US CMS

The Compact Muon Solenoid

Sensor production readiness

G. Bolla, Purdue University
for the USCMS FPIX group

PMG review 02/25/2005

Outline

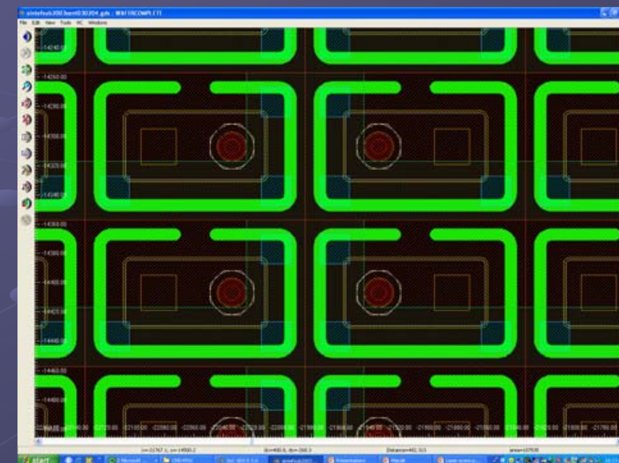
- Sensor requirements
  - Geometry
  - Radiation hardness
- Development
  - Guard Rings
  - P-stops
- The final design (performance)
  - Laser measurements (CCE)
  - FNAL test beam results
  - CERN test beam results
- Conclusions

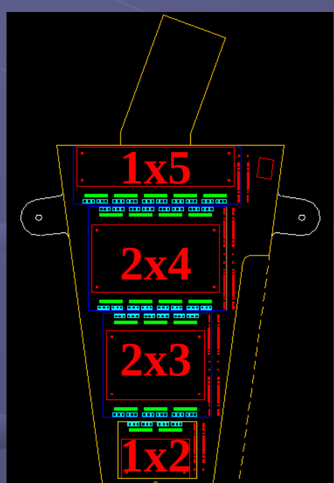
US CMS

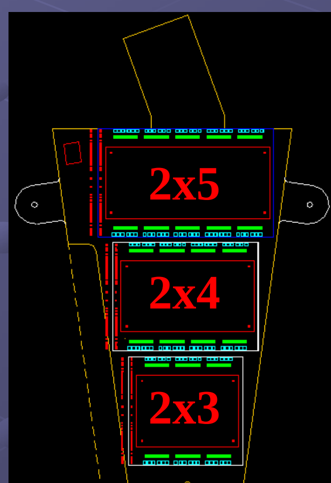
The Compact Muon Solenoid

Sensor requirements Geometry

- Pitches are set by the ROC design
  - 150 µm x 100 µm pitch
  - 100-200 x 100 bonding pitch
- Dimensions are set by the blade design
  - 7 different sensors are needed for a blade
    - 5 different geometries

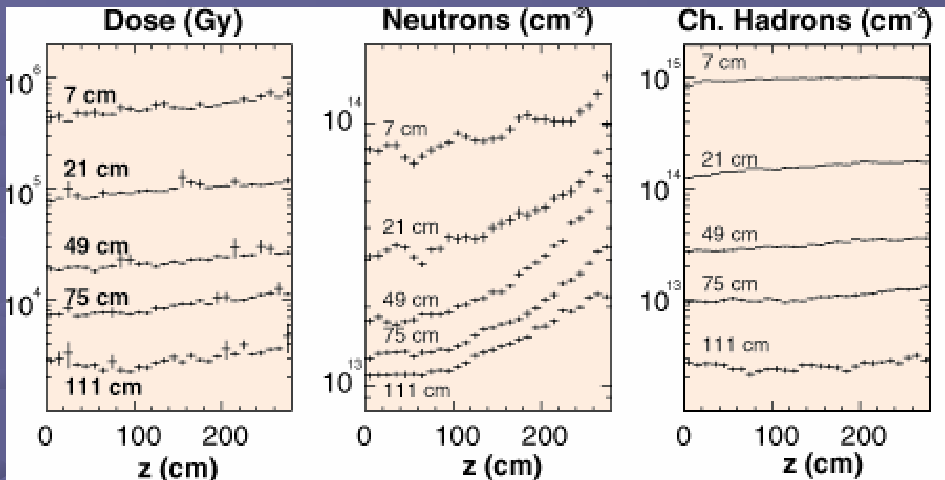






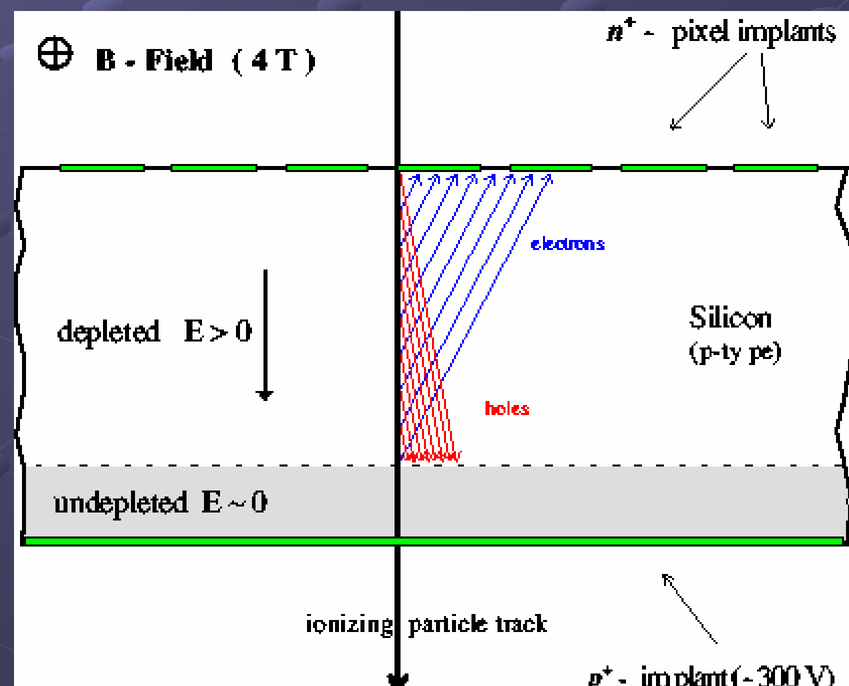
Sensor geometry	Active area X [µm]	Active area Y [µm]	Edge to Edge X [µm]	Edge to Edge Y [µm]
2x1	16200	8100	18594	10494
3x2	24300	16200	26694	18594
4x2	32400	16200	34794	18594
5x2	40500	8100	42894	18594
5x1	40500	16200	42894	10494

Sensor requirements
Radiation hardness



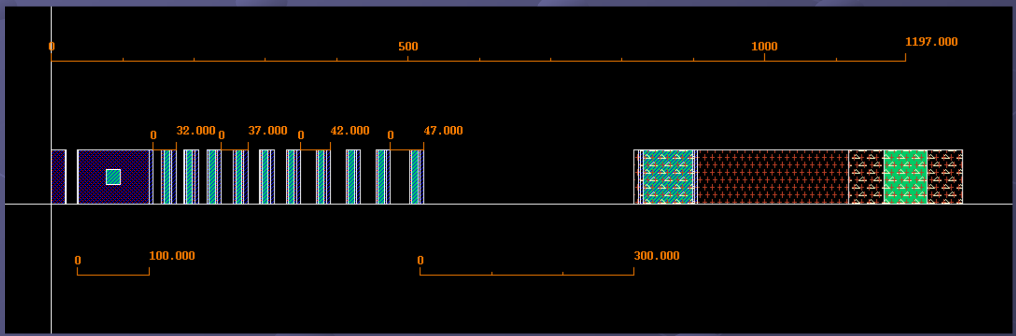
All components of the pixel detector are specified to remain operational up to a particle fluence of at least 6 10^{14} mip/cm^2

