CMS Pixel Detector Upgrade

Daniel Pitzl, DESY
DESY Instrumentation Seminar 16.9.2011

- Present pixel detector
- 4-layer upgrade
- Read out chip modifications
- Module assembly, testing, and calibration
- preparations in Hamburg
CMS and its pixel detectors

Panels of the Forward Pixel Detector

Forward Pixel Detector has 2 disks on each side at $z = 34.5 \text{ cm}$ and $46.5 \text{ cm}$. FPix has 672 modules.

Barrel Pixel Detector has 3 layers at $R = 4.4 \text{ cm}$, $7.3 \text{ cm}$, and $10.2 \text{ cm}$. BPix has 768 modules.

Total of $\sim 15,840$ readout chips, 66M pixels.
CMS at present: 3 barrel pixel layers

- Developed and built at PSI, CH, 1994 - 2008.
- Active length 52 cm.
- 3 layers:
  - $<R> = 4.4, 7.3, 10.2$ cm
- 768 modules
- 12,000 chips
- 51M pixels
- 1.5 kW
- 5.2 kg
Present barrel pixel detector

K. Eklund 2009
Barrel Pixel insertion 2008

- The CMS pixel detector is accessible and removable during extended Christmas maintenance.
- Removal required for beam pipe bake out (vacuum conditioning).
- There is space for a 4th barrel layer.

Conical beam pipe: smaller at the IP.
Pixel operation in 2010

- 98.7% alive barrel modules.
- 96.4% alive forward modules.

status Aug 2010
Hybrid pixel detectors

Silicon sensors with $100 \times 150 \, \mu m^2$ pixels, bump bonded to CMOS readout chips.

Requires special bump bond technology.
Cost driver: 2c/bump.

Indium deposited

170°C reflow
CMS Pixel hit resolution

Drift in crossed E and B fields: Lorentz angle \((\tan \alpha_L = \mu B)\) is \(\sim 28^\circ\) for e in pure Si at 3.8 T. Leads to beneficial charge sharing.

A hit resolution of 12 \(\mu m\) has been achieved in 2010 collision data.
CMS track impact parameter resolution

Reach 20 $\mu$m at high momentum.
Ultimately expect 12 $\mu$m.

Limited by multiple scattering at low momenta and/or high rapidity.
CMS impact parameter resolution

- 18-fold $\phi$ structure due to pixel cooling pipes visible at low $p_T$.
- Well described by the detector simulation.
Nuclear imaging

- Reconstructed nuclear interaction vertices.
  - Barrel pixel region.

- CMS tracker is shifted by ~3 mm relative to the machine beam pipe.
  - Upgrade: center pixel around pipe!

- Pixel modules, cooling pipes and support rails visible.
  - Upgrade: reduce the material budget!
LHC plan (S. Bertolucci PLHC 2011)

- **2009**: Start of LHC
  - Run 1: 7 TeV centre of mass energy, luminosity ramping up to few $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, few fb$^{-1}$ delivered

- **2013/14**: LHC shut-down to prepare machine for design energy and nominal luminosity
  - Run 2: Ramp up luminosity to nominal ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$), ~50 to 100 fb$^{-1}$

- **2017 or 18**: 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$^{-1}$

- **~2021/22**: Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling
  - Run 4: Collect data until > 3000 fb$^{-1}$

- **2030**: ILC, High energy LHC, ... ?
LHC 10 year plan as of June 2011
Event pile-up at high luminosity

Simulation

Data 2011:
7 pile-up events at $2 \cdot 10^{33}$ and 50 ns bunch spacing
F. Hartmann, sensor testing, CMS Tracker Week Sep 2009
http://indico.cern.ch/conferenceDisplay.py?confId=47301

- 3000 fb⁻¹ = 20 years.
- This decade: 300 fb⁻¹.
- Pixel region: dominated by pions.
- Layer at R = 3 cm:
  - flux 500 MHz/cm²,
  - may need replacement every year (200 fb⁻¹).
CMS Pixel Chip

