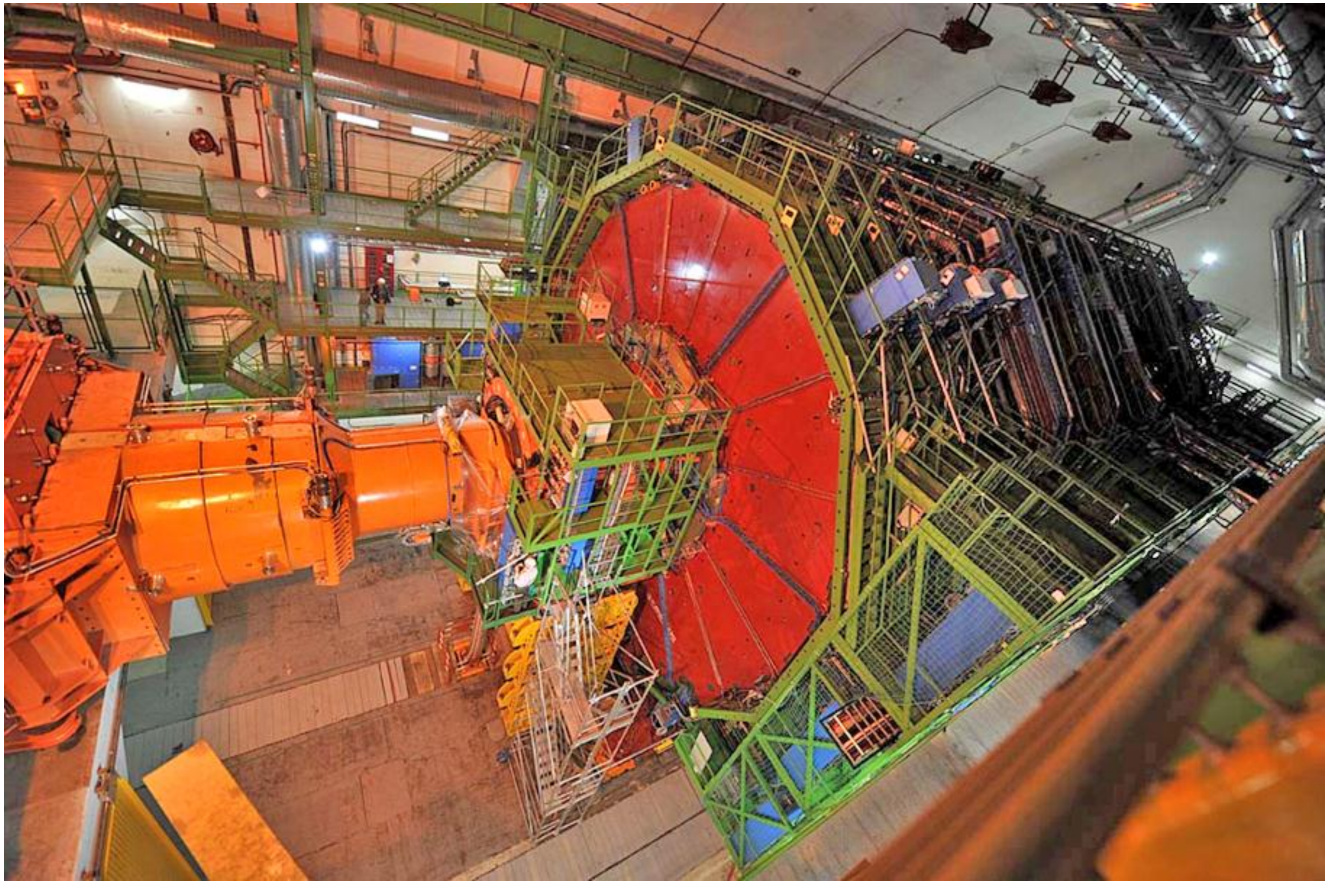
The CMS Upgrade



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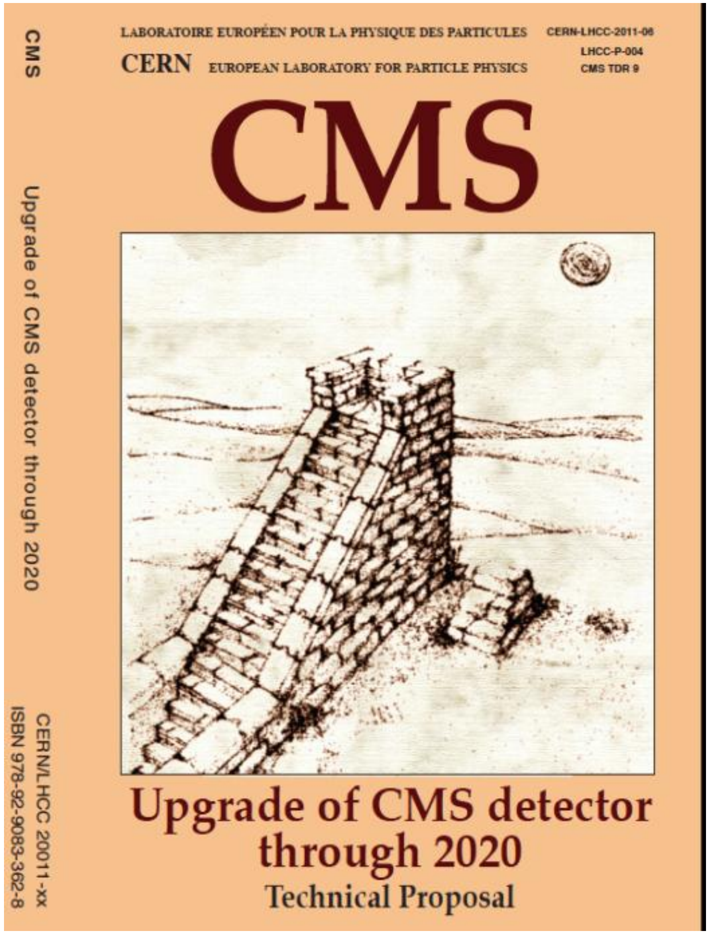
For the CMS Collaboration

Outline

- **LHC performance**
- **LHC luminosity upgrade plan**
- **The physics goals of the upgrade**
- **Challenges of high luminosity**
- **The CMS upgrade plans for Phase 1**
  - **Muon System**
  - **Pixel Detector**
  - **Hadron calorimeter**
  - **Trigger**
- **The issues for Phase 2, after 2020**
  - **Tracking Trigger**
  - **Forward Calorimetry**
- **Conclusions**

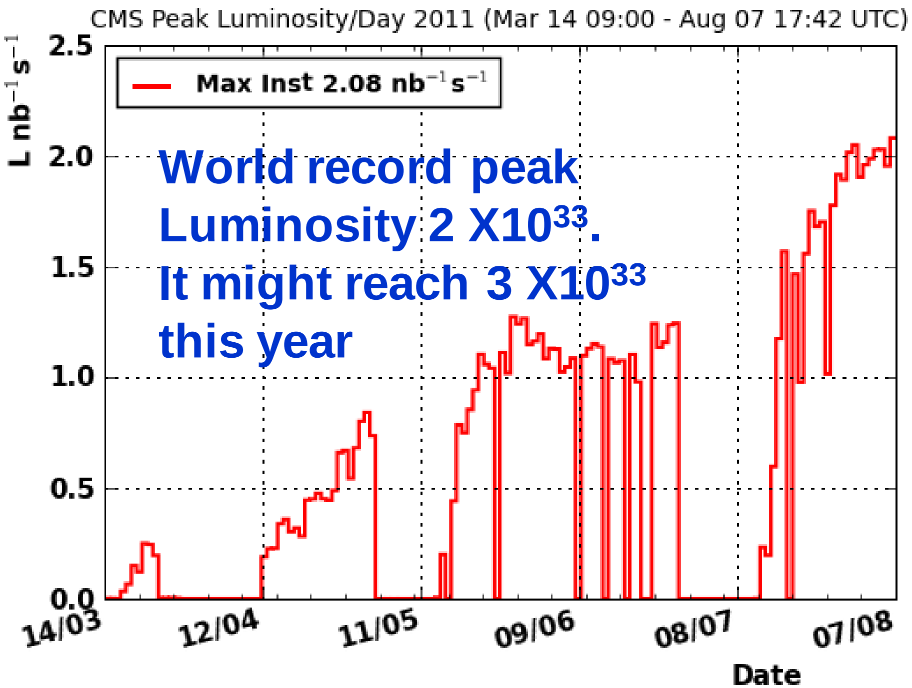
The Technical proposal

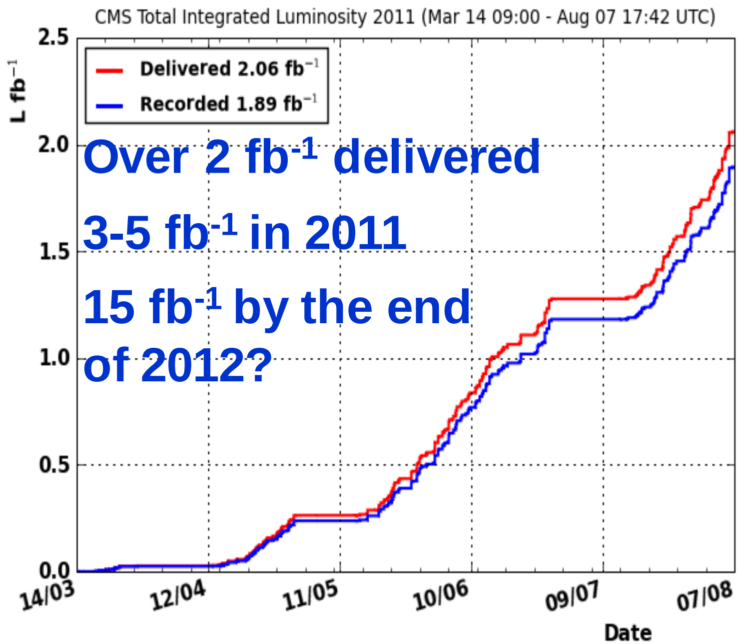


http://cdsweb.cern.ch/record/1355706?ln=en

Spectacular machine performance

- **Great 2010:**
  - **pp achievements: 368 colliding bunches, 150 ns spacing, peak luminosity 2 $\times 10^{32}$ cm^{-2} s^{-1}, integrated luminosity 46 pb^{-1} /experiment**
  - **Pb-Pb: ~9.5mb^{-1} /experiment delivered.**
- **Exceptional 2011: 1380 bunches , 50 ns spacing**
- **The average fraction of operational channels per CMS sub-system >99%. Overall data taking efficiency ~92%.**





LHC upgrade timeline

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — Long shutdown 1: LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Long shutdown 2: Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

PHYSICS OF DISCOVERY

~2021/22 — Long shutdown 3 to reach the High-luminosity LHC ($5x10^{34}$ cm^{-2} s^{-1}). New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

HL-LHC: 3,000 fb^{-1} for PRECISION measurements

2030 — High energy LHC, e^+e^- collider, ... ?

From Bertolucci at PLHC Perugia

Prediction in 2010

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				0.07
2011	3.50	0.25	2.00	796	8.0E+10	6.4E+13	36.0	1.886E+32	1.2643				1.04
LS 1													1.0
2013	6.50	0.20	0.55	796	1.15E+11	9.2E+13	96.1	2.632E+33	17.6429	45.3	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
LS 2											0.0	0.0	66.3
2017	7.00							1.000E+34	19.0000	216.0	240.0	51.8	118.1
2018	7.00							1.701E+34	32.3251	411.6	240.0	98.8	216.9
2019	7.00							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							5.390E+34	102.4060	1350.5	220.0	297.1	1884.2
2027	7.00							5.390E+34	102.4060	1350.5	220.0	297.1	2181.3
2028	7.00							5.390E+34	102.4060	1350.5	220.0	297.1	2478.4
2029	7.00							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

Surpassed by x10

Almost all of PHASE 1 running expected at peak $L>L_{nominal}$

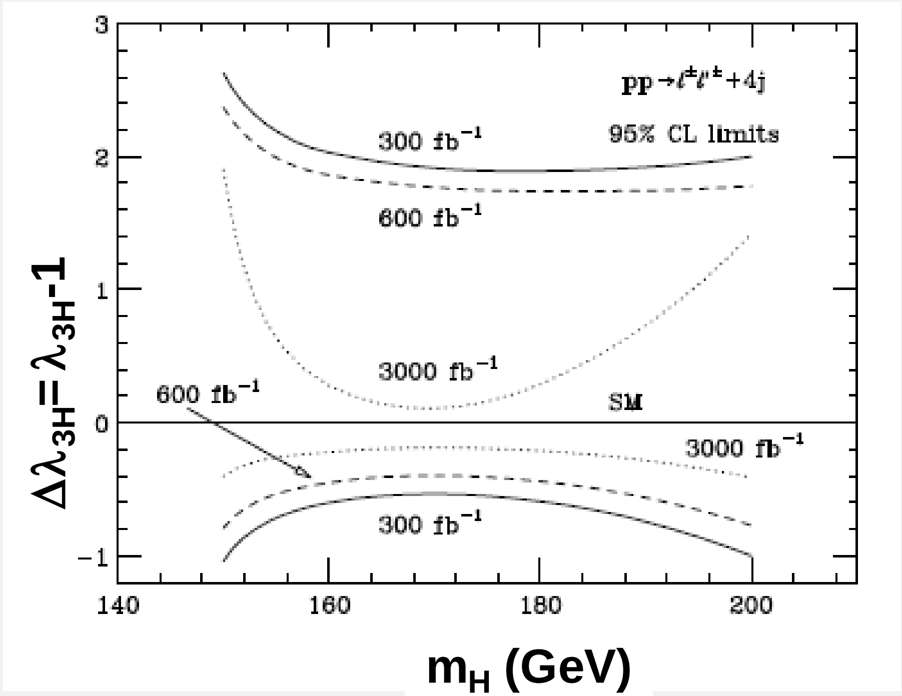
In PHASE 2 may run with 50 ns bunch interval, so pile up may be 200!

Upgrade Physics Goals

More luminosity allows to move from exploration to precision studies

- **Higgs physics**
  - **Higgs anomalous couplings to SM fermions and bosons**
  - **Higgs self-couplings**
  - **Rare Higgs decays; multi-Higgs (MSSM or not)**
  - **Dynamics of EW symmetry breaking**
- **Electroweak physics**
  - **anomalous gauge boson self-couplings**
  - **top quark flavor violating decays**
- **Supersymmetry**
  - **extend the mass gluino/squarks reach to 3 TeV.**
- **Extra dimensions, New forces**

