Overview of the Chinese Activities on the ATLAS Detector Upgrades

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On behalf of the ATLAS Chinese Clusters

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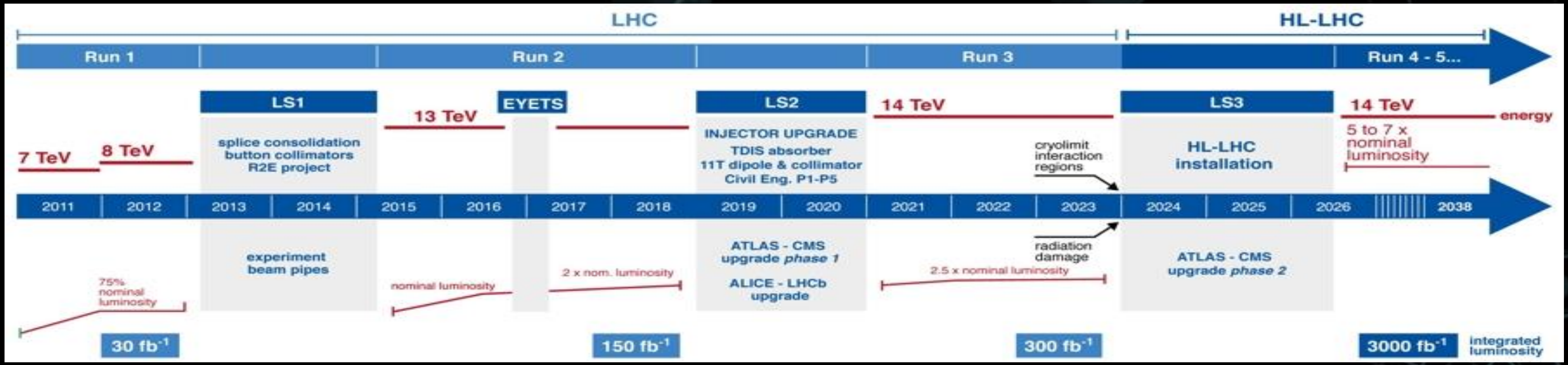
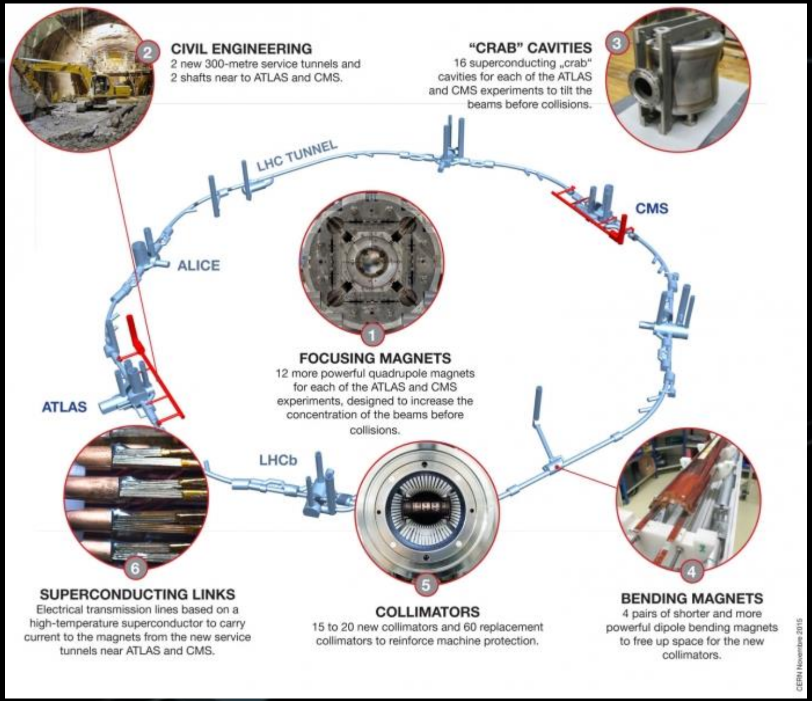
OUTLINE

- LHC and HL-LHC program
- ATLAS Detector Upgrades
- Summary and outlook

HIGH LUMINOSITY LHC TIMELINE

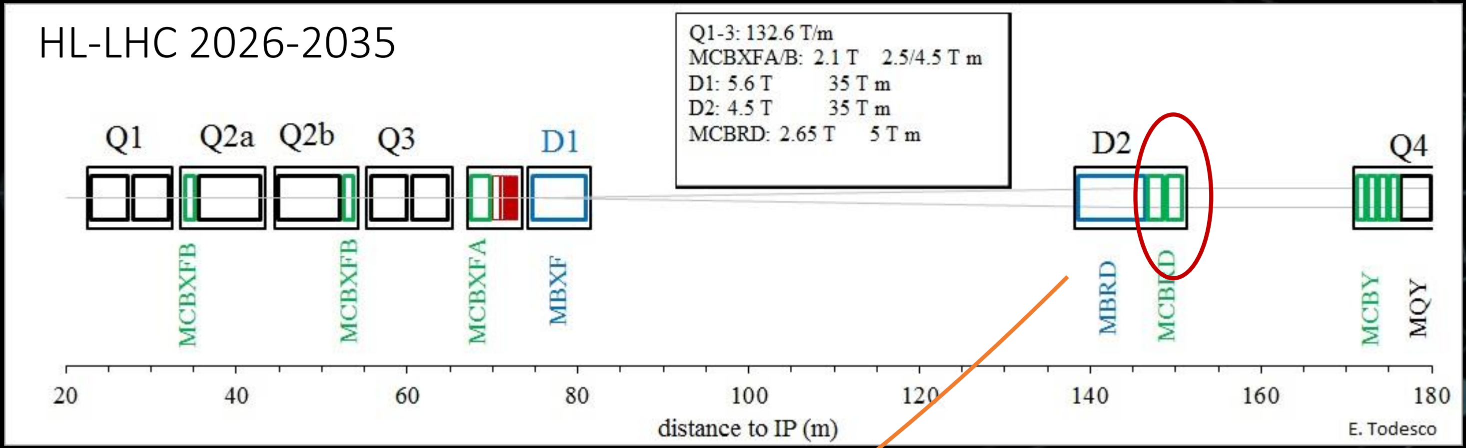


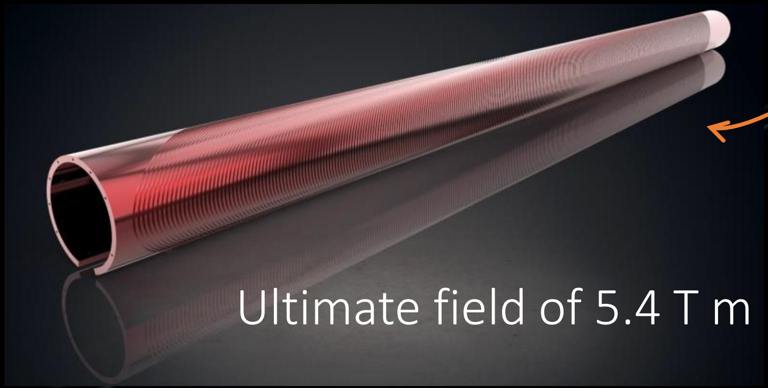


- *"[...] Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030 [...]"*

CCT Corrector Magnets for HL-LHC

- Canted Cosine-Theta (CCT) corrector magnet (horizontal/vertical corrector in both apertures), based on superconducting NbTi wires – joint efforts by IHEP, IMP and WST to deliver 12 units (+1 prototype)

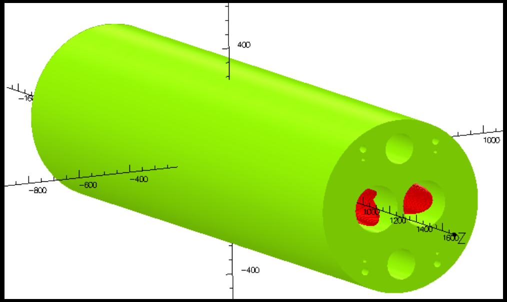




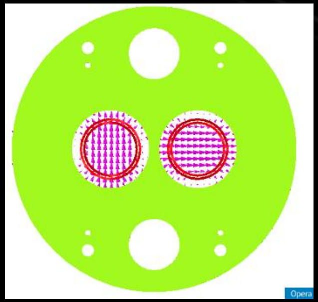
Official MoU signed!

