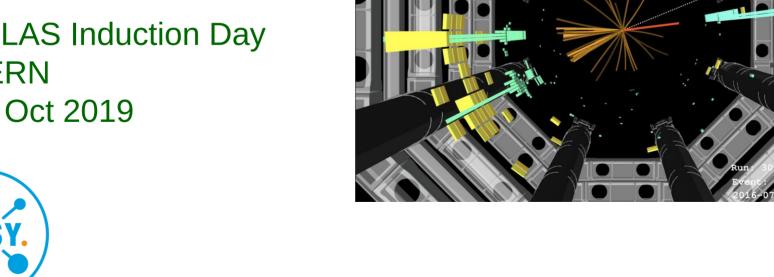
Overview of ATLAS Physics Performance and Analysis

Klaus Mönig and Stéphane Willocq

ATLAS Induction Day CERN 21 Oct 2019

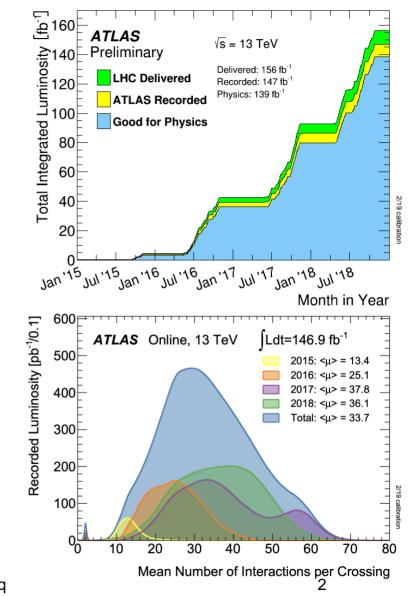






Run 2 data taking

- 147 fb⁻¹ recorded at \sqrt{s} = 13 TeV
- Excellent data taking efficiency and data quality (139 fb⁻¹ usable for physics)
- However high pileup in 2017 & 2018 $(\langle \mu \rangle = 37, \text{ design was 20})$
- Many analyses already published with 2015 & 2016 data (36 fb⁻¹) in release 20.7
- First results (mainly searches) with full dataset and release 21 have come out



Run 2 dataset: a gold mine

- This is a great time to be joining ATLAS!
- You can help fulfil the fantastic physics potential of Run 2
- You will have access to the largest dataset ever recorded at a hadron collider, at the highest collision energy ever achieved
- An enormous amount of work has already gone into
 - collecting and calibrating the data
 - understanding the detectors
 - understanding the physics objects (electron, muons, jets, b-tagging...)
 - developing advanced algorithms for physics performance & analysis
- You can (and should!) play a role in improving all of the above

ATLAS: a multi-purpose experiment

ATLAS is a multi-purpose hadron collider experiment. It can address many interesting questions in various subfields of particle and nuclear physics:

- Standard Model Measurements
 - QCD and Top physics
 - Electroweak and Higgs physics
 - Flavor (mostly B) physics
- Searches for beyond the Standard Model (BSM) physics from very heavy particles, to very rare processes, to long-lived particles
- Heavy ion physics

Expect >200 publications on the full Run 2 dataset

Many opportunities and often not enough people to do everything we'd like to do

Many analyses need additional people! (see talks from **ATLAS Week in Berlin**)

Structure of Performance & Physics Groups

Combined Performance groups:

Physics groups:

Electrons / Photons

Standard Model physics

Muon

Top physics

Tau leptons

Higgs physics

Jet / Etmiss

B-physics & light states

Tracking

Heavy ion physics

Flavour tagging

Searches for Supersymmetry

Searches for exotic phenomena

BSM Higgs and di-bosons

Upgrade physics

Physics modelling

- Fora and other groups: Statistics, machine learning, long-lived particles
- Joint subgroups: Isolation and fake leptons, common dark matter
- Important tools and support groups: Analysis software, MC production, simulation, derivation coordination, physics validation, physics office

Structure of Performance & Physics Groups

Combined performance or physics working group **Contact persons:** CP groups MC production Upgrade Trigger **Subgroup A** Subgroup B Physics modelling Analysis 1 Analysis 1 Can have common activity groups: Analysis 2 Analysis 2 - reconstruction - software - backgrounds - MC modelling

