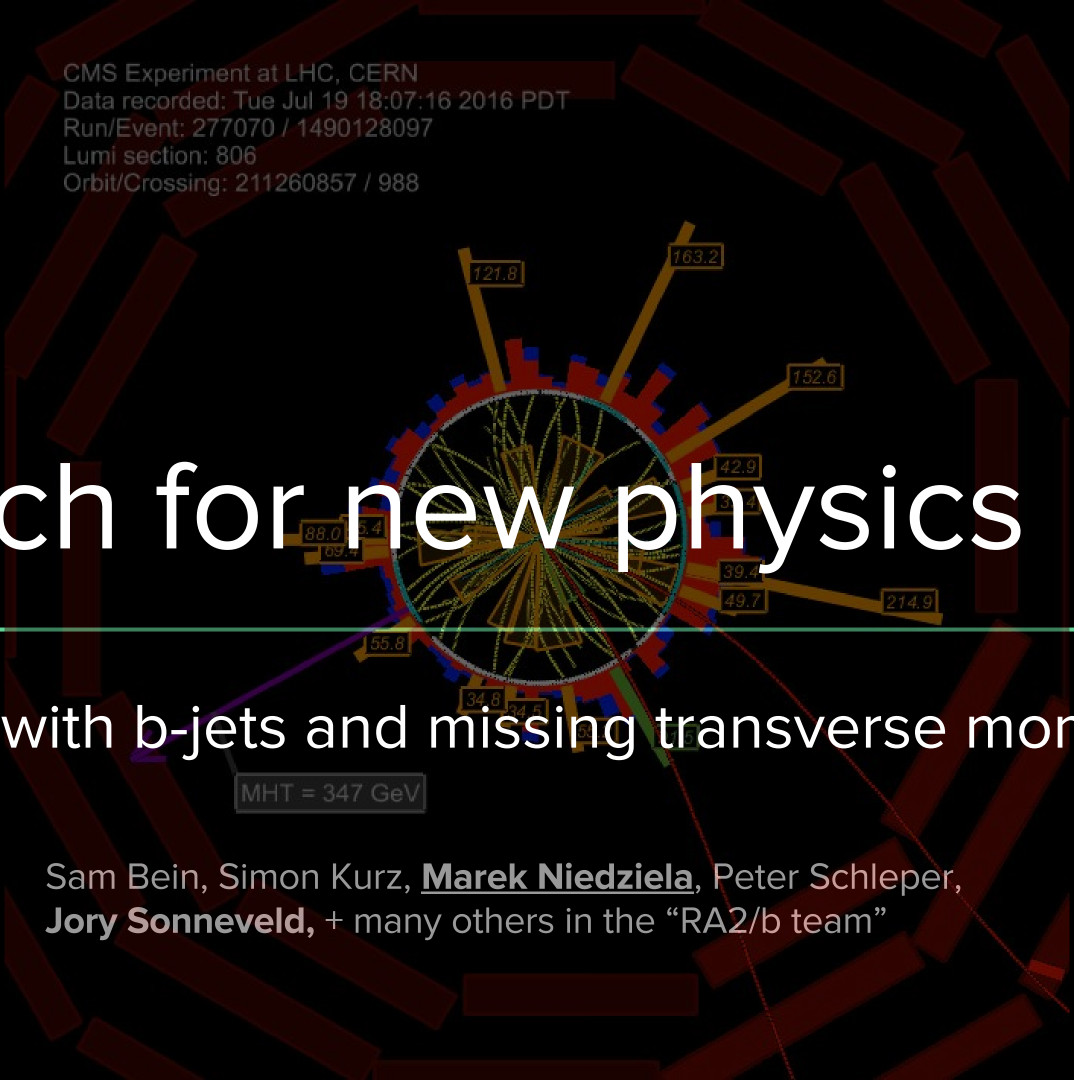


Search for new physics

in events with b-jets and missing transverse momentum

Sam Bein, Simon Kurz, **Marek Niedziela**, Peter Schleper,
Jory Sonneveld, + many others in the "RA2/b team"

CMS Experiment at LHC, CERN
Data recorded: Tue Jul 19 18:07:16 2016 PDT

Search for supersymmetry in multijet final states in proton-proton collisions at 13 TeV

A. Borzou[1], K. Hatakeyama[1], H. Liu[1], J. W. Gary[2], A. Ghiasi[2], F. Lacroix[2], O. Long[2], J. Bradmiller-Feld[3], J. Richman[3], M. Franco Sevilla[3], A. Ovcharova[3], W. T. Ford[4], F. O. Jensen[4], T. Mulholland[4], K. Stenson[4], V. D. Elvira[5], J. Hirschauer[5], K. Pedro[5], N. Tran[5], A. Whitbeck[5], S. Bein[6], S. Kurz[6], M. Niedziela[6], J. Sonnenveld[6], A. Rane[7], S. Sharma[7], B. Mahakud[8], G. Mohanty[8], K. A. Ulmer[9], and R. Patel[9]

[1] Baylor University
[2] University of California, Riverside
[3] University of California, Santa Barbara
[4] University of Colorado Boulder
[5] Fermi National Accelerator Laboratory
[6] University of Hamburg
[7] Indian Institute of Science Education and Research, Pune
[8] Tata Institute of Fundamental Research
[9] Texas A&M University

New physics search motivated by supersymmetry

Supersymmetry is a required symmetry in supergravity and is the only possible way to combine spacetime symmetries and internal symmetries.

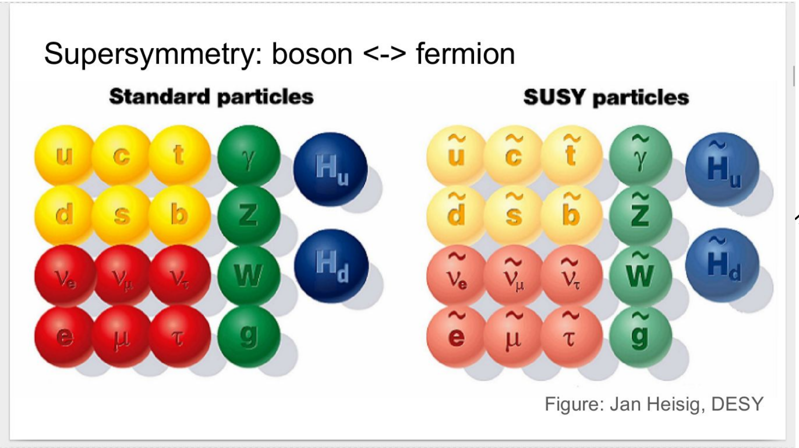
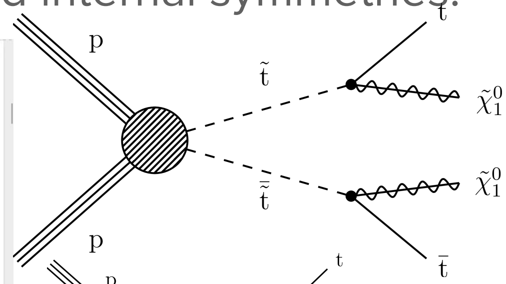
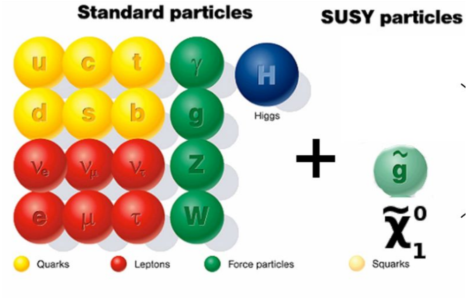
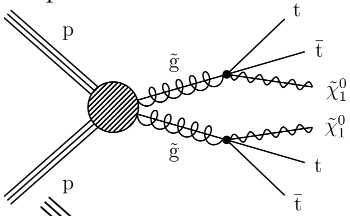
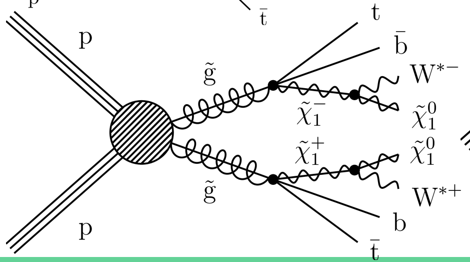