- n^+-on-n sensor for potential partially depleted operation post bulk-inversion
  - Double sided process with 10 masks (5 per side)
- Foreseen HV operations above 300 V
  - Need for multi-guard-rings at the sensor periphery

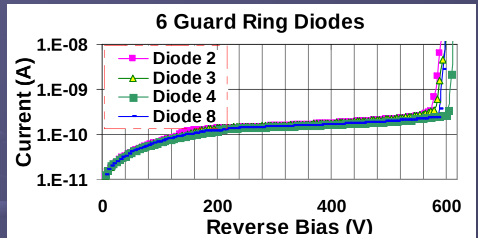


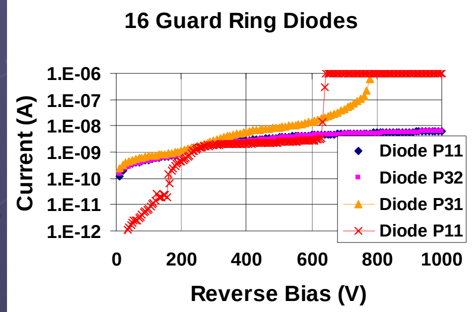
HV operations Guard Rings

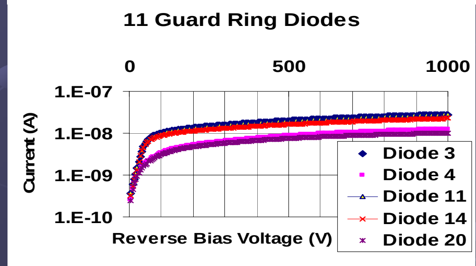
- Finalized in 1999 with the engineering run
  - PSI-JHU-PURDUE-BTeV
  - Two vendors
    - Sintef
    - CSEM (later Colibris later out of business)
  - Vdep ~ 180-200 V
- 10+1 Guard-rings add ~1.2 mm on each edge of the sensor
  - Holds >1000V before irradiation
  - Holds >800V after 6 10^{14}

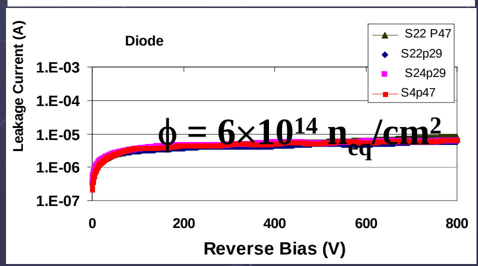


Nucl.Instrum.Meth.A461:182-184,2001





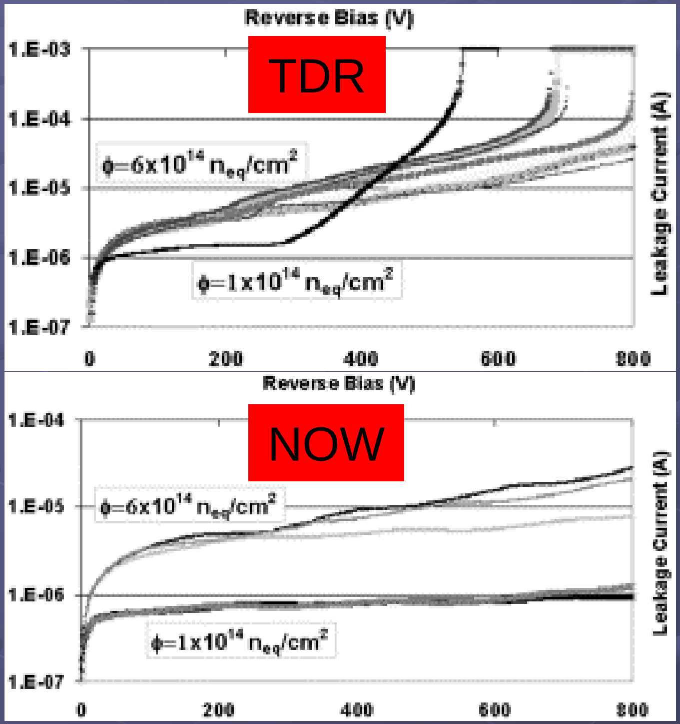


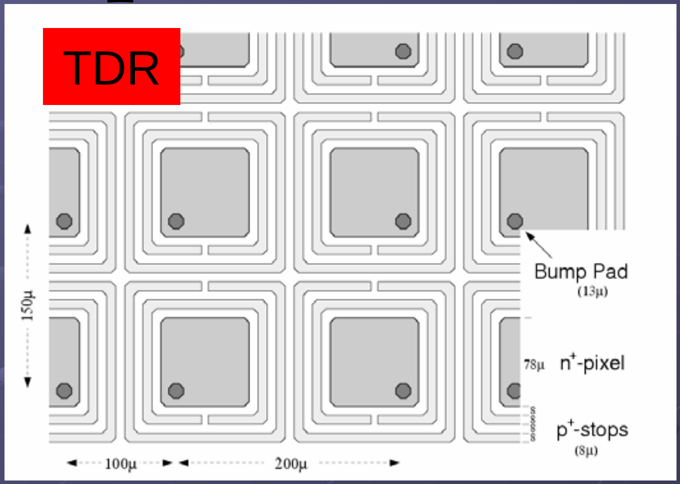


US CMS
The Compact Muon Solenoid

HV operations p-stops

- P-stops edges are the points with high electric field
  - Shapes and distances strongly affects the maximum HV reachable



