CMS Upgrade Plans SLHC-PP Public Event 2011

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Outline

- The SLHC-PP Project and CMS
- Overview of upgrade plans
- Upgrades in the next decade
  - Phase I Technical Proposal
- Upgrades for Higher Luminosity Running

SLHC-PP and CMS

- The SLHC-PP Project gave extra resources to CMS to help us to put together a plan for the upgrades of the detector during the lifetime of the LHC – and put together a team in CMS to coordinate this activity
- Much of the planning concentrated on the coming decade
- The main deliverable has been a Technical Proposal for upgrades of CMS which was submitted to the LHCC for review in November
- We are grateful to the EU for their support in this activity!

Last year CERN announced the plan for shutdowns over the next 10 years

The 10 year technical Plan

For good reasons, this plan has changed yet again after Chamonix this year…

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

Progression in luminosity – what these models imply…

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

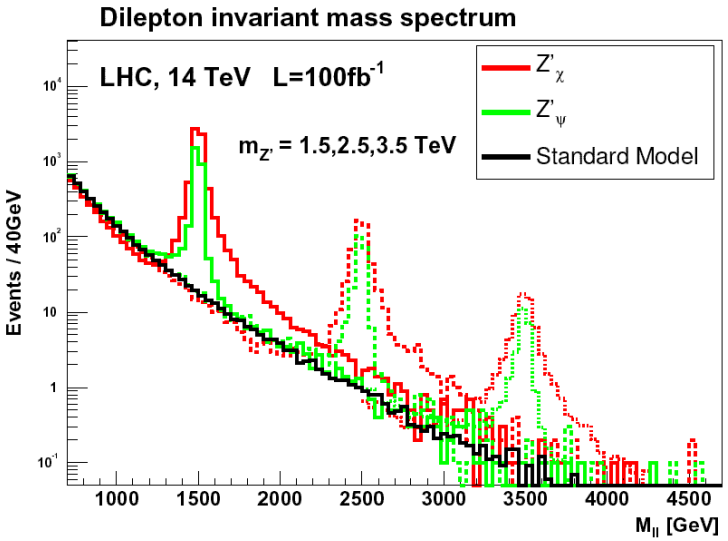
2020-2030 – High Lumi LHC

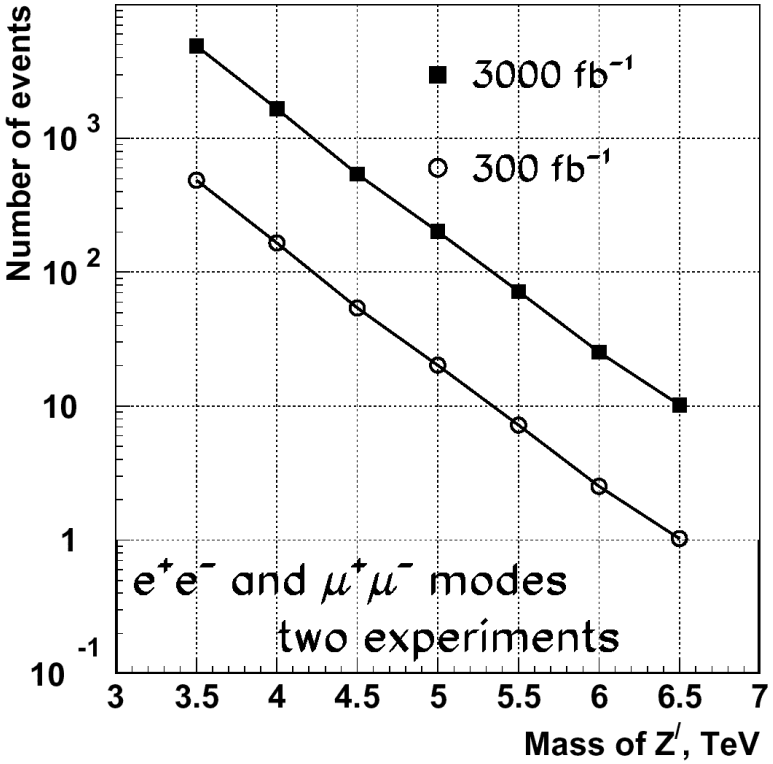
- Continued operation of the LHC beyond a few 100/fb will require substantial modification of detector elements
- The goal is to achieve 3000/fb in phase 2
- Need to be able to integrate ~250/fb-yr
- Will require new tracking detectors for CMS
- Still substantial R/D required for the detectors to be able to operate at these higher luminosities
  - A preview of this R&D is included as an appendix to the upgrade Technical Proposal

SLHC Physics: Extra gauge bosons

- SLHC extends reach for Z'
  - Cross sections fall with E
  - SLHC gives access to higher E
- Good electron resolution required (including understanding saturation)

Just give us the Integrated Luminosity!



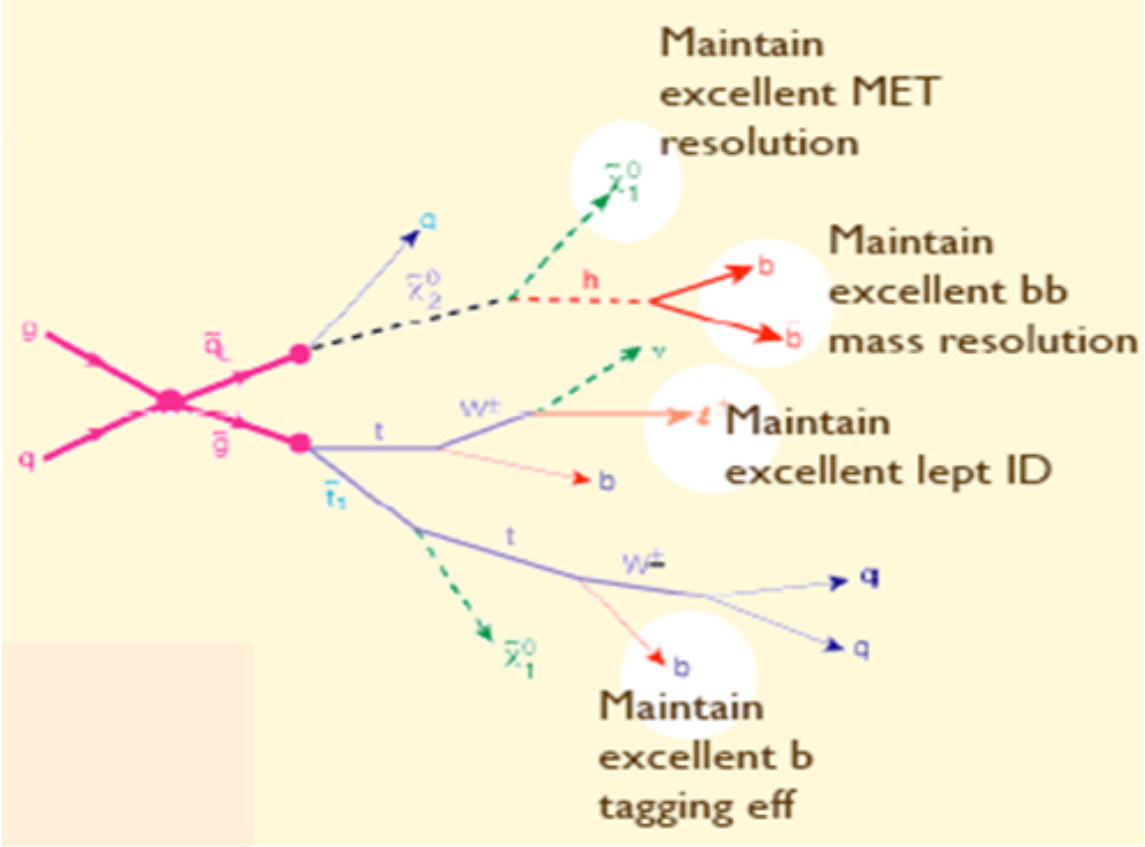


Z' mass (TeV)	1	2	3	4	5	6
$\sigma(Z' \to e^+e^-)(fb)$	512	23.9	2.5	0.38	0.08	0.026
$\Gamma_{Z'}$ (GeV)	30.6	62.4	94.2	126.1	158.0	190.0

SUSY searches - measurements

Here we need a lot of Integrated Luminosity, but needs to be high quality. Lower pile-up may be important.

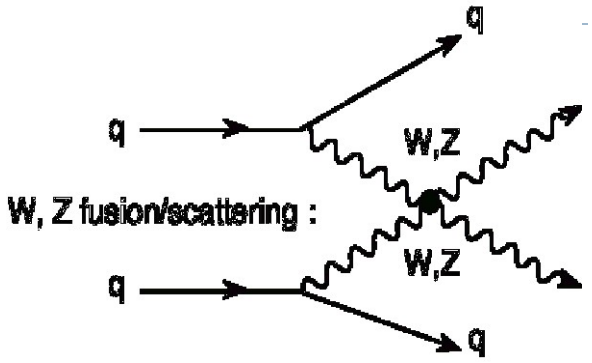
- SLHC statistics will be vital in reaching understanding of complicated SUSY channels
  - Sparticles seen, but statistics for reconstruction limited at LHC
- Performance of the detector here is vital
  - B-tagging
  - Lepton id



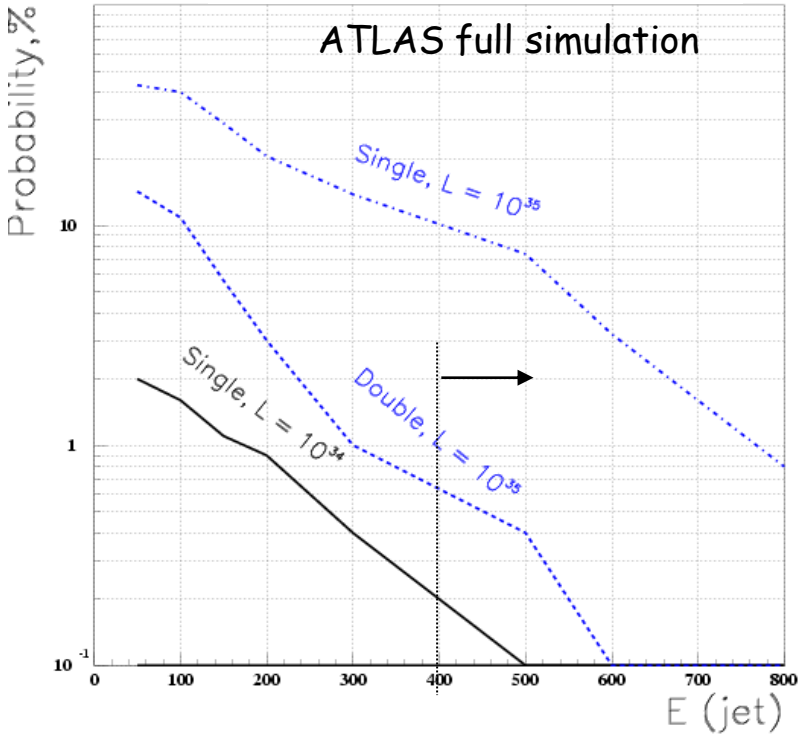
What if no Higgs is found?

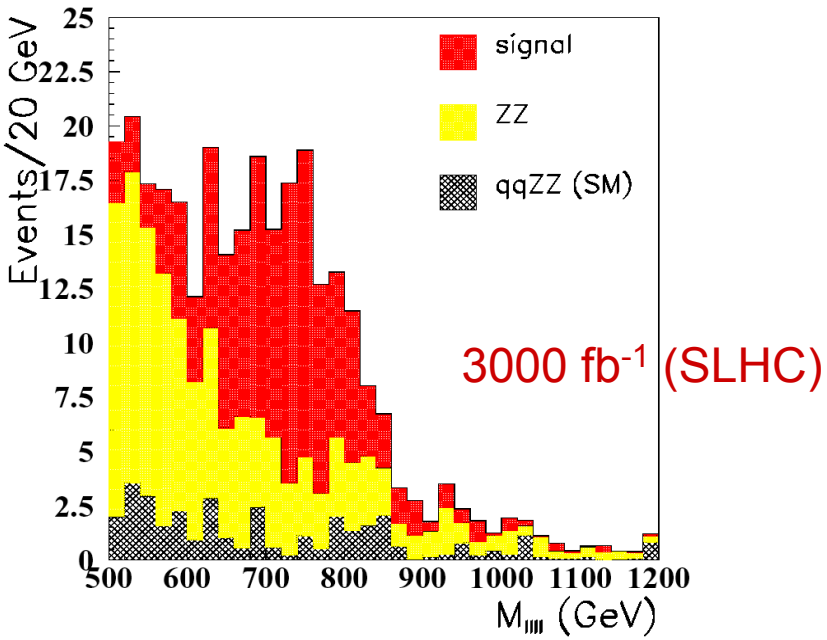
Forward tagging is essential

- Will need to look at WW scattering
  - Some mechanism required to avoid unitarity violation
- Forward Jet Tagging Essential

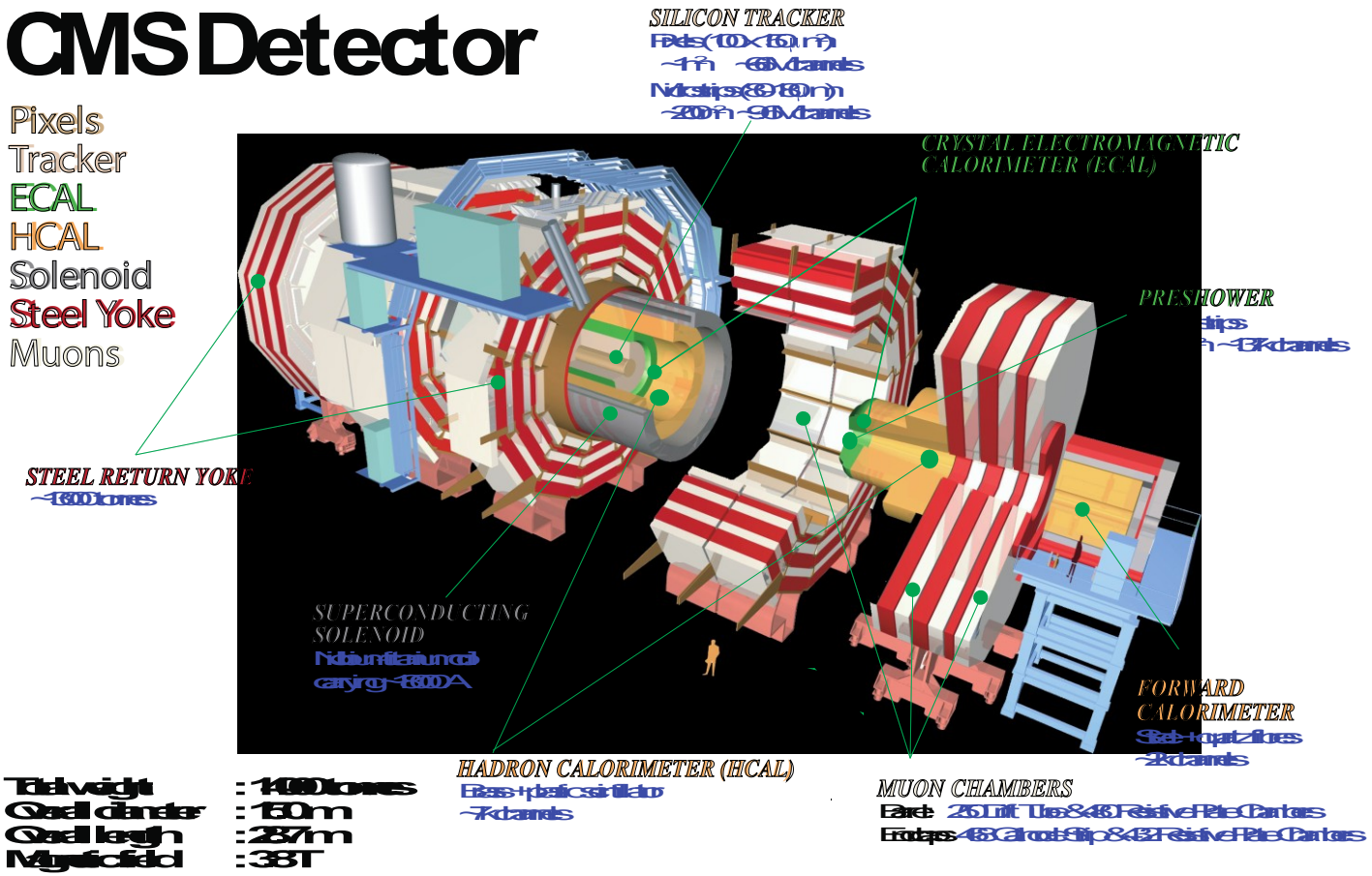


Fake fwd jet tag ($|\eta| > 2$) probability from pile-up (preliminary ...)

