Summary: 3rd Workshop on Advanced Silicon Radiation Detectors (3D and P-type Technologies)

M. Lozano[1], G. Pellegrini[1], G. Casse[2]

1- CNM-IMB (CSIC) Barcelona, Spain
2- University of Liverpool, UK

Some numbers

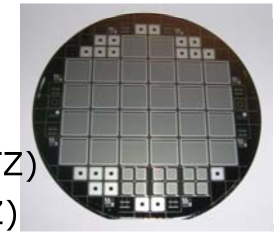
- 14-16 April 2008 at Barcelona
- 51 attendants from 11 countries
- 25 presentations
- 1 live exhibition
- 1 dinner by the beach

P-type detectors

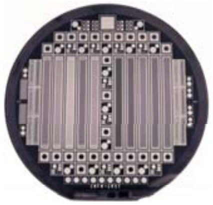
- Summary and results by Liverpool and SCIPP (G. Casse, A. Affolder, H. Sadrozinsky)
- Advantages:
  - N-side read-out can be implemented on n-type substrates (with numerous successful examples). But requires double sided processing (backplane guard rings patterning). Will be effective after space charge sign inversion to *p-type*.
  - P-type substrate more natural choice: no type inversion, no backplane processing.
  - Easier to handle (not to take care of special gluing on the backside due to the presence of guard-rings, possibility of operating under-depleting also before irradiation)
  - Up to 60% discount with respect to n-in-n!!

Recent production of Silicon Strip, Pixel and Pad detectors (<u>non exclusive list</u>):

- <u>CIS Erfurt, Germany</u>
  - 2005/2006/2007 (RD50): Several runs with various epi 4" wafers only pad detectors
- <u>CNM Barcelona, Spain</u>
  - 2006 (RD50): 22 wafers (4"), (20 pad, 26 strip, 12 pixel),(p- and n-type),(MCZ, EPI, FZ)
  - 2006 (RD50/RADMON): several wafers (4"), (100 pad), (p- and n-type),(MCZ, EPI, FZ)

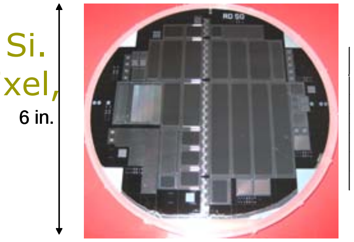


- <u>HIP, Helsinki, Finland</u>
  - 2006 (RD50/RADMON): several wafers (4"), only pad devices, (n-type),(MCZ, EPI, FZ)
  - 2006 (RD50) : pad devices, p-type MCz-Si wafers, 5 p-spray doses, Thermal Donor compensation
  - 2006 (RD50) : full size strip detectors with 768 channels, n-type MCz-Si wafers



- <u>IRST, Trento, Italy</u>
  - 2004 (RD50/SMART): 20 wafers 4" (n-type), (MCZ, FZ, EPI), mini-strip, pad 200-500μm
  - 2004 (RD50/SMART): 23 wafers 4" (p-type), (MCZ, FZ), two p-spray doses 3E12 amd 5E12 cm^{-2}
  - 2005 (RD50/SMART): 4" p-type EPI
  - 2006 (RD50/SMART): new SMART mask designed

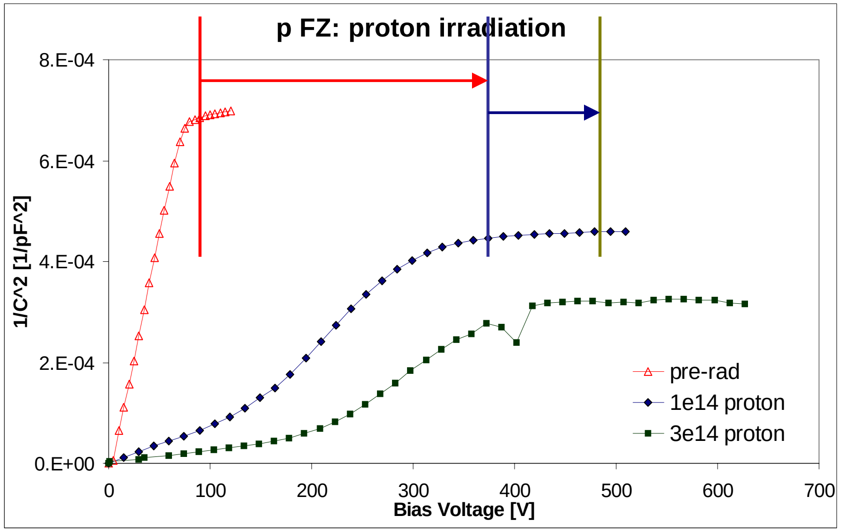
- <u>Micron Semiconductor L.t.d (UK)</u>
  - 2006 (RD50): 4", microstrip detectors on 140 and 300μm thick p-type FZ and DOFZ Si.
  - 2006/07 (RD50): 93 wafers, <u>6 inch wafers</u>, (p- and n-type), (MCZ and FZ), (strip, pixel, pad)

