Neutralino Mass Measurement in Dilepton Final States

Niklas Mohr, Katja Klein,
Lutz Feld

Physics at the Terascale -
Kickoff Workshop
Hamburg 04.12.2007

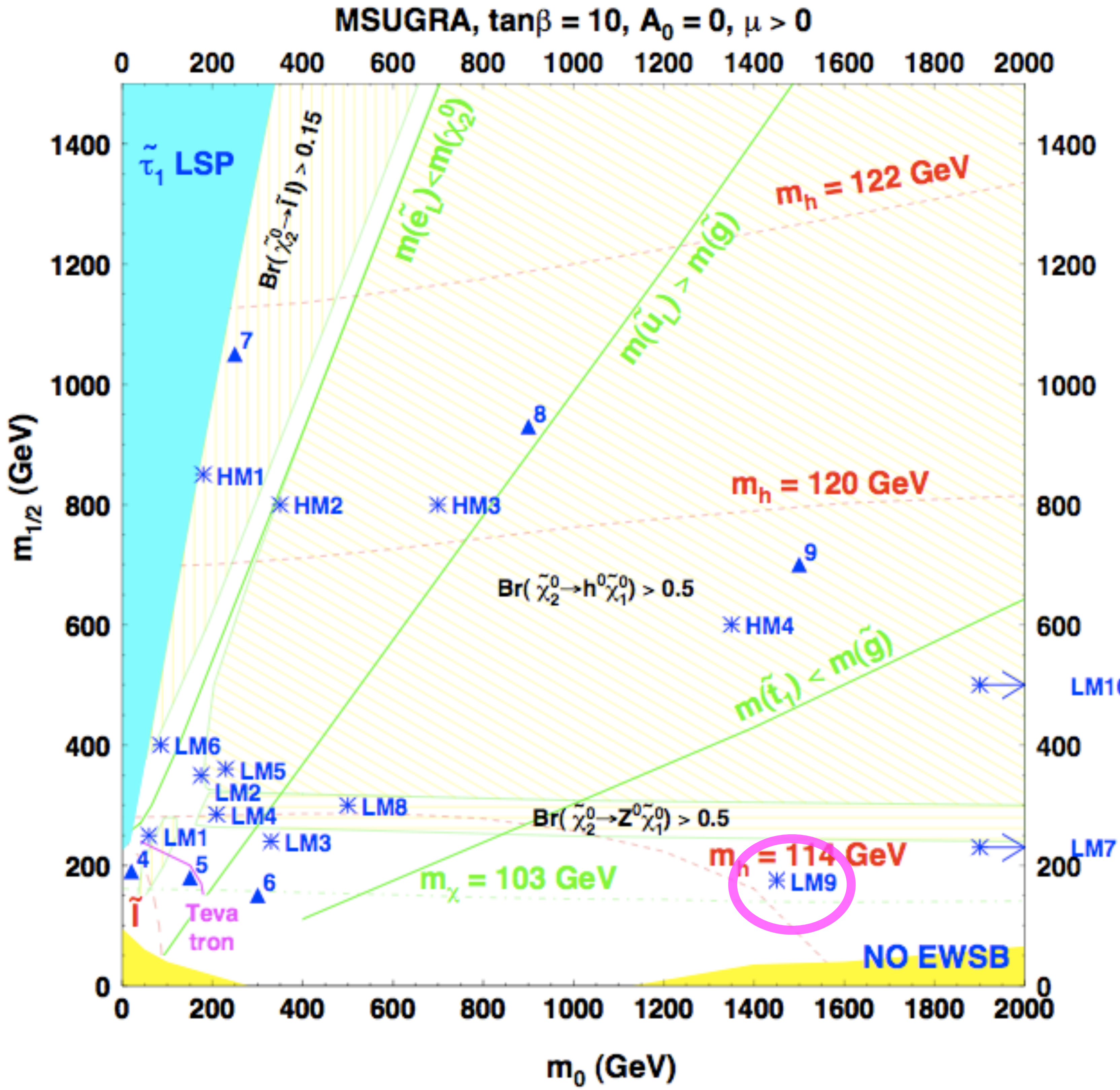
Outline

- Introduction
  - CMS benchmark points and motivation
- Analysis
  - Lepton cleaning
  - Standard model background and event selection
  - Expected results for $1 fb^{-1}$
- Misalignment studies
- Trigger studies
- Outlook

CMS benchmark points (mSUGRA)

- mSUGRA
  - 5 free parameters
- 10 low mass mSUGRA benchmark points
- At each of these points an early discovery (< 1 fb^{-1}) is possible
  - Cover different signatures
- LM9:

M_0	1450 [GeV]
$M_{1/2}$	175 [GeV]
tan(β)	50
A_0	0
sgn(μ)	+1



Motivation

- After/at discovery: Extract the SUSY parameters

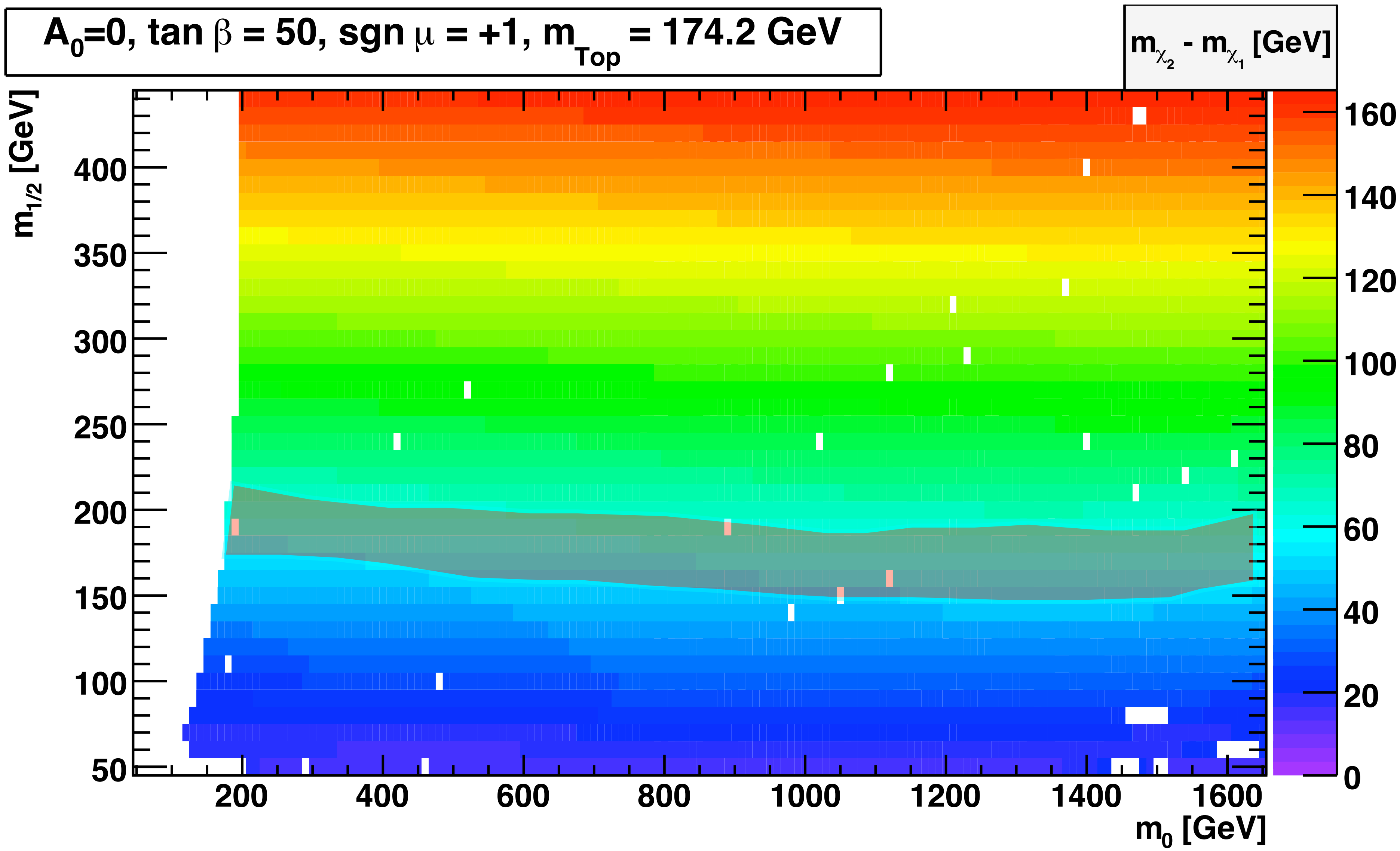
$$\sigma_{\tilde{g}\tilde{g}} = 36.9\ pb$$
$$\sigma_{\tilde{q}\tilde{g}} = 2.7\ pb$$

Prospino NLO

- Compatible with WMAP and EGRET

$$\tilde{g} \rightarrow q\bar{q}/g + \tilde{\chi}_2 \rightarrow q\bar{q}/g + \tilde{\chi}_1 + l^+l^- \qquad BR \approx 3\%$$

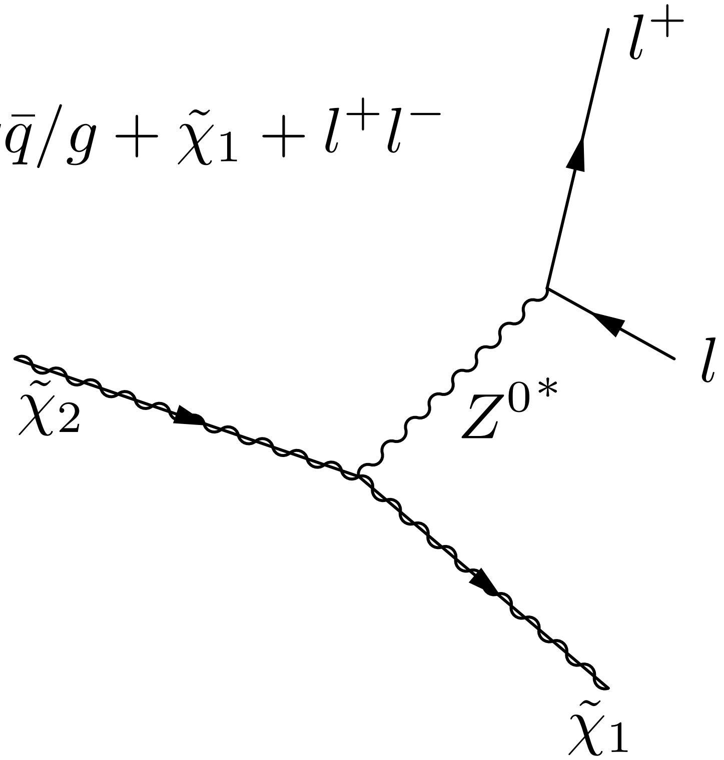
- Determine the mass difference of the two lightest neutralinos
- Experimental signature:
  - 2 same flavour opposite sign leptons
  - High jet multiplicity
  - Missing transverse energy

