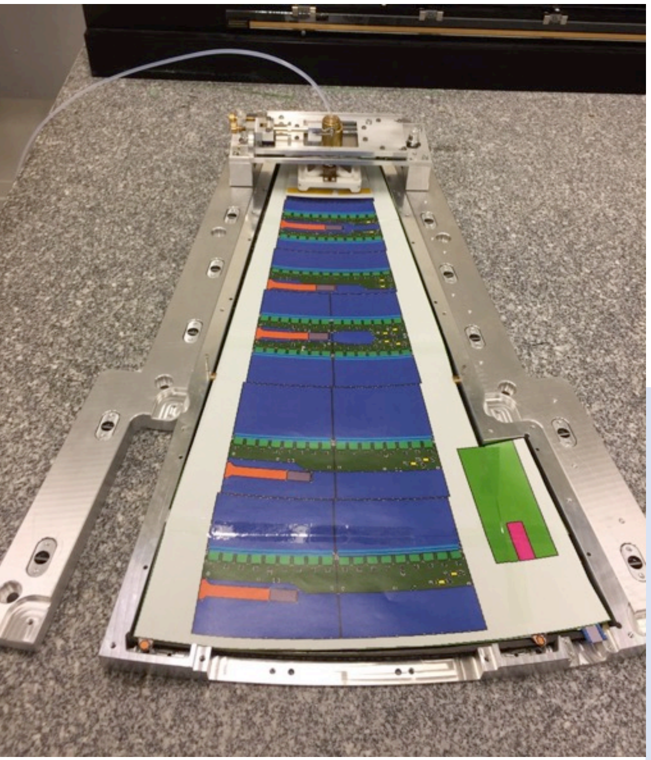
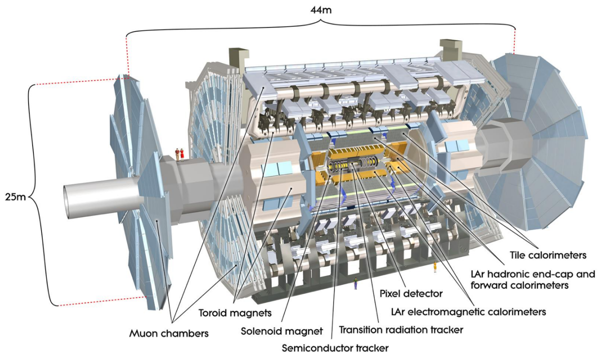
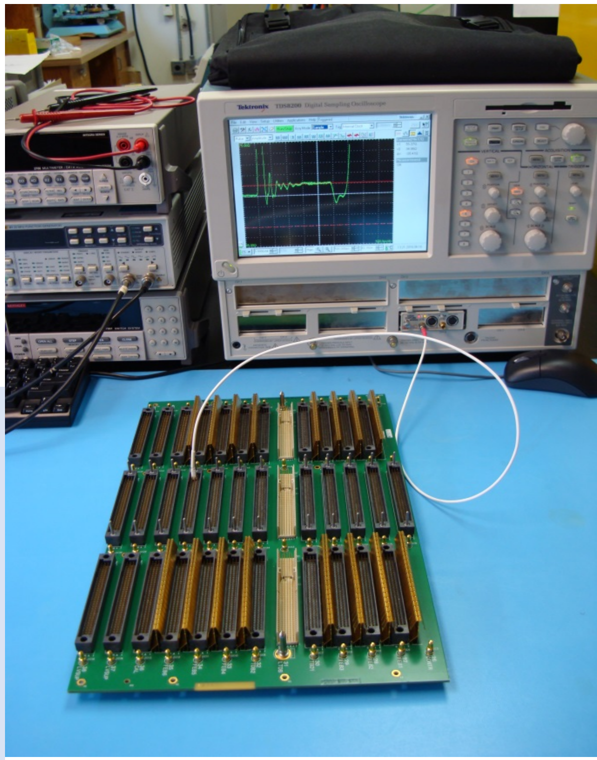
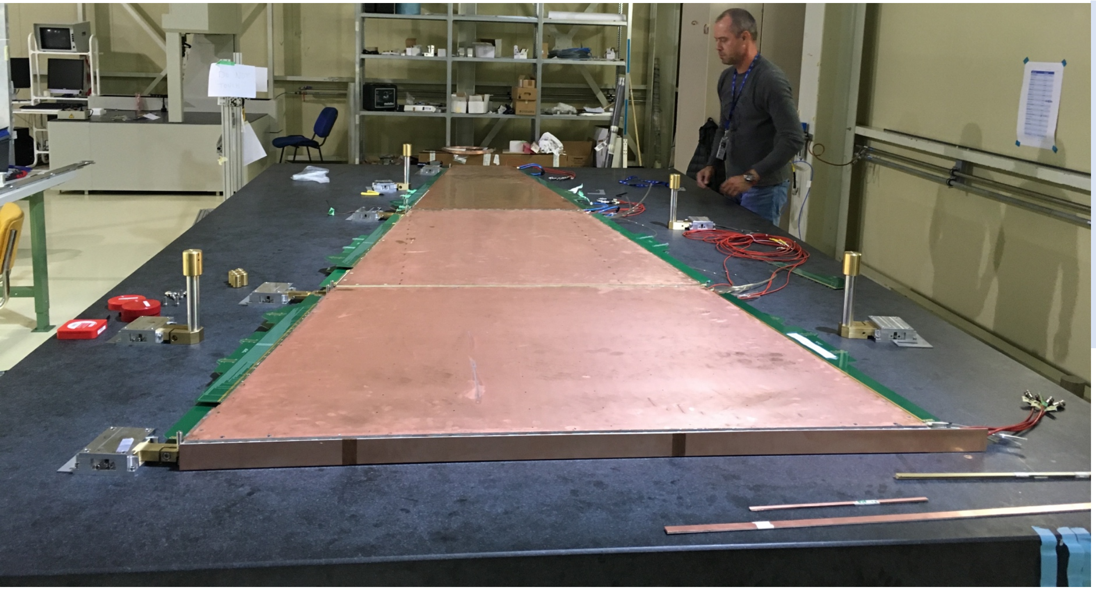






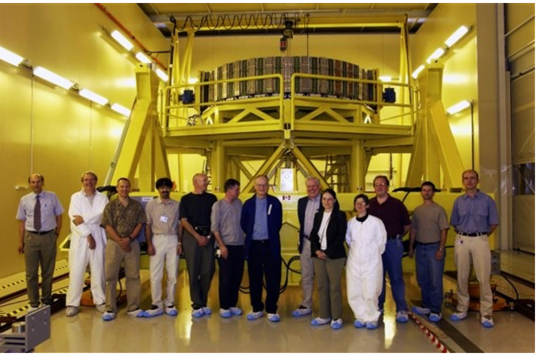
Upgrading the ATLAS Detector for a Long and Luminous Career



Isabel Trigger

TRIUMF

CAP 2017



Overview: Canada and ATLAS

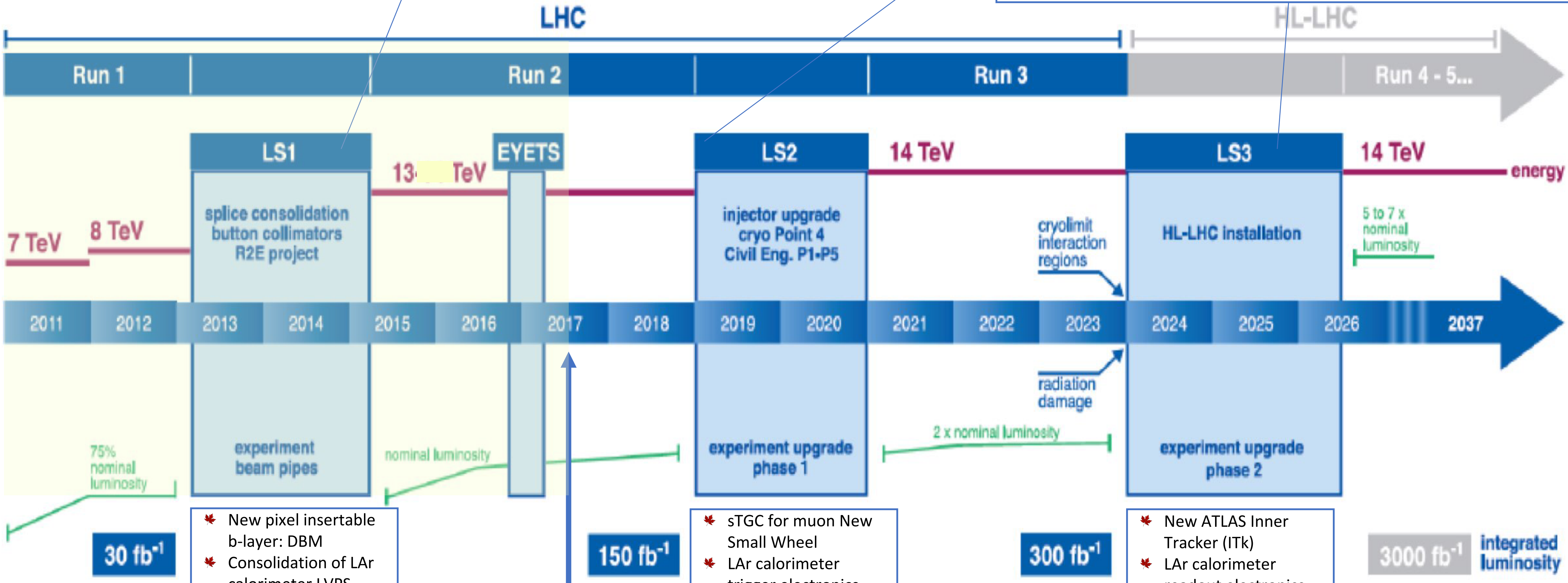
- Canada officially joined LHC in 1996
- … Canadians were on ATLAS from (before) its foundation in 1992
- Built large parts of Liquid Argon (LAr) calorimeters: Hadronic EndCaps, Forward Calorimeter, cryo feedthroughs, and their electronics
- Plus: contributions to pixel tracker, beam conditions monitors, diamond beam monitors, luminosity monitor LUCID, Medipix/ Timepix for cavern background monitoring, Transition Radiation Tracker electronics, and personal contributions to many other systems
- We operate the detector
- We analyze the data
- And we continue to upgrade to keep pace with accelerator progress

LHC timeline

Consolidation, $\sqrt{s}$=13 TeV, 25 ns bunch space, $L \approx 1 \times 10^{34}$ $cm^{-2}s^{-1}$ ($\mu \approx 30—50$) $\int L \approx 150$ fb^{-1}

Likely $\sqrt{s}$=14 TeV; $L \approx 2 \times 10^{34}$ $cm^{-2}s^{-1}$ ($\mu \approx 60$); $\int L \approx 300$ fb^{-1}

$L \approx 7 \times 10^{34}$ $cm^{-2}s^{-1}$ ($\mu \approx 200$); $\int L \approx 3000$ fb^{-1}



