Standard Model results from ATLAS and CMS

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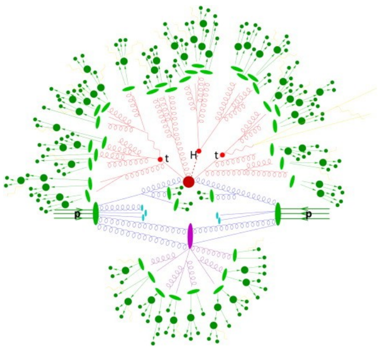
On behalf of ATLAS and CMS

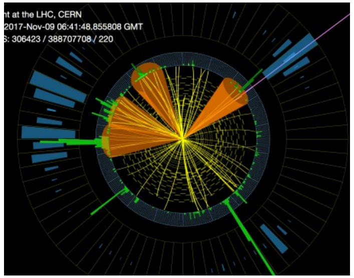
Why measuring the SM?

- Most successful theory ever, precision physics also at LHC, search for deviations, “legacy” measurements
- Conventionally, does not include:
  - top, Higgs, HF decays, HI
- Includes: Vector Boson production, Jets, Photons, soft QCD, EW:
  - Study and test QCD in corners of phase space
  - extract PDFs
  - tune MC
  - understand jet structure
  - precision measurements of SM constants (like α_s, M_W…)
  - place limits on Effective Field Theory extensions of the SM

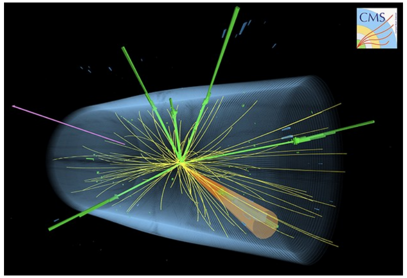
Many different experimental signatures

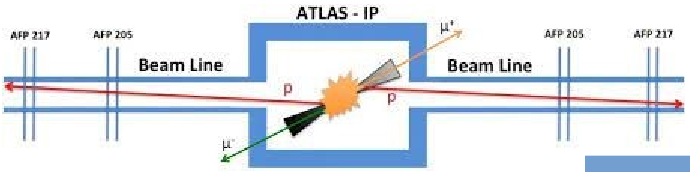
Soft QCD:
underlying event, MC tuning, study of hadronisation





Jets and photons:
perturbative QCD, PDFs, substructure, α_s





Vector bosons:
QCD, EW, PDFs, $\sin\theta_W$, EFT, α_s

Intact protons: QCD, EFT, invisible states

Will just give four examples:
α_s determination from jets and Z bosons, and EFT limits from intact protons

α_s from jets: Transverse Energy-Energy Correlation (and Asymmetry)

- TEEC: Transverse-energy weighted distribution of azimuthal difference between jet pairs

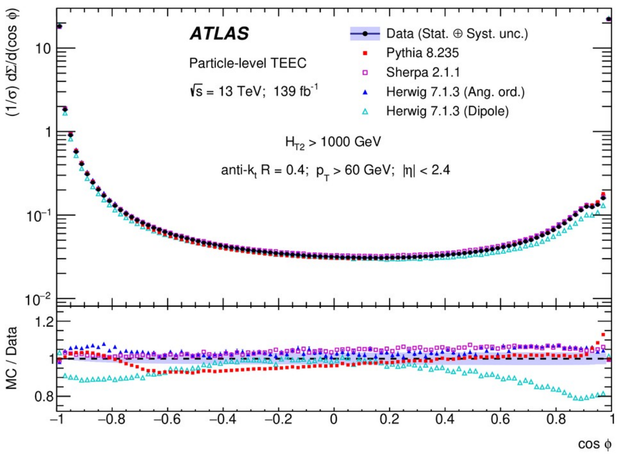
$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} \equiv \frac{1}{\sigma}\sum_{ij}\int \frac{d\sigma}{dx_{Ti}dx_{Tj}d\cos\phi}x_{Ti}x_{Tj}dx_{Ti}dx_{Tj} = \frac{1}{N}\sum_{A=1}^{N}\sum_{ij}\frac{E_{Ti}^{A}E_{Tj}^{A}}{\left(\sum_k E_{Tk}^{A}\right)^2}\delta(\cos\phi - \cos\varphi_{ij}),$$

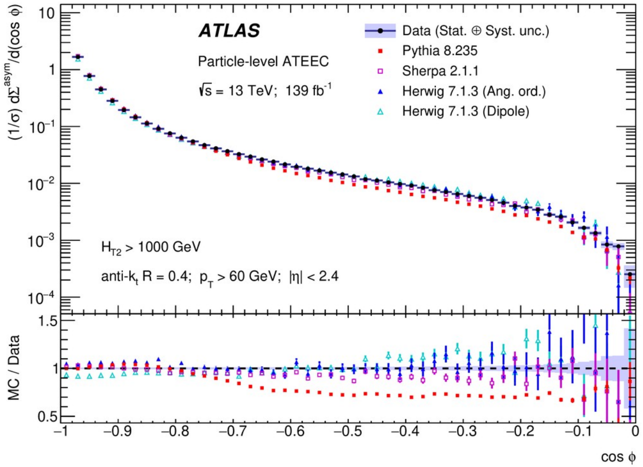
- ATTEC: difference between forward and backward part of TEEC

$$\frac{1}{\sigma}\frac{d\Sigma^{asym}}{d\cos\phi} = \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}\bigg|_{\phi} - \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}\bigg|_{\pi-\phi}.$$

