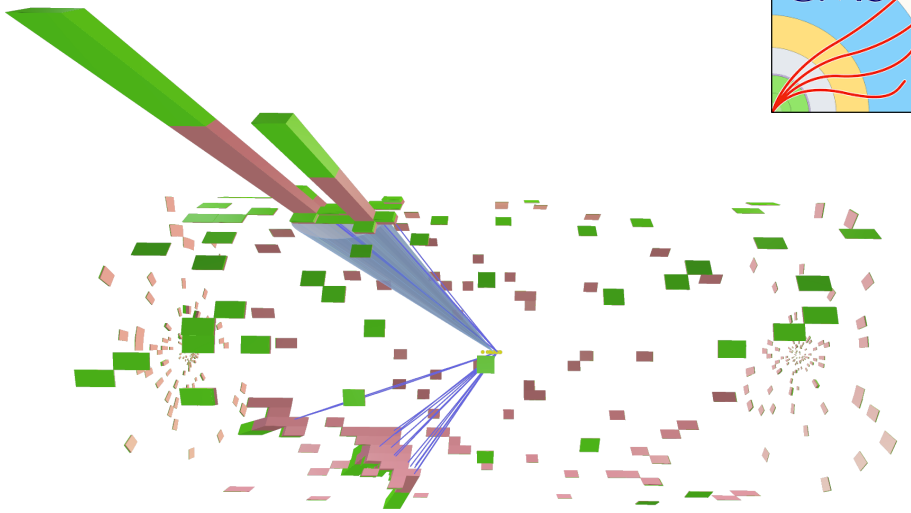
W JET MASS.

Measurement of the jet mass and W boson mass in hadronic decays of boosted W bosons at 13 TeV

CMS-PAS-SMP-24-012

Andreas Hinzmann
on behalf of the CMS collaboration

30.7.25



How to weigh the W boson using hadrons

HELMHOLTZ

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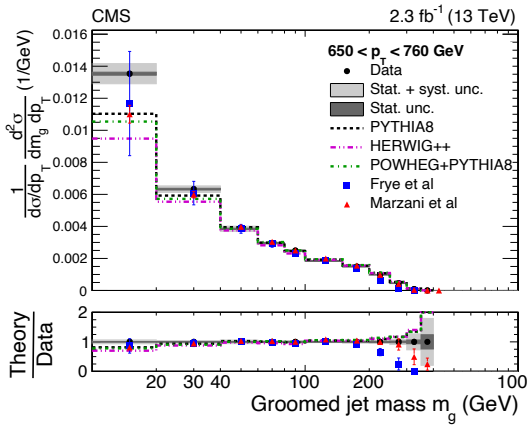
Quark and gluon jet mass

- Testbed for precision QCD predictions (NLO+NLL'+NP)

q/g jets



JHEP 11 (2018) 113

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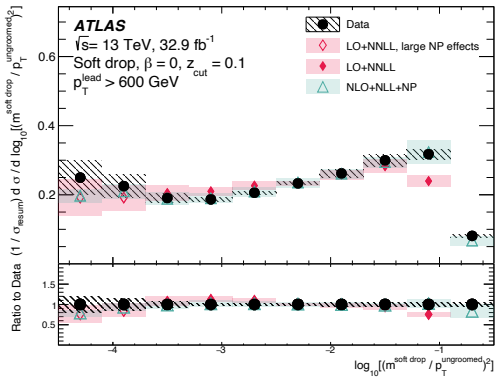

Phys. Rev. Lett. 121 (2018) 092001

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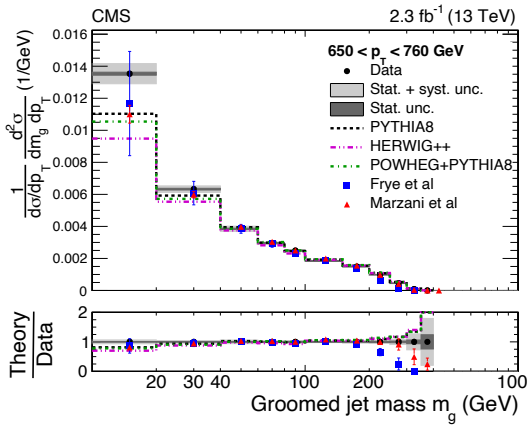

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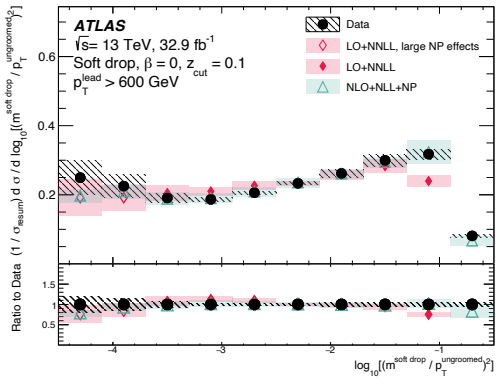

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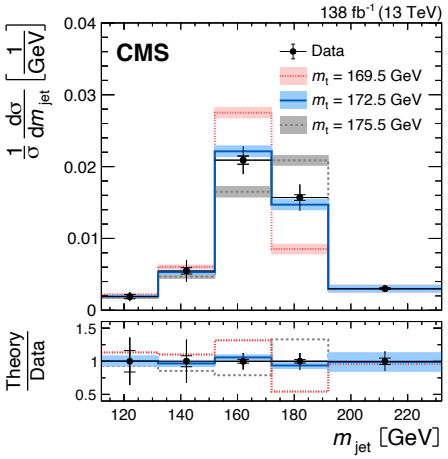

Eur. Phys. J. C 83 (2023) 560

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- Sensitive to b hadronization

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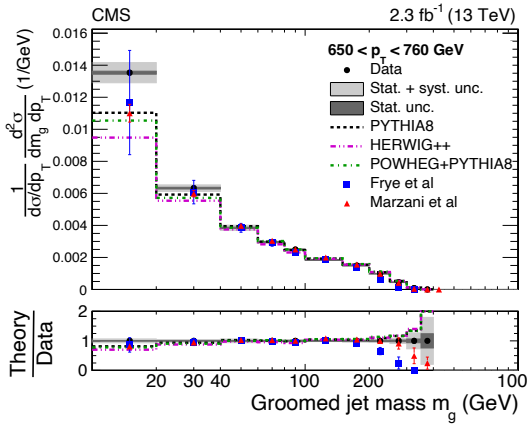

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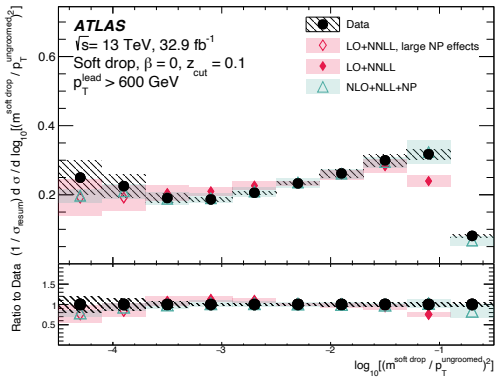

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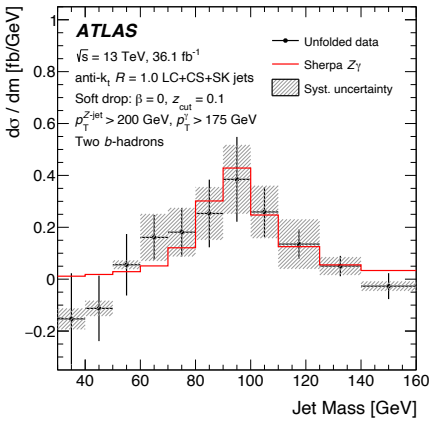

Phys. Lett. B 812 (2021) 135991

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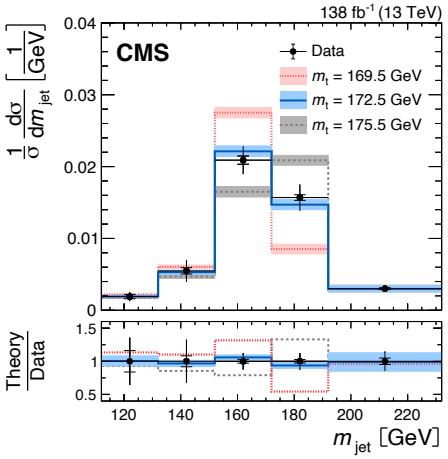

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W(qq) jet mass

- Today!

