Full-3D sensors for CLIC

C. Da Viá, The University of Manchester, UK for 3DC

ISSUES TO BE ADDRESSED

❖ Speed – time stamping capabilities –

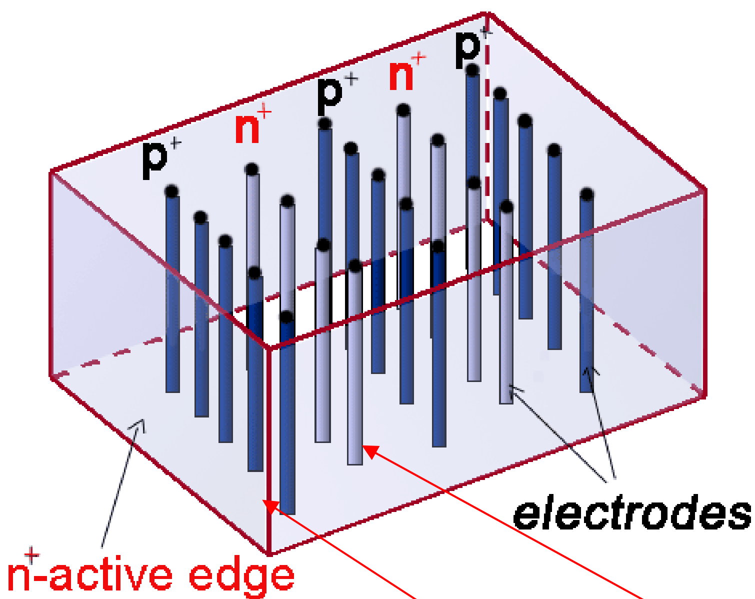
❖ Acceptance and material budget:
Active edge = optimised tracker acceptance (edge response < 4 microns) – material budget 65% of current design– thinning of FE chip

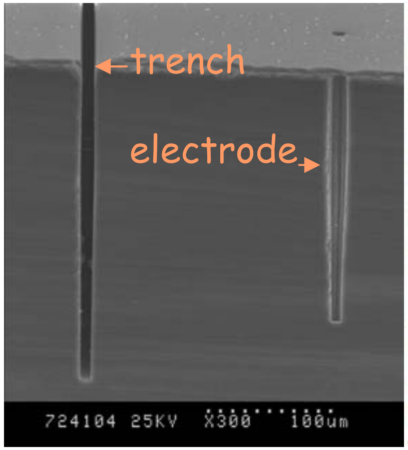
❖ Spatial resolution – test beam results and proposal for :
optimised design taking advantage of natural dual RO structure of 3D sensors

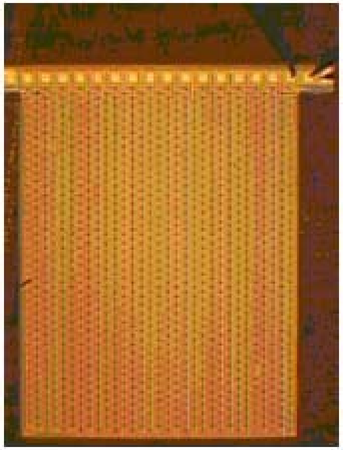
❖ Radiation tolerance – not an issue

❖ Status of development
and Present perspectives of industrial production

3D silicon sensors fabricated at Stanford by J. Hasi (Manchester) and C. Kenney (MBC)







3D silicon detectors were proposed in 1995 by S. Parker, and active edges in 1997 by C. Kenney.

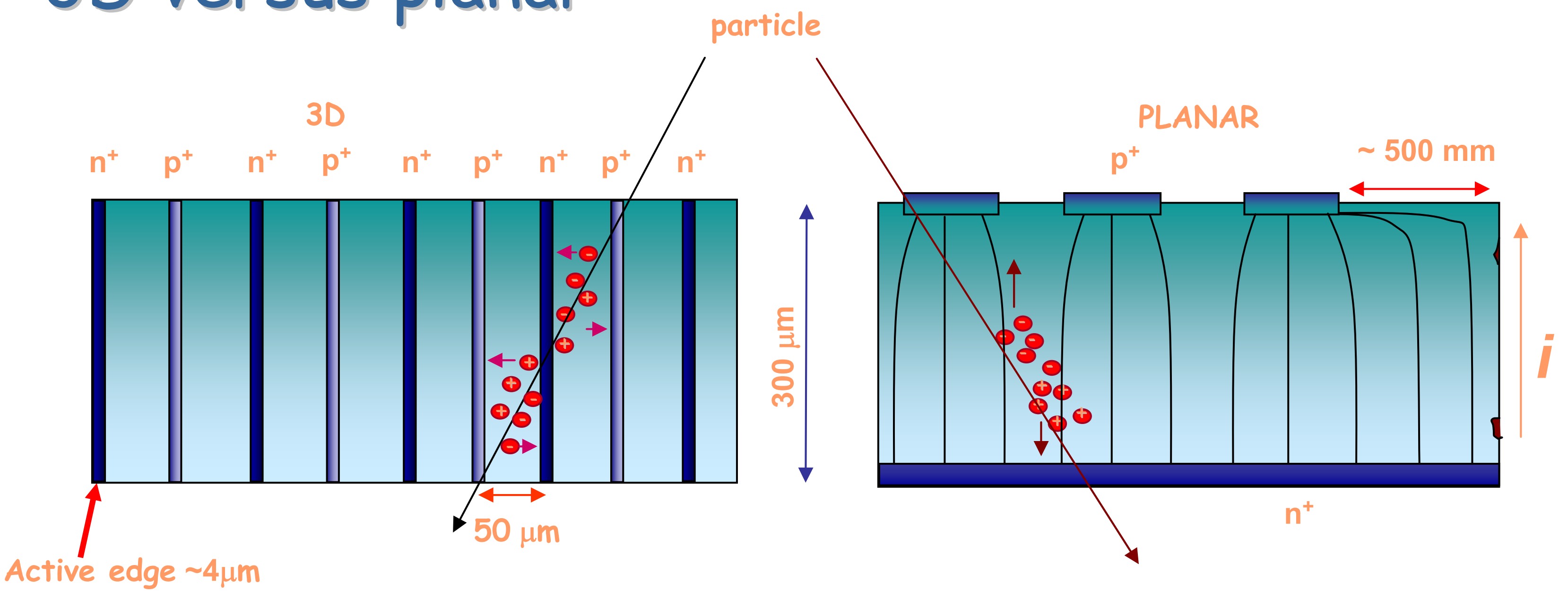
Combine traditional VLSI processing and MEMS (Micro Electro Mechanical Systems) technology.

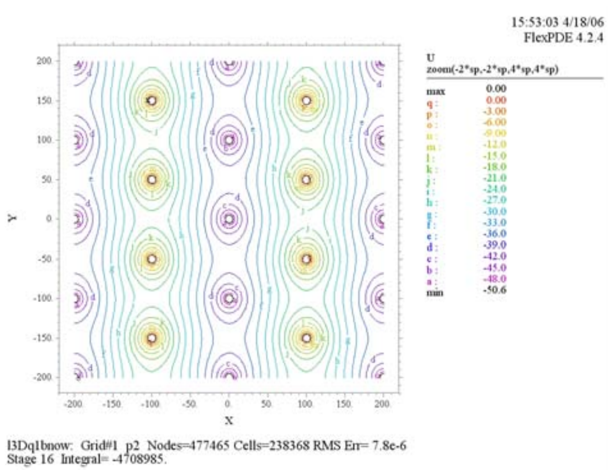
Both electrode types are processed inside the detector bulk instead of being implanted on the Wafer's surface.

