



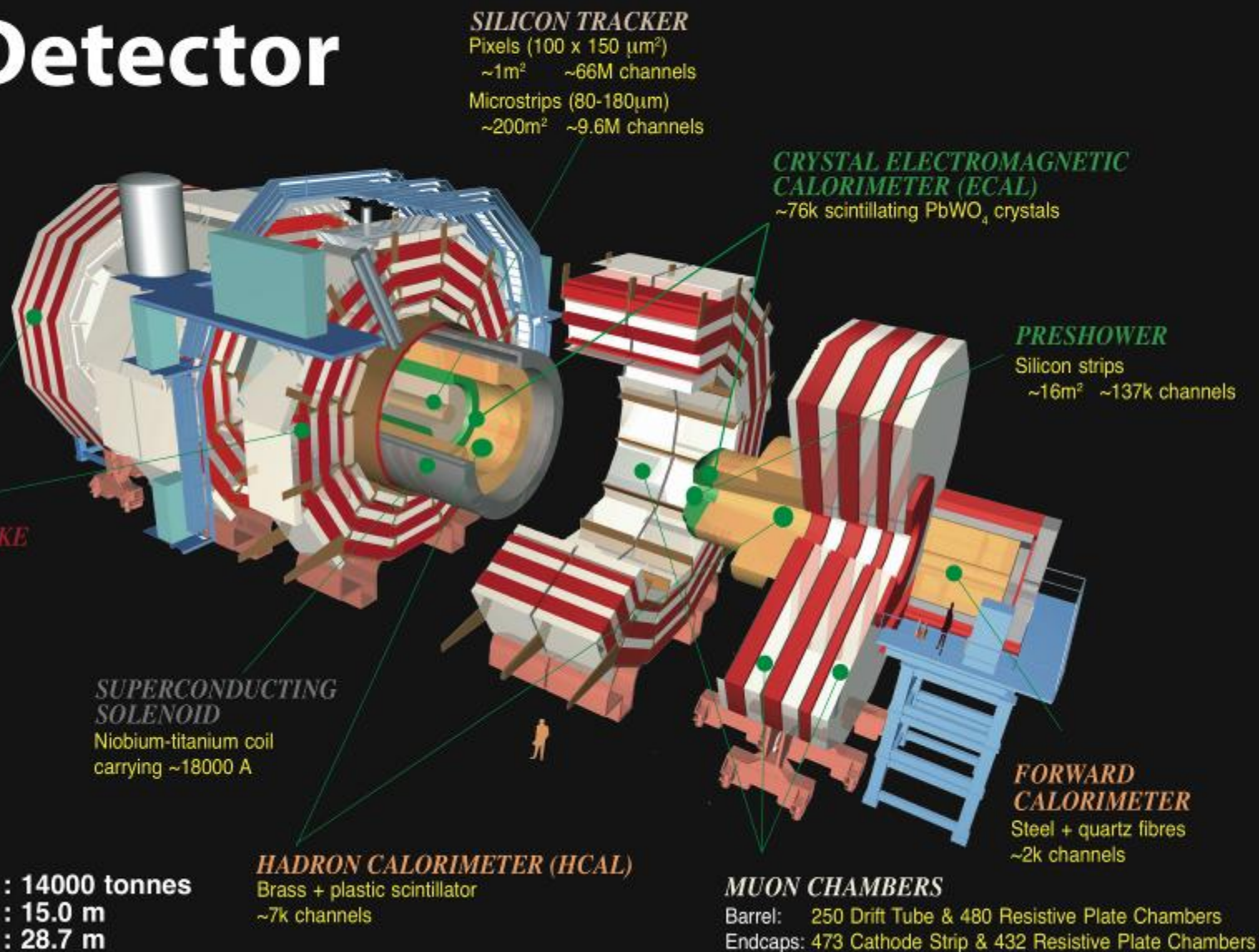
Wir schaffen Wissen – heute für morgen

Planar sensors for the upgrade of the CMS pixel detector

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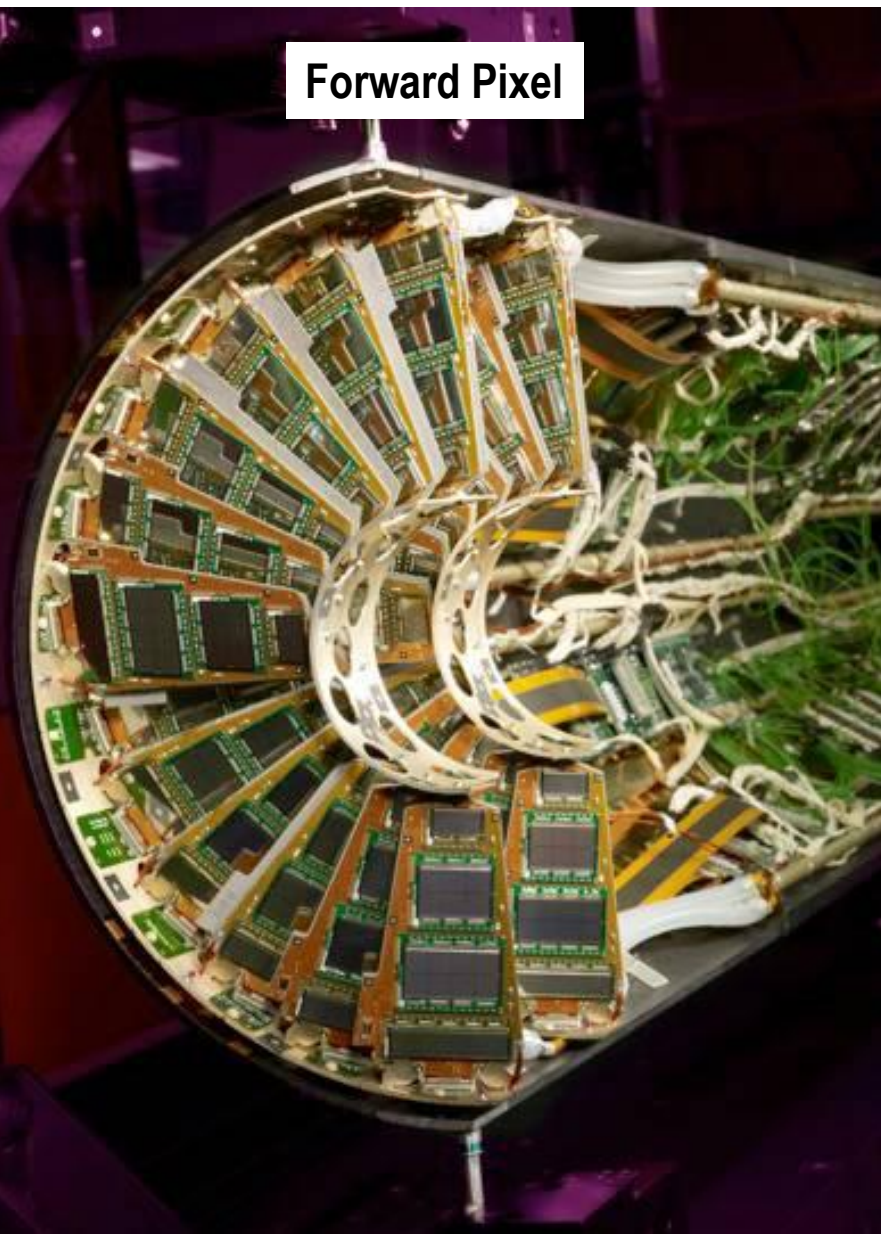
¹Paul Scherrer Institut ²University of Kansas