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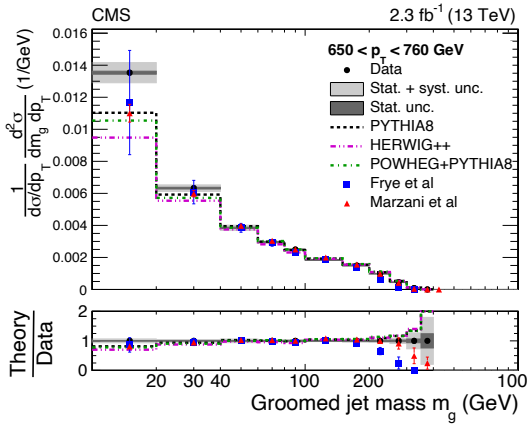

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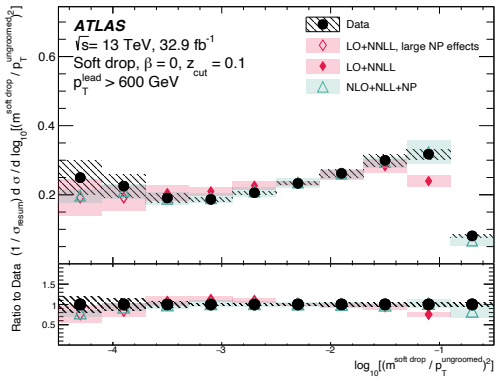

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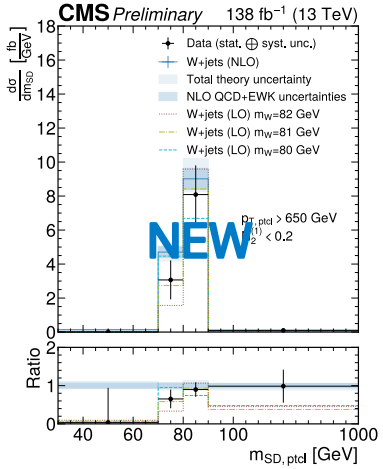

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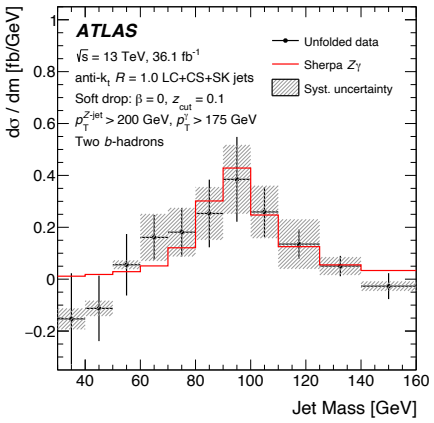

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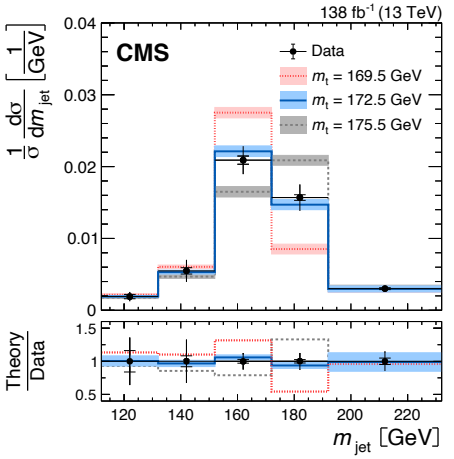

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Goals and challenges

First measurement of hadronic W mass at hadron collider – why even try?

W mass m_W= 80 360.2 ± 9.9 MeV [submitted to Nature]

- Prospect for HL-LHC ± 30 MeV [JHEP 1902 (2019) 003]
- Here → proof of principle

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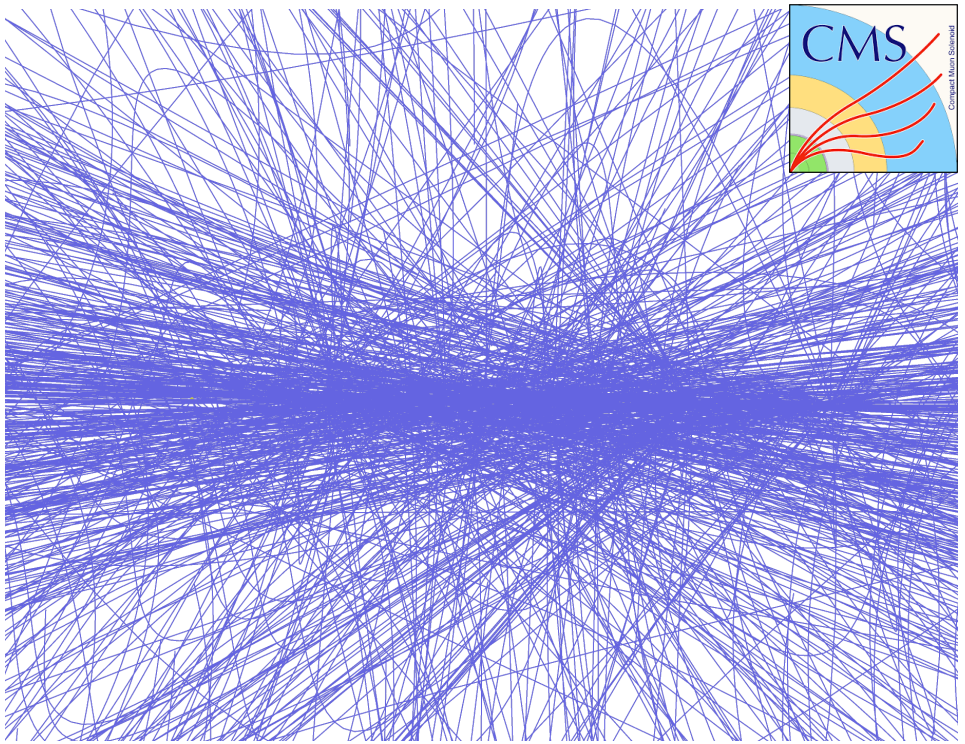

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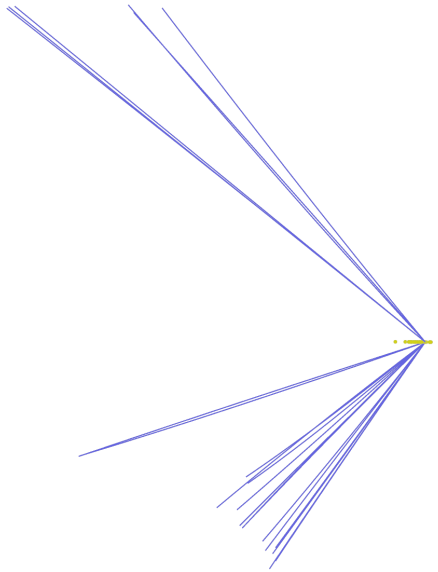

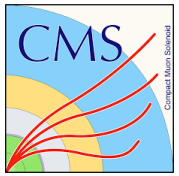

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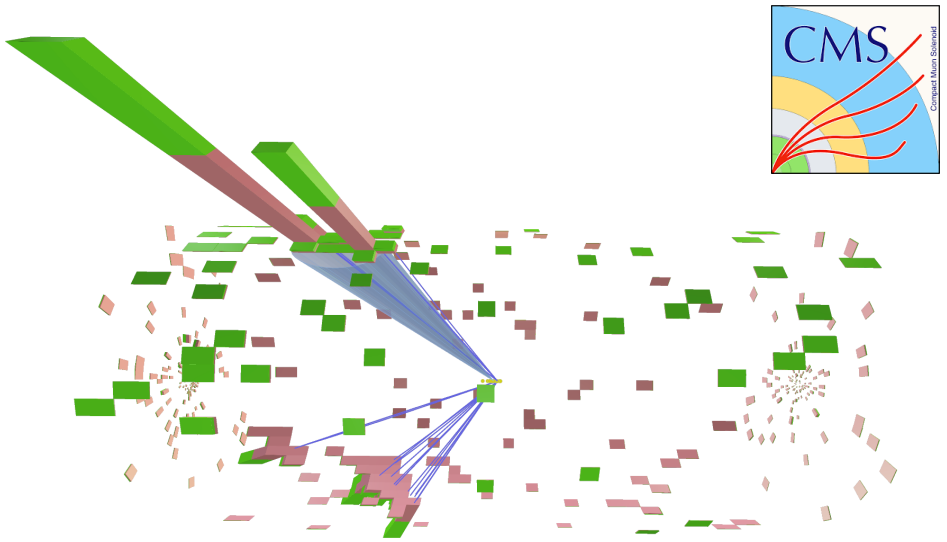