Back-to-back jets

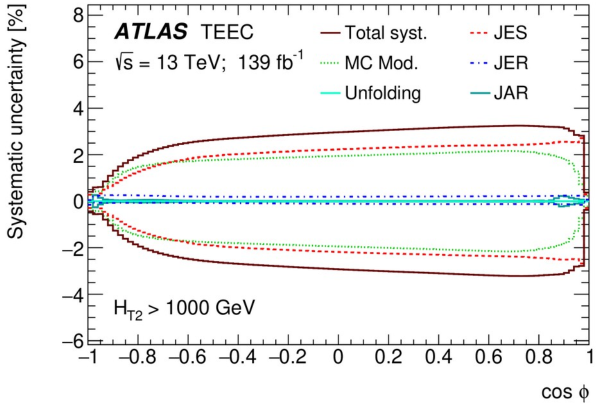
Self-correlation of collinear jets

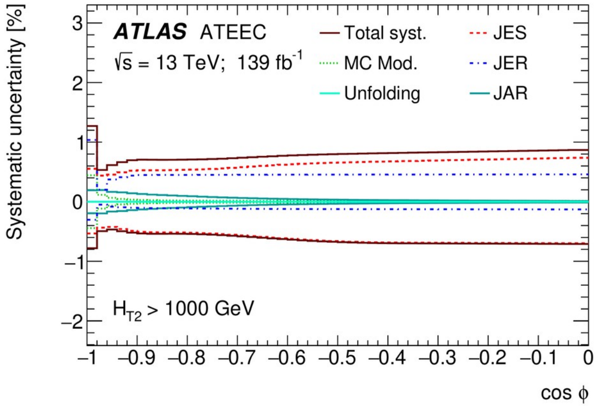




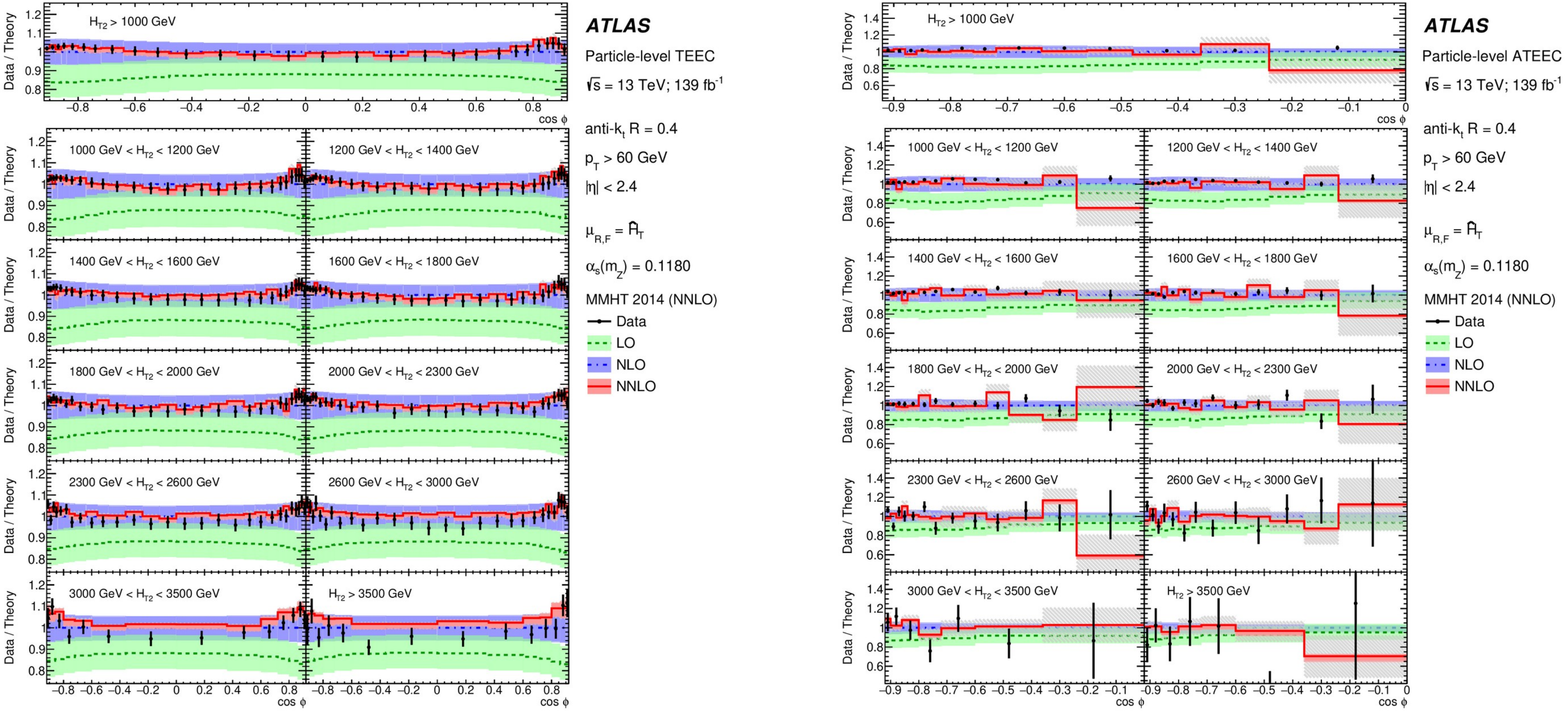
Selection and systematics

- Use 139/fb of ATLAS data from 2015 to 2018 with <μ> = 33.6
- At least 2 PFlow anti-kt 0.4 jets with pT>60 GeV and η < 2.4.
- $H_{T2} = p_{T1} + p_{T2} > 1$ TeV
- TEEC and ATEEC measured in 10 intervals of H_{T2}
- Results unfolded to particle level using iterative Bayesian method
- Main systematics from jet energy scale and resolution; reduced in asymmetry





