ATLAS Detector Upgrade for SuperLHC

Sandro Palestini – CERN
On behalf of the ATLAS collaboration
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LHC plans – *phase-1 upgrade*

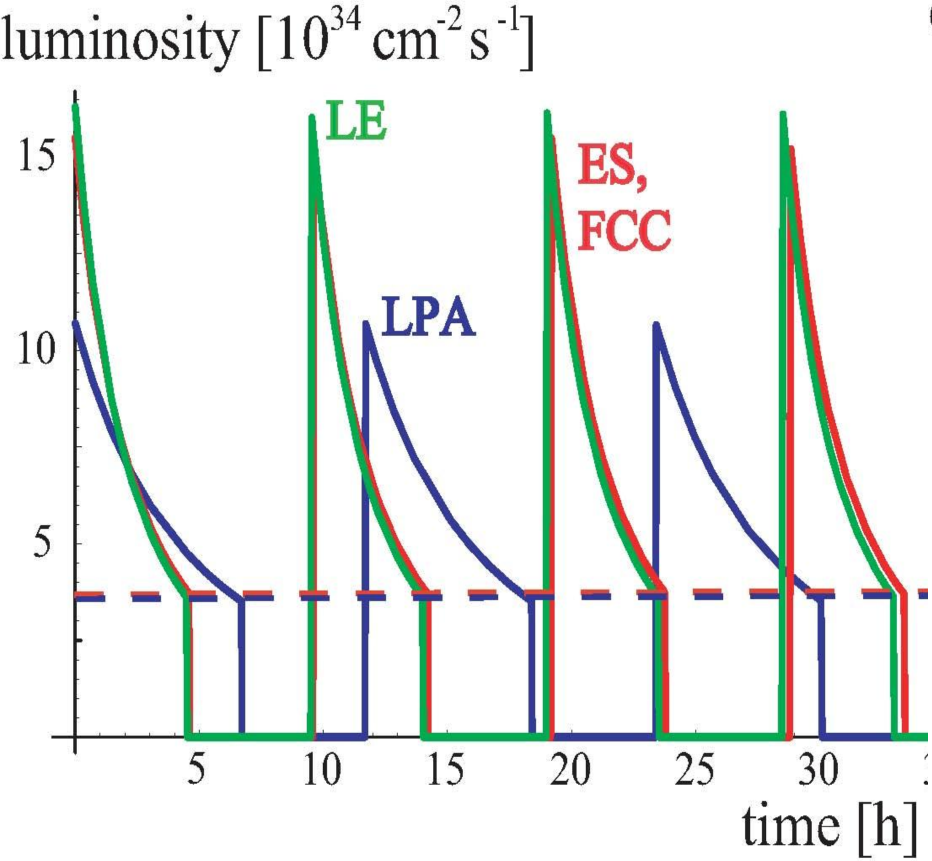
- LHC is advancing on the program of repairs and safety measures, which aims at collisions in late 2009, and a long run in 2010, with luminosity up to $\sim 1 \cdot 10^{32}$ $cm^{-2}s^{-1}$, and the aim of reaching an integrated luminosity of $\sim$200 pb^{-1} at c.m. energy of 8-10 TeV
- The road to high luminosity requires:
  - new NbTi triplets, D1, TAS,
  - $\beta^* \sim 0.25$-0.3 m in IP1 & 5,
  - beam from new Linac4 (160 MeV vs. 50 MeV in Linac2)

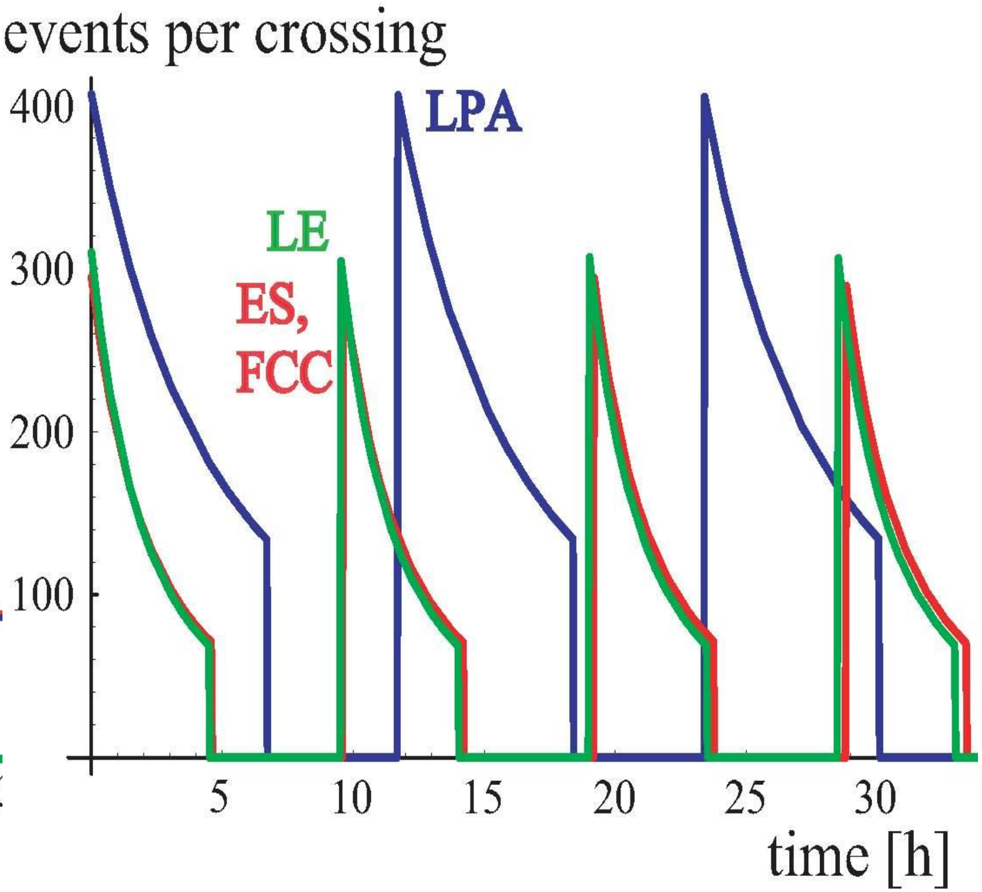
  This is the "Phase-1 upgrade" scenario, which calls for a transition in the shutdown 2013-2014, with peak luminosity of about $3 \cdot 10^{34}$ $cm^{-2}s^{-1}$ reached afterwards (corresponding to about 60 interactions per beam crossing).

