Micromegas detectors for the upgrade of the ATLAS Muon Spectrometer

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On behalf of the ATLAS Muon Collaboration

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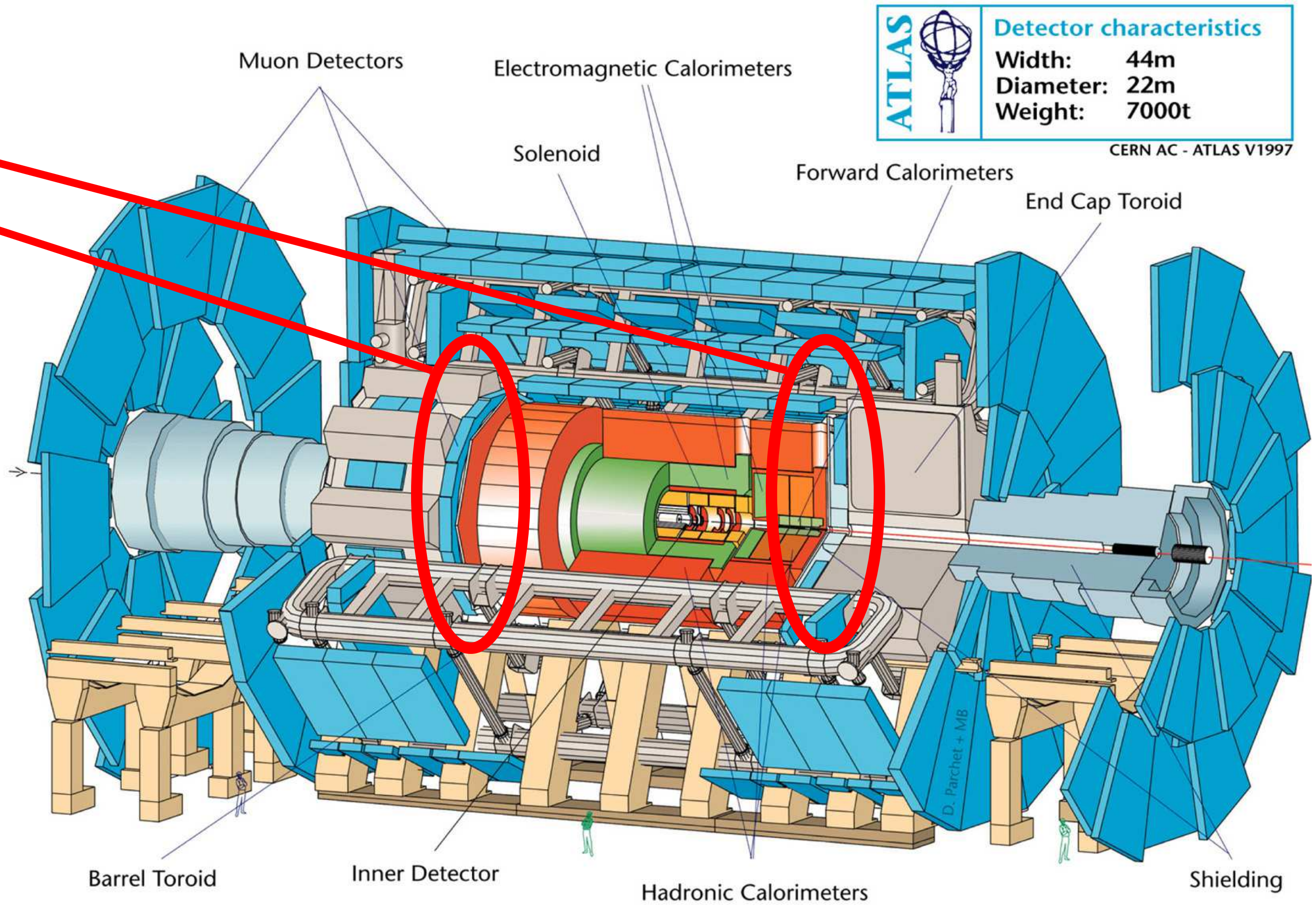
Present ATLAS Muon System

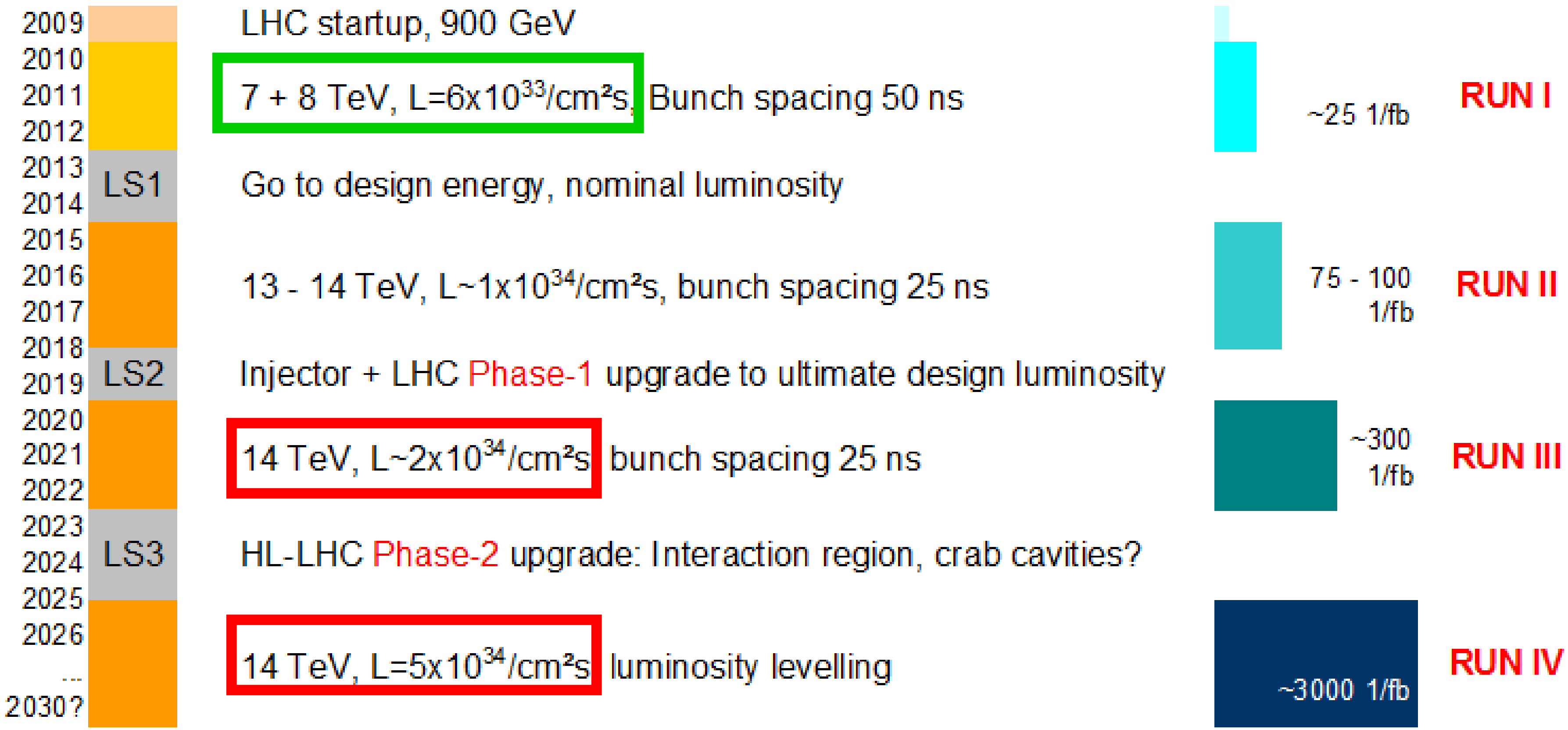
ATLAS muon spectrometer inner endcap: „Small Wheels“



Outline

- Upgrade of the ATLAS Muon Spectrometer with increasing LHC luminosity
- Micromegas for the High Luminosity LHC Environment
- New Small Wheel (NSW)
- NSW electronics
- Status and outlook

Planned LHC Upgrades



- After the Long Shutdown 2 (LS2), the current ATLAS muon system would have:
  - Level 1 trigger inefficiency
  - Tracking resolution and efficiency degradation