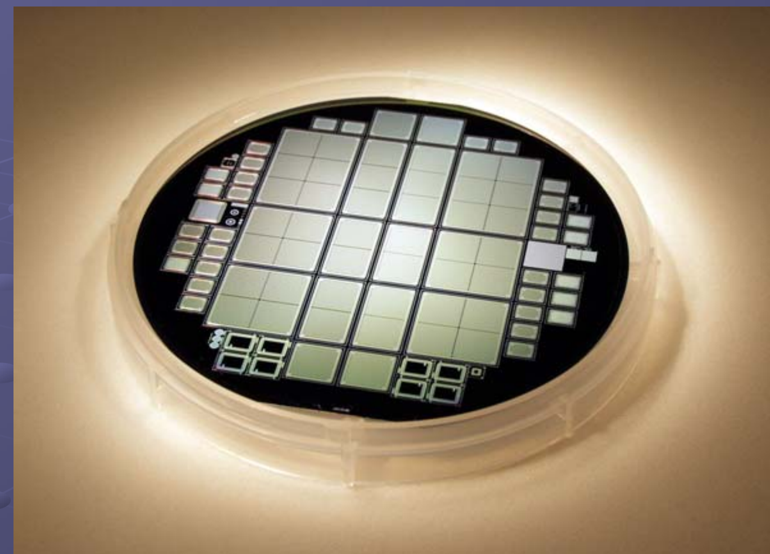


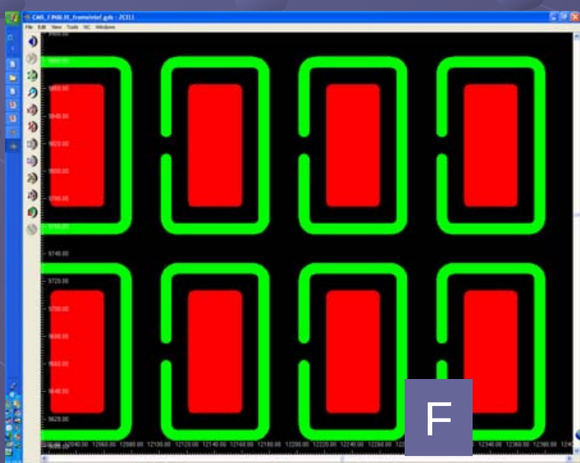
Nucl.Instrum.Meth.A501:160-163,2003

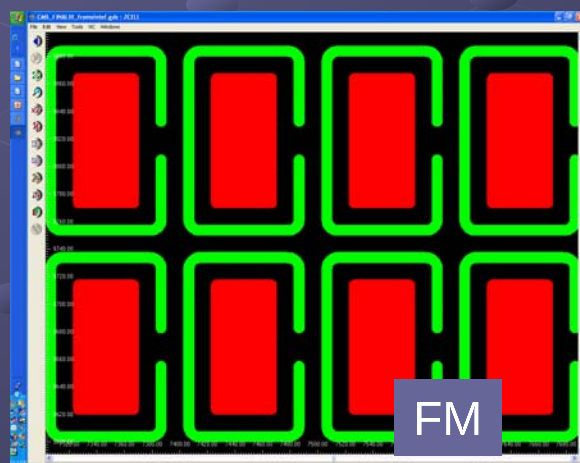
F and FM design

2001: submission with Sintef with

- Only 2 design left for large sensors
  - PSI30 Honeywell (irradiated and bumped at PSI)
  - PSI43 DMILL (bumped at MCNC and IZM)
  - PSI46 ¼ µm (bumped at IZM and VTT)





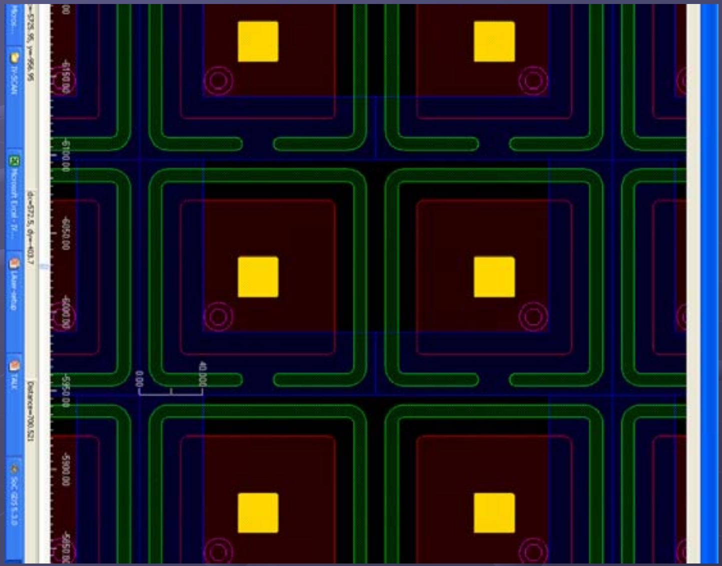


- Assembly experience
- CCE measurements
- Test beam

US CMS
The Compact Muon Solenoid

P-stops geometry and CCE (Charge Collection Efficiency)

- 1064 nm laser (goes through more than 300 µm of Si)
- Beam size ~10 µm
- Scans in ≥2 µm steps
- Technique allows:
  - One to one comparison on the CCE performance of the 2 design (F and FM).
  - Dependence on Vbias



