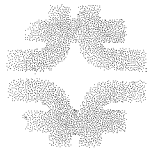
FERMILAB-SLIDES-08-006-CMS



"Fermilab's Role on CMS: CMS Operations and Upgrade"

Physics Advisory Committee Meeting
Nov 3, 2008

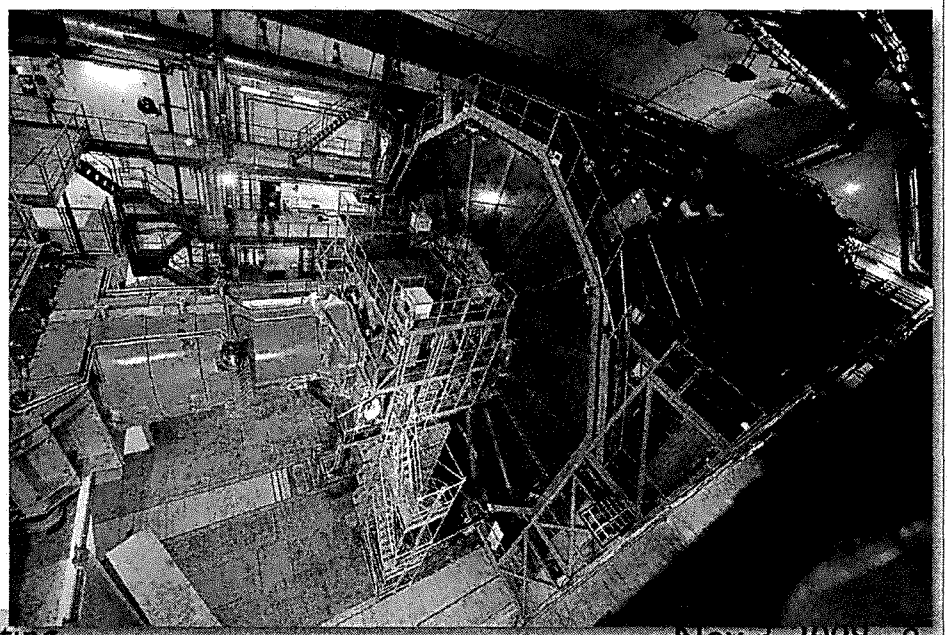
L.A.T.Bauerdick/Fermilab

Outline

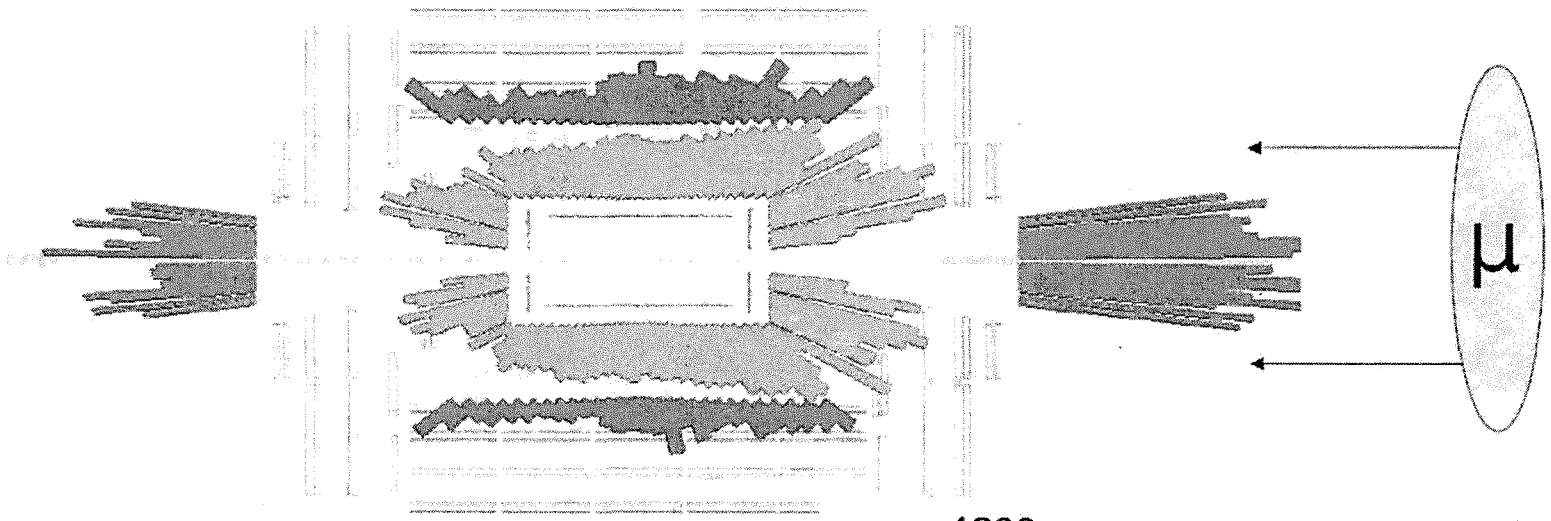
- CMS Progress and Commissioning
  - ★ First Beam
  - ★ Cosmic Runs
  - ★ Computing
  - ★ Remote Operations
  - ★ Conclusions
- CMS Upgrade for SLHC
  - ★ Upgrade Plans for subcomponents
  - ★ 2008/9 activities
  - ★ R&D budget
  - ★ Conclusions
- Physics Activities and LHC Physics Center —> Chris' talk

Recent CMS Progress

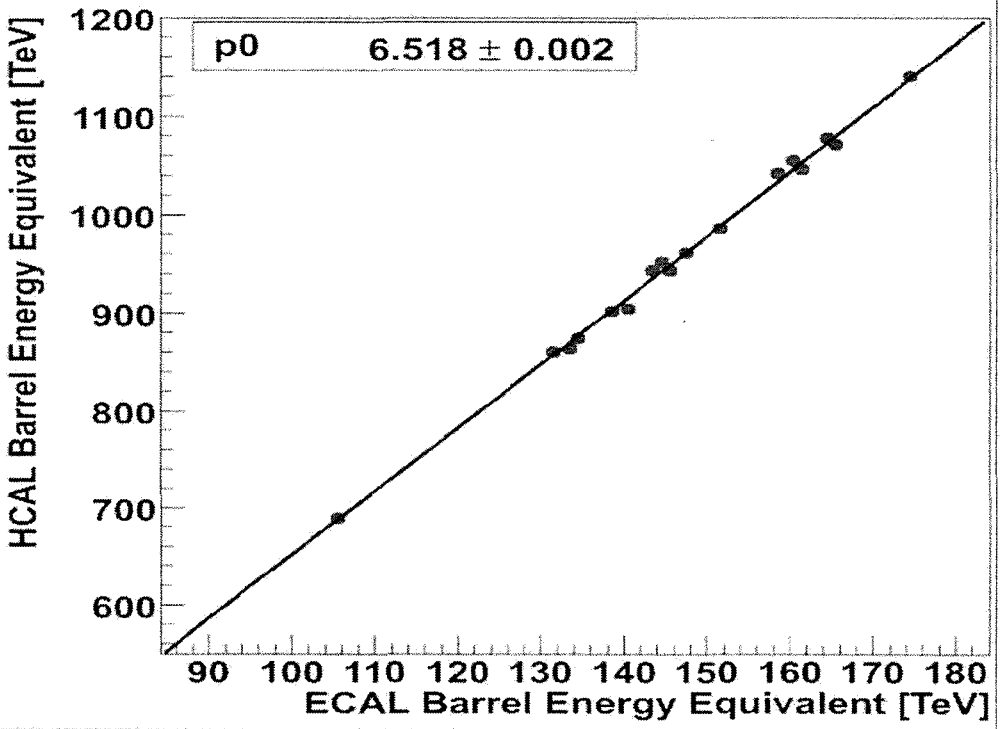
- The CMS Detector is complete, minus the pre-shower
  - ★ Full Si Tracker and Pixel Detectors installed, commissioned, operational
  - ★ Both ECAL endcaps installed, commissioned, operational
  - ★ Magnet operating at full field of 3.8 Tesla
  - ★ Trigger and DAQ chains operational for 50 kHz readout, 300 Hz HLT rate
  - ★ Software & Computing infrastructure prepared, data taking releases deployed, MC simulation of several 100M events datasets ongoing
  - ★ Preparations for physics going strong —> Chris' talk
- Commissioning Timeline
  - ★ Run series over past six months
    - May~August: CRUZET1..4
      - Cosmic RUnning at ZEro Tesla
    - Sept. 10 beam runs
      - "beam splash" and captured beams
    - Oct/Nov: Cosmic Running At "Four" Tesla
  - ★ CRAFT ongoing, will end ~Nov. 10



First Beams

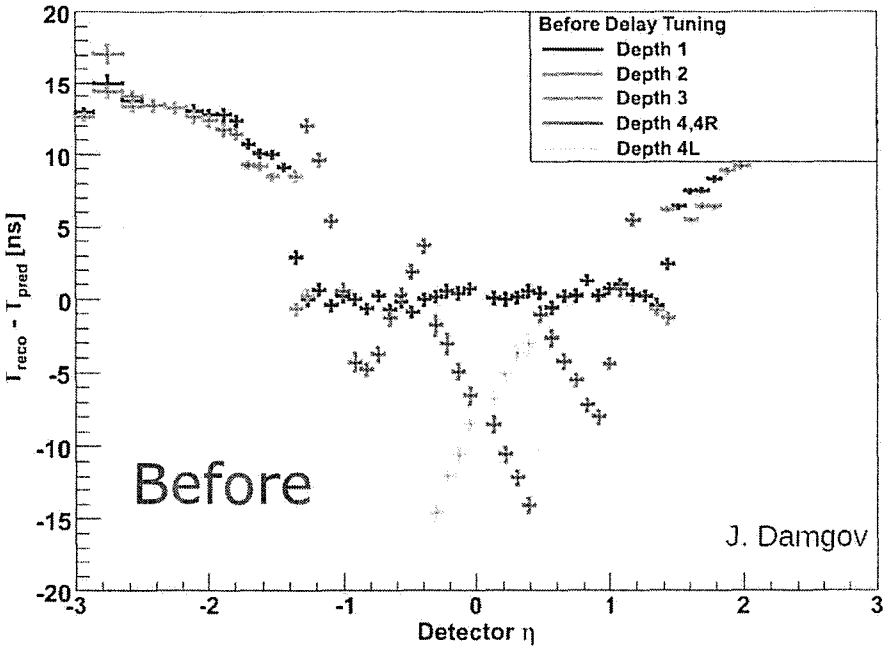


- ★ Sun/Mon Sep 7/8
  - ✦ single shots of Beam 1 onto collimator 150m upstream CMS
- ★ Tue Sep 9
  - ✦ 20 shots of Beam 1 onto collimator
- ★ Wed Sep 10
  - ✦ nice splash events (beam onto collimators) observed 100-1000 TeV in ECAL/HCA
  - ✦ Halo Muons observed when beam passing through CMS