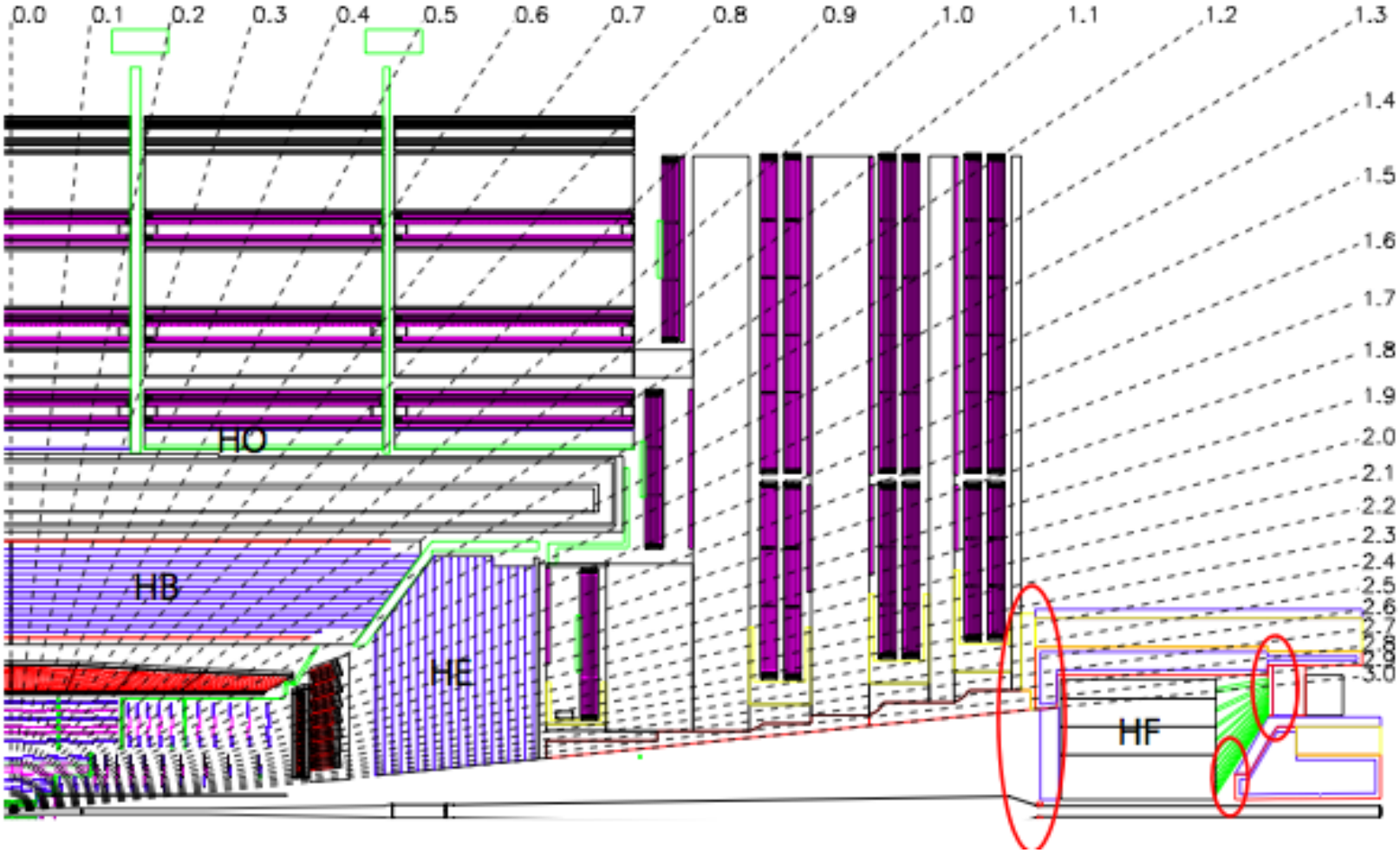




What needs to be upgraded?



Forward Regions and the inner detectors are vulnerable as luminosity increases



CMS Upgrade Scope

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

2017

2013

2017

These are questions for the Forward Calorimetry Task Force

2013/ 2017

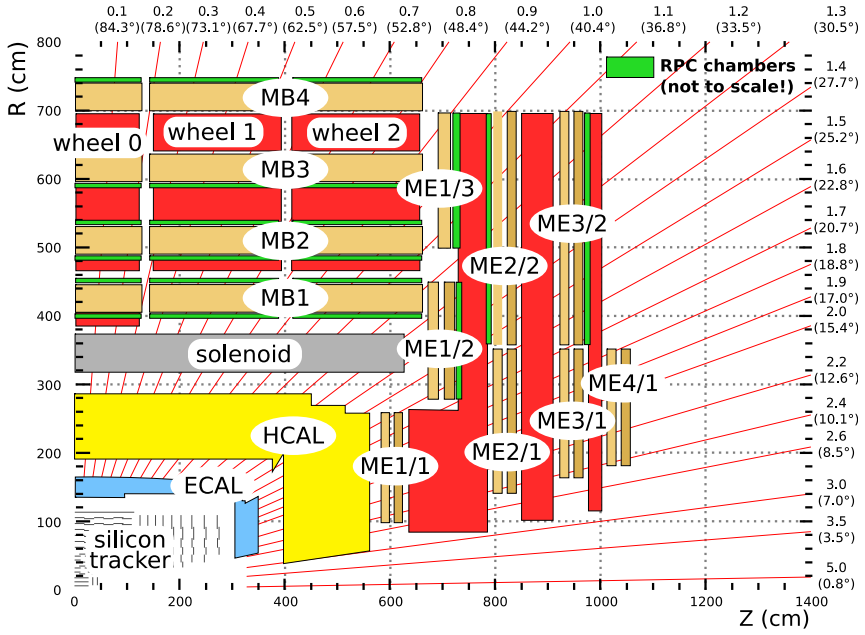
2017

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

- They should be able to operate with a peak luminosity of up to 2×10^{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

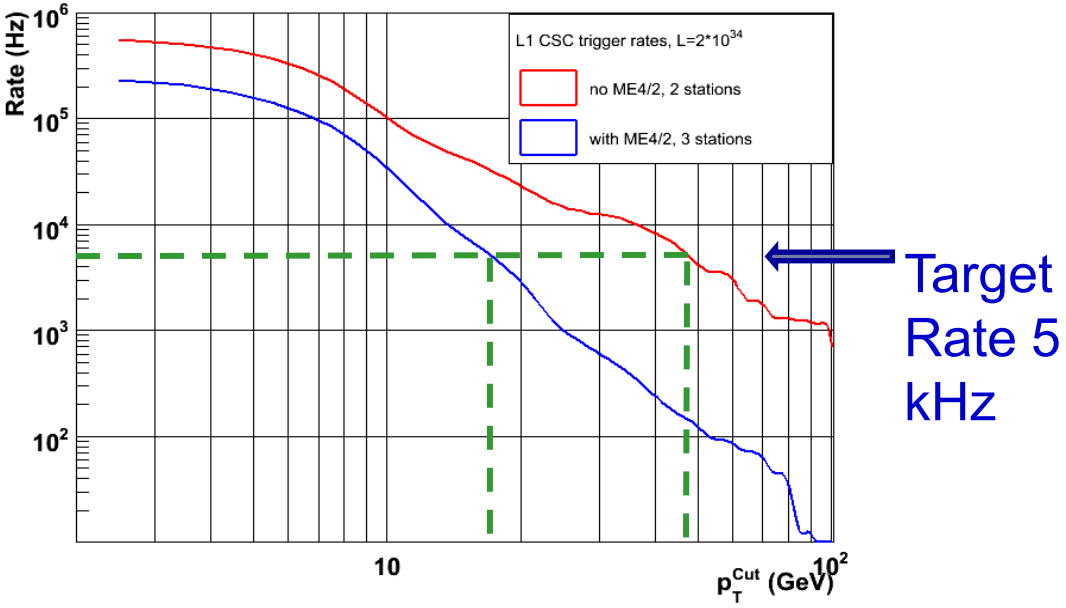
2012: Muons

- 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

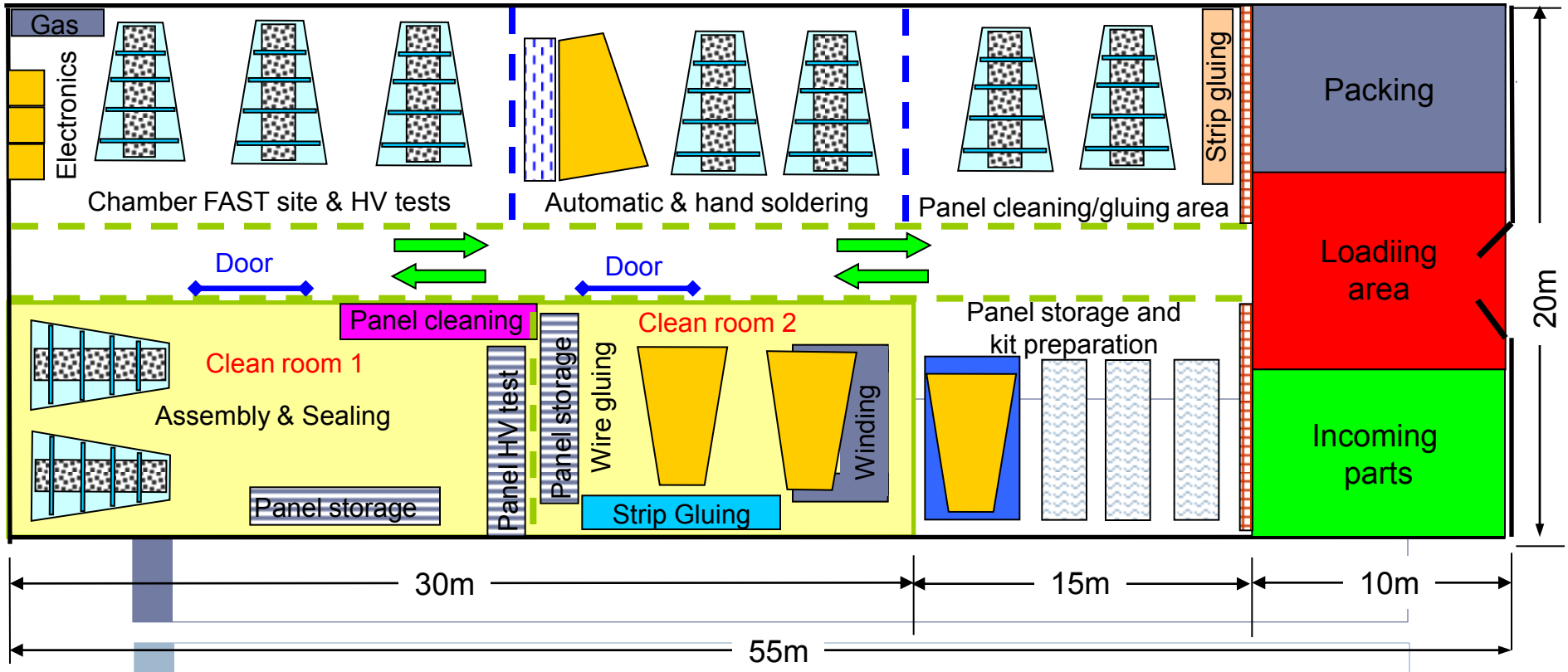
5 chambers already installed



- 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

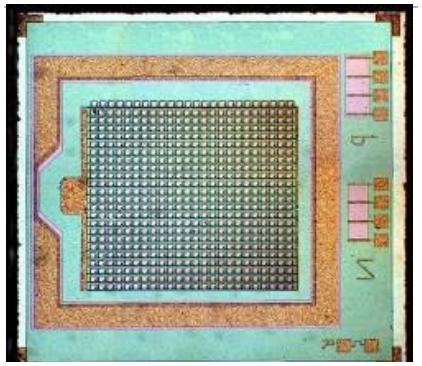
Floor plan layout at Bldg 904 (Draft)

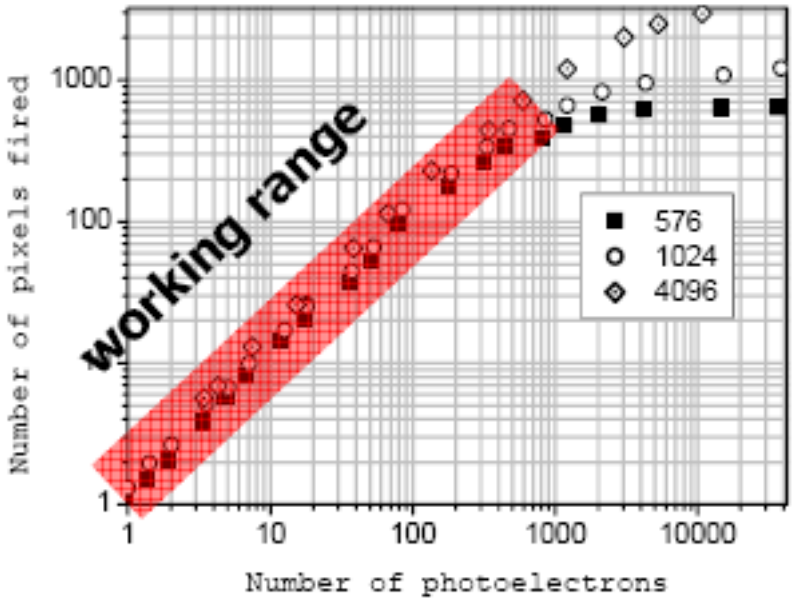


Based on experience of ME4/2 prototype production the proposed area at 904 of ~ 1000 m2 should be enough to place a factory production and FAST test site. For the completed chambers we need additional storage area of ~ 250m^2.