- New pixel insertable b-layer: DBM
- Consolidation of LAr calorimeter LVPS

- sTGC for muon New Small Wheel
- LAr calorimeter trigger electronics

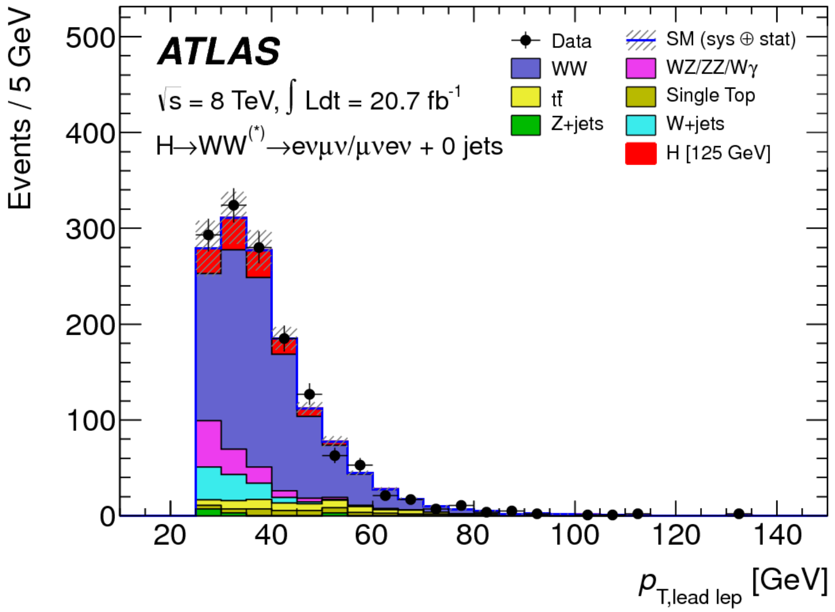
- New ATLAS Inner Tracker (ITk)
- LAr calorimeter readout electronics (front-end and back-end)

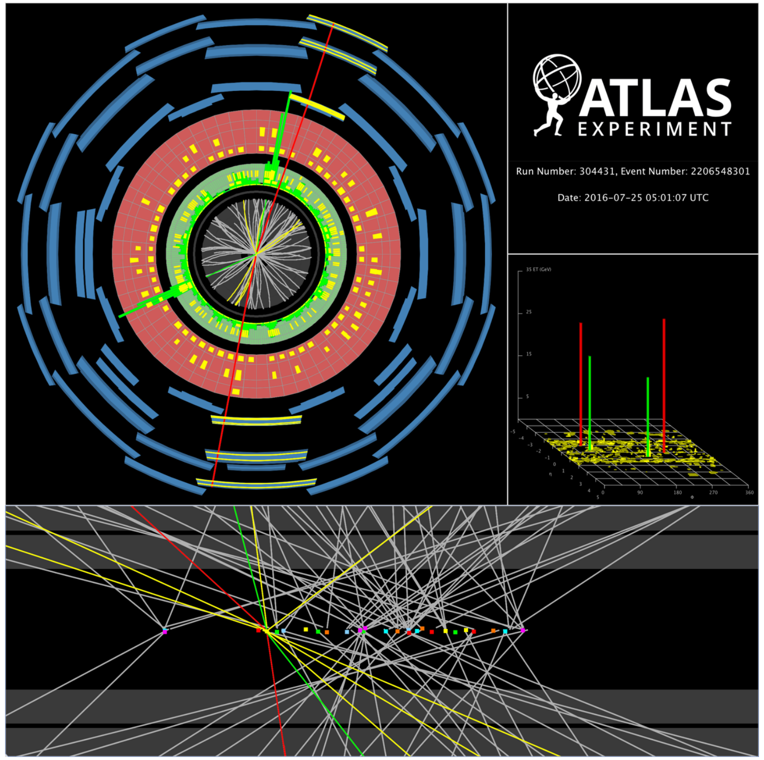
We are here

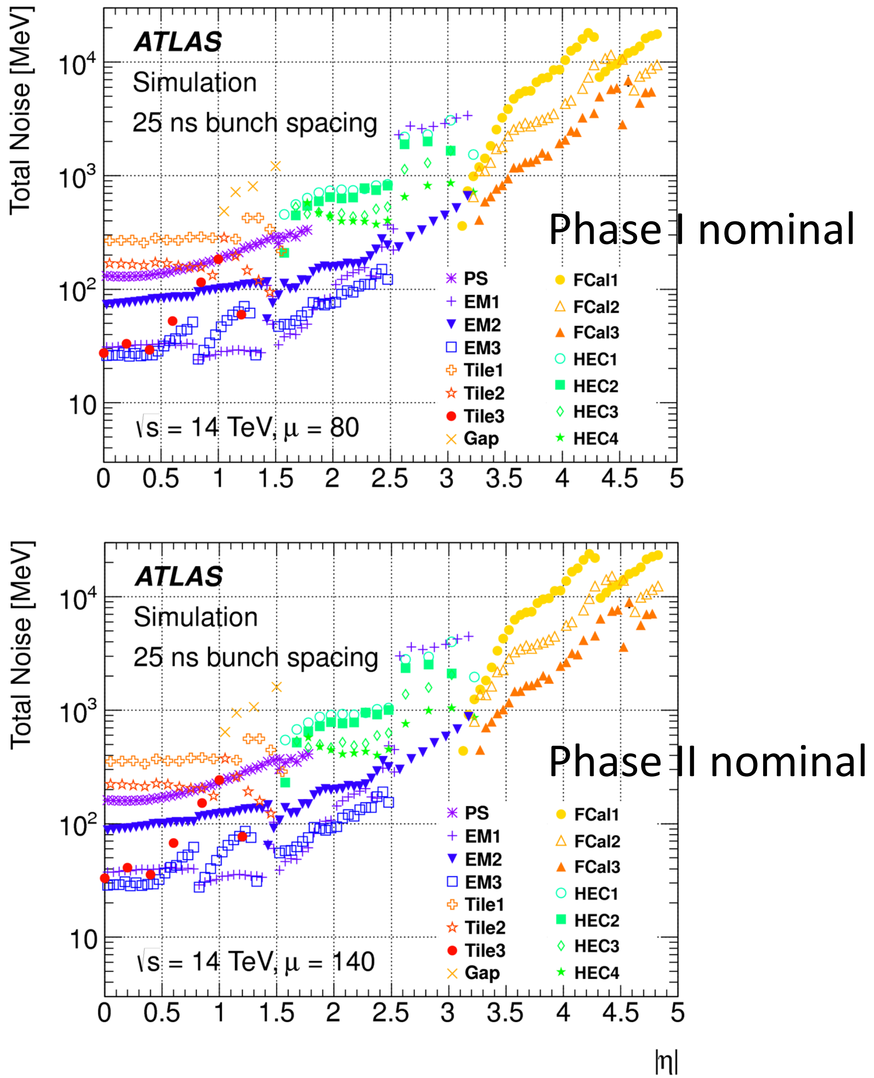
The challenge of high luminosity: keeping up!

Where we are now

- Typical Run 2 trigger thresholds:
  - Single e: 26 GeV
  - Single mu: 26 GeV

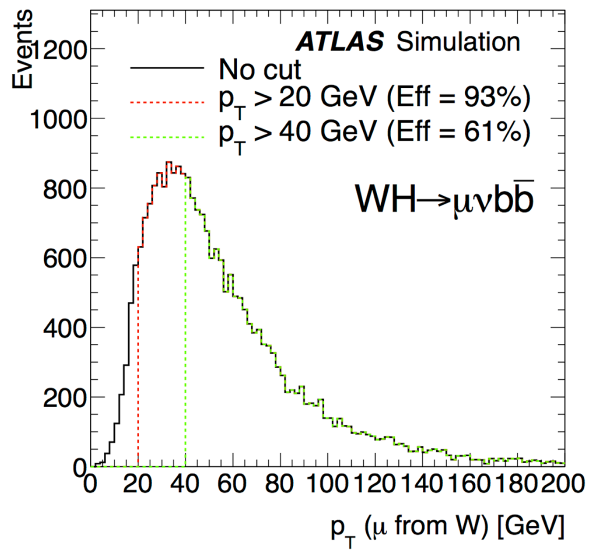


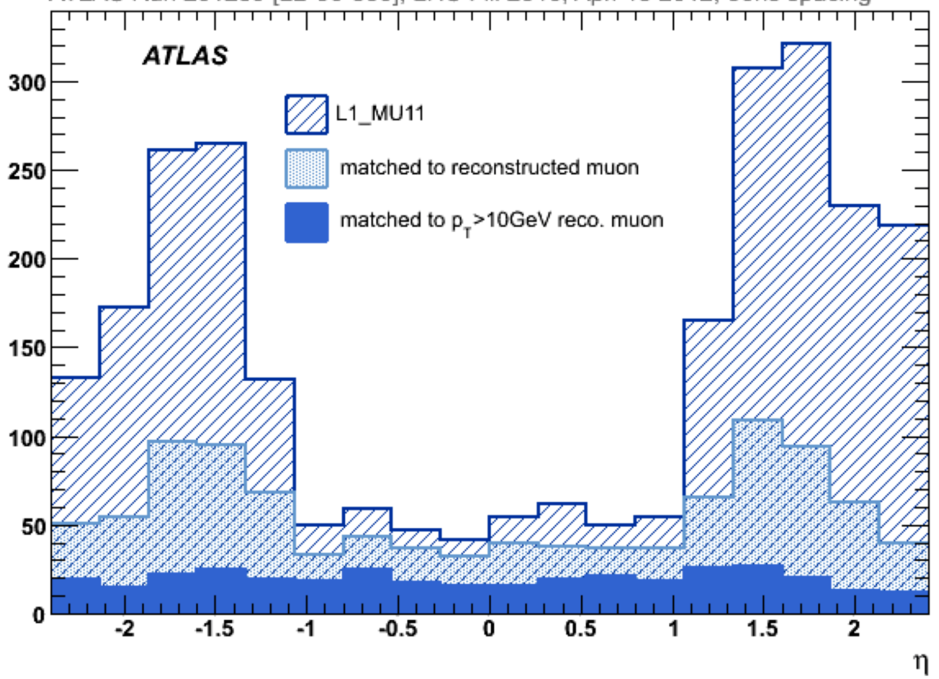




Goal of Phase I upgrades

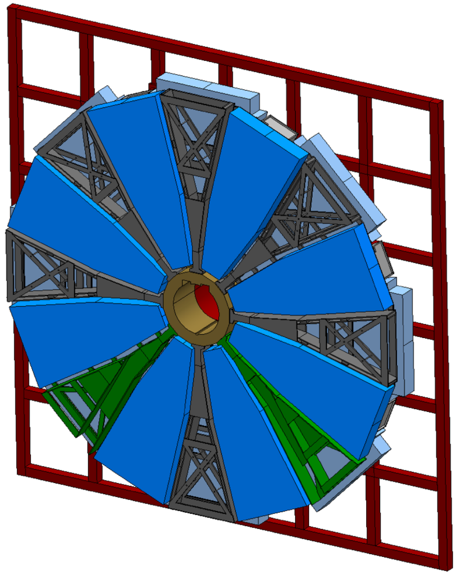
- Keep ability to trigger on low-p_T (~20 GeV) leptons by killing fakes
  - LAr: let trigger use more of full detector granularity so shape info allows better online electron / hadron discrimination - keep low-pT electrons without being swamped in high-pileup events
  - Muons: fakes mostly from activation of forward toroids – supplement Big Wheel trigger (downstream of toroids) with New Small Wheel to provide matching trigger segments upstream – keep low-pT muons without being swamped