LHC plans – *phase-2 upgrade: superLHC*

- The reach of the LHC program could be extended by a more complex upgrade that would be actuated in the years following 2018, aiming at peak luminosity of $\sim 1 \cdot 10^{35}$ $cm^{-1}s^{-1}$
- The upgrade include new design of the IR, for which different schemes are foreseen:
  - IR components closer to the interaction point might be required
  - The bunch spacing would remain at 25ns, or increase to 50ns (the 12.5ns option is currently discarded)
  - The machine cycle, the peak luminosity and the number of interactions per bunch crossing depend on the different schemes

Phase-2 scenarios





Different IR schemes (see also backup slide) :
ES: early separation, FCC: full crab crossing; LPA: large Piwinski angle; LE: low emittance

ATLAS and LHC upgrades – phase-1

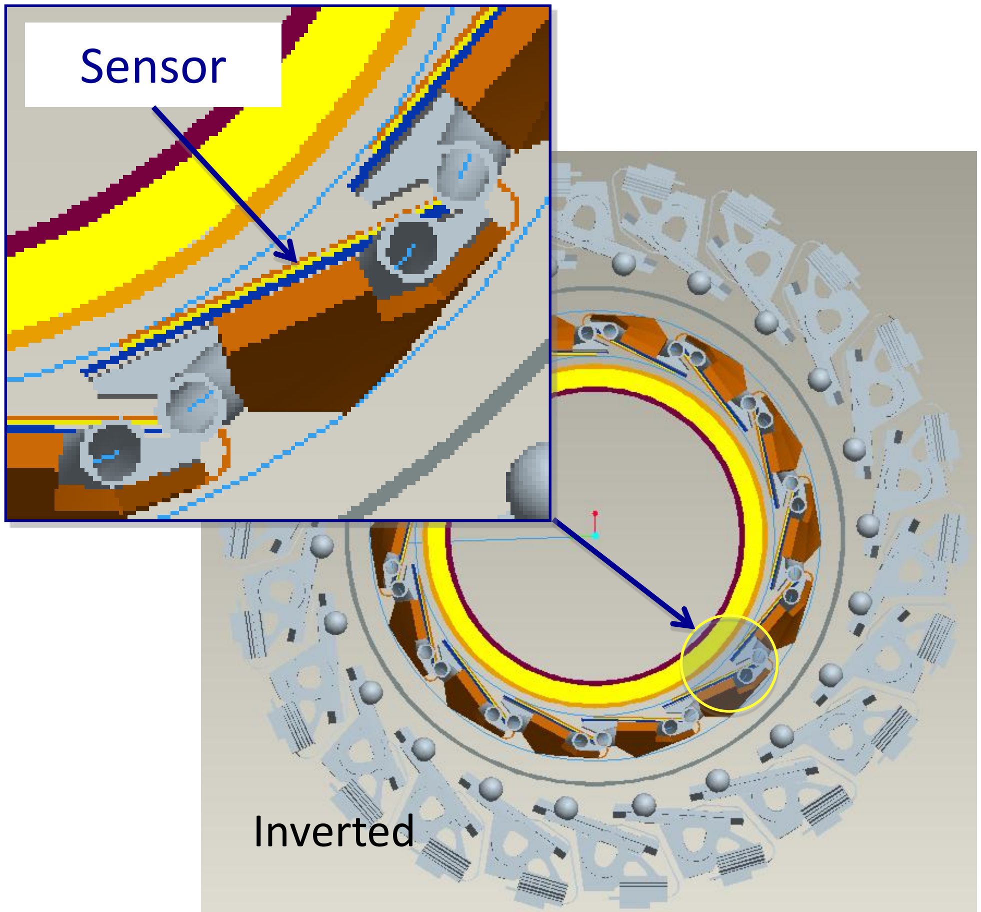
- The *ultimate* LHC luminosity of ~ $3 \cdot 10^{34}$ $cm^{-2}s^{-1}$ is beyond the design value, and ATLAS is completing an analysis to understand whether all sub-systems would perform optimally, and whether event selection could be made more efficient at Level-1 and Level-2 trigger.
- The innermost tracking system (the pixel detector) is designed for:
  - LHC nominal number of interactions per bunch crossing,
  - an integrated luminosity of up to ~700 fb^{-1} .

  The latter is short of the range expected between the achievement of phase-1 and the foreseeable shut-down for phase -2;

  in addition the performance starts to degrade at the ultimate LHC luminosity because of channel occupancy.
- Therefore a program for a new innermost pixel layer, the *Insertable -B-Layer* (IBL), has been started.

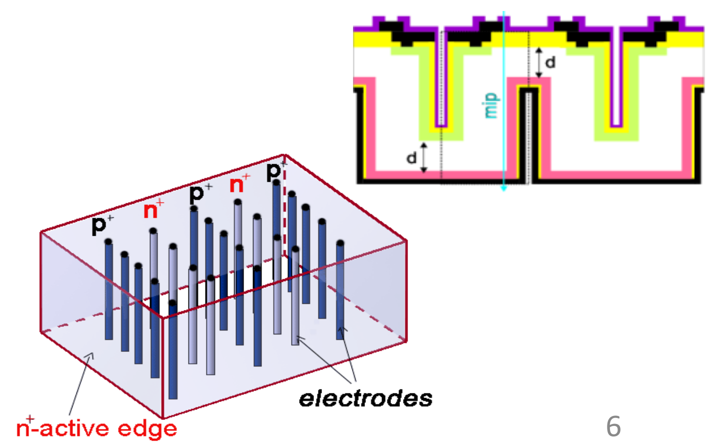
IBL program

- An example of IBL layout: 14 staves at R_{min}=~3.2 cm



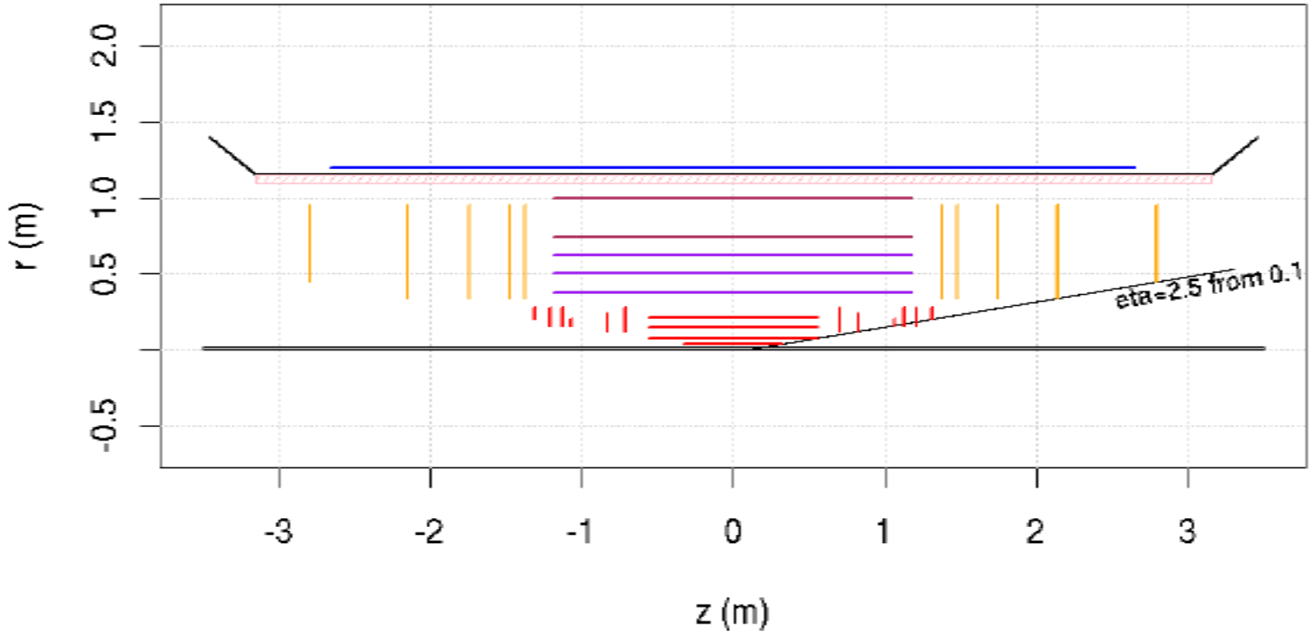
Different options being considered for the sensors:

- Planar-Si (also being studied for radiation hardness suitable for sLHC)
- 3D Sensors



Detector upgrade for phase-2 (*sLHC*)

- The main upgrade involves the *Inner Detector* .
- ATLAS is built with an ID designed for LHC luminosity, formed by an innermost silicon pixel detector, layers of silicon strips, and a *Transition Radiation Tracker* with thin tubes for tracking and particle identification)
- The new ID for sLHC may be entirely based on silicon sensors.

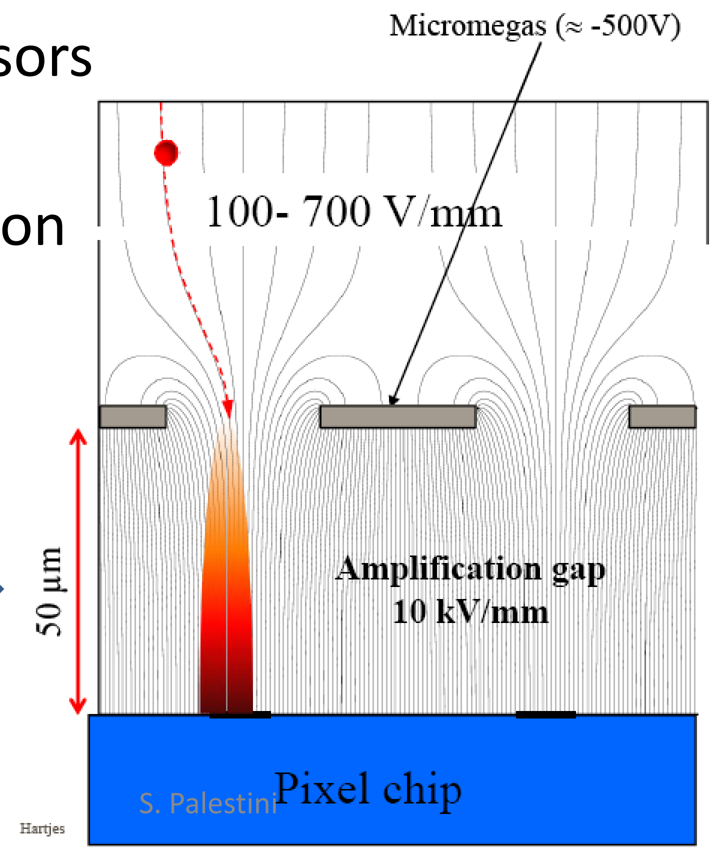


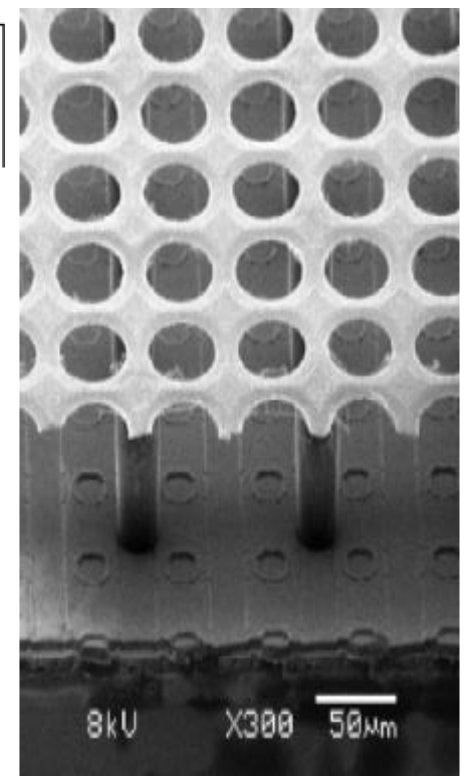
sLHC baseline design:
- 1 B-layer (pixel layer 0)
- 3 pixel layers
- 3 short strip layers
- 2 long strip layers

Parameters/options for new *ID*

- Particle rate: ~ 0.9 GHz cm^{-2} in innermost (*B*-) layer
- Fluence for 3000 fb^{-1} : $3.4 \cdot 10^{16}$ cm^{-2} charged particles, or $2.0 \cdot 10^{16}$ n_{eq} cm^{-2}

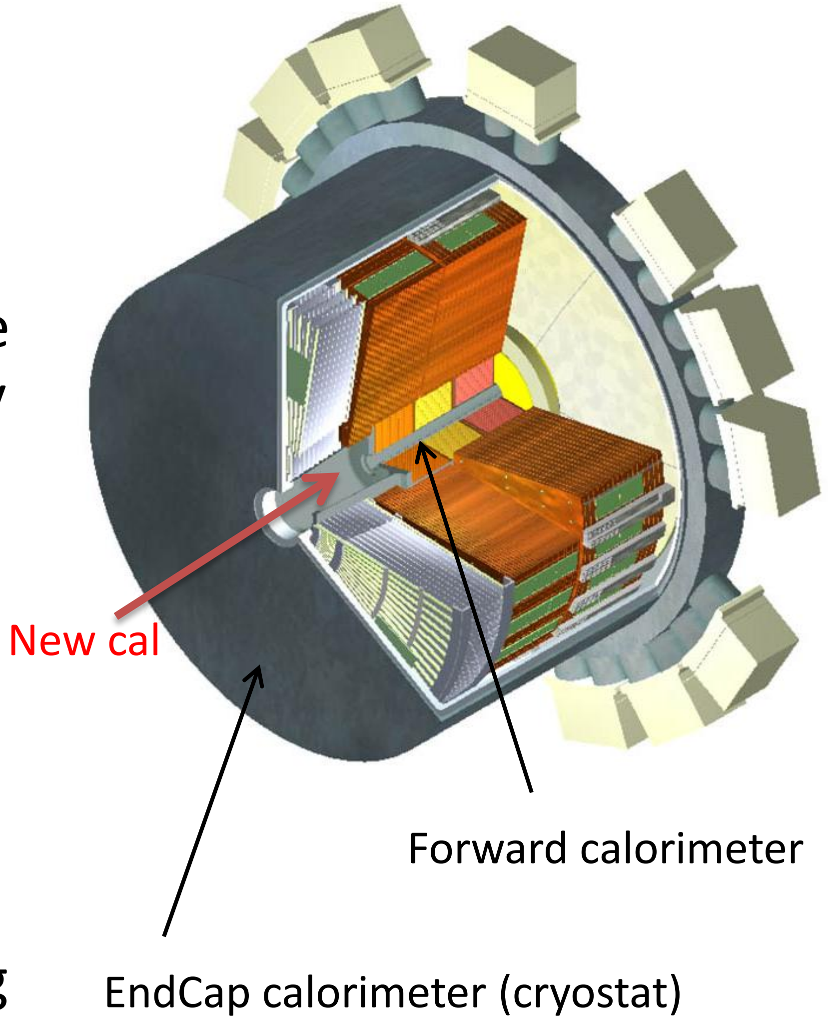
- Current options for sensors (R&D projects)
  - Rad-hard planar silicon
  - 3D silicon
  - Diamond
  - Gas-pixel detectors (*Gossip*)