Unfolded results with fixed α_s

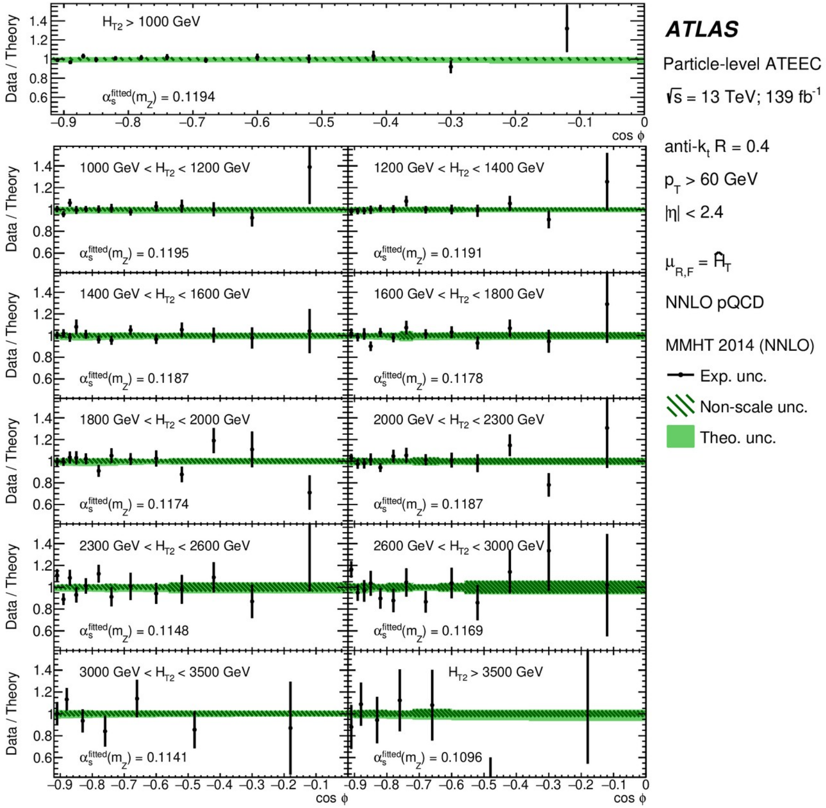


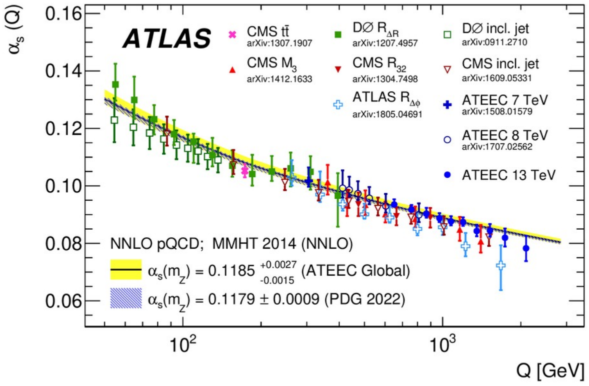
Compare with MMHT 2014, using its standard value of $\alpha_{s\,(MZ)} = 0.1180$

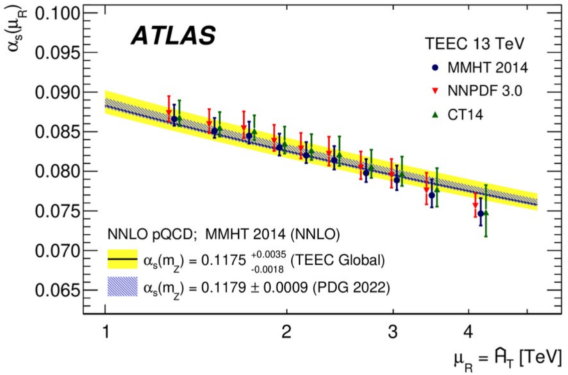
Observables sensitive to α_s since angle between jets sensitive to gluon emission.

First NNLO α_s extraction of from this observable (new NNLO predictions!)

Determination and running of α_s





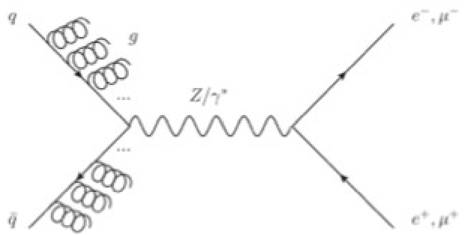


Leaving the value of α_s as a free parameter, it can be fitted as a function of HT (using Q = HT/2), show its running and obtain final combined values

$\alpha_s(M_{Z,\,TEEC}) = 0.1175 \pm 0.0006\ (\text{exp.}) + 0.0034 - 0.0017\ (\text{theo.})$ and

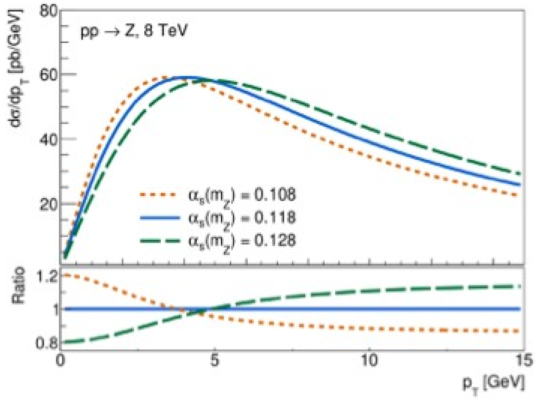
$\alpha_s(M_{Z,\,ATEEC}) = 0.1185 \pm 0.0009\ (\text{exp.}) + 0.0025 - 0.0012\ (\text{theo.})$

The most precise α_s: Z pT New!



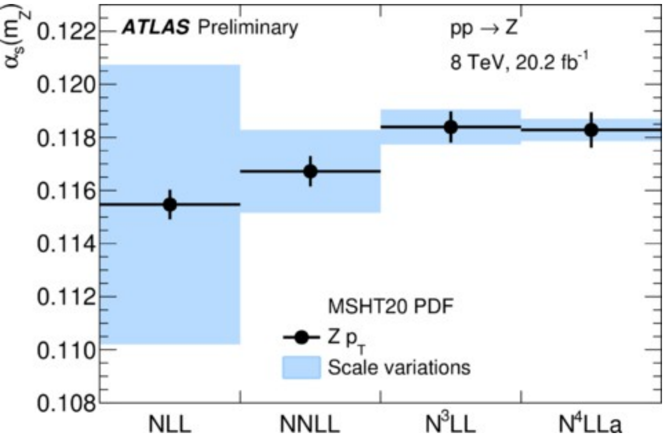
Possible because Z pT strongly depends on initial gluon emission.

Theory prediction from DYTurbo, interfaced to xFitter. Full N4LL in Sudakov, approximate in hard coefficient, corrected for QED ISR



Sudakov part not used in PDF determination, so fit limited to pT<29 GeV

Evaluate a χ2 that includes experimental and theory uncertainties, and at each value of α_s, a reweighting technique is used to get the PDFs that best fit the data. Expected sensitivity 0.05%.

