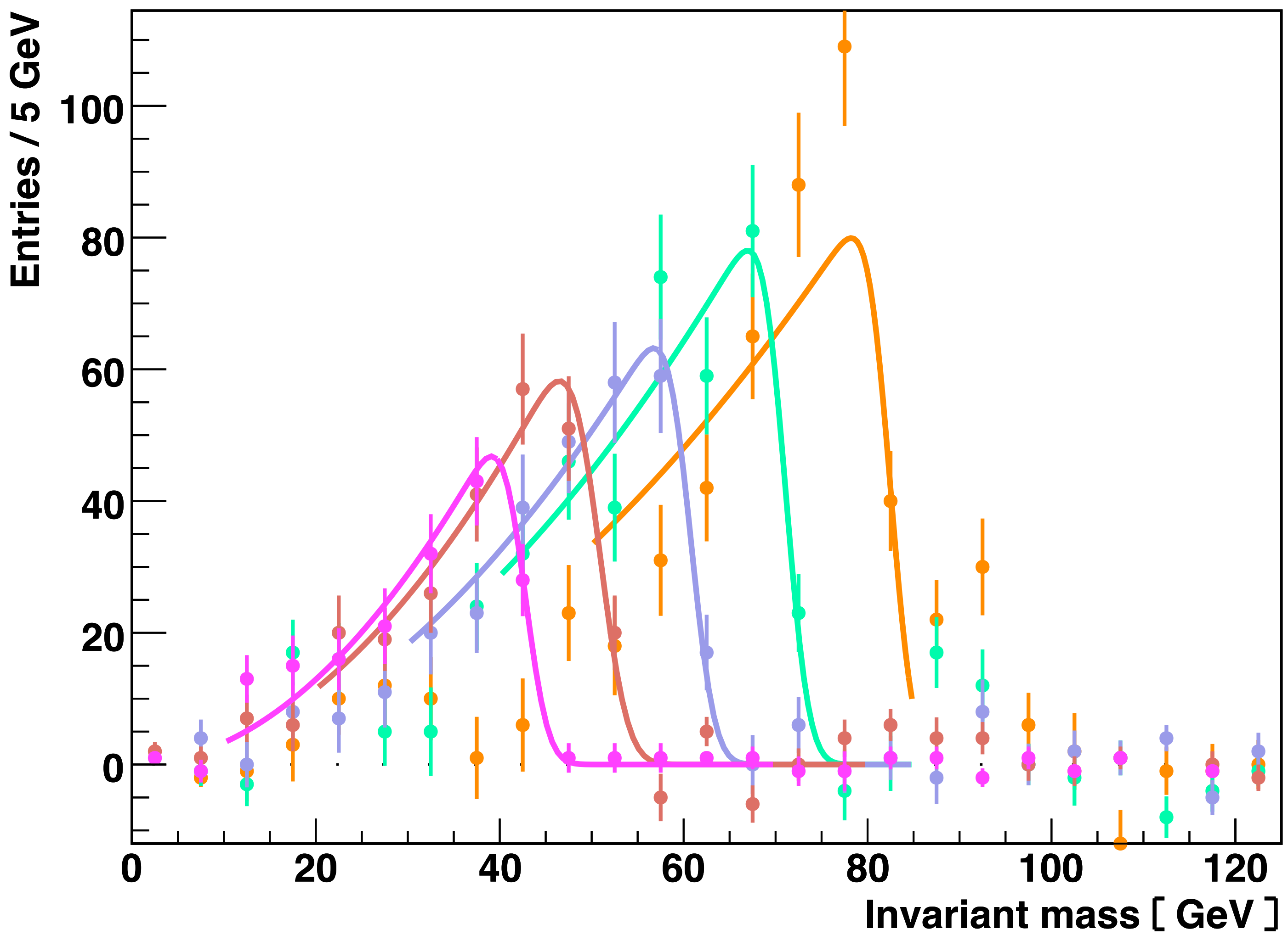
$S_{CL} = 26$

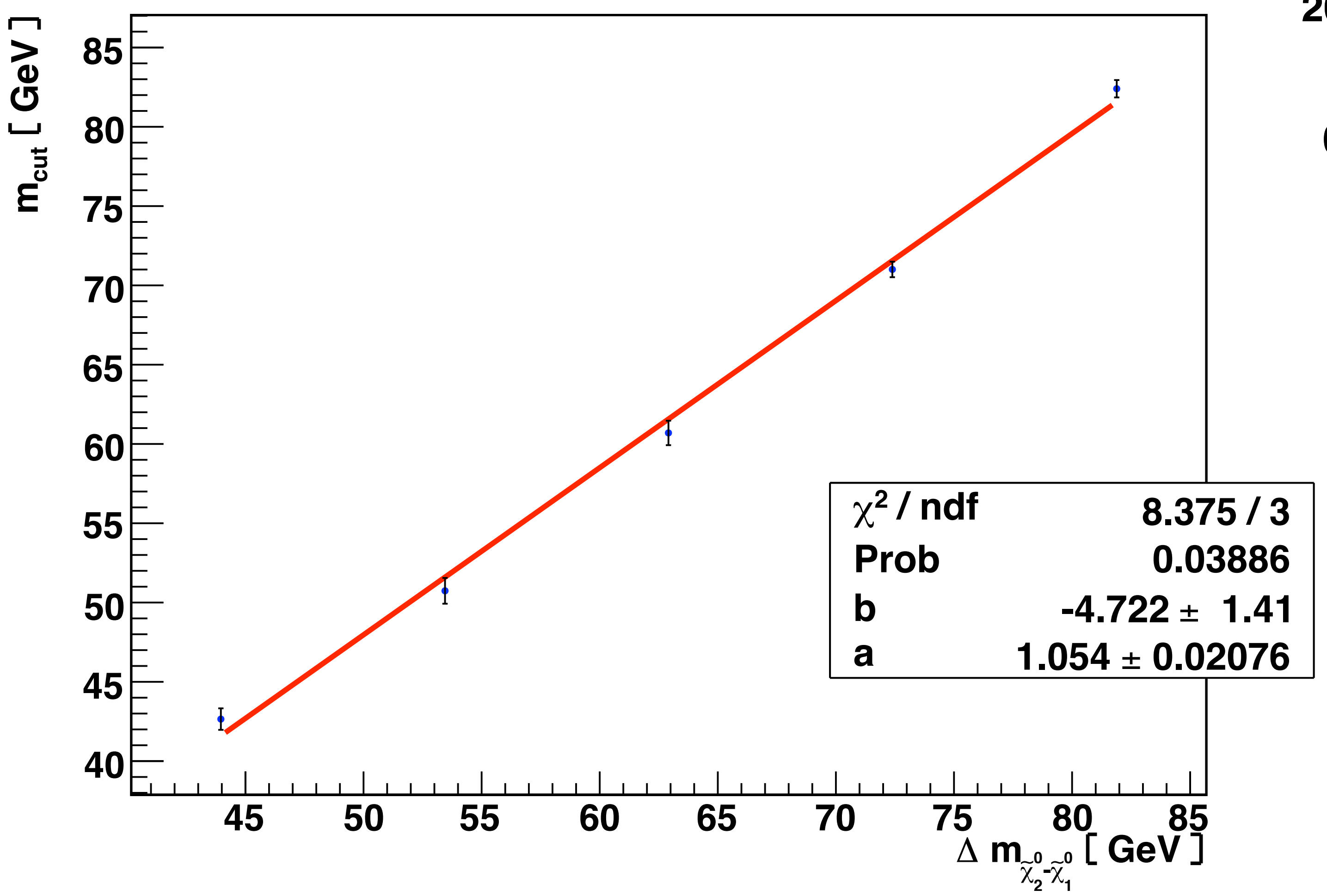
$$S_{CL} = \sqrt{2\left[(s+b)\ln\left(1+\frac{s}{b}\right)-s\right]}$$

