CMS Detector Upgrades for High Luminosity LHC

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Journée LHC à Haute Luminosité,
IRFU/SPP CSTC, November 4, 2011

LHC & CMS Performance

Nb = 1404 | I tot ~ 1.8e+14 | **Peak Lumi ~ 3.4 e+33** | **pb-1/day ~ 100 pb**

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

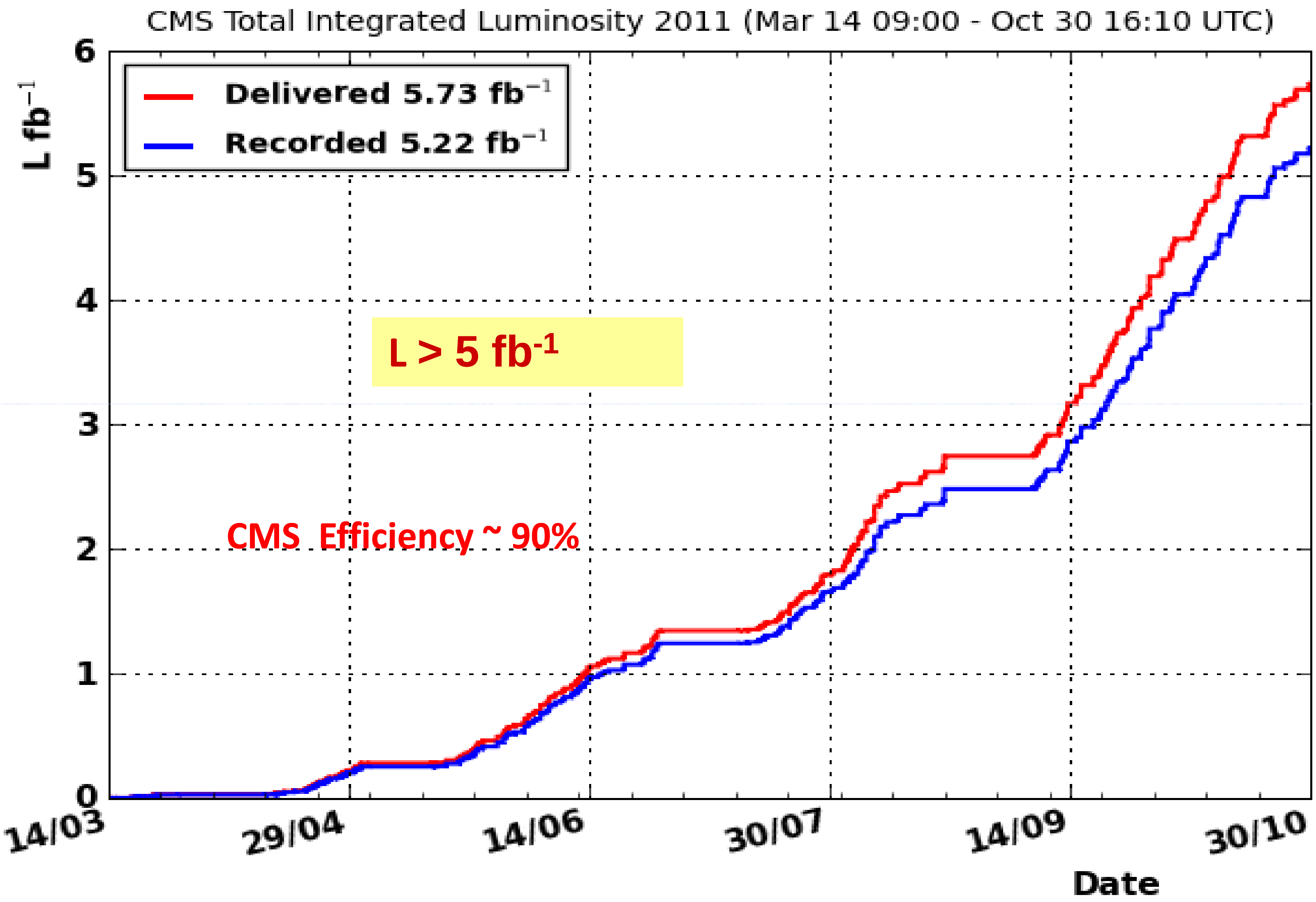
A few highlights from the run this year:

Peak Instantaneous Luminosity: $3.55*10^{33}$ in fill 2256, Oct. 26, 2011
Delivered luminosity in one Fill: 123 pb^{-1} in fill 2219, Oct. 16, 2011
Maximum Luminosity in one Day: 136 pb^{-1}, Oct. 13, 2011

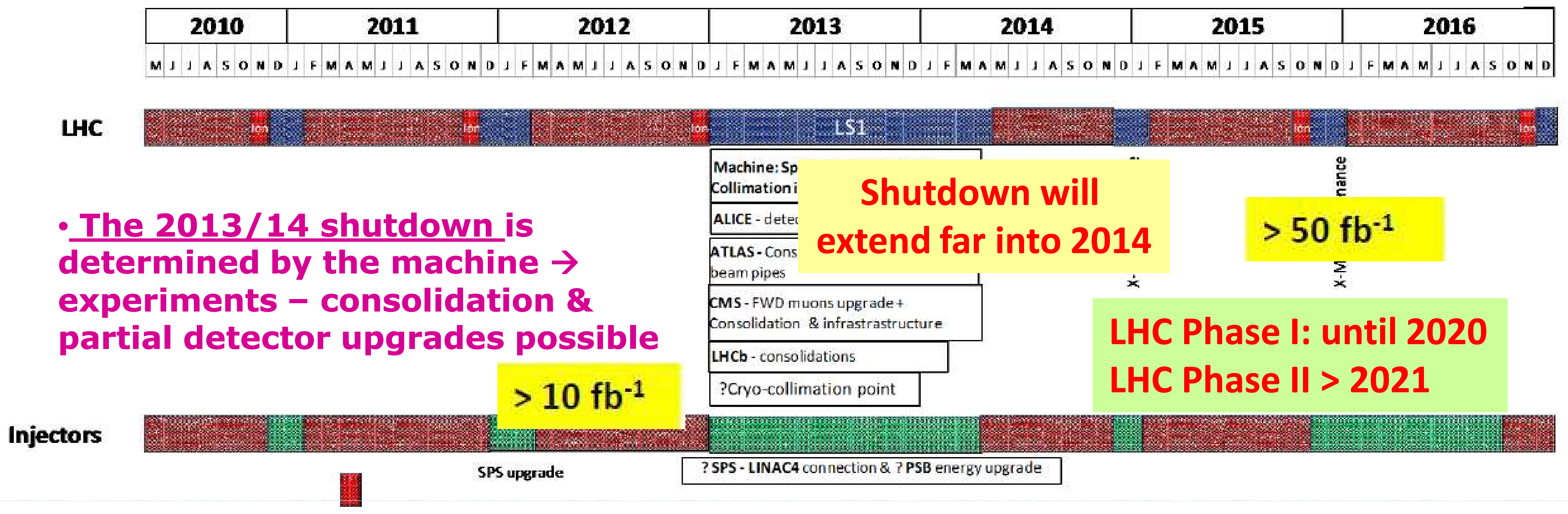
Maximum Luminosity Delivered in one Week: 538 pb^{-1} in week 41
Maximum Luminosity Delivered in one Month: 1614 pb^{-1} in October