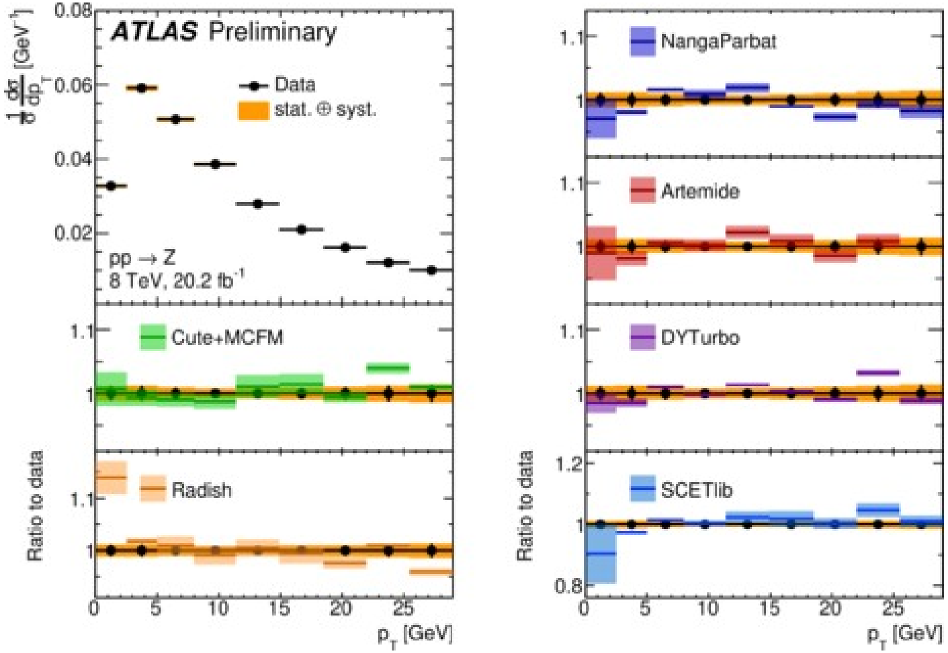


Final result is the midpoint of the (μ_R, μ_F) scale variation envelope

Nice convergence as we increase the perturbation order

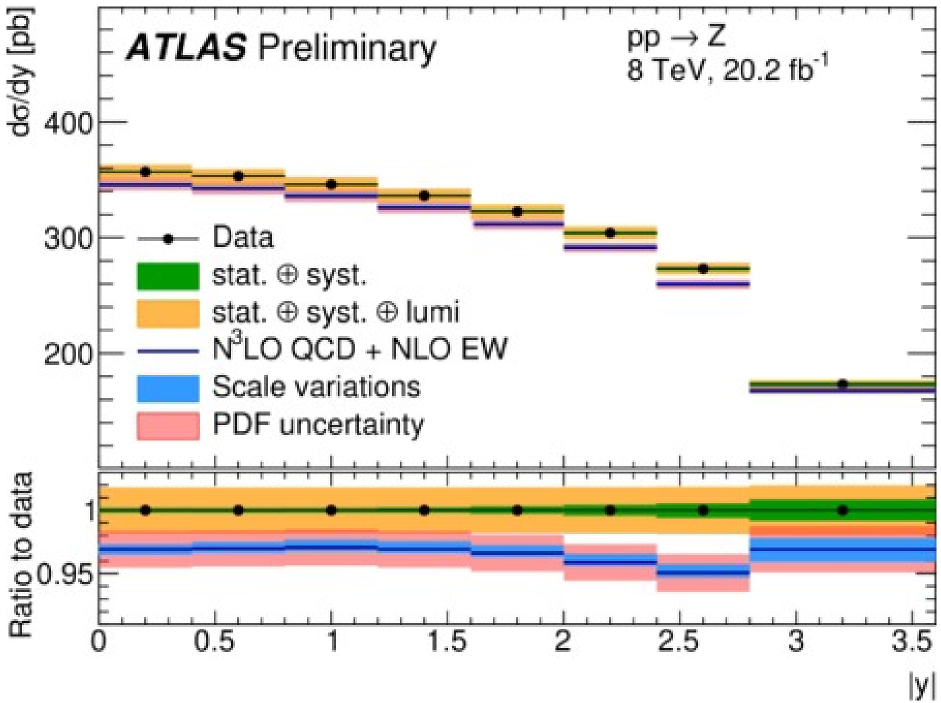
α_s = 0.11828 +0.00089 –0.00094

Comparison data/theory predictions

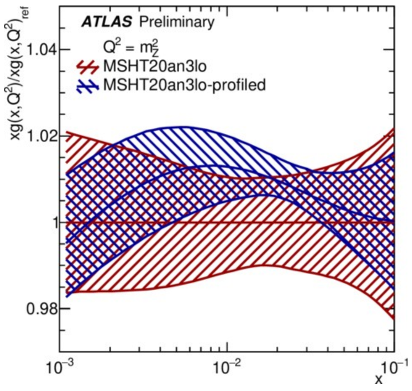


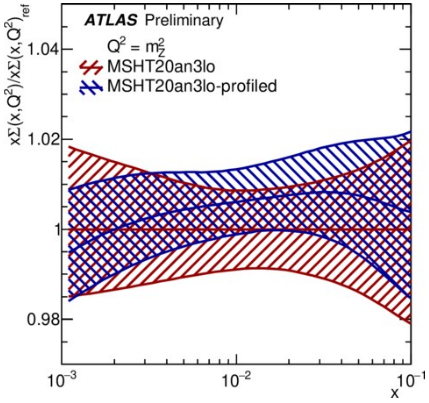
Pt distribution in data vs various resummation codes. They all include approximate N4LL resummation and (apart from Artemis) fixed order α_s^3 contributions

Rapidity distribution compared to DYTURBO predictions, with experimental and theory uncertainties



