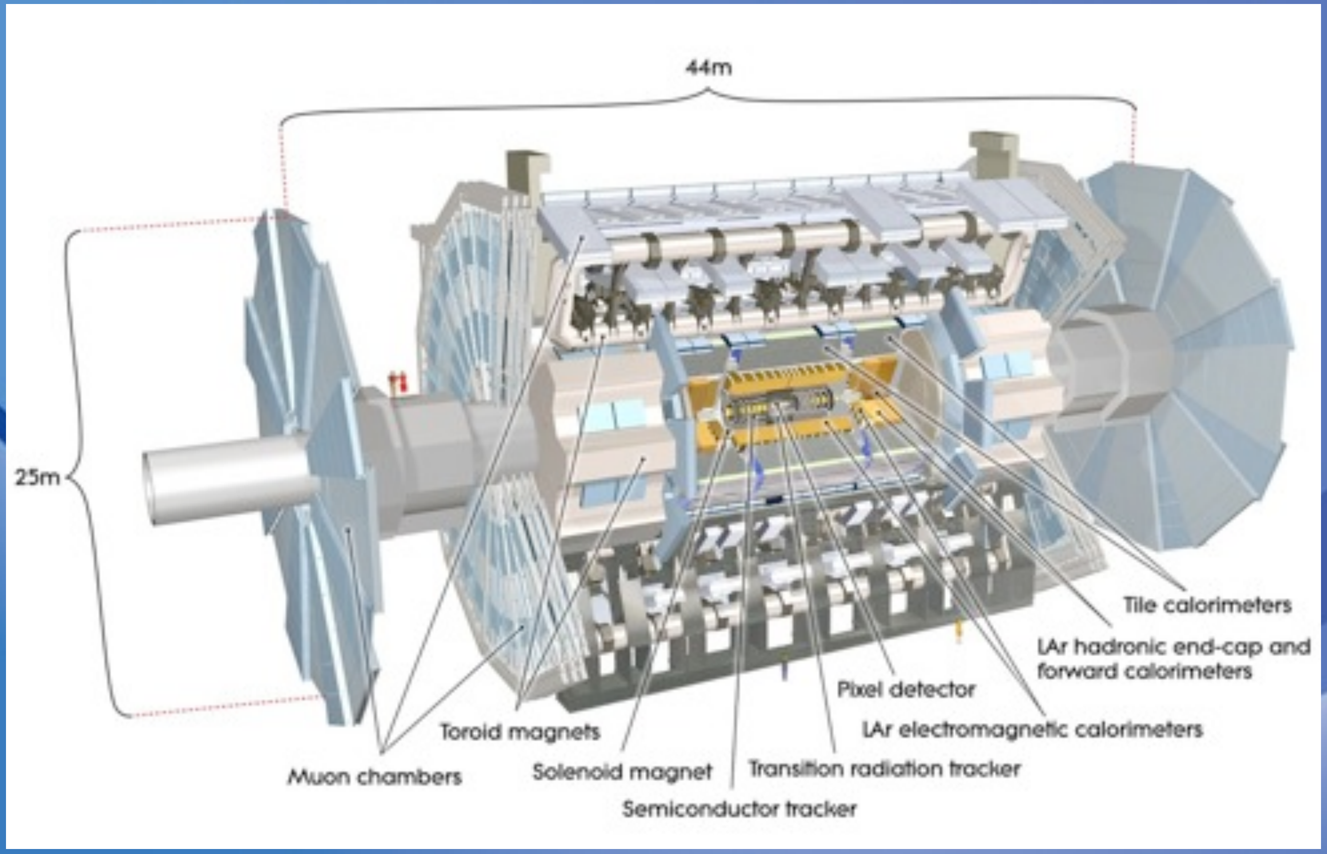
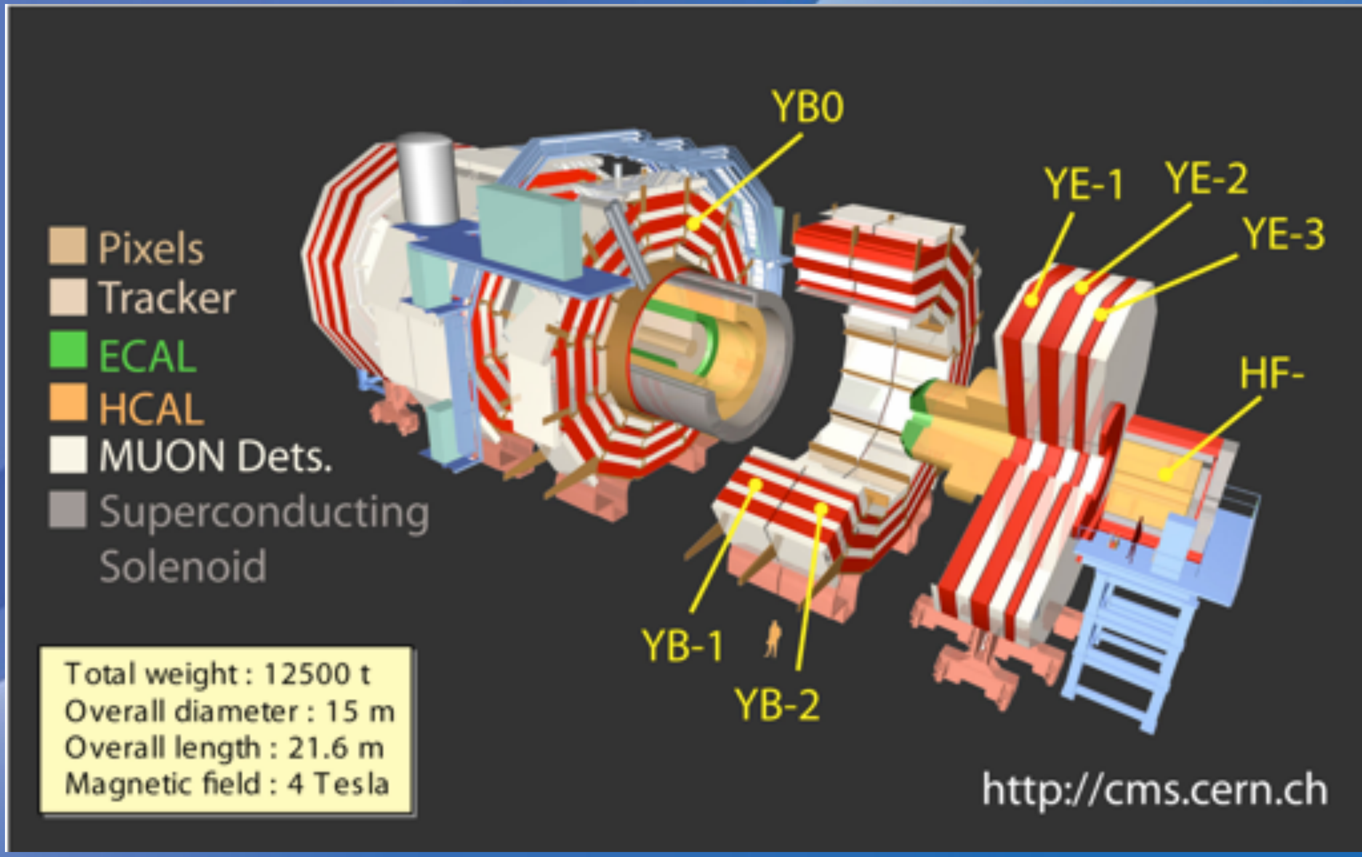
Evolution of the LHC detectors

F. Lanni
on behalf of the ATLAS and CMS collaborations





Outline

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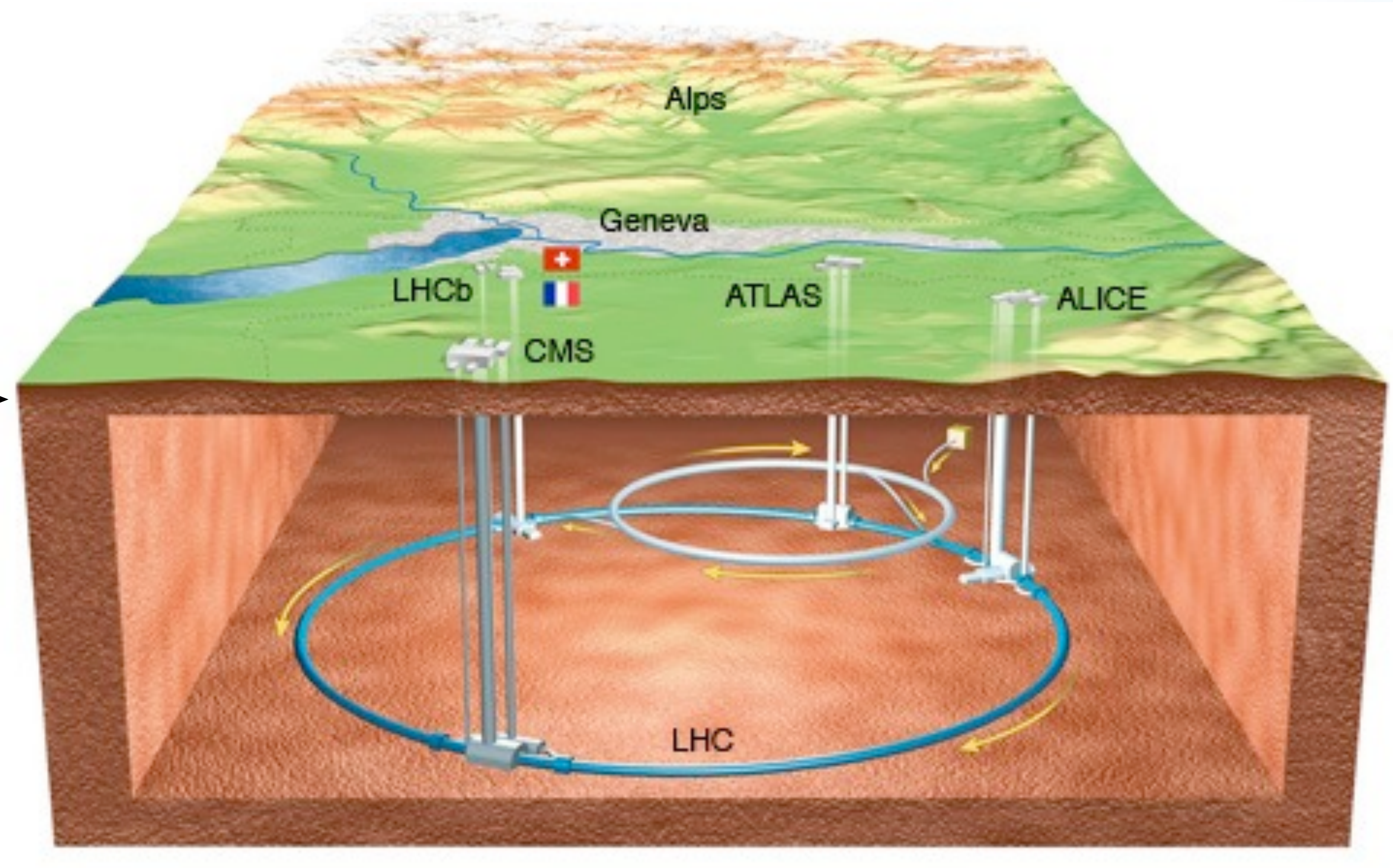
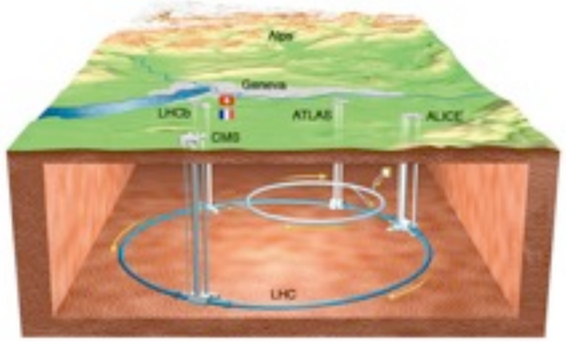
- Introduction
- LHC Phase-I/II: limitations of the experiments
- ATLAS and CMS:
  - ✓ Phase-I Upgrade plans
  - ✓ Phase-II Detector Challenges
- Short description of LHCb and ALICE upgrade plans
- Final Remarks





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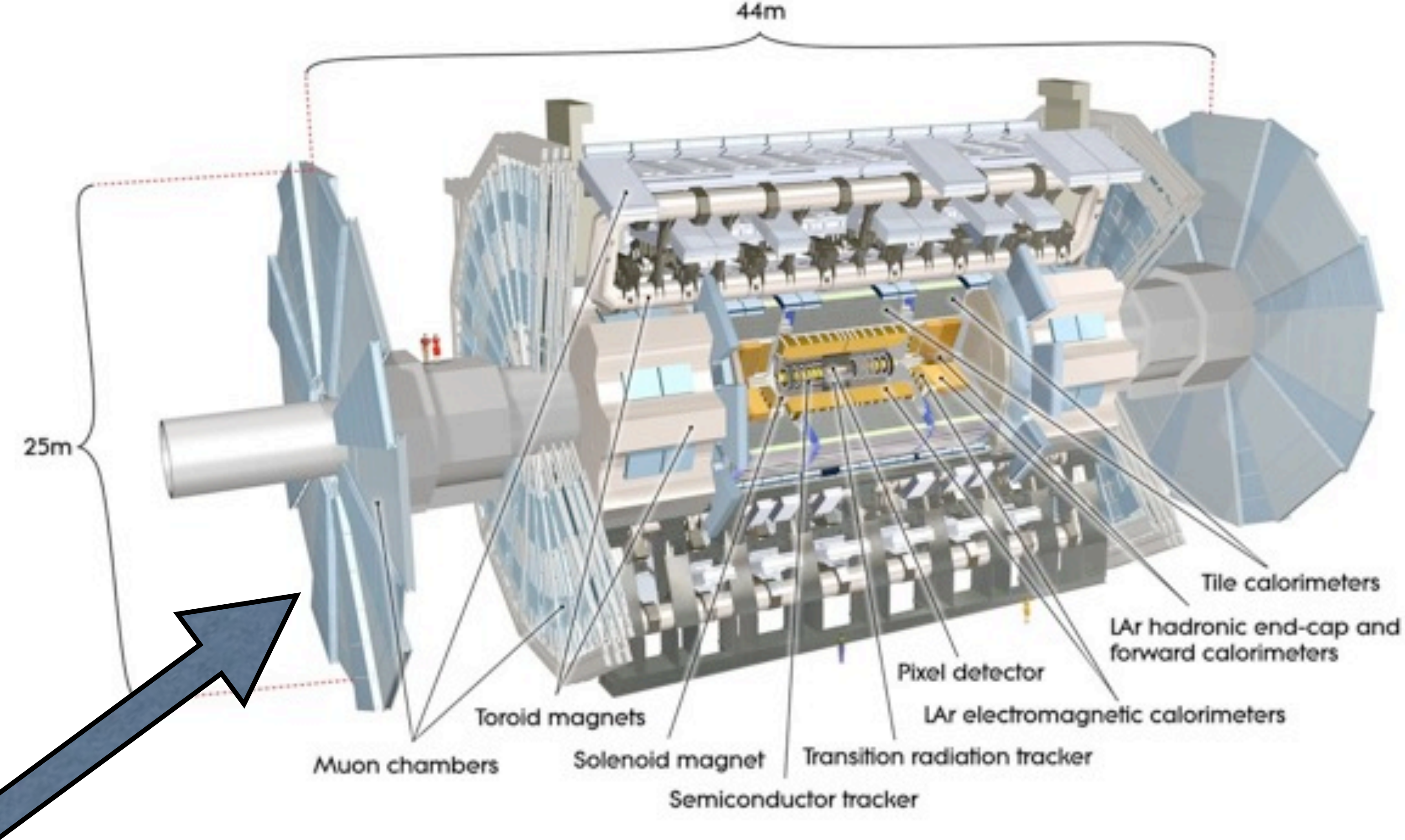

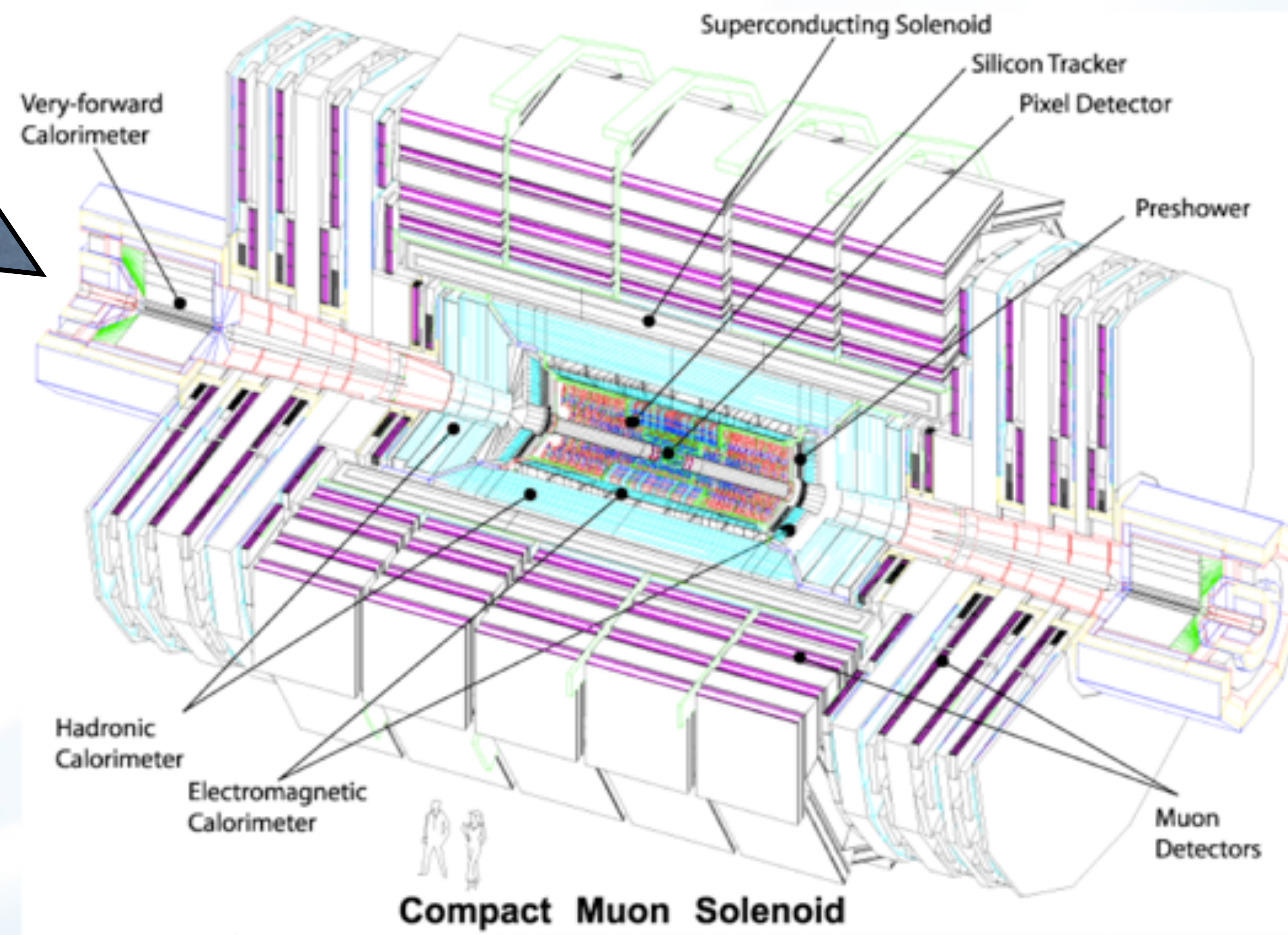

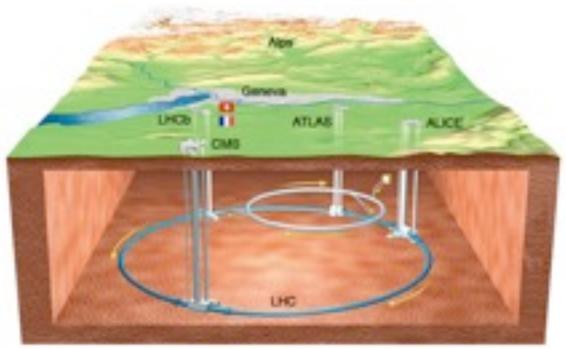

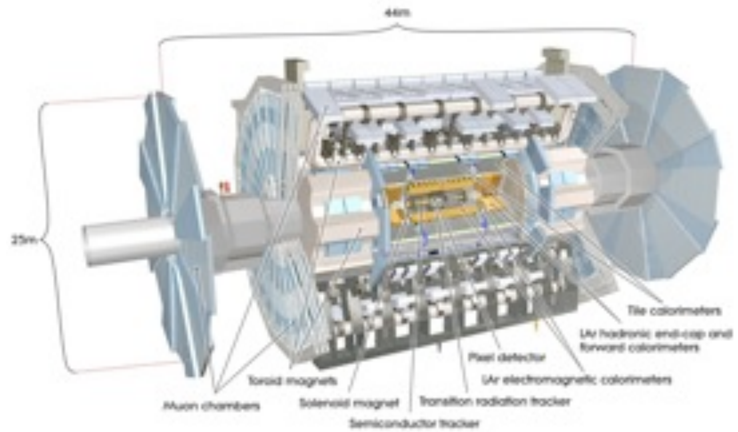

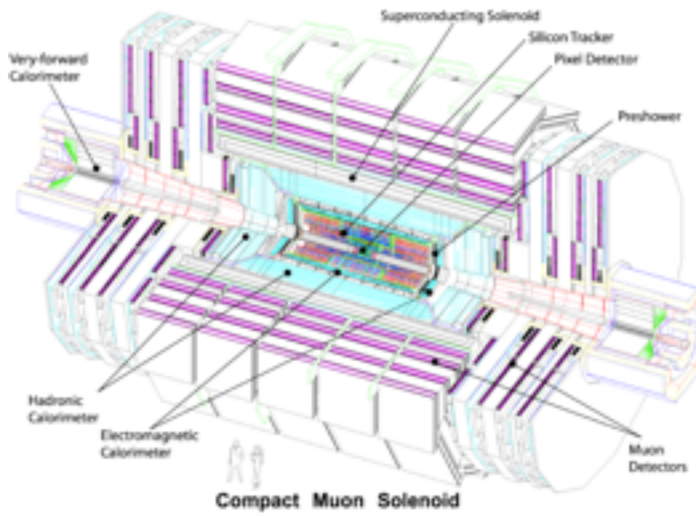

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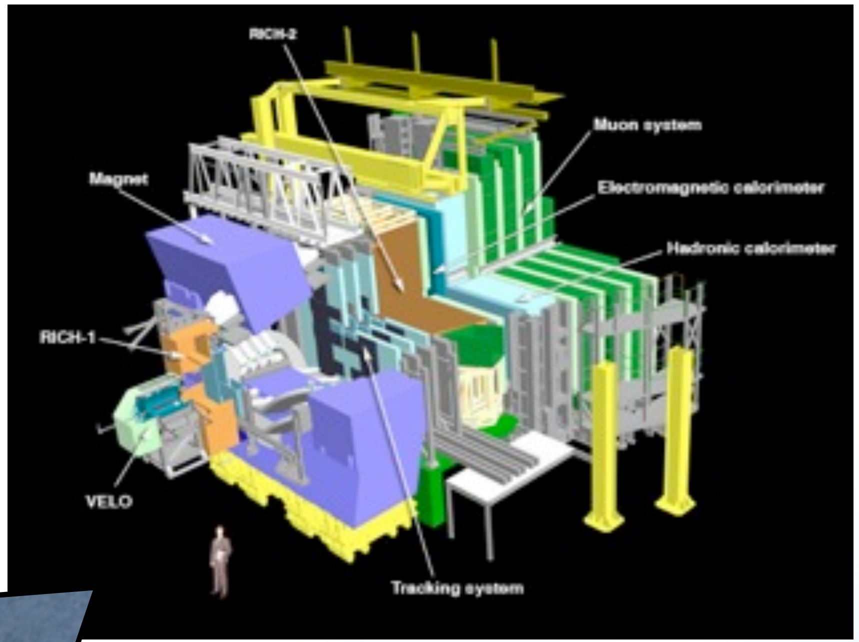

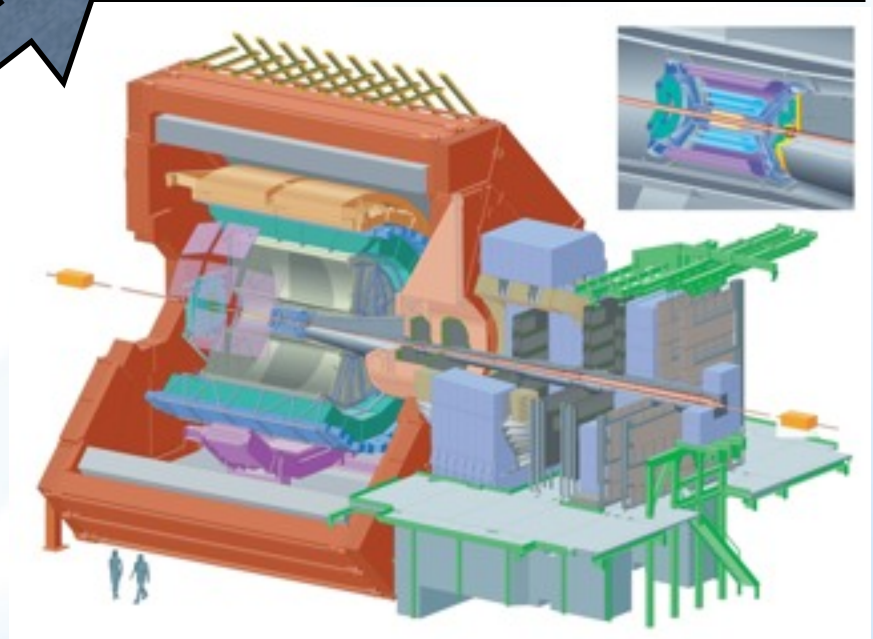

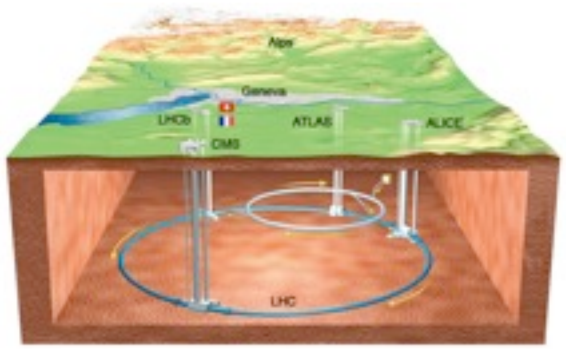

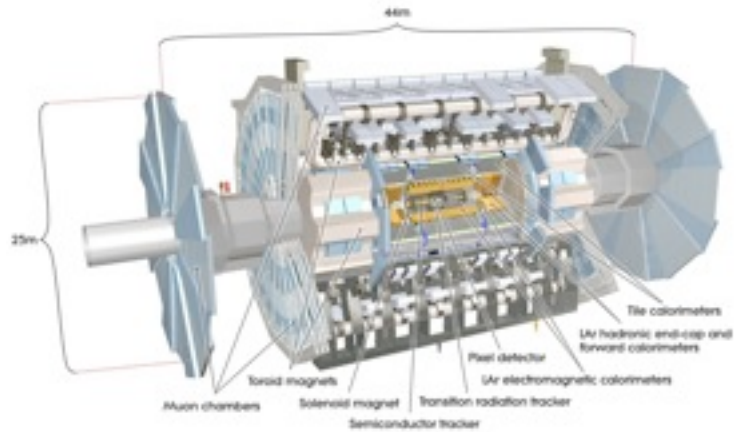

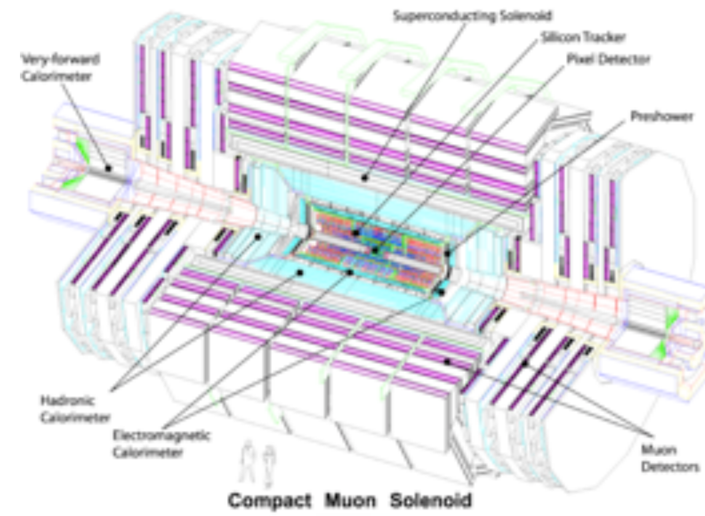

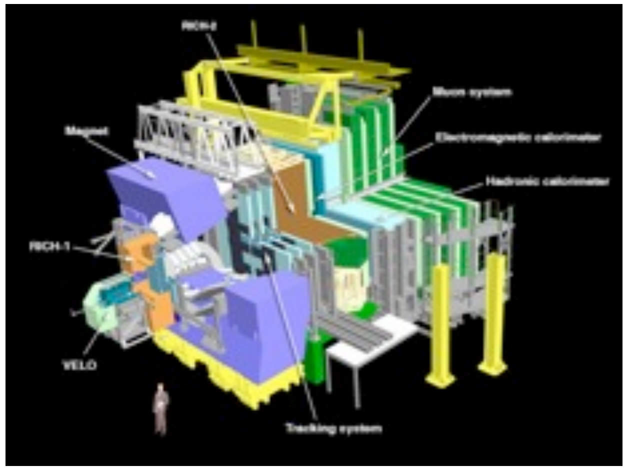

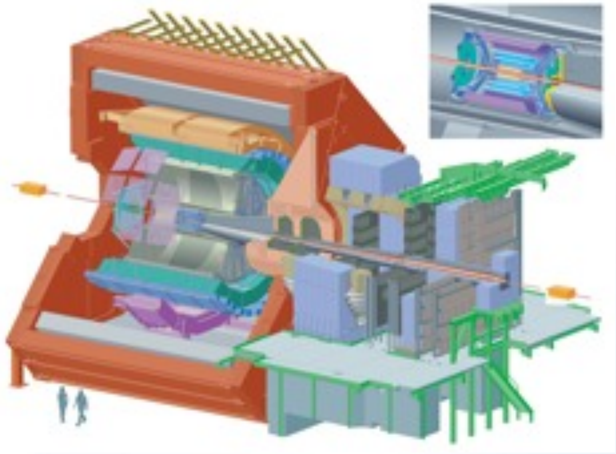

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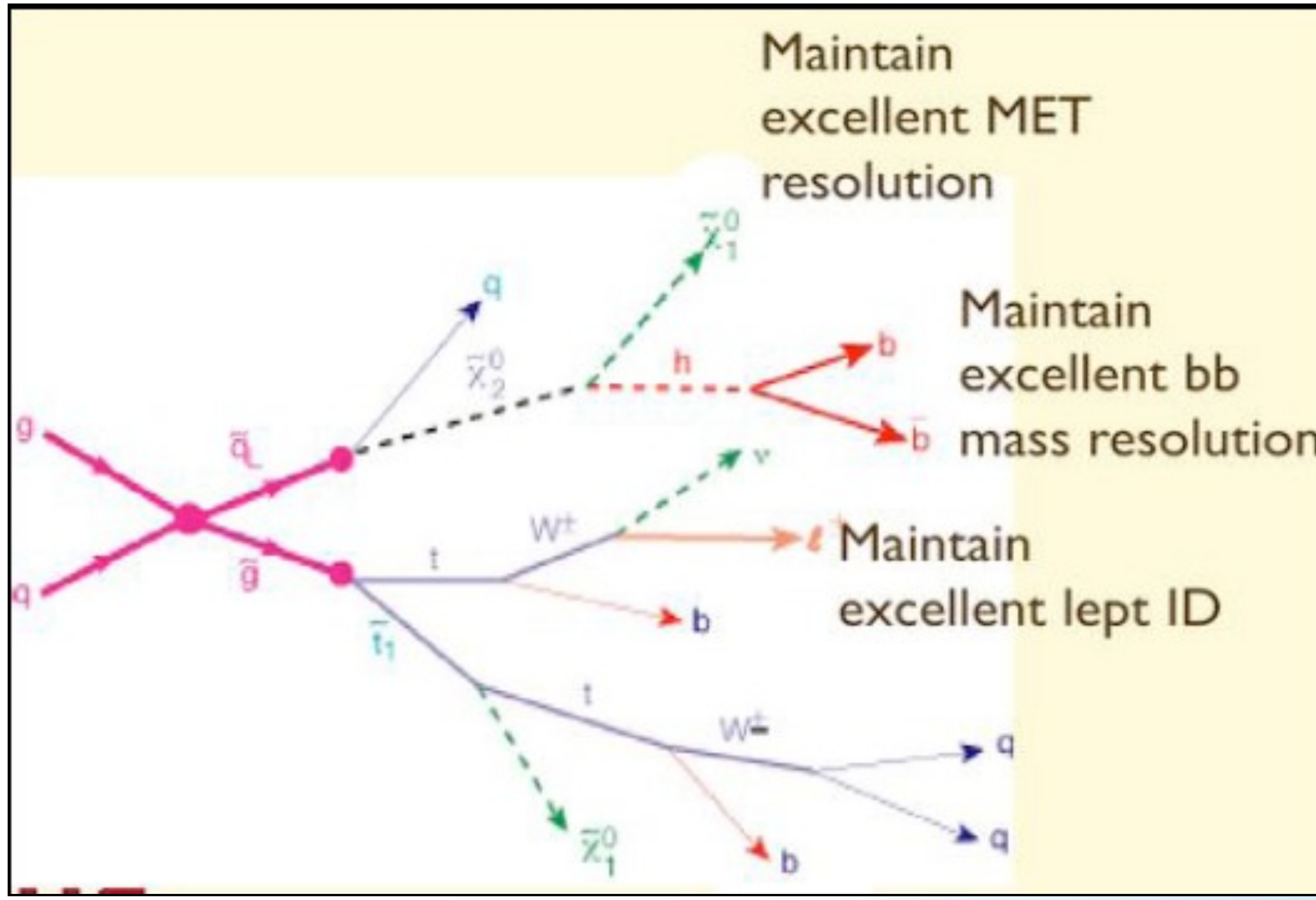
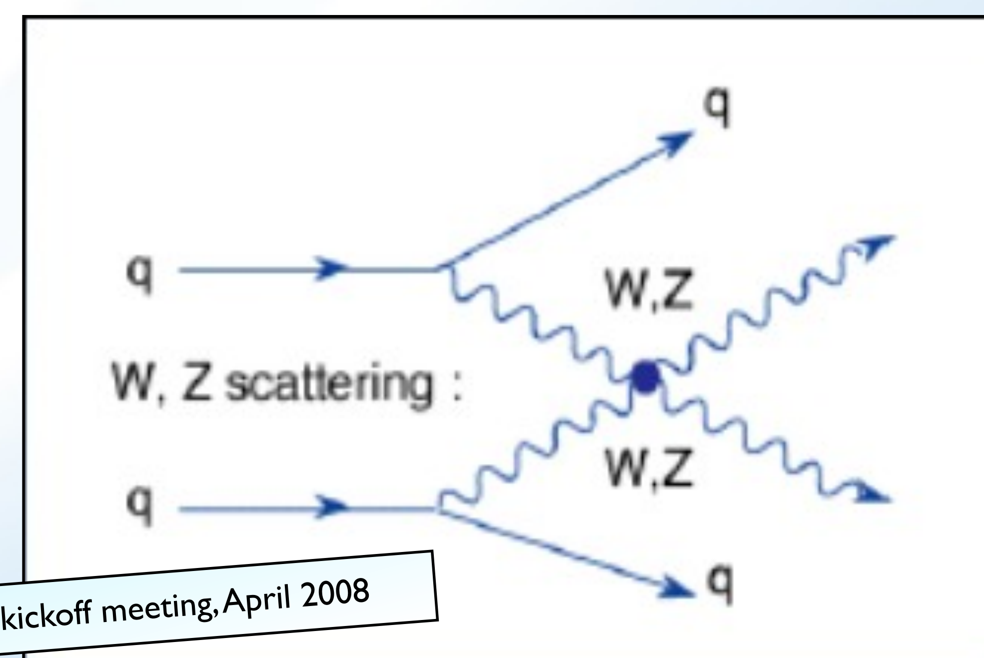
- Evolution of the detectors at LHC is based on:
  - ✓ Increased integrated luminosity by a factor ~5-10 with a peak instantaneous luminosity up to 10^{35} $cm^{-2}s^{-1}$ max ($5x10^{34}$ with leveling).
  - ✓ Plans are extending for the next 10 years or more
  - ✓ There are, on the long term, large uncertainties that depend on what physics the LHC will find.
- Many ATLAS/CMS sub-system will start failing around 500-1000 fb^{-1} (pixel detectors excluded).
  - ✓ New detectors require at least 5 years of construction,

Why we want more integrated luminosity beyond LHC nominal design.

- Improve measurements of new phenomena seen at the LHC:
  - ✓ Higgs coupling and VB self-couplings
  - ✓ Properties of SUSY particles (mass, decay BR's,...)
  - ✓ Couplings of new Z' or W' gauge bosons (e.g. L-R symmetry restoration?)
- Search low-rate phenomena inaccessible at LHC:
  - ✓ $H \rightarrow \mu^+\mu^-$, $H \rightarrow Z\gamma$
  - ✓ top quark FCNCs



- Push sensitivity to new high-mass scales:
  - ✓ new forces (Z', W_R)
  - ✓ Quark substructures



M. Mangano, *Physics Opportunities for the sLHC*, sLHC kickoff meeting, April 2008

Why we want more integrated luminosity beyond LHC nominal design.

Detector Performance Requirements from Physics

- Improve measurements of new phenomena seen at the LHC:
  - ✓ Higgs coupling and VB self-couplings
  - ✓ Properties of SUSY particles (mass, decay BR's,...)
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- Search low-rate phenomena inaccessible at LHC:
  - ✓ $H \to \mu^+\mu^-$, $H \to Z\gamma$
  - ✓ top quark FCNCs

- Energies/masses in the few-100 GeV range:
- Detector performance @ sLHC needs to be maintained (or improved) despite pile-up

- Push sensitivity to new high-mass scales:
  - ✓ new forces (Z', W_R)
  - ✓ Quark substructures

- Very high energies/masses (~1 TeV):
- Not very demanding on detector performance
- Slightly degraded detector performance probably acceptable
  - ✓ low backgrounds

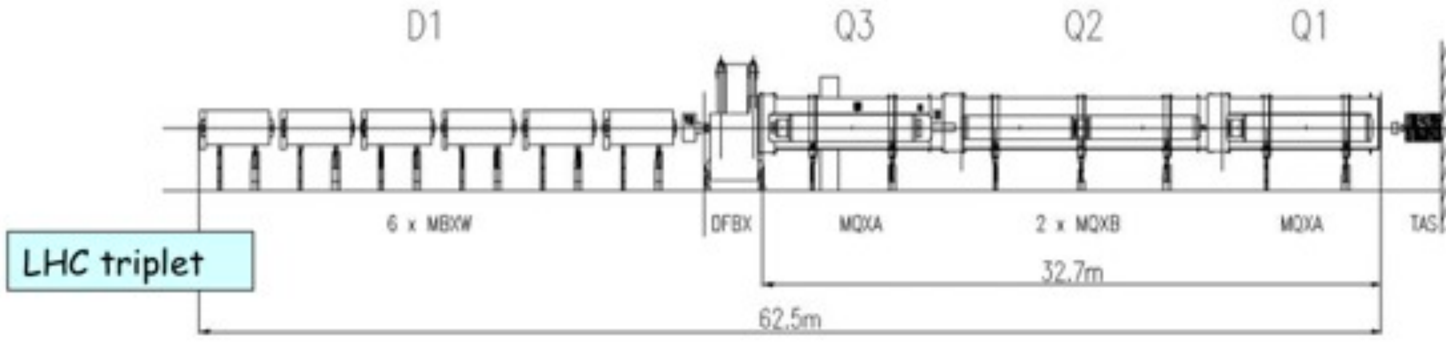
- Maintain p_T, MET resolution, trigger efficiencies for many channels of interests.
- Maintain vertexing capabilities BUT:
  - ✓ Higher occupancy
  - ✓ Radiation damage
- Maintain electron ID and muons (for W/Z, W'/Z', Higgs and SUSY)
  - Electron trigger efficiencies
- Jet tagging in the forward calorimeters and central jet veto (from WW scattering - Higgs couplings or VBF)

M. Mangano, *Physics Opportunities for the sLHC*, sLHC kickoff meeting, April 2008

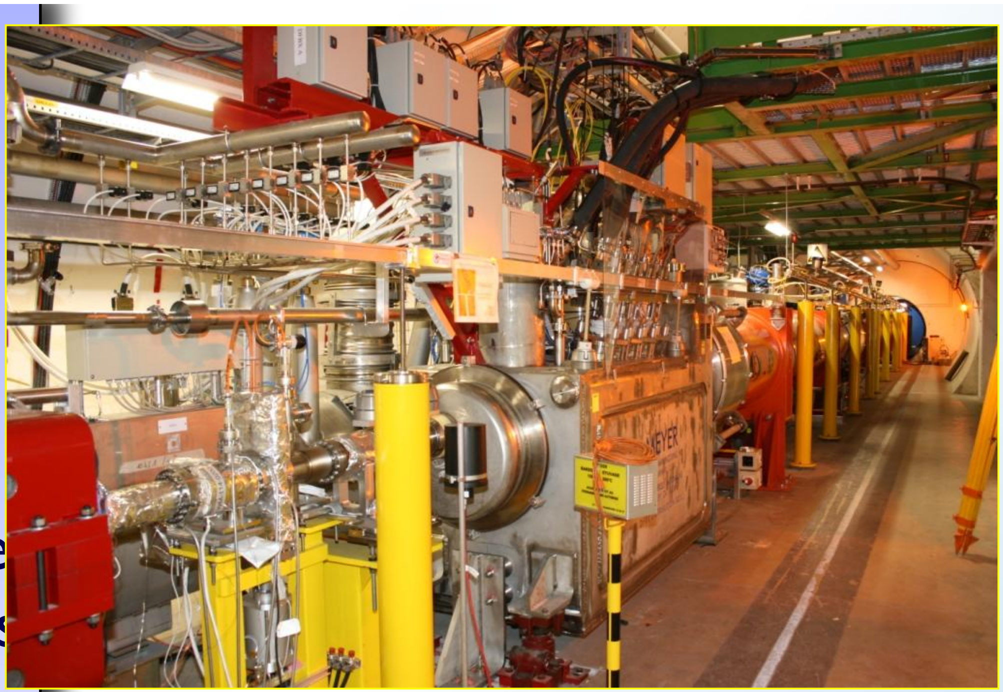
LHC Upgrade Plans: Phase-I

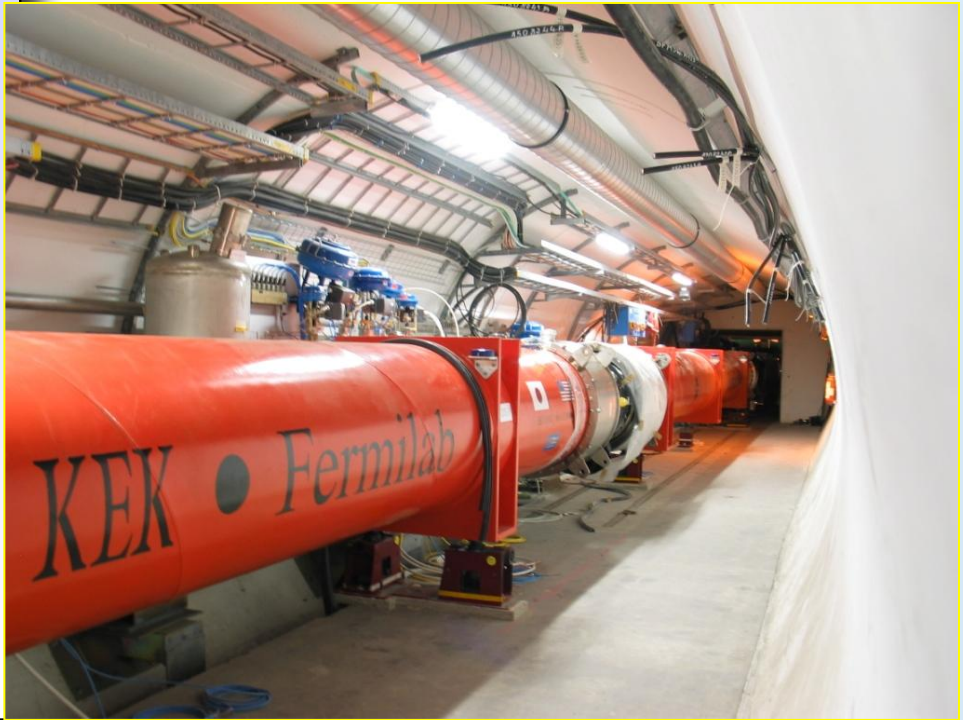
http://lhc-commissioning.web.cern.ch/lhc%2Dcommissioning/luminosity/09-10-lumi-estimate.htm

LHC collisions late this year with a long run in 2010. Peak luminosity up to ~2x10^{32} $cm^{-2}s^{-1}$, aiming at an integrated luminosity of ~150pb^{-1} at 7-10TeV c.m. energy



- Road to ultimate luminosity (~2-3 x$10^{34}cm^{-2}s^{-1}$) include:
  - ✓ Beam from a new Linac4
  - ✓ Replace the present triplets with wide aperture quadrupoles based on the LHC dipole NbTi cables cooled at 1.9K
  - ✓ Upgrade the D1 separation dipoles, front quadrupole absorbers (TAS) and other beam-line equipment so as to be compatible with the inner triplets
  - ✓ β^*~0.25-0.3m in ATLAS and CMS interaction points
- **Phase-I upgrade:** a transition in the 6-12 months shutdown in 2014-2015, with **peak luminosity of 3 x$10^{34}cm^{-2}s^{-1}$** afterwards.
- Possible **Phase-II upgrade** of the machine (~2019-2020) to achieve **peak luminosity of $10^{35}cm^{-2}s^{-1}$** max. (decision by 2012?)