Designs and Prototypes

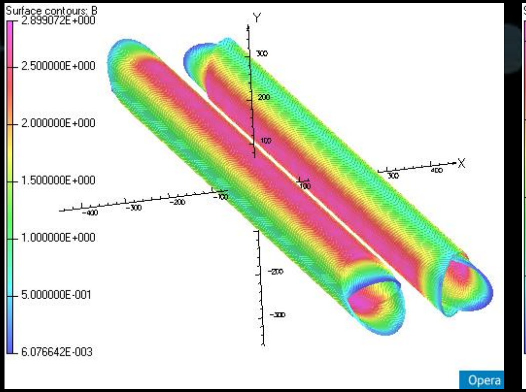
2.2 m magnet design



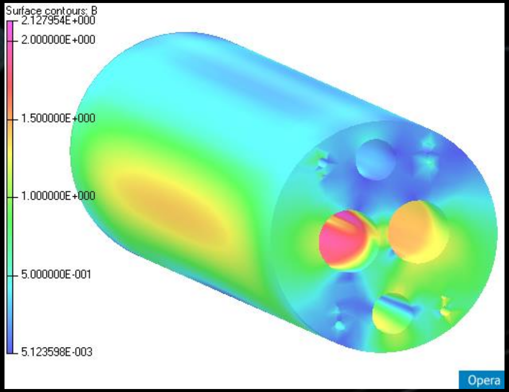
2.2-m long CCT Dipole



Magnetic flux

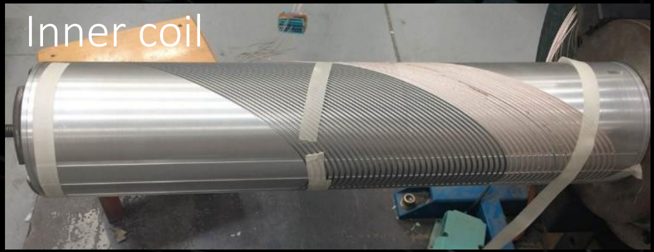


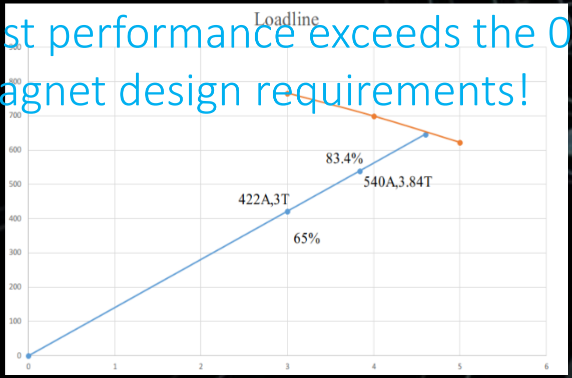
Magnetic Flux density in coils



Magnetic Flux density in yoke

0.5 m prototype

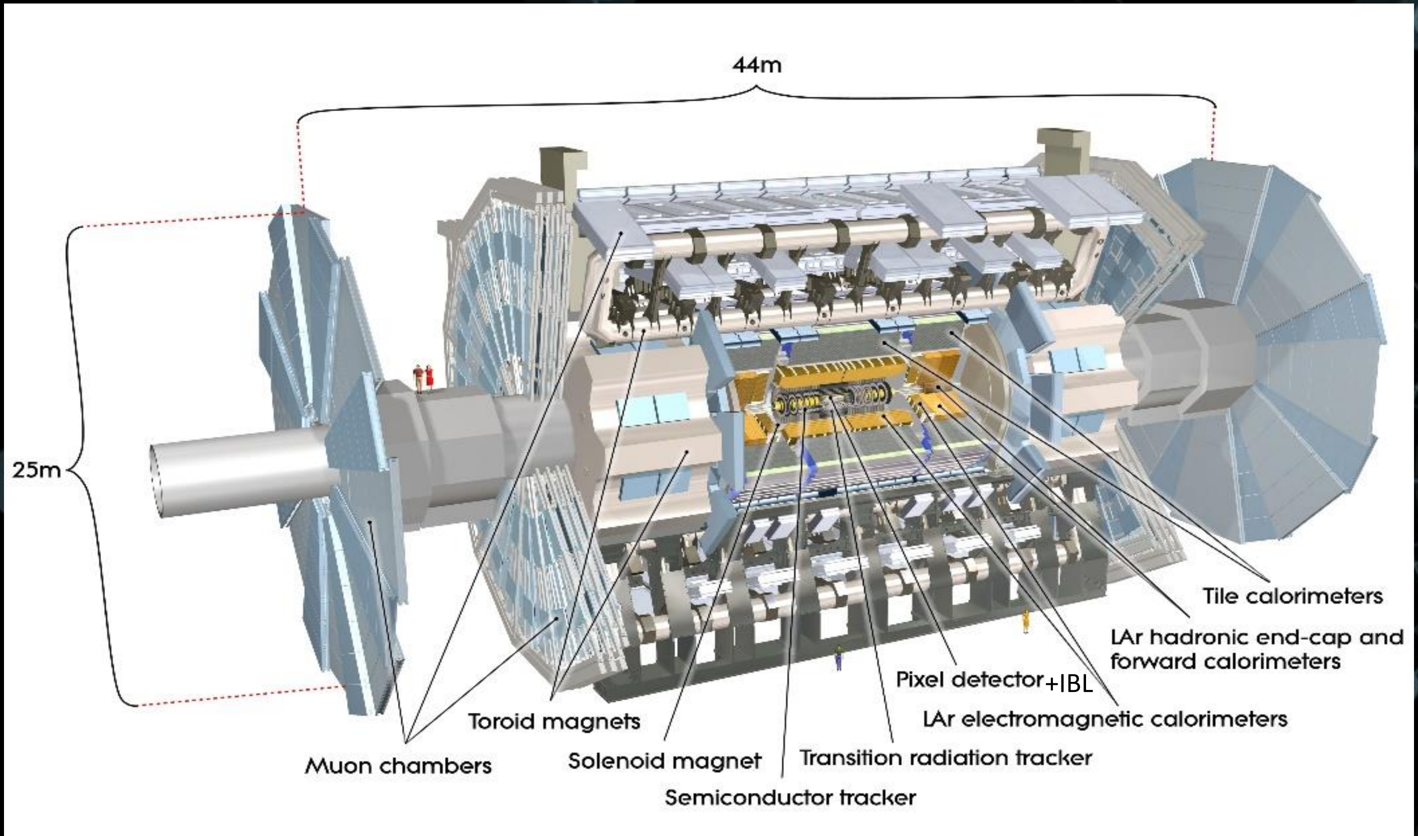




Test performance exceeds the 0.5m magnet design requirements!