Example: Higgs self-coupling sensitivity

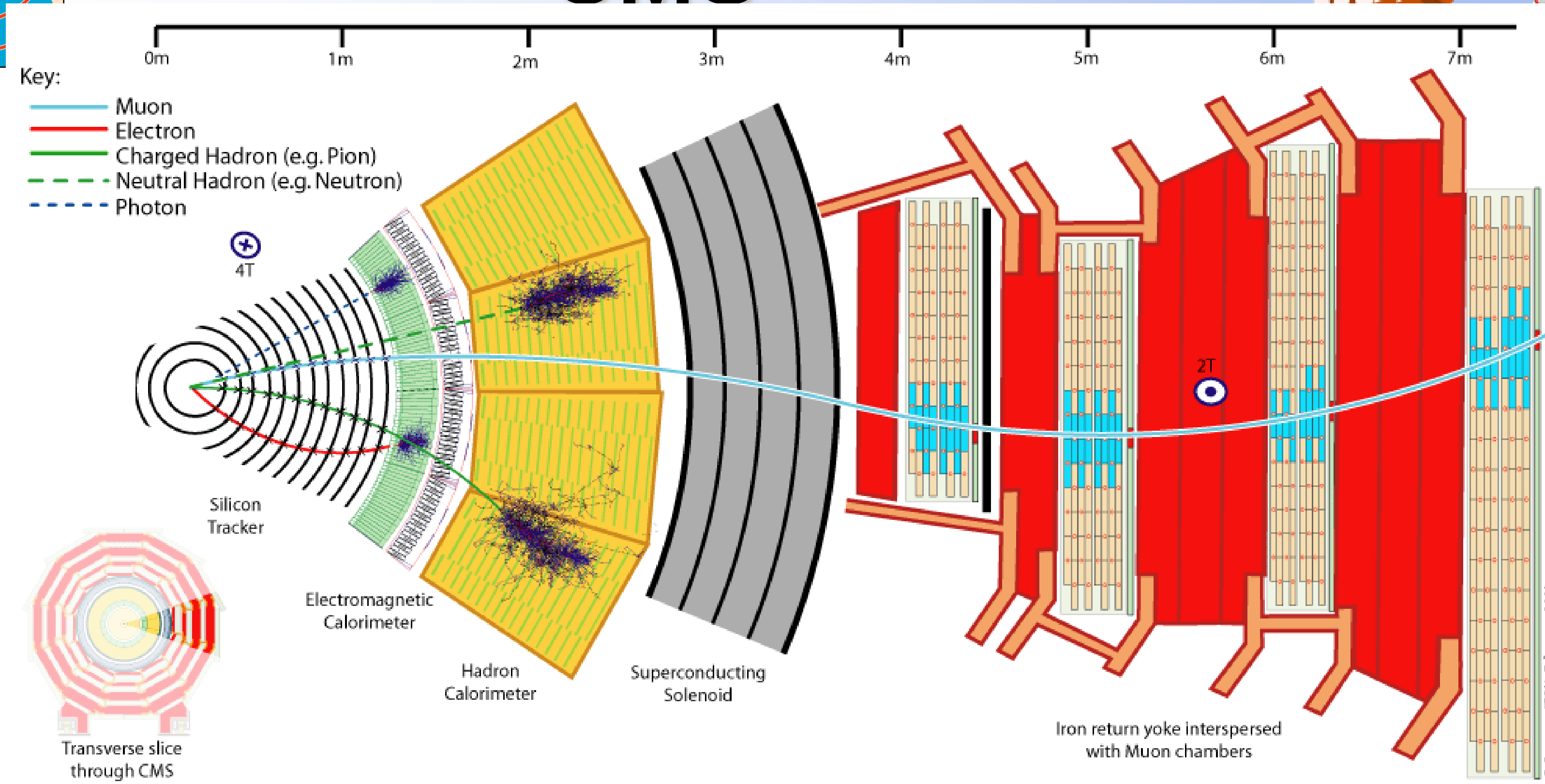


Luminosity upgraded LHC:

With 300 fb^{-1} λ_{3H}=0 can be excluded at 95% CL

With 3000 fb^{-1} λ_{3H} can be determined to 20÷30%

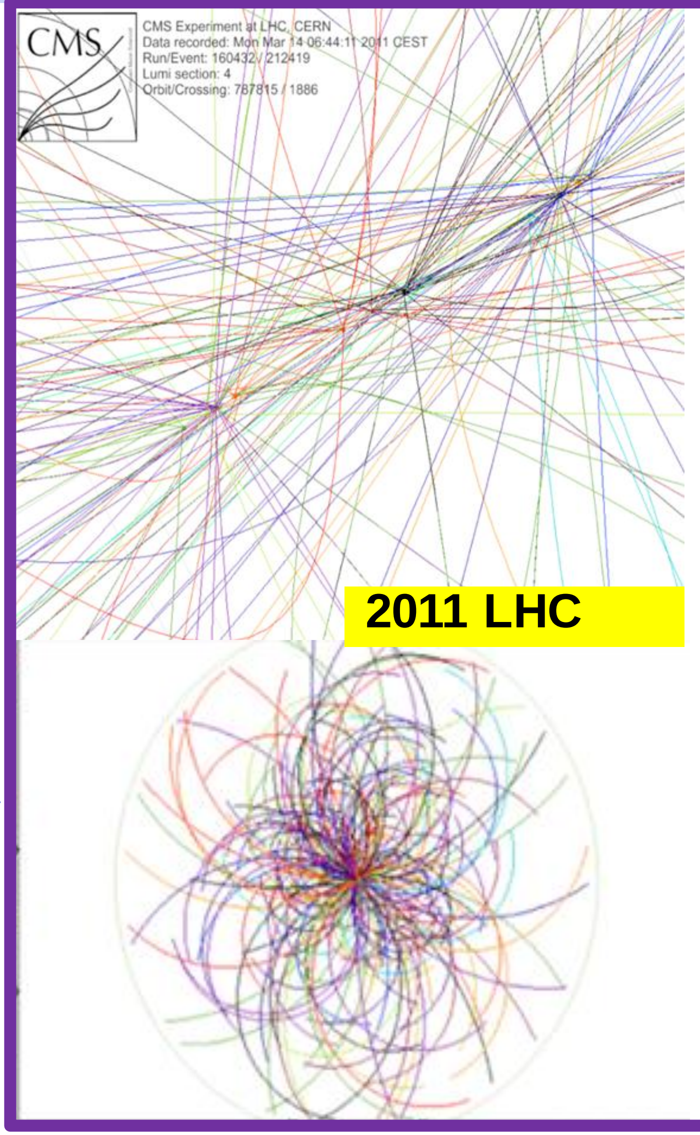
CMS



- **Excellent momentum and secondary vertex resolution provided by 200 m^2 all silicon tracker in 3.8 T B field**
- **High resolution PbWO4 crystal EM calorimeters (~ 0.5% @ E_T ~ 50 GeV) measure energy and position of electrons and photons**
- **Brass scintillator sampling hadronic calorimeters for jet energy measurements $\sigma(E)/E=100\%/\sqrt{E}+0.05$**
- **Muon spectrometer (+ tracker) identifies and measures muon momentum (dp/p<1% @ 100GeV and <10%@1 TeV)**
- **Neutrinos inferred through measurement of missing transverse energy**

Detector Upgrade issues

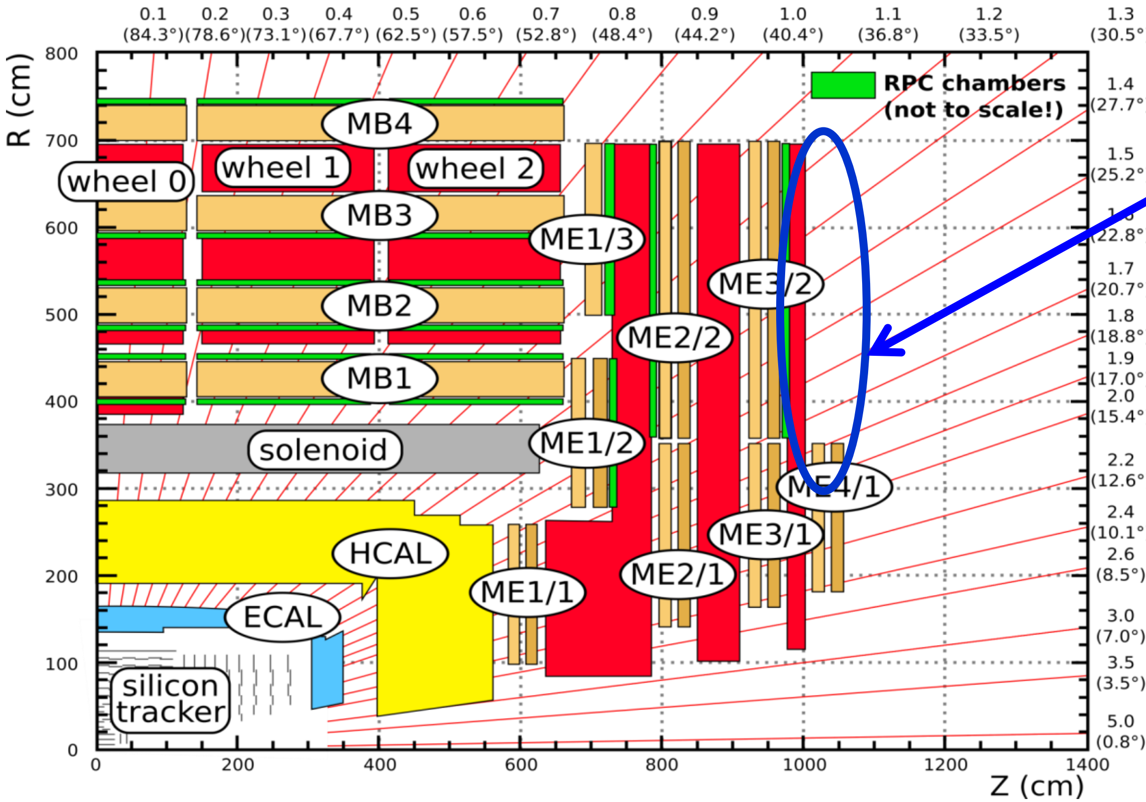
- **Increase number of interactions/crossing leads to:**
  - **Trigger performance degradation**
  - **Increase occupancy & more complex event reconstruction at all levels**
  - **Data losses due to latencies & limited buffering**
  - **Increase in radiation damage worsening the response of detectors in the innermost layers and in forward regions close to the beam**
  - **Decreases discrimination of electrons from jets**
  - **Material budget becomes critical to reduce occupancy and maintain momentum resolution**
- **CMS plans to upgrade the detectors to maintain/improve the physics performance**
  - **Most data will be collected with peak luminosity beyond the one for which the detector was designed (10^{34})**
  - **Take advantage of new technology to achieve better performance**
  - **Limit deterioration of performance due to detector's aging**



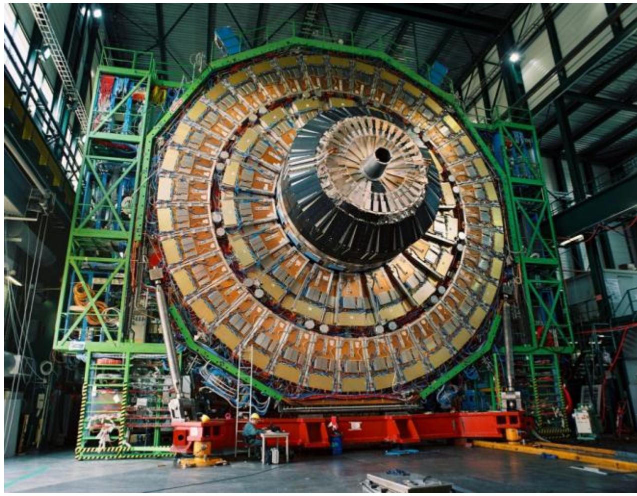
CMS Improvements and Upgrades Timeline

Shutdown	System	Action	Result	Physics
LS 1	Muon (ME42,ME11)	RPC and CSC (Complex YB4 installation) New electronics	Improved μ trigger and reconstruction ($1.1<\lvert\eta\rvert<1.8$, $2.1<\lvert\eta\rvert<2.4$)	W acceptance WH, $H^{\pm} \rightarrow \tau\nu$
LS 1	Hadron Outer	Replace HPDs with SiPMs to reduce noise	Single μ trigger Tails of very high p_T jets	Muons from τ $Z/H\rightarrow\tau\tau\rightarrow\mu X$
LS 1	Hadron Forward	Install new PMT to reduce window hits	Forward jet tagging Improves MET	Vector-boson fusion H
LS 1	Beam Pipe	Install new beam pipe	Easier pixel installation	b-tagging
LS 2	New Pixel system	Low mass 4 Layers, 3 Disks with new ROC	Reduces dead time Improves b-tag.	$H\rightarrow bb$, SUSY decay chains
LS 2	HCAL Barrel and Endcap uTCA trigger	Replace HPDs with SiPMs for longitudinal segmentation New electronics	Reduces pileup effects Improves MET Improves τ, e, γ clustering and isolation	SUSY $H\rightarrow\tau\tau$ $H\rightarrow ZZ\rightarrow ll\tau\tau$
LS 3	TRACKER New Trigger Endcap Calo.	Replace tracker Replace trigger ?	Maintain performance at high SLHC Lumi	Guided by early discoveries

CMS Muon Detector Issues



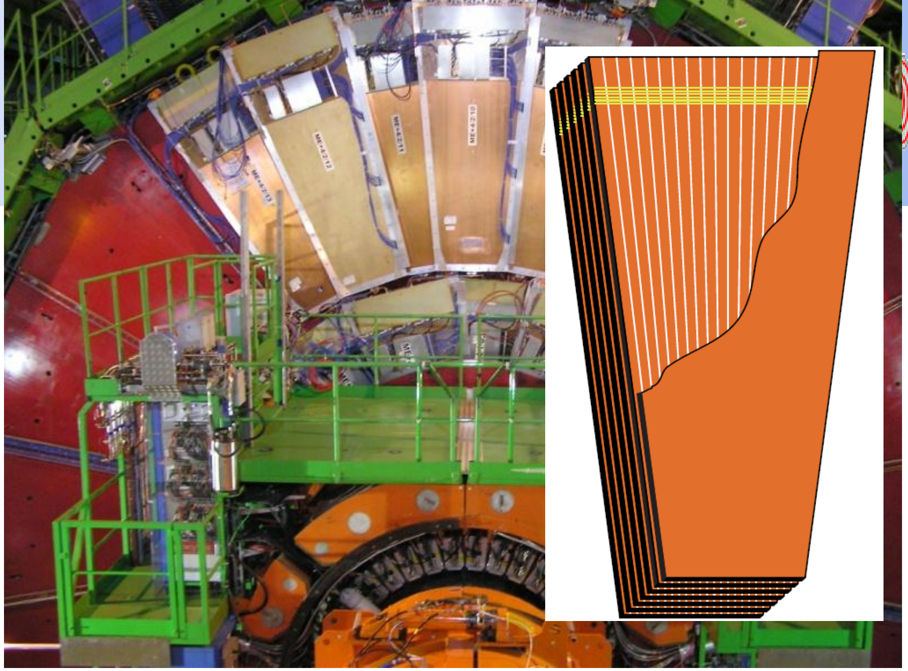
- The CSCs and RPCs were descoped in the ENDCAP
  - Missing 4th layer at η=1.2-1.8 leads to muon pt mismeasurements when using 2 out of 3 at high pileup
  - Triggers problems at 2×10^{34} cm^{-2} s^{-1} at 25 ns bunch crossings (10^{34} cm^{-2} s^{-1} at 50 ns bc)

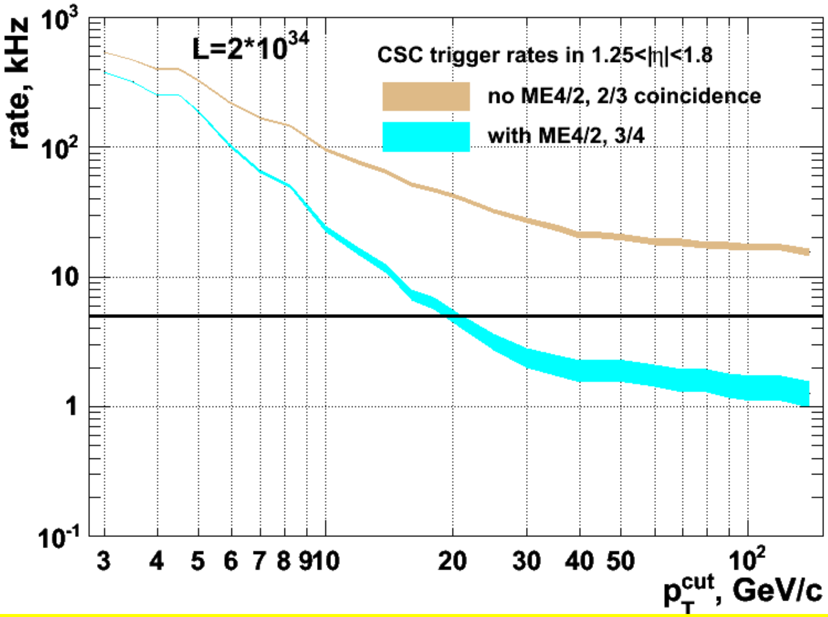


- Three technologies: Drift Tube (DT), Resistive Plate Chamber (RPC), and Cathode Strip Chamber (CSC)
  - Barrel and endcap are covered by two of these subsystems
  - Muon triggers MUST BE PRESERVED

CSC Upgrade

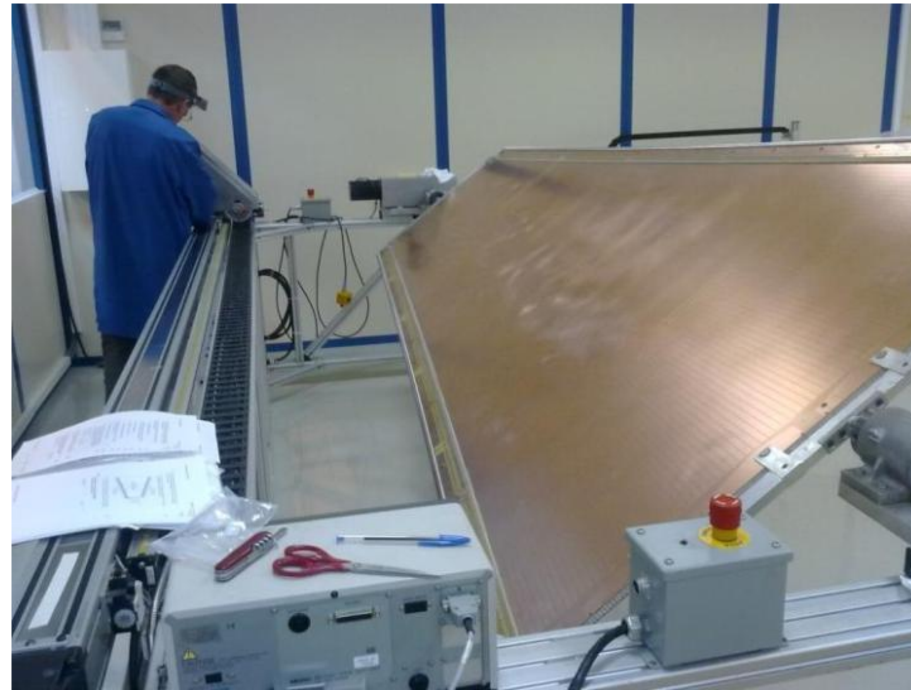
- Build 72 chambers to complete the 4 CSC layer called ME4/2
  - Identical to chambers already built and working well
- This redundancy is important for muon trigger system
  - CSC chambers have 6 planes/chamber ⇒ good ability to reject neutron hits
  - Each station provides a “mini-vector” for calculation of momentum
  - Upgrade: Use of 3 out 4 and 4 out of 4. With ME4/2, the GMT rate is 5 kHz at 20 GeV/c threshold
  - Without ME4/2, trigger rate/threshold is substantially higher
- Similar upgrade for RPCs
  - Complete RE4/2 and RE4/3 rings. Need 144 chambers.