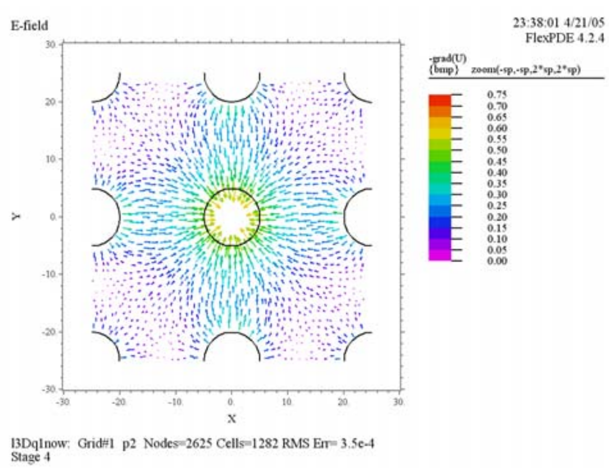
The edge is an electrode! Dead volume at the Edge < 5 microns!

1. NIMA 395 (1997) 328
2. IEEE Trans Nucl Sci 464 (1999) 1224
3. IEEE Trans Nucl Sci 482 (2001) 189
4. IEEE Trans Nucl Sci 485 (2001) 1629
5. IEEE Trans Nucl Sci 48 6 (2001) 2405
6. CERN Courier, Vol 43, Jan 2003, pp 23-26
7. NIM A 509 (2003) 86-91
8. MIMA 524 (2004) 236-244

3D versus planar







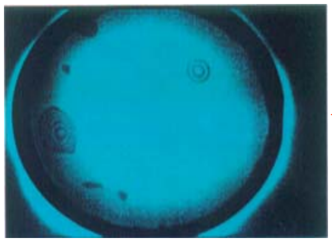
	3D	planar
V_{dep}	< 5-10 V	50-70 V
Q_{1mip}	24000e$^-$	24000e$^-$
C	40-80fF	50-200fF

Simulations using FlexPDE by S. Watts

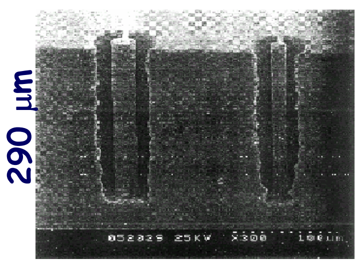
Key processing steps (25-32)

1- etching the electrode

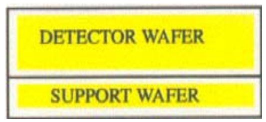
2-filling them with dopants



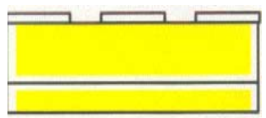
WAFER BONDING
(mechanical stability)
Si-OH + HO-Si -> Si-O-Si + H_2O



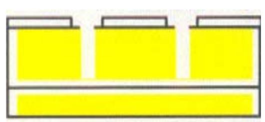
DEEP REACTIVE
ION ETCHING (STS)
(electrodes definition)
Bosh process
SiF_4 (gas) +C_4F_8 (teflon)



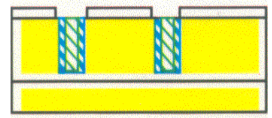
Step 1-3 field implant, oxidize and fusion bond wafer



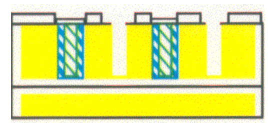
Step 4-6 pattern and etch p^+ window contacts



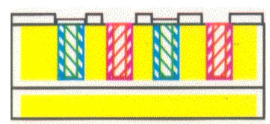
Step 7-8 etch p^+ electrodes



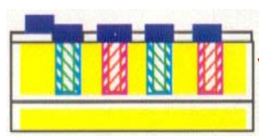
Step 9-13 dope and fill n+ electrodes



Step 14-17 etch n^+ window contacts and electrodes

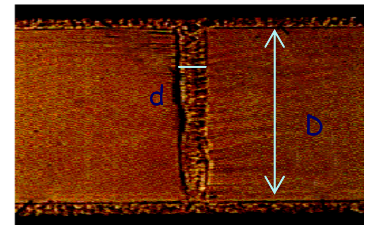


Step 18-23 dope and fill p+ electrodes



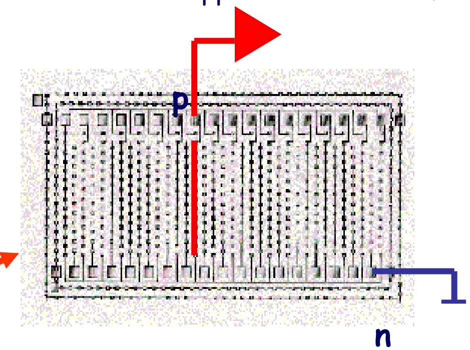
Step 24-25 deposit and pattern Aluminum

Aspect ratio: D:d = 11:1



LOW PRESSURE
CHEMICAL VAPOR
DEPOSITION
(Electrodes filling with
conformal doped polysilicon
SiH4 at ~620C)
$2P_2O_5$ +5 Si-> 4P + 5 SiO_2
$2B_2O_3$ +3Si -> 4 B +3 SiO_2

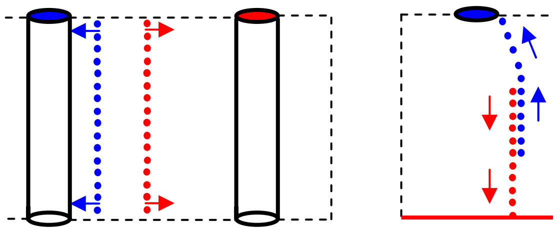
Both electrodes appear on both surfaces



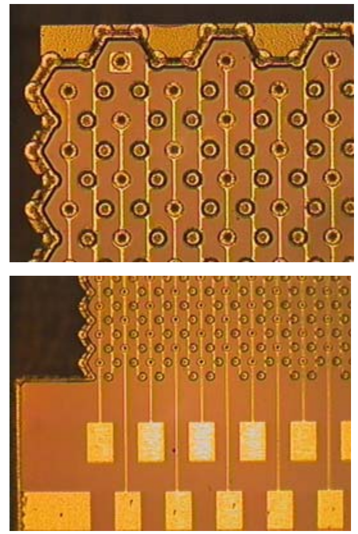
METAL DEPOSITION
Shorting electrodes of the same type
with Al for strip electronics readout
or deposit metal for bump-bonding

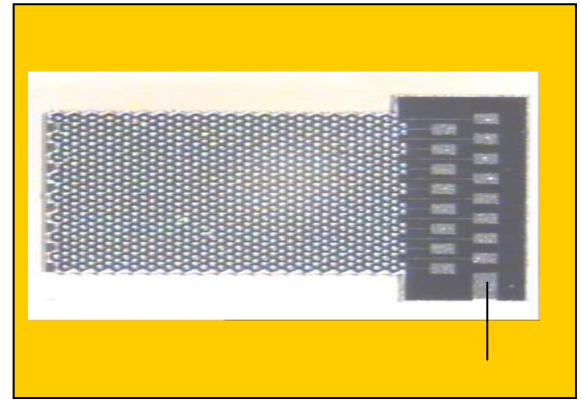
Full-3D sensor speed

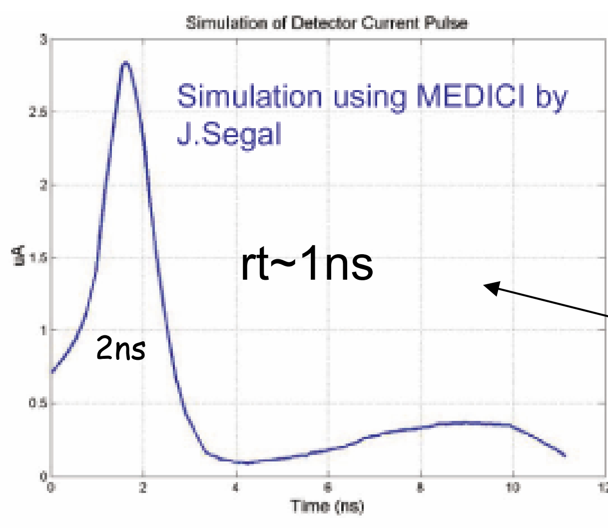
3D Tests with 0.13 μm CMOS Amplifier chip
(A Kok, S. Parker, C. Da Viá, P. Jarron, M. Depeisse, G. Anelli), fabricated at Stanford By J. Hasi, C. Kenney



