CMS Upgrade Technical Proposal LHCC 103

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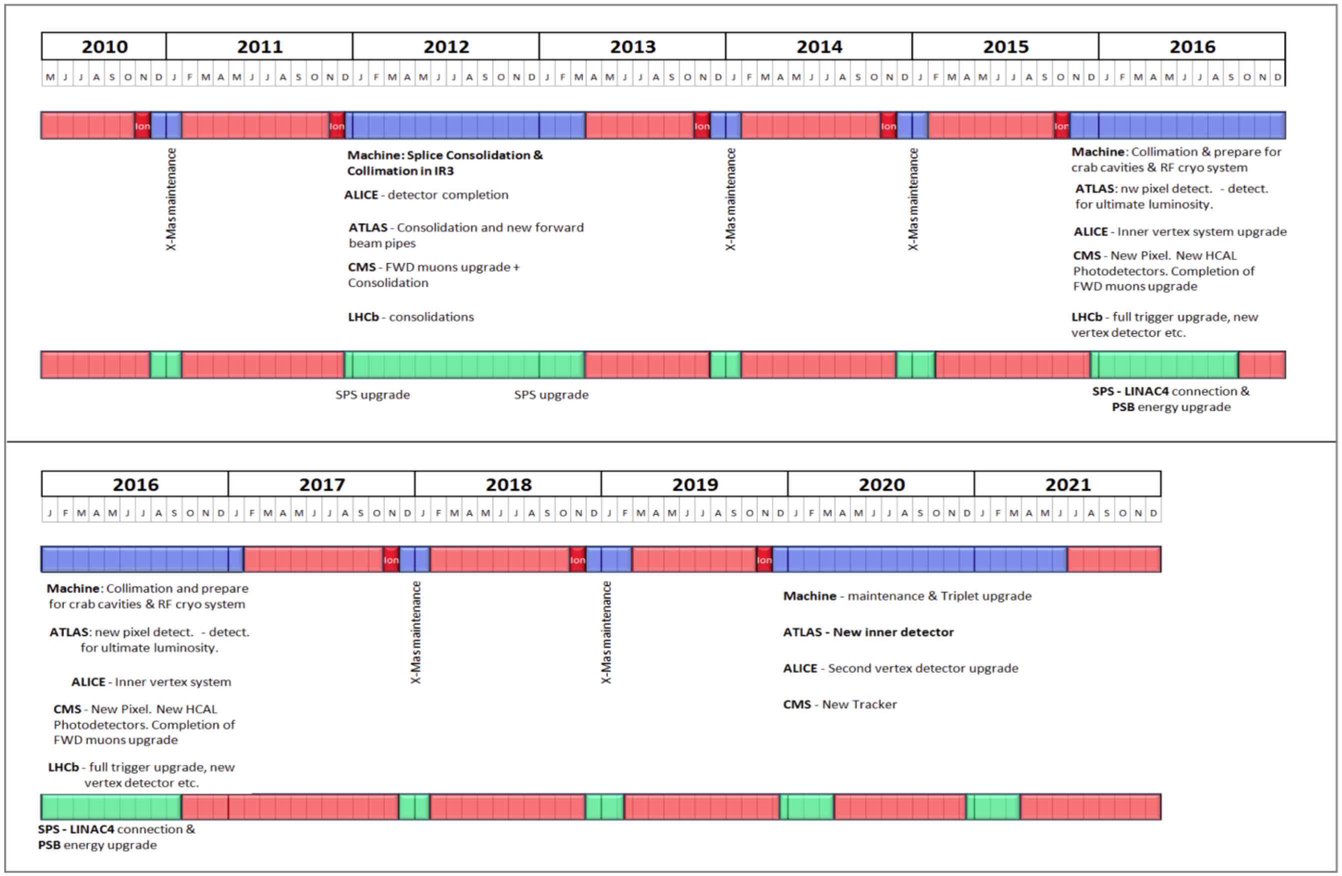
Outline

- Overview of upgrade plans
- Muon upgrades
- Hadronic Calorimeter Upgrades
- Pixel Tracker Upgrades
- Other Upgrades and plans for document submission

CERN has announced the plan for shutdowns over the next 10 years

The 10 year technical Plan



This plan is very consistent with what CMS had been planning for upgrades

Progression in luminosity

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

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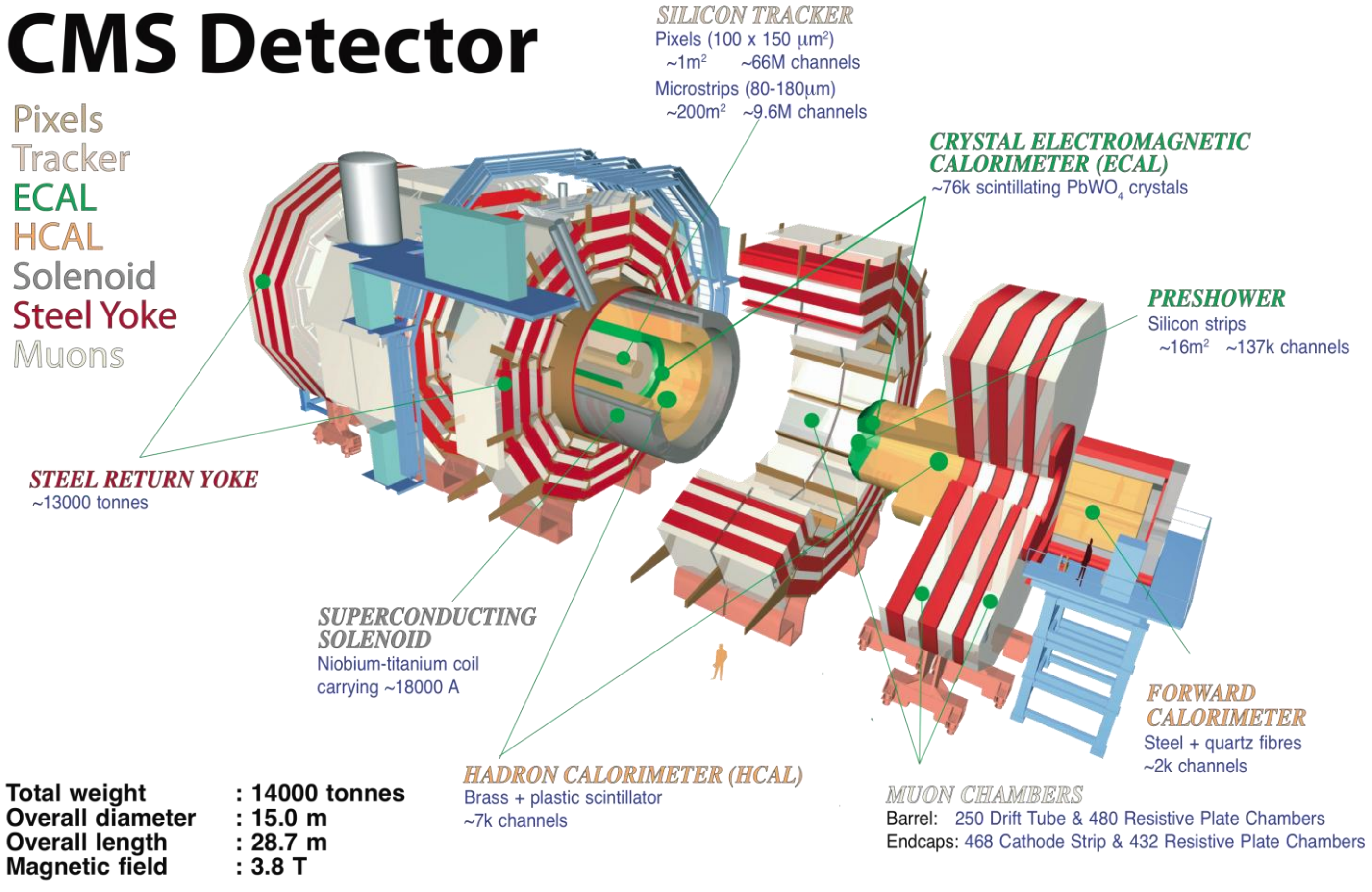
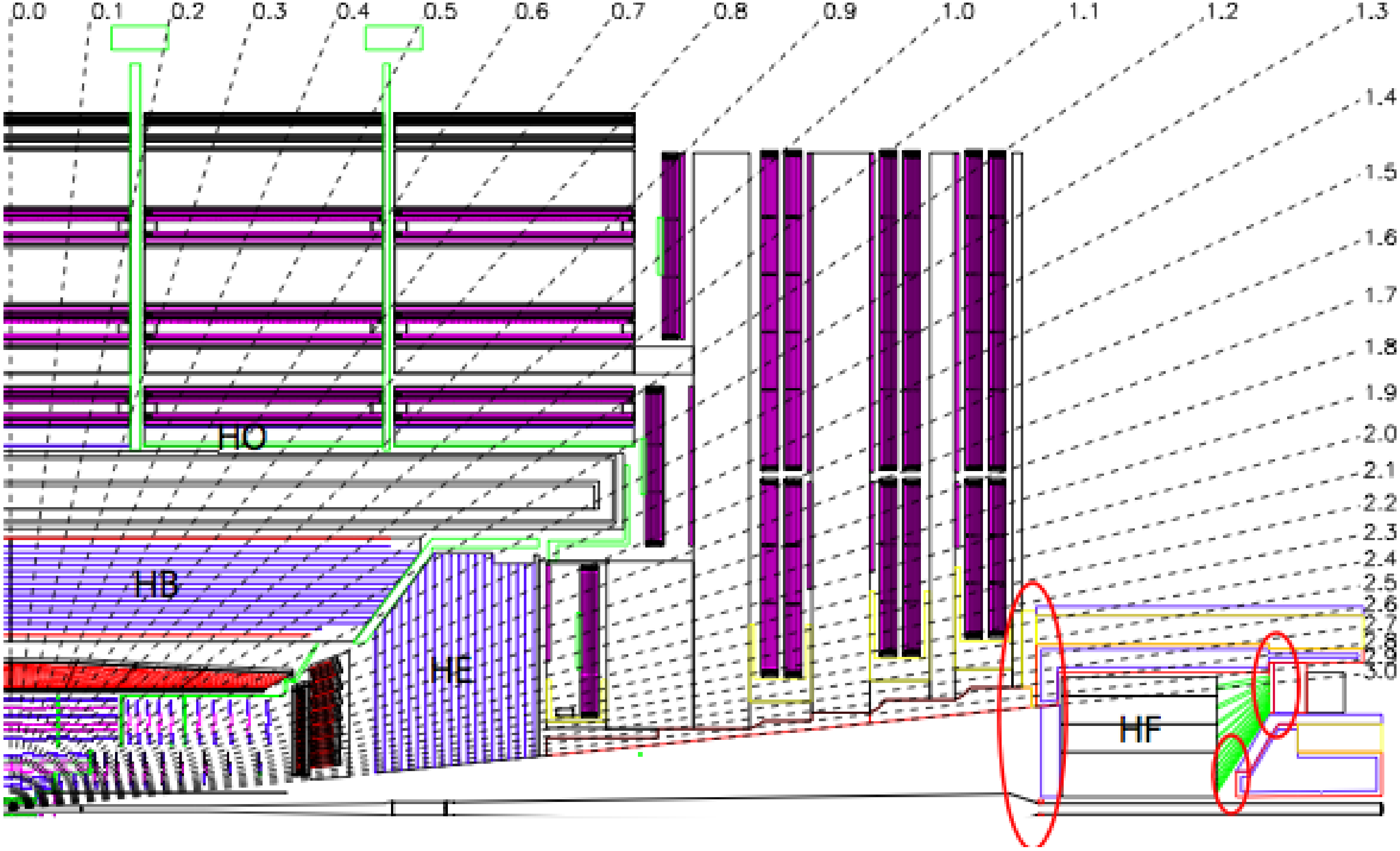
Requirements for the phases of the upgrades: ~2010-2020

- This decade will see the initial operation of the LHC and the increase of energy and luminosity towards the design luminosities.
- Goal of extended running in the second half of the decade to collect ~100s/fb
  - 80% of this luminosity in the last three years of this decade
  - About half the luminosity would be delivered at luminosities above the original LHC design luminosity
- Motivation for upgrades during this phase
  - may be based on required performance for higher luminosity, better physics performance, better reliability of operation

2020-2030 – High Lumi LHC

- Continued operation of the LHC beyond a few 100/fb will require substantial modification of detector elements
- The goal is to achieve 3000/fb in phase 2
- Need to be able to integrate ~300/fb-yr
- Will require new tracking detectors for CMS
- Still substantial R/D required for the detectors to be able to operate at these higher luminosities
  - A preview of this R&D is included as an appendix to the upgrade Technical Proposal


CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² ~137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
FORWARD CALORIMETER
Steel + quartz fibres
~2k channels
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T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1.5
1.6
1.7
1.8
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2.0
2.1
2.2
2.3
2.4
2.5
HO
HB
HE
HF

Agreed at the May 2008 Upgrades Workshop
http://indico.cern.ch/conferenceDisplay.py?confId=28746

CMS Upgrade Scope

2016

2012

2016

2012
/2016

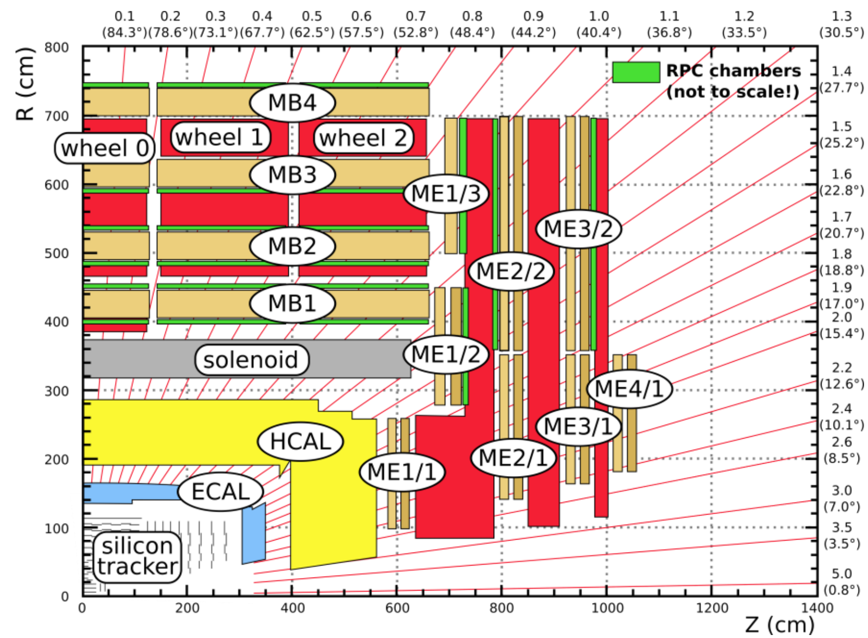
2016

What is required of new detectors for operation up until 2020?