Pixel cell: 0.1 × 0.15 mm²

PSI46 V2.4

0.25 μm CMOS IBM process

radiation hard design operational after 130 kGy γ irradiation

1.3 M transistors

V_A = 1.5 V
V_D = 2.5 V
30 μW / pixel
0.12 W / chip

noise 130 e
Double column readout

Sources of inefficiency:
now → upgrade

Pixel busy:
pixel insensitive until hit transferred to data buffer (column drain mechanism)

2BC → 1BC

Double column busy:
Column drain finds hit pixels and transfers hits from pixel to data buffer. Maximum 3 pending column drains requests accepted

3 → 8 pending

Data Buffer full:
size: 80 (32)

Double column: 2×80 pixel, 0.024 cm²
L1 trigger: after 3.2 us (130 BC).
at 500 MHz/cm²:
0.3 tracks / DC / BC,
40 tracks in buffers.

Timestamp Buffer full:
size: 24 (12)

Readout and double column reset:
Wait for token, reset after r/o

40 MHz analog readout → 160 MHz digital

26 x / ROC
Data loss mechanisms

Present PSI46 readout chip simulated at LHC design luminosity
Pythia physics generator + detector and chip simulation:

- Pixel busy:
  - 0.04% / 0.08% / 0.21%
  - Pixel insensitive until hit transferred to data buffer (column drain mechanism)

- Double column busy:
  - 0.004% / 0.02% / 0.25%
  - Column drain transfers hits from pixel to data buffer. Maximum 3 pending column drains requests accepted

- Data Buffer full:
  - 0.07% / 0.08% / 0.17%

- Timestamp Buffer full:
  - 0% / 0.001% / 0.17%

- Readout and double column reset:
  - 0.7% / 1% / 3.0%
  - for 100kHz L1 trigger rate

- LHC parameters:
  - 1xLHC: $10^{34}$cm$^{-2}$s$^{-1}$
  - 11 cm / 7 cm / 4 cm layer
  - Total data loss @ 100kHz L1A:
    - 0.8%
    - 1.2%
    - 3.8%
Data loss mechanisms

Present PSI46 readout chip simulated at $2 \times$ LHC design luminosity

- **Pixel busy:**
  - $0.09\% / 0.18\% / 0.48\%$

- **Double column busy:**
  - $0.003\% / 0.18\% / 1.3\%$

- **Data Buffer full:**
  - $0.09\% / 0.17\% / 0.83\%$

- **Timestamp Buffer full:**
  - $0 / 0.05\% / 6.8\%$

- **Readout and double column reset:**
  - $1.1\% / 2.1\% / 6.7\%$
  - for $100\text{kHz}$ L1 trigger rate

- **Total data loss @ 100kHz L1A:**
  - $1.3\% @ 11\text{cm}$
  - $2.7\% @ 7\text{cm}$
  - $16\% @ 4\text{cm}$
Data loss with extended buffering

Pixel busy: 0.72%
pixel insensitive until hit transferred to data buffer (column drain mechanism)

Double column busy: 2.03%
Column drain finds hitted pixels and transfers hits from pixel to data buffer. Maximum 3 pending column drains requests accepted

Data Buffer full: 0.68%
size: 80 (32)

Timestamp Buffer full: 0.01%
size: 24 (12)

Readout and double column reset: 2.20% for 100kHz L1 trigger rate

luminosity: $2 \times 10^{34}$ cm$^{-2}$sec$^{-1}$
layer 1 @ $R = 38$ mm

total data loss in layer 1 at run start: 5.63%

H.C. Kaestli
Oct 2009
Data loss vs luminosity

Pixel readout chip simulation with increased buffering

Factor ~3 improvement compared to the present chip.

Inefficiency averaged over a luminosity fill is factor 2 smaller.

Further design modifications under study: aim for 2.5% at $2 \times 10^{34}$

H.C. Kaestli
Oct 2009
Radiation damage in silicon

- **Leakage current:**
  - \( \frac{I}{Vol} = \alpha \Phi \) (fluence \( \Phi \) [particles/cm\(^2\)])
  - all silicon materials (FZ, Cz, epi) have the same damage \( \alpha \).
  - only cooling helps to reduce leakage current (factor 2 / 8\(^\circ\)C).