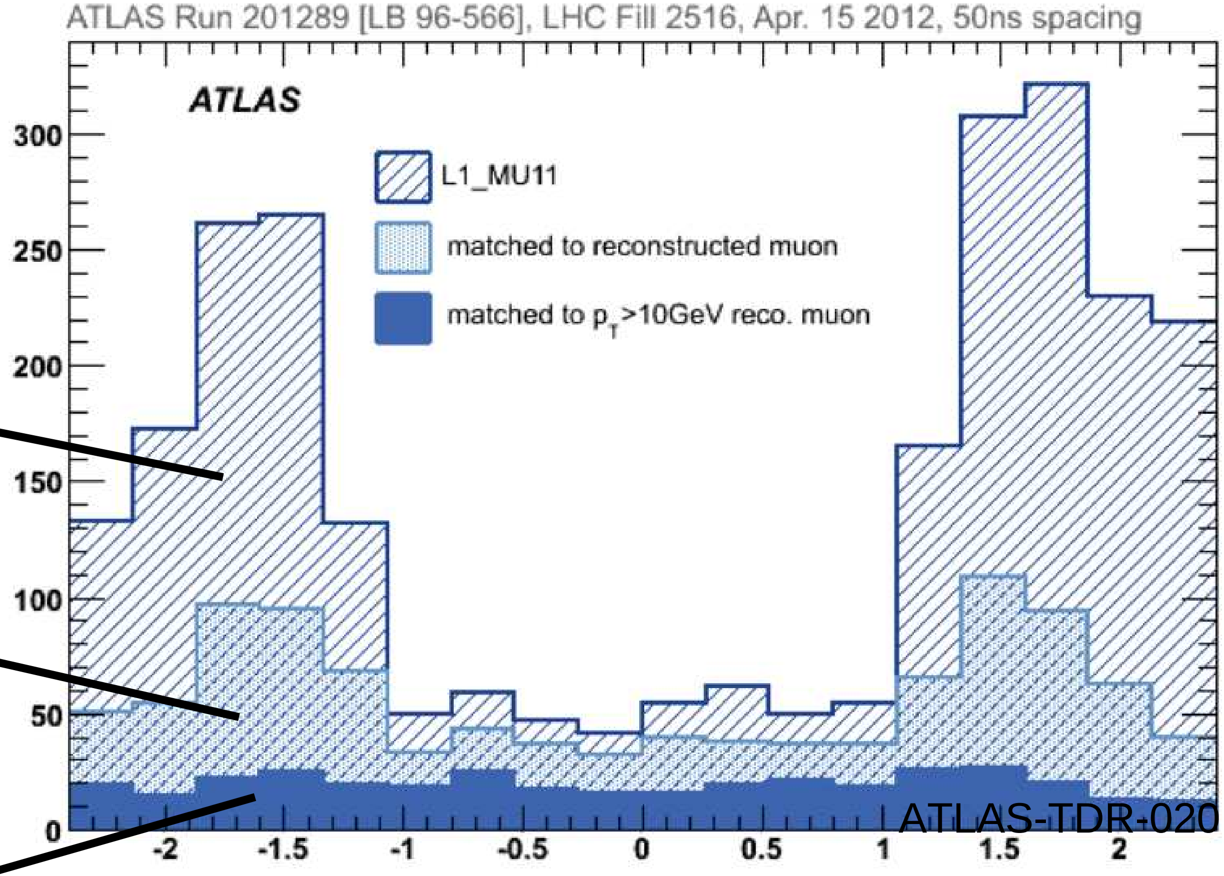
Present Trigger Status

Endcap muon triggers dominated by „fakes“

All
L1_MU11
(P_t>11 GeV)

Reconstructed
P_T > 3 GeV

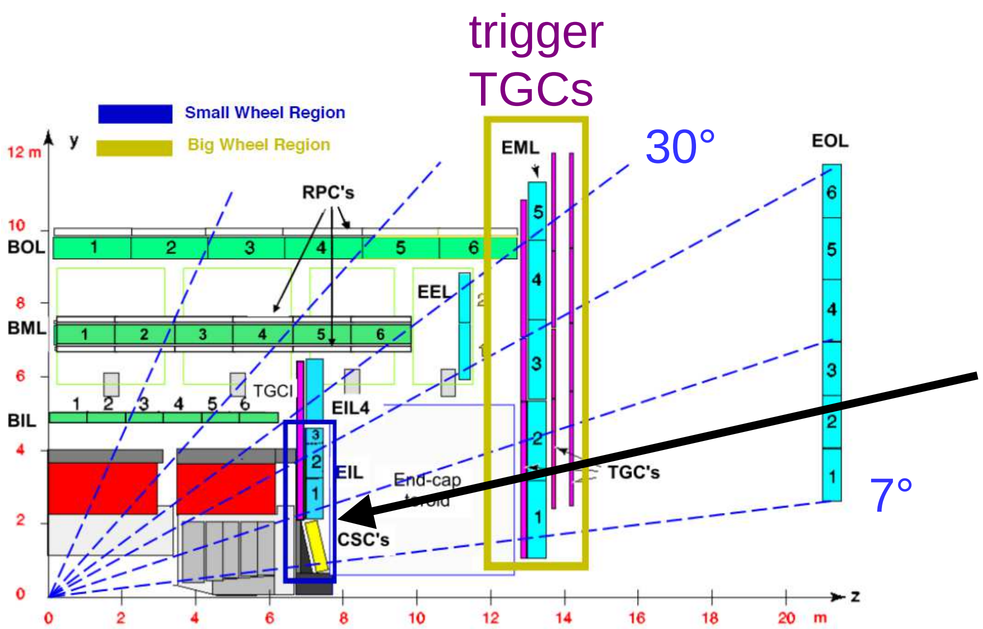
Reconstructed
P_T > 10 GeV



endcap | barrel | endcap

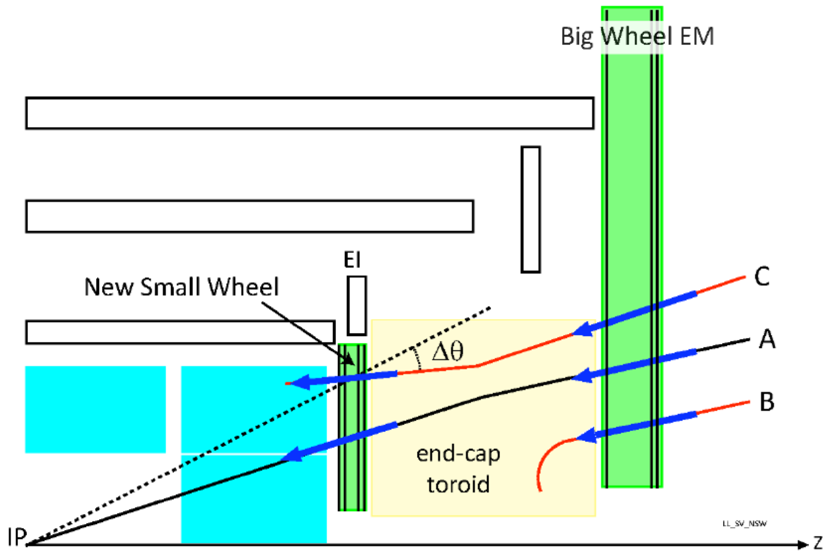
L1_MU20 @3x10^{34}/cm²s = 60 kHz Close to max. available 100 kHz