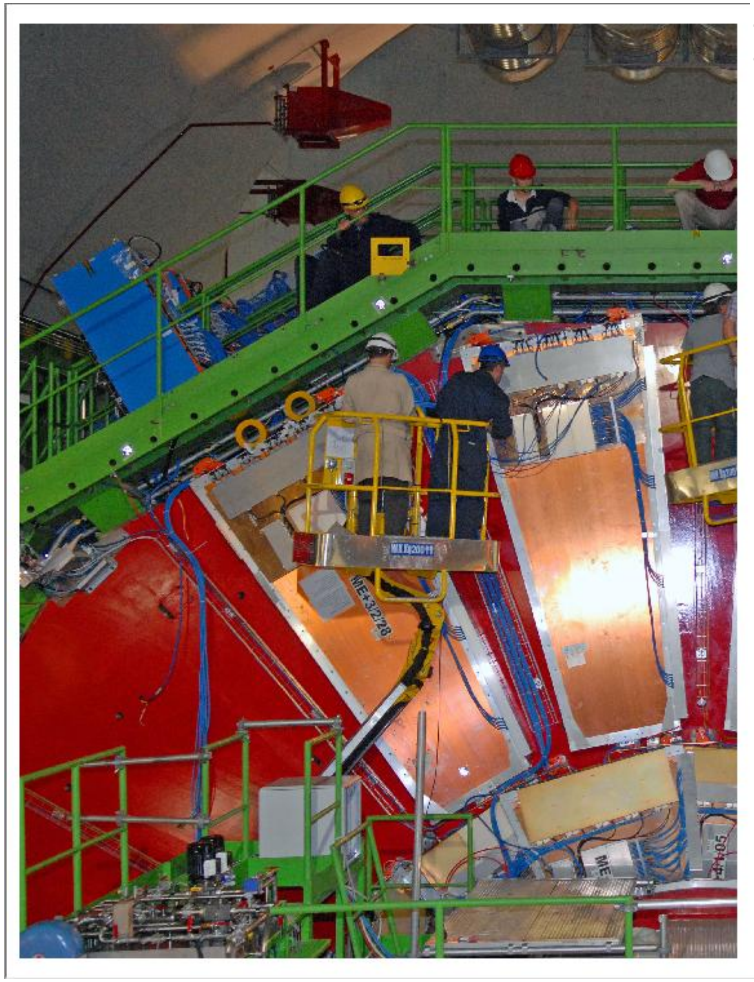
- They should be able to operate with a peak luminosity of up to 2 x 10^{34}
- They should be able to cope with an integrated luminosity of up to as much as 700/fb
  - Looking at potential increase in luminosity, this now not an issue until late in the decade.
  - Be able to cope with whatever scenario develops before the long shutdown to replace triplets/tracking detectors
- They should offer increased physics performance

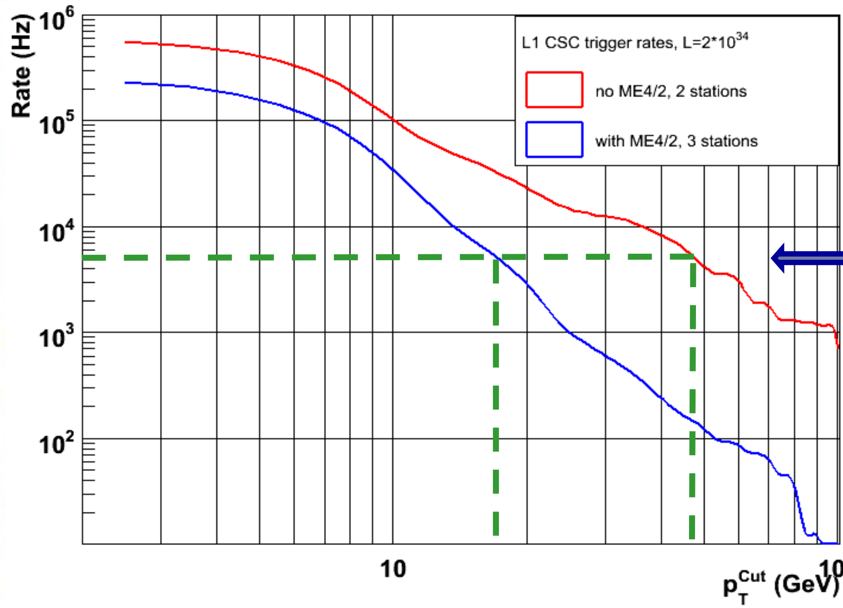
2012: Muons

- CMS design has space for a fourth layer of forward muon chambers – both Cathode Strip Chambers and RPCs
  - They give much better trigger robustness – especially at higher luminosities
  - A fourth layer of shielding is also for-seen (YE4)
- These are built to the same design as those already installed
- Technically ready to produce chambers
  - Funding is the main reason the chambers are not yet produced
- Imminent Steps
  - bat 904 has been prepared for CSC Production



Phase 1 : Muons ME4/2 upgrade motivation





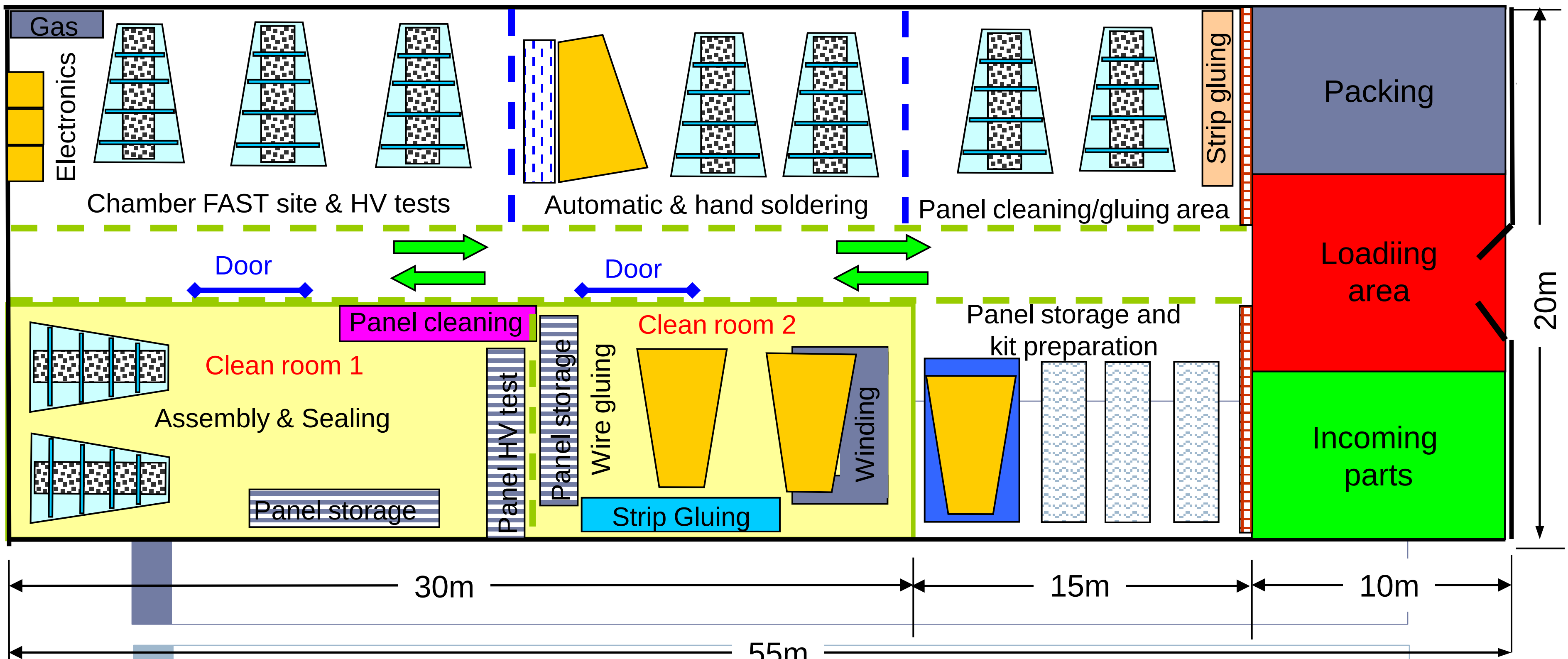
Target Rate 5 kHz

5 chambers already installed

- Compare 3/4 vs. 2/3 stations:
  - (Triggering on *n* out of *n* stations is inefficient and uncertain)
- Recent simulation with & without the ME4/2 upgrade:
  - The high-luminosity Level 1 trigger threshold is reduced from 48 → 18 GeV/c

CSC Factory Production Site at CERN

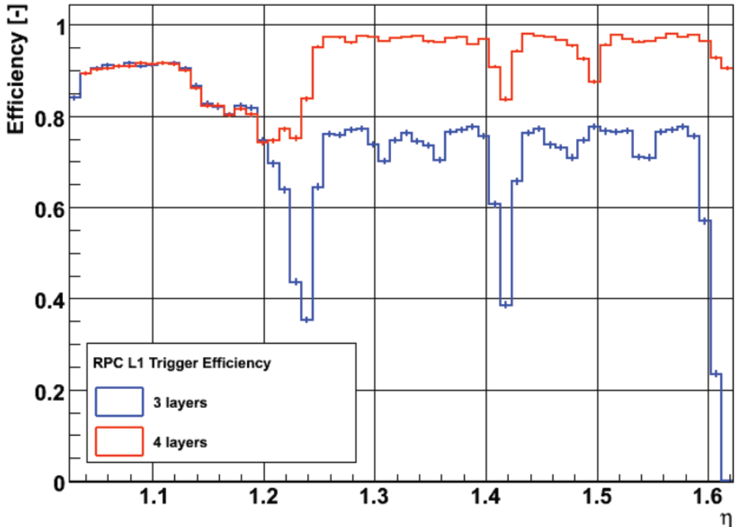
Floor plan layout at Bldg 904 (Draft)

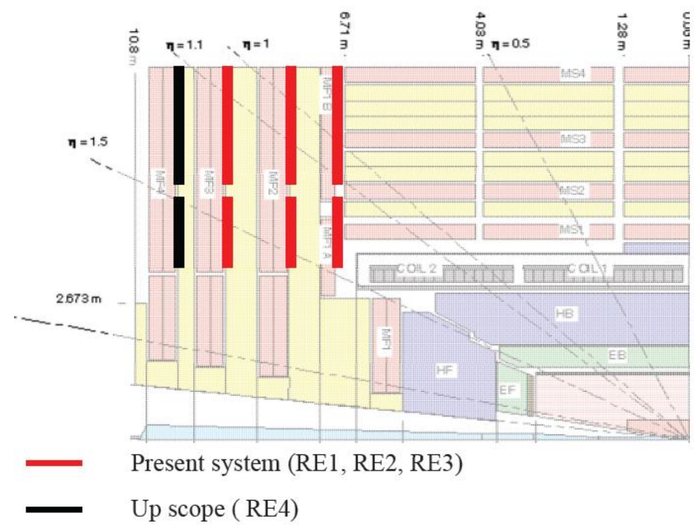


Based on experience of ME4/2 prototype production the proposed area at 904 of ~ 1000 m2 should be enough to place a factory production and FAST test site. For the completed chambers we need additional storage area of ~ 250m^2.

RPC: The RE4/2

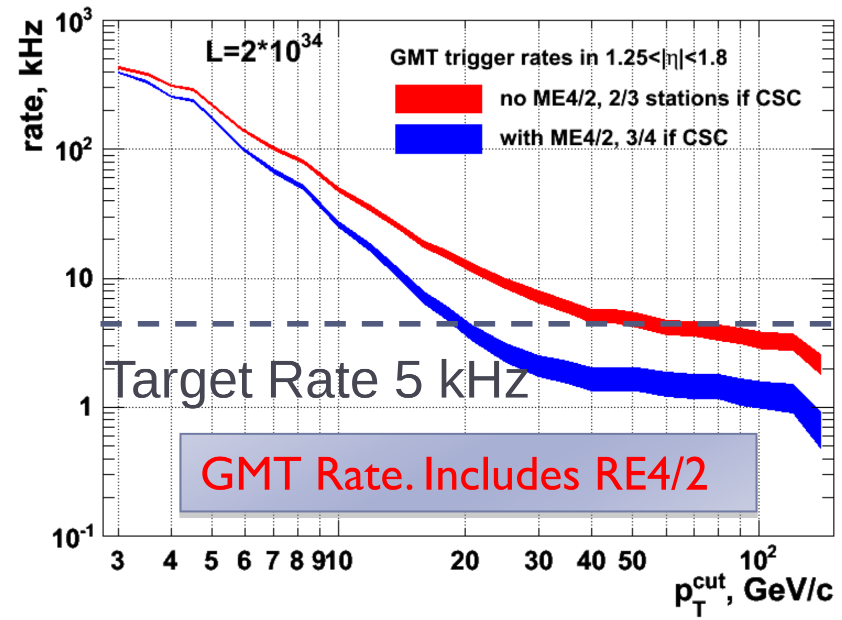
- RPC trigger requires three out of three station coincidence
  - With two points, the rate is just too high due to noise and random coincidences
- Leads to a substantial inefficiency of the RPC trigger
  - Better efficiency requires extra redundancy, i.e. station RE4

