Measurement of Neutralino Mass Differences with CMS in Dilepton Final States at the Benchmark Point LM9

Benedikt Mura, Katja Klein,
Lutz Feld, Niklas Mohr

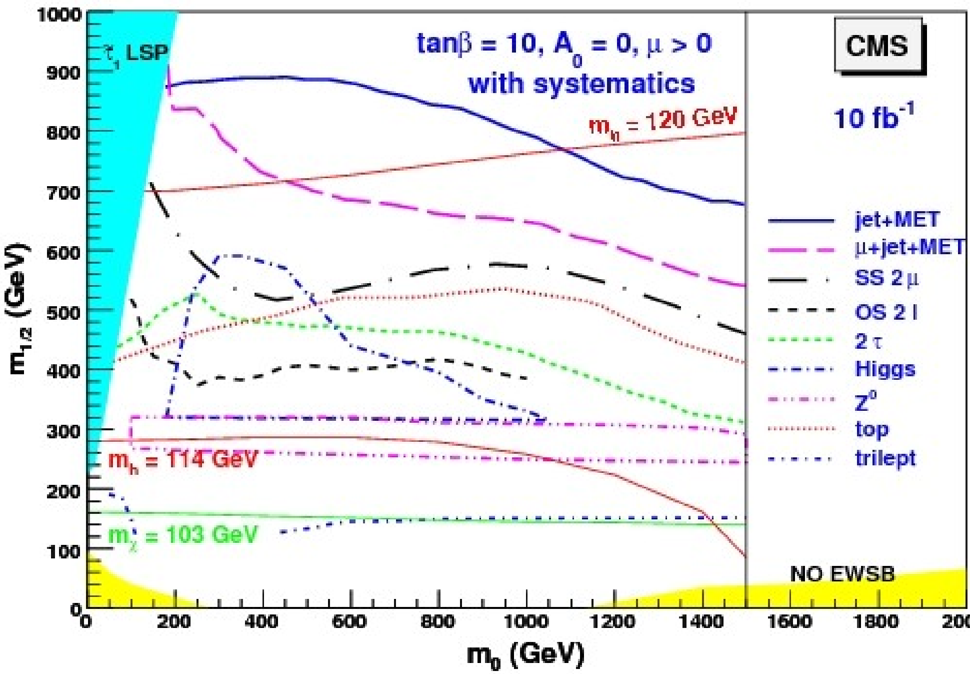
1. Physikalisches Institut B
RWTH Aachen

bmb+f - Förderschwerpunkt
CMS
Großgeräte der physikalischen
Grundlagenforschung

Introduction

- Fast discovery of SUSY at the LHC likely
  - Large parts of mSUGRA parameter space accessible
- First quantities to measure:
  - Sparticle masses and mass differences from kinematic endpoints
  - e.g. in leptonic decays of light Charginos or Neutralinos (this talk)

  ⇒ input for parameter determination



- Challenges:
  - SUSY and Standard Model backgrounds
  - Endpoint determination (uncertainties)

Aim and Concept

- Aim:

  Determination of mass difference $M(\tilde{\chi}_2^0) - M(\tilde{\chi}_1^0)$
  in R-parity conserving mSUGRA model

- Method:
  - Reconstruction of the leptonic decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^+ + l^-$,
  - its Dilepton invariant mass distribution (M_{ll}),
  - and finding its kinematic endpoint (maximum value)

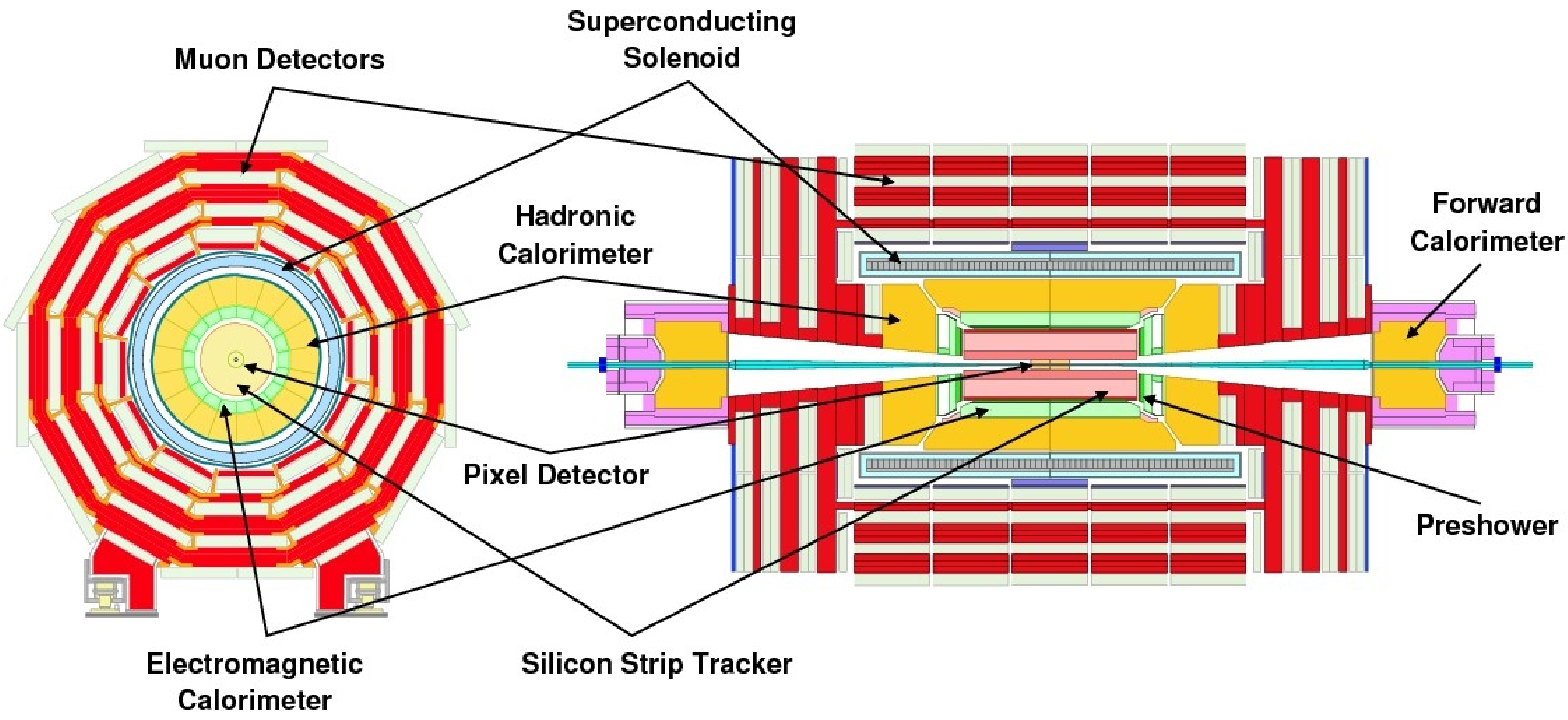
  Interpretation of endpoint:

  - In direct (3-body) decay: $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + Z^* \rightarrow \tilde{\chi}_1^0 + l^+ + l^-$

    $M_{ll}^{max} = M(\tilde{\chi}_2^0) - M(\tilde{\chi}_1^0)$
  - In subsequent 2-body decay: $\tilde{\chi}_2^0 \rightarrow \tilde{l}^\pm + l^\mp \rightarrow \tilde{\chi}_1^0 + l^+ + l^-$

    $M_{ll}^{max} = M(\tilde{\chi}_2^0) \sqrt{(1 - (M(\tilde{l})^2 / M(\tilde{\chi}_2^0)^2)) \cdot (1 - (M(\tilde{\chi}_1^0)^2 / M(\tilde{l})^2))}$

The CMS detector



Case Study: The LM9

mSUGRA benchmark point LM9:

m_0	**1450 GeV**
$m_{1/2}$	**175 GeV**
A_0	**0**
tan(ß)	**50**
sign(µ)	**+**

- σ_{tot} = 39.8 pb (NLO)
- gluino ($m_{\tilde{g}}$=507 GeV) pair production dominant $\sigma(\tilde{g}\tilde{g})$= 37 pb
- heavy sleptons & squarks (~1-1.5 TeV)
- light charginos and neutralinos
  M($\tilde{\chi}_2^0$)=117.84 GeV
  M($\tilde{\chi}_1^0$)=65.63 GeV

Processes of interest:

Gluino decay chains ending with leptonic decay of $\tilde{\chi}_2^0$

$$\tilde{g} \to \tilde{\chi}_2^0 + q\bar{q}/g \to \tilde{\chi}_1^0 + l^- l^+ + q\bar{q}/g \qquad \text{BR}_{\textbf{total}} \approx 1.7\%$$

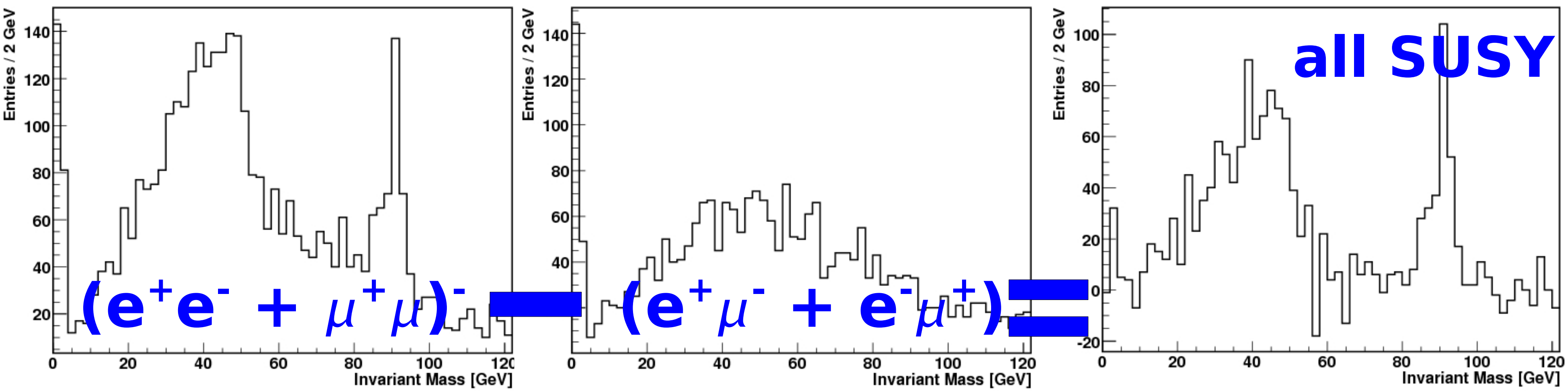
$$\tilde{g} \to \tilde{\chi}_2^{\pm} + q\bar{q} \to \tilde{\chi}_2^0 + W^{\pm} + q\bar{q} \to \tilde{\chi}_1^0 + l^+ l^- (+l^{\pm}\nu) + q\bar{q} \qquad \text{BR}_{\textbf{total}} \approx 0.4\%$$

