Summary of ATLAS-Canada Upgrades

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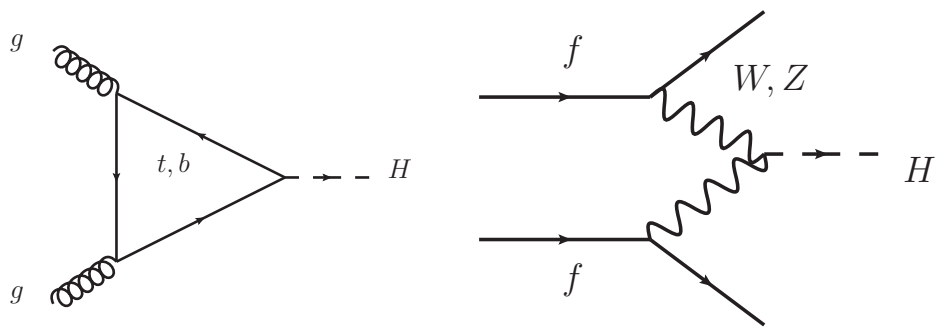
Outline

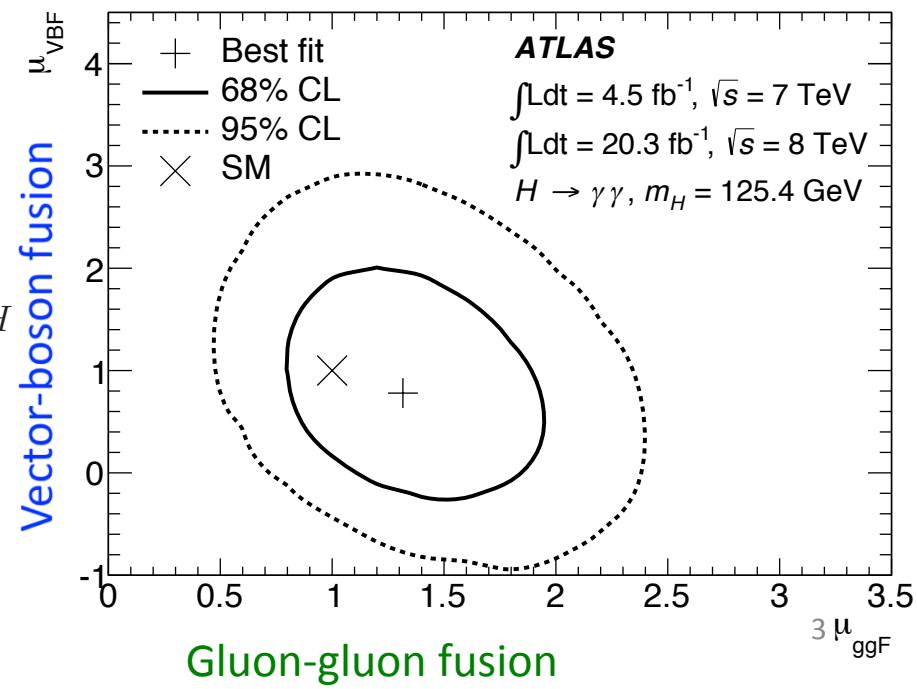
- Introduction: Background and Motivation
- Phase-1: The New Small Wheel
- Phase-1: LAr Electronics
- Phase-2: LAr Upgrades
- Phase-2: The ITk
- Summary and Conclusion

Higgs Production

- The Standard Model did not predict the Higgs mass but it does have predictions for the couplings of the Higgs to other particles.
- Precision measurement of these couplings will provide a further test of the Standard Model and probe for new physics.
- One way to access the couplings is via the signal strengths μ ($=\sigma_{measured}/\sigma_{predicted}$) of different Higgs production mechanisms.
- The main mechanisms are gluon-gluon fusion (which dominates) and vector-boson (W or Z boson) fusion (VBF).

Phys. Rev. D. 90, 112015 (2014)





Above, Feynman diagrams for Higgs production; right, best-fit values for signal strengths from diphoton Higgs decays (H->γγ).

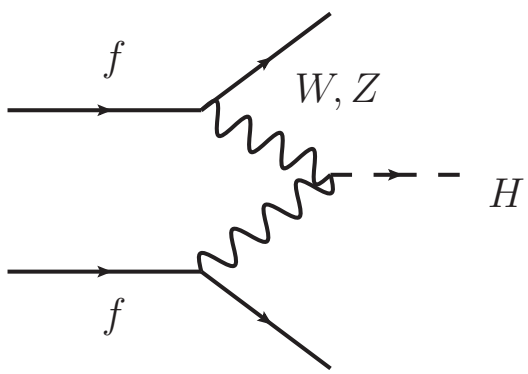
Higgs Decay

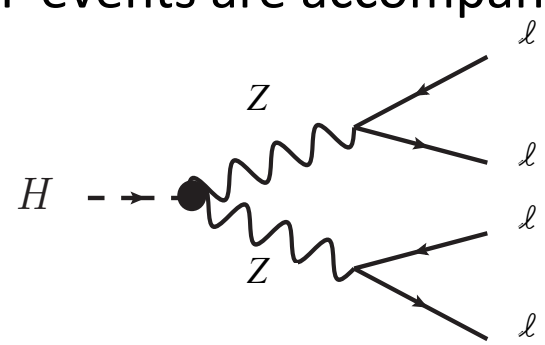
Of course, in order to find the Higgs one must know what its decay products are. Ideally one would like for the decay products to be

1. Completely reconstructed in the detector (no neutrinos)
2. Well reconstructed in the detector (good energy resolution)
3. Lacking in backgrounds (no contributing QCD processes)

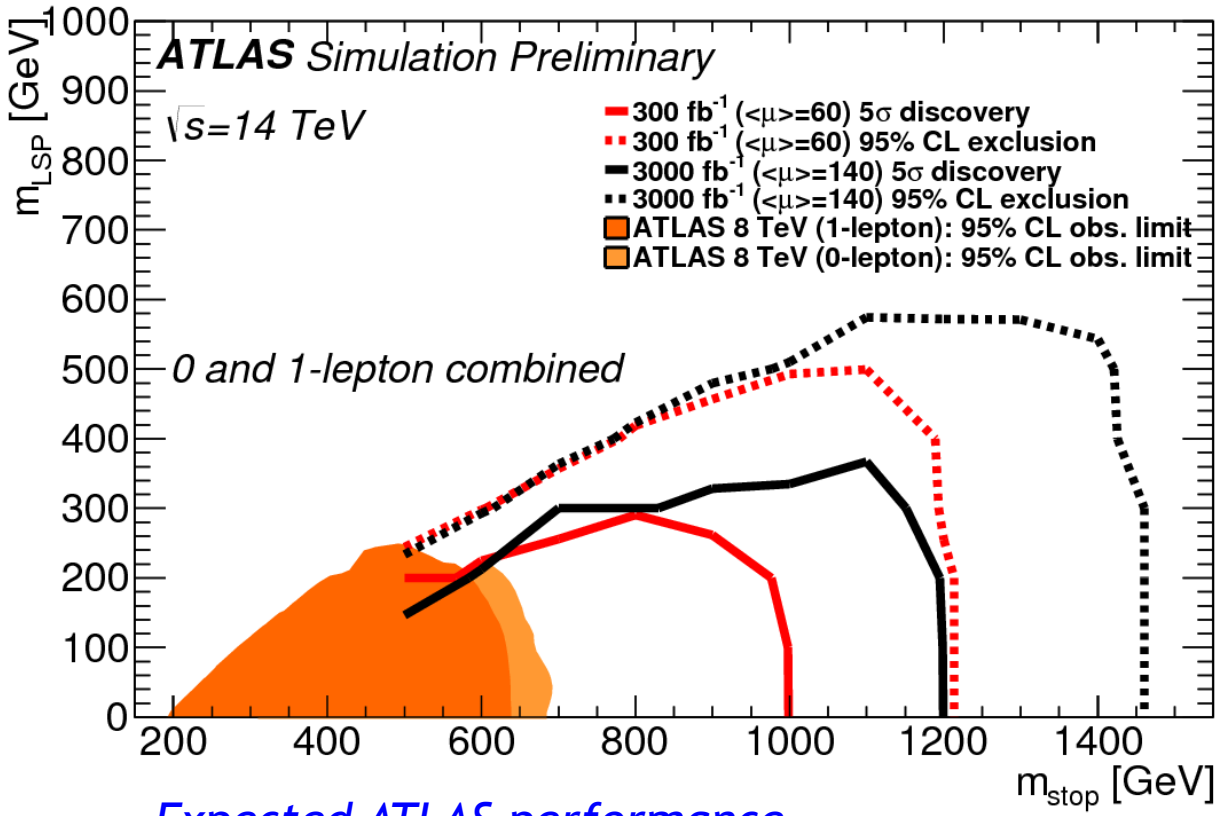
The "golden channel" in terms of these requirements is a Higgs decay to two Z bosons which then both decay leptonically, H->ZZ$^{(*)}$->4ℓ. (The ℓ can be $e^{+/-}$ or $\mu^{+/-}$.)

H->ZZ and Z->$\ell\ell$ both have small branching ratios, so this is a rare process. Other particles in the event are also important for distinguishing between production mechanisms: e.g., VBF events are accompanied by jets.