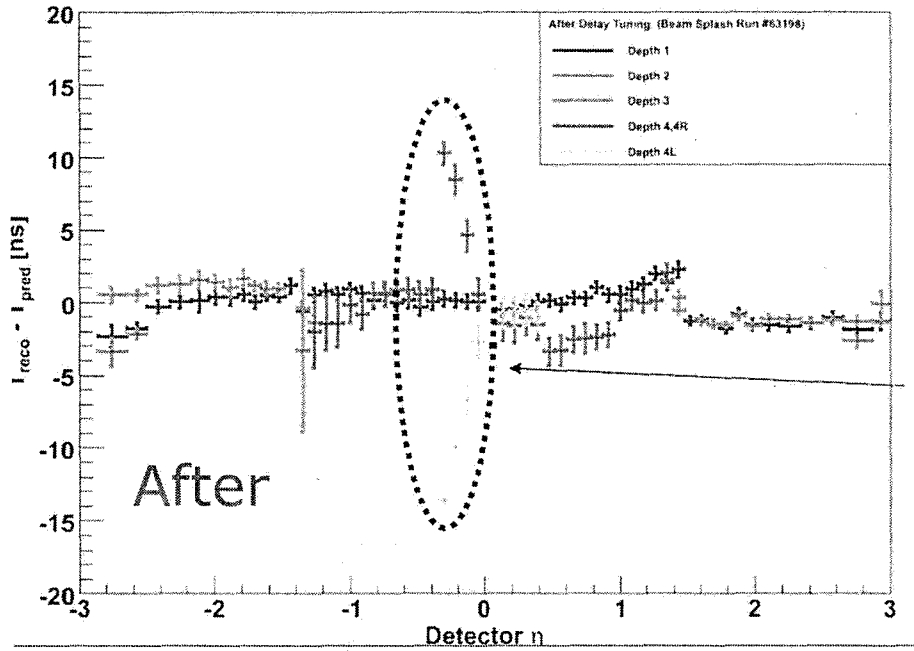


CMS

HCAL Timing with Beam Splash Data



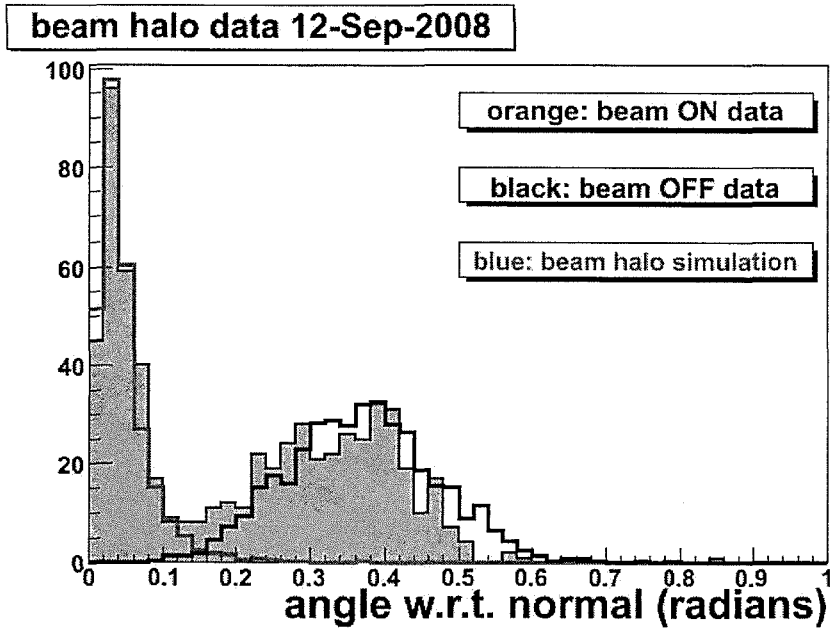
- Example of detailed detector calibration work.
- Timing of HCAL modules adjusted and verified using beam splash data.

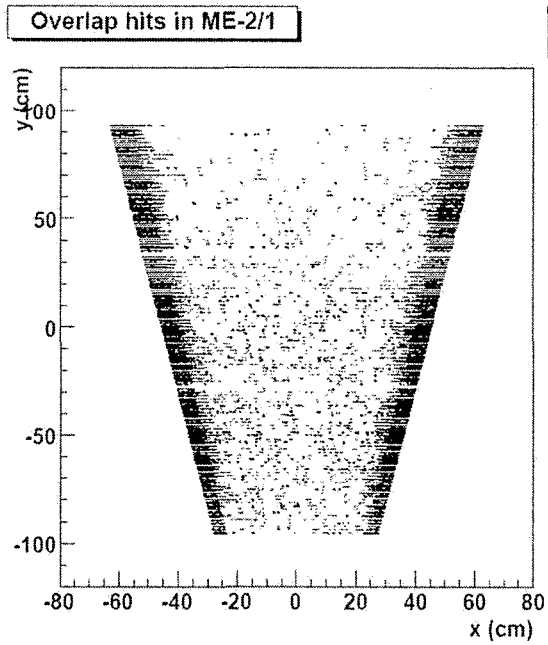


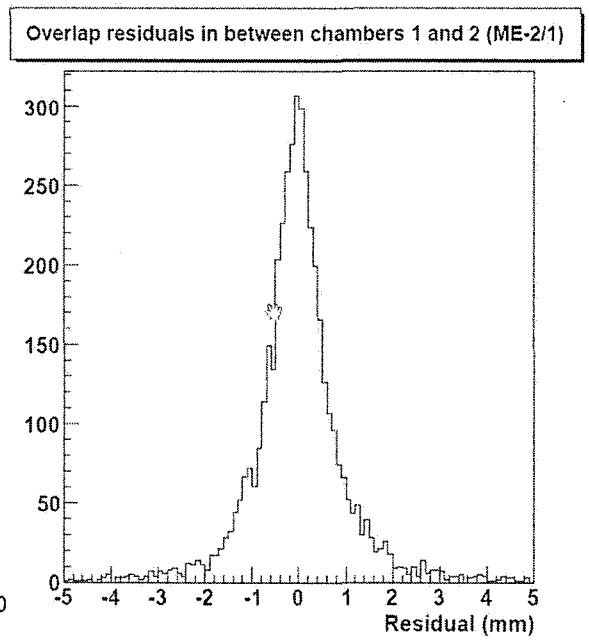
Sign error in calibration file

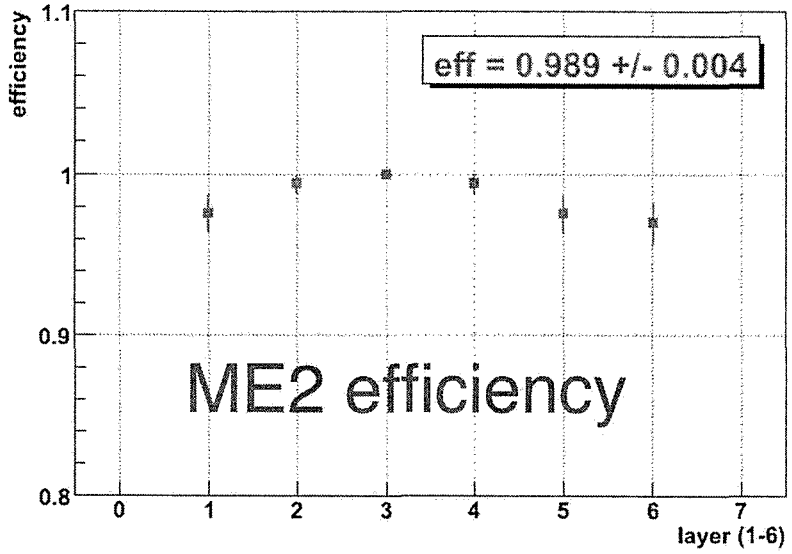
CMS

Muon CSCs with Single Beam





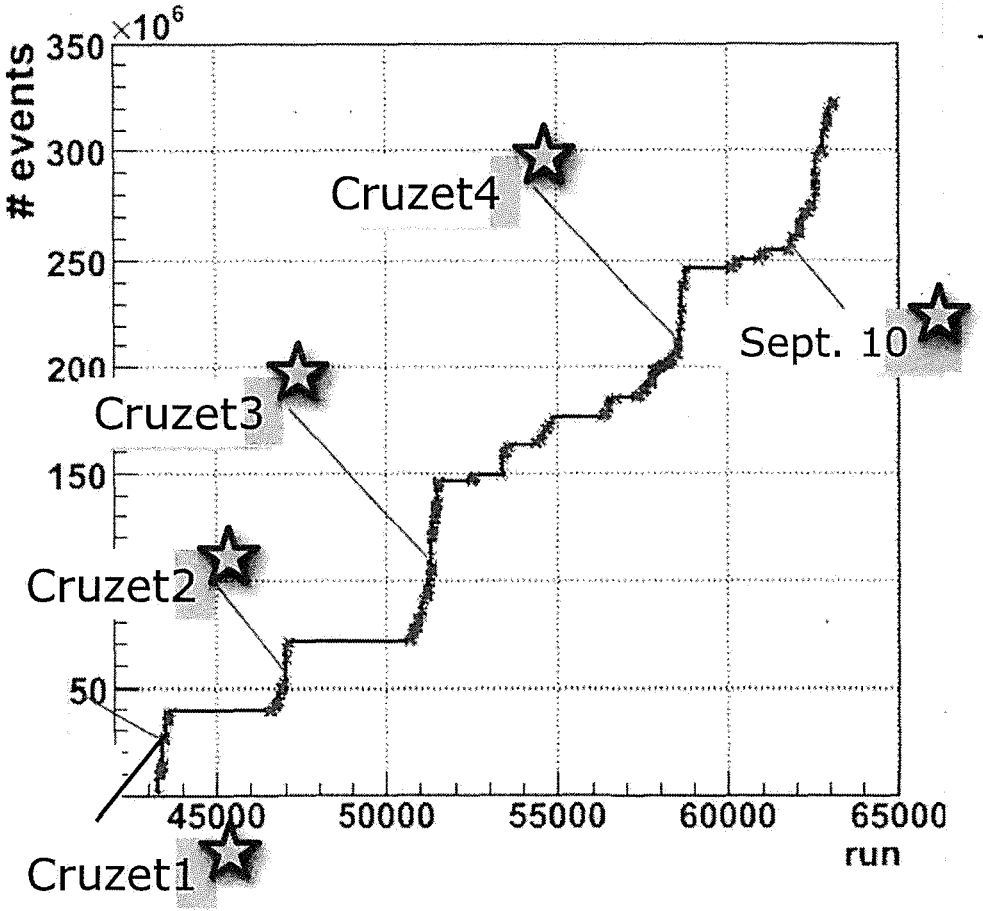




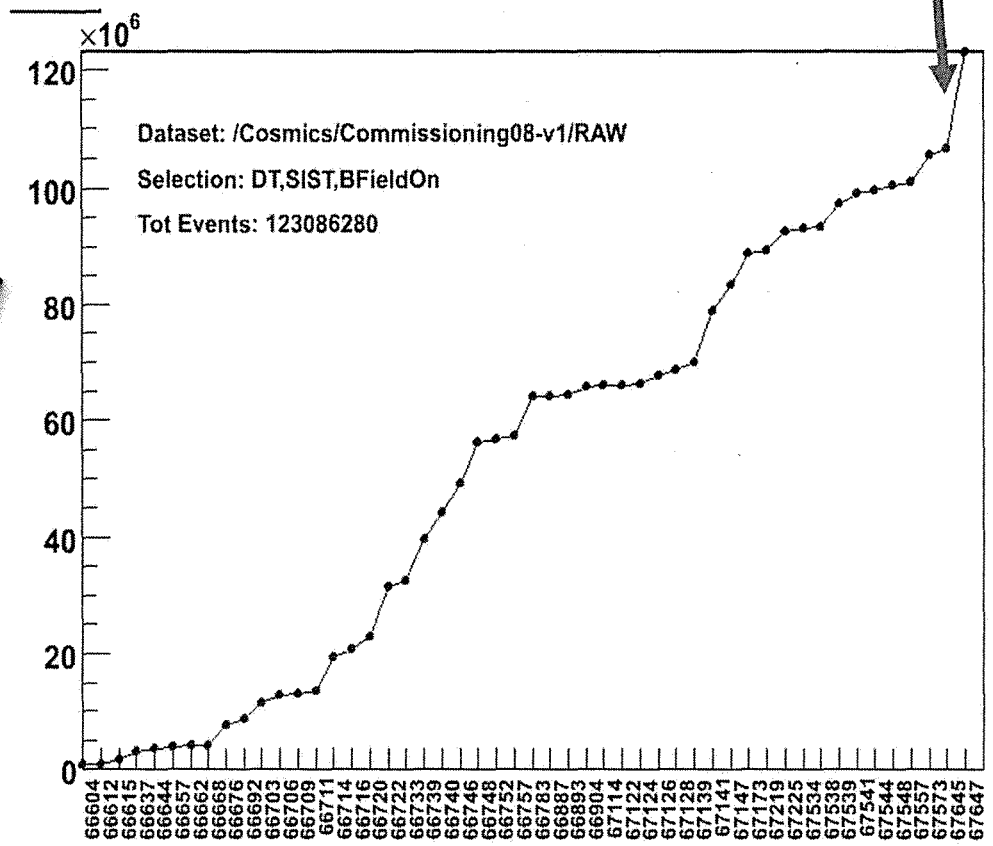
- Quantitative studies of CSC efficiency and resolution using beam data

Triggers Taken Since May 2008

Recent 16 hour run, with 17 M cosmic triggers provides "stress test" for prompt reconstruction at Tier-0



May – Sept.

