CMS Experiment:
Current and Future Activities

Shashikant R. Dugad on behalf of
TIFR-CMS-A Group

07 May 2018

Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m

CMS

ECAL 76k scintillating $PbWO_4$ crystals

HCAL Scintillator/brass Interleaved ~7k ch

3.8T Solenoid

IRON YOKE

MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)

Preshower
Si Strips ~16 m^2
~137k ch

Foward Cal
Steel + quartz Fibers
~2k ch

YBO

YB1-2

YE1-3

Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

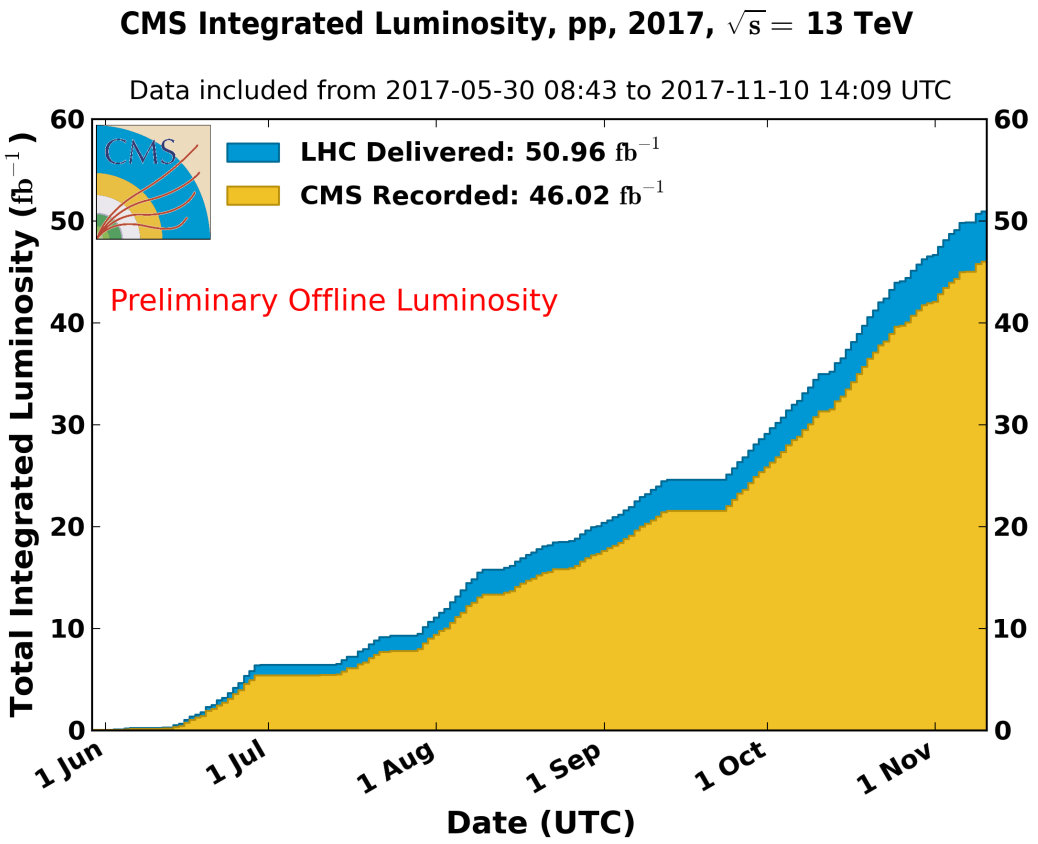
Pixels & Tracker
- Pixels (100x150 μm^2) ~ 1 m^2 ~66M ch
- Si Strips (80-180 μm) ~200 m^2 ~9.6M ch

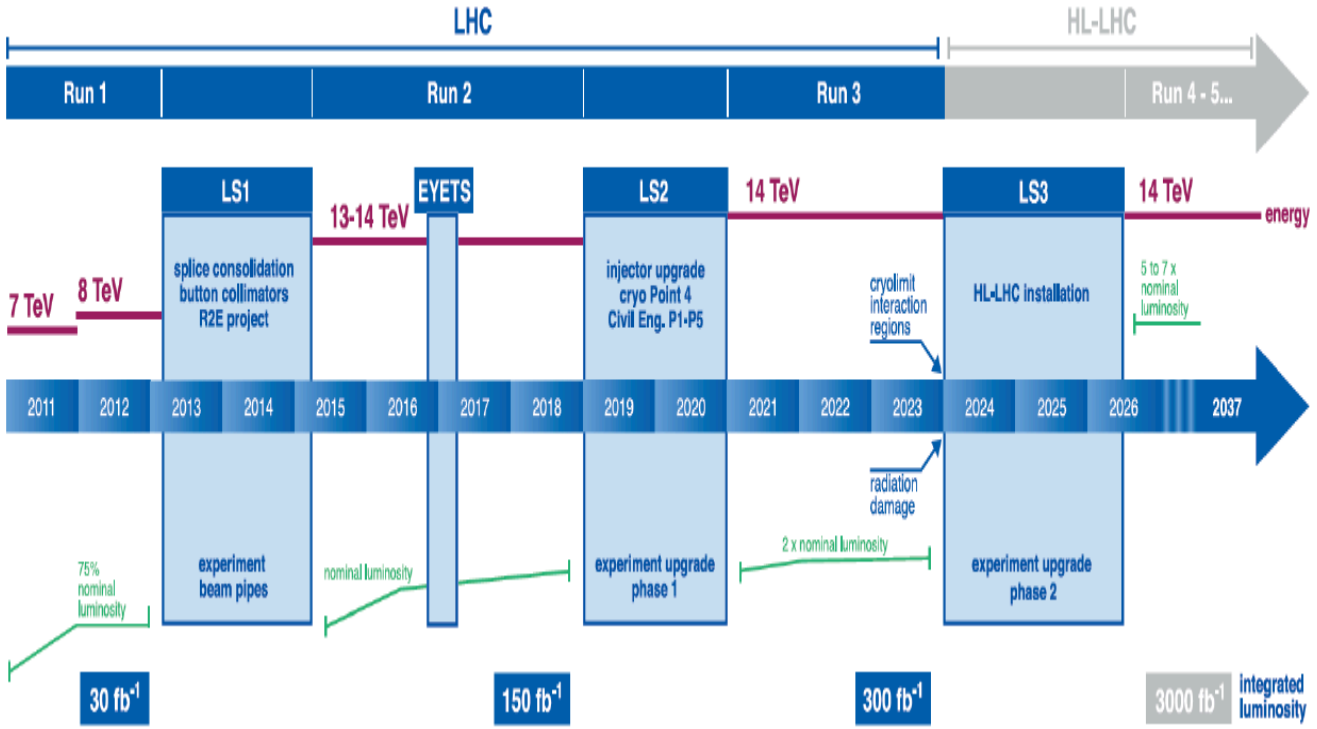
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)

Outline

- **Many DAE institutes and universities have been collaborating with CERN on Accelerator, Computing as well as two major high energy physics experiments (CMS and ALICE)**
- **India has made significant contributions on all these fronts**
- **TIFR is part of CMS experiment since the beginning and have taken many major responsibilities and have successfully executed them**
- **Recent activities of the group and future plans will be presented**

2017 CMS Data and Future Expectations





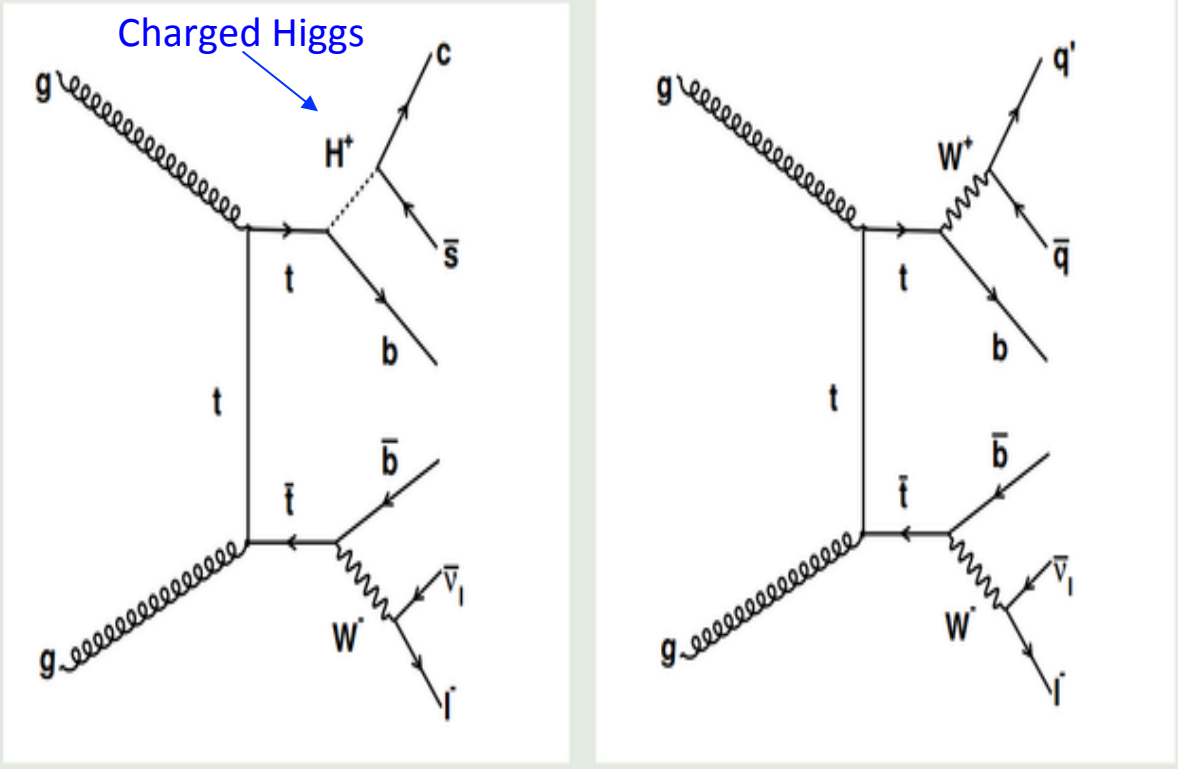
Current and Future Activities

- **Search for New Physics (Search for Lepto-quarks, Charged Higgs)**
- **Precision test of Standard Model**
- **Design of Trigger Electronics for Phase-2 Silicon based End-cap Calorimetry (HGCAL)**
- **High Level Trigger for Phase-1 Tracker with parallel computing architecture**
  - **Extension of this expertise to HGCAL**

Search for Charged Higgs in CMS data

Signal event topology : 4-jet, 1-lepton + MET
SM bkg($t\bar{t}$+ jets, single top, W+jets, VV, QCD)

H^+(signal) $t\bar{t}$ (dominant bkg)



Available on the CMS information server **CMS AN-18-061**

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2018/05/04
Head Id:
Archive Id: 457623M
Archive Date: 2018/04/06
Archive Tag: trunk

Search for a light charged Higgs Boson in the $H^{\pm} \to c\bar{s}(\bar{c}s)$ channel with lepton+jets final states at 13 TeV, in the CMS experiment

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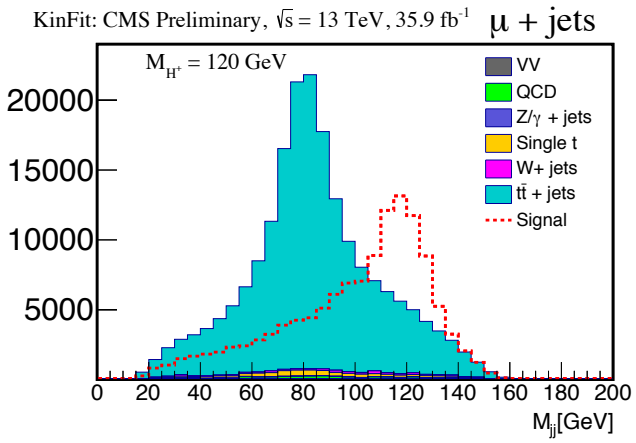
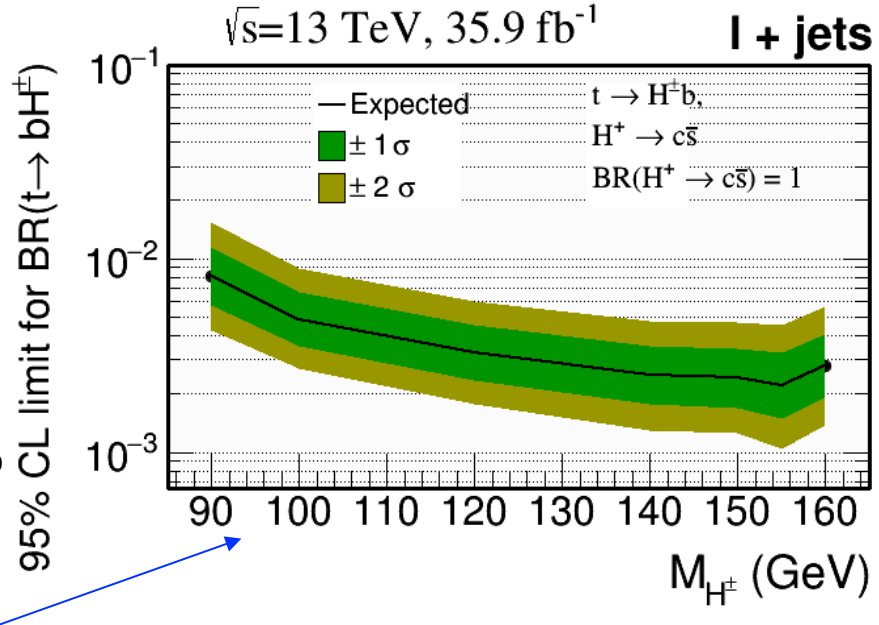
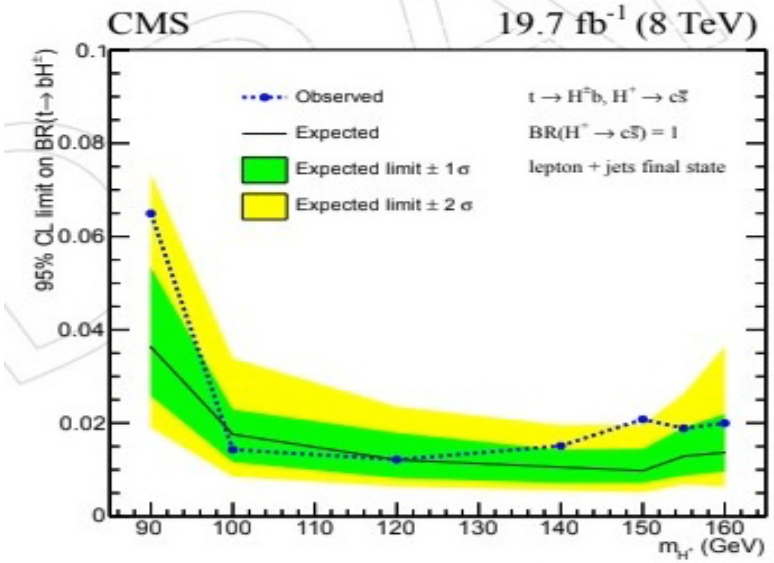
Abstract

CMS experiment in 2016 has recorded pp collision events at center of mass energy, $\sqrt{s} = 13$ TeV with an integrated luminosity of 35.9 fb^{-1}. Large number of events due to $t\bar{t}$ production are observed in this data. Under minimal supersymmetric standard model (MSSM) one of the top quark can decay into charged Higgs and b-quark and other top quark in W Boson and b-quark. Charged Higgs boson is assumed to decay into cs ($H^{\pm} \to c\bar{s}(\bar{c}s)$) with branching ratio ($\mathcal{BR}$) of 100%. The W Boson is expected to decay leptonically ($W^+ \to l^+\nu$). Events satisfying topology of a single electron (or muon), at least 2 bjets, 2 non-bjet, and missing energy are selected for this search of charged Higgs. In absence of signal, the upper limit on the $\mathcal{BR}$ of top-quark decaying to charged Higgs and b-quark, as a function of charged Higgs mass, is obtained using 2016 data. Results are presented in this note.

Final Limits: 13 TeV vs 8 TeV







Only expected limit at 13 TeV because the data is still blinded.

$M_{H^\pm}$(GeV)	-2σ	-1σ	median	$+1\sigma$	$+2\sigma$
90	0.42 (1.9)	0.57 (2.6)	0.81 (3.6)	1.14 (5.3)	1.53 (7.3)
100	0.27 (0.9)	0.35 (1.2)	0.48 (1.8)	0.66 (2.3)	0.89 (3.4)
120	0.17 (0.6)	0.23 (0.8)	0.32 (1.2)	0.45 (1.8)	0.60 (2.4)
140	0.13 (0.6)	0.17 (0.7)	0.24 (1.1)	0.35 (1.4)	0.47 (2.0)
150	0.12 (0.5)	0.16 (0.7)	0.24 (1.0)	0.34 (1.4)	0.46 (2.0)
155	0.10 (0.7)	0.14 (0.9)	0.22 (1.3)	0.32 (1.9)	0.45 (2.6)
160	0.13 (0.6)	0.19 (1.0)	0.27 (1.4)	0.40 (2.2)	0.56 (3.6)

Table 6: Expected 95% CL limit on $\mathcal{BR}(t \to bH^+)$ (in percent) from 13 TeV (8 TeV) for lepton + jets channel.

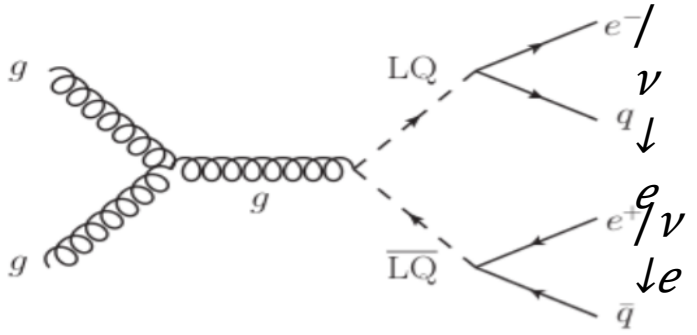
The limit at 13 TeV is better as that of 8 TeV by a factor of ~4

L*σ(13)/L*σ(8) = 5.9

Search for first generation scalar leptoquarks

EXO-17-009

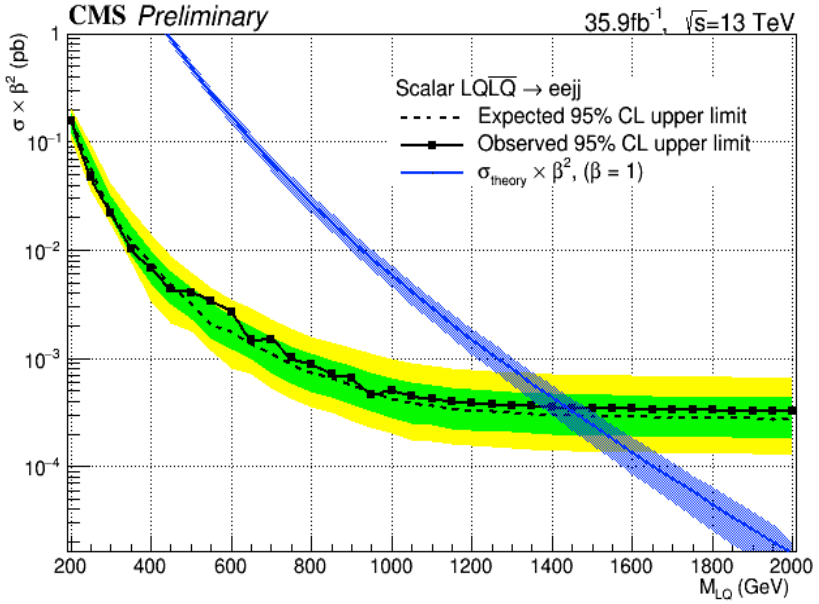
- A new class of bosons carrying both lepton and baryon numbers, and fractional charge
  - ➢ Present in several new physics models such as technicolor and GUTs
  - ➢ Can be scalar or vector particles
- We are looking for pair-produced 1st generation scalar leptoquarks (LQs) in pp collision data recorded at 13 TeV
- Considered two final states: eejj and evjj with $\beta = BF(LQ \rightarrow eq)$ is a free parameter



- In absence of a statistically significant signal, 95% CL upper limits are set on $\sigma\beta^2$ and $\sigma 2\beta(1-\beta)$ for eejj and evjj, respectively

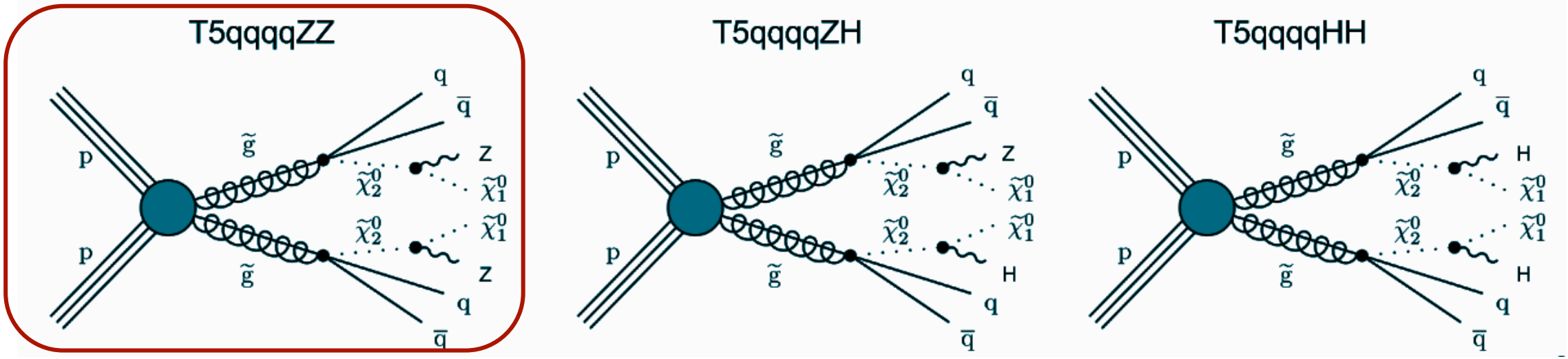
  - ➢ Expected limit on the LQ mass: 1465 (1209) GeV for eejj (evjj) while the corresponding observed limit is less by 30 (13) GeV

- ❑ Limits in the evjj channel obtained for the first time at 13 TeV
- ❑ Significant improvements over results obtained in 2015 data and 8 TeV
- ❑ Publication draft is under internal review



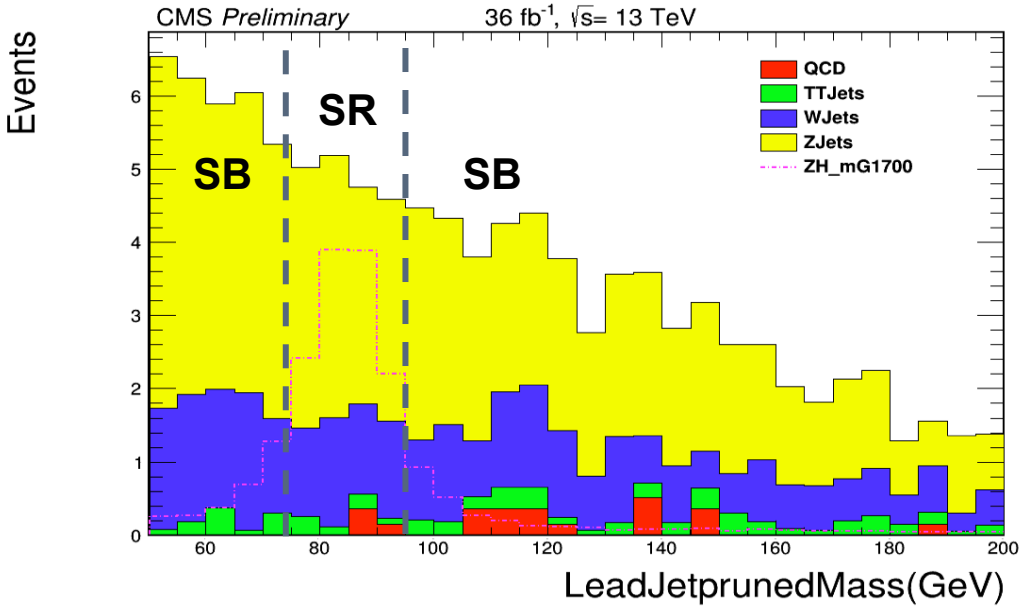
Search for supersymmetry in jets+MET final state

- Looking for pair produced gluinos in the final state of boosted vector bosons and missing transverse energy (MET) due to escaping neutralinos ☛ candidate for dark matter



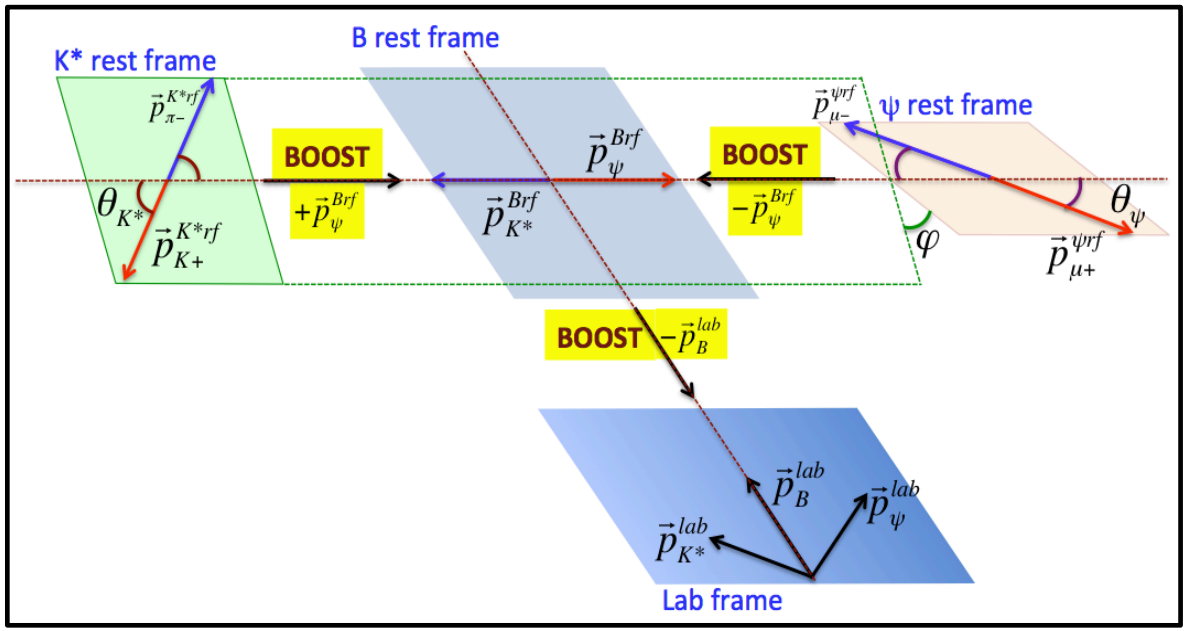
- In development a classic cut-and-count analysis method with the invariant mass of the leading large-radius jet as the final variable
- Signal is expected to peak around the nominal Z mass while SM backgrounds are smoothly falling

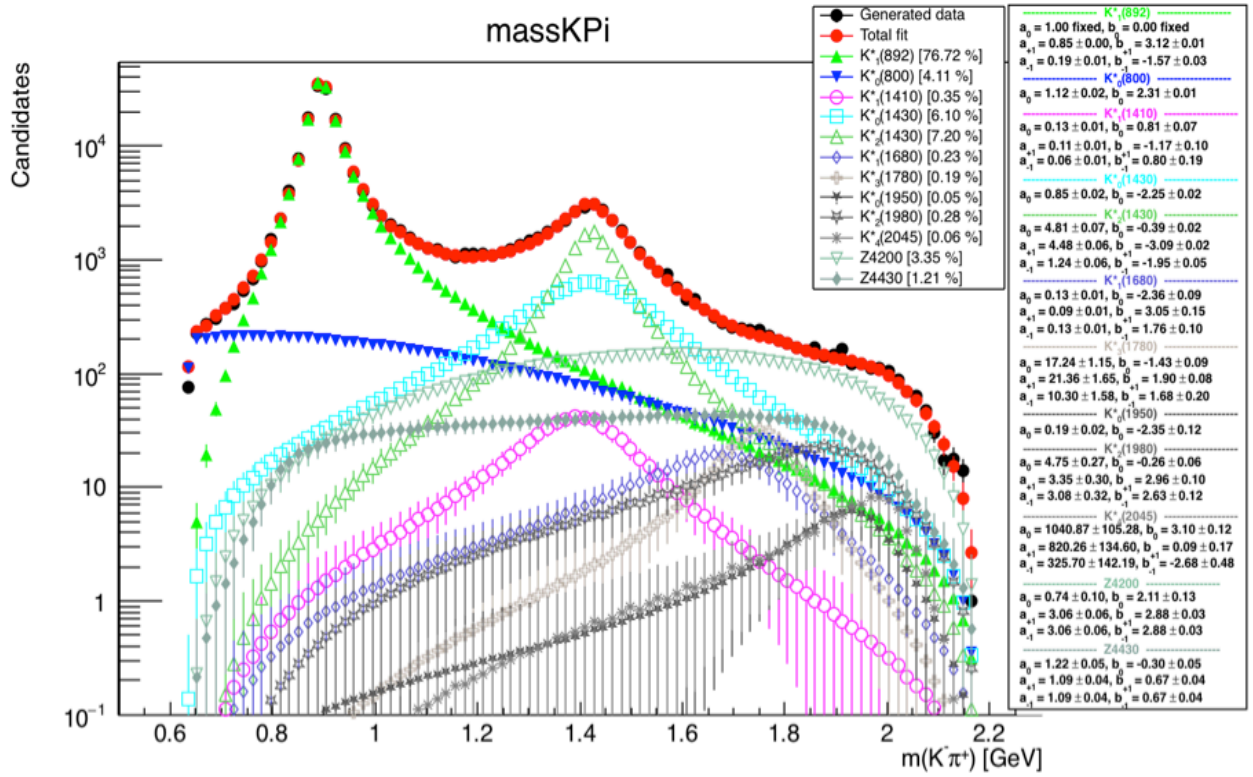
➢ Fully data-driven background estimation will be employed
➢ Encouraging results from a preliminary look



Search for exotic charmonium-like state

- Charged charmonium-like Z states are manifestly exotic and potential candidates for tetraquark states with minimal quark content $|cc\,du>$
- We are searching for $Z(4200)^{-}$ and $Z(4430)^{-}$ states in the $B^0 \to (J/\psi\pi^{-})K^{+}$ decays in pp collision data recorded at 8 TeV ☛ found by Belle a while ago but without any results from other experiments including LHCb
- Developed a robust angular analysis framework based on $\Phi \equiv (M_{K\pi^2}, M_{J/\psi^2}, \theta_{J/\psi}, \phi)$





- Framework is validated in pseudo-date samples
- Shall look at once the internal review is done

Fetching LHC Fill Information from Online DB to Offline DB

FillInfo O2O works at this step.
It fetches Fill information (such as energy of beams, magnetic field, luminosity per bunch crossing etc) from OMDS and stores to the ORCON.

OMDS: Online Master DataBase System
ORCON: Offline Reconstruction Condition database for ONline use.

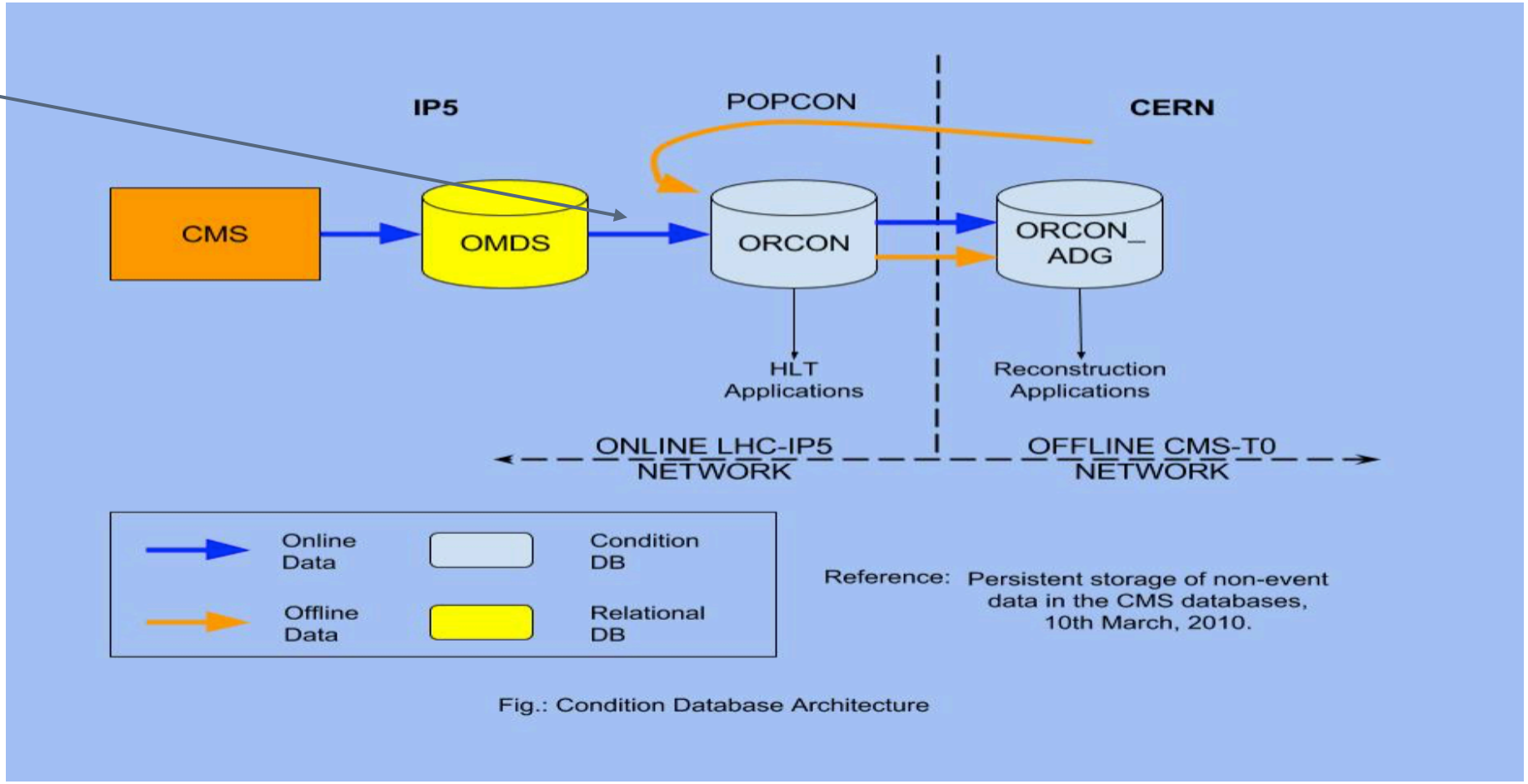


Fig.: Condition Database Architecture

The modified FillInfo package was accepted and officially merged in the CMSSW 10_X_Y in March 2018.

- https://github.com/cms-sw/cmssw/pull/22527#event-1514741512
- https://github.com/cms-sw/cmssw/pull/22668#event-1542523437

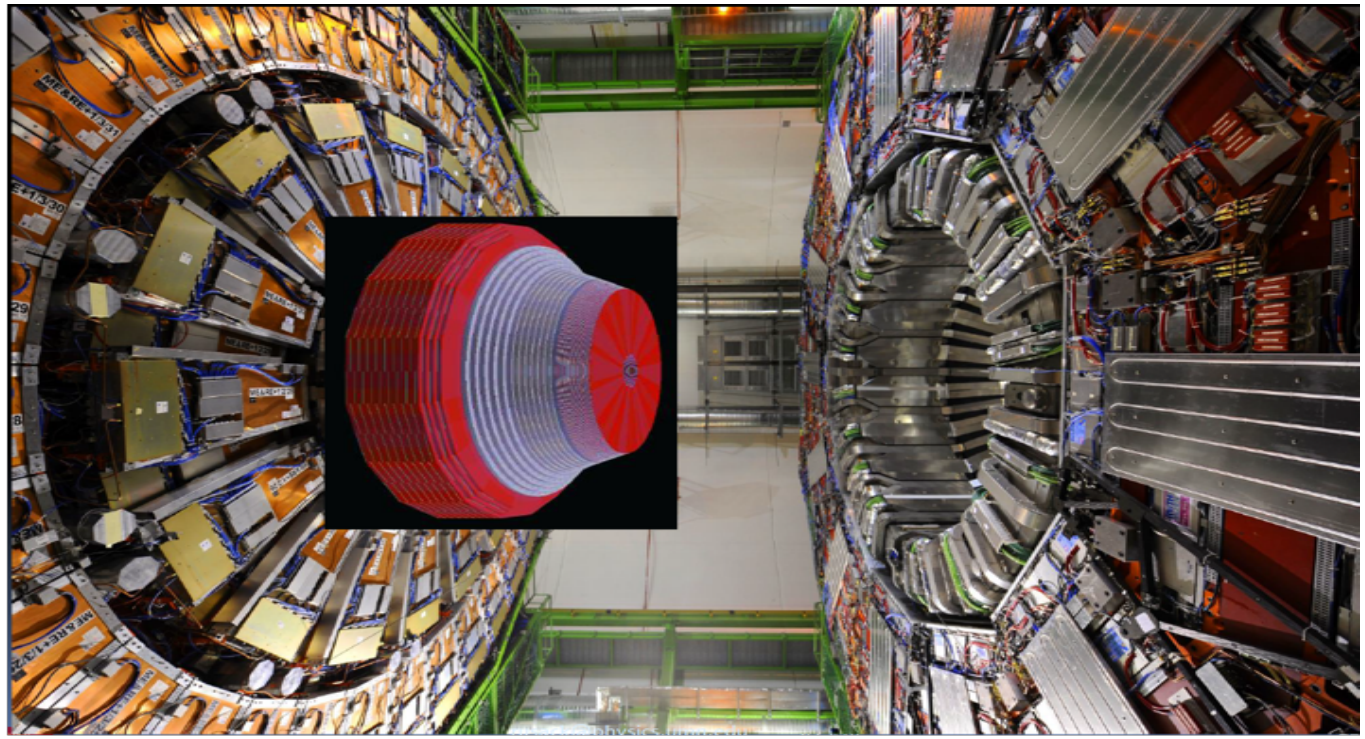
Upgrade of Endcap Calorimeter: High Granularity Calorimeter

Existing Endcap scintillator based calorimeter (1.5<|eta|<3.0) to be replaced with silicon + scintillator based calorimeter; Scintillators to be readout by SiPM

Next Generation Calorimeter at LHC

Designed to withstand integrated luminosity of 3000 fb^{-1}

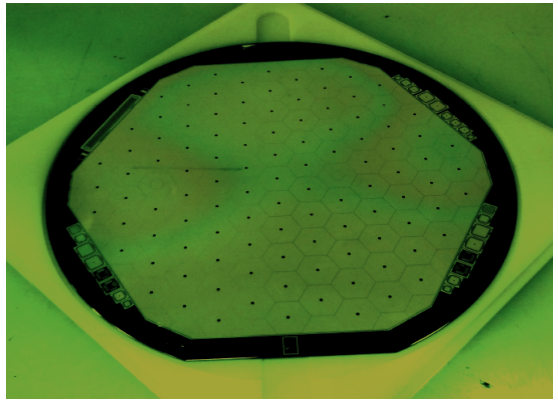
- Silicon Sensors Qualifications
- Module Assembly
- Front-End Electronics
- Back-End Electronics
- Trigger Generation



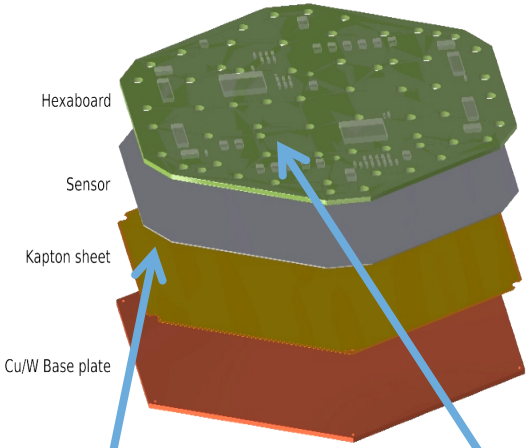
HGCAL Workshop was organized at TIFR in November 2015 (Web: https://indico.cern.ch/event/455465/)

The project manager and several other senior members of HGCAL collaboration participated in the workshop to have direct and intense interaction with India-CMS community and the Industry

Project manager visited India several times to interact with the India-HGCAL collaboration



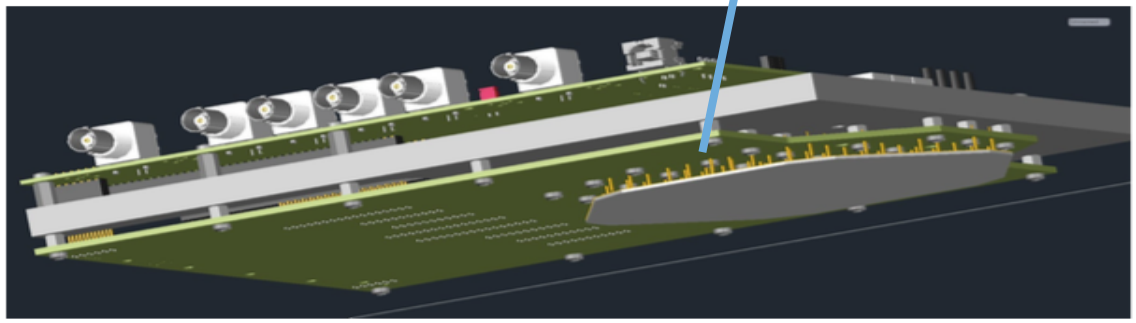
Silicon Pad Sensor



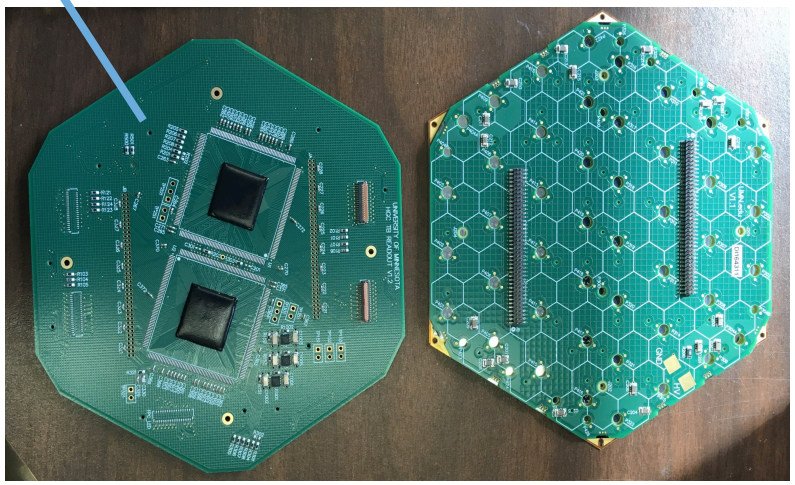
Silicon Sensor Module Assembly

Mini Gantry (Glue Dispenser)

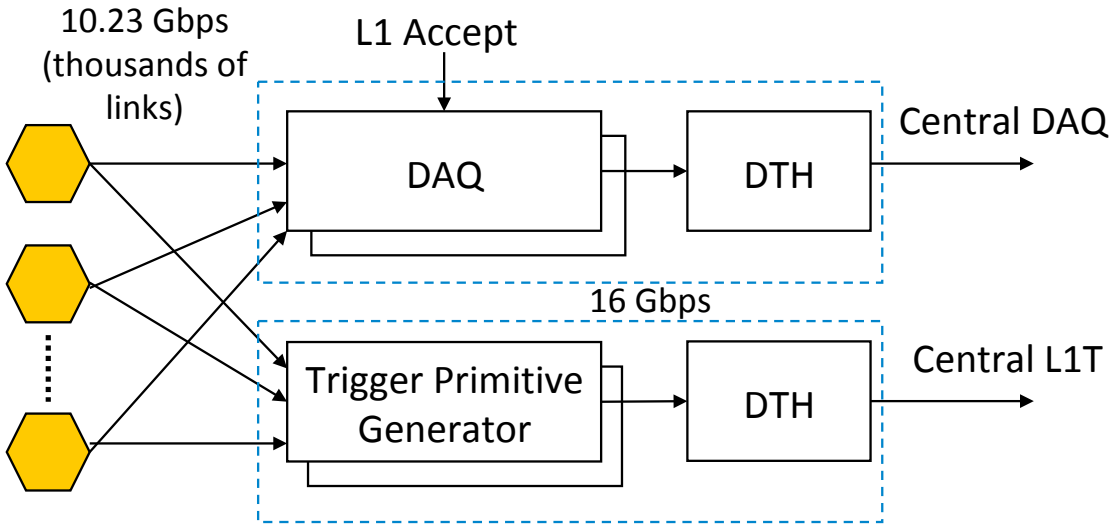
Wire Bonder

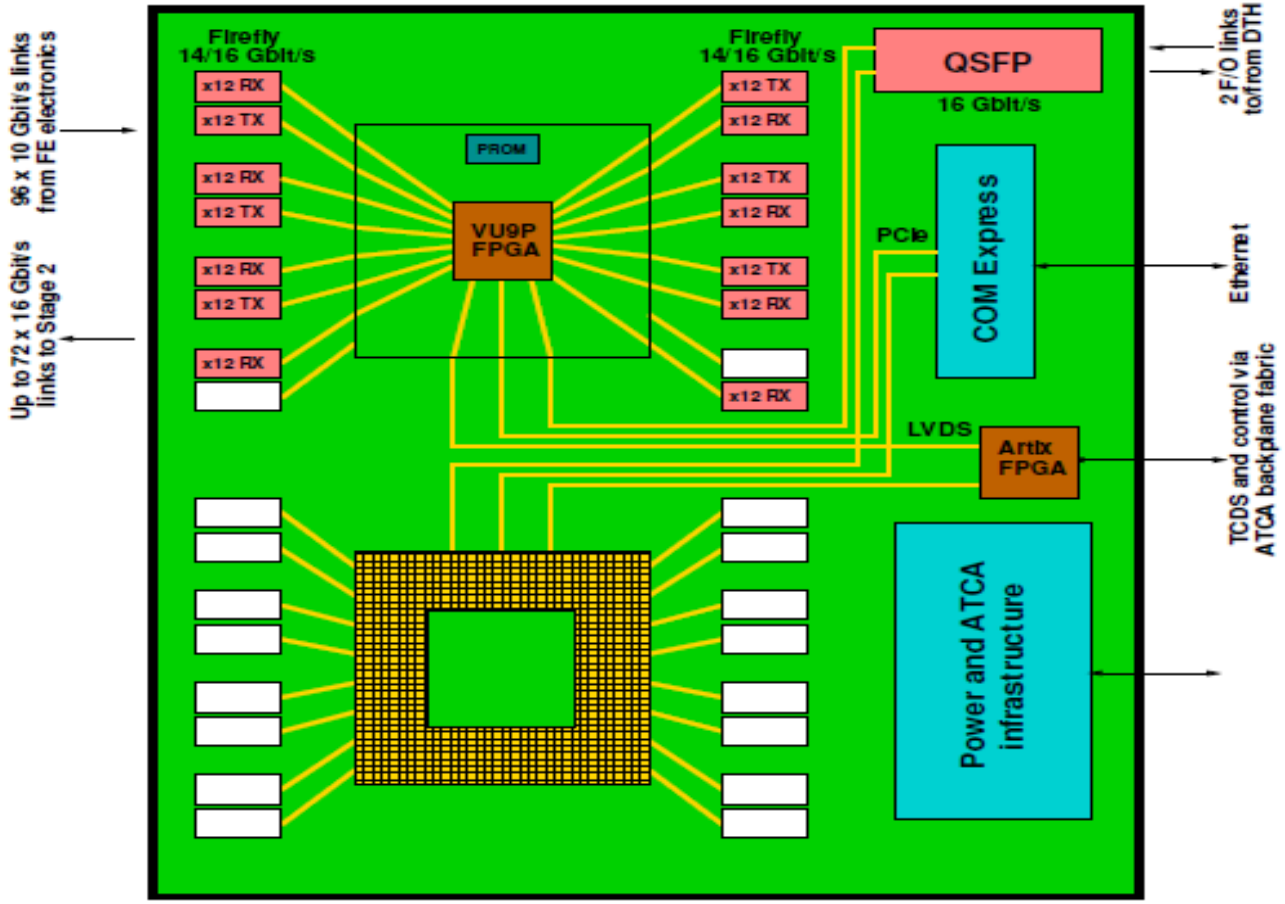


Silicon Sensor Qualification



HGCAL Readout

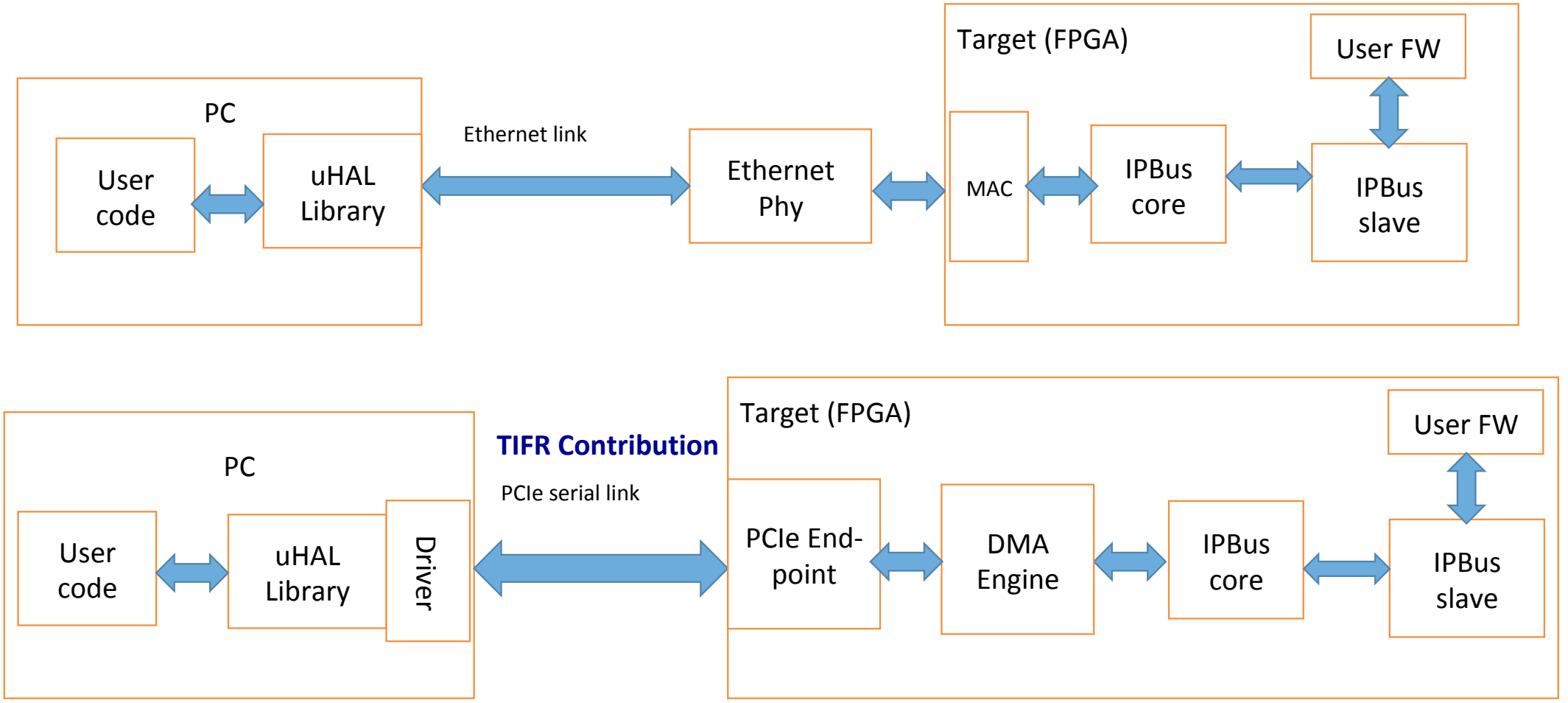




- The sensor data is divided into two streams: DAQ and Trigger
- Trigger data is acquired every bunch crossing (25 ns), whereas DAQ data only acquired when *L1 accept* is received from central L1T

PCIe Framework under IPBus-uHAL

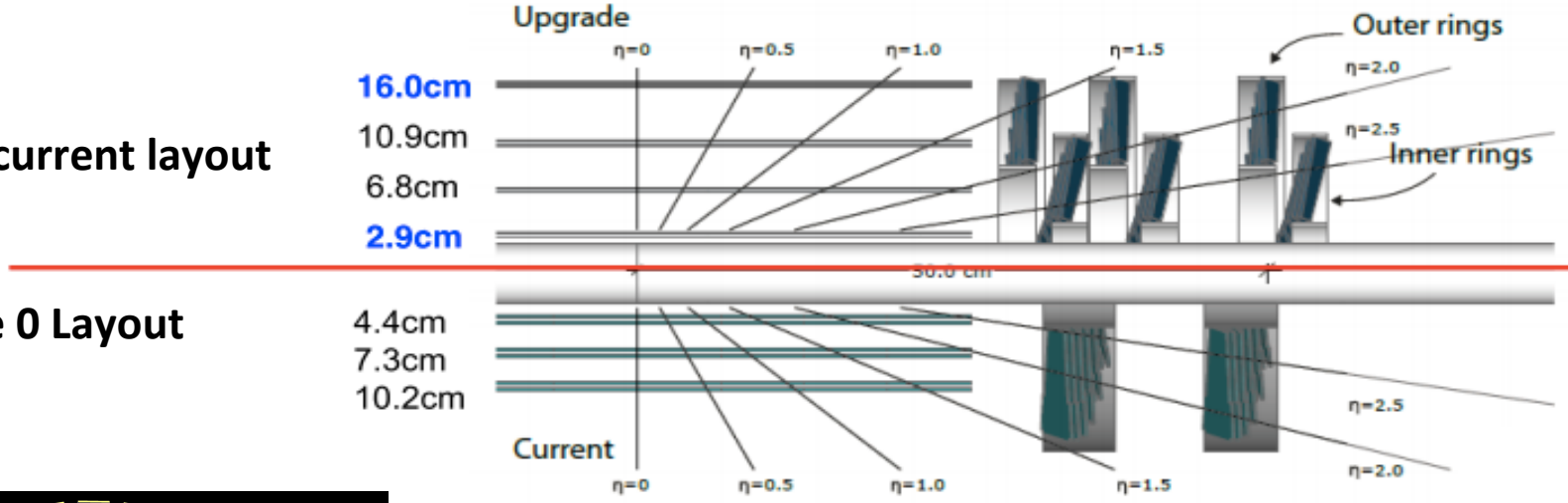
Talk By Irfan Mirza



CMS Phase-1 Pixel Detector

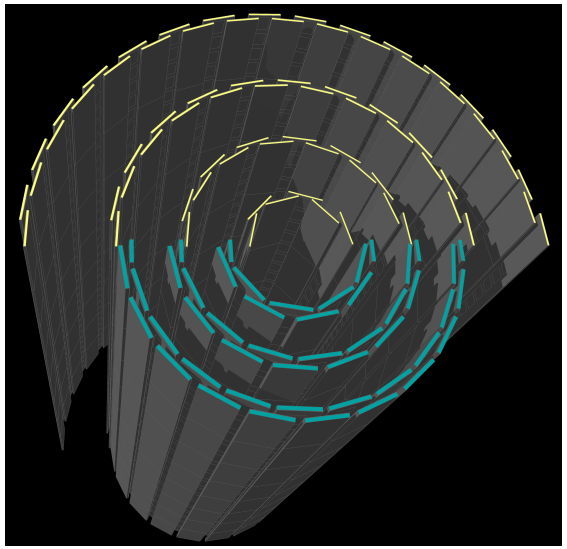
Phase 1 current layout

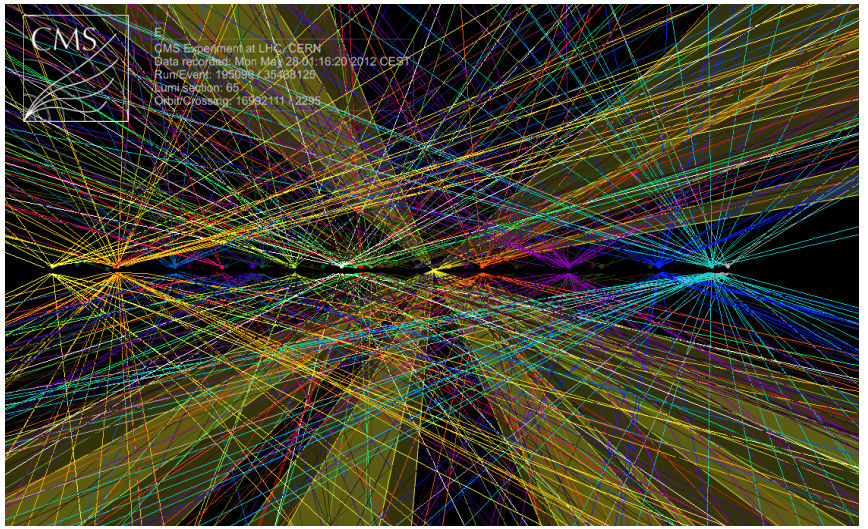
Phase 0 Layout



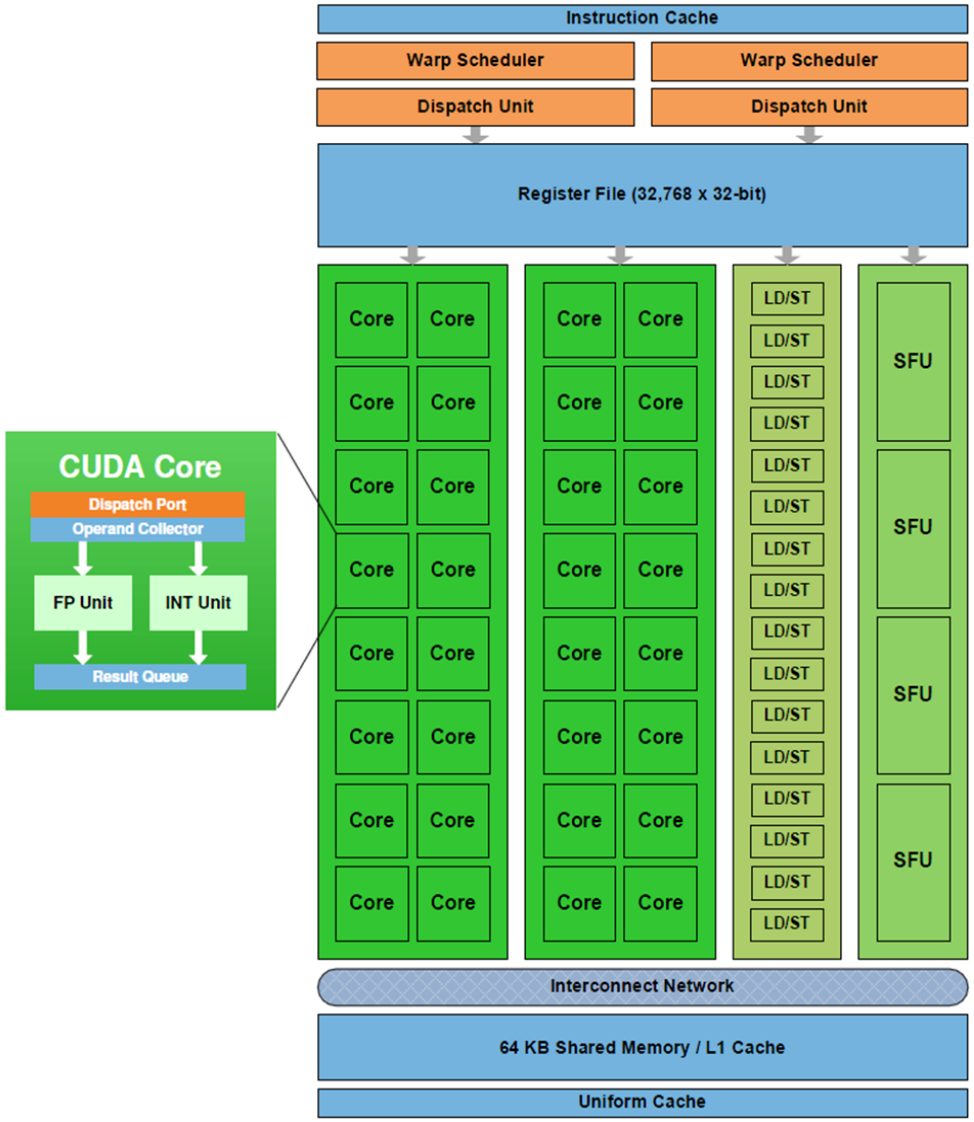
1856 modules
124M pixels

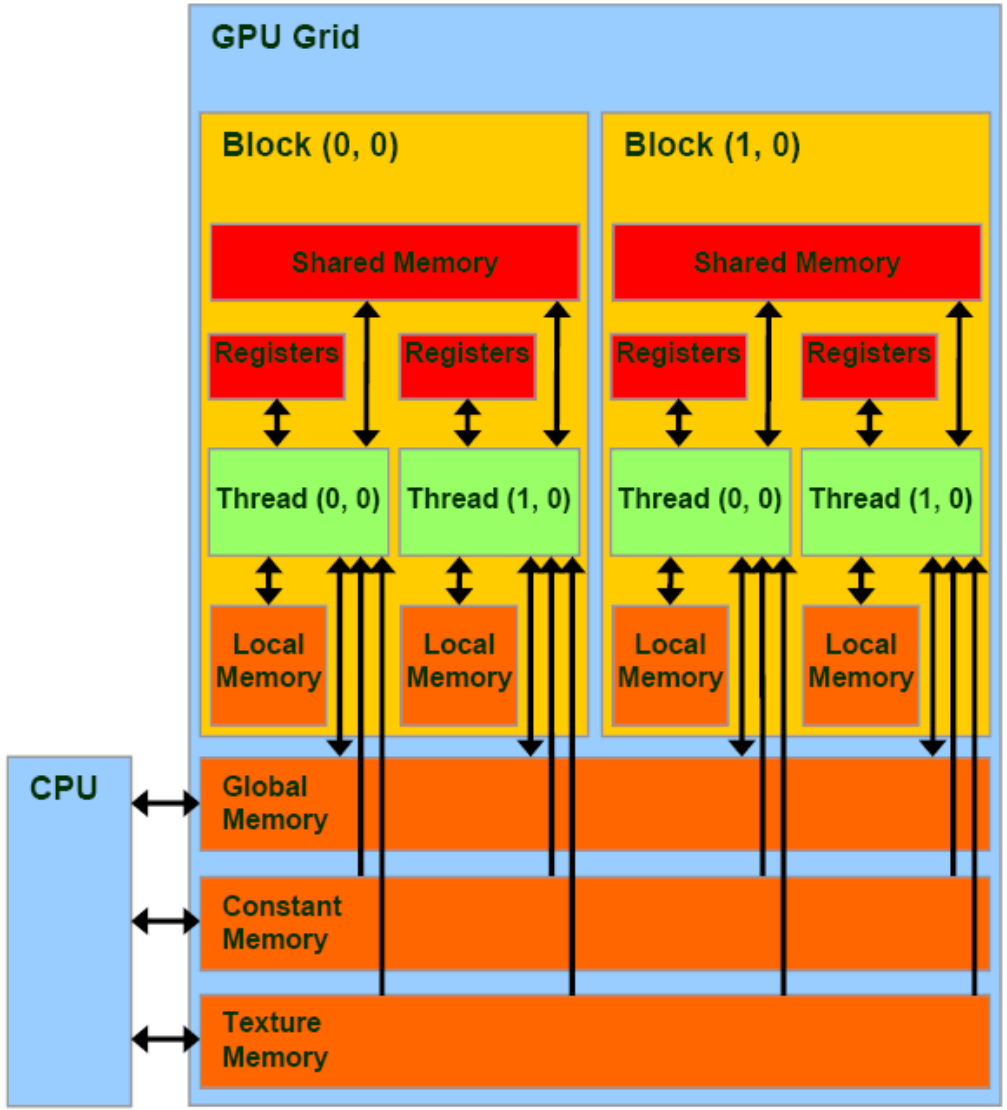
1440 modules
66M pixels



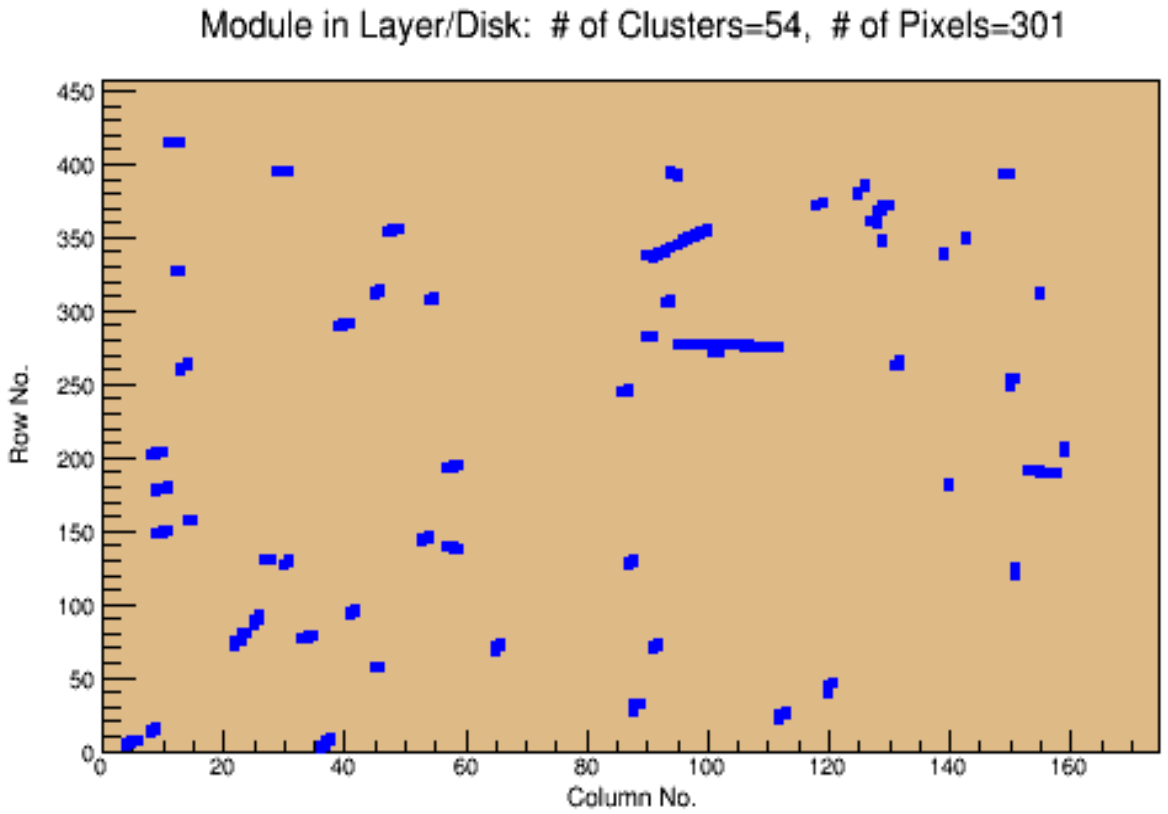


GPU Architecture





Clusterisation of Phase-1 Pixel Detector Data using GPUs



CPU:
Intel(R) Core(TM) i7-4771
CPU @ 3.50GHz

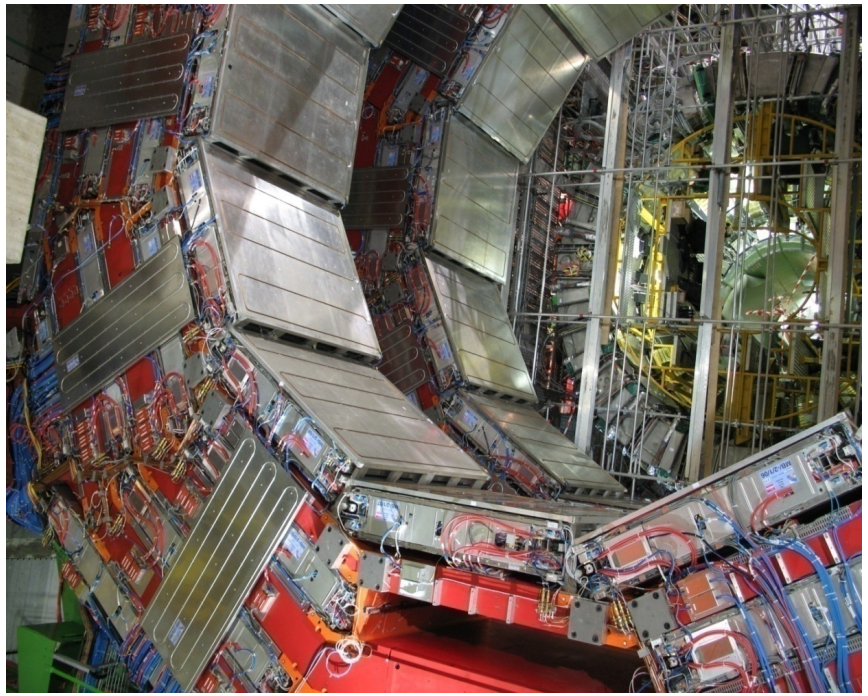
GPU:
GeForce GTX 1080, CUDA
Compute Capability- 6.1

CPU/GPU: 37 !!!

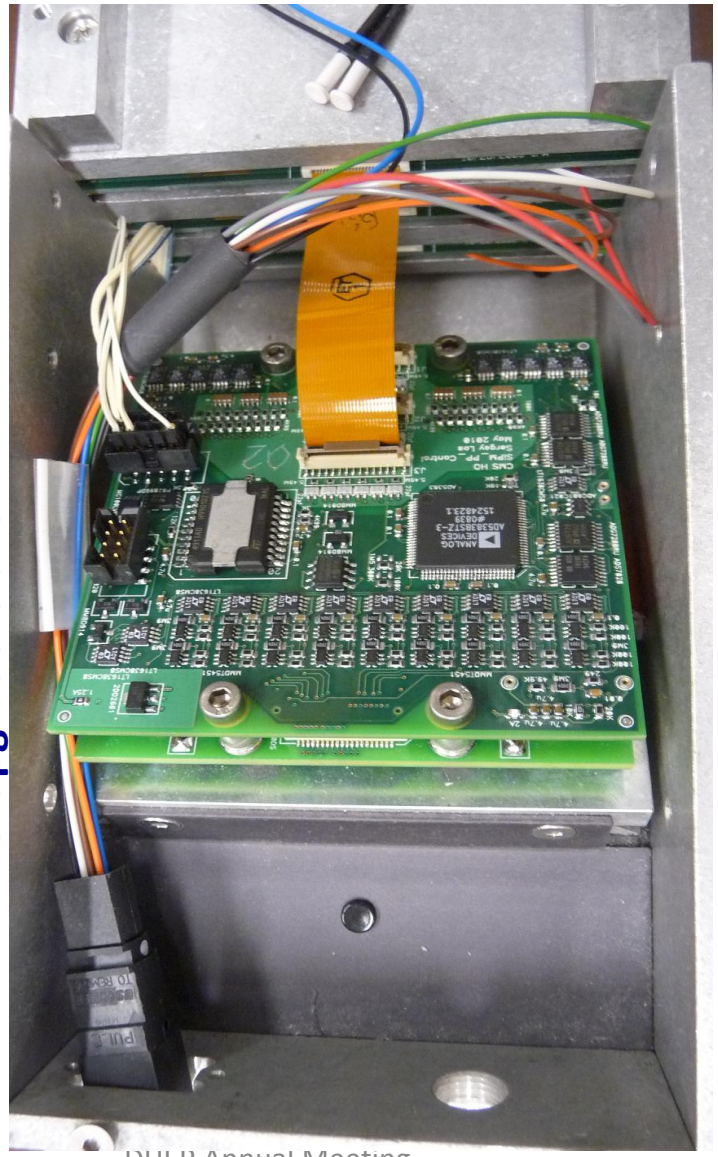
(R2Digi, Clusteriastion and CPE)

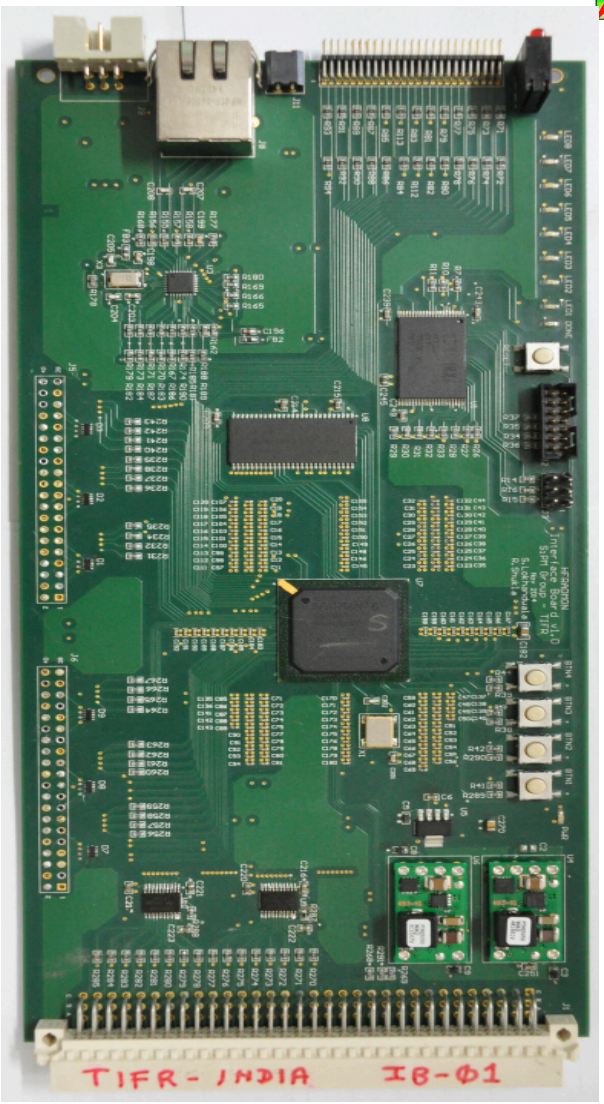
Past Experience of Participating Institutes

Outer Hadron Calorimeter



HO Upgrade Sith SiPM





Summary

CMS will be providing 150 fb^{-1} of data by end of this year at 13 TeV

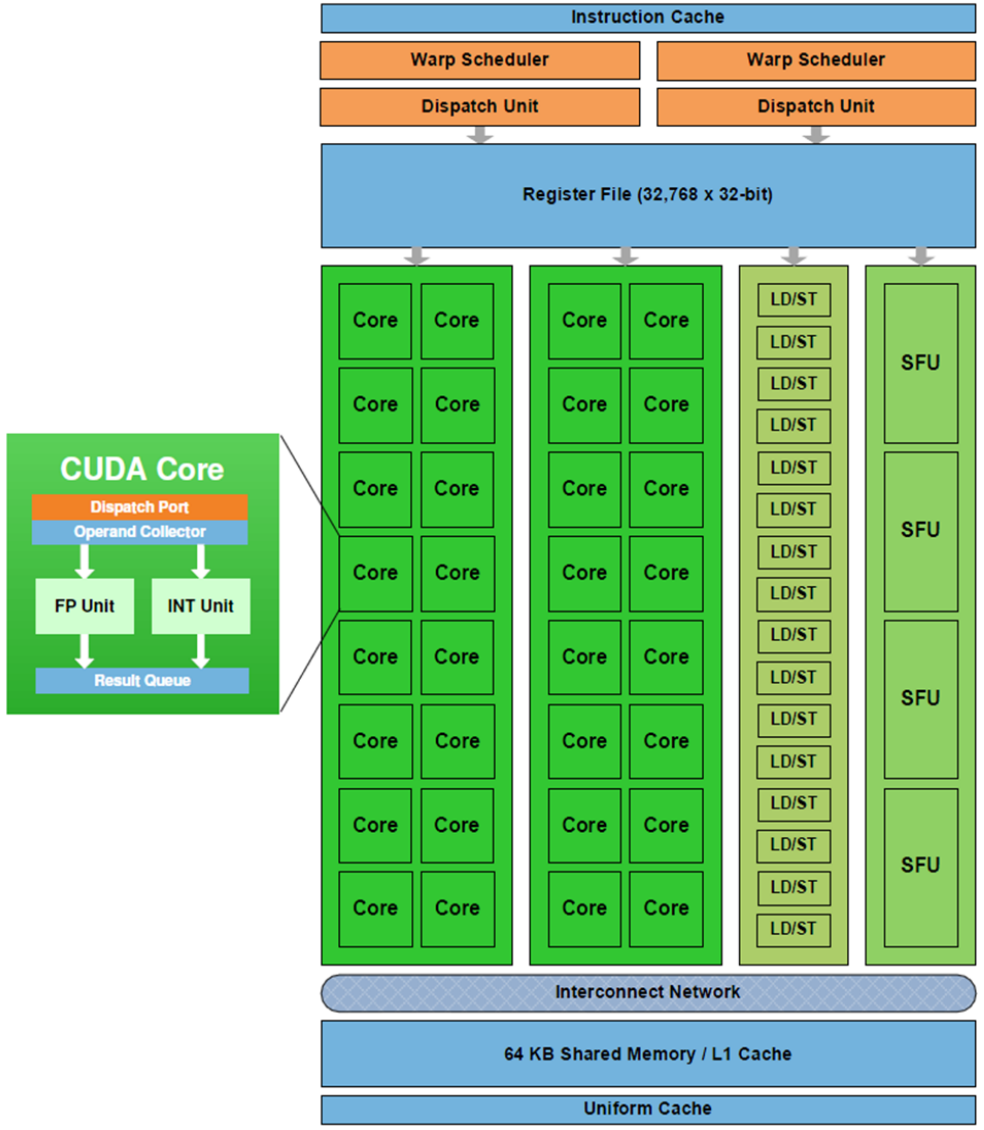
Physics BSM to be probed critically with high statistics data at 13 TeV

Properties of SM Higgs to be studied in detail

Challenging activities towards Detector upgrade, Algorithm development, Parallel computing, Machine learning

GPU Architecture: Two Main Components

- Global memory
  - Analogous to RAM in a CPU server
  - Accessible by both GPU and CPU
  - Currently up to 6 GB
  - Bandwidth currently up to 177 GB/s for Quadro and Tesla products
  - ECC on/off option for Quadro and Tesla products
- Streaming Multiprocessors
  - Perform the actual computations
  - Each SM has its own:
    - control units, registers, execution pipelines, caches
    - LD/ST: load and store unit
    - SFU: special function unit



CUDA Memory

CUDA Threads

- CUDA threads are conceptually similar to data-parallel tasks
- Each thread performs the same operations on a subset of a data structure
- Threads execute independently
- CUDA threads must execute the same kernel

Each thread can:

- Read/write per-thread registers
- Read/write per-thread local memory
- Read/write per-block shared memory
- Read/write per-grid global memory
- Read/only per-grid constant memory