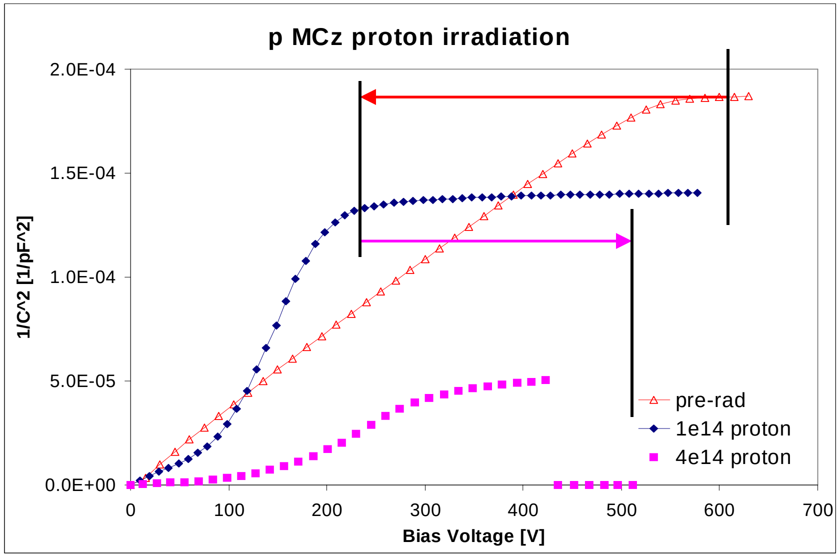


- <u>Sintef, Oslo, Norway</u>
  - 2005 (RD50/US CMS Pixel) n-type MCZ and FZ Si Wafers
- Hamamatsu, Japan
  - In 2005 Hamamatsu started to work on p-type silicon in collaboration with ATLAS upgrade groups

- M.Lozano, 8th RD50 Workshop, Prague, June 2006
- A.Pozza, 2nd Trento Meeting, February 2006
- G.Casse, 2nd Trento Meeting, February 2006
- D. Bortoletto, 6th RD50 Workshop, Helsinki, June 2005
- N.Zorzi, Trento Workshop, February 2005

Protons & P-type: Compare FZ and MCz

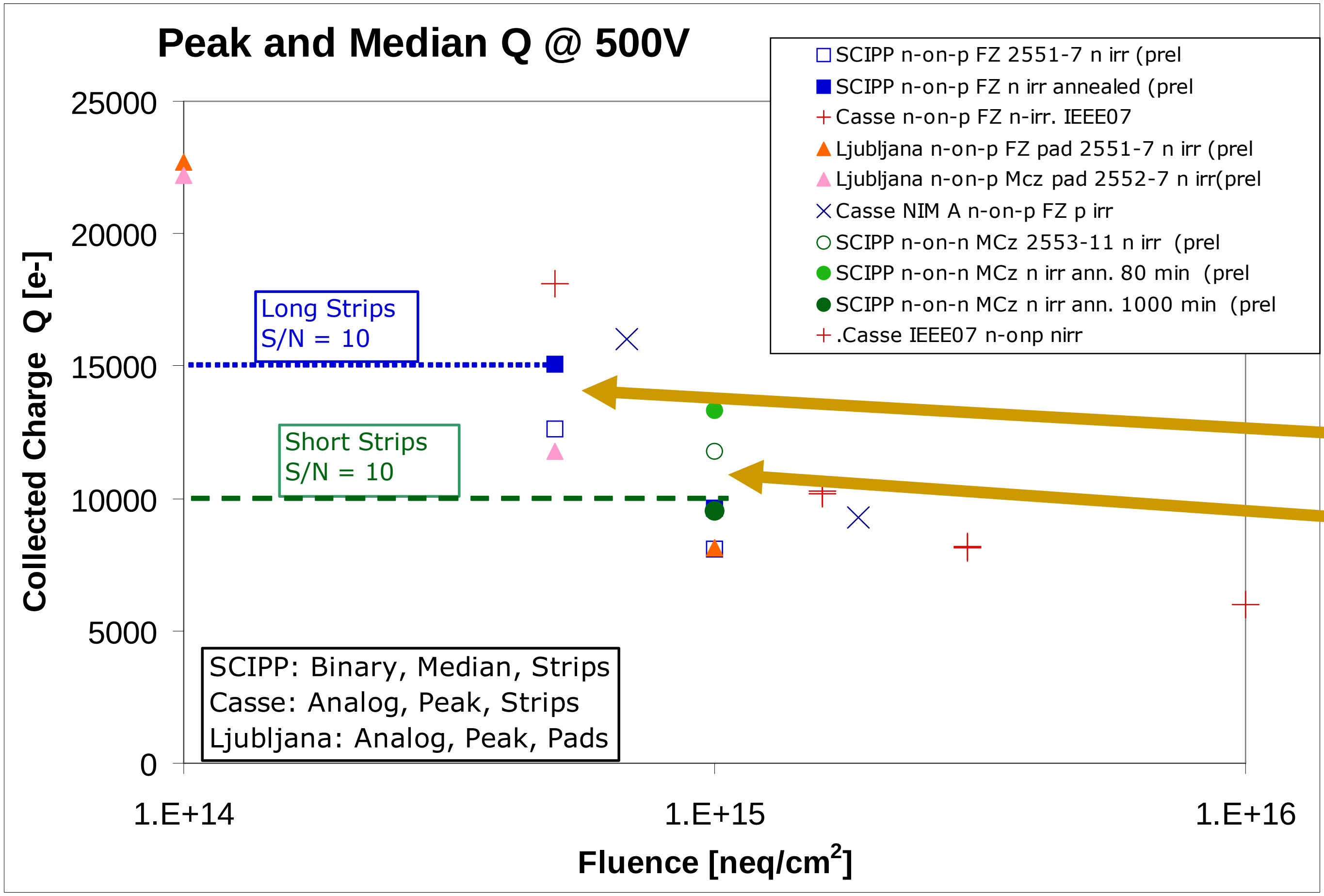




- p-type FZ:
  - Monotonic Increase in Full Depletion Voltage:
  - Monotonic Introduction of Acceptors
  - Material becomes more p-type
  - Introduction rate not constant? Donor removal?
- p-type MCz
  - Non-Monotonic Increase in depletion voltage:
  - Introduction of Donors
  - Material becomes initially more n-type:
  - Type inversion?
  - Large initial donor introduction rate

Charge Collection in Upgrade Strips

ATLAS bias voltage is constraint to < 500V (cables!).

