ATLAS full run-2 luminosity combination

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- Brief overview of the full run-2 13 TeV pp luminosity combination
  - Reminder of uncertainties and combination
  - Combination methodology
  - Details of correlation assumptions

- More details in ATLAS-CONF-2019-021

Uncertainties and combination – from yesterday

- Per-year uncertainty summary
  - Treating 2015+16 as one dataset
  - Absolute vdM calibration subtotal
  - +Contributions to to physics lumi.
  - Total uncertainties for individual years are 2.0-2.4%
    - Largest single uncertainty from calibration transfer
- Combination of years
  - Taking correlations into account
  - */+=fully/partially correlated
- Total run 2 lumi: 139.0±2.4 fb^{-1}
  - Uncertainty **1.7%**, dominated by calibration transfer and then long-term stability
  - Significant reduction in error as some sources only partially correlated

Data sample	2015+16	2017	2018	Comb.
Integrated luminosity (fb^{-1})	36.2	44.3	58.5	139.0
Total uncertainty (fb^{-1})	0.8	1.0	1.2	2.4
Uncertainty contributions (%):				
DCCT calibration†	0.2	0.2	0.2	0.1
FBCT bunch-by-bunch fractions	0.1	0.1	0.1	0.1
Ghost-charge correction*	0.0	0.0	0.0	0.0
Satellite correction†	0.0	0.0	0.0	0.0
Scan curve fit model†	0.5	0.4	0.5	0.4
Background subtraction	0.2	0.2	0.2	0.1
Orbit-drift correction	0.1	0.2	0.1	0.1
Beam position jitter†	0.3	0.3	0.2	0.2
Beam-beam effects*	0.3	0.3	0.2	0.3
Emittance growth correction*	0.2	0.2	0.2	0.2
Non-factorization effects*	0.4	0.2	0.5	0.4
Length-scale calibration	0.3	0.3	0.4	0.2
ID length scale*	0.1	0.1	0.1	0.1
Bunch-by-bunch σ_{vis} consistency	0.2	0.2	0.4	0.2
Scan-to-scan reproducibility	0.5	1.2	0.6	0.5
Reference specific luminosity	0.2	0.2	0.4	0.2
Subtotal for absolute vdM calibration	1.1	1.5	1.2	-
Calibration transfer†	1.6	1.3	1.3	1.3
Afterglow and beam-halo subtraction*	0.1	0.1	0.1	0.1
Long-term stability	0.7	1.3	0.8	0.6
Tracking efficiency time-dependence	0.6	0.0	0.0	0.2
Total uncertainty (%)	2.1	2.4	2.0	1.7

Combination methodology

- Straightforward error propagation:
  - Total integrated luminosity is sum of all years: $L_{\text{tot}} = \Sigma_i L_i$
  - Variance of the total depends on covariance matrix $\mathbf{V_L}$ encoding the errors on individual years:

$$\sigma^2_{L_{\text{tot}}} = \mathbf{G V_L \tilde{G}}$$

  - **G** is vector of derivatives:
    - Unit vector as combination is simple sum

$$\mathbf{G} = \left(\frac{\mathrm{d}L_{\text{tot}}}{\mathrm{d}L_1}, \frac{\mathrm{d}L_{\text{tot}}}{\mathrm{d}L_2}, \frac{\mathrm{d}L_{\text{tot}}}{\mathrm{d}L_3}, \ldots \right) = (1, 1, 1, \ldots)$$

- Evaluation of the covariance matrix $\mathbf{V_L}$:
  - Sum of individual sources with uncertainties σ_i in each year (many separate uncorrelated and correlated sources):

$$V_L = \begin{pmatrix} \sigma_1^2 & 0 & 0 \\ 0 & \sigma_2^2 & 0 \\ 0 & 0 & \sigma_3^2 \end{pmatrix} + \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2 & \sigma_1\sigma_3 \\ \sigma_1\sigma_2 & \sigma_2^2 & \sigma_2\sigma_3 \\ \sigma_1\sigma_3 & \sigma_2\sigma_3 & \sigma_3^2 \end{pmatrix} + \ldots$$

uncorrelated correlated

  - Some sources are not relevant in all years, so have some σ_i=0
  - Sources with both correlated and uncorrelated parts are handled by being broken into two separate contributions to V_L

vdM uncertainty correlations

- Separate vdM scan session in each year
  - ‘Random’ uncertainties should be uncorrelated
  - ‘Systematic’ uncertainties should be correlated – always have the same bias
- Random/uncorrelated uncertainties
  - Bunch-to-bunch and scan-to-scan σ_{vis} consistency
  - Reference specific luminosity (i.e. comparison of Σ_x, Σ_y from different algorithms)
    - All these fluctuate a lot from year to year, depending on quality/consistency of scan sets
  - Orbit drift corrections (depend on details of what happened in each scan session)
  - Background subtraction (dominated by statistical fluctuations, small, 0.2% / year)
  - Length scale calibration (independent calibration each year, orbit drift unc.)
- Fully or partially correlated uncertainties
  - Non-factorisation – not really understood, likely same underlying cause each year
  - Beam-beam effects: common MADX-based calculation
  - Fit model – partially correlated
    - Different pairs of fit functions used to set error in 2016 and 2017+2018
  - Beam position jitter – correlated 2015-17 (from run-1), new evaluation for 2018

More uncertainty correlations

- Bunch population product
  - DCCT partially correlated (only calibration source and bunch-pattern dependence)
  - FBCT uncorrelated – dominated by electronic noise (statistical)
  - Ghost and satellite corrections correlated
    - Common instrumentation and methodology (but small, <0.1%)
- Calibration transfer uncertainties
  - Tile vs. track-counting comparison – largely correlated
    - Larger value of 1.6% in 2016 c.f. 1.3% in 2017-18
    - Take correlated uncertainty of 1.3% in all years, plus 0.9% uncorrelated in 2016 only
- Long-term stability
  - Taken to be uncorrelated – dominated by different detector comparisons in the different years, no common trends in time
    - Apart from start-of-year effects, which affect only a small fraction of the total luminosity
  - Tracking efficiency time dependence only an issue for 2016

Conclusion

- Common beam energy throughout Run-2
  - Physics analyses usually analysing the full data sample as a single dataset
    - c.f. separate 7 and 8 TeV one-year samples from run-1
- Need to address the uncertainty correlations between years
  - Separate vdM calibration each year implies that uncertainties are not fully correlated
  - But methodology is the same – think carefully about what is / is not correlated
- For ATLAS run-2 dataset, preliminary combined uncertainty is 1.7% from 2.0-2.4% in individual years
  - Correct treatment of the correlations is important – potentially large gain
  - This will likely become increasingly important in Run-3 and Run-4
    - Beam energy and peak luminosities reach their limits, physics analyses will combine data samples taken over many years