MPP Annual Project Review

19-th December 2017

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

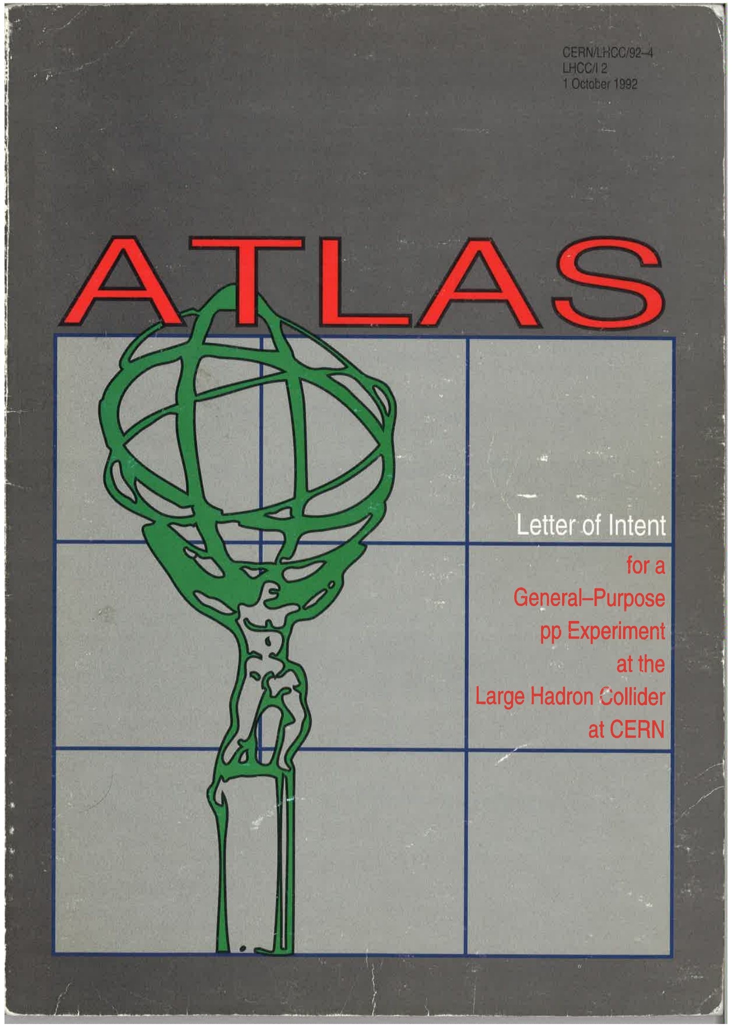
ATLAS: Past, Present and Future

25 years 1992-2017 ATLAS EXPERIMENT

Andrey Kiryunin

on behalf of the MPP ATLAS group

ATLAS — 25 Years



Max-Planck-Institut für Physik, Munich, Germany

M.Aderholz, W.Blum, H.Brettel, F.Dydak*, J.Fent, A.Halley, K.Jakobs, C.Kiesling, H.Kroha, E.Lorenz, G.Luetjens, G.Lutz, H.Oberlack, P.Ribarics, Rainer Richter, Robert Richter, P.Schacht, U.Stiegler, U.Stierlin, R.St.Denis, G.Wolf

Scientific Members of the MPP ATLAS Group (2017)

- **Director:**
  S. Bethke
- **Project leaders:**
  S. Kluth (Computing),
  H. Kroha and S. Kortner (Muon System),
  S. Menke (Calorimetry),
  R. Nisius (Inner Detector)
- **Senior scientists:**
  T. Barillari, A. Kiryunin, O. Kortner,
  H. Oberlack*, R. Richter*, D. Salihagic,
  P. Schacht*, S. Stonjek,
  H. von der Schmitt*
- **Postdocs:**
  A. Knue, A. La Rosa, A. Macchiolo,
  T. McCarthy, F. Müller, B. Pearson,
  P. Rieck, M. Spalla, E. Takasugi,
  A. Verbytskyi, Z. Zinonos
- **Guest scientists:**
  S. Abovyan, V. Danielyan, S. Nowak
- **PhD students:**
  J. Beyer, K. Ecker, Ph. Gadow, A. Hönle,
  J. Junggeburth, N. Köhler, D. Krauss,
  S. Maschek, R. Röhrig, N. Savic,
  K. Schmidt-Sommerfeld, L. Scyboz,
  F. Spettel, V. Walbrecht
- **Master students:**
  C. Bruce, M. Chatterjee, J. Graw,
  F. Klimpel, M. Rendel, S. Schulte,
  M. Sinner, C.-F. Strid, R. Taibah
- **Six bachelor students**

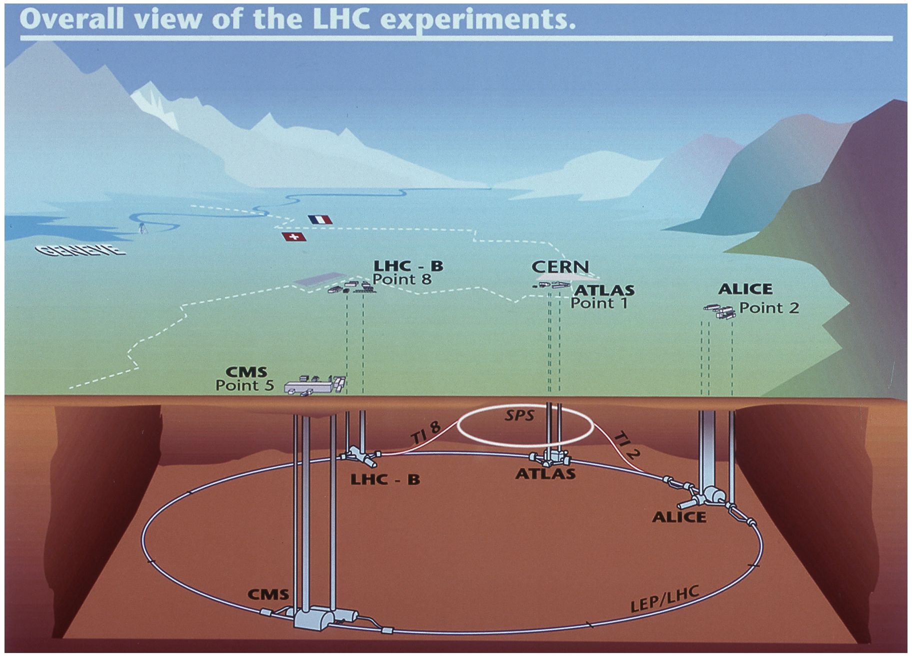
* retired

Many thanks to the technical departments of MPP!