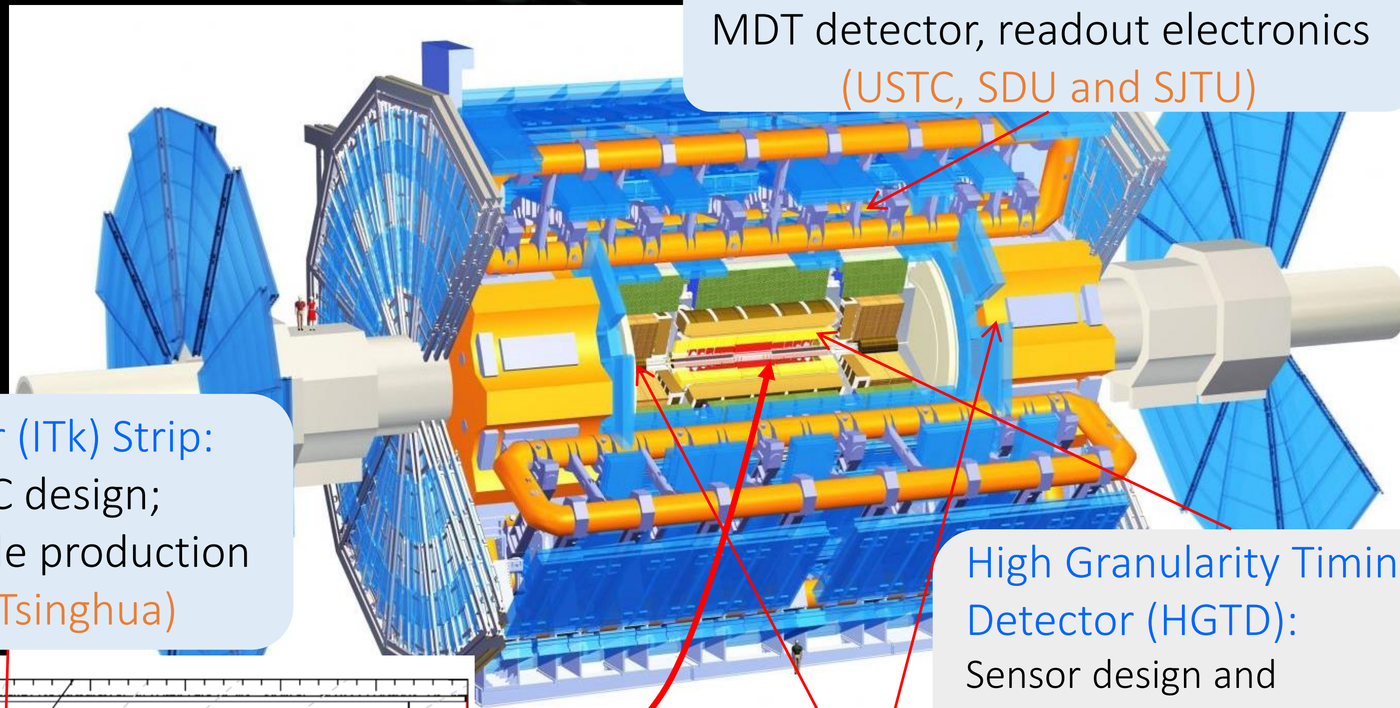
- Move forward to the 2.2 m prototype and series, and then prepare for the production – completion expected by the end of 2021

CURRENT ATLAS DETECTOR



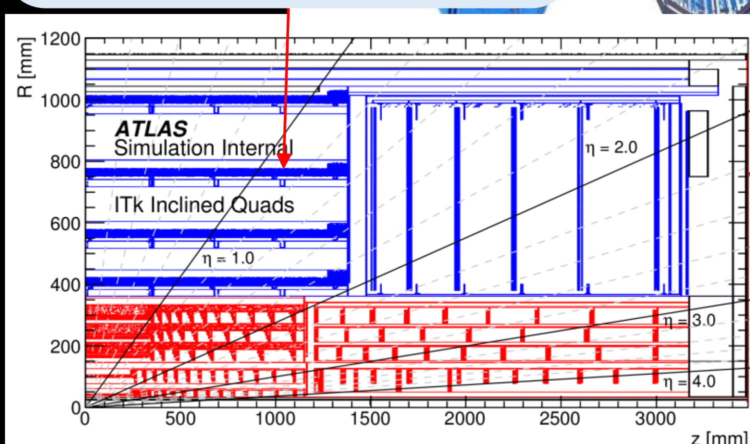
- Critical to maintain or even improve the (sub-)detectors performance under the much harsher HL-LHC collision environment, e.g. radiation damage and high pileup, and maximize the physics potential

Our Involvements



Muon Detector Upgrade:
MDT detector, readout electronics
(USTC, SDU and SJTU)

Inner Tracker (ITk) Strip:
Readout ASIC design;
Barrel module production
(IHEP & Tsinghua)

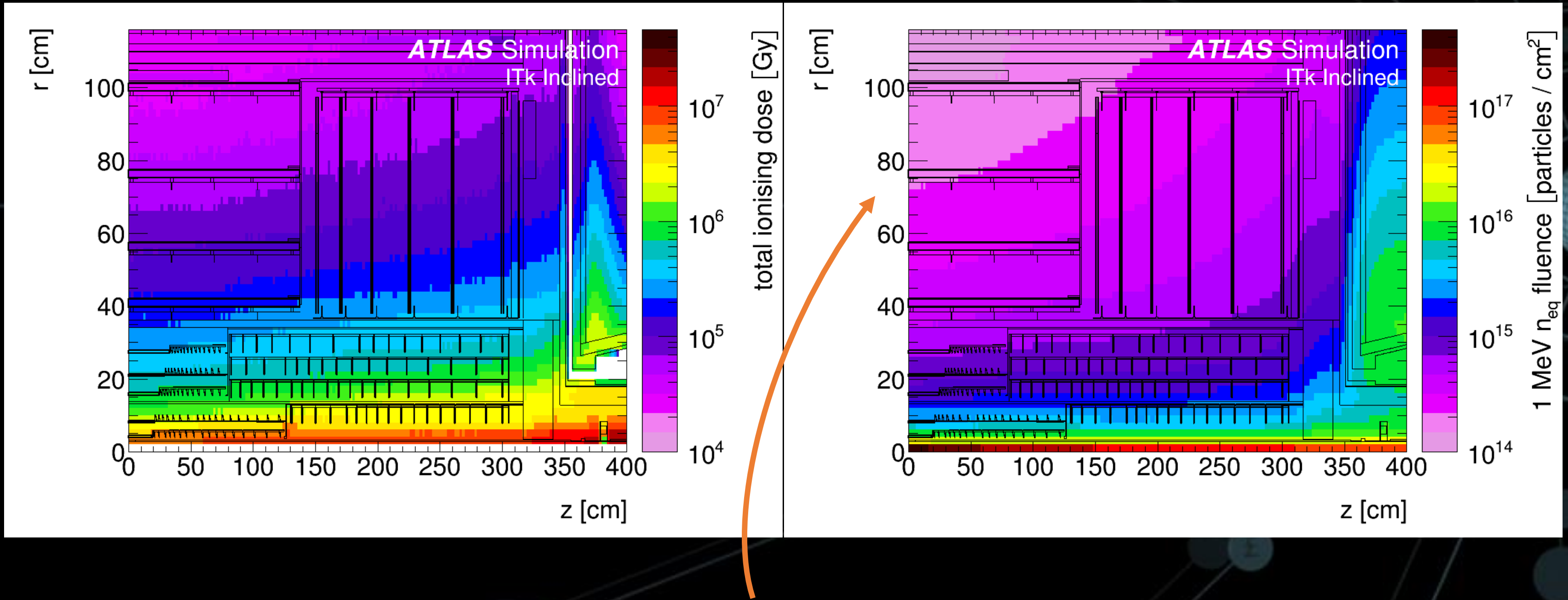


High Granularity Timing Detector (HGTD):
Sensor design and characterization; *module and stave construction*

New Small Wheel (Phase I):
TGCs detector (SDU), Readout electronics (USTC)

Inner Tracker

- To replace the current Inner Detector (ID) with the full silicon Inner Tracker (ITk) → state-of-the-art silicon detector technologies



- We contribute to the outer tracker (ITk-Strip), in particular production of barrel modules.