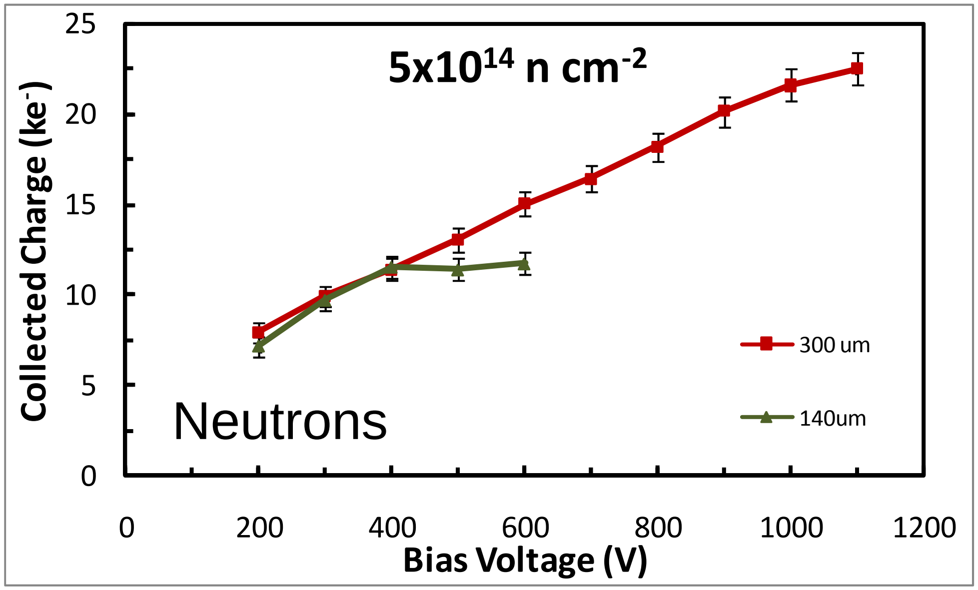


- **At 800V bias voltage enough charge,**
- **At 500V in the limit**
- **FZ improves after annealing**
- **MCZ degrades**
- **Non conclusive data yet**

N-on-p strip sensors are sufficiently radiation-hard for the sLHC ?

Thin Sensors

- CCE comparison made between 140 μm & 300 μm thick n-in-p FZ sensors using 40 MHz analogue electronics (SCT128)
  - Leakage current measurements corrected to 1×1 cm^2 surface area and -25 C° operating temperature



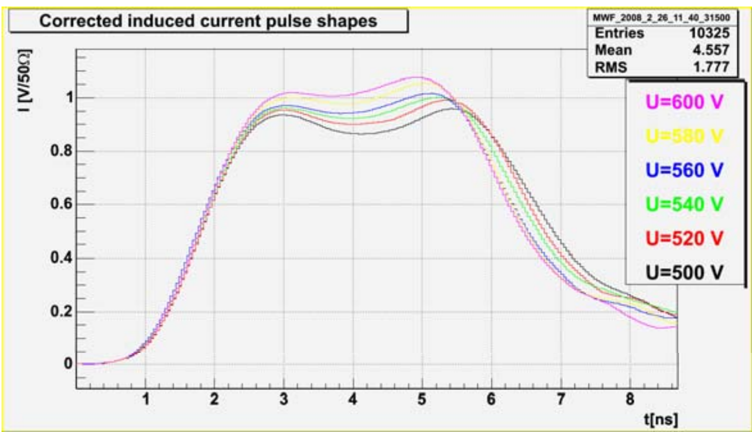
Bias current unavailable as thin sensor was breaking down above 200 V

Summary of p-type

- P-type is a mature and well proven technology!
- 1 p-type module present in the LHCb-VELO detector and the replacement is anticipated to be all p-type!
- Exhibits the required radiation hardness, adequate for most of the LHC upgrade detectors middle region (not for pixels)
- Cheaper and easier to handle than n-in-n. Single sided processing allows more manufacturer to be interested in the production.
- Big number of samples processed. Extremely good post-irradiation noise and break-down behaviours. No evidence of insufficient interstrip resistance over a large range of irradiation doses (very low doses to be explored). Both p-spray and p-stop have adequate performances.
- No charge collection improvement seen with thin sensors (140 mm)
  - At point of saturation of thin sensor’s CCE, thick sensors have 10-20% more leakage current
  - If limited to 500 V, thin sensor only have lower current up to ~3×1015 neq cm-2
- MCZ behaviour not clear: donor introduction?
- This good performance could be also used by the pixel community

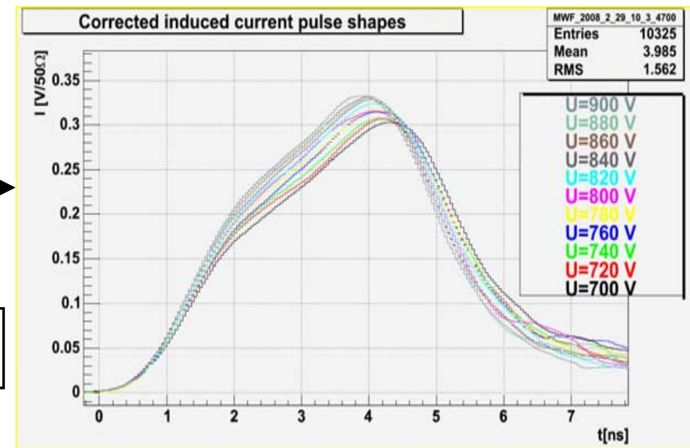
More on MZ

- SMART Collaboration (Donato Creanza) proved that “For both MCz-p and MCz-n diodes irradiation bring to the creation of a junction on the back of the device.”