- **Space charge creation ('type inversion'):**
  - leads to high depletion voltage at high fluence.
  - oxygenated silicon is better (DOFZ, mCz).
  - cooling reduces activation of defects.

- **Charge trapping:**
  - reduces charge collection efficiency
  - collecting electrons (n-in-p or n-in-n) is better than holes (p-in-n).
  - no 'defect engineering' method known to help.
  - Charge amplification at high bias, earlier in thin sensors or 3D.
Radiation damage effects in silicon

leakage current

\[ \Delta I / V [A/cm^2] \]

\[ \Phi_{eq} [cm^{-2}] \]

cooling!

factor 1/2
every -8°C

depletion voltage

\[ |N_{eff}| [10^{12} cm^{-3}] \]

\[ \Phi_{24 GeV/c proton} [10^{14} cm^{-2}] \]

trapping

\[ 1/\tau [ns^{-1}] \]

\[ \Phi_{eq} [cm^{-2}] \]

24 GeV/c proton irradiation

- data for electrons
- data for holes

no known cure

oxygenated Si used!

Keep Si cool
to avoid activation of defects.
Silicon charge collection vs fluence

Detectors made from oxygenated Si and collecting electrons should operate up to a few \(10^{15} \text{n}_{\text{eq}}/\text{cm}^2\) with tolerable efficiency and resolution degradation: that's several 100 fb\(^{-1}\) at \(R = 3\) cm.

References:
(p/n-FZ, 300\(\mu\)m, (-30°C, 25ns)
(p-FZ, 300\(\mu\)m, -20°C to -40°C, 25ns)
Further upgrade considerations

- Smaller beam pipe for improved impact parameter resolution:
  - B-tagging

- 4\textsuperscript{th} layer for better track seeding efficiency and improved stand-alone tracking:
  - High Level Trigger

- Less material (mechanics, chips, cooling, cables):
  - less multiple scattering, photon conversions, nuclear interactions
CMS pixel upgrade: 4 layers

2 identical half-shells.
1184 modules (79M pixels)
(1.6 × present barrel)

\[ R_1 = 29 \text{ mm, 96 modules} \]

(reduce beam pipe diameter from 59 to 45 mm)

\[ R_2 = 68 \text{ mm, 224 modules} \]

\[ R_3 = 109 \text{ mm, 352 modules} \]

Italy, CERN

\[ R_4 = 160 \text{ mm, 512 modules} \]

Germany
Pixel track impact parameter resolution

Pixel stand-alone tracks as used in the High Level trigger

\[ \sigma(d_{CA}) = 160 \, \mu m / pt \oplus 72 \, \mu m \]

\[ \sigma(d_{CA}) = 62 \, \mu m / pt \oplus 20 \, \mu m \]

present \( R_{BP} = 29 \, mm \)

upgrade \( R_{BP} = 22 \, mm \)

D. Pitzl (DESY): CMS Pixel Upgrade
Radiation damage

4-layer upgrade
$R_{BP} = 22$ mm

$\sigma(d_{CA}) [\mu m]$ vs $p_t [GeV]$ graph showing:
- Fresh $\sigma_i = 10 \mu m$
- Radiated $\sigma_i = 15 \mu m$
- Upgrade narrow 4 thin layers
Tracking performance with pile-up 50

- t-tbar simulation with pile-up of 50 minimum bias events ($2 \times 10^{34}$ with 25 ns spacing).
- Pixel-based track seeding.
- 4-layer upgrade improves seeding efficiency. z-gaps remain
- 4-layer upgrade reduces fake rate.
b-tagging performance with pile-up 50

- Detailed simulation of the physics performance on going:
  - at high level trigger,
  - at full analysis level.

