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very recently CMS approved analysis:

Search for supersymmetry in hadronic final states using M_{T2} with the CMS detector

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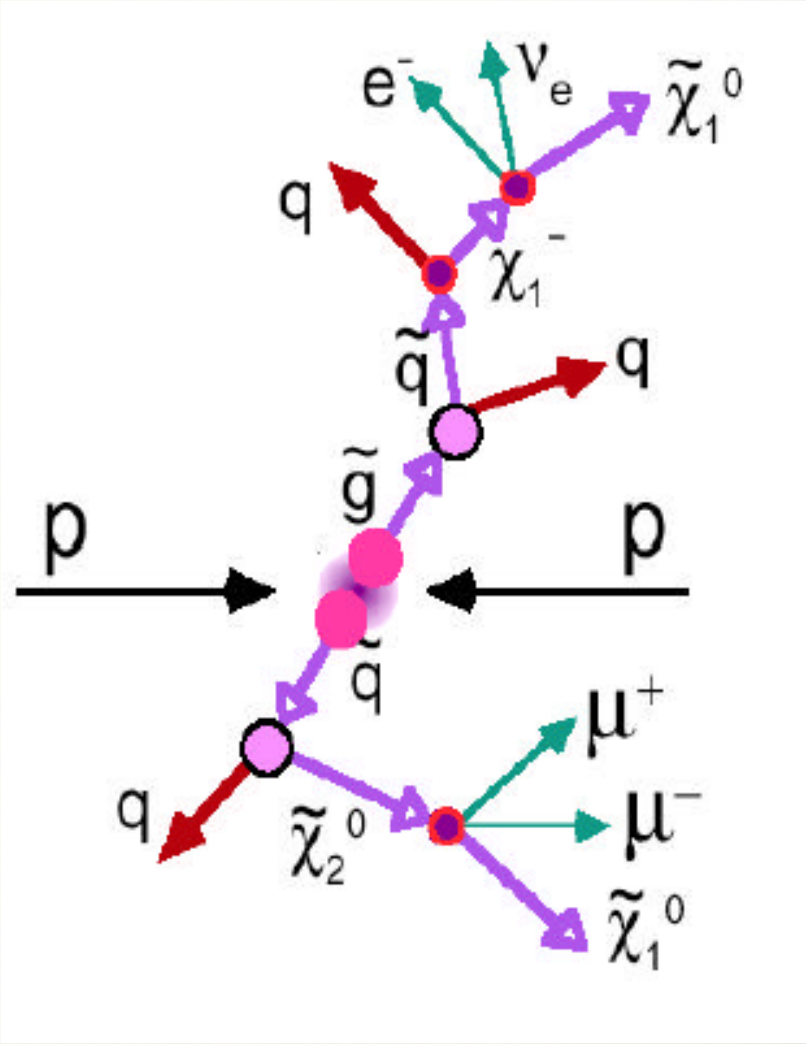
hadronic SUSY searches in CMS

- if SUSY comes with a stable dark matter candidate and if it is in reach of the LHC energy, it can be observed in final states containing jets and missing transverse energy MET (due to an unobserved LSP)

- why searching for SUSY in fully hadronic final states?
  - most sensitive to SUSY since it only relies on the strong production of the squarks and gluinos.



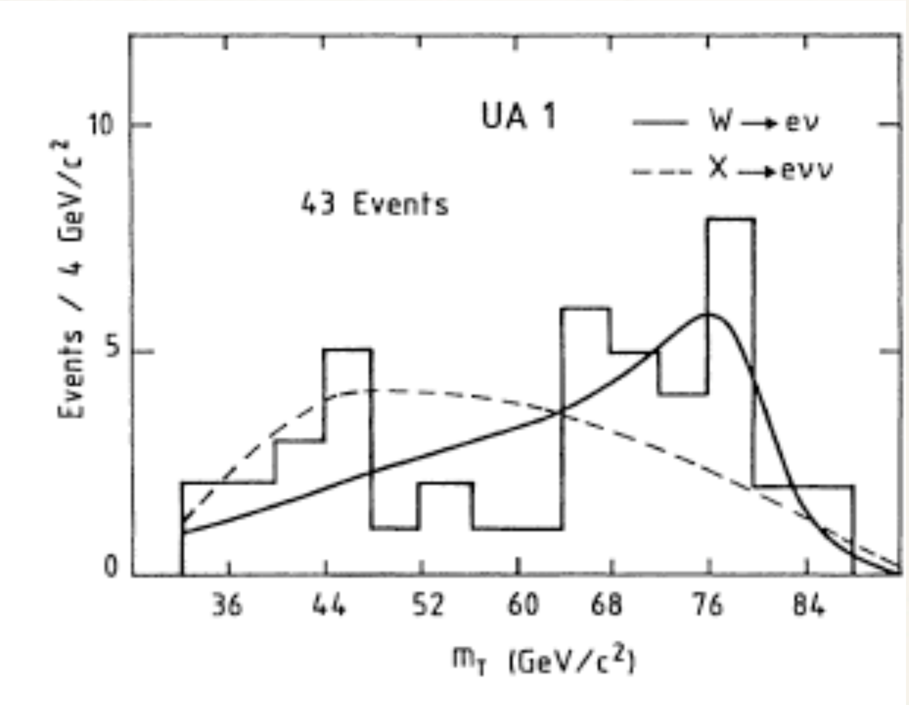
- this motivates a search based on jets and missing transverse energy

$$H_T = \sum_{jets} p_T \quad \overrightarrow{MET} = - \sum_{\text{particles}} \vec{p}_T$$

- the difficulty is to control the large Standard Model backgrounds
  - much larger backgrounds compared to leptonic searches
  - especially need to control the QCD background

- there are various hadronic SUSY searches in CMS
  - either based on classical MET and H_T or different kinematic variables (α_T, Razor, M_{T2})

from M_T to M_{T2}



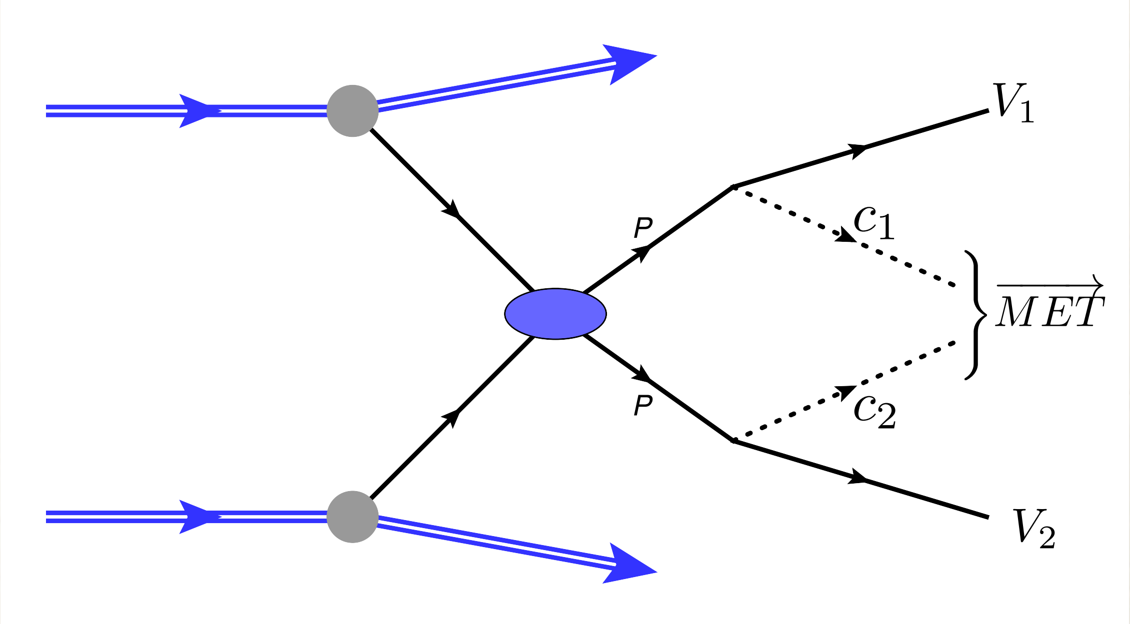
- let's recall the discovery of the W-boson in UA1
  - in the decay W(eν), the W-mass is accessible via its transverse projection M_T
  - M_T has an endpoint at the true W-mass

