Upgrading LHC Calorimeters

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

FSP 101 ATLAS

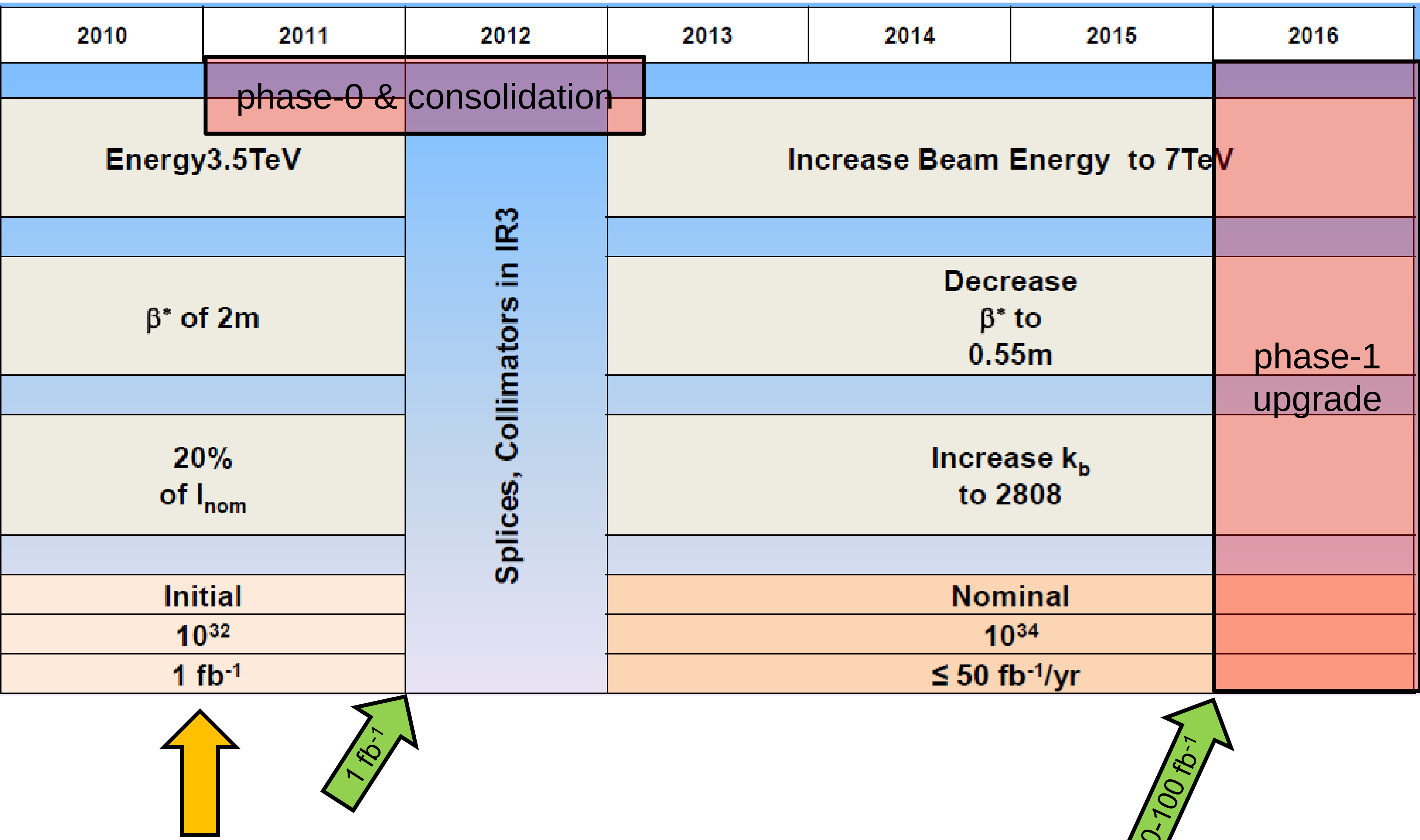
Deutsche Forschungsgemeinschaft DFG

3. Detector Workshop
Helmholtz Alliance "Physics at the Terascale"
Heidelberg, October 4-5, 2010

Outline

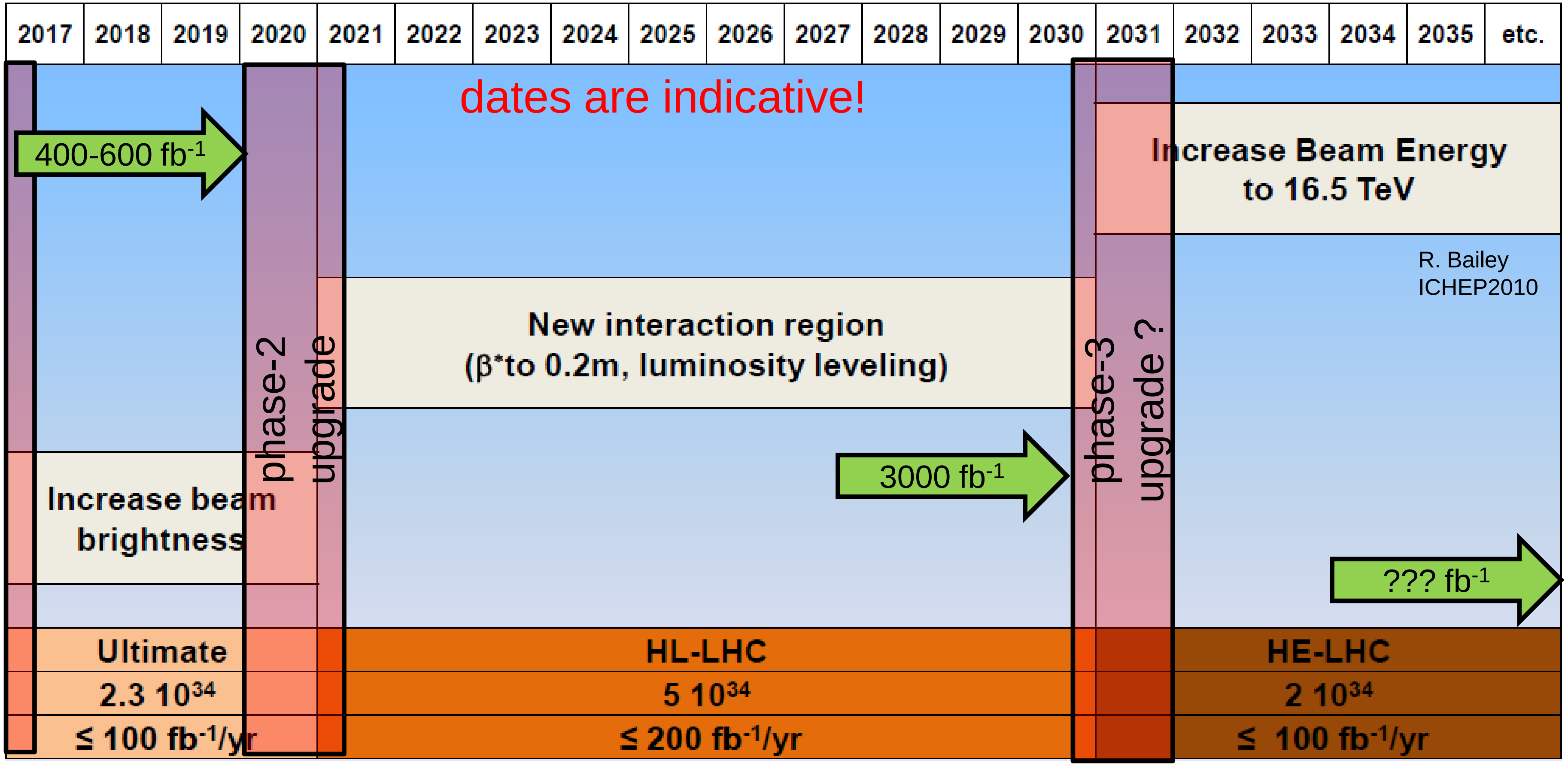
- Introduction
- CMS and ATLAS calorimeter upgrade plans
- ATLAS forward calorimeter (FCal)
- Calorimeter read-out electronics upgrade
  - CMS HCAL and CASTOR detectors
  - ATLAS LAr and Tile Calorimeters
- Summary

R. Bailey ICHEP2010



we are here, $L=0.5 \times 10^{32}\ cm^{-2}s^{-1}$ $\int L \approx 8\ pb^{-1}$

LHC Upgrade Path– Part 2



- in each upgrade phase the detectors must be prepared for the optimistic luminosity scenario

- total luminosities of ~400 pb^{-1} and 3000 pb^{-1} → total dose effects
- peak luminosities L= 2 x 10^{34} cm^{-2}s^{-1} and 5 x 10^{34} cm^{-2}s^{-1} → rate/occupancy effects

- all upgrade options, in particular for phase 2, should be motivated by physics performance

ATLAS – Calorimeter Upgrade Plans

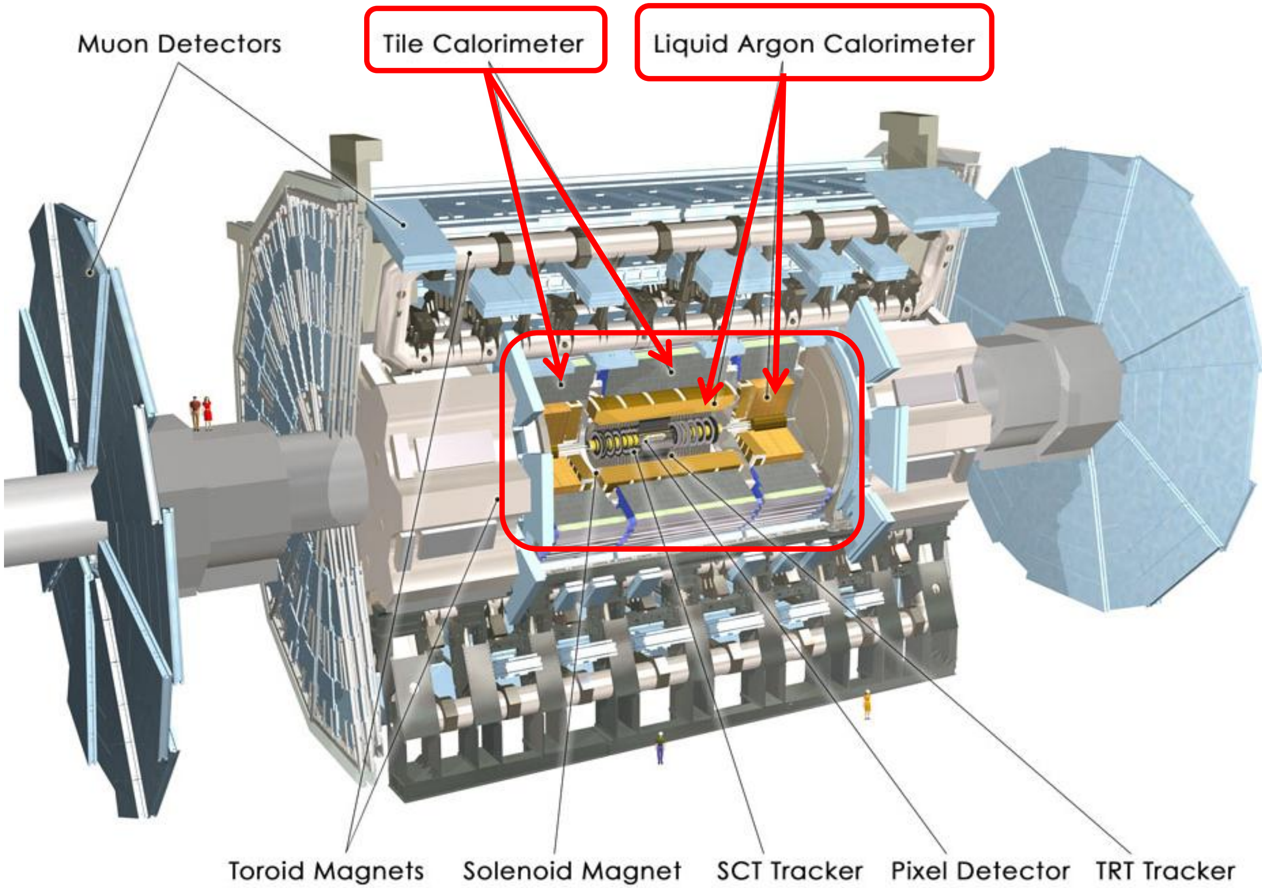
- consolidation phase (2011-2012):
  - replacement of non-reliable electronics on the detector (low-voltage power supplies, optical transceivers, slow-control boards)
  - improve accessibility of electronics (hadronic endcap)

- 1st upgrade phase (2016) / 2nd upgrade phase (2020):

- free-running readout electronics for LAr and Tile calorimeters
- new digital L1 Calorimeter trigger electronics

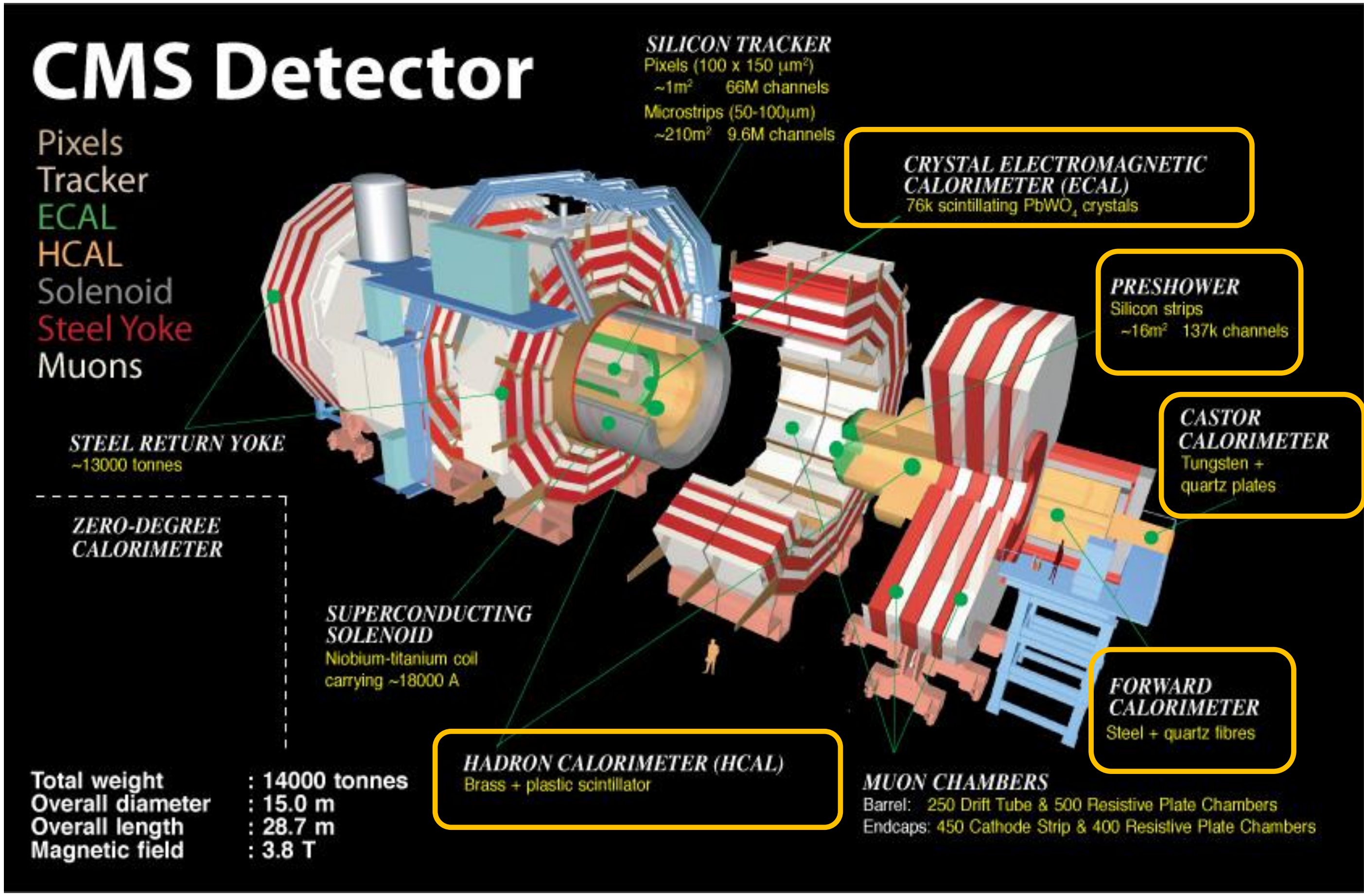
- possible replacement of HCAL cold electronics

- possibly new diamond-Cu sampling forward calorimeter (MiniFCal) or
- new forward LAr-Cu calorimeter (sFCal1)



CMS – Calorimeter Upgrade Plans

- phase 0 (2012):
- new SiPM photodetectors for Hadronic Calorimeters in the outer barrel region (HO)
- new PMT's for SPACAL / CASTOR Calorimeter

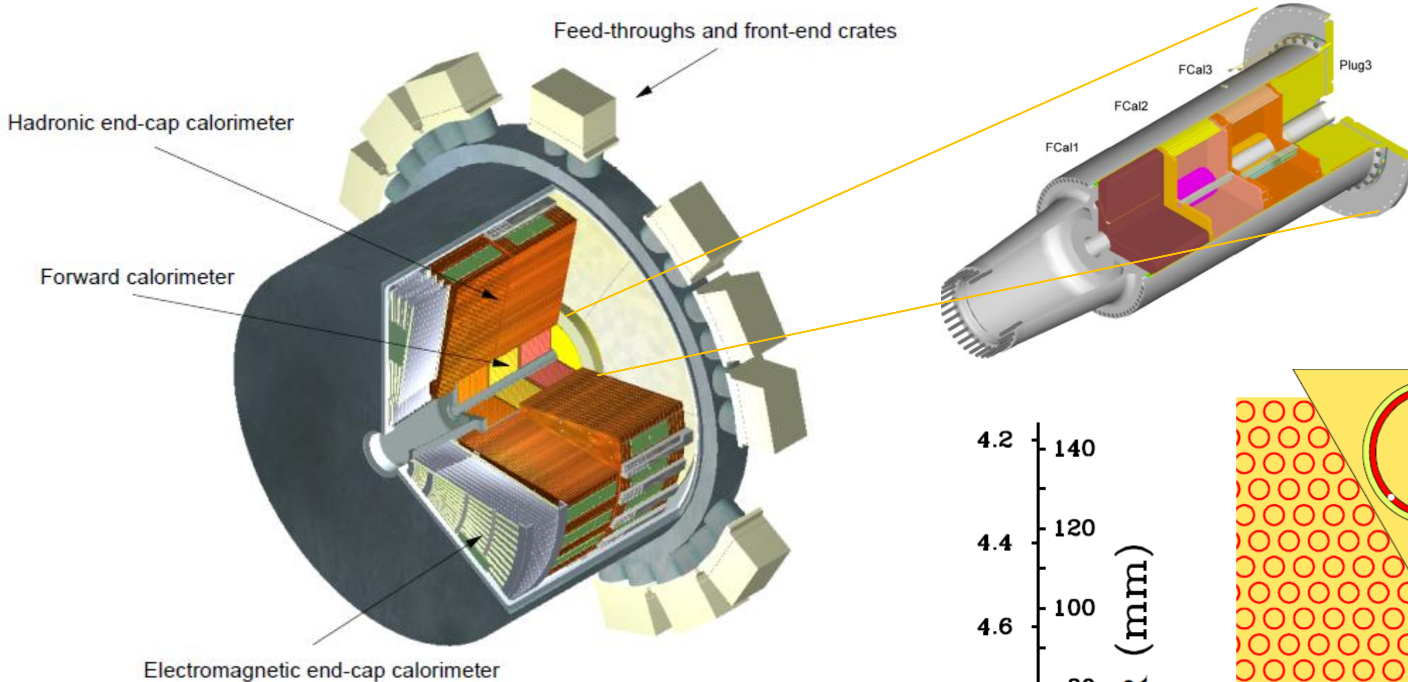


- phase 1 (2016):
- replacement of HPD photodetectors for Hadronic Calorimeters (HB, HE)
- new PMT's and fibers for forward Hadronic Calorimeter (HF)

- phase 2 (2020):
- possible modification of APD readout of ECAL barrel
- possibly replacement of ECAL $PbWO_4$ endcaps

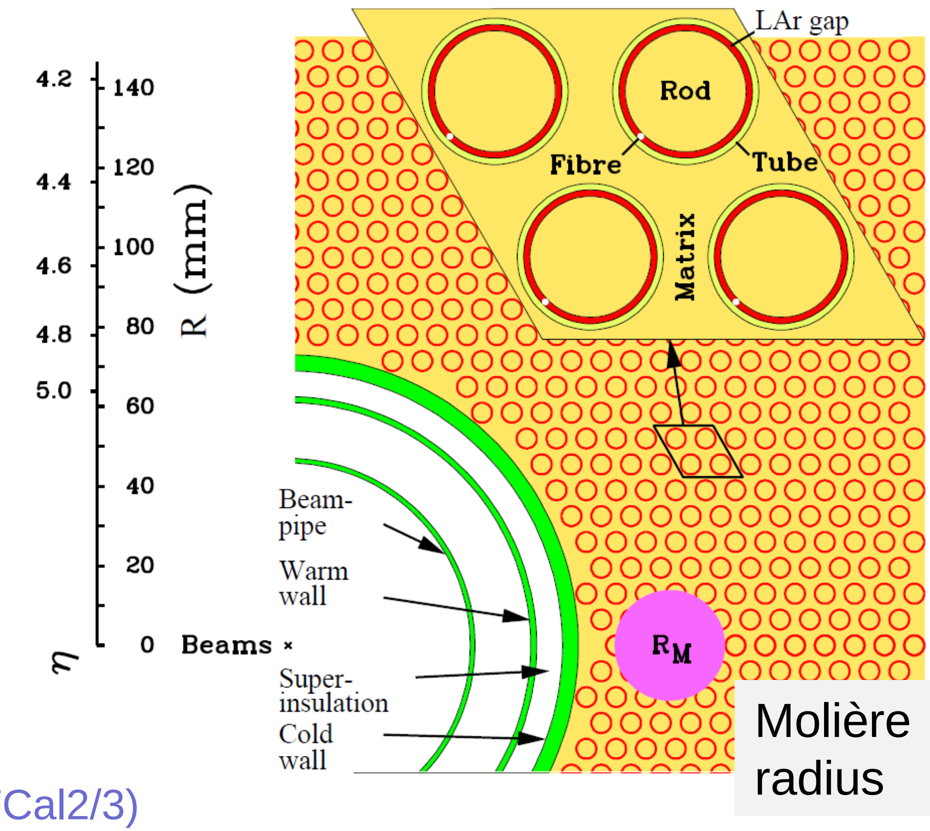
- trigger/DAQ system upgrade

ATLAS Current FCal



- 3 sections: FCal 1/2/3
- FCal1: Cu absorber, LAr active material → e.m. showers
- FCal2/3: W+LAr → hadronic showers