Calibration of the estimator

$$f(x) = \frac{a}{\sqrt{2\pi}\sigma} \int_0^{m_{cut}} dy \cdot y^2 e^{\frac{-(x-y)^2}{2\sigma^2}}$$

- 3 parameters
  - a, σ and m_{cut}
- m_{cut} is the estimator for the mass difference





- 5 MC datasets from CMS fast simulation
- Varied $m_{1/2}$ to obtain five mass differences
- Allows a calibration of m_{cut}

Systematic error

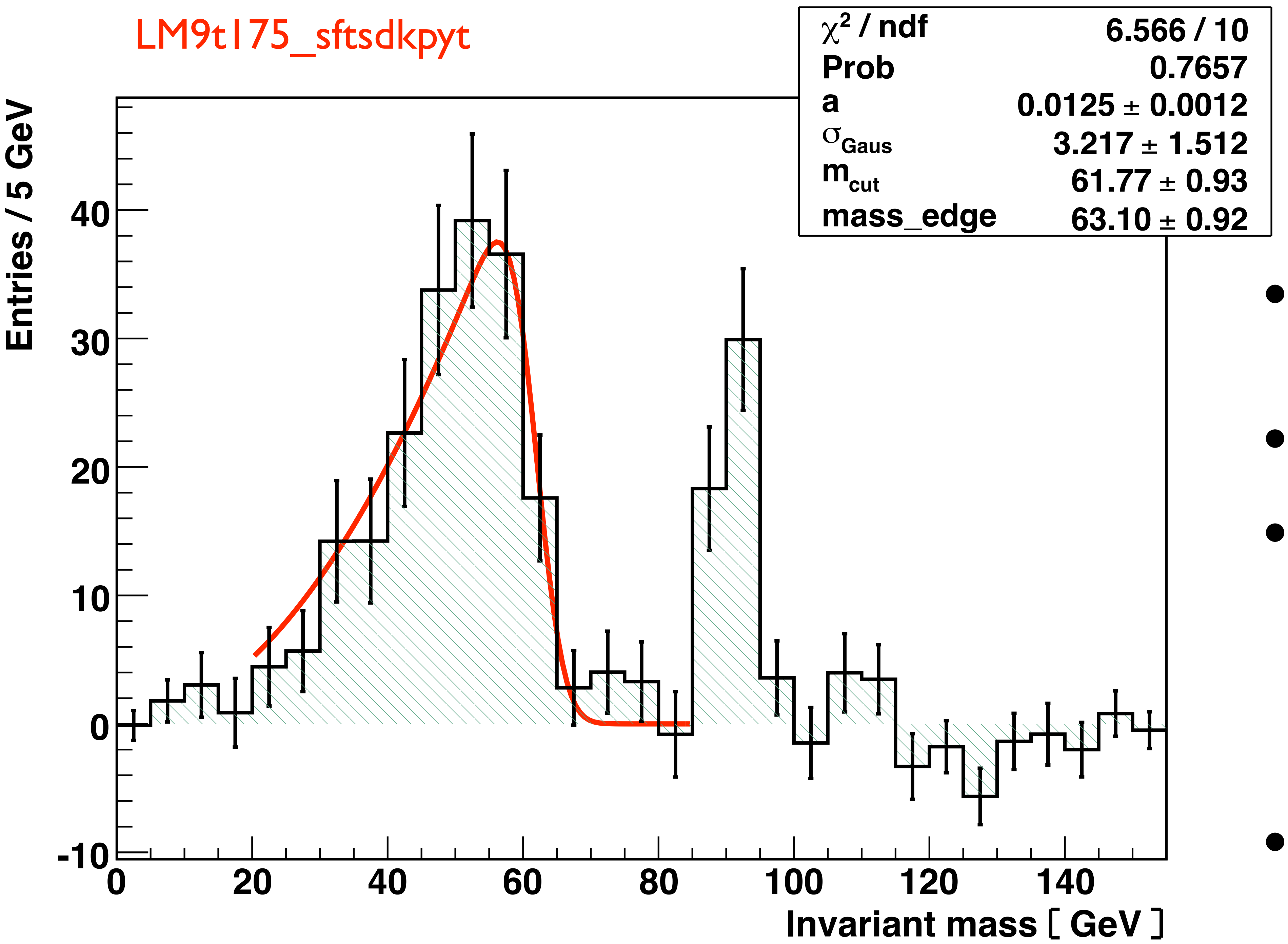
- All systematic uncertainties are evaluated for m_{cut}
- All cuts have been varied
  - Only significant variations are considered
  - A variation of the binning and the fit range

$$\frac{m_{final} - m_{var}}{\sqrt{\left|\sigma^2_{final} - \sigma^2_{var}\right|}} > 1$$

- Uncertainty on SM background is estimated by 20%
  - PDF, Parton Shower, Underlying Event, Pile-up, Fragmentation etc.
- Uncertainty in lepton energy scale of 2% is considered
- Uncertainty in jet energy scale of 10% is considered
- Misalignment Tracker and Muon system
  - CMS 10 pb^{-1} scenario
  - Alignment of the detector after 10 pb^{-1} of data
  - Conservative estimation of the misalignment

$m_{cut,syst}$	Δm_- [GeV]	Δm_+ [GeV]
Var. of all cuts	-1,4	+0,7
SM background	-	-
Lepton energy scale	-	-
Jet energy scale	-	-
Misalignment	-1,5	+1,5