CMS Detector

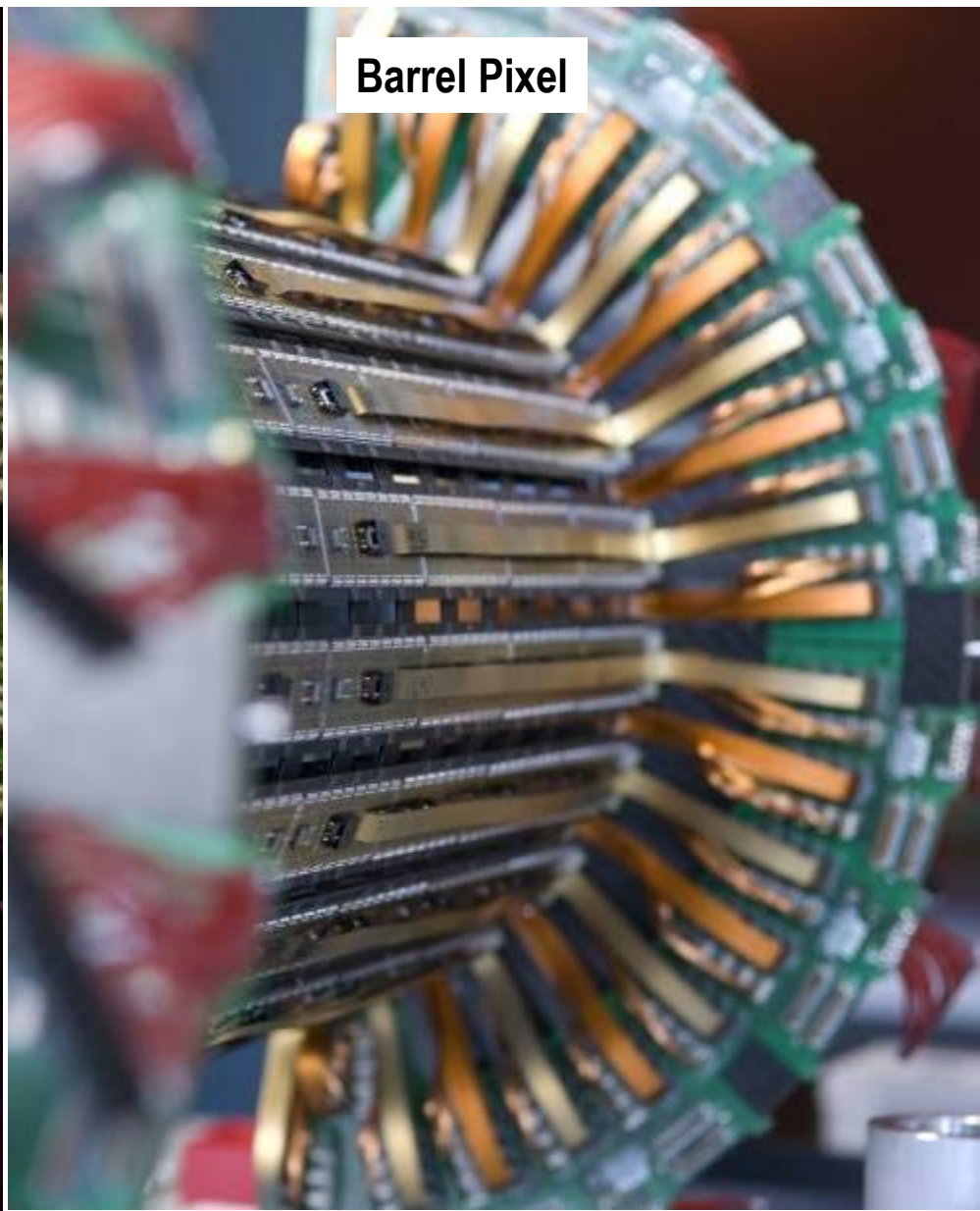


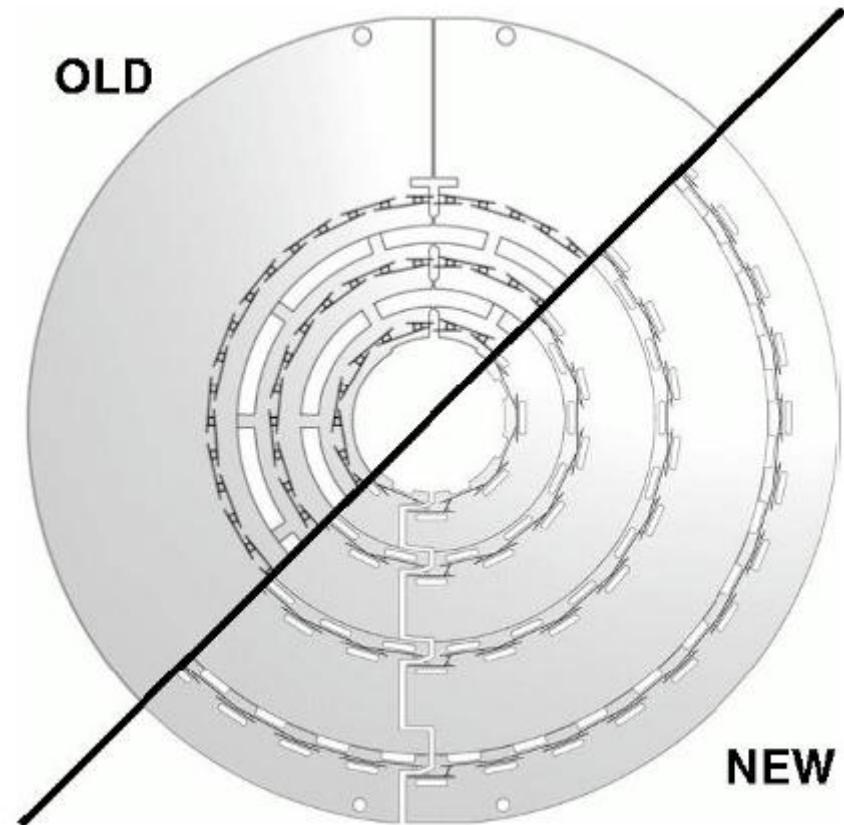
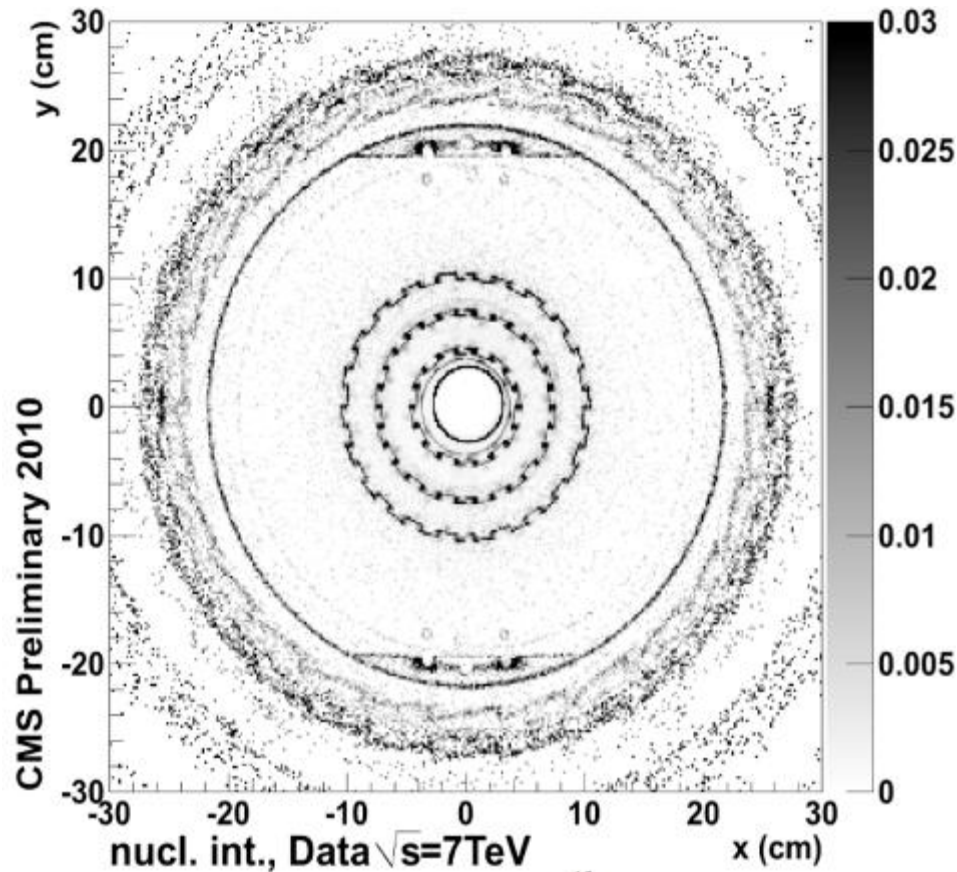
The CMS pixel detector

