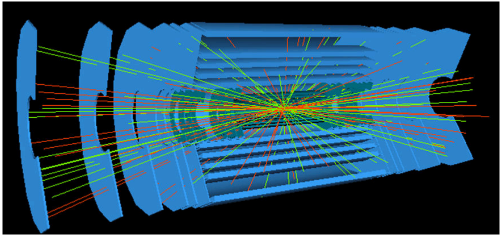
Swedish contribution to ATLAS upgrades

Geoffrey Mullier on behalf of the ATLAS Swedish institutes
Lund University

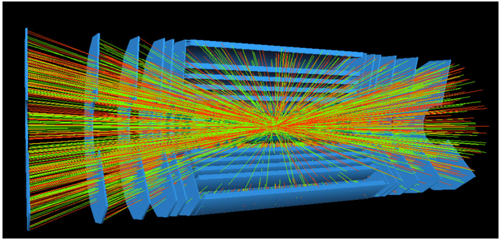
Partikeldagarna – Linköping – 2/10/2019

Challenges of the High Luminosity LHC (HL-LHC)?

23 simultaneous events



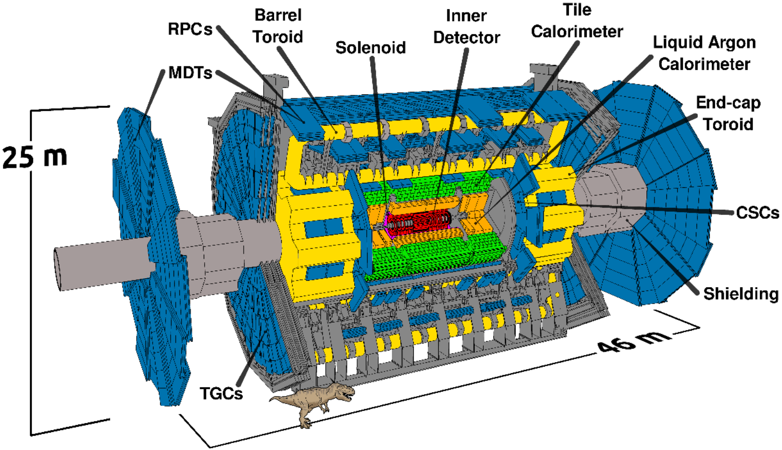
230 simultaneous events



Increase in pileup means a need for

- ↳ More bandwidth
- ↳ Higher granularity
- ↳ Higher radiation damage resiliency
- ↳ Better triggering capabilities

ATLAS Upgrade program Full overview in scoping document (click me)



[CERN-LHCC-2015-020]

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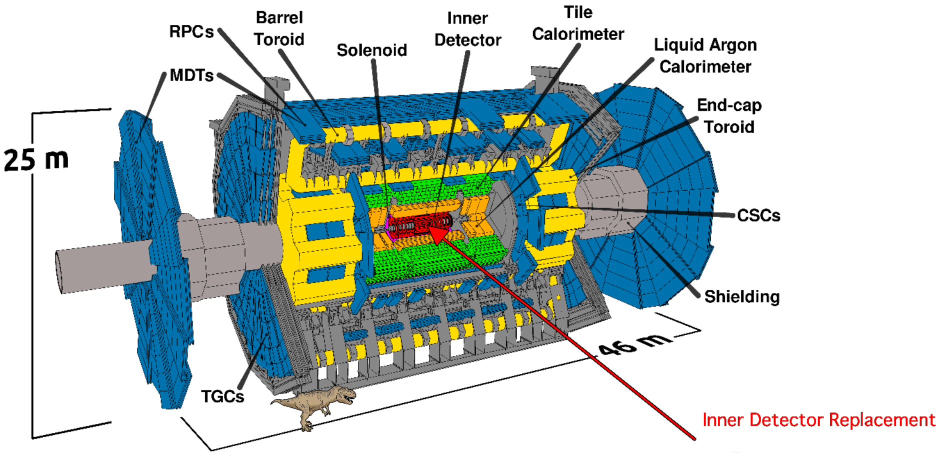

[CERN-LHCC-2015-020]

