The upgrade of the ATLAS experiment at LHC for exploring the high-energy frontier of particle physics.

Outline:

(1)LHC and the upgrade of the ATLAS experiment

(2)Upgrade of the ATLAS Muon Spectrometer

(3)The Micromegas detectors for the New Small Wheel

1 – LHC and the upgrade of the ATLAS experiment

The Large Hadron Collider (LHC)

- Since 2009 LHC provides pp collisions to 4 large HEP experiments (ATLAS, CMS, Alice, LHCb)
- Laboratory for the Particle Physics at the Energy Frontier

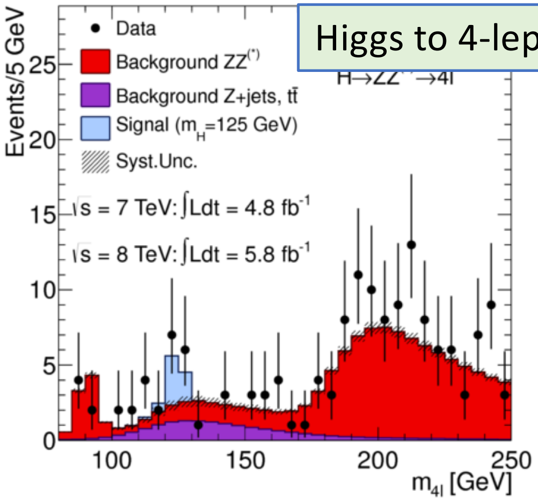
→Experimental test of the Standard Model predictions (including Higgs boson production and decay)

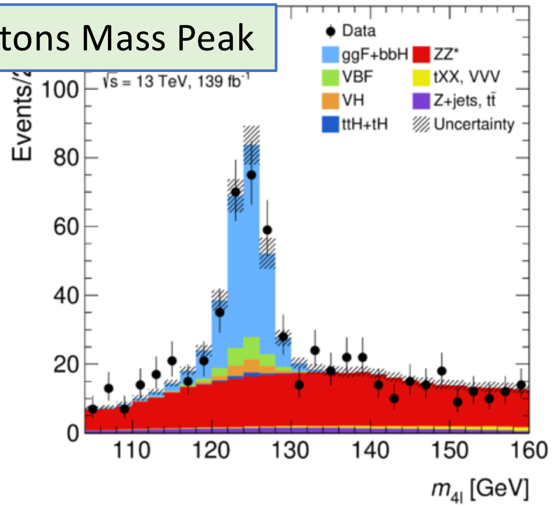
→Searches for signals of physics beyond it

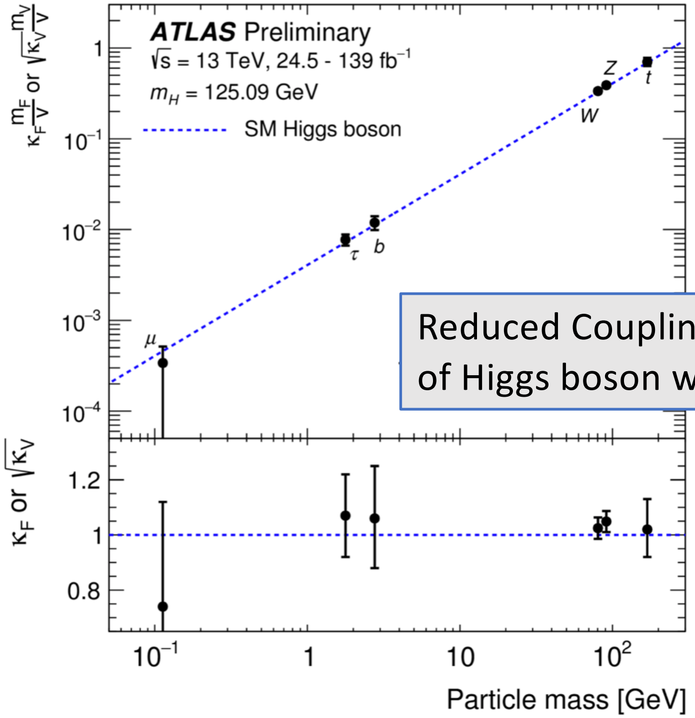
Higgs discovery (2012)
~ 10 fb^{-1} @ E_{cm} = 7 – 8 TeV

Run-2 (2016-2018) luminosity
= 140 fb^{-1} @ E_{cm} = 13 TeV

Higgs to 4-leptons Mass Peak







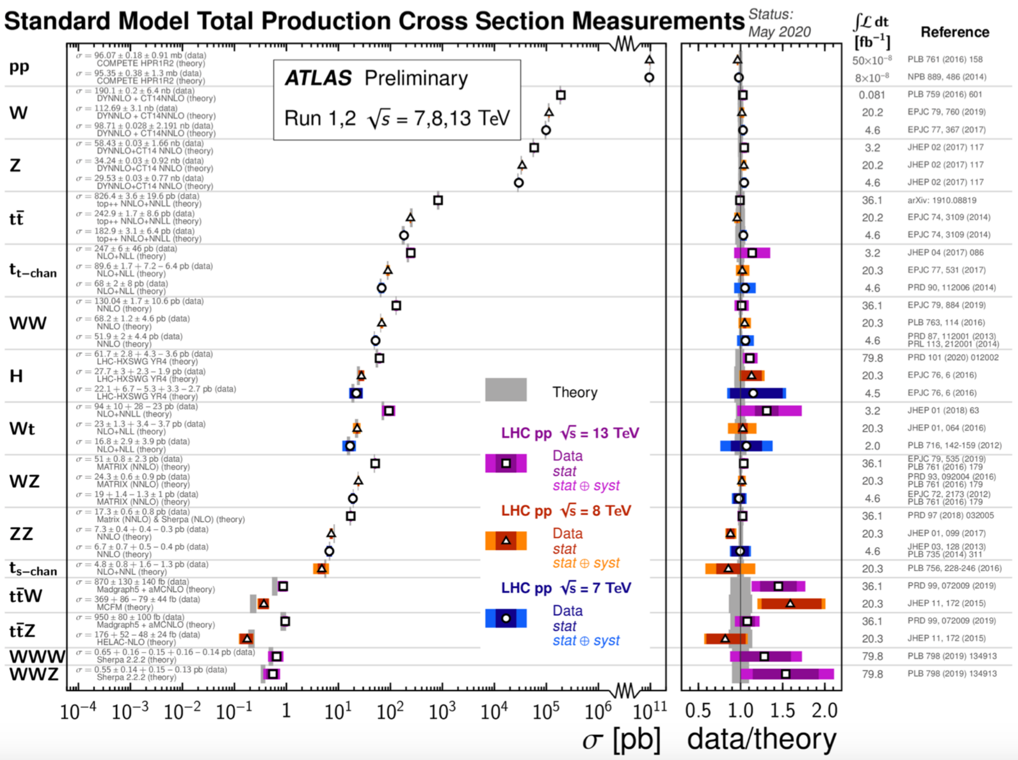
Reduced Coupling-strengths
of Higgs boson with SM particles

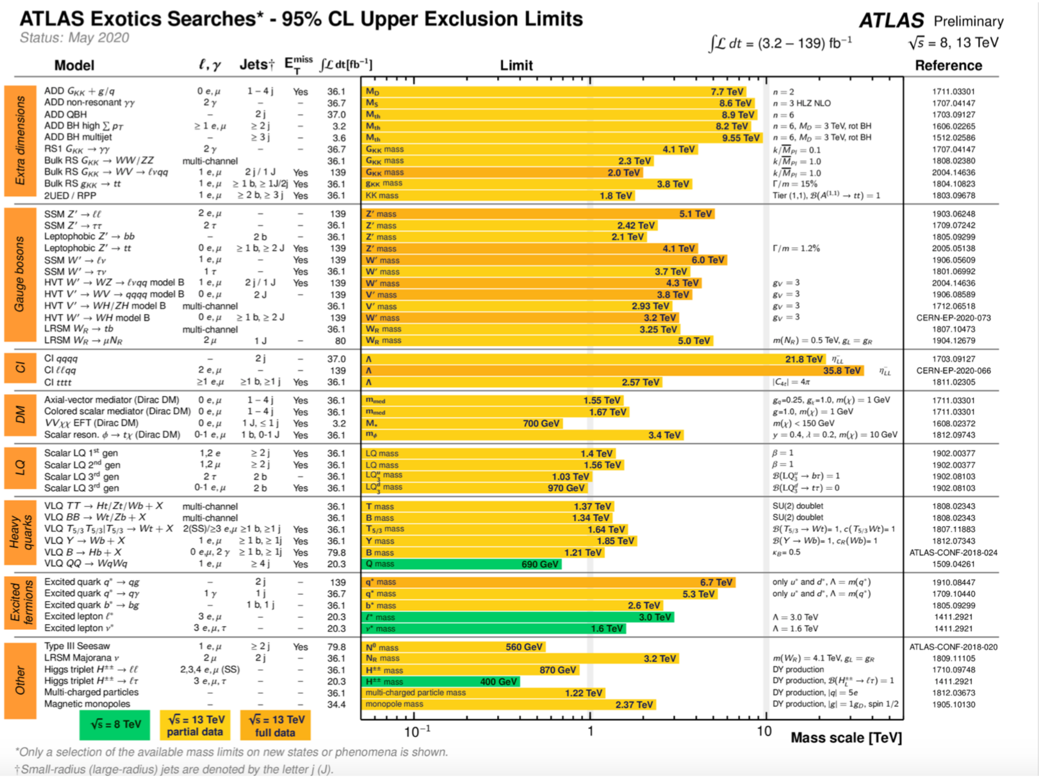
The LHC physics

~ 900 published papers in ~10 years

Wide spectrum of physics (Higgs, Standard Model, SuperSymmetry, Exotics, Heavy-Flavour, Heavy-Ions):