Forward Pixel



Barrel Pixel

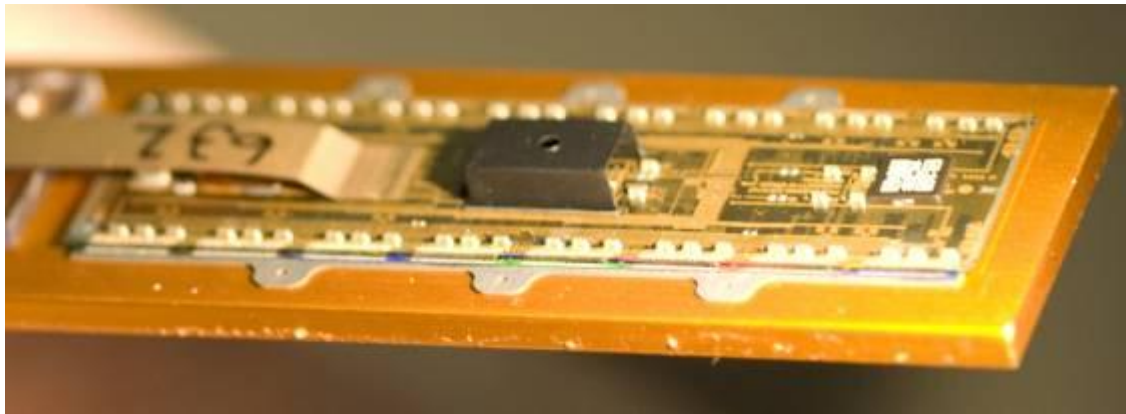




Part of the motivation for the upgrade/replacement visible in this plot:

- Reduction of material
- Fill the gap between pixel and tracker inner barrel (TIB)

4th layer roughly doubles the number of modules, therefore costs of components (sensors) are important
To reduce complexity of system and assembly, use barrel-type modules also in the forward part



HDI: Very thin, very fine pitch flexible HDI with token bit manager chip (TBM) and passive components

Upgrade: redesign TBM, less passive components

Sensor: n-in-n, DOFZ (fpix: FZ)

Upgrade: unchanged (options: mCz, n-in-p, later)

16 **ROCs**: 0.25 μ m

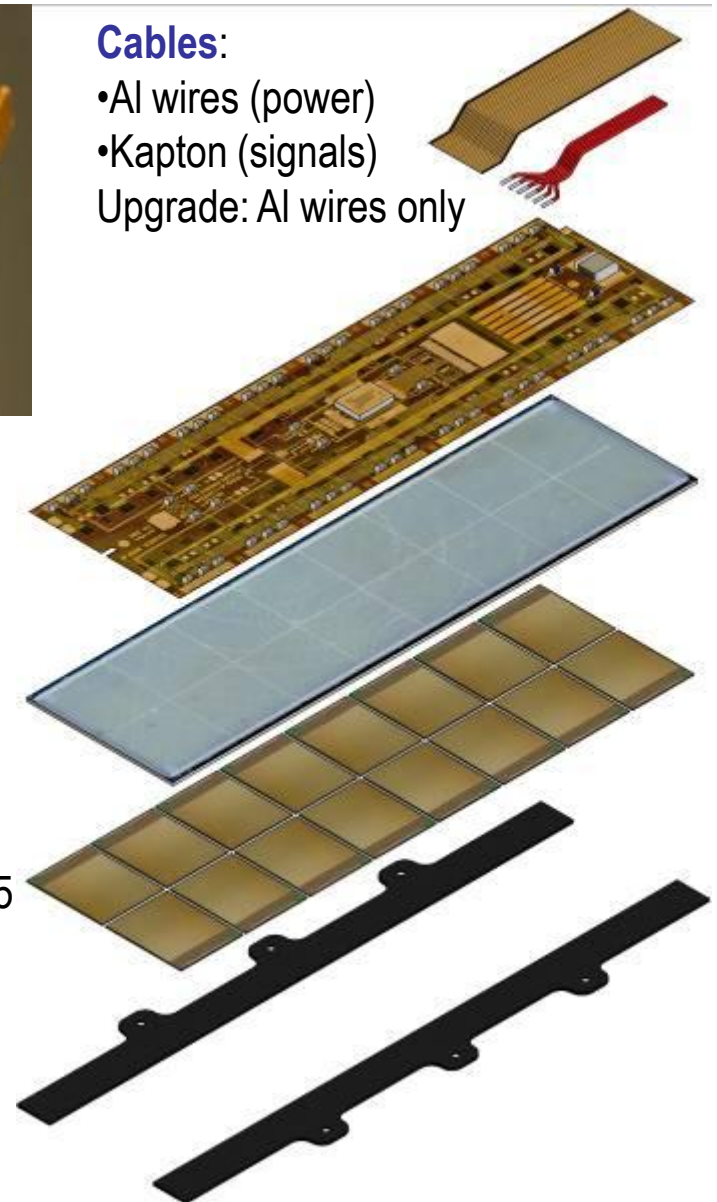
Upgrade: chip will be upgraded (but no complete redesign) still 0.25

2 **base strips**

Upgrade: omitted

Cables:

- Al wires (power)
 - Kapton (signals)
- Upgrade: Al wires only



Collect electrons (n-side readout)

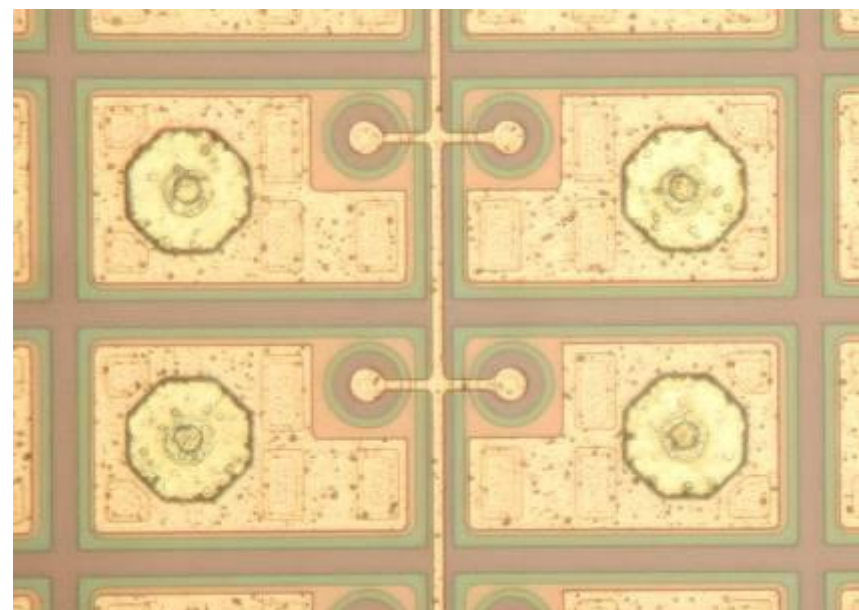
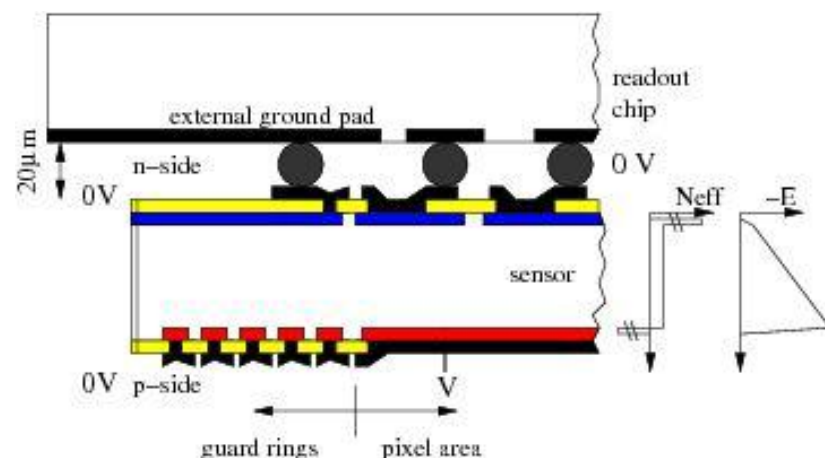
- Less prone to trapping
- Larger Lorentz angle
- n-side isolation required