ITk-Strip Activities

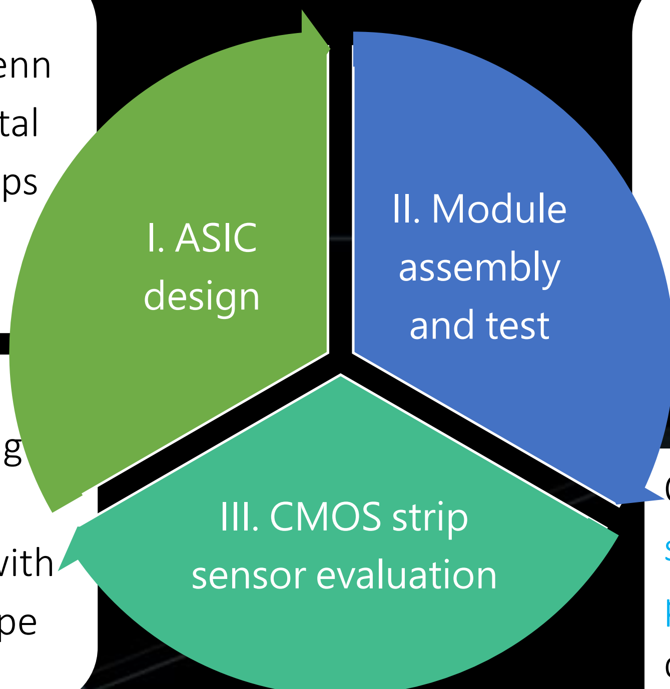
- Committed to deliver to ATLAS 1,000 barrel modules (installed), which account for ~10% of the total barrel modules; Interim MoU to be signed

- **Rad-hard ASIC design:**

In collaboration with CERN/UPenn to design and verify critical digital blocks; close-to-final design chips back from foundry; validation work ongoing at RAL;

- **Novel technology R&D**

CMOS strip sensors as promising candidate for future larger area tracker; In close collaboration with SLAC/UCSC to evaluate prototype sensor performance



- **Ultimate commitment:**

In close collaboration with RAL to define the critical QA/QC steps for module production; completed thermal-mechanical, electrical modules; irradiation and test beam

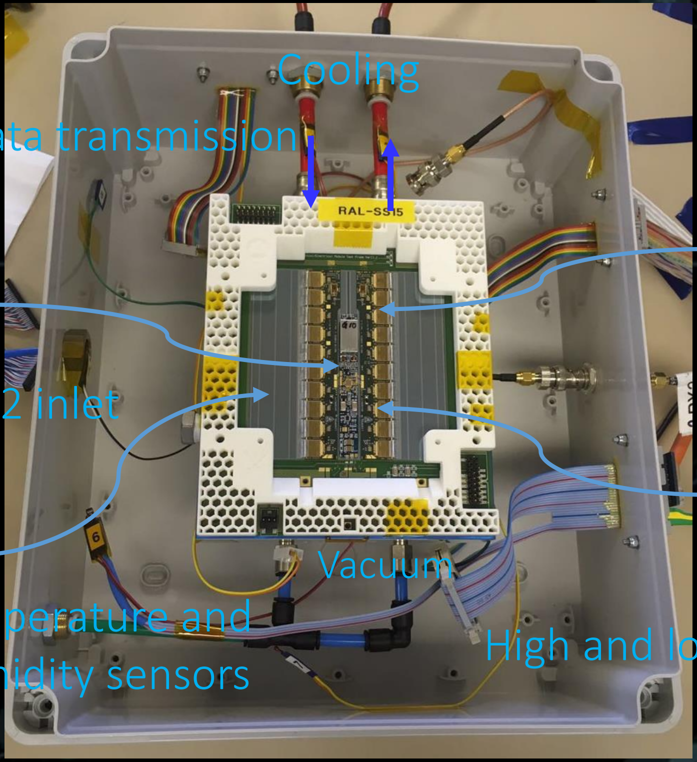
Q3 2019 pre-production and site qualification, followed by production between 2021-2023; dedicated clean almost ready

- Extending activities to wafer probing/module loading (RAL), and detector integration, installation, commissioning and operation (CERN).

BARREL MODULE

- Electrical barrel module assembled (ASIC to hybrid, hybrid/power board to sensor gluing, and wire-bonding >5000 bonds) and fully tested

Chinese colleagues based at RAL~ 2FTE



Powering control and monitor、DC-DC、HV-Mux

HPK strip sensor

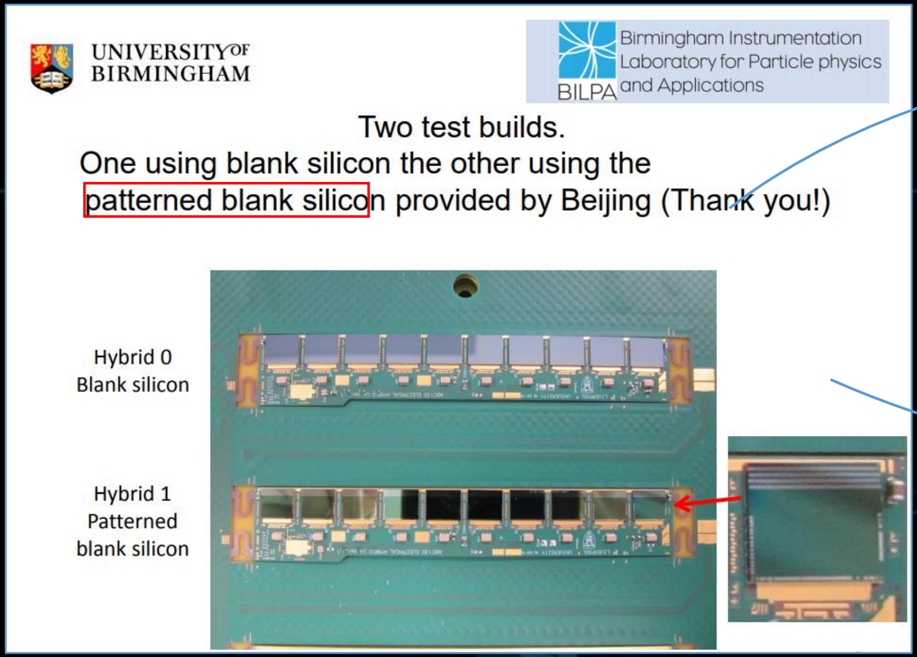
Hybrid controller ASIC (HCC130/STAR)