1000 min.
annaling 80°C

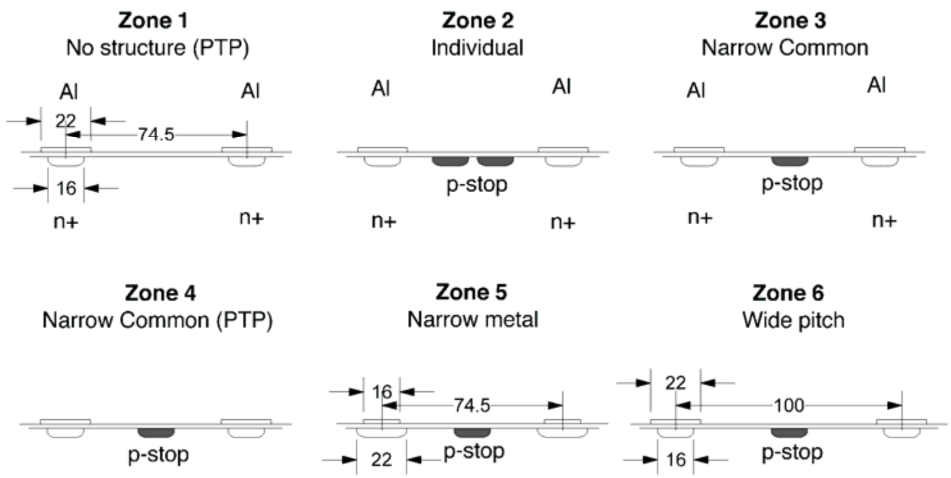
$8.80 \cdot 10^{14} n_{eq}/cm^2$



- With fluence $8.80 \cdot 10^{14} n_{eq}/cm^2$ the junction on the back is always almost equivalent in height with the one on the front.

Hamamatsu 150mm production

- Industrial production of p-type strips in 150 mm wafers started
- Y. Unno presented the results from HPK
  - 2006 p-type 6-inch (150 mm) wafer (ATLAS06)
    - FZ-1(100)(~6.7k Ωcm), FZ-2(100)(~6.2k Ωcm)
    - MCZ(100)(~2.3k Ωcm)
  - 2007 p-type 6-inch (150 mm) wafer (ATLAS07)
    - FZ-1(100)(~6.7k Ωcm), FZ-2(100)(~6.2k Ωcm)
- Many different insulation schemes
- Wafers from '06 already irradiated and results presented
- Preseries from '07 distributed



Measurement setups and simulations

- Several setups for measurement were presented
  - Using SCT128 (I. Mandic)
  - A beam telescope (P. Luuka)

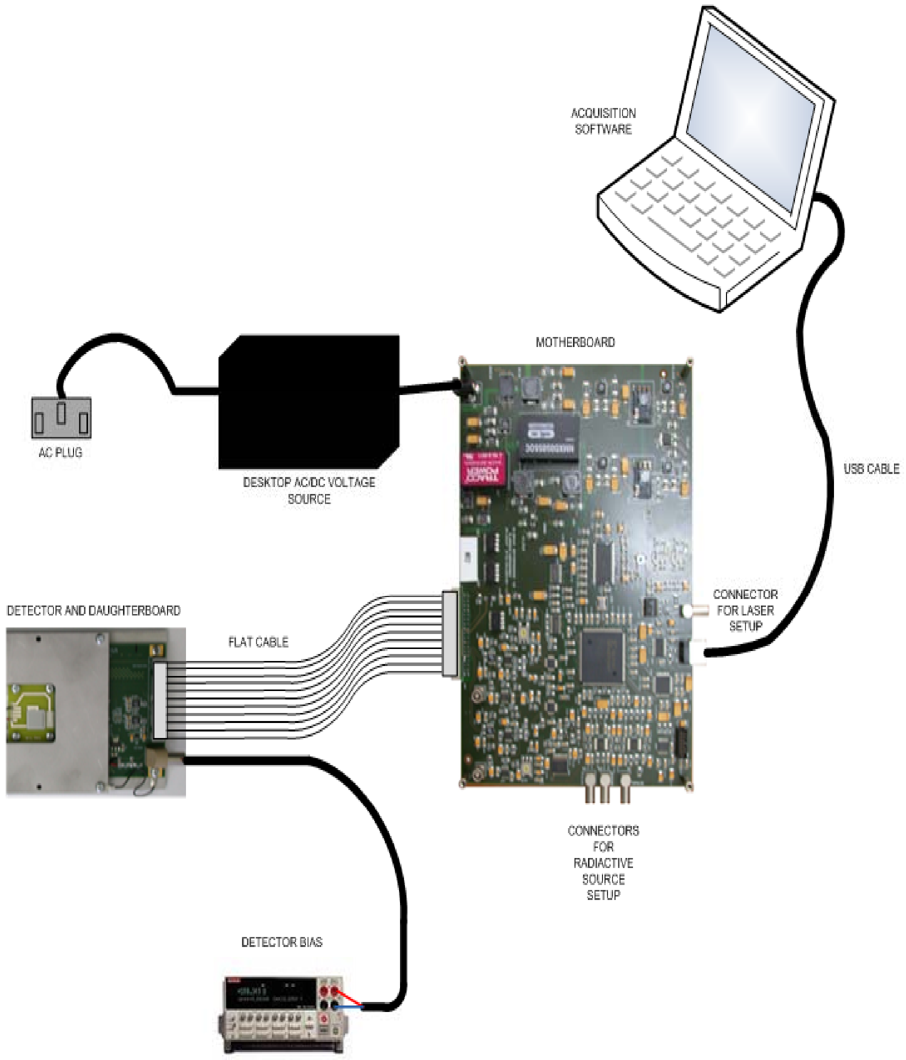
- Combined simulation using Dios/Gridgen/Tesca
  - MPI Munich groups (M. Beimforde)
  - Applied to thin detectors