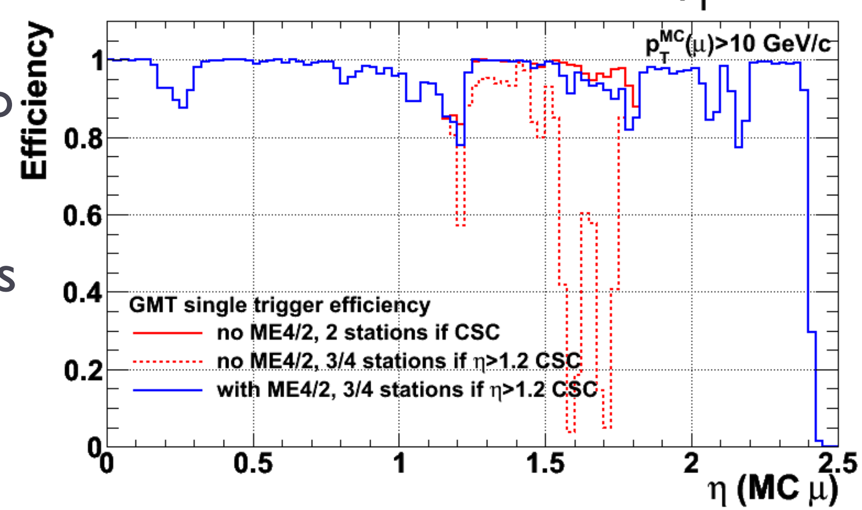




CSC: The ME4/2

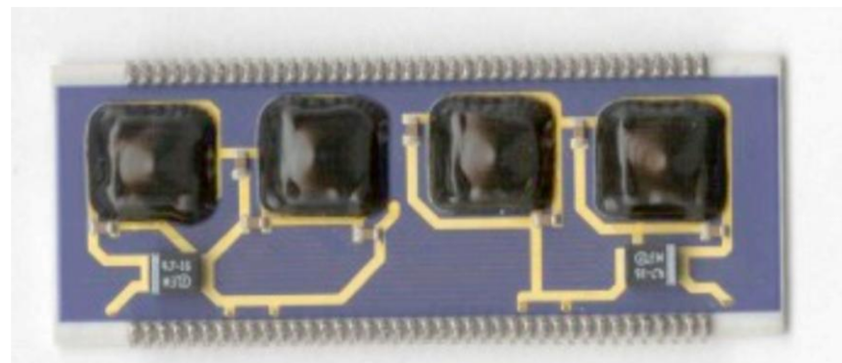
- At higher luminosity, trigger rate becomes large and flat
  - Caused by mismeasured soft muons
- The reason is that the trigger requires a two station coincidence
  - Not enough to control soft muon mismeasurements
- Cant require three station as efficiency losses are too large due to lack of redundancy
  - Not all backgrounds included, e.g. no beam backgrounds
  - Real life efficiencies are always even worse, e.g. dead chamber electronics
- ME4/2 has critical importance for Global Muon Trigger performance



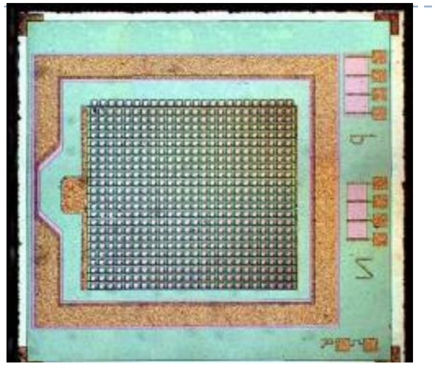


Upgrades to DT electronics

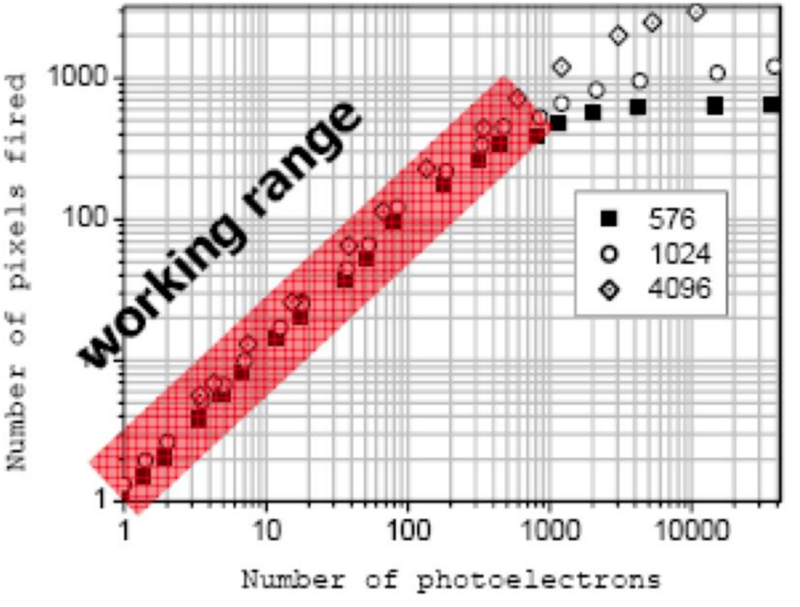
- On Detector BTIM ASICs have been failing
- Limited spares available – process no longer available
- Move some electronics to FPGA to create spares
- Move some electronics out of the UXC to the USC
  - Transmit data by optical fibre from UXC to USC
  - More robust, easier access to make repais



New photo-detectors for Hadronic Calorimeter



- Array of avalanche photo diodes ("digital" photon detection)
  - Array can be 0.5x0.5 up to 5.0x5.0 mm^2
  - Pixel size can be 10 up to 100µ
- All APDs connect to a single output
  - Signal = sum of all cells
- Advantages over HPDs:
  - 28% QE (x2 higher) and 10^6 gain (x500 higher)
  - More light (40 pe/GeV), less photostatistics broadening
  - Very high gain can be used to give timing shaping/filtering



SiPMs already being installed in the HO

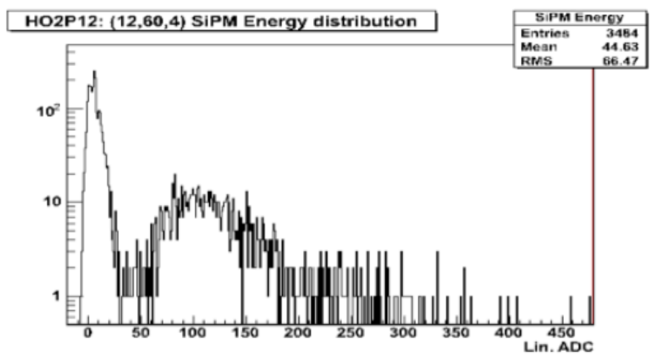


Figure 10a: Individual energy distribution, mwgr18, for a single HO channel, HO(ieta=12, iphi=60). Here energy E_μ is not corrected for muon angle of incidence.

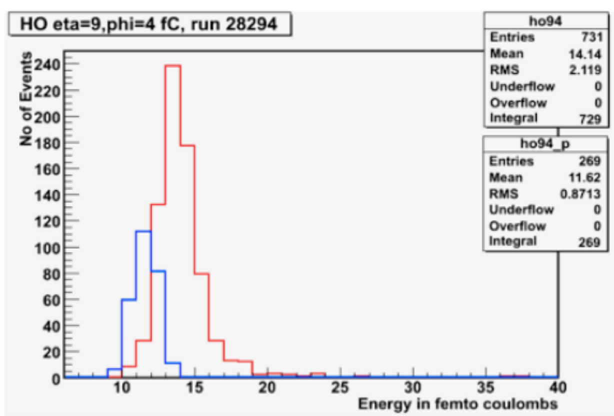
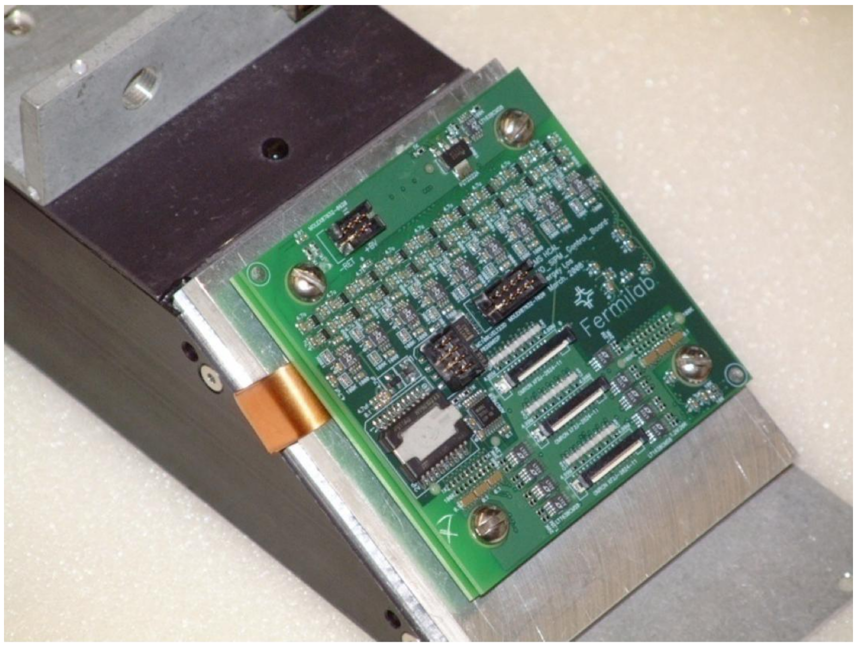
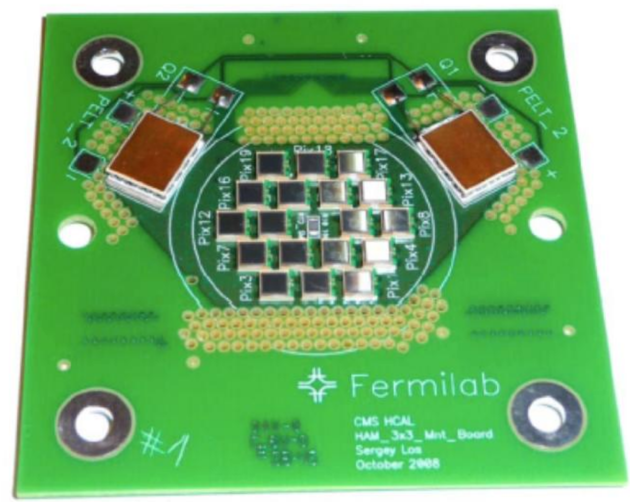


Figure 10b: For comparison, individual energy distribution, single HO channel read out with HPD, TB2007 data. Blue line: pedestal events, red line: muon signal.

- HPDs show increased noise in the magnetic field region where HO is operated
  - They show this effect much less at full field or at 0 field
- Decided to replace the HPDs in HO with SiPM
  - Have already installed some modules
- SiPM Signal/Noise is a factor of 10 better than with the HPDs currently on the detector