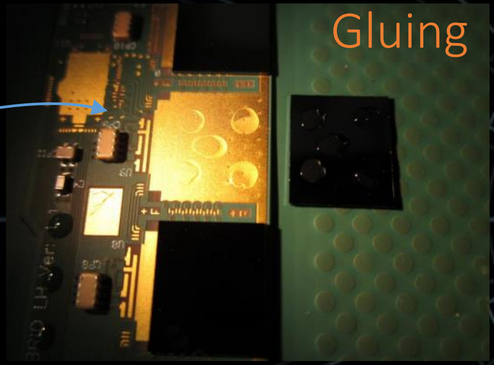
FE readout ASIC (ABC130/STAR)

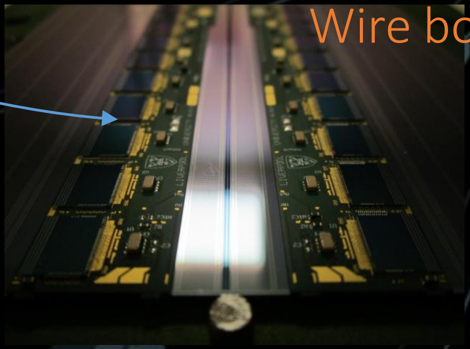
- Plan to produce the first electrical module in the new IHEP clean room before the Chinese New Year … STAY TUNED

Learning the Tricks

- Patterned silicon ASICs fabricated at IME and distributed for ASIC to hybrid gluing practice and parameter tuning for ASIC to hybrid and ASIC to sensor wire bonding → cost effective for detector prototyping





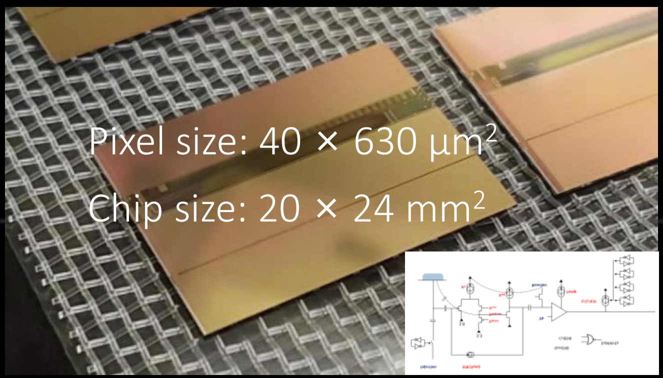


- Colleagues on one satellite-based experiment adopted the same idea for their silicon detector R&D

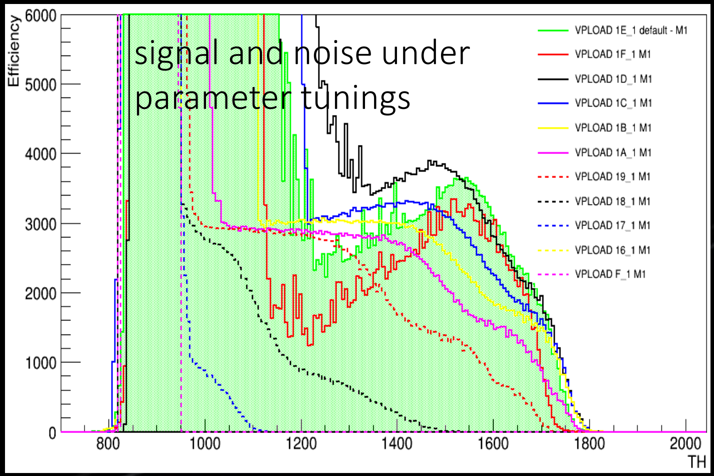
CMOS Strip Sensor

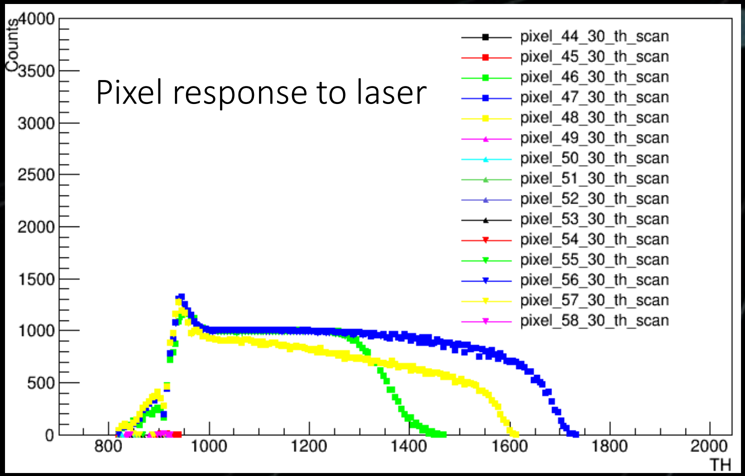
- Sensing element and readout electronics integrated on the same silicon substrate → high resolution, low power consumption, low material …

CHESS (CMOS HV Evaluation for Strip Sensors)



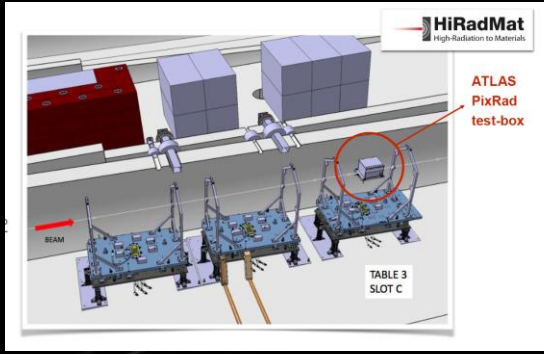
- Charge injection to search for the working parameters for the imperfect in-pixel circuitry
- Test system upgrade (cooling, mechanical support, external source) and improved firmware/software
- Observed reasonable pixel response to laser and to tune further the parameters → *test beam*

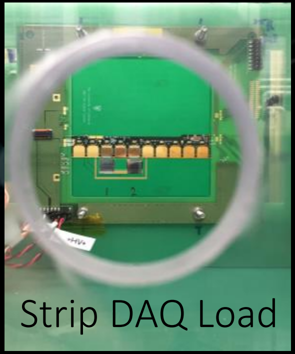


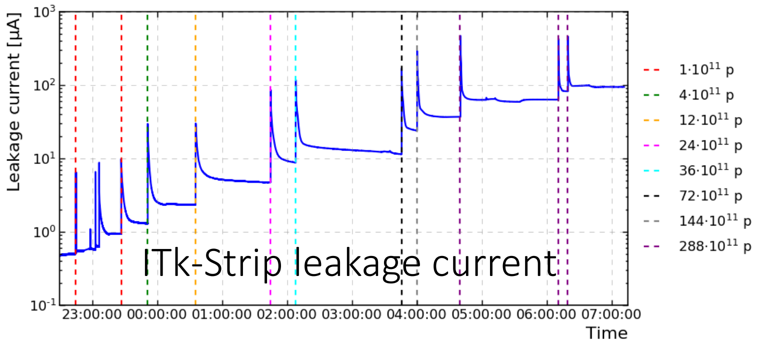


Damage induced by fast extracted proton beam

- ATLAS silicon tracker detectors designed to sustain high integrated dose over several years of operation . It is also critical to study effects of accidental beam-loss scenarios for upgraded ATLAS tracking detectors.
  - Provide a realistic estimate of the damage threshold for sensors and electronics;
  - Evaluate the performance degradation due to the radiation damage
- Two beam tests performed in 2017/18 @ HiRadMat facility at CERN which is able to provide high-intensity pulsed beam.
  - IHEP contributes to the experimental setup, installation, data taking and data analysis. *More details in Claudia's talk*
  - Results already presented in several conferences: HSTD11, Vertex2018, Pixel2018