Reason for Trigger Problems



Present L1 trigger based on TGC information from Big Wheel

Small Wheel currently not included in L1 rigger

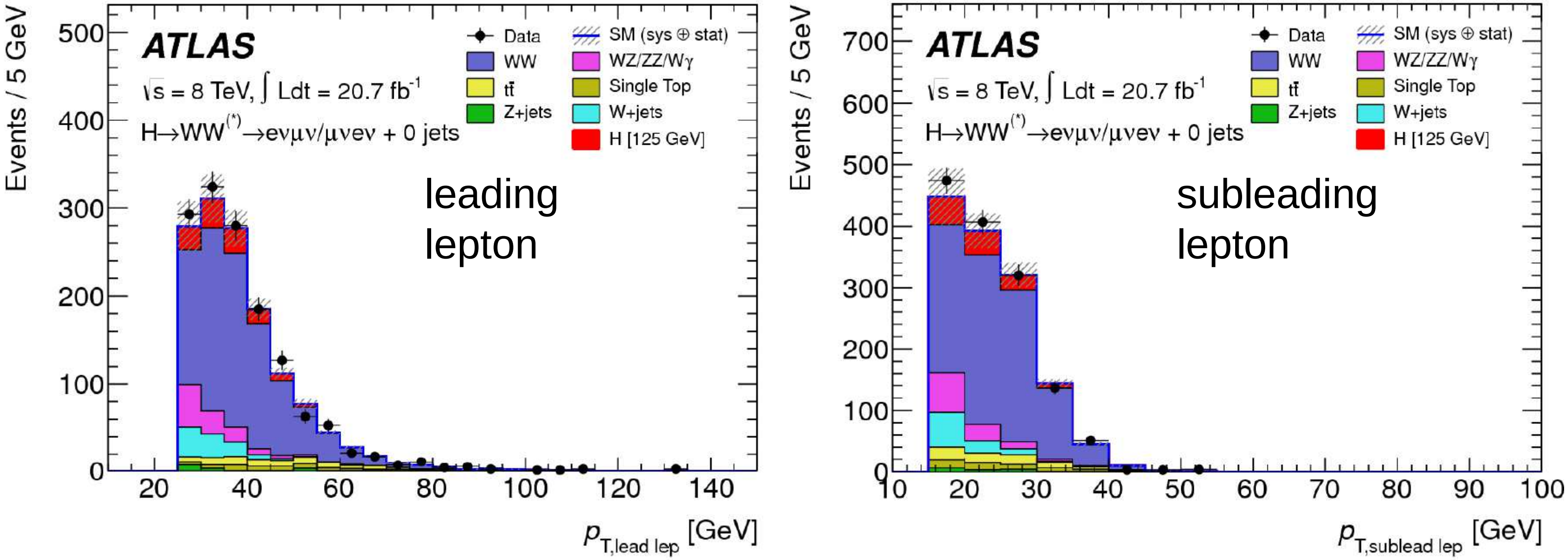


Phase-I:
Include Small Wheel angular information

Phase II Requirement:
IP pointing better than
1 mrad resolution

Importance of low Muon P_t Threshold

gg fusion -> H -> WW* -> lν lν + 0 jets

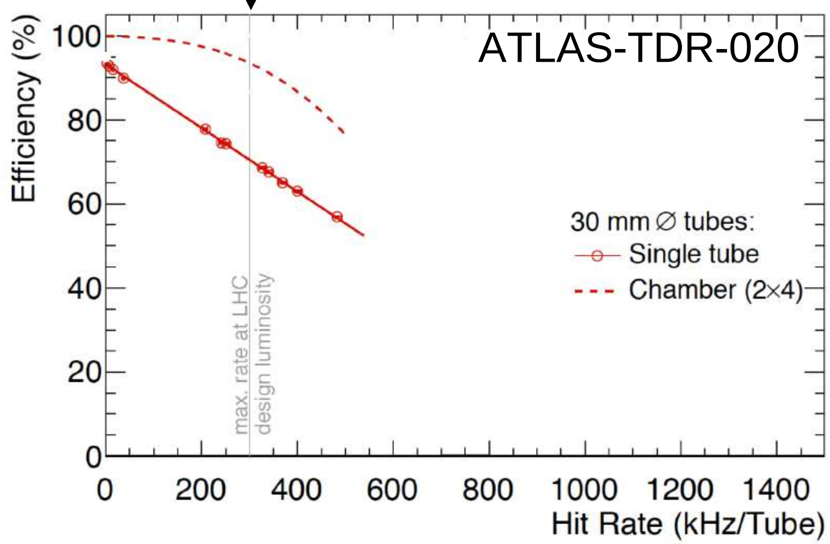


Raise of the muon trigger threshold to reduce the Level 1 trigger rate results in a significant loss of physics data

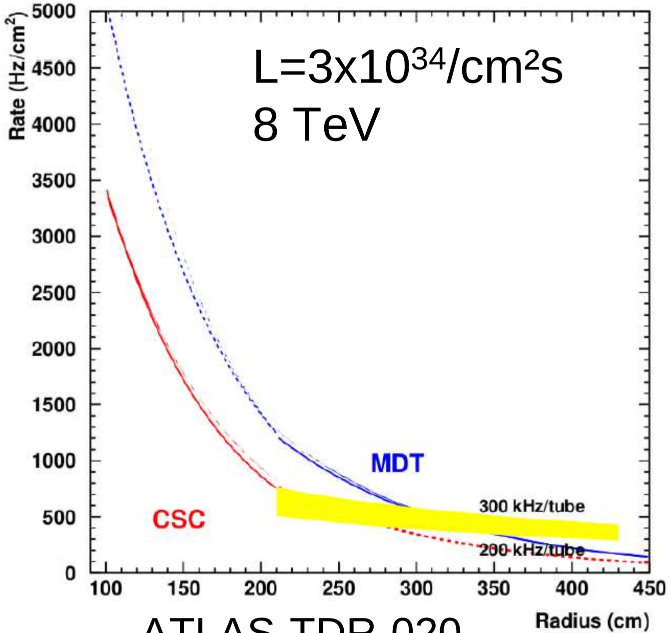
MDT Detection Limit

- The innermost currently installed Small Wheel precision chambers (MDT) are not able to fulfill the requirements at L>10^{34}/cm²s

L=10^{34}/cm²s



Extrapolation



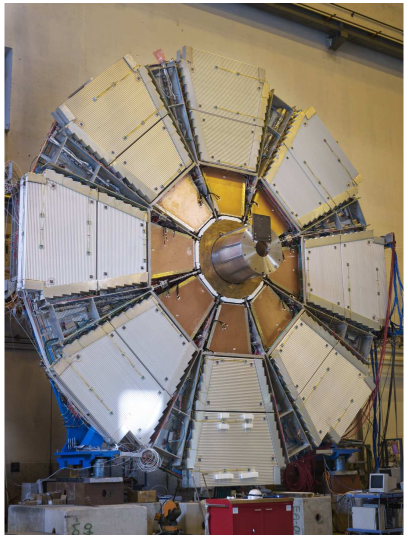
ATLAS-TDR-020

- Extrapolation of measured hit rates to L=3x10^{34}/cm²s at 8 TeV: exceed MDT capabilities
- Rate @5x10^{34}/cm²s @14 TeV: **15 kHz/cm²** for the innermost Small Wheel detectors

Design Values for the New Small Wheel Detectors

• single plane spatial resolution	100 μm, independent of track angle
• track segment reconstruction	50 μm = 10% @(P_t = 1 TeV)
• track segment efficiency	97% @(P_t > 10 GeV)
• online angular resolution (trigger)	1 mrad
• trigger response time	< 25 ns (bunch crossing identification)
• spatial resolution second coordinate	~cm from stereo strip layers
• hit rate capability	15 kHz/cm^2
• accumulated charge w/o ageing	1 C/cm^2 (including a safety factor of 5)

Old Small Wheel

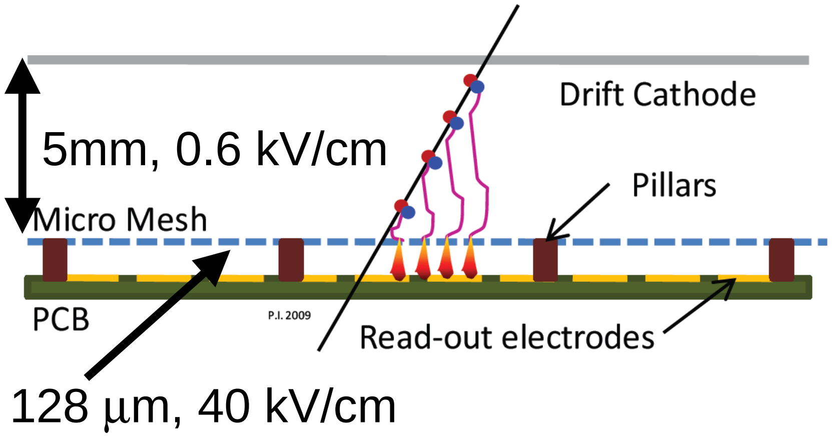


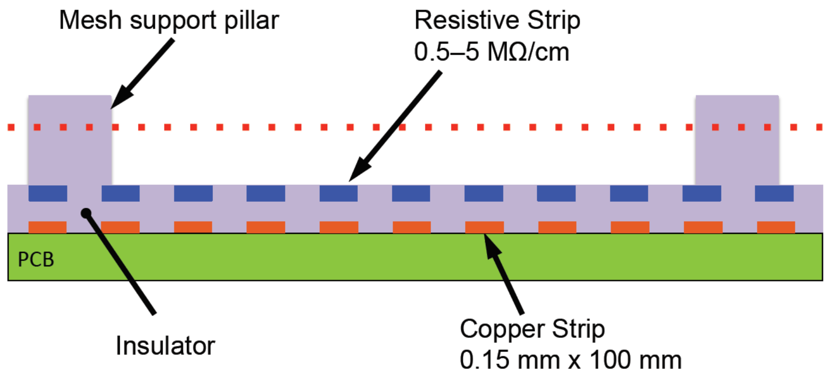
=> New Small Wheel

• Micromegas:	precision coordinate + trigger
• sTGCs:	trigger + precision coordinate