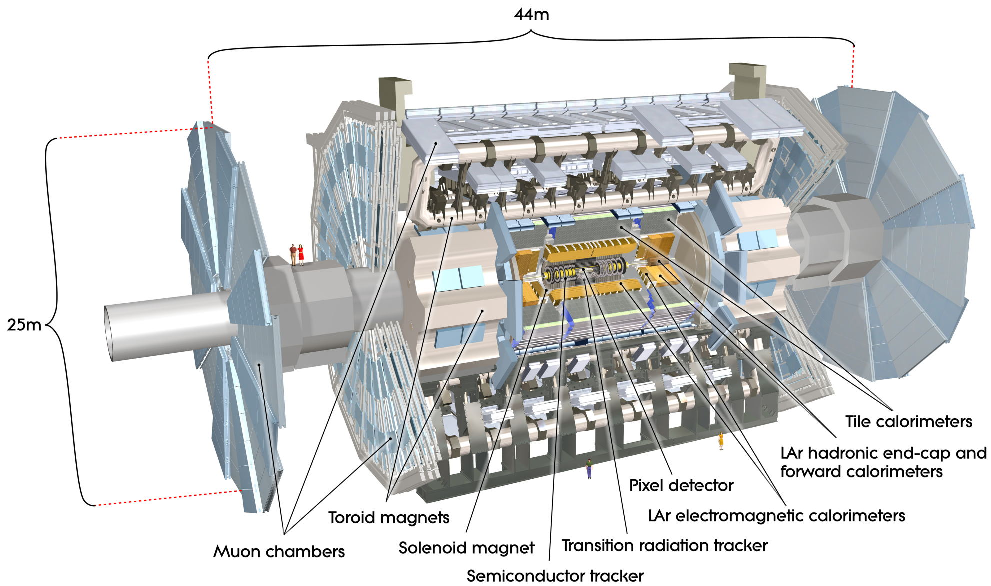
LHC and ATLAS

Large Hadron Collider (LHC)

- Proton-proton (and heavy ion) collider at CERN
- Circular tunnel: 27 km long, 50-175 m deep underground
- Swiss/France border near Geneva
- Four main experiments
- Design energy of pp collisions: $\sqrt{s} = $ **14 TeV**
- Design luminosity: $\mathbf{1 \times 10^{34}\ cm^{-2}s^{-1}}$



A Toroidal LHC Apparatus (ATLAS)



MPP ATLAS contributions:

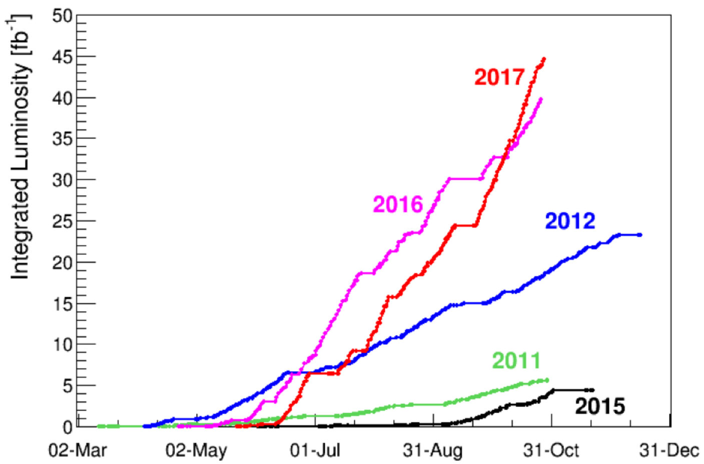
- Muon system
- Liquid argon (LAr) calorimetry
- Inner detector
- Computing and software development
- Physics analysis:
  see talks by **B. Pearson** and **P. Rieck**

LHC and ATLAS Operation in 2017

Very successful year for LHC and experiments

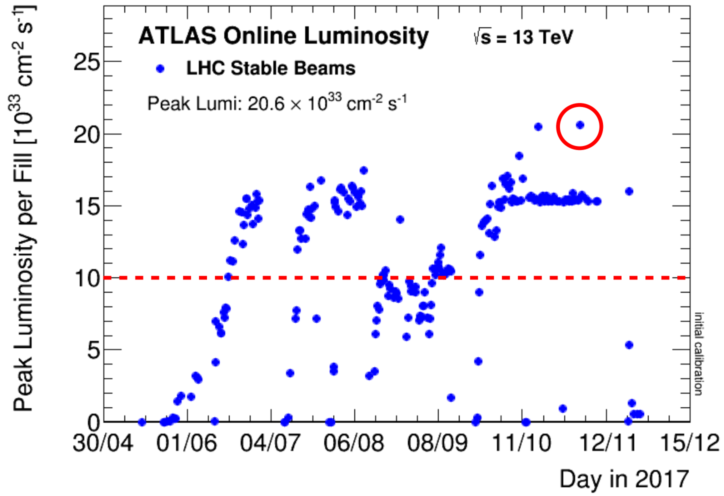
- pp collisions at $\sqrt{s} = 13$ TeV
- The 2017-target of $45\ \mathrm{fb}^{-1}$ was reached and surpassed
- Fastest accumulation of luminosity of all years

LHC integrated luminosity

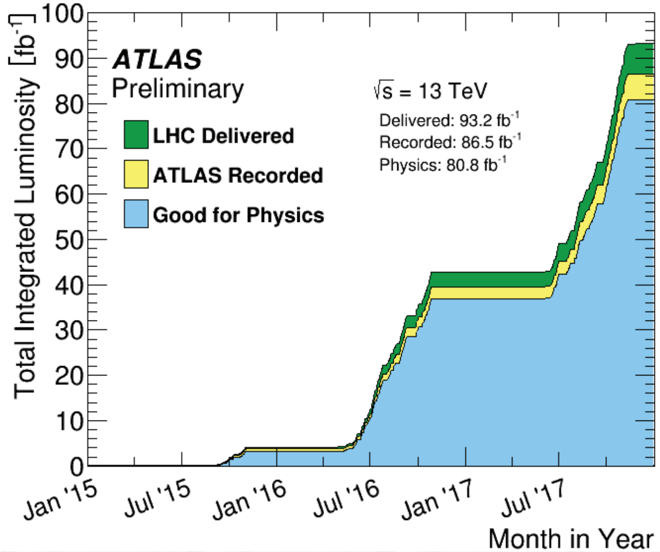


- Records in 2017:
  - peak stable luminosity delivered: $\mathbf{2.06 \times 10^{34}\ cm^{-2}s^{-1}}$
  - maximum average number of collisions per bunch crossing (pileup): **78.6**
- Total luminosity recorded by ATLAS
  - in 2017: $\mathbf{47.1\ fb^{-1}}$
  - at $\sqrt{s} = 13$ TeV (2015-2017): $86.5\ \mathrm{fb}^{-1}$

