Perspectives on the determination of systematic uncertainties at HL-LHC

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on behalf of the ATLAS and CMS Collaborations

Workshop on the physics of HL-LHC,
and perspectives at HE-LHC
CERN, 19th Jun 2018
Outline

- Introduction
- YR18 approach
  - Guiding principles
  - How to apply systematics to projection studies
- Overview of main uncertainties
  - Theory and method
  - Jets and MET
  - Heavy-flavor tagging
  - Tau reconstruction & ID
  - Electrons and Photons
  - Muons
- Summary and outlook

Questions & Discussion
Importance of systematics

- The large HL-LHC dataset will enable accurate measurements and unprecedented sensitivity to very rare phenomena.
- Necessarily, the current understanding of systematic uncertainties will become a limiting factor for more and more analyses.

Simplest approaches for systematic uncertainties so far:
1) assume the same uncertainties as in Run-2
2) no systematic (i.e. statistical uncertainty only)
Types of systematic uncertainties

- Incredibly complex analyses
- Large variety of qualitatively-different sources of uncertainty

Representative case: H → ττ
- data and MC statistics
  - also for backgrounds when constrained in Control Regions
- Theory normalization and modeling
  - both for signal and backgrounds
- Method uncertainties
- Experimental systematics
  - detector-driven, including simulation accuracy
- Luminosity

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Profit</th>
<th>Postfit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>τ_{e} energy scale</td>
<td>1.2% in energy scale</td>
<td>0.2–0.3</td>
</tr>
<tr>
<td>e energy scale</td>
<td>1–2.5% in energy scale</td>
<td>0.2–0.5</td>
</tr>
<tr>
<td>e misidentified as τ_{τ} energy scale</td>
<td>3% in energy scale</td>
<td>0.6–0.8</td>
</tr>
<tr>
<td>μ misidentified as τ_{τ} energy scale</td>
<td>1.5% in energy scale</td>
<td>0.3–1.0</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>Dependent upon p_{T} and η</td>
<td>—</td>
</tr>
<tr>
<td>p_{T}^{miss} energy scale</td>
<td>Dependent upon p_{T} and η</td>
<td>—</td>
</tr>
<tr>
<td>τ_{τ} ID &amp; isolation</td>
<td>5% per τ_{τ}</td>
<td>3.5</td>
</tr>
<tr>
<td>τ_{τ} trigger</td>
<td>5% per τ_{τ}</td>
<td>3</td>
</tr>
<tr>
<td>τ_{τ} reconstruction per decay mode</td>
<td>3% migration between decay modes</td>
<td>2</td>
</tr>
<tr>
<td>e ID &amp; isolation &amp; trigger</td>
<td>2%</td>
<td>—</td>
</tr>
<tr>
<td>μ ID &amp; isolation &amp; trigger</td>
<td>2%</td>
<td>—</td>
</tr>
<tr>
<td>e misidentified as τ_{τ} rate</td>
<td>12%</td>
<td>5</td>
</tr>
<tr>
<td>μ misidentified as τ_{τ} rate</td>
<td>25%</td>
<td>3–8</td>
</tr>
<tr>
<td>Jet misidentified as τ_{τ} rate</td>
<td>20% per 100 GeV τ_{τ} p_{T}</td>
<td>15</td>
</tr>
</tbody>
</table>

Z → νν/ττ estimation
- Normalization; 7–15%
- Uncertainty in m_{τ}/ττ, p_{T}(ℓ/ττ), and m_{ν} correlations

W + jets estimation
- Normalization (eμ, τ_{τ}, τ_{ν}, τ_{τ}); 4–20%
- Unc. from CR (eτ_{ν}, μτ_{τ}); ±5–15
- Extrapol. from high-m CR (eτ_{ν}, μτ_{τ}); ±5–10%

Diboson estimation
- Normalization (eμ, τ_{τ}, τ_{ν}); ±10–20%
- Extrapol. from anti-iso. CR (eτ_{ν}, μτ_{τ}); 20–70%
- Extrapol. from anti-iso. CR (τ_{ν}, τ_{ν}); 3–15%
- Extrapol. from anti-iso. CR (τ_{ν}, τ_{ν}); 3–10%