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

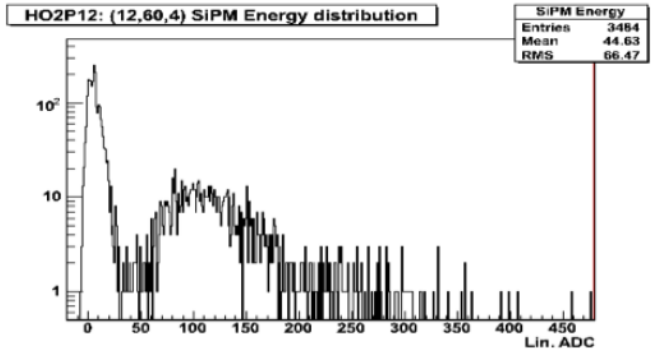


Figure 10a: Individual energy distribution, mwgr18, for a single HO channel, HO(ieta=12, iphi=60). Here energy E_{μ} is not corrected for muon angle of incidence.

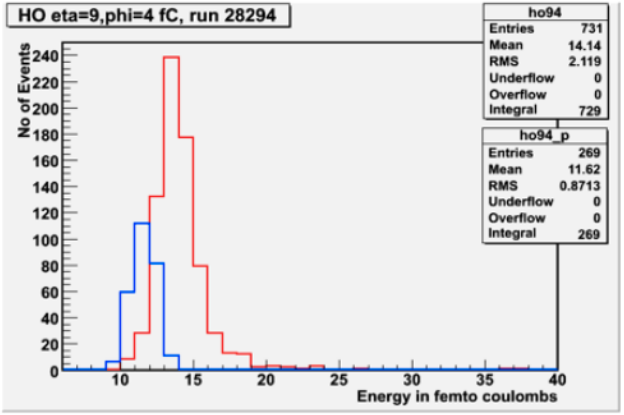
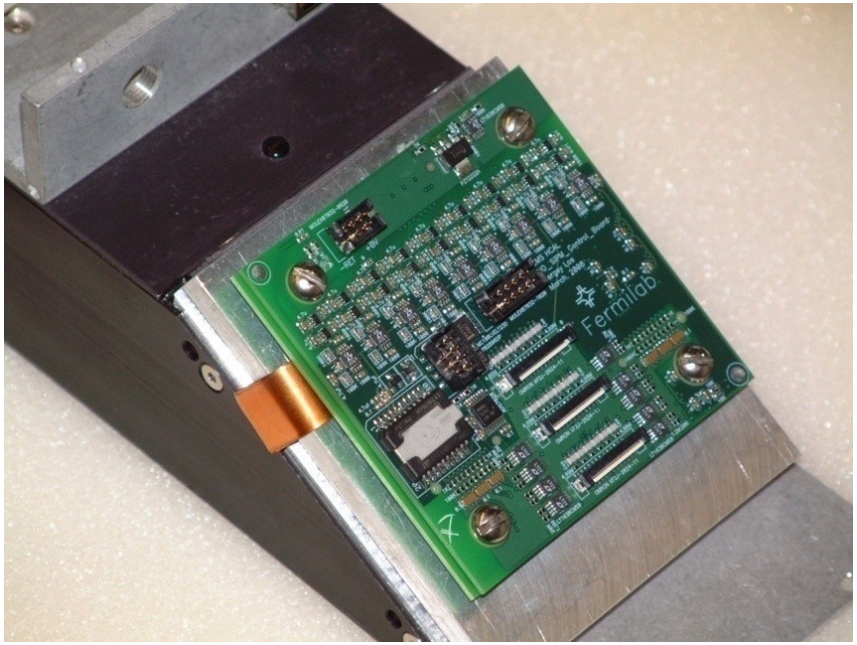
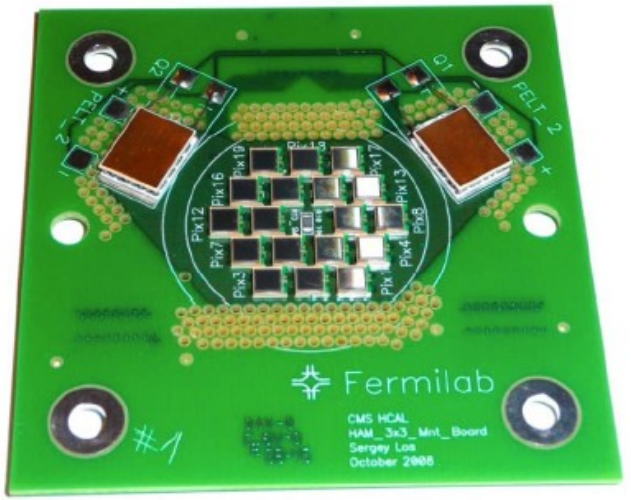


Figure 10b: For comparison, individual energy distribution, single HO channel read out with HPD, TB2007 data. Blue line: pedestal events, red line: muon signal.

- 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

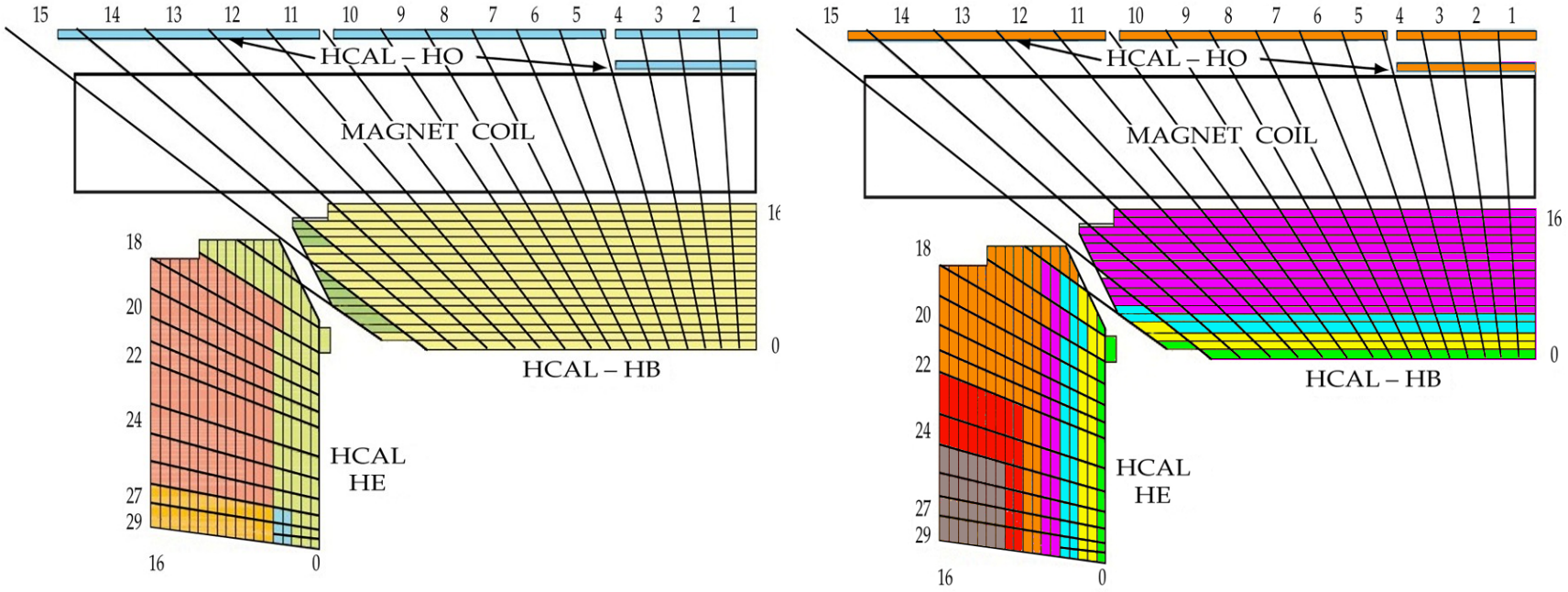
HO SiPMS





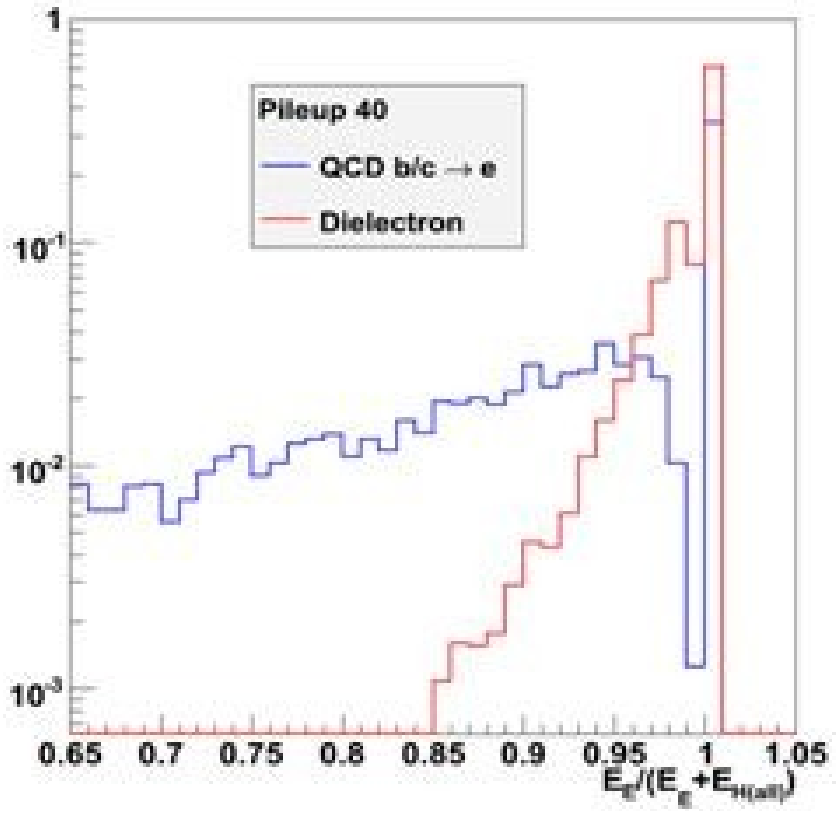
Plug in replacement for HPD

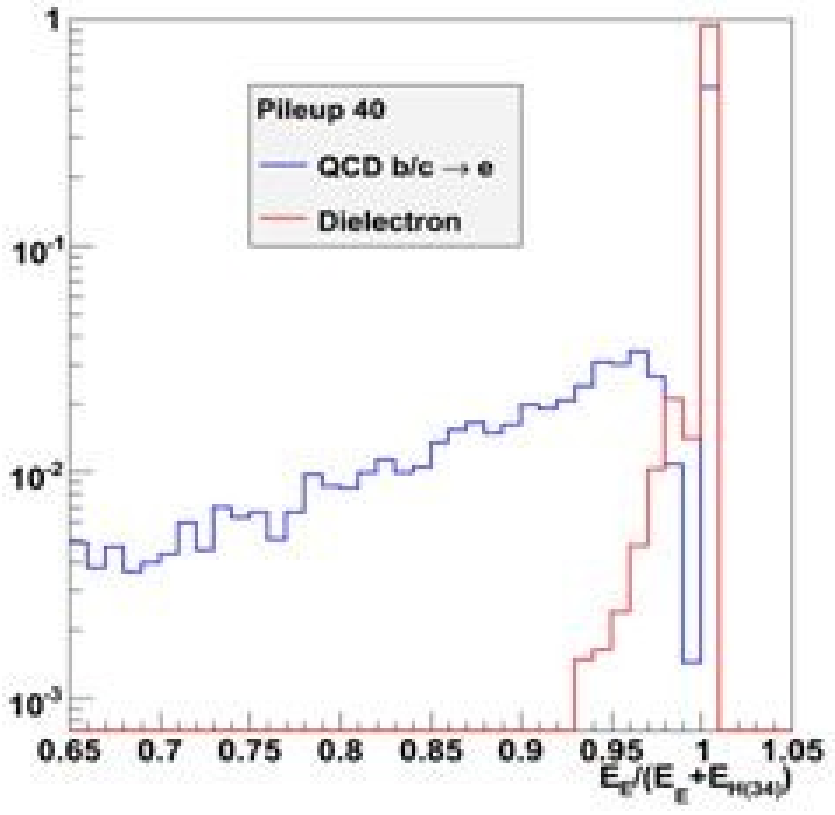
New Photodetectors allow finer segmentation of readout in depth



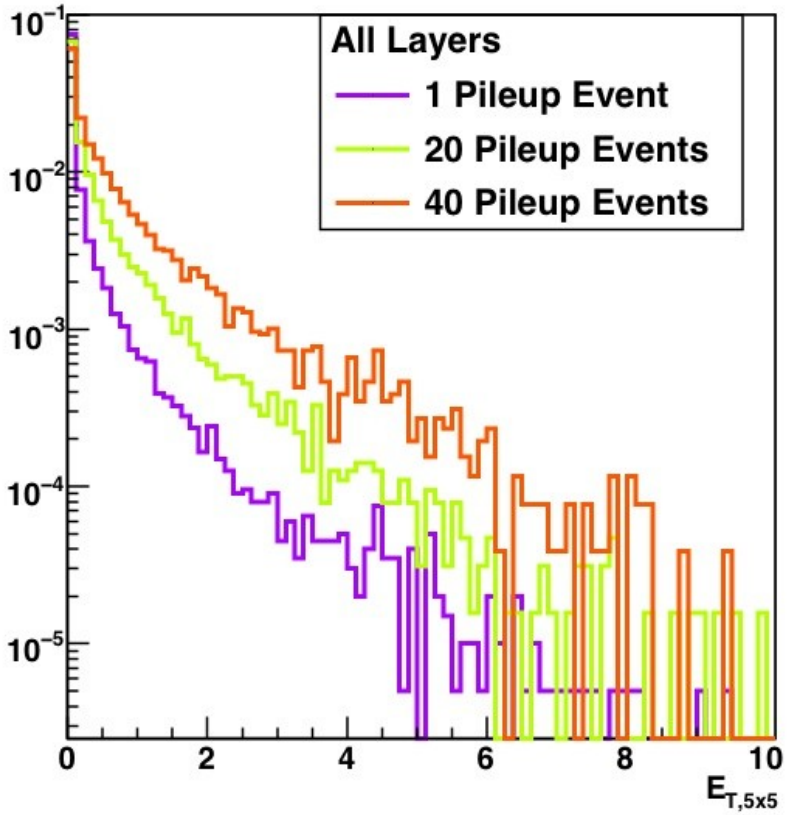
New segmentation – more robust against damage to inner scintillator layers

