# 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

S. Pagan Griso

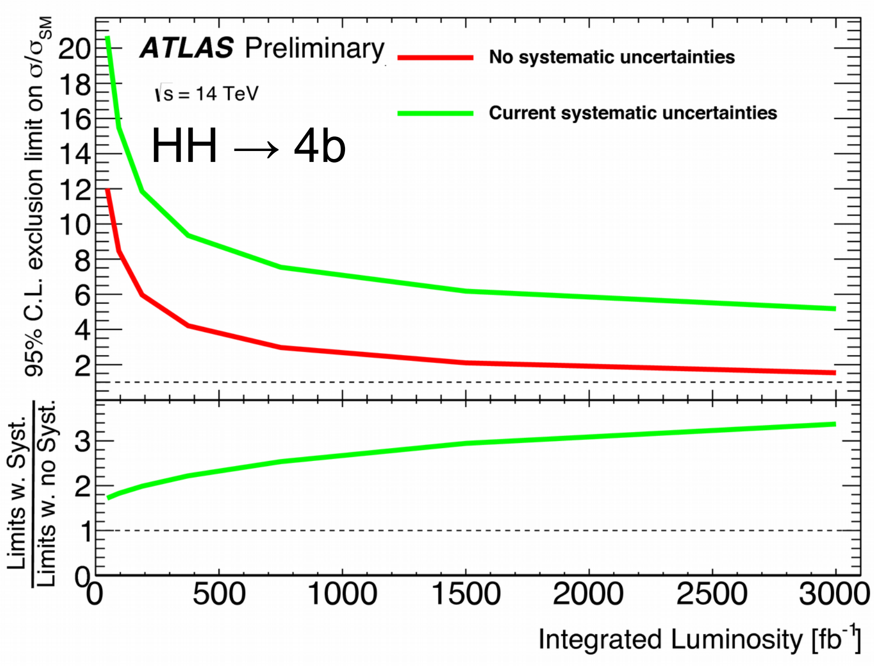
  - Heavy-flavor tagging
  - Tau reconstruction & ID
  - Electrons and Photons
  - Muons
- Summary and outlook

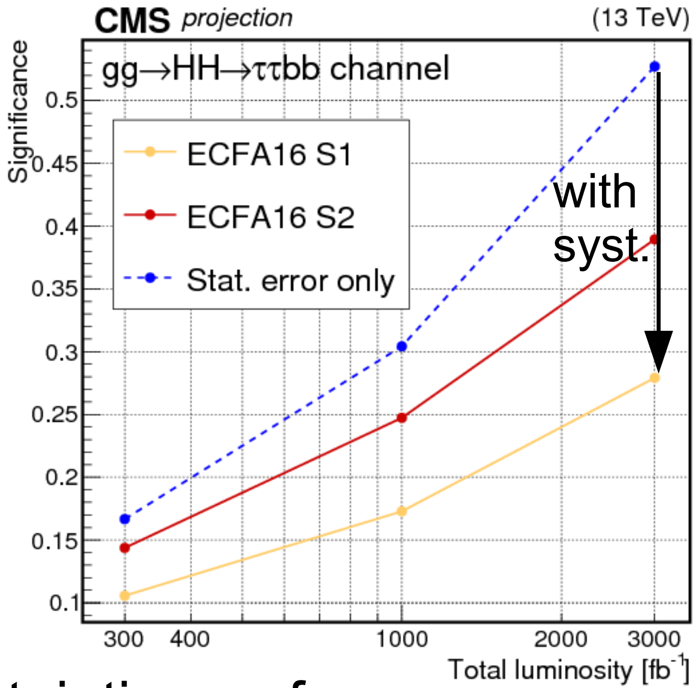
M. Narain

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



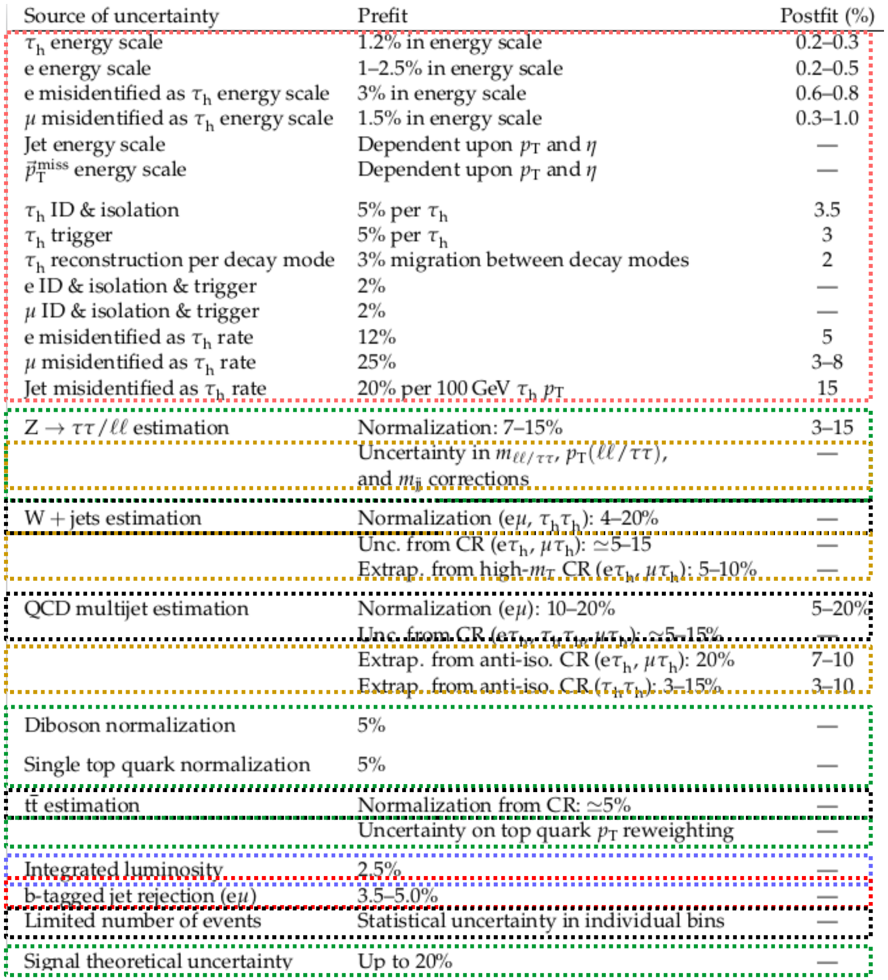


- Simplest approaches for systematic uncertainties so far:
  1) assume the same uncertainties as in Run-2
  2) no systematic (i.e. statistical uncertainty only)

# 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



| Source of uncertainty | Prefit | Postfit (%) |
|---|---|---|
| $\tau_h$ energy scale | 1.2% in energy scale | 0.2–0.3 |
| e energy scale | 1–2.5% in energy scale | 0.2–0.5 |
| e misidentified as $\tau_h$ energy scale | 3% in energy scale | 0.6–0.8 |
| $\mu$ misidentified as $\tau_h$ energy scale | 1.5% in energy scale | 0.3–1.0 |
| Jet energy scale | Dependent upon $p_T$ and $\eta$ | — |
| $\vec{p}_T^{miss}$ energy scale | Dependent upon $p_T$ and $\eta$ | — |
| $\tau_h$ ID & isolation | 5% per $\tau_h$ | 3.5 |
| $\tau_h$ trigger | 5% per $\tau_h$ | 3 |
| $\tau_h$ reconstruction per decay mode | 3% migration between decay modes | 2 |
| e ID & isolation & trigger | 2% | — |
| $\mu$ ID & isolation & trigger | 2% | — |
| e misidentified as $\tau_h$ rate | 12% | 5 |
| $\mu$ misidentified as $\tau_h$ rate | 25% | 3–8 |
| Jet misidentified as $\tau_h$ rate | 20% per 100 GeV $\tau_h$ $p_T$ | 15 |
| $Z \to \tau\tau/\ell\ell$ estimation | Normalization: 7–15% | 3–15 |
|  | Uncertainty in $m_{\ell\ell/\tau\tau}$, $p_T(\ell\ell/\tau\tau)$, and $m_{jj}$ corrections | — |
| W + jets estimation | Normalization (e$\mu$, $\tau_h\tau_h$): 4–20% | — |
|  | Unc. from CR (e$\tau_h$, $\mu\tau_h$): $\simeq$5–15 | — |
|  | Extrap. from high-$m_T$ CR (e$\tau_h$, $\mu\tau_h$): 5–10% | — |
| QCD multijet estimation | Normalization (e$\mu$): 10–20% | 5–20% |
|  | Unc. from CR (e$\tau_h$, $\tau_h\tau_h$, $\mu\tau_h$): $\simeq$5–15% | — |
|  | Extrap. from anti-iso. CR (e$\tau_h$, $\mu\tau_h$): 20% | 7–10 |
|  | Extrap. from anti-iso. CR ($\tau_h\tau_h$): 3–15% | 3–10 |
| Diboson normalization | 5% | — |
| Single top quark normalization | 5% | — |
| $t\bar{t}$ estimation | Normalization from CR: $\simeq$5% | — |
|  | Uncertainty on top quark $p_T$ reweighting | — |
| Integrated luminosity | 2.5% | — |
| b-tagged jet rejection (e$\mu$) | 3.5–5.0% | — |
| Limited number of events | Statistical uncertainty in individual bins | — |
| Signal theoretical uncertainty | Up to 20% | — |

Jun 19th, 2018

# Towards YR'18

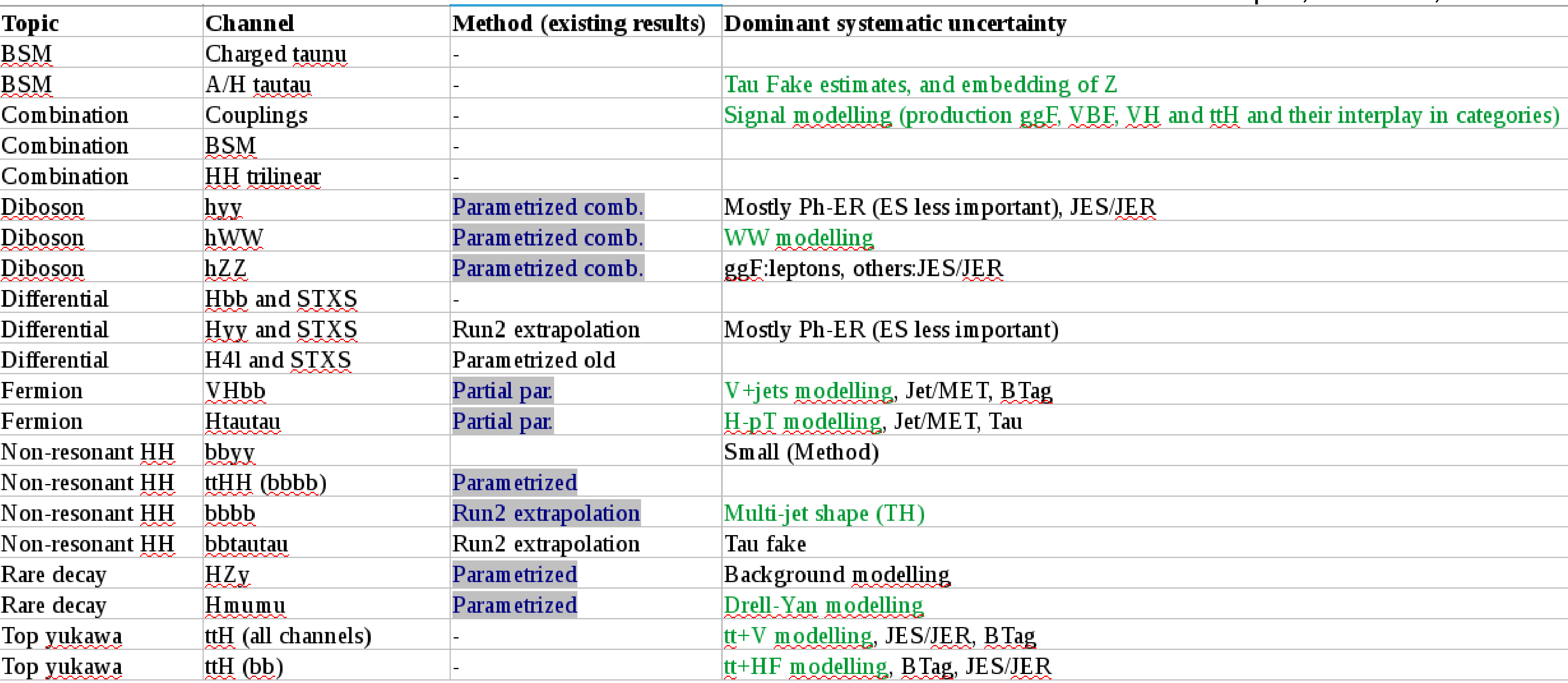
- Synergy of ATLAS and CMS in many physics projection and complexity of the problem demands a common treatment
  - build on top of previous discussions (e.g. ECFA efforts, …)
  - dedicated discussions/meetings with performance groups