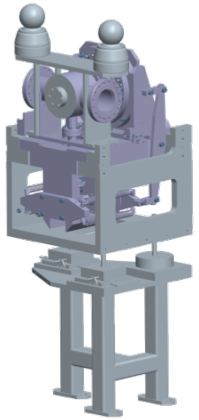


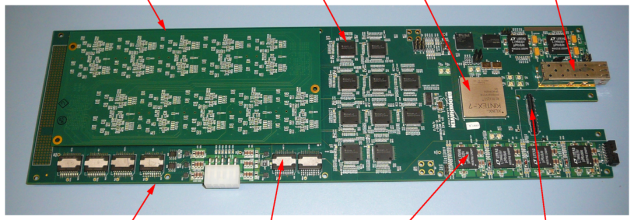


ATLAS Phase I upgrades (in construction)

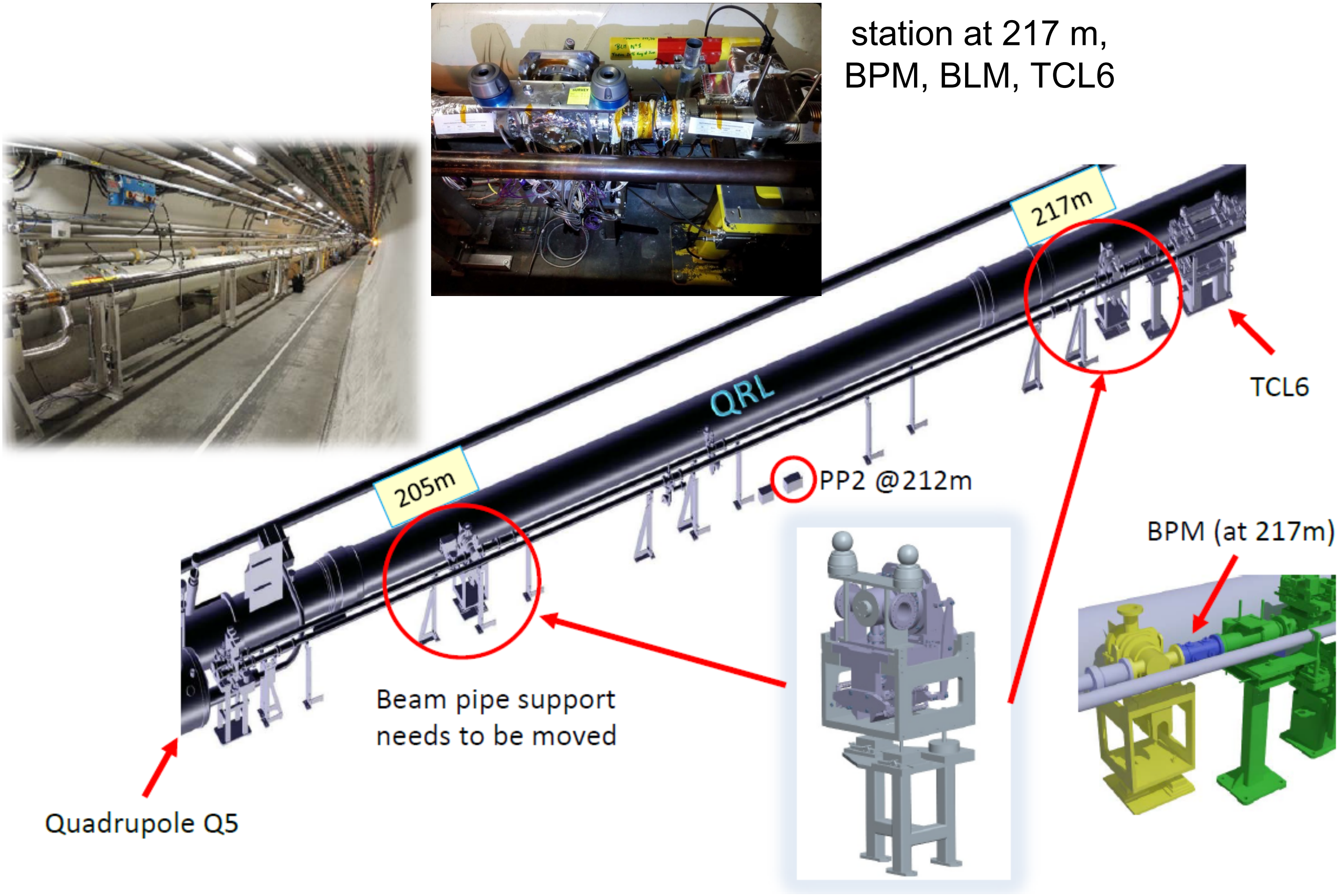
- **New Muon Small Wheel (NSW)**
- **High Precision Calorimeter Level-1 Trigger**
- **Fast Track Trigger (FTK)**
- **Topological Level-1 Trigger Processor**
- **New forward diffractive physics detectors AFP**
- Trigger-DAQ







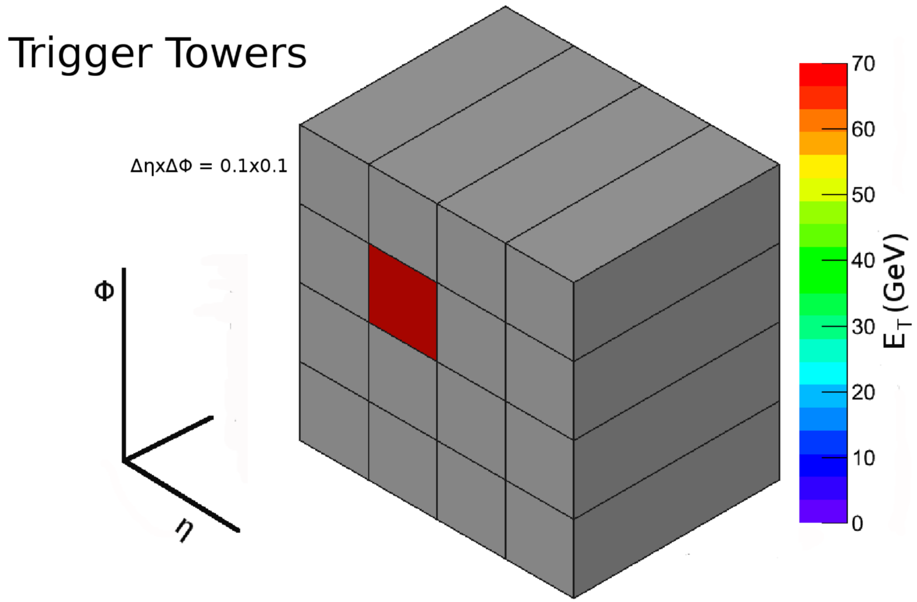
ATLAS Forward Proton Detector

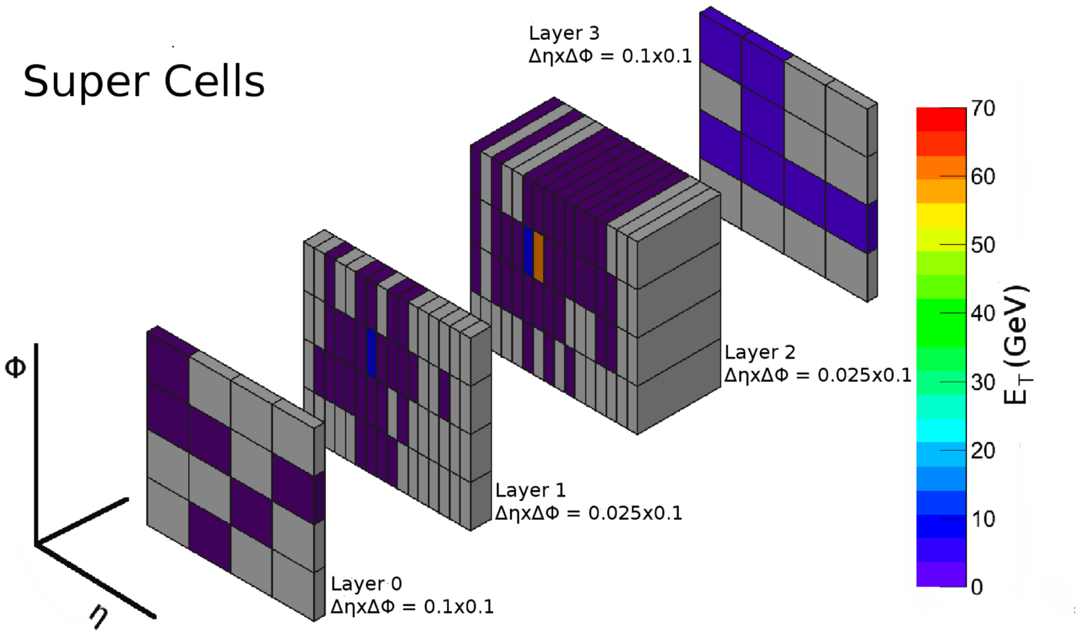


- Silicon-based tracker in Roman pots plus quartz bar time-of-flight system 2-3 mm from beam, 210 m away from ATLAS interaction point
- "Early" phase-1 upgrade: already installed (1 side Roman pots in 2015-16 shutdown, 2nd plus both sides ToF in 2016-17)

LAr Phase I trigger electronics upgrade

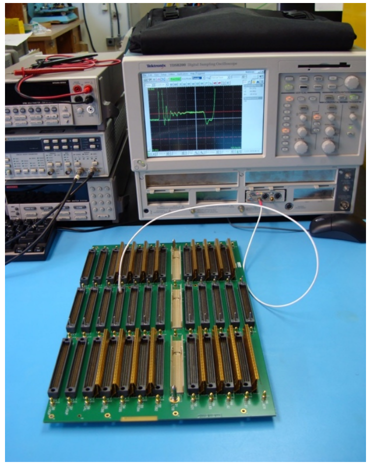
- Increase granularity of trigger towers ~10x
- Improved trigger energy resolution & efficiency for e, γ, τ, jets, E_T^{miss}
- Much better electron/hadron/pileup discrimination in trigger
- Lets single-electron threshold remain low enough for electroweak physics

