February 2015

CENTRO DE CIENCIAS DE BENASQUE PEDRO PASCUAL

Parton Distributions for the LHC

2015, Feb 15 -- Feb 21

Plans for PDF measurements at Run II and role of PDFs in MC tuning in ATLAS

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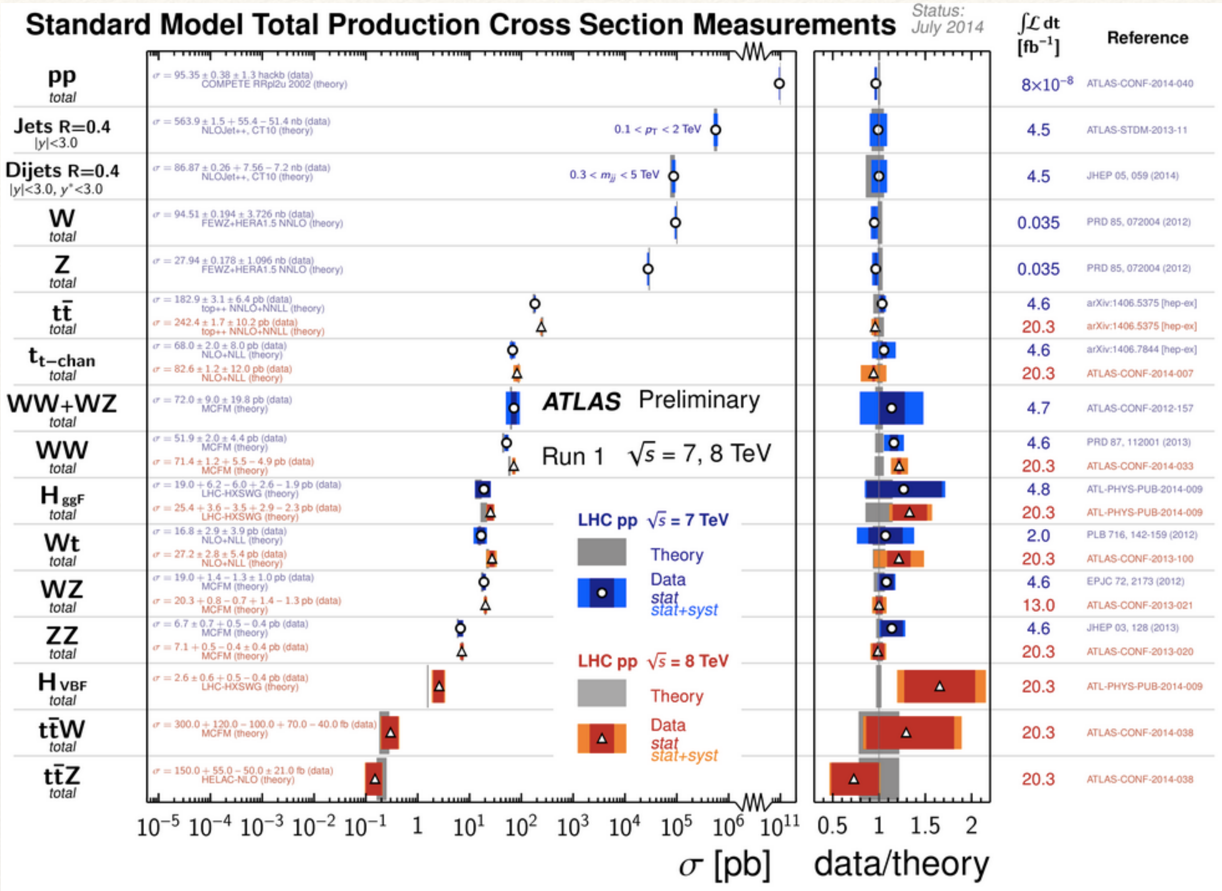
on behalf of

the ATLAS Collaboration

ATLAS

The LHC measurements from Run1

- Successful run in 2010 - 2012 at the LHC confirmed and tested SM



– 0.05 / fb (7 TeV, 2010)
– 4.6 / fb (7 TeV, 2011)
– 20.3 / fb (8 TeV, 2012)

- Remarkable agreement with SM predictions
- Measurements can be used for PDF improvements

1. W and Z production —> valence, light sea quarks
2. W+c production —> strange
3. Drell-Yan: low and high invariant mass —> sea quarks at high-x, test evolution formalism at low x
4. Inclusive Jet, Di-Jet and Tri-jet production —> gluon and alphas
5. Prompt Photon + Jets —> gluon
6. Top, ttbar —> gluon and alphas
7. W,Z +jets or ZpT —> gluon

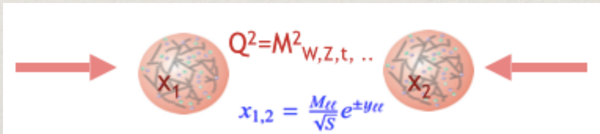
[see talk of S. Cheatham]

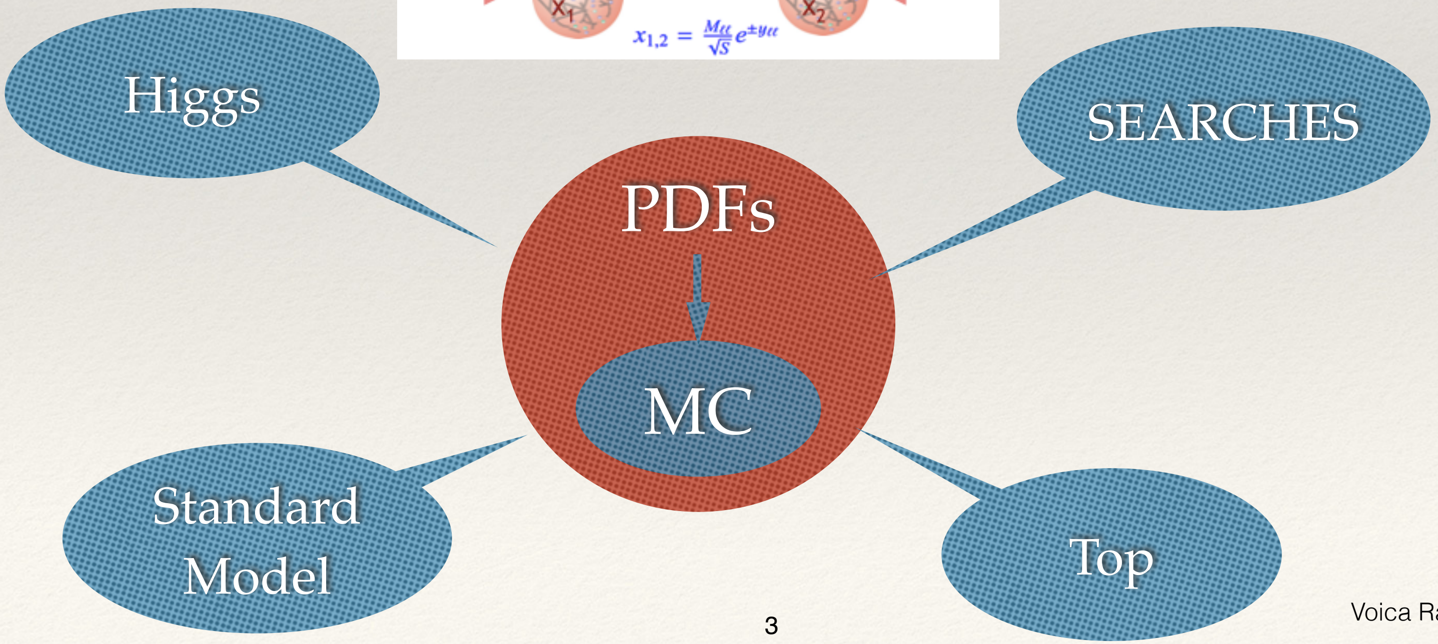
Why do we still care about PDFs?

- Discovery of new exciting physics relies on precise knowledge of proton structure.
  - PDFs are one of the main theory uncertainties in Mw measurement
  - PDFs are one of main theory uncertainties in Higgs production
  - PDF uncertainties very large (>100%) for new heavy particle production
- **Factorisation theorem:**
  - Cross section can be calculated by convoluting short distance partonic reactions (calculable in pQCD) with PDFs:

$$d\sigma(h_1 h_2 \to cd) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, \mu_F^2) f_{b/h_2}(x_2, \mu_F^2) d\hat{\sigma}^{(ab\to cd)}(Q^2, \mu_F^2)$$

  - PDFs cannot be calculated in perturbative QCD, however they are process independent (universal) and their evolution with the scale is predicted by pQCD:





ATLAS for Run 2

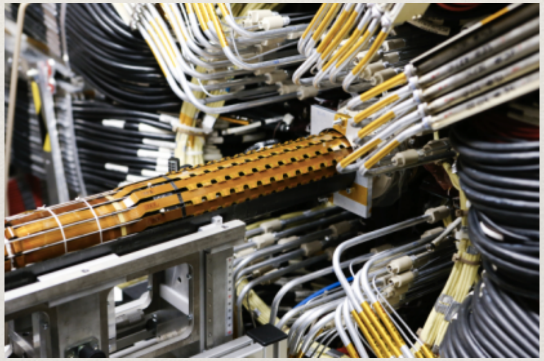
- Experimental environment for Run 2 will be more stressful:
  - higher pile-up
  - larger trigger rate
  - larger data

<u>LHC Run 1 conditions:</u>
$\sqrt{s}$=900 GeV, 7 TeV, 8TeV
L: up to 7x10^{33} cm^{-2} s^{-1}
Pileup: up to 35
Int. Lum ~30 fb^{-1}

→

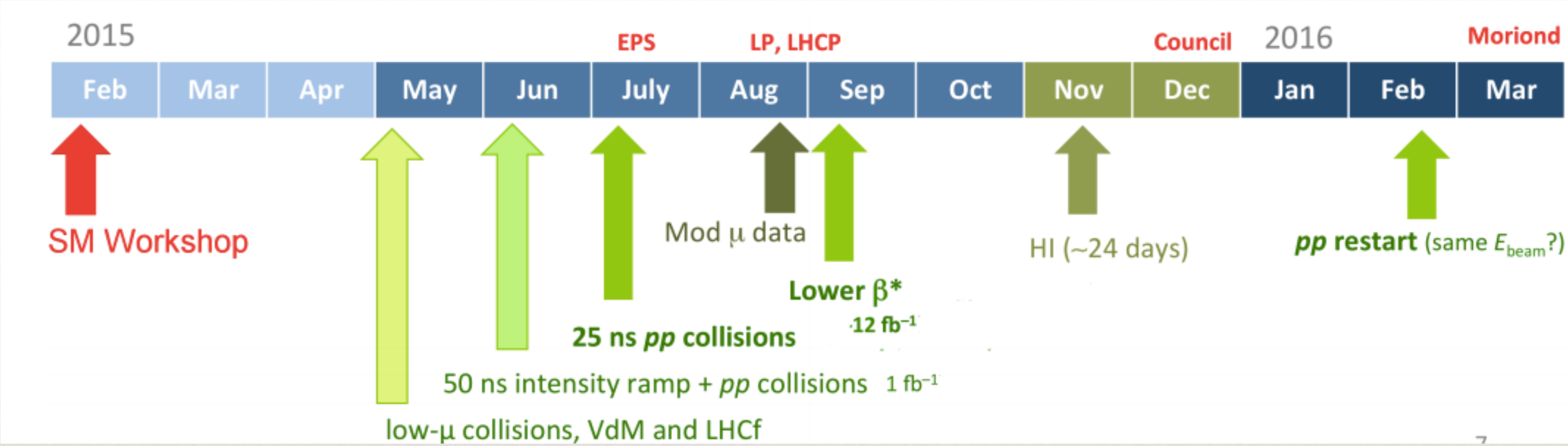
<u>Expected LHC Run 2 conditions:</u>
$\sqrt{s}$=13 TeV
L: up to 1.6x10^{34} cm^{-2} s^{-1}
Pileup: up to ~50
Int. Lum ~150 fb^{-1}

