Present and Future ATLAS Detector

Oliver Kortner on behalf of the MPP ATLAS group

Annual MPP Project Review, 14.12.2015

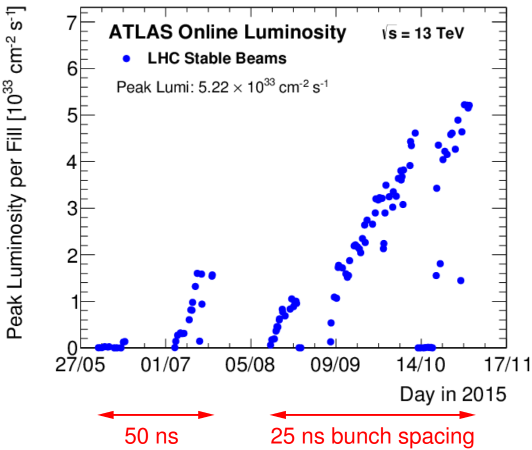
proton-proton collisions at
13 TeV centre-of-mass energy

Run: 265545
Event: 5720351
2015-05-21 10:39:54

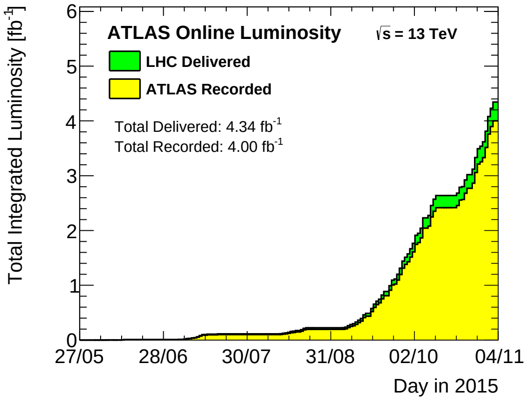
Luminosity evolution

- After consolidation of LHC magnet interconnections restart of the LHC at $\sqrt{s} = 13$ TeV in 2015.

