TRIUMF

SFU SIMON FRASER UNIVERSITY

Lessons learned from Canada's work on the ATLAS Upgrade(s)

(a few selected examples)

June 24th 2026

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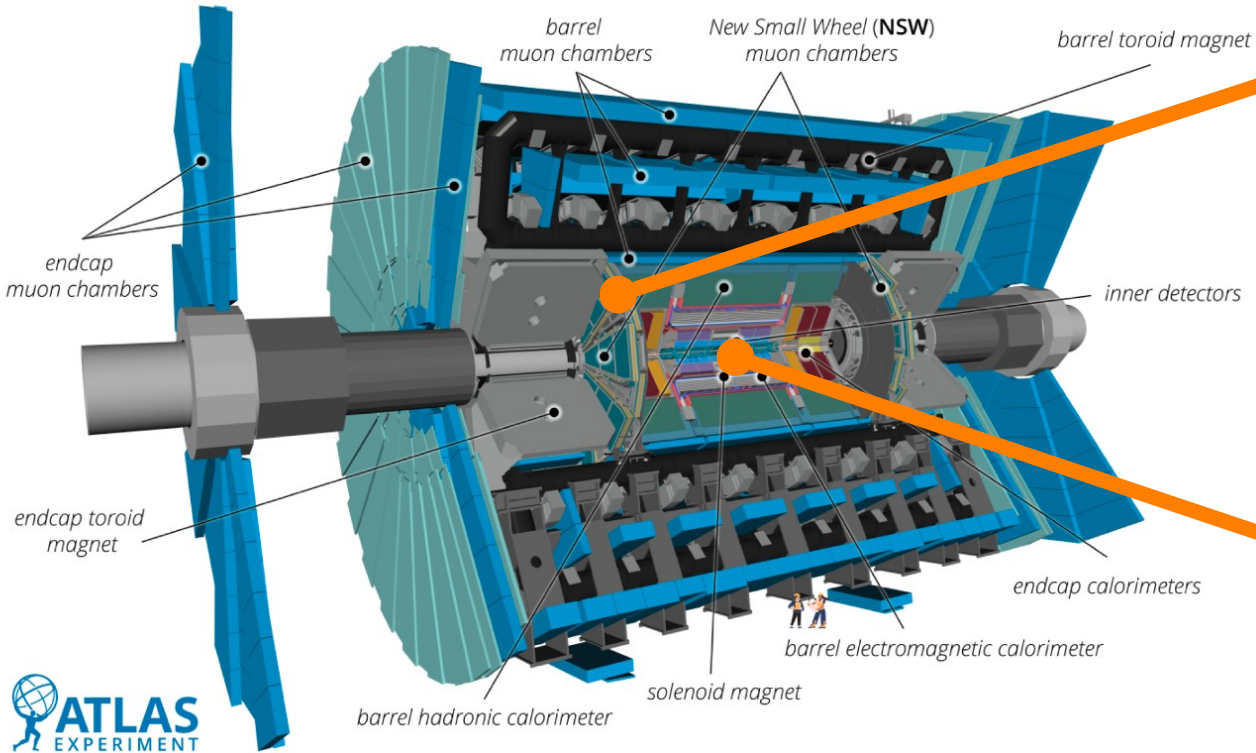
(with input from a lot of people!)

Three (selected) topics for today



Phase-1 Upgrade:
New Small Wheels
"Scaling up is not straightforward"

DAQ and readout-focused upgrades
"Keep it simple"

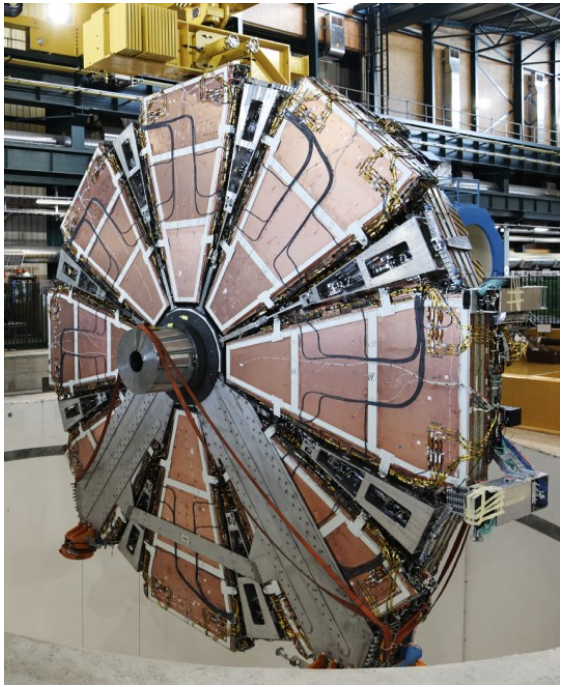
Phase-II Upgrade:
ATLAS Inner Tracker
"More can be more"