Expected results for 1 fb^{-1}

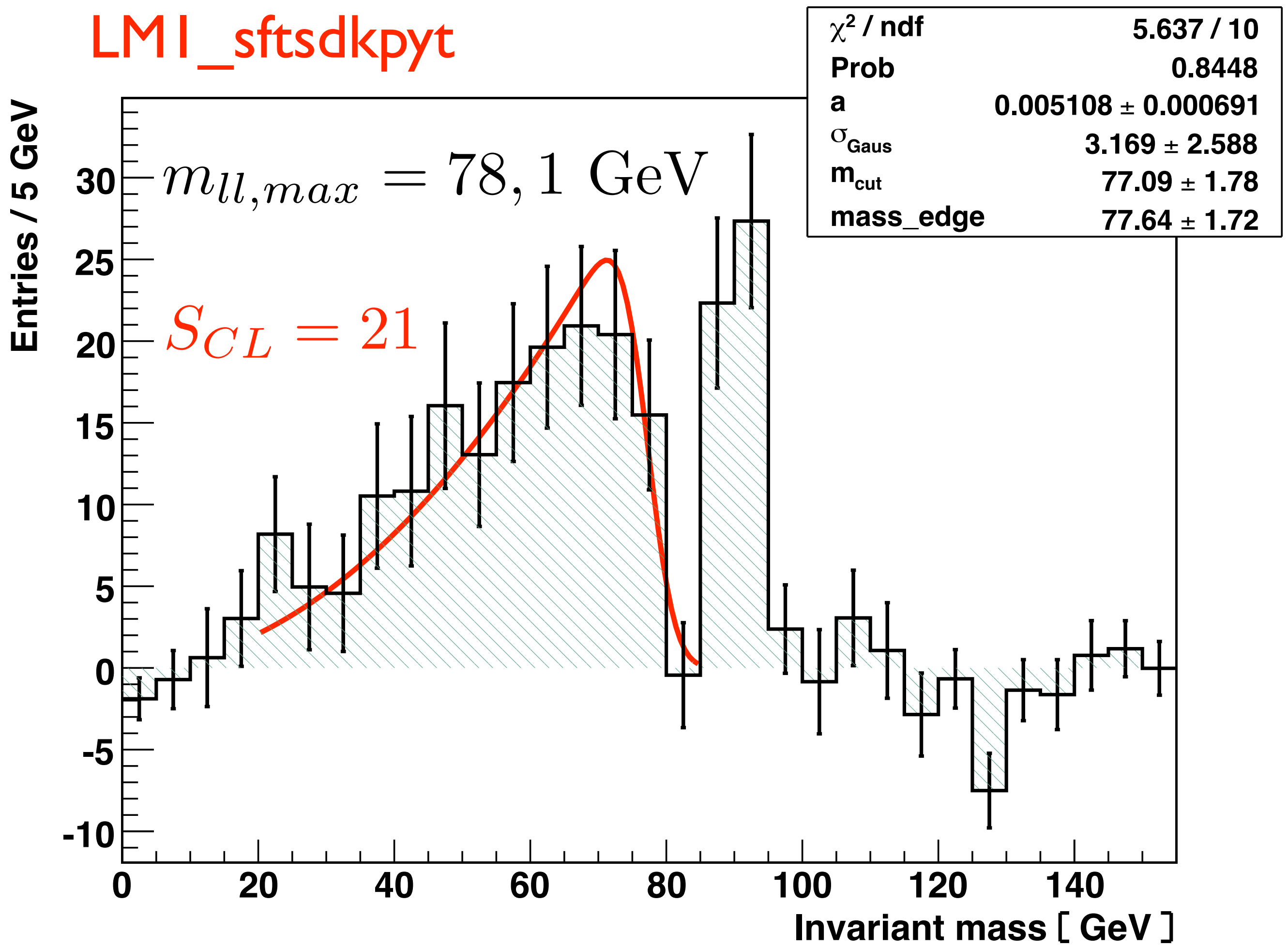


$$\Delta m_{\tilde{\chi}_2^0 - \tilde{\chi}_1^0} = \left(63.1 \pm 0.9_{stat.} {}^{+1.6}_{-2.0}{}_{\,syst.}\right) \text{ GeV}$$

$$\Delta m_{theo} = 62.91 \text{ GeV}$$

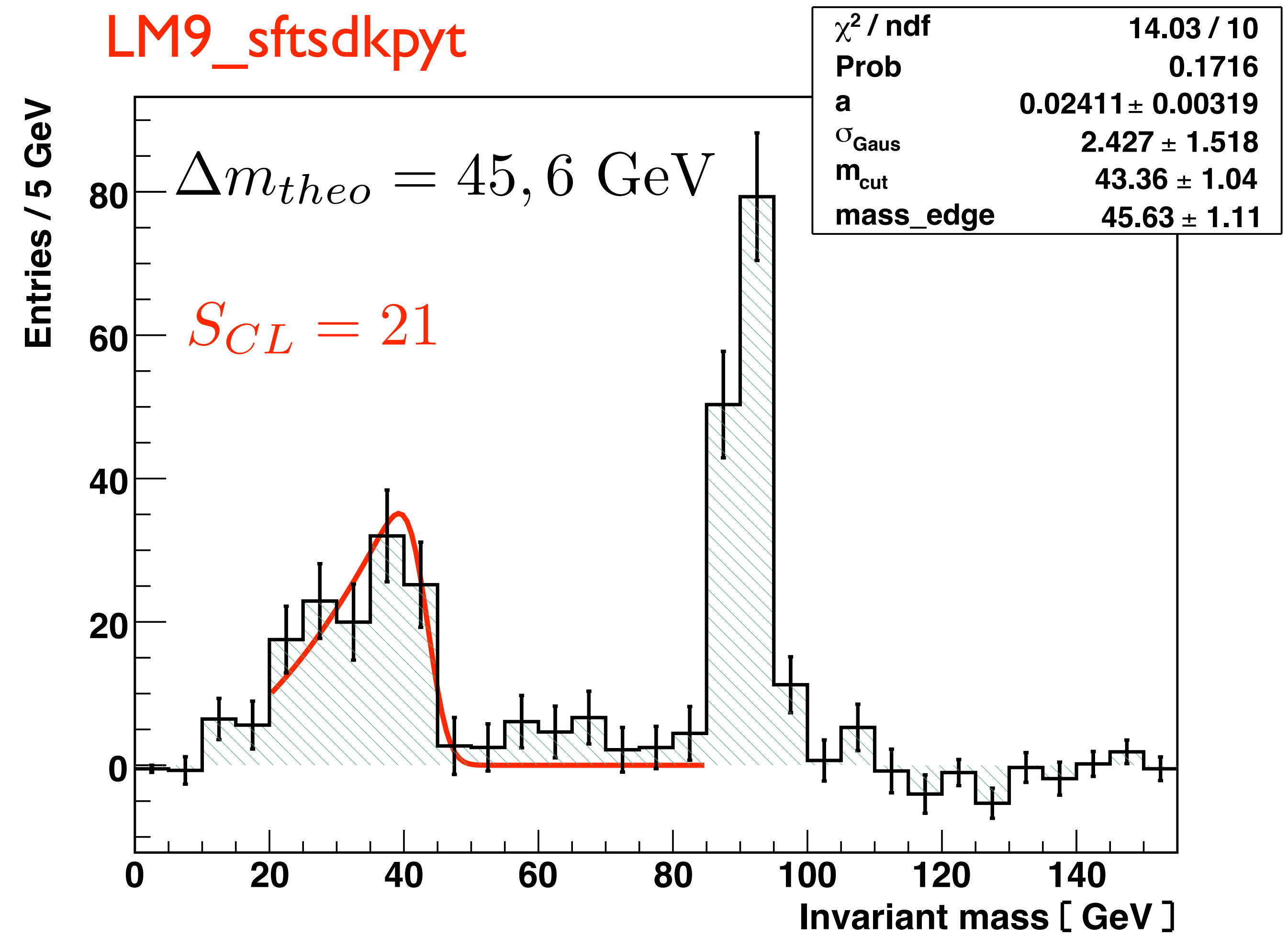
- Cuts optimised for this point
- Statistical error of 1,5%
- Systematical error of 3%
  - Significant contribution due to misalignment of the detector
- Theoretical mass difference is reproduced within the error

Different benchmark points (1fb^{-1})



$$m_{ll,exp} = \left(77.6 \pm 1.7_{stat.}\ {}^{+1.5}_{-2.2}\ {}_{syst.}\right)\ \text{GeV}$$