Peak luminosity

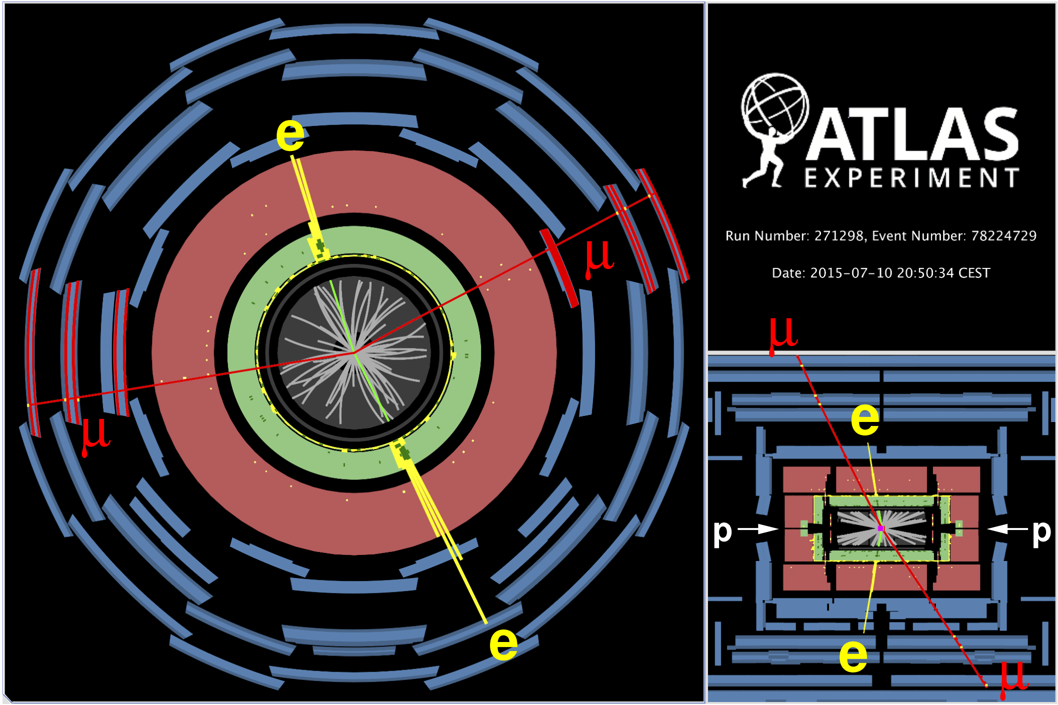


Integrated luminosity

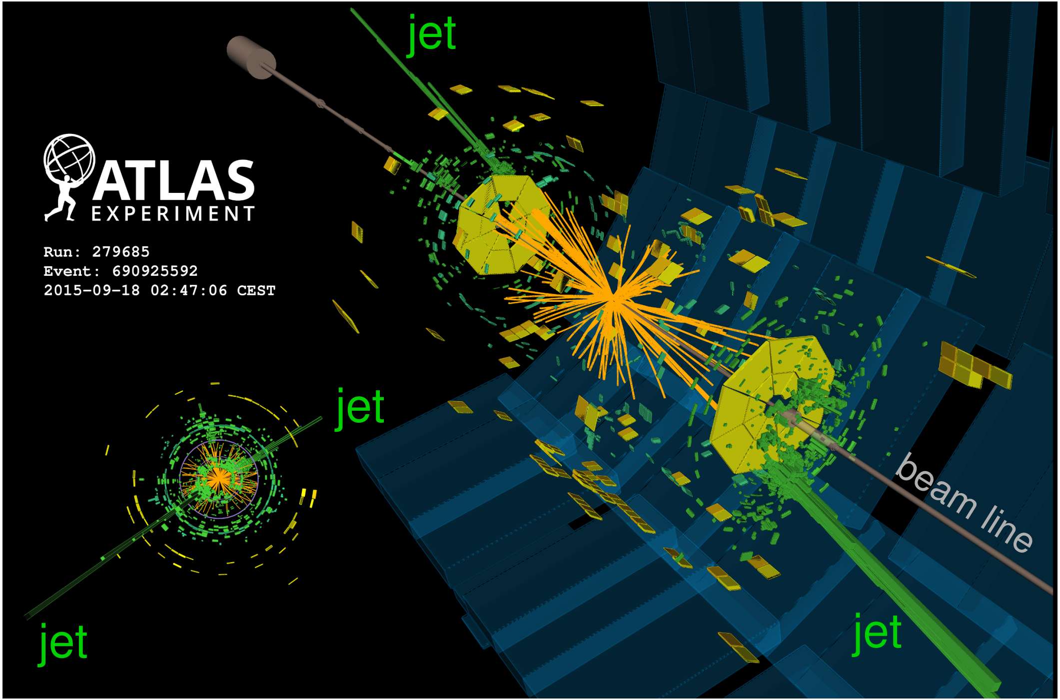


- Maximum peak luminosity of half the LHC design luminosity reached at the end of the taking period.
- pp data recorded by ATLAS: $4.00\ \text{fb}^{-1}$ at data taking efficiency of 92%.

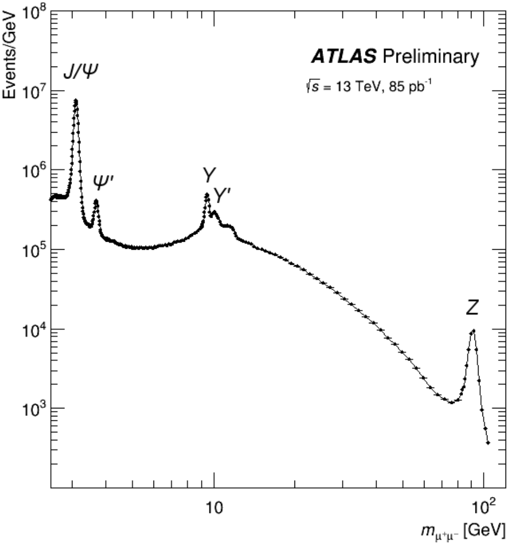
Event with a $ZZ \to e^+e^-\mu^+\mu^-$ candidate



High-mass di-jet event ($m_{jj} = 8.8$ TeV)



Rediscovery of known resonances at $\sqrt{s} = 13$ TeV



- One of the first public results: from the MPP muon group.
- $J/\psi \to \mu^+\mu^-$ and $Z \to \mu^+\mu^-$ decays immediately used for muon efficiency measurement.

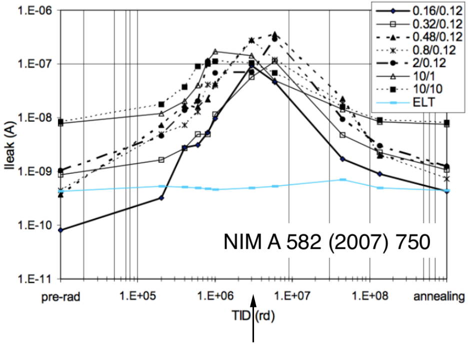
Detector efficiency

Fraction of working channels

Inner tracker			Calorimeters		Muon spectrometer			
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC
98.5	99.7	100	99.1	100	100	99.3	100	100

All subsystem with efficiencies close or equal to 100%!

Origin of the reduced pixel efficiency (98.5%)

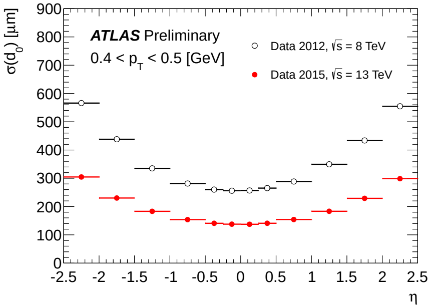


~total ionisation dose accumulated in 2015

- Pixel inefficiency attributed to the new inner pixel layer (IBL).
- IBL temporarily was switched off at the occurance of too high leakage currents caused by the transistors of the read-out chips (in IBM 130 nm NMOS technology).
- Leakage currents expected to drop with further increased total ionising dose.

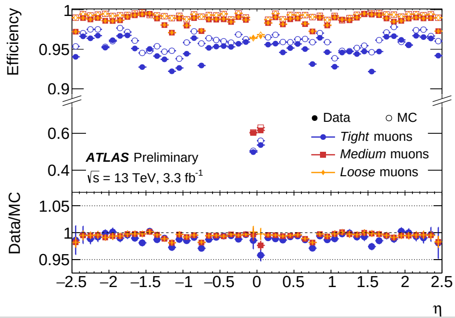
Detector operation and performance

Impact parameter resolution



Substantial improvement of the impact parameters resolution thanks to the new additional inner pixel layer commissioned under MPP leadership.