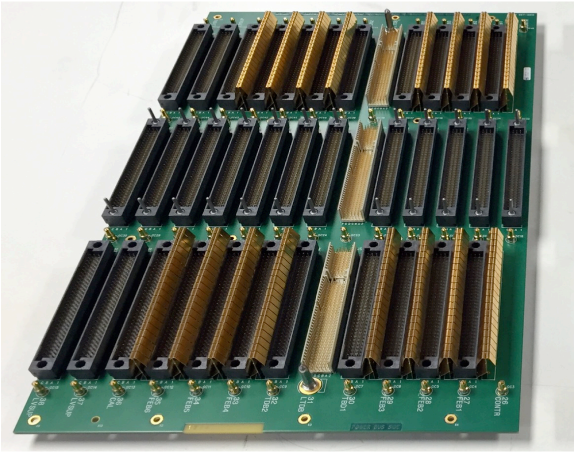


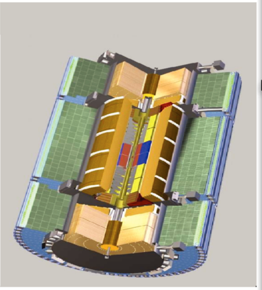


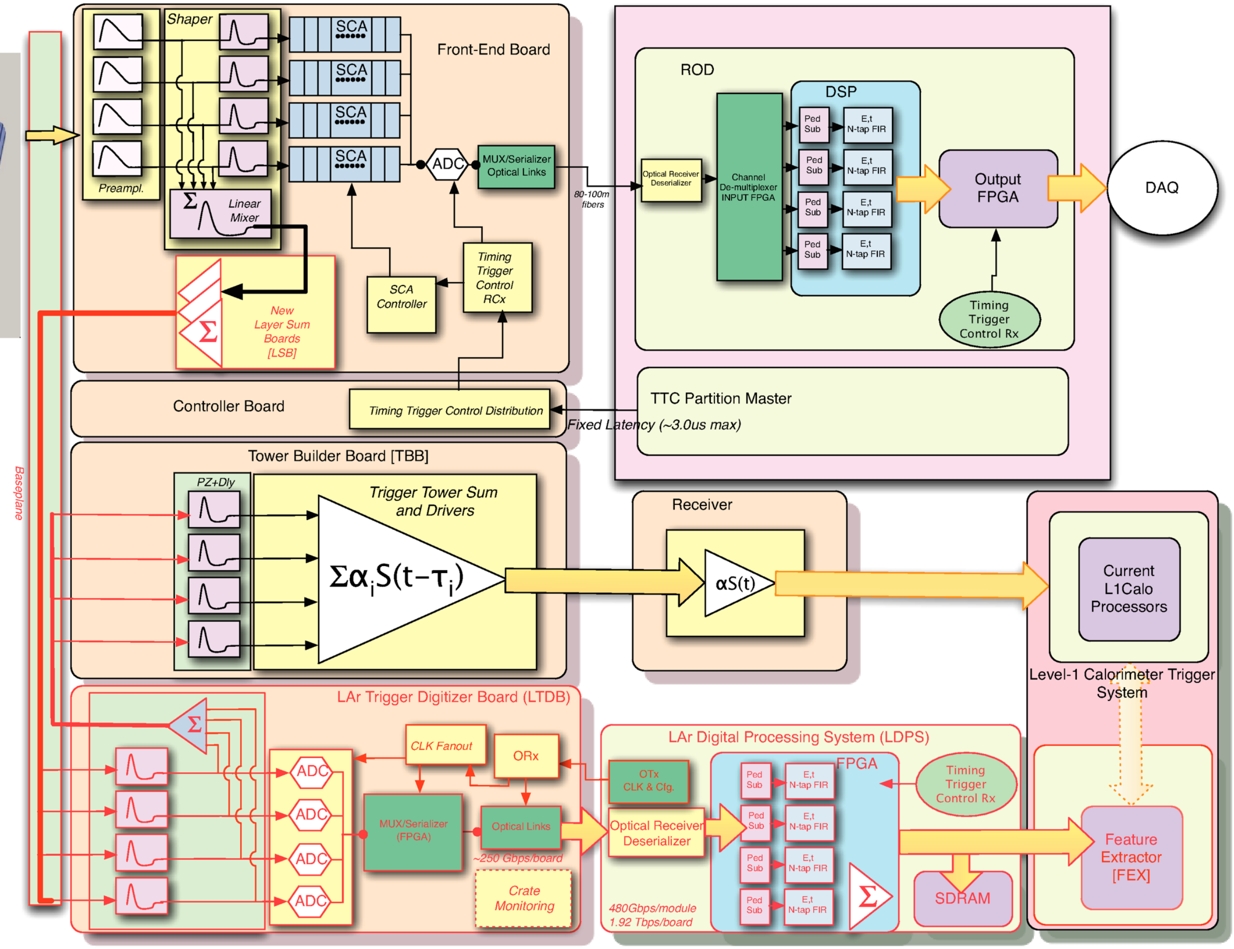
LAr Phase I in Canada

- Digitize signals earlier, allowing more granularity for shower shape information in trigger decision
- Replace local analog summing boards, New trigger digitizers & trigger processors
- New baseplanes for on-detector crates, since new electronics must fit in same space as old
- TRIUMF & U.Victoria building the 8 baseplanes for Hadronic End-Cap crates
- Design, prototypes, assembly at TRIUMF, acceptance tests at UVic
- Plus Canadian “core” contribution to trigger digitizer boards & ADCs





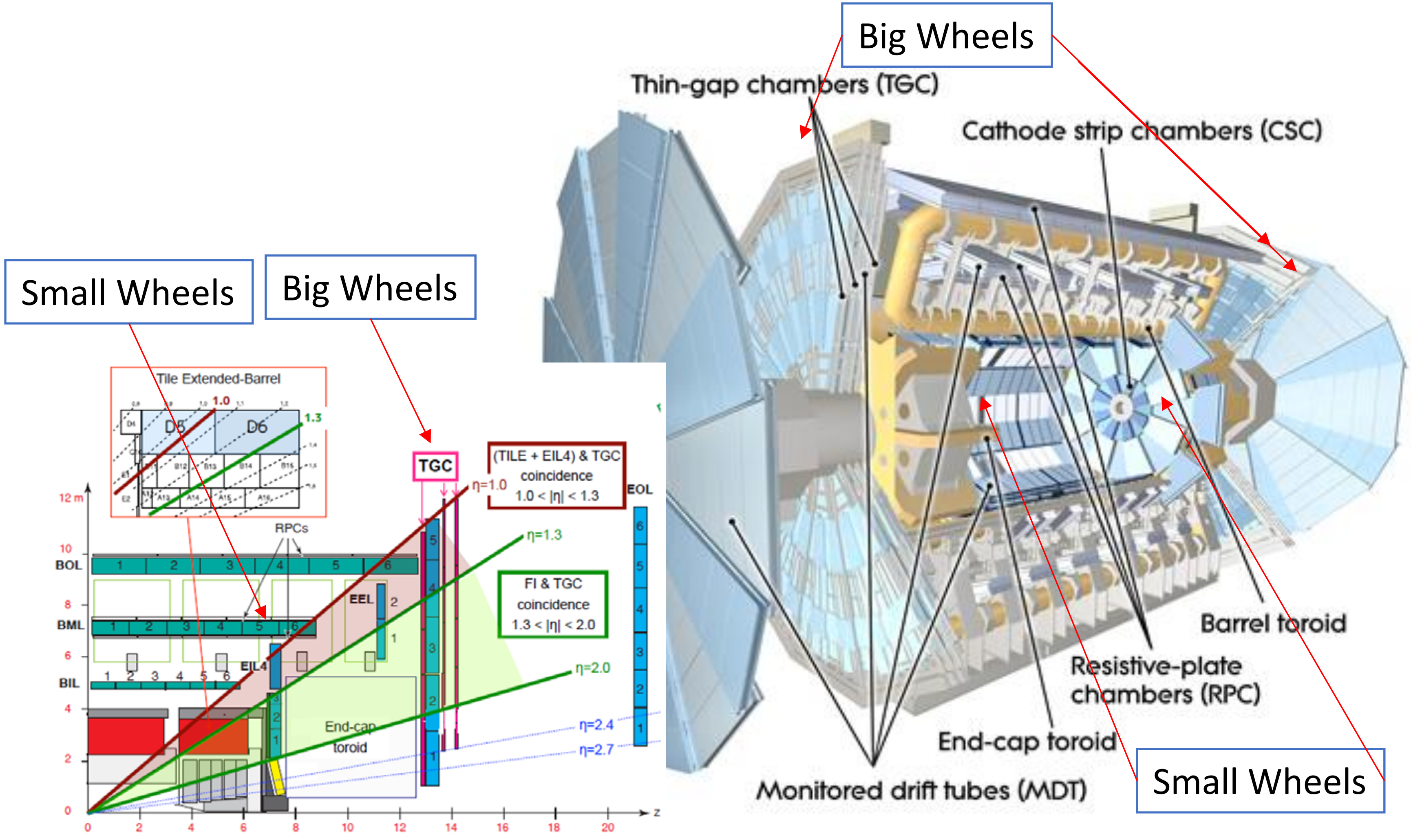




2017/05/31

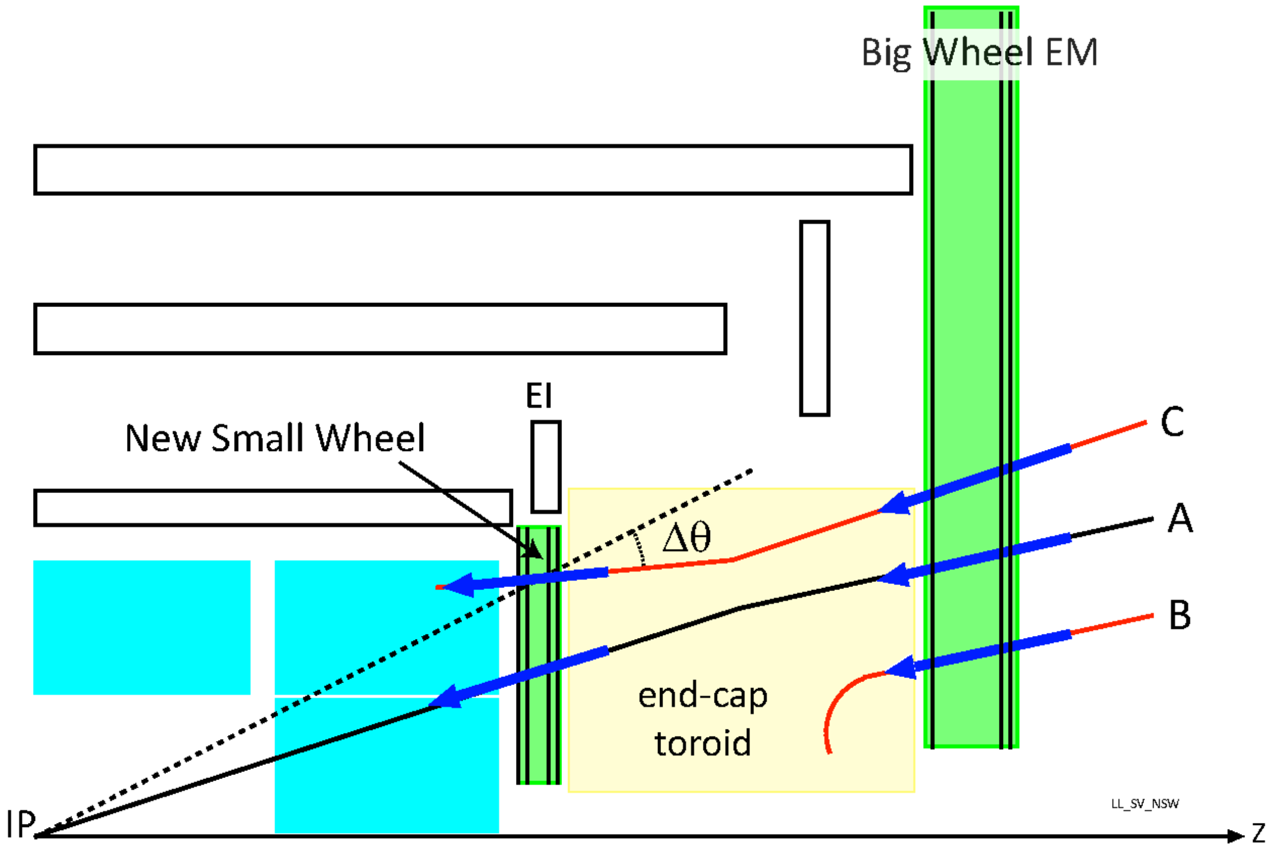
Muon Spectrometer New Small Wheel (NSW)

