ATLAS muon NSW

Conception, construction, completion and current status

A quick history from the beginning

27.10.2023

T. Kawamoto

Upgrade of small wheels → NSW

A major ‘phase-1’ upgrade

Installed during LS2

Started operation from 2022

A long time ago in a galaxy ….

- Discussions/studies of ATLAS upgrade have been around since ~ 2004, well before the completion of ATLAS detector and start of pp collisions.

- This is in the context of LHC luminosity upgrade, which is inspired by the fact that the lifetime (radiation damage) of the triplet (focusing) magnets comes after several 100 fb^{-1}.

- New triplets will be designed for replacement, and at the same time allowing much higher instantaneous luminosity: ~ 5×10^{34}. sLHC → HL-LHC

- Main interest of ATLAS (and CMS) was inner tracker.

- Muon system did not have specific idea of upgrade. Some worry about increase of cavern background : background hit rate -> performance degradation (MDT).
  - Some R&Ds started looking for muon detector for high rate

- Serious Muon studies started after the collision data have been collected (essentially from 2010): hit rate measurements, and some surprise.

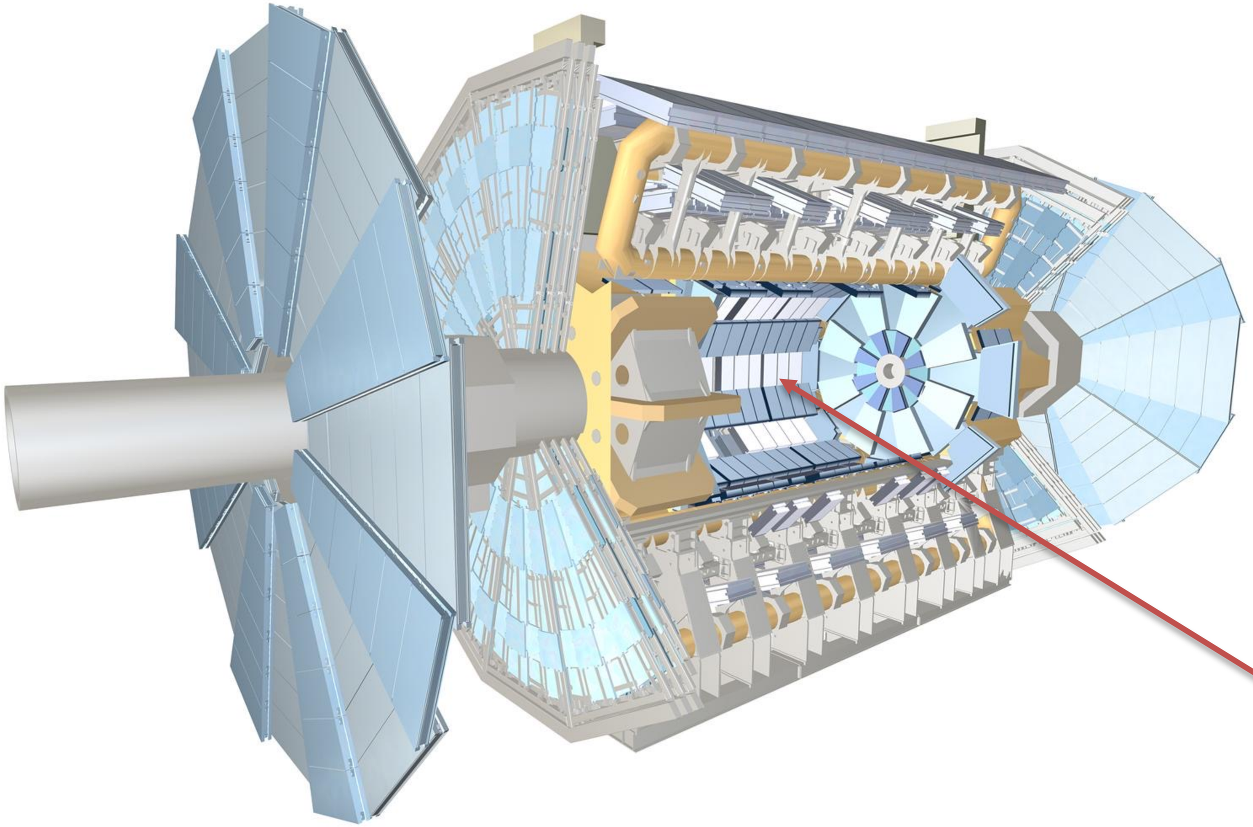
Cavern background

The space outside of the calorimeter
Is filled by huge number of particles
(mostly low energy).

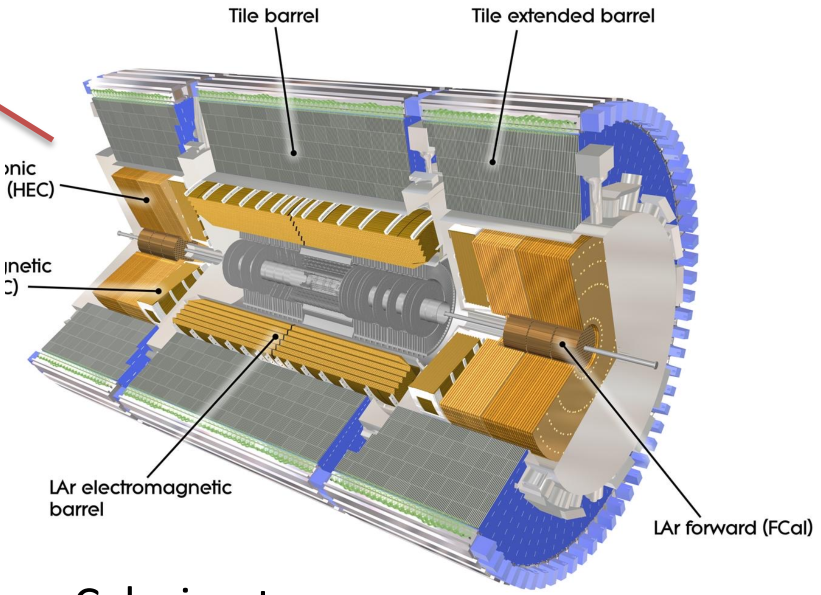
- Leak from calorimeters
- Leak from beam pipe shieldings

The muon system is irradiated by the
“cavern background” particles

- Background hits
- Radiation damage

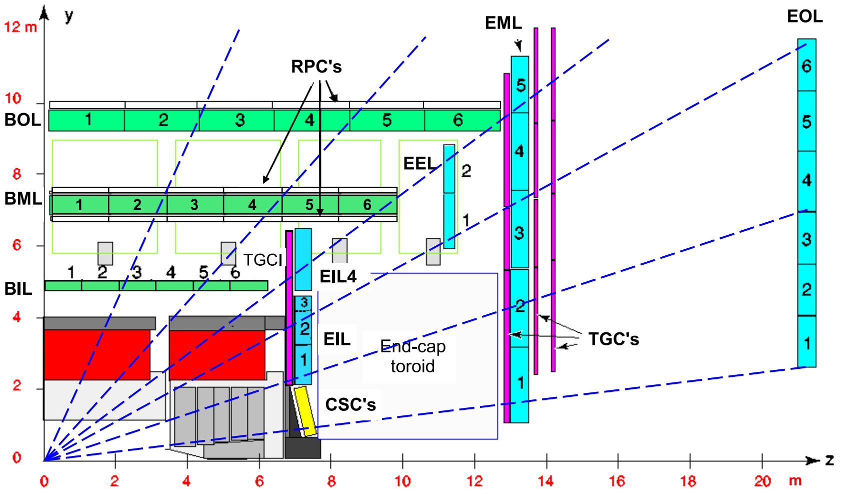


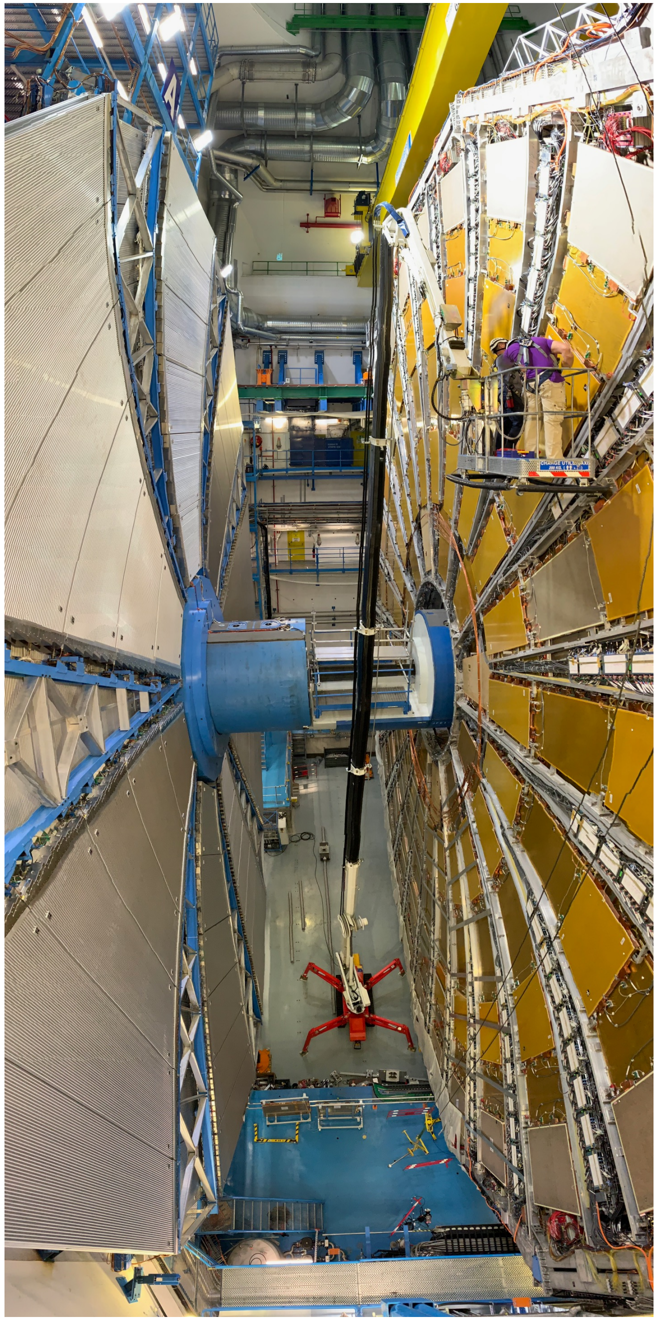
Muon system



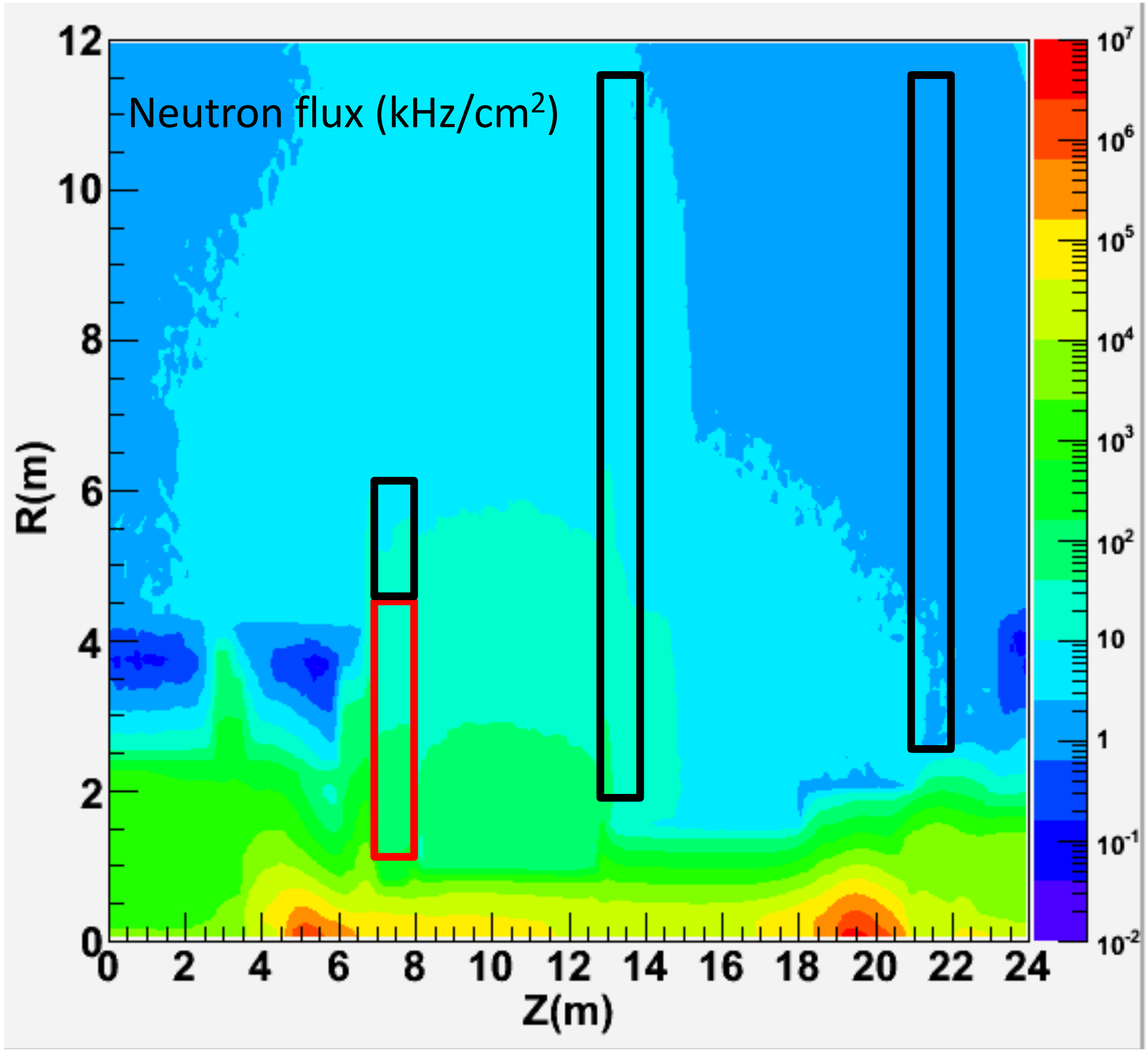
Calorimeters

ATLAS muon detecter original





Cavern background



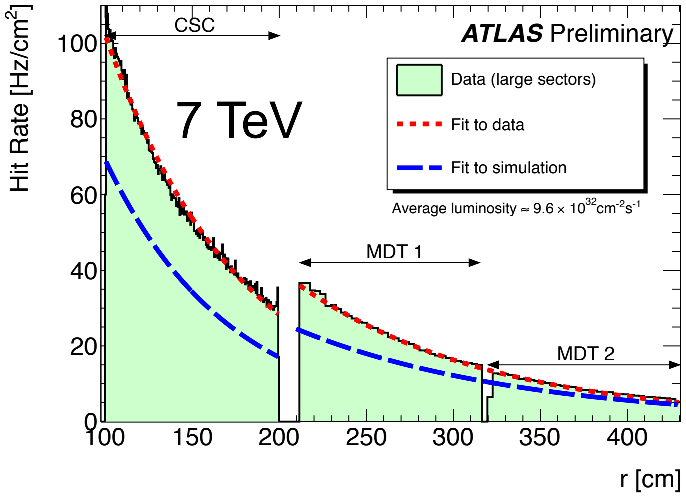
Mostly low energy photons, and neutrons
+ much lower level of charged particle flux.

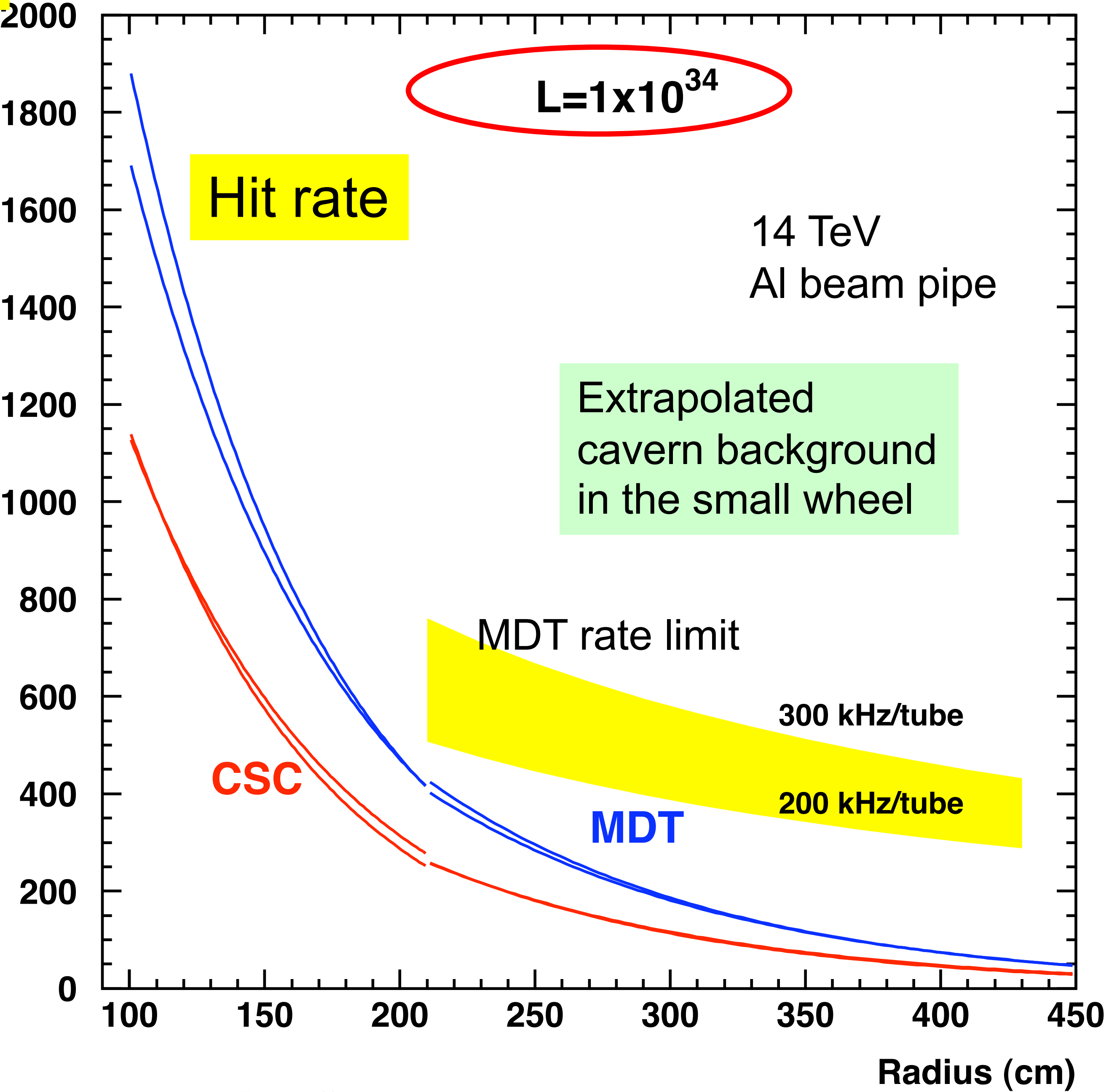
Muon detector and electronics were designed based on the estimation (simulation available at that time) + safety factor (typcally x5), but for the design luminosity ($1x10^{34}$).