R. Ostojic- "*LHC IR Upgrade Phase-I*", LHCC review, February 2009

Detector Requirements and Plans for Phase-I Upgrades

- Detectors should be able to operate at a peak luminosity of 3 $\times 10^{34} cm^{-2} s^{-1}$
- Should be able to cope with an integrated luminosity of 700 fb^{-1}
- Limited time for installation - 6 to 8 months in ~2014/2015

M. Nessi, *"Upgrade and consolidation for nominal luminosity and above"*
ATLAS Summary Week - Oct 2009:
http://indico.cern.ch/conferenceDisplay.py?confId=47256

ATLAS

- Pixel: Insertable B-layer
- Transition Radiation Tracker (TRT): upgrade HV system and straw cooling
- TileCal: new gaps/crack scintillators
- Muon: Installation of tracking/triggering detectors in the forward region (CSCs)
- Trigger: L1-Calo Preprocessor upgrades, High Level Trigger/DAQ processing upgrades
- Shielding: new Endcap Toroid shielding

Agreed at the May 2008 Upgrades Workshop
http://indico.cern.ch/conferenceDisplay.py?confId=28746

CMS

Upgrade Scope

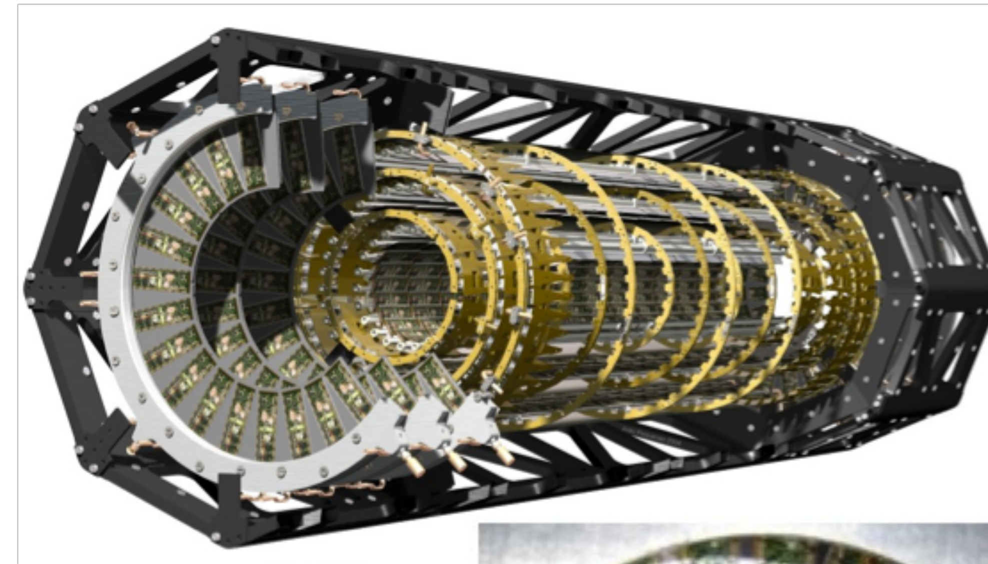
System	Phase 1	Phase 2
Pixel	New Pixel Detector (1 or 2 iterations?)	
Tracker	FEDs?	New Tracking System (incl Pixel)
HCAL	Electronics + PD replacement	HF/HE?
ECAL	TP (Off Detector Electronics) ?	EE?
Muons	ME4/2, ME1/1 ,RPC endcap, Minicrate spares, some CSC Electronics	Electronics replacement
Trigger	HCAL/RCT/GCT to µTCA	Complete replacement

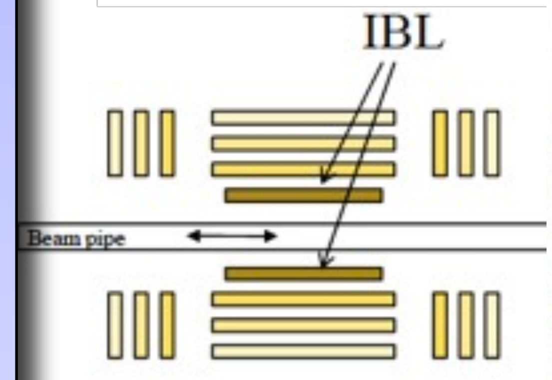
9 J. Nash - CMS Upgrades 28 October 2009

ATLAS

Pixel Detectors: IBL

- el Detectors: 3 layers in the barrel and 3 disks in EC regions
- Inner Layer of the pixel system enables the identification of b-flavor in jets through displaced:
  - ✓ High efficiency required and high rejection ratio of light-quark jets.





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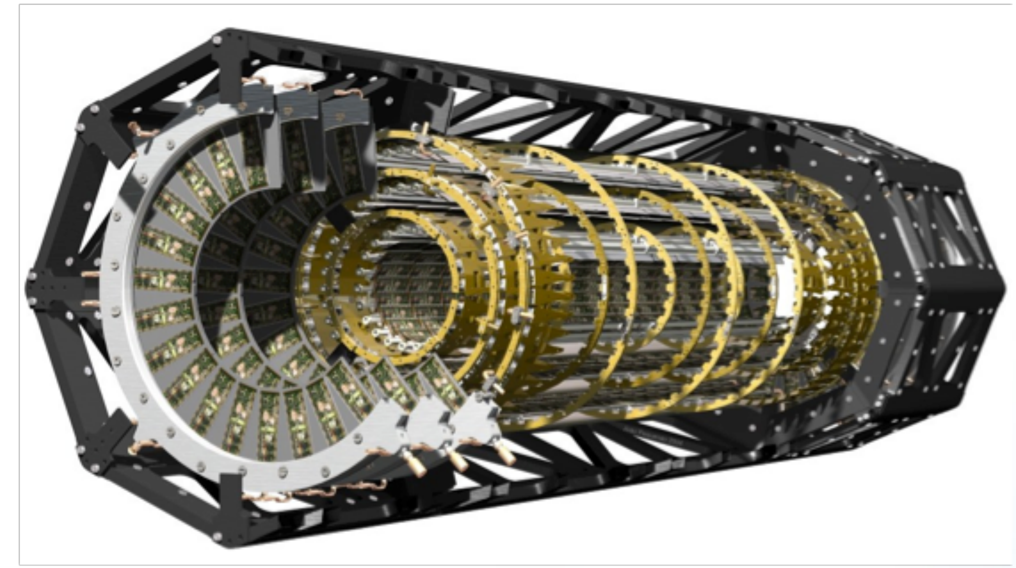
- **Above 10^{34}cm^{-2}s^{-1} layer inefficiencies become important:**
  - ✓ Component failures (all layers and indep. on lum.)
  - ✓ **Rate saturation**
  - ✓ Radiation damage (sensors and electronics)
    - **>300fb^{-1} equivalent of accumulated dose sensor signals degrade at unacceptable level**
    - There are however substantial uncertainties in the radiation dose estimates



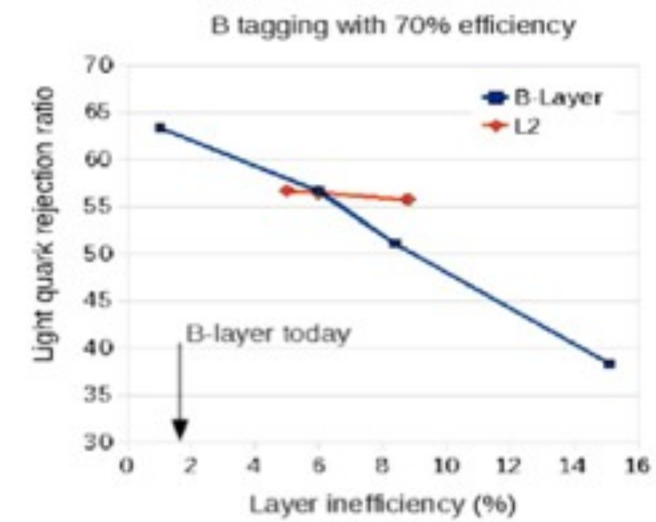


***Figure 7**: Light quark rejection ratio vs. hit inefficiency for 70% efficient b tagging in top events. The B-layer line assumes a 6% inefficiency for other layers. The L2 line assumes a 6% inefficiency for other layers, including the B-layer*

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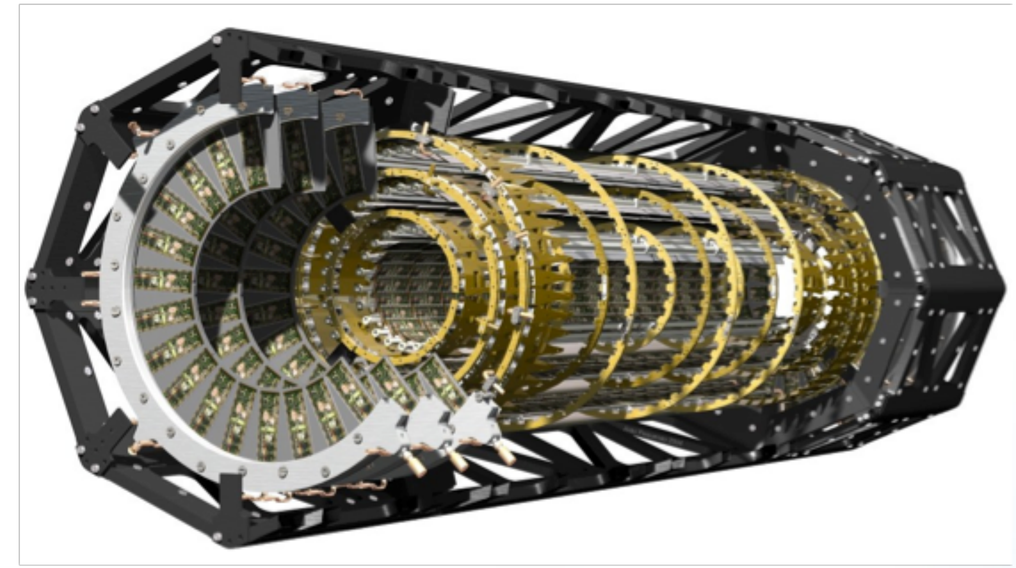
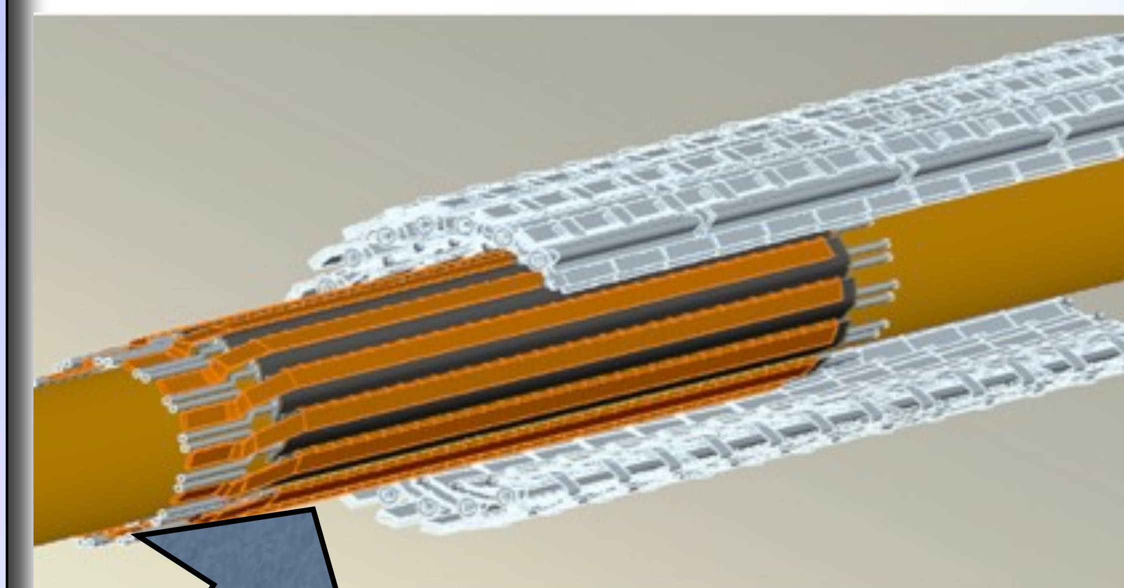
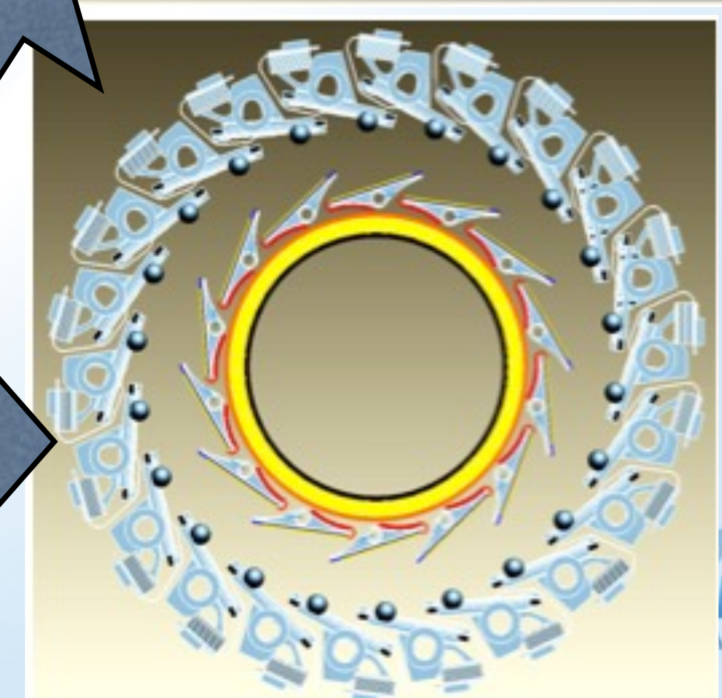
  - ✓ **Rate saturation**
  - ✓ Radiation damage (sensors and electronics)
    - **>300fb^{-1} equivalent of accumulated dose sensor signals degrade at unacceptable level**
    - There are however substantial uncertainties in the radiation dose estimates
- It is not possible to remove in ATLAS the current pixel detector, remove the B-layer and re-install the system in.
  - ✓ Operation would require a much longer shutdown.
- **Proposal to insert a new layer at a smaller radius and a new beam pipe inside the current innermost layer.**
  - ✓ IBL = Insertable B-Layer
- New Readout ASIC (FEI-4) based on .13µm CMOS process



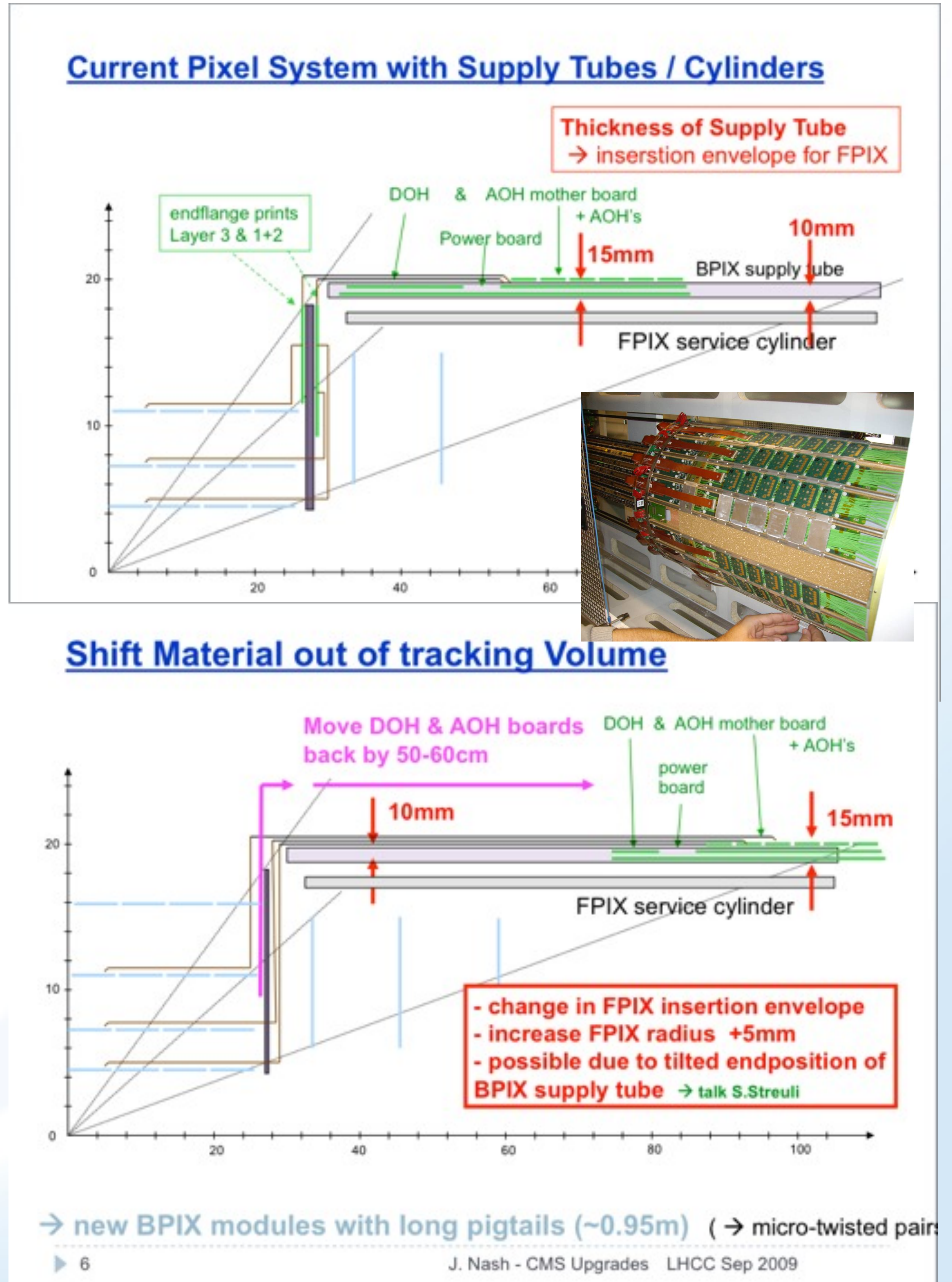




CMS

Pixel Detectors

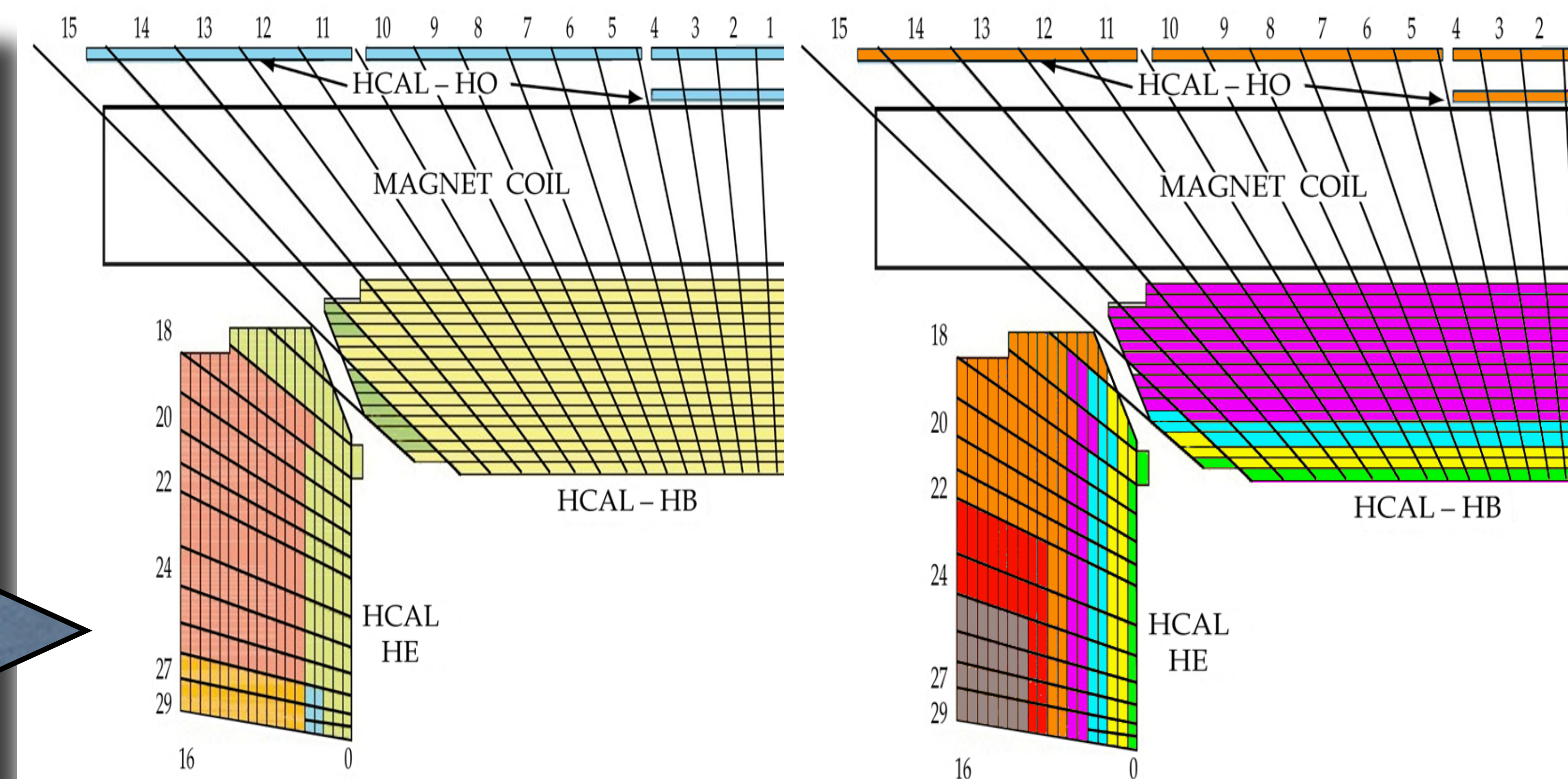
- Pixel Detectors: 3 layers in the barrel and 2 disks in Endcap regions
- Irradiation studies of single-chip pixel detectors at PSI:
  - ✓ @2.8×10^{15} MIP signals still >5k electrons if sensors are biassed >800V
  - ✓ Readout Chip (ROC) fully operational up to 5×10^{15} fluence
- Issues of the sensors:
  - ✓ Efficiency loss
  - ✓ Charge distribution, i.e. resolution
  - ✓ Current HV power supply and cable limit operation at bias of 600V
- **CMS Pixel system can be replaced quickly.**
  - ✓ **Proposal to upgrade the full Pixel system (4 layers in the barrel, 3 discs in the Endcap regions)**
  - ✓ **CO_2 cooling**
  - ✓ **Reduction of material (x3 in the barrel, x2 in endcaps) also thanks to cooling**

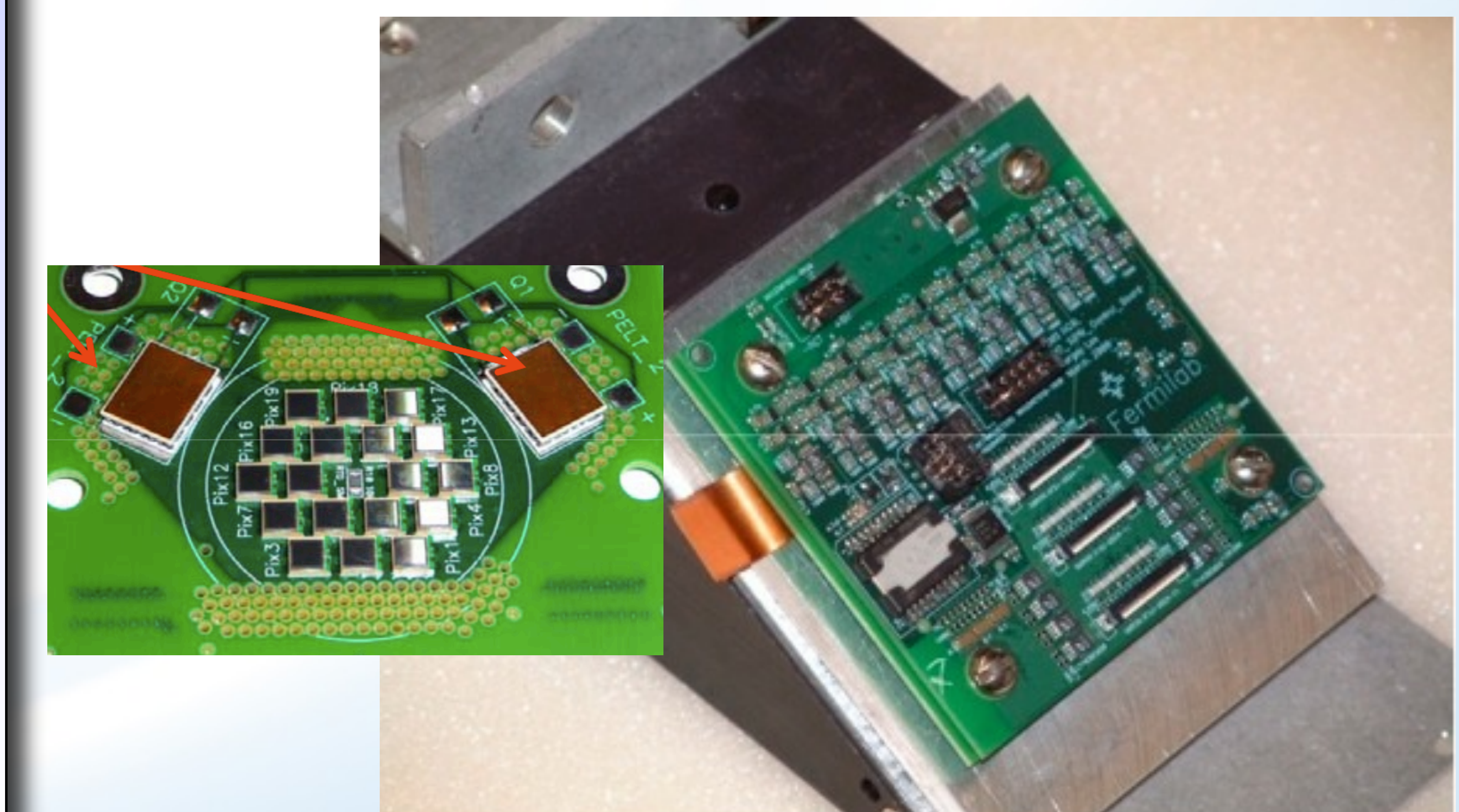


Calorimeter Phase-I Upgrades

36 wedges both in the hadronic barrel (HB) and endcap (HE) calorimeters of scintillating tiles summed optically to form towers readout by embedded WLS fibers connected to **Hybrid Photodiodes (HPD)**.

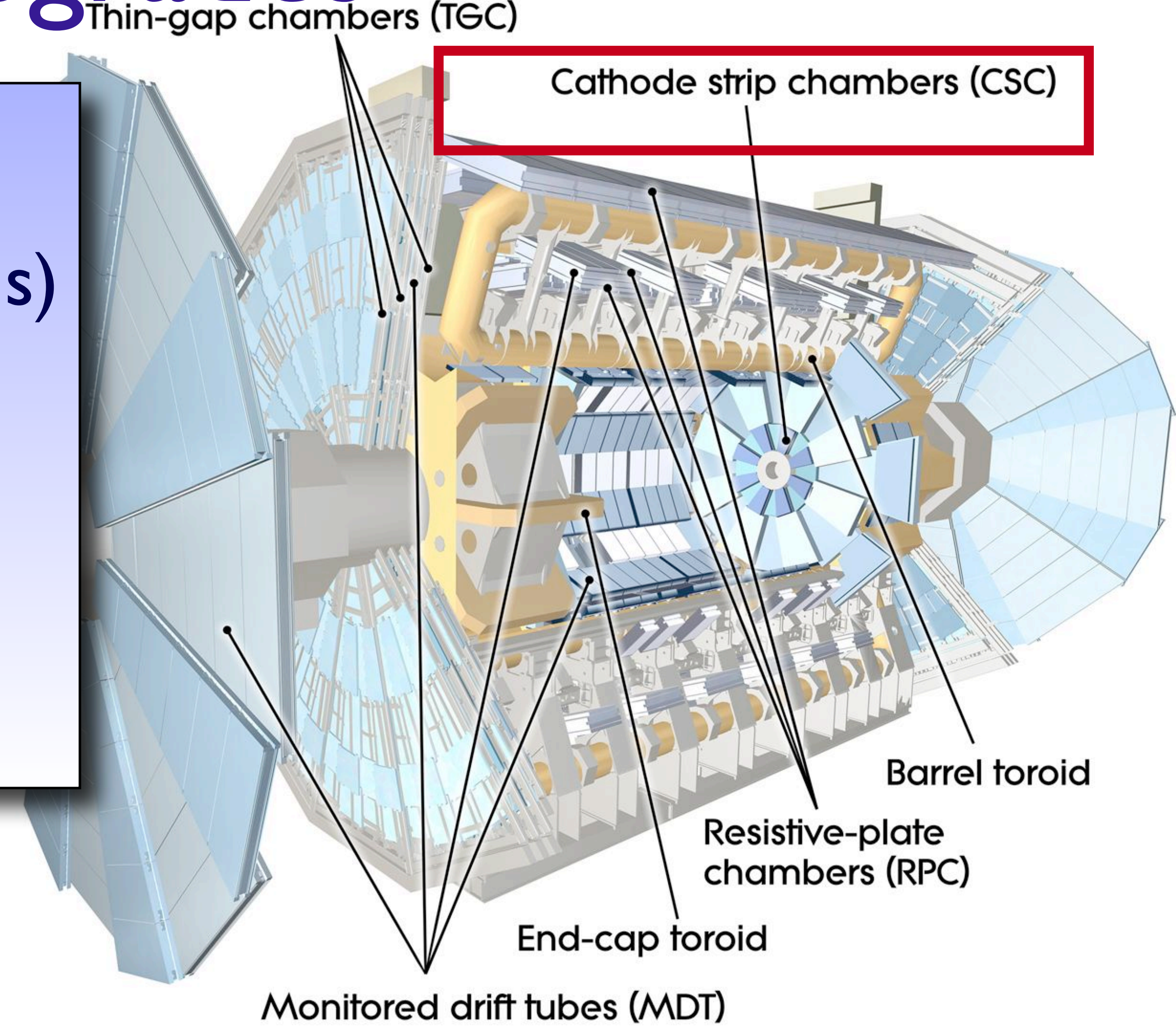
- Additional scintillator layer (HO) outside the coil (probably part of M&O program).
- **Increase depth segmentation in the Hadronic Calorimeter (HCAL)**
- HPD carry some risk for >10 years operation
  - ✓ HV discharges and ion feedback.
  - ✓ HB/HE: 144x19 HPDs (16 layers).
  - ✓ HO: 132x19 HPDs (1-2 layers)
- **Silicon Photomultipliers (SiPM) packaged to replace HPDs.**
  - ✓ Higher S/B
  - ✓ Insensitive to magnetic fields
  - ✓ But temperature regulation needed to compensate for gain dependency
- **New Front-End ASIC**.

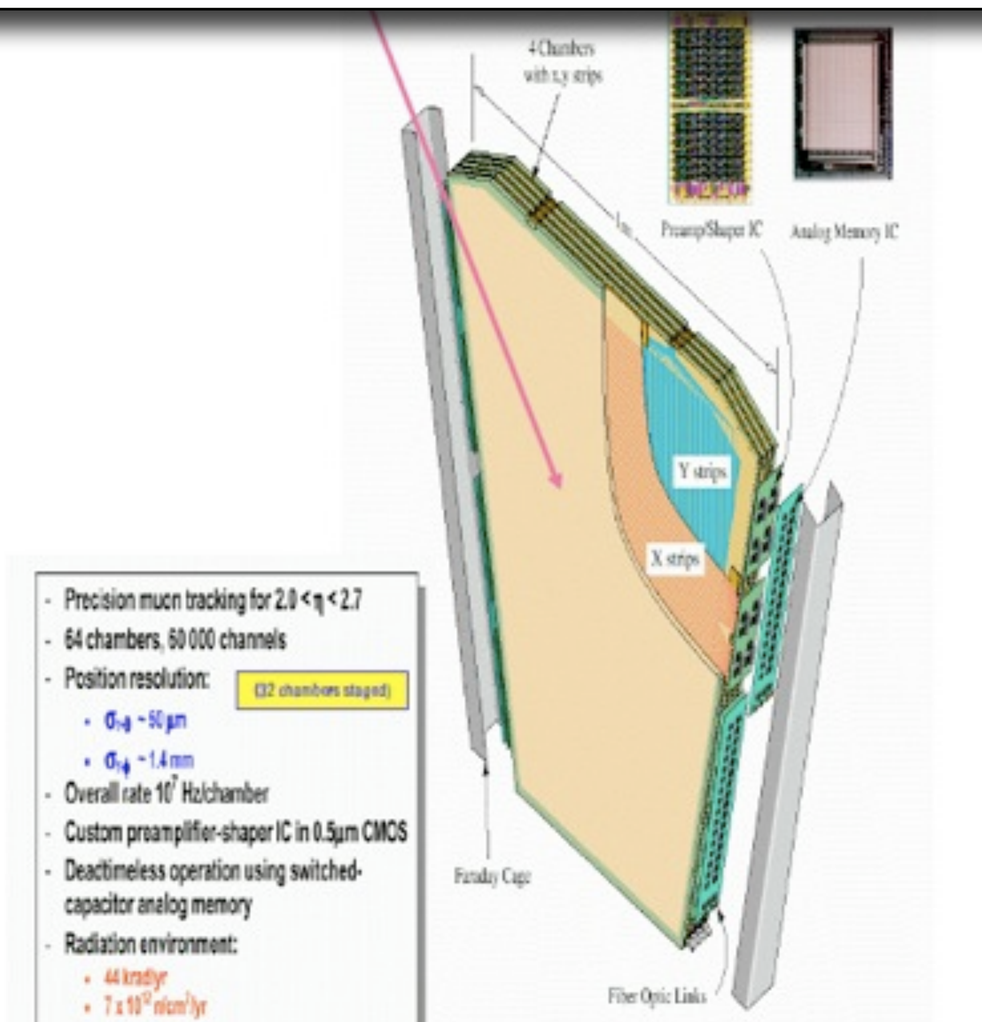


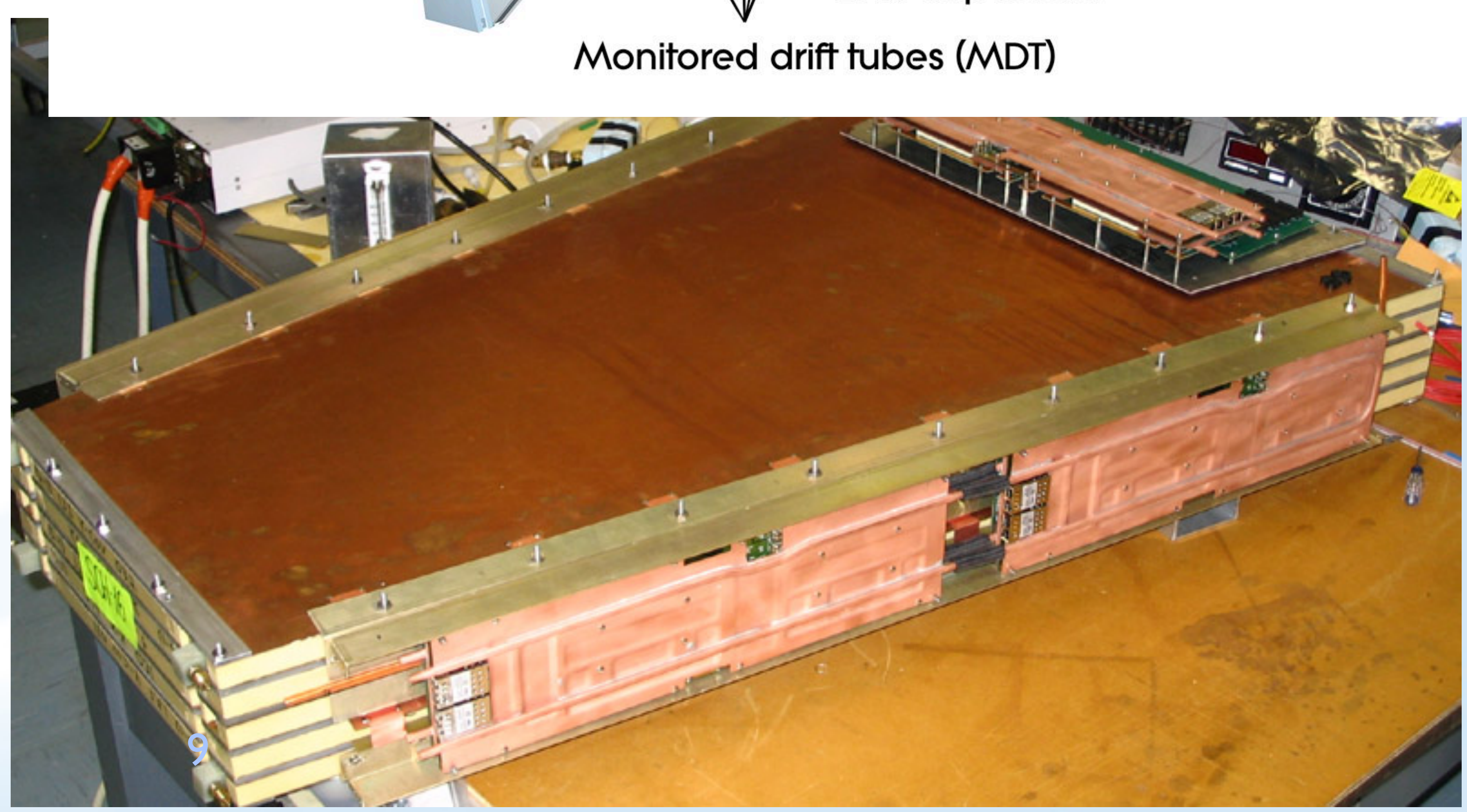


Muon Phase-I Upgrades

- **CSC original design:**
  - ✓ 32 4-layer chambers (31,000 channels)
  - ✓ 27% coverage of the full Muon Spectrometer in η
  - ✓ Capable to handle high rates in the forward ATLAS muon (1kHz/cm^2)







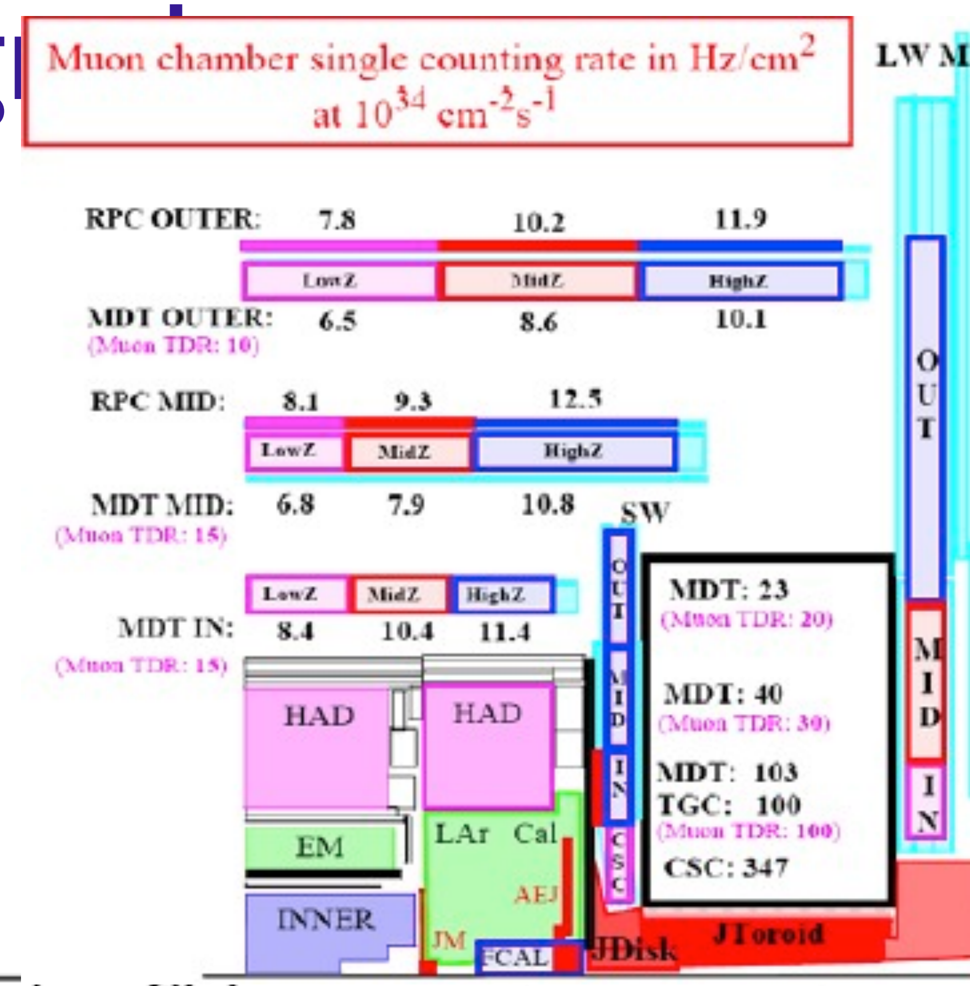
ATLAS

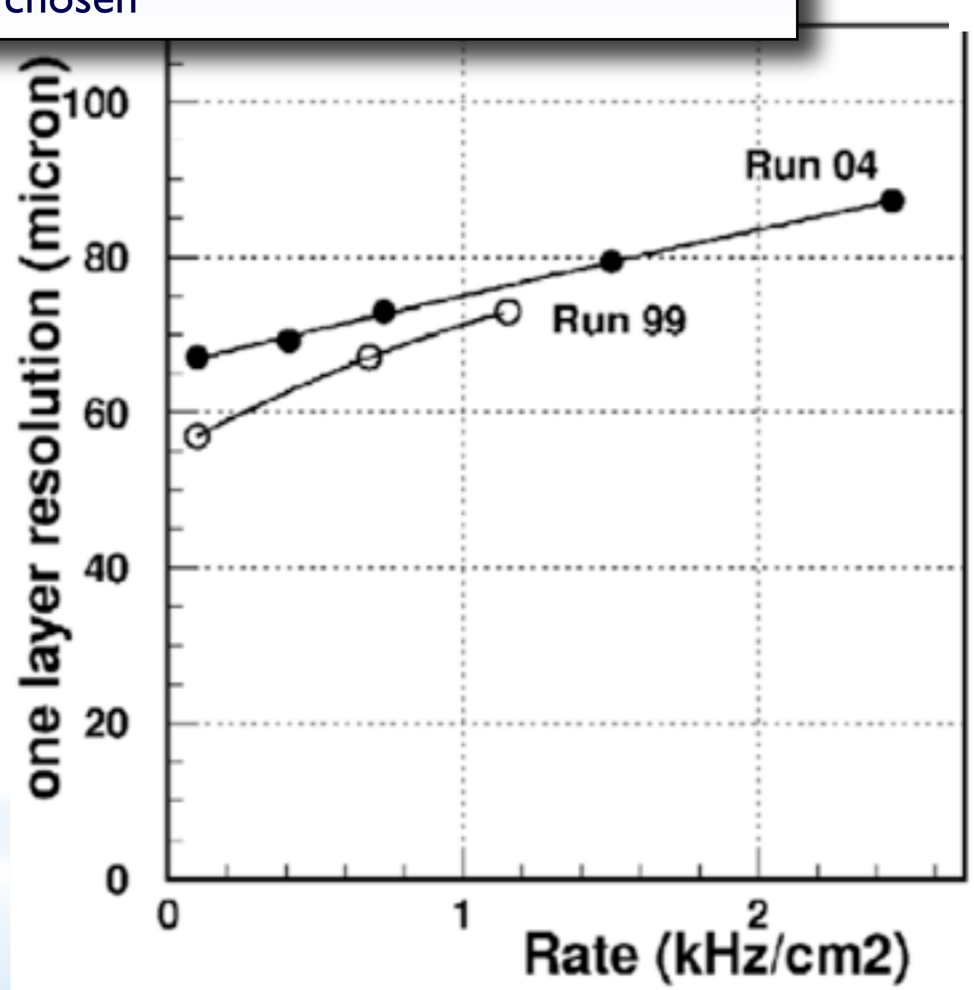
No safety factors

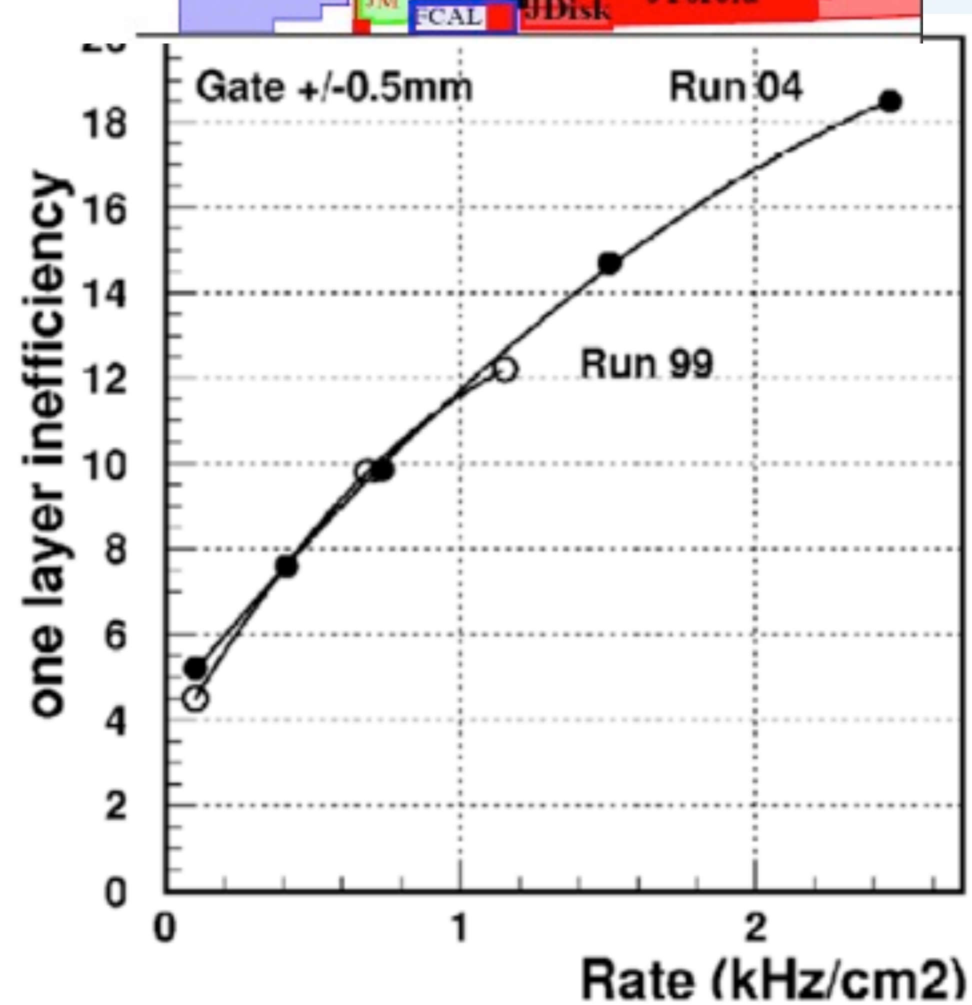
Muon Phase-I Upg

Rates driven by cavern backgrounds. Large uncertainties associated (could be as much as x5 higher).