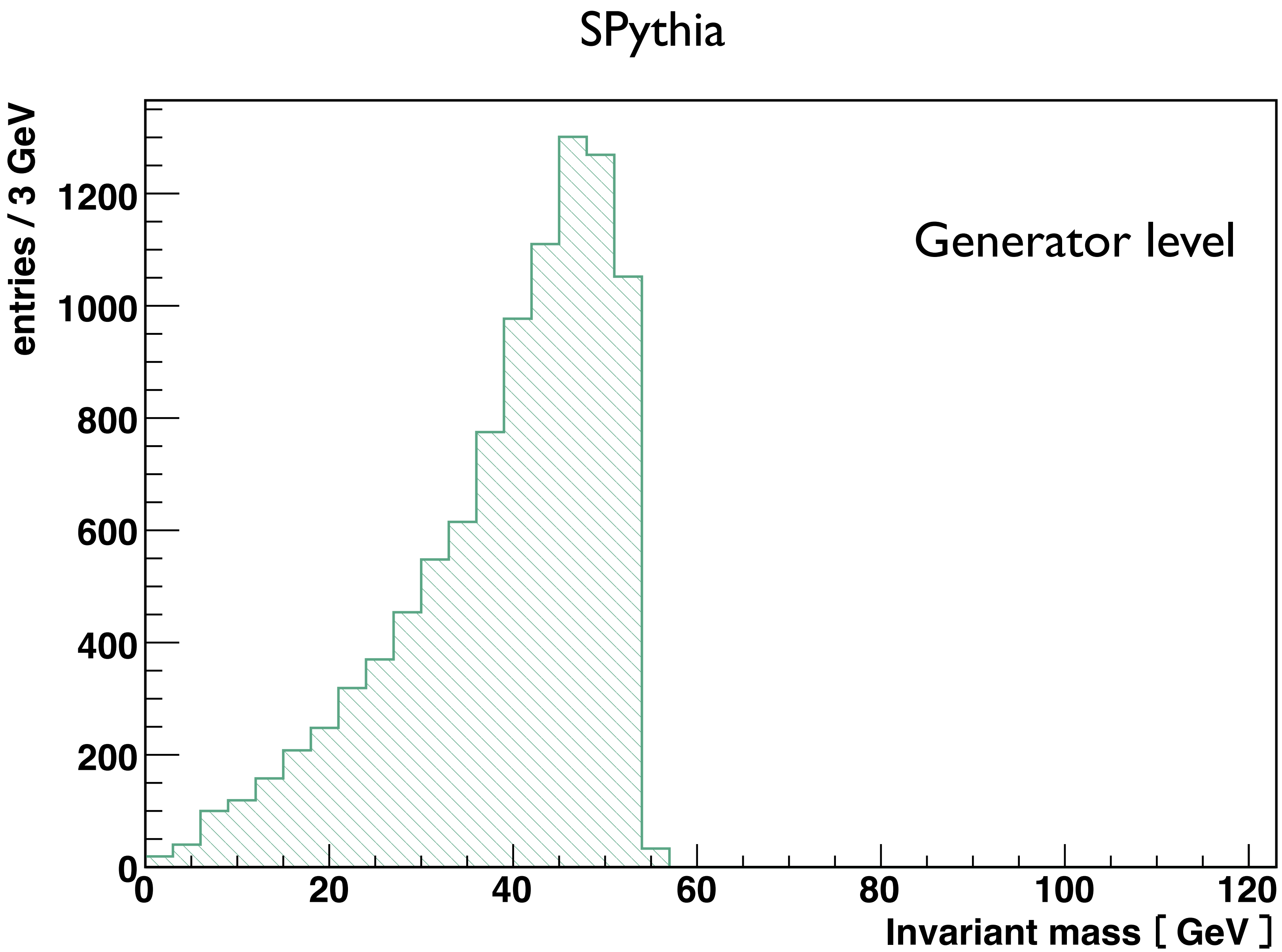


Determination of the mass difference

- Fit of the invariant mass distribution of the leptons
  - Endpoint represents the mass difference

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





- Only numerical calculations of the shape exist
- Detector resolution and applied cuts change the shape
- Fit method contains a quadratic term convoluted with a gaussian

Lepton cleaning and isolation

- Kinematical cuts on the leptons
  - $|\eta| < 2$
  - $p_T > 10$ GeV

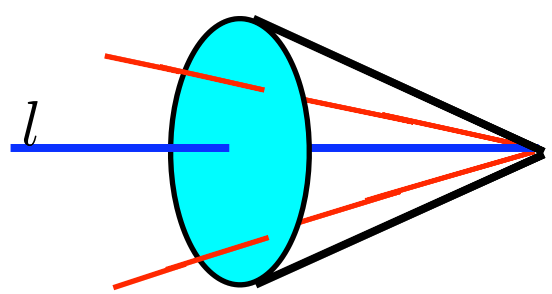
- Electron cleaning
  - Energy and Momentum $\frac{E}{p} > 0.75 \quad ; \quad \left|\frac{1}{E} - \frac{1}{p}\right| < \frac{0.02}{[GeV]}$
  - HCAL and ECAL energy $\frac{H}{E} < 0.1$
- Muon Cleaning
  - Number of Hits $\#Hits > 14$
  - Quality of track fit $\frac{\chi^2}{ndof} < 6$

SUSY	Electrons	Muons
Candidates	26380	9219
Cleaning	8797	8080
Isolation	2943	3580
Accept. Cuts	2343	2718
Generated	4355	4945
Purity	90,9%	99,9%
Efficiency	48%	55%
Purity (Signal)	99,1%	99,9%
Eff. (Signal)	51%	79%

- Lepton isolation (QCD background)
  - Energy fraction in a cone around the lepton

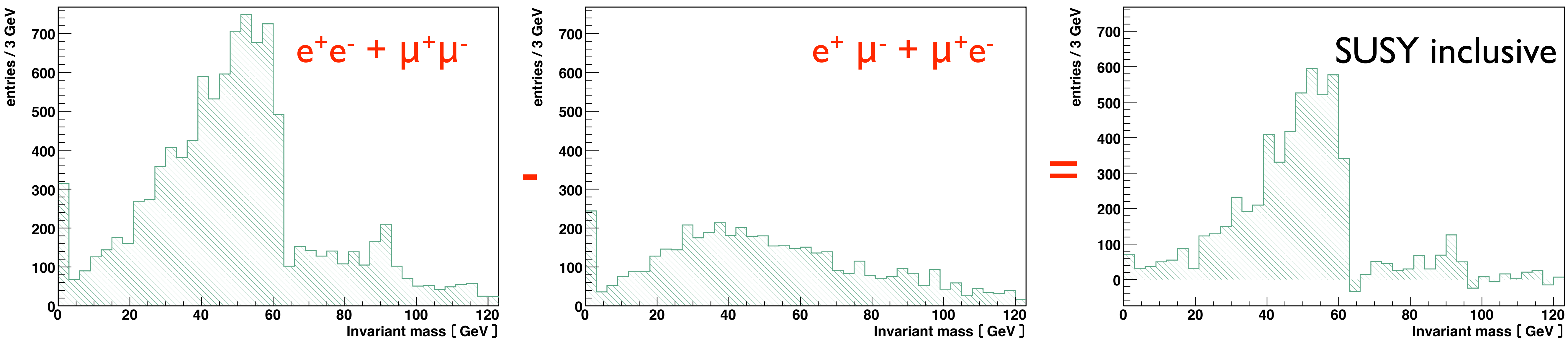
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

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



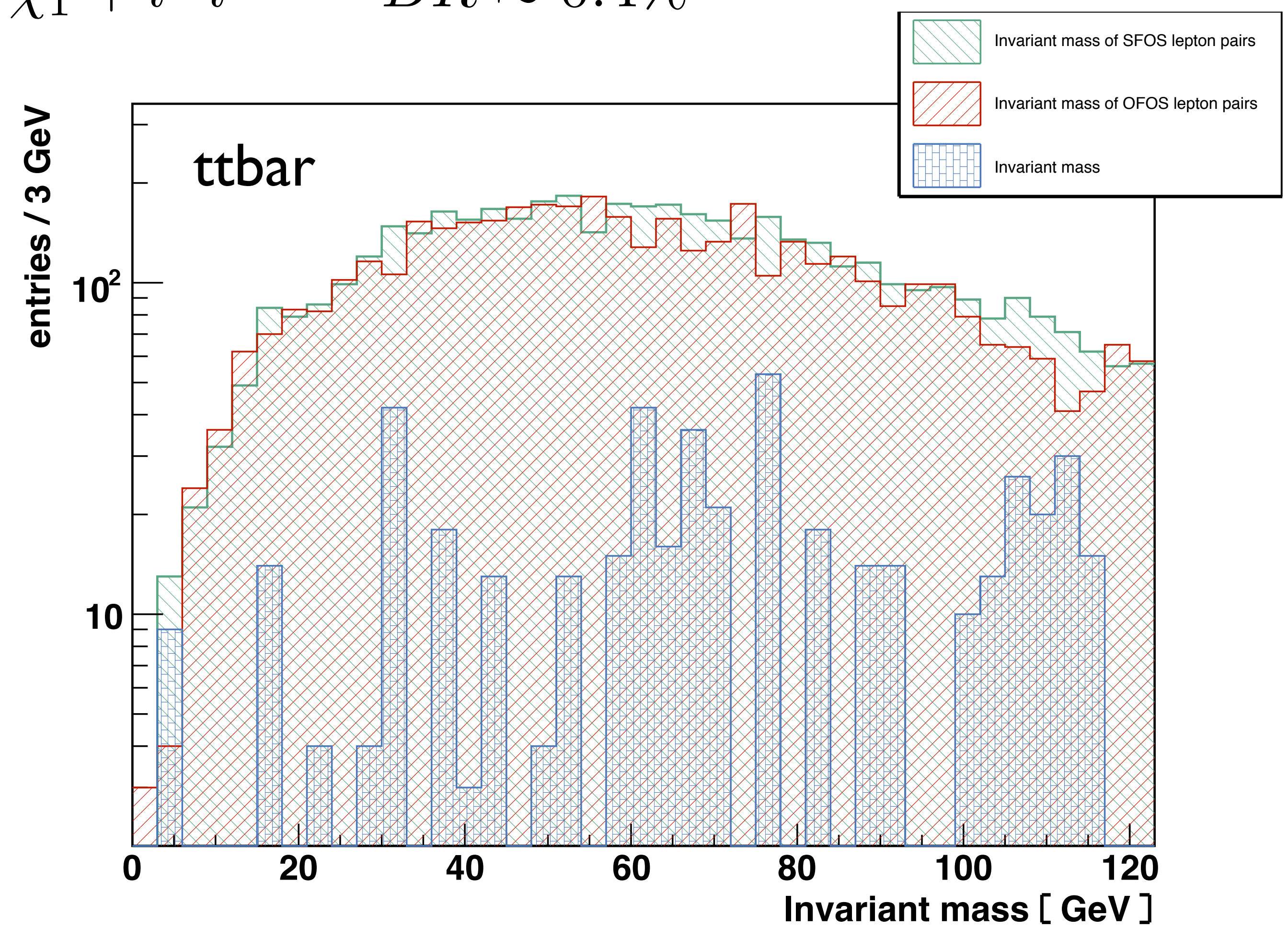
$$\Delta R_{cone} < 0.2$$

Statistical subtraction



$$\tilde{g} \rightarrow q\bar{q}' + \tilde{\chi}_2^{\pm} \rightarrow q\bar{q} + W^{\pm} + \tilde{\chi}_2 \rightarrow q\bar{q} + l^{\pm}\nu + \tilde{\chi}_1 + l^+l^- \qquad BR \approx 0.4\%$$