Cavern background

1×10^{34} is OK, but
little margin
for higher lumi

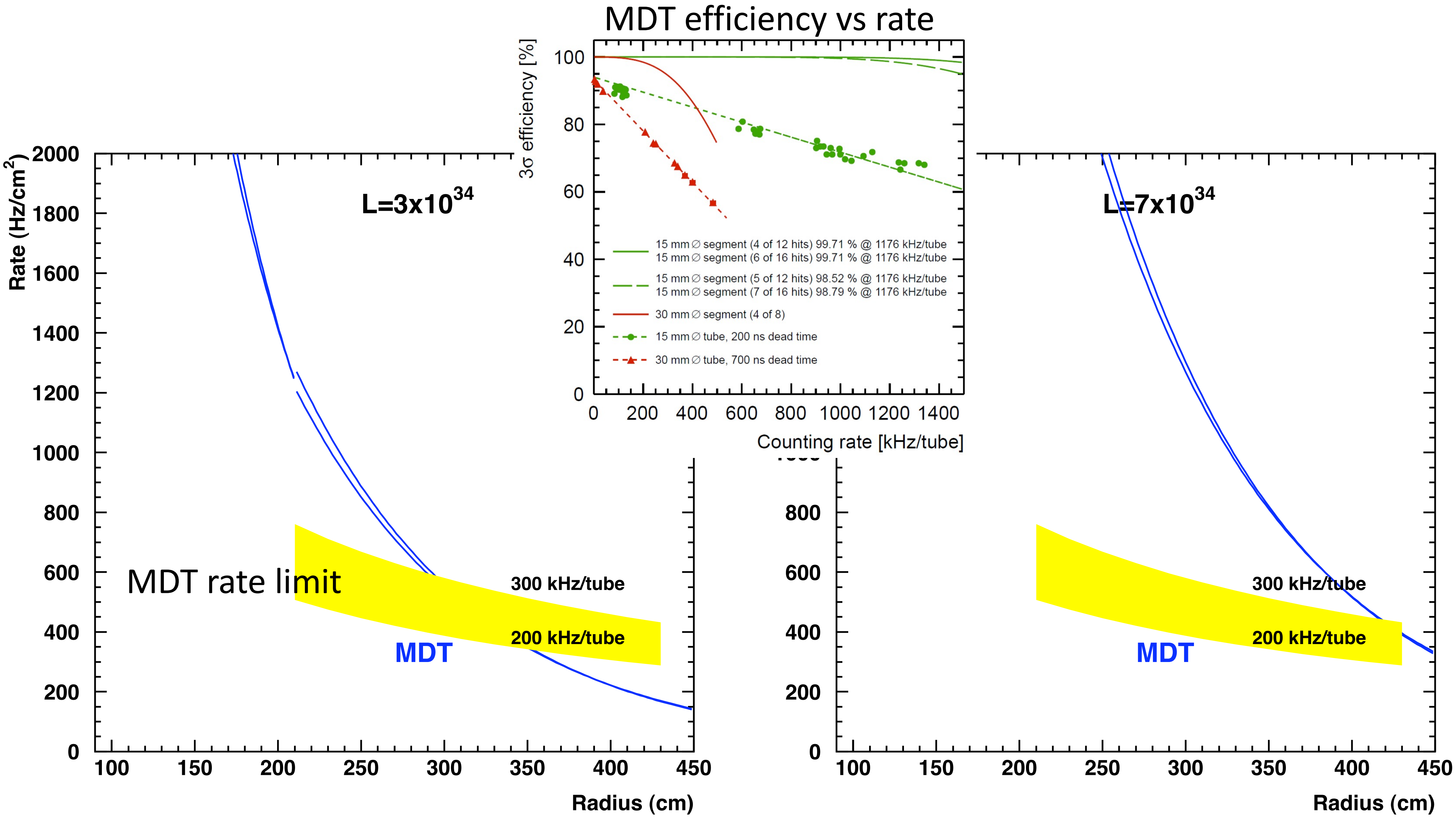
Measured
cavern background
in the small wheel





Extrapolated
cavern background
in the small wheel

MDT cavern background issue



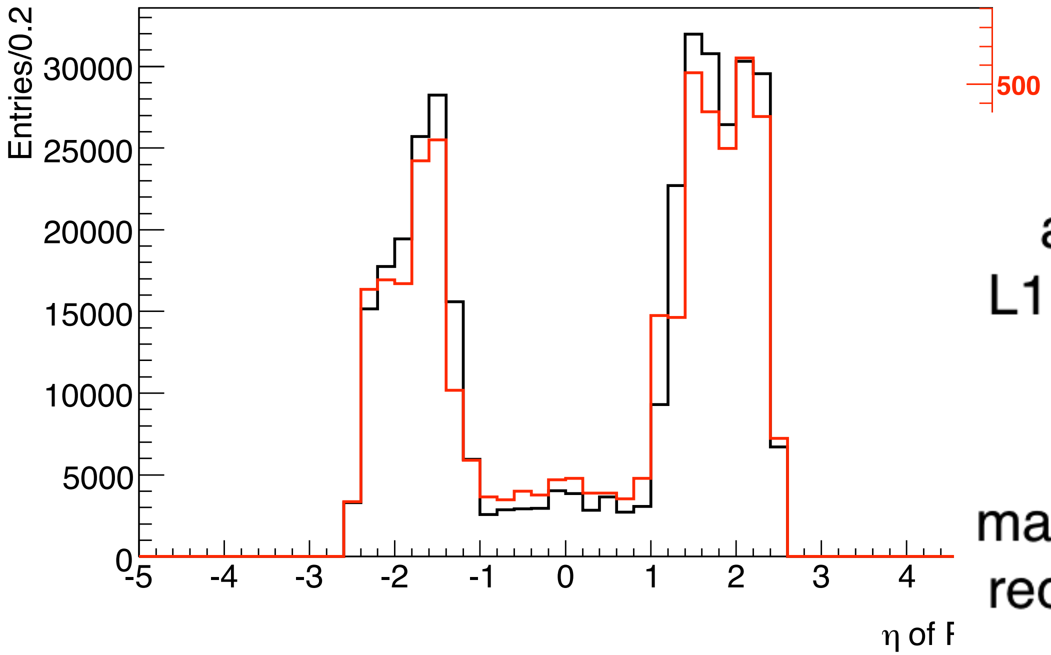
MDT (and perhaps CSC) of Small Wheel will need upgrade for high luminosity.

More serious problem : Muon L1 issue

Background trigger will saturate the L1 bandwidth at high lumi

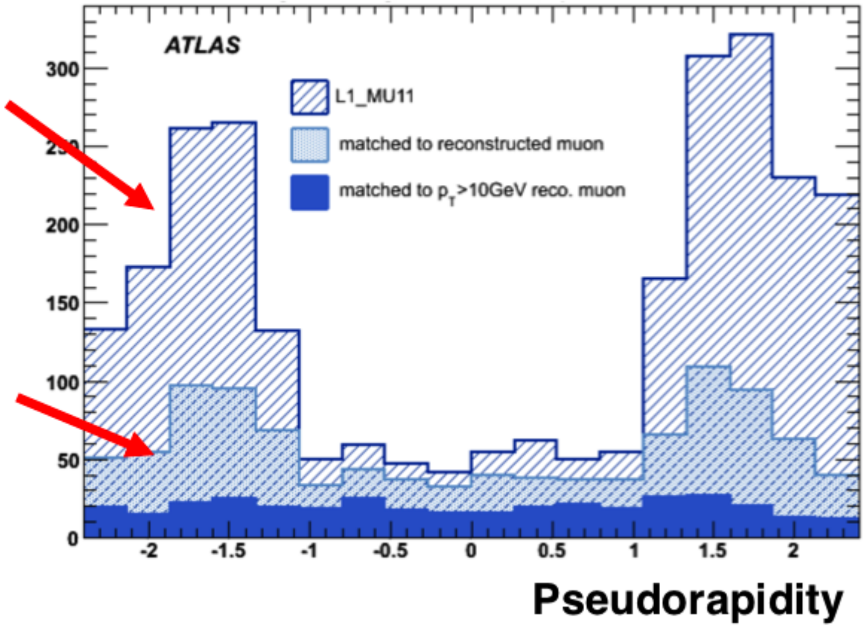
MU20 vs η 2010/2011 data

50 ns interval



all muon L1 triggers

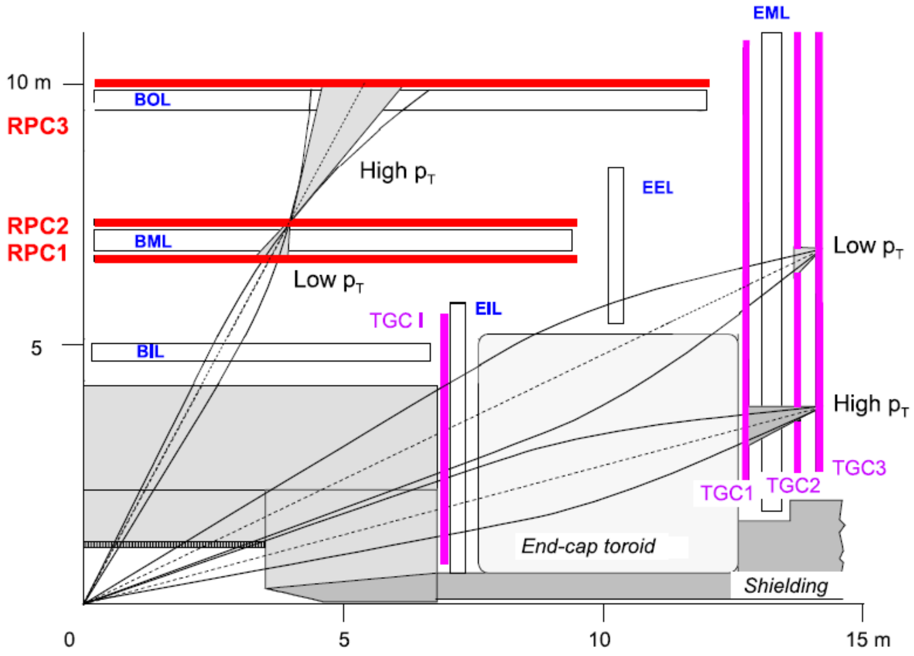
matched to reco muon



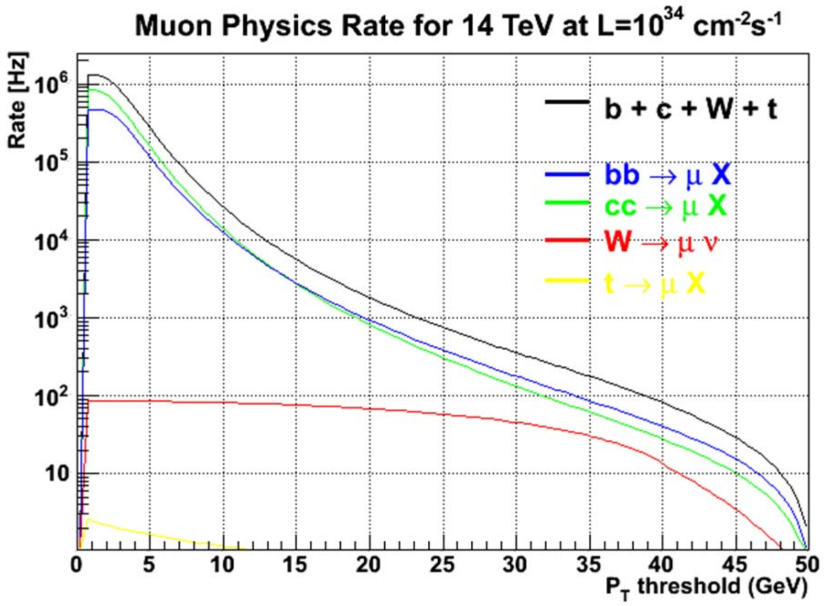
- A-C asymmetry

suggests that the background particles are charge asymmetric, combined with the toroidal field.