Further irradiation results

- Ljubljana group (G. Kranberger, V. Cindro) presented sistematic results from irradiation with protons, neutrons, and pions
  - In mixed irradiations the damage seems to be additive (at least in FZ)
  - “effective acceptor removal” is very strong for MCz-p
  - Interms of trapping, hadrons are more damaging that neutrons
  - Trapping in p-type silicon similar to trapping in n-type

ALIBAVA System

- Alibava (A Liverpool, Barcelona, Valencia) System is ready and was presented.
- A live demonstration was organized during the Workshop
- Now ready for distribution



3D detectors

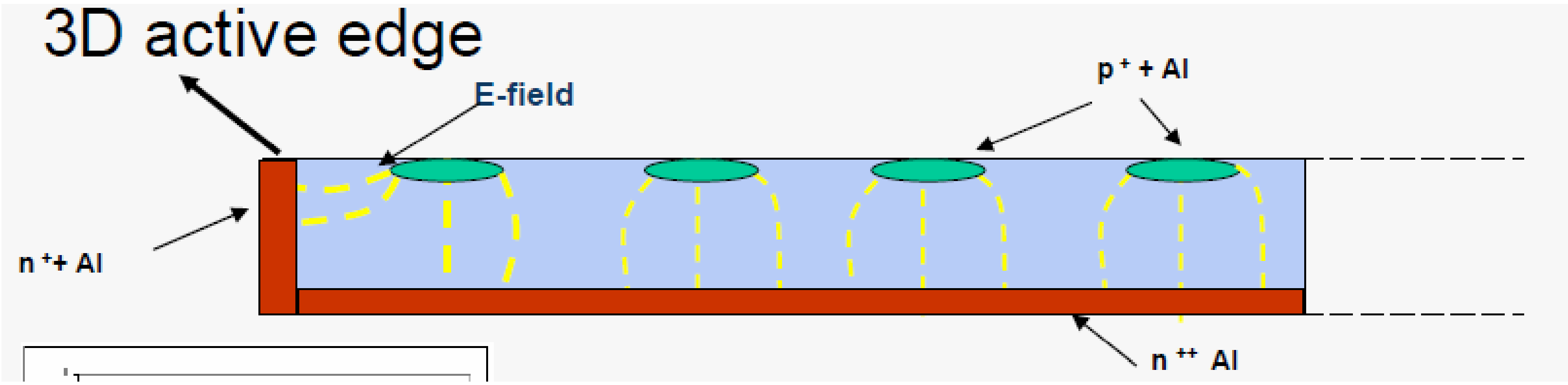
- Activity in 3D detectors is pushing up with new results from different groups
- S. Parker presented an interesting extended summary on the history and present situation of 3D detectors
- C. da Via presented a detailed talk on the potential advantages of 3D detectors for the pixel detector of ATLAS upgrade:
  - Spatial resolution
  - Timing
- Terminology:
  - SSST: Single side, single type
  - SSDT: Single side, double type
  - DSDT: Double side, double type

Fabrication activities

- Presentations of the fabrication activities and measurement at different laboratories were presented
- RD50 two institutes involved
  - CNM – no Wafer Bonding, full hole process
  - FBK – no Wafer Bonding, hole etch to come
- Stanford
  - Research lab with full capabilities
- Sintef
  - use Stanford poly filling
- IceMOS
  - Wafer Bonding, hole etching, planarization (CMP), poly process
  - Not a detector fabricator!

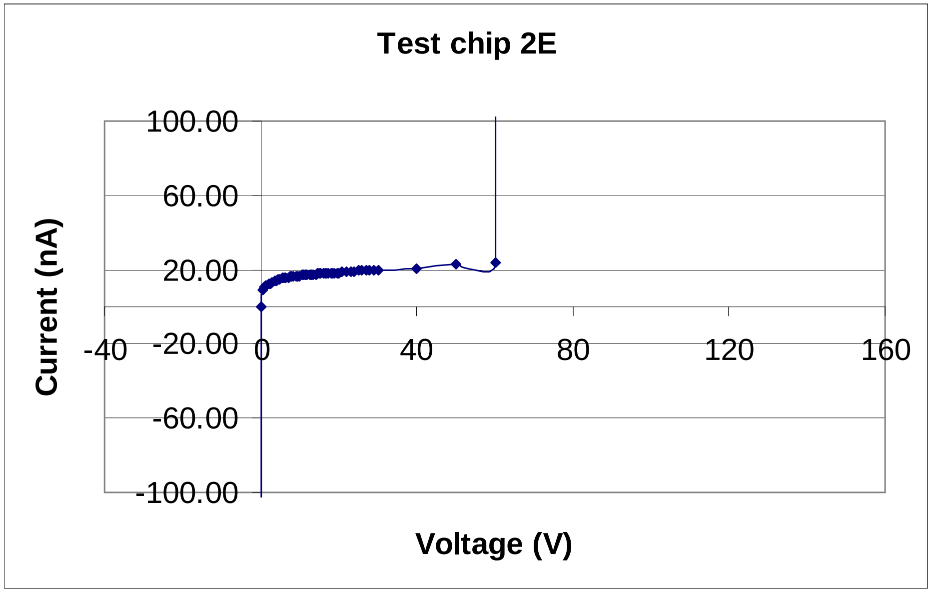
Stanford

- Stanford activity included in C. da Via talk.
- Now processing with Sintef
- They are also developing a fast readout electronics with a 0.13 µm CMOS technology
- Measured time resolution is: average 131 ps, maximum 286 ps, minimum 40 ps. (partial, very preliminary)
- Also activity in active edges



