ATLAS Status Report
Operations, Physics & Upgrades

P. Krieger, University of Toronto
(on behalf of ATLAS Canada)

IPP AGM, Burnaby, BC, June 7, 2019

ATLAS Canada Collaboration

Alberta
Carleton
McGill
Montréal
SFU
Toronto
TRIUMF
UBC
Victoria
York

Founded in 1992:	M. Lefebvre, UVic
Spokespersons:	R.S. Orr U of T 1994–2007
	R. McPherson, IPP/UVic 2007-2015

Current Management

Spokesperson, PI (2015 –):	P. Krieger, U of T
Deputy:	I. Trigger, TRIUMF
Physics Coord:	D. Gillberg, Carleton
Computing Coord:	D. Gingrich, Alberta

38 University/Lab faculty (≈ 35 FTE) [signed last grant request]
+ several new hires in 2018, 2019
30 Postdocs, 80 GS (Fall 2018), ≈ 25 UG students/year
Plus engineers and technicians (some MRS funded)
Group now includes 6 IPP Research Scientists (5 FTE)

ATLAS Canada Activities & HQP

- **Canadians playing key roles in ATLAS and the ATLAS Physics program**
  - Deputy Spokesperson, Physics Coordinator, Physics Group Convener (Exotics), Performance Group Convener (Tracking), MC production coordinator
  - Also physics and performance sub-group conveners
  - Operations (2018): subsystems Run Coordinators (2018), detector experts, computing, also during LS2
  - Speakers Committee, Authorship Committee, Other
- **Well represented in Phase-1 and Phase-2 upgrade projects**
  - Both technical leadership and management roles
- **HQP training:**
  - 88 PhDs awarded on ATLAS (Sept 2018), 56 with collisions (Run 1, Run 2)
    - increase of 8 since time of 2018 IPP AGM
    - similar number of MSc degrees over the same period
  - Close to 100 RAs have been trained within ATLAS Canada
  - 4 ATLAS-Canada alumni (students, postdocs) hired into Canadian faculty positions in past 12 months

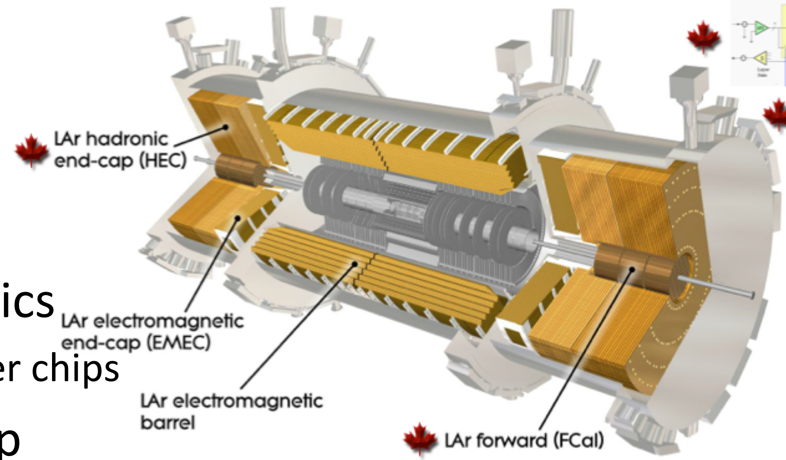
The Large Hadron Collider at CERN

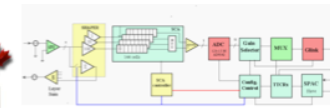
- **The world's highest-energy particle collider:**
  - Likely to remain at the energy-frontier for at least another two decades
  - Excellent performance over Run-2 (2015-2018)
- **Almost 850 scientific ATLAS publications (published or submitted)**
  - about 100 in past year
- **Higgs discovery in 2012 $\rightarrow$ 2013 Nobel Prize to Higgs and Englert**
  - Investigations of Higgs properties still important and on-going
  - Run-2 results including $H \rightarrow b\bar{b}$, $t\bar{t}H$ and di-Higgs production
- **Run-2 complete: Long Shutdown 2 (LS2) now in progress**
  - Accelerator upgrades and Phase-1 detector upgrades
  - Increase to 14 TeV may not happen for start of Run-3
  - After energy increase, only improvements come from luminosity upgrade:
    - Dealing with this is the main goal of the ATLAS detector upgrade program
- **Canadians playing leading roles in a number of upgrade projects**
  - Funding from CFI: IF 2015 (Phase-1) and IF 2017 (Phase-2)
  - In each case following on from RTI support from NSERC during the R&D phase

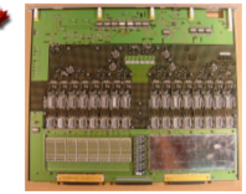
Canadian Hardware Contributions to ATLAS

Canadian hardware contributions to ATLAS

- Hadronic Endcap calorimeter
  - Two of four wheels
- Hadronic Forward calorimeter
  - All four modules
- Liquid argon front-end electronics
  - Switched capacitor array controller chips
- Liquid argon calorimeter endcap signal feed-throughs



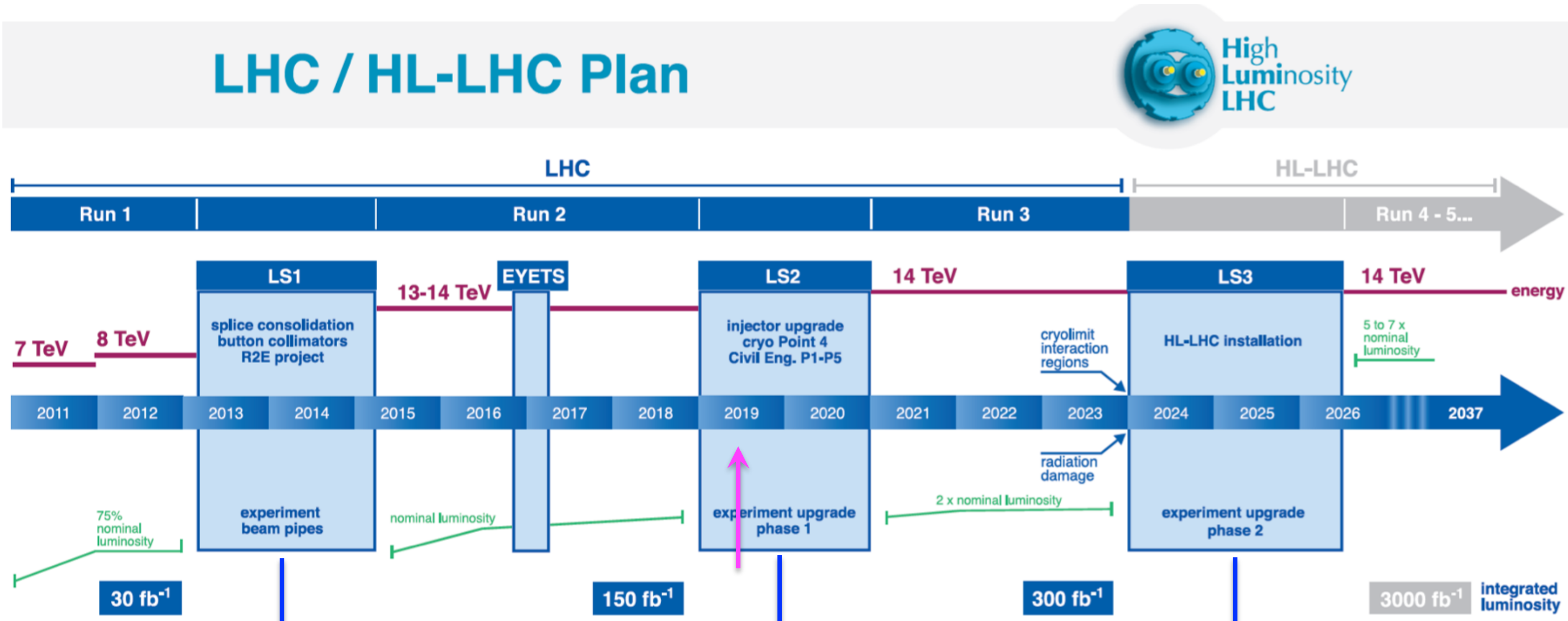




Also a $40M Canadian contribution to the LHC

- ATLAS Tier-1 and Tier-2 Computing facilities
- High-level trigger (HLT) processors
- Diamond Beam Conditions Monitor (also used for luminosity)
- MediPix / TimePix for cavern background monitoring, luminosity
- LUCID luminosity monitor and upgrade in LS1 (2013-2015)
- Diamond Beam Monitor (telescope) installed in LS1 (2013-2015)
- Inner Detector (TRT) readout
- ATLAS Forward Protons (AFP) – installation completed in 2016/17 shutdown