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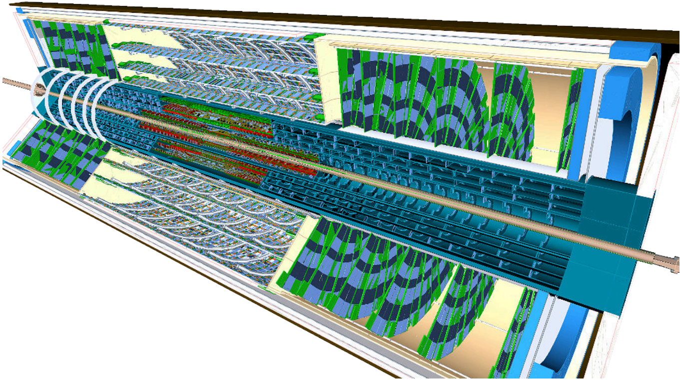
LUND UNIVERSITY

The ATLAS Inner TracKer (ITk) (Click me)

- New ATLAS Tracking detector
- Full silicon
- Strip $17,888$ Modules 59.87M Channels (current 4088 modules with 6.3M Channels)
- Pixel $10,276$ Modules ≈ 800M Channels (current 2024 modules 92M channels)



[CERN-LHCC-2017-021]

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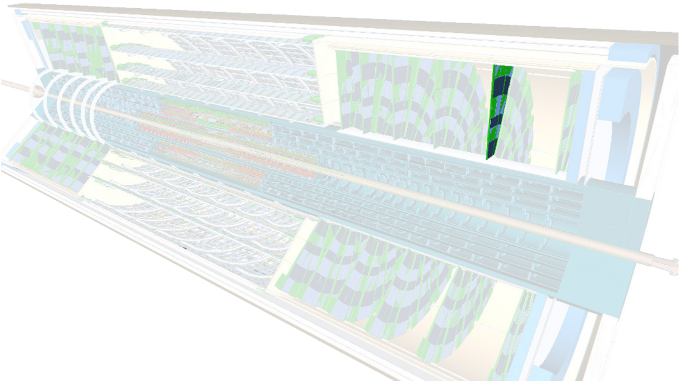

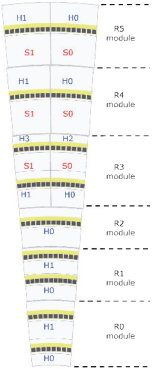

[CERN-LHCC-2017-021]

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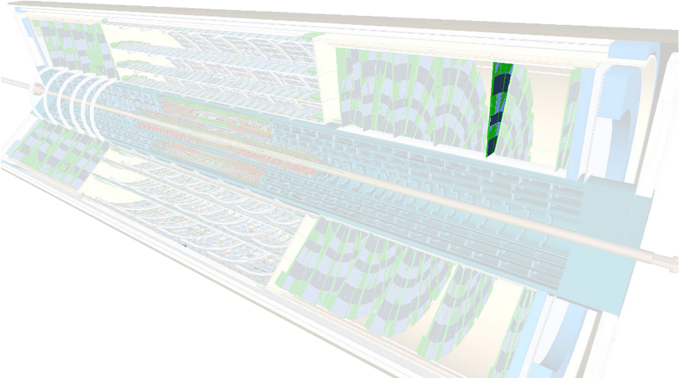
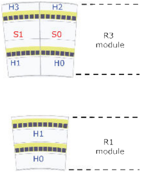
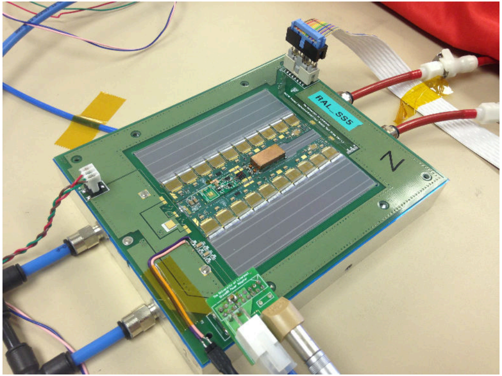


