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SFB 676 – Projekt B2

# Data Driven Background Estimation

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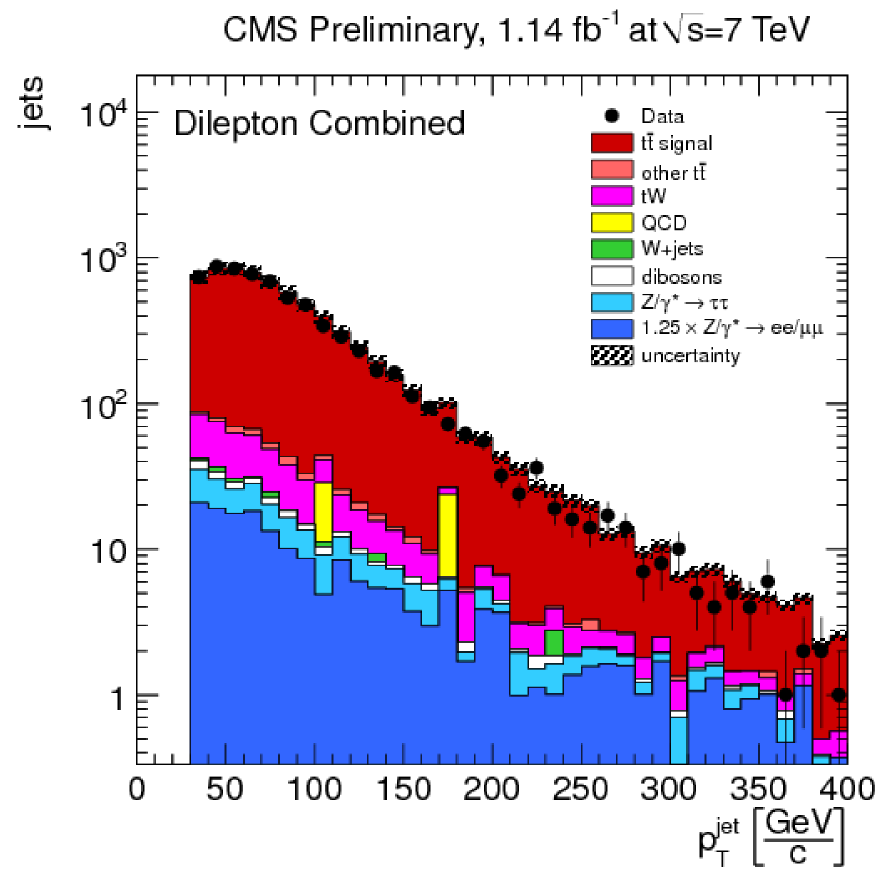
# Outline

- **Background from Monte Carlo**
- **“Bump hunts”**
- **Motivation for data driven backgrounds**
- **Control sample weighting**
  - Factorization / “ABCD” Methods
- **Control events weighting**
  - Inversion techniques
  - Fake methods
  - Replacement/Removal techniques
- **QCD Background – Rebalance and Smear**
- **Application: hadronic SUSY search with jets and MET**

# Background from Monte Carlo

- Monte Carlo (event generation + full detector simulation) widely used in HEP experiments
  - Excellent agreement for most of the observables
  - Evaluation of systematic uncertainties
    - Scale for Data/MC differences (trigger, efficiencies ...)
    - Simulation with different settings (scale variations, pdf, fragmentation model ...)
    - Systematic variation of properties of reconstructed particles (jet energy scale uncertainties ...)

**→ Valid approach for final states which are well understood**




**Example:** Jet $p_T$ for dilepton ttbar selection

CMS PAS TOP-11-013

# Scaled Monte Carlo Simulation

- If shape of simulated distribution is well simulated

  → Use background dominated region to normalize prediction

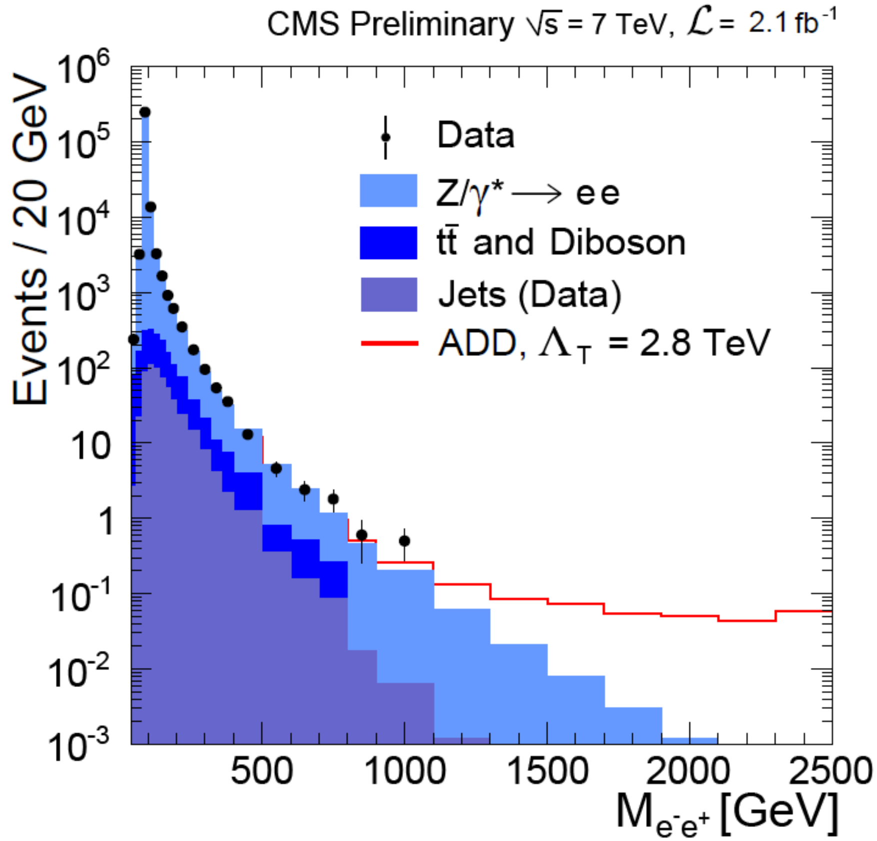
  **Example:** Normalize DY background in invariant mass window around *Z* peak

