Standard Model Results from ATLAS
(early 13 TeV data)

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IFJ PAN

On behalf of the ATLAS Collaboration

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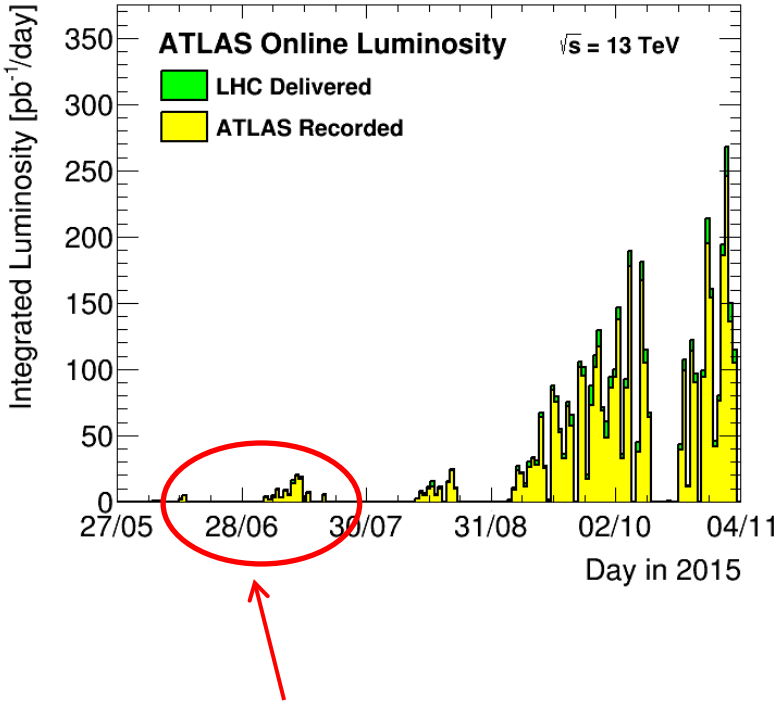
Overview

- Outline of discussed measurements:
  - Charged particle production (ALT-CONF-2015-028)
  - Underlying event (ATL-PUB-2015-019)
  - Inelastic pp cross-section (ATL-CONF-2015-038)
  - Inclusive jet cross-section (ATLAS-CONF-2015-034)
  - W/Z cross-sections (ATL-CONF-039, ATL-CONF-041, ATL-PHYS-PUB-2015-021)
  - Z+jet cross-section (ATLAS-CONF-2015-041)
  - Inclusive photons (ATL-PHYS-PUB-2015-016)
  - ZZ cross-section @ 13 TeV - see Stefan Richter's talk on Saturday

- 2015 LHC at 13 TeV data:
  - low average number of pp interactions/bunch crossing, $\langle\mu\rangle$ – a good place to study basic event properties at new energy frontier, large cross-section processes
  - high $\langle\mu\rangle$ – hard physics at new energy, small cross-section processes

Introduction

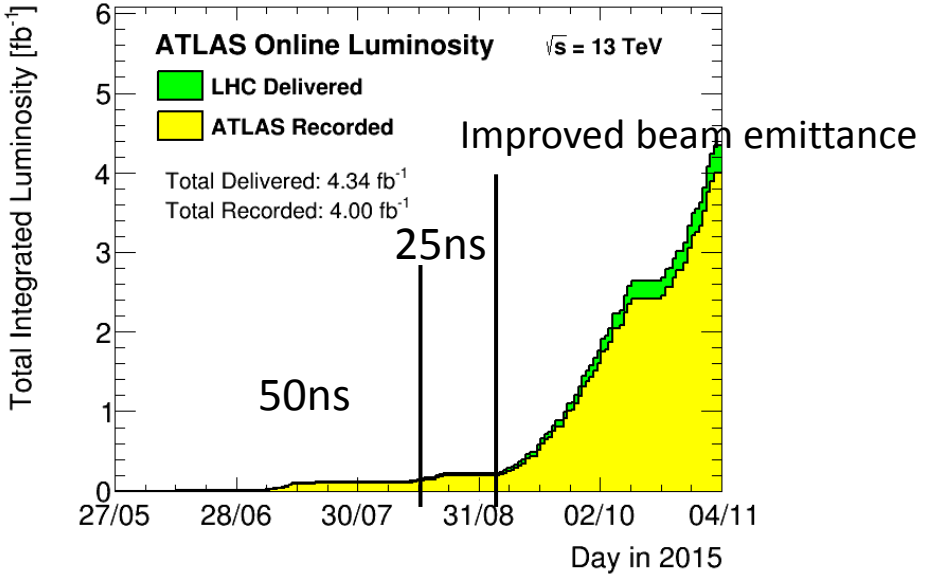
2015 – LHC RUN2 with √s = 13 TeV



Presented results coming from this period
Also with extremely low pile-up

Machine works well

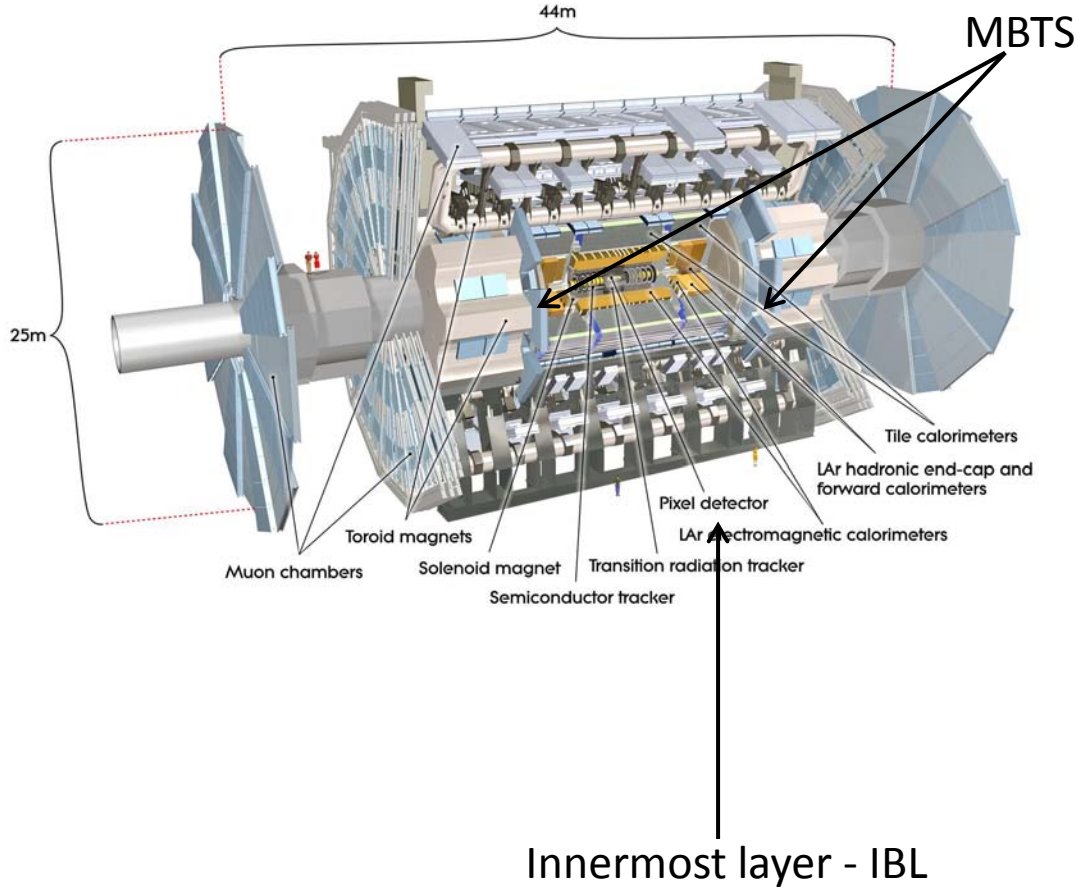
Good ATLAS overall data taking efficiency