Avoid problems in module design

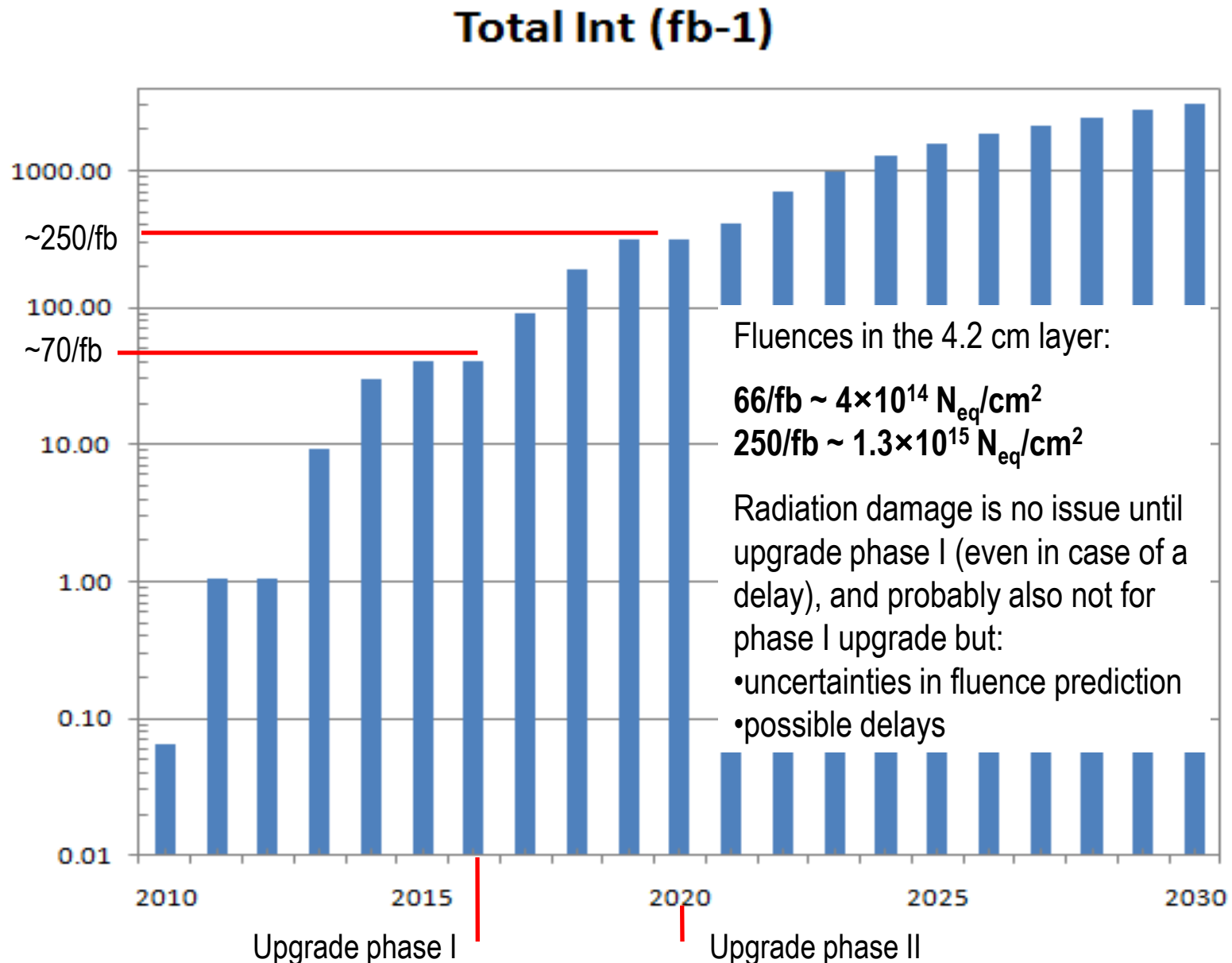
- N-Substrate (FPIX: 100-FZ, BPIX: 111-DOFZ)
- Guard rings (and junction) on back side
- All sensor edges on ground potential
- Double sided processing
 - Limits choice of producers
 - FPIX: Sintef
 - BPIX: CiS

Pixel cell layout

- FPIX
 - Open p-stops, some overdepletion needed to separate channels
 - large gaps, smaller C (value not yet measured)
- BPIX:
 - Moderated p-spray with bias grid (lower voltages, insensitive area)
 - Small gaps, homogenous drift field, higher C $\sim 80\text{fF}$



Prediction of integrated luminosity (estimation)



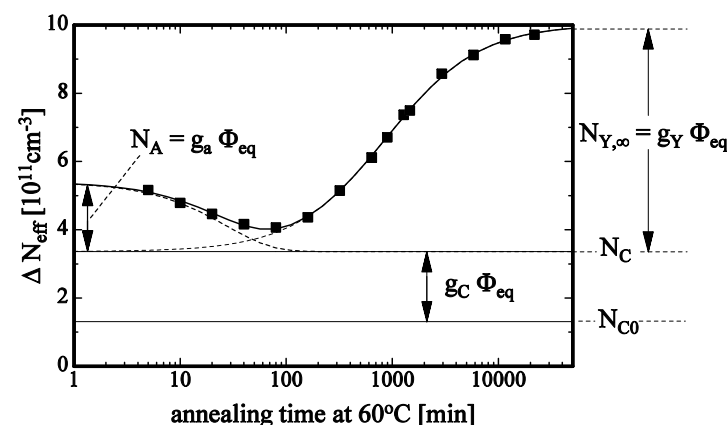
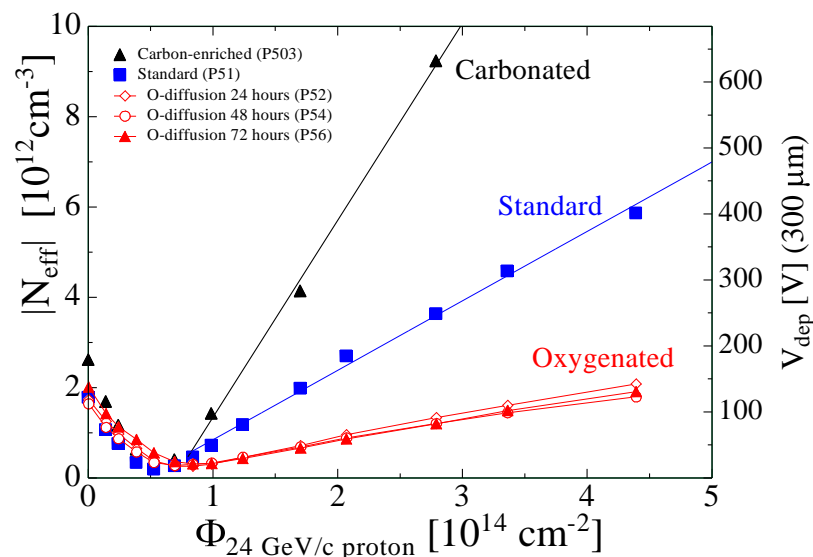
[Steve Myers, ICHEP 2010]

$\Phi < \sim 10^{15} N_{eq}/cm^2$ ($J_L < 250/fb$):

- Bias voltage has to be increased to obtain full signal
- Leads to decrease of spatial resolution

$\Phi > \sim 10^{15} N_{eq}/cm^2$ ($J_L > \sim 250/fb$):

- Reduced signal (trapping) leads to loss in efficiency
 - recent measurements with n-in-p strip detectors (RD50) show that measured signal is higher than expected if bias voltage can be increased to values $\gg 600V$.
 - High voltage limited in CMS by connectors, cables and power supplies.
- Leakage current rising proportional with Φ becomes significant fraction of the power load (cooling)
 - Leakage current in segmented sensors is higher than in diodes
 - Edge current is difficult to predict
 - Radiation studies with full modules are under way (collaboration between Karlsruhe and Aachen)



