Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

ATLAS EXPERIMENT

Data-driven background measurement for the SUSY search in multileptonic final states with the ATLAS detector at $\sqrt{s} = 13\ \mathrm{TeV}$

Stefan Maschek

November 7th 2016

Motivation: Supersymmetry

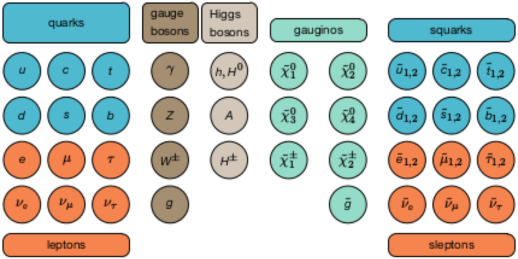
- Standard Model is only part of a more complex theory
- Experimental observations (Dark Matter, neutrino masses)
- Theoretical motivations (hierarchy problem)

Supersymmetry

- Assigns a superpartner to each SM particle
- Same quantum numbers except spin
- Spin differ by 1/2
- SUSY is a broken symmetry

R-parity (protective quantum number)

-
  - $+1$ for SM particles
  - -1 for SUSY particles
- Conserved (RPC)
  $\rightarrow$ lightest supersymmetric particle (LSP) is stable
- Violated (RPV)
  $\rightarrow$ allows decay of LSP into SM particles



The benchmark model

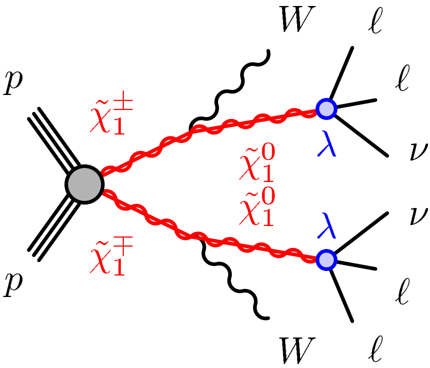
Why four-lepton signature?

- Sensitive to a variety of SUSY models
- Special scenario: R-parity violating (RPV) model
- Very low Standard Model background

R-parity violating Superpotential term

$$\frac{1}{2}\lambda_{ijk}\mathbf{L}_i\mathbf{L}_j\bar{\mathbf{E}}_k$$

i, j, k: Lepton generation



$\longrightarrow$ Search for such a process with the ATLAS detector at $\sqrt{s} = 13$ TeV

Search for SUSY in final states with at least four leptons with ATLAS

- **Four light charged leptons** (= electrons, muons)

$$p_{\mathrm{T}}^{\text{electron}} > 5 \ \ \mathrm{GeV}$$
$$p_{\mathrm{T}}^{\text{muon}} > 7 \ \ \mathrm{GeV}$$

- **Z-Veto:** discard event if:

$$m(\ell, \ell, ...) \approx m_Z$$

- **Effective mass**:

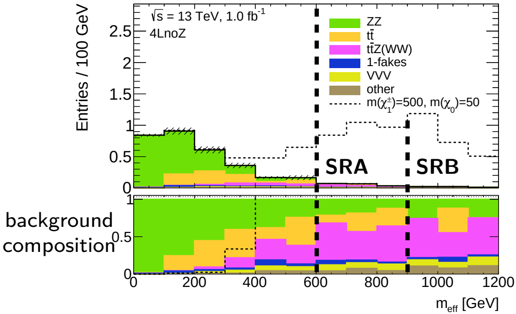
$$m_{\mathrm{eff}} = \sum_{\text{leptons}} p_{\mathrm{T}} + \sum_{jets} p_{\mathrm{T}} + \left| \vec{E}_T^{\text{miss}} \right|$$

$$\vec{E}_T^{\text{miss}} = - \sum_{\text{all objects}} \vec{E}_T$$

→ **Two signal regions (SR):**

- $m_{\mathrm{eff}} > 600 \ \mathrm{GeV}$ → signal region A (SRA)
- $m_{\mathrm{eff}} > 900 \ \mathrm{GeV}$ → signal region B (SRB)

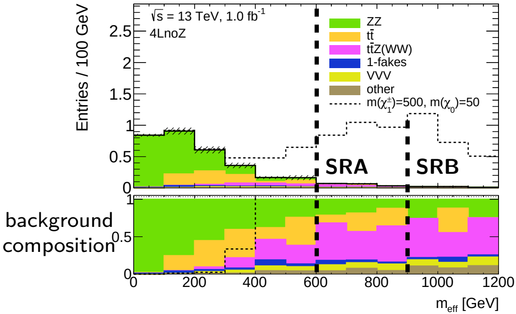
Background expectation



Dominant background processes

- ZZ for low m_{eff}
- $t\bar{t}Z$ for high m_{eff} (SR)
- Also high contribution of $t\bar{t}$