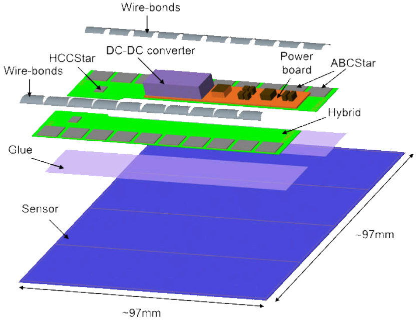


[CERN-LHCC-2017-021]

Silicon Strip Module

Here barrel module just for illustration purposes (End-Caps modules are equivalent)

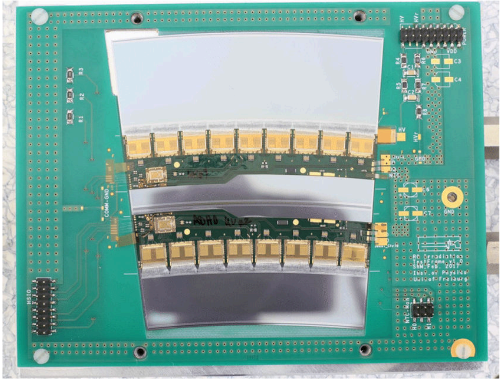




Scandinavian effort

- Four participating institutes in Scandinavia
  - Lund University
  - Uppsala University
  - Niels Bohr Institute
  - University of Oslo
- Pledged for $\approx 10\%$ of the whole end-caps
  - ↳ 432 modules of two types $50/50$ split
  - ↳ R1 and R3 modules
- Production in industry (NOTE)
- Test of modules in institutes

Swedish contributions to manufacturing and test



Uppsala/NOTE

- Module manufacturing expertise from SCT
- Wire bonding expertise
- Gluing expertise

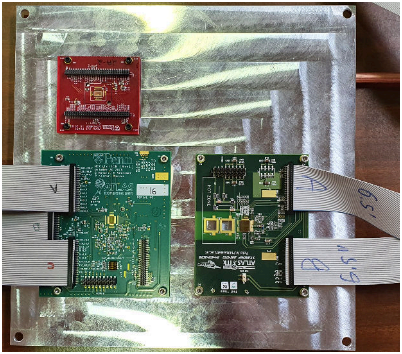
Lund

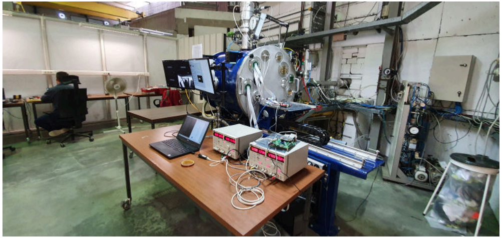
- Module testing
- QA/QC
- DAQ expertise

Swedish contributions to prototypes testing

ITk Strip chip irradiation campaign

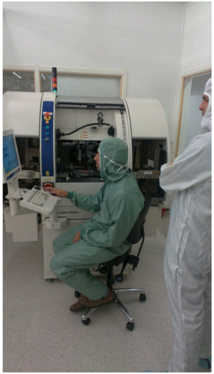
- Testing single event upset rates
- Sets minimum threshold for maximum fluence operation
- Excellent results