Diboson normalization | 5% | — |
Single top quark normalization | 5% | — |
B estimation | Normalization from CR; ±5% | — |
Integrated luminosity | Uncertainty on top quark p_{T} reweighting | 3.5% |
Top quark energy resolution | Uncertainty on top quark p_{T} reweighting | 3.5% |
B-tagged jet rejection (eμ) | 3.5–5.0% | — |
Limited number of events | Statistical uncertainty in individual bins | — |
Signal theoretical uncertainty | Up to 20% | — |

Jun 19th, 2018
Synergy of ATLAS and CMS in many physics projection and complexity of the problem demands a common treatment
- build on top of previous discussions (e.g. ECFA efforts, …)
- dedicated discussions/meetings with performance groups

Develop common set of guidelines / extrapolations
- discussions in many of the individual YR working groups
  - e.g. Higgs: dedicated internal meeting (indico) and specific presentations (F. Caola, E. Scott, A. Calandri, …)
  - encourage dedicated analysis-specific meetings between analyzers

Effort to produce a realistic projection
- Focus on systematics that are most important for the projection studies we need (can't be comprehensive!)
- Clearly we don't want to be over-conservative, nor over-optimistic i.e. sometimes will be still pessimistic, sometimes may be optimistic
### Dominant uncertainties

**Example above for a subset of Higgs projections**

- **Most “wanted”: Jet/γ Energy Scale/Resolution, MET, B-tagging, Tau**
- **Theory uncertainties will be playing a prominent role**

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**June 19th, 2018**

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<table>
<thead>
<tr>
<th>Topic</th>
<th>Channel</th>
<th>Method (existing results)</th>
<th>Dominant systematic uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM</td>
<td>Charged taunu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSM</td>
<td>A/H tau tau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>Couplings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>BSM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>HH nonlinear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diboson</td>
<td>h(\gamma\gamma)</td>
<td>Parametrized comb.</td>
<td>Mostly Ph-ER (ES less important), JES/JER</td>
</tr>
<tr>
<td>Diboson</td>
<td>hWW</td>
<td>Parametrized comb.</td>
<td>WW modelling</td>
</tr>
<tr>
<td>Diboson</td>
<td>hZZ</td>
<td>Parametrized comb.</td>
<td>ggF:leptons, others:JES/JER</td>
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<tr>
<td>Differential</td>
<td>Hbb and STXS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential</td>
<td>H(\gamma\gamma) and STXS</td>
<td>Run2 extrapolation</td>
<td>Mostly Ph-ER (ES less important)</td>
</tr>
<tr>
<td>Differential</td>
<td>H4l and STXS</td>
<td>Parametrized old</td>
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</tr>
<tr>
<td>Fermion</td>
<td>VHbb</td>
<td>Partial par</td>
<td>V+jets modelling, Jet/MET, BTag</td>
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<tr>
<td>Fermion</td>
<td>Htautau</td>
<td>Partial par</td>
<td>H-(pT) modelling, Jet/MET, Tau</td>
</tr>
<tr>
<td>Non-resonant HH</td>
<td>bb(\gamma\gamma)</td>
<td></td>
<td>Small (Method)</td>
</tr>
<tr>
<td>Non-resonant HH</td>
<td>tH (bb) (bbbb)</td>
<td>Parametrized</td>
<td></td>
</tr>
<tr>
<td>Non-resonant HH</td>
<td>bbb</td>
<td>Run2 extrapolation</td>
<td>Multi-jet shape (TH)</td>
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<tr>
<td>Non-resonant HH</td>
<td>bbtautau</td>
<td>Run2 extrapolation</td>
<td>Tau fake</td>
</tr>
<tr>
<td>Rare decay</td>
<td>H(\gamma\gamma)</td>
<td>Parametrized</td>
<td>Background modelling</td>
</tr>
<tr>
<td>Rare decay</td>
<td>H(\mu\mu\mu)</td>
<td>Parametrized</td>
<td>Drell-Yan modelling</td>
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<tr>
<td>Top yukawa</td>
<td>HtH (all channels)</td>
<td></td>
<td>tt+V modelling, JES/JER, BTag</td>
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<tr>
<td>Top yukawa</td>
<td>HtH (bb)</td>
<td></td>
<td>tt+HF modelling, BTag, JES/JER</td>
</tr>
</tbody>
</table>
Common Guiding Principles

- **Statistics-driven sources:** data $\rightarrow \sqrt{L}$, simulation $\rightarrow 0$
  - account for large statistics available
  - assume will overcome limitations in generating large simulations

- **Intrinsic detector limitations stay $\sim$constant**
  - usage of full simulation tools for detailed analysis of expected performance, thanks to the large effort for TDRs preparation
  - detector simulation advances and operational experience may compensate for e.g. detector aging

- **Theory uncertainties tentatively halved**
  - applies to both normalization (x-sec) and modeling
  - more dedicated discussions with *inputs from theorists* welcome!