SUSY

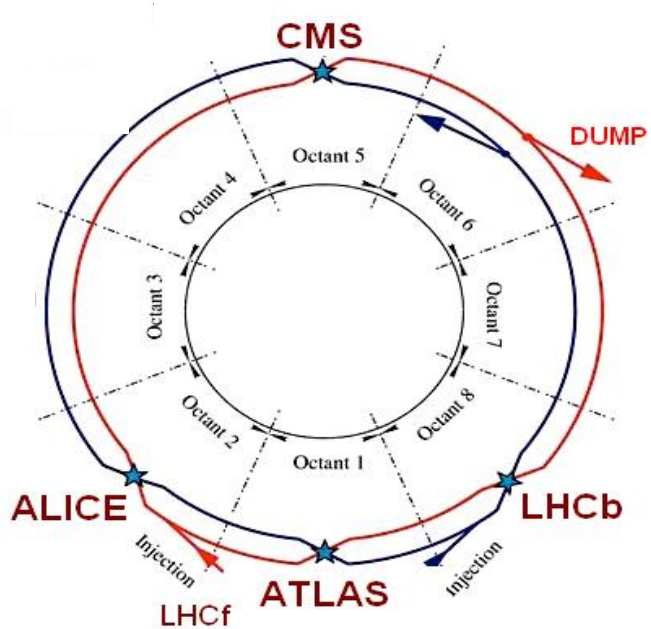


Expected ATLAS performance
ATL-PHYS-PUB-2013-011

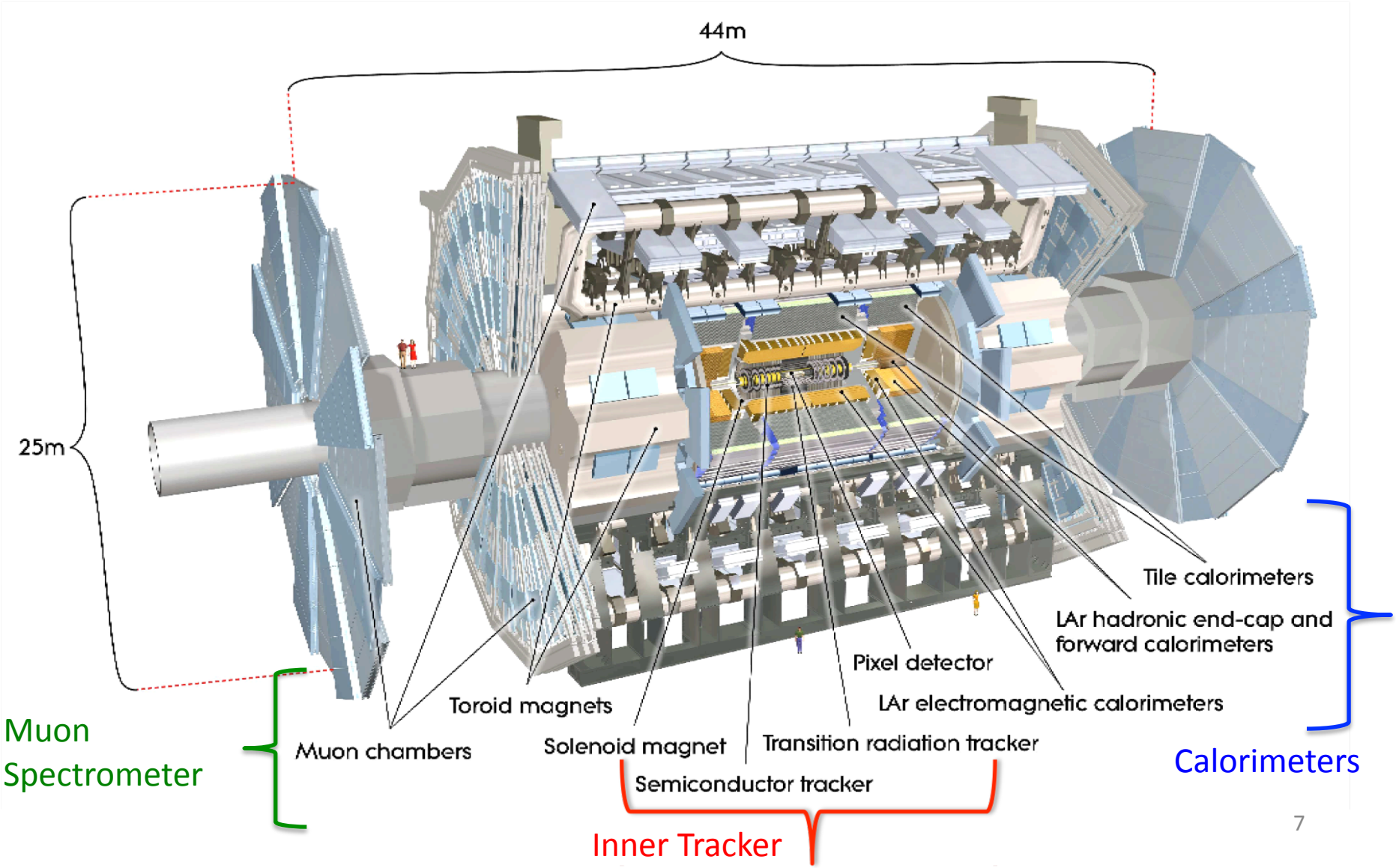
It's not just the Higgs: additional searches for BSM physics, including especially supersymmetry, are also planned.

The LHC

- All these processes are very rare and require lots of energy, so many high-energy collisions will be needed to make precision measurements.
- The energy and number of collisions at the LHC are largely determined by three parameters:
  - Center-of-mass energy
  - Bunch spacing: accelerators are pulsed, with particles arriving in bunches, rather than continuously. The bunch spacing is the time between two bunches.
  - (Instantaneous) Luminosity: essentially measures the rate at which the accelerator produces collisions (collisions/area/time).



The ATLAS Detector

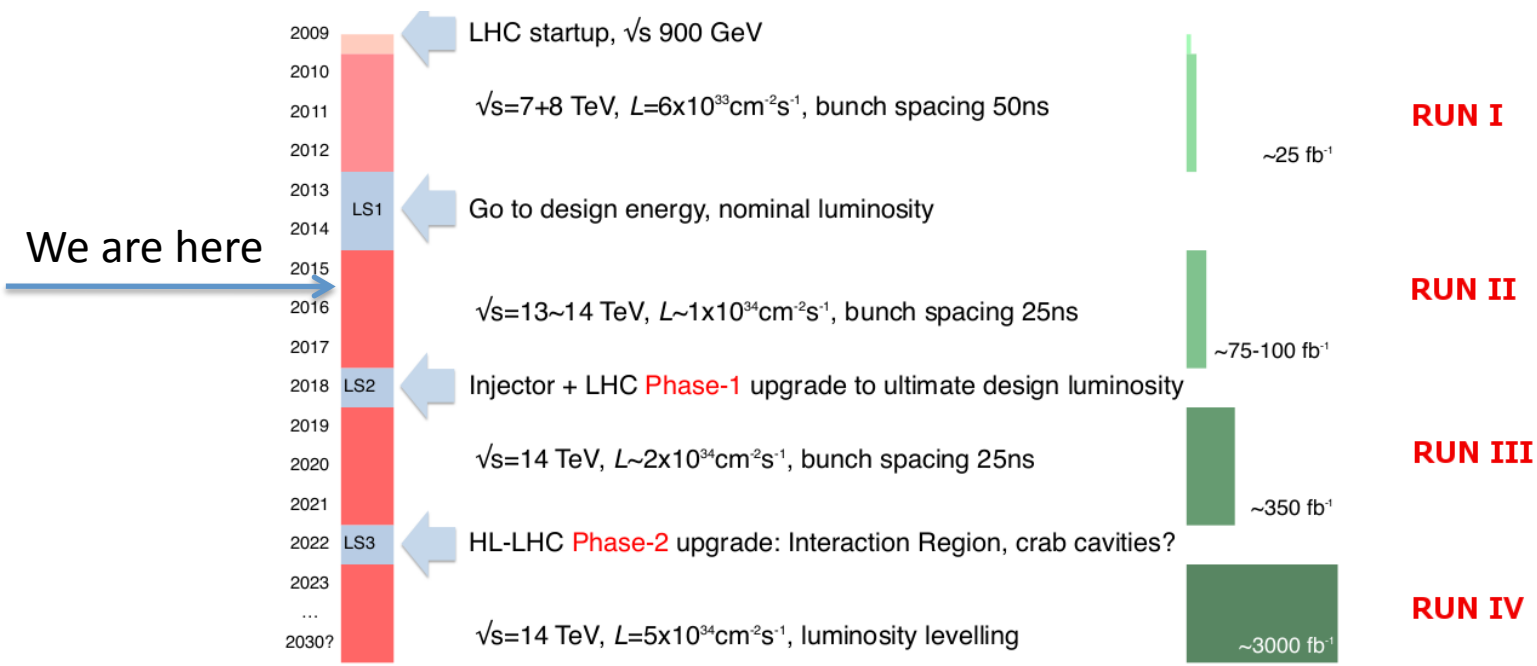


Triggering

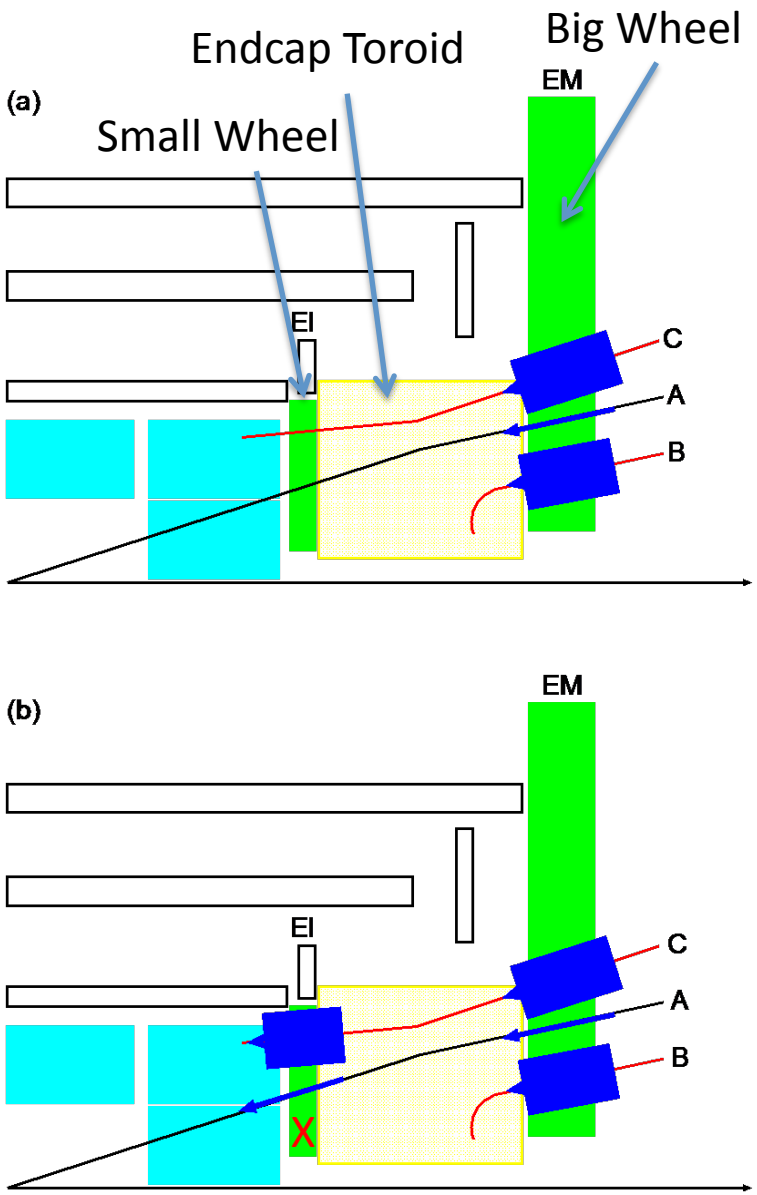
- The vast majority of collisions will still not produce anything interesting, of course, and ATLAS lacks the capability to process and save every single collision it sees.
- The solution is to identify potentially interesting collisions by looking for easily-identifiable features, known as “triggers”.
- One such feature is a high-energy (usually expressed in terms of p_T, the momentum transverse to the beam axis) particle, as defined by an energy deposition in the calorimeter, a track in the muon spectrometer, or a track in the inner detector.

LHC Upgrades

- More luminosity + more energy + less bunch spacing=more Higgs (and more of everything else, as well).
- The recently-completed Long Shutdown 1 (LS1) improved all these parameters.
- LS2 (scheduled for 2018-2019) and LS3 (scheduled for 2022-2023) will improve the luminosity even further, pushing it even beyond the original design goal of the LHC.

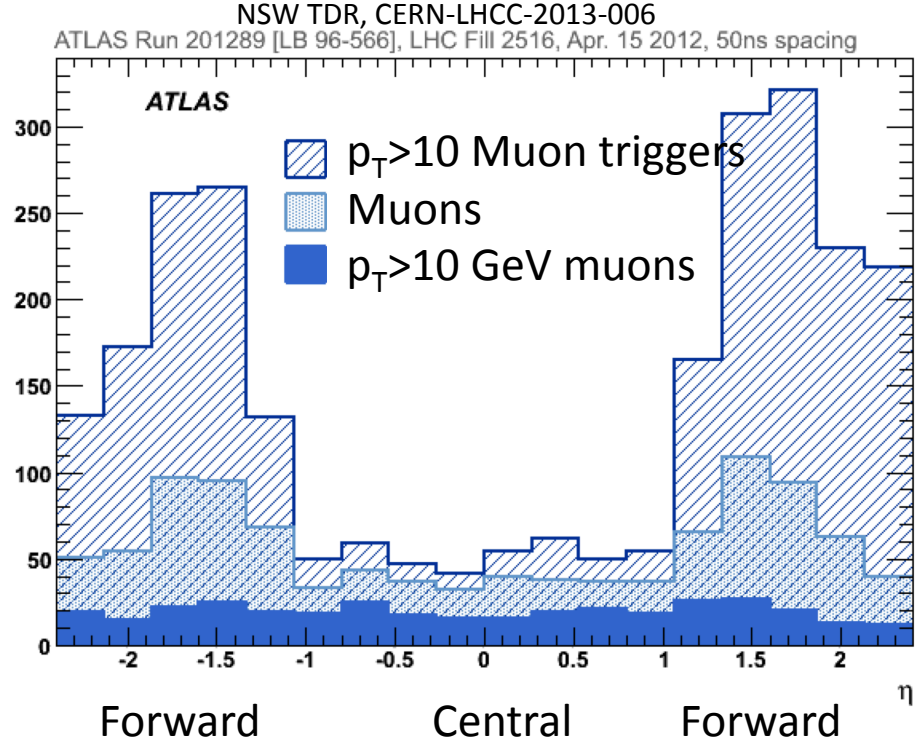


Why a New Small Wheel?