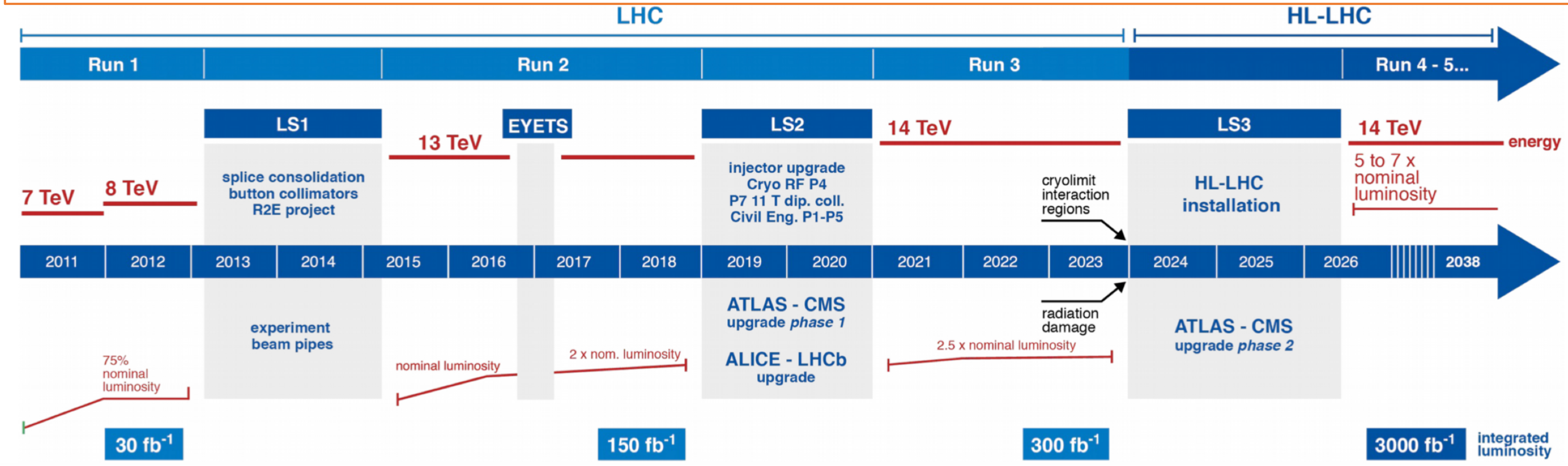
→ ***Summary plots from ATLAS***: (2 examples)





LHC upgrade program – I

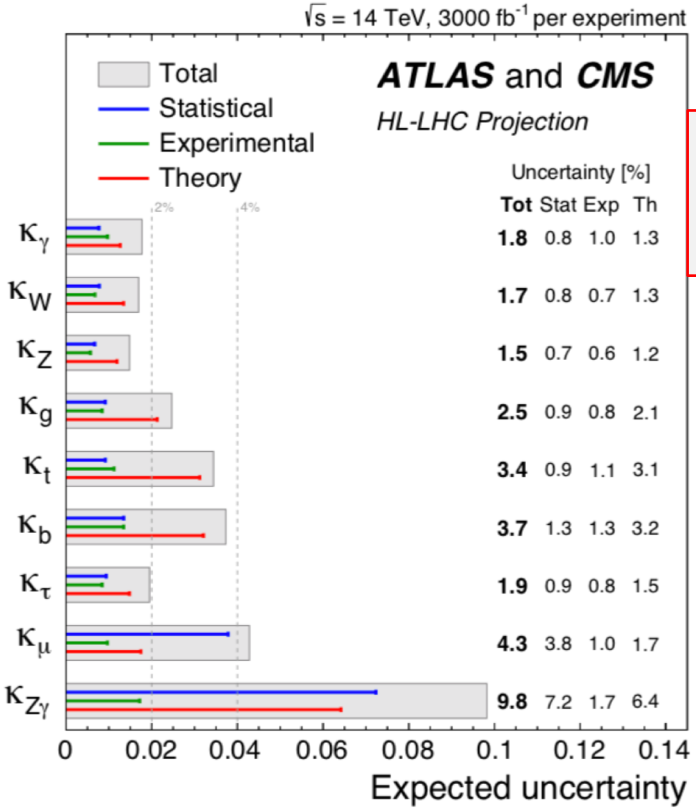
- “Ambitious“ long-term program to get as much as possible from the present infrastructure
- **HL-LHC** upgrade of the LHC:
  - Achieve the project E_{cm} = 14 TeV;
  - increase **instantaneous luminosity** from 10^{34} to $5\text{x}10^{34}$ $\text{cm}^{-2}\ \text{s}^{-1}$ (ultimate: $7.5\text{x}10^{34}$ $\text{cm}^{-2}\ \text{s}^{-1}$),
  - Total **integrated luminosity** of 3000 fb^{-1} (ultimate: 4000 fb^{-1})



LHC upgrade program – II

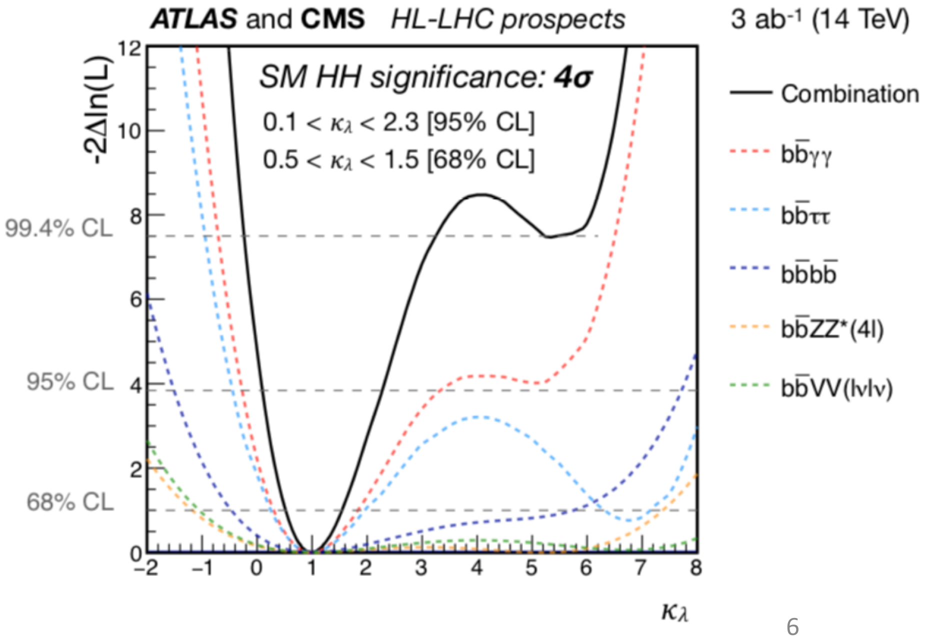
- Extend the search for physics beyond the Standard Model
- Increase precision on Standard Model observables (e.g. Higgs):

M.Cepeda et al, arXiv:1902.00134 **Higgs Physics at the HL-LHC and HE-LHC**
J.deBlas et al, arXiv:1905.03764 **Higgs Boson studies at future particle colliders**



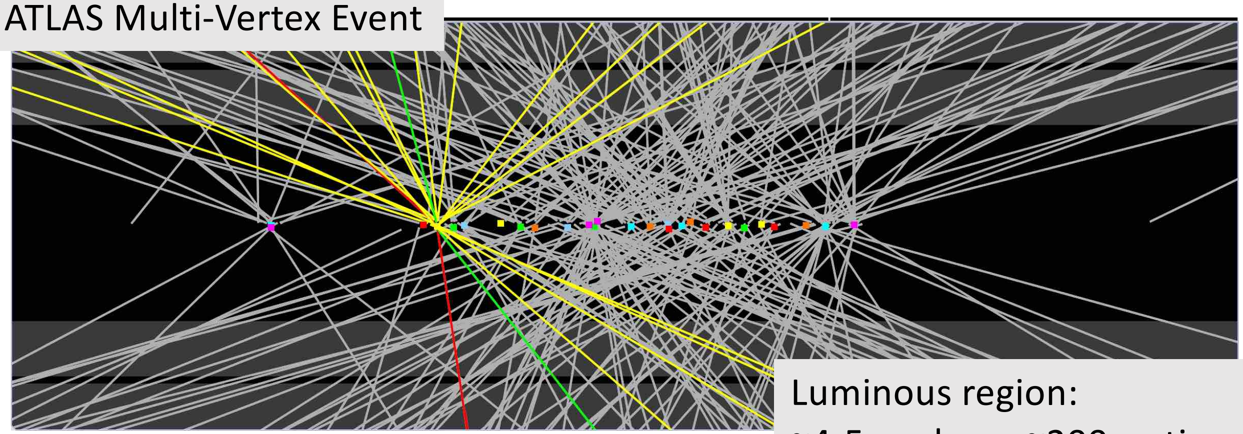
Precision Higgs Physics:
All couplings at % level