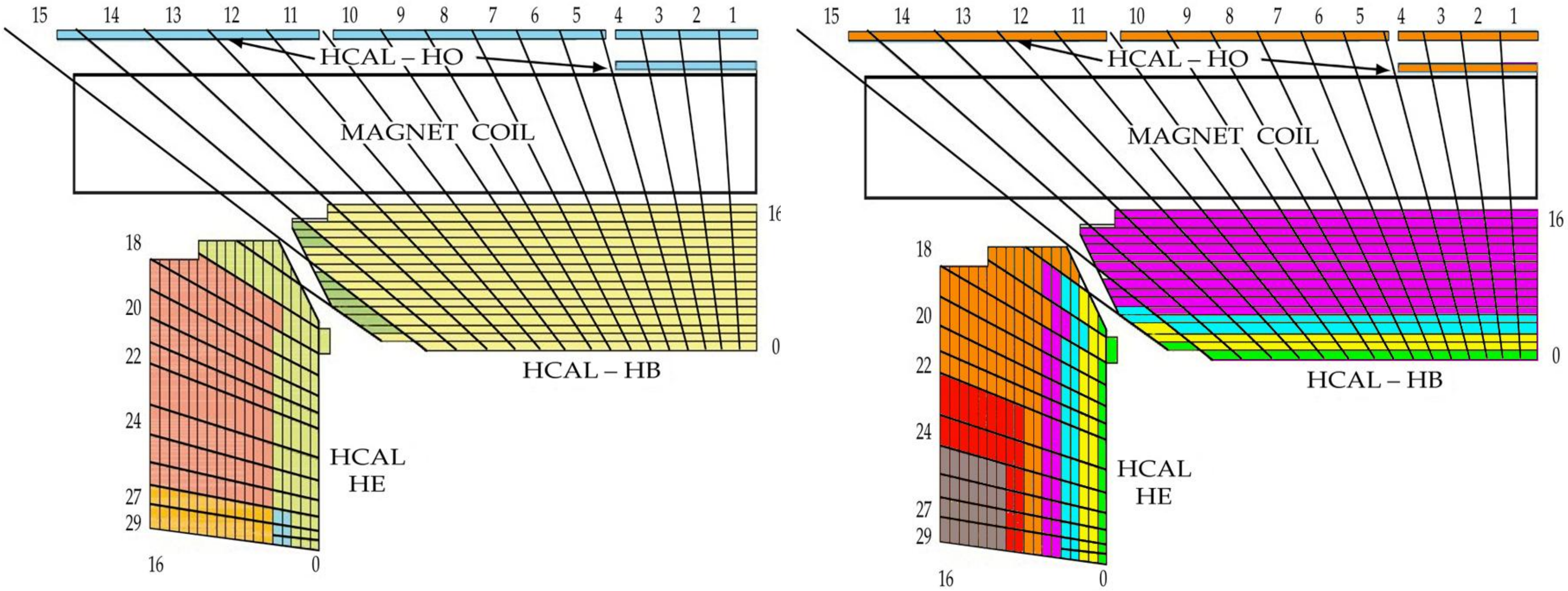
HO SiPMS





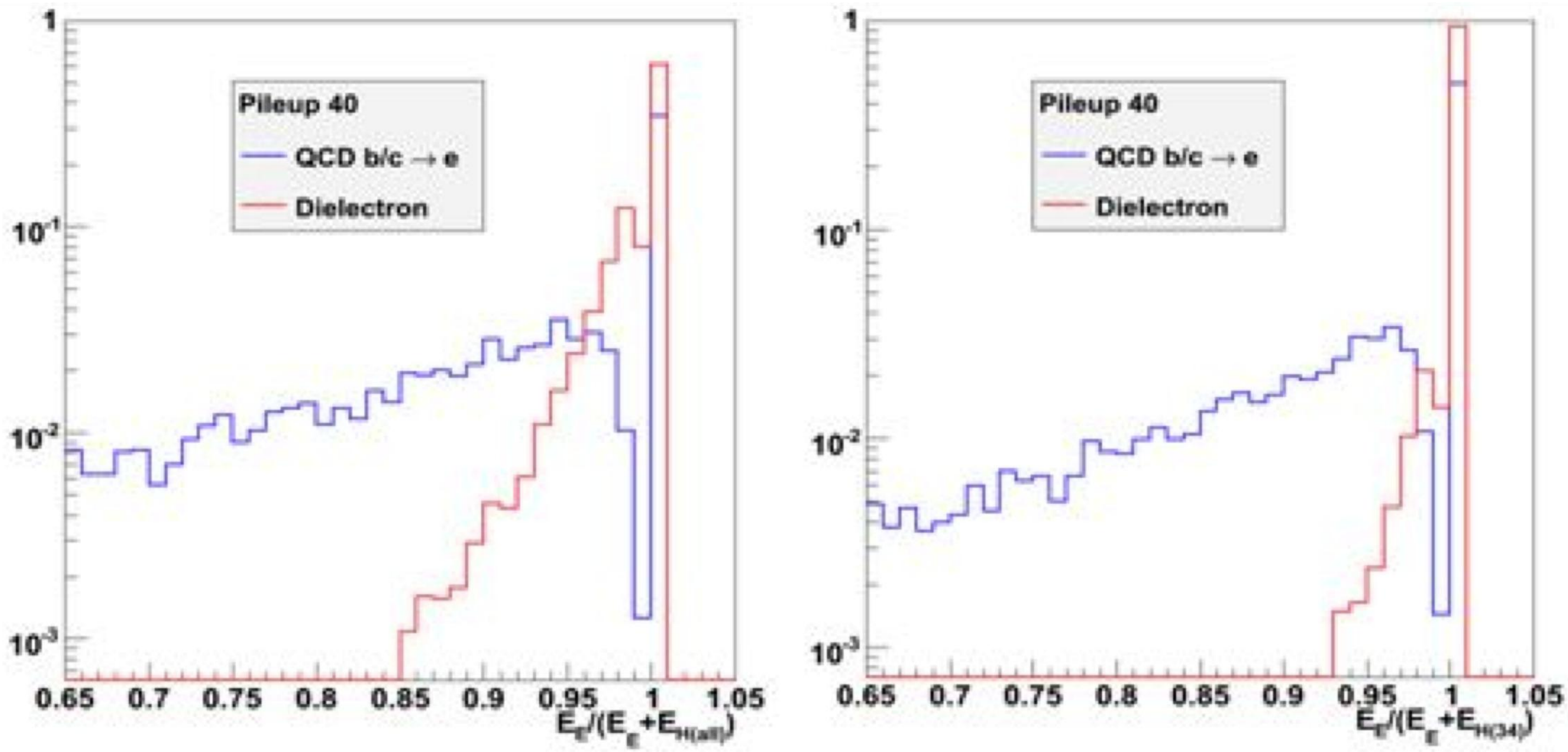
Plug in replacement for HPD

New Photodetectors allow finer segmentation of readout in depth

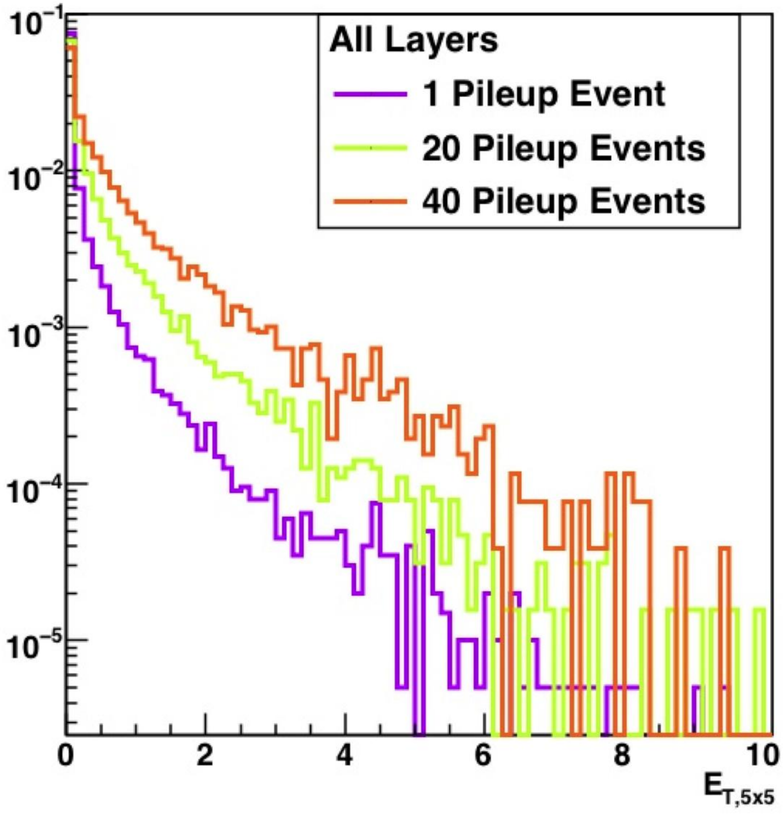


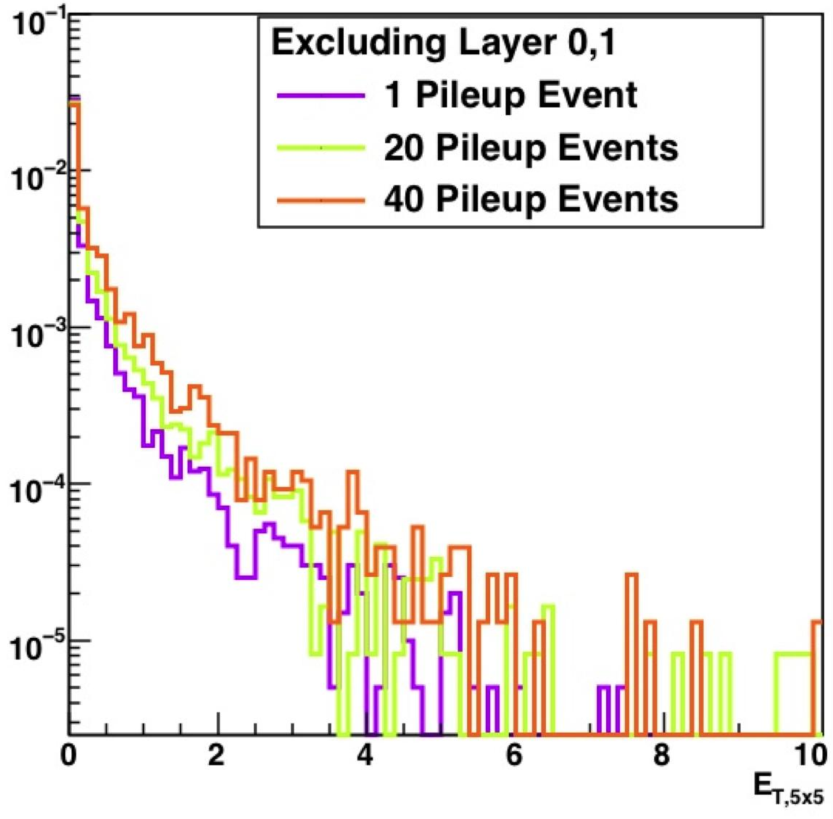
New segmentation – more robust against damage to inner scintillator layers