- Engage in discussions in analysis, subgroup, and group meetings
- Contribute to common tasks within working group
- Organize your work in well connected, reasonably sized analysis groups
- Do not embark on isolated analysis projects: stay connected

Combined Performance Groups

- Many important results are the fruit of years of investment in understanding and improving of detectors + optimization of reconstruction, identification, and calibration
- Three examples:
 - Higgs mass: precision calibration of photons and electrons/muons
 - High-mass resonance decaying to dibosons or top-quarks: boosted jets
 - Observation of H→bb decays: b-tagging, charm- and light-jet rejection
- This work is coordinated in the Combined Performance (CP) groups:
 - Forum where analyzers discuss performance needs for each analysis \rightarrow cross-fertilization
 - Work is often very challenging and interesting
 - Place to bring in new ideas and commission resulting techniques
 - Opportunity to get additional publications and show broader interest
- Systematics limitation of some analyses can be improved with Run 2 data, new techniques
- → Investment is key to success of ATLAS Run-2 physics program

Physics Modelling Group

Responsible for:

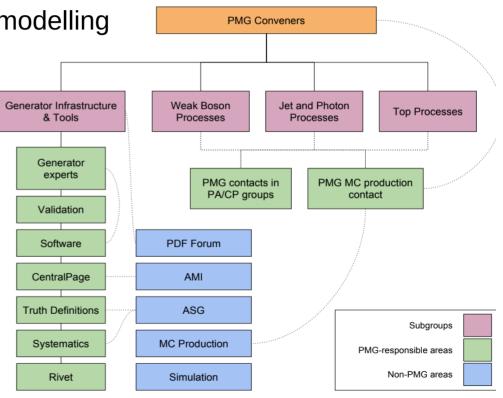
- Development and validation of Monte Carlo event generators
- Setting common recipes for theory systematics and re-weighting procedures to correct modelling

 Planning of Monte Carlo production and approval of requests

Coordinated work via:

- MC production contacts
- Physics contacts following needs of each group

PMG processes subgroups define the MC setup for the main SM processes (mainly based on ATLAS measurements)



Analysis and Paper Approval (in a nutshell)

Working group:	Idea	
Analysis coordinator/contact editor	Expression of interest	
	Kick-off meeting	Publication committee:
Subgroup conveners	Analysis pre-approval	Editorial board
Working group conveners	Analysis approval	
Physics coordinators	Paper Approval Meeting	PubCom chair
	Paper Closure Meeting	

- Regular presentations and discussion in working group are key to success
- Do not embark on isolated paper projects
- Nobody "owns" an analysis, you are allowed to join, where you like

Planning for Run 2: General Considerations

The Run 2 dataset will have a long lifetime:

- Long shutdown in 2019 and 2020
- Commissioning year in 2021 for LHC
- Production years in 2022 and 2023 (expect ~ 200 fb⁻¹)
- Probably need both production years to surpass the Run 2 dataset
- Some high pT and high mass searches will profit from higher LHC energy earlier (if higher energy is available)
- Will take time to understand the Run 3 dataset as well as the Run 2 dataset will be understood, with precision CP recommendations etc.
- We are developing a plan where interesting results are produced throughout that 5-year period

New analysis ideas & improvements needed for papers over that period

Current Run 2 Publication Plan

- Early/medium-term Run-2 papers (2019/2020)
 - Many searches and statistics-limited measurements
- Comprehensive search papers (2020)
 - Merging signal regions, sensitivity optimization, detailed background understanding, coherent interpretation papers
- Systematically limited measurements (2020+)
 - Profits from precision CP work, improved physics modelling, MC statistics extensions, sophisticated analysis techniques and background estimates
- High precision measurements (2020++) e.g. W mass, $\sin^2\theta_w$
 - Profits from ultimate performance of Run 2, improved event generators, etc.