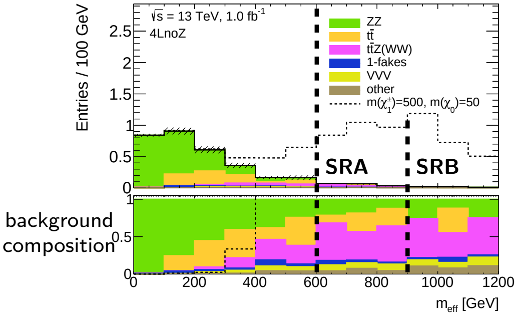
Background expectation



Dominant background processes

- ZZ for low m_{eff} $\rightarrow$ irreducible
- $t\bar{t}Z$ for high m_{eff} (SR) $\rightarrow$ irreducible
- Also high contribution of $t\bar{t}$ $\rightarrow$ **reducible**

Background expectation

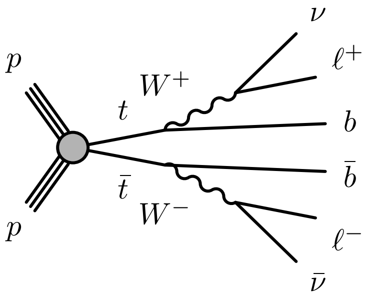


Dominant background processes

- ZZ for low m_{eff} → irreducible → Monte Carlo
- $t\bar{t}Z$ for high m_{eff} (SR) → irreducible → Monte Carlo
- Also high contribution of $t\bar{t}$ → **reducible** → difficult to simulate! → data-driven

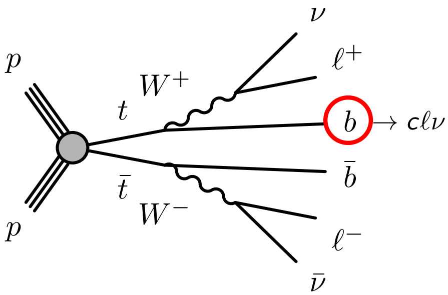
⟶ This talk concentrates on reducible background

Reducible background and "fake leptons"



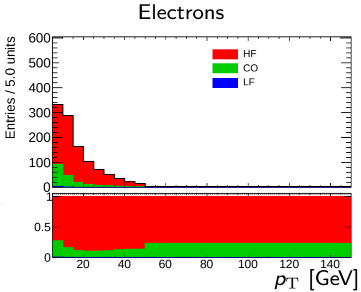
Fake leptons contributions:

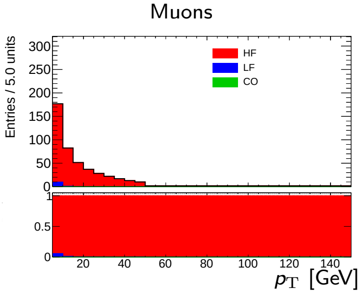
Reducible background and "fake leptons"



Fake leptons contributions:

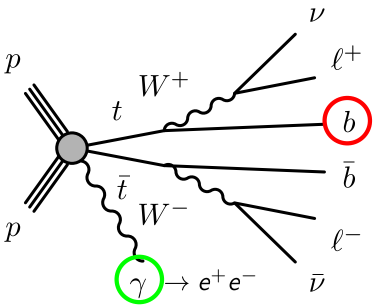
- **HF:** Decay of heavy flavor hadrons ($>$ 90%)

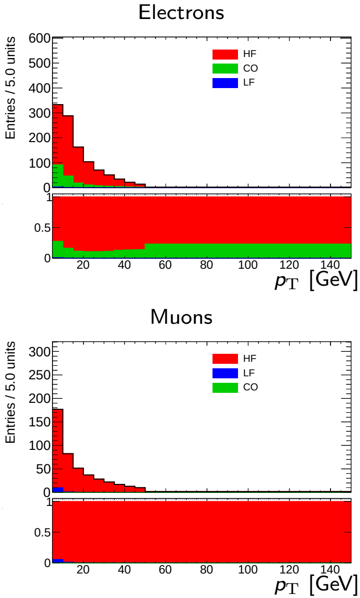




Most of the fake leptons are rejected by **signal object criteria**

Reducible background and "fake leptons"





Fake leptons contributions:

- **HF:** Decay of heavy flavor hadrons ($> 90\%$)
- **CO:** Photon conversion, $\gamma \rightarrow e^+e^-$ ($\approx 20\%$ of fake electrons)

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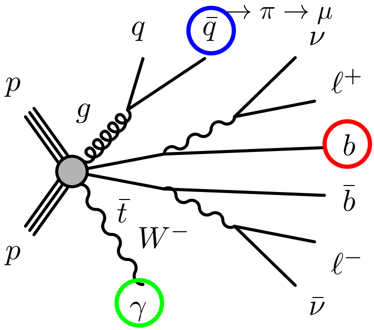
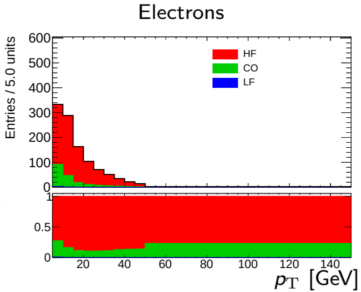
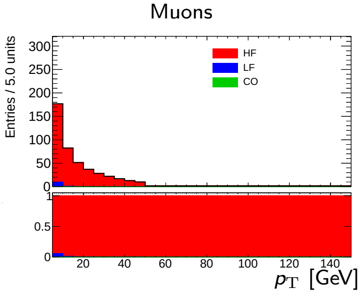
Reducible background and "fake leptons"







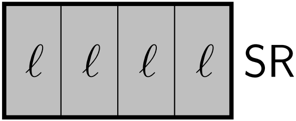
Fake leptons contributions:

- **HF:** Decay of heavy flavor hadrons ($>$ 90%)
- **CO:** Photon conversion, $\gamma \to e^+e^-$ ($\approx$ 20% of fake electrons)
- **LF:** Decay/misidentified light flavor mesons ($\approx$ 5% of fake muons)

Most of the fake leptons are rejected by **signal object criteria**

Data-driven background estimation

1. Define control leptons:
   Reconstructed leptons failing the signal criteria



Data-driven background estimation

1. Define control leptons:
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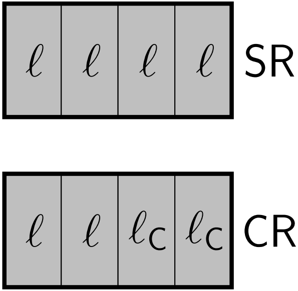
2. Define control region (CR):
   Replacing two signal leptons by control leptons.



Data-driven background estimation

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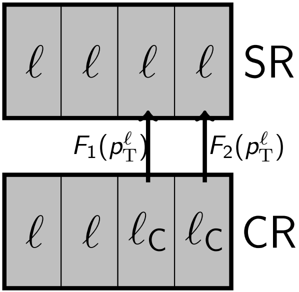
3. Determine reducible background by extrapolating CR data,
   $N_{SR} = N_{CR} F_1 F_2$.



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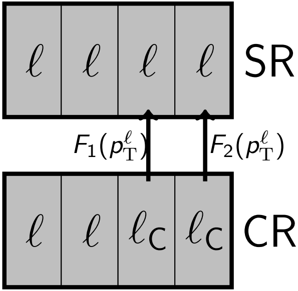


Lepton fake factor

$$F(p_{\mathrm{T}}^{\ell}) = \frac{P(\text{signal})}{P(\text{control})} = \frac{P(\text{signal})}{1 - P(\text{signal})}$$

Fake factor determination: Default approach

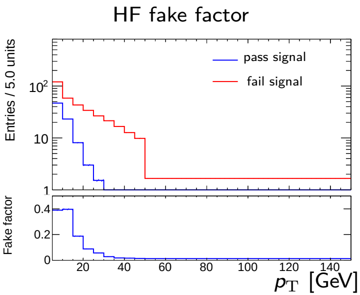
Determination of the weighted average fake factor

$$F = \sum_{i=\mathrm{HF,LF,CO}} R^i F^i C^i$$

- R^i: Expected fractional contribution
- F^i: Determination of the fake factor from Monte Carlo
- C^i: Data-driven correction in data
  - Done for HF
  - For LF, CO: Assumed large uncertainties