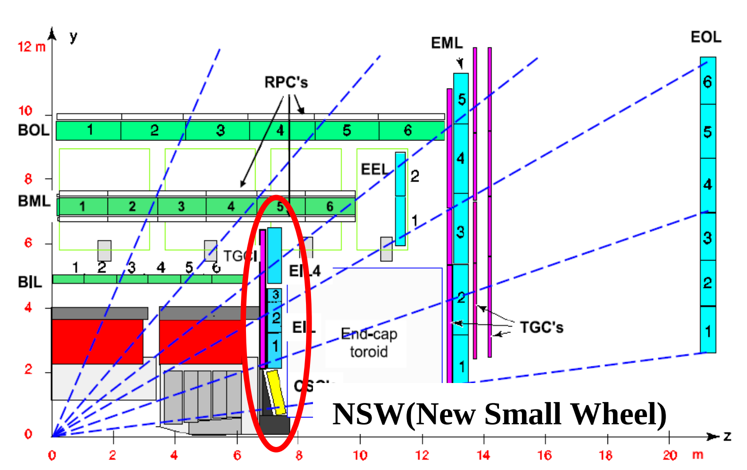




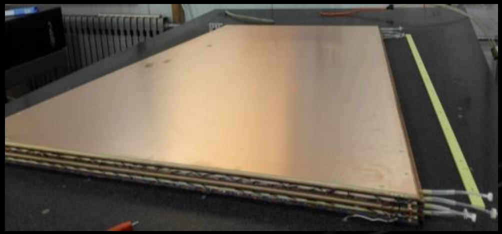


Muon Detector Upgrades

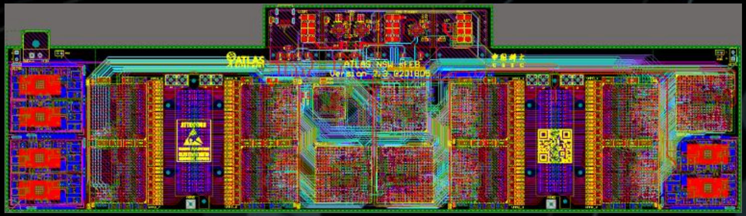
- Contributions to Muon New Small Wheel (Phase I): 128 sTGC QS2 chambers (SDU) + 1840 Front-end readout (FEB) boards (USTC)



- sTGC mass production @ SDU
  - 10% of chambers made and passed quality tests
  - All China chambers expected to be ready by the mid of 2019

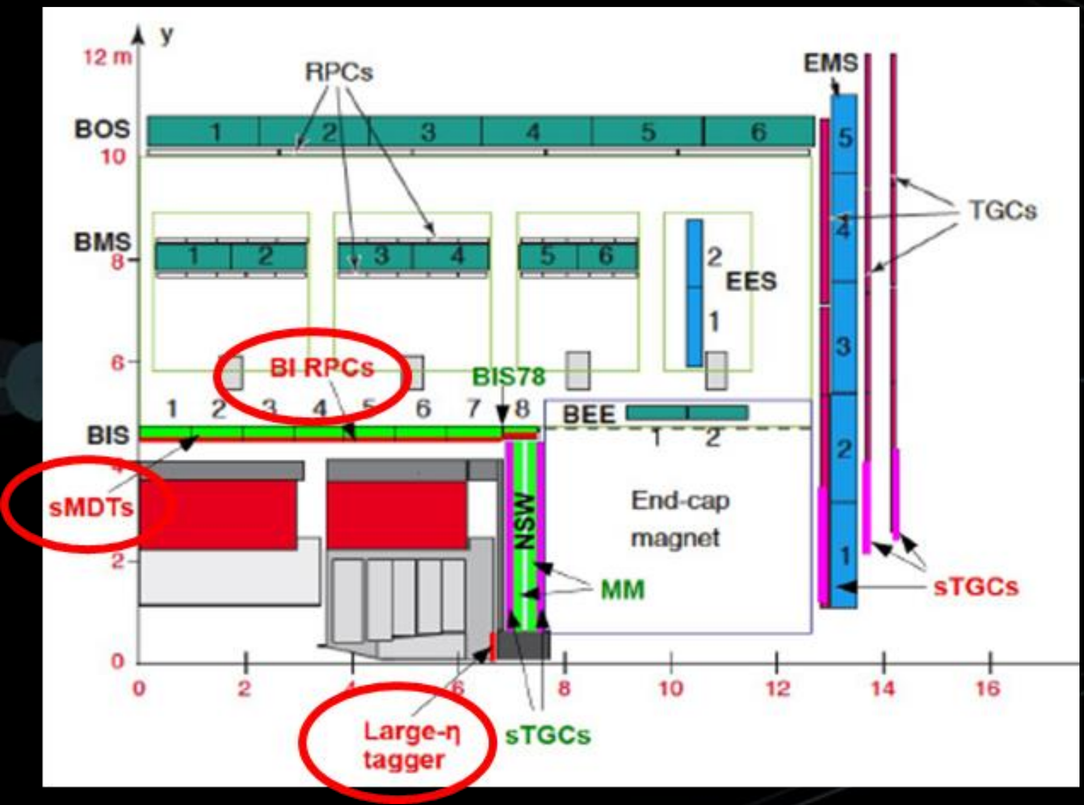


- FEB design and production @ USTC
  - Version 2.3a proved functional in beam test
  - Final Design Review on 2018.11.20
  - Full FEB mass production on schedule



China's sTGC and FEB productions stay on schedule toward Phase I Installation

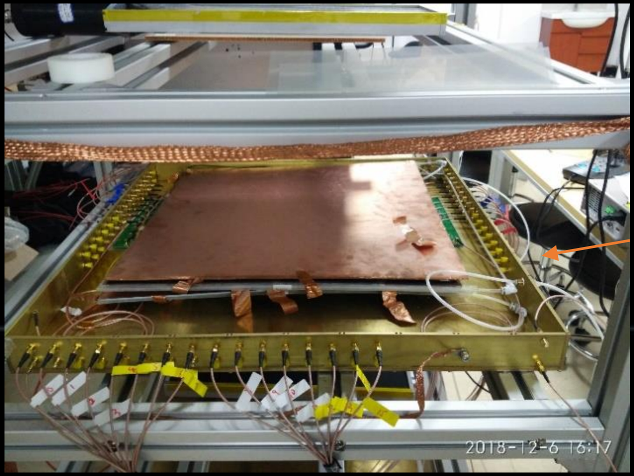
Phase II Muon Upgrades



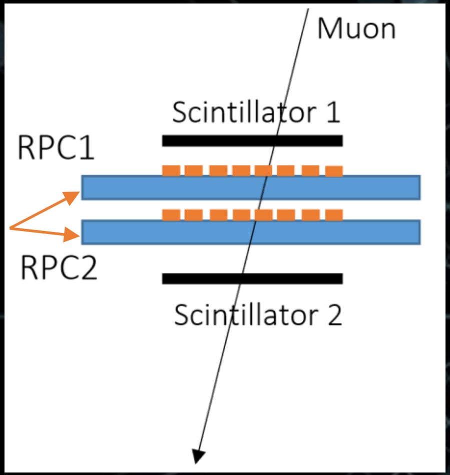
- BI RPC
  - Simulation on signal induction
  - Thin-gap RPC prototype test
  - FE electronics design & test
- MDT TDC ASIC
  - New ASIC with TSMC 130nm
  - Trigger and triggerless mode
- Large-η tagger
  - Multi-gap Resistive GEM
  - DLC resistive layer