⇒ Branching ratios small

⇒ Background from other SUSY decays

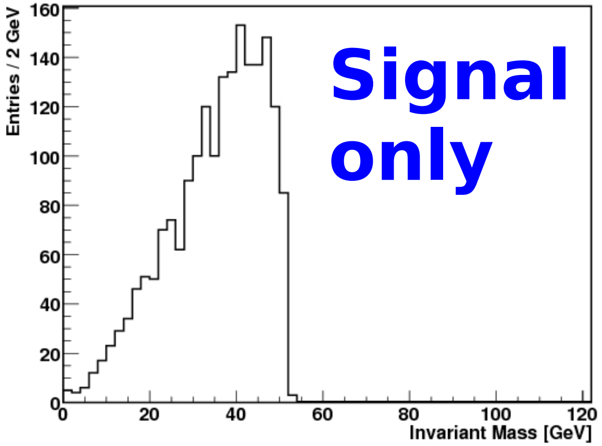
Combinatorial Background Subtraction

- Simulated SUSY Events from Isajet + Pythia
- Combinatorial subtraction of SUSY background:



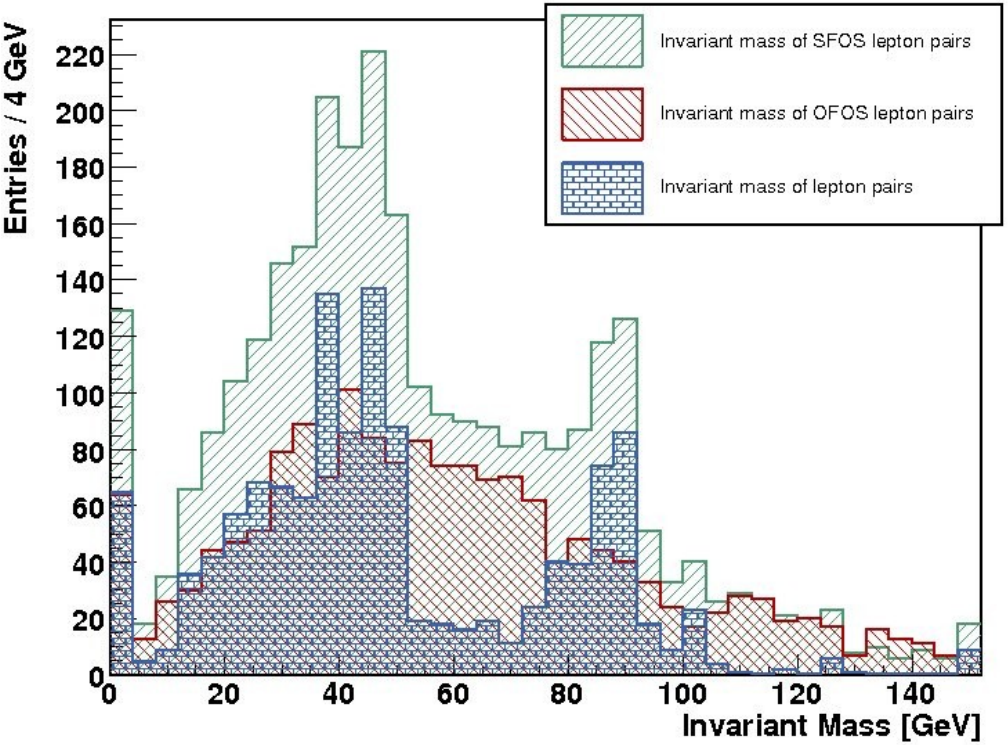
Wrong pairings of „same flavor, opposite sign“ leptons (SFOS) cancel with „opposite flavor, opposite sign“ leptons (OFOS)

⇒ Works best with high statistics



CMS Detector Simulation

- Apply simulation of the CMS detector
- Some cuts necessary for selection of reconstructed leptons
  - transverse momentum: $p_T > 15$ GeV
  - pseudorapidity: $\eta < 2.0$
  - isolation from jets: $dR=(d\eta^2+d\phi^2) > 0.1$
  - electron identification cuts



- Result corresponding to $L_{int} = 1$ fb^{-1}
- Same shape of dilepton invariant mass distribution as on generator level (previous slide)

