SUSY search in the fully hadronic final state

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PHYSICS AT THE TERA SCALE
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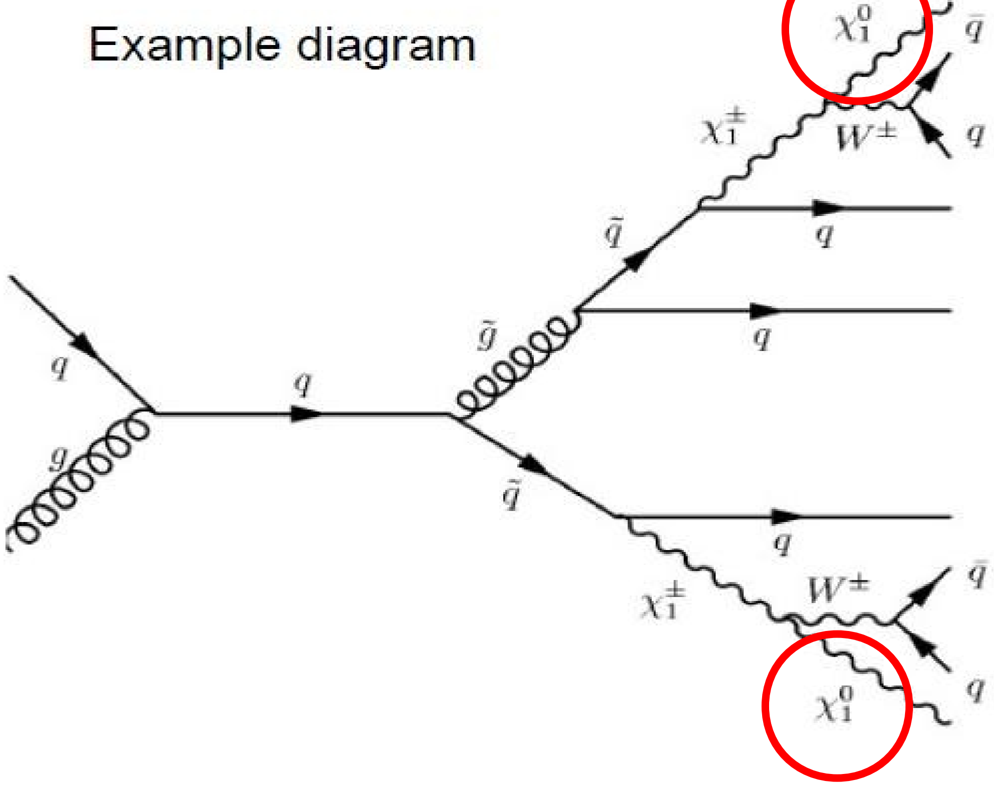
Outline

- Introduction to SUSY search in the fully hadronic channel
- Data-driven background estimation methods: **QCD**
  - **Factorization method (ABCD)**
  - **Rebalance and Smear method**
- Data-driven background estimation method: **$t\bar{t}$ & W+jets**
  - **Lost Lepton** method
  - Tag and Probe method
- Combination of background estimates
- Summary

At the LHC particles with colour charge are produced dominantly.
The initial states are therefore squark/gluino, 2 squarks or 2 gluinos.

Typical SUSY decay cascade



R-parity conservation

- ➔ pair/associated SUSY production
- ➔ stable LSP

Cascade decay of primarily-produced SUSY particles

- ➔ missing ET
- ➔ many Jets
- ➔ possibly leptons

Inclusive Hadronic Analysis

For the inclusive Njet SUSY search the following cuts are applied:

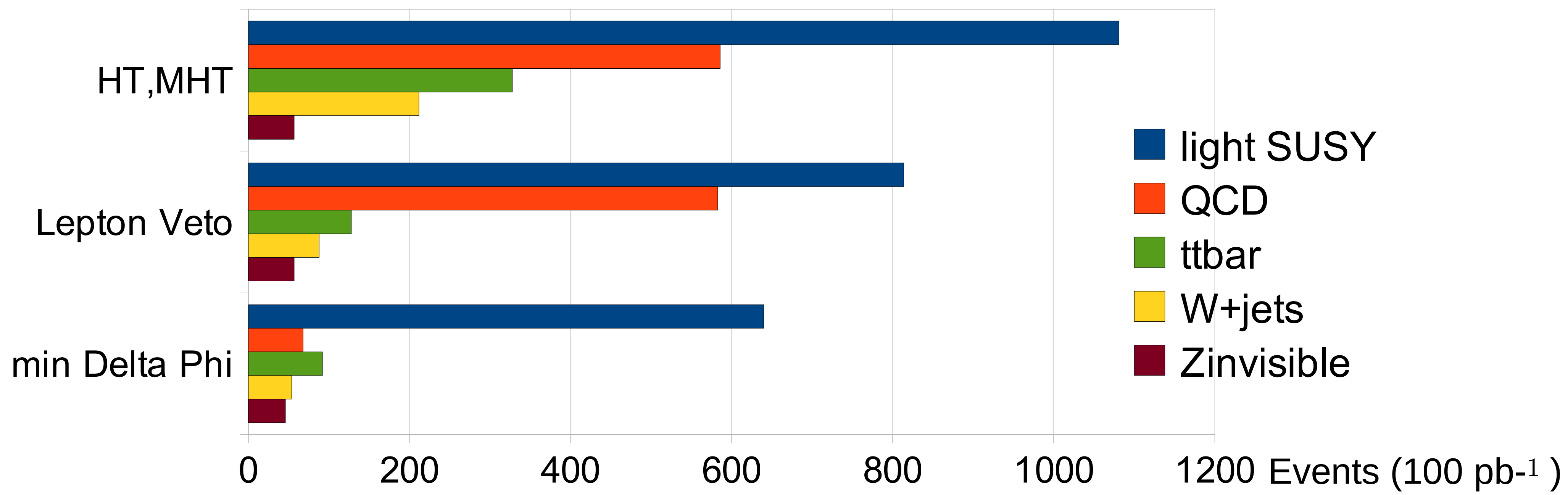
3 Jets with P_T > 50 GeV , |η| < 2.6

H_T > 300 GeV (scalar sum of jets with P_T> 30 GeV)

Missing H_T > 150 GeV (vectorial sum of jets with P_T> 30 GeV)

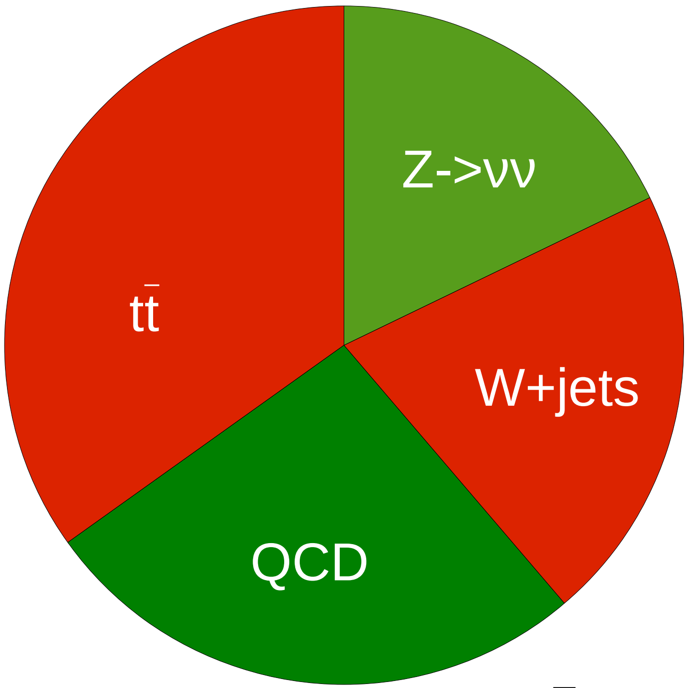
Direct Lepton Veto (= no isolated lepton allowed)

ΔΦ > 0.3 (0.5 Jet2) (ΔΦ (Jet1/2/3, missing H_T))



Direct Lepton Veto (DLV) mainly rejects leptonic Ttbar and W+jet events

Inclusive Hadronic Background



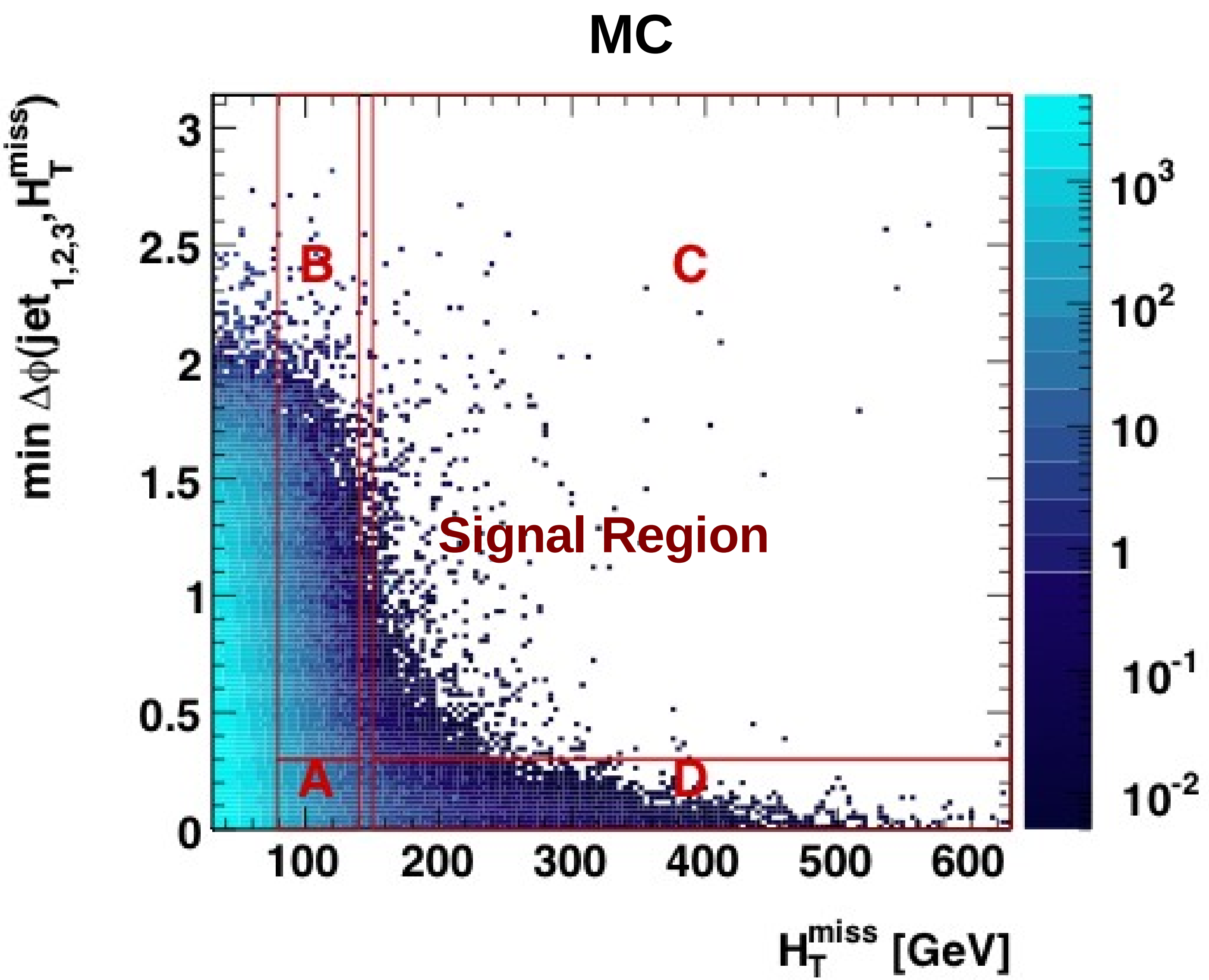
Events after selection

<u>Estimating background in HH:</u>
Factorization-method for QCD
Resolution for jet smearing for QCD
Lost Lepton in ttbar and W+jets
→ Limit / reach calculation

- **Even if the simulation describes our detector well:**
  - **QCD multijet dynamics poorly modelled**
  - **Lepton isolation/identification (in)efficiencies should be measured in data**

Factorization method for QCD (ABCD)

- In QCD: Missing H_T is produced via jet mismeasurement
- Correlation between worst measured jet and Missing HT vector
- Influence on Missing HT from other jets approximately Gaussian (since coming from Gaussian part of jet resolution)