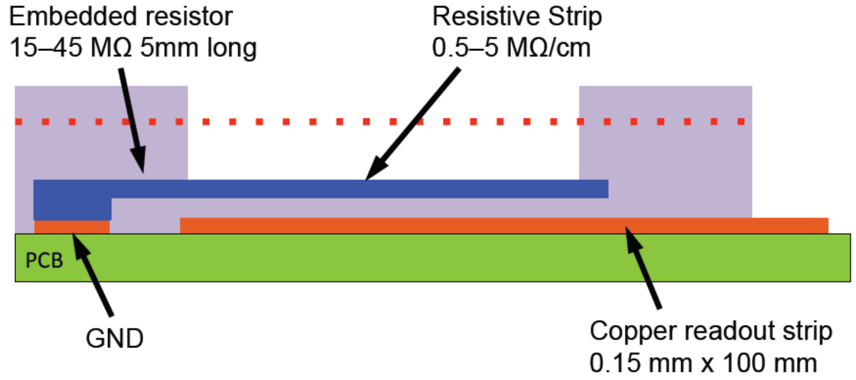
Resistive Strip Micromegas

- High-rate capable planar gaseous detector technology
- Readout boards from standard industry pcb production process
- Discharge insensitivity by additional resistive strip layer above the readout plane



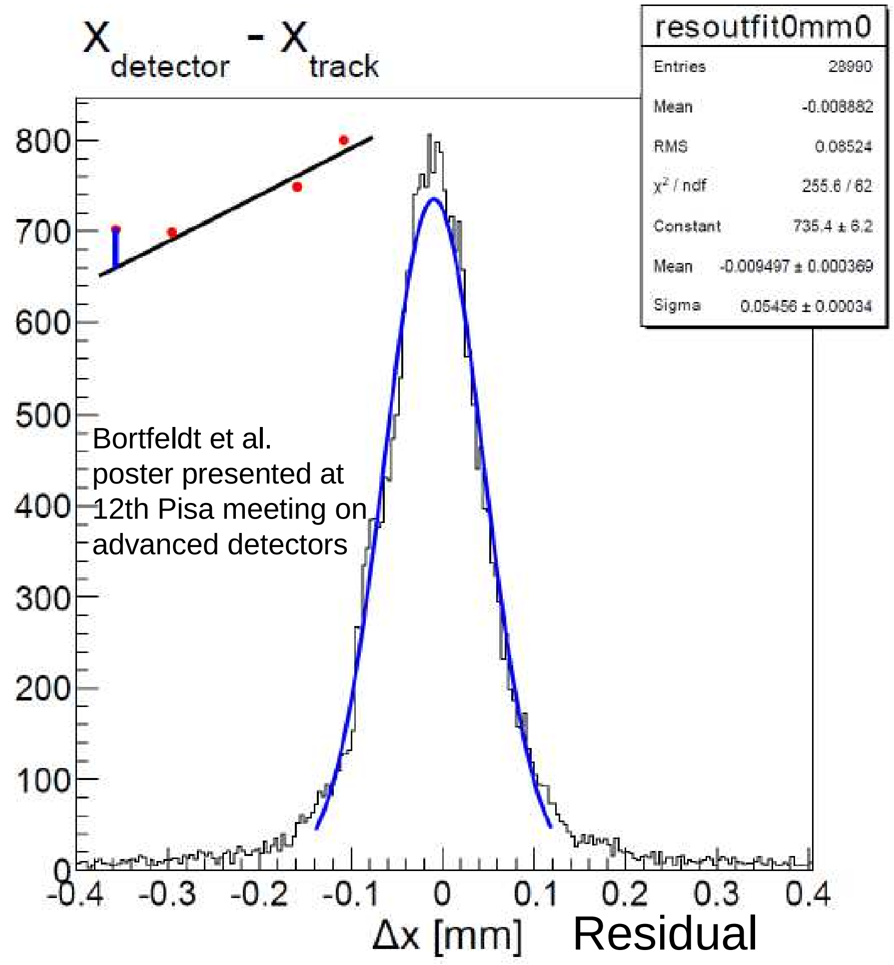


No dead time due to discharges



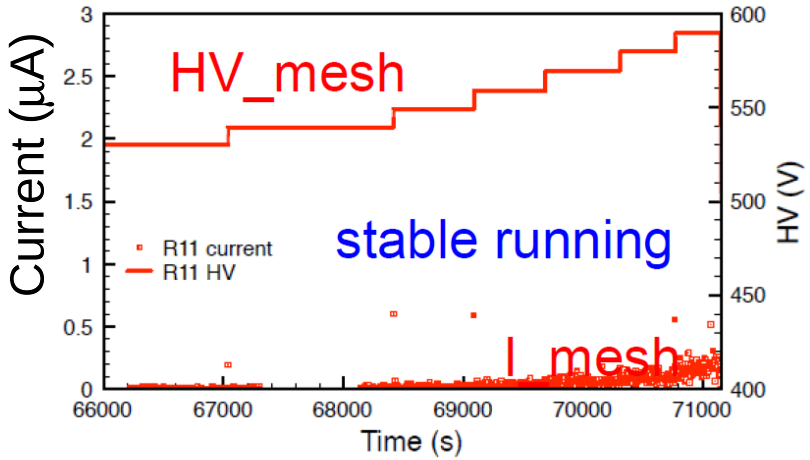
Standard Micromegas Performance

- LMU Munich Micromegas detector beam telescope in CERN SPS 120 GeV π test beam, perpendicular incidence.
- Detector size 10 x 10 cm²
- Residual width: σ_{ex}= 55 μm @250 μm strip pitch
- Three detectors define π-track
- One detector excluded from fit

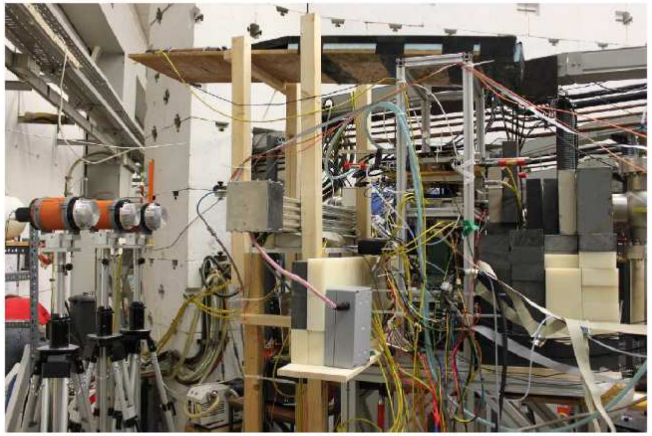


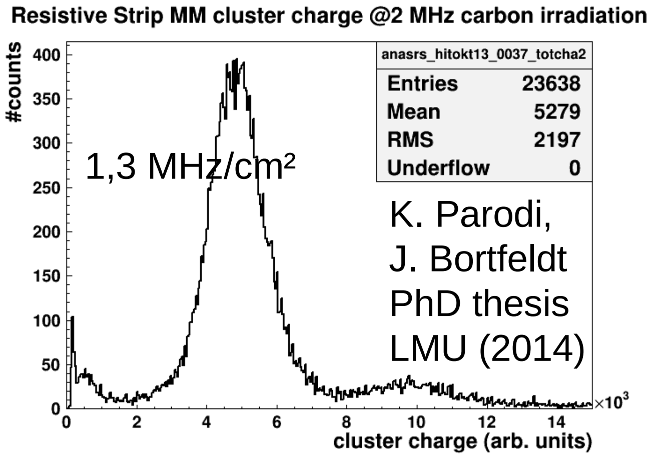
$$\sigma_{sr} = \sqrt{\sigma_{ex}^2 - \sigma_{track}^2}$$