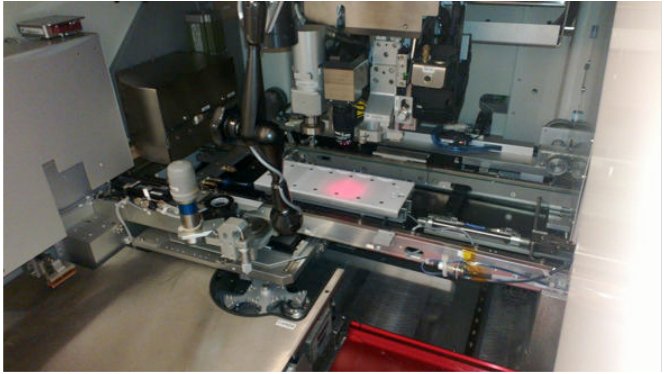




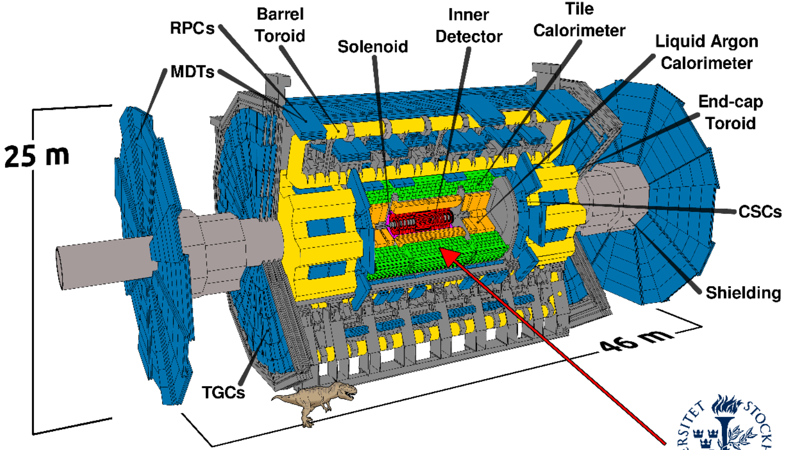
NOTE and synergy between academy and industry

- Agreement with NOTE to work with engineers and technicians on site.
- Payment for personnel and infrastructure for time booked (Extremely cost efficient for prototyping).
- Allows for efficient production for large scale project for smaller investments





ATLAS Tile Calorimeter Upgrade: Stockholm (Click me)

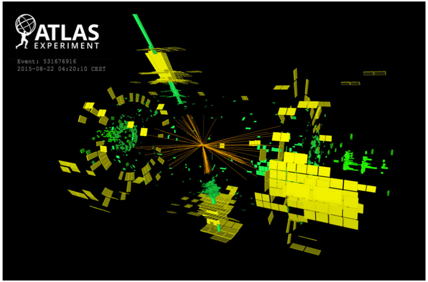


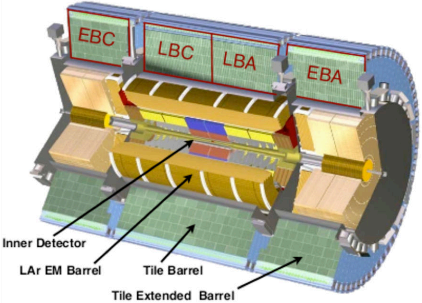
Hadronic Calorimeter:
Replacement of Readout electronics

[CERN-LHCC-2017-019]

ATLAS Tile Calorimeter Upgrade

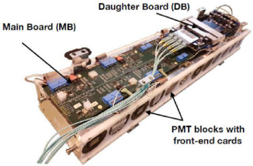
- Measures hadronic jet energies in ATLAS up to 1.5 TeV per calorimeter cells.
- Crucial for jet identification and missing momentum measurements, **central to most searches for BSM physics**.
- Single pion energy resolution $\frac{\delta E}{E} \approx \frac{45\%}{\sqrt{E}} \oplus 0.01\%$
- High Luminosity requires replacement of all readout electronics - Higher radiation hardness + Fully digital Trigger

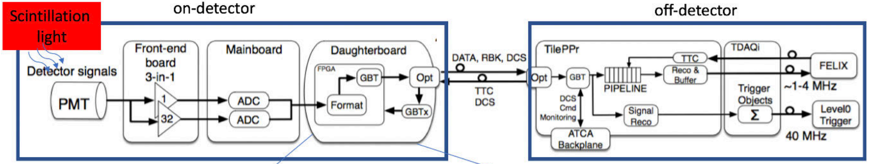




Why a High Lumi Upgrade of the Tile Calorimeter? (Daughter Card)

- New High Luminosity read out strategy
  - On-detector electronics to send out all digitized data at LHC frequency
  - Fully digital full granularity trigger at 40 MHz – much more capable trigger
  - All buffer pipelines moved to off-detector electronics due to radiation
- Detector components
  - 10% most irradiated photomultipliers out of 10,000
  - Higher redundancy in data links and power distribution thus improvement in the system reliability