Peak luminosity in 2017



Total integrated luminosity

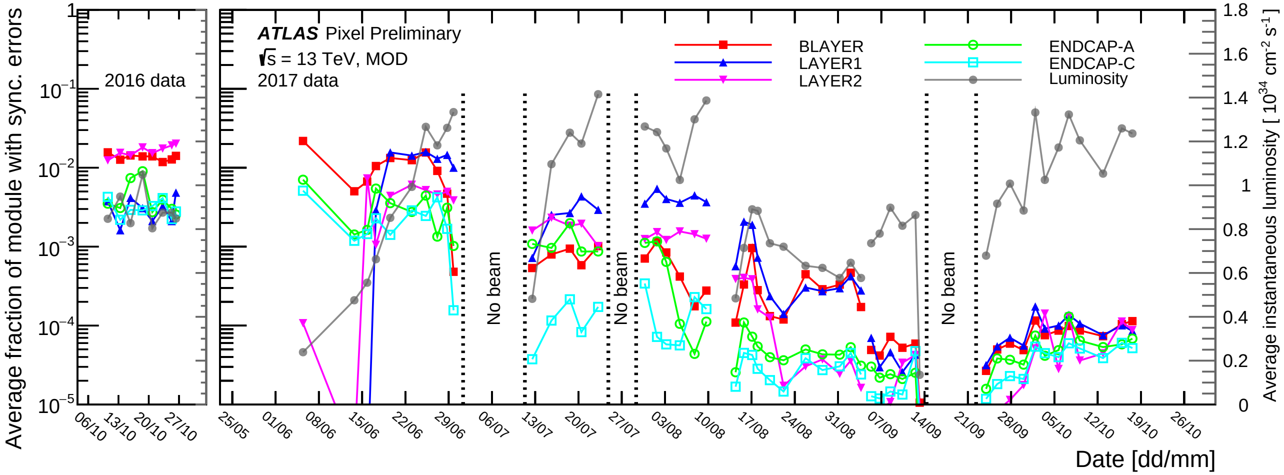


ATLAS Operation and Performance in 2017

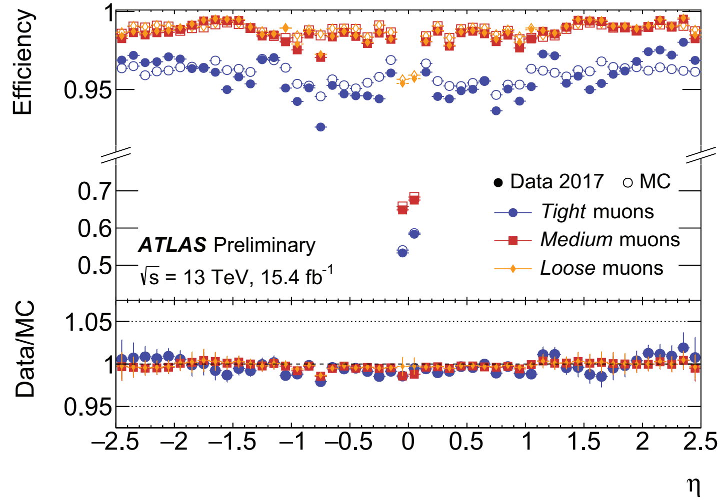
MPP ATLAS team is significantly involved in detector operation and in performance studies

- New muon chambers in operation
- Calibration of the muon system
- Support of low-voltage power supplies for the hadronic endcap calorimeter (HEC)
- Operation of the pixel detector

Average fraction of pixel modules with readout errors

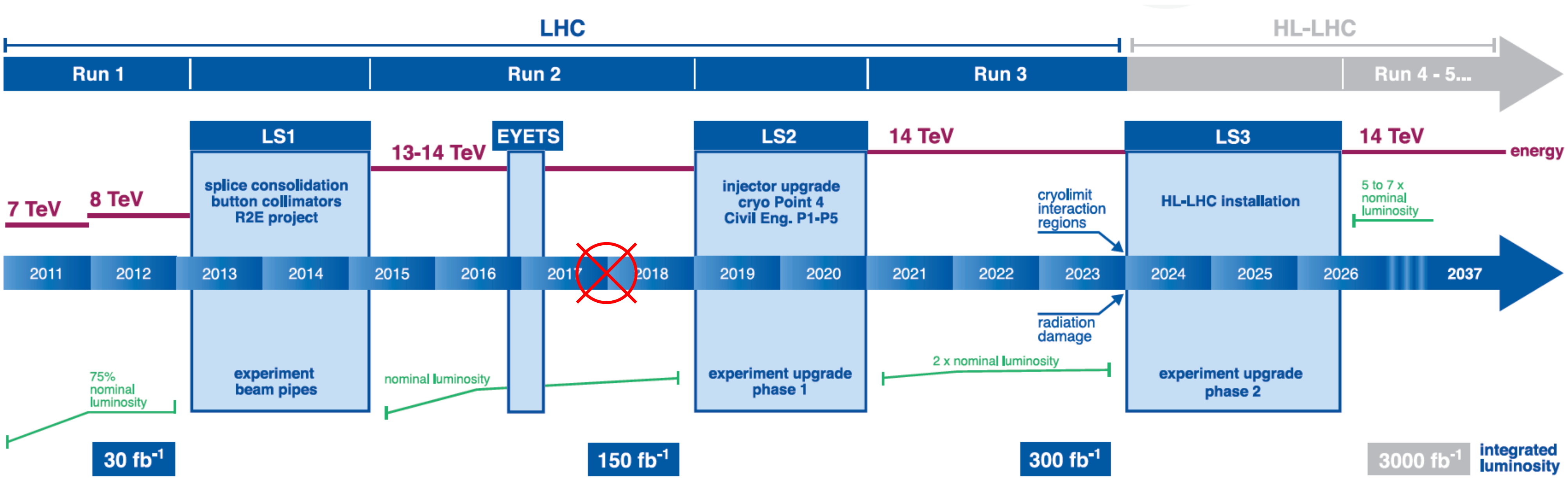


Efficiency of muon reconstruction



- Reconstruction of muons
- τ-lepton energy scale and resolution
- Development of tools for topological clustering, hadronic calibration, pileup suppression

LHC — High-Luminosity LHC Roadmap



- Run 1 (2010-2012): pp collisions at $\sqrt{s} = 7$ and 8 TeV
- Run 2 (2015-2018): pp collisions at $\sqrt{s} = 13$ TeV
- Run 3 (2021-2023): pp collisions at $\sqrt{s} = 14$ TeV
- Three long shutdowns (LS)

- **High-luminosity LHC** (HL-LHC): 2026-...
- Levelled instantaneous luminosity: 5 - 7.5 $\times 10^{34}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Pileup: up to 200 collisions per bunch crossing
- $3\ 000\ \mathrm{fb}^{-1}$ after 10 years of running
- Essential upgrade of the accelerator complex and detectors for HL-LHC (during LS3)

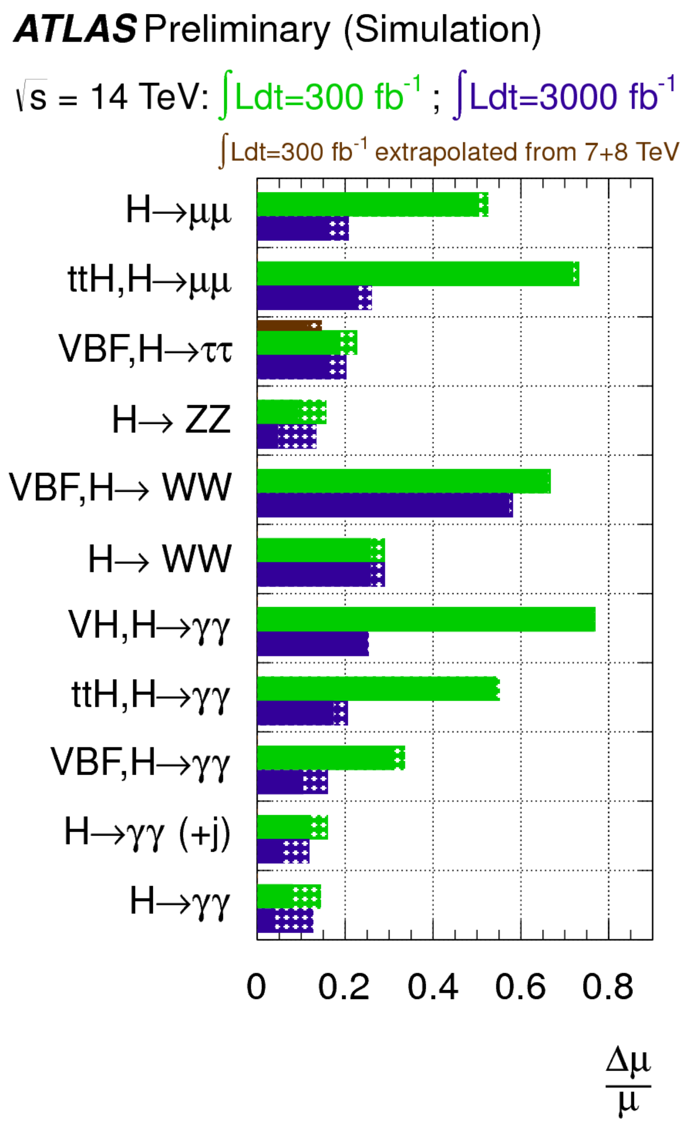
HL-LHC: Physics Motivations

Higgs as a portal to physics beyond the Standard Model (SM)

- Higgs coupling measurements to few percent level and discovery of rare Higgs decays (e.g. $H \to \mu\mu$, $H \to Z\gamma$)
- First constraints on the Higgs self-coupling via Higgs pair production
- Direct search for extensions of the SM Higgs sector (additional Higgs bosons, Higgs interaction with dark matter, exotic Higgs boson decays)

Essentially increased discovery reach for new physics processes

- Significant improvements in the range of SUSY parameters over which a discovery signal could be observed
- Search for dark matter particles
- Search for new heavy resonances in di-jets, di-photons, di-leptons, $t\bar{t}$, di-bosons
- etc.