Staggering of papers makes it possible to publish updates of already published analysis, e.g. show improved analysis in a combination paper

Plans for Combined Performance Papers

- Write first set of CP papers to support early physics papers (based on 2015-2017 data initially, now using full Run 2)
- Challenging given limited number of people but papers can be concise
- Many advantages to CP contributors and to the collaboration
- Acknowledges CP work, needed to support physics results
- Write detailed CP papers later to support higher precision measurements
- Ideally the CP papers are early enough that they can be cited by the physics papers

Opportunities for the next Runs

- Preparations for release 22, the software release to be used at the beginning of Run 3
- Trigger opportunities for Run 3: what we do not trigger on is lost forever! We will have new trigger hardware for Run 3 and now is the time to work on improved triggers!
- Preparations for ATLAS detector Phase-II upgrade

In many of these areas only small analysis teams are working You can have a large impact!

Run 2 physics workshop

 Physics workshop on the finalization of the Run 2 results during the P&P week in December: https://indico.cern.ch/event/822577/

- This will give you a detailed overview of what is going on in physics analysis
- Will help you choose a performance and/or physics analysis if you are still looking for one



ATLAS workshop at CERN 9 – 13 December 2019



A Few Recommendations

ATLAS needs people everywhere!

- There is usually room for committed individuals even in activities that seem well staffed; If you do good work, your contributions will be valuable and valued
- Analysis work in ATLAS is complex
 - Do not try to work everything out on your own
 - Don't get discouraged, ask for help or guidance (meetings, e-groups, JIRA), stay connected: work in reasonably-sized, well-connected groups

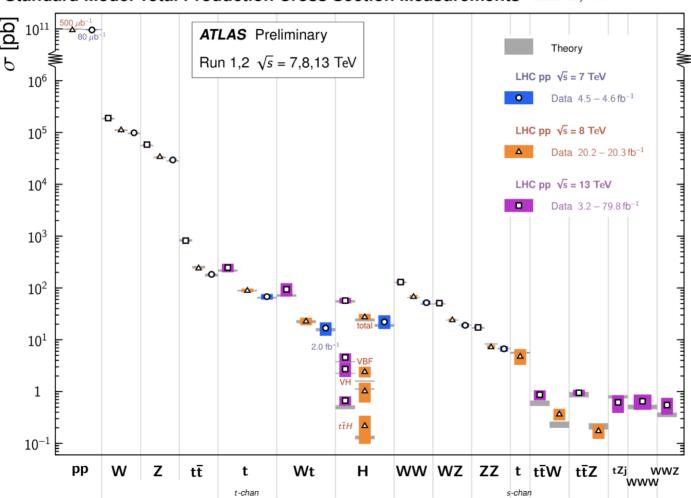
Learn something(s) new and have fun!

- More important to contribute broadly (e.g. Performance, Physics, Trigger, Software & Computing, Detector, Upgrade) than produce many physics papers
- But don't stretch yourself too thin
 - > strike a balance to contribute to a few areas significantly
- You will learn a lot and develop valuable skills in the process