Improved triggering is required given the increase in fake muons.
The New Small Wheel will reduce trigger fakes by an order of magnitude at the cost of ~7% of efficiency, while simultaneously improving tracking performance.

NSW TDR, CERN-LHCC-2013-006

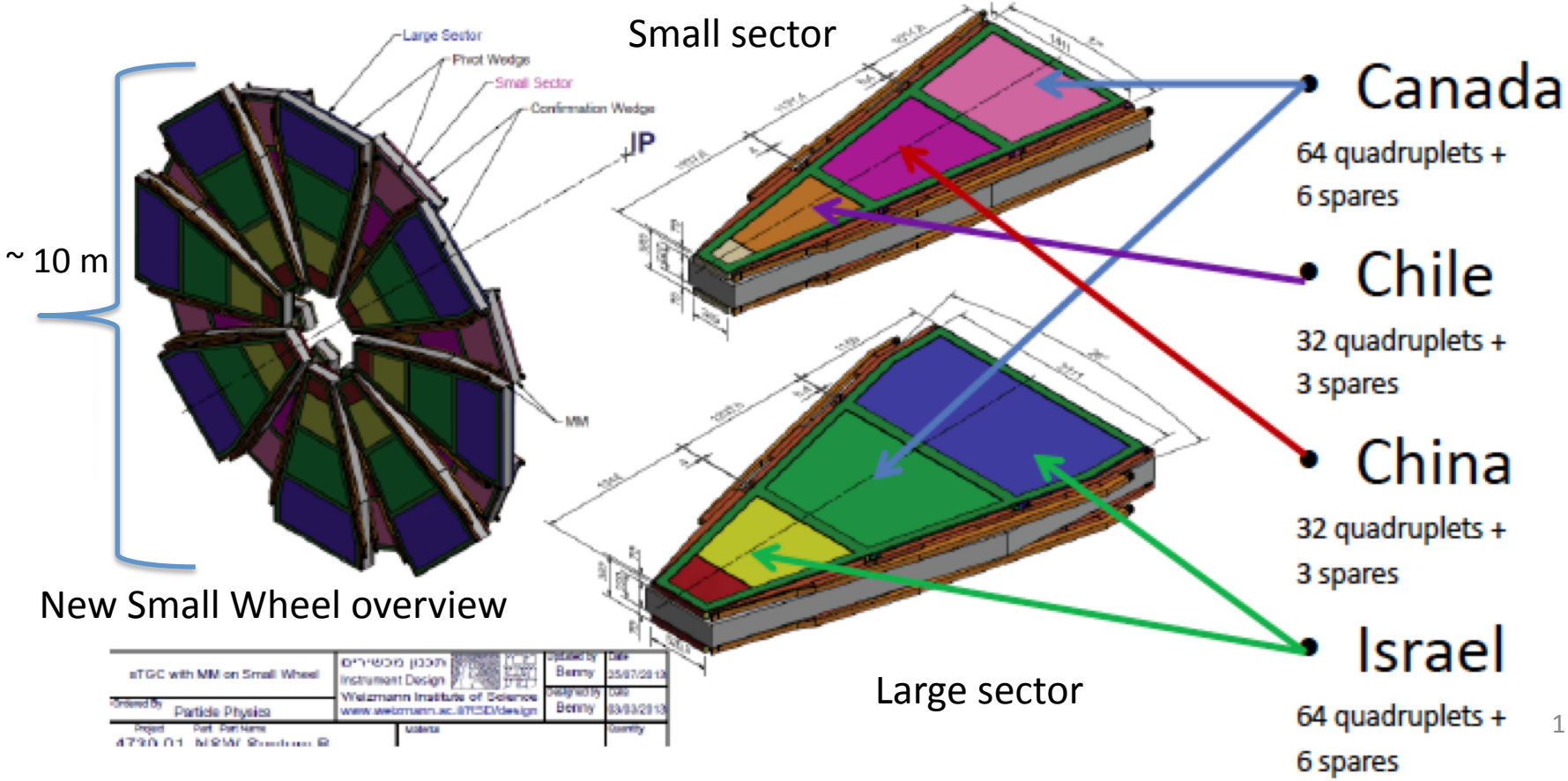


New Small Wheel Technologies

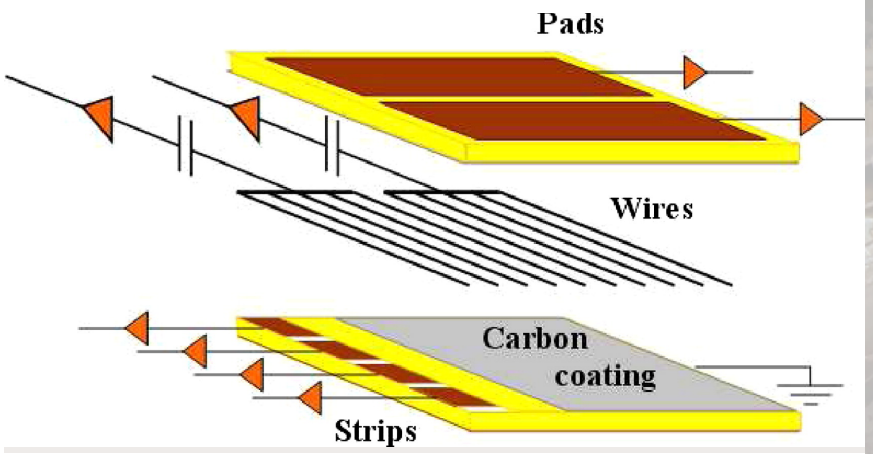
The NSW must provide angular resolution of 1 mrad or less to the IP, and so a spatial resolution of 100 um per point or less, in 1 μs or less.

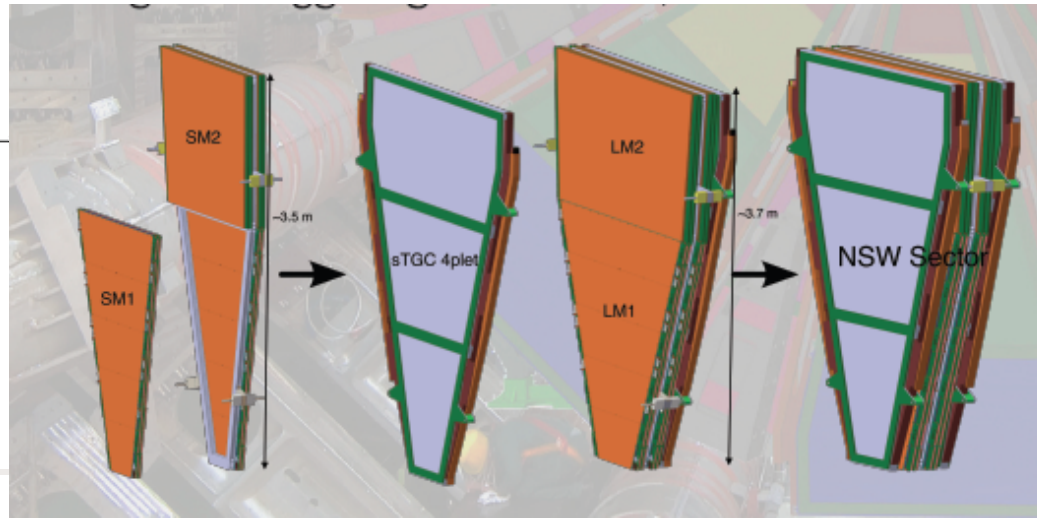
To satisfy the requirements, use two separate technologies:

1. sTGC (in color below) as the primary trigger (very fast)
2. MicroMegas (in grey) as the primary tracker (high-resolution)



Thin Gap Chambers

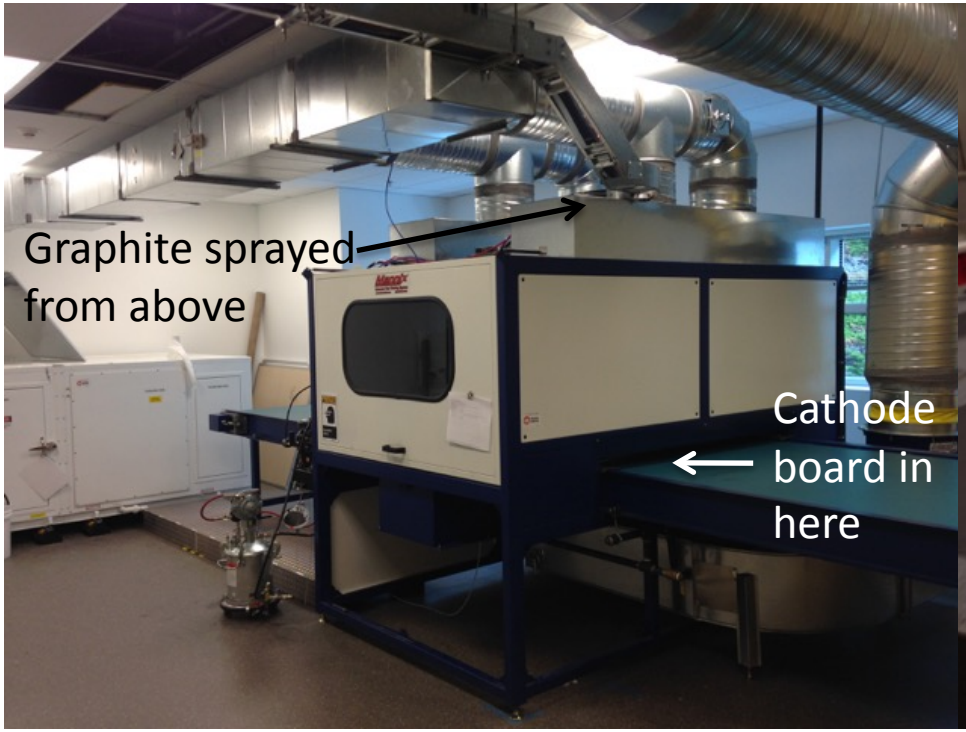


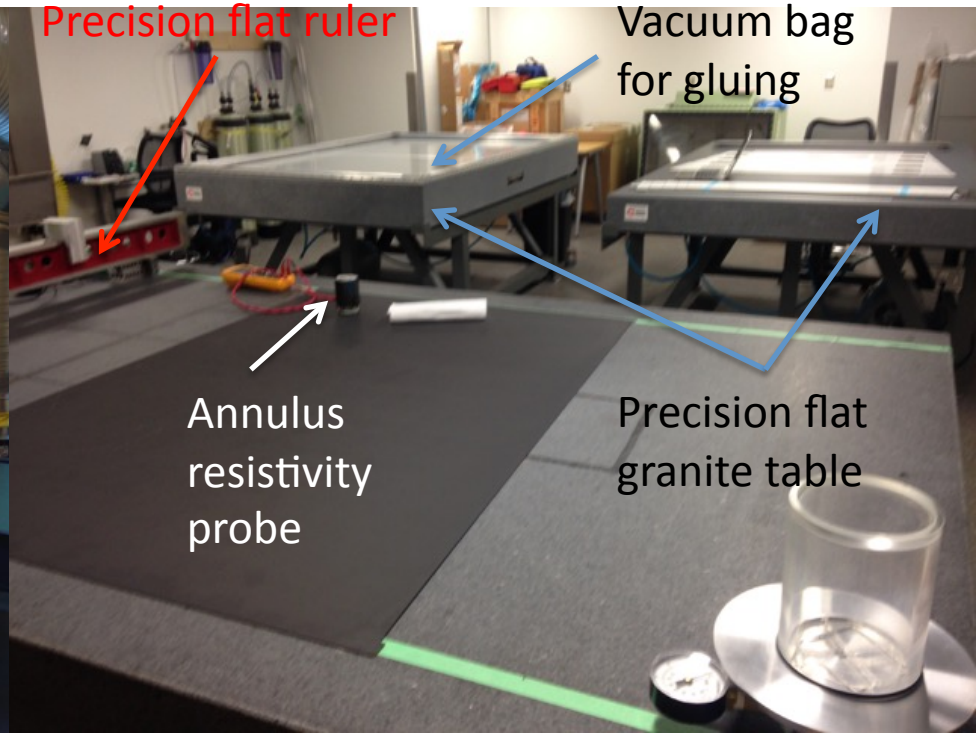


Very thin wire chambers (cathode-wire distance < wire-wire distance). Each chamber is composed of 4 sTGC's, and each sector has two sTGC quadruplets (sandwiched around two MicroMega quadruplets).