Profiled PDFs, uncertainties



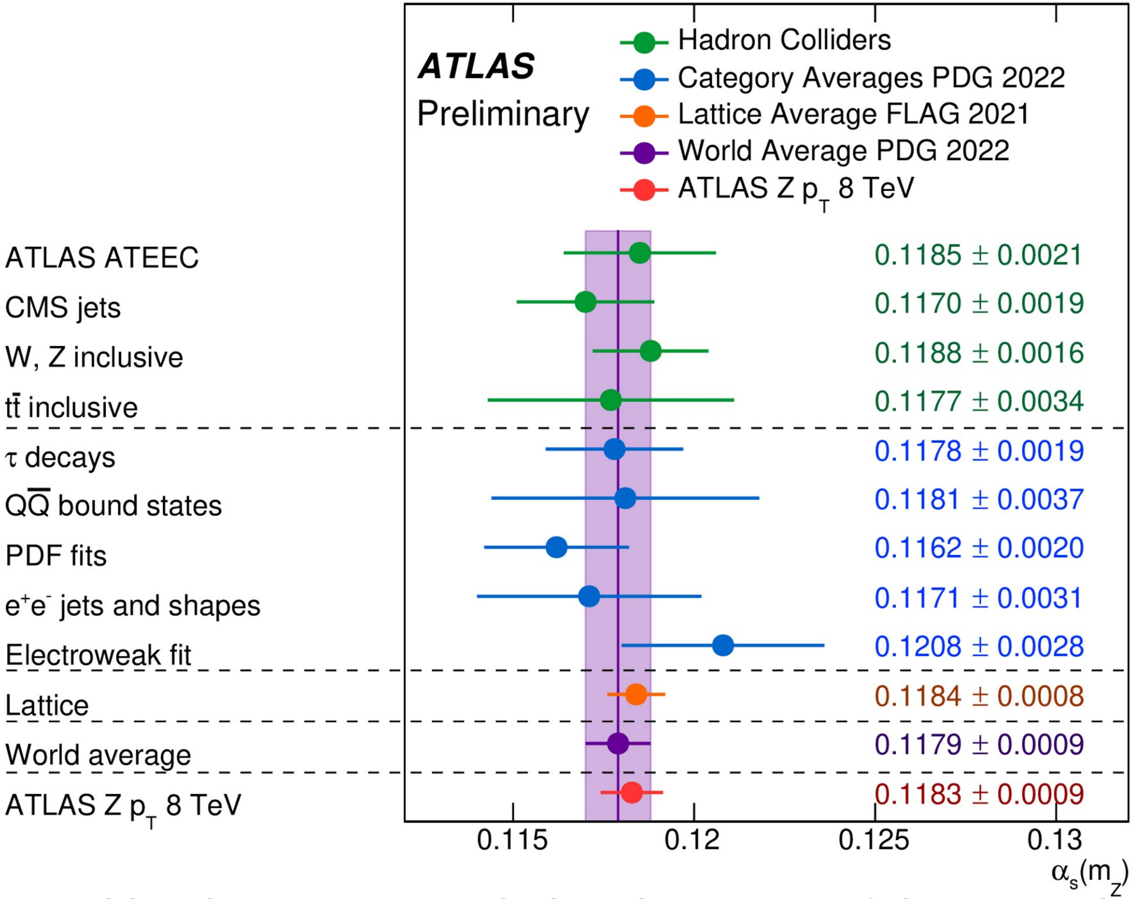


Being relatively orthogonal, result does not impact PDFs too much, but slightly decreases uncertainties for gluons and light quarks

Still, PDFs are the largest source of theory uncertainty.
Experimental uncertainty matches with expectation.
Performing a full N3LL fit to α_s and PDFs, using NNLO DGLAP evolution, uncertainty increases to 0.001

Experimental uncertainty	+0.00044	-0.00044
PDF uncertainty	+0.00051	-0.00051
Scale variations uncertainties	+0.00042	-0.00042
Matching to fixed order	0	-0.00008
Non-perturbative model	+0.00012	-0.00020
Flavour model	+0.00021	-0.00029
QED ISR	+0.00014	-0.00014
N4LL approximation	+0.00004	-0.00004
Total	+0.00084	-0.00088
Inflated total	+0.00089	-0.00094

Global picture



Measurement dominated by theory uncertainties, but most of them can be constrained with more precise cross-section measurements

PDFs and α_s from dijets (CMS PAS SMP 21-008)

Dijet events have a huge cross-section and are the typical QCD process. Sensitive to high-order perturbation, PDFs and α_s.

The two jet rapidities y1 and y2 define

rapidity separation $y^* = |y1-y2|/2$ and

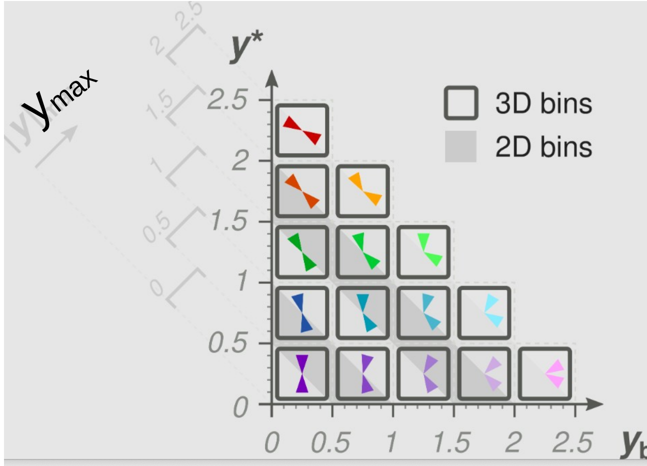
boost $y_b = |y1+y2|/2$ together with invariant mass or average momentum, they allow 2D or 3D differential cross-section.

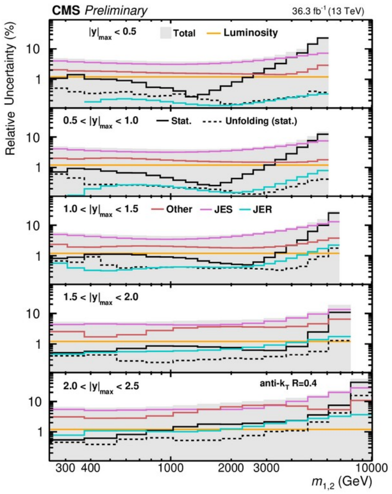
CMS measured on 36.3/fb of 13 TeV data Pflow dijets of R = 0.4 and 0.8 < |η| < 3 and pT > 100 and 50 GeV respectively.