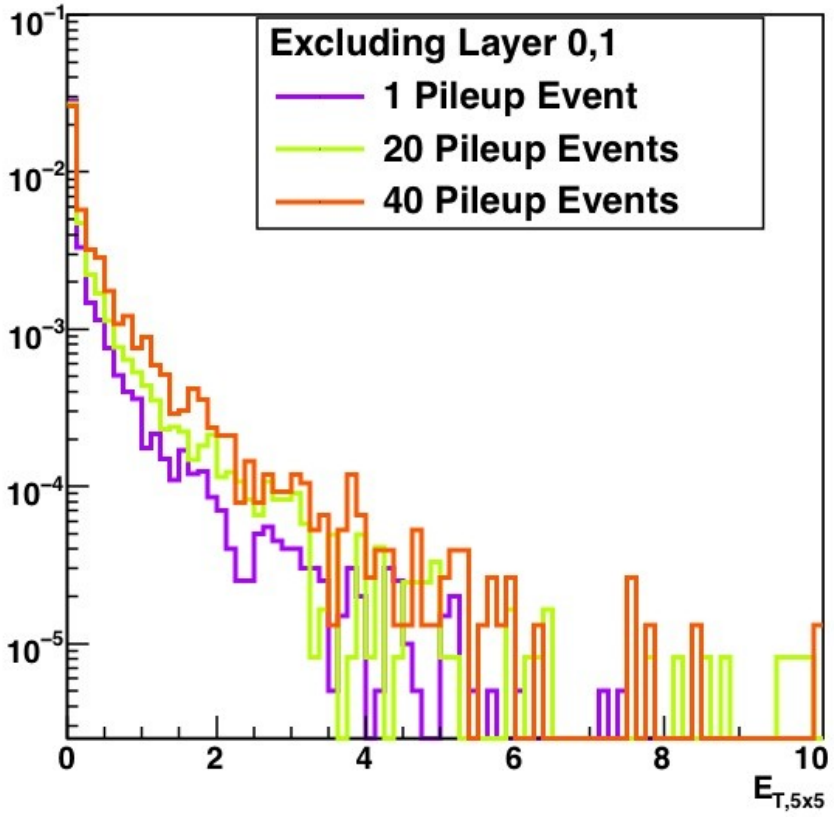
Segmentation – Electron isolation



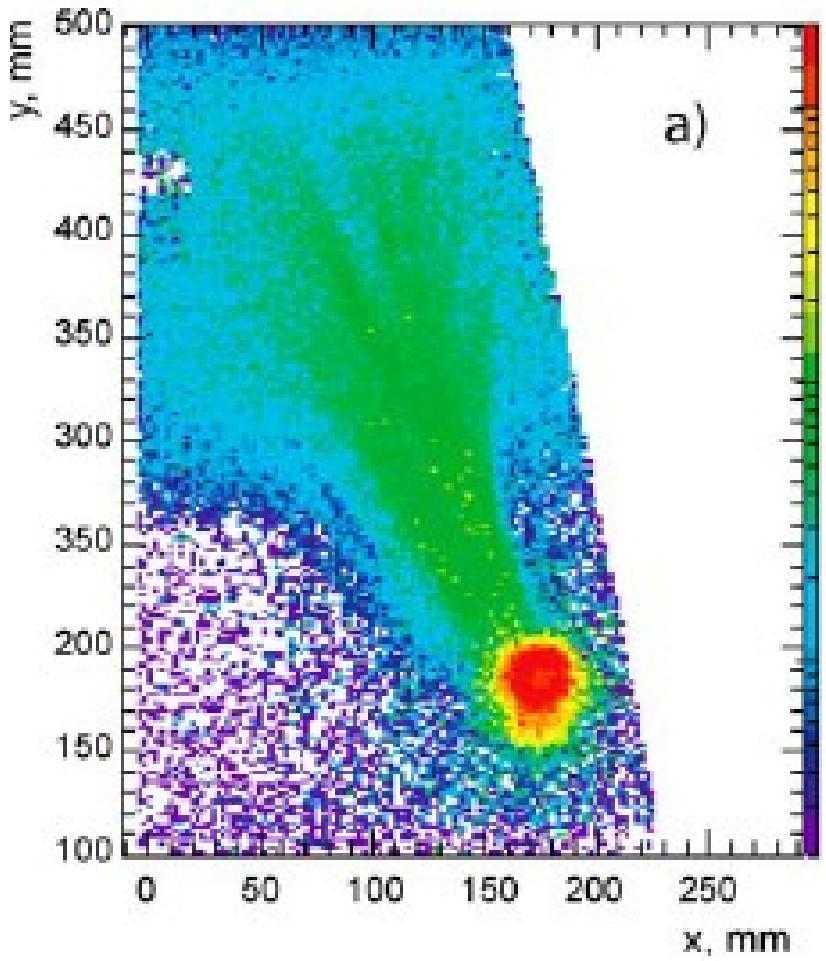


Segmentation





Upgrades to the HF phototubes

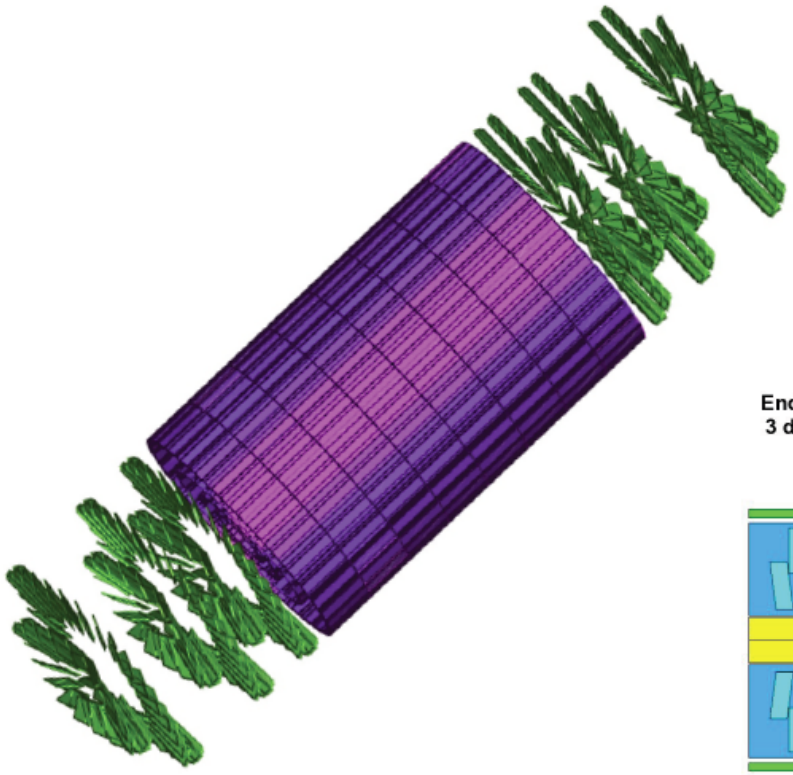


- Large signals are created in the phototubes by particles passing through either the phototube window (red) or fibre bundles (green)
- Replace phototubes with new PMT
  - Thinner front window reduce cerenkov light
  - Four way segmented anodes to reject PMT events by energy deposition pattern

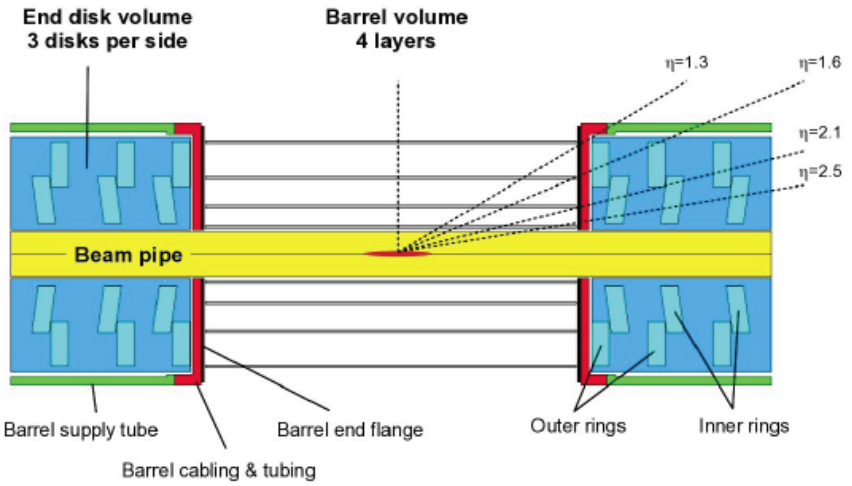
2nd Shutdown: A new Pixel detector

- Well developed plan for a new 4 Barrel layer, 3 end disk low mass pixel detector
- Main 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
    - Current detector first layer has very large dead time with ultimate luminosity (worse with 50ns bunches)
  - Extra seeding layer for tracking gives better tracking performance in higher luminosity environment
  - Improved B tagging capabilities – gives much improved physics performance

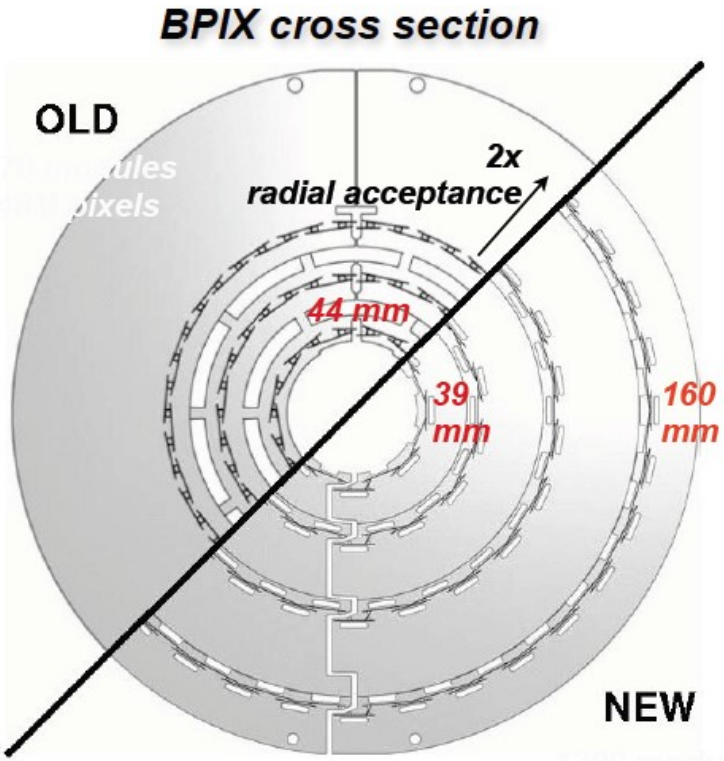
New Pixel detector overview



- **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

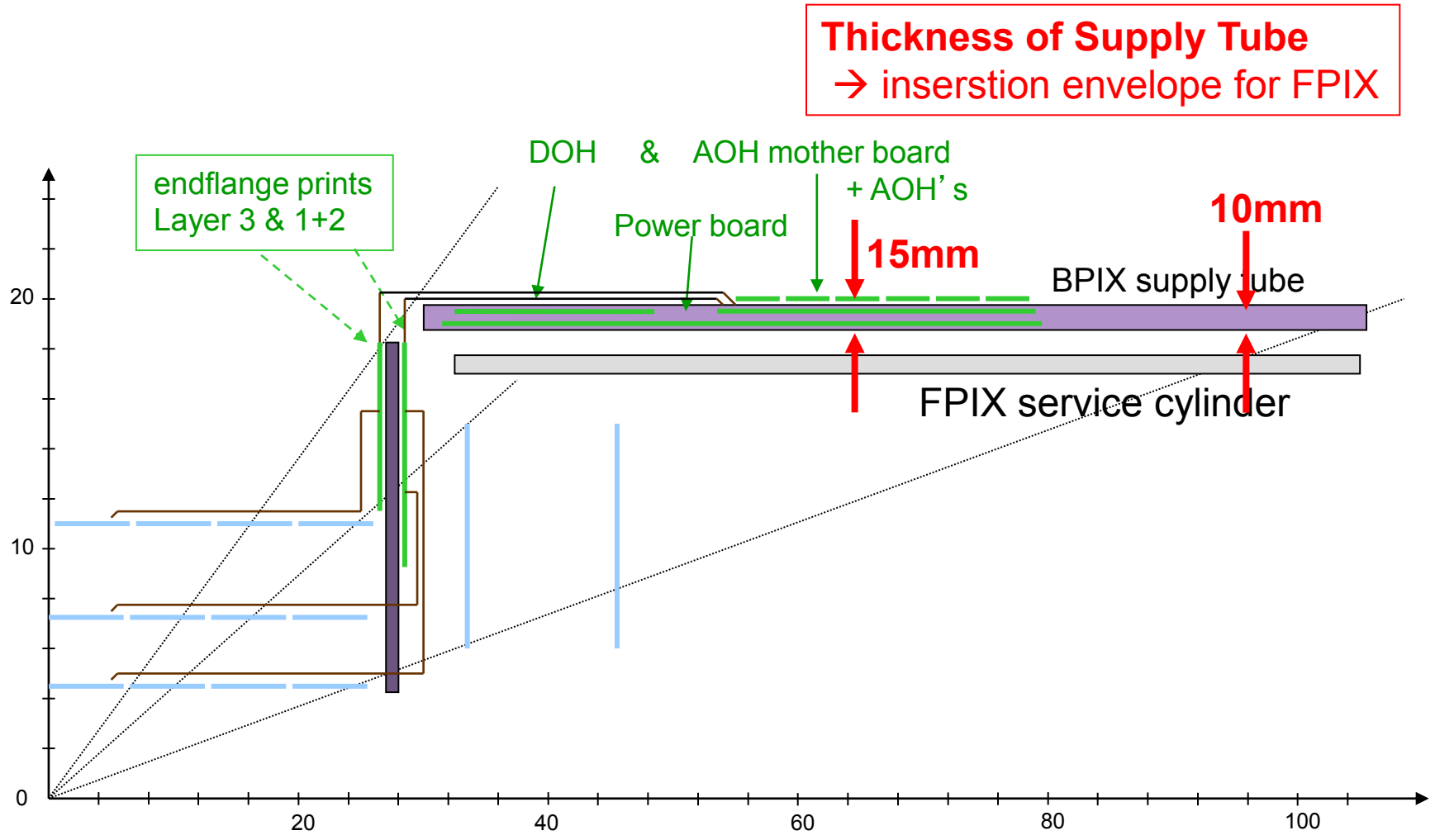


New Barrel Pixel design



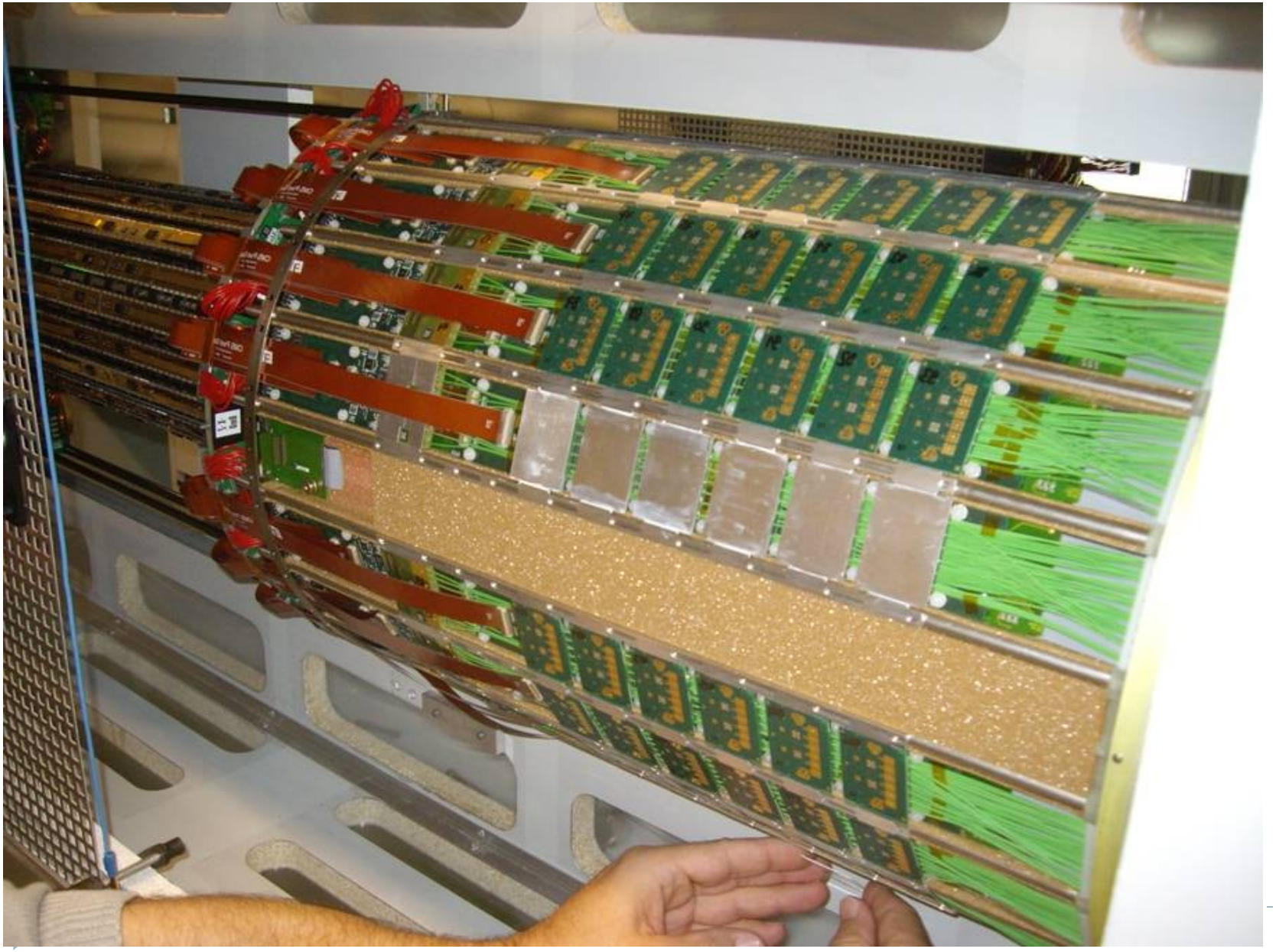
- Innermost layer with reduced radius (39mm)
- Additional outermost layer at 160mm
- ~2x radial acceptance
- ~65% more pixels
- Only one module type