- 4-layer upgrade is needed to maintain present performance at high luminosity
  - Expect improved pixel b-tagging in the HLT.
Pixel upgrade motivations

• Prepare for $2 \times$ higher luminosity than design: $2 \cdot 10^{34}/\text{cm}^2/\text{s}$:
  ▶ maintain pixel efficiency

• Less material (mechanics, chips, cooling, cables):
  ▶ less multiple scattering, photon conversions, nuclear interactions

• 4th layer for better track seeding efficiency and improved stand-alone tracking:
  ▶ High Level Trigger

• Smaller beam pipe for improved impact parameter resolution:
  ▶ B-tagging

• Add redundancy in the tracking system:
  ▶ independent of the luminosity evolution
Pixel upgrade implications

• Prepare for 2× higher luminosity than design: 2 \times 10^{34}/\text{cm}^2/\text{s}:
  ‣ Requires a new readout chip with more buffering.

• Less material:
  ‣ Low mass supports, CO$_2$ cooling, optical converters outside the tracking volume.

• 4\textsuperscript{th} layer for better track seeding efficiency and improved stand-alone tracking:
  ‣ Digital readout and DC-DC power converters (have to use the same outer power cables and optical fibers)

• Smaller beam pipe for improved impact parameter resolution:
  ‣ Accepted by LHC machine group.

• Add redundancy in the tracking system:
  ‣ Be ready early, almost independent of the luminosity evolution.
CMS pixel upgrade

Present BPIX module
Sensor 285 µ
ROC 175 µ
weight = 1.38gr

Thin BPIX module
Sensor 285 µ
ROC 75 µ
weight = 1.07gr

Sensor 225µ thick
Future bare module
weight = 0.89 gr
→ 65% of present

R. Horisberger
June 2009
Upgrade carbon fiber frame

Ultra-light weight carbon fibre frame and airex end flange with pipes for CO2 cooling.
CMS pixel upgrade

Weight Layer1 42g + 7g CO₂

100 bar pressure tested Tubes, 50µ wall thickness
Upgrade: CO$_2$ cooling

- 2-phase CO$_2$ cooling: large latent heat
- operating at -35°C, good viscosity
- reduces Si leakage current
- reduces defect activation in Si

- Thin tubes, 50 bar
- material reduction
Barrel Pixel services

Analogue-Optical
Digital-Optical

Optical Fibers
Moving readout material out of the tracking region

- End flange prints with connectors
- 3 barrel layers
- η=1.2
- η=1.5
- η=2.0 strip detector tracking volume
- BPIX supply tube
- FPIX service cylinder
- AOH & mother board
- Power boards
- DOH
- 2 disks
- 4 barrel layers
- η=2.0
- micro twisted pair cables
- Connector boards
- Opto hybrids & mother board
- 3 disks
- Sensitive areas
Barrel pixel material budget

Up to 12% of all hadrons are lost due to nuclear interactions in the present pixel barrel.  
Upgrade will give up to factor 2 reduction.
Services

- CMS tracker cable channels are full:
  - have to use the existing services.
- Optical fibers:
  - go from 40 MHz analog to 320 MHz digital readout.
- Power:
  - Use DC-DC converters at the detector.
- Sensor bias:
  - 600 V → 1000 V.
- CO2 cooling:
  - pipe-in-pipe for 100 bar.

- DC-DC converter developed in Aachen:
  - air-core coil, 10V → 3.3 V, 3 A, η=75%
  - radiation resistant AMIS 2 chip (CERN), switching at 1.2 MHz,
  - optimized design for low noise.
CMS barrel pixel module

- **Signalcable**
- **Powercable**
- **SMD-Components**
- **Token bit manager**
- **wire bonds**
- **TBM**
- **HDI High density interconnect**
- **Sensor 16×62 mm²**
- **66'560 pixels**
- **bump bonds**
- **glued**
- **ROCs Read-out chips**
- **SiN Basestrips**

**upgrade: micro twisted pairs**

D. Pitzl (DESY): CMS Pixel Upgrade

full-module \( \triangleq \) 16 ROCs
Bump bonding at PSI

Indium pads deposited on the Si sensor.

After re-flow at 150°C in N₂ and CH₂O₂ atmosphere. 15 µm diameter.

Involves many steps: sputtering, photo lithography, etching...

