Roger Rusack – The University of Minnesota

A HIGH GRANULARITY CALORIMETER FOR CMS.

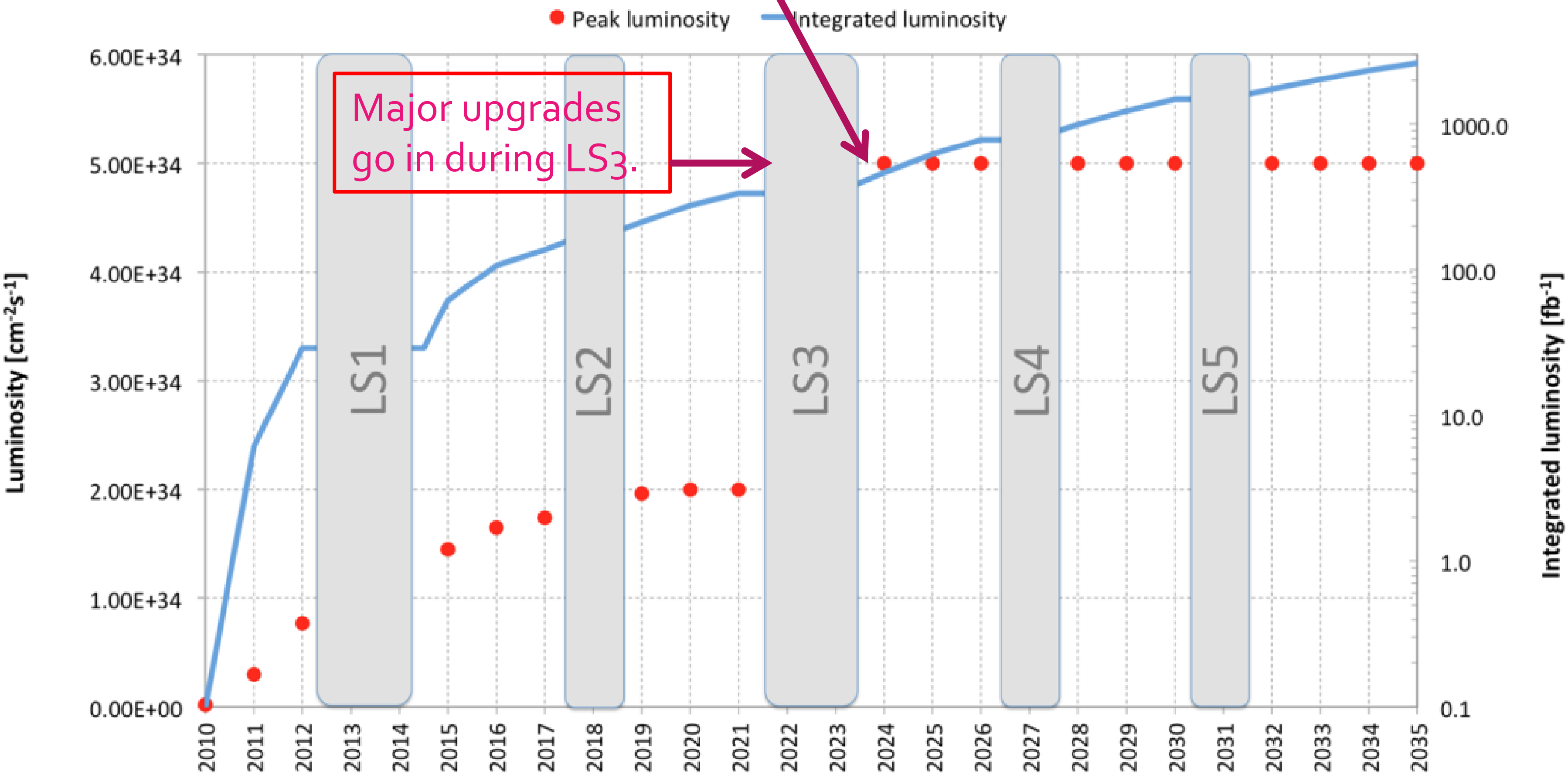
Contributing Institutions

Athens, Beijing, CERN, Demokritos, Imperial College, Iowa, LLR, Minnesota, SINP (Kolkata) & UC Santa Barbara

I will report on the work of many people from these institutions - this list is growing and we welcome new members.

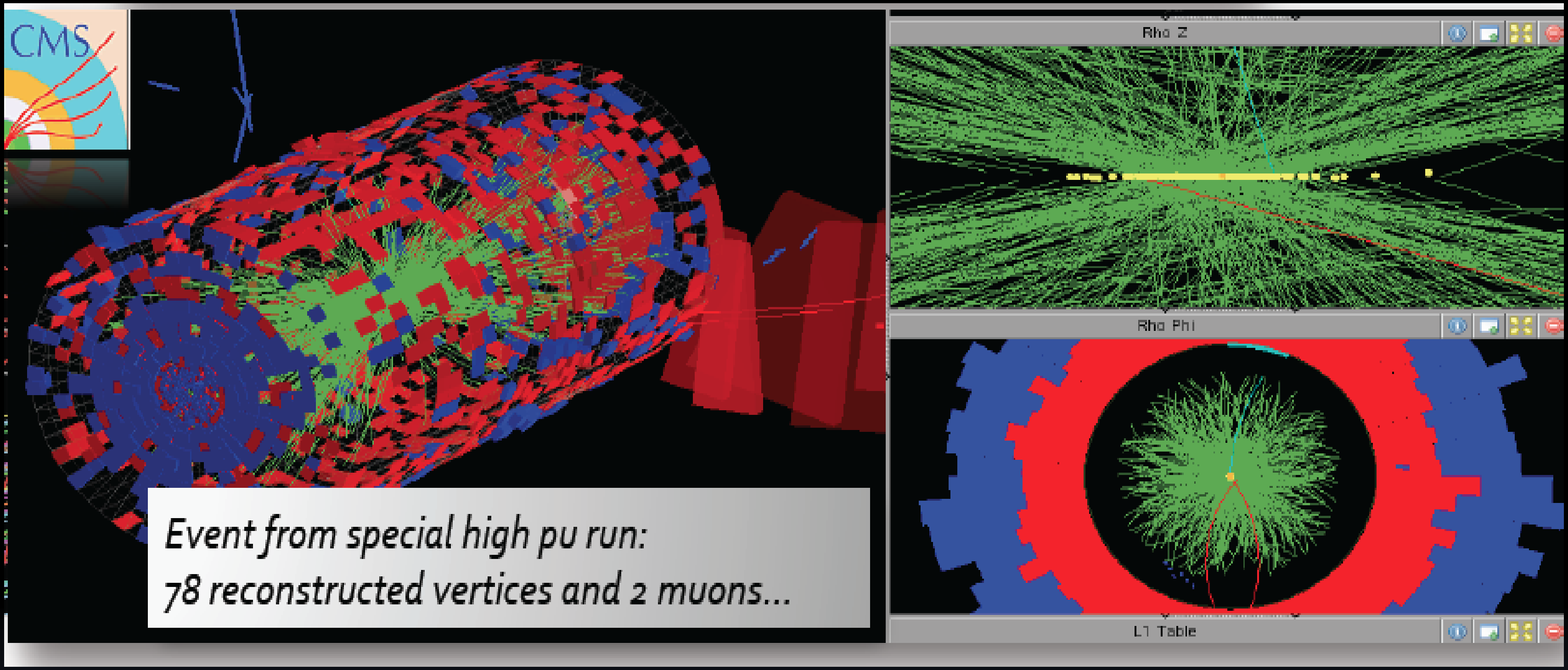
The LHC and HL-LHC Plans

Peak luminosity will be leveled to ~ 5×10^{34}



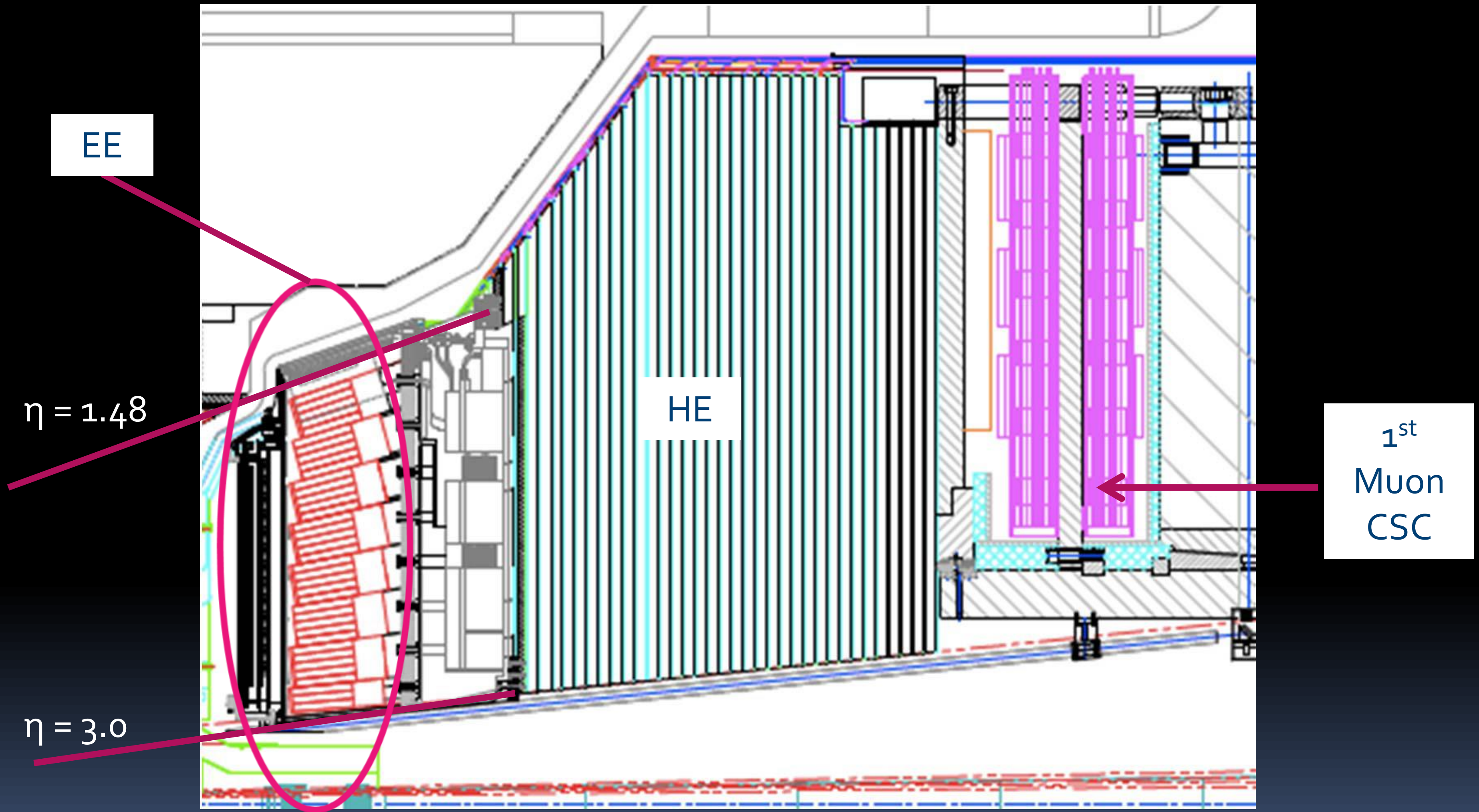
The proposed CERN schedule discussed at the ECFA meeting last October.