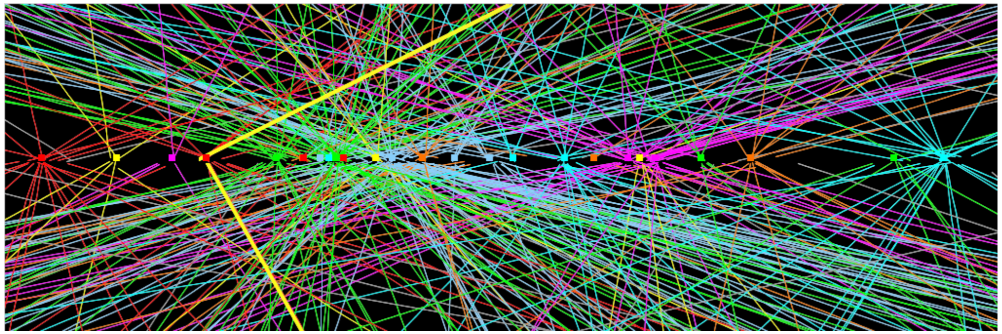
Expected measurement precision on the signal strength

Upgrades for HL-LHC

Detector challenges

- Higher **instantaneous luminosity**:
  - increasing number of interactions per bunch-crossing
  - higher detector occupancy
  - higher trigger rates
- Large **integrated luminosity**:
  - increasing radiation damage
  - increasing activation of materials
- Aging of detector components

A candidate $Z \to \mu\mu$ event with 25 reconstructed vertices



Upgrade projects at MPP

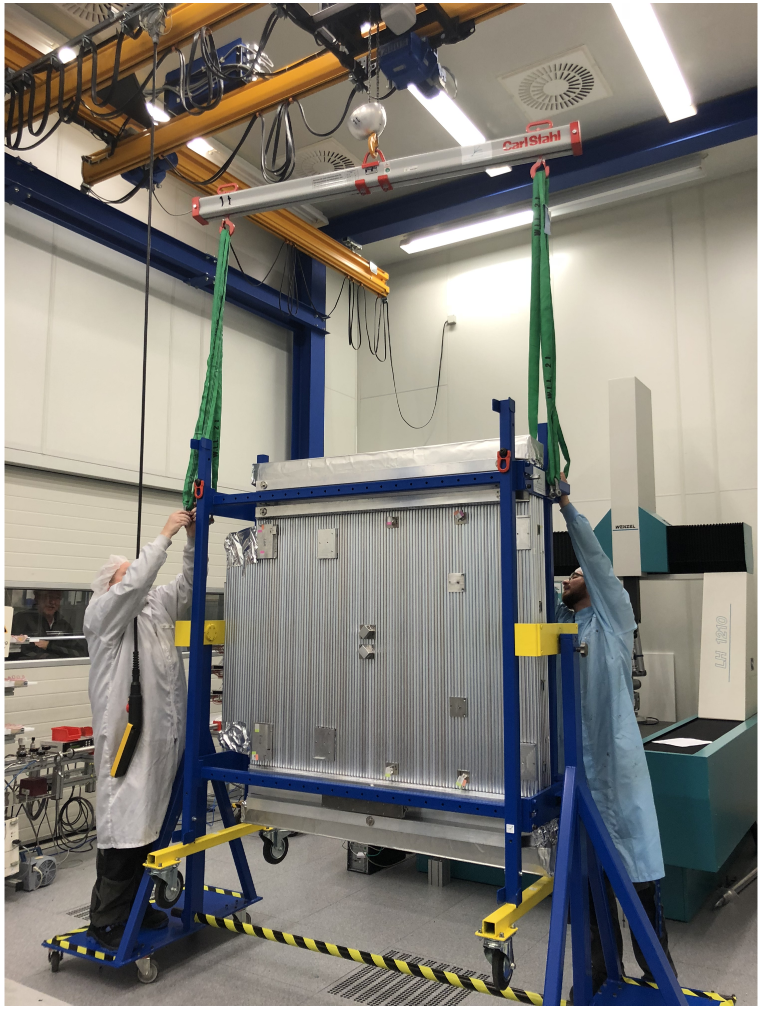
- **Muon system**
  - New small-diameter muon drift tube chambers and new thin-gap resistive plate chambers in the inner barrel region
  - Muon-track trigger
  - New readout electronics
- **LAr calorimeter**
  - HEC front-end electronics
  - HEC low-voltage power supplies
  - Treatment of signals from forward calorimeter at high luminosities
- **Inner tracker**
  - Planar pixel detector
  - Cooling system

Upgrade: Muon System

Small-diameter Muon Drift Tube (sMDT) chambers

- sMDT chambers in the inner barrel region to improve the muon acceptance and momentum resolution
- Design and construction at MPP
- In comparison with standard MDT:
  - diameter 15 mm (instead of 30 mm)
  - $\mathbf{5\ \mu m}$ sense wire positioning accuracy (instead of $20\ \mu\text{m}$) — **world record**
  - 10 times higher rate capability
  - much shorter assembly time

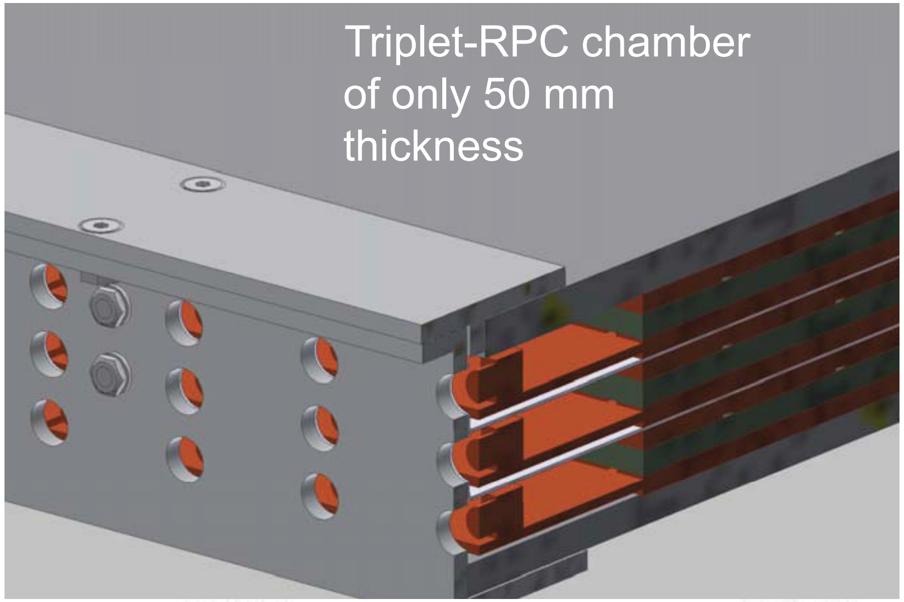
First of 16 new sMDT chamber assembled in December 2017