- Additional leptons (cf. from W decays) lead to a SUSY background
- In some SM backgrounds leptons are produced uncorrelated (cf. in Top decays)
- Different flavour subtraction
  - Needs high statistics to work properly
  - Balance between lepton reconstruction efficiency/purity



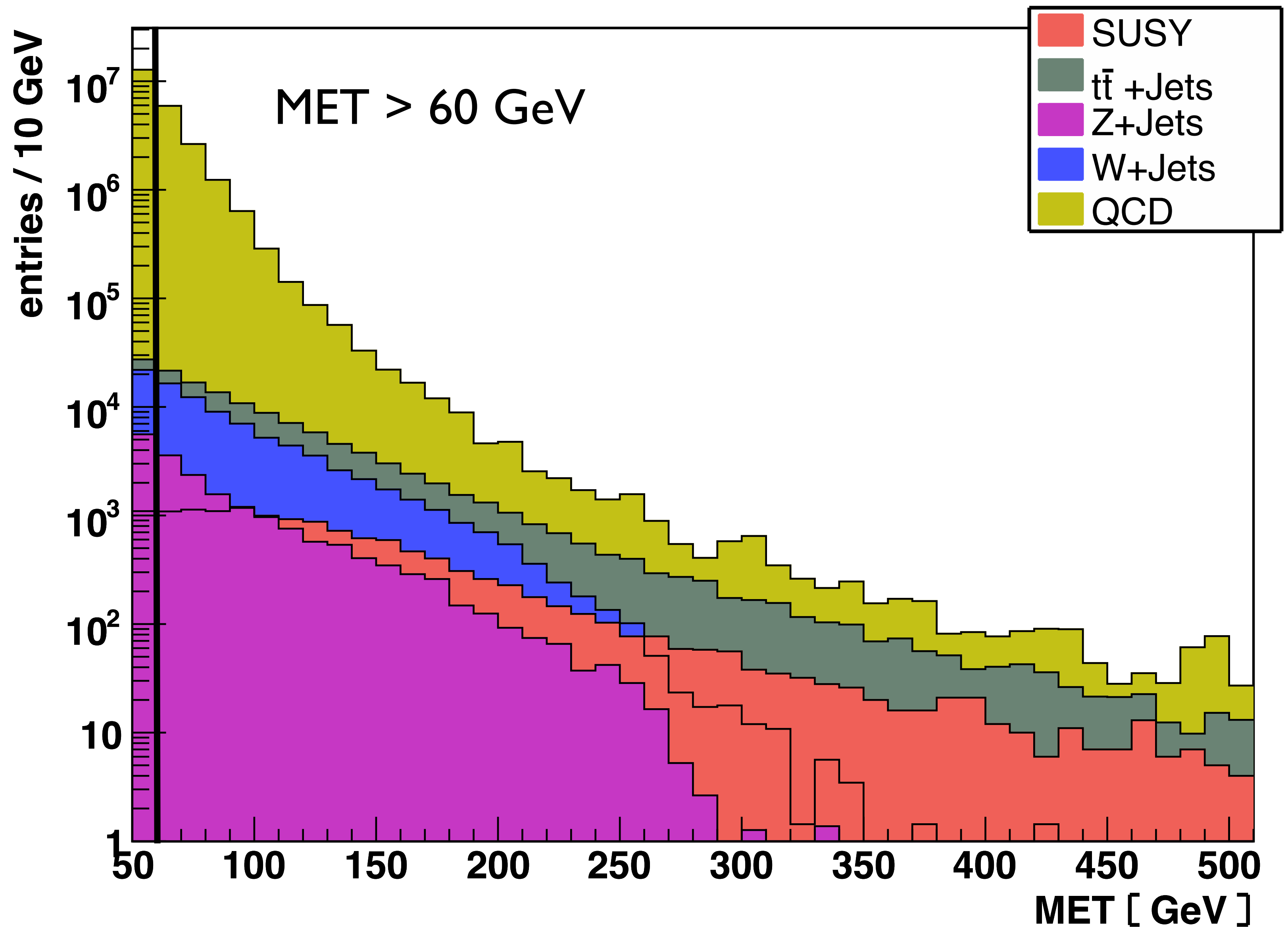
Standard Model backgrounds

- Preselection
  - 2 leptons (5 GeV)
  - 2 Jets (80, 30 GeV)
  - MET (50 GeV)

SUSY σ_{LO} = 25 pb

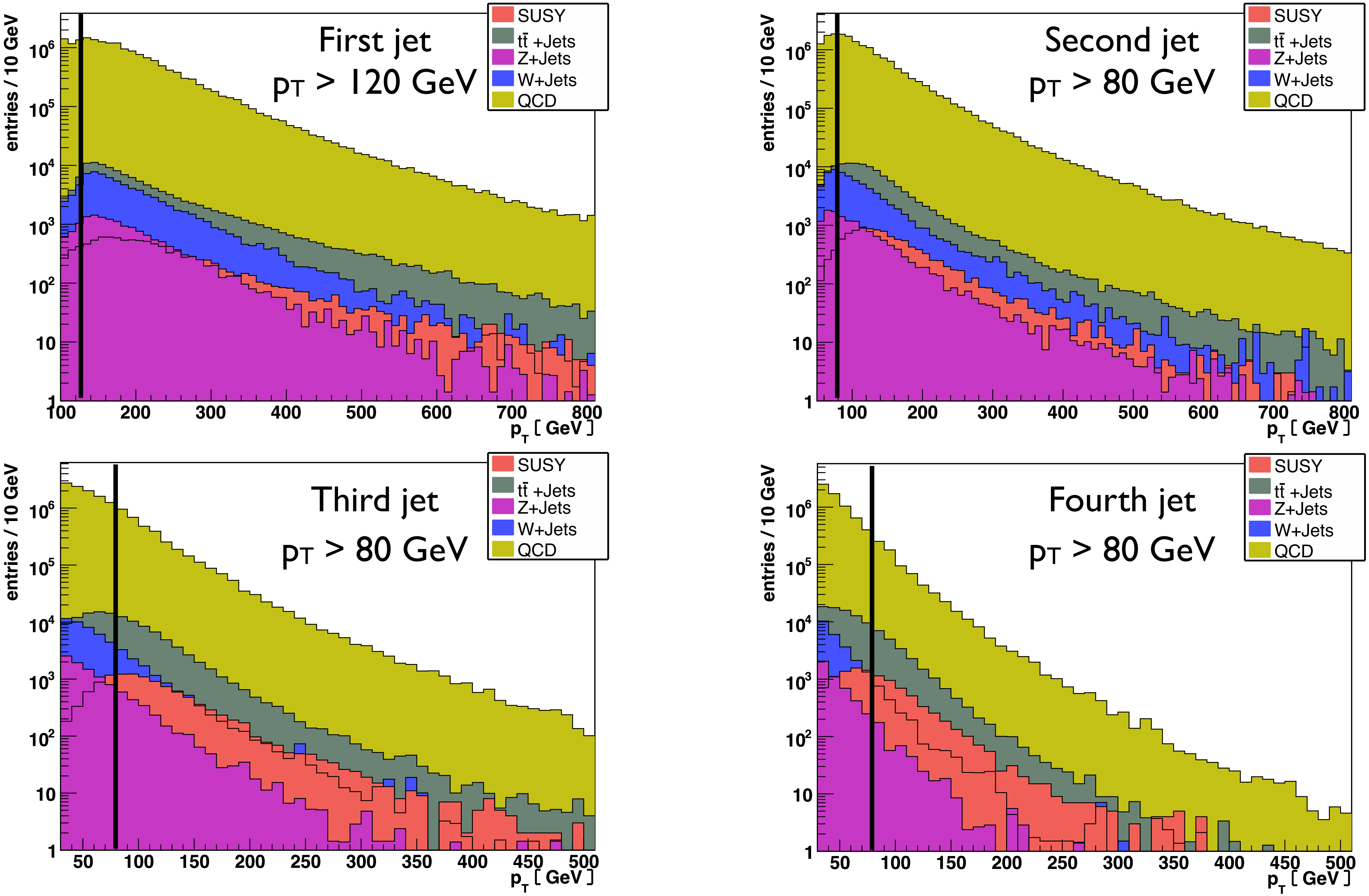
- Top pair + Jets (Alpgen)
  - σ = 480 pb
- Z+Jets (Alpgen)
  - σ = 14 nb
- W+Jets (Alpgen)
  - σ = 41 nb
- QCD (Pythia)
  - σ = 819 μb

Missing transverse energy



- LM9 has a soft MET spectrum comparable to the main Backgrounds
  - No hard cut is possible