Implanted n+ pixel (also metalized) ~98 µm square

P-stops ring 8 µm wide with 12 µm gaps

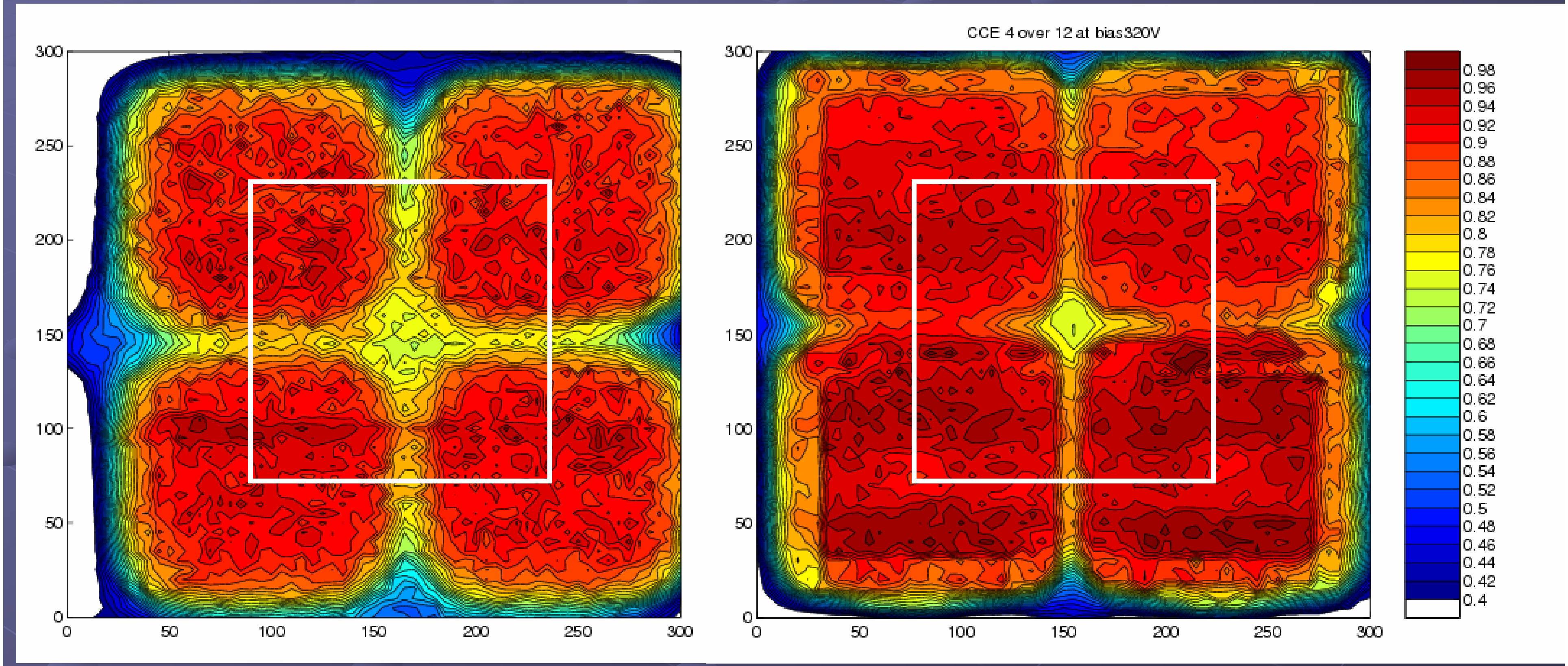
Metal grid on the p-side

Contact between the Al and the n+ implanted pixel

F vs FM direct comparison

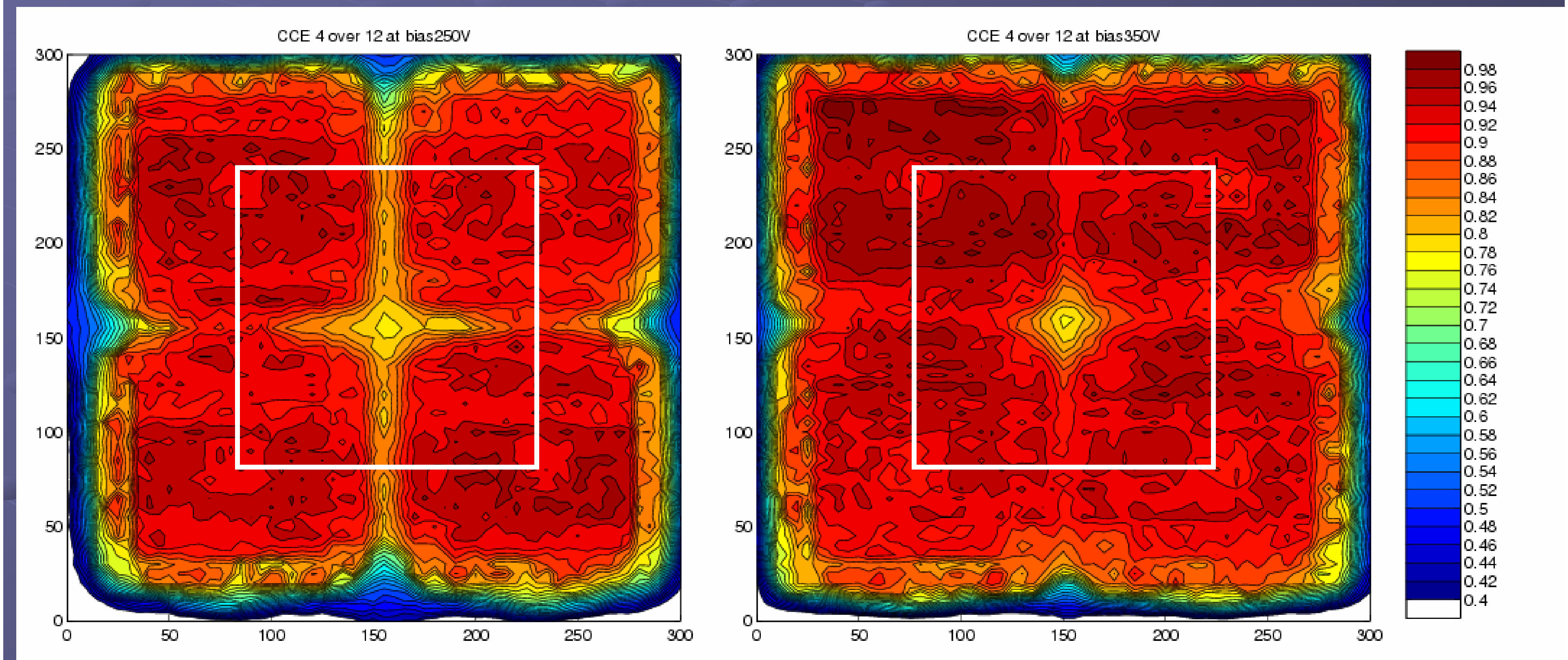
F design at 320 V

FM design at 320 V



CCE vs Vbias

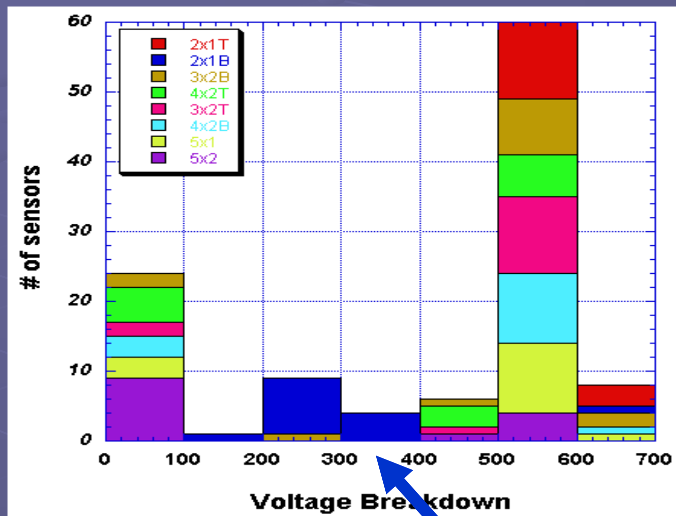
FM design at 250 V   FM design at 350 V

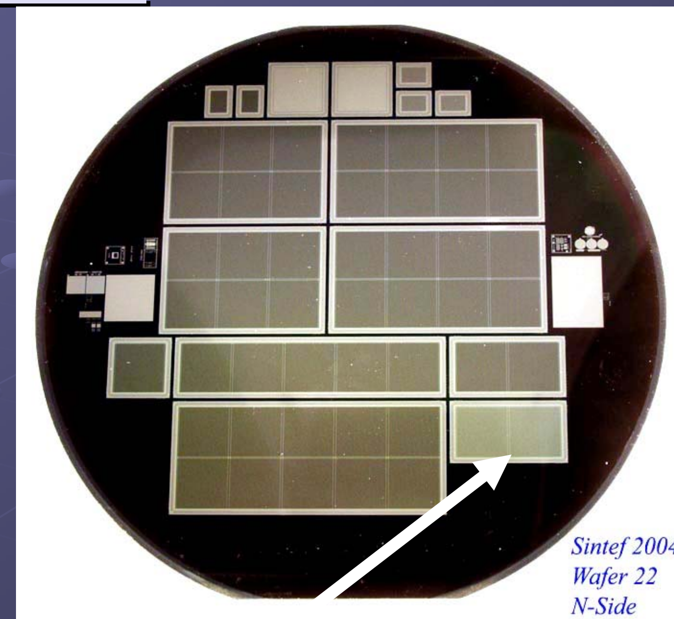


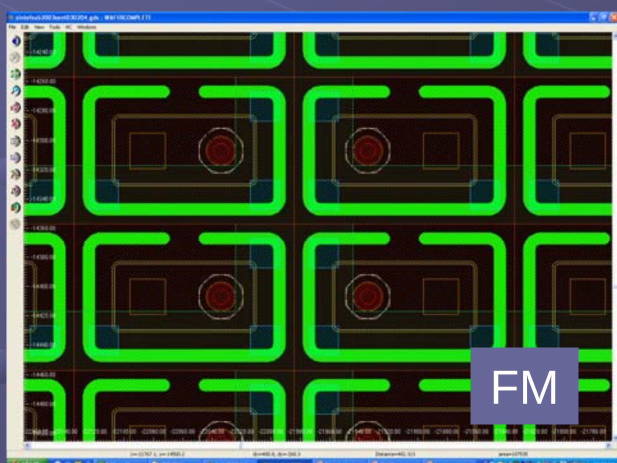
The decision to move to a higher resistivity (90-100 V depletion on diodes versus the 180-200 V of the 2001 submission) allows for more over depletion to be applied and so better CCE (lower inefficiencies) in the corner regions.

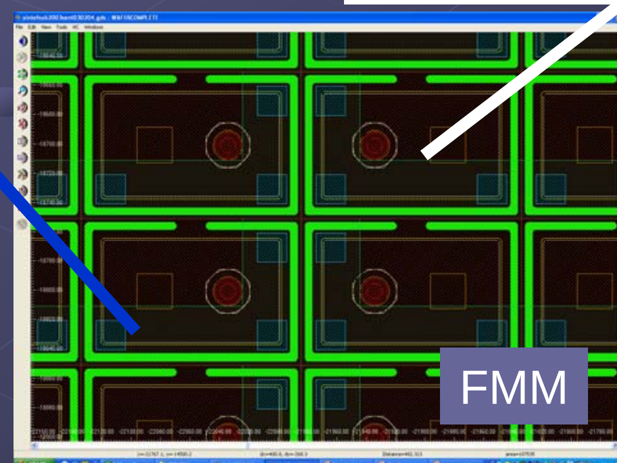
US CMS
The Compact Muon Solenoid

Can we squeeze it even more?