Muon reconstruction efficiency

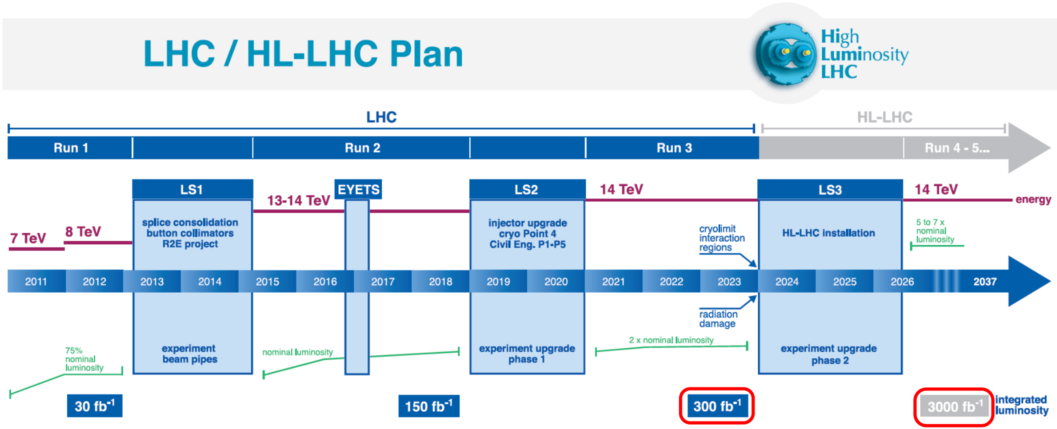


MPP responsibility: muon calibration.

- Muon calibration centre.
- Muon efficiency measurement.
- Muon momentum scale and resolution.

The roadmap to High-Luminosity LHC

- Plan to increase the LHC luminosity by an order of magnitude.
- Physics motivation and interests of the MPP group on the next 3 slides.
- Increase of the particle fluxes/rates by an order of magnitude from the LHC to the HL-LHC requires a major detector upgrade.



MPP contributions:

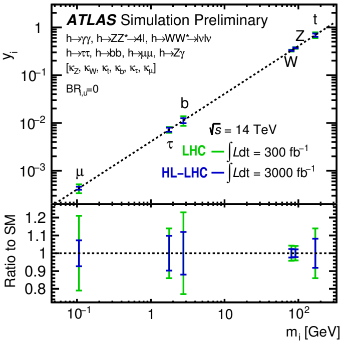
Muon system:
BMG chamber installation

Muon system:
BIS7/8 chamber installation

Phase–II upgrade of the **inner detector, forward calorimeter, muon system**

Higgs physics at the HL-LHC

- Precision measurements of Higgs boson couplings and spin-CP quantum numbers as a probe for physics beyond the Standard Model.

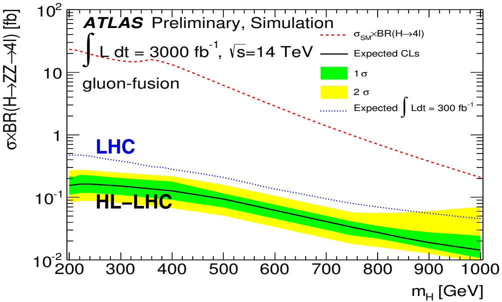


Measurement of deviations of Higgs couplings from SM values with per-cent precision at the HL-LHC.

Search for deviations from SM and for rare and invisible Higgs decays.

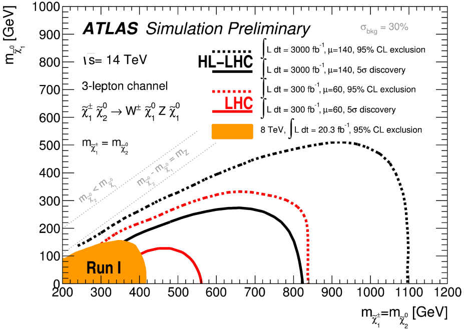
Evidence for Higgs boson self-coupling possible at the HL-LHC.

- 3-4 times higher sensitivity in direct searches for additional Higgs bosons at the HL-LHC than the LHC.



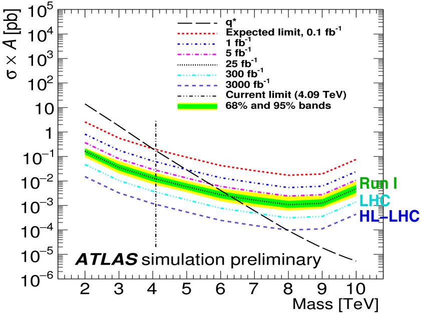
Supersymmetric and other new particles at the HL-LHC

Search for supersymmetric particles



- Much larger area of the SUSY parameter space accessible at the HL-LHC than at the LHC.
- Sensitivity to 1.5 times larger neutralino and chargino masses in WZ-mediated SUSY at the HL-LHC than the LHC.
- If SUSY is found at the LHC, the HL-LHC needed to study its exact nature.

Model independent search for heavy resonances (di-jet, di-photon $\ell\ell$, tt)



- Search performed in several final states, e.g. di-jet, di-photon, di-lepton, $t\bar{t}$.
- Di-jet resonances predicted by several theories, e.g. excited quarks, quantum black holes.
- 4 times higher sensitivity to di-jet resonances at the HL-LHC than at the LHC.

Dark matter at the HL-LHC

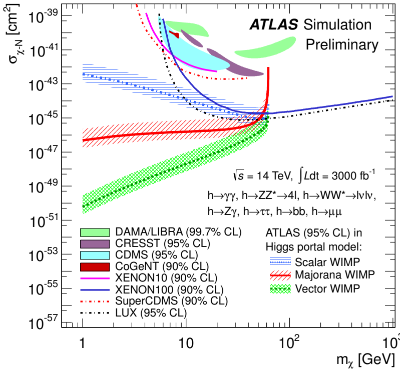
Search for dark matter in Higgs boson decays

- Signature of Higgs boson decays into dark matter: $H \rightarrow invisible.$
- Direct search in vector boson fusion and W/Z associated Higgs boson production.