- Don't forget about remaining contributions from other SM processes

- **Important:**

  Assign uncertainty to model assumption:

  **"Same shapes in data and simulation?"**




**Example:** Search for ADD models

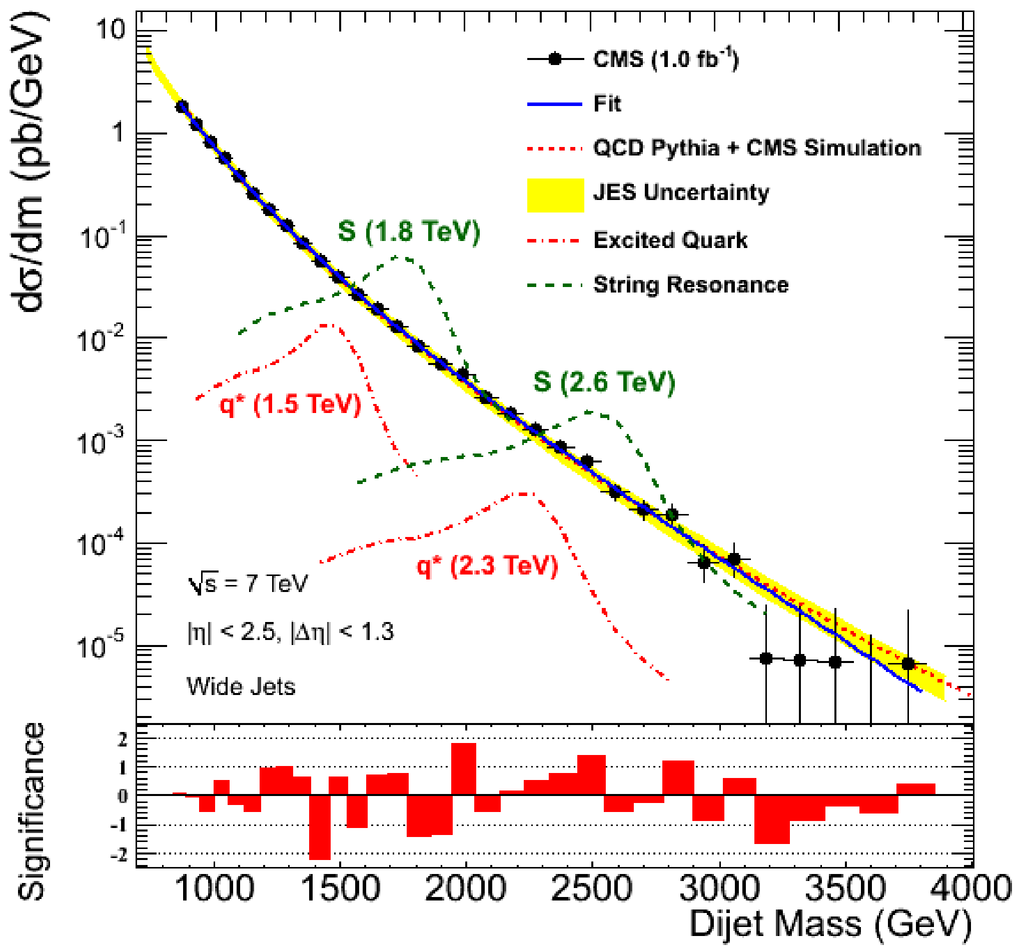
Invariant $e^+e^-$ mass

CMS PAS EXO-11-087

# "Bump Hunts"

- Search for narrow resonances over smooth background (shape not well predicted by theory)
- Limit depends on model assumption (fit function)
  - Statistical uncertainties from fit variance
  - Systematic uncertainties on fit function is challenging to assign, if function is not based on physics principles

  → **Possibility:** validate in control region, where no excess is expected (not always possible).