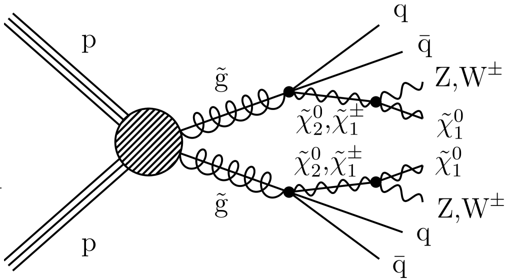
Figure: Jan Heisig, DESY







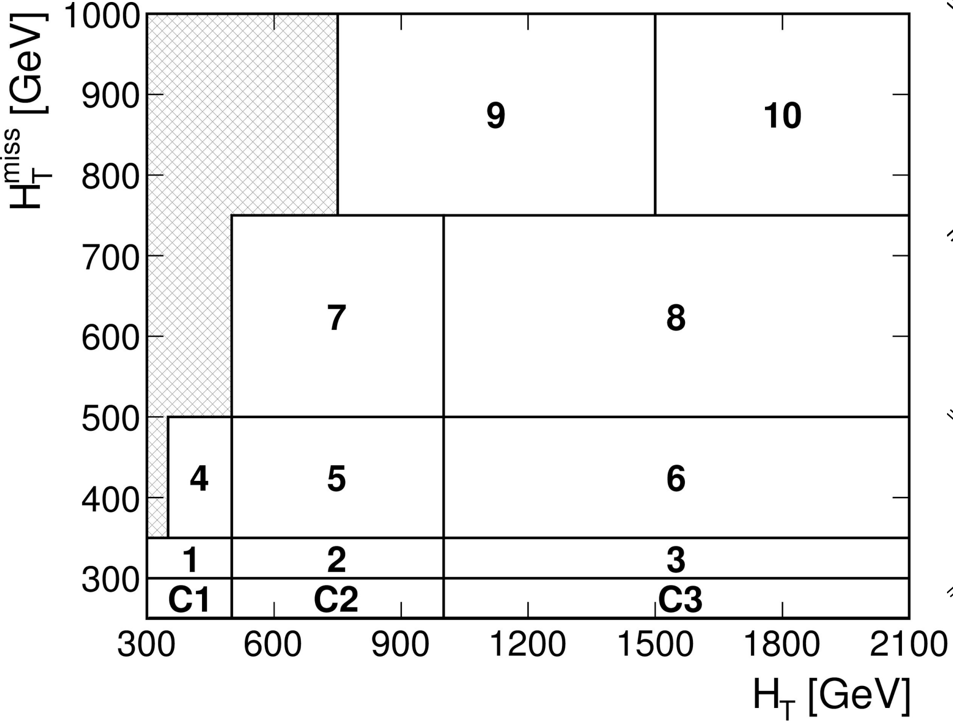


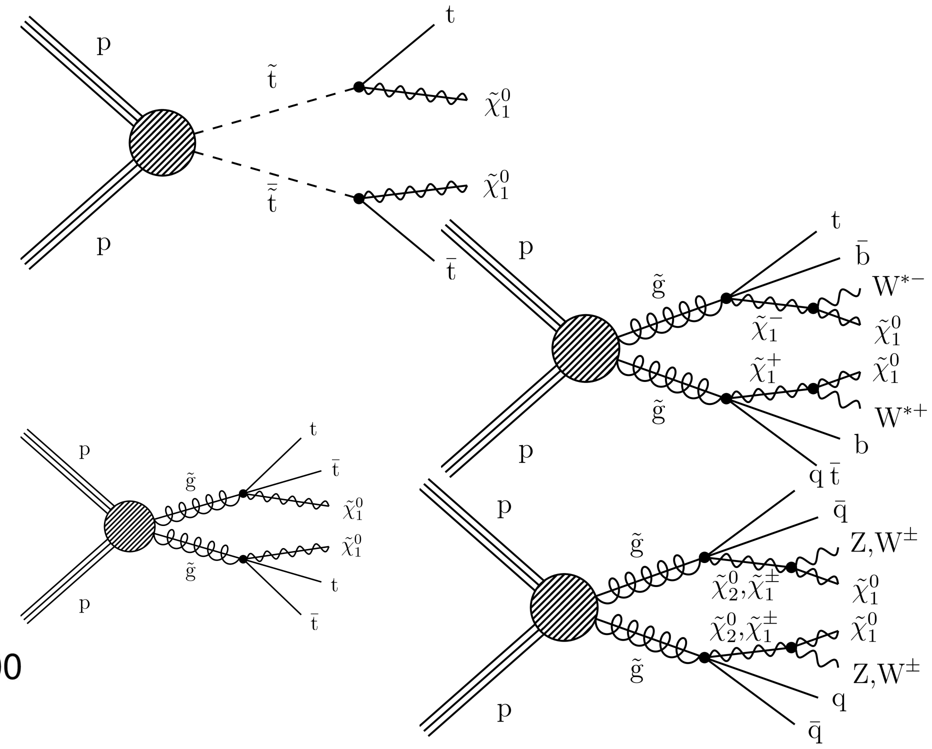


CMS-SUS-16-033, arXiv:1704.07781

extra material

Search regions: (missing) transverse momentum

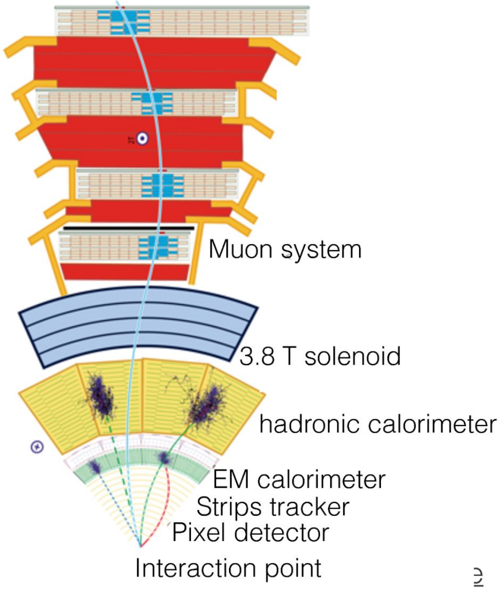




Object and event selection

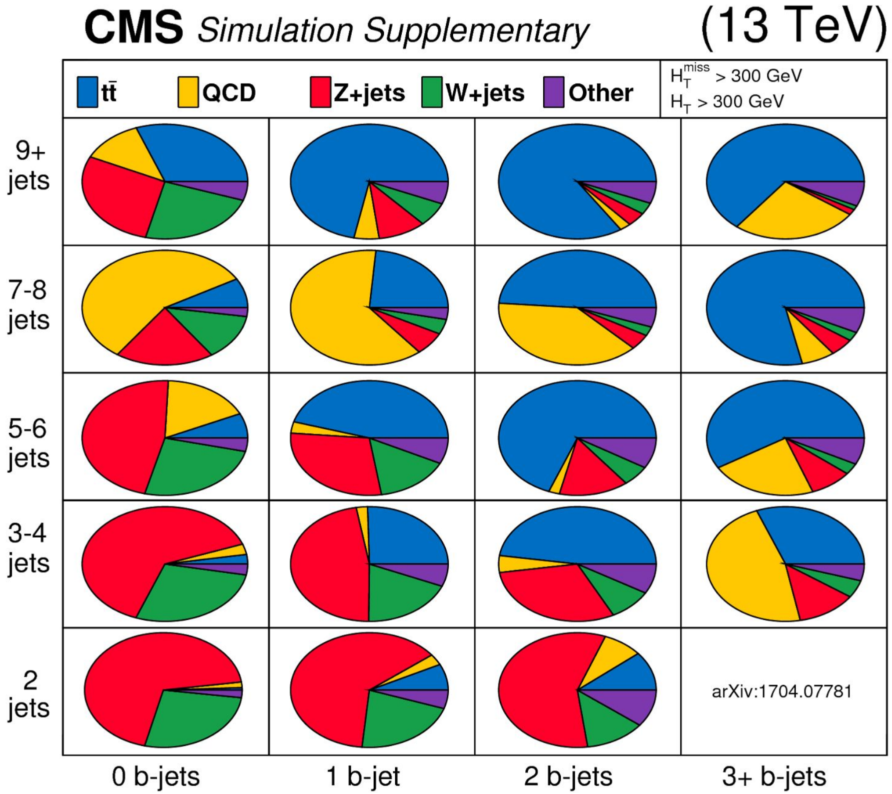
- particle candidates (Particle Flow algorithm)
- jets: anti-KT algorithm, $|\eta| < 2.4\,(\mathrm{H_T},\ \mathrm{n(jets)},\ \Delta\phi)$, and $|\eta| < 5.0\,(\mathrm{H_T^{miss}})$
- electrons (muons): isolated, $p_\mathrm{T} > 10\,\mathrm{GeV}$, $|\eta| < 2.5\,(2.4)$

- trigger: $H_\mathrm{T}^\mathrm{miss}$ and $E_\mathrm{T}^\mathrm{miss} > 100\,\mathrm{GeV}$
- $\mathrm{H_T} = \sum_j (p_\mathrm{T})_j > 300\,\mathrm{GeV}$
- $\mathrm{H_T^{miss}} = |-\sum_j (\vec{p}_\mathrm{T})_j| > 300\,\mathrm{GeV}$
- $\mathrm{n(jets)} \geq 2$
- $\mathrm{n(e)},\ \mathrm{n}(\mu) = 0$
- $\Delta\phi(j1,\ j2,\ j3,\ j4) > (0.5, 0.5, 0.3, 0.3)$
- $\mathrm{n(iso.\,track)} = 0$