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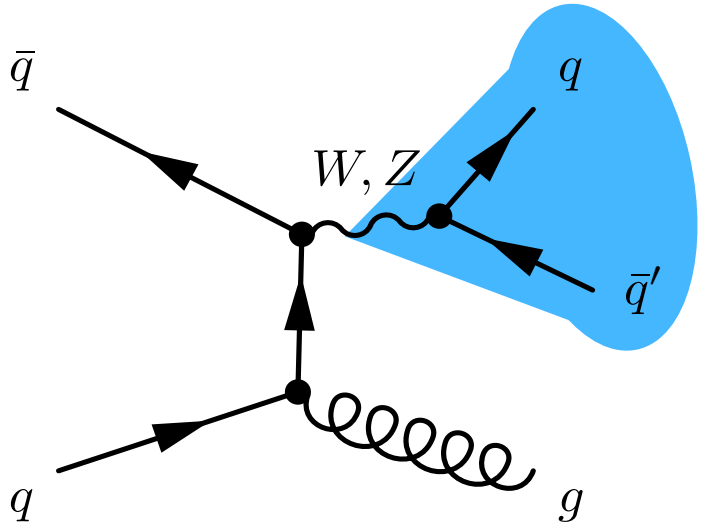
The final state and observable

And how to make it measurable

Features of W+jets

- No color connection to rest of the event
- Large QCD jet background (mainly dijet)
- Need at least 1 extra jet to get triggered (p_T>500 GeV)
- To first order W is a 50-50 pick



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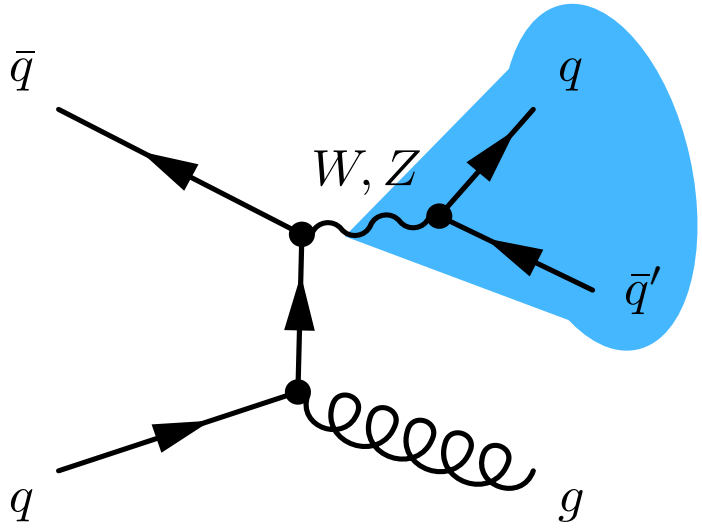
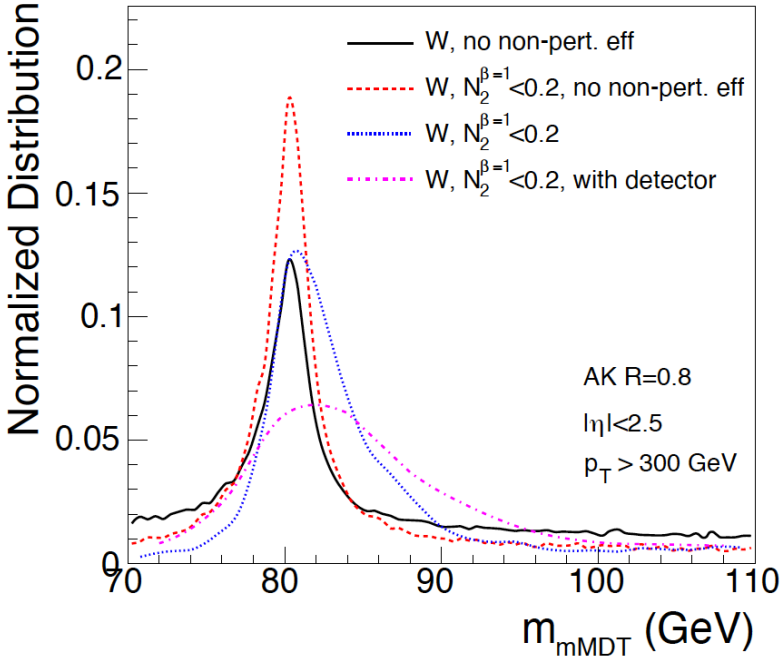
Observable

- Leading p_T anti-k_T R=0.8 jet in event
- Softdrop jet mass m_{SD} (β=0, z_{cut}=0.1) / mMDT

$$z = \frac{\min(p_T^1, p_T^2)}{p_T^1 + p_T^2} \quad z > z_{cut} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$





[JHEP 1902 (2019) 003]

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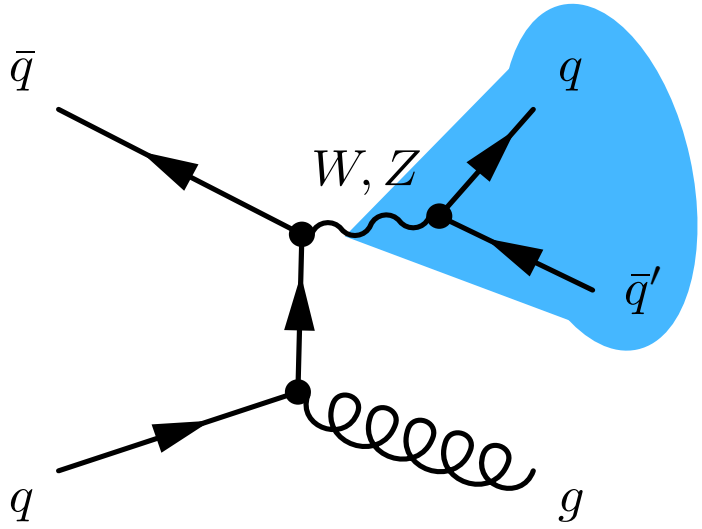

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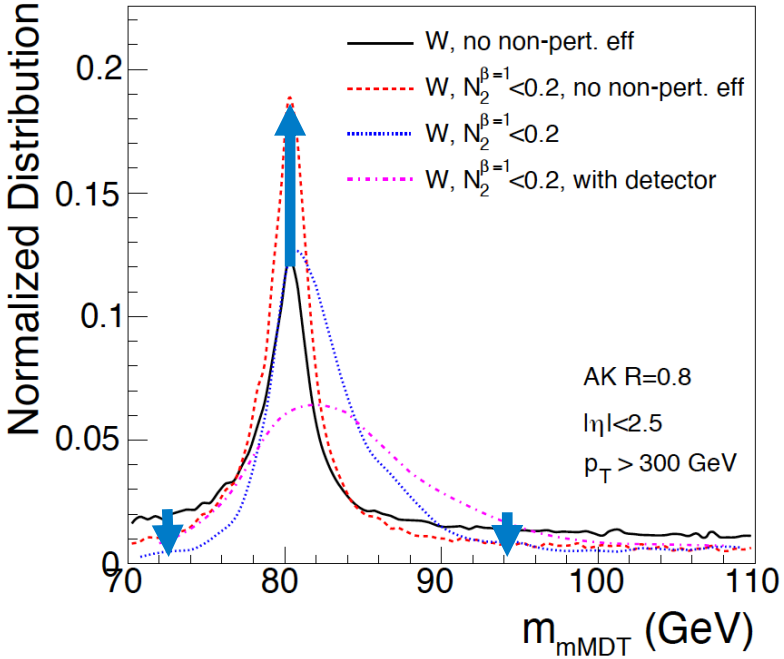
Jet substructure tagging

- Helps resolve ambiguity between jets
- Helps to remove background
- Here: energy correlation functions $N_2^{(1)} < 0.2$

$$N_i^{(\beta)} = \frac{{}_2e_{i+1}^{(\beta)}}{\left({}_1e_i^{(\beta)}\right)^2} \qquad {}_2e_3^{\beta=1} = \sum_{1\le i\le j\le k\le n_J} z_i z_j z_k \min\left\{\Delta R_{ij}\Delta R_{ik}, \Delta R_{ij}\Delta R_{jk}, \Delta R_{ik}\Delta R_{jk}\right\}$$