Current Pixel System with Supply Tubes / Cylinders

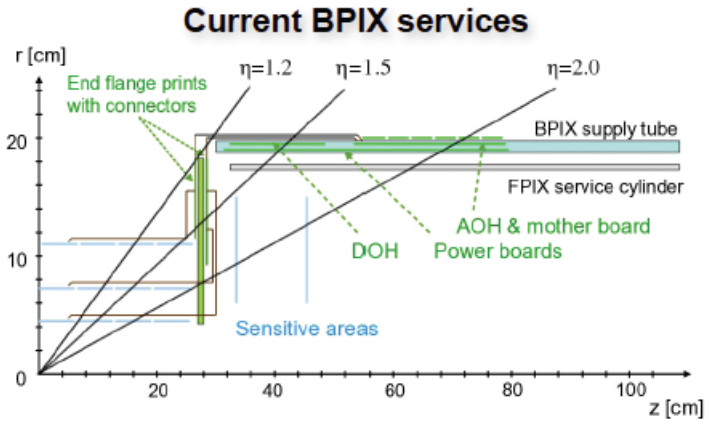


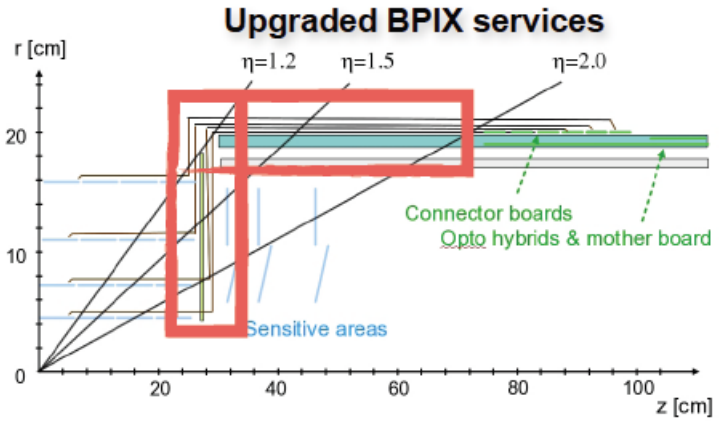
R. Horisberger

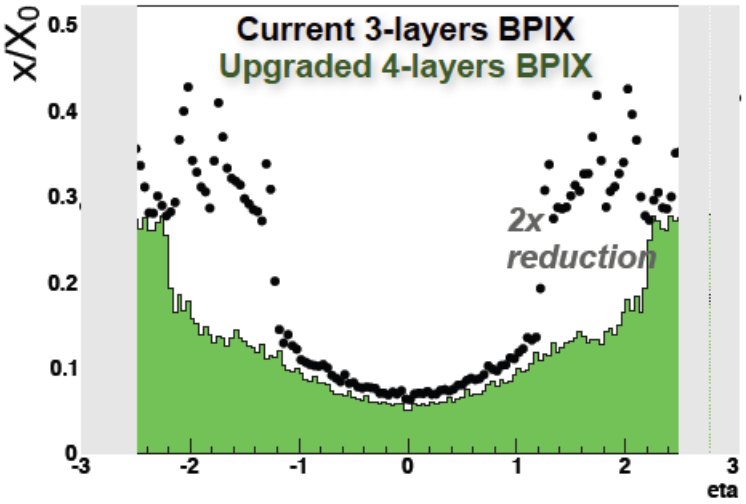
BPIX & Supply Tube with AOH, DOH, PCBs & Fibres

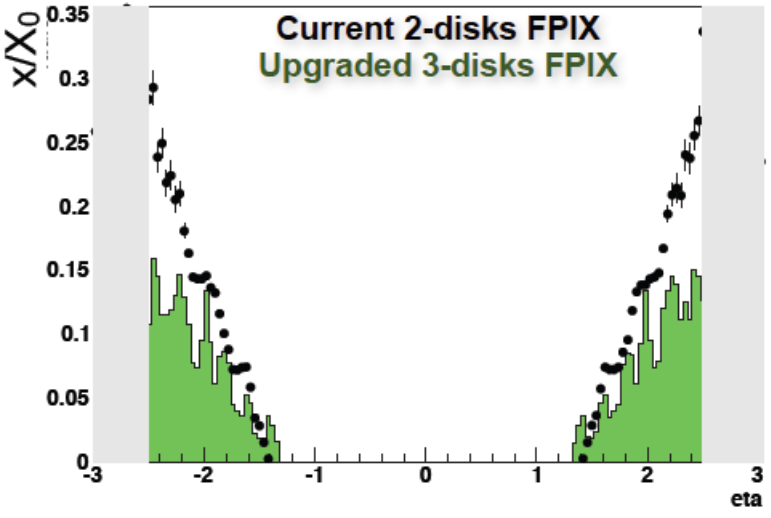


Pixel Material budget improvement



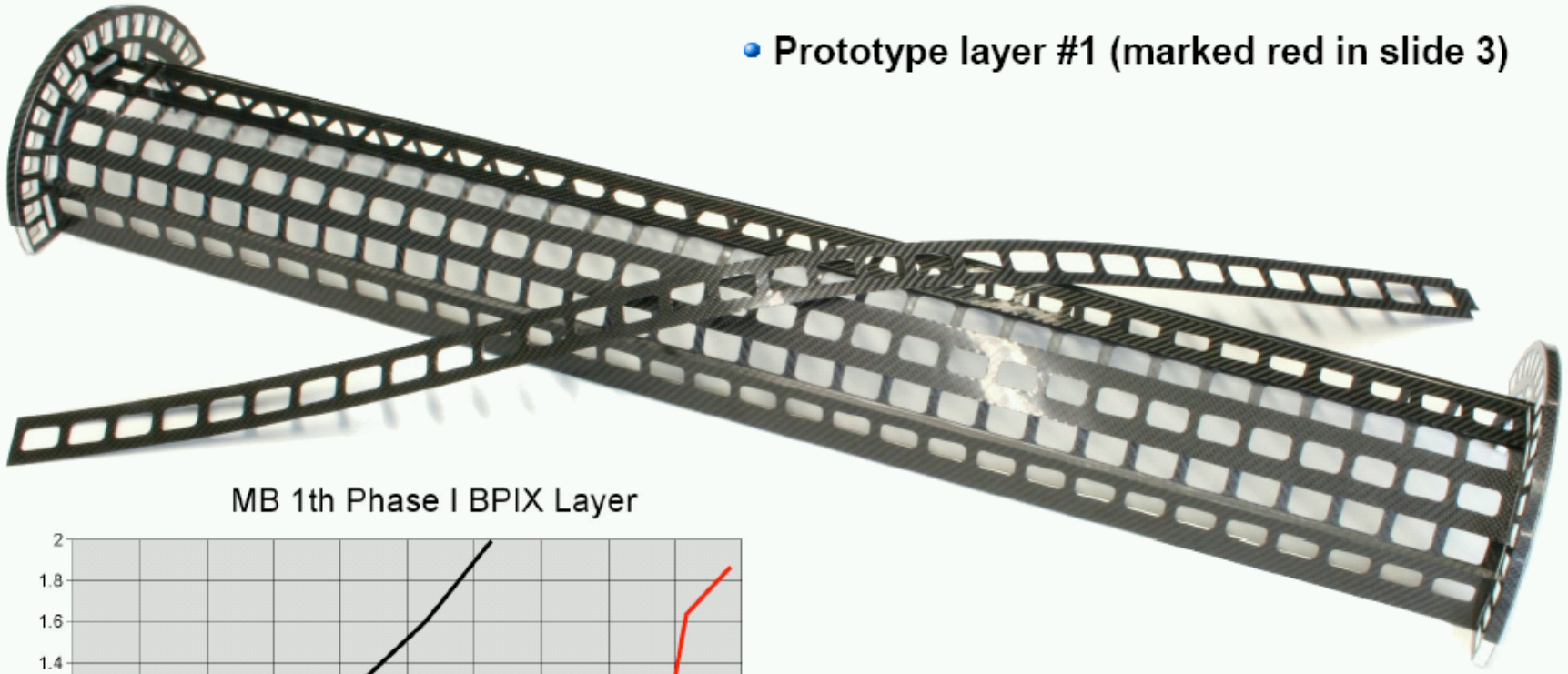




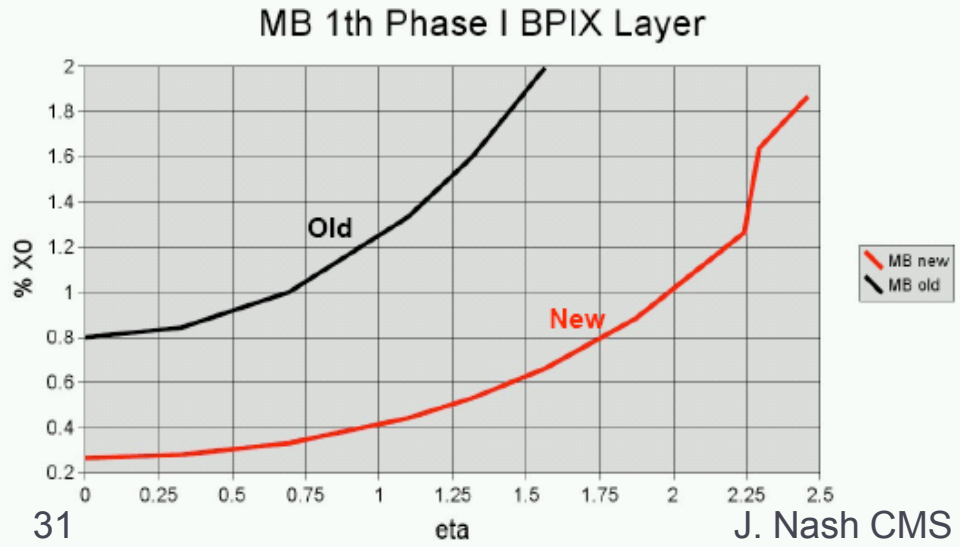


1 Layer of new Ultra Light Mechnaics

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

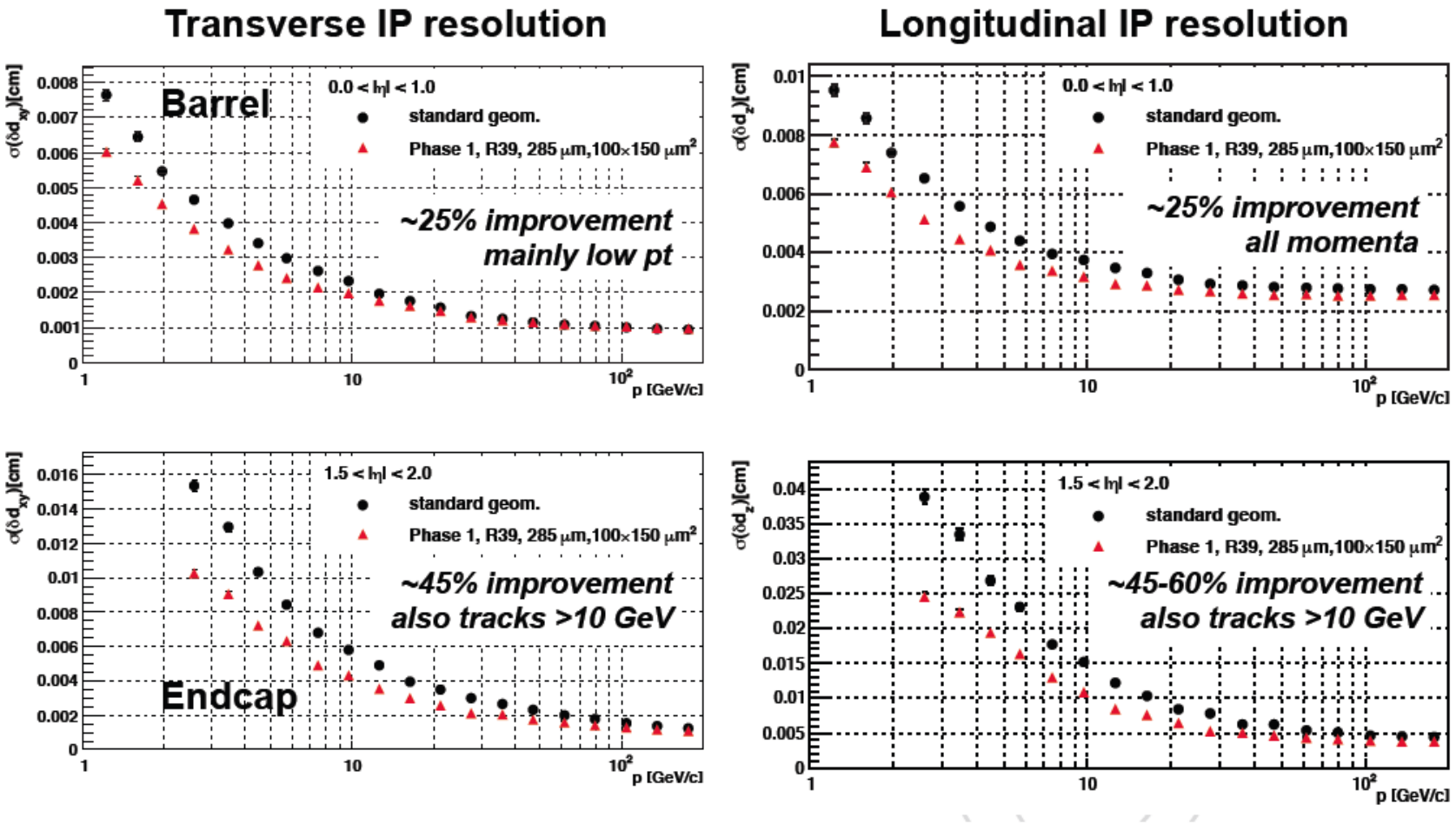


- Prototype layer #1 (marked red in slide 3)