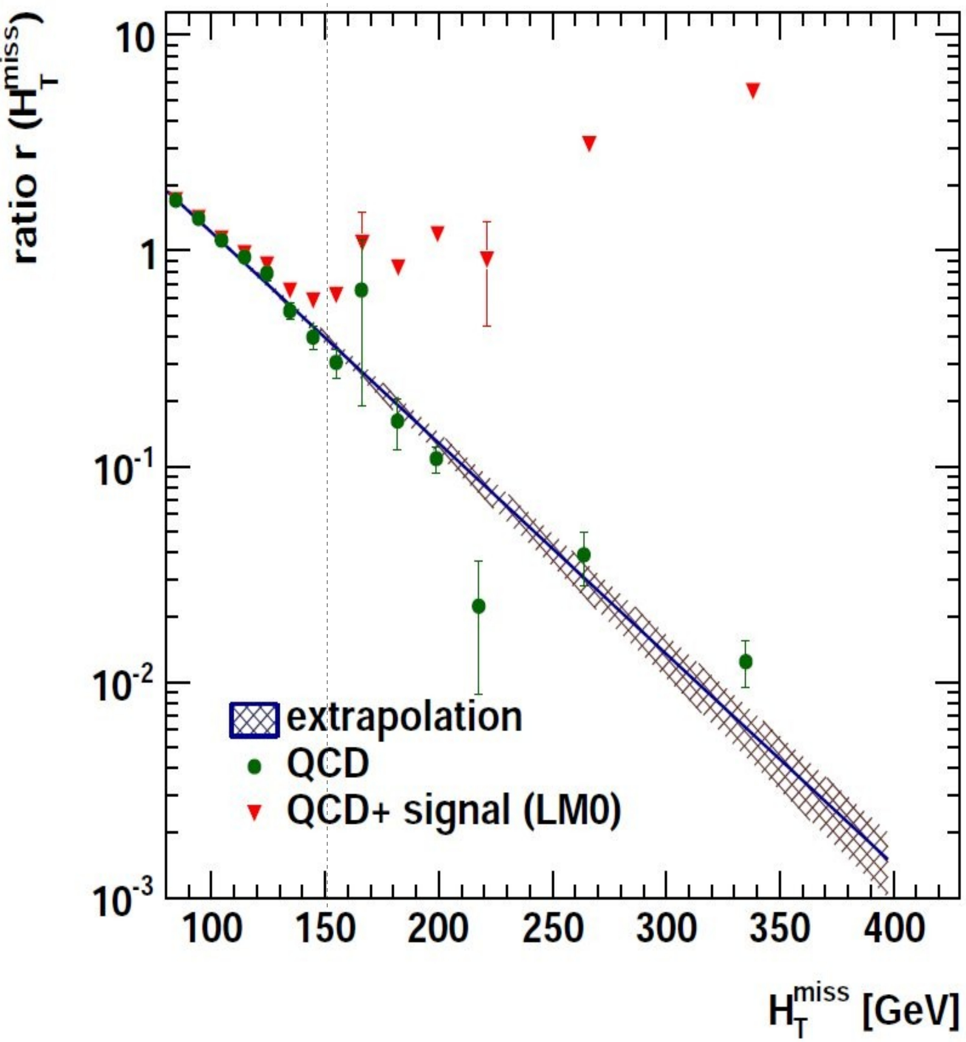


Background regions (A,B,D) are QCD dominated

QCD estimation in presence of a SUSY Signal

- Ratio of events that pass the min ΔΦ-cut to events that fail the cut falls exponentially with HTmiss
- Example SUSY signal (LM0) has impact on high Missing HT region
- Control region for the fit must be in the QCD dominated region
- Variation of upper boundary shows the influence on the extrapolation

MC

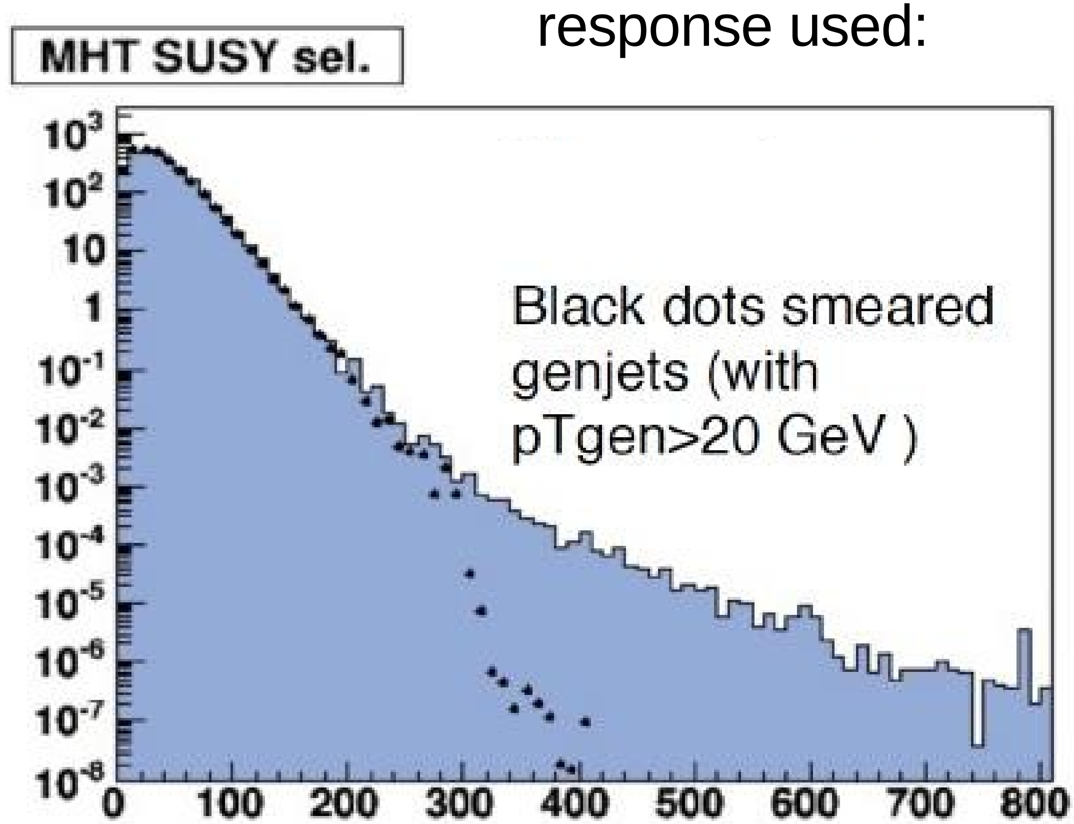


Motivation: Data driven prediction of MHT from QCD

Rebalance & Smear method:

- Rebalance detector level jets to particle level jets
- Smear rebalanced jets to predict MHT
- Jet response enters twice
- Non-Gaussian tails are important for high MHT tail

Only Gaussian jet response used:

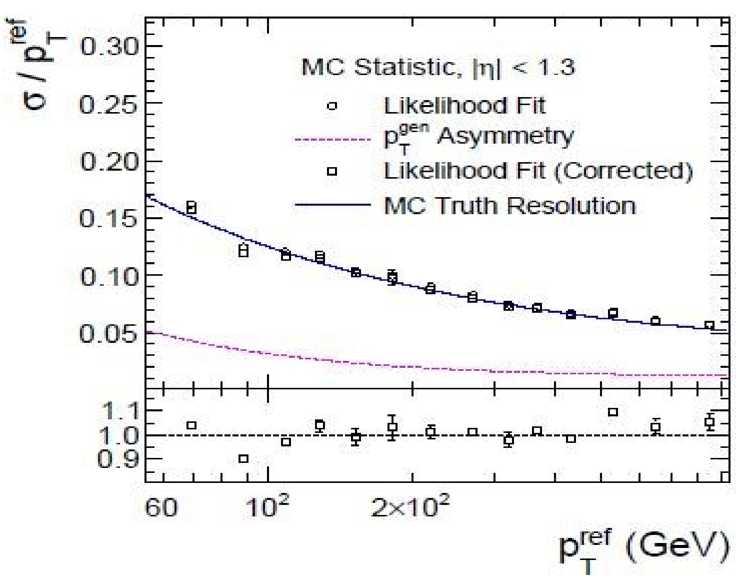


Unbinned maximum likelihood fit of dijet imbalance

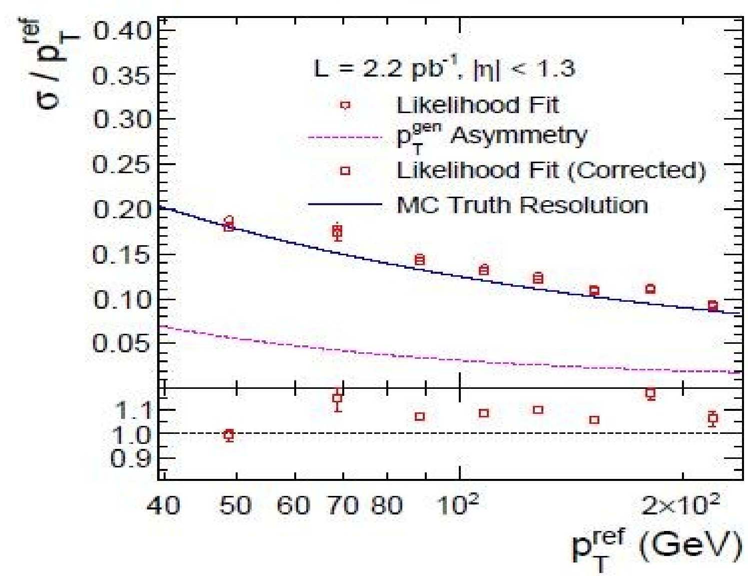
Assumption Two jets with equal particle level jet p_T

Method Adjust response to describe measured p_T imbalance

MC (closure test)



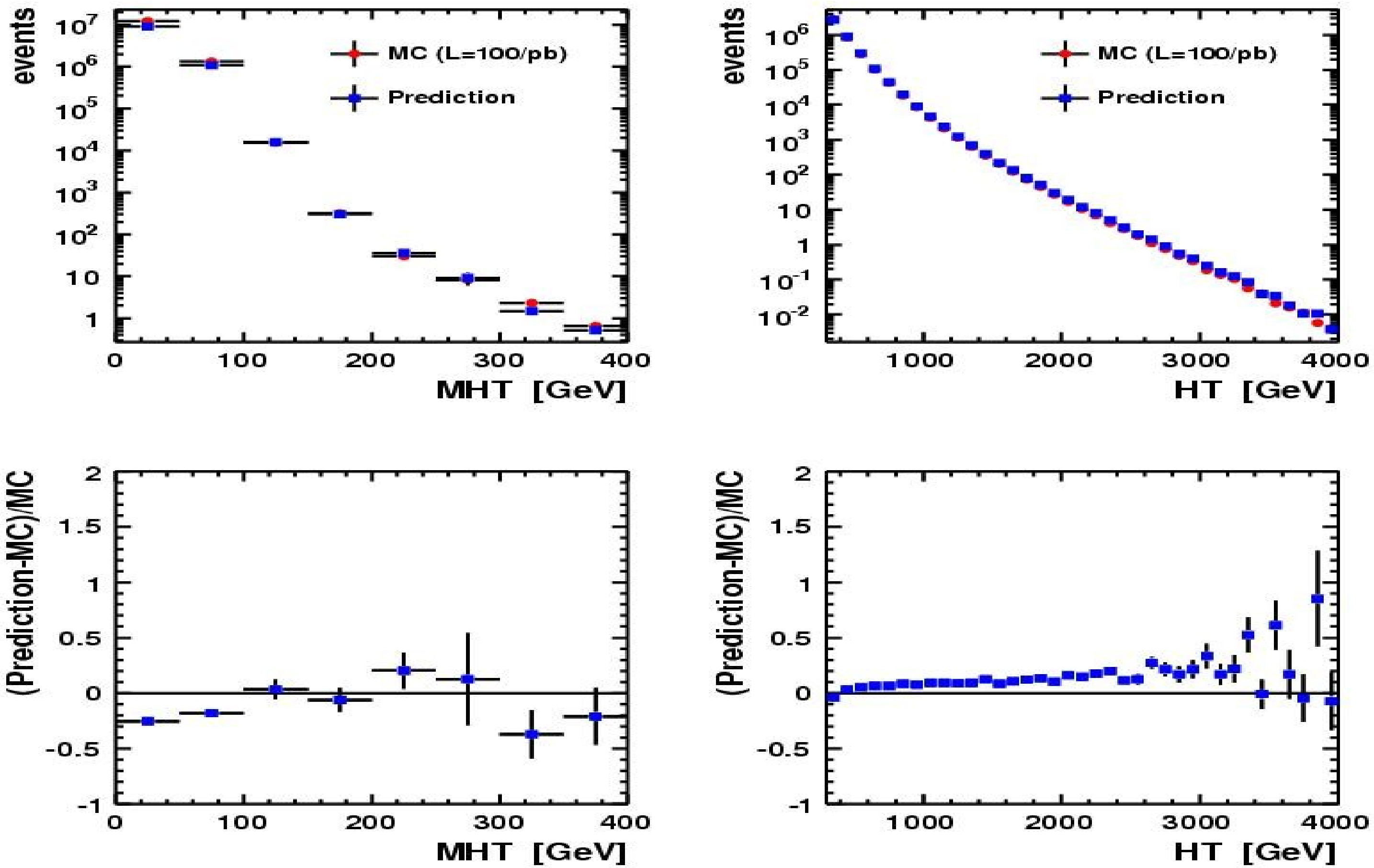
Data



MC Closure of the method — agreement to true resolution

Data Measured resolution 10% larger than simulated

Test of Rebalance and Smear



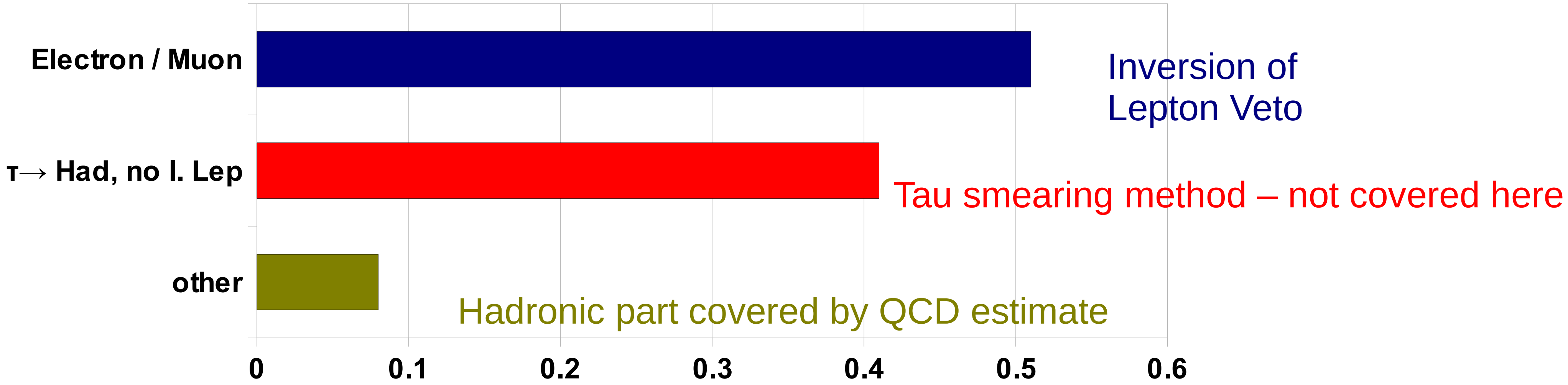
- Good agreement between Prediction and MC for HT and MHT
- Shown after jet- and cleaning-cuts
- Resolution taken from MC with tails