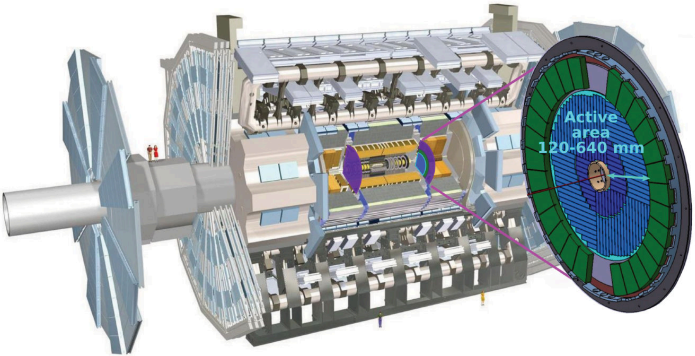




Daughterboard: design R&D and production under Stockholm University Responsibility

Final design review expected next summer
prototypes extensively tested

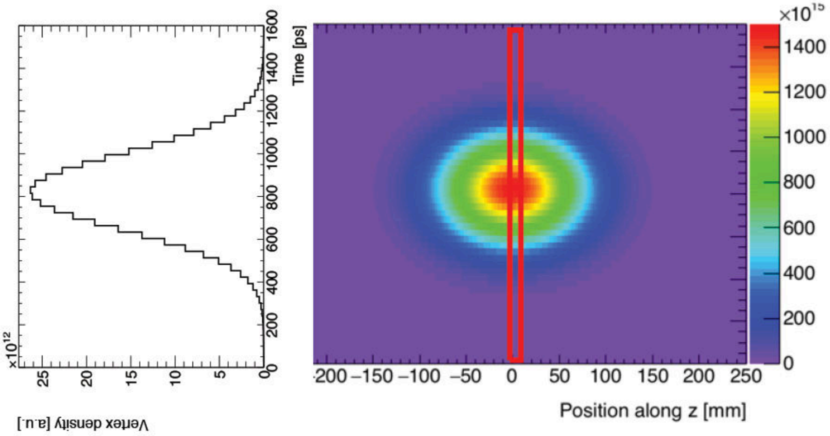
High-Granularity Timing Detector (HGTD): KTH (Click me)



[CERN-LHCC-2018-023]

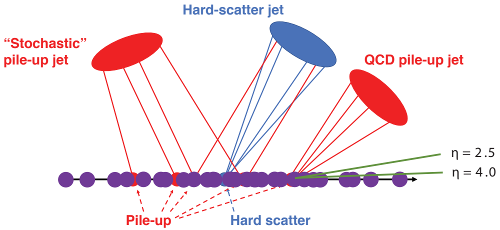
High-Granularity Timing Detector Principles (HGTD)

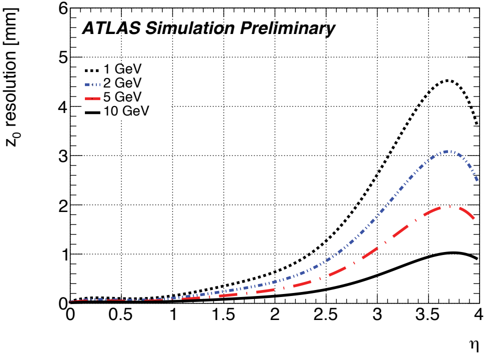
- Collisions can happen at same location in z
- But not at the same time...



High-Granularity Timing Detector Principles (HGTD)

- The forward region is specially challenging at $\langle \mu \rangle = 200$
- Improvement in track to vertex association by comparing arrival times

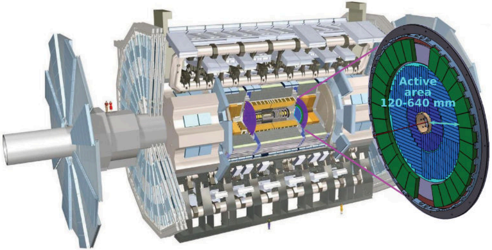




High-Granularity Timing Detector (HGTD): KTH

Mitigate pileup by exploiting that beam spot has time dimension, spread of around 200ps