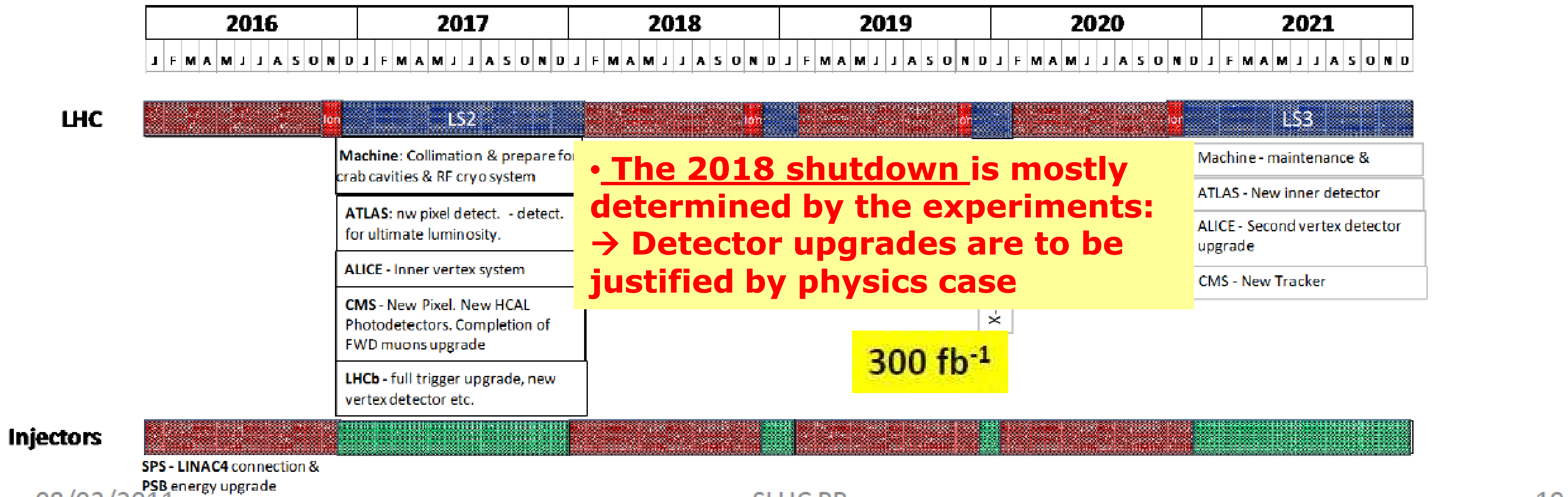
The LHC were in stable beams 1364 hours (55 days) this year.

CMS Luminosity



Latest Rough Draft 10 Years Plan for LHC 10 years plan





CMS Upgrade Plans & Scope

BASED ON THE TECHNICAL PROPOSAL FOR THE UPGRADE OF THE CMS DETECTOR THROUGH 2020: https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=2717

	System	2010-2020	2020-2030
2017	Pixel	New Pixel Detector	
	Tracker		New Tracking System (incl Pixel)
2013 2017	HCAL	HPD replacement with SiPM + Electronics	HF/HE?
	ECAL	Trigger Primitives (Off Detector Electronics) ?	EE
2013 /2017	Muons	ME4/2, ME1/1 ,RPC endcap, some CSC Electronics	Electronics replacement
2017	Trigger	HCAL/RCT/GCT to mTCA	Complete replacement

J. Nash, LHCC Upgrade Meeting (Updated Slides), 16.11.2010

Planned CMS Detectors Upgrades and Improvements

- **2013 Shutdown**
  - **Start Completion of Forward Muon System (ME 4/2 CSC, RPC)**
  - **Install new smaller radius (r=23-25 mm) Be-beampipe;**
  - **HO (Hadronic Calorimeter Tail Catcher) replacement of HPD with SiPMs**
  - **HF thin-window PMTs & segmented anodes (Forward Hadron Calorimeter: η ~ 3-5)**
  - **Pixel Luminosity Telescope (diamond) for luminosity measurement**
- **2017 (?) Shutdown**
  - **Install new low-mass pixel detector (4 barrel layers);**
  - **HB/HE replacement of HPD with SiPMs and modified FEE/trigger electronics**
  - **Install new trigger system (calorimeter, muon track finder, global trigger)**
- **2021 (?) Shutdown**
  - **Install new full tracker (pixel + strips); Tracker in Level-1 Trigger**
  - **Major consolidation/replacement of electronics systems**
    - **Including potentially ECAL electronics**
  - **ECAL Endcaps (subject of a task force)**
  - **DAQ system upgrade**

J. Nash, LHCC Upgrade Meeting (Updated Slides), 16.11.2010

Phase I Upgrades

2011-2020

Pixel Detector Upgrade for 2016

Motivation: maintain high tracking efficiency at luminosities up to 2 * 10^{34}

- BPIX 3 Layer → 4 Layers
- FPIX 2x2 Disk → 3x2 Disk

Increase number pixel tracking points 3 → 4

- CO_2 cooling based Ultra Light Mechanics
- Shift material budget out of tracking η–region

Significant X/X_0 reduction

- Minimize 1 Layer radius

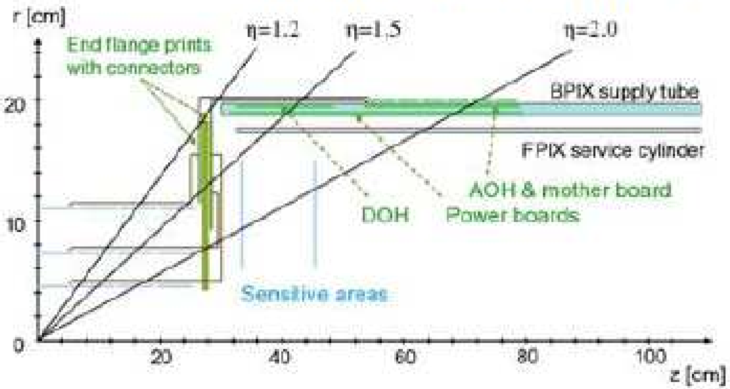
reduced impact δ_{xy} & δ_z error

- New readout chips (ROC) to reduce trigger latency related data losses
- ROC modifications for operation up to L ~ 2×10^{34}

- Pixel upgrade to 4 hit system significantly improves and robustifies pixel track seeding and vertexing
- Reduced and displaced material budget significantly improves impact parameter resolution and therefore vertexing and b-tagging
- Pixel standalone tracking crucial in HLT → particularly useful for electron and tau triggers