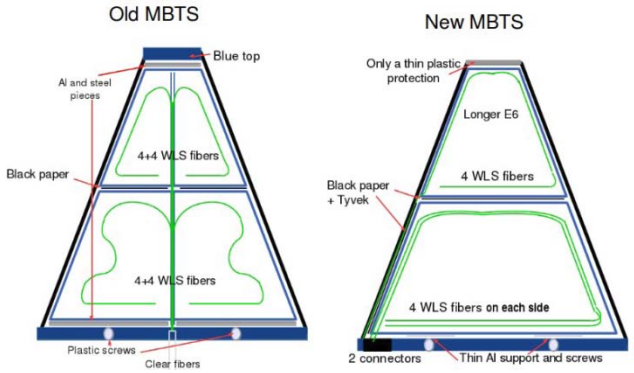


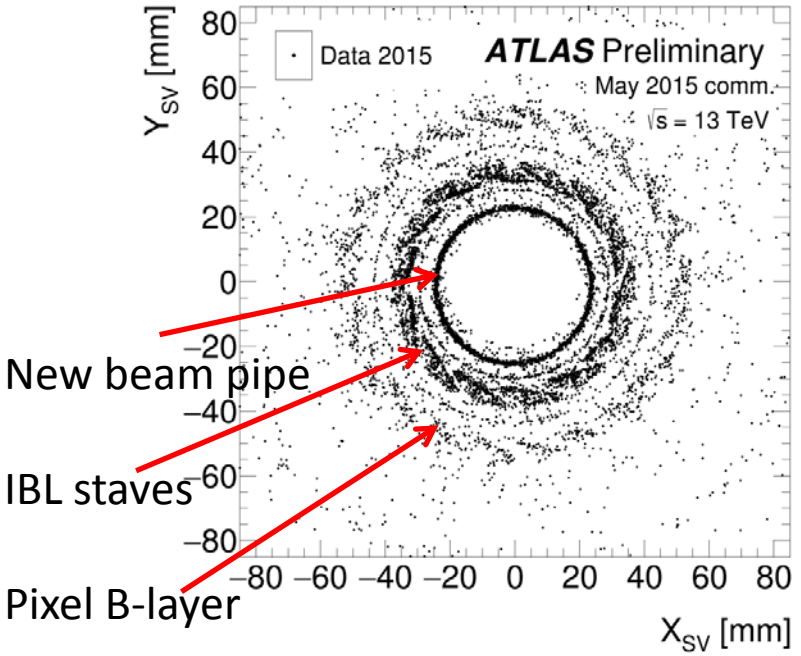
Introduction

Refurbished/upgraded ATLAS detector
- Insertable B Layer (IBL)
- MBTS

For details see Martin Wessels and Hoong Ma presentations







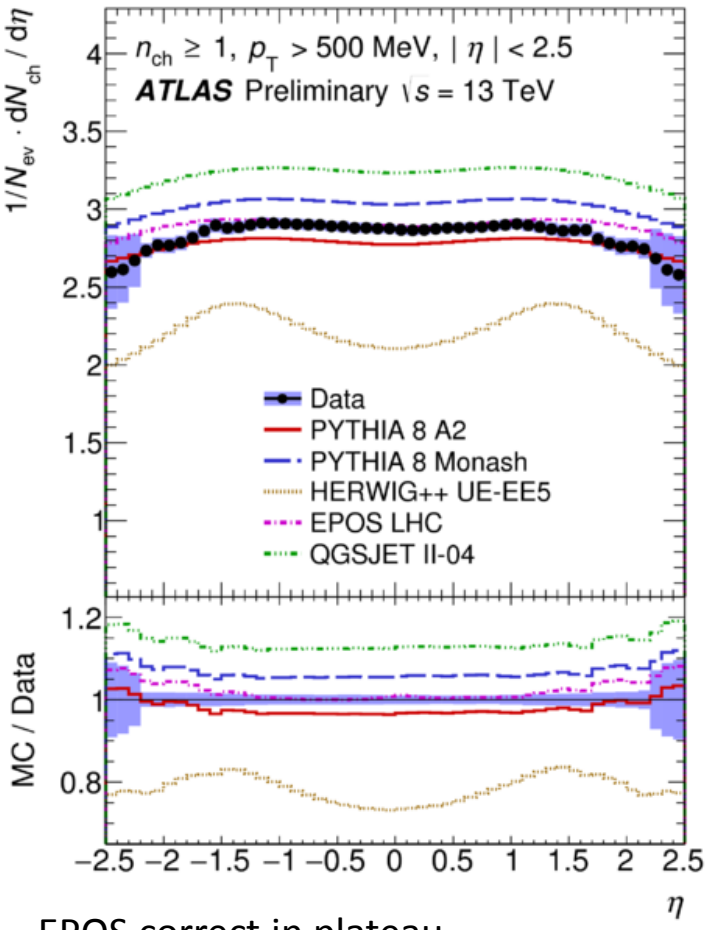
Charged particle production

Charged particle production at 13 TeV

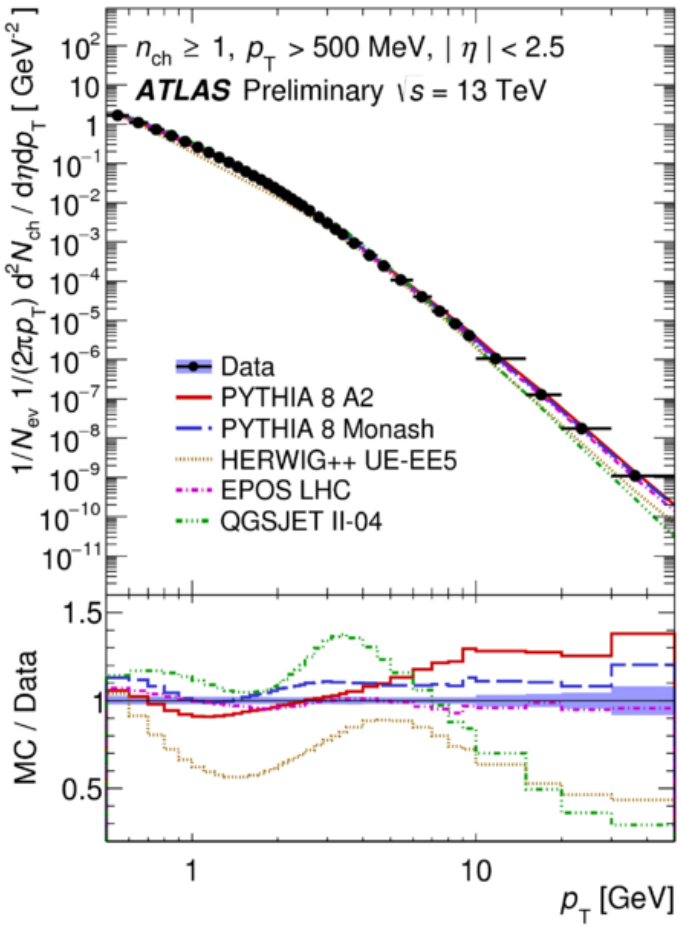
- Basics, insight into the non-perturbative QCD, MC models tuning, constraining multi-parton interactions
- Measure charged particle distributions: η, p_t, n_{ch}, $\langle p_t \rangle$ vs. n_{ch}
- Data: 170 μb^{-1} (~9 000 000 events), $\langle \mu \rangle = 0.005$
  Only primary particles:
  stable charged: $\tau > 300$ ps produced in pp collisions
  or charged decay products of particles with $\tau < 30$ ps
  strange baryons excluded
  Previously charged particles with 30 ps < τ < 300 ps were included (strange baryons)
- Main parts: TRT, SCT and pixels (IBL), MBTS
- Requirements: trigger – minimum bias, vertex, track quality, $p_t > 500$ MeV/c, $|\eta| < 2.5$
- Predictions:

Generator	Version	Tune	PDF	Focus	Who
Pythia 8	8.186	A2	MSTW2008LO	MB	ATLAS
Pythia 8	8.186	Monash	NNPDF2.3LO	MB/UE	Author's
Pythia 8	8.186	A14	NNPDF2.3LO	UE/shower	ATLAS
Herwig++	2.7.1	UEEE5	CTEQ6L1	UE	Author's
EPOS		LHC		MB	AstroPart.
QGSJET – II	II-04	Default		MB	Author's