  95% confidence upper limits on BR($H \rightarrow inv.$)

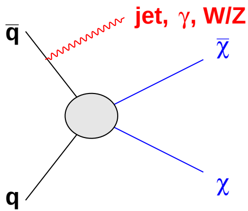
Run I	LHC	HL-LHC
0.49	0.22	0.13

- Indirect search via precision measurement of Higgs boson couplings.



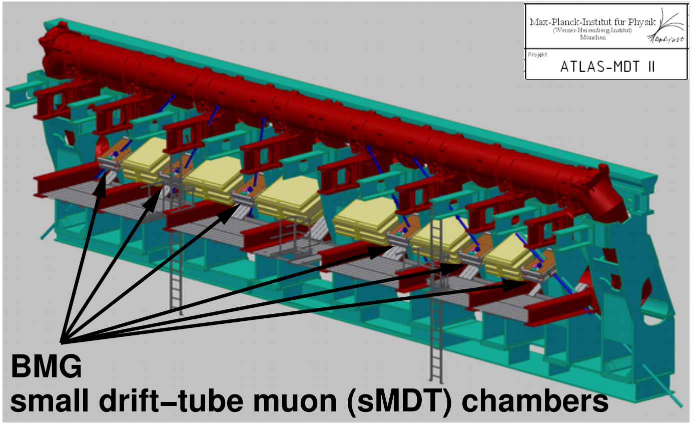
Search for dark matter production in association with Standard Model particles

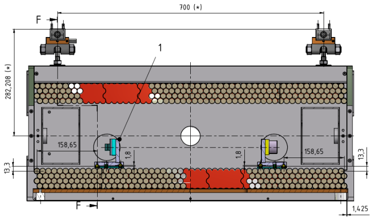
Similar increase in sensitivity from LHC to HL-LHC as above.



Phase-I BMG muon chamber upgrade

In 2017 installation of 12 new BMG small drift-tubes precision muon chambers in the detector feet to improve the muon momentum resolution.





10 times higher high-rate capability than present MDT chambers.
Needed because of increased background rates in muon spectrometer at HL-LHC.

ATLAS muon upgrade coordinator: O. Kortner.

Production and test of drift tubes at MPP

- Semi-automated drift-tube assembly and test performed at MPP by technicians from IHEP Protvino.
- Production of 4200 drift tubes for all BMG chambers including module 0 is completed.
- Only 4% of the tubes fail the standard ATLAS quality criteria.

Endplug and wire insertion

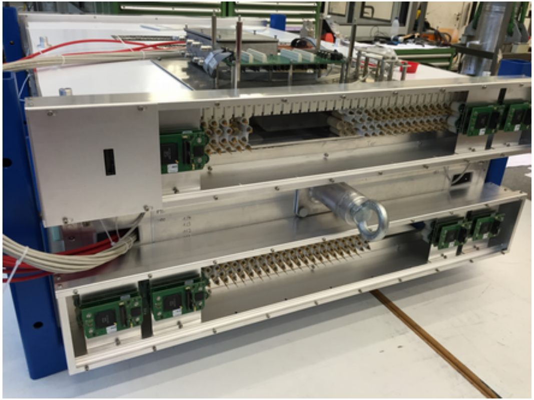
Wire tensioning, tension measurement

- Spacer frames for BMG chambers produced at IHEP Protvino.

PhD theses: Korbinian Schmidt-Sommerfeld, Philipp Schwegler.

Bachelor thesis: J. Corella Puertas.

Status of BMG chamber production at MPP

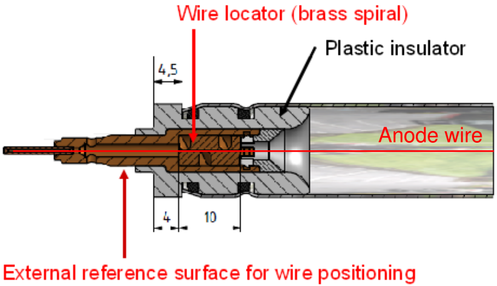


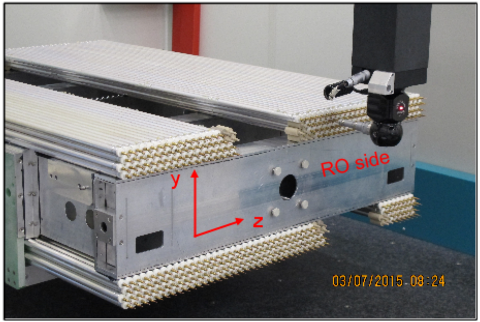
- September 2015 - October 2016: Series production.
- Module 0 + 2 series chambers produced so far.
- 3^{rd} series chamber in production.

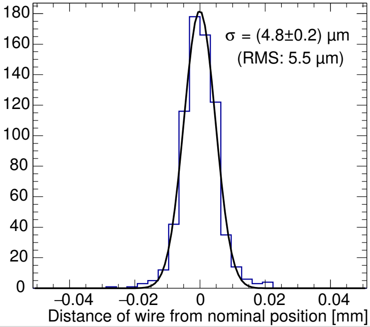
Wire position accuracy

- Tube reference surfaces accessible in chambers thanks to endplug design.

⇒ Possibility of measuring the wire positions with a coordinate measurement machine.