UPGRADE will yield Muon trigger robustness in 1.2<|η|<1.8

CSC production at CERN Building 904 factory



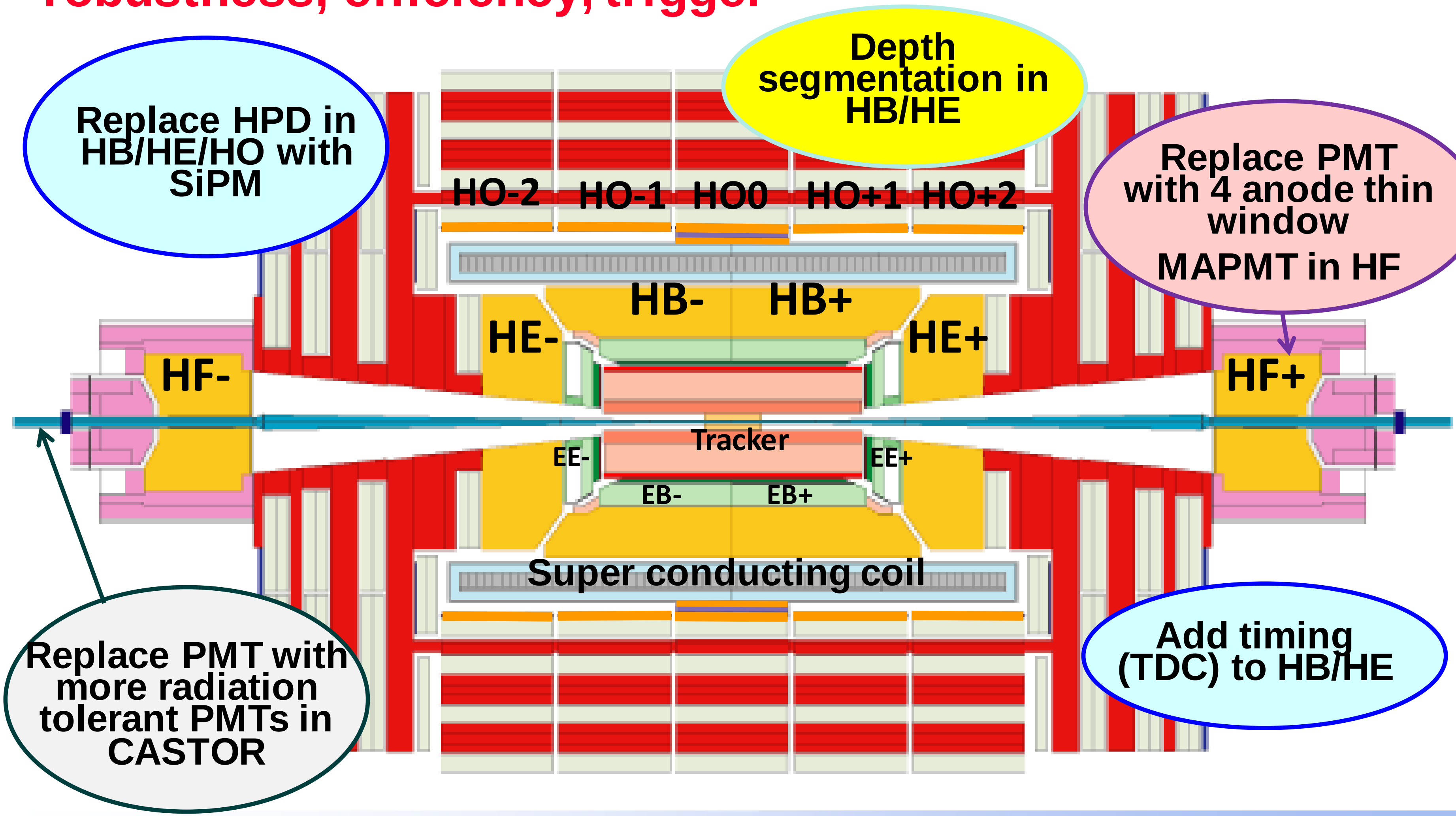
- **Wire winding in one of the Clean room on Building 904**
- **Two anode panels completed and we are ready to wind 3rd**

HCAL Upgrade Motivation

- **HCAL designed for 10 years operation at 10^{34} cm^{-2}s^{-1}**
- **Operation at 2×10^{34} cm^{-2} s^{-1} with 25 ns bunch crossings (or even at 10^{34} cm^{-2} s^{-1} with 50 ns bunch crossings) leads :**
  - **Pileup increase**
  - **Radiation damage especially in highest eta layers of the endcap**
- **Physics impact**
  - **Reduces quality of the hardware-level trigger for a wide range of trigger paths**
  - **Increased luminosity opens up possibilities for measurement of rare processes**
    - **Must mitigate rare backgrounds**
      - **Cosmics, halo, electronics "burps", limitations of the current HCAL transducers, other non-BX-related effects**
    - **Need to preserve accurate MET and JET measurements**
- **The upgrade mitigates current known problems that threaten the physics contribution from HCAL**

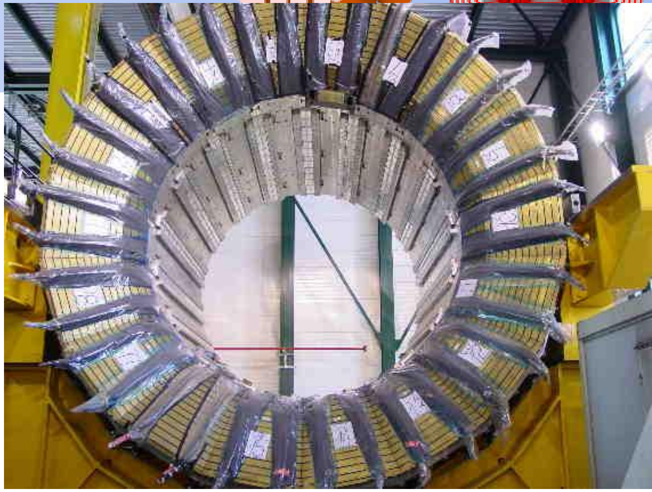
Upgrade to Hadron Calorimeters

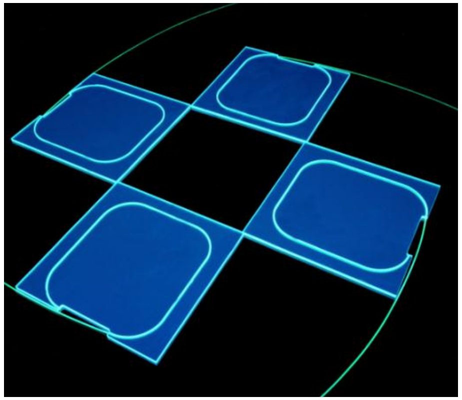
- **Upgrade driven by effect of peak instantaneous luminosity, robustness, efficiency, trigger**

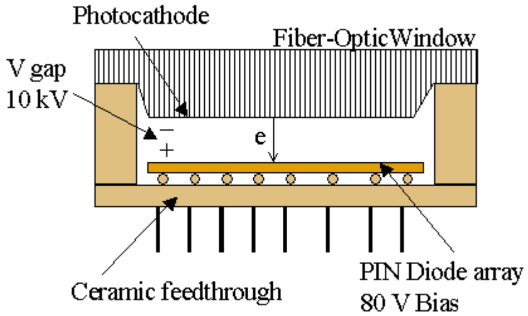


Replacement of HPDs with SiPMs

- **Problems with HPDs (Hybrid Photodiodes)**
  - **Low gain (~1000) and poor S/N prevents**
    - **Splitting signal for longitudinal segmentation and/or for timing output**
  - **High Voltage (7-9 KV)**
    - **Causes breakdown, sometimes destructive**
  - **B-field behavior is complicated**
  - **Current HPDs are no longer manufactured**
- **Replace with SiPMs (Silicon Photomultipliers)**
  - **Array of pixelized Avalanche Photo Diods operating in Geiger mode**
    - **Few mm x few mm with up to 30,000 pixels**
    - **Output proportional to number of photons hitting pixels, delivered as one output/chip**
    - **New technology**

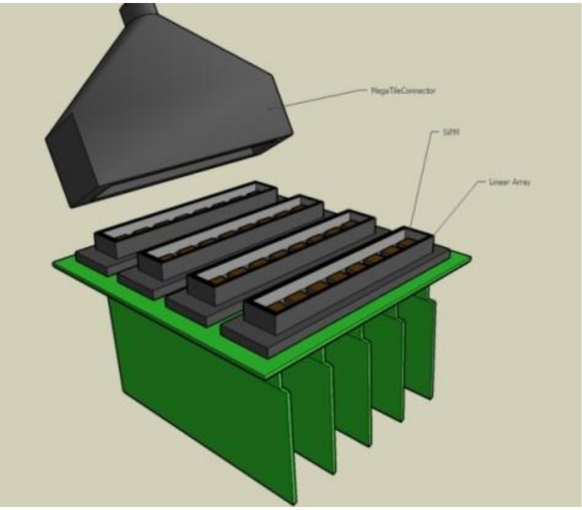


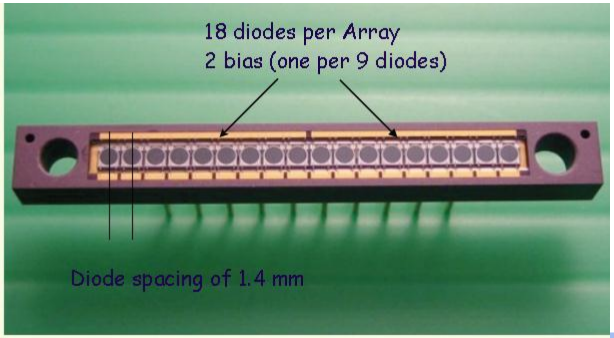




Silicon PM (SiPM)

- **Great advantages over current HPDs:**
  - **Not effected by magnetic fields**
  - **Low voltage (50-100V vs ~7k for HPDs)**
    - **No discharges or ion feedback**
  - **Higher gain (x50-x500) and QE (x2) over HPD**
    - **S/N increases by x10**
  - **“Digital” device. Pixels count photons**
    - **Linear up to high energy where >1 γ/pixel**
  - **Compact and inexpensive**
- **Allows**
  - **Longitudinal segmentation in HB/HE**
  - **Timing determination at hardware level**
  - **Simple implementation**
    - **Fibers from each layer can be brought out in a connector which plugs into a unit containing SiPM arrays**
    - **Output can be ganged electrically**

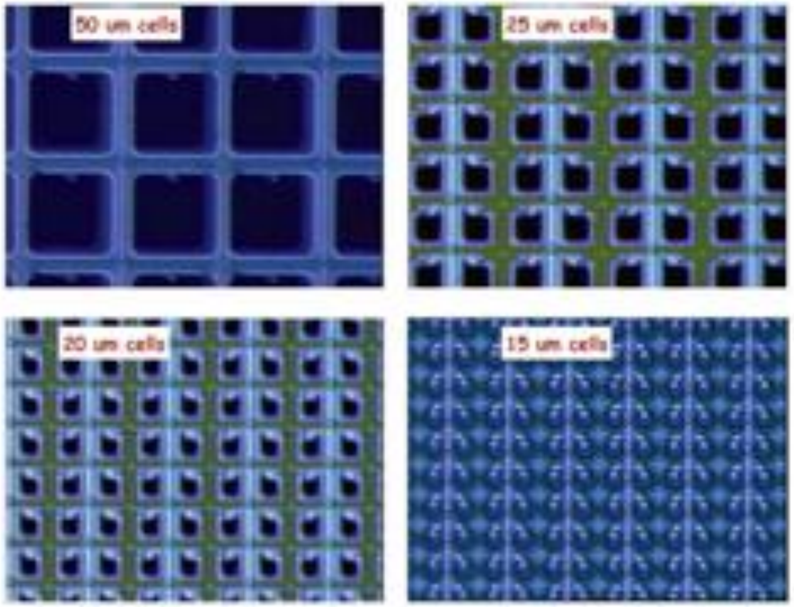


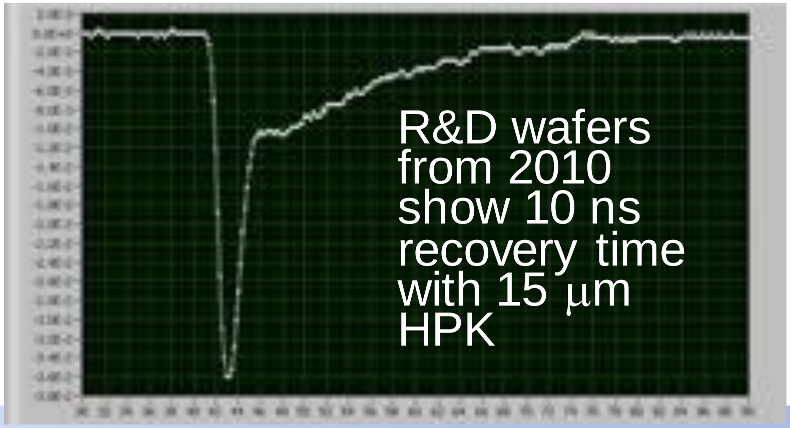


Key Issues for SiPM R&D

- **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 controlled to minimize cell-to-cell variation**
- **Radiation tolerance to prevent long-term performance degradation from leakage current increase**
- **Each individual requirement has been met. We may now have SiPMs that meet them all (still checking radiation hardness)**
  - **Working Zecotek, Hamamatsu and FBK**
  - **Decision expected by end 2011 or beginning of 2012**