Ch. Broennimann et al.: Development of an Indium bump bond process for silicon pixel detectors at PSI
NIM A565(2006)303-8
Flip chip assembly at PSI

- Precision: $1 \div 2 \mu m$
- Production rate:
  - 6 modules / day + tests
  - automated: 1 hr/module
- Bare module test:
  - IV-curve
  - ROC functionality
  - bump yield
  - rework: 80% success

Precision x-y-z stage
Computer controlled
Commercially available.
Alternative

- Start with high-precision balls.
- Drop through capillary towards pad.
- Melt by laser pulse during fall.
- Solidify on pad.
- Step-motor controlled.
- 5 ball / second.
- 40 $\mu$m balls at 80 $\mu$m pitch possible now.
- 30 $\mu$m balls under development.

http://www.pactech.de/index.php?option=com_content&view=article&id=154&Itemid=21 68
Laser reflow bonding

1) Pickup Die & Align (±5 μm)

2) Contact (10kgf)

Neodym-dotierter Yttrium-Aluminium-Granat-Laser 1064 nm

3) Laser Reflow (20msec, Nd³⁺YAG)

LaPlace Assembly System™ PacTech

Placement accuracy: +/- 15μm: 3000 - 5000 UPH
Placement accuracy: +/- 10μm: ~2000 UPH
Placement accuracy: +/- 5μm: ~1000 UPH
Placement accuracy: +/- 2.5μm: ~500 UPH

Units per hour

Laser based assembly allows localized heating:

- Selective to individual die
- Energy localized to bumped areas
- Ability to differentiate between solder alloys
- Low stress
- Minimizes IMC (time/temp)

3) SnPb 1) Sn 2) Sn 3) SnPb

Mp SnPb = 183°C  Mp Sn = 232°C

PacTech publication 66
Nov 2009
PacTech test structures

- Two 200-mm Wafers with 275 Chips each
- 5-µm electroless Ni/Au UBM on both
- 40-µm SAC305 Solder Jetting with SB2 on one
- Wafer Sawing & Chip Singulation

Available since Dec 2010.
Used with 4 machines/vendors.

Karsten Hansen, DESY FEC
D. Pitzl (DESY): CMS Pixel Upgrade
### Industry Standard, Expensive, Slow

**Pac Tech: SB2 Jet**

Solder Ball Placer:
- Pre-formed balls are placed sequentially at 6-7 Hz
- Fused by laser heating
- 30 µm balls being certified, 40 µm ordered for test.

### For Placing and Re-flow Heating. Used at IZM.

**SET: FC 150 Flip-chip bonder**

- Industry standard, expensive, slow.
- For placing and re-flow heating.

**SET: Kadett K1**

- **Unitemp:** RS-350-110
- PSI design: cheapest, slow.
- No > 50 mm heating chuck available.

**Tacking Tests completed on small samples:**
- > 0.6 g/ball @ 155°C for chip & substrate.
- Re-flow tests completed: OK.


**Pac Tech: Laplace**

- **RFA 300M**

**Tacking Tests completed:**
- Low force with chip at 195°C for 1s.
- Reflow Tests completed: OK.

**Finetech: FINEPLACER femto**

- Novel FC 150 competitor: medium price.
- Placing and re-flow heating, low-force, fast.

**Tacking / re-flow tests under way.**

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D. Pitzl (DESY): CMS Pixel Upgrade

Karsten Hansen, DESY FEC

DESY Instrumentation Seminar, 16.9.2011
Bare module test at PSI

- Test bare module after flip-chip bump bonding:
  - Sensor I-V curve.
  - Test 16 readout chips.
  - Determine bump yield.
- Rework bad modules:
  - replace individual chips.