Cuts on four leading jets



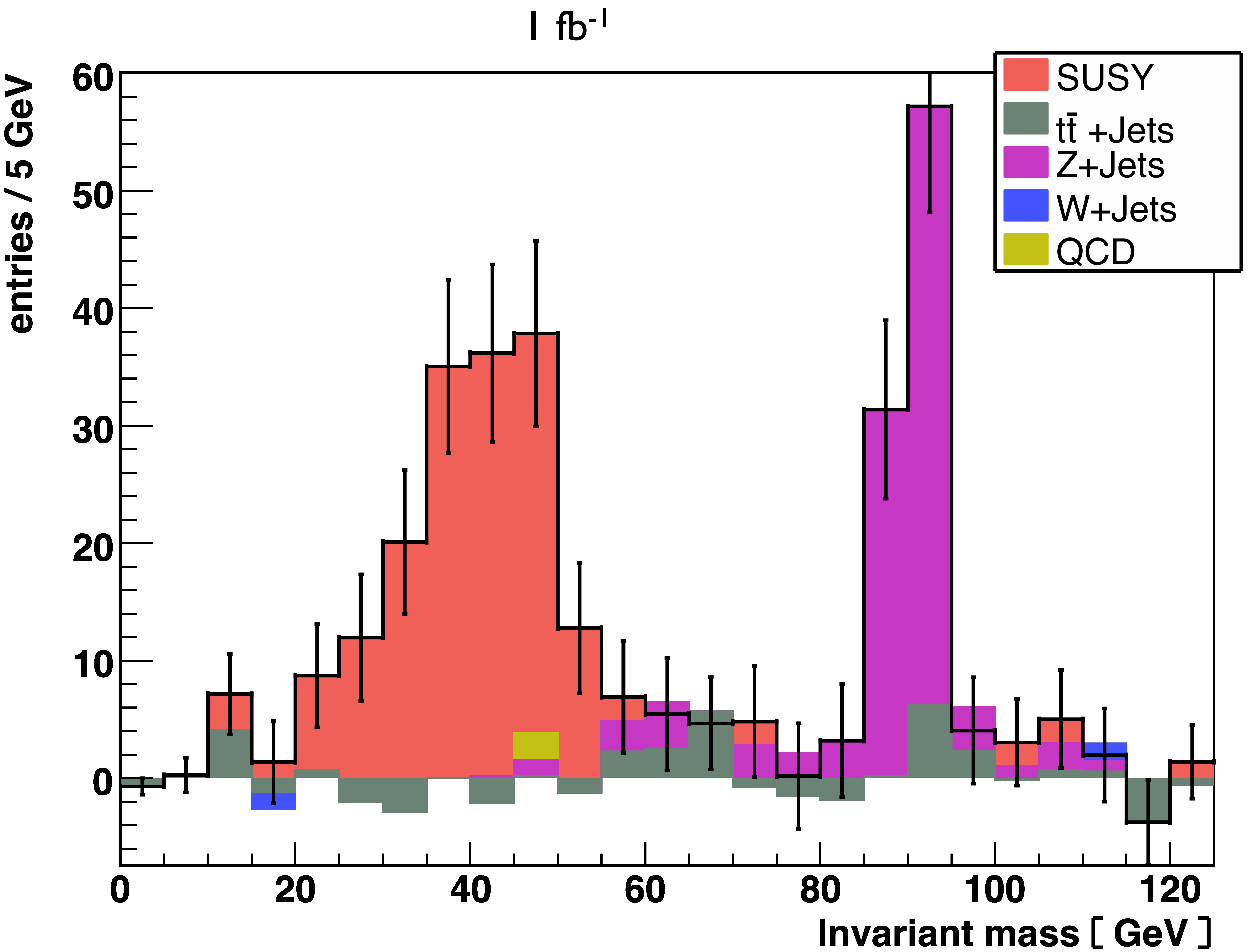
- Alpgen background ⇒ to obtain most correct multijet description

Cutflow

Cut	SUSY	$t\bar{t}$+jets	Z+jets	W+jets	QCD
All events	36777	$1{,}2 \cdot 10^{6}$	628594	$8{,}3 \cdot 10^{7}$	$8{,}14 \cdot 10^{13}$
Preselection	11375	133283	17616	90192	$2{,}8 \cdot 10^{7}$
MET cut	9172	106618	12167	68716	$1{,}2 \cdot 10^{7}$
4 jets	4576	22873	478	2419	590930
2 isolated leptons	243	609	127	11	5

- Only jet cuts and MET cut:
  - Large number of background events
- Without two isolated leptons no background reduction possible due to soft missing transverse energy spectrum

Expected results for 1 fb^{-1}



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

- SUSY signal is clearly visible
- Fit of the endpoint is possible
- Alpgen background description

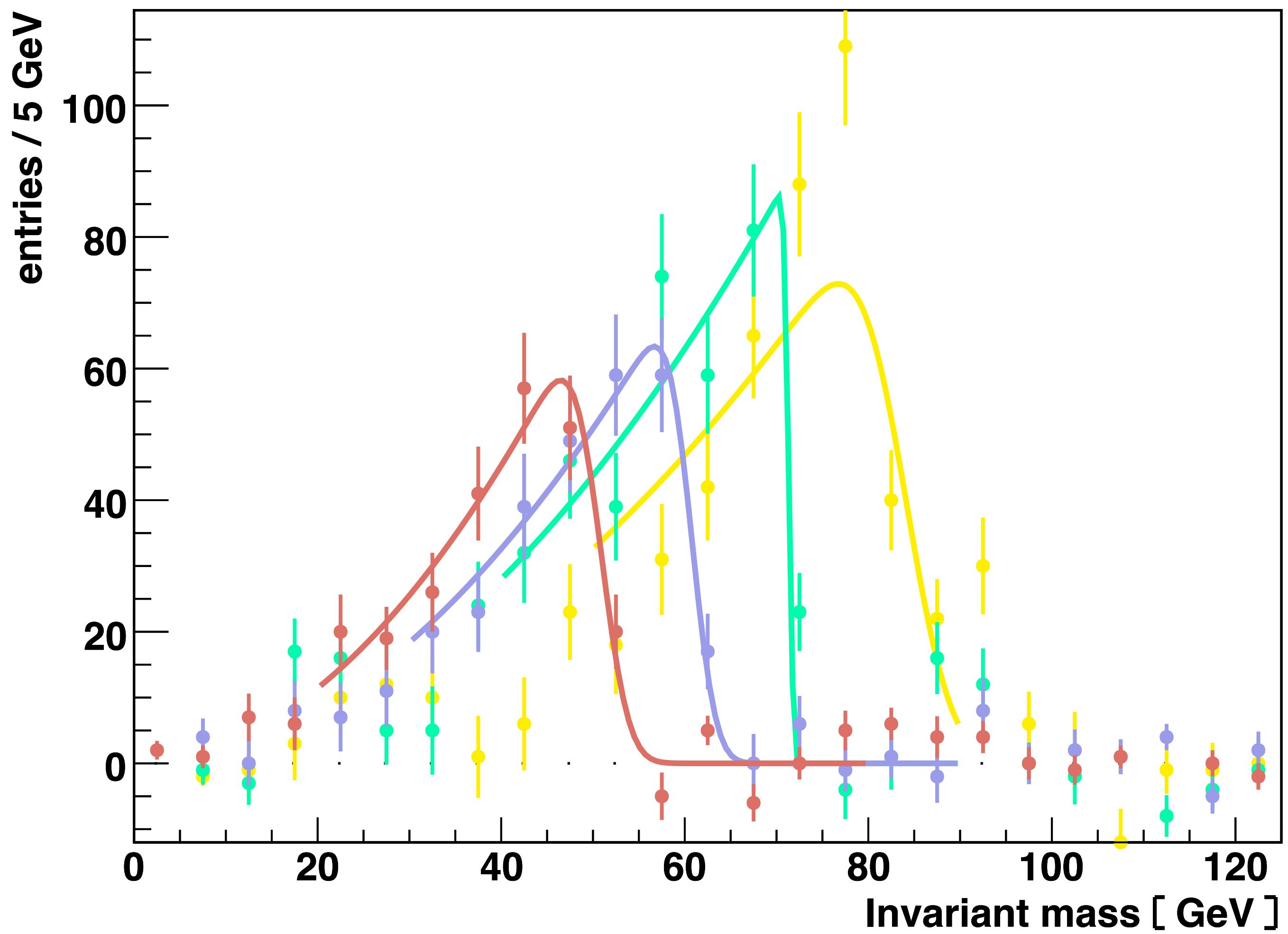
Entries 0-70 GeV	all cuts
SUSY	171
tt+jets	5
Z+jets	10
W+jets	0
QCD	2