Endcap muon trigger chambers

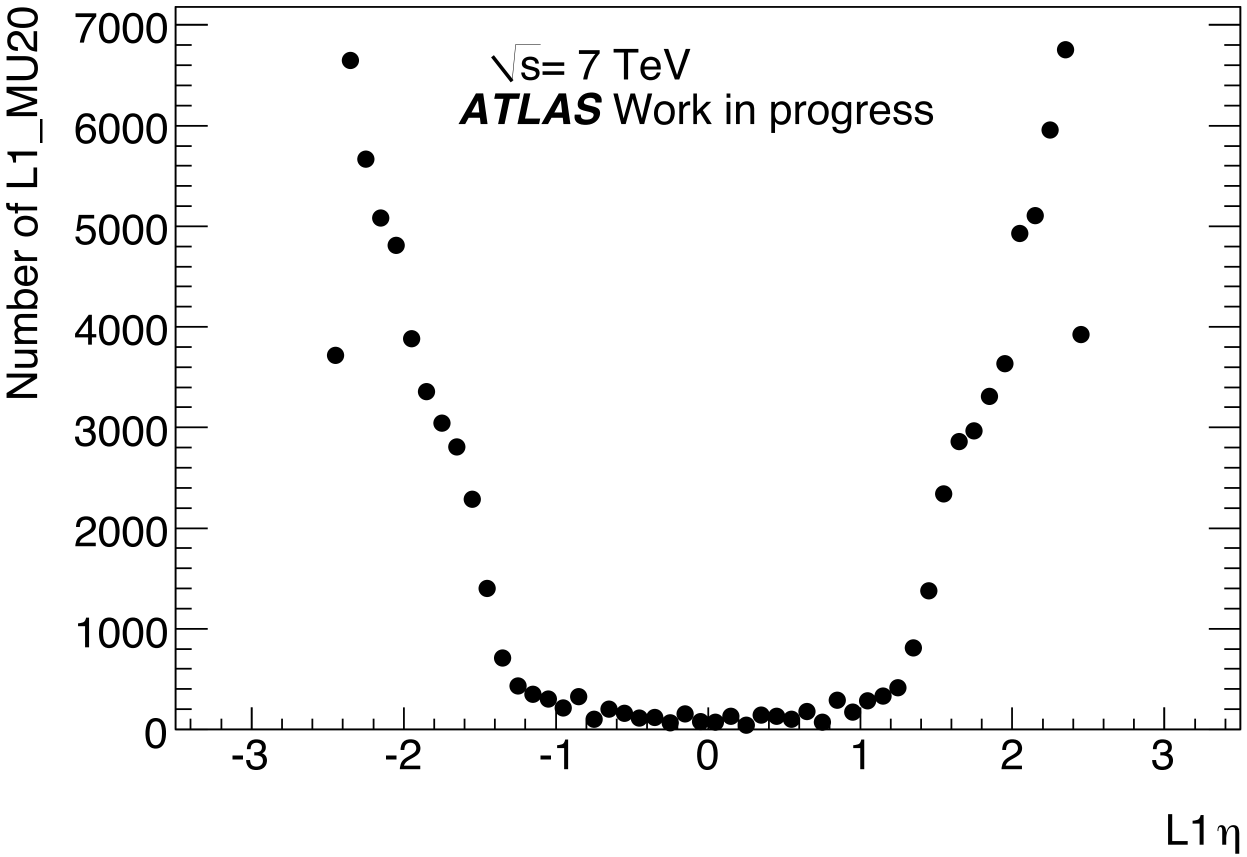


► Cross sections



Muon L1

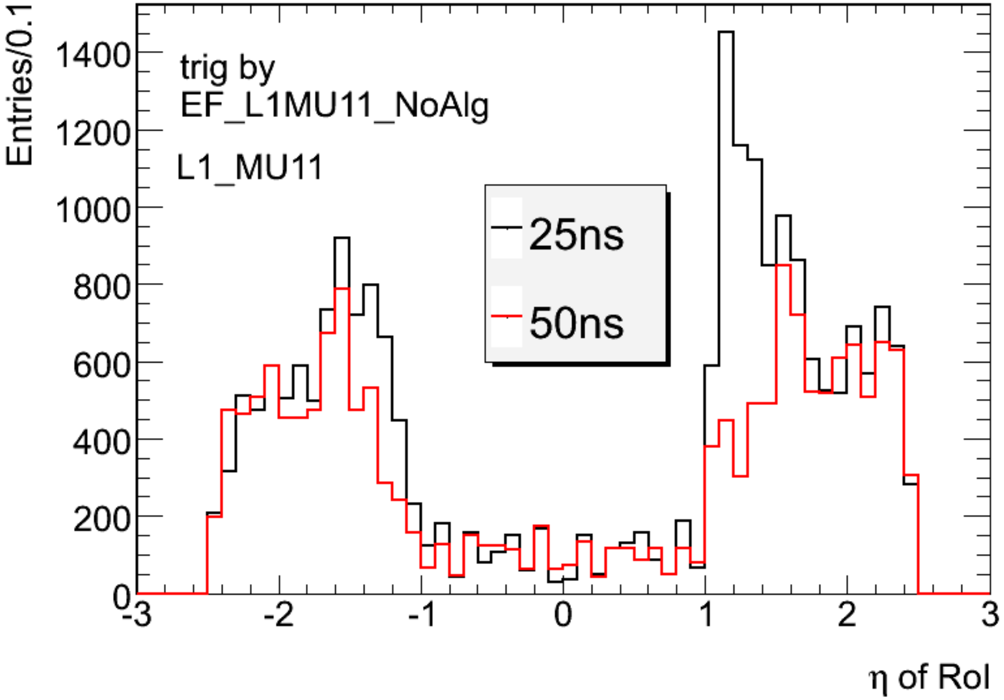
Toroidal field OFF data



F-B symmetry restores when magnet is OFF

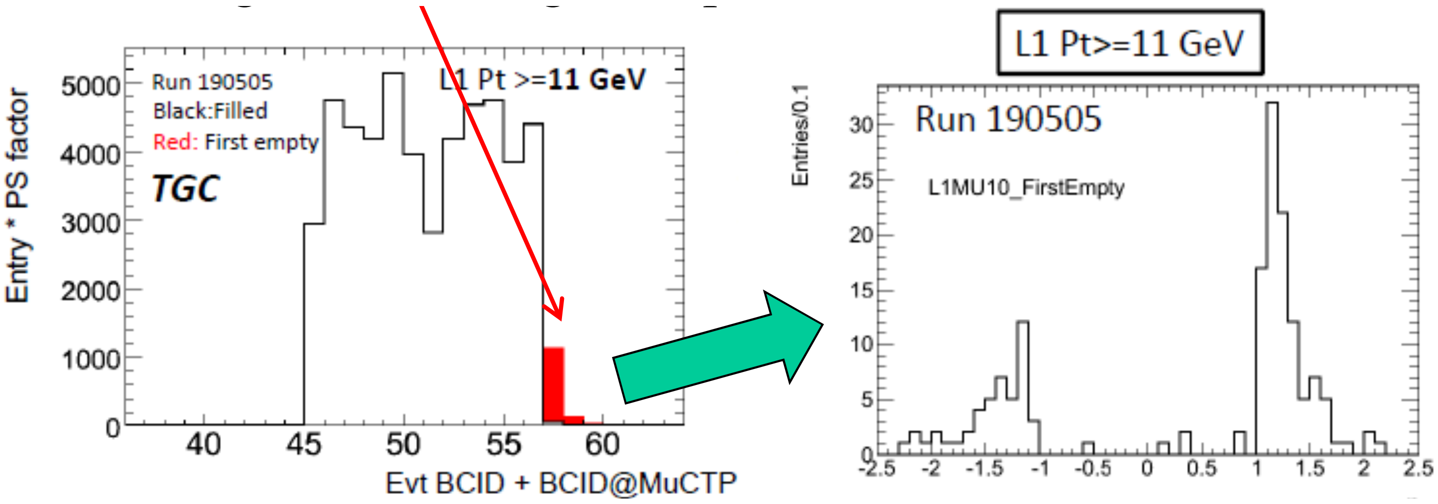
Suggests charge asymmetry of particles

MU11 vs η 25 ns test in 2011



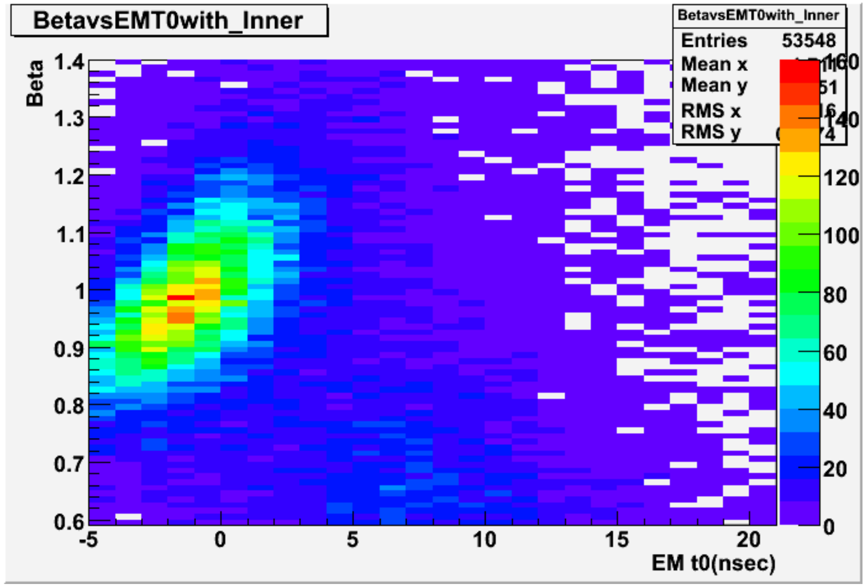
Additional rate at small η (large R)

Slow particles : out of time, but captured at the next bunch crossing with 25 ns interval.

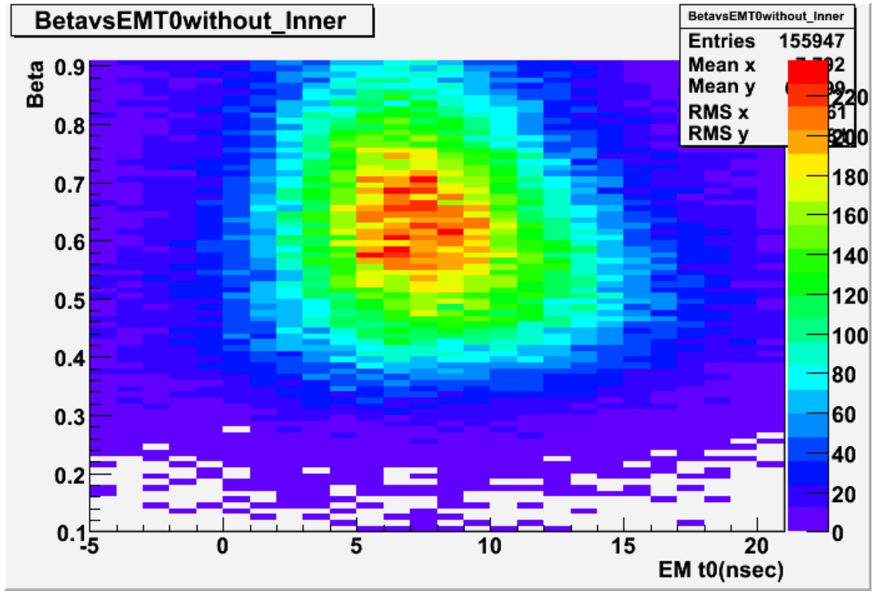


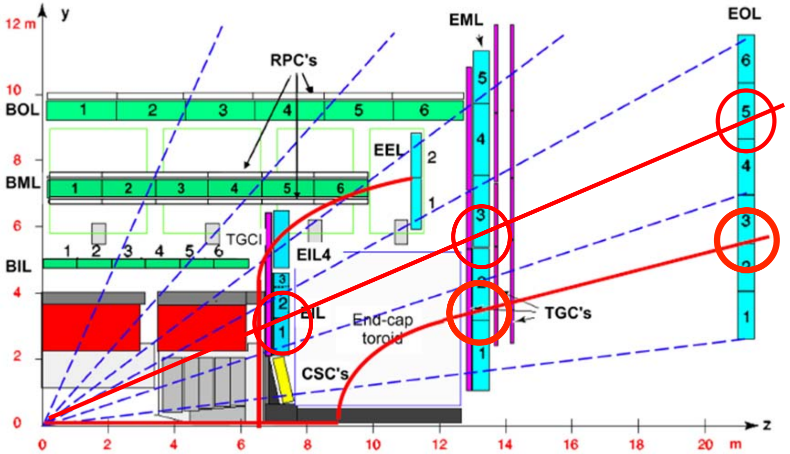
Study of TOF between EM and EO (using T0 refit of MDT data)

With EI hits : β ~ 1



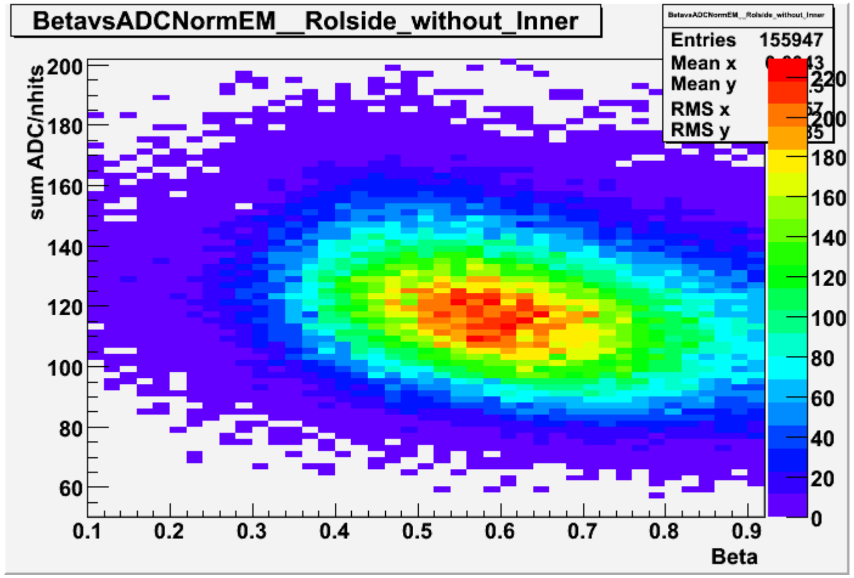
Without EI hits : β ~ 0.6

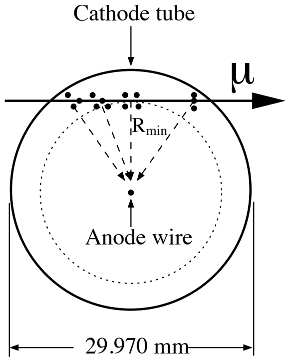


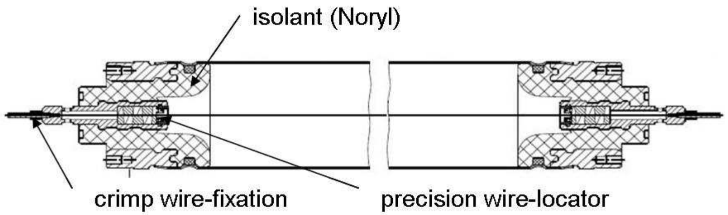


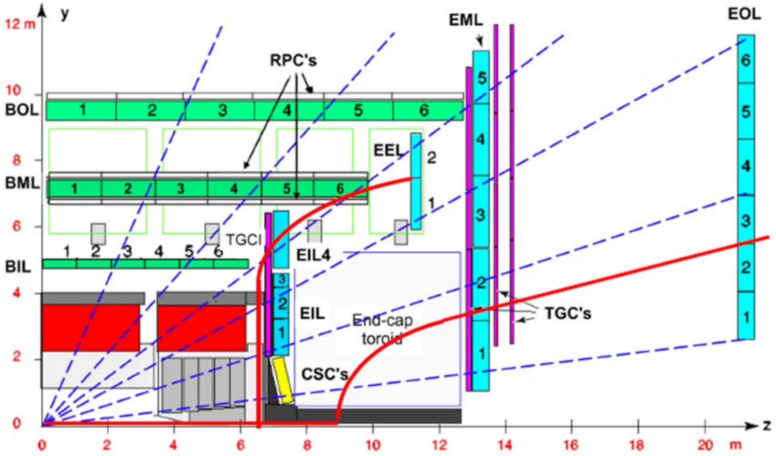
Suggests the background particles may be protons of p ~ 1 GeV