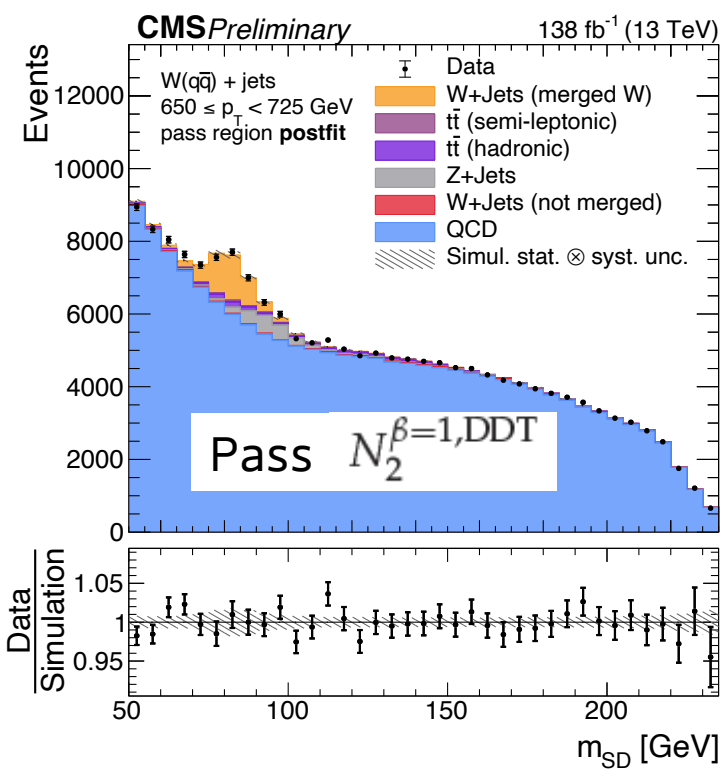
$${}_1e_2^{\beta=1} = \sum_{1\le i\le j\le n_J} z_i z_j \Delta R_{ij}.$$

- Need to maintain background predictable



[JHEP 1902 (2019) 003]

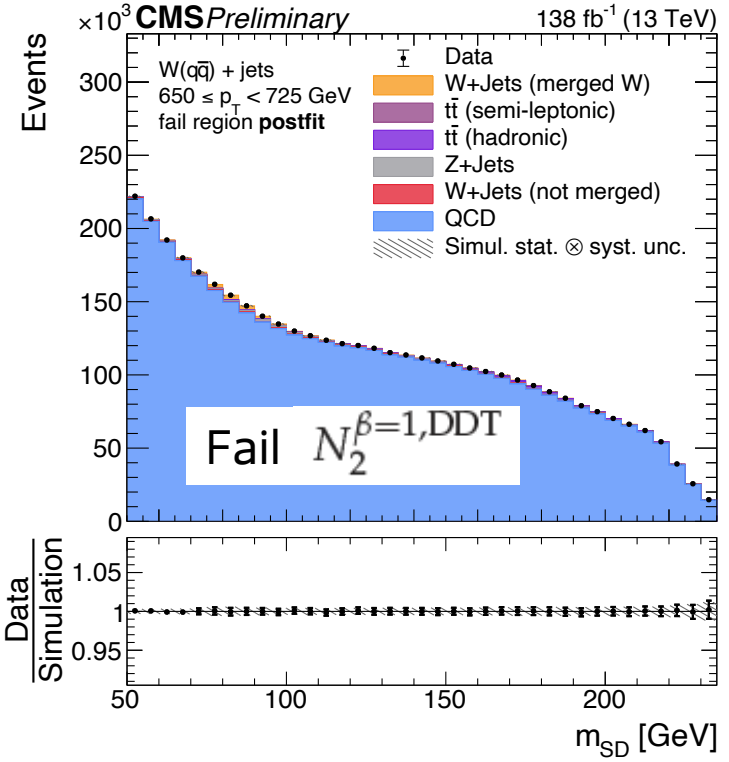
Event categorization



$N_2^{(1)}$ [Designed Decorrelated Tagger](#)

[CMS-DP-2020-002, JHEP 05 (2016) 156]

	$N_2^{\beta=1,\mathrm{DDT}}$	
	$\varepsilon_{W\ \mathrm{jets}}$	$\varepsilon_{\mathrm{backg.}}$
pass	18.54%	4.14%
fail	81.46%	95.86%



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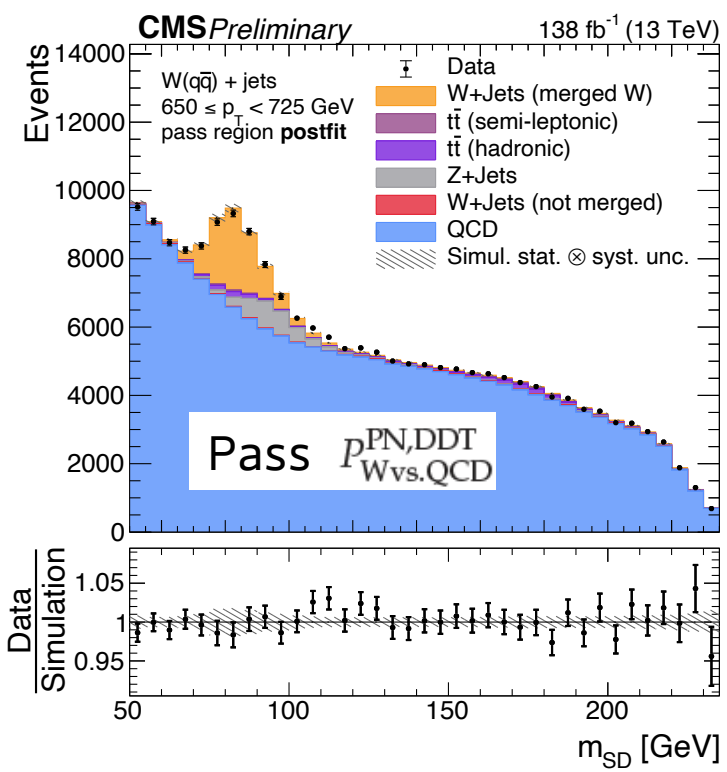
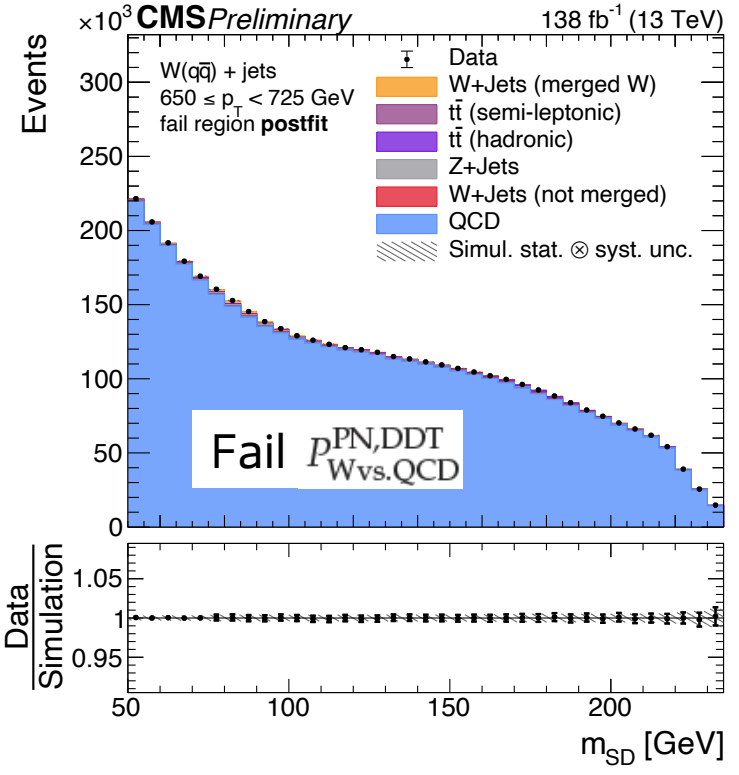