year 1985

today

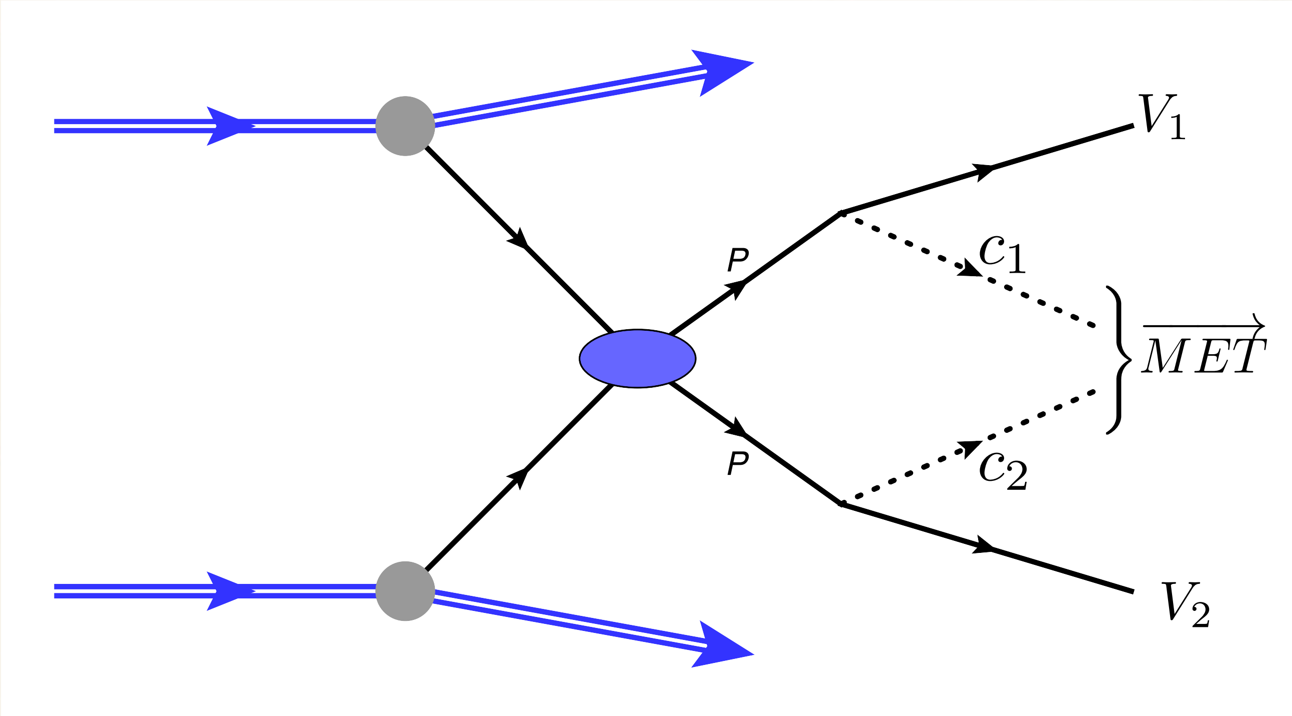
- at the LHC, assuming R-Parity conservation, SUSY events give rise to two decay chains (legs) with an unobserved child (c_1 and c_2) at each end.

- the "stransverse mass" M_{T2} was introduced as an extension of the transverse mass M_T for the SUSY case of one unobserved particle from each decay chain.



what is M_{T2} ?

$$M_{T2}(m_c) = \min_{p_T^{c(1)} + p_T^{c(2)} = p_T^{miss}} \left[\max \left(m_T^{(1)}, m_T^{(2)} \right) \right]$$



- M_{T2} remains a function of the mass of the unobserved child m_c
- in case m_c were known, the endpoint of M_{T2} would correspond to the parent mass m_p.

- M_{T2} was designed to measure SUSY masses once an excess is observes
  - here we use it purely as a discovery variable to distinguish between SM and SUSY-like events

why M_{T2} in a hadronic search?

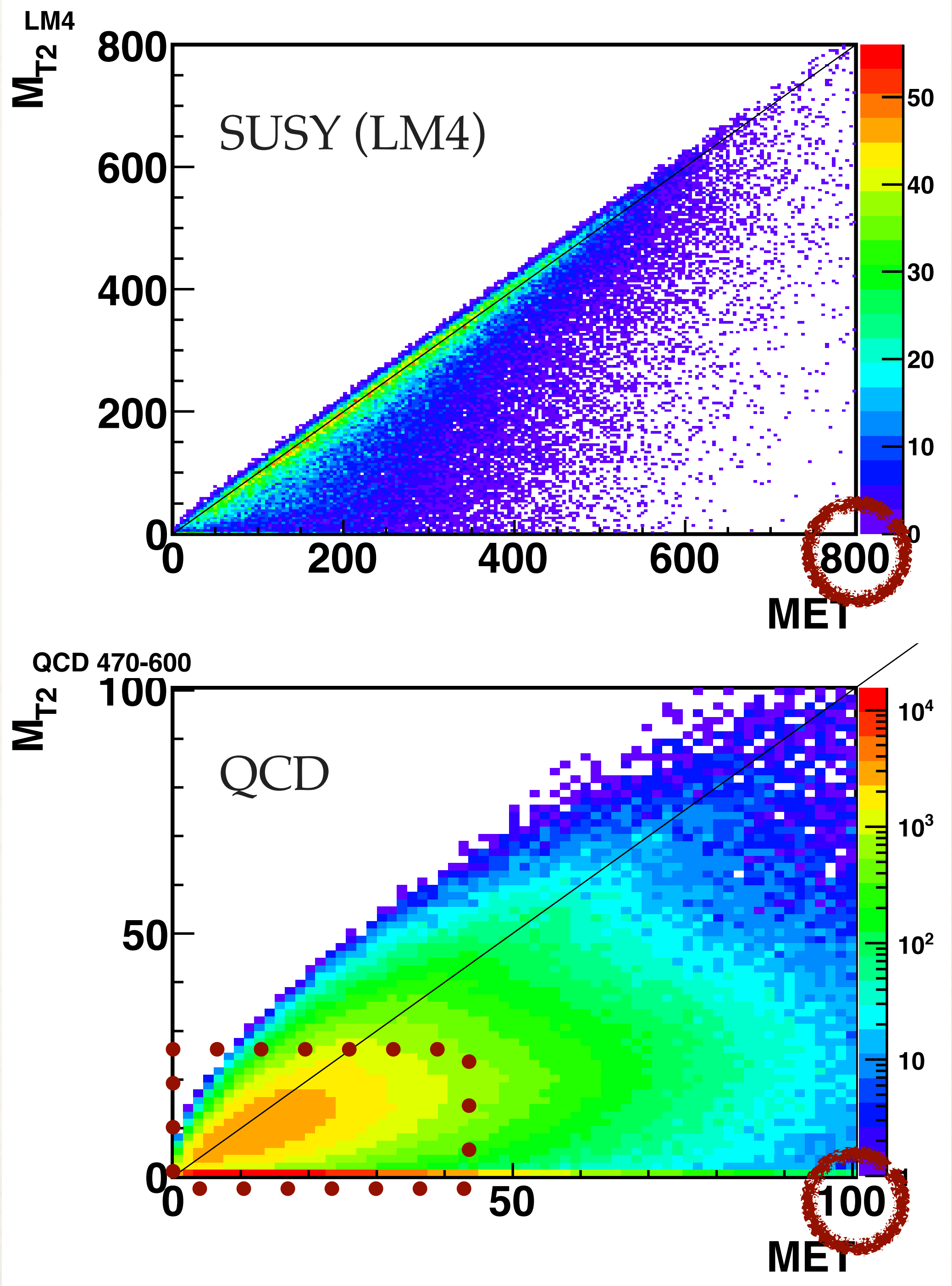
- in the simplified case of no ISR / upstream transverse momentum and zero masses of the visible systems and the unobserved particles, we have

$$M_{T2}^2 = 2p_T^{(1)}p_T^{(2)}(1 + \cos\phi_{1,2})$$

- from this we know:
  - $M_{T2} = 0$ for back-to-back systems
  - $M_{T2} \approx$ MET for symmetric systems i.e. $p_T^{(1)} = p_T^{(2)}$

- (symmetric) signal like events have $M_{T2} \approx$ MET

- QCD with no genuine MET:
  - well measured events give back-to-back (pseudo)-jet, hence $M_{T2} \approx 0$
  - nearly back-to-back but asymmetric (i.e. imbalanced) (pseudo)-jets are typical for QCD mis-measurements. in this case $M_{T2} <$ MET.