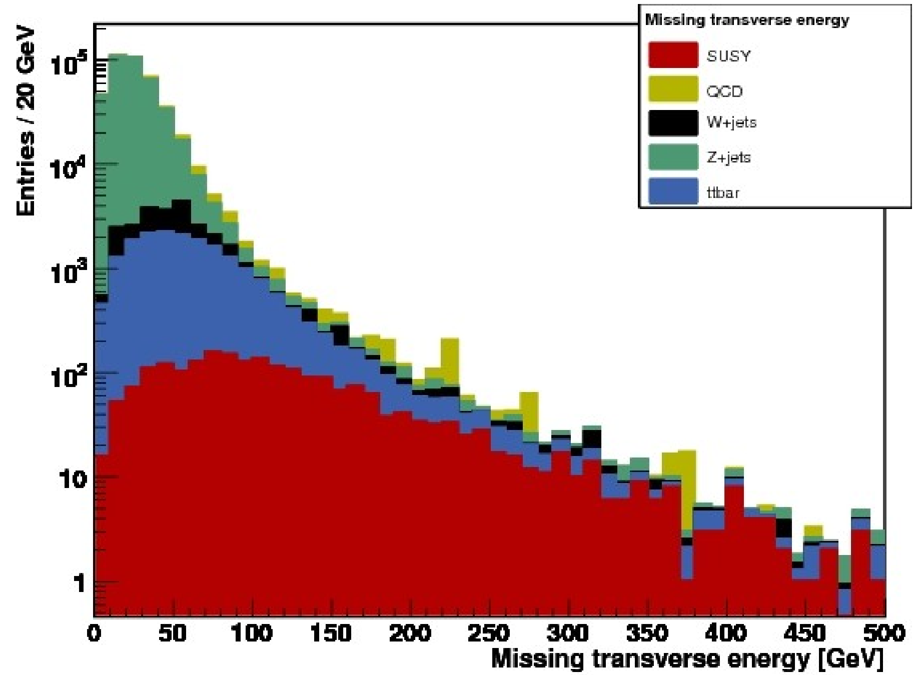
Standard Model Backgrounds

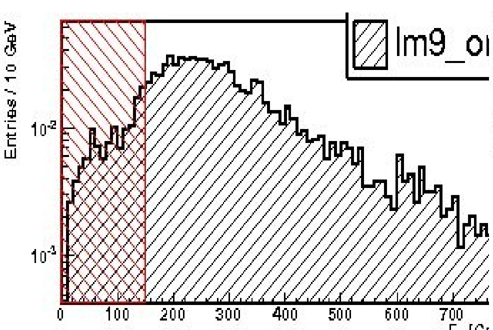
- Considered processes (LO pythia MC)
  - QCD dijet events σ = 819 µb ($\hat{p}_T > 20$ GeV)
  - ttbar σ = 488 pb
  - W+jets σ = 41 nb
  - Z+jets σ = 14 nb
  - LM9 (for comparison) σ = 26 pb (LO)
  - WW/WZ/ZZ, Drell-Yan (contributions are negligible)

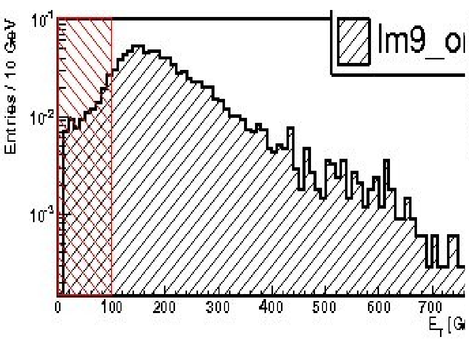
- Backgrounds are large
- Need to be suppressed by additional cuts

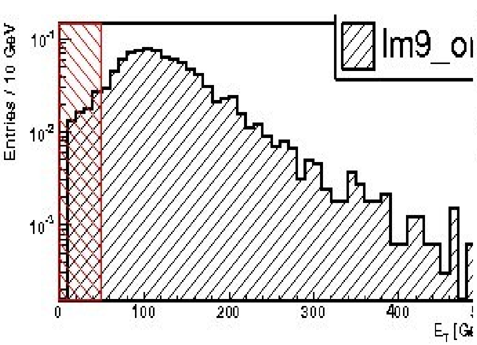
Discrimination of Backgrounds

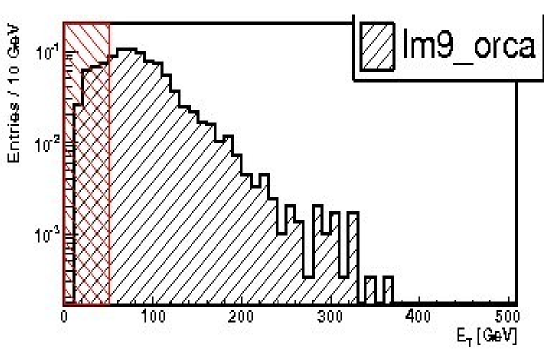
- Discriminate SM events by:
  - Missing E_T > 90 GeV
    - Soft spectrum at LM9, not sufficient
  - Jet transverse energy:
    - Jet 1: E_T > 150 GeV
    - Jet 2: E_T > 100 GeV
    - Jet 3: E_T > 50 GeV
    - Jet 4: E_T > 50 GeV