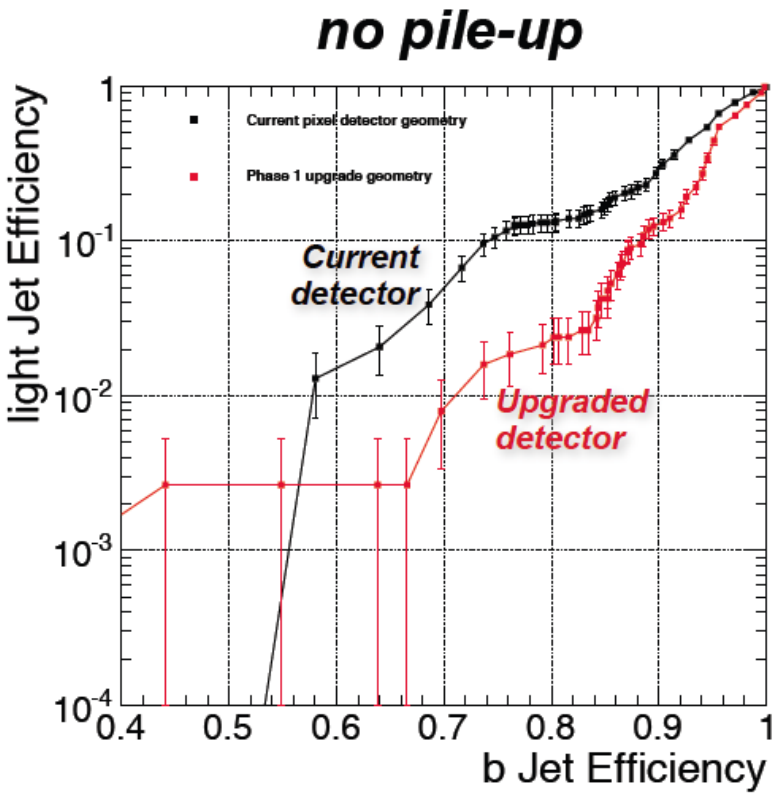


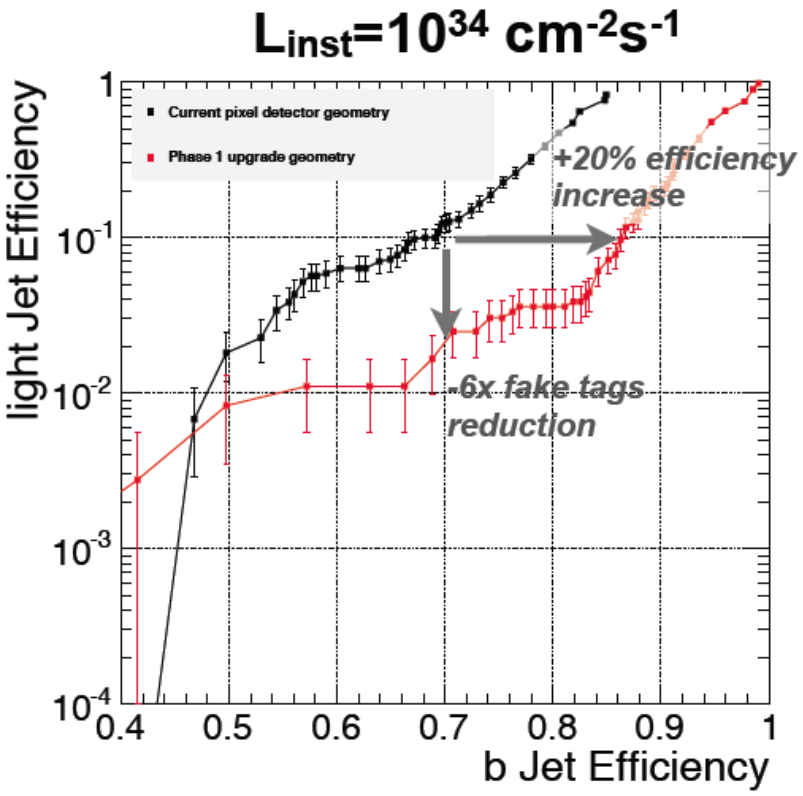
- New material budget is 30% off current BPIX

Improved impact parameter resolution



Improved B tagging





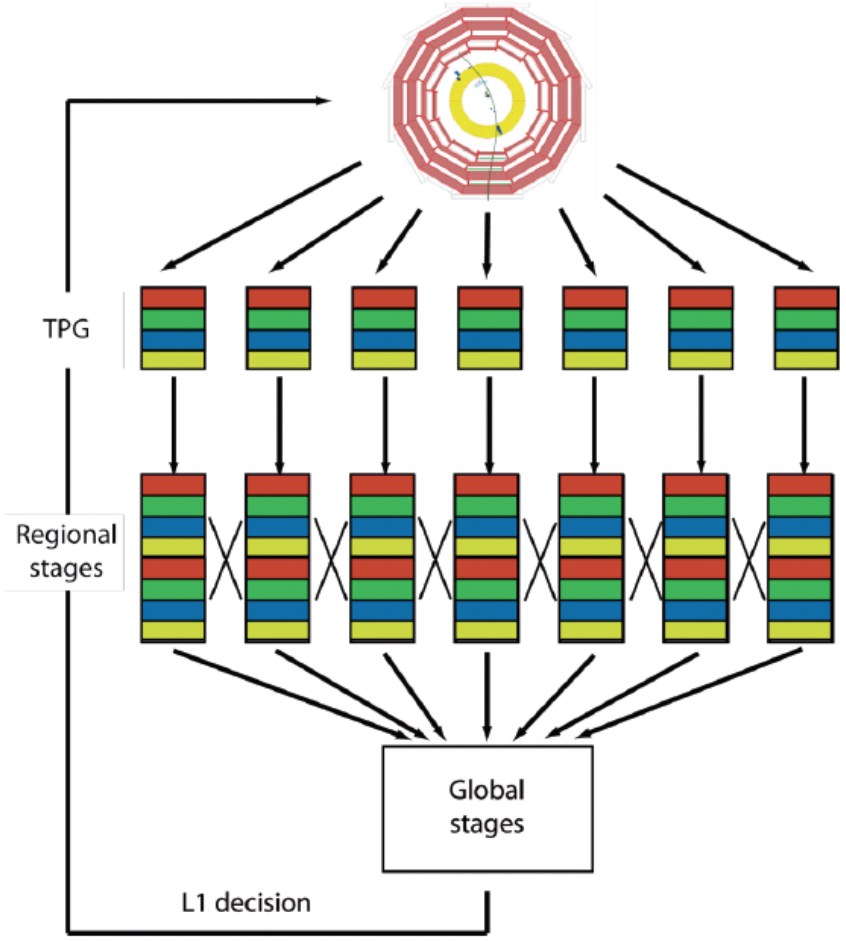
Improved efficiency and fake rate contributing exponentially with the number of b-tagged jets (e.g. Top, Susy, etc.)

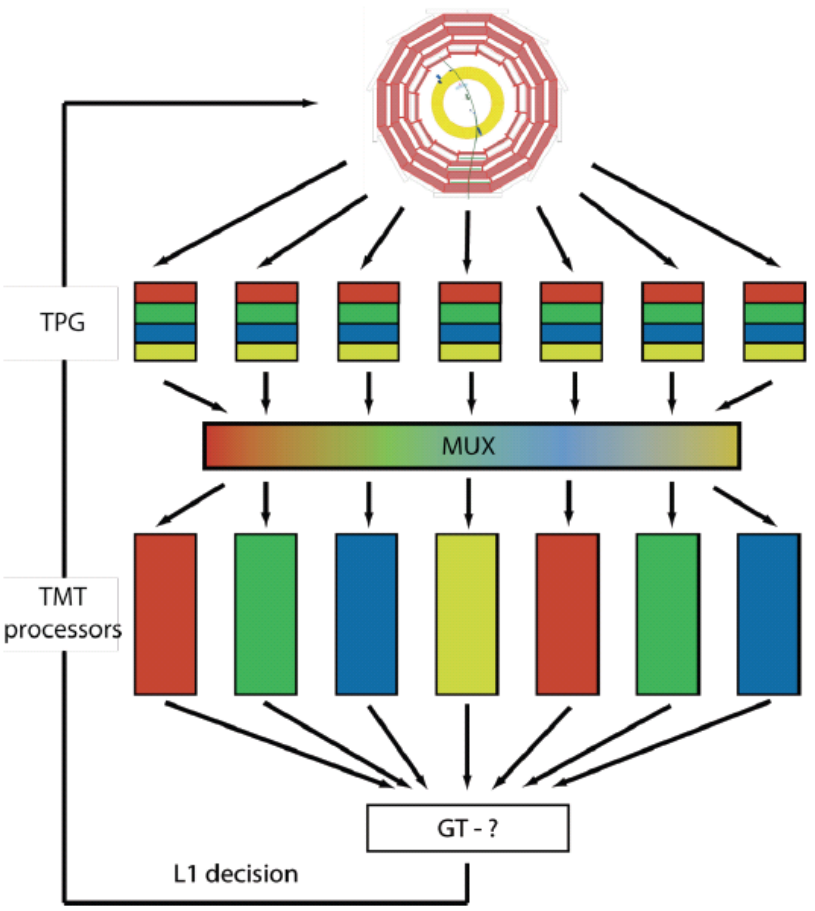
QCD 80<p_t<120 GeV
Combined Secondary Vertex tagger

2nd 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

R&D - New Technologies under study for trigger Example: Time Multiplexed Trigger





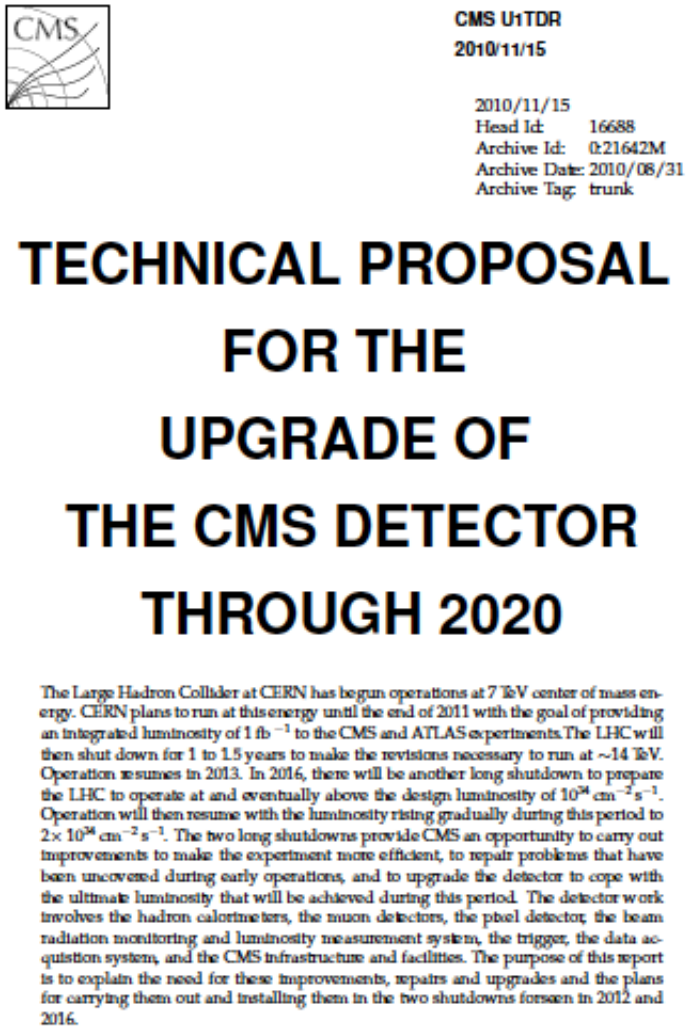
Tom Gorski & Greg Iles

CMS Upgrades ideal scenario

- 2013 Shutdown
  - Begin Installing forward muon systems
  - HO SiPMs (Hadronic Calorimeter Tail Catcher)
  - HF PMTs (Forward Hadron Calorimeter eta 3-5)
  - Pixel Luminosity Telescope
- 2017 (?) Shutdown
  - Install new beampipe – possibly now try for 2013…
  - Install new pixel detector
  - Install HB/HE photo-detectors
  - Install new trigger system
- 2021 (?) Shutdown
  - Install new tracking system
  - Major consolidation/replacement of electronics systems
    - Including potentially ECAL electronics
  - Calorimeter Endcaps (subject of a task force)
  - DAQ system upgrade

Technical Proposal – "pilot design"

- We have finished the Technical Proposal.
  - >300 page report
- This has been submitted to the LHCC
  - Is under review, should be "approved" at LHCC March meeting
- R/D for HL-LHC is also going on and appears as an appendix to the TP



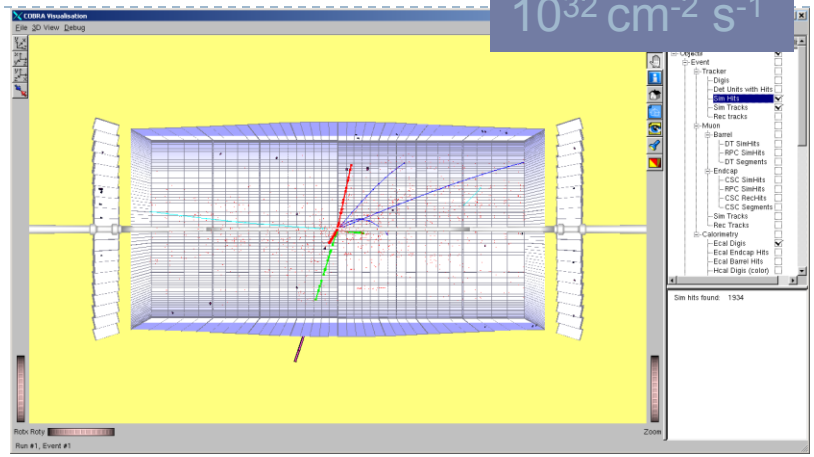
CMS U1TDR
2010/11/15

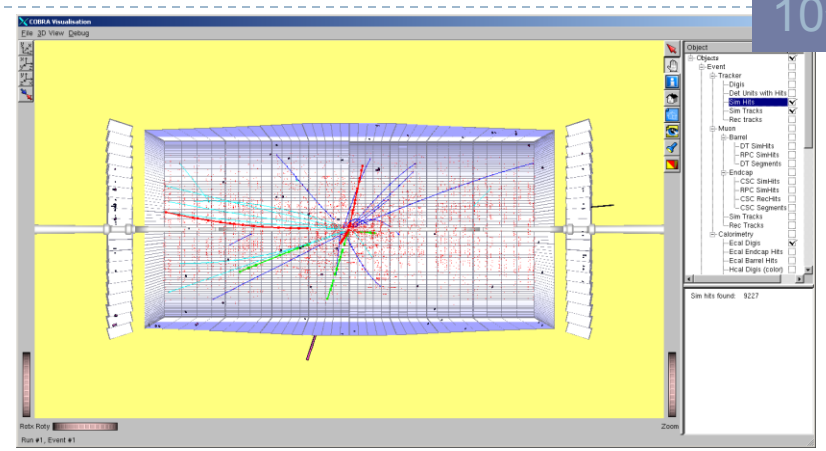
2010/11/15
Head Id: 16688
Archive Id: 0:21642M
Archive Date: 2010/08/31
Archive Tag: trunk