- ✓ Under the most adverse assumptions predicted rates could be as high as 5kHz/cm2 - well off scale in the plot.
- Even for nominal rates a x3 increase in luminosity makes the operation of the CSC chambers marginal
  - ✓ **Recover performance degradation with additional chambers (total 8 layers)**
- Detector technology under consideration (MicroMegas, Monitored Drift Tubes, Thin Gap Chambers) [see later on Phase-II]
- Electronics Readout ASIC that can be adaptable to any detector technology chosen





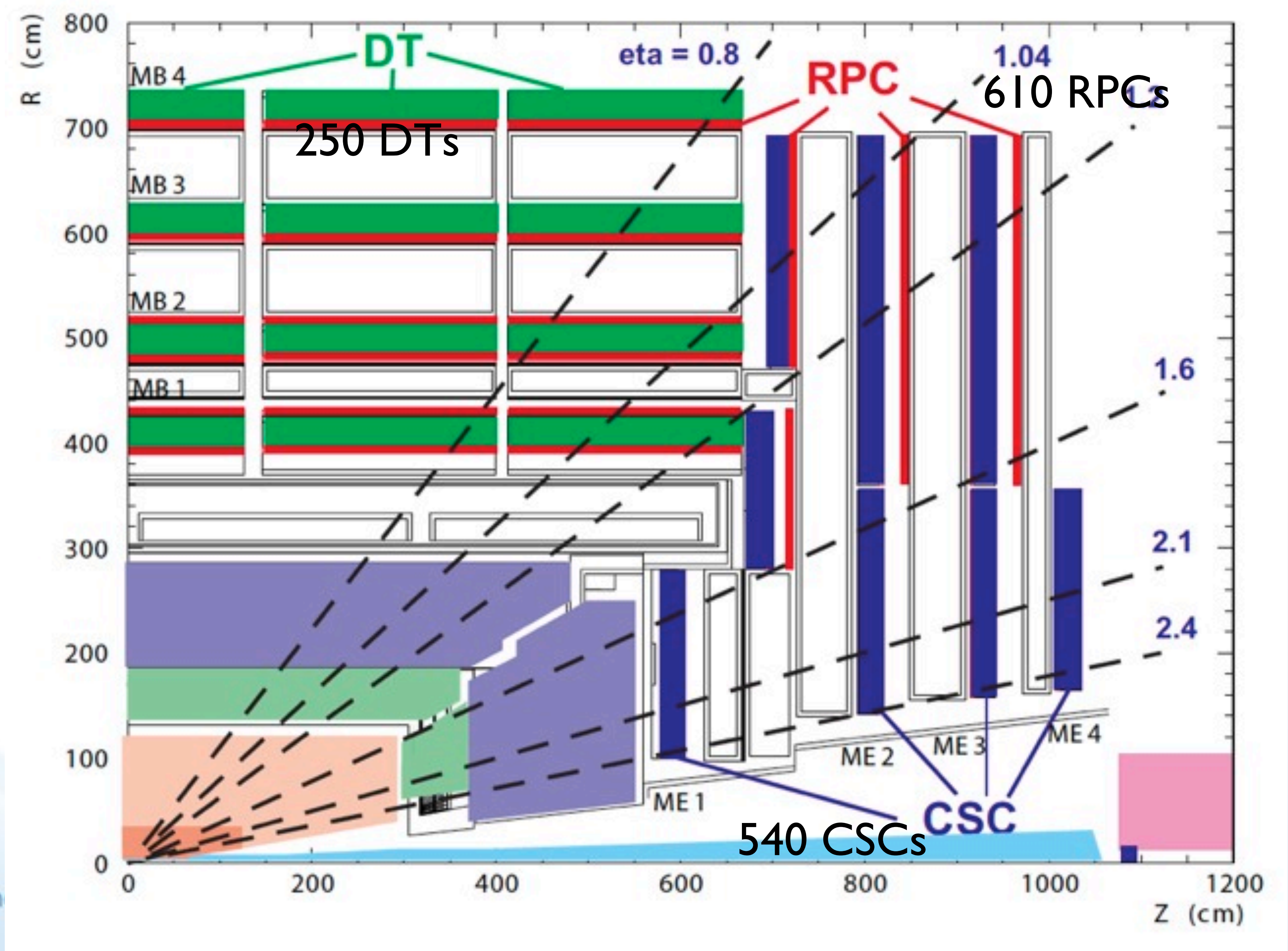


CMS

Muon Phase-I Upgrades

- **CSC Upgrades**
  - ✓ ME4/2 72 new CSC chambers (1.5m x3.4m)
  - ✓ ME1/1 7x72 Digital Front-End Boards (CFEBs)
    - ...and associated trigger (TMB) and readout (DMB) boards

- RPC Upgrades
  - ✓ Another station in the endcap region at η~1.6
- DT Upgrades
  - ✓ Considering upgrade of the electronics



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Muon Phase-I Upgrades

CMS

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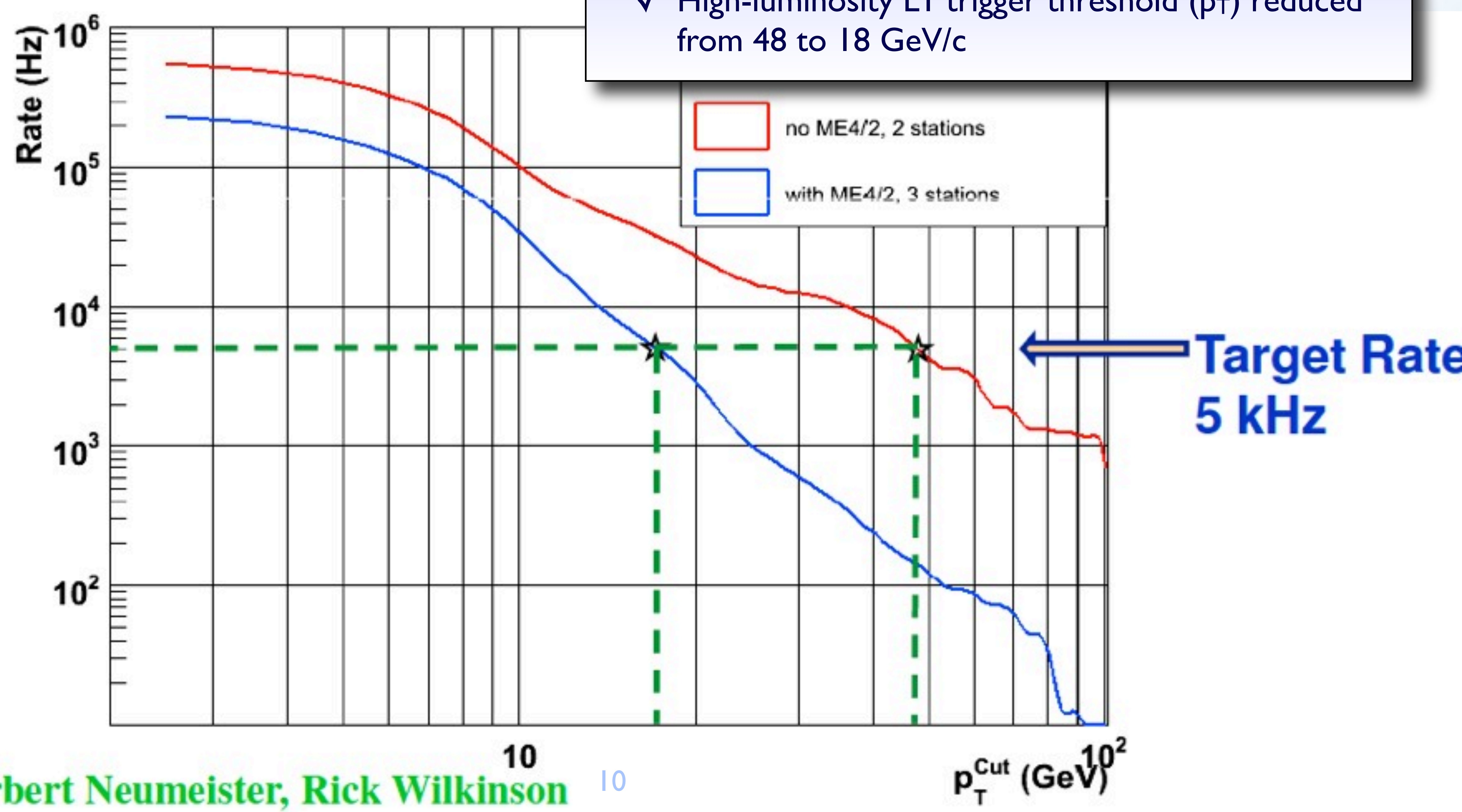
    - ...and associated trigger (TMB) and readout (DMB) boards

Motivations of ME4/2 upgrades

- Comparison 3/4 vs. 2/3 stations (triggering on n out of n stations is inefficient and uncertain)
- Recent simulations with & without the ME4/2 upgrade
  - ✓ High-luminosity L1 trigger threshold (p_T) reduced from 48 to 18 GeV/c



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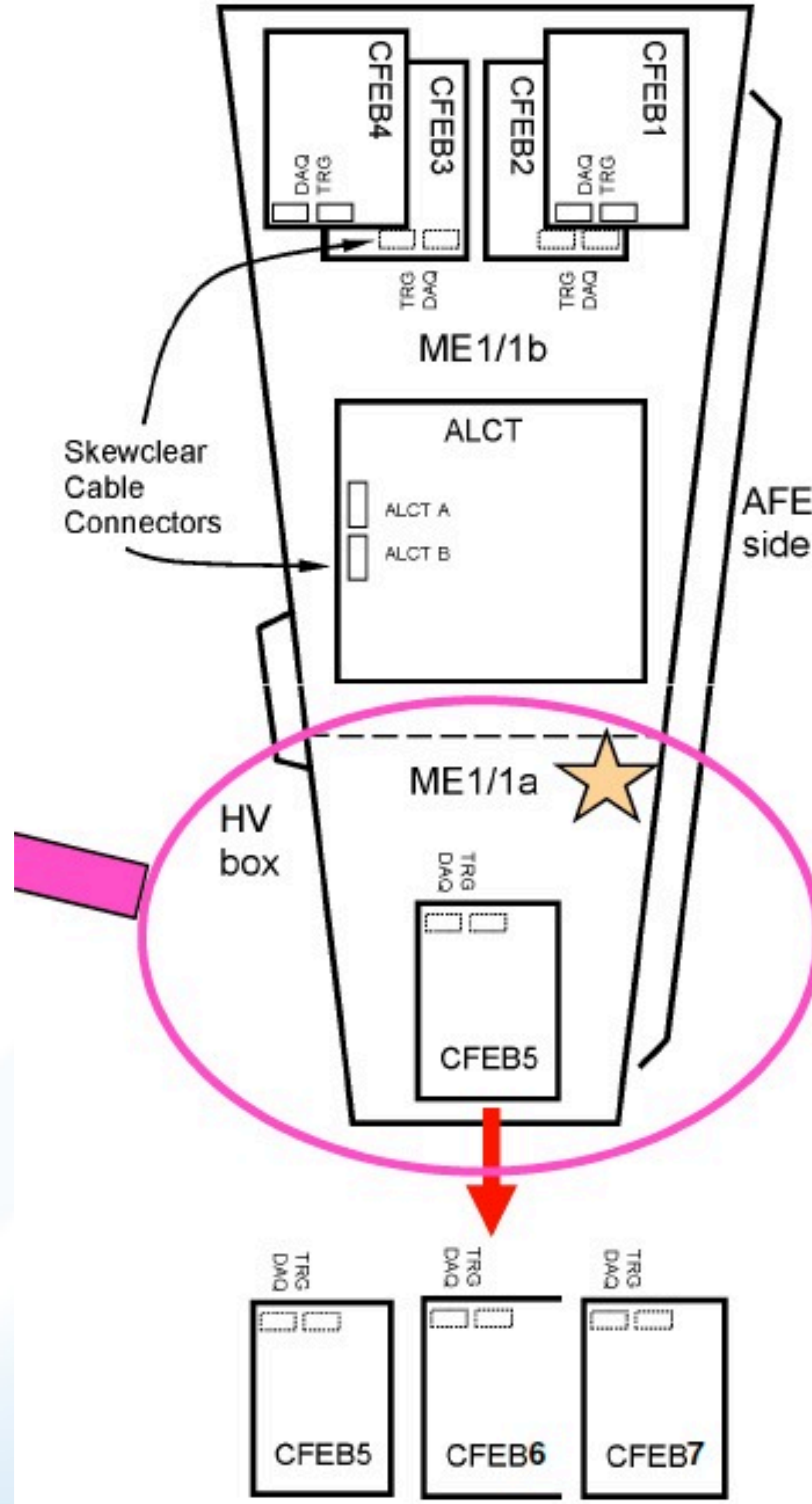
High-η section of ME1/1:

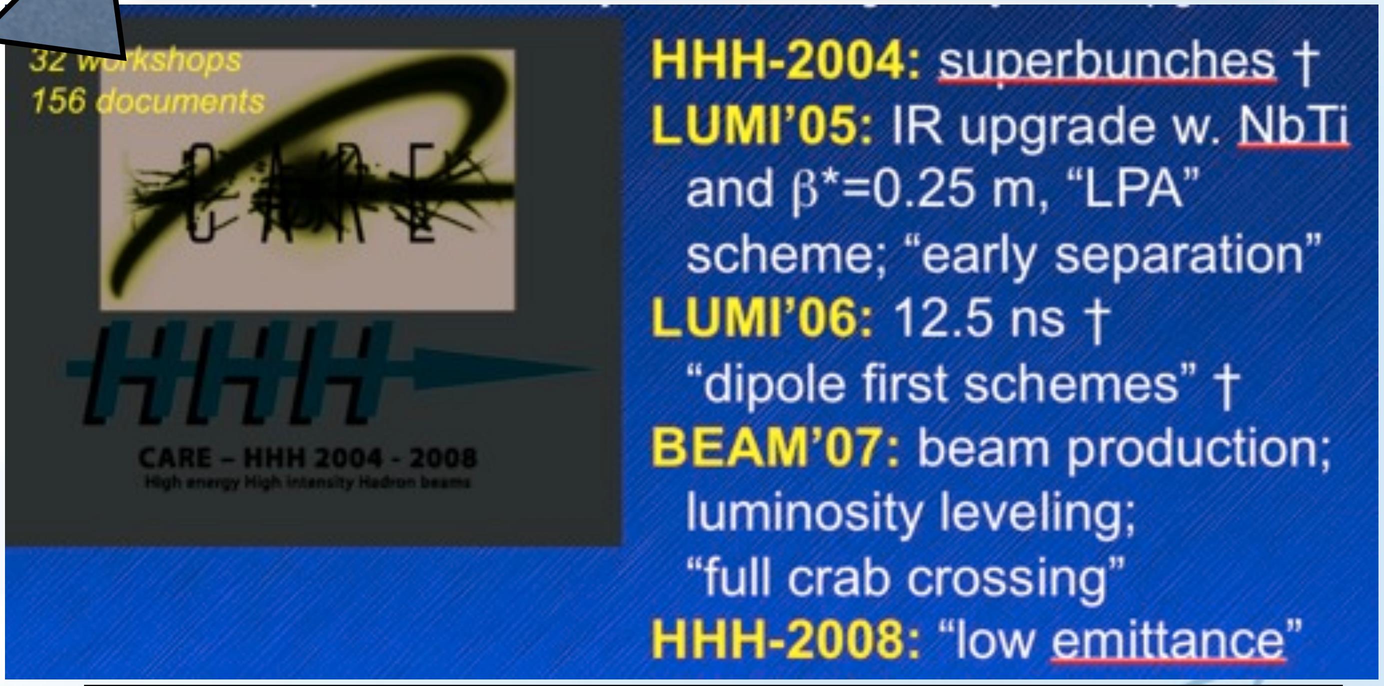
- Currently cathode strips are ganged 3:1
- Install additional electronics to readout separately individual strips



LHC Evolution - Phase-II

- The reach of the physics programs at the LHC can be extended by a significant upgrade toward the end of next decade (2018-2020), aiming at:
  - ✓ a x10 increase of a peak luminosity (i.e. $10^{35} cm^{-2} s^{-1}$) or...
  - ✓ a x10 increase of the integrated luminosity per year.
- Ideas and studies of possible evolution of the machine is a very active development since the first feasibility study in 2001/2002
  - ✓ Several scenarios under-study
  - ✓ Pre-condition: upgrade of collimation system
  - ✓ Injector improvements - higher current and reliability, shorter fill time
  - ✓ New machine elements:
    - Magnets inside the experiments
    - Crab cavities
    - Luminosity Leveling
- **Revisit the long plan when we will have run the LHC for a few years (2012/2013?)**

- **Key Upgrade Drivers:**
  - ✓ Head-on beam-beam limit
  - ✓ Detector pile-up
  - ✓ Long-range beam-beam effects
  - ✓ Crossing angle
  - ✓ Collimation and machine protection
  - ✓ Beam from injectors
  - ✓ Heat load (e.g. e-cloud)

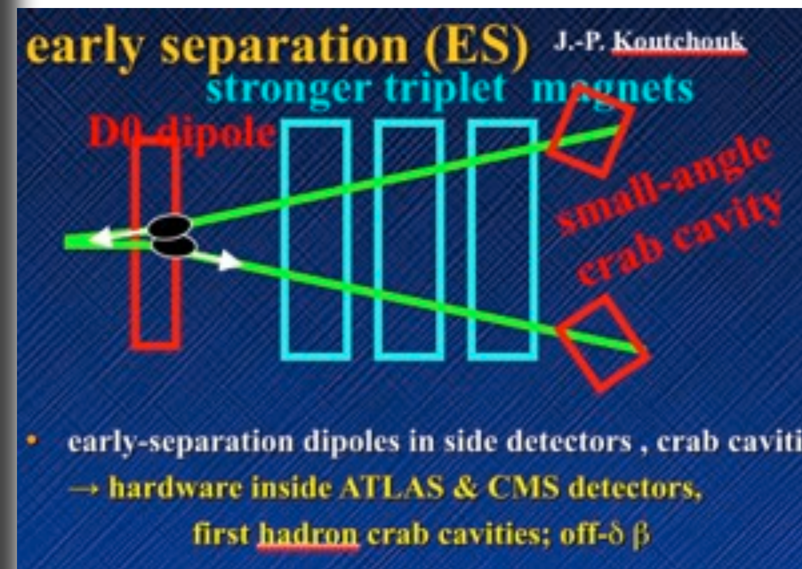


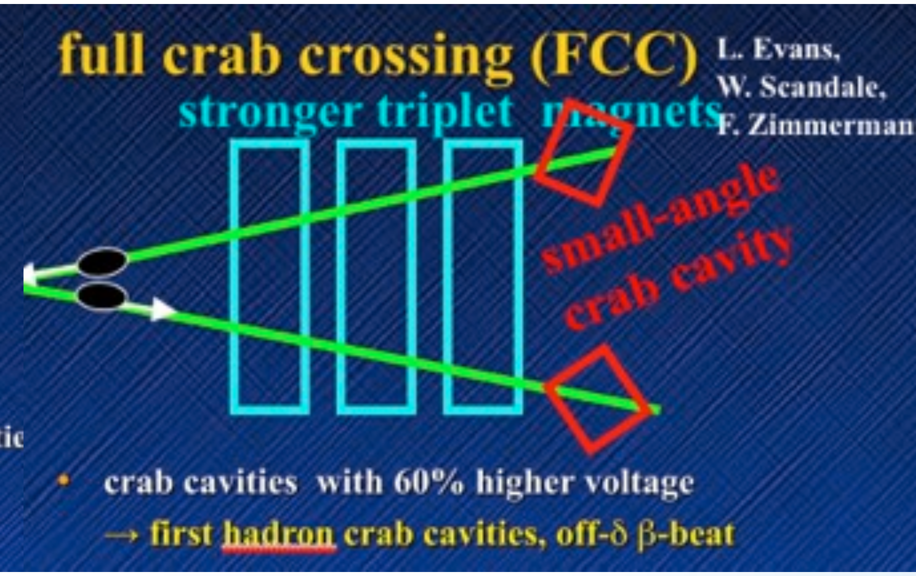
F. Zimmermann - *"LHC Upgrade"*, LHCC review, February 2009

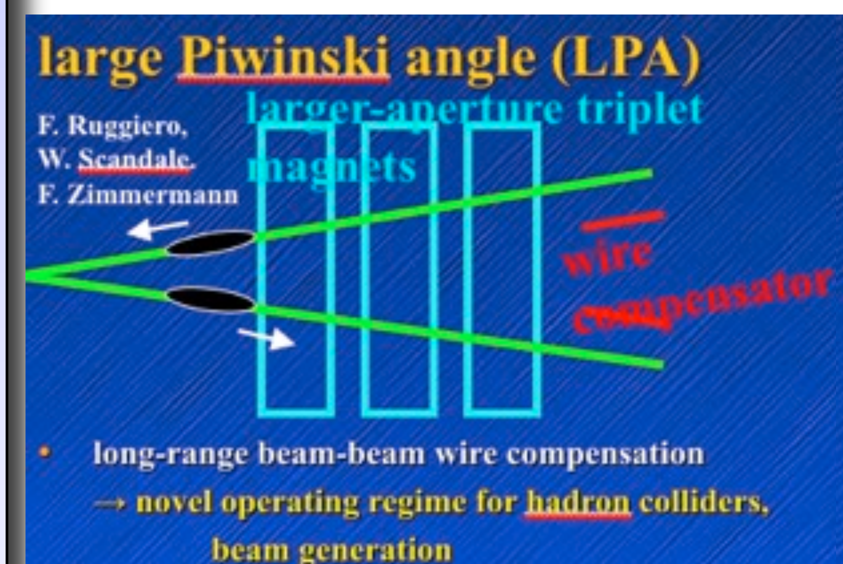
LHC Phase-II (sLHC) scenarios

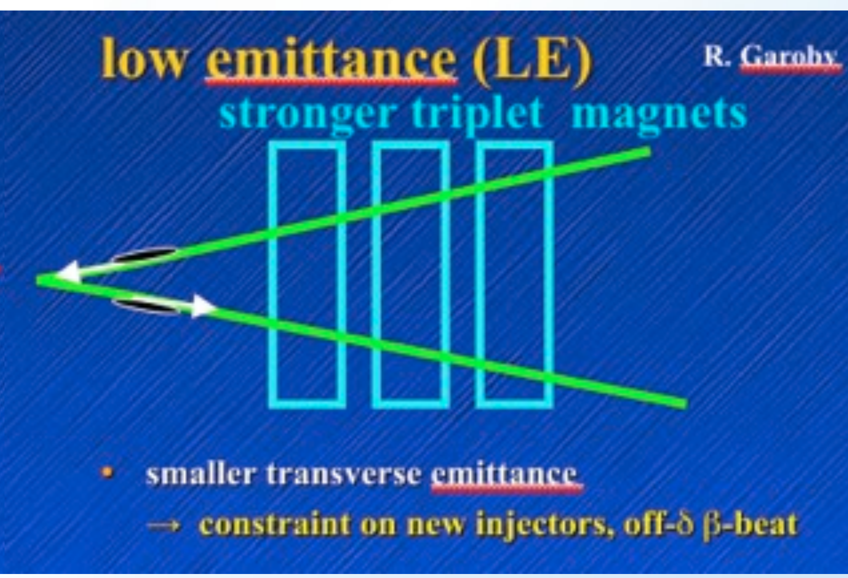
- Early Separation (ES)
  - ✓ β^* ~0.1m, 25ns, N_b=1.7x10^{11}, detector embedded dipoles
- Full Crab Crossing (FCC)
  - ✓ β^* ~0.1m, 25ns, N_b=1.7x10^{11}, local and/or global crab cavities
- Large Piwinski angle (LPA)
  - ✓ β^* ~0.25m, 50ns, N_b=4.9x10^{11}, "flat" intense bunches
- Low emittance (LE)
  - ✓ β^* ~0.1m, 25ns, $\gamma\varepsilon$~1-2µm, N_b=1.7x10^{11}
- **Luminosity leveling**

F. Zimmermann - *"LHC Upgrade"*, LHCC review, February 2009









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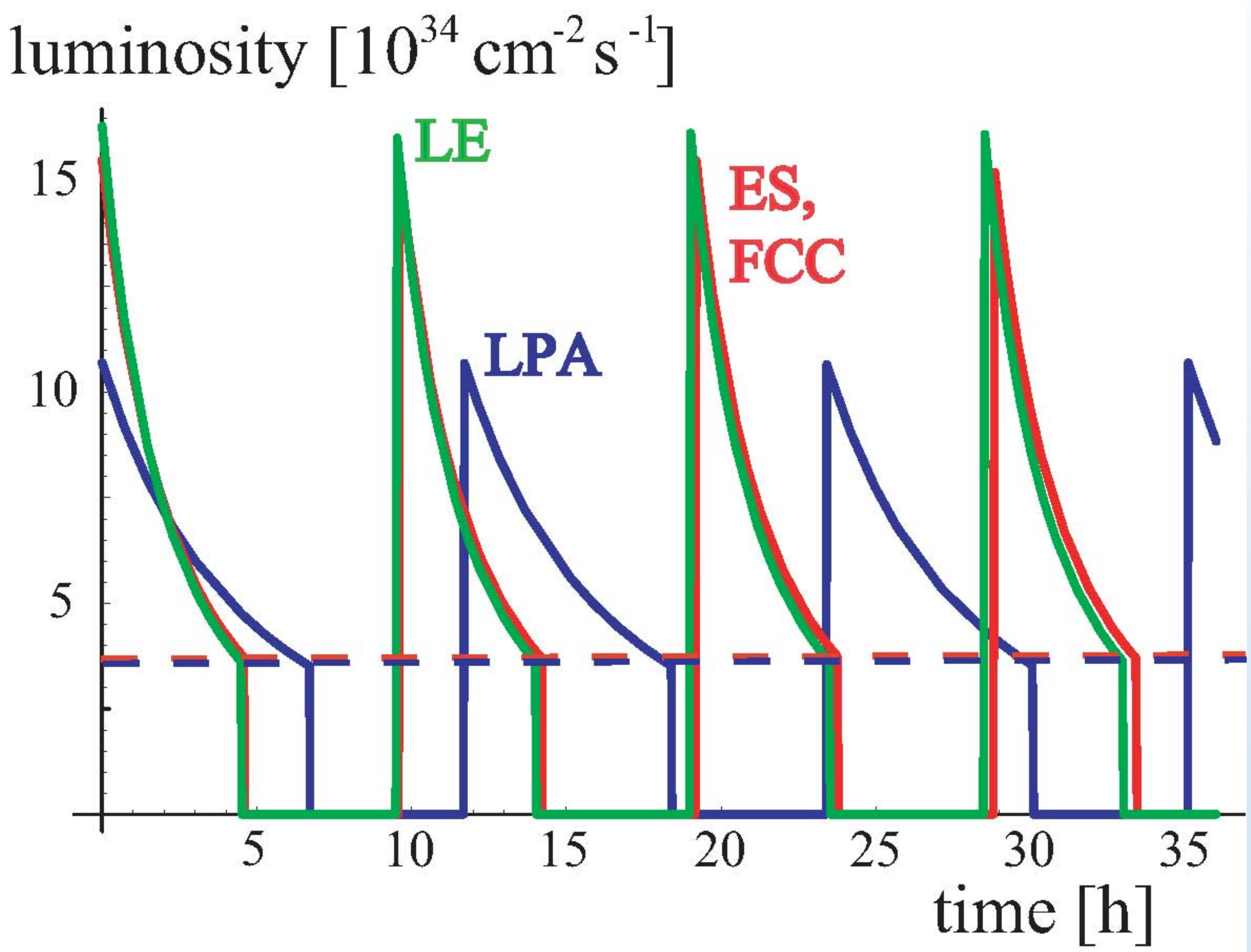

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LHC Phase-II (sLHC) scenarios

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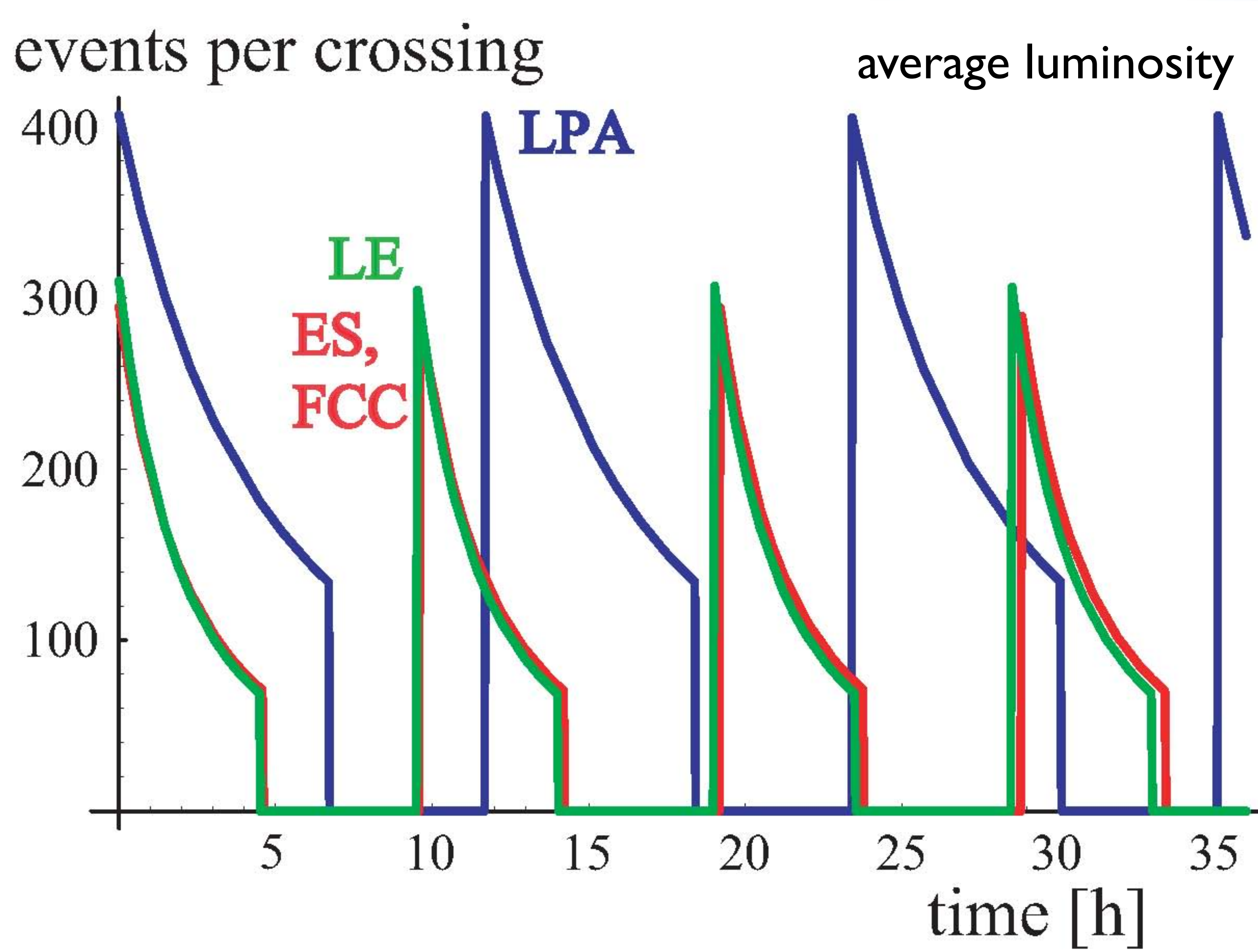

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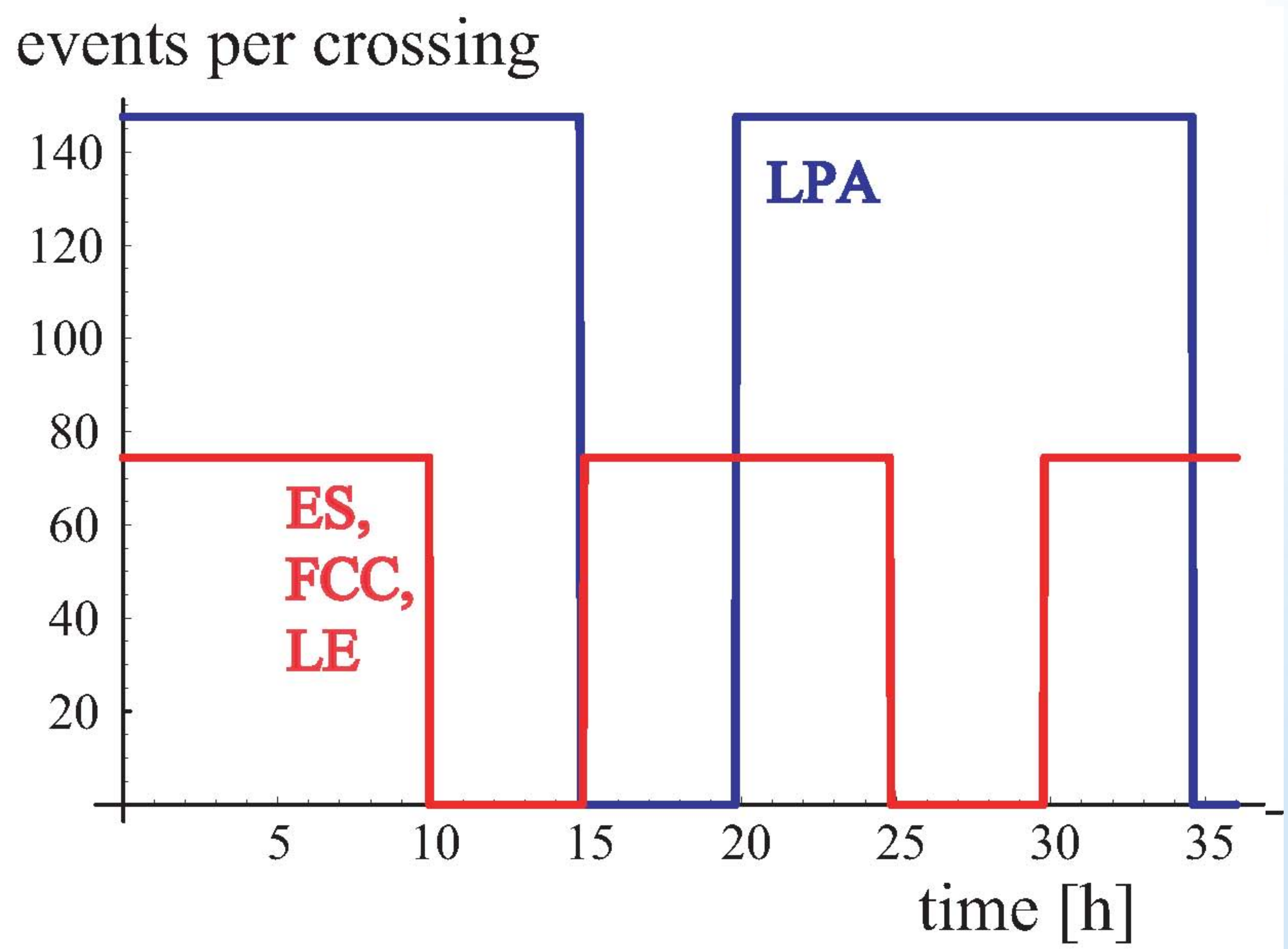

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Conditions at sLHC

- 400/500 pile-up events from minimum bias at the start of the spill
- Want to survive at least 3000 fb^{-1} recorded luminosity

  ✓ Safety factor (x2, i.e. 6000 fb^{-1})

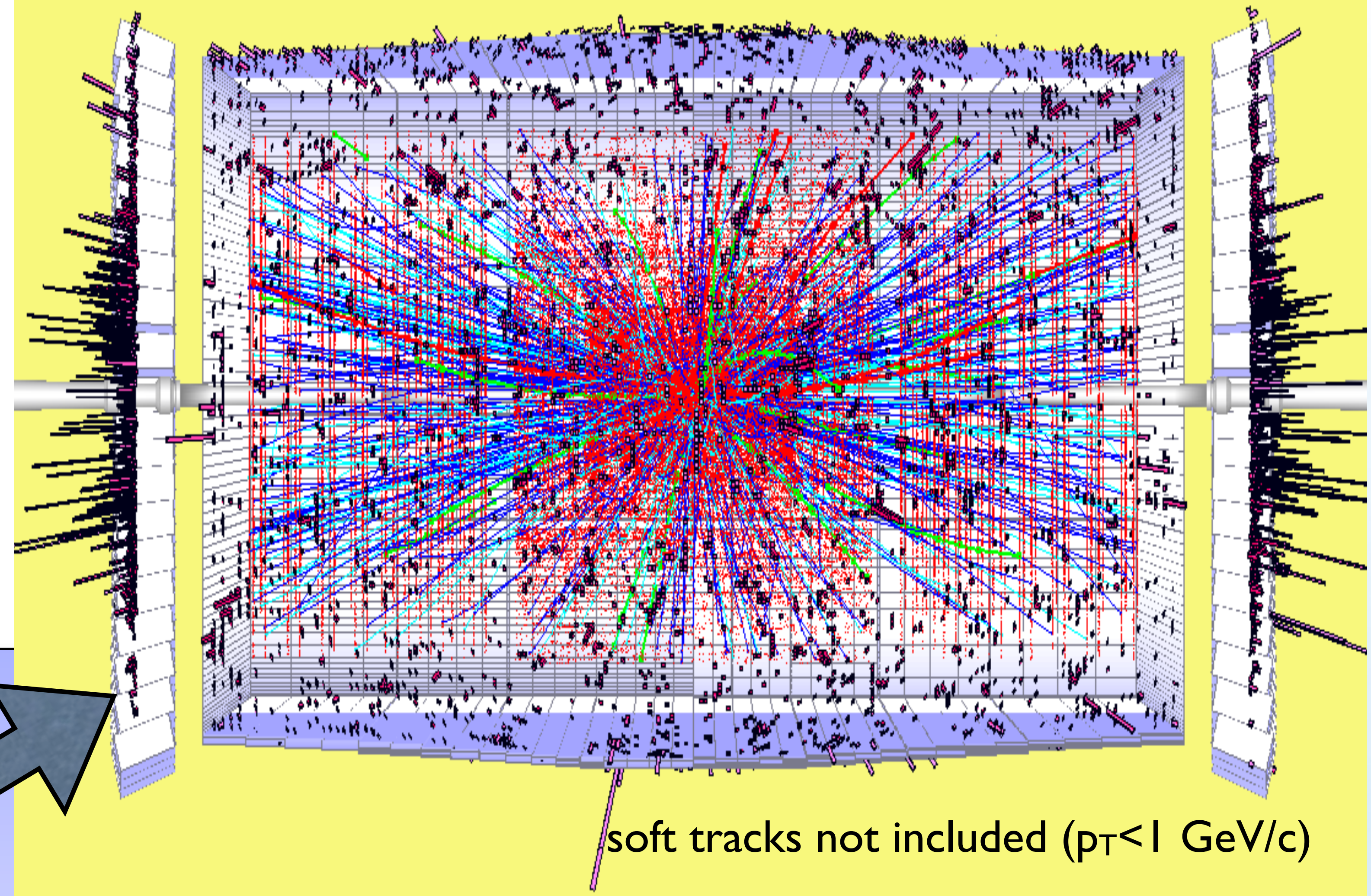
Two classes of detector issues:

Conditions at sLHC

- 400/500 pile-up events from minimum bias at the start of the spill
- Want to survive at least 3000 fb^{-1} recorded luminosity

  ✓ Safety factor (x2, i.e. 6000 fb^{-1})

CMS simulation: $10^{35} cm^{-2} s^{-1}$, 25ns, i.e. 200-300 min-bias events/BC



soft tracks not included (p_T<1 GeV/c)

Two classes of detector issues:

- Instantaneous peak luminosity (pileup and cavern background):
  - ➡ Very demanding for many part of the detectors (ID, trigger, some aspects of calorimeters and muons, forward region, machine interface)
  - ➡ Resolution degradation (e.g. calorimeters)
  - ➡ Detector inefficiency due to high occupancy/ rates (e.g. tracker systems and muon spectrometers)
  - ➡ Loss of functionality of detectors (e.g. ATLAS LAr forward calorimetry)

Conditions at sLHC

- 400/500 pile-up events from minimum bias at the start of the spill
- Want to survive at least 3000 fb^{-1} recorded luminosity

  ✓ Safety factor (x2, i.e. 6000 fb^{-1})

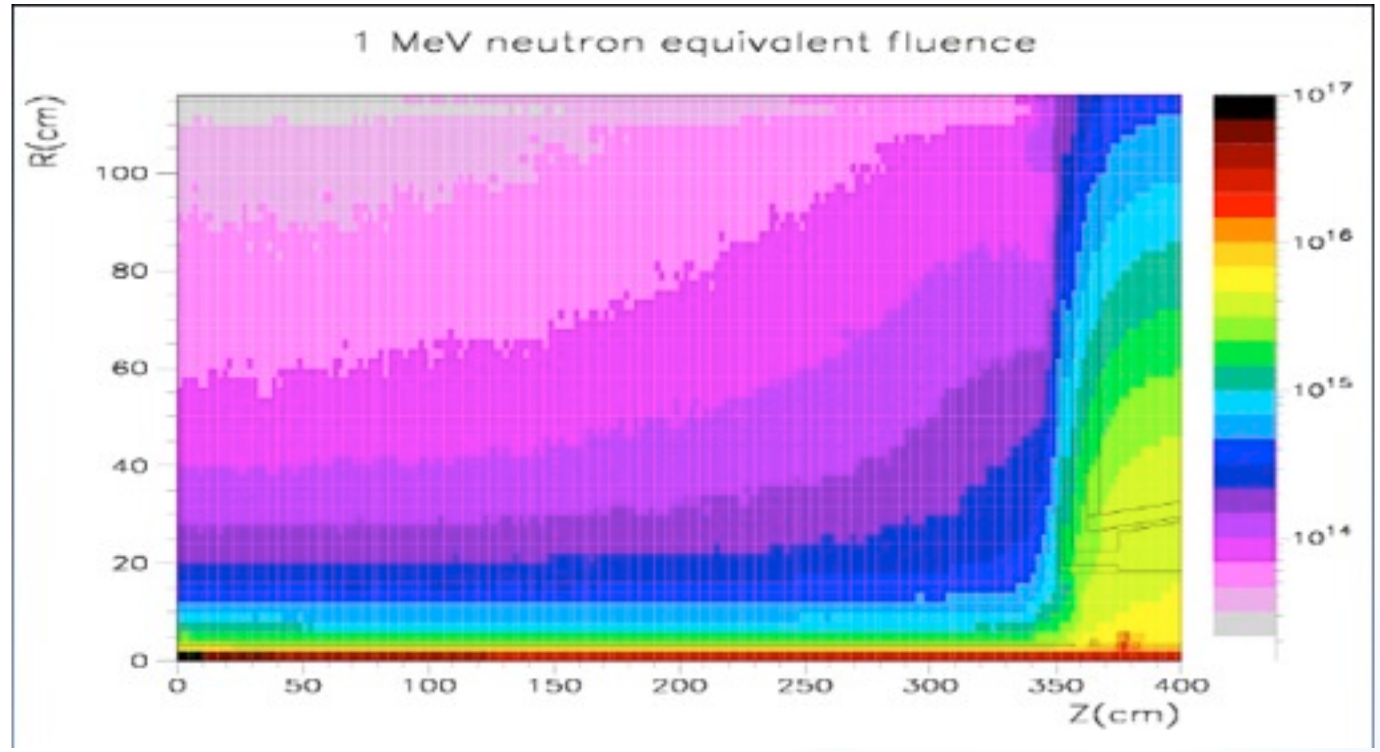
Two classes of detector issues:

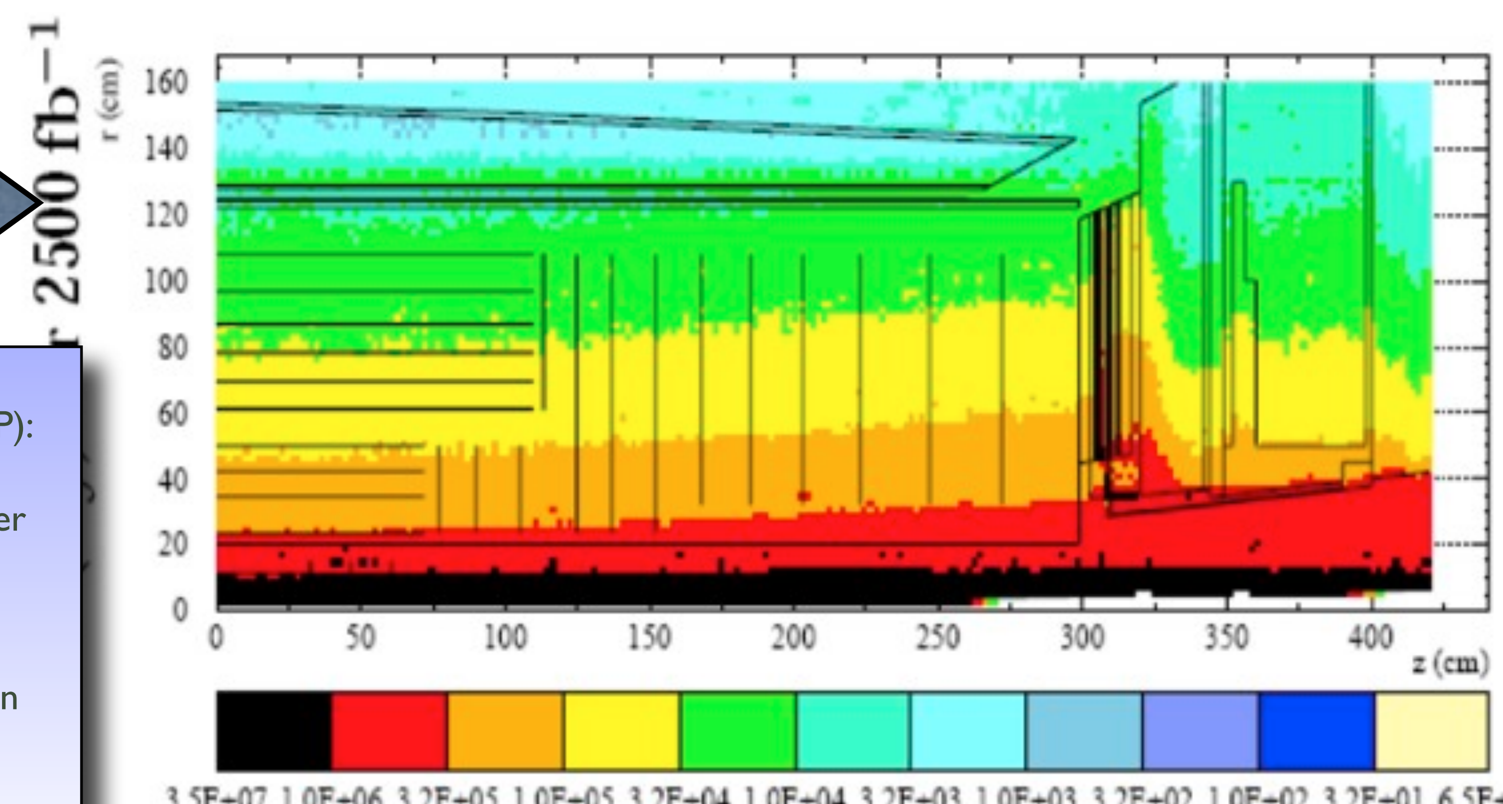
- Integrated luminosity:
  - ➡ Radiation tolerant limits of the sensors and of the readout electronics
  - ➡ Particularly severe for the tracker systems.

Example - ATLAS pixel B-layer (at 37mm from the IP):

- ➡ ~30 tracks/cm^2 per bunch crossing
- ➡ >10^{16} 1-MeV equivalent neutron fluence
- ➡ >10MGy of total ionizing dose

Neutron Fluence





Total Ionizing Dose

Beam Pipes and Shielding

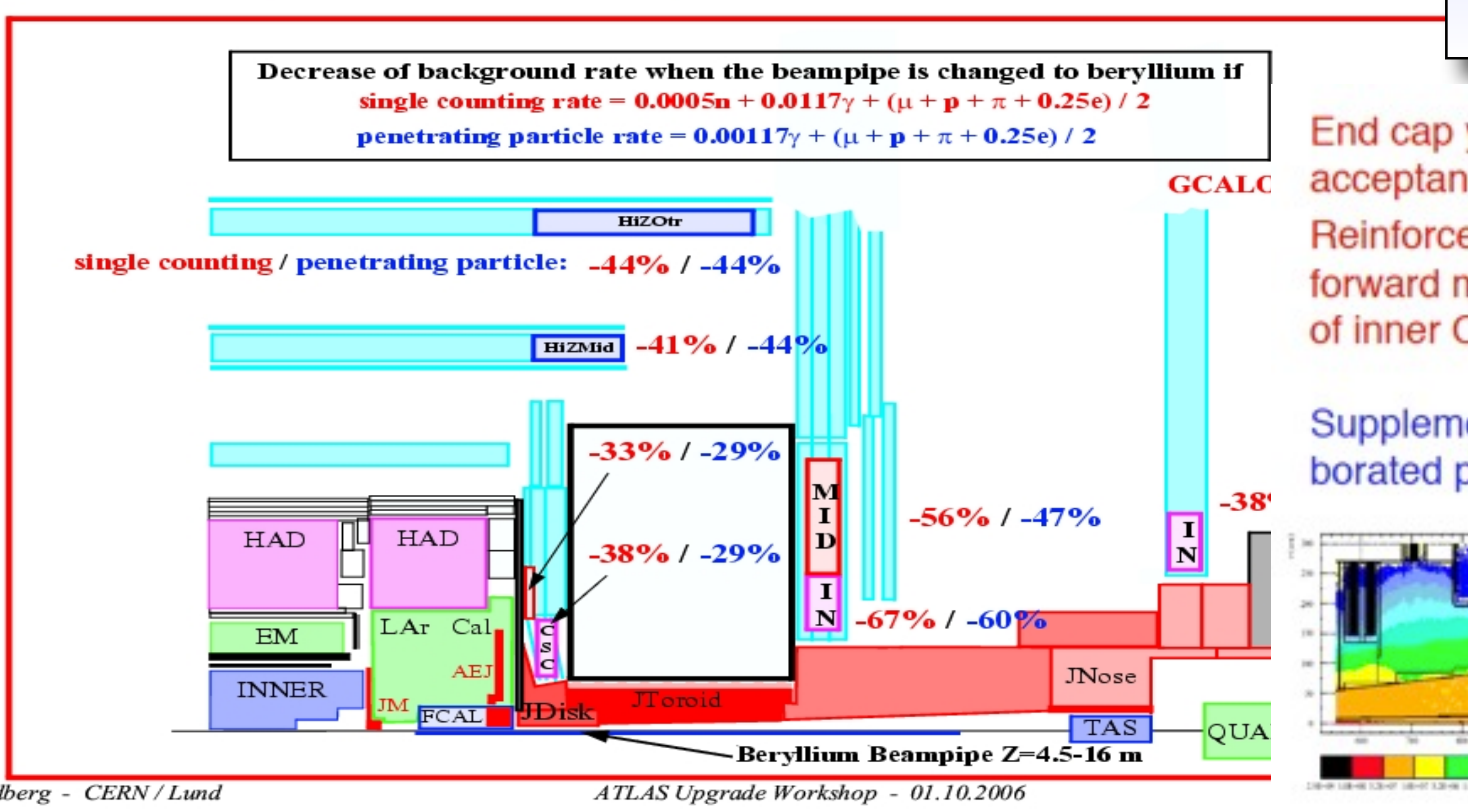
- In both experiments cavern backgrounds dominates the rates of the muon chambers
- To reduce it effectively two different strategies are being considered:

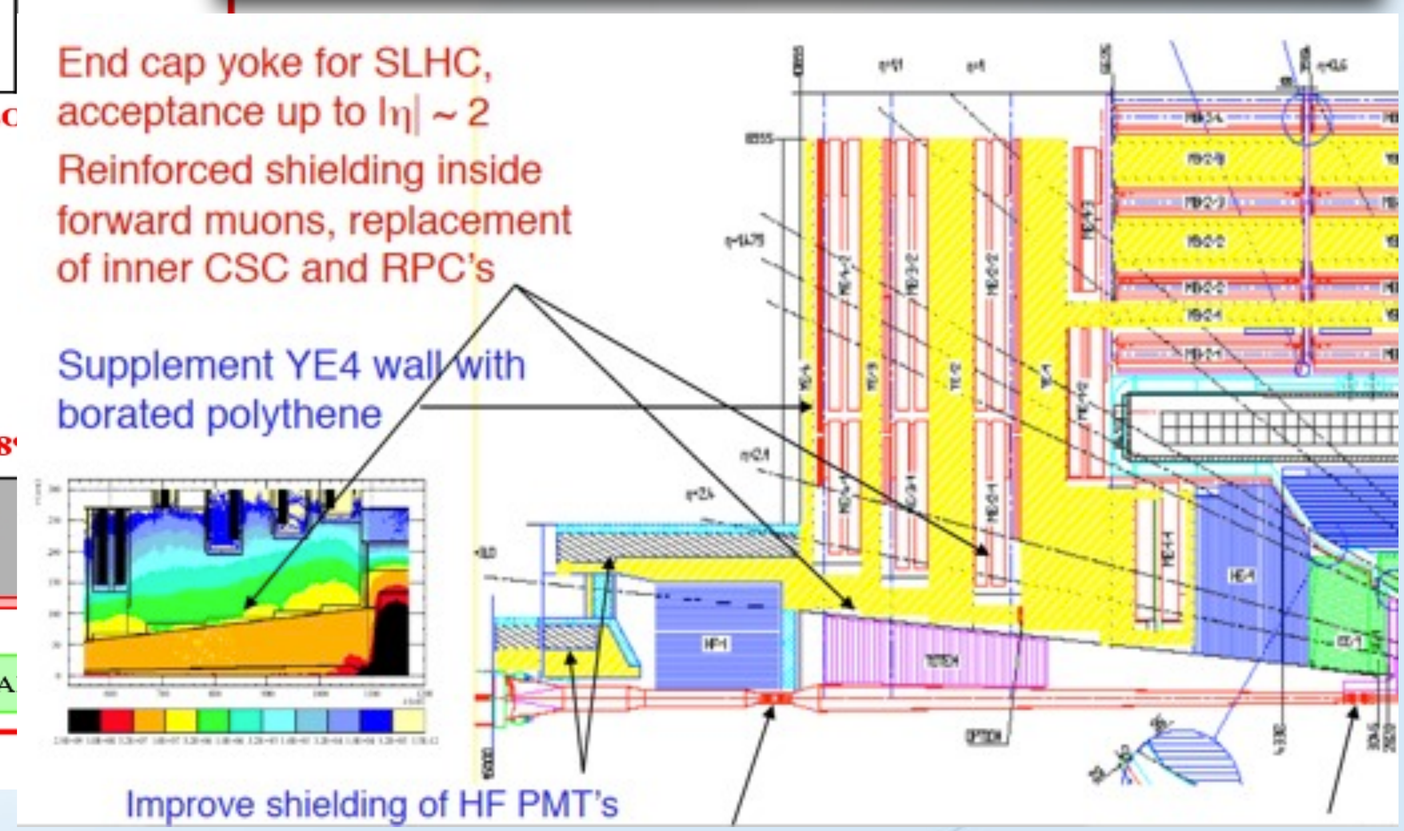
ATLAS

- All-beryllium beam-pipe
  - ✓ Expensive but much cheaper than replace most of the muon chambers

CMS

- More forward shielding (at η=2)
  - ✓ Adding borated polythene to better shield PMTs of the HF detector.
  - ✓ reducing the spectrometer acceptance from |η|<2.5 to about |η|<2.0

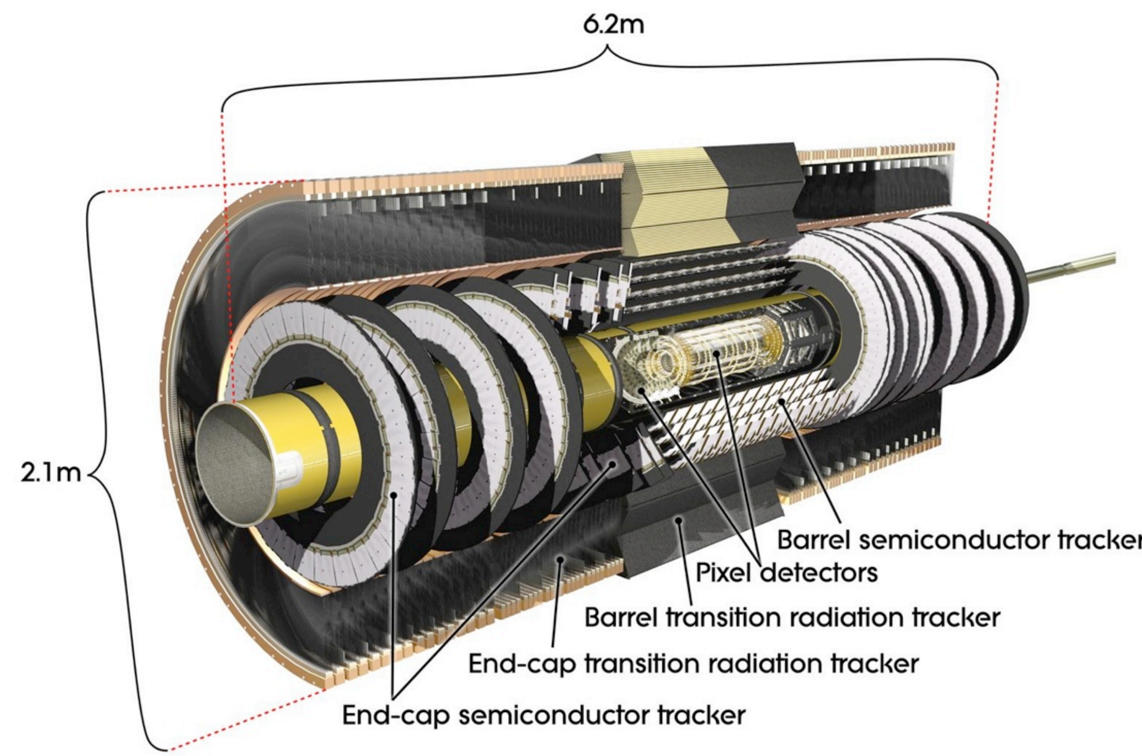


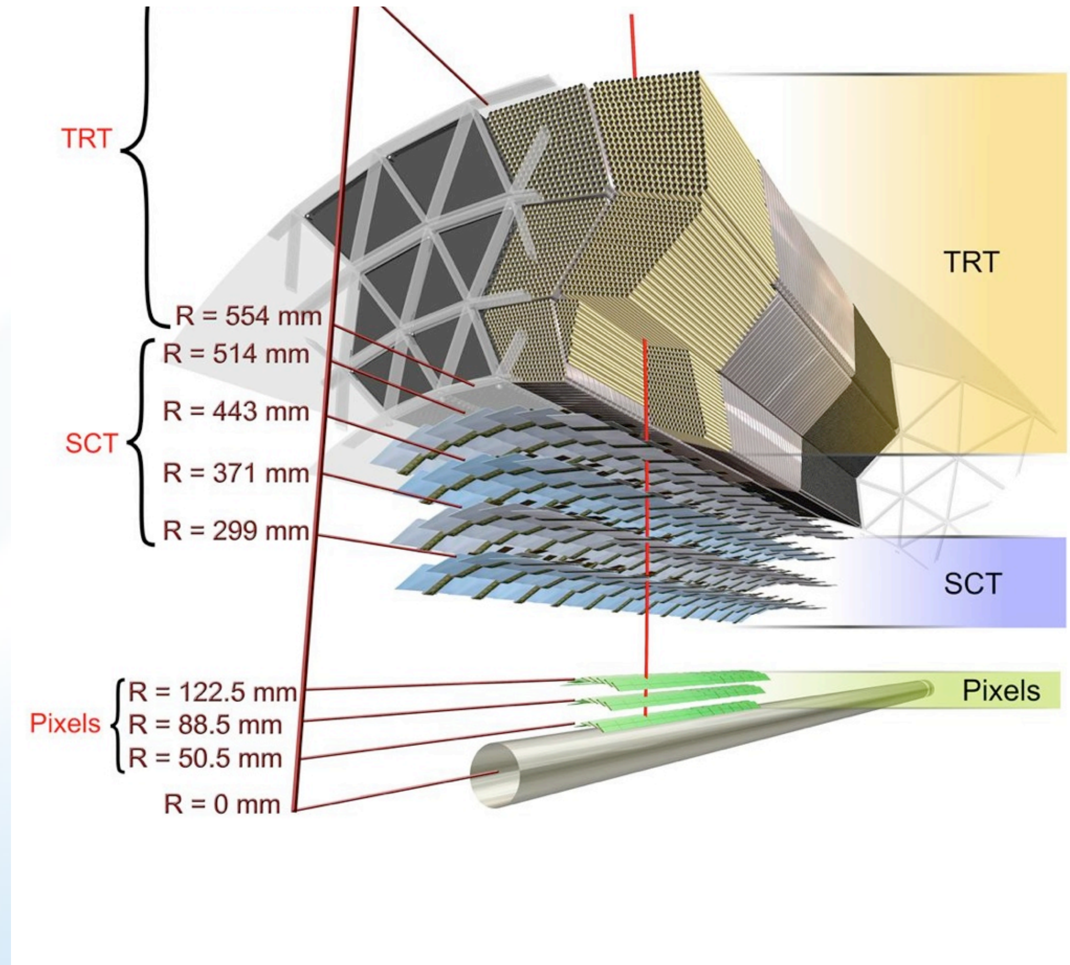


ATLAS

Inner Tracker Systems

- Upgrade motivation:
  - ✓ Increasing occupancy in the Transition Radiation Tracker (TRT) inner layers:
    - Already 30% at Linst ~ $10^{34}cm^{-2}s^{-1}$
  - ✓ Radiation damage to SemiConductor Tracker (SCT) above 700 fb^{-1}
  - ✓ High SCT occupancy at $10^{35}cm^{-2}s^{-1}$
- Goals of Tracker Upgrade:
  - ✓ Have tracking capabilities at 10^{35} that meet or exceed existing tracker at 10^{34}
  - ✓ Allow collection of up to 6000fb^{-1} of data with good performance





ATLAS

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  - ✓ Have tracking capabilities at 10^{35} that meet or exceed existing tracker at 10^{34}
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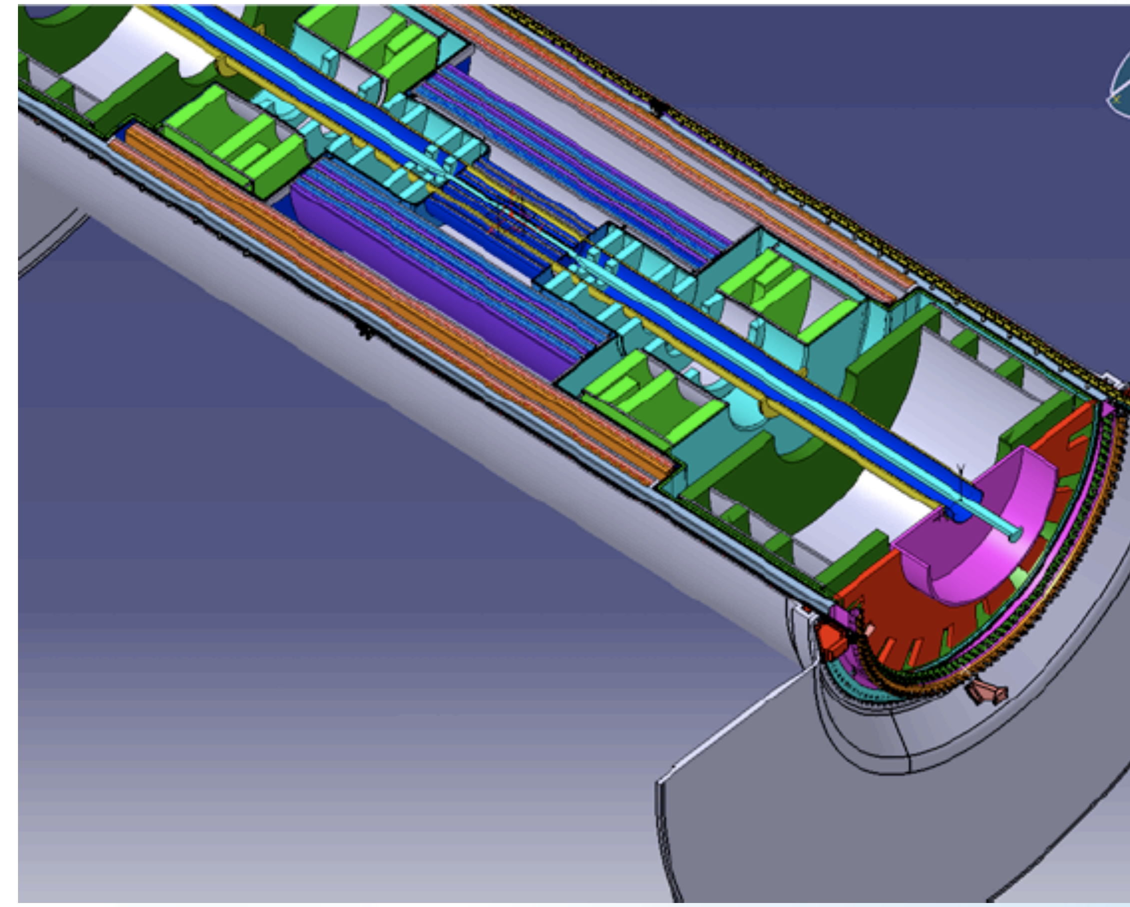
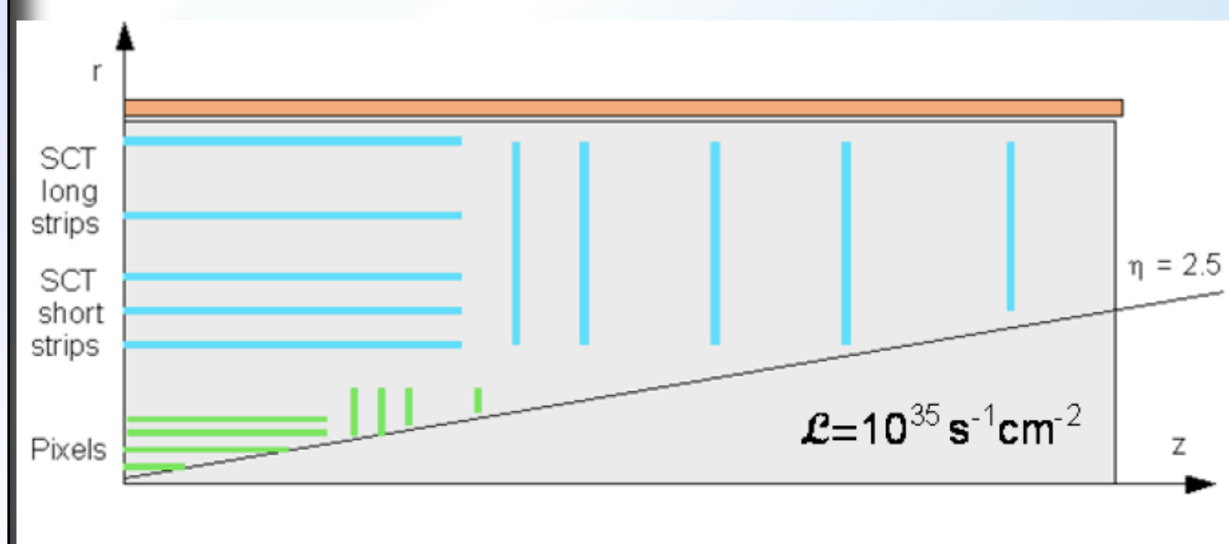
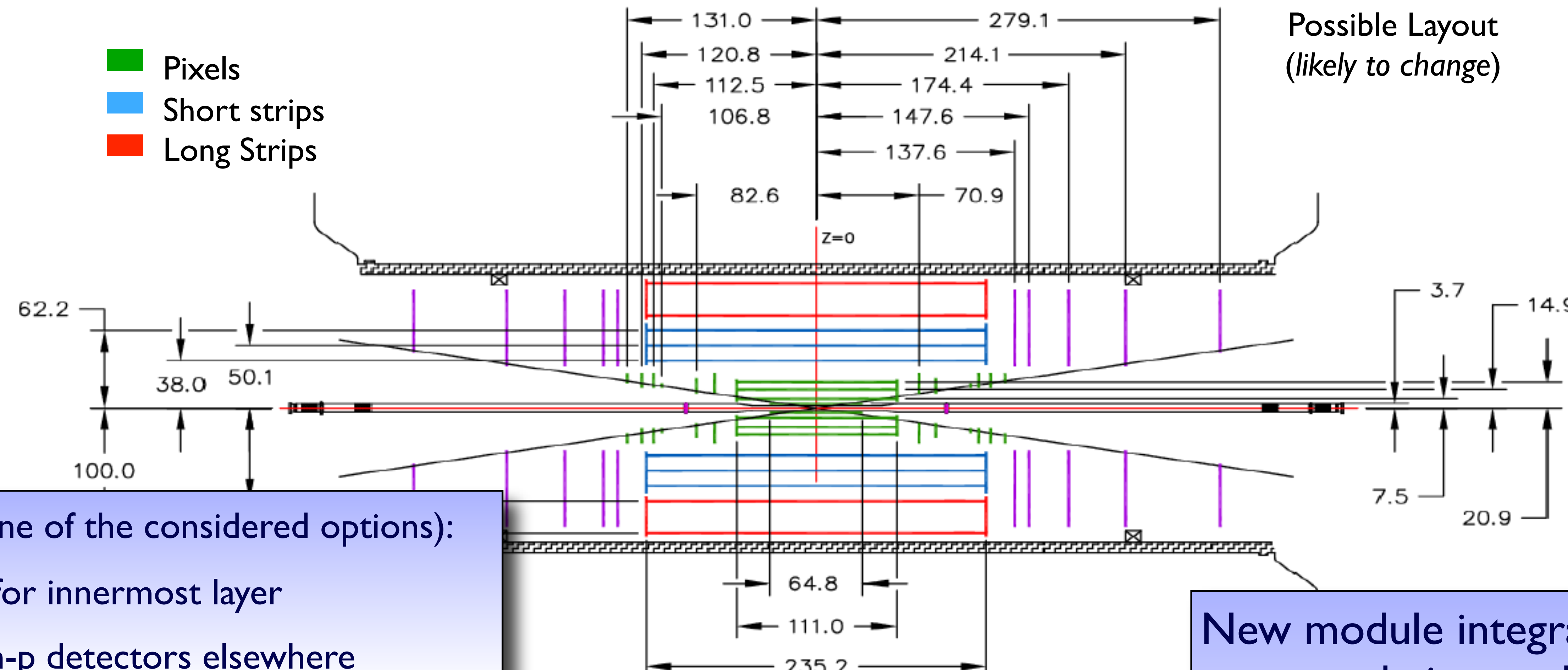
- **Complete Si Tracker replacement proposal:**
  - ✓ Finer granularity to keep the occupancy acceptably low (for 400 min-bias/BC, track multiplicity up to 14k). Goal is to keep occupancy <1.6% in the innermost strip layer.
  - ✓ Layout studies and optimization undergoing





ATLAS

Inner Tracker Systems

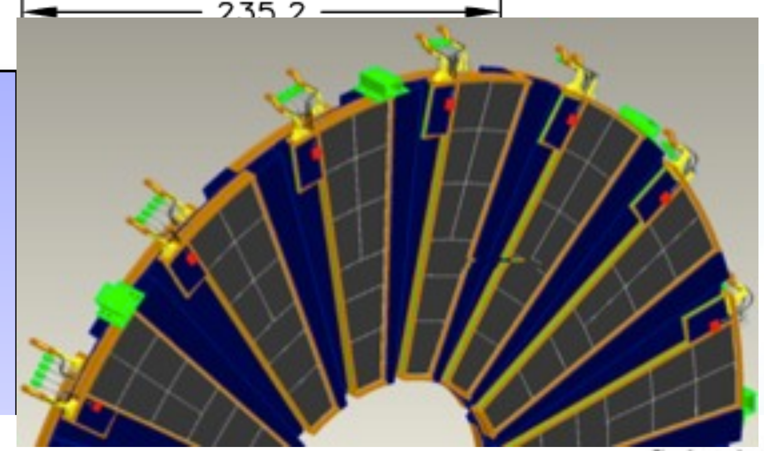


Pixels (one of the considered options):

- 3D for innermost layer
- n-on-p detectors elsewhere

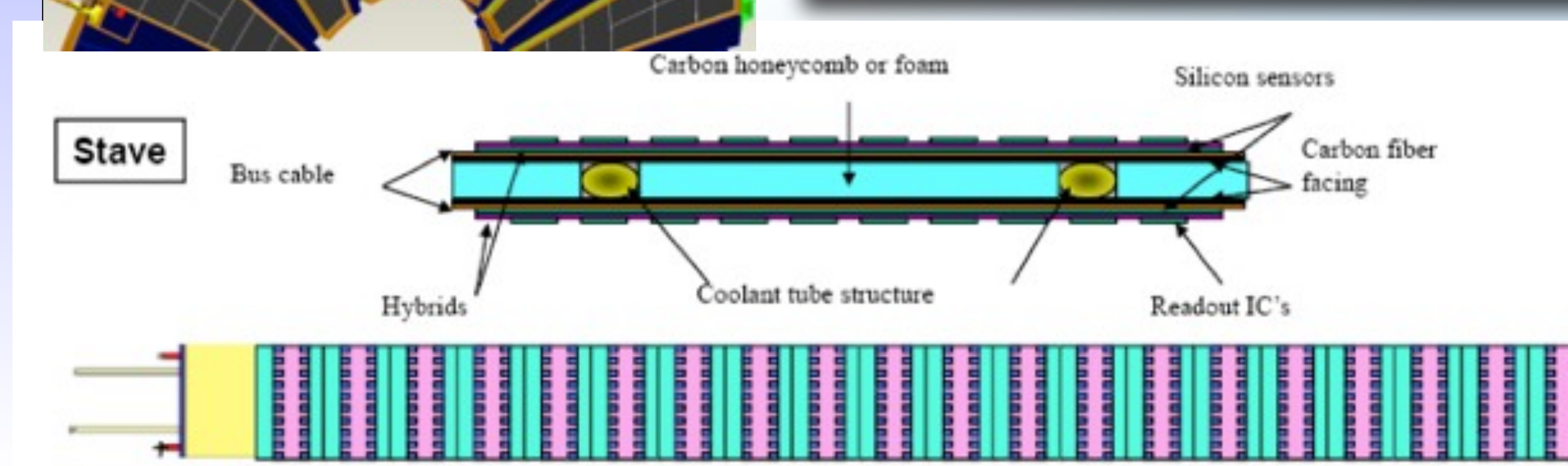
Strips:

- 5 Barrel layers: @38,49,60,75 and 95 cm
- 3 inner layers: 24mm long strips (short strips)
- 2 outer layers: 96mm long strips (long strips) Strips organized in modules assembled on large staves, housing also power services and FE.
- The 3 outer layers + end-cap discs will replace the TRT detector.