For the NSW, precise construction methods are also essential: the cathode boards must be extremely flat and precisely aligned.
Flatness: RMS <80 µm
Strip alignment: parallel to within 100 µm

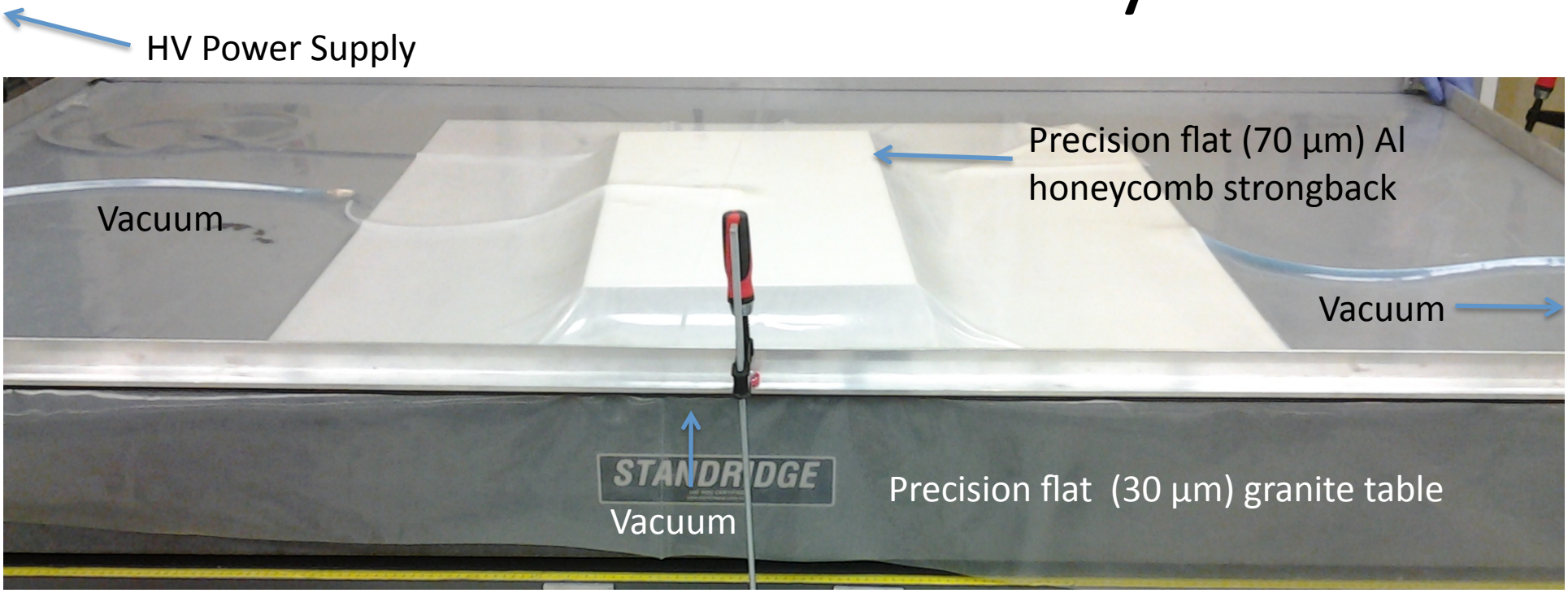
Cathode Board Preparation



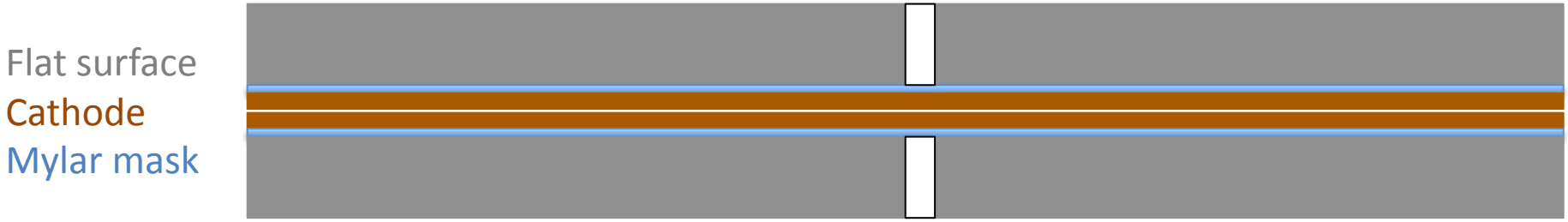


Cathode boards are first sprayed with a uniform layer of graphite in the precision spraying machine (above left). The graphite is polished to achieve an approximate resistivity of 100 kΩ/□.
Then the frames and supports are glued on before shipping to the next construction site (above right).

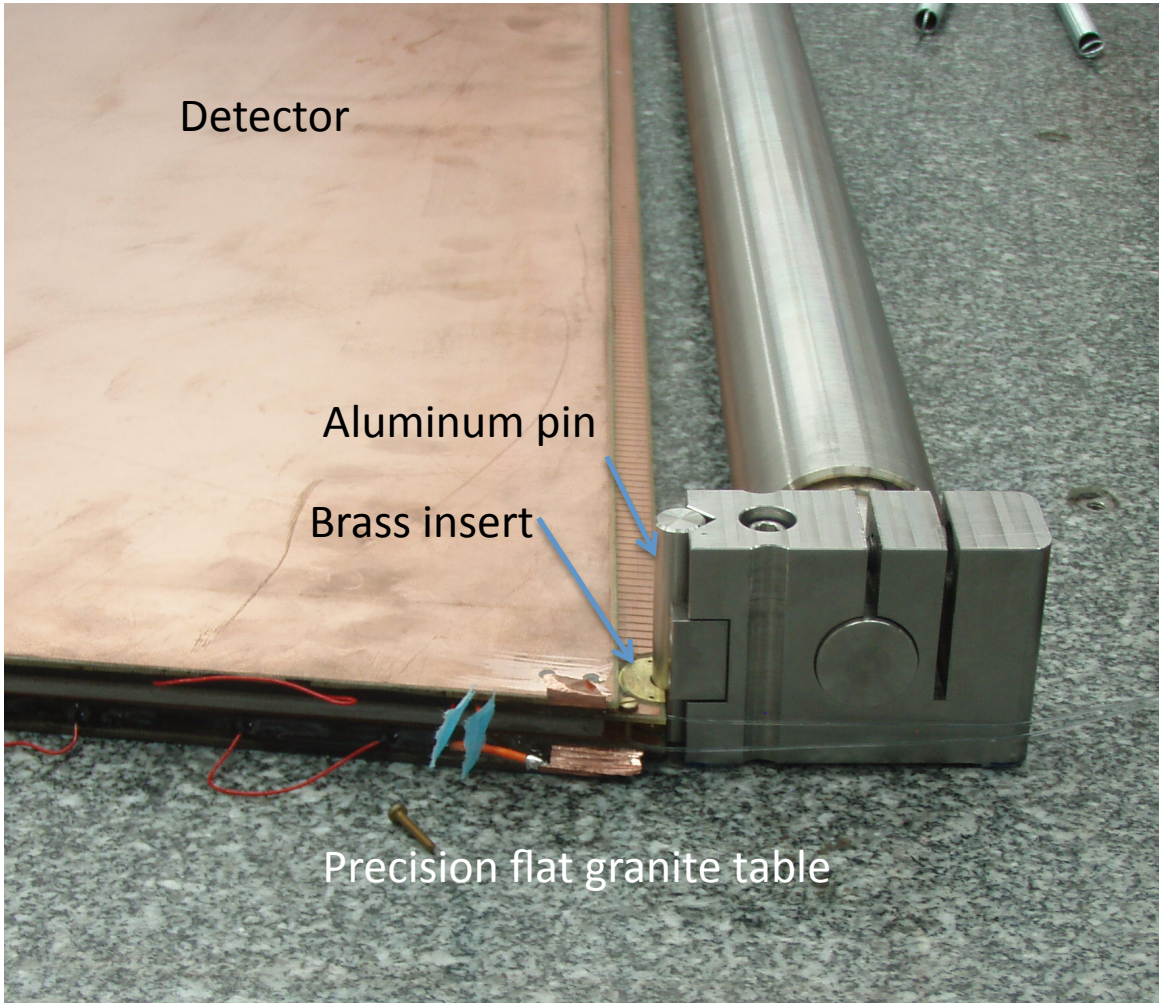
Chamber Assembly



Above: picture of small sTGC prototype being assembled
Below: cartoon of assembly during gluing process.