ATLAS calorimeters at sLHC

- Both e.m. and hadronic calorimeters expected to perform generally well at sLHC.
- However the forward calorimeter (LAr, $3.1<\eta<4.9$) will suffer from the rate, both because of cell geometry (space charge) and power dissipation (LAr stability vs. boiling)
  - Option of a new FCAL (smaller gaps, more cooling) - requires opening the LAr cryostat
  - Alternatively, insert a warm calorimeter (copper/tungsten-diamond) in front of the existing calorimeter



- Additionally, upgrade of the read-out electronics of the calorimeter is being considered, in order to increase the radiation hardness, the bandwidth, and the triggering capabilities.
- The possibility of a low-level trigger based on tracking detectors is also being considered.

Muon chambers

- Performance under high background rate,
- Long term stability,
- Read-out bandwidth,
- Triggering capabilities

are the key topics for the Muon system at sLHC. We'll discuss them briefly, together with three upgrade options

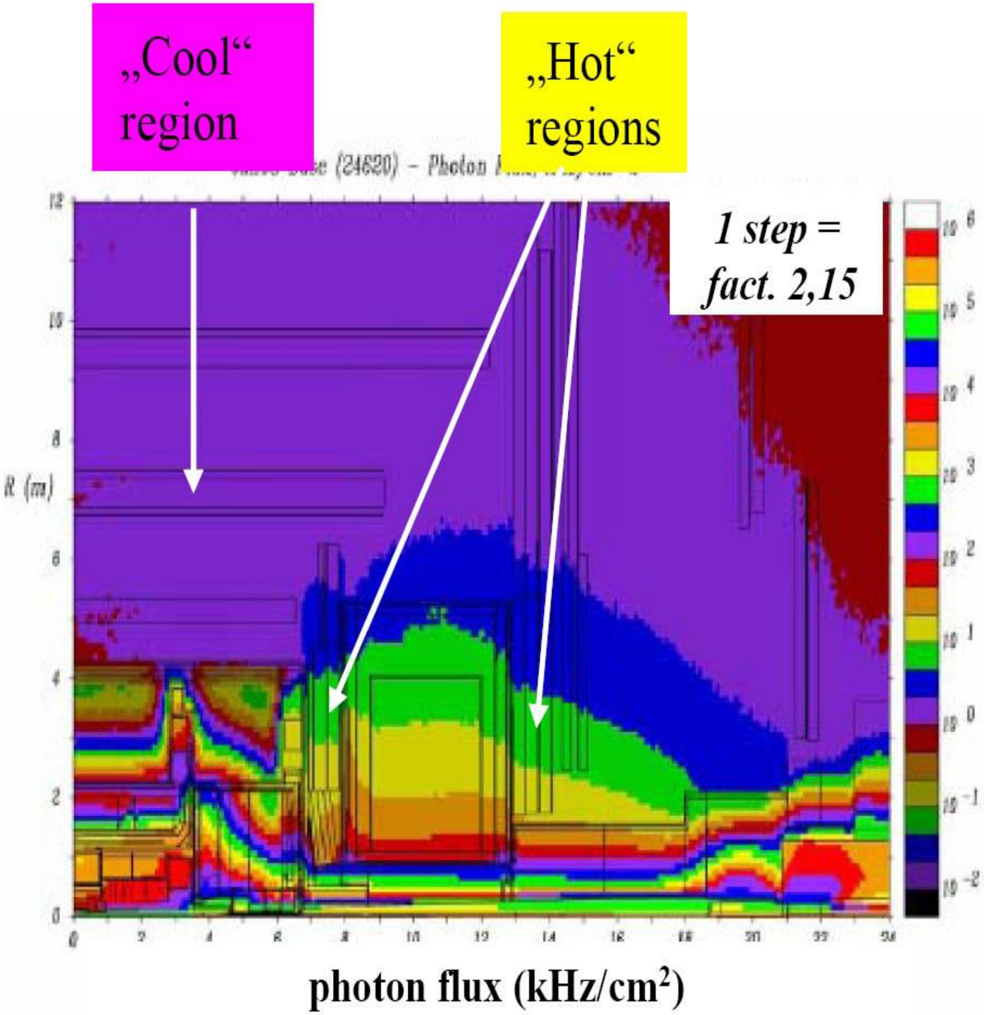
Background in the Muon system

Dominated by asynchronous, low energy background from photons and neutrons. Expected particles rates at LHC ranging from ~10 Hz cm^{-2} to ~400 Hz cm^{-2}.

Large uncertainty in the prediction

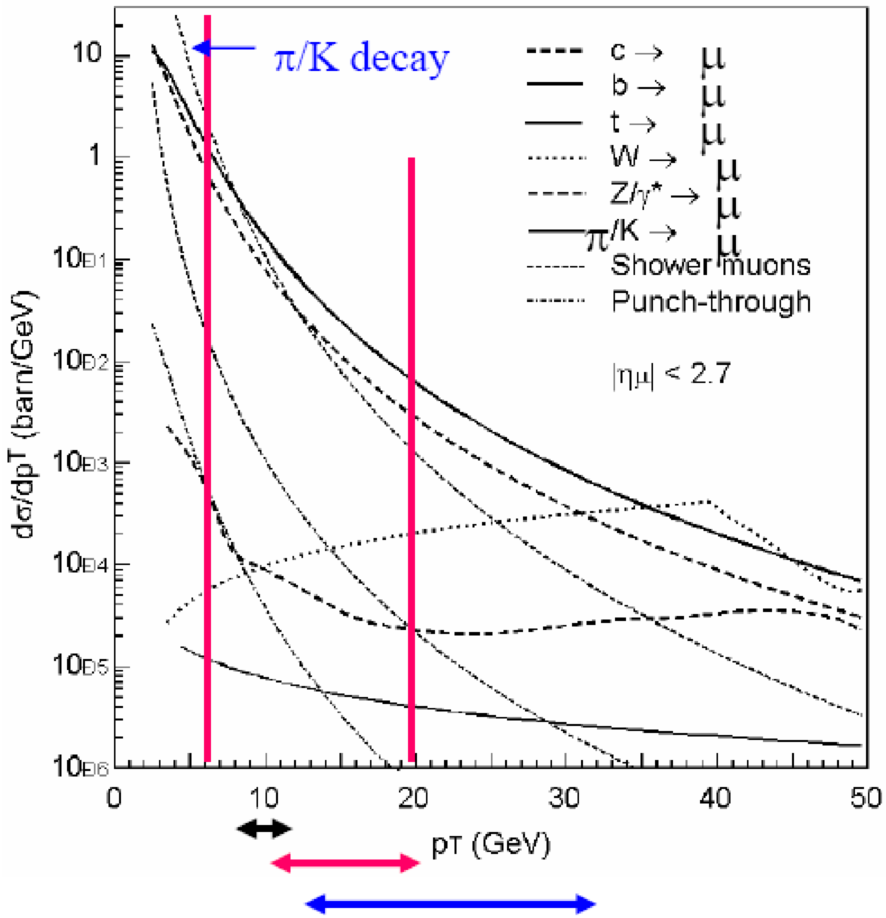
- combination of uncertainty in simulation with the large variations of particle flow (decreasing) and detector efficiency (increasing) in the critical range of 0.1 - few MeV.