$$S = \frac{s}{\sqrt{b}}$$

$$S = 41.5$$

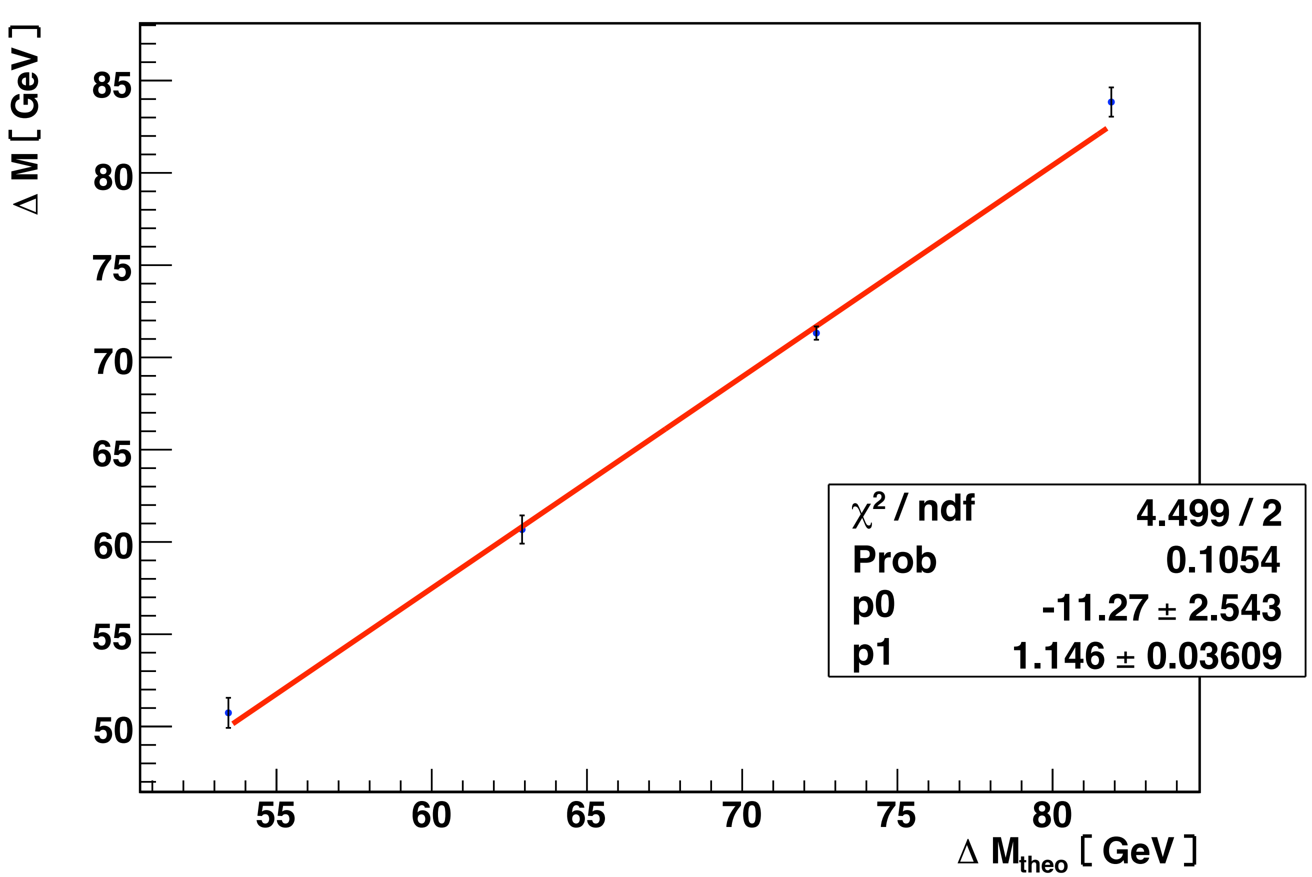
Calibration of the estimator

CMS fast simulation



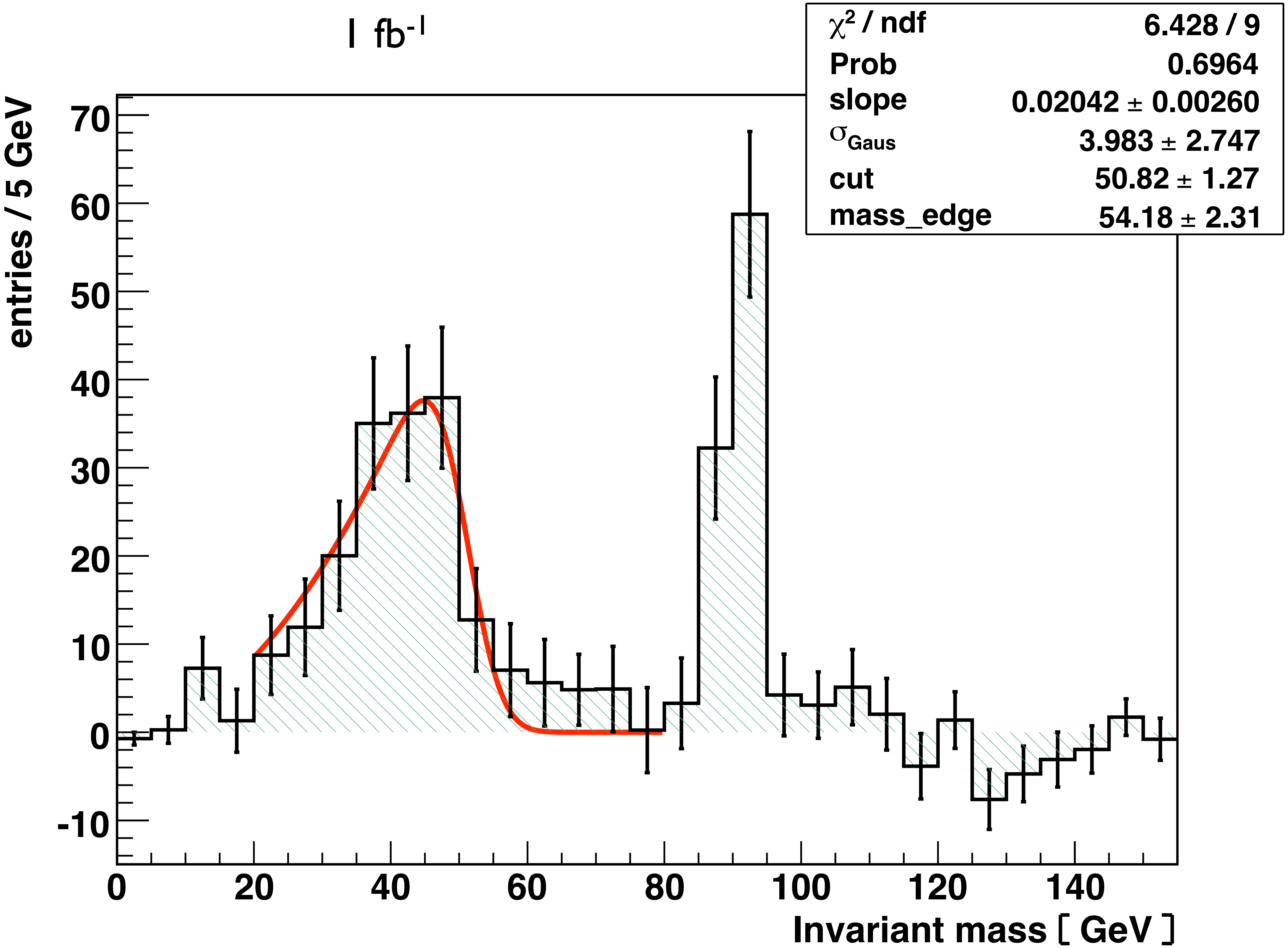
- Fit underestimates the theoretical value
- Calibration is needed
- Varied $m_{1/2}$ to obtain 4 samples with different mass difference

Calibration



- Calibrate the estimator using different mass differences
- Same cuts applied
- Done with the CMS fast simulation

Results for 1 fb^{-1}



$$\Delta M_{exp} = (54.2 \pm 2.3(stat) \pm \mathcal{O}(5)(syst)) \;\; GeV$$

- Calibration improves the resolution
- Fit reproduces the theoretical mass difference within the error

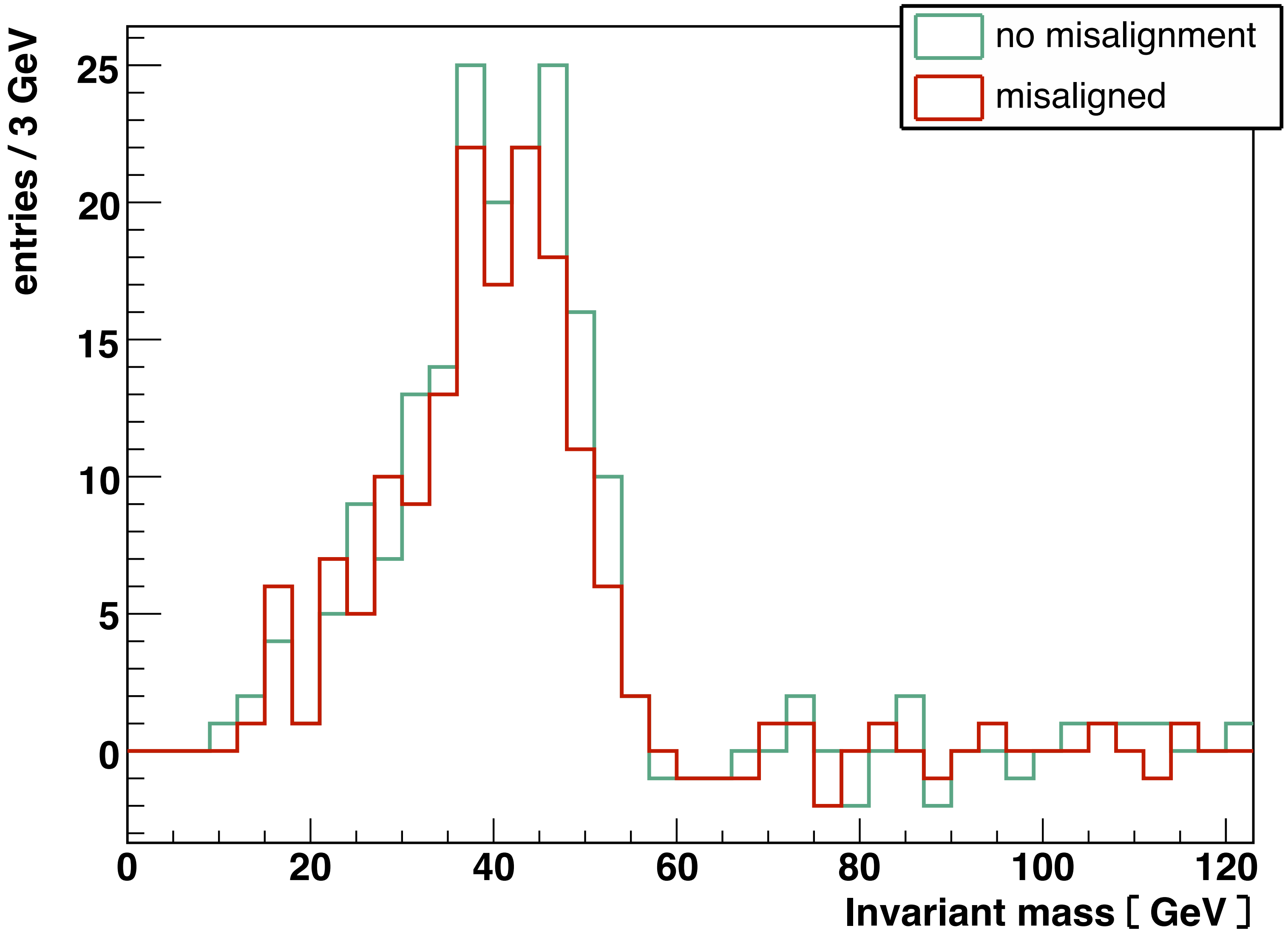
$$\Delta M_{theo} = 54.34 \; GeV$$

- Systematic uncertainty remains to be determined
- Prior studies: roughly 5 GeV

Impact of Tracker + Muon misalignment

- Positions of detector modules are not known to ultimate precision
- Random displacements to simulate the impact of misalignment

Invariant mass of lepton pairs

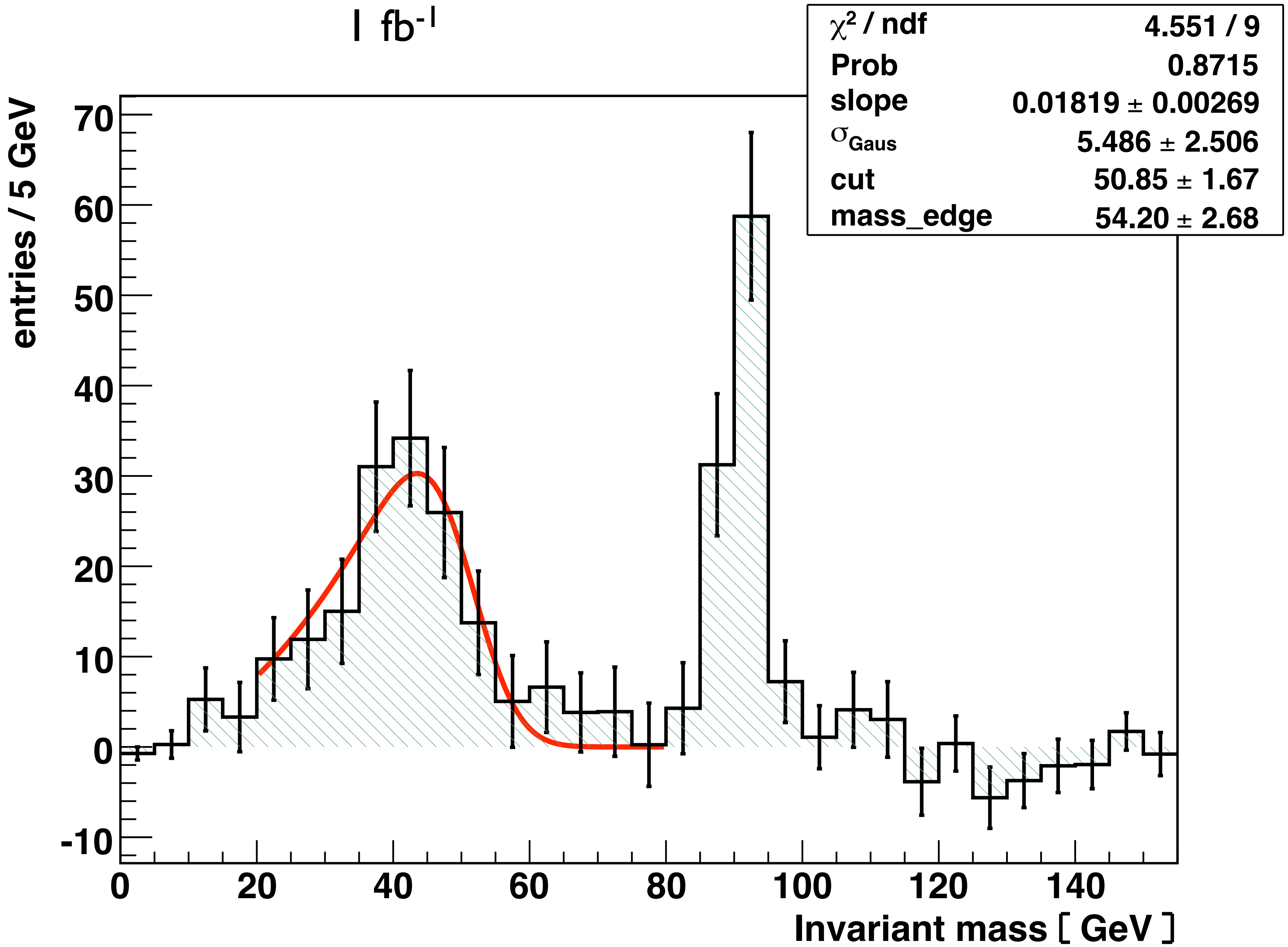


- CMS 10 pb^{-1} scenario included
  - Estimates from survey measurements and alignment with cosmics
  - Worst case scenario
- Alignment position error taken into account
- No p_T, η and φ dependence for electrons and muons is visible
- Drop for electrons 17%
- Drop for muons 12%