- event cleaning, pileup mitigation



Backgrounds: data-driven estimates

- **Z to invisible:**
  (Z ➔ neutrinos) + jets
- **Lost lepton:**
  (ttbar to) W ➔ [$e\nu_e$, $\mu\nu_\mu$]+ jets
- **QCD:**
  QCD multijet events with missing energy from mismeasured jets
- **Hadronic tau:**
  (ttbar to) W to tau + jets



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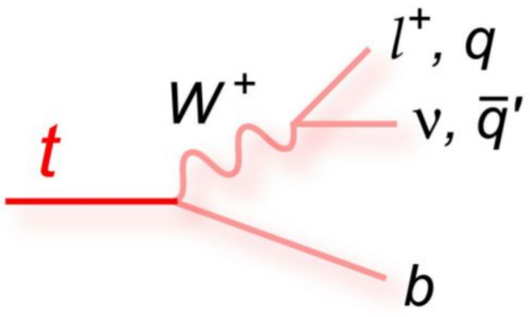
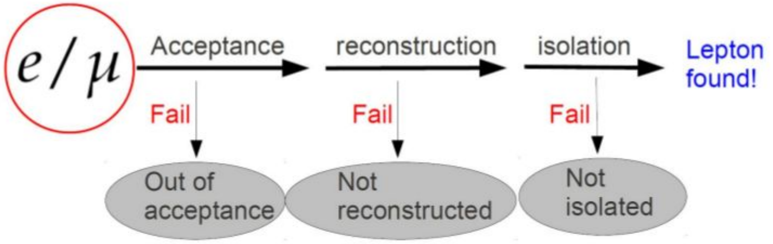
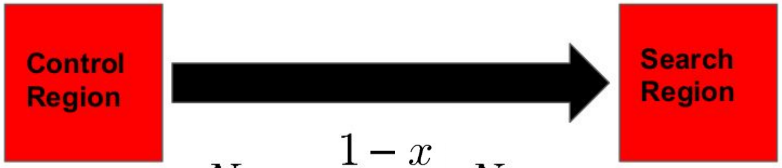
(t →) W → $e\nu_e$($\mu\nu_\mu$): lost lepton background

1. Invert lepton veto to select single-lepton control sample
2. Scale control sample to 0-lepton prediction using efficiencies:
   a. Reco (data)
   b. Iso (data)
   c. Acceptance (simulation)







$$N_{\mathrm{SR}} = \frac{1-x}{x} \cdot N_{\mathrm{CR}}$$

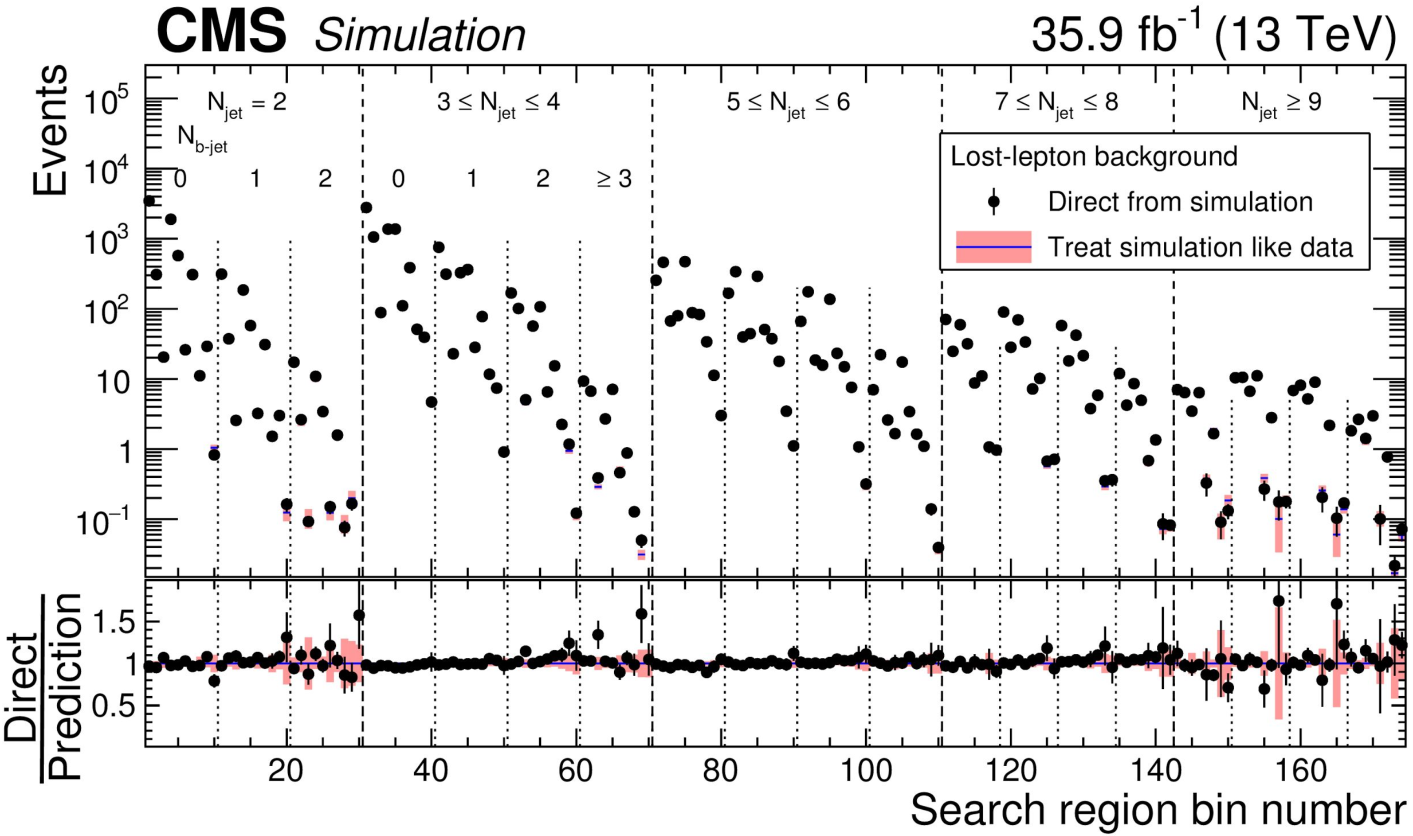
$$\hat{N}_{0\ell} = (\epsilon_{\mathrm{id}} N_{1\ell}^{\mathrm{obs}})\frac{1-x}{x}, \;\; x \equiv P(\mathrm{acc})P(\mathrm{rec}|\mathrm{acc})P(\mathrm{iso}|\mathrm{reco},\mathrm{acc})$$