- **Extrapolation based mostly on methods available now**
  - challenges as pile-up compensated by algorithmic improvements
• Approach depends on specific projection sensitivity and readiness

<table>
<thead>
<tr>
<th>Implemented Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data statistics</td>
</tr>
<tr>
<td>S1</td>
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<tr>
<td>✔</td>
</tr>
<tr>
<td>Scaling of statistical uncertainty $\sqrt{L}$</td>
</tr>
<tr>
<td>Detector improvements</td>
</tr>
<tr>
<td>✔</td>
</tr>
<tr>
<td>Accounts for expected improvements of detector performance and degradation due to additional pile-up</td>
</tr>
<tr>
<td>Projection of systematics</td>
</tr>
<tr>
<td>✔</td>
</tr>
<tr>
<td>Accounts for expected systematic uncertainties achievable at HL-LHC</td>
</tr>
</tbody>
</table>

• Whenever feasible present results as

\[ \text{value} \pm \text{stat} \pm \text{syst}_\text{exp} \pm \text{syst}_\text{theory} \pm \text{syst}_\text{lumi} \]
Systematics in Run-2 extrapolations

- Usually based on existing statistical frameworks
  - capture the full complexity of multi-variables / multi-region analyses

- Account for expected performance by scaling signal/backgrounds yields

- Systematics implemented as numerous nuisance parameters
  - consider/scale leading sources for HL-LHC projections
  - provide expected scaling for most common leading uncertainties

- Profiling can lead to over-constraints or loss of validity of correlation model
  - scale uncertainty a-posteriori when fit is not adequate
Systematics in “truth-based” projections

- Parametrized detector performance or delphes “reconstruction”
  - more rarely full-simulation samples too
  - allows re-optimization of selections and direct usage of parametrized performance of upgraded detector

- Consider leading systematic uncertainties if dominant over stat.
  - Applied shifting “reconstructed” quantities and assessing impact

- Non-trivial extrapolation to run-2 “inaccessible” regions/features
  - detector capabilities (timing, ...)
  - kinematics (large $\eta$ tracking, high $p_T$,...)
Theory uncertainties

- Signal/Background simulations rely on advances in x-section integrators and generators

- General guideline for normalization and modeling → **halved**
  - e.g. improvements in higher-order corrections and resummation
  - some observables may improve more (p_T(top)?) → theorists' input

- PDF uncertainties unlikely to improve as significantly
Method/Modeling uncertainties

- Expected background often constrained in dedicated control regions
- Extrapolation from control to signal region:
  - MC prediction $\rightarrow$ modeling uncertainty
  - entirely data-driven methods $\rightarrow$ check assumptions often in MC
- In both cases expect:
  - closure of method $\rightarrow$ harder to predict, keep same
  - statistics in control region $\rightarrow$ $\sim\sqrt{L}$
  - theory uncertainty critical $\rightarrow$ halved

- Theorists' input crucial on a case by case

Jun 19th, 2018
Experimental: Jet Energy Scale

- Used as example of experimental systematic with various sources
- Starting point: latest run-2 public results
- Will go in a bit more detail for this important systematic to illustrate the type of process ongoing
**Example: Anatomy of Jet energy scale**

- **Absolute “in-situ” JES**
  - low-medium $p_T$ from $Z+$jets balance study
    - dominated by generator differences, pile-up rejection, radiation
    - overall expect improvements to balance challenges → **keep same**
  - high-$p_T$ dominated by photon energy scale in $\gamma+$jets balance
    - Expect better accuracy with large statistics → **halved**
  - Other components will be neglected, based on current experience
Flavor composition and response

- mainly comes from how generators model gluon jet radiation
- rely on fragmentation measurements and re-tuning of parton shower generators
- Propose to have two scenarios:
  - Optimistic → halved
  - Baseline → keep same
JET ENERGY RESOLUTION / MET

