Review of Current Standard Model Results in ATLAS

Gerhard Brandt on behalf of ATLAS
Detector and Data

Precision SM Physics:
- 2011: 4.6 fb\(^{-1}\) of 7 TeV data
- 2012: 20.3 fb\(^{-1}\) of 8 TeV data

Establishing SM at 13 TeV:
- 2015: 4.2 fb\(^{-1}\) of 13 TeV data
- 2016: 41 fb\(^{-1}\)
- 2017: 18.6 fb\(^{-1}\) so far

→ LHC far exceeds expectations

- General Purpose detector with 4π coverage
- Sub-detectors optimized to reconstruct final states as produced by SM processes:
  - Jets, charged leptons, neutrinos
Can measure from soft interactions ...
- Test non-perturbative QCD
- Hadronization, underlying event, multi-parton interactions, long-range color exchange
- Parametrization of phenomenological models used MC (generator tuning)
- Parton distribution functions

... to hard scattering
- Test perturbative QCD
- Jets (large multiplicities, substructure)
- Precision fundamental SM parameters
- Vector boson and photon production
- Electroweak physics: Multi-boson final states, VBF, VBS
- Searches for new physics
  - Deviations from the SM (constraints on models)
  - Background predictions for BSM searches
Huge number of results (more than 120 publications - not all in plot)
General good agreement of theory and data
A few recent highlights presented here
Charged Particle Production and Underlying Event

- Measurement of charged particle production ("minimum bias") very important to describe pile-up
- Measured in all data sets, with track $p_T$ down to 100 MeV

- Underlying event (= everything except hard scatter, ie. ISR, FSR, MPI, CR) from charged particles at 13 TeV (1.6 nb⁻¹)
- Measurement in transverse region with respect to leading particle ($p_T > 500$ MeV)
- Agreement with models within ~5%

- → All MB and UE data used in model tunes
Reconstructed using anti-\( k_t \) jet clustering algorithm with \( R = 0.4 \) and \( R = 0.6 \) in \( |\gamma| < 3 \)

Dominant systematic uncertainty: jet energy calibration

Significant reduction of the uncertainties compared to previous jet cross section Measurements (at 7 TeV and 2.76 TeV)

QCD predictions at NLO with MMHT2014 PDF set corrected for non-perturbative and ew. effects describe data well

Various other new PDF sets investigated

Description within 10%-20% at low \( p_T \)

HERAPDF2.0 too low in regions

JHEP 02, 153 (2015) 7TeV
\( \alpha_s \) from transverse correlations in multijets

- Energy-energy-correlations of multijet events measured in transverse plane (TEEC) and its asymmetry (ATEEC) are sensitive to \( \alpha_s \).

- ATEEC fits yield the most precise values (smaller scale uncertainties).

7 TeV: PLB 750, 427 (2015)
8 TeV: 1707.02562 (Subm. EPJC)
Prompt Photon Production

- Prompt photon production is a colorless probe of pQCD
- At 13 TeV for $p_T^\gamma$ up to 1.5 TeV (~8 TeV reach already)
- Main challenge: background from jets misidentified as photons (data-driven subtraction)
- Good agreement with NLO calculation (JetPhox) and MC (PYTHIA, SHERPA)

- Inclusive Diphoton cross sections at 8 TeV
- Important background for $H \rightarrow \gamma\gamma$
- NLO calculation (DIPHOX) fails to describe data
- RESBOS (NLO+NNLL) and 2yNNLO improve description
- SHERPA works best
Results from Precision W/Z Cross Sections

- High precision measurements by ATLAS using 7 TeV data (4.6 fb⁻¹)
- Cross sections measured to 0.6% (W⁺), 0.5% (W⁻), 0.32% (Z) precision

| Reaction                  | σ_{W→ℓν}^{tot} [pb]                          | σ_{Z/γ^*→ℓℓ}^{tot} [pb] |
|---------------------------|---------------------------------------------|--------------------------|
| W⁺ → ℓ⁺ν                  | 6350 ± 2 (stat) ± 30 (syst) ± 110 (lumi) ± 100 (acc) | 990 ± 1 (stat) ± 3 (syst) ± 18 (lumi) ± 15 (acc) |
| W⁻ → ℓ⁻ν                  | 4376 ± 2 (stat) ± 25 (syst) ± 79 (lumi) ± 90 (acc) |
| W → ℓν                    | 10720 ± 3 (stat) ± 60 (syst) ± 190 (lumi) ± 130 (acc) |