dE/dX vs β



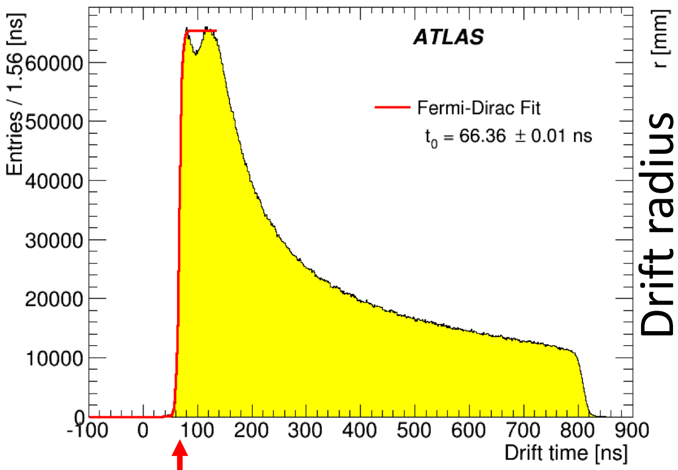






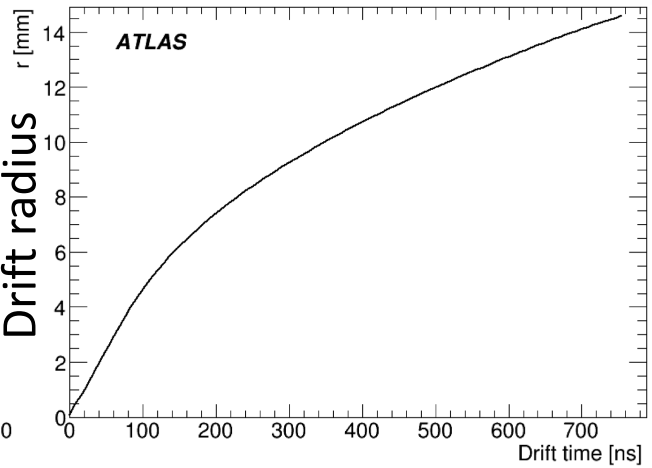
40 ns

65 ns



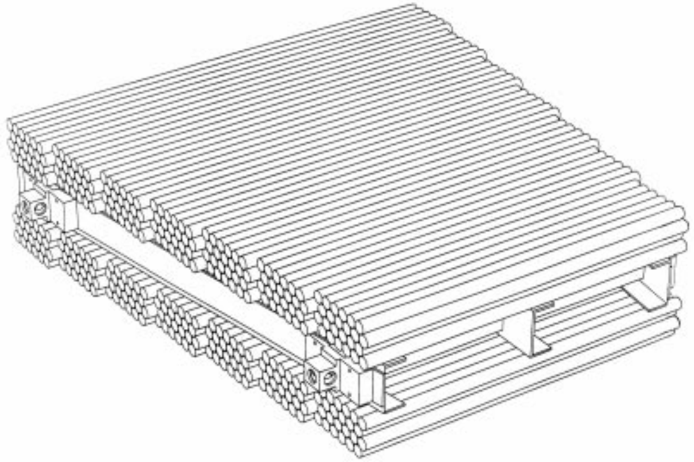
time spectrum

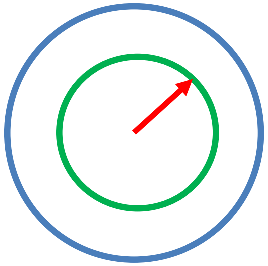
t_0



Drift radius

Drift time

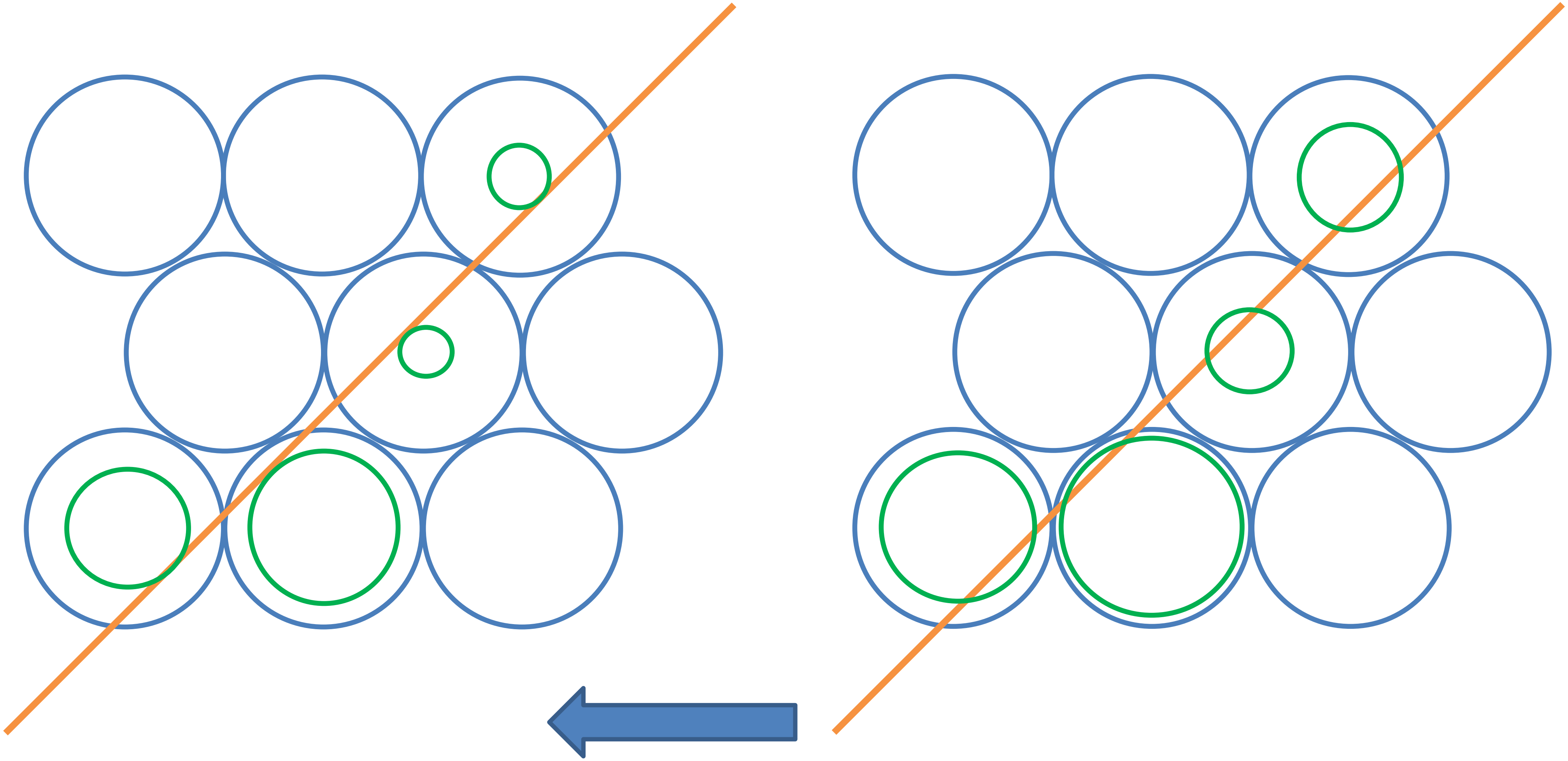




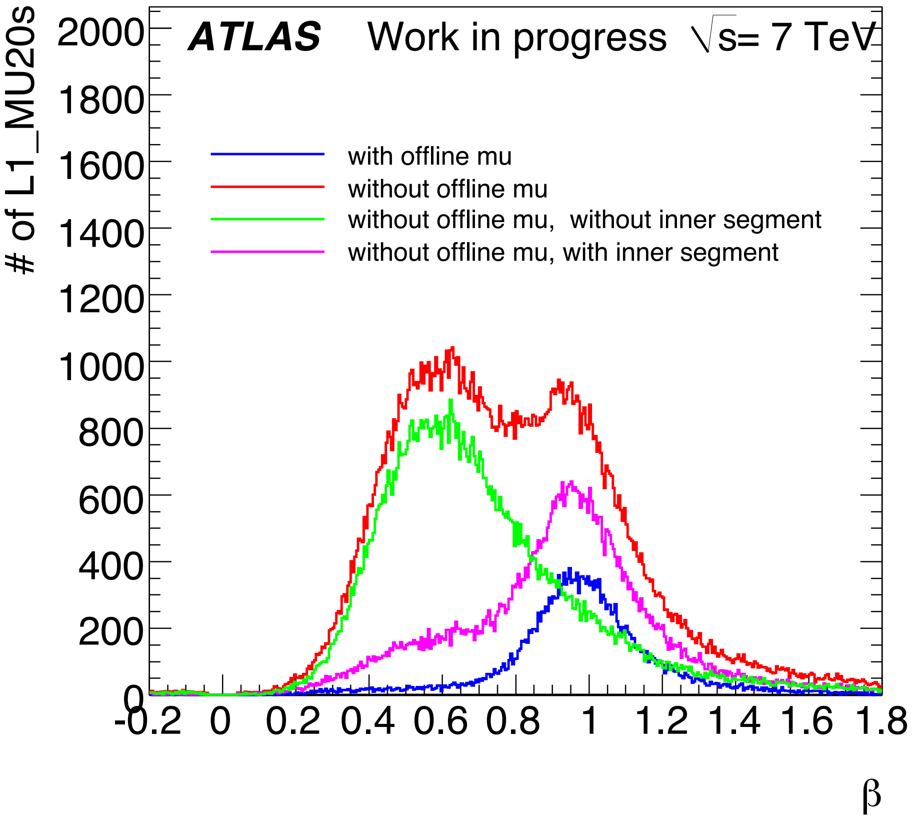
Time measurement → Drift circle

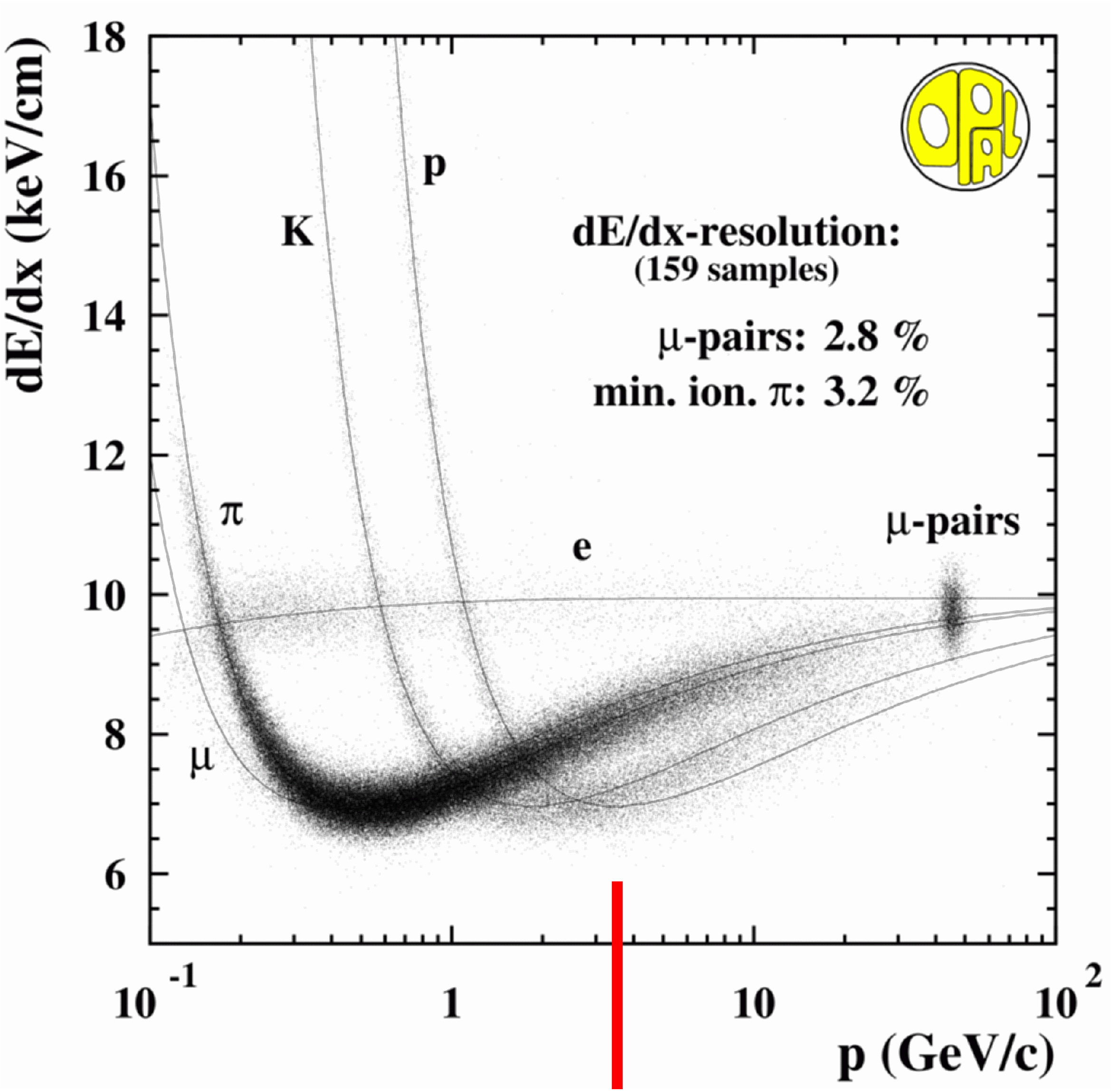
A particle of correct timing ($\beta = 1$)

Late arriving particle ($\beta<1$)



t_0 adjustment (t_0 refit) : determination of precise timing

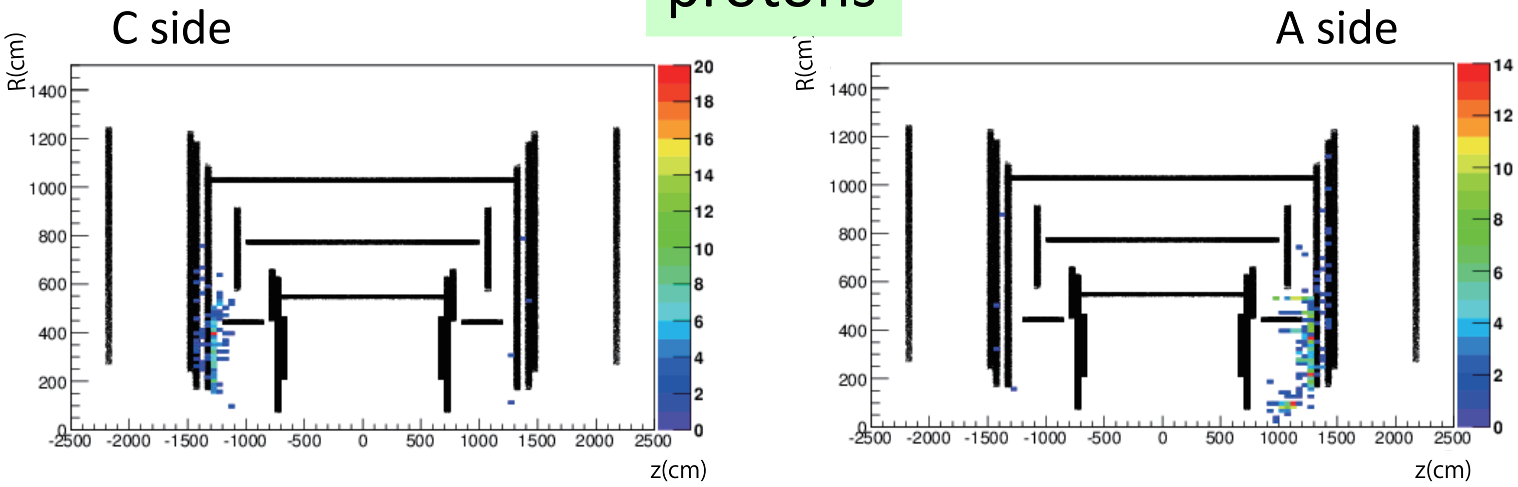




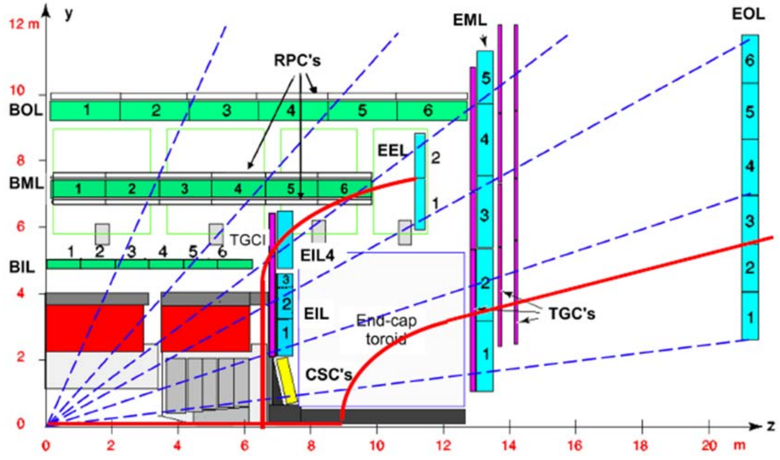
- Without offline μ, without EI hits
- With offline μ, with EI hits

Monte Carlo simulation

protons



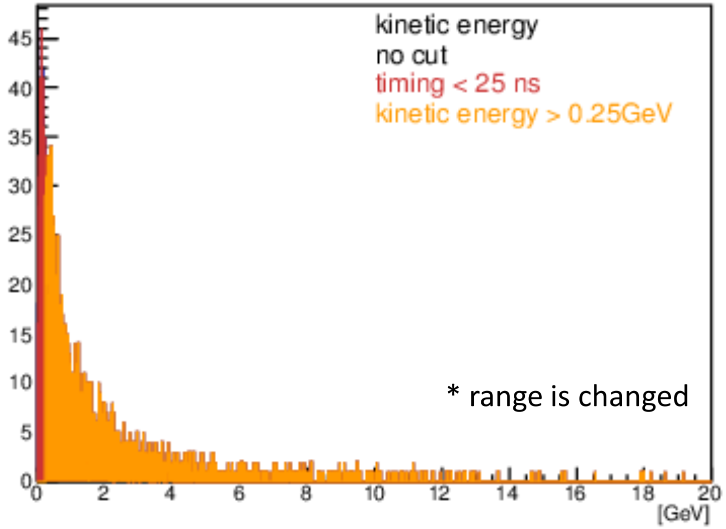
Map of birth positions of fake trigger particles



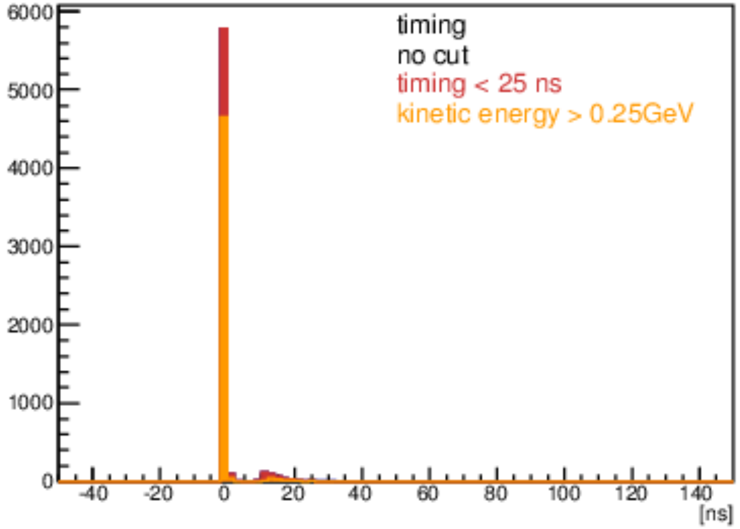
Interpretation

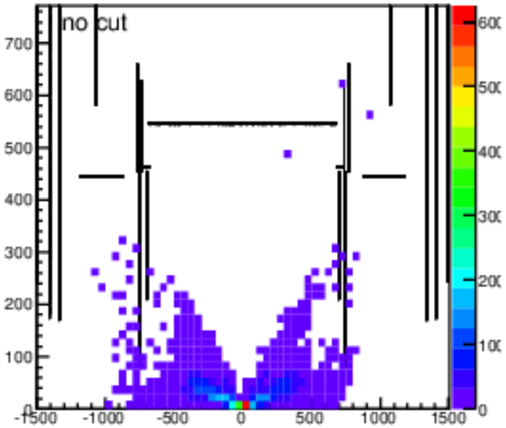
Fake muons are due to protons resulting from complex nuclear reactions in front of EM station.

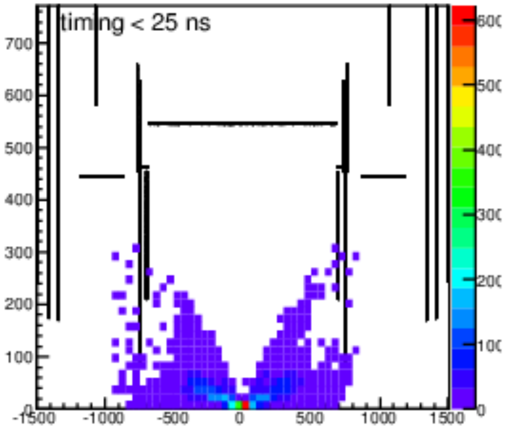
for comparison, $\mu+$

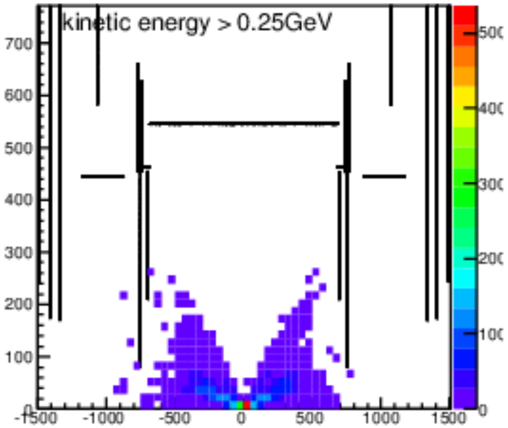


* range is changed

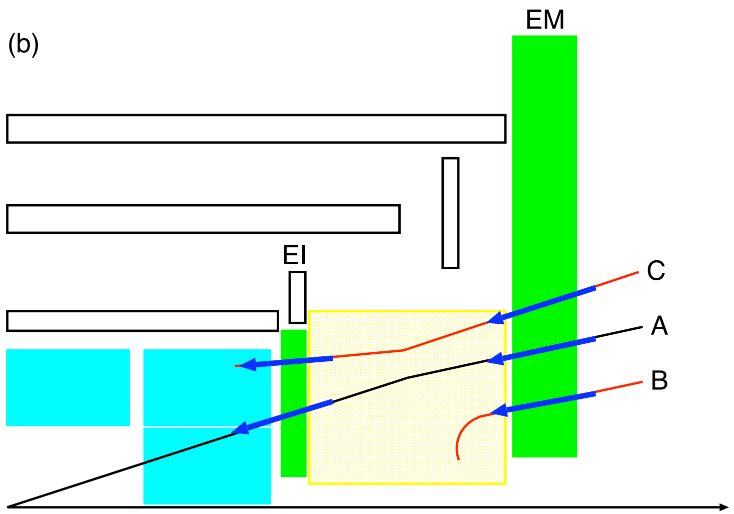








Doing these studies and considerations, idea converged to a new small wheels.