Charged particle production at 13 TeV



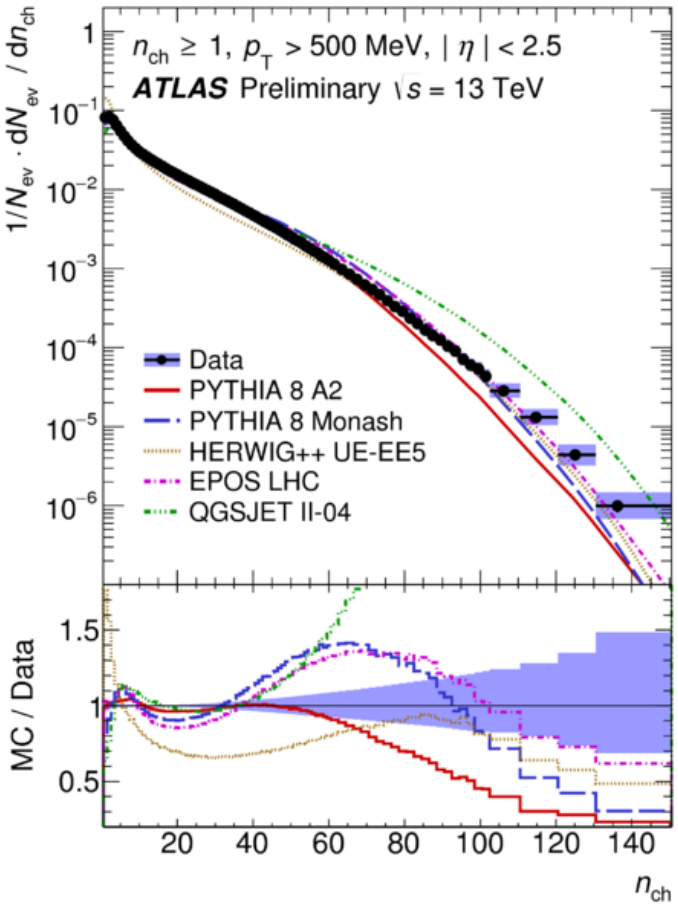
Largest uncertainties from tracking

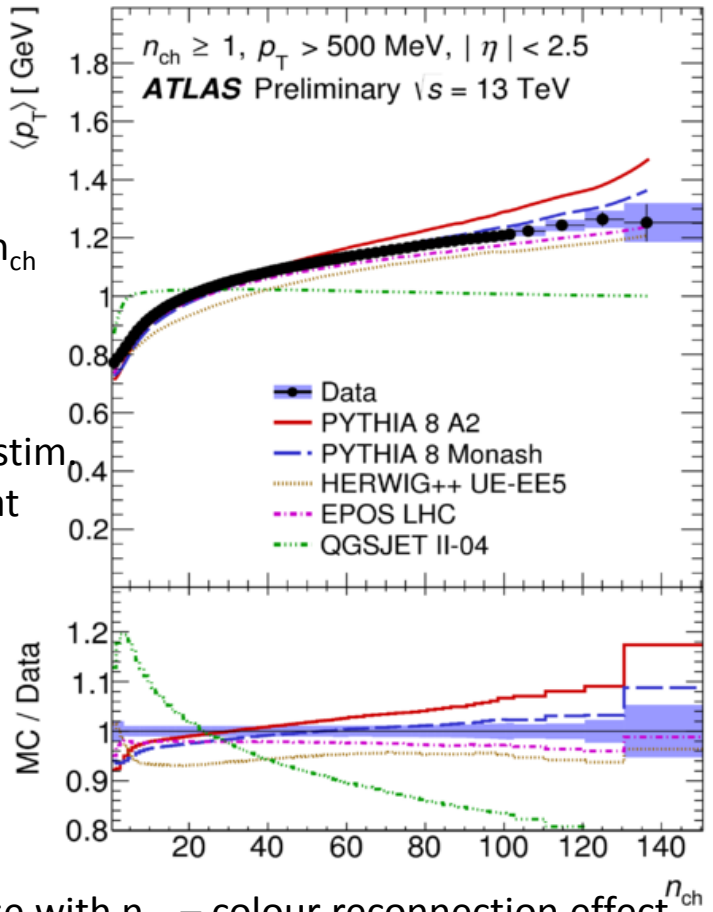


EPOS correct in plateau
QGSJET-II & Pythia 8 MONASH – overpredict (15%, 5%)
PYTHIA 8 A2 – below at mid-rapidities (3%),
fine for $|\eta|>2$
HERWIG++ UE-EE5 fails but no min. bias data in tune

EPOS does well
PYTHIAs reasonable,
overpredicting for larger p_T
QGSJET-II, HERWIG++ UE-EE5 fail

Charged particle production at 13 TeV





$\langle p_T \rangle$ increases with n_{ch}

EPOS fine
PYTHIAs 8 steeper
HERWIG++ underestim,
QGSJET-II nearly flat

$\langle p_T \rangle$ increase with n_{ch} – colour reconnection effect

PYTHIA 8 A2 proper description for $n_{ch} < 50$,
PYTHIA 8 MONASH, EPOS and QSGJET-II:
reasonable for $n_{ch} < 30$
HERWIG++ UE-EE5 fails

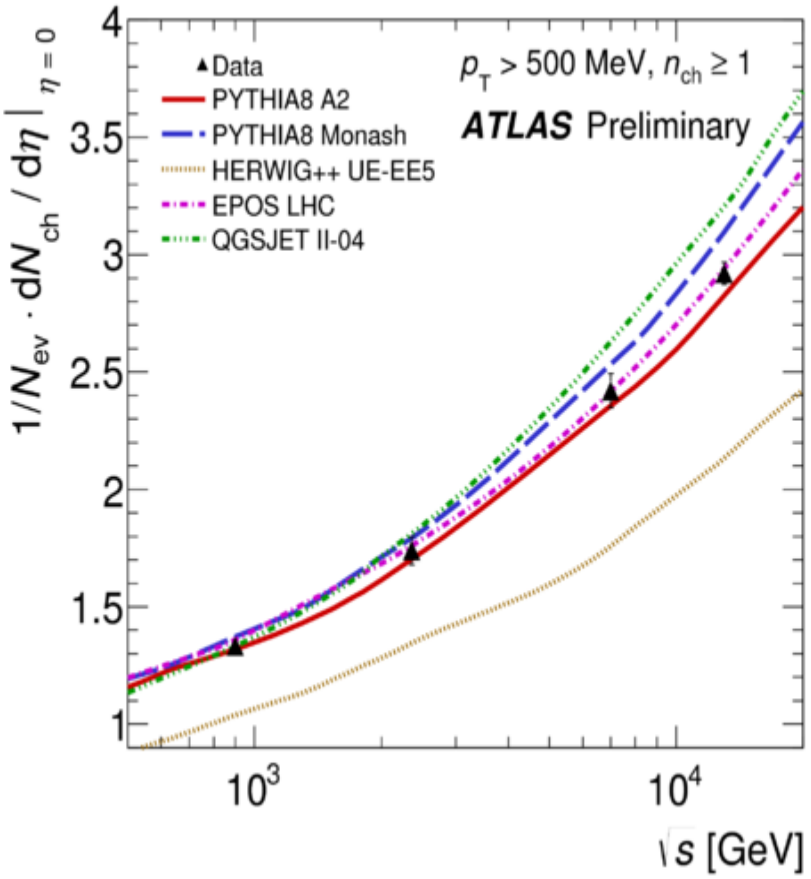
If MPI dominates large n_{ch} => $\langle p_T \rangle$ approximately flat
if no colour reconnection
If c.r. on => multiplicity decreases for a given number
of MPIs and p_T per track increases

Charged particle production at 13 TeV

- Calculate charged multiplicity within $|\eta| < 0.2$
  To compare with previous measurements strange baryons correction included:
  Δn_{ch} = 1.015+-0.009

- Data:
  factor of ~2.2 between 900 GeV and 13 TeV
  ~1.2 between 8 TeV and 13 TeV
  match with lower energy results

- MC predictions:
  PYTHIA 8 A2 and EPOS do well
  PYTHIA 8 MONASH and QGSJET-II overestimate
  HERWIG++ underestimates



Summary:
EPOS – best description
PYTHIA 8 A2 & MONASH - reasonable
QGSJET-II and HERWIG++ - the worst

Underlying event

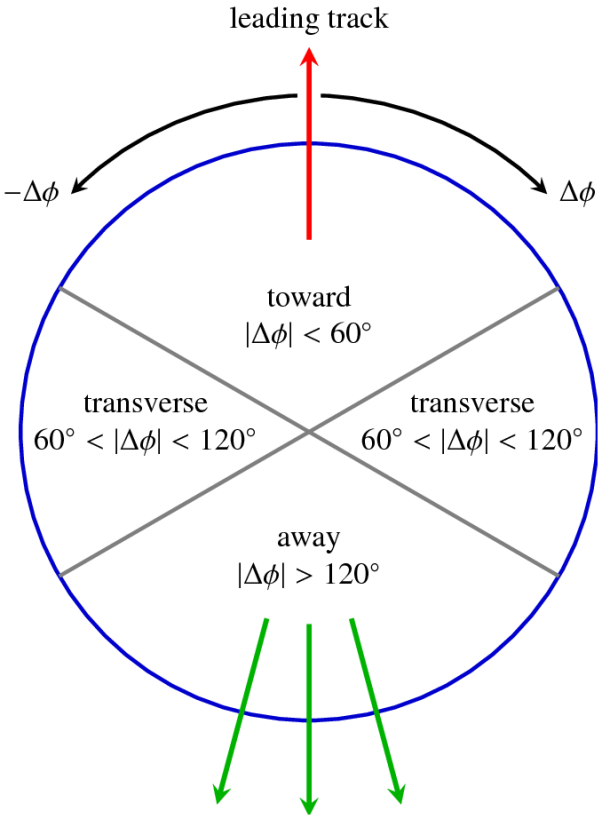
Underlying event (UE)

- UE – activity accompanying any hard scattering in a collision event, beam remnants, MPI, also ISR and FSR contribute

  cannot be uniquely separated from hard process on the event-by-event basis

  look at the production in the plane perpendicular to hard scatter - diminished influence of hard process - sensitivity to UE

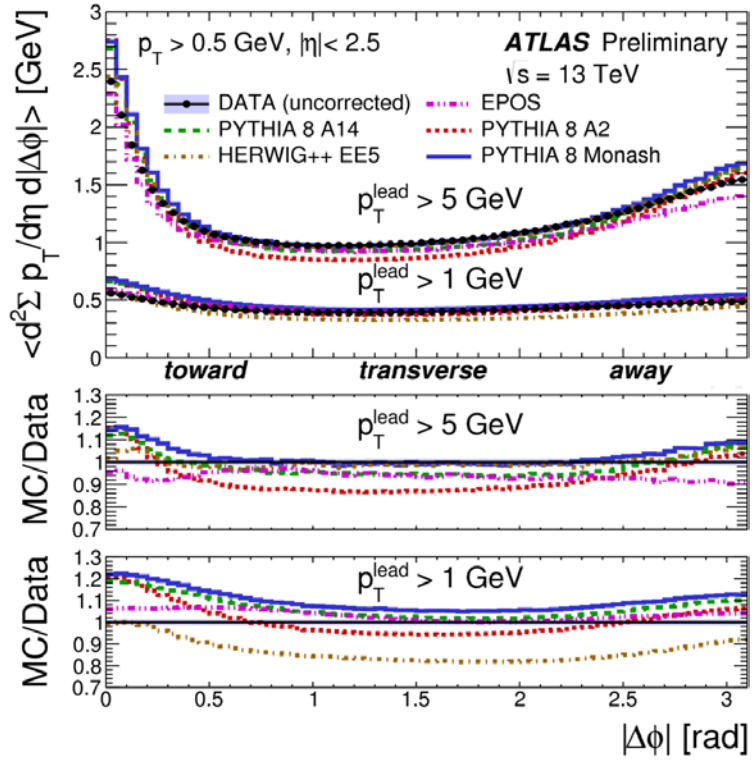
Compare the detector level quantities & MC predictions