LHC/HL-LHC Schedule & ATLAS upgrade planning



- New Pixel insertable b-layer (IBL): DBM
- Consolidation of LAr calorimeter LVPS
- LUCID upgrade
- Forward protons (AFP)

Completed

- sTGC for Muon New Small Wheel
- Liquid Argon Calorimeter trigger electronics

sTGCs under construction
LAr: installation in progress

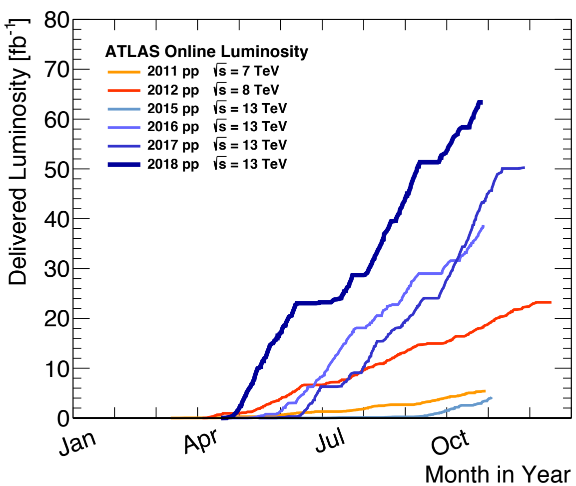
- New ATLAS Inner Tracker (ITk)
- Liquid Argon Calorimeter readout electronics

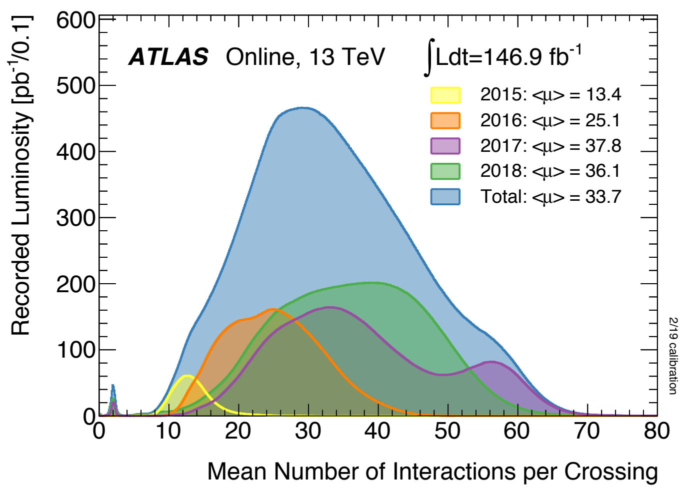
In progress

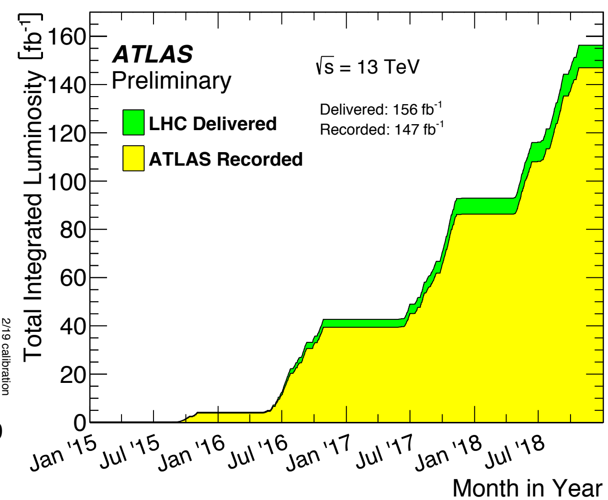
Main ATLAS Canada shutdown / upgrade activities (detector)

LHC / ATLAS Operations 2018

- **First 2018 stable beams collisions April 17 (was May 23 in 2017)**
- **Continued excellent performance:**
  - **51% of time in stable beams! (was 49% in 2017 which was also excellent)**
- **Integrated luminosity:**
  - 63.3 fb^{-1} delivered to ATLAS (for total of 156 fb^{-1} for Run-2)
  - 60.6 fb^{-1} recorded by ATLAS (for total of 147 fb^{-1} for Run-2)
- **ATLAS Data quality:**
  - 60.1 fb^{-1} good for physics in 2018 (for total of 139 fb^{-1} for Run-2)



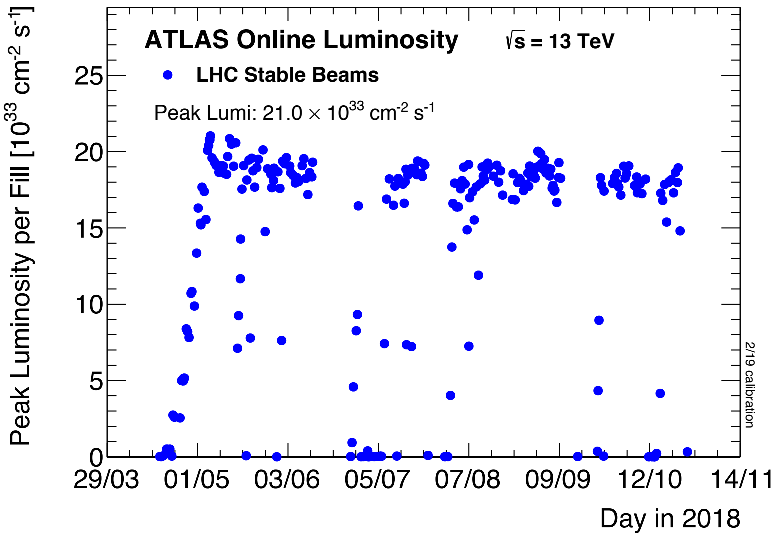




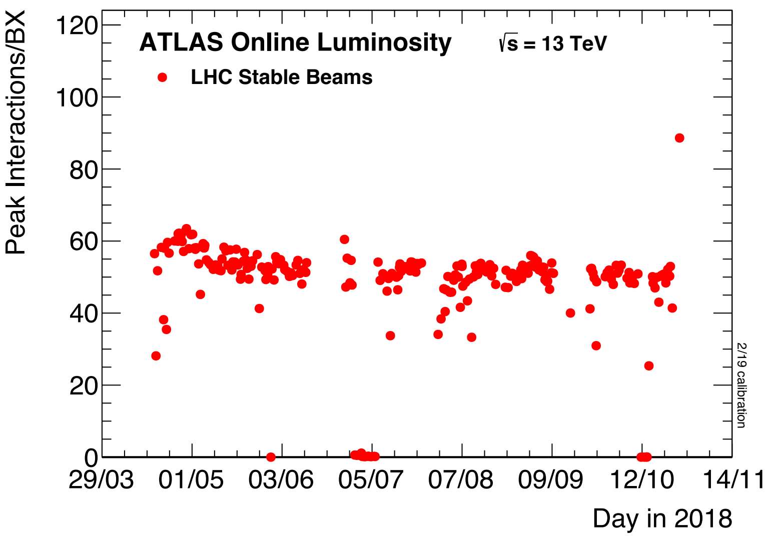
LHC / ATLAS Operations 2018

ATLAS Run-2 Detector Status (from March 2019, END OF RUN 2)

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	95.7%
SCT Silicon Strips	6.3 M	98.6%
TRT Transition Radiation Tracker	350 k	97.2%
LAr EM Calorimeter	170 k	100 %
Tile Calorimeter	5200	99.5%
Hadronic End-Cap LAr Calorimeter	5600	99.7%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger	7160	99.9%
LVL1 Muon RPC Trigger	383 k	100%
LVL1 Muon TGC Trigger	320 k	99.9%
MDT Muon Drift Tubes	357 k	99.7%
CSC Cathode Strip Chambers	31 k	93.0%
RPC Barrel Muon Chambers	383 k	93.3%
TGC End-Cap Muon Chambers	320 k	98.9%
ALFA	10 k	99.9%
AFP	430 k	97.0%