analysis strategy

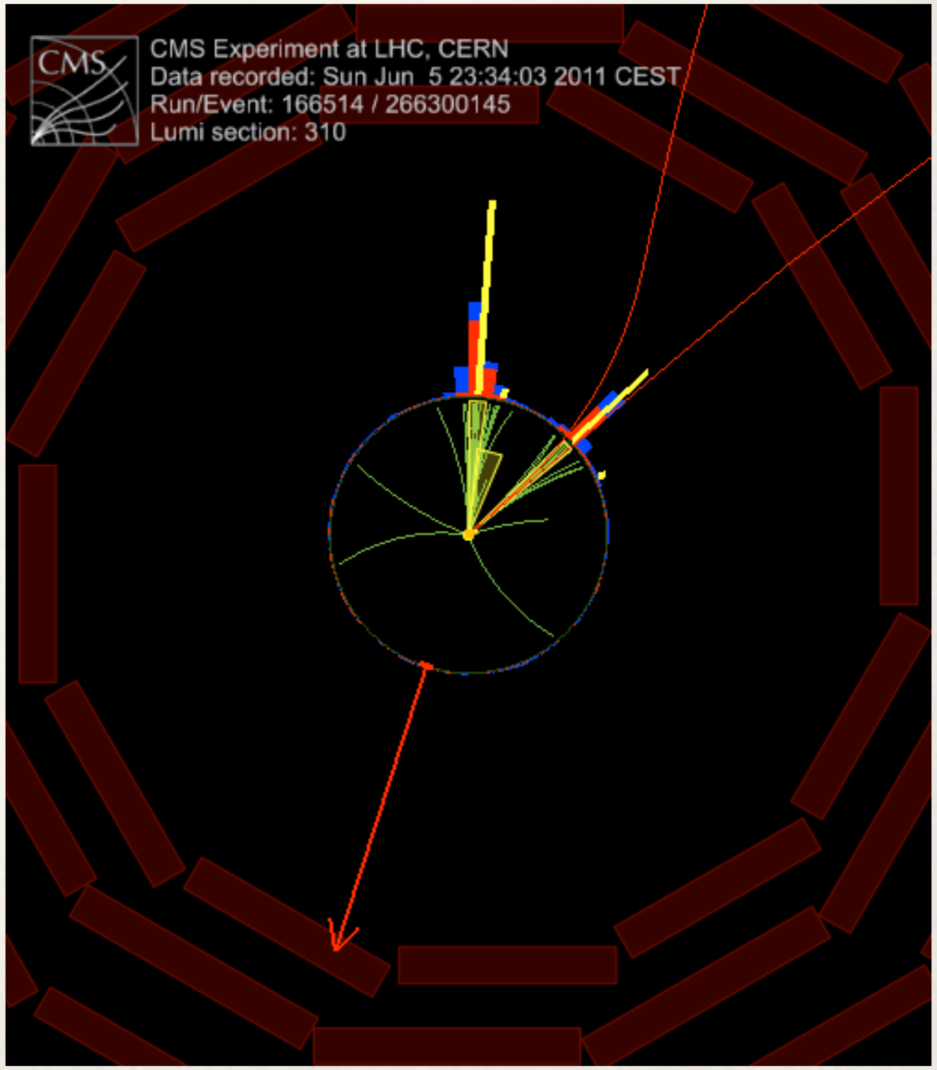
- this is a tail search for SUSY based on H_T (large hadronic activity) and M_{T2} (where the "usual" cut on MET is replaced by a cut on M_{T2})

- cut and count experiment:
  - select events with large HT (significant hadronic activity) and use M_{T2} as a search variable

- two lines of approach:

- "high M_{T2} analysis" with a hard cut on M_{T2}
  - sensitive to SUSY-like signals with large HT and large MET
- "low M_{T2} analysis" with a lower cut on M_{T2}
  - targeting SUSY-like signals with relatively little MET

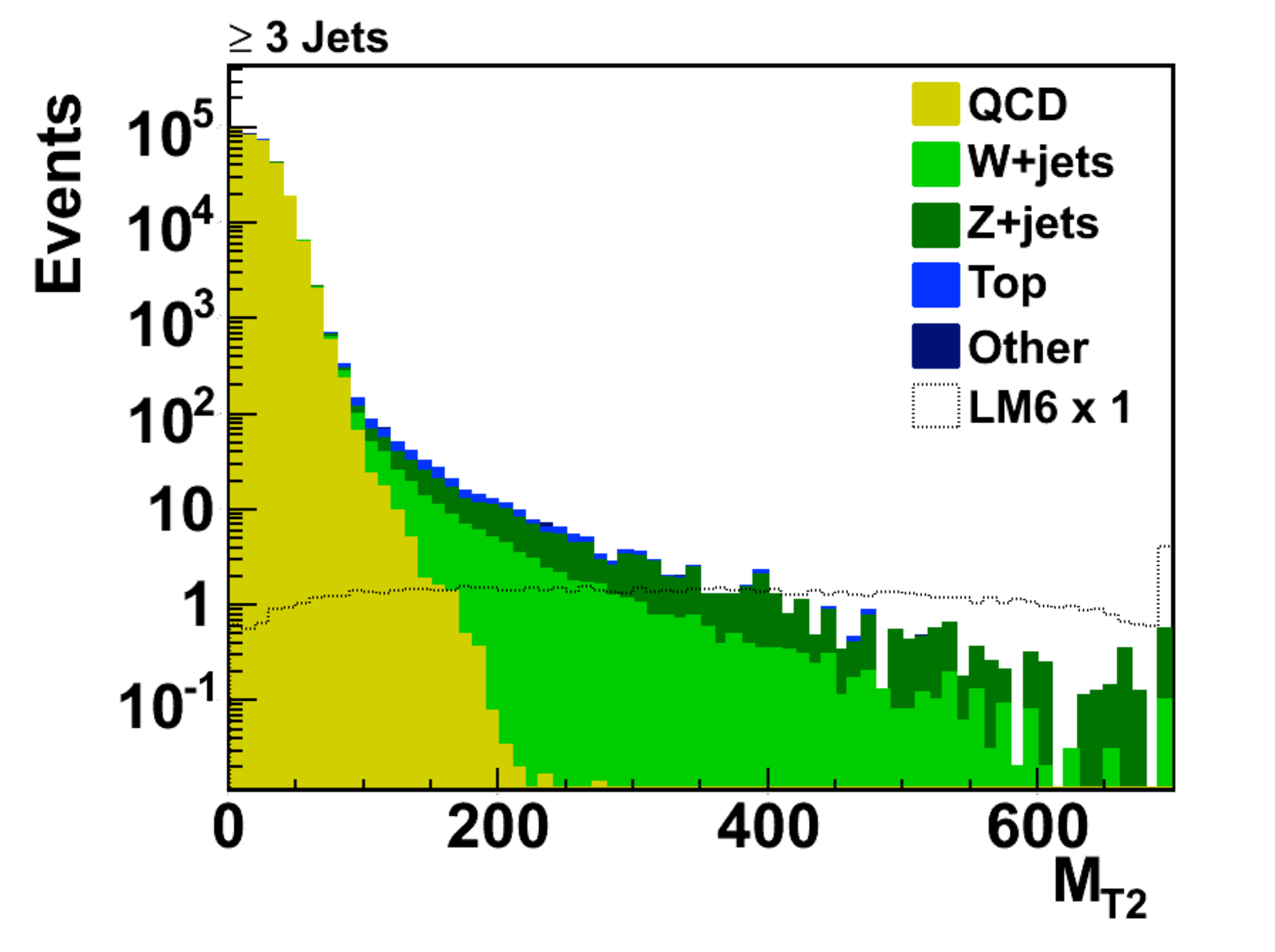
- on the right you see an example for the kind of events we are looking for



analysis strategy: high M_{T2} analysis

- high M_{T2} analysis
  - at least 3 jets
  - HT > 600 GeV
  - M_{T2} > 300 GeV

- low M_{T2} region is dominated by QCD
  - at high M_{T2}, the QCD contamination is very small
- at high M_{T2}, the dominant backgrounds are:
  - leptonic W+jets decays where the lepton is "lost" (not isolated or outside the acceptance)
  - invisible Z(νν)+jets decays.