HPK

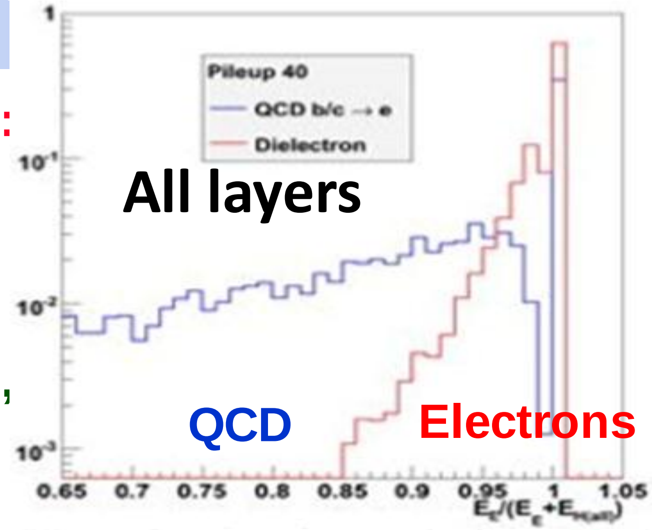


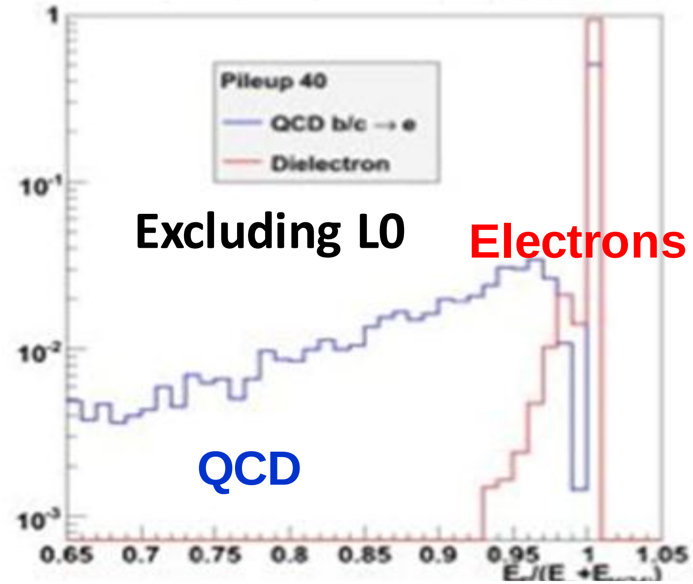


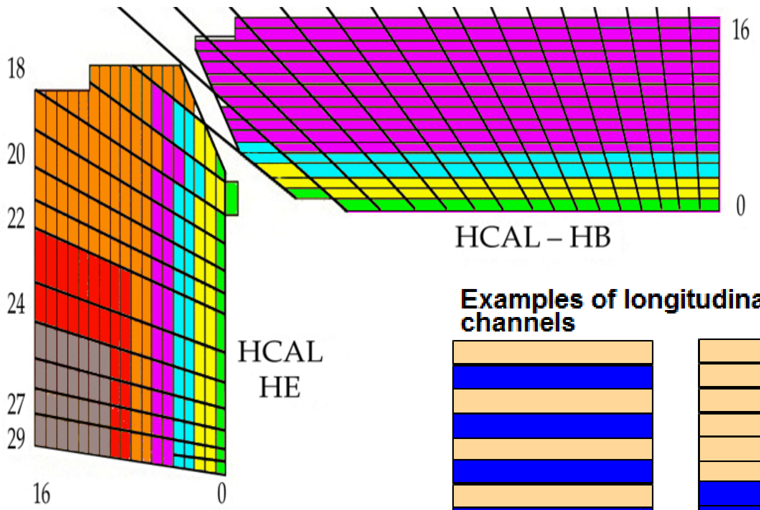
Segmentation in HB/HE

40 pileup events @ 1E34 and 50 ns spacing

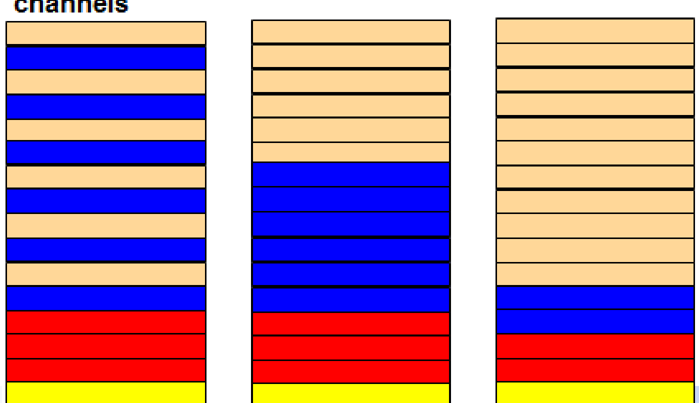
- **SiPMs allows longitudinal segmentation, providing:**
  - **Reweighting of inner layer, important for:**
    - **Correcting for radiation damage to inner layers**
    - **Mitigating underlying event punch-through, important for triggering on isolated electrons**





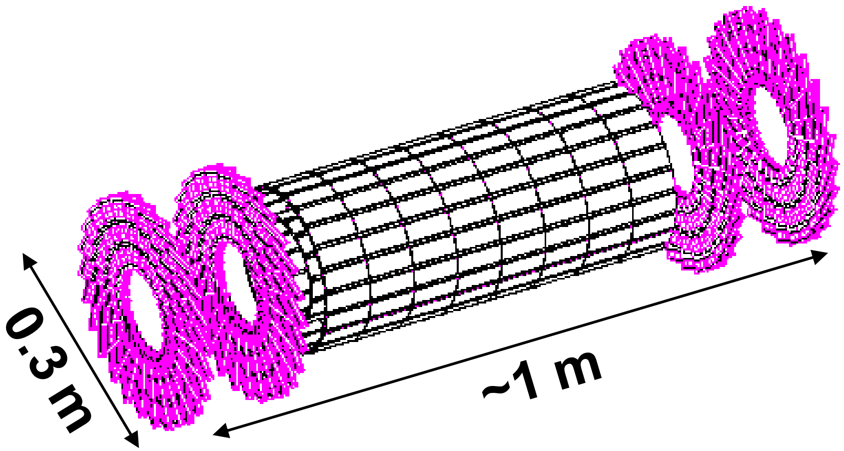


Examples of longitudinal segmentation into 4 channels

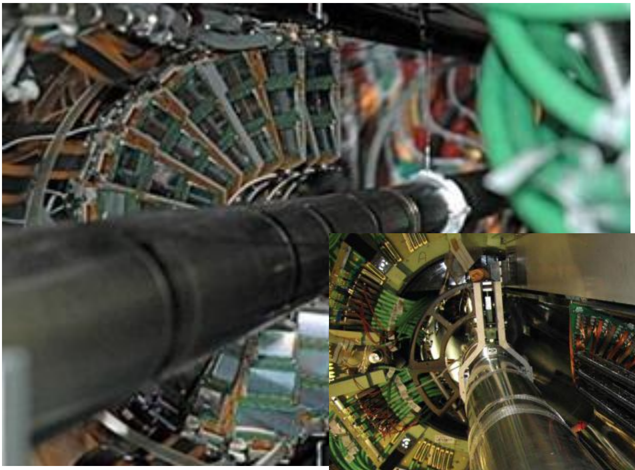


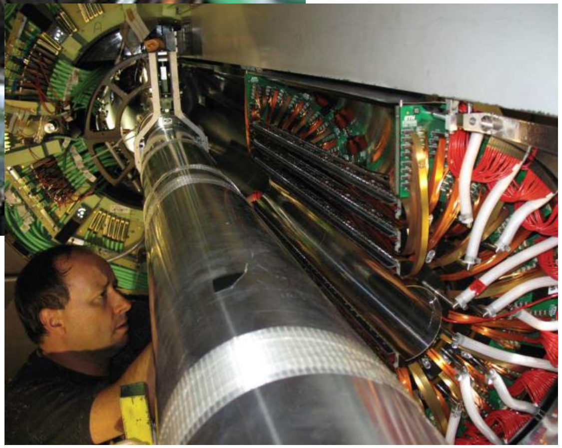
Isolation of e and γ $E_{ECAL}/(E_{ECAL}+E_{HCAL})$ is impacted by pileup in L0.

Pixel system



- **3 barrel layers (BPIX)**
  - **r=4.3, 7.2 and 11 cm**
  - **48 Mpixels (100 μm x 150 μm)**
  - **Total area 0.78 m^2**
- **4 disks (FPIX)**
  - **18 Mpixels (100 μm x 150 μm)**
  - **Total area 0.28 m^2**

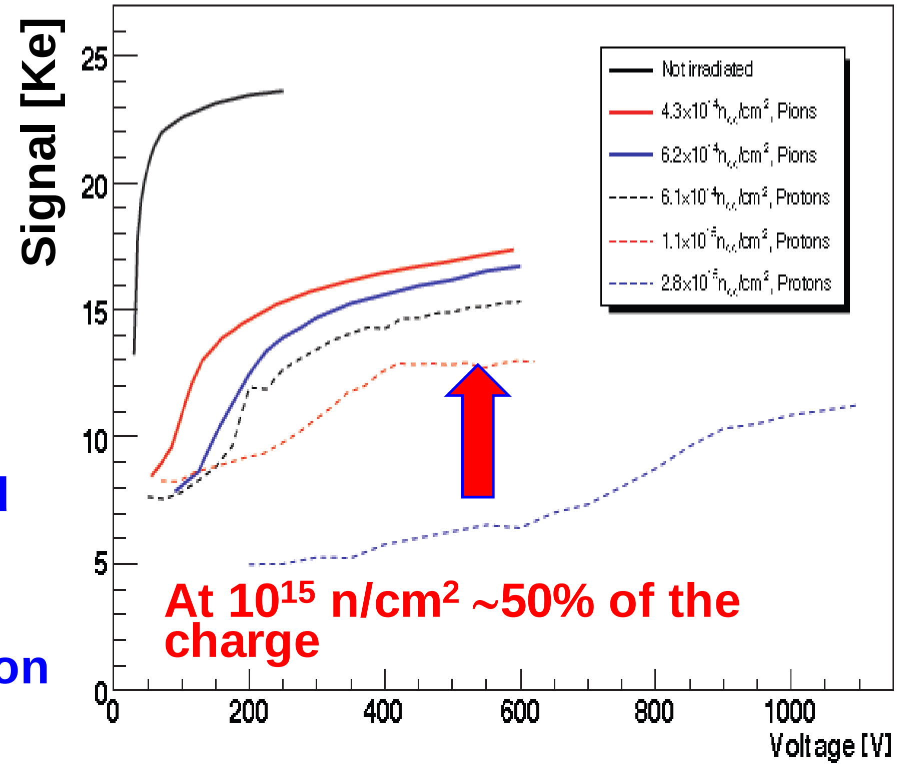




- **Current BPIX and FPIX are working well**
  - **>99% single hit efficiency**
  - **13 μm (25 μm)resolution in r-ϕ (r-z)**
  - **Pixel threshold of 2450 electrons**
  - **Easily removable during shutdowns**
  - **Highly successful as "seed" for rest of tracking**
  - **Finds primary and secondary vertices**
  - **Excellent b-tagging performance**

Problems at High Luminosity

- **Radiation hardness**
  - **Radiation tolerance of n-on-n pixel sensors is $6x10^{14}$ n/cm^2. After $1x10^{15}$ n/cm^2 resolution and efficiency degrade**
- **Buffer sizes ⇒ data losses**
  - **Readout is designed for 10^{34} cm^{-2} s^{-1} with 25 ns bunch crossing. If we run at 10^{34} cm^{-2} s^{-1} and 50 ns bunch crossing, limited buffers on ROC lead to 16% data loss on inner layer**
  - **At $2x10^{34}$ cm^{-2} s^{-1} with 50 ns bunch crossing, >50% of loss of efficiency on inner layer and significant losses on the next two layers**
- **B tagging and seeding capabilities**
  - **Impaired due to efficiency loss and pulse height loss (which degrades charge sharing and position resolution)**



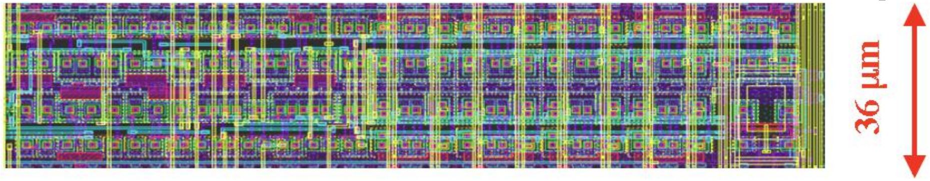
- **Lower material budget could improve performance**

The Pixel Upgrade Plan

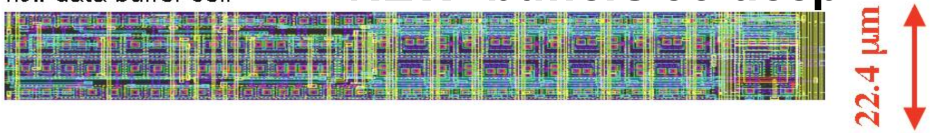
BASELINE: 4 layers and 3 disks/side

- New 250 nm PSI46dig ROC with expanded buffers, embedded digitization to reduce data losses
- Inner layer closer to IR (from 44 mm to 39 or 29 mm)
- Outer layer and disks: closer to Tracker Inner Barrel (160 mm w.r.t 106 mm present detector)
- Major reduction of material (x2 or 3)

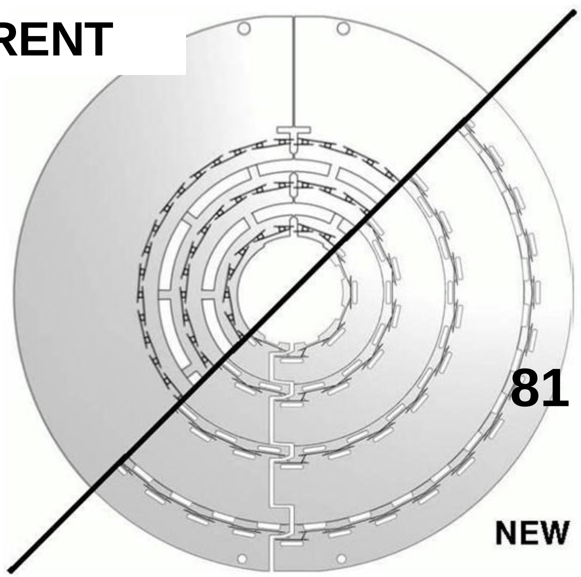
existing data buffer cell **CURRENT buffers 32 deep**

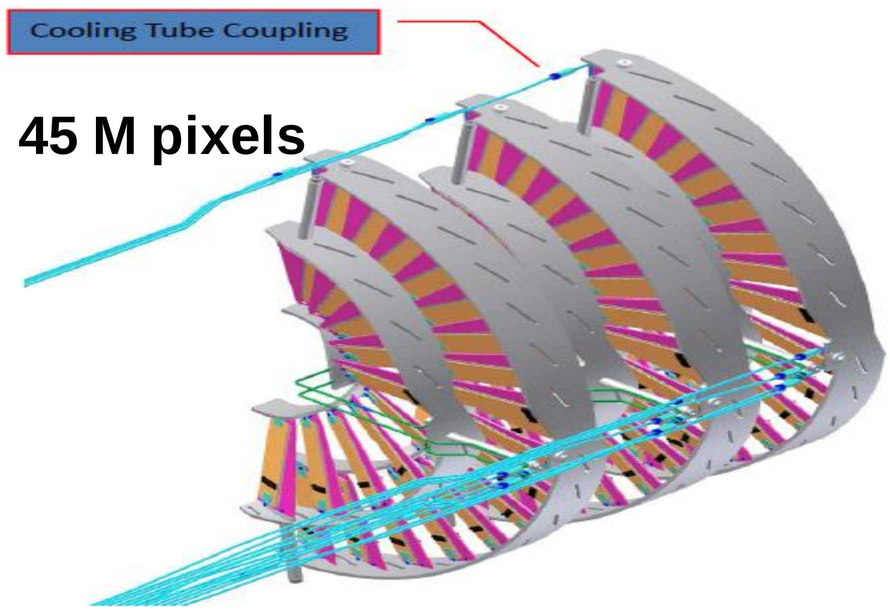


new data buffer cell **NEW buffers 96 deep**



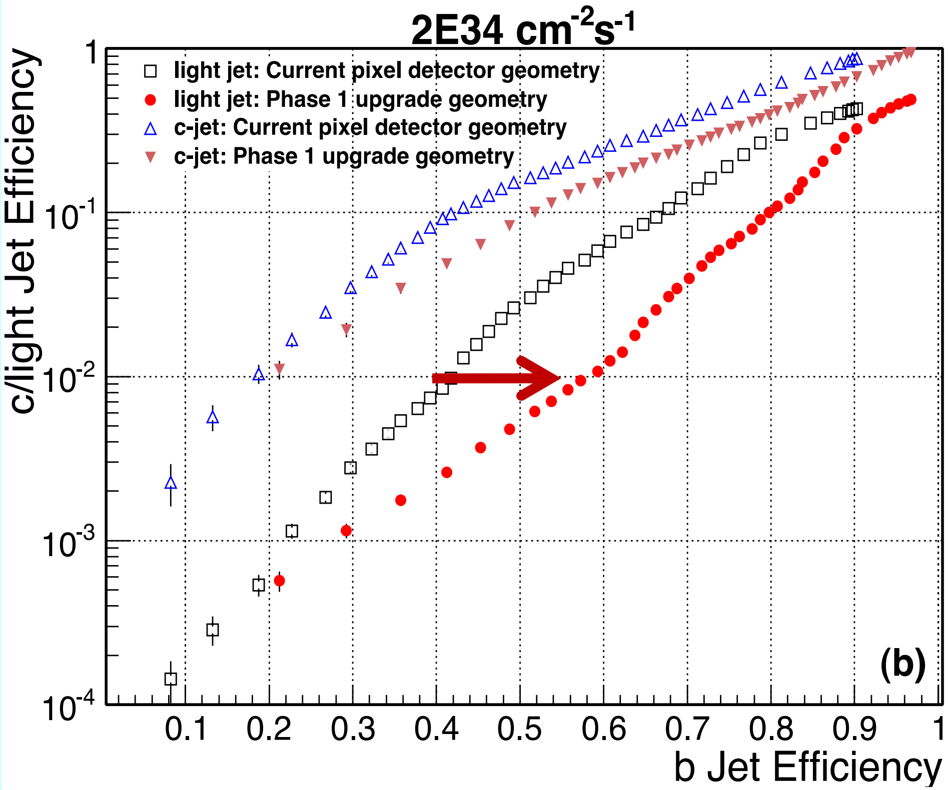
- Inner layers and inner disks designed for easy replacement.