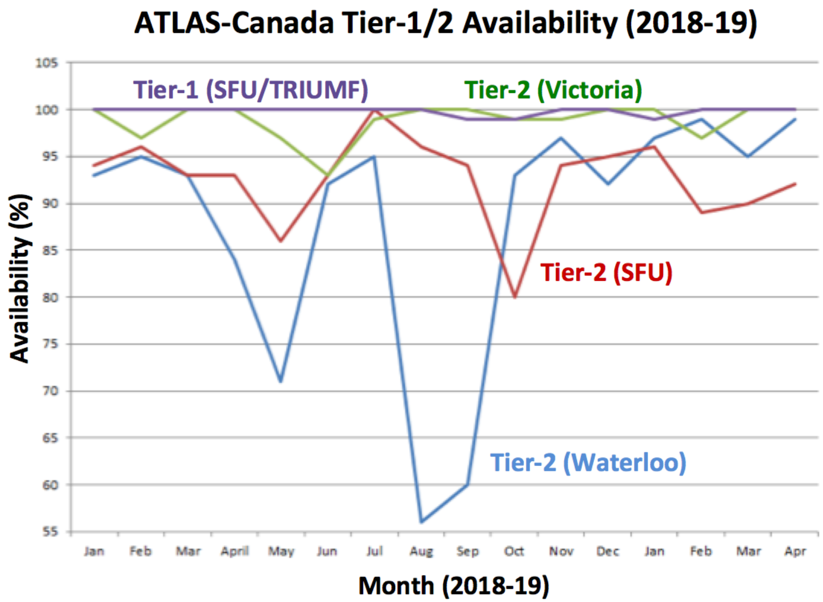
ATLAS pp data: April 25-October 24 2018										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.8	100	99.7	100	99.8	99.7	100	100	100	99.6
Good for physics: 97.5% (60.1 fb^{-1})										



Overall excellent performance in 2018 of the LHC machine, the ATLAS detector, and ATLAS computing facilities (WLCG)

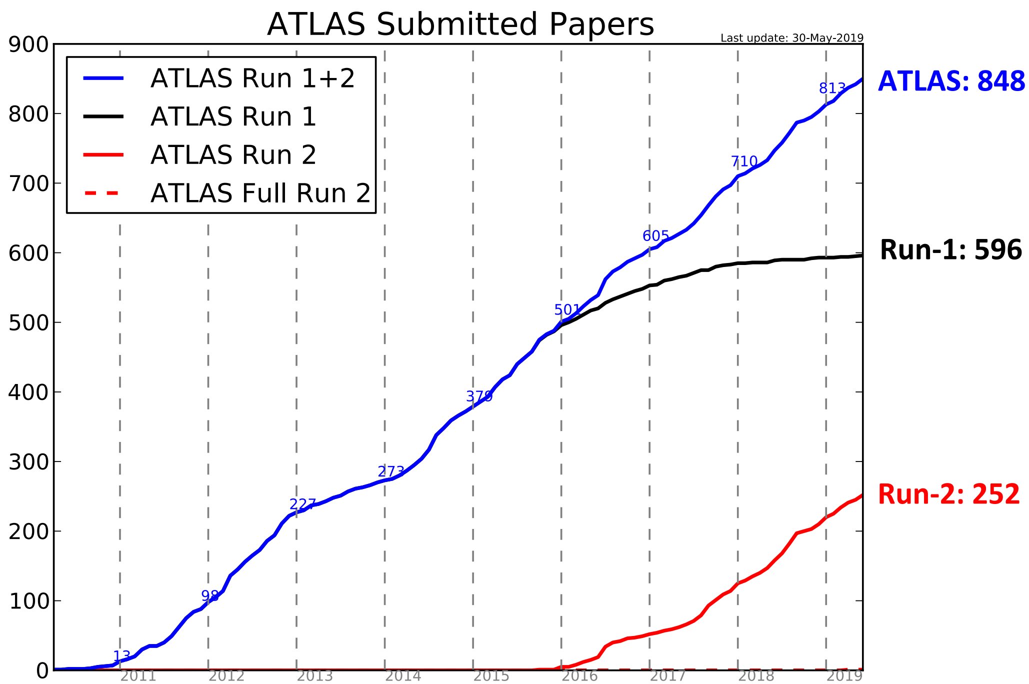
Operations: ATLAS Canada Computing

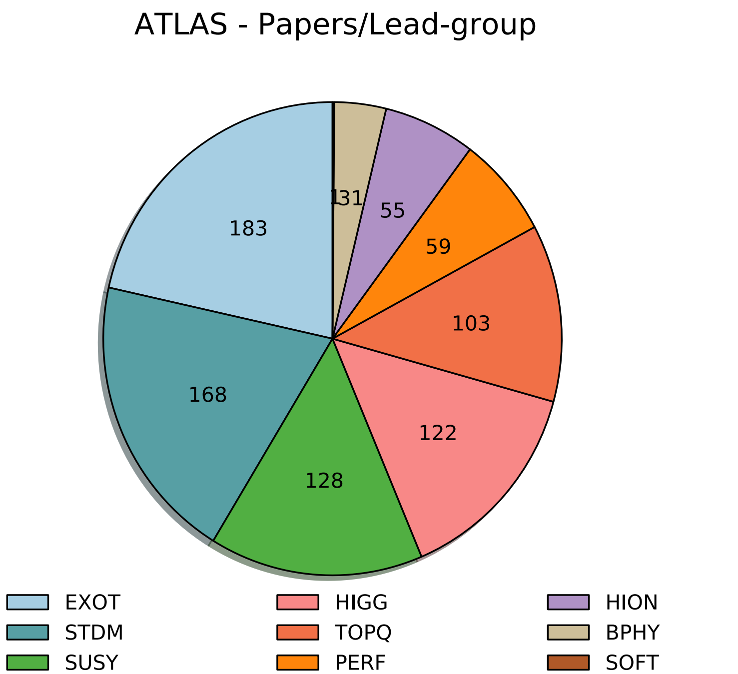
- **Canada hosts 1 of the 10 ATLAS Tier-1s**
  - Typically one of the highest reliability sites
  - Relocated from TRIUMF to SFU in 2018
  - Hardware funding through to 2020, via CFI IF 2017 competition
- **We also provide 5% of ATLAS Tier-2 resources, via Compute Canada:**
  - Compute Canada recently performed a site consolidation: still adjusting to new configuration (performance improving)



- **ATLAS continues to rely on resources beyond those "pledged" to the WLCG, in the form of opportunistic access to HPC and cloud resources**
  - ATLAS-Canada group members also play a leading role in ATLAS cloud computing effort
  - Canadians also involved in development of ATLAS core computing
- **Digital Research Infrastructure strategy:**
  - ATLAS Canada experts on Tier-1, Tier-2, Cloud computing involved in writing of IPP brief for ISED; our thoughts / concerns are summarized there