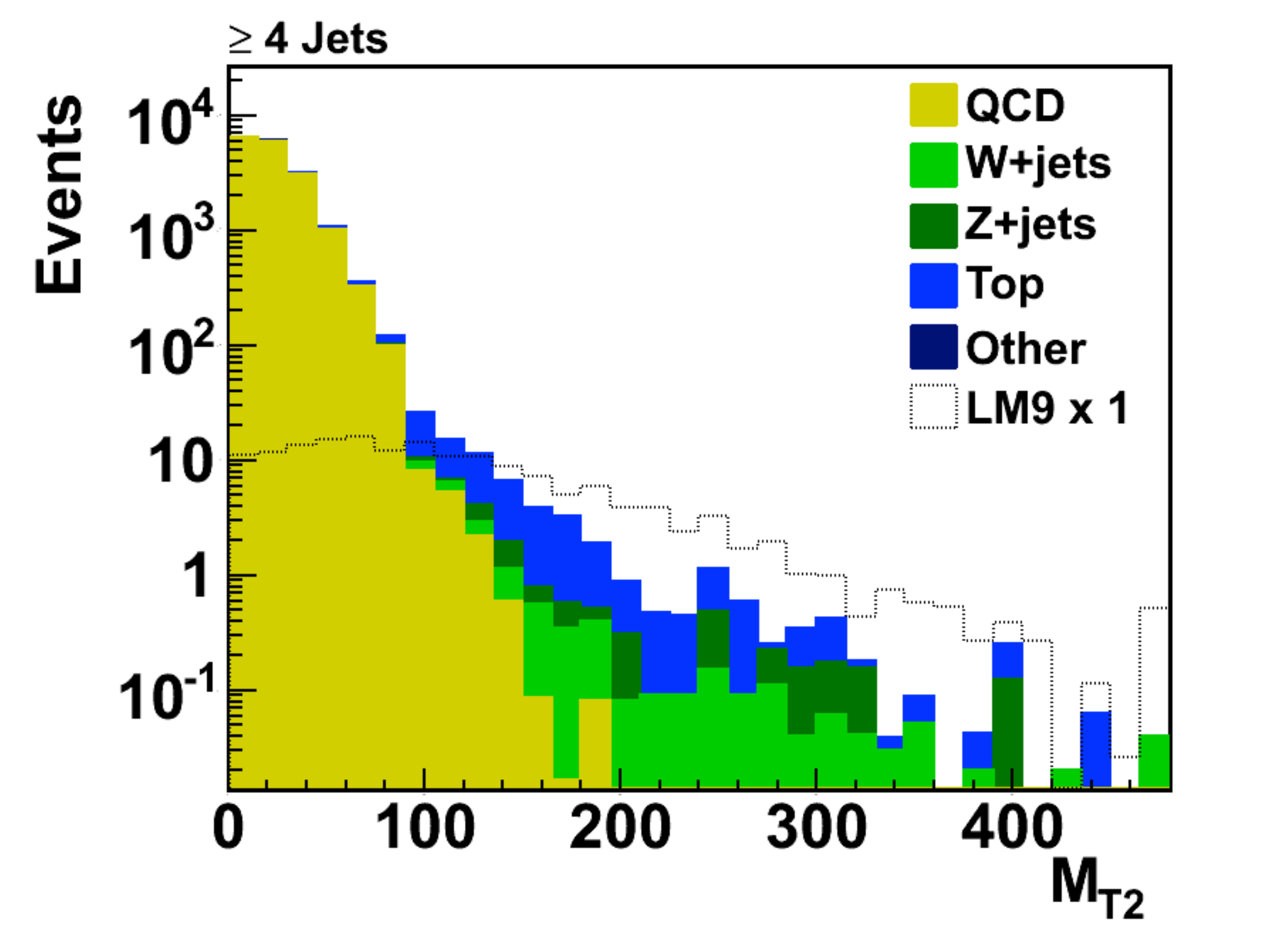


analysis strategy: low M_{T2} analysis

- second line of approach: increase the sensitivity to SUSY signals with heavy squarks and light gluinos, where relatively little MET is produced

- low M_{T2} analysis
  - at least 4 jets
  - at least 1 b-tagged jet
  - HT > 650 GeV
  - M_{T2} > 150 GeV

- this gives a different composition of the dominant backgrounds
  - W+jets and Z(νν) largely reduced
  - ttbar is the dominant background (predominantly semi-leptonic ttbar with a "lost lepton" or hadronic tau decays)



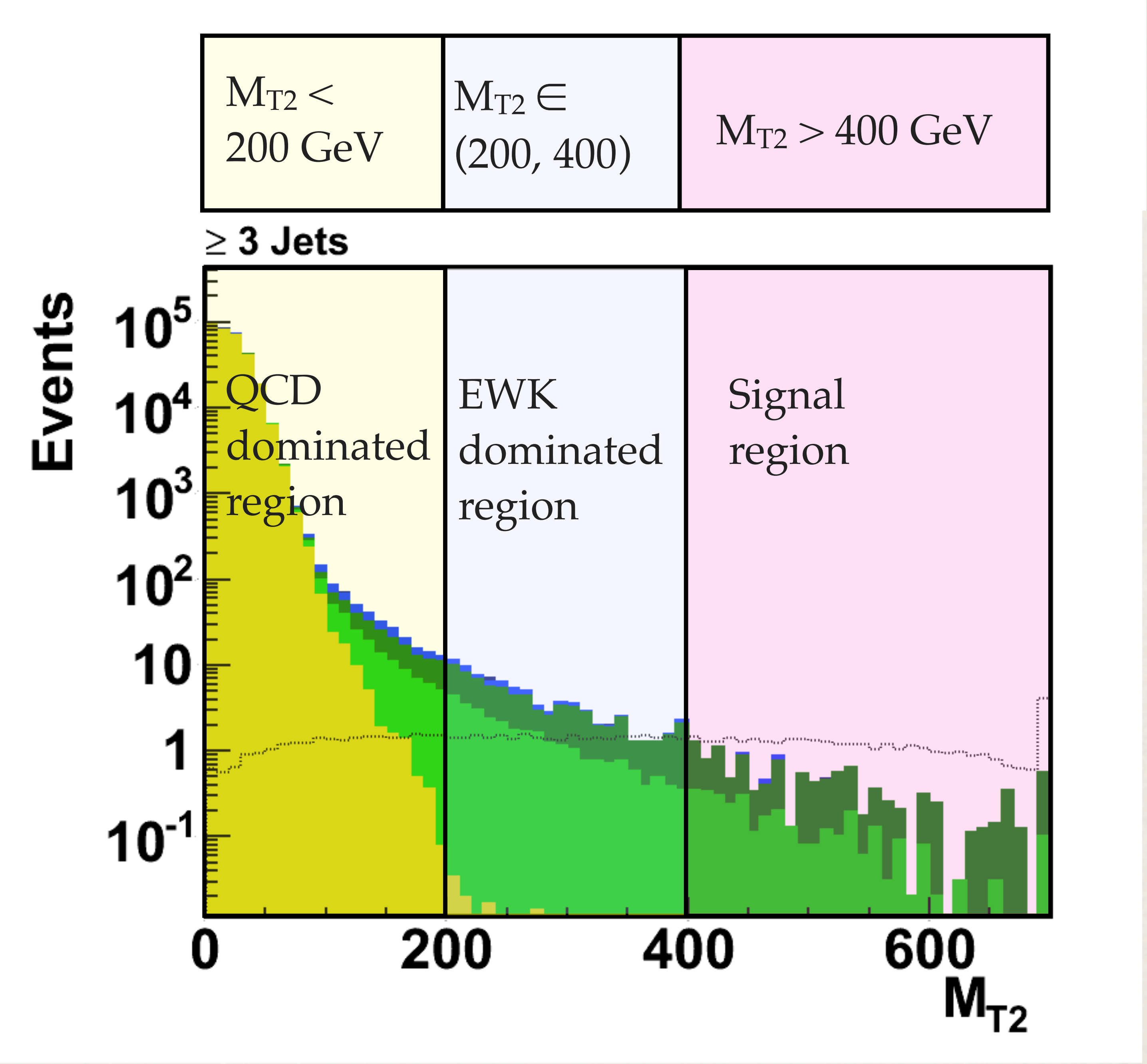
background prediction strategy

- we need a reliable and robust background estimate in the signal region for $M_{T2} > 400$ GeV

- QCD background estimated very conservatively from data

- data driven methods to assign uncertainties to the individual components of EWK and Top backgrounds in the EWK control region
    - in the signal region, scale the data-driven uncertainties according to MC ratio of uncertainties in control and signal regions

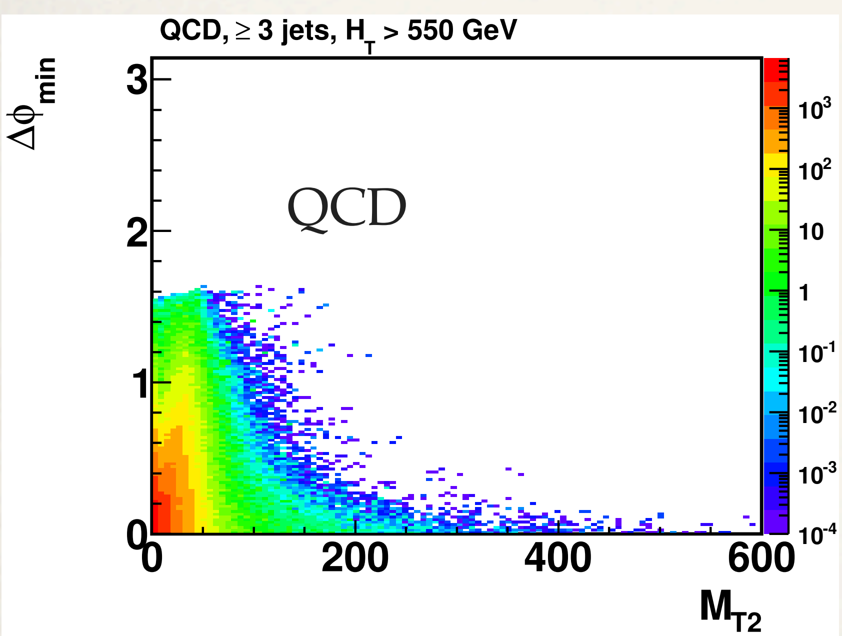
- EWK and Top MC calibrated to data in the EWK dominated region ($200 < M_{T2} < 400$ GeV).