- Not optimised for LM1
  - Larger error
- "wrong" theoretical model
- Theoretical value is reproduced within the error



$$\Delta m_{\tilde{\chi}^0_2 - \tilde{\chi}^0_1} = \left(45.6 \pm 1.1_{stat.}\ {}^{+1.6}_{-2.5}\ {}_{syst.}\right)\ \text{GeV}$$

- Larger SUSY Z-Peak
- Different mass difference due to change in top mass
- Mass difference is reproduced within the error

Conclusion

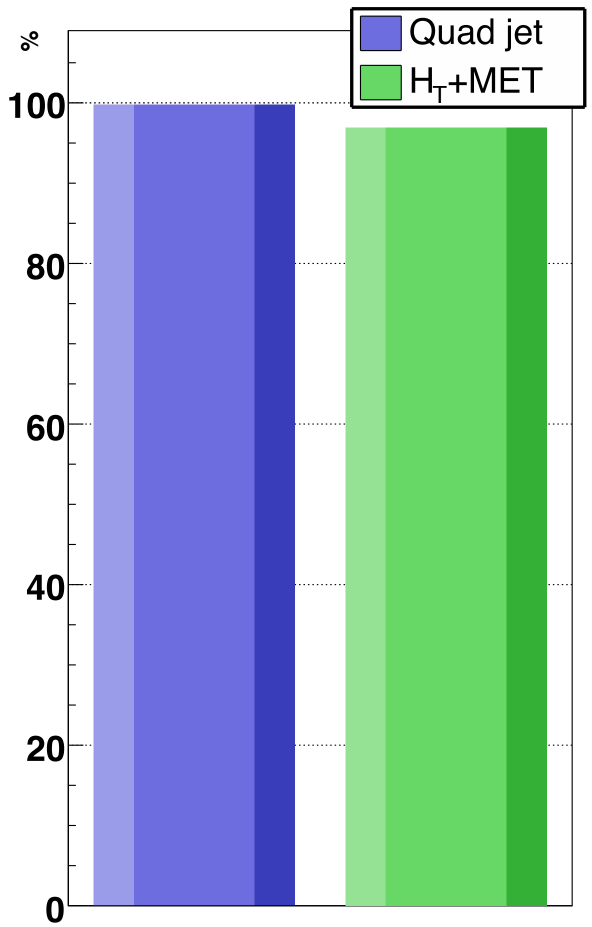
- SUSY signal is visible at LM9 and LM1 with an integrated luminosity of 1 fb^{-1}
  - including misalignment (10 pb^{-1} scenario) (for LM9)
  - 100% trigger efficiency on the final event selection (LM9)
- High significance of the signal
- Statistical error of 1,5% (LM9)
- Systematical error of 3% (LM9)
- If SUSY is realised in such a scenario: a measurement with a precision of 5% seems possible with 1 fb^{-1}

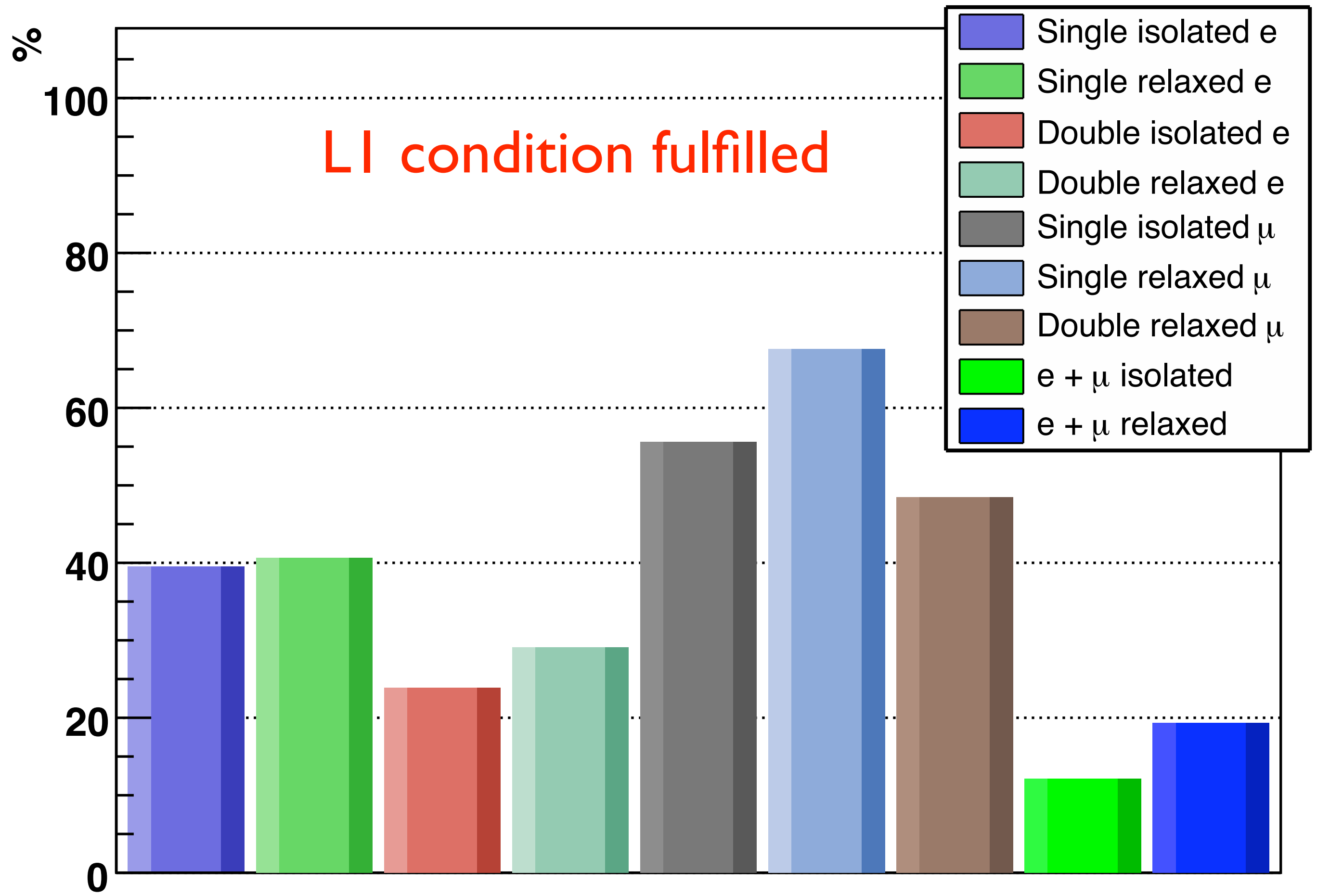
Outlook

- Determine lepton reconstruction efficiency from data
- Develop methods of background estimation from data
  - e.g. fit eμ background and look for excess in ee and μμ distribution

BACKUP

Trigger efficiency at LM9





Leptonic triggers 97,9%

- Single isolated e (15 GeV)
- Single relaxed e (17 GeV)
- Double isolated e (10 GeV)
- Double relaxed e (12 GeV)
- Single isolated μ (11 GeV)
- Single relaxed μ (16 GeV)
- Double relaxed μ (3,3 GeV)
- e + μ isolated (8,7 GeV)
- e + μ relaxed (10,10 GeV)

Hadronic triggers 100%

- Quad-Jet (60 GeV)
- H_T + MET (350,65 GeV)