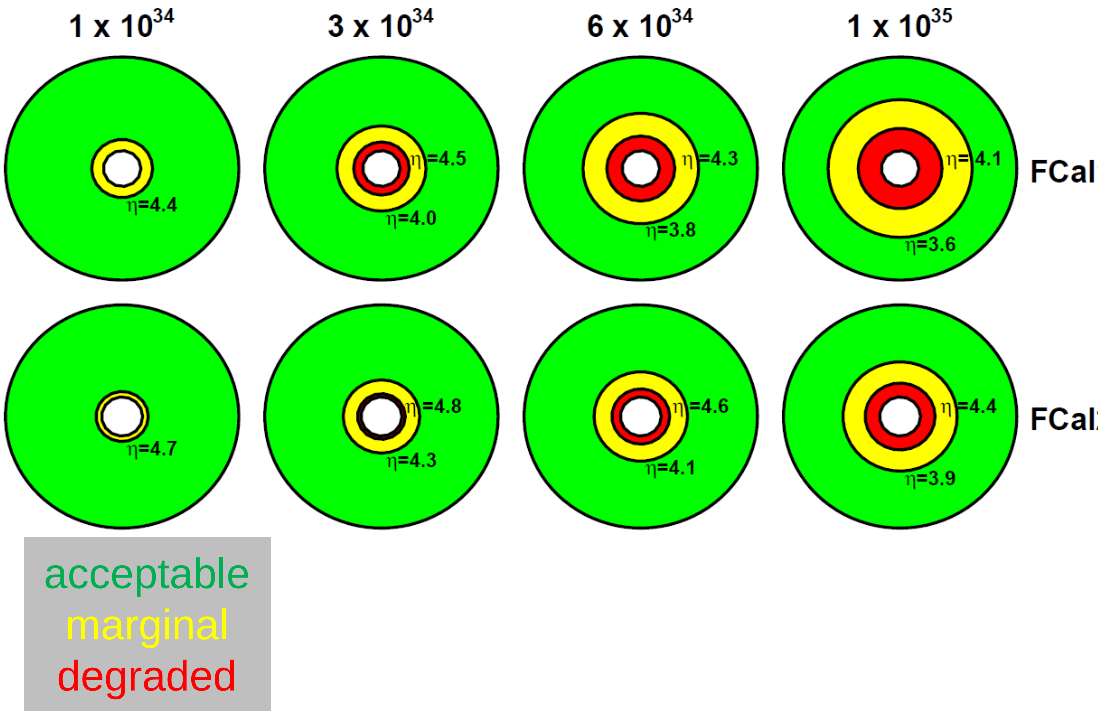
- detector concept:
  - absorber matrix with hollow tubes
  - inside: precision metal rod fixed with fibre
  - gap sizes: 269 μm (FCal1) 376/508 μm (FCal2/3)

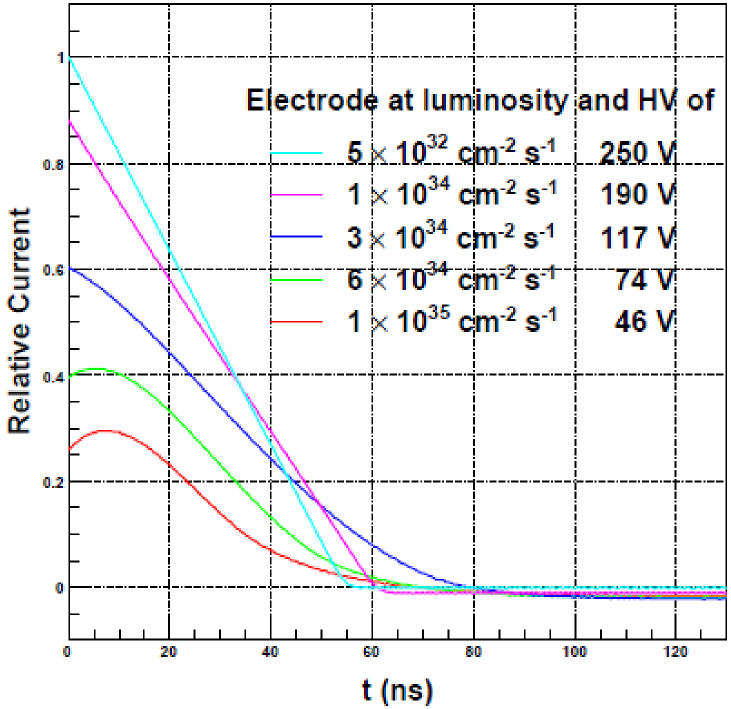


Limitations of Current FCal

- current FCal1 will work properly up to luminosities of 1×10^{34} $cm^{-2}s^{-1}$
- the FCal1 will however not work efficiently above $\sim 3 \times 10^{34}$ $cm^{-2}s^{-1}$
- reasons:
  - positive Ar ion buildup leads to field distortion and to signal distortion
  - high HV currents lead to voltage drop
  - heating of LAr and boiling (only at very high luminosities → additional LN_2 cooling)

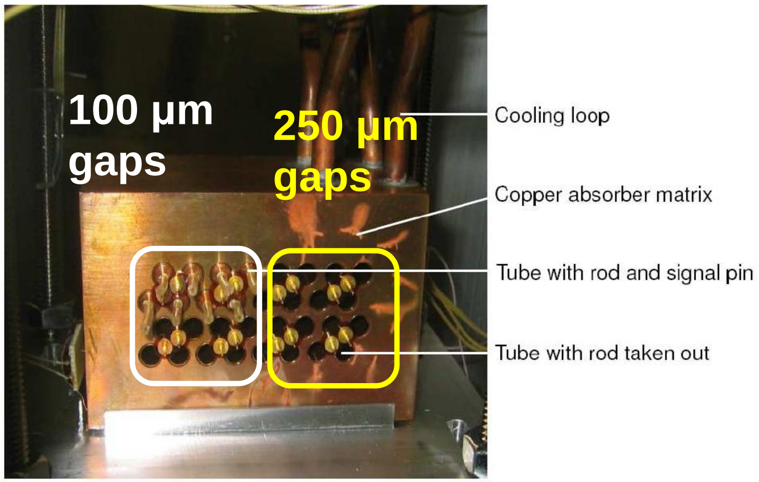
- all effects related to particle rate ~peak luminosity

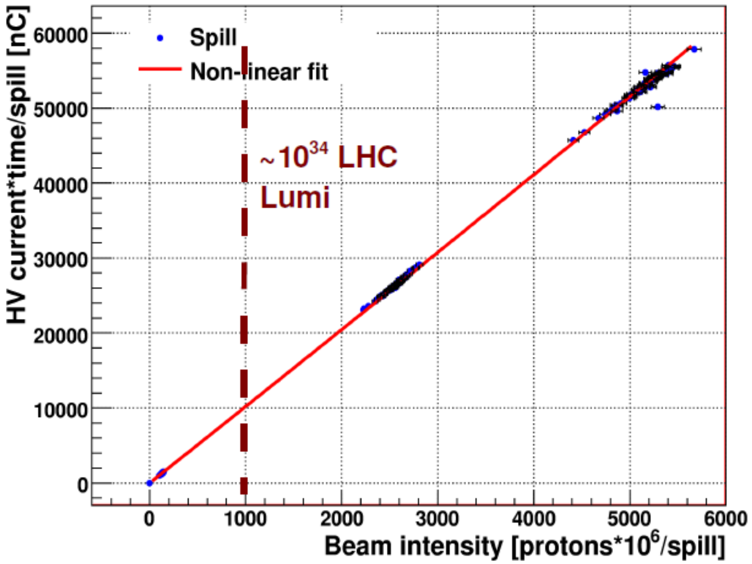




ATLAS sFCal

- solution 1: smaller LAr gaps reduce ion build-up effects and HV drop
- build new sFCal (Cu/LAr) calorimeter with 100 µm gaps instead of 250 µm to replace FCal1
  - test beam measurement of pulse shapes in Protvino/Russia with a high-intensity proton beam





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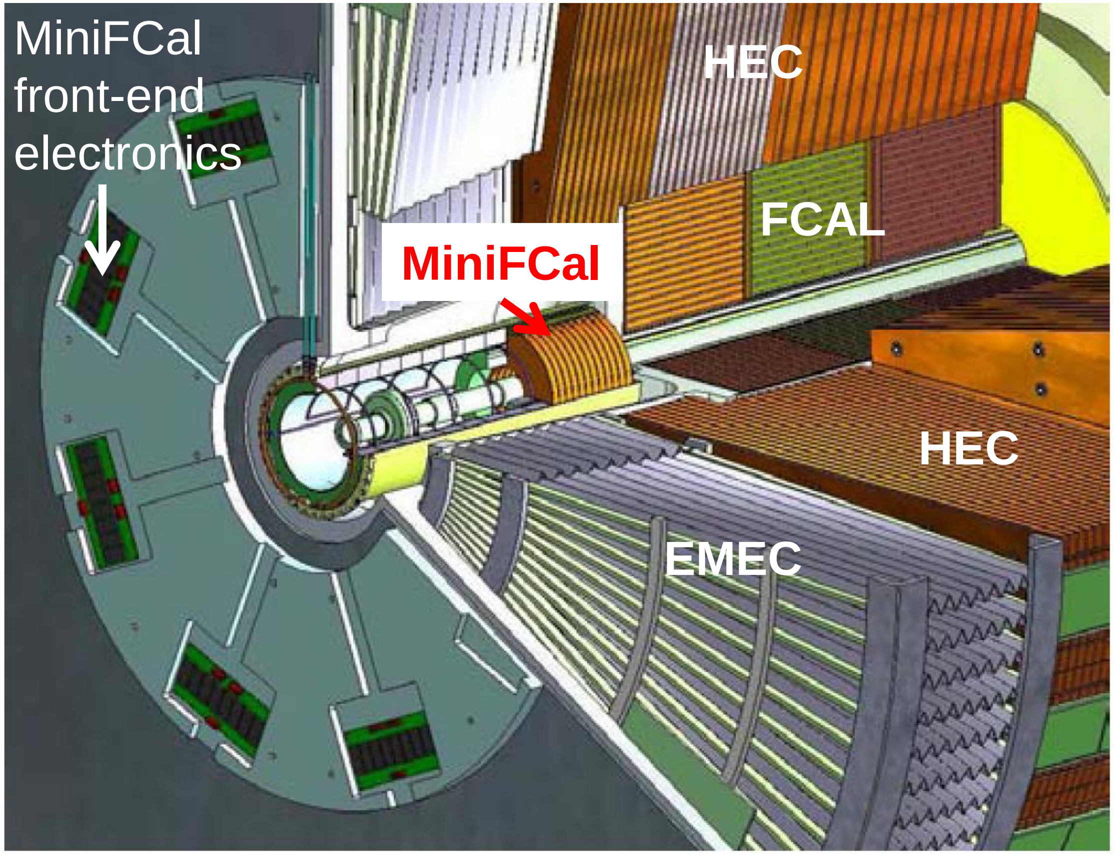
JINST 5 (2010) P05005

- in FCal test module with 250 µm gaps:
  - HV current proportional to beam intensity up to $6x10^9$ p/spill → no strong ion build-up effect → $6x10^{34}$ $cm^{-2}s^{-1}$ at inner FCal1 radius
- in electromagnetic endcap (EMEC) test module:
  - non-linear behaviour observed above critical intensity of ~10^8 p/spill → ion-build up effects
- more understanding of ion-build-up effects needed

ATLAS MiniFCal

- new sFCal would require an opening of the endcap cryostat
  - very difficult and risky operation
  - components will be activated → requires additional safety measures during module extraction
  - only performed if new front-end electronics for the hadronic endcap calorimeter is needed

- solution 2: new MiniFCal in front of current FCal → in front of endcap cryostat

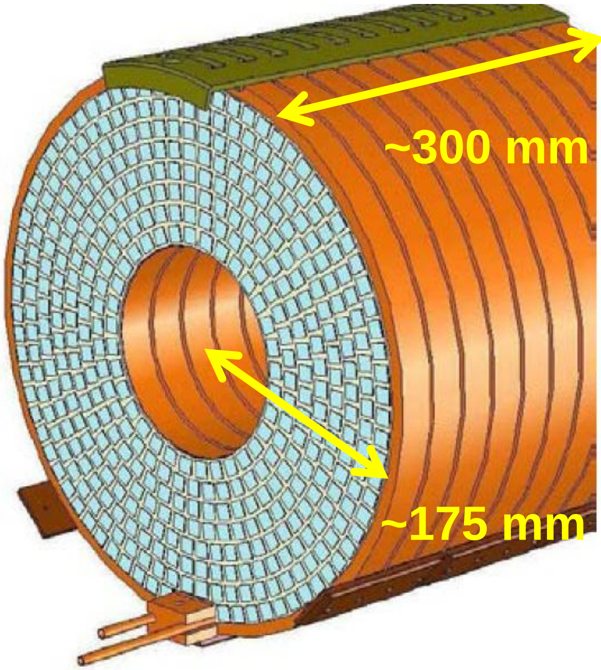


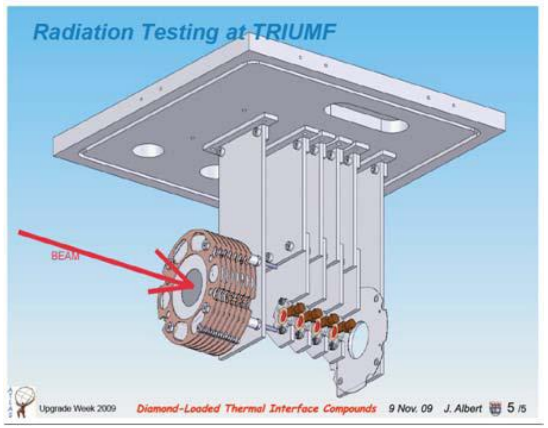
ATLAS MiniFCal

- technology: Cu absorbers and diamond detector disks
- neutron flux ~5 x 10^{17} n/cm^2 (10 yr HL-LHC)

- 12 Cu disks and 11 detector planes
- 18.8 radiation lengths, sampling fraction 0.005
- ~5000 diamond pixels 1cm x 1cm
  → geometry, shape and ganging to be optimized

- absorption in Cu disks reduces energy deposit in FCal1 by 45%
- voltage drop in FCal less than 50 V for radius>11 cm
  → only 3% of FCal affected by HV-drop





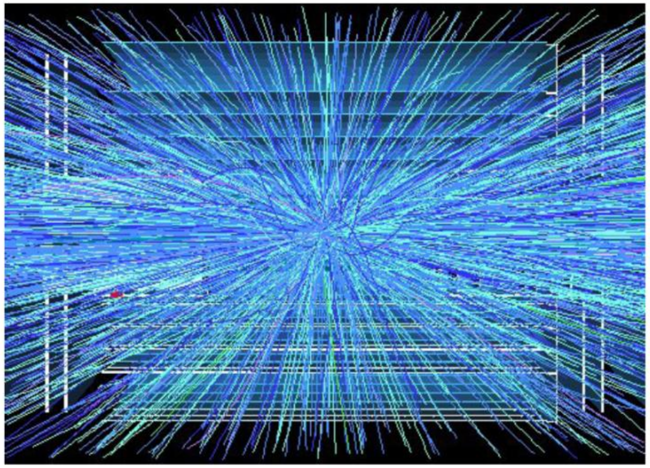
- pCVD diamond sensors are being tested in test beams, e.g. at TRIUMF (Canada): delivers >10^{17} protons/cm^2 in 10 days
- signal characteristics and radiation tolerance

- thicknesses between 200 µm and 800 µm are tested
- 3 different quality grades are available

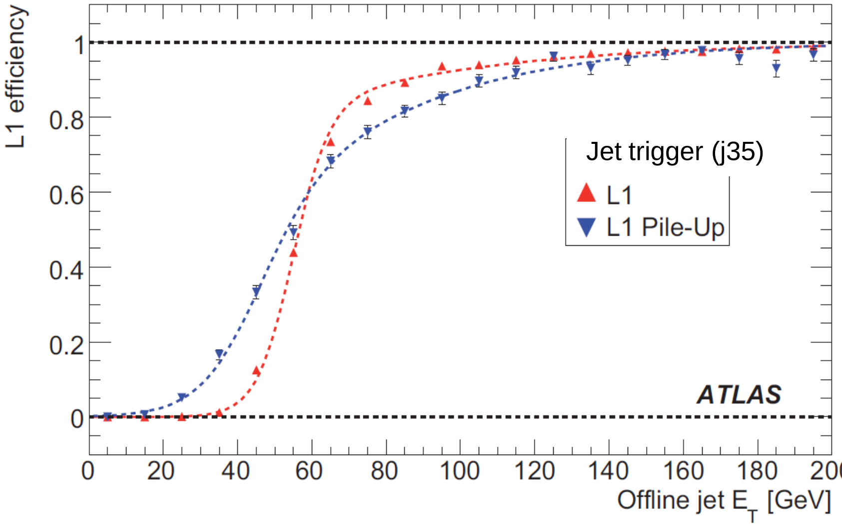
Motivation for Upgrade of Read-out Electronics

- improve current read-out electronics where it does not perform as expected
- exploit high detector granularity as input to trigger electronics
- main reasons: reduce pile-up background by taking finer detector details into account, e.g.
  - better isolation of leptons from hadronic jets
  - sharper trigger threshold for hadronic jets
- go for free-running read-out scheme
→ improve on read-out speed and increase bandwidth
- improve radiation tolerance
- ageing of electronic components
  - current electronics will run for >10 years by 2020
  - not much experience in HEP community for such long operational time

$10 \times 10^{34}\ cm^{-2}s^{-1}$



Plots from Abdel Abdesselam, June 2010



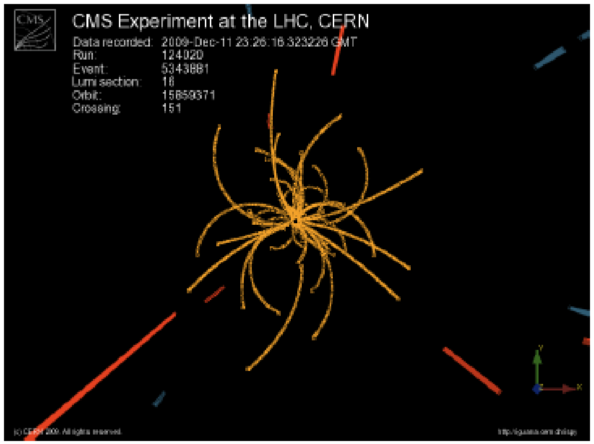
CERN-OPEN-2008-020

CMS: Anomalous Signals in Calorimeters

- in collision data, CMS observes anomalous signals in ECAL and HCAL (now reproduced in simulation and taken into account/corrected in data analysis)

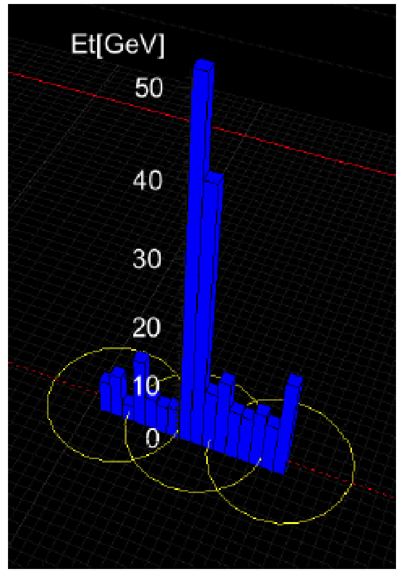
G. Tonelli ICHEP2010

ECAL



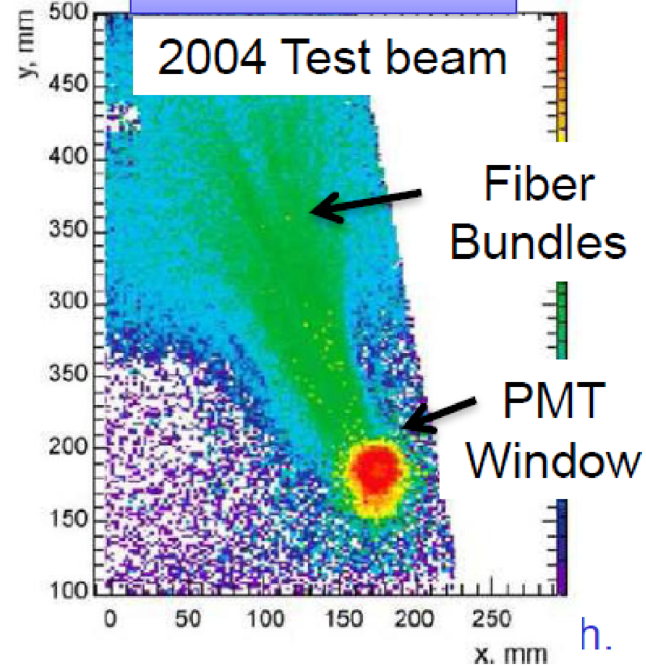
- Appear mostly in a single crystal
- In time with collisions but with wider time-spread (also occur in cosmics at a much lower rate)
- Caused mostly by deposits in APDs by highly ionising secondary particles.

HCAL: HB,HE



- Appear in 1-72 channels
- Random, low rate, ~ 10-20 Hz (E>20 GeV)
- Caused by ion feedback, noise & discharges in HPDs

HCAL: HF



h.

- In time with collisions
- Caused by C^v light by particles going through PMT glass

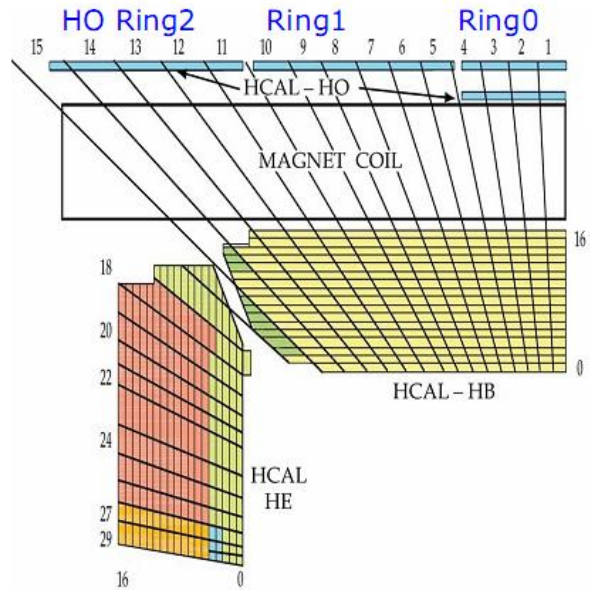
G. Tonelli, CERN/INFN/UNIPI ICHEP10 Paris July, 26 2010 50

Beginning of 2009

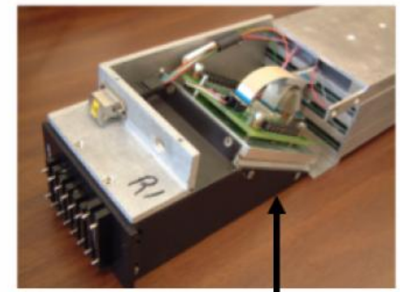
- Replaced HPD's with SiPM in HO (2 readout boxes,~150 channels)
  → good operation experiences

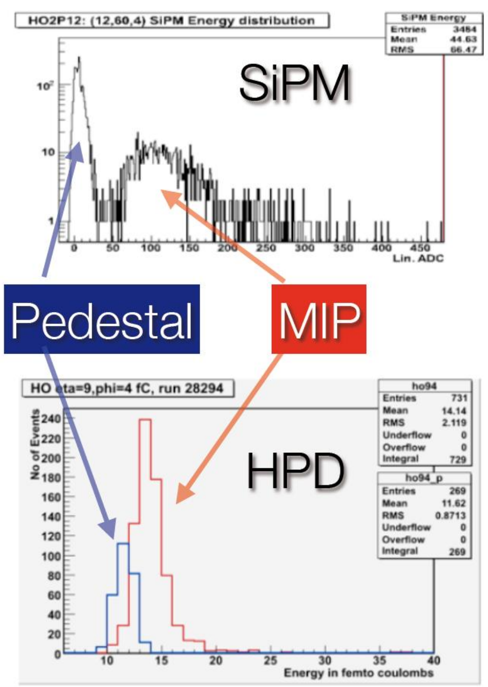
Next Stop: 2012 (?)