- LHC detector upgrades during the long shut down period:
  - The ATLAS Insertible B Layer (IBL):
    - Additional layer of pixels (built/installed during 2013-2014)
    - Improved impact parameters
    - Insurance against radiation damage
    - More robust B tagging
  - The Fast Track Trigger (FTK):
    - With luminosity increase, trigger must be more selective
    - Requires dedicated hardware track finder
  - Jet Reconstruction Improvements:
    - Discriminate jets from hard-scatter and pile-up
    - Improve jet resolution



LHC Run 2 Schedule

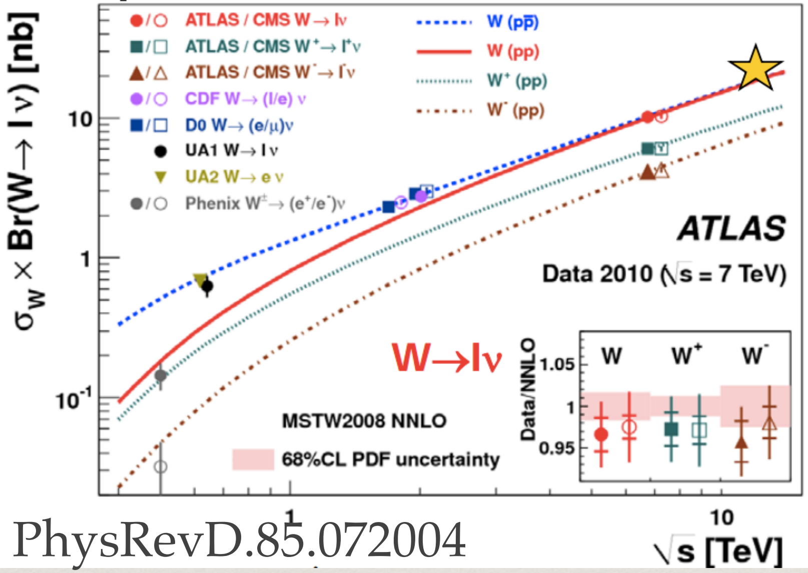
First beam foreseen on Monday 23 March.



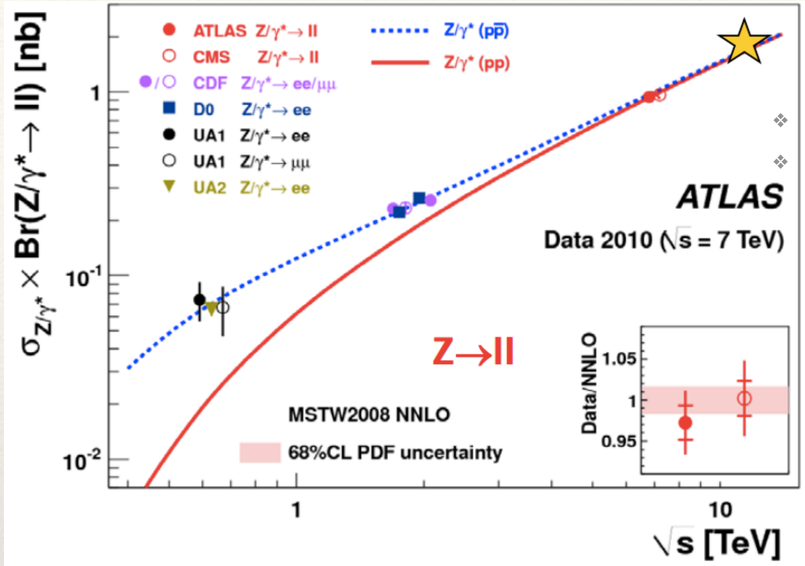
- ~1 fb-1 @ 13TeV, 50ns:
  - accumulate about half of 2011 dataset of W,Z
  - **test SM in new kinematic regime, re-establish standard candles, help to re-commission ATLAS**
- ~10 fb-1 @ 13TeV, 25ns:
  - accumulate about the size of 2012 dataset , ~ 4x2011 dataset of W,Z
  - **use abundant data for ultimate precision**

Dependence on √s

- W→lν, Z→ll: Inclusive NNLO cross-sections from FEWZ with MSTW2008NNLO)



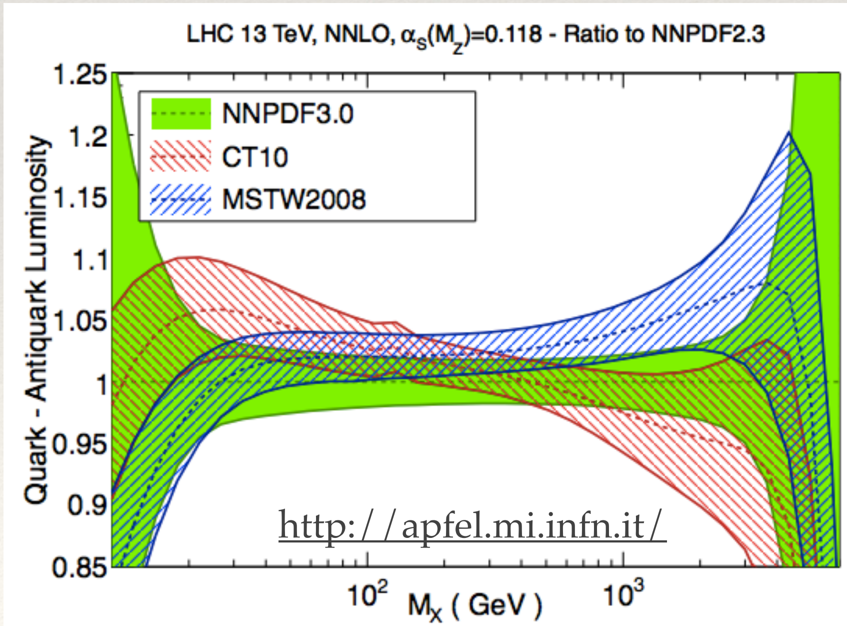
PhysRevD.85.072004



$\sigma(13\text{TeV})/\sigma(7\text{TeV}) = 1.9$
$\sigma(13\text{TeV})/\sigma(8\text{TeV}) = 1.7$

- Current theory precision at 13 TeV (on total inclusive)

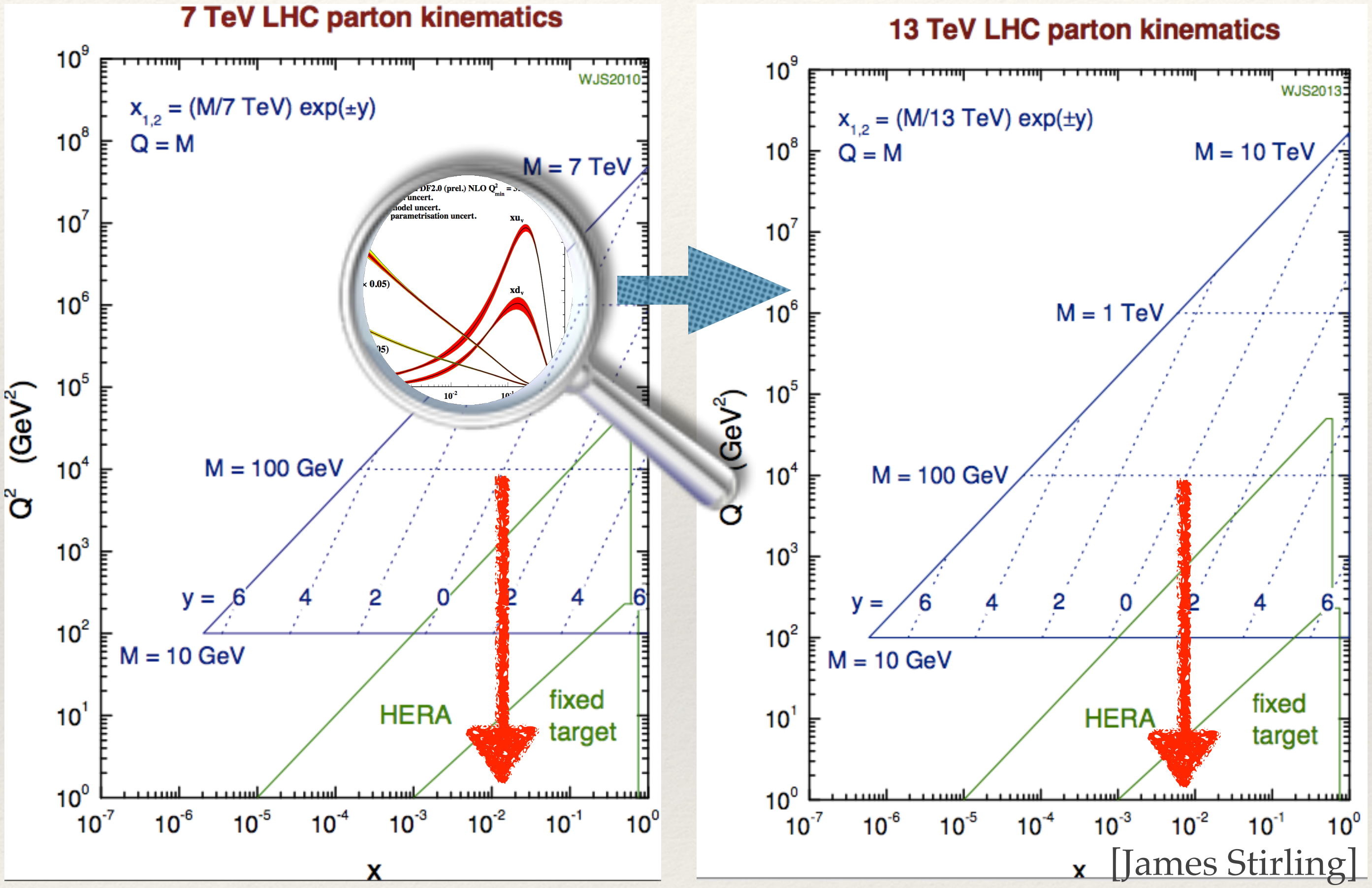
Total theory precision ~5% -> can be improved with newer PDF sets?