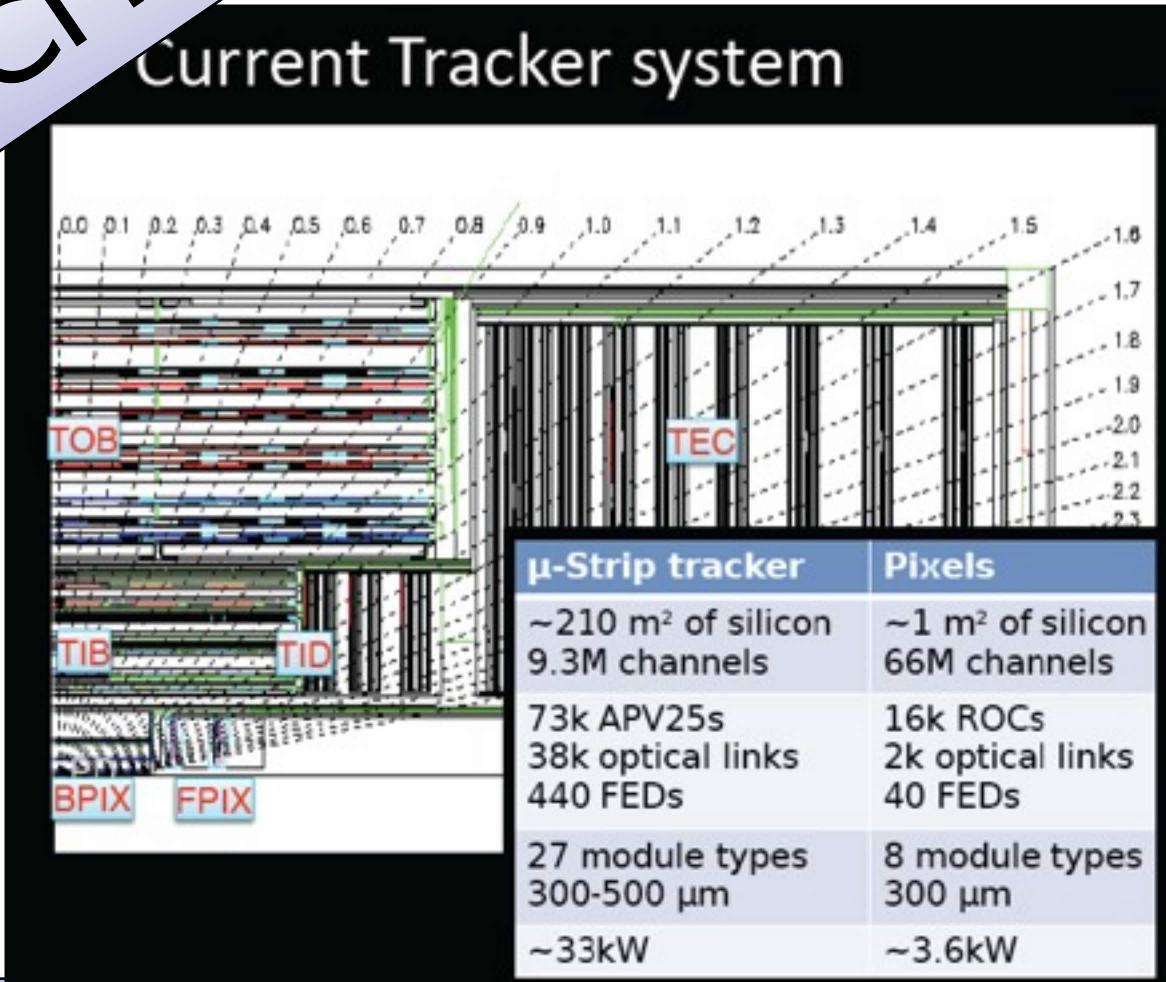
New module integration concepts being studied:

- Staves (1.2m long) for the barrel
- Petals for the EC



CMS

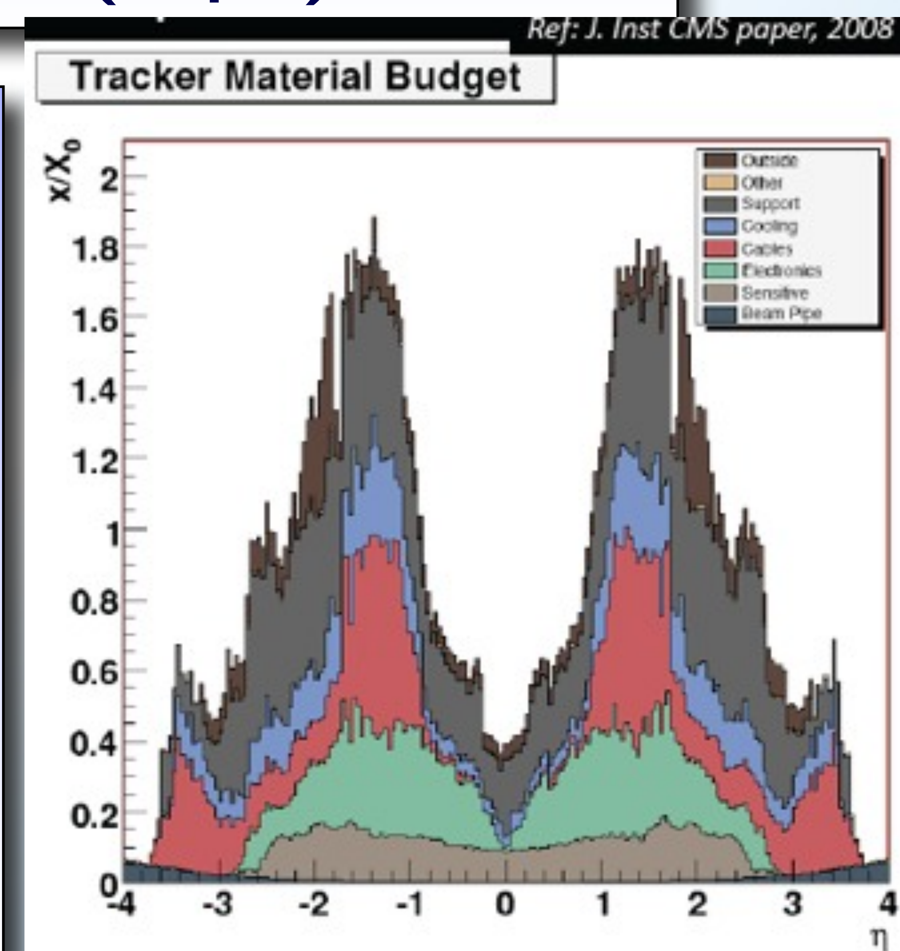
Inner Tracker Systems



μ-Strip tracker	Pixels
~210 m² of silicon 9.3M channels	~1 m² of silicon 66M channels
73k APV25s 38k optical links 440 FEDs	16k ROCs 2k optical links 40 FEDs
27 module types 300-500 μm	8 module types 300 μm
~33kW	~3.6kW

Pixels:

- Phase-I pixel size will pro
  $150 \times 150 \mu m^2$ (it may chan
- Detector designed for easy removal
- **New pixel detector for Phase-II.**
- **It would require reduced pixel size**
- **... and smaller feature size readout ASICs (.13μm)**



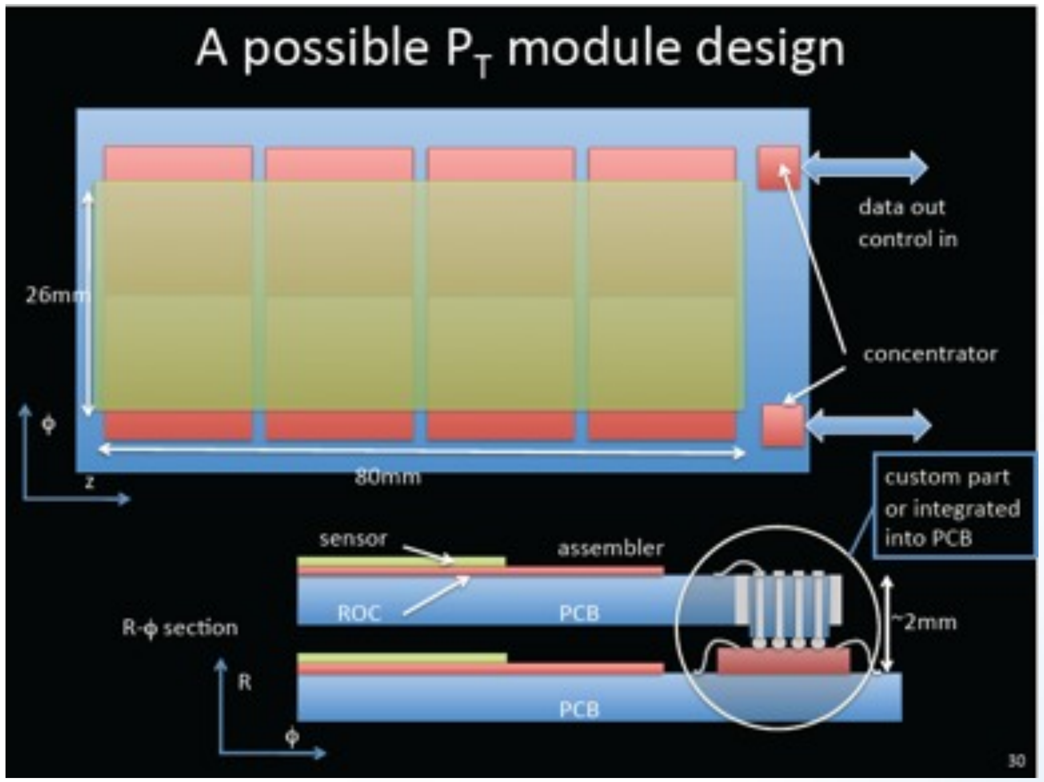
Full Tracker Upgrade:

- Straightforward requirements:
  - ✓ Higher granularity to maintain occupancy at a few %
  - ✓ Greater rad-resistance
  - ✓ Maintain and possibly improve performance
  - ✓ Budget material to minimize. Lots of services (power cables, cooling, support structures), particularly between barrel and endcaps
- **Replacement of the full system including the pixel detector and the re-optimization of the layout.**

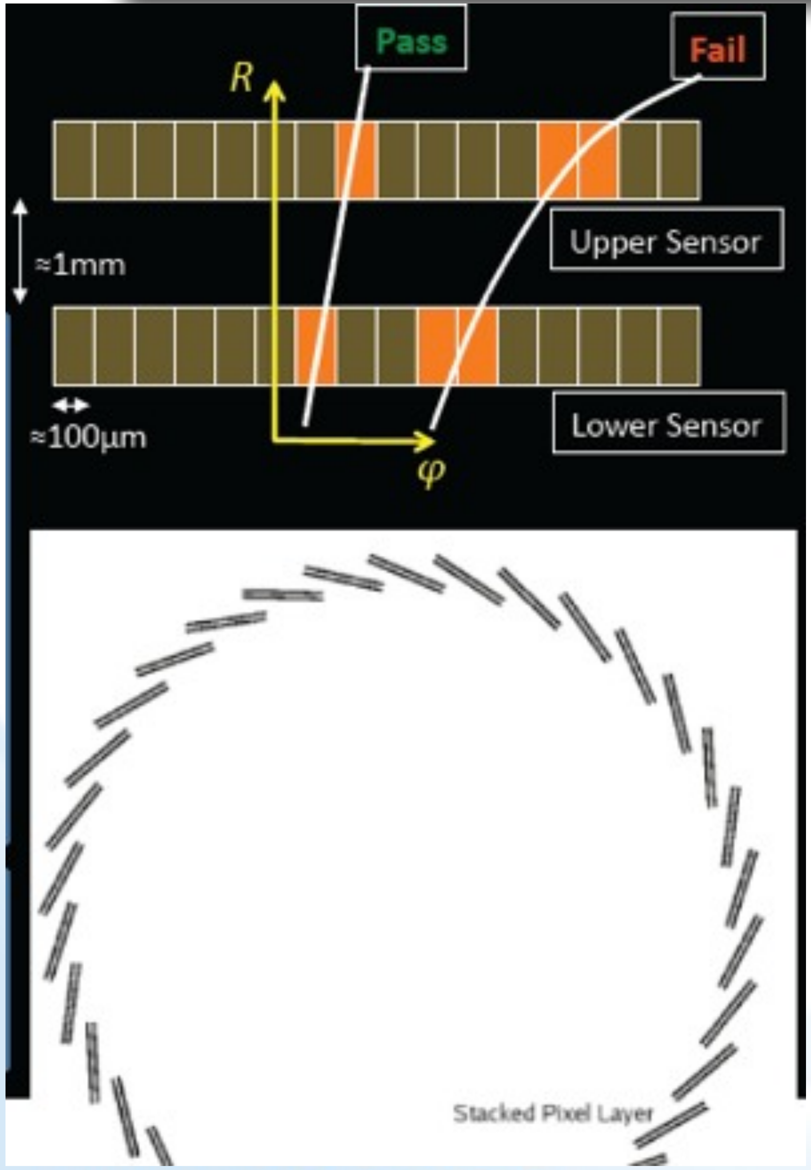
Inner Tracker Systems

P_T Layers:

- Closely stacked layers (~1mm separation)
- P_T cut set by angle of the track in the stack
- Off-detector correlate track stubs from different stacked layer.
- Optimal option for radial range 20-40cm in barrel
- Provide (some) z-information at L1
- Being considered for larger radii also (strips).

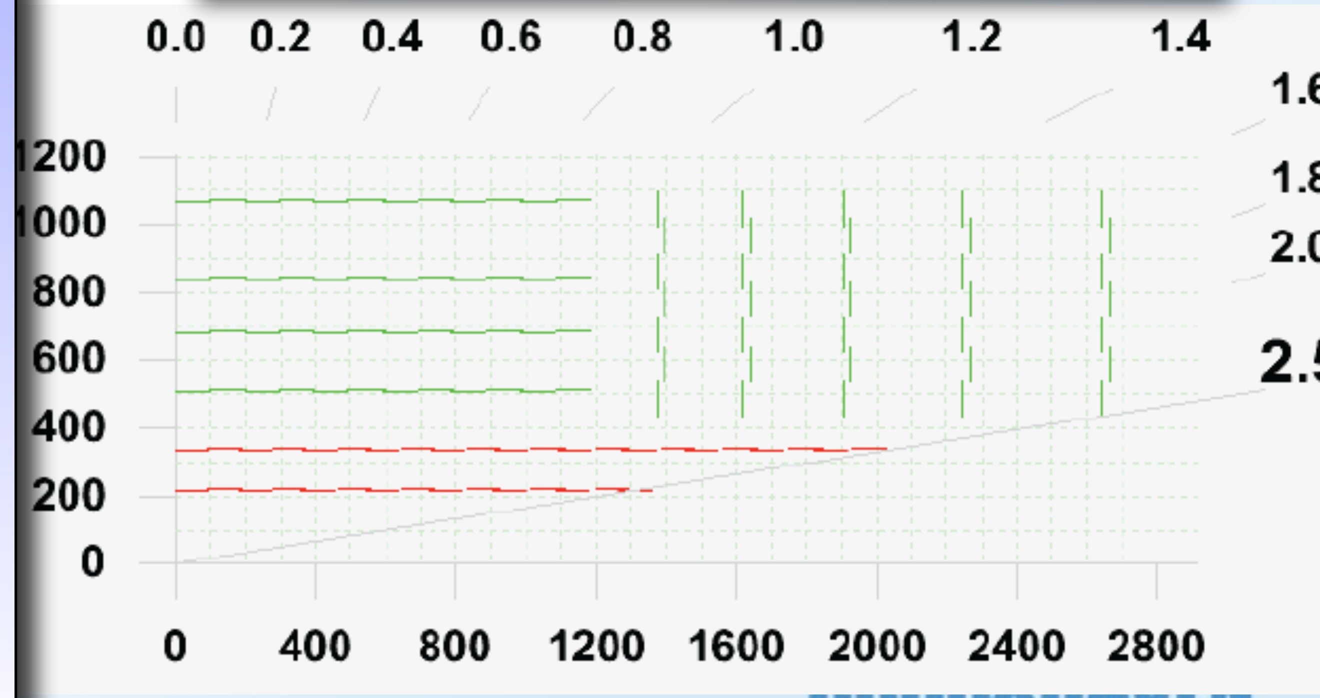


- Several designs of stacking and modules being developed
  - ✓ Vertical 3D-integration
- Possible layouts under study



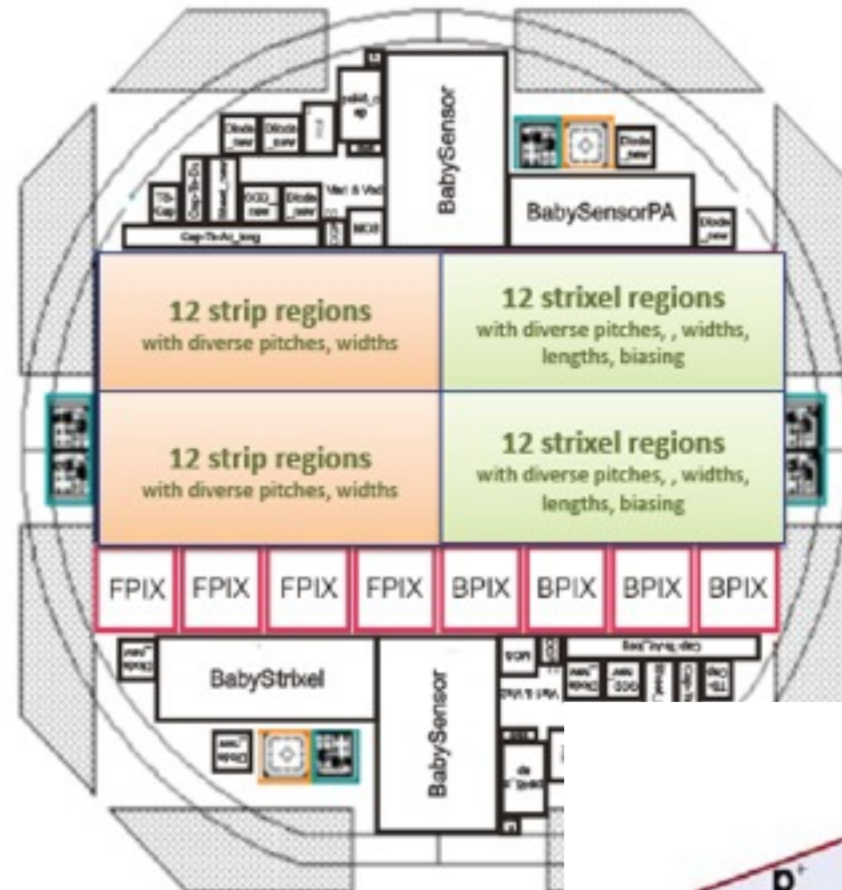
Hybrid Layout

- 2x barrel 'PT layers'
  - ✓ R1~22cm, R2~35cm
  - ✓ Stacked modules
  - ✓ 100m x 2mm pixels
- Outer Tracker
  - ✓ Barrel and endcap
  - ✓ Strip 2.5cm, 5cm, ~10m pitch

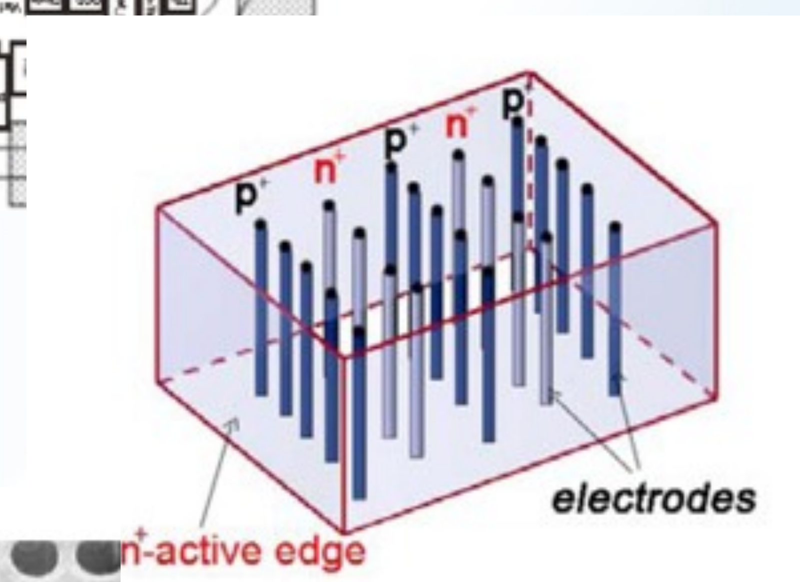


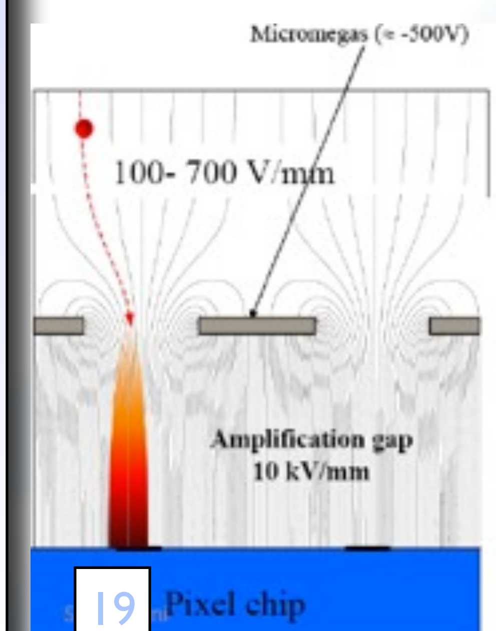
Inner Tracker Systems: R&D on Sensors

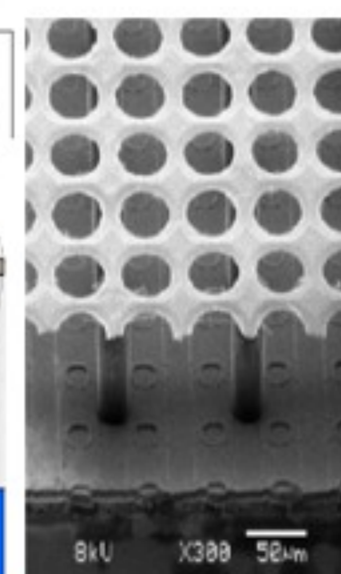
- Both experiments are making significant investment in R&D on sensors.
  - ✓ Complete investigation of geometrical and technological phase-space
- Radiation hard Silicon planar sensors:
  - ✓ n-on-p/p-on-n
  - ✓ FZ/MCZ/EPI and different resistivity material
  - ✓ thinner wafers (75-200µm)
- 3D pixels
- (p)CV diamonds
- Micro-Pattern Gas Detector: GOSSIP

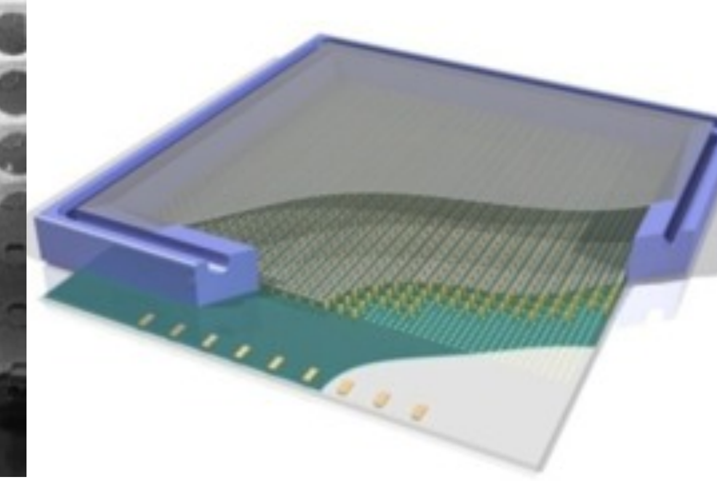


Example: CMS R&D on planar sensor with HPK







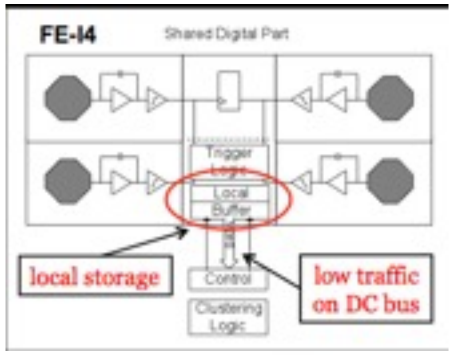


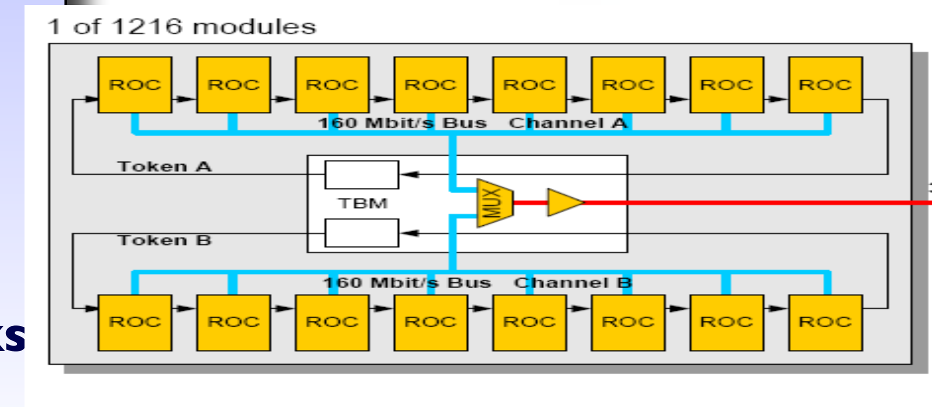
ATLAS & CMS

Inner Tracker Systems: Electronics and Services

Radiation Hard Front-End Readout and Data transfer:

- Deep Sub Micron processes (.13μm) are promising but very challenging. Basic requirements:
  - ✓ Rad hard, SEU tolerant, low analog noise
  - ✓ Low power (essential given increased granularity of the trackers)
  - ✓ **Foundry, masks and engineering costs of ultra-scaled technology becoming prohibitive for low-volume application**
- High data rates require also **high speed optical and electrical links**
  - ✓ Common development for both experiments

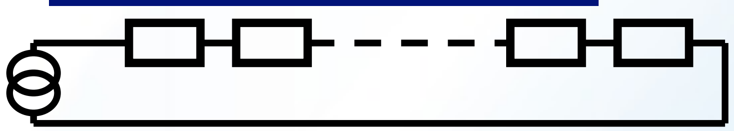




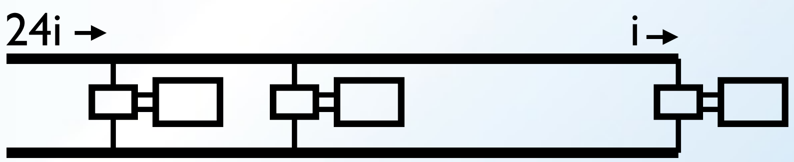
Powering:

- Future generation of trackers will require ~50kW. Systems currently implemented hugely inefficient and with large ohmic losses in the cables
- Two main schemes being developed: basic DC-DC schemes (simple high frequency buck converters) and serial powering with protection circuitry.
- High efficiency, low noise, safety (over-voltage/current/temperature).
- Monitor and Control integrated.

Serial Powering



DC-DC Powering



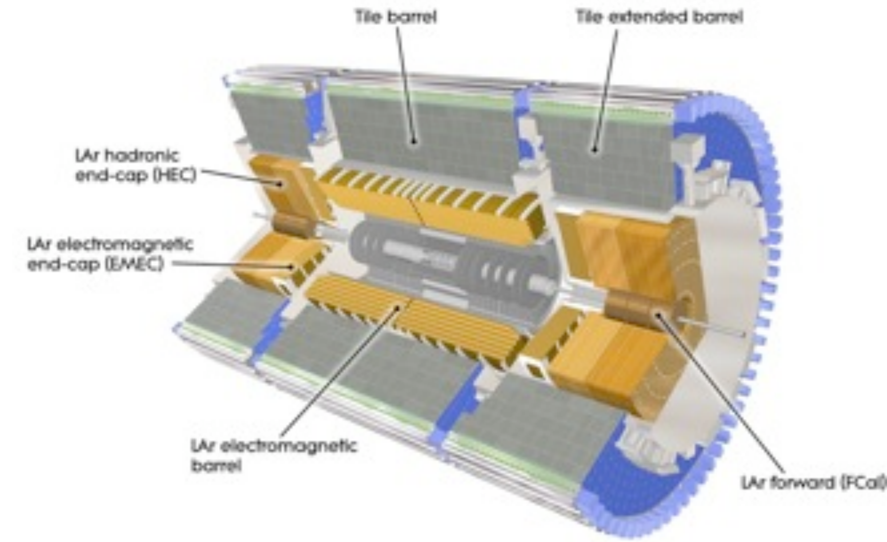
Cooling:

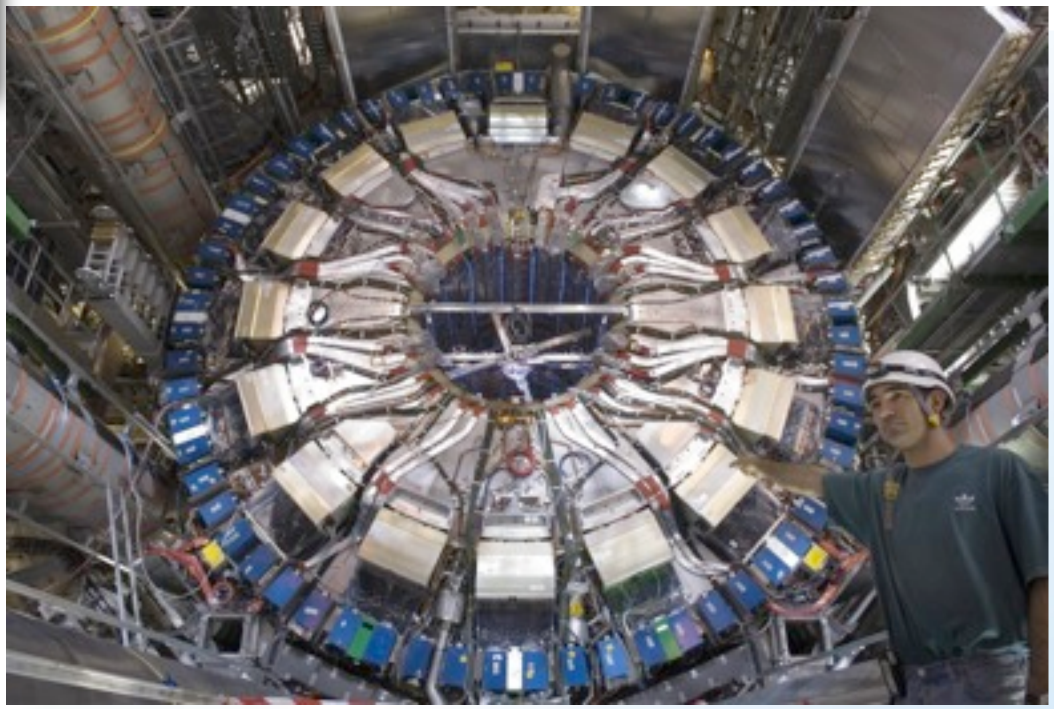
- Both experiments developing R&D on bi-phase CO_2 large capability cooling systems.

Calorimeters

ATLAS

- In ATLAS EM and HAD calorimeter detectors should still perform at sLHC.
- Pileup worsens the resolution, partially compensated by optimizing sampling and shaping in the front-end electronics.
- Readout Electronics will be replaced.



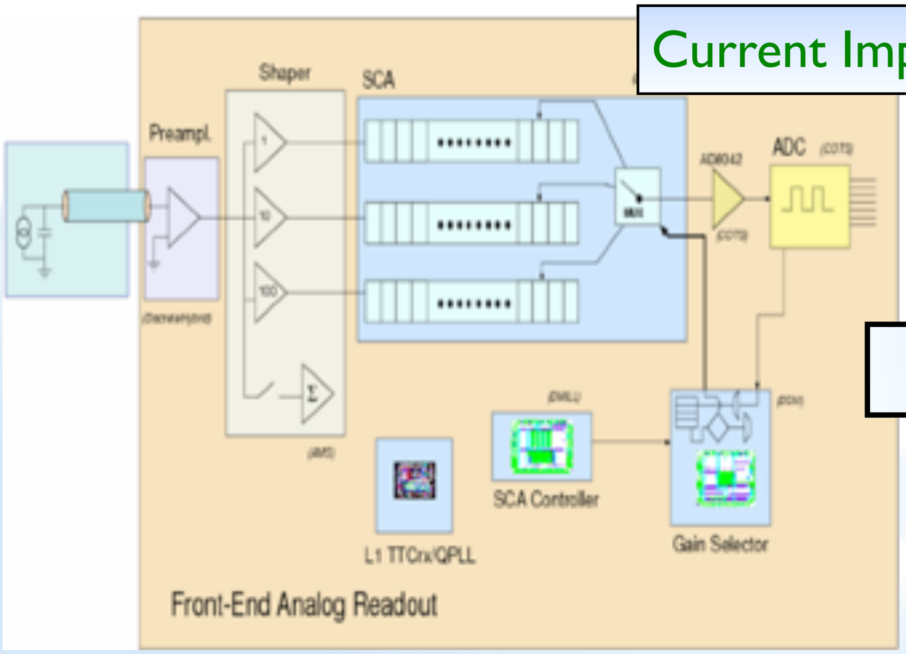


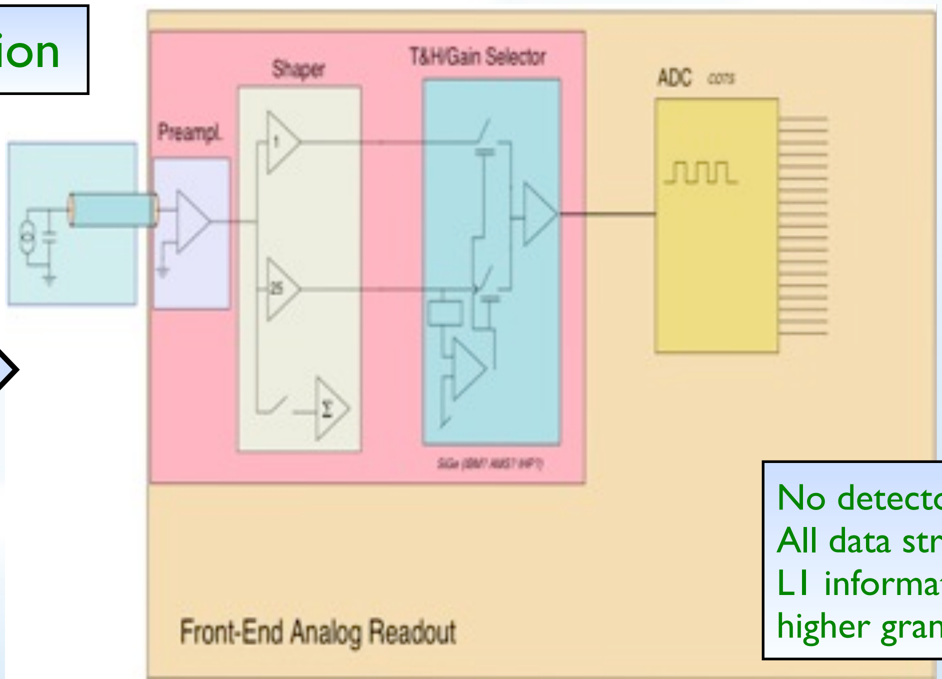
Example of Liquid Argon Calorimeters:

MOTIVATION: The current Front-End is designed for 10yrs of operations @ 10^{34}

- Current system will not survive radiation doses for long in Phase-I. Starts failing at 700-1000fb^{-1}
- It is based on 13 ASICs w. different technologies, some are already obsolete and not available.
- Partial upgrade is not conceivable.
- Upgrade of the Front-End will result in the upgrade also of the RODs and of the L1-Calo interface
- **Hadronic Tile Calorimeter also with a similar upgrade strategy of the Front-End**

Current Implementation





Proposed Baseline Architecture for sLHC

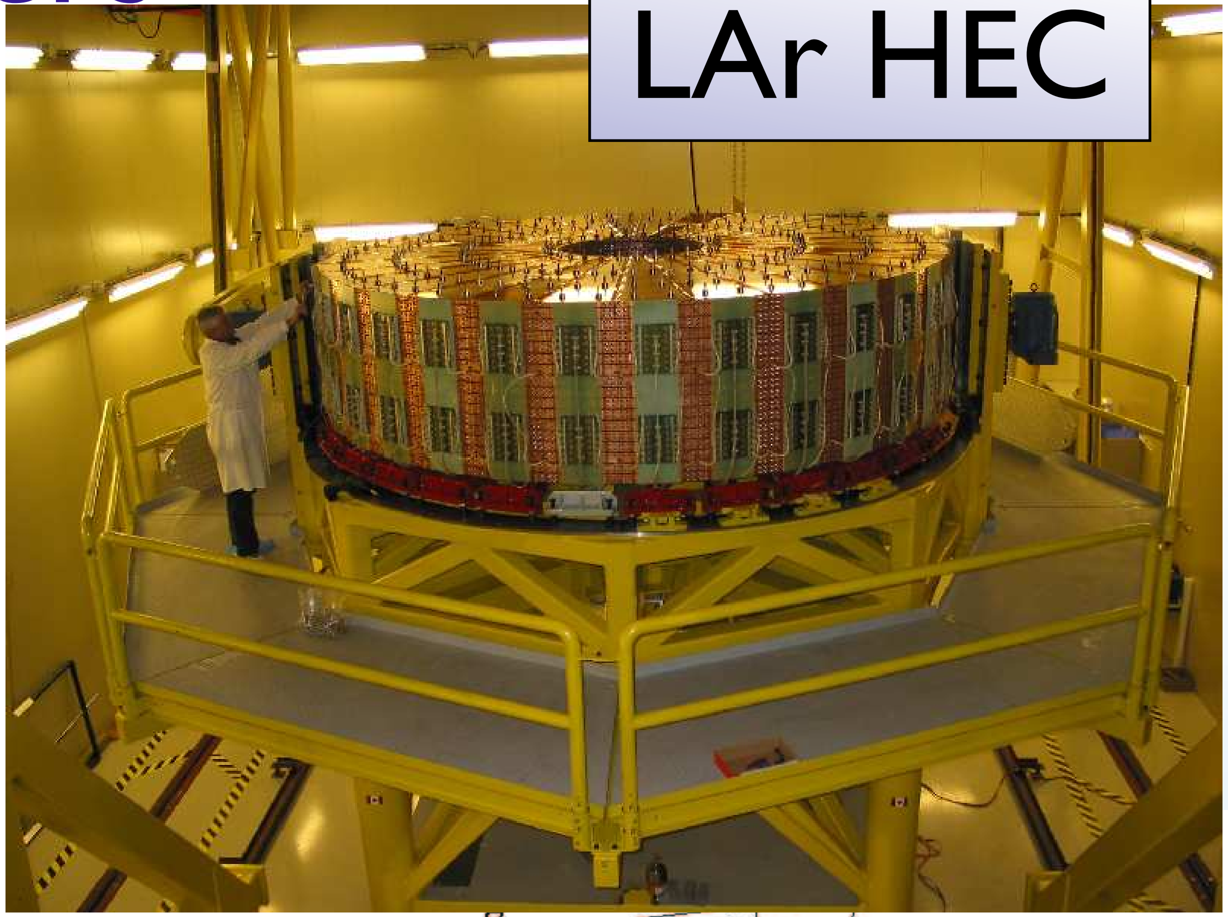
No detector pipeline, nor Level-1-trigger logic.
All data streamed off-detector.
L1 information prepared in the ROD modules with higher granularity (both transversally and long.)

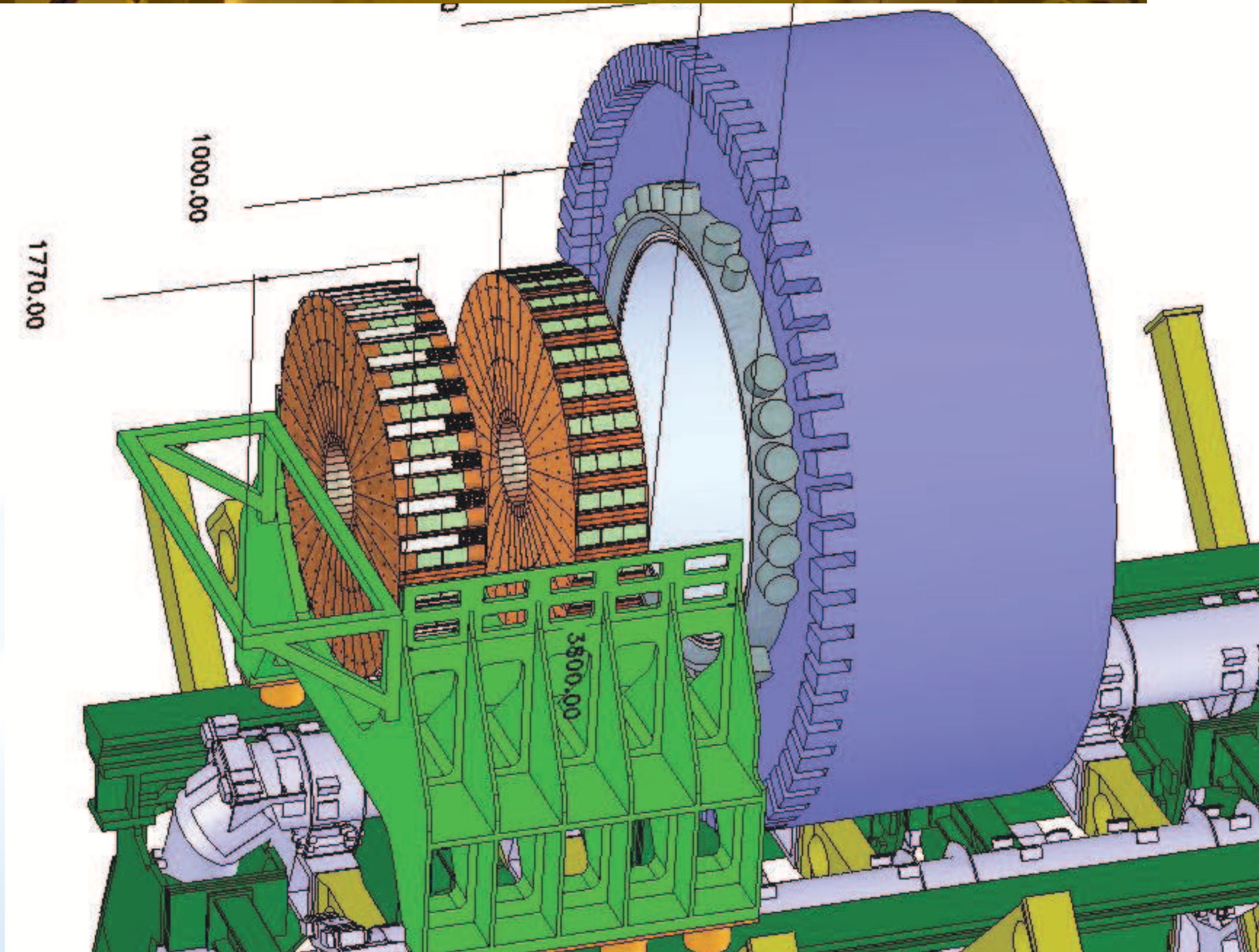
ATLAS

Calorimeters

- LAr Hadronic Endcap (HEC) uses cryogenic GaAs preamplifiers mounted on the outer diameter of the two HEC wheels
  - ✓ Radiation resistance beyond Phase-I is being assessed. LHC data will help understand safety factors used for rad. qualification
  - ✓ R&D on possible replacements is on-going
- If upgrades needed, each endcap cryostat will need to be open, the HEC wheel moved and the preamplifier replaced.
  - ✓ Long operation. Need 18 months shutdown.
- The need of upgrading the HEC cold electronics will also determine the detector option for the Forward Calorimeters.

LAr HEC



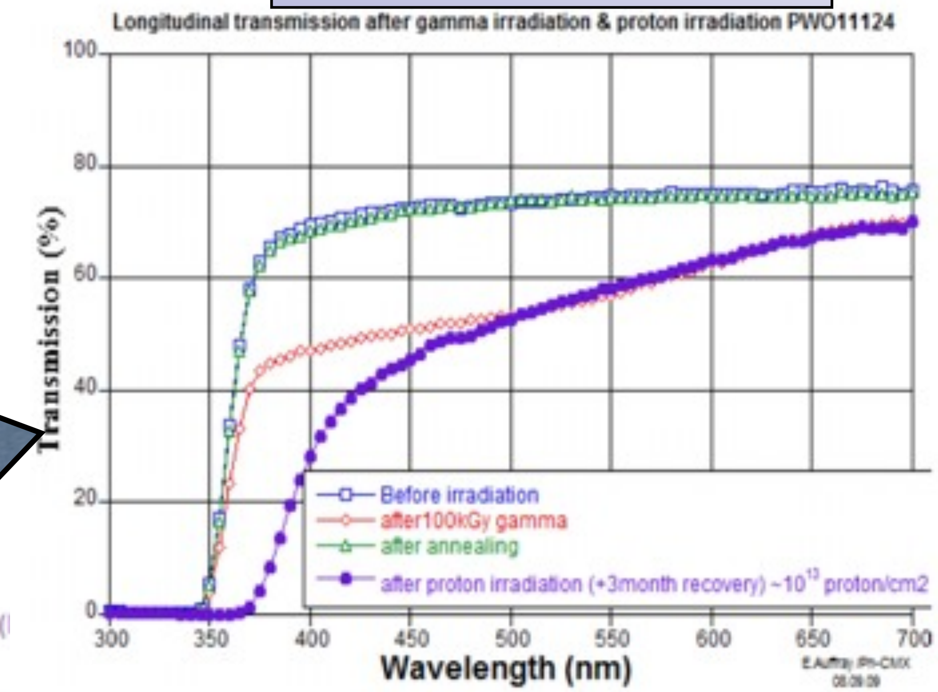


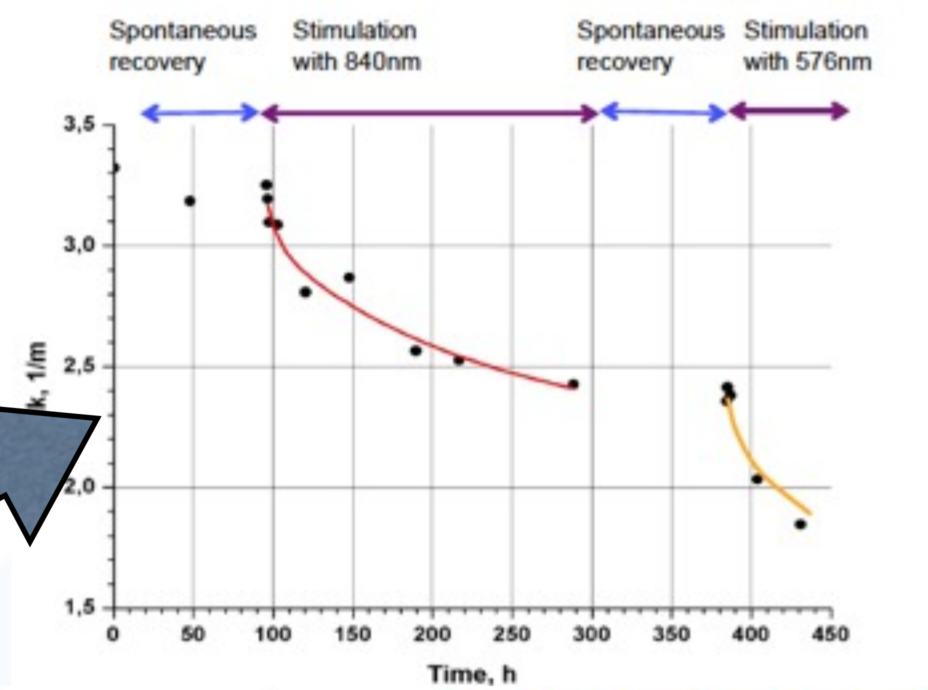
CMS

Calorimeters

ECAL

- **CAL crystals in $PbWO_4$** with Avalanche Photodiodes (APD) and Vacuum PhotoTriodes (VPT) in the barrel (EB) and endcap (EE) calorimeters respectively.
- **EE crystal rad. induced aging to be understood**.
  - ✓ Crystals and photo-detectors damage by gammas and neutrons well known: effects are either negligible or will be corrected by light monitoring system.
  - ✓ Hadron induced damage is cumulative/permanent and degrades the EE performance significantly. Crystal transparency and uniformity potentially compromised at sLHC.
    - Stochastic and global constant term of the energy resolution degraded
  - ✓ **Irradiation tests and simulations predict 50% degradation due to crystal damages and 60% due to radiation damages of the VPT**.
    - On-going testbeams of irradiated crystal matrices to verify prediction and quantify
- On-going R&D for Phase-II:
  - ✓ New crystals: PWMO, LYSO
  - ✓ Stimulated recovery: acceleration of radiation damage recovery by energy flux injection in the crystal: heating, ultra-sonic (multi-phonon absorption), specific wavelength photon.
- **R&D on photosensors (GaInP and GaAs)**
- Higher occupancy @ sLHC also results in increased ECAL data volumes and bandwidth. Improved integration of the ECAL trigger and readout paths could be implemented.