ATLAS Physics Results

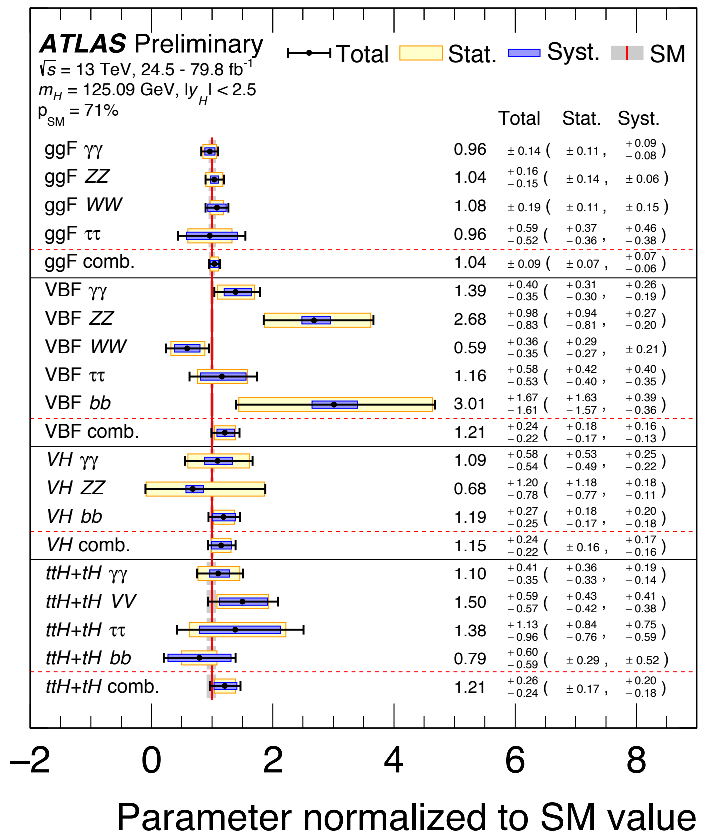


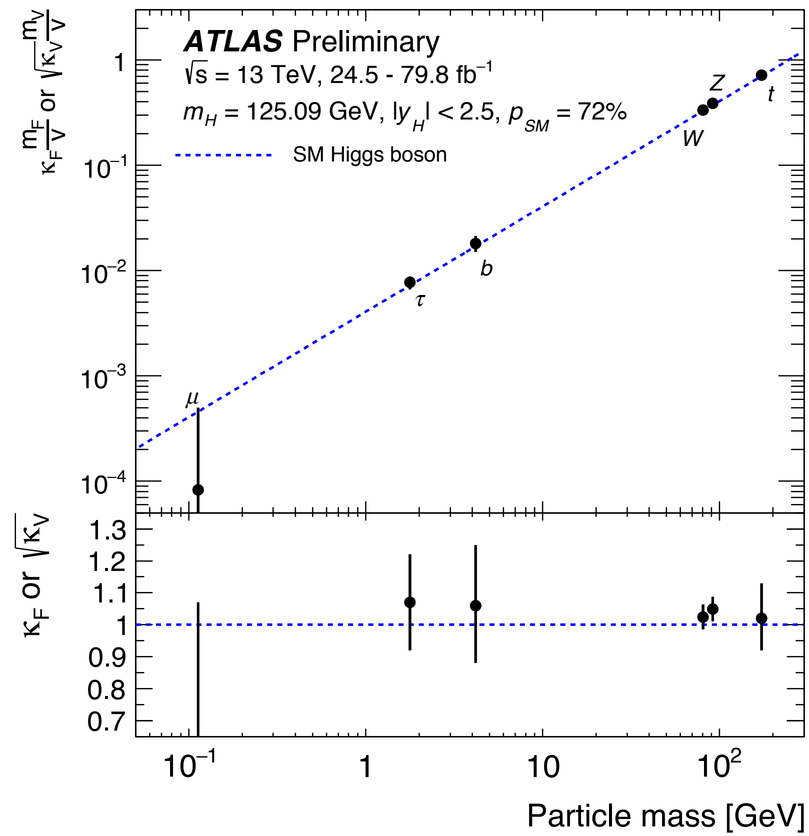


- **Run-1/2 papers +6/+89 since last years AGM talk**
  - Canadians heavily involved in Higgs, SUSY, Exotic, SM and top physics programs
    - See CAP talks (summary by B. Stelzer) – I show only a few results & summary plots
  - Initial Run-2 papers based mainly on 2015 + 2016 data (36 fb^{-1})
  - Publication strategy now focused on papers based on the full Run-2 dataset
    - motivated in part by desire to redirect effort to performance improvements
    - 14 public results with full Run-2 dataset (13 CONF Notes, 1 paper)
    - 8 of these were new for LHCP 2019 (late May) https://indico.cern.ch/event/687651/

Combined Higgs Boson Studies

Combined Higgs coupling results based on 2015—2017 data (80 fb^{-1})

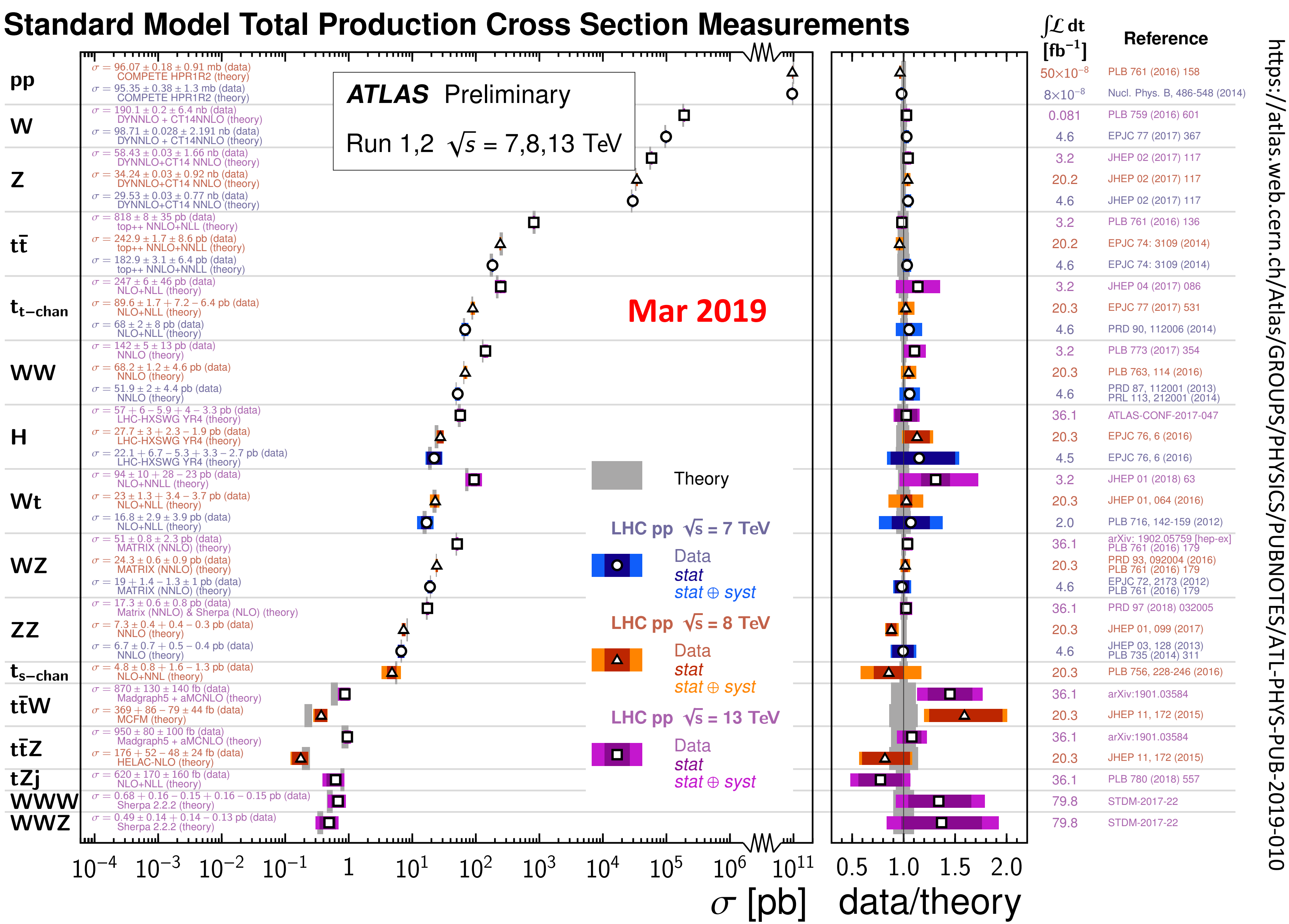




Various ways to interpret the set of measured production cross-section times branching ratio measurements