Upgrade: Muon System

Thin-gap Resistive Plate Chambers (RPC)

- New thin-gap RPCs for barrel inner layer to improve muon trigger efficiency
- In comparison with present RPCs:
  - twice smaller gas gap and electrode thickness
  - 10 times better high-rate capability
  - much better time resolution
- Thinner gap allows extending the **lifetime** at HL-LHC by a **factor of 10**
- Challenging mechanical design (by MPP) to fit three gas gaps into 50 mm thick package
- Part of EU AIDA 2020 project (gas detectors development)
- Work on industrialisation of RPC gas gap fabrication
- Successful beam tests of a prototype chamber in November 2017

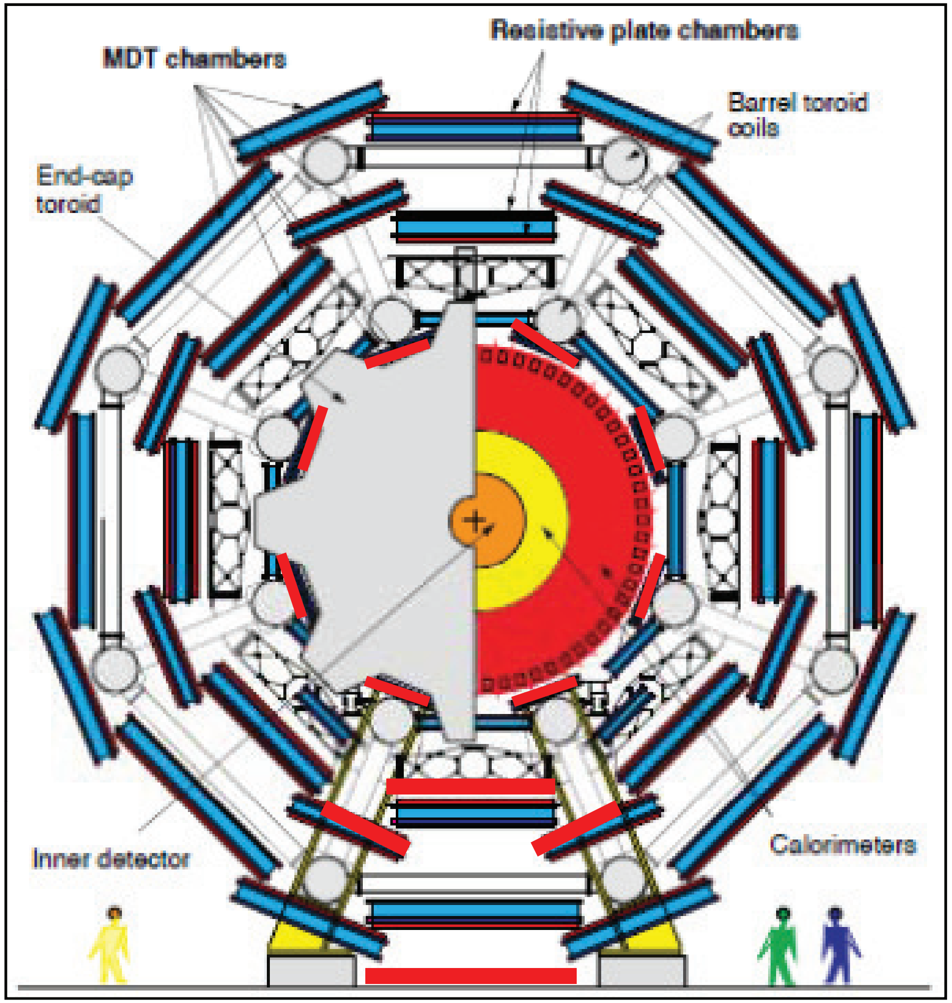


Upgrade: Muon System

Installation of chambers

- 2014 (long shutdown 1):
  Two sMDT chambers to improve the muon momentum resolution in the bottom barrel sector
- January-March 2017:
  12 new sMDT chambers to improve the muon momentum resolution in the regions of the detector feet
- 2019-2020 (long shutdown 2):
  16 new (sMDT + RPC) chambers to improve the trigger selectivity and the rate capability in the barrel inner layer

  Pilot project for upgrade for HL-LHC
- 2024-2026 (long shutdown 3):
  96 sMDT + 236 RPC chambers replacing the barrel inner layer to increase the robustness and acceptance of the barrel muon trigger

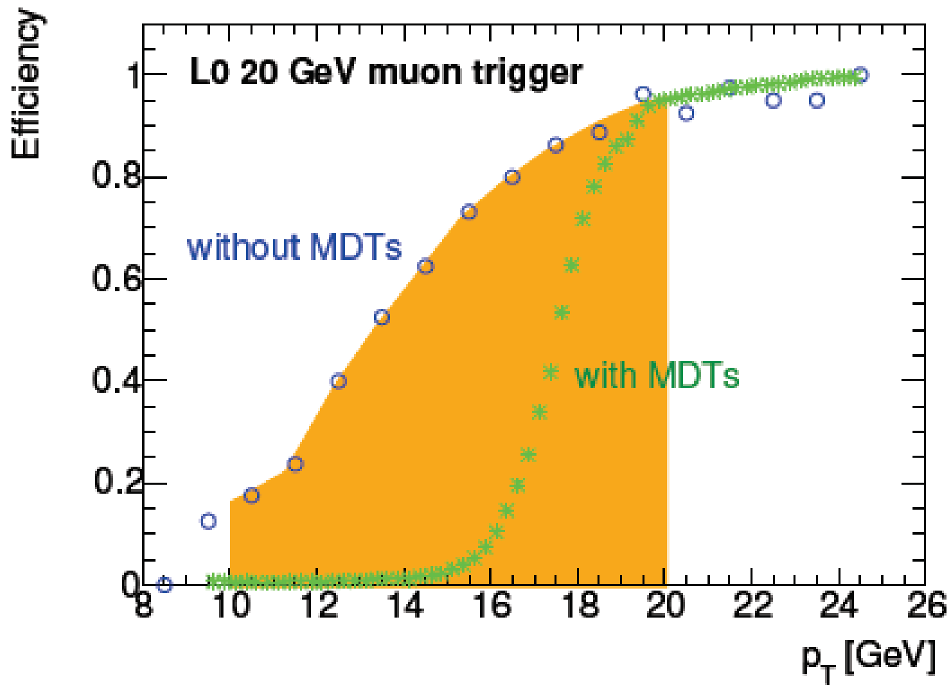


Work sharing between MPP, University of Michigan, IHEP Protvino and industry

Upgrade: Muon System

Muon-track trigger

- ATLAS trigger upgrade for HL-LHC:
  First-level trigger with **1 MHz trigger rate** and **6 μs total latency** from muon system and calorimeters
- Improvement of the spatial and momentum resolution of the first-level muon trigger by a factor of 10 to the current high-level trigger resolution using fast track reconstruction in the sMDT/MDT precision muon tracking chambers
- Sharpening of the single-muon trigger threshold to reduce the muon trigger rate due to low p_T muons by a factor of 3.5