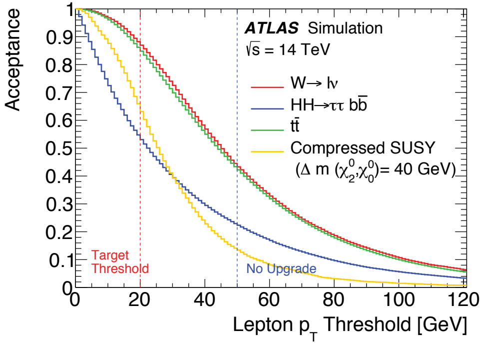
- Two endcap disks at $z = \pm 3.5$m, Si-based Low Gain Avalanche Diode technology, $1.3 \times 1.3\text{mm}^2$ pixels
- $\sigma_t = 30$ ps/track in acceptance: $120 \text{ mm} < R < 640 \text{ mm}$ $2.4 < |\eta| < 4.0$
- KTH responsibility: functionality to use as luminometer by off-detector FPGA-based electronics boards



Hardware Track Trigger (HTT): Uppsala (click me)

With increased luminosity, increased numbers rate of events, but bandwidth does not change. Two options to keep taking data.

- Raising minimum P_T of all recorded objects
  ↳ Losing efficiency
- Improving trigger by improving trigger level reconstruction
  ↳ No loss in efficiency but requires faster solution than CPUs

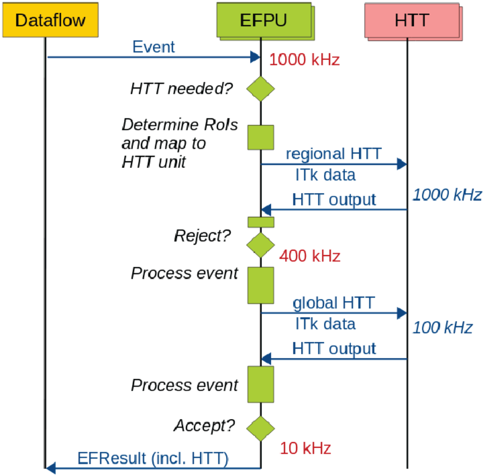


[CERN-LHCC-2017-020]

Hardware Track Trigger (HTT): Uppsala

UPPSALA UNIVERSITET

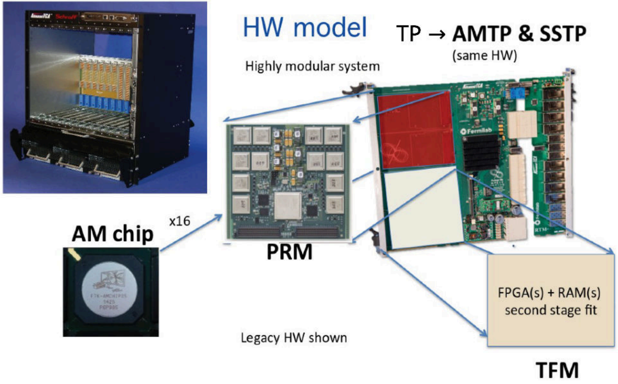
- Baseline system, single level-Hardware co-processor under Event Filter
- Regional tracking rHTT ($\approx 10\%$ of tracker volume) at 1 MHz
  $p_T > 2$ GeV with 8 ITk layers
- Global tracking gHTT at 100 kHz
  $p_T > 2$ GeV with all ITk layers



Hardware Track Trigger (HTT): Uppsala

Massively parallelised system

- 576 pattern recognition boards (AMTP) for both rHTT and gHTT including custom made 11520 Associative Memory (AM) ASICs
- 96 Track fitting boards (SSTP)for full track fitting in gHTT
- Total system hit rate is 3.2 Tb/s
- Average power is consumption 289 kW (peak 385 kW)