- ❖Short collection distance
- ❖High average e-field at low V_{bias}
- ❖Parallel charge collection

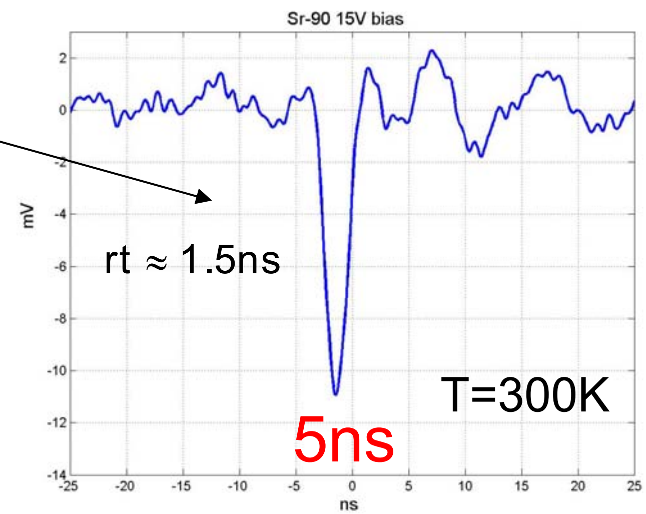






Raw oscilloscope trace

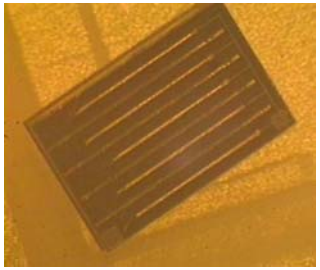
3D signal simulation



3D Inter-electro spacing = 50 μm

Preliminary analysis of the time resolution at room temperature

S. Parker



.20 pulses from the the hex sensor

•a preliminary version of a 0.13 μm integrated circuit readout

•using data from un-collimated 90-Sr βs

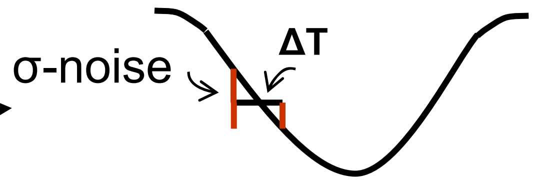
•(A wall-electrode with parallel plates would give shorter times, but the hex sensor already has the same output rise time as a 0.8 ns input rise time pulse generator, so the output shape is primarily determined by the amplifier, not the sensor).

•To simulate a constant fraction discriminator set at 50% (where slope is steepest):

•Fit leading baseline, and measure noise,

•Fit top and find halfway point,

•ΔT = σ-noise / slope



•With wall-electrode sensor and a parallel beam, might do better fitting entire pulse.

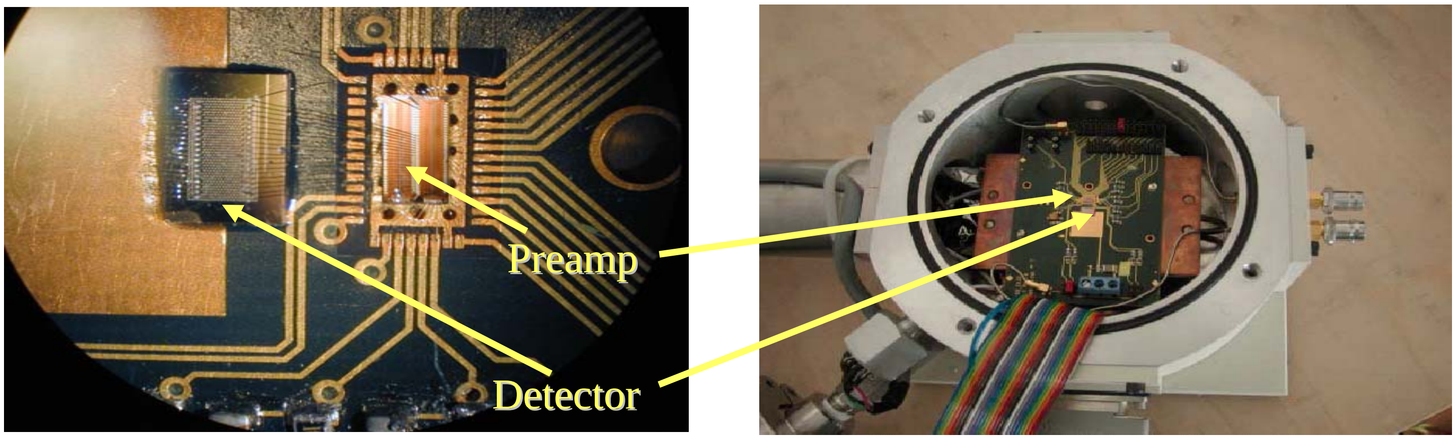
The measured **ΔT** values for first 20 pulses (other than two channel cases): **average 131 ps, maximum 286 ps, minimum 40 ps**. (partial, very preliminary)

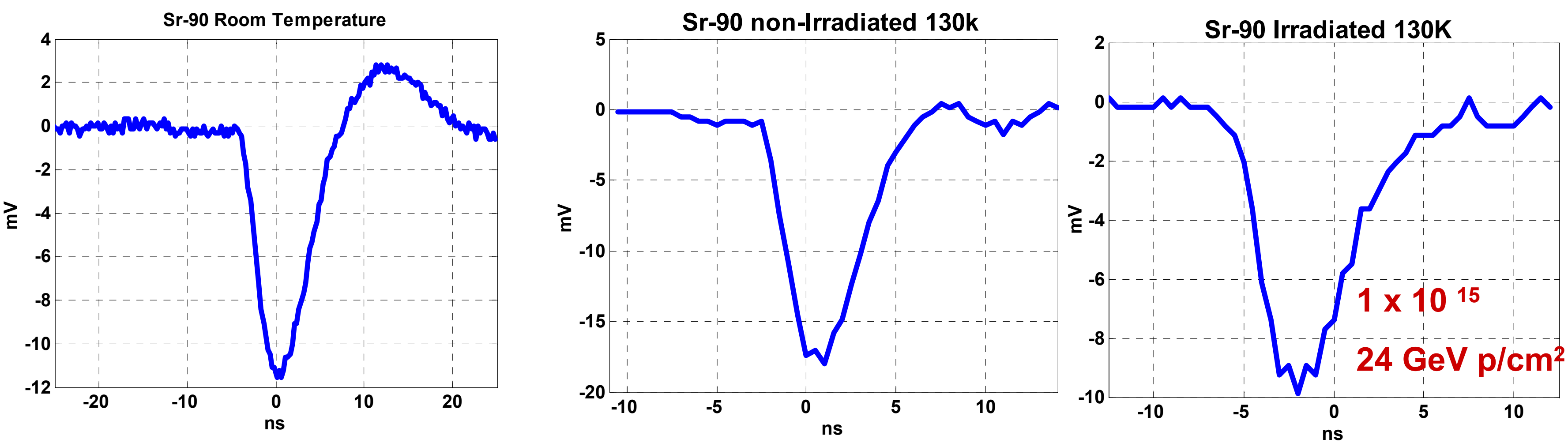
If random, 9 layers would give **44, 95, and 13.3 ps**. But watch out for beam pipe fields!