**Example:** Search for resonances in di-jet mass

**CMS PAS EXO-11-015**

# Data Driven Methods in MET Searches

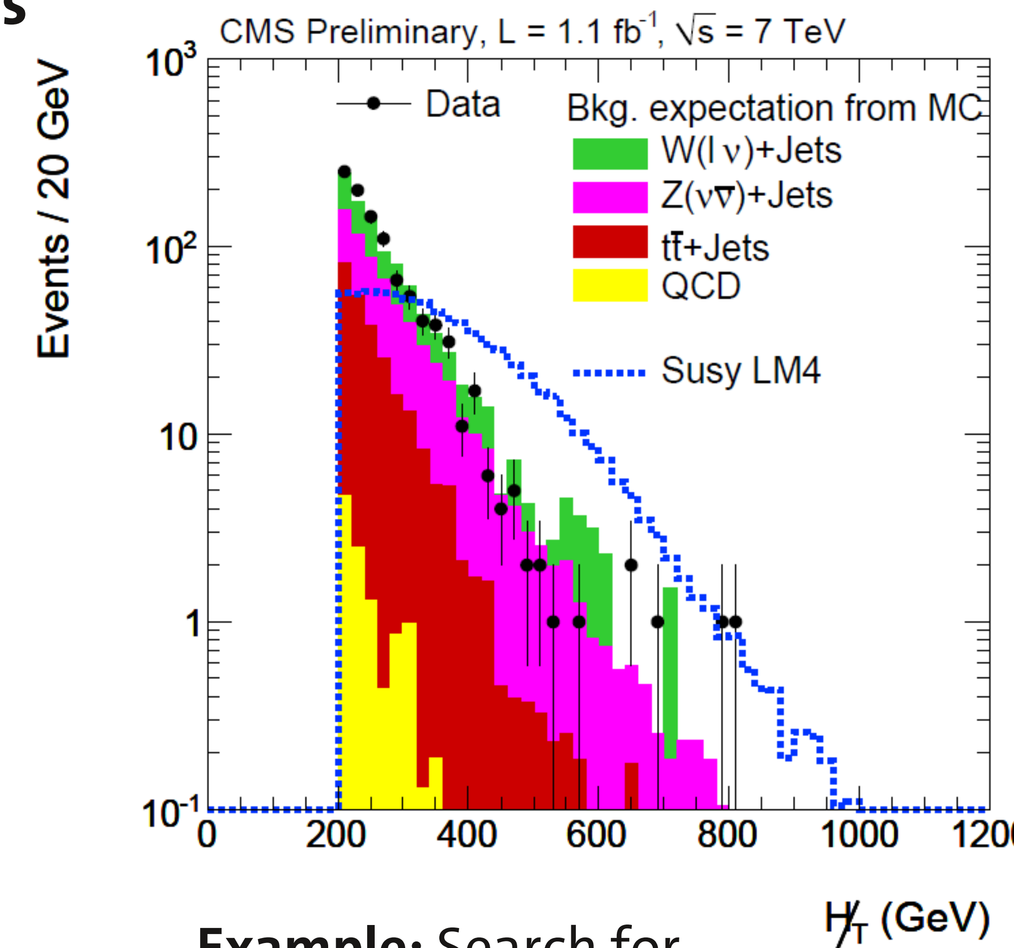


**Searches for NP → excess in MET tails**

**→ Plain simulation at the limit**

- SM backgrounds with large MET:
  - **Backgrounds from out-of-acceptance, isolation, or reconstruction**
    *example*: $(W \rightarrow e/\mu + \nu)$+*jets*
  - **Fake backgrounds**
    *example*: $(W \rightarrow \tau_{had} + \nu)$+*jets*
  - **Irreducible backgrounds**
    *example*: $(Z \rightarrow \nu\nu)$+*jets*
  - **Mismeasurements**
    *example: QCD multi-jet production*

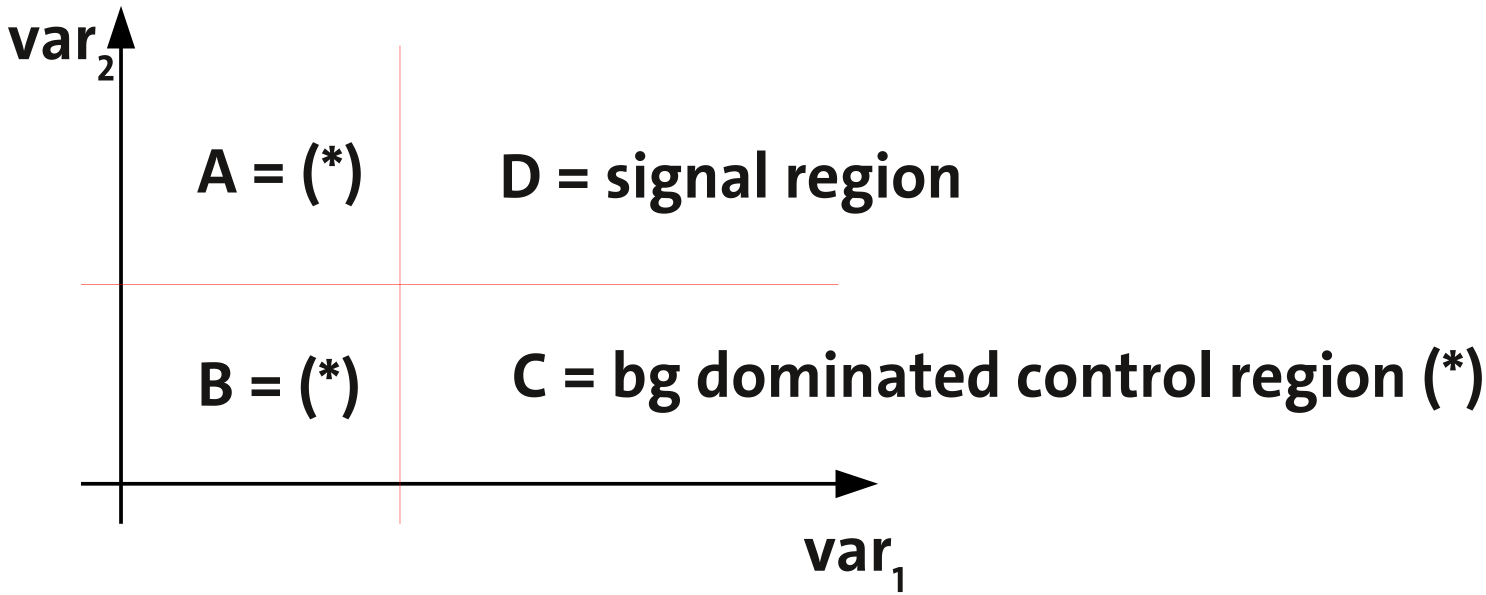
**→ Each bg requires special methods**




**Example:** Search for supersymmetry in all-hadronic events with missing energy
**CMS PAS SUS-11-004**

# Factorization / "ABCD"-Method

- If search region is defined by sequential cuts, e.g. on $var_1$ and $var_2$ (with discriminative power, e.g. MET and HT)




- If variables are uncorrelated (has to be verified)
  → shape of $var_1$ distribution independent of choice of $var_2$
  → background in signal region predicted by scaling of control sample