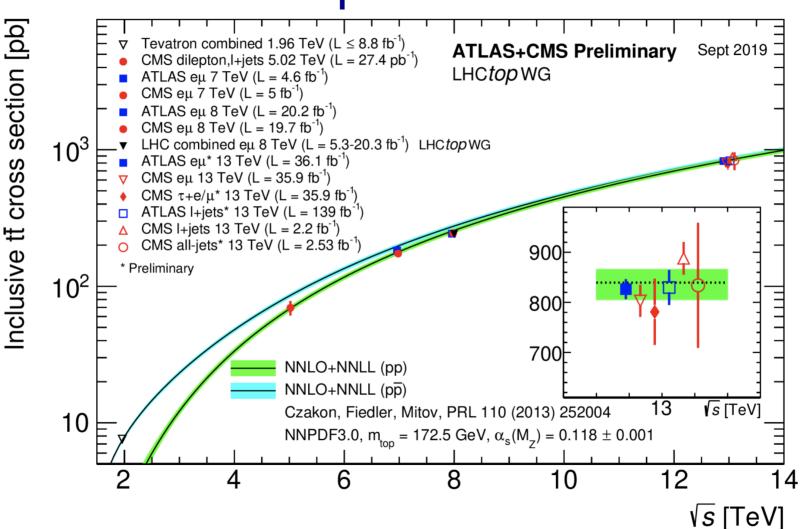
Backup

Standard Model Measurements

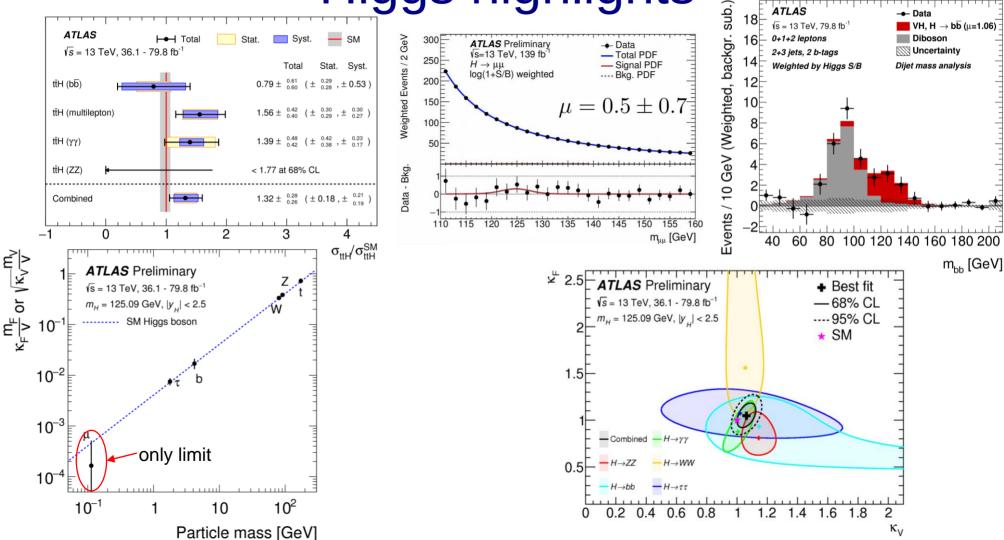
Standard Model Total Production Cross Section Measurements Status: July 2019