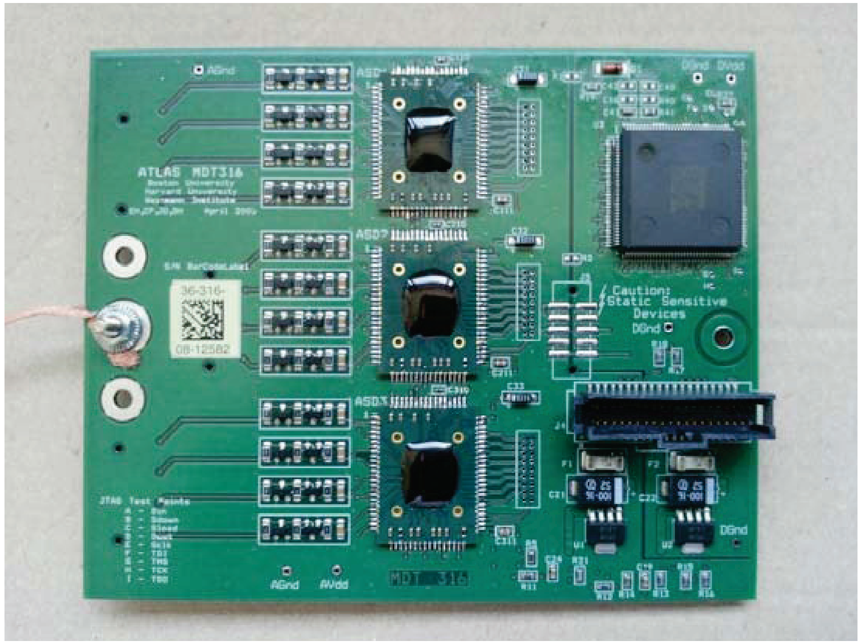


- Development of the fast (**3.6 ns !**) muon tracking algorithm and implementation on RISC processors by MPP
- Trigger electronics demonstration chain (developed at MPP): tested on a MDT chamber in the muon beam at CERN under the high background irradiation conditions

Upgrade: Muon System

New MDT front-end electronics

- Complete replacement of the MDT readout electronics necessary for HL-LHC
  - to cope with up to 1 MHz trigger rate (increased bandwidth)
  - to implement new continuous, triggerless drift tube readout for MDT-based first-level muon-track trigger



- New MDT readout electronics:
  - MDT front-end board design by MPP
  - Amplifier-Shaper-Discriminator (ASD) chips
    - ∗ final submission in August 2017
    - ∗ prototype chips arrived at MPP for evaluation
  - TDC chip for drift time measurements (design started 2017)

Upgrade: Calorimeter Electronics

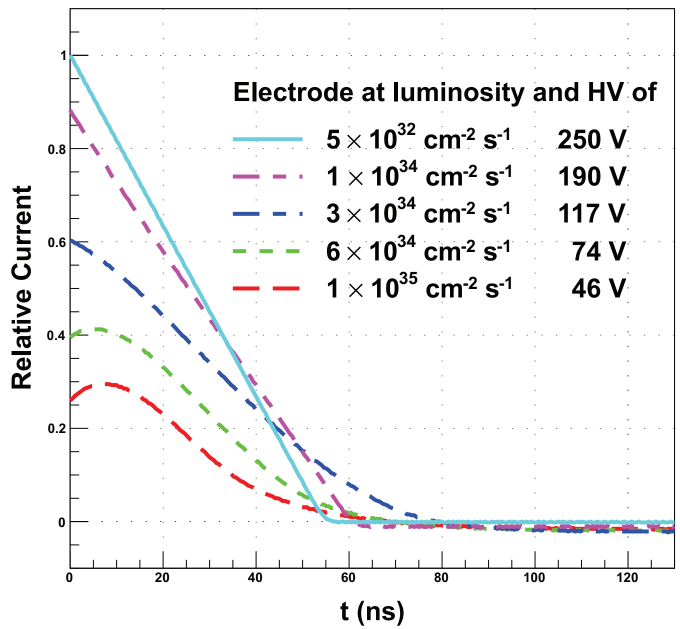
Front-end electronics for Hadronic Endcap Calorimeter (HEC)

- HEC cold electronics will remain unchanged
- The new LAr read-out electronics (ASICs with pre-amplification and shaping) need special adjustments for the HEC (signal polarity, timing, gain)
- MPP calorimetry group is involved in optimization of the front-end electronics, based on detailed simulations

Signal pulse in Forward Calorimeter (FCal)

- FCal modules will not be upgraded
- Degradation of FCal pulses (magnitude and shape) is expected at luminosities above $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - HV drop due to increased current in LAr gaps and 1 MOhm protection resistors
  - space charge due to ion-buildup
- Special runs: lower HV on FCal modules in the beginning of the fills
  - HV drop is already observed
  - not enough data to analyse shapes

FCal pulse degradation

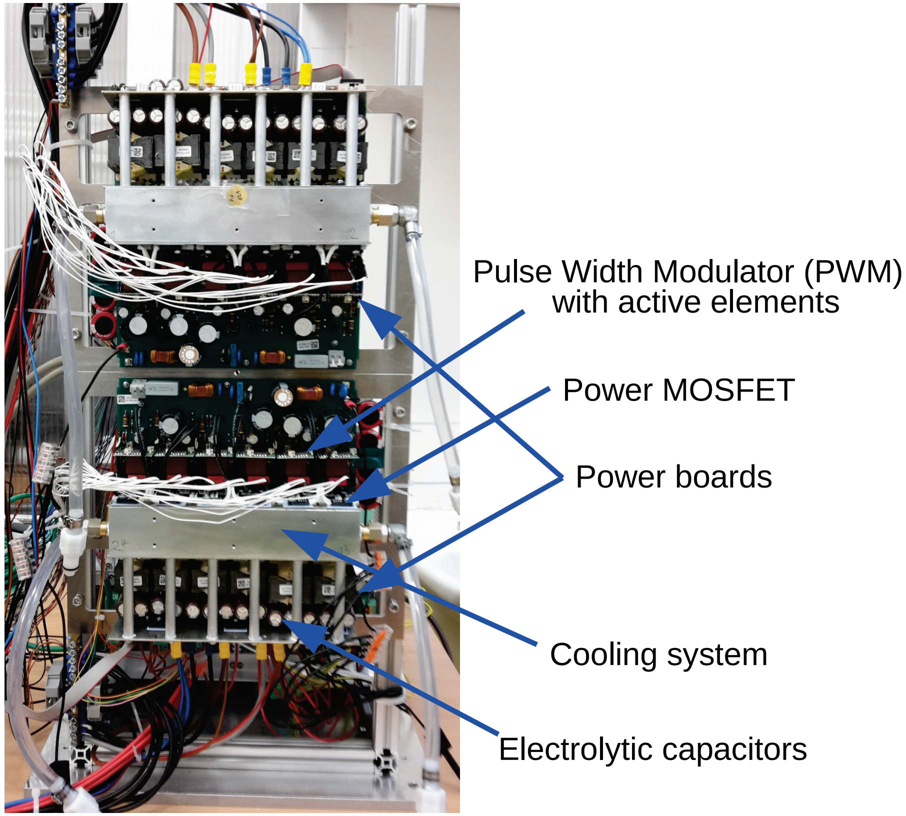


Upgrade: Calorimeter Electronics

HEC Low-Voltage Power Supplies (LVPS)

- LVPS provide voltages needed for HEC cold electronics
- One LVPS box serves a quadrant of the endcap
- New HEC LVPS are needed for HL-LHC:
  - aging of many components
  - new radiation conditions
- New HEC LVPS can largely follow the design of the current HEC LVPS
- Alternative positions, with better accessibility with ATLAS in closed state, will be further investigated
- Individual radiation-hard components are selected and tested by MPP
- A set of prototype power boards with DC/DC converters has been already produced by Wiener and is under tests by MPP team