- 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

Thx to: S. Jezequel, M. Testa, M. Kado



| Topic | Channel | Method (existing results) | Dominant systematic uncertainty |
|---|---|---|---|
| BSM | Charged taunu | - | |
| BSM | A/H tautau | - | Tau Fake estimates, and embedding of Z |
| Combination | Couplings | - | Signal modelling (production ggF, VBF, VH and ttH and their interplay in categories) |
| Combination | BSM | - | |
| Combination | HH trilinear | - | |
| Diboson | hγγ | Parametrized comb. | Mostly Ph-ER (ES less important), JES/JER |
| Diboson | hWW | Parametrized comb. | WW modelling |
| Diboson | hZZ | Parametrized comb. | ggF:leptons, others:JES/JER |
| Differential | Hbb and STXS | - | |
| Differential | Hγγ and STXS | Run2 extrapolation | Mostly Ph-ER (ES less important) |
| Differential | H4l and STXS | Parametrized old | |
| Fermion | VHbb | Partial par. | V+jets modelling, Jet/MET, BTag |
| Fermion | Htautau | Partial par. | H-pT modelling, Jet/MET, Tau |
| Non-resonant HH | bbγγ | | Small (Method) |
| Non-resonant HH | ttHH (bbbb) | Parametrized | |
| Non-resonant HH | bbbb | Run2 extrapolation | Multi-jet shape (TH) |
| Non-resonant HH | bbtautau | Run2 extrapolation | Tau fake |
| Rare decay | HZγ | Parametrized | Background modelling |
| Rare decay | Hmumu | Parametrized | Drell-Yan modelling |
| Top yukawa | ttH (all channels) | - | tt+V modelling, JES/JER, BTag |
| Top yukawa | ttH (bb) | - | tt+HF modelling, BTag, JES/JER |

- 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**

# Common Guiding Principles

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

# YR'18 Approach

- Approach depends on specific projection sensitivity and readiness

**Implemented Strategy**

CMS PAS FTR-16-002

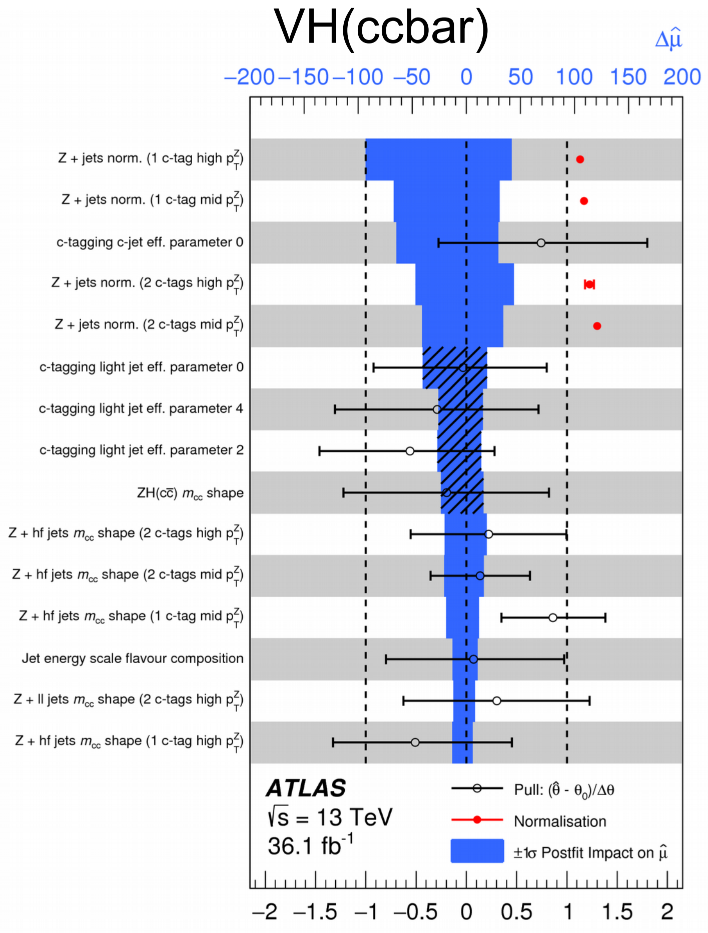
| | S1 | S1+ | S2 | S2+ | |
|---|---|---|---|---|---|
| Data statistics | ✓ | ✓ | ✓ | ✓ | Scaling of statistical uncertainty √L |
| Detector improvements | | ✓ | | ✓ | Accounts for expected improvements of detector performance and degradation due to additional pile-up |
| Projection of systematics | | | ✓ | ✓ | Accounts for expected systematic uncertainties achievable at HL-LHC |

- Whenever feasible present results as

**value ± stat ± syst_exp ± syst_theory [± syst_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



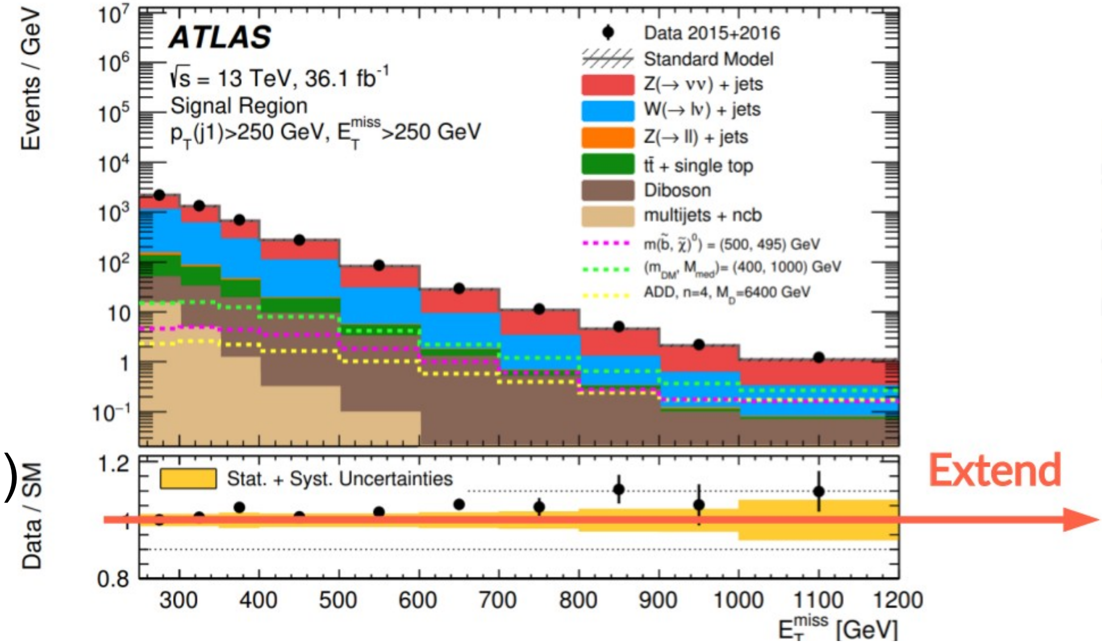
VH(ccbar)

# 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 η tracking, high $p_{T}$,...)



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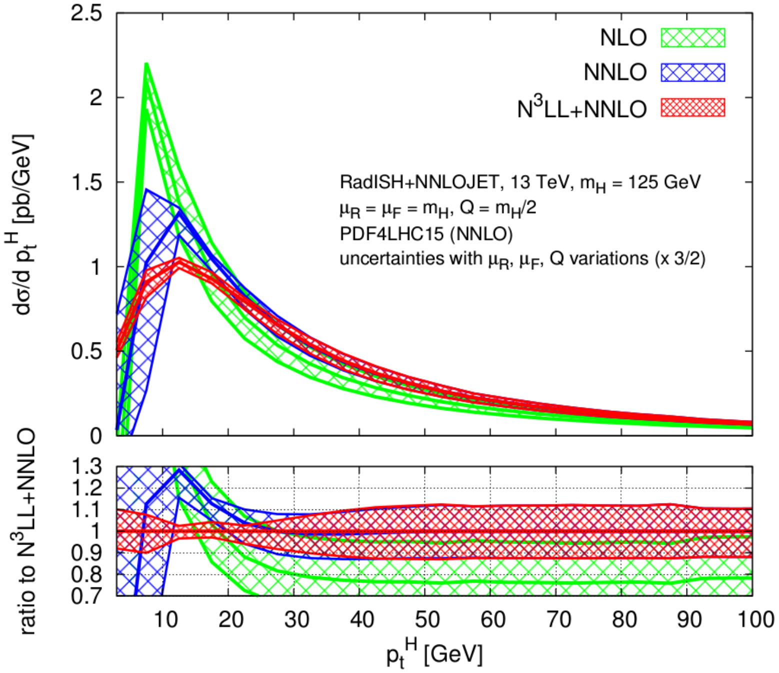
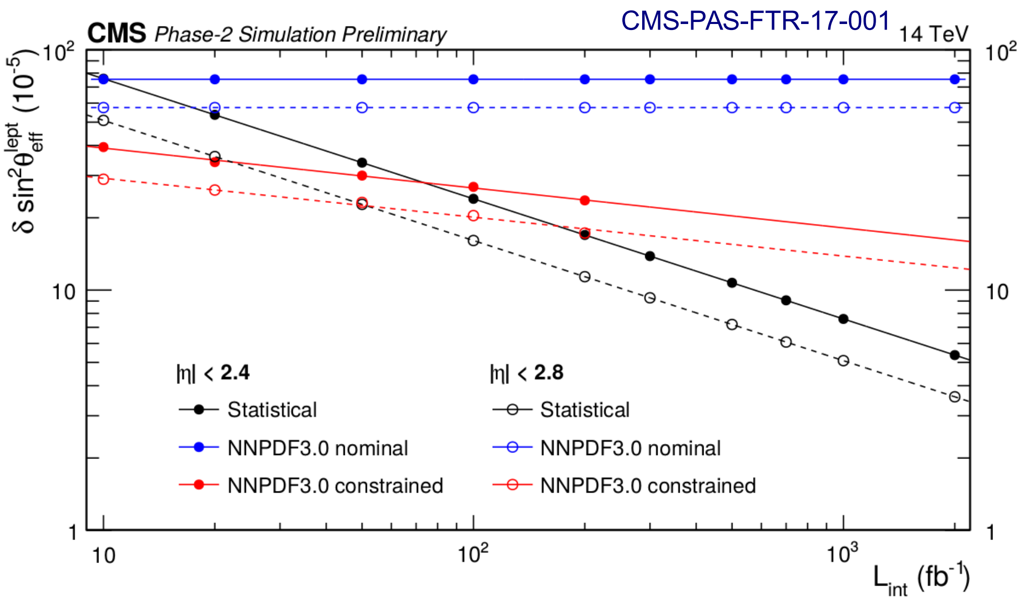
# Theory uncertainties

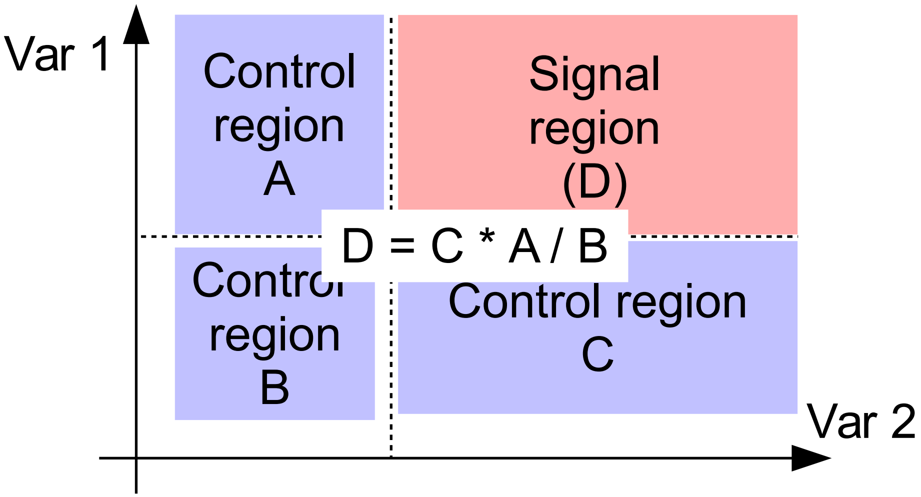
- Signal/Background simulations rely on advances in x-section integrators and generators
- General guideline for normalization and modeling → **halved**
  - e.g. improvements in higher-order corrections and resummation
  - some observables may improve more ($p_T$(top)?) → theorists' input
- PDF uncertainties unlikely to improve as significantly

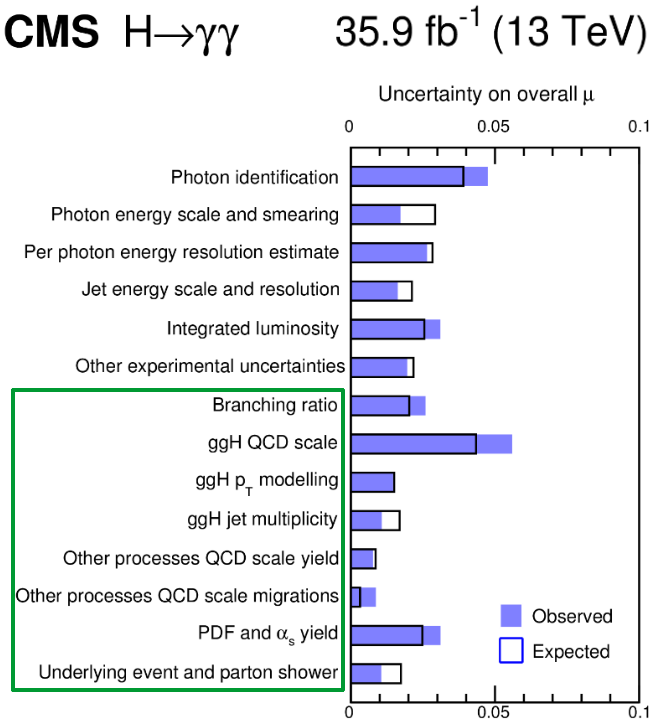




# Method/Modeling uncertainties

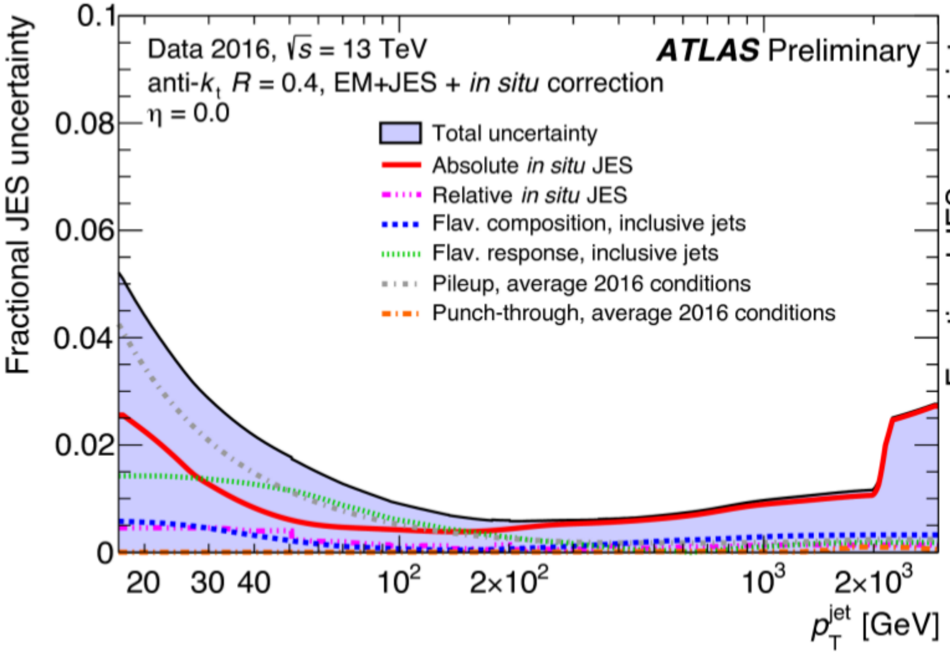
- Expected background often constrained in dedicated control regions
- Extrapolation from control to signal region:
  - MC prediction → modeling uncertainty
  - entirely data-driven methods → check assumptions often in MC
- In both cases expect:
  - closure of method → harder to predict, **keep same**
  - statistics in control region → **~sqrt(L)**
  - theory uncertainty critical → **halved**
  -