t tbar production



Higgs highlights



Searches for new particles

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

ATLAS Preliminary

Sta	atus: May 2019					$\int \mathcal{L} dt = 0$	$3.2 - 139) \text{ fb}^{-1}$	$\sqrt{s} = 8, 13 \text{ TeV}$
	Model	ℓ , γ	Jets†	E _T miss	∫£ dt[fb			Reference
Extra dimensions	ADD $G_{KK}+g/q$ ADD non-resonant $\gamma\gamma$ ADD QBH ADD BH high $\sum p_T$ ADD BH multijet RS1 $G_{KK} \to \gamma\gamma$ Bulk RS $G_{KK} \to WW/ZZ$ Bulk RS $G_{KK} \to WW \to qqqq$ Bulk RS $G_{KK} \to t$ 2UED / RPP	$\begin{array}{c} 0 \; e, \mu \\ 2 \; \gamma \\ - \\ \geq 1 \; e, \mu \\ - \\ 2 \; \gamma \\ \text{multi-channe} \\ 0 \; e, \mu \\ 1 \; e, \mu \\ 1 \; e, \mu \end{array}$	$1-4j$ - 2j $\geq 2j$ $\geq 3j$ - el 2 J $\geq 1 \text{ b, } \geq 1 \text{ J}$ $\geq 2 \text{ b, } \geq 3 \text{ b, } \geq 3 \text{ J}$		36.1 36.7 37.0 3.2 3.6 36.7 36.1 139 36.1 36.1	Mo 7.7 TeV Ms 8.6 TeV Mth 8.9 TeV Mth 8.2 TeV Mth 9.55 TeV GKK mass 4.1 TeV GKK mass 2.3 TeV GKK mass 1.6 TeV GKM mass 3.8 TeV KK mass 1.8 TeV	$\begin{split} n &= 2 \\ n &= 3 \text{ HLZ NLO} \\ n &= 6 \\ m_O &= 3 \text{ TeV, rot BH} \\ n &= 6, M_O &= 3 \text{ TeV, rot BH} \\ k/M_{Pl} &= 0.1 \\ k/M_{Pl} &= 0.1 \\ k/M_{Pl} &= 1.0 \\ f/m &= 15\% \\ \end{split}$ Tier (1.1), $\mathcal{B}(A^{(1.1)} \to tt) = 1$	1711.03301 1707.04147 1703.09127 1806.02265 1512.02586 1707.04147 1806.02380 ATLAS-CONF-2019-003 1804.10823 1803.09678
Gauge bosons		1 e, μ 1 τ		- - /2j Yes Yes Yes -	139 36.1 36.1 139 36.1 139 36.1 139 36.1 80	Z' mass 5.1 TeV Z' mass 2.42 TeV Z' mass 2.1 TeV Z' mass 3.0 TeV W' mass 6.0 TeV W' mass 3.6 TeV V' mass 2.93 TeV W _R mass 3.25 TeV W _R mass 5.0 TeV	$\Gamma/m=1\%$ $g_V=3$ $g_V=3$ $m(N_R)=0.5 \ {\rm TeV}, g_L=g_R$	1903.06248 1709.07242 1805.09299 1804.10823 CERN-EP-2019-100 1801.06992 ATLAS-CONF-2019-003 1712.06518 1807.10473 1904.12679
C	Cl qqqq Cl ℓℓqq Cl tttt	– 2 e, μ ≥1 e,μ	2 j - ≥1 b, ≥1	– – j Yes	37.0 36.1 36.1	Λ Λ Λ 2.57 TeV	21.8 TeV η_{LL}^- 40.0 TeV $\eta_{LL}^ C_{4t} =4\pi$	1703.09127 1707.02424 1811.02305
MO	Axial-vector mediator (Dirac DM) Colored scalar mediator (Dirac DM $VV\chi\chi$ EFT (Dirac DM) Scalar reson. $\phi \rightarrow t\chi$ (Dirac DM)	0 e, μ	1-4j 1-4j $1 J, \le 1j$ 1 b, 0-1 J		36.1 36.1 3.2 36.1	m _{mod} 1.55 TeV m _{mod} 1.67 TeV M _* 700 GeV m _g 3.4 TeV	$\begin{split} &g_{\rm q}{=}0.25, g_{\chi}{=}1.0, m(\chi) = 1 {\rm GeV} \\ &g_{\rm g}{=}1.0, m(\chi) = 1 {\rm GeV} \\ &m(\chi) < 150 {\rm GeV} \\ &y = 0.4, \lambda = 0.2, m(\chi) = 10 {\rm GeV} \end{split}$	1711.03301 1711.03301 1608.02372 1812.09743
77	Scalar LQ 1 st gen Scalar LQ 2 nd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen	1,2 <i>e</i> 1,2 <i>μ</i> 2 <i>τ</i> 0-1 <i>e</i> , <i>μ</i>	≥ 2 j ≥ 2 j 2 b 2 b	Yes Yes - Yes	36.1 36.1 36.1 36.1	LO mass 1.4 TeV LO mass 1.56 TeV LO** mass 1.03 TeV LO** mass 970 GeV	$\begin{split} \beta &= 1 \\ \beta &= 1 \\ \mathcal{B}(LQ_3^u \rightarrow b\tau) &= 1 \\ \mathcal{B}(LQ_3^d \rightarrow t\tau) &= 0 \end{split}$	1902.00377 1902.00377 1902.08103 1902.08103
Heavy quarks		1 e, μ	el	j Yes	36.1 36.1 36.1 36.1 79.8 20.3	T mass 1.37 TeV B mass 1.34 TeV T _{1,1} mass 1.64 TeV Y mass 1.85 TeV B mass 1.21 TeV Q mass 690 GeV	SU(2) doublet SU(2) doublet SU(2) doublet $\mathcal{B}(T_{5/3} \rightarrow Wt) = 1$, $c(T_{5/3} Wt) = 1$ $\mathcal{B}(Y \rightarrow Wb) = 1$, $c_R(Wb) = 1$ $c_R(Wb) = 1$	1808.02343 1808.02343 1807.11883 1812.07343 ATLAS-CONF-2018-024 1509.04261
Excited fermions	Excited quark $q^* \to qg$ Excited quark $q^* \to q\gamma$ Excited quark $b^* \to bg$ Excited lepton ℓ^* Excited lepton ν^*	- 1 γ - 3 e, μ 3 e, μ, τ	2 j 1 j 1 b, 1 j - -	- - - -	139 36.7 36.1 20.3 20.3	q* mass 6.7 TeV q* mass 5.3 TeV b* mass 2.6 TeV c* mass 3.0 TeV v* mass 1.6 TeV	only u^* and d^* , $\Lambda=m(q^*)$ only u^* and d^* , $\Lambda=m(q^*)$ $\Lambda=3.0~{\rm TeV}$ $\Lambda=1.6~{\rm TeV}$	ATLAS-CONF-2019-007 1709.10440 1805.09299 1411.2921 1411.2921
Other	Higgs triplet $H^{\pm\pm} \to \ell \tau$ Multi-charged particles Magnetic monopoles $\sqrt{s} = 8 \text{ TeV}$	1 e, μ 2 μ 2,3,4 e, μ (SS 3 e, μ, τ - - = 13 TeV	≥ 2 j 2 j S) - - - - - - full o		79.8 36.1 36.1 20.3 36.1 34.4	N° mass 560 GeV N _a mass 3.2 TeV H±± mass 400 GeV mail:charged particle mass 1.22 TeV monopole mass 2.37 TeV	$\begin{split} m(W_R) &= 4.1 \text{ TeV, } g_L = g_R \\ \text{DY production} \\ \text{DY production, } \mathcal{B}(H_1^{t,p} \to t\tau) = 1 \\ \text{DY production, } q &= 5e \\ \text{DY production, } g &= 1g_D, \text{ spin } 1/2 \\ \end{split}$	ATLAS-CONF-2018-020 1809.11105 1710.09748 1411.2921 1812.03673 1905.10130
			- Tun c		,		Mass scale [TeV]	