- Precision tracker that works at high rate (including the phase 2 environment)
- Provide real time EI segments to validate the EM L1 segments
- Tracking performance as good as the existing small wheel

+ good online angular resolution (1 mrad) to allow better P_T resolution (sharper L1 threshold) at Phase-2 combined with improved EM angular resolution (e.g. using MDT).

Proposals of detector technologies and launch of R&Ds

sMDT(small tube), sTGC(small strip), mRPC(narrow gap), MM(mpgd), ….

ATLAS LoI for phase-1 upgrade CERN LHCC-2011-012 (November 2011)

Several detector options

- sMDT (tracking) + sTGC (trigger + tracking ϕ & R)
- sMDT (tracking) + mRPC (trigger + tracking ϕ)
- MM (tracking + trigger)

Towards TDR, technology choice

Workshop at Le Brassus (Suisse Jura) Jan. 2012
→ insead of converging, .. another proposal sMDT+sTGC (Outer) + MM (Inner)

Totally confused. → Further discussions

Eventually converged to the present NSW design after ~ 1 year of many discussions and additional R&D milestones

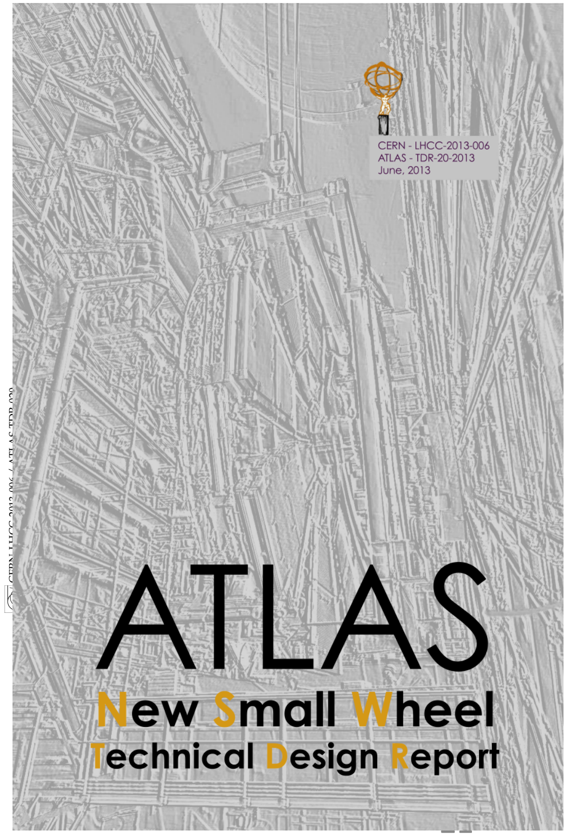
High redundancy was one of the reasons.

two technologies for both tracking + trigger

Technical Design Report

- Initial design review : with sTGC + MM proposal,
  but with milestones to be achieved by the end of the year
- Kick off institute meeting August 2012 ~ 50 institutes
- NSW milestone review Jan 2013 Aix les Bains
- EB approval
- CB approval
- TDR & iMoU

NSW TDR CERN-LHCC-2013-006, June 2013



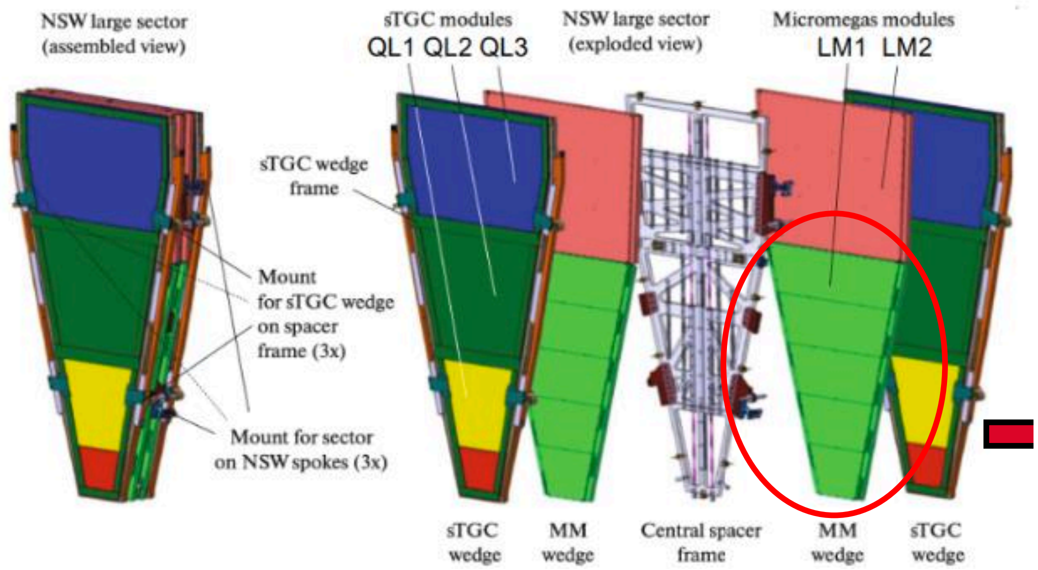
CERN - LHCC-2013-006
ATLAS - TDR-20-2013
June, 2013

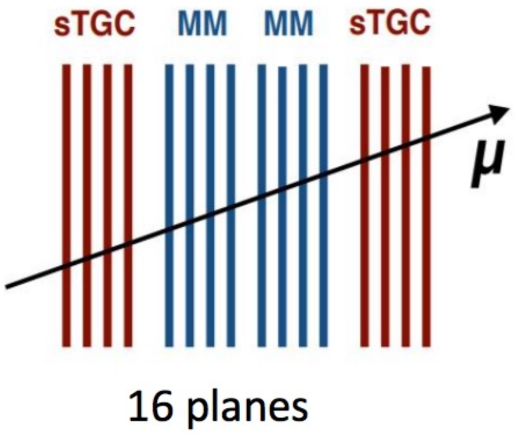
ATLAS
New Small Wheel
Technical Design Report

In the meantime, the TGC of the old SW and Tile signal were included
In L1 In coincidence with EM → reduction of rate as expected,
Justifying the basic idea of NSW for rate reduction.

NSW overview

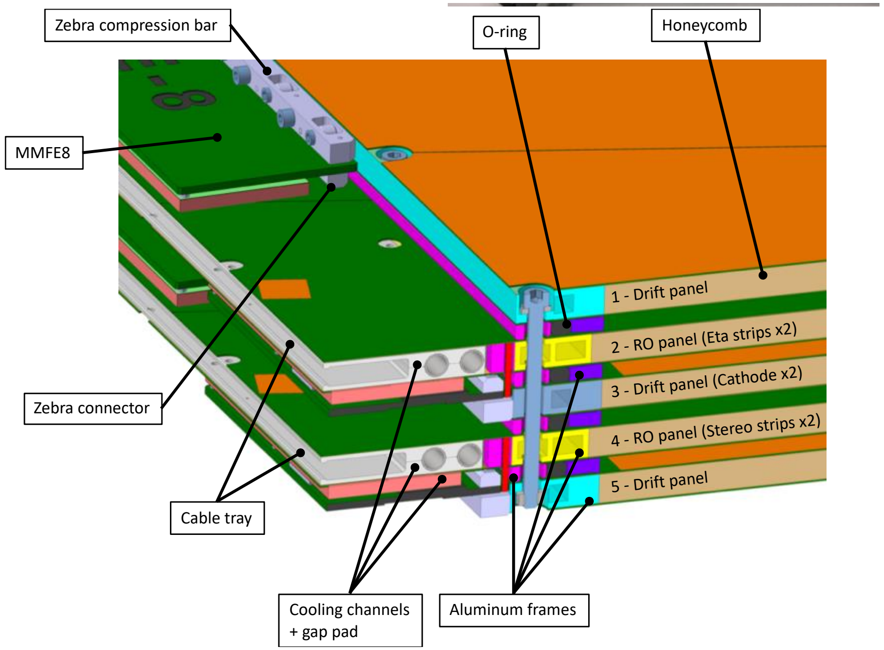
I myself was involved in development and construction of MM chambers at Tokyo and Saclay

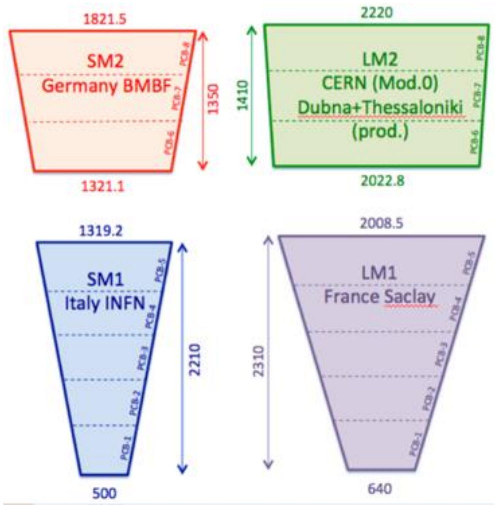




MM chambers

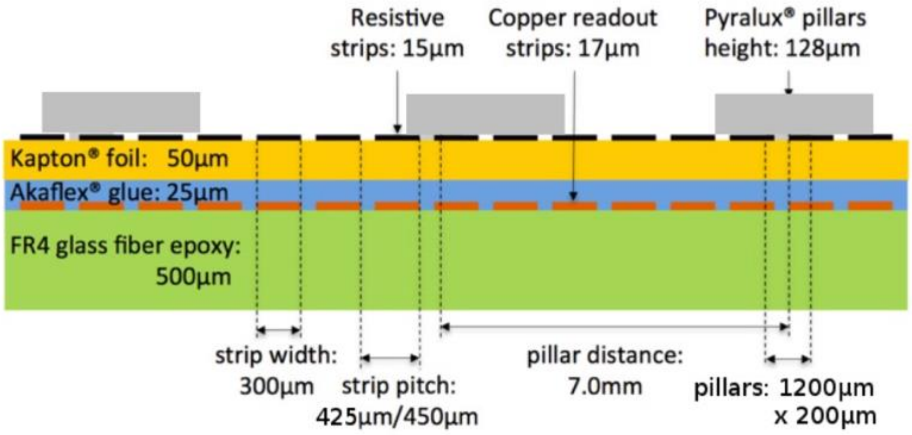
Basic quadruplet unit





4 construction sites:
- SM1 → Italy/INFN
- SM2 → Germany
- LM1 → France/Saclay
- LM2 → Russia/Dubna – Greece/Thessaloniki (+ Cern)

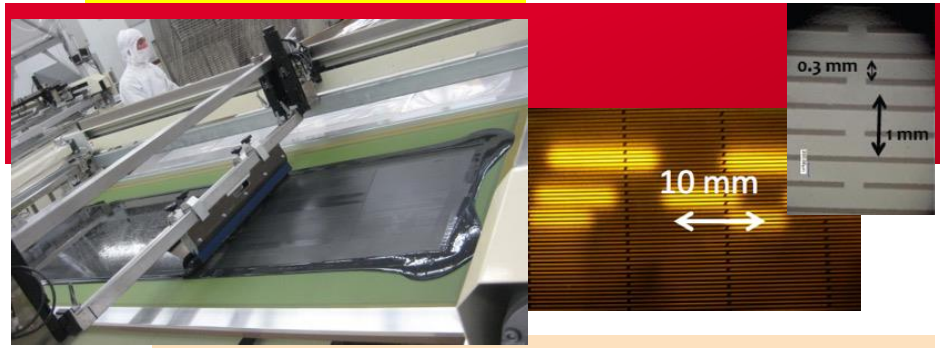
MM chambers



- 1022 strips/board
- Readout strips: 300 µm width, 425 or 450µm pitch
- Screen-printed resistive strip pattern with same pitch
- Resistive strips interconnected; pattern interrupted in the center → two HV sections per board
- HV supply via silver line from the side
- Elongated pillars: 1200µm x 200µm
- Readout strips routed to pads for elastomeric connectors (Zebra)

MM chambers

Board Production Process



Typical resistivity ~ 10-20 MΩ/cm (~800 kΩ/□)

I. Photolithographic creation of copper pattern
standard process.
complex due to: size of board, required precision & board elongation (humidity).

II. Cutting of Kapton foil with resistive pattern
non-standard but simple & required accuracy only ±1mm

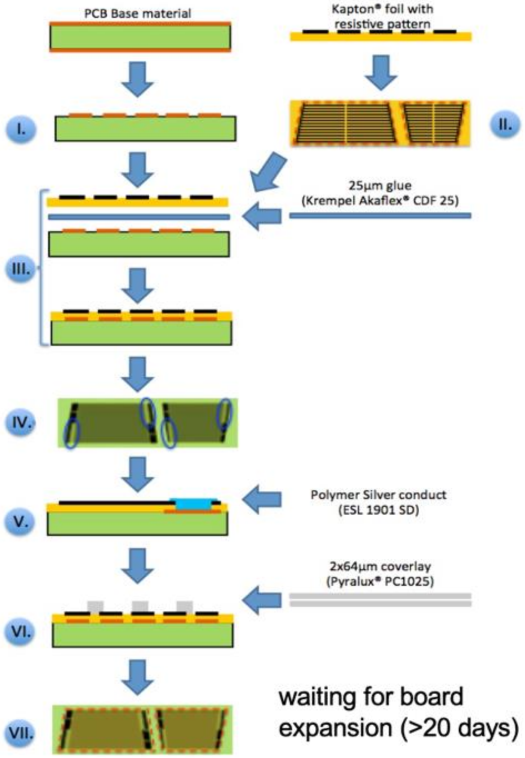
III. Stacking and gluing at high P&T of Kapton foil, glue foil and board
standard process for small boards
complex due to: size of board & required cleanliness.

IV. Chemical silver plating of copper pads
standard process

V. Screen-printing of silver paste
non-standard but rather simple & required accuracy only ± 1mm

VI. Lamination of coverlay & pillar creation
standard process for small boards.
complex due to: size of boards, highly non-standard pattern, required flatness

VII. Cutting of boards and drilling of non-precision holes
standard process on CNC machine.
complex due to size of boards, required cutting precision & board elongation (humidity).

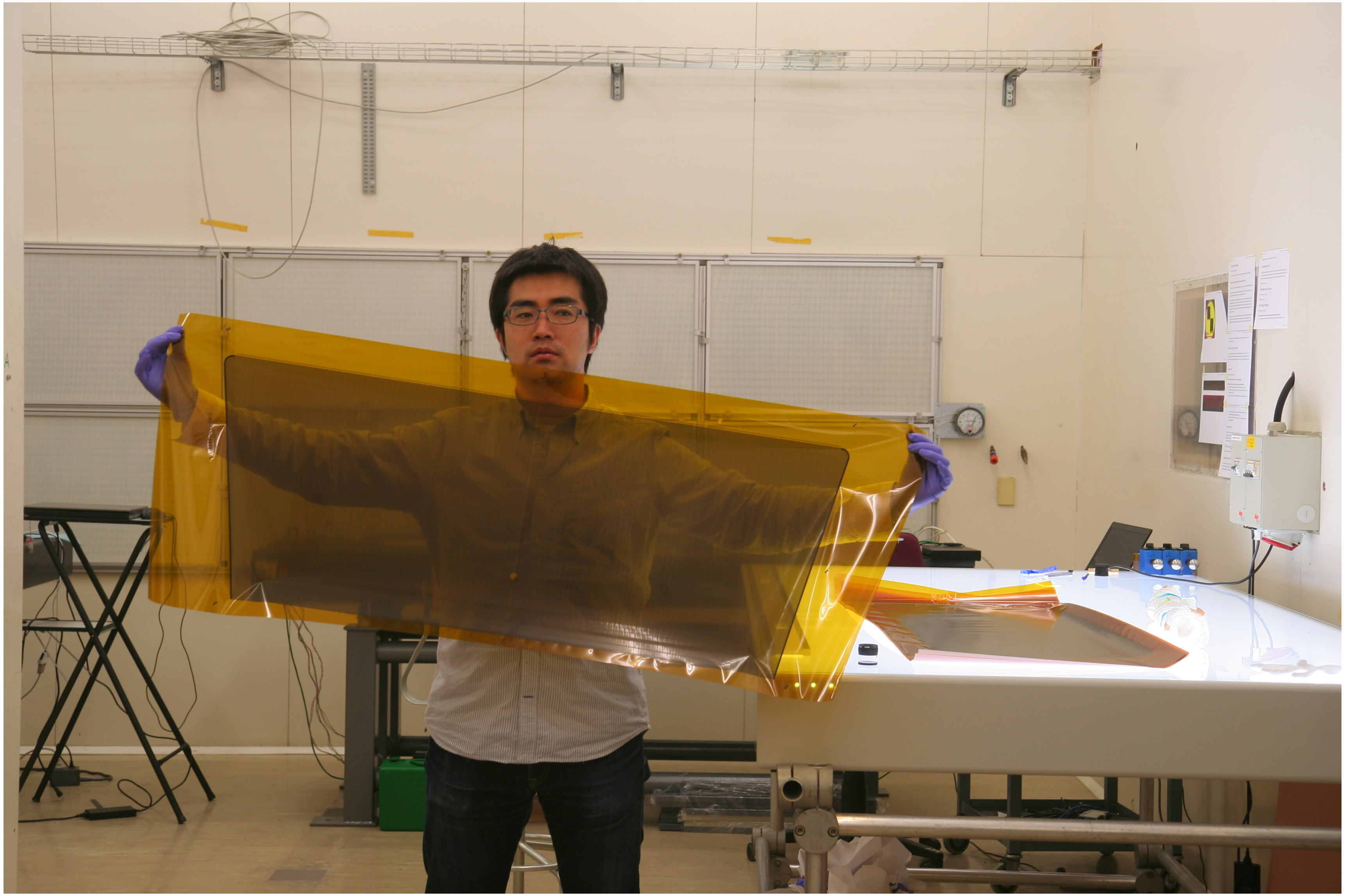


waiting for board expansion (>20 days)