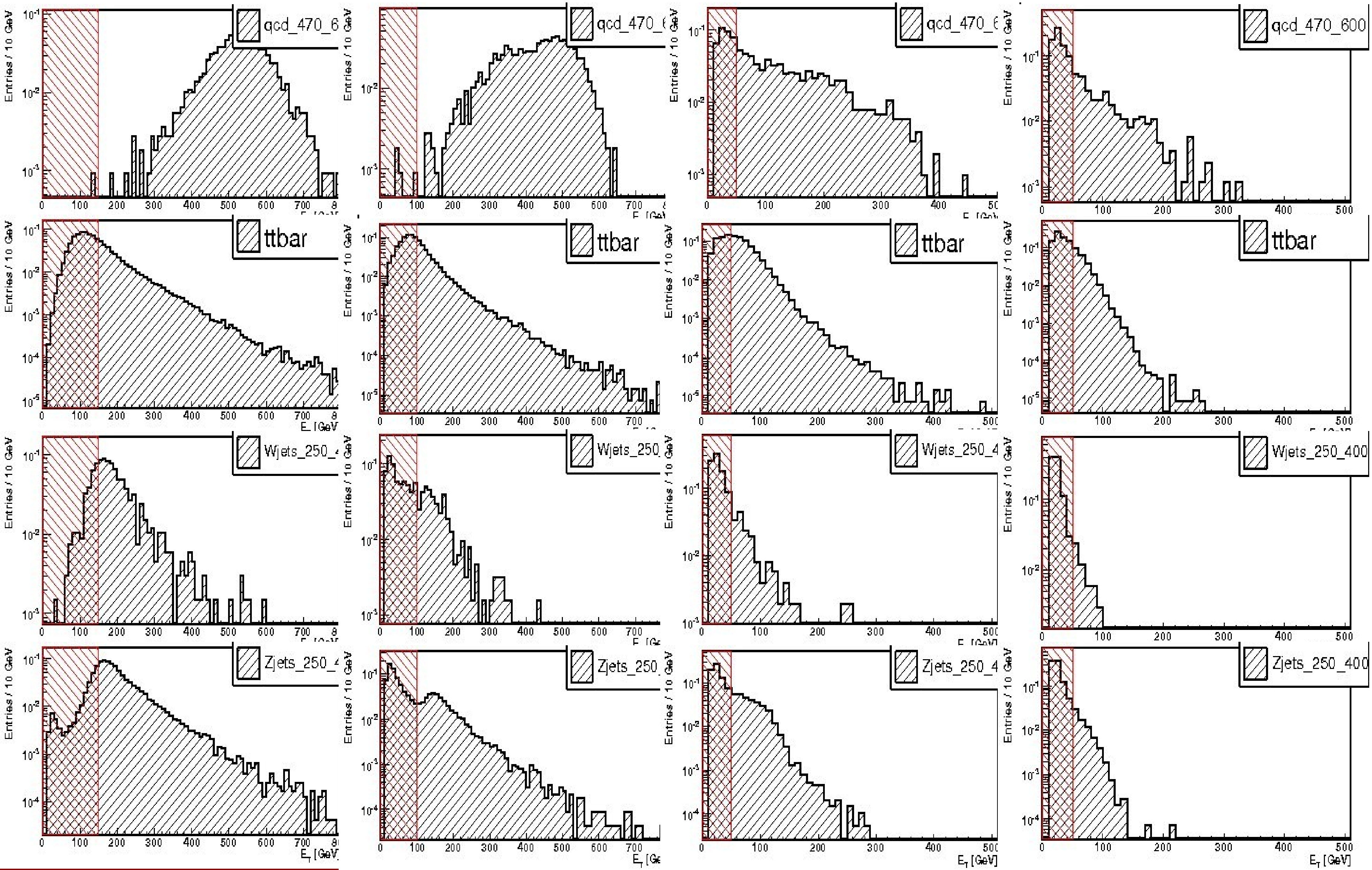








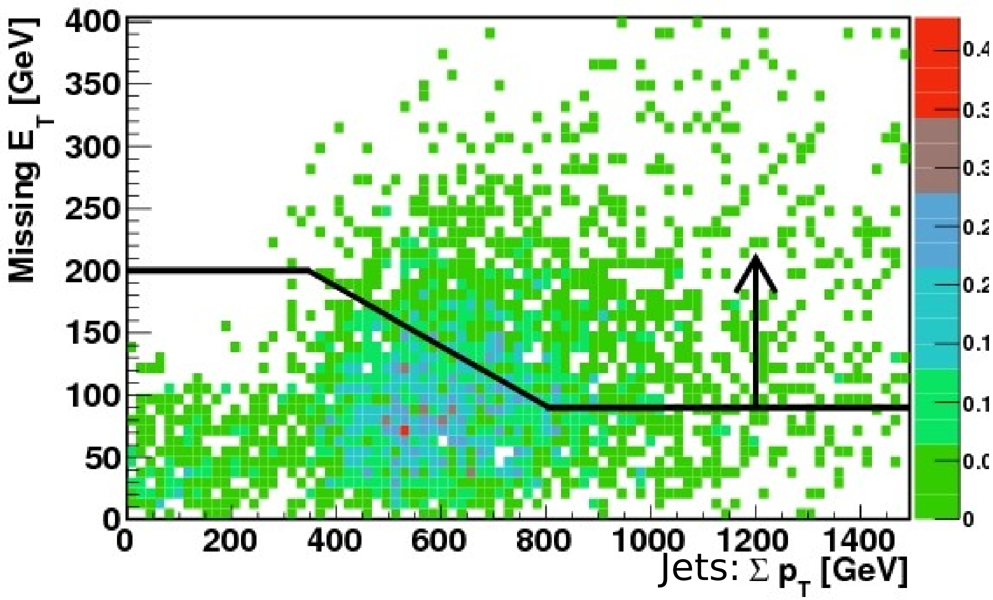
Discrimination of Backgrounds



Discrimination of Backgrounds

- Discriminate SM events by:
  - Missing transverse energy
  - Jet transverse energy
  - Combination of both:

  Sum of E_T of four jets vs. Missing E_T



After all cuts:

- **Purity** for 10 GeV < M_{ll} < 80 GeV:

P= 91% SUSY events in the final sample

- **Efficiency of selection:**

7% of signal events remain in the final sample

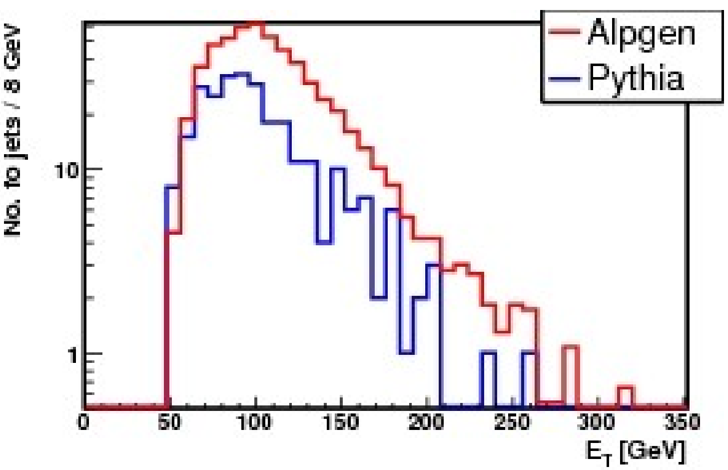
•

Discrimination of Backgrounds

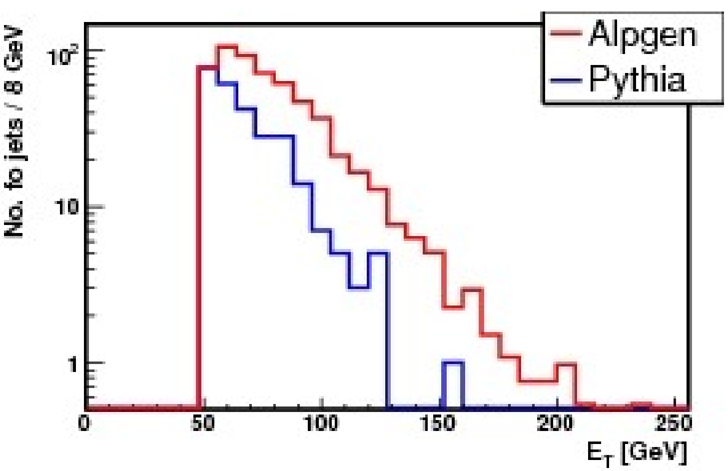
- Understanding of jet spectra crucial for background discrimination
- Check background with matrix element calculations for up to 4 partons in the final state
- ALPGEN QCD Monte Carlo compared to Pythia samples
  - Harder transverse energy spectra of 3rd & 4th jet
  - Approx. 2x more events left after jet selection cuts (same luminosity)