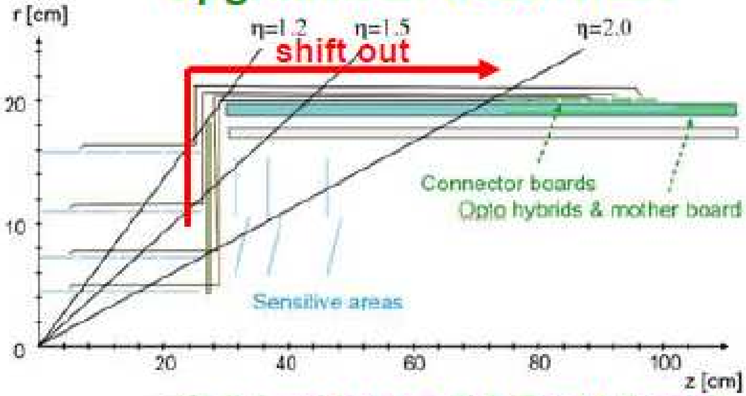
Shift material budget out of tracking region

Current BPIX Services

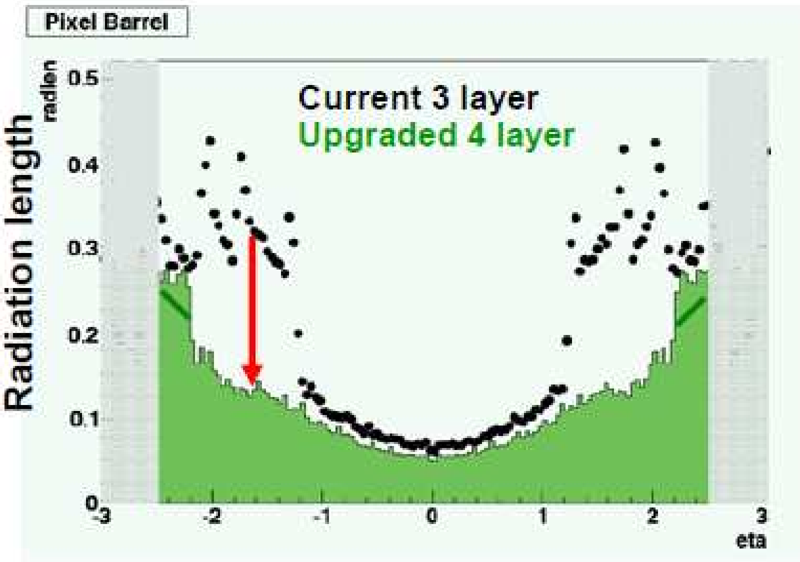


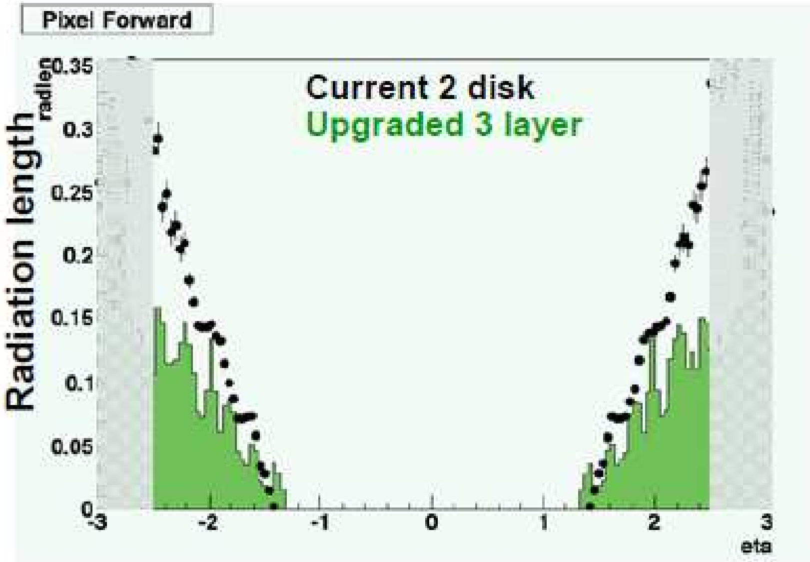
η<2.2 : weight = 16.9 Kg (3 layer)

Upgraded BPIX Services



η<2.2 : weight = 6.5 Kg (4 layer)