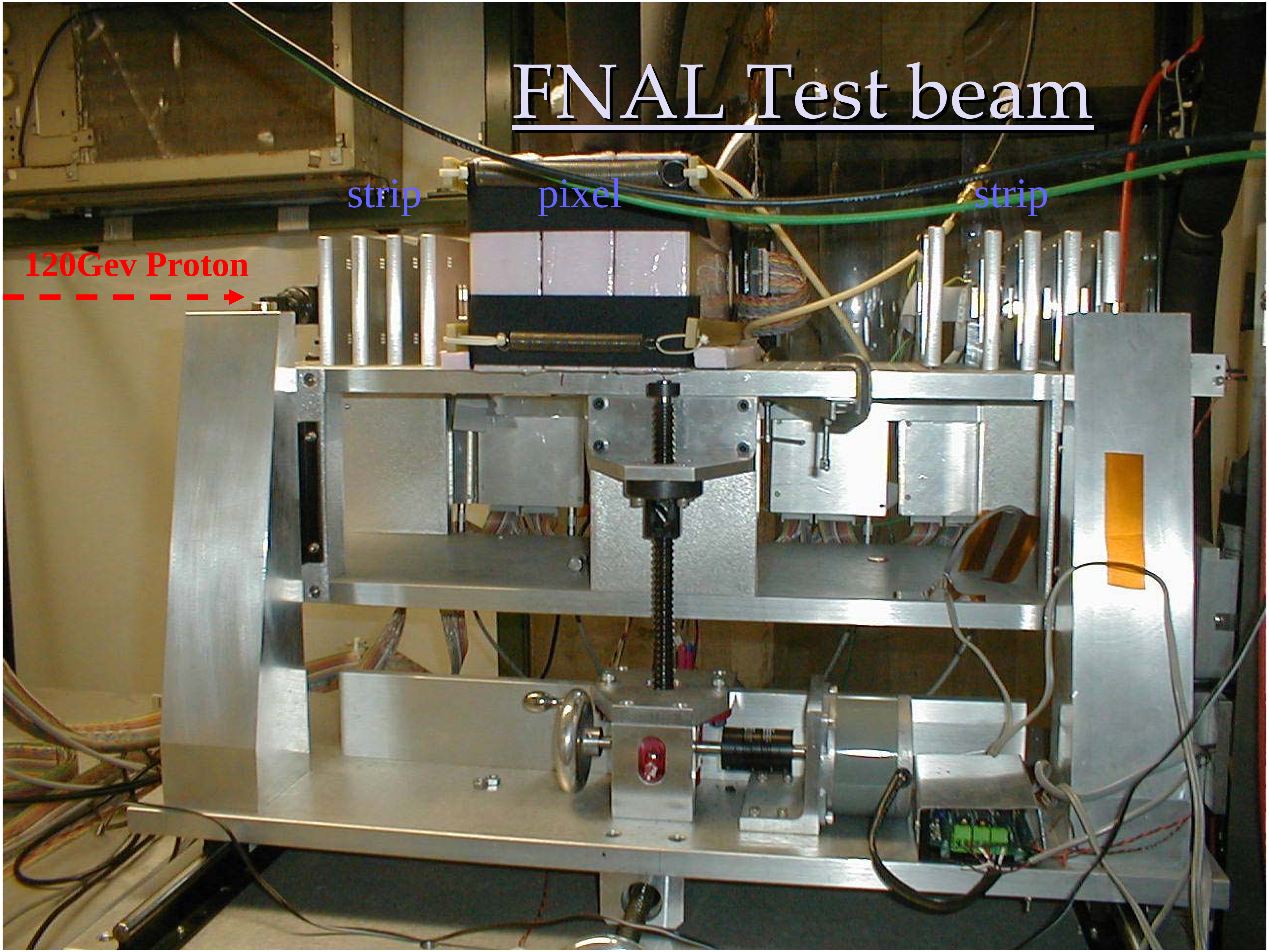






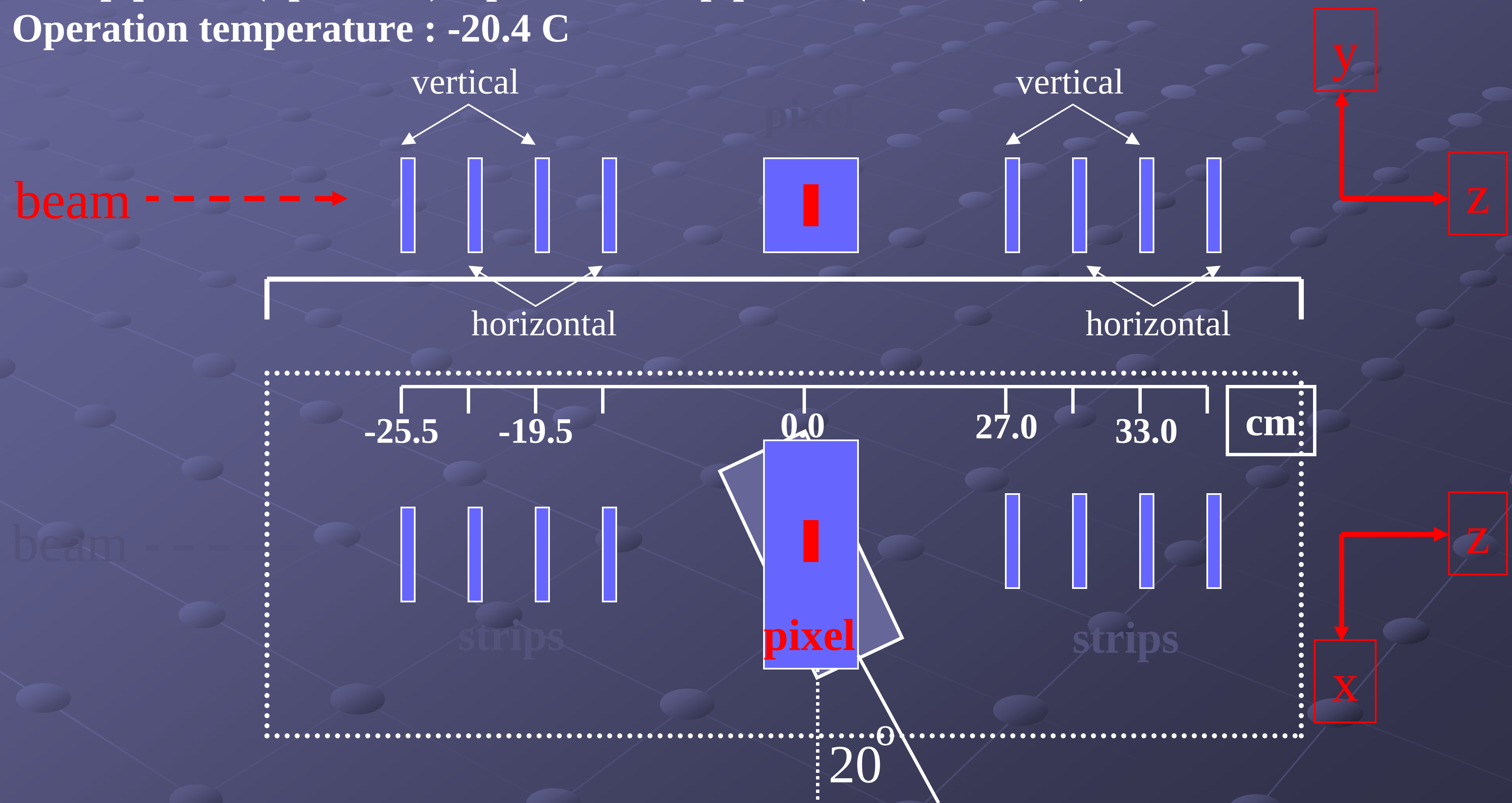


FNAL Test beam



FNAL Test beam

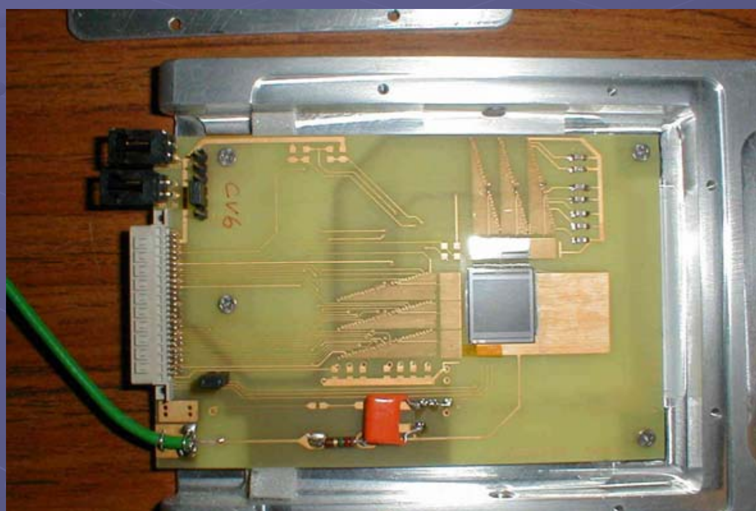
- beam : 120GeV Proton,
  6-12 spills/min, few 1000 trgs/spill, 300events/spill,
- 4 strip planes (upstream) + pixel + 4 strip planes (downstream)
- Operation temperature : -20.4 C

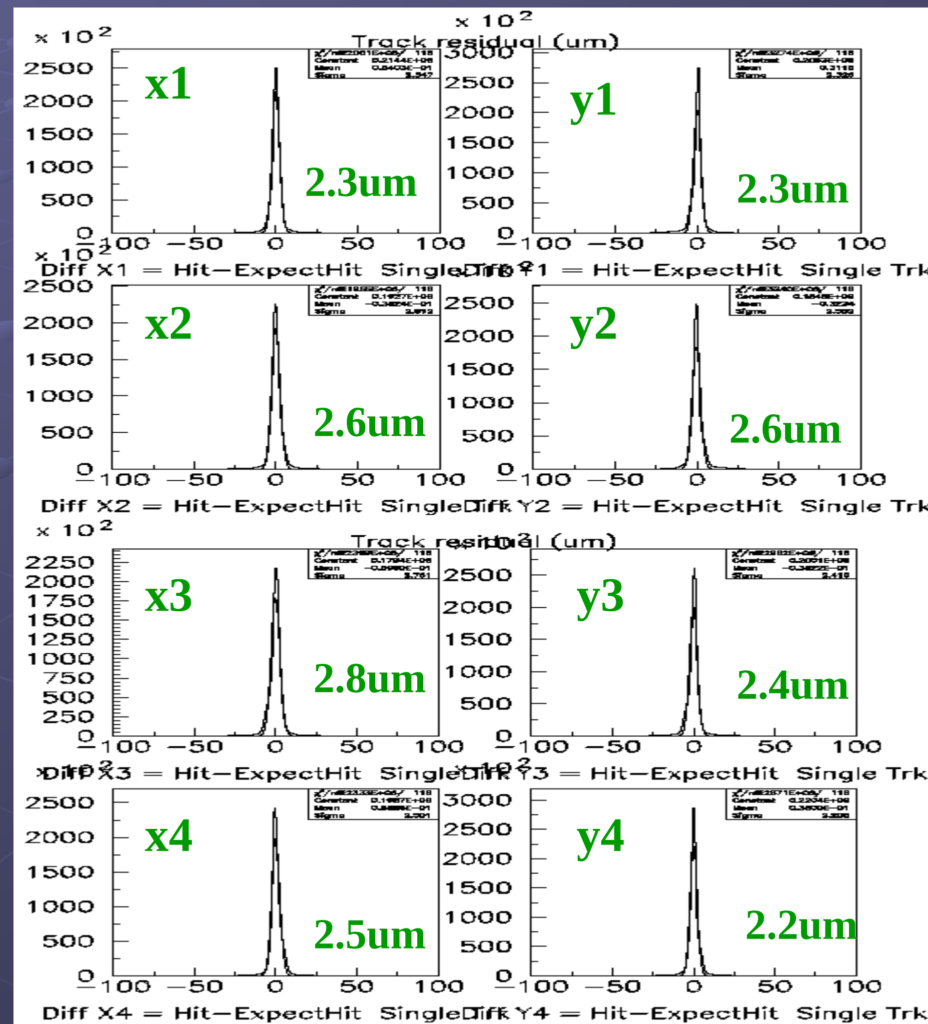


FNAL Test beam

Beam telescope

- 8 strip planes(4X + 4Y)
- 1 plane = 2 ROC's = 2 x 128 ch
- Strips pitch : 50um





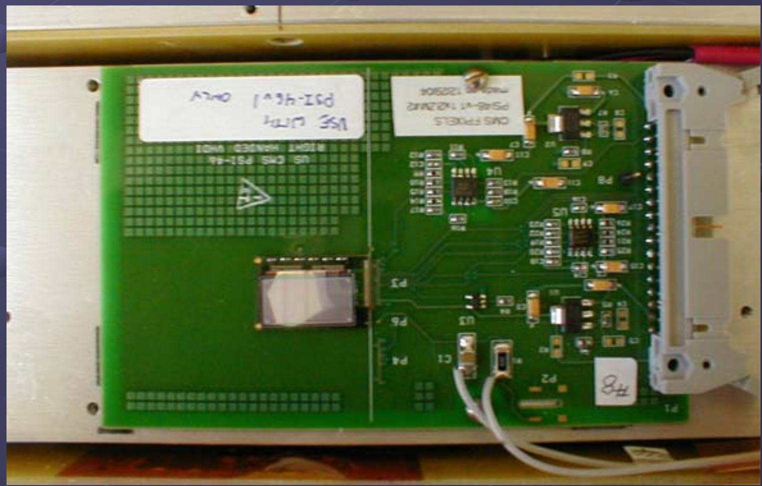
- single cluster is used for tracking
- alignment variables : theta, offset
- track_residual < 3um

FNAL Test beam

- Months of data taking with the DMILL PSI43
  - Unstable performance
- 12/20/04 switched to ¼ μm PSI46v1
  - Reliable operation and robust efficiency measurements
  - No charge information: a binary chip

Pixel detector

•Sensor design : FM
• 4160 pixels/ROC
•Chip : PSI46v1, 1x2 chip
→ 1 chip has 52 columns and 80 rows
→ 8.1 mm x 8.1 mm
→ No charge information
•Pixel size : 150um(col) x 100um(row)



US CMS

The Compact Muon Solenoid

Data set

Not tilted

run	Bias Volt.	Data Size
2635*	-350	250k
2643	-250	250k
2644	-400	250k
2645	-300	250k
2646	-200	250k
2648	-250	250k
2649*	-350	250k
2650*	-350	250k
2653*	-350	250k

Tilt 20 degree

run	Bias Volt.	Data Size
2663	-350	250k
2665	-300	250k
2666	-250	250k
2667	-200	250k
2668	-400	250k
2669	-350	250k