(Semi-)leptonic $t\bar{t}$ & W+jet background

Most important reasons why no lepton is identified:

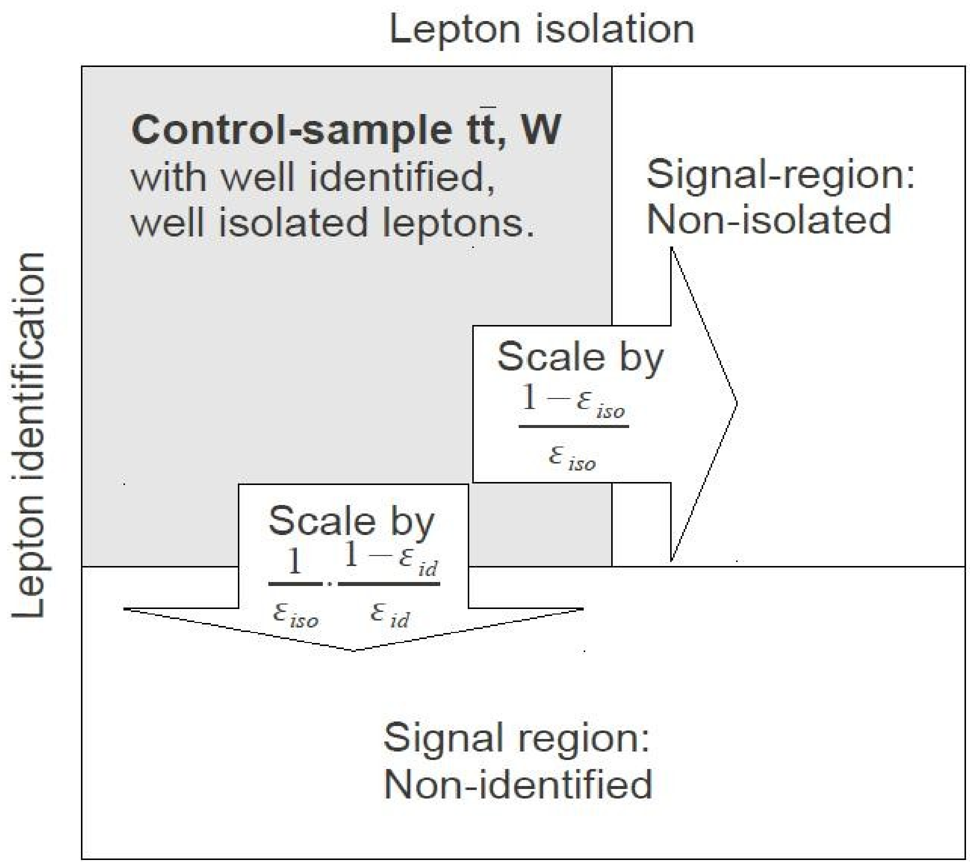
- Lepton is a tau that decays hadronically
- Lepton is out of acceptance (pt or eta)
- Lepton is not reconstructed
- Lepton is reconstructed, but not isolated

Fraction of ttbar background:



Also tau -> electron/muon in Lost Lepton method – hadronic tau may also be present

Lepton Veto-Cut Inversion (e/mu - channel)



Reconstruction efficiencies (ε_{ID}):

- function of P_T and η
- from tag and probe method $Z \rightarrow ll$

Isolation efficiencies (ε_{Iso}):

- function of ΔR(lep,jet) and P_T to resolve differences between $t\bar{t}$,W+jet and Z-events

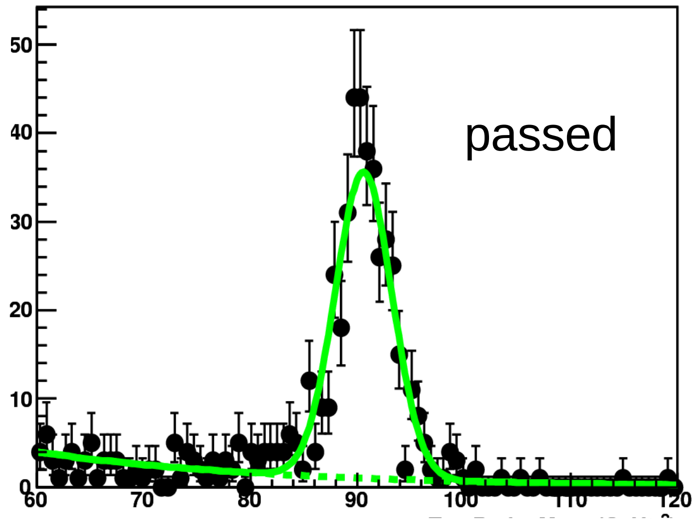
Acceptance:

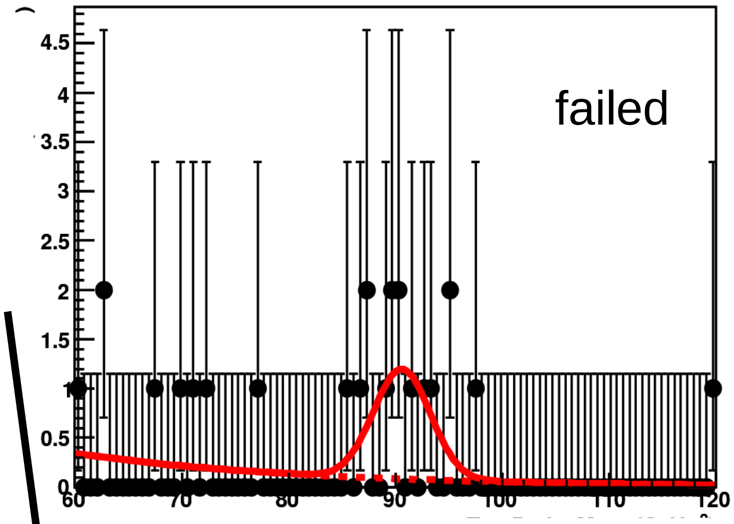
- P_T / η distribution from simulation (small uncertainties)

Total $t\bar{t}$ and W+jets background =
Bkg(non-isolated) + Bkg(non-identified) + Bkg(out of acceptance)

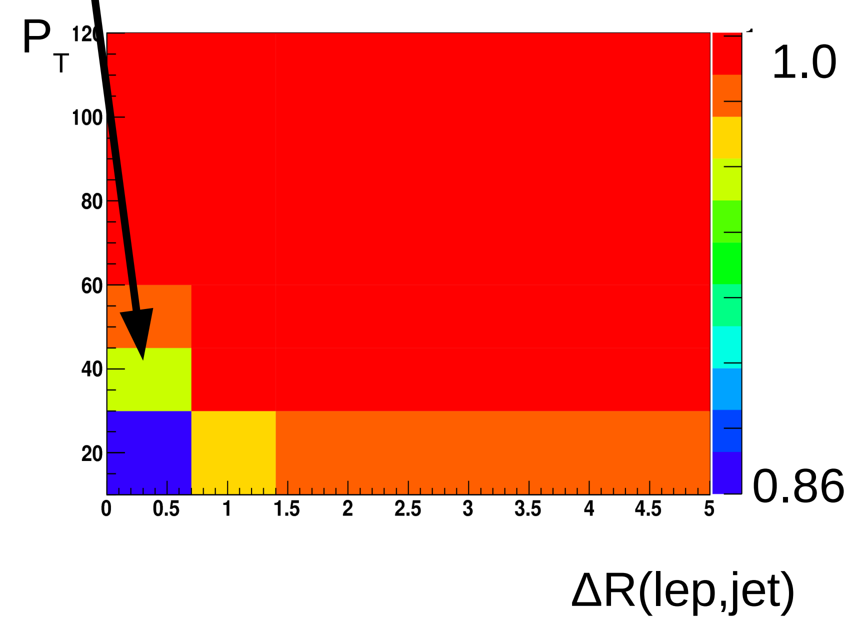
Tag & Probe Muon Isolation Efficiency

15/pb - data



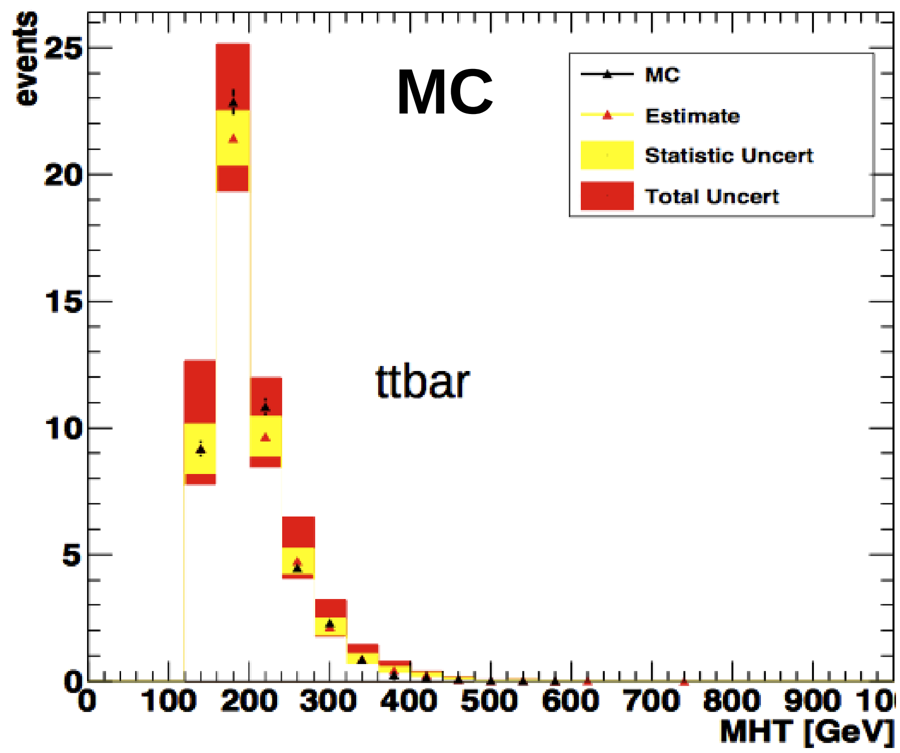


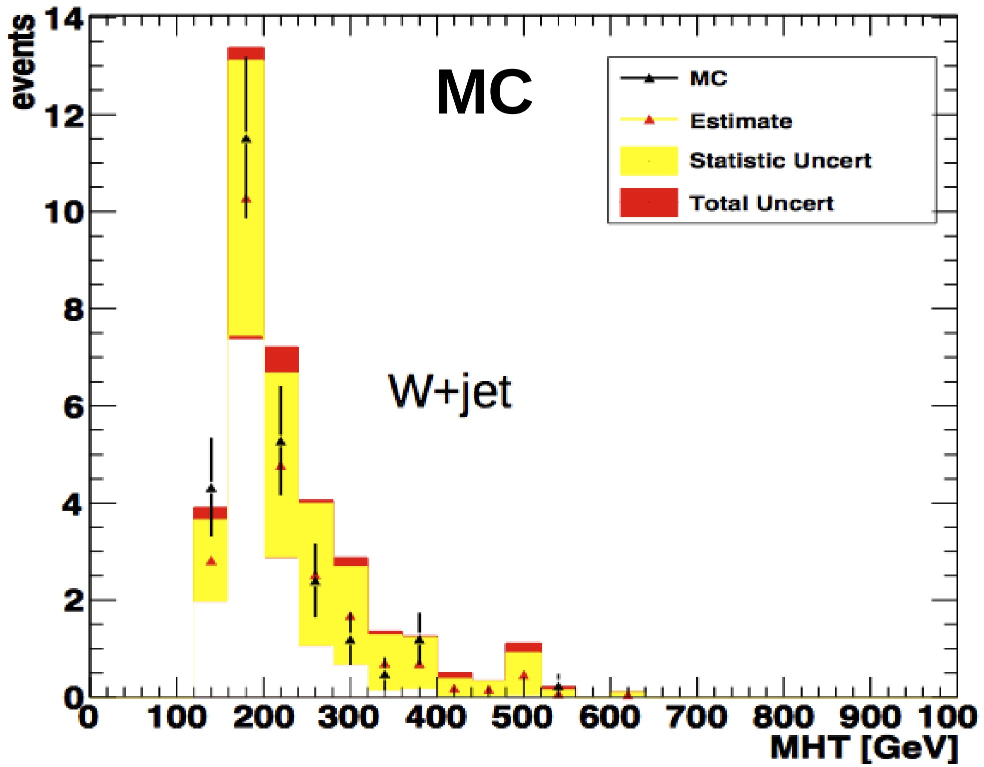
$\frac{\text{passed}}{\text{passed + failed}}$ mass