Pile-Up



With a 25 ns bunch crossing interval the pileup will be <140> at a luminosity of 5×10^{34} Hz/cm^2.

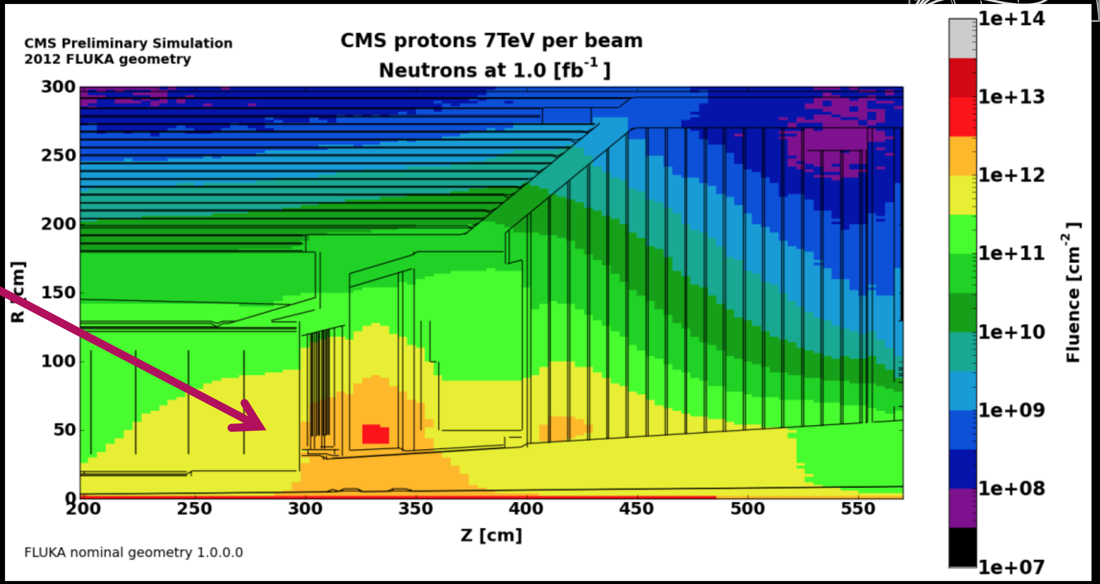
Endcap Calorimeters



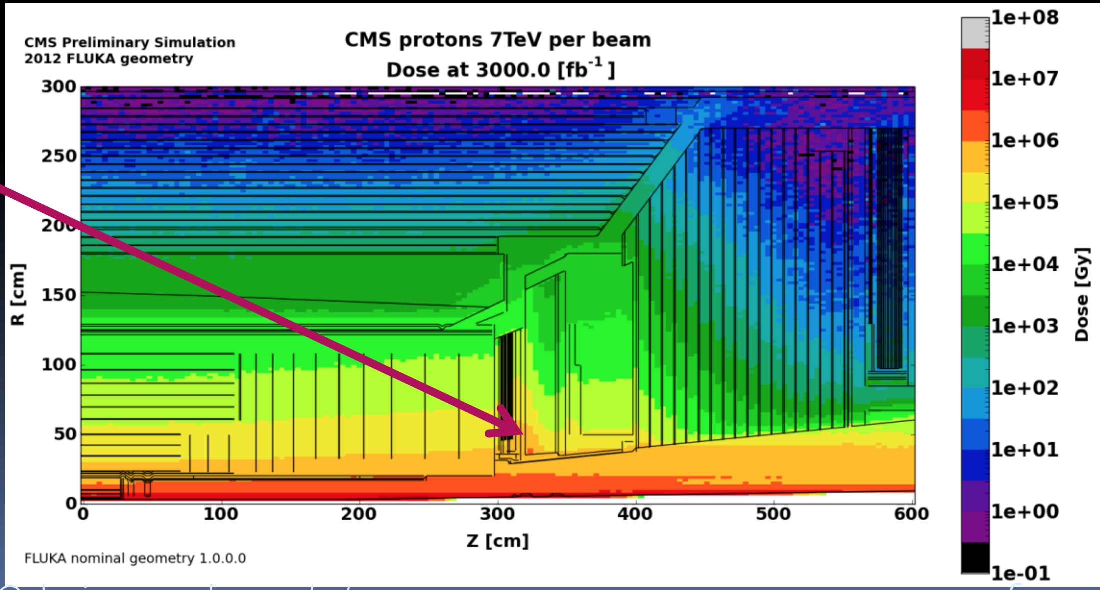
Both the endcap crystal calorimeter and the plastic scintillator calorimeters will need to be replace after LHC operations due to radiation damage.

HL-LHC environment

Neutron fluence will be ~3×10^{16} neutrons/cm^2 after 3,000 fb^{-1} at the highest eta region of the EM calorimeter.



Absorbed dose will be in the region of 10^6 Gy in the same region.



Challenges

- The HL-LHC is a machine to look for rare processes and to make precision measurements.
  - Capture as many of the VBF forward jets as possible in a single "crackless" calorimeter. This requires moving to higher eta the current boundary between the endcap and forward calorimeters.
  - Good energy em and hadronic energy resolution. "Good" means at least as good as our current detector.
  - Enable a powerful and flexible trigger

CMS Phase 2 Upgrades

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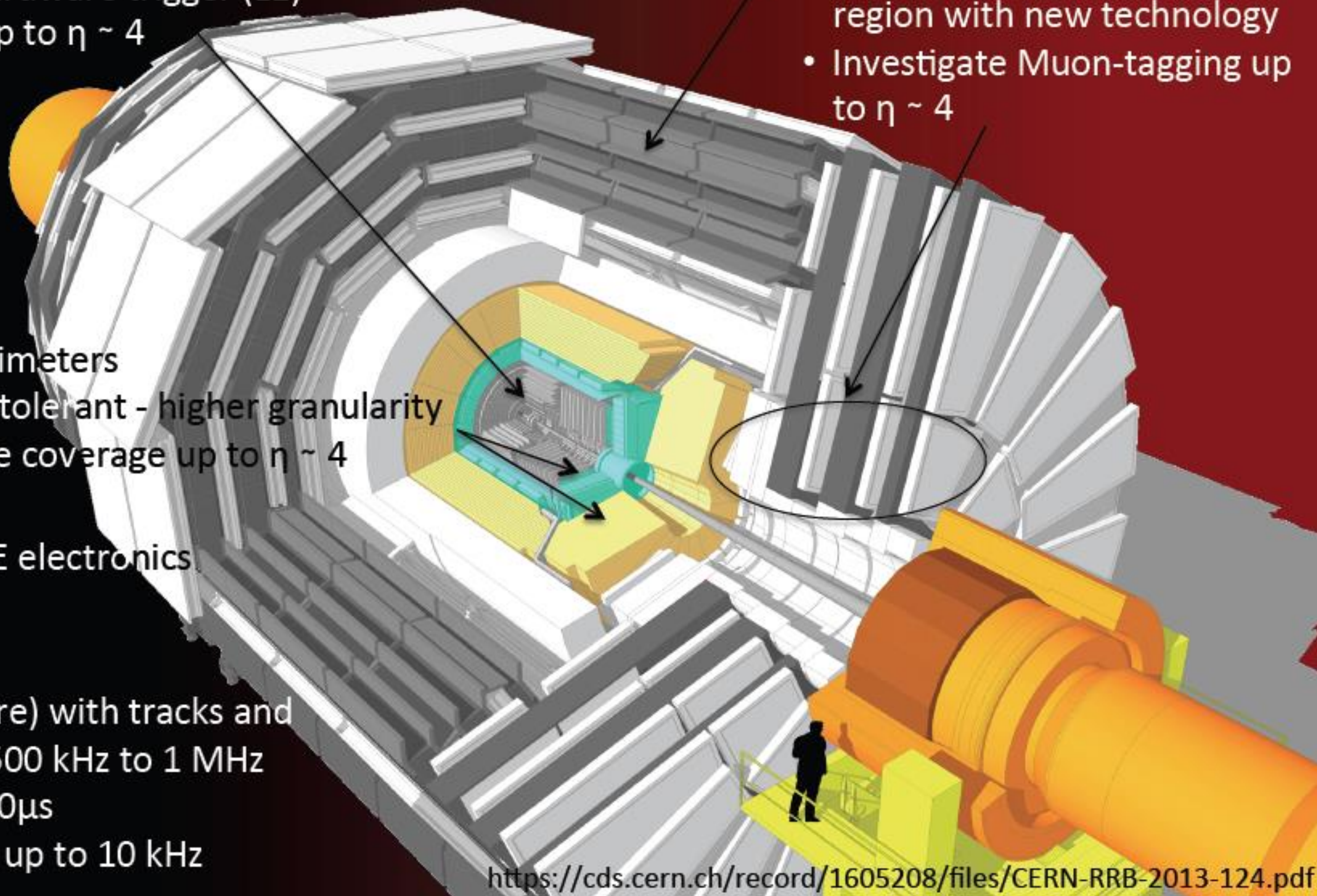
Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