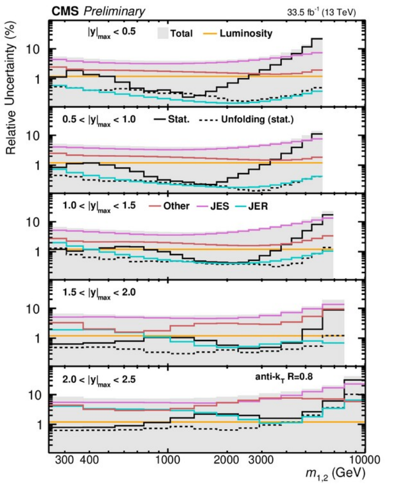
Events unfolded with Tunfold

As usual in this kind of measurements, uncertainty

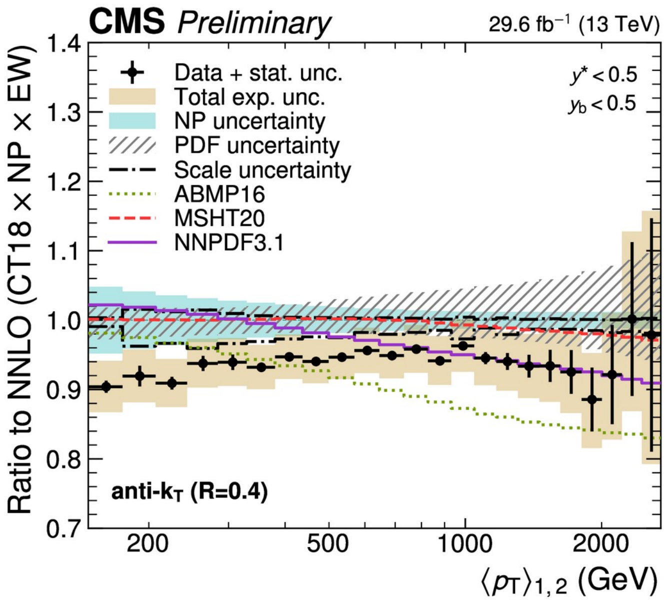
dominated by JES and JER





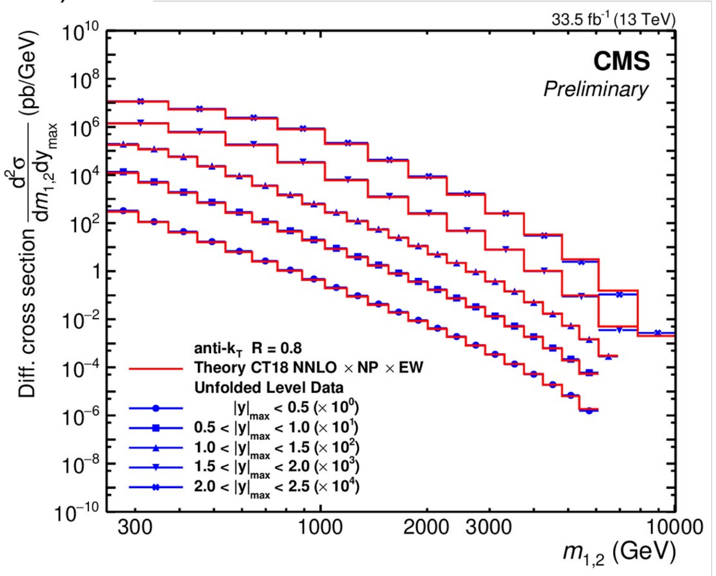


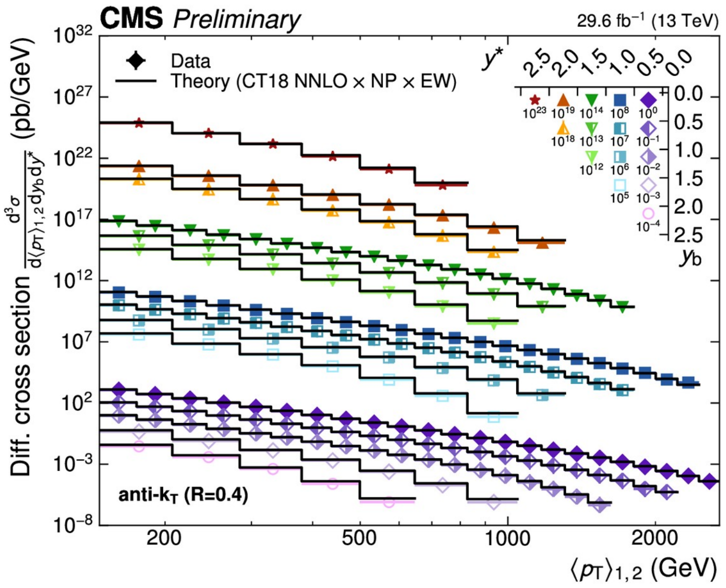
1D, 2D and 3D results



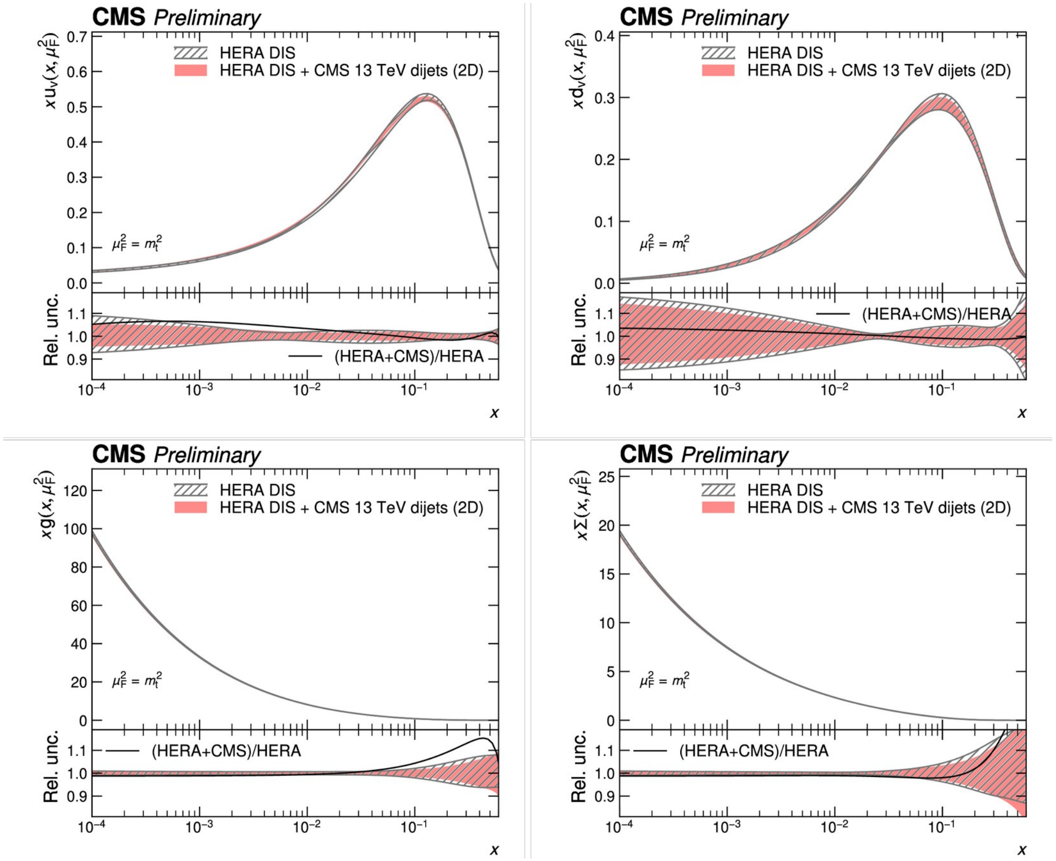
Example the ratio of the <pT> distribution for the first rapidity region with various PDF sets