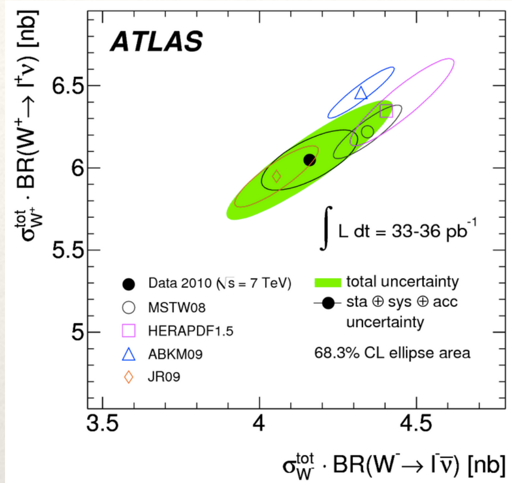
http://apfel.mi.infn.it/

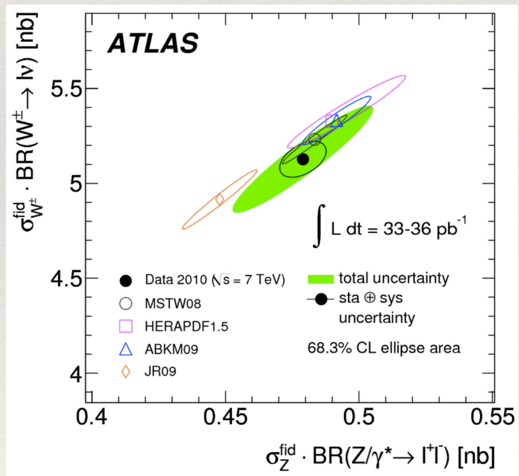
W, Z inclusive with early data at 13 TeV

- Worthwhile to measure inclusive W, Z cross sections:
  - access to a different kinematic region in x which provides different PDF sensitivity



[James Stirling]





[PhysRevD.85.072004]

- W+/W-, W/Z with first 13 TeV data
  - implicitly obtained when keeping track of correlations (many systematic cancel out)

—> Inclusive fiducial & total W,Z cross-section measurements and ratios

Inclusive cross sections of W,Z at different √s

- The 13 TeV measurements would complement the measurement at 7 TeV, and 8 TeV [JHEP08(2012)010]
  - Cross section ratios: process X at different √s= E1,E2: R(X)

$$R_{E_2/E_1}(X) \equiv \frac{\sigma(X,E_2)}{\sigma(X,E_1)}$$

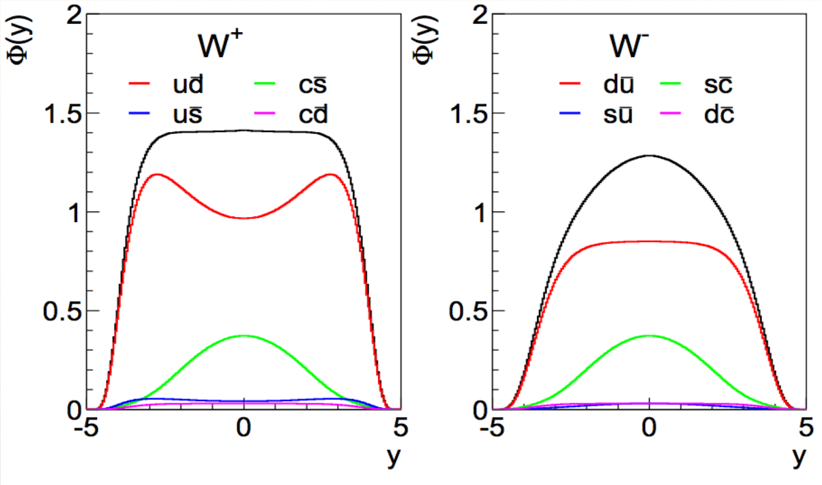
    - Less sensitive to variations of e.g. α_S, PDF, scales
    - Reduction or cancellations of common exp. uncertainties
  - Super ratios processes X, Y at different √s: R(X,Y)

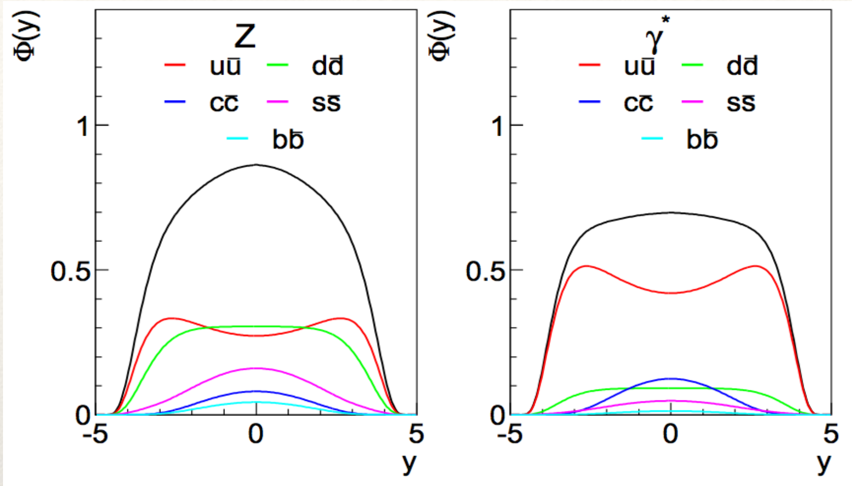
$$R_{E_2/E_1}(X,Y) \equiv \frac{\sigma(X,E_2)/\sigma(Y,E_2)}{\sigma(X,E_1)/\sigma(Y,E_1)} \equiv \frac{R_{E_2/E_1}(X)}{R_{E_2/E_1}(Y)}$$

      - ttbar/Z, ttbar, Z, W+, W-:
  - Ratios with W, Z require extra considerations:
    - same lepton selection, trigger selection, use of similar MC (PDFs and PS uncertainties)

W , Z inclusive with Run 2 data

- Inclusive cross sections of W and Z are well understood theoretically at NNLO
  - exploit different PDF flavour sensitivity:





  - With 13 TeV we access different x range compared to the 7, 8 TeV, respectively
    - W/Z on-shell differential (W+, W-, Z, differential cross sections, ratios 13/√s)

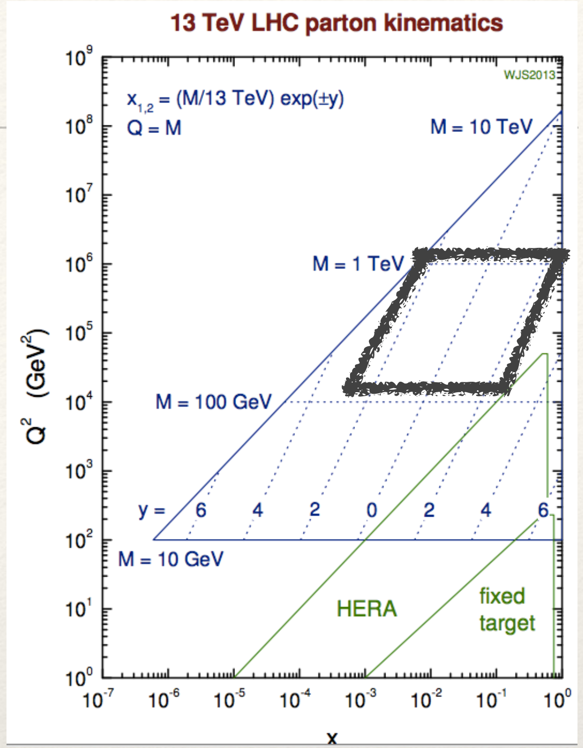
- What precision do we want for our measurements?
  - Aim to have better experimental uncertainties than theoretical precision:
    - Theory precision is ~5% for $m_{ll} < 400$ GeV
    - huge theory uncertainty for $m_{ll} < 20$ GeV

- Early Run2 measurements with 2015 data may not yet be competitive with precision Run1 results

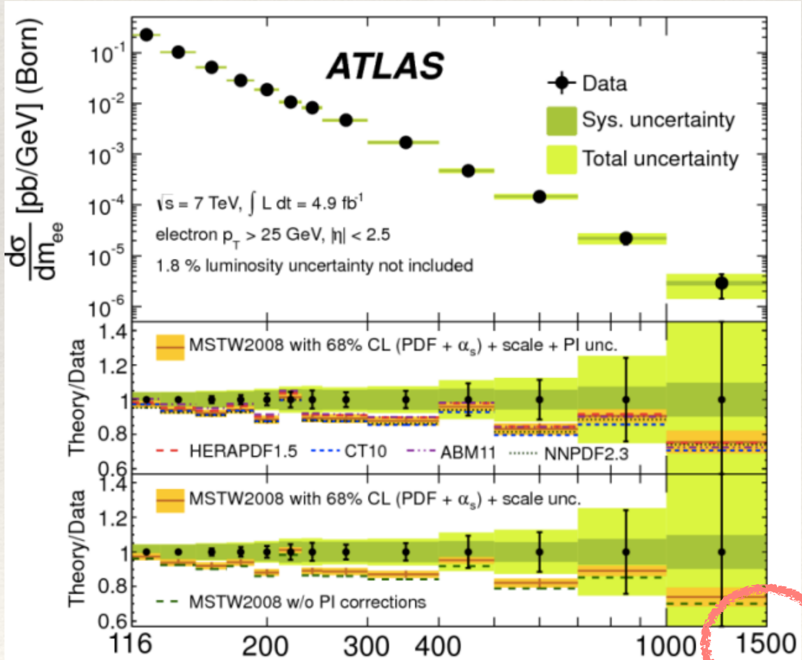
HM DY measurement

- High Mass DY measurement with the 13 TeV centre of mass energy can extend the di-lepton mass distribution up to 3 TeV:
  - differential measurements in m_{ll}, y

—> **an extra in lever arm in x for constraining PDFs**

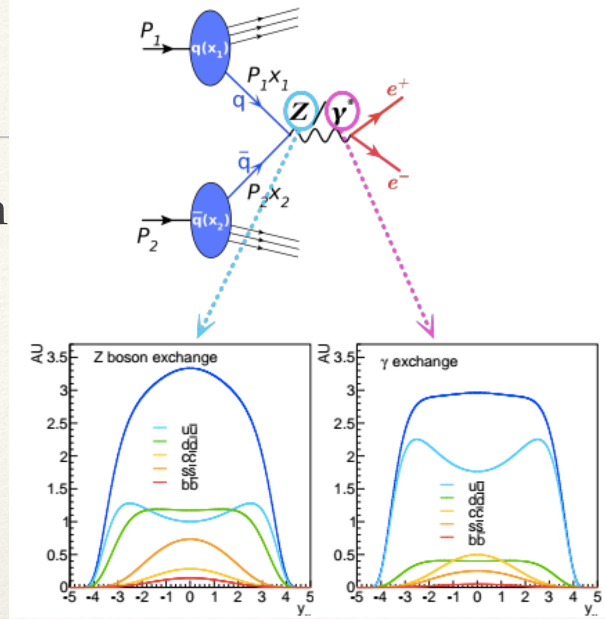


- The photon induced piece if not subtracted from the signal, measurement provides sensitivity to the photon PDF:
  - 4% signal fraction at m_{ll} ~ 300 GeV at high m_{ll}
- 13 TeV data can bring considerable improvement in the statistical uncertainty compared to Run 1
  - Statistical uncertainty dominates for m_{ll} > 400
- An important cross check analysis for the Z′ searches

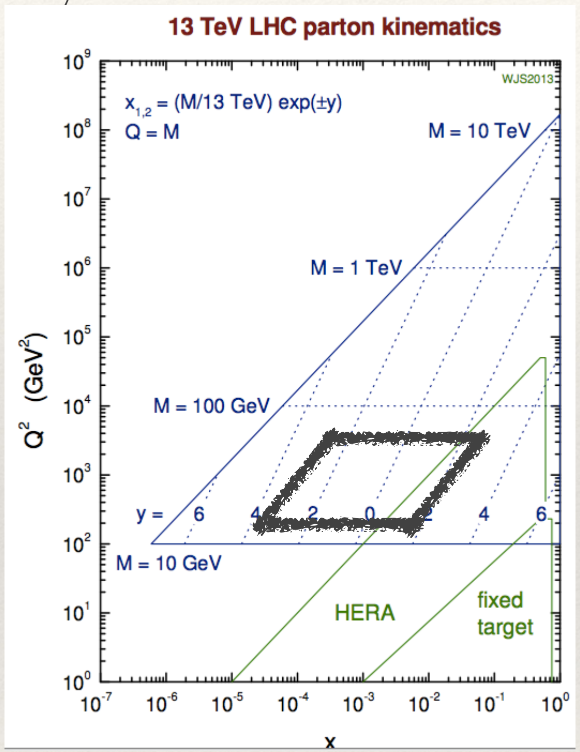


Phys. Lett. B 725 (2013)