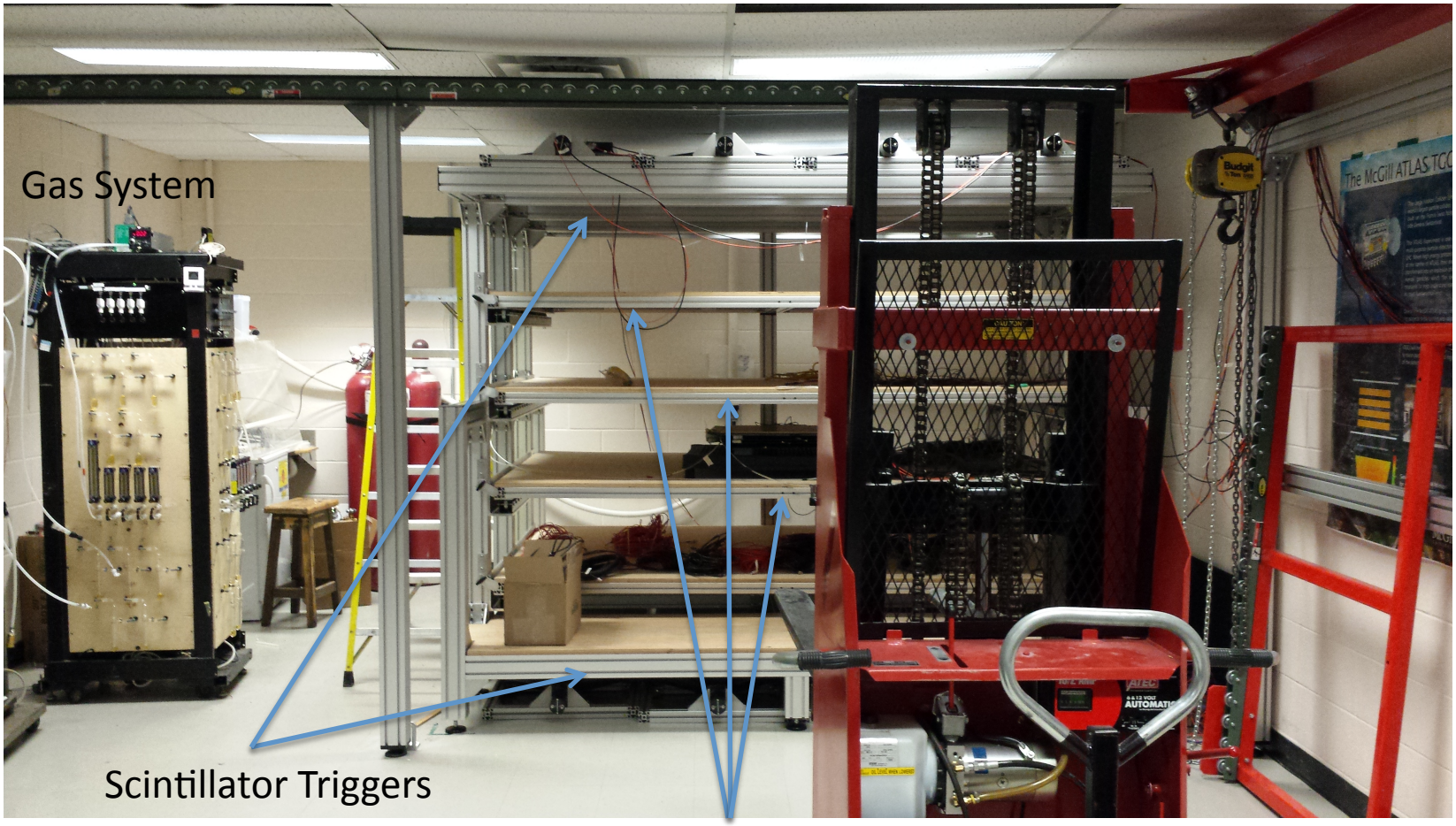


Chamber Assembly



Alignment is achieved by precision brass inserts (machined into the strip boards) which are aligned using precision aluminum pins.

Cosmic Ray Testing

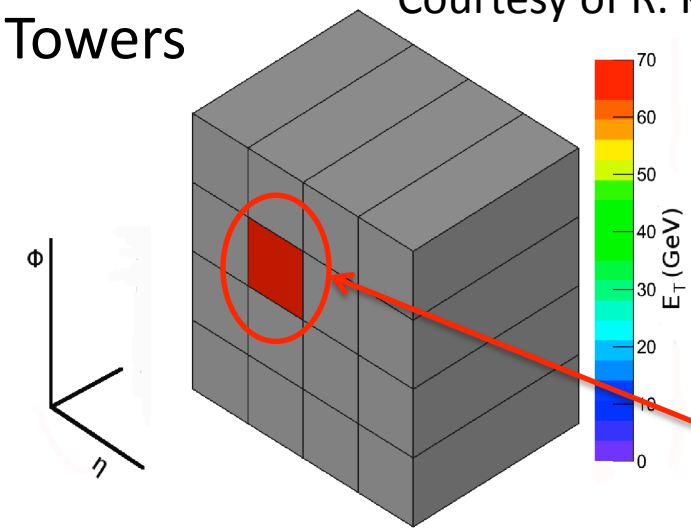


All quads are tested with cosmic rays prior to being sent to CERN to determine pad efficiency and strip resolution.

Supercell Proposal

16 Trigger Towers

Courtesy of R. Keeler

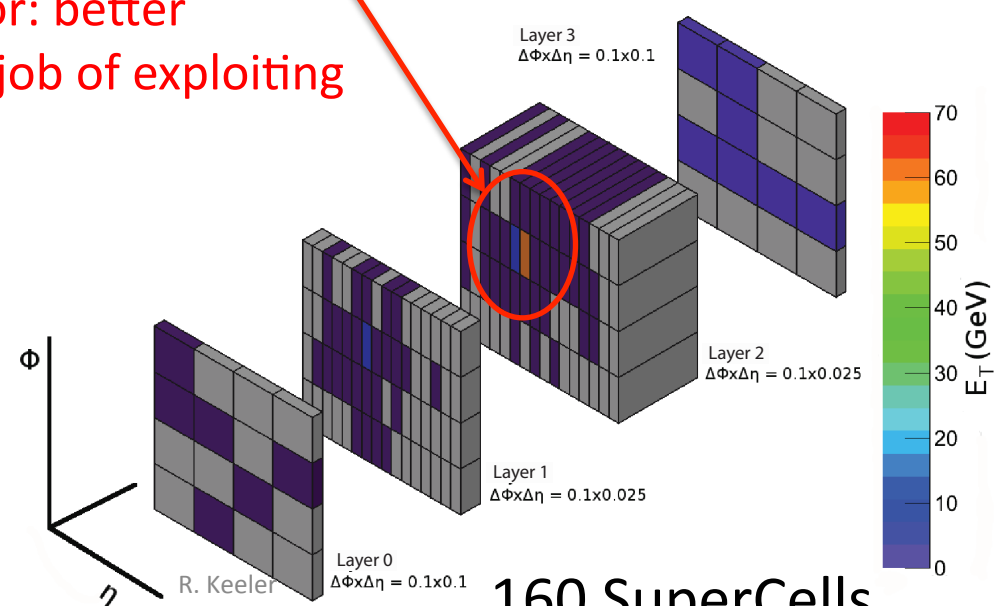


Trigger Tower compared to a Supercell for a 70 GeV electron

Trigger Object

We don't need a new detector: better electronics let us do a better job of exploiting the detector we have.

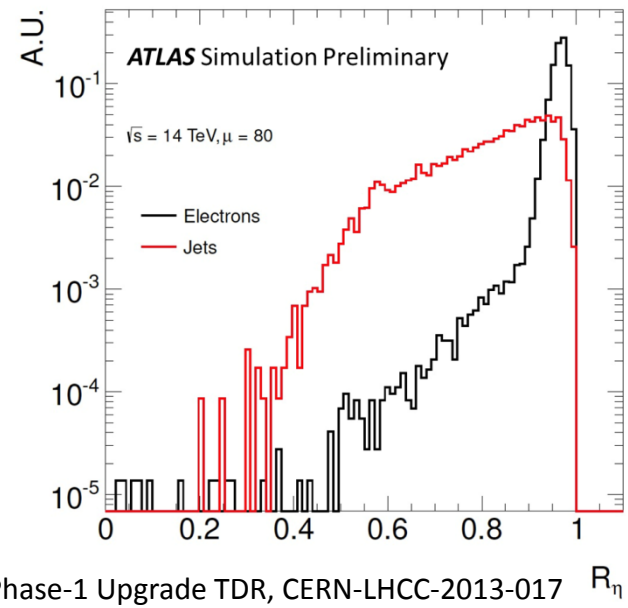
The newer finer granularity cells are called supercells



R. Keeler

160 SuperCells

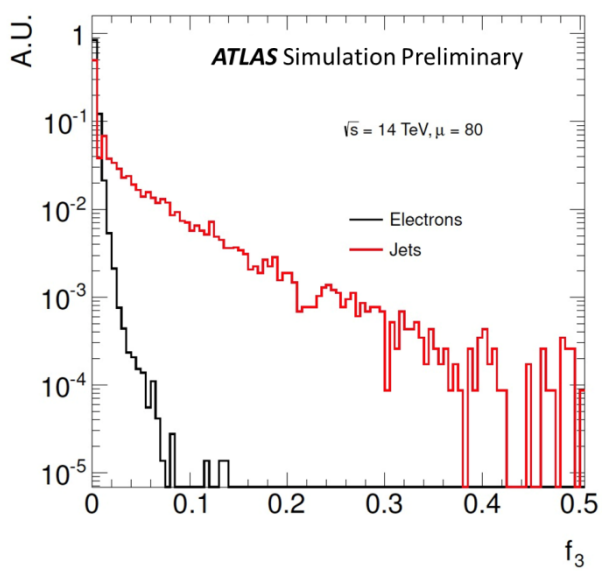
Electron Identification



LAr Phase-1 Upgrade TDR, CERN-LHCC-2013-017

$$R_\eta = \frac{E^{(2)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.175\times0.2}}$$

More granularity in the detector allows for a better characterization of the shower shape and so better discrimination between objects (here, jets and electrons). Using this superior discrimination in the trigger allows for further reduction in trigger rates (as well as performance improvements).



$$f_3 = \frac{E^{(3)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.2\times0.2}}{E^{(1)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.075\times0.2} + E^{(2)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.075\times0.2} + E^{(3)}_{\mathrm{T},\Delta\eta\times\Delta\phi=0.2\times0.2}}$$