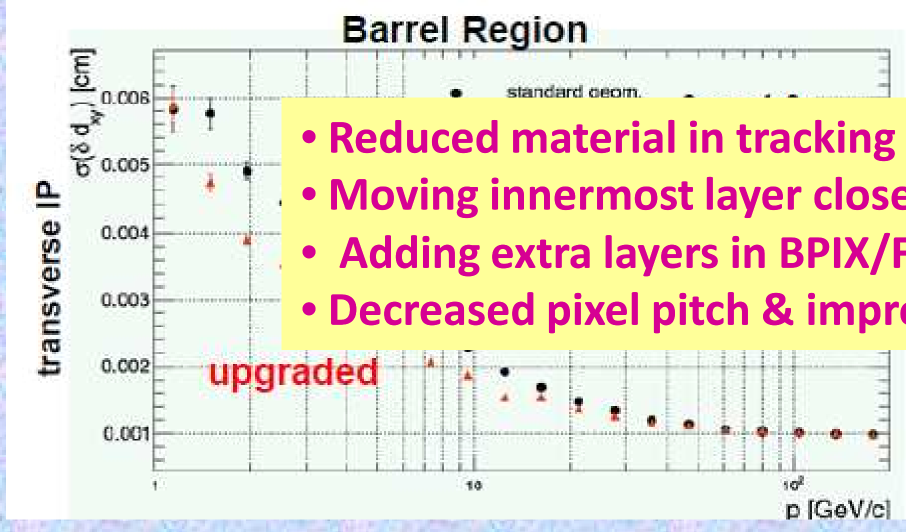


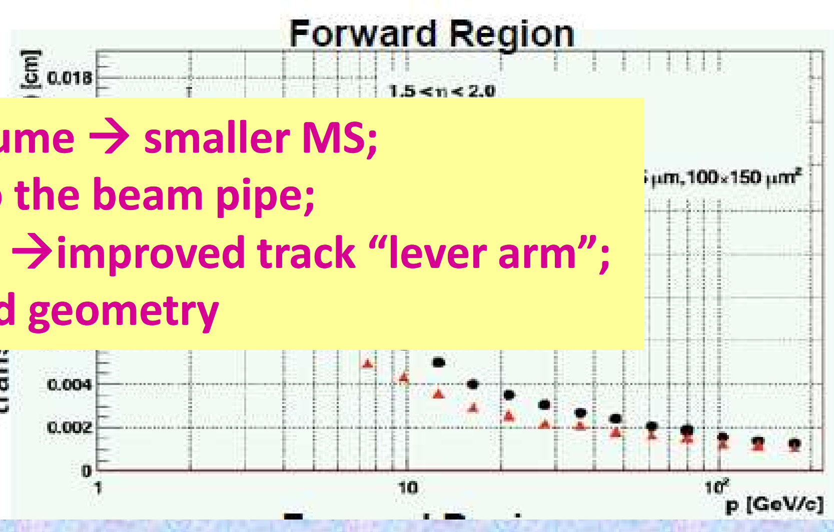


η ~1.5 : γ-conversion for H→ γγ from 22% to 11% for new 4 Layer Pixel System

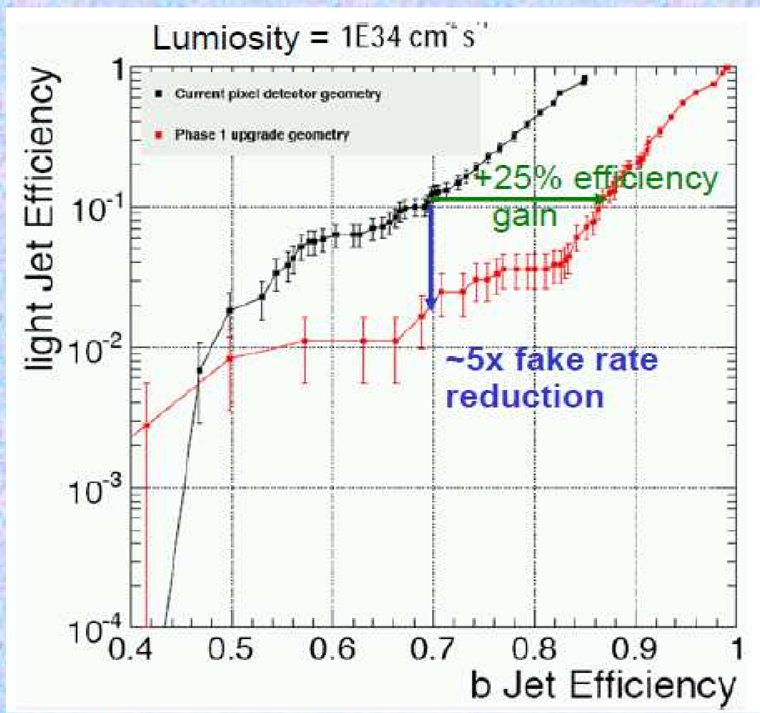
Physics Performance of Upgraded Pixel Detector

Impact Parameter of Current/Upgraded Pixel System





- Reduced material in tracking volume → smaller MS;
- Moving innermost layer closer to the beam pipe;
- Adding extra layers in BPIX/FPIX →improved track “lever arm”;
- Decreased pixel pitch & improved geometry



B-tagging of Current/Upgraded Pixel System:

Efficient b-tagging crucial to many analysis →

e.g. 4-b jet channel → fake-rate reduction by factor of 600 or ~2.4x signal gain

R. Horisberger, LHCC Upgrade Meeting, 16.11.2010

HCAL Calorimeter Upgrades

Motivation for the upgrades

- Improve lepton isolation and jet separation variables at high luminosity
- Accurate measurement of MET and particle-flow contributions to Jets, places strict requirements on HCAL performance in noise and efficiency
- HCAL performance directly impacts the quality of the trigger for a wide range of trigger paths
- Quality of HCAL measurements becomes increasingly important for high luminosity searches for rare physics

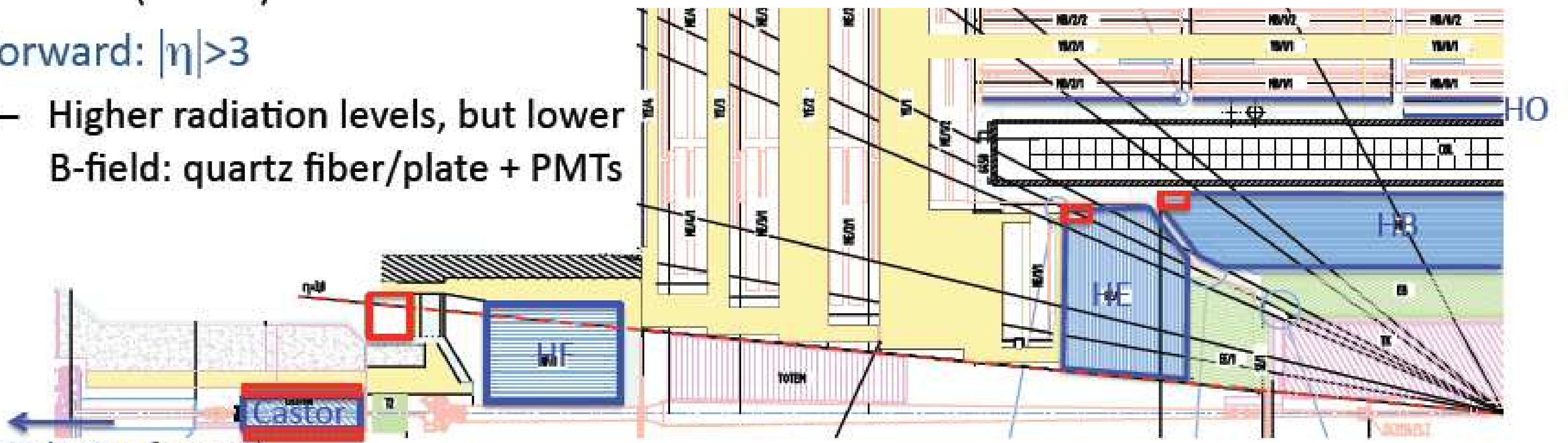
device	η range	absorber	active material	photo-detector
Barrel Hadron Calorimeter (HB)	$0 < \|\eta\| < 1.39$	brass	scintillator	HPD
Outer Hadron Calorimeter (HO)	$0 < \|\eta\| < 1.30$	cryostat	scintillator	HPD
Endcap Hadron Calorimeter (HE)	$1.39 < \|\eta\| < 3.0$	brass	scintillator	HPD
Forward Hadron Calorimeter (HF)	$3.0 < \|\eta\| < 5.0$	steel	quartz fiber	PMT
CASTOR	$-6.6 < \eta < -5.2$	tungsten	quartz plate	PMT
Zero Degree Calorimeter (ZDC)	$\|\eta\| > 8.3$	tungsten	quartz fiber	PMT

Central: $|\eta|<3$

- Plastic scintillator + WLS fiber, HPD (B-field)

Forward: $|\eta|>3$

- Higher radiation levels, but lower B-field: quartz fiber/plate + PMTs



ZDC (140m from IP)

J. Spalding, LHCC Upgrade Meeting, 16.11.2010

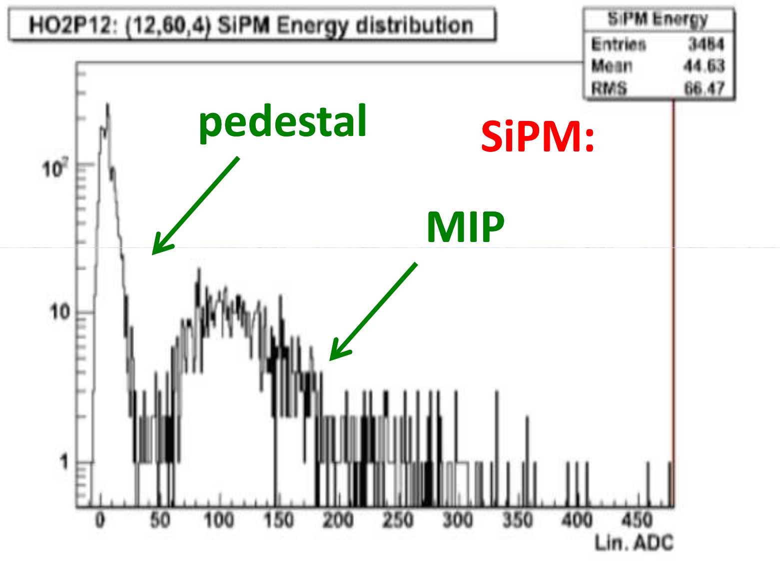
Outer Hadron Calorimeter (HO) Upgrade for 2013