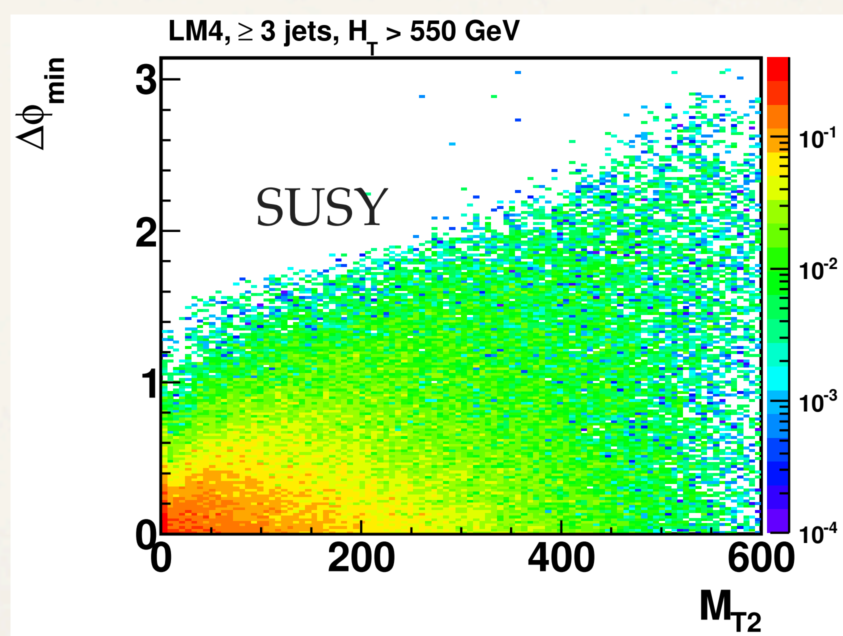


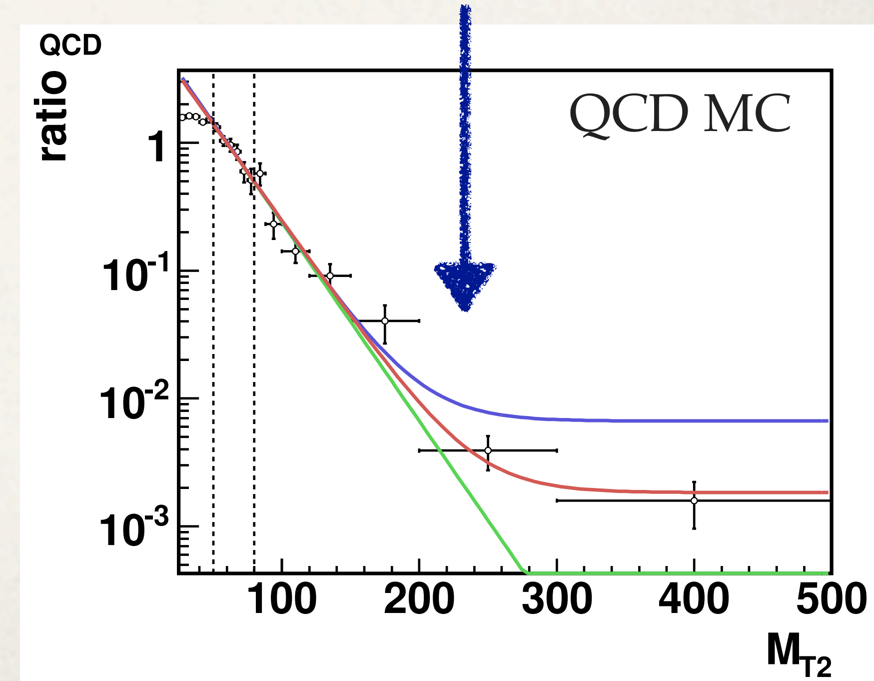
QCD estimate

- the QCD background in the signal region is small compared to the electroweak backgrounds
  - need to extract an upper limit on the QCD contamination in the signal region to be ready for a discovery!
- well measured QCD events do not have MET=M_{T2}=0: MET comes from mis-measurements!
  - an under-measured jet produces a MET-vector aligned with the jet → small Δϕ(jet, MET)
- QCD events with large M_{T2} have large MET and thus small minΔϕ(jets, MET).
- we predict the QCD contamination in the signal region (at minΔϕ > 0.3) from a QCD enhanced control region (at minΔϕ<0.2).
- since minΔϕ and M_{T2} are correlated, we need to know the functional form

$$r(M_{T2}) = \frac{N(\min\Delta\varphi \geq 0.3)}{N(\min\Delta\varphi \leq 0.2)} = \exp\left(a - b \cdot M_{T2}\right) + c$$







W+jets and ttbar lost lepton background

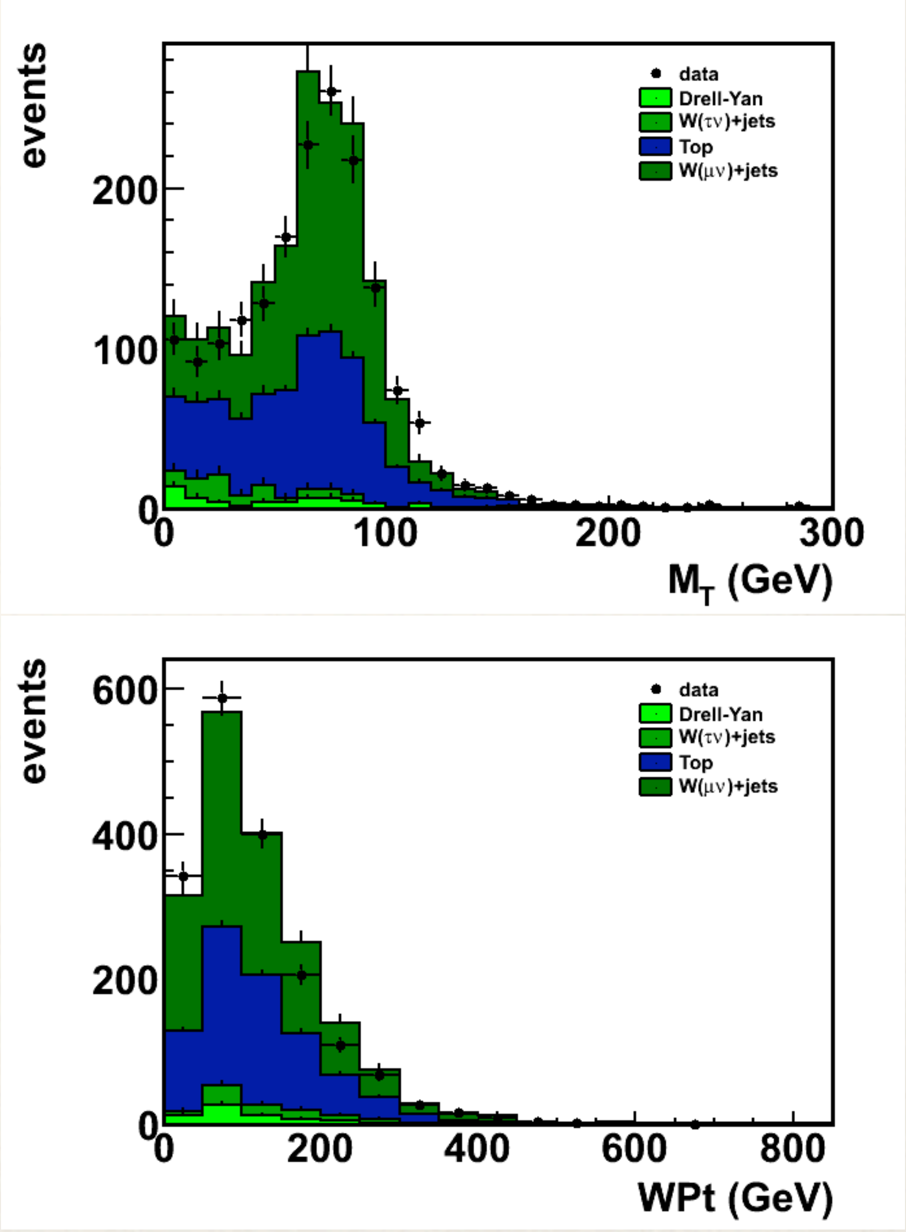
- electroweak and ttbar backgrounds in tail of M_{T2} must have large MET
  - W(lν) and (semi)-leptonic ttbar with a high p_T ν
  - this background can be largely reduced by vetoing events with electrons and muons
- remaining background
  - hadronic τ-decays
  - e or μ outside the acceptance
  - e or μ not isolated or not identified

} → lost lepton

- we estimate the "lost lepton" contribution from W+jets and semi-leptonic ttbar from electrons or muons

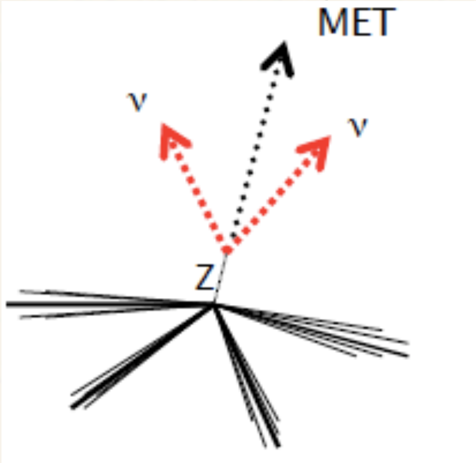
$$W_{e,\mu}^{pass\ veto} = (N_{e,\mu}^{reco} - N_{e,\mu}^{bg})\frac{1-\varepsilon_{e,\mu}}{\varepsilon_{e,\mu}}$$

- $\varepsilon_{e,\mu}$: probability for a W(lν) event to have a e or μ reconstructed (taken from MC)