- Replace HPD's in HO Ring 1,2
  project approved by CMS and underway
- Approval procedure for Ring 0 under way

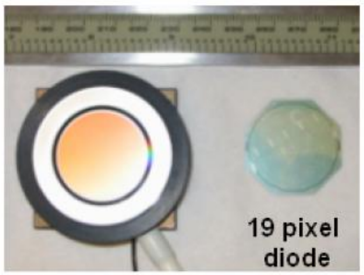


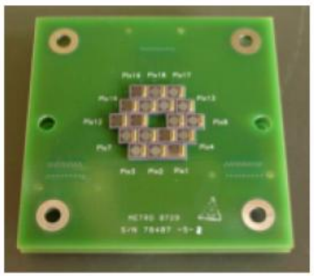
HCAL readout module
4 fibers per tile





Simple replacement of HPD with SiPMs





- Funding from Landes-Excellence Cluster between DESY and University of Hamburg available for HO Ring 0.
- Collaborative effort by DESY, ITEP in Moscow and RWTH Aachen

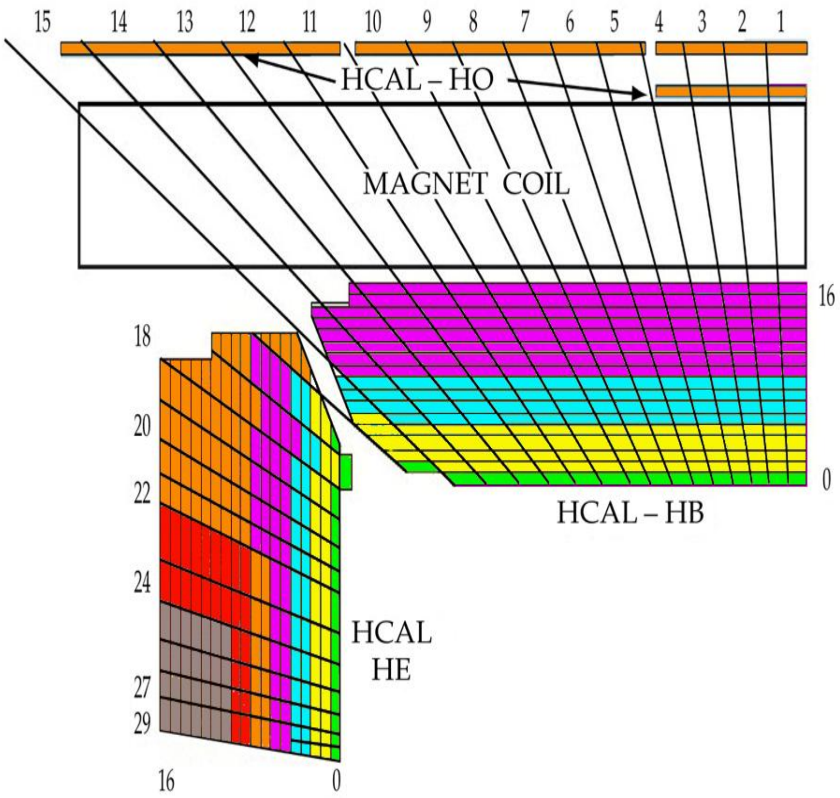
Information provided by K. Borras

Phase-1 Upgrade Plans for HCAL

Next Stop: 2016

under discussion:

- Replace all HPD's with SiPM
- Increase longitudinal segmentation
  18 → 48/64 in HB & HE (4x)
  in HF only 2x
- additional TDC measurement
  improves timing and lepton ID
- Improvements in the readout electronics Front-End (new chips) and Back-end (μ-TCA)
- Changes in the trigger
  (new electronics, granularity x12)



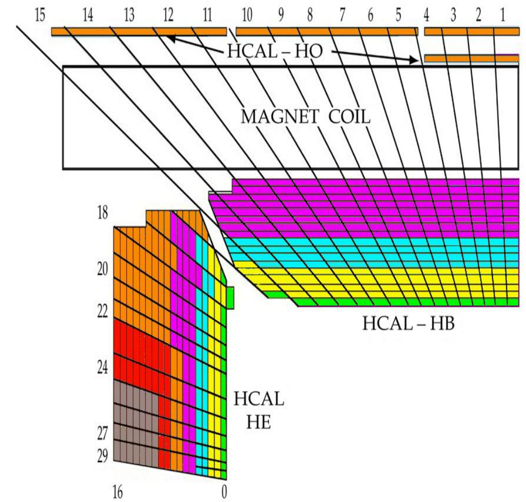
Even farther in the future: very high Lumi 2020/22(?)

- Replace front HE at high η with Quartz-plates or Thick GEM

Information provided by K. Borras

Possible Contributions to HCAL Barrel Upgrade

Depending on approval of third party funding (decision by beginning of November).



If approved, contribute to

- SiPM : choice of sensor, operation and integration aspects

$\rightarrow$ synergy with CALICE experience at linear collider

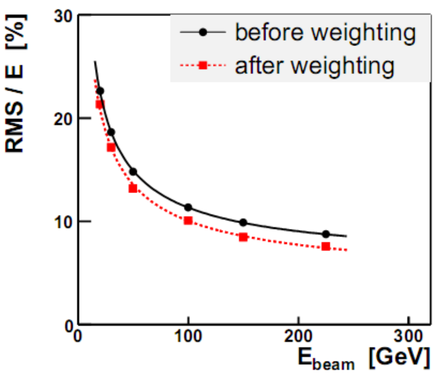
- new Back End (μTCA) electronics

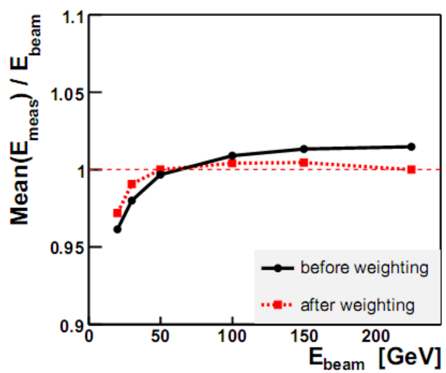
$\rightarrow$ synergy with CALICE and XFEL

- Finer granularity → weighting algorithms for energy reconstruction studied with stand-alone Monte Carlo

→ better resolution & linearity

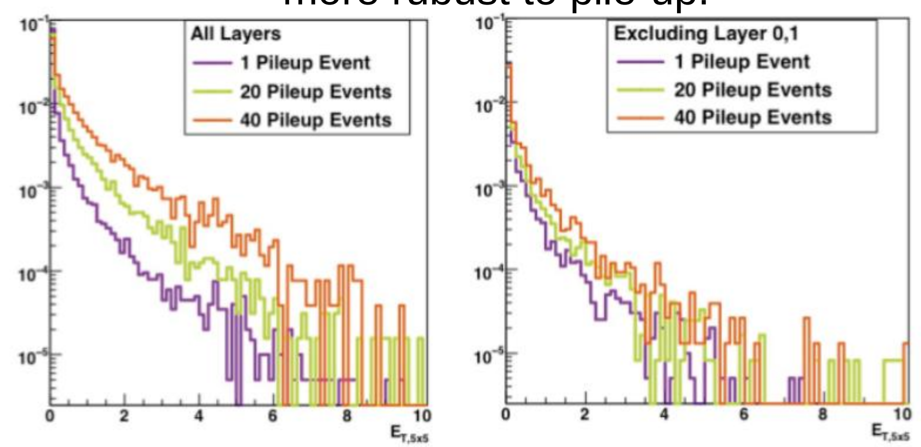
→ implementation in CMS software and further optimization





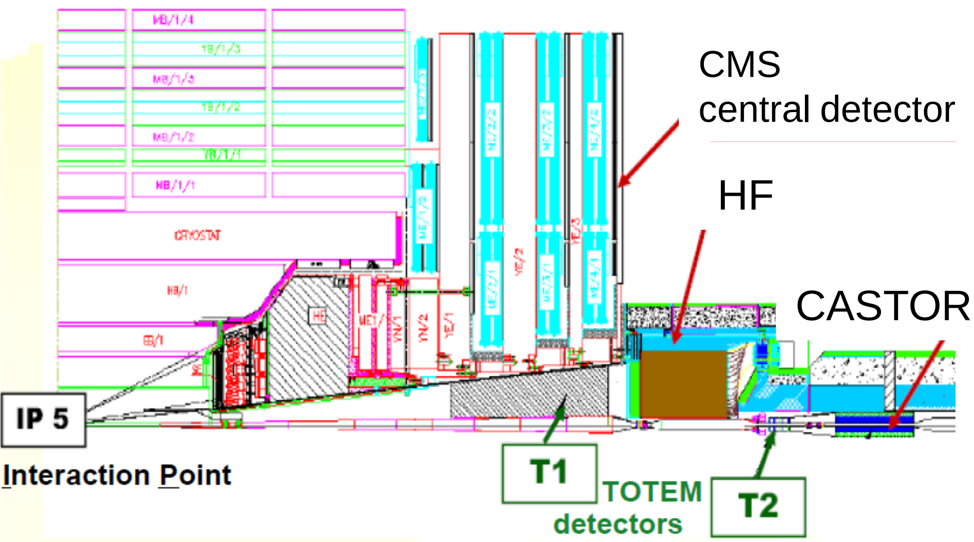
(Matthias Stein, DESY)

more rubust to pile-up:



Information provided by K. Borras

CMS forward HCAL (HF)



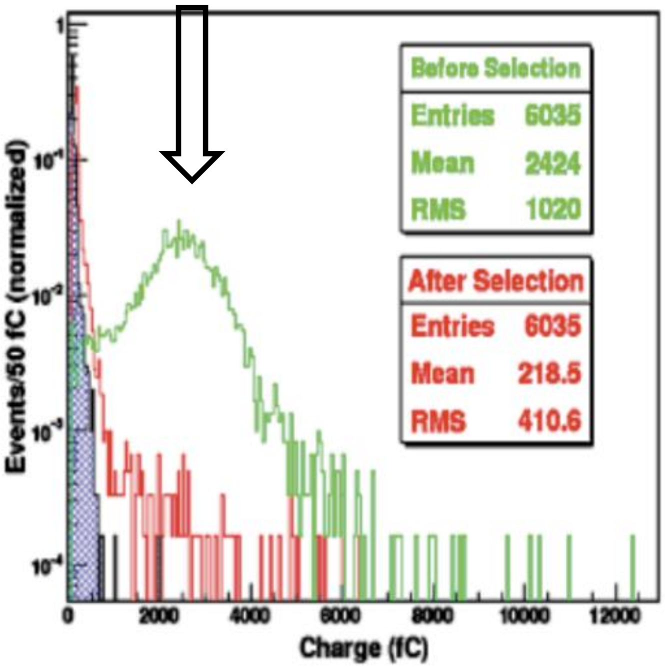
- HF detector: steel absorber structure
- active medium:
  - quartz fibers: fused-silica core and polymer hard-cladding
  - Cherenkov light from quartz fibers is practically insensitive to neutrons and to activation noise

  → fluorine-doped silica cladding more radiation tolerant, replacement considered

- for phase-2 (>2020):
  - maybe complete replacement incl. absorber
  - → Forward Calorimeter Upgrade Task Force (ECAL + HCAL)

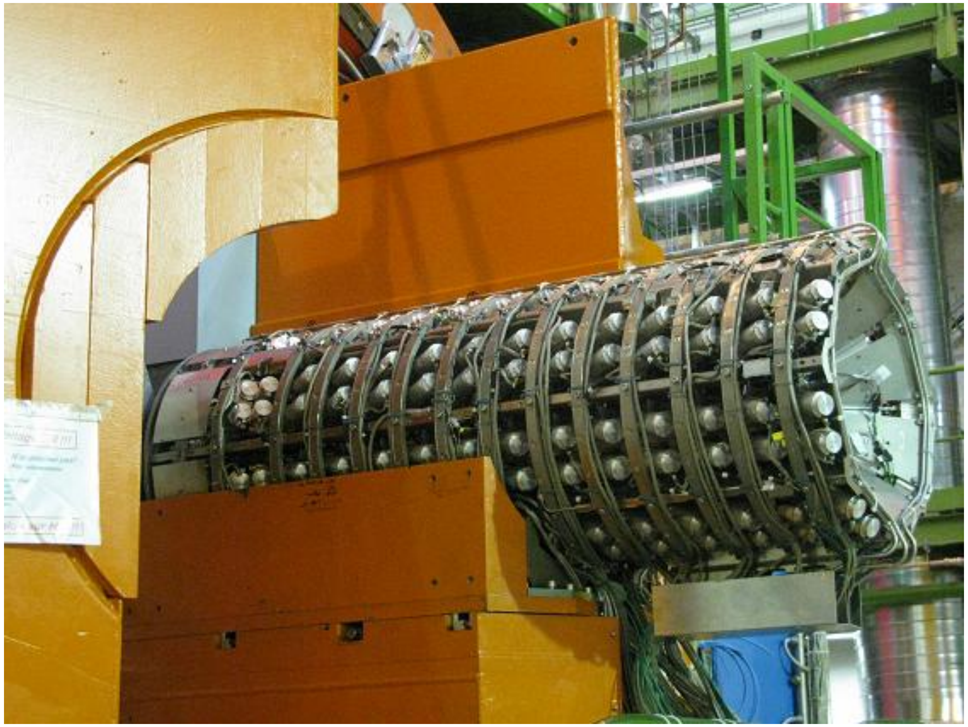
- muons which hit phototube window create high energy signals in forward HCAL

- replace HF phototubes:
  - thinner window (<1 mm)
  - better shielding (metal envelope)
  - 4-way segmented anodes to reject muons hitting PMT window



B. Bilki
CALOR 2010

Upgrade for the CMS CASTOR Calorimeter



Reminder: high magnetic stray field

→needed to change the type of PMT almost on the spot

→ re-cycled fine-mesh PMT`s of the SPACAL Calorimeter of the H1 Experiment

→ working & physics goals reachable

SPACAL PMT’s not radiation hard

→ problem for luminosity > 2012

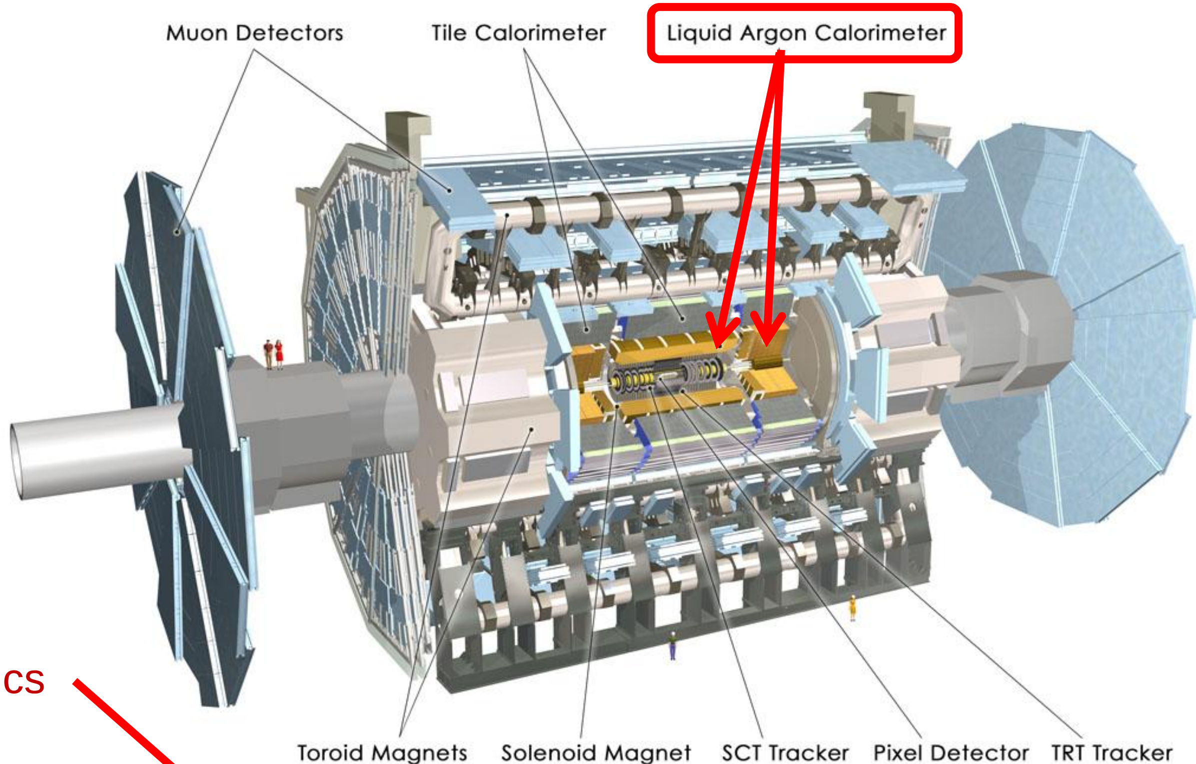
→ need to change PMT’s in 2012 to radiation hard version (very expensive)

→ contributions by Turkey, Brazil and newly approved Helmholtz Young Investigator Group in Karlsruhe for Pierre Auger & CASTOR: high energetic cosmic ray & forward hadron flow at LHC (model tuning)

Information provided by K. Borras

The ATLAS Calorimeter Electronics

- 4 high granularity LAr calorimeters
- 182486 readout channels

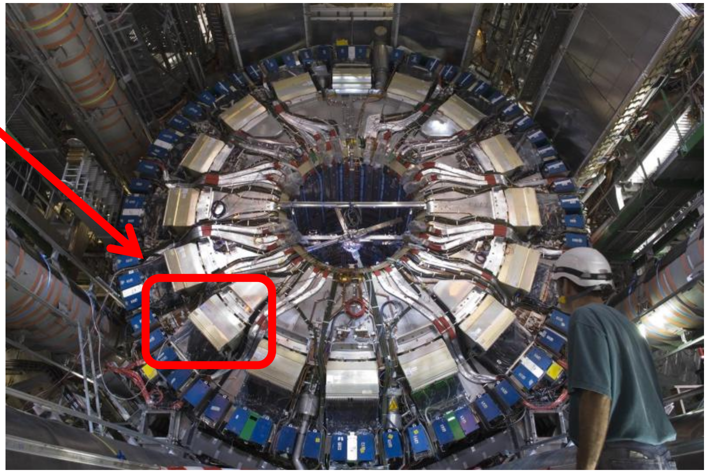


- front-end and trigger-sum electronics
  - 1524 front-end boards (FEB)

  → on-detector in radiation environment

- back-end electronics and more trigger logic
  - 192 read-out driver boards (ROD)

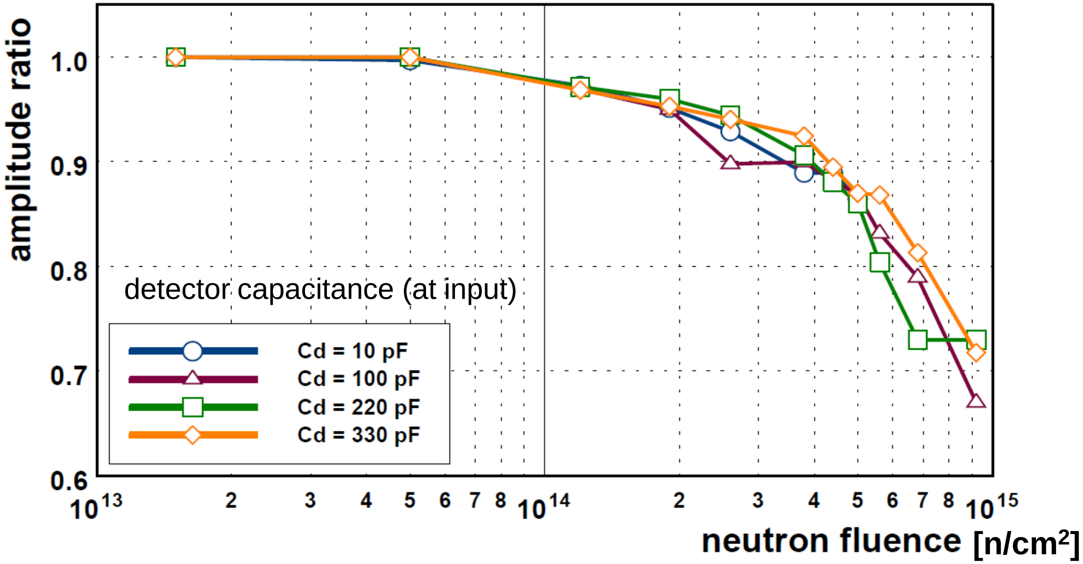
  → shielded counting room



ATLAS LAr Hadronic Endcap Electronics

- front-end electronics of ATLAS Hadronic Endcap (HEC) is mounted inside the cryostat
- ASIC for preamplifier and summing of trigger signals in GaAs 1µm technology
- 0.2×10^{14} n_{eq}/cm^2 expected for 10 years at nominal LHC luminosity (~1000 fb^{-1})
- signal amplitude degrades at ~3×10^{14} n_{eq}/cm^2
- could be at the margin for HL-LHC (+ageing !)