Semi-automatic probe station at PSI:
load manually, step and measure automatically.
Probe station at DESY FEC

Süss Microtech PA 300 Probe Station

up to 300 mm wafers
Semi-Automatic
Shielded
Thermo chuck -40 .. +125°C

Probe-Card Holder

will order 42 needle probe card for testing ROCs after bump bonding.

auctioned from Qimonda in Dec 2009
Barrel pixel module assembly line at PSI

- Production rate:
  - 4 full + 2 half modules / day
  - or 6 full modules / day

- Three glueing steps:
  - glue basestrips to raw module
  - underfill sensor with glue
  - glue HDI to complete assembly

- Important: custom-made tools

Tools and assembly line being prepared at Uni Hamburg.
Pixel module cold calibration

- Challenges
  - Huge number of channels: $5 \div 6 \times 10^7$
  - Multy-dimensional parameter space: 29 DACs/ROC
  - Temperature dependence: tests done at $-10^\circ C$ and $+17^\circ C$ **upgrade: -20^\circ C**

- Test set up
  - Programmable cooling box
  - 4 modules at a time
  - Custom built test-boards with FPGA

- Procedure
  - Start-up adjustments
  - Full Test at $-10^\circ C$
  - 10 thermal cycles
  - Full Tests and IV at $-10^\circ C$ and $+17^\circ C$

Cold calibration set up will be set up at DESY.
Pixel gain calibration

- Ultimate position resolution comes from pulse height interpolation.
- Need pixel-to-pixel gain calibration.
- Large amplitudes:
  - internal test pulse.
- Close to threshold:
  - X-ray lines (Mo, Ag, Ba).
- X-ray stand being prepared at Uni HH.

H.C. Kästli et al., NIM A565 (2006) 188-194

Fig. 8. Analog signal transmission.
Universal pixel test board

Design and firmware by Beat Meier, PSI

bias voltage

psi46 chip

ADC

memory

FPGA

6 V power

USB to laptop
psi46 pixel readout chip

-adjustable by programmable DAC, 26 per ROC

programmable register, 3 per pixel
gain and linear range

- One pixel.
- 2 Vcal ranges (PSI X-ray calibration):
  - CtrlReg 0 or 4,
  - $65 \pm 5 \text{ e/DAC}$,
  - $450 \text{ e/DAC}$.
- Linearity for small pulses important for spatial resolution using charge sharing.
- Saturation around $36'000 \text{ e} (~1.6 \text{ MIP})$. 

![Graph showing gain and linear range](image)
Linear range vs $V_{sf}$

- One pixel
- Analog pulse height vs calibrate amplitude and source follower voltage.
- Best linearity in valley.
Comparator threshold

- One pixel
- Analog pulse height vs threshold and calibrate amplitude.
- White region:
  - no signal.
- Colored bands are not vertical:
  - time walk.
Threshold curve

one pixel

vary test pulse amplitude

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X-ray calib:
1 DAC = 65 e

threshold broadened by noise
fit by error function
noise: 130 e
Threshold variation

4160 pixels / cip

CMS transistor variations:
threshold spread 290 e

the same chip, trimmed:

4-bit DAC trimming:
threshold spread 50 e
Source test setup

- **$^{106}$Ru source mounted above the chip:**
  - Activity $\sim$14 kHz,
  - electrons up to 3.5 MeV.

- **FPGA:**
  - data clock cycle stretched up to 1 ms,
  - trigger,
  - readout,
  - store in memory.

- Final readout by USB.
Source test event display

- A single event integrating over 1 ms:
  - ~15 hits per trigger
- Low energy electrons:
  - Scattering in the source holder,
  - wide angles of incidence,
  - large clusters.
  - tracks visible.
- Clusters of pixels identified by software.
• Ru source, 100s.

• Wire placed across the chip.

• Pixel map ($\phi$-$z$):
  ▶ shadow of the wire
  ▶ 2 noisy pixels.
  ▶ long and/or wide pixels at 3 edges.
Cluster multiplicity vs. bias voltage

- Ru106 source.
- All scans with:
  - Internal trigger
  - Clock stretch 1 ms
  - 10s run for one Vbias value
- Cluster efficiency saturates below -50 V.
- Plateau variation:
  - Source position,
  - Thresholds.
Beam test setup

crossed finger scintillators

beam collimator

EUDet telescope

PSI46 test board
Pixel hit map

- 2 GeV e+ beam.
- After space and time alignment:
  - 4 kHz coincidence rate
  - Fill test board memory: 60MB in 3.5 min.
  - USB transfer takes another ~2 min.
- One chip fully illuminated.
- Border pixels have double size and rate
- Corner pixels have quadruple size and rate
Pixel hit map