- Original Run-1 end-cap trigger:
  - Big Wheel segments
  - fakes from activation of toroids are 90% of trigger rate, increase with luminosity
- During Run-2, added Small Wheels to trigger
  - Helps (~30% fake reduction), but coarse, only partial geometric coverage



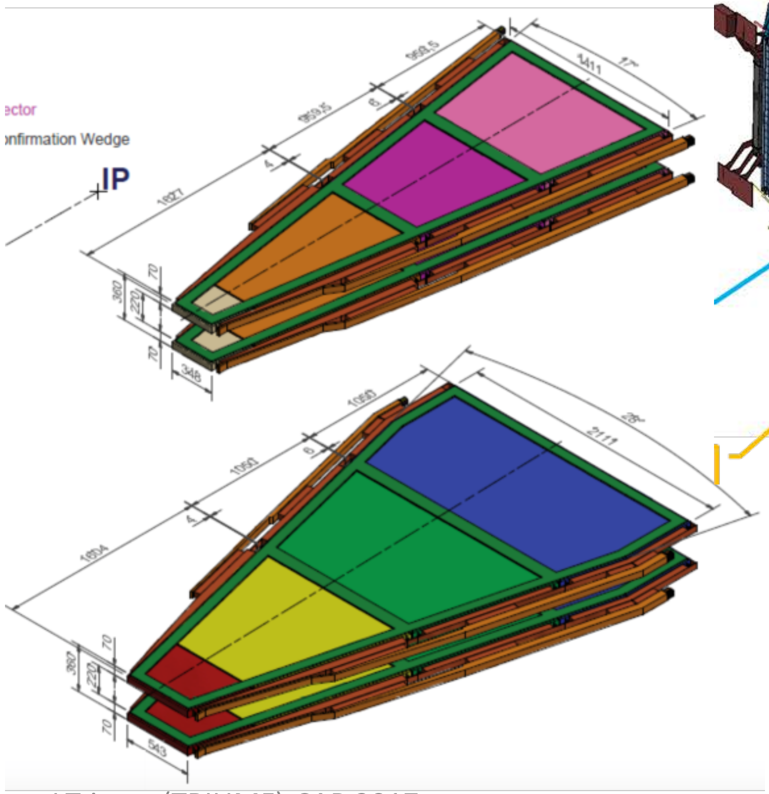
Muon Spectrometer New Small Wheel (NSW)

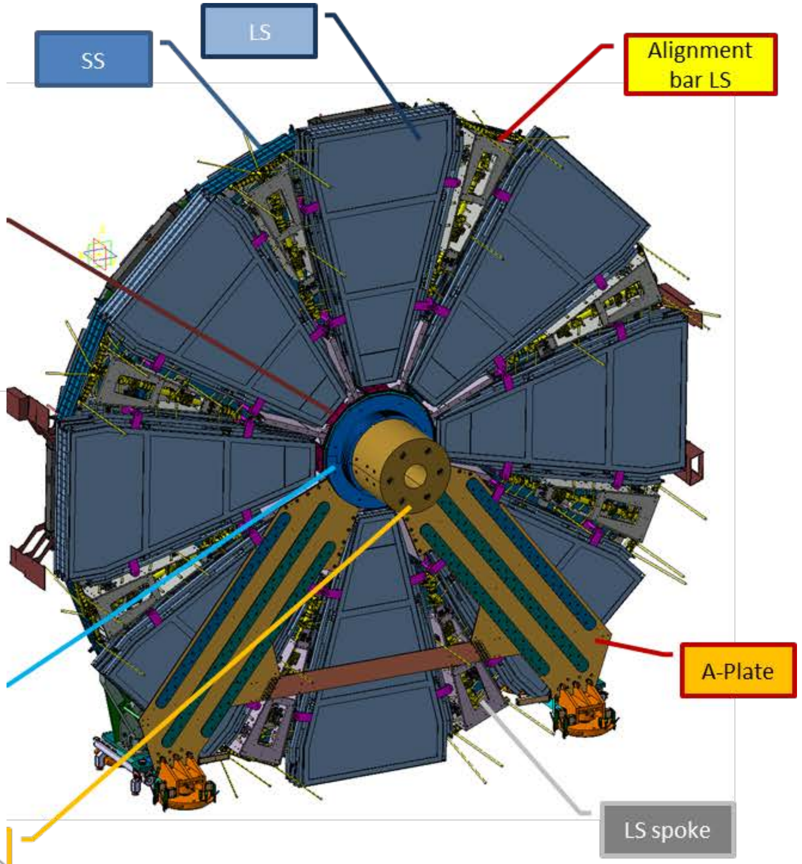
- New for Run-3, NSW will give precise segments pointing to IP
- Can be matched to Big Wheel regions of interest to avoid fake triggers (Big Wheel triggers ~90% fake!)
- Designed for up to 15 kHz/cm^2
- Consistency with IP must be <7 mrad, requiring angular resolution ~1 mrad (for Phase-II)



NSW Design

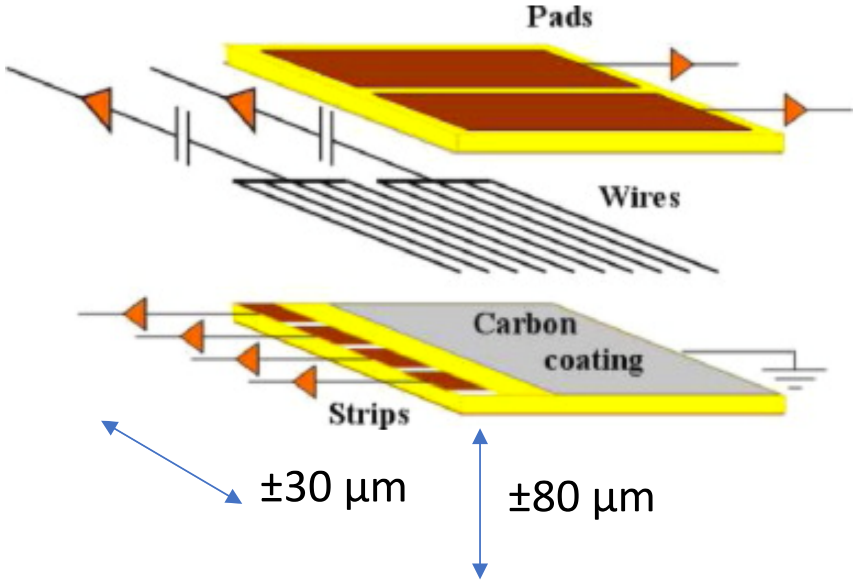
- One wheel each side of ATLAS
- Each consists of 8 large sectors & 8 small sectors kinematically mounted on wheel structure
- Each sector consists of:
  - Central spacer frame
  - With MicroMegas chambers for precision tracking mounted directly on each side and
  - sTGC (small-strips Thin Gap Chamber) wedges kinematically mounted on each side



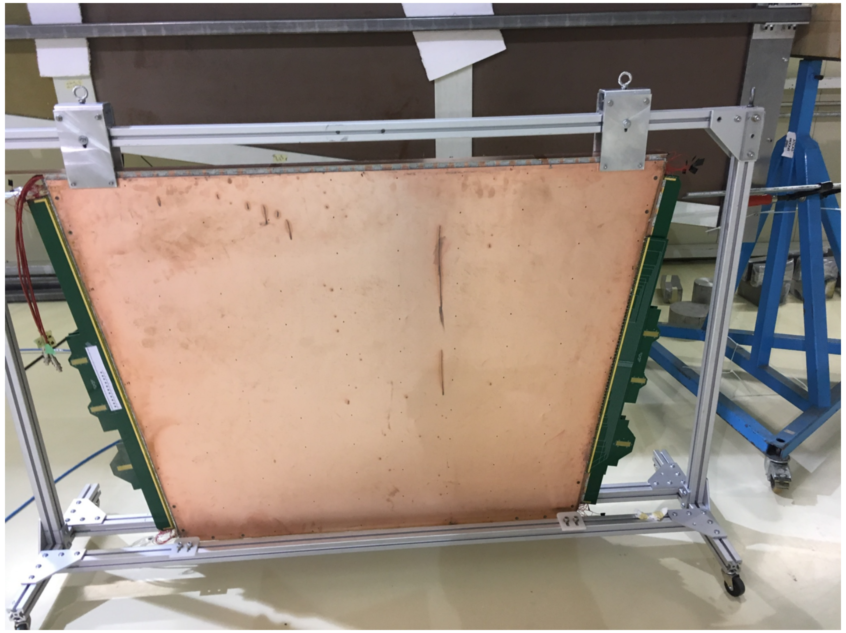


sTGC Quadruplets

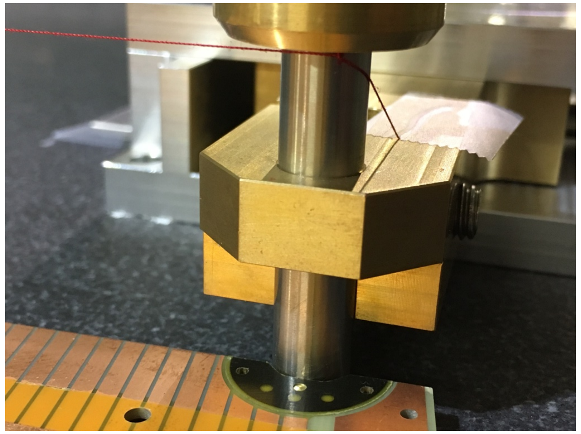
- Pad and strip cathode boards produced in industry (~1 m x ~1.5-2 m precision PCBs)
- Half-gaps prepared at TRIUMF:
  - Mask boards, spray resistive graphite/resin layer
  - Glue gas frames, spacer bars & buttons
- Carleton:
  - Winds wires onto pad boards
  - Glues gaps closed & adds spacer layers
  - Glues gaps into doublets
  - Glues doublets into quads
- McGill: cosmic-ray testing (talk from Felix)

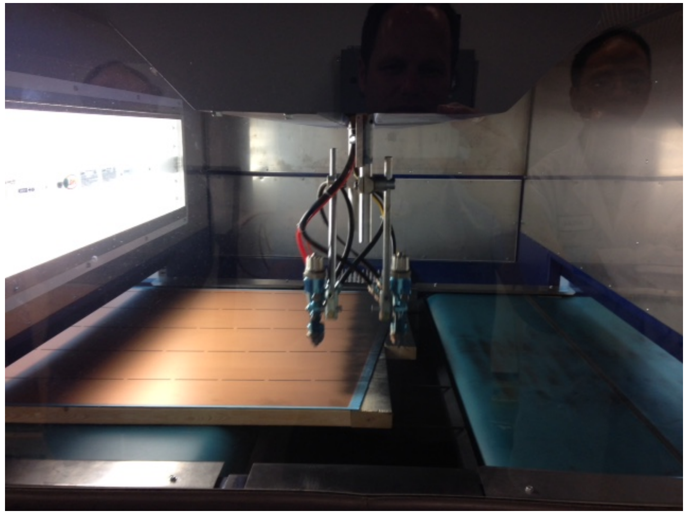


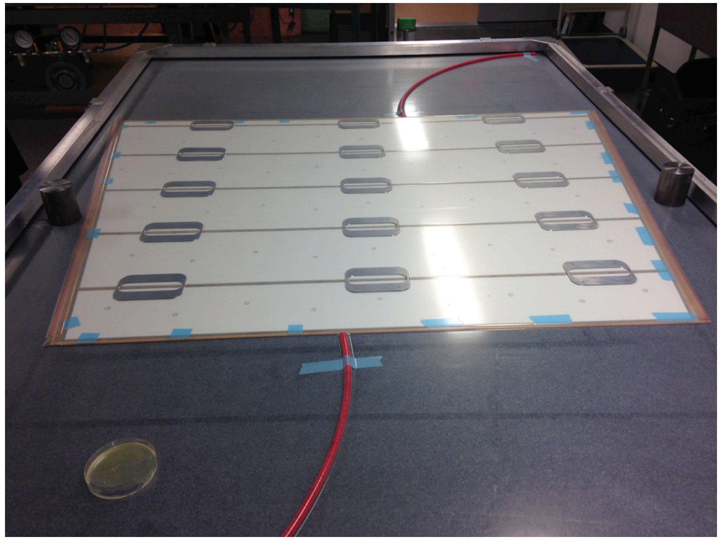
Precision is key: must know strip positions to 30 µm in-plane, 80 µm in depth