2D and 3D distributions using m12 and <pT> compared to CT10 NNLO





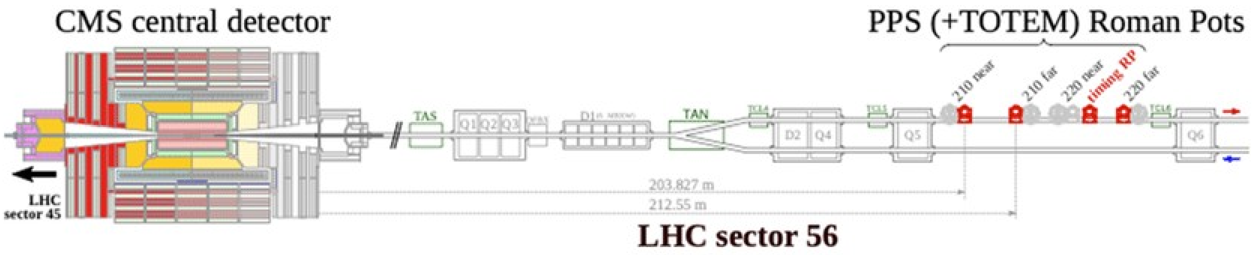
Impact on PDFs and α_s

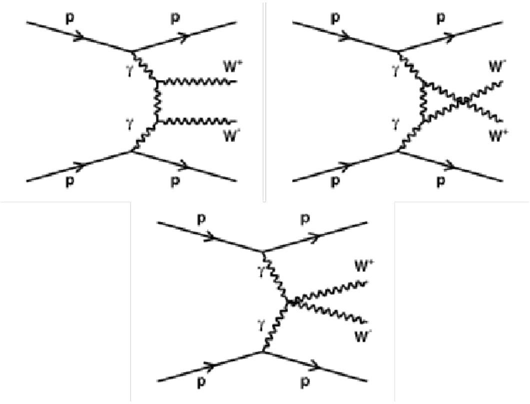


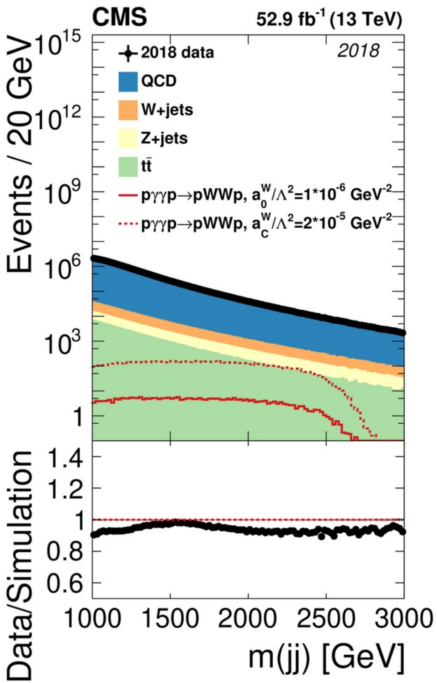
Including this measurement in the HERAPDF set produces a small but visible improvement on low-x up and down, and high-x gluon. A common fit of the PDFs and of αs yields (for the 3D measurement)

$$\alpha_s(m_Z) = 0.1201 \pm 0.0010\,(\text{fit}) \pm 0.0005\,(\text{scale}) \pm 0.0008\,(\text{model}) \pm 0.0006\,(\text{param.})$$
$$= 0.1201 \pm 0.0020\,(\text{total}),$$

Search for WW, ZZ → jj and intact protons with CMS/TOTEM PPS







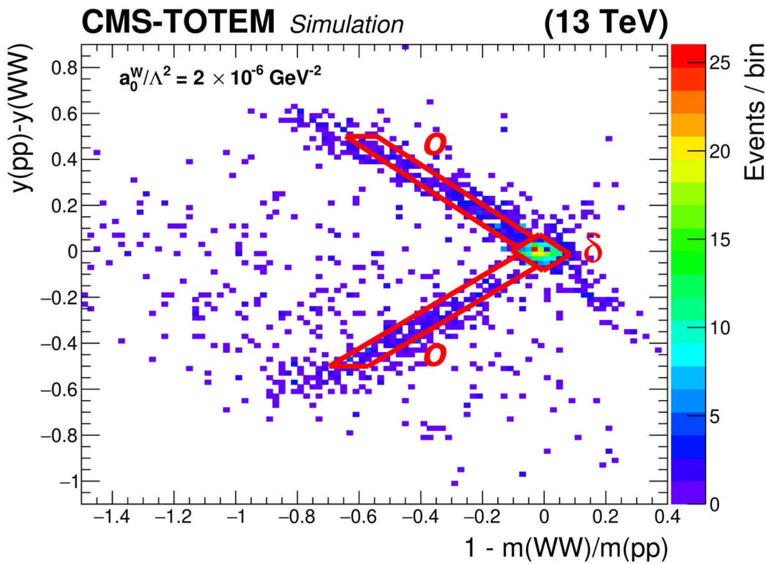
Dijets with Mjj > 1 TeV and two intact forward protons with fractional energy loss $0.04 < \zeta < 0.20$