- Gauss fit to Z-peak for passed and failed isolation
- Sideband subtraction of background
- Low statistic for small ΔR(lep.jet) in Z-Sample
- High efficiency except for small ΔR and P_T

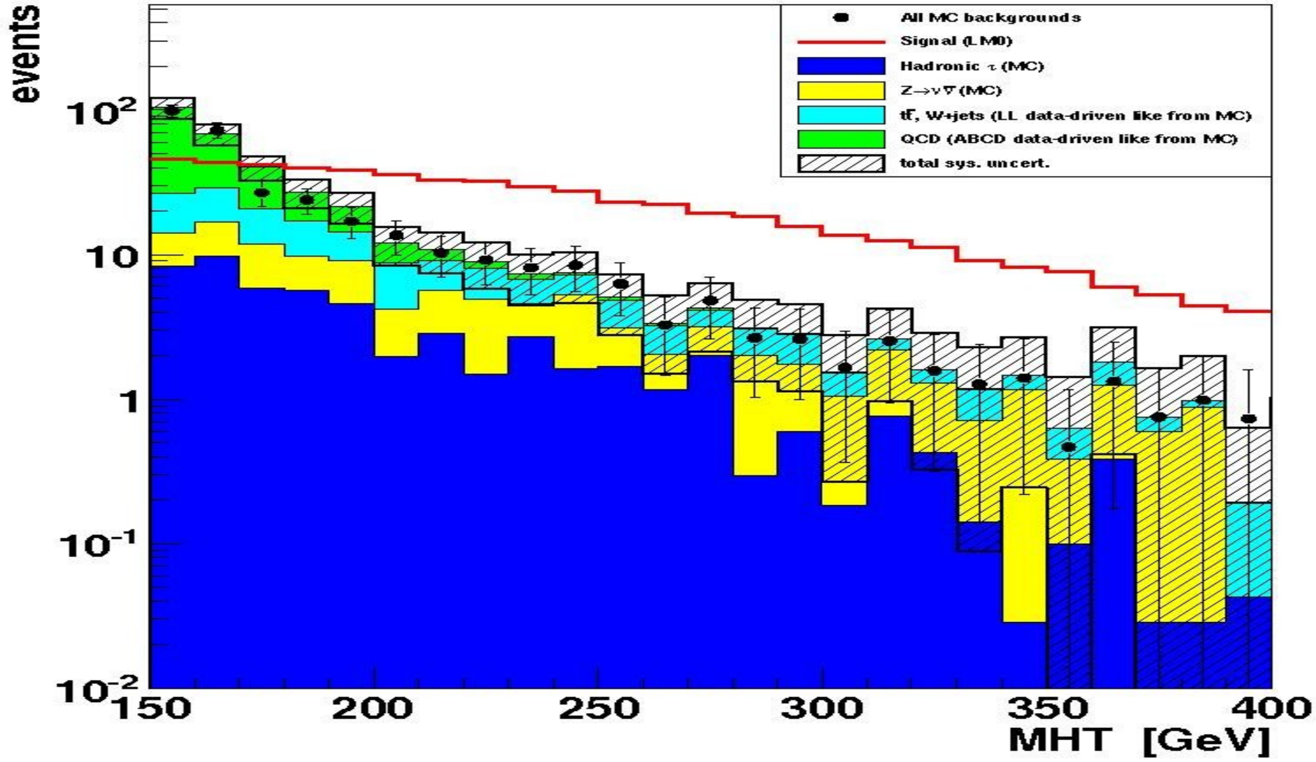
Closure Test: $t\bar{t}$/w+jets





- Shape and predicted number of events agree within uncertainties
- Largest systematic uncertainty comes from the efficiency measurements
- Full statistic in control sample used ($t\bar{t}$ ~ a few fb^{-1} W+jets ~400pb^{-1}), but #events rescaled to 100 pb^{-1}

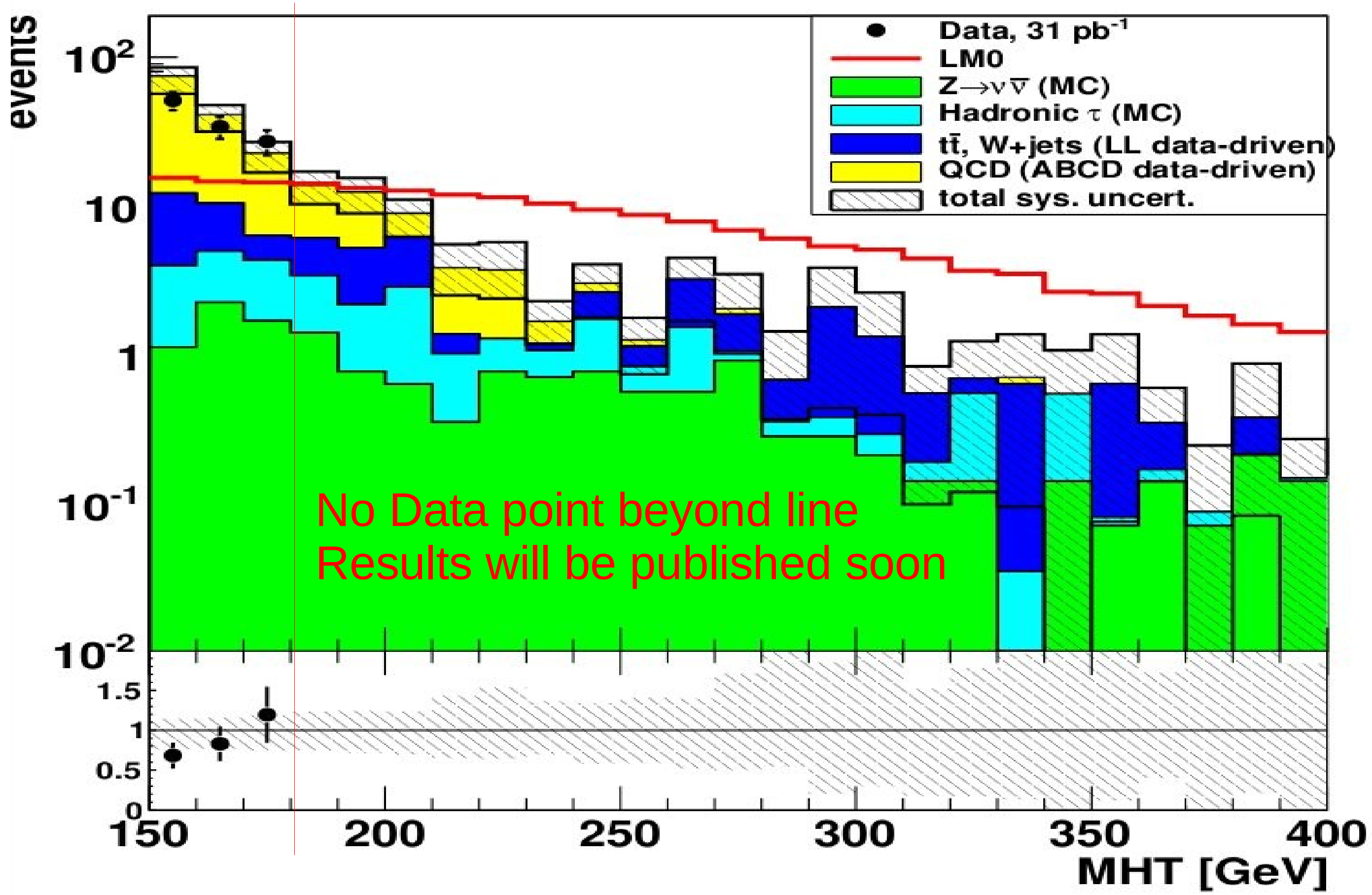
Combination of Results (MC)



Scaled to 100/pb

- Comparison between pure MC and data driven methods on MC
- Systematic uncertainies used for MC: **J**et **E**nergy **S**cale, Luminosity, Lepton Isolation
- Main Systematic uncertainties from data driven methods: JES (QCD), Tag & Probe efficiencies (lost lepton), Error from fit (ABCD)

Combination of Results (Data)



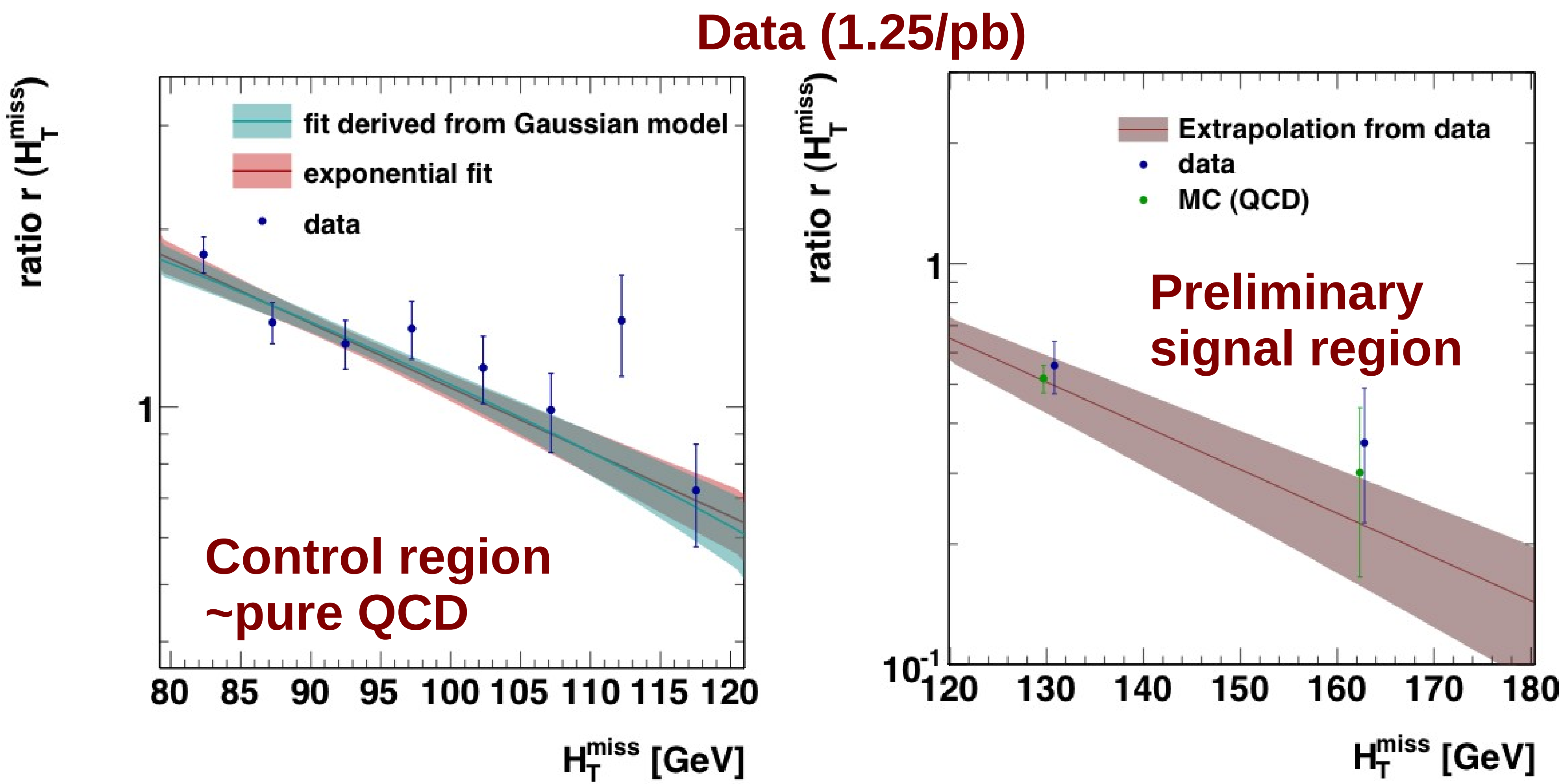
- Use data driven methods where highest uncertainties in MC expected
- Add estimation methods from other groups
- Result not public, yet