The New Small Wheel Muon System

Addition to the muon system intended to keep the muon trigger rate manageable during Run 3

Good News:
amazingly, completed and installed by Run 3 and keeping trigger rate under control

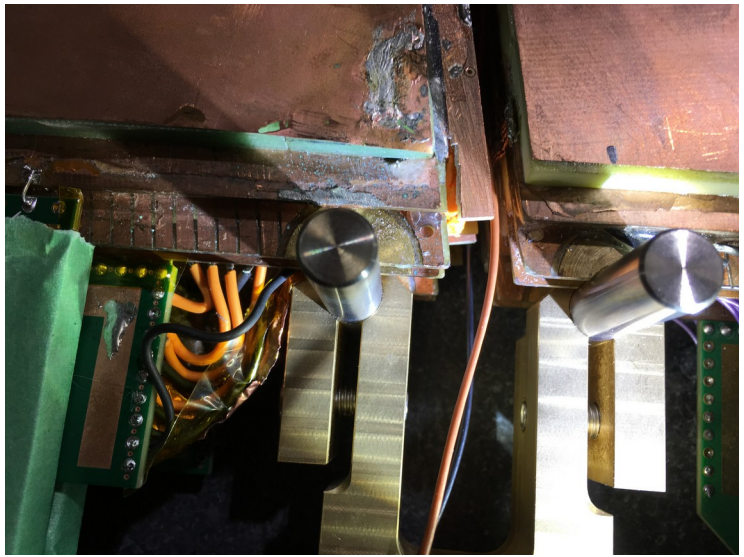
News typical for large projects:
- significantly increased construction time
- significantly higher cost (mostly labour)
- significant technical challenges



The Story of the New Small Wheel

(selected) Issues of the small-strip Thin Gap Chamber (sTGC) effort

- Joined project after design largely fixed
- Underestimated difficulty of converting known technology to higher precision, at large scale
- Procedures successfully exercised in expert R&D difficult to translate to mass production:
  - Extremely tight glue alignment requirements
  - Procedures with stringent safety needs
  - Companies struggling with tolerances on large components



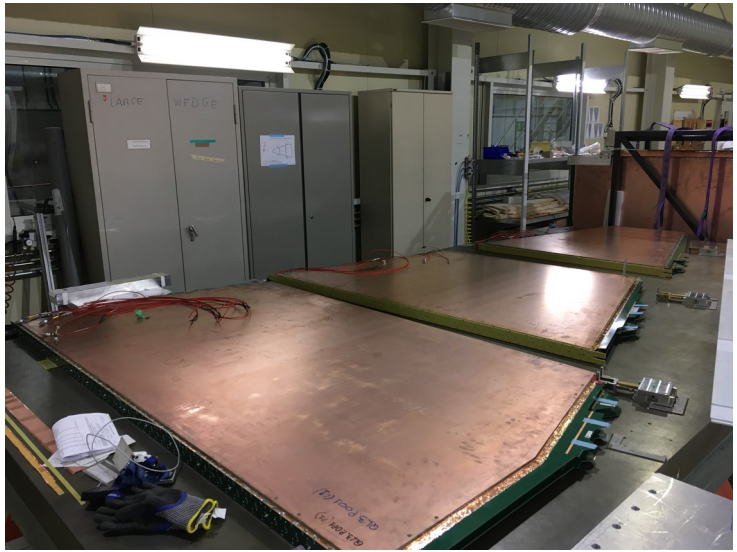
Lessons earned from the NSW

Common project planning lessons:

- Cost is always at least 200% higher than expected
- You will need more spares
- Canada is a very big country when you split the assembly chain between opposite coasts
- You should understand your yields before you plan numbers of spare parts
- You will likely need more spares anyway