  ⇒ no significant impact on this analysis

Spectrum of 3rd jet

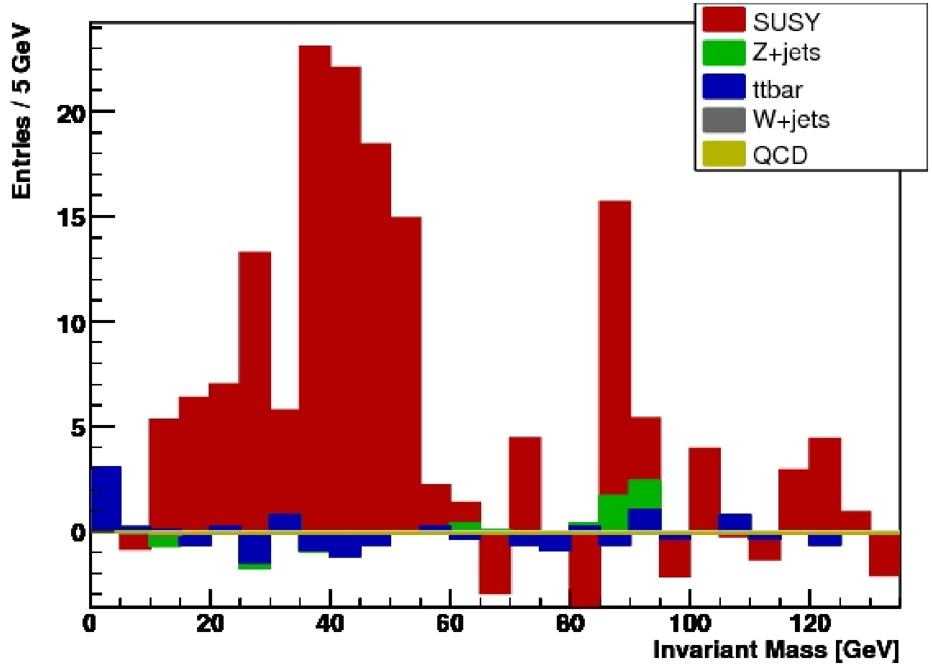


Spectrum of 4th jet



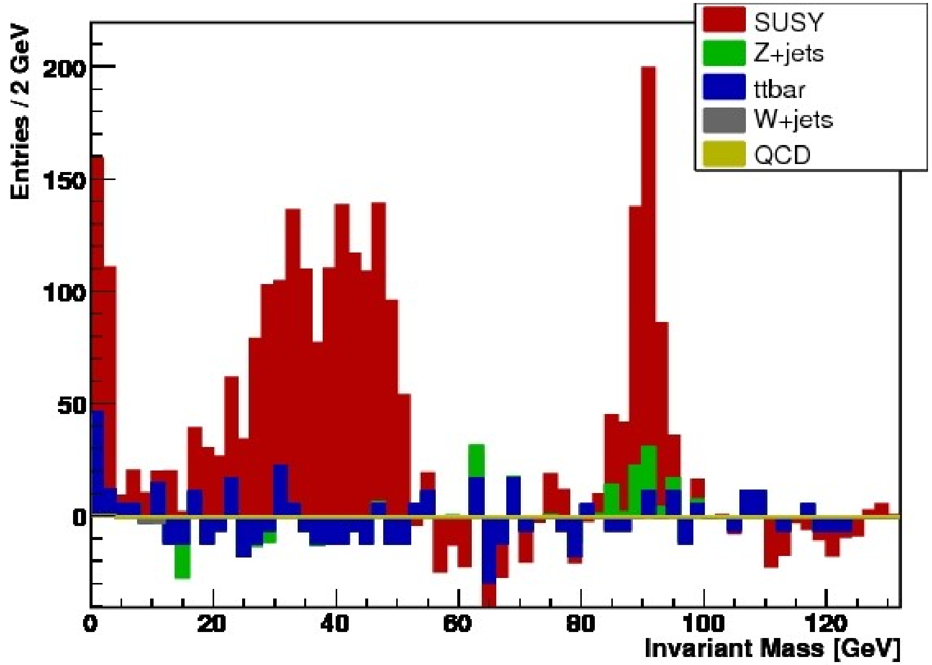
Expected Signal

L_{int} = 1 fb^{-1}
(full detector simulation)



- Background suppression works
- Signal visible but poor statistics
- Shape depends strongly on binning
- QCD statistics much too low – smoothed distribution

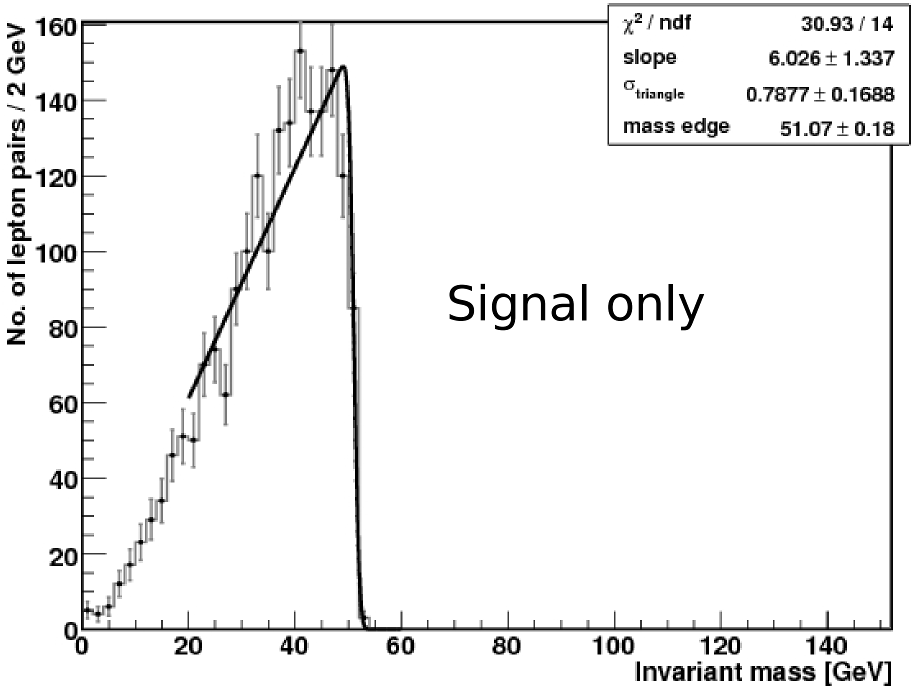
L_{int} = 20 fb^{-1}
(fast detector simulation)



- Nice signal shape!

The neutralino mass difference

- Endpoint of distribution indicates mass difference
- Triangular-like shape at LM9 (not in general)
  - 2-body: strictly triangular
  - 3-body: phase-space dependent
- Fit with convolution of triangle and gaussian
  - delivers position of the „edge", not the endpoint
  - if statistic is good endpoint is underestimated.
  - theoretical shape being calculated by group of M. Krämer