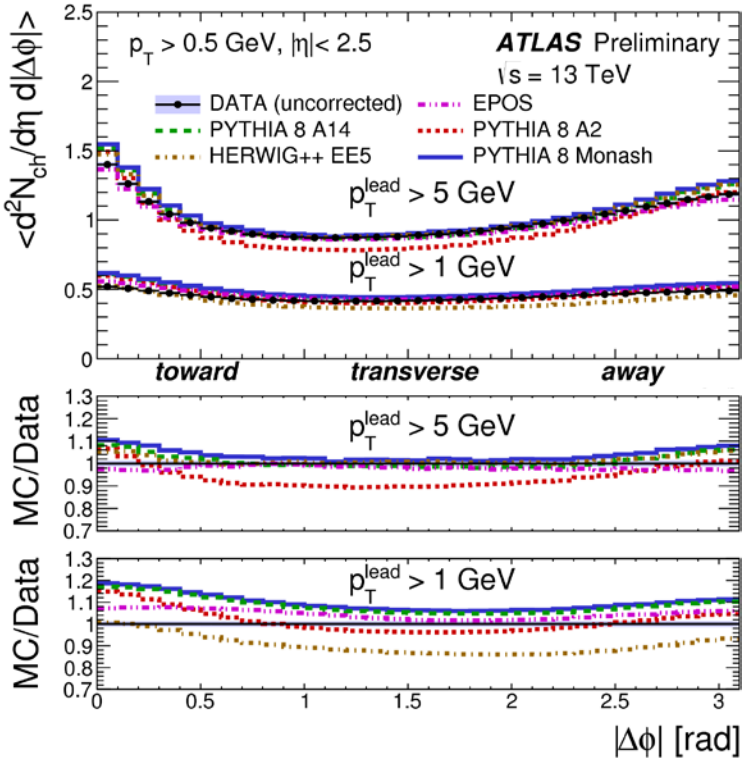


- Data: 170 μb^{-1} (~9 000 000 events), $<\mu> = 0.005$

  1. MBTS trigger
  2. A leading track with $p_t > 1$ GeV/c -> fully efficient trigger
  3. Primary vertex + pile-up veto
  4. $p_t > 500$ MeV/c, $|\eta| < 2.5$ + quality cuts

Underlying event

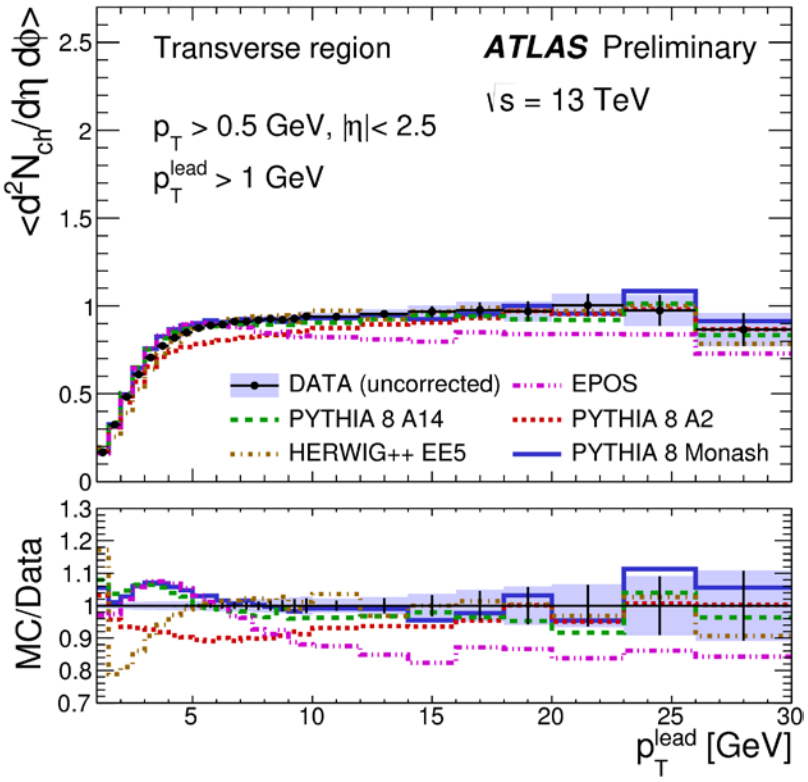


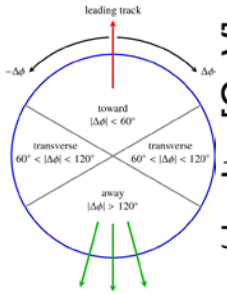


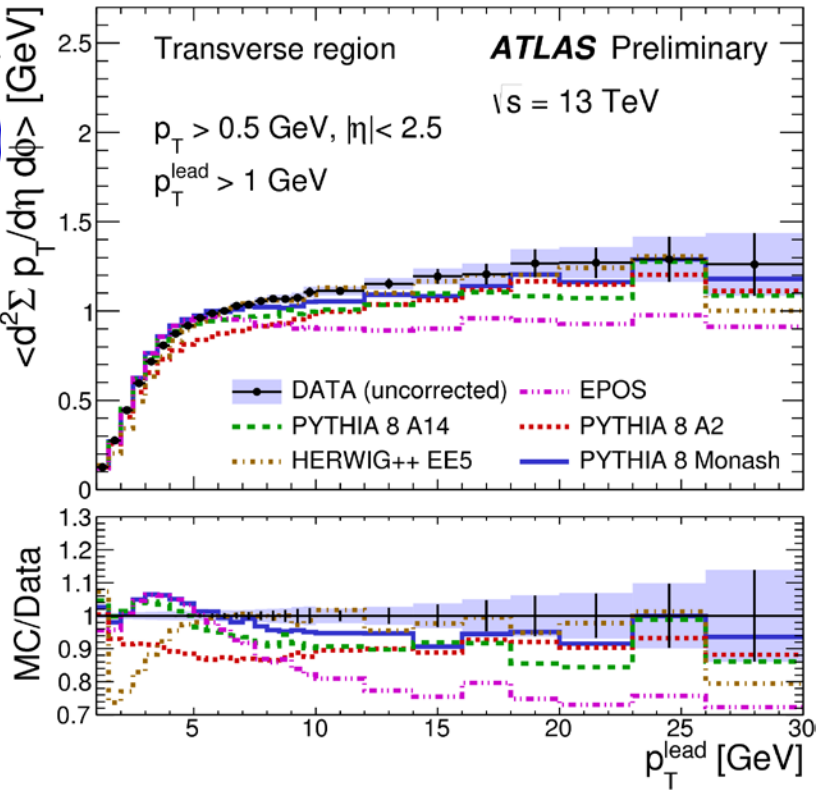
Expectations: gradual transition from inclusive min. bias to hard with increasing p_T^{lead}

PYTHIA A2 and EPOS better for lower p_T^{lead} – tuned to min. bias data
PYTHIAS A14 & MONASH, and HERWIG++UEEE5 for p_T^{lead} > 5GeV – UE tunes

Underlying event







An approximate plateau for $p_T^{lead} > 6$ GeV/c

PYTHIAs 8, HERWIG++ close to data for $p_T^{lead} > 6$ GeV/c

Σp_T rise – not properly described

EPOS poor for higher p_T^{lead} – absense of semi-hard min. bias

Inelastic cross-section

Inelastic cross-section

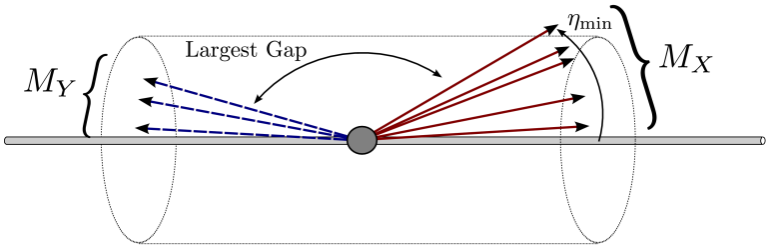
- Non-perturbative QCD domain
  Colorless (diffractive) or colored exchange
  Basic measurement but important also for cosmic ray investigations
  Energy dependence limited by $\ln^2 s$ – F-M bound

- ATLAS elastic scattering measurement yields:

  σ_{inel}=71.34±0.34(stat.)±0.90(syst.)mb@7TeV (Nucl. Phys. B889 (2014) 486)

- Measure fiducial cross-section and extrapolate it
  The largest gap is used to define two collection of hadrons – dissociation systems
  larger invariant mass (M_X) defines

$$\xi = \frac{M_X^2}{s}$$



  Elastics: $\xi > 6*10^{-9}$
  MBTS efficient above 50% if $\xi > 10^{-6}$

- Fiducial cross-section:

$$\sigma_{inel}(\xi > 10^{-6}) = \underbrace{\frac{N_{ev} - N_{bckg}}{\varepsilon_{trig} \cdot L}}_{\text{Data}} \cdot \underbrace{\frac{1 - f_{\xi<10^{-6}}}{\varepsilon_{sel}}}_{\text{Monte Carlo}}$$