International project planning lessons

- Safety standards are country-dependent, evolve and can be surprisingly expensive to implement
- Shipping is more expensive than you think
- Especially for very big and delicate parts
- If multiple companies are involved in production, they each need to demonstrate working prototypes



DAQ/Readout-based upgrades (ongoing)

Similar patterns emerging in multiple DAQ/readout-related projects

- Complexity of upgrade effort (e.g. firmware) was underestimated
- Expertise/Experience needed was underestimated (e.g. for firmware)
- Electrical engineering work (e.g. firmware) attempted by physicists

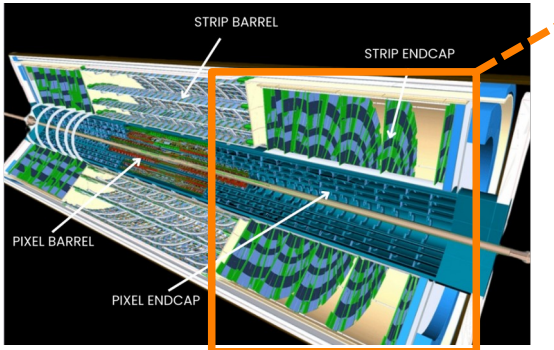
Too much work distributed between too few contributing institutes;
late scope reduction or use of simpler fall-back solutions

Potential future approaches to avoid similar patterns

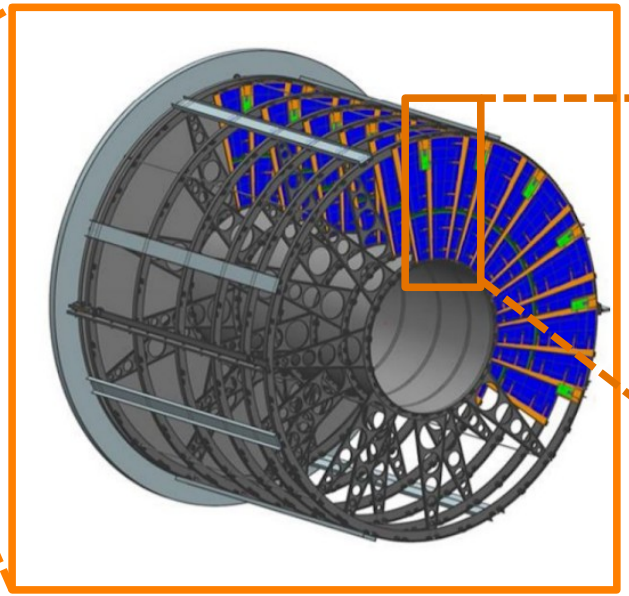
- Collaboration with electrical engineering departments for EENG work (e.g. firmware)
- Inclusion of skilled labour (engineers) in budgets (e.g. for firmware)
- Collate enough effort to support lengthy integration and debugging

The ATLAS Inner Tracker

Part of the Phase-II Upgrade: replacement of Inner Detector



The future
ATLAS Inner Tracker



One end-cap (out of 2)

One petal (out of 384)

Canada within in the ITk

Vancouver:
- QC for 1/4 of end-cap sensors
- Assembly and QC of 1/6 of end-cap modules
- Assembly and QC of 1/4 of all petals
- System tests/DAQ