The Muon system for LHC was designed with a background safety factor equal to 5, and it will be most interesting to measure the rates with LHC collision.

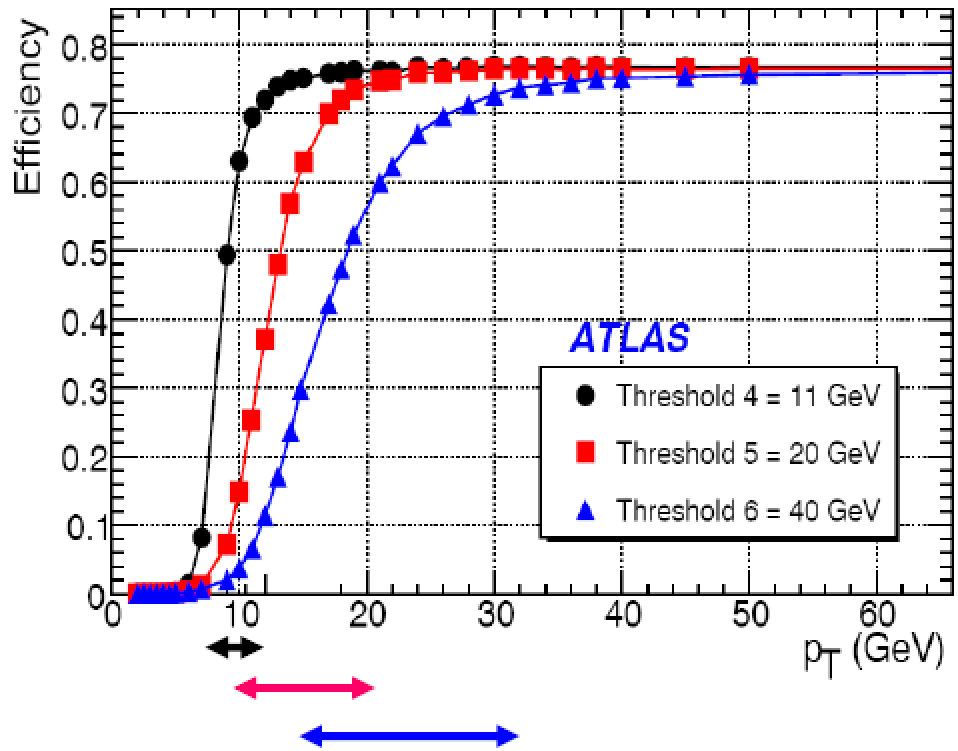


Muon Level-1 trigger

A *sharper* Muon trigger would be beneficial at sLHC luminosity

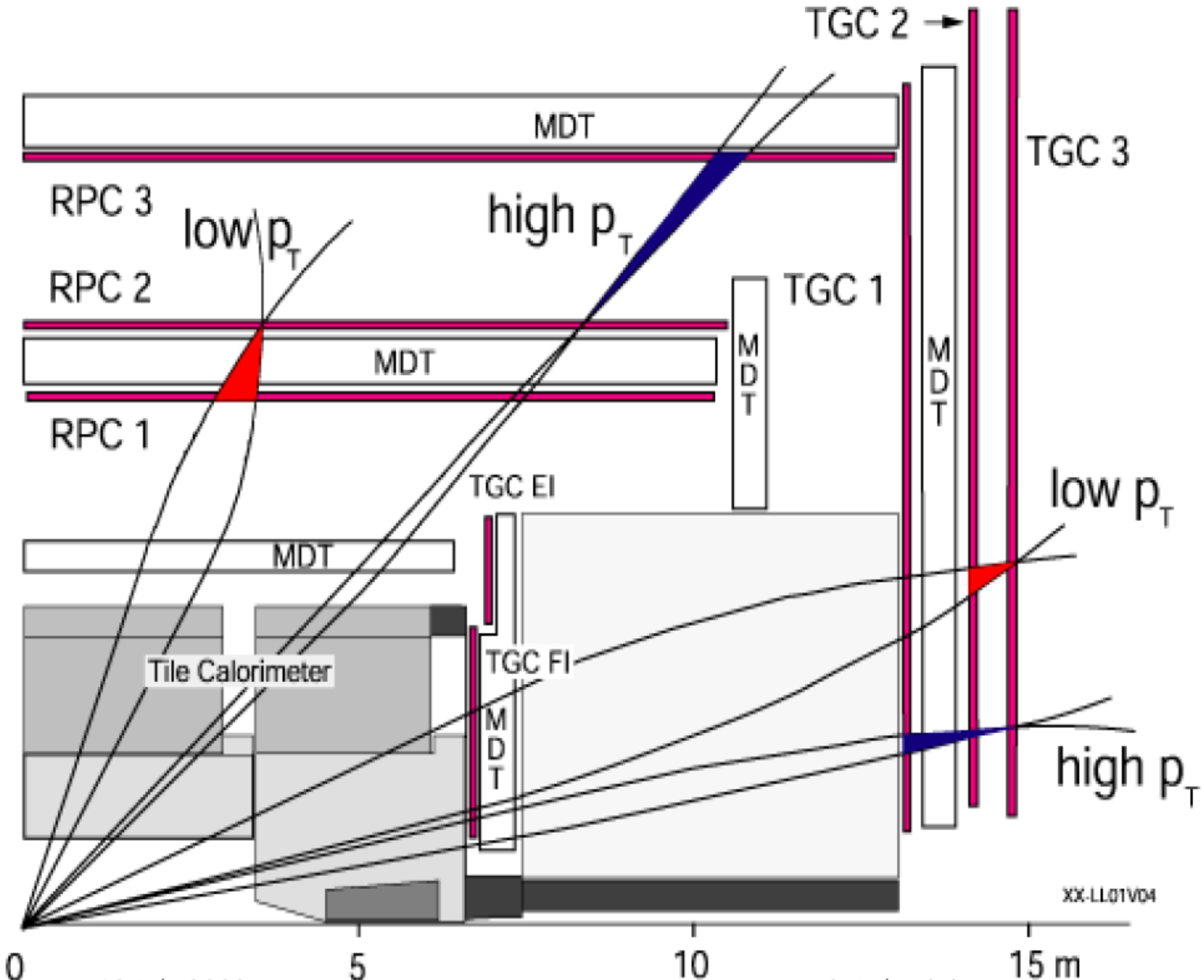


Muon cross-sections as a function of p_T at production, integrated in the region $|\eta|<2.7$



Selectivity of momentum cut in the muon trigger is decreasing with increasing threshold

Muon Level-1 trigger



Studies on possible schemes to increase the trigger resolution are underway.