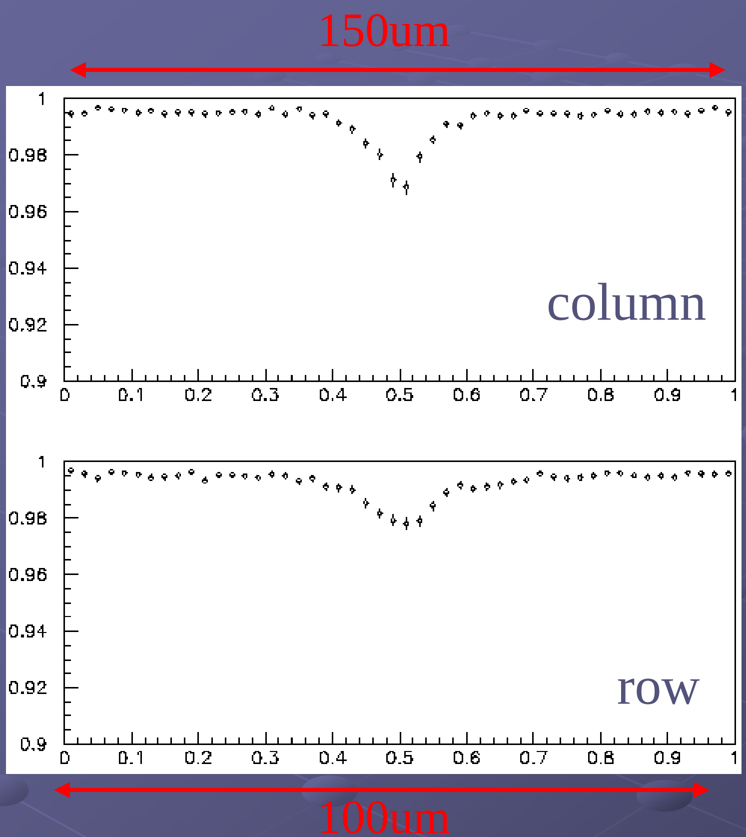
Runs with the * have been combined to get a high statistic sample

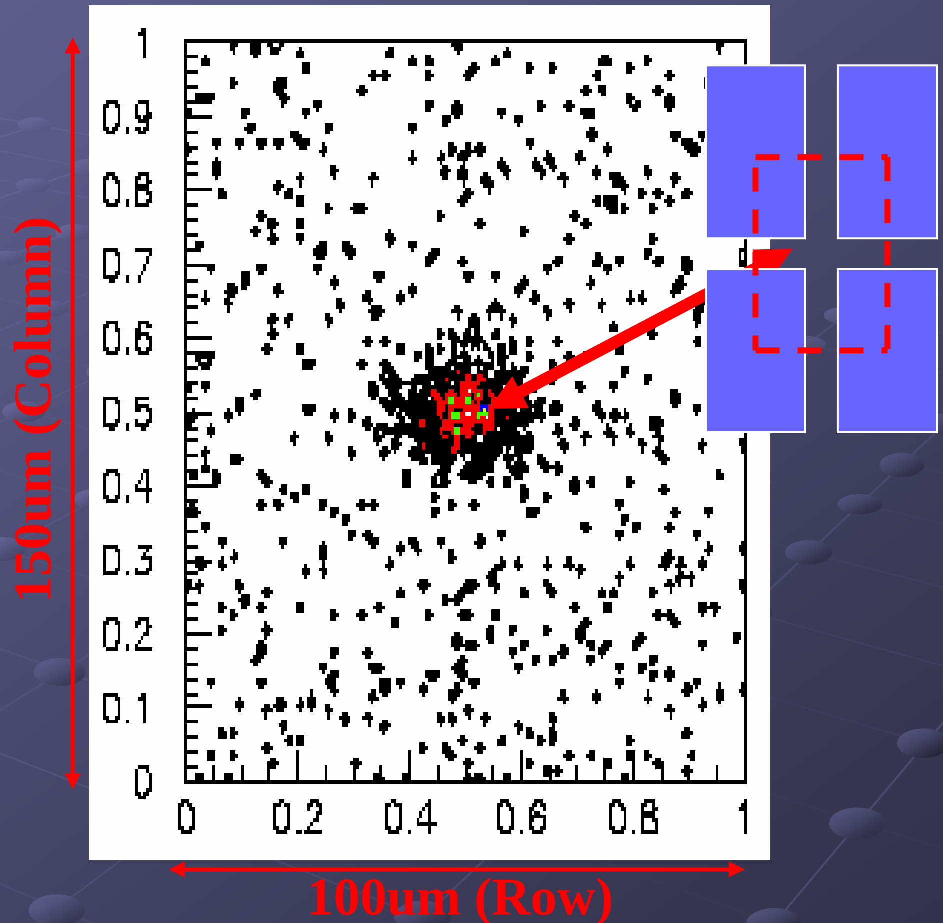
Cuts

Number listed here for the 1M evts (4 runs combined)

Cut	Number of events	System/Sensor efficiency
	~ 1M	
Single track from the telescope	699299	30% have multiple tracks
Track quality	483700	15% with single tracks have poor track resolution
Pointing to the pixel array	309534	18 % are pointing outside of the pixel array
BAD TBM trailer	306263	A small percentage have DAQ troubles
Find pixel hits	304990	99.6 ± 0.3 %
Trk-pixel residual	304022	99.3 ± 0.3 %

No tilt Efficiency: 99.3 ± 0.3 %





- Inefficiency is dominant at the corner of 4 pixels
- Consistent with the laser results

Rotation: 0° vs 20°

Bias Voltage	# of Events	Good trk	Good hits	Efficiency
-200	250k 250k	70348 74938	68002 73005	96.7 % 97.4 %
-250	250k 250k	76221 75618	75553 75013	99.1 % 99.2 %
-300	250k 250k	70868 71511	70394 71046	99.3 % 99.3 %
-350	1M 250k	306263 76304	304022 75820	99.3 % 99.4 %
-400	250k 250k	70370 73734	69185 73310	99.5 % 99.4 %

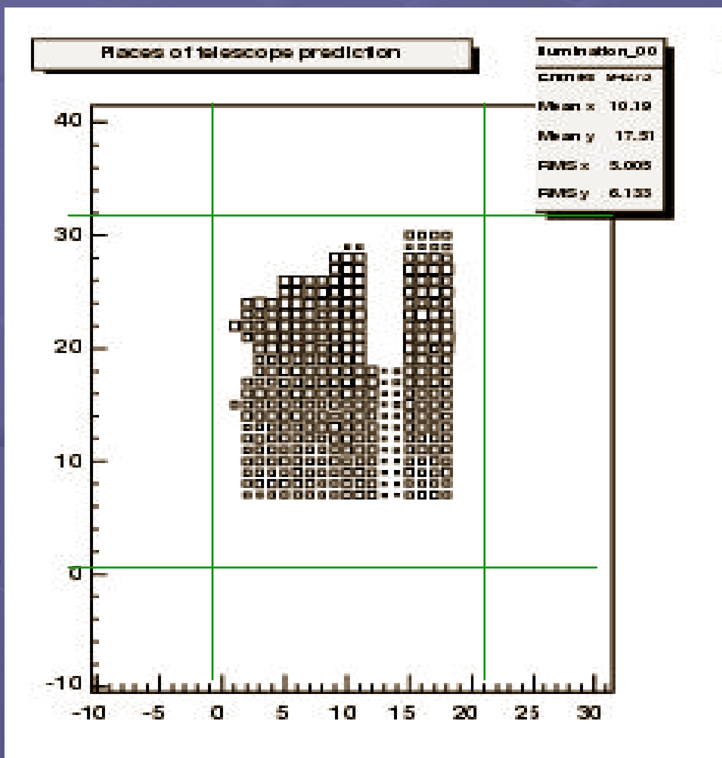
Post irradiation: CERN

- CERN test beam data from fall 2004
- Different ROC
  - PSI30 (Honeywell from late 90s)
    - Different pitch 125μm x 125 μm
    - Analog charge available
    - Threshold-less
- Pre-bump irradiation at CERN (6 10^{14})
- Bumped at PSI (indium)
  - Single die metallurgy
  - Many un-bonded pixels
- Post irradiation efficiency measurements