Segmentation – Electron isolation



Segmentation

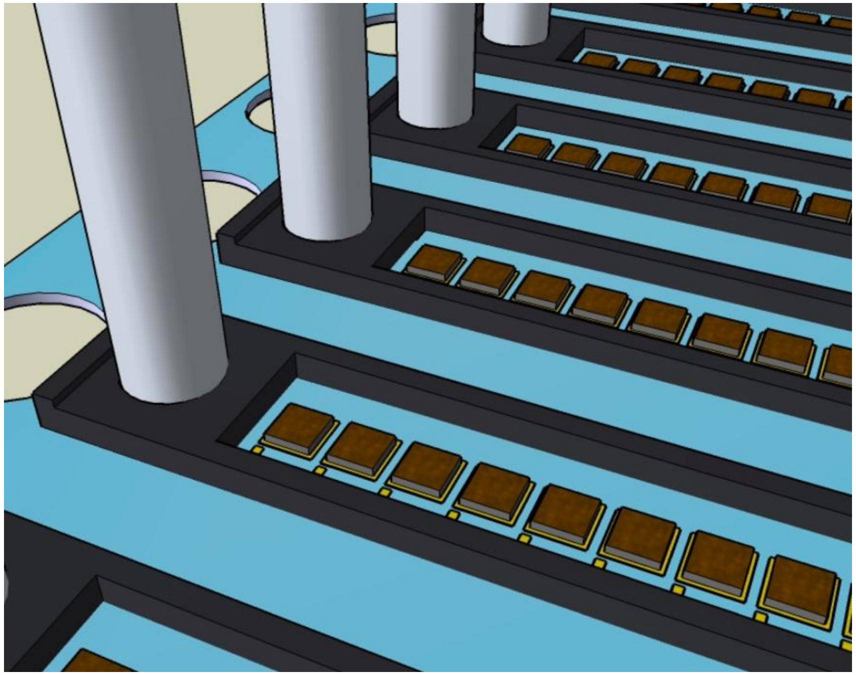


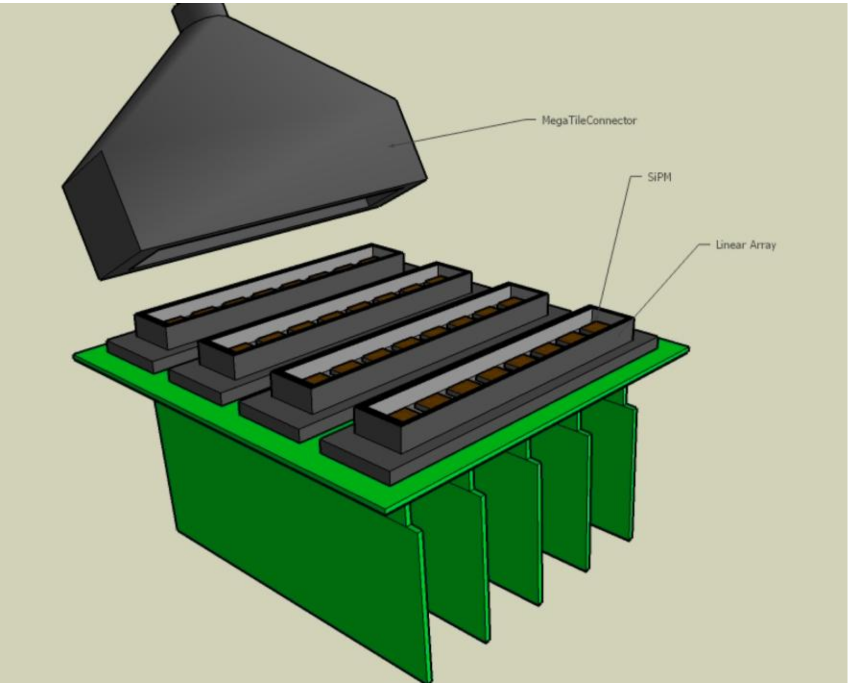


SiPMs in the Barrel HCAL

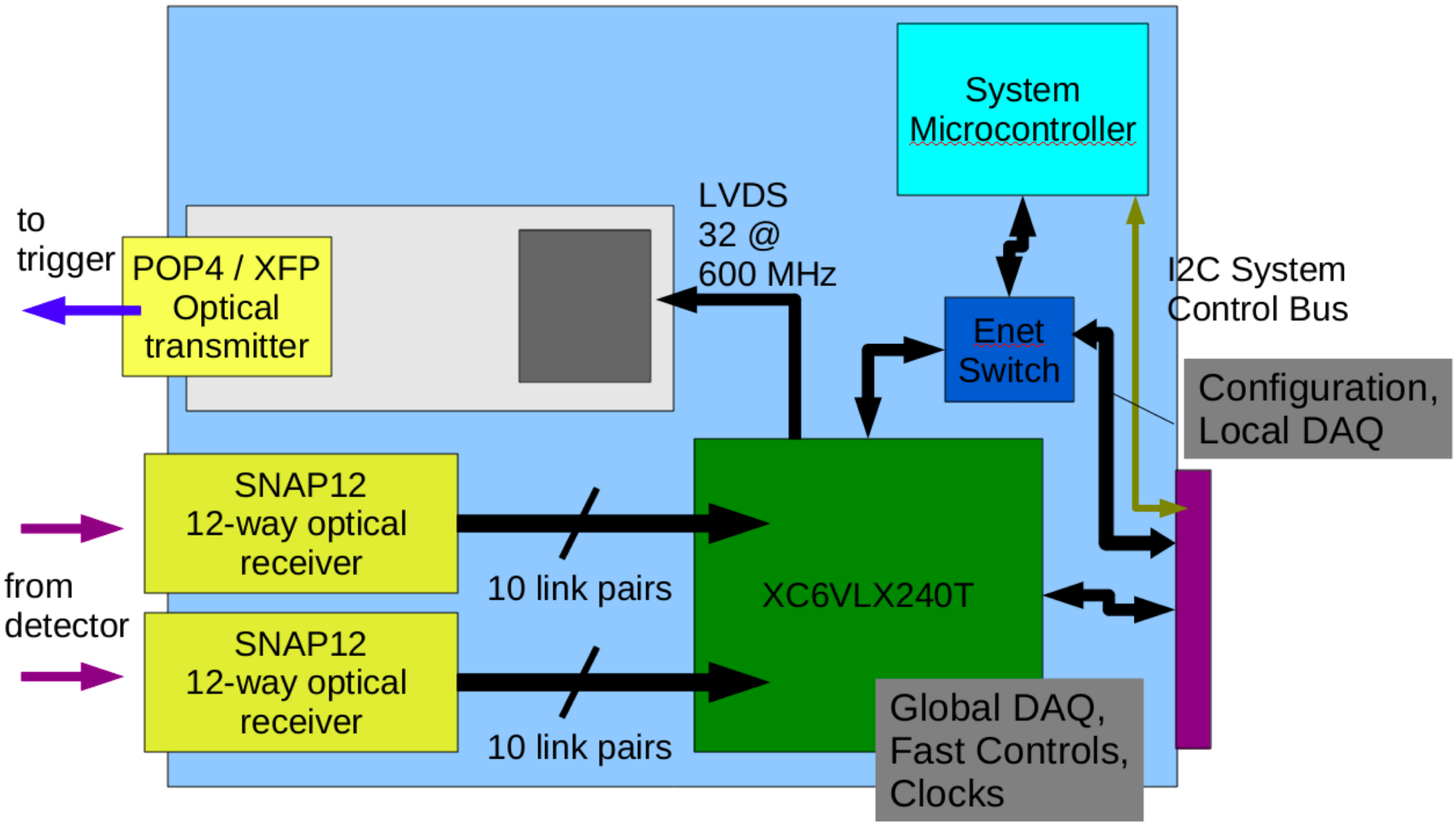
One SiPM per fibre

Plug compatible with current optics

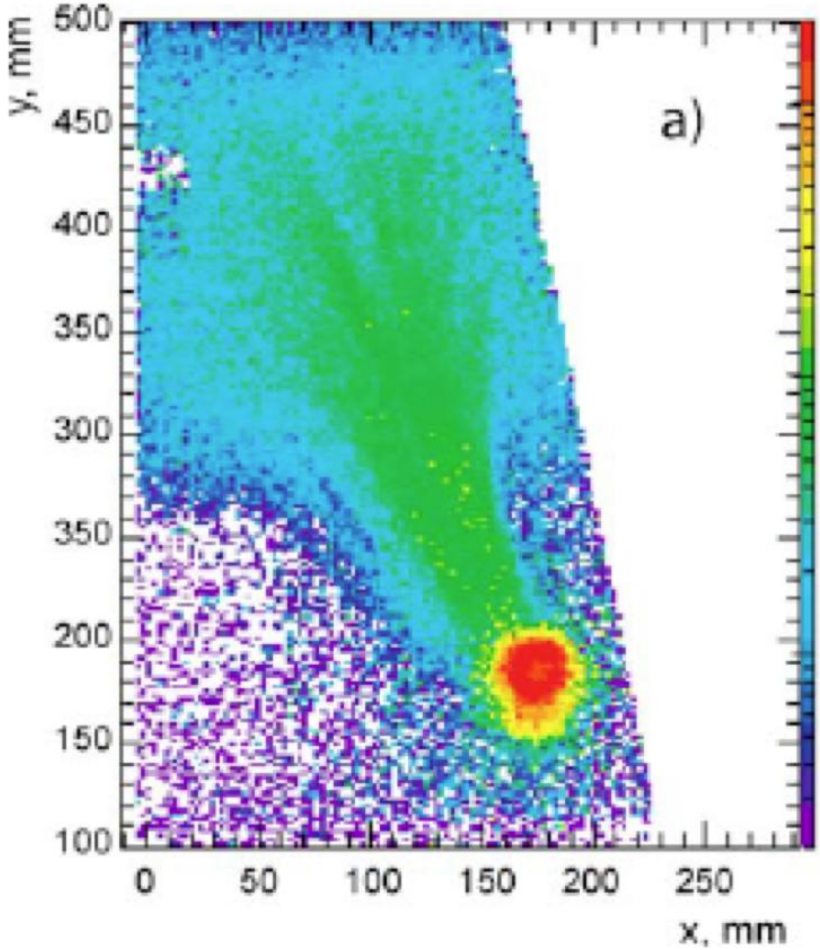




New HCAL Back end electronics under development



Upgrades to the HF phototubes

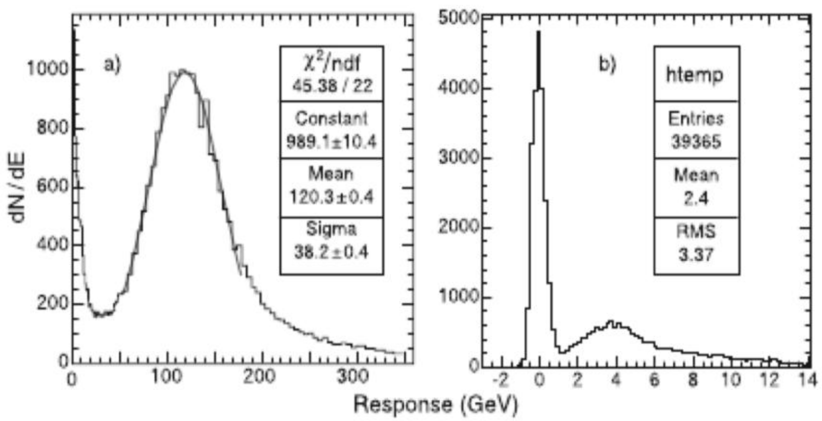


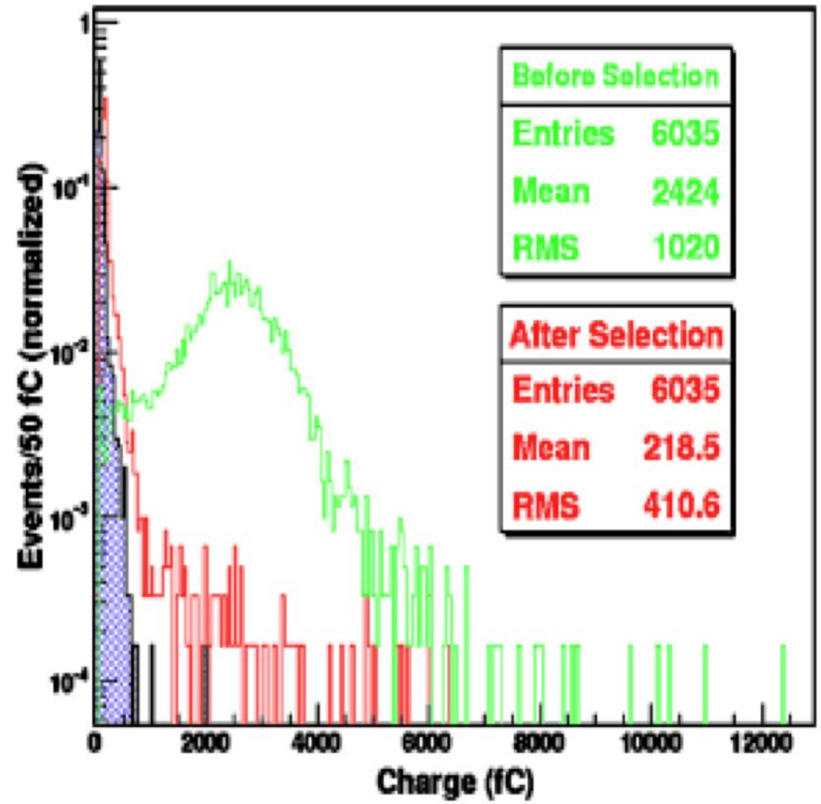
- Large signals are created in the phototubes by particles passing through either the phototube window (red) or fibre bundles (green)
- Replace phototubes with new PMT
  - Thinner front window reduce cerenkov light
  - Four way segmented anodes to reject PMT events by energy deposition pattern

New 4 anode phototube allows fake signal rejection

Large fake energy deposits

Single photo electron peak



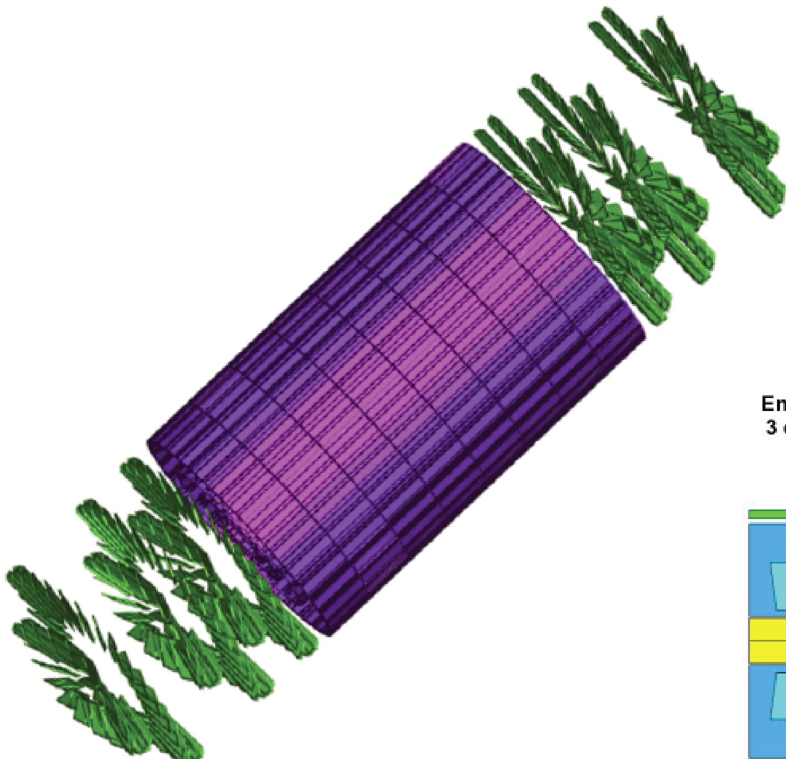


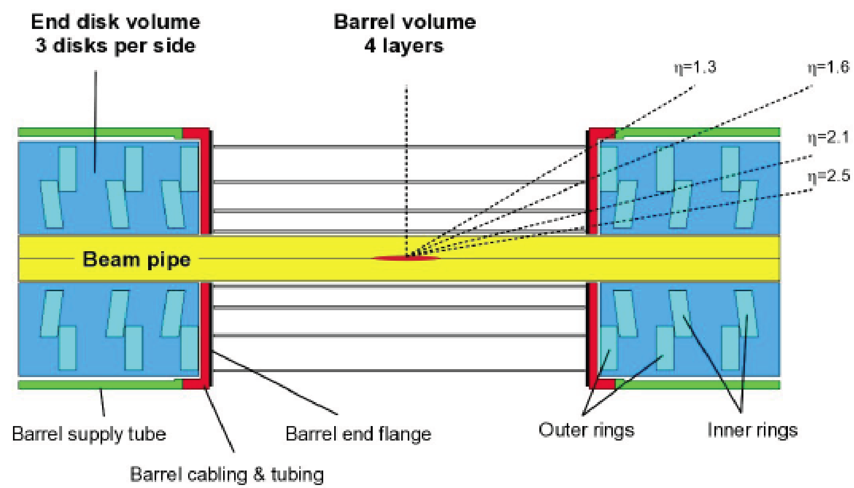
2^{nd} Shutdown: Pixels

- Well developed plan for a new 4 Barrel layer, 3 end disk low mass pixel detector
  - Fall forward scenario – gives a way to proceed at full speed with the current mature design while giving aggressive options
- Issues for Pixel replacement
  - Radiation hardness, reparability of the inner layer(s)
  - Buffer sizes (data loss at higher luminosities)
    - Including the case where we achieve luminosity using 50ns bunch spacing – giving higher number of interactions/bunch
  - B tagging capabilities

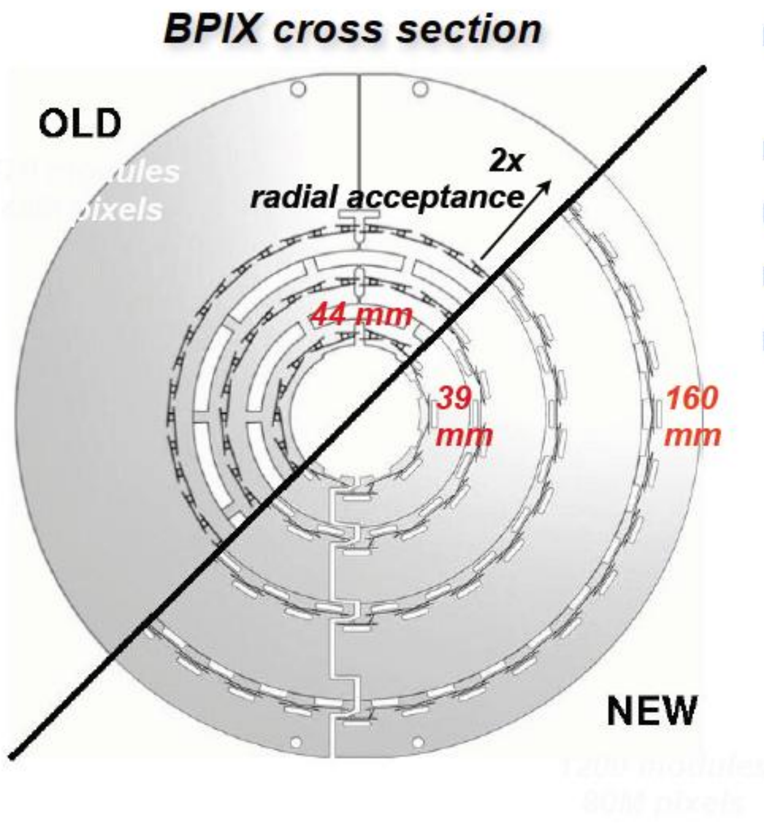
New Pixel detector overview

- **Main features of the new detector:**
  - 4 barrel layers and 3 endcap disks at each side
  - New readout chip with expanded buffers, embedded digitization and high speed data link
  - CO_2 two-phases cooling and displaced optical transceivers
  - Powering based on DC-DC converters



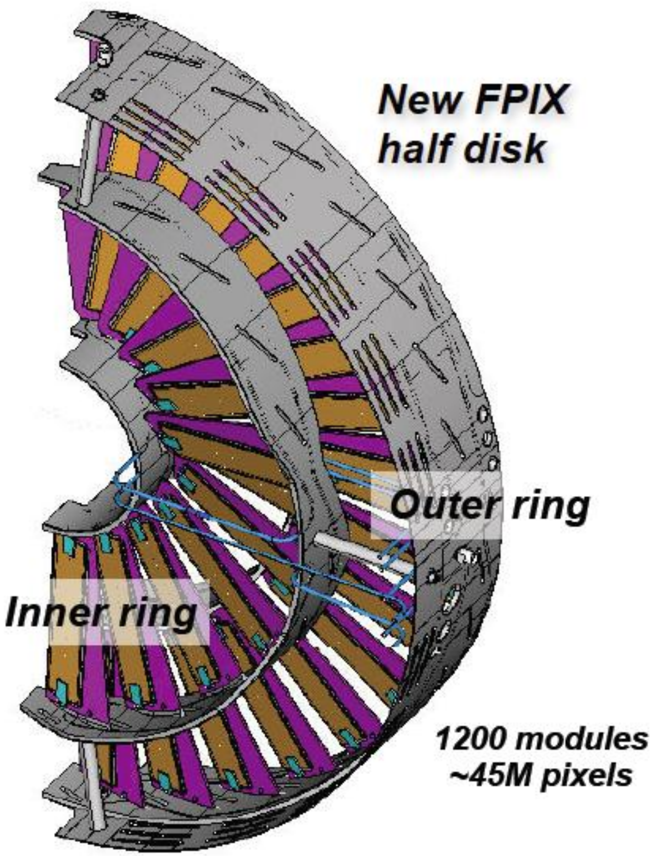


New Barrel Pixel design

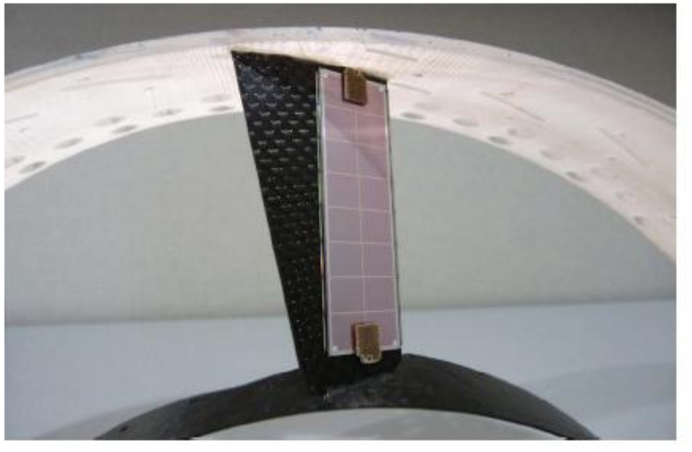


- Innermost layer with reduced radius (39mm)
- Additional outermost layer at 160mm
- ~2x radial acceptance
- ~65% more pixels
- Only one module type