Problem: hybrid photomultipliers (HPD) are susceptible to discharge at intermediate B-fields (~0.2 – ~3.5 T) → about 15% fail at 3.8T (HB/HE), and <u>about 50% at 0.2-0.3T (HO R1/2)</u>

• <u>HO (R1/R2) are not able to operate at nominal gain</u> (and remain a source of spurious noise when HPD E-field is not well aligned with local B-field) → <u>unable to identify muons, reduced contribution to jet measurement</u>

Replace HO (R0/R1/R2) HPD with Silicon PhotoMultipliers (SiPM) (new technology to HEP):

- **SiPM photon detection efficiencies >2x HPDs and gain a factor of 50 to 500 larger;**
- **SiPMs are compact and operate at ~100V compared to ~10KV for HPDs;**
- **SiPMs are not affected by magnetic fields**



Key SiPM R&D Issues:

- Pixel recharging time: sufficiently short to not degrade measurements in subsequent bunch crossings
- Pixel density for a given photo-detection area must provide required dynamic range and linearity for full range of expected signals
- SiPM temperature and voltage stability to minimize cell-to-cell variation
- Radiation tolerant to prevent long-term performance degradation from leakage current increase
- Signal from a single neutron interaction should be minimized

HB/HE Calorimeter Upgrades

Motivation: Replacement of HPD with SiPMs to eliminate the sources of anomalous signals and to improve the front-end signal-to-noise by an order of magnitude

SiPM: added capabilities for HB and HE

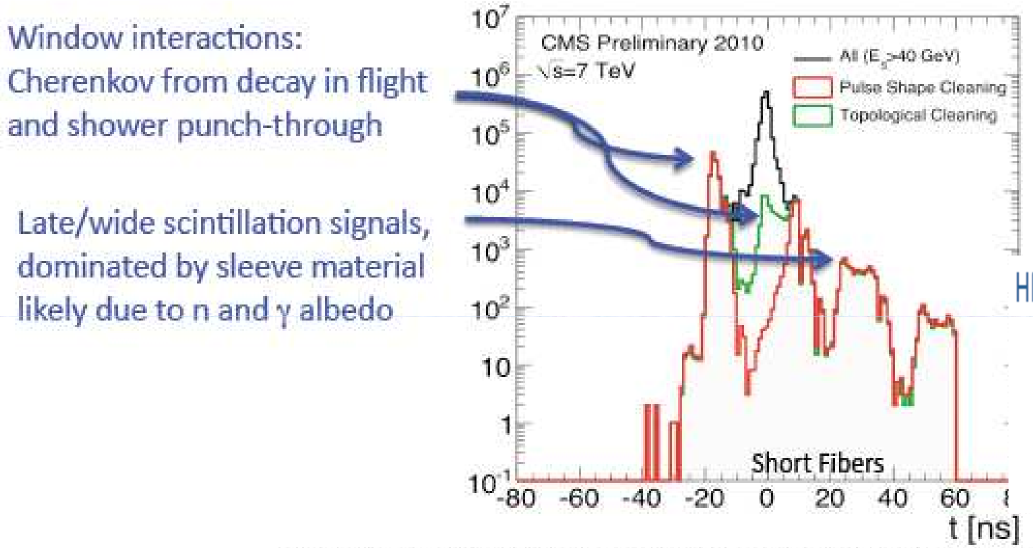
- Signals from approximately 71,000 individual scintillating tiles are brought to the edge of the calorimeter by fibers
- Compact size and high gain of the SiPM allows smaller grouping of fibers (even individual fiber)
- Can provide information on the energy profile with longitudinal depth segmentation, and improved timing

Depth Segmentation: Separate Layer-0 Readout

- Layer-0 is different: No absorber in front, x2.4 thickness and 20% brighter scintillator (~3 nominal layers in MIP sensitivity)
- Designed to catch shower tails from low energy pileup – originally designed to be readout separately
- Can provide in situ MIP calibration – avoiding biases due to dead material between ECAL & HCAL
- Single layer gives good timing

HF Calorimeter Upgrade

– In collision data anomalous signals contaminate the MET tail
– Dominant sources: Cherenkov in PMT windows, and scintillation in light guides
– Both effects extensively studied in test beam and at P5. Both addressed in upgrade



Background identified by cleaning algorithms in low occupancy min bias data
Algorithms: L/S isolation, pulse shape/timing

Timing plays a critical role

HF Cherenkov signals are fully contained in 10 ns

- Can provide a very powerful handle for identifying background signals (Example: signals from window interactions arrive ~4-6 ns early)
- Currently seriously limited by 25ns BX sampling

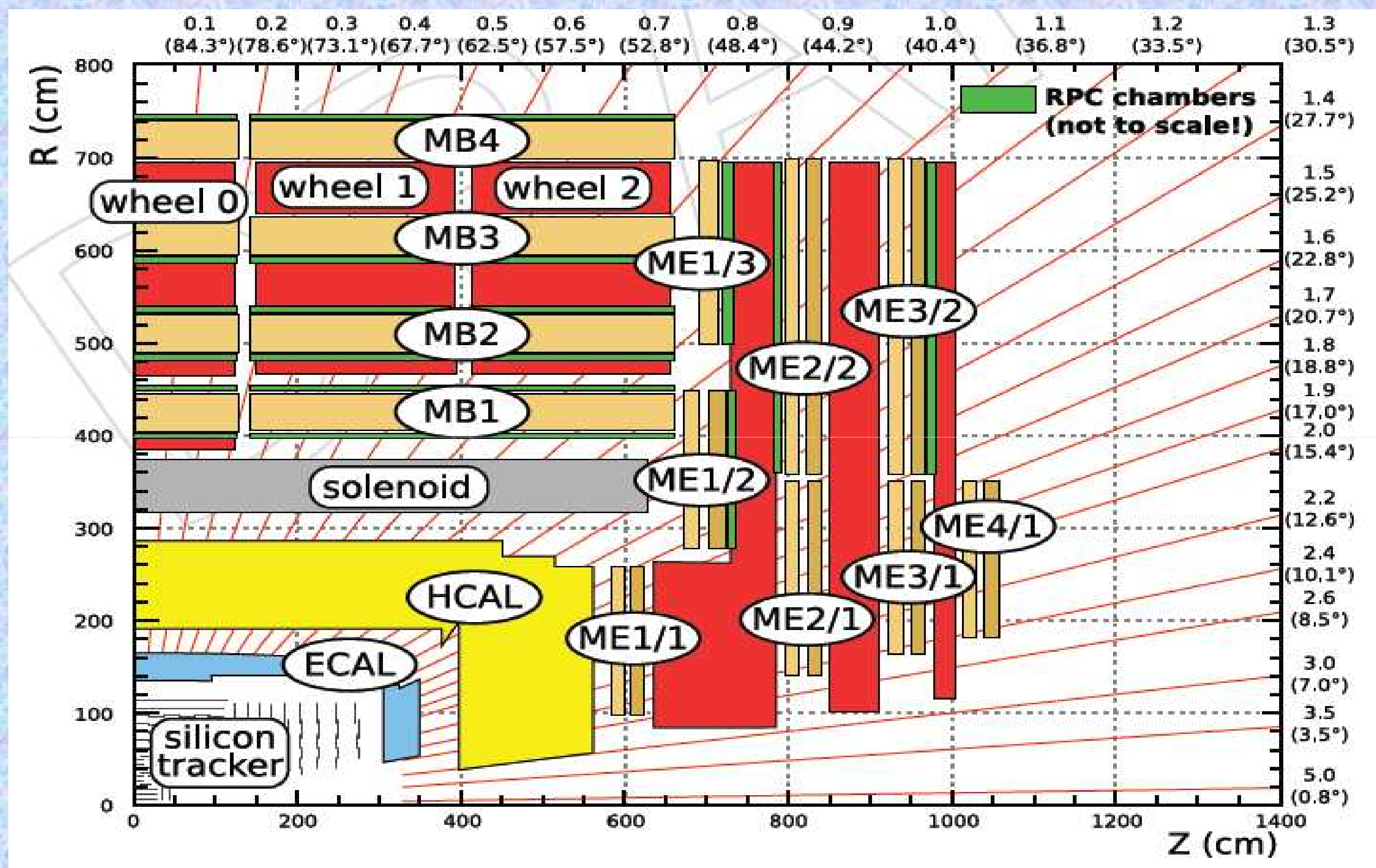
2012 { – New PMTs: 4-channel, thin window, 45% peak QE (2x existing PMTs)
– Reduces energy from Cherenkov interactions by a factor 5