Try to make all production steps as close as possible to standard processes in industry

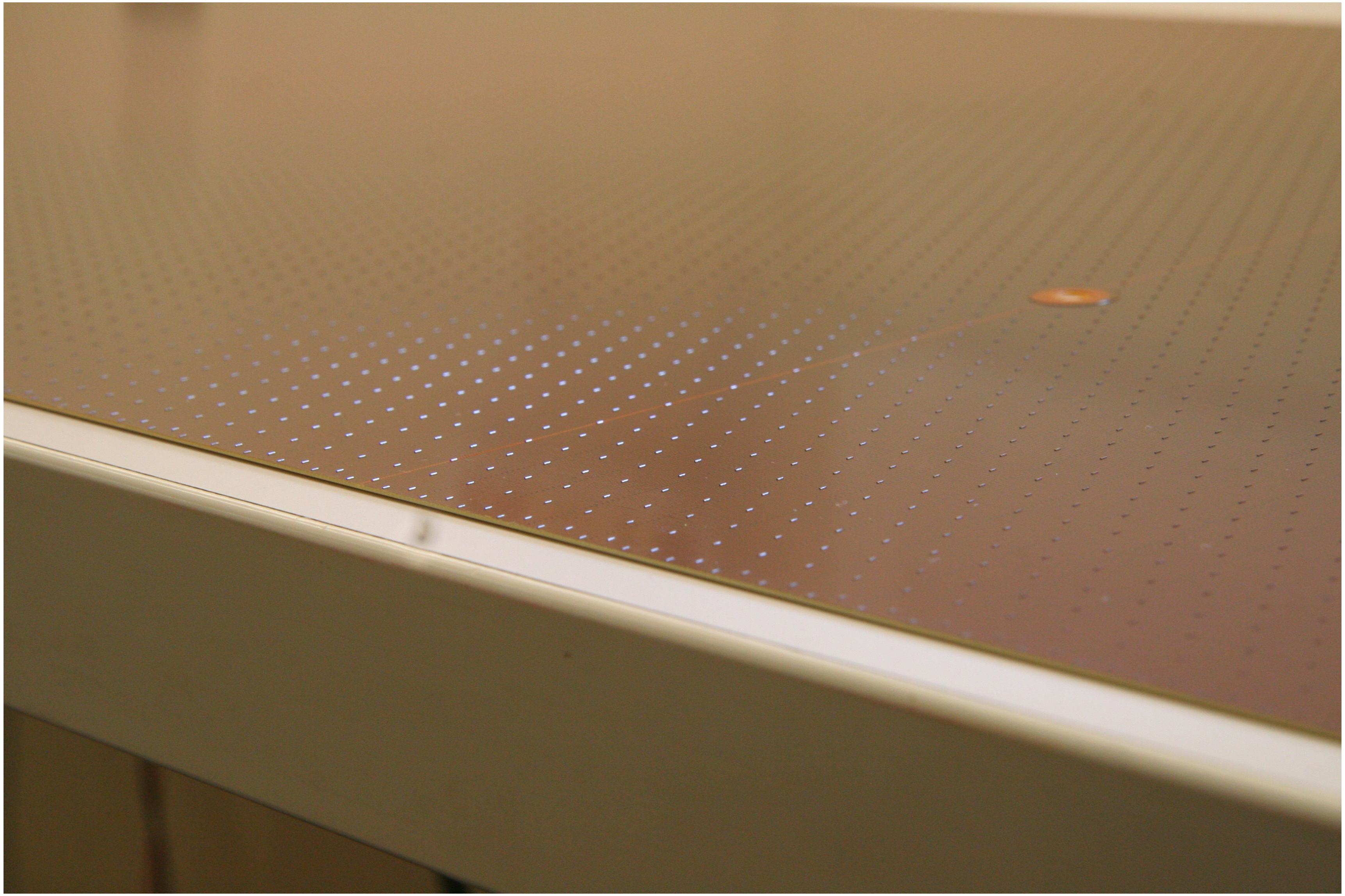
MM chambers

Prof. Masubuchi, U.Tokyo



MM chambers

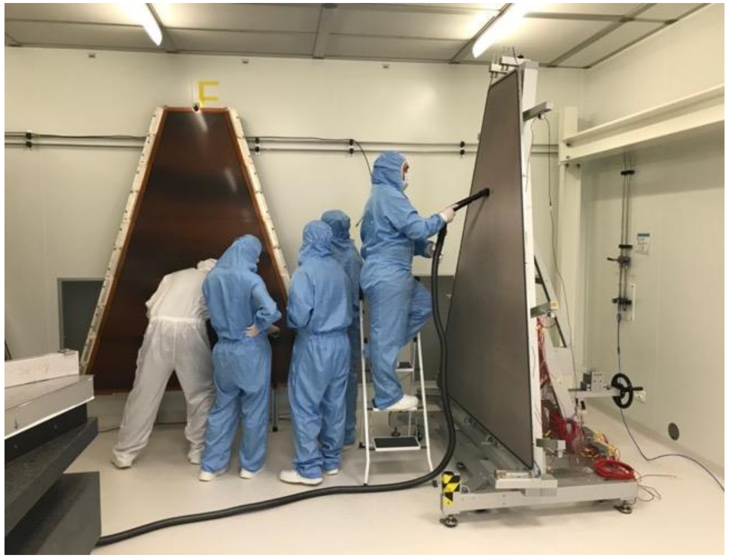
MM chambers

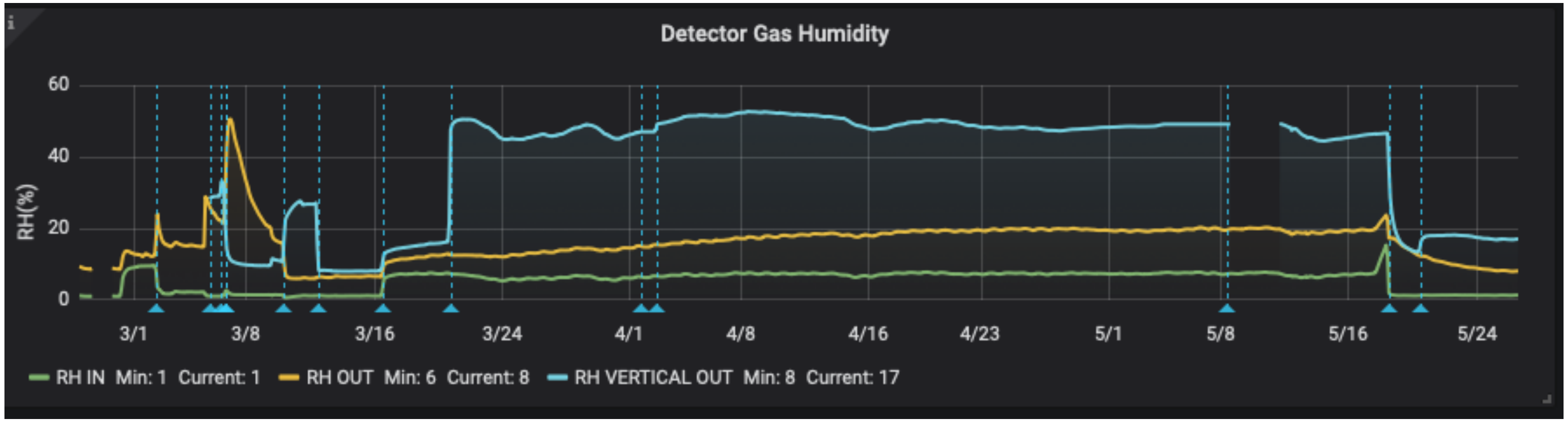


MM HV issue

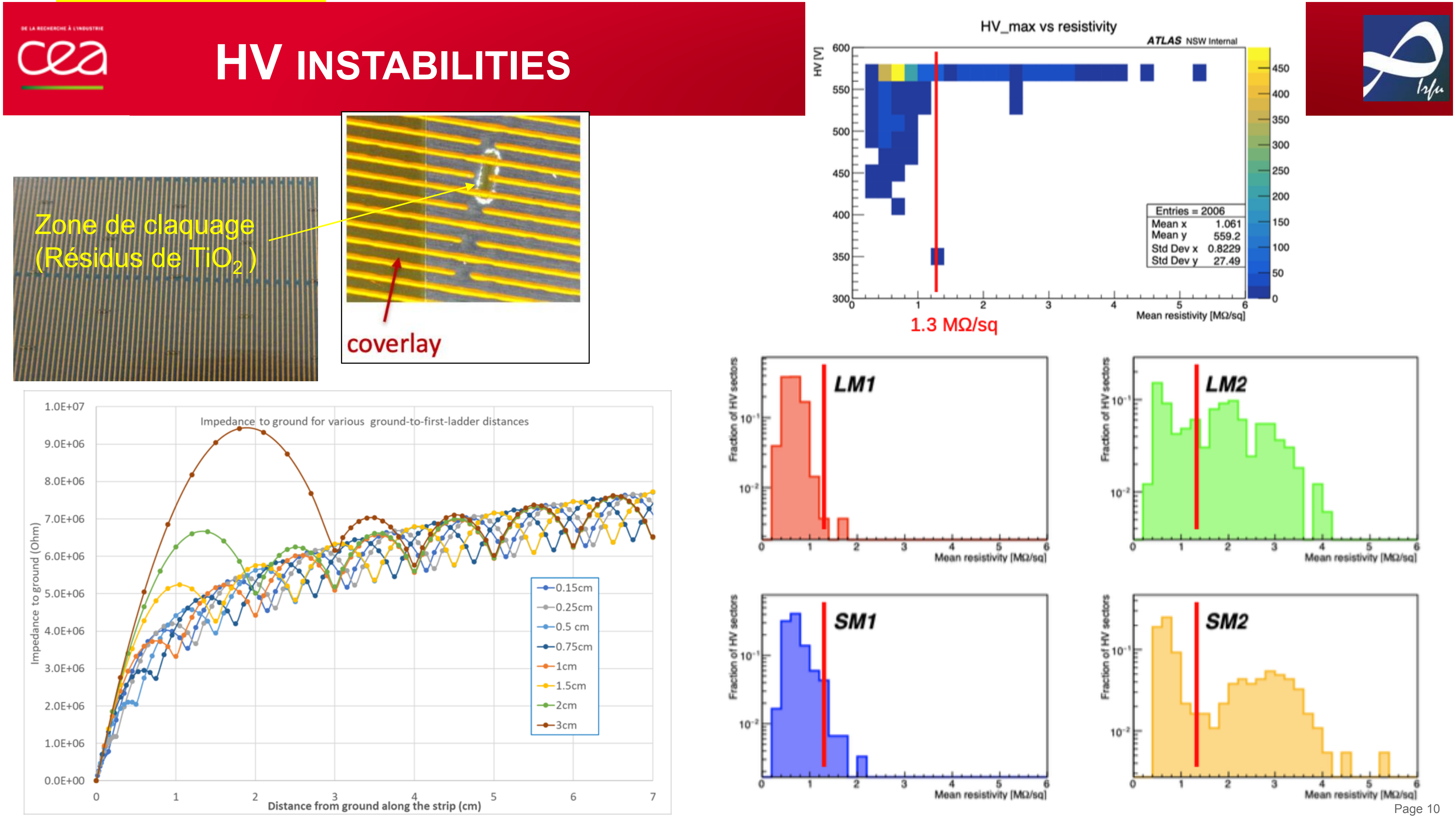
HV INSTABILITIES: CAUSES

- ☐ Residual ionic contamination → cleaning procedures reviewed
- ☐ Mesh mechanical imperfections → mesh polishing
- ☐ Humidity → monitor humidity, dry panels and modules, increase gas flux
- ☐ Low resistivity of anode resistive strips
- ☐ ~~Low quenching gas mixture~~





MM HV issue



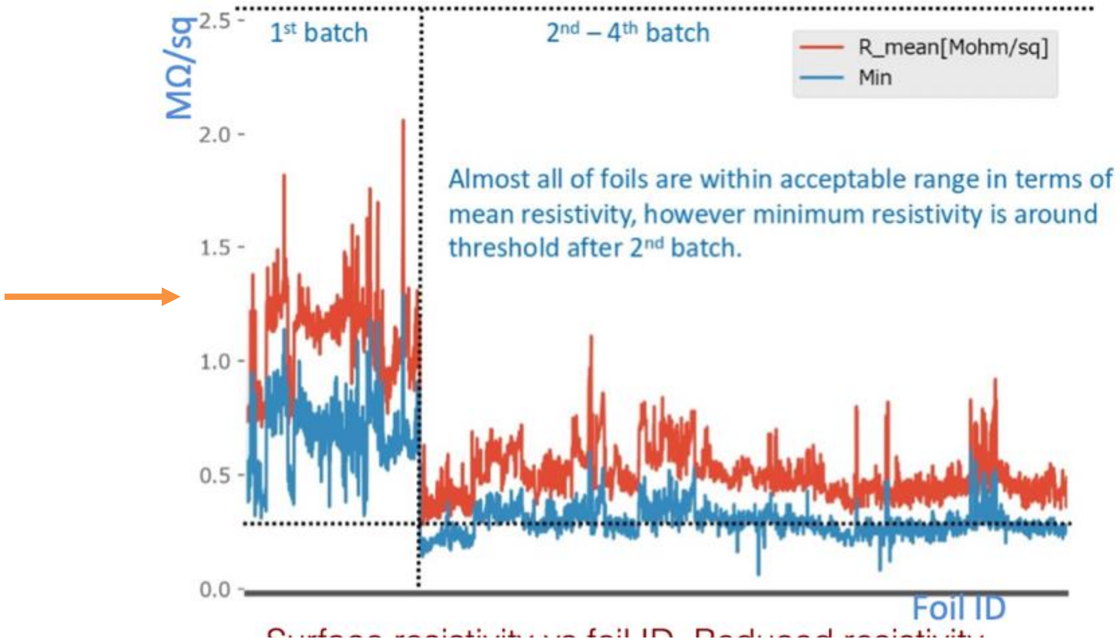
HV INSTABILITIES

Zone de claquage (Résidus de TiO_2)

coverlay

1.3 MΩ/sq

MM HV issue



Almost all of foils are within acceptable range in terms of mean resistivity, however minimum resistivity is around threshold after 2nd batch.

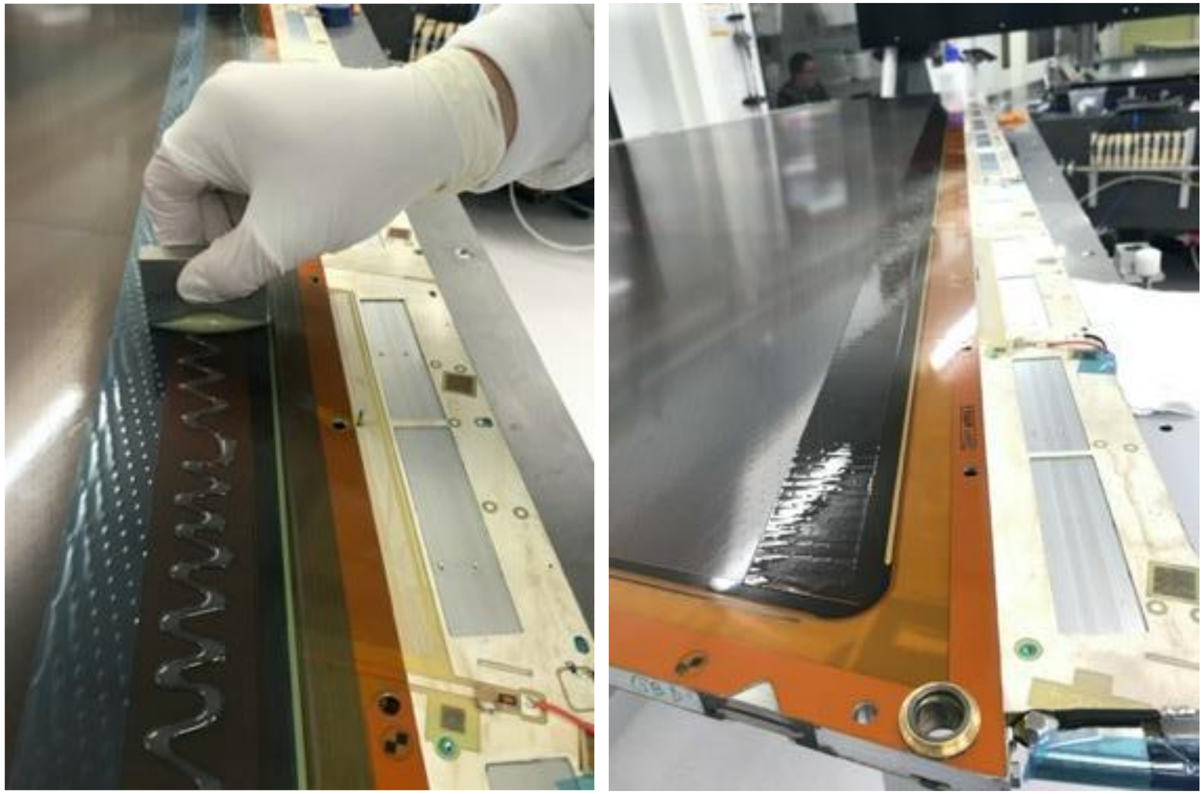
It was difficult to control the resistivity

Batch to bach variation of resistive paste.