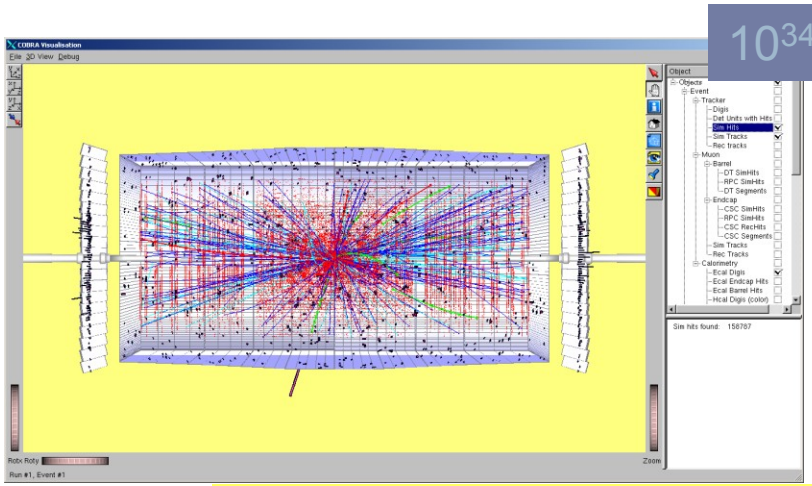
TECHNICAL PROPOSAL FOR THE UPGRADE OF THE CMS DETECTOR THROUGH 2020

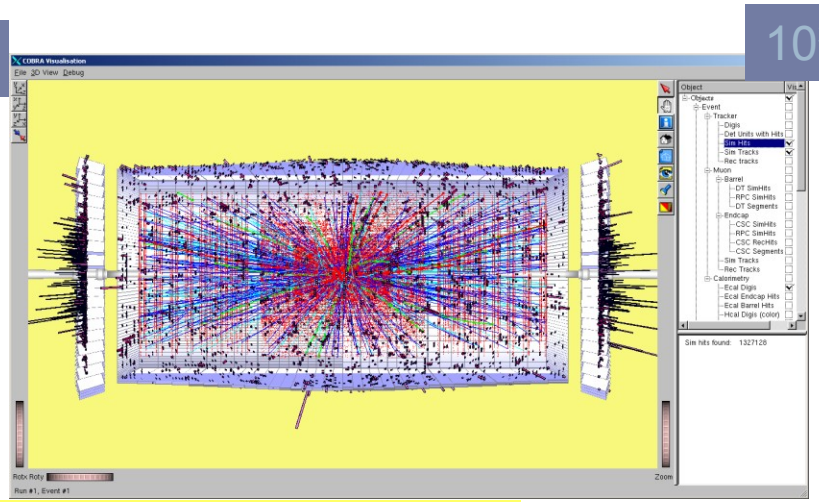
The Large Hadron Collider at CERN has begun operations at 7 TeV center of mass energy. CERN plans to run at this energy until the end of 2011 with the goal of providing an integrated luminosity of 1 fb^{-1} to the CMS and ATLAS experiments. The LHC will then shut down for 1 to 1.5 years to make the revisions necessary to run at ~14 TeV. Operation resumes in 2013. In 2016, 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 shutdowns foreseen in 2012 and 2016.

Detector Challenges
CMS from LHC to SLHC





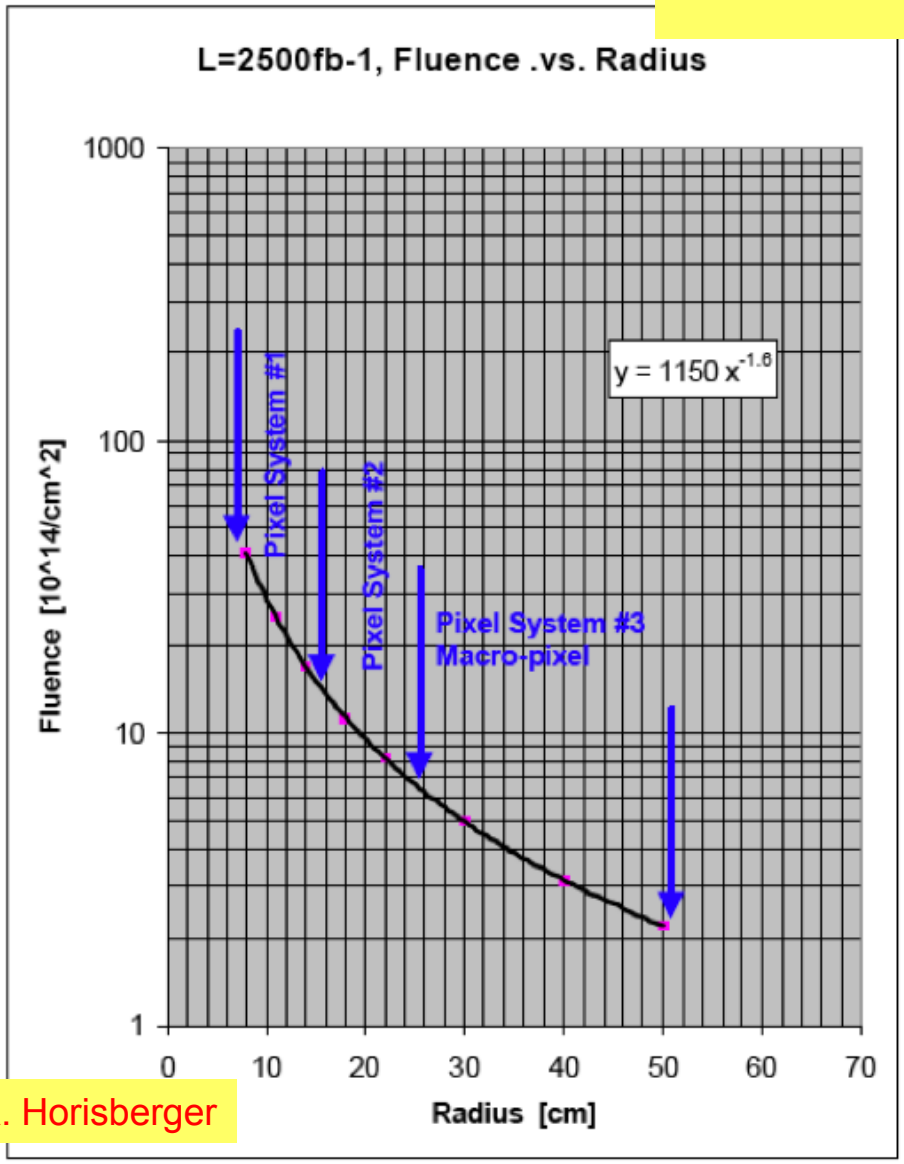




The tracker is the key detector which will require upgrading for SLHC Phase 2

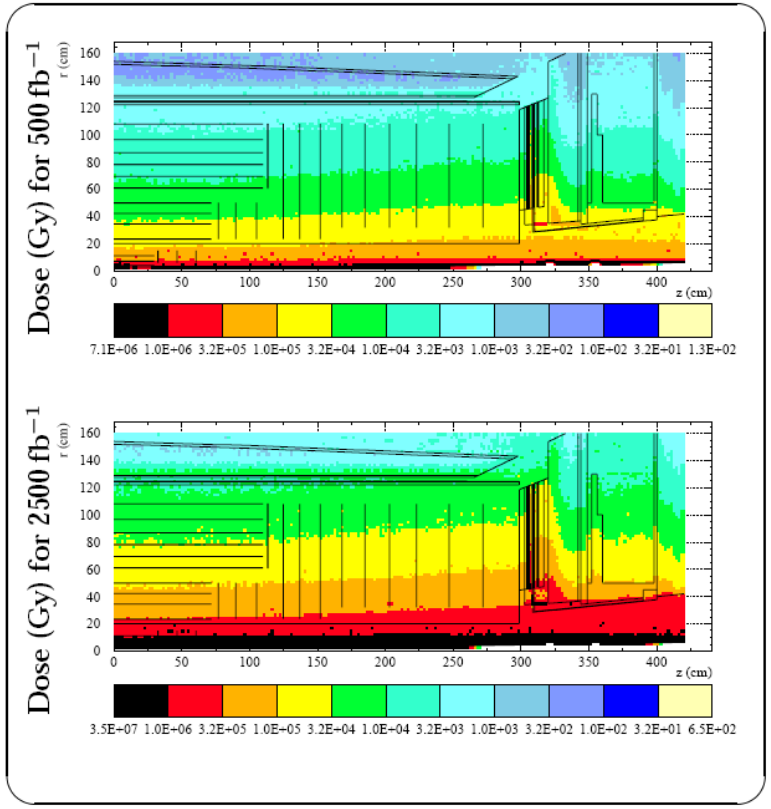
Radiation environment for trackers

Except for the very innermost layers many current technologies should survive SLHC



R. Horisberger

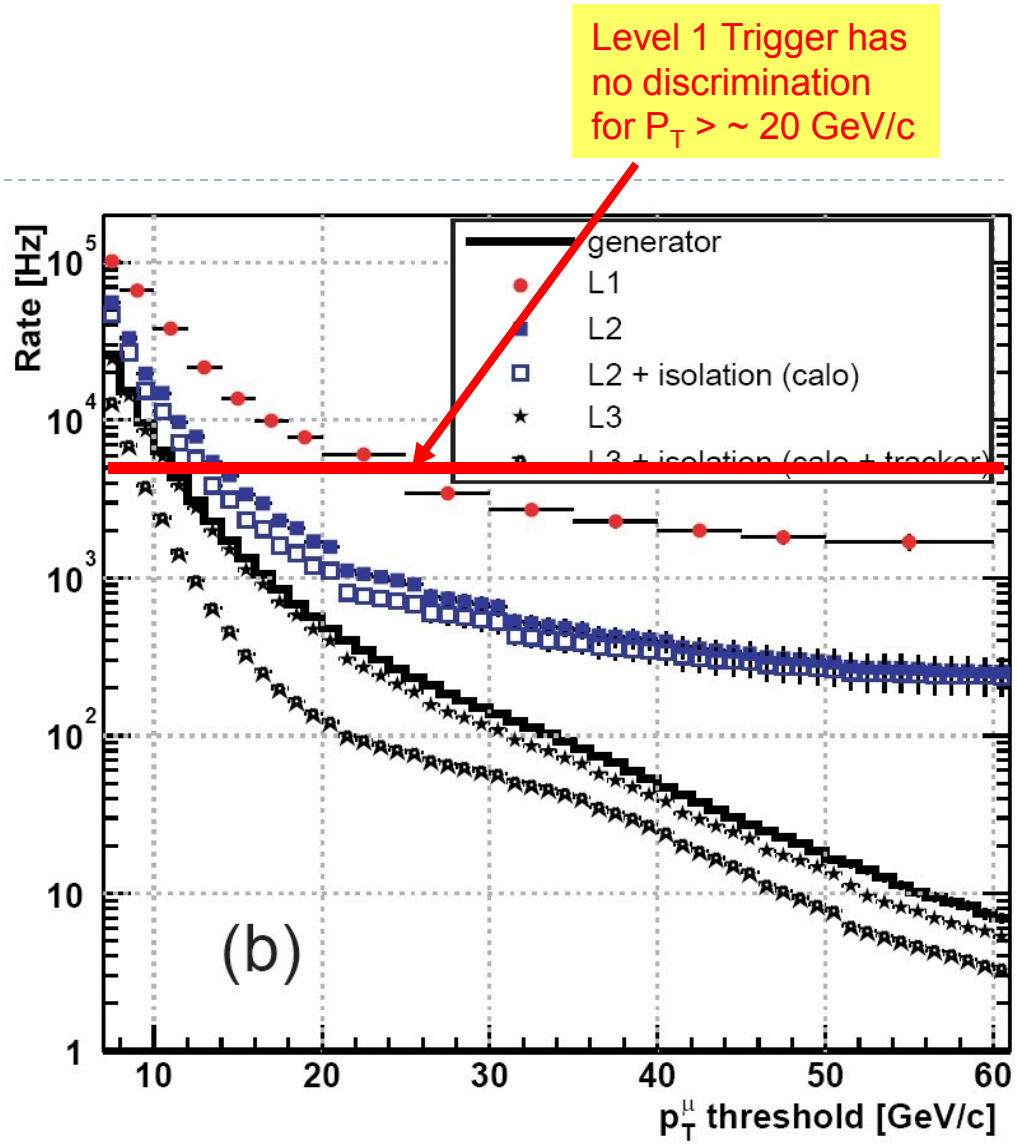
Radiation Dose in Inner Detectors



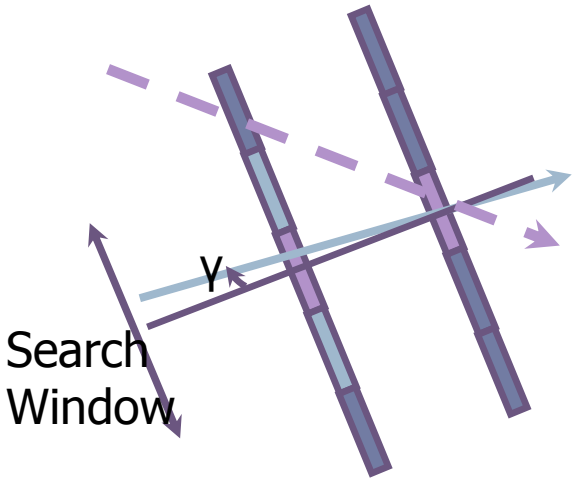
M. Huhtinen *SLHC Electronics Workshop 26 February 2004* 3

Level 1 Trigger

- The trigger/daq system of CMS will require an upgrade to cope with the higher occupancies and data rates at HL-LHC
- One of the key issues for CMS is the requirement to include some element of tracking in the Level 1 Trigger
  - One example: There may not be enough rejection power using the muon and calorimeter triggers to handle the higher luminosity conditions at HL-LHC
- Adding tracking information at Level 1 gives the ability to adjust P_T thresholds
- Single electron trigger rate also suffers
  - *Isolation criteria are insufficient to reduce rate at* $L = 10^{35}\ cm^{-2}.s^{-1}$