Endcap Disk design

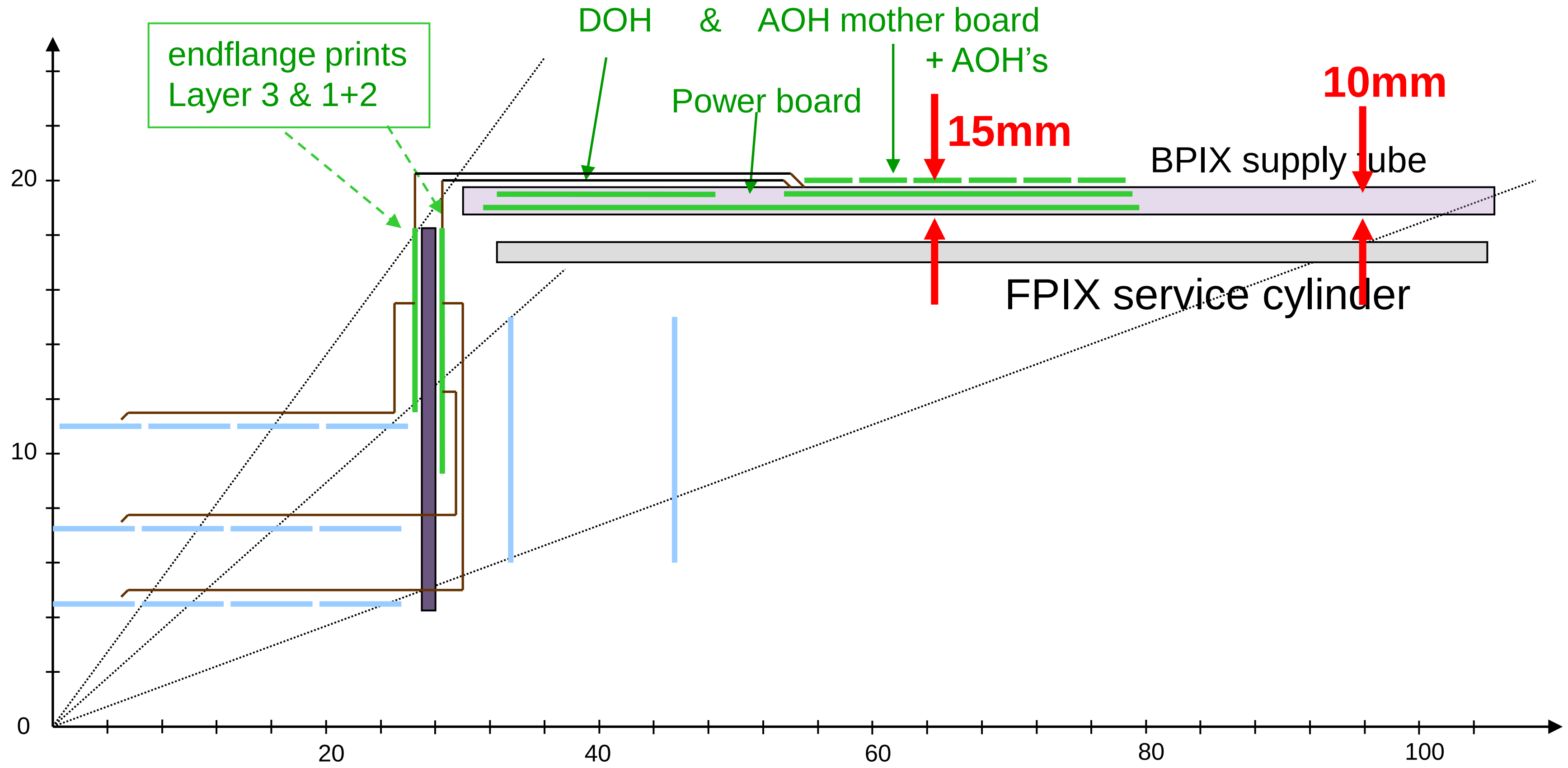


- FPIX half disks divided in inner and outer rings for easier replacement
- Smaller pitch oriented along phi
- 8x2 ROC modules as for the barrel
- 18M -> 45M pixel

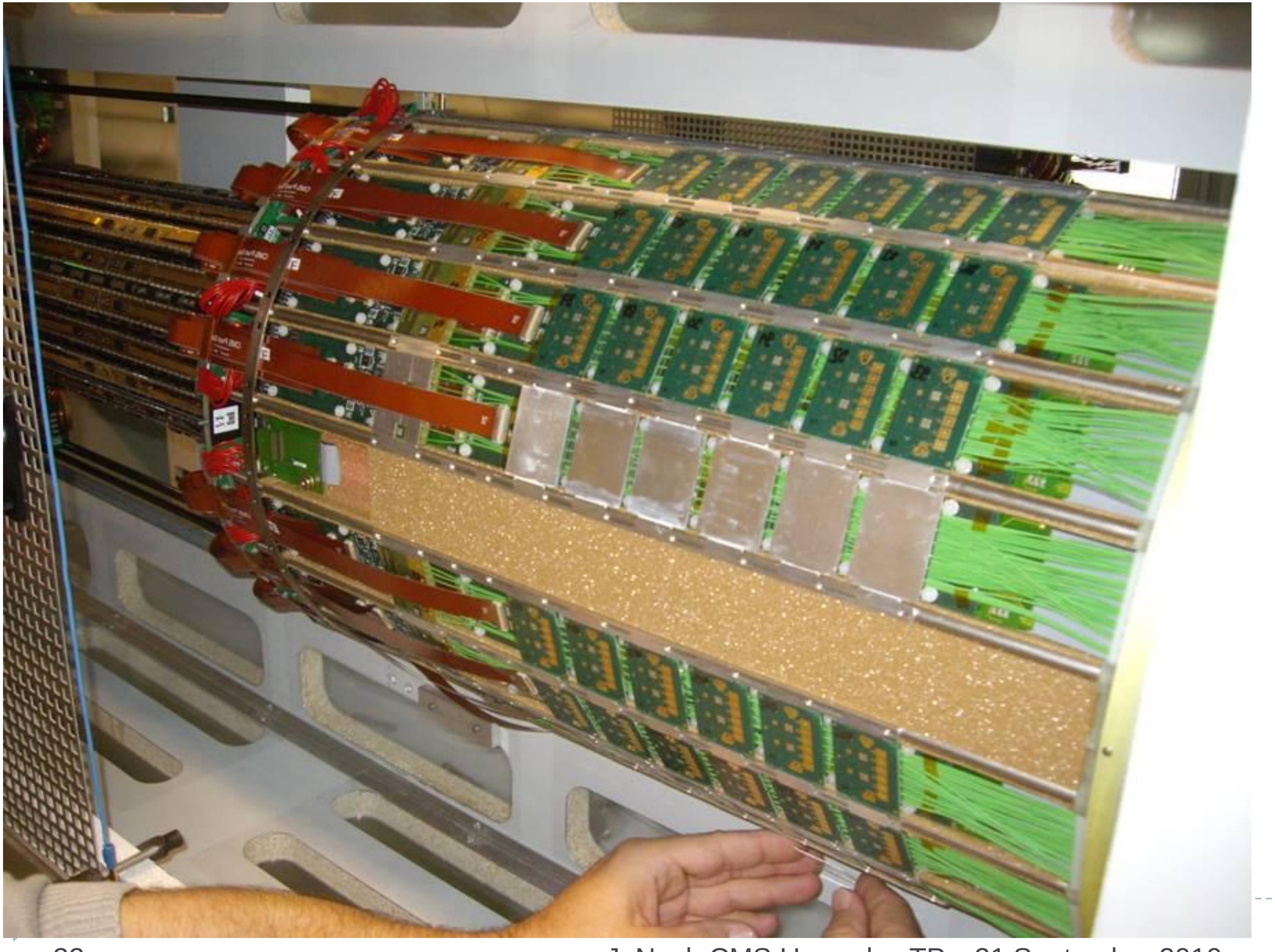


Current Pixel System with Supply Tubes / Cylinders

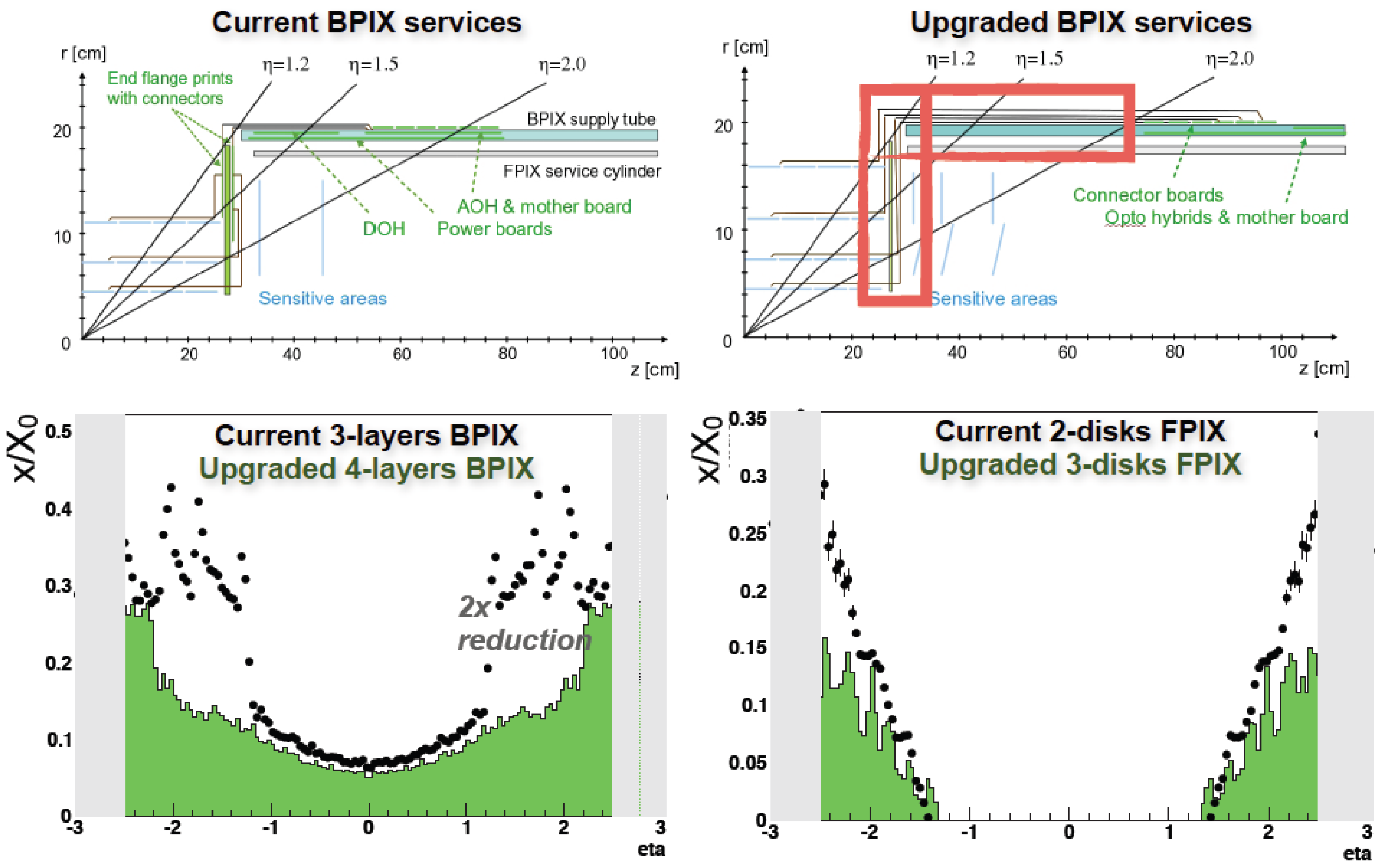
Thickness of Supply Tube
→ inserstion envelope for FPIX