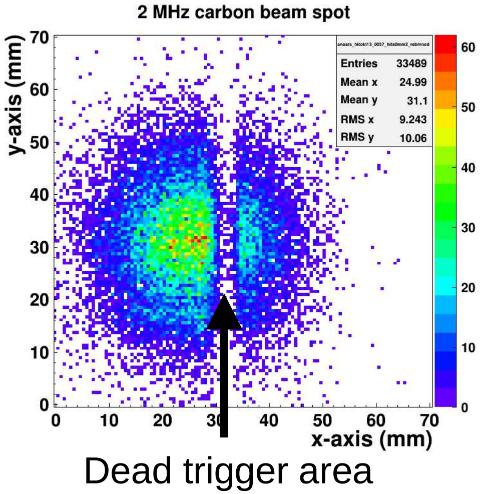
Resistive Strip Micromegas in Neutron and Carbon Ion Beam

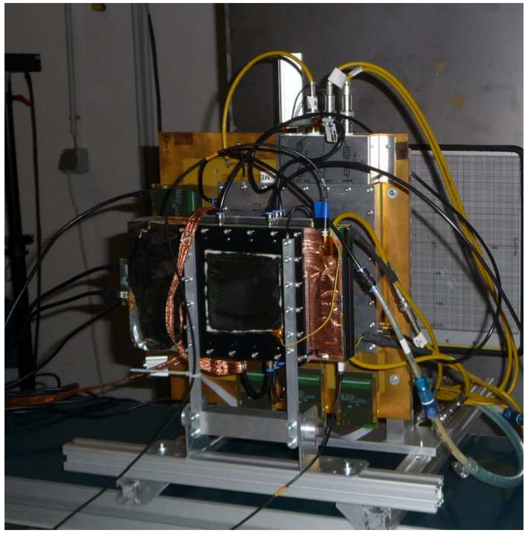


10^7 n /cm^2 s   30x30cm^2









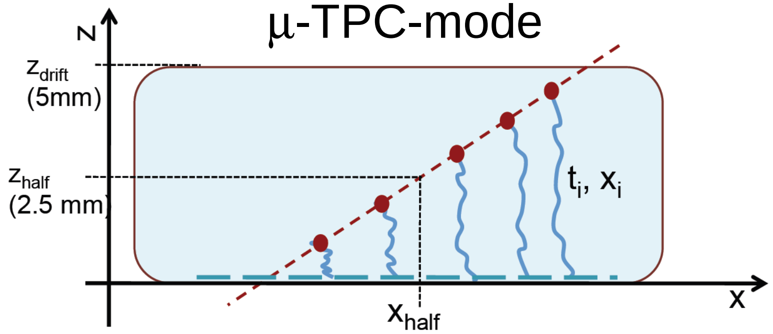
Stable running @ >>HL-LHC current
Variety of additional ageing test, no problems observed

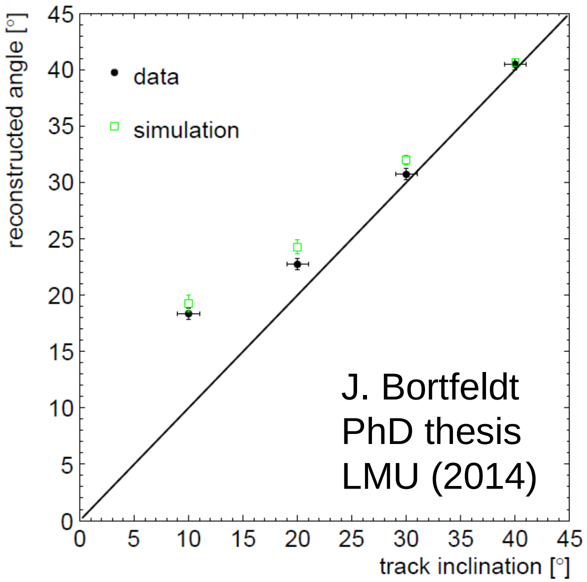
Resistive Strip Micromegas @inclined tracks

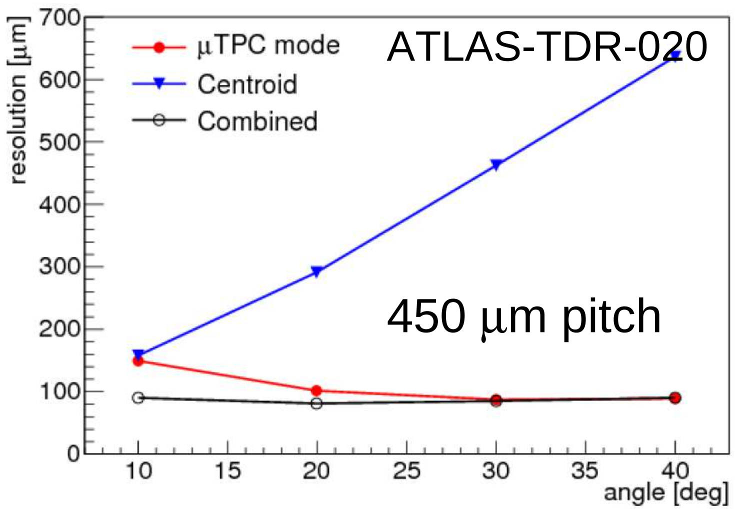
• Combination of centroid cluster position determination and micro-TPC mode