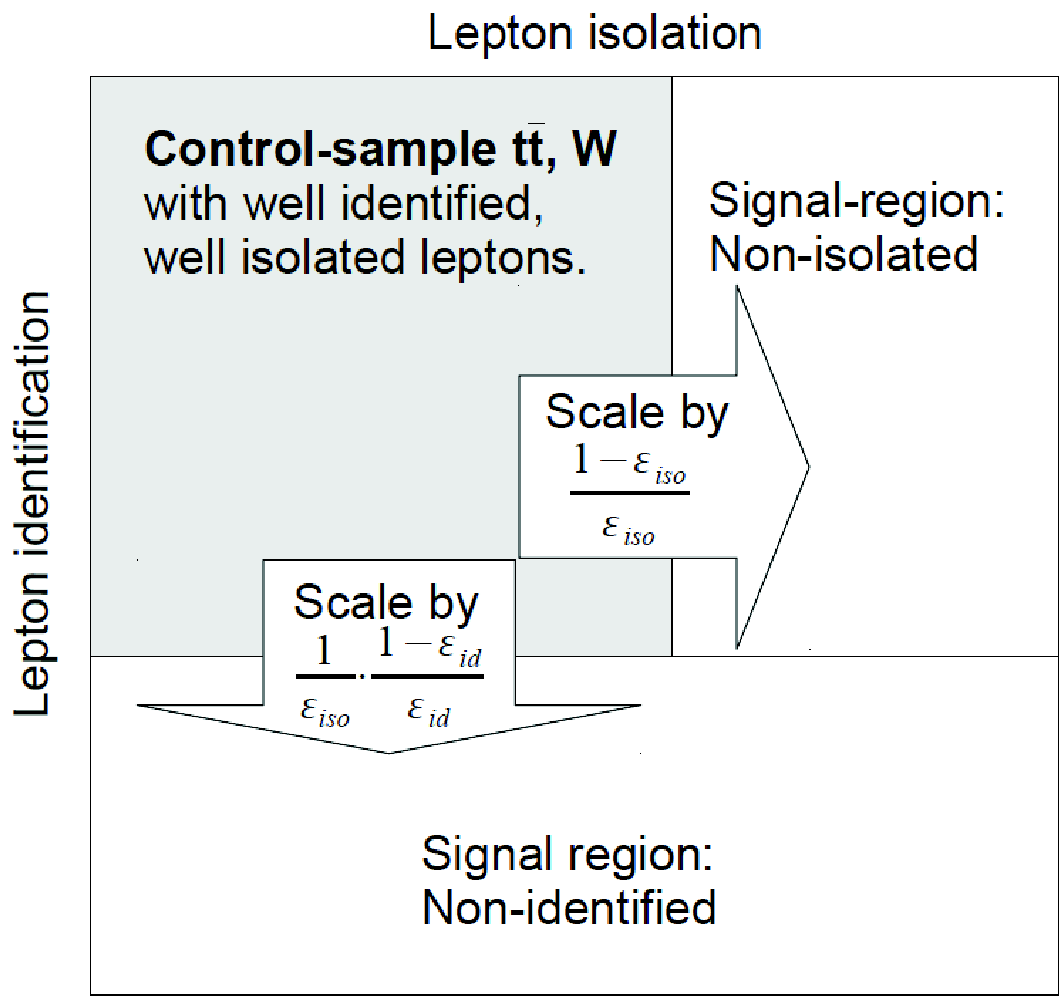
$$N_D = N_C \cdot N_A / N_B$$

- Modification for correlated variables possible, however challenging!