BPIX & Supply Tube with AOH, DOH, PCBs & Fibres

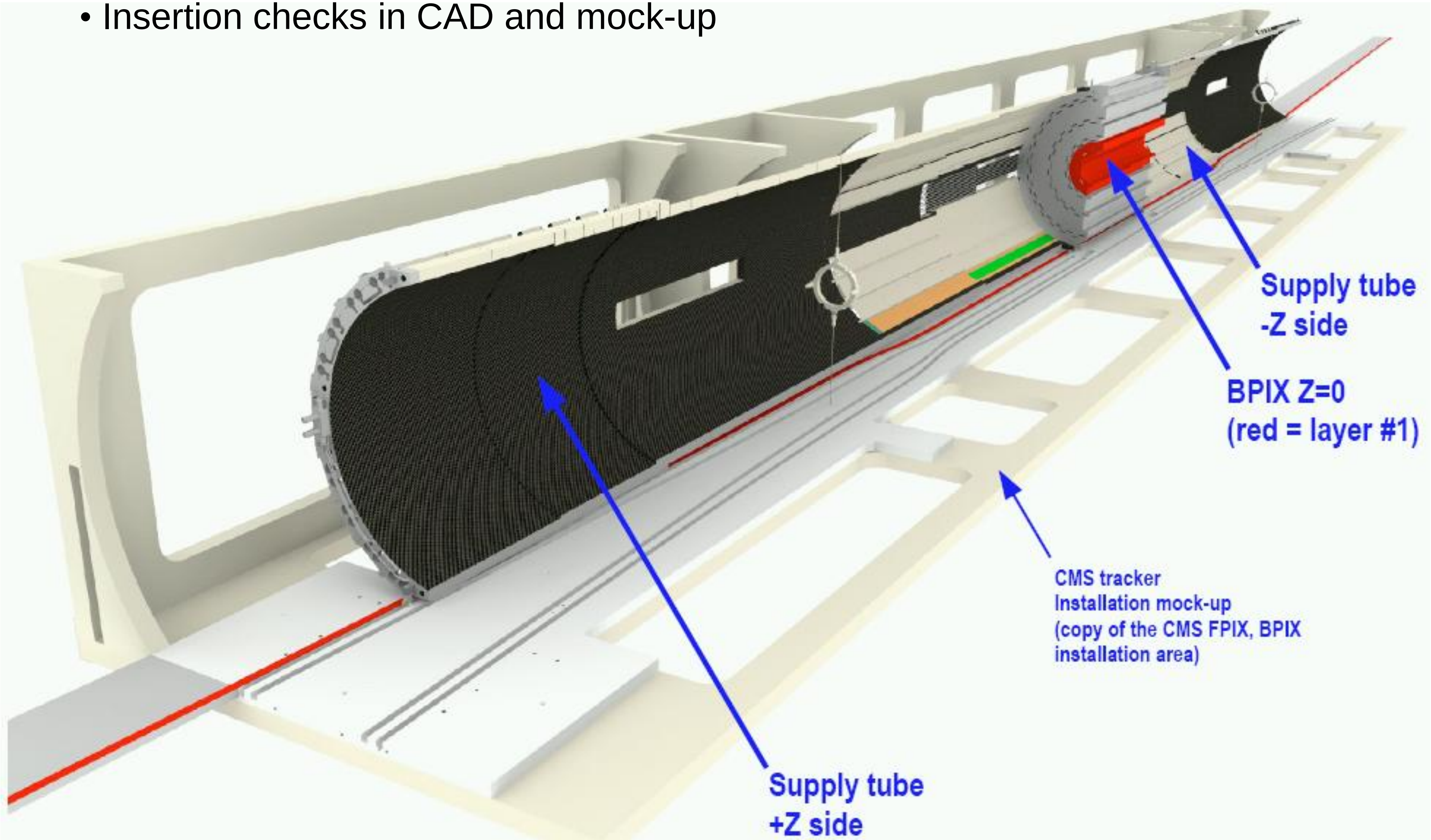


Pixel Material budget improvement



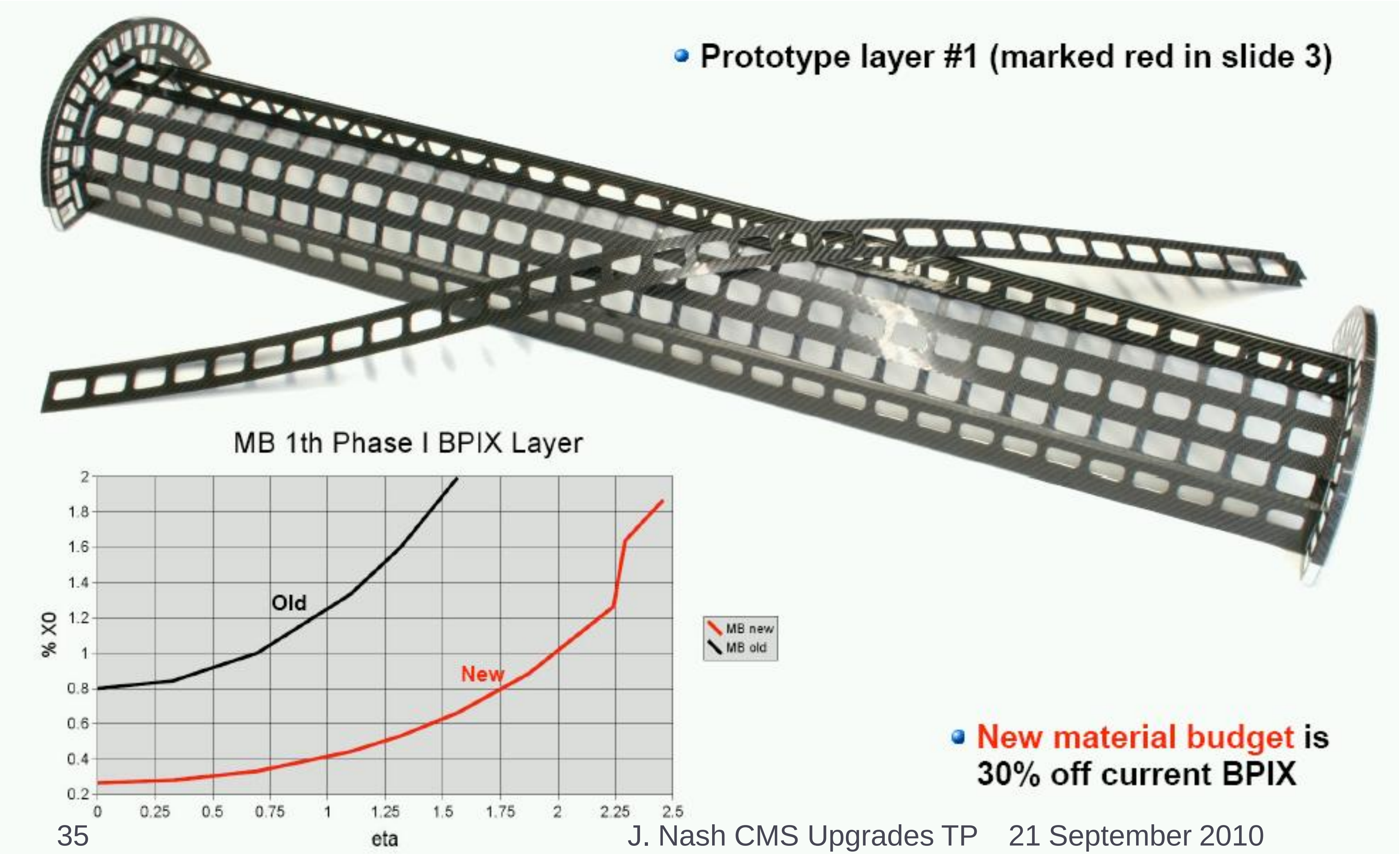
Overview of 2015 4 Layer BPIX System

- Insertion checks in CAD and mock-up

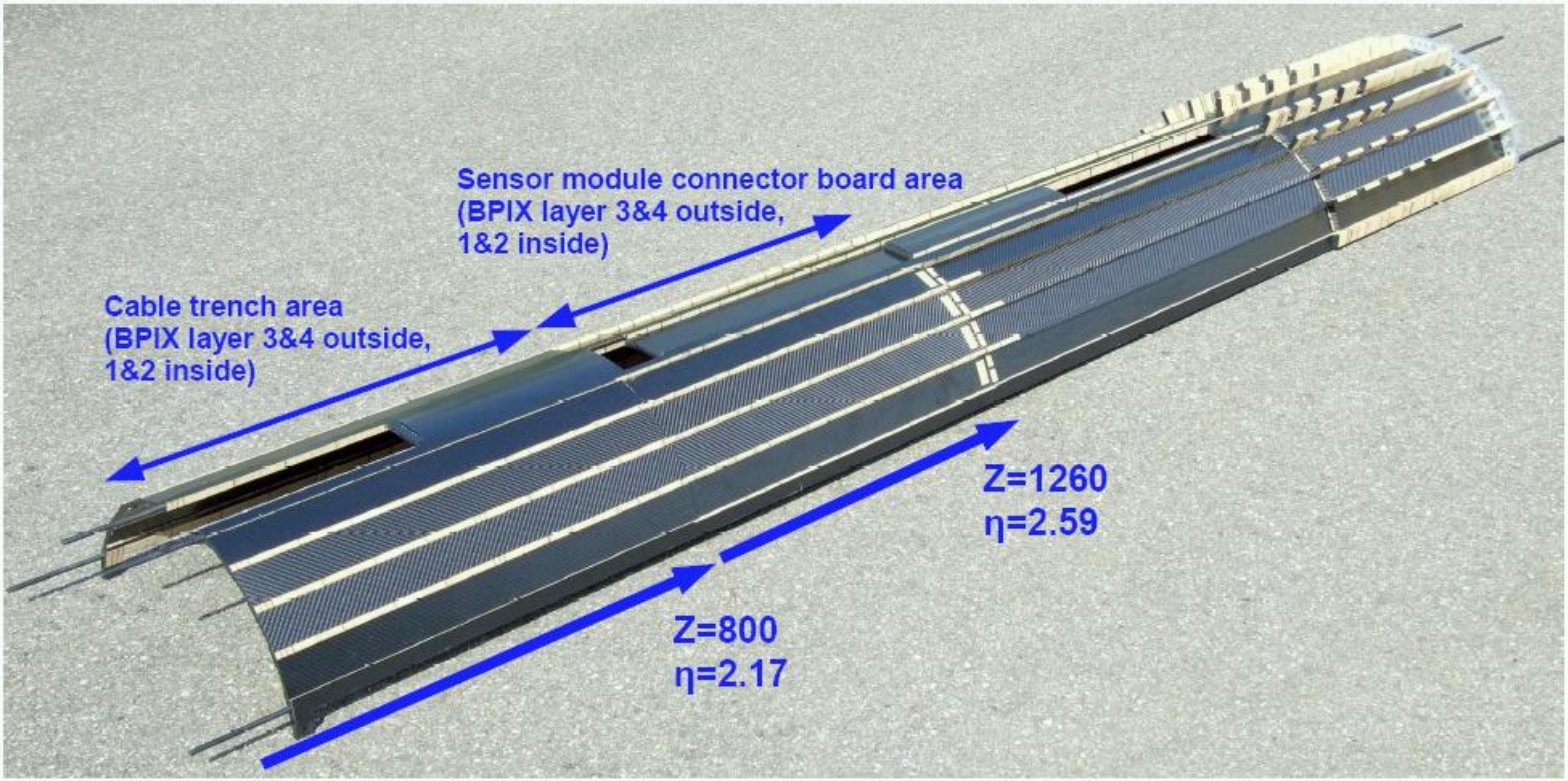


1 Layer of new Ultra Light Mechnaics

- CO_2 cooling circuit (50μm wall thickness tubes) pressure tested to 100 bar



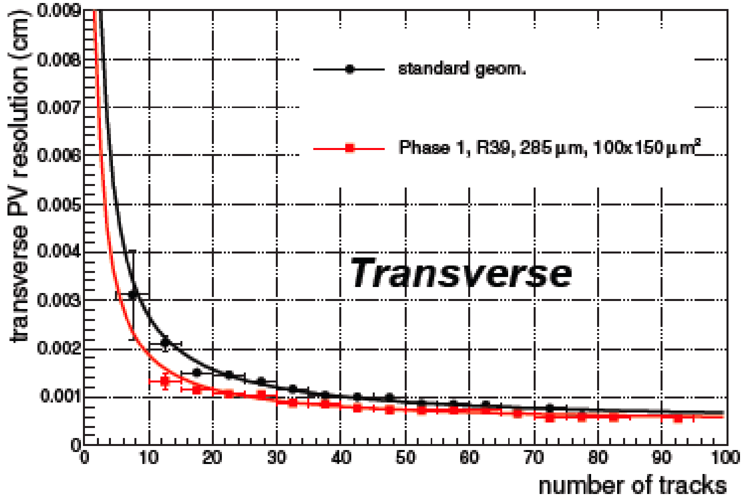
New BPIX Supply Tube

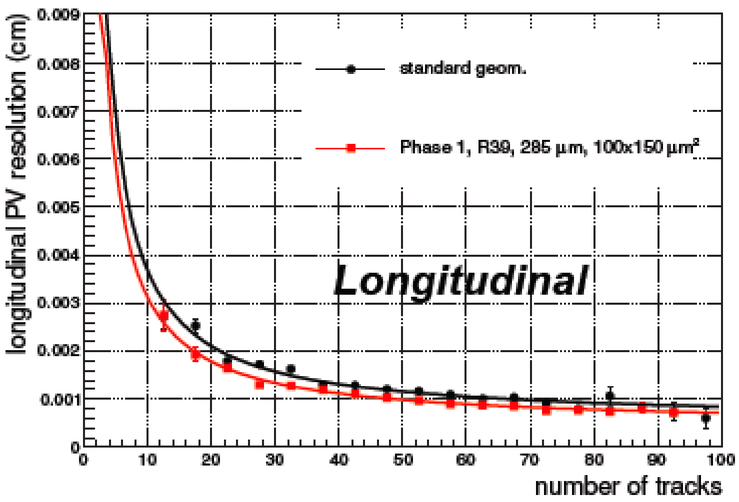


- Note: Some minor carbon fiber parts not yet glued.