• Resolution below 100 μm, independent from track inclination

• TPC-like track angle reconstruction well understood

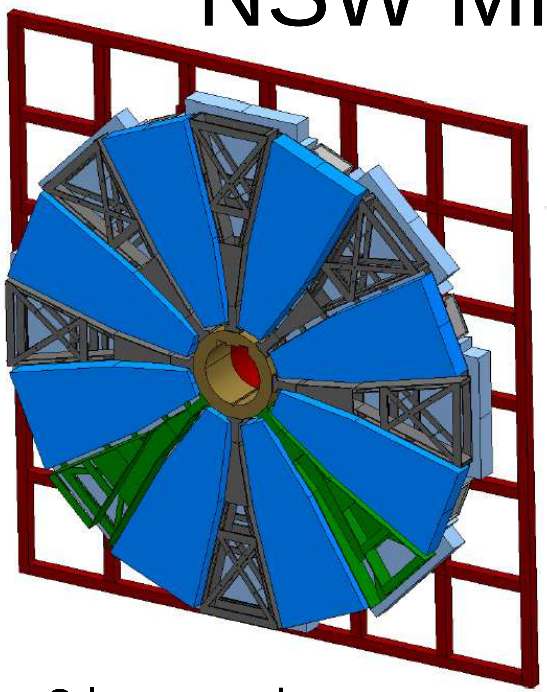






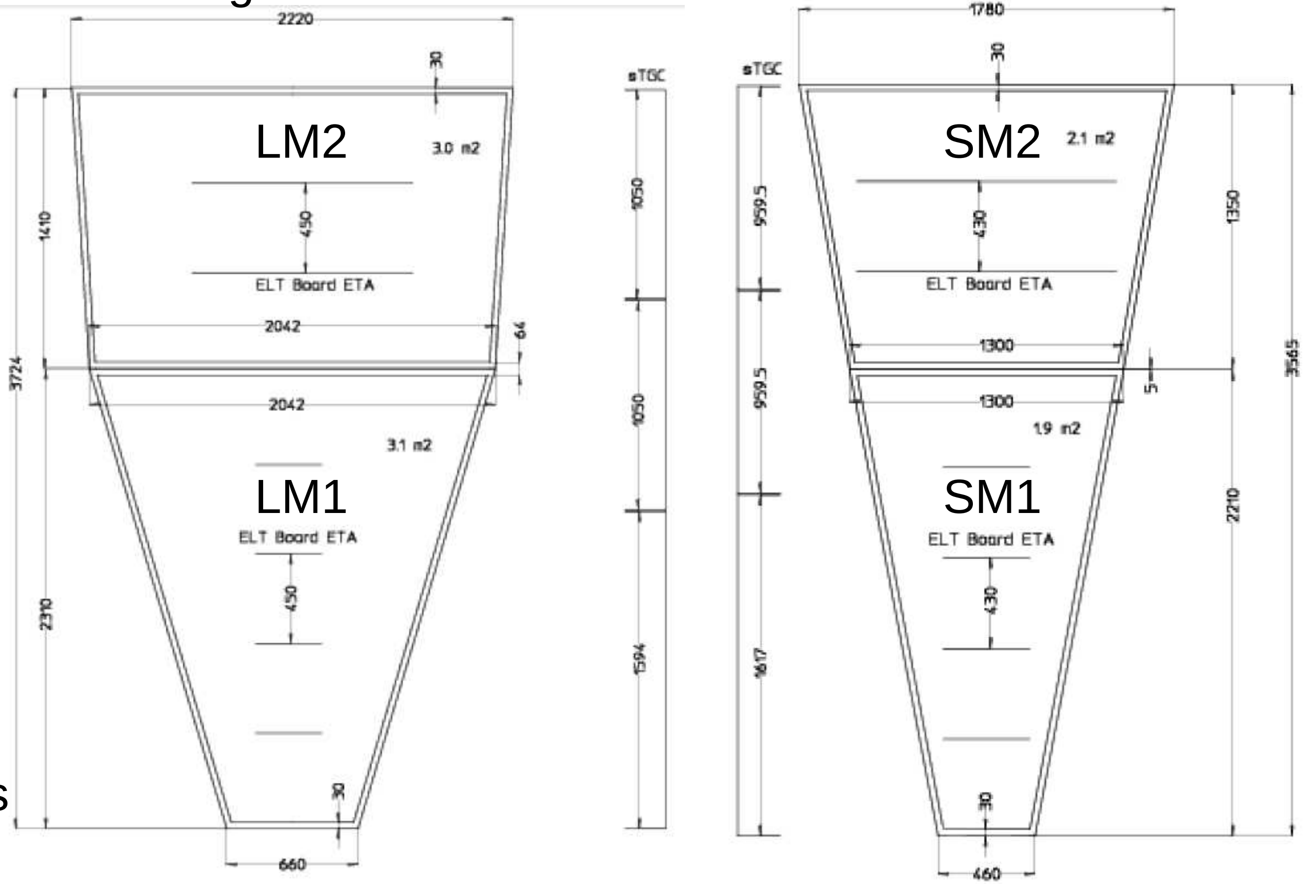
• Additional trigger information from frontend chips with 1 mrad angular resolution

NSW Micromegas Sector Layout



Large Module

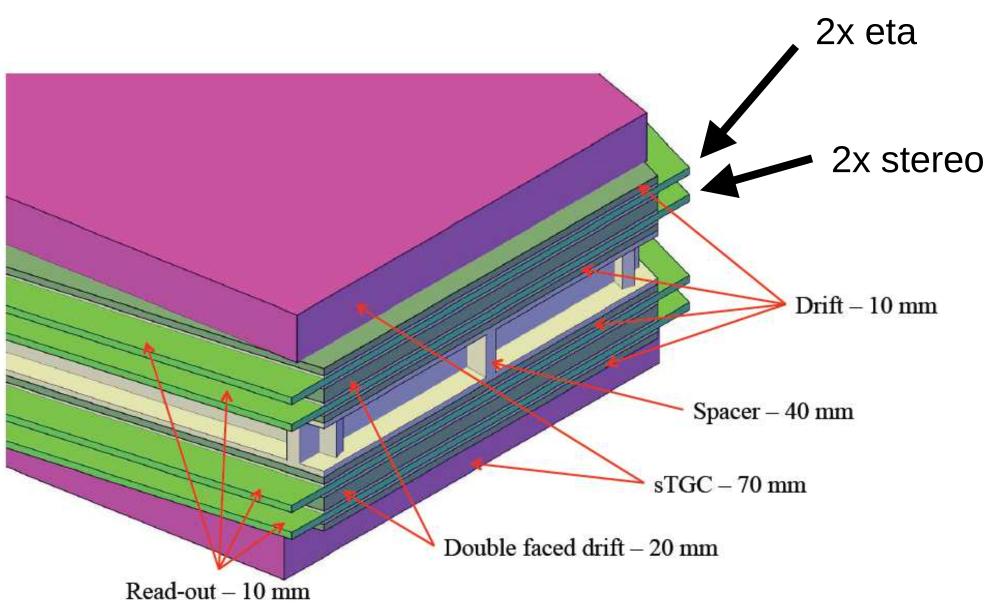
Small Module

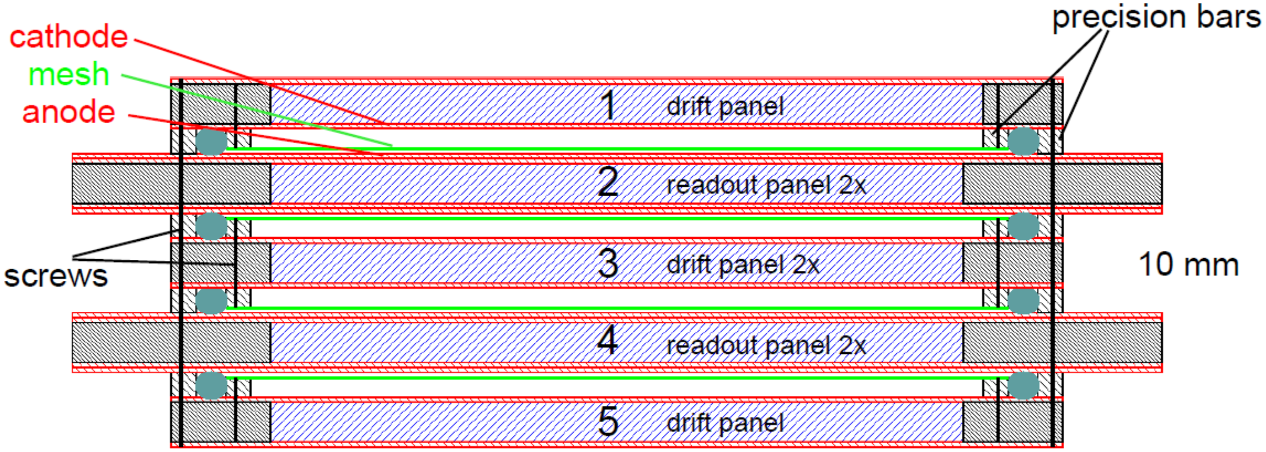


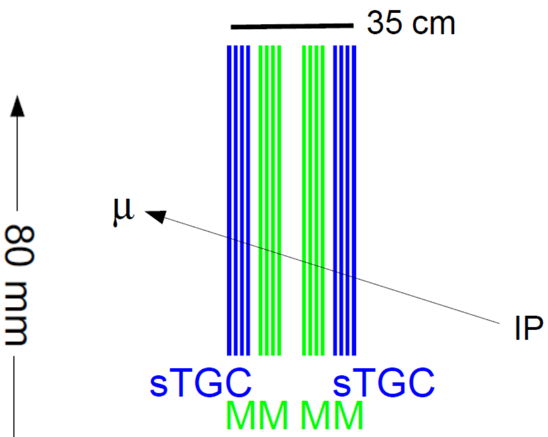
- 8 large and 8 small sectors
- 2 modules per sector
- Micromegas Module construction in institutes
  Italy: SM1
  France: LM1
  Germany: SM2
  Russia, Greece: LM2

NSW Micromegas Module Layout

- Eight layers Micromegas and 8 layers sTGC in total
- Micromegas: 2 layers eta plus 2 layers stereo strips
- 2 quadruplets per module with readout-panel back-to-back
- Precision requirement: 40 μm