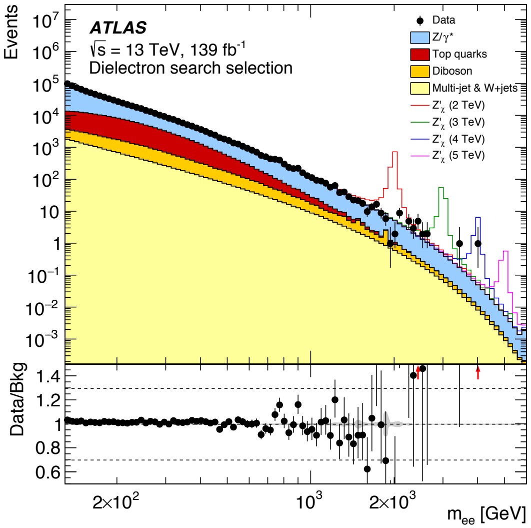
ATLAS-CONF-2019-005

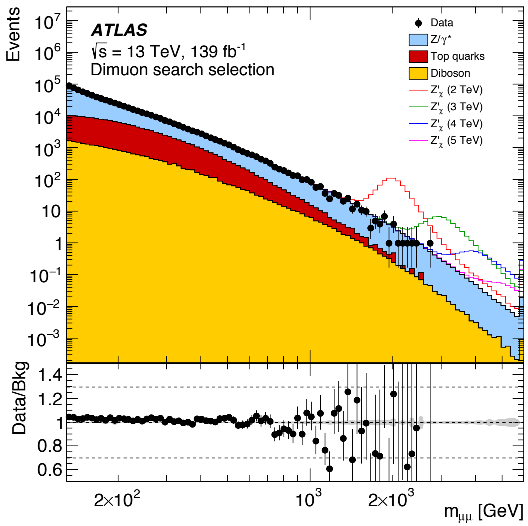
Standard Model Cross-section Measurements

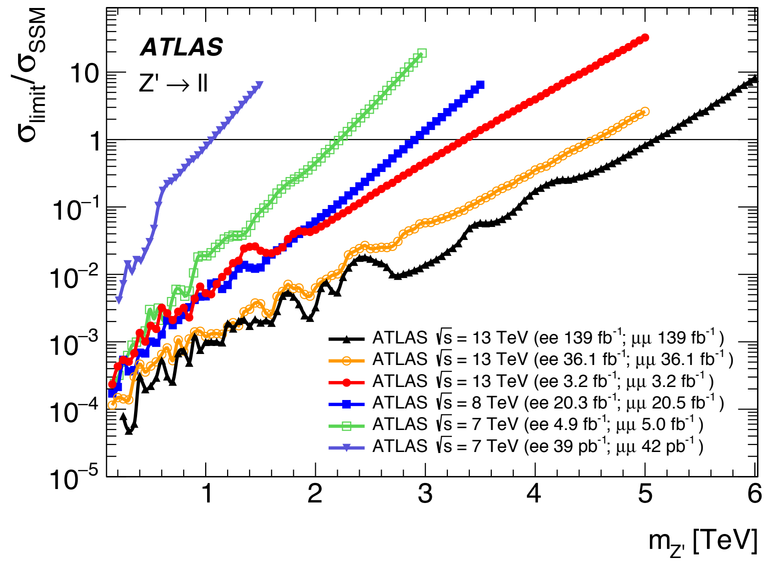


Resonances Searches (full Run-2 dataset)

Dilepton arXiv:1903.06248

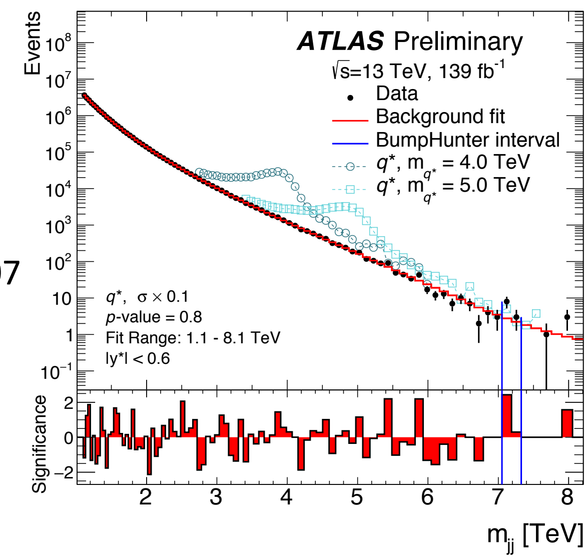


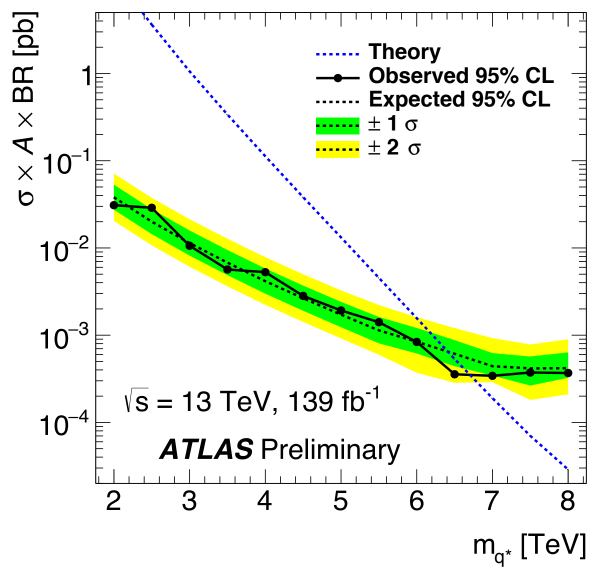




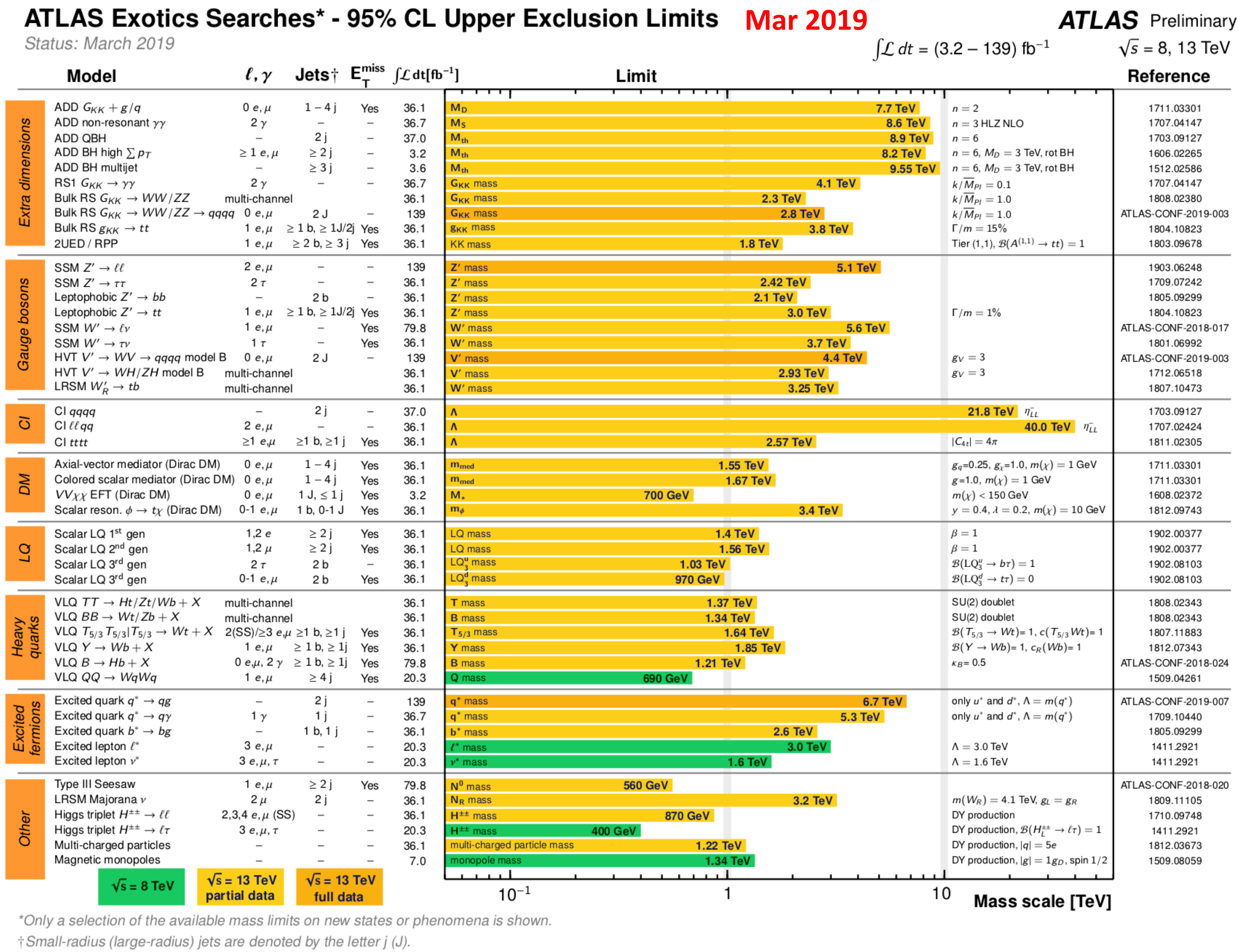
Dijet

ATLAS-CONF-2019-007





Exotics Search Summary



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/

For SUSY see https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/ (and backup slides)