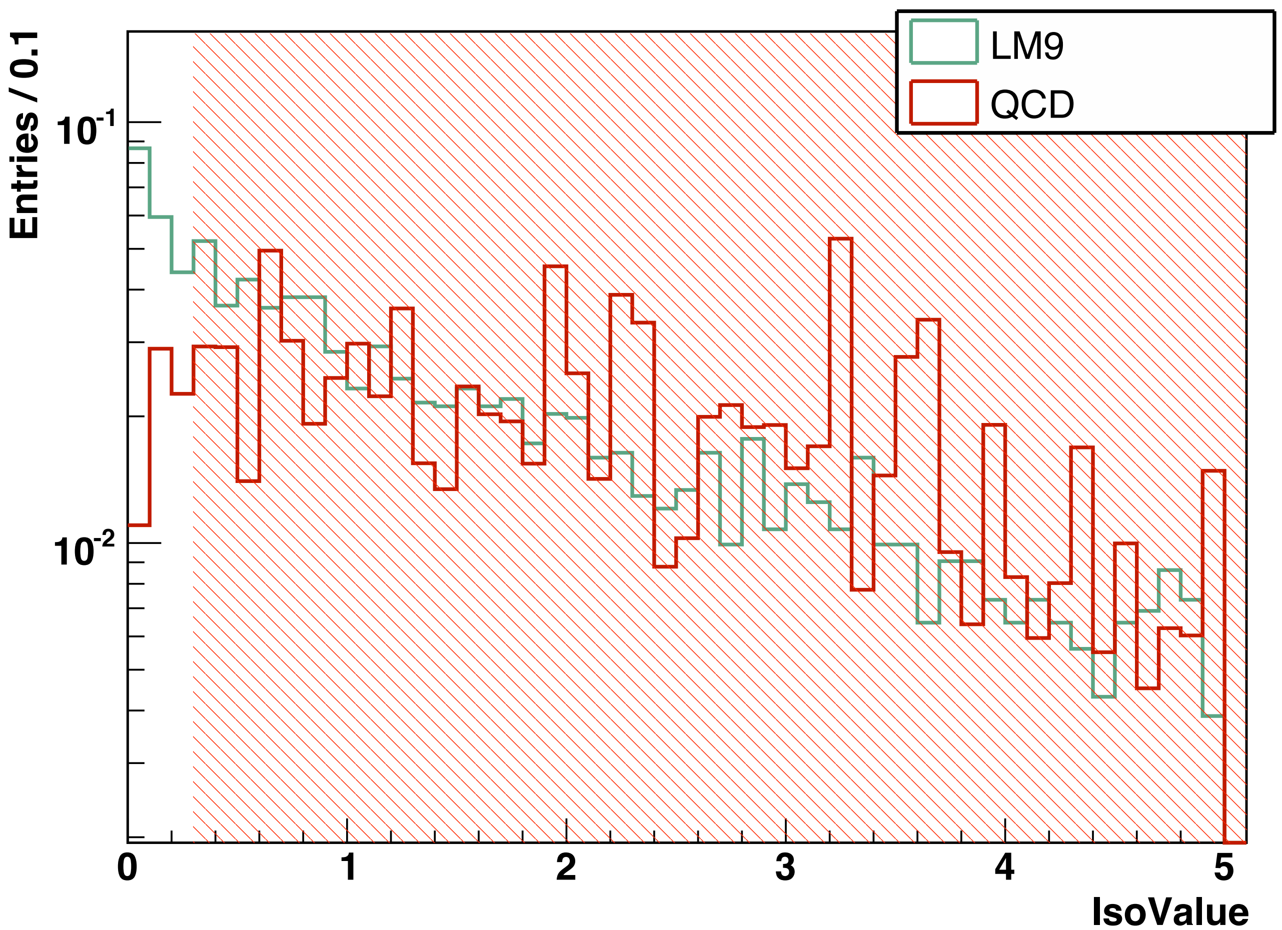
- Full trigger efficiency using two small sets of triggers
- No correction needs to be taken into account

Lepton selection and isolation

- $p_T > 10$ GeV
- $|\eta| < 2$

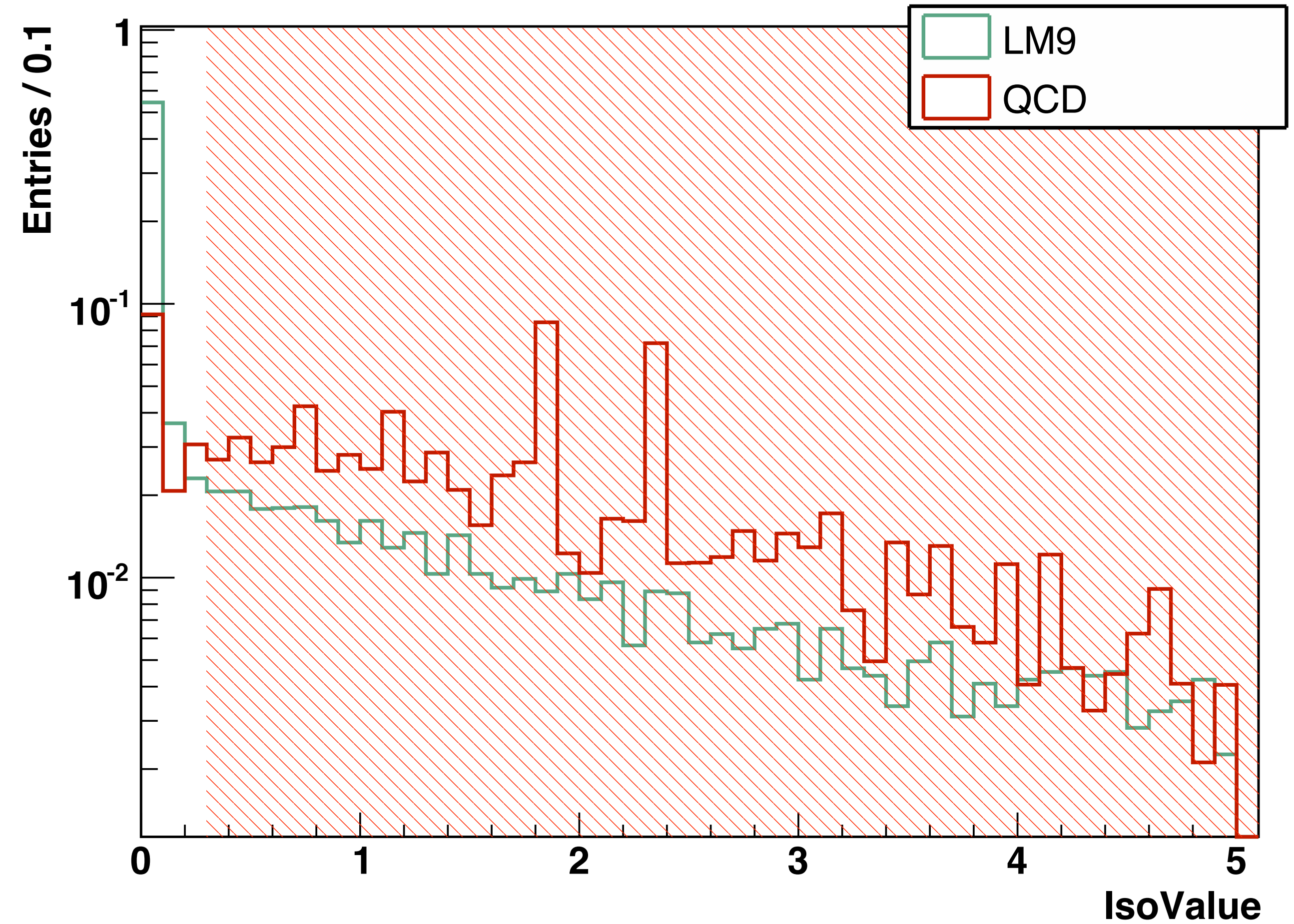
Electrons

- Energy and momentum
- ECAL and HCAL energy



Muons

- Quality of the muon track fit



Lepton isolation

- Reduction of the QCD background
- Energy in a cone around the lepton is required to be smaller than 30%