- the same run
- a few dead pixels
- non-uniformity:
  - beam profile,
  - misalignment between sensor and scintillator,
  - limited trigger region (~1 cm$^2$) just enough to cover 0.8×0.8 cm$^2$ chip.
Cluster charge: Ru source vs beam

- Chip 8, -90V bias, Vthr 100
- 2 GeV e+ test beam:
  - Minimum ionizing particles
- Ru 106 source:
  - long tail of stronger ionizing electrons (not fully relativistic)
Cluster multiplicity vs. bias voltage

- 2 GeV $e^+$ beam.
- Cluster efficiency saturates below -80 V:
  - Need more bias voltage to reach full efficiency for minimum ionizing particles.
Project time line

- Produce assembly tools since 2010
- Develop assembly procedures 2011
- Develop testing and calibration procedures 2011
- Bump bonding tests 2010-2011
- Decide on bump bonding technique end 2011
- Assembly and test procedures established 2012
- Receive all components for series production 2013
- Module assembly and calibration 2013-2015
- 4th layer assembly and test mid 2015
- Full system test at CERN 2015-2016
- Ready for installation in CMS mid 2016
# Work packages in D-CMS

4\textsuperscript{th} layer: 512 modules + 100 spares + 88 rejects = 700

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People at DESY and Uni Hamburg 2011

- **DESY:**
  - Günter Eckerlin, deputy CMS group leader, DPix coordinator
  - Daniel Pitzl, pixel upgrade project leader
  - Carsten Niebuhr, Doris Eckstein, staff
  - Maria Aldaya, Jan Olzem, Alexey Petrukhin, Hanno Perrey, postdocs
  - Karsten Hansen, Jan Hampe, staff FEC
  - Carsten Muhl, Holger Maser, engineering

- **Uni Hamburg:**
  - Peter Schleper, professor
  - Georg Steinbrück, staff
  - Thomas Hermanns, postdoc
  - Lutz Berger, technical support
Summary

• The present CMS pixel detector is working very well and is an essential tool for track reconstruction and vertexing.

• The LHC luminosity is expected to exceed $10^{34}$ /cm$^2$s in this decade:
  ▶ the present pixel readout chip will become inefficient.
  ▶ at least the inner pixel layer has to be exchanged after 250 fb$^{-1}$.

• A 4-layer replacement with a new readout chip has further benefits:
  ▶ Better resolution, efficiency, and purity for pixel-based tracking,
  ▶ Reduced material in the tracker volume with CO2 cooling, low mass design, services moved out of the tracking region.

• The German CMS institutes have been asked to contribute:
  ▶ Design optimization and physics evaluation,
  ▶ module assembly and testing,
  ▶ DC-DC converter development and production.

• Preparations are underway.
Acknowledgments summer 2011

- Aleksander Gajos
  - 2011 summer student from Cracow

- Fedor Glazov
  - 2011 summer intern

- Beat Meier (PSI), Thomas Weiler (KIT), Tilman Rohe (PSI):
  - for code and advice.

- Ulrich Koetz (DESY):
  - for lab space, NIM crate and modules, oscilloscope

- Wladimir Hain (DESY):
  - for the source

- Carsten Muhl (DESY):
  - for the source holder

- Torsten Külper (DESY):
  - for the TTL trigger adapter

- Ingrid Gregor (DESY, test beam coordinator):
  - for instructions and test beam hospitality

- Norbert Meyners (DESY, test beam coordinator):
  - for help with collimator and wire target

- Samuel Ghazaryan (DESY, test beam support):
  - for help with moving system and rate monitor

- Holger Maser (DESY):
  - for the test board support frame

- Erika Garutti (DESY and Uni HH):
  - for the finger scintillator and PM

- DESY Machine Group:
  - for the steady test beam
Backup slides
The CMS Tracker upgrade

– DESY contributions –

April 15, 2010

The DESY CMS Group

Abstract

A 4-layer low mass replacement of the CMS Barrel Pixel detector is planned for the middle of the decade. DESY is interested to contribute to the module production, in collaboration with the universities in Hamburg, Karlsruhe and Aachen. At a later stage, the entire silicon tracker needs replacement to cope at higher luminosity with increased track density and larger radiation dose while the material budget should be reduced. DESY R&D activities within the Central European Consortium involving the above mentioned universities and those in Barcelona, Louvin and Vilnius are described.