Also significant Canadian involvement in 2019 Dark Matter Summary paper (based on 2015 + 2016 data)

Published for SISSA by Springer

Received: *March 6, 2019*
Accepted: *May 9, 2019*
Published: *May 23, 2019*

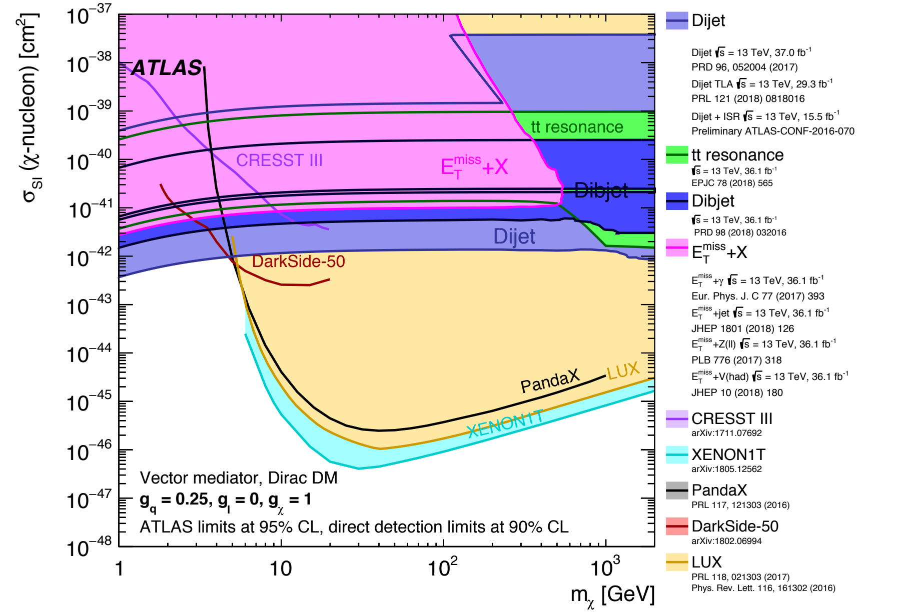
Constraints on mediator-based dark matter and scalar dark energy models using $\sqrt{s} = 13$ TeV pp collision data collected by the ATLAS detector

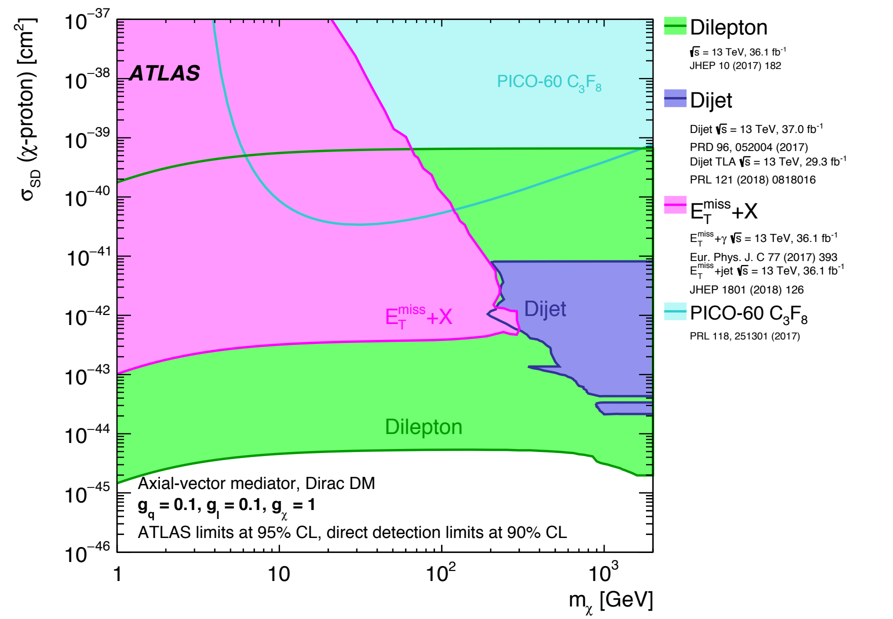
JHEP 05 (2019) 142

The ATLAS collaboration

See Tuesday CAP symposium talks by:

- C. Anelli (Dark Matter Searches)
- A. Lister (Dark Sector Searches)

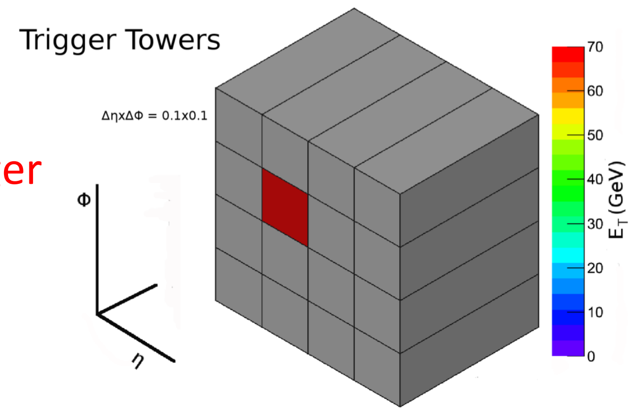




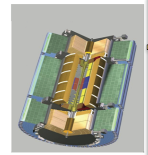
Phase-1 Upgrades: LAr Calorimeter Electronics

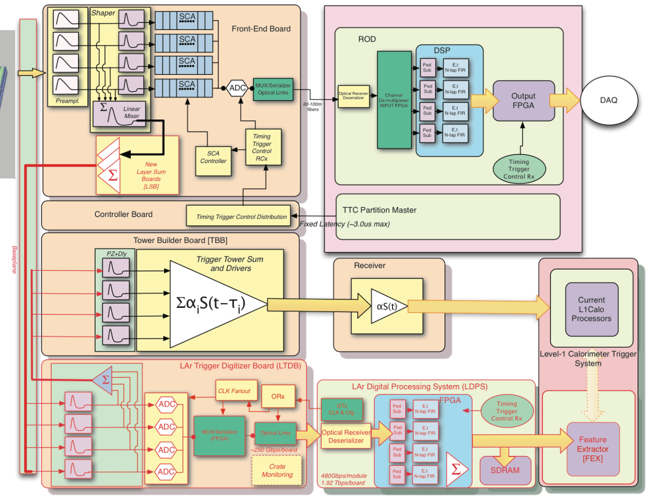
- **Key component of the ATLAS trigger strategy for Run-3**
- **Improve granularity of information supplied to the L1 trigger**
  - Provide additional background suppression at trigger level

Current trigger granularity



(a)