In a scheme being studied, trigger chambers are added to the inner stations of Barrel and EndCap

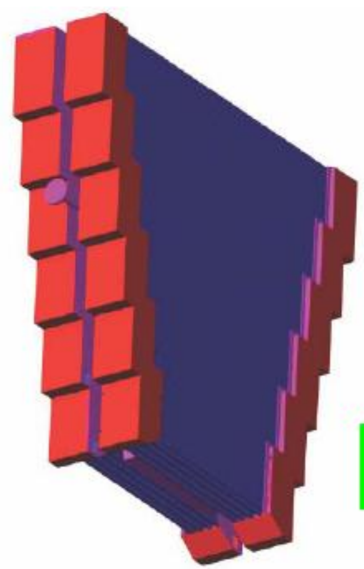
Muon upgrade: new chambers for highest rate regions

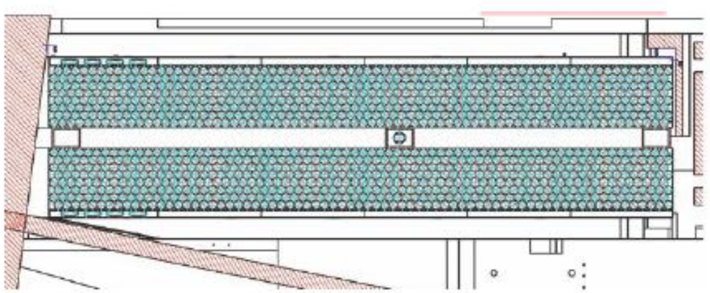
Various options are being considered for a replacement of chambers in the forward region:

1. *Monitored Drift Tubes* chambers with *small* tubes

MDTs (drift tubes operated at 3 bar) are the precision chambers used in all stations of the ATLAS Muon system.

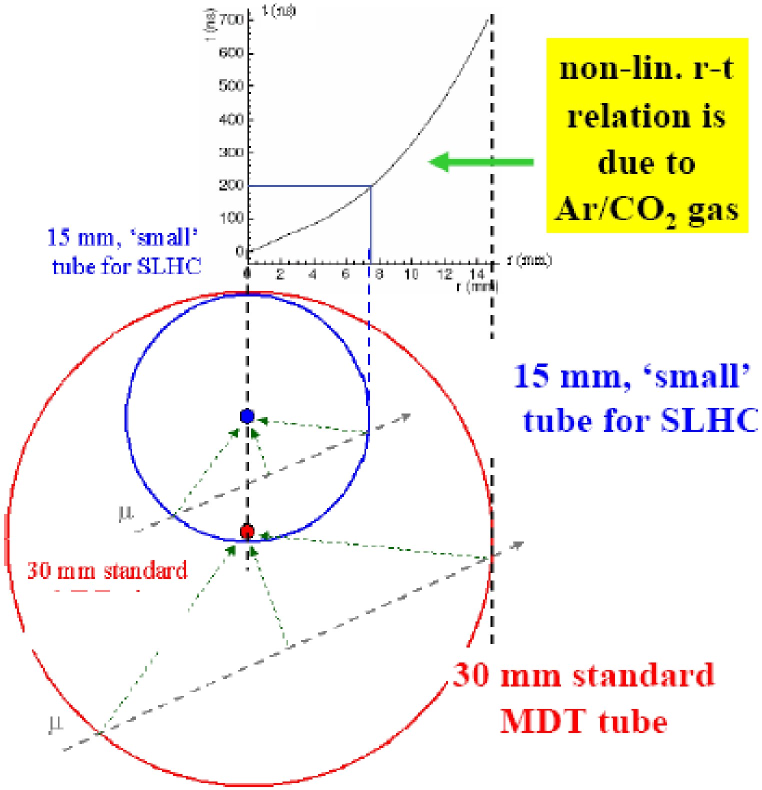
An version with smaller diameter tubes (15 mm rather than 30 mm) is an option for sLHC .

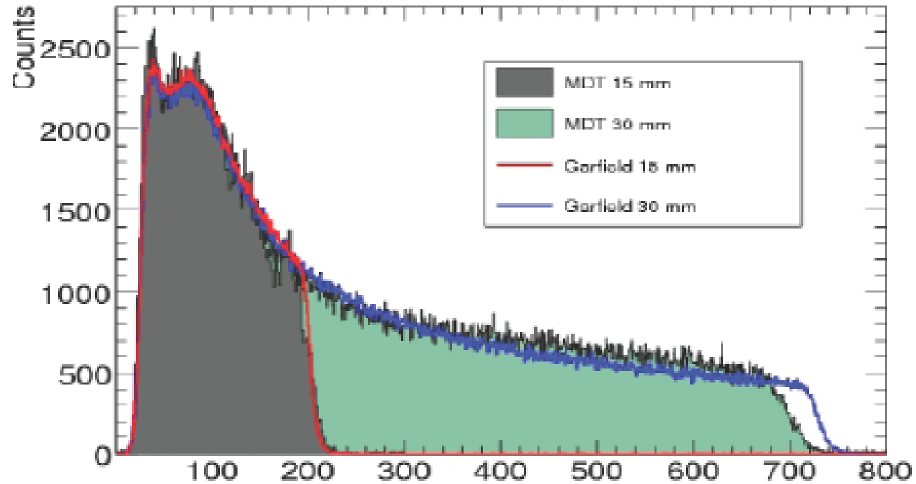




an endcap chamber with 2 x 8 tube layers

Small-tube MDTs





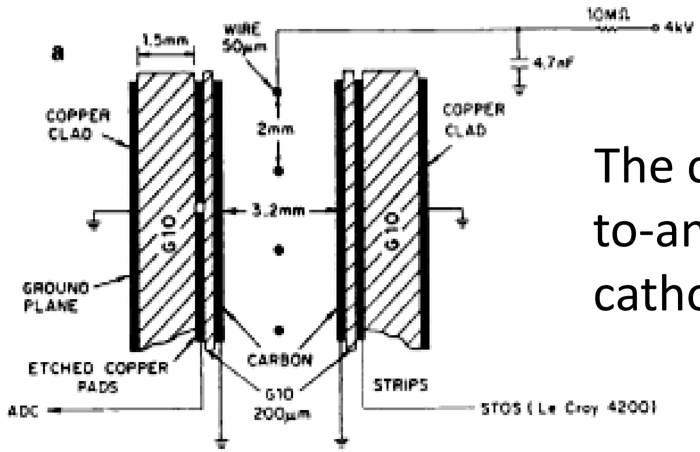
drift time spectr. w. large and small tubes

Smaller tubes provide reduced channel cross section (x 1/2) (reduced occupancy)
shorter pulse, shorter maximum charge collection time (x 1/3),
reduced space charge (~ R^{-3} = 1/8) (affecting chamber resolution at large *r*)