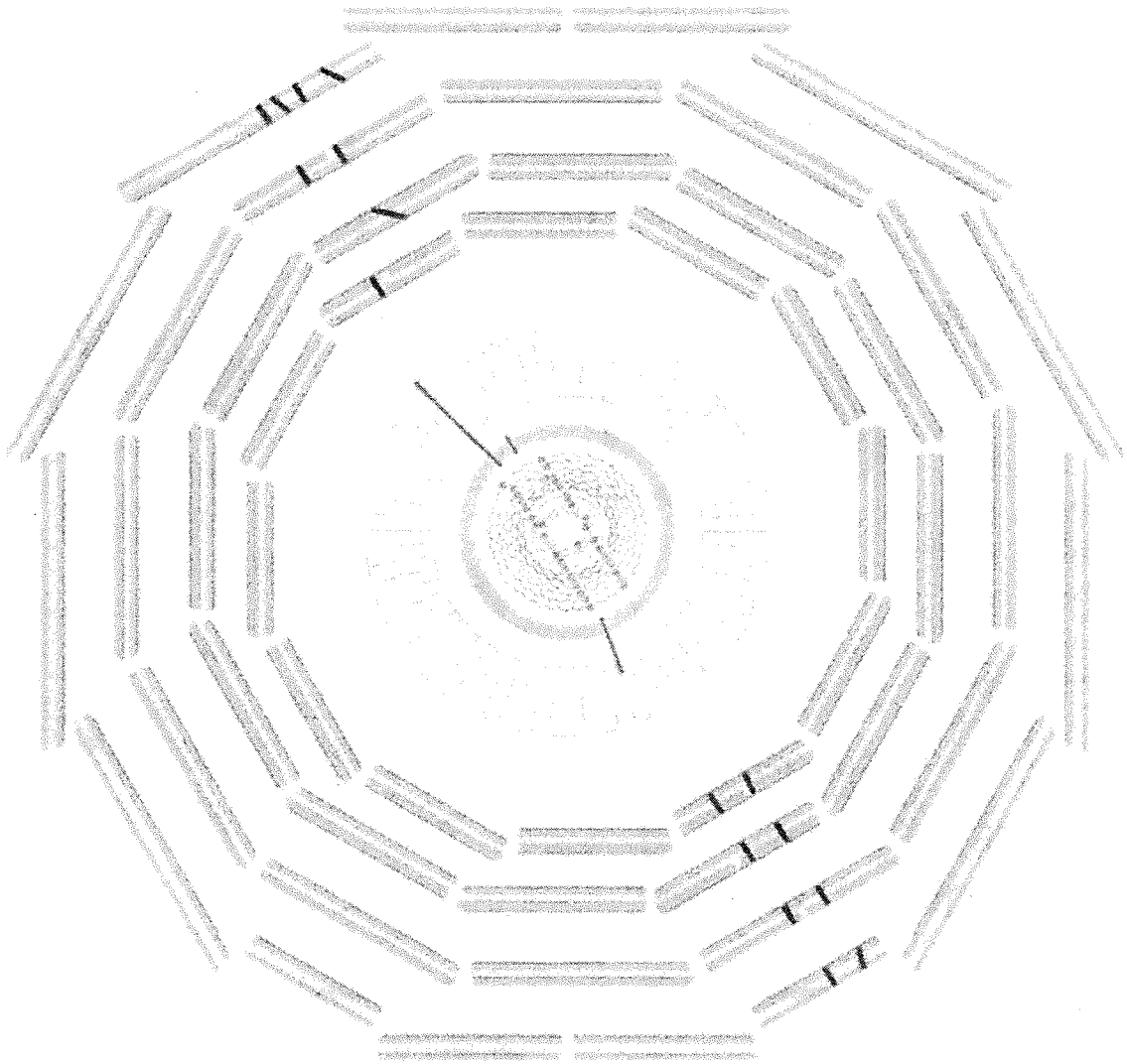


Oct/Nov CRAFT

operated / monitored by Fermilab teams from ROC

CMS

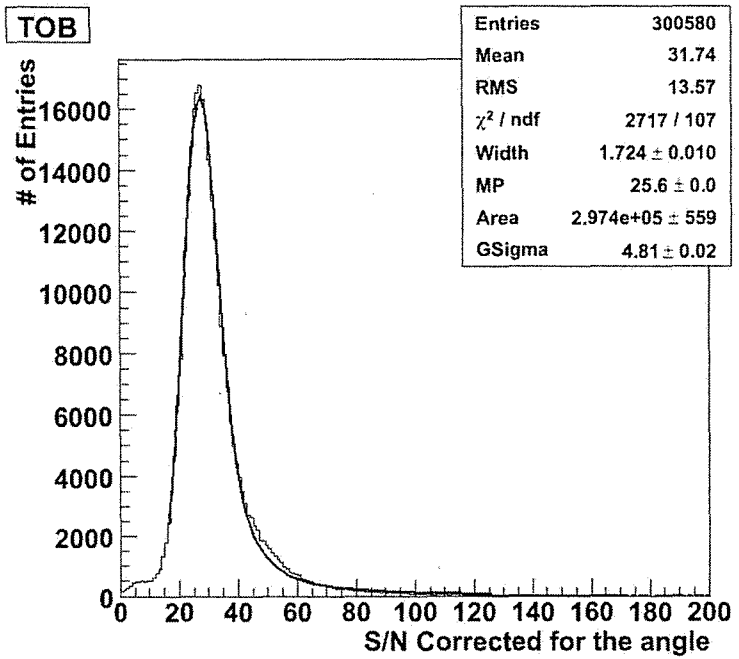
Silicon Tracker Commissioning

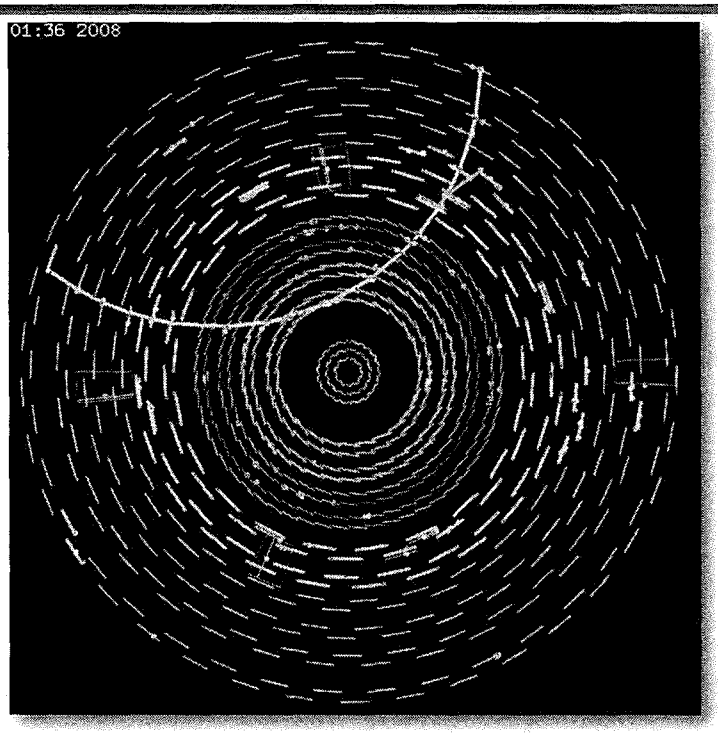


- ★ SiTrk participating in global runs after cooling issues
- ★ Temporary cooling, commissioned with the help of FNAL technicians, allowed running at ~10°C
- ★ Collected data allowed the group to stabilize the operating procedures, to verify the detector performance after move to P5, and to begin alignment studies