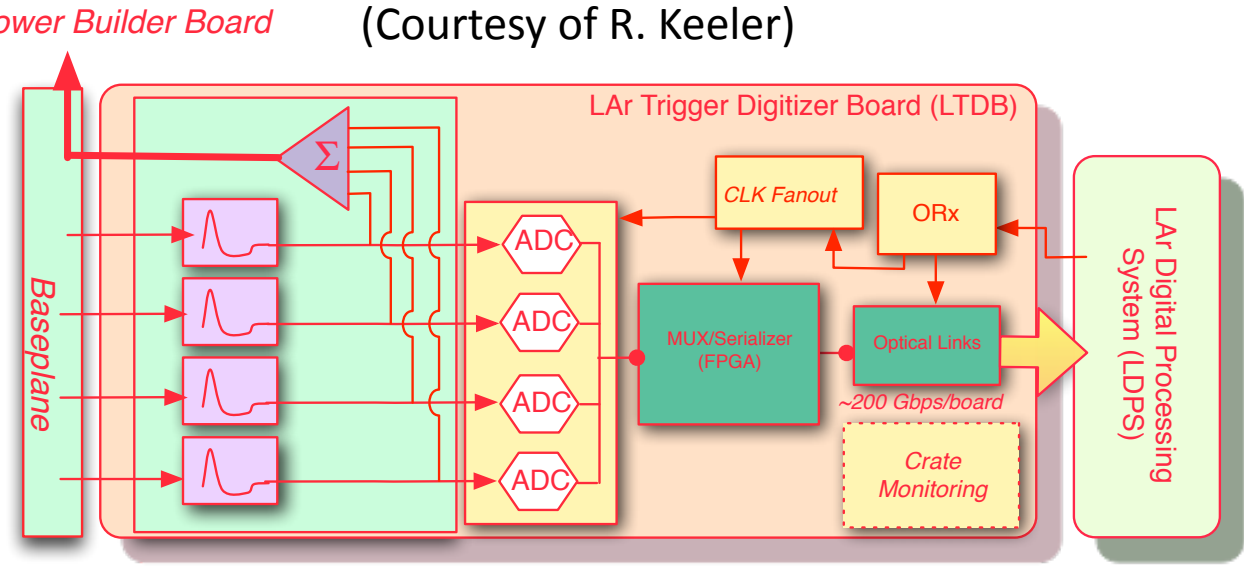
Upgrade Components

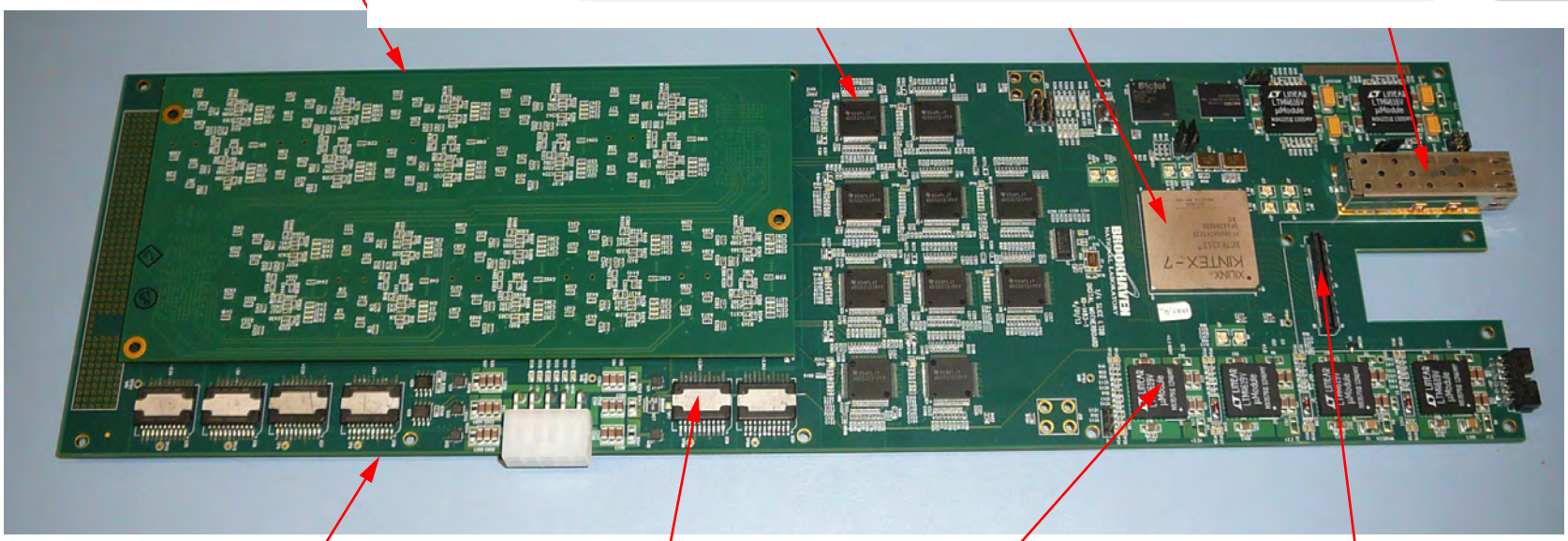
- New Layer Summing Boards for consistency with the improved granularity.
- The new LAr Trigger Digitizing Board (LTDB) will be added to the electronics.
- A new base plane will allow for transmission of additional signals from the calorimeter to the LTDB's.
- A new LAr Digital Processing System will receive information from the LTDB's and pass it on to the trigger.
- Groups at UVic and TRIUMF will be responsible for providing and installing the baseplanes and LTDB's for the Hadronic Endcap Calorimeter.

LTDB Progress

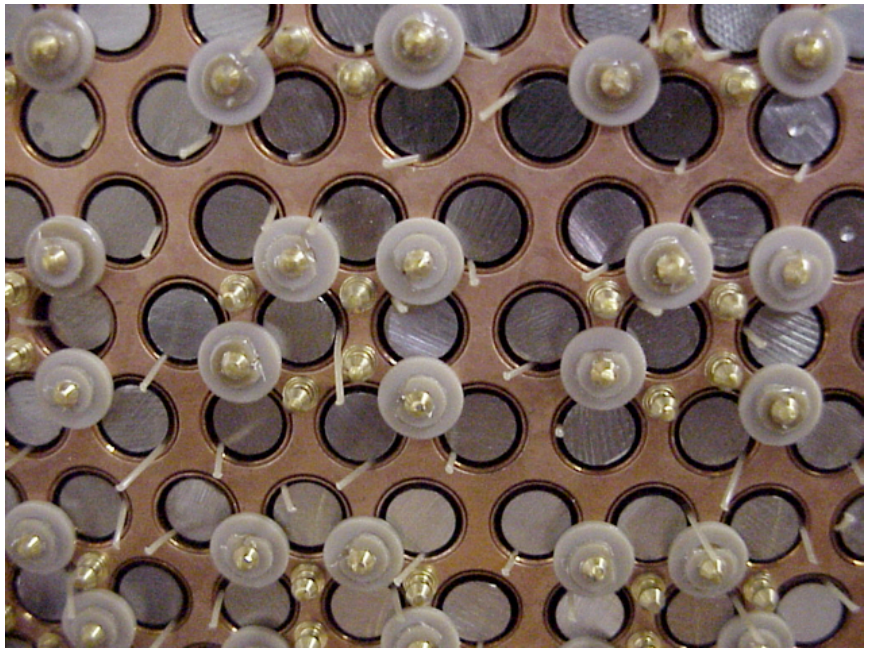
(Courtesy of R. Keeler)

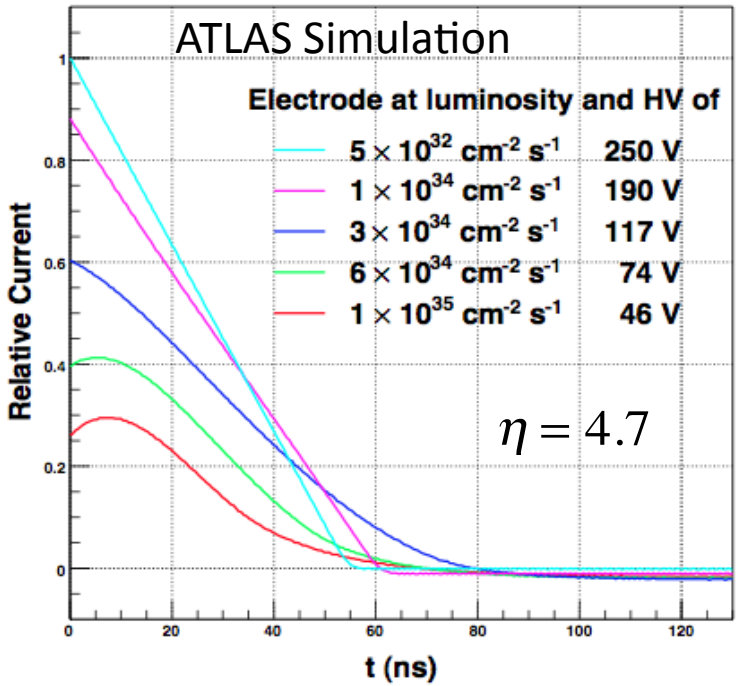
Quarter sized prototype exists





The FCal in Phase-2





Phase-2 Upgrade LOI (CERN-LHCC-2012-022)

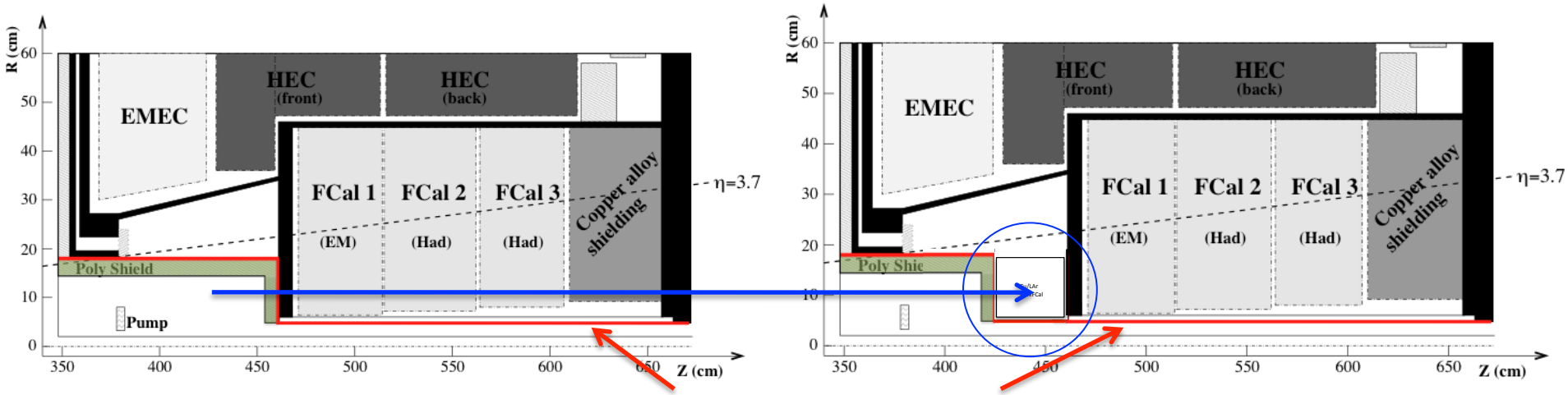
The FCal consists of a metal matrix containing holes with electrodes. Liquid argon goes in the gap between the electrode and the matrix, which is 250-500 µm wide.

This is too wide for the higher luminosities planned following LS3 (2022-23): ions will build up in the gaps, reducing the electric field and degrading the response.

Option 1: A New FCal

- The sFCal would avoid this problem by shrinking the gaps to 100 μm in the EM section (and slightly larger in the hadronic parts).
  - The current proposal would also have better readout granularity than the current detector.
- This is the best option for performance, but it is the riskiest (the FCal would have to be removed) and most expensive.
- Simulation studies are underway.

Option 2: the miniFCal



•Rather than replacing the calorimeter entirely, add another small calorimeter in front of the current one to absorb some of the incoming energy.

•30 cm of copper should do it, using a Cu-LAr design similar to the current FCal only with 100 µm gaps, as in the sFCal proposal.

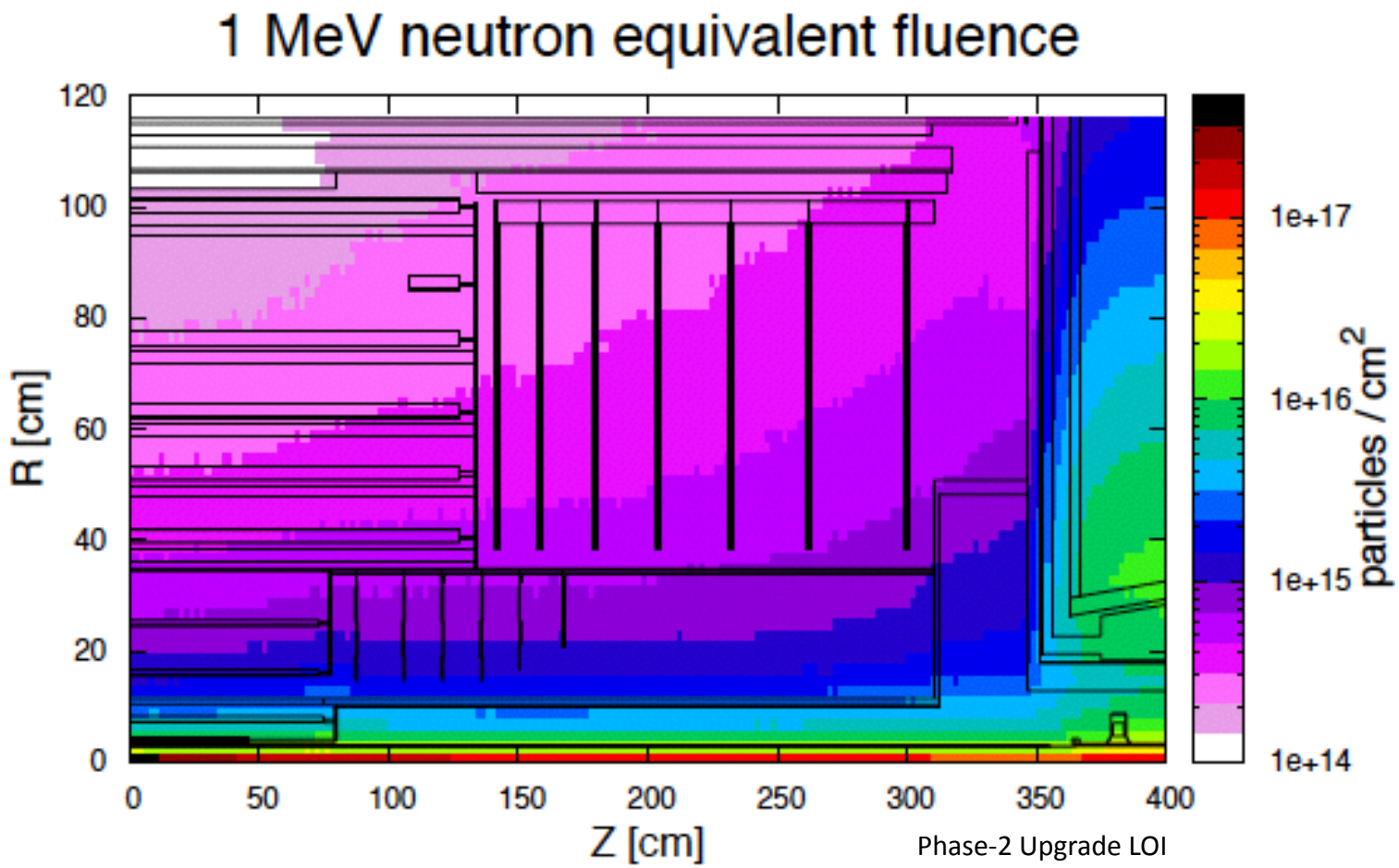
•Much cheaper and easier to do than a full FCal replacement.