2016 { – 2-channel readout gains another factor 20. Add timing measurement
(with electronics upgrade)

Muon System Upgrades

Motivation: Complete Muon Detector (4th layer) to achieve redundancy for muon trigger rates

3 types: Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)

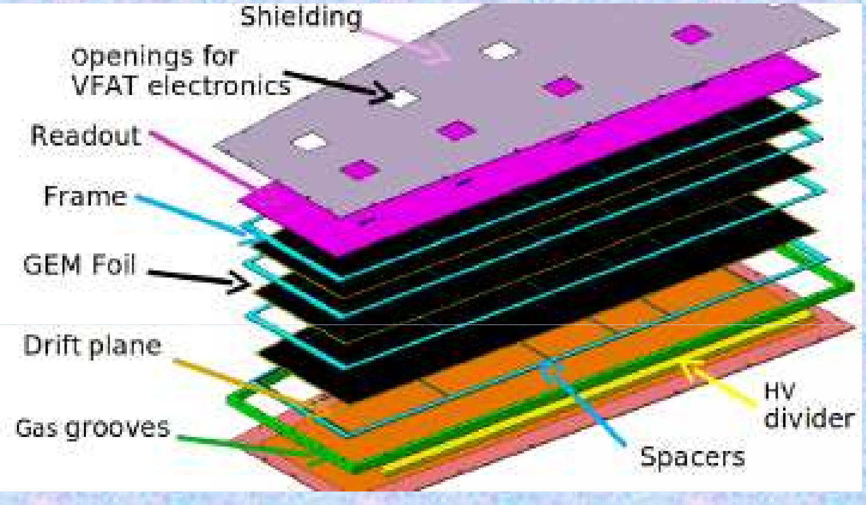


- **CSC:** only part (ME 4/1) of the 4th endcap station installed → complete 4th station (ME 4/2)
- **RPC:** construct & install the 4th RPC station (RE4)
- **MPGD/GEM (?):** add redundancy in the region $1.6 < h < 2.4$ not covered of the RPC

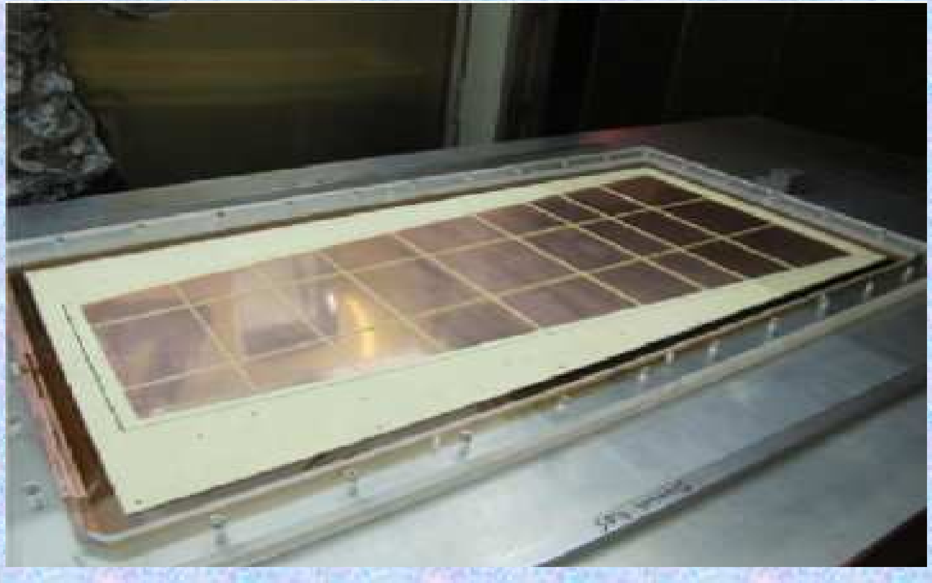
Large-Area GEM Detectors for CMS Muon System

GEM/CMS Collaboration (~20 institutes, 100 people)

GEM feasibility studies for extension of CMS Muon System: high-eta (h > 1.6) upgrade



First prototype of trapezoidal shape with triple GEM
Total area of 99 x 45-22 cm^2 ~ 1/3 m^2
Divided into 4 eta regions readout with radial strips



TWO-SECTORS TRIPLE-GEM PROTOTYPE FOR TOTEM T1 UPGRADE ($60x60\ cm^2$)

Estimated Particle Rates in CMS Muon System

RPC Region	Rates Hz/cm^2 LHC (10^{34} cm^2/s)	High Luminosity LHC	SLHC ?? (10^{35}cm^2/s)?
RB	30	Few 100	kHz
RE 1, 2, 3,4 $\eta < 1.6$	30	Few 100	**kHz**
Expected Charge in 10 years	0.05 C/cm^2	0.15 C/cm^2	~ C/cm^2
RE 1,2,3,4 $\eta > 1.6$	**500Hz ~ kHz**	**Few kHz**	**Few 10s kHz**
Total Expected Charge in 10 years	(0.05-1) C/cm^2	few C/cm^2	Few 10s C/cm^2

Personal remark : MPGD can "enter" anytime if particle fluxes in HL-HLC are higher that can be tolerated by the current Muon Detector technologies (e.g. for RPC < 1 KHz)