Double Higgs Production:
Close to observation



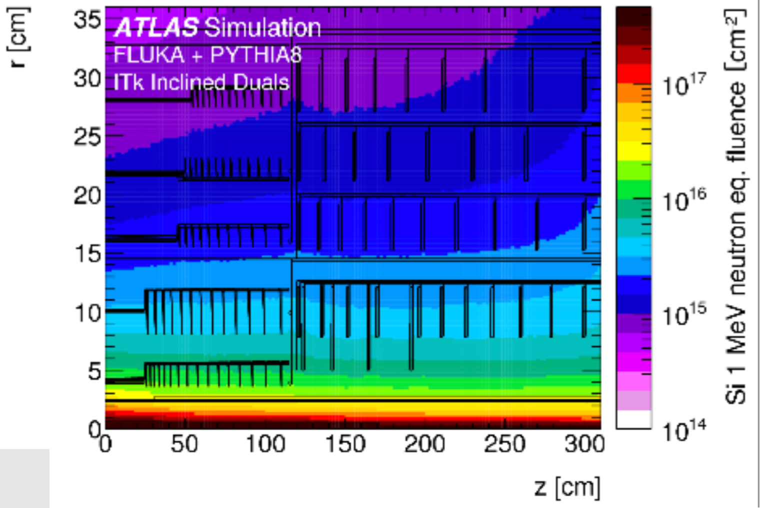
Impact on the experiments

- NB: the LHC experiments were designed for L = 10^{34} $cm^{-2}s^{-1}$
- The increase in instantaneous luminosity (~ x7) poses strict requirements on detector design and operation:
- 1 bunch crossing / 25 ns → up to ~200 pp collisions → ~ 10^4 particles
  - Strong impact on trigger: fast decision accept/reject the bunch-Xing
  - Strong impact on detector operation: huge particle rates and integrated doses
  - Strong impact on reconstruction: assign tracks to correct vertices



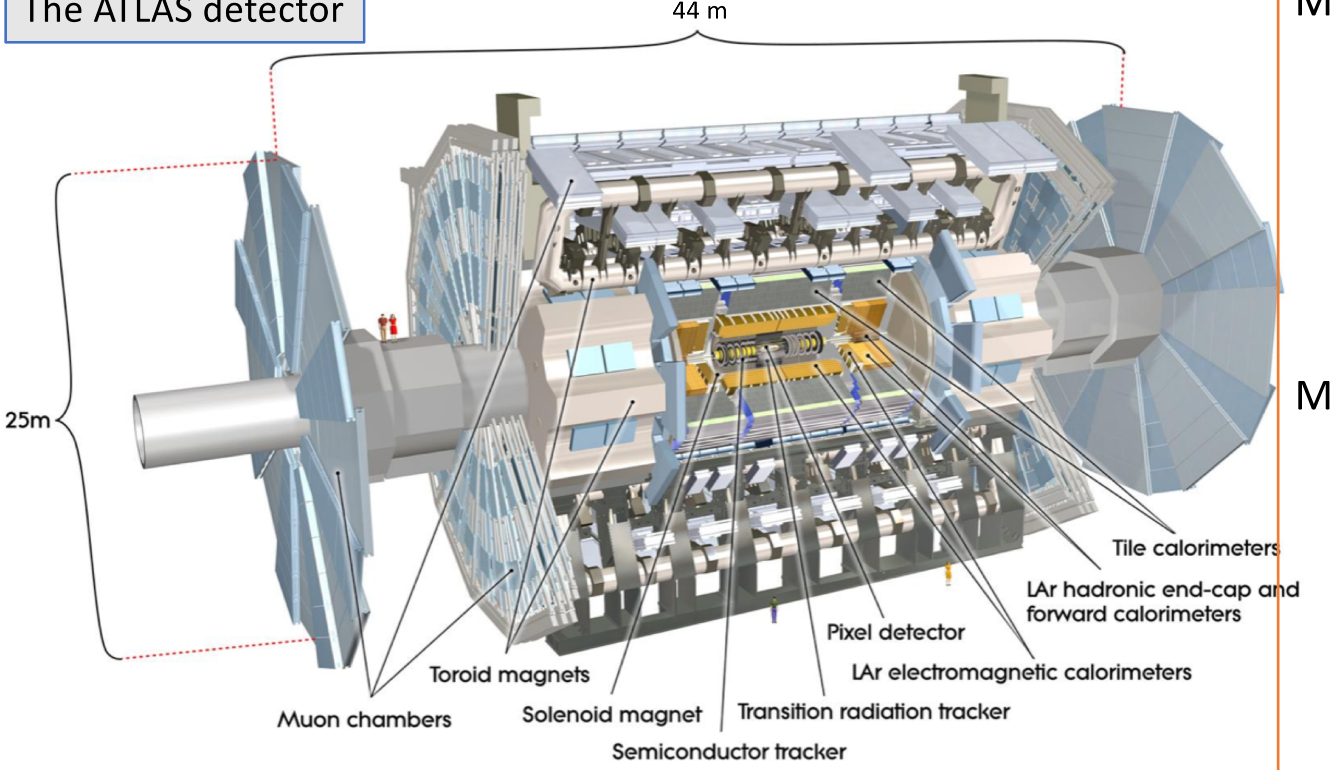
ATLAS Multi-Vertex Event

Luminous region:
~4-5 cm long, ~200 ps time spread



ATLAS Upgrade program – overview

The ATLAS detector



Sapienza Rome ATLAS group, about 35 physicists
Activities in many areas of the experiment

Most detectors need improved capabilities:

- *Discrimination between <u>tracks and vertices</u>*
- *Velocity and flexibility in taking <u>trigger</u> decisions*
- *Capability to keep high efficiencies in a large <u>irradiation environments</u>*
- *<u>Radiation hardness</u>*

Main ATLAS upgrade projects:

- ***Inner Tracker*** → *completely new detector (pixel + strips structure), higher <u>granularity</u> , higher <u>angular coverage</u>*
- ***Trigger*** → *increase <u>robustness</u> and <u>bandwidth</u> capability*
- ***Calorimeters*** → *improve forward sections + proposal of HGTD (High Granularity Timing Detector)*
- ***Muons*** → (see later in the talk)

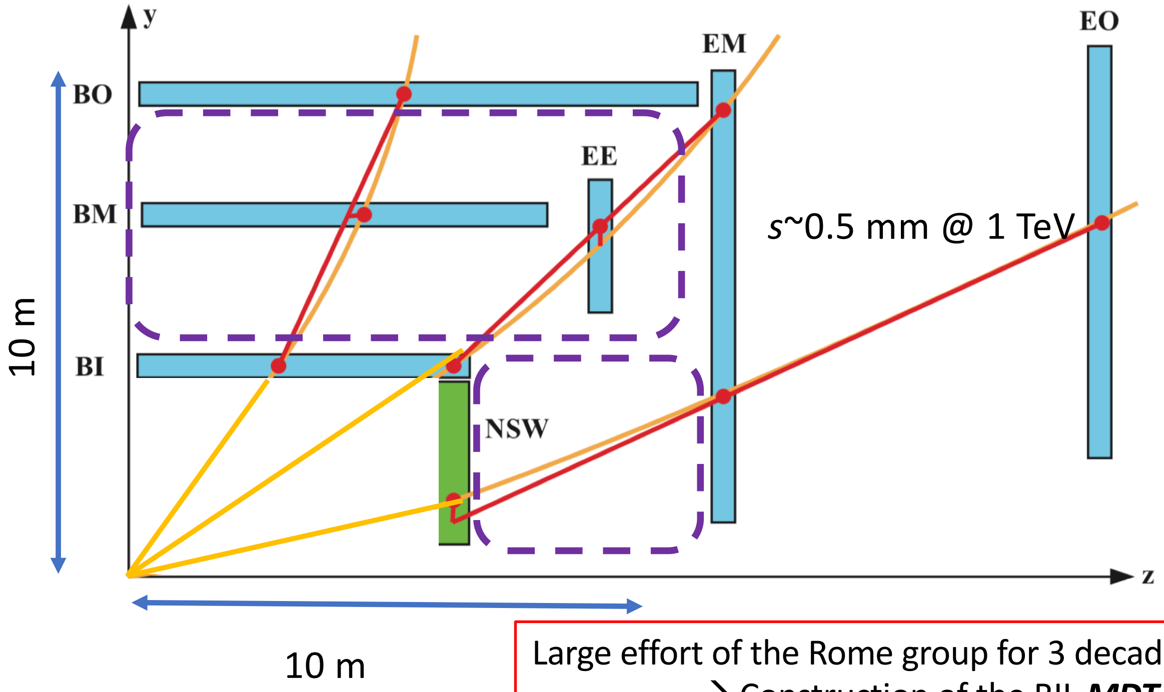
2 – Upgrade of the ATLAS Muon Spectrometer