  13% in total

- With available statistics:
  no change of the shape of the dilepton edge visible

Results with misalignment



$$\Delta M_{exp} = (54.2 \pm 2.7(stat) \pm \mathcal{O}(5)(syst))\ \ GeV$$

- Background not misaligned
- No systematic shift
- Lower statistics
- Small contribution to the total systematic uncertainty

0-70 GeV	All cuts
Signal	150
Background	17

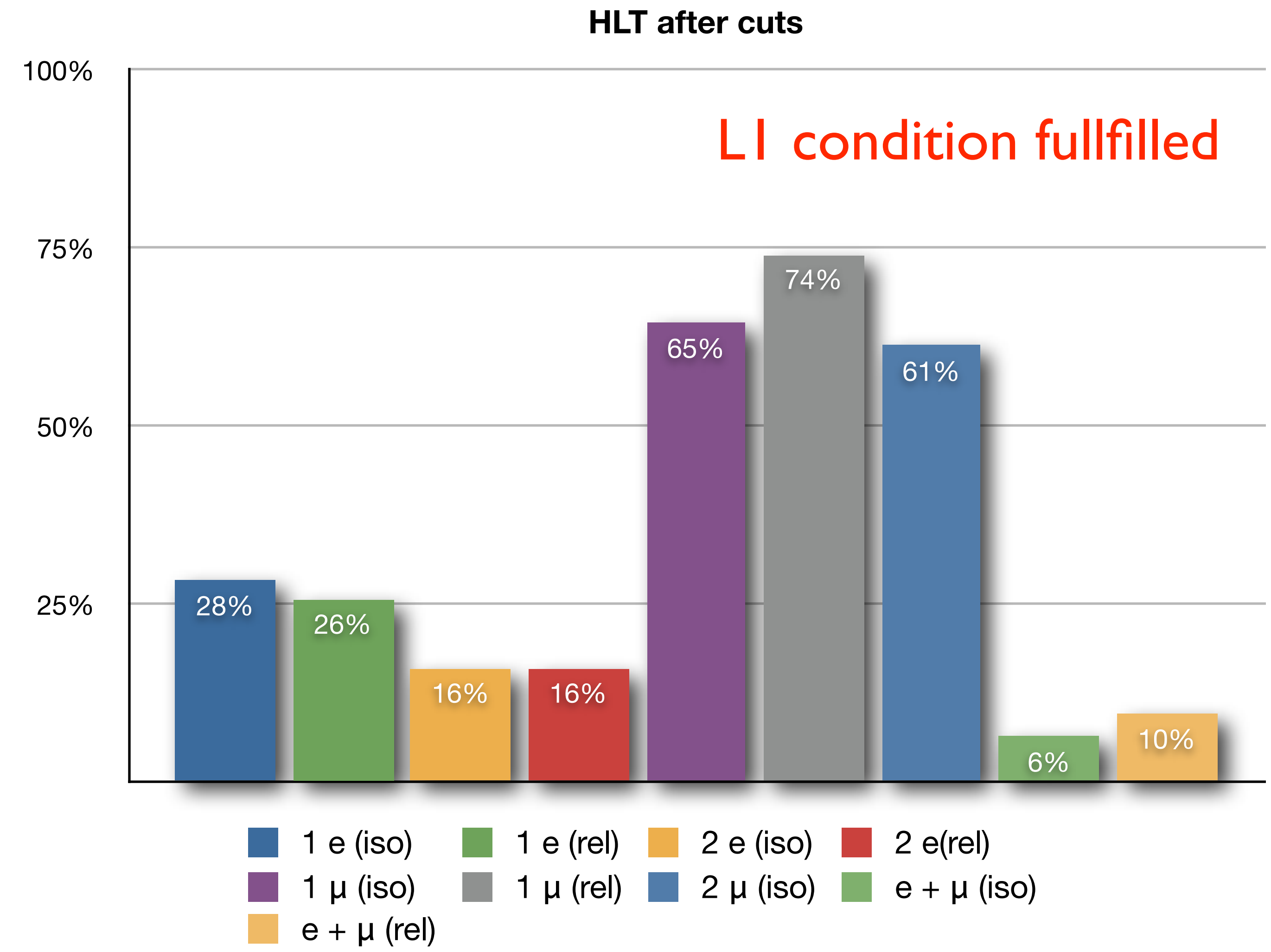
$$S = \frac{s}{\sqrt{b}}$$

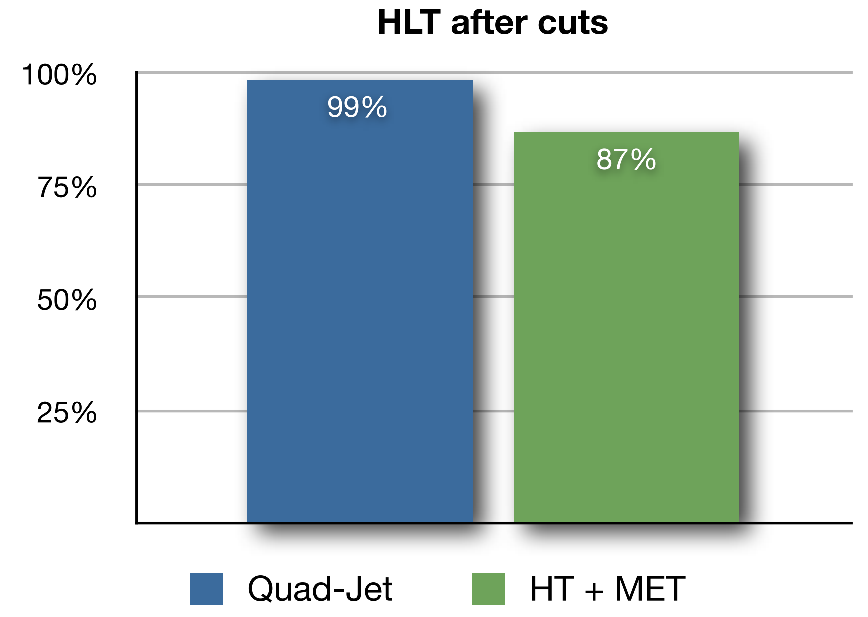
$$S = 35.9$$

Selected triggers

- Leptonic triggers 97,4%
  - 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)



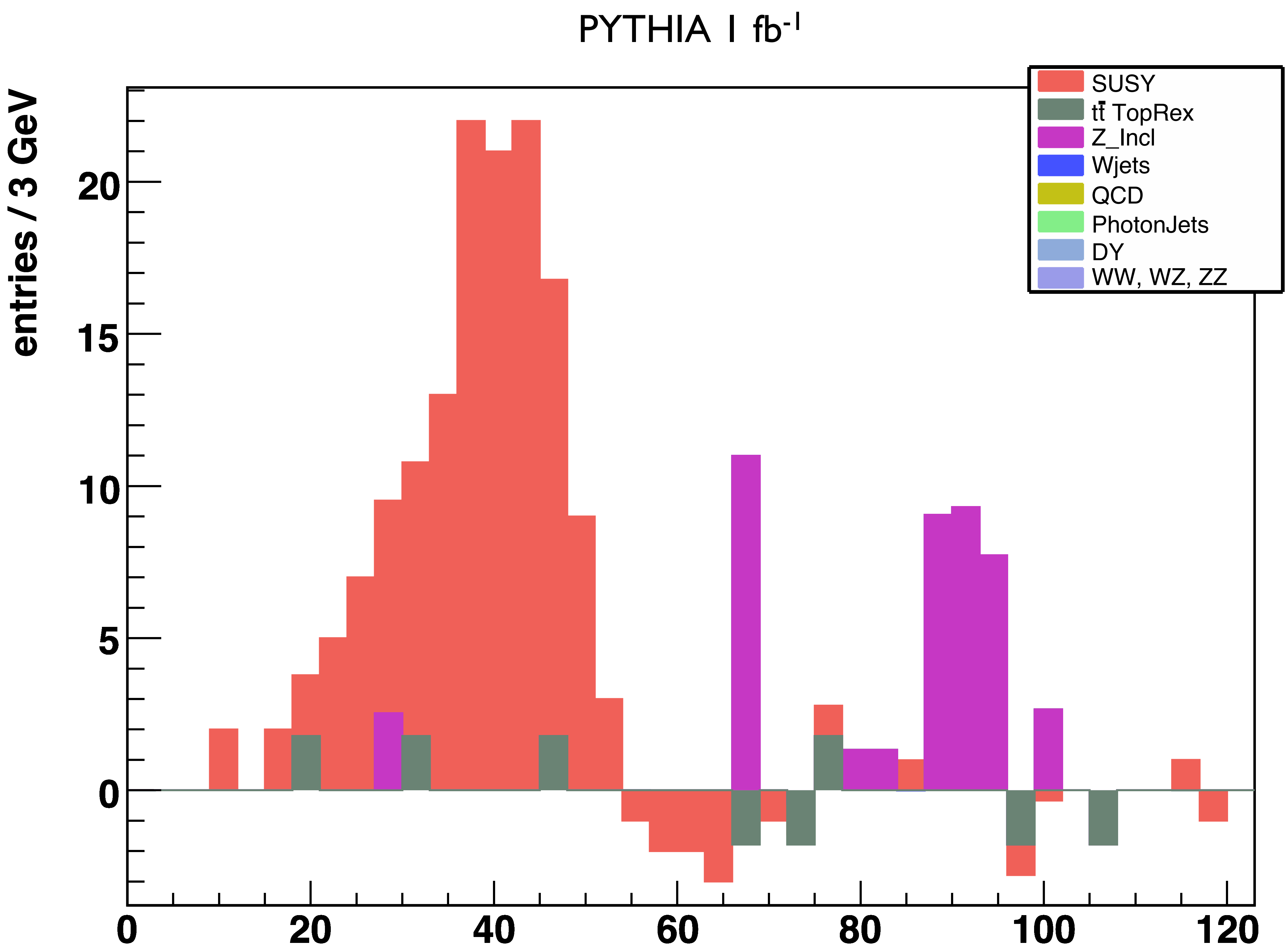


Summary/Outlook

- Dilepton edge visible with 1 fb^{-1} (first year of LHC running)
  - with misalignment
  - and Alpgen background description
- Misalignment gives only a small contribution to systematic uncertainty
- Full trigger efficiency with a few triggers
- Statistical error of 2 GeV on mass difference can be achieved
- Measurement with precision of 10% seems to be possible
- To-do-list:
  - Estimate systematic uncertainty
  - (Check analysis at different benchmark points)