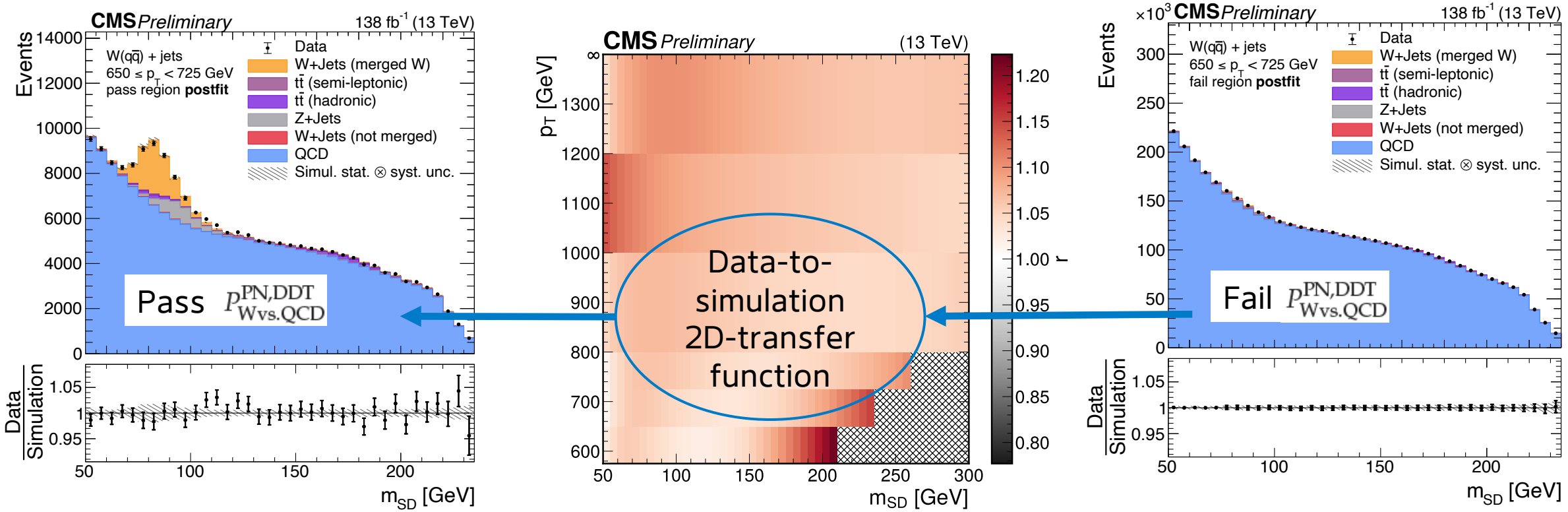
ParticleNet with MD+DDT

[CMS-DP-2020-002, Phys. Rev. D 101, 056019 (2020)]

	$p^{PN,DDT}_{Wvs.QCD}$	
	$\varepsilon_{W\ jets}$	$\varepsilon_{backg.}$
pass	38.20%	4.20%
fail	61.80%	95.80%



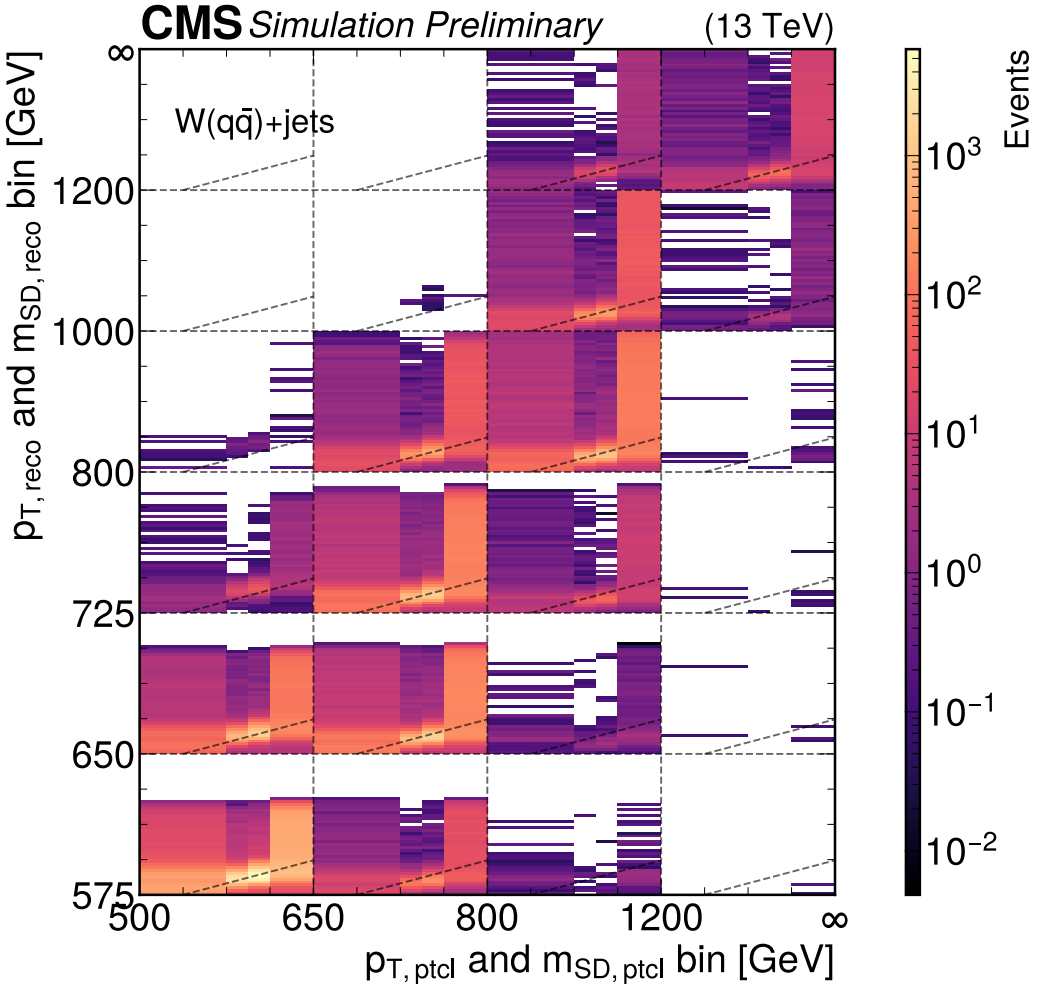
Background estimation



Unfolding

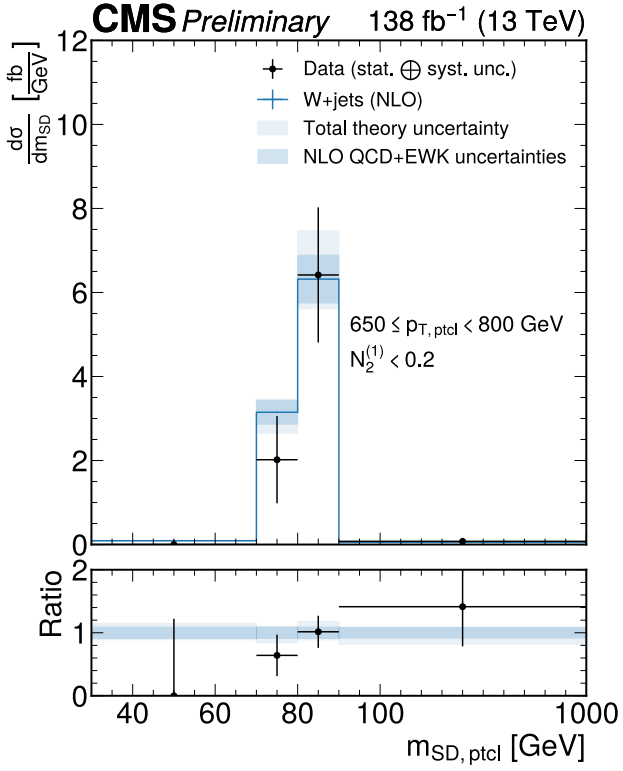
From detector-level to particle-level

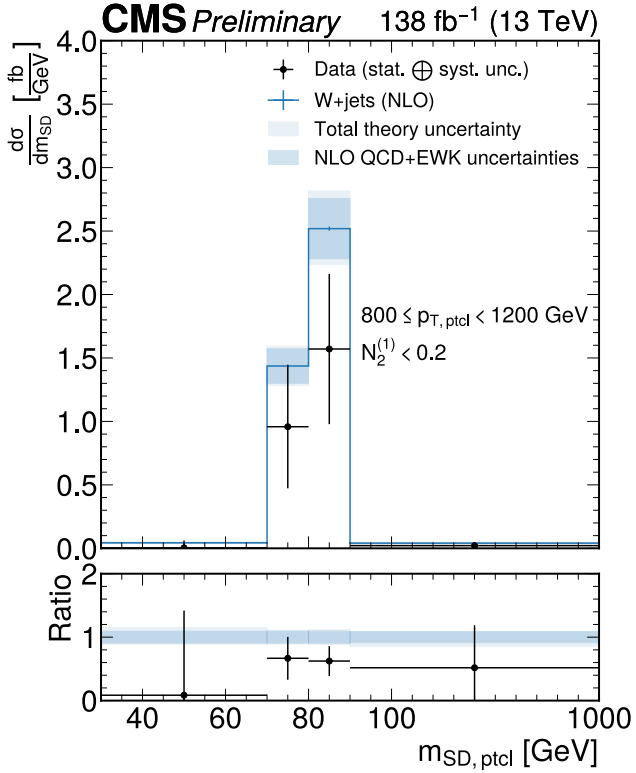
- Maximum likelihood approach implemented with combine
  - In one go with background estimate
  - Uncertainties profiled
- Detector-level response for W(qq)-matched events from Madgraph+Pythia simulation
- SVD regularization
- Main systematic uncertainties
  - Jet energy calibration
  - Shower variations
  - Hadronization model (Pythia/Herwig)