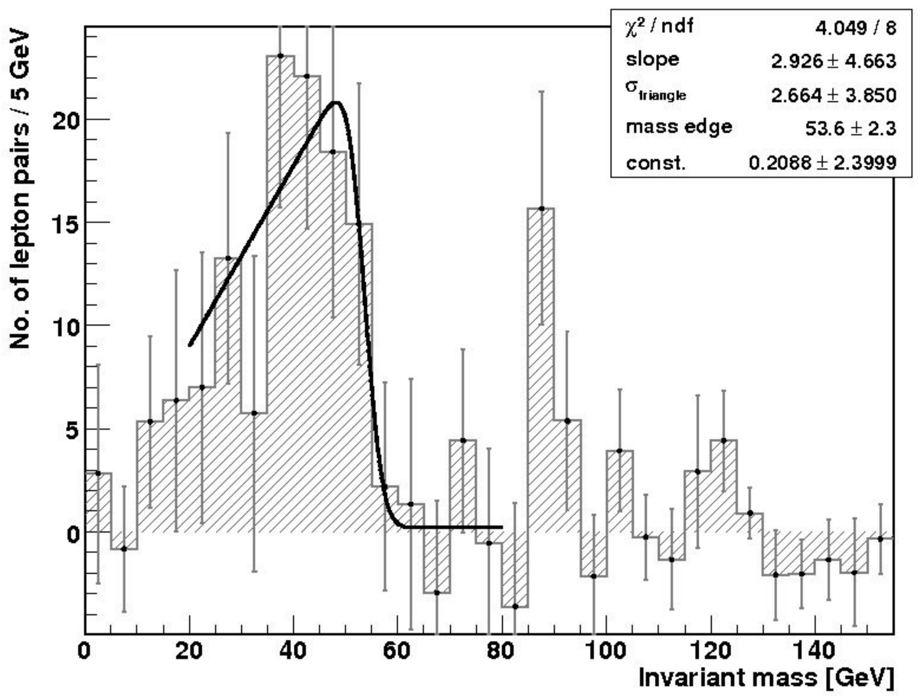


Fit result:
$M_{edge} = 51.01 \pm 0.19_{stat}$ GeV

True mass difference at LM9:
$\Delta M = 52.21$ GeV

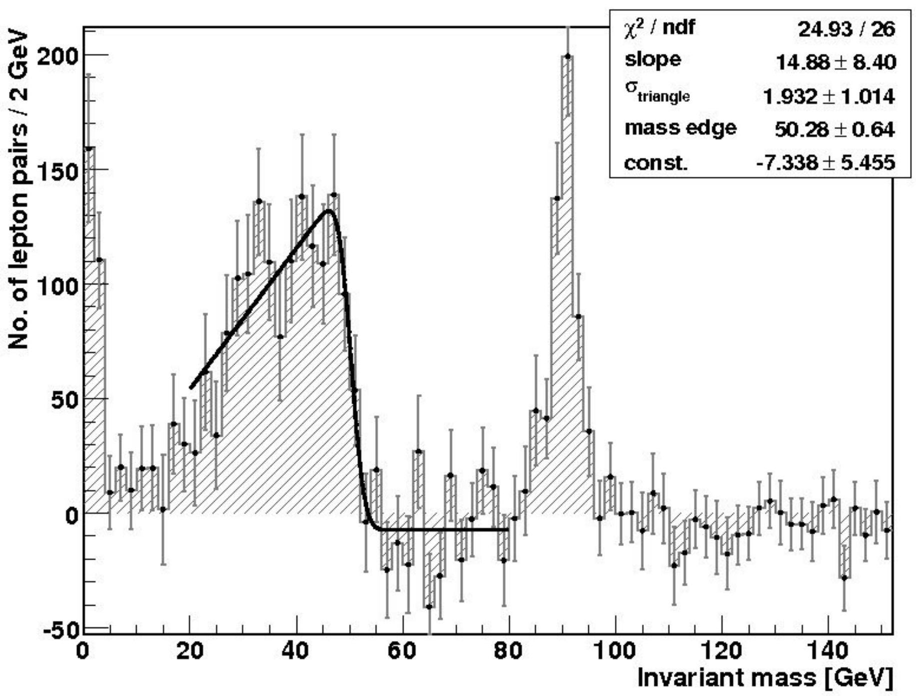
Results

$L_{int} = 1\ fb^{-1}$



$M_{edge} = 53.6 \pm 2.3_{stat}$ GeV

$L_{int} = 20\ fb^{-1}$



$M_{edge} = 50.28 \pm 0.64_{stat}$ GeV

True Mass difference: ΔM=52.21 GeV

Systematic Uncertainties

- Contributions to systematic uncertainty:
  - Selection cuts
  - Fit parameters
  - Binning
- Dominant contributions:
  - cuts on muon p_T
  - muon pseudorapidity
  - electron selection

- Resulting uncertainties:
  - $L_{int} = 1\ fb^{-1}$:

    $$\sigma = \left({}^{+1.9}_{-5.5}\,_{syst} \pm 2.3_{stat} \right) GeV$$

  - $L_{int} = 20\ fb^{-1}$

    $$\sigma = \left({}^{+1.1}_{-1.3}\,_{syst} \pm 0.64_{stat} \right) GeV$$

⇒ Systematic uncertainties dominate!

Summary

- Signal of leptonic neutralino decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^+ + l^-$ visible at LM9
- Standard Model backgrounds can be controlled using jets and missing transverse energy.
- Mass difference can be determined from kinematic endpoint
  - Fit approximates the mass difference
  - For L_{int} = 1 fb^{-1} a statistical error of 4% can be reached, while systematic uncertainties are dominant with 10%
  - For L_{int} = 20 fb^{-1} the statistical error decreases to 1% and the systematic uncertainties is strongly reduced to 2.5%
  - Theoretical value is reproduced within 1-2 standard deviations – though probably still some bias in the estimator

Outlook:

- Reduce systematic uncertainty
- Fit with theoretical edge shape