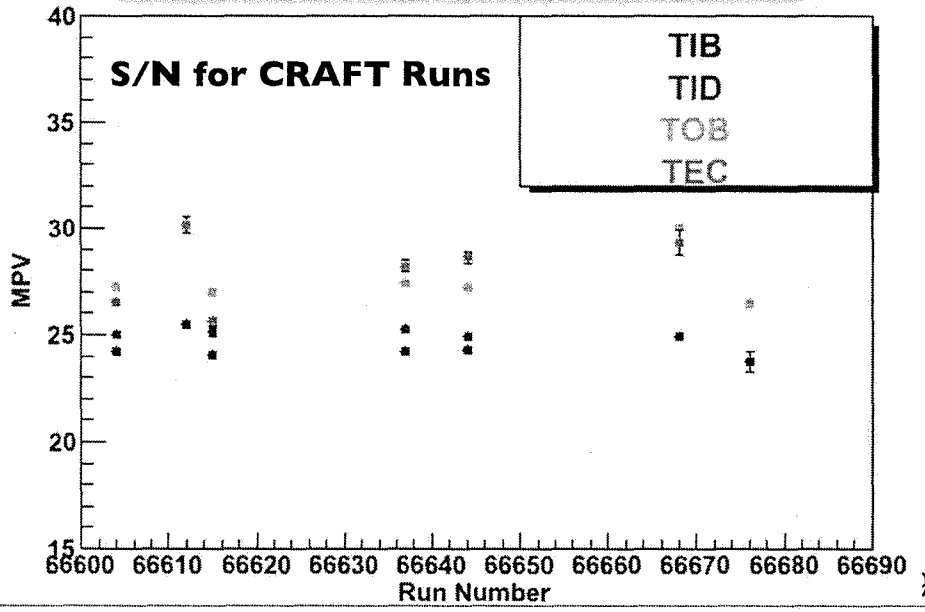
CMS

SiTrk in Cosmic Runs



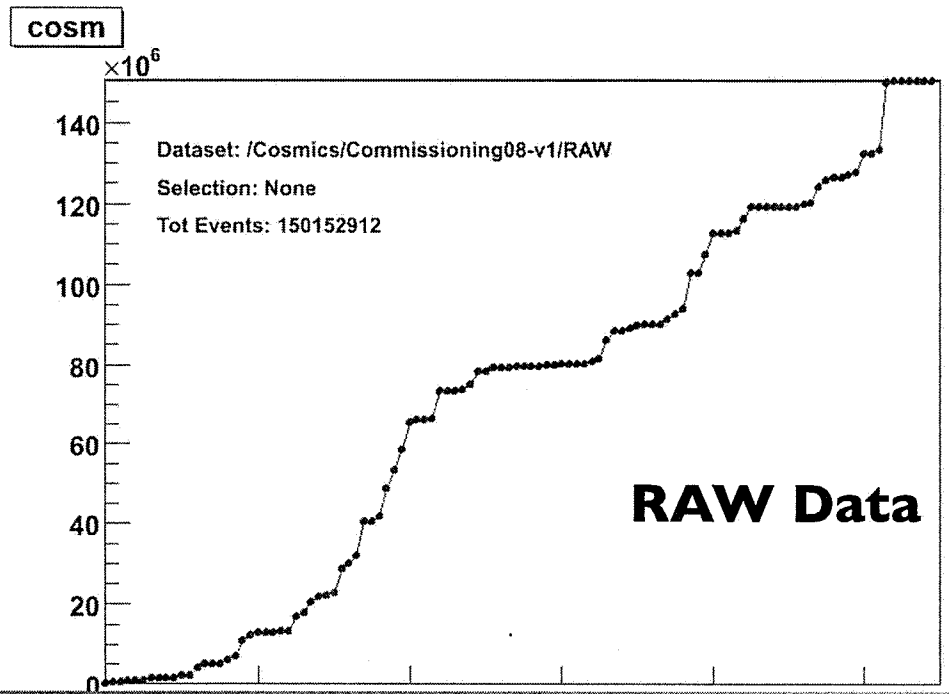


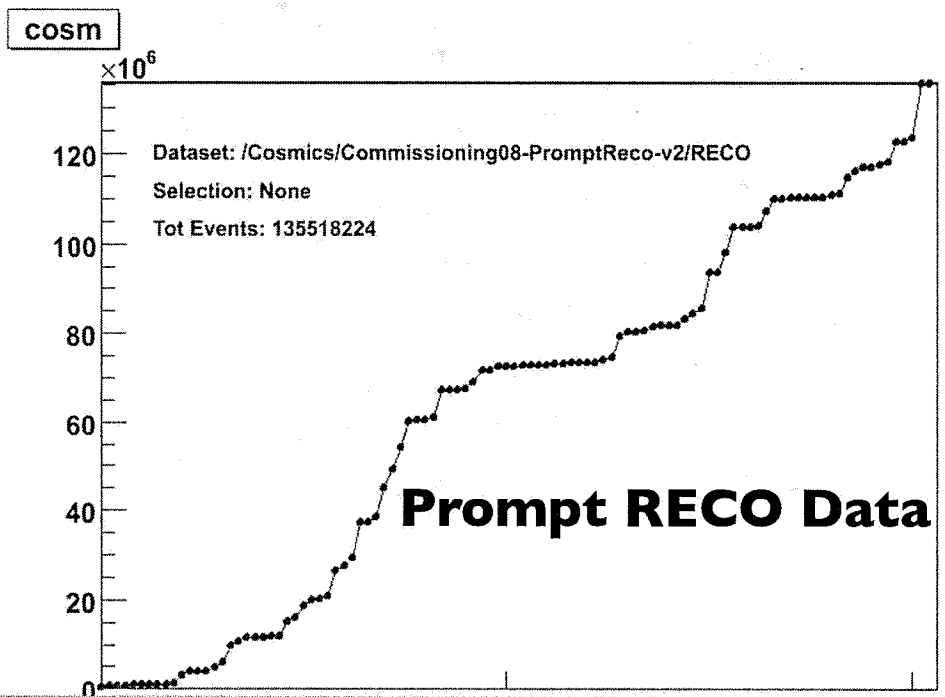
- Millions of tracks reconstructed
  - ★ tracker performing beautifully
- Nice Landau distributions observed
- S/N at design values



Initial Run Experience w/ Computing

- Throughout 2008, offline systems getting successively ready for data
  - ★ data/computing challenges, global runs, first beam, cosmics run w/ field
- CMS S&C services behave well under data taking conditions
  - ★ initial beam data taking was very successful
  - ★ chain of data and work flows from HLT farm through Tier-0/1/2/3 works
    - currently taking Cosmic data at 300Hz for several weeks





CMS

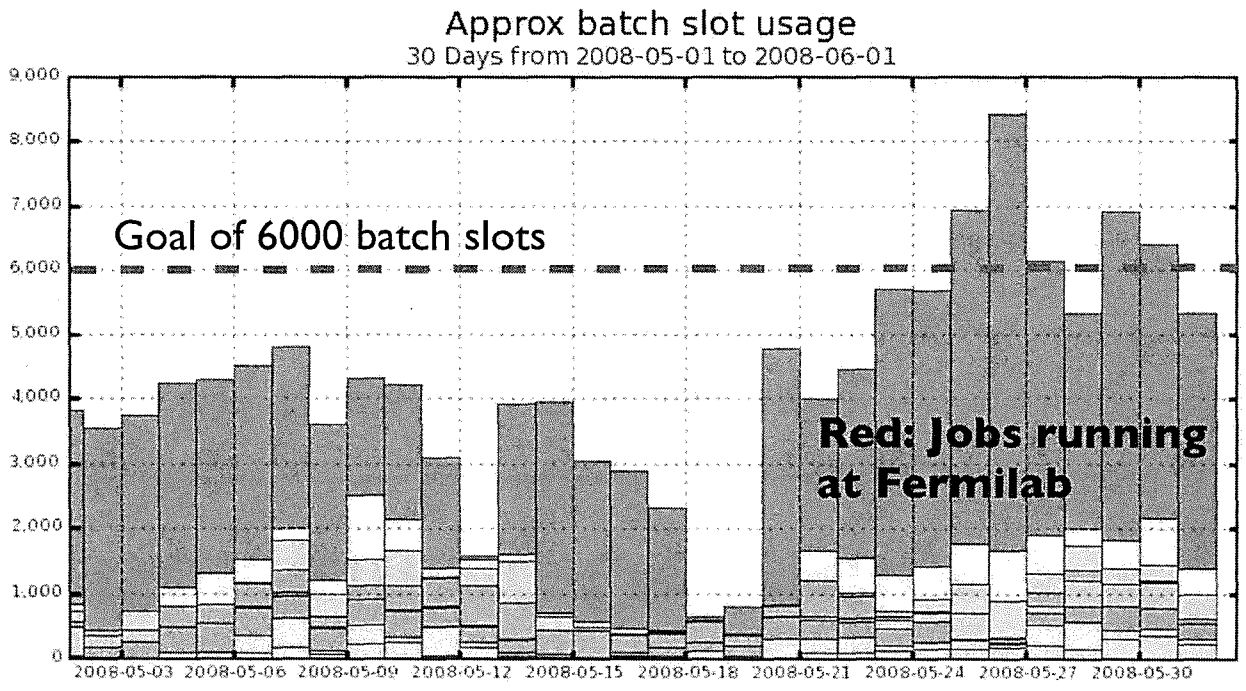
Data Processing at Fermilab's Tier-1

★ Fermilab Tier-1 has reached facility goals of a four-year procurement

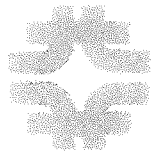
FNAL Tier-1 and LPC Summer 2008	Tier-1+LPC	7500 Batch Slots	Processing Nodes
	Tier-1+LPC	11MSI2k	Processing Capacity
	Nominal Split	5100 T1, 2400 LPC	
	Disk T1	2.0PB	dCache (1600MB/s IO)
	Disk LPC	0.5PB	Dedicated to Local Analysis
	Network	20Gb/s	CERN to FNAL
	People	30FTE	Includes Developers and Ops

★ successfully demonstrated all CMS workflows needed for data processing

- ✦ re-reconstruction
- ✦ skimming
- ✦ stripping



Software and Computing Operations

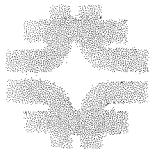


- Software and Computing ready for sustained operations
  - ★ organized, deployed and trained operations teams + "volunteers"
  - ★ maintaining support for development/integration/commissioning needs
- Fermilab responsible for Data Operations, together with MIT
  - ★ two teams, working at Fermilab and at CERN to cover all time zones
    - operating out of Fermilab Remote Operations Center
  - ★ handling all data and work flows globally, including at CERN
    - prompt reconstruction, alignment/calibration, re-processing, skimming workflows, MC production, data transfers, data certification, running the Tier-0
  - ★ working with Facility Operations teams
    - staff at Tier-1 centers, Tier-2 data managers, OSG/EGEE Grid support
  - ★ demonstrated to be able to sustain 24/7 operations
    - computing shifts, on-call experts, offline and computing run coordinators
- regular software releases, release validation, software distribution
  - ★ routine QA process for each software release, then deploy everywhere
  - ★ specific campaigns to address issues: software, computing, integration

Remote Operations at Fermilab

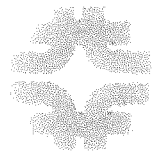
- Fermilab ROC operational and heavily used
  - ★ Fermilab initiative to create Remote Operations Center very successful
    - joined by CMS Meyrin Center, and DESY ROC, more coming
- Continuously used for
  - Official DQM shifts, Computing Shift, DataOps on-call, sub systems
  - Tier 1 operations, LHC operations, Meetings of DataOps, Facility Ops, Accelerator physicists with LHC
  - Headquarters for USCMS operations group and LPC ROC team
  - A visible center of activity for Fermilab outreach and education
- Live monitoring of CMS commissioning runs
  - Live video with P5 control room, Meyrin center

Fermilab Leadership Roles in CMS



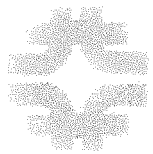
- Fermilab has a unique concentration of leadership & expertise in CMS
  - essential resource for CMS as a whole
  - ★ Fermilab people in international CMS leadership
    - Non-exhaustive list of "Level-1" and "Level-2" task leaders
      - CMS Collaboration Board Chair (D. Green)
      - HCAL Project Manager (J.Spalding)
      - CMS Computing Coordinator (P. McBride)
      - CMS Jet/MET Physics Object Group Convener (D. Elvira)
      - CMS Tracking Physics Object Group Convener (K. Burkett)
      - CMS QCD Physics Analysis Group Convener (V. O'Dell)
      - Several CMS offline software coordination roles
        - CMSSW Framework (L. Sexton-Kennedy)
        - Computing Integration (I. Fisk)
        - Data Operations (LATBauerdick)
        - Data/Workflow management (D. Evans)
      - CMS SLHC Upgrade Coordinator (J.Butler)
  - ★ Leadership in U.S. CMS
    - RPM (Butler), M&O (Freeman), S&C (Bauerdick, Fisk), L2s HCAL (Whitmore), Operations (Maeshima), DAQ (O'Dell), Software (Sexton-Kennedy), Tier-1 (Bakken), Grids (Pordes)