	Unit	GaInP Photomultiplier Chip™	GaAs Photo multiplier Chip™	SiPMT MPPC®
Absorber		GaInP	GaAs	Si
Wavelength range	nm	280-650	280-900	300-900
Detection Efficiency	%	25-50	25-50	10-50
Dark Counts @25°C	Mcps/cm²	0.1	50	50
Bias Voltage	volts	<100	<100	<100
Tolerate B fields		YES	YES	YES
Radiation Hard		VERY	YES	No
Cost		LOW	LOW	Moderate

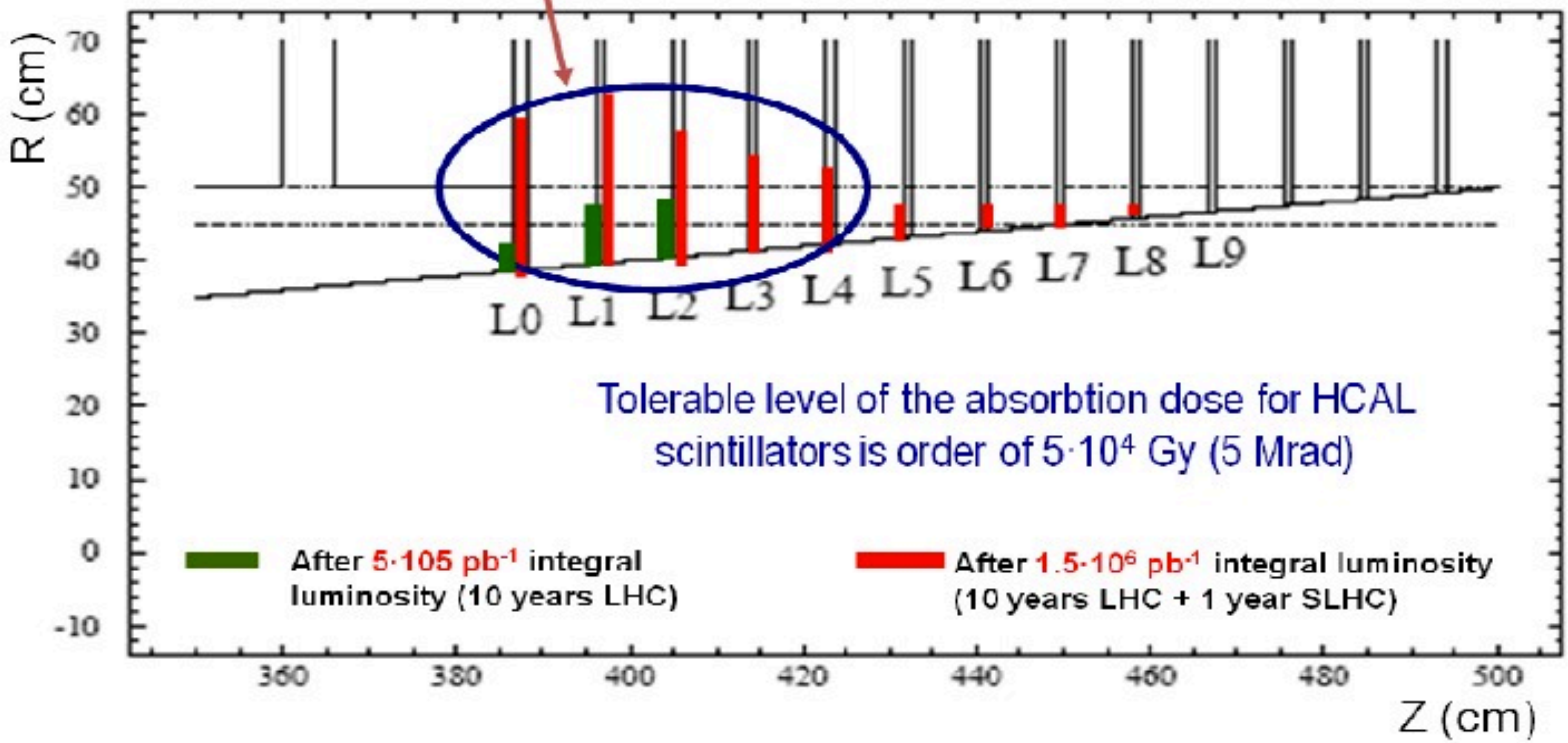
CMS

Calorimeters

HCAL

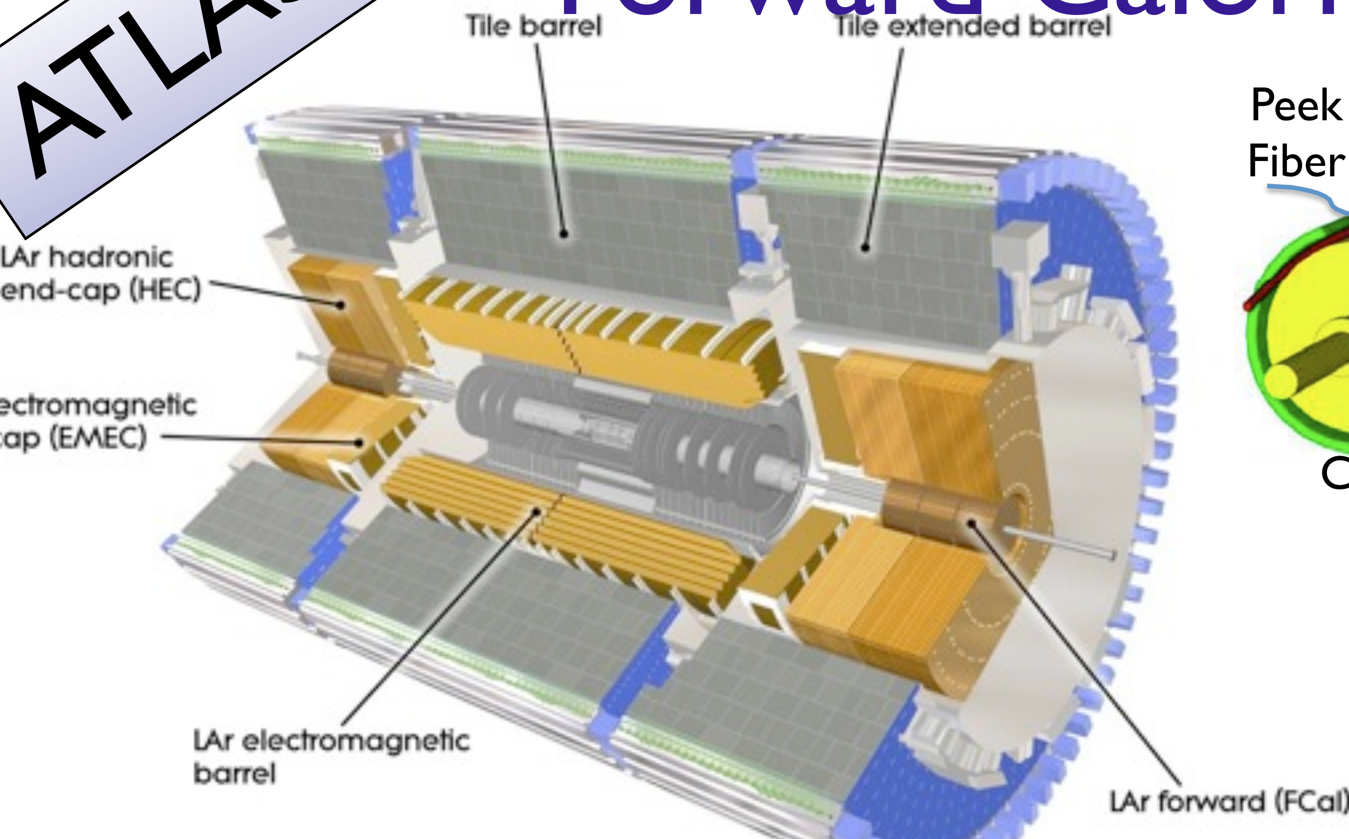
- Main concerns are radiation induced damages in the HE 5 layer megatiles
- Development of a robust, well integrated and functional detector

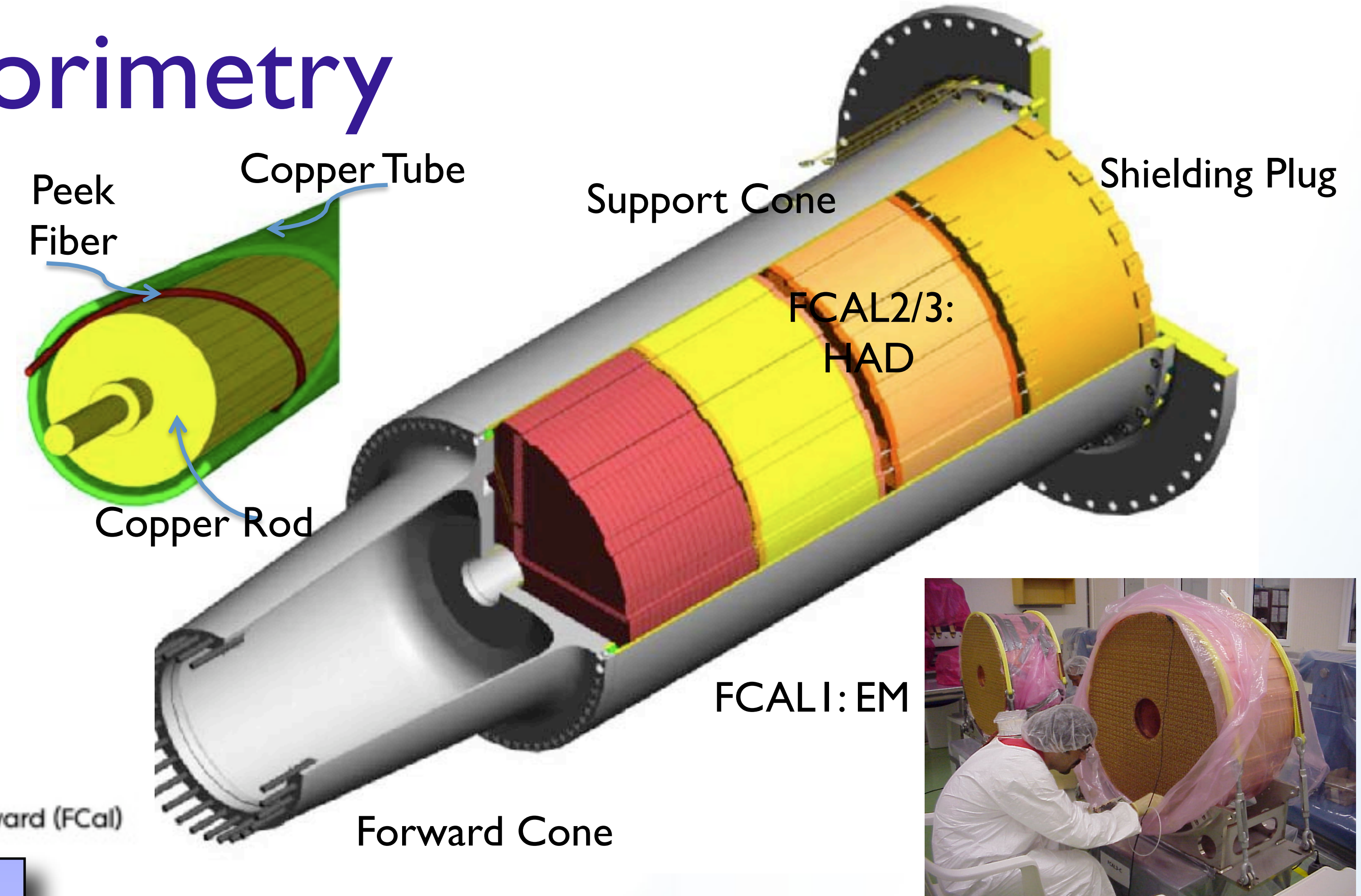
5 layers of HCAL megatiles will be affected severely



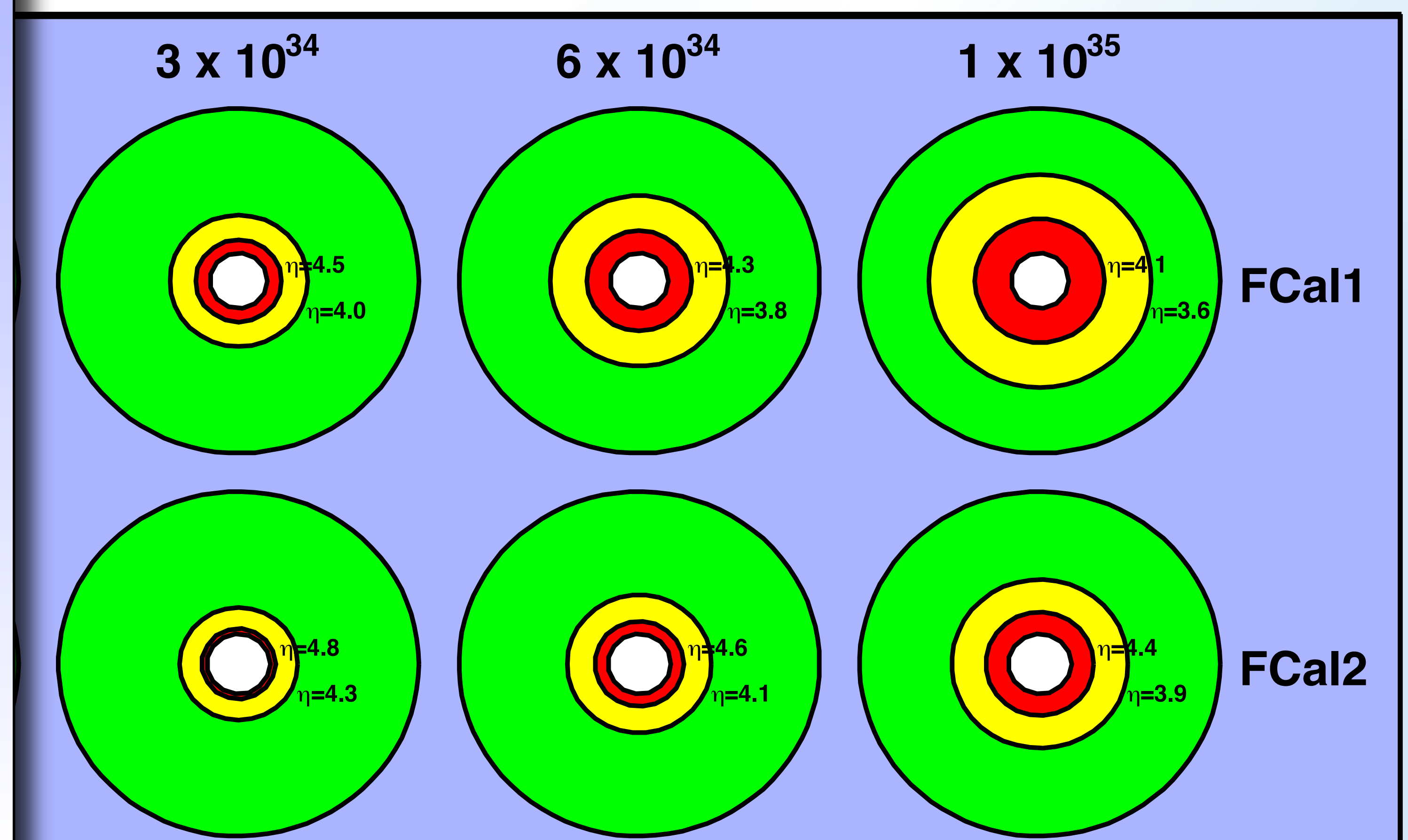
ATLAS

Forward Calorimetry





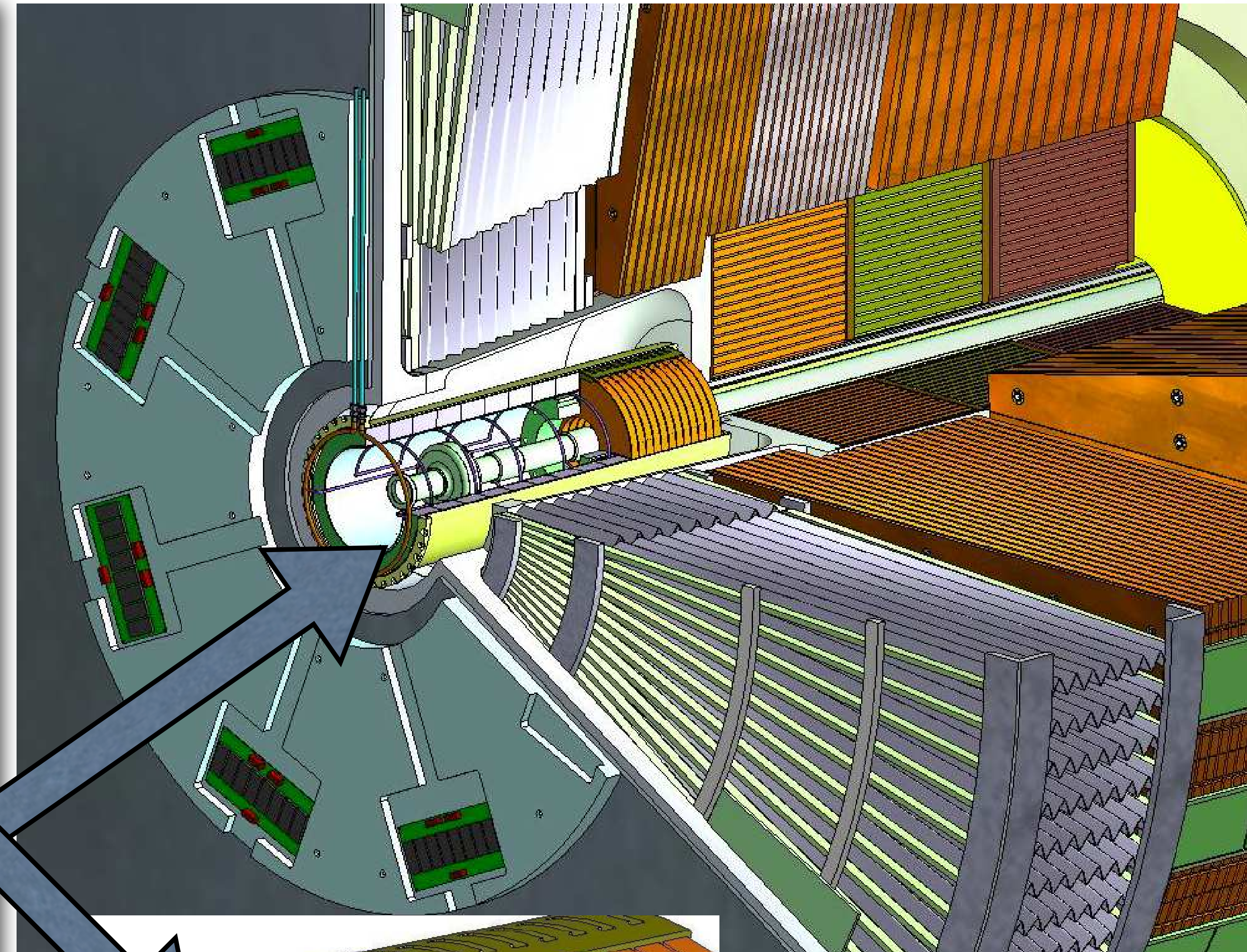
- Loss of functionality and η-coverage above 10^{34}cm^{-2}s^{-1} because of background rates and average energy deposited per bunch crossing due to minimum bias events.
  - ✓ Excessive HV drop in the LAr gaps, because of the HV distribution network
  - ✓ Space charge effects due to Ar+ ion build-up which makes charge collection inefficient
  - ✓ Potential boiling of LAr
- Studies underway and two options being explored:

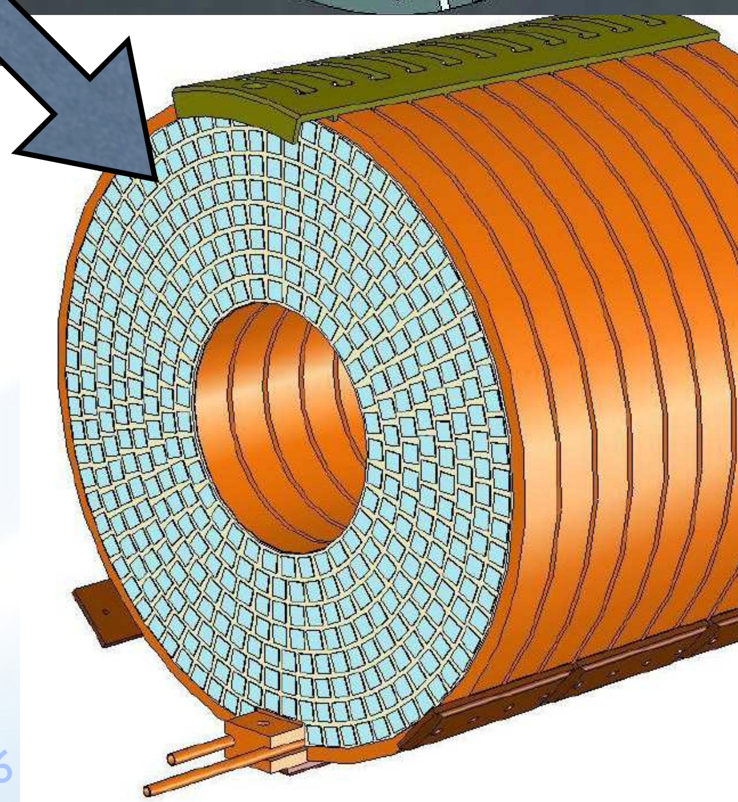


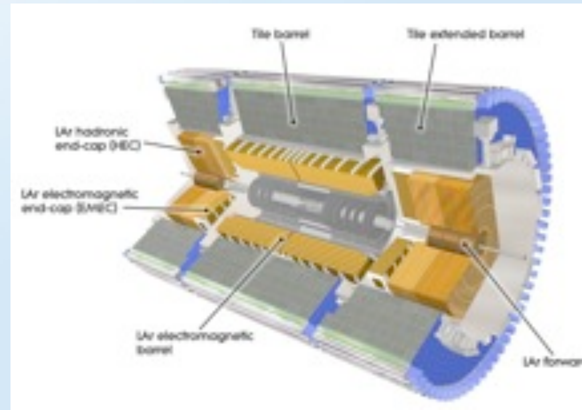
Forward Calorimetry

ATLAS

- **Replace Forward Calorimeters (FCAL calorimeters** with similar technology but newly optimized geometry (i.e. smaller LAr gaps and extra cooling loops).
  - ✓ It requires open cryostat, insert complete new FCAL and dispose of the old one as radiation waste. A complex and lengthy installation.
- **Warm mini-FCAL inserted in front** of the current FCAL.
  - ✓ Simpler installation but
  - ✓ Challenging technology - R&D on pCVD diamond sensors w. Cu absorbers
  - ✓ Effects of the mini-FCAL on the adjacent detectors need to be understood.







CMS

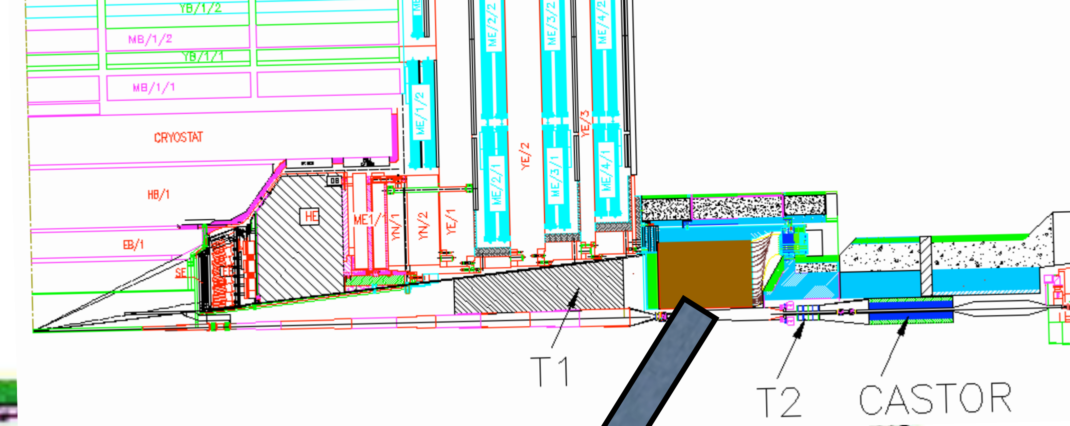
Forward Calorimetry

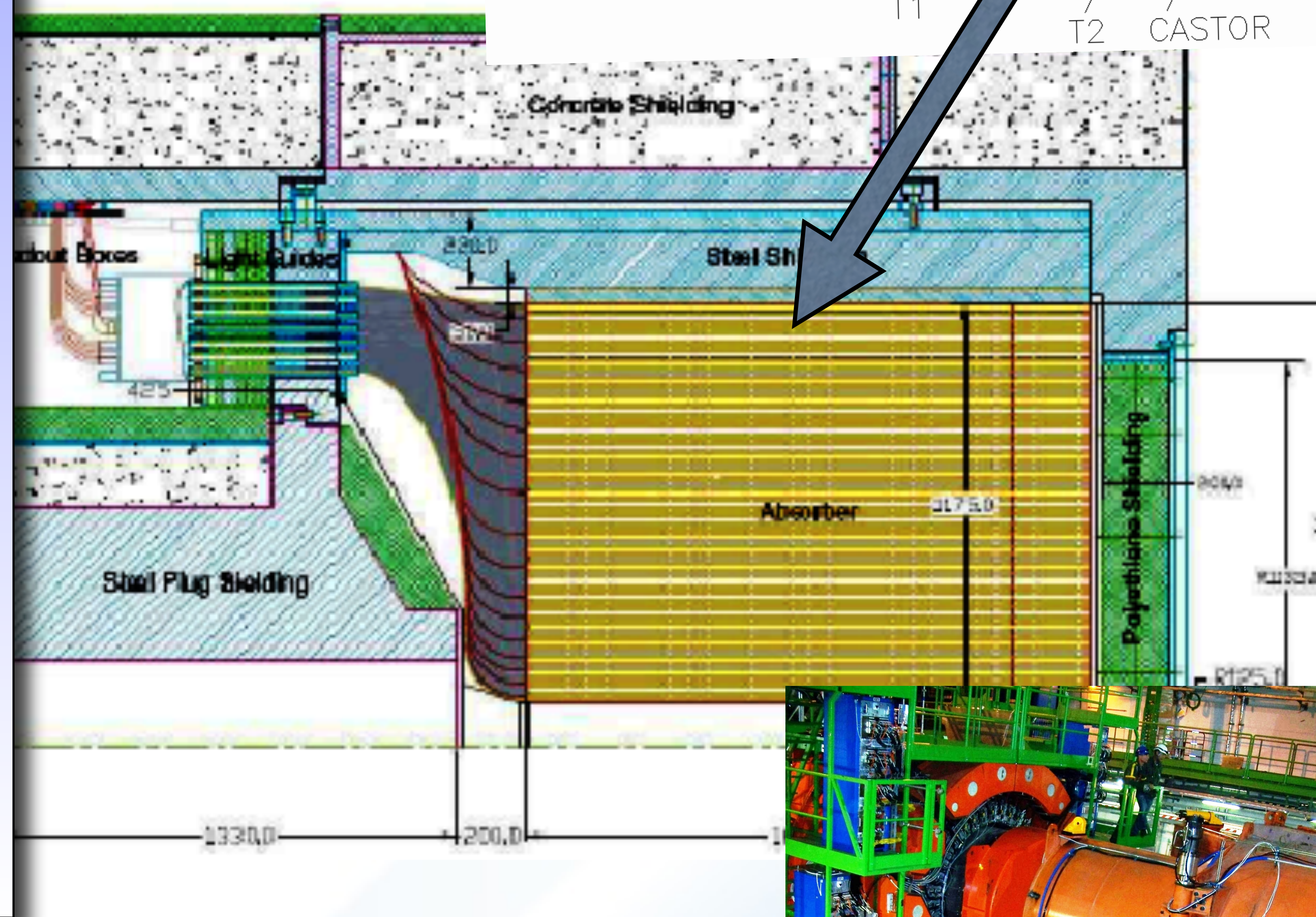
Replacement of polymer clad silica core optical fibers may (QP) be necessary (if feasible).

✓ Fibers radiation limit is 1Grad

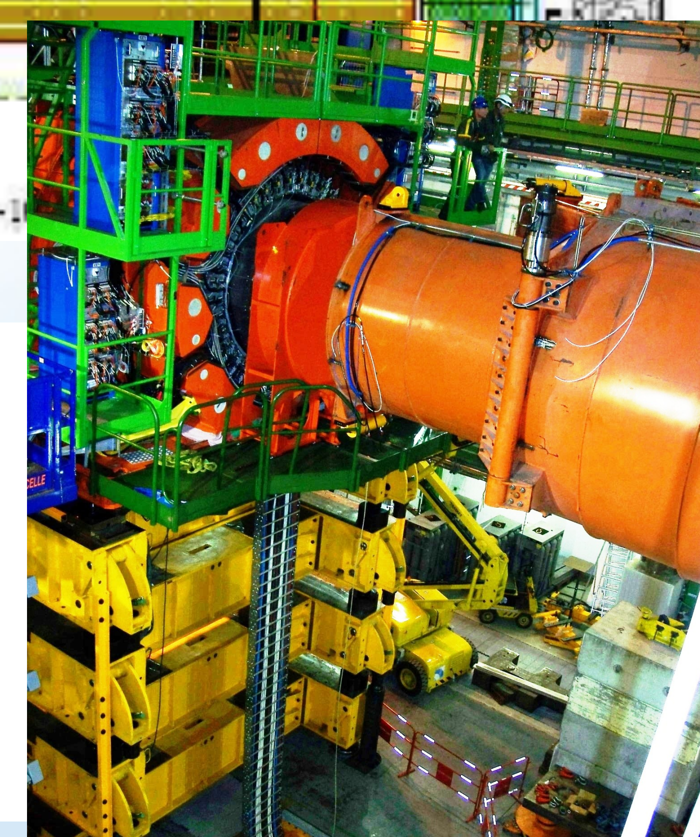
✓ Safety procedures for manipulation of HF activated parts are challenging.

- If prohibitive replacement of full absorber matrix is being considered as upgrade option.
- Alternative options and R&D: liquid or gas Cerenkov radiator, parallel plate avalanche chambers, rad-hardened semi-conductors (Si,GaAs, Diamond/W), secondary emission, quartz plates with enhancement technology.





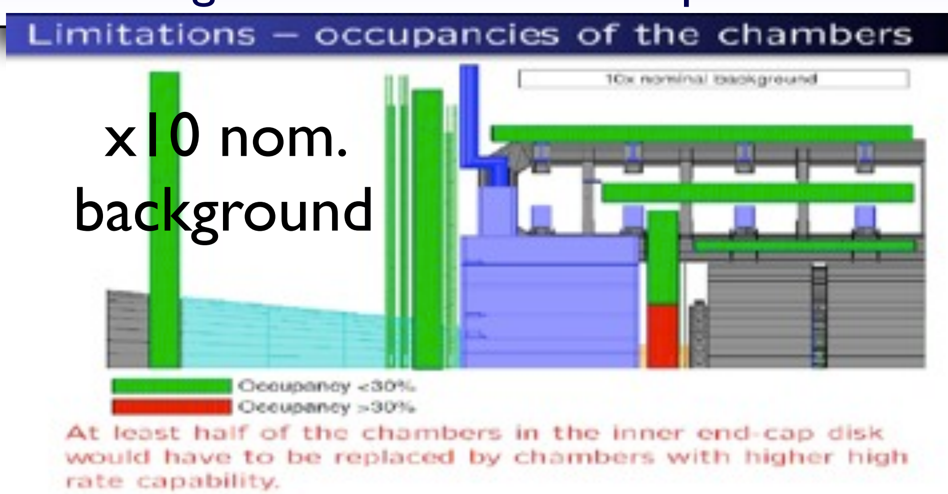
Luminosity	Ring 1-5	Ring 6-9	Ring 10-13
LHC (at 10^{34})	1 Mrad/year	10 Mrad/year	100 Mrad/year
Phase I (1.5 *10^{34})	1.5 Mrad/year	15 Mrad/year	150 Mrad/year
Phase II (3 *10^{34})	3 Mrad/year	30 Mrad/year	300 Mrad/year
SLHC (10^{35})	10 Mrad/year	100 Mrad/year	1 Grad/year

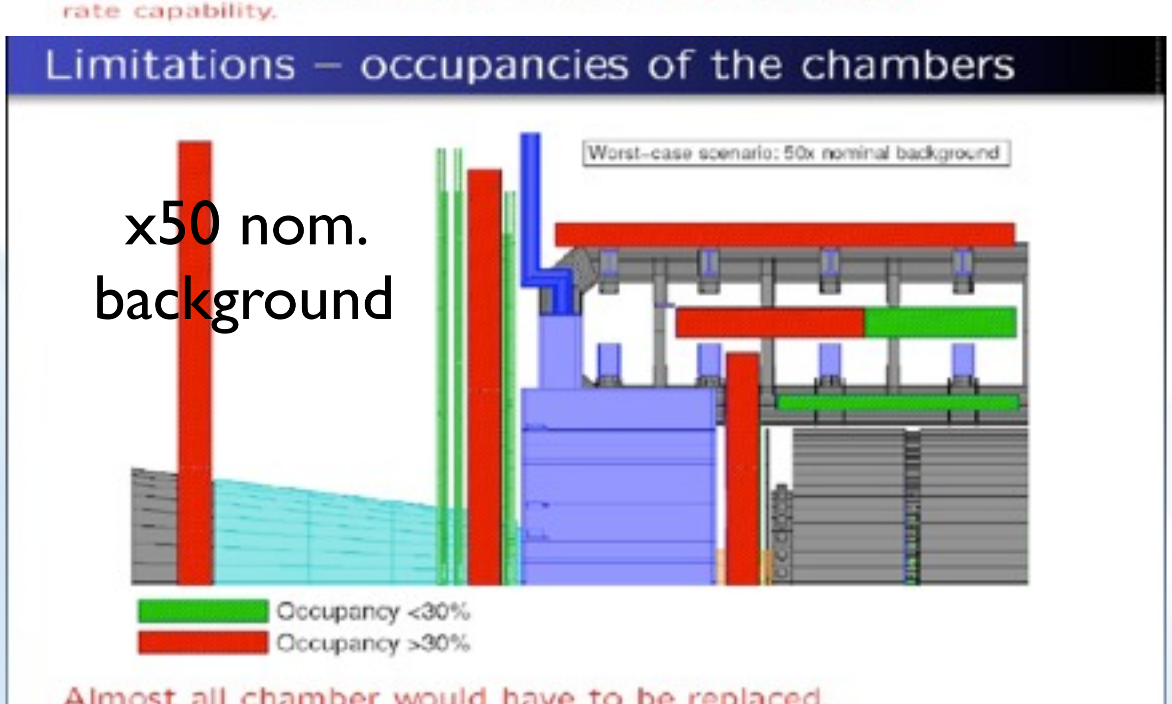


Muon System

Key topics @ sLHC:

- ✓ Performance under high backgrounds.
- ✓ Long term stability.
- ✓ Readout bandwidth
- ✓ Triggering capabilities
- Rates in the muon chambers determined by asynchronous, low energy backgrounds from photons and neutrons.
  - ✓ at LHC rates in the range 10-400Hz/cm^2
  - ✓ Large uncertainties in the prediction.





CMS shielding probably sufficient for current chambers.

- ✓ New readout electronics may be needed
- ✓ At 1.6<η<2.4 possible need of new chambers.

ATLAS air core toroids result into higher cavern backgrounds.

- ✓ x5 safety factor used in the original design.

Depending on background, ATLAS muon system might need a minimal or a very large fraction of chambers replaced.

- Need to measure actual backgrounds to understand at what extent the safety factors can cope with the increased rates at sLHC.
- Improving shielding:
  - ✓ Current design is highly optimized, so quite difficult.
  - ✓ Other possibility is to develop chambers both for precision position measurements and trigger.

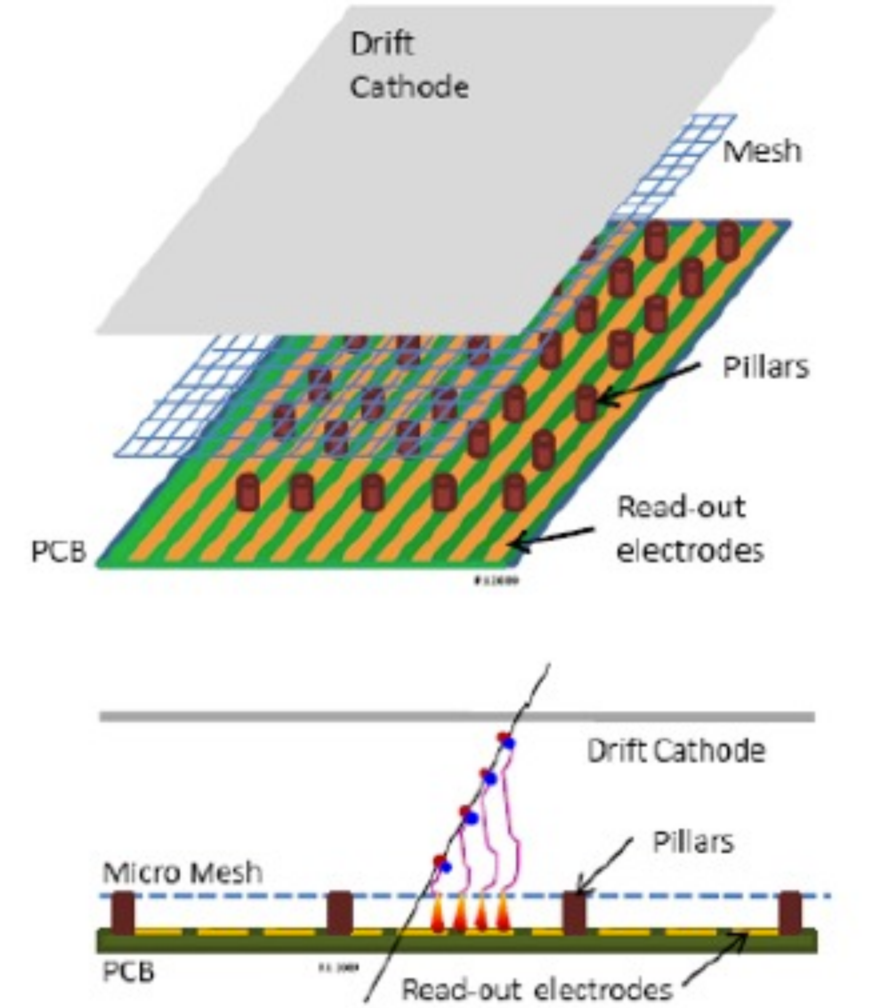
ATLAS

Muon Detectors R&D: MicroPattern Gas Detectors

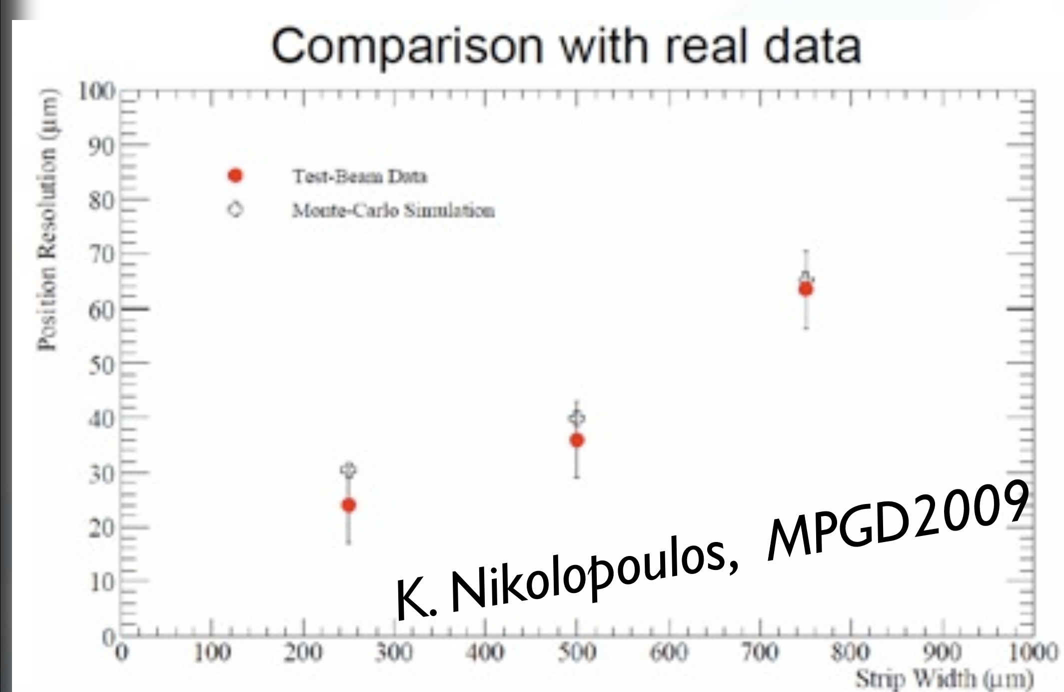
Bulk MicroMegas can be a suitable technology for both tracking and trigger in a single chamber at sLHC

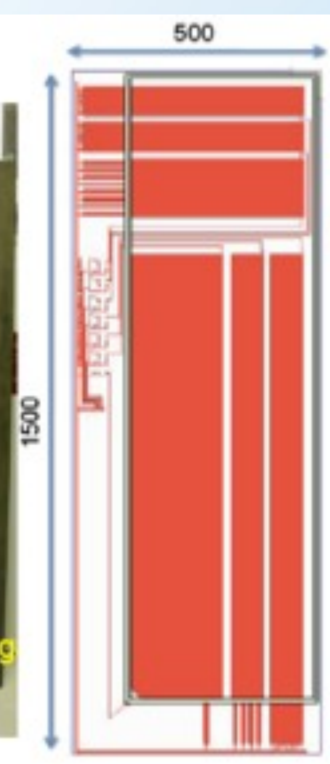
- ✓ Wire mesh and standard PCB technology
- ✓ Very high rates (kHz/mm^2)
- ✓ Good spatial and time resolution (goals: σ_x~100μm σ_t~5ns)
- ✓ Scalable to large area (industrial process)

- Possible cons (for all MPGDs): sparking and spark time recovery control.