Victoria:
System tests/DAQ

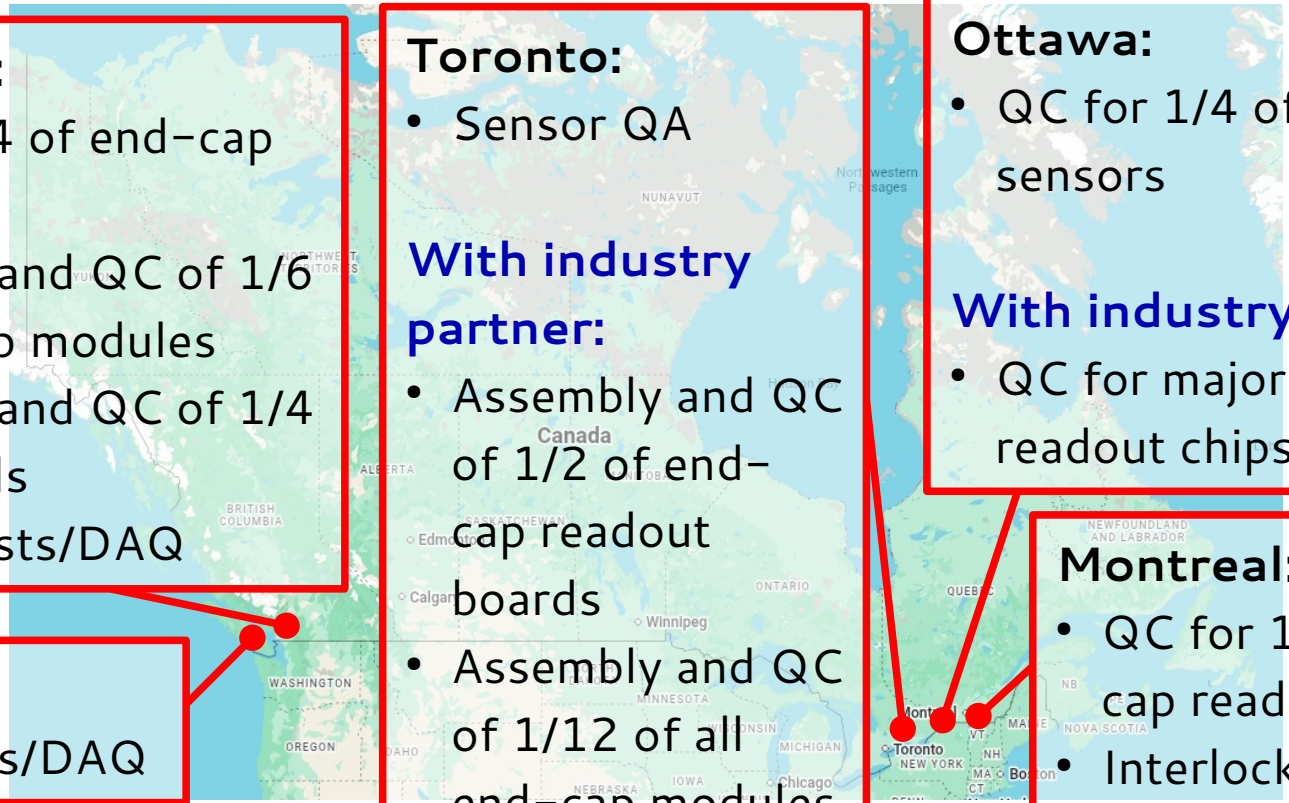
Toronto:
- Sensor QA

With industry partner:
- Assembly and QC of 1/2 of end-cap readout boards
- Assembly and QC of 1/12 of all end-cap modules

Ottawa:
- QC for 1/4 of end-cap sensors

With industry partner
- QC for majority of readout chips

Montreal:
- QC for 1/3 of end-cap readout boards
- Interlock system



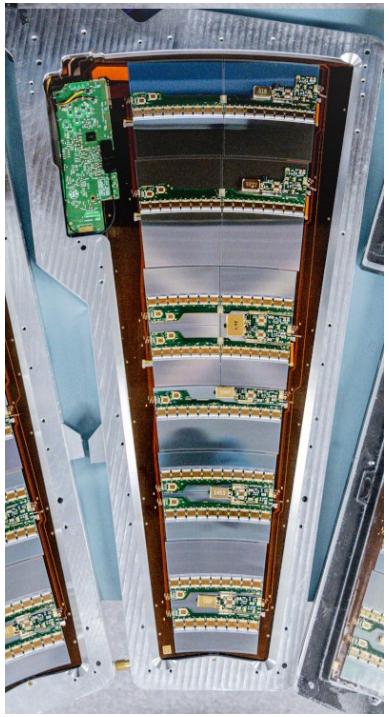
Canada's unique role

Bottleneck for entire ATLAS Inner Tracker assembly: module assembly

Complication for end-cap modules:
Petals can only be built if every single part is available!