- CO_2 cooling loops are to be inserted

Vertex resolution

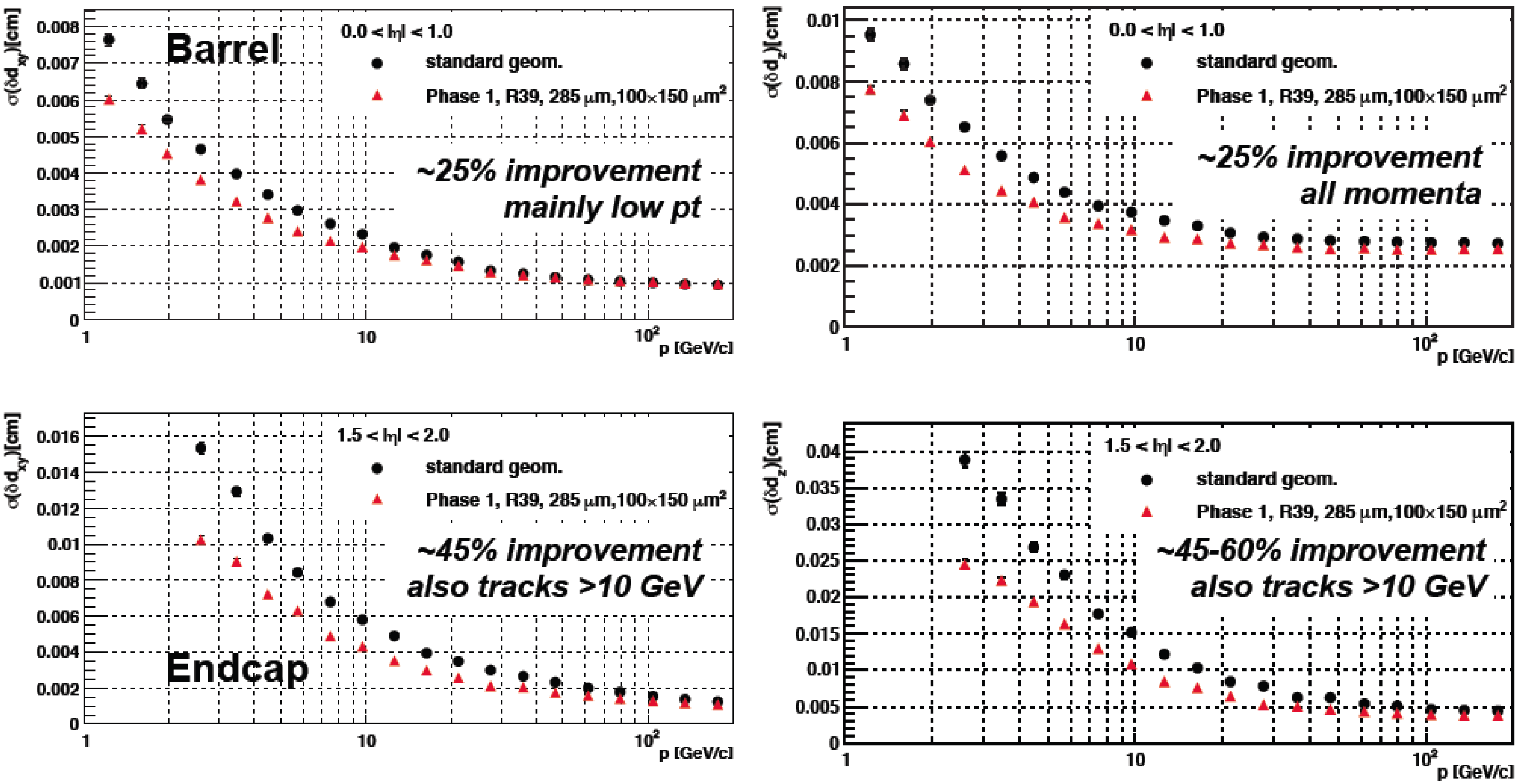




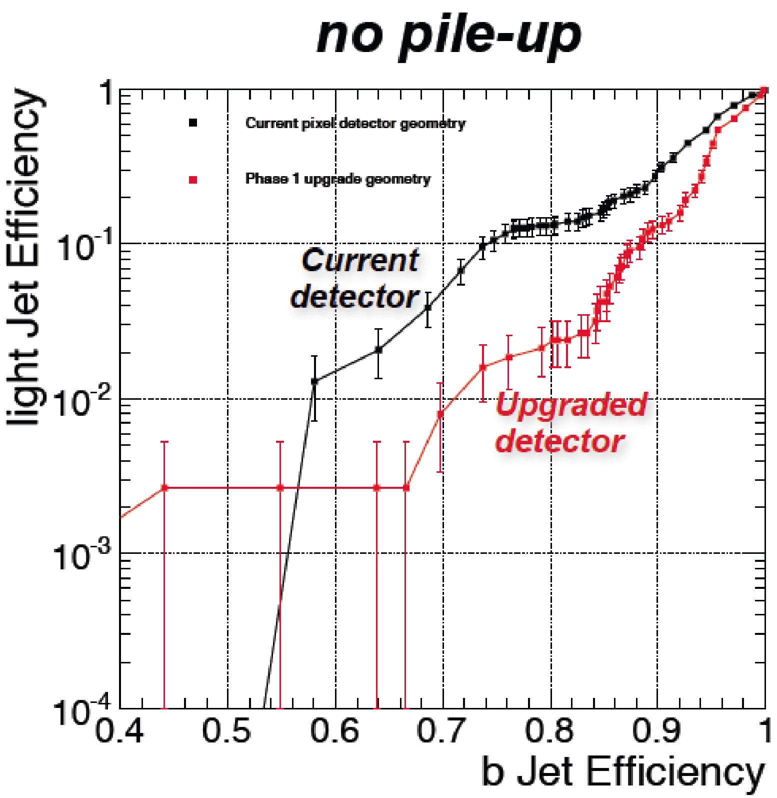
- Vertexing tested both with zero and 25 pileup events with ttbar signal
- 20% resolution improvement along both coordinates
- Will help resolving **multiple interactions** and improve **lifetime measurements** (e.g. b-fractions, etc.)

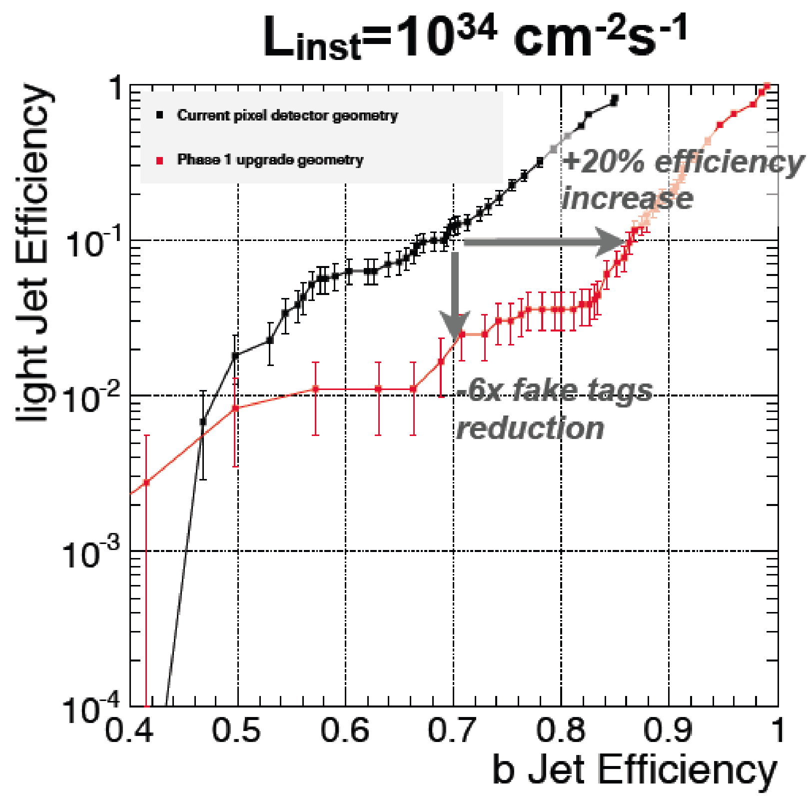
Improved impact parameter resolution

Transverse IP resolution | **Longitudinal IP resolution**



Improved B tagging

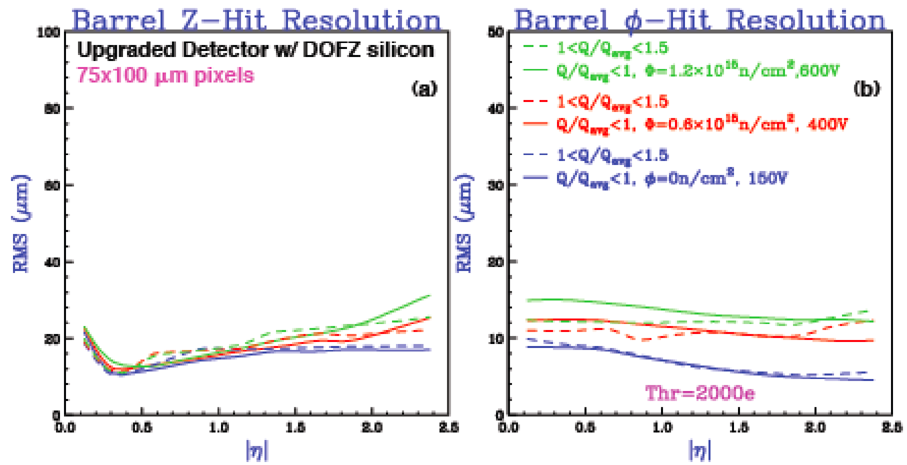




Improved efficiency and fake rate contributing exponentially with the number of b-tagged jets (e.g. Top, Susy, etc.)

QCD 80<p_t<120 GeV
Combined Secondary Vertex tagger

Fall-forward possible improvements



- Replacement of layer 1 opens door for attractive opportunities
  - New chip based on 130nm or smaller CMOS technology
  - Can implement smaller pixel cells
  - Aim at lower readout threshold

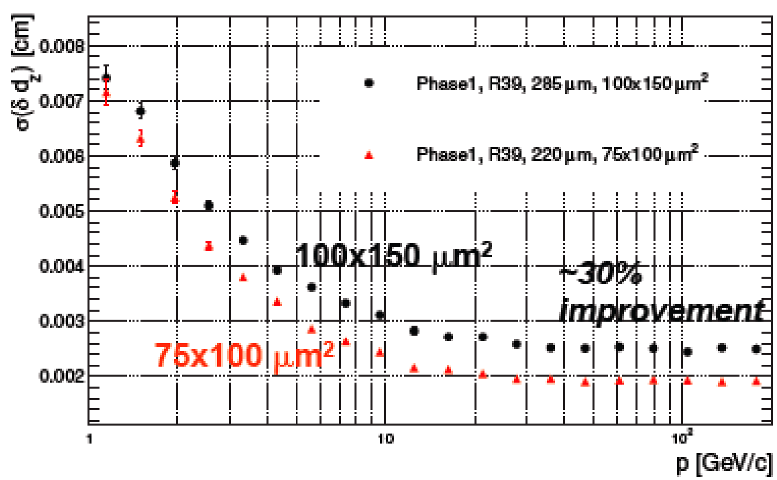
- Smaller pixels with lower readout thresholds can better preserve **position resolution** after irradiation

- Improve **impact parameter** resolution

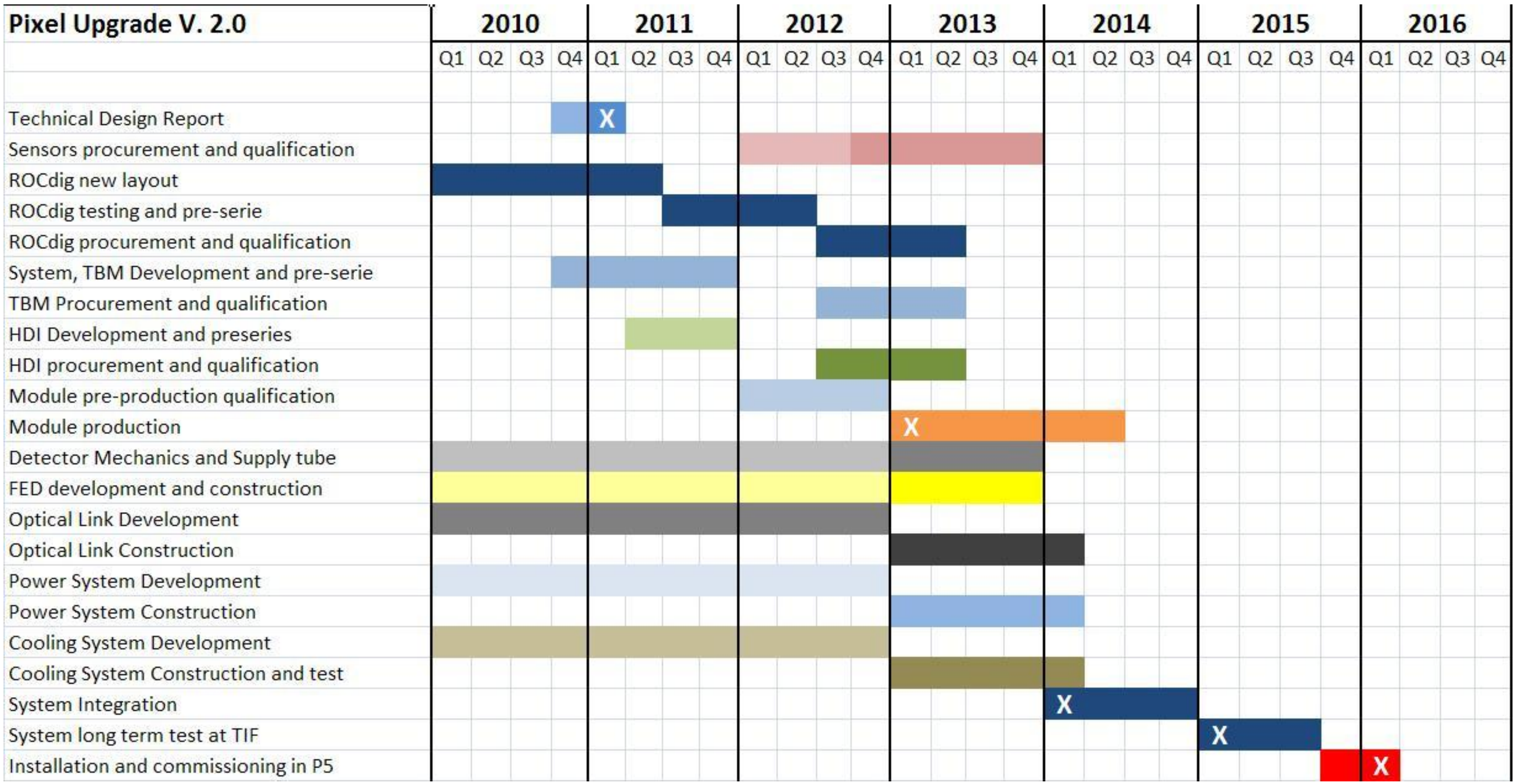
- Add resolving power for **high pt jets** and boosted objects (b, tau, top)

- Better **vertex resolution** in a high pile-up environment and improved **lifetime measurements**

Longitudinal IP resolution



Pixel detector schedule



2^{nd} shutdown: Trigger

- Issues for Trigger upgrade
  - New technology for trigger systems
    - More common components, easier to maintain
  - Finer granularity processing – better performance

  - Key Issue: How to smoothly integrate a new trigger into a running experiment
    - Parallel operation
    - Slice tests of new detector back/ends and trigger system

CMS Upgrades ideal scenario

- 2012 Shutdown
  - Begin Installing forward muon systems
  - HO SiPMs (Hadronic Calorimeter Tail Catcher)
  - HF PMTs (Forward Hadron Calorimeter eta 3-5)
  - Pixel Luminosity Telescope
- 2016 Shutdown
  - Install new beampipe
  - Install new pixel detector
  - Install HB/HE photo-detectors
  - Install new trigger system
- 2020 Shutdown
  - Install new tracking system
  - Major consolidation/replacement of electronics systems
    - Including potentially ECAL electronics
  - ECAL Endcaps (subject of a task force)
  - DAQ system upgrade

Technical Coordination: Shutdown planning 2011-13: 1^{st} draft

Time	Est. Int. Lumi/fb-I	Tasks	Logistic Scenario
2011-2013	30-50	Infrastructure modifications (i-ix)	fully open both ends
		Test beampipe region RP shielding	
		HO & CASTOR phototransducer change	
		YE4-z shielding wall/YE4+z shielding wall	
		4'th muon endcap station –z (CSC + RPC)(+ possibly RPC for +z)	
		CASTOR, TOTEM, ZDC removed for pp	
		Pixel Luminosity Telescope (PLT) installed.	
		BSC extension, FSC completion	
		ZDC crane installation	

Technical Coordination: Shutdown planning 2014-16: 1st draft

Timeframe	Est. Integrated Luminosity/fb-1	Tasks	Logistic Scenario
2014-2016	30-50	central beamipe, ϕ —–> 50mm	fully open both ends
		Pix/BCM removed, bakeout required	
		HB/HE front end re-build +z and -z	
		HF phototube replacement +z and -z	
		1'st muon station readout granularity +z and –z	
		Muon barrel front-end revision	
		4 layer, low-mass pixel tracker	
		BSC replacement.	
		Trigger modifications for high lumi	

Technical Proposal

- We have nearly finished the Technical Proposal.
- Chapters have been through internal review of sub-detectors
- Document is going through final tidying and editing, and a pass through the entire collaboration
- Will aim to finish all content by time of the RRB, and finish all edits (and submit to LHCC) by the end of October
- Have given the LHCC the latest draft, but ask you to review only chapters 1,3,4,5,6 – you can glance at the rest to see the scope of work

Conclusions

- Firm planning for the upgrades in this decade
  - Technical Proposal describing the work is nearly finished, work on detailed planning for the upgrades well underway
  - TDRs for substantial work to follow
    - Expect TDR for the Pixel Upgrade to come early next year
- R/D for the upgrades in the next decade is going on in parallel
- There are some smaller projects for this decade which fill in some gaps and are not yet agreed by CMS, but we are evaluating them