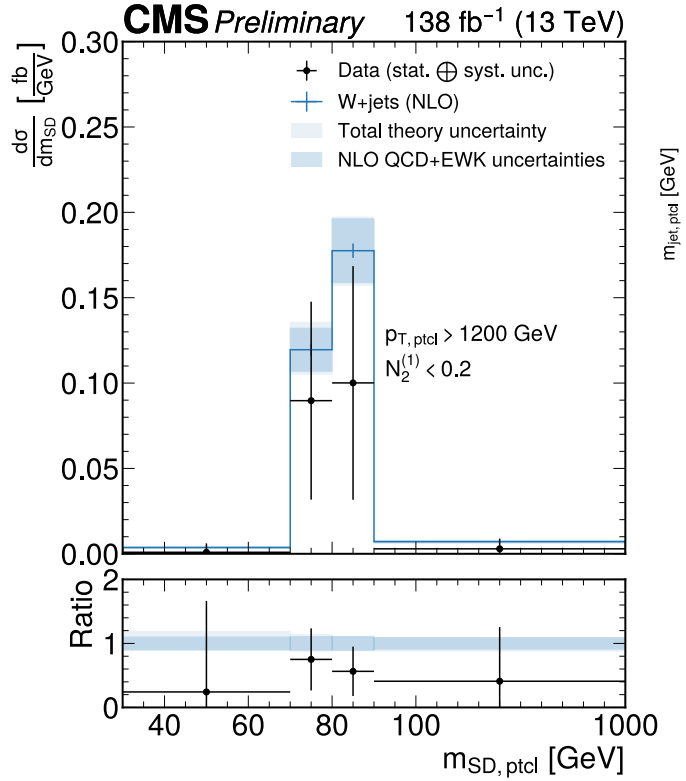


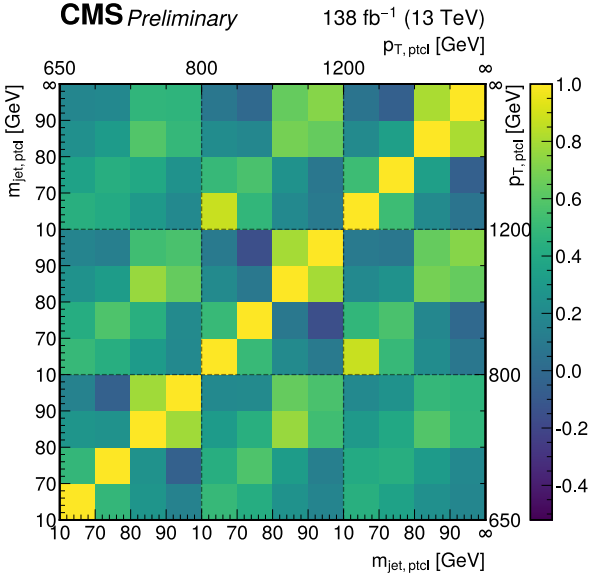
Results

- Madgraph+Pythia with CP5 tune and corrections to NLO QCD+EWK describe peak reasonably well
- Large uncertainties outside W peak region, where background dominates