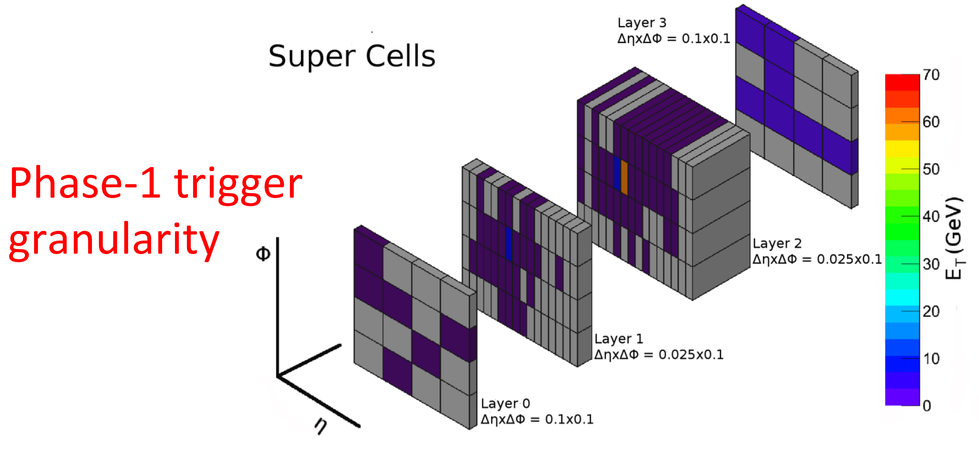




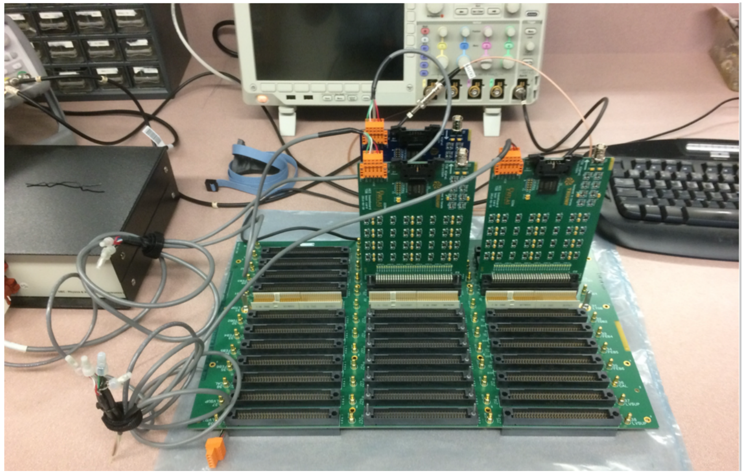
- **Implementation requires new Front-End Crate baseplanes**
- **For the HEC, these are being developed and produced by TRIUMF / Victoria**
  - Testing at UVic (shown above): half have been delivered to CERN so far
  - Just part of overall LAr upgrade work:
    - All boards need to be removed from Front-end crates, to allow baseplane replacements
    - New trigger boards to be installed (including new ASICs that had to be developed)
    - New back-end boards required to receive and process all the new information
    - This installation work has begun: project is on schedule and few risks remain

Phase-1 Upgrades: LAr Calorimeter Electronics

- **Key component of the ATLAS trigger strategy for Run-3**
- **Improve granularity of information supplied to the L1 trigger**
  - Provide additional background suppression at trigger level



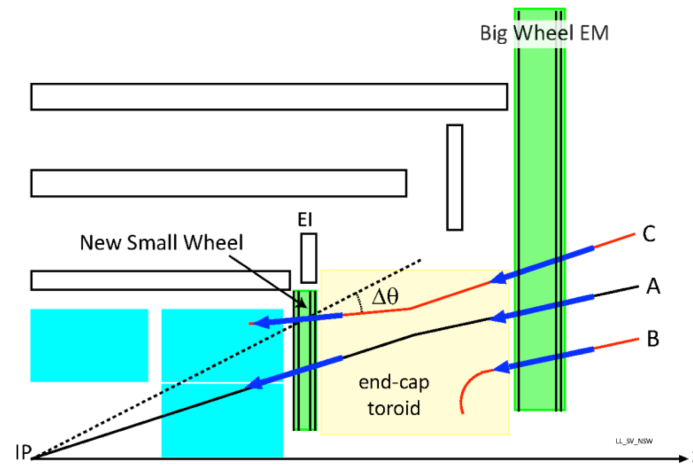
(b)



- **Implementation requires new Front-End Crate baseplanes**
- **For the HEC, these are being developed and produced by TRIUMF / Victoria**
  - Testing at UVic (shown above): half have been delivered to CERN so far
  - Just part of overall LAr upgrade work:
    - All boards need to be removed from Front-end crates, to allow baseplane replacements
    - New trigger boards to be installed (including new ASICs that had to be developed)
    - New back-end boards required to receive and process all the new information
    - This installation work has begun: project is on schedule and few risks remain

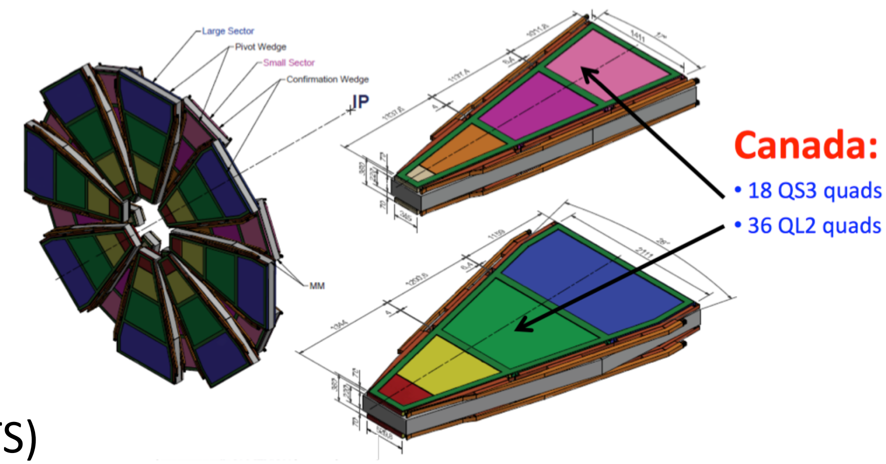
Phase-1 Upgrades: Muon New Small Wheel

- **Another key component of the Run-3 trigger (fake μ rejection with pointing)**
- **sTGC construction / testing infrastructure: TRIUMF, Carleton, McGill, Victoria**
- **Leading coordination roles in NSW project:**
  - Leadership of sTGC project
  - Overall project management, schedule, finances
  - Wedge assembly at CERN
  - Software / simulation
  - Electronics / software for cosmic-ray test station
  - Production test pulser board for sTGCs



- **Past sTGC delays due to component procurement (now resolved), but:**
  - Also delays for other NSW subsystems
    - Micromegas (MM) for precision tracking
    - Custom readout ASICs
  - Expect installation of only one NSW in LS2
  - Second to be installed during a future Extended End-of-Year Technical Stop (EYETS)

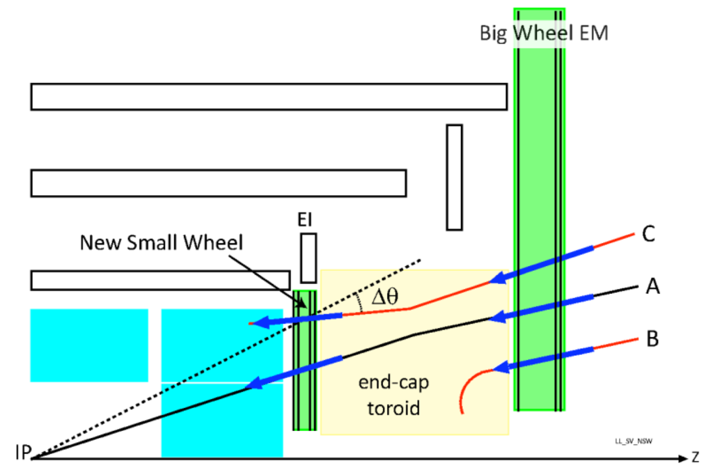
  See CAP talk by Jesse Heilman



Canada: ¼ of all sTCG modules

Phase-1 Upgrades: Muon New Small Wheel

- **Another key component of the Run-3 trigger (fake μ rejection with pointing)**
- **sTGC construction / testing infrastructure: TRIUMF, Carleton, McGill, Victoria**
- **Leading coordination roles in NSW project:**
  - Leadership of sTGC project
  - Overall project management, schedule, finances
  - Wedge assembly at CERN
  - Software / simulation
  - Electronics / software for cosmic-ray test station
  - Production test pulser board for sTGCs