- Six different module types
- Six different sensor shapes
- 13 different readout boards
- 5 different power boards

Lesson to be learned: reduce number of shapes and keep them simple (similar for sTGC)

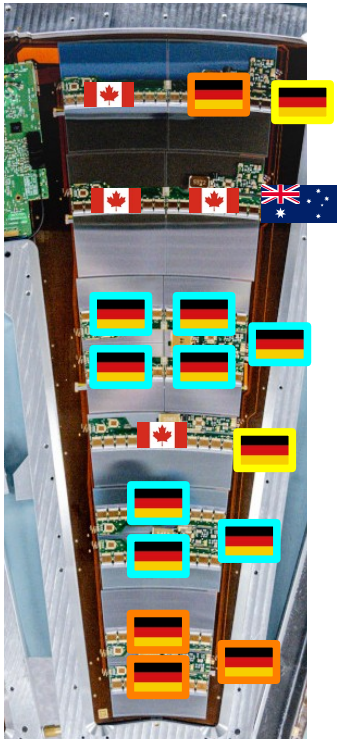


Canada's unique role in ITk end-caps

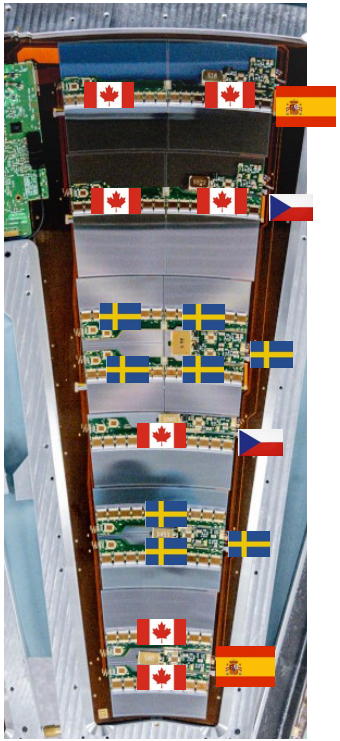
Canada

Europe 1

Europe 2



Europe 3



Canada's unique role in ITk end-caps

Canada | Europe 1 | Europe 2 | Europe 3

Canada is the only cluster which contains the **full assembly chain** of

- readout boards,
- modules
- petals

within the same country,

Also **relying heavily** on

- Industrial assembly
- Engineers for sustained effort

Extremely advantageous combination;
Most advanced production so far

Lessons learned from ITk involvement

- Production:
  -> Containing majority of production chain in one cluster produced peak efficiency
  -> Dedicated QC sites provided expertise to debug frequent technical issues
  -> Critical mass within ITk provided (some) needed influence on decisions
  -> Delays frequently caused by interfaces with other activities

- Industry involvement:
  -> Beneficial for mass assembly of components
  -> Joining after design phase without industry-involvement produced industry-incompatible processes; should join earlier next time

- Planning for technical problems/design iterations can avoid surprise extra cost/time

- Don't let physicists do work engineers are much better equipped for

What we can learn for future projects

- Choose projects building on existing experience; aim to maintain built-up experience
- Joining during the R&D phase would have helped to shape designs and procedures for better compatibility with our abilities – joining too late caused problems
- Industry involvement is extremely beneficial, but must be integrated in design process
- More institutes involved in the same project can multiply impact (decision power)
- Covering the full chain of required activities helps tremendously to stay on track; issues most frequently occurred at interfaces with outside institute
- Do not underestimate the cost (people, time, money) of shipping chains – local assembly is hugely beneficial. Otherwise, aim for the ability of in-house repairs
- Communicating potential resources is extremely helpful for instrumentation work: e.g. use of MRS resources (Montreal, Carleton, Victoria, ...)
- Don't let physicists do the jobs of engineers

Backup

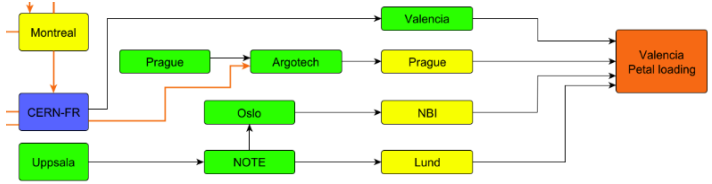
Backup – more lessons learned

Don't underestimate firmware

Don't glue anything to your sensor
Don't glue anything to anything unless you are 100% sure you will never ever want to attempt to remove it again

Don't believe the weight limit on your freight elevator when it comes to granite tables
Don't underestimate shipping cost and the effort needed for logistics

If anyone says "we can't make it to the required tolerances but we'll take lots of measurements and fix it in software" you should simply announce that the project cannot be completed and walk away



If anyone proposes an assembly chain where five institutes are needed to build the same number of modules handled by a single institute in other clusters, join a different cluster