And unexpected systematic errors should be expected.

3D – Time Response Using 0.25 μm CMOS amplifier

(P. Jarron, G. Anelli, A. Kok, C. Da Via, in A. Kok thesis)





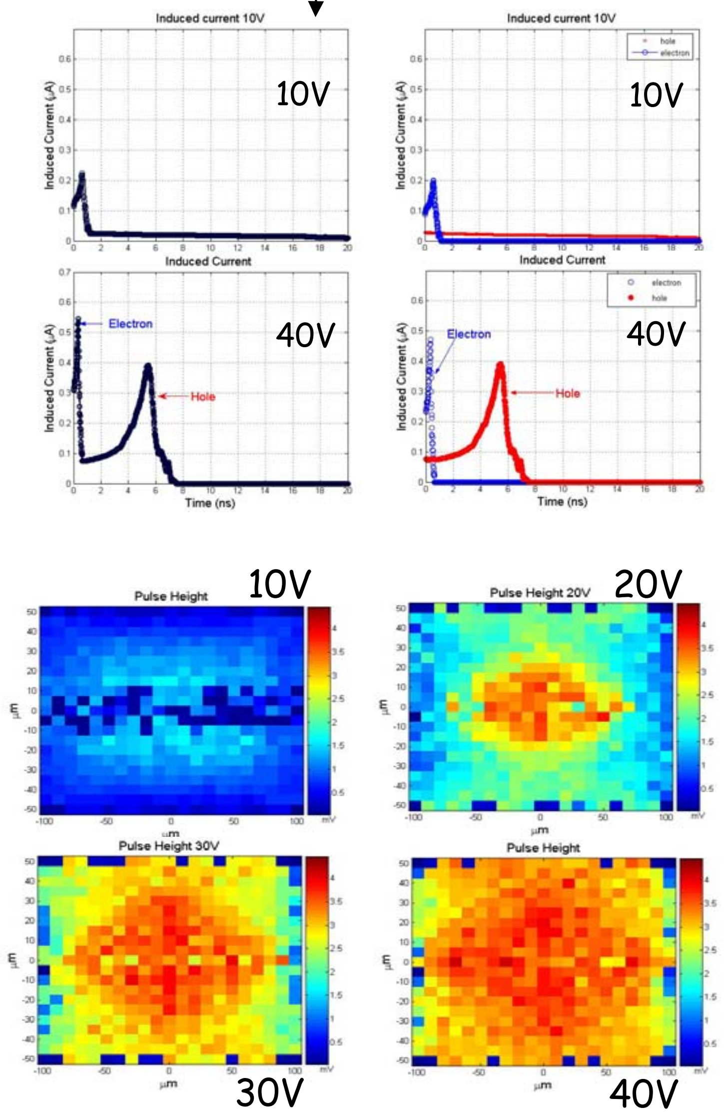
300K, RT=3.5ns
Amplifier limit

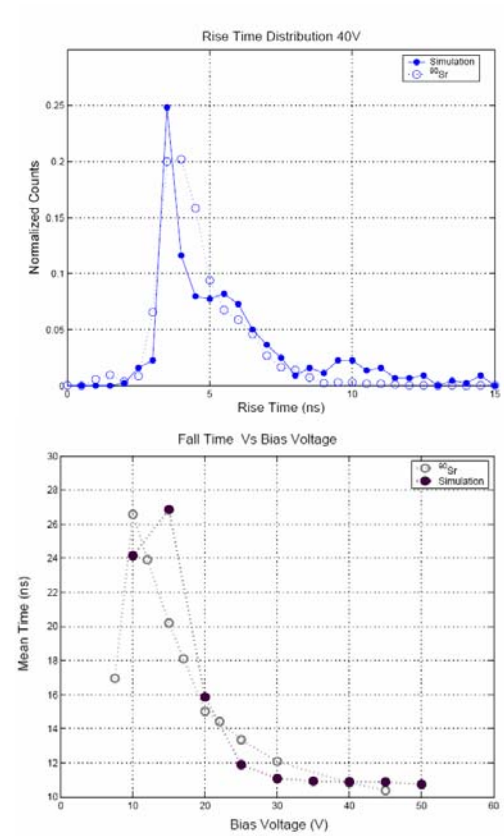
130K, RT=1.5ns

130K, RT 1.5ns
After irradiation

3D signal modelling and data fit using a 0.25μm FE chip (Jarron, Anelli, Cern MIC)

A. Kok PhD Thesis





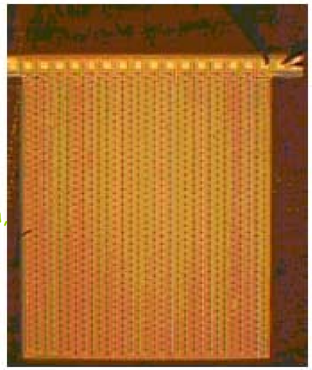
Simulation of signals rise and fall time distributions over a cell (full dot) and ^{90}Sr data (open dot)

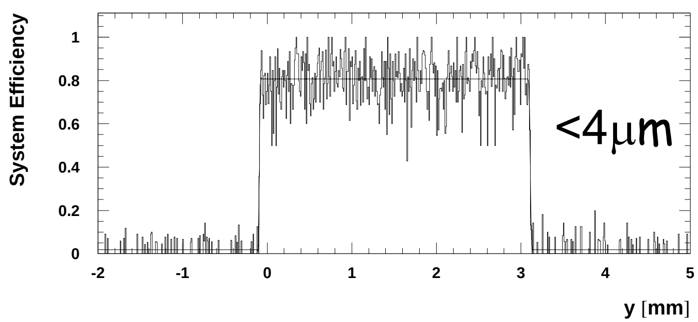
3D silicon- Material budget and active edges

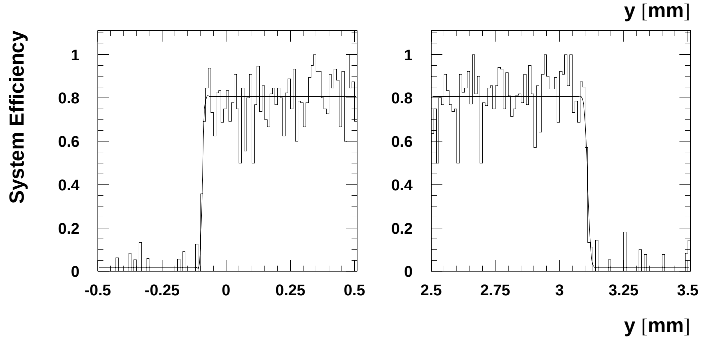
processed at Stanford by J Hasi, Manchester, C. Kenney, MBC

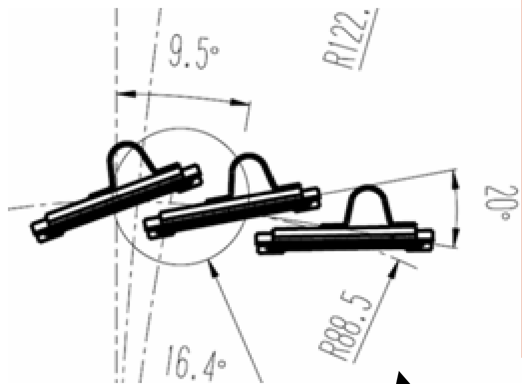
Cinzia Da Viá - Clic Workshop, CERN 17 October 2007

Measurements taken
In 2003 with 120 GeV
Muons
C. Da Vià*, M. Deile*, J. Hasi, A. Kok, C. Kenney, Sherwood Parker*, S. Watts, V. Avati, VB assetti, V. Boccone, M. Bozzo, K. Eggert, F. Ferro, A.Inyakin, P. Jarron, J. Kaplon, J.J. Lozano-Bahilo, A. Morelli, H. Niewiadomski, E. Noschis, F. Oljemark, M. Oriunno, K. Österberg, G. Ruggiero, W. Snoeys, S. Tapprogge.