- JER: expect to achieve run-1 performance, despite harsher conditions
  → run-1 values

- MET systematics driven by object scale/resolution uncertainties
  - Soft-term uncertainties are rarely dominant and hard to extrapolate
    → keep same
      - discuss exceptions on a case-by-case
Electrons/Photons:

- Run 2 ATLAS: 0.5% $e/\gamma$
  - Reco and ID
- Run 2 CMS:
  - Reconstruction: 0.2-1% (depends on eta)
    - depends on the working point
- HL-LHC:
  - With higher statistics and upgraded detector, effects due to background modeling, ISR modeling, signal resolution may decrease
  - However, effects due to pileup, especially for isolation may lead to increased systematics
- Current studies indicate a projected systematics for
- reco/ID: 0.5% for electrons (including isolation)
**e/γ Energy Scale**

- **ATLAS Run 2**
  0.1%(0.2%) to 0.3%(0.5%) for e (γ)

- **CMS Run 2**
  - measured vs nominal peak position of Z
  - propagate difference to $H \rightarrow 4\mu$ (4e) leading to uncertainty of 0.04% (0.3%) for 4µ (4e)

→ keep same for HL-LHC
  - larger dataset will help in monitoring detector stability
  - critical understanding of detector, seems difficult to go much further
  - expect to be able to mitigate larger pile-up effects
e/γ Energy Resolution

• Detector dependent

• ATLAS HL-LHC:
  • Study resolution for different pileup
  • Increase due to pileup noise at low $p_T$

• CMS HL-LHC
  • Study energy resolution as a function of aging and PU
Muons:

- **Run 2 ATLAS**: 0.1% (reco & ID)
- **Run 2 CMS**: ~0.1-0.5%
  - Reco: 0.1-0.4% muons (depends on eta)
  - Identification & isolation: 0.4% muons
  - depends on the working point
- **HL-LHC**:
  - With higher statistics and upgraded detector, effects due to background modeling may decrease
  - In general robust against pileup
  - However, isolation dependence on PU may lead to increased systematics
- **Projected systematics for**
  - reco/ID and isolation: 0.1-0.4% for muons
    - (depends on working point and eta)
  - Scale and resolution also well measured
Di-Muon Mass Resolutions

- Tracker upgrade improvements in the dimuon/4µ mass resolution needs to be folded in the projections based on Run2
**Taus**

- **Tau ID efficiency systematics:**
  - Run2 uncertainty: ~5% (ATLAS and CMS)
    - Simulation $\tau$ modeling
    - Tracking eff. systematics (CMS: 3.5% for low $p_T$)
      - Expect to improve with new tracker
    - Fake backgrounds $j \rightarrow \tau_h$ multiplicity of charged hadrons in hadronization of q/g jets
  - For HL-LHC
  - Use Run2 floor of 4-7% (depending on decay mode).
    - Effect of pileup on isolation possibly dominates
    - Under discussion $p_T > 250$ GeV
    - Improvements can be expected from further developments e.g. advanced machine learning for ID & pileup mitigation.
    - In case the analysis has a high impact from this uncertainty, we recommend to also quote the result with half the uncertainty.

- **Tau Energy Scale systematics:**
  - Expect floor of ~ 1.5-3% (depending on eta)
    - Theory modeling, detector, in-situ
      - advancement in methods may further reduce the in-situ unc.
Flavor tagging

- Goal: systematic uncertainties for b-, c-, light & PU jets parameterized vs jet $p_T/\eta$
- Run 2 systematics:
b-jet tagging

- b-jet tagging efficiency and systematics in Run2:
- ATLAS and CMS:
  - measurements from data rely on ttbar events for jet $p_T$ range: 30-300 GeV
- CMS:
  - Multijets with muon from semileptonic b hadron decays cover $p_T$ range 20-1000 GeV
- Several methods are used for each sample.
  - Their combination allows to reduce the overall uncertainty.
b-jet tagging systematics in Run2

• Common or partially common in both sets of methods:
  • b quark fragmentation, branching fractions of b and c hadrons, jet energy scale and resolution, pileup modeling.