Summary

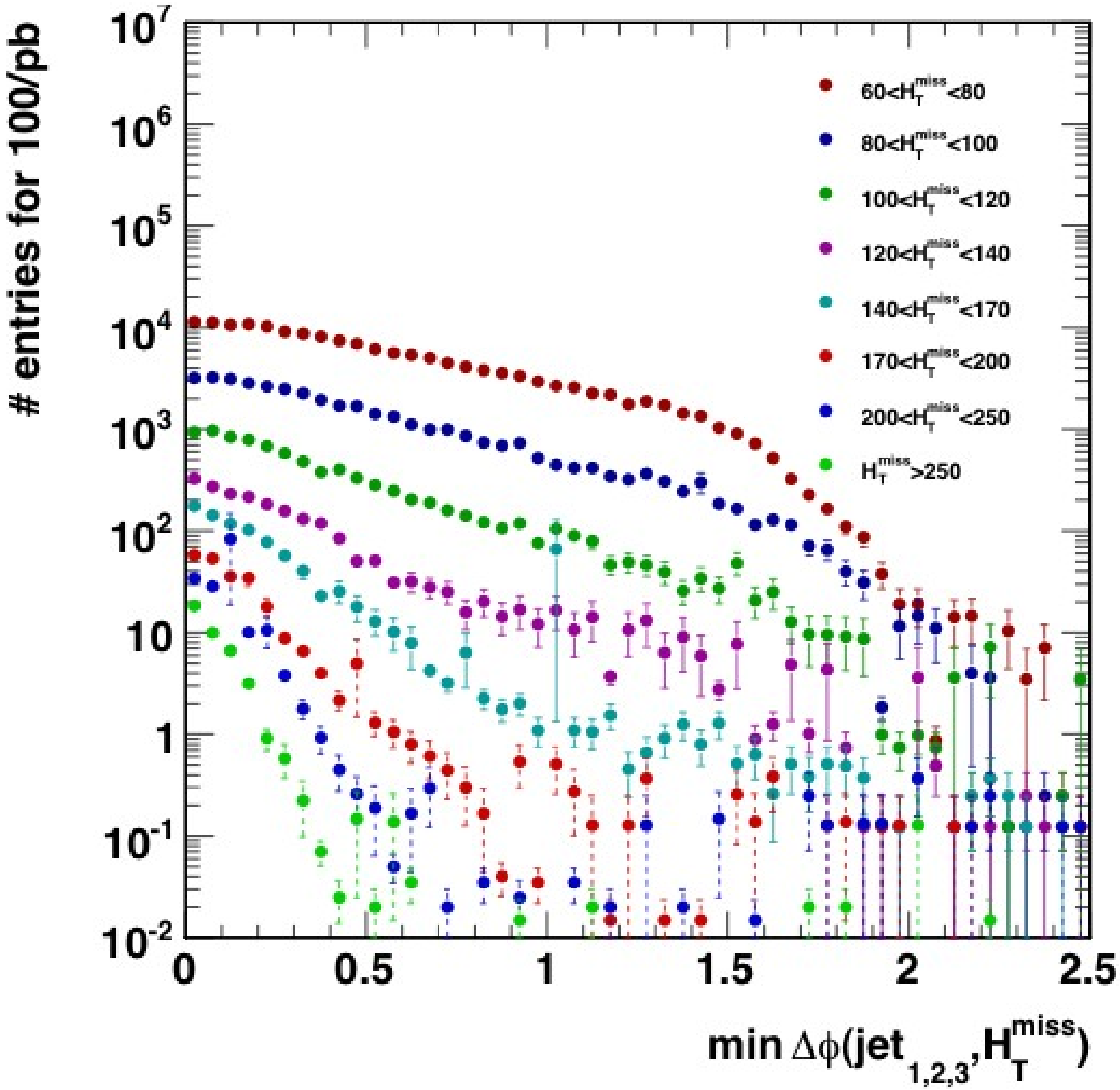
- QCD, $t\bar{t}$ and W+jets are very important backgrounds, data-driven estimation methods are in place (@Hamburg)
- No overlap between methods – complementary
- Search is running and first results will be available soon
- Full hadronic channel has best reach for SUSY searches if backgrounds can be estimated robustly

BACKUP

Factorization method for QCD in Data



An exponential function approximates the Gaussian model in the region where it is valid (left), and the extrapolation to higher Missing H_T (right) approximates the influence of the tail


entries for 100/pb
min Δφ(jet_{1,2,3}, H_T^miss)
60<H_T^miss<80
80<H_T^miss<100
100<H_T^miss<120
120<H_T^miss<140
140<H_T^miss<170
170<H_T^miss<200
200<H_T^miss<250
H_T^miss>250

Relaxed

Selection cuts:

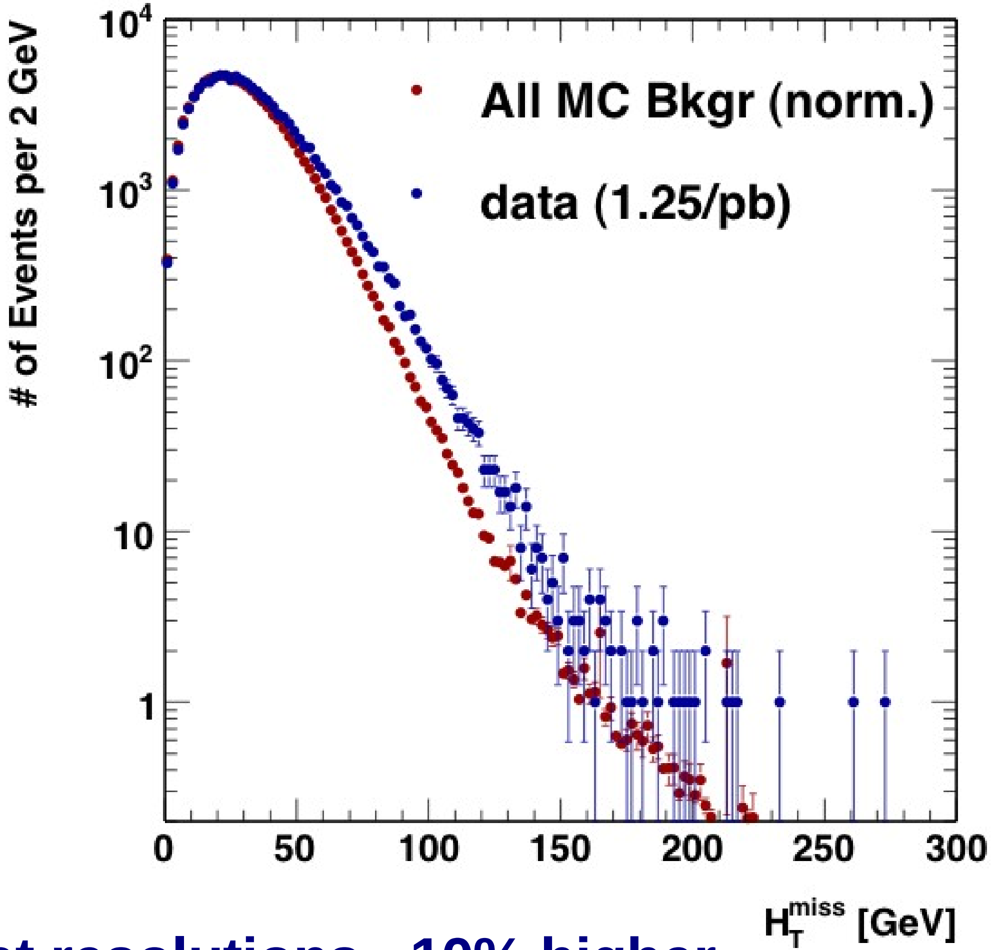
Jet_1 > 90 Gev (instead of HT cut)

$Jet_{2,3}$ > 50 GeV

$|eta|_{1,2,3}$ < 2.5

Lepton Veto

HLT Jet50U trigger

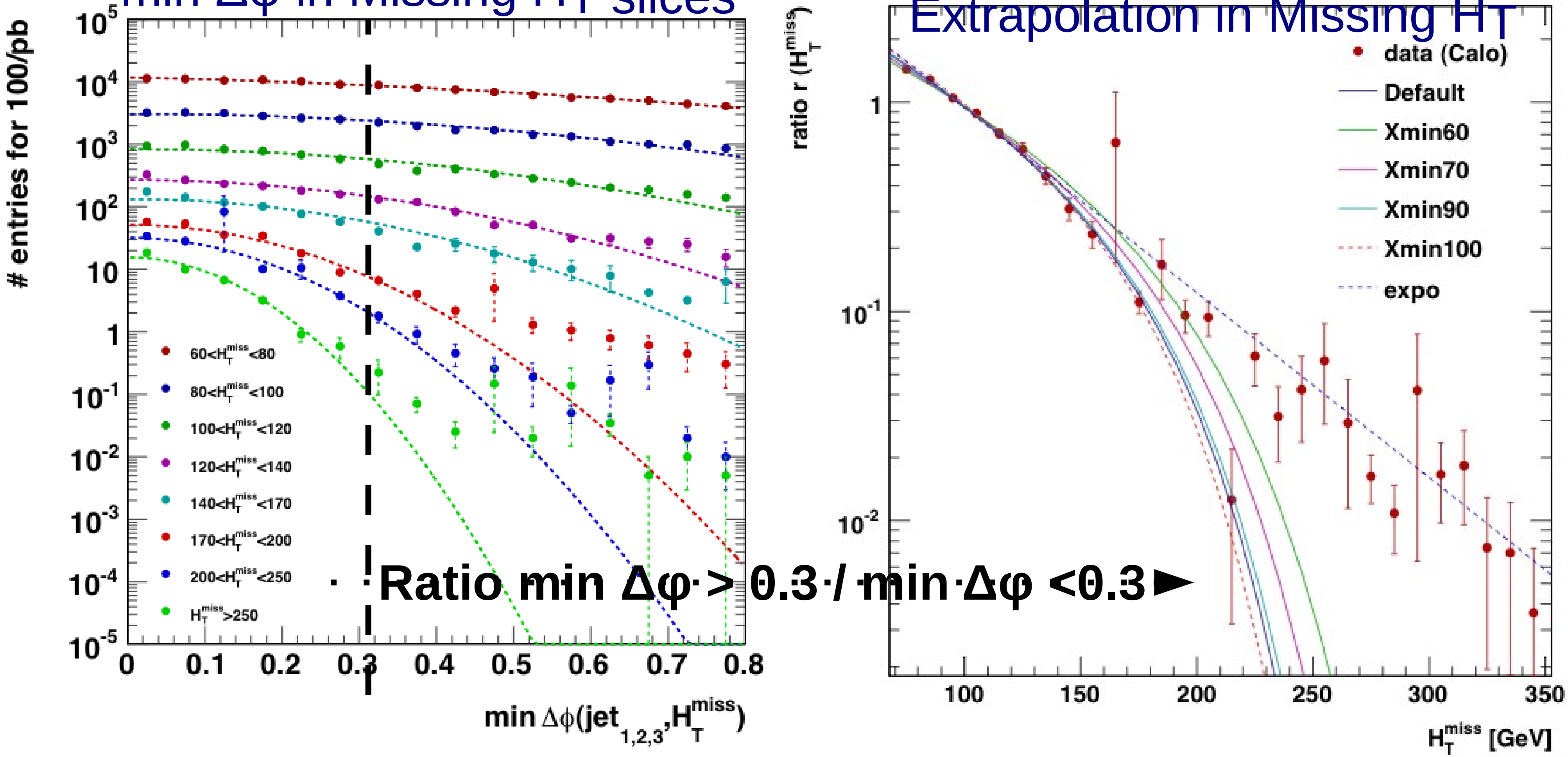


- **Tail in data (high Missing HT): jet resolutions ~10% higher than expected, other detector issues, physics?**
- **First look: Signal region Missing HT > 120 GeV**