(+ terms for 2-lepton contamination, iso track veto)

Validation of the lost lepton background estimation

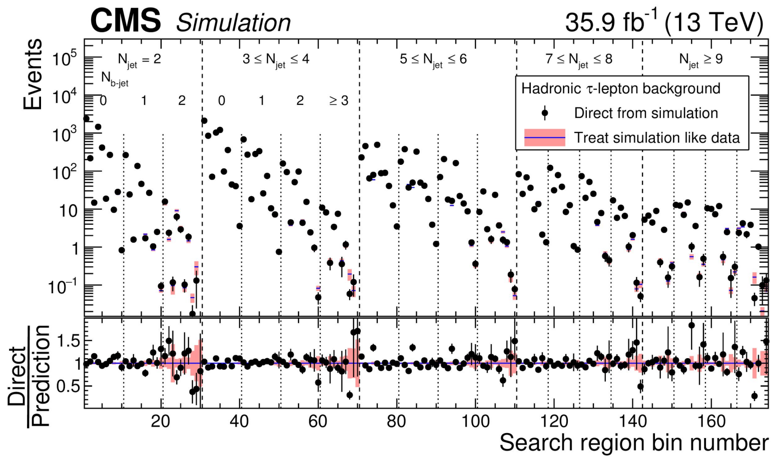
ttbar, single top quark, W+jets, diboson, and rare-event simulation

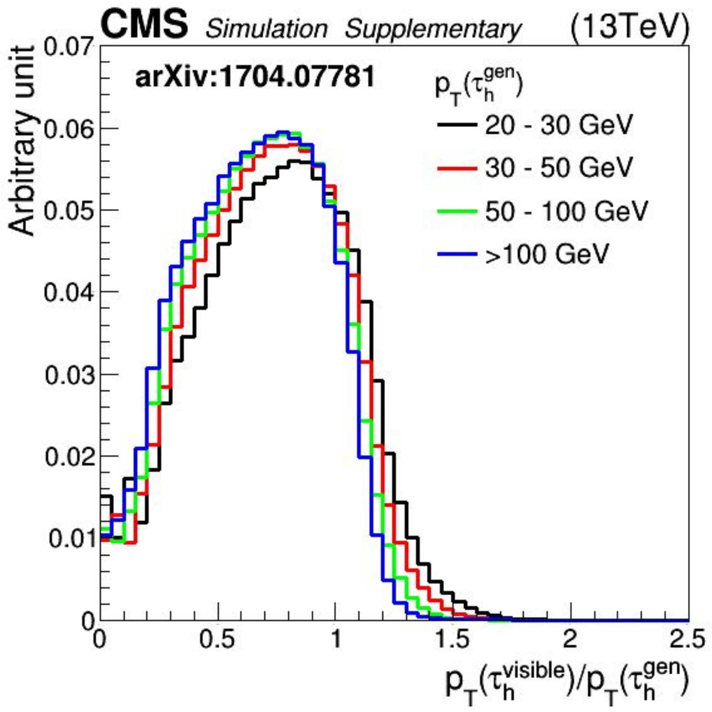
lost-lepton background determination procedure applied to simulated electron and muon control samples



Hadronic taus from W ➔ $\tau\nu_\tau$ + jets

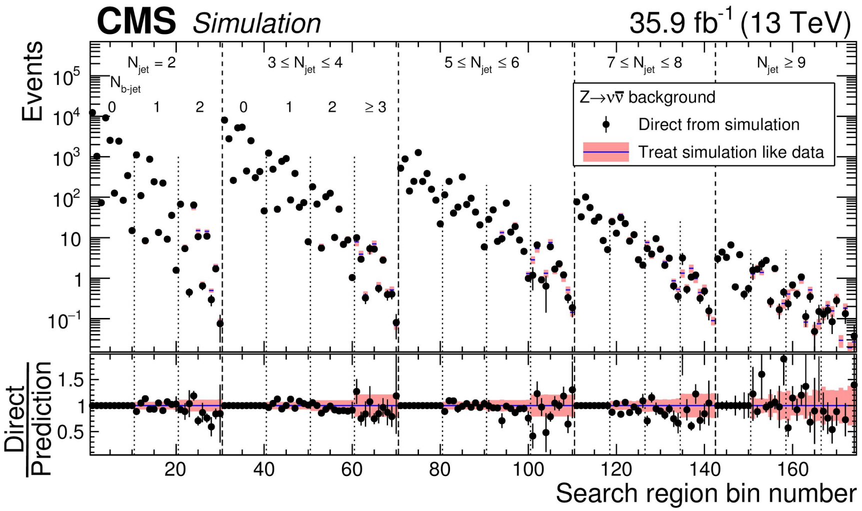
1. Select single-muon collected with single muon trigger (online pT > 27-30 GeV);
2. Reweight muon events with efficiencies derived from data-corrected simulation (sim.);
3. Smear muons using tau response templates (sim.).





Z to invisible (Z ➜ νν + jets)

1. Select single-photon events and remove photons ➜ **photon+jets CS**
2. Select events with opposite-sign e/μ with invariant mass m_Z and remove leptons ➜ **dilepton+jets CS**
3. Get Z/γ ratio from simulation and data/simulation scale factor RR
4. Reweight photon+jets CS with Z/γ ratio for 0b bins
5. Use dilepton+jets to get scale factors to extrapolate to bins with n(b)> 0

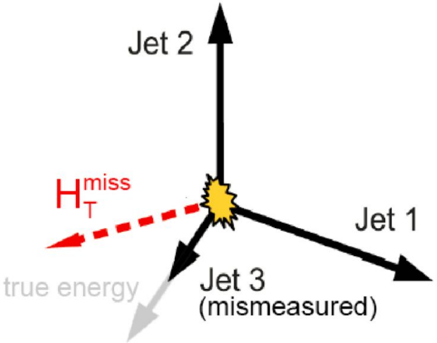


$$\hat{N}_{Z\rightarrow\nu\bar{\nu}} = \mathcal{R}\mathcal{R}^{\text{obs}}_{\text{sim}} \cdot \mathcal{R}^{\text{sim}}[Z(\nu\bar{\nu}/\gamma)] \cdot \epsilon \cdot N^{\text{obs}}_{\gamma}$$