SINTEF

- A. Kok presented the activity at SINTEF, in collaboration with Stanford, Manchester and Hawaii
- First run: 25 wafers, 100mm, n-type substrate
- Limitations at SINTEF
  - Polysilicon filling and boron doping performed at Stanford
- Big difficulties:
  - Severe wafer deformation
  - Large voids on some wafers
  - Difficult to achieve a uniform resist coating on the surface
  - Etching problems
- 2 completed wafer show diode characteristic
- New RIE system: Alcatel AMS 200

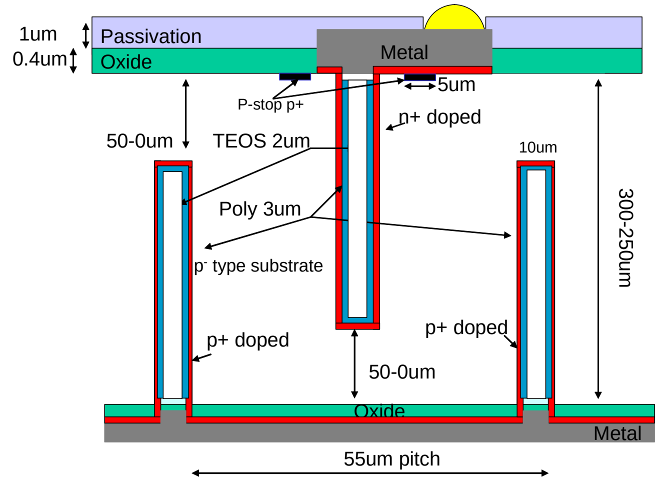


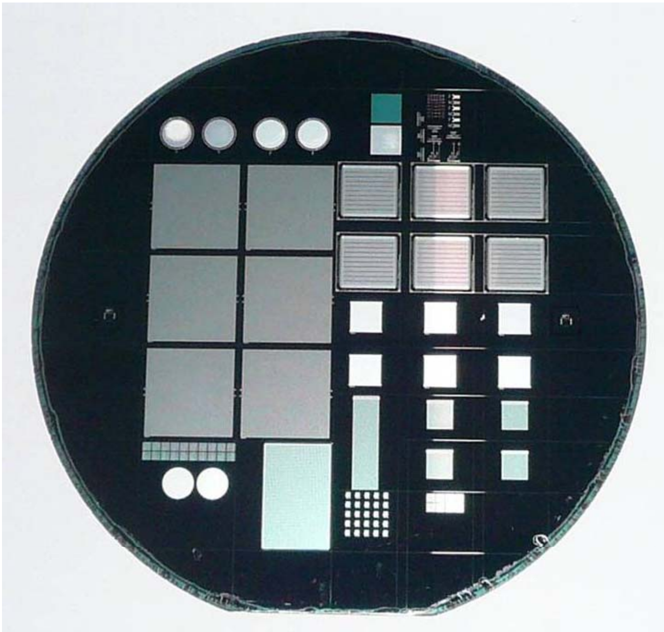
CNM

- G. Pellegrini presented new 3D devices.
- DSDT 3D technology developed at CNM
- ICP etching of the holes: Bosch process, ALCATEL 601-E
- Two types of poly filling.

- First complete run with pad, strips and pixels finished
- 3D Medipix pixel detectors bump bonded to Medipix MXR2.0 chips

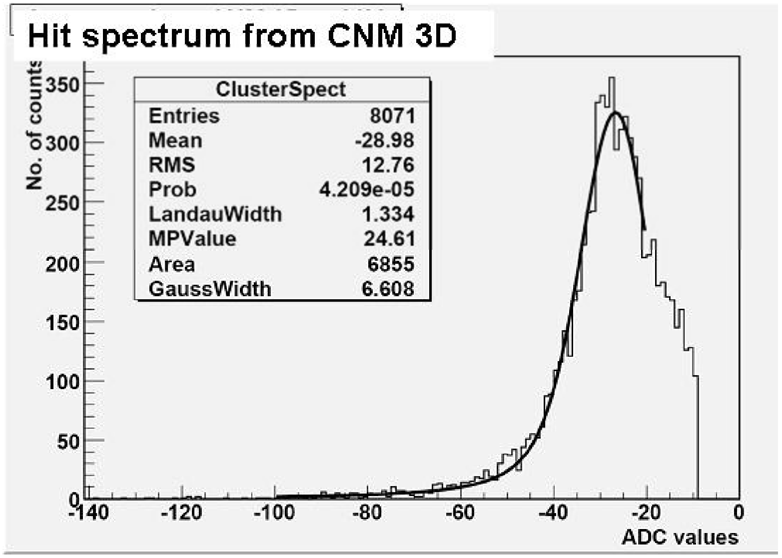
- More results will be presented by G. Pellegrini and C. Parkes in this Workshop