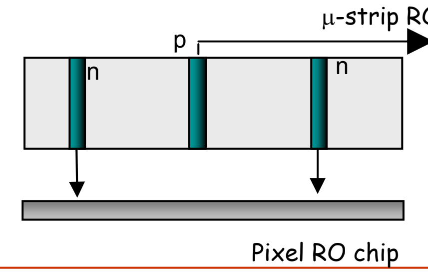






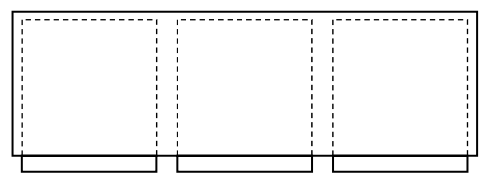
From M. Garcia-Scievers talk Presented at the ID ATLAS Upgrade Workshop. Liverpool 6-8 December 06

Improve the spatial resolution with reduced Material budget: dual RO – C. DaViá et al. Will be explored in our next R&D run

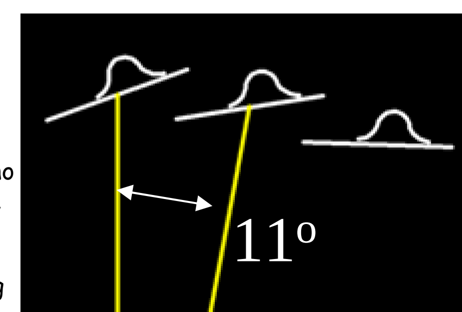


Active edges only would reduce the effective Si thickness by 65%!!!

Effective Si thickness	**680 μm**	**515μm**



Module looks the same, but there is no dead margin on the sensor perimeter, allowing less overlap.
Still 2 pixel radial overlap in phi.
This could be a good baseline starting point. M. Garcia-Scievers

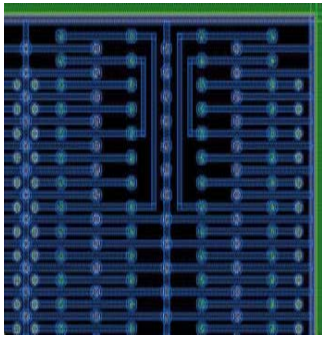


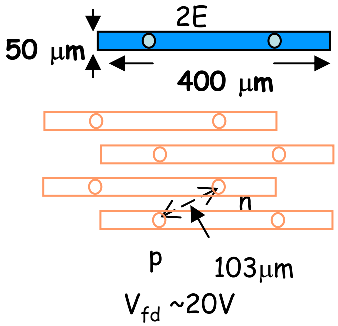
3D electrode configurations

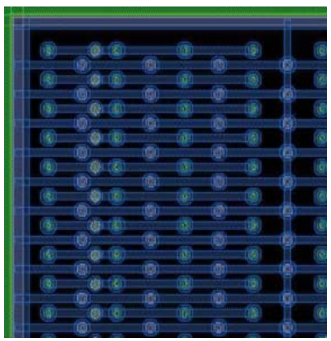
Financial support:
STFC-UK for the FP420 project
DOE, USA for ATLAS Upgrade

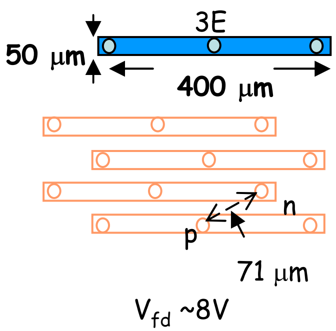
Design and fabrication by:
J. Hasi, Manchester
C. Kenney, MBC at CIS-Stanford

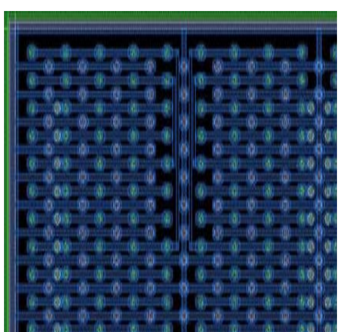
Thickness <250 μm>
p-type substrate 12kΩcm