Result:

$\sigma_{inel}(\xi>10^{-6})$ = 65.2±0.8(exp.)±5.9(lum.) mb

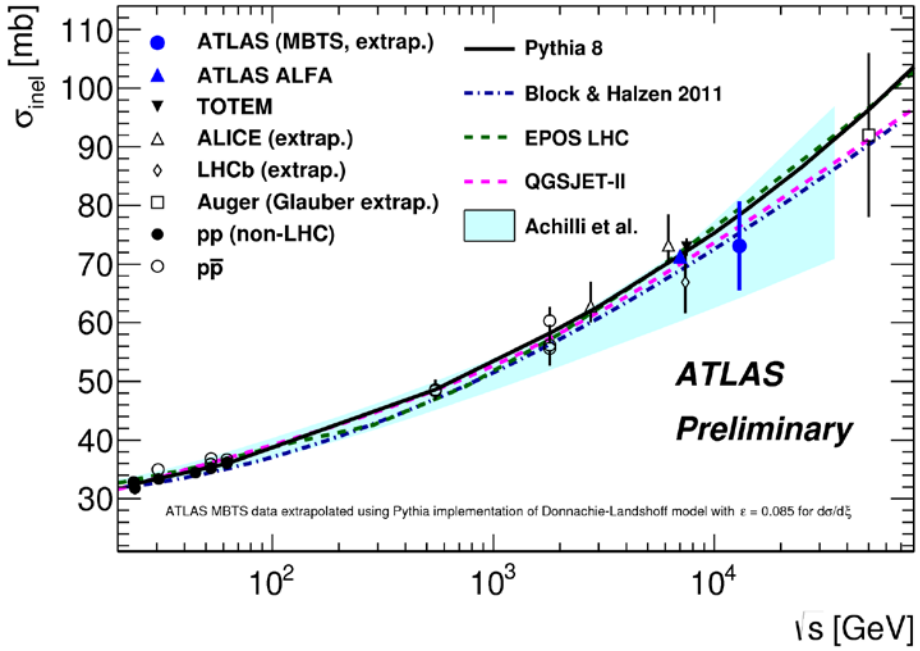
Inelastic cross-section

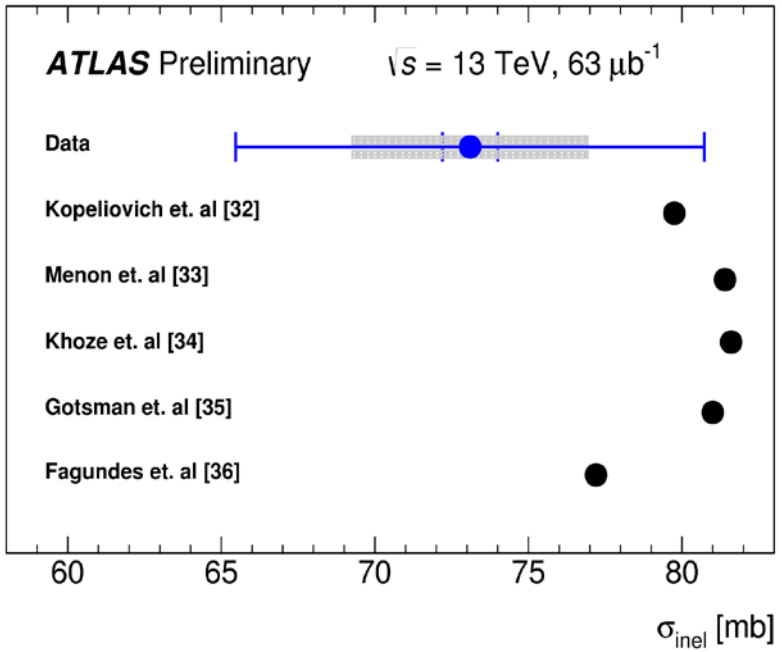
Extrapolation:

PYTHIA 8 DL 0.085 and $f_D = \frac{\sigma_{SD} + \sigma_{DD}}{\sigma_{inel}}$ (from data): fraction of events with $\xi > 10^{-6}$: 0.891±0.046

Acceptance with different MC models between 0.876 and 0.937 -> extrapolation uncertainty

$$\sigma_{inel} = 73.1 \pm 0.9(\exp.) \pm 6.6(lum.) \pm 3.8(extr.)mb$$

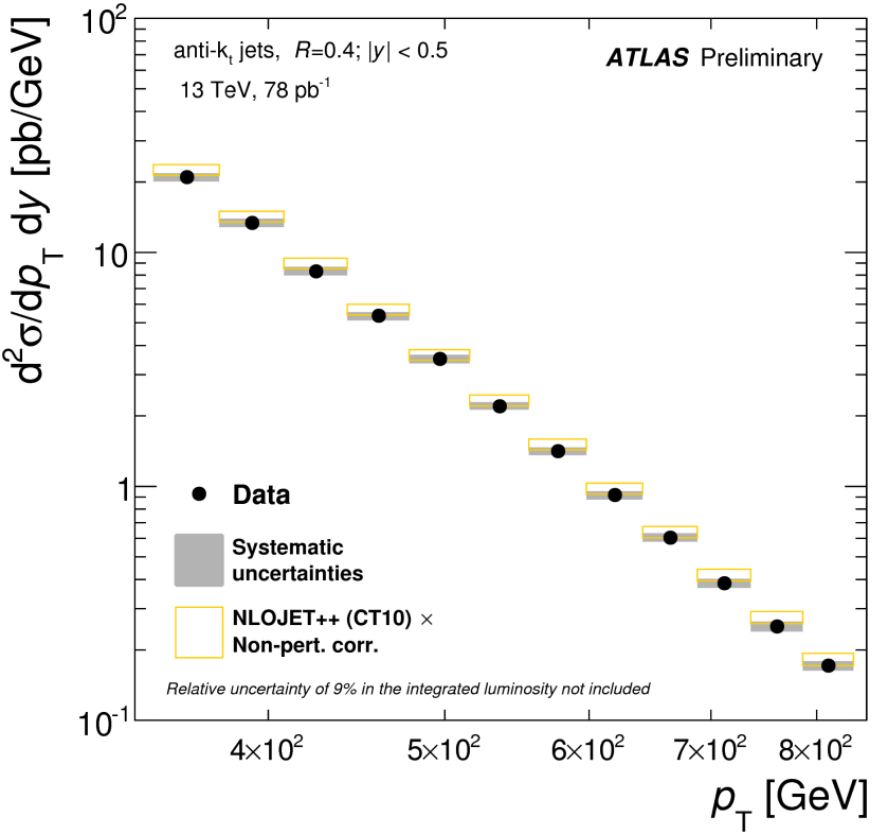




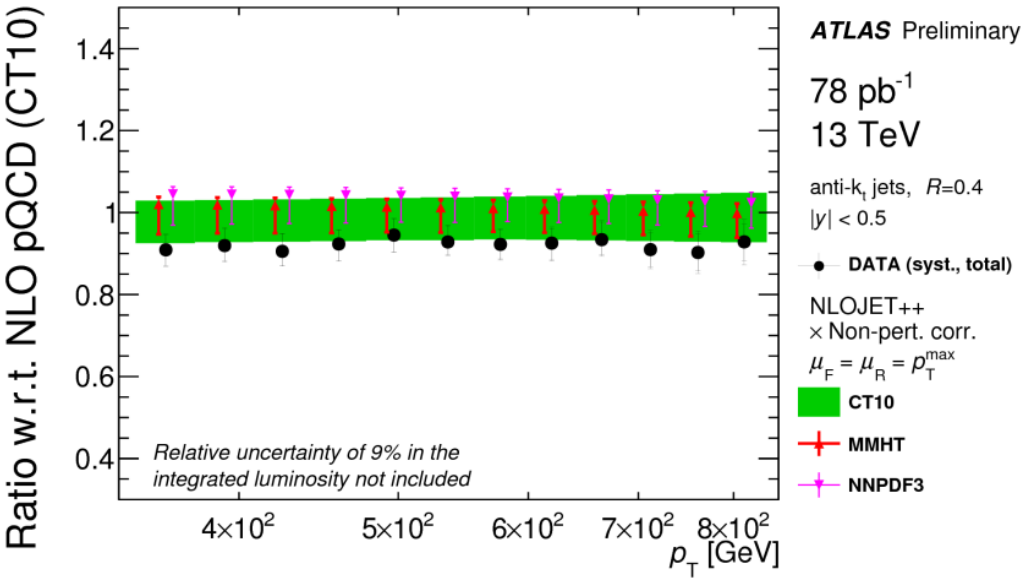
Good match with lower energies and predictions

Inclusive jet cross-section

Inclusive jet cross-section – QCD at TeV scale



Jets with anti-k_t, R = 0.4, $|y| < 0.5$, 78 pb^{-1}



Inclusive jet cross-section well described by NLO pQCD + CT10 + non-perturbative effects
Reasonable agreement for ratios using MMHT and NNPDF3 NLO sets