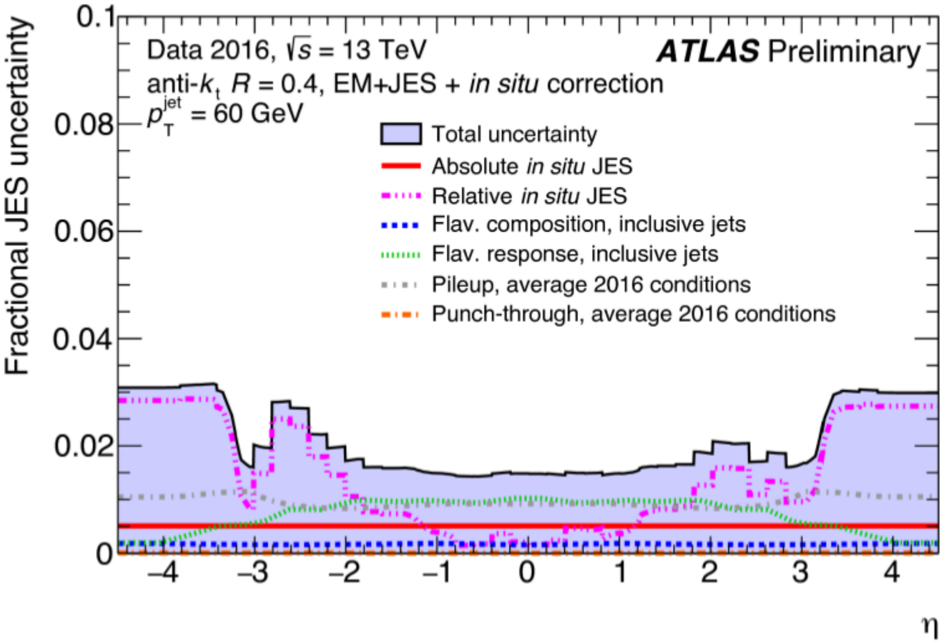




- Theorists' input crucial on a case by case

# Experimental: Jet Energy Scale



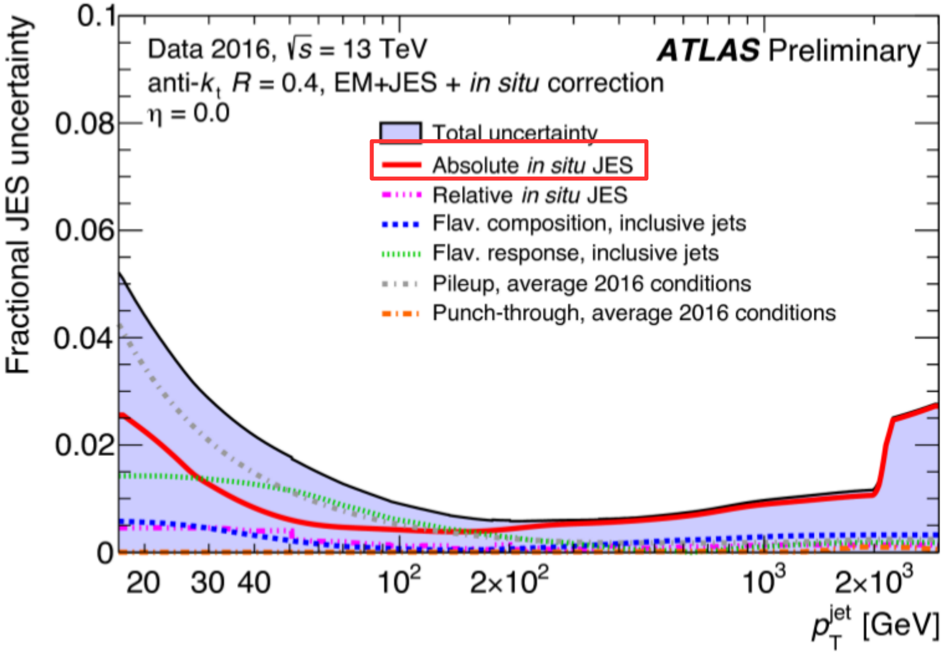


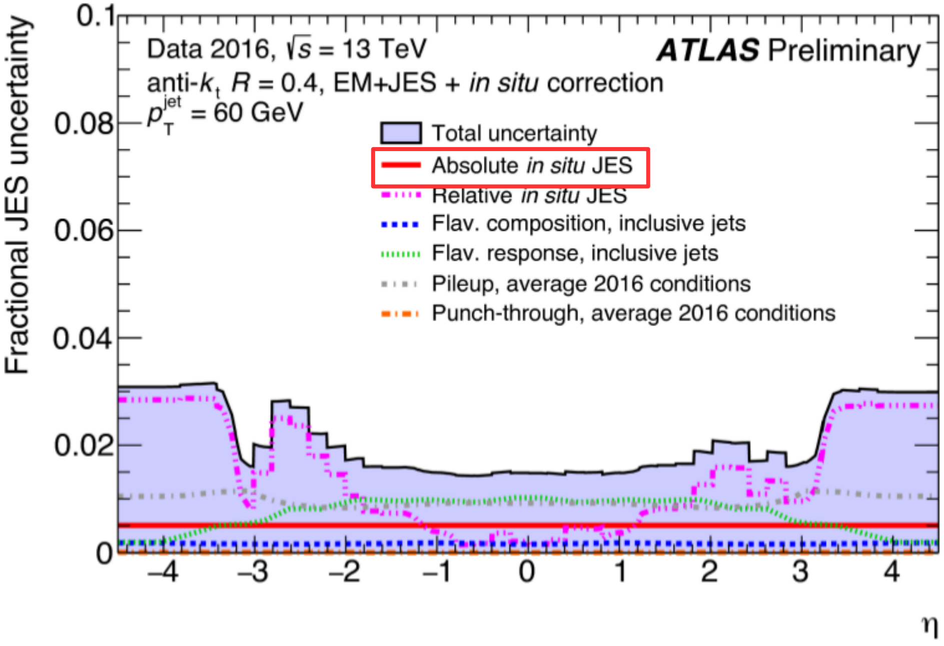
- Used as example of experimental systematic with various sources

- 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

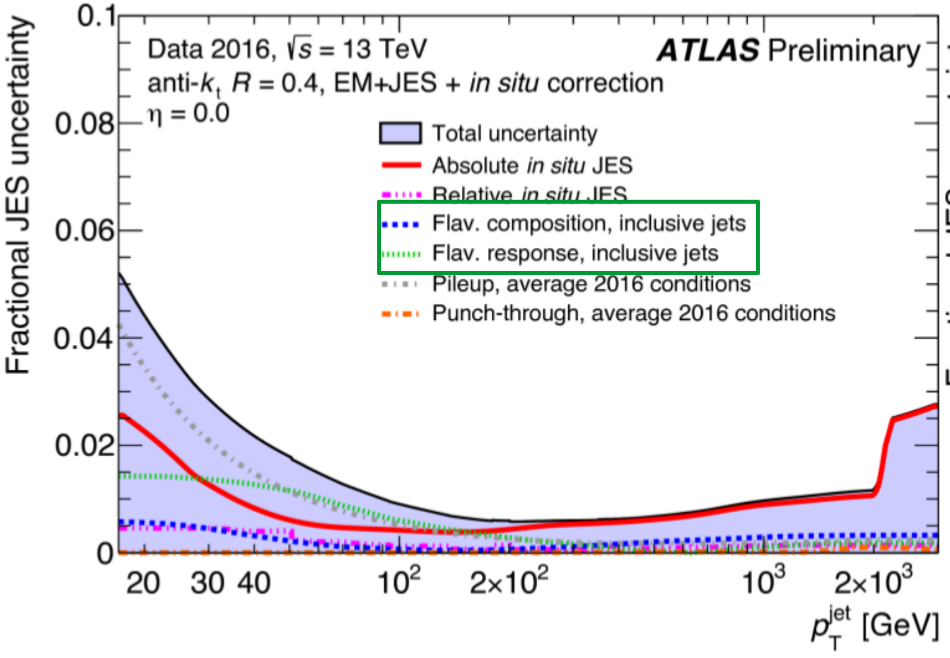
# Example: Anatomy of Jet energy scale

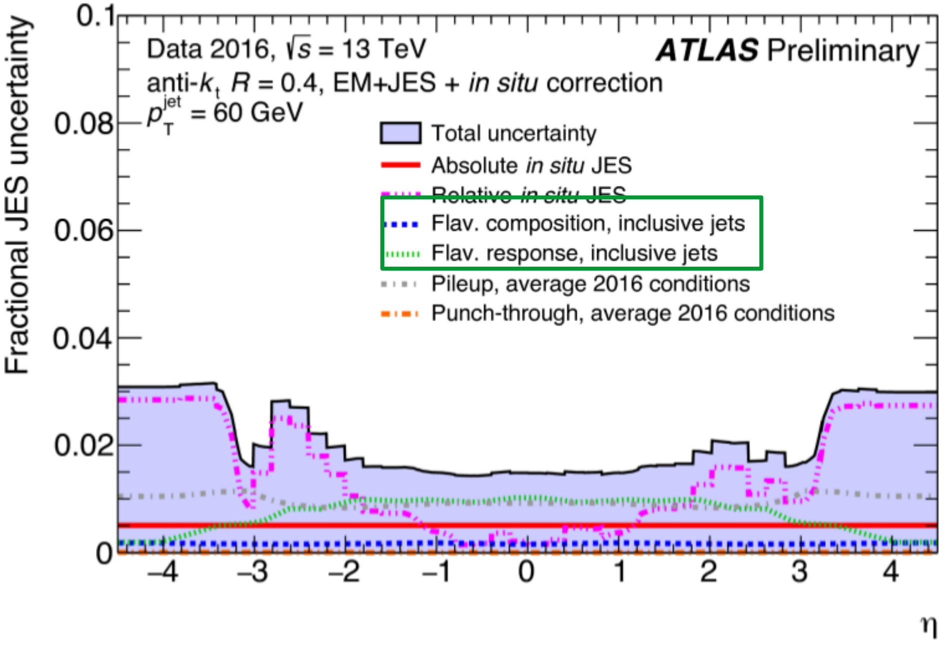




- Absolute “in-situ” JES
  - low-medium $p_T$ from Z+jets balance study
    - dominated by generator differences, pile-up rejection, radiation
    - overall expect improvements to balance challenges → **keep same**
  - high-$p_T$ dominated by photon energy scale in γ+jets balance
    - Expect better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

# Example: Anatomy of Jet energy scale



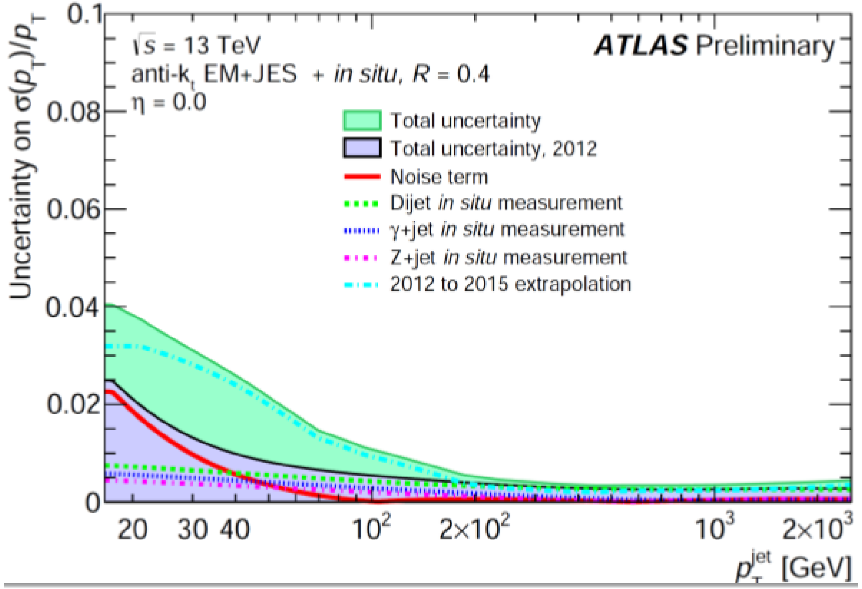


- Flavor composition and response
  - mainly comes from how generators model gluon jet radiation
  - rely on fragmentation measurements and re-tuning of parton shower generators
  - Propose to have two scenarios:
    - Optimistic → **halved**
    - Baseline → **keep same**