• Systematics specific to the ttbar methods:
  • Factorization & renormalization scales
  • Modeling ttbar generator & simulation
  • physics background yield
  • tagging of non-b jets
  • missing ET modeling
  • ID/isolation of lepton from W decay

• Systematics specific to muon-jet methods:
  • fraction of gluon splitting into b quark pair
  • muon selection
  • calibration and contribution from non-b jets
  • b jet template
b-jet tagging systematics for HL-LHC

- CMS Run2:
  - ttbar & muon-jet methods provide compatible b jet tagging efficiencies within a precision of 1% (20-300 GeV)
    - Probably due to intrinsic difference in b jets with or without a muonic decay
  - systematic uncertainty rises from 2--6% between 400-1000 GeV

- ATLAS:
  - main systematic contribution is due to the ttbar simulation modeling
  - with introduction of non-ttbar based b-tagging calibration methods, able to reduce the uncertainties for jet $p_T > 300$ GeV to values similar to CMS

- For HL-LHC:
  - assume that all systematic uncertainties on
  - the b jet tagging efficiency will be
  - reduced by a factor of two.
  - A parametrization of the overall uncertainty is derived as a function of the b jet $p_T$, with a minimum set at 1% around 100 GeV.
c-jet tagging systematics for HL-LHC

- ATLAS and CMS: measurements from the data in Run 2 rely on single lepton ttbar events and on W+c events
- Common or partially common in both methods:
  - parton distribution function, factorization and renormalization scales, c quark fragmentation, W-lepton ID/isolation, jet energy scale and resolution, pileup modeling.
- Systematics specific to ttbar method:
  - cross-section of the simulated processes
  - integrated luminosity
  - tagging of light flavour jets & b jets
- Systematics specific to W+c method:
  - $D \to \mu$ branching fraction
  - soft muon requirement
  - number of tracks in the jet
  - background estimate, missing ET modeling
- The overall systematic uncertainty on the tagging efficiency is typically a factor two to three larger for c jets than for b jets.

- For HL-LHC: assume that the systematic uncertainties on the c jet tagging efficiency will be reduced by a factor of two at HL-LHC.
Light-jet tagging systematics for HL-LHC

- ATLAS & CMS rely on the negative tag method
- ATLAS also applies an adjustment of the Monte Carlo simulation to the data in order to estimate the mistag rate.
- Main systematics of the negative tag method:
  - sign flip probability
  - fraction of b and c jets in multijet sample
- Other systematic uncertainties are due to
  - fraction of gluon jets in the multijet sample
  - contribution from K_{0S} and λ decays
  - secondary interactions in the detector material
  - fraction of mismeasured tracks
  - event sample dependence
  - pileup modeling.
- ATLAS MC adjustment method:
  - the main systematics on the are due to track uncertainties (impact parameter resolution, mismeasured tracks)
  - The most significant systematics can be directly estimated from data measurements
  - Assume that they will be reduced by a factor two at HL-LHC and is estimated to be 5%, 10%, 15% uncertainty for the operating points with 10%, 1%, and 0.1% mistag rates
Boosted jets:

- A caveat: The boosted jets effort continue to benefit from advanced ML/AI techniques. Currently such improvements are underway, but too early in the study to derive their impact for projected systematics

- For now, we use uncertainties same as Run 2
  - Jet mass scale uncertainty: 1%
  - Jet mass resolution: 10%
  - W tagging efficiency: 10% (governed by Herwig vs Pythia)

- Higgs tagging – values x2 improvement compared to Run2 (CMS)
  - H jet mass scale and resolution: 1%
  - H jet $\tau_{21}$ selection: 13%
  - H-tagging correction factor: 3.5%
Summary of Experimental Uncertainties*

<table>
<thead>
<tr>
<th>Source</th>
<th>YR2018 Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>1-1.5%</td>
</tr>
<tr>
<td>Muon efficiency (ID, iso)</td>
<td>0.1-0.4%</td>
</tr>
<tr>
<td>Electron Efficiency (ID, iso)</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tau efficiency (ID, trigger, iso)</td>
<td>5% (if dominant use 2.5%)</td>
</tr>
<tr>
<td>Photon efficiency (ID, trigger, iso)</td>
<td>2%</td>
</tr>
<tr>
<td>Jet Energy Scale</td>
<td>1-2.5% #</td>
</tr>
<tr>
<td>Jet Energy Resolution</td>
<td>1-3% #</td>
</tr>
<tr>
<td>b-jet tagging efficiency</td>
<td>1%</td>
</tr>
<tr>
<td>c-jet tagging efficiency</td>
<td>2%</td>
</tr>
<tr>
<td>light-jet mistag rate</td>
<td>5% (@10% mistag rate) #</td>
</tr>
</tbody>
</table>

* Note: These uncertainties are representative values. The dependence for example of $p_T$ and eta and the operating points, if applicable, need to be taken into account.