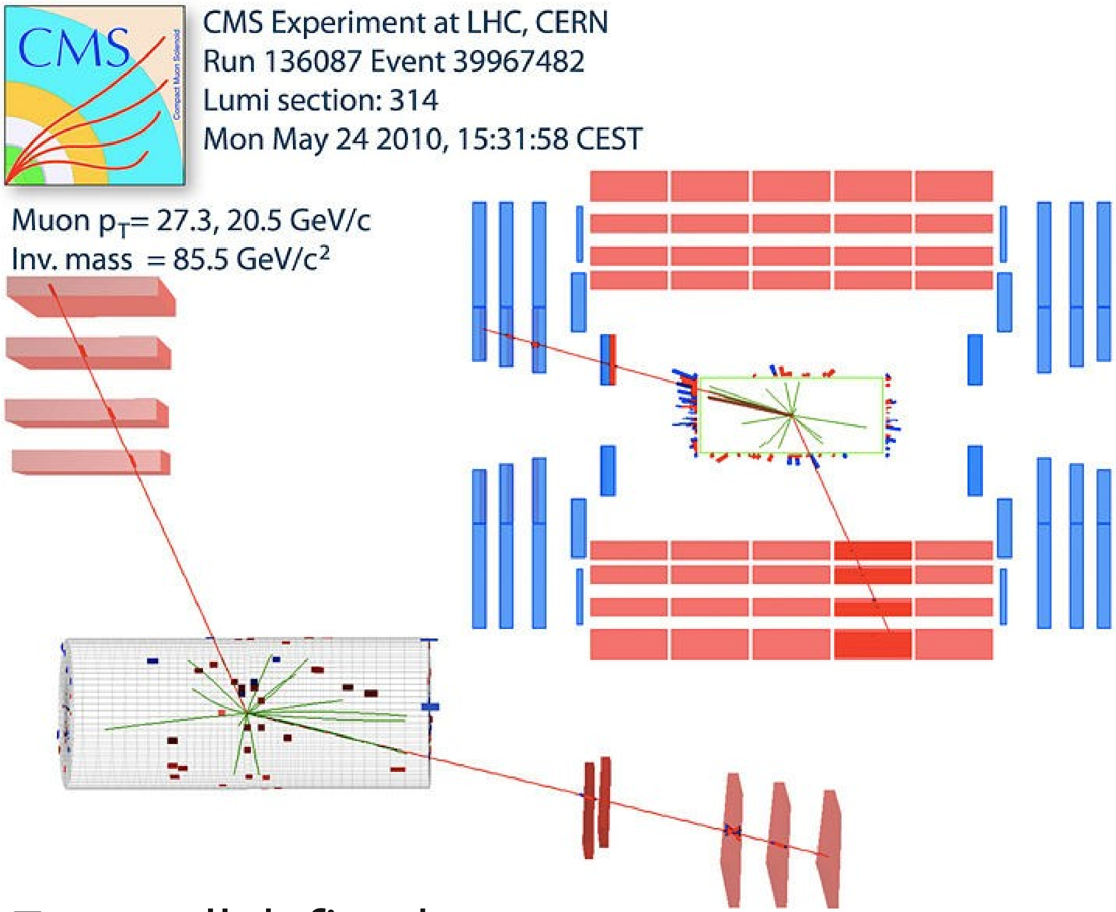
# Inversion Techniques

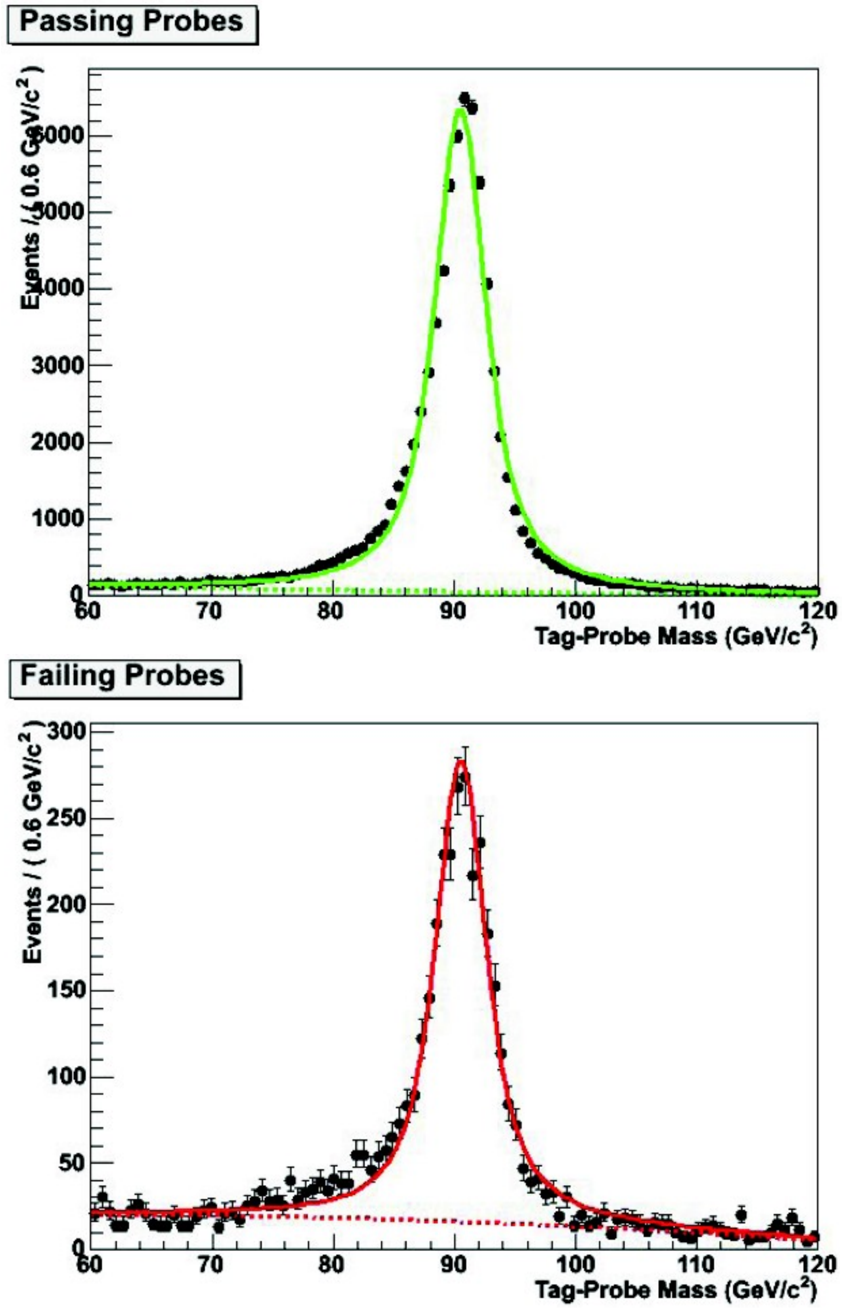
***Example:*** *full-hadronic search requires explicitly no isolated lepton! Events with leptons contribute to bg, because not reconstructed, not isolated or out of acceptance!*

- Select events with exactly one isolated lepton
- **Reweight events** according to isolation and reconstruction efficiencies (probabilities that a lepton is reconstructed or isolated)
  - Efficiencies depend on event kinematics (e.g. high jet multiplicity → low isolation efficiency)
  - Obtain efficiencies from data in sufficient binning in relevant variables (e.g. distance of lepton to nearest jet)
- **Apply acceptance correction from MC**



# Tag and Probe – Efficiencies from Data




**Tag:** well defined muon

**Probe:** loose definition of muon

$m_{\mu\mu}$ compatible with $Z$ mass → Probe is muon

**pass/(pass+fail)** ratio of probe is efficiency

# Fake Techniques

***Example:*** *full-hadronic search requires explicitly no isolated lepton! Events with leptons contribute to bg, because of taus decaying hadronically and thus faking a jet!*

- Select a control sample with exactly one isolated light lepton (e.g. muon)