BACKUP

Invariant mass distribution

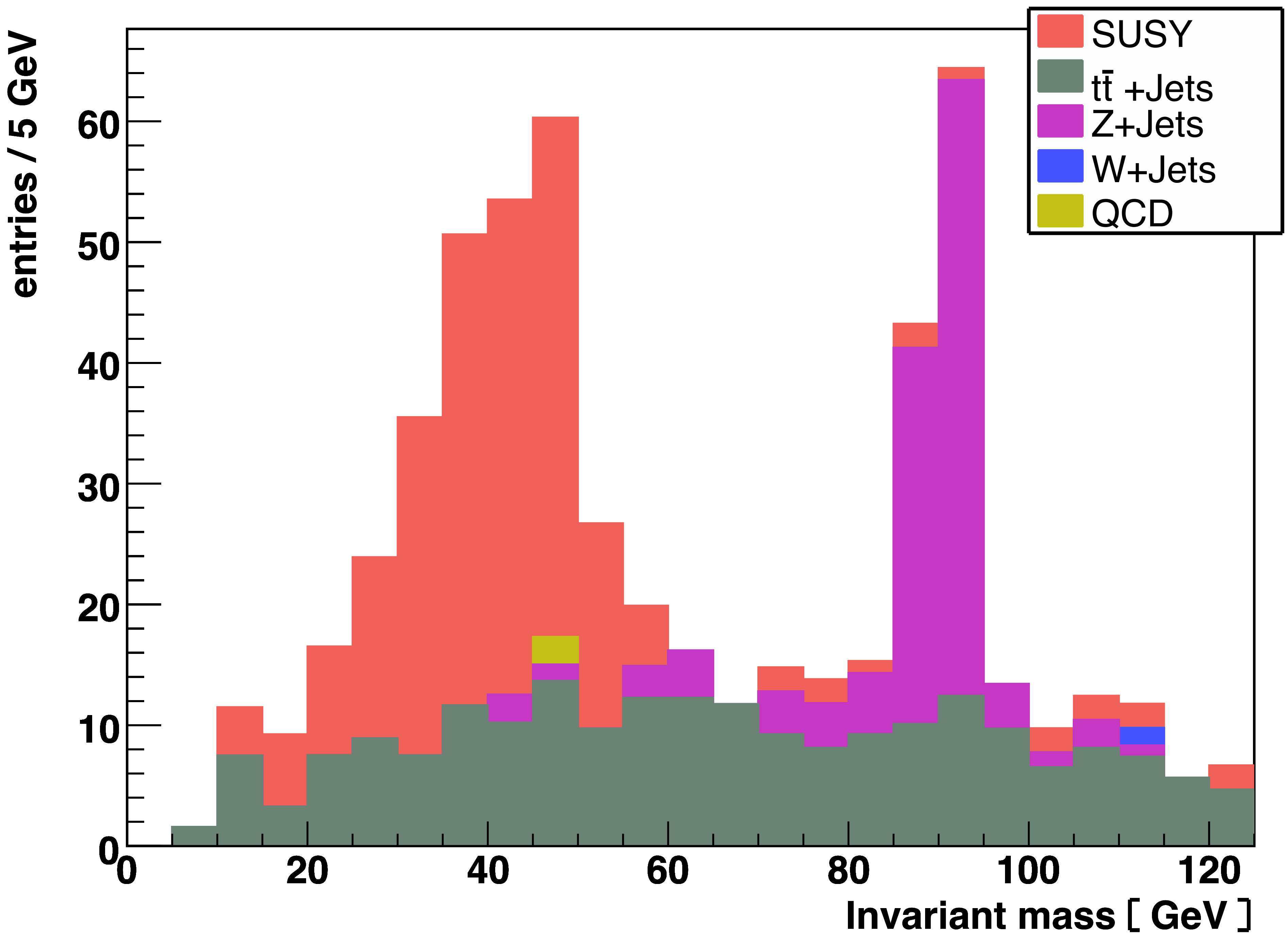


$\tilde{\chi}_2 \rightarrow \tilde{\chi}_1 + l^+ l^-$

- Dilepton edge is clearly visible
- Main remaining Backgrounds: Top Pairs Z+Jets
- Determination of the endpoint is possible

Events after selection	
SUSY	136
ttbar	5,3
Z+Jets	2,5

SFOS


entries / 5 GeV
60
50
40
30
20
10
0
0
20
40
60
80
100
120
Invariant mass [GeV]
SUSY
$t\bar{t}$ +Jets
Z+Jets
W+Jets
QCD

Misalignment scenarios

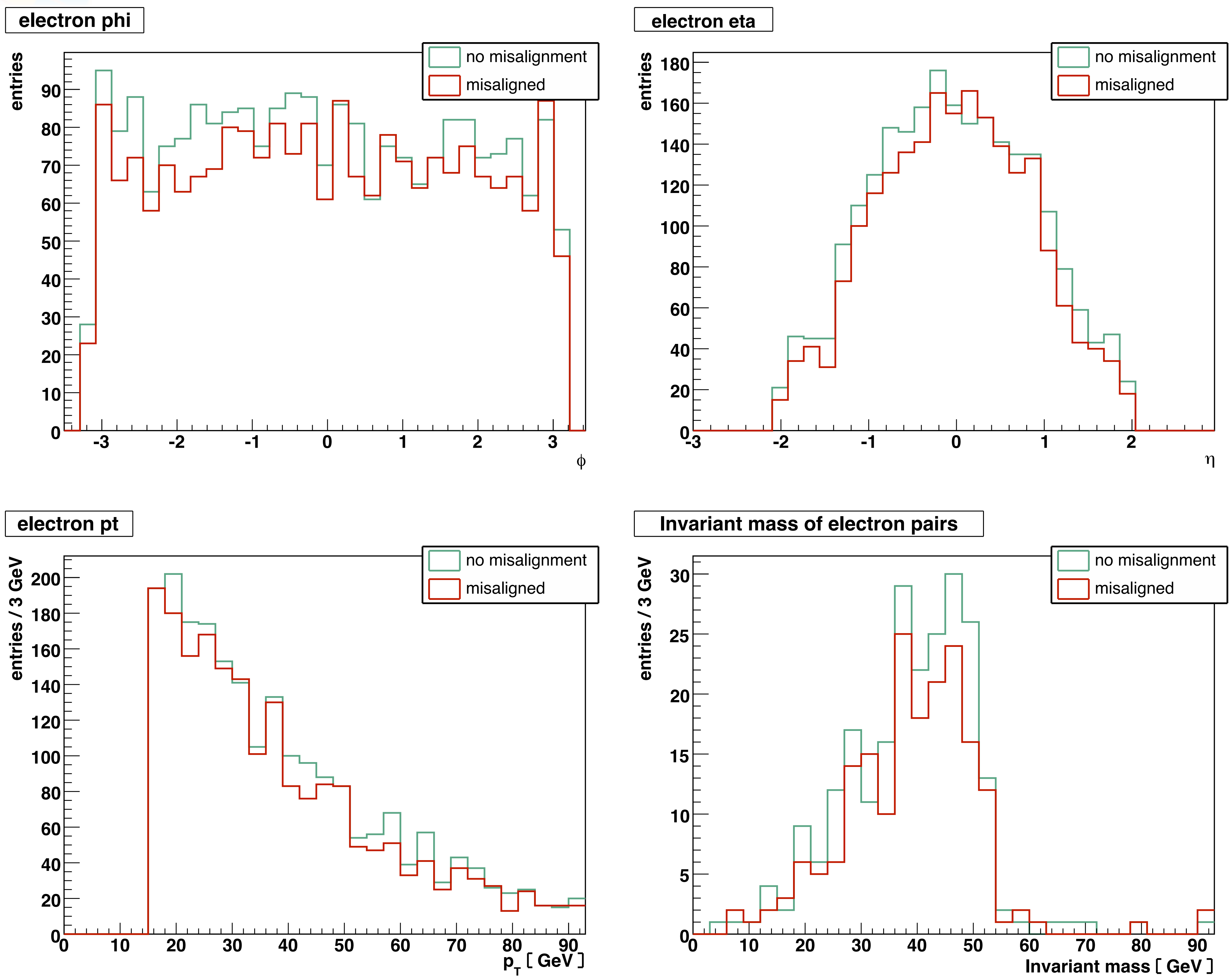
Tracker 10 pb^{-1}	Updated initial uncertainties	[μm] x, y, z	*10* pb^{-1} Scale	[μrad] ϕ
TPB				
Dets	G60	60	1.00	270
Rods	U50	10	0.35	7
PixelHalfBarrelLayers	U100	10	0.17	7
TPE				
DetUnits	G5, ϕ:G100	5	1.00	100
Panels	G10, ϕ:G200	10	1.00	200
Blades	G10, ϕ:G200	10	1.00	15
HalfDisks	G50, ϕ:G1000	10	0.20	15
TIB				
Dets	G180	180	1.00	412
Rods	G450	100	0.22	65
BarrelLayers	G750	100	0.13	65
TOB				
Dets	G32	32	1.00	75
Rods	G100	100	1.00	40
BarrelLayers				
HalfBarrels	$r\phi$: G60, z: G500	60/100	1/0.2	10
TEC				
Dets	G22	22	1.00	50
Petals	G70	70	1.00	30
EndcapLayers	$r\phi$: G60 z: G150	60/150		15
TID				
Dets	G54	54	1.00	250
TIDRings	G185	185	1.00	850
TIDLayers	G350	250	0.71	380

- For a more realistic study
- Misalignment of tracker and muon system
- The modules of the CMS detector are shifted and rotated
- Misalignment is implemented in reconstruction
- A complete reconstruction is necessary
- Worst case scenario (10 pb^{-1} scenario)
  - Represents alignment knowledge after 10 pb^{-1} of data (<1 month of running)
- Both muon and tracker misalignment in the same step

Muon 10 pb^{-1}	Barrel		Endcap	
	Position [mm]	Orientation [μrad]	Position [mm]	Orientation [μrad]
structures	X/Y 2, Z 3	250	X/Y 2, Z 5	250
chambers	0,5	-	0,5	-

Alignment position error (APE) taken into account!