+

Initially defined tolerance was not quite correct

MM HV issue



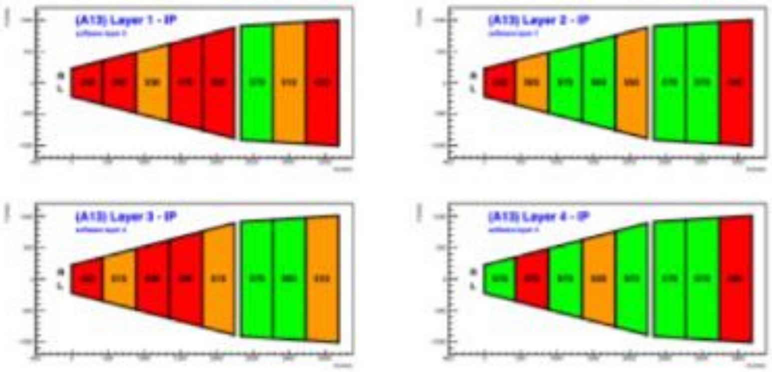
Passivation
To ensure sufficient resistance from the silver line,
sacrificing the active area.

MM new gas mixture to save

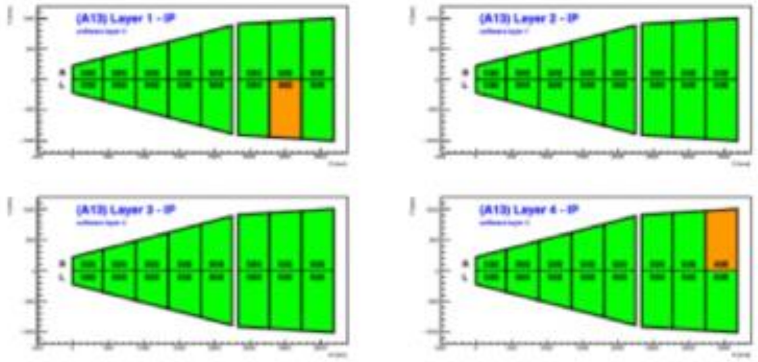
Adding 2% of iC_4H_{10} greatly improved the HV stability + same gain at lower HV.

Took ~1 year to convince people and ourself to switch the gas mixture.
with Irradiation tests, etc.

Ar:CO_2 93:7

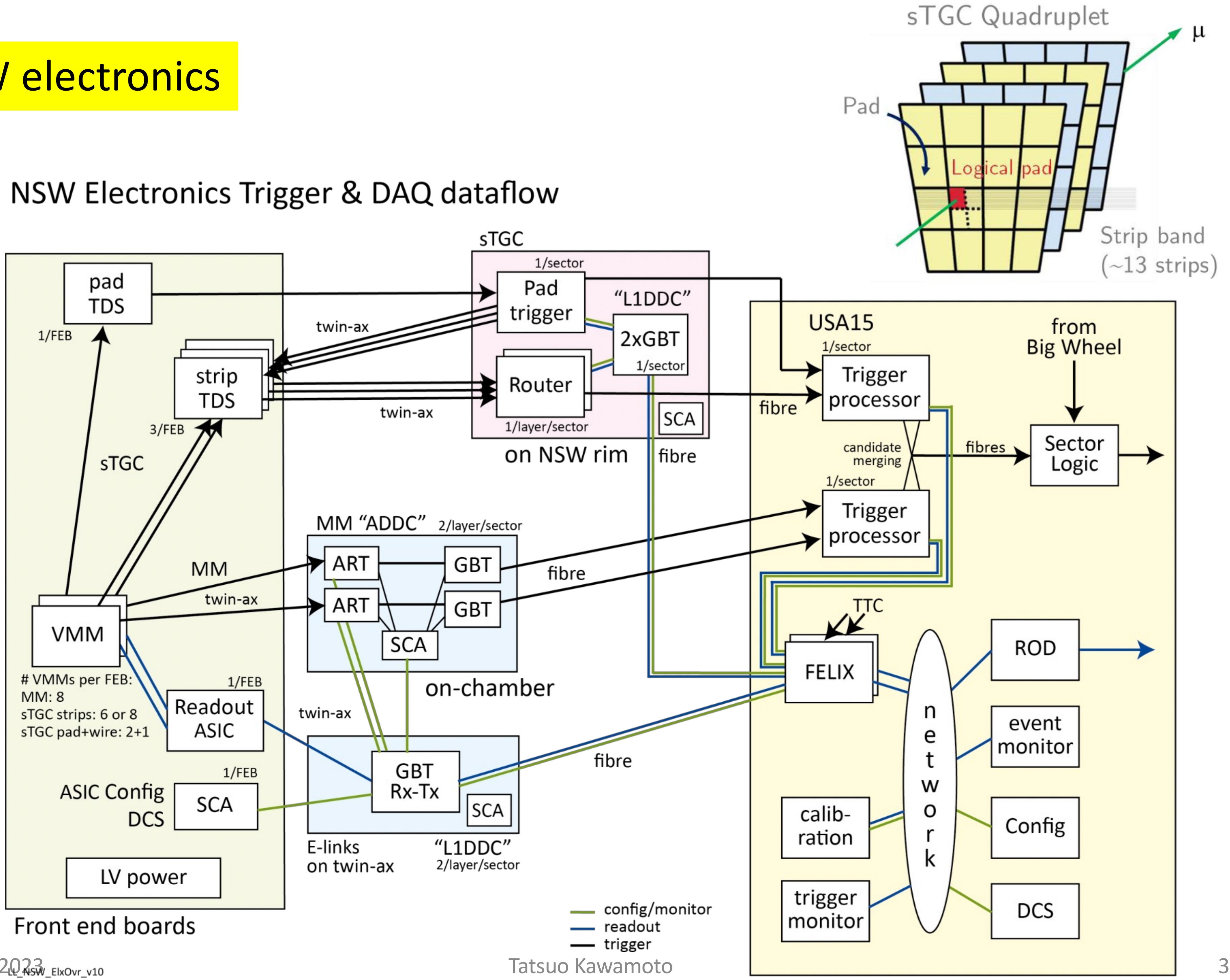


Ar:$CO_2iC_4H_{10}$ 93:5:2



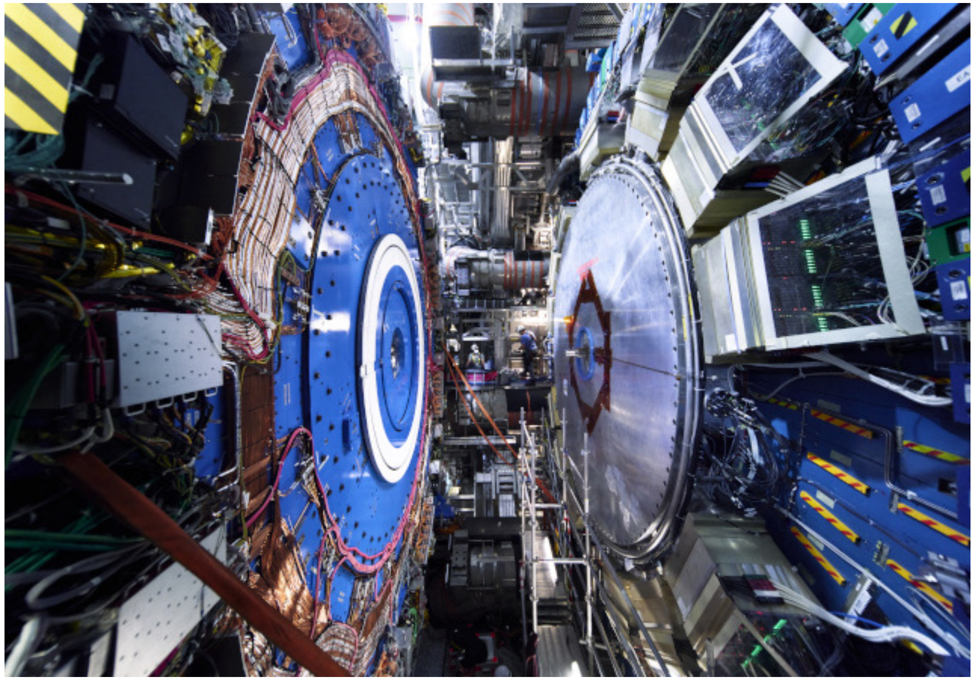
NSW electronics

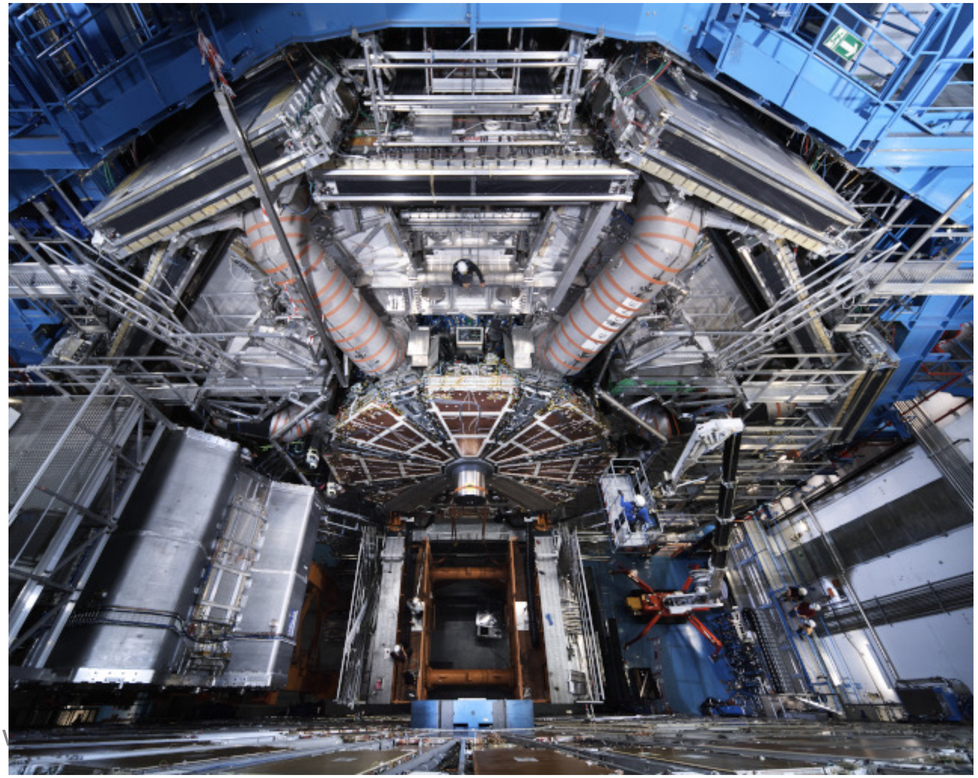
NSW Electronics Trigger & DAQ dataflow



Assembly and surface commissioning

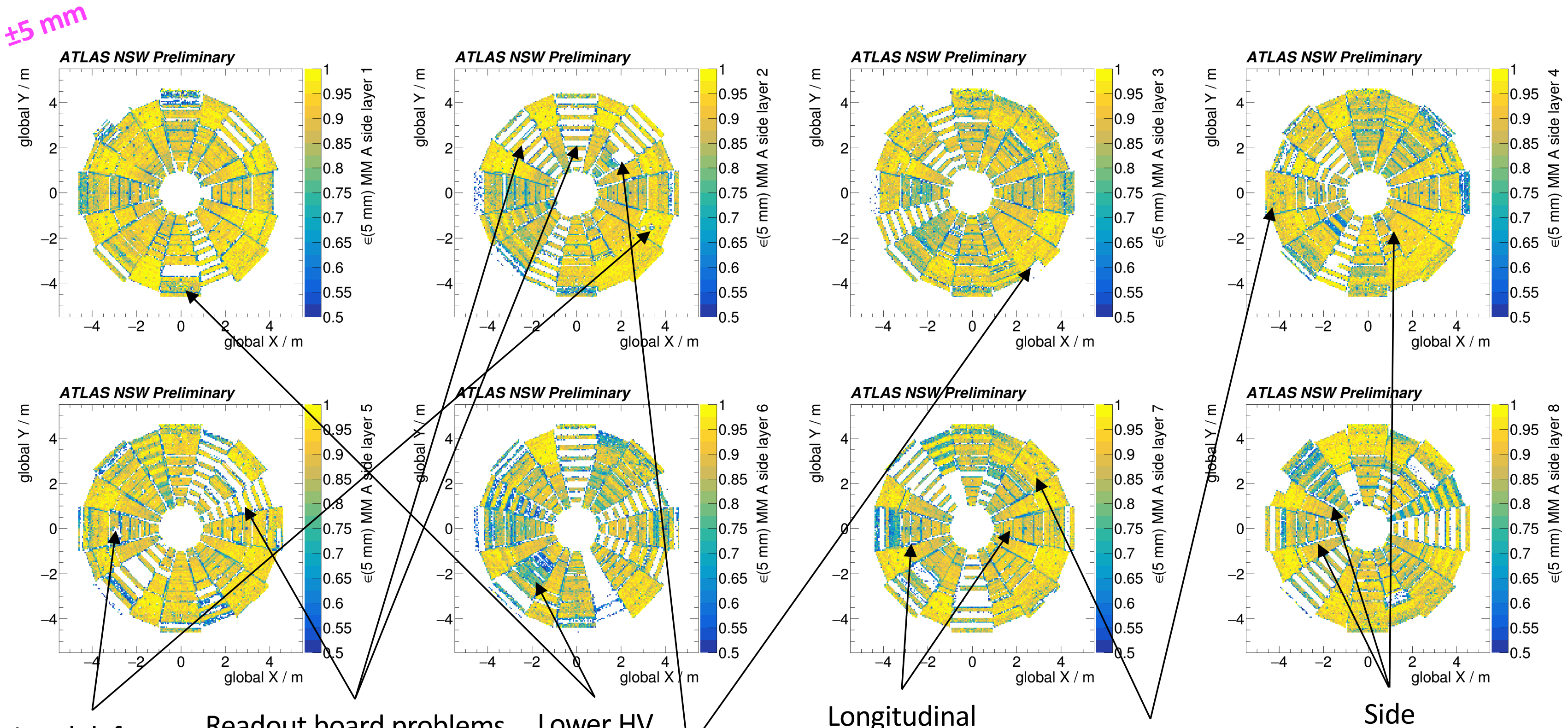
Installation in ATLAS





NSW Preliminary Performance: MM Single layer efficiency

Inclusive of all inefficiencies (detector, HW, DAQ)



Local defects

Readout board problems or LV board problems (from these maps is impossible to distinguish between the problems)

Lower HV

Half HV channel disconnected

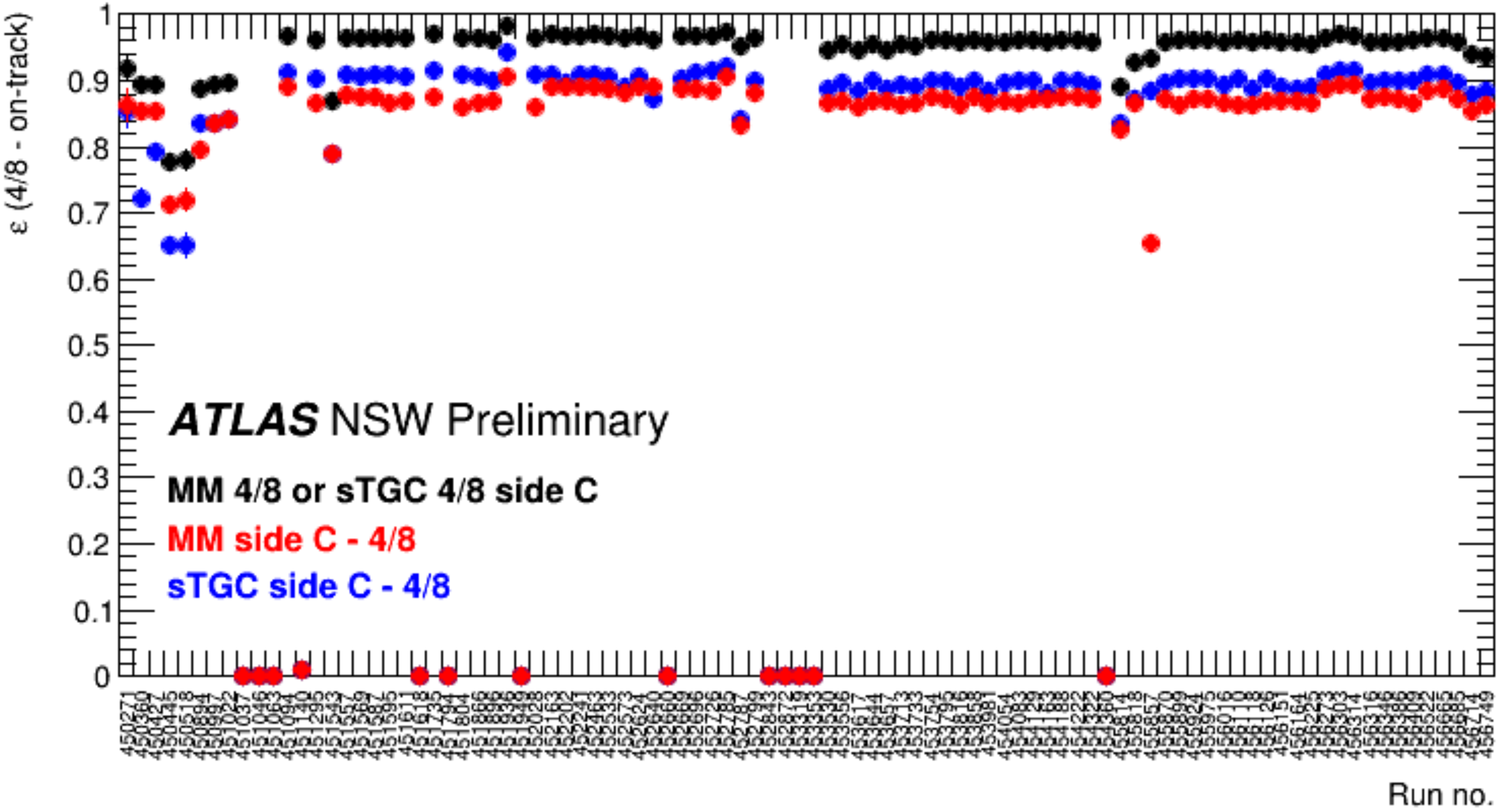
Longitudinal passivations (non active area)