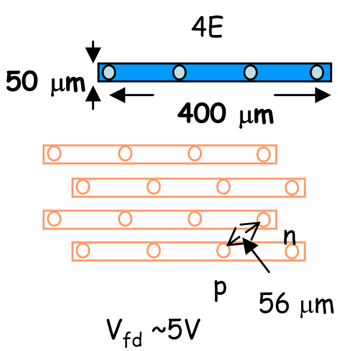


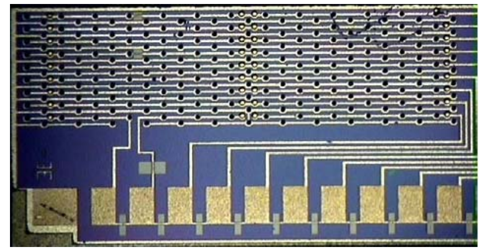


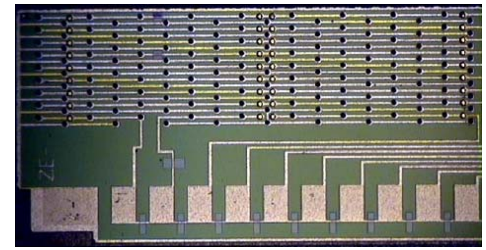


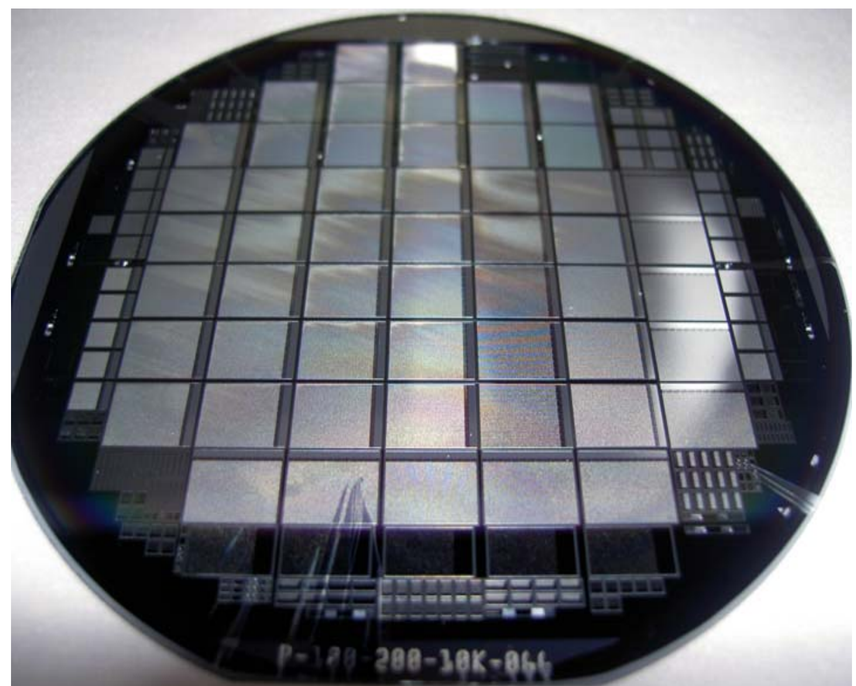







Baby-2E

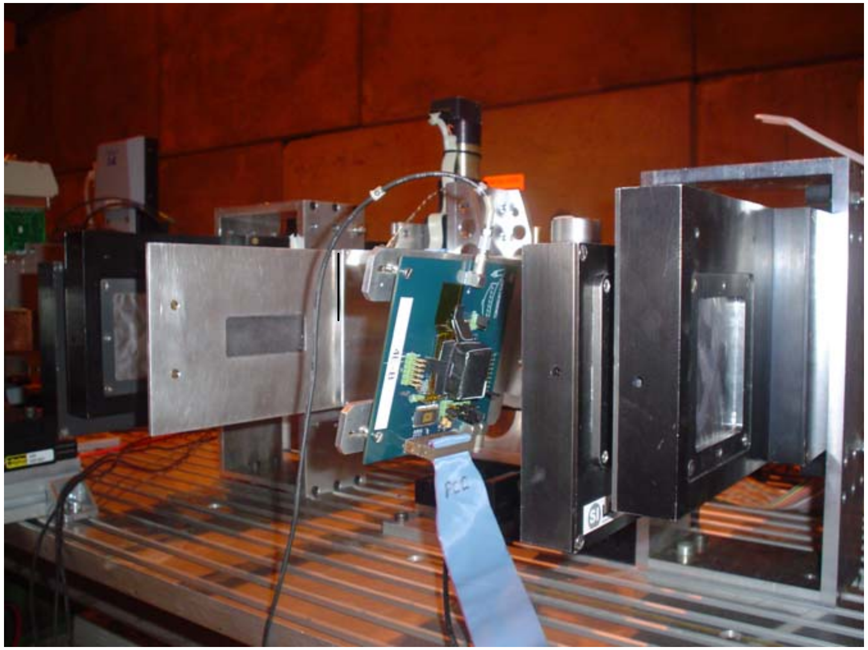

Baby-3E

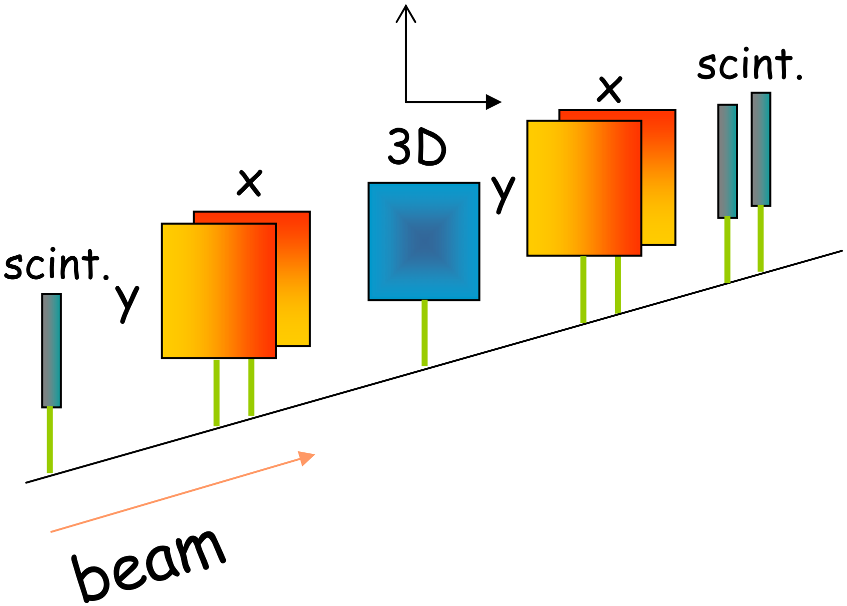


10 wafers competed. Yield~80% (1 wafer)

Aug. 17 Sept. 3, 2006
H8 Cern beam line

M. Mathes1, C. DaVia2, J. Hasi2, S. Parker3, M. Ruspa4, L. Reuen1, J. Velthuis1, S. Watts2, M. Cristinziani1, K. Einsweiler4, M. Gracia-Sciveres4,K. Kenney5, N. Wermes1
1Bonn, Germany
2Manchester University, UK
3University of Hawaii, USA
4LBL, Berkeley, USA
5Molecular Biology Consortium, Stanford, USA



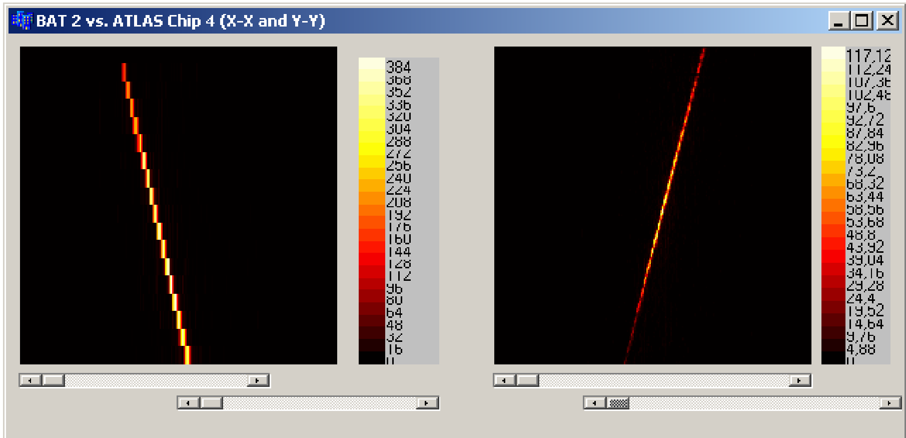


Telescope, daq and on-line monitor by Lars Reuen, Atlas pixel setup and data conversion Markus Mathes (Bonn group)