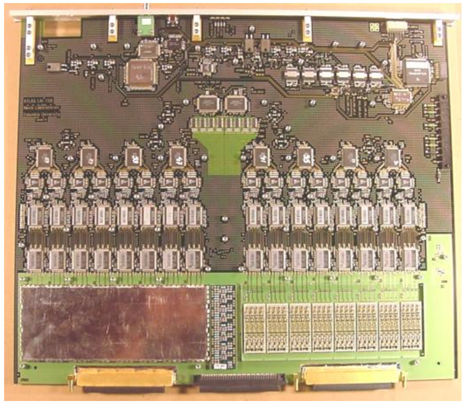
- if HEC electronics must be replaced
→ cryostat must be opened
→ very delicate and long operation



- new ASIC technologies tested (MPI Munich)
- must operate at room and LAr temperature (87 K) with equal performance
→ low power, low noise, stable signal amplitude, small gain variation between channels (<1%)

- candidate technologies:
  - SiGe Bipolar → radiation tolerant up to 2×10^{15} n_{eq}/cm^2 , but gain is temperature dependent
  - Si CMOS 250/350 nm and GaAs 250 nm
  → radiation tolerant and good temperature stability

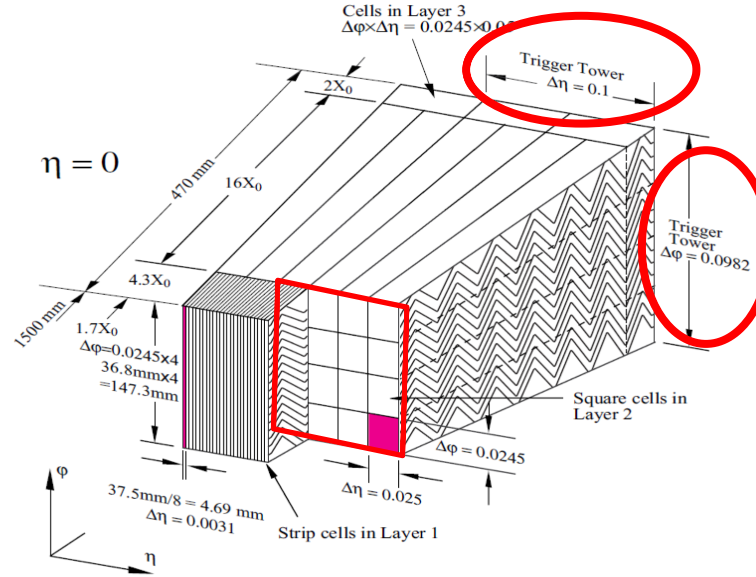
Current Limitations of ATLAS LAr Front-End



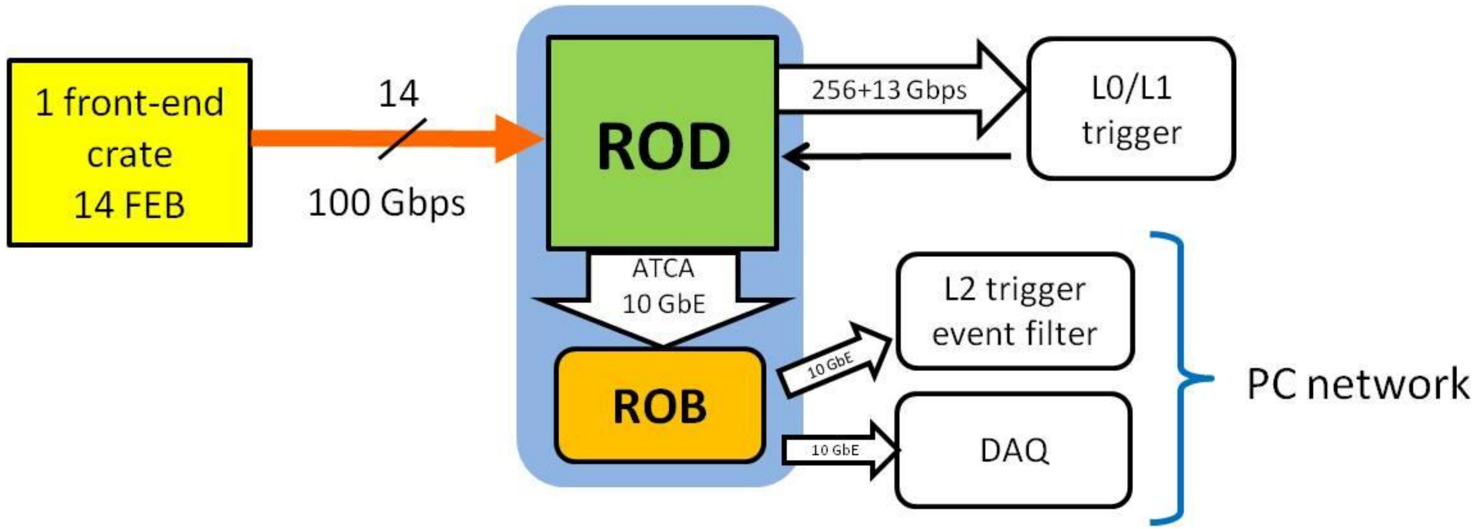
- main concern:
  - electronics will run >>10 years in 2020
  - qualified for radiation levels of 10 years of normal LHC operation (incl. safety factors)
  - HL-LHC: 300 Gy and 10^{13} n_{eq}/cm^2
  - small number of spares (6%)

- current performance limitations:
  - fixed analog trigger sums
  - small analog buffer
    → incompatible with longer L1 latency
    → dead-time

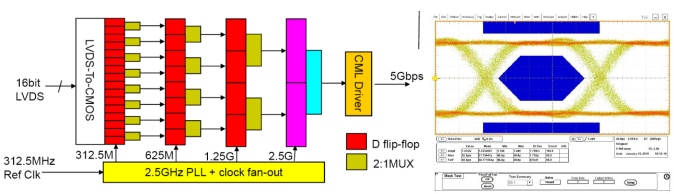
- read-out and trigger concept for HL-LHC:
  - front-end and read-out driver prepare digital data for hardware triggers



New Prototype Design



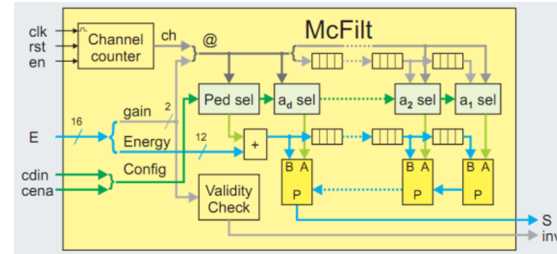
- R&D baseline:
  - shaping and digitization at high rate on front-end board → 128 channels at 40 MHz
  - transfer rate to off-detector electronics → 100 Gb/s per front-end board → total 150 Tb/s
  - radiation tolerant optical links at ~10 Gb/s
  - multi-fiber optical link



  - fully digital off-detector trigger
    → digital pipeline on Read-Out Driver (ROD) → long latency buffer up to ms
    → fast trigger sums on ROD → calorimeter trigger
    → more flexible and higher trigger granularity

Development of new Read-Out Driver

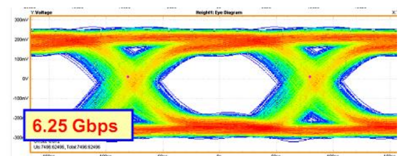
- digital part of the readout is based FPGAs (tested: Xilinx Virtex 5+6, Altera Stratix II and IV)



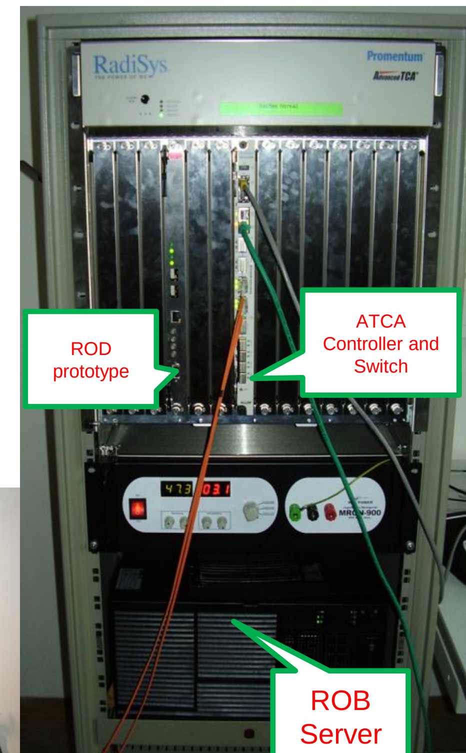
S. Stärz, TU Dresden

- ongoing R&D by LAPP Annecy, Arizona, BNL, Helmholtz YI Group at TU Dresden

- design and proof-of-principle for high bandwidth readout:
  - ROD prototypes in ATCA form factor with and w/o mezzanine cards (AMC)
  - test of serializer-deserializer:
    - 6.25 Gb/s x 12 = 75 Gb/s achieved

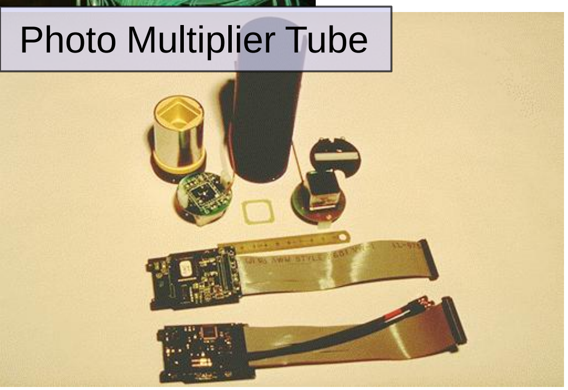


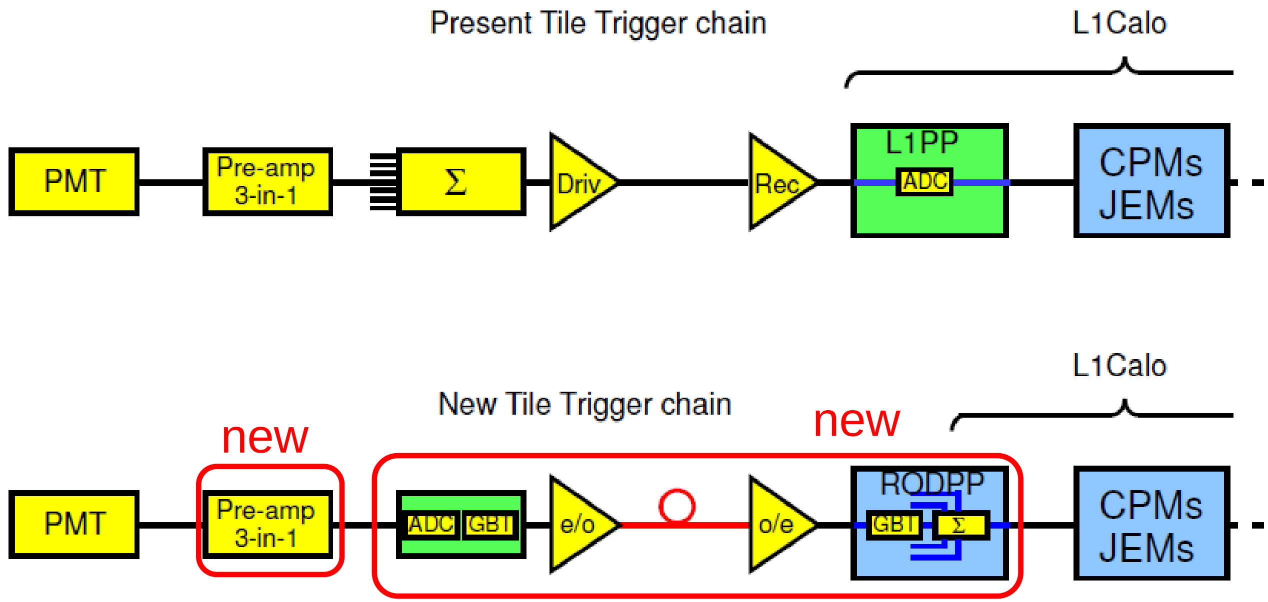
  - digital signal filter design with minimal latency
    - suppress electronic and pile-up noise @ 40 MHz
  - interface for L0/L1 trigger
    - pre-processing of data for L0/L1 input
    - long-latency data buffering
  - interface to DAQ based on standard protocol, e.g. FPGA sending data to server CPU memory via 10 Gb/s Ethernet



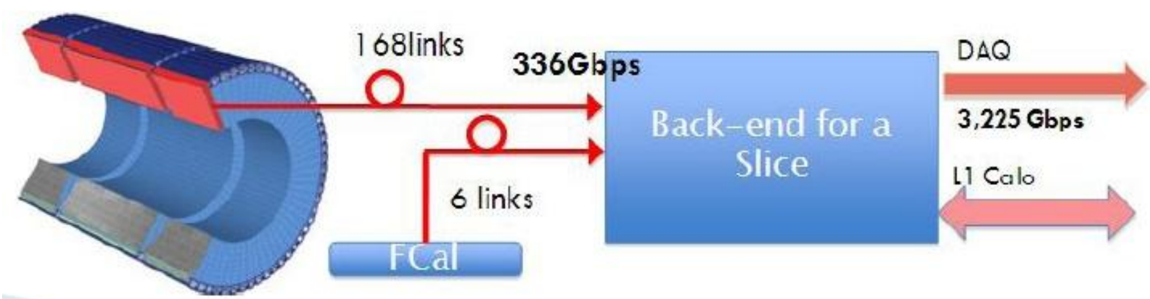
- simulation of free-running read-out

New ATLAS Tile Calorimeter Electronics

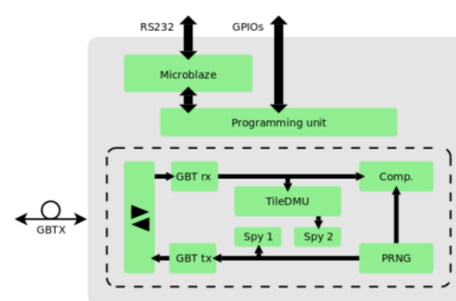




- new active HV dividers for PMTs → more stable signal amplification in dynodes
- prototypes for pre-amplifier, shaper, integrator are being developed (ASIC)
- digital signals for trigger and DAQ



total data rate:
336 Gb/s x 64 = 20 Tb/s



- signal transmission is tested using FPGA, similar to LAr
- protocol based on CERN Gigabit Transceiver (GBT) project

Summary

- ATLAS and CMS calorimeters require upgrades
  - of components that do/will not operate as expected (ageing, noise, failures)
  - in high radiation areas → mainly endcap and forward region

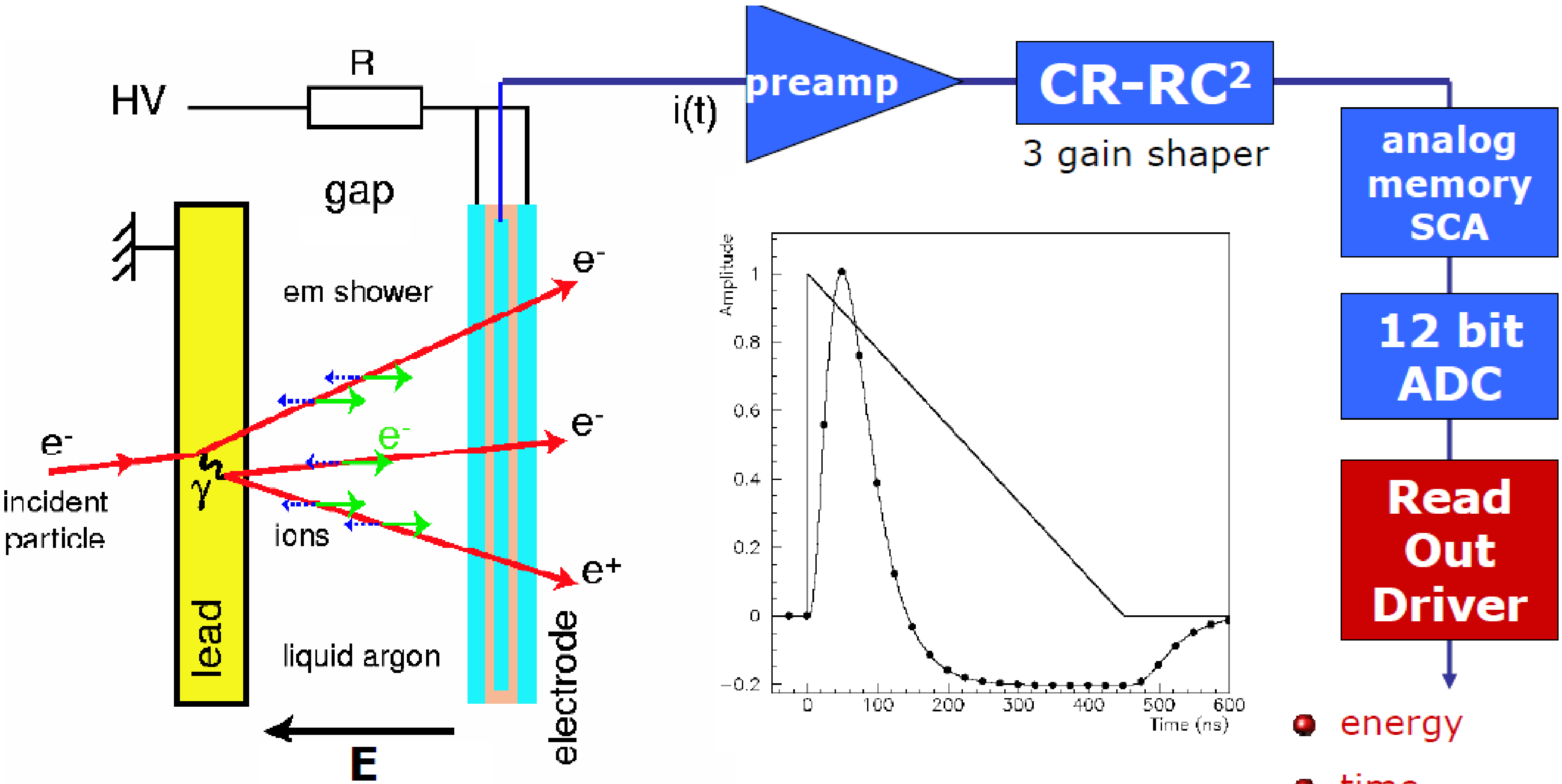
- LHCb is testing reliability of ECAL calorimeter in testbeam and LHC tunnel

- upgrade plans for 2012/13 and 2016, large uncertainties for 2020 :
  - Technical Proposal by CMS, Letter of Intent by ATLAS

- ongoing R&D:
  - tests of forward and endcap detectors in high radiation environment expected at HL-LHC
  - develop and test sensor technology and electronics individually and in prototypes
  - work on system integration only started for the long-term projects
  - simulation and optimization of detector performance with different upgrade options

Backup

LAr Calorimeter Signal

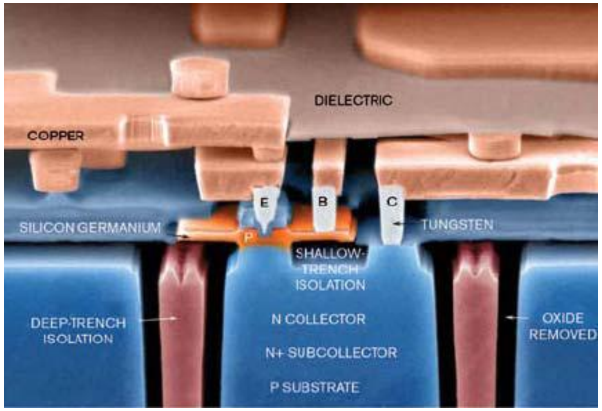


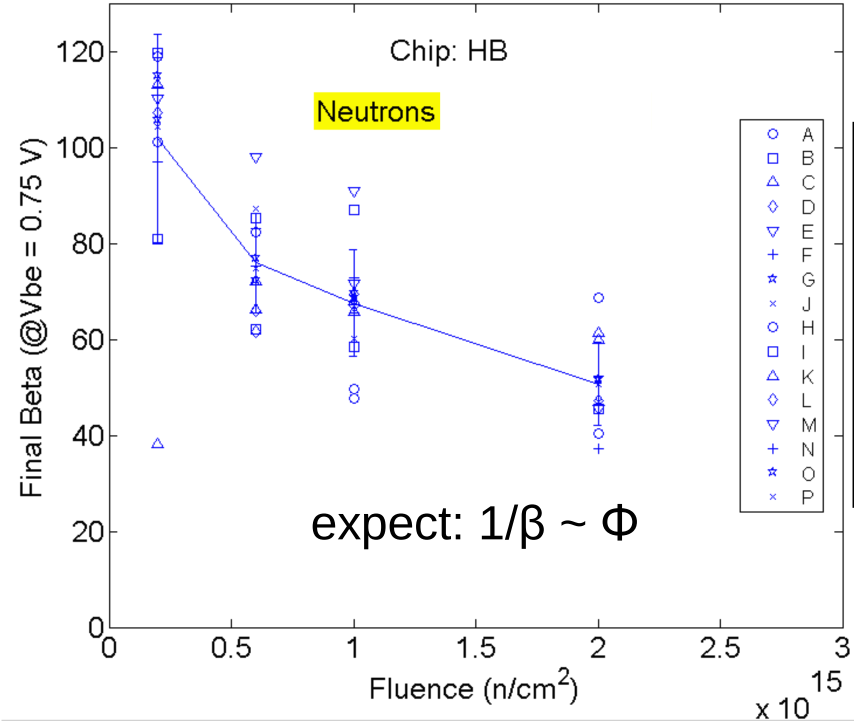
- energy
- time
- quality factor
- monitoring

Analog Front-End R&D

- SiGe IBM 8WL BiCMOS process (0.13 micron)
  - technology also studied for ATLAS silicon strip tracker readout and ILC detectors

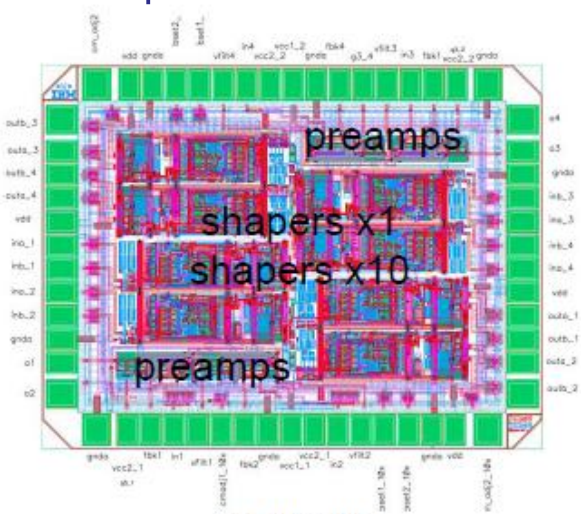
- irraditation tests with spare IBM test structures
- example: final gain after neutron irradiation:
  - $\beta > 50$ at 10^{14} n_{eq}/cm^2





Tr.	Emitter size
A	.12x.52x1
B	.12x1x1
C	.12x2x1
D	.12x3x1
E	.12x4x1
F	.12x8x1
G	.12x12x1
H	.12x1x2
I	.12x3x2
J	.12x8x2
K	.12x12x2
L	.12x3x4
M	.12x8x1
N	.12x3x6
O	.12x8x6
P	.12x16x6