# Jet Energy Resolution / MET

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

  → **run-1 values**

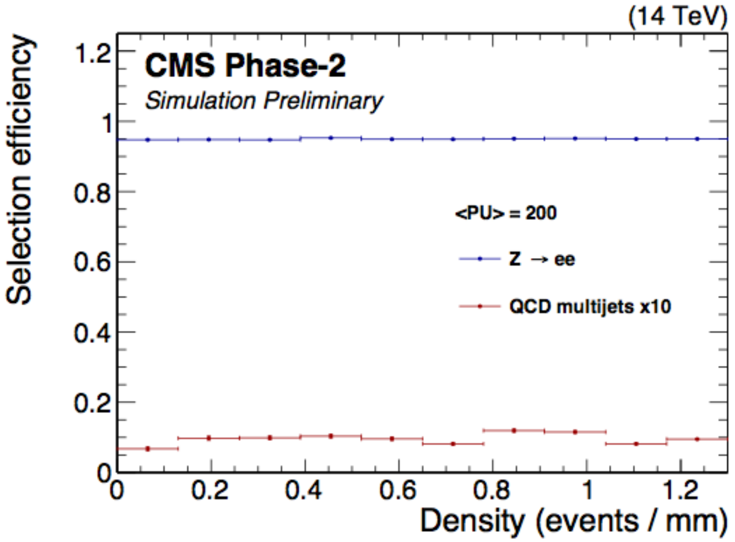


- MET systematics driven by object scale/resolution uncertainties
- Soft-term uncertainties are rarely dominant and hard to extrapolate

  → **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

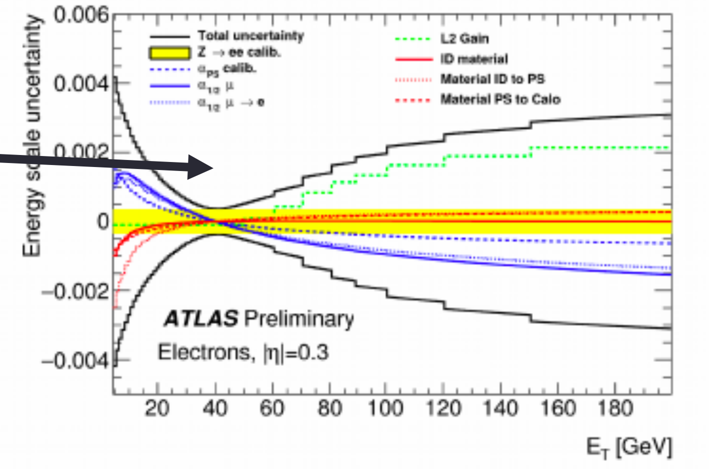


- HL-LHC:
  - With higher statistics and upgraded detector, effects due to background modeling, ISR modeling, signal resolution may decrease
  - However, effects due to pileup, especially for isolation may lead to increased systematics
- Current studies indicate a projected systematics for
- reco/ID: 0.5% for electrons (including isolation)

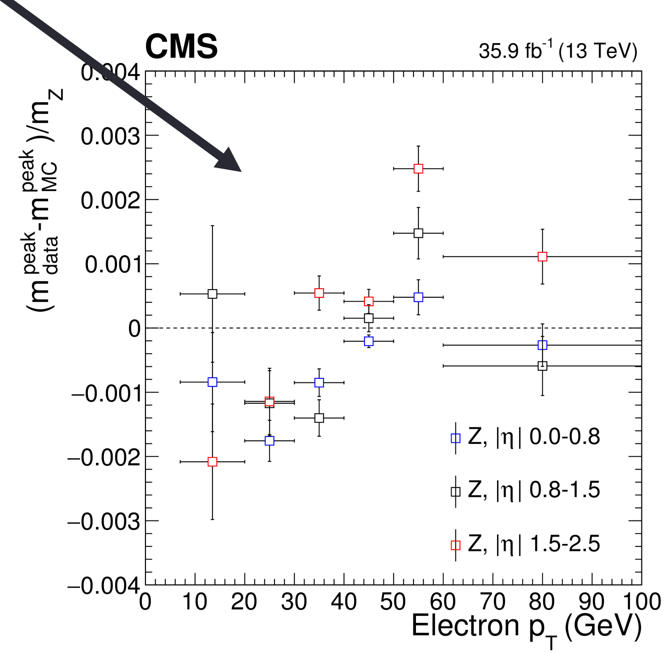
# e/$\gamma$ Energy Scale

- ATLAS Run2

  0.1%(0.2%) to 0.3%(0.5%) for e ($\gamma$)



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

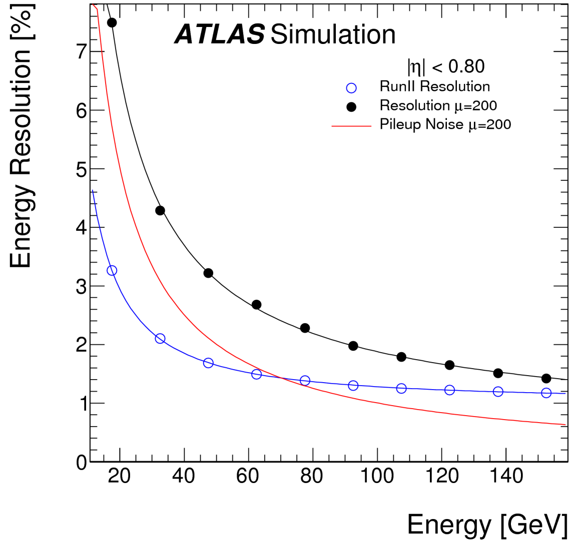


→ keep same for HL-LHC

- 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

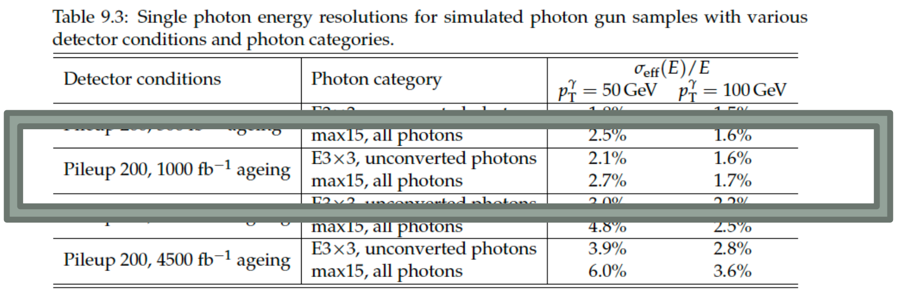
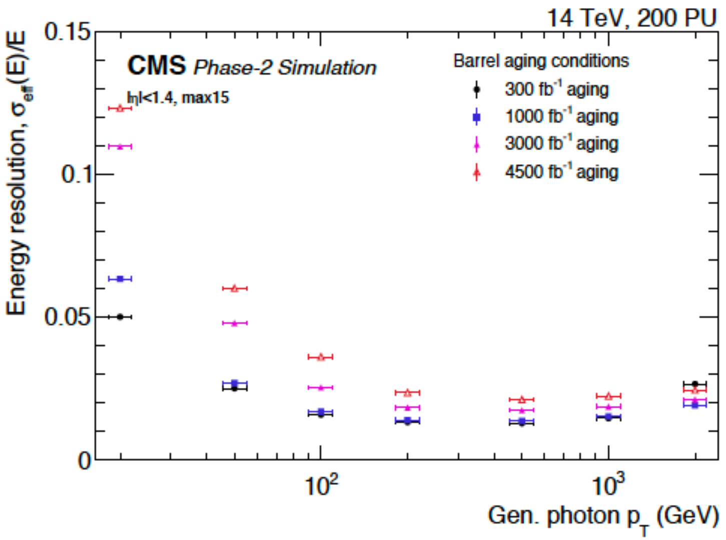
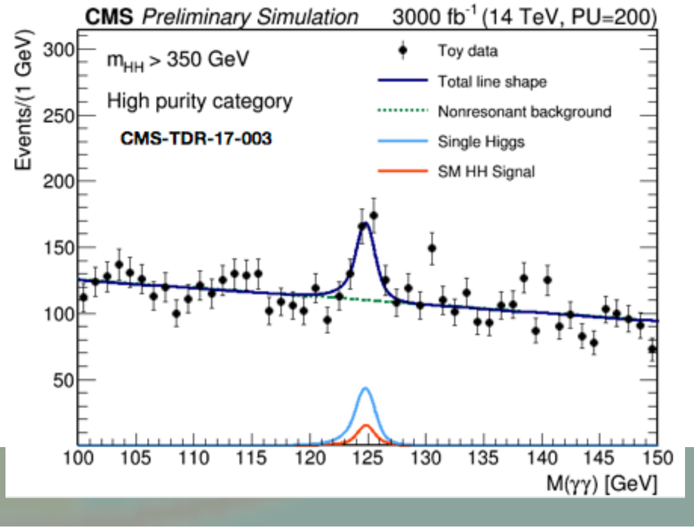


Table 9.3: Single photon energy resolutions for simulated photon gun samples with various detector conditions and photon categories.

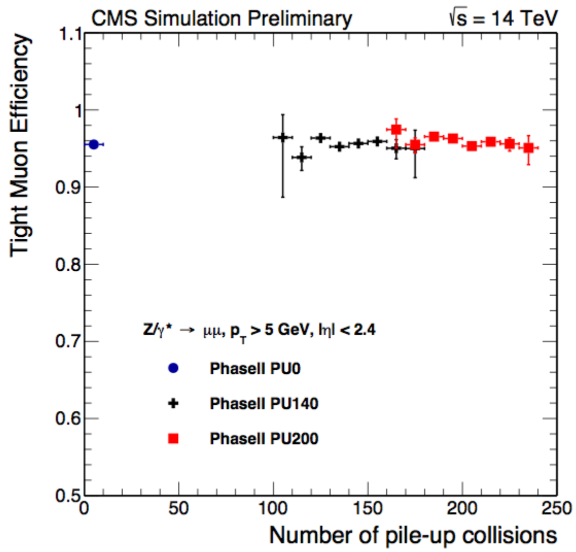
| Detector conditions | Photon category | $\sigma_{\text{eff}}(E)/E$ $p_T^\gamma = 50\,\text{GeV}$ | $\sigma_{\text{eff}}(E)/E$ $p_T^\gamma = 100\,\text{GeV}$ |
|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] |
| | max15, all photons | 2.5% | 1.6% |
| Pileup 200, 1000 fb$^{-1}$ ageing | E3×3, unconverted photons | 2.1% | 1.6% |
| | max15, all photons | 2.7% | 1.7% |
| [illegible] | [illegible] | [illegible] | [illegible] |
| | max15, all photons | 4.8% | 2.5% |
| Pileup 200, 4500 fb$^{-1}$ ageing | E3×3, unconverted photons | 3.9% | 2.8% |
| | max15, all photons | 6.0% | 3.6% |