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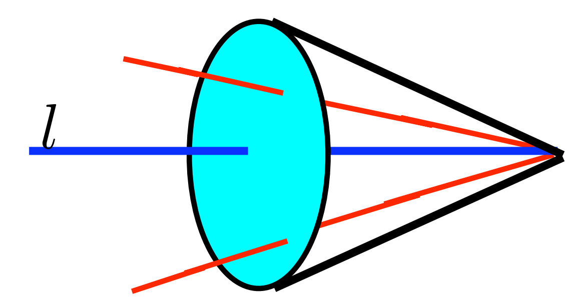
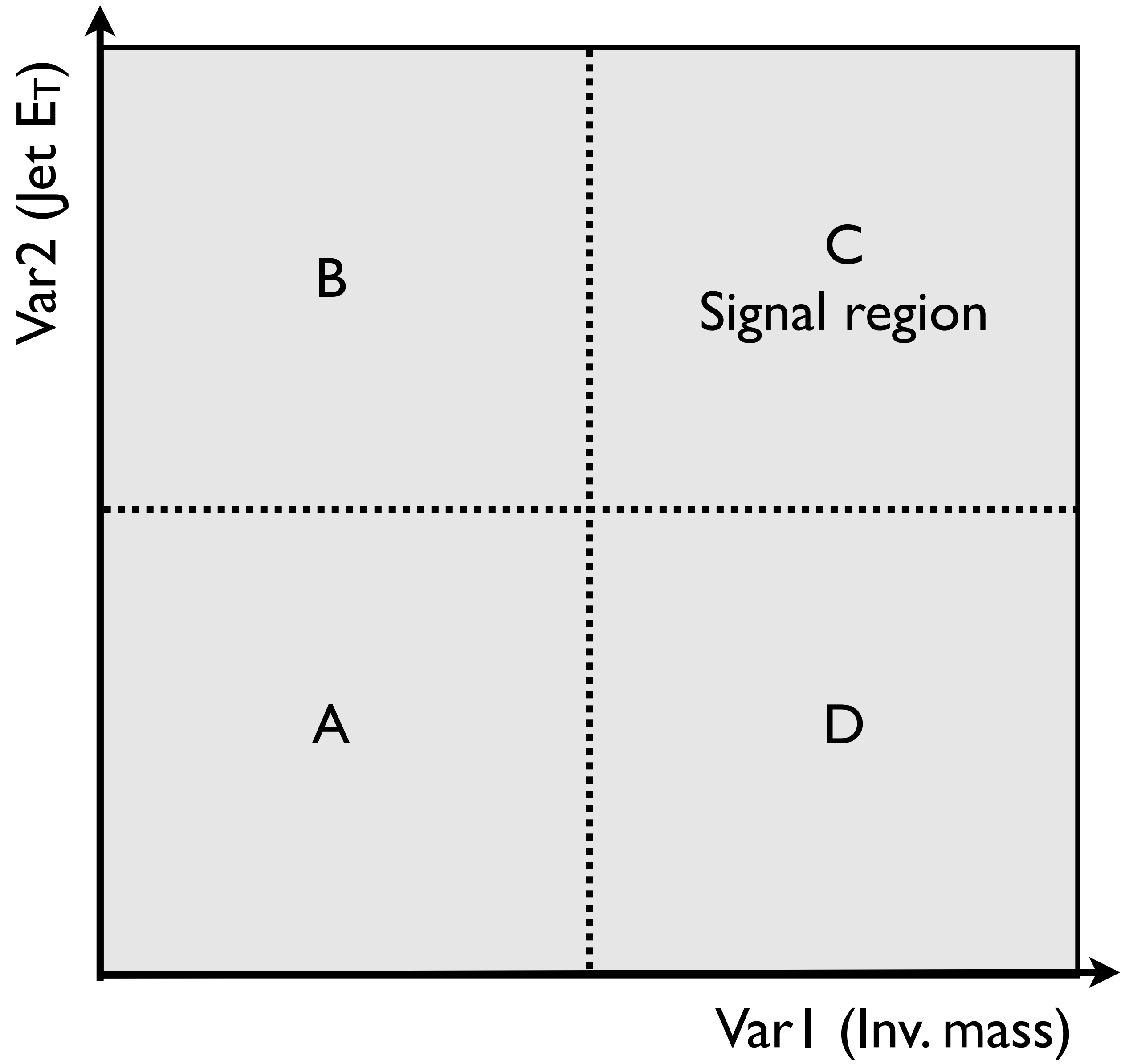
$$\frac{E_{cone} - E_{lept}}{E_{lept}} < 0.3$$