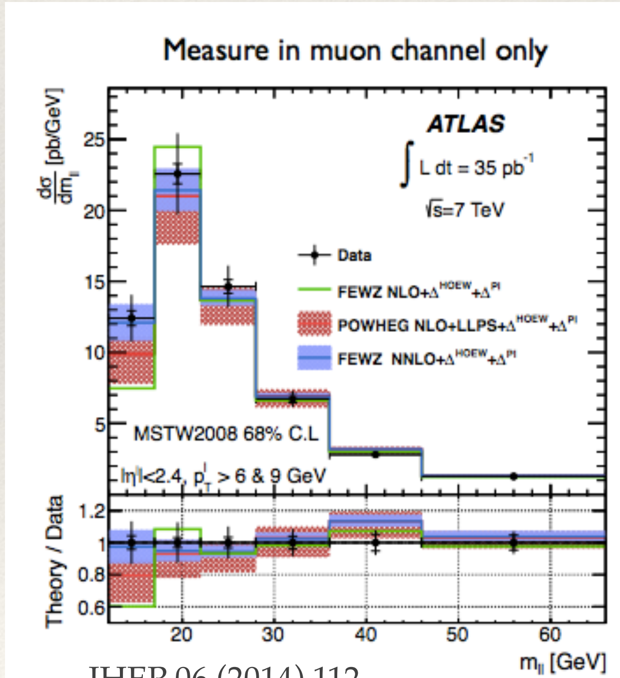
LM DY measurement



- The LM DY is an interesting measurement as it accesses with its low mass ranges $12<m_{ll}<60$ GeV PDFs down to $x \sim 10^{-4}$:
  - exploit the interference effects between Z and γ^* (u,d)
  - sensitivity to the low x effects?



- 13 TeV data could provide an increased experimental precision in the lower mass bins of m_{ll} distribution
  - Theoretical uncertainty can be reduced when using lower pt muon cuts and resummed calculations



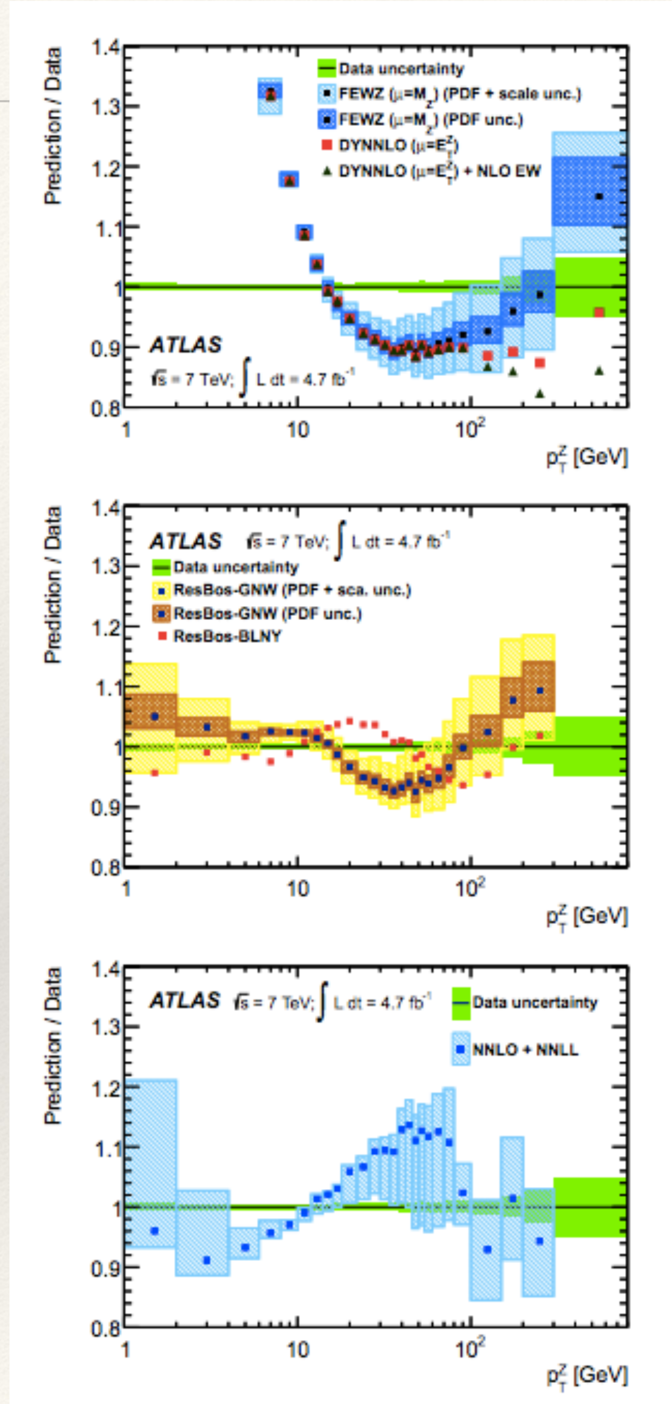
JHEP 06 (2014) 112

http://arxiv.org: 1406.3660.

Z P_T / φ*

- Z P_T (> 40 GeV) an interesting observable:
  - Important because uniquely sensitive to α_S x gluon x quark
  - In principle, theoretically clean as it is free of large logs, and also precise experimentally (with uncertainties < 1%)
  - measurement compared to pQCD and resummed predictions
  - 2-σ discrepancy in region where (N)NLO should be reliable that needs to be understood.

—> interesting measurement for 13 TeV



W/Z + jets measurements

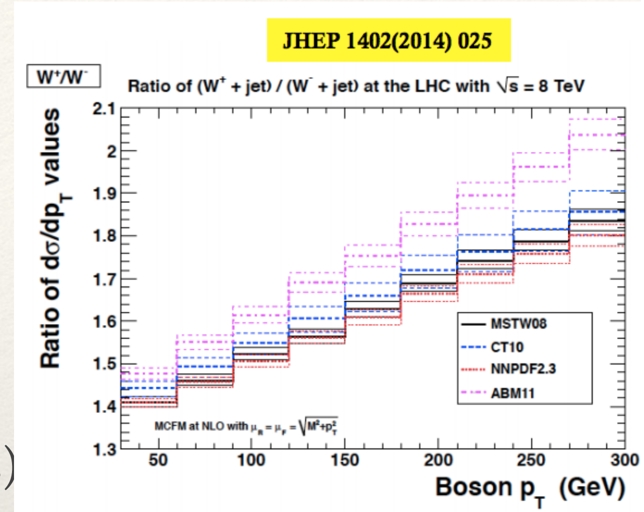
- W/Z +jets (inclusive) probe different aspects of QCD:
  - it provides a precision test of pQCD (NLO) in the new regime at 13 TeV
  - it is a background to SM measurements, Higgs and possible new phenomena
  - it provides grounds for validation of the ME+PS MCs:
    - scale choice, ME-PS matching, flavour scheme
  - it has the potential to impact PDFs understanding (measurements in fiducial region)
    - W/Z + jets inclusive: d/u ratio

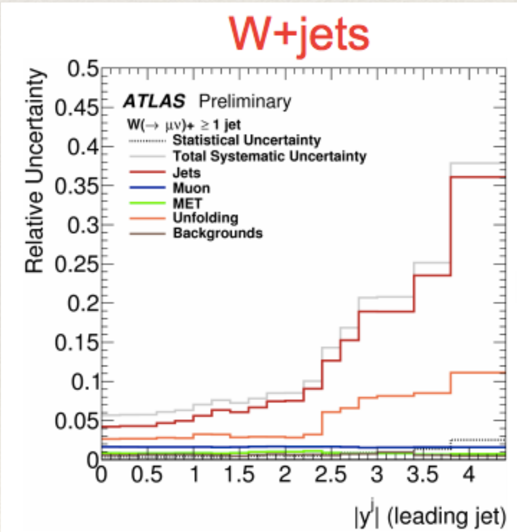
- With 13 TeV, the background control will represent an important challenge:
  - Signal is scaling with the increased energy from 8 TeV to 13 TeV by approx factor 2
  - EW background from tau decay is expected to scale as signal
  - Top bkg will hugely increase: σ(13TeV) ~3.5 σ(8 TeV)

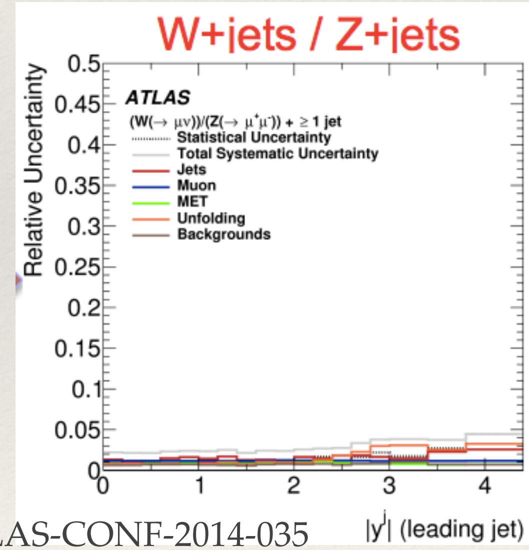
- Theory:
  - W/Z+jets available at NLO up to 5 jets, while NNLO calculations are still missing
  - NLO EW corrections available but not included in MCs:
    - HO QCD and EW effects important at high jet pT
    - At 13 TeV larger phase space available for parton radiation

Ratio Measurements for W/Z+jets

- Ratio measurements allow for cancellations of uncertainties (exp. and theory)
  - Ex: jet calibration uncertainties, lumi etc.
- Different combination of ratios can enhance different effects:
  - **R=W⁺+jets/W⁻+jets:**
    - large spread in theory predictions
    - sensitive to PDF: interesting input for u/d at large x
    - insensitive to high-order QCD and EW corrections
  - **Rjets = W+jets/Z+jets:**
    - High precision test of pQCD (cancellation of systematics)







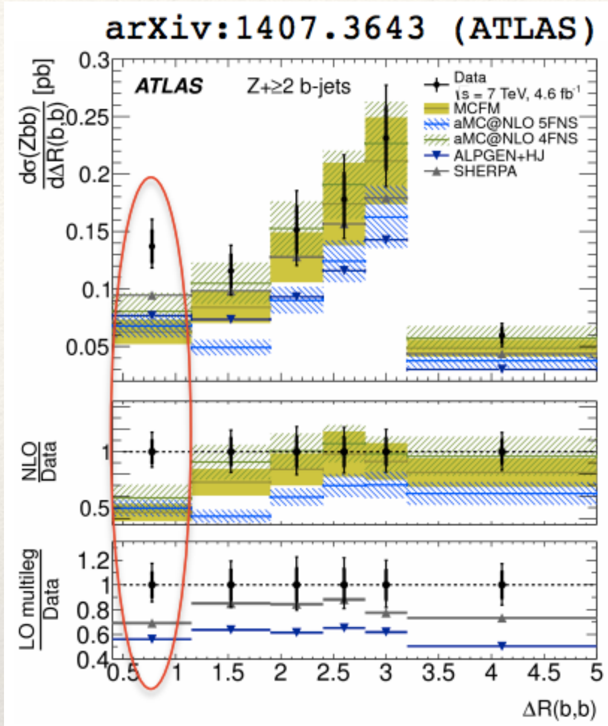
ATLAS-CONF-2014-035

- **Ratio 13 TeV/8 TeV:**
  - exploiting different reach in kinematics
  - requires careful consideration of correlations