- Irradiated numerous samples consisting of a small sensor and 1 ROC
 - Pions (300MeV) at PSI Pi-E1 up to $\sim 6 \times 10^{14} n_{eq}/cm^2$
 - ($> 10^{15} n_{eq}/cm^2$ Aug 2010)
 - Protons (21GeV) at CERN-PS up to $\sim 5 \times 10^{15} n_{eq}/cm^2$
 - Protons (24MeV) at Karlsruhe up to $\sim 5 \times 10^{15} n_{eq}/cm^2$
- Measured charge value obtained from a Sr-90 beta particles
- Leakage current of small samples stayed within “limits”
- Presently no independent trigger
(no efficiency measurement possible)
 - Setup is upgraded with scintillator trigger

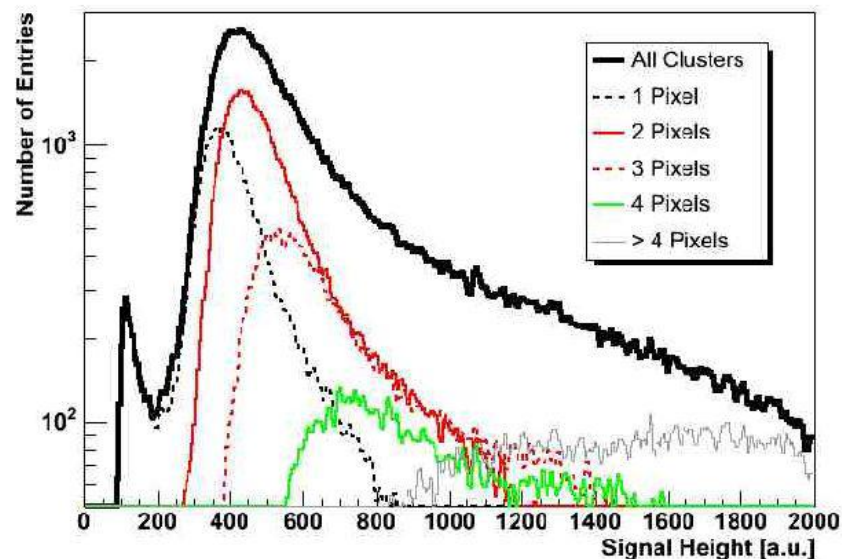
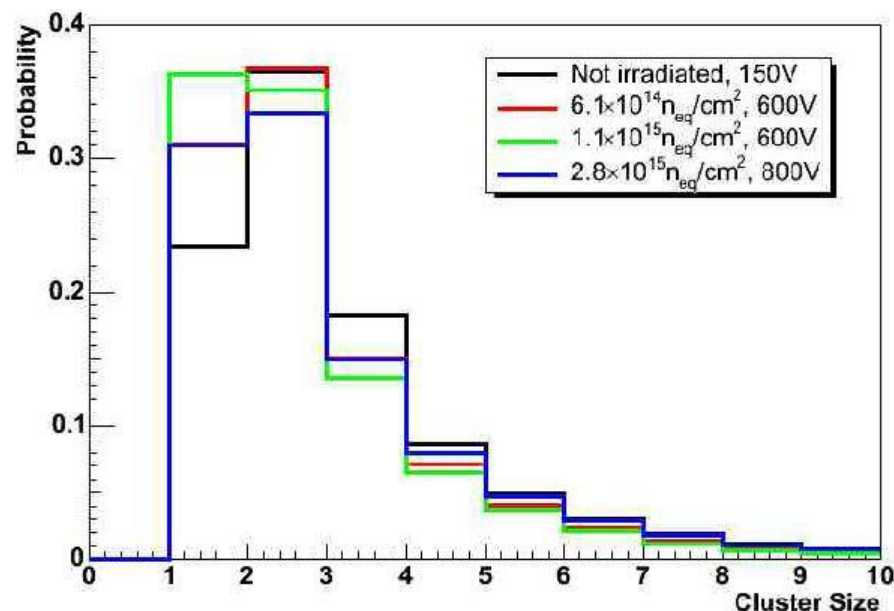


photomultiplier

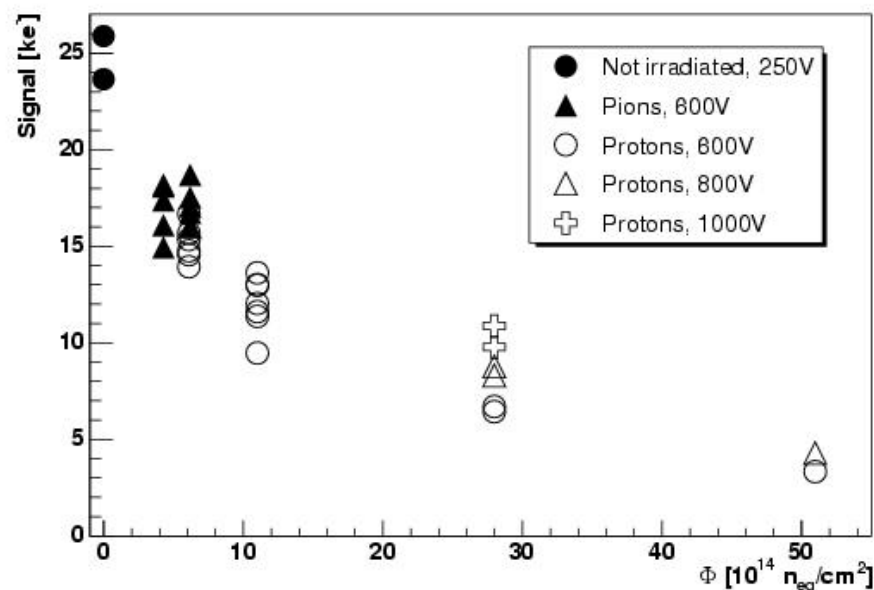
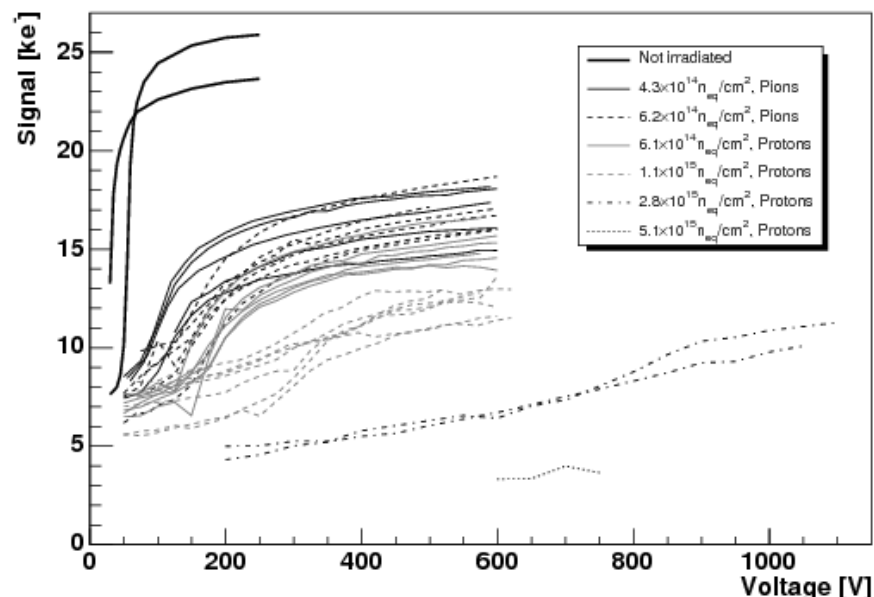
Beta-spectrum of Sr-90 contains many low energetic particles

- Tail with large clusters
- For clusters > 3 pixels spectrum is not described by Landau
- For clusters of size 1-3 the MPV depends on cluster size