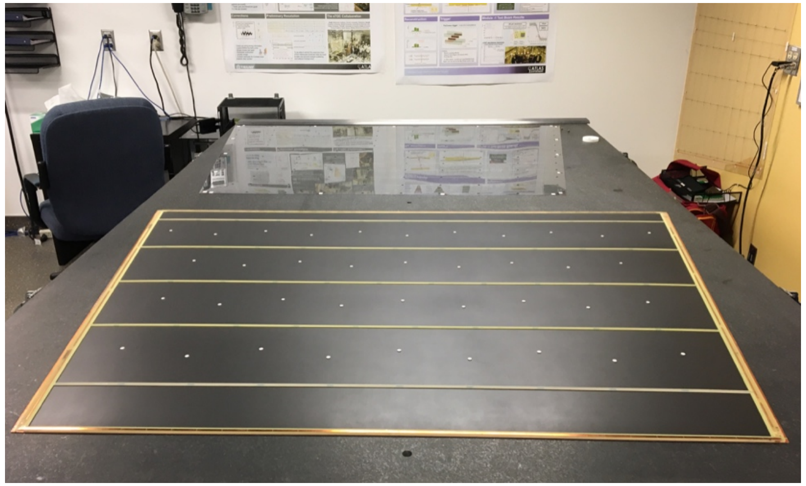


sTGC Chamber Construction

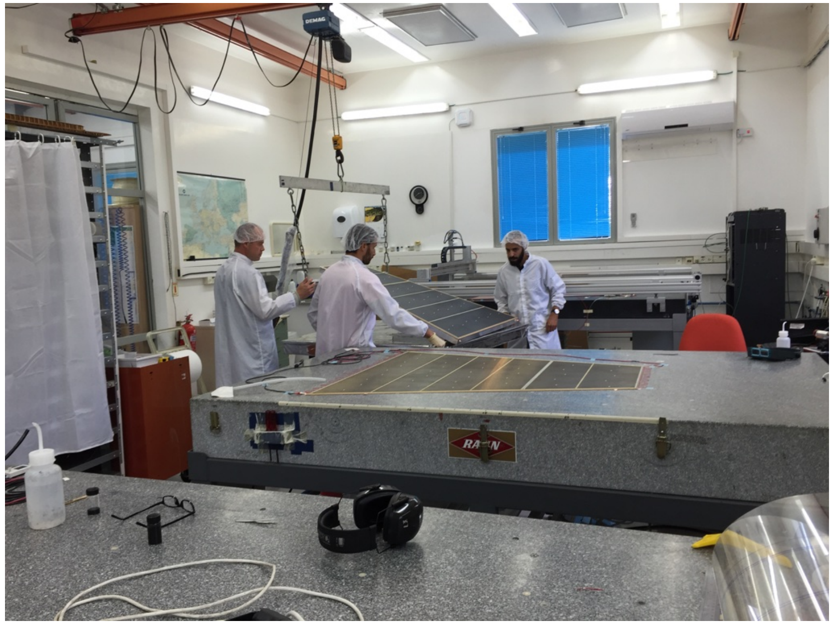


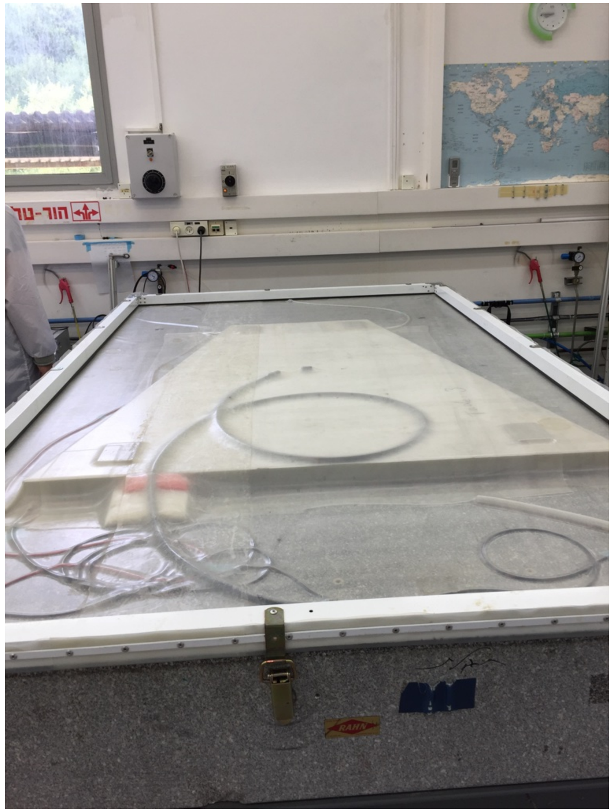






sTGC Construction 2

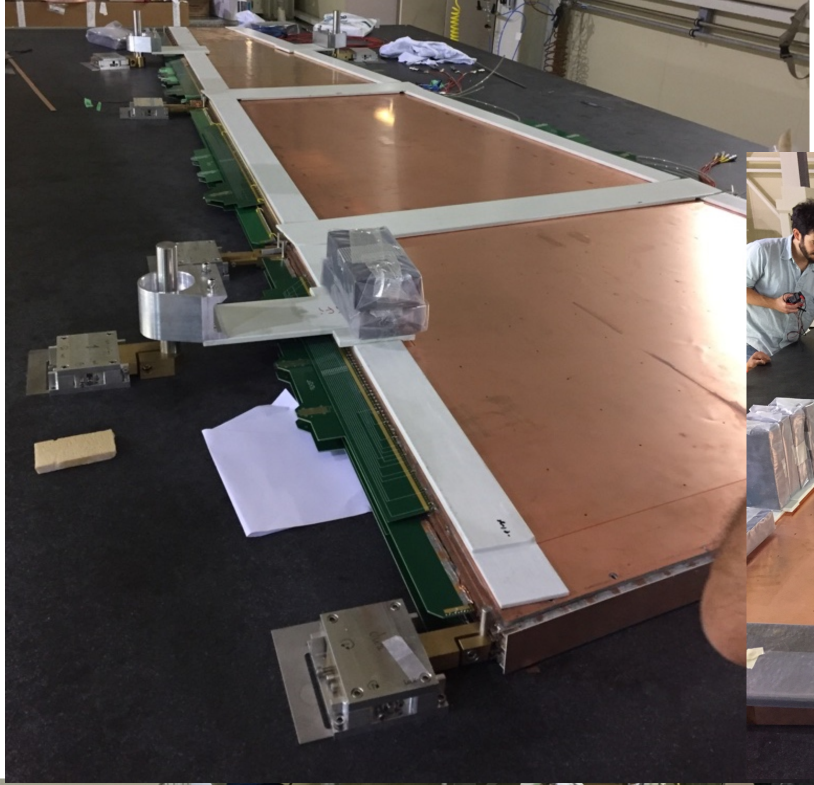


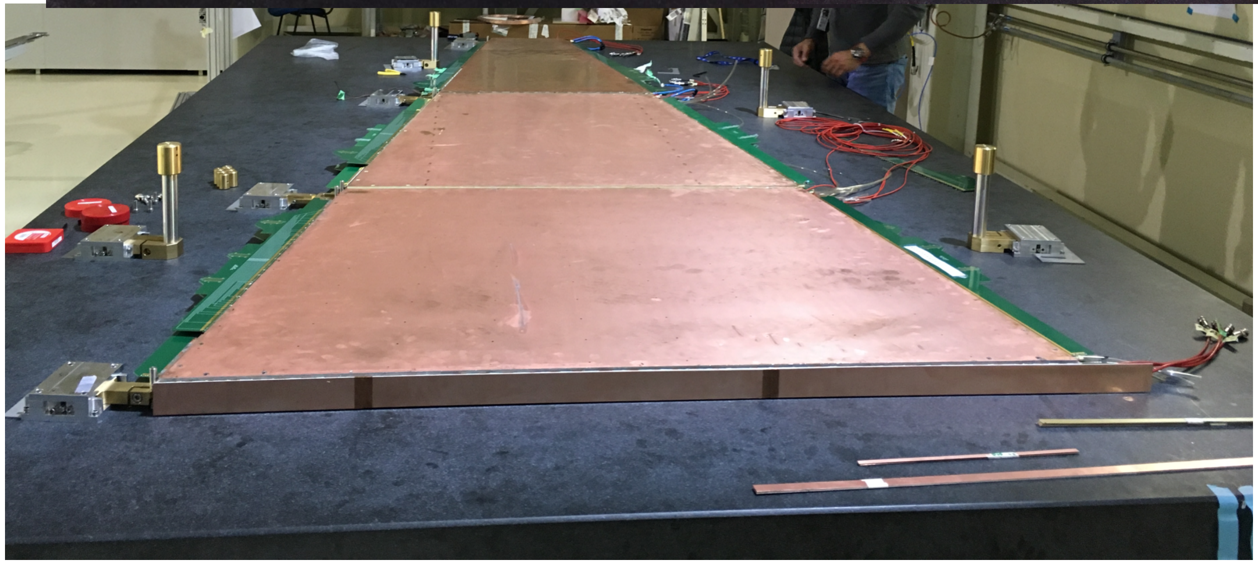


- Close all four gaps
- Glue pairs of gaps with paper honeycomb spacer to make doublets
- Glue two doublets with honeycomb spacer to make quad

sTGC Wedges

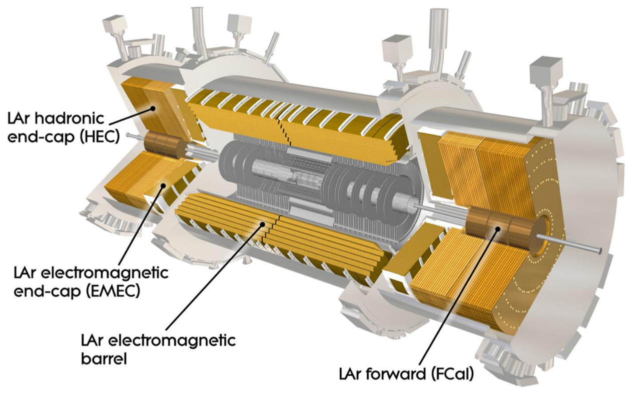
- Each sTGC wedge consists of 3 quadruplet (4 gas-gap) chambers precisely mounted in a fibreglass frame
- Canada is building QS3 (large quads in small wedges) and QL2 (middle quads in large wedges)
- Wedges assembled at CERN, integrating Canadian chambers with others from Chile, China, Israel and Russia
- Precision alignment of quads during assembly is critical