•Note that this proposal was originally developed by the Canadian FCal group.

Option 3: Do Nothing

- This option is only viable if we're sure the liquid argon in the FCal will not start to boil: if it does, then we have to do something.
- If that's not an issue, though, this option saves time and money at the expense of accepting some performance degradation.
- Studies of the LAr boiling and the precise extent of the deterioration in response are under way.
- Performance studies are also being carried out for the other two options.
- The final decision will likely be made sometime in the fall.

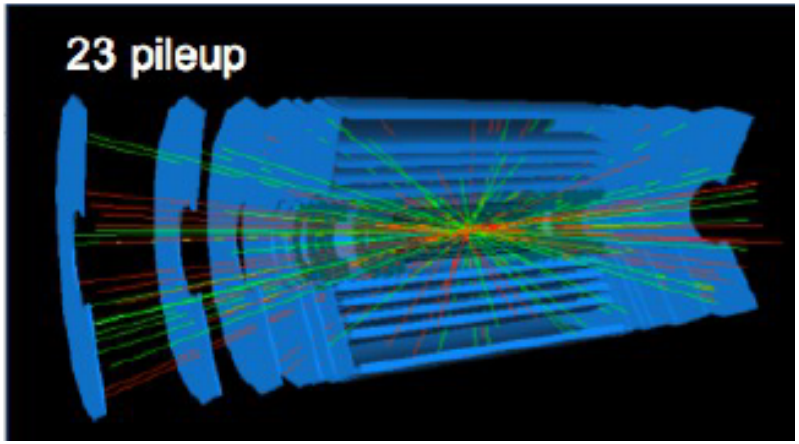
The Inner Detector

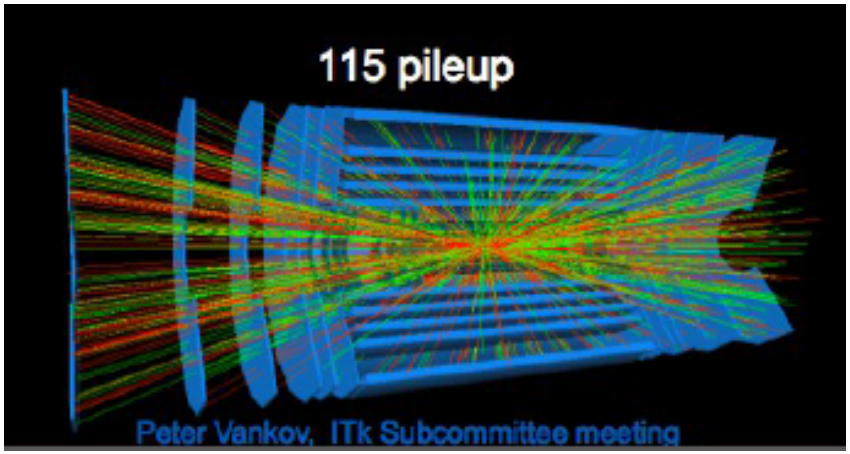


Phase-2 Upgrade LOI

The Inner Detector will simply not be able to handle the radiation damage accumulating over thousands of fb^{-1} of data.

The Inner Detector

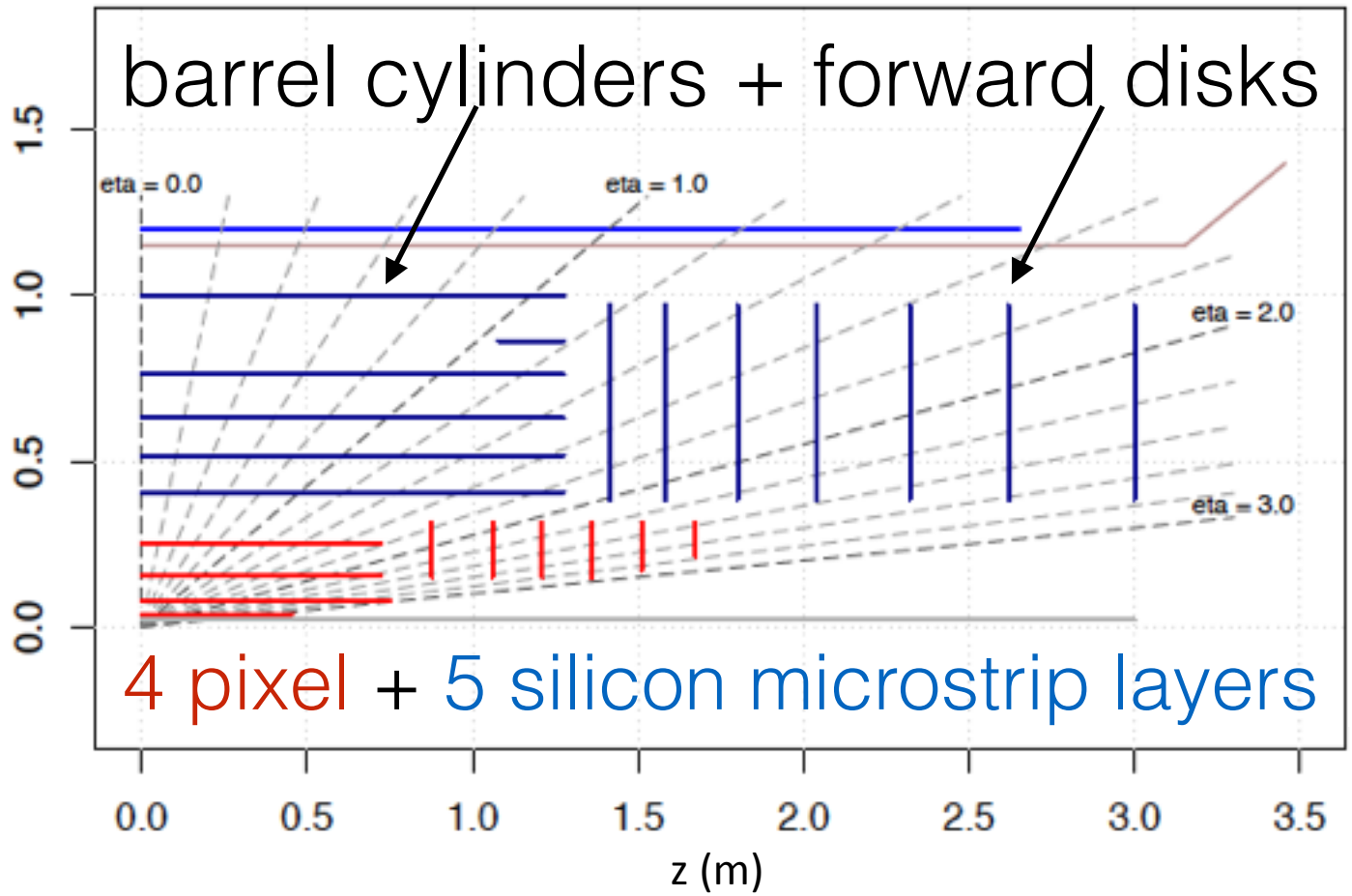




More luminosity → More pileup → More occupancy

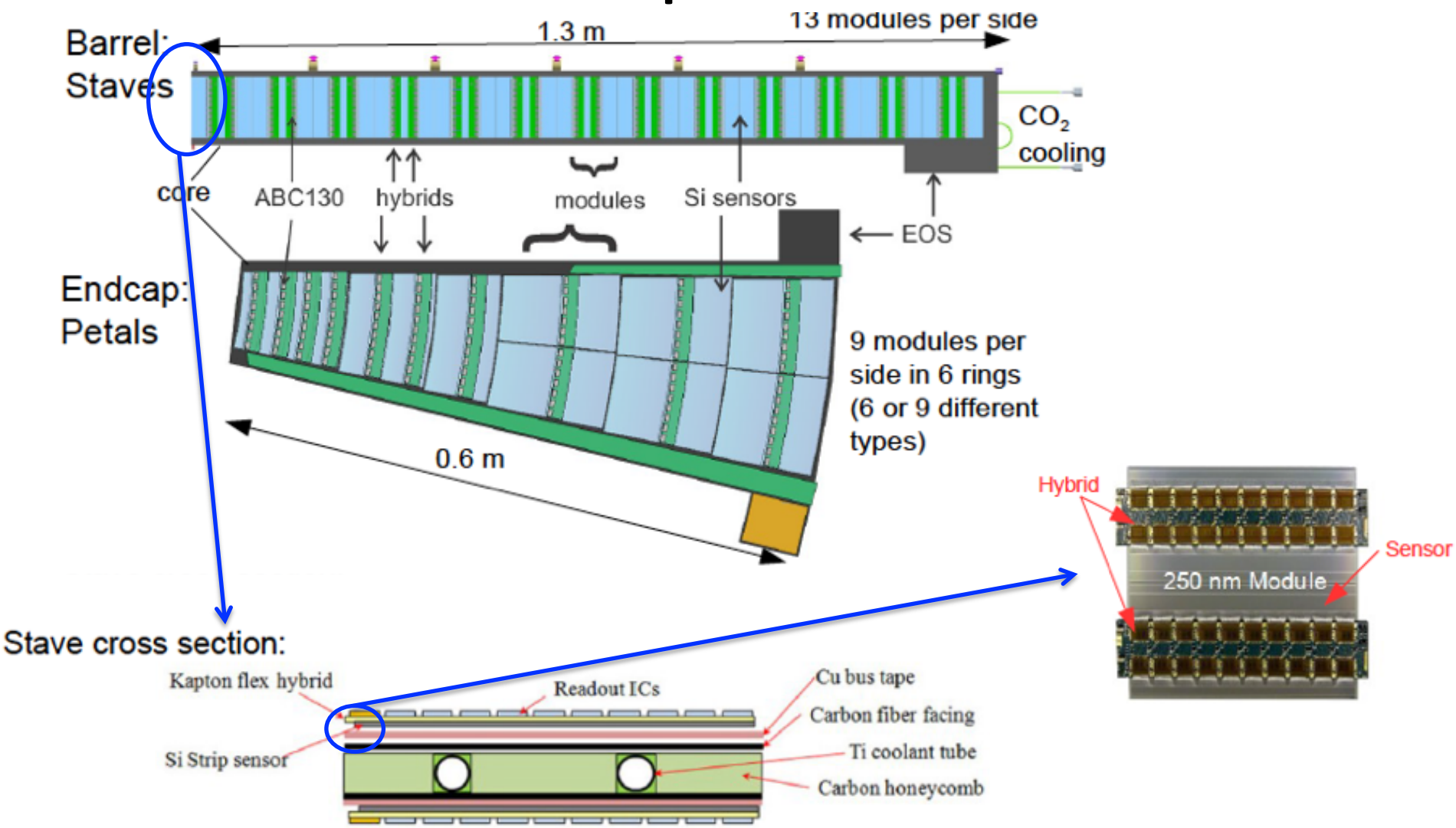
At projected phase-2 luminosities, some parts of the current Inner Detector would have 100% occupancy: that is, every channel would fire for every event, rendering the detector useless.