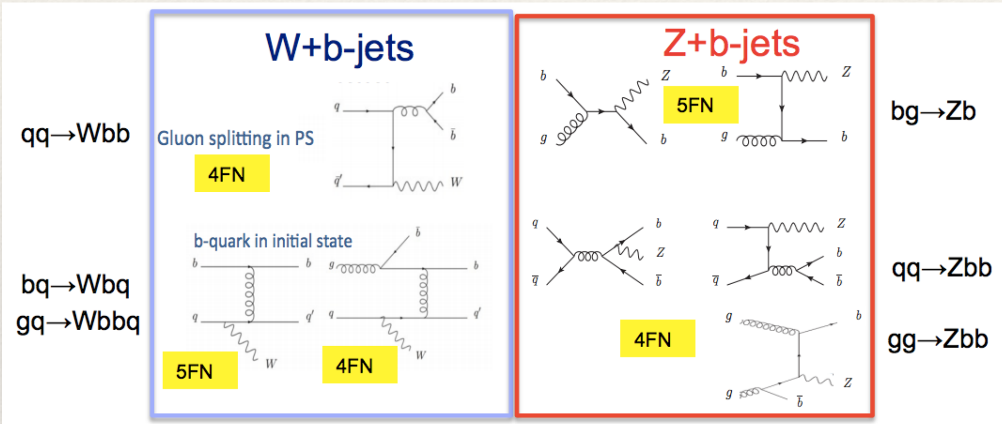
W/Z + heavy flavours in Run 2

W/Z+heavy flavour affected by larger theoretical uncertainties:

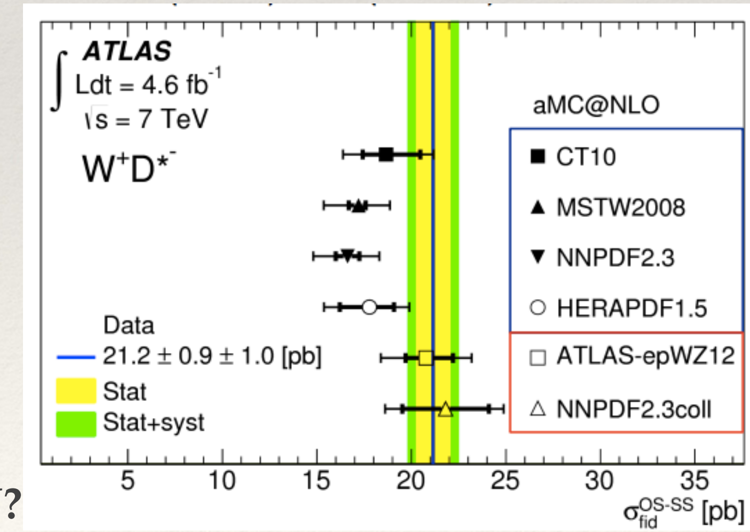
- heavy-quark content in the proton
- modelling of gluon splitting (initial state, final state)
- dealing with the heavy flavour schemes



- **W,Z+b-jet measurements interesting to explore the heavy flavour scheme dependencies:**



- **W+c-jets and W+ D* —> important constraint on strange**
  - 2011 analysis: statistically dominated
  - 13 TeV 2015 data could reduce stat. unc. by a factor 2
    - insertion of IBL could allow the widening of the phase space toward lower pT tracks



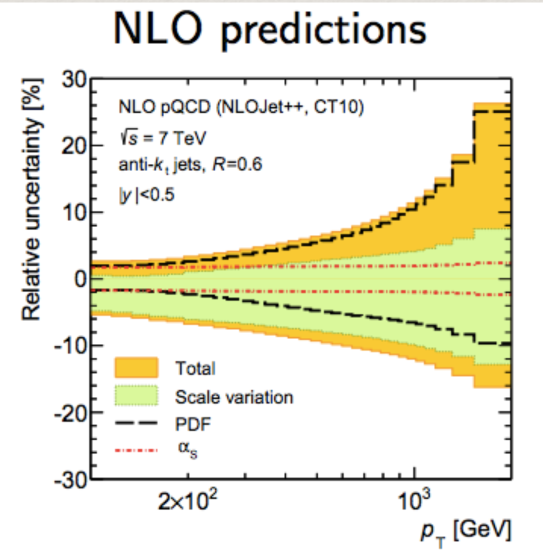
JHEP05(2014)068 (ATLAS)

ATLAS data suggests s-quark enhancement, what about 13 TeV?

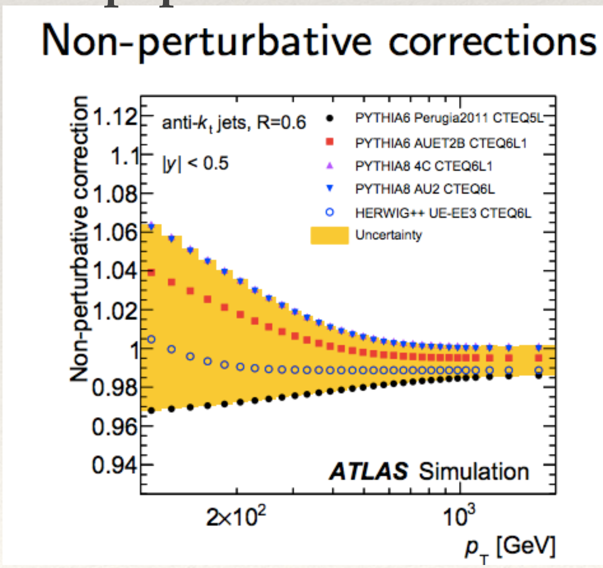
Jet measurements from Run 2

- Jet measurements can provide the following answers to:
  - is there any new physics?
  - do we have a good control of the underlying QCD?
- Early 13TeV data will likely lack the precision for SM free parameter constraints, but will be an important step in preparation for potential new physics phenomena:
  - Control of the JER/JES precision an important task for the jet cross section measurements
- Available theory predictions/tools:
  - Grid generation (NLOJet++), Convolution with PDFs (APPLgrid),
  - Will jet NNLO calculation become available for 2015?

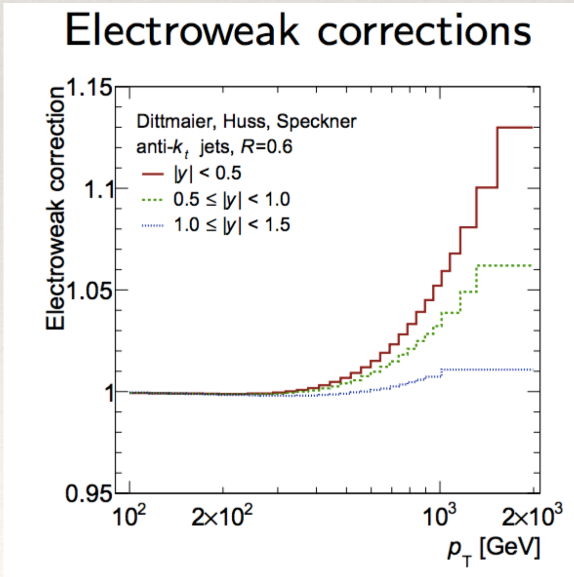
shown here from 7 TeV inclusive paper:



->New PDFs gave smaller unc. for 13 TeV



->from MC PYTHIA and HERWIG, new strategies for 13 TeV



-> Shifts QCD prediction up at high-pT

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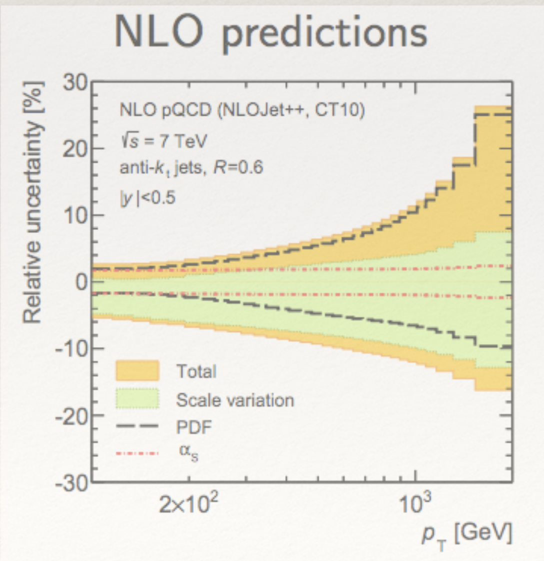
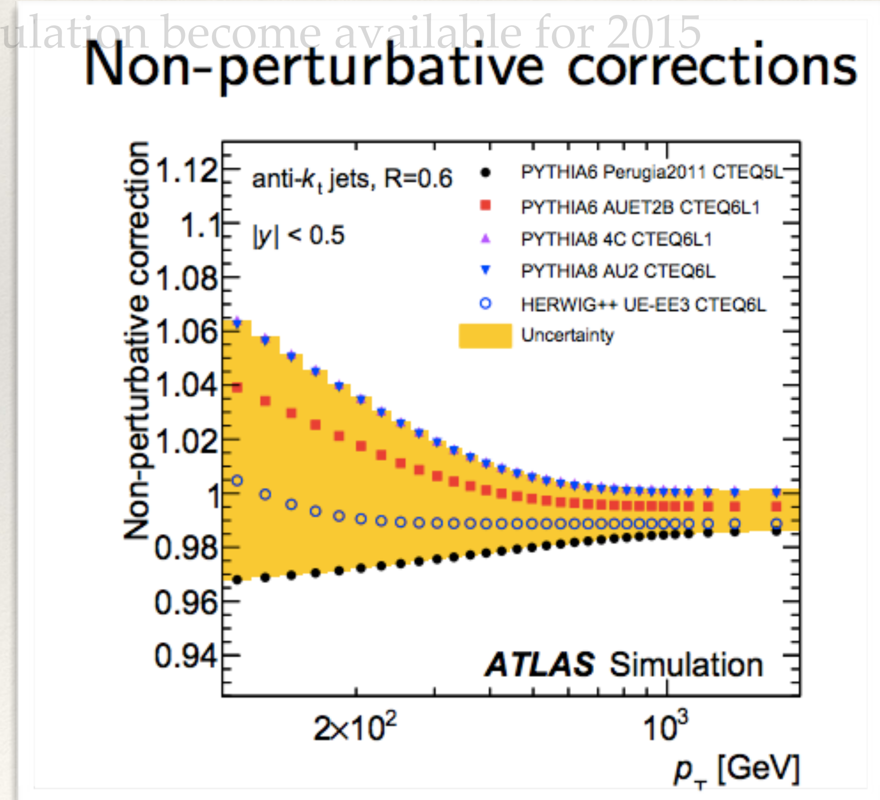
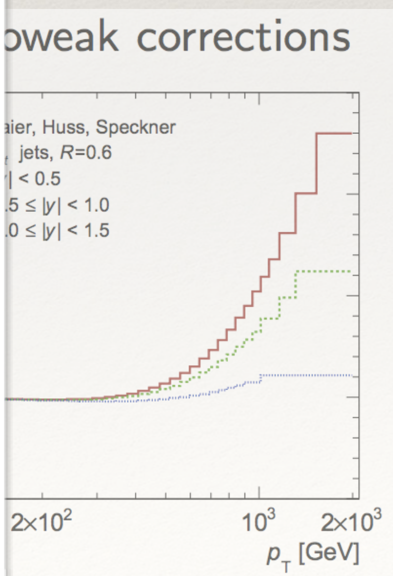
How to treat non pQCD uncertainties in the PDF fits?