QCD multijet background

2 methods:

- Delta-phi extrapolation
- **Rebalance and smear**



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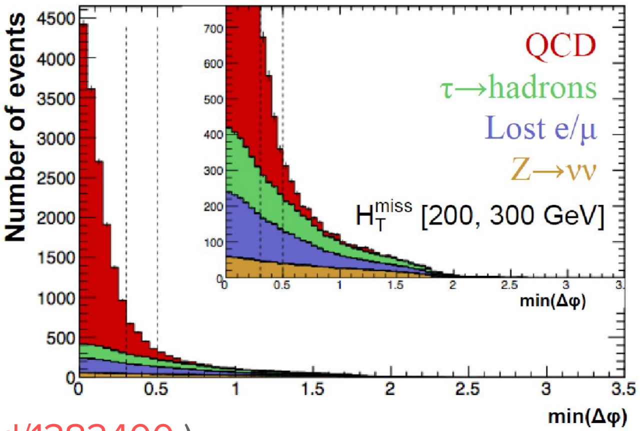
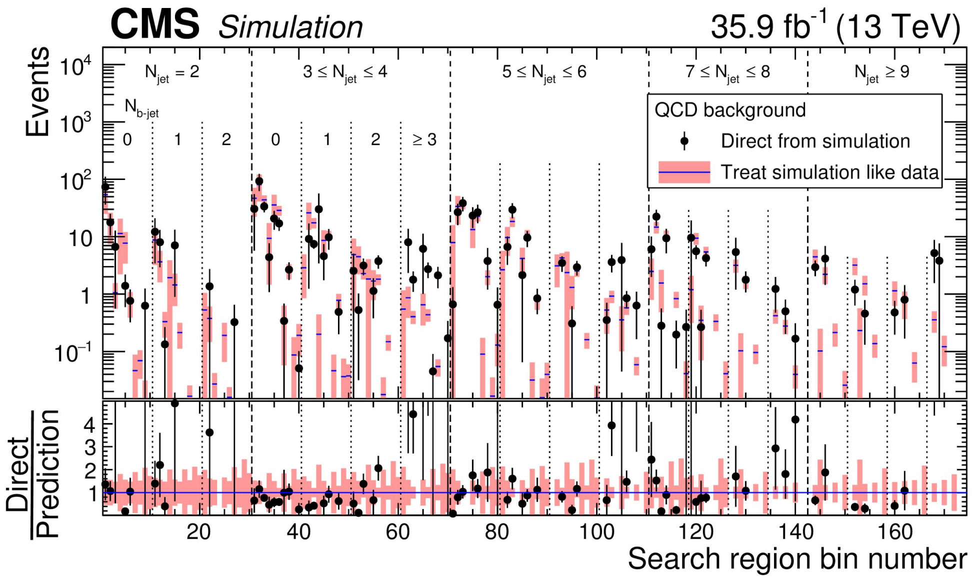


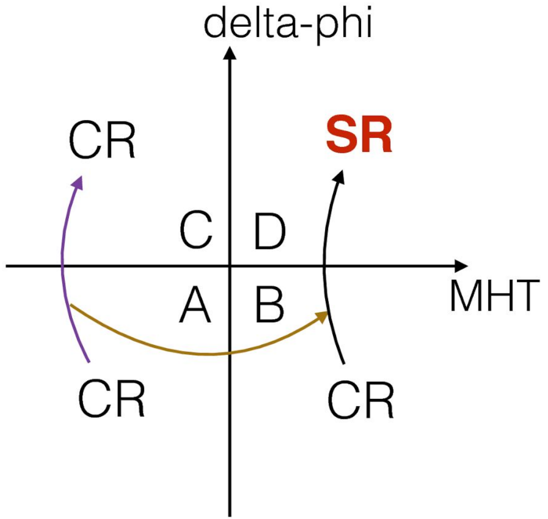
Formerly involved in rebalance and smear:

- Christian Sander
- Matthias Schröder
- Kristin Goebel
- Sue Ann Koay (original work: http://cds.cern.ch/record/1382400)

QCD-dphi: Delta-phi extrapolation

1. Obtain extrapolation factor low delta-phi ➜ high delta-phi from data;
2. Obtain extrapolation factor low MHT ➜ high MHT from simulation;
3. Extrapolate a background prediction in the signal region as in “ABCD method”.





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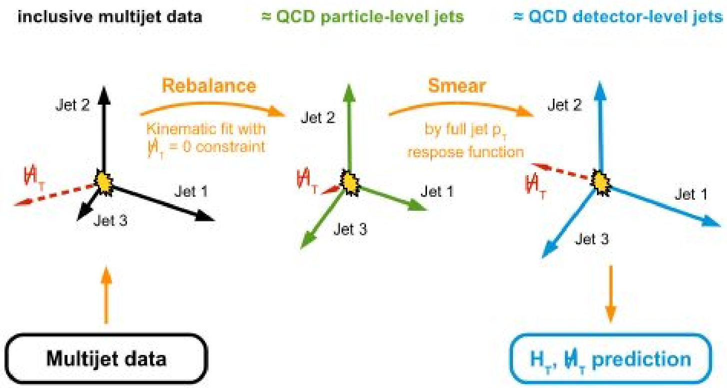
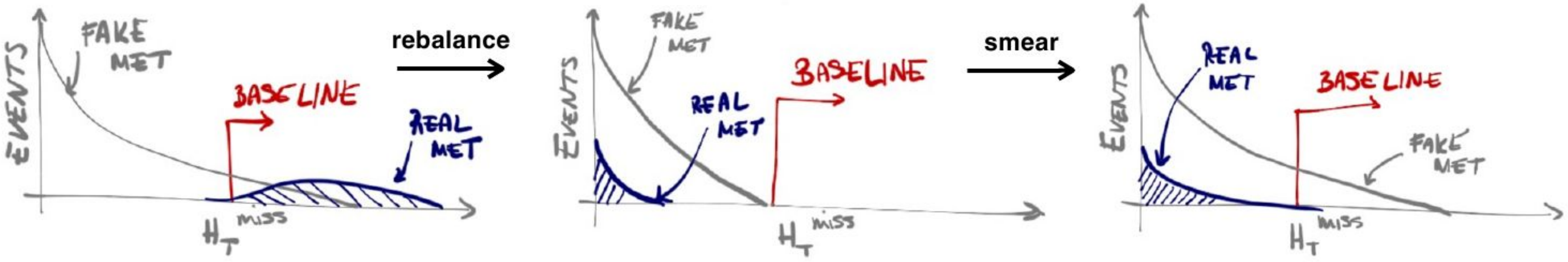
QCD-rns: Rebalance and smear

1. **Rebalance** event back to particle-level like QCD event (low-MHT);
2. **Smear** the particle-level jets by randomly sampling a jet response (from simulation).