Monte Carlo fake factor $F = \sum R^i F^i C^i$

- Use $t\bar{t}$ sample
- In simulation the fake type is known



Monte Carlo fake factor $F = \sum R^i F^i C^i$

- Use $t\bar{t}$ sample
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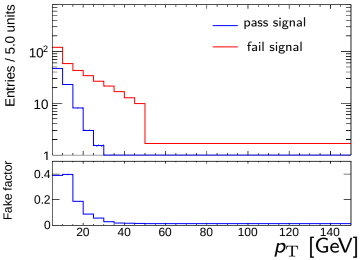
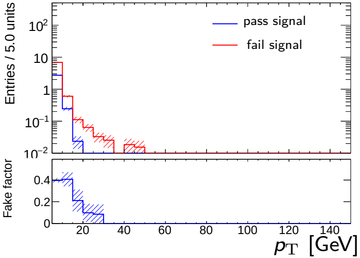
Fake factor depends strongly on transverse momentum
$\rightarrow F = F(p_{\mathrm{T}})$

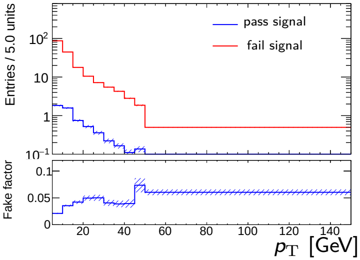
HF fake factor



LF fake factor



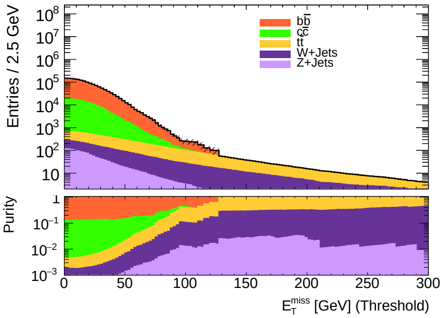
CO fake factor



Data-driven determination of the correction for HF fake factor $F = \sum R^i F^i C^i$

Tag-and-probe: $b\bar{b}$ ($c\bar{c}$) enriched region

- Muon within b-jet ("tag")
- Exactly one further lepton ("probe") $\rightarrow$ probe must be HF fake

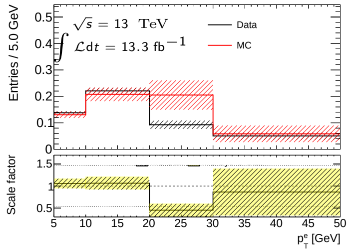


Correction factor

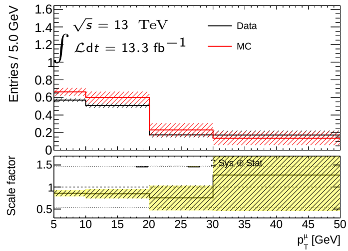
$$C^{HF}_{t\bar{t}} = C^{HF}_{b\bar{b}} = \frac{F^{\text{data}}_{b\bar{b},\text{HF}}}{F^{\text{MC}}_{b\bar{b},\text{HF}}},$$

Resulting correction factor, $F = \sum R^i F^i C^i$

Electrons



Muons



⇝ **Average correction factor**

Electrons

$C_{(e)}^{HF} = 1.011 \pm 0.079$

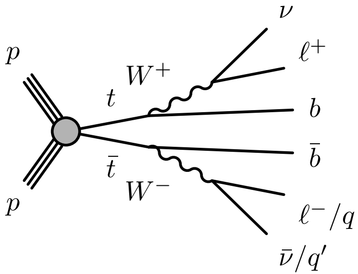
Muons

$C_{(\mu)}^{HF} = 0.848 \pm 0.053$

Fake factor determination: Alternative approach

Direct measurement of the fake factor **in data**

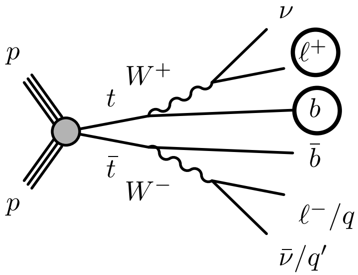
in the $\mathbf{t\bar{t}}$ production.



Fake factor determination: Alternative approach

Tag-and-probe: $t\bar{t}$ enriched region

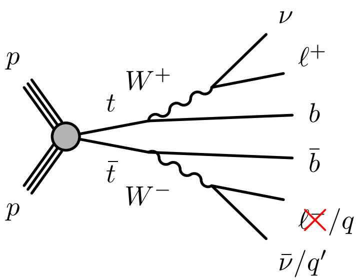
- One high energy signal muon ("tag"),
- At least one b-jet,