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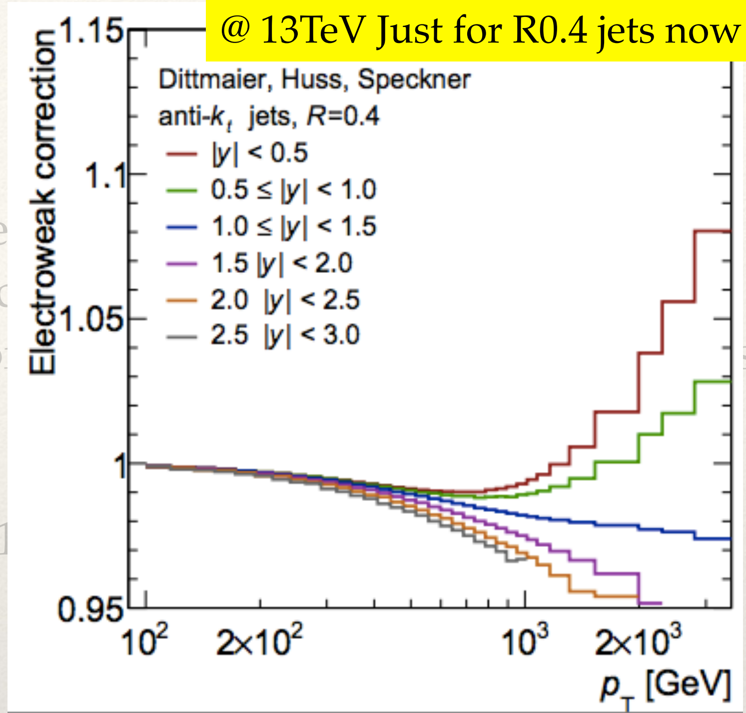
@ 13TeV Just for R0.4 jets now



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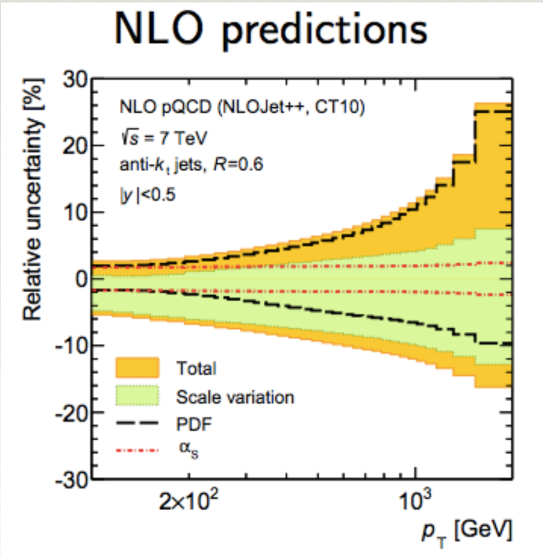

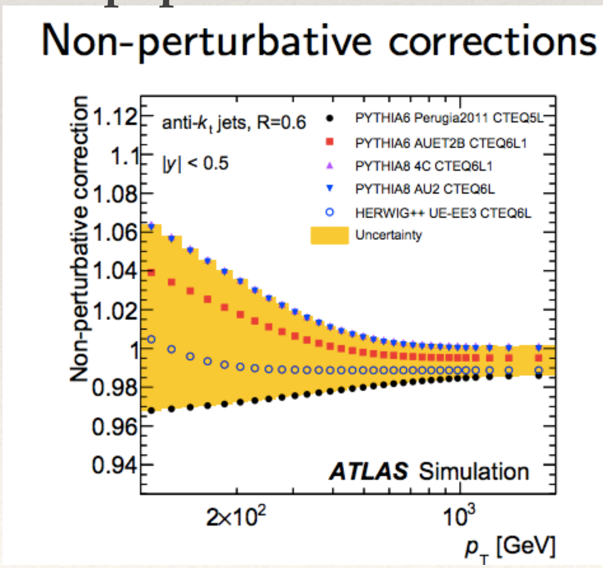

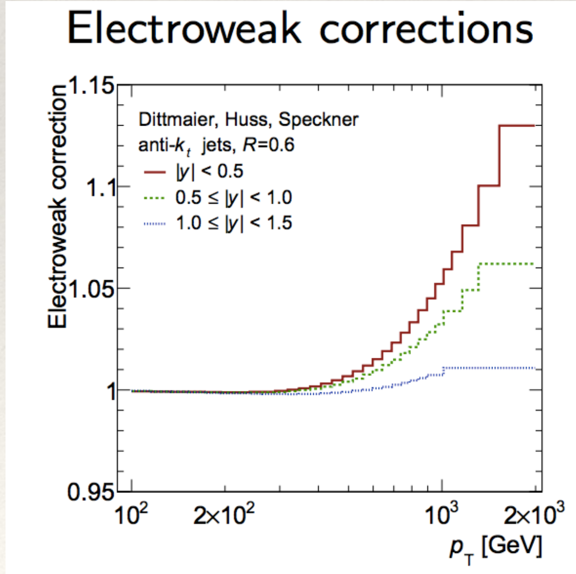

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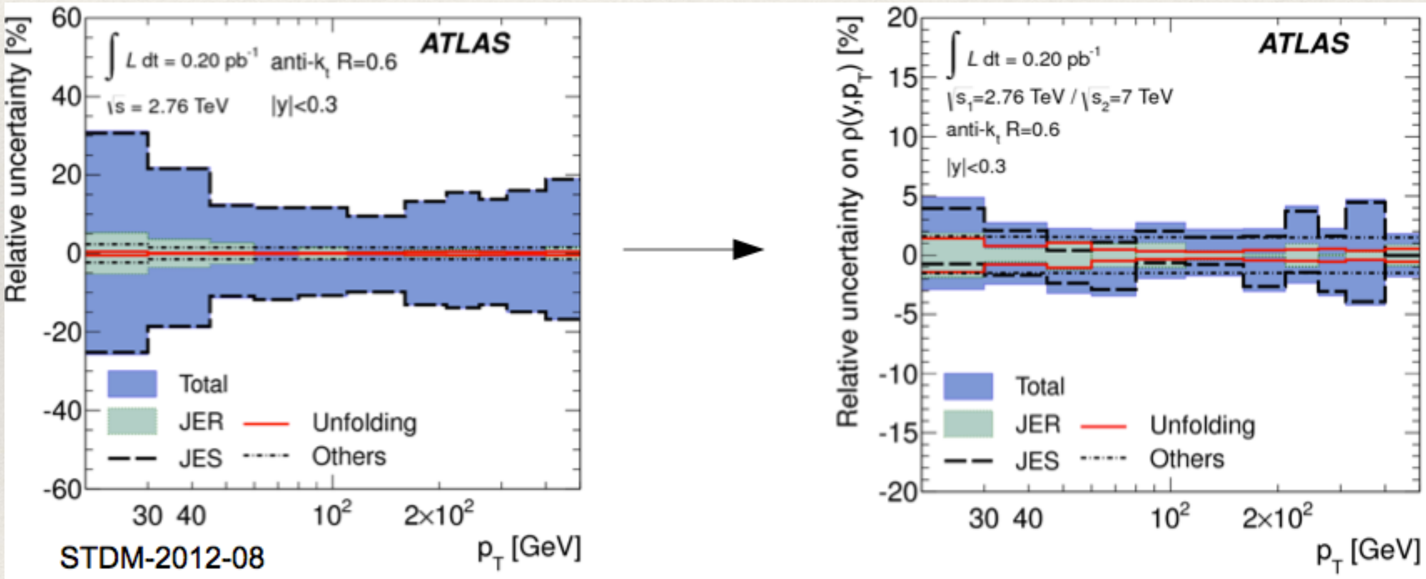
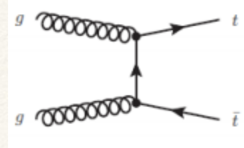
Jet measurements from Run 2

- Precise understanding of systematic uncertainties is essential if we want to use inclusive jet measurements in the PDF fits
- Jet measurements of 2015 bring a new kinematic reach with jet p_T up to 3.5 TeV, interesting to observe if it will help to further constrain PDFs
- Exploiting ratio measurements to better control the dominant JES uncertainty, as done for 2010 data:

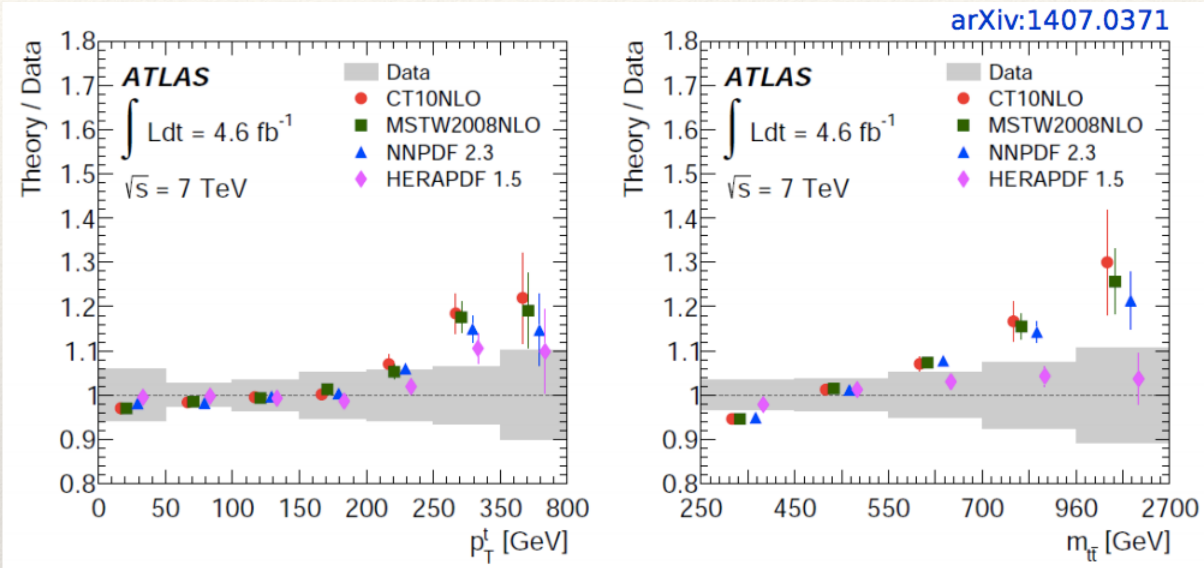


- Other measurements:
  - Dijet invariant mass,
  - multijet measurements, etc..