Inclusive W/Z production

Inclusive $W^{\pm}/Z$ production

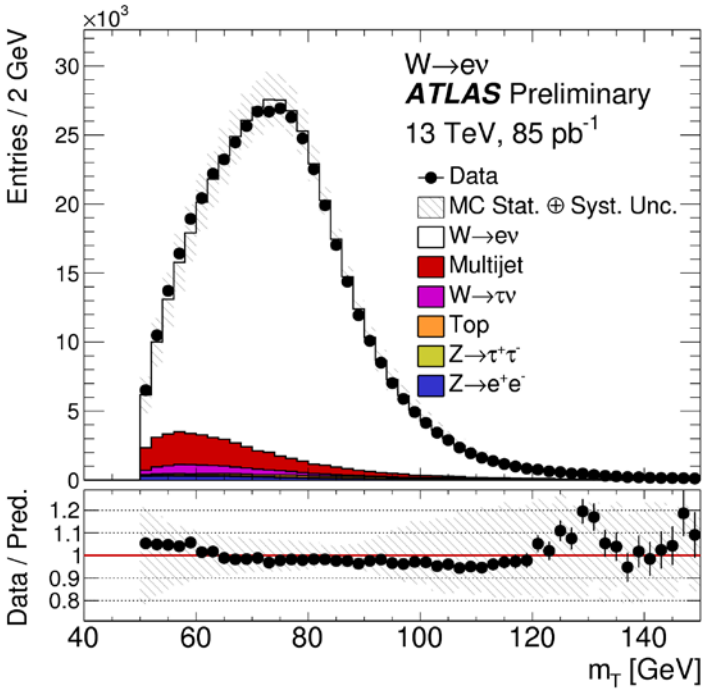
- Leptonic final state easily identifiable decay mode
- Theory prediction QCD@NNLO (includes EWK@NLO), cross-section depends on the PDFs -> a tool to test parton dynamics
- Data: 85 pb^{-1} at 13 TeV, peak $L = 1.7 \cdot 10^{33}$ $cm^{-2}s^{-1}$, $<\mu> = 19$

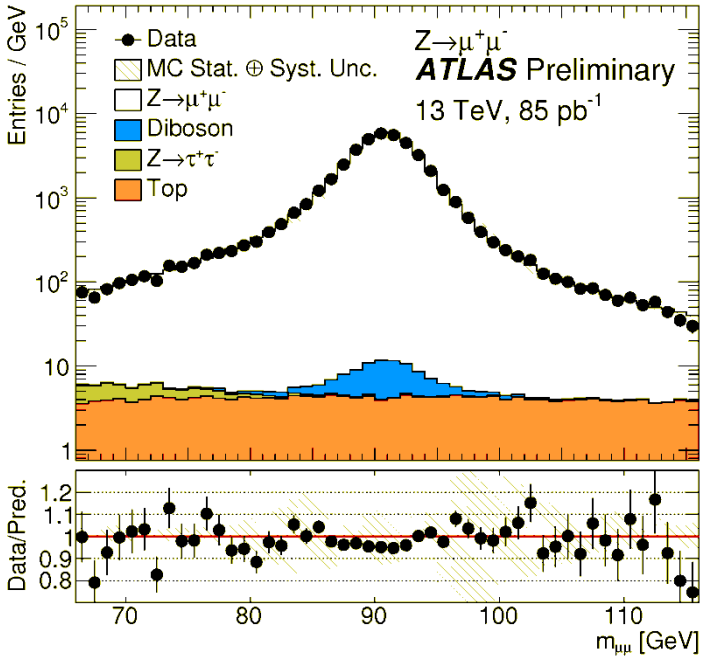
W:

$$p_T^l > 25GeV$$
$$E_T^{miss}, p_T^{\nu} > 25GeV$$
$$|\eta_l| < 2.5$$
$$m_T = \sqrt{2 p_T^l p_T^{\nu}[1-\cos(\phi_l - \phi_{\nu})}) > 50GeV$$

Z:

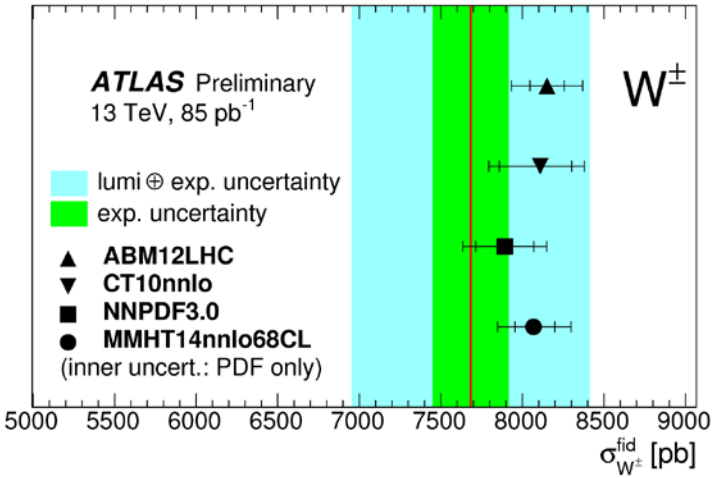
$$p_T^l > 25GeV$$
$$|\eta_l| < 2.4$$
$$66 < m_{ll} < 116GeV$$

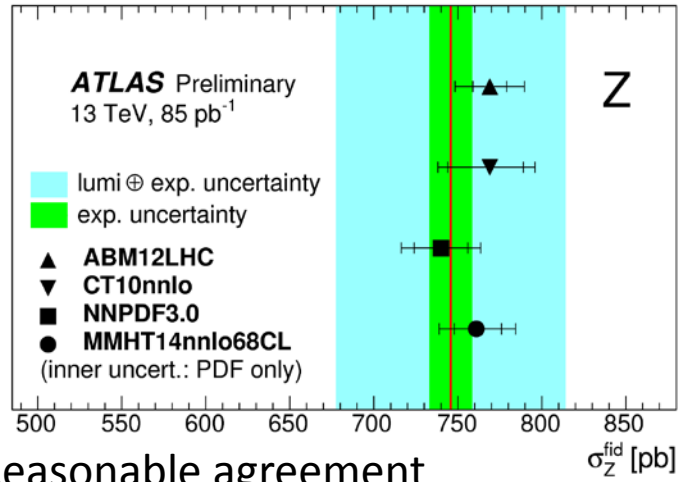




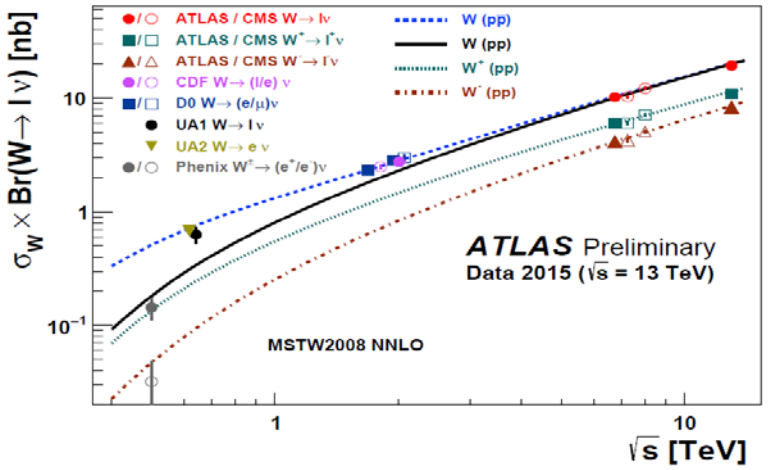
Inclusive $W^{\pm}/Z$ production

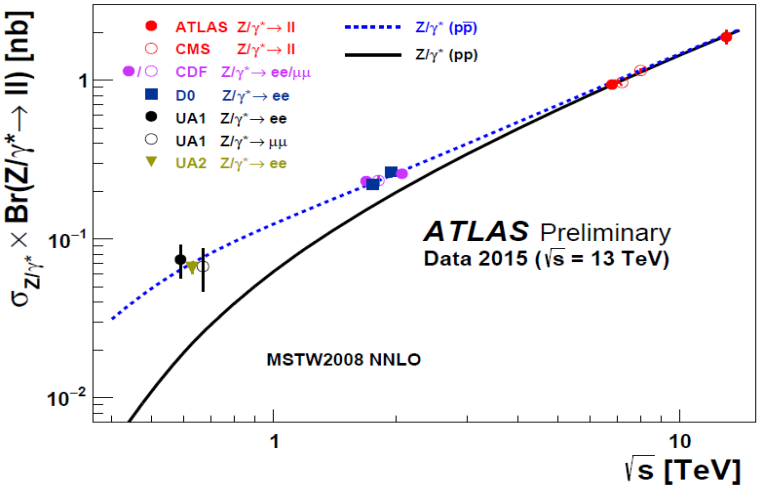
$\sigma_{fid.}$ – avoid theoretical uncertainties