Set of power boards for neutron tests

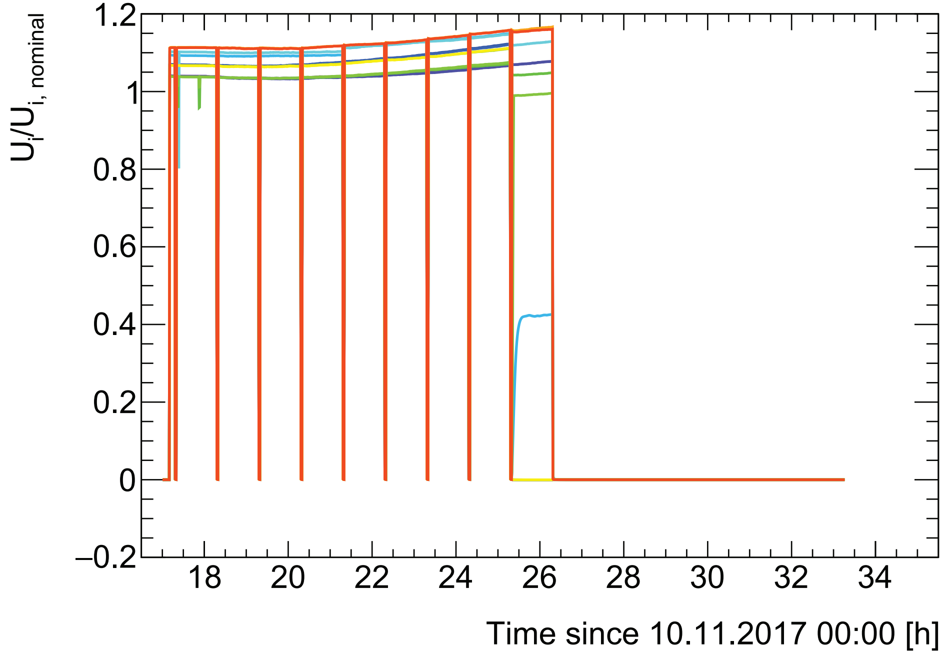


Upgrade: Calorimeter Electronics

Neutron tests of HEC LVPS

- Two prototype power boards from Wiener were tested under Neutron Irradiation at Rez (by Prague) in November 2017
- Power boards were power-cycled every hour with a down time of ∼2 min before power-up
- Last successful power cycle of all DC/DC converters was at 24.3 h
- Corresponding "survival" fluence = $5.9 \times 10^{12}\ \mathrm{n_{eq}/cm^2}$
- Each power-cycle interval at Rez corresponds to $4\ 000\ \mathrm{fb}^{-1}$
- Obtained results show that prototype power boards are radiation hard with total **safety factor** at least **8**

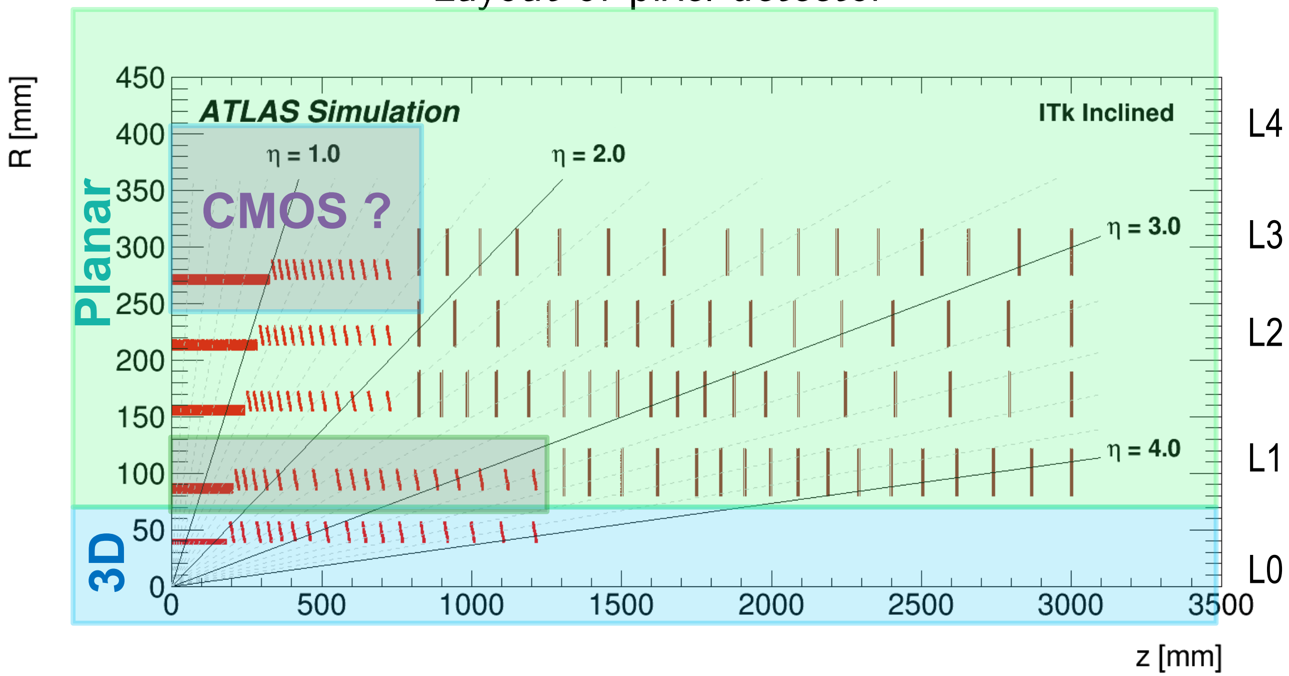
Output voltage / Nominal voltage



Upgrade: Inner Tracker

- Completely new all-silicon inner tracker (ITk) for HL-LHC
- MPP is involved in design and optimization of the pixel detector
- Close collaboration with the **Halbleiterlabor** (HLL) of the Max-Planck-Society
- Full pseudorapidity coverage up to $|\eta| = 4$
- From 4 to 5 pixel layers $\rightarrow$ robustness against missing single hit
- **Thin n-in-p planar sensors** as baseline technology for four outer layers
- Thin pixel sensors: to limit material, bias voltage and power dissipation
- Innermost two layers designed to be replaceable to cope with radiation damage
- MPP plans to provide in kind the $100\ \mu m$ thin sensors for one barrel layer