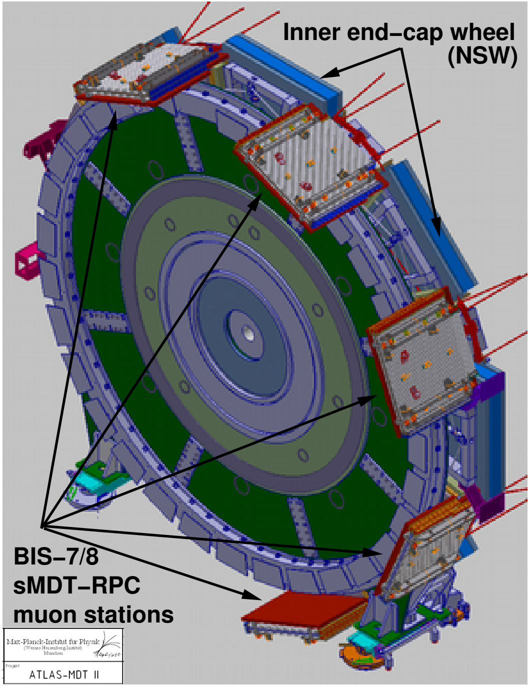
Unprecedented wire positioning accuracy of 5 μm

4 times higher accuracy than in present MDT chambers.

Most precise wire chamber!

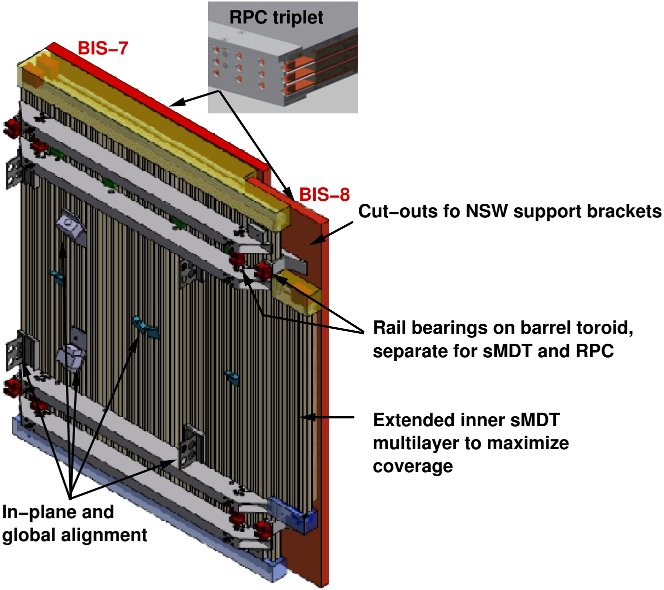
sMDTs presently only technology for precision muon tracking at future hadron colliders (FCC).

Phase-I BIS-7/8 muon chamber upgrade



- 16 new muon stations inside the barrel toroid coils at the boundary between barrel and end caps.
- Purposes:
  - Improvement the selectivity of the muon trigger in the barrel end-cap transition region.
  - Increase of high-rate capability.
- Technology:
  - sMDT chambers for precision tracking.
  - New thin-gap resistive plate chambers (RPC) for triggering.
- Installation during LS2 (2019-2020).

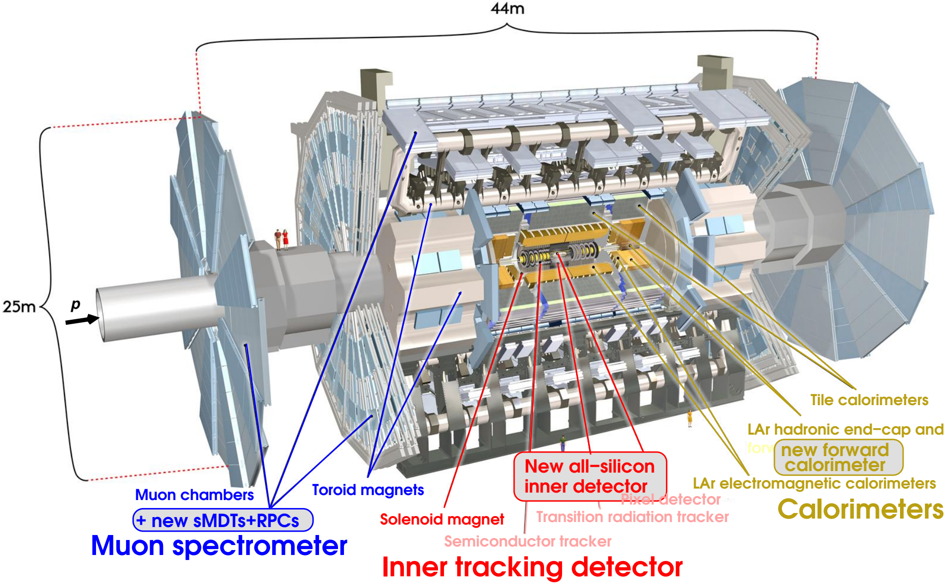
Design of BIS-7/8 sMDT and RPC chambers at MPP



- Integrated BIS 7/8 sMDT and RPC design.
- Development of new thin-gap RPCs with 10 times better high-rate capability than present RPCs.
- Thin-gap RPCs presently only technology with high-enough time resolution for muon triggers at future hadron colliders.
- RPC prototype planned for early 2016.

Phase-II upgrade of the ATLAS detector for HL-LHC

ATLAS detector at the HL-LHC



+ new electronics for new trigger architecture

MPP contribution to the upgrade of the muon spectrometer

Electronics upgrade

- At the HL-LHC the ATLAS experiment will adopt a new two-level trigger architechture consisting of the first-level and the high-level trigger.
- Rate of first level: 1 MHz. Latency of first level: 6 μs.

⇒ The present muon drift-tube (MDT) chamber read-out chain is incompatible with the new trigger architecture and needs to be replaced.

⇒ Opportunity to incorporate the MDT in the first trigger level.