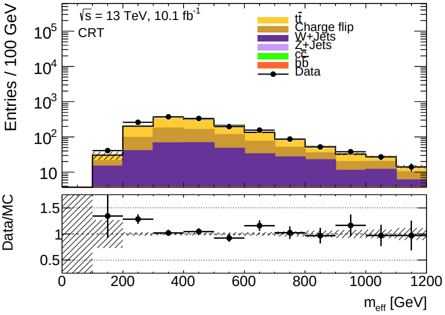
Fake factor determination: Alternative approach

Tag-and-probe:
$t\bar{t}$ enriched region

- One high energy signal muon ("tag"),
- At least one *b*-jet,
- Additional lepton ("probe") has **same charge** as the tag
  $\longrightarrow$ probe is a fake lepton



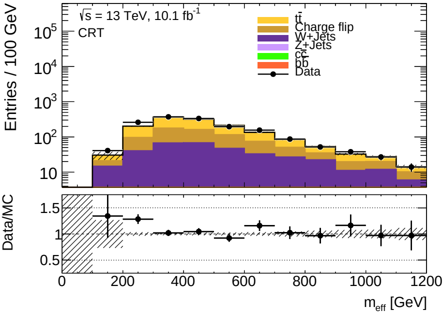
Composition of the $t\bar{t}$ control region



Contamination

- From $W + jets$
- From "charge-flip" for electrons

Composition of the $t\bar{t}$ control region



Contamination

- From $W + jets$
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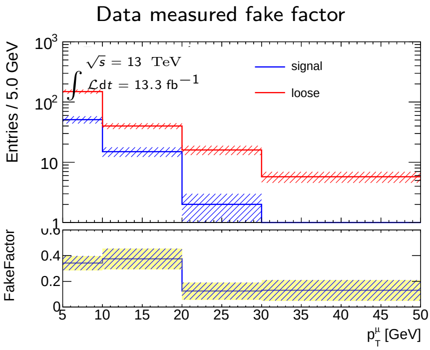
Solution

- $W + jets \rightsquigarrow$ cut on jet multiplicity
- Charge-flip: Data-driven determination

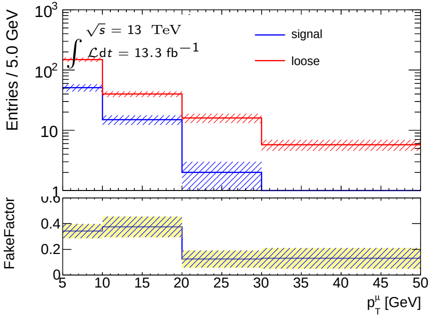
→ For now: Subtract Monte Carlo estimation from data

Data measured fake factor

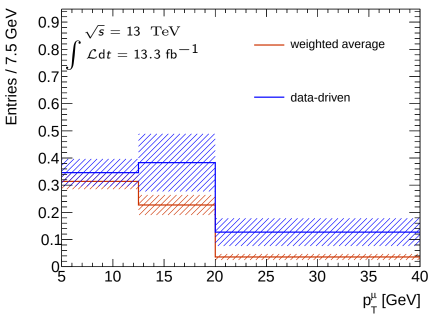


Data measured fake factor vs default approach

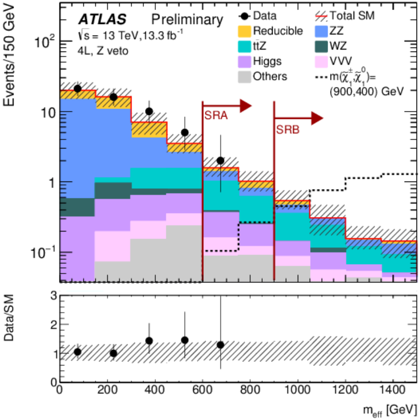
Data measured fake factor



Comparison with the first approach



Results of run 2 analysis



- Integrated luminosity 13.3 fb^{-1}
- Data-MC comparison in low m_{eff} validation of background estimation
- 2 events recorded
- Consistent with SM

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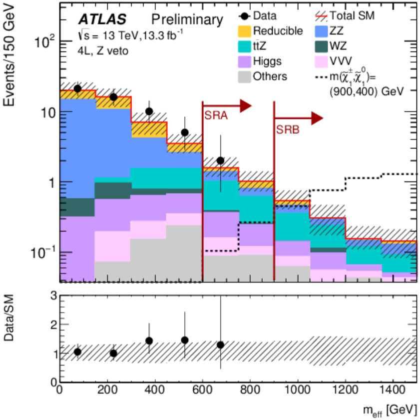