$\Delta R_{cone} < 0.2$

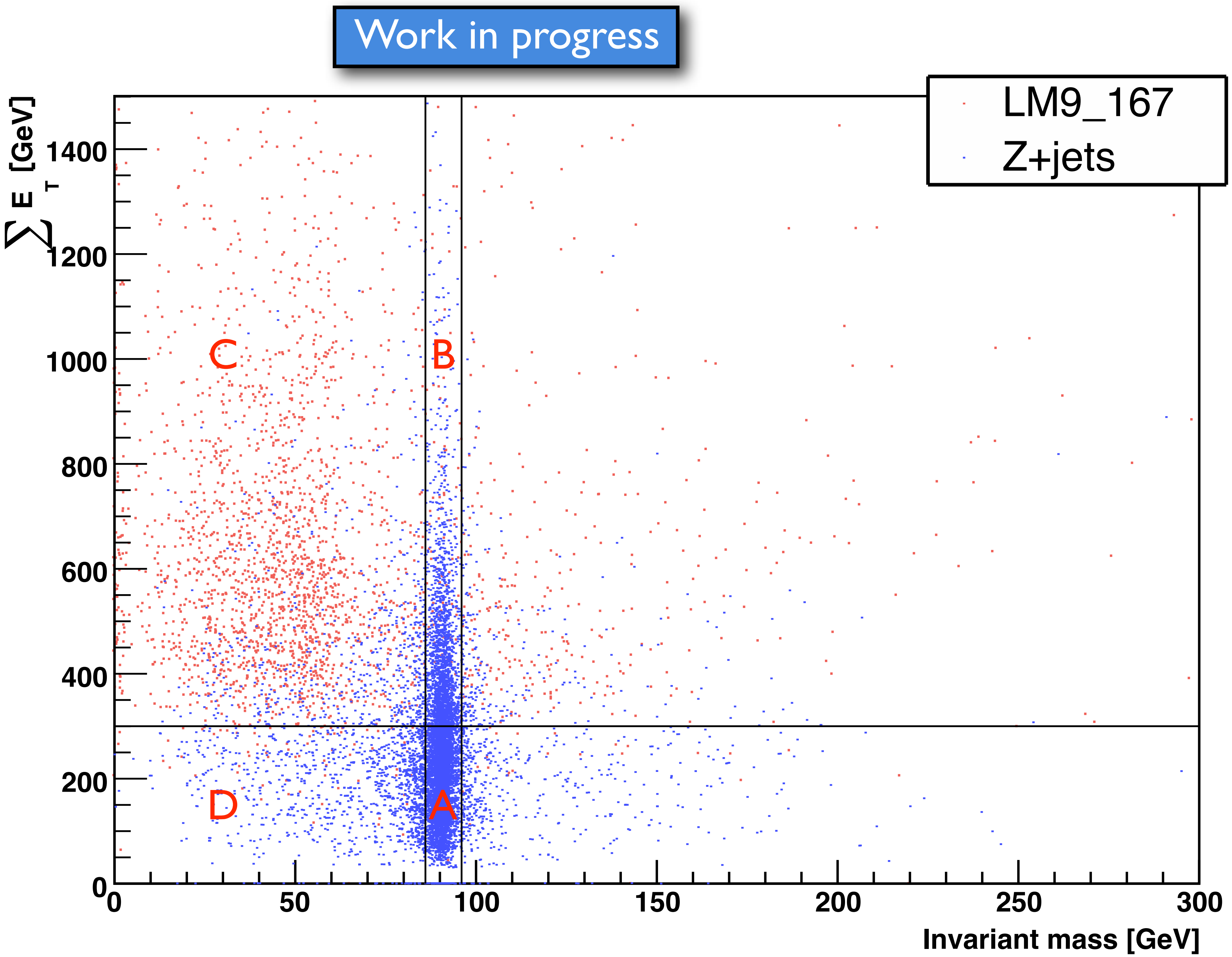
Background estimation from data



- If Var1 and Var2 are uncorrelated
- and have separation power
  - Background can be extrapolated from D to C

$$N_C = N_D \cdot \frac{N_B}{N_A}$$

- Dilepton analysis
  - Var1: Invariant mass
- Uncorrelated
  - Transverse jet energy
  - MET (not enough separation power at LM9)
- Possible for tt+jets, Z+jets, W+jets
- QCD background isolation of leptons could be used
  - Probably not uncorrelated?

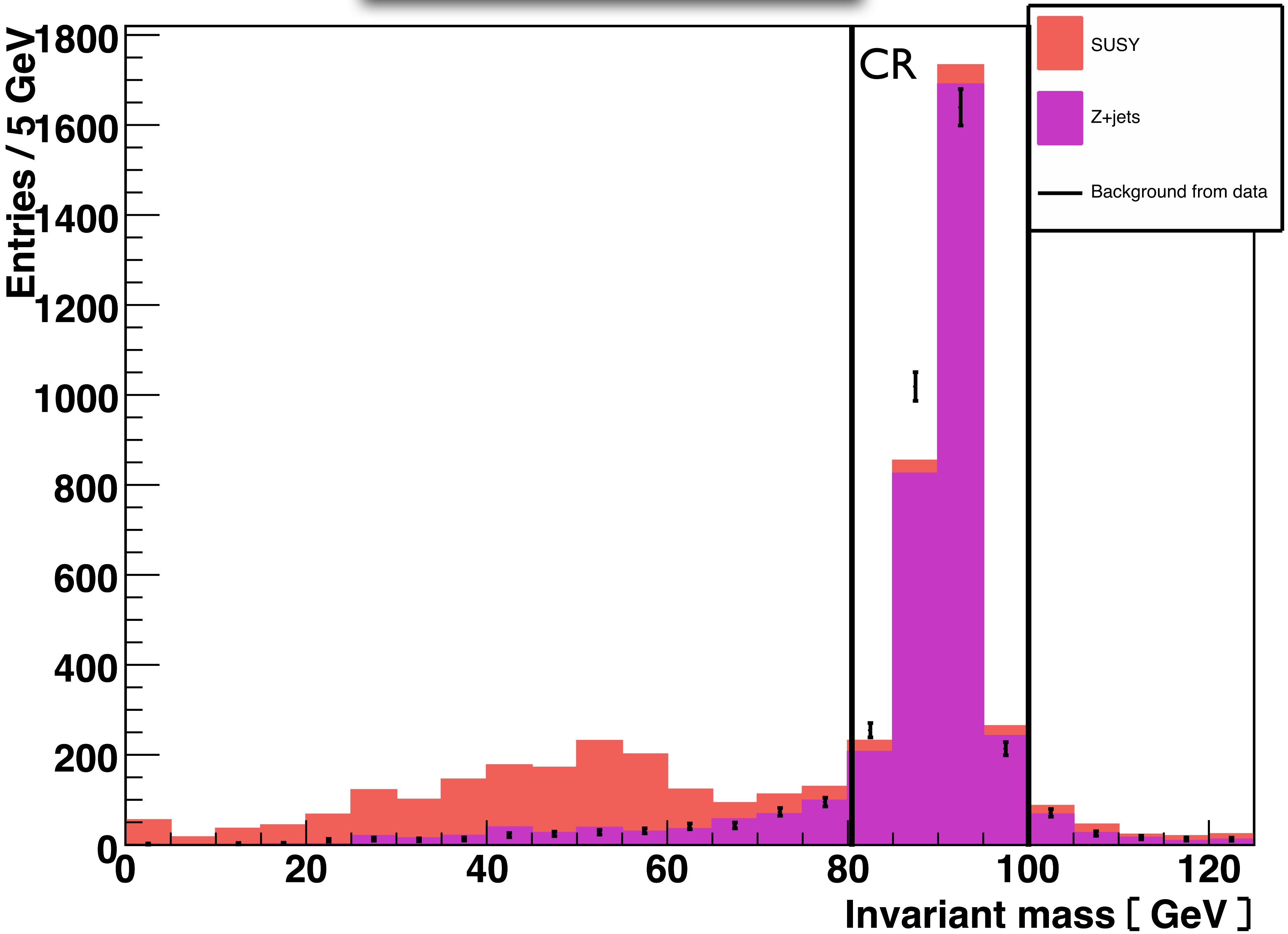


Corr = -0,028

Corr = -0,027

- Sum of E_T of four hardest jets is used
- Background is separated from signal in both variables
- Problem: do not know where the signal appears
- Could decay as well mostly via real Z boson