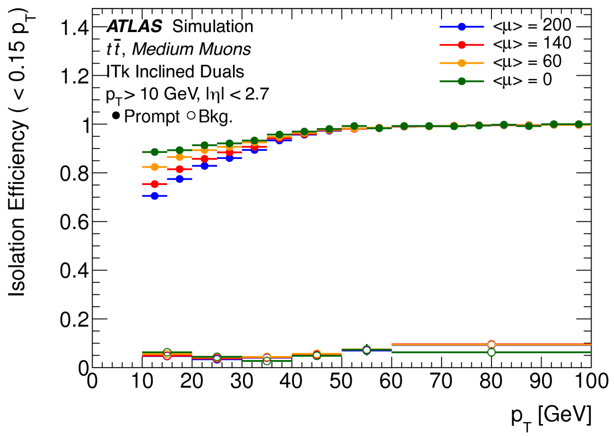


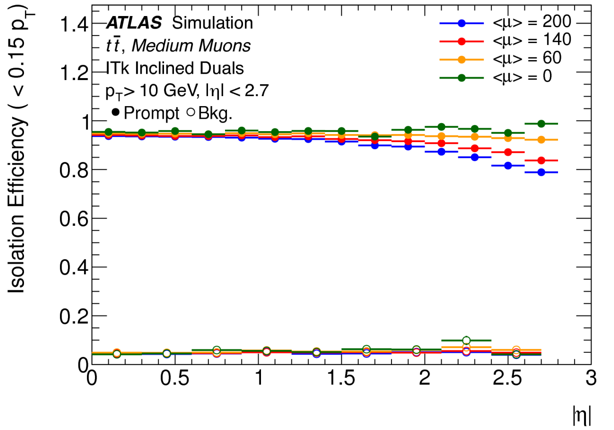


# Muons:

- 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

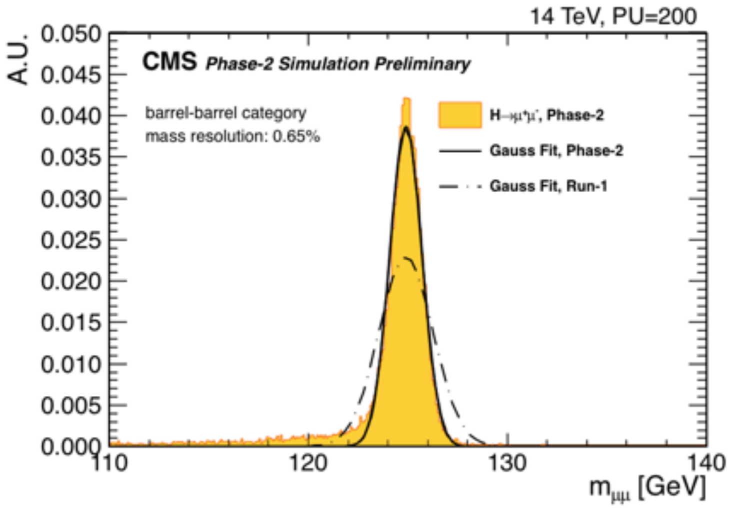


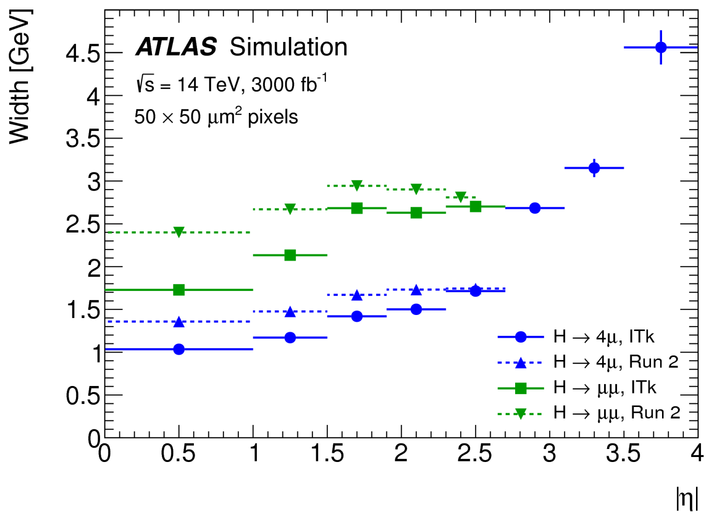


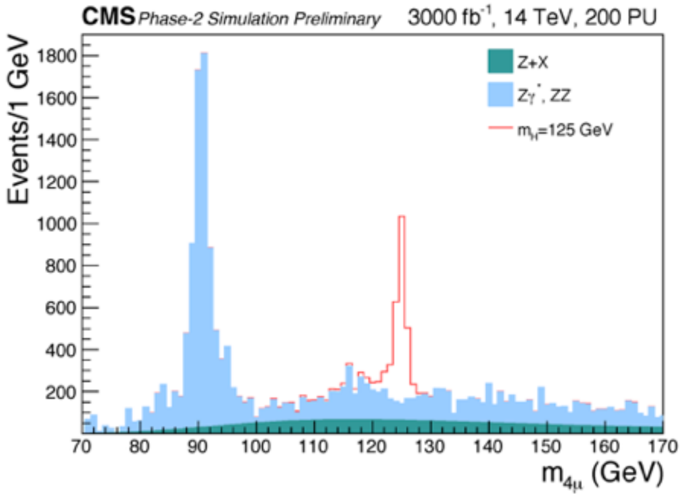


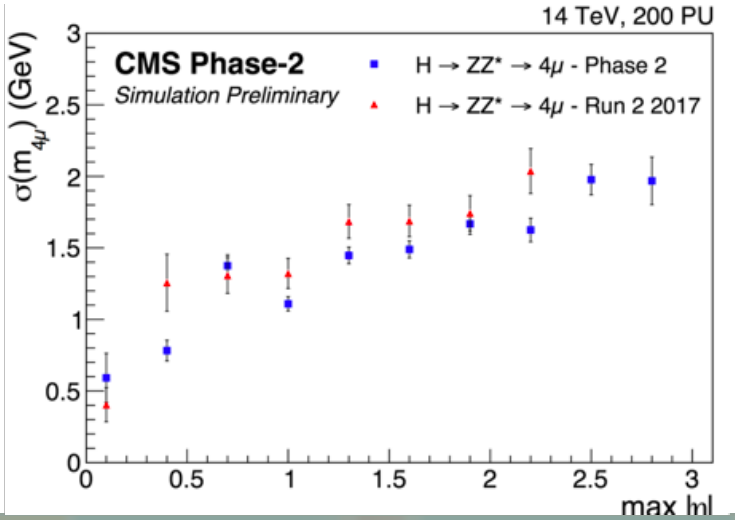
# Di-Muon Mass Resolutions

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







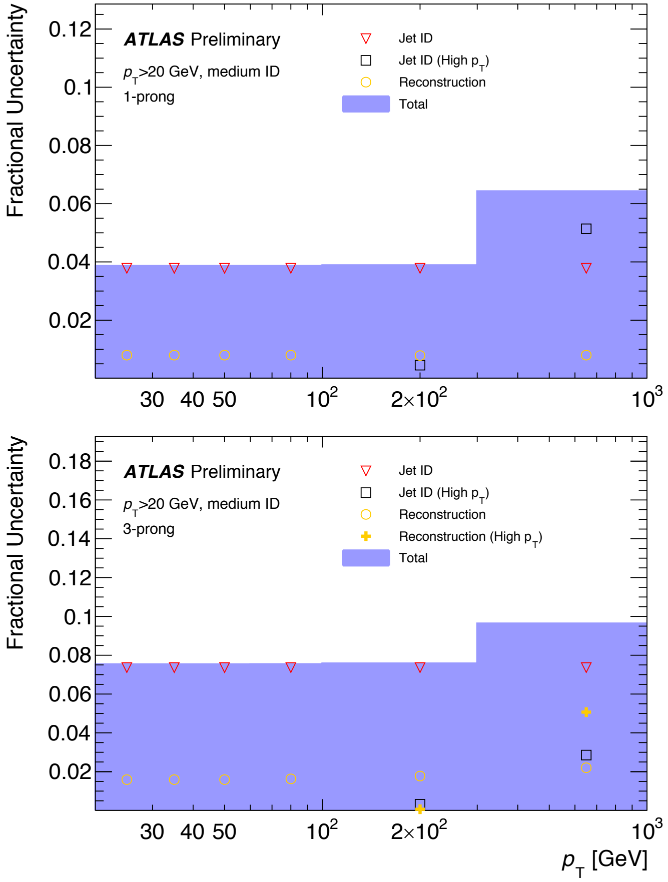


# Taus

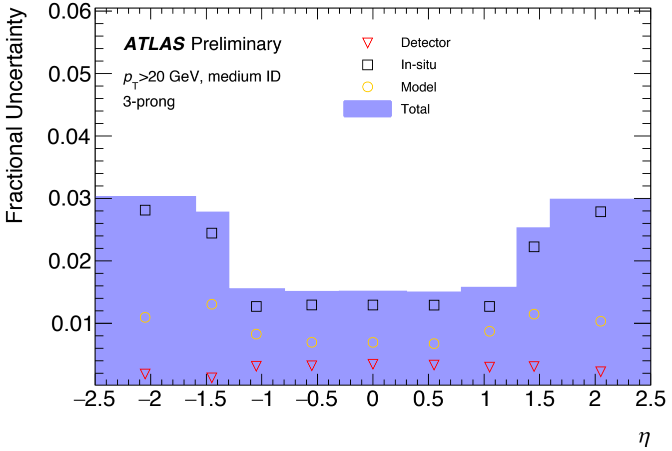
- Tau ID efficiency systematics:
- Run2 uncertainty : ~5% (ATLAS and CMS)
  - Simulation $\tau$ modeling
  - Tracking eff. systematics (CMS: 3.5% for low $p_T$)
    - Expect to improve with new tracker
  - Fake backgrounds $j \rightarrow \tau_h$ multiplicity of charged hadrons in hadronization of q/g 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.