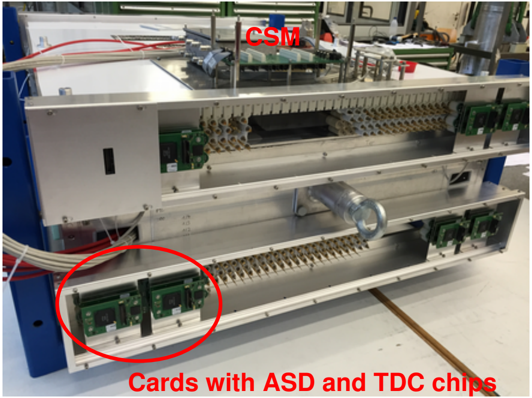
Muon chamber upgrade

- To sustain high muon trigger efficiency installation of new thin-gap RPCs+sMDT chambers with excellent high-rate capability.

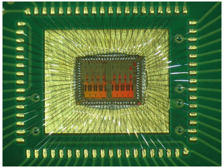
Role of the MPP group

- Muon HL-LHC upgrade projects initiated by the MPP group.
- Leading role in R&D.
- MPP contribution crucial to the success of the muon spectrometer upgrade.

Upgrade of the MDT front-end electronics



So far in ATLAS only MPP has worked on the new MDT read-out chain:



New ASD chip
on testing board

CSM demonstrator

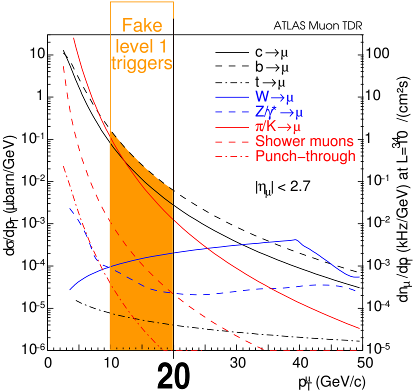
PhD theses: S. Nowak, K. Schmidt-Sommerfeld

Bachelor theses: S. Annies und C. Schmid

- The MPP group will design and produce the new ASD and TDC chips in 2019 and 2020.

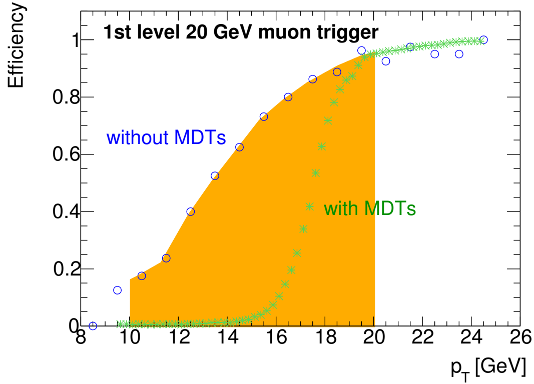
Need to integrate of the MDT data in the 1^{st} trigger level

Inclusive muon cross section



Muon first-level trigger efficiency

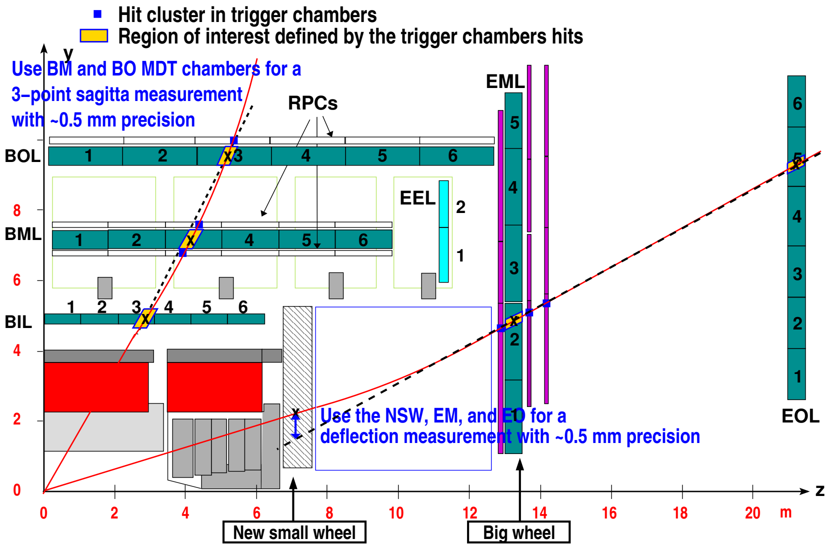
Master thesis P. Gadow



- The interesting electroweak physics is mainly at $p_{\rm T} > 20$ GeV.
- The inclusive muon cross section is very steeply rising with decreasing $p_{\rm T}$.
- Present 1st level 20 GeV muon trigger accepts a lot of muons with 10 GeV< $p_{\rm T}$ <20 GeV due limited spatial resolution of trigger chambers.

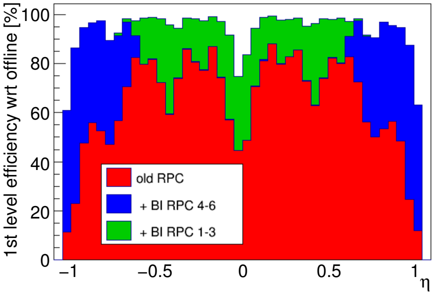
$\Rightarrow$ Sharpening of trigger turn-on curve by the use of precision muon drift-tube (MDT) chambers to limit the trigger rate.

MDT muon trigger concept



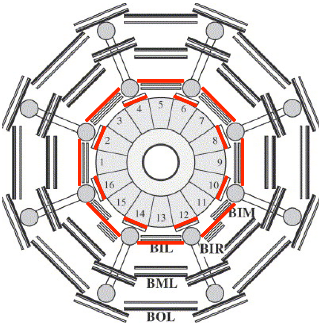
- Continuous stream of MDT hit data to off-detector MDT trigger processors.
- Use of MDT hits for the refinement of muon p_{T} measurement in regions of interest defined by the trigger chambers.
- MPP contribution: Design and production of MDT trigger processors.