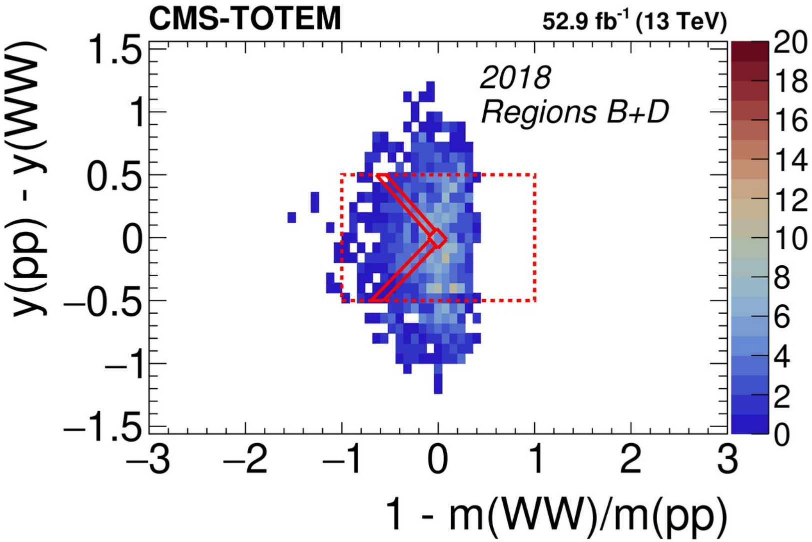
SM signal very small, but can be enhanced in the presence of anomalous couplings (EFT)

Since conditions changed, data from 2016, 2017 and 1018 analysed independently

Central-forward matching

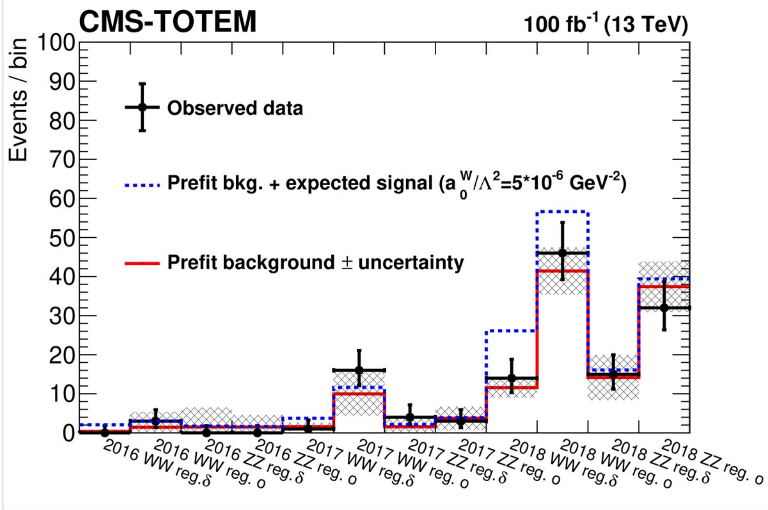
For well-matched signal, we expect invariant mass and rapidity from central detector match the prediction from the forward proton. Events in the diagonal have only one correctly assigned proton

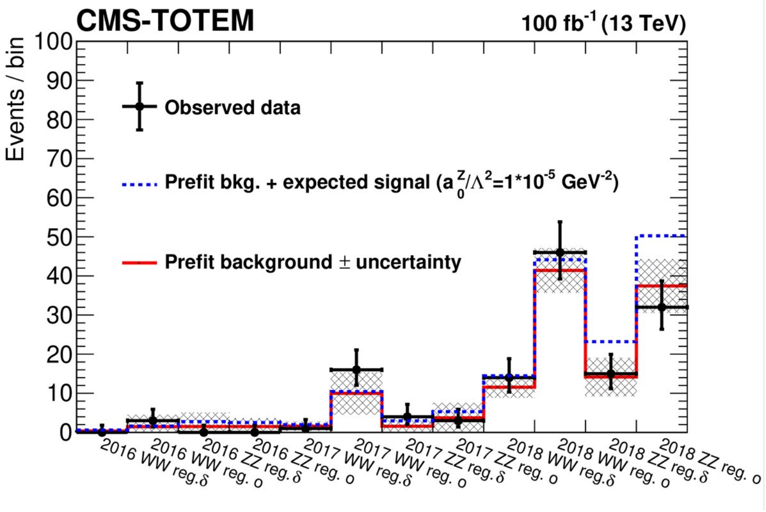




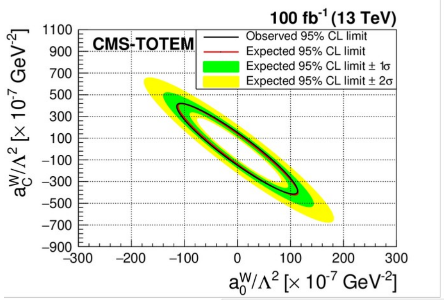
After requiring jets to have a substructure compatible with WW or ZZ, background estimated from data, by requiring acoplanarity > 0.1 (reversing the cut for signal).

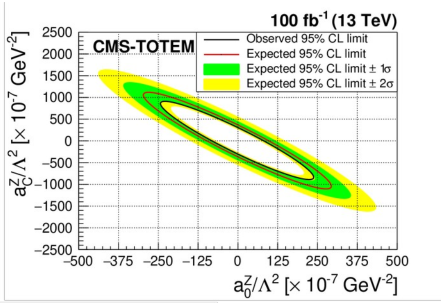
Results and limits

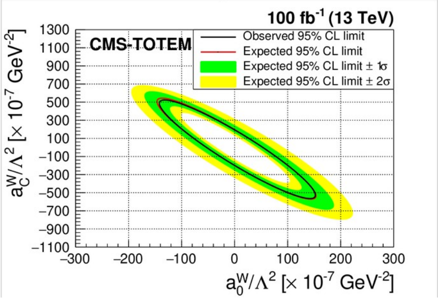




For all years considered and final states, data is compatible with data-driven background. No indication of anomalous coupling, translated into limits to EFT operators







Conclusions

- SM measurements are meant to stay as “legacy” results, require very careful analysis and can lead to high precision
- Many possible final states and physics aims
- Only gave a few examples
- Keep testing the most precise theory in science