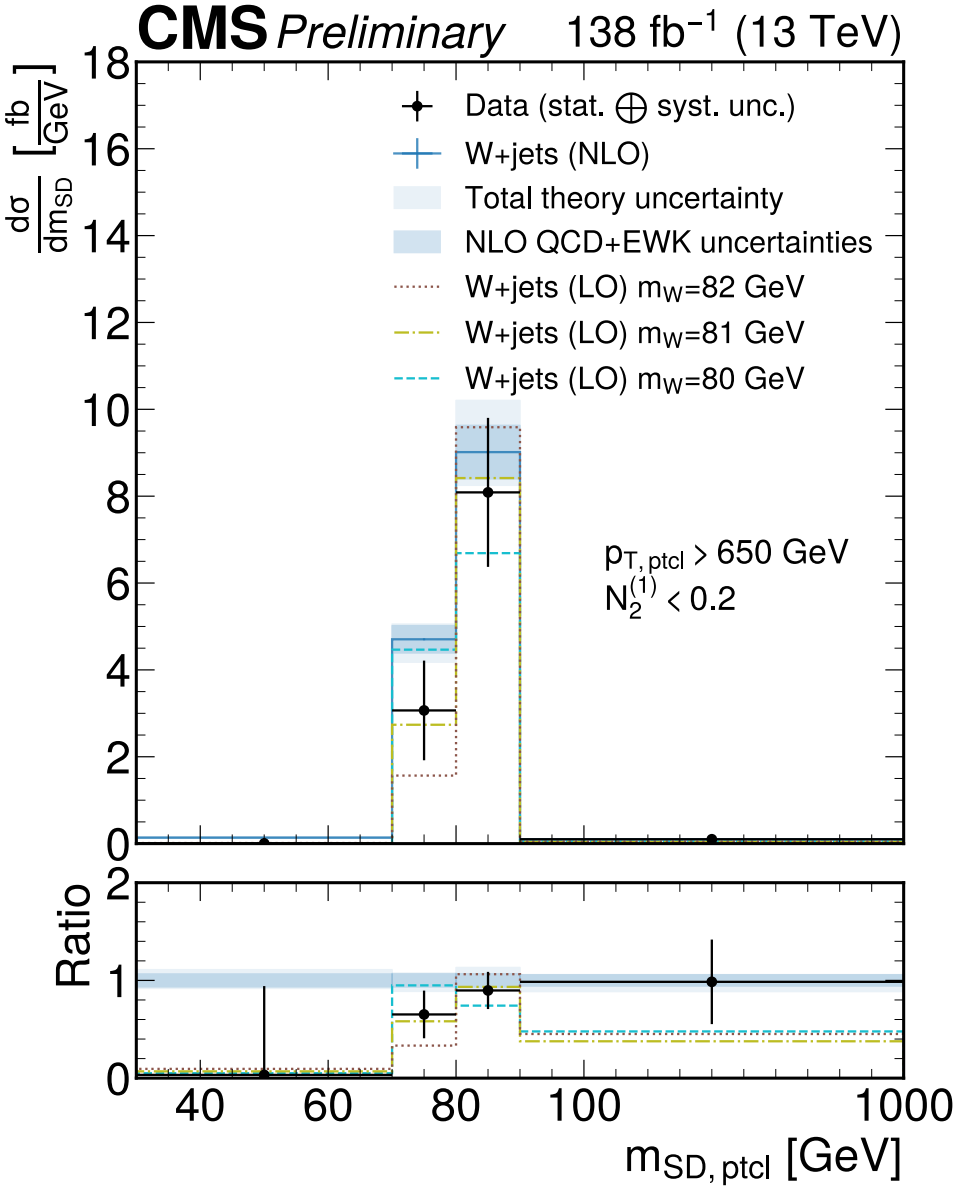






W mass measurement

- Pythia-only prediction agrees with NLO prediction in peak region



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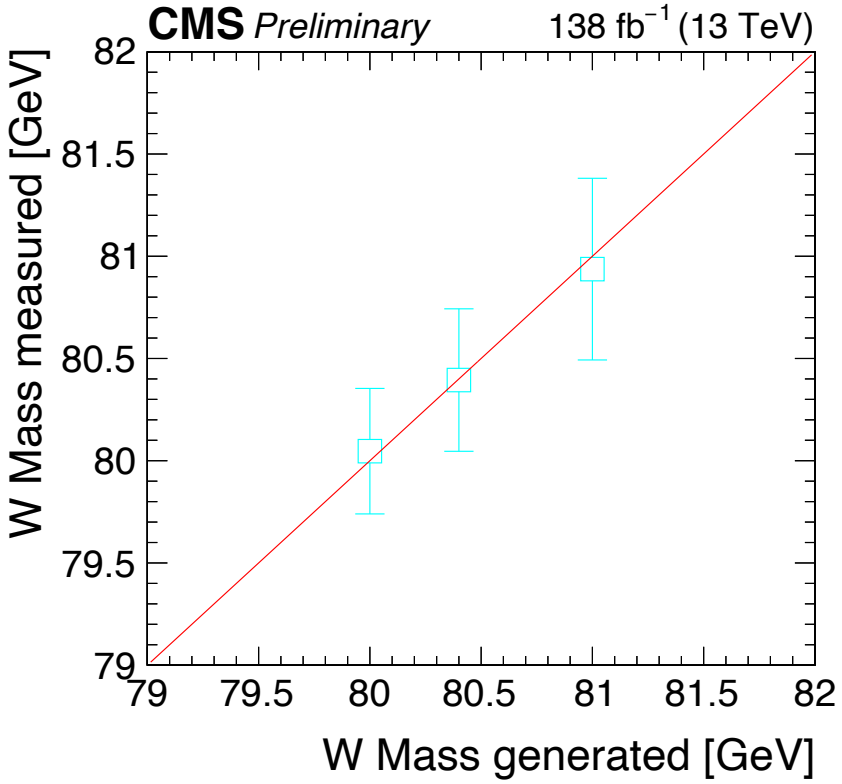
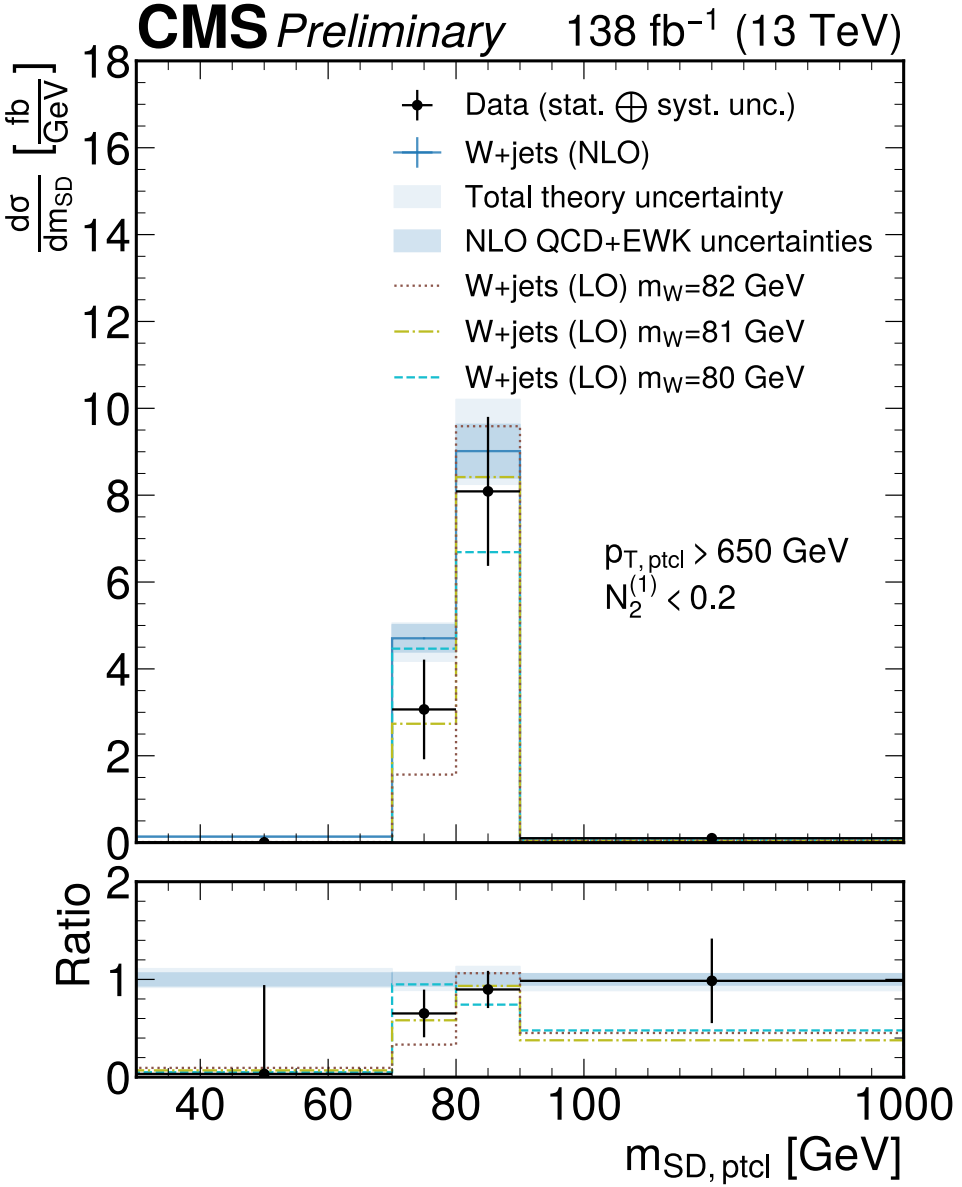
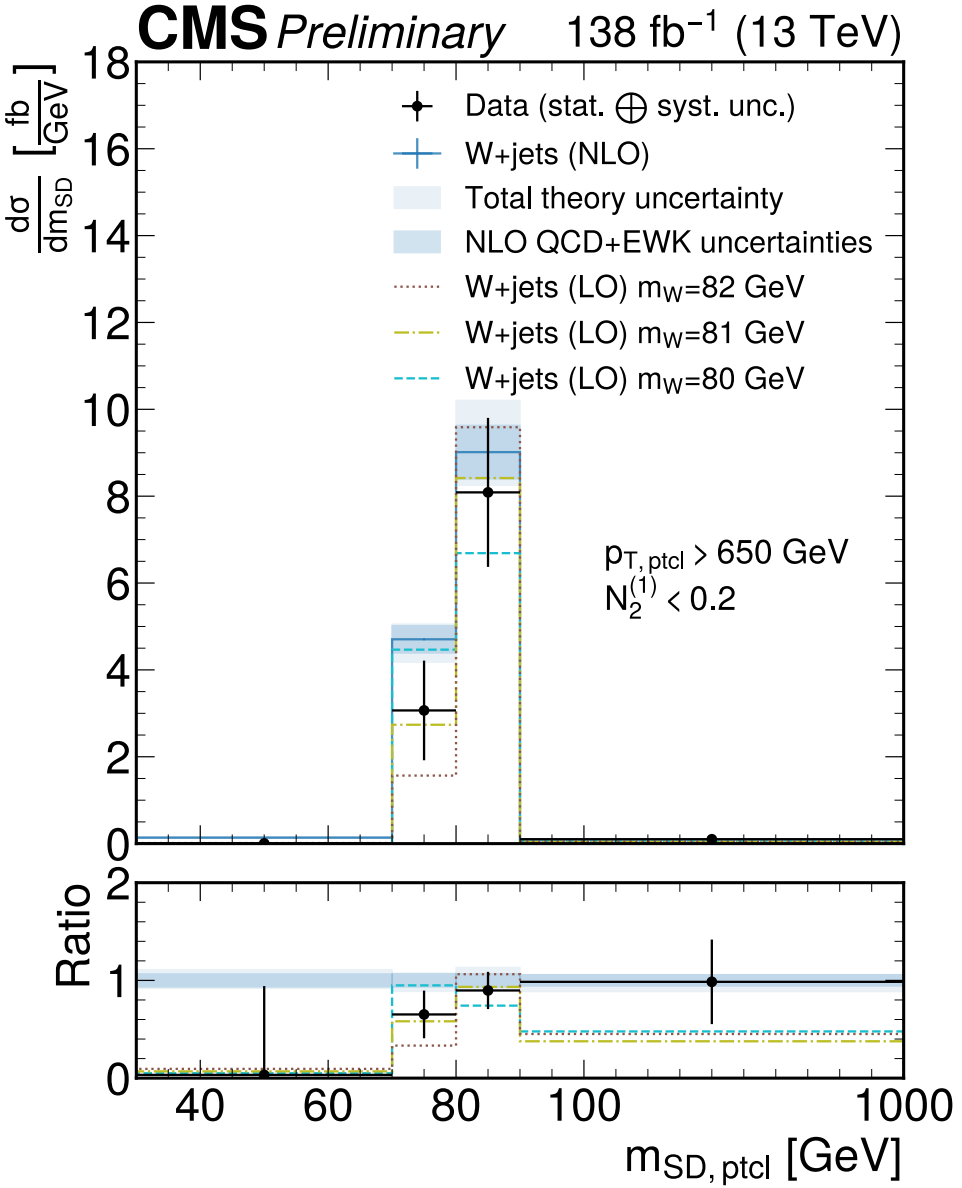
- Peak region used to extract W mass parameter with template fit