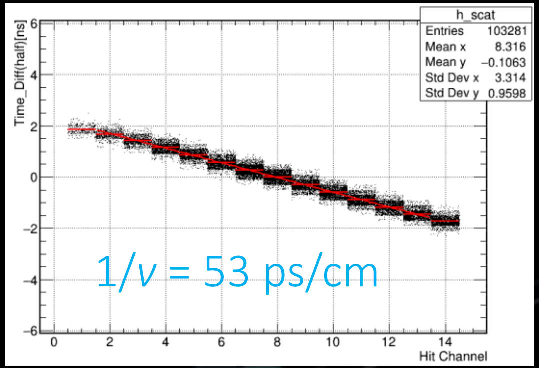
BI RPC Development

- Thin-gap RPC with fast front-end electronics allows high rate data-taking

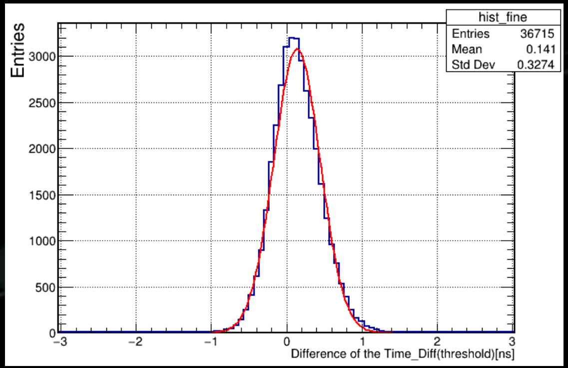


RPC prototypes with two-end readout under test with cosmic rays

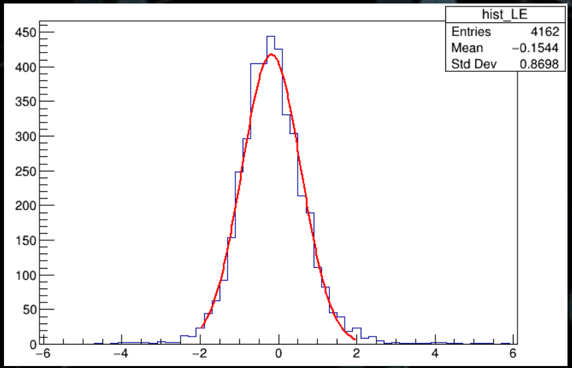




Transmission speed

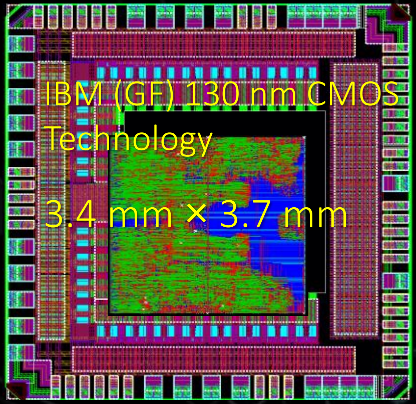


Spatial resolution: ~ 2 cm

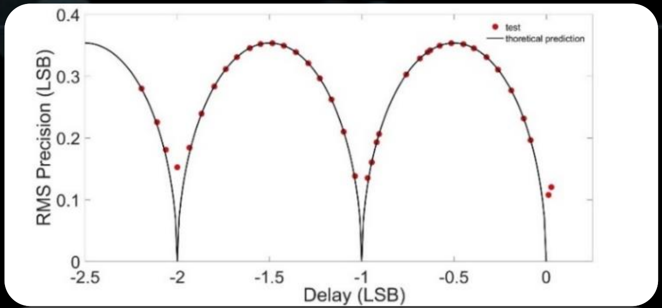


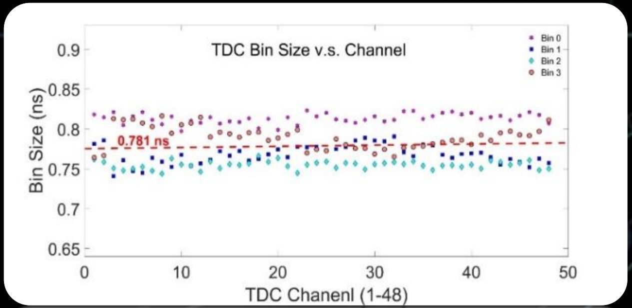
Time resolution: ~ 500 ps

MDT TDC Design



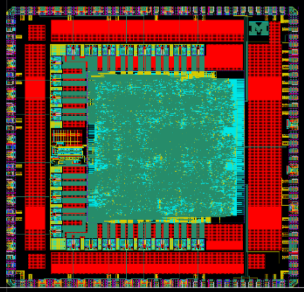
- MDT TDC ASIC features:
  - Time digitization based on Multiphase clock interpolation
  - Compatible with trigger/triggerless data readout mode
  - High speed serial data transfer interface
- Design and testing of TDC V1

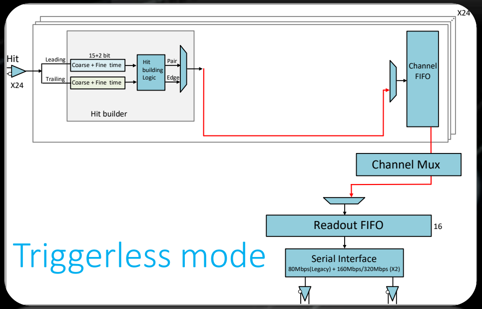




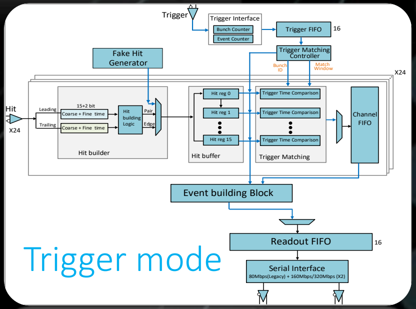
- Design and testing TDC V2

Logic design compatible with both trigger and triggerless data readout mode





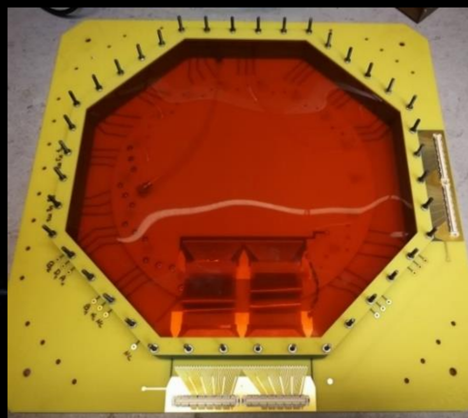
Triggerless mode

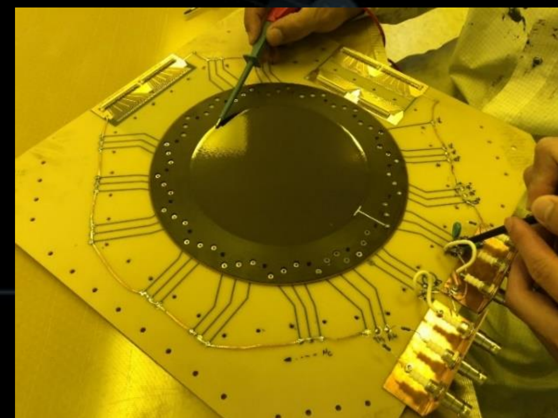


Trigger mode

MULTI-GAP RESISTIVE GEM

- Multi-gap Resistive GEM with Diamond Like Carbon (DLC) resistive layer aimed for the large-η muon tagger