- Obtained new PDF set ATLAS-epWZ16 by combining with HERA ep data in NNLO QCD analysis
- Many results derived
- Example: Constraints to parton behavior at low x: strange to light sea quark density is close to unity
First measurement of $m_W$ at the LHC

$$m_W = 80370 \pm 19 \text{ MeV}$$

Use $Z^0$ as standard candle for calibration

Extract from fits to charged lepton $p_T$ and reconstructed $m_T^W$

Largest exp. systematics: lepton energy/momentum scale

Largest modeling systematics: PDFs, parton showers

Consistent with global EW fit

Precision better than LEP combination, not far from Tevatron combination, compatible results
Z+jets Cross Sections at 13 TeV

• Vector boson production with associated jets measured differentially with jet multiplicities of up to 7 now

• Very important background to many searches

• Previous measurements include W+jets and W/Z+jets, also V+HF

• Agreement with data in range up to $p_T = 500$ GeV within systematic uncertainties

• Measured cross section as function of incl. jet multiplicity disagrees for Sherpa, Alpgen+Py6 and MG5_aMC+Py8 FxFx in high jet multiplicity region (jets in the parton shower become important)
Diboson and Triboson Final States

- Large number of diboson processes and more complex processes observable and analysed
- Generally good agreement with SM
- Whole industry extracting constraints on aTGC, aQGC and effective QFT parameters

- More complex final states now in reach: VBF, VBS, Triboson production
- Some of them already observed
Electroweak Vector Boson Production

- Important background to Higgs and BSM searches
- Spectacular signature of two fwd. jets, rap. gap and high $p_T$ central leptons
- Mixed with QCD diagrams, large backgrounds
- Observation $>5\sigma$ in $W,Z+\text{jj}$, cross sections extracted

**LHC electroweak $X_{jj}$ production measurements**

**ATLAS**

- Data
- EW $W_{jj}$
- QCD $W_{jj}$
- Top quarks
- Multijets
- $Z_{jj}$ and dibosons
- Uncertainty

**Events / GeV**

**ATLAS** $W_{jj}$ signal region

$\sqrt{s} = 7 \text{ TeV}, 4.7 \text{ fb}^{-1}$

**M_{jj} [GeV]**

**Events / GeV**

Data / Prediction

| $M_{jj}$ [GeV] | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 |
|----------------|-----|------|------|------|------|------|------|
| Events / GeV   |     |      |      |      |      |      |      |
| 10^0           |     |      |      |      |      |      |      |
| 10^1           |     |      |      |      |      |      |      |
| 10^2           |     |      |      |      |      |      |      |
| 10^3           |     |      |      |      |      |      |      |
| 10^4           |     |      |      |      |      |      |      |

**Stat. uncertainty**

**Total uncertainty**

**Theory uncertainty**

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**Standard Model at ATLAS**

Light Cone 2017
Same-sign WW Scattering at 8 TeV

- Unique same-sign dilepton + MET signature
- Various EW and QCD processes contribute to VBS in the SM
- VBS alone not gauge invariant
- Fundamental test of unitarity of EW sector
- Not yet observed by ATLAS (8 events obs / 3.3 exp. in enhanced region)
- Already sensitive to aQGC parameters → set limits
A wealth of Standard Model Measurements from LHC data available
  ○ Could only pick a few raisins here

Probing energy frontier with hardest objects and highest multiplicities

Standard Model holding up very well to tests

Only the beginning, have analyzed only ~2% of total expected LHC dataset

Depending on what the scale is for new physics, the future of LHC physics could be (exclusively) in precision SM physics!
Differential Jet Cross sections and Jet Substructure

Dijet
Trijet
Fourjet
Jet charge
Jet shapes