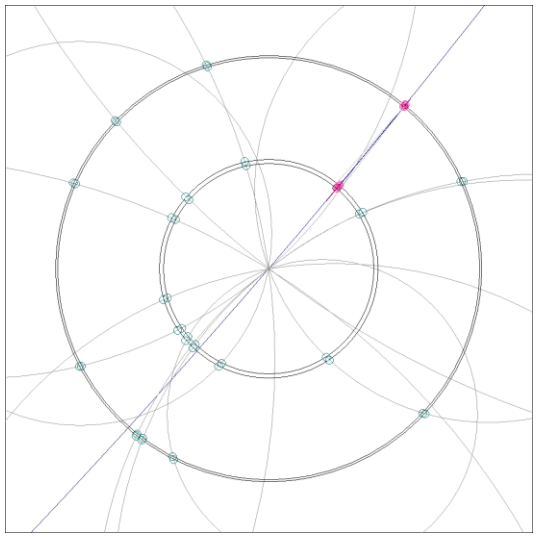


Concepts:Tracking Trigger



High momentum tracks are straighter so pixels line up

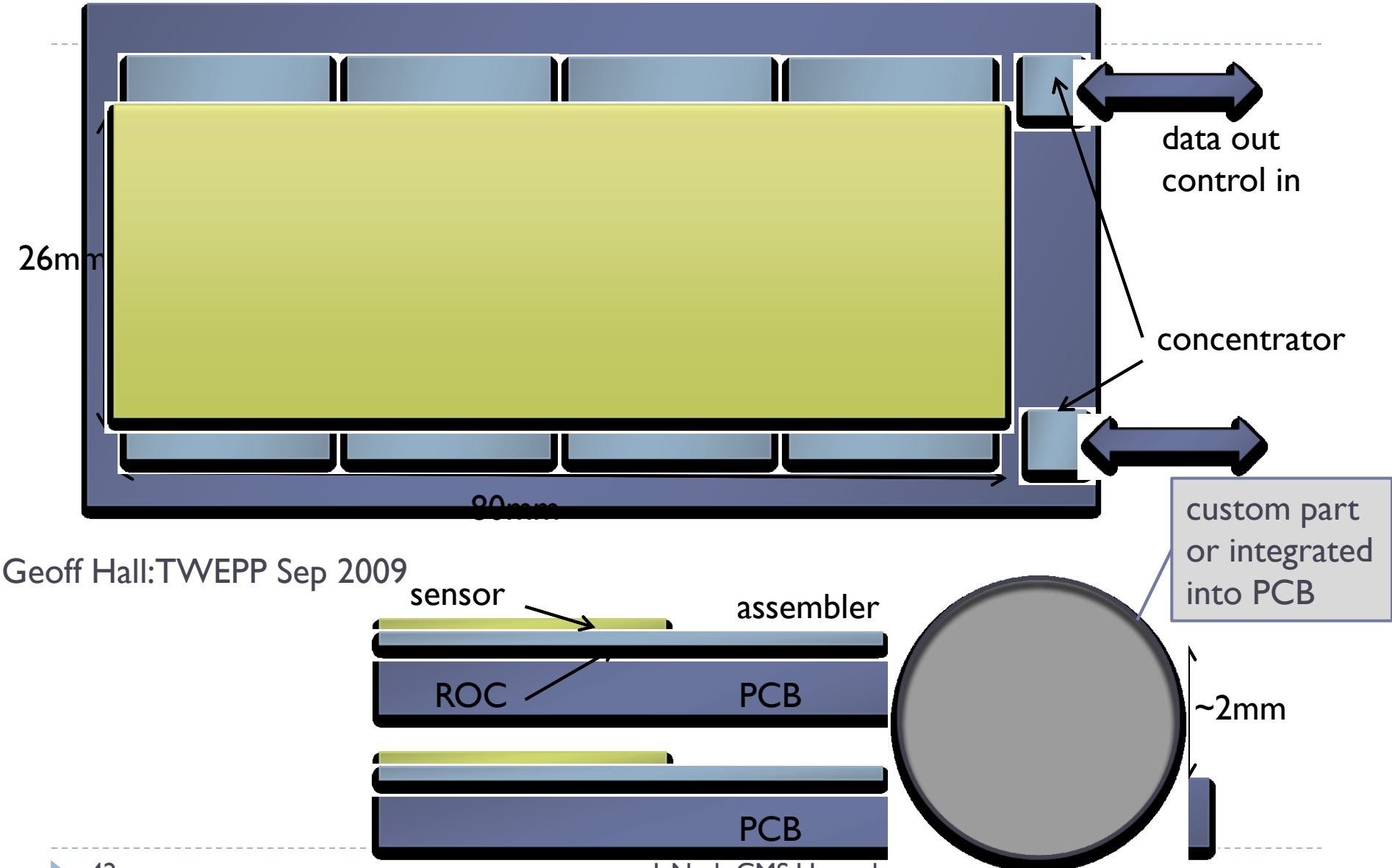
Pairs of stacked layers can give a P_T measurement



Geometrical p_T-cut - J. Jones, A. Rose, C. Foudas LECC 2005

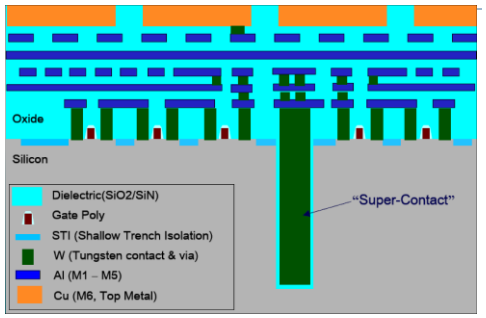
- Why not use the inner tracking devices in the trigger?
  - Number of hits in tracking devices on each trigger is enormous
  - Impossible to get all the data out in order to form a trigger
  - How to correlate information internally in order to form segments?
- Topic requiring substantial R&D
  - "Stacked" layers which can measure p_T of track segments locally
    - Two layers about 1mm apart that could communicate
  - Cluster width may also be a handle

Module schematic

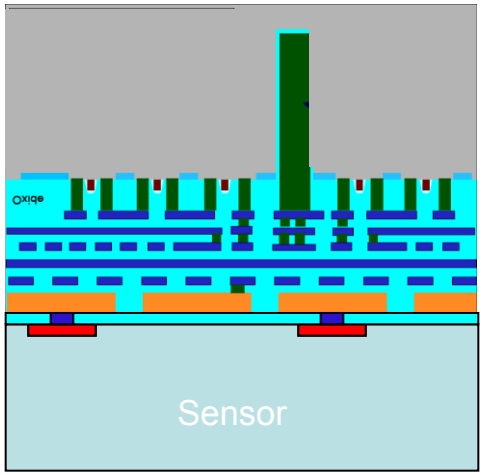


Geoff Hall:TWEPP Sep 2009

Building a Trigger module with 3D

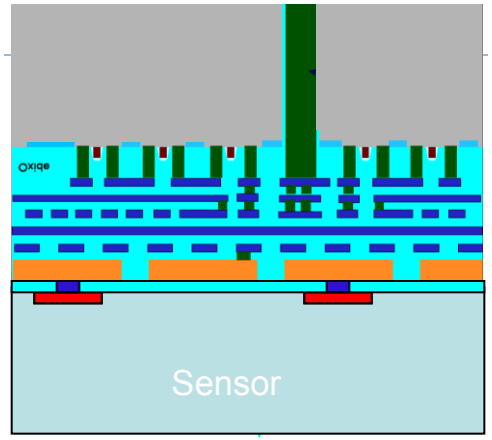


Readout IC wafer with TSV from foundry

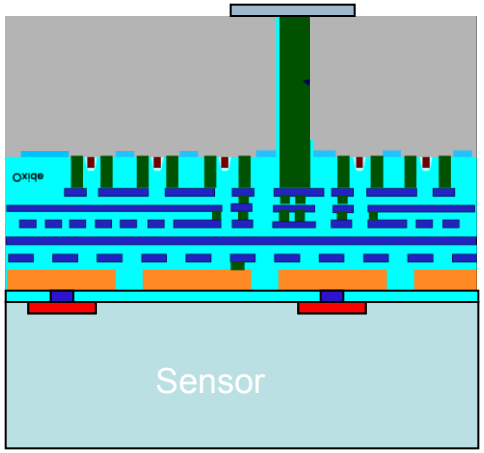


DBI bond

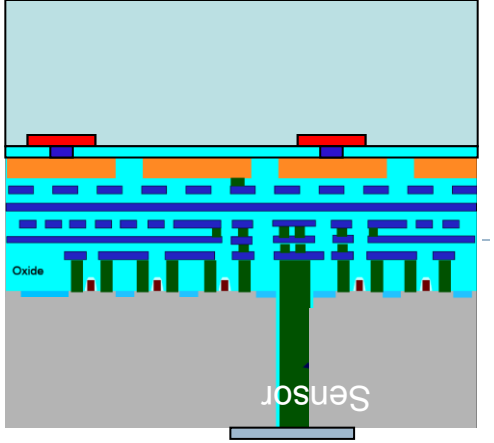
Oxide bond diced ROIC to sensor Wafer.

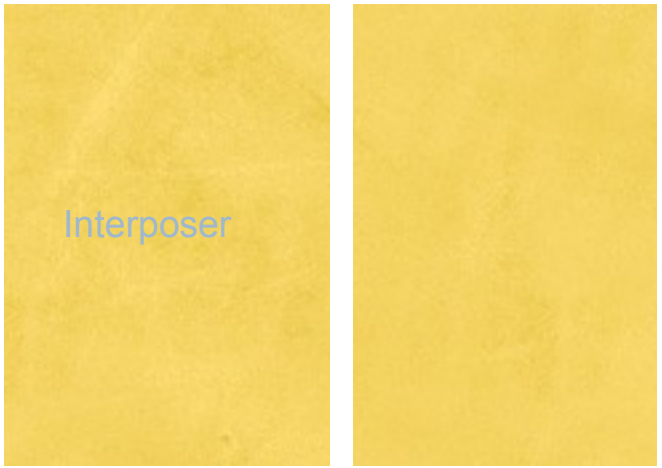


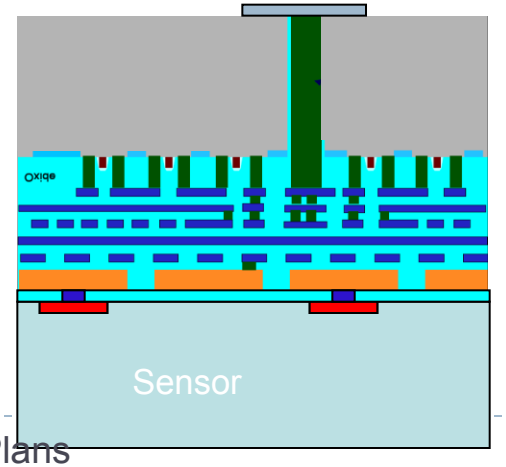
Thin to expose TSV



Contact lithography provides
Access to topside pads for vertical data path



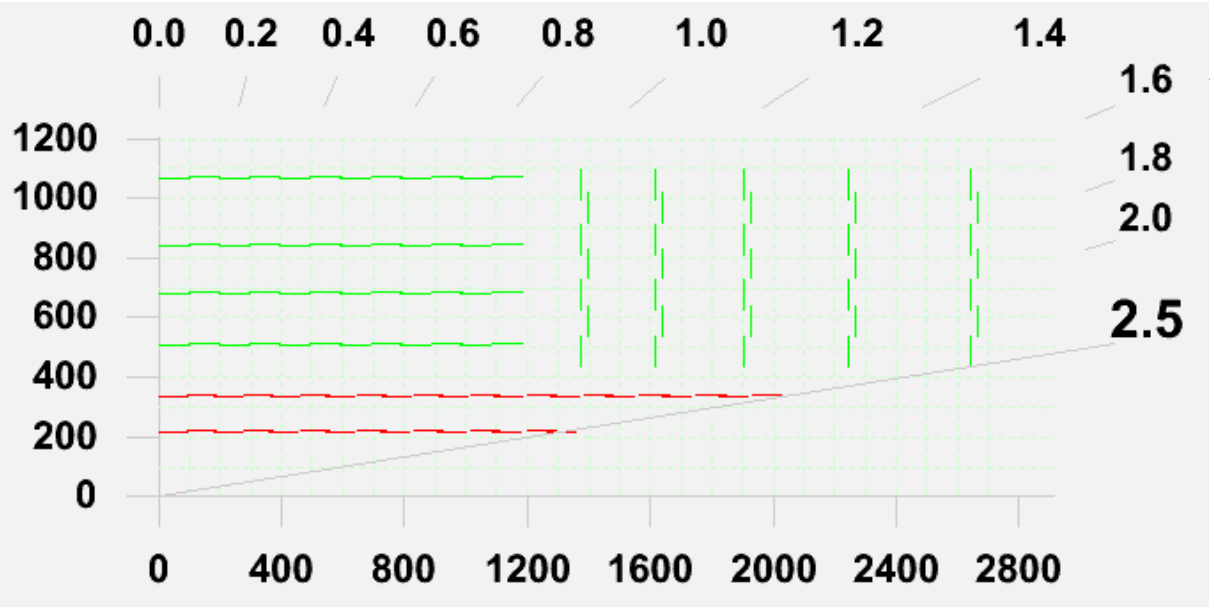


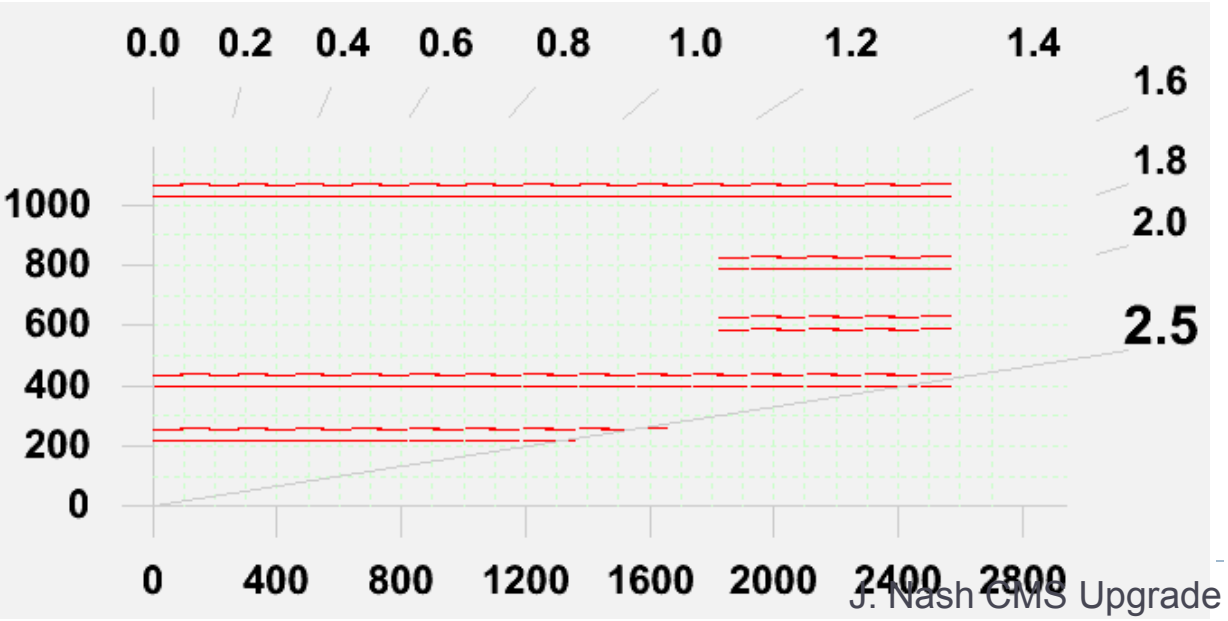


Bump Bond module

R. Lipton

CMS – Studies of new tracker layouts





- Studying several potential layouts for a new outer tracker
- Want to increase granularity as well as minimize material in future tracker
- Need to understand how many triggering layers (in red at left), and where they need to be located in order to provide adequate triggering capability
- No final decision on layout of tracker until final requirements determined

Conclusions

- CMS has outlined its plans for upgrades in this decade
  - Technical Proposal describing the work is submitted, work on detailed planning for the upgrades well underway
- R/D for the very challenging upgrades required for the next decade is going on in parallel