Ramifications of LHC Incident



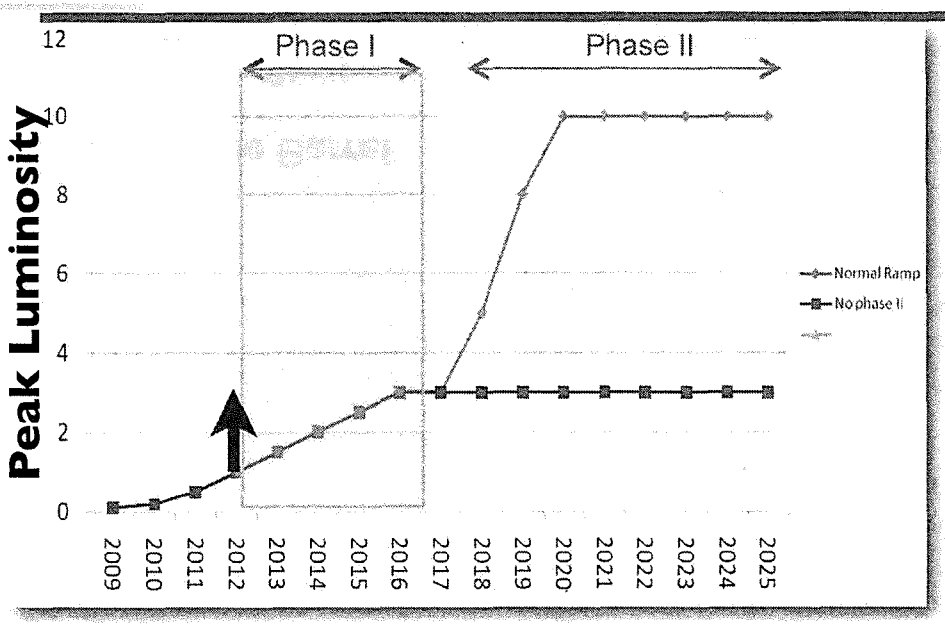
- We have shown that CMS can take good quality data
  - Now finish series of cosmic runs with magnet at 3.8T ~> Nov 10
- We then shut down for (yearly) water cooling system maintenance
- Actual shutdown ~same length as if machine incident had not occurred
- Two major shutdown activities
  - Preshower installation for which the detector must be opened
    - Preshower detectors will be ready for installation at the end of December
  - Tracker cooling system (C6F14) repairs
- There are a list of minor shutdown activities that are being discussed
  - If the startup is delayed, the list of activities undertaken will grow – in particular, more work will be done on the tracker cooling system

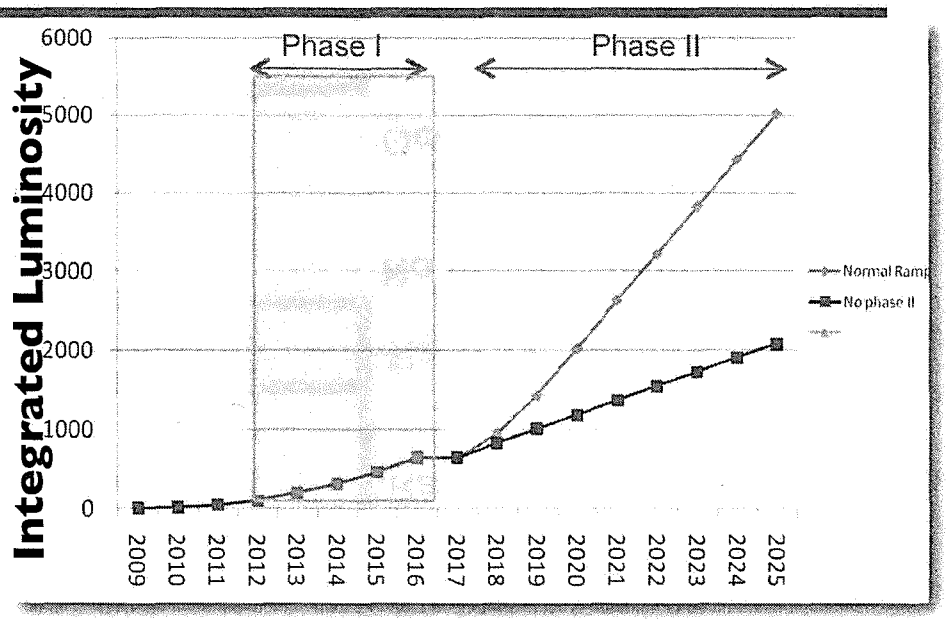
Conclusions CMS Operations



- After 9 years of construction and assembly the CMS detector is now ready for first collisions
  - ★ All CMS subsystems (except for preshower) are installed and in the advanced commissioning stage
  - ★ Much of the ongoing detector check out/commissioning exercises CMS Software and is a prelude to actual physics analysis on real data
  - ★ There are some problems, but none appears serious enough to threaten successful operation of the CMS detector
  - ★ Preparations for Software and Computing are going very well. We are ready for taking and analyzing data
  - ★ The Fermilab group has contributed successfully to the construction, installation and commissioning in most areas of CMS, with large responsibilities and leadership in the experiment
- We eagerly await collisions

Luminosity Upgrade: Issues for CMS





- ★ LHC upgrade PHASE I to start in 2013, PHASE II to be decided in 2011
- ★ CMS upgrade: detector needs for luminosities >> 10^{34} cm^{-2} s^{-1}
  - ✦ Issues that must be addressed
    - ✦ Radiation damage
    - ✦ High occupancy affecting reconstruction or triggering
    - ✦ High occupancy that leads to overflows buffers, problems with link bandwidth
    - ✦ Pileup creating dead time or affecting trigger
    - ✦ Sensitivity to very rare events: "fakes" via accidentals often involving cosmics
    - ✦ CMS is accessible, designed to be opened, therefore relatively "easy" to upgrade

CMS

CMS Upgrade Plan

Reduced performance

Severe degradation

Component	1E+34	3E+34 (Phase I)	1E+35 (Phase II)
TRACKER Pixel	OK	Rad/Occ: Replace/Add layers/disks	Rad/Occ: Full Replacement
TRACKER Strip	OK	OK	Rad/Occ: Full Replacement
ECAL Barrel	OK	OK	OK
ECAL Endcap	OK	OK	Rad high η: replace
HCAL Barrel	OK	Performance: Upgrade readout X4	No further action
HCAL Endcap	OK	Rad: Upgrade readout X4	Rad high η: new scintillators
HCAL Forward	OK	Rad: Upgrade readout X2	Rad/Occ: replace
HCAL Outer	HPD upgrade	No further action	No further action
MUONDrift Tube Barrel	OK	Change minicrates	Occ: upgrade electronics
MUON Cathode Strip chambers Endcap	OK	Occ: Add planes	Occ: upgrade electronics
MUON Resistive chambers Endcap	OK	Occ: Add planes	Occ: upgrade electronics
TRIGGER	OK	Enhancements	Occ: tracking in trigger

LHC Operations Program Manager: Slide shown at JOG this Friday

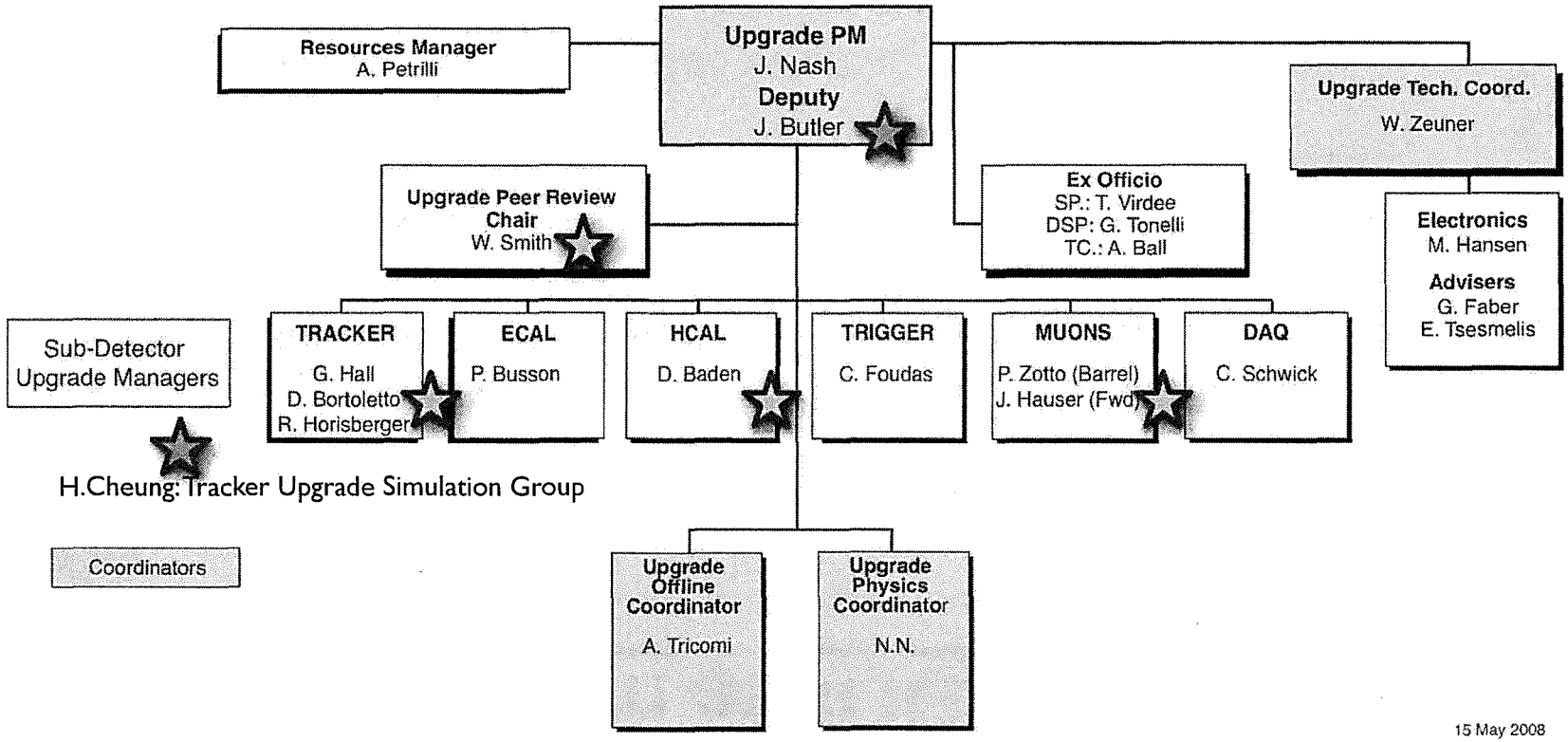
Planning LHC Upgrade Projects

- On September 11, the collaborations presented detector upgrade plans including cost profiles
  - U.S. CMS focus on Phase I plans
  - U.S. ATLAS on the longer term including the full replacement of the tracker targeted for 2017.
- Both agencies have indicated interest, but details of cost-sharing, funding levels and the process and criteria by which proposals would be evaluated has not been determined at this time.
  - Understanding the full scope of the upgrades and major items of equipment for both phase I and phase II within an overall budget implies a pre-proposal phase
  - As currently understood, CD-0 for the phase I LHC detectors upgrades is planned for Spring '09 such that funds could be available in 2011.
- The LHC schedule and the performance of the detector components as a function of instantaneous and integrated luminosity remain uncertain.