2. Upgraded *Thin Gap Chambers*

- TGCs are used in the Muon EndCap the *BigWheel* (middle station) and in the *SmallWheel* (inner station) as triggering and 2nd coordinate detectors.
- The space resolution is determined the number of wires grouped together in the 1st coordinate measurement ($\sim r$), and by the size of the read-out pads in the 2nd ($r \cdot \varphi$) direction.
- An upgraded detector for sLHC might be characterized by:
  - Lower surface resistivity for pad read-out (10-20 KOhm/square)
  - Precise coordinate analog read-out by pads
  - Second coordinate by suitable grouping of wires

Upgraded TGCs



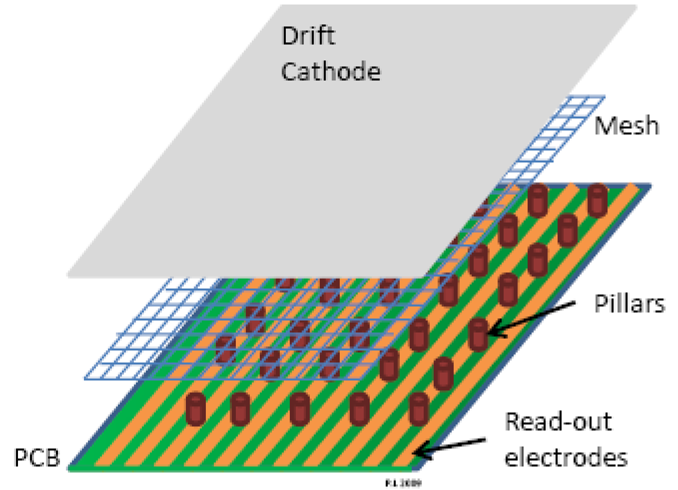
The cell geometry for sLHC might have anode-to-anode distance of 1.8 mm and cathode-to-cathode distance of 2.8 mm.

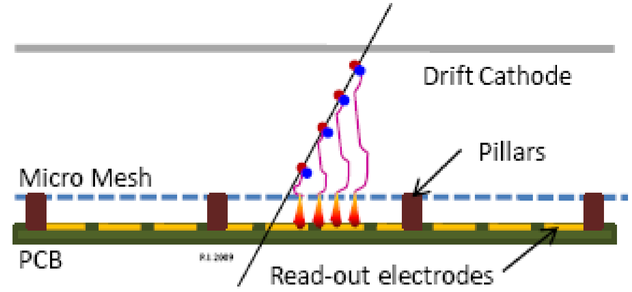
Current activities include test of full size prototype, performance at high rates, stability for long exposures, different gas mixtures.

The upgraded TGC would be suitable as both precision-tracking and triggering detectors in the region of highest rates.

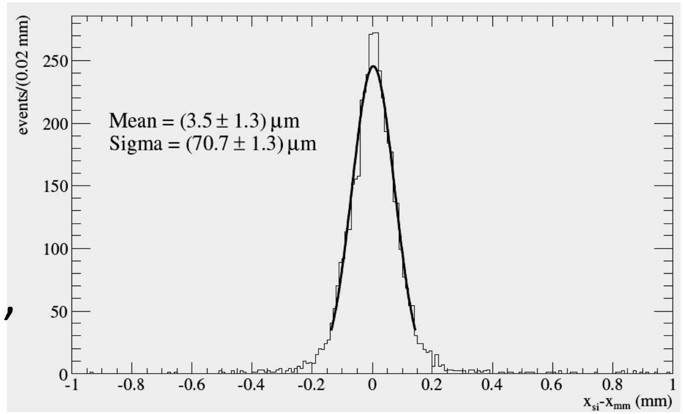
3. Micromegas

This technology is suitable for:
• precision tracking,
• operation at high rate,
• optimization of read-out segmentation for 2nd coordinate
• triggering





An R&D program is focusing on the construction of relatively large detectors, and on the optimization of response for tracks with incidence angle between 90 and 45 degrees



Test beam result: intrinsic resolution ~40 μm, pitch 500 μm, amplification gap 128 μm

Micromegas

Observed characteristics:

- Electron transparency >90%
- Gas amplifications 10^3-10^4
- $\varepsilon > 98\%$

Gas: Ar-CF_4-iC_4H10 (88-10-2 %) and other mixtures (including Ar-CO2)

Strip pitch 250-2000 μm
(500 μm used most frequently)

The latest, *large size* prototype

Conclusions

- While the detector for LHC is getting ready for first collisions, programs for upgrades have started.
- A new, innermost layer of silicon pixels is being designed for installation in about 5 years from now, at the moment when the accelerator will be upgraded to reach, and slightly exceed, the LHC design luminosity.
- For the upgrade to a higher luminosity collider (sLHC), R&D and design activities have started, including those concerning a new inner tracking detector, and new Muon chambers for the regions of highest rate.

References and credits:

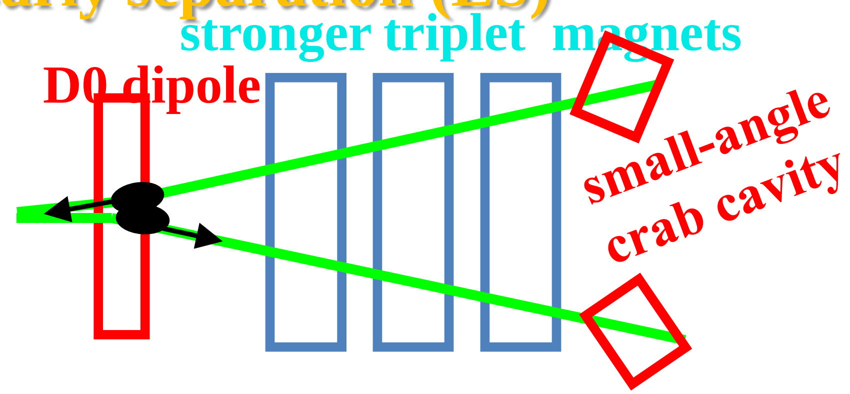
- sLHC machine upgrade scenarios: F. Zimmermann, presentation at LHC-Committee, Feb. 2009, http://indico.cern.ch/materialDisplay.py?contribId=0&materialId=slides&confId=52276
- IBL design work: N. Hartman (see: http://indico.cern.ch/getFile.py/access?contribId=25&sessionId=5&resId=1&materialId=slides&confId=54685;

  3D sensors: C. Da Via for the 3D sensor ATLAS R&D group (see also: http://indico.cern.ch/materialDisplay.py?sessionId=3&materialId=0&confId=45460)
- ID baseline layout: N. Hessey
- *Gossip* R&D: H. van der Graaf for the gaseous pixel detector R&D group; see also A. Romaniouk et al., ATL-UPGRADE-SLIDE-2009-141 http://cdsweb.cern.ch/record/1180841?ln=en
- Radiation and background: V. Hedberg, see also CERN report CERN-ATL-GEN-2005-001 (http://cdsweb.cern.ch/record/814823?ln=en)
- Upgraded MDTs: H. Kroha and R. Richter for the small-tube R&D group (see: http://indico.cern.ch/materialDisplay.py?contribId=1&materialId=slides&confId=43987)
- Upgraded TGCs: G. Mikenberg for the TGC upgrade group (see: http://indico.cern.ch/materialDisplay.py?contribId=4&materialId=slides&confId=43987)
- ATLAS micromegas: J. Wotschack for the *MAMMA* activity (see: http://indico.cern.ch/materialDisplay.py?contribId=3&materialId=slides&confId=43987 and P. Iengo et al., ATL-UPGRADE-SLIDE-2009-149, http://cdsweb.cern.ch/record/1183853?ln=en)