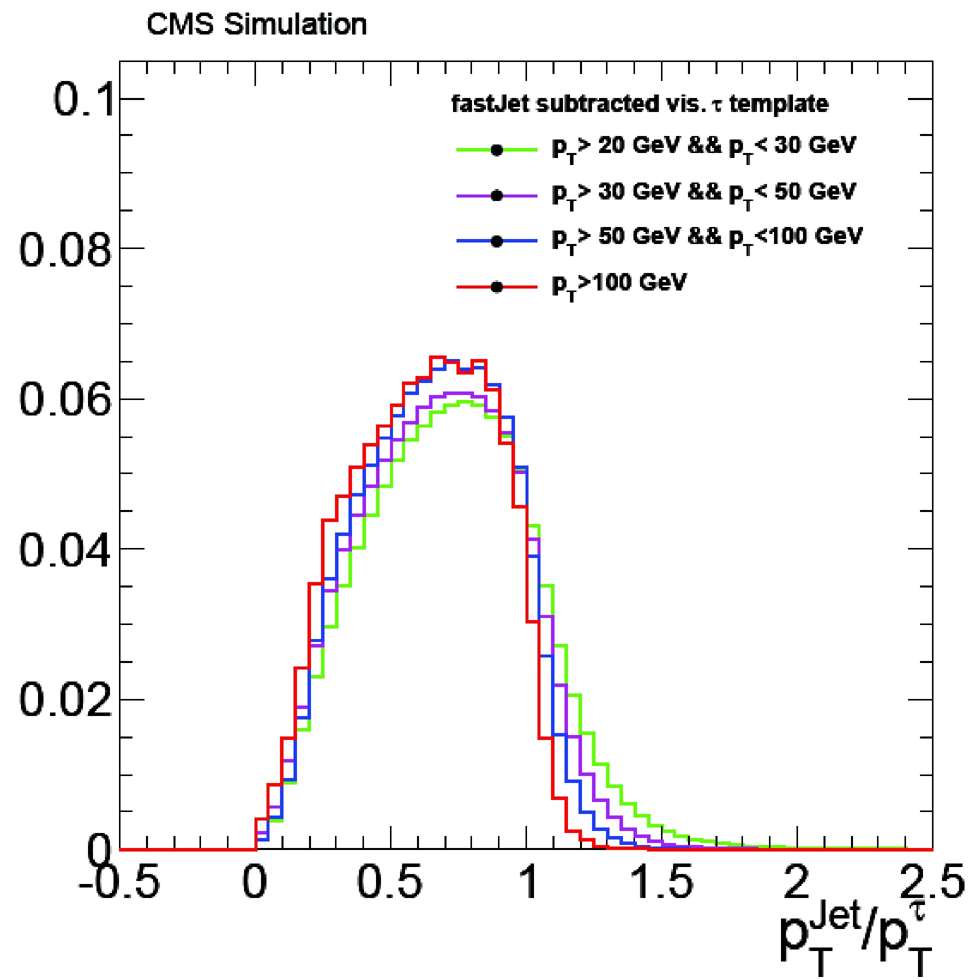
- **Weight events** according to muon reconstruction and isolation efficiencies

- **Use universality of leptons**

  → same number of taus

- **Weight events** according to hadronic branching fraction and tau reconstruction efficiencies

- **Replace muon by hadronic tau-jet** (draw random $p_T$ from templates) and recalculate MHT, HT ...



# Replacement/Removal Techniques

***Example:*** *irreducible background to full-hadronic search is (Z→νν)+jets!*

- Select events with same kinematics but light leptons instead of neutrinos

$$\sigma \cdot \mathbf{Br}(\mathbf{Z} \to \nu\nu) = \underbrace{\frac{\mathbf{Br}(\mathbf{Z} \to \nu\nu)}{\mathbf{Br}(\mathbf{Z} \to \mathbf{e}^+\mathbf{e}^-)}}_{\text{From theory}} \cdot \frac{\mathbf{N}_\mathbf{Z}^{\mathbf{observed}} - \mathbf{N}_\mathbf{Z}^{\mathbf{background}}}{\mathbf{acceptance}_\mathbf{Z} \cdot \mathbf{efficiency}_\mathbf{Z} \cdot \int \mathbf{Ldt}}$$

- **Remove leptons from event**
- **Recalculate MHT**
- Alternatively on can use *W*+jets or photon+jets events
  - Similar behavior at high transverse momentum of the boson
  - **Advantage:** higher statistics
  - **Disadvantage:** systematic uncertainties more difficult to estimate

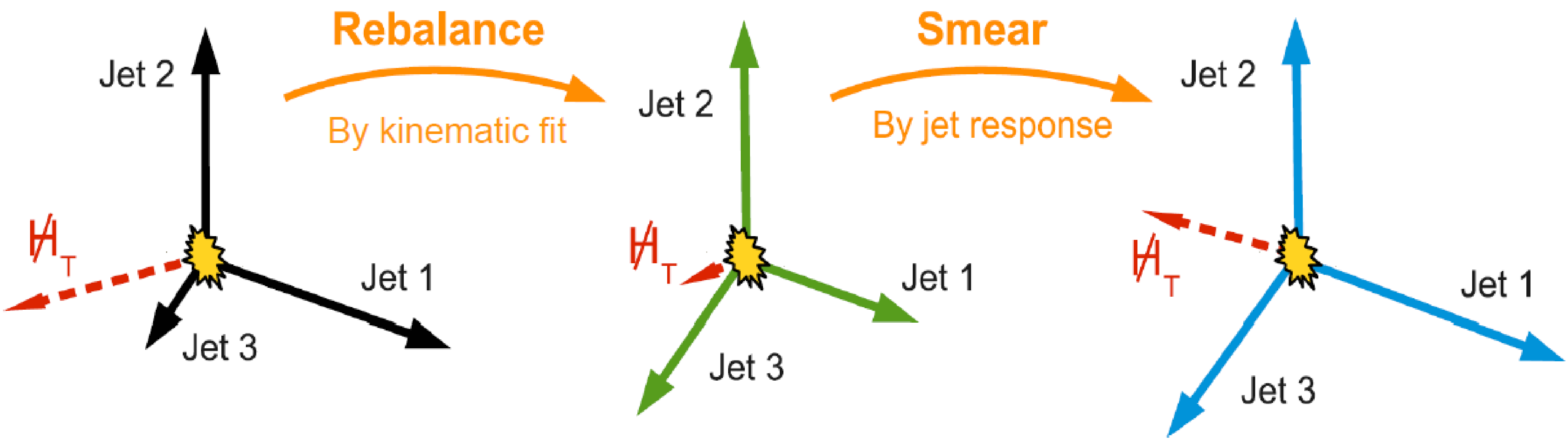
# Rebalance and Smear

- Large uncertainties in QCD multi jet prediction and detector simulation of tails