CMS Upgrade Organization

- US CMS has been supporting upgrade R&D and has strong leadership in the CMS upgrade management

CMS Upgrade Project



CMS

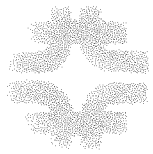
US R&D proposal submitted to CMS

1. Research and Development for CMS tracker in SLHC era Lenny Spiegel (Fermilab), Regina Demina, Yuri Gotra, Sergey Korjenevski (University of Rochester) + others Euoropean groupsSeptember 2006 Approved 06.01
2. SLHC Calorimeter Trigger R&D Program University of Wisconsin October 2007 Approved 07.04
3. CSC Level-1 Track-Finder Trigger upgrade Florida, Rice, UCLA October 2007 Approved 07.05
4. Study of suitability of magnetic Czochralski silicon for the SLHC CMS strip tracker Panja Luukka, Jaakko Härkönen, Regina Demina, Leonard Spiegel[illegible]ober 2007 Approved 07.06
5. R&D for Possible Replacement of Inner Pixel Layers With Aims for an SLHC Upgrade Alice Bean , Timothy Bolton, Aaron Dominguez, Wolfram Erdmann, Cecilia Gerber, Roland Horisberger, Angel L´opez October 2007 Approved 07.07
6. CSC Endcap Muon Upgrades Contact Person: Jay Hauser October 2007 Approved 07.10
7. Reference Link Project For High Speed Optical Data Link R&Ds SMU, Minnesota and OSU October 2007 Approval Pending 07.11
8. The Versatile Link Common Project Francois Vasey and Jan Troska, Physics Department, CERN, Geneva, Switzerland Christian Olivetto and Jean-Marie Brom, Institut Pluridisciplinaire Hubert Curien, Strasbourg, France
   Cigdem Issever, Todd Huffman and Tony Weidberg, Department of Physics, Oxford University, United Kingdom
   Jingbo Ye, Department of Physics, southern Methodist University, Dallas TX, USA November 2007 Approved 07.12
9. 3D detectors for inner pixel layers Daniela Bortoletto/Simon Kwan[illegible]ecember 2007 Approved 07.13
10. CMS HCAL Calorimeter Electronics Upgrade Drew Baden, University of Maryland December 2007 Approved
11. Proposal for US CMS Pixel Mechanics R&D at Purdue and Fermilab in FY08 Daniela Bortoletto, Simon Kwan, Petra Merkel, Ian Shipsey, J.C. Yun December 2007 Approved 07.15
12. R&D for Thin Single-Sided Sensors with HPK Contact Person: Marcello Mannelli Januar[illegible]008 Approval Pending 08.01
13. Power Distribution System Studies for the CMS Tracker Fermilab[illegible]owa, Mississippi (Contact Person: Simon Kwan[illegible]une 2008 Approved 08.04
14. US CMS detector upgrades for PHASE 1 of the LHC luminosity upgrade US CMS (Contact Persons: Daniela Bortoletto, Joel Butler[illegible]uly 2008 Approved 08.05

OUT of the 22 R&D proposals submitted to CMS

Indicates direct Fermilab involvement

Pixel Upgrade Plans



- Baseline: 3 layers (4 layer option) & 3 disks in each end cap
  - ★ Detector technology to improve radiation hardness
    - Single sided n-on-p sensors (cheaper, more rad-hard?) / n-on-n (fallback)
    - Evaluating 3D sensors industrialization for innermost layer at 4 cm.
  - ★ Readout Chip
    - Double ROC buffer size to reduce dead time (sufficient for Phase I)
    - In 250 nm CMOS an extra 0.8 mm needed for periphery
      - Minimal R&D. Design, verification, testing at high beam rates
      - Mechanical changes
    - Further gains possible with 130 nm CMOS (needed for Phase II, R&D required)
  - ★ Improve layout, mechanical assembly, and cooling to reduce material budget by about a factor of 3 in barrel and 2 in forward
    - $C0_2$ cooling (as in VELO for LHCb)
    - Low mass module construction and simplified thermal interfaces
    - Further material reduction can be achieved with on module digitization:
      - R&D needed: It requires new ADC and Token Bit Manager changes

CMS

Development of a replacement plan

2013 Pixel Replacement/Upgrade Discussion Meeting

Thursday 09 October 2008
from 09:00 to 18:50
Europe/Zurich
at CERN (*17-1-007*)

Description: PW for file uploads: pixmeet

EVO PW: pixmeet

Thursday 09 October 2008

09:00 Welcome (10') (Slides)
09:10 CMS Tracker Upgrade Program (10') (Slides)
09:20 BPIX Options for Phase 1 (15') (Slides)
09:35 Fpix scenarios (15') (Slides)
09:50 Beam Pipe Bake-out & Pixel Re-Installation (10') (Slides)
10:00 break

10:10->*11:10* COOLING

10:10 CO2-Cooling : Possibilities & Properties (15') (Slides)
10:25 Cooling Loops for a 3 or 4 Layer CO2 Cooled BPIX (05') (Sli
10:30 CO2 R&D at FNAL (10') (Slides)

11:10->*12:10* MECHANICS&GEOMETRY

11:10 Possible Geometry for a 3 or 4 Layer Pixel System (05') (Slides)
11:15 First thoughts about a CO2 Cooled BPIX Mechanics (05') (Slides)
11:20 BPIX Integration: Lessons learned (05') Stefan Koenig (*Paul Scl* (Slides)
11:25 Panel material studies (10') (Slides)
11:35 Layout optimization (10') (Slides) Harry Cheung (*Fermi National*
12:10 Lunch break

13:30->*14:30* POWER,CABLES,DCS

13:30 Power cables: Status & Constraints (10') (Slides) Wilhelm Bertl (*PSI*)
13:40 First Results from a On-Chip 2:1 Step Down Converter (10') (Slides) Beat Meier (*ETHZ*)
13:50 Power studies (10') (Slides) Simon Kwan (*Fermilab*)

14:30->*15:30* READOUT

14:30 Phase I Pixel ROC (10') (Slides ; more information) Hans-Christian Kaestli (*PSI*)
14:40 Very low power links through micro twisted pairs (10') (Slides) Beat Meier (*ETHZ*)
14:50 AOH replacements (10') (Slides)

15:30->*16:30* SENSORS&MODULES

15:30 BPIX Sensors: Production, Testing and Qualification (10') (Slides) Tilman Rohe (*Nuclear and Particle Physics Department*)
15:40 Low Mass modified BPIX modules: Design & Fabrication (05') (Slides) Stefan Koenig (*Paul Scherrer Institut, 5232 Villigen PSI, Switzerland*)
15:45 BPIX Module Qualification (10') (Slides) Andrei Starodumov (*Labor fur Hochenergiephysik*)
15:55 FPIX Sensors R&D (10') (Slides) Gino Bolla (*Purdue University*)
16:05 FPIX Material reduction & Module Development (10') (Slides) Kirk Arndt (*Purdue*)

16:30->*17:30* SOFTWARE&COMMISSIONING

16:30 Lessons from Commissioning (10') (Slides) Anders Ryd (*Cornell University*)

17:30->*18:30* SCHEDULES

17:30 Schedules for various BPIX replacement/upgrade scenarios (15') Roland Horisberger (*PSI*)
17:45 Schedules for FPIX scenarios (15')

Roland Horisberger (PSI)

- Development of layout is allowing to proceed to:
  - Conceptual design
  - Small prototyping
  - Full scale prototyping

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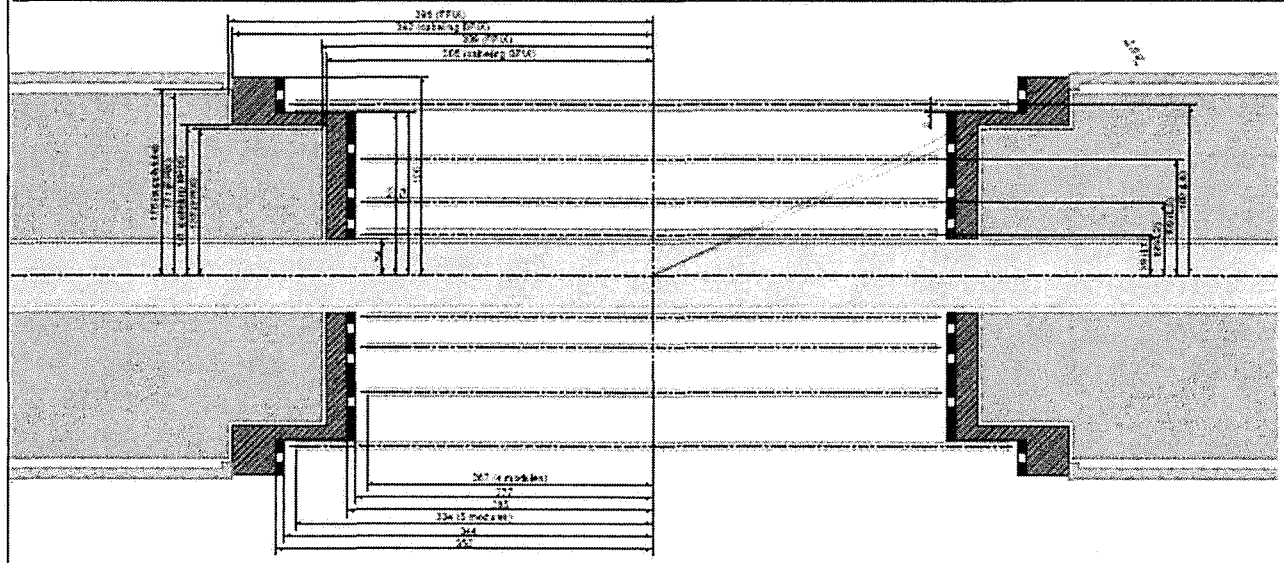
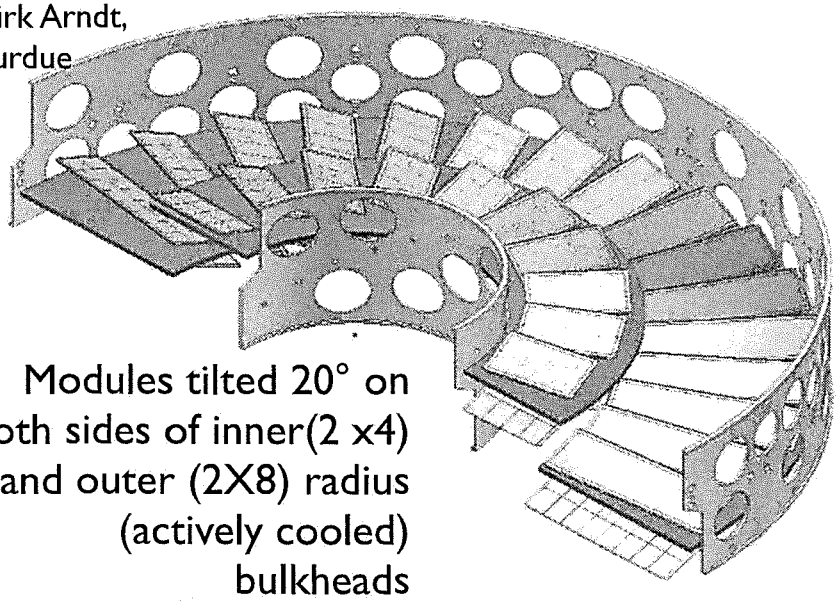
Layout under discussion



- Developing barrel and disks conceptual design
  - Fewer module types
  - CO_2 cooling

Kirk Arndt, Purdue



Modules tilted 20° on both sides of inner(2 x4) and outer (2X8) radius (actively cooled) bulkheads

- ✦ Barrel:
  - ★ Only one type (2x8) of modules (2 now)
  - ★ Two identical half shells
  - ★ Layer 1 closer to beam-pipe (44mm → 39mm)
- ✦ Endcap Disk
  - ★ Two types (2x8 and 2x4) of modules(5 now)