## Run2 Tau reco/ID

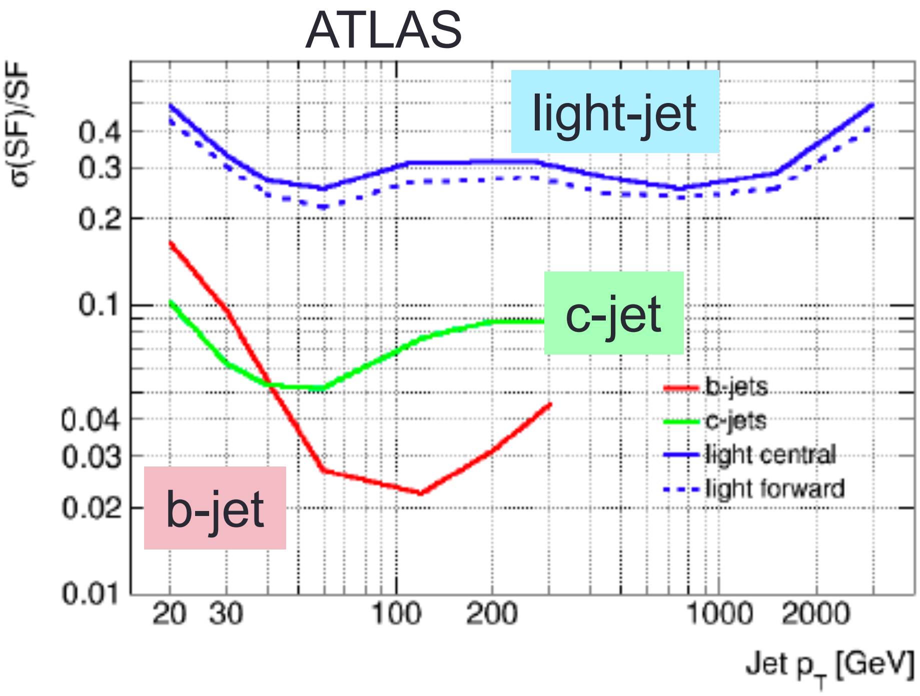


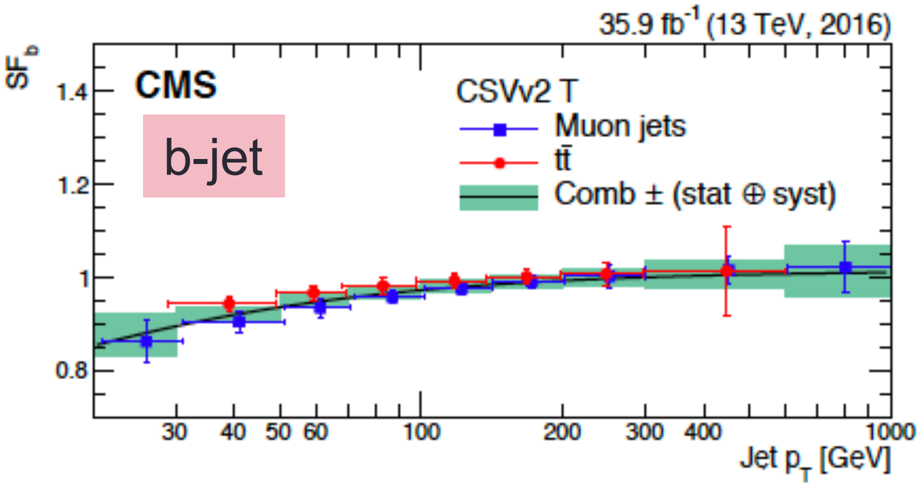
## Run2 Tau energy scale

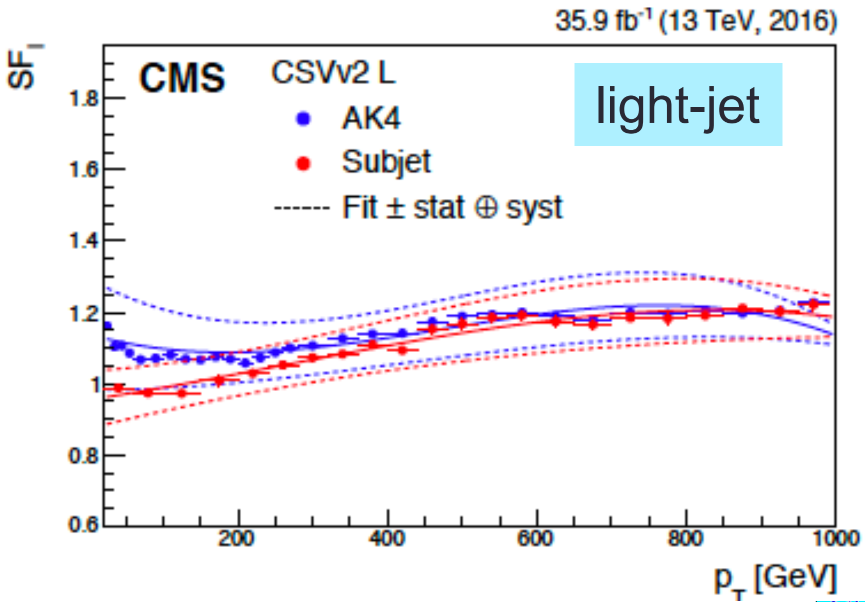


# Flavor tagging

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

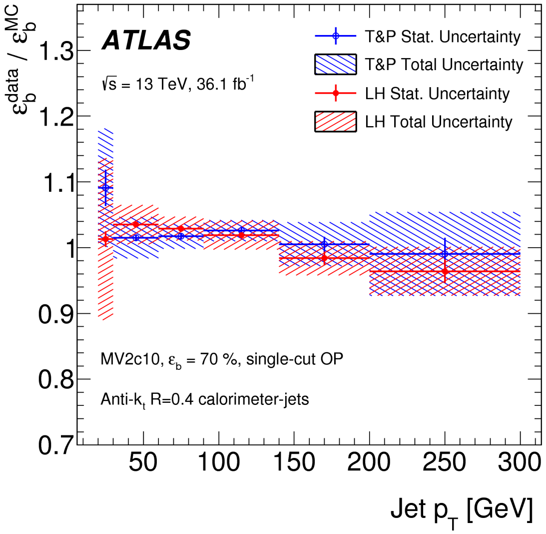


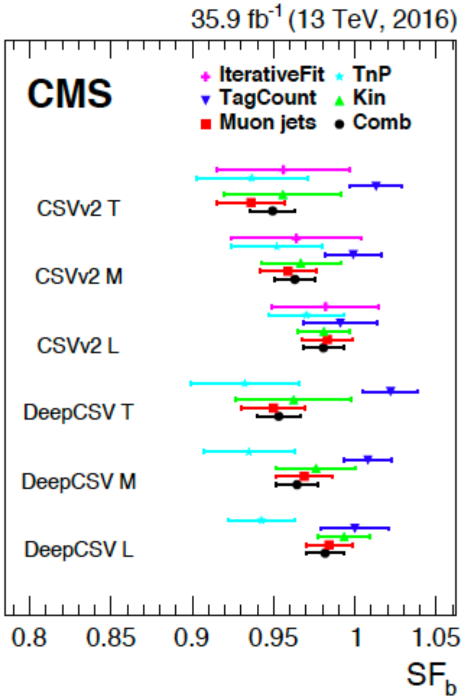




# b-jet tagging

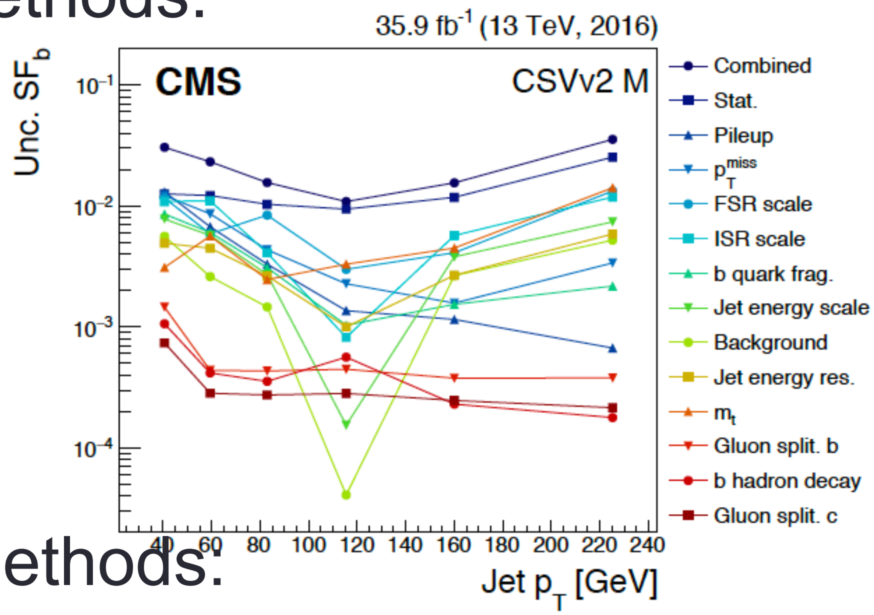
- b jet tagging efficiency and systematics in Run2:
- ATLAS and CMS:
  - measurements from data rely on ttbar events for jet pT range: 30-300 GeV
- CMS:
  - Multijets with muon from semileptonic b hadron decays cover pT range 20-1000 GeV
- Several methods are used for each sample.
  - Their combination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





# b-jet tagging systematics in Run2

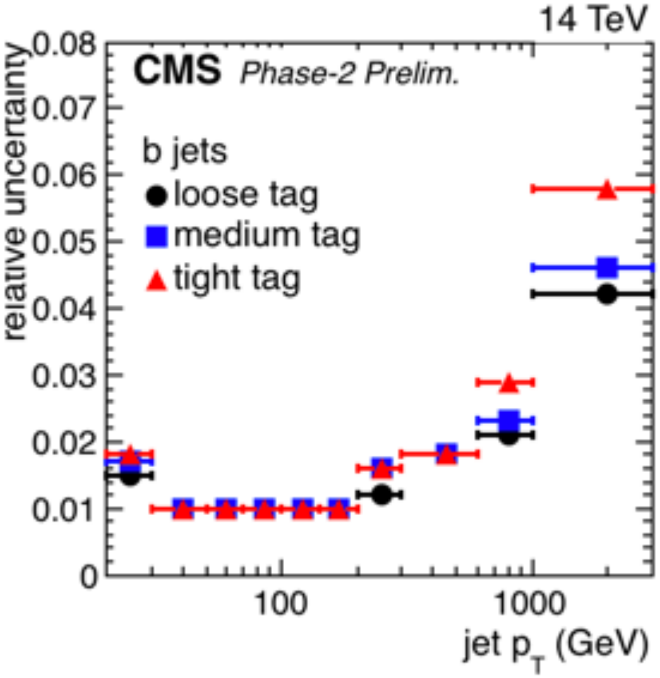
- Common or partially common in both sets of methods:
  - b quark fragmentation, branching fractions of b and c hadrons, jet energy scale and resolution, pileup modeling.
- Systematics specific to the ttbar methods:
  - Factorization & renormalization scales
  - Modeling ttbar generator & simulation
  - 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

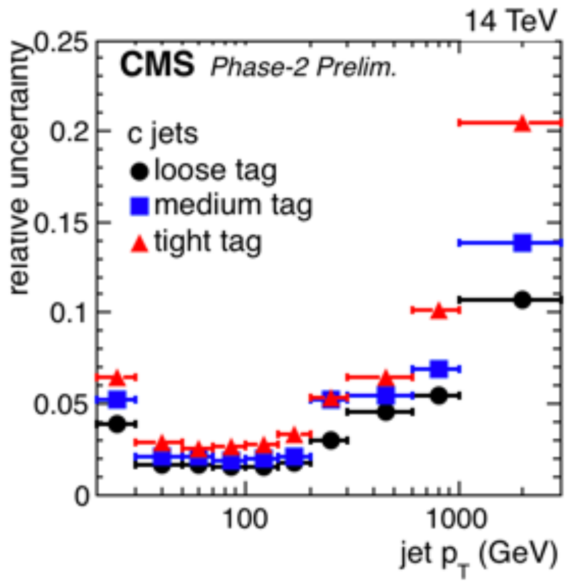
# b-jet tagging systematics for HL-LHC

- 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 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 $\rightarrow \mu$ branching fraction
  - soft muon requirement
  - number of tracks in the jet
  - background estimate, missing ET modeling

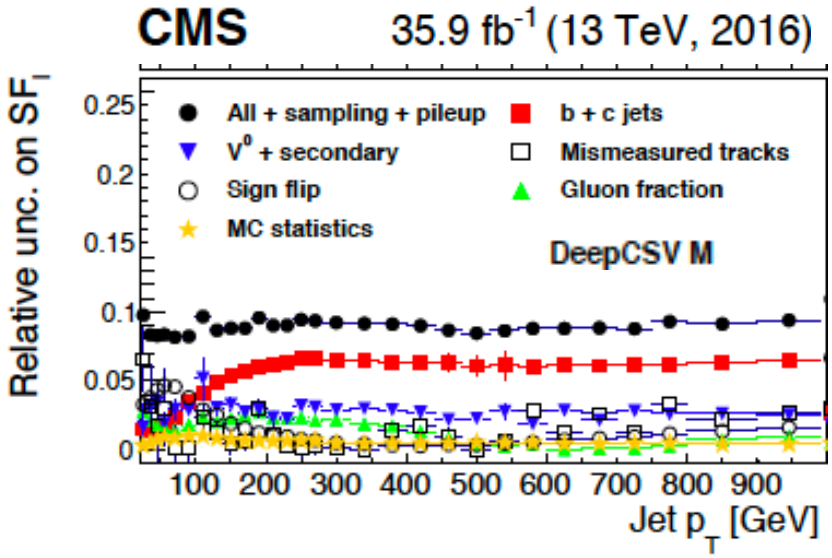


- The overall systematic uncertainty on the tagging efficiency is typically a factor two to three larger for c jets than for b jets.

- 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 $K^0_S$ 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*

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

* 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

# Summary and outlook – 1/2

- 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 → √L, simulation → 0**
  - **intrinsic detector limitations stay ~constant**
    - often new methods are expected to compensate pile-up effects
  - **theory normalization/modeling → ½**

- “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 ½ 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 ½ 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

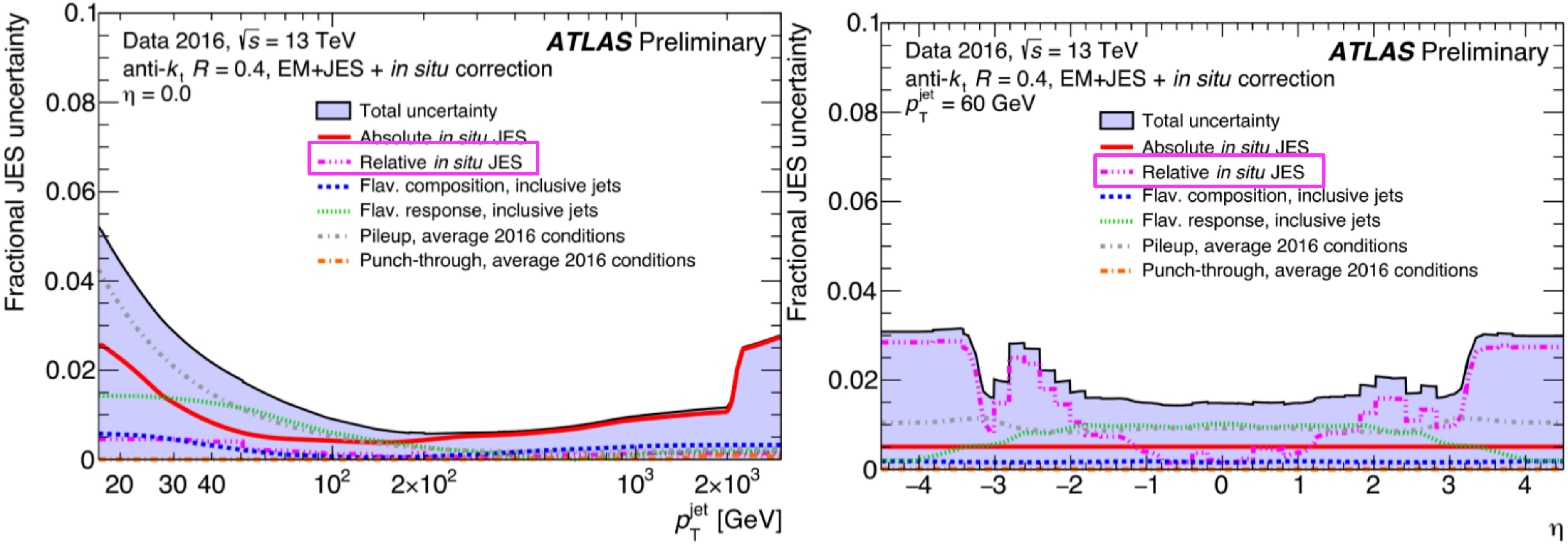
A huge thank you to the many colleagues inside ATLAS and CMS who made this possible!