Local passivation (interconnections screws, non active area)

Side passivations (non active area)

Status of NSW

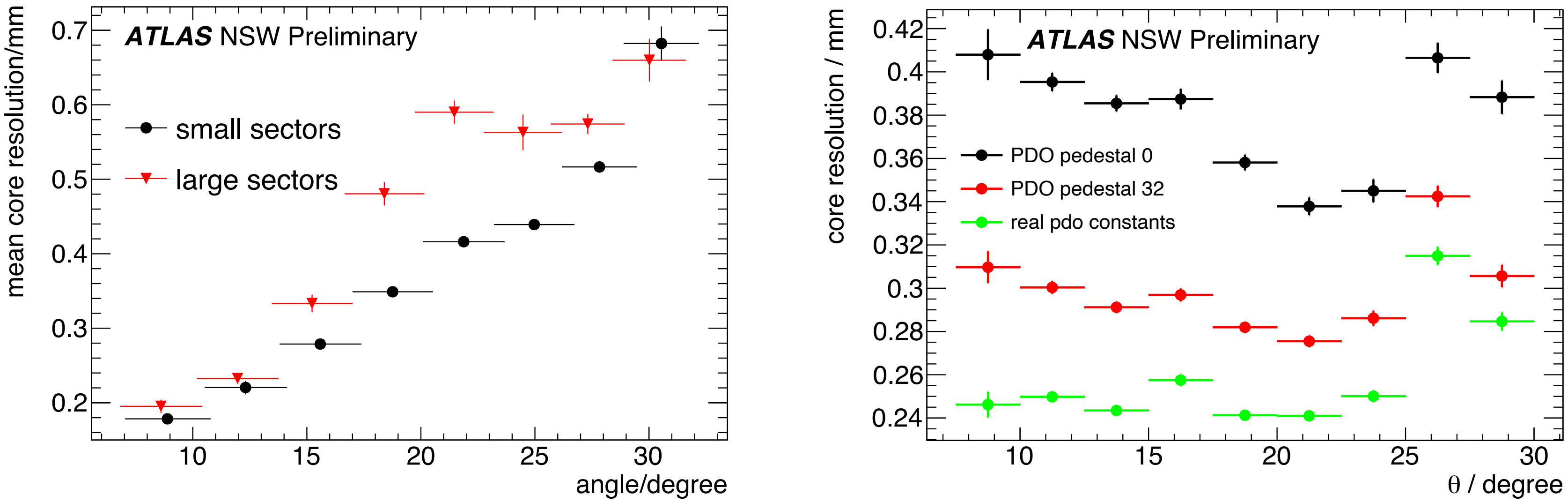
Segment efficiency



Redundancy helped

Status of NSW

Position resolution



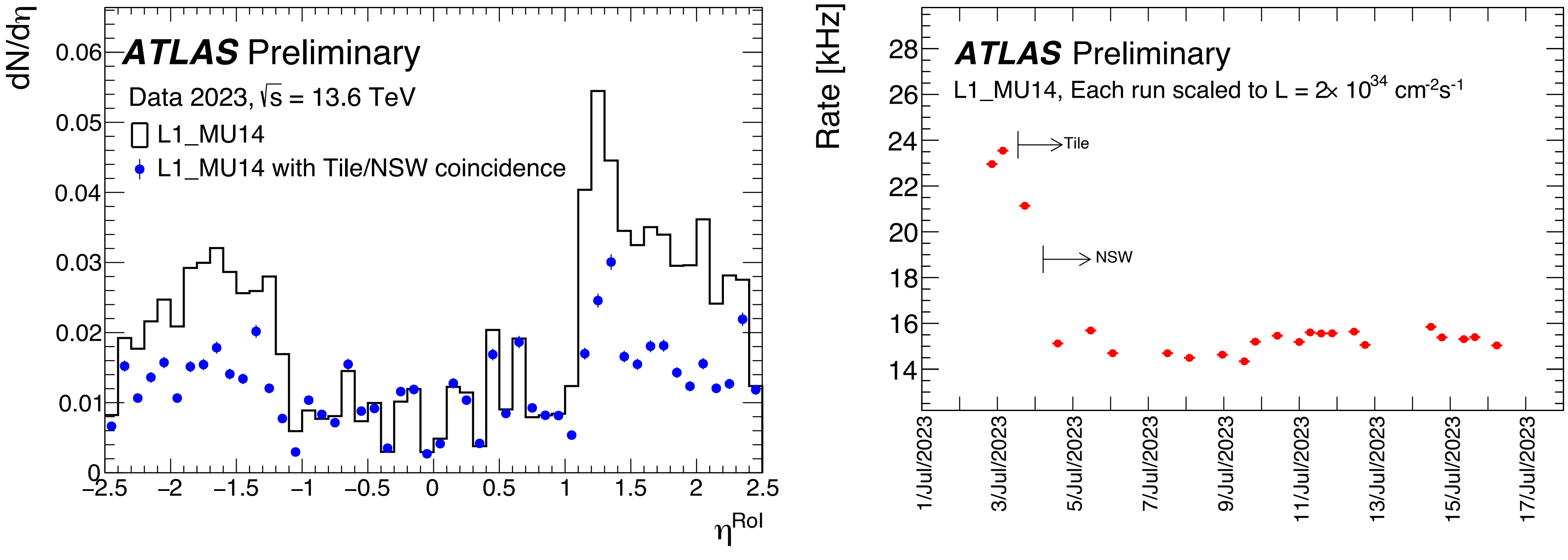
(a) (b)

Figure 3: (a) Micromegas position resolution extracted by comparing the cluster position on two neighbouring layers corrected by the track angle for small and large sectors [7]. (b) sTGC resolution for different values of the charge calibration of the readout electronics. The resolution is calculated between the reconstructed cluster position on each layer and the muon track reconstructed with the full ATLAS detector [7].

Status of NSW

Reduction of L1 rate using 100/144 sTGC pad-tower.

sTGC strips and MM trigger will follow.



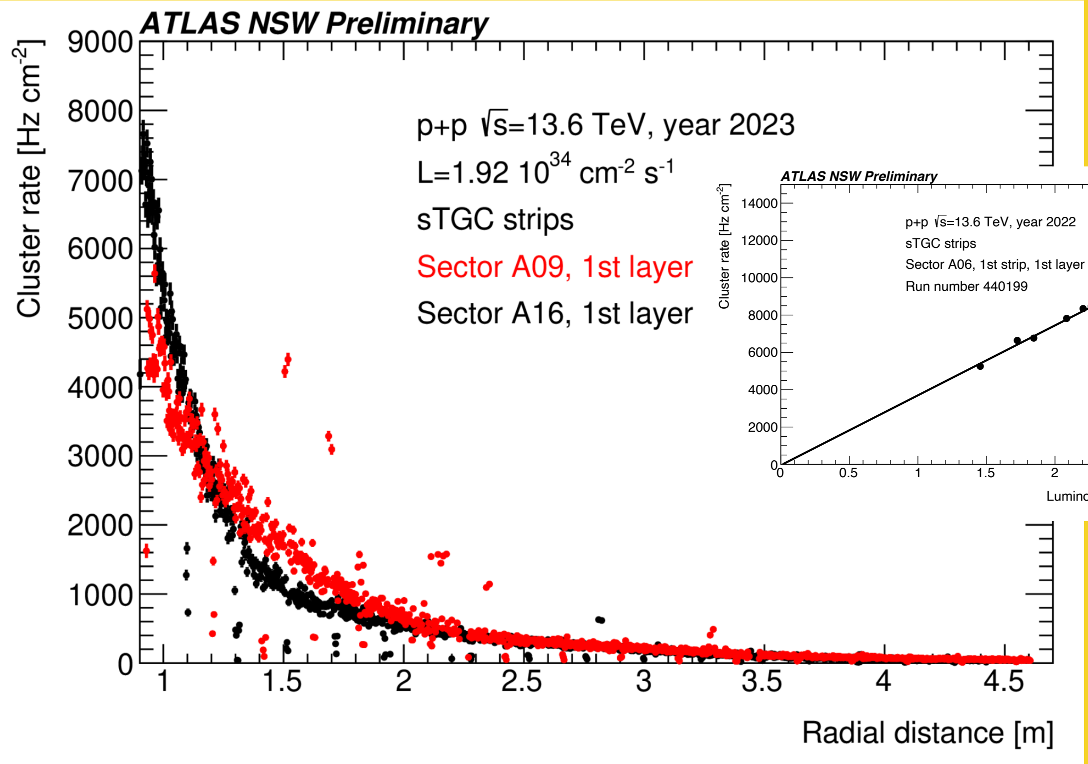
(a) (b)

Figure 4: (a) The pseudorapidity (η) distribution of the level-1 (L1) Region-of-Interests, which fulfill the primary L1 muon trigger with a threshold of the transverse momentum of 14 GeV before and after the deployment of the Tile and NSW coincidences in the L1 trigger decisions in 2023 data. Only the sTGC-Pad readout is used for the NSW coincidence of the track candidates [8]. (b) The trigger rate of the primary L1 muon trigger with a threshold of the transverse momentum of 14 GeV (L1_MU14), scaled to the instantaneous luminosity of $2 \times 10^{34}\ cm^{-2}\ s^{-1}$, as a function of time in 2023. The rate reduction after the reactivation of the Tile coincidence and after the inclusion of the NSW Pad Trigger was measured to be $\sim 2\ kHz$ and $\sim 6\ kHz$ respectively [8].

Covern background hit rate

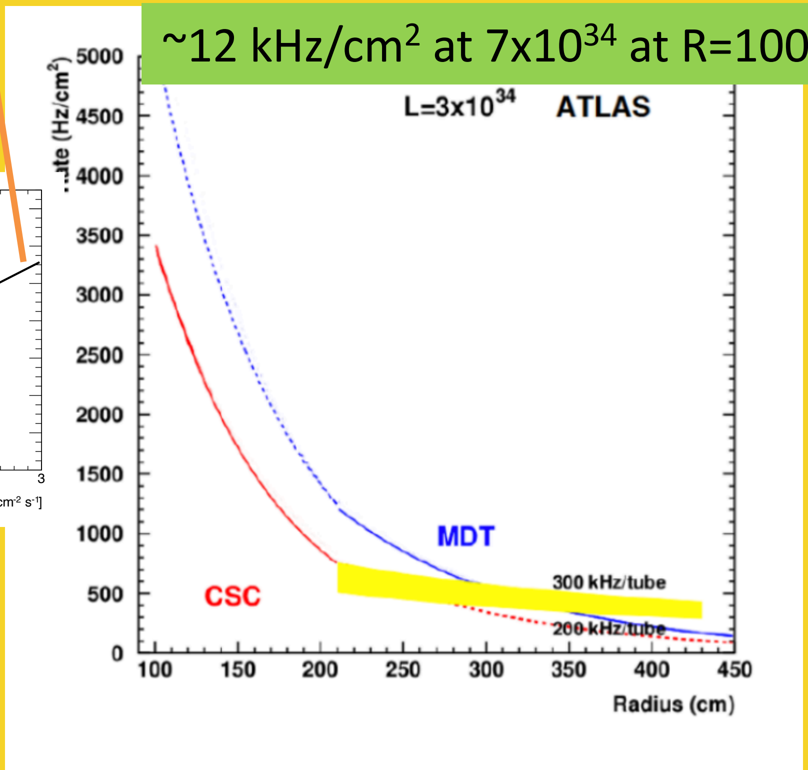
~25 kHz/cm^2 at 7x10^{34} at R=100

2023 data



NSW TDR ATLAS

~12 kHz/cm^2 at 7x10^{34} at R=100



sTGC rate values from p+p data at R=100 cm:
small sector: ca. 7800 Hz cm-2
large sec

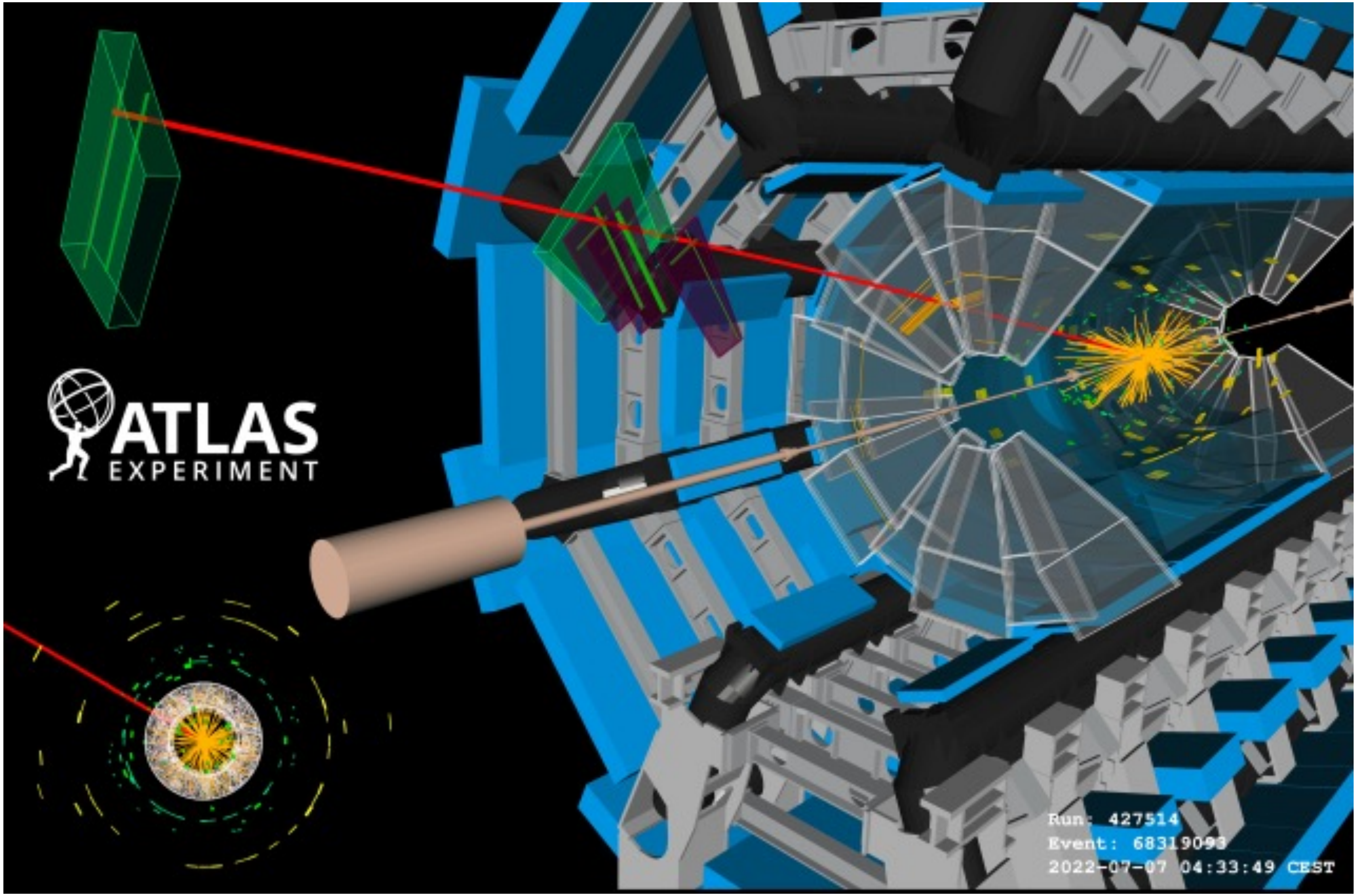
sTGC rate
small sec ca 750 Hz cm-2
large sector: ca 750 Hz cm-2

The rate at R=100 m, from the CSC based estimate of
om L=3x10^{34}
Hz cm^{-2}

urements
extrapolated to 14 TeV and to L=1.92x10^{34} cm^{-2} s^{-1} is ca. 750 Hz cm-2

Measured hit rate is higher than initially considered, but it is still OK.

Different detector sensitivity, thinner radiation shielding, …


ATLAS
EXPERIMENT
Run: 427514
Event: 68319093
2022-07-07 04:33:49 CEST