Reinforcement of the barrel muon trigger



- Muon spectrometer will be exposed to a ten times higher background of neutrons and γ rays than at the LHC.

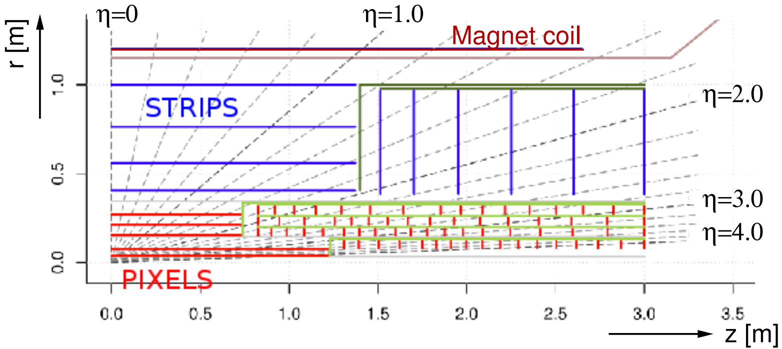
$\Rightarrow$ The present RPCs can only be operated with significantly reduced efficiency.



- Installation of additional RPCs with increased high-rate capability in the inner barrel layer to recuperate the reduced muon trigger efficieny.
- Replacement of MDT chambers with sMDT chambers in small barrel sectors to free space for RPCs.
- MPP contribution:
  - Design of RPCs and sMDT chambers.
  - Production of 50% of the sMDT chambers.
  - Pilot project: BIS-7/8.

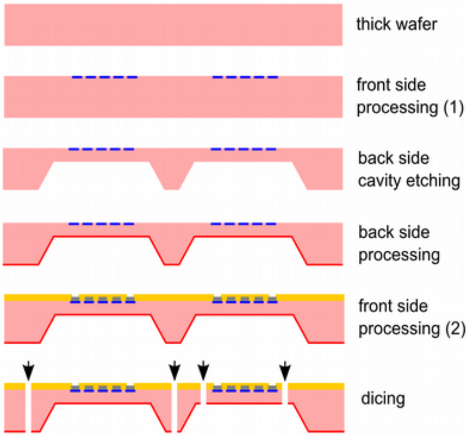
All-silicon inner tracker for HL-LHC

Layout of a new all-silicon inner tracker



- Challenging environment
  - High radiation level of $\sim 10^{16}$ $n_{eq}cm^{-2}$.
  - 200 inelastic pp collisions per bunch crossing.
- MPP contributions
  - Optimization of the pixel sensor design.
  - Assembly of pixel modules.
  - Design and construction of parts of the CO_2 cooling system.
  - A. Macchiolo: ATLAS pixel sensor upgrade co-coordinator.

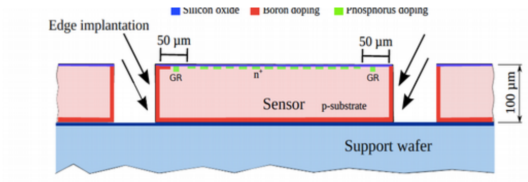
Optimization of the production of thin planar sensors



- Use of 50-150 μm thin pixel sensors to avoid loss of charge carriers by trapping and to minimize the inner detector's material budget.
- Standard production techniques use handle wafers which have to be removed after sensor production.
- No handle wafer needed by the cheaper and easier wet etching technique developed by MPP and company CIS.

Process successfully demonstrated with first 4" wafer production!

Maximizing the active sensor area by active edges



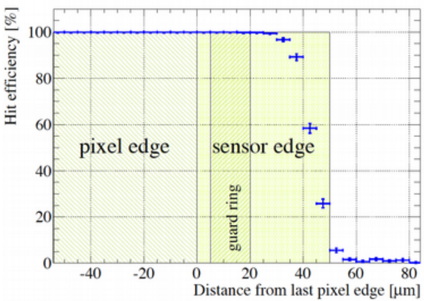
- No overlap of pixel sensors in z direction due to lack of space.

⇒ Need to minimize the inactive area in z direction!

- Potential solution: Pixel sensors with active edges.

- Production of sensors with active edges by MPP at the company ADVACAM completed recently.

Doctoral thesis S. Terzo

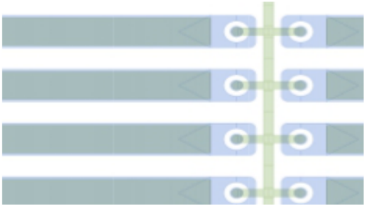


- Evaluation of the sensors ongoing.
- First results show significant increase in sensitive area!

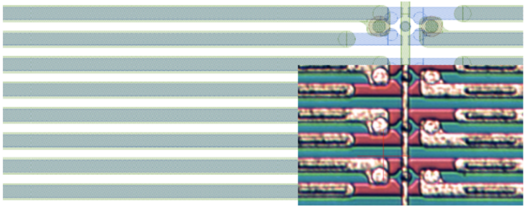
Optimization of the ground pad grid

Way of applying the ground pads before interconnection to chips influences the efficiency close to the connection points.

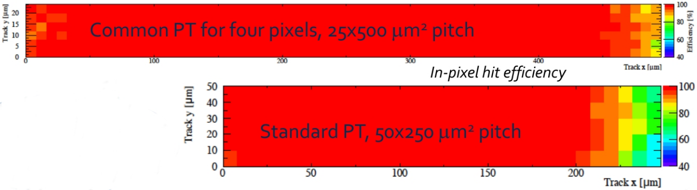
Standard punch-through



Optimized (common) punch-through



Doctoral thesis M. Savić

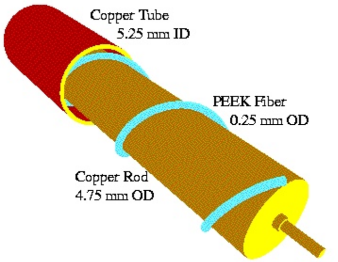


Increase of pixel efficiency from 95.6% to 99.4% with the optimized punch-through!