Time is short…

we need everyone's help and input to finalize this now

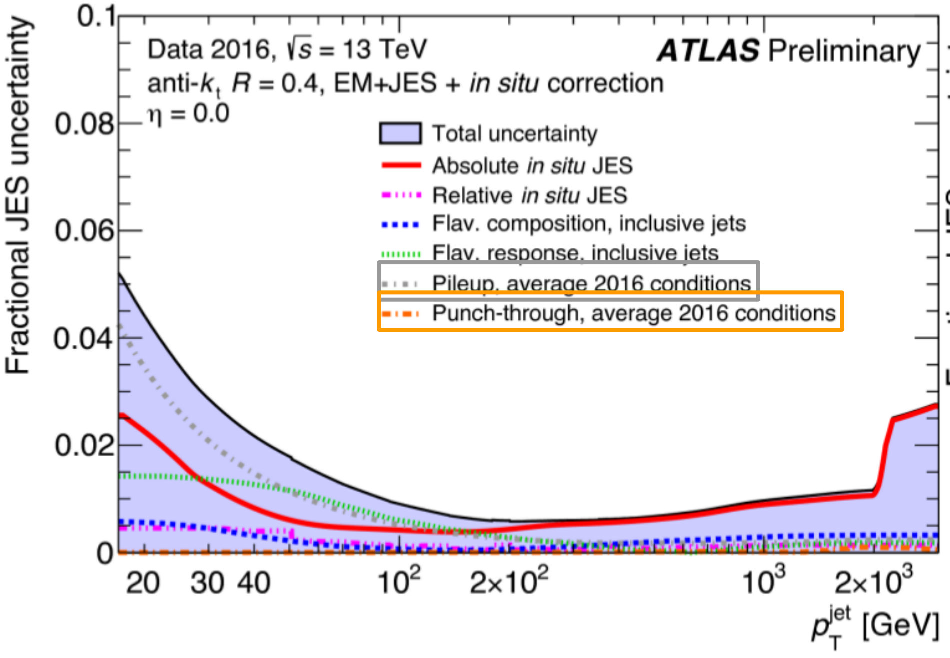
# Backup

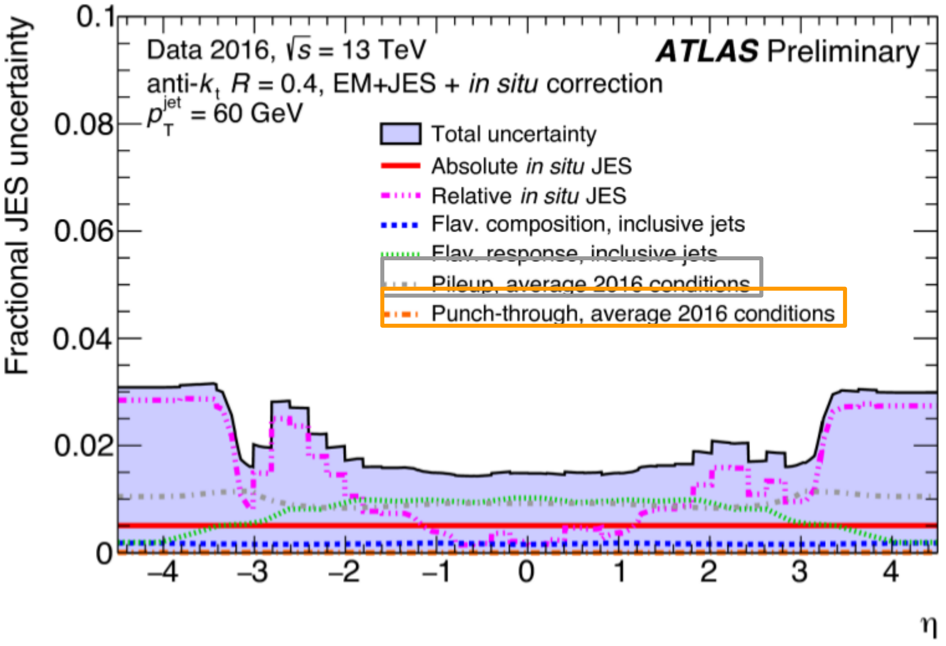
# Example: Anatomy of Jet energy scale



- 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 → **0**

# Example: Anatomy of Jet energy scale

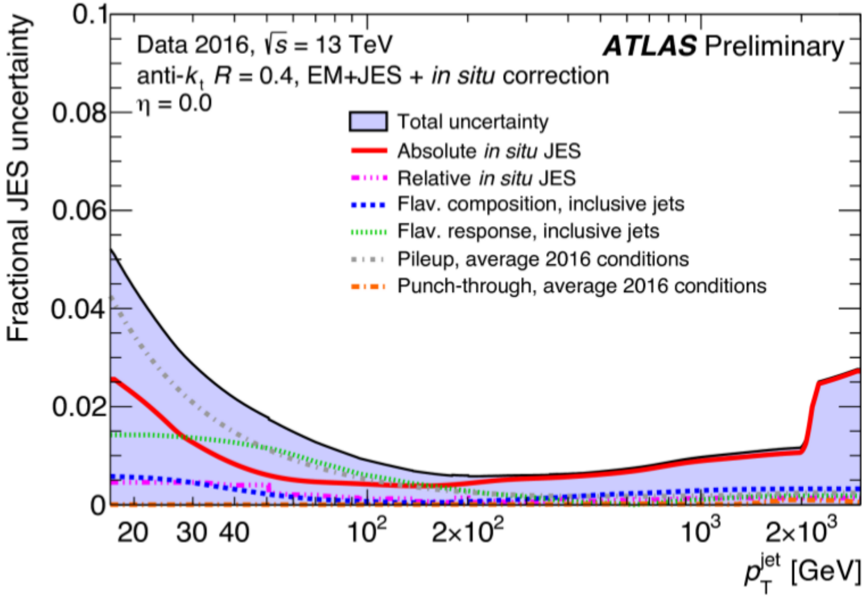


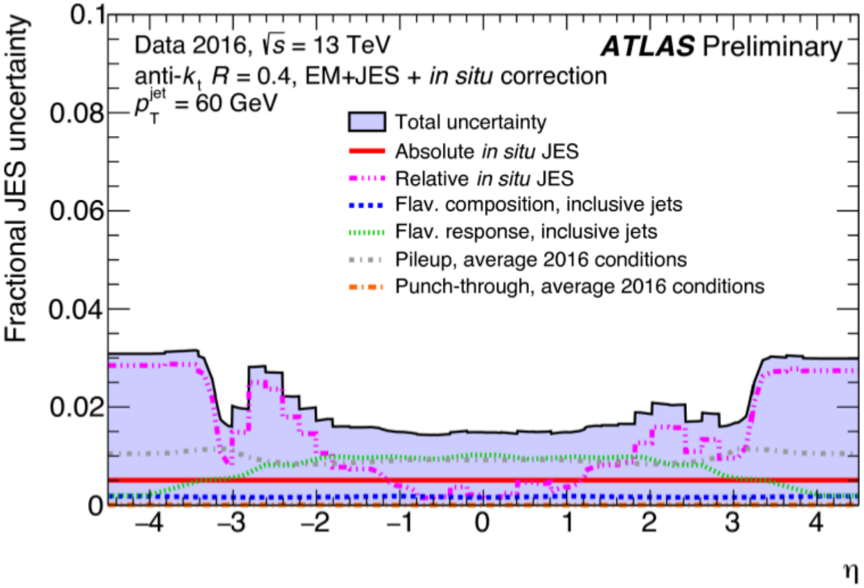


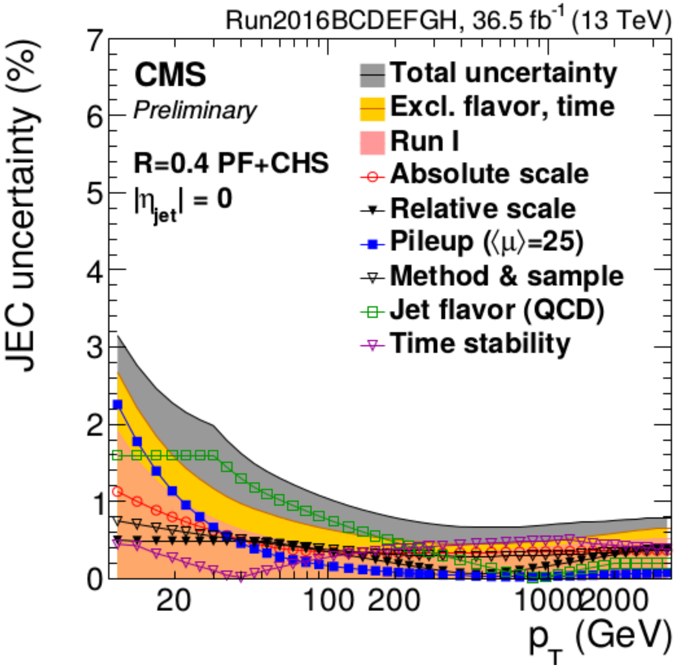
- Pile-up
  - Current method bring an increase uncertainty with pile-up
  - Expect new methods will be developed to at least compensate
  - Two scenarios:
    - Baseline → **keep same**
    - Optimistic → **halved**

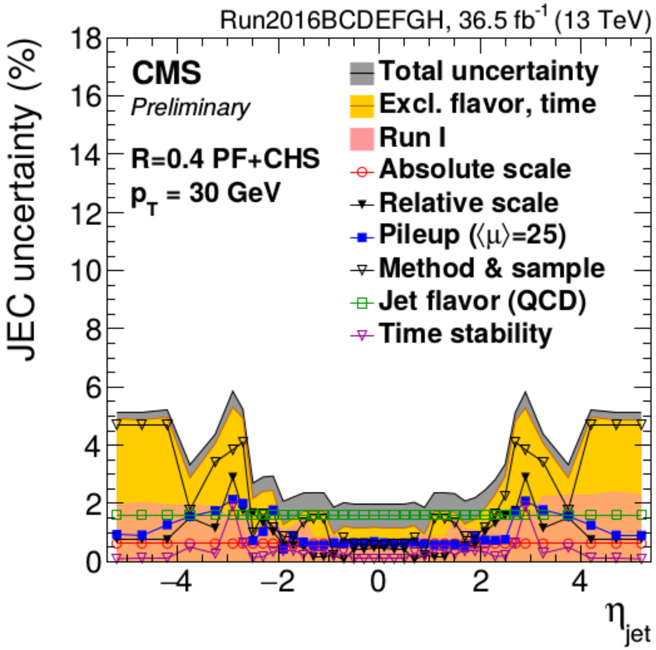
- Punch-through, high-pT
  - single particle response but kicks in when we run out of statistics in the multijet balance
  - expect large statistics will allow us to make this negligible → **0**

# Jet Energy Scale









# Jet Energy Resolution

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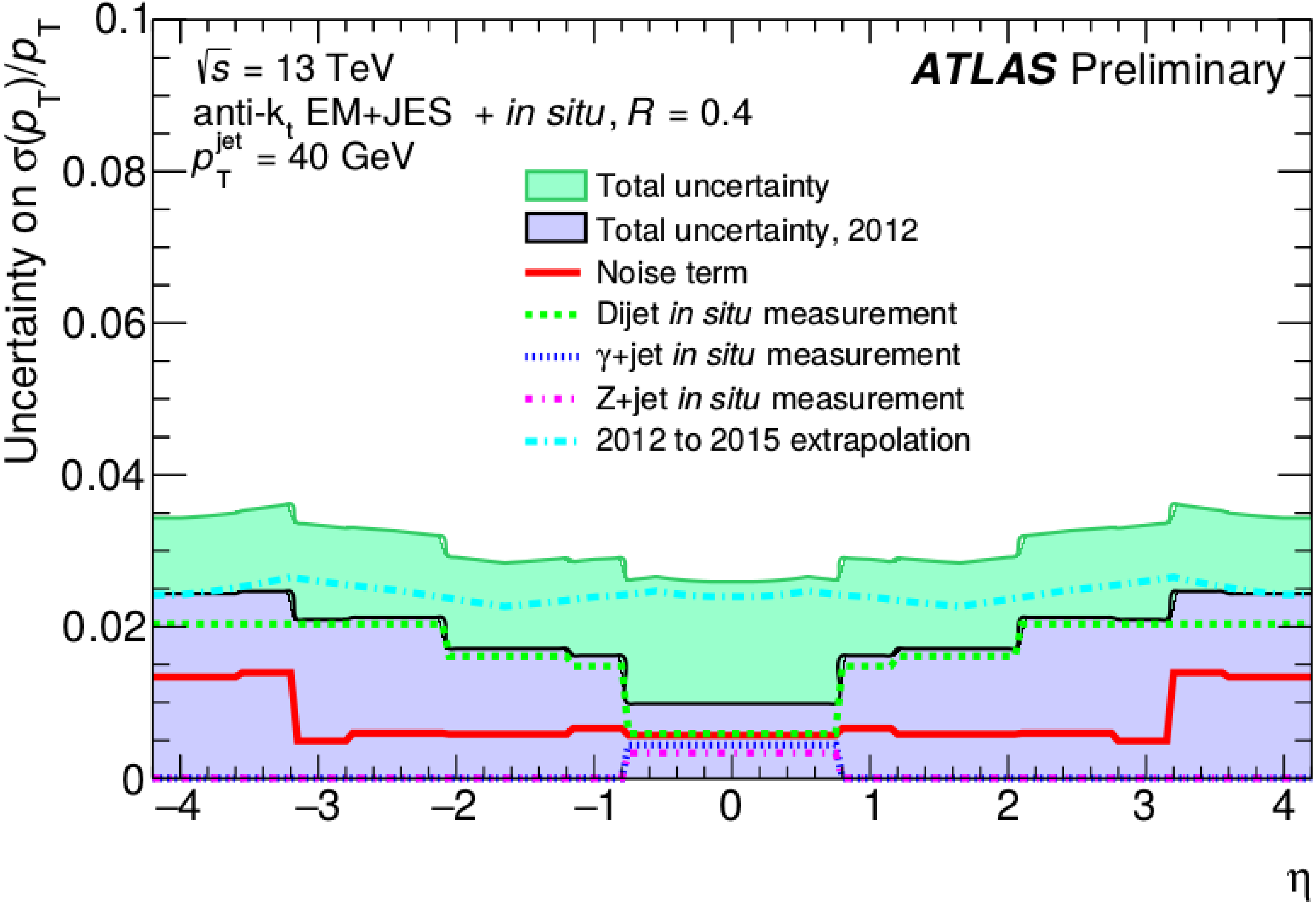
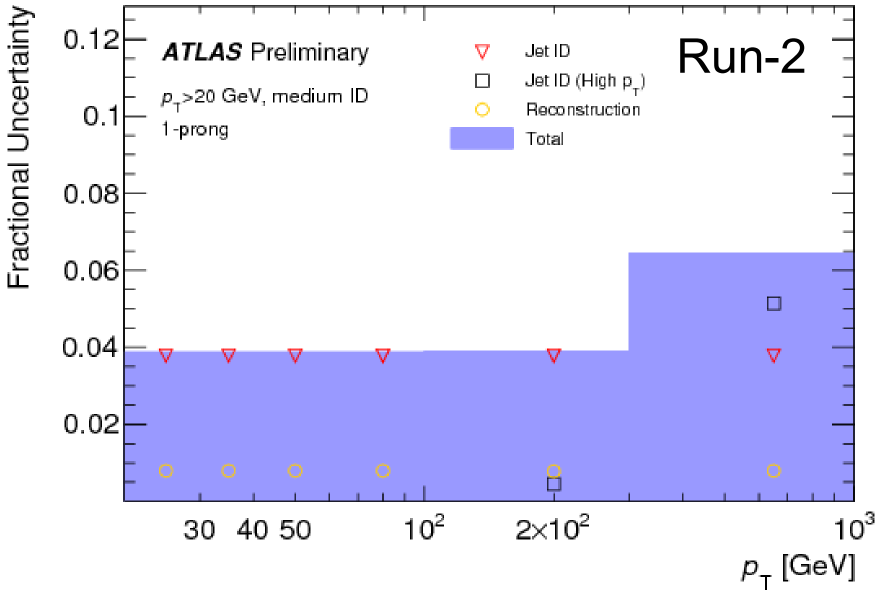
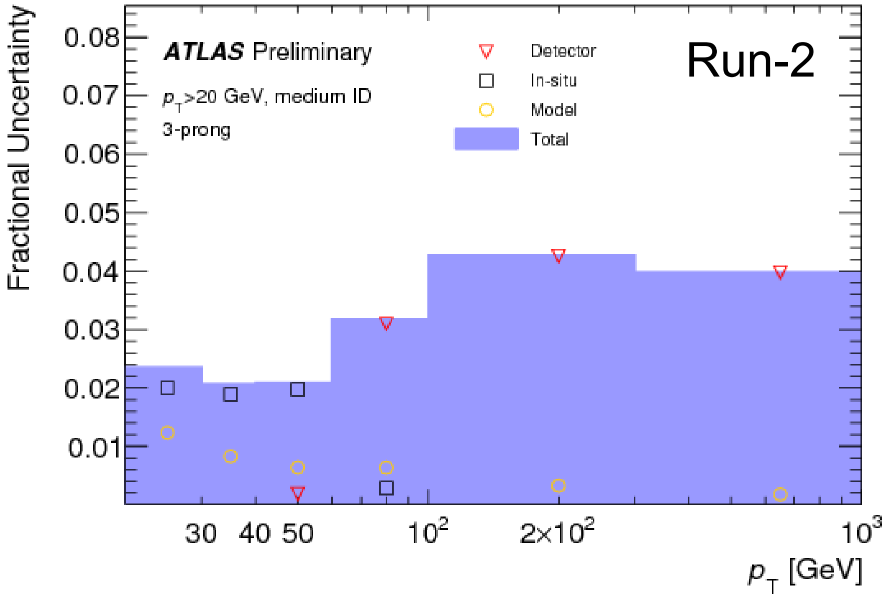