- CERN-RD51 R&D program on MPGD
- Excellent preliminary results from testbeam in terms of resolution.
  - ✓ Electron transparency >90%
  - ✓ Gas Amplification: 10^3-10^4
  - ✓ Efficiency: 98%
  - ✓ Tested different gas mixture (e.g. Ar-CF_4-iC_4H_{10}) [88-10-2%]

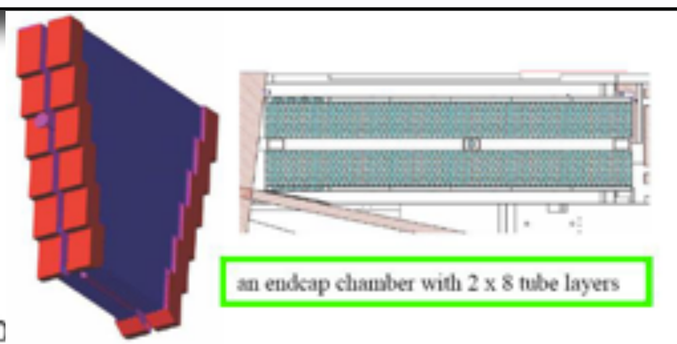


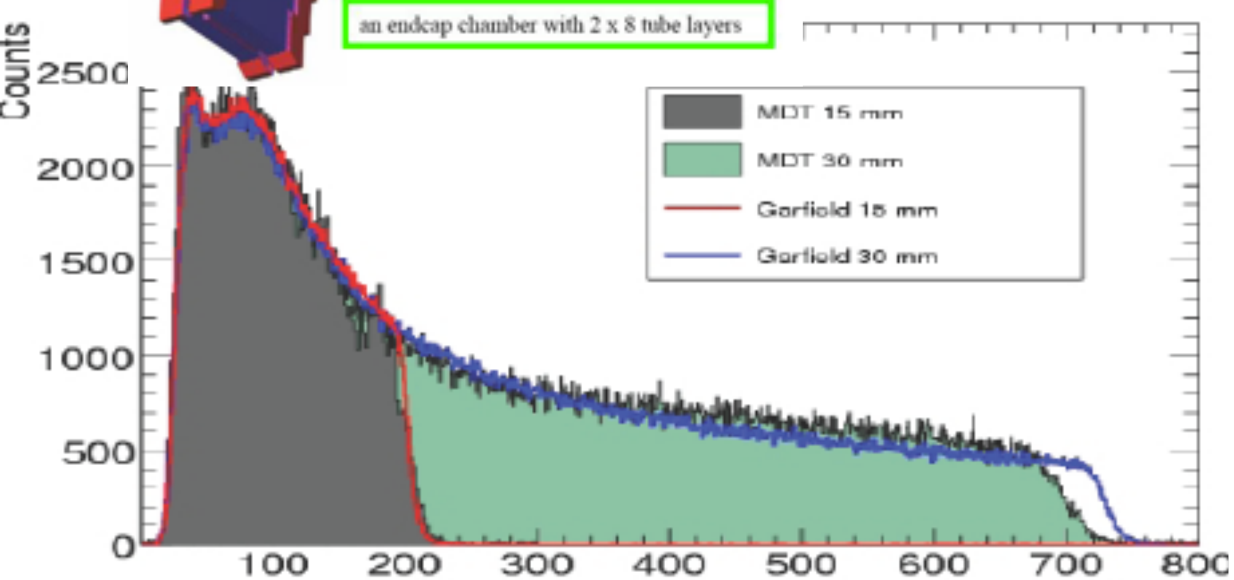


ATLAS

Muon Detectors R&D: MDT and TGC upgrades

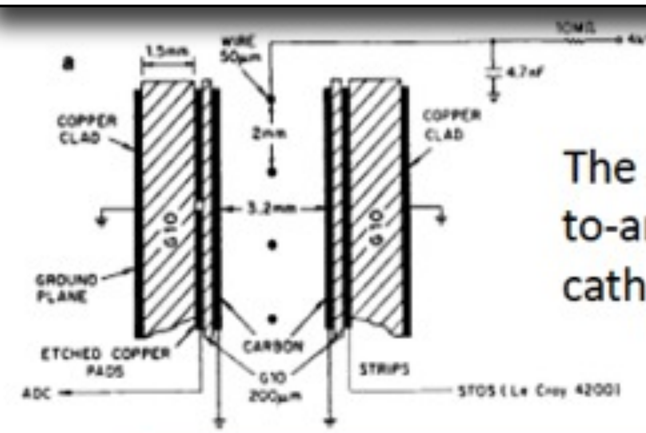
- Monitored Drift Tubes (MDT) are currently used for precision measurements in all station of the ATLAS Muon Spectrometer.
- **R&D on smaller diameter tubes (15mm instead of 30mm) as option for sLHC**
  - ✓ Would reduce occupancy, shorten pulses and charge collection, reducing space charge effects





drift time spectr. w. large and small tubes

- Thin Gap Chambers are used for 2nd coordinate and triggering detectors in the EndCap wheels.
- TGC upgrade R&D for sLHC:
  - ✓ Lower surface resistivity (10-20kΩ/square) to help with high rate capability
  - ✓ Precise coordinate (along wires) by analog read-out of fine width strips
  - ✓ Additional pad readout is being considered for: extract possible trigger information, help reducing readout bandwidth by specifying region of interest, disentable multiple hits on strips/wires
  - ✓ **Upgraded TGC chambers are a possible option as both precision-tracking and triggering detectors in the region of highest rates**



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

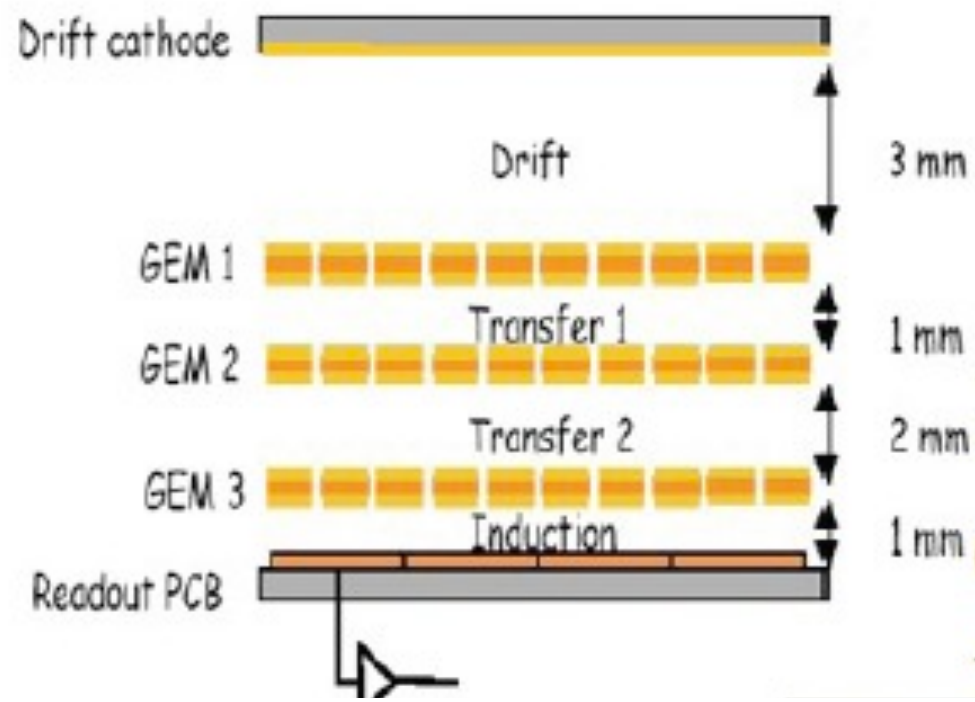
Muon Detectors: MGPD R&D

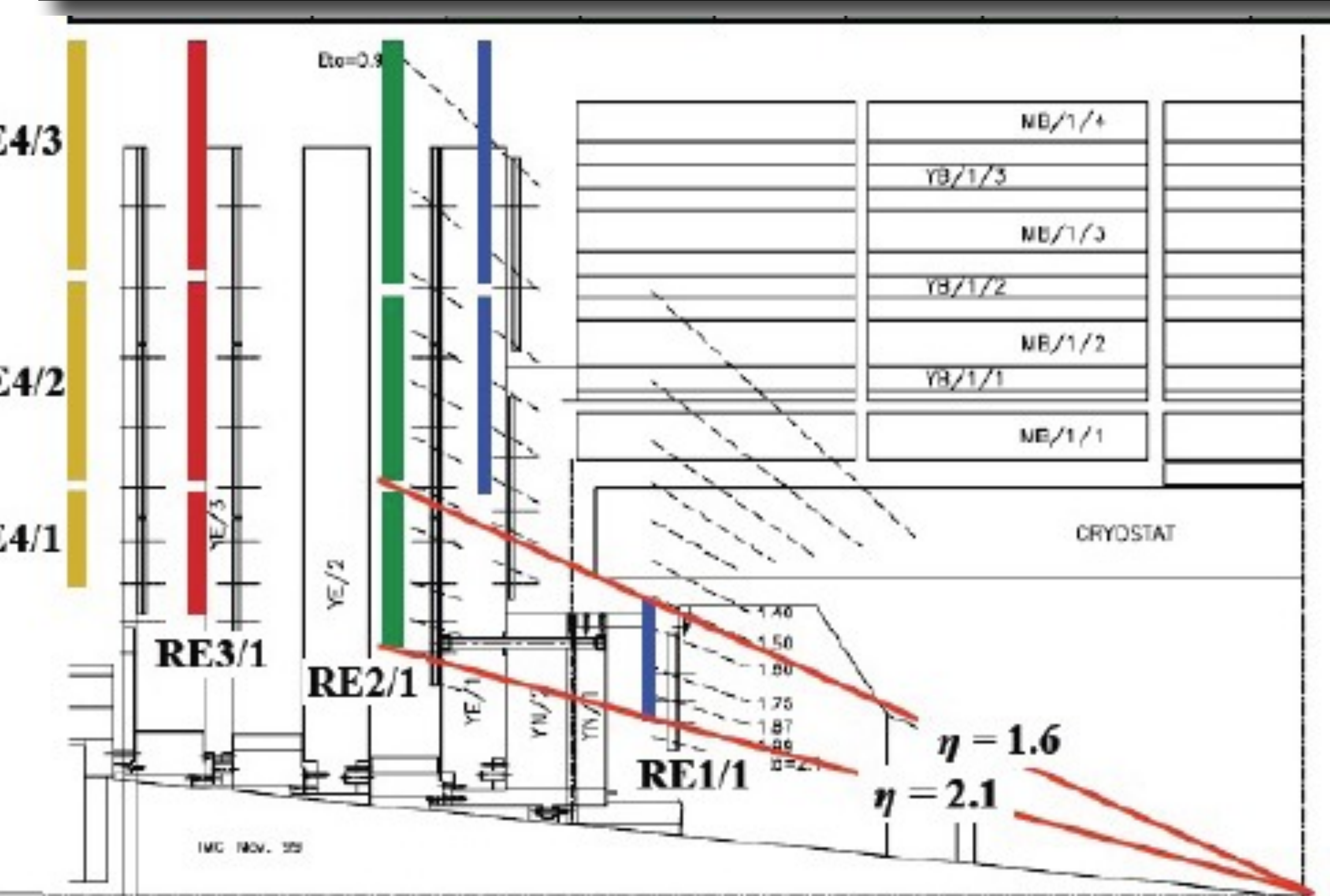
CMS

Proposal to instrument region $1.6<\eta<2.4$

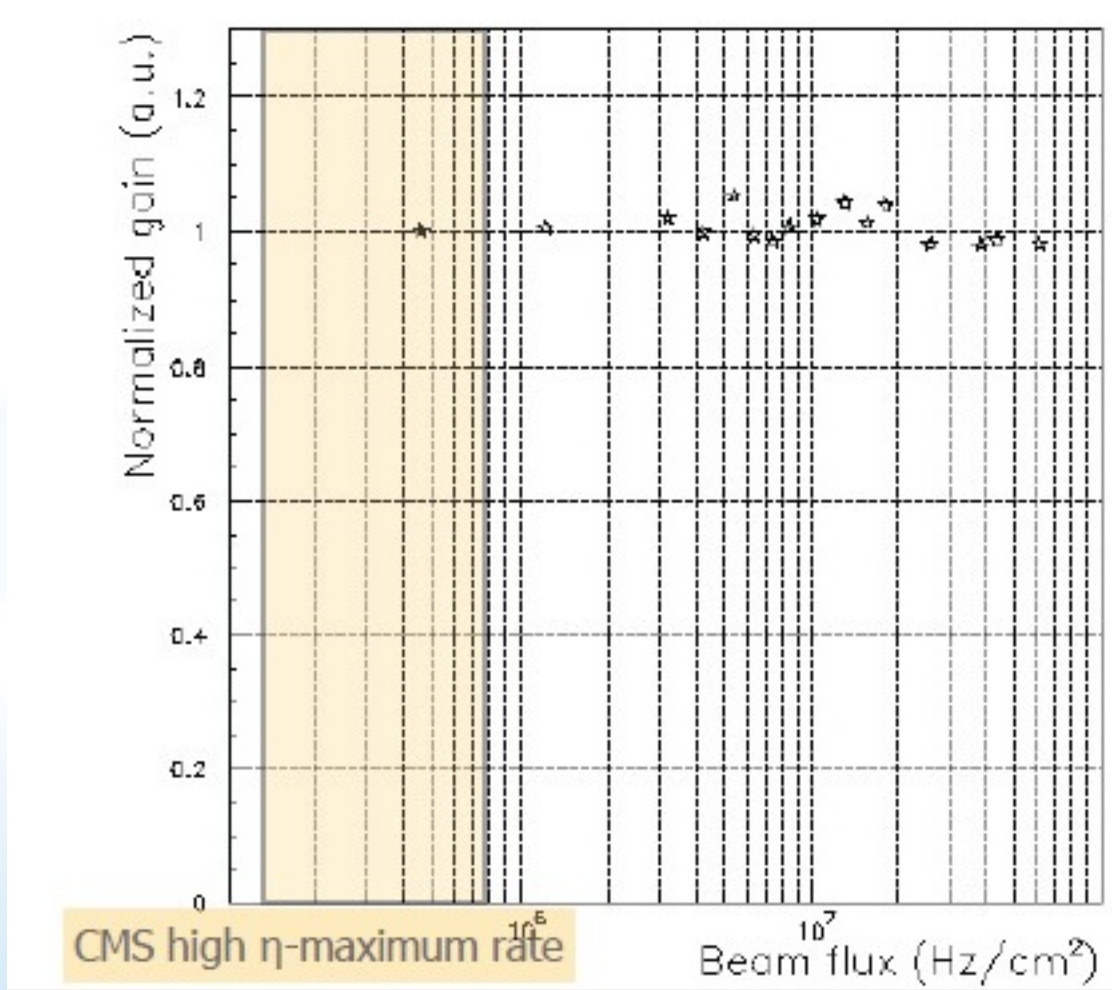
4 layers of GEM detectors

- Enhance and optimize the readout (η-ϕ) granularity by improved rate capability:
  - ✓ Rates >5kHz/cm2 and efficiency ~98%
  - ✓ Argon CO_2 mixture





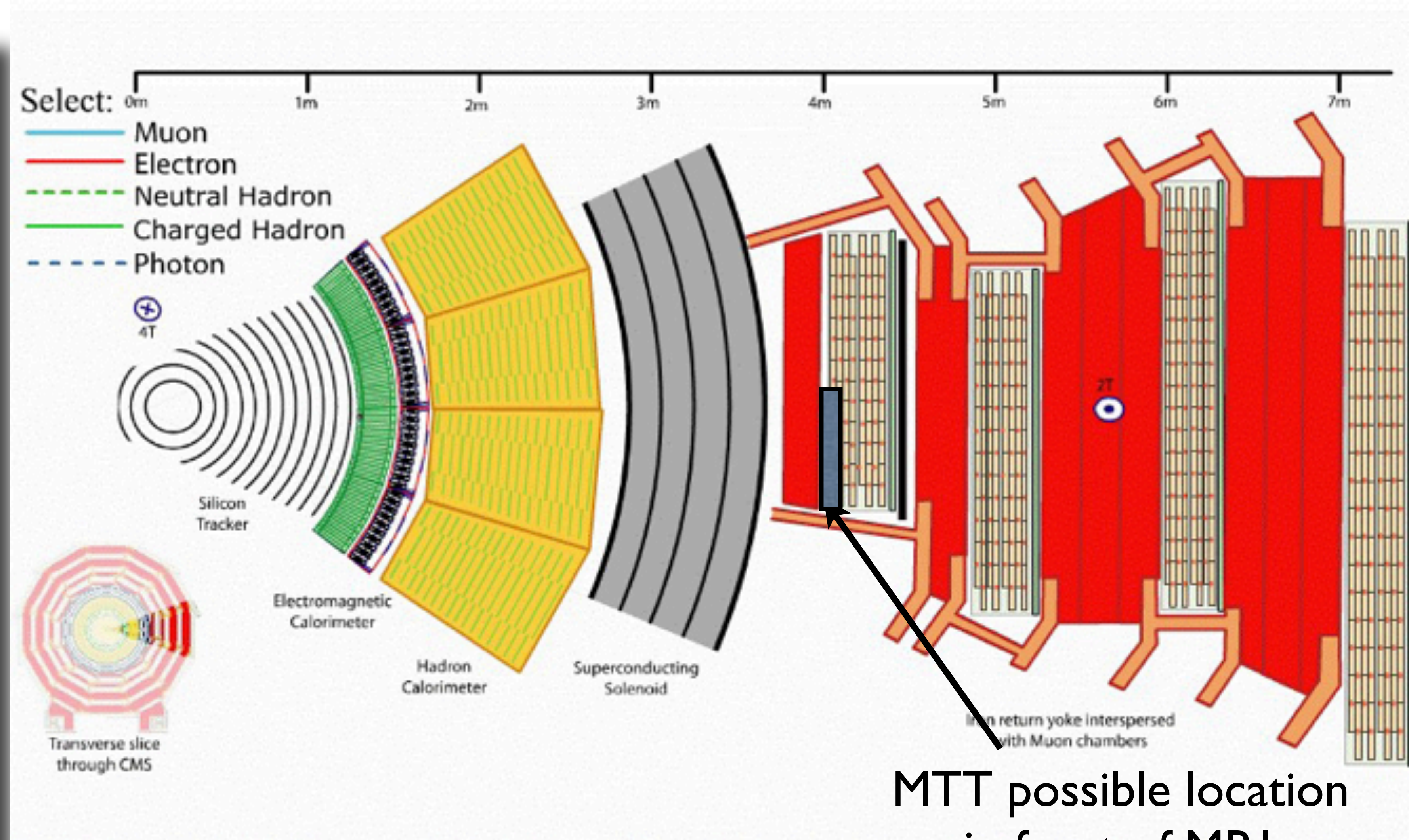
-Argon CO_2 (non flammable mixture -big plus)



CMS

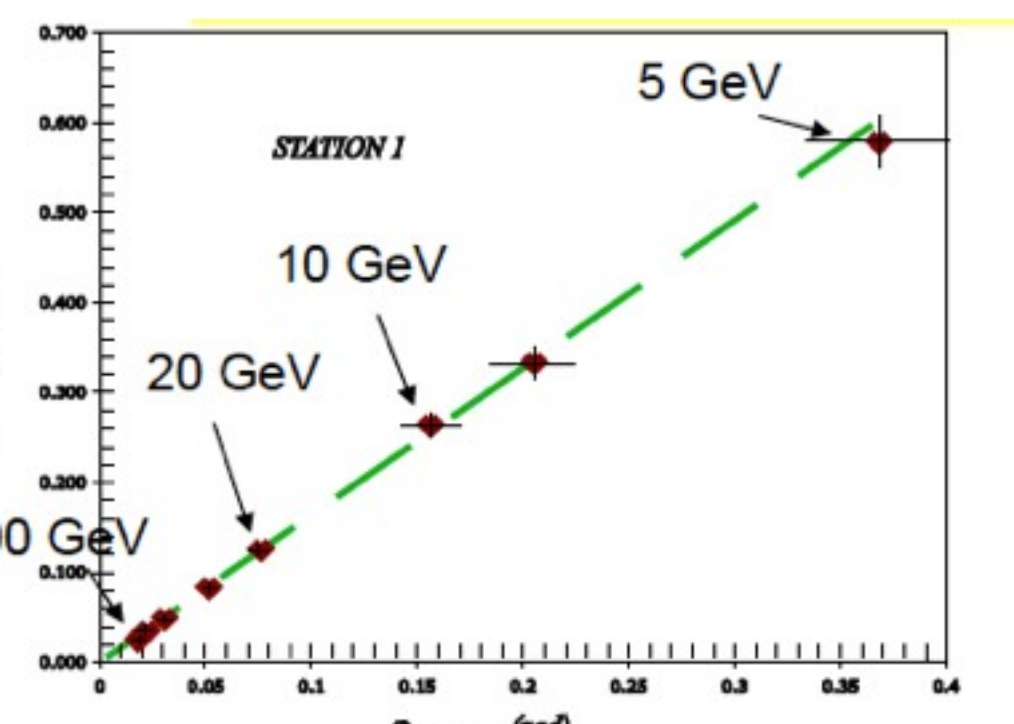
Muon Detectors: Muon Track fast Tag (MTT)

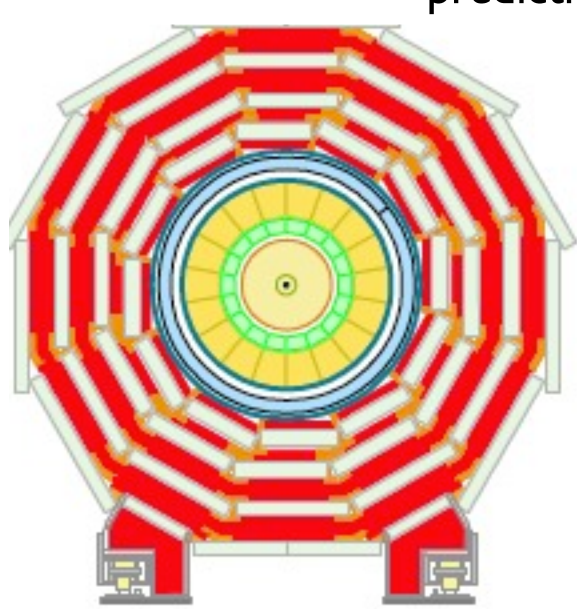
- Proposal to send fast muon tag (L0 trigger) to tracker sensors or to some trigger stage.
  - Reduced bandwidth of Tracker data sent to following trigger stages in counting room (USC)
- Various hardware implementation under study:
  - ✓ New RPC with 2D readout
  - ✓ Scintillating tiles + embedded wavelength shifting fibers + SiPM readout

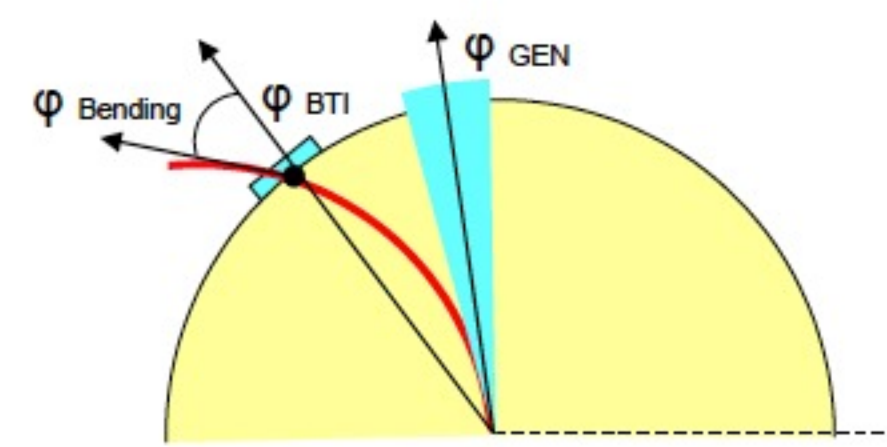


MTT possible location in front of MB1

Strong correlation between deviation and bending angle measured in MB1 allows th prediction of the muon position at any depth in CMS







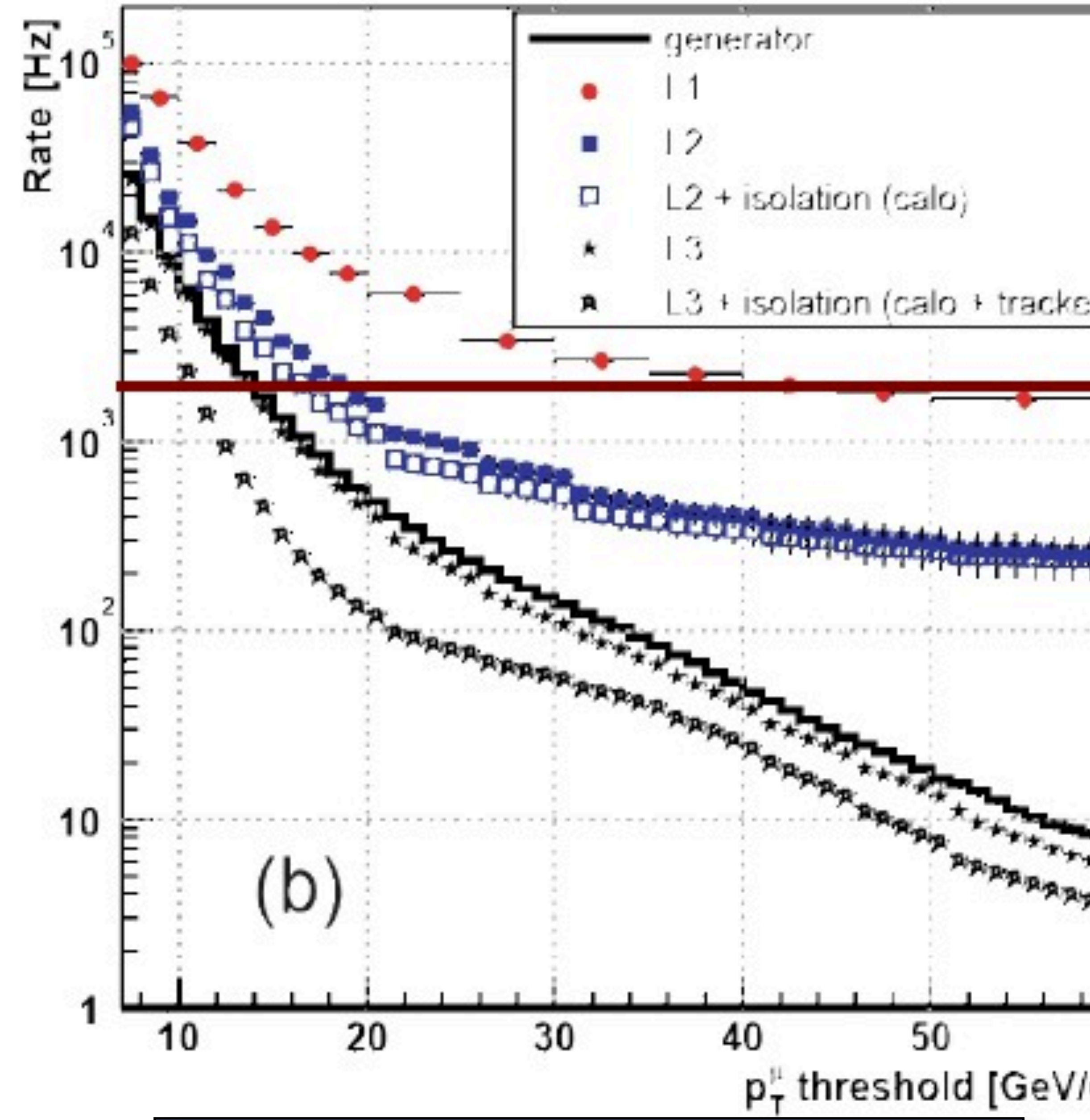
$\varphi_{Predicted} = m\ \varphi_{Bending} + q - \varphi_{BTI} + \varphi_{sector}$

ATLAS & CMS

L1 and Track Trigger

- ATLAS and CMS are considering implementing Inner Tracker Triggers at Level-1
- Muon trigger rate constant for $p_T >$ 20-30GeV/c.
  - ✓ Due to multiple scattering at CMS and the width of the RPC strips at ATLAS.
  - ✓ No margin of improvements in both experiments.
  - ✓ Having tracking information available in L1 would allow a more precise pT determination, a better selectivity and an overall L1 rate reduction
- For electrons, a rate of 50kHz is predicted by CMS at $10^{35}cm^{-2}s^{-1}$ with a threshold of E_T=30GeV.
  - ✓ High rates of fake electrons from jets
  - ✓ Validate electron candidates by looking for a matching track in the Inner Tracker (currently done by High-Level Trigger systems).

A. Ryd, *CMS L1 Track Trigger for sLHC*, VERTEX 2009



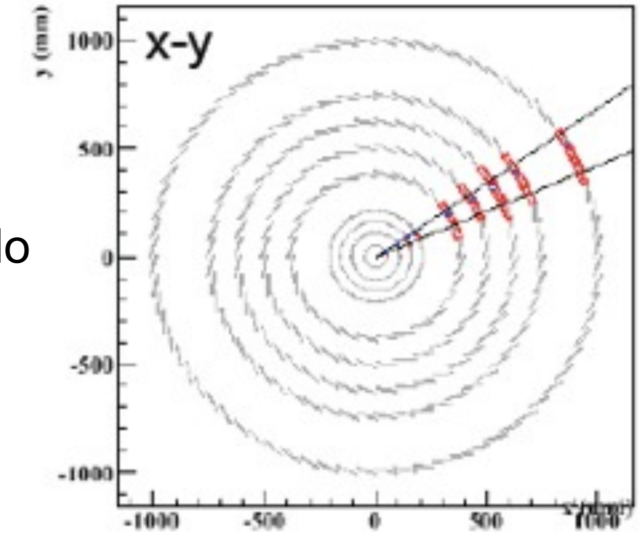
- Several ideas to investigate Inner Tracker Triggers (ASIC development challenges)
- L1 systems basically have to be redesigned

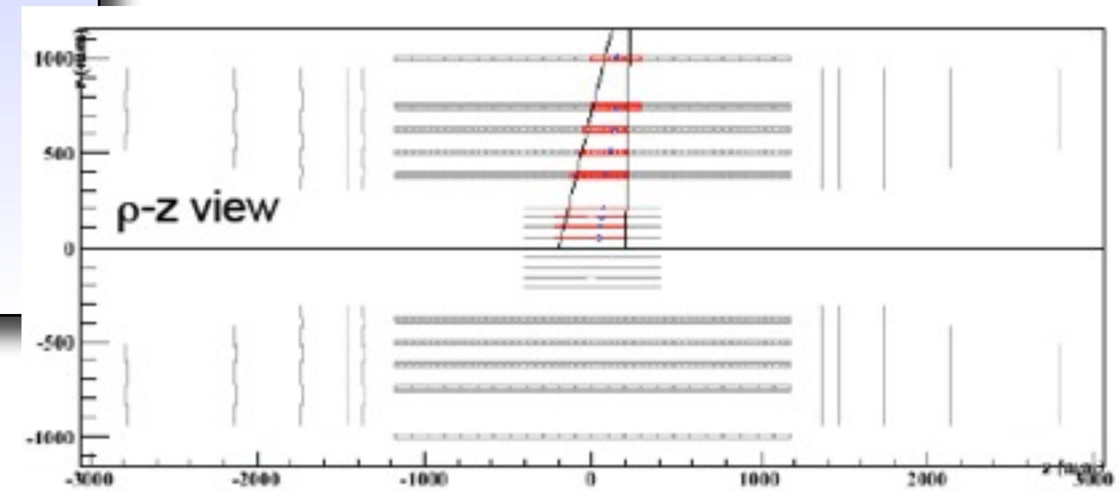
L1 and Track Trigger

ATLAS

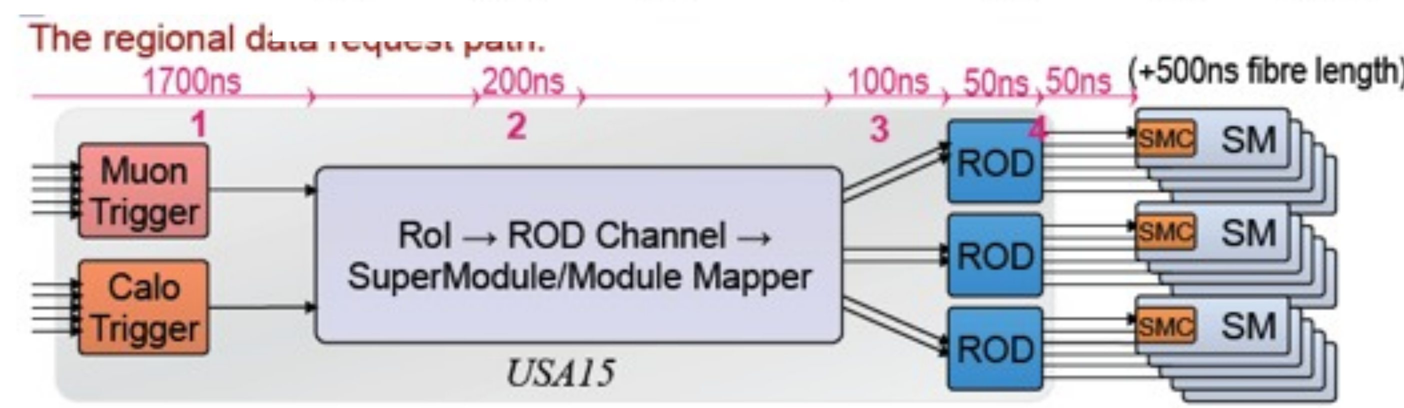
- ATLAS is planning to completely redesign the L1 system:
  - ✓ L1Muon rates >100kHz for p_T>20GeV/c
  - ✓ L1Calo rates >200kHz for E_T>30GeV
- Benefit from detector upgrades:
  - ✓ **L1Calo may have access to much higher granularity of the calorimeters**
  - ✓ **L1Muon is investigating the installation of additional chambers and new electronics for sharpening the muon pT thresholds in the efficiency curves**
    - Particularly for the barrel with the MDT information.

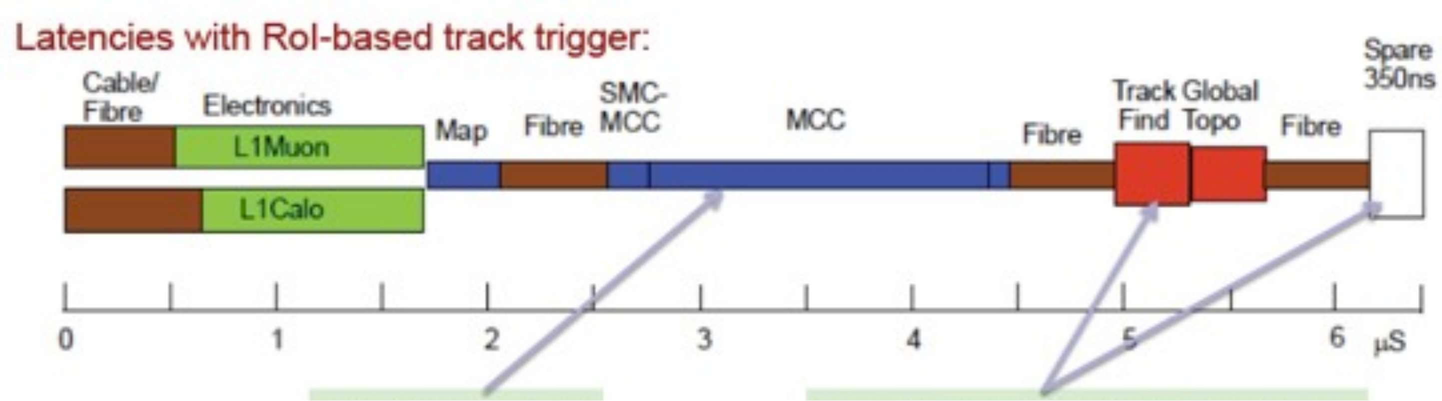
RoI: $\Delta\varphi$=0.2, $\Delta\eta$=0.2 at Calo
Δz=40cm at beam line





- Started investigating L1Tracker. Two Strategies:
  - ✓ Standalone Track Trigger
    - Coincidences between closely spaced pairs of Silicon pairs
  - ✓ **Regional tracker readout driven by L1Calo/L1Muon**
- Studies on-going on the feasibility (e.g. latency required) and data volume reduction effectiveness





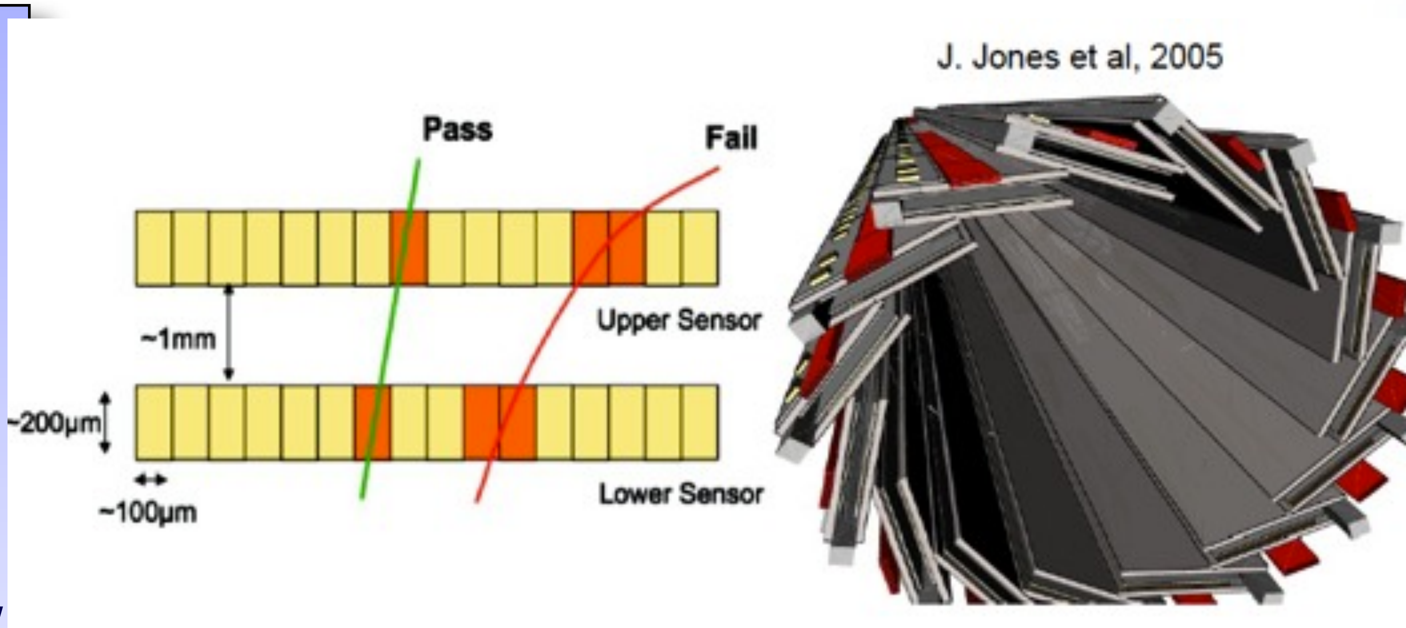
N. Konstatinidis, ATLAS *Track Trigger for sLHC*, VERTEX 2009

L1 and Track Trigger

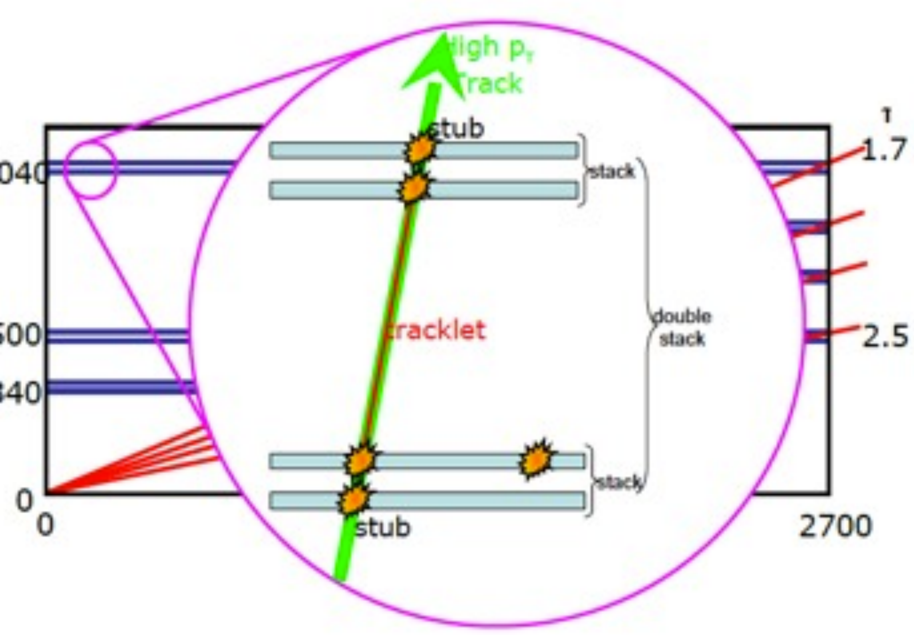
CMS

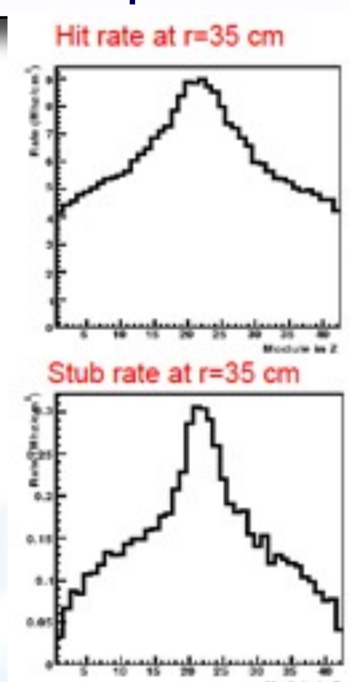
L1 Primary goal is to match track information with electrons and muons candidates from L1 primitives.

- Besides, also investigating the possibility of:
  - ✓ Measuring z-vertex to discriminate from different pp-interactions.
  - ✓ Exploit isolate track capabilities for τ-identification (requires tracks down to 2 GeV/c)
- On-going studies with the Hybrid P_T-layer tracker layout.
  - ✓ Use of 4T CMS solenoidal field
  - ✓ Simulations with 200 min-bias events per BC



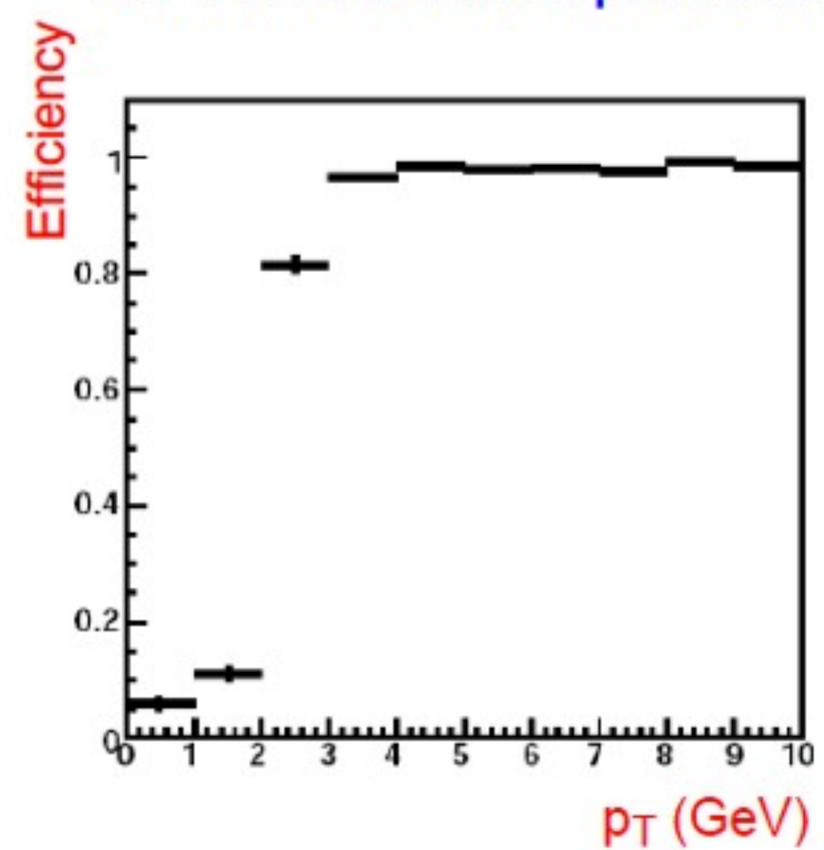
A. Ryd, *CMS L1 Track Trigger for sLHC*, VERTEX 20089





- Hit rate in 200 PU events.
- Using CMS fast sim. Does not include out of time PU.
  - Hit rate low by factor of ~2-3.
- Stub rate lower by a factor of 30

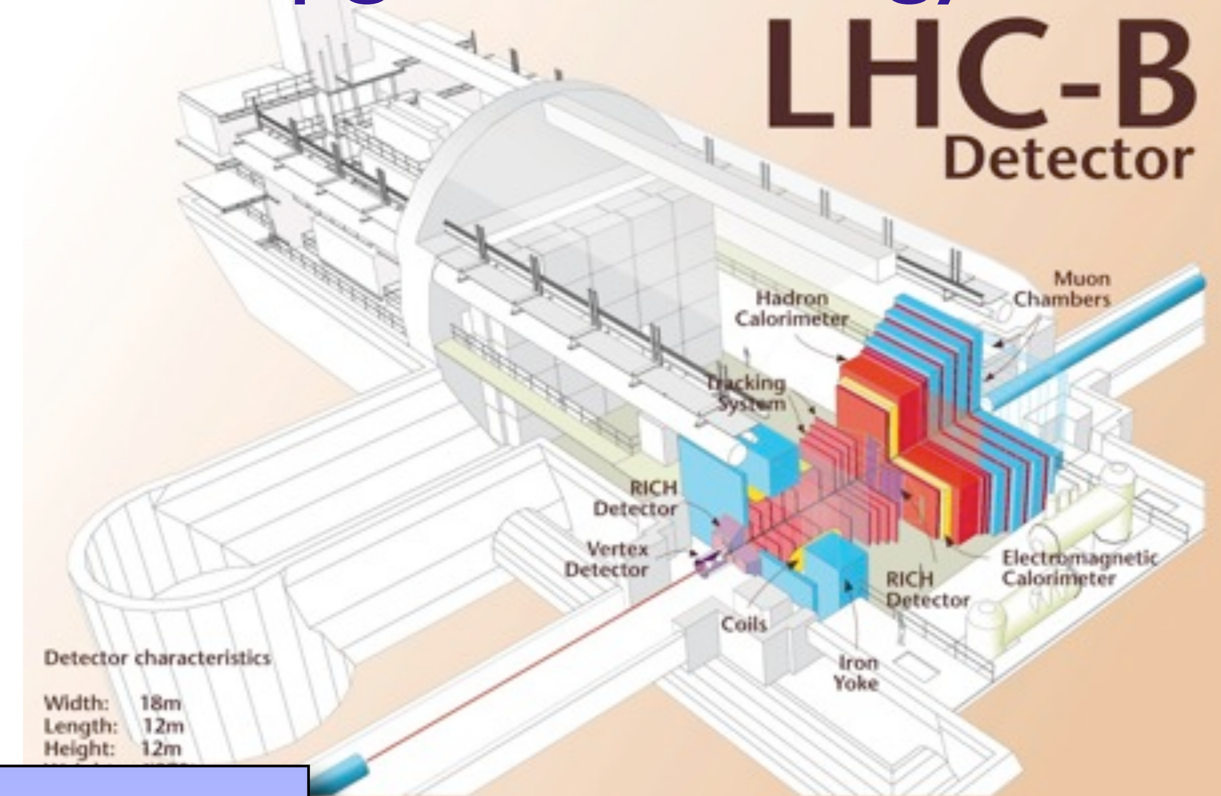
Stub finding efficiency as function of p_T. At r=35 cm for 1 mm stack separation.