Ultra-low mass Pixel detector

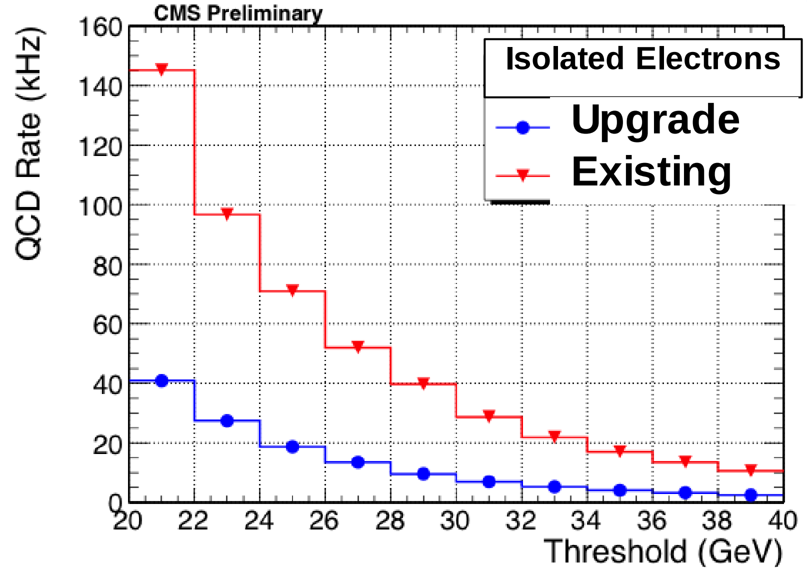
- **Material Minimization**
  - New system has more electronic channels
  - To keep material lower than the existing detector
    - Use DC-DC conversion to bring less current into the detector to need less cooling
    - Use evaporative CO_2 cooling which is more efficient and requires much less material than the existing C_6F_{14} fluid system
    - Use new light weight materials (Thermal Pyrolitic Graphite in FPIX)
    - More of the support electronics will be located out of the tracking volume

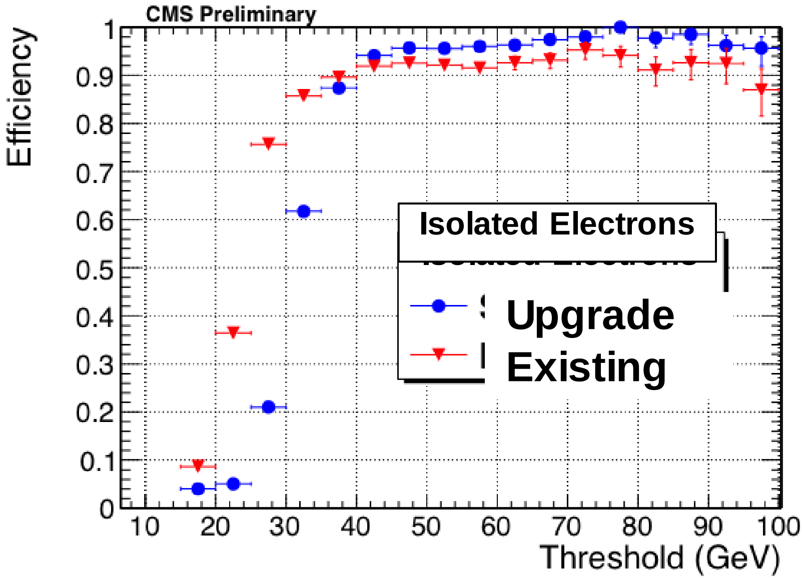


Material reduction by a factor of 2-3 leads to a b-tagging increases from 42% to 60% for 10^{-2} fake rate.

CMS Trigger Upgrade

- **Constraints**
  - **Output rate at 100 kHz**
  - **Input rate increases x 2 over LHC design (10^{34}) and number of interactions in a crossing (Pileup) goes up by x4 at 50 ns**
  - **Present L1 algorithms inadequate above 10^{34}**
    - **Pileup degrades object isolation**
- **Strategy for Phase 1 Calorimeter**
  - **Use full granularity of calorimeter trigger information**
  - **Phase in microTCA architecture for higher bandwidth data collection**
  - **Rely on modern FPGAs with huge processing & I/O capability to implement more sophisticated algorithms**
- **Achieve factor of 2 reduction in rate as shown with initial L1 Trigger studies.**





Phase 2 Upgrades

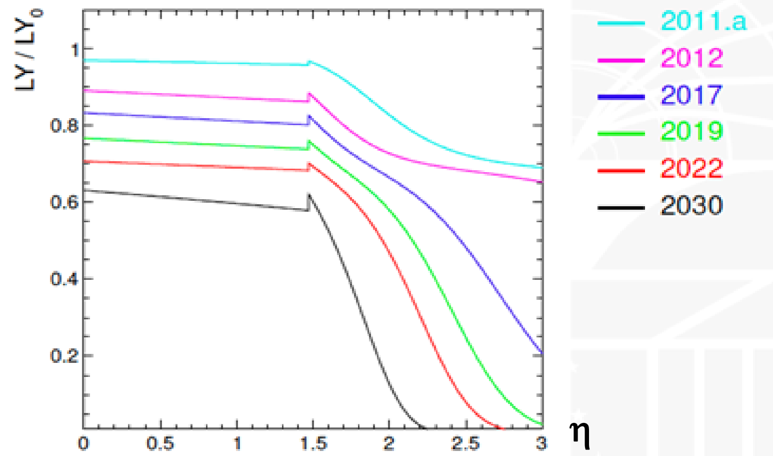
- Once the machine approaches $5X10^{34}$ cm^{-2} s^{-1} with 50 ns (or hopefully 25ns) beam crossings, there will be
- A pileup of
  - 200 interactions/crossing at 50 ns (easier for machine to achieve high luminosity)
  - 100 interactions/crossing at 25 ns (preferred by experiments).
- This leads to
  - Severe occupancy problems in the tracker
  - Radiation issues for the pixel sensors and the forward calorimeters
    - Must tolerate as much each year as they did for previous decade!
  - Severe breakdown of the Level 1 trigger
  - Need to expand the data acquisition system and the HLT
- This will require a substantial rebuild of much of CMS
  - Projected to take at least two years to install and commission
- Substantial R&D is needed to address the challenge
  - This R&D must be accomplished in the next ~3-4 years so one can start to build circa 2015 to be ready for installation circa 2021/22

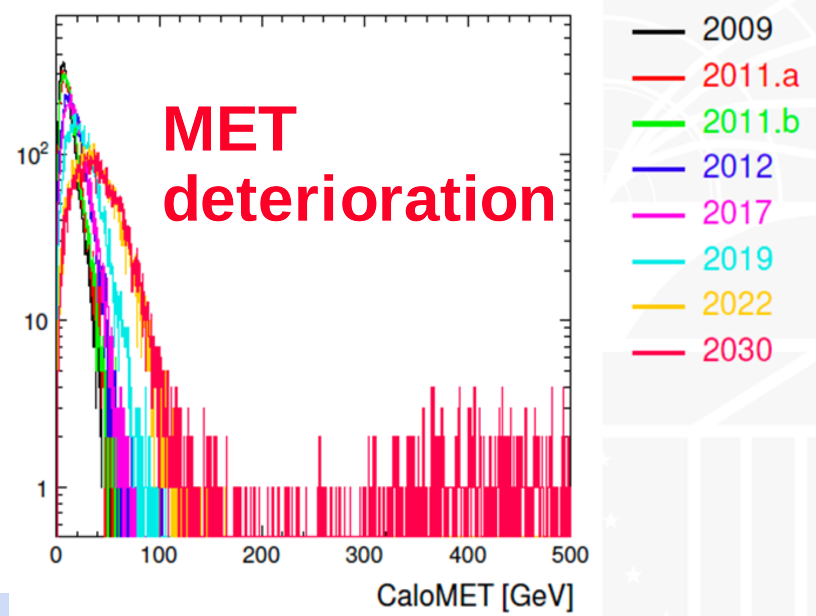
Radiation effects on endcap calorimetry

Scenario

Light Loss in ECAL

Year	Bunch Spacing [ns]	Energy [TEV]	L [cm^{-2} s^{-1}]	Pile Up	L [fb^{-1}]
2011.a	50	7	1.0E+33	3	1
2011.b	50	7	2.0E+33	6	3
2012	50	7	5.0E+33	16	5
2017	25	14	1.0E+34	19	118
2019	25	14	2.2E+34	42	336
2022	25	14	5.4E+34	102	716
2030	25	14	5.4E+34	102	3073





New Detector Materials for Calorimetry

- **Possible radiation-hard sensor options have been identified (not inclusive):**

Radiation Hard Materials	Challenges
New Crystals: LYSO, CeF	Cost and Availability
Transparent ceramics	R&D just started
Quartz plates	R&D Ongoing
Liquid scintillators	R&D Ongoing
Crystal fibers	R&D limited applicability
PhotoDetectors: GaAs/GaInP	R&D Ongoing

- **Possible radiation-hard photodetectors**
  - **Photodetectors – GaAs/GaInp – pixelated radiation hard Geiger –mode detectors, which need R&D that we are now undertaking**

Transparent ceramics

Crystal structure	Scintillator	ρ (g/cm3)	Z_{max}	λmax (nm)	Decay (ns)	Light Yield (Ph/MeV)	511 keV Rad. Length (cm)
Must be cubic	Ideal	>8	<72	~450	<25	>80,000	0.9
	Acceptable	>5	<72	>340	<50	>4000	<2.5
GARNET	$A_3B_5O_{12}$(Ce) : A = Gd, Lu, Y B = Al, Ga, Sc	5.8-6.8	71	530	20-80	30,000 - 60,000	1 -2
PEROVSKITE	ABO_3(Ce) : A = Sr, Ba B = Ti, Zr, Hf	6 -8	72	400	50	~10,000	0.7-2
BIXBYITE	A_2O_3 (undoped) : A = La, Y, Lu, Ce	5 - 9.4	71	370	30	~20,000	0.73-2.3
FLUORITE	AO_2 (undoped) : A = Zr, Y, Hf, Ce	5.7 - 8	72	370	30	~20,000	0.7-2

GYGAG(Ce), 1 in³

- For DHS/DNDO, we identified a high light yield phase-stable garnet for gamma spectroscopy (R = 4% @ 662 keV)
- We are optimizing properties and scaling up to 5 in³ sizes

Existing ongoing program at LLNL

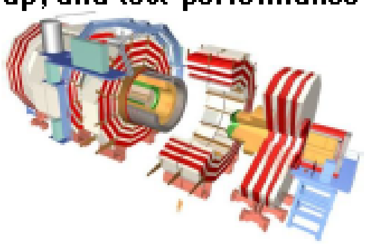
$(Gd,Lu)_2O_3$(Eu)

Transparent 2" plate

- For DOE/Enhanced Surveillance, we identified a high light yield phase-stable bixbyite for radiography (LY = 70,000 Ph/MeV)
- We are optimizing properties and scaling up to 12" sheets

Existing ongoing program at LLNL

For LHC, we would like to work in collaboration with CMS team and industrial partner to identify promising a transparent ceramic, scale it up, and test performance



Proposed new activity

Tracking at L1

$L = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

- Electron and photon trigger
  - Single: 30 GeV threshold $\Rightarrow$ 1.5 KHz
  - Double : 10 GeV Threshold $\Rightarrow$ 1.4 KHz
- Muon trigger
  - Single: 10 (25) GeV threshold $\Rightarrow$ 11 (4.1) KHz
  - Double : 5GeV Threshold $\Rightarrow$ 1.3 KHz

$L = 5 \times 10^{34}\ cm^{-2}\ s^{-1}$

- Electron and photon trigger
  - Single > 50 GeV threshold $\Rightarrow$ 20 KHz
  - Double : 30 GeV threshold $\Rightarrow$20 KHz
- Muon trigger
  - Single: No control
  - Double : 20 GeV threshold $\Rightarrow$10 KHz
- Double trigger could have additional pile up contributions which are not included

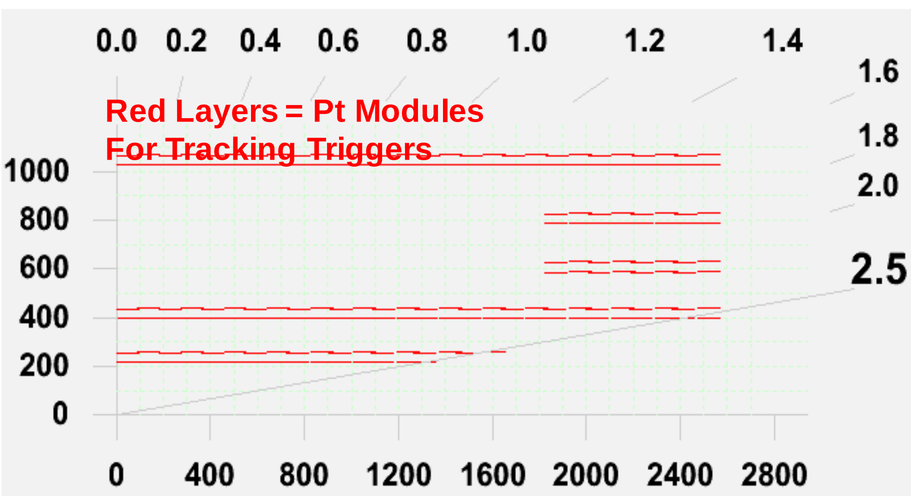
- At $2x10^{34}\ cm^{-2}s^{-1}$, we will be using the full granularity and resolution of the muon system and calorimeters and will be able to trigger on the important physics efficiently
- When the luminosity goes above $2x10^{34}\ cm^{-2}s^{-1}$ the Level 1 trigger rates are too high and the Level 1 trigger becomes inefficient
- We must add information from the inner tracker to the Level 1 trigger

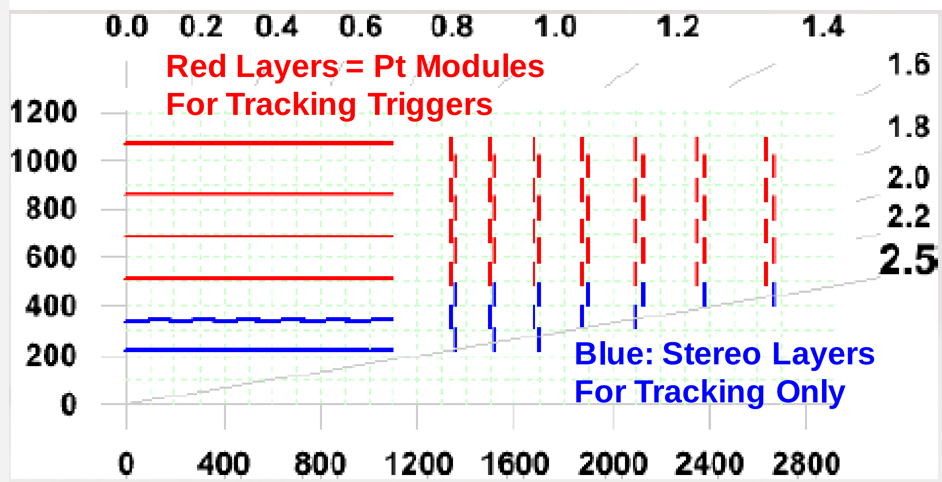
Rebuilding the Tracker

- The Tracker has to be rebuilt for higher luminosities because
  - The occupancy will be too high for good, efficient pattern recognition with pileup of 100 $\Rightarrow$200
  - Radiation damage will become a problem at integrated luminosity > 500-700 fb^{-1} .
- Tracking information is needed in the Level 1 trigger
  - The new Tracker will probably have > 200M pixels, >100M strips
  - Getting all the hit data off the detector, several MBytes at 40 MHz, is not possible with any technology that we can envision
- Currently solution:
  - Arrange the Tracker layers so it is possible to identify hits of tracks of "moderate" P_t (above ~2 GeV/c) inside the Tracker volume with local electronic.
  - Move off the detector to Level 1 electronics only the hits of that subset of tracks and correlate them with signals from the calorimeter and muon detector
- Many ideas under studies. Two are shown on the next two slides