Reasonable agreement

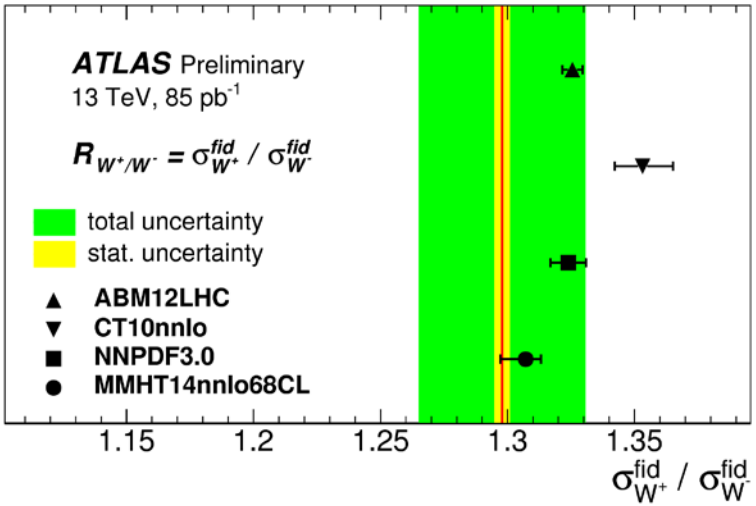


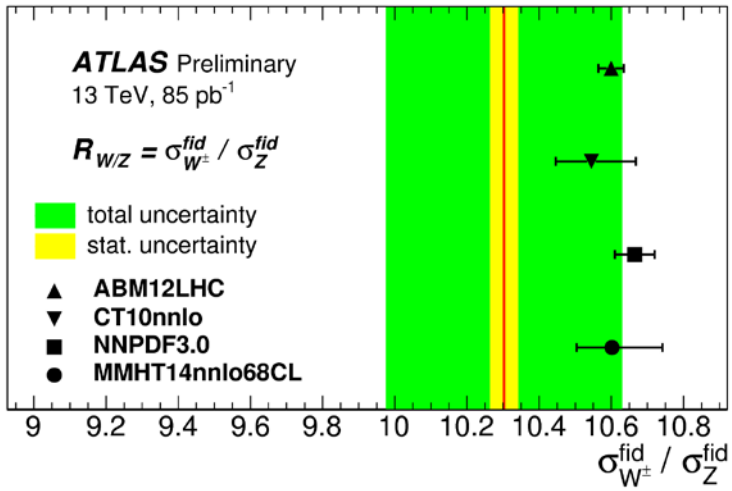


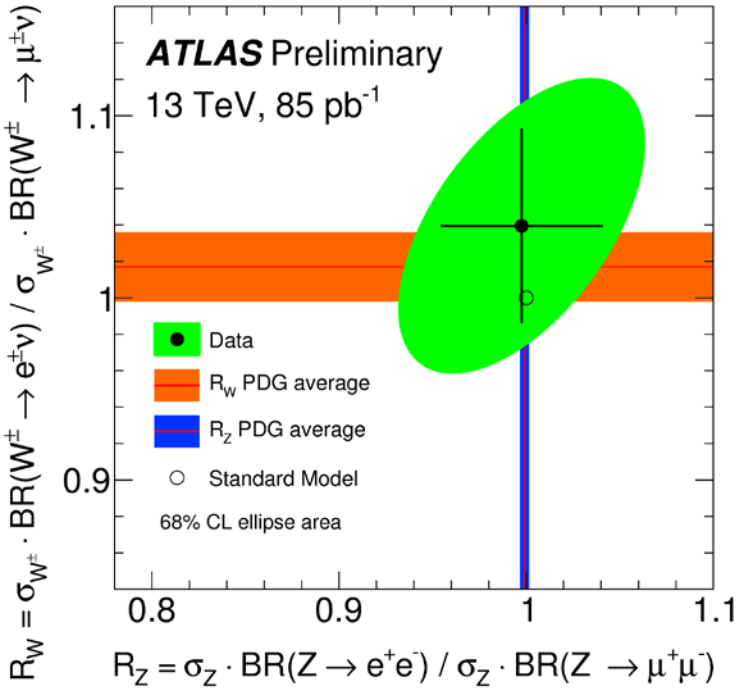
Good match with lower energy measurements

At the moment luminosity uncertainty limits the precision

Inclusive $W^{\pm}/Z$ production







Reasonable agreement with SM predictions

Ratios show potential to discriminate among PDFs

Z+jets cross-section

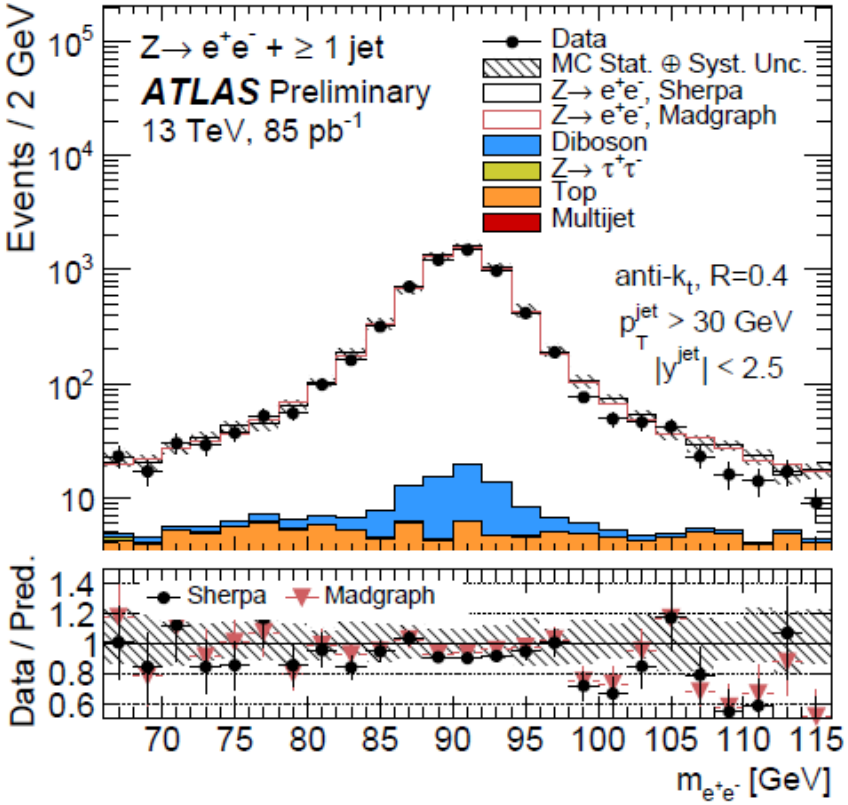
Z + jets cross-section

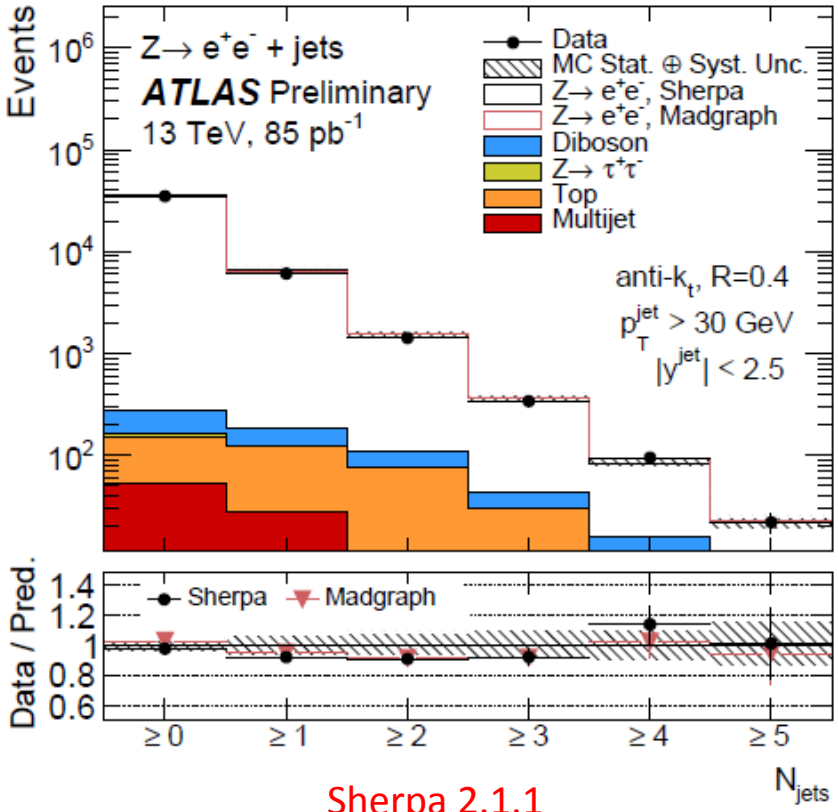
Benchmark for pQCD+EW processes
Backgrounds to Higgs and new physics

Data: 85 pb^{-1}

$$Z \to l^+l^- \quad l^\pm = e^\pm, \mu^\pm$$
$$p_T^l > 25GeV, |\eta_l| < 2.4$$
$$66 < m_{ll} < 116GeV$$