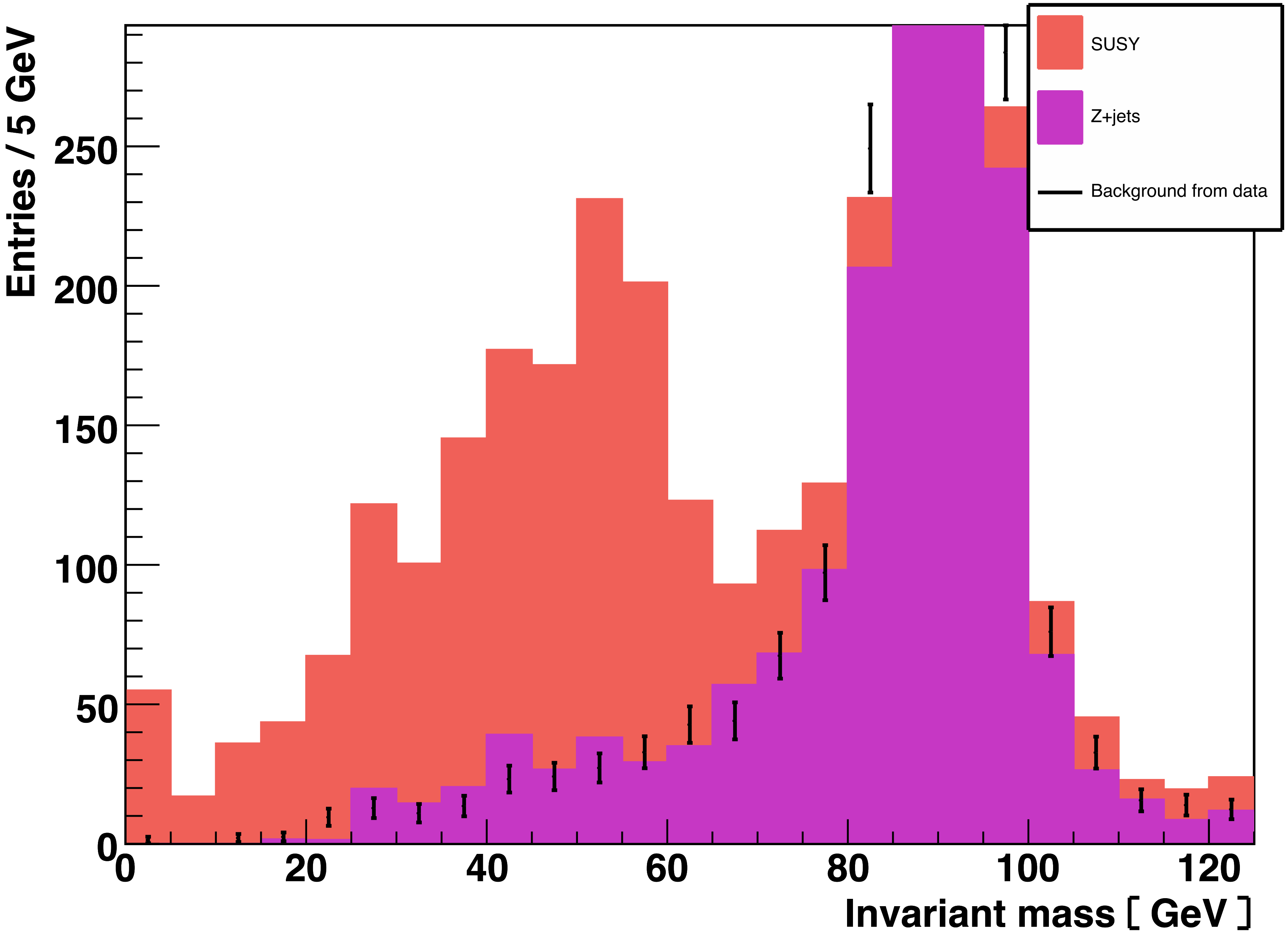
No statistical subtraction



- Both signal and background used in the control dataset
- Almost no signal contamination in the control dataset
- Estimation of the background in bins of 5 GeV in the signal region

$$N_C = N_D \cdot \frac{N_B}{N_A}$$

Z+Jets



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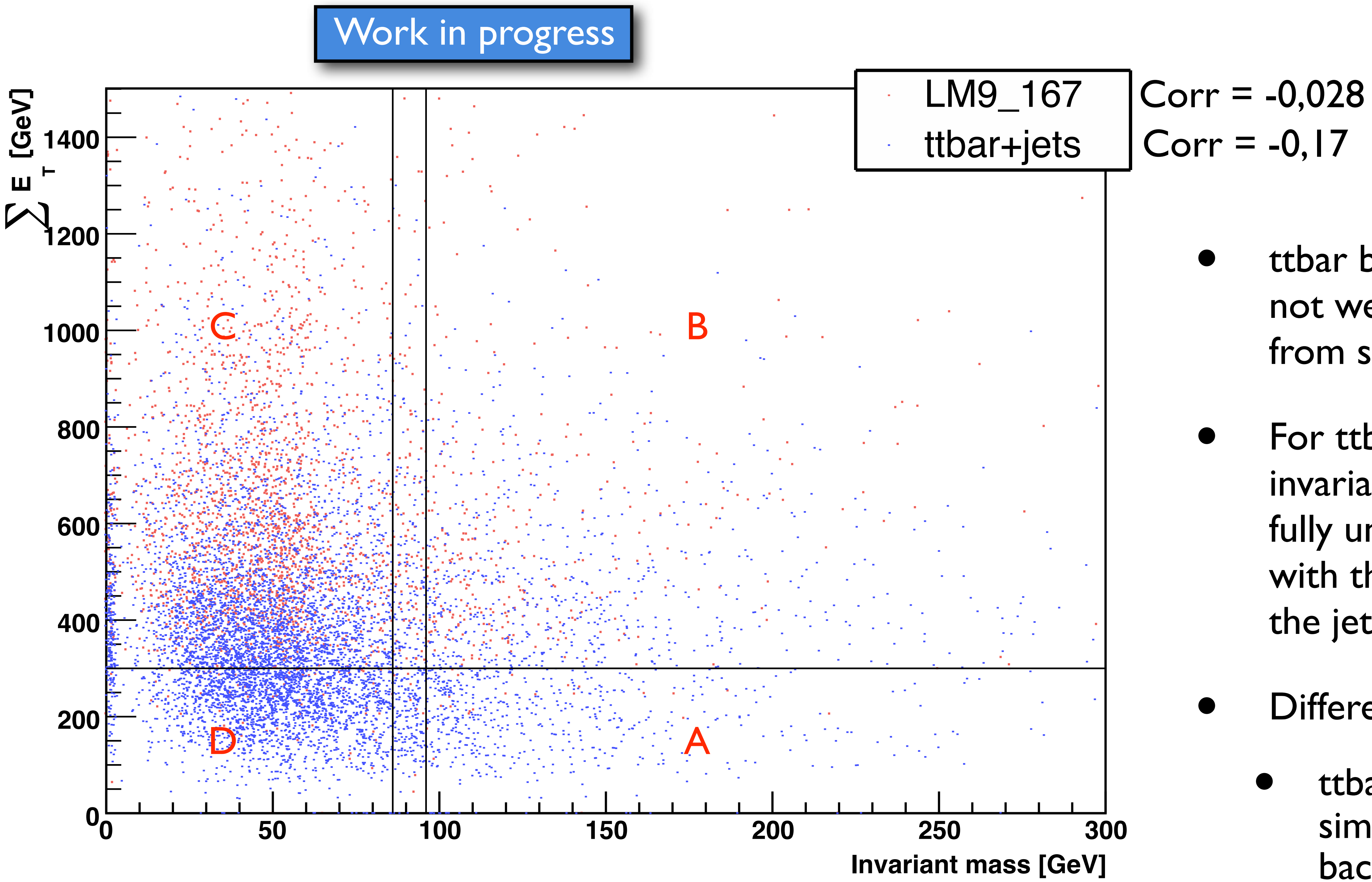
$$N_C = N_D \cdot \frac{N_B}{N_A}$$

ttbar



- ttbar background is not well separated from signal
- For ttbar events the invariant mass is not fully uncorrelated with the E_T sum of the jets
- Different variable?
  - ttbar is very similar to the background