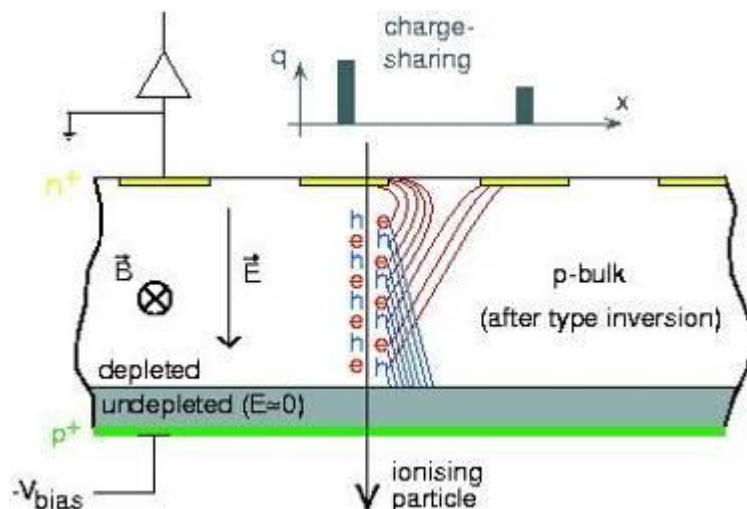
Only single pixel clusters are used



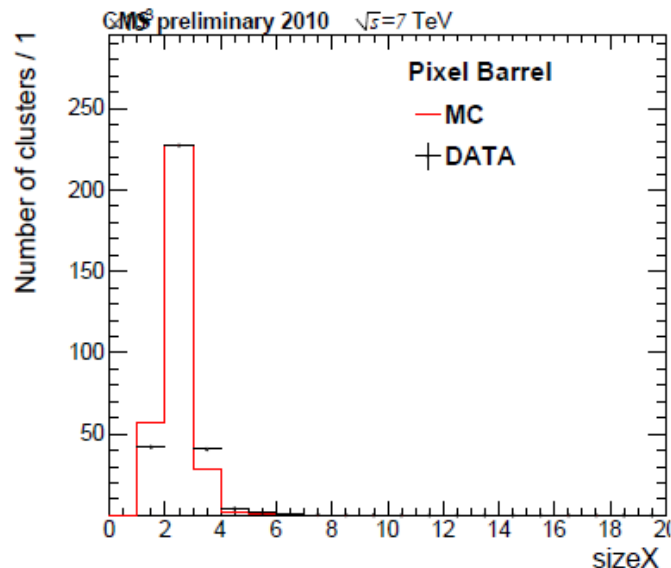
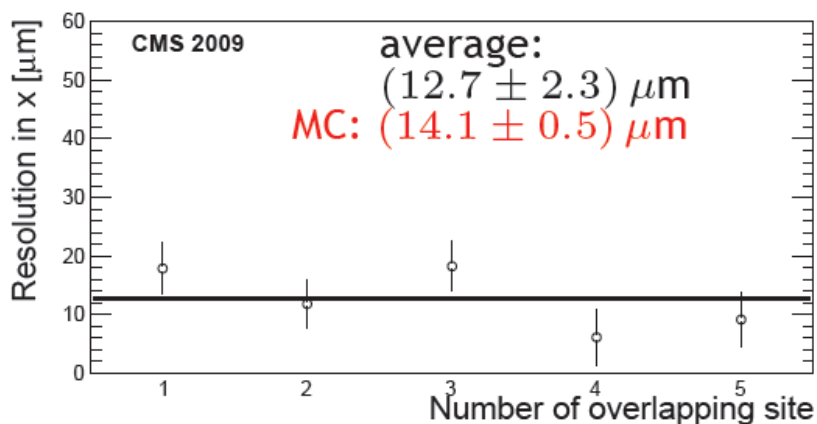
- Highly irradiated sensors operative up to 1kV
 - Problems with high voltage capability of the setup (connectors, PCBs, humidity etc.)
- No signal saturation with bias for $\Phi > 2 \times 10^{15} n_{eq}/cm^2$
 - Is this already a hint for charge multiplication?
- Sensor with $\Phi = 2.8 \times 10^{15} n_{eq}/cm^2$ delivers $> 7ke$ (at 800V)
 - Expect “decent” particle detection efficiency
 - High voltage limited in CMS by connectors, cables and power supplies.



- Present CMS-pixel detector displays good spatial resolution ($\sim 13\mu\text{m}$)
 - High fraction of 2-pixel clusters
 - High magnetic field (3.8T)
 - High mobility of electrons
 - Low bias voltage (150V in the barrel)
 - Interpolation techniques in 2-pixel clusters



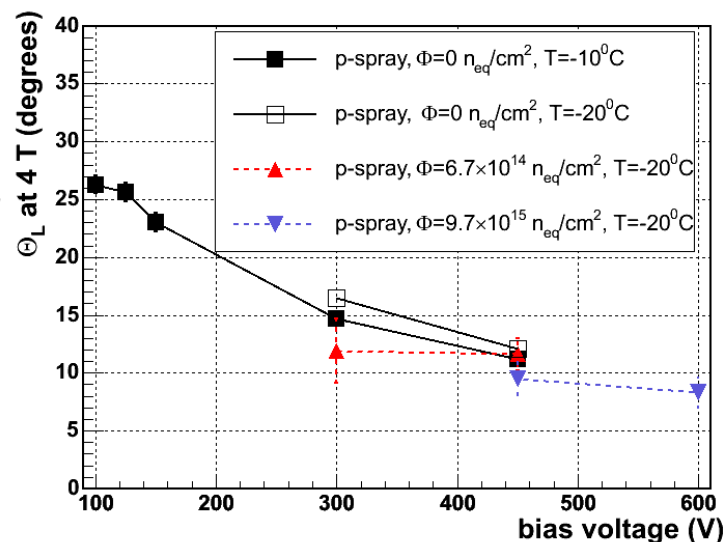
Distribution of cluster size (in $r\phi$)



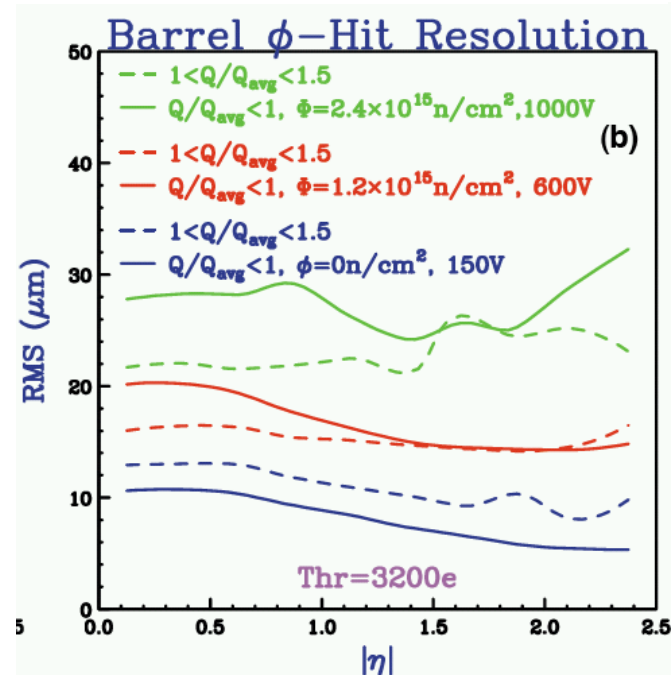
From a study using overlapping modules (see talk by U. Langenegger)

Degradation of spatial resolution ($r\phi$)

- Cumulative radiation damage requires increase of bias voltage
- High electric field reduces mobility of charge carriers
- Lorentz angle is also reduced
- Fraction of double hits is reduced
- Resolution slowly degrades up to the binary value (pitch/sqrt(12) ~ 30 μm with current pitch)
- Process is slow and steady
- Detector might become “useless” for impact parameter measurement although detection efficiency is still high (>95%)
 - Present operational limit
- $1.2 \times 10^{15} N_{\text{eq}}$ (~250 fb⁻¹, 4cm layer) reachable
- Any higher demand requires a smaller pitch in $r\phi$
 - Not realistic in the time scale of the phase I upgrade (~2016)
 - A point of consideration for phase II (> 2020)