The ATLAS Muon Spectrometer

Momentum measurement concept:

Barrel: 3-points *sagitta*

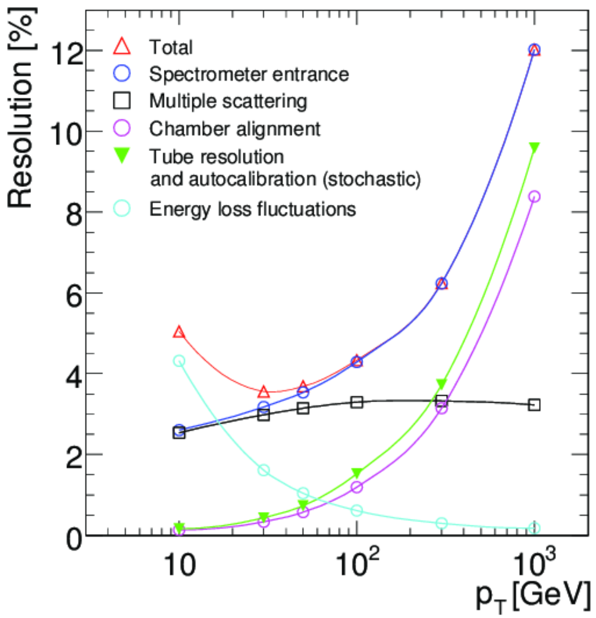
EndCap: point-direction



Transverse momentum resolution

Importance of alignment

O(10%) @ p_T = 1 TeV



Large effort of the Rome group for 3 decades on design, construction and operation of the MS

→ Construction of the BIL ***MDT chambers***

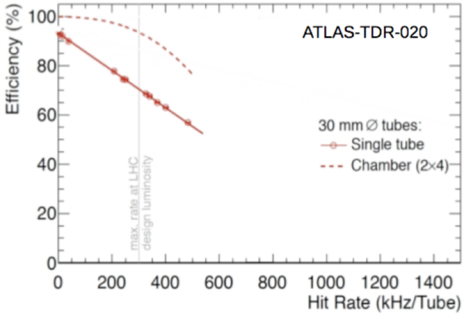
→ Design and realization of the ***Barrel Muon Trigger***

→ Several contributions now on the ***upgrade project***

The ATLAS Muon Spectrometer upgrade

Detector problem

- Efficiency loss at high rates (MDT, CSC)



Trigger problem

- Maximum muon trigger rate acceptable
- Higher Luminosity → higher trigger rate, above maximum

→ 2 possibilities:

(1) increase trigger threshold (eg $p_T>20$ GeV to $p_T>50$ GeV)

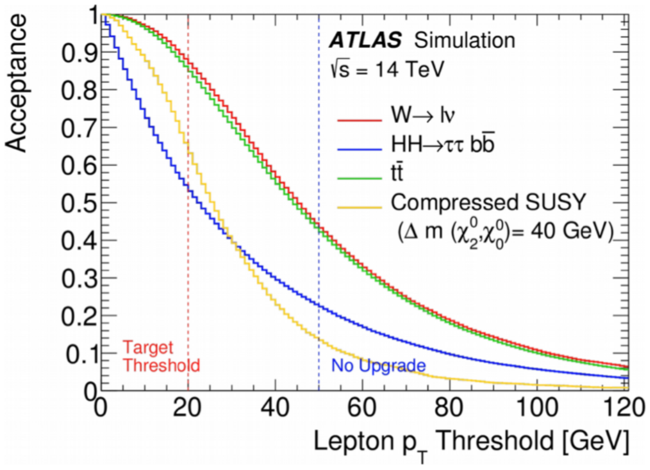
(2) improve trigger "intelligence" and "robustness"

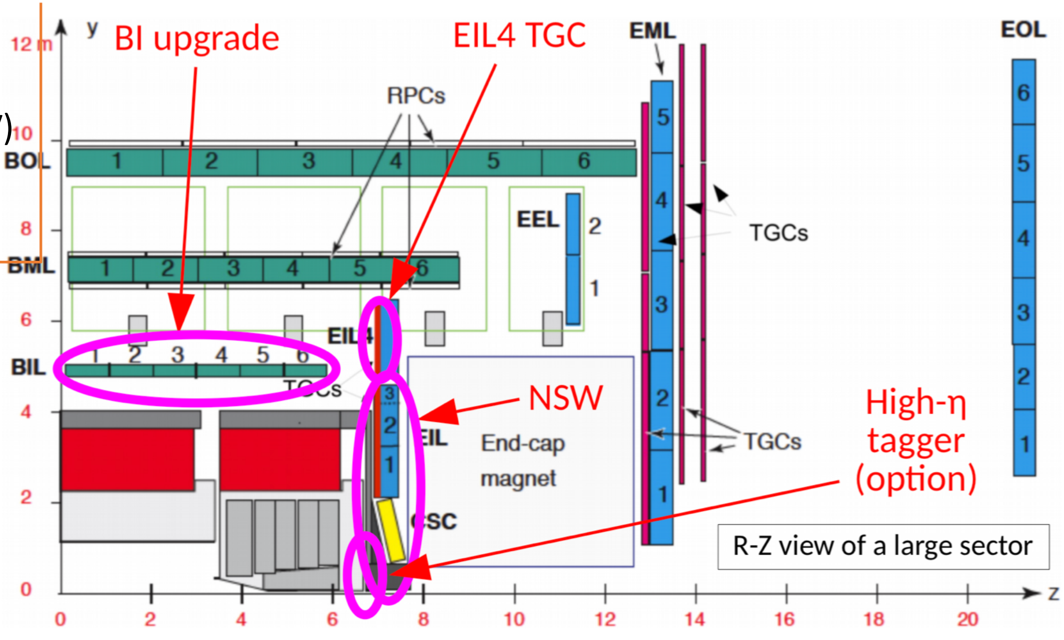
keep the same threshold reducing fake rate

Two main upgrade areas:

→ Innermost Endcap Station (NSW)

→ Innermost Barrel Station (BI)




BI upgrade

EIL4 TGC

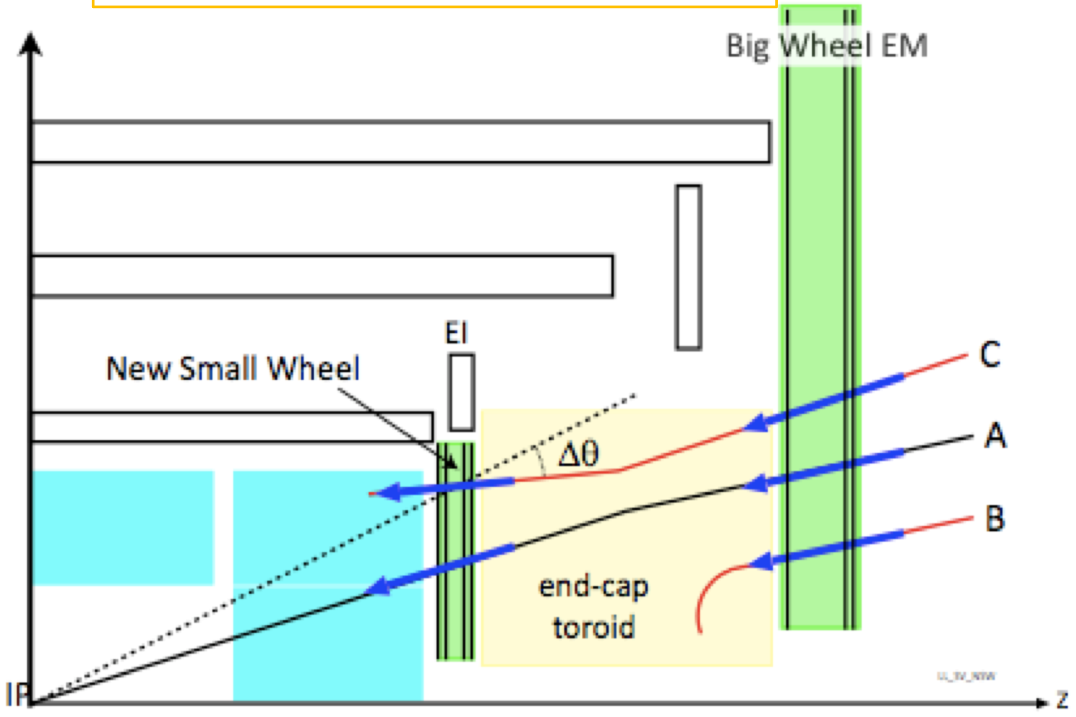
NSW

High-η tagger (option)