100 GeV π^-
Triggers: 3x3 mm^2 , 12x12 mm^2

3E-G correlation plots, hit maps and residuals

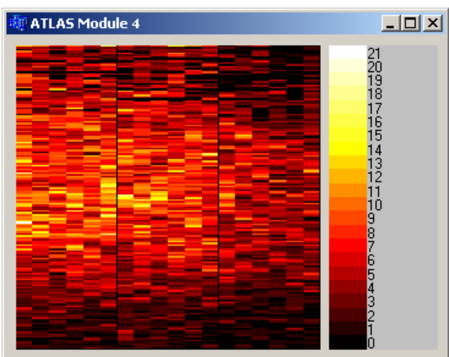
X-X



Y-Y

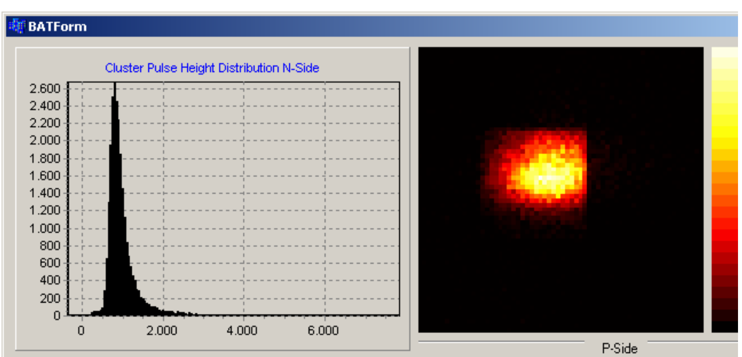
V_{bias} =15V

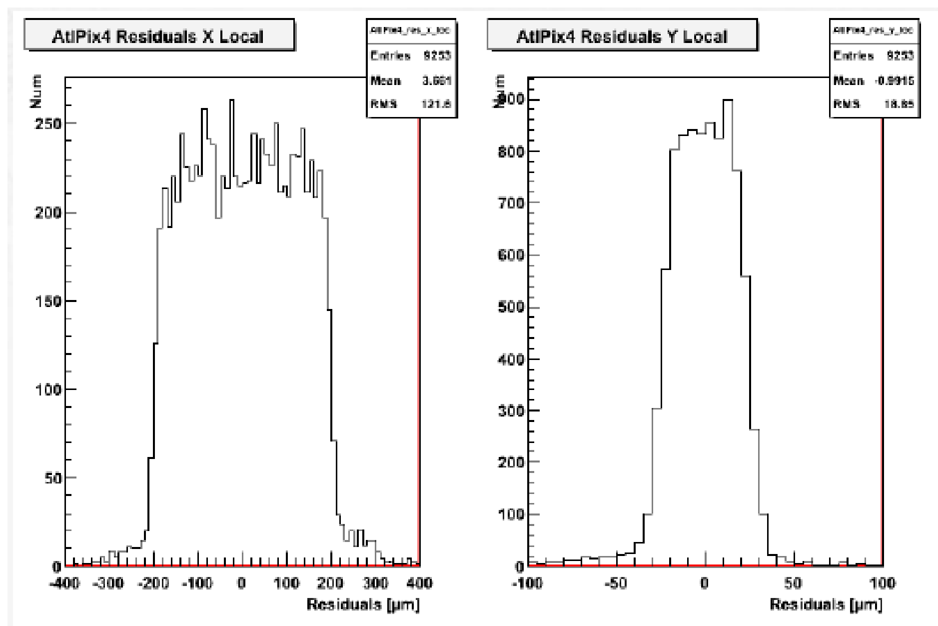
Th. = 4000e^-



3D

Telescope

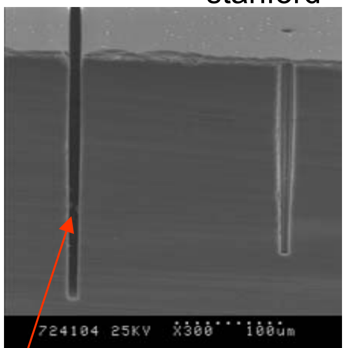




Thickness and electrodes response

Aspect ratio D/d 19:1 , already 21:1 with Alcatel etcher
Etching time ~ 5μm/min

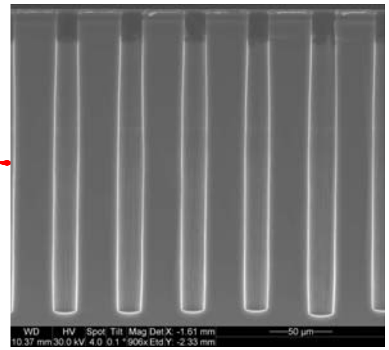
stanford

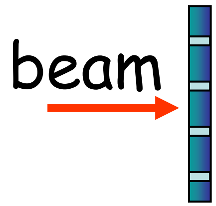


trench

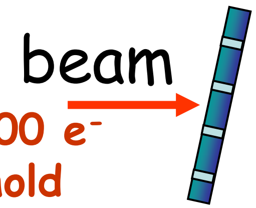
250 μm

sintef

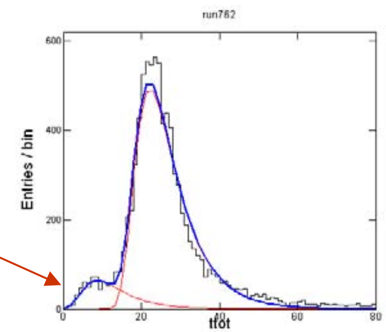




4E 4000 e⁻ threshold

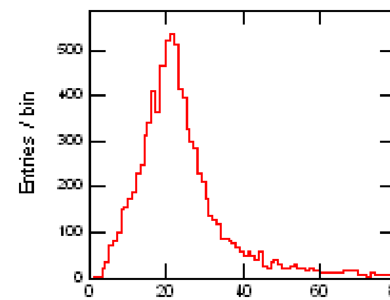


Could be used for alignment

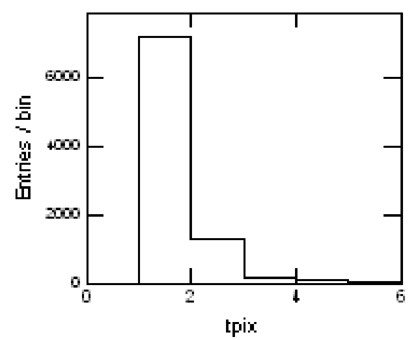


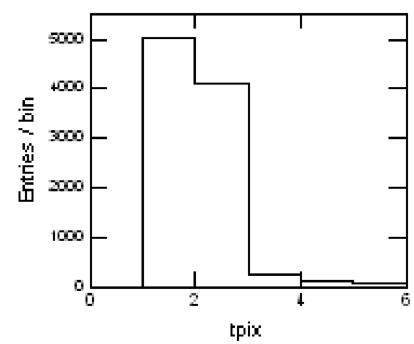
run762 zero degrees

run824 10 degrees

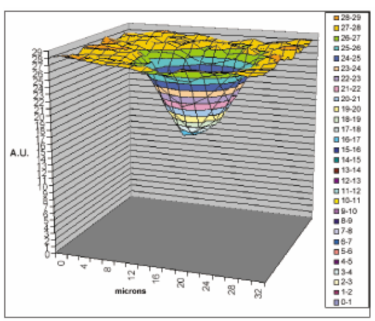


run824 10 degrees



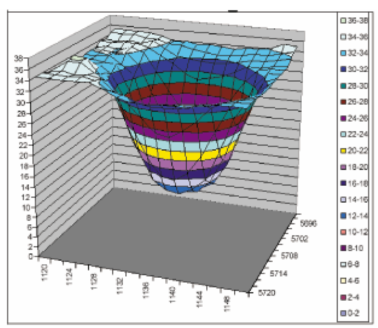


J. Hasi PhD Thesis - 2004



N – Electrode

Signal Reduction 43%



P – Electrode

Signal Reduction 66%

Differences between N and P:

Grain size of poly, Diameter, Diffusion rate, Trapping, Doping

M. Mathes1, C. DaVia2, J. Hasi2, S. Parker3, M. Ruspa4, L. Reuen1, J. Velthuis1, S. Watts2, M. Cristinziani1, K. Einsweiler4, M. Gracia-Sciveres4, K. Kenney5, N. Wermes1