# Note: factor of 2 improvement compared to Run 2
• Systematics play an important role in assessing HL-LHC potential
  – Effort to ensure coherence of CMS/ATLAS approaches

• Good agreement over common general guidelines:
  – **statistics-driven sources**: data → $\sqrt{L}$, simulation → 0
  – **intrinsic detector limitations** stay ~constant
    • often new methods are expected to compensate pile-up effects
  – **theory normalization/modeling** → $\frac{1}{2}$

• “Floor” of systematics & scaling of nuisance parameters ~finalized
  – is **1% luminosity uncertainty** suitable for YR projections?
  – some experimental systematics still on the conservative side, but if dominant could test more aggressive scenarios and compare
  – Caution has to be taken in not **over-constraining systematics**
    • a-posteriori error scaling for such cases?
Summary and outlook – 2/2

- Theory uncertainties “ansatz”:
  - Clear **need of specific inputs from theorists** beyond the general $1/2$ guideline
    - especially for modeling uncertainties, discussions within each working group and analyses are extremely beneficial
    - common processes as ttbar, V+Jets, dibosons, … ?
  - **PDF uncertainties** won't likely be reduced by $1/2$ by end of HL-LHC
    - Alternative proposals?

- Uncertainties on methods that are continuously improving
  - some cases accounted for as extra pile-up mitigation
  - some others will go beyond what is foreseeable right now
    - new calibration techniques
    - new background estimation methods
    - new measurements
    - new detectors (e.g. timing, …)
    - …
  - inherently conservative in this realm
A huge thank you to the many colleagues inside ATLAS and CMS who made this possible!

Time is short…

we need everyone's help and input to finalize this now
• Relative “in-situ” JES
  - dominated by statistics and simulation modeling
  - in this case it was felt advances in modeling can be substantial
  - Expect it will become negligible $\rightarrow 0$
**Example: Anatomy of Jet energy scale**

- **Pile-up**
  - Current method brings an increase in uncertainty with pile-up
  - Expect new methods will be developed to at least compensate
  - Two scenarios:
    - Baseline → *keep same*
    - Optimistic → *halved*

- **Punch-through, high-pT**
  - Single particle response but kicks in when we run out of statistics in the multijet balance
  - Expect large statistics will allow us to make this negligible → 0

Jun 19th, 2018
Jet Energy Resolution

\[ \sqrt{s} = 13 \text{ TeV} \]

\( \text{anti-}k_t \text{ EM+JES } + \text{in situ, } R = 0.4 \]

\( p_T^{\text{jet}} = 40 \text{ GeV} \)

- Total uncertainty
- Total uncertainty, 2012
- Noise term
- Dijet in situ measurement
- \( \gamma + \text{jet} \) in situ measurement
- \( Z + \text{jet} \) in situ measurement
- 2012 to 2015 extrapolation
• Most important components:
  - ID efficiency
  - Tau Energy Scale
  - others less important → neglected

• Tau ID
  - Mostly limited by systematics
    • Simulation $\tau$ modeling
    • Fakes background
  - Expect “floor” of $\sim 5\%$
  - Under discussion $p_T > 250$ GeV

• Tau Energy Scale
  - Theory modeling, detector, in-situ
  - Expect “floor” of $\sim 2-3\%$
  - Under discussion for high $p_T$
Theory/Method uncertainties

- Signal/Background simulations
  - Rely on advances in x-section integrators and generators
  - General guideline for normalization and modeling → **halved**
- Data-driven backgrounds limited by
  - statistics in control region → will get better with ~sqrt(L)
  - closure of method → harder to predict, **keep same**

- Both require some judgments on a case by case, but guidelines above could still be useful
## Summary: CMS Projections for JET Energy Scale