Muons
- Replace DT FE electronics
- Complete RPC in forward region with new technology
- Investigate Muon-tagging up to η ~ 4



Endcap Calorimeters
- Radiation tolerant - higher granularity
- Investigate coverage up to η ~ 4

Barrel ECAL
- Replace FE electronics

Trigger/DAQ
- L1 (hardware) with tracks and rate up ~ 500 kHz to 1 MHz
- Latency ≥ 10µs
- HLT output up to 10 kHz

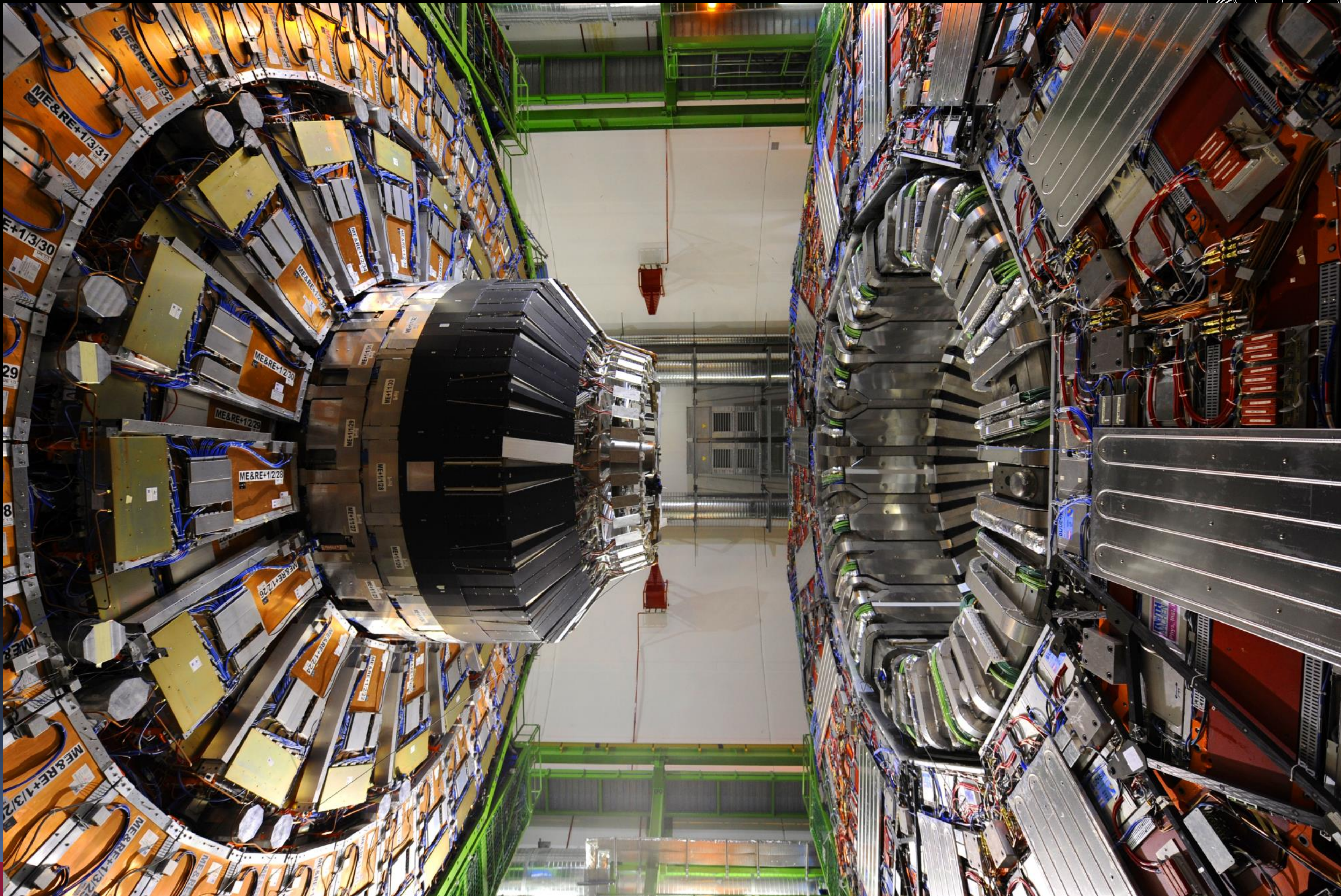
https://cds.cern.ch/record/1605208/files/CERN-RRB-2013-124.pdf

Endcap Calorimeter

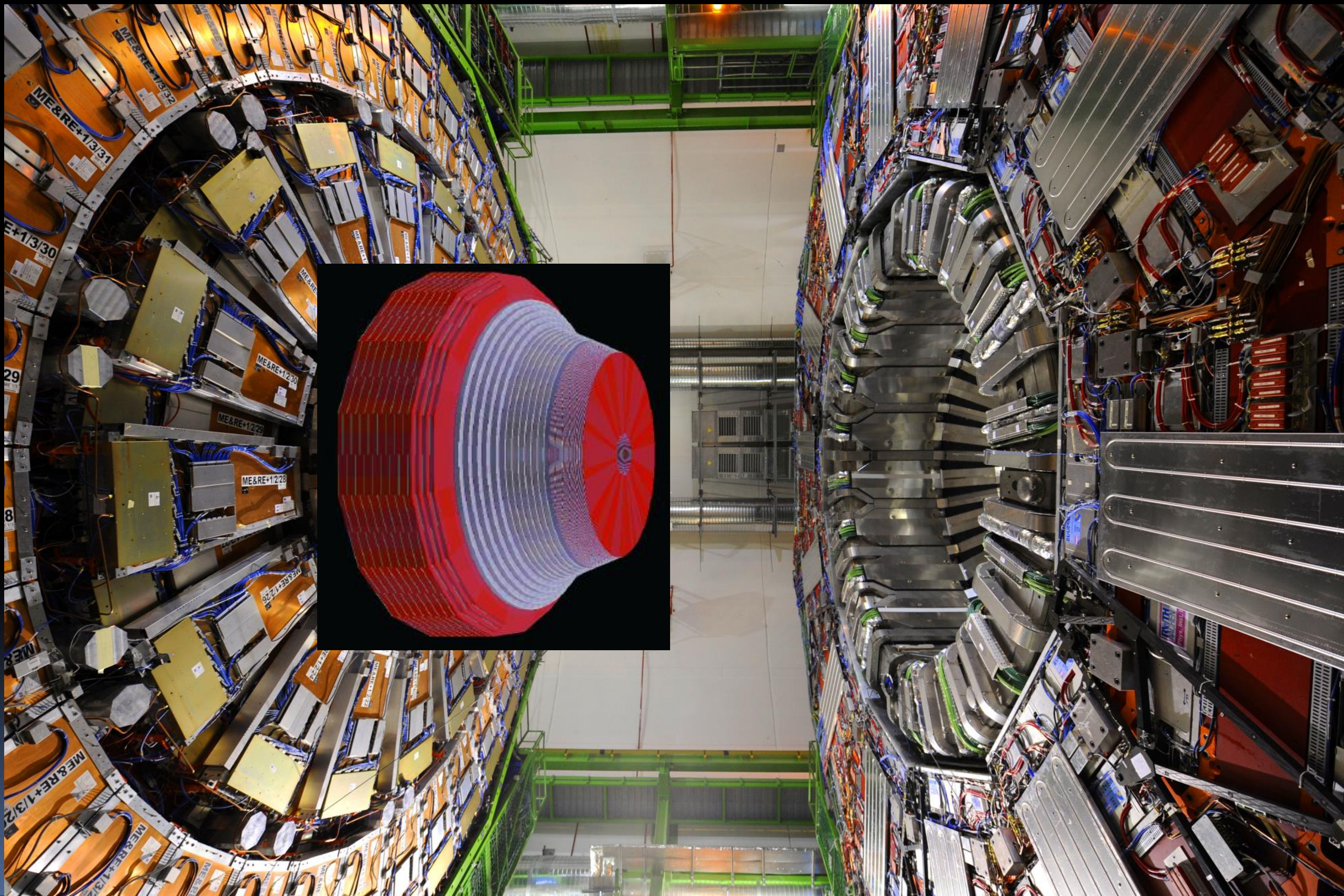
We are investigating in detail the possibility of using a high granularity calorimeter with ~2.5M channels of silicon pads (5M total).

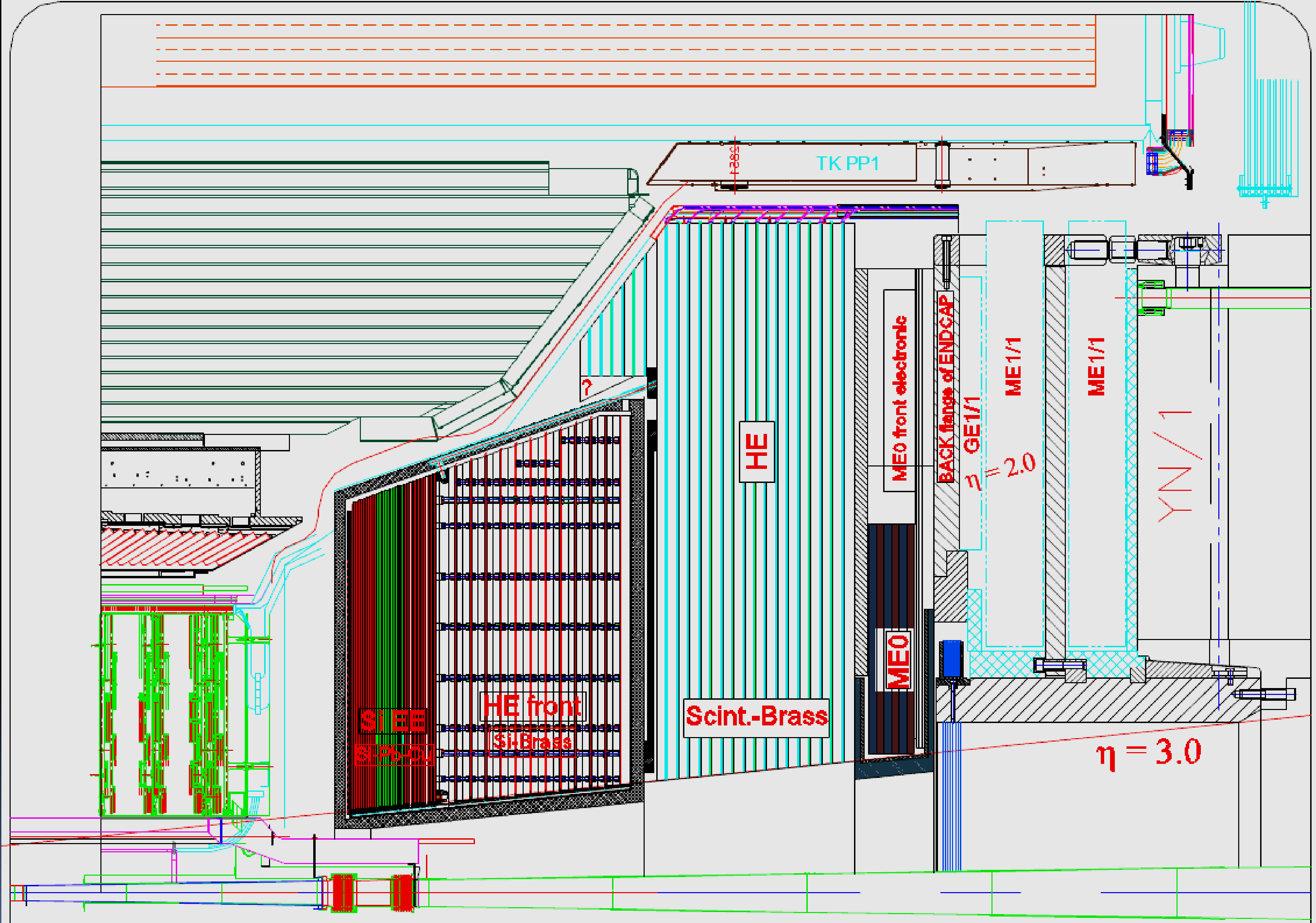
We expect that with such detailed information from the calorimeter, coupled with a precision silicon tracker, we will be able to measure physics objects with high precision.

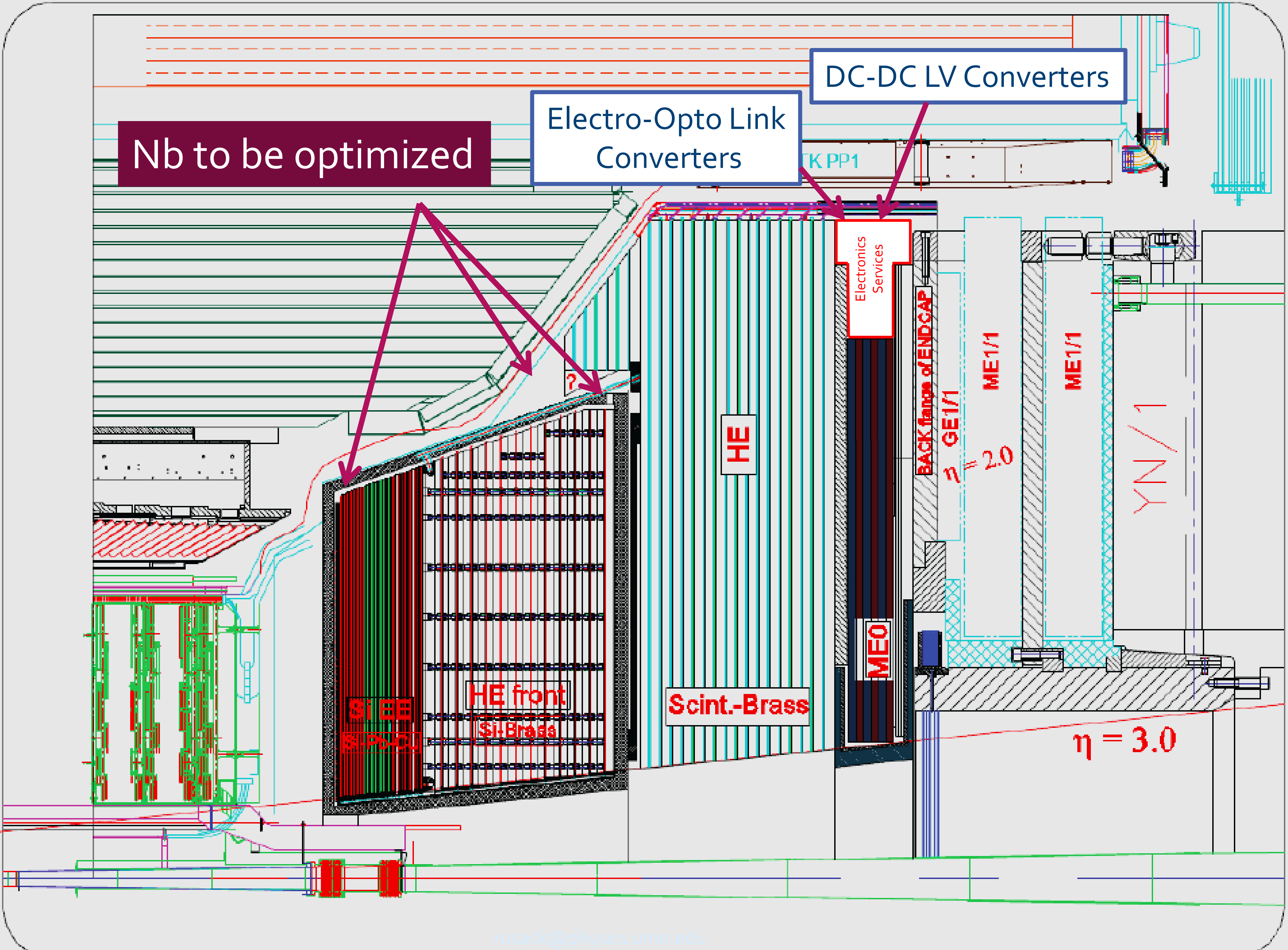
Current Detector



An Si Based HGC CMS at the HL-LHC




TK PP1
?
HE
ME0 front electronic
BACK flange of ENDCAP
GE1/1
ME1/1
ME1/1
YN/1
$\eta = 2.0$
ME0
Si EE
Si-Pb-Cu
HE front
Si-Brass
Scint.-Brass
$\eta = 3.0$



Nb to be optimized
Electro-Opto Link Converters
DC-DC LV Converters
TK PP1
Electronics Services
BACK flange of ENDCAP
GE1/1
ME1/1
ME1/1
$\eta = 2.0$
YN/1
HE
?
ME0
Scint.-Brass
HE front
Si-Brass
Si EE
Si-Pb-Cu
$\eta = 3.0$

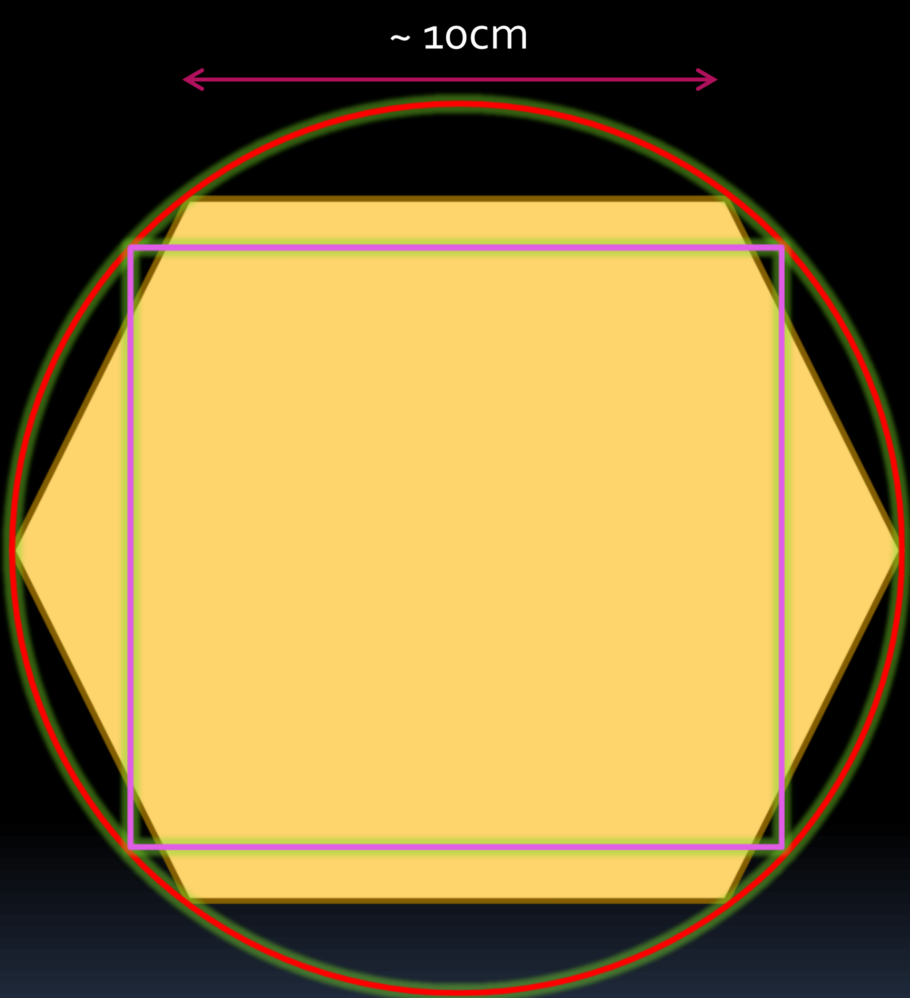
Parameters

- Electromagnetic Calorimeter:
  - 31 layers of lead/copper total of 25 X_0
    - 11 layers of 0.5 X_0/10 layers of 0.8 X_0/10 planes of 1.2 X_0.
    - Pad size 0.9 cm^2 for first 20 layers 1.8 cm^2 at back.
  - 420 m^2 of silicon pad detectors.
  - 3.7M channels.
- Front Hadronic Calorimeter
  - 4 interaction lengths.
  - 12 layers of brass/silicon.
  - Pad size is 1.8 cm^2
  - 1.4M channels.
- Backing calorimeter
  - Five interaction lengths.
  - Radiation levels are much lower can use plastic scintillator or MPGD's. To be decided based on cost and performance.

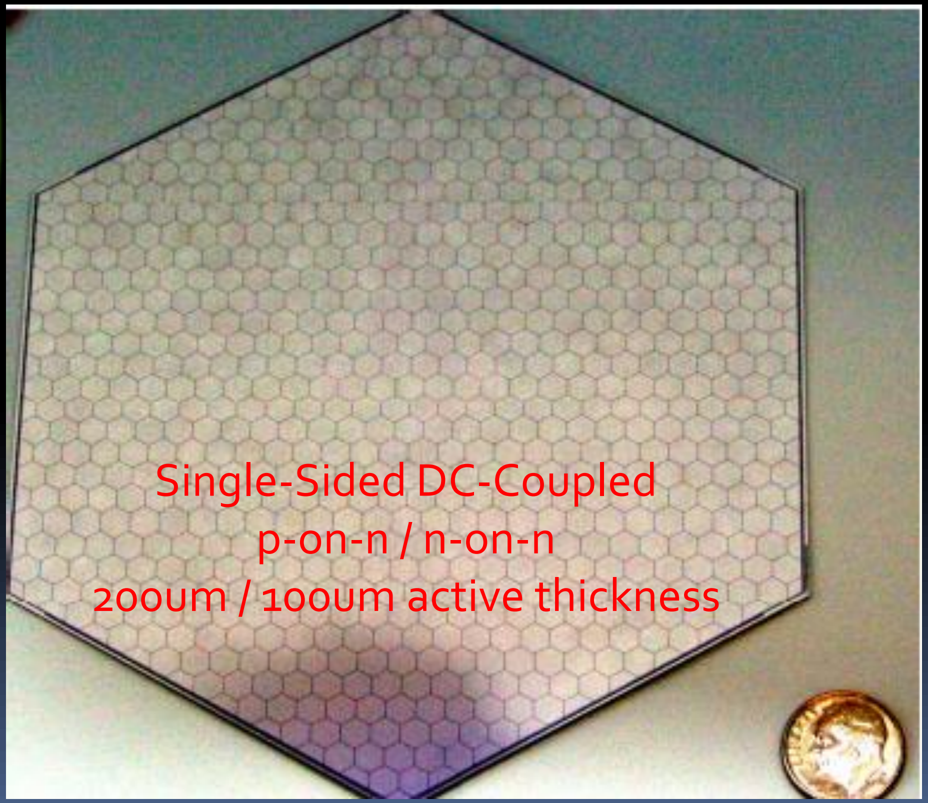
Major Engineering Challenges

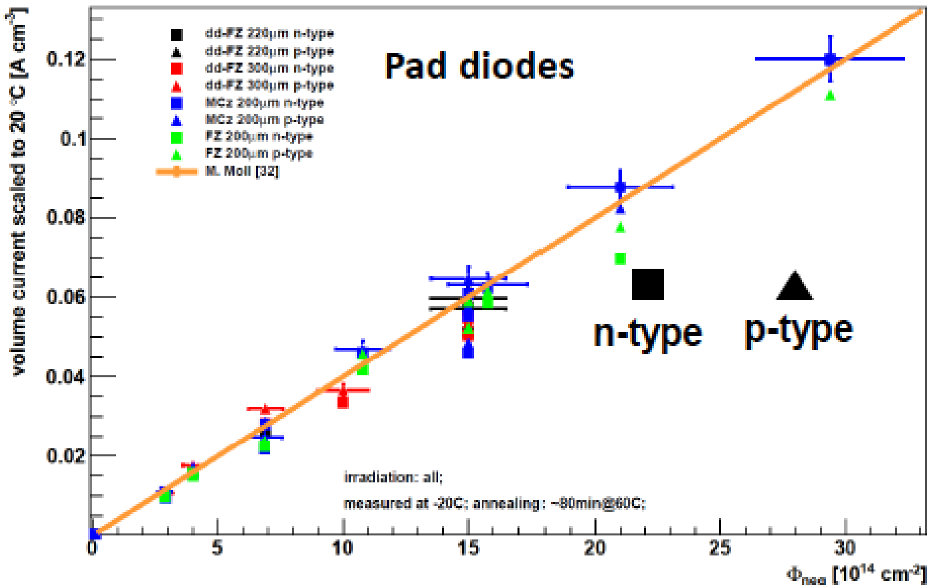
- 600 m^2 of Silicon in a high radiation environment.
  - Cost.
  - Very high radiation levels – need to plan for 3×10^{16} neutrons in the highest
- Cooling.
  - We need a compact calorimeter with small gaps between absorber plates.
  - We need to operate at – 30°C
  - Total power is ~100 kW.
- Data and Trigger
  - Channel count is 5M. Producing a prodigious amount of data.
  - Data used in the Level- 1 CMS event trigger

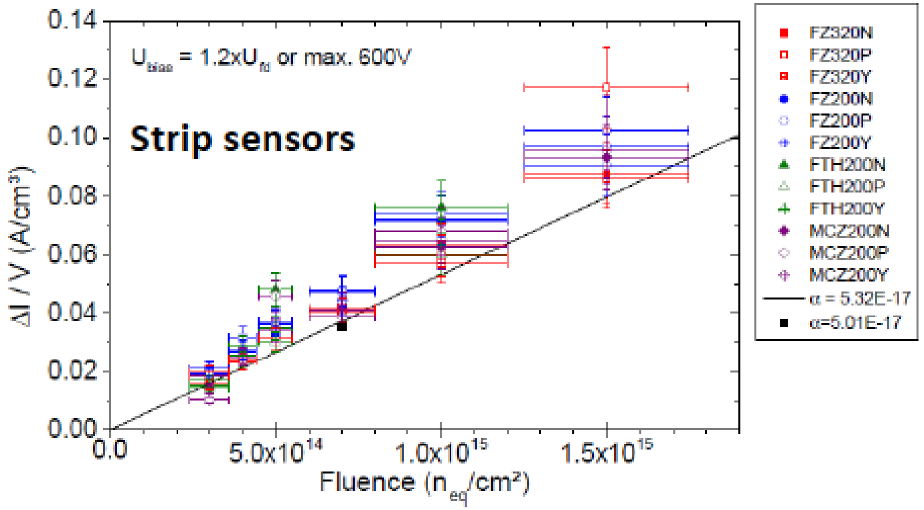
HGC Silicon Sensors



	Sensor Surface cm^2	
	Square	Hexagonal
6” wafers	~ 100	~ 130
8” wafers	~ 180	~ 230







Measured @V_dep+5%, -20°C, scaled to +20°C

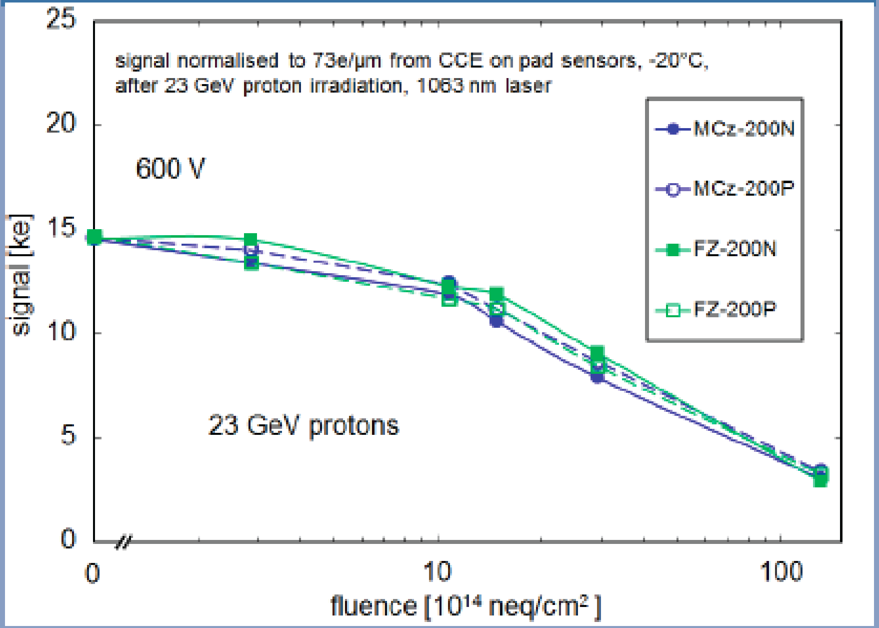
- Volume current scales with fluence:
- Scaling parameter independent of Si material, oxygen concentration
- Scaling parameter agrees with previous measurements M. Moll, PhD thesis, Hamburg 1999
- Note: Increased current seen in strip sensor

$$\frac{\Delta I}{V} = \alpha \Phi_{eq}$$

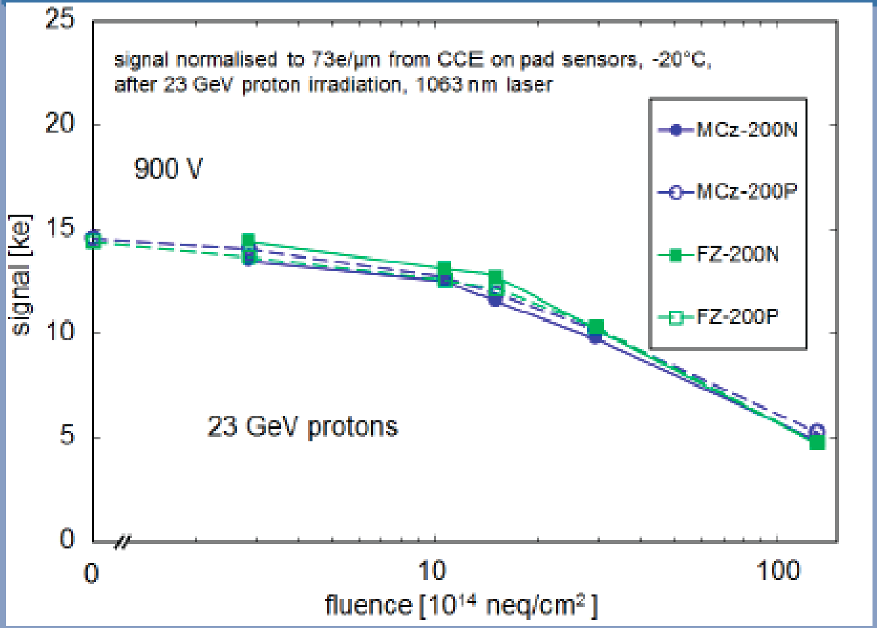
→ Current/ fluences understood
→ Independent of material
→ Independent of polarity
→ Cold operation necessary!

Collected Charge from IR-TCT

V_B= 600 V



V_B= 900 V



→No difference found for MCz and FZ both N and P
Weighting field and E-field in structured devices might lead to a different picture

Readout - Ideas

- Front End Electronics.
  - Dynamic range ~ 1 – 10,000 mips.
  - Shaping time ~ 25 ns.
  - Noise floor - ~ 1 mip.
  - Low power – 15 mW/channel.
- Data links.
  - Use CERN LPGBTx (5 Gbps/3.2 Gbps) drive electical signal on Twinax or micro-coax to back of calorimeter.
  - Use Rad Hard FPGA (eg. IGLOO2) to convert to 10 Gbps link at back of calorimeter.

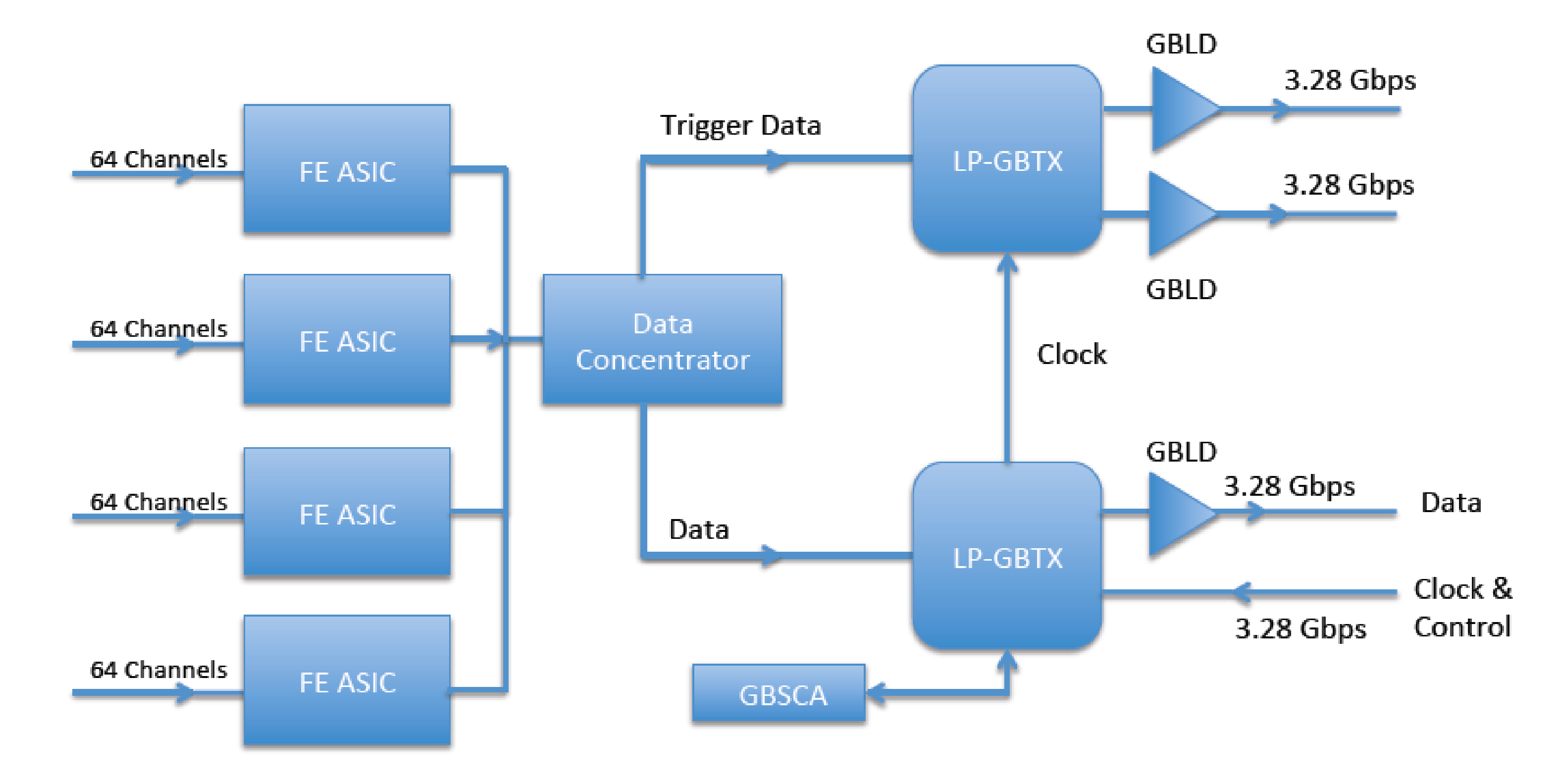
HGC Proposed FE architecture

C_{in} 100 ~ 200pF; τ ~ 10ns; ~ 1MIP -> 10kMIP

On Chip digitization for each channel at 40MHz

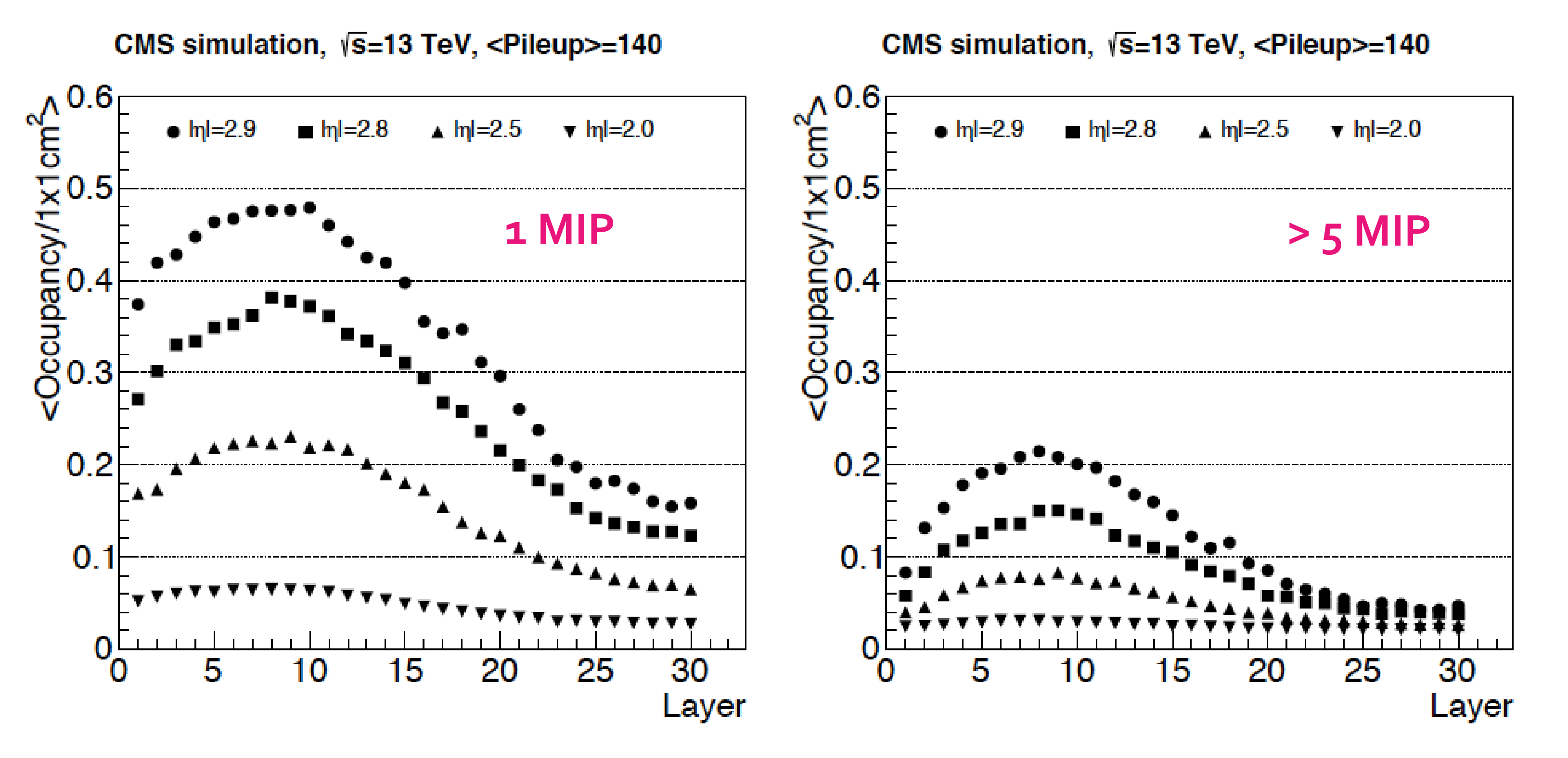
Sum 4(2) adjacent pads -> L1 Trigger primitives with 8 bit resolution

Readout at 1MHz L1 accept rate with 12 bit resolution



Occupancy.

Exploit Low Occupancy
Digitize only when there is a relevant signal present

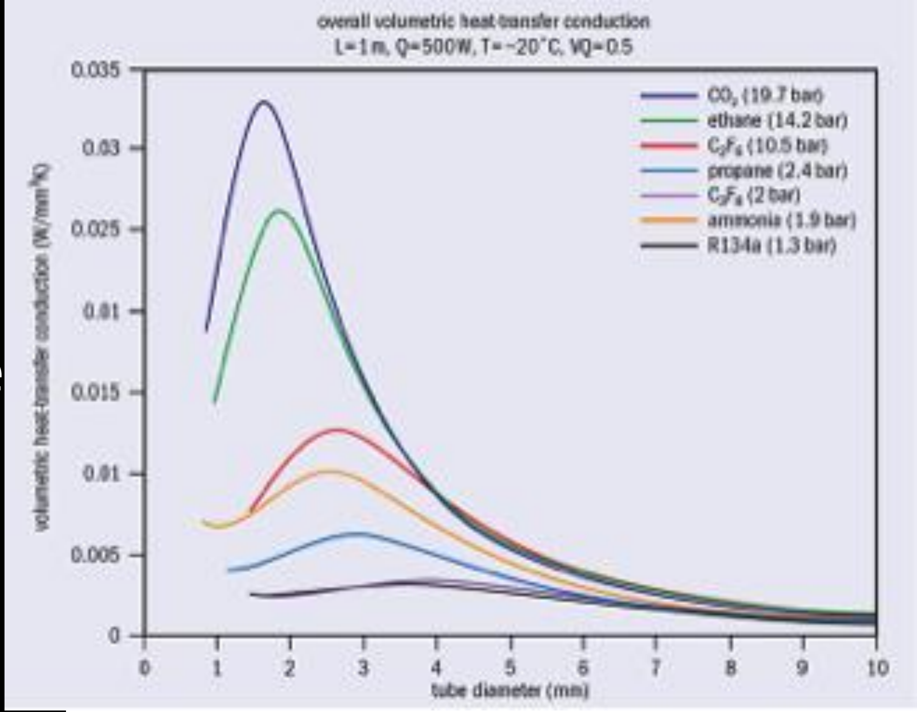


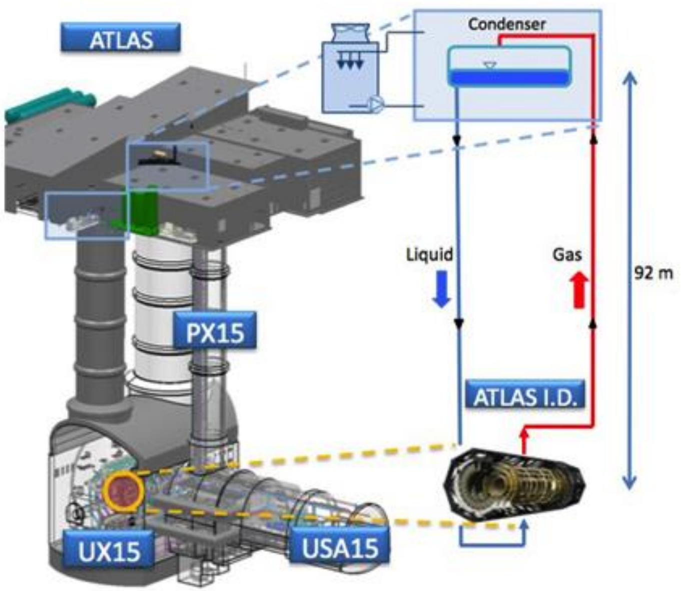
Occupancy in 1cm² pads with <PU> = 140

Cooling Options:

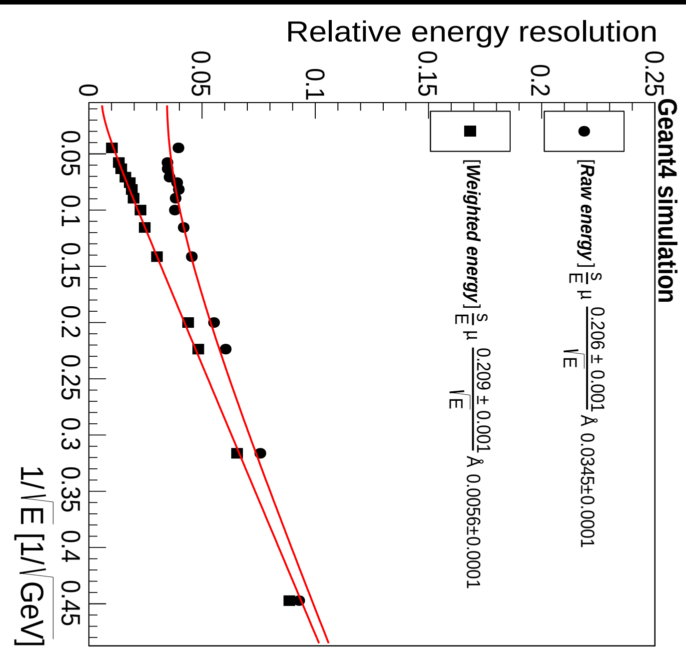
- CO_2 bi-phase cooling.
  - Planned for CMS phase 2 tracke
  - High pressure good heat transfer.
- ATLAS thermo syphon with standard refrigerants.
  - Uses C_3F_8
  - Operates at 1 – 2 atm.

Without the luxury of switching of the electronics between bucnh crossings, cooling becomes a major engineering challenge for this detector.

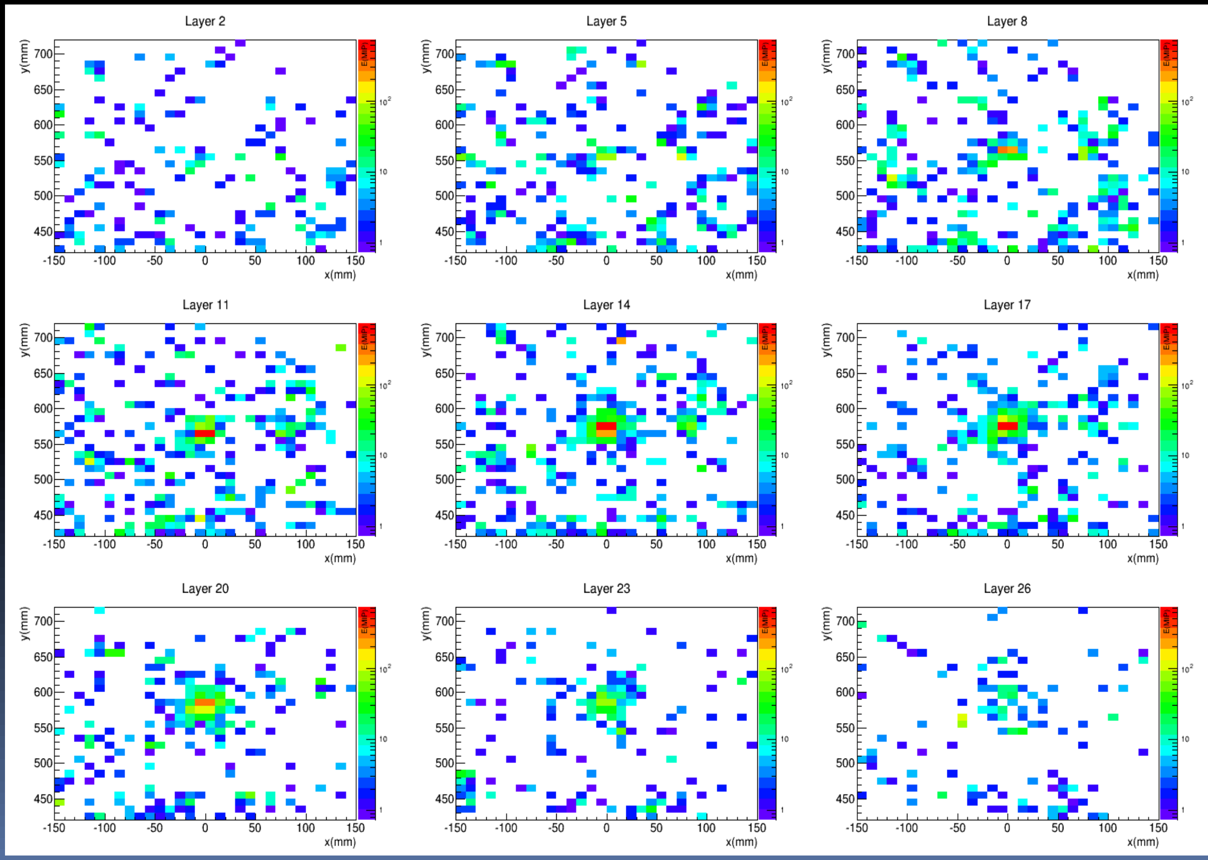




Performance – I

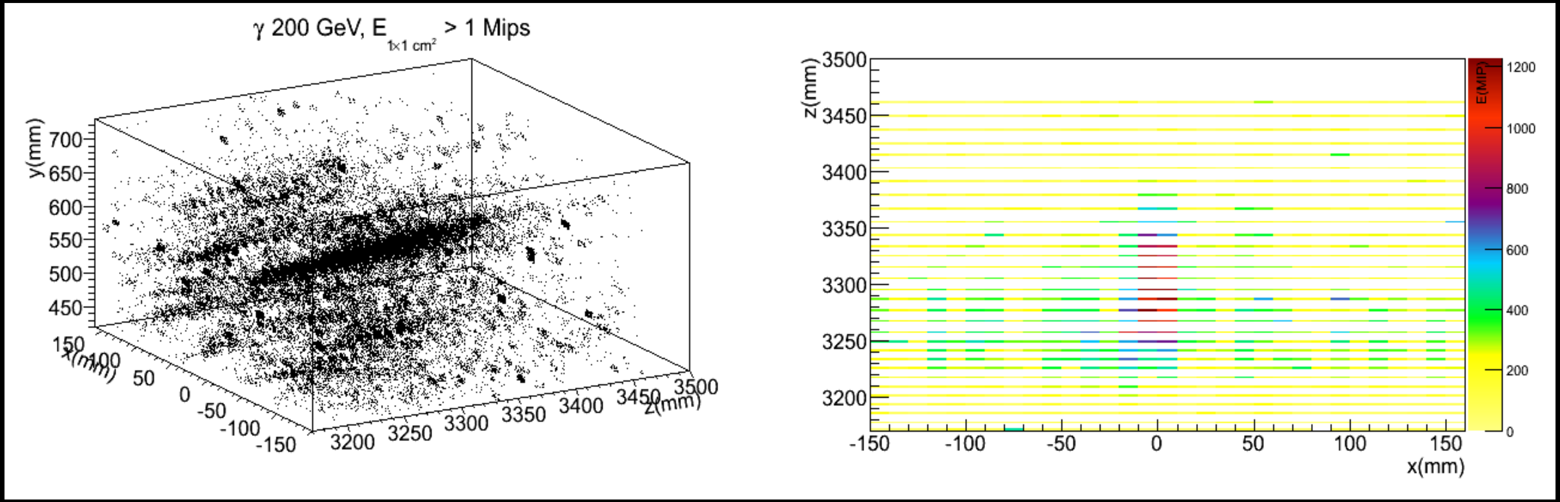


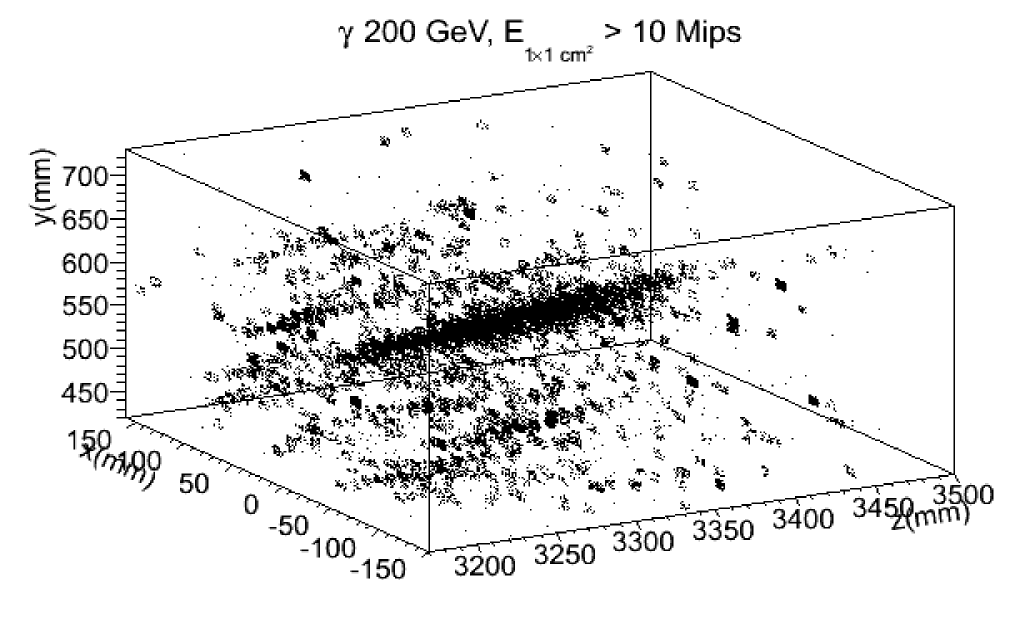
200 GeV photon at η = 2.5 with 140 pileup events.



Resolution of 20%/√E stochastic
Estimate constant term ≤ 1%.

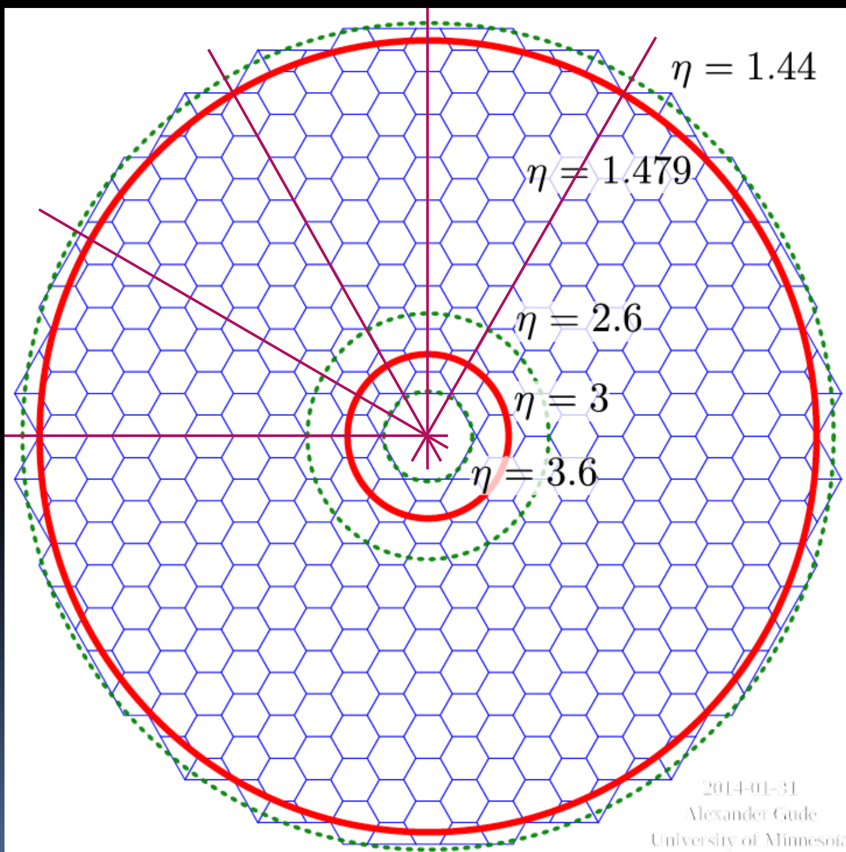
Performance-II

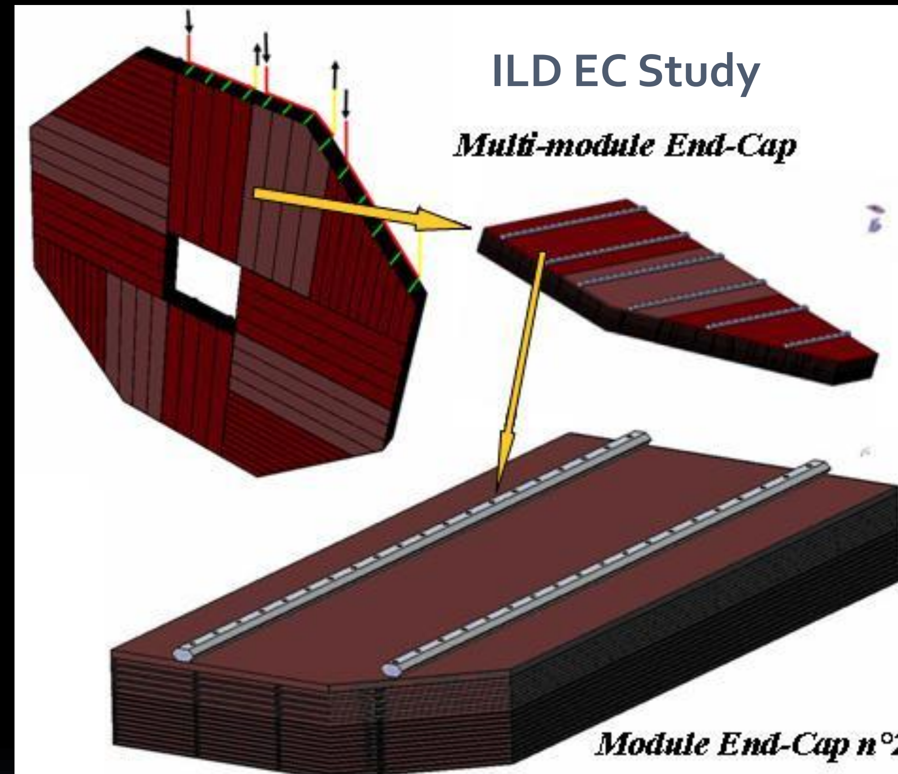




Evolving Mechanics and Cooling

Possible Phi-Sector Geometry





Organization of services within Sector will be studied with a mock-up

Summary

- CMS is investigating building a silicon-based calorimeter for the forward region of CMS.
- There are many engineering challenges.
- We are benefitting from the work of CALICE/CLIC communities.
- There is a much work ahead and we welcome new collaborators.