Glasgow measurements on CNM devices

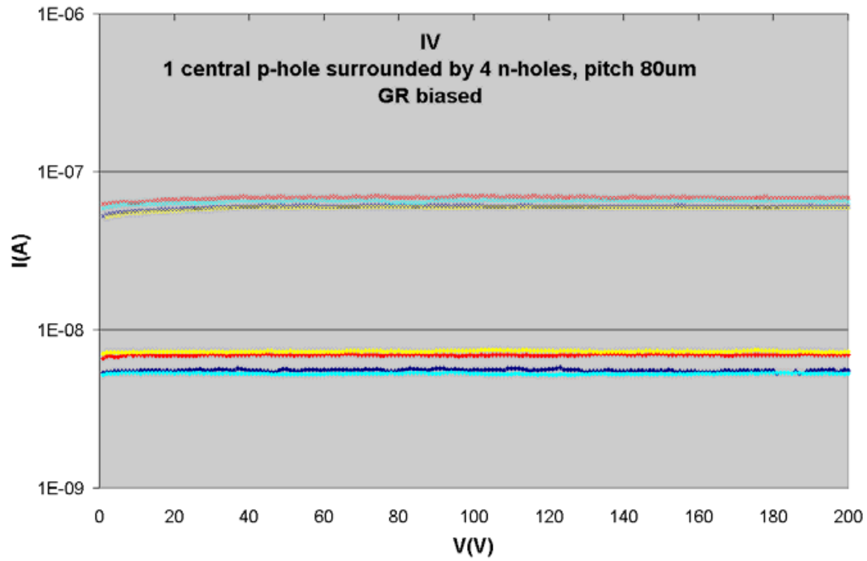
- Pad and strip detectors from CNM were irradiated with neutrons at Ljubljana nuclear reactor
- Unirradiated pad detectors show lateral depletion at 2.4 V, full depletion at 8.5 V



- 3D strip detectors before irradiation:
  - 100 pA/strip (2 pA/hole)
  - Signal/noise = 15
  - Very low charge sharing compared to planar detectors
- 3D strips after irrad (5×10^{15} neq/cm^2):
  - Difficult to test due to high leakage currents, need to re-test with cooling
  - I > 20 μA/strip
  - Not fully depleted at 40 V
- CCE tests still to do

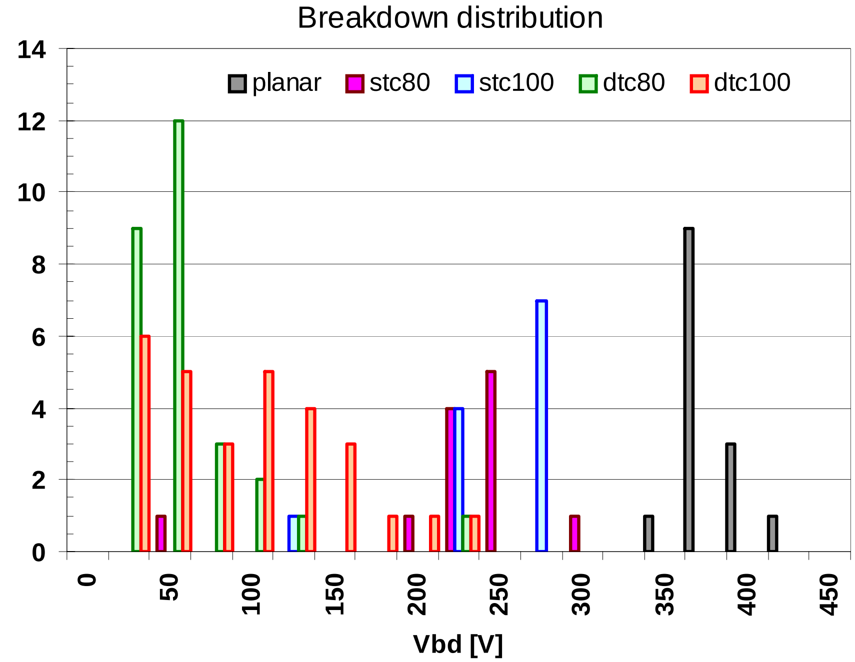
IceMOS Technology Ltd, Belfast

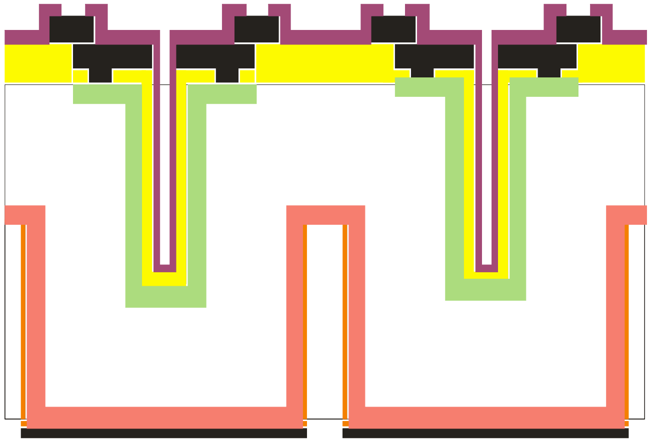
- R. Bates presented the experience of Glasgow group with a commercial manufacturer.
- Leading supplier of:
  - Thick film bonded SOI (Silicon On Insulator) wafers.
  - Trench etch and refill technology
  - Dielectrically isolated substrate preparation
- Characteristics:
  - 150 mm
  - STS Machine (Surface Technology Systems Plc)
  - B-doping outsourced
- First run SSDT.
- Over etched p-holes
  - Alignment problem
  - Excess current
- Working devices showed good results
- Next run: DSDT