Factorization method for QCD

min Δφ in Missing H_T slices

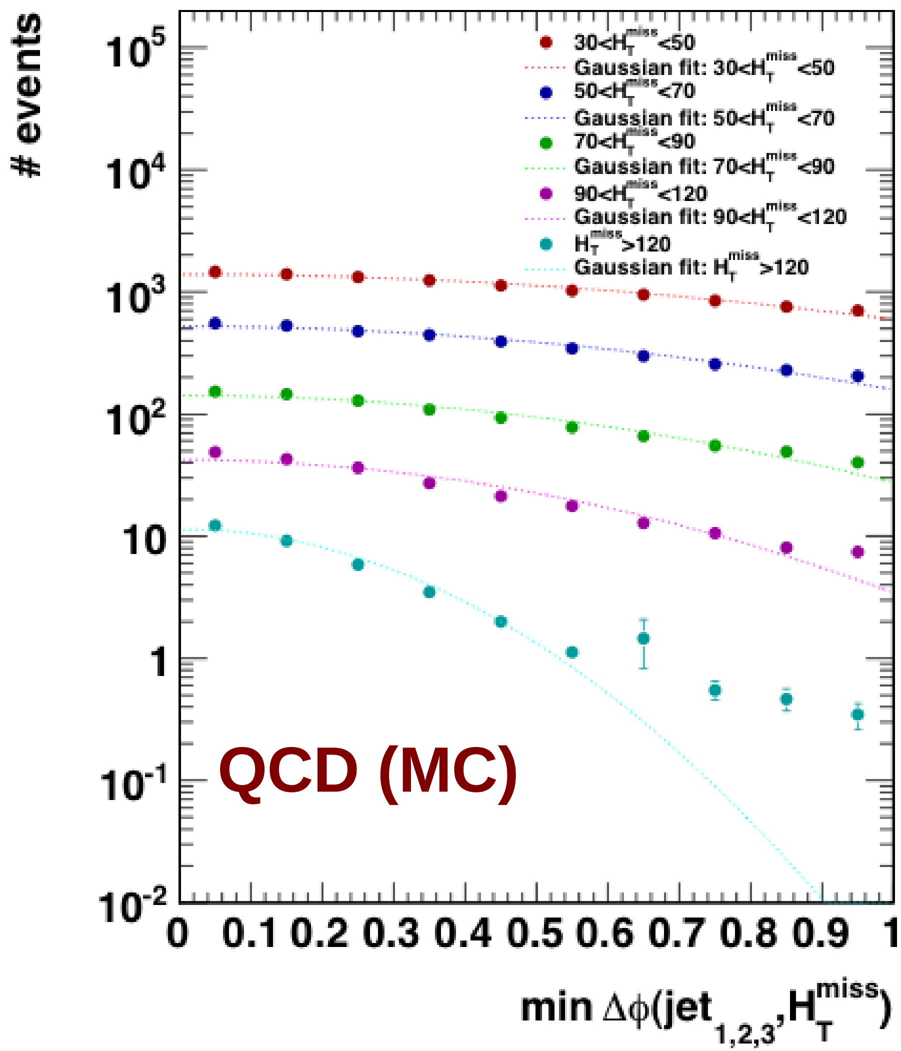
Extrapolation in Missing H_T

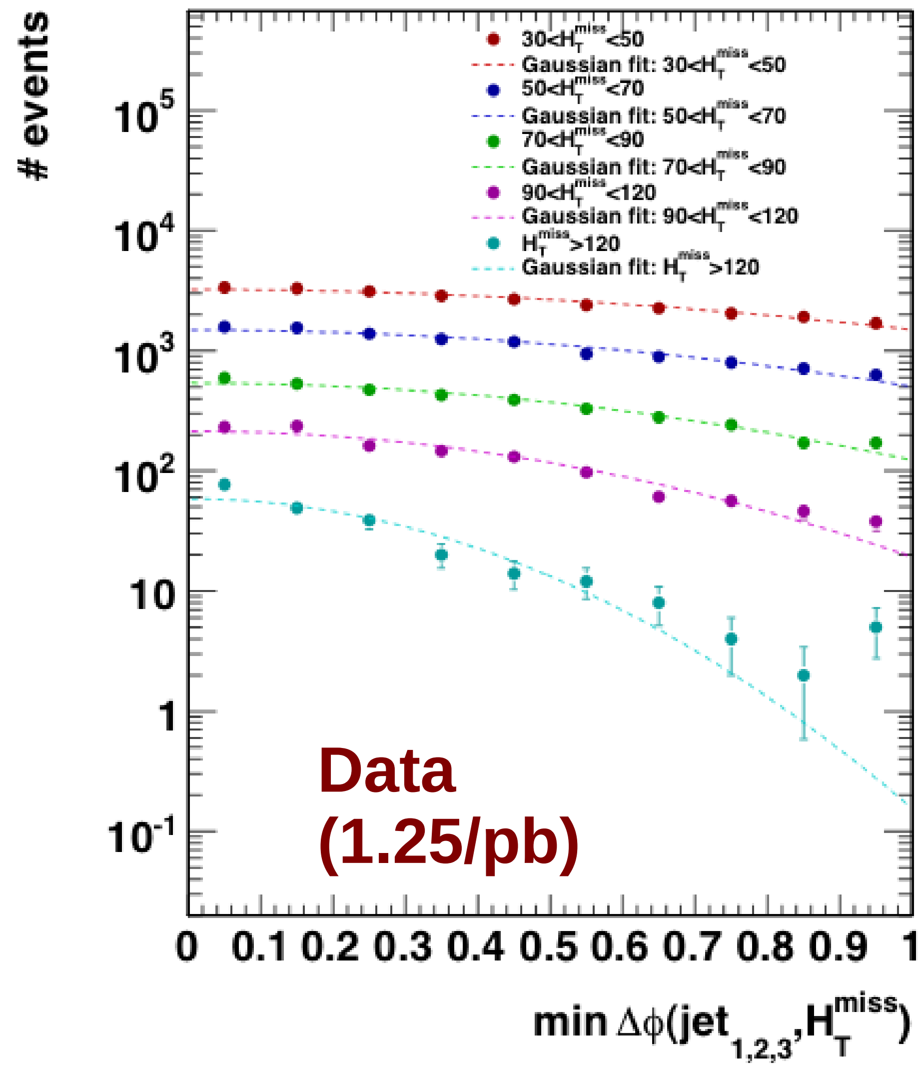


- **Tail coming from most mismeasured jet not aligned with Missing H_T vector**
- **Exponential function approximates the Gaussian model where it is valid and is able to describe the tail**

Factorization method for QCD in Data

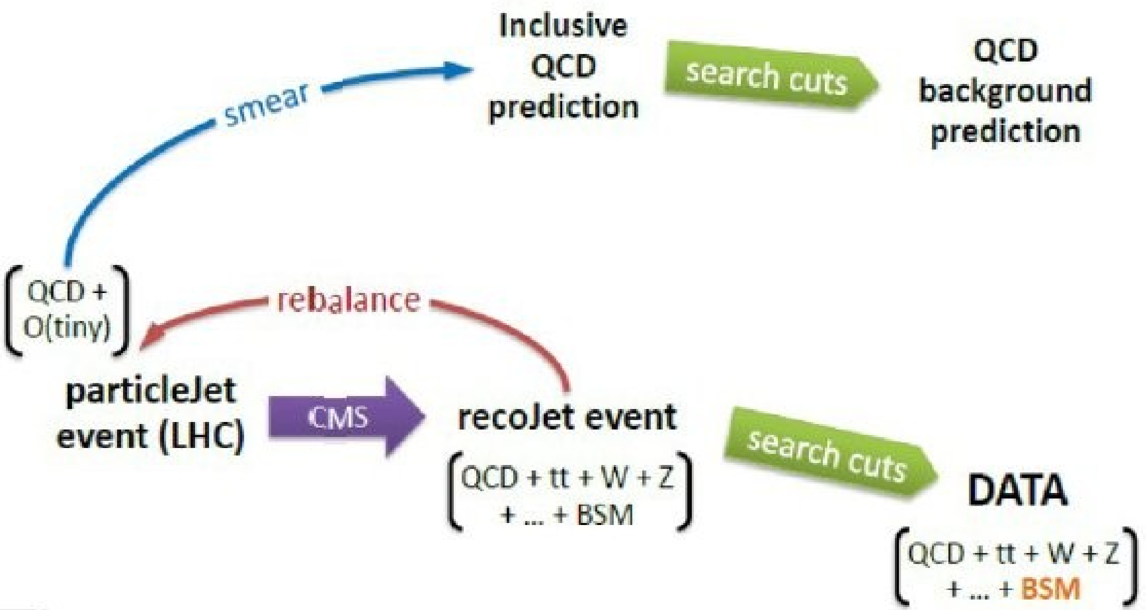
min Δφ in Missing HT slices

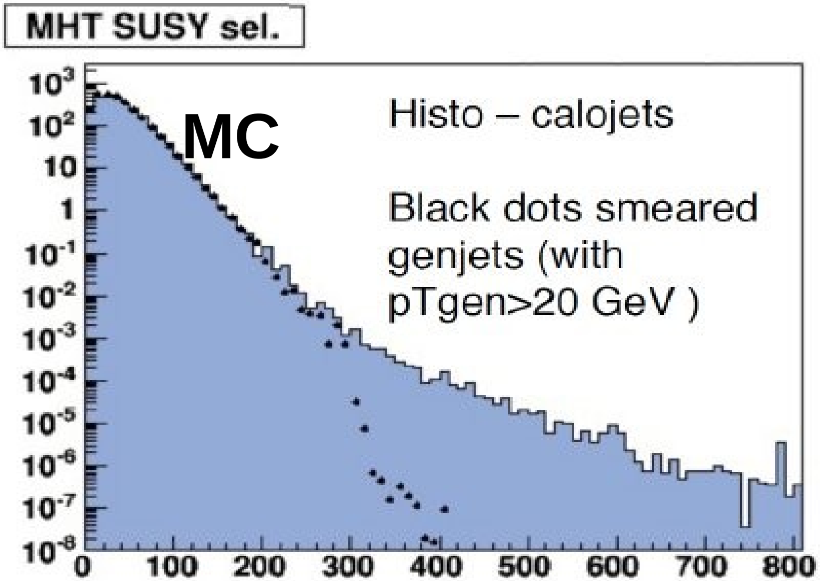




Motivation: data driven prediction of MHT from QCD

- Rebalance+Smear method [Sue Ann]
  - Rebalance detector level jets to particle level jets
  - Smear rebalanced jets to predict MHT
- Response enters twice





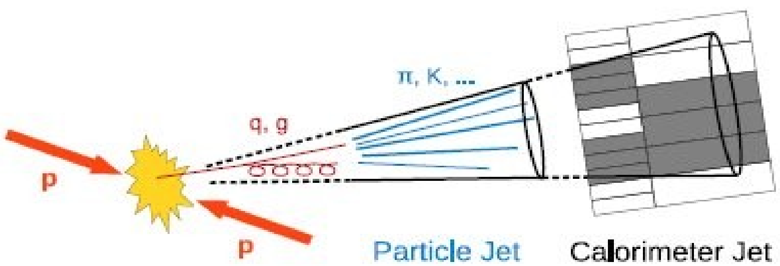
- Simple example [Seema]
  - Gaussian MC truth resolution
  - Smearing of GenJets

Prediction of high MHT requires knowledge of **full response function** incl. non-Gaussian tails

How to Measure the Jet p_T Resolution?

Response $R = p_T / p_T^{gen}$

Resolution $\sigma = \sqrt{V(R)}$

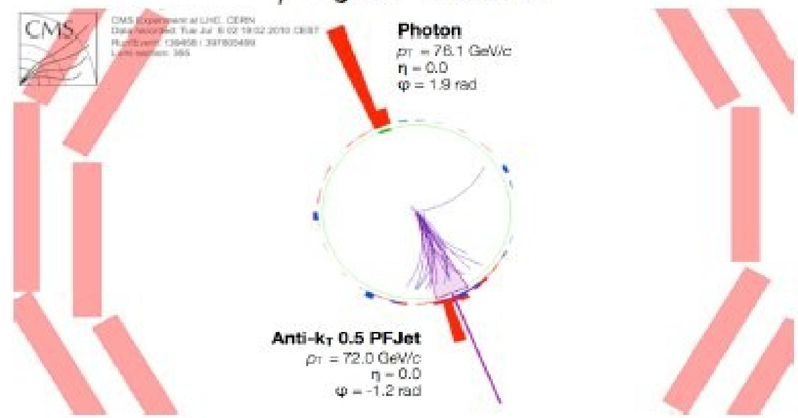


- Measurement using p_T balance
  - Balancing of jet and well measured object e.g. γ+jet
  - Imbalance of dijets

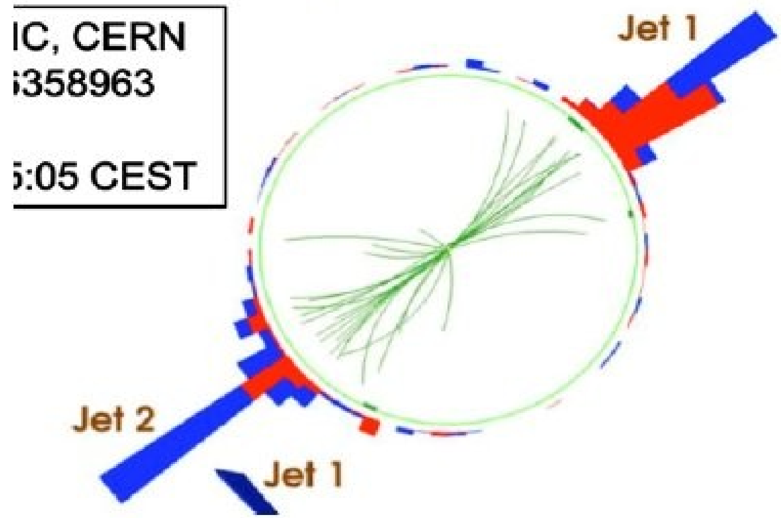
$$A = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}} = \frac{\Delta p_T}{p_T^{ave}}$$