Tracker Layouts

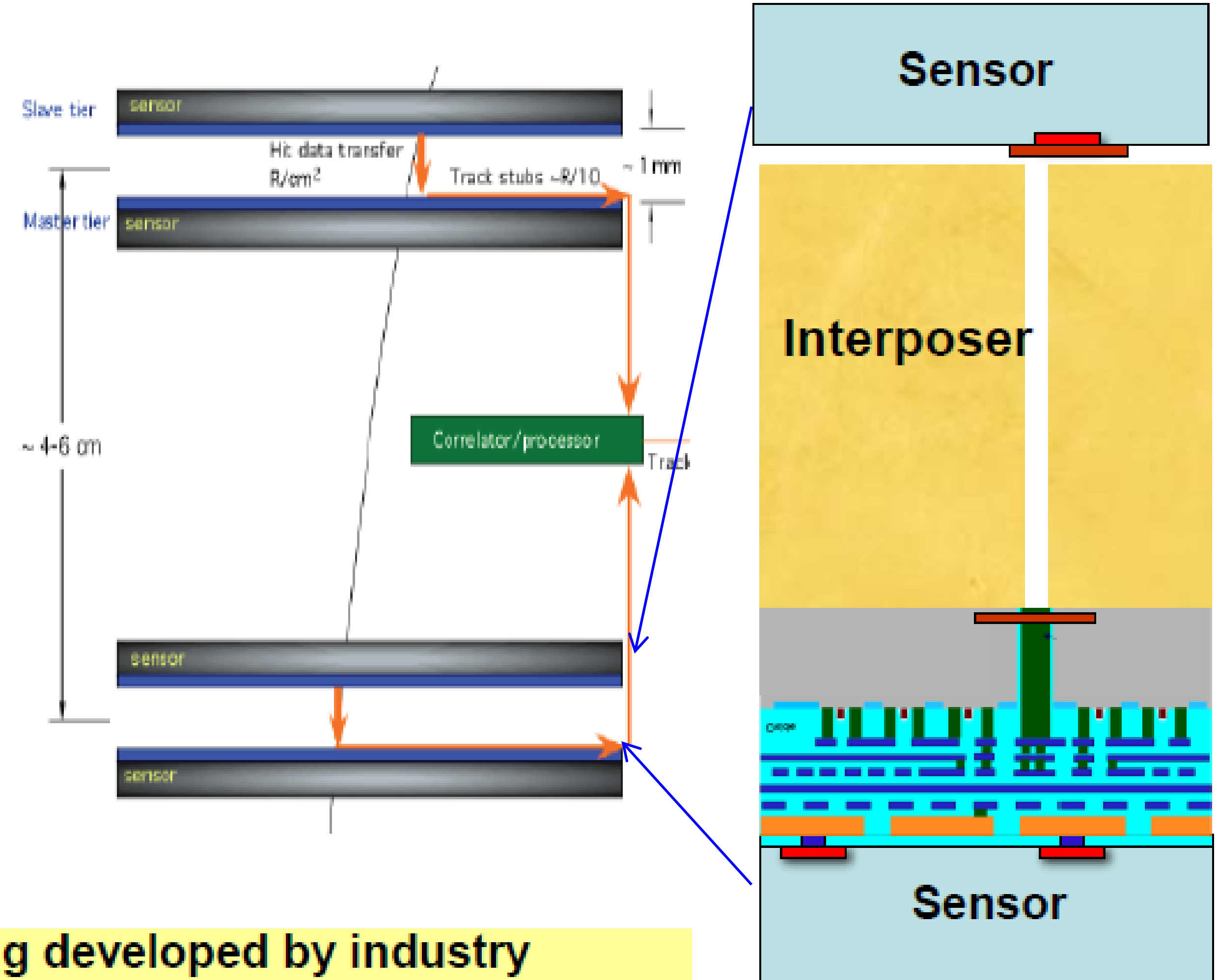
- Complementary Layouts ⇒ Optimize the performance
  - Long Barrels vs Barrels and End-Cap Discs
  - Optimal radius for deploying Strip and/or Pixelated Pt module
  - Pitch and number of tracker modules
  - Arrangement and number of Pt Layers
- A layout toot (tkLayout) has been developed to facilitate this process:
  - Creates a 3D model of the layout
  - Uses a simple description of design parameters including active and support services





Trigger Scheme for Long Barrel

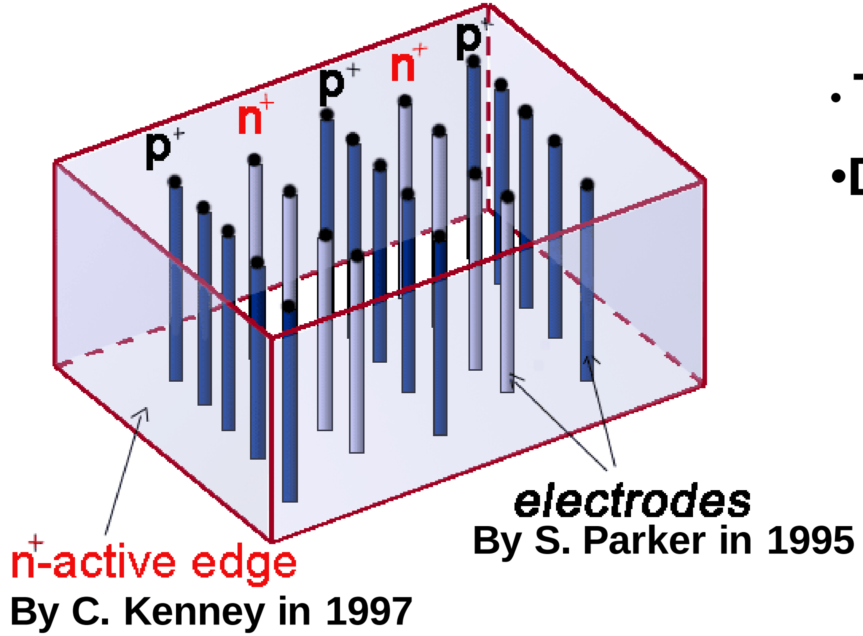
- Stack of two detectors separated ≈1mm in r
- Correlate hit information from both sensors on the detector
- Reject hits that do not have a match in the other detector, consistent with p_T>threshold
- Move selected hits to off-detector processor



- techniques being developed by industry
- collaborate with industrial partners

Ultra rad hard sennors

- Investigating Diamond & 3 D or semi 3 D sensors
- Participating in the 3 DC which includes group of CMS and ATLAS

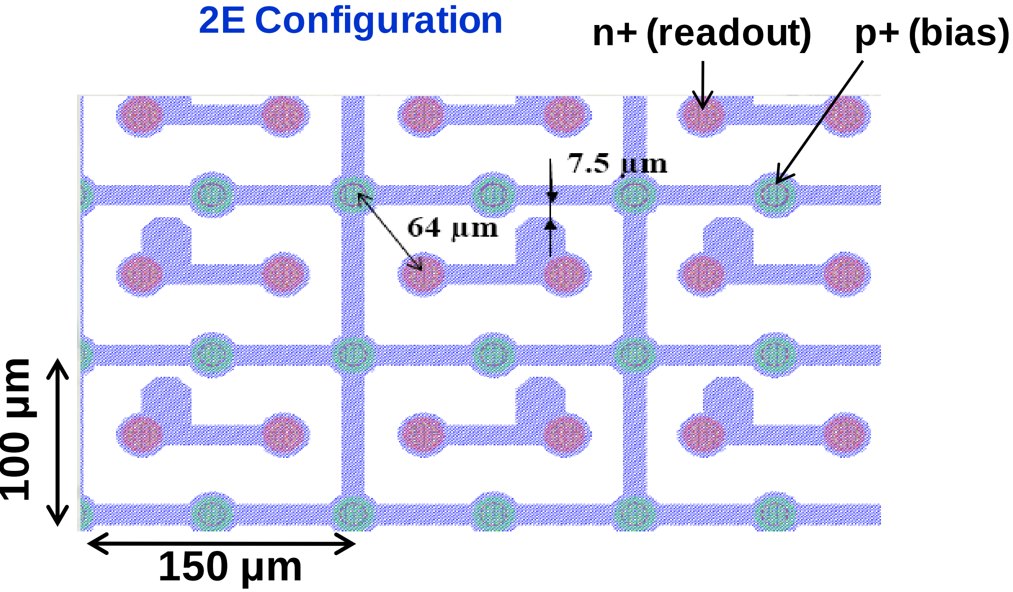


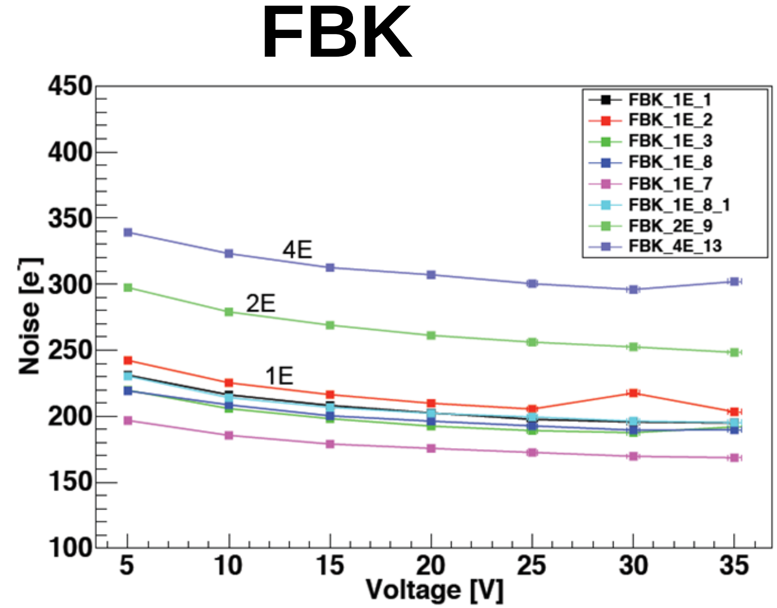
- The edge is an electrode!
- Dead volume at the Edge < 2 microns!

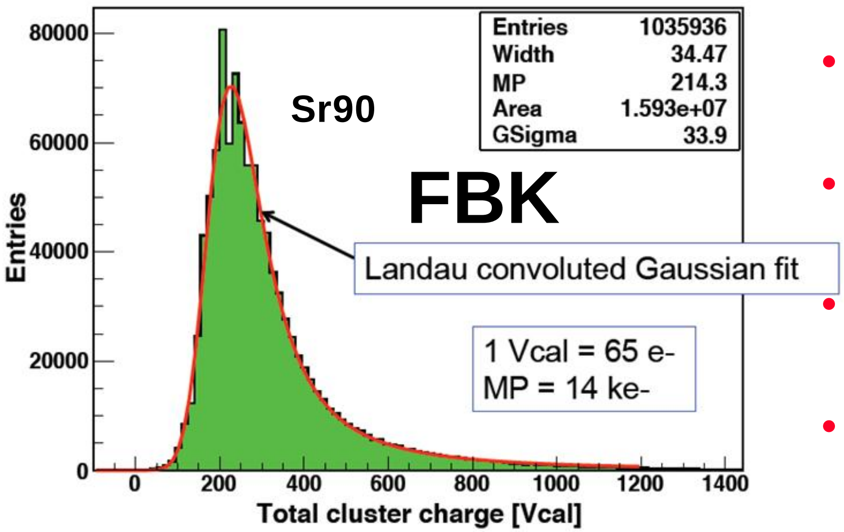
Advantages:
- Lower depletion voltage
- Fast response
- Short drift length
- Less trapping

Disadvantages:
- Non standard processing
- Yield, cost, reliability

3D sensors







- **CMS is working with SINTEF, FBK, and CNM**
- **3D sensors are no longer a "single source product"**
- **So far there is no show stopper detected for application**
- **Performance (whenever measured) is good. Irradiation studies are underway**

Summary

- **The LHC is opening the exploration of the Terascale**
- **CMS is superbly designed to elucidate this energy scale but its performance is limited to operation with ~20 interactions/crossing and a few hundred fb^{-1} integrated luminosity**
- **The LHC will eventually run at peak luminosities that imply100-200 interactions/crossing and produce integrated luminosity of 300 fb^{-1}/year**
- **An incremental upgrade path for CMS has been developed to deal with the luminosity growth. This plan outlines the necessity for rebuilding major portions of the detector to handle the highest rates**
- **The physics we are learning from the initial LHC operation might influence the exact path we take for the Phase 2 upgrades**

- **The LHC is the intensity frontier for the next twenty years and we must preserve the ability of the experiments to take full advantage of the data it will deliver.**

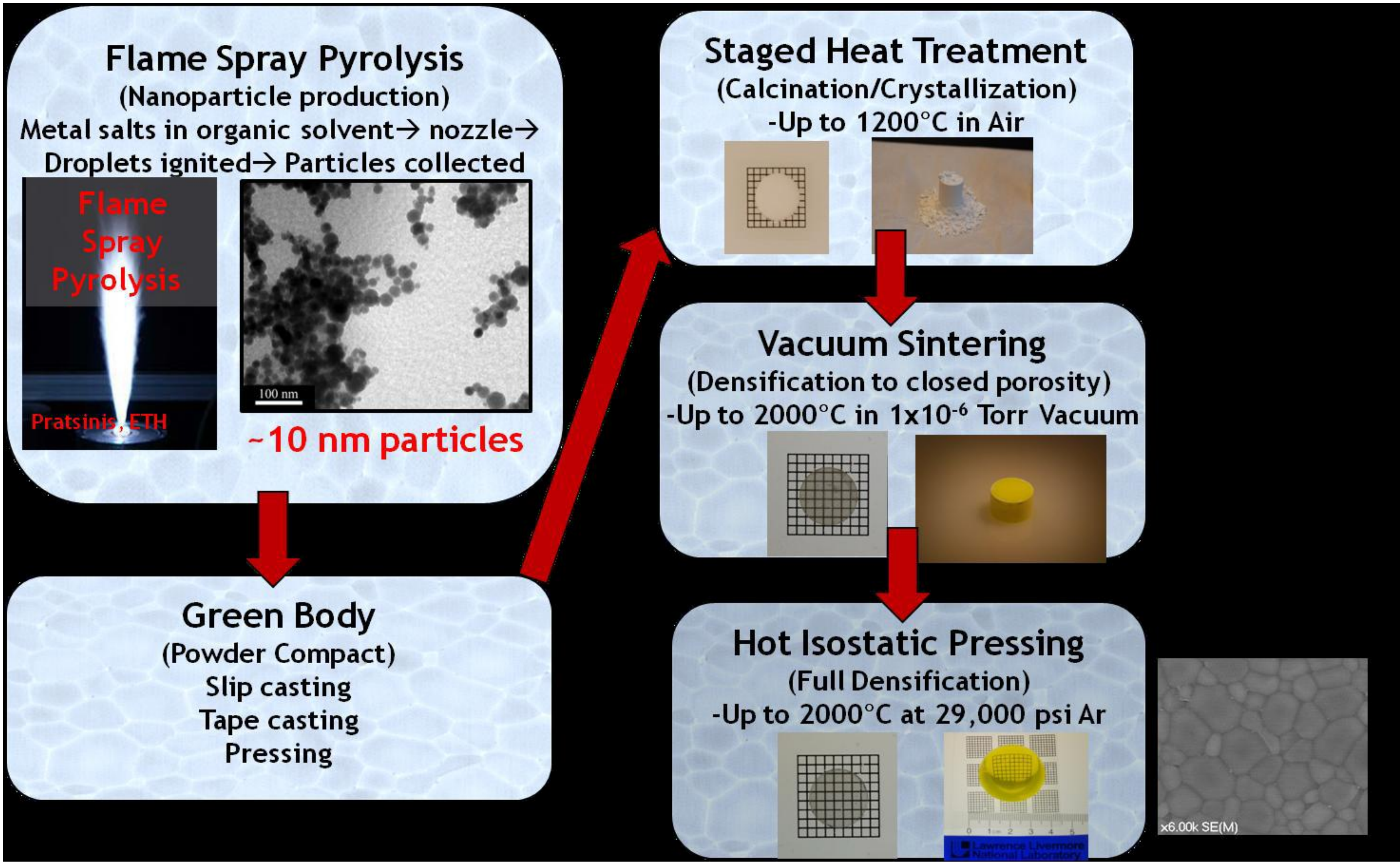
LHC performance

	2011 so far	Nominal
Energy [TeV]	3.5	7
β^* [m]	1.5	0.55
Emittance [μm]	**1.5**	**3.75**
Transverse beam size at IP [μm]	40	16.7
Bunch population	**1.2×10^{11} p**	**1.15×10^{11} p**
Number of bunches	1092/IP	2808
Stored energy [MJ]	100	360
Peak luminosity [$cm^{-2}s^{-1}$]	1.6×10^{33}	1×10^{34}