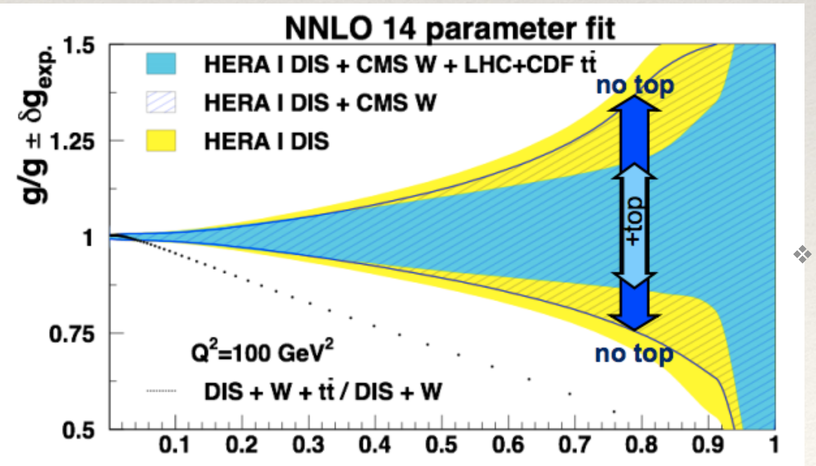
Sensitivity to PDFs from Top Production



- Top-quark pair production at the LHC probes high-x gluon (x ≈ 0.1):
  —> there is a strong correlation between g(x), αs and the top-quark mass mt
- Precise measurements of the total and differential (normalised and absolute) cross section of ttbar pair production can constrain and de-correlate αs, gluon, mt



  - compared with theory (NLO) using different PDFs
  - NNLO theory calculations are becoming available …



arXiv:1406.0386

- —> Expect improvement with 2015 data

Roles of PDFs in MC tuning

- Long tradition of ATLAS tunes, mostly for Pythia6 and Pythia8 generators:
  - Most recent tune is a global tune of Pythia8, prepared for Run 2: the A14 Tune

	Parameters	
Hard scattering	Factorization and renormalization scales, PDF, $\alpha_s(M_Z)$	Predicted by first principle in pQCD (pEW), “non-tunable”
Beam remnants	Primordial k_T smearing	Primordial k_T tuned with $p_T^Z < 5$ GeV
Parton shower ISR and FSR	$\alpha_s(M_Z)$, shower infrared cut-off, PDF	FSR tuned to LEP data and validated with jet shapes, ISR tuned to p_T^Z, dijet angular decorrelation, etc..
Multi-parton-interactions (MPI)	$\alpha_s(M_Z)$, infrared cut-off, PDF	Tuned to hadron collider data: minimum bias and underlying event observables
Color reconnection	Reconnect range, reconnect probability	Underlying event, minimum bias, ttbar
Hadronization	Fragmentation function, heavy flavour fragmentation fractions, etc...	Tuned to LEP data (f.i. e+ e- → Z → hadrons)
Decays	lifetime and decay widths	From PDG, validated with data

- In general, we have to tune the non-perturbative parameters of the models, since they cannot be derived (yet) by first principles.
  - it is usually considered ok to adjust some of the perturbative parameters to reabsorb higher order corrections (ISR, FSR, and MPI renormalisation scales, which are adjusted through the corresponding values,and recently the POWHEG hdamp scale
  - MC parameters are expected to be universal, the same set of parameters, or Tune, should be able to describe various processes, various collider energies, different types of collider

PDFs used in tuning PYTHIA 8

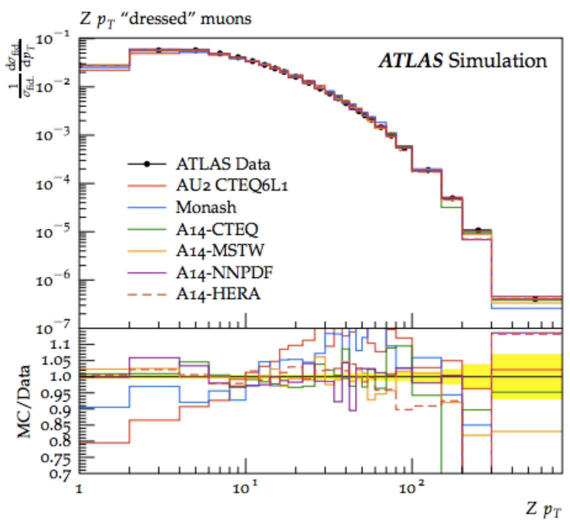
- **AU2** Tunes (previous Pythia8 standard):
  - Based on Pythia8 4C tune, but with x-dependent matter profile for MPI, as in 4Cx
- **AZ and AZNLO** Tunes (specific Z, W inclusive Tunes):
  - Based on Pythia8 4C Tune
- **A14 Tunes (new Pythia8 pre-recommendation)**
  - A global tune of shower and MPI
  - Using only LO PDF, following authors' recommendation
    - Represent our best starting point for Run 2 MC samples

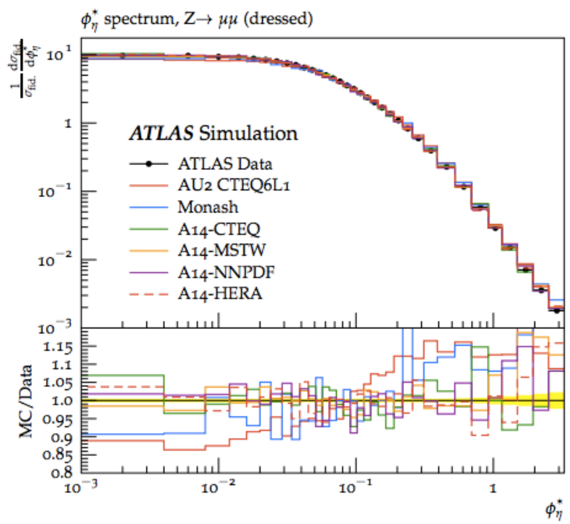
ATL-PHYS-PUB-2014-021 http://arxiv.org: 1406.3660.

PDFs used for tuning Pythia 8:

CTEQ6L1,
MSTW2008LO,
NNPDF23LO,
and HERAPDF15LO
—>a set of four tunes as
the "A14" (ATLAS 2014) tune series.

plan also inclusion of ATLAS PDF set?





- even if NLO and multileg are the standards it is still important to have a good shower:
  - For multijet matching the Sudakov factors typically are generated from showers. Therefore the accuracy of the matching is limited by the accuracy of the shower, and a correct high-pT behaviour has an impact, even if less so than the low-pT one.

Generators for Run 2

- Baseline generators considered for W, Z:
  - **Powheg+Pythia8 (NLO+PS)**
    - **main generator for W,Z inclusive (other generators for systematic assessment)**
  - Sherpa (2.X)
  - Alpgen, Madgraph

- Improvement in tuning methodologies:
  - the chi2 method used in automatisation is not a well defined quantity:
    - how to account for correlations?
    - take example of chi2 used in PDFs?
      - eig-tune method is an approach to account for different variations, but it does not take into account the correlations.

ATL-PHYS-PUB-2014-021

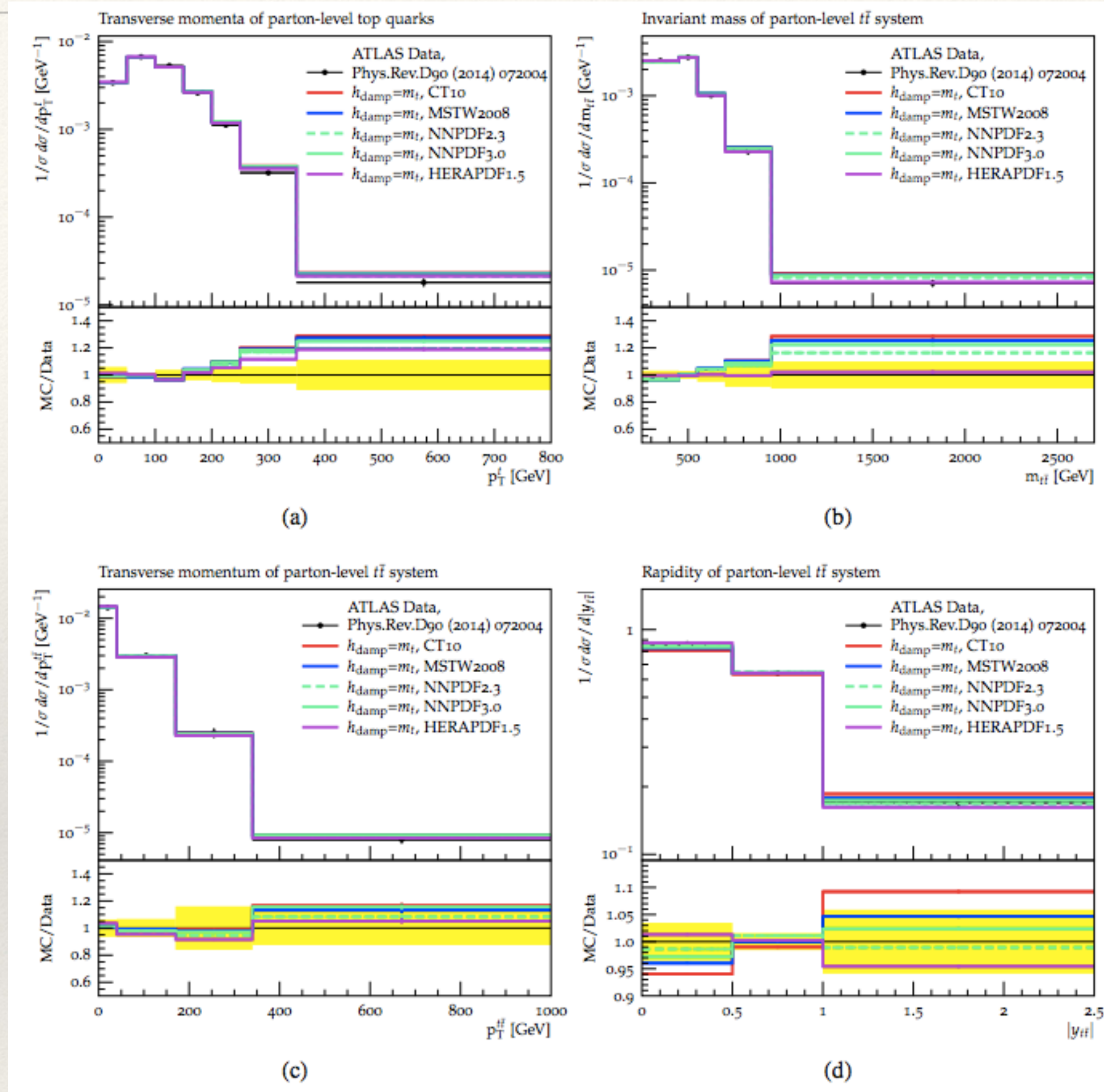
Modeling of final state particles in top production

- MC modelling is one of the major systematic uncertainties in top quark cross sections and of top quark properties in Run 1 measurements
- The choice of the PDF can have a significant impact on the kinematics of the $t\bar{t}$ process:
  - Powheg+Pythia6 samples with different PDF variations are compared to the transverse momentum of the top quark
    - PDF mainly changes the invariant mass and rapidity of the $t\bar{t}$ system

The discrepancy between the prediction and the experimental data for high top quark pT cannot be solved by any of the used PDF sets.

Newer generators:

- Powheg+Pythia8
  - produces too many additional jets
- MadGraph5_aMC@NLO+Herwig++
  - give a better description of the data



ATL-PHYS-PUB-2015-002

Summary

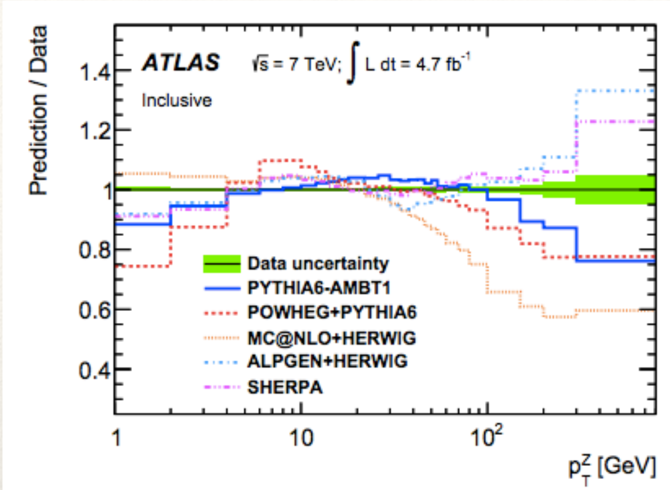
- The Run 2 will provide tests of the Standard Model in a new kinematic regime:
  - re-establishing the standard candle measurements
  - the early data will help to improve the machine performance to allow for precision physics
- The Run 2 is expected to impact PDFs by accessing a different kinematic region:
  - interplay of measurements at different centre of mass energy worth exploiting
  - use of super-ratios to enhance QCD effects
- MC modelling of data requires more studies:
  - choice of PDFs (as a free parameter in the tuning) is investigated for different cases
  - explore new methodologies to account for different variations and account for correlations?

back-up slides
not necessarily useful ...