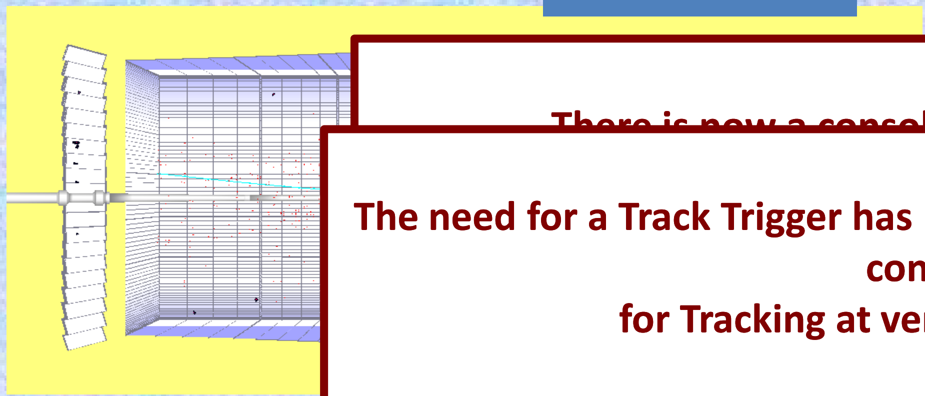
Phase II R& D

> 2020

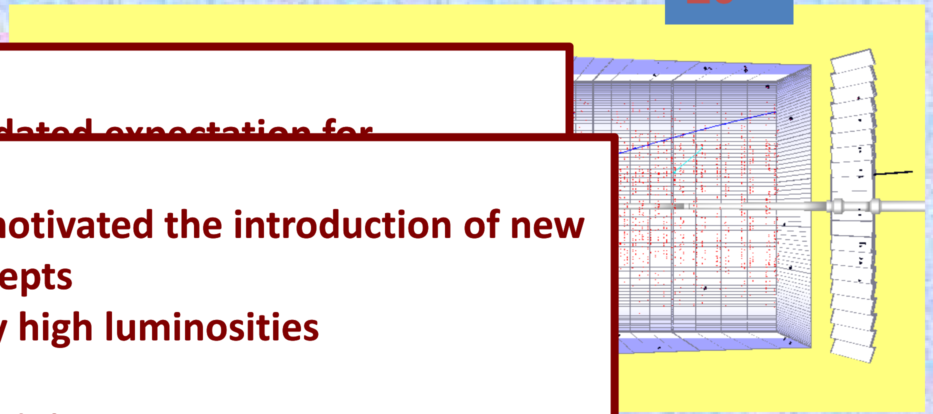
LHC Operation: From Phase I to Phase II (> 2021)

Motivation for L1 Tracking Trigger:

10^{32} cm^{-2} s^{-1}



10^{33}

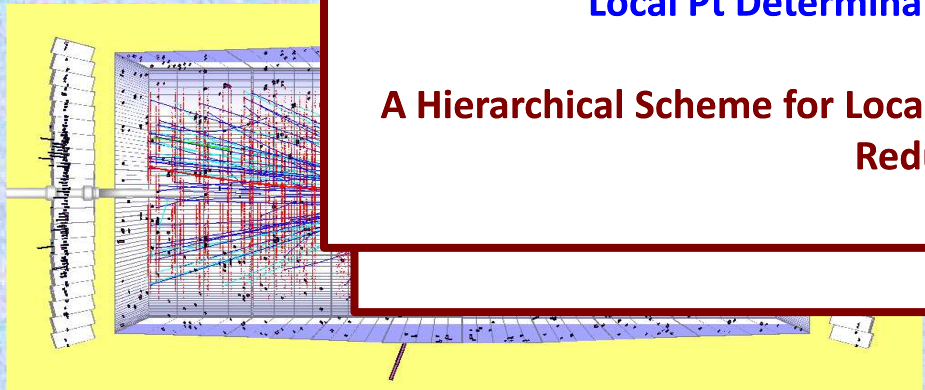


There is now a consolidated expectation for

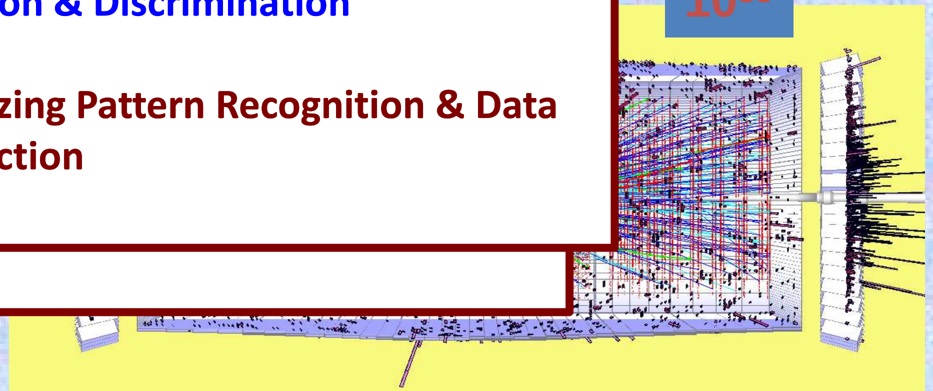
The need for a Track Trigger has motivated the introduction of new concepts
for Tracking at very high luminosities

Pt Module:
Measure Locally both track position and direction
Local Pt Determination & Discrimination