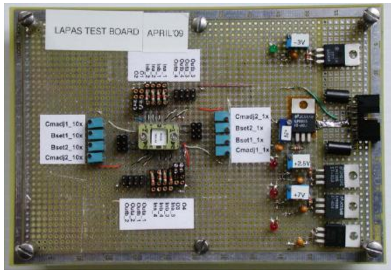
- SiGe used for pre-amplifier + shaper:
  - low noise (2.2 nV/√Hz)
  - high dynamic range (16 bit)
  - low power

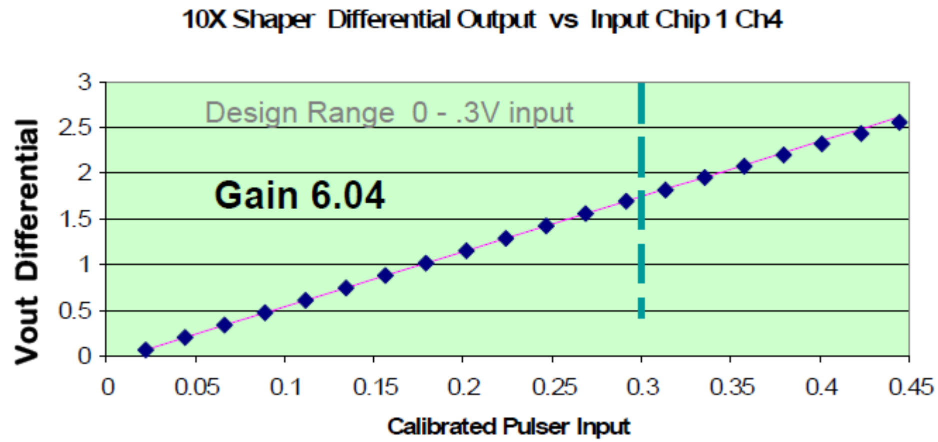


LAr Chiplet
2mm X 2mm

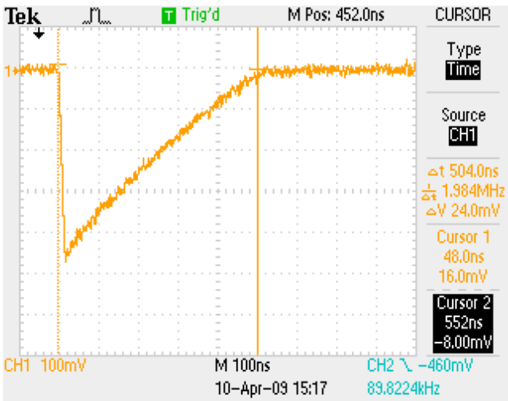
Preamp and Shaper Prototype Tests

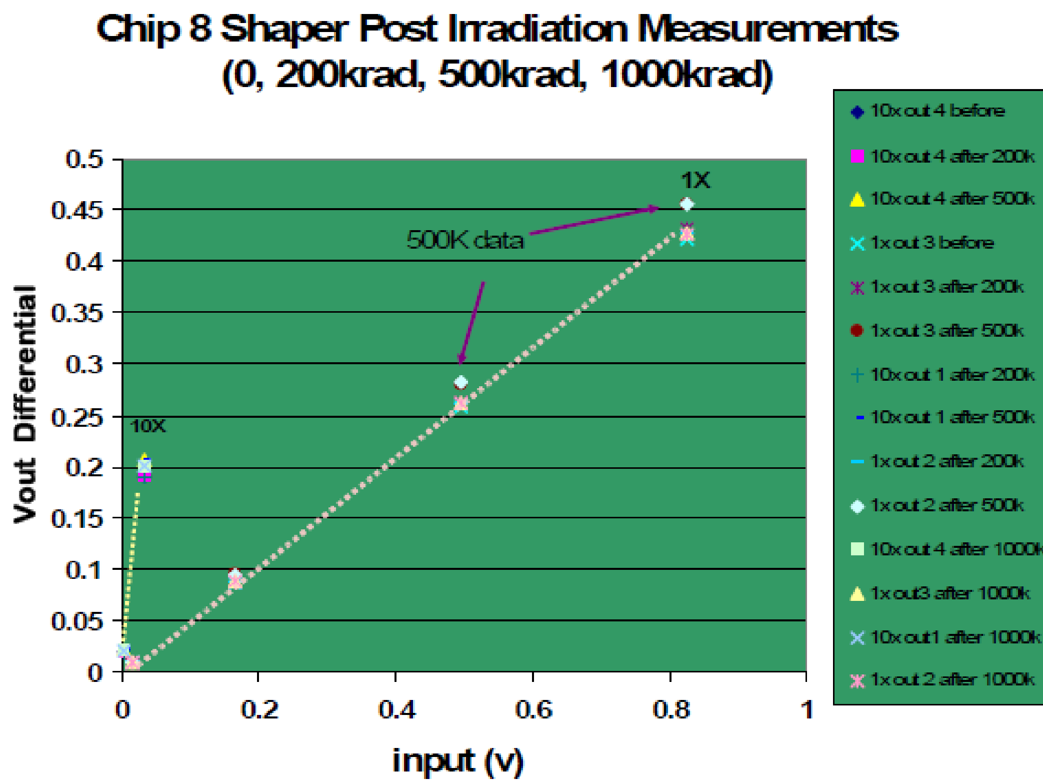
- Test board:

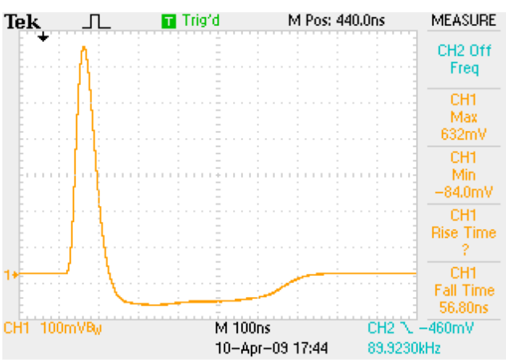




Shaper Input Signal



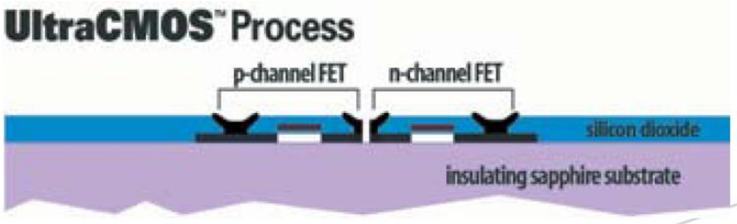




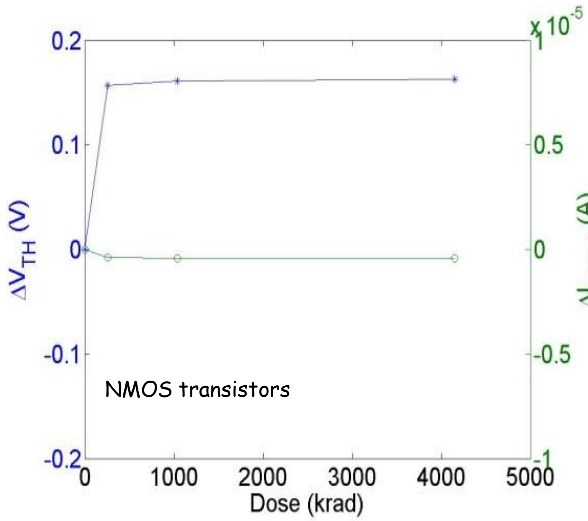
LAPAS Shaper Output

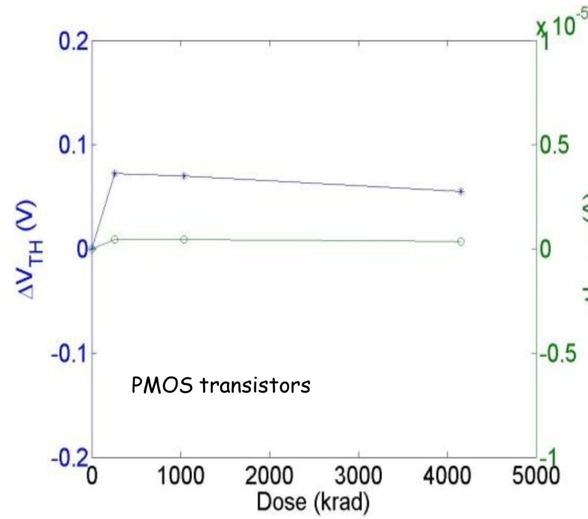
ATLAS Raditation Hard Optical Links

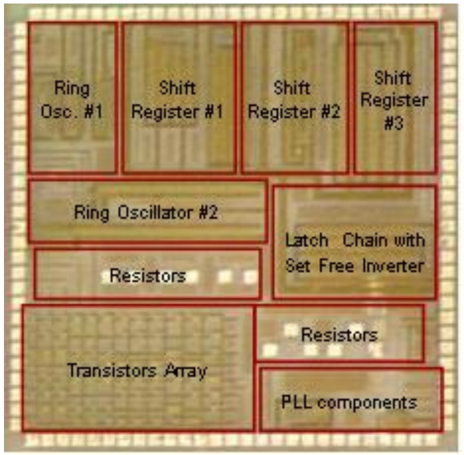
- Silicon-on-Sapphire (SoS) technology:
  - 0.25 µm UltraCMOS by Peregrine Semiconductors
  - low power, low cross talk
    → good for mixed-signal ASIC designs



- TID and SEE radiation tests performed in 2007:
  - gamma irradiation with ^{60}Co source up to 4 Mrad = 40 kGy





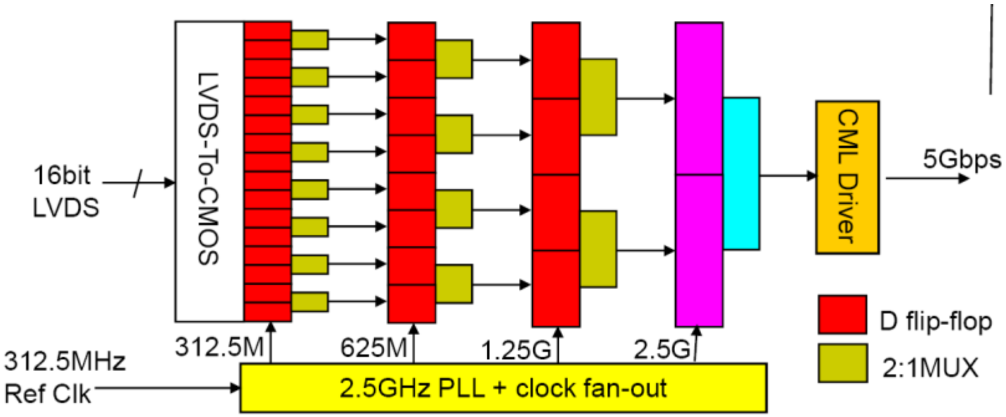


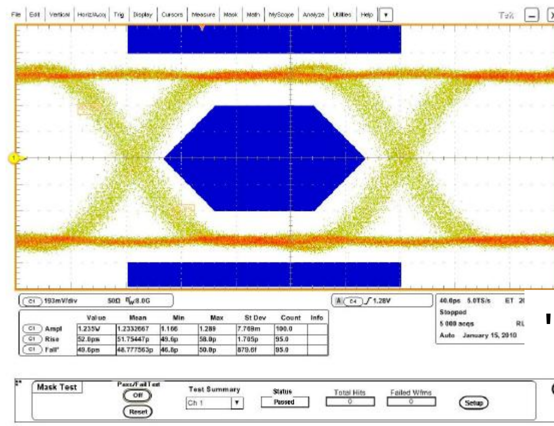
    - small leakage currents (250 nA) and small threshold voltage increase

  - irraditation in 230 MeV proton beam
    - no SEE observed in shift registers at a flux of 7.7×10^{8} p/cm^2/sec
    - still correctly functioning after total fluences of 1.9×10^{15} p/cm^2 (106 Mrad(Si))

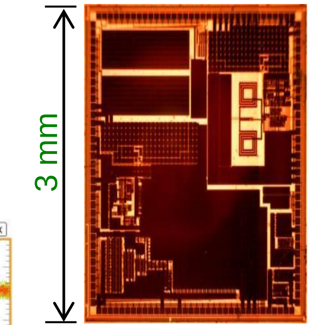
ATLAS Link-On-Chip Prototype

- goal: send data at 10 Gb/s on optical link → need to serialize input data
- current prototype manages 5 Gb/s with 3 stage multiplexing and 1 high-performance D-flip-flop





"eye diagram"

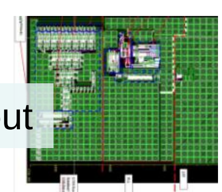


SMU_P1

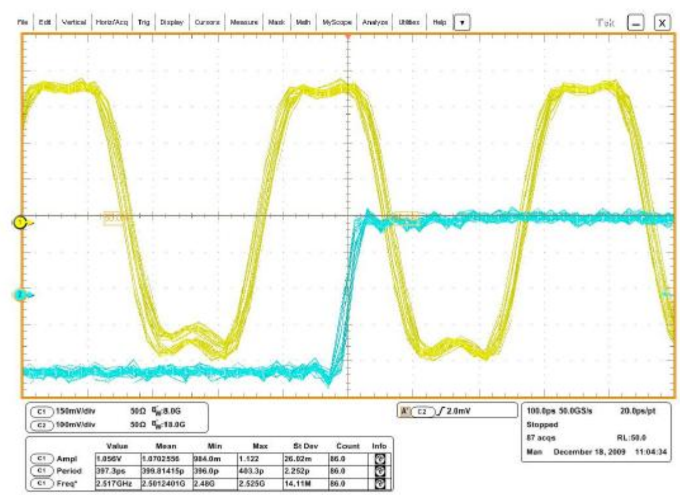
- transmission bit error rate lower than 1×10^{-12}
- power consumption is below 100 mW/Gbps.

- effort towards a 5 GHz Phase Lock Loop:
  - needed for ultimate goal of a ~10 Gbps link
  - first tests are OK
    (jitter, power consumption, locking frequency, ...)

- optimistic for 10 Gb/s



LOC2 layout

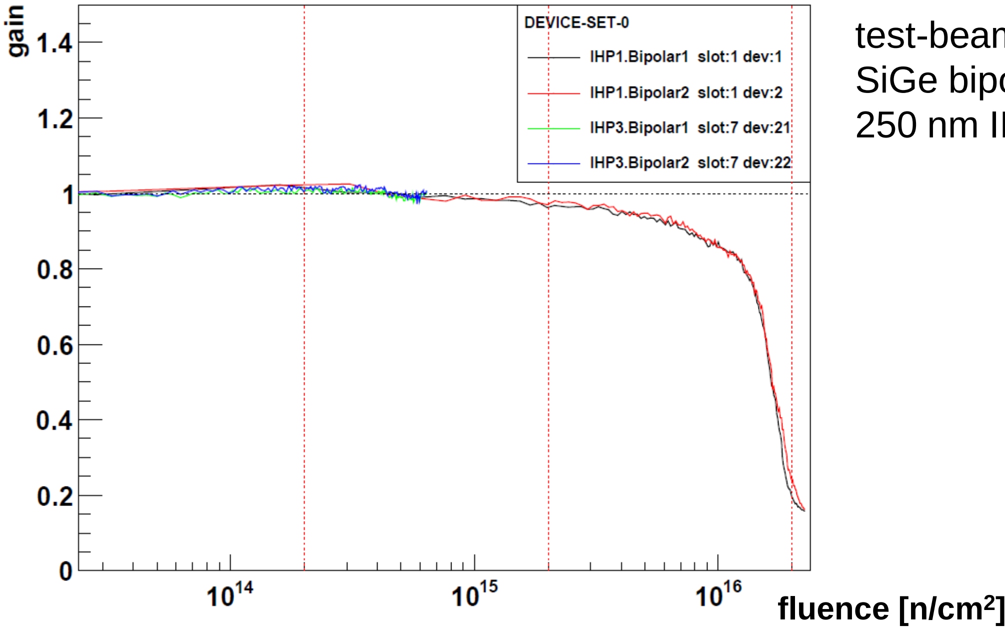


The output clock locks to the input clock.

ATLAS LAr Hadronic Endcap Electronics

- new ASIC technologies tested by MPI Munich
- must operate at room and LAr temperature (87 K) with equal performance
  → low power, low noise, stable signal amplitude, small gain variation between channels (<1%)

- candidate technologies:
  - SiGe Bipolar → radiation tolerant up to 2 x 10^{15} n_{eq}/cm^2 , but gain is temperature dependent
  - would require adjustment at LAr temperature



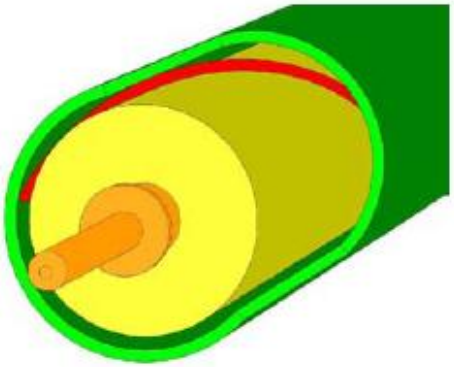
test-beam example:
SiGe bipolar transistors
250 nm IHP process

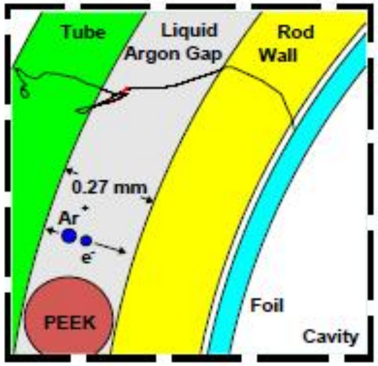
  - Si CMOS FET 250/350 nm technology → radiation tolerant and good temperature stability
  - GaAs FET 250 nm technology → radiation tolerant and good temperature stability

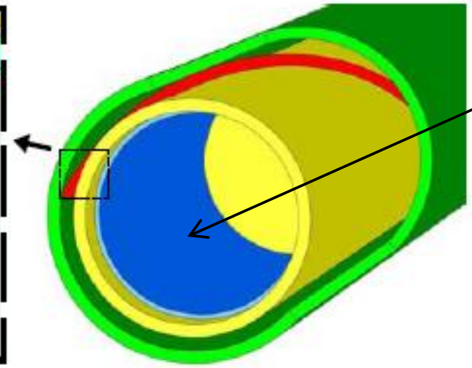
- SiGe and CMOS will be further pursued

ATLAS sFCal

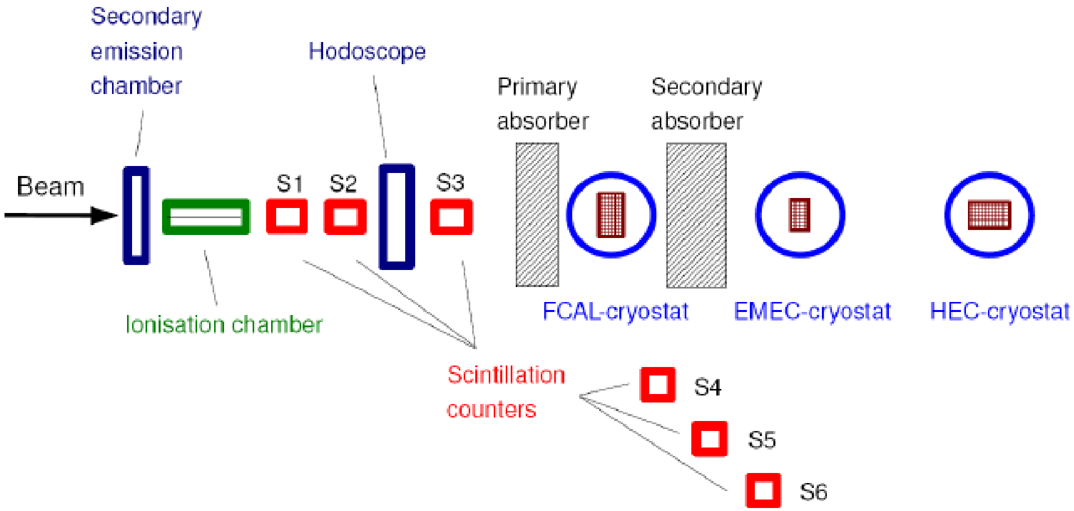
- solution 1: smaller LAr gaps reduce ion build-up effects and HV drop
- build new sFCal (Cu/LAr) calorimeter with 100 μm gaps instead of 250 μm to replace FCal1
- two on-going R&D projects:
  - test FCal-tube with ^{90}Sr foil inside a hollow rod to measure ion-build effects

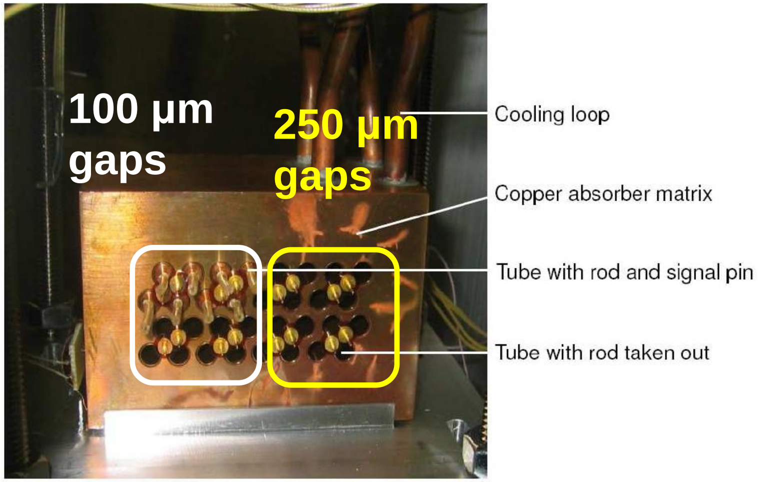






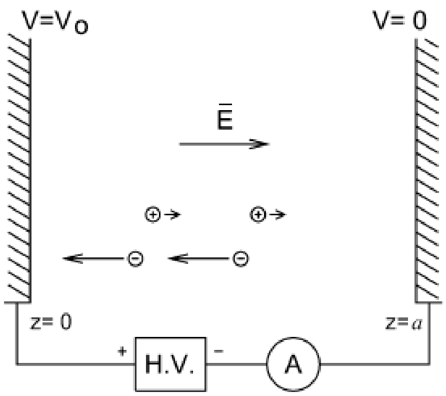
  - test beam measurement of pulse shapes in Protvino/Russia with a high-intensity proton beam

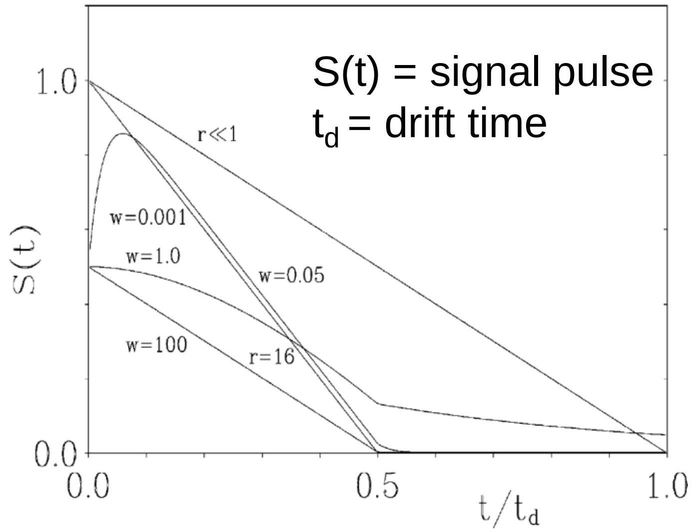




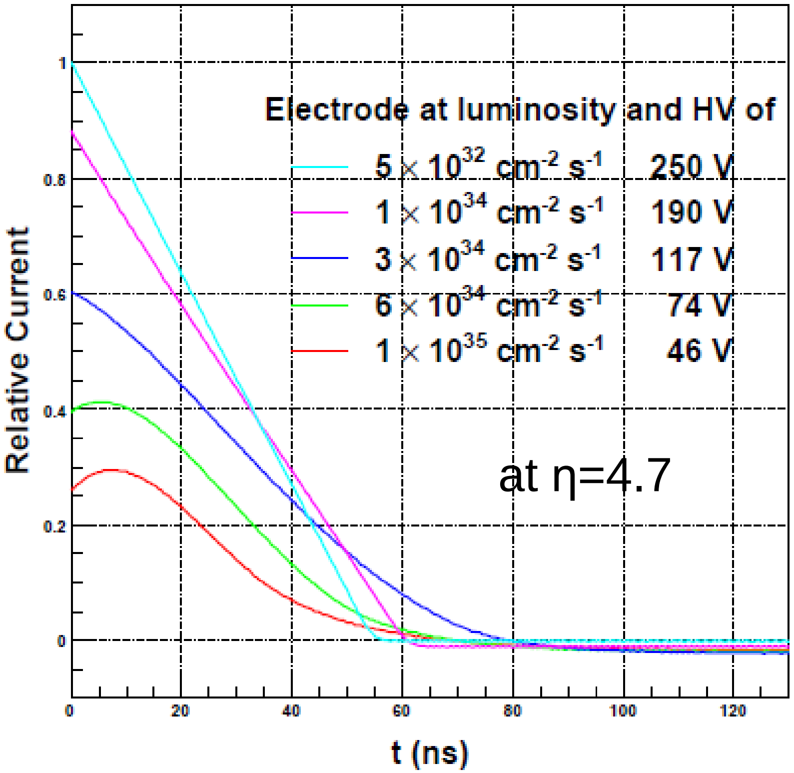
Signal degradation in LAr gap

- critical ionisation rate: rate of newly created Ar+ ions equal to rate in which ions are removed from the gap
- r = rate relative to critical rate
- relative of LAr+ e- recombination rate w
  - w=0 no recombinations
  - w→∞ recombination removes practically all Ar+ e- pairs
- signal is obtained from fast-moving e- (Ar+ are slow)



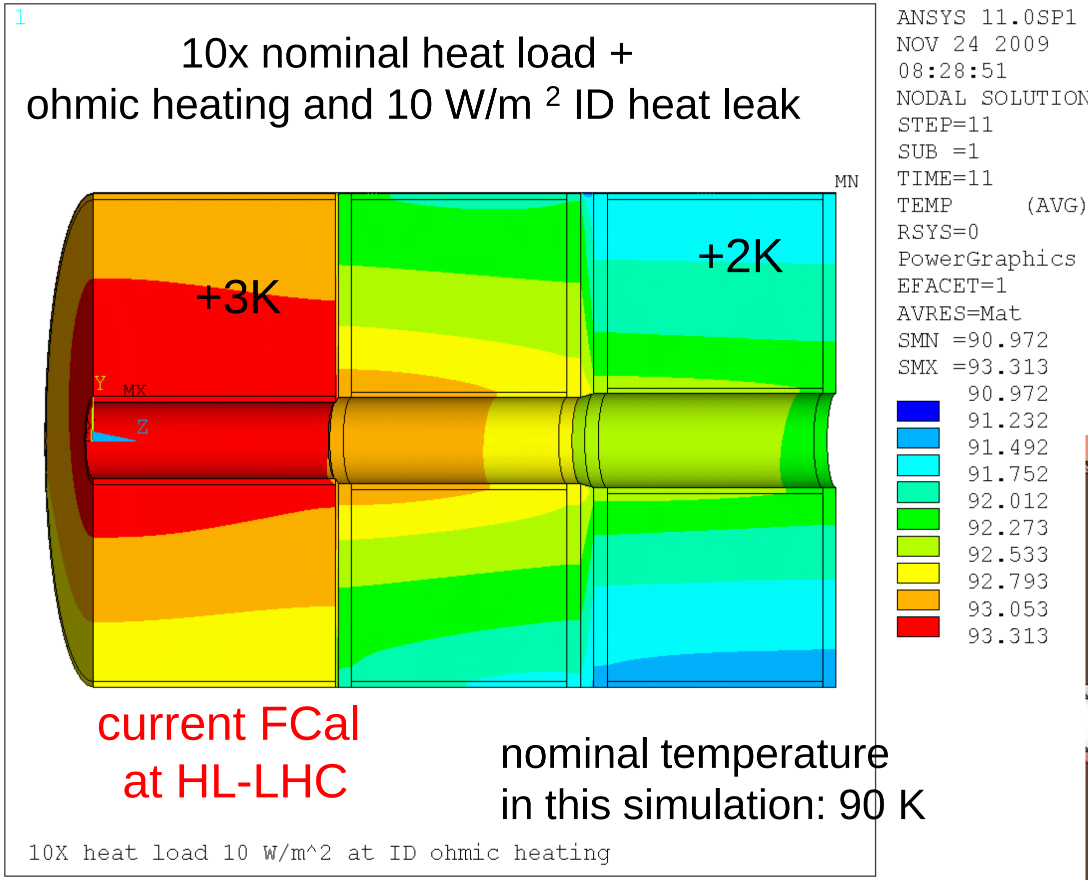


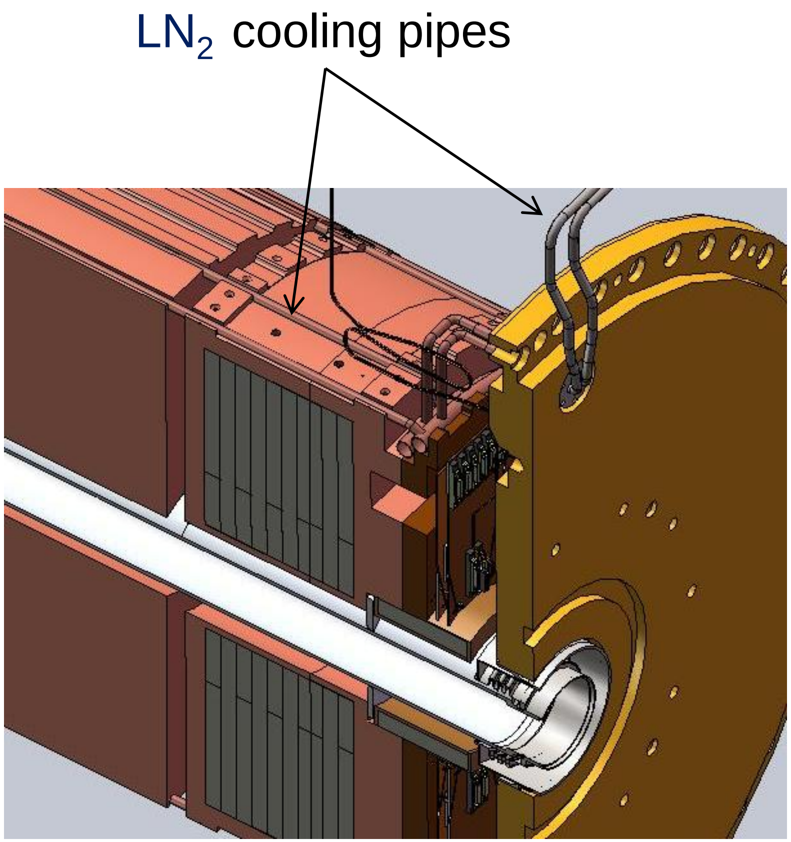
- at high luminosity
  - not all Ar+ are removed from gap → ion build-up
  - recombination rate rises → slow-rising pulse
  - although HV resistors have high value
    → voltage drop over LAr gap
- amplitude no more proportional to energy deposit



Limitations of Current FCal

- LAr heating/boiling can possibly be cured with additional LN_2 cooling loops

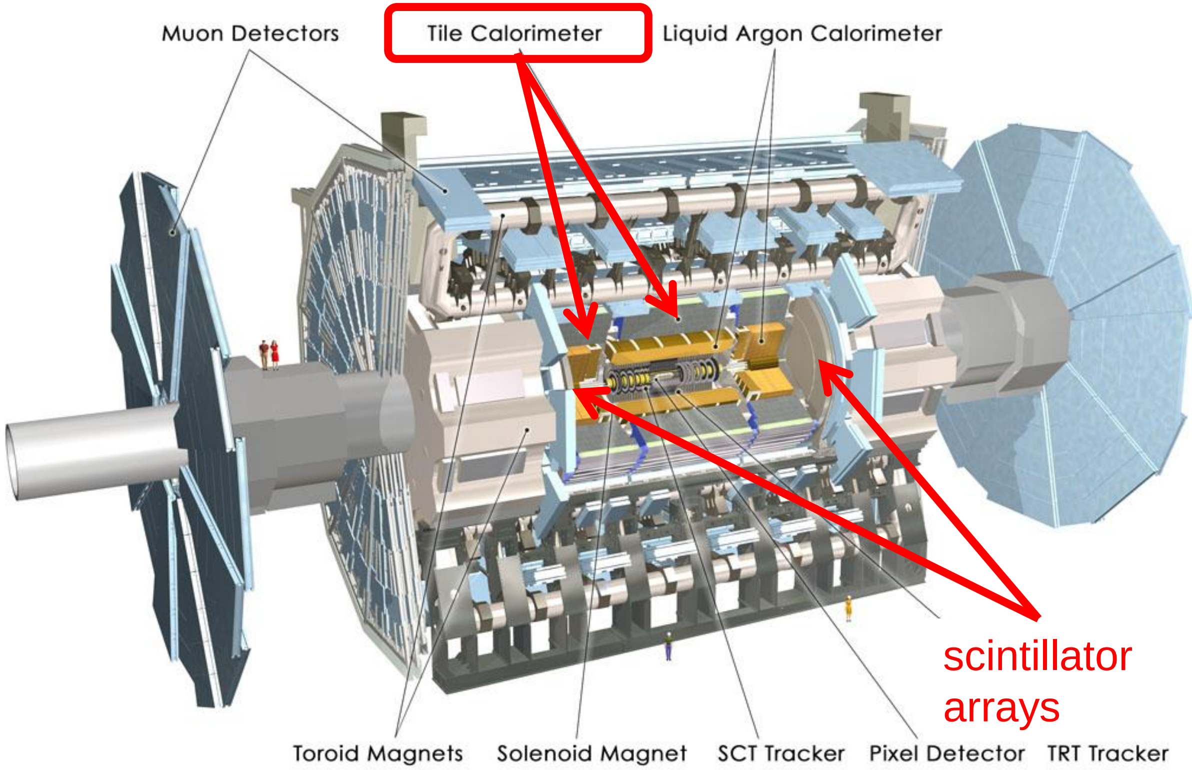




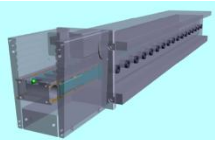
- LN_2 cooling can remove a 10x LHC heat load (562 W on 3.787 m^2 surface) using a flow of 0.0028 kg/s at 0.070 m/s

The ATLAS Tile Calorimeter Electronics

- Tile Calorimeter: Fe/Scintillator



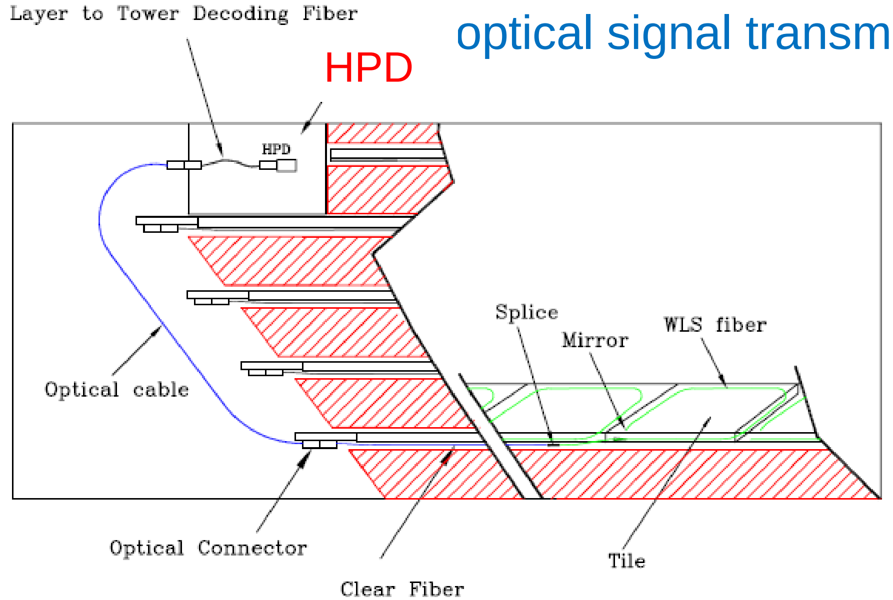
- Tile Calorimeter upgrade plans:
  - electronics, connectivity, cooling is arranged in "drawers" → replace with newly designed modules
  - replacement of gap and cryostat scintillators



- new readout-electronics (same arguments as for LAr read-out)
  - higher radiation tolerance, normal ageing of components
  - improved trigger capabilities → higher granularity

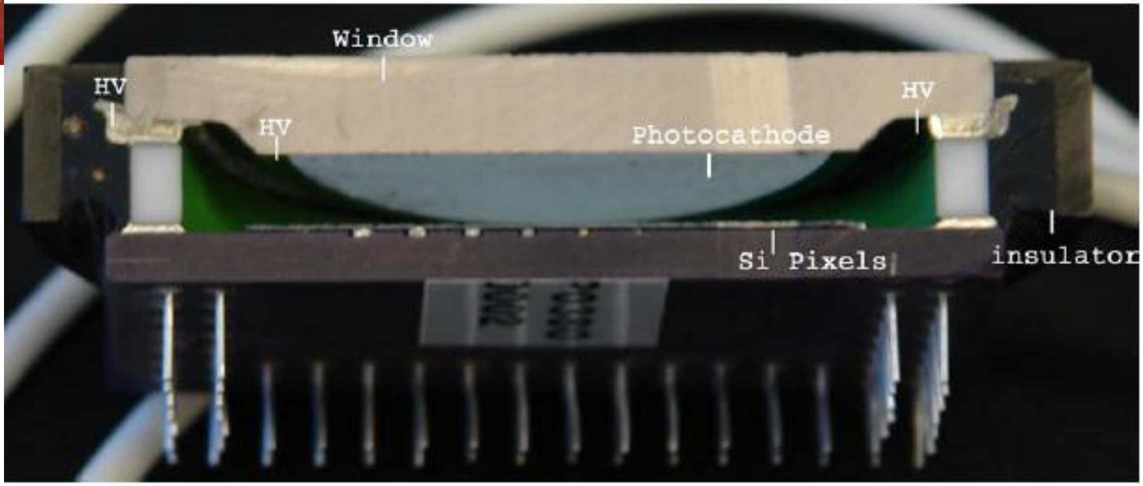
CMS HCAL barrel today

optical signal transmission



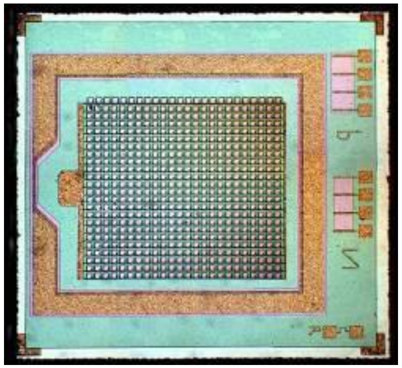
WLS=wavelength-shifting fibre

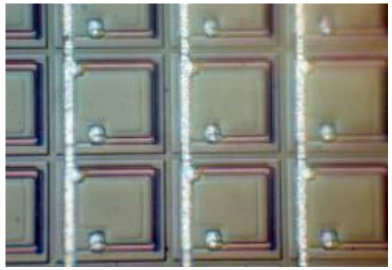
Hybrid Photo Diode

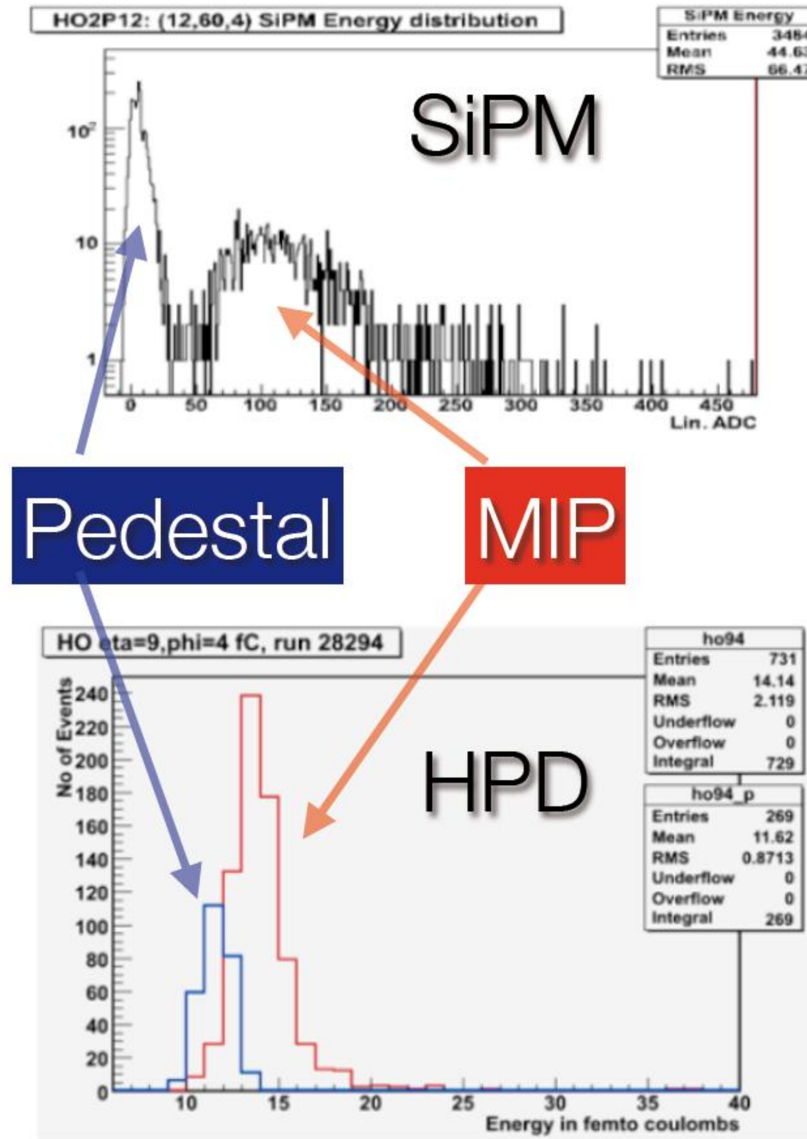


CMS HCAL Barrel and Endcap with SiPM

- Silicon Photo Multiplier (SiPM)







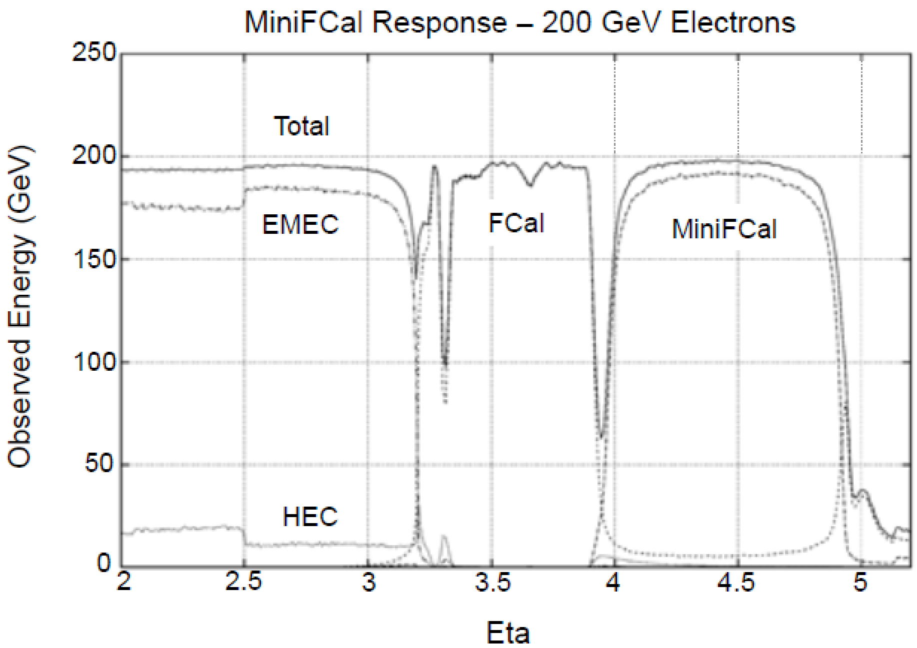
- array size 0.5x0.5 mm² up to 5x5 mm²
- pixel size 10 µm to 100 µm

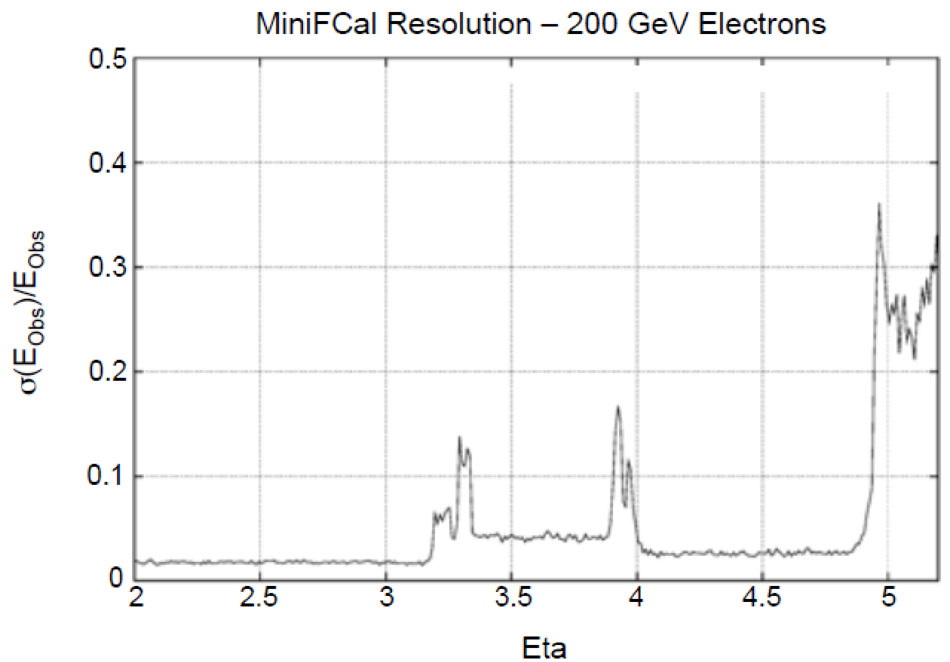
- about 30% quantum efficiency (x 2 of HPD)
- gain ≈ 10^6 (x 500 of HPD)
- more light (40 photo-electrons/GeV), less photostatistics broadening

I.K. Furic ICHEP2010

ATLAS MiniFCal

- simulated energy response and resolution to single electrons of 200 MeV:





- resolution typically <5% in MiniFCal region
- edge-effects need further studies

- radiation dose deposited in CMS inner tracker after 500 fb^{-1} (~10 years of operation)

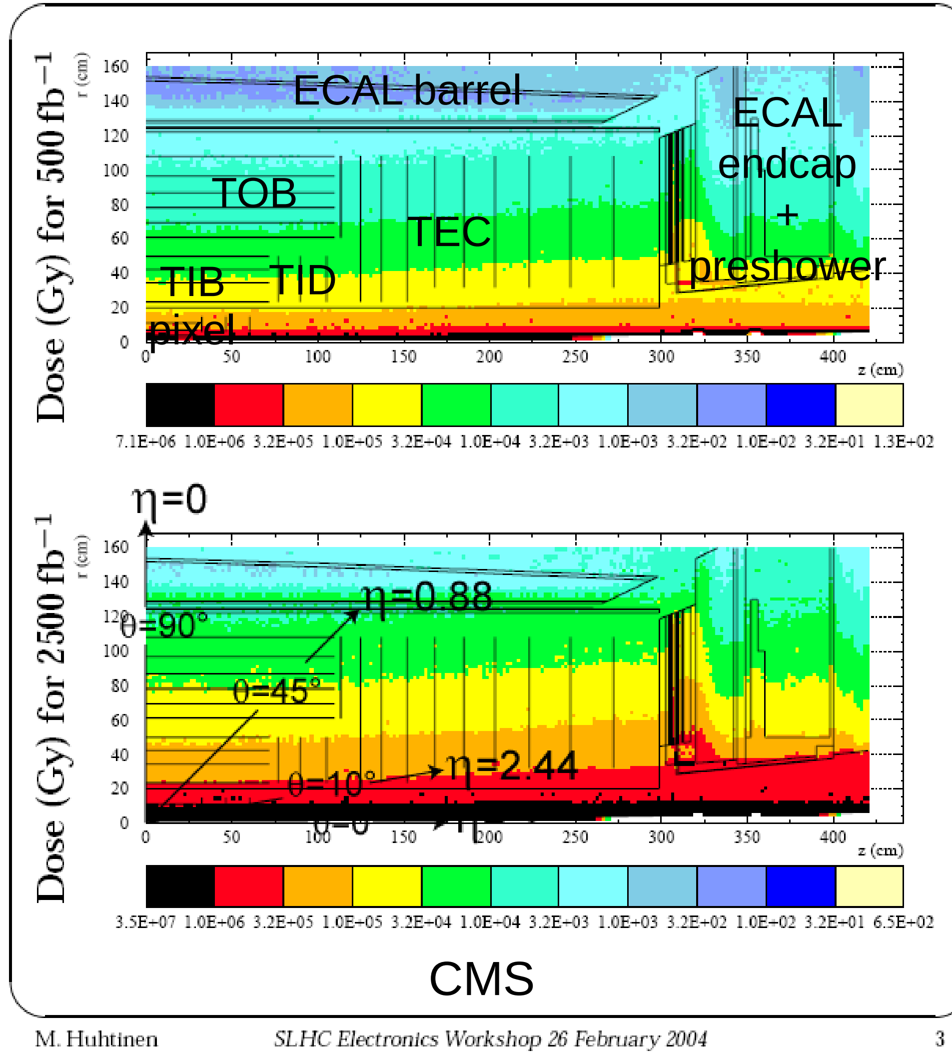
Radius (cm)	Fluence of fast hadrons (10^{14} cm^{-2})	Dose (kGy)	Charged particle flux ($cm^{-2}s^{-1}$)
4	32	840	10^8
11	4.6	190	
22	1.6	70	6×10^6
75	0.3	7	
115	0.2	1.8	3×10^5

- 1 Gy = 1 Joule/kg
- fast hadron fluence approx. equivalent to 1 MeV neutron equivalent fluence

- during detector design safety factors of ~2 are applied for radiation tolerance
- for non-commercial and commercial electronics: safety factor 2-5

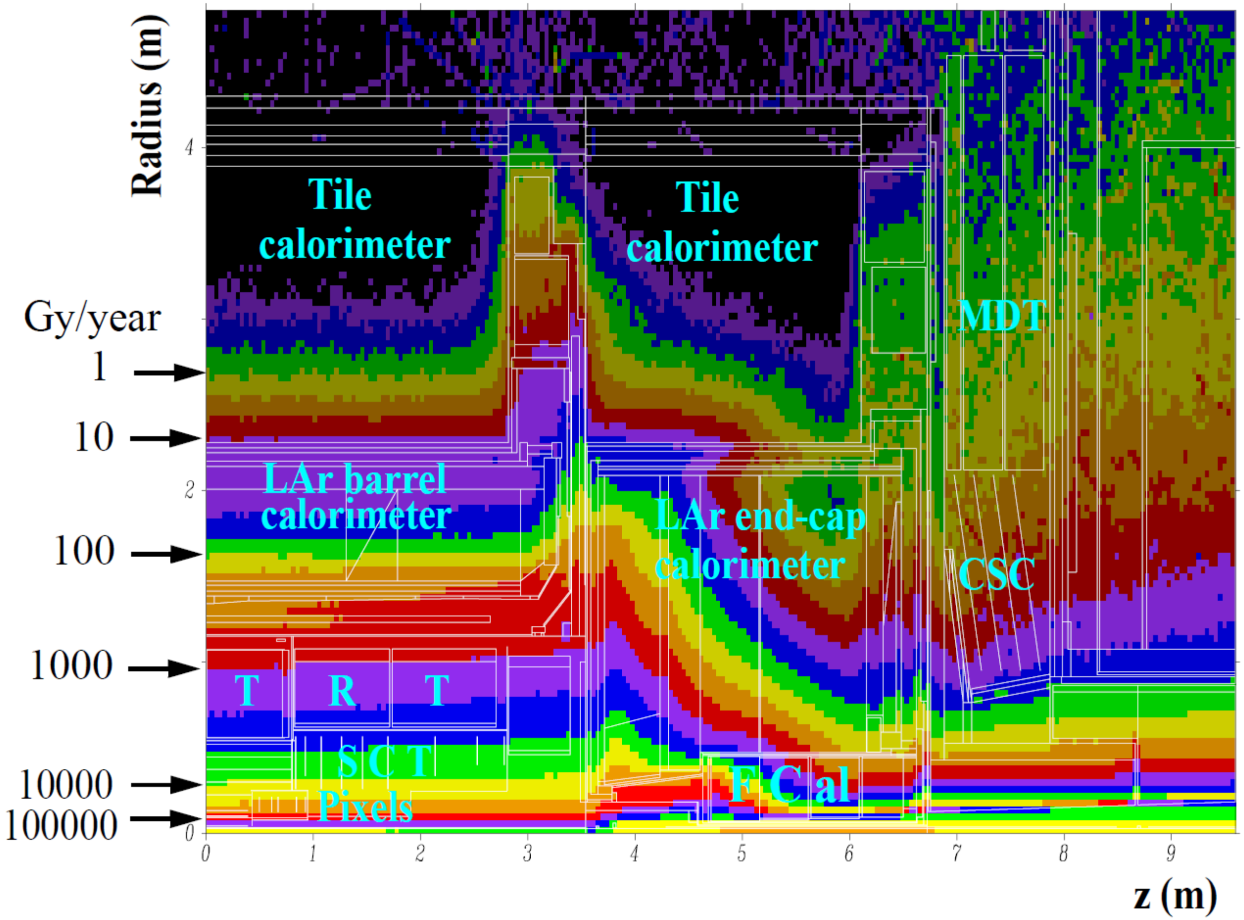
- CMS ECAL after 10 years of nominal LHC:
- 0.5 kGy and 5×10^{13} n/cm^2 at the outer circumference of the endcaps
- 20 kGy and 7×10^{14} n/cm^2 at $|\eta|$ = 2.6

→ photo-detectors on the back of the $PbWO_4$ crystals



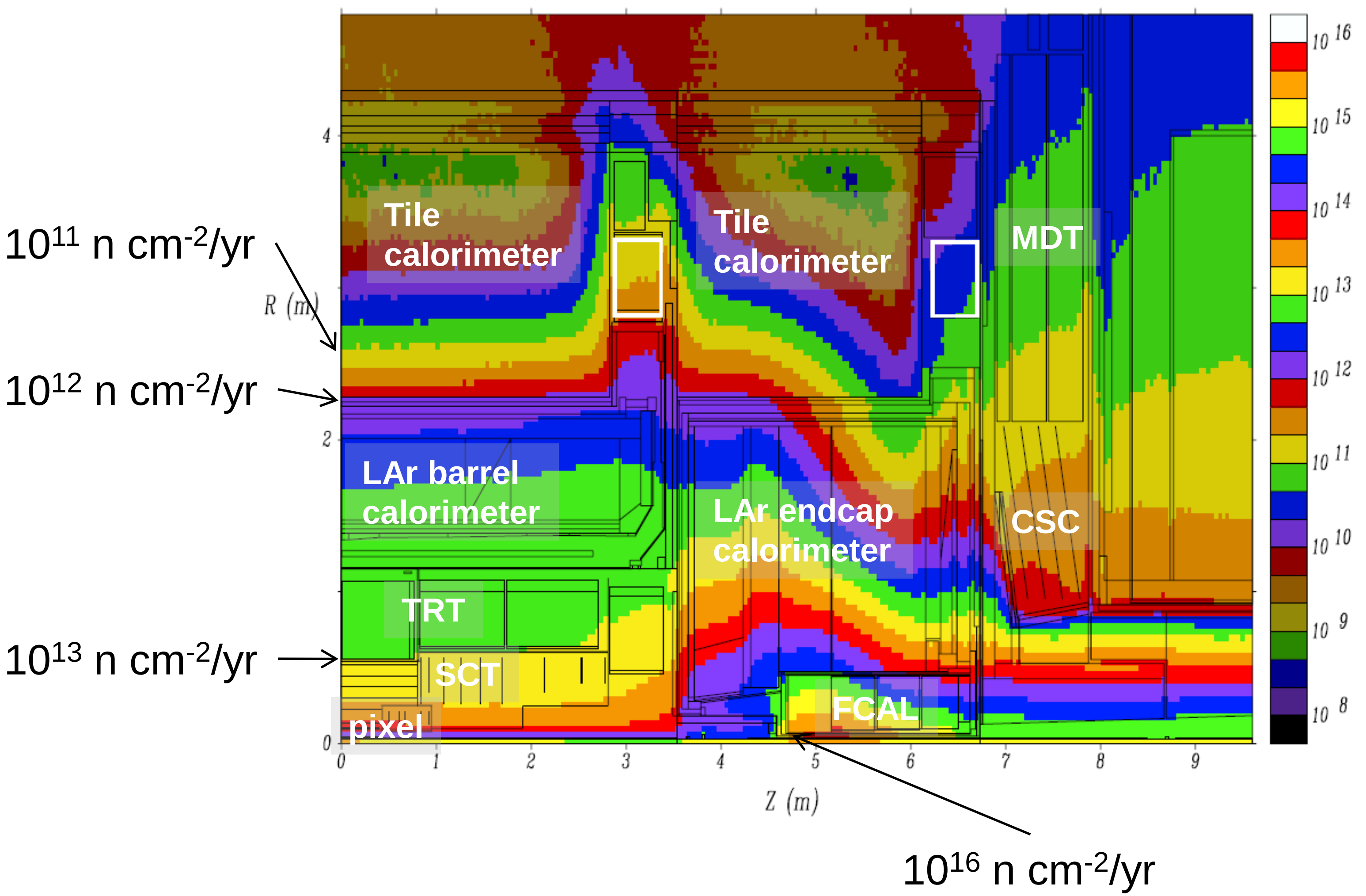
Radiation and background - ATLAS

- total ionisation dose in Gy/year at L=10^{34} $cm^{-2}s^{-1}$
- for σ_{MB}=80 mb and one year of 10^7 s

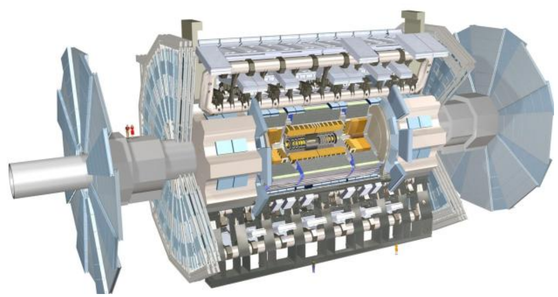


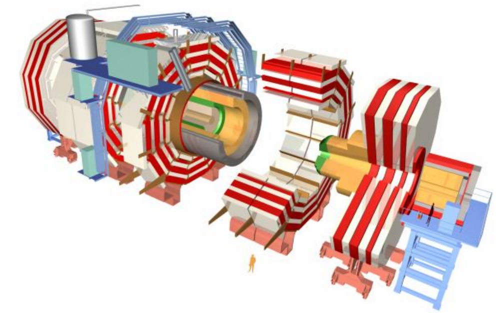
Radiation and background - ATLAS

- non-ionising dose per year
- 1 MeV neutron equivalent fluence at L=10^{34} $cm^{-2}s^{-1}$



ATLAS & CMS Today

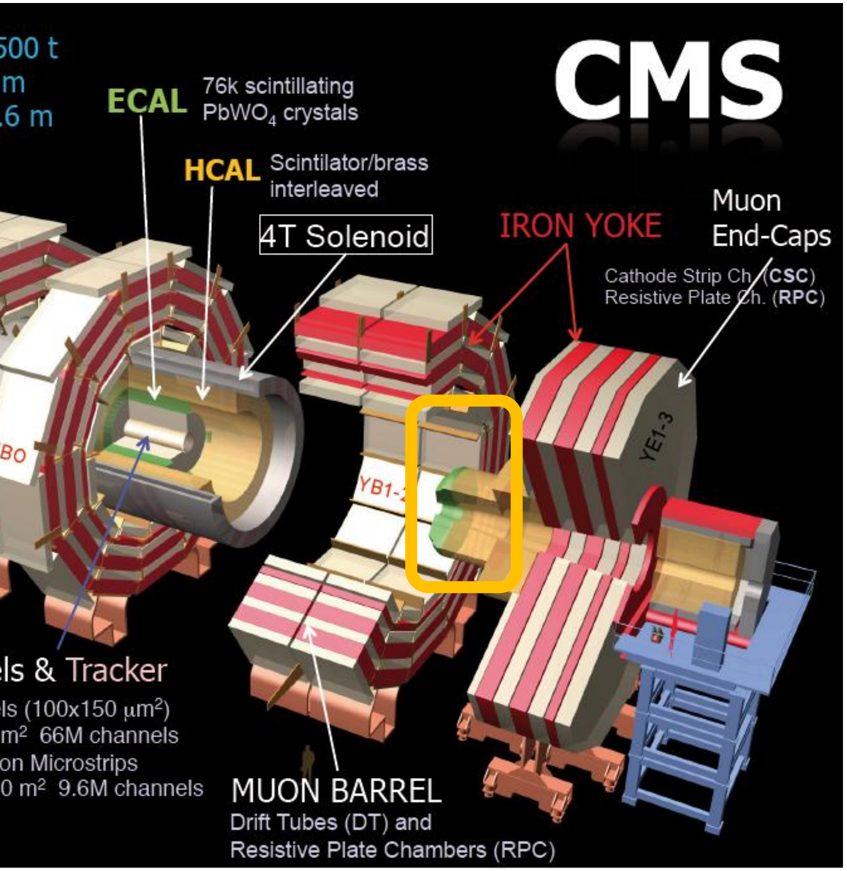


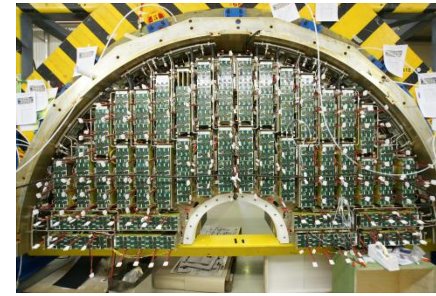


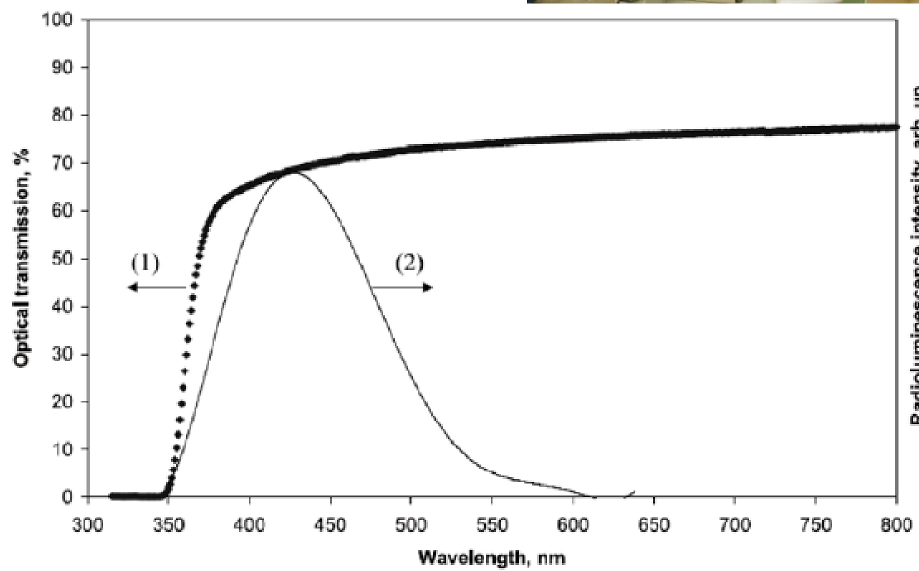
	ATLAS		CMS	
B-Field	2 T (solenoid)	4 T (toroid)	3.8 T (solenoid)	
Tracking	Si (strips+pixel) + gas (TRT)	$\sigma(p_T)/p_T$ at 100 GeV: 3.8 %	Si (strips+pixel)	$\sigma(p_T)/p_T$ at 100 GeV: 1.5 %
ECAL	Pb - LAr (high granularity)	$\sigma(E)/E$ = 9%/√E + 0.7%	$PbWO_4$ crystals (high E resolution)	$\sigma(E)/E$ = 3%/√E + 0.25%
HCAL	Fe – scintillator (10 λ)	$\sigma(E)/E$ (ECAL+HCAL)= 70%/√E + 3.3%	brass – scintillator (7 λ)	$\sigma(E)/E$ (ECAL+HCAL)= 70%/√E + 8%
Muon Spectrometer	ion. chambers, air-core magnet	$\sigma(p_T)/p_T$ at 1TeV: 7 %	ion. chambers, instrumented iron	$\sigma(p_T)/p_T$ at 1TeV: 5 %

- D. Froidevaux, P. Sphicas, General-purpose Detectors for the Large Hadron Collider, Annu. Rev. Nucl. Part. Sci. 2006. 56:375–440

CMS ECAL endcap crystals





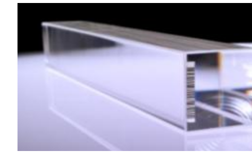


- ionisation reduces light transmission in crystals like $PbWO_4$
- absorption bands due to colour centres in crystal caused by oxygen vacancies and impurities
- scintillating light produced by hadrons and e.m. particles is not affected
- concerns when exposed to extremely high radiation dose in mixed particle beams

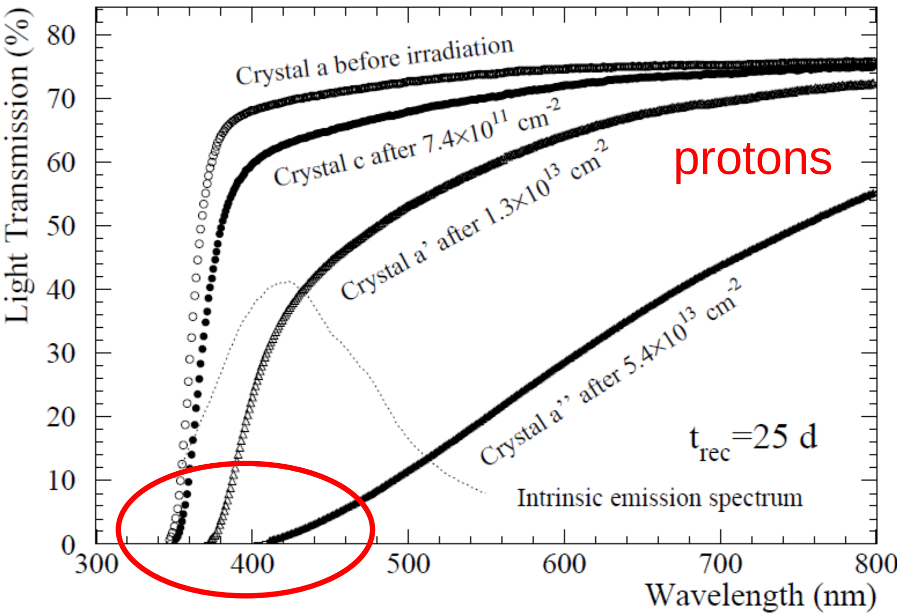
CMS ECAL endcap crystals

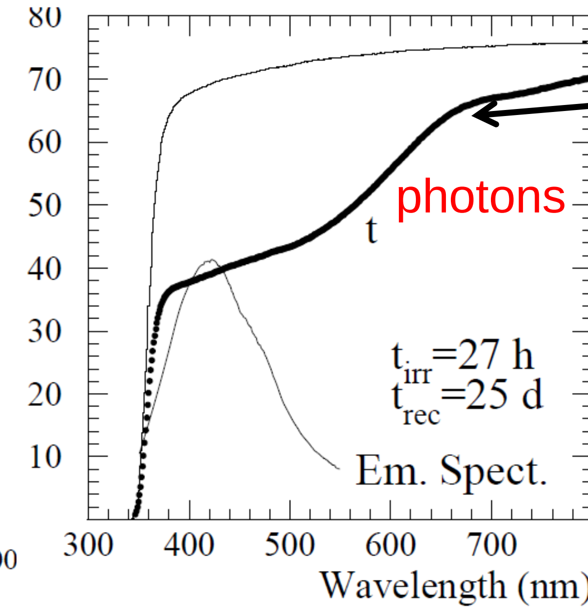
hep-ph/0511012

- reduced light transmission is observed in test beam
- not caused by ionising radiation damage but cumulative hadron-specific damage