Z P_T / φ*

http://arxiv.org: 1406.3660.

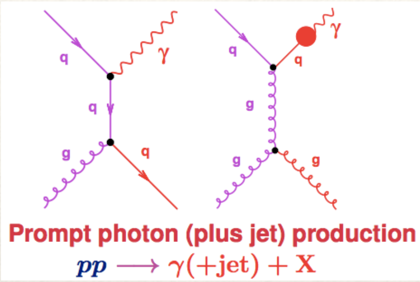
- ZPt is an ideal observable for tuning the ISR model parameters and the transverse momentum of the incoming partons,
  - The full ZpT range is sensitive to the shower evolution and can be used to tune the value of $\alpha s(M_Z)$ for the initial state radiation
  - The data are compared to predictions from Pythia6-AUET2B, Powheg+Pythia6-AUET2B, MC@NLO, Alpgen and Sherpa.
  - measurement used to tune PS for the Pythia8 and Powheg +Pythia8 generators (restricted to low Pt where PS dominate)

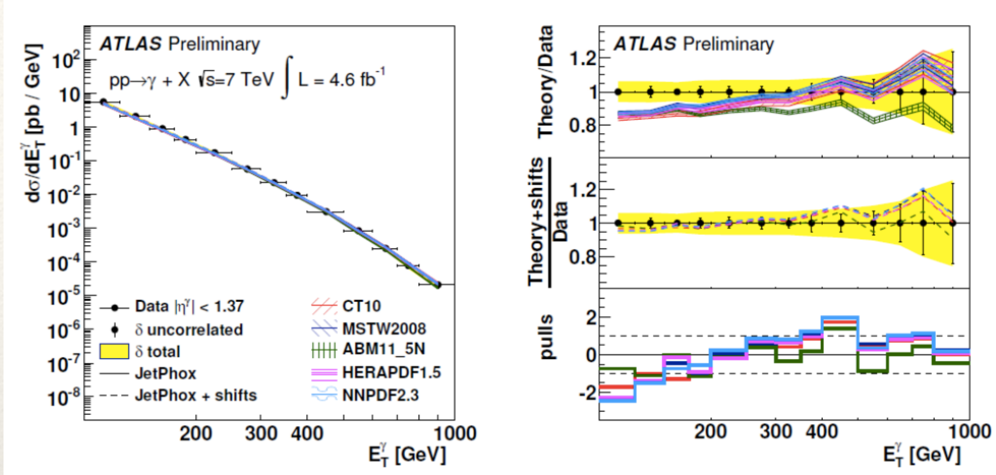


—> interesting measurement to better control MC tunes

Prompt Photon measurement from Run 2

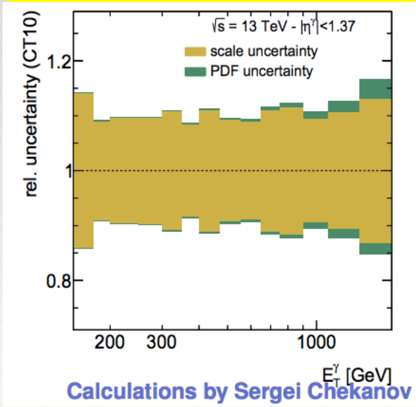
- Measurements of the production of high pT prompt photons (in association with jets) and pairs of photons in hadron colliders could be interesting constraining gluon PDF





- input to understand QCD background to Higgs production and BSM searches via MC tuning of models
- However, the theoretical uncertainty dominated by missing higher orders —> NNLO?

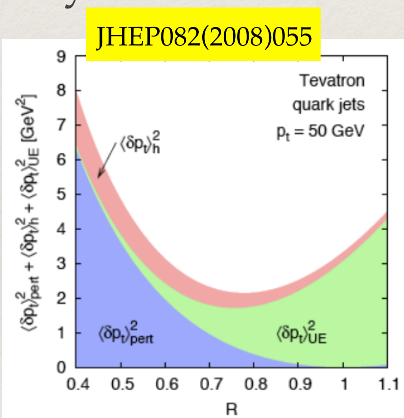
th. unc for 13 TeV

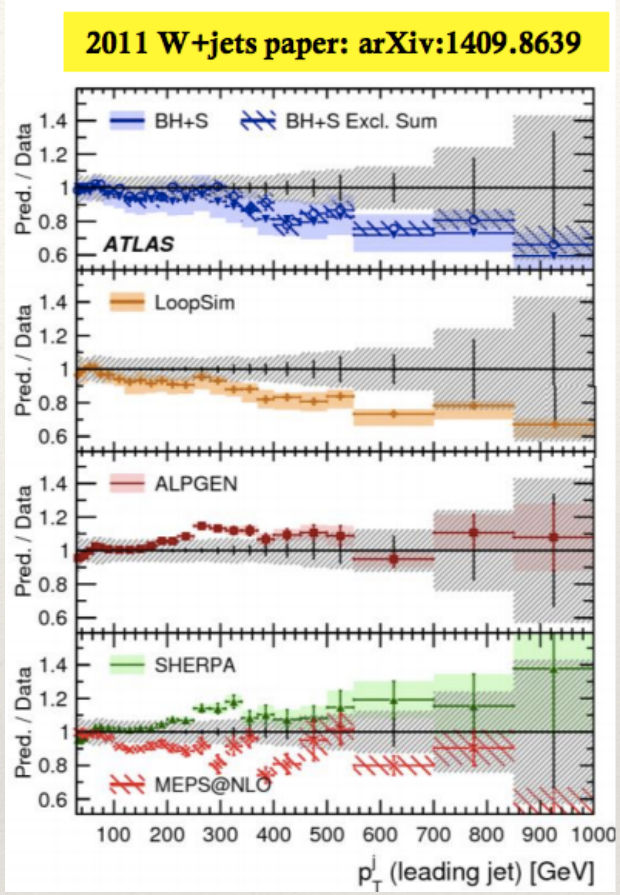


- Measurements of ratio σ(13 TeV)/σ(8 TeV):
  - SM test/PDF fits with reduced uncertainties ?

W/Z + jets as a probe in "extreme region"

- In Run 2 higher energy will allow to test higher pT region testing the validity of pQCD:
  - high Ht and Njets, or shapes with boosted boson and/or high jet pT in Z ...
- Measurements with different jet radii could reveal QCD effects:
  - could provide inputs for PS modelling and for the validity of the calculation

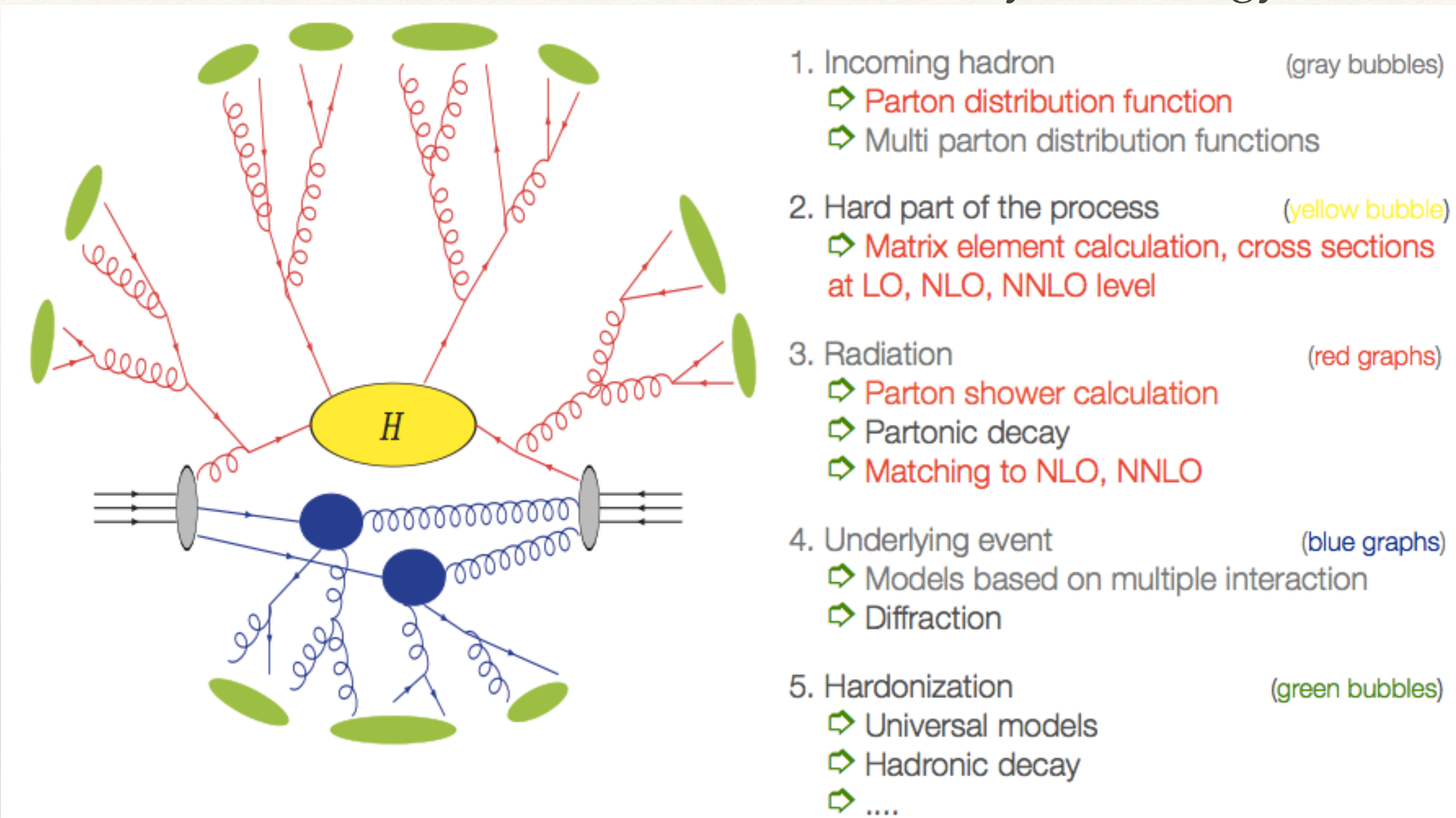




  - Scale uncertainty for W/Z+n-jets can depend on jet size:
    - hadronisation effects become larger as R decreases —> restriction in the gluon phase space can affect the scale dependence

Roles of PDFs in MC tuning

- Structure of an event at the LHC (courtesy of Z. Nagy)



Perturbative framework:

- LO: easy to calculate: several matrix element generators are available:
  - ALPGEN, HELAC, MADGRAPH, SHERPA
  - Strong dependence on the unphysical scales
  - well defined with LO PDF
- NLO is the New Standard: HELAC, MADGRAPH, SHERPA+BLACKHAT, AUTODIPOLE, TEVJET, AMC@NLO
  - The scale dependence can be still big in some processes
- NNLO & NkLO: Resummation - Parton Showers: POWEHEG

Pythia8 ATLAS tunes

- AU2 Tunes (previous Pythia8 standard):
  - Based on Pythia8 4C tune, but with x-dependent matter profile for MPI, as in 4Cx
- AZ and AZNLO Tunes (specific Z, W inclusive Tunes):
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- A14 Tunes (new Pythia8 pre-recommendation)
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