A Hierarchical Scheme for Localizing Pattern Recognition & Data Reduction

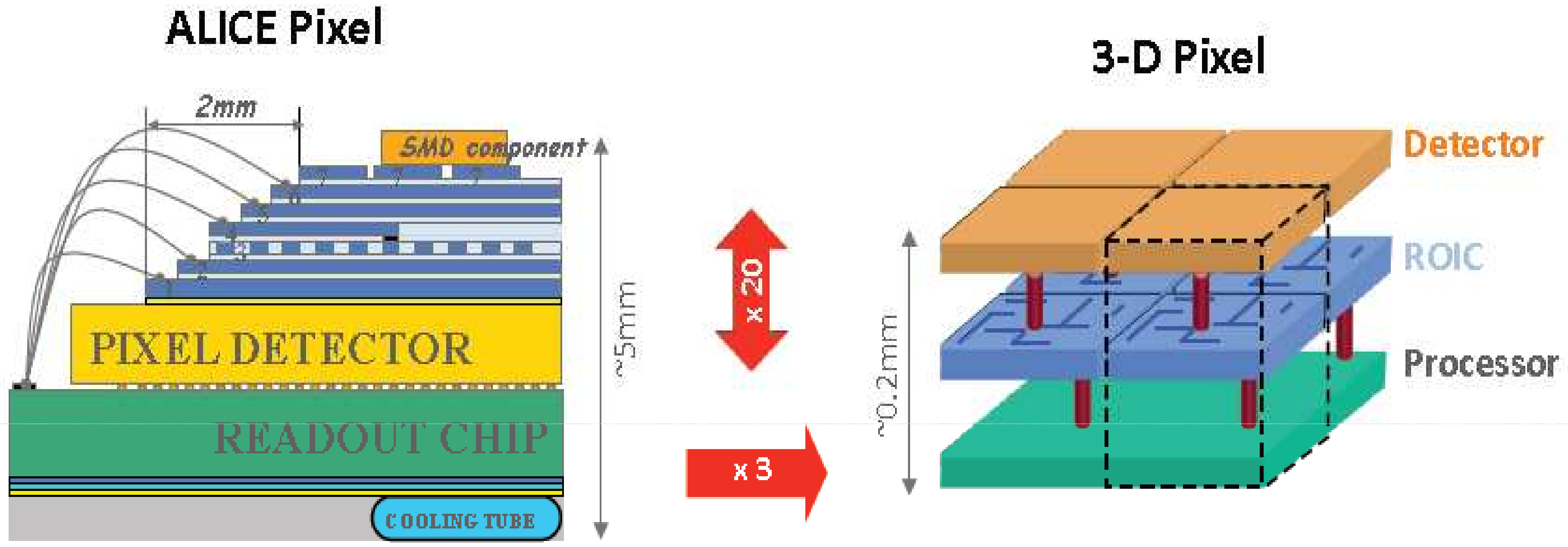


10^{35}



At LH-LHC (Phase II) faces new challenges, in particular for both Tracking and Triggering

Integration of Functionality



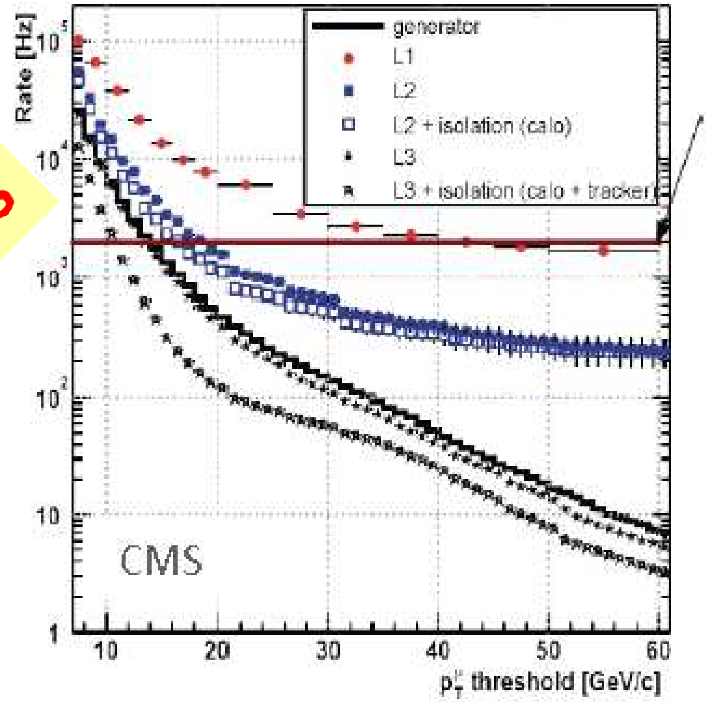
- 3D Silicon Technology: vertical integration of thinned and bonded silicon tiers with vertical interconnects between the IC layers
- Technology driven by industry; offers potential for transformational new detectors
- Through integration low power, very short interconnects, local processing power increased substantially (trigger)
- Possibilities limited by imagination if technology is industrialized

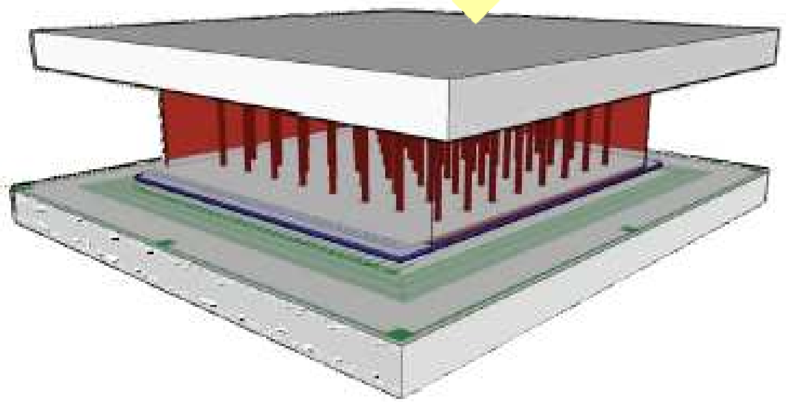
CMS Project: Integration of Detector and Electronics

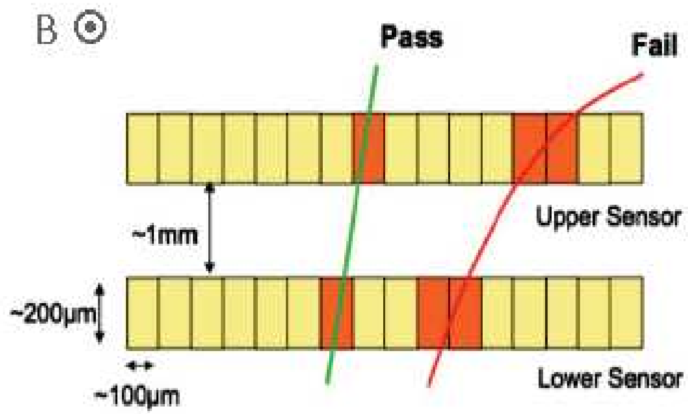
- High rate environments: at the sLHC triggers saturate the available bandwidth
  - Muon trigger rate at L1 > 20 kHz at $L=10^{35}\ cm^{-2}s^{-1}$, flat in p_T
- A solution: tracking information available at L1
  - Collect info from 10^8 pixels in ... of silicon at 40 MHz for tri...
- An implementation: ...dules that provide a mome... ...ter

Upgrade of L1 Track-trigger →
Potential interest in IRFU/CMS

Muon rates at $L=10^{34}\ cm^{-2}s^{-1}$







Forward Calorimetry Technology R&D

Barrel performance degradation will be insignificant when compared to other effects, such as the equivalent noise introduced into the energy measurements due to the pileup at HL-LHC.

CMS Taskforce activities have led to a consensus that most of the elements of forward calorimetry will require upgrade or replacement > 2020:

- I. R&D specialized to the best possible electromagnetic resolution (select rad. hard crystal to replace PbWO4)

II. R&D specialized to producing a compensating forward calorimeter (e.g. equalize e/h by using detector layers combining scintillation light emission and detection and Cerenkov light)

- III Detector R&D to develop radiation hard components for I and II

CMS Upgrade Plans & Outlook

	System	2010-2020	2020-2030
2017	Pixel	New Pixel Detector	
	Tracker		em (incl Pixel)
2013 2017	HCAL	HI	:?
	ECAL	Trig	
2013 /2017	Muons	ME4/2, ME1/1 ,RPC endcap, some CSC Electronics	Electronics replacement
2017	Trigger	HCAL/RCT/GCT to mTCA	Complete replacement

Future Upgrade Meetings:

- **CMS Upgrade Workshops→ 7-10 Nov 2011**
- **HL-LHC workshop → 16-18 Nov 2011**
- **LHC Chamonix 2012 → Janv 2012**

• **Upgrade opportunities may "open-up" depending from LHC/CMS Performance**