Jets: anti-k_t, R=0.4, $|y|<2.5$, $p_T>30$GeV

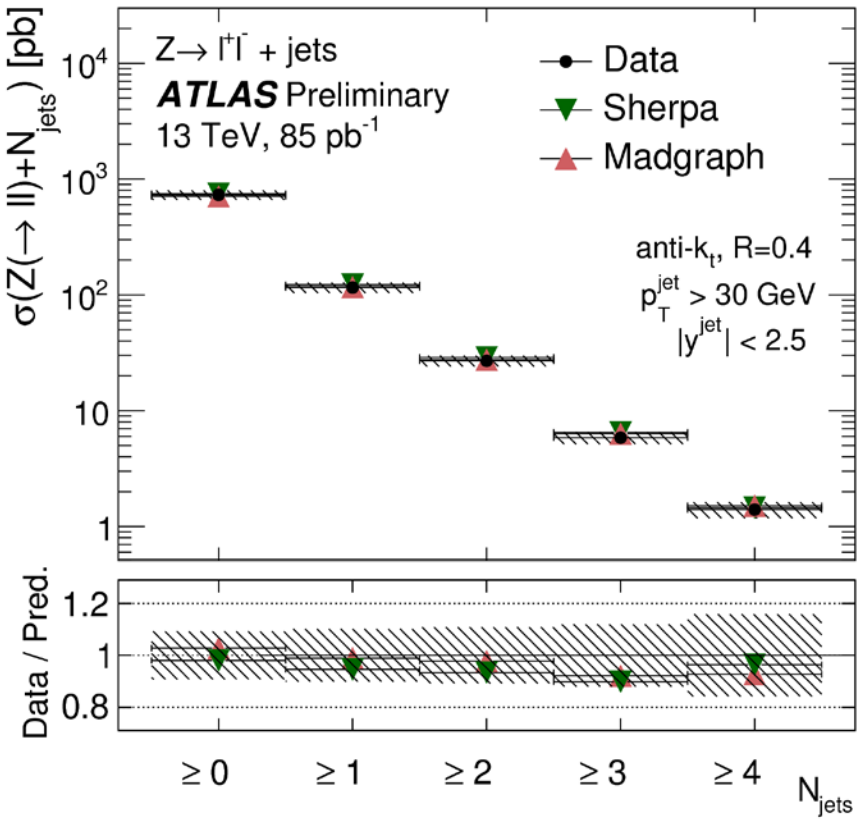


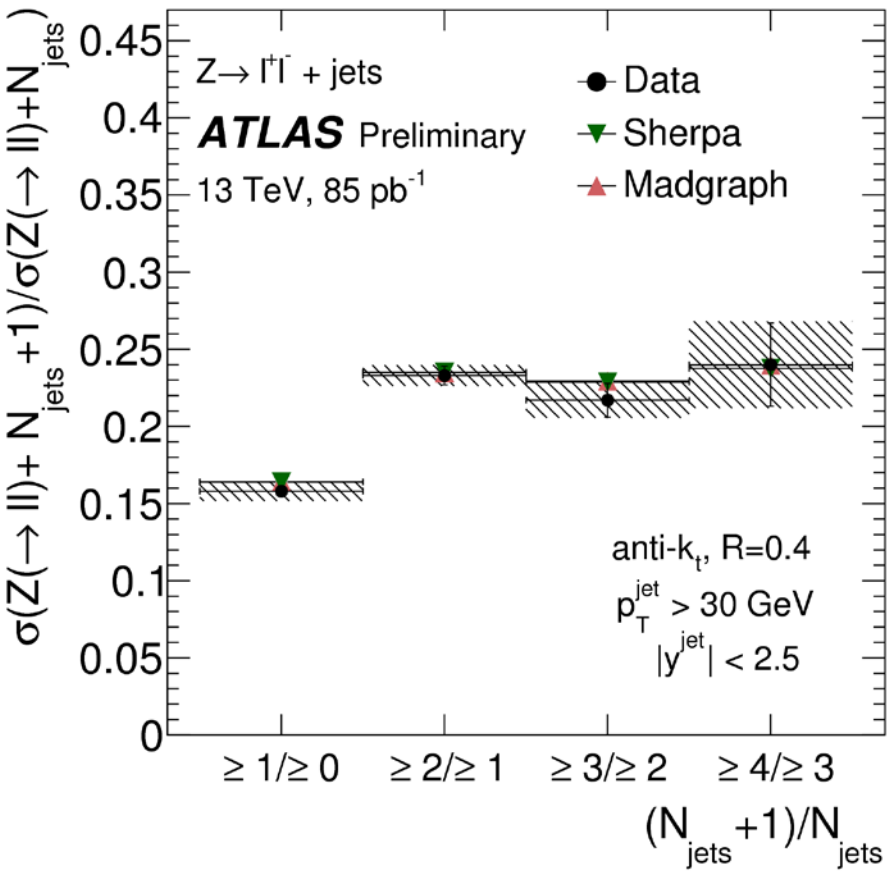


Reasonable description by MC models

Sherpa 2.1.1
Madgraph5_aMC@NLO 2.2.2

Z + jets cross-section





Sherpa 2.1.1
Madgraph5_aMC@NLO 2.2.2

Combined data: cross-sections & their ratios reasonably described by both models

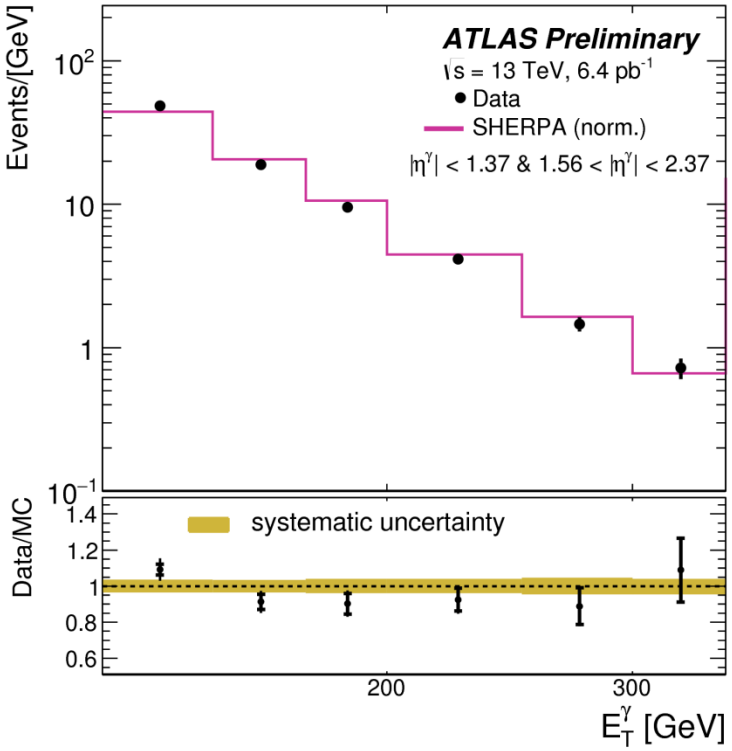
Inclusive isolated photon

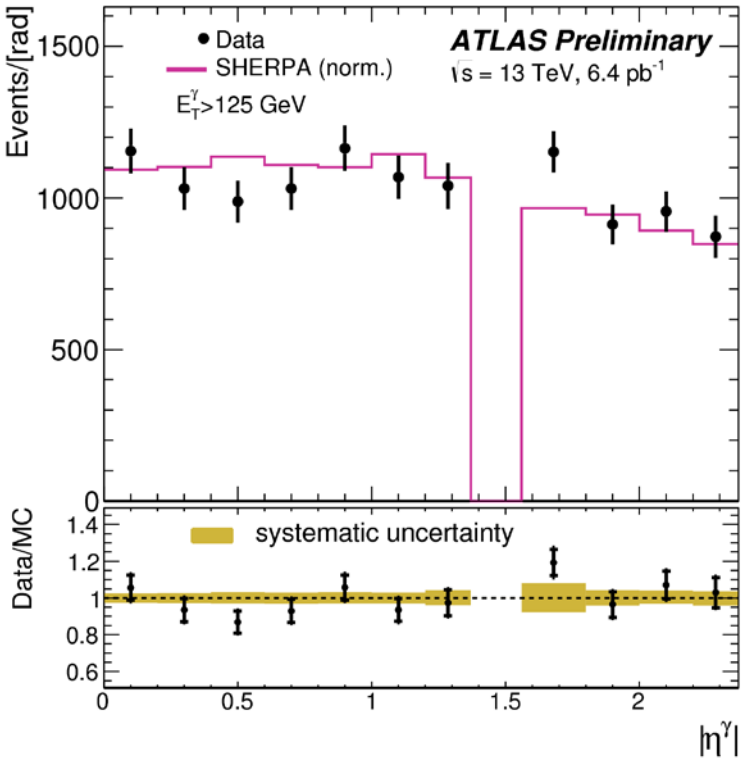
Inclusive isolated photon

Direct photon – directly from hard interaction
Fragmentation photon – emitted in high p_T parton fragmentation

Perturbative QCD test-bed in a cleaner environment in comparison to jets

Look for isolated photons with $E_t^\gamma > 120$ GeV and $|\eta^\gamma| < 2.37$ – isolated EM clusters, conversions
Isolation and backgrounds from data





SHERPA 2.1 in a good agreement with data

Summary

- Machine in a very good shape and improving
- Selected results based on early Run2 data on soft/hard QCD were presented
- Large energy range in a single experiment 0.9 – 13TeV
- Inelastic cross-section $\sigma_{inel} = 73.1 \pm 0.9(\exp.) \pm 6.6(lum.) \pm 3.8(extr.)mb$
- Preliminary data on W/Z production show already discriminating power
- Measurements match lower energy ones
- At the moment luminosity uncertainty limits the precision
- Reasonable agreement with theoretical predictions
- Monte Carlo models tuned using lower energy data reasonably describe the 13 TeV data