- expected hadron fluences in ECAL barrel (endcap) after 10 yrs of LHC: 10^{12}(10^{14}) hadrons/cm^2
- proton and photon induced damage measured with photo-spectrometer:





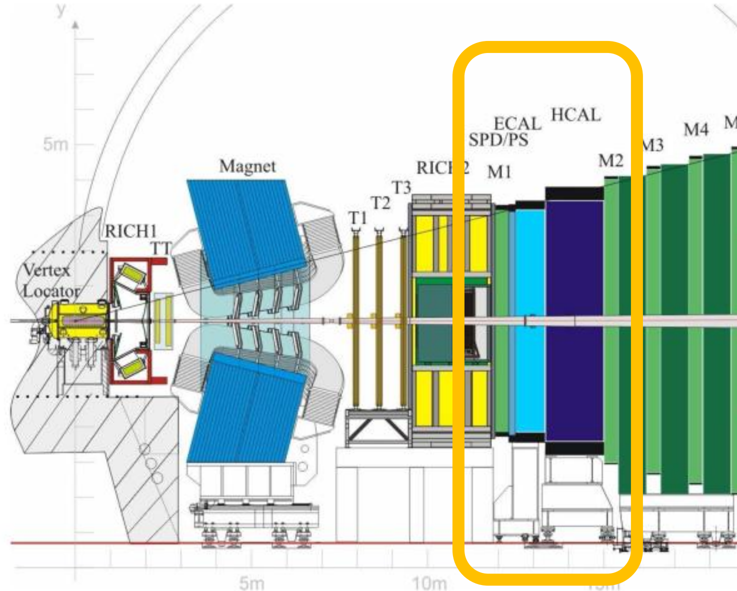
at 1 kGy/h ~ 10^{12} p/cm^2/h

cumulative damage by hadron fluence: band-edge shift

- loss in light transmission could be monitored by external light injection → crystal calibration
- replacement of ECAL endcap crystals is under discussion

LHCb Calorimeter Modules

- LHCb ECAL is a lead/scintillator sampling calorimeter ("shashlik" calorimeter)
- scintillating light is extracted by wavelength-shifting fibers
- photo detection with PMTs

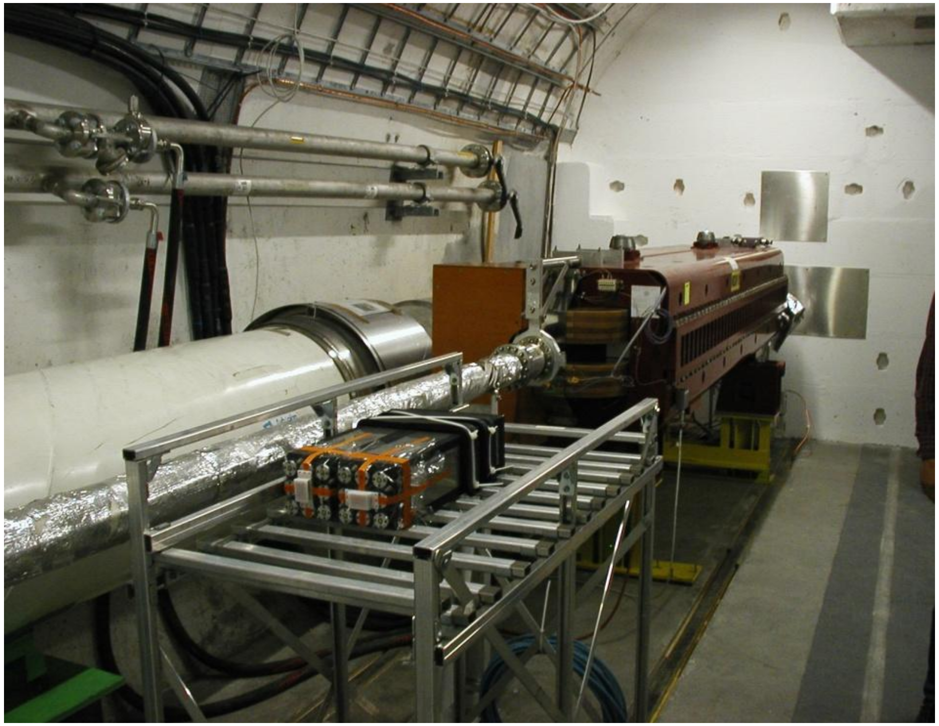


- expected maximum dose at 2×10^{32} $cm^{-2}s^{-1}$:
    - 2.5 kGy/year in the inner region

- calorimeter built to cope with this radiation level for 10 years
- no reliable information for higher doses
- the problem mainly concerns the inner modules

- idea emerged to make a test in the most realistic conditions → LHC tunnel
- in parallel: perform a test (high dose) at Protvino test beam

LHCb Calorimeter Module Irradiation Tests



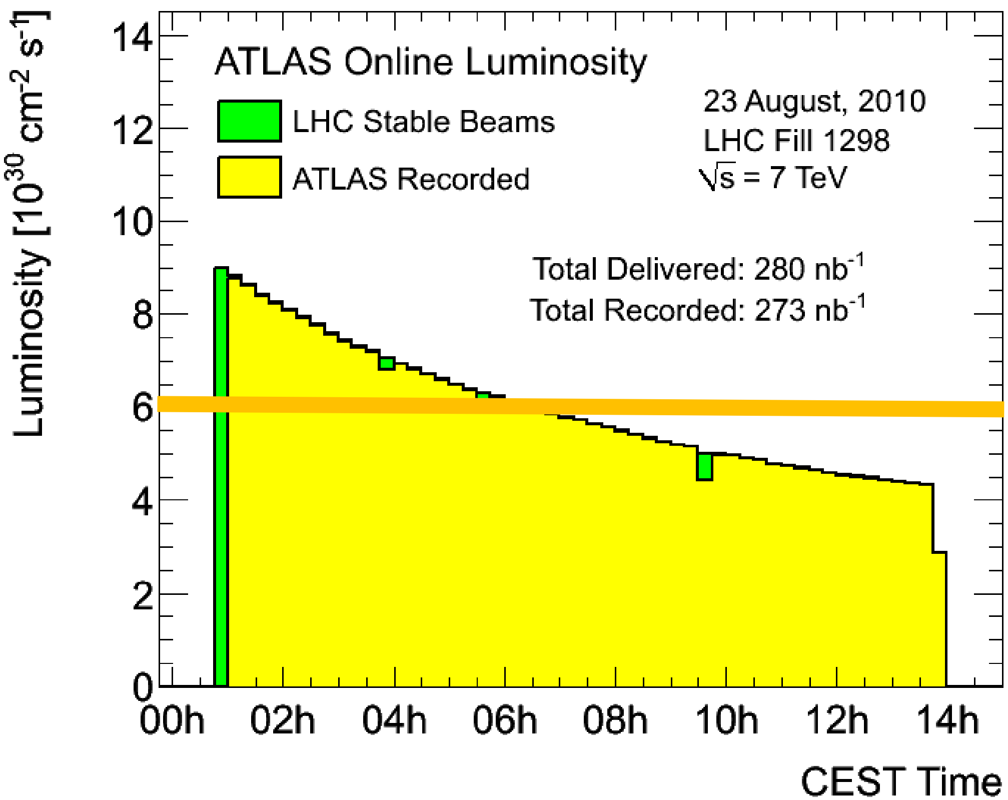
- installation of 2 modules in the LHC tunnel in September 2009
- close to LHCb interaction point (on the LHC side of the wall of the LHCb cavern)

- modules have been carefully calibrated before installation for future comparison
- dose monitoring by 5 passive and 2 active dosimeters

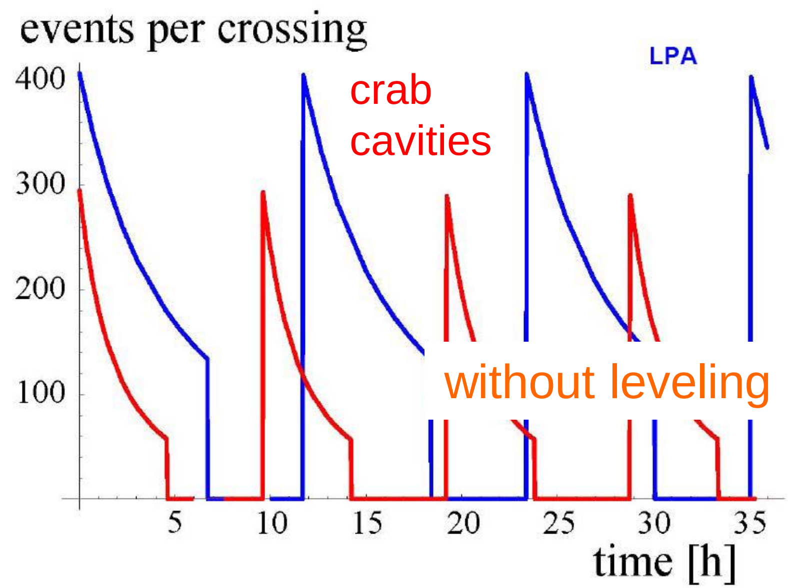
- results expected soon

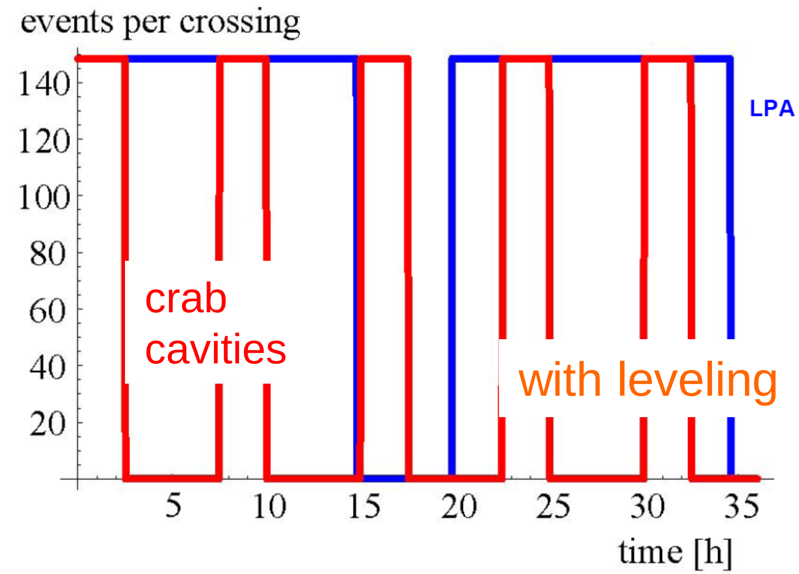
Luminosity Leveling

- luminosity evolution today in one fill:



- possible luminosity evolution at HL-LHC:





- luminosity leveling:
  - reduced and constant pile-up rate during one fill

Shutdown and Upgrade Scenario

Activities Planned in Shutdown Periods

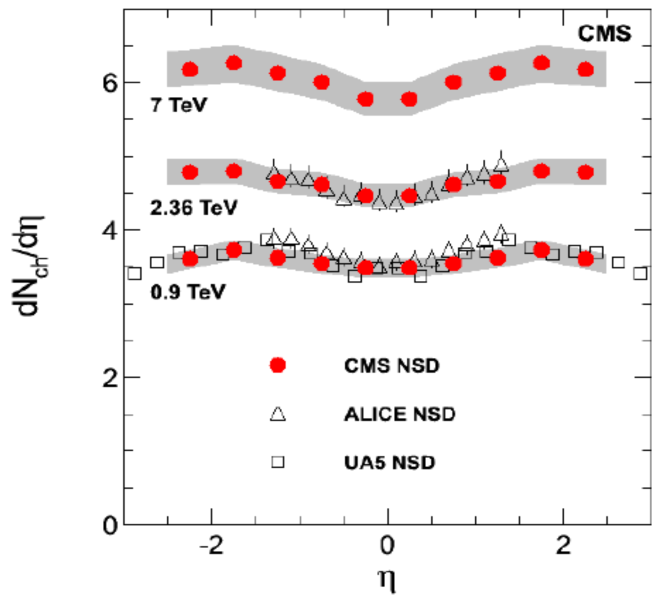
	2012	2016	2020
LHC machine and injection line	•splices for 7 TeV •collimators in IR3 •PSB energy upgrade •SPS upgrade	•collimation phase II •prepare for crab cavitites •new RF cryo system •Linac4 connection to PSB •PSB energy upgrade •PS, SPS consolidation	•new triplet magnets •crab cavities •consolidation work on injector complex
Int. luminosity expected at shutdown time	•1fb^{-1} @ 7 TeV	•40-100 fb^{-1} @ 14 TeV	•300-600 fb^{-1} @ 14 TeV
LHC experiments	•ALICE – TID and calorimeter •ATLAS – forward beam pipe •CMS – forward muon upgrade and consolidation •LHCb – conical beam pipe	•ALICE – new vertex detector •ATLAS – pixel detector layer + L1 trigger •CMS – forward muon upgrade, HCAL photo detectors, new pixel detector •LHCb – full trigger and readout upgrade, new vertex detector	•ALICE – vertex detector upgrade •ATLAS - new inner detector + readout/trigger •CMS – new inner detector + readout/trigger •LHCb – ECAL?

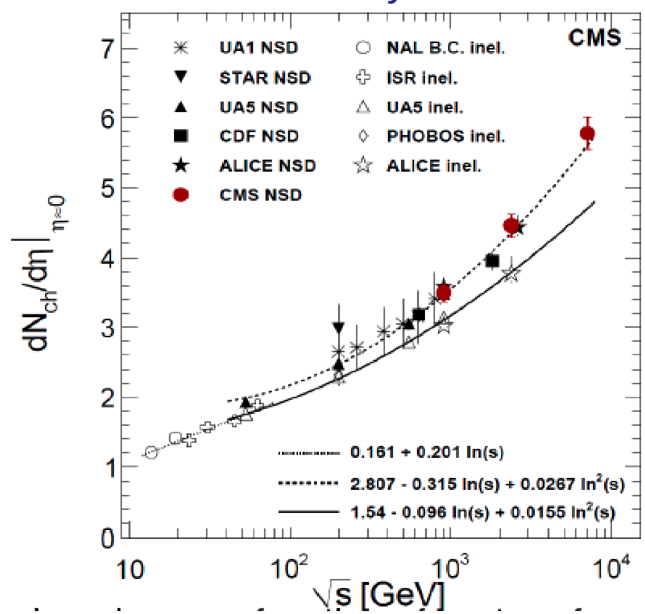
Pile-up background

- Pile-up events are from simultaneous pp collisions in the same bunch crossing
- In-time pile-up simply scales with luminosity, cross-section of minimum-bias events, and beam-crossing time (25 ns):

$$N_{\mathrm{pile-up}} = \sigma_{\mathrm{MB}} \mathcal{L} \Delta t$$

- minimum bias event shapes and particle rates are already studied in current data:





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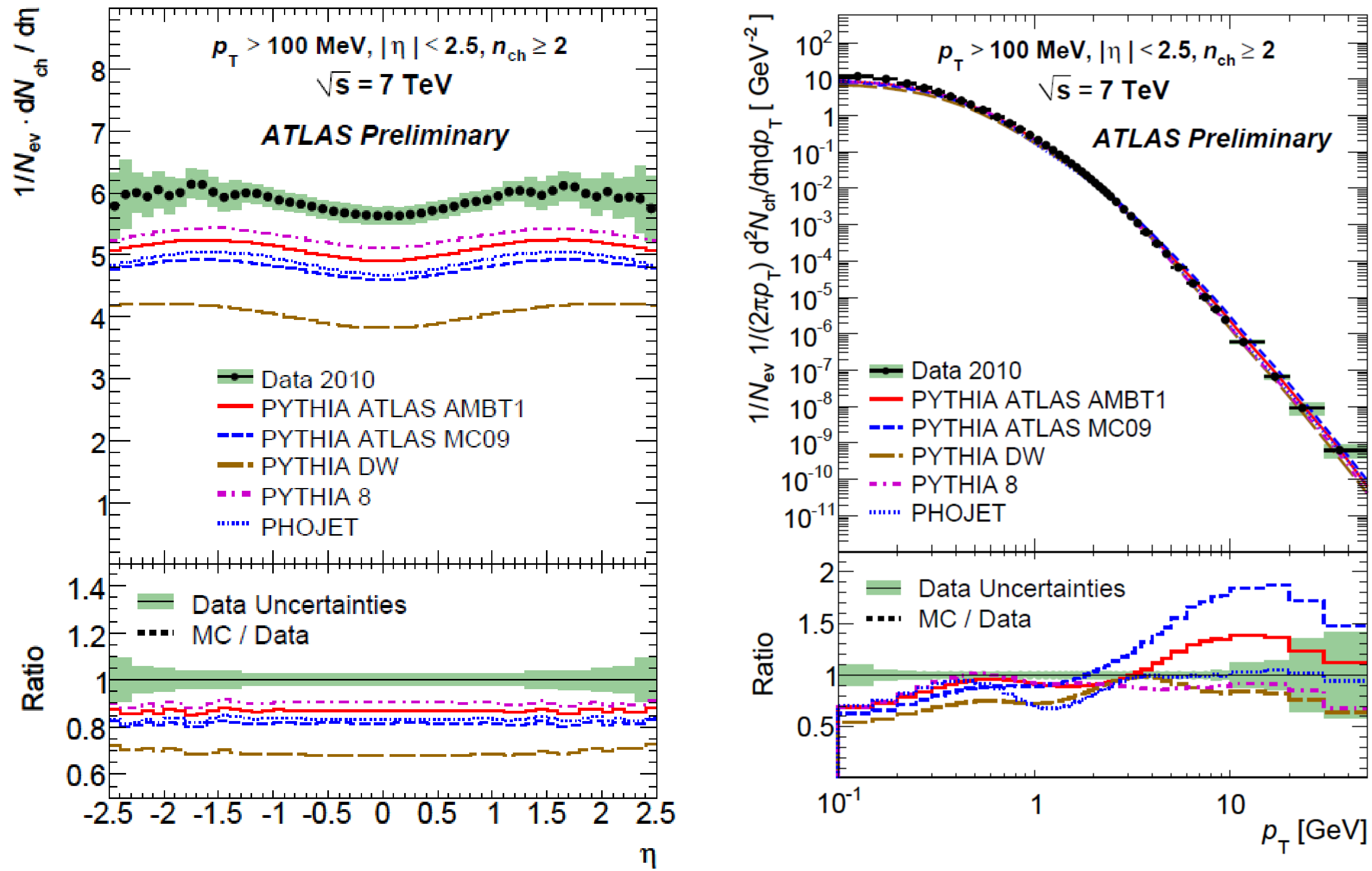
- important background is expected also in forward detector regions up to $\eta \approx |\frac{1}{2} \ln m_p^2/s| = 9.6$
- this needs further measurements, after forward detector performance is well understood

- with this data expectations for high-luminosity running at 14 TeV can be extrapolated using MC models

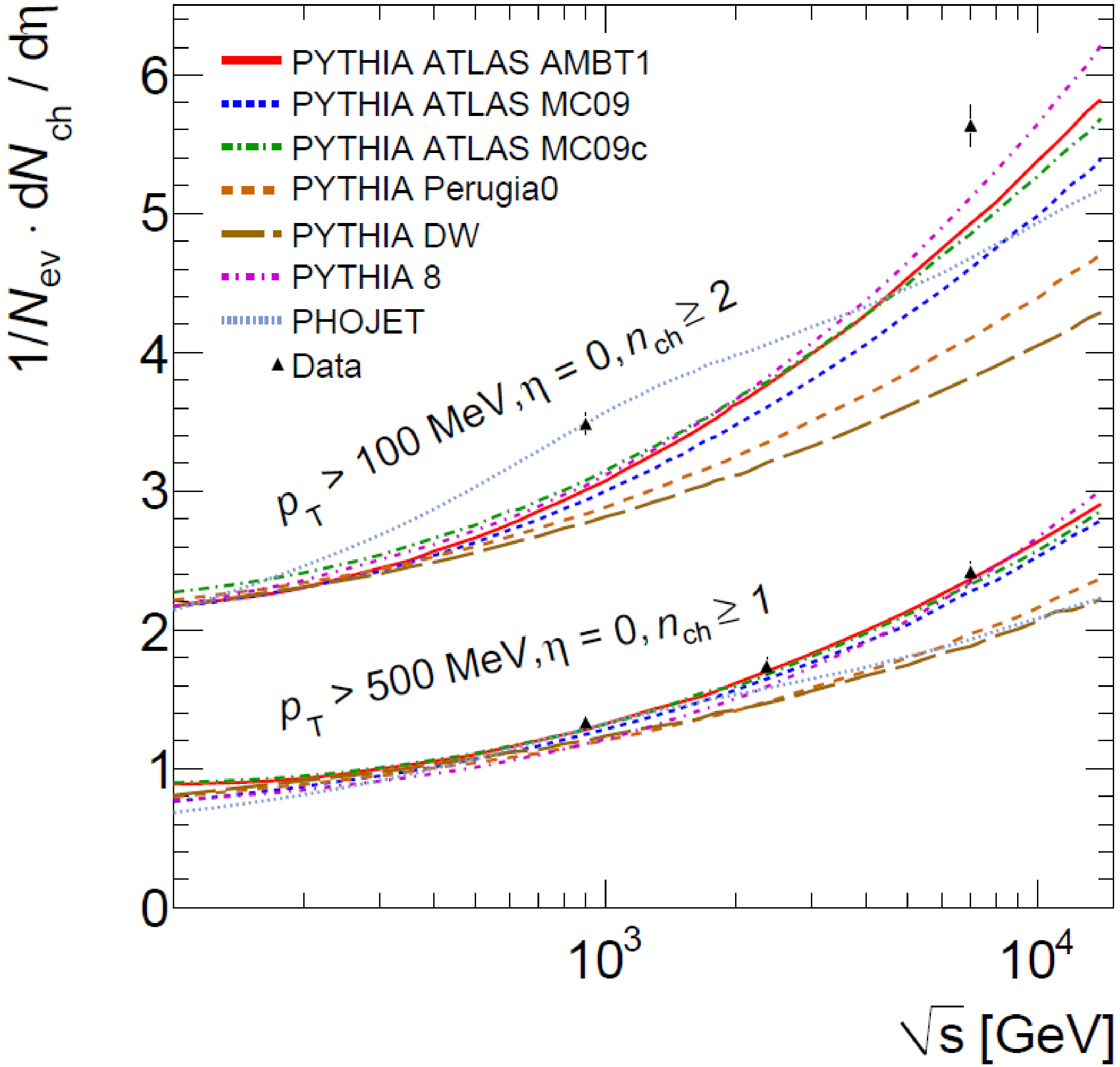
Minimum Bias Measurement

- recent measurement to very low pT tracks of 100 MeV (corrected to particle level)



Minimum Bias Measurement

- different tunings and high-energy extrapolations



- based on tracks: only central region
- forward region should also be studied

→ detector level comparison would already be very useful