Upgrade of the forward calorimeter (FCAL)

Assembly of present FCAL

Schematic drawing of the electrode



$\sim 250~\mu$m gap filled with liquid argon

Limitations of the present FCAL at the HL-LHC

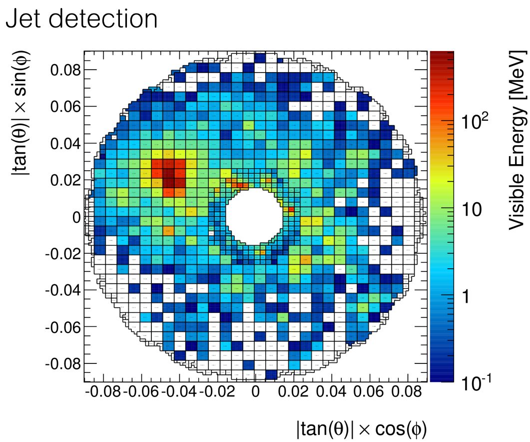
- Build-up of positive ions in the liquid argon gaps leads to distorted signals.
- Increased heat in the FCAL can lead to the formation of argon bubbles (boiling) making the FCAL inoperable.

$\Rightarrow$ Replacement of the present FCAL by a new FCAL with smaller LAr gaps and higher granularity to mitigate the pile-up effects.

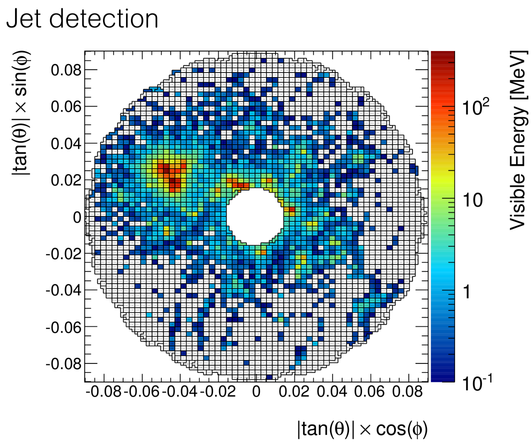
Optimization of the forward calorimeter granularity

Higher granularity of FCAL need to cope with much increased pile-up level at HL-LHC.

Present FCAL



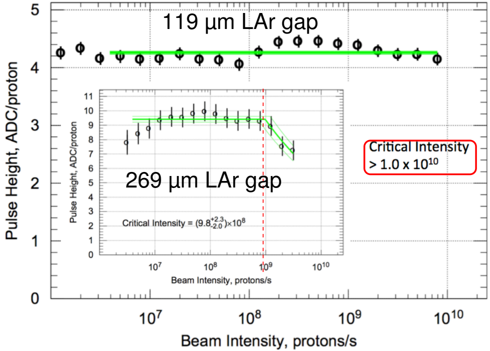
High-granularity FCAL



Jet structure better resolved by the high-granularity FCAL!

MPP contributions to the calorimeter upgrade

- R&D for a new high-granularity FCAL with $\sim 100\ \mu$m liquid argon gaps.



Proton beam test results

- FCAL 269 μm gaps: Drop of pulse height for beam intensities $> 10^9$ protons/s.
- sFAL 119 μm gaps: No pulse height degradation up to 10^{10} protons/s.

- Production of 25% of the sFCAL modules.
- Development and production of new radiation hard low-voltage power supplies for the hadronic end-cap calorimeter.
- S. Menke: ATLAS liquid Argon electronics upgrade co-cordinator.

Summary

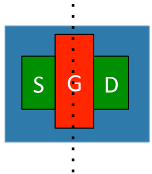
Operation of the ATLAS detector at the LHC

- Successful restart of the LHC at $\sqrt{s}$ =13 TeV in 2015.
- 4 fb^{-1} of pp collision data recorded with a fully functional detector at $>$90% data taking efficiency.

Upgrade of the ATLAS detector for HL-LHC

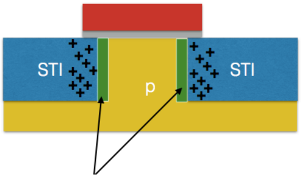
- LHC and HL-LHC will dominate accelerator particle physics for the next 20 years.
- Leading role of the MPP group in the ATLAS upgrade projects for HL-LHC.
- Detector R&D for HL-LHC has also high impact on experiments at future hadron colliders.

<u>**TID effects in IBM 130nm NMOS transistor**</u>

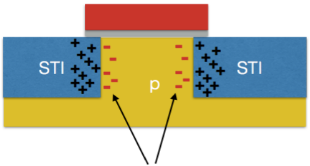


TID gives origin to two types of defects:

- Trapped positive charge in the bulk of the oxide
- Interface traps



Trapped positive charge in the bulk of the (Shallow-Trench-Isolation) STI oxide at the edge of the NMOS gives origin to the source-drain leakage current. Such current as TID accumulate shows a peaks at ~ 2-3Mrad (at room T and high dose rate)



Layer of interface traps with trapped electrons

Interface traps are filled with electron in NMOS structures, so this layer of negative charge compensates for the effect of trapped hoes in the bulk of the STI → Leakage current decreases !

These phenomena are **dose rate** and **temperature dependent**.

6