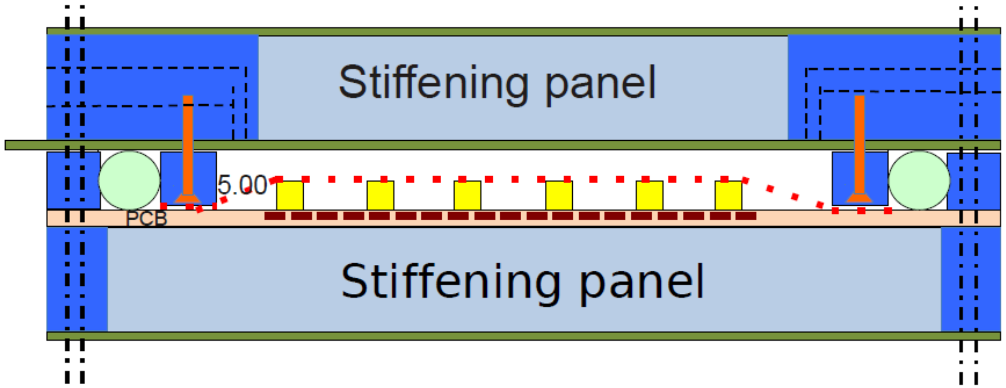


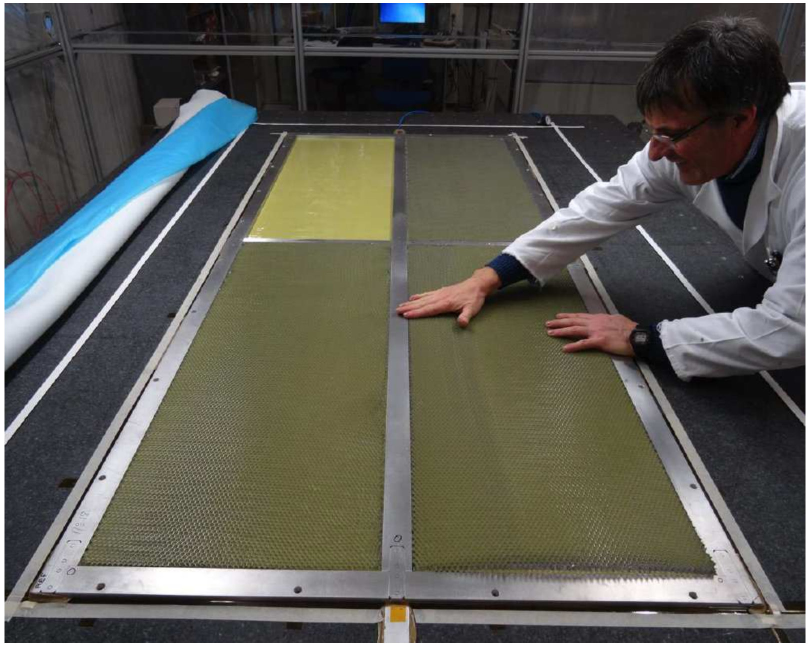


NSW Micromegas Panel Layout

• Drift panels carrying grounded meshs and readout panels are built separately and will be joined during module assembly

• Pillars on the readout structure assure precise mesh-anode distance





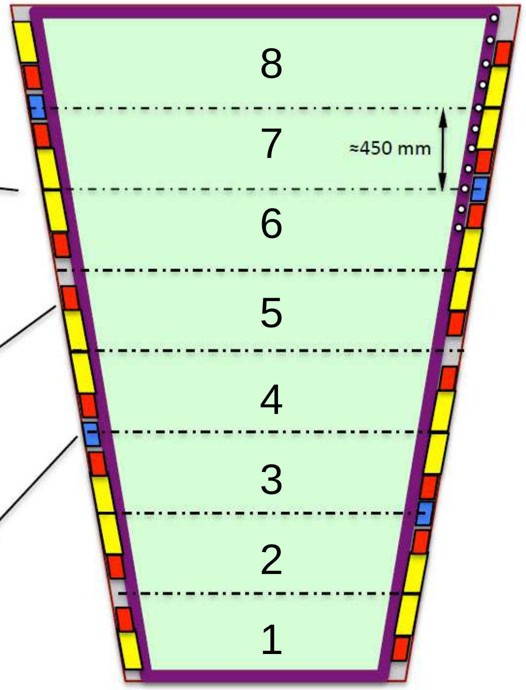
VMM Electronics

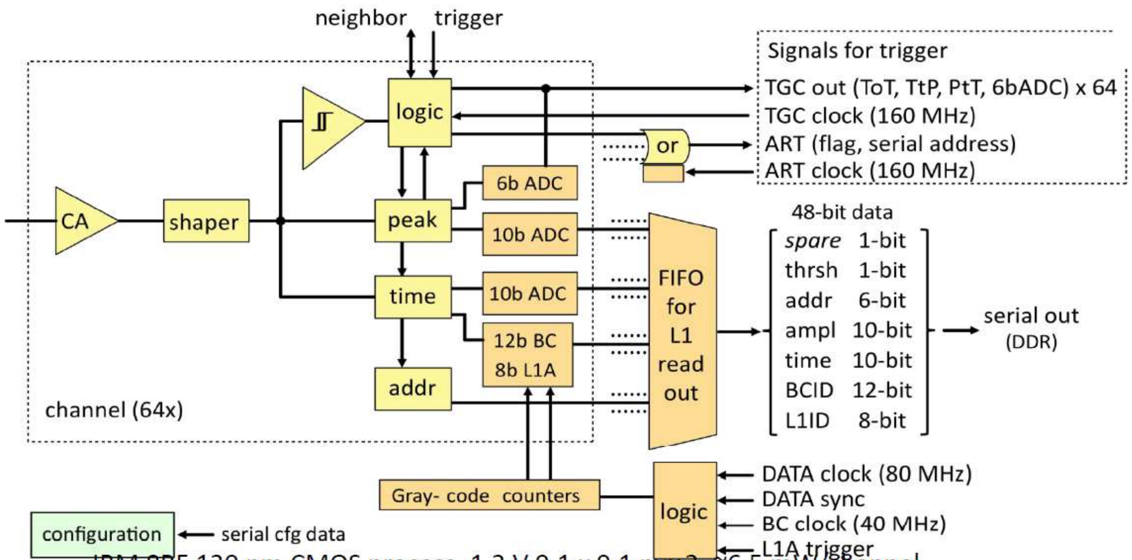
- Common frontend chip for Micromegas and sTGCs
- On-chip time and amplitude extraction and digitization => Zero Suppression
- VMM2 chip currently in production
- VMM3 for final detectors

Electronics boards
8 VMM chips à 64 ch
Total: 512 ch/board

GTB trigger boards
1 link 32 VMM chips
Total: 16 boards/mp

GBT data boards
1 link 64 VMM chips
Total: 4 boards/mp

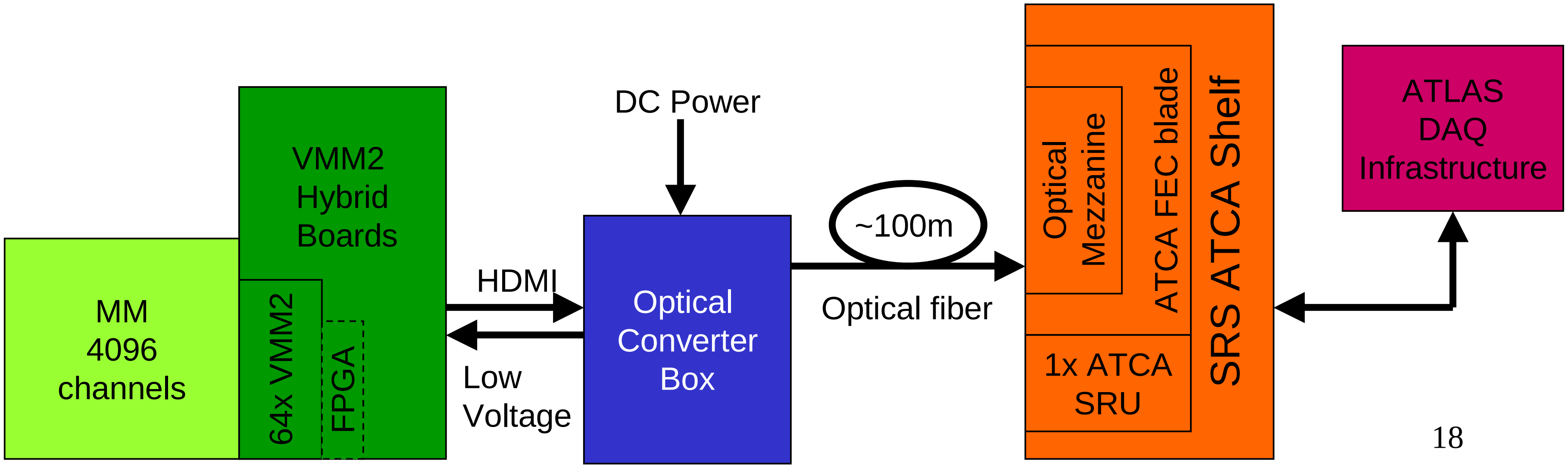




IBM 8RF 130 nm CMOS process, 1.2 V 9.1 x 9.1 mm2, ~6.5 mW/channel

1m x 0.6m Fully Working Quadruplet for ATLAS (2014)