NSW: our main activity area today

Upgrade of the innermost endcap station → The New Small Wheel – I

Forward Muon Spectrometer



Present scheme (Small Wheel):
Trigger on Big Wheel + coincidence on Small Wheel

→Muon Trigger on endcap dominated ***by fake muons***
Not sustainable for HL-LHC

New scheme (New Small Wheel):
Pointing trigger on Big Wheel and on New Small Wheel

→Accept **topologies A** reject **B / C**
→ **Factor ~3 reduction on rate**
Sustainable keeping minimum p_T threshold at HL-LHC

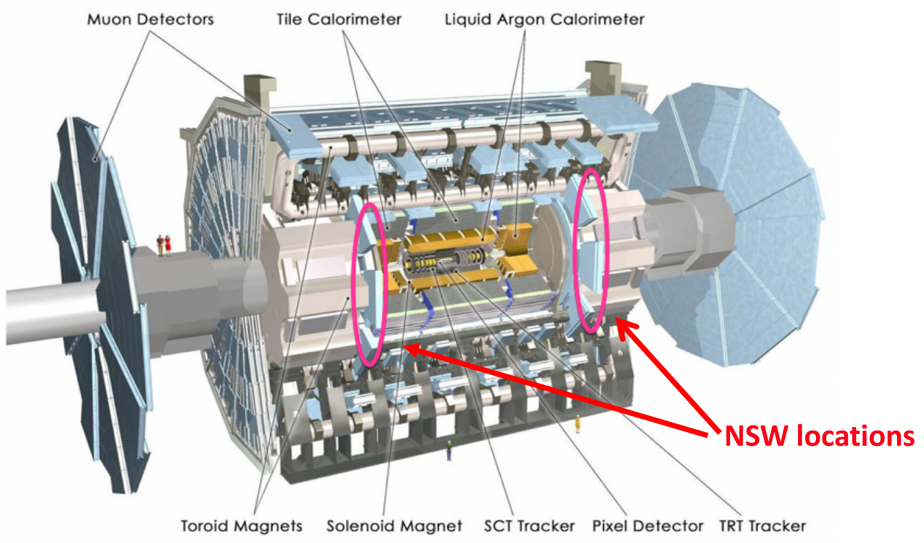
Upgrade of the innermost endcap station → The New Small Wheel –

The ATLAS Collaboration decided to build Two New Small Wheels:

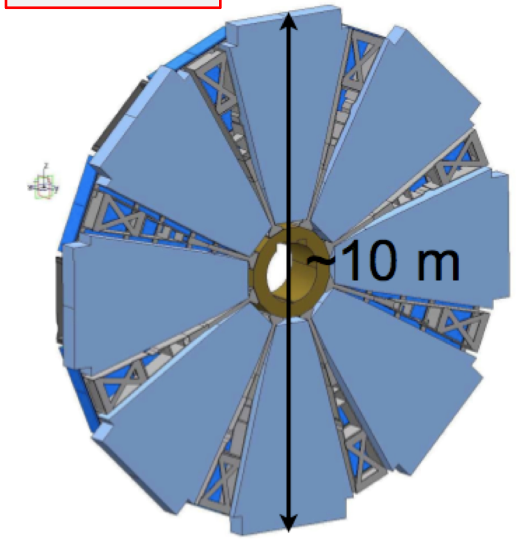
Based on two different detector technologies

sTGC (small-strip TGC)

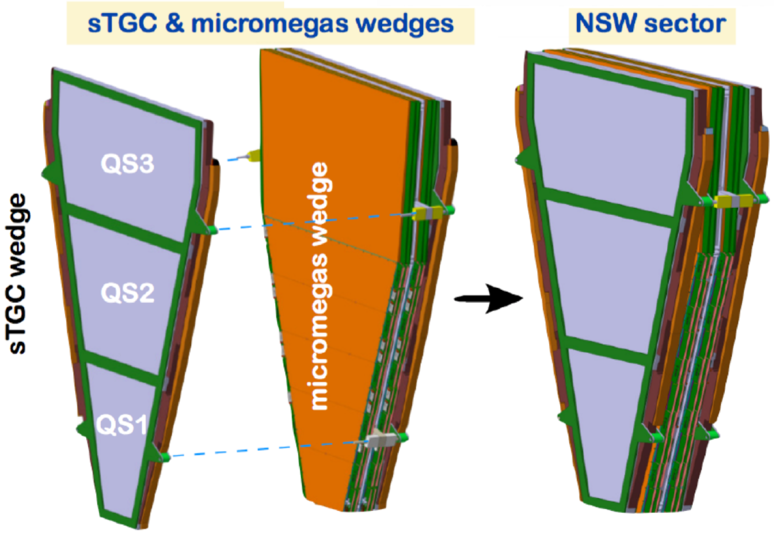
Micromegas

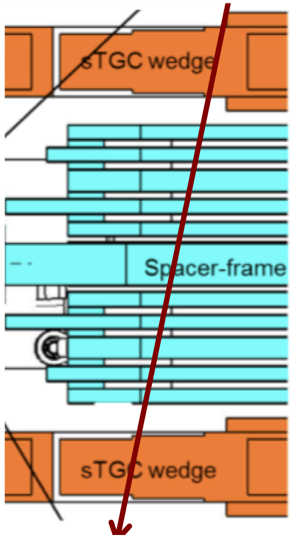


The Wheel



One sector



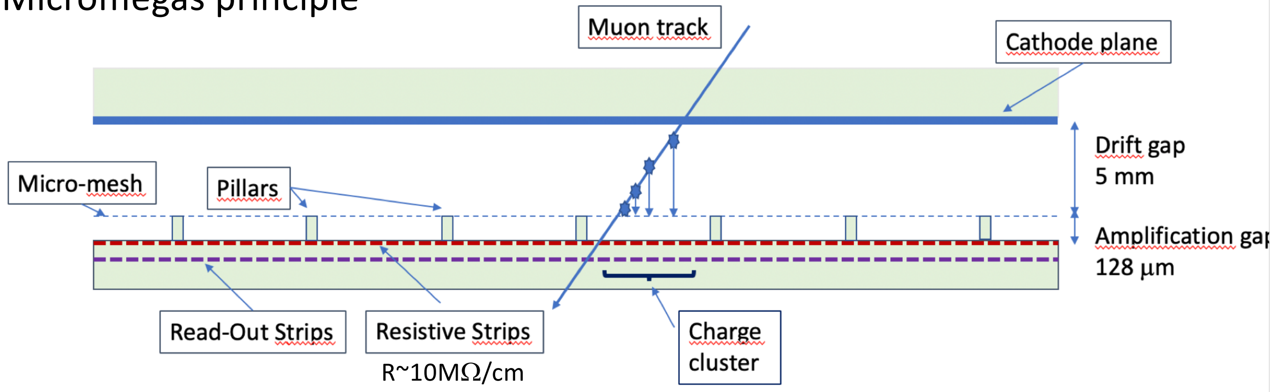


3 –The Micromegas detectors for the New Small Wheel

The Micromegas chambers

In the ‘90s → development of MicroStripGasDetectors:
Keep high **space and multi-track accuracy** in **high rate** environments
Micromegas = proposed in 1996 by Y.Giomataris and G.Charpak