A. Dorokhov NIM A530 (2004) 71-76



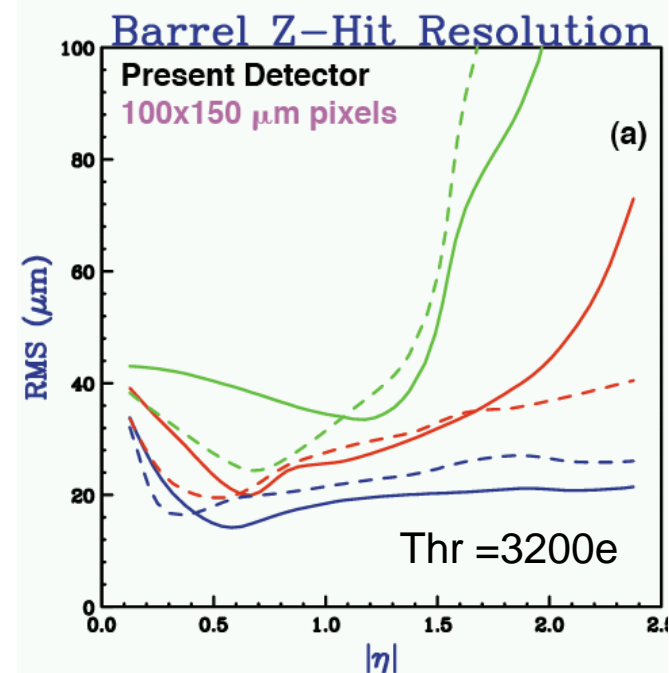
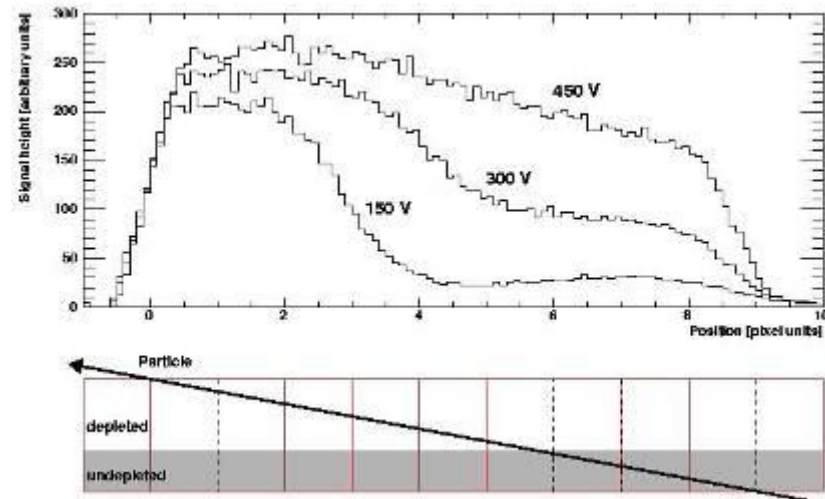
[Morris Swartz, JHU, taken from the draft TDR]

New detector:

- Very low η (cluster length: 1): $\sim 150\mu\text{m} \times \sqrt{12} \sim 40\mu\text{m}$
- “optimum” (cluster length 2): best interpolation possible $\sim 15\text{--}20\mu\text{m}$
- Larger η (cluster length >2): Interpolation more difficult. Fluctuations in the centre of the cluster do not contain information.
- Reach in average $\sim 28\mu\text{m}$ (overlap studies)

In irradiated sensor:

- Shape of cluster has to be taken into account (“template algorithm”)
- If fluence is too high/signal too low:
 - level is low (pitch is smaller than thickness)
 - fluctuations might lead to “hole” in the clusters
 - Present software cannot “glue” to clusters together
 - Large errors in position determination
- Smaller pitch makes things worse
- Need
 - Lower threshold (only possible for phase II > 2020)
 - Powerful software tools to “reconnect” broken cluster, which is difficult in multi track environment inside jets



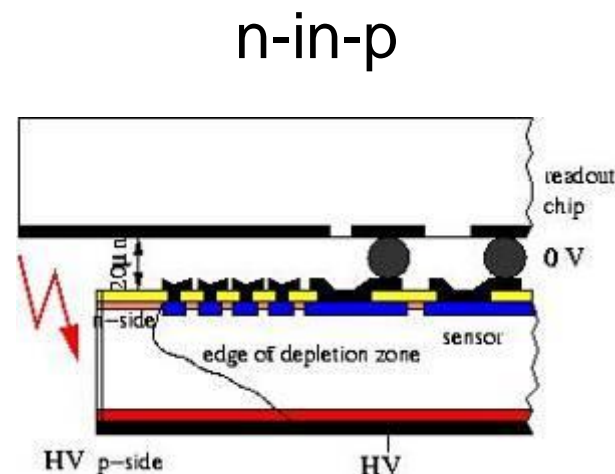
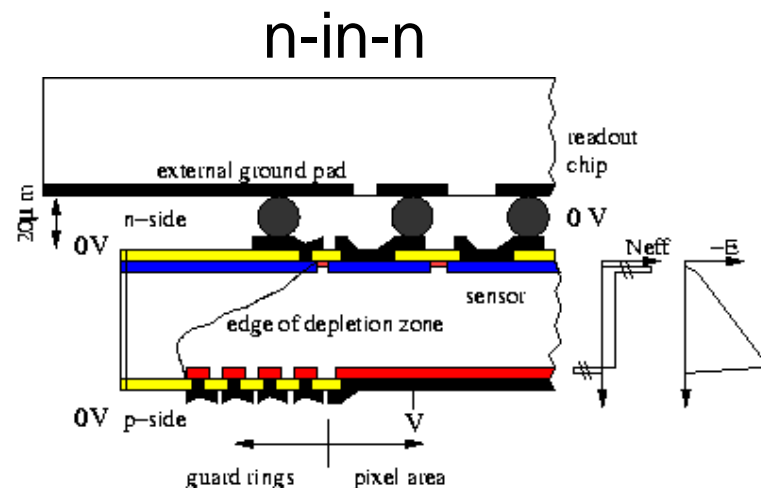
[Morris Swartz, JHU, taken from the draft TDR]

Present CMS pixel detector uses n-in-n-sensors

- double sided processing (back side is structured)
- all sensor edges on ground
- most expensive part of the module (only bump boning is more expensive)

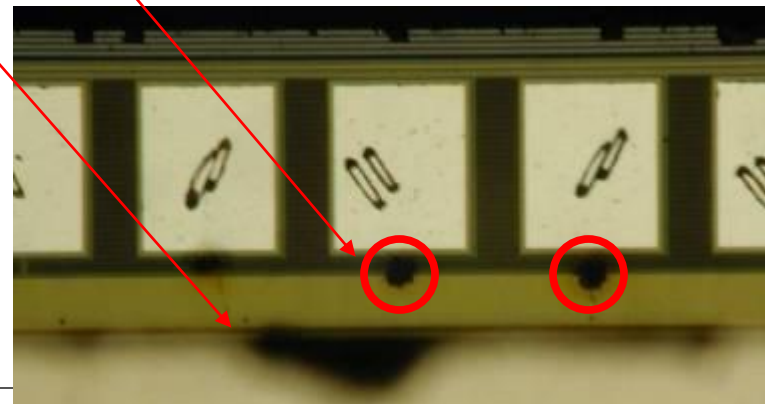
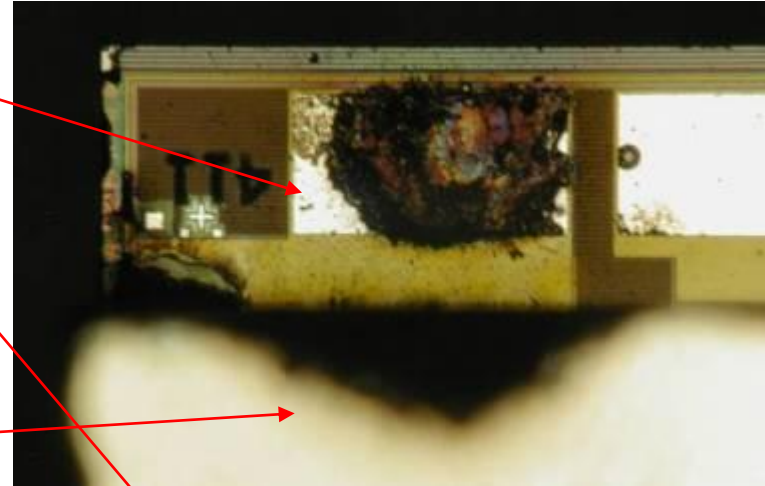
Exploring n-in-p sensors as alternative