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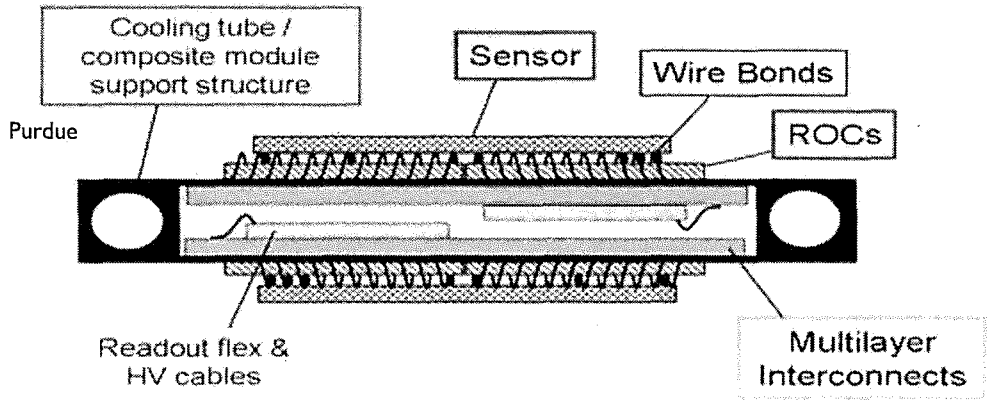
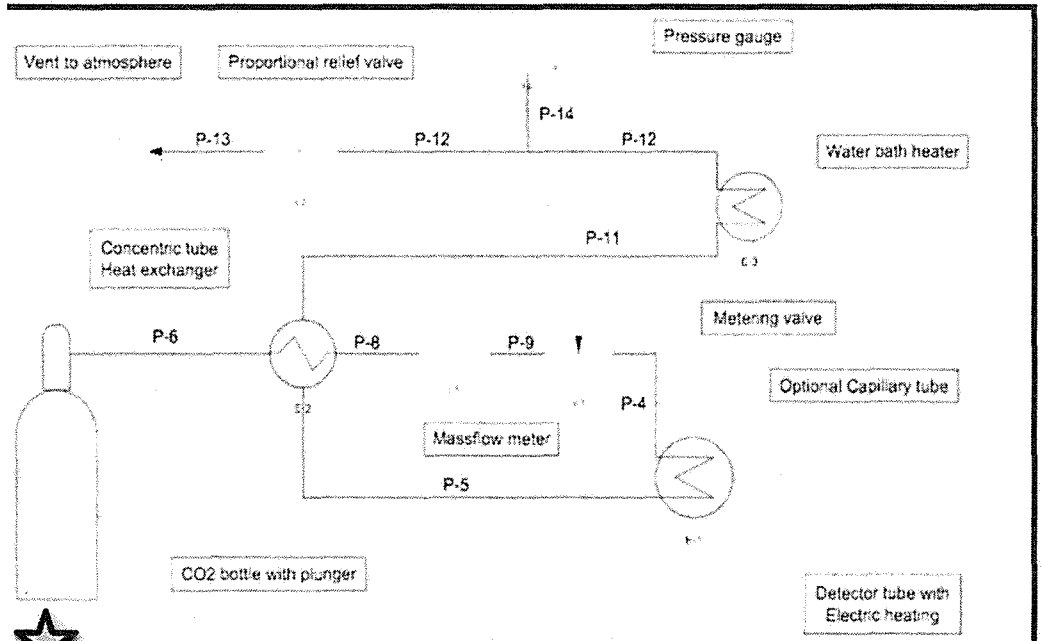
Forward Pixel Mechanical R&D for material reduction

- Integrated modules conceptual design: Flip chip modules mounted on high heat transfer/stiff material.





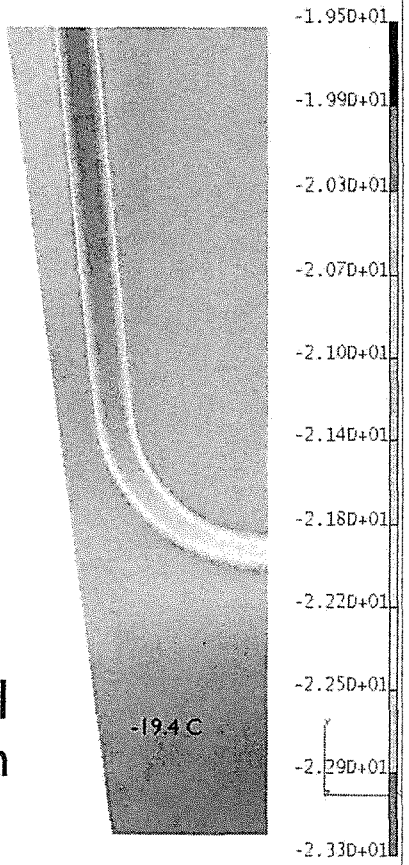
Pixel CO2 Cooling Test setup schematics

June 2008 H. Postema

Panel Conceptual design

$\Delta T = 3.8$ C across substrate

- Two substrates with cooling tubes in between.
- Material selected for substrate
  - Low mass TPG laminated with carbon-fiber facing
  - High thermal conductivity: ~ 1600 W/mK, $X_0 = 18.9$ cm
- High pressure CO_2 cooling/small tubes
- The cooling channels will be imbedded in pocofoam
- Finite Element Analysis with 200 % heat load shows acceptable performance



FNAL

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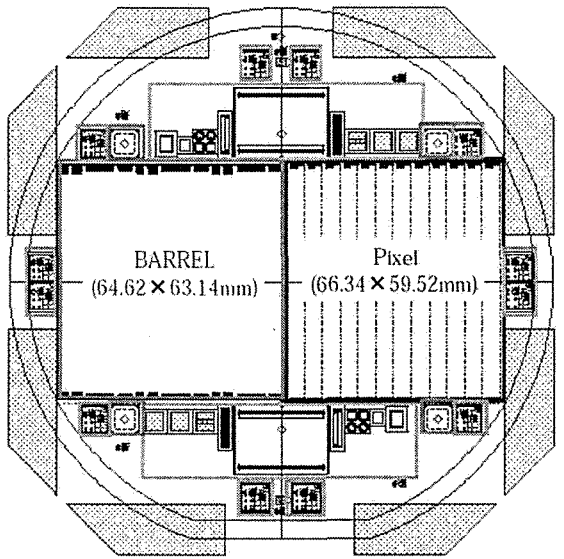
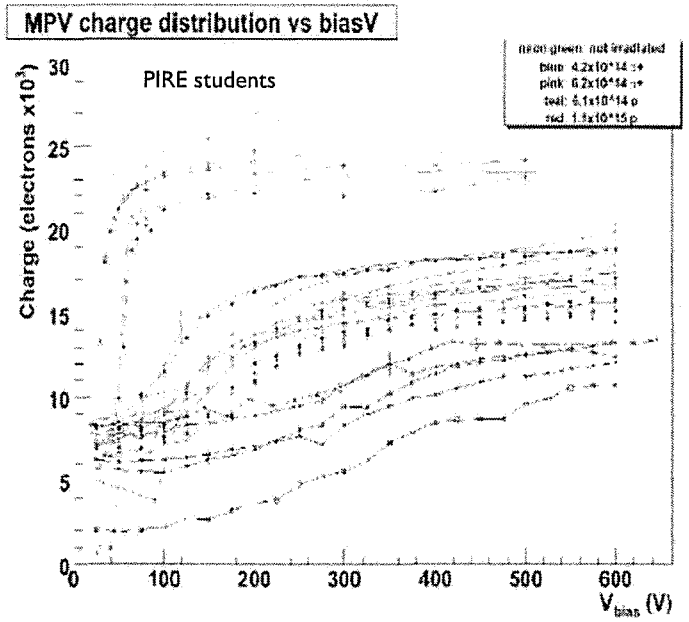
Pixel Sensor R&D

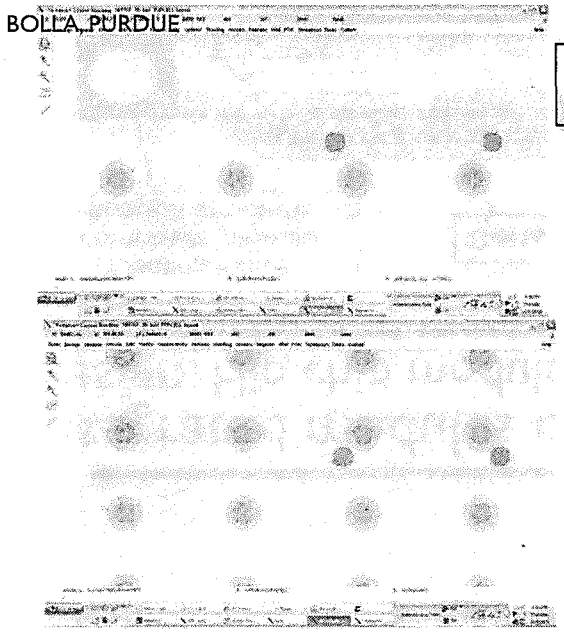


- n-on-p Submission with HPK:
  - Test different substrates
  - Different thickness
  - n-on-p versus n-on-n
  - Pixel isolation (p-spray and p-stop)
  - Order should be submitted this month
  - Turn around time 6 month

n-on-p Rad hard up to ~3×10^{15} cm^{-2}



- 3D - Submission with Sintef

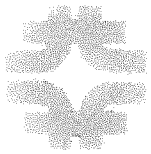


3D Rad hard up to ~10^{16} cm^{-2}

- Shared with ATLAS and MEDIPIX
- Implemented 2 variation
  - 2 columns pixel
  - 4 columns pixel
- Order out
- Turnaround time ~ 6 months

- Test beam available (FNAL/ROCHESTER/BROWN) et al.
  - T. Mäenpää, et al. Nucl. Instr. and Meth. A 593 (2008) 523-529.

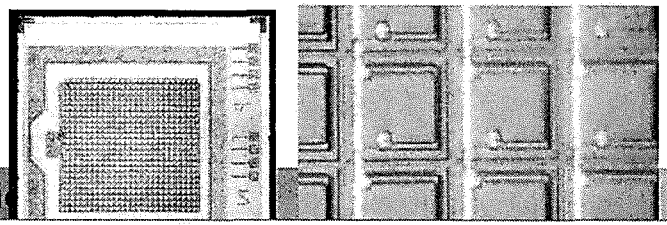
HCAL Upgrade Proposal



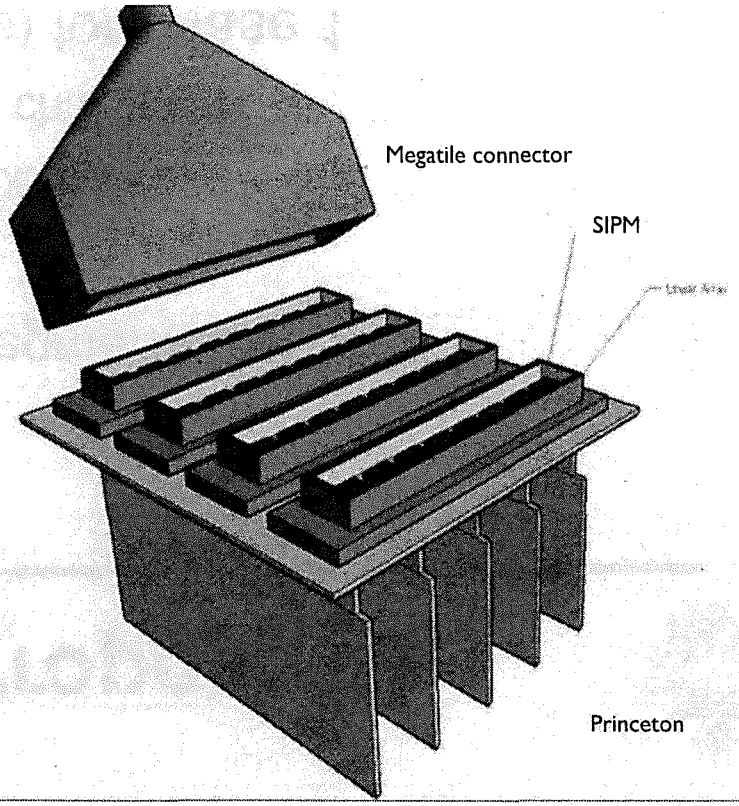
- Replace HB/HE/HF Front End for phase 1
  - ★ Change from Hybrid Photo Diode to SiPM
  - ★ Add longitudinal (HB/HE) and lateral (HF) segmentation
  - ★ Add shaping (HB/HE) and timing (all)
  - ★ Keep current fiber plant and front-end services
    - Big cost and schedule savings but with technical challenges
- Replace Trigger/Receiver (VME electronics) for phase 1
  - ★ Needed to accommodate HB/HE/HF front-end changes at Phase 1
  - ★ Allows for a more powerful system at L1 trigger level
  - ★ Synergistic w/ other CMS subsystems (RCT/Wisc, GCT/IC, ECAL)
  - ★ Minimize cost
    - Use same processing board as currently being developed by RCT/GCT
    - Leverage telecommunications technology
    - Much less R&D compared to current VME-based TR system
- Changes will make a more powerful and robust HCAL
  - ★ And decrease exposure to the unknown