Micromegas principle



Muon track

Cathode plane

Drift gap
5 mm

Micro-mesh

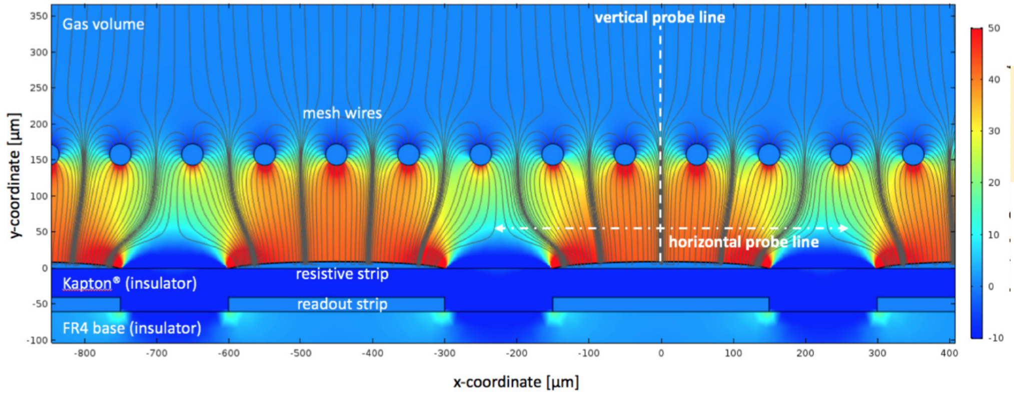
Pillars

Amplification gap
128 μm

Read-Out Strips

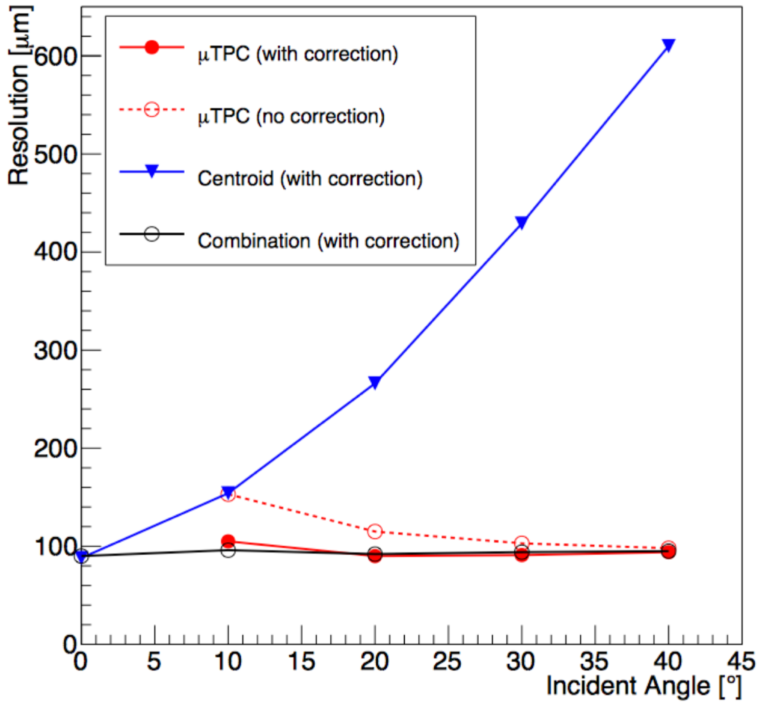
Resistive Strips
R~10MΩ/cm

Charge cluster



Transparency for electrons
Fast evacuation of ions

Space resolution measured on a Test-Beam



Prototypes 10x10 cm^2 built and tested at CERN
(Ref. T.Alexopoulos et al., NIMA937 (2019) 125)

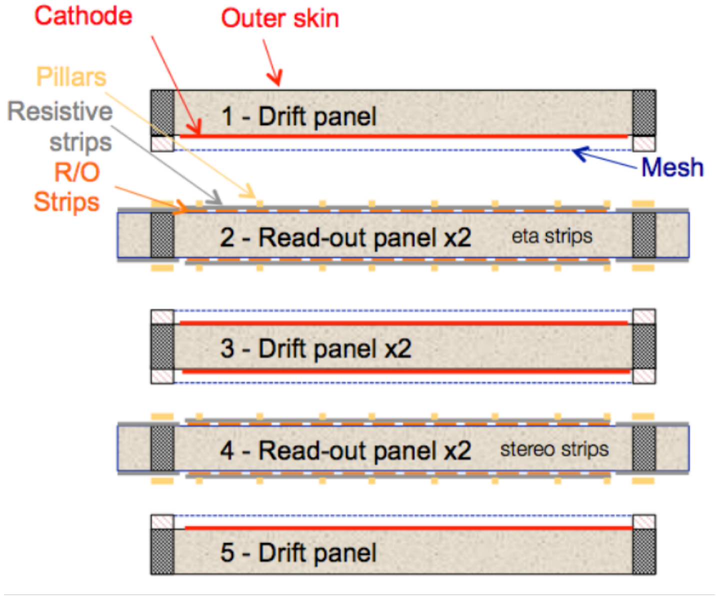
MicroMegas for ATLAS NSW - construction

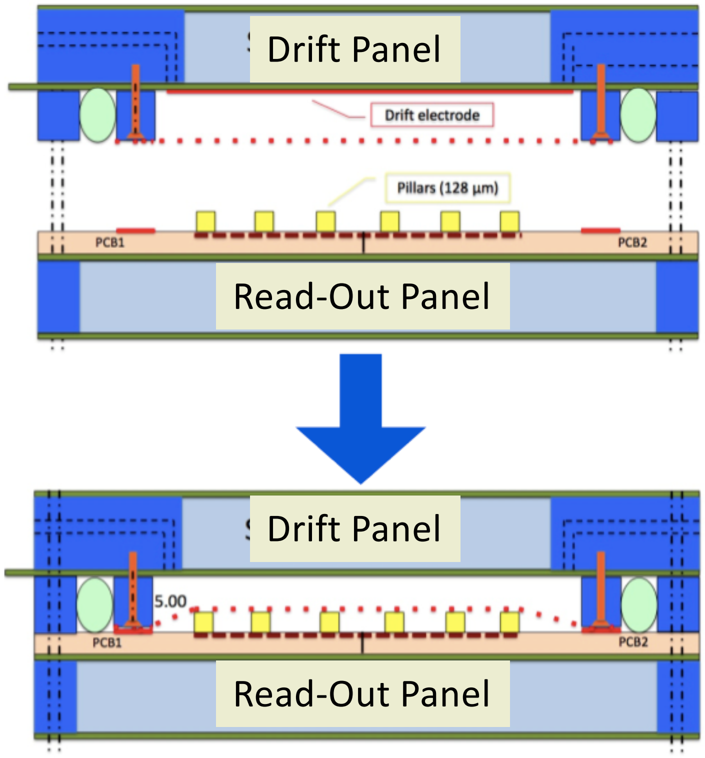
Extend the technology to high surface detectors (2 ÷ 3m^2) keeping the strict requirements on geometrical accuracy (30 ÷ 80 µm)

→ **A new construction technique has been developed**

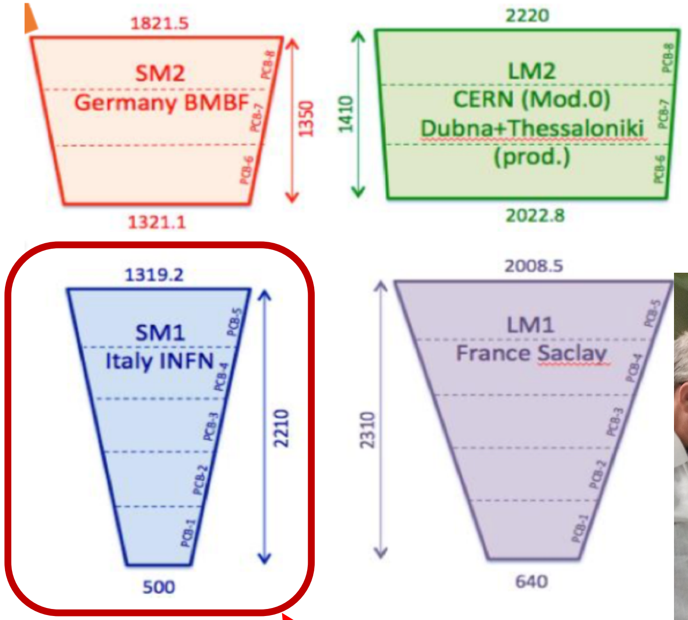
Assembly technique: **floating mesh**
(see T.Alexopoulos et a., NIMA955 (2020))

5 panels: stiffness and good planarity RMS<40µm) → **Qplet**
1 cm thickness ; 2 m^2 surface:
2 RO panels (with RO PCB)
3 Drift panels (with cathode) + stretched mesh