- Installation of a precisely built pre-series
4-layer 4kch. Micromegas chamber during LS1 (2014)
- Full integration into ATLAS data acquisition infrastructure
- Test of detector design and electronics under real ATLAS environmental conditions
- Event-by-event comparison of Micromegas measurements with
Small Wheel data during Run II (2015 – 2017)
- DAQ electronics based on RD51 Scalable Readout System (SRS) and VMM2
frontend chip

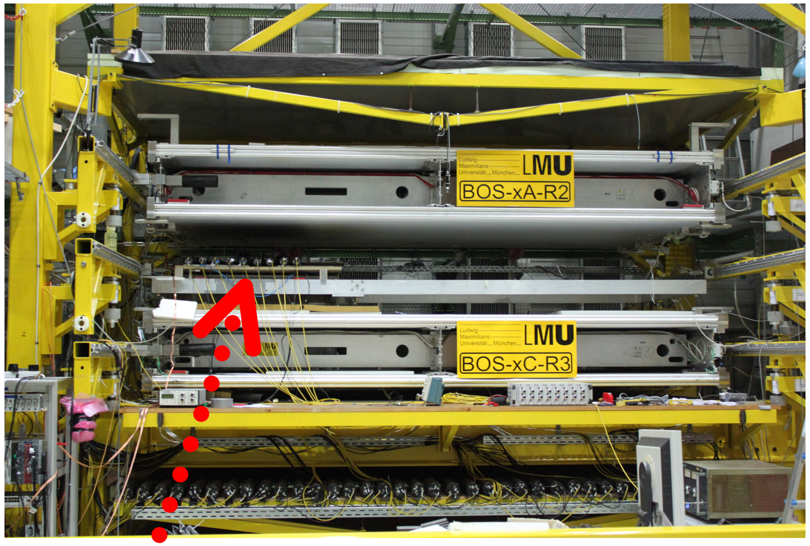


Electronics Integration Test Setup

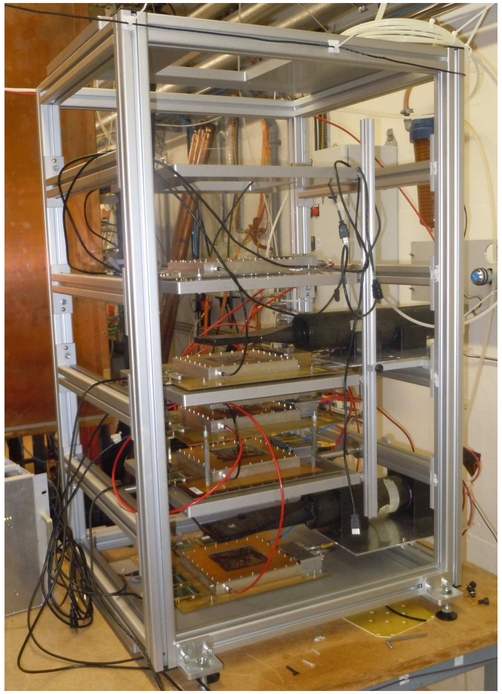
Validation of SRS-based DAQ infrastructure in different ATLAS-like environments:

• Test setup at CERN with Readout System (ROS) running ATLAS DAQ software

• Installation of 1 m² L1 Micromegas detector in LMU Munich Cosmic Ray Facility for track comparison with 9 m² MDT reference chambers, using ATLAS trigger and DAQ hardware



L1 Micromegas



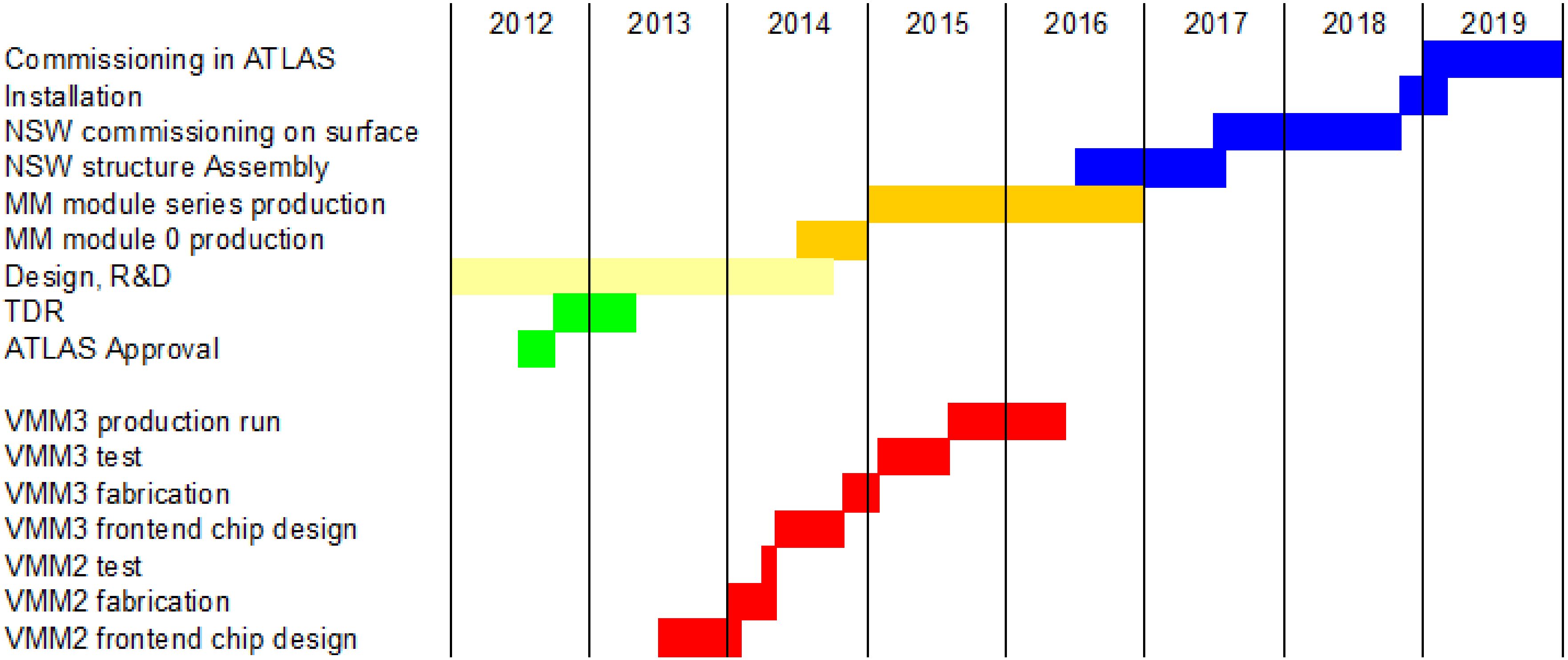
Readout of APV25 frontend chips

Up to 8k channels, zero suppressed data from 4 frontend boards

Tested at 70kHz+ trigger rate

No invalid data observed

Project status



Summary

• Future LHC luminosity upgrades will lead to rates in the ATLAS Small Wheels that are too high for the presently installed detectors

• During the LHC Long Shutdown 2, these innermost endcap muon stations will be replaced by New Small Wheels, which contain Resistive Strip Micromegas as precision tracking and trigger devices

• This high-rate capable technology shows an excellent spatial resolution over a large range of track angles. Its integration into the muon trigger will solve issues with fake muon triggers

• The size of the single detector modules reaches up to 3.1 m^2, containing more than 80 k readout channels each, for a total of 1 Mch. per wheel, resulting in the largest Micromegas detector system ever built

• A pre-series Micromegas chamber with 4096 channels will be installed on a Small Wheel already in 2014. Its integration into the ATLAS data acquisition infrastructure yields the unique opportunity to operate this chamber with four readout planes under real LHC conditions, and to study its performance within the ATLAS muon tracking system