The Inner Tracker (ITk)



The proposed new ID, the ITk, would consist entirely of silicon, pixels close to the beam and strips further away. (This is the layout from the Letter of Intent, it should not be regarded as final.) Currently the plan is to triple the silicon detector area from what it is in the ID now.

ITk Strip Modules



ITk and Canada

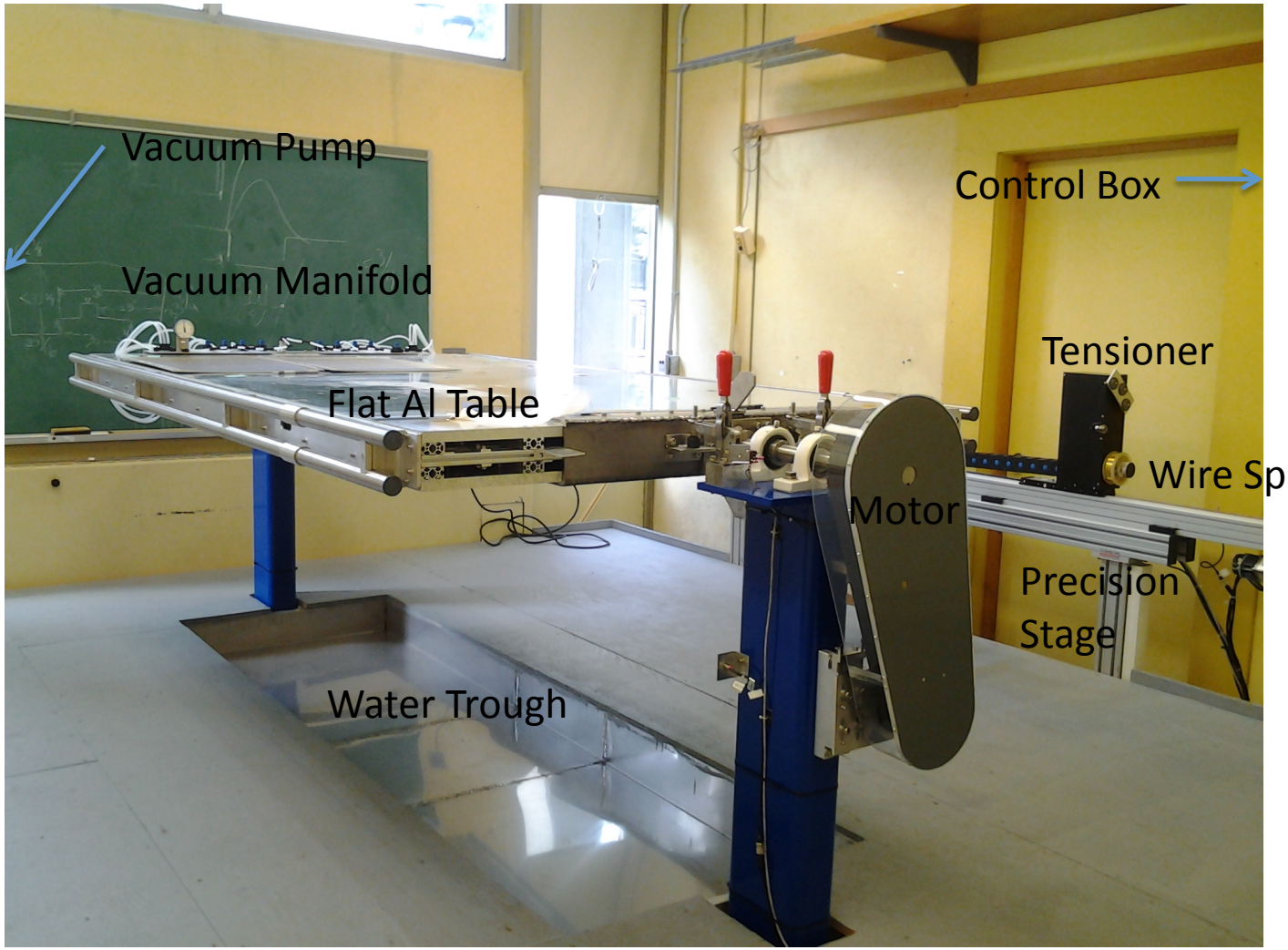
- In the immediate future:
  - Layout studies continue
  - Developing test system for readout electronics
  - Learning to build Si strip modules
- In the long run:
  - Production and QA of Si strip modules at two sites
  - Regional production centers on the NSW model

Summary and Conclusion

- LHC upgrades provide the opportunity to really improve our knowledge of the Higgs and search for new physics.
- However, in its current state ATLAS would be unable to take advantage of these opportunities.
- Upgrade work for installation during the next shutdown is ongoing.
- Plans for LS3 are being finalized.
- ATLAS Canada is in the middle of a number of important efforts for the future of ATLAS.

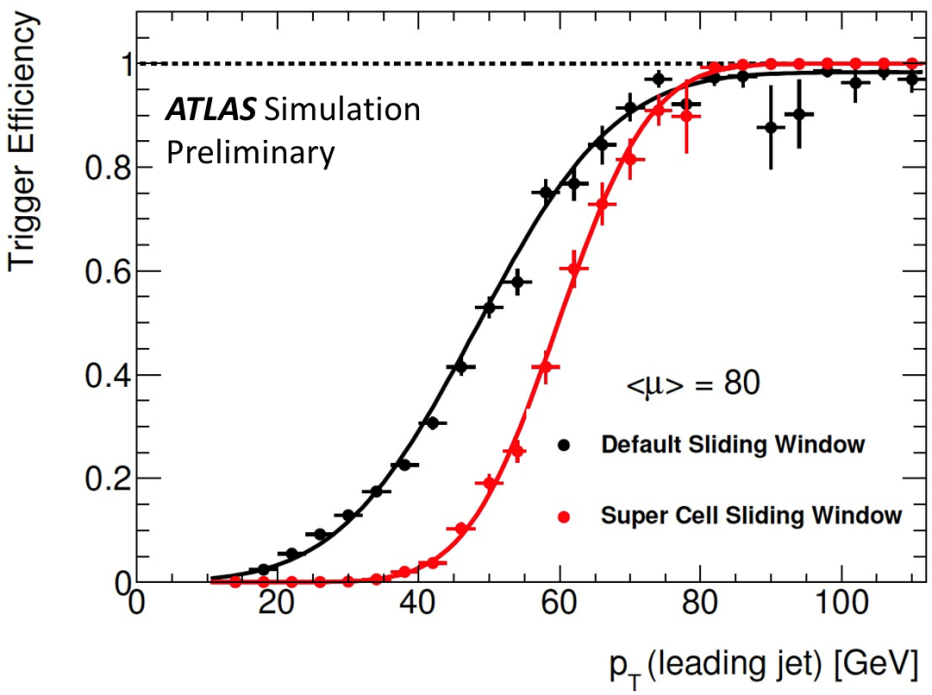
Backup

Chamber Assembly

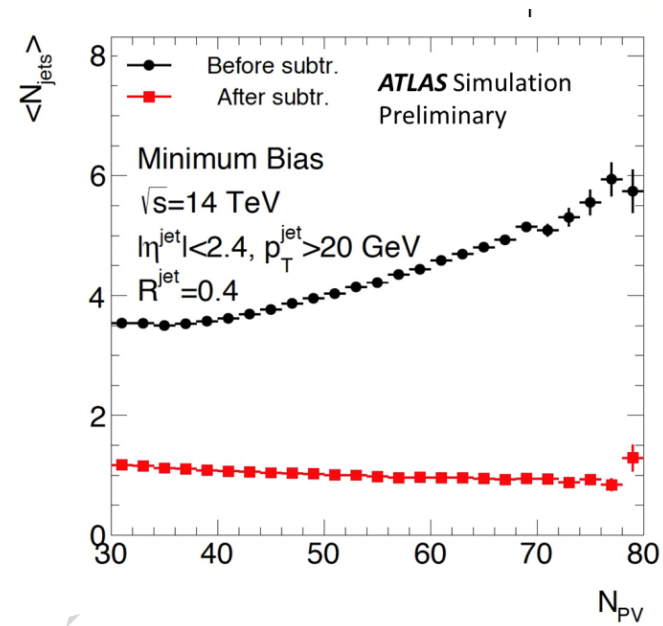


Chambers are wired using a winding table which provides precise wire location and tension, essential for maintaining a uniform electric field in the chamber.

Pileup Rejection

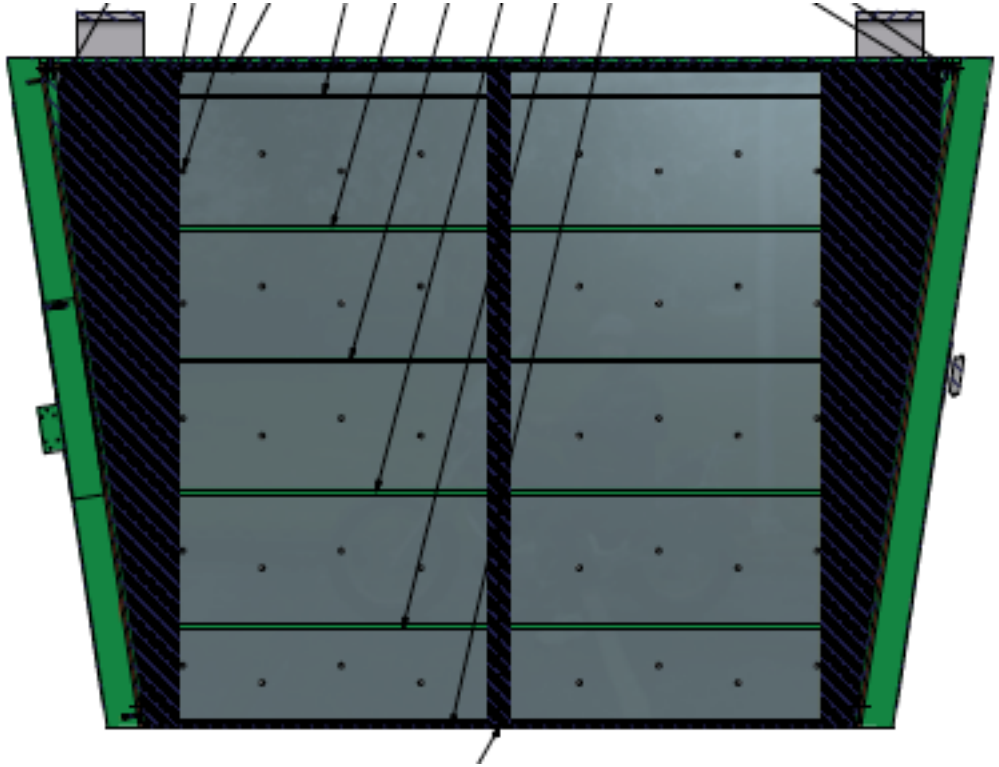


LAr Phase-1 Upgrade TDR



Above left, new electronics will make for a sharper jet trigger turn-on curve; above right, new electronics will allow for a pileup subtraction procedure similar to that currently done in offline processing.

Cathode Board Preparation



Then the frames, buttons, and supports are attached to the board using a vacuum pressing system (which will be discussed in more detail later).

New Baseplanes

- Fitting more traces into the same area presents challenges
  - Tighter spacing means more possible crosstalk
  - The eventual radiation dose will also be higher
- Studies (using simulations and physical models) are ongoing.