Impact on electrons



- Drop for electrons

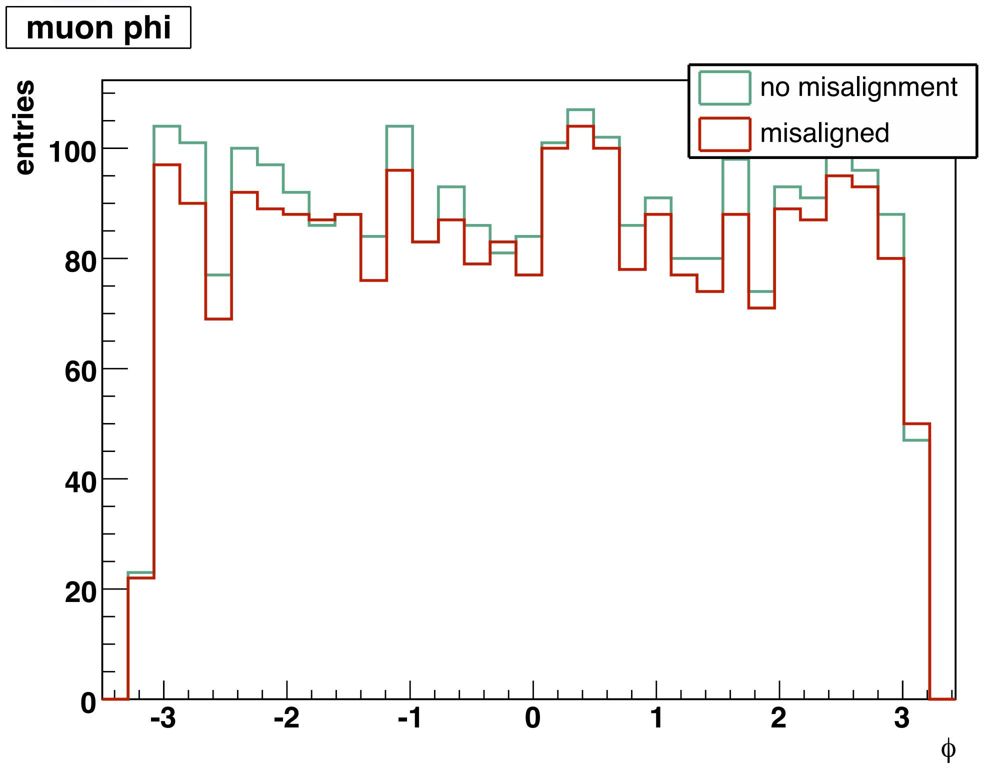
  8 %

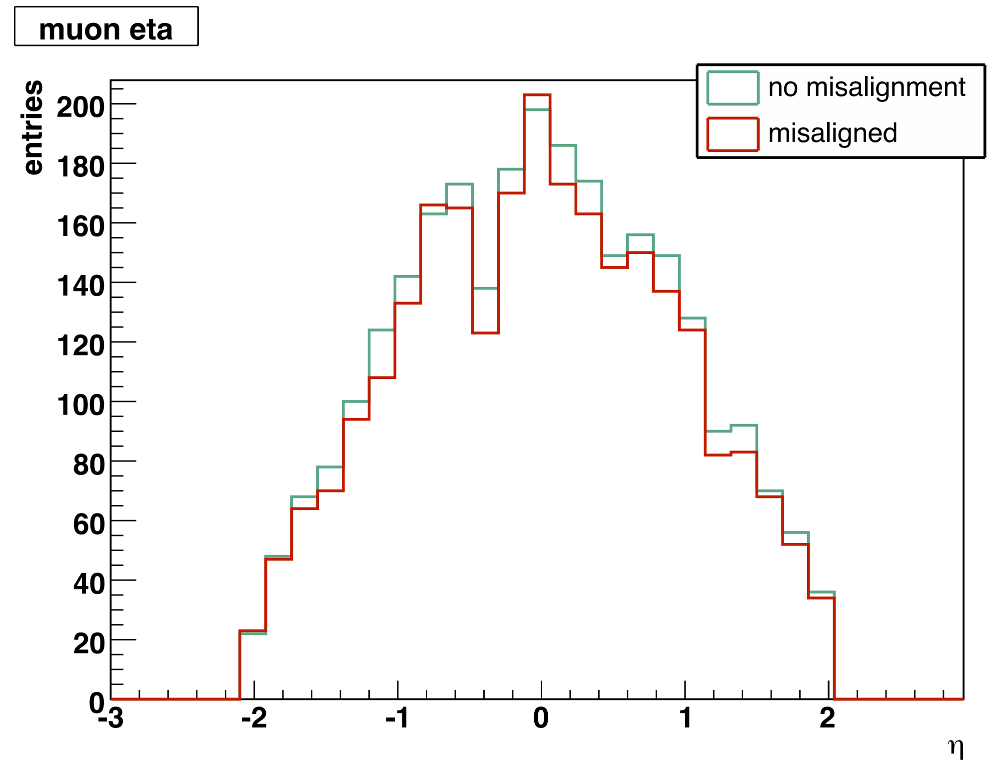
- No p_T, η or φ dependence visible

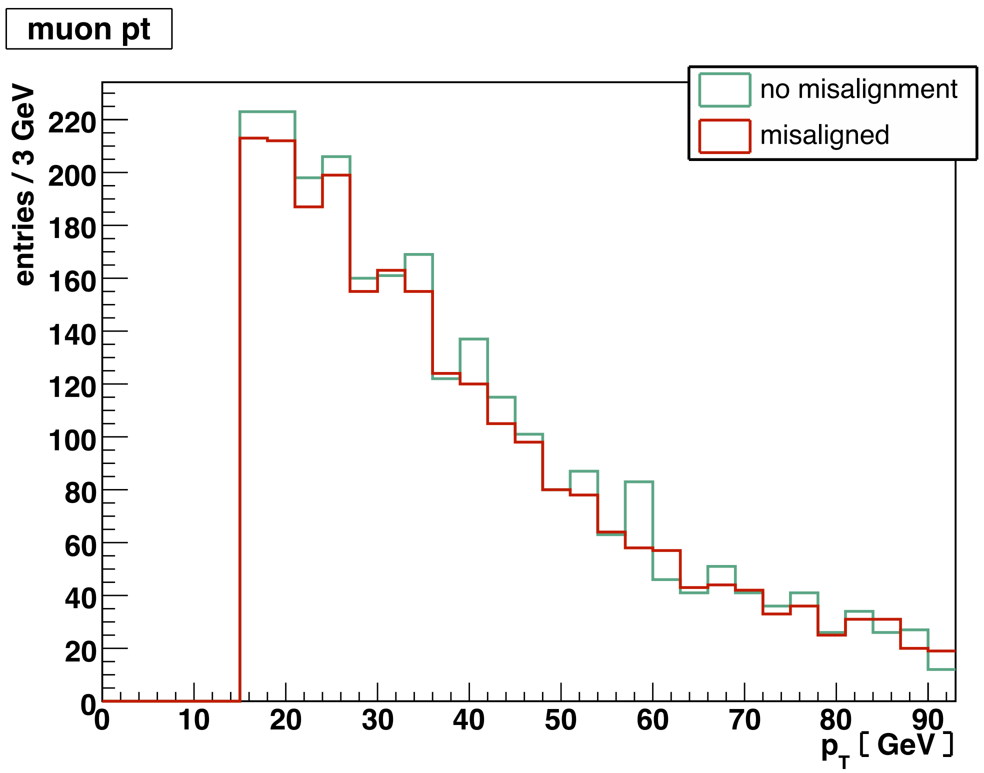
- Drop in di-electron invariant mass distribution (without event selection cuts)

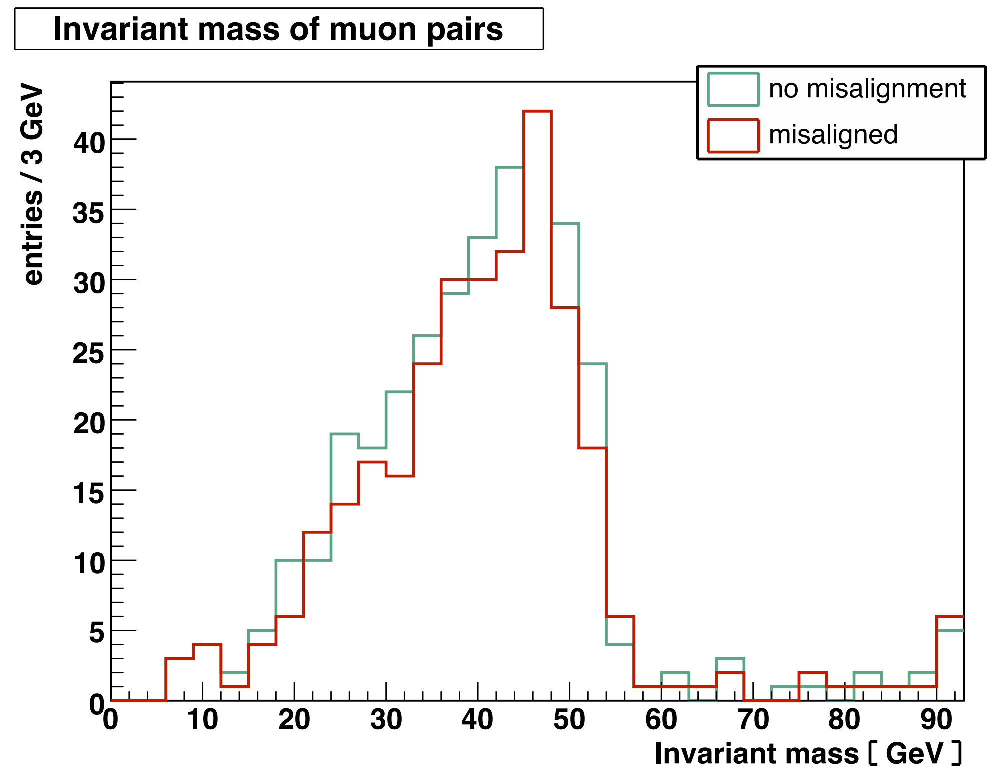
  20%

Impact on muons









- Drop for muons

  4 %

- No p_T, η or φ dependence visible

- Drop in di-muon invariant mass distribution (without event selection cuts)

  10%

CMS Trigger System

- LHC luminosity at startup: $L = 10^{32}\ cm^{-2}\ s^{-1}$
  - Select the "important" things
- L1 trigger (3 µs)
  - 40 MHz input (LHC bunch spacing)
  - 17 kHz output
  - Hardware trigger
- HL trigger (40 ms)
  - 150 Hz output
  - Pure software (filter farm)
- Prompt reconstruction with 150 Hz