US CMS
The Compact Muon Solenoid

Data set

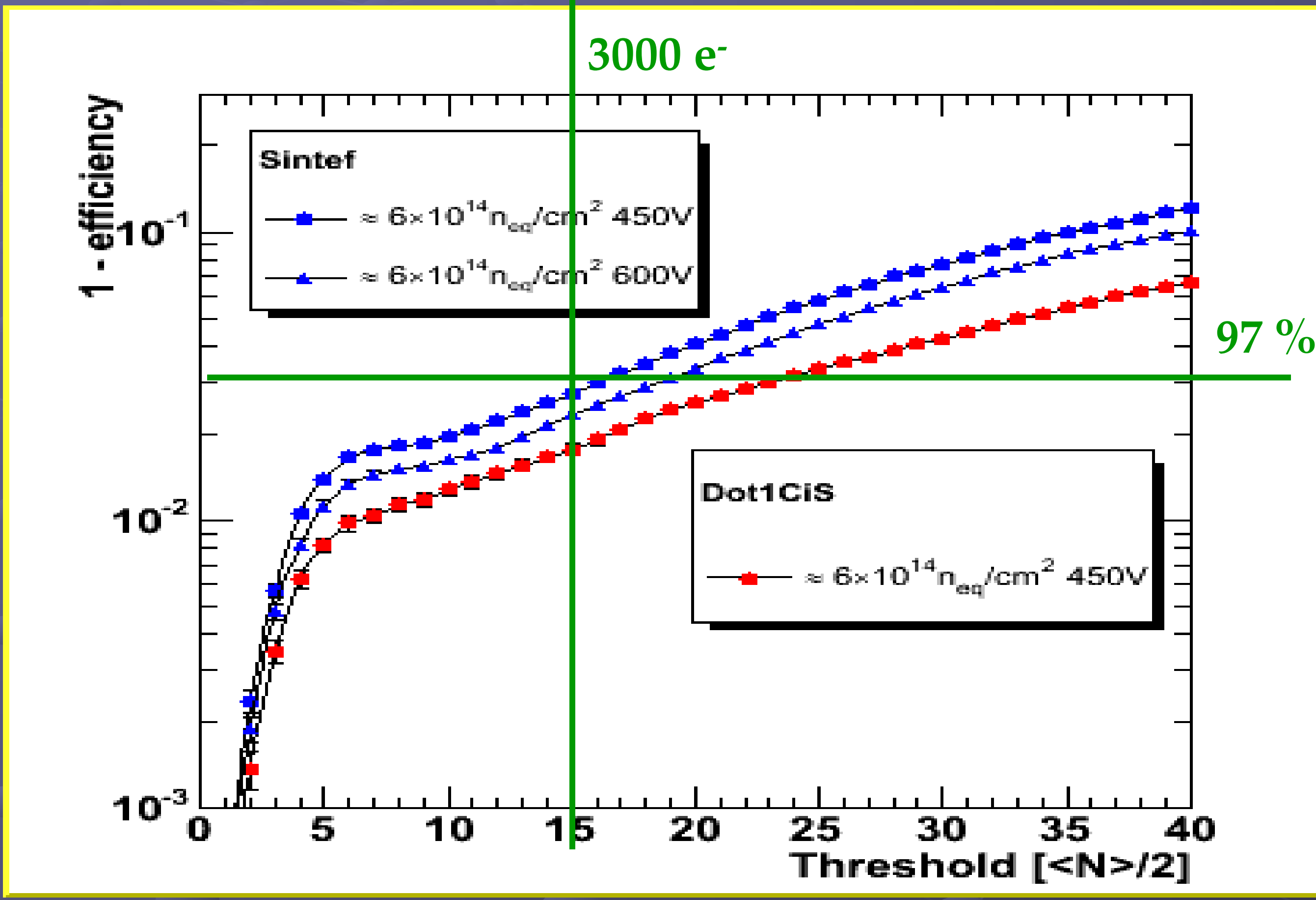
Illumination



Sensor	Bias Volt.	Dose	# of events
F	-300	Unirradiated	1424700
FM	-450	6 10^{14}	1400000
FM	-600	6 10^{14}	1040000

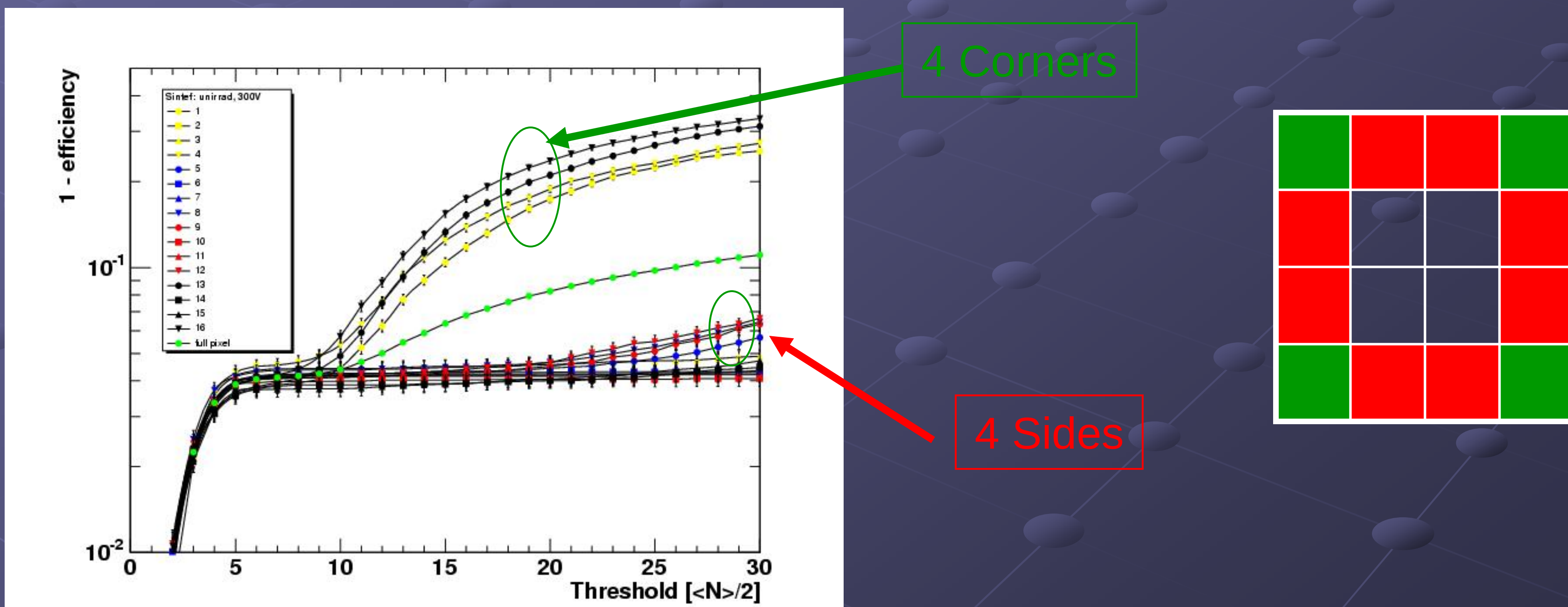
- No un-irradiated FM design to be compared with the results from FNAL

Efficiency measurements



Other results

- Signal to noise ratio of ~44 post $6\ 10^{14}$ irradiation (~45 for the p-spray as a comparison)
- No evidences of micro-discharges up to 600 V on irradiated device
  - True also around un-bonded pixels



US CMS
The Compact Muon Solenoid

Conclusions

- Sensors for the CMS FPIX project have been developed.
- The geometry is driven by the other components of the system
- High voltage operation are guaranteed according to the TDR specification
- The particle detection efficiency is > 99% before any irradiation and after 6x10^{14} is still above 97 %
- The designed sensors are fully compatible with the goals of the project
- Daniela will present the results from the preproduction run