$$\sigma(A) = \sigma(R)/\sqrt{2}, \quad \text{for } p_T^{ave} = p_T^{gen}$$

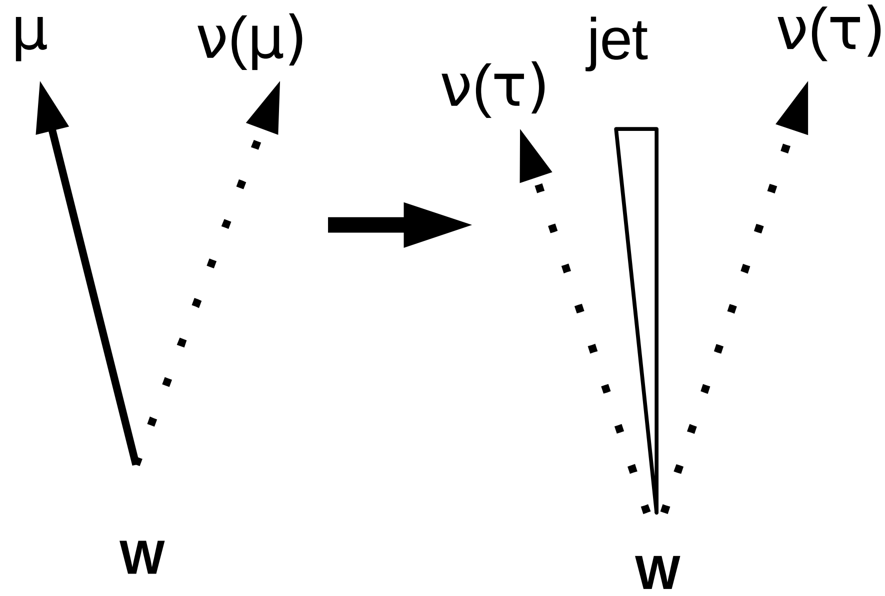
γ+jet event

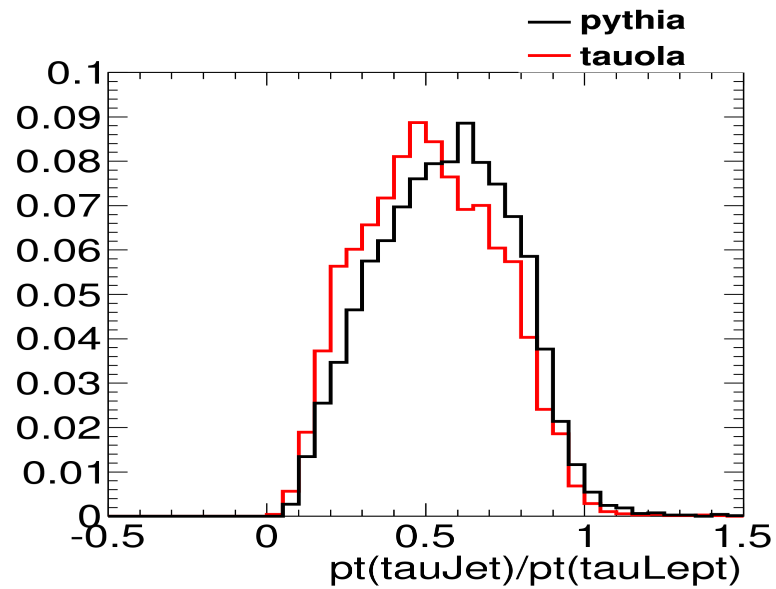


Djet event



Tau smearing method



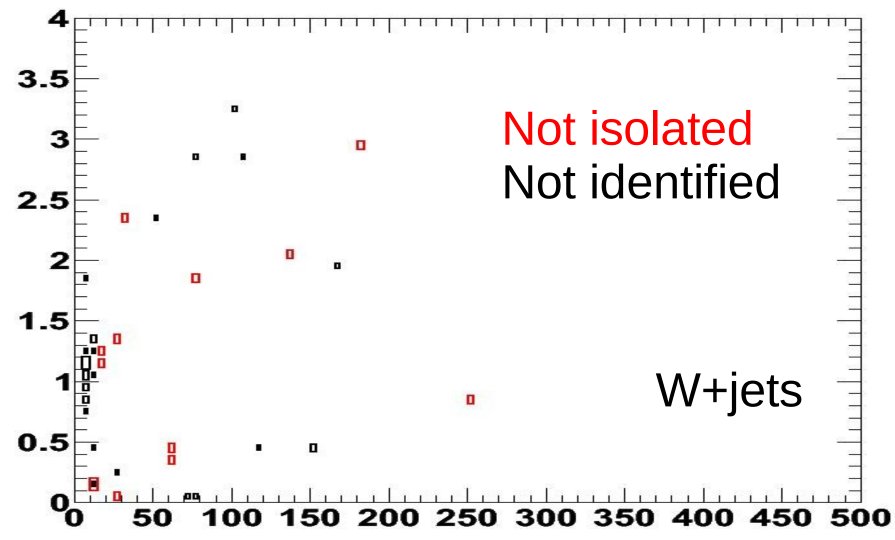


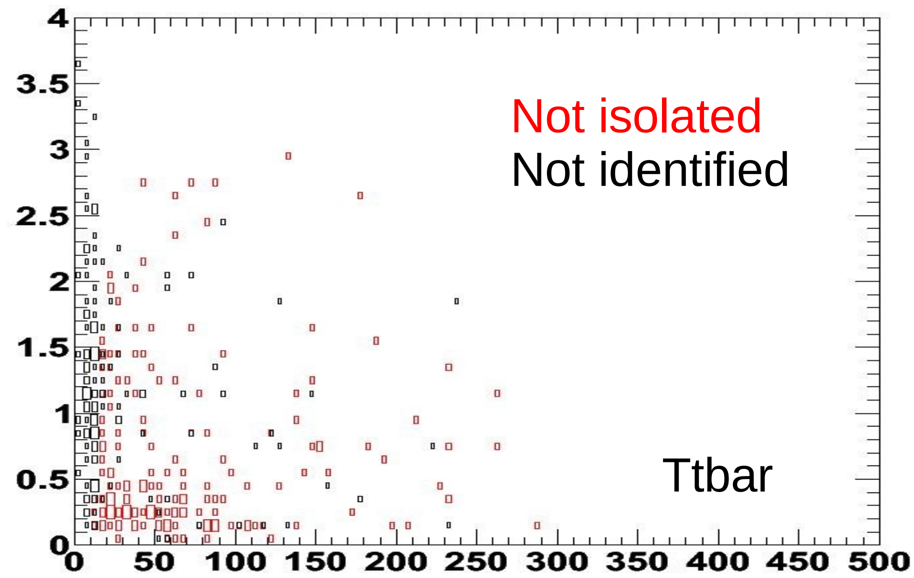
	$\pi\nu$	$\pi\pi^0\nu$	$\pi\pi^0\pi^0\nu$	$\pi\pi\pi\nu$	$\pi\pi\pi\pi^0\nu$
BR	11%	25%	9%	10%	4%
expected visible fraction	0.5	0.66	0.75	0.75	0.80

- Construct a control sample with jets and one clean muon
- Correct for the different branching fractions of hadronic τ and μ
- Correct for reconstruction- / isolation efficiency, acceptance and μ from τ
- Replace the muon by a jet and missing Et from the neutrino
- Perform selection on new HT and MHT distributions

Background Properties

DR(lep,jet) Events after selection





Muon channel

Problem:

Different topology in Ttbar and W+jet events:

Boosted top emits W (and therefore lepton) and b close to each other

- ➔ Closest jet is in most cases the associated b-jet
- ➔ Isolation efficiency lower for Ttbar events

- ➔ Efficiency in bins of ΔR

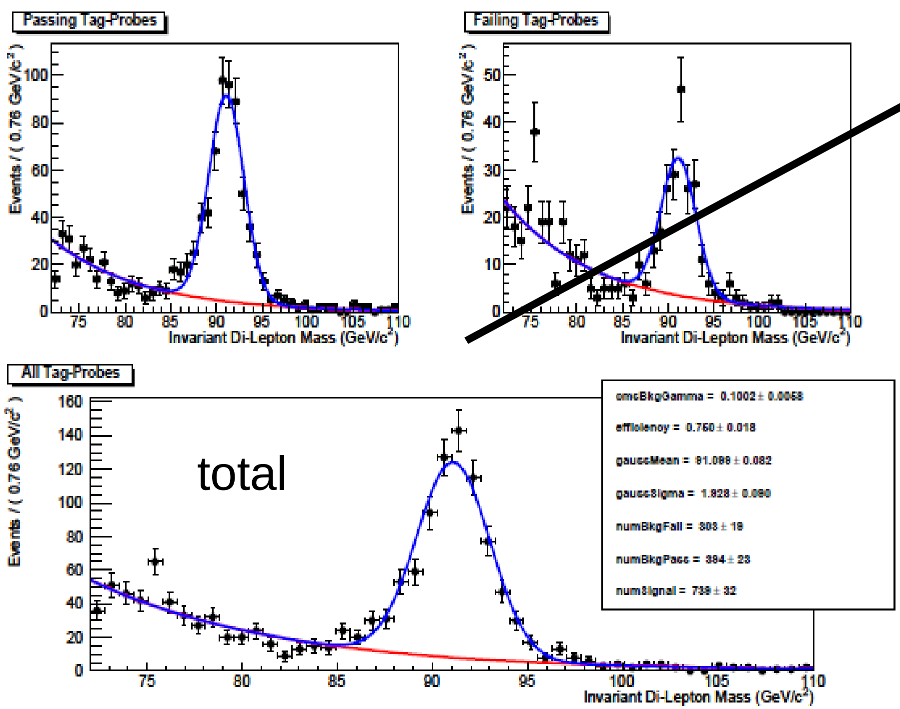
Low statistic in control sample in bins of small ΔR