  → **Obtain seed sample directly from data**, by stripping off transverse momentum imbalance by kinematic fit (method intrinsically safe against non-QCD contributions)

  → **Smear $p_T$ of rebalanced jets by jet response** (corrected for data/MC differences)

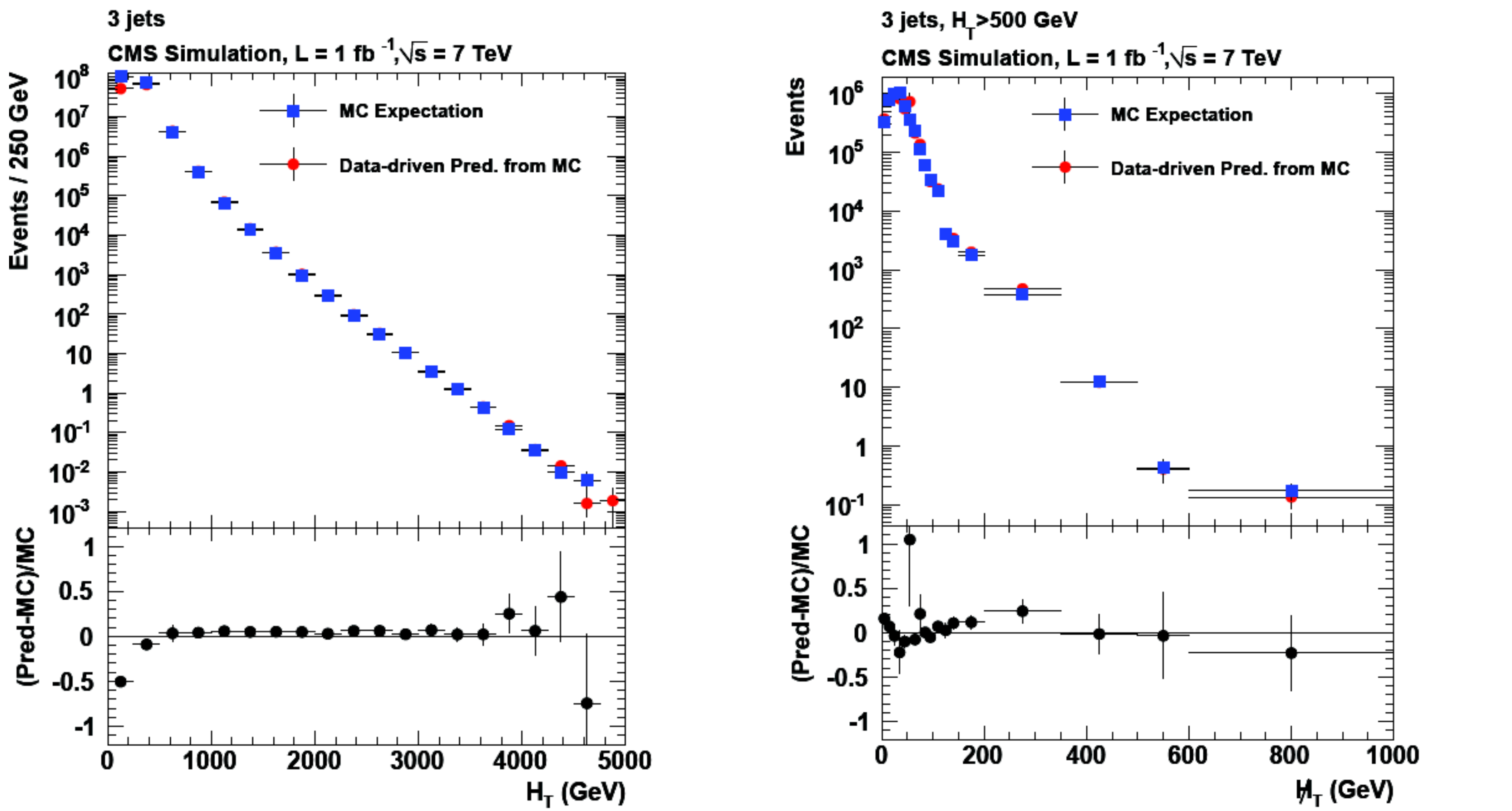
  → **Smeared sample describes full kinematic properties of QCD events**