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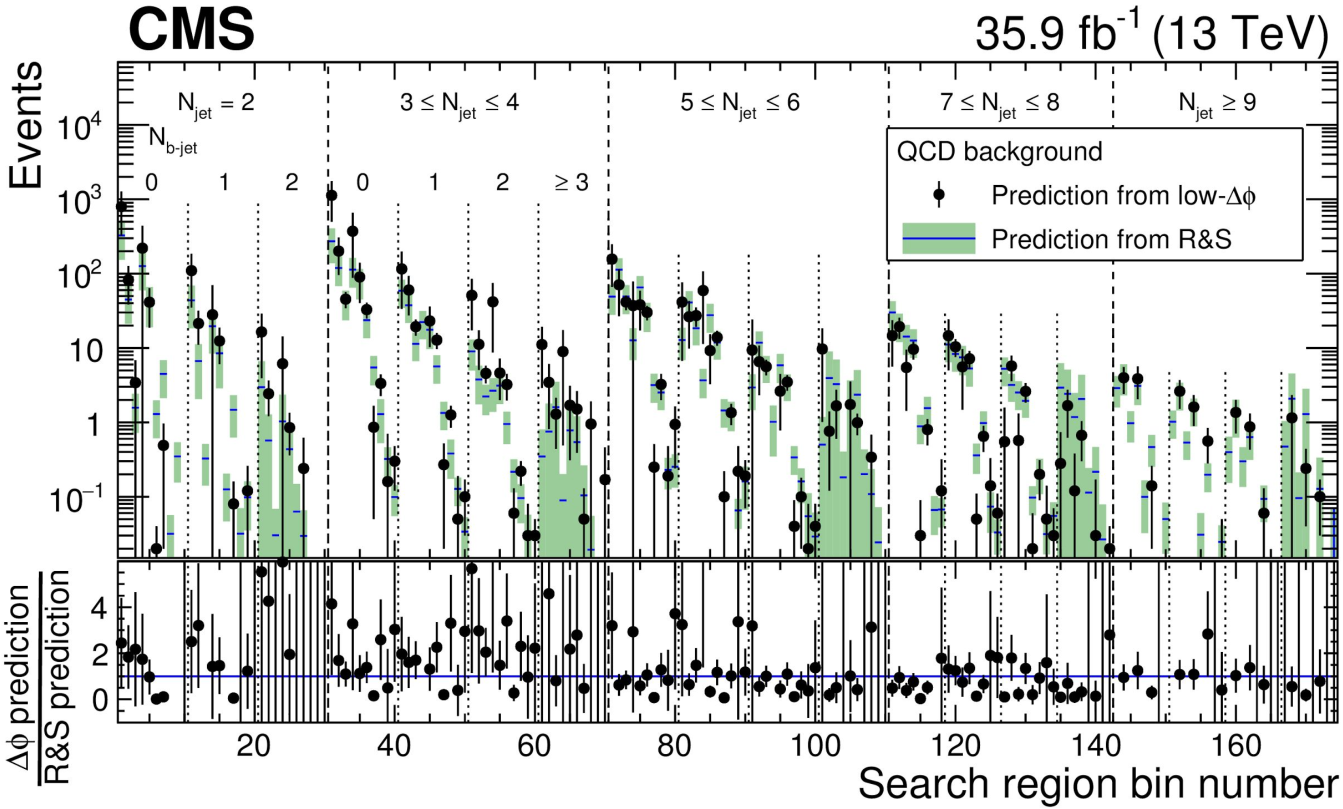
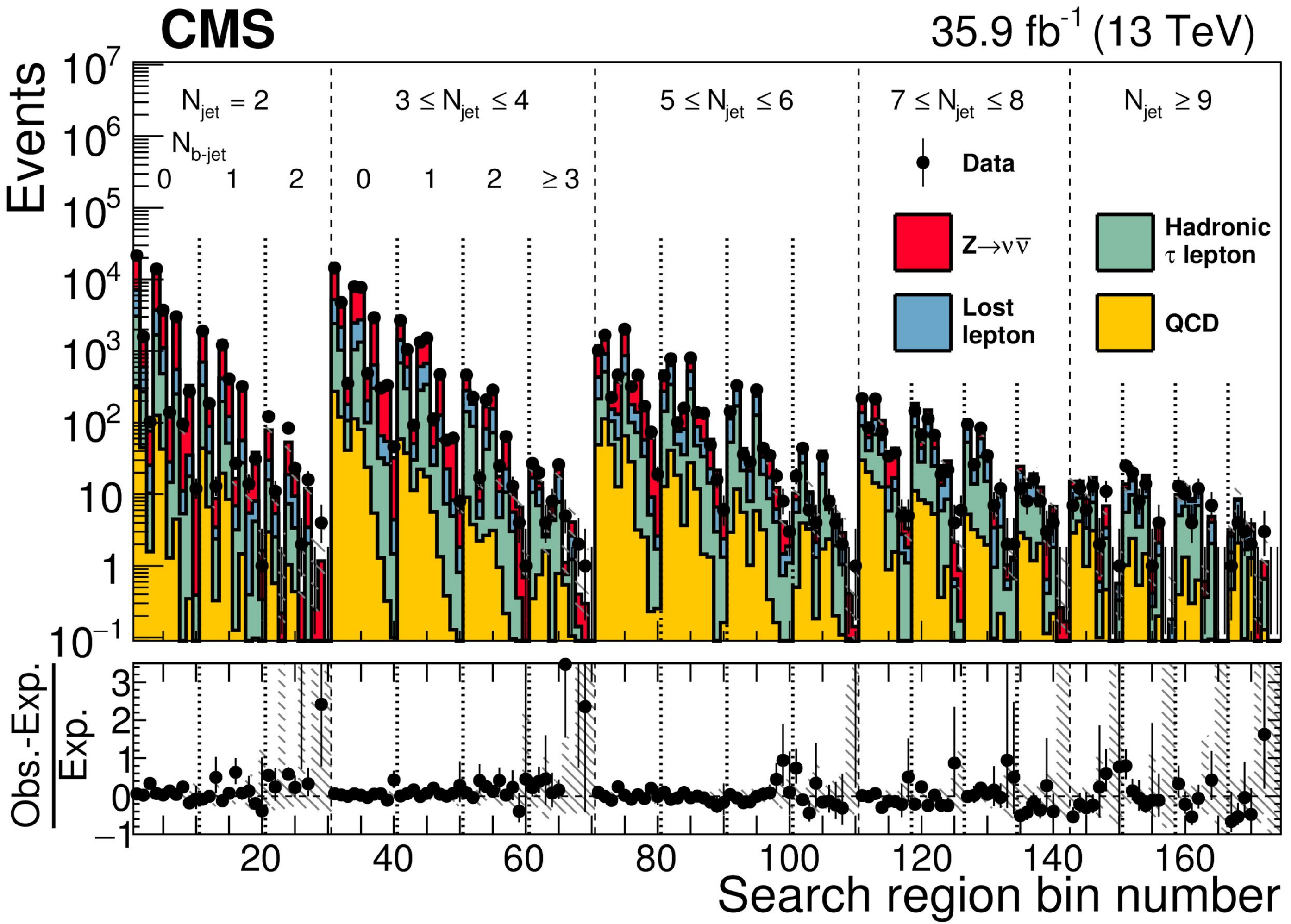
QCD-rns: validation