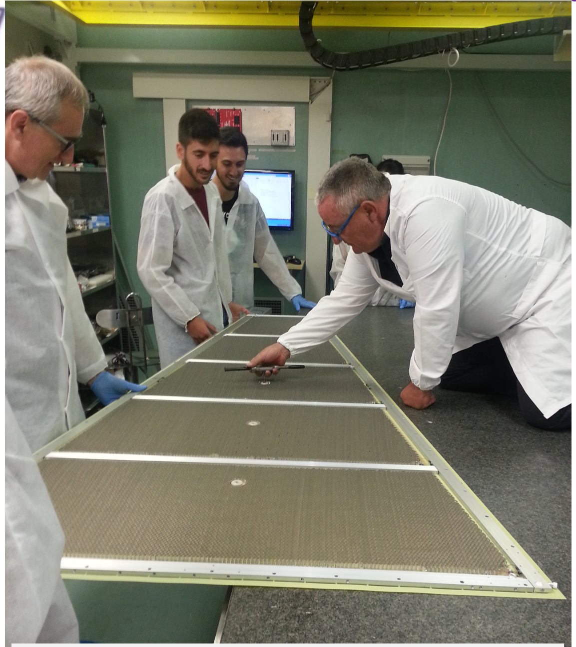


SM1 chambers – production



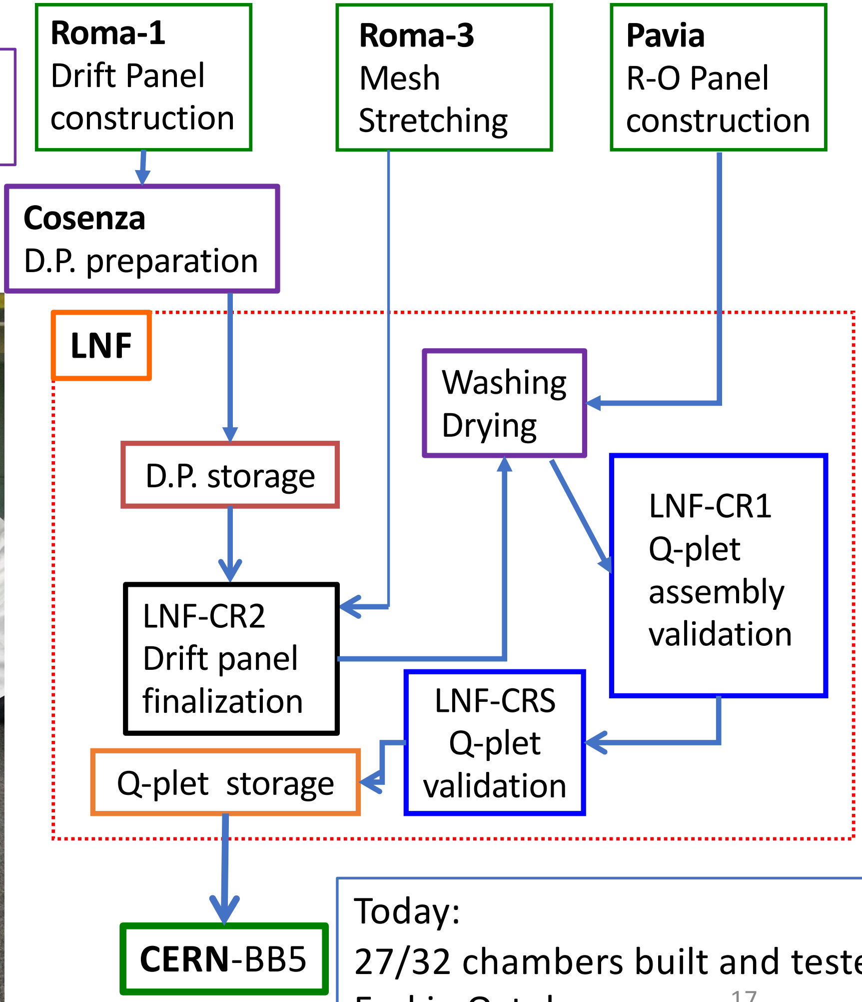
The construction is distributed among 5 different INFN sites

INFN consortium
(Cs, Le, LNF, Na, Pv, Rm1, Rm3):
→ Build and validate
32 Q-plets SM1



All SM1 Drift Panels built in our INFN mechanical workshop

SM1 production: INFN organization



Roma-1
Drift Panel construction

Roma-3
Mesh Stretching

Pavia
R-O Panel construction

Cosenza
D.P. preparation

LNF

D.P. storage

Washing
Drying

LNF-CR2
Drift panel finalization

LNF-CR1
Q-plet assembly validation

LNF-CRS
Q-plet validation

Q-plet storage

CERN-BB5

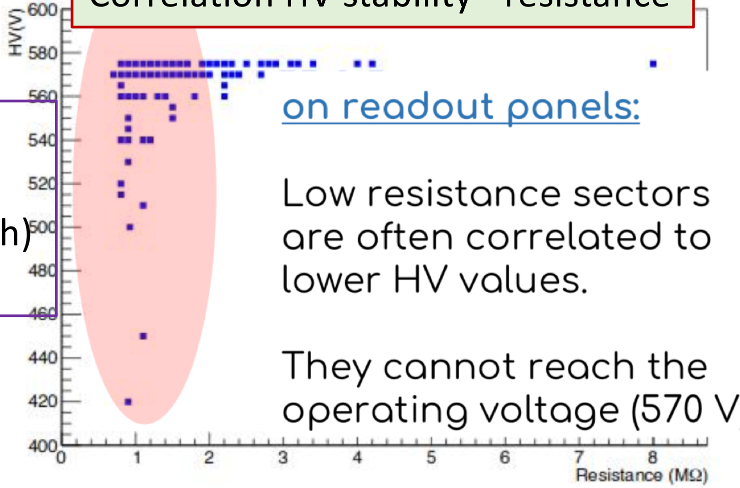
Today:
27/32 chambers built and tested
End in October

The HV stability problem – I

Starting from Module0 (2016) and first production modules (2017) observed problems of HV stability of the chambers

Attempts to mitigate the problem:
1) Reduction of gas RH
2) Cleaning protocol (anode and mesh)
3) Discovery of resistivity problem

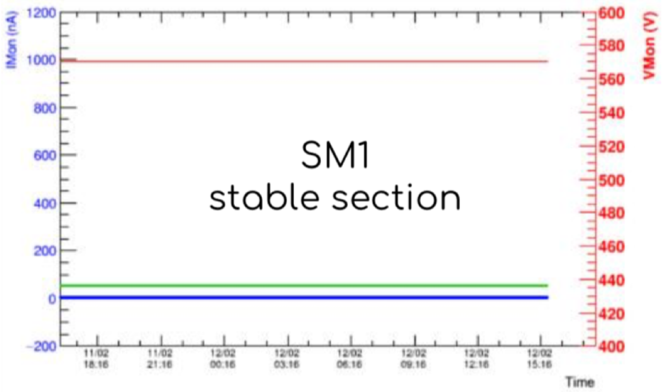
Correlation HV stability - resistance



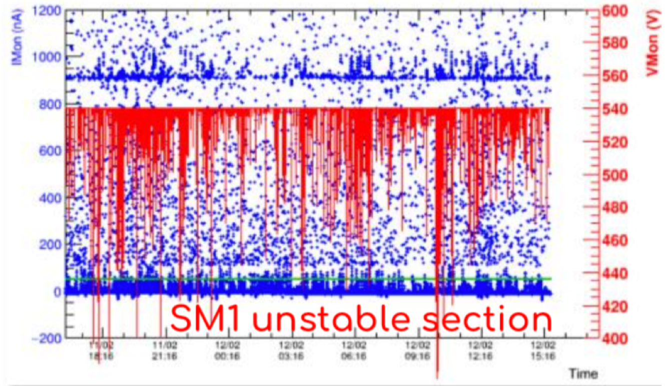
on readout panels:

Low resistance sectors are often correlated to lower HV values.

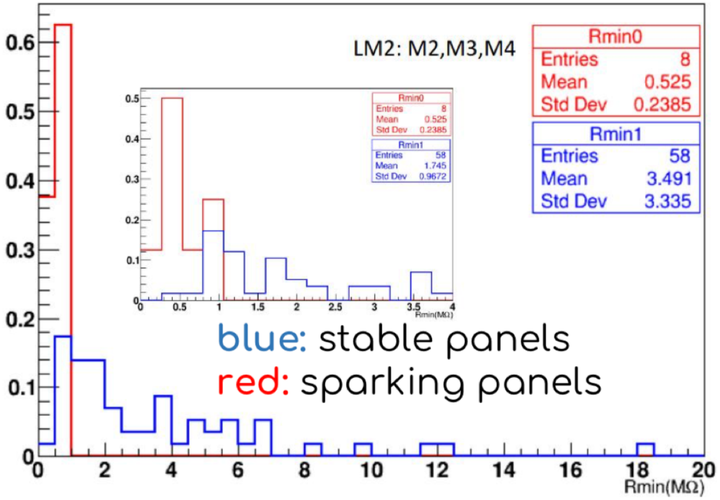
They cannot reach the operating voltage (570 V)



SM1
stable section



SM1 unstable section



blue: stable panels
red: sparking panels

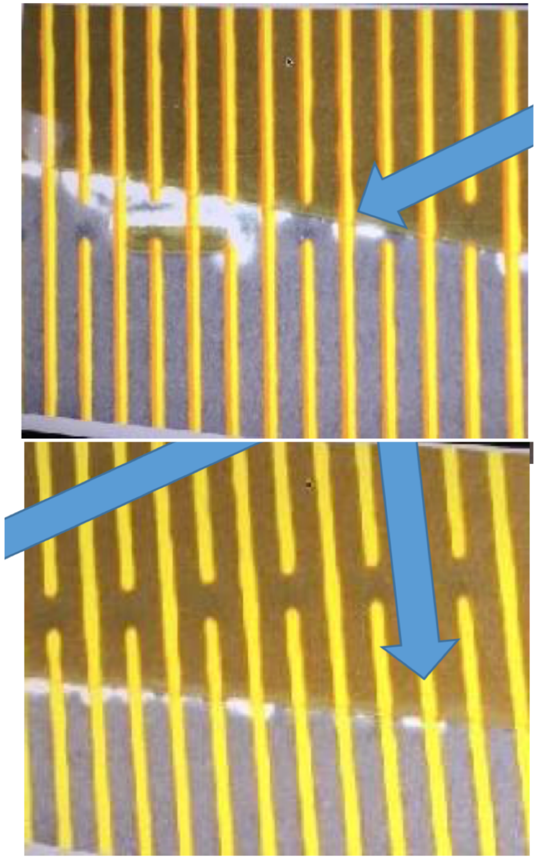
The HV stability problem – II

Observation: discharges happen close to the anode edge where Resistance is lower (weak points)