$$L = \frac{N_b^2 n_b f_r \gamma}{4\pi\varepsilon_n \beta^*} F$$

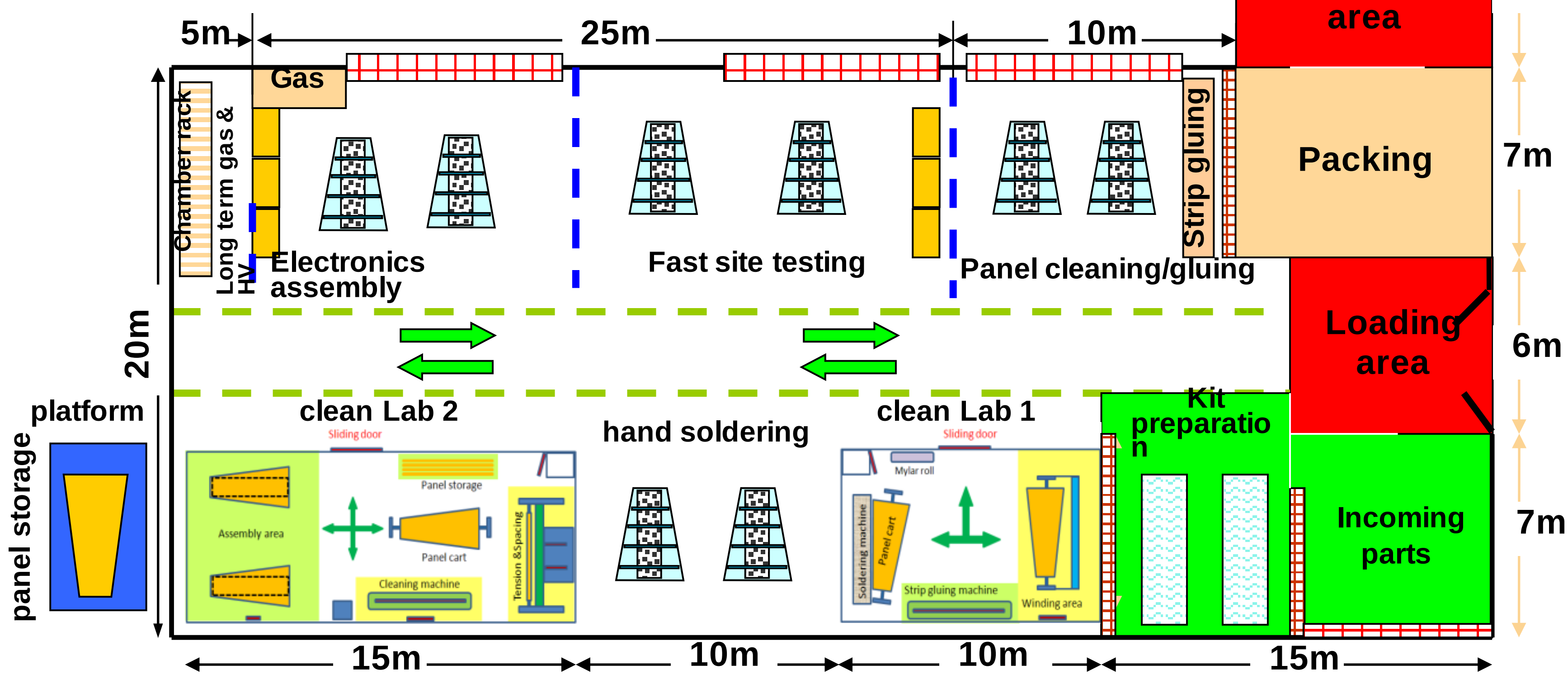
- **Bunches with a charge of 2.5E11 have been tested**
- **β^*= 1m could be possible**
- **No apparent showstopper for 25ns (tests will be done over summer)**
- **Mini-Chamonix workshop**
  - **Continue with 50ns**
  - **Operate with minimum emittance (2μm)**
  - **Adiabatically increase the bunch intensity (1.55E11)**
  - **Reduce β^* to 1m (LATER after next Technical Stop)**
- **Pileup already challenging**
- **Reevaluate maximum energy for 2012 after Following measurements of the copper stabilizers resistances during the Christmas stop (Chamonix 2012)**

Ceramics Fabrication



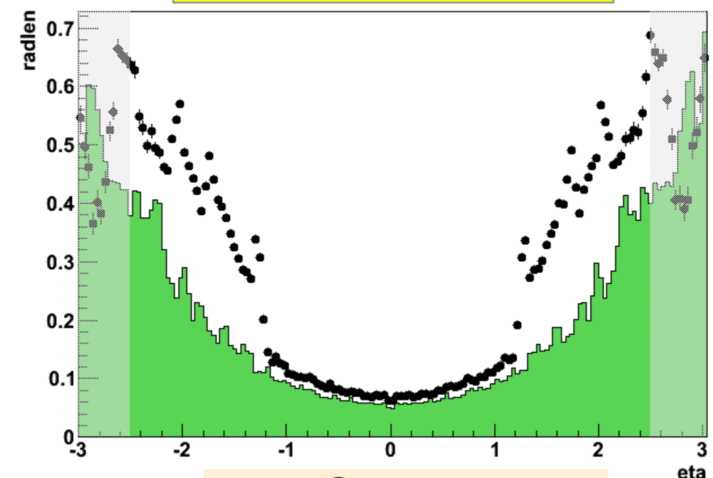
CSC production workflow at CERN Building 904 factory

- Incoming parts
- Kit preparation
- Panel bar gluing
- Wire wiring, gluing, soldering (Lab 1)
- Electrical components hand soldering
- Chamber assembly & test (Lab 2)
- Long term gas, HV tests
- Electronics assembly & Fast site test
- Final inspection packing, storing



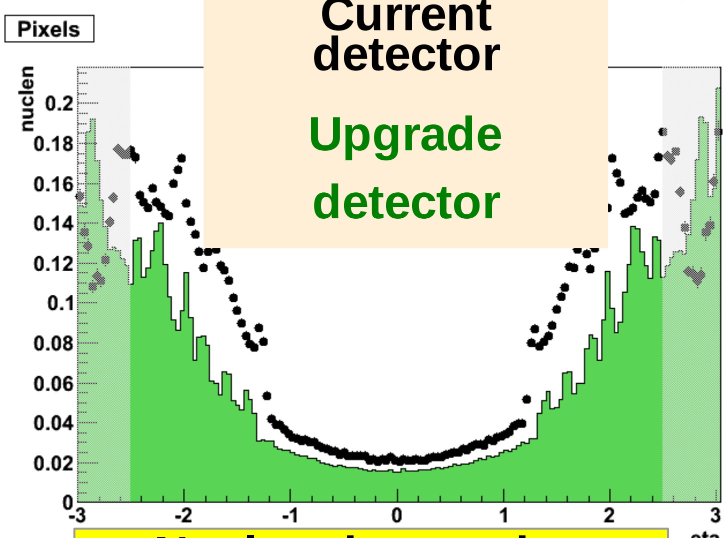
Material Budget and B Tagging Performance

Radiation length

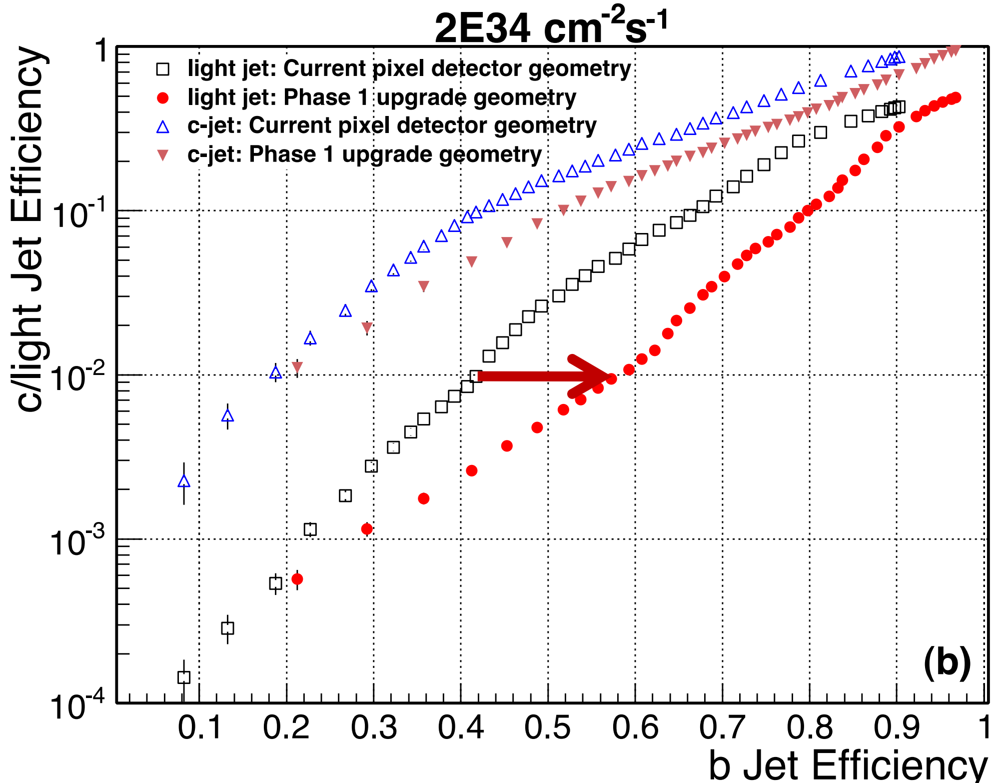


Current detector

Upgrade detector



Nuclear interaction length



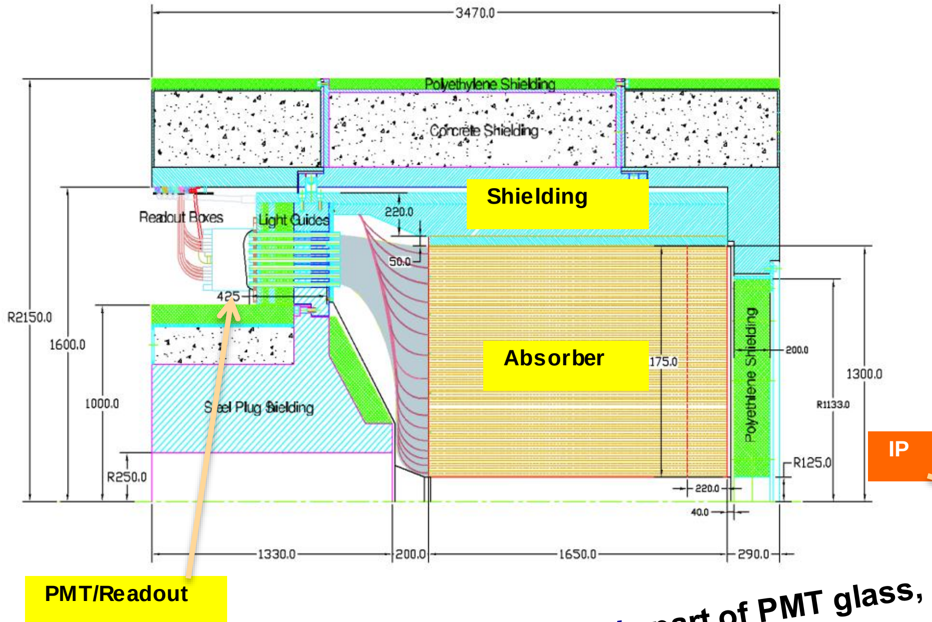
Material reduction by a factor of 2-3 leads to a b-tagging increases from 42% to 60% for 10^{-2} fake rate.

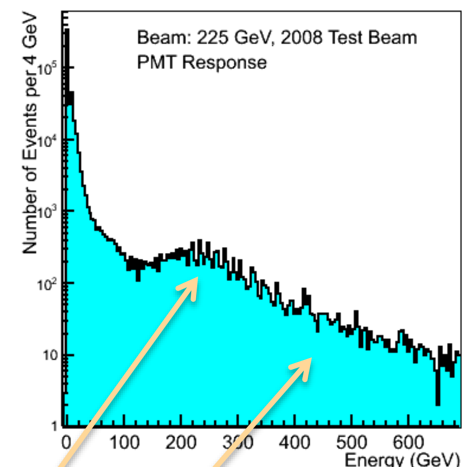
Improved Timing

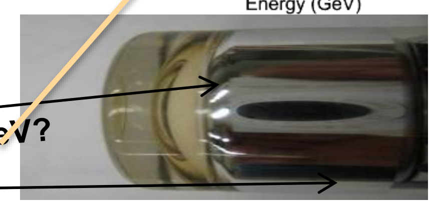
- HB and HE signals are ~3 BX full width
  - Well formed calorimeter signals currently provide offline sub-BX timing
    - Will disappear at higher luminosity
  - Hardware timing information will aid in identification of malformed signals from background and pileup
  - Will also allow redundancy and contribute to eliminating non-BX-related signals
- The Tevatron has background from cosmics and stray beam halo falling in coincidence with a real interaction
  - The Tevatron has only one crossing every 396 ns compared to one every 25 ns at the LHC
    - Need good timing to defend against higher backgrounds

HF Upgrade

- **Steel absorber w/horizontal quartz fibers, detects cerenkov γs, few GeV/photon readout with high gain PMTs**



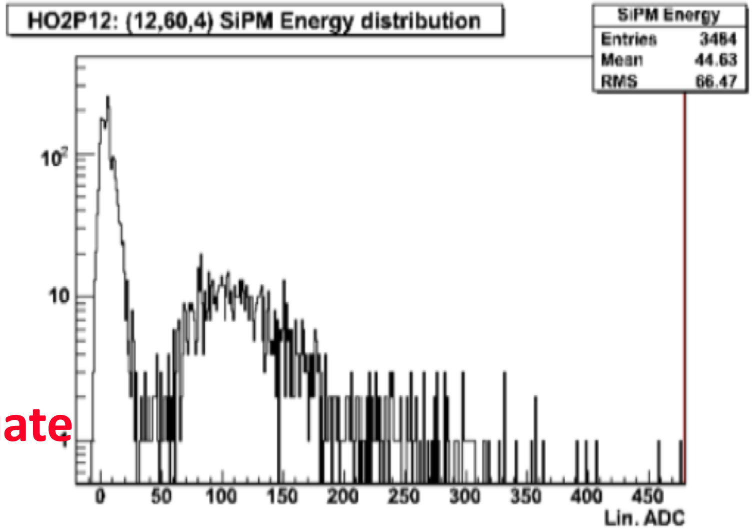




- **In collision data anomalous signals contaminate MET tail**
  - **Well known, studied in testbeam ("Window Events")**
- **Easy to mitigate using thin window PMTs with metal sides**

HCAL Outer (HO)