- **Past sTGC delays due to component procurement (now resolved), but:**
  - Also delays for other NSW subsystems
    - Micromegas (MM) for precision tracking
    - Custom readout ASICs
  - Expect installation of only one NSW in LS2
  - Second to be installed during a future Extended End-of-Year Technical Stop (EYETS)

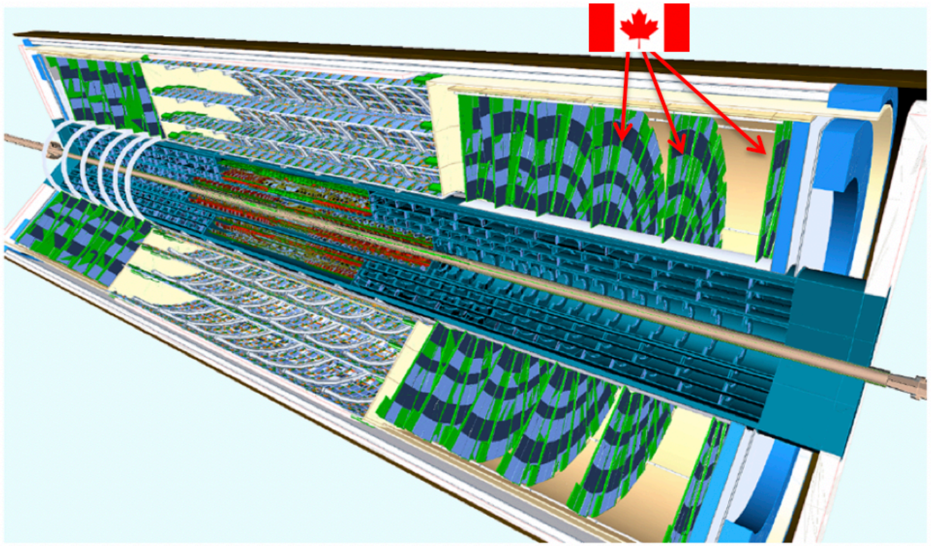
ATLAS at the High Luminosity LHC

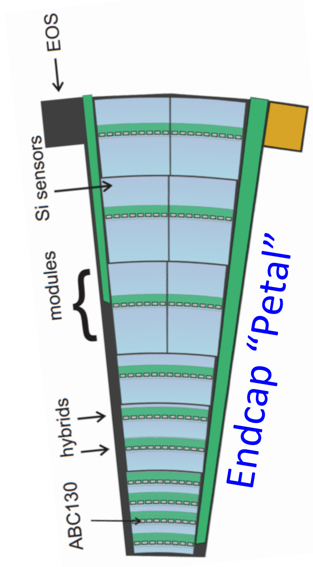
- **Proposed instantaneous luminosity of 7.5 × 10^{34} $cm^{-2}s^{-1}$ (μ≈200)**
  - Needed for the desired (×10) increase in integrated luminosity
  - Rate and accumulated dose causes problems for some detector subsystems
  - Need for pileup suppression becomes crucial issue for detector upgrades

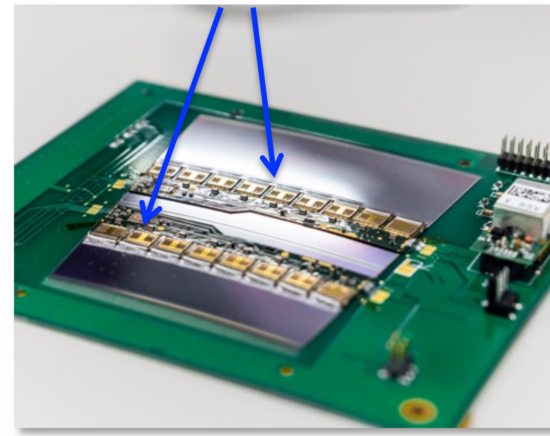
- **Proposed L0/L1 trigger scheme with rates of 1MHz/400KHz is incompatible with both tracker and calorimeter readout electronics:**
  - **Calorimeter front- and back-end electronics must be entirely replaced**
  - **Tracker to be entirely replaced by a new all-silicon tracker, the ITk**
    - Pixels at low radius, strips at higher radius.
      - Coverage out to |η| = 4.0 (from 2.5 for current inner tracker)
    - 160 m^2 of silicon. Almost half the cost / effort of Phase-II upgrades

- **Also other upgrades: Canada involved only in the ones just described**
  - **Canadian participation funded by CFI in IF 2017 competition**
  - We have multiple technical leadership & management roles in both projects

Phase-2 Tracker Upgrade (ITk)







- **Excellent tracking needed for the HL-LHC physics program**
  - Need precision vertexing to identify the primary vertex from high pileup
- **Canadian group contributing to construction of the Endcap Strips detector:**
  - about 18k Si strip modules needed (~7000 in endcap):
  - plan for 1500 in Canada (2 sites: Vancouver, Toronto)
  - Also, industrialized production of "hybrid boards", module placement on support structure for Endcap "petals", readout electronics ASIC wafer probing and dicing, simulation infrastructure. *Canada making ~ 2.5 Endcap discs (40% of one endcap)*

Significant progress on all items in 2018-19

Phase-II LAr Calorimeter Upgrade Work

- **Phase-1 upgrade is to trigger path electronics**
- **Phase-2 upgrade is to main readout path electronics**
  - Front-end readout
  - Calibration system
  - Off-detector readout (previously "back-end")
- **Canadian groups integrated into this effort:**
  - Naturally follows our Phase-I work and historical contributions to ATLAS
  - Focus on front-end electronics for the HEC
    - HEC was built in part in Canada
    - Differs from other LAr subsystems, due to cold preamplifiers in the cryostat
      - Exploiting particular Canadian expertise in the HEC readout
  - Also taking leadership role in development of FPGA-based off-detector system
    - Data handling
    - FPGA-based filtering algorithms used for energy reconstruction
- **Canadians occupy a significant fraction coordination roles:**
  - Simulation group, Front-End group, Resources, Firmware

Summary

- **LHC/ATLAS operations were excellent in 2018**
  - Smooth startup in 2018. $\mathcal{L}_{int}$ slope ≈ that achieved towards end of 2017
  - Earlier start to 2018 run year:
    - target of delivered luminosity of 60 fb^{-1} was exceeded
- **Canadian group successfully engaged in all aspects of ATLAS**
  - Important and visible roles in the Collaboration
  - Physics output (analysis, review, physics group & sub-group convenors, etc.)
  - Detector operations (run coordinators for multiple subsystems), computing
  - Strong participation in detector upgrade activities
    - Phase-1: LAr trigger electronics, sTGCs for NSW
    - Phase-2: LAr readout electronics, ITk
    - Including leadership roles in both Phase-1 and Phase-2 projects
- **Canadian contribution to the HL-LHC accelerator upgrade**
  - Pursued with the help of the IPP Director and the support of TRIUMF
  - Funding announced by Science Minister Duncan in June 2018:
    - $10M for development & construction of cryo-modules to house the crab-cavities
    - Project to be managed by TRIUMF, with involvement of Canadian industry

ATLAS Canada Talks at the 2019 CAP Congress

Invited

- Searches for Dark Sector on ATLAS, *A. Lister*
- Overview of Dark Matter Searches by the ATLAS Experiment, *C. Anelli*
- Upgrades to the ATLAS Detector at the LHC, *J. Heilman*
- Run-2 Physics Results from the ATLAS Detector at the LHC, *B. Stelzer*

Contributed (upgrade hardware)

- Stress Evaluation of ITk Strip Endcap Modules in Coldbox Setup Using FEA Simulations for the ATLAS Phase-II Upgrade

Contributed (physics)

- The search for exotic dilepton signatures in the full LHC Run-2 dataset collected with the ATLAS detector
- Improvement of missing transverse momentum reconstruction for ATLAS experiment at LHC
- Vector Boson Scale Factor Measurement with the ATLAS Detector
- Search for Magnetic Monopoles and High Electric Charge Objects in the ATLAS Detector
- In-situ measurements of the ATLAS jet energy resolution using 13 TeV pp data (poster)
- Fiducial Differential Cross Section Measurements in the HZZ4l Channel with the ATLAS Detector (poster)
- Search for SUSY with missing transverse momentum and multiple b-jets (poster)