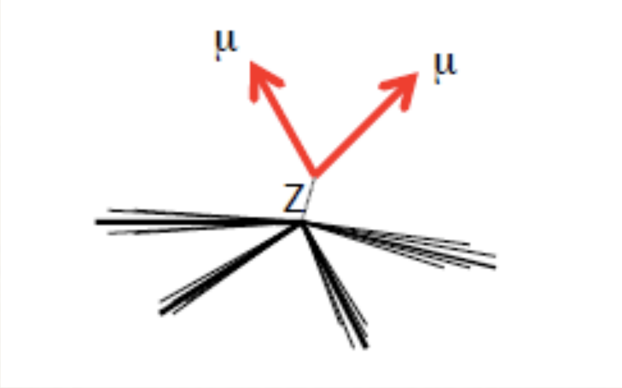


Z(νν) background for high M_{T2} analysis

- the dominant SM contribution to the M_{T2} tail in the "high M_{T2} analysis" is due to Z(νν)+jets

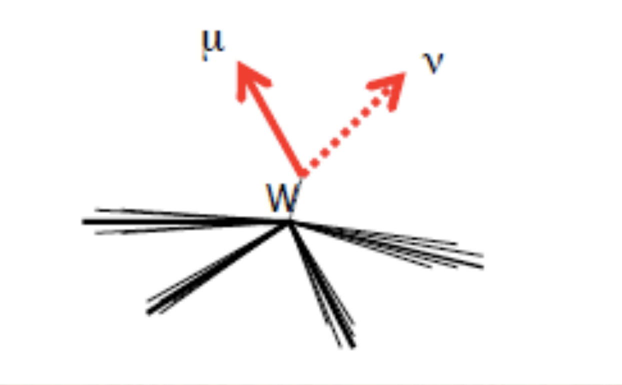


- Z(l+l-) with removed leptons
  - statistically very limited :(
  - very much data-driven: same kinematics



- only used as a cross-check

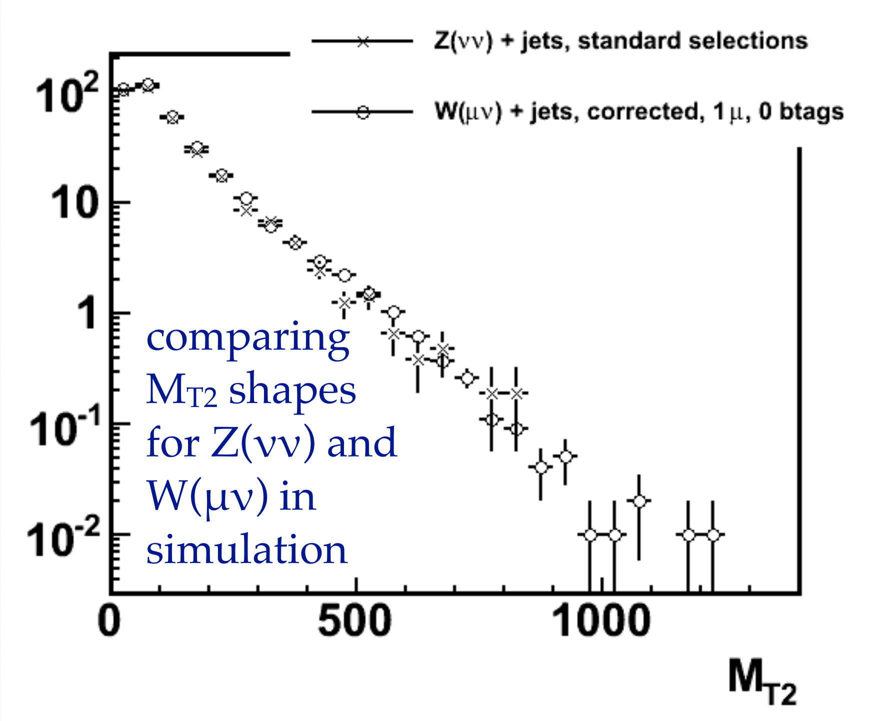
- W(μν) with removed lepton
  - enough statistics
  - need correction factor to account for different kinematics: determined from MC



- main method

Z(νν) background estimate from W(μν)

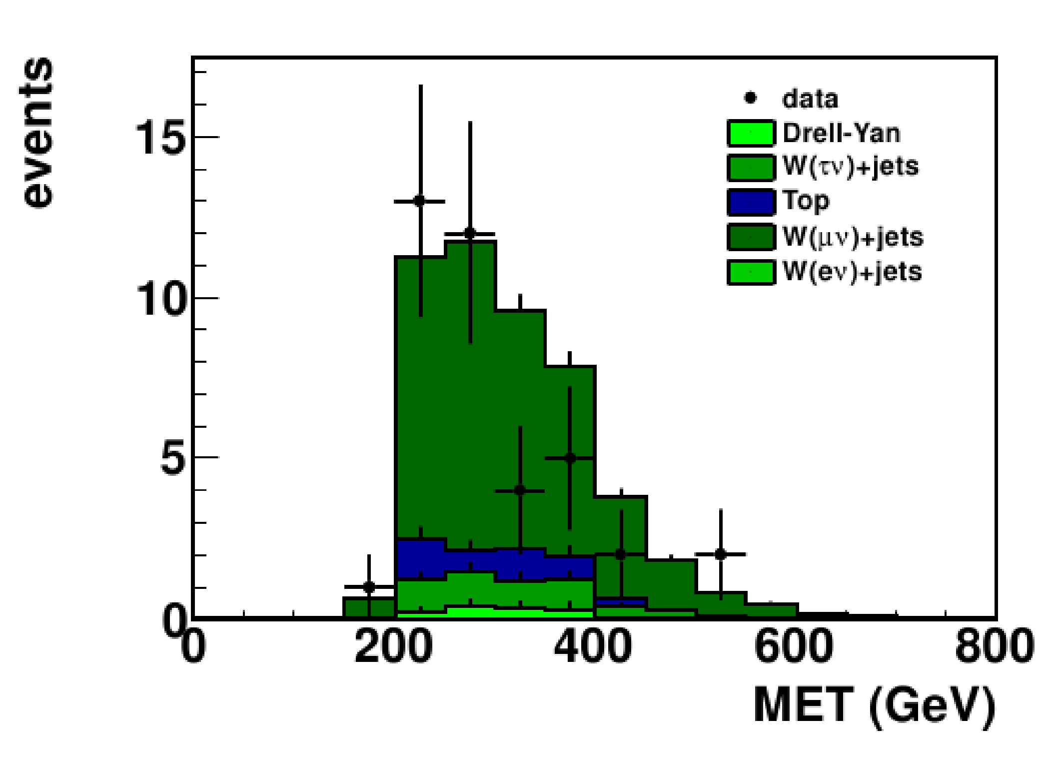
- W(μν) enriched sample is obtained with all the selection cuts and:
  - request of exactly 1 muon
  - b-tag veto to suppress ttbar background
  - $200 < M_{T2} < 400$ GeV (control region)



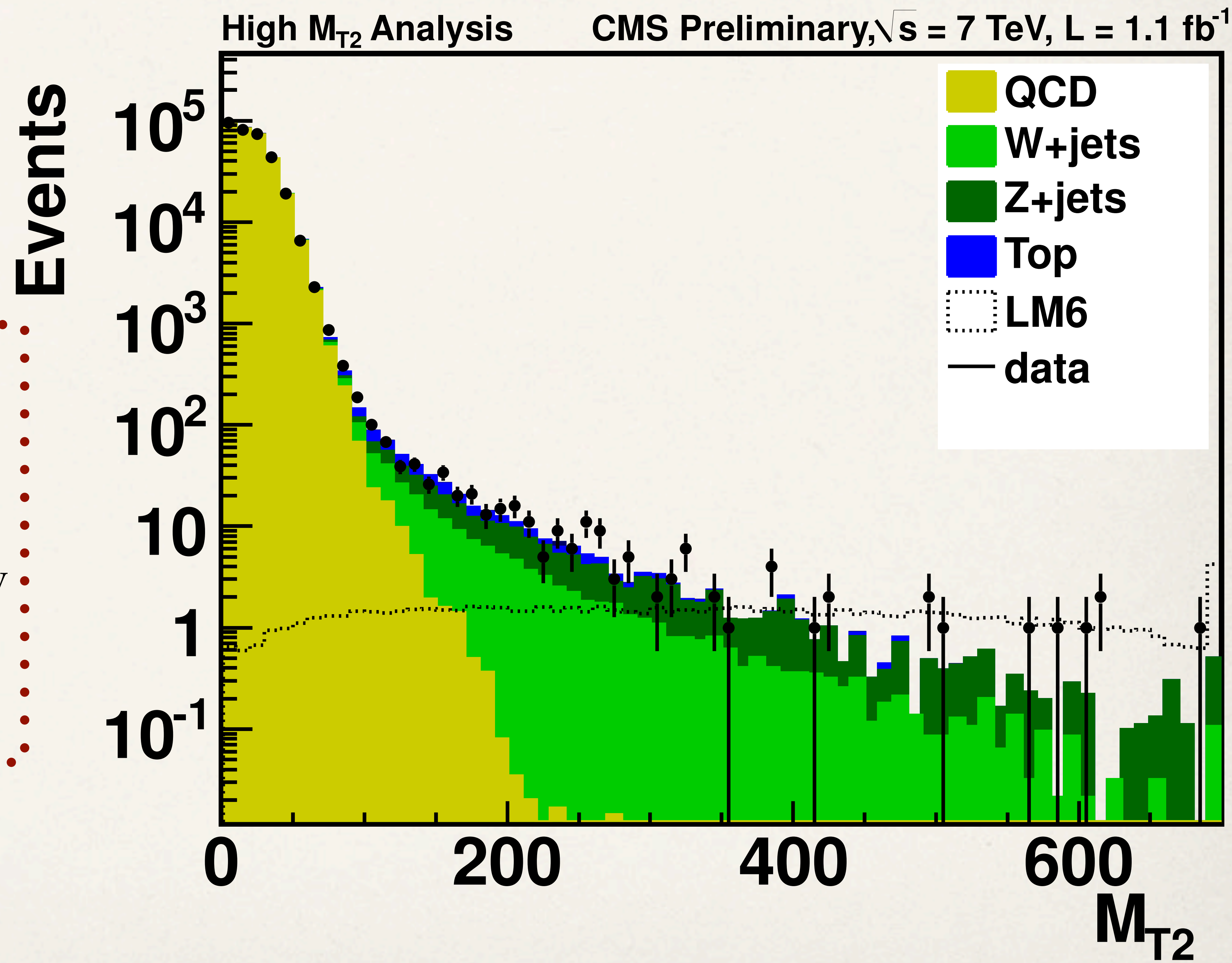
- Z(νν) events are mimicked by removing the muon (adding it to the MET-vector) and recomputing relevant quantities