- ➔ Only a very rough binning in Pt possible
- ➔ Increased uncertainties

Z-Resonance

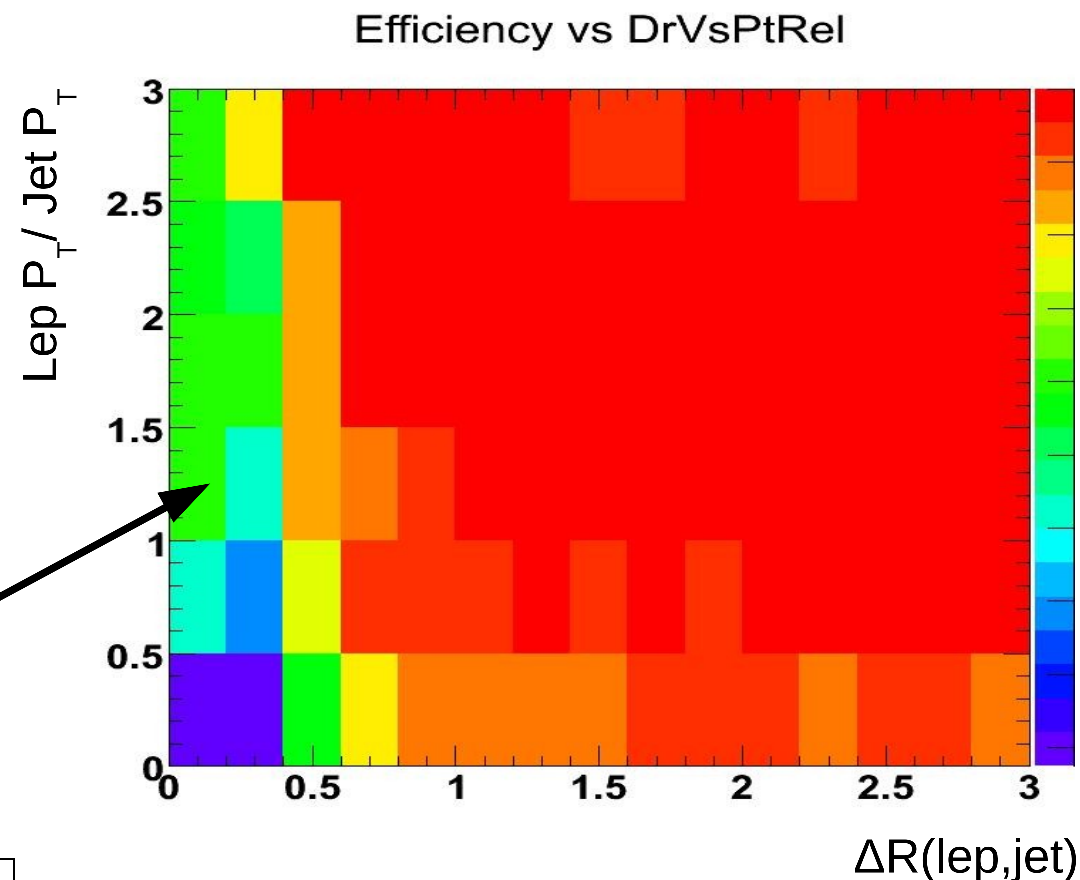
passing

failed

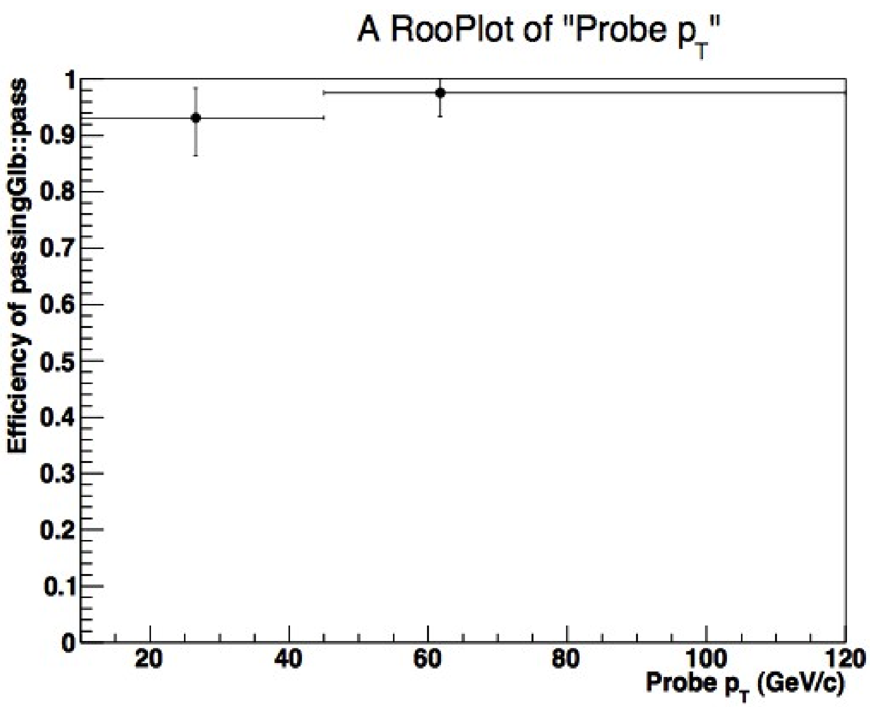


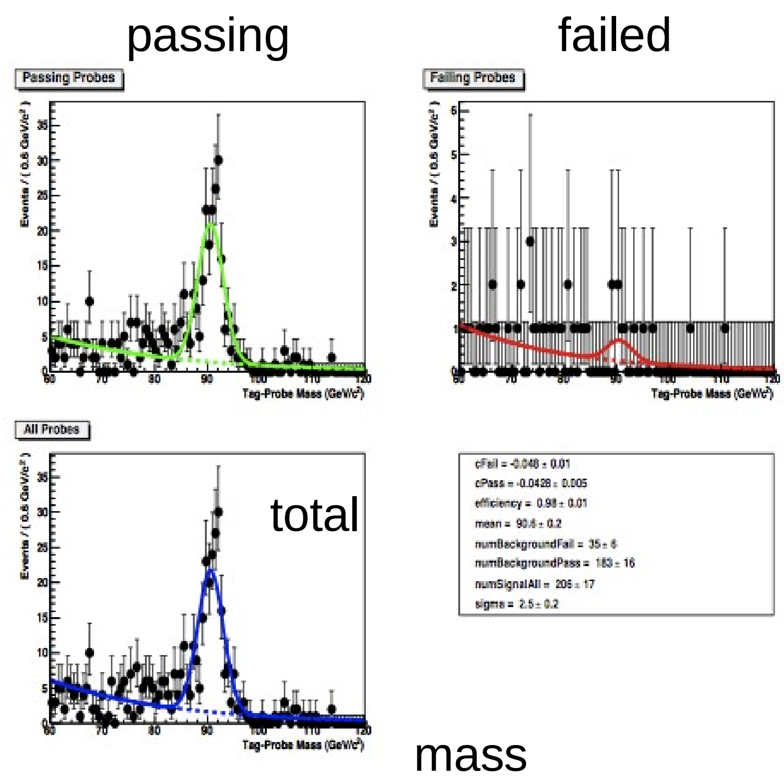
total

mass



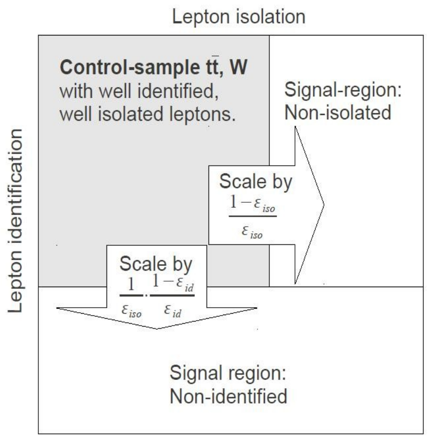
Data: Efficiencies





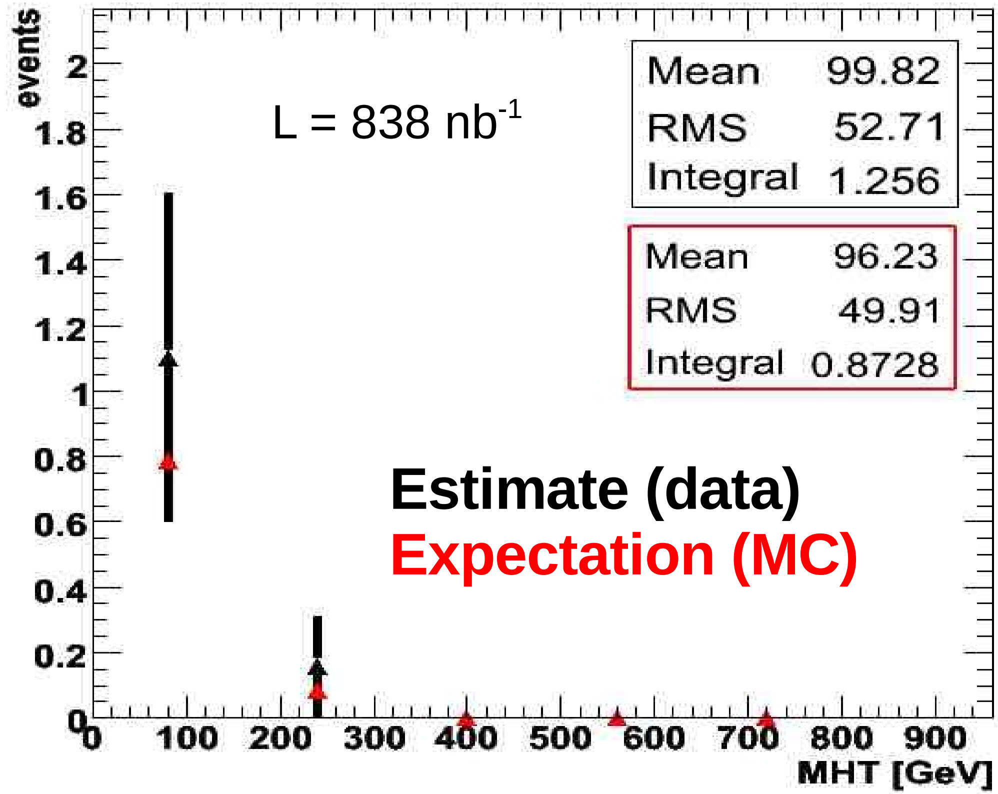
- Example: Tag & Probe Method for reconstruction Efficiency
- All steps tested on data, but rough binning due to low statistic
- ~ 30-50 pb^{-1} integrated Luminosity needed for useful estimate

Data: first test



Relaxed Selection cuts:

Jet_1 > 90 Gev
$Jet_{2,3}$ > 50 GeV
$|eta|_{1,2,3}$ < 2.5
MHT > 60 GeV
Lepton Veto



Control Sample:

Same as selection cut,
But exactly one good muon

- ~ 30% QCD contamination in control sample expected
- Only a problem with relaxed cuts
- Efficiencies taken from T&P method on large MC sample
- Waiting for more data...

Uncertainties

Lost Lepton Method:

- Low statistics in control sample in small ΔR-bins - these events get a large correction factor
  - This can be reduced by binning in jet multiplicity but an error has to be assigned to the differences in the samples
- Uncertainty of the isolation efficiency
  - To a large extend this is a statistical uncertainty with T&P
  - Can also be reduced using jet multiplicity
- Uncertainty of the electron reconstruction efficiency
  - Overestimated at the moment
  - Change binning
- Acceptance from MC
- Treatment of BSM contamination (e.g. Reshuffling method)

Unbinned maximum likelihood fit of dijet imbalance

Assumption: Two jets with equal particle level jet p_T

Method: Adjust response to describe measured p_T imbalance

Probability density (*pdf*) of dijet event

$$g_{\mathbf{b}}(p_{T,1}, p_{T,2}) \propto \int_0^\infty \mathrm{d}p_T^{\text{true}}\, f\left(p_T^{\text{true}}\right) \cdot r_{\mathbf{b}}\left(p_{T,1} | p_T^{\text{true}}\right) \cdot r_{\mathbf{b}}\left(p_{T,2} | p_T^{\text{true}}\right)$$

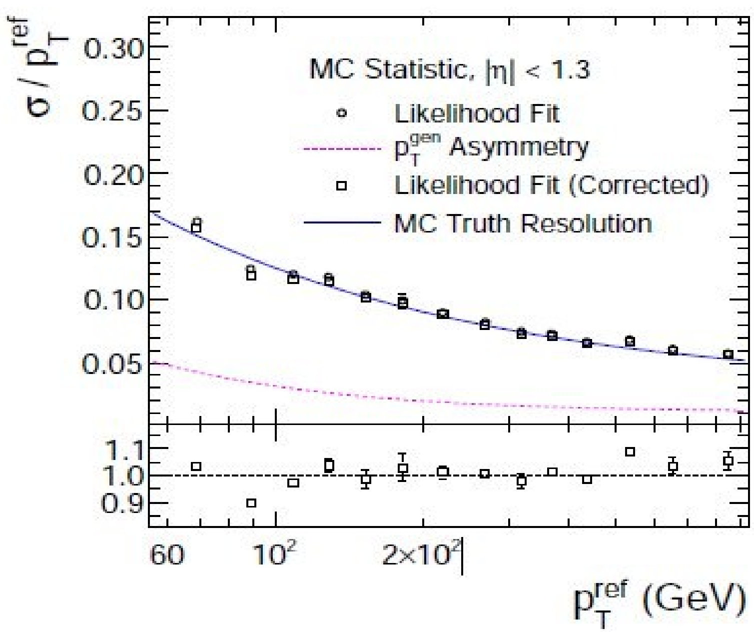
- $r_{\mathbf{b}}(p_{T,i}|p_T^{\text{true}})$: pdf of the jet p_T
- $f(p_T^{\text{true}})$: pdf of the particle jet p_T

- Biases from additional jets — correction by extrapolation

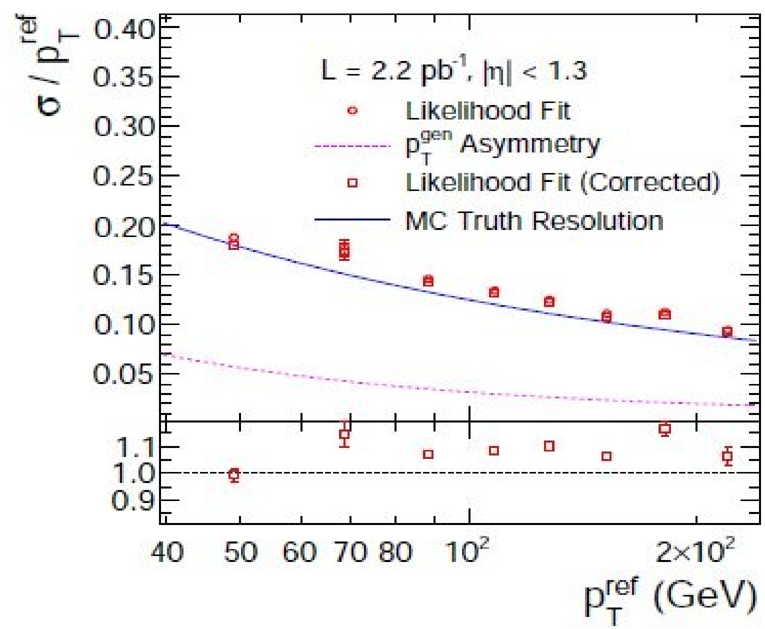
1. $\langle p_T^{\text{true}} \rangle$ estimator for $\langle p_T^{\text{gen}} \rangle$ $\rightarrow$ compensation of selection biases
2. Fit of response $r_{\mathbf{b}}(p_{T,i}|p_T^{\text{true}})$
   - Results for Gaussian response
   - Strategy to measure full response function

Resolution from Unbinned Fit in MC Simulation and Data

MC Simulation (closure test)



Data



- Measured resolution as function of p_T^{true}

MC Simulation	Closure of the method — agreement to true resolution
Data	Measured resolution 10% larger than simulated (as observed before)

To cover all possible basic SUSY signatures CMS divides its searches in the following **R**eference **A**nalyses:

Hadronic search	RA1	Exclusive (mainly dijets)
	RA2	**Inclusive**
	RA3	Photon +X (gauge med. SUSY breaking)
Leptonic search	RA4	Single lepton
	RA5	Same sign dilepton
	RA6	Opposite sign dilepton
	RA7	Trilepton
	RA8	Dilepton + Photon

Hadronic inclusive search (RA2) has the best reach for most of the SUSY parameter space

RA2 contribution from HH: **data driven background estimation** for QCD and Ttbar/W+jets and **framework for combining** these

Direct Lepton Veto: no lepton in event with:

Muon:

P_T > 10 GeV
|η| < 2.4
} acceptance

relative isolation < 0.15
rel isolation = (trackIso + EcalIso + HcalIso) / P_T
} isolation

'globalMuonPromtTight' (e.g. Cut on χ^2 of track fit)
|d0| < 0.2 cm
Hits in tracker ≧ 11
} reco

Electron:

P_T > 15 GeV
|η| < 2.5
} acceptance

relative isolation < 0.15 } isolation

'eIDloose'
|d0| < 0.2 cm
} reco