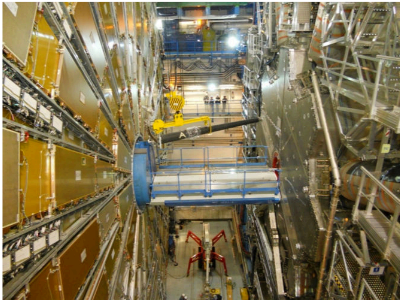


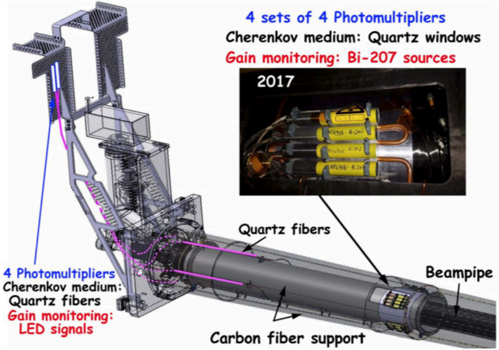
Uppsala contributions to HTT

- HTT Project Office
- Development of an alternative pattern recognition to AM ASIC based on Hough Transform run in commercially available FPGAs
- Coordination of data formats and exchange in the system
- Comparison of performances between AM and Hough based systems.
- Comparison of two hardware-based hit filtering methods for trackers in high-pileup environments, Journal of Instrumentation, ISSN 1748-0221, E-ISSN 1748-0221, Vol. 13 (click me)
- To catch a long-lived particle: hit selection towards a regional hardware track trigger implementation, in review at Journal of Instrumentation (click me)

LUminosity Cherenkov Integrating Detector (LUCID2): Lund

- Main online/offline ATLAS luminosity detector for Run 2
- Also used in the trigger
- Detector and luminosity analysis contributed by Lund with V. Hedberg as LUCID project leader.





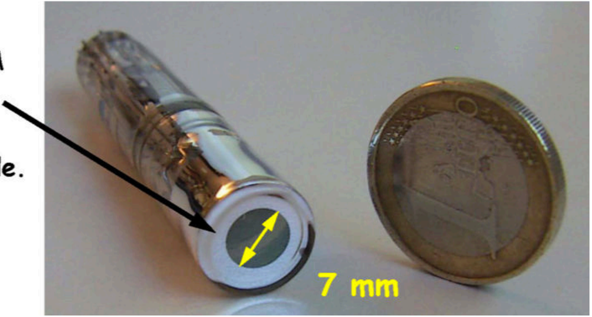
https://doi.org/10.1088%2F1748-0221%2F13%2F07%2Fp07017

LUminosity Cherenkov Integrating Detector (LUCID3): Lund

- LUCID 2 refurbished with new PMs to be Main online/offline ATLAS luminosity detector for Run 3.
- HL-LHC requires development of new detector LUCID3.
- Make it smaller but have more of them.
- First tests promising.

The modified (MOD) or BIM photomultipliers have a ring of aluminium between the window and the photocathode.

The idea is to reduce their acceptance.



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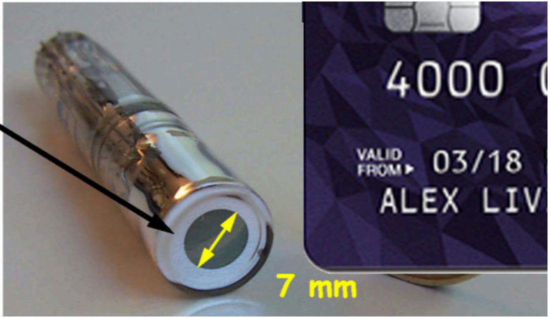

Conclusions

- **All-silicon Inner Tracker (ITk): Lund & Uppsala**
  - Increased pileup requires both improved performance and more radiation hard detectors
  - Readout: Current Inner Detector cannot handle HL-LHC occupancies, ITk readout enables new hardware-based tracking in the trigger system
- **High-Granularity Timing Detector (HGTD): KTH**
  - Silicon precision-timing detector exploits time spread of beam spot
  - KTH responsible for luminometer functionality
- **Tile calorimeter: Stockholm**
  - Design and production of 1200 daughter boards
  - Critical part of readout electronics, all data goes through this path
- **Hardware Track Trigger (HTT): Uppsala**
  - Hardware tracking can cope with high pileup thus improve trigger and allow unchanged thresholds
  - Uppsala responsible for design and testing of Pattern Recognition Mezzanine cards
- **LUminosity Cherenkov Integrating Detector (LUCID): Lund**
  - Luminosity critical for entire ATLAS physics program, LUCID main detector so far
  - HL-LHC pileup requires upgraded detector: several prototypes being investigated

Thank you for your attention!

Questions?