<table>
<thead>
<tr>
<th>Source</th>
<th>Current</th>
<th>Proposal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Scale</td>
<td>0.5%</td>
<td>0.1% - 0.2%</td>
<td>Scales with Z(-&gt;mumu)+jet statistics, update methods to avoid low pT inefficiencies at high PU</td>
</tr>
<tr>
<td>Relative Scale</td>
<td>0.1% - 3%</td>
<td>0.1% - 0.5%</td>
<td>Improvements in ECAL modelling will reduce pT dependence and its uncertainty, and Z+jet and γ+jet will help constraint low pT response</td>
</tr>
<tr>
<td>Pile up</td>
<td>0% - 2%</td>
<td>0% - 2%</td>
<td>With updated methods, effect of additional pileup could be mitigated, the uncertainty can be kept the same</td>
</tr>
<tr>
<td>Method &amp; Sample</td>
<td>0.5% - 5%</td>
<td>0%</td>
<td>difference between derivation methods and channels - likely to be understood and removed</td>
</tr>
<tr>
<td>Jet Flavor</td>
<td>1.5%</td>
<td>0.75%</td>
<td>Halved by taking Pythia/Herwig mixture as baseline, further with improved tunes and data-based methods</td>
</tr>
<tr>
<td>Time Stability</td>
<td>0.2%</td>
<td>0%</td>
<td>Assuming stability of data taking, and detector conditions, this can be removed</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>2% - 5%</td>
<td>1%-2.5%</td>
<td></td>
</tr>
</tbody>
</table>
## b-jet tagging systematics (ATLAS LH method)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Scale factor</td>
<td>1.013</td>
<td>1.035</td>
<td>1.029</td>
<td>1.019</td>
<td>0.984</td>
<td>0.964</td>
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<td>Total uncertainty</td>
<td>0.123</td>
<td>0.030</td>
<td>0.018</td>
<td>0.022</td>
<td>0.026</td>
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<td>Statistical uncertainty</td>
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<td>Systematic uncertainty</td>
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<td>0.030</td>
<td>0.018</td>
<td>0.021</td>
<td>0.024</td>
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### Systematic Uncertainties [%]

<table>
<thead>
<tr>
<th>Source</th>
<th>20–30</th>
<th>30–60</th>
<th>60–90</th>
<th>90–140</th>
<th>140–200</th>
<th>200–300</th>
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<tbody>
<tr>
<td>Matrix element modelling (( t\bar{t} ))</td>
<td>3.2</td>
<td>0.3</td>
<td>0.9</td>
<td>1.1</td>
<td>1.1</td>
<td>0.7</td>
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<tr>
<td>Parton shower / Hadronisation (( t\bar{t} ))</td>
<td>9.0</td>
<td>1.5</td>
<td>0.3</td>
<td>1.0</td>
<td>1.4</td>
<td>2.2</td>
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<tr>
<td>NNLO top ( p_T ), ( t\bar{t} ) ( p_T ) reweighting (( t\bar{t} ))</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>PDF reweighting (( t\bar{t} ))</td>
<td>0.9</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>More / less parton radiation (( t\bar{t} ))</td>
<td>1.7</td>
<td>0.9</td>
<td>0.4</td>
<td>0.3</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Matrix element modelling (single top)</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
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<tr>
<td>Parton shower / Hadronisation (single top)</td>
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<td>0.1</td>
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<tr>
<td>More / less parton radiation (single top)</td>
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<td>0.0</td>
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<tr>
<td>DR vs. DS (single top)</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
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<tr>
<td>Modelling (Z+jets)</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.9</td>
<td>0.6</td>
<td>1.2</td>
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<tr>
<td>( p_T ) reweighting (Z+jets)</td>
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<td>0.0</td>
<td>0.1</td>
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<td>MC non-closure</td>
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<td>Normalisation single top</td>
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<td>Normalisation Z+jets</td>
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<td>Normalisation misid. leptons</td>
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<td>0.7</td>
<td>0.6</td>
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<tr>
<td>Pile-up reweighting</td>
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<td>Electron efficiency/resolution/scale/trigger</td>
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<tr>
<td>( E_T^{miss} )</td>
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<td>Jet energy scale (JES)</td>
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<td>Jet energy resolution (JER)</td>
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<td>Light-flavour jet mis-tag rate</td>
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<td>0.0</td>
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<td>0.1</td>
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<td>0.1</td>
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</table>