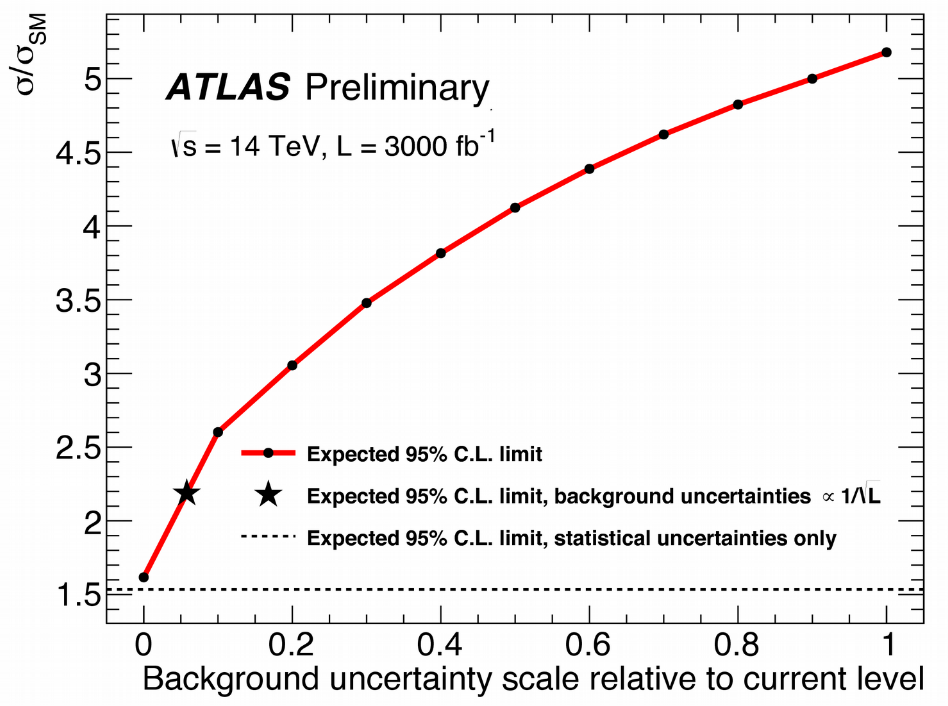
# Tau

- Most important components:
  - ID efficiency
  - Tau Energy Scale
  - others less important
    → **neglected**
- Tau ID
  - Mostly limited by systematics
    - Simulation τ modeling
    - Fakes background
  - Expect **“floor” of ~ 5%**
  - Under discussion $p_T$ > 250 GeV
- Tau Energy Scale
  - Theory modeling, detector, in-situ
  - Expect **“floor” of ~ 2-3%**
  - Under discussion for high pT



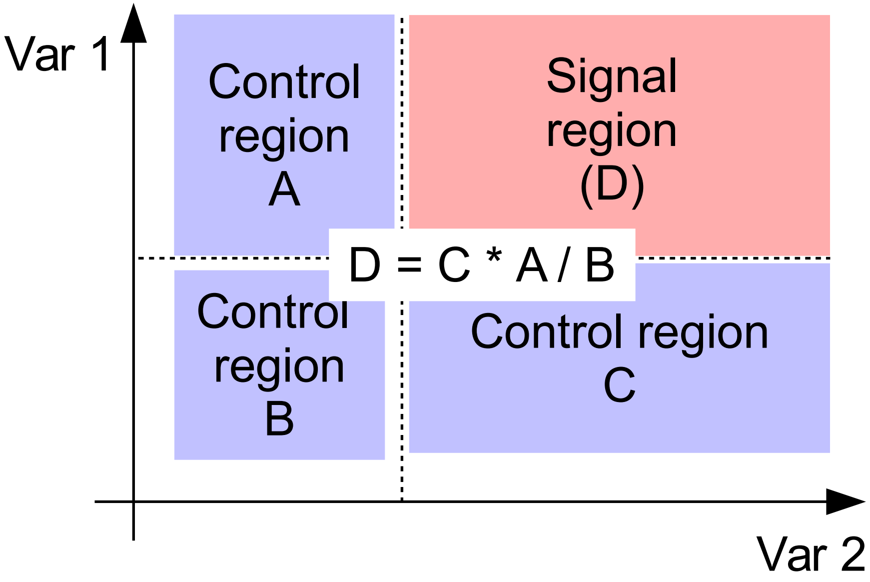


# HH → 4b


ATLAS Preliminary
$\sqrt{s}$ = 14 TeV, L = 3000 fb$^{-1}$
$\sigma/\sigma_{SM}$
1.5
2
2.5
3
3.5
4
4.5
5
0
0.2
0.4
0.6
0.8
1
Background uncertainty scale relative to current level
Expected 95% C.L. limit
Expected 95% C.L. limit, background uncertainties $\propto 1/\sqrt{L}$
Expected 95% C.L. limit, statistical uncertainties only

# 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**



Var 1

Control region A

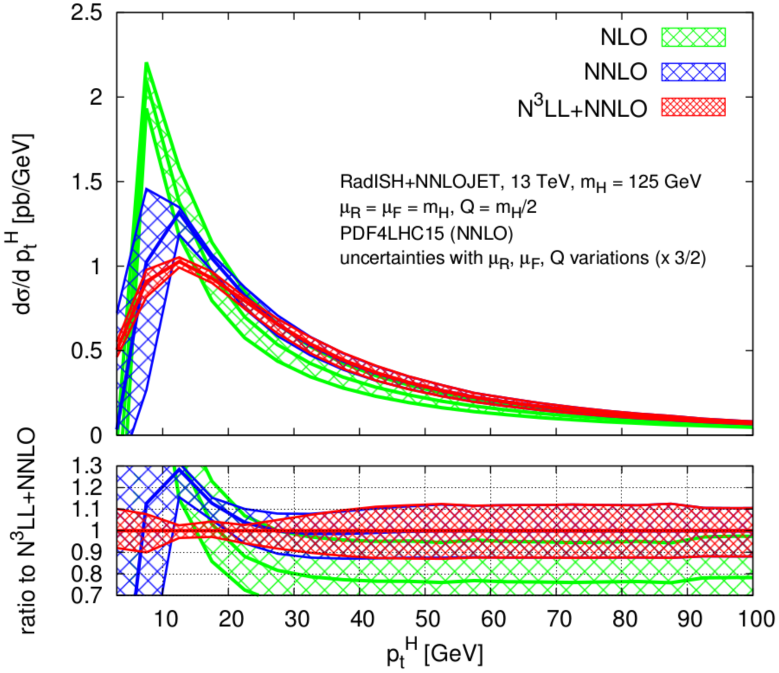
Signal region (D)

D = C * A / B

Control region B

Control region C

Var 2

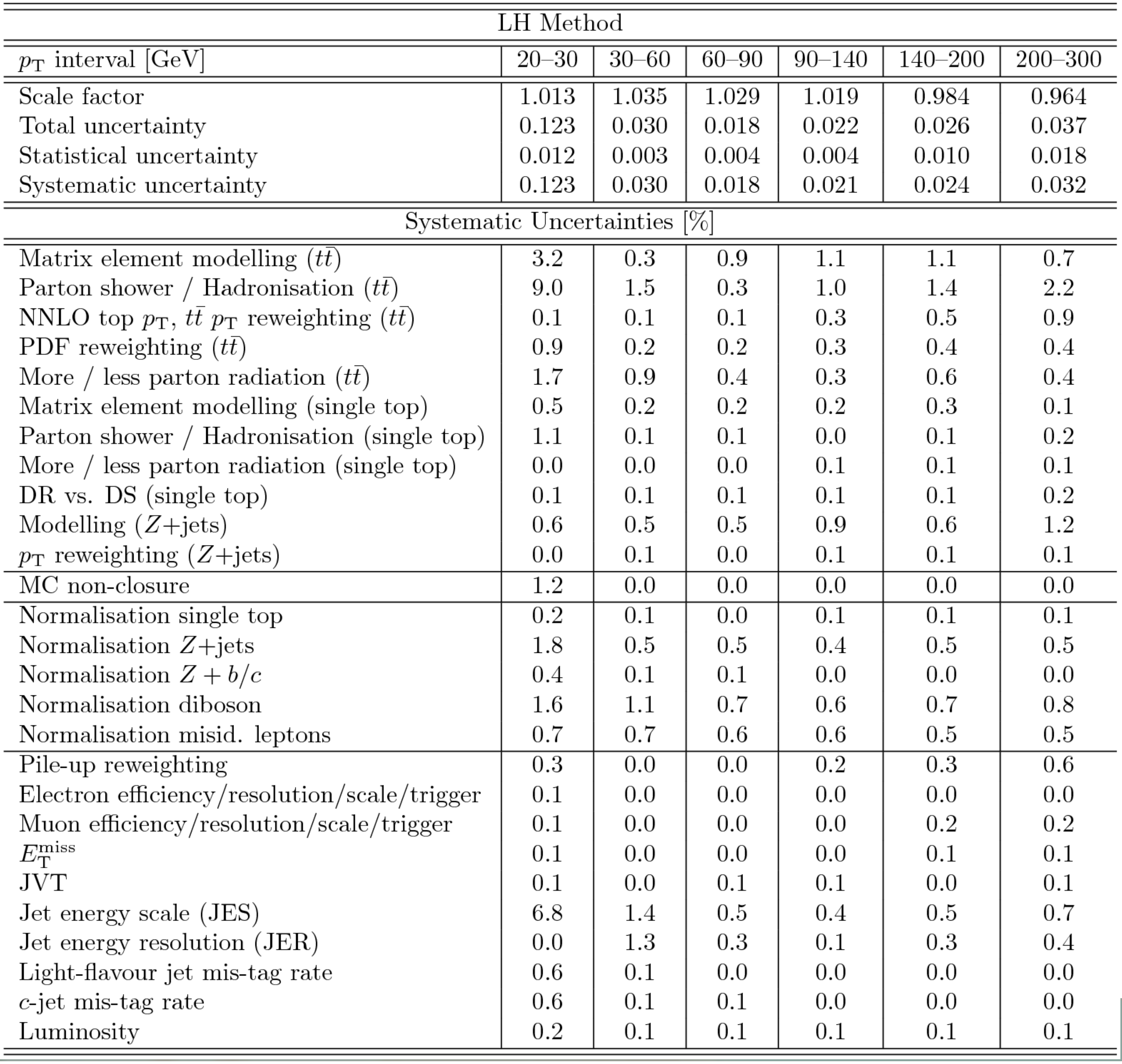


- Both require some judgments on a case by case, but guidelines above could still be useful

# Summary: CMS Projections for JET Energy Scale

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

# b-jet tagging systematics (ATLAS LH method)



LH Method

| $p_T$ interval [GeV] | 20–30 | 30–60 | 60–90 | 90–140 | 140–200 | 200–300 |
|---|---|---|---|---|---|---|
| Scale factor | 1.013 | 1.035 | 1.029 | 1.019 | 0.984 | 0.964 |
| Total uncertainty | 0.123 | 0.030 | 0.018 | 0.022 | 0.026 | 0.037 |
| Statistical uncertainty | 0.012 | 0.003 | 0.004 | 0.004 | 0.010 | 0.018 |
| Systematic uncertainty | 0.123 | 0.030 | 0.018 | 0.021 | 0.024 | 0.032 |
| **Systematic Uncertainties [%]** | | | | | | |
| Matrix element modelling ($t\bar{t}$) | 3.2 | 0.3 | 0.9 | 1.1 | 1.1 | 0.7 |
| Parton shower / Hadronisation ($t\bar{t}$) | 9.0 | 1.5 | 0.3 | 1.0 | 1.4 | 2.2 |
| NNLO top $p_T$, $t\bar{t}$ $p_T$ reweighting ($t\bar{t}$) | 0.1 | 0.1 | 0.1 | 0.3 | 0.5 | 0.9 |
| PDF reweighting ($t\bar{t}$) | 0.9 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 |
| More / less parton radiation ($t\bar{t}$) | 1.7 | 0.9 | 0.4 | 0.3 | 0.6 | 0.4 |
| Matrix element modelling (single top) | 0.5 | 0.2 | 0.2 | 0.2 | 0.3 | 0.1 |
| Parton shower / Hadronisation (single top) | 1.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 |
| More / less parton radiation (single top) | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 |
| DR vs. DS (single top) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Modelling ($Z$+jets) | 0.6 | 0.5 | 0.5 | 0.9 | 0.6 | 1.2 |
| $p_T$ reweighting ($Z$+jets) | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 |
| MC non-closure | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Normalisation single top | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 |
| Normalisation $Z$+jets | 1.8 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 |
| Normalisation $Z + b/c$ | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Normalisation diboson | 1.6 | 1.1 | 0.7 | 0.6 | 0.7 | 0.8 |
| Normalisation misid. leptons | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 |
| Pile-up reweighting | 0.3 | 0.0 | 0.0 | 0.2 | 0.3 | 0.6 |
| Electron efficiency/resolution/scale/trigger | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Muon efficiency/resolution/scale/trigger | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 |
| $E_T^{miss}$ | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| JVT | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 |
| Jet energy scale (JES) | 6.8 | 1.4 | 0.5 | 0.4 | 0.5 | 0.7 |
| Jet energy resolution (JER) | 0.0 | 1.3 | 0.3 | 0.1 | 0.3 | 0.4 |
| Light-flavour jet mis-tag rate | 0.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| $c$-jet mis-tag rate | 0.6 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Luminosity | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |