CMS: Present Status, Limitations, and Upgrade Plans

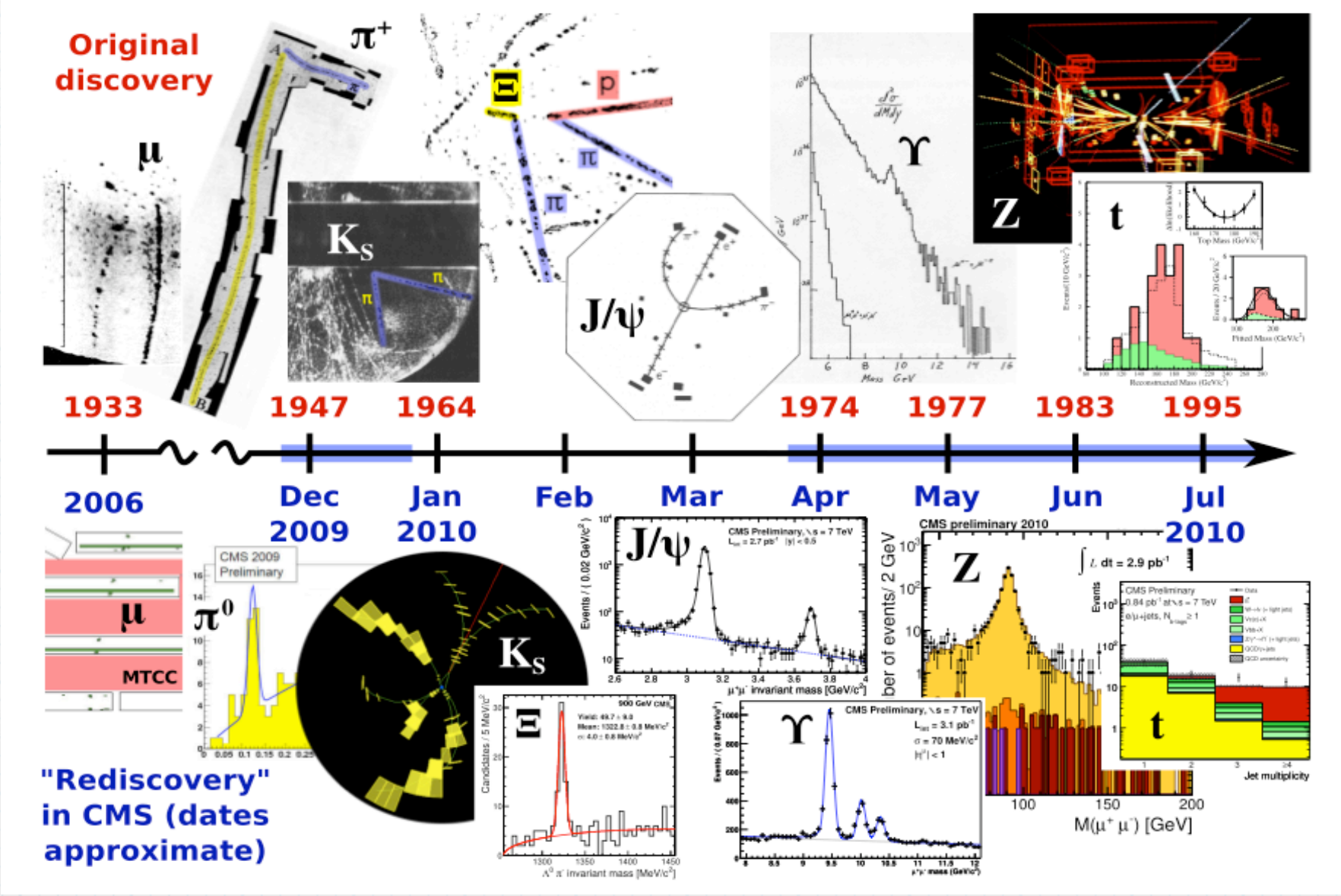
Harry W. K. Cheung

for

The CMS Collaboration

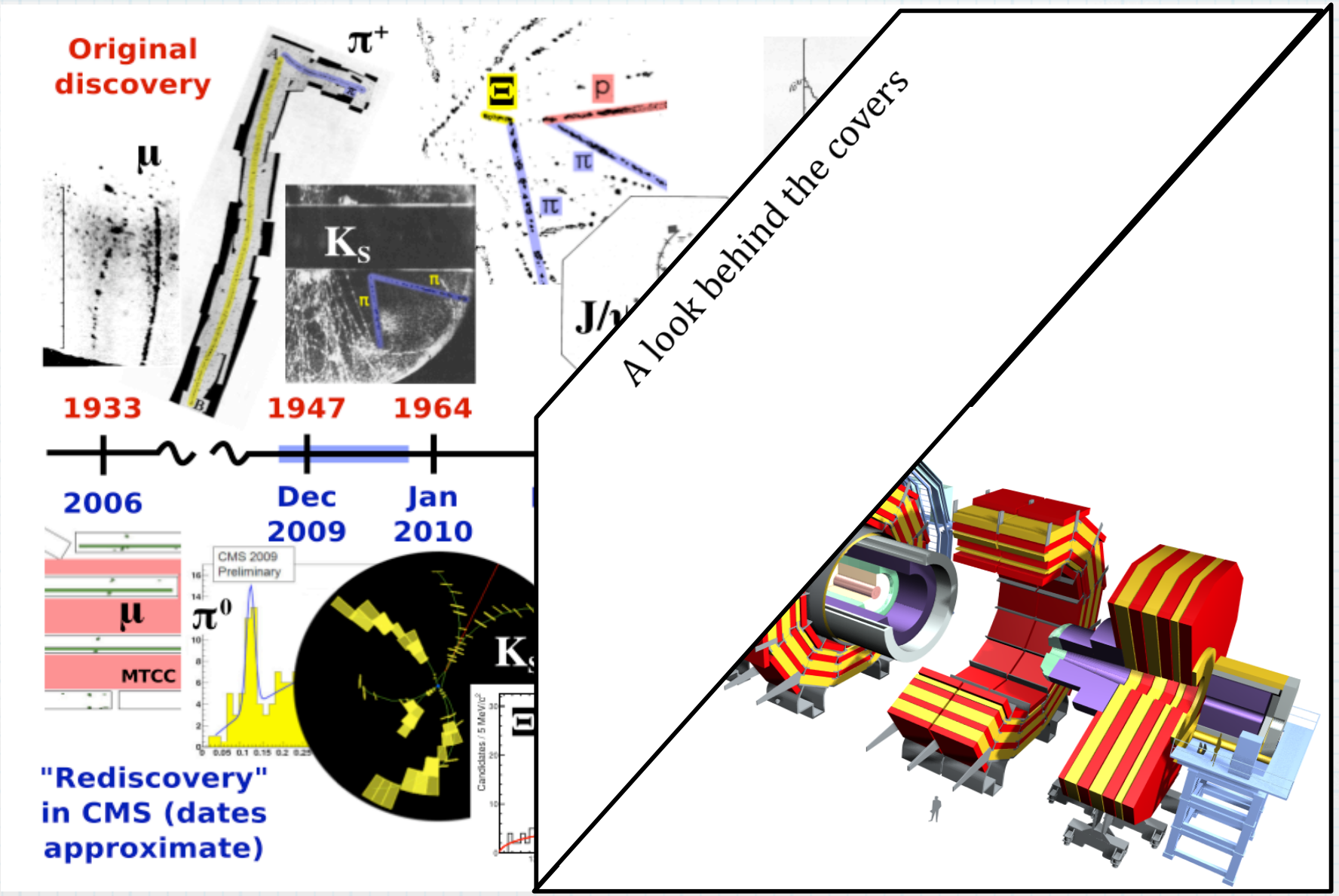
Rediscovering the Standard Model at 7 TeV

- Great performance of the CMS Detector so far



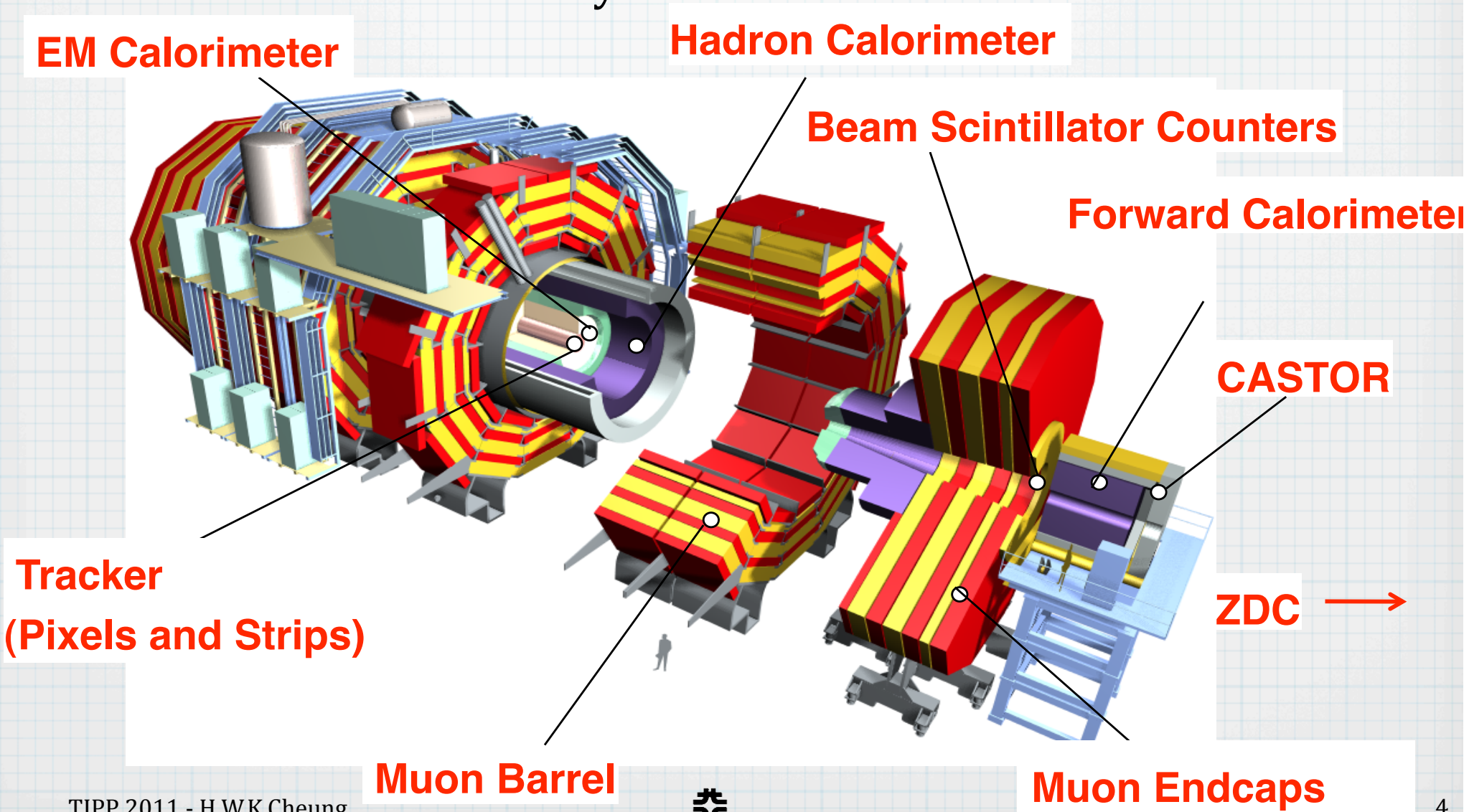
Rediscovering the Standard Model at 7 TeV

- Of course nothing is perfect…



The CMS Experiment

- Current status and review of performance given in Ettore Focardi's talk on Friday 14:00



Of course, the normal expected problems

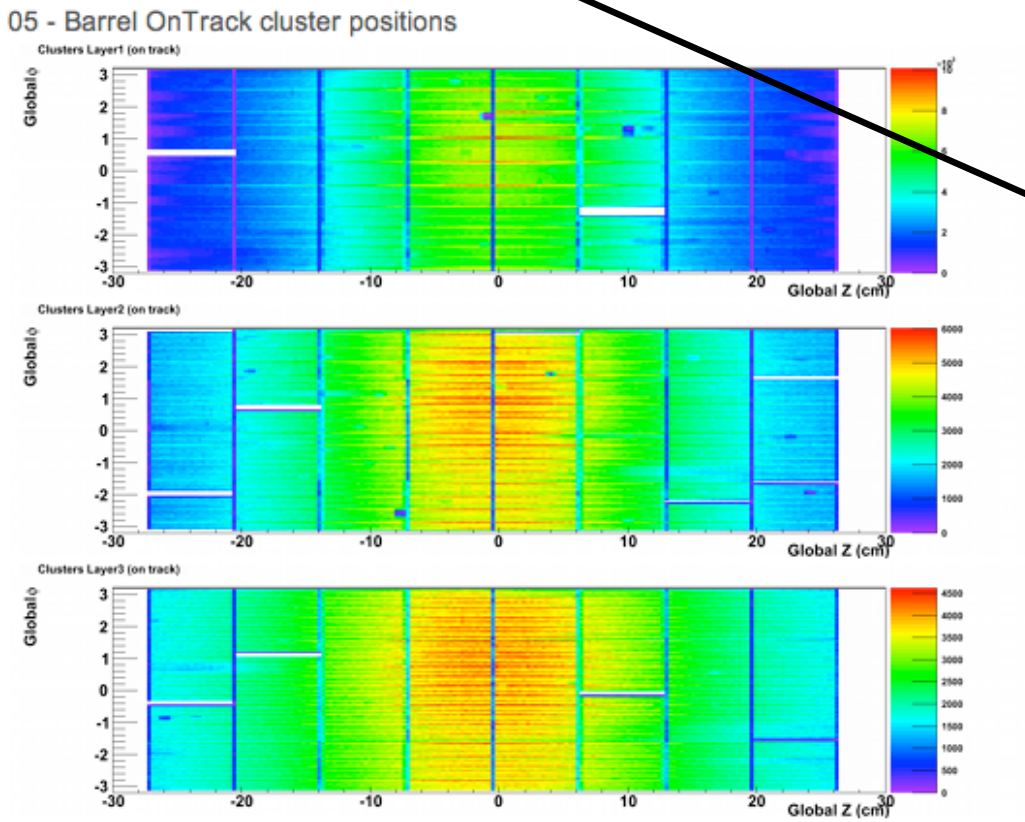
- Usual: Not all channels are working, e.g. for pixel detector

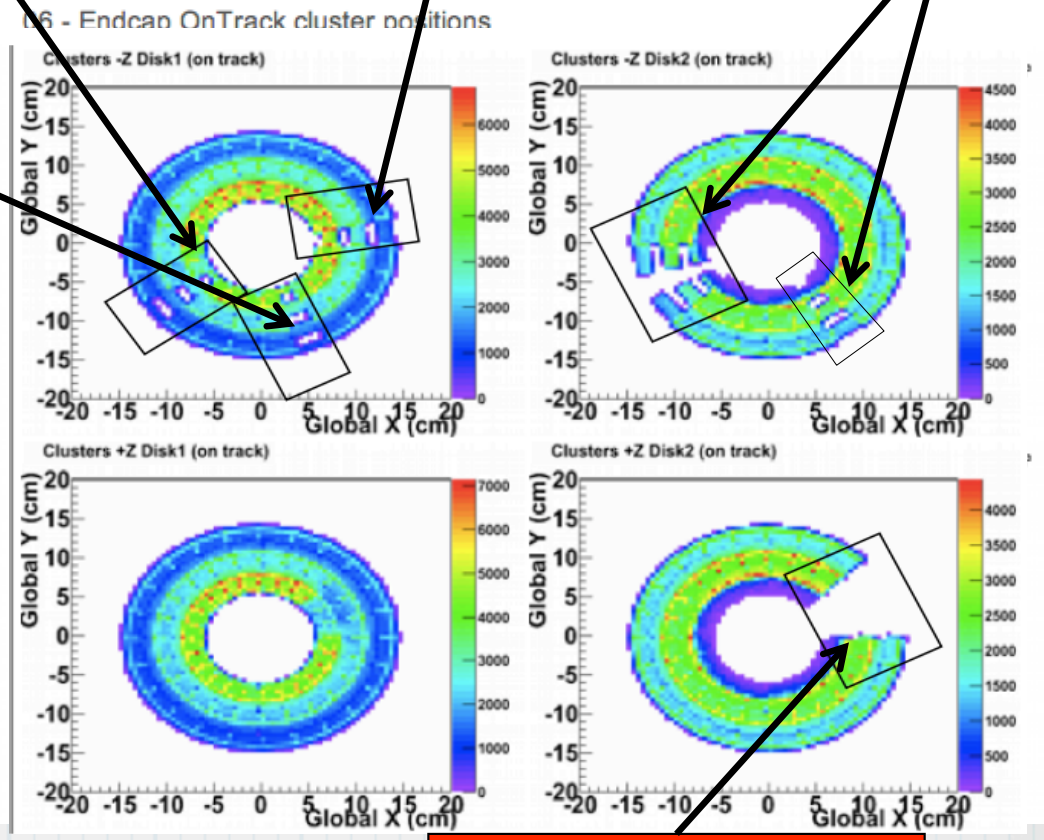
One ROC no-signal: 1/192 (0.5%) Recoverable.

Too Low signal amplitude (TBM): 1/192 (0.5%)

No signal output: 1/192 (0.5%)

Slow panels: 5/192

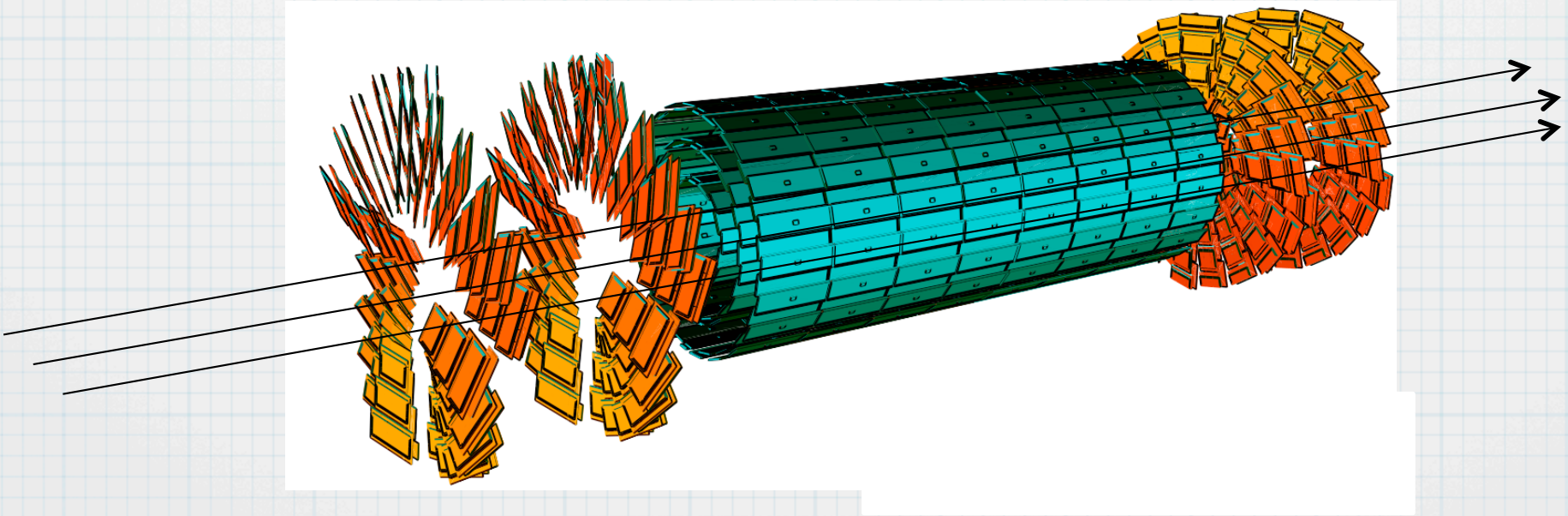




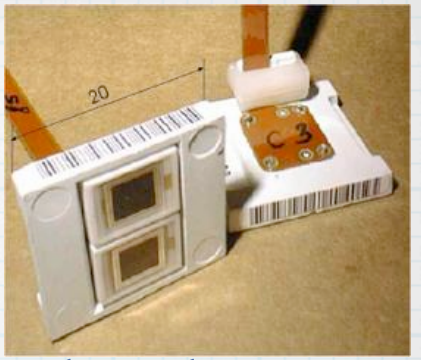
No I2C communication with AOH: 6/192 (3.1%)

Some less expected problems

- Beam gas interactions in the straight session of the LHC close to the experiment generates shower of particles that enter the pixel detector along the beam line. ("PKAM events")
  - Large number of pixels above threshold in the barrel if the track hits the sensor, generating many hits in a single readout channel causing timeouts.
  - Visible since early 900 GeV collisions and scales with beam intensity.
  - Implemented new FED firmware to dump the long events and holdoff triggers. Initially took some time to understand the problem.

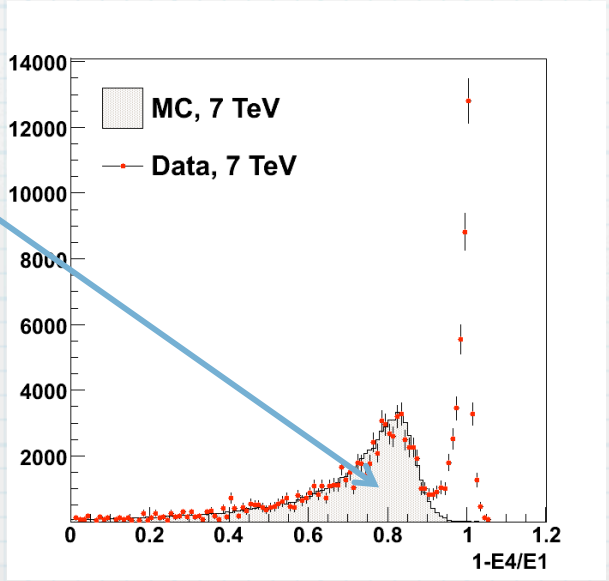


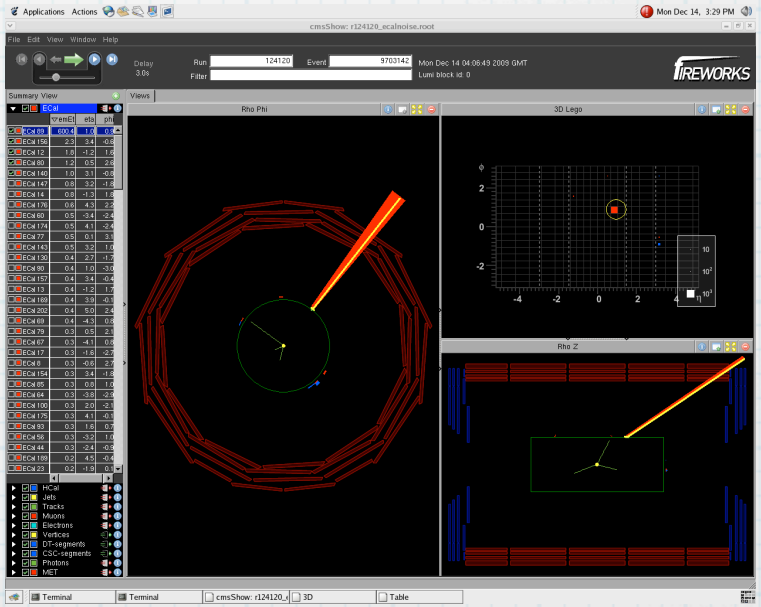
Some less expected problems



- Anomalous ECAL Signals
  - In collision data we observe anomalous signals in barrel ECAL where the readout is by APD (avalanche photodiode), having the appearance of large energy deposits in a single crystal.
  - The origin of the signal is energy deposited by heavily ionizing particles in the APD.
  - At the cluster level the anomalous signals appear as energy in a single crystal, while in e.m. showers the energy is typically shared between neighbouring crystals. This fact is used to tag anomalous signals.

MC without recording interactions in the APD as hits





Focus on issues relevant to upgrades for Phase 1

- Old 10 year plan: luminosity profile (from July 2010)
  - 2/3rd of data collected in Phase 1 will be with >10^{34} $cm^{-2}s^{-1}$
  - CMS designed for 10^{34} $cm^{-2}s^{-1}$; Limitations operating above this
  - Upgrade to CMS to maintain performance

Year	TeV	OEF	β*	Nb	Ib	Itot	MJ	Peak luminosity	Pile up	pb-1/day	Physics Days	Integrated (fb-1/year)	Total Int (fb-1)
2010	3.50	0.20	2.00	796	8.0E+10	6.4E+13	36.0	1.886E+32	1.2643	3.3	20.0	0.1	0.07
2011	3.50	0.25	2.00	796	8.0E+10	6.4E+13	36.0	1.886E+32	1.2643	4.1	240.0	0.98	1.04
2012												0.0	1.0
2013	6.50	0.20	0.55	796	1.15E+11	9.2E+13	96.1	2.632E+33	17.6429	45.5	180.0	8.2	9.2
2014	7.00	0.20	0.55	1404	1.15E+11	1.6E+14	182.5	5.000E+33	19.0000	86.4	240.0	20.7	30.0
2015	7.00	0.20	0.55	2808	1.15E+11	3.2E+14	365.0	1.000E+34	19.0000	172.8	210.0	36.3	66.3
2016											0.0	0.0	66.3
2017	7.00	0.25	0.55	2808	1.15E+11	3.2E+14	365.0	1.000E+34	19.0000	216.0	240.0	51.8	118.1
2018	7.00	0.28	0.55	2808	1.50E+11	4.2E+14	476.1	1.701E+34	32.3251	411.6	240.0	98.8	216.9
2019	7.00	0.30	0.55	2808	1.70E+11	4.8E+14	539.6	2.185E+34	41.5198	566.4	210.0	118.9	335.8
2020											0.0	0.0	335.8
2021	7.00	0.20	0.30	2808	1.70E+11	4.8E+14	539.6	4.006E+34	76.1197	692.3	150.0	103.8	439.7
2022	7.00	0.27	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1257.3	220.0	276.6	716.3
2023	7.00	0.27	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1257.3	220.0	276.6	992.9
2024	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1290.0
2025	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1587.1
2026	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1884.2
2027	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2181.3
2028	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2478.4
2029	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2775.5
2030	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	3072.6

Phase 1

Upgrade with constraints imposed by running experiment, maybe with "discovery in progress"

Phase 2

Upgrade to Muon Systems

- Upgrade driven by effect of peak instantaneous luminosity on muon trigger and by maintenance

DT (barrel)

Work on DT trigger boards: Replace failing ASICs in theta boards with FPGAs (improves resolution); recover ASICs for spares; move parts of trigger to low radiation/ magnetic field region

RPC (barrel and endcap)

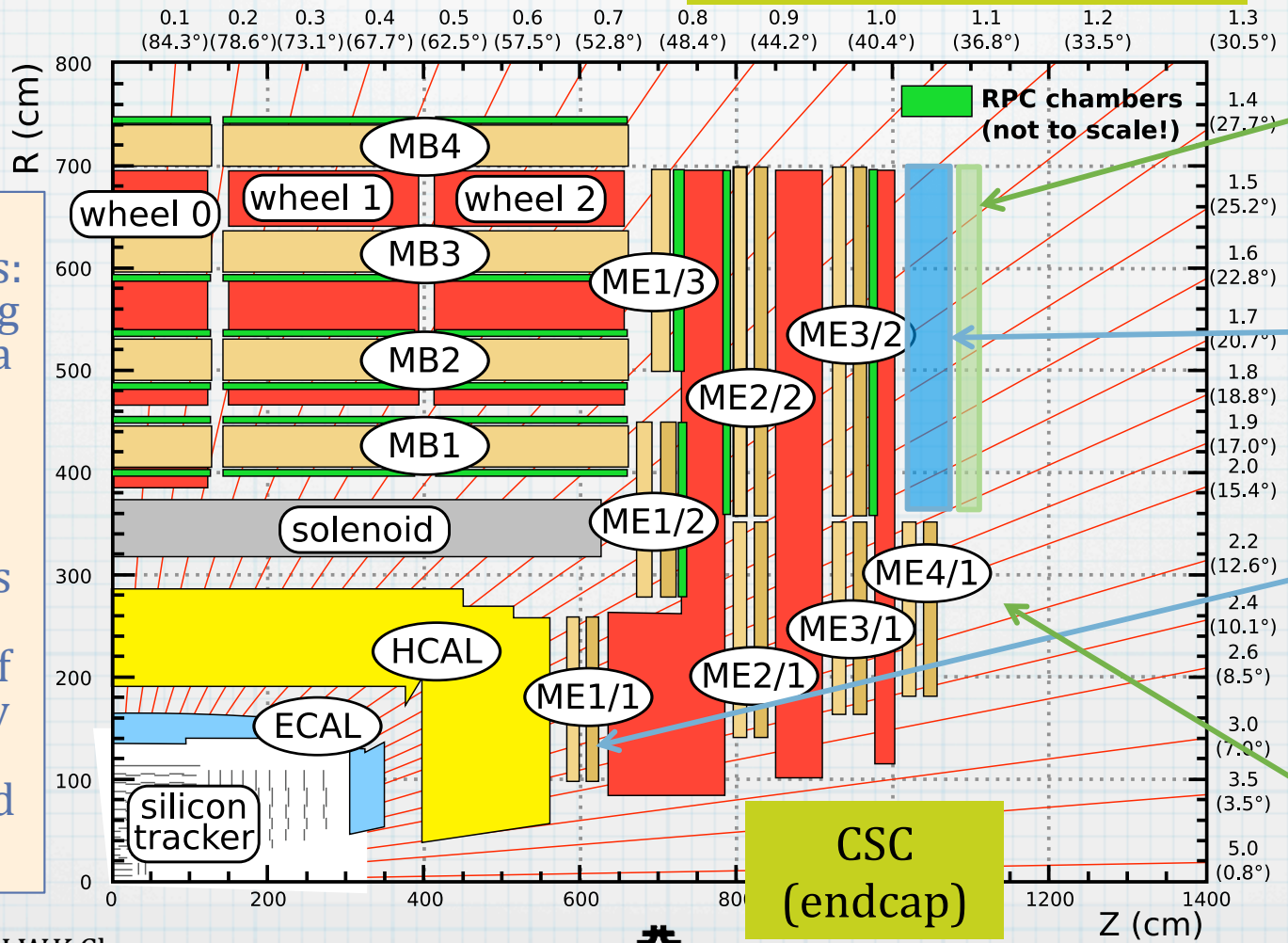
New RE4 RPC

New ME4/2 CSC

Work on ME1/1 and trigger

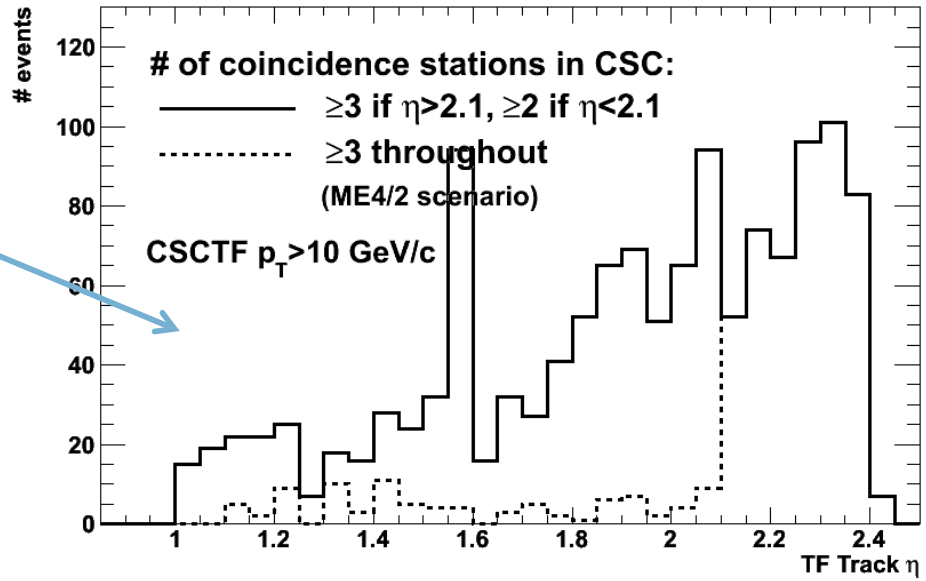
Extend eta range of RPC

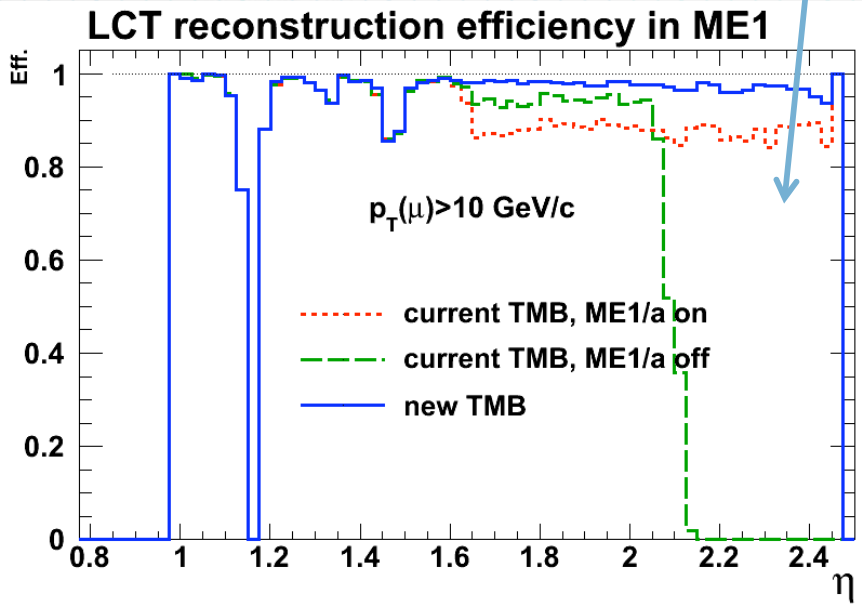
CSC (endcap)

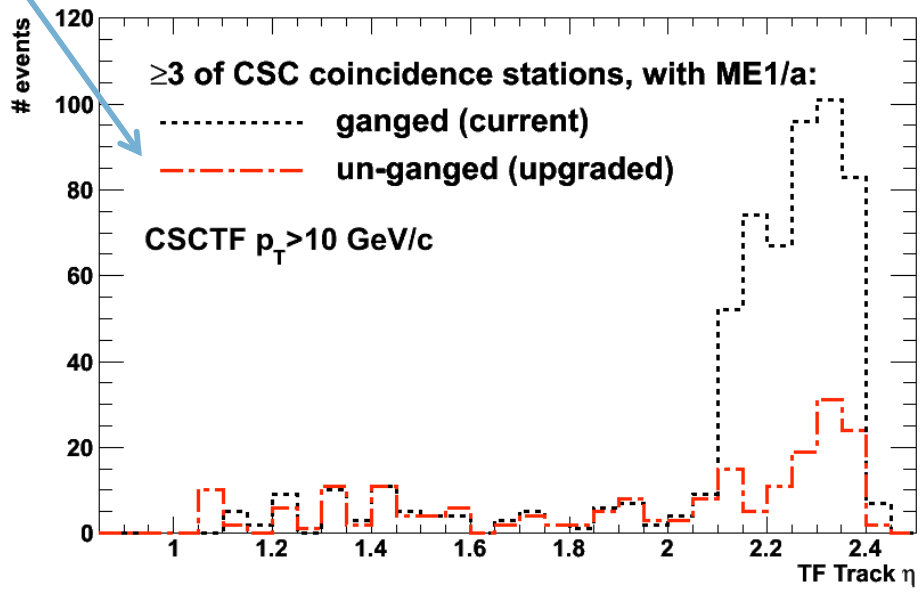


L1 Muon Rate Limitations at High Luminosity

- Need 3 hits to reduce L1 rates (better p_T resolution), need 4 chambers to keep high efficiency
- Remove 3-to-1 ganging of ME1/1 to lower L1 rates
- Replace CSC trigger board (FPGA) to increase efficiency over all CSC eta range

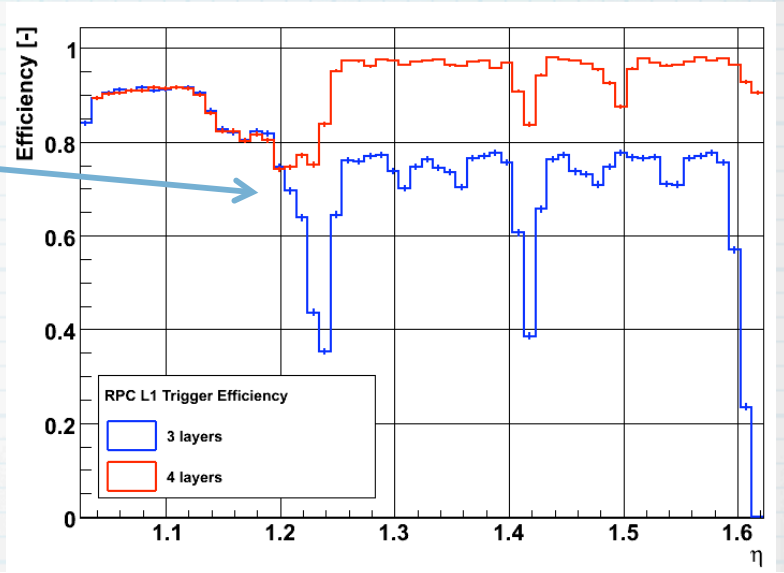


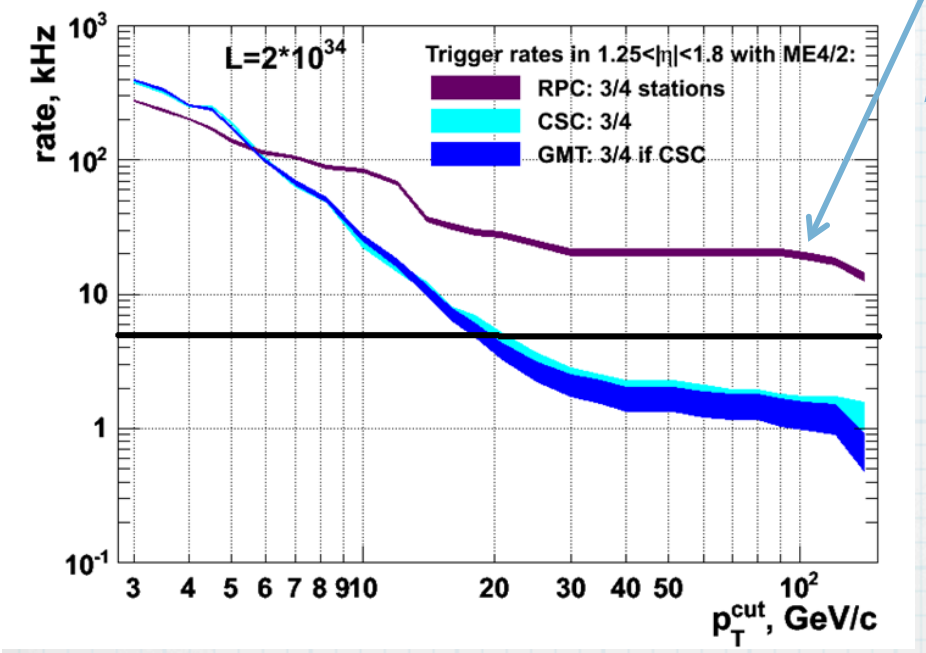


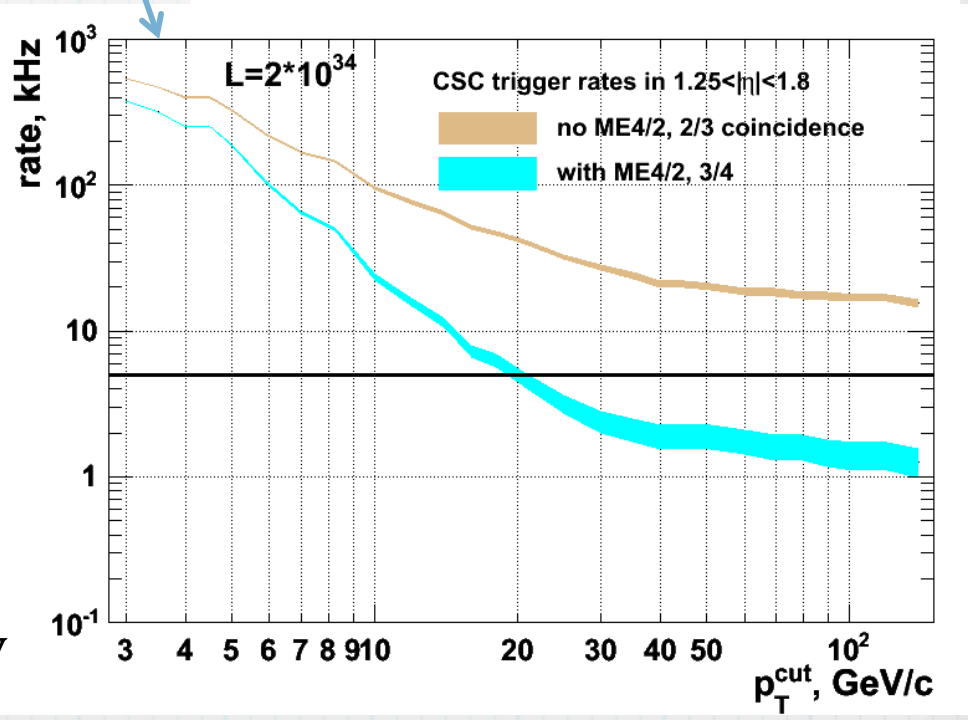


Upgrade to Muon CSC and RPC Endcaps

- Additional 4th chamber for RPC increases RPC trigger efficiency
- Projected improvement in muon L1 trigger for 2×10^{34} $cm^{-2}s^{-1}$
  - RPC Trigger optimized for high efficiency



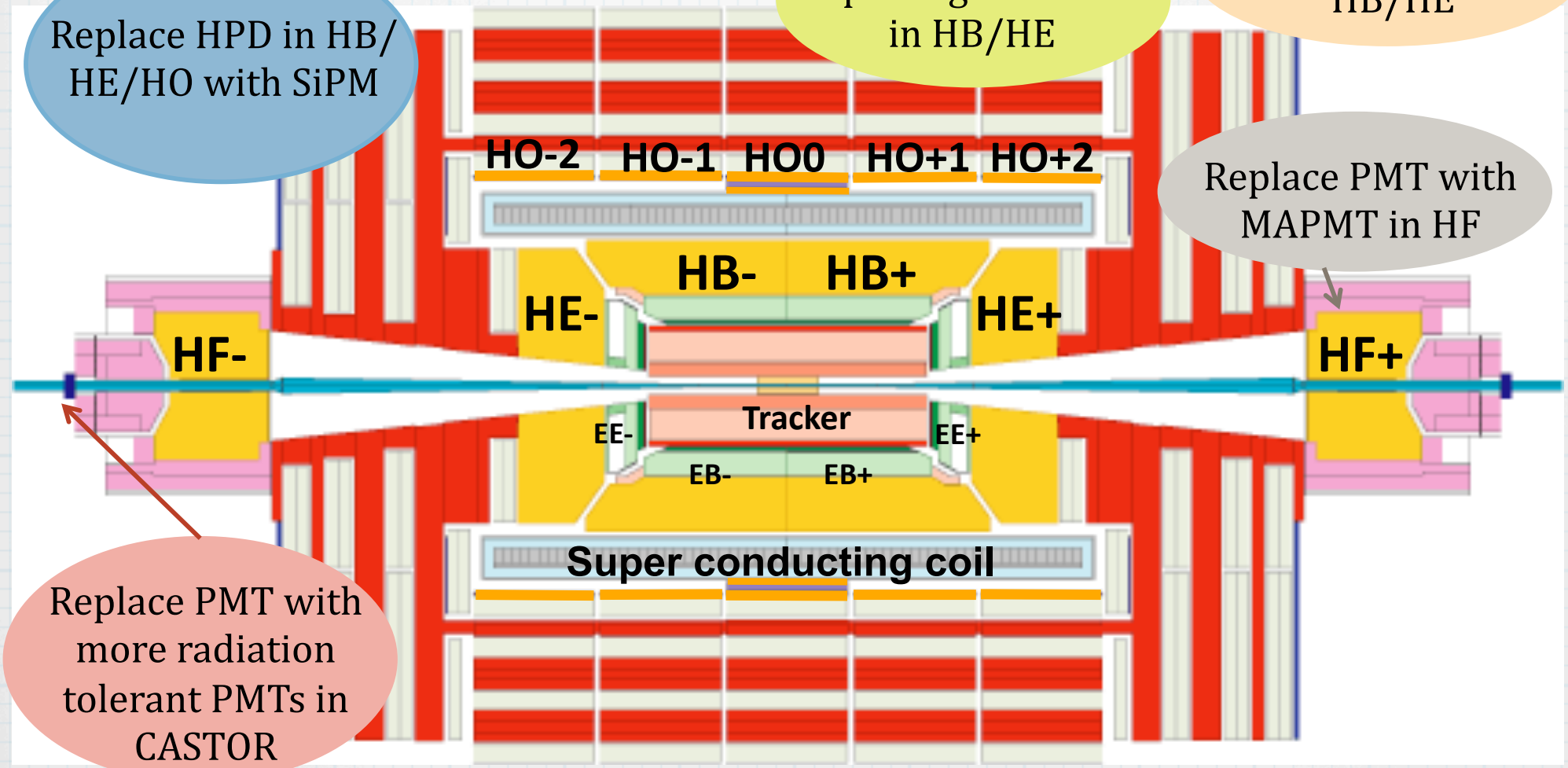




R&D for GEM extension of RPC eta range see talks: Paul Karchin and Tania Moulik on Monday

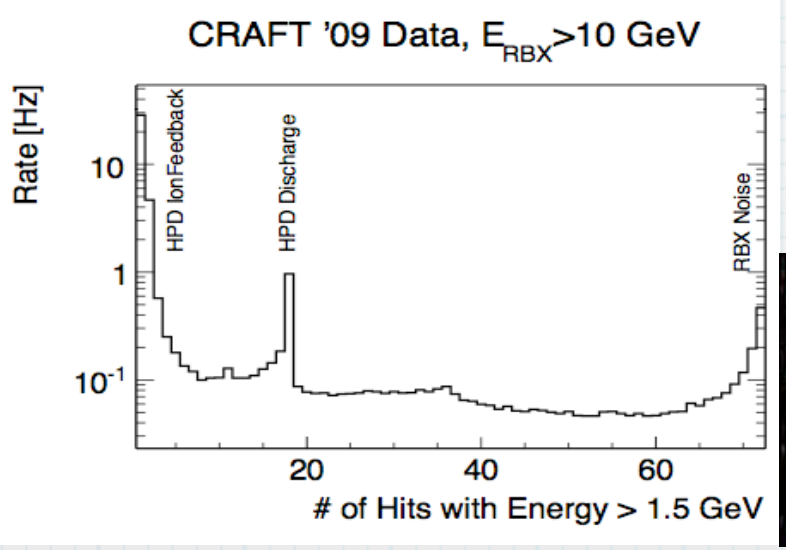
Upgrade to Hadron Calorimeters

- Upgrade driven by effect of peak instantaneous luminosity, robustness, efficiency, trigger

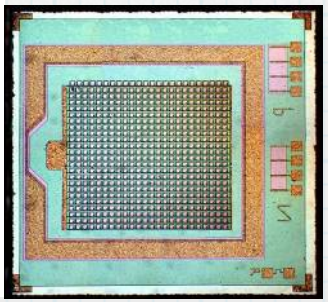


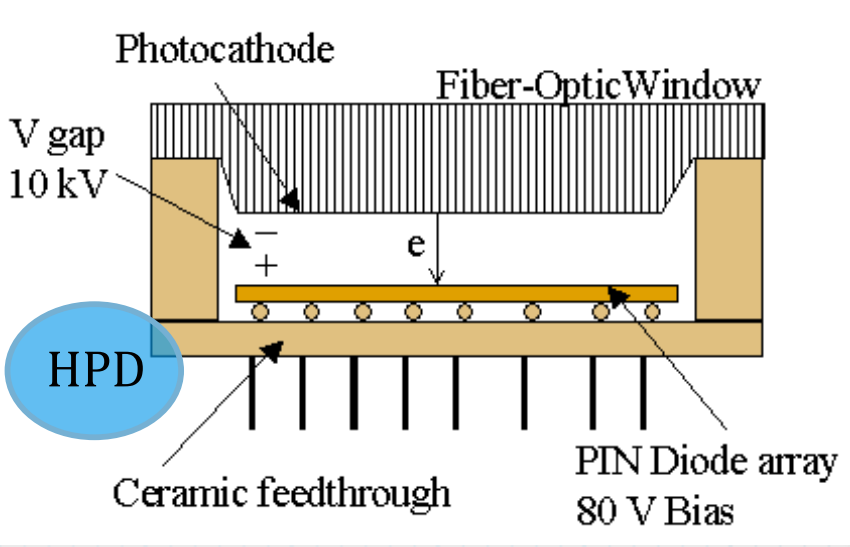
Anomalous/Noise Signals in HB/HE/HO

- Electronics noise from the Hybrid PhotoDiode (HPD) and Readout Box (RBX) used for HB, HE, and HO, (worse in HO due to 0.2-0.3T region, need to run at lower HV)
- The HPD has 18 channels/device; There are 4 HPDs in a RBX
  - HPD and RBX noise is random and the overlap with physics is very low, and HPD/ RBX noise produce distinct patterns in HCAL
  - Filters have been developed making use of hit patterns, timing, pulse shape, and EM fraction
- Replace HPD with Silicon PhotoMultiplier (SiPM)
  - Essential for HO; Enables HB/HE upgrade for robust and efficient operation



SiPM

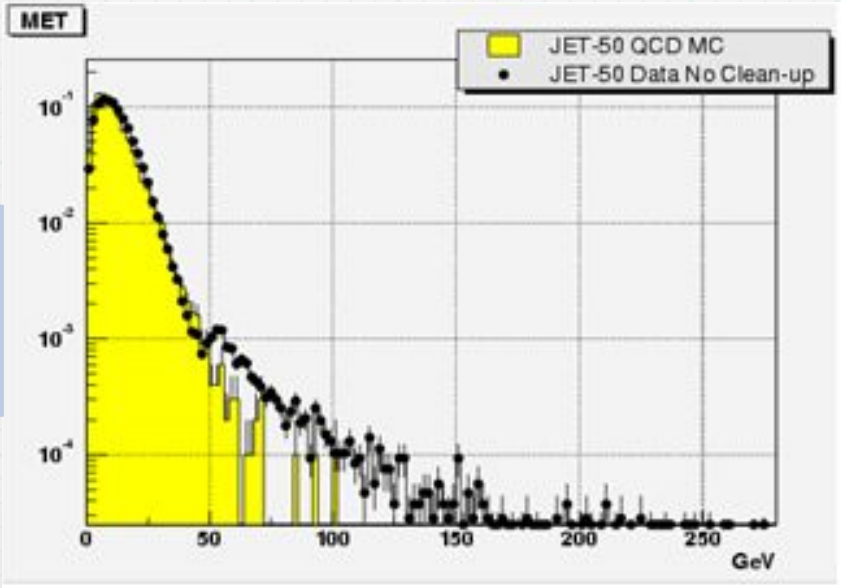


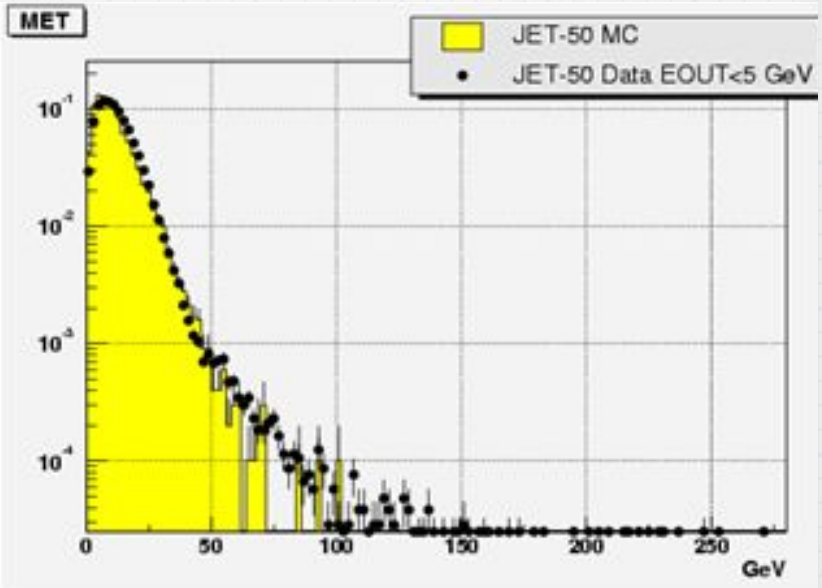


Upgrades to HB and HE

- See Jake Anderson's SiPM HO upgrade talk on Friday
- SiPM provides much better S/N to deal with increased occupancy (poorer timing determination and isolation)
  - Can split signal to TDC (reduce background/noise contributions)
  - Can give longitudinal segmentation (x4) for readout
    - Electron isolation (e/pi) and triggering; muon isolation and id
    - Compensate for radiation damage in front/inner part of HE

Using timing to clean MET in CDF

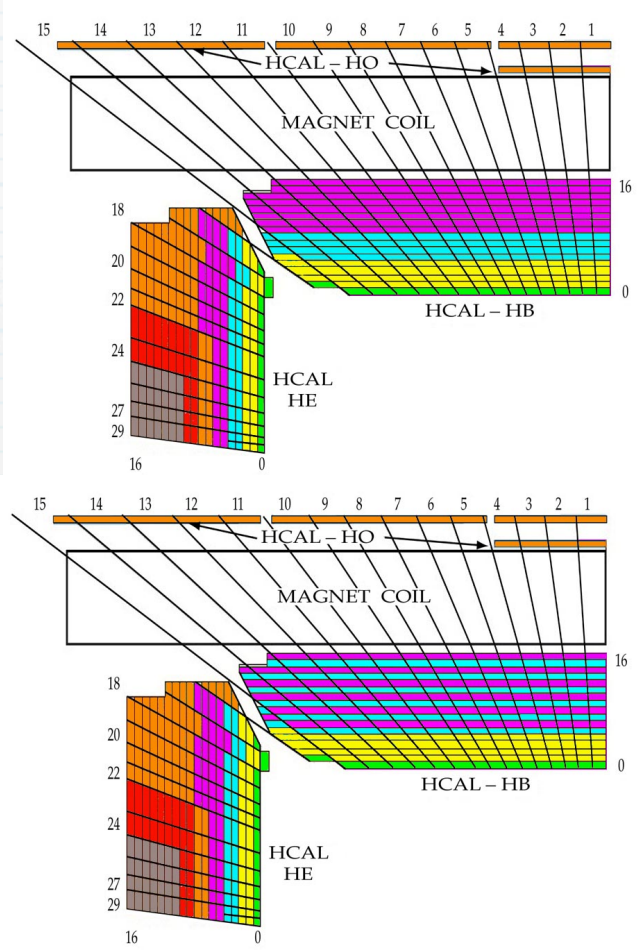


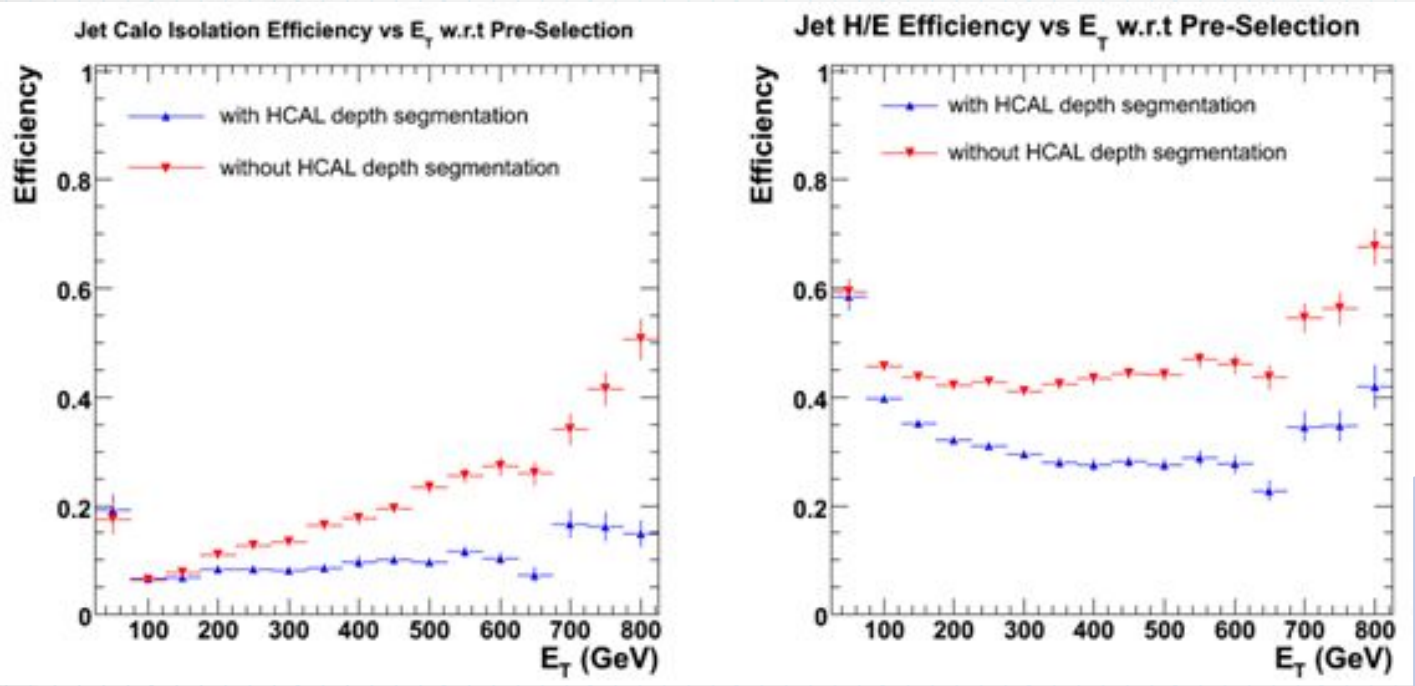


Upgrades to HB and HE

(x4) Segmentation options to study

- R&D still needed
  - SiPM specifications (esp. rate for HE/HB)
  - Optimization of FE/electronics (readout, trigger, infrastructure)
  - Simulation studies

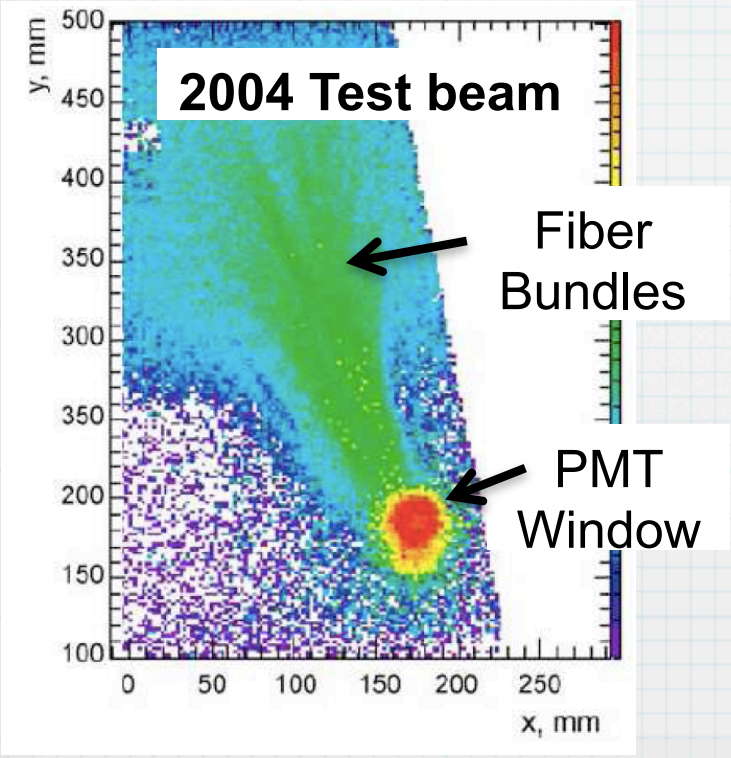




Isolation efficiency for background jet sample at low lumi (2 segments)

Anomalous Signals in HF (Forward Calorimeter)

- HF Extends eta coverage from 3 to 5; For tagging jets, missing E_T, and determining luminosity (e.g. VBF Higgs, 70% of signal have a jet >30GeV in HF)
  - Quartz fibers in iron. Long fibers: extends for the full length of HF. Short fibers: start at a depth of 22cm from the front of HF (separate readout)
  - Low amount of Cherenkov light from quartz readout fibers. Cherenkov light produced by interactions in the window of the HF PMTs
  - Glass window thickness in the center is ~1mm increasing to ~6.1mm on the edge



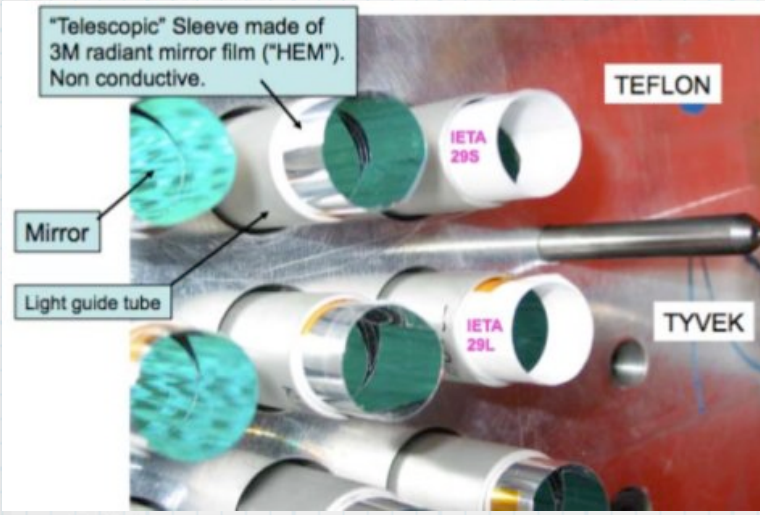
150 GeV muon looks like a 120 GeV jet; seen in test beam

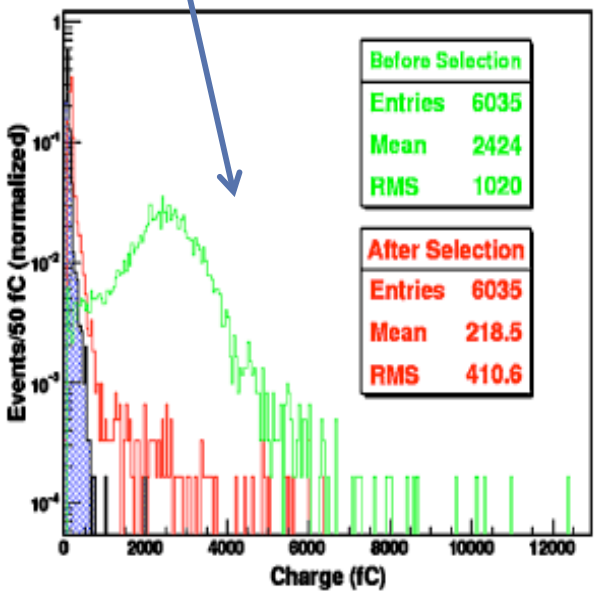
In collision running, can get "1 TeV jet" PMT events.

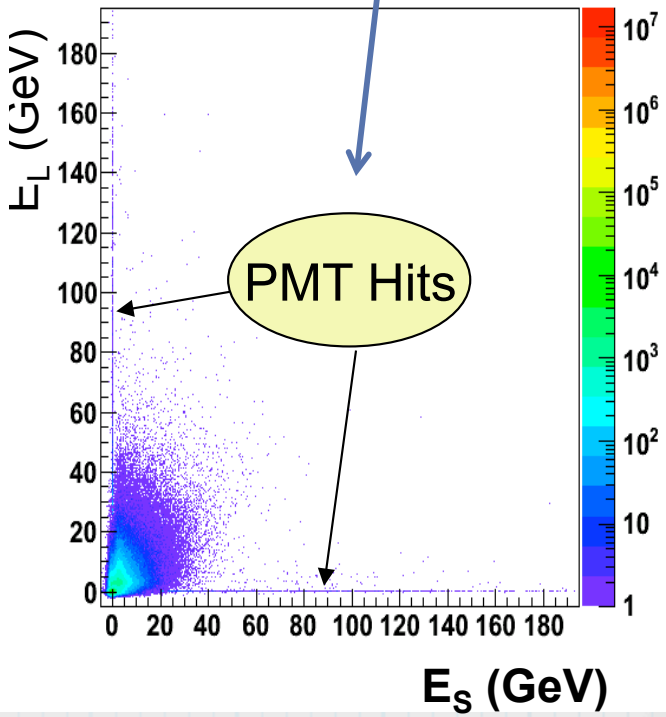
Dominant sources are muons from decays in flight and hadron shower punch through

Anomalous Signals in HF (Forward Calorimeter)

- Most of the HF PMT hits can be identified based on the energy sharing between the Long and Short fibers. Filters have been developed to effectively remove anomalous signals with little impact on real energy deposits.
- Can tag PMT events offline but only with 80% efficiency, not sufficient for very rare processes
- Replace with thinner window (<1mm) MAPMT (4 anodes); pattern of light used to eject PMT events with 96% efficiency in test beam



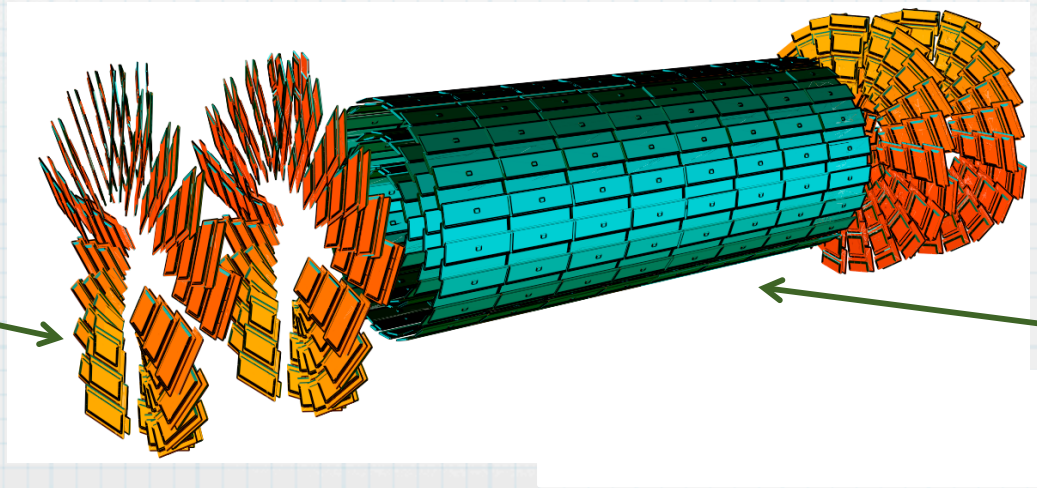




Other anomalous HF pulses from scintillation in mirror sleeve; sleeves replaced Jan. 2011. New connection with non-scintillating material for upgrade.

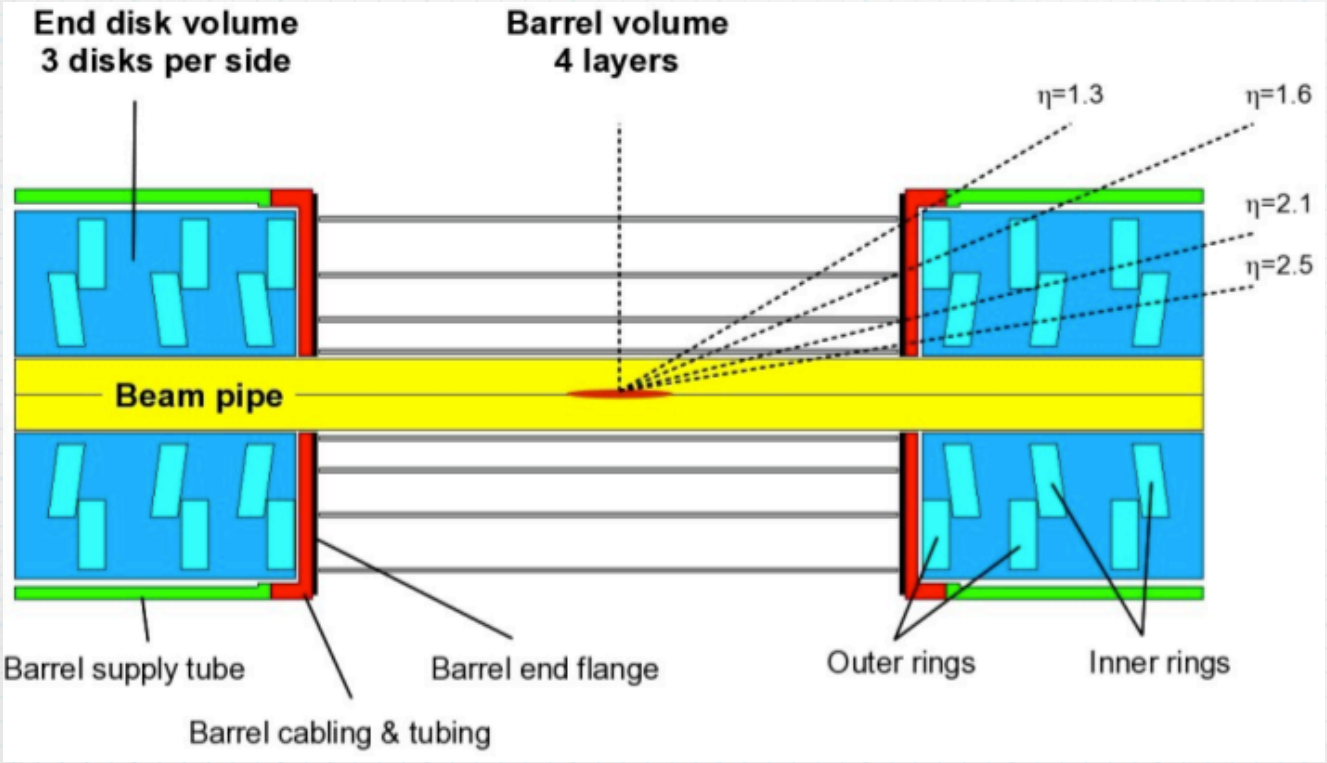
Upgraded Pixel Detector Replacement

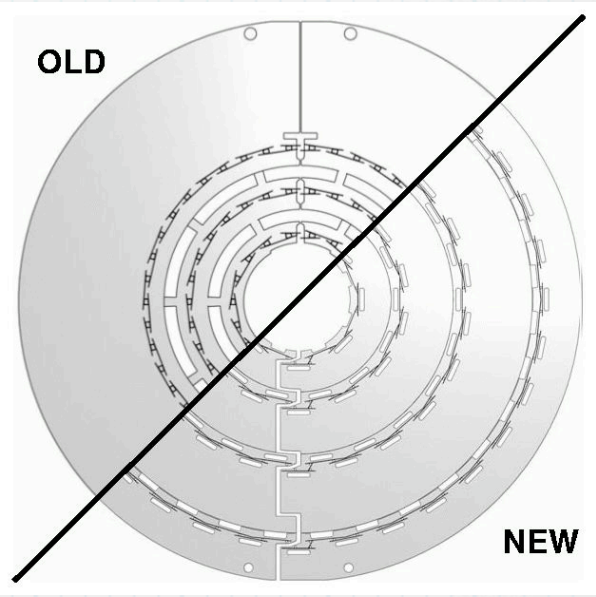
- Upgrade driven by instantaneous luminosity, robustness, efficiency
  - Pixel readout chip (ROC) just adequate for 10^{34} cm^{-2} s^{-1} with 4% (16%) dynamic data loss at 25ns (50ns) crossing time (due to readout latency and buffer)
    - At $2\times10^{34}cm^{-2}$ s^{-1} data loss is 15% (50%) for crossing time of 25ns (50ns)
  - Three hit coverage not hermetic, leading to 10-15% inefficiency when requiring 3-of-3 hits in high luminosity environment. This limits HLT tracking trigger efficiencies and slows tracking algorithm
  - Inner regions need replacement before the end of Phase 1 when ~350 fb^{-1} data will have been collected



Upgraded Pixel Detector Replacement

- Replace with new pixel detector with additional layer using redesigned ROC, and higher BW readout and DC-DC converters to reuse current cables and fibers
  - Reduce material by using CO_2 cooling instead of C_6F_{14}, lighter construction, and relocating services out of tracking volume
  - Smaller diameter beampipe; first layer closer to IP





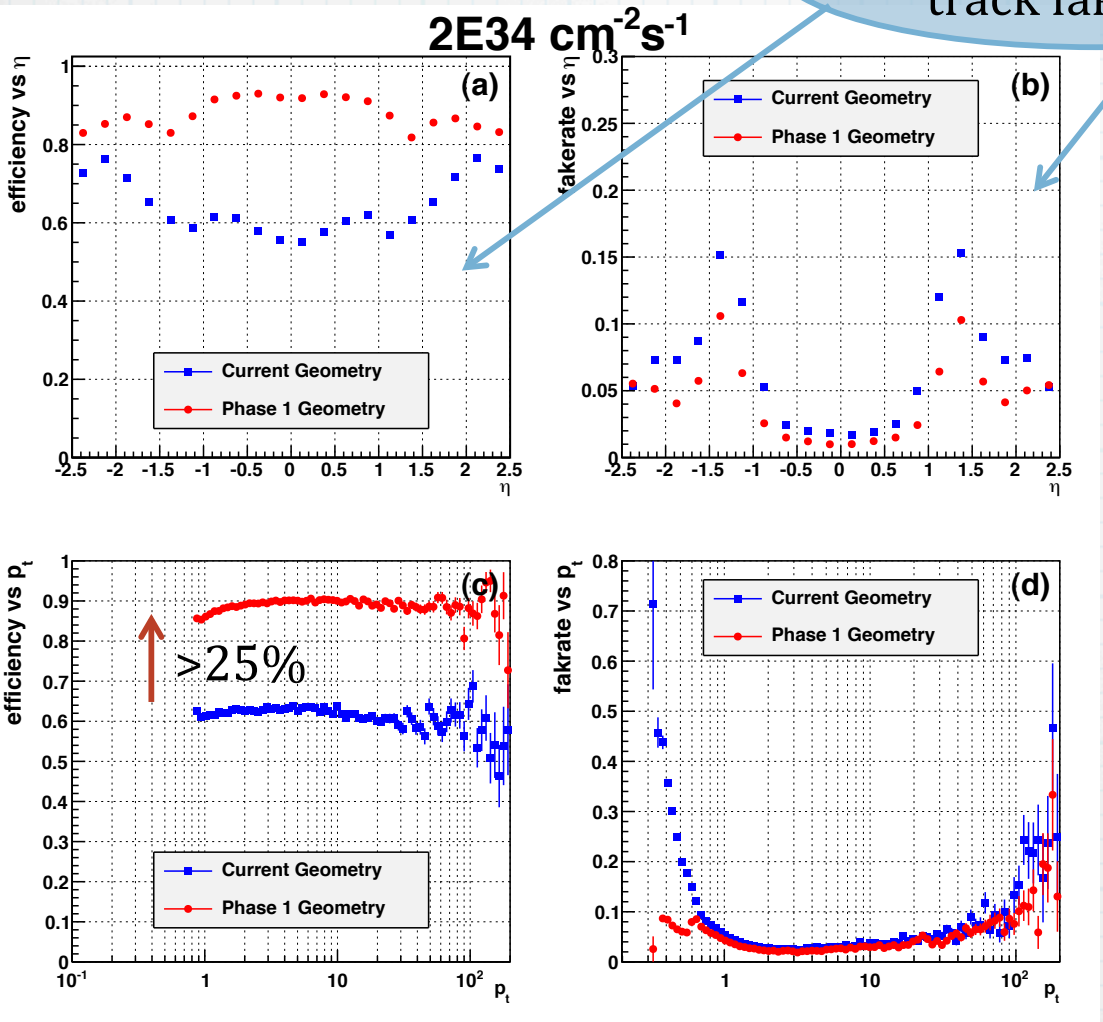
4th barrel layer closer to strip detector to help mitigate any losses for inner strip layer

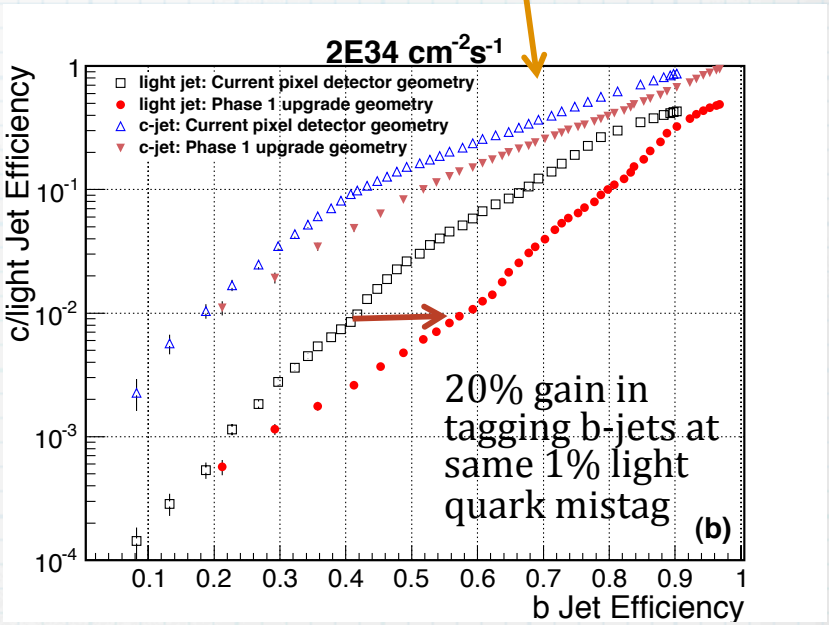
Simulations of Upgraded Pixel Detector

- Simulations with Geant4 for 2×10^{34} cms^{-2}s^{-1} @ 25ns including data losses in ROC

Tracking efficiency and track fake rates

b-tagging performance



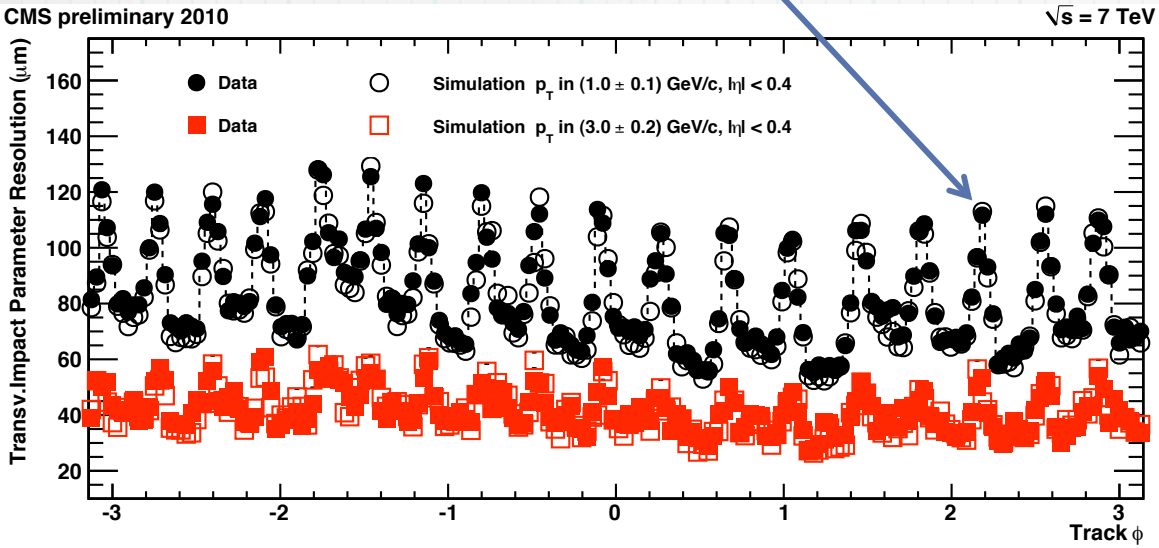


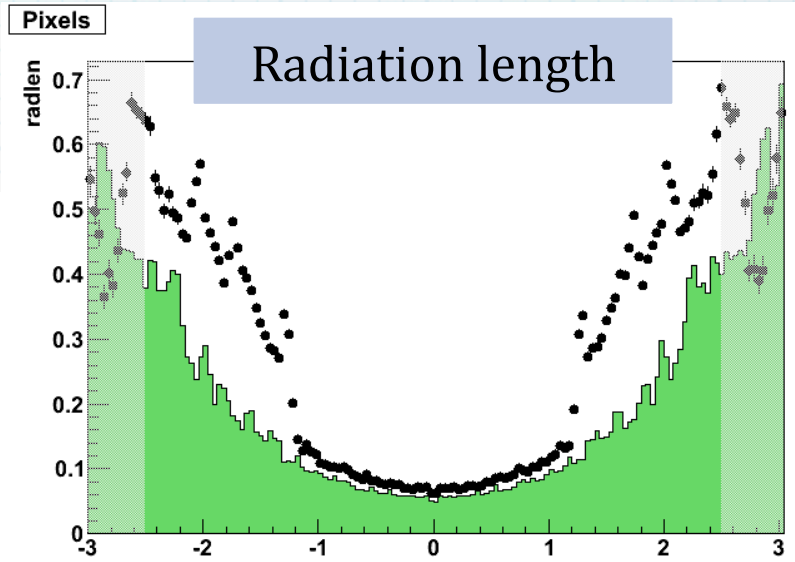
See poster by Pratima Jindal, Friday/ Monday in room Chicago 6&7 for more details

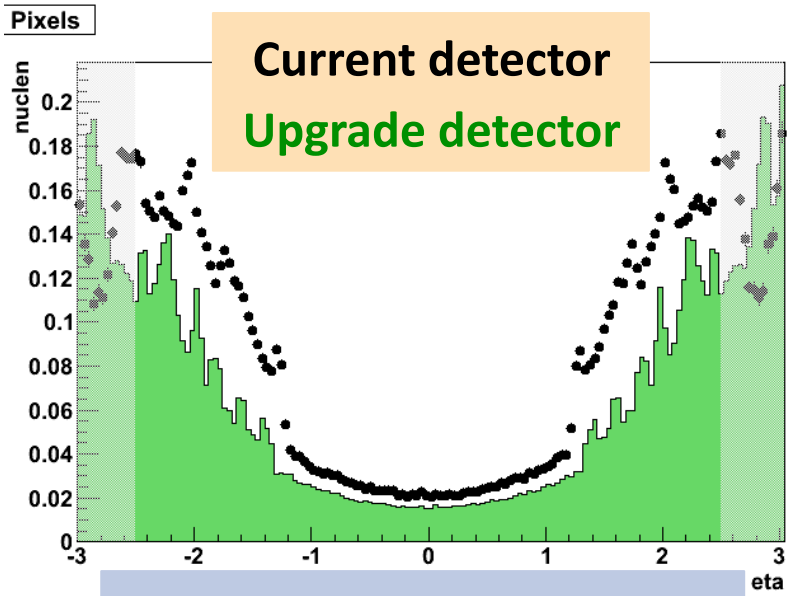
Reduce Material in Upgraded Pixel Detector

- Affects track resolutions and photon conversions

Can see effect of 18 cooling pipes in resolution of low momentum tracks



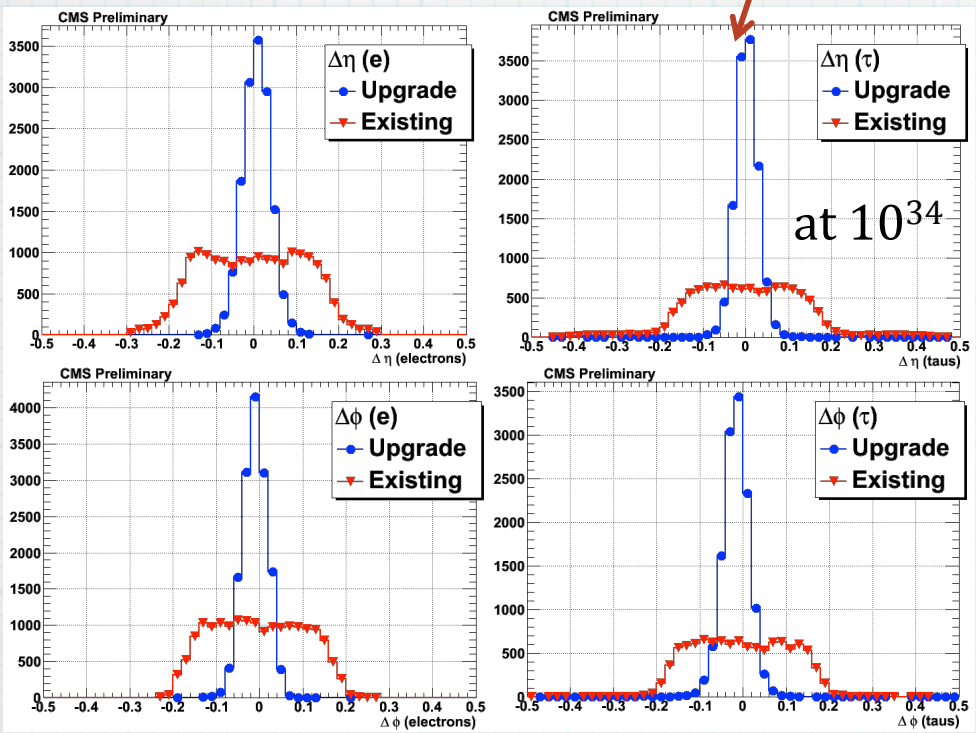


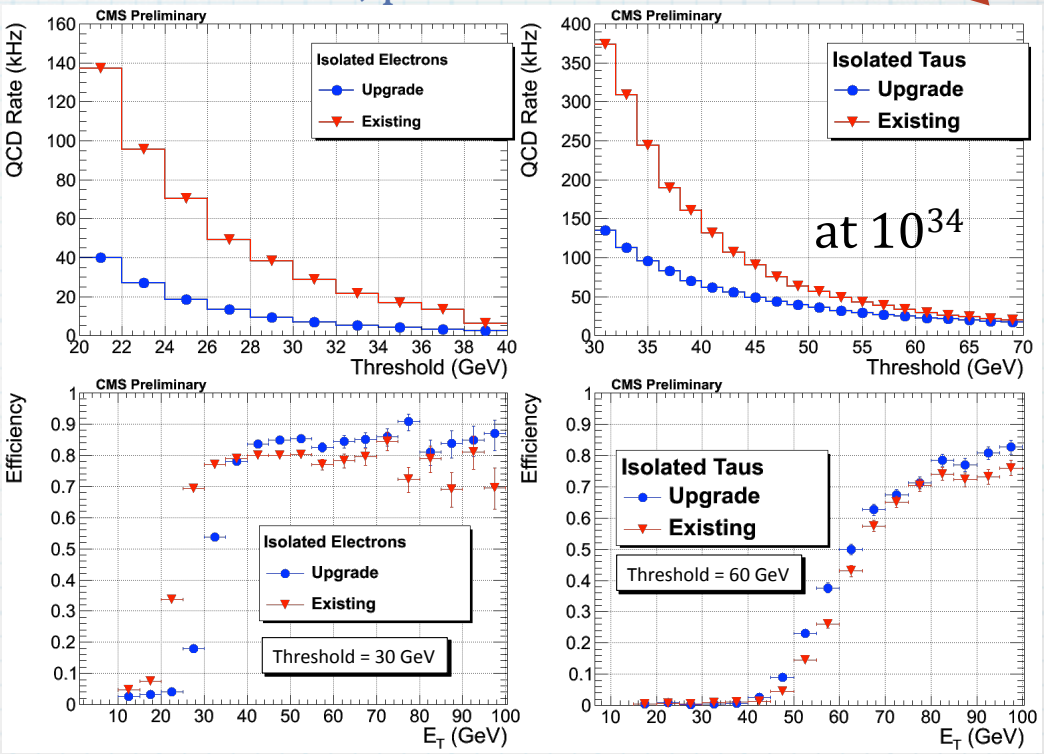


R&D involved for all components:
ROC itself and digital readout; CO_2 cooling components and system; ASIC for rad-hard DC-DC converter; rad-hard sensors; simulation of layout

Phase 1 Trigger Upgrade

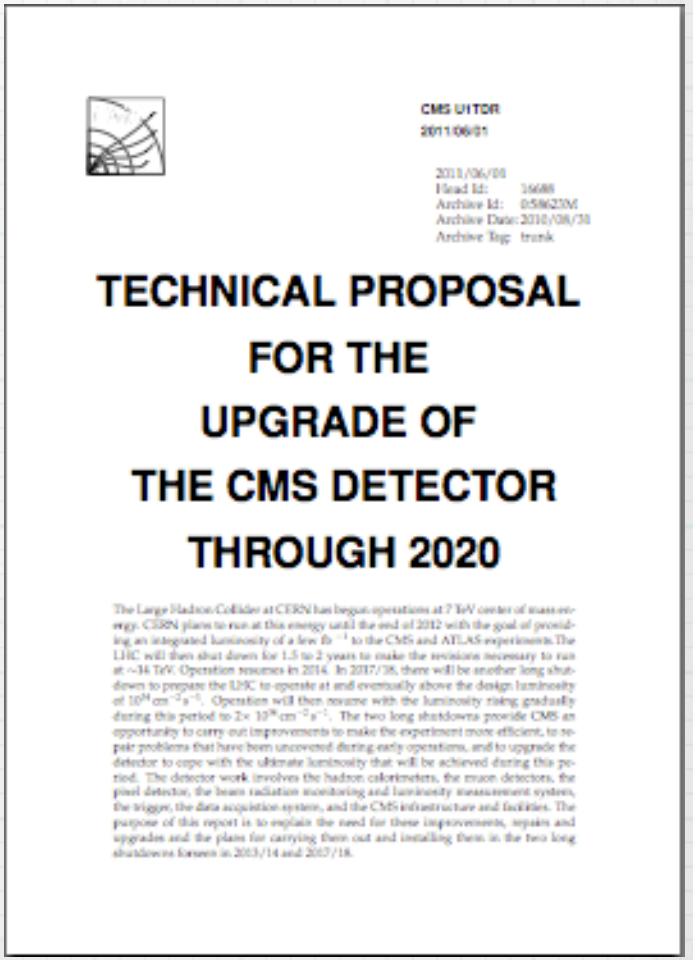
- Upgrade driven by instantaneous luminosity, other subdetectors, robustness
- Keep L1 at 100 KHz, so extra data to be handled by DAQ
  - Regional calorimeter trigger to use full granularity for internal processing, and more sophisticated clustering and isolation algorithms to handle higher rates and complex events (e.g. improved position resolution and trigger performance)
  - New infrastructure based on µTCA for increased BW, maintenance, and flexibility
  - Upgrade to muon trigger to handle addition channels, plus faster FPGA





Other Subsystem Upgrades

- Upgrade to DAQ to address larger data sizes and readout channels, additional HLT processing resources, reliability
  - See talk from Frans Meijers on Saturday
- Additional upgrades
  - Beam instrumentation and luminosity monitoring, includes R&D on suitable detectors, and updates to cavern simulation
  - Lots of work on CMS common systems, infrastructure and facilities
    - E.g. experimental beam pipe, safety systems, utilities, shielding
- We have produced a Phase 1 Technical Proposal document with some details


CMS UITDR
2011/06/01

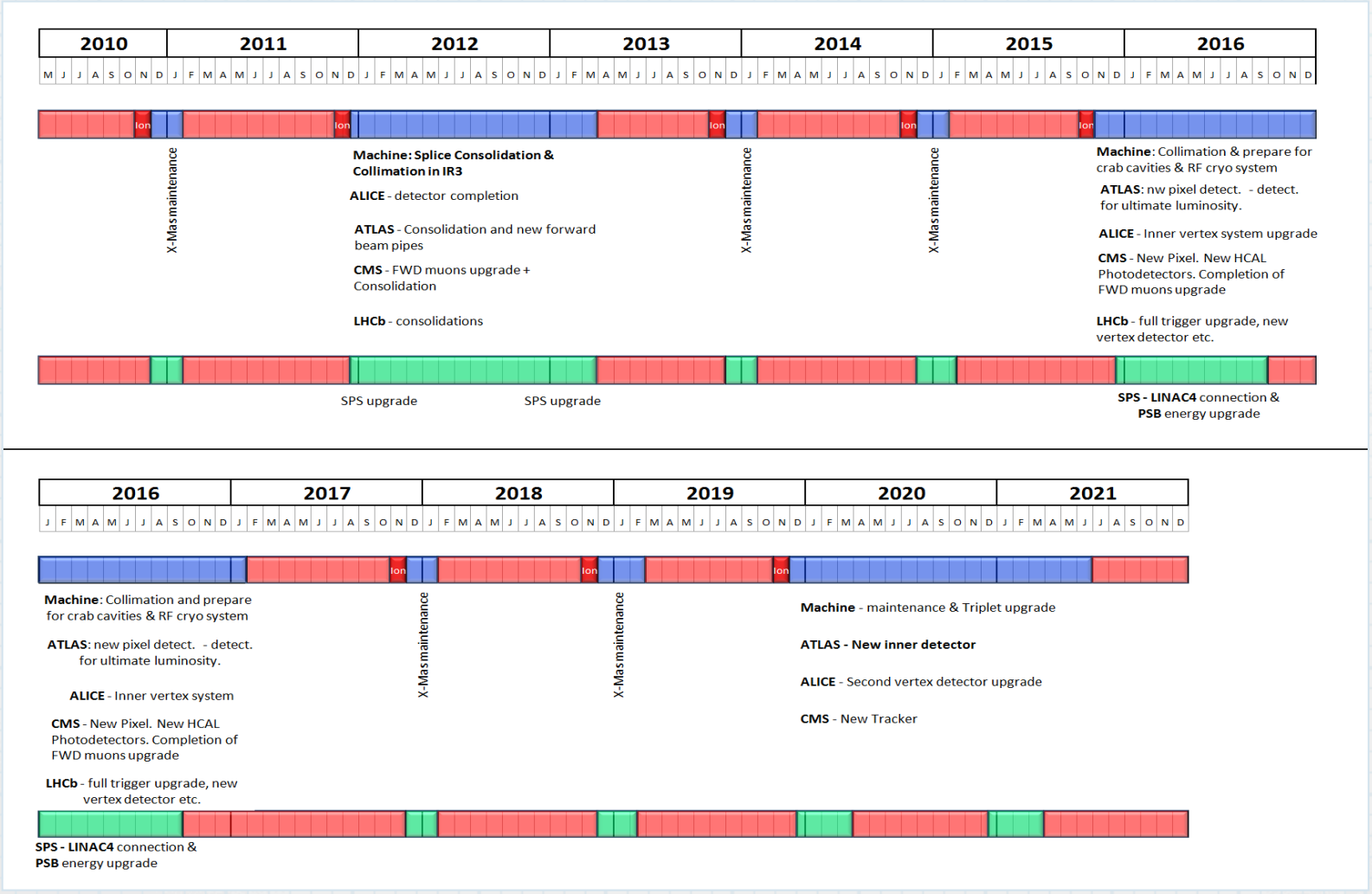
2011/06/01
Head Id: 16688
Archive Id: 0.586220M
Archive Date: 2010/08/30
Archive Tag: trunk

TECHNICAL PROPOSAL
FOR THE
UPGRADE OF
THE CMS DETECTOR
THROUGH 2020

The Large Hadron Collider at CERN has begun operations at 7 TeV center of mass energy. CERN plans to run at this energy until the end of 2012 with the goal of providing an integrated luminosity of a few fb^{-1} to the CMS and ATLAS experiments. The LHC will then shut down for 1.5 to 2 years to make the revisions necessary to run at ~14 TeV. Operation resumes in 2014. In 2017/18, there will be another long shutdown to prepare the LHC to operate at and eventually above the design luminosity of 10^{34} cm^{-2}s^{-1}. Operation will then resume with the luminosity rising gradually during this period to 2×10^{34} cm^{-2}s^{-1}. The two long shutdowns provide CMS an opportunity to carry out improvements to make the experiment more efficient, to repair problems that have been uncovered during early operations, and to upgrade the detector to cope with the ultimate luminosity that will be achieved during this period. The detector work involves the hadron calorimeters, the muon detectors, the pixel detector, the beam radiation monitoring and luminosity measurement system, the trigger, the data acquisition system, and the CMS infrastructure and facilities. The purpose of this report is to explain the need for these improvements, repairs and upgrades and the plans for carrying them out and installing them in the two long shutdowns foreseen in 2013/14 and 2017/18.

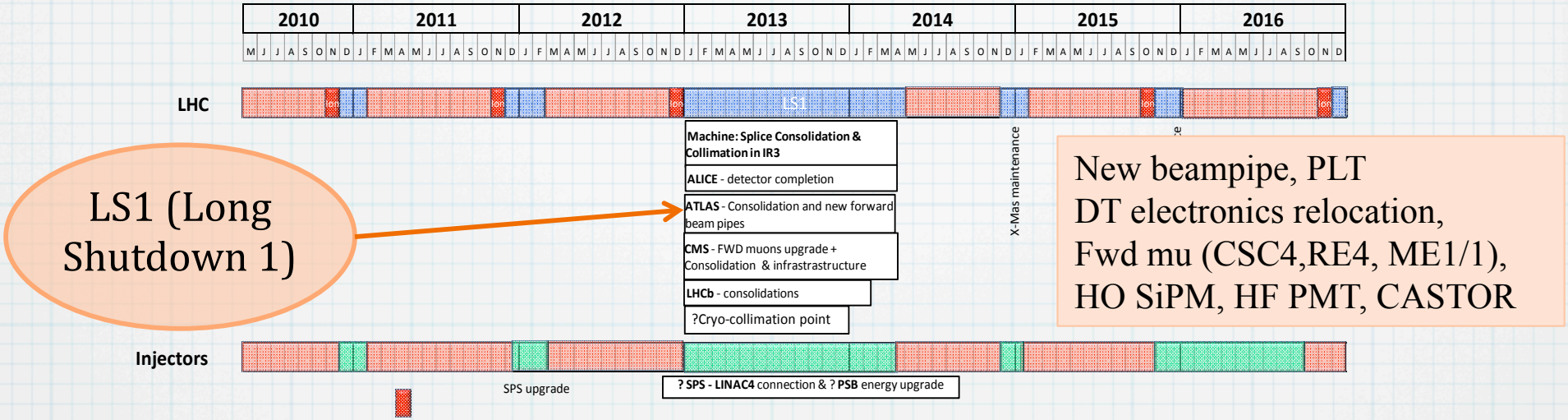
Some Words on the Schedule

- "Old" 10 year technical Plan from July 2010
  - Real schedule likely to change a number of times



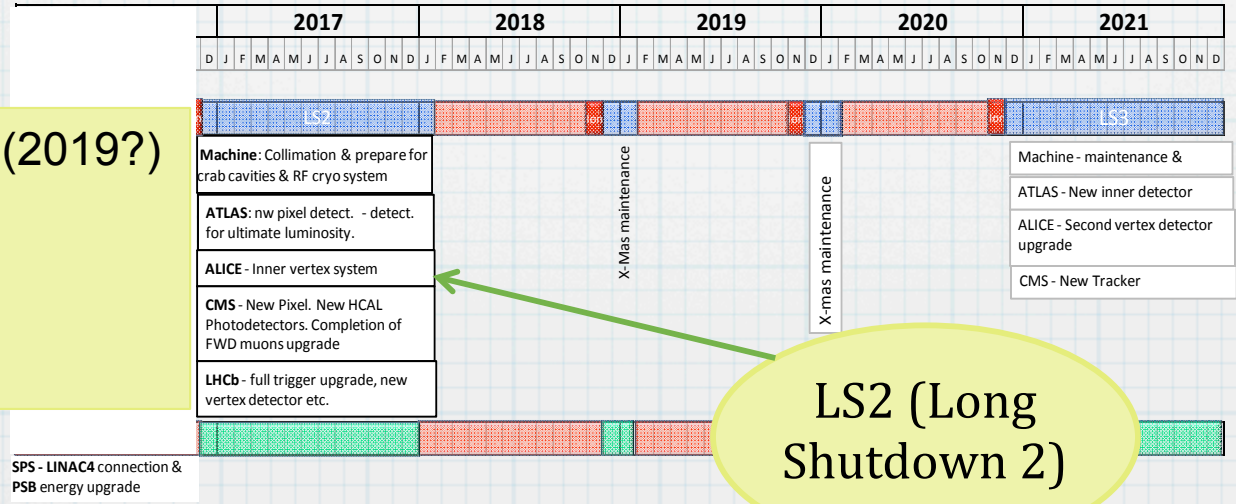
Schedule will be Driven by Physics

- New draft 10 year plan (Steve Myers, 3/8/2011 SLHC-PP)



LS1 (Long Shutdown 1)

New beampipe, PLT
DT electronics relocation,
Fwd mu (CSC4,RE4, ME1/1),
HO SiPM, HF PMT, CASTOR



LS3 (Long Shutdown 3)

"driven by expts" (2019?)
HB/HE SiPM
and segmentation,
Pixel replacement,
Trigger, DAQ

LS2 (Long Shutdown 2)

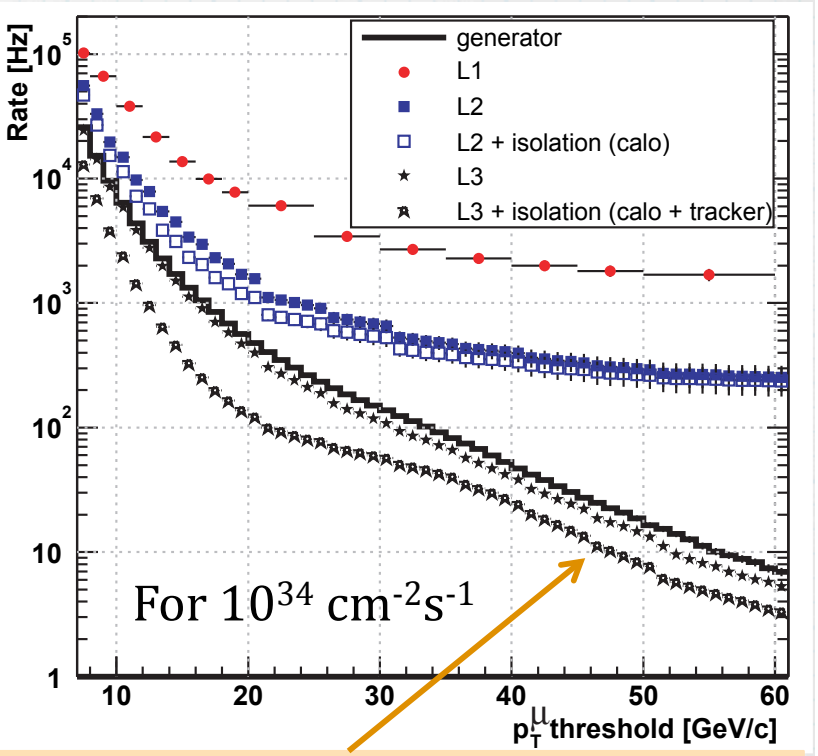
Also expect to use technical stops (winter shutdowns)

Phase 2 Upgrade R&D

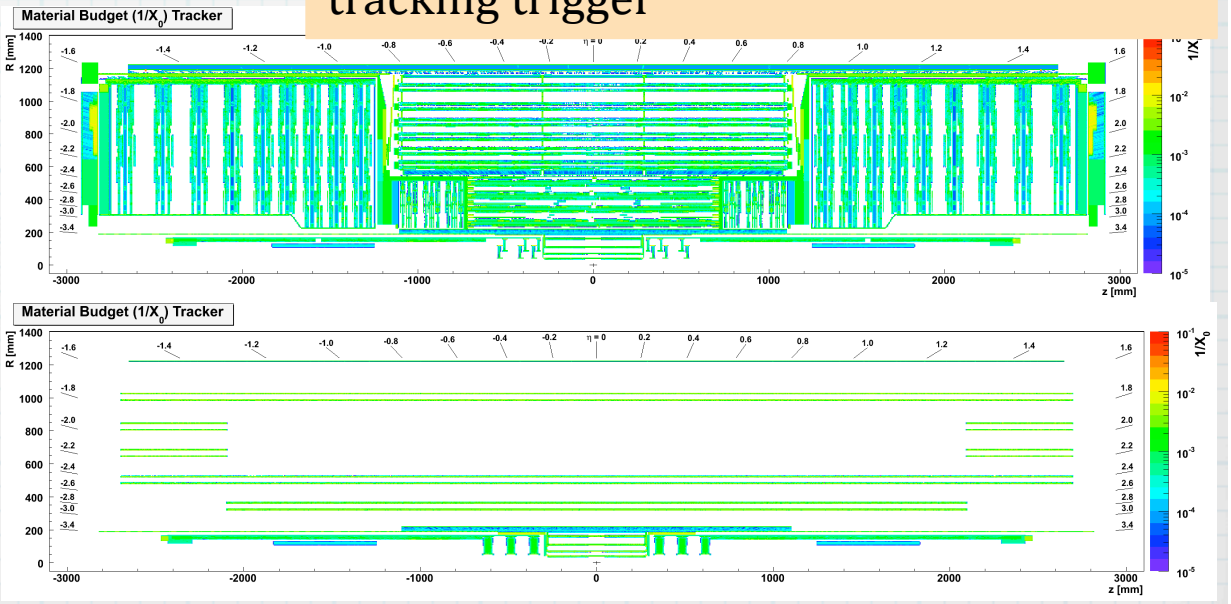
- Builds on Phase 1 upgrade work
- Replace tracking system to handle 5×10^{34} $cm^{-2}s^{-1}$ and 3000 fb^{-1}; includes producing L1 track trigger
  - R&D on sensors, ASICs, data links, power distribution, CO_2 cooling, trigger functionality

Talks from Selcuk Cihangir, Lenny Spiegel, Giuseppe Broccolo; and posters by Stefano Mersi, Pramod Lamichhane

- Work on EB; and forward EE,HE,HF
- New muon electronics, MPGDs for RPC
- Trigger electronics upgrade, increase L1 latency X2, integrate L1 tracking trigger



Single muon L1 trigger at 5×10^{35} $cm^{-2}s^{-1}$ needs tracking information; motivates L1 tracking trigger



Summary

- CMS is working well and expectations are great for making the most of the LHC luminosity (as we have done so far)
  - There have of course been some problems; many of which are expected for a new experiment
  - We had our share of more interesting problems which we have solved/ managed, a few were presented
  - Some of these, and some others will be relevant at Phase 1 luminosities and require upgrades
- Described the proposed upgrades for CMS during Phase 1: covering the driving factors, the proposal of changes, constraints, and R&D needed
  - See the other talks/posters at this conference for more details
- We have produced a Phase 1 upgrade technical proposal document
- The proposed changes should prepare the CMS detector for coming challenges and (additional) discovery opportunities to come!