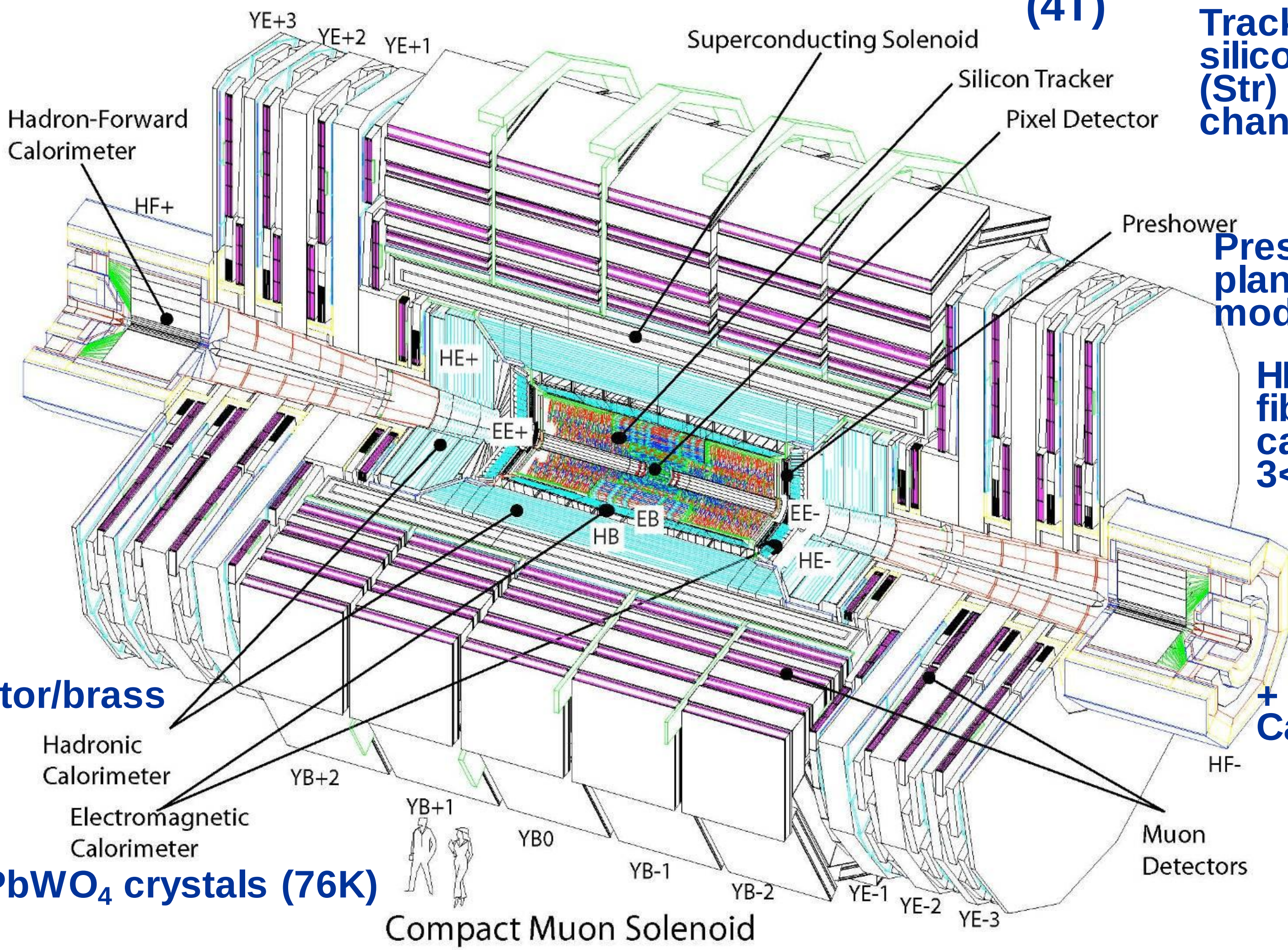
- **HPDs susceptible to discharge at intermediate B-fields.**
  - Mitigated by lowering gain but that causes problems with S/N for min-ionizing (muons) and reduced contribution to jet measurement
- **Will replace HPDs with SiPMs (see below) for all HO for performance improvement and to provide a common system.**
- **Operated 2 RBXs with SiPMs in situ for the last year: shows 10x improvement in S/N for muons**
- **Dynamic range required for HO is met by current generation SiPMs and existing digitizer (QIE)**
- **2012 Timeline:**
  - Replace all HPDs with SiPM
  - Retrofit existing electronics for new SiPM
- **Status**
  - SiPM order placed, first production deliveries soon
  - Mechanics and electronics R&D finished
- **Imperative: HPDs will likely not last, S/N inadequate for muon contribution**
- **Risks: very few, not a technically challenging fix**



CMS - The Compact Muon Solenoid

(4T)

Tracker: 210 m^2 of silicon sensors: 9.6M (Str) & 66M (Pix) channels



Preshower: 2 planes of silicon modules for ECAL

HF: Iron / Quartz fiber fwd calorimeter, $3<|\eta|<5$;

+ Castor, $5<|\eta|<6.55$

+ Zero Degree Calorimeter

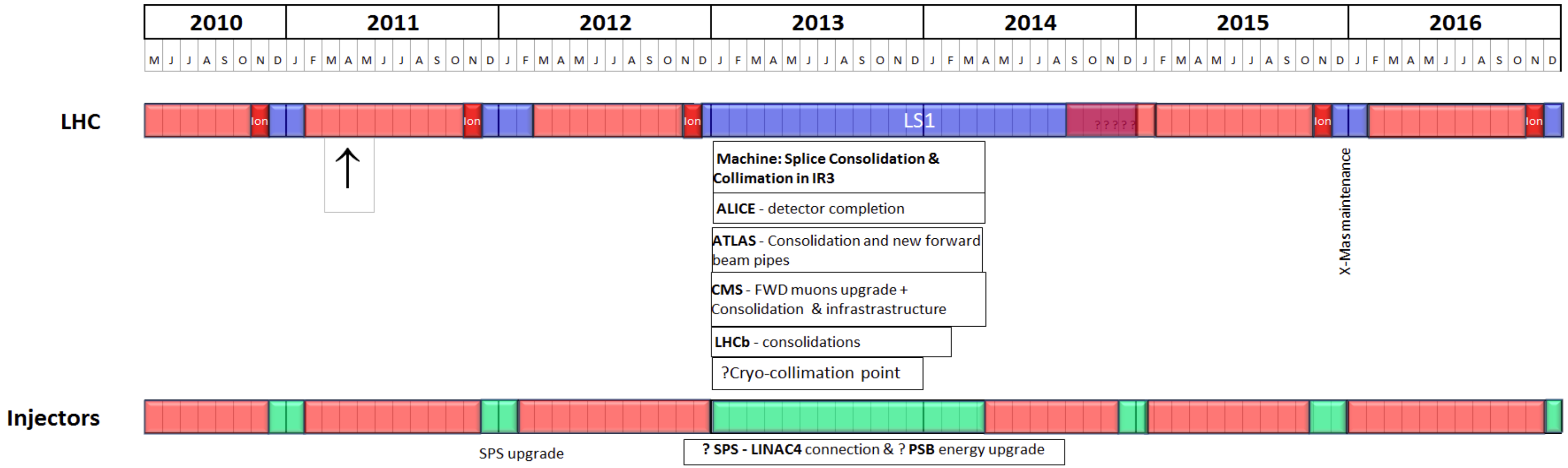
Scintillator/brass

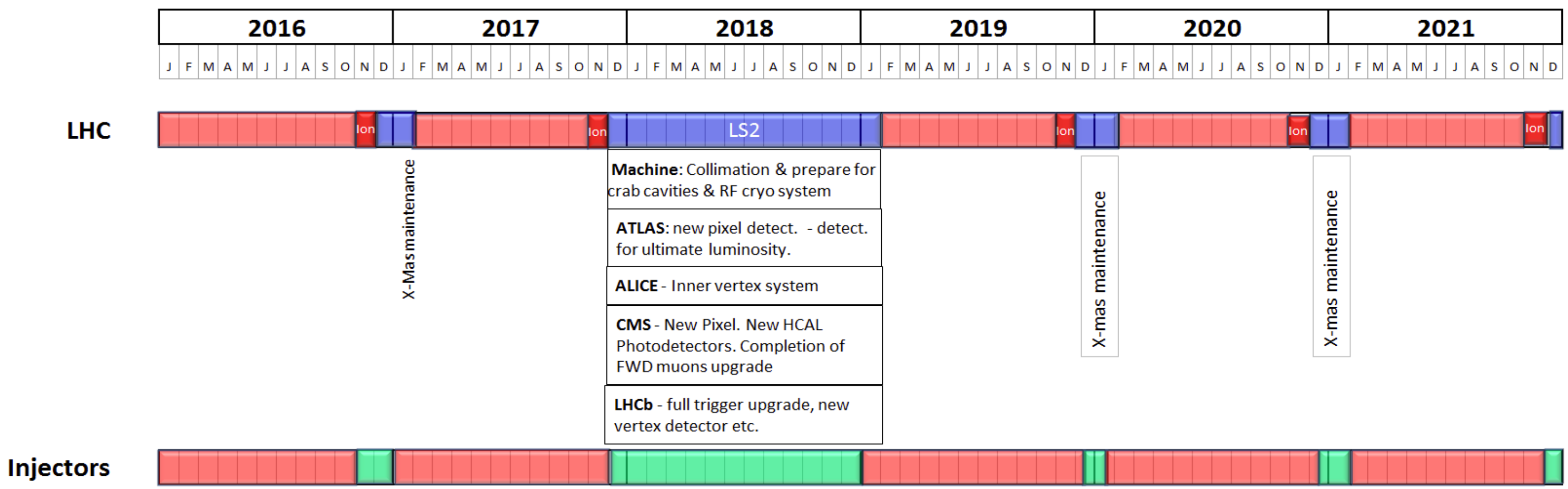
$PbWO_4$ crystals (76K)

Muon detectors: Cathode Strip Chambers,

Drift Tubes, Resistive Plates

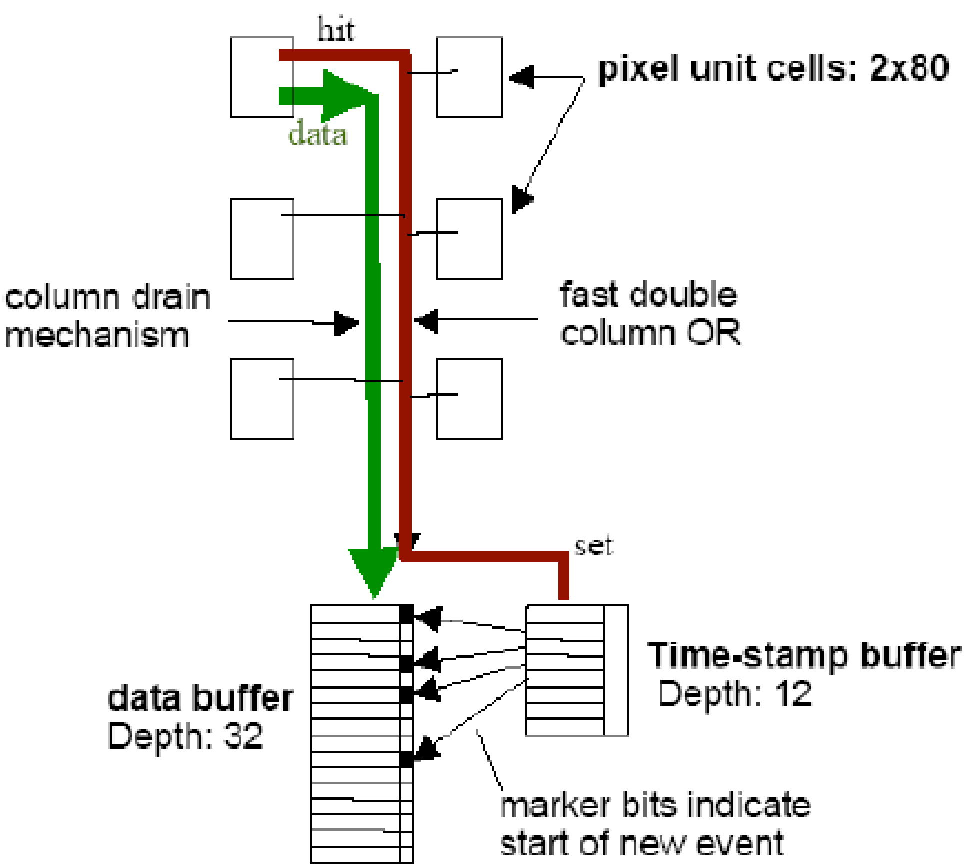
New rough draft 10 year plan





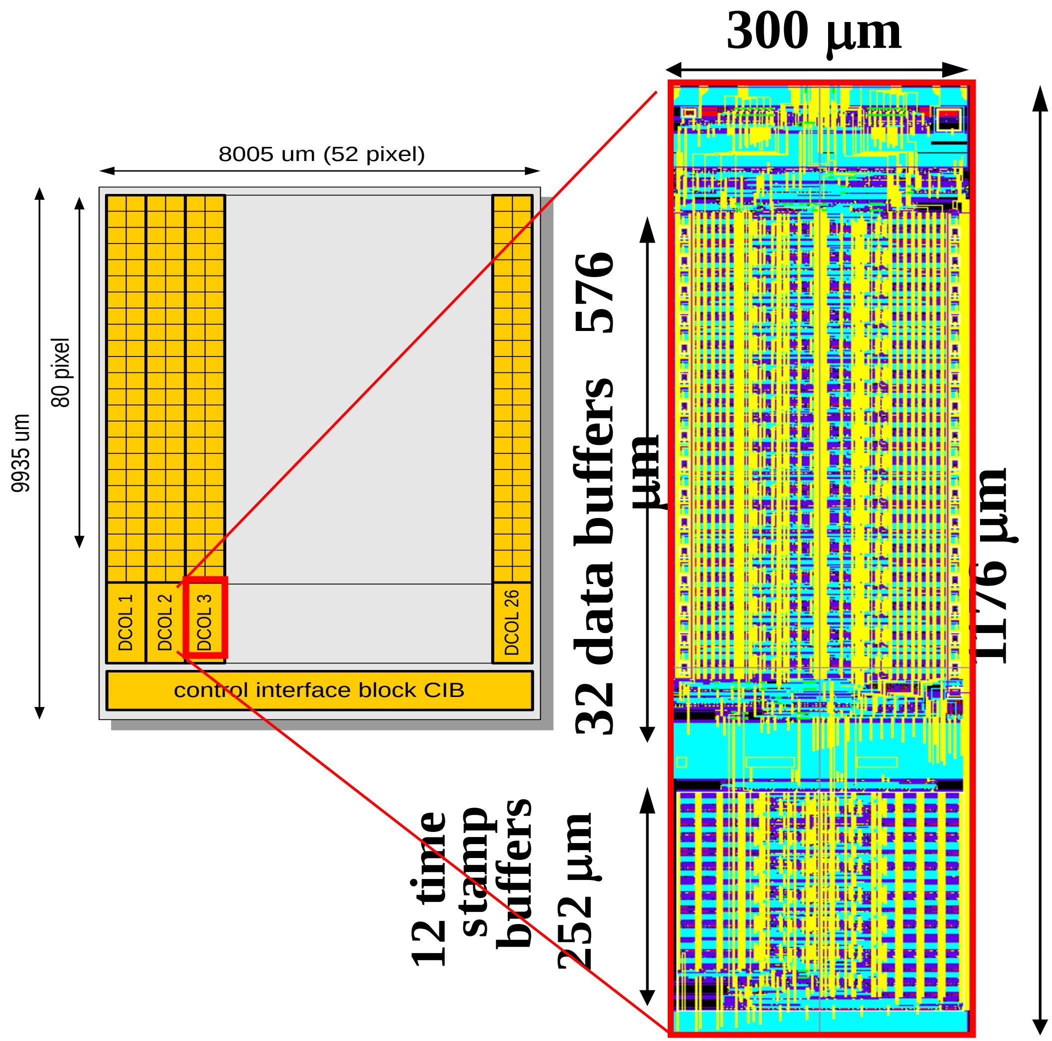
PSI46 ROC

sketch of a double column



- •Zero suppression in pixel cell
- •Pixel hit information transferred to time stamp and data buffer
- •Kept there during L1 trigger latency
- •Double column stops data aquisition when confirmed L1 trigger ⇨ dead time starts
- •Double column resets after readout ⇨loosing history (trigger latency)
- •Serial readout: 8 (16) ROCs daisy chained. Controlled through readout token

PSI46DIG



Reduce data losses by:

1) increase depth of
   - data buffer 32 → 96
   - timestamps 12 → 24
2) add readout buffer
3) 160Mbit/sec serial binary data out
4) deal with PKAM events

Tests with LHC rate beams
   - rare errors with data
   - SEU errors

Submission planned Sept. 2011

Next data losses term after 1) & 2) is **dc-reset loss**, removal possible by use of an extra marker bit (*)

→ **modify data buffer logic !**

Submission possible in 2012 !