- Z(νν) background estimated as:

$$N_{Z\nu\nu}(est) = W(\mu\nu) \cdot \frac{1}{\epsilon_{acc}\epsilon_{reco/iso}} \cdot R_{ZW}$$



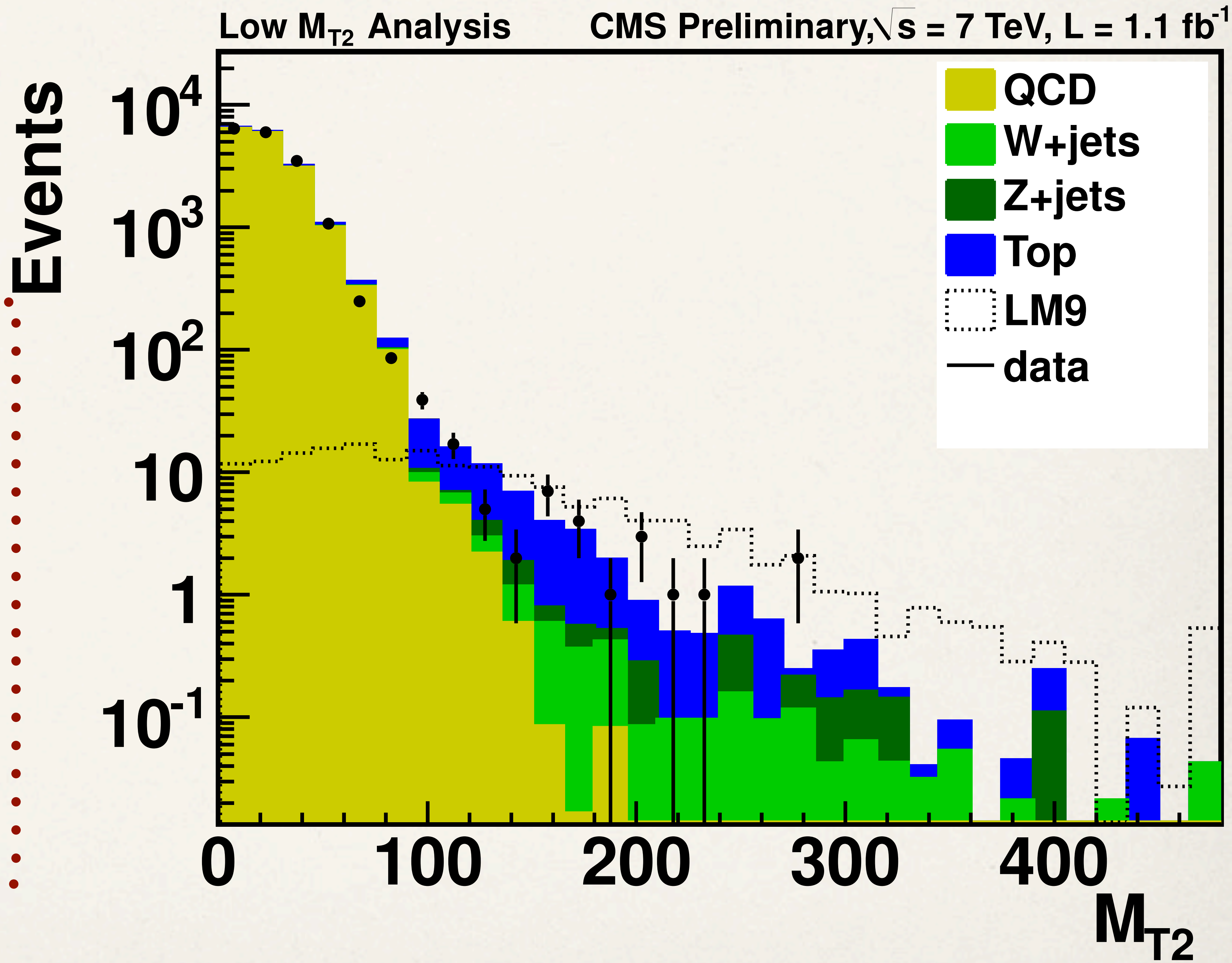
results for High M_{T2} Analysis



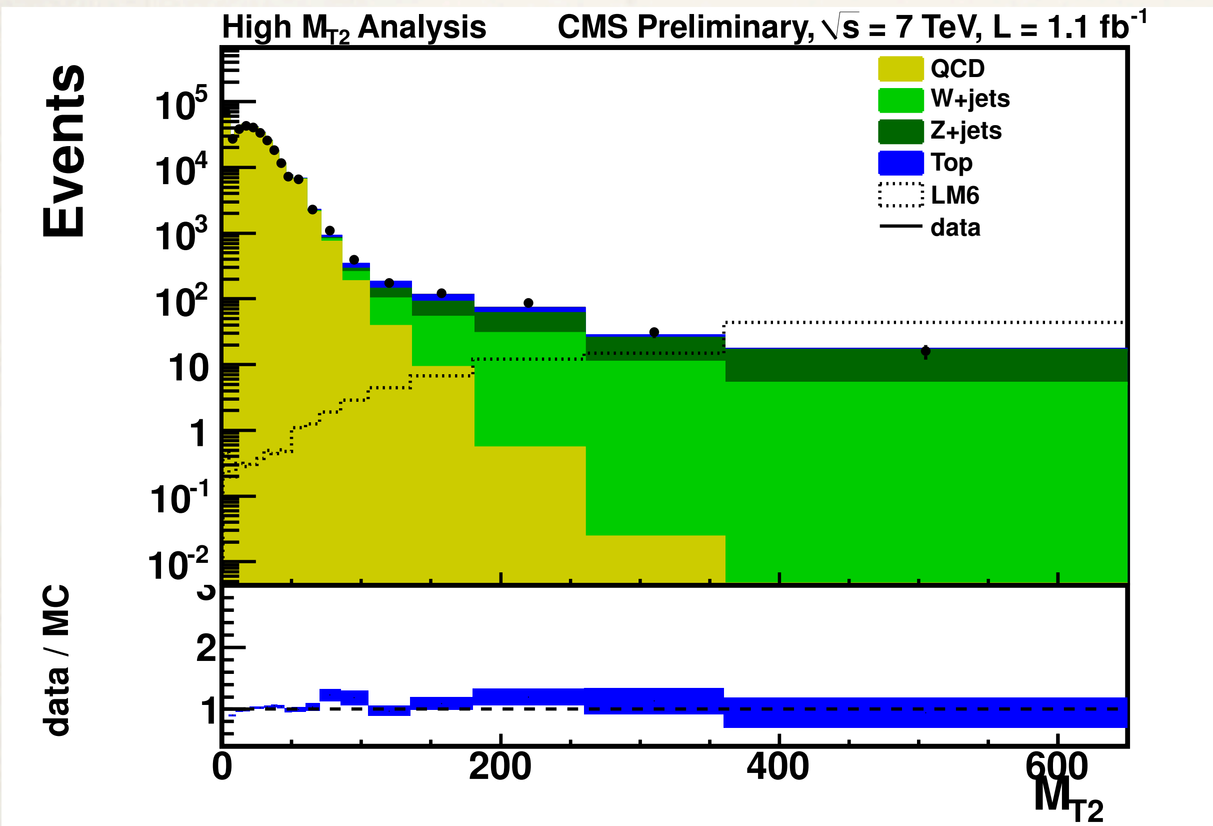
- data compared to simulation "out-of-the-box".
  - simulation scaled to 1.1 fb^{-1}
  - good agreement between data and simulation for low M_{T2} (QCD dominated) as well as in the EWK dominated region.