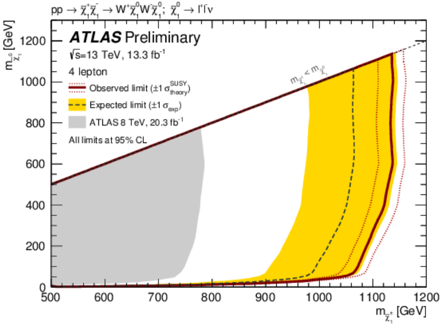

- Integrated luminosity 13.3 fb^{-1}
- Data-MC comparison in low m_{eff} validation of background estimation
- 2 events recorded
- Consistent with SM

- Interpretation: Mass exclusions in benchmark model
- Limits of run 1 are extended $0.75 \ \mathrm{TeV} \rightarrow 1.14 \ \mathrm{TeV}$

Conclusions

- Search for R-parity violating decays in the **four-lepton** channel with the ATLAS detector with $\sqrt{s} = 13\ \mathrm{TeV}$
- Presentation of a **data-driven background determination** of the **reducible $t\bar{t}$ background**
- Two different approaches to measure the **fake factor** $\longrightarrow$ show consistent results
- **Exclusion** of chargino masses in the RPV-model up to $1.14\ \mathrm{TeV}$

Danke für die Aufmerksamkeit

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Backup: Superpotential

MSSM

$$W_{\mathrm{MSSM}} = y_u^{ij} \vec{\bar{U}}_i \vec{Q}_j H_u - y_d^{ij} \vec{\bar{D}}_i \vec{Q}_j H_d - y_e^{ij} \vec{\bar{E}}_i \vec{L}_j H_d + \mu H_u H_d,$$

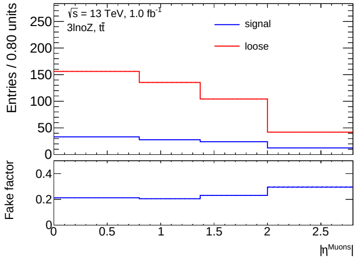
RPV Terms

$$W_{\mathrm{RPV}} = \frac{1}{2} \lambda_{ijk} \vec{L}_i \vec{L}_j \vec{\bar{E}}_k + \lambda'_{ijk} \vec{L}_i \vec{Q}_j \vec{\bar{D}}_k + \kappa_i \vec{L}_i H_u + \frac{1}{2} \lambda''_{ijk} \vec{\bar{U}}_i \vec{\bar{D}}_j \vec{\bar{D}}_k,$$

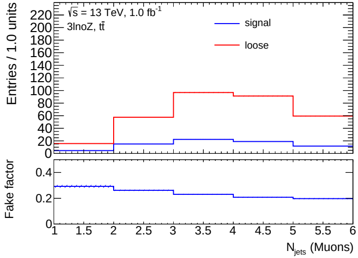
Backup

Other variables

- Polar coordinate



- Jet multiplicity



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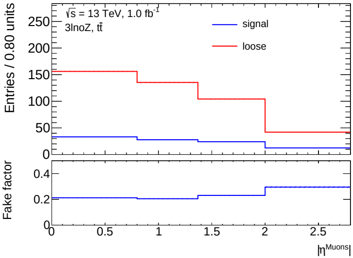

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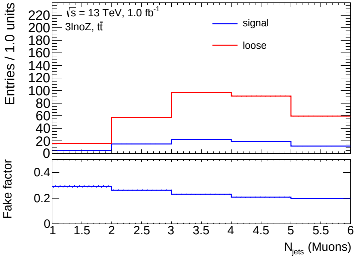
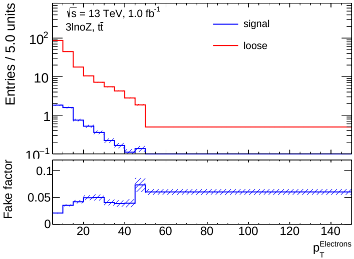
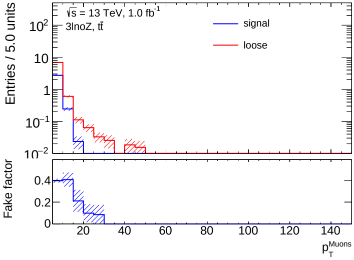