SiPM R&D for HCAL Upgrade

- Array of avalanche photo diodes ("digital" photon detection)
  - Array 0.5x0.5 up to 5.0x5.0 mm2
  - Pixel size can be 10 up to 100μm
- ★ Are almost "off the shelf" parts
- ★ Advantages over HPDs:
  - 28% QE (x2 higher) and 10^6 gain (x500 higher)
  - More light (40 pe/GeV), less photo-statistics broadening
  - Very high gain can be used for timing shaping/filtering
  - Excellent performance in B-field
  - Good results in initial rad hardness studies
- Investigating SiPMs for HO



- Conceptual Design to connect SiPM to Megatiles
  - SiPMs (1mm^2) are wire bonded to gold pads on glass-fiber substrate
  - Metal pins locate the cables
  - Precision molded plastic barrel provides light tightness and proper spacing of fibers above the SiPMs



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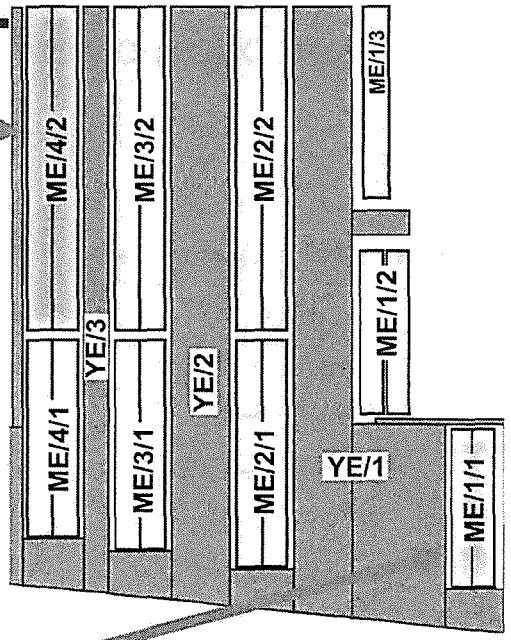
Endcap MUon EMU Upgrade



- Build ME4/2 chambers (72)
  - ★ for high-luminosity triggering over η range of 1.1-1.8
  - ★ improve μ reconstruction
- Uses same technology as other US-built chambers
  - ★ Low technical risks, costs & schedule well known
  - ★ materials to assemble prototype has been procured, new panels made and milled
  - ★ Assembly schedule:
    - gluing, winding, soldering
      - Fermilab, Nov-Dec
    - tension tests, sealing; FAST site tests
      - CERN, Mar-Apr
- Rebuild ME1/1 cathode cards with FlashADC version
  - ★ restores trigger to η 2.1-2.4
  - ★ handles highest rates
- Update ME1/1 off-chamber elec.
  - ★ accommodate new cathode cards
  - ★ improve trigger
- Make a full production plan updated for prototype experience
  - ★ LHC schedule now compatible w/ deploying ME4/2 prototype in 2009?

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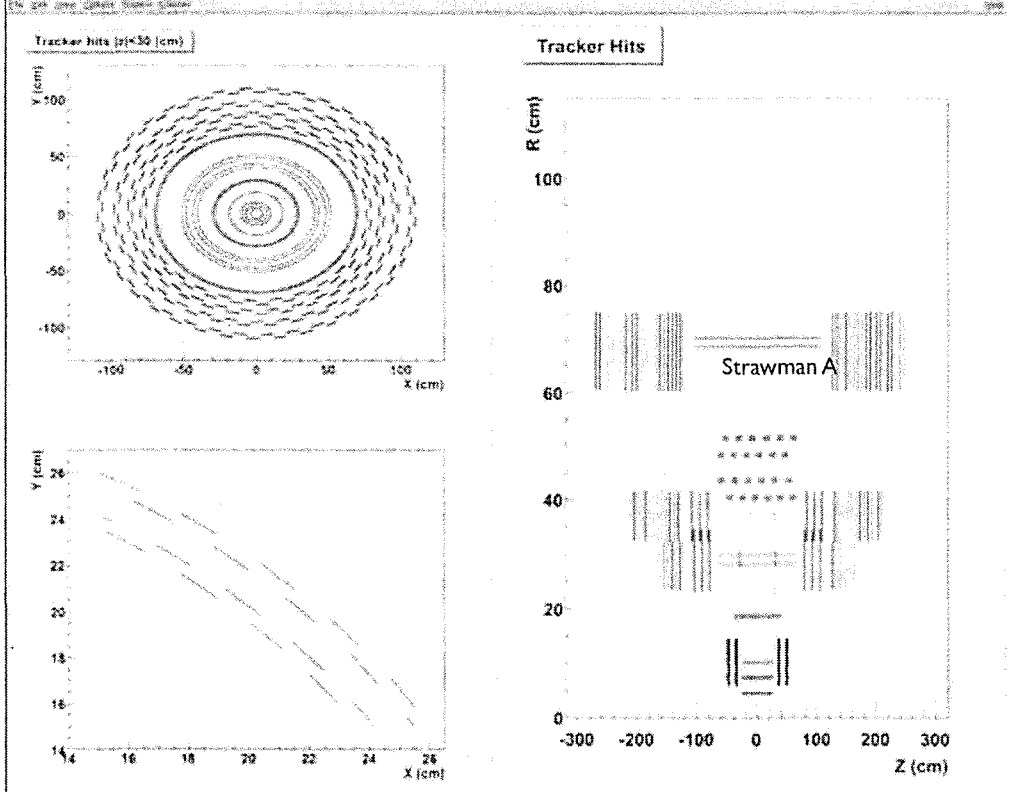
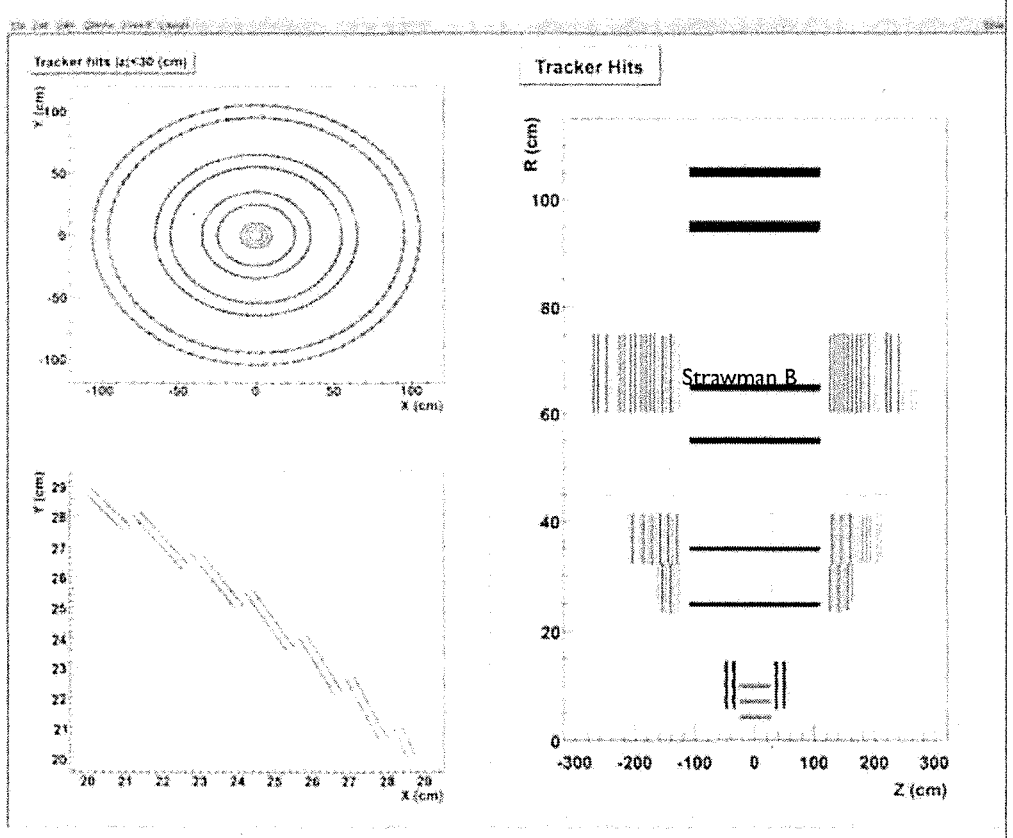
Upgrade Simulation Software

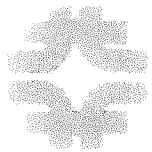
- Example strawman geometries as starting points for simulation studies





- Highest priority Simulations studies:
  - Phase 2 studies to see whether a (buildable) trigger doublet would work, how many are needed and what their parameters should be
  - Studies with an extra 4th barrel pixel layer and extra forward disk for both Phase 1 and Phase 2 LHC upgrade

US CMS upgrade R&D



- Develop R&D plan from the ground up by requesting proposals
  - ★ evaluated at CMS level
- Tight budget guidance, difficult choices were made
  - ★ requests were $4,733k
  - ★ Focus on phase 1 needs and critical phase 2 issues

- Breakdown
  - Phase 1: 83 %
  - SiPM: 15%
  - Pixel mechanics/cooling/ power: 30%
  - Phase 2: 17%

System	FY08	FY09
HCAL	285,000	488,000
ECAL	50,000	49,000
EMU	15,000	260,000
STRIP	183,000	234,816
PIXEL	670,000	842,072
TRIGGER	0	269,268
DAQ	0	40,000
SIMULATION	100,000	90,000
DATA LINKS		226,844
TRAVEL	50,000	
TOTAL	1,353,000	2,500,000

FY09 going to Fermilab: $1,188k

Conclusions Upgrades

- SLHC physics requires detector upgrades to maintain performances
- Detector upgrades will require a strong R&D program
  - Large interest at Fermilab and in the US in R&D program
  - Excellent coordination with CMS
- Moving rapidly to conceptual design for Phase I upgrade
  - Phase I replacement/upgrades are stepping stone for Phase II upgrade
- Progress on addressing the largest challenges for Phase II
  - Simulation of performance: what's required, how to build it, within budget
  - Power delivery / distribution (also for Phase I to deploy 4th pixel layer)
  - Provision of triggering data
- A vigorous R&D activity for the SLHC Phase I and Phase II will entail significant progresses in the area of particle detector developments, and therefore will ultimately have impacts on future machines
  - Upgrade workshop at Fermilab Nov 19-21
    - Goals: Working plan for the Phase I, Review progress on Phase II R&D