FBK-IRST, Trento

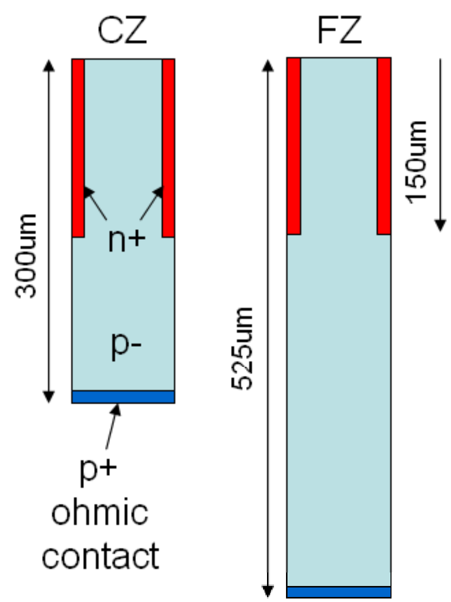
- M. Boscardini presentd current activities of FBK, and A. Zoboli results of irradiated SCST devices
- RIE AMS200 operative
- Detectors feature columns of both doping types, but the process (column depth) is not optimized
  - Double side, no hole filling
- First batch of DCDT finished
  - show early breakdown
- DCDT on p-type substrates (including ATLAS pixel layout) should be completed by the end of july

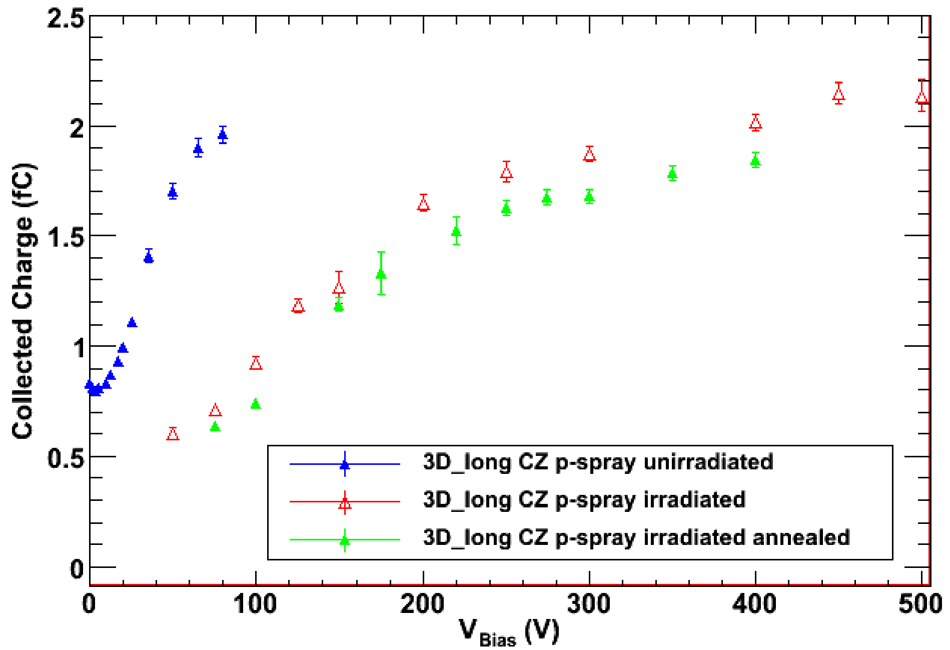




FBK-IRST, Trento

- 3D_STC after irradiation are still working
- The annealing has affected the CCE:
  - on CZ probably due to trapping of holes between columns
  - on FZ mostly because the annealing was too long and Neff has increased significantly





Other technologies for pixels

- D. Münstermann presented the activities on pixel detectors for the ATLAS upgrade.
  - Many technologies, including but not only 3D devices, under evaluation
  - Bump bonding is the main cost

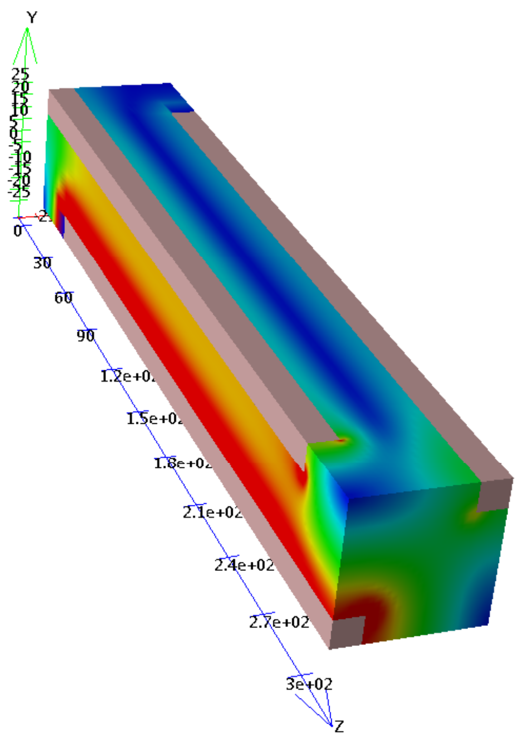
- Y. Unno presented a different alternative: SOI Monolithic Pixel Detector
  - SOIPIX collaboration
  - This is a specific "flavour" of MAPS
  - Results with OKI (Japan) SOI-CMOS 0.15 μm technology

- H.-G. Moser presented an exahustive summary of 3D technologies for interconnection.
  - Information from Ringberg Castle Conference

http://indico.mppmu.mpg.de/indico/conferenceDisplay.py?confId=184

Simulations of electric field

- S. Watts showed some calculations on weighting fields and the influence of Ramo's Theorem in detectors with high trapping (irradiated devices)
  - Using general PDE solver (FlexPDE) with modified Poisson equations.



- Z. Li showed simulations of weighting fields in 1 columns (stripixel) and two columns designs

Conclusions on 3D detectors

- Activity in 3D detectors is growing
- Fabrication facilities other than Stanford have shown the capability to produce 3D detectors.
- Different alternatives to the original Parker and Kenney design and technology shown
  - DSDT with electrodes going through the complete bulk is the best option
- SSST design seems not be good enough for sLHC
- New interesting results on DSDT 3D detectors fabricated at CNM were presented by Glasgow.
  - Results from pad and strip
  - Results from pixels in this conference