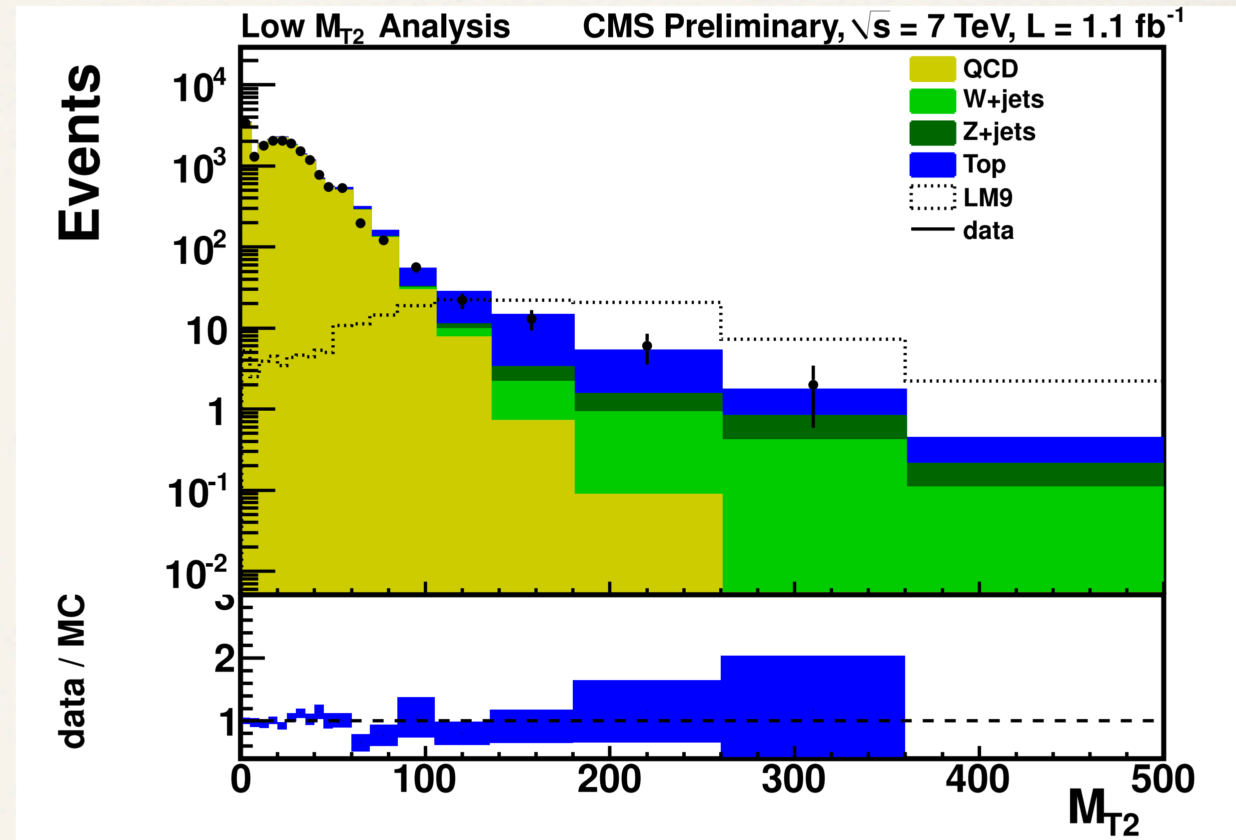
results for Low M_{T2} Analysis

- data compared to simulation "out-of-the-box".
  - simulation scaled to 1.1 fb^{-1}
  - limited statistics in control region $100 < M_{T2} < 150$ GeV
  - good agreement between data and simulation for low M_{T2} (QCD dominated) as well as in the Top dominated region.



results for High and Low M_{T2} Analyses





- results for 1.1 fb^{-1} of integrated luminosity:

Search	MC bkg prediction	Data	Final bkg prediction
High M_{T2}	10.6	12	12.6 ± 1.3 (stat) ± 3.5 (sys)
Low M_{T2}	14.3	19	10.6 ± 1.9 (stat) ± 4.8 (sys)

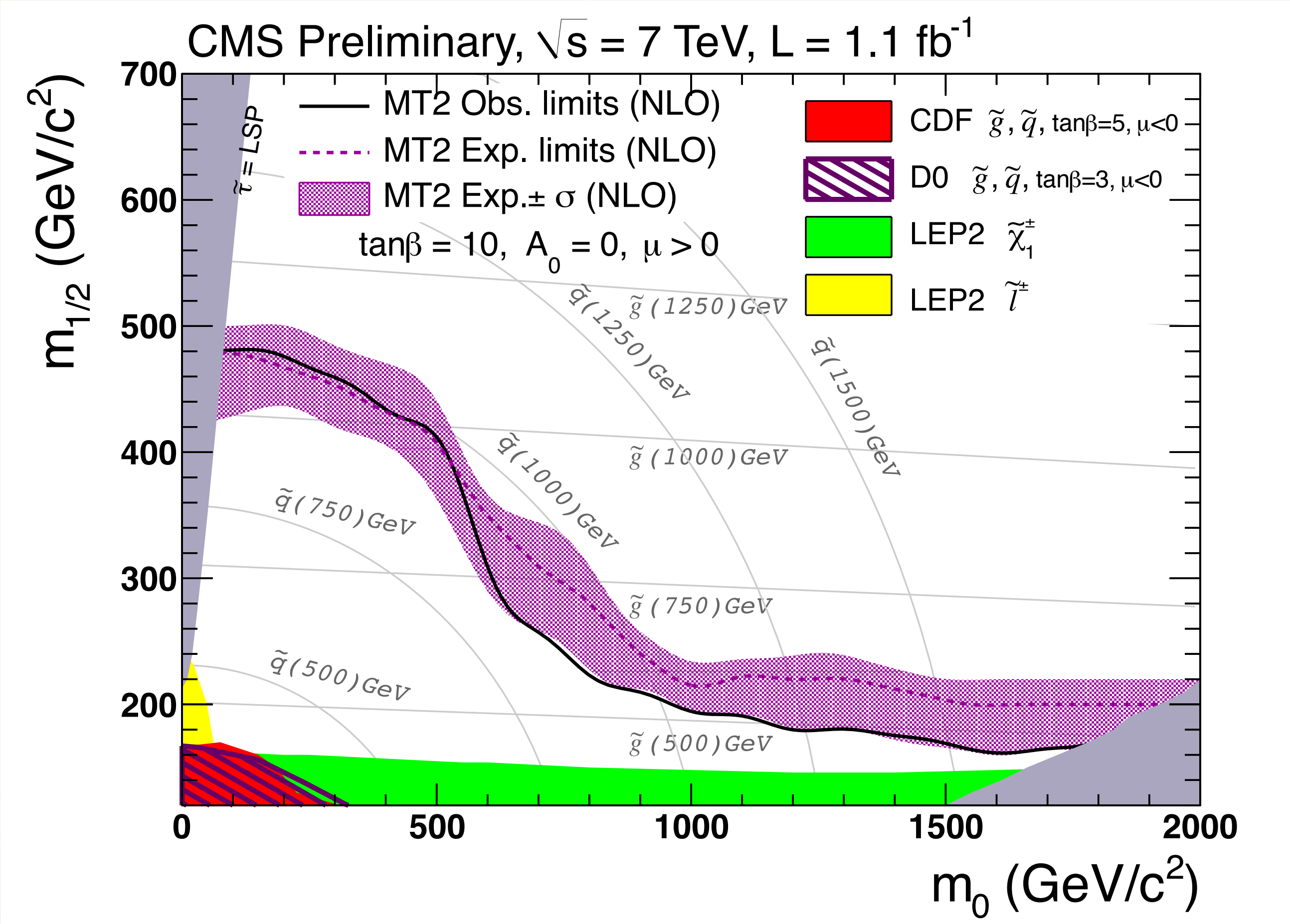
due to down-fluctuation of data in the control region $100 < M_{T2} < 150$ GeV

interpretation

- model independent limits on a signal are derived:
  - upper limits at 95% C.L. on cross-section times branching ratio within our acceptance (using CLs method with a Gaussian for the nuisance parameters).

Process	$\sigma \times$ BR (pb)	
	observed limit	expected limit
High M_{T2} analysis	0.010	0.011
Low M_{T2} analysis	0.020	0.014

- exclusion limits at 95% C.L. have been determined in the mSUGRA/CMSSM (m_0, $m_{1/2}$) plane:
  - results are shown for A_0 =0, μ >0 and tanβ =10



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summary

- motivated the use of the "stransverse" mass M_{T2} to separate SM from SUSY like events
- presented a new search for SUSY in fully hadronic final states with the CMS detector using 1.1 fb^{-1} of data
  - this is a tail search based on H_T and M_{T2}
- the analysis follows two lines of approach:
  - high M_{T2} analysis: for signal with large MET
  - low M_{T2} analysis: for signals with large H_T but relatively low MET
- no signal has been observed. exclusion limits in the CMSSM plane have been set.
- more info ...
  - given on our public Twiki-page
  - public CMS Physics Analysis Summary can be found on the CERN document server