• DESY PRC document for the CMS Tracker upgrade.
• Pixel and Strips
• Hamburg and Zeuthen
• Submitted April 2010.
• Positive recommendation.
CMS Pixel

A. Dorokhov
Uni Zurich
2005
2011 data
Pixel operation in 2010

One ROC no-signal: 1/192 (0.5%) Recoverable.

Too Low signal amplitude (TBM): 1/192 (0.5%)

No signal output: 1/192 (0.5%)

Slow panels: 5/192

No I2C communication with AOH: 6/192 (3.1%)

status end 2010
CMS tracker material

All trackers

Barrel pixel

Upgrade:
factor 2 less in center
factor 4 less in endcaps

pixel note 2009
Pixel sensors

- Planar sensors, CiS Erfurt.
- 111-oxygenated float zone.
- n-in-n, p-spray insulation.
- collecting faster electrons:
  - larger Lorentz angle,
  - less trapping.
- pn-junction on back side (initially):
  - edges at ground,
  - double sided processing.

100 µm (rφ) x 150 µm (z)

Grounding grid for testing before bump bonding
1 pixel

T. Rohe, PSI
2.11.2009
pic73.jpg
CMS Barrel and Forward pixel sensors

Figure 1.11. Sensor designs for the CMS barrel detector (left) and end-caps (right).
Figure 1.12. The masks for the p–spray design. Left: The mask layout of the pixel side. The distances are in μm. Right: The mask layout of the backside.

T. Rohe (PSI), from A. Dorokhov (Uni Zurich) 2005
Sensor radiation damage

Signal collection in CMS pixel sensors

- Inner barrel layer:
  - $70 \text{ fb}^{-1} = 4 \cdot 10^{14} \text{ n/cm}^2$
  - $250 \text{ fb}^{-1} = 13 \cdot 10^{14} \text{ n/cm}^2$
- 50% signal loss after 250 fb-1.
- Also leads to factor 2 degradation of the hit resolution (less charge sharing and Lorentz angle)
- Bias voltages above 600 V not possible with the present CMS HV system.
- MCz being considered.

T. Rohe, Pixel2010
Enlarged on-chip buffer

- Dominant data loss mechanism → larger buffers needed
- Data loss simulations performed
  - Data buffer from 32 to 80 cells
  - Timestamp buffer from 12 to 24 cells
- Simple scaling would increase ROC size by >1.1 mm
- 800 μm more space allowed with new detector mechanics
  → Need more compact buffer layout
**Enlarged on-chip buffer**

**Figure 1.** Layout of the existing readout chip (ROC). A detailed view of the double column interface with size of the new chip compared to the old one.
Karlsruhe and Aachen

• Karlsruhe:
  ▶ Ulrich Husemann, Thomas Müller, professors
  ▶ Marc Weber, professor, director IPE
  ▶ Thomas Blank, staff AVT
  ▶ Michele Caselle, Alexander Dierlamm, Frank Hartmann, Thomas Weiler, staff
  ▶ Stefan Heindl, phd student
  ▶ Tobias Barvich, technical support

• Aachen:
  ▶ Lutz Feld, professor
  ▶ Katja Klein, staff
  ▶ Jan Sammet, phd student
  ▶ technical support
Switzerland

- Roland Horisberger, Wolfram Erdmann, Hans-Christian Kästli, Tilman Rohe, Beat Meier, Silvan Streuli, Willi Bertl, Urs Langenegger, Danek Kotlinski
- Rainer Wallny, Andrei Starodumov
- Peter Robmann