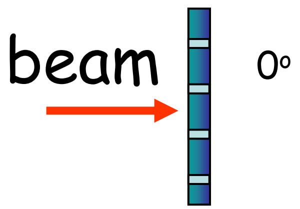
Tracking efficiency - 2006 test beam

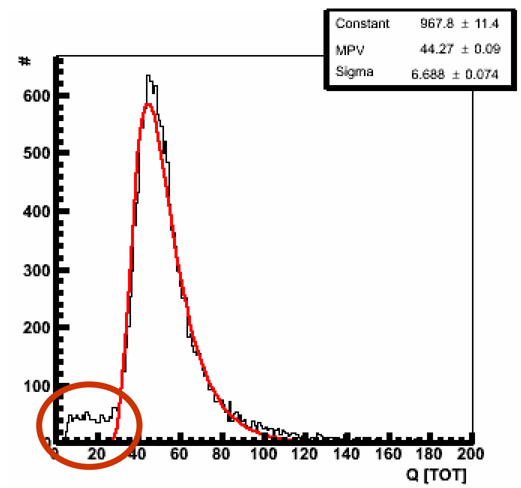
bump-bonding at IZM (Bonn)- not problematic

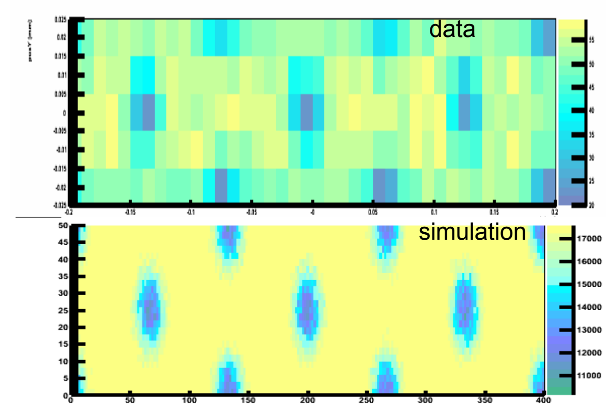
M. Mathes1, C. DaVia2, J. Hasi2, S. Parker3, M. Ruspa4, L. Reuen1, J. Velthuis1, S. Watts2, M. Cristinziani1, K. Einsweiler4, M. Gracia-Sciveres4, K. Kenney5, N. Wermes1
1Bonn, Germany
2Manchester University, UK
3University of Hawaii, USA
4LBL, Berkeley, USA
5Molecular Biology Consortium, Stanford, USA

3E 3200 e^- threshold

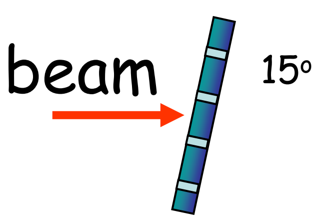
Data analyisis and silulation by M. Mathes, M. Cristinziani (Bonn)
S. Watts (Manchster)

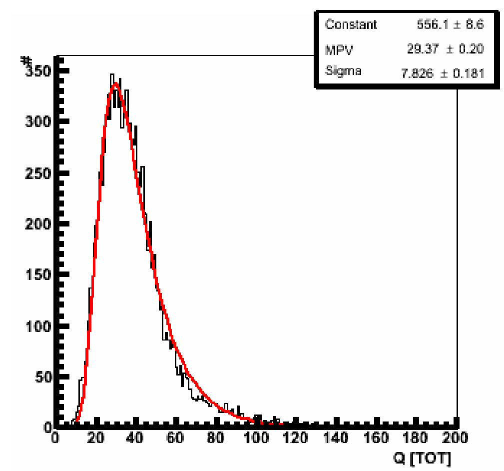


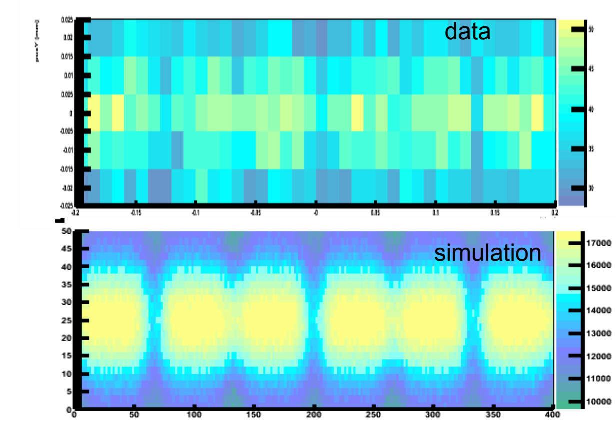




ε = (95.9 ± 0.1) %



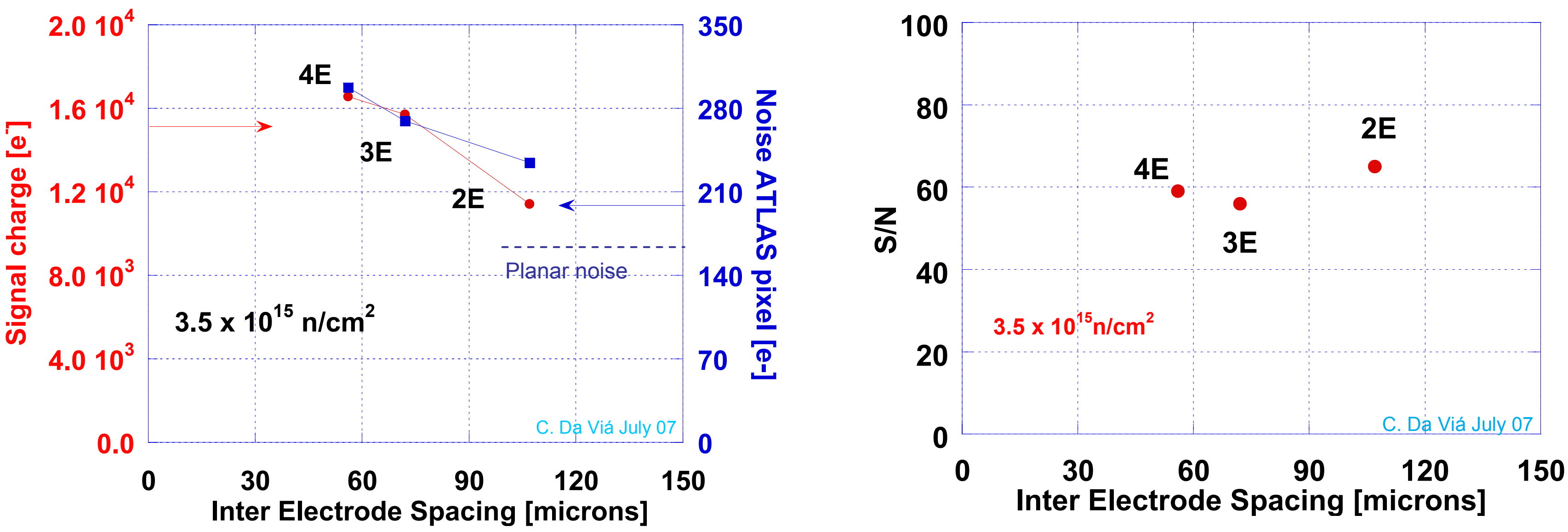




ε = (99.6 ± 0.1) %

Estimated S/N at 3.5×10^{15} n/cm^2

Noise measured on non-irradiated bump-bonded full size FE-I3-ATLAS chips



Noise measurements performed at CERN by E. Bolle and O. Rohne (Oslo)
Help from K. Einweiler, M. Garcia-Sciveres (LBL)

Status of development and present perspectives For industrial production

- Stanford produced its 5th generation of full 3D with active edges
- For CLIC R&D run needed to improve:
    - electrode response,
    - dual readout,
    - speed layout
- Stanford technology transferred to SINTEF, Norway. First run completed by end of 2007
- Other Industries have 3D technology capabilities: CNM/Spain, ICEMos/Ireland, IRST/Italy. Prototypes with double columns by end 2007
- FP420 project has full 3D with active edges as baseline technology.
- ATLAS Upgrade project on 3D sensors approved