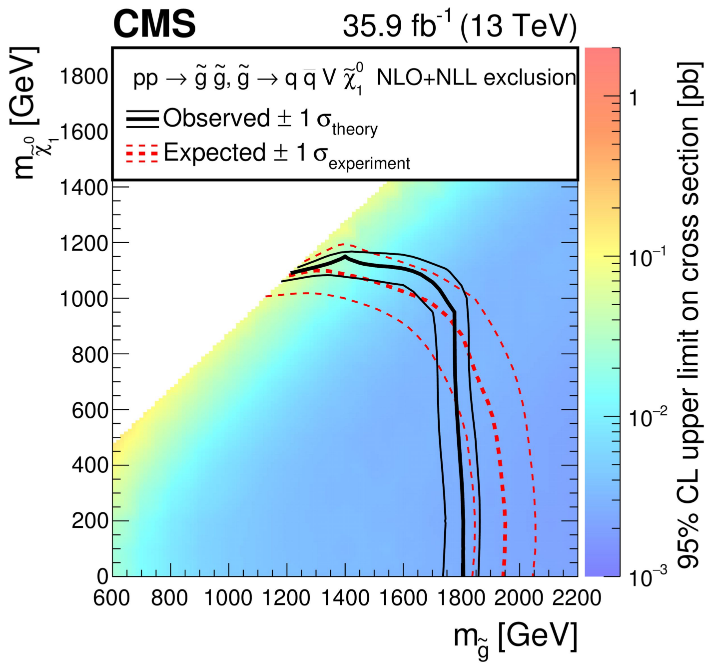


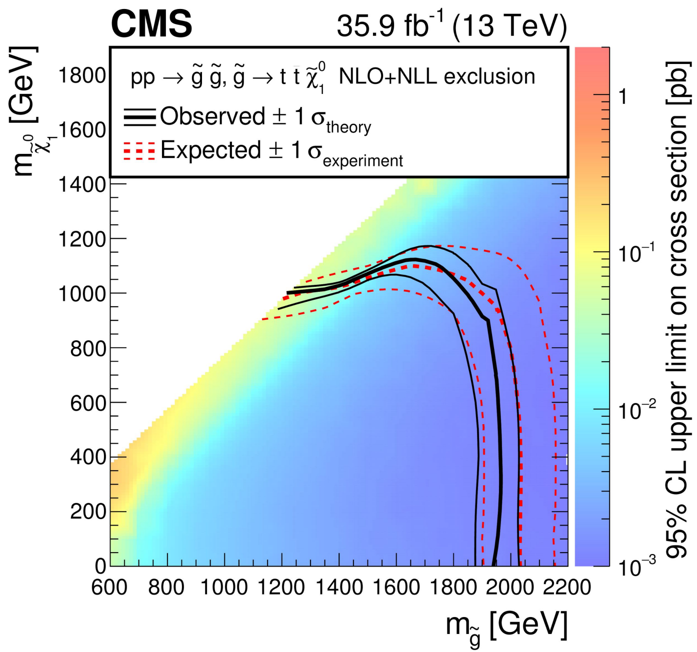
Largest uncertainty: jet energy resolution scale factors, especially from the tails in high MHT regions.

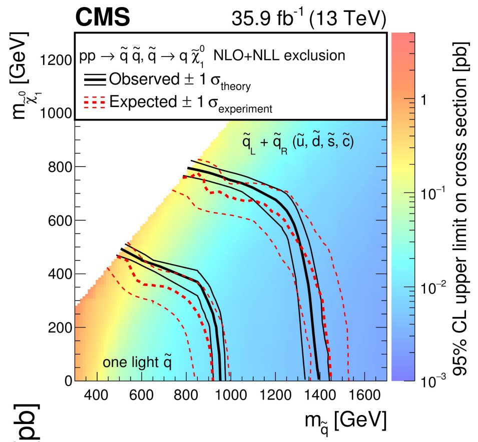
Results


CMS
35.9 fb^{-1} (13 TeV)
Events
$N_{jet} = 2$
$3 \le N_{jet} \le 4$
$5 \le N_{jet} \le 6$
$7 \le N_{jet} \le 8$
$N_{jet} \ge 9$
$N_{b\text{-jet}}$
0 1 2
0 1 2 ≥ 3
Data
$Z\rightarrow\nu\bar{\nu}$
Lost lepton
Hadronic τ lepton
QCD
Obs.-Exp. / Exp.
Search region bin number

Simplified model results







Model-dependent:
(σ x Br)-dependent

See talk by Malte Mrowietz for a way to interpret these results in terms of "real" models of physics beyond the Standard Model

Summary

Search for supersymmetry in the all-hadronic channel with data-driven background estimates:

- No significant excess BSM prediction is observed;
- Interpretation in terms of simplified models sets show sensitivity to gluino masses of 1800-2000 GeV assuming a light LSP;

Additional material

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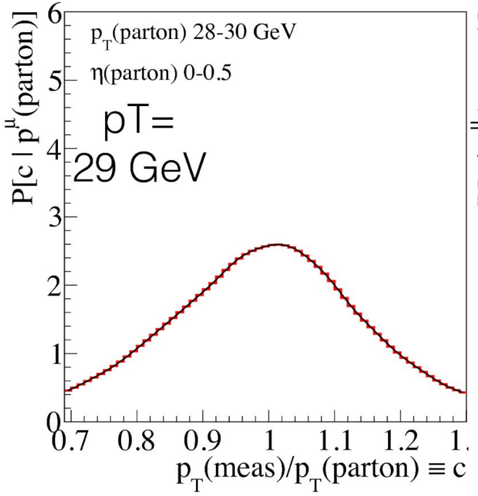
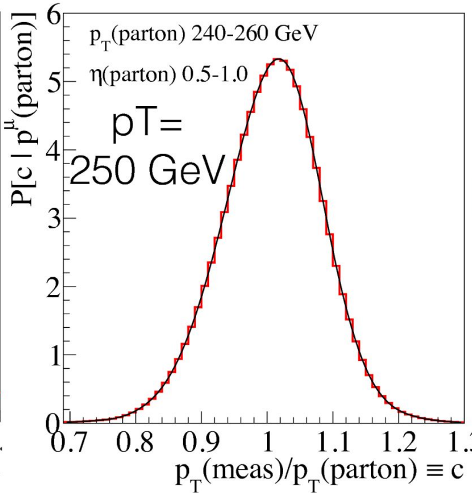
QCD-rns: Rebalancing an event

- Rebalance by maximizing the posterior density:

$$\mathrm{P}(\vec{J}_{\text{part}}|\vec{J}_{\text{meas}}) \sim \mathrm{P}(\vec{J}_{\text{meas}}|\vec{J}_{\text{part}}) \cdot \pi(\vec{J}_{\text{part}})$$

$$\mathrm{P}(\vec{J}_{\text{meas}}|\vec{J}_{\text{part}}) = \prod_{i=1}^{n_{\text{jet}}} \mathrm{P}(p^{\mu}_{i,\text{meas}} \mid p^{\mu}_{i,\text{part}}) = \prod_{i=1}^{n_{\text{jet}}} \mathrm{P}(c_i \mid p^{\mu}_{i,\text{part}})$$





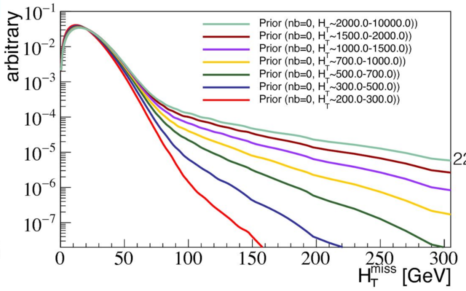
Likelihood binned in jet eta, pt

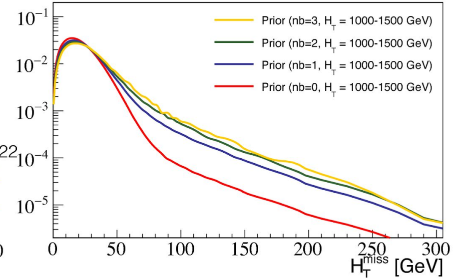
- Rebalance by maximizing the posterior density:

$$\mathrm{P}(\vec{J}_{\text{part}}|\vec{J}_{\text{meas}}) \sim \mathrm{P}(\vec{J}_{\text{meas}}|\vec{J}_{\text{part}}) \cdot \pi(\vec{J}_{\text{part}})$$