Other fake processes

- CO: $\gamma \rightarrow e^+ e^-$



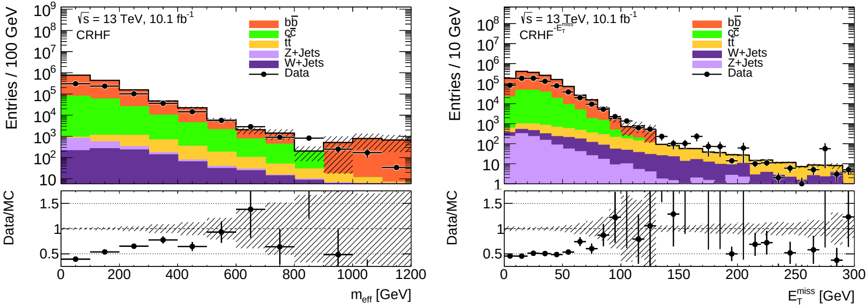
- LF: z.B.: $\pi \rightarrow \mu \, \nu_\mu$



2) Data measurement: Correction for HF fake factor $F = \sum(R^i F^i C^i)$

Advantages

- Very pure in HF
- Very good statistics in data
- Application possible to other HF fake factors (e.g.: Z+jets)



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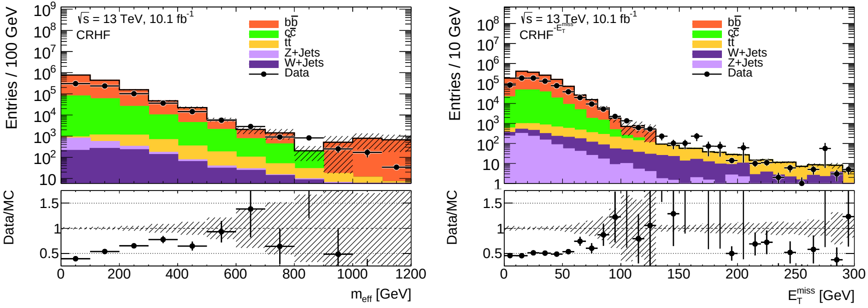
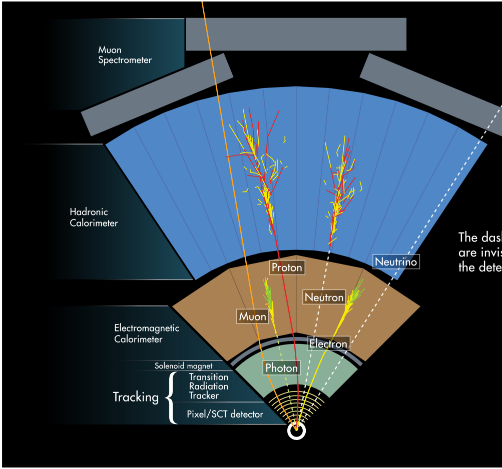
Problem

Bad MC $b\bar{b}$ samples available



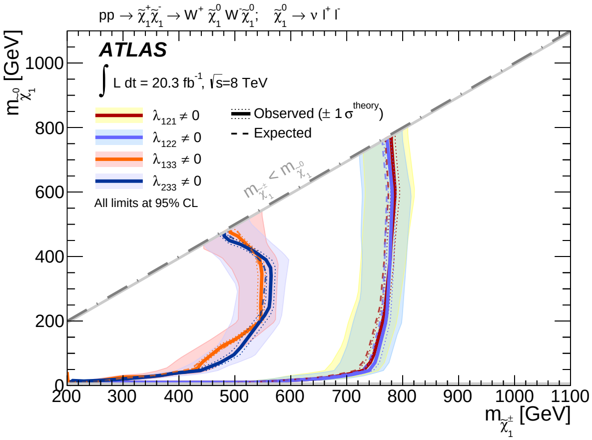
ATLAS

- 4π solid angle
- Uses magnets to measure momenta of charged particles
- Measures deposite energy in calorimeter
- Detects nearly all SM particles (except neutrino)
- Identifies e.g. electrons, muons, hadrons (jets, b-jets)
- Missing transverse momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$



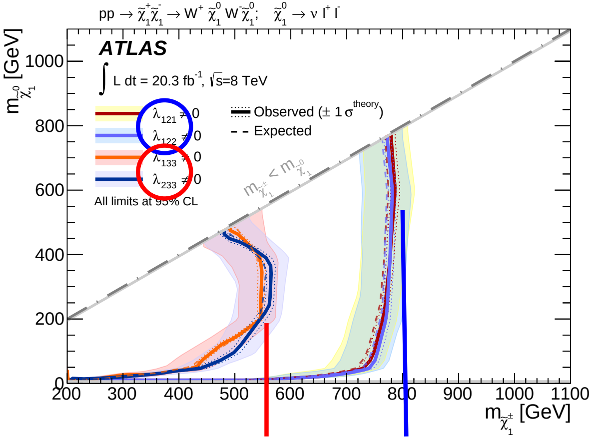
Conclusion of the four-lepton search at $\sqrt{s} = 8$ TeV

- No significant excess from the Standard Model predictions
- Set exclusion limits to some SUSY scenarios, e.g.