LHCb Upgrade Strategy

Upgrade strategy is **independent on sLHC scenarios**:

- Operate the detector at $2 \times 10^{33} cm^{-2} s^{-1}$ maintaining tracking and PID performance
- Accumulate $10 fb^{-1}$ @LHCb in 5 years
- Install substantial upgrade during the long shutdown before the machine Phase-II
- Accumulate $100 fb^{-1}$ in a further 5 years operation
  - x20 statistics in hadron channels
  - x10 statistics in lepton channels
- EOI submitted April 2008/TDR planned for 2010



All subsystems must be fully read out at 40 MHz

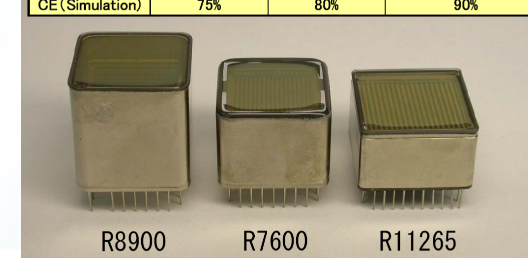
- Replace most FE electronics (Tracker, Particle ID and calorimeters).

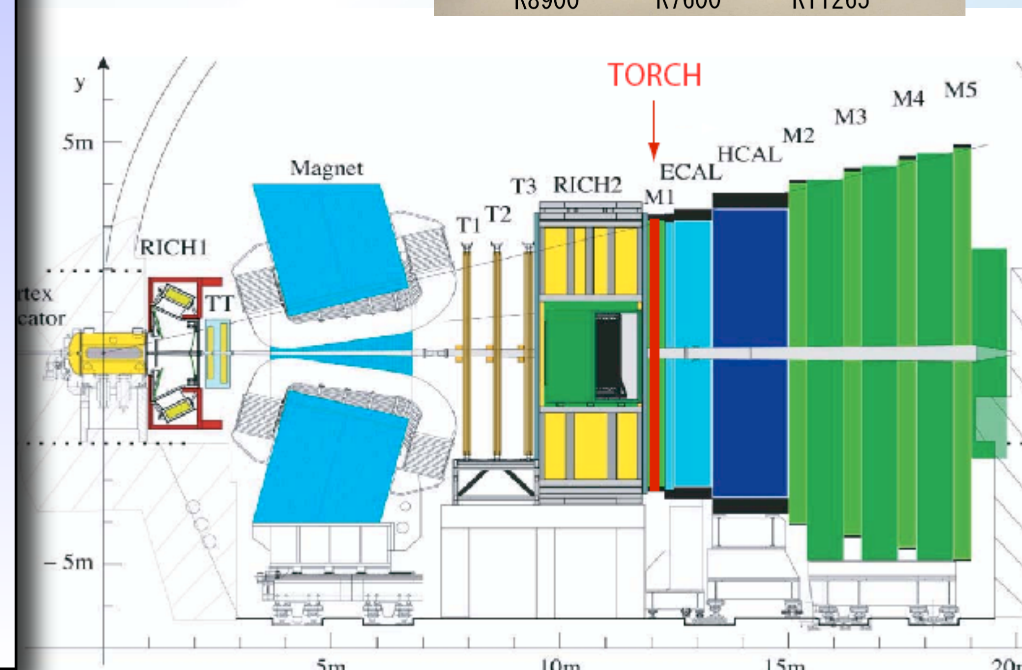
VErtex LOcator detector eventually will be replaced. Two phases:

- **Phase-I: upgrade only FE ASICs with 40MHz readout. Device will be rad. tolerant to ~$20 fb^{-1}$**
- **Phase-II: replacement. Module and Sensor R&D is undergoing.**
  - ✓ Rad hard n-in-p Silicon, Diamond, 3D pixels

- **Particle ID in the RICH detectors will also be extensively upgraded:**
- **Photo-sensors** and FE ASICs:
  - ✓ Upgraded HPDs
  - ✓ Use of pixilated multi-anode PMTs (MaPMT: ~0.3M channels)
- **System Geometry Layout**:
  - ✓ Baseline approach: keep current geometry RICH1 (aerogel+C4F10) and RICH2 (CF4)
  - ✓ Alternative: replace aerogel with an innovative TOF system (**TORCH** after RICH2)

	R8900	R7600	R11265
Total length	34mm	27mm	23mm
Effective area	23.5mm	18mm	23mm
CE (Simulation)	75%	80%	90%

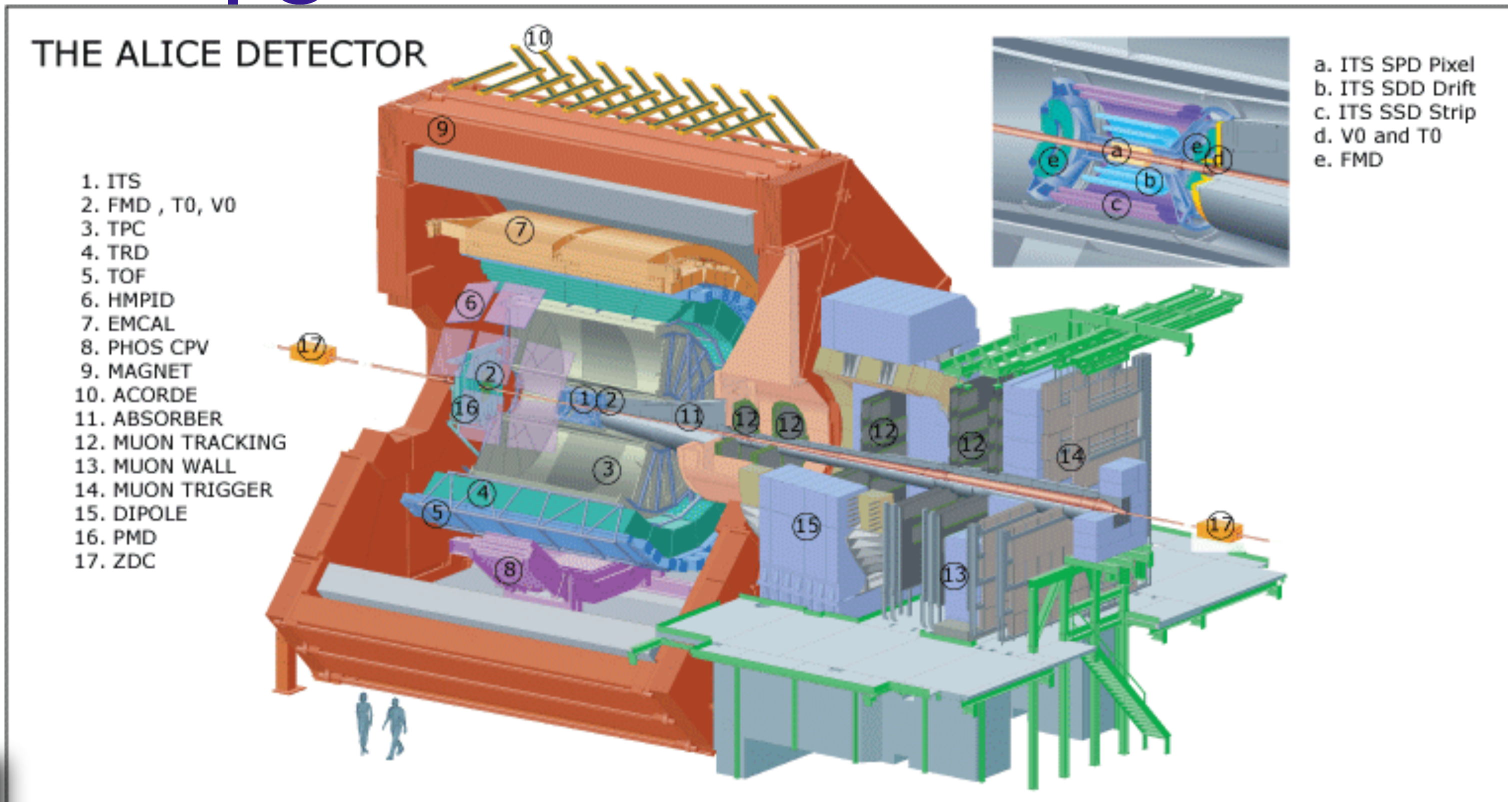




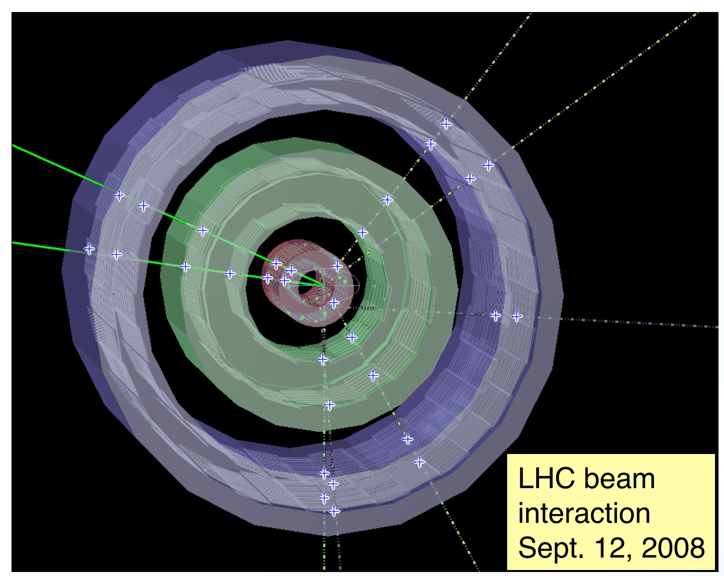
P. Collins, *LHCb Upgrade*, LHCC meeting, Sep 2009

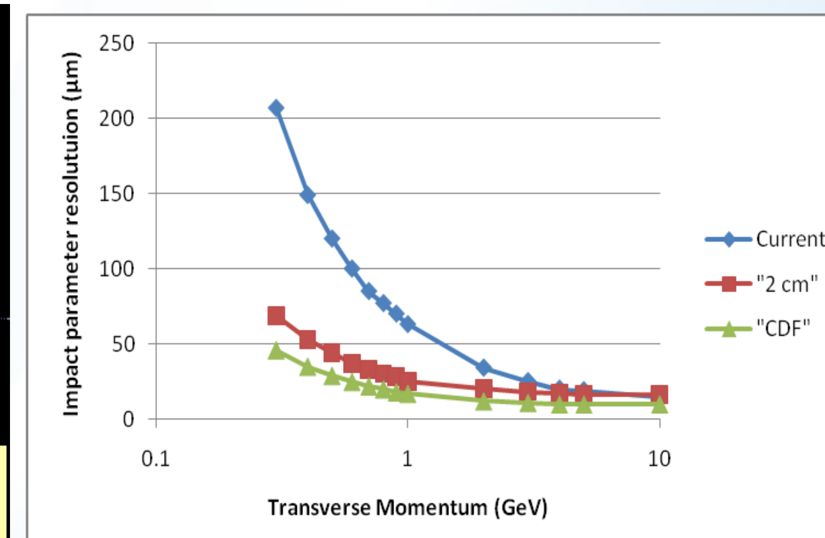
ALICE Upgrades

- pp Physics @ ALICE is "minimum bias" at low luminosity
  - ✓ collection of comparison data as a tool to understand HI
  - ✓ Optimal Luminosity for pp: 10^{29}-10^{31}cm^{-2}s^{-1}
- ALICE plans for the future are not directly linked to the LHC high luminosity upgrade program



- Completion of the detector undergoing:
  - ✓ TRD (approved much later than other central sub-systems)
  - ✓ New EMCAL to be completed by 2010/2011
- Upgrade ideas beyond 2010/2011:
  - ✓ **2nd generation Vertex Detector**
    - ➡ **Heavy flavor baryons, fully reconstructed B's, total B production cross section at very low p_T, flavor tagging improvement**
  - ✓ New Forward tracker and calorimeters
    - ➡ Low-x measurements in pA,AA collisions
  - ✓ Particle ID Upgrade:VMHPID detector
    - ✓ High p_T (>5GeV) particle identification event by event and trigger.
  - ✓ Calorimeter Upgrade (extend EMCAL to opposite ϕ):
    - ➡ Improve γ-jet acceptance, dijet measurements





- Install new beam-pipe with lower radius (~2cm against ~2.9cm). Considering reducing thickness to 0.8mm
  - ✓ Access and installation sequence requires a long shutdown (>6 months)
  - ✓ Goal: factor of 2 improvement in impact parameter resolution or better.
  - ✓ Replace at least the two innermost pixel layers

P. Giubellino, *ALICE Upgrade plans*, LHCC meeting, Sep 2009

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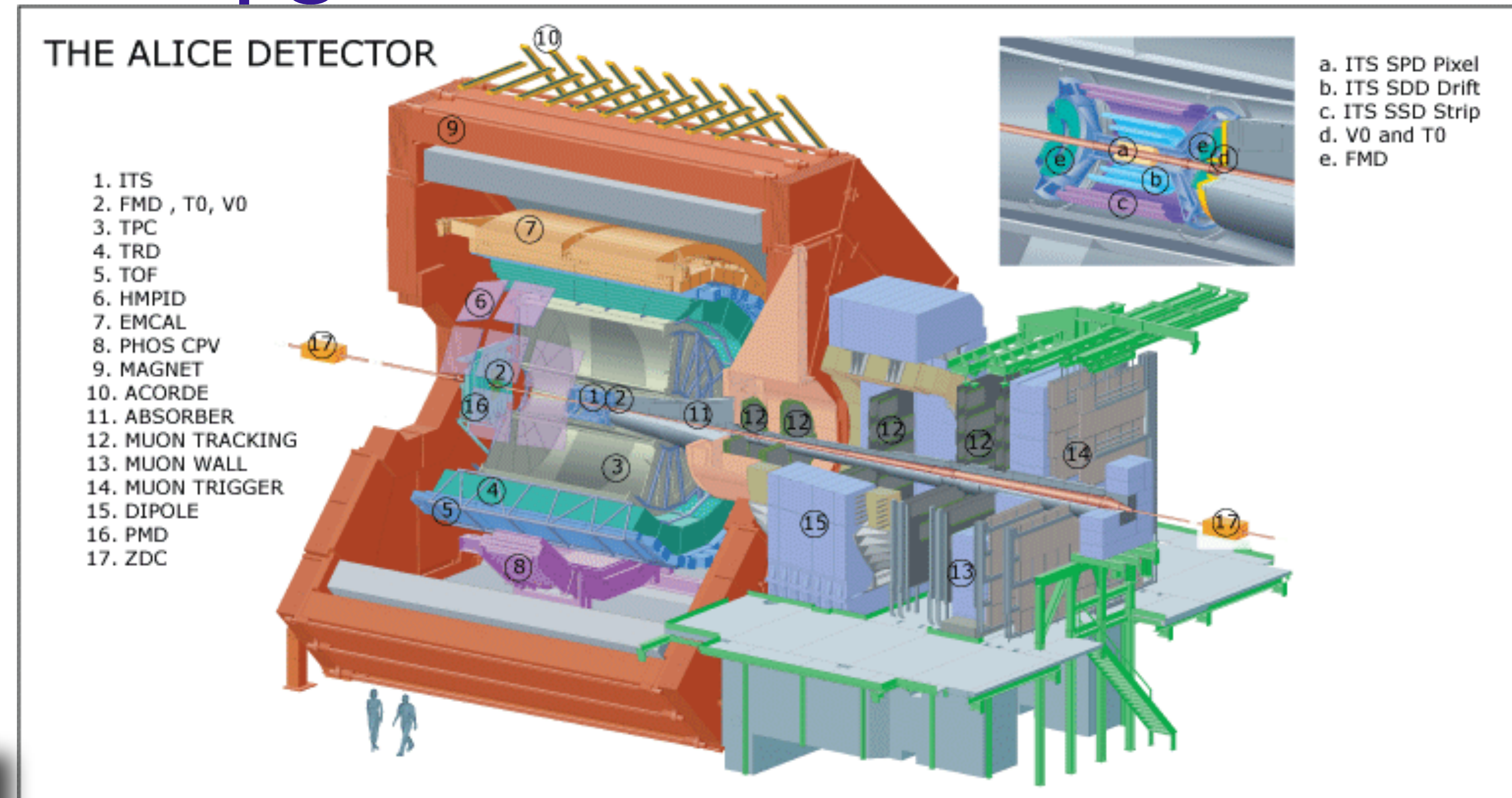

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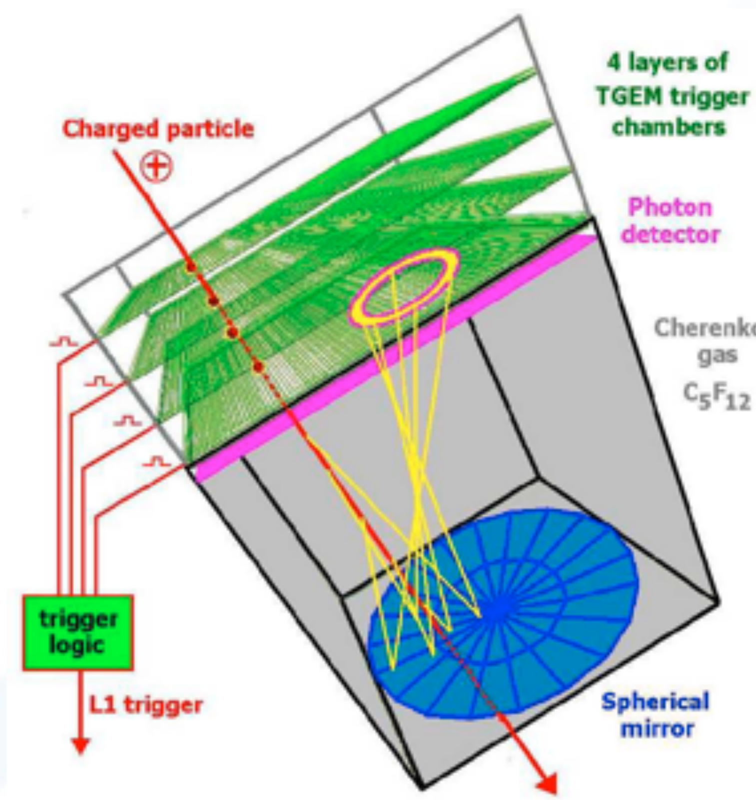
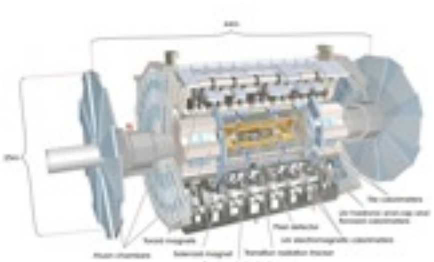


- Spherical mirror. 80cm Radiator C_4F_{10} (C_5F_{12})
- Photon Detector Options:
  - ✓ MWPC with CsI photon converter and pad readout
  - ✓ Resistive Thick GEM (>2 layers) with CsI photon converter.
- 4 Layer of GEMs detector with algorithms for high p_T particle selection in dedicated trigger logic

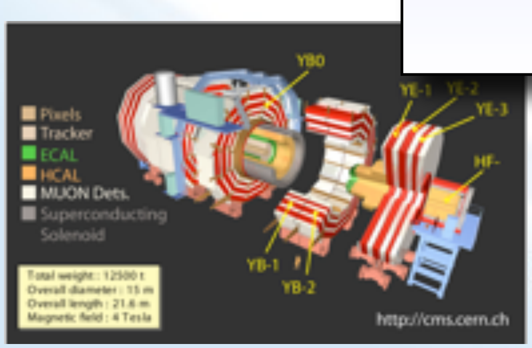
P. Giubellino, *ALICE Upgrade plans*, LHCC meeting, Sep 2009

Planning, Organization and Activities

- Working Groups inside detector sub-systems
- Typical Steering Group and Project Offices linked to Technical Coordination inside collaborations to cover overall organization and coherency of the projects
- R&D projects covering specific topics (open, approved and reviewed by SG)
- Major workshops inside experiments. In a few cases also across (possible common developments)



- Phase-I upgrades will need their LoI and TDRs completed by 2010-2011. Changes will be in the ~10-15% of original costs (depending on ambitions)
- Phase-II changes are more significant. Probably close to 40-50% of the existing detectors.
  - ✓ LoI process being completed (CMS prepared, ATLAS mid 2010)
  - ✓ Technical Proposals and complete system TDRs will likely be completed by 2013-2015
  - ✓ Still ID trackers may be considered a special problem because of the long lead time needed for a complete replacement and because they are required in any scenarios.



- Interactions with LHCC on regular basis
- Increasing focus toward complete Phase-I plan and Phase-II scope

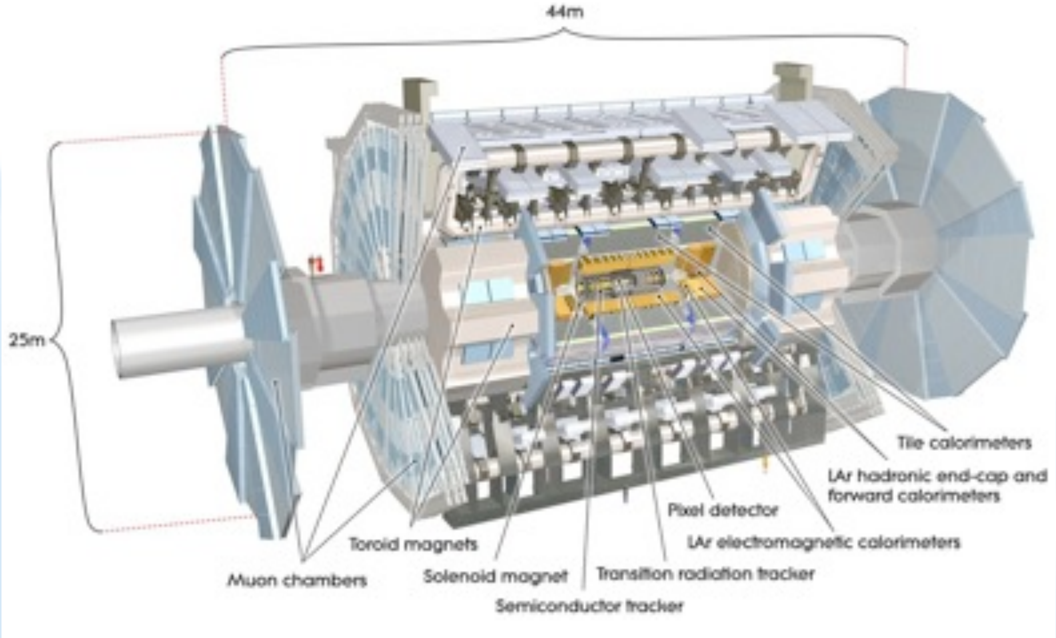
Summary

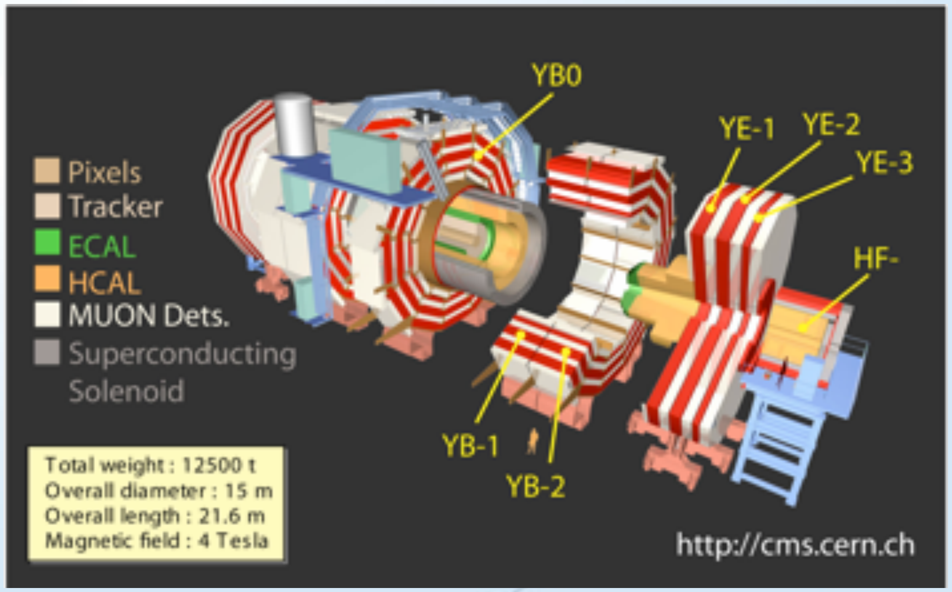
- Detectors are ready for first collisions and early physics results. Obviously the priority!
- However experiments are considering upgrade programs that would enrich physics reach and discovery potentials at the LHC into the '20s
- More and more focus within the collaborations on detector improvements to keep the experiment running for long time (i.e. consolidation activities, upgrades for phase-I and II)
  - ✓ Phase-II upgrades are significant changes of the detector (likely >40% of the costs)
  - ✓ Attention in instrumentation conference is switching from detector commissioning results to upgrade R&D activities

- **Phase-I upgrade around 2014-2015 leading to $3x10^{34}cm^{-2}s^{-1}$** peak luminosity:
  - ✓ **Improve (ATLAS) or replace (CMS) pixel systems**
  - ✓ Adapt the Muon spectrometers, particularly in the end-cap/forward regions to larger background rates.
  - ✓ Quasi-adiabatic upgrade of Trigger/DAQ
    - ✓ CMS: significant change in hardware. Changes from VME to µTCA based architecture
    - ✓ ATLAS: regional L1 trigger

- **Phase-II upgrades around 2020** (given all uncertainties) for additional total integrated luminosity (recorded) of **$3000fb^{-1}$** (peak luminosity depending on the scenarios)
  - ✓ **Complete replacement of the Tracker detectors and significant changes in most other detector systems**. Still the scope and the extent of the upgrade programs is under evaluation
  - ✓ Decision by CERN for Phase-II probably not before 2012/2013. By then there will be likely a complete description of the detector upgrades, which takes into account early data taking

Backup Slides





Physics benchmarks, detector performance and issues @ sLHC

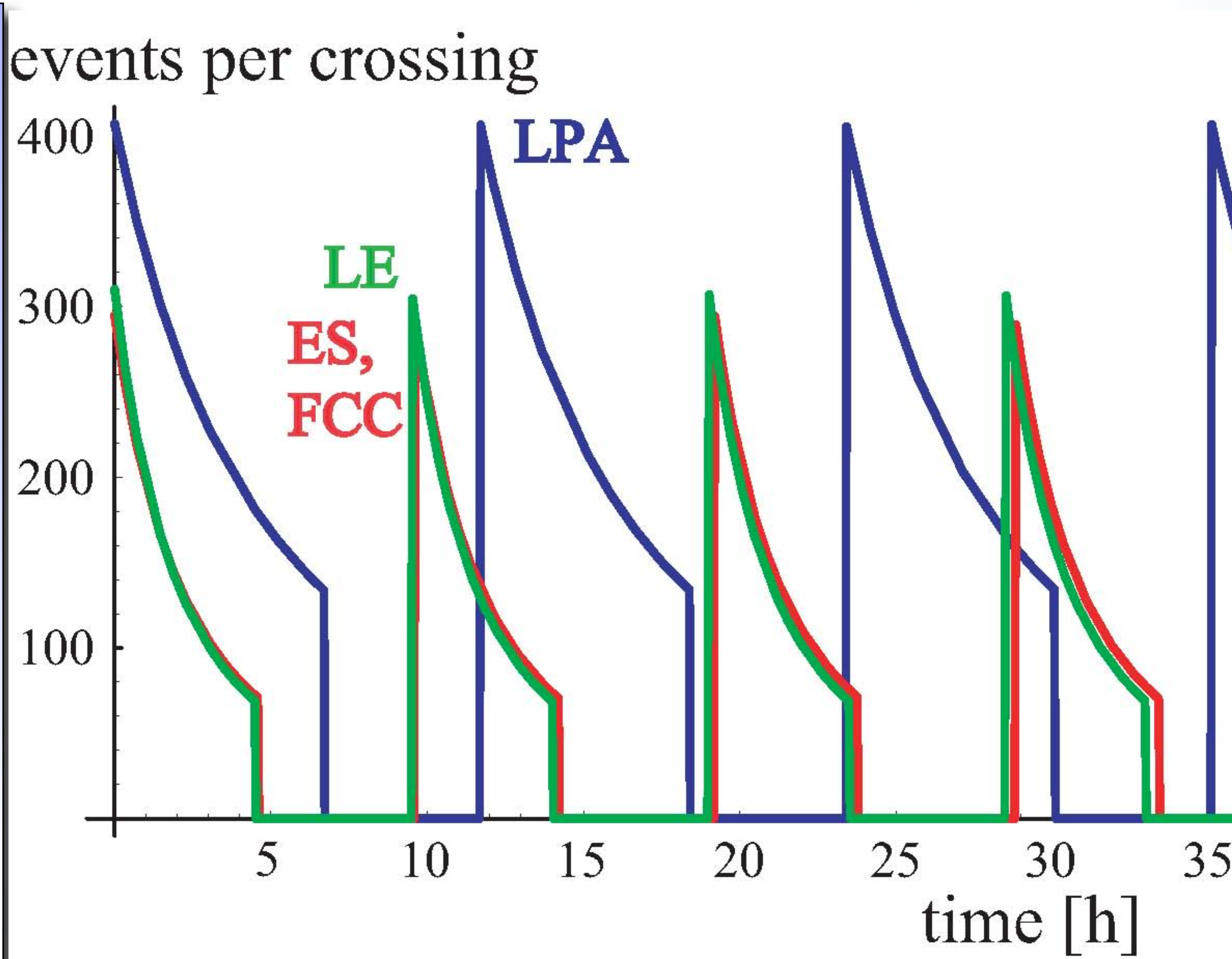
The performance @10^{34} $cm^{-2}s^{-1}$ should be taken as a minimal reference goal

Objects	Physics Benchmark	Detector Performance Parameter	Issues
b-jets & τ	Higgs identification, BR's measurements.	Tagging efficiency vs. purity (statistics and background suppression).	Tracker Rad. tolerance Pileup
b-jets	Higgs mass measurement, background suppression	Mass resolution in the few 100 GeV region	
fwd jets	Vector Boson Fusion: • Measurement of H couplings • Search for strong WW phenomena (if no Higgs exists)	Forward Jet tagging efficiency and fake rate vs jet E_T Jet E_T resolution	Final focus magnets Acceptance Background Resolution Pileup/cavern background
central jets	Jet veto for VBF searches Mass spectroscopy	Fake rate Mass resolution	Pileup Pileup
electrons	W/Z ID, SUSY decays W'/Z' properties	ID efficiency and fake rate	Pileup
muons	W/Z ID, SUSY and Higgs decays W'/Z' properties, etc...	Forward acceptance and fake rate	Albedo Forward efficiency Cavern background

M. Mangano, *Physics Opportunities for the sLHC*, sLHC kickoff meeting, April 2008

Luminosity leveling and pileup

- Luminosity leveling schemes are preferred by experiments:
  - ✓Reduce pileup rates
  - ✓and cavern backgrounds...
  - ✓for the same integrated luminosity...



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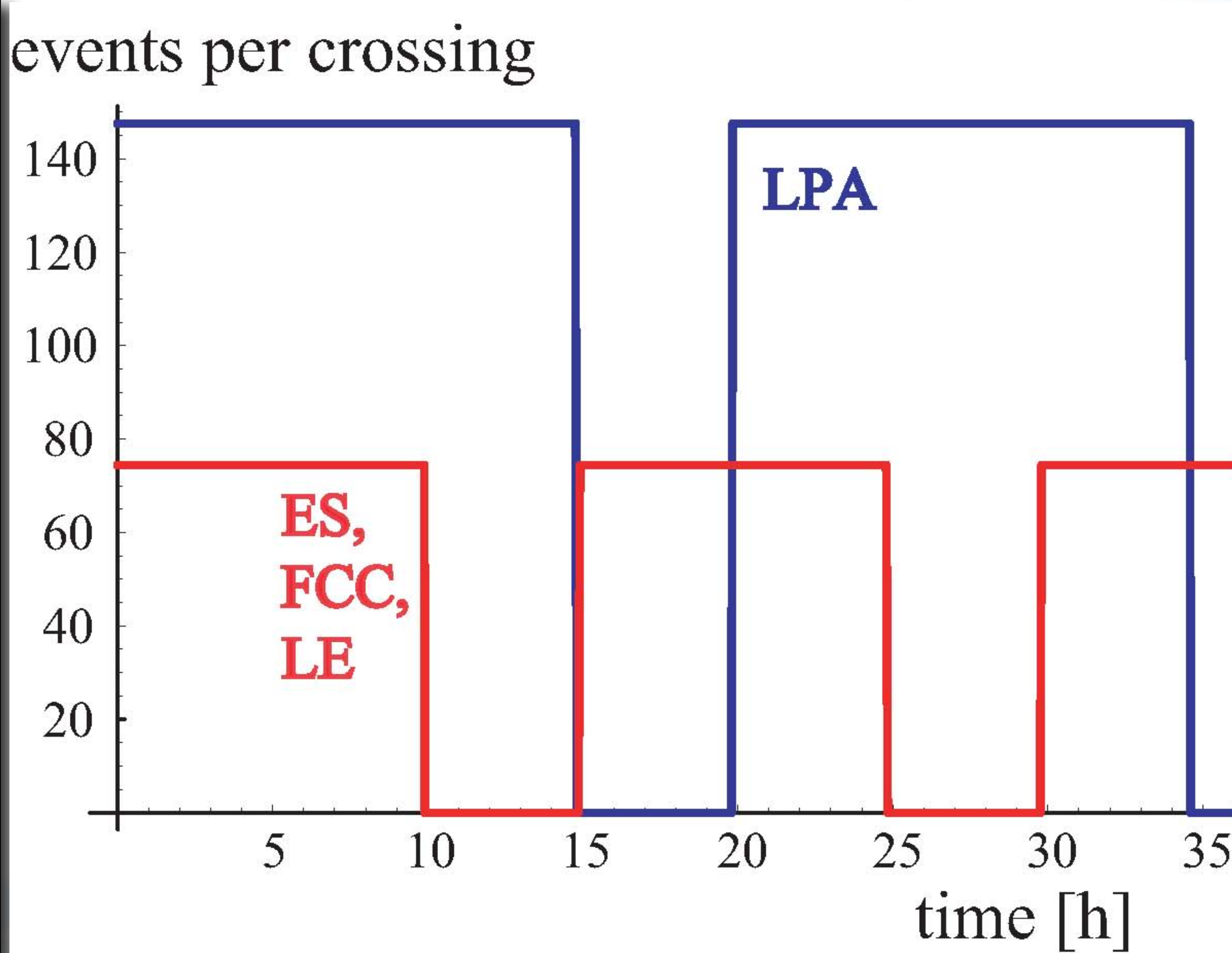
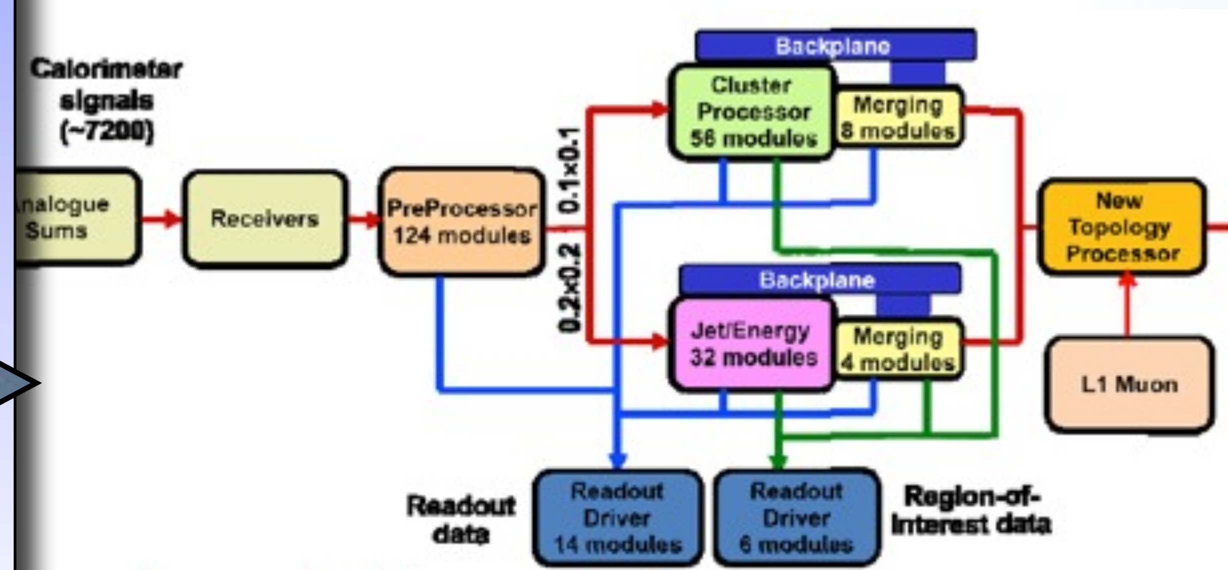


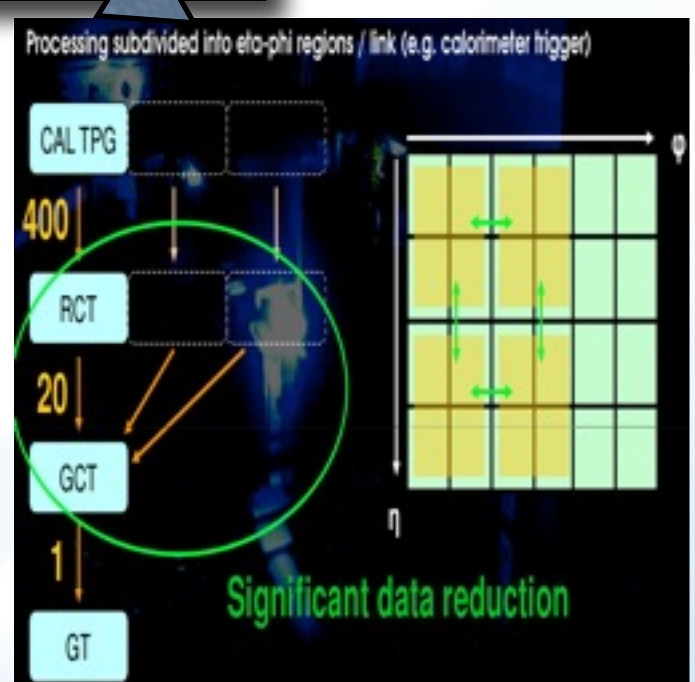
Trigger/DAQ Phase-I Upgrades

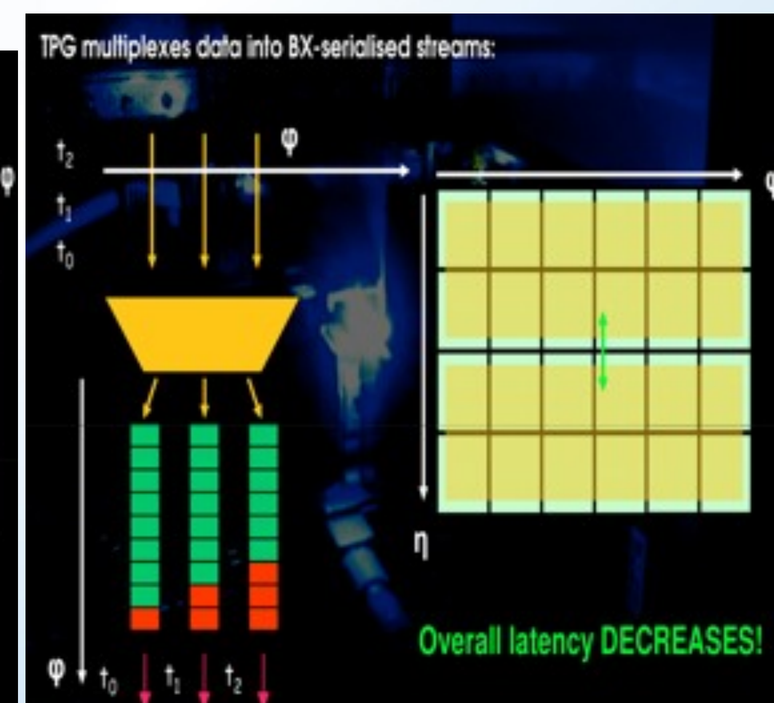
- Both experiments will continuously upgrade TDAQ to cope with rates and take advantage of new processing power.
- **For Phase-I upgrades, both experiments will improve selectivity of the trigger in order to moderate increased requirements on data bandwidth and to maintain trigger rates, max. latency of L1, consistently with the currently implemented readouts.**

- **L1 trigger sub-system (Calo and Muon) upgrades that enable selections based on event topology**
- Examples of L1Calo:
  - **ATLAS: Cluster Merging Modules (CMM) and Topological Processor that combines different trigger elements (e.g. muon with no-jet) in performing topological trigger selection.**
  - CMS: Time-Multiplexed Data Serialization. At the expense of an initial lost time due to multiplexing, provides a compact (boundary sharing translates into pipeline issues), redundant and overall faster (topological processing at an earlier stage, no pre-clustering) system



- **Upgrades that incorporates inner detector tracks into the trigger as early as practical in the decision chain**
  - ✓ **track trigger in L1 at CMS**
  - ✓ Fast track finder in ATLAS for Phase-I based on a content-addressable memory (CAM) between L1 and L2 - similar solution to that used by the Silicon Vertex Trigger of CDF.
- **Increased processing power of High Level Triggers (both hardware and software upgrades)**





J. Jones, " *CMS - A Future Trigger Architecture*", CMS Upgrade workhsop, Oct 2009