BACKUP SLIDES

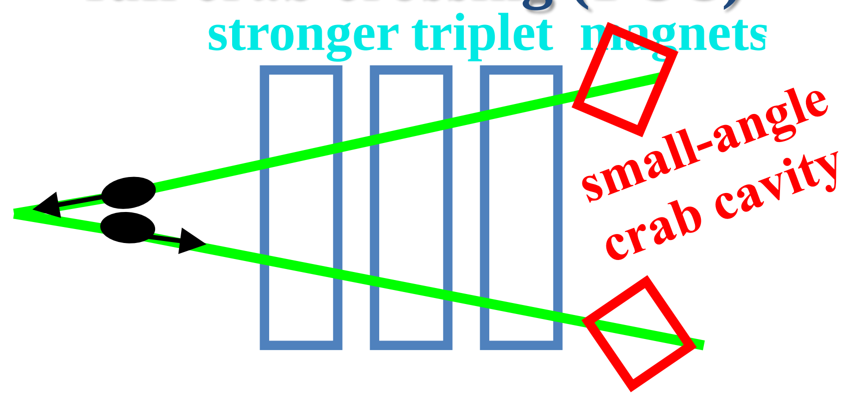
sLHC:"phase-2" IR layouts

early separation (ES)



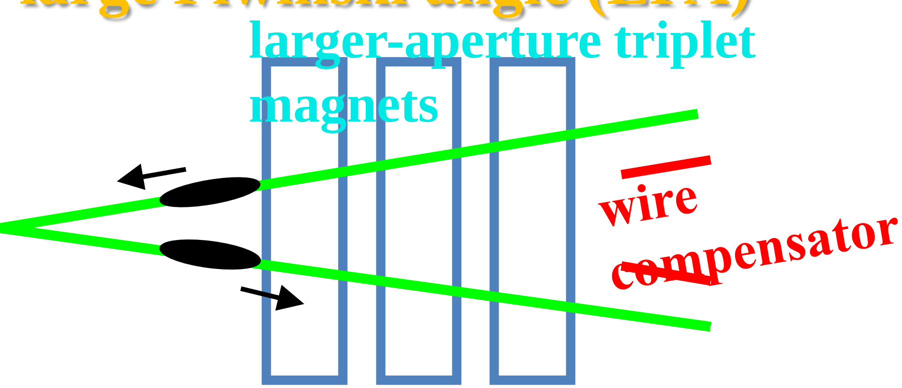
- early-separation dipoles in side detectors , crab cavities
  → **hardware inside ATLAS & CMS detectors,**
  first hadron crab cavities; off-δ β

full crab crossing (FCC)



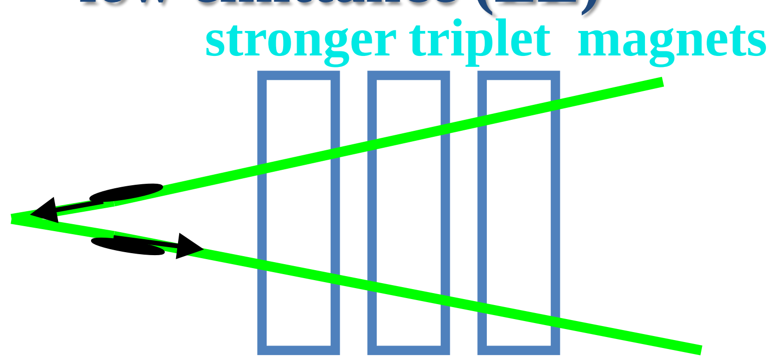
- crab cavities with 60% higher voltage
  → **first hadron crab cavities, off-δ β-beat**

large Piwinski angle (LPA)



- long-range beam-beam wire compensation
  → **novel operating regime for hadron colliders,**
  beam generation

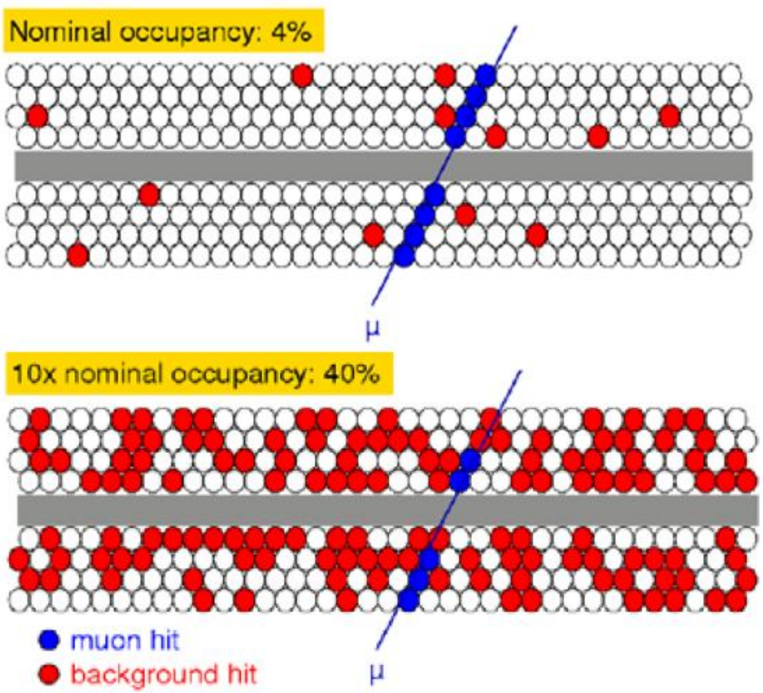
low emittance (LE)



- smaller transverse emittance
  → **constraint on new injectors, off-δ β-beat**

[Frank Zimmermann, 27 Feb 2009]

Upgrade of Muon precision chambers



Typical channel occupancy for MDT chambers in the highest rate regions for LHC and sLHC.
Remark: MDT integration time:~1.5 μs, ±3 σ equivalent for tracking: ~ ± 14 ns.
Multi track recognition however might suffer from limited resolution in 2nd coordinate.

Contents:

- LHC plans
  - Startup; operations up to 2013
  - Phase-1 and phase-2 upgrades
- Machine changes, different scenarios
- ATLAS: implications of higher intensity: occupancy, tracking in ID, more energy in calorimeter, more rate in Muon chambers; implications on trigger
- ATLAS: phase-1 upgrade: IBL
- ATLAS: phase-2 upgrade:
  - New ID, upgrades in calorimeters
  - New Muon chambers in the forward stations
    - Different options for New Muon chambers