Layout of pixel detector



Upgrade: Inner Tracker

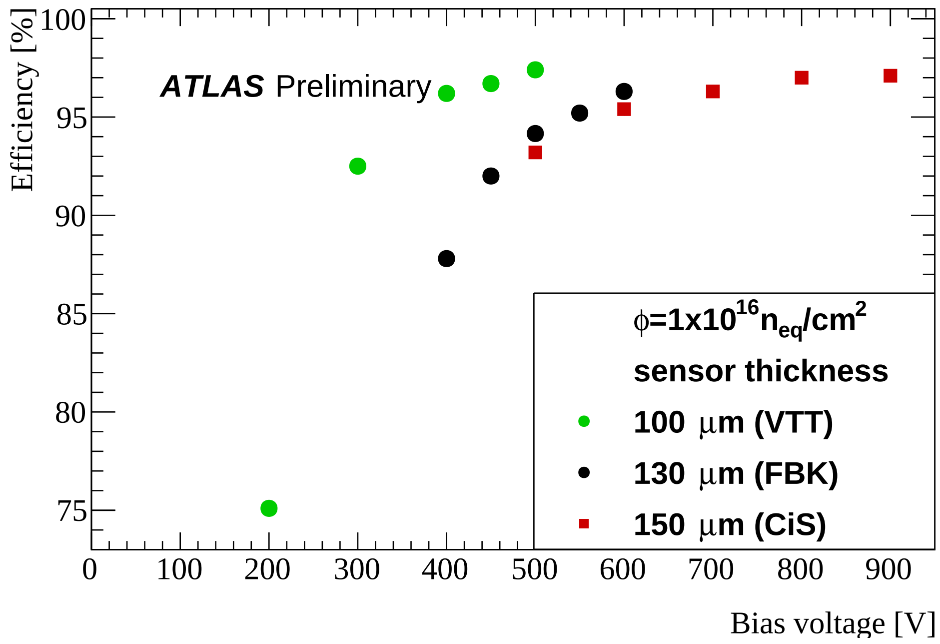
- MPP has played the essential role in proving the feasibility of employing 100 and 150 μm thin planar sensors for ITk
  - Several test of performance in terms of hit efficiency of different designs after irradiation
  - Estimation of power dissipation $\rightarrow$ input to the cooling system design
  - Optimization of fabrication process together with HLL and CIS corporation

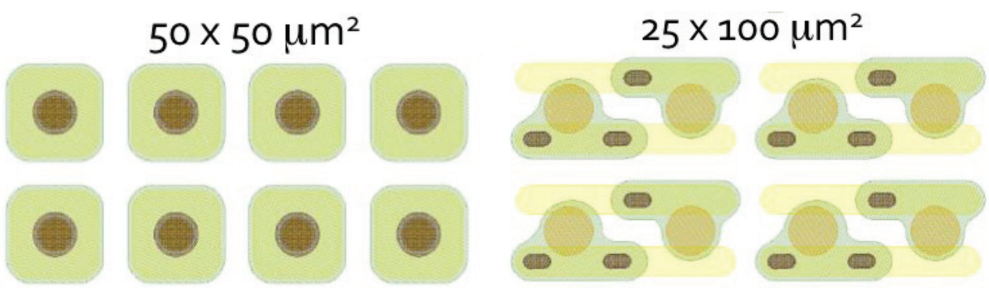
- RD53 (common effort with CMS): new readout chip

- Pixels of $50 \times 50\ \mu m^2$ and $25 \times 100\ \mu m^2$ compatible with it

- Time schedule:
  - 2018: Market survey for sensors
  - 2019: Pre-production (10 % of the total need)
  - 2020-2022: Sensor production

Hit efficiency at $\Phi = 10^{16}\ n_{eq}/cm^2$ vs bias voltage

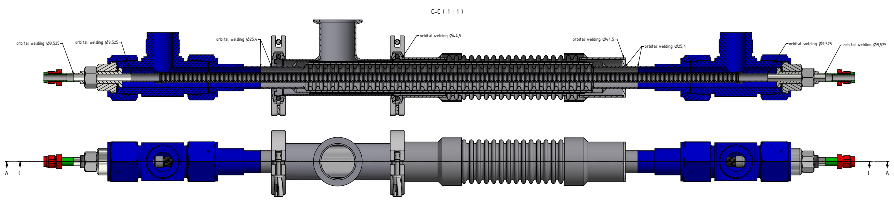


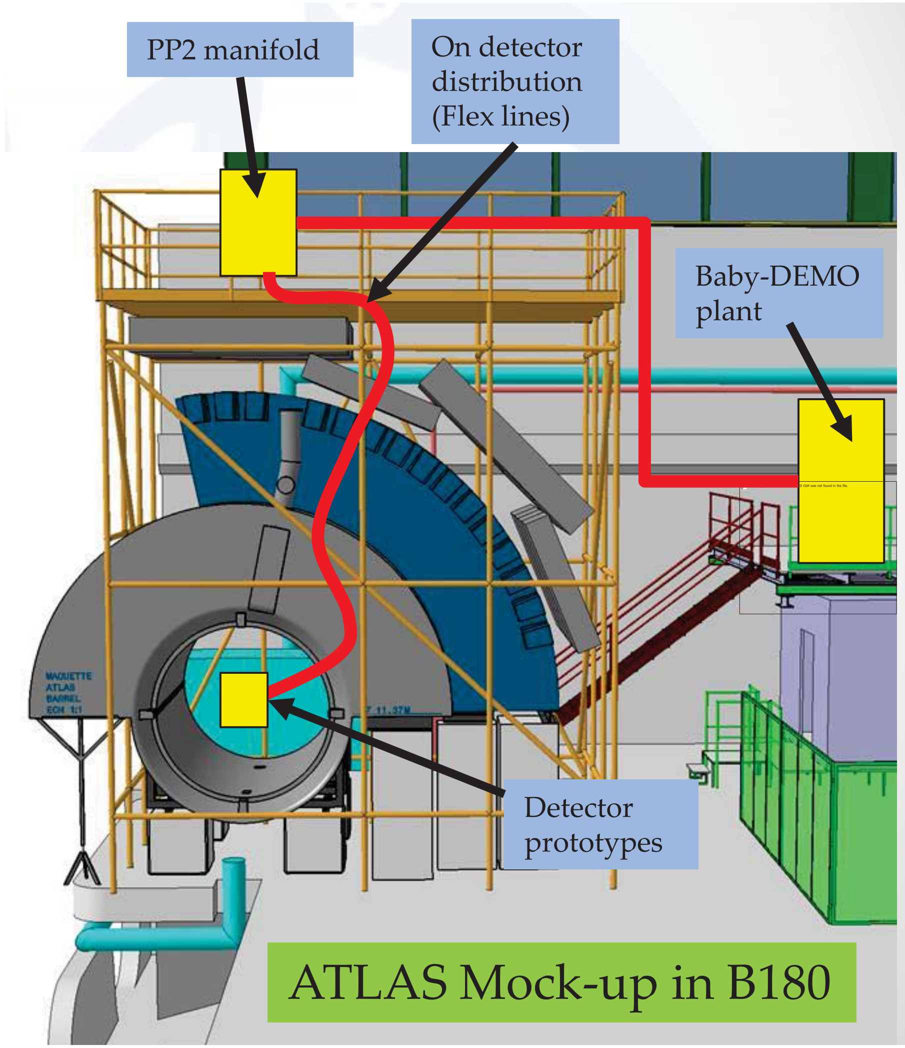


Upgrade: Inner Tracker

CO_2 cooling system

- The MPP contributes to the distribution system of the CO_2 cooling of the ITk
- Long-term R&D towards the final system
- The present project is the "Baby demonstrator": Low temperature operation will be demonstrated for a small CO_2 cooling plant
- MPP designs distribution boxes and flexible transfer lines
- The MPP flexline design has been built at the Witzenmann Sachsen company in Germany





Summary

- 2017 was very successful year for LHC and ATLAS
- MPP ATLAS team contributes significantly to ATLAS detector operation, performance studies and, of course, physics analysis
- Members of the group play crucial role in upgrade projects for High-Luminosity LHC: in muon system, LAr calorimetry and new inner tracker
- The group is strongly involved in the preparation of the Technical Design Reports for the ATLAS high-luminosity upgrades:
  - ATLAS Muon Spectrometer Phase-II Upgrade TDR (approved in December 2017)
  - ATLAS Liquid Argon Calorimeter Phase-II Upgrade TDR
  - TDR for the ATLAS ITk Pixel Detector
  - ATLAS Trigger and Data Acquisition Phase-II Upgrade TDR