W mass measurement

- Pythia-only prediction agrees with NLO prediction in peak region
- Peak region used to extract W mass parameter with template fit
- Result: 80.77 ± 0.57 GeV
  80.77 ± 0.36 (stat. + bg.) ± 0.43 (sig. sys) GeV
  - Yes, we can
- More in CMS-PAS-SMP-24-012
  How to weigh the W boson using hadrons



Vielen Dank

Kontakt

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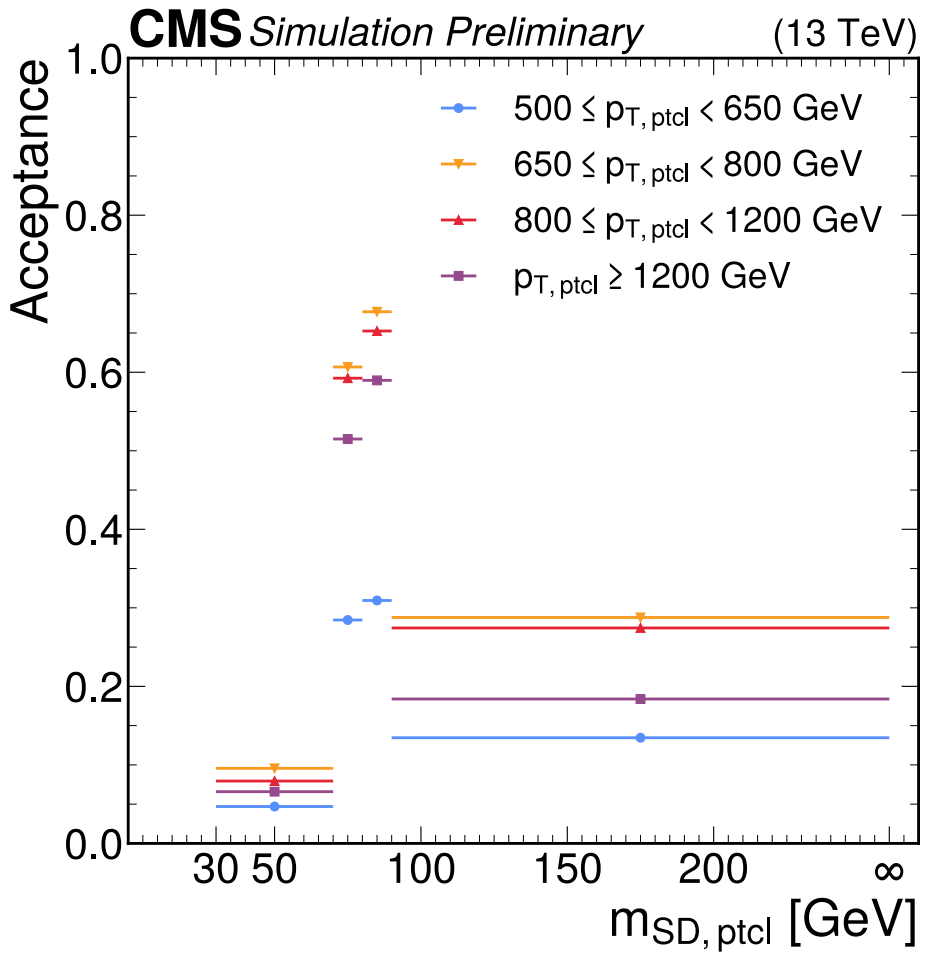
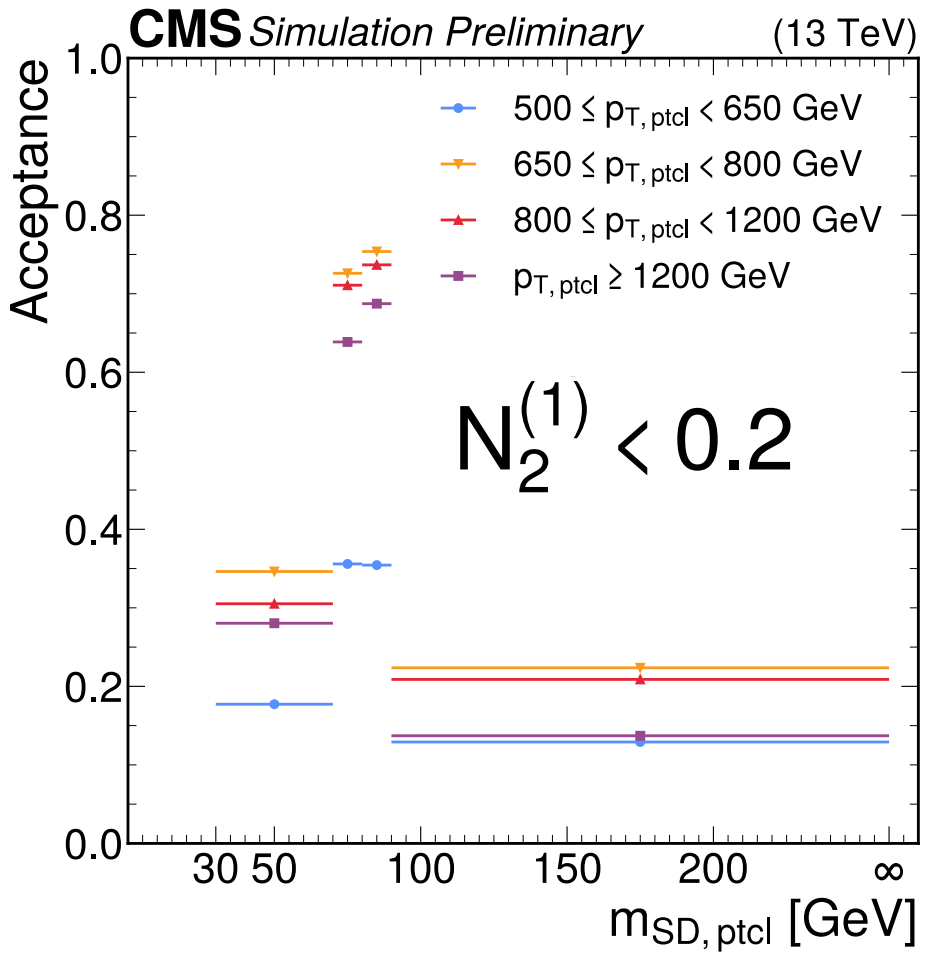
Acceptance


CMS Simulation Preliminary (13 TeV)
Acceptance
1.0
0.8
0.6
0.4
0.2
0.0
500 ≤ pT, ptcl < 650 GeV
650 ≤ pT, ptcl < 800 GeV
800 ≤ pT, ptcl < 1200 GeV
pT, ptcl ≥ 1200 GeV
30 50
100
150
200
∞
mSD, ptcl [GeV]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pT, ptcl ≥ 1200 GeV
$N_2^{(1)} < 0.2$
30 50
100
150
200
∞
mSD, ptcl [GeV]

Systematic uncertainties

Uncertainty	$p_T^{ptcl} \in [500, 650)$
W-tagging efficiency	<0.1 – 17.4 %
Z+jets normalization	<0.1 – 13.5 %
QCD multijet estimate	<0.1 – 4.3 %
Jet energy correction	<0.1 – 16.0 %
Final state radiation	<0.1 – 25.4 %
Initial state radiation	<0.1 – 9.2 %
Pileup reweighting	<0.1 – 5.1 %
V+jets QCD NNLO	<0.1 – 20.2 %
W+jets EW fixed order	<0.1 – 2.8 %
Z+jets EW fixed order	<0.1 – 0.2 %
Luminosity	<0.1 – 2.2 %
Top p_T reweighting	<0.1 – 1.5 %
Trigger scale factor	<0.1 – 4.0 %
Hadronization model	<0.1 – 6.5 %