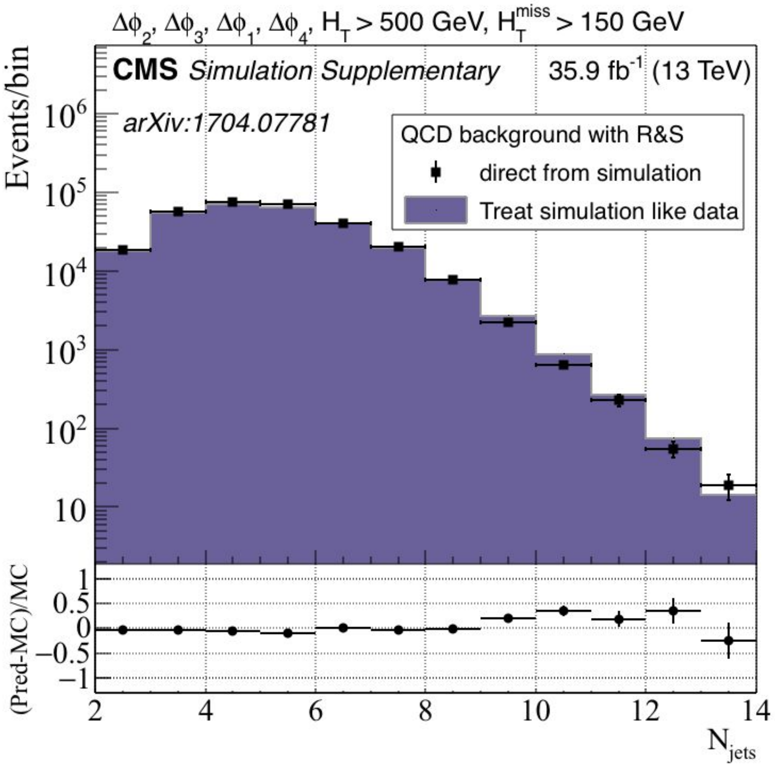
gen/sim MHT

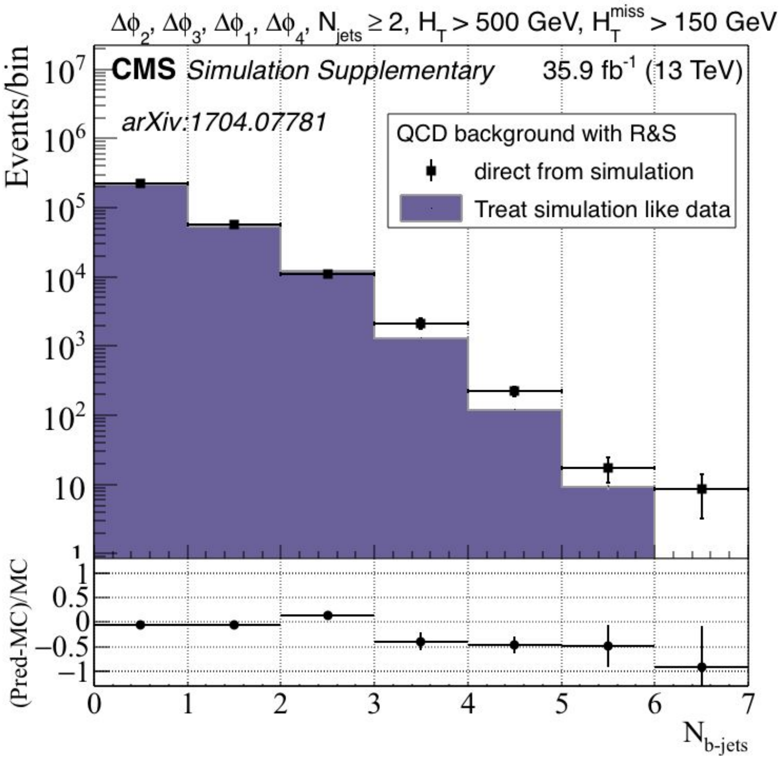
Prior binned in HT and n(b-tags)



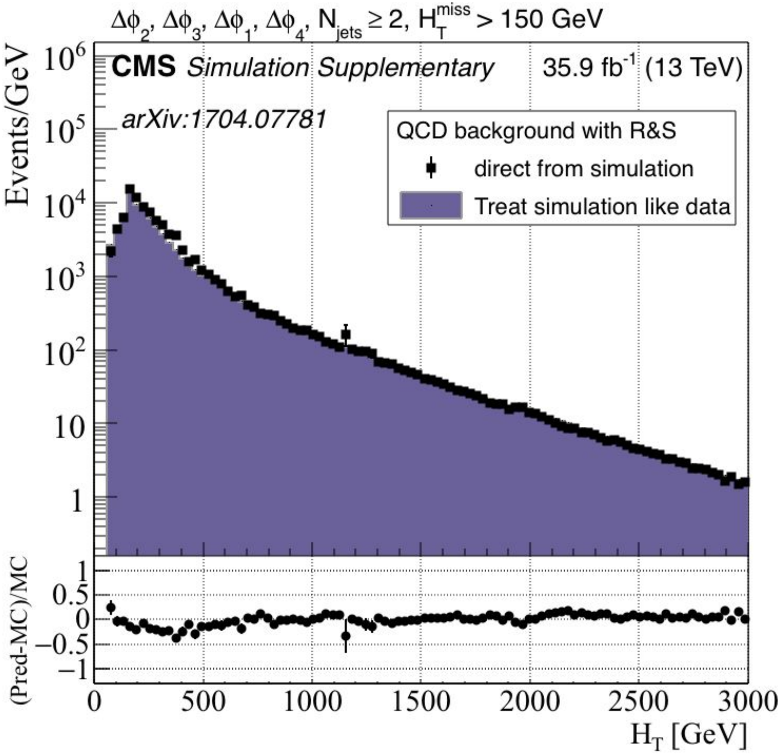


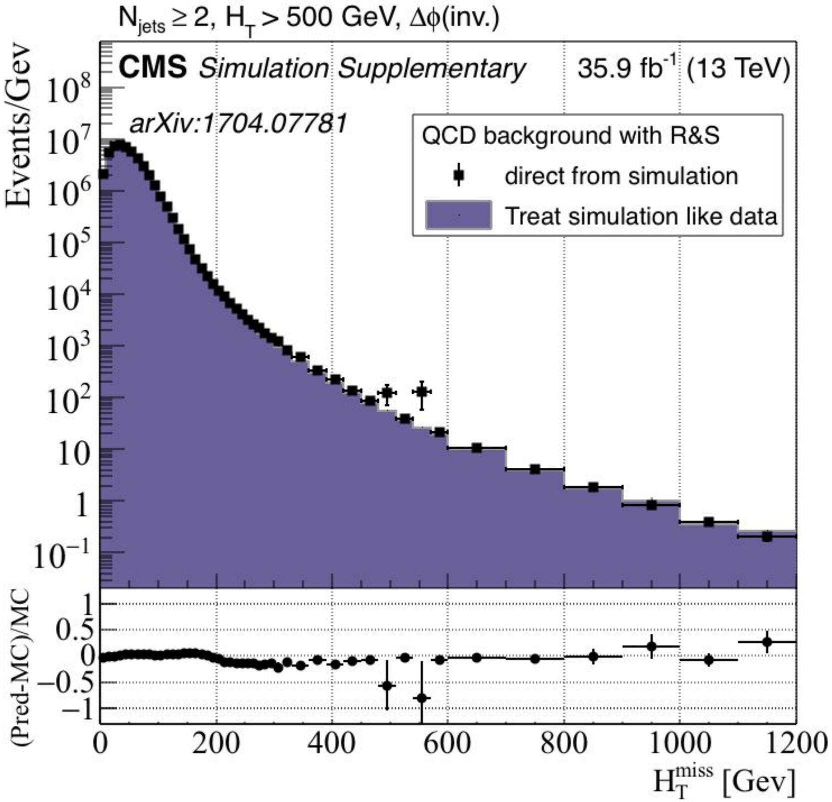
QCD-rns validation





QCD-rns validation





QCD-rns: validation