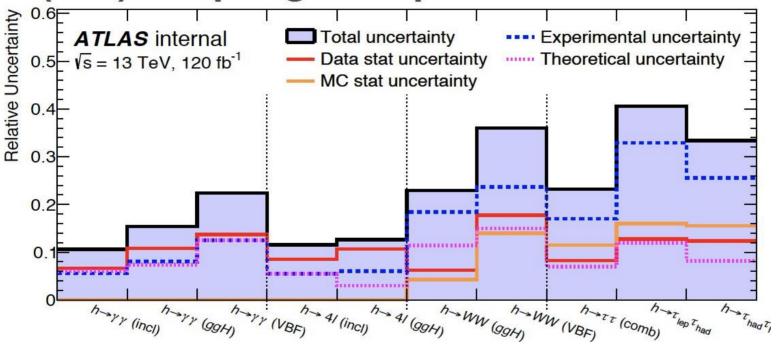
^{*}Only a selection of the available mass limits on new states or phenomena is shown.

[†]Small-radius (large-radius) jets are denoted by the letter j (J).

Limiting factors in recent ATLAS analyses

Example from Higgs group

h(125) coupling extrapolation to 120 fb⁻¹

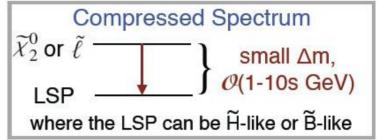


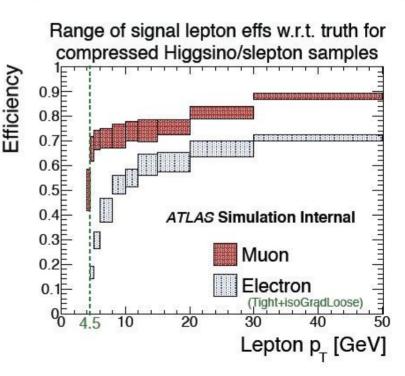
• Note: ttH(bb,ML),VH(bb) syst.-limited with 36 fb⁻¹, need large MC samples

R&D in object reconstruction

Low-p_⊤ leptons

- Example of physics motivation: SUSY EWK searches, compressed scenarios
- New low-p, muon selection recovers efficiency for 3 < p, < 5 GeV
- Foreseen improvements with dedicated triggers
- Electrons now supported down to 4.5 GeV
- Soft electrons (a la Run 1) could be revived but need people
- Improvements on calibrations ("E-p) and efficiency meas. (Z->eey) underway
- CP work can open new opportunities for searches and measurements, e.g. for searches the increased mass/pt reach is now rather limited while with more work, new signatures open up





R&D in object reconstruction

- In some cases large improvements are possible, e.g.:
- b-tagging using VR- track jets
- t-tagging using DNN
- tau-tagging using RNN