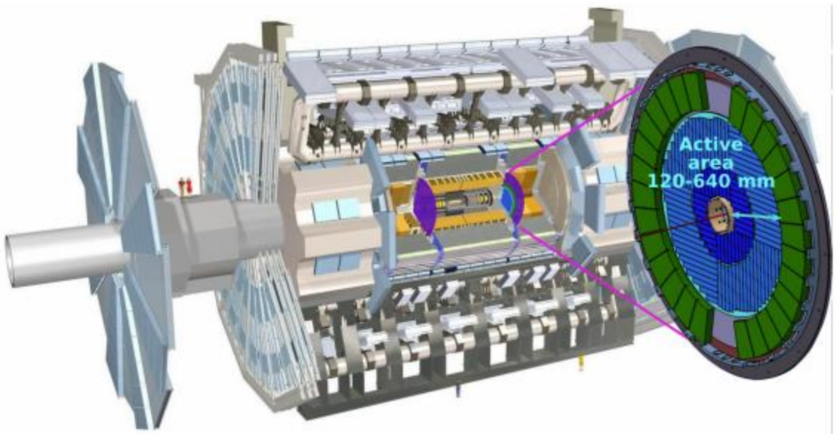


GEM built with resistive layers, Prototype GEM with 4 gas gaps

Detector optimized and under test, further R&D toward more gas gaps

High Granularity Timing Detector

- Using timing information to reject pileup background; significant impact on several physics cases, e.g. VBF Higgs and weak mixing angle measurement



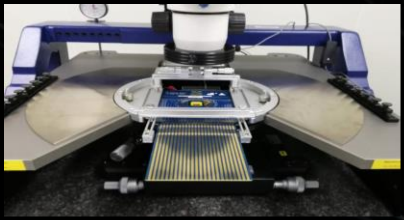
Pseudorapidity coverage: $2.4<|\eta|<4.0$
Radial extension: 12 cm < R < 64 cm
z position: 3.5 m
Thickness in z: 7.5cm
2 double planar layers per endcap

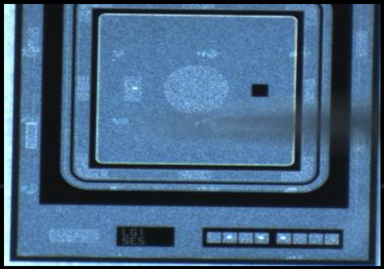
Requirements:
- Excellent time resolution (30ps/track), flat in η
- radiation-hard (up to $3.7\text{x}10^{15}\ n_{eq}/cm^2$ and 4.1MGy)
- Low occupancy

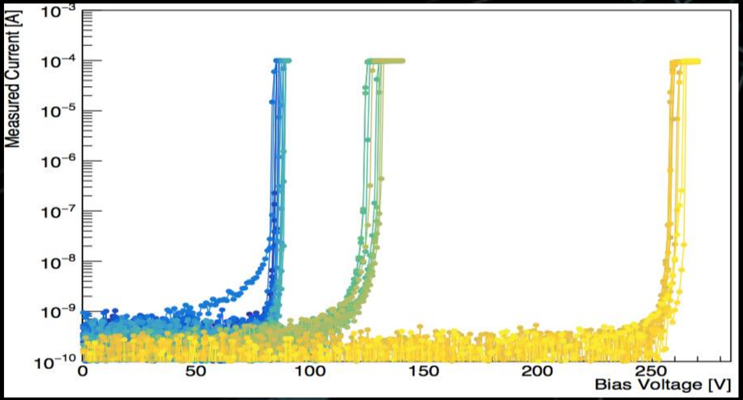
- **Low Gain Avalanche Detector sensors (LGADs)**
- **Pixel size: *1.3x1.3* mm²**
  - Occupancy lower than 10%, low electronic noise
- **2 double planar layers per endcap**
  - Average number of hits per track = 2-3, depending on R

HGTD Sensor Test

- Sensor Characterizations for TDR
- Two Leading tasks:
  - I-V, C-V: “single” probes: singles, 2x2 arrays (cold)
  - I-V: Probe card: 5x5 arrays
- Four Contributing tasks:
  - TCT with Laser: 2x2 arrays
  - I-V: Probe card: 15x15 arrays
  - I-V: Breaking (X-rays)
  - ASIC Read-out
- Test beam participation
  - Participated test beam at CERN in October with shifts
  - Contributing to the data analysis

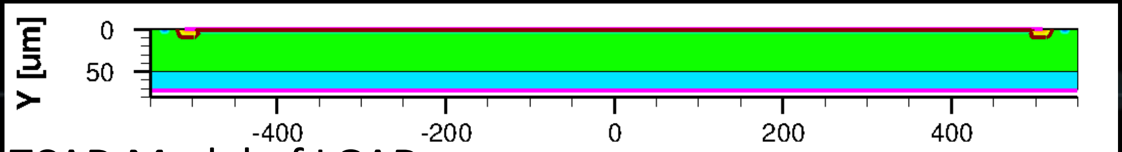






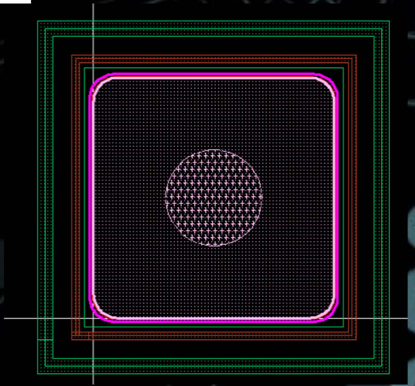
LGAD SENSOR DESIGN

- Sensor simulation
  - Build TCAD simulation model
  - Adjust the structure parameter and doping profile of the model, simulate the I-V, Gain and signal performance
  - Make sure each process of sensor fabrication



TCAD Model of LGAD sensor

- Sensor trial fabrication
  - Wafers of high resistivity: 4 inch, >10kΩ㎝ FZ, 5kΩcm FZ
  - Find foundry in China, adjust doping process
  - Draw layout of the sensor (4 inch wafer first)
  - Almost ready to manufacture LGAD sensor


Single sensor layout

Interested in future module construction in China
--> *Bump bonding of sensor to ASIC*

Summary and Outlook

- ATLAS detector upgrades to maintain or improve detector performance under the harsh (HL-)LHC collision environment;

- We are actively involved in several critical upgrade projects and promise/commit to their construction
  - *Inner Tracker Strip, Muon Upgrades, HGTD*

Thank You!

Why Participating in Upgrades

- This would allow us to continue exploring the rich physics program and sharing the outstanding achievements at the energy frontier;
- Upgrade projects require many state-of-the-art detector and electronics technologies, some of which might be under strict export control, e.g. radiation hard ASICs. Active participation in (construction commitments) upgrade projects would not only help alleviating relevant export control issues, but also bring in expertise and new ideas that will eventually boost future domestic projects in HEP and beyond.
  1. *High resolution and radiation hard silicon detectors*
  2. *Novel large-area muon detectors with high rate and efficiency*
  3. *High granularity calorimeter with timing*
  4. *High density and radiation hard ASICs*
  5. *…*