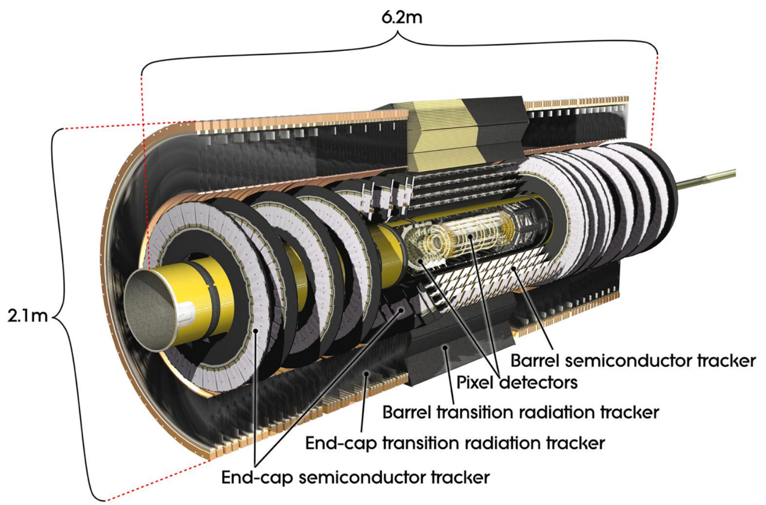




Goals of Phase-II upgrades

- HL-LHC extends LHC lifetime by ~10 years, increases luminosity x ~7.5 with respect to design
- 10-fold increase in size of dataset enables precision electroweak physics in Higgs sector
- Detector readout needs to keep pace with event rate (~200 pp collisions per bunch crossing)
  - For LAr calorimeters, replace readout electronics so out-of-time pile-up can be measured and subtracted from current bunch crossing
  - For inner tracker, straw tubes saturate at very high rates and silicon parts will have received their lifetime dose and become inefficient: replace whole inner detector with all-silicon Inner Tracker (ITk)



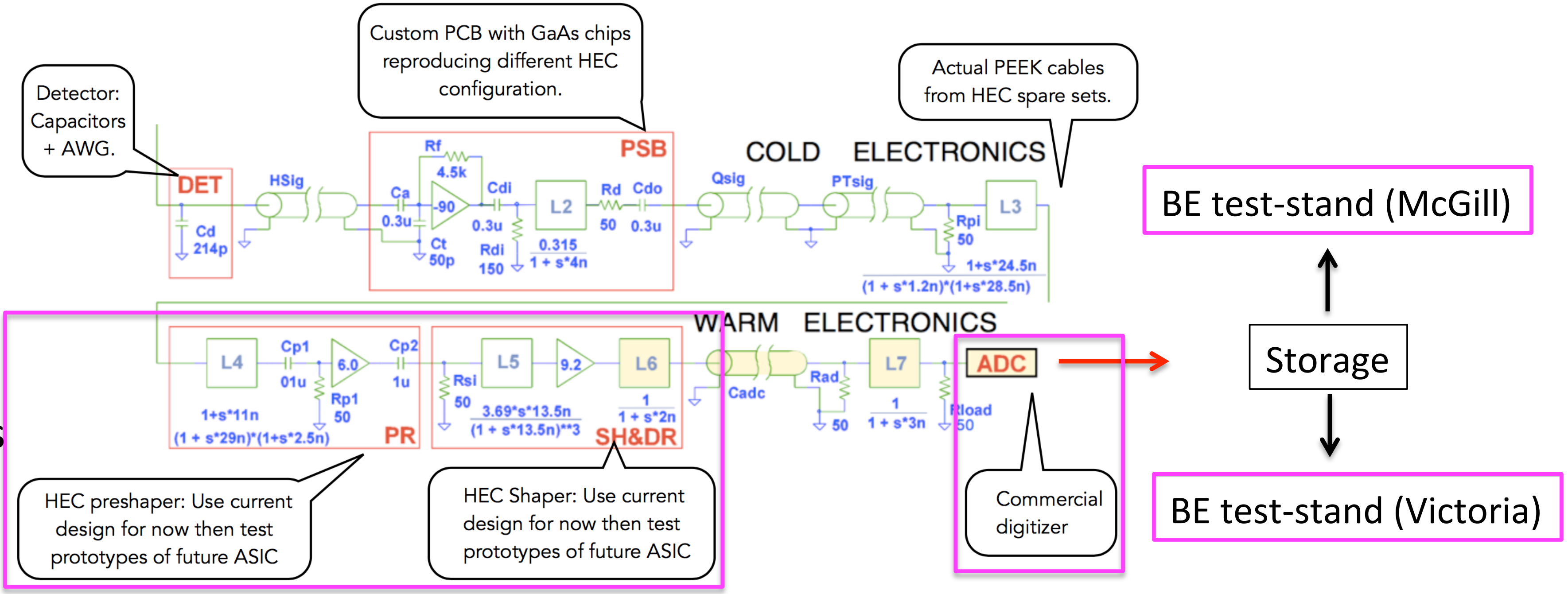


ATLAS Phase II upgrades

- **All new Tracking Inner Detector**
- **Calorimeter Electronics Upgrades**
- **Muon system upgrades**
- **Level-1 track trigger**
- **Trigger-DAQ**
- High Granularity Timing Detector (R&D)

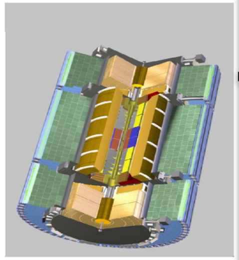
Phase-II LAr Readout Electronics

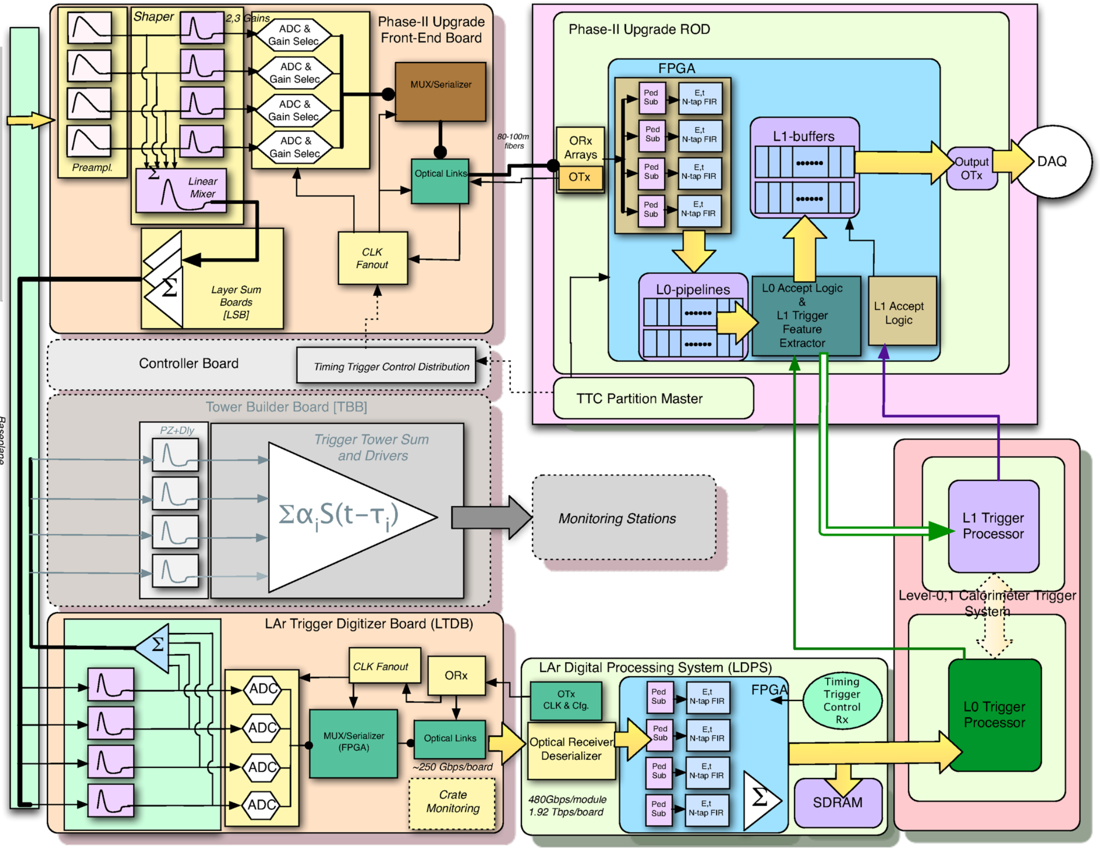
- Existing analog readout located on/in detector cryostat close to source, minimizes noise, rad-hard to 1000 fb^{-1}
- Analog pipeline cannot exceed trigger accept rates of 100 kHz
- Expected trigger rates at HL-LHC 1MHz/400 kHz (L0/L1)
- By digitizing signals on-detector, can move most of front-end functionality out of high-rad zone, process faster, with front-end electronics imposing no limits on latencies or rates
- Back-end (off-detector) pre-processor boards convert optical signals from FE to electronic, deserialize, filter and process signals



Canadian effort on LAr Phase-II

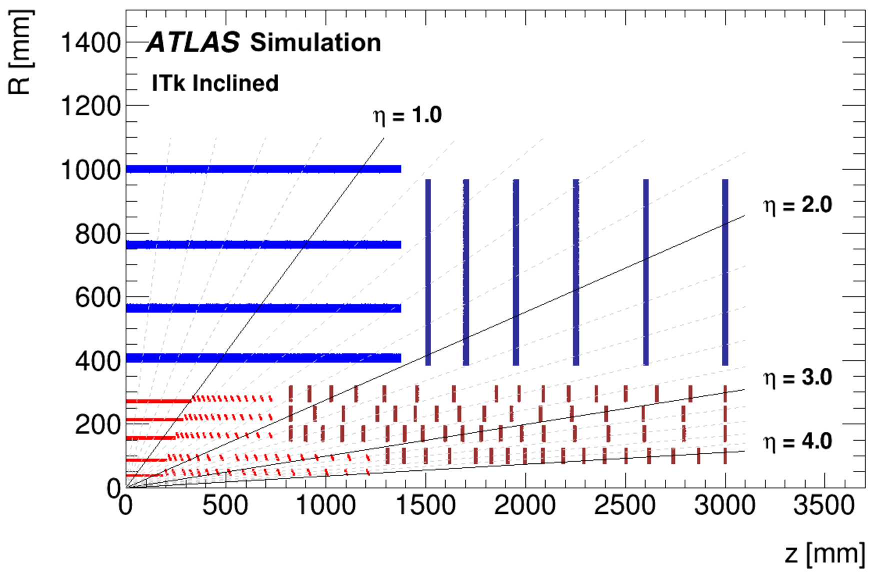
- So far:
  - Equipment / components for construction of mockup of HEC FE electronics chain
  - Equipment purchased – some components still to be obtained
- Near-term:
  - Equipment and components to allow signals from HEC mockup to be investigated for prototype FE designs and digitized as inputs to test system for digital filtering algorithms applied in the BE.
  - Equipment to set up test stands (Victoria, McGill) for evaluation of BE signal filtering algorithms.
- Planned scope:
  - Participation in FE design for HEC (for which we have particular expertise)
  - Work on development / design of BE processing algorithms
  - Capital costs of a fraction (~5%) of final electronics board for upgrade