- recent studies show radiation hardness
- single sided process promise prize benefit of factor 2-3
 - important as the pixel area will be doubled
- Absence of guard rings on back side lead to the risk of (destructive) sparking to the ROC



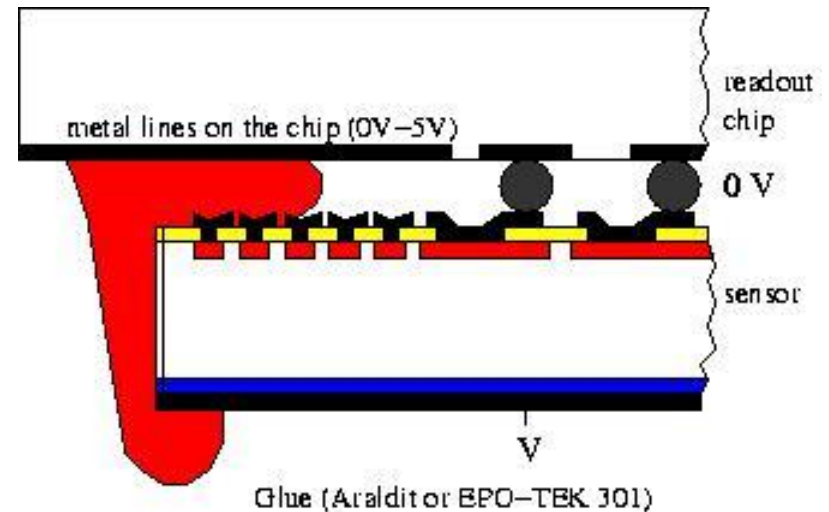
Sparking at Sensor Edge

- Bump bonded rejected material from PSI-PILATUS project (p-in-n sensors and defective ROCs)
- Applied bias voltage to the sensor while ROC was grounded
- Breakdown occurs at ~500V
 - Grounded pad on ROC completely destroyed
 - Other pads also damaged
 - Voltage surprisingly high
 - spark comes from sensor back side?
 - 500V \rightarrow 500 μ m air?
 - Aluminium also evaporated on sensor backside



Tried to passivate edges with glue

- Araldit (standard)
 - used as underfill and glue in CMS module production
 - no change of break down voltage
- EPO-TEK 301
 - very liquid, fills part of the gap
 - break down at $\sim 700\text{V}$



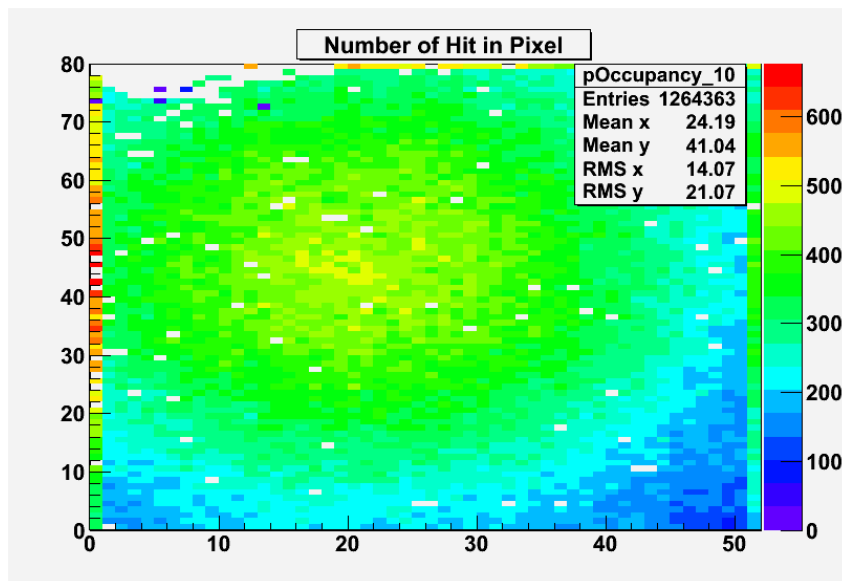
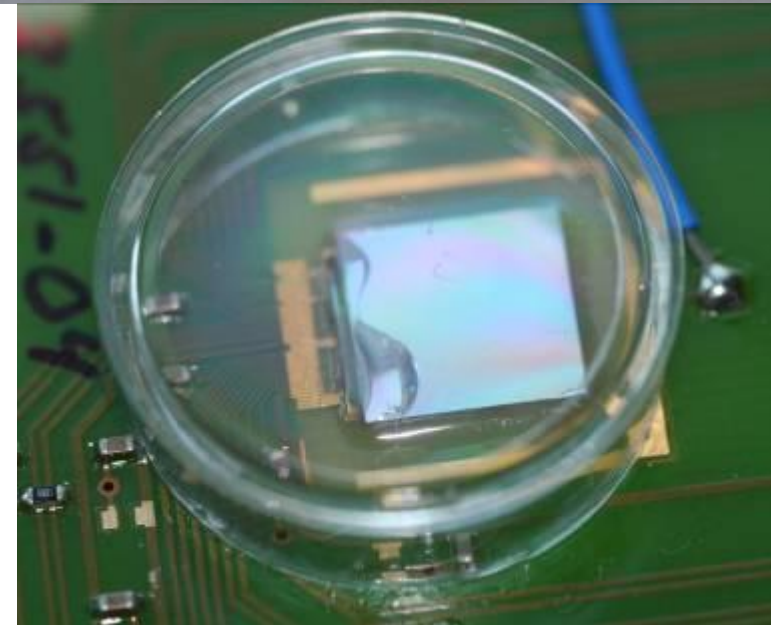
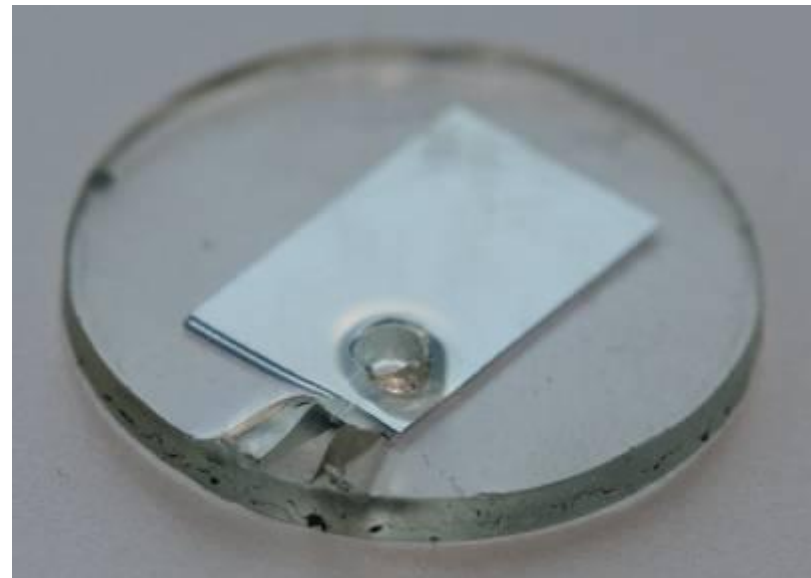
EPO-TEK 301

Araldit

First “hot” samples

Now using EPO-TEK 302

- Also rather liquid (partly filling the gap)
- Desperately embedded the sample completely (is not meant for a real detector !)
- Enclosed the edges of some new sensors
- Tested them with the Sr-90 source
- Are confident enough to bump bond and irradiate some samples



- ...CMS will replace its pixel detector in 2016 by a 4 layer system with lower material (phase I upgrade)
- ...this upgraded detector might be exposed to considerable pion fluences
- ...however, the degradation of signal height is expected not to be critical
- ...operation of the inner pixel barrel layer will be limited by the degradation of the spatial resolution
- ...single sided n-in-p sensors provide potential cost savings
- ...problems of module construction (sparking) have to be solved