# R+S – Closure Tests

**All data driven methods have to be validated on simulated samples!**

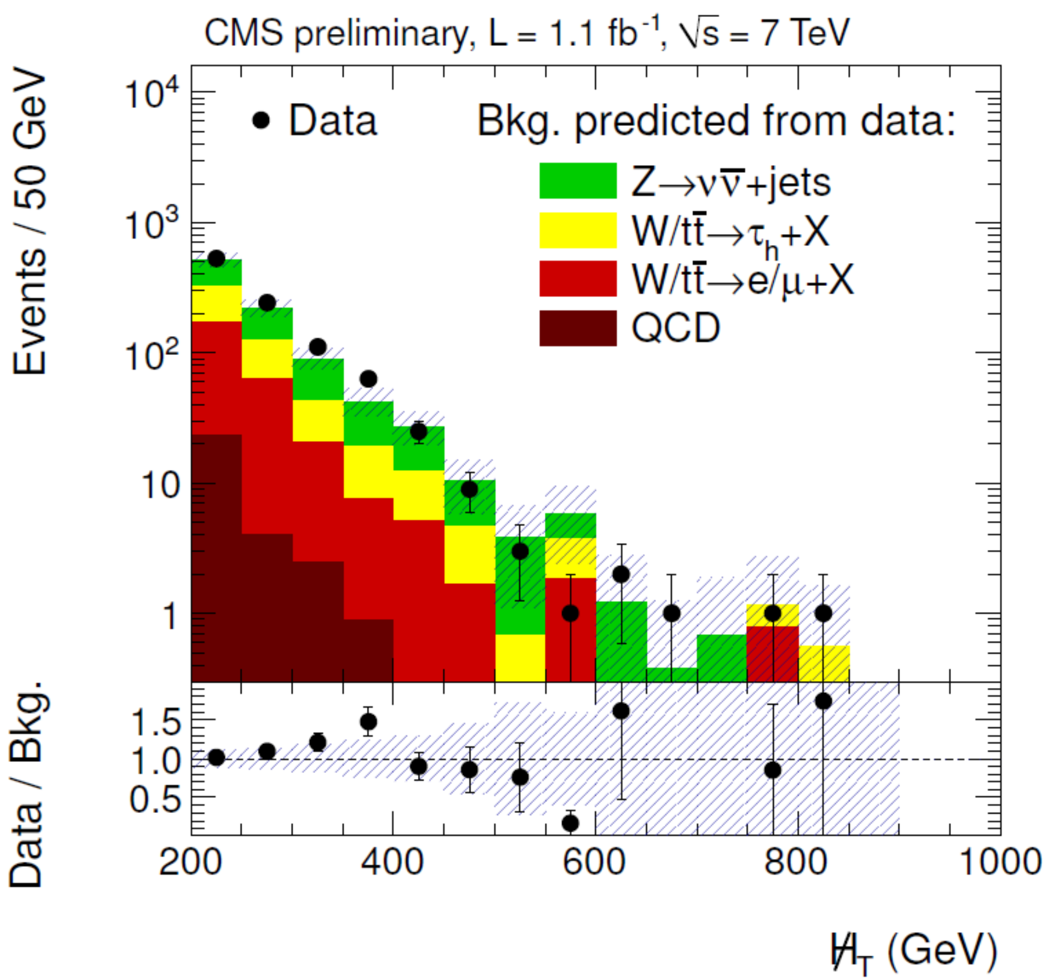
**→ "Closure Tests"**

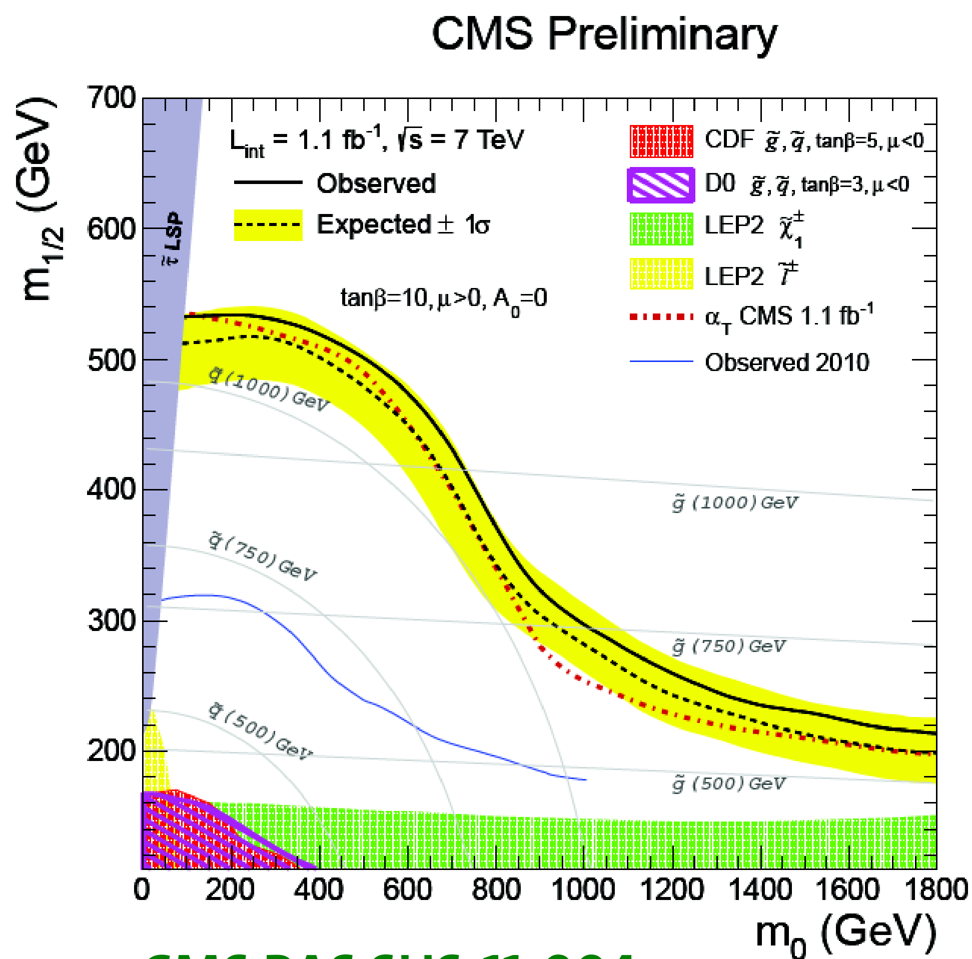



**→ Good performance on simulated events (here: QCD Pythia)**

- Put together all data driven background predictions

→ **Good agreement with data! → Set very sensitive limits!**




CMS PAS SUS-11-004

# Summary

- Data driven methods are crucial for many searches for which the uncertainties from simulation are large or simply not known
- Often many techniques are used in one analysis
  - To estimate different backgrounds
  - To have independent cross checks
- Each method has to be validated on simulated events (“Closure tests”)
- **Most of the work:** evaluation of systematic uncertainties

**→ But it's worth the effort, since we would like to prepare for discoveries … in 2012?**

# Backup

# Rebalance and Smear

**Detector effects:** Jet resolution, dead ECAL cells, Punch through ...

**Physics:** Leptonic heavy flavor decays

→ **mismeasured jets (→ large MHT)**

Full jet response (incl. tails) measured from data

↓

Select or mimic particle jets (rebalance seed events):

↓

Smear seed events according to measured jet resolutions

↓

Smeared sample resembles full kinematic