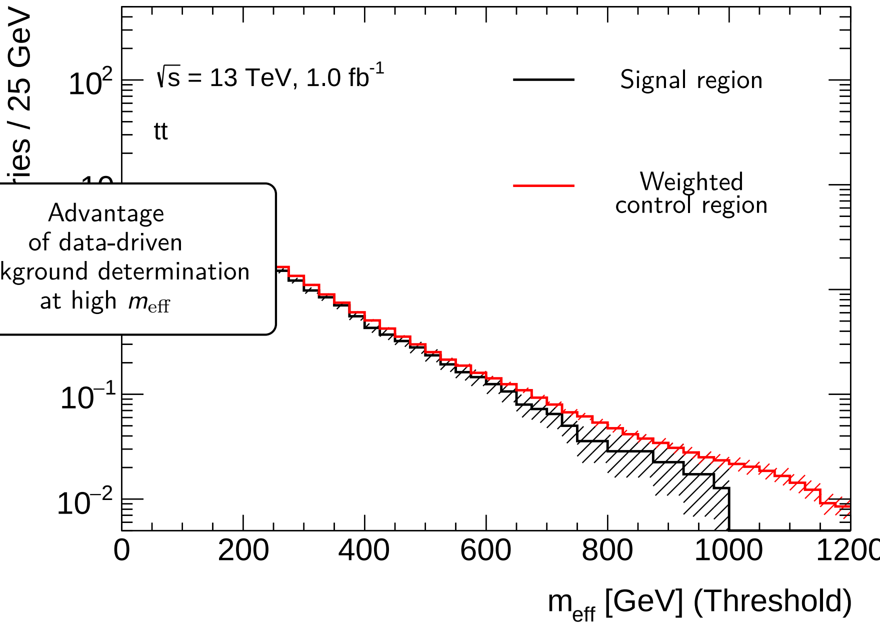
Conclusion of the four-lepton search at $\sqrt{s} = 8$ TeV

- No significant excess from the Standard Model predictions
- Set exclusion limits to some SUSY scenarios, e.g.
  - decay to only light leptons ($\lambda_{121}, \lambda_{122}$):
  - decay partially to τ-leptons ($\lambda_{133}, \lambda_{233}$):



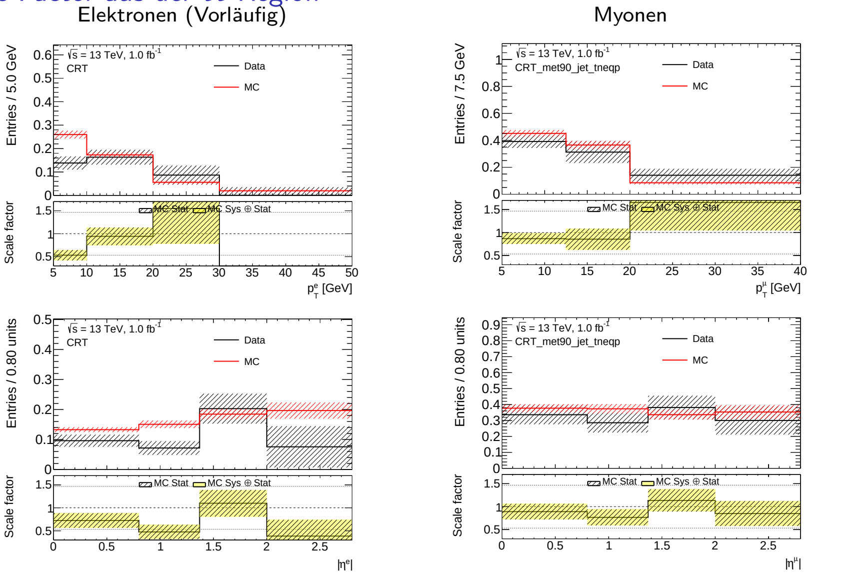
$\tilde{\chi}_1^0 \rightarrow \tau, \mu, e$ $\tilde{\chi}_1^0 \rightarrow \mu, e$

Closure test



Advantage of data-driven background determination at high m_{eff}

Scale Factor aus der $t\bar{t}$ Region



$$sf^{HF}_{(e)} = 0.728 \pm 0.108$$

$$sf^{HF}_{(\mu)} = 0.909 \pm 0.103$$