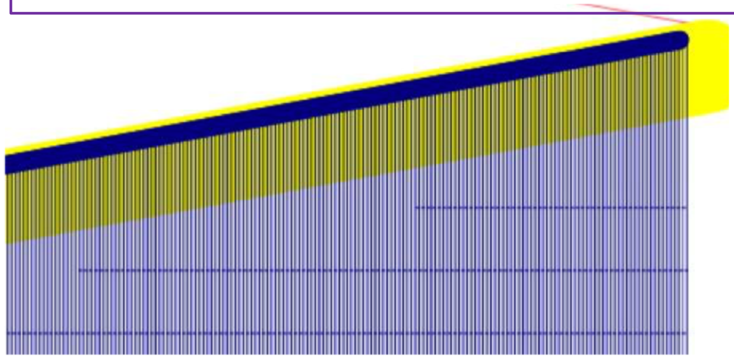
Emerging picture:

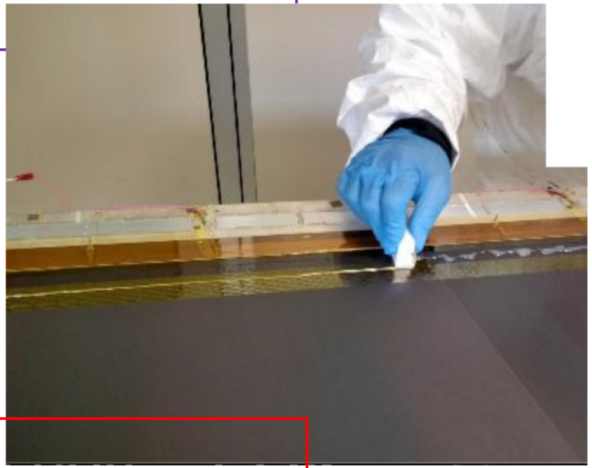
→ Spark causes:
  - Residual material Humidity
  - Residual ionic contamination
  - Mesh mechanical imperfections
  - Other imperfections

→ Spark protections:
  - Act on resistive layer
  - Gas mixtures (addition of isobutane)



Passivate “weak“ regions: some active area is loss (reducing overlap regions) but the detector now works!

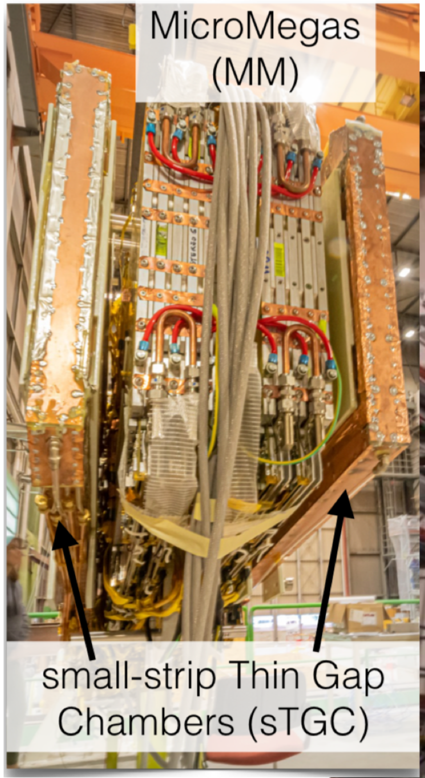




Technique introduced at Frascati by INFN consortium
then used by all other construction sites: best effect in large chambers
➔ Efficiencies larger than 90% for all chambers
Additional possibilities: improve gas mixtures increase of HV granularity

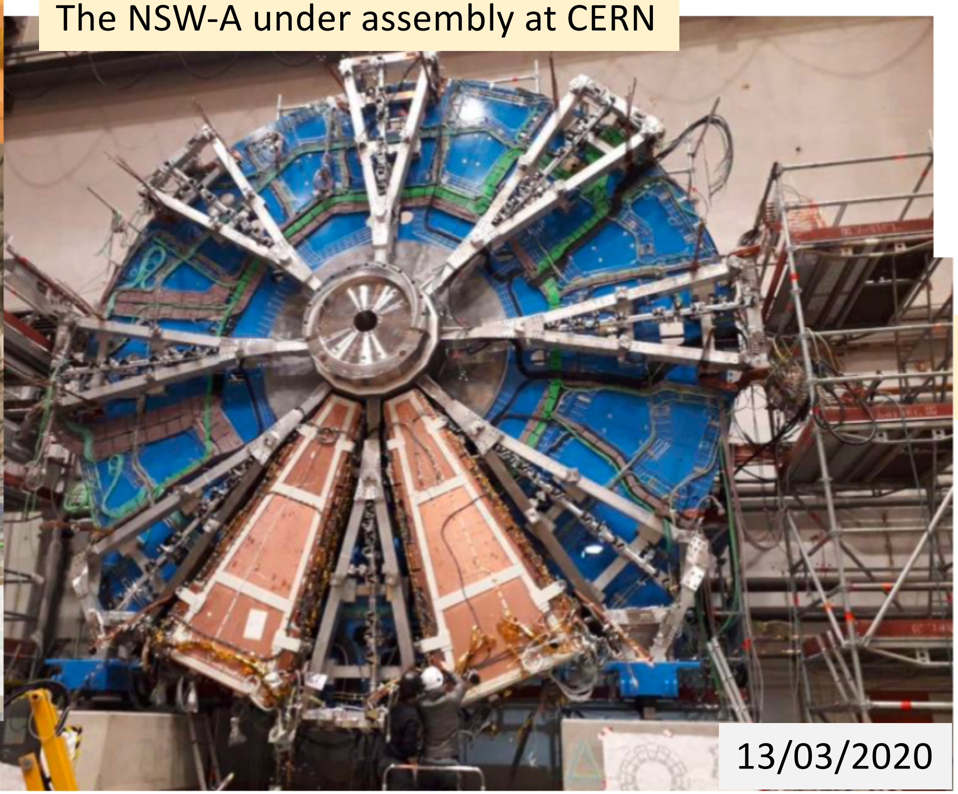
Integration at CERN

Chambers → Wedges → Sectors → Wheels



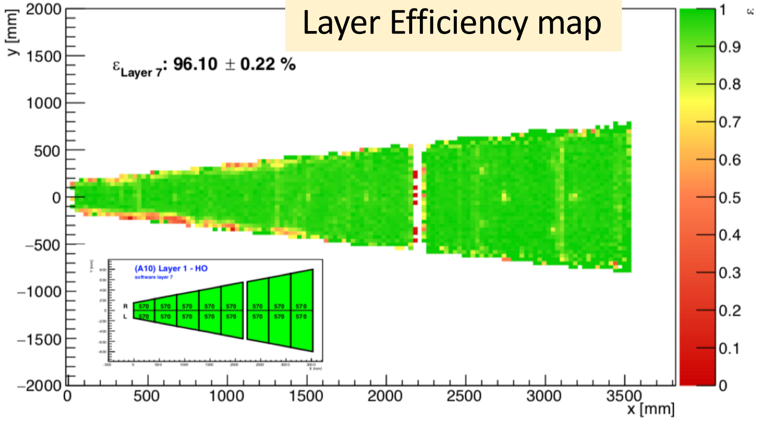
MicroMegas (MM)

small-strip Thin Gap Chambers (sTGC)

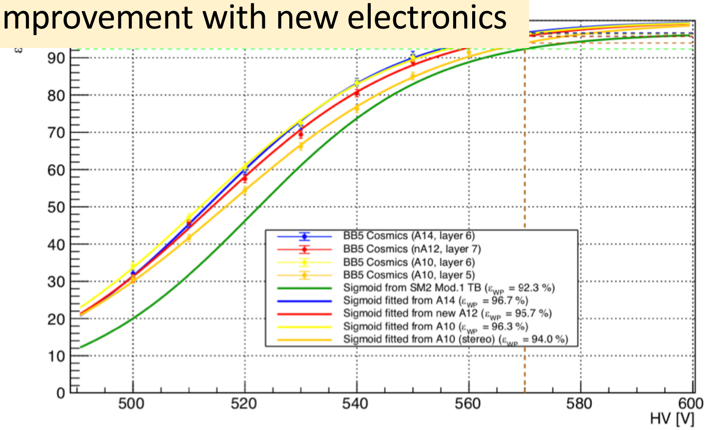


The NSW-A under assembly at CERN

13/03/2020



Layer Efficiency map



Efficiency plateau
Improvement with new electronics

Prospects

- The New Small Wheels are essential for the success of ATLAS in HL-LHC
- Both NSW-A and C should be installed in ATLAS by ~january 2022
  - Covid-19 → the schedule is now tighter, very challenging to be in time for installation
- In 2022 LHC will resume its operation with the so called Run3 (E_{cm}= 14 TeV, L=$2x10^{34}$ $cm^{-2}s^{-1}$)
  - Commission the NSWs and the MM chambers and integrate them for physics

- Update of the European Strategy for Particle Physics (June 2020)
- *The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques.* ***The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.***

backup