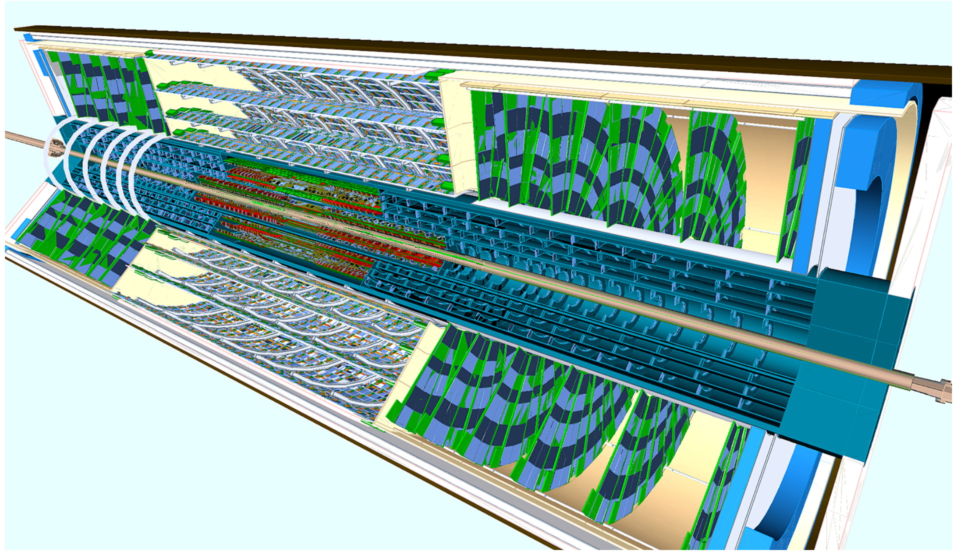




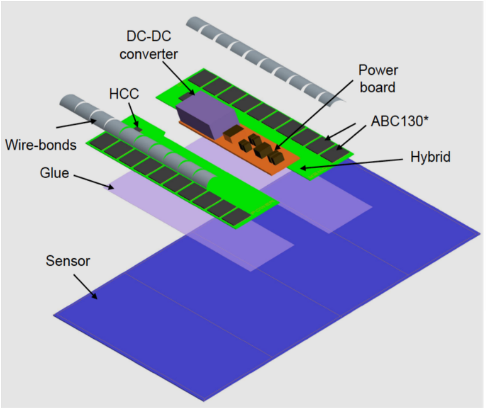
Phase-II Inner Tracker (ITk)

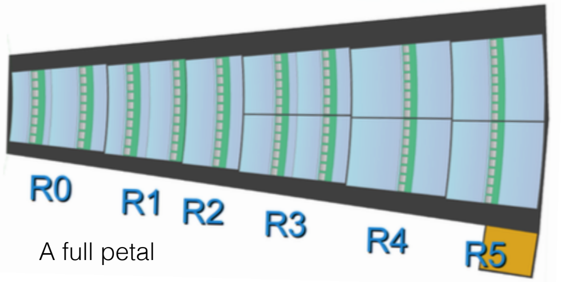
- All-silicon
  - Strips: 4 barrels and 6+6 endcap discs
  - Pixels: 5 barrels and many endcap rings
  - Nearly 50 million total channels
  - 160 m^2 total area
  - Extends coverage to $|\eta|=4.0$ (from 2.5 now)
- Canada plans to build 1500 silicon-strip endcap modules
  - Out of ~7000 endcap & 18 000 total
- Current efforts focused on construction site qualification





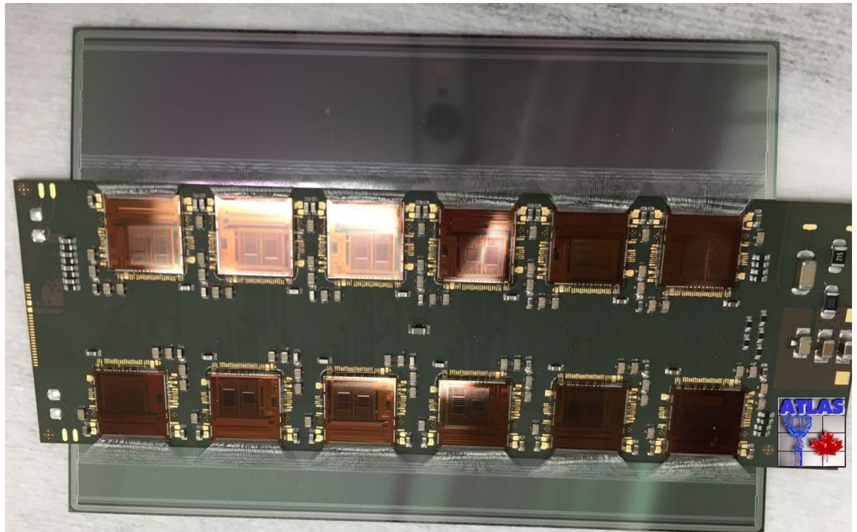
ITk Canada-East





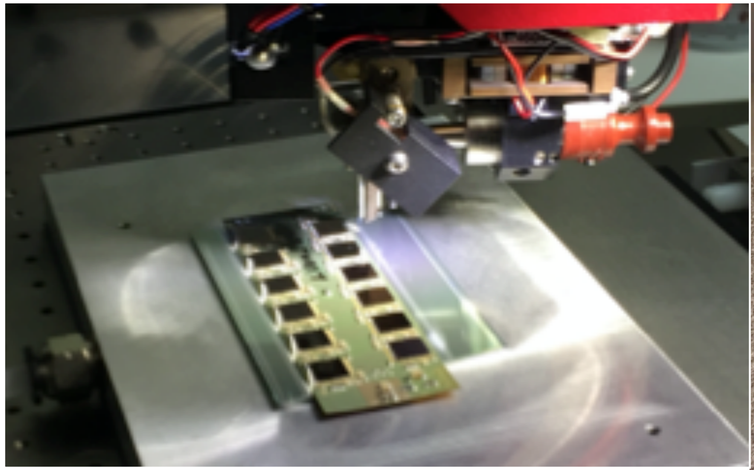
- Industrial production of hybrid boards that form first stage of module readout (all Canadian + ~2500 for other countries)
  - Eastern consortium based at U of T (+Carleton, York, UdeM)
  - wire-bonding in local industry (Celestica – also hybrid production)
  - ASIC wafer probing & dicing at DA-Integrated in Ottawa
- Module assembly in industry for 500 modules
- Sensor probing at Carleton

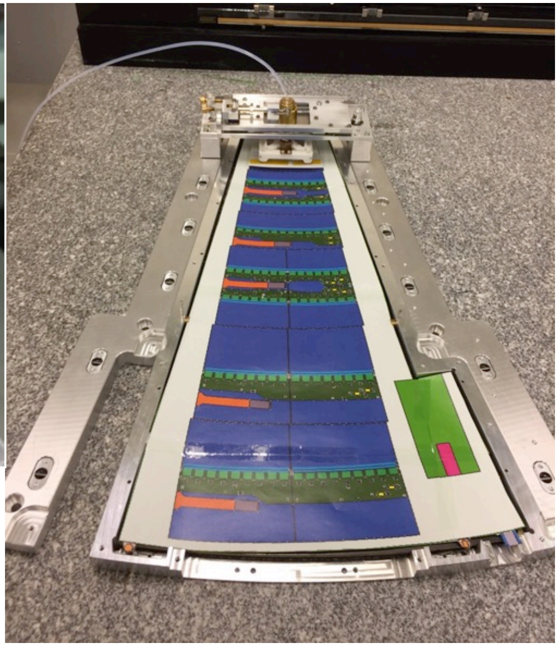
U of T crew at Celestica



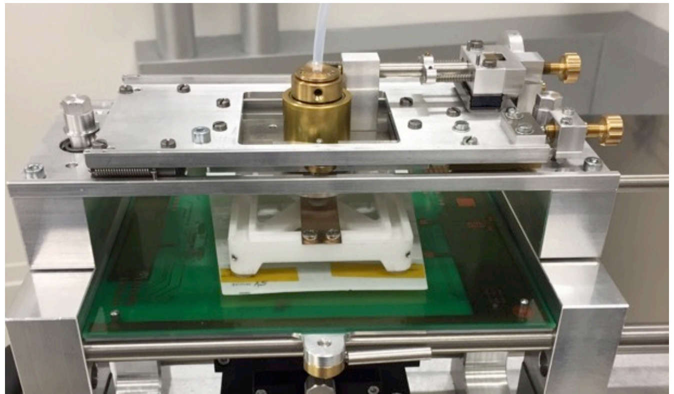
Example of 1 of 3 modules made at UofT & Celestica
1 module then shipped to Carleton and successfully tested

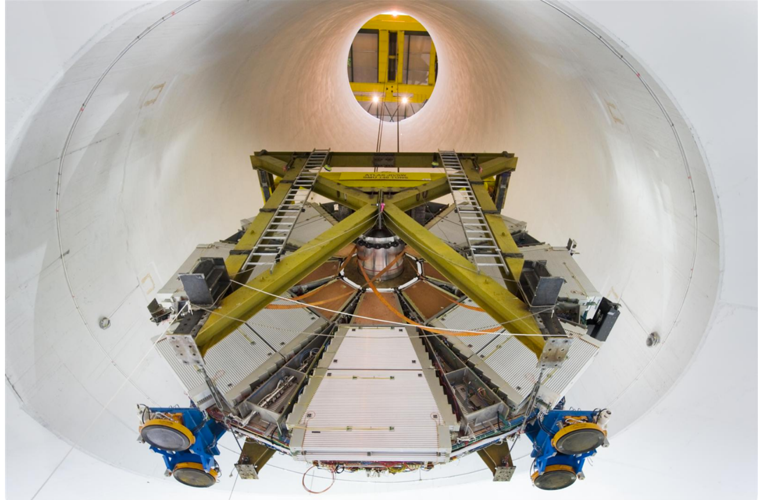
ITk Canada-West





- Vancouver-based consortium
  - Fabrication at TRIUMF of ~1000 modules
  - QA at SFU; UBC: sensor readout /DAQ R&D
  - Infrastructure and equipment related to Si R&D
  - New clean room for Si
- Module-on-core work: precision placement of endcap strip modules on support structure that provides all cooling & electrical services





Outlook

- Phase I upgrade activities in Canada started around 2012 around when technical design reports (TDR) were published
  - Series production of LAr baseplanes proceeding as scheduled
  - Series production of sTGC quads (54 in Canada) starting now, with ramp-up production of cathode boards in industry, and is on a very tight schedule to get all quads made & integrated into wheels by 2020 at latest in LHC Long Shutdown 2
- Canadian Phase II involvement funded before TDRs
  - Substantial infrastructure already in place
  - Less than ten years to replace a large fraction of the original ATLAS detector by ~2026 LHC Long Shutdown 3: production for ITk to start in 2018
- And then: new upgraded ATLAS will be active until ~2035 accumulating more than 3000 fb^{-1} of proton-proton collisions