IFD2014

INFN Workshop on Future Detectors for HL-LHC

Calorimetry at the HL-LHC [introduction and overview]

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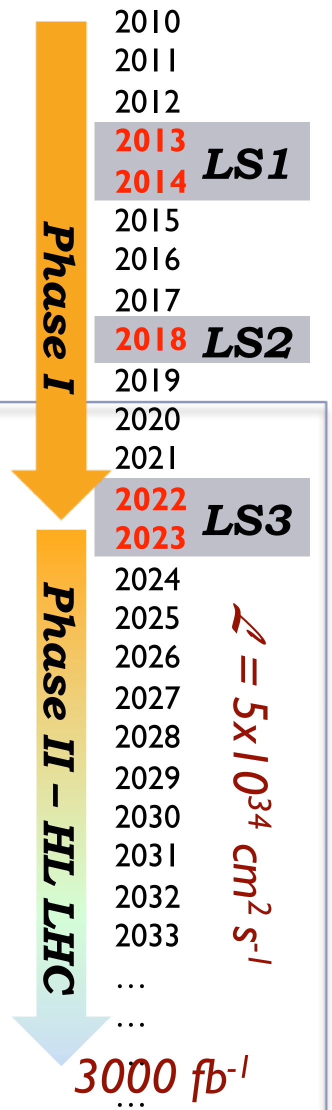
HL-LHC and the calorimeters

- ALICE and LHCb physics program not directly impacted by the luminosity upgrade of HL-LHC
  - Planned upgrades (LS1÷LS2) not driven by HL-LHC
  - Limited scope of upgrades foreseen for Phase II

- Upgrades of the ATLAS and CMS calorimeters to enable full exploitation of the HL-LHC potential
  - **Retain e/gamma identification and resolution**
    - "Higgs boson stoichiometry" in exclusive decay modes
    - Access to rare processes (e.g.H→Zγ, HH→γγbb, …)
  - **Good jet reconstruction in the forward direction**
    - Exclusive Higgs boson production modes via VBF scattering
    - EWSB test via WW scattering (WW system in the barrel)
  - **Good missing E_T resolution**
    - Key signature of 'new physics' and in Higgs decay modes



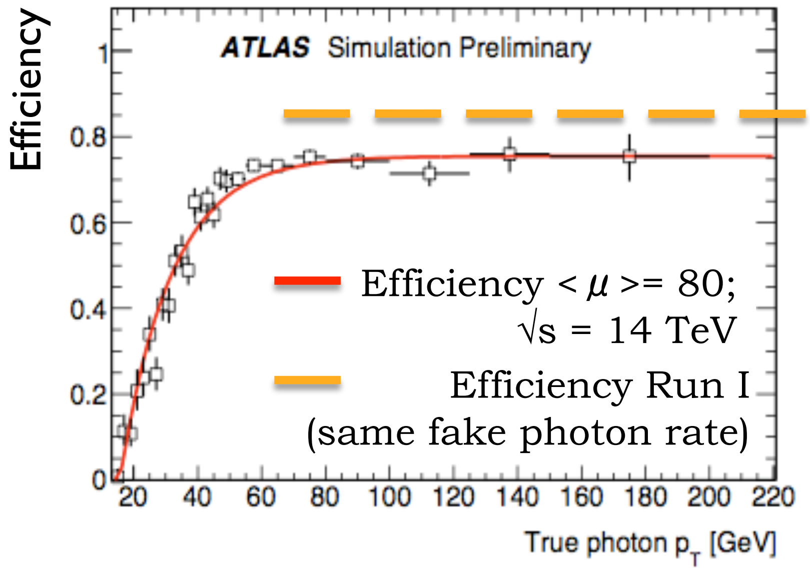
“140 vehicles were collided after a mass pile-up“
Texas, Thanksgiving 2013

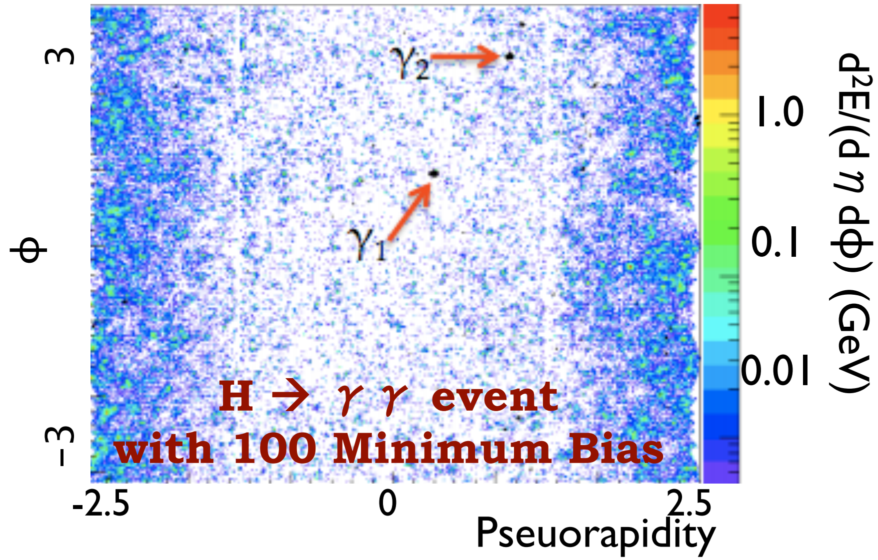
…

Pileup environment and performance challenges

Interactions per beam crossing: $< \mu > \sim 140$

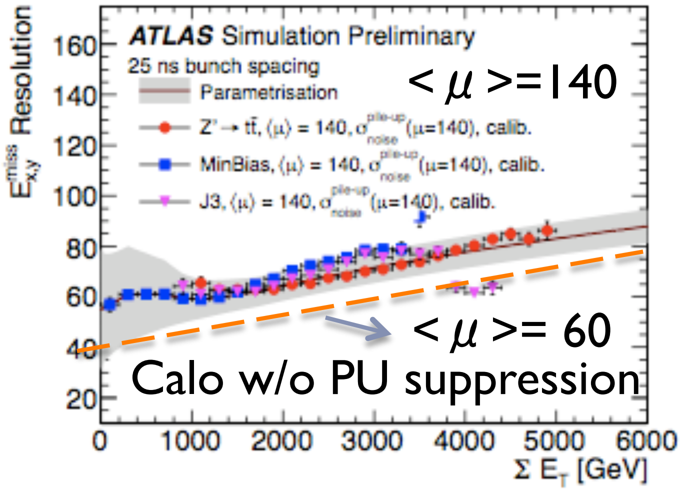
Pileup and photon reconstruction



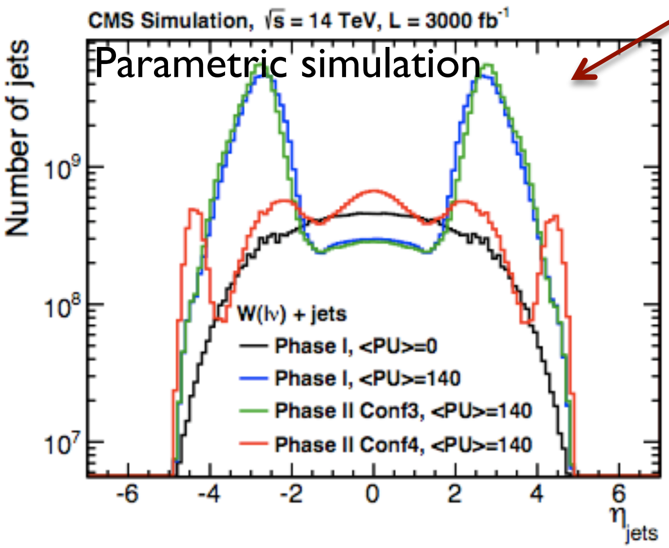


- Photon identification efficiency moderately damaged
  - E.g. ATLAS test with current offline algorithms
- Photon resolution possibly somewhat degraded
  - Additional term of O(1%) to the energy resolution of a H→ γ γ photon in the barrel, *induced by RMS fluctuations of the energy flow under a typical photon* ***defined by the Molière radius*** (*my guess, not an official ATLAS/CMS statement*)
  - Additional contribution to the noise term

Pileup and jet reconstruction



- Fake jet rate from merged pileup jets
- Additional (soft) component to jets
  - Affect missing E_T and VBF tagging
- Mitigation (will require tuning at HL-LHC)
  - Increased thresholds on calorimeter hits, PFlow reconstruction / soft track filtering
  - Association of charged particles to the vertices
    - Extended tracking from | η |<2.5 to | η |<4 beneficial

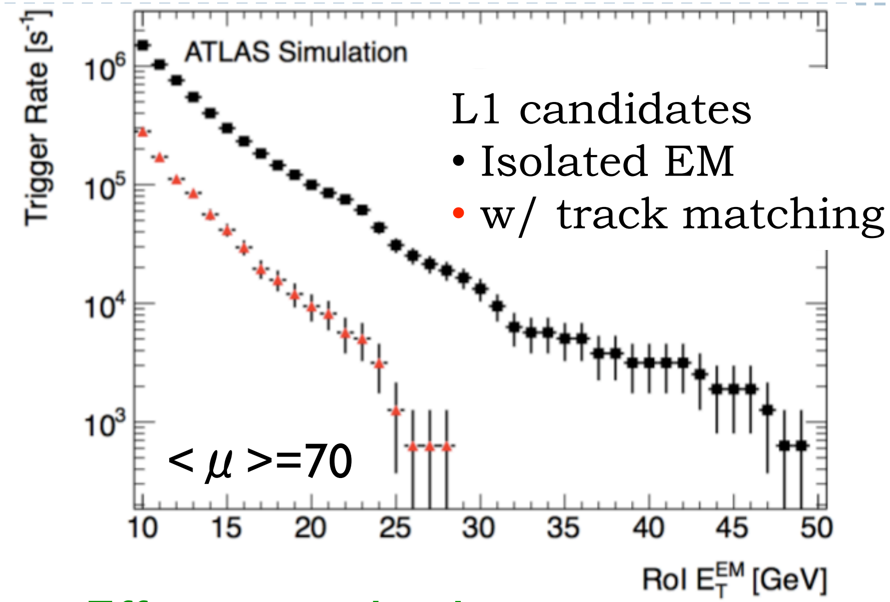


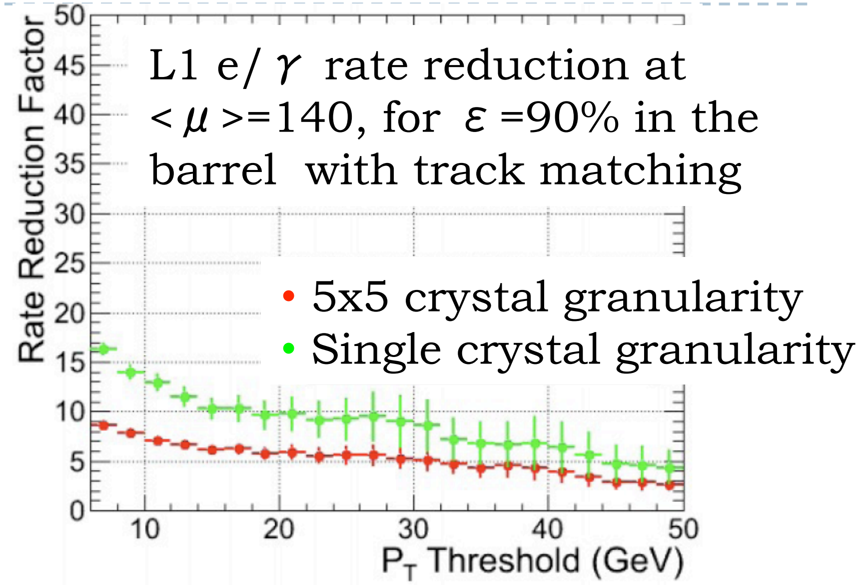
- Possible additional handle from *extreme* time resolution on shower deposits (30-40% of jet energy from neutrals)
    - Spread of vertex time ~ 300 ps (bunch length)
    - 'Effective occupancy' similar to current LHC for time resolution ~30 ps
  - Designated device for shower timing
  - Exploitation of timing in existing calorimeters

Details P. Meridianis' talk

INFN MiB, Rm1, To, Ts

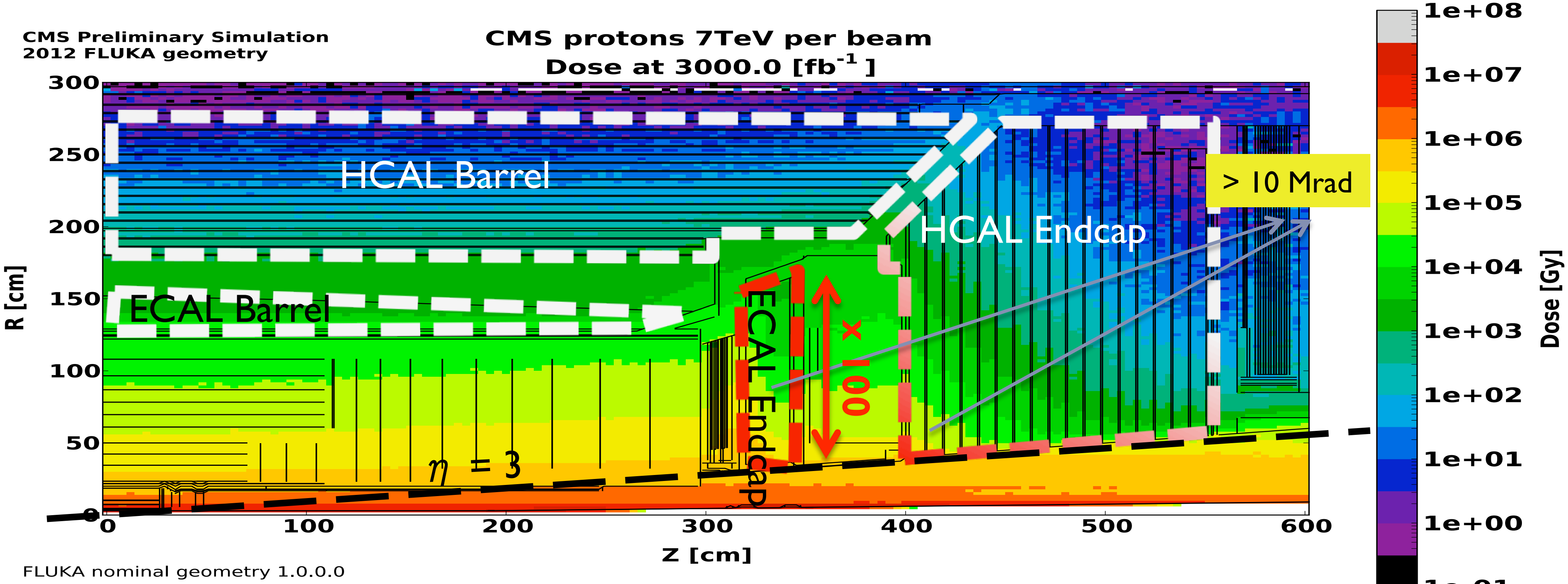
Pileup and calorimetric triggers





- Efficient and selective triggers at low thresholds require
  1. Combination with tracker information (efficient tau-id, ele-id)
  2. Highly granular information (crystal / cell level rather than 'tower')
- **Planning electronics upgrades for full 40 MHz data transfer from the calorimeters (both ATLAS and CMS)**
  - Increase bandwidth and latency, powerful HW/MW for processing
  - ***Address longevity in parallel***: install front-end radiation tolerant components – if necessary

Details F. Tartarelli's talk

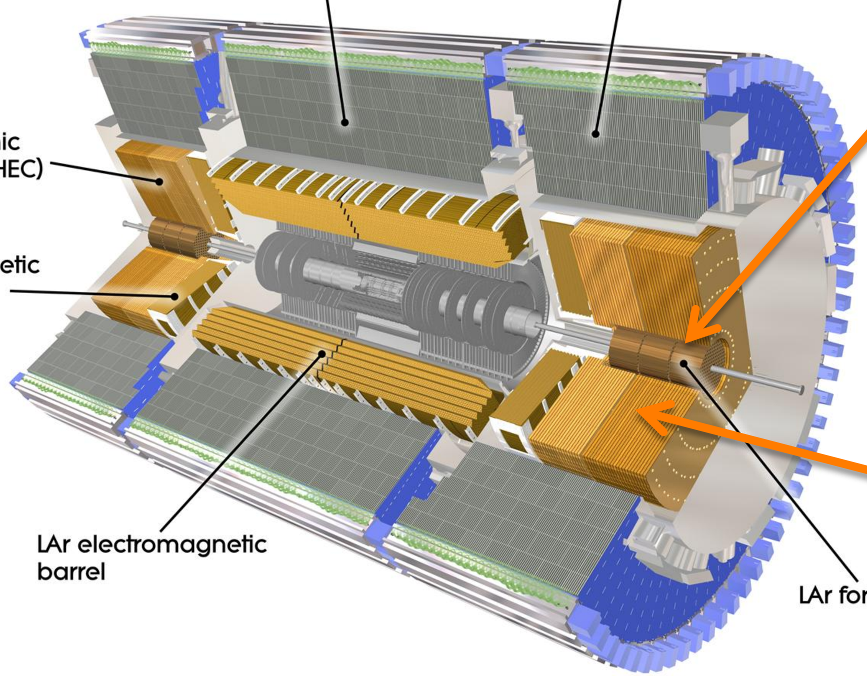


Radiation environment and longevity issues

Radiation six times higher than nominal LHC design

ATLAS: longevity appraisal and upgrade plan

- LAr intrinsically radiation tolerant
- Moderate radiation damage in TileCal (operable throughout Phase II)
- FCAL (LAr) may suffer at high instantaneous rate
  - Space charge effect, excessive heat could lead to bubble formation



- ***Possible*** upgrade of the FCAL calorimeter
  - Replace with smaller gaps or add module in front to reduce particle fluence

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- **Upgrade of FE/BE readout (both LAr and TileCal): 40 MHz data stream**
- ***Possible*** upgrade of the cryogenic analog front-end of the LAr HEC (radiation damage)

Details on electronics upgrade in F. Tartarelli's talk

Atlas: FCal mitigation options

1. Do nothing
   (rate effect manageable)

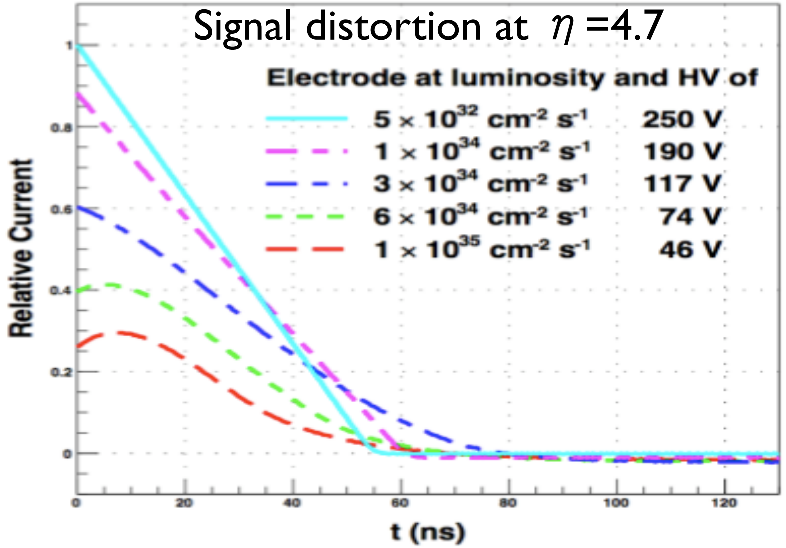
2. Replace FCal with a new sFCal
   - Smaller gaps (100μm), smaller resistor (100KΩ), cooling loops
   - Requires opening of the LAr endcap cryostat

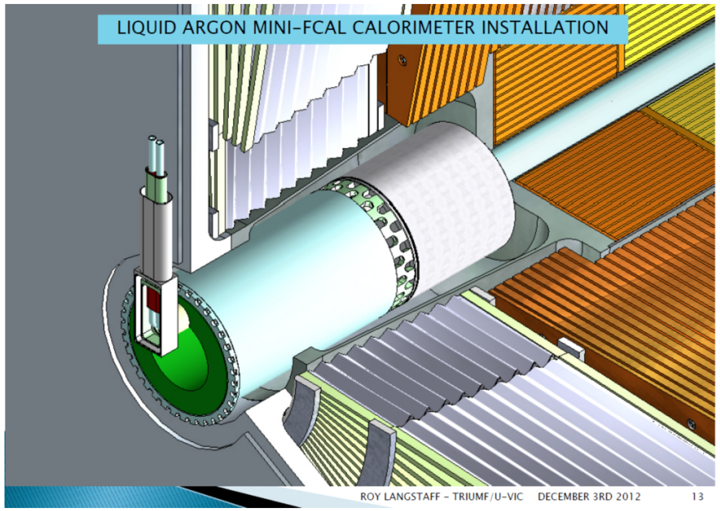
3. Install additional calorimeter in front (MiniFCal) to decrease the particle flunece
   - Various possibilities
     (LAr, Xe, diamond sensors)

- Studies still ongoing

INFN not involved

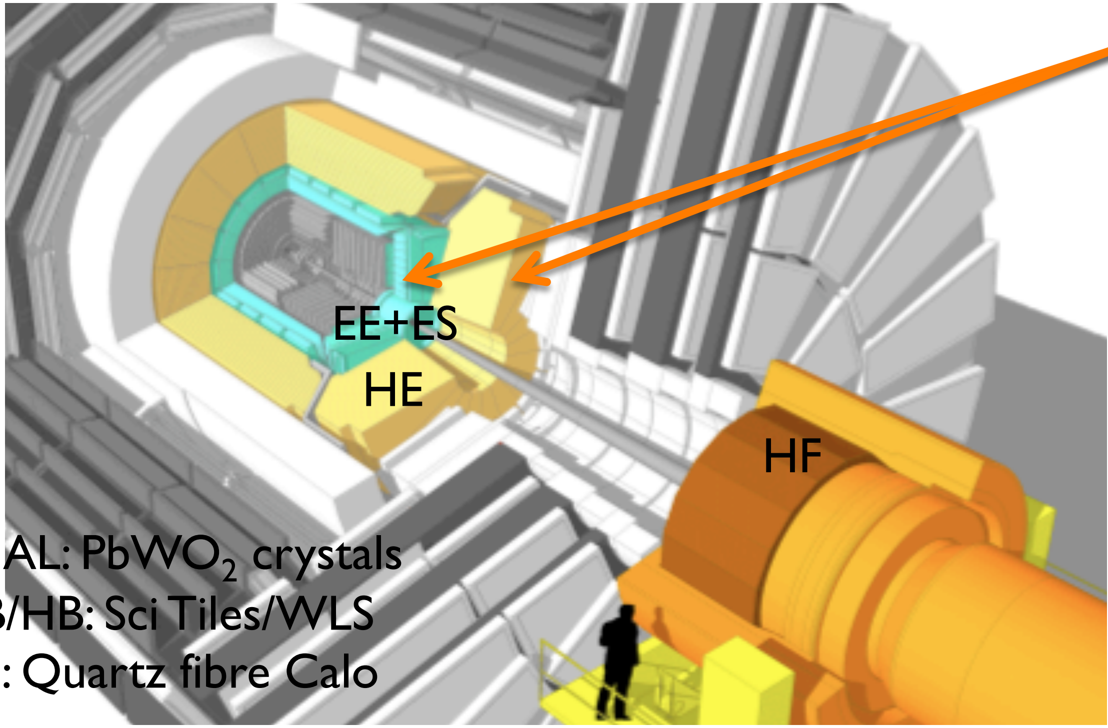
ATLAS FCAL Simulation:
Signal distortion at η =4.7





CMS: longevity appraisal and upgrade plan

- *Substantial* performance degradation in the ECAL and HCAL endcaps
- *Moderate* damage in the ECAL and HCAL barrel
  - Increase of APD dark current in ECAL will require mitigation
- Moderate degradation in HF (operable throughout Phase II)



ECAL: $PbWO_4$ crystals
HB/HB: Sci Tiles/WLS
HF: Quartz fibre Calo

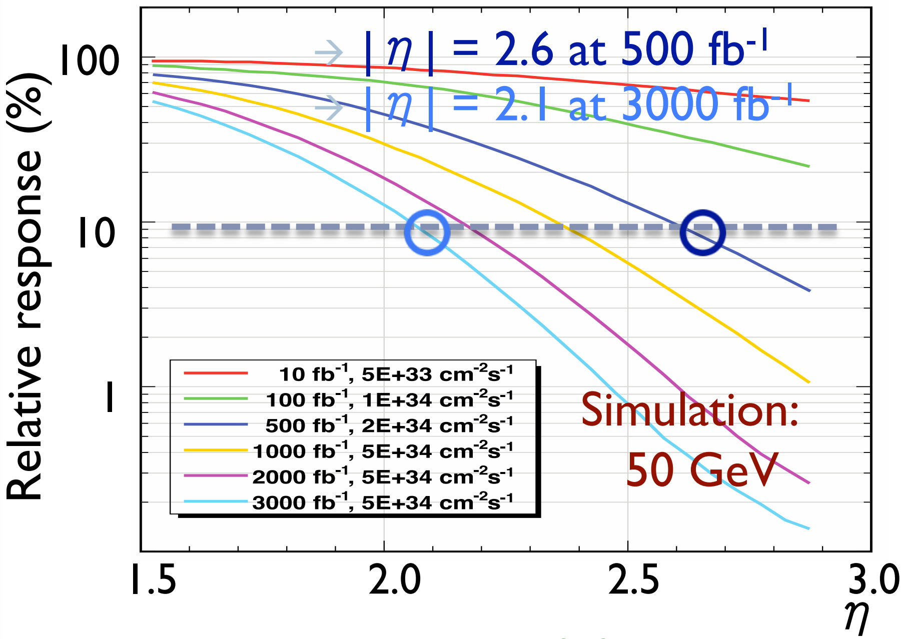
- **Replacement/upgrade of both ECAL and HCAL endcaps in LS3**
- **Upgrade of the ECAL FE electronics: 40 MHz data stream (barrel)**
  - HCAL upgrade in LS2
- ***Possible*** mitigation of the APD current
  - VFE with faster shaping time (also, improved timing, spike rejection)
  - Cooling of the barrel

Details on electronics upgrade in F. Tartarelli's talk

CMS: Projected radiation damage

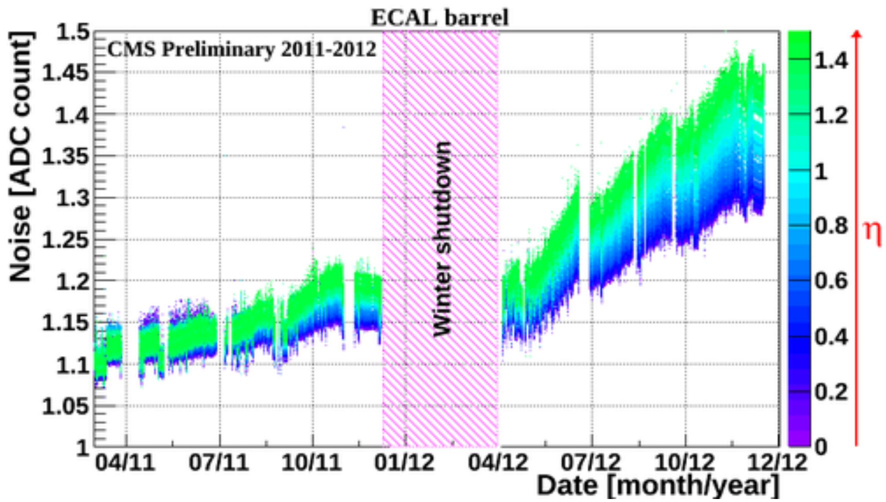
- *ECAL endcap* extensive test beam studies under proton-irradiation
  - Progressive deterioration of energy resolution and trigger efficiency

→ Light output below 10% beyond



→ Resolution at | η |=2.2 would degrade **from ~2% at 500 fb^{-1}** ***to ~10% at 3000 fb^{-1}***

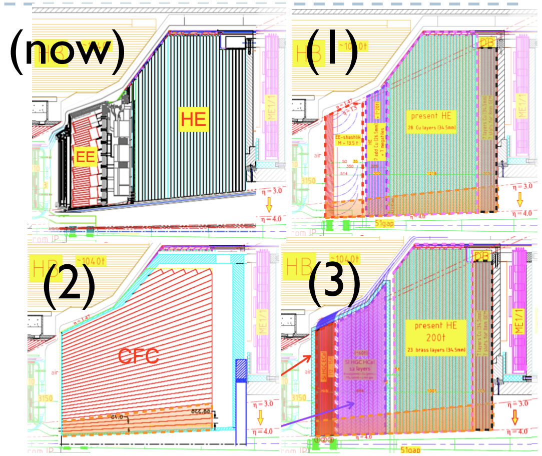
- *ECAL barrel* APDs current increase would sizably impact the noise term contribution to the resolution
  - Further appraisal with designated irradiation test ongoing (INFN Rm1)



- *HE* extrapolation from *in-situ* data
  - Differential loss with depth (mitigated by longitudinal segmentation in LS2)
  - Less than 5% response at | η |>2.1 beyond 500 fb^{-1}

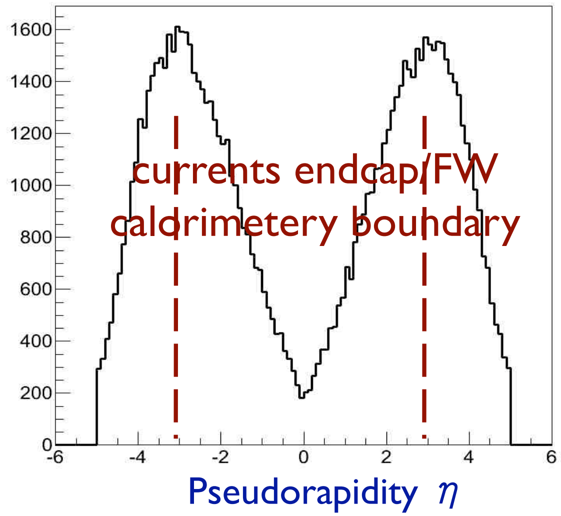
CMS endcap options for HL-LHC

- (1) Maintain current structure
  - Replace ECAL and refurbish HCAL with rad-hard technologies and improved granularity
  - ***"Emphasis on photon reconstruction"***
- (2) Merge EM and HAD compartments into a (rad-hard) dual readout calorimeter
  - ***"Emphasis on jet resolution"***
- (3) Finely segmented calorimeter (à la CALICE)
  - ***"Readout as much information as possible"***



- Bonuses (common to ~all option)
  - Extra space for an additional muon station
  - Extension to | η | = 4 under consideration
  - Possible integration of a fast-timing module
- Down-selection process in progress
  - 'No more than two options in the CMS Technical Proposal for HL-LHC (this fall)'

Generator level VBF Jets η distribution



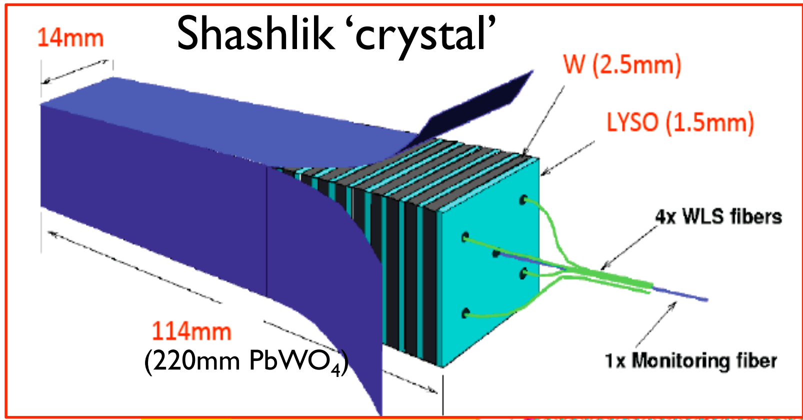
CMS Endcap 1: EE Shashlik + HE rebuild

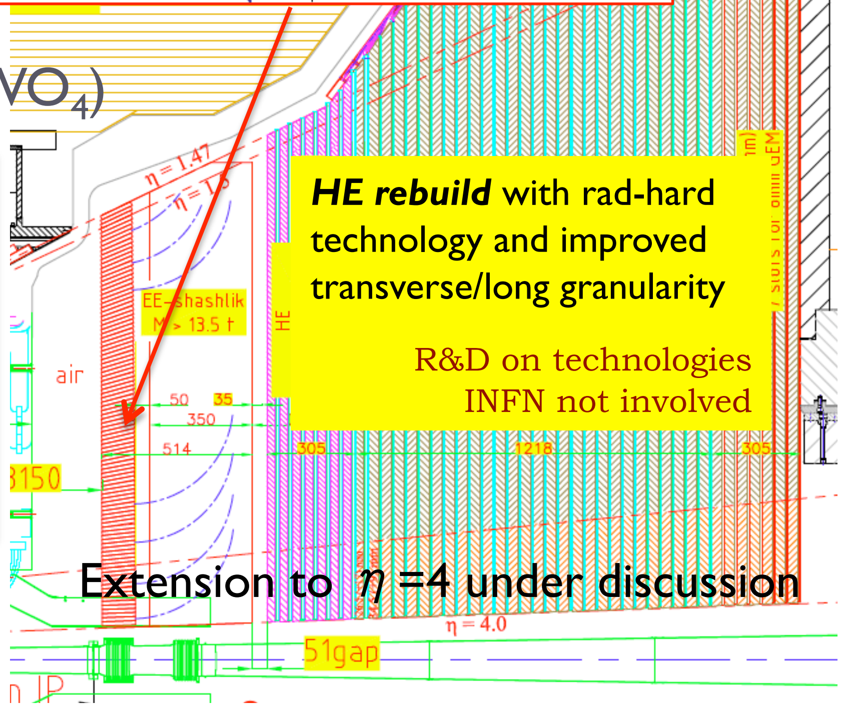
- Driving design concepts
  - Increased transverse granularity
  - Radiation hard technology
  - Same structure of current endcap with emphasis on EM compartment
- EE Shashlik:
  - LYSO / W (alternate: CeF_3 / W)
  - **Molière radius 1.4 cm** (2.2 cm in $PbWO_4$)

FBK/INFN

- R&Ds and challenges
  - **Rad-hard WLS fibre** (several options)
    - SiO_2:Ce matches CeF_3 emission spectrum
  - **Photosensors GaInP- / Si-PM**
    - at remote location if rad-hard insufficient (fluence on detector up to 10^{16} n/cm^2)
  - Mechanics and assembly

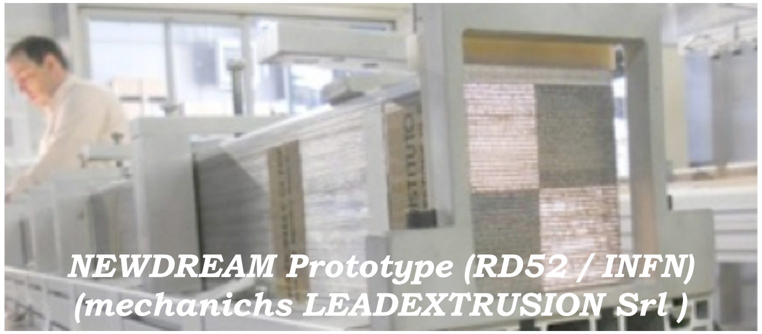
Details in M.Lucchini's and A.Gola's talks

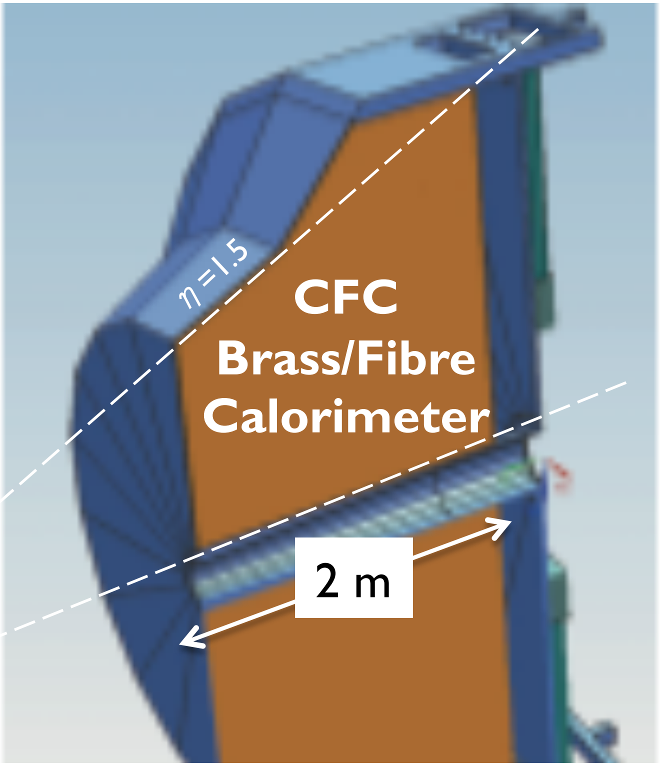




CMS Endcap 2:
Combined Function Calorimeter (CFC)

- Dual readout of Cerenkov (Q) and scintillation (S) light
  - Optimal hadron energy resolution
  - Q/S ratio additional handle in jet/photon ID
- CFC layout (optimization ongoing)
  - **Brass / Quartz / SiO_2:Ce fibres**
    - Packing fraction ~10% (fibres pitch ~2 mm)
    - [10000 km and ~5 millions of fibres]
  - **Molière radius 2.0 cm** (2.2 cm in $PbWO_4$)
  - Depth from pulse time profile (~10 samples)





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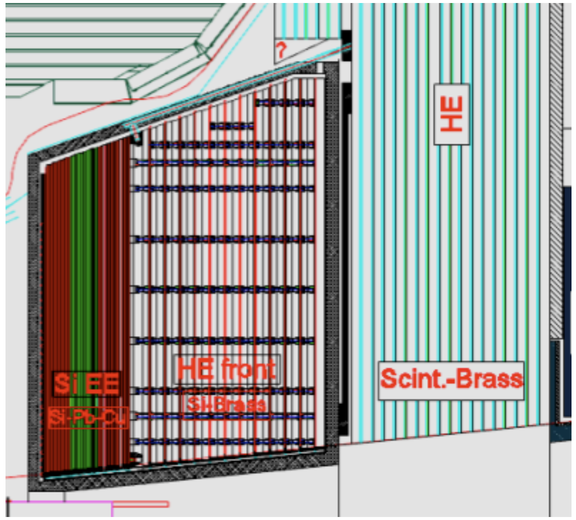
- R&Ds and challenges
  - **Rad-hard scintillation fibre** (2 m long)
  - **Photosensors GaInP- / Si-PM / VPTs** (less demanding than / common to Shashlik)

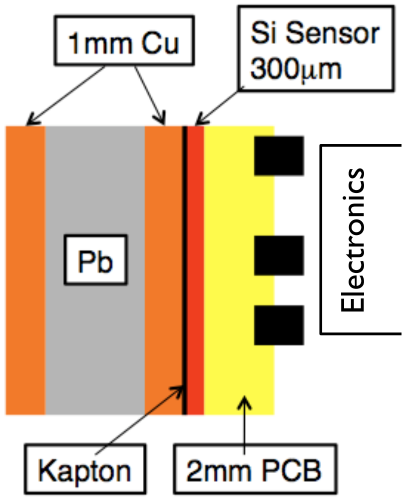
More in M.Lucchini's and A.Gola's talks

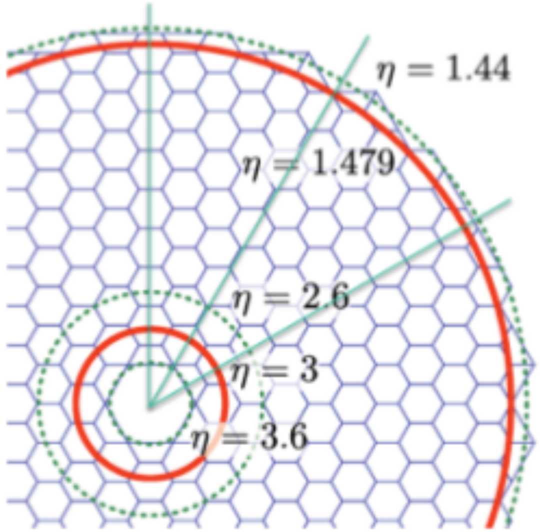
CMS Endcap 3: High Granularity Calorimeter (HGC)



- Granular readout for pileup mitigation
- ECAL section: **Si/Pb-Cu** (optimization ongoing)
  - Si pads (from 0.9x0.9 cm^2 to 1.8x1.8 cm^2)
  - **Molière radius 2.5 cm** (2.2 cm in $PbWO_4$)
- HCAL section: **4 λ Si/Brass + 5 λ HE (rebuild)**
  - 16 planes ECAL + 15 planes HCAL

- R&D and challenges
  - Rad-hard Si sensors (<300 μm):
    - Hexagonal pads from 8" wafers
    - 670 m^2 – 5.1 million channels
  - Cooling to -30 °C (~300 W/m^2)
    - Low power electronics, large scale cooling system
  - Trigger formation/signal readout
    - High bandwidth links





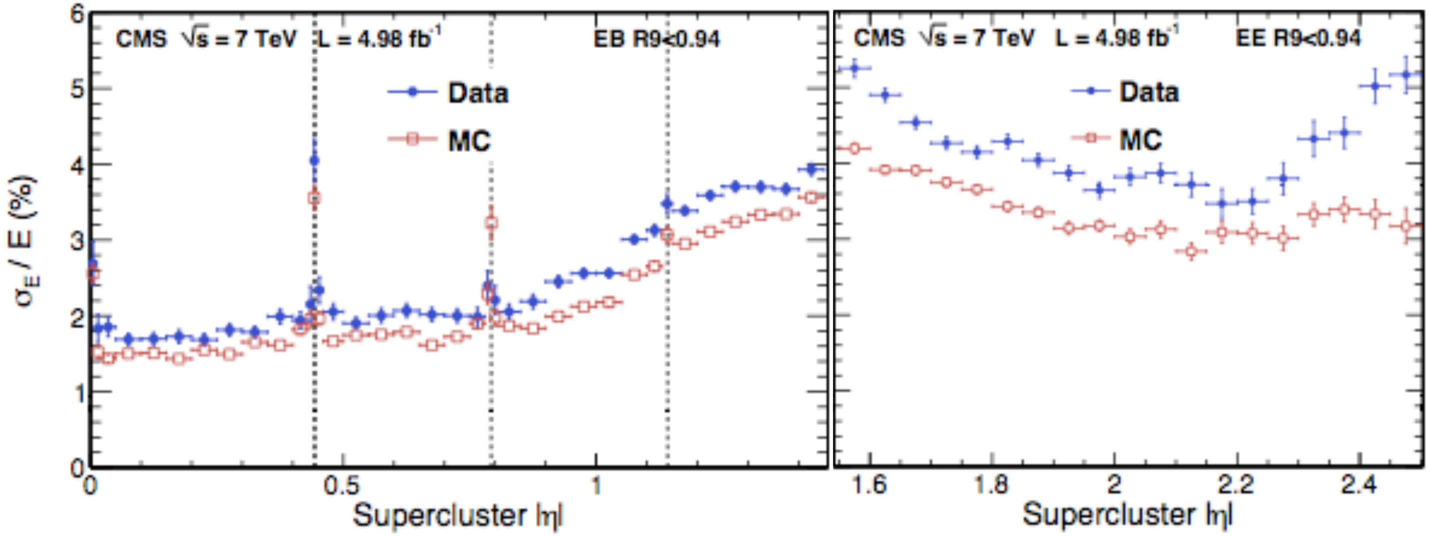
Calorimetry upgrade summary

- Detector upgrades are ***specific to the experiments***
  - Mainly driven by longevity issues with optimization of the new detectors to better cope with HL-LHC environmental challenges
  - Targeted R&Ds in progress:
    Details in M. Lucchini's, A. Gola's and P. Meridiani's talks

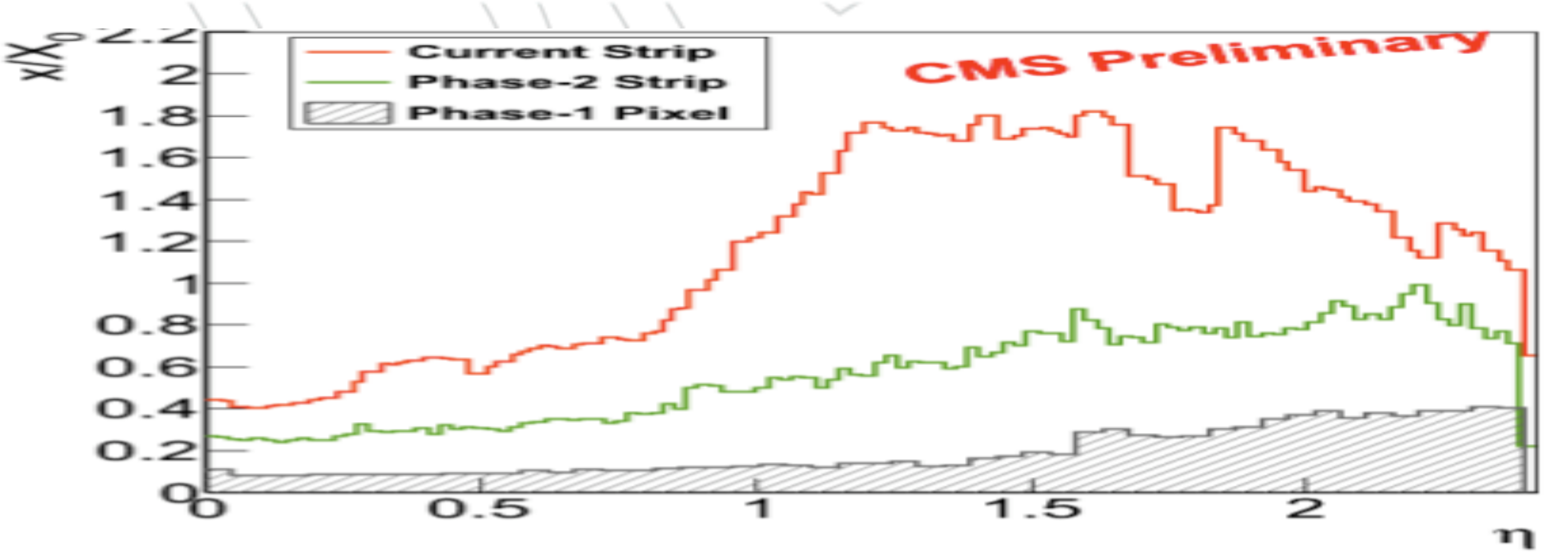
- Electronic upgrades share a common goal (ATLAS and CMS):
  - Ditial part: provide highest possible granularity and resolution at the Level-1 trigger processors to handle increasing pileup
    - Send all data off detector for trigger and readout at 40 MHz
    - Process the data with more powerful hardware or software
    - Install front-end components which are more radiation tolerant – if necessary
  - Upgrade to the analog electronics under consideration
  - **Details in F. Tartarelli's talk**

BONUS

Impact of upstream material



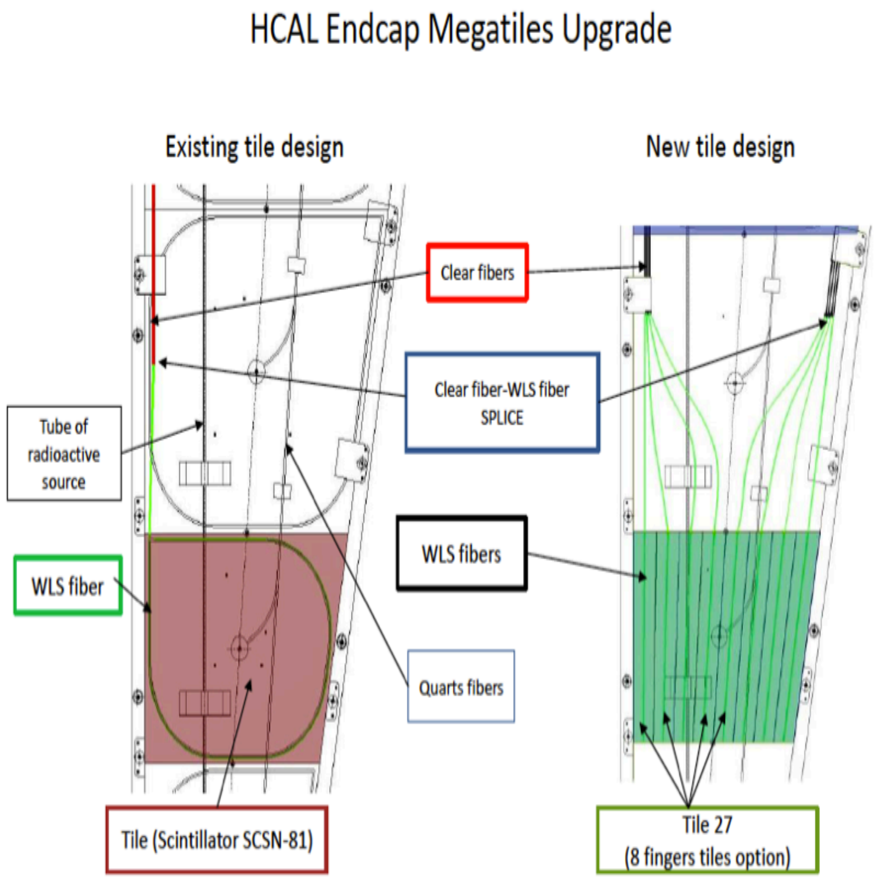
2011 data:
electrons with bremsstrahlung in the tracker (i.e. resembling photons with conversions in the tracker)



TK material
– Now
– Phase II

HE Rebuild R&D goals

- Technology of HE is inexpensive and effective, but not radiation tolerant for full HL-LHC program in the front of HE
- R&D into replacement with
  - Different geometry (finger tiles) and different materials
    - Liquid scintillator
    - Green scintillators with red/orange WLS
    - Quartz tiles
    - Crystal fibers
  - Rebuild of the absorber also being considered
    - Too active to be worked on in LS3
    - Can be pushed towards IP given EE compactness



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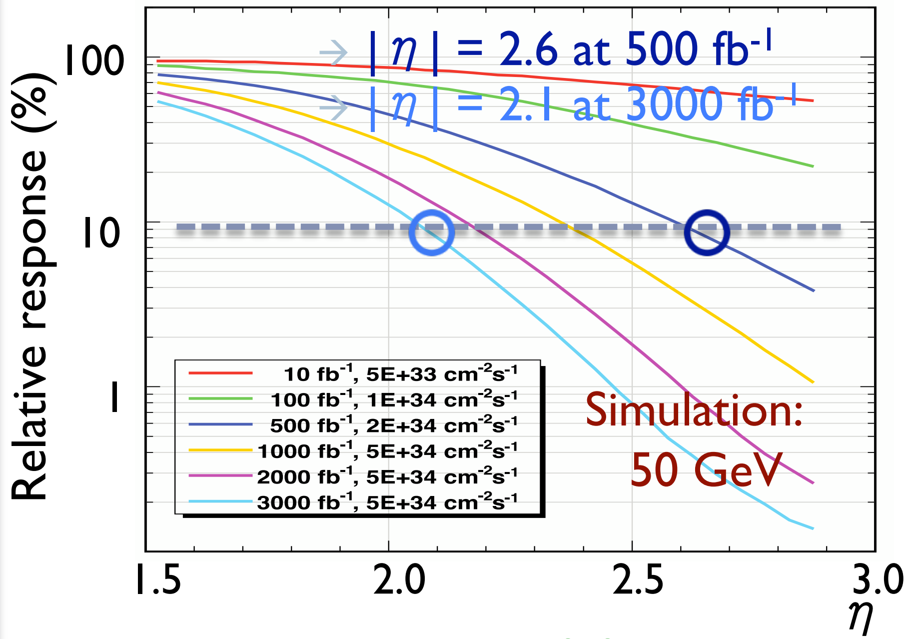

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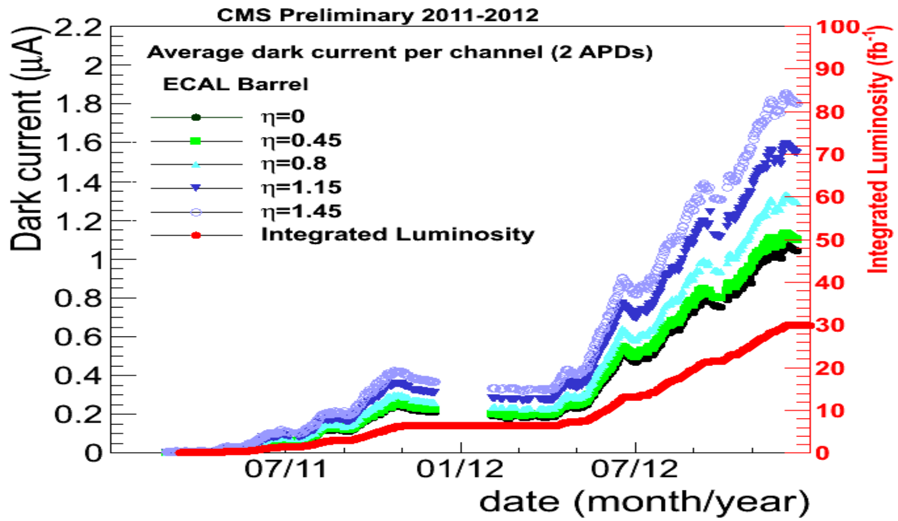

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CMS Endcap2: High Granularity Calorimeter (HGC)