3D ACTIVE EDGE SILICON SENSORS TEST RESULTS

3Dc

Cinzia Da Via', Brunel University UK

FP420 Collaboration

OUTLINE

- ❖Requirements for tracking detectors beyond LHC
- ❖3D silicon technology at Stanford
- ❖Present results
- ❖Conclusions and Future plans

C. Kenney (MBC), L. Reuen, R. Kohrs, M. Mathes, J Velthuis, N. Wermes (Bonn Univ.) J. Hasi, A. Kok, S. Watts (Brunel U.K.) S. Parker (U. of Hawaii) G. Anelli, M. Deile, P. Jarron, J. Kaplon, J. Lozano and the TOTEM Collaboration (CERN), V. Bassetti (Genova), M. Garcia-Scievert, K. Einsweiler (LBL), V. Linhart, T. Slavicheck, T Horadzof, S. Pospisil (Technical University, Praha), M. Ruspa (Torino).

Special thanks to Harris Kagan for a life saving bbq at his place on a Sunday (when all the restaurants are closed) during the test beam.

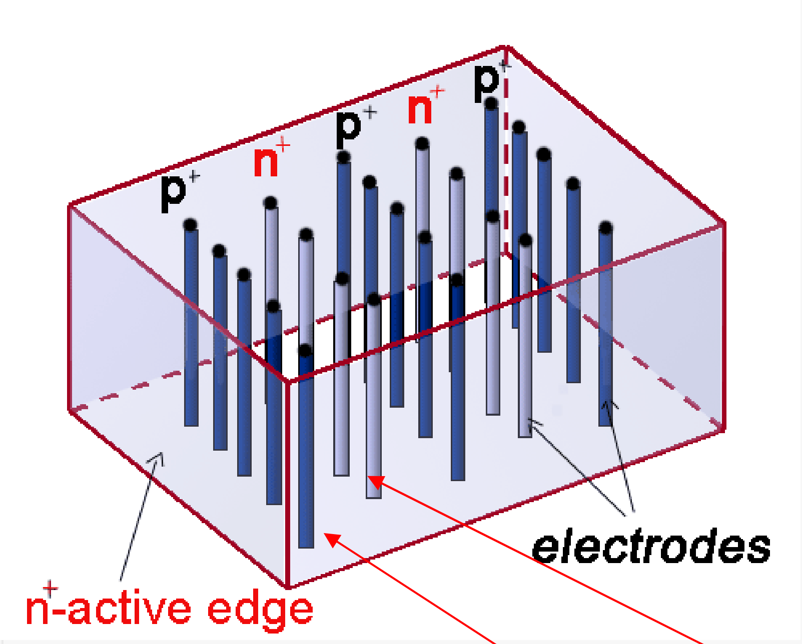
Requirements tracking detectors beyond LHC

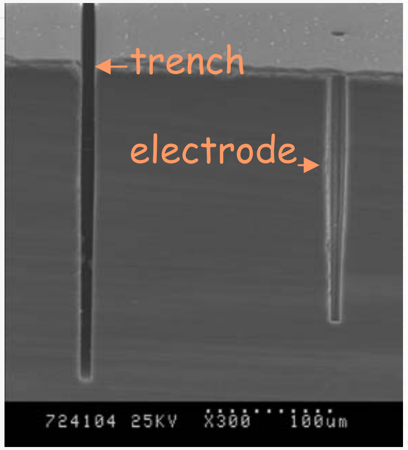
- Speed
  - Reduced bunch crossing, Linear colliders, Rare decay measurements
- Reduced dead edge
  - Material Budget, Forward physics (Totem, FP420), Medical and biological imaging
- Efficiency
- Radiation hardness
  - SLHC, B-Layers, Forward physics
- High Yield + Large Area

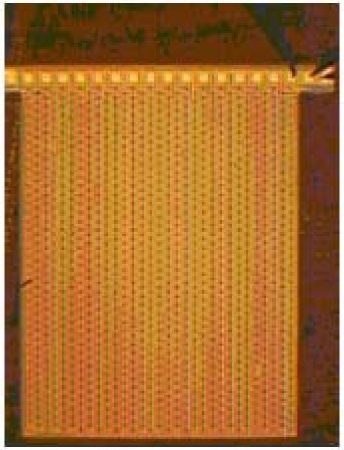
If FZ-silicon is the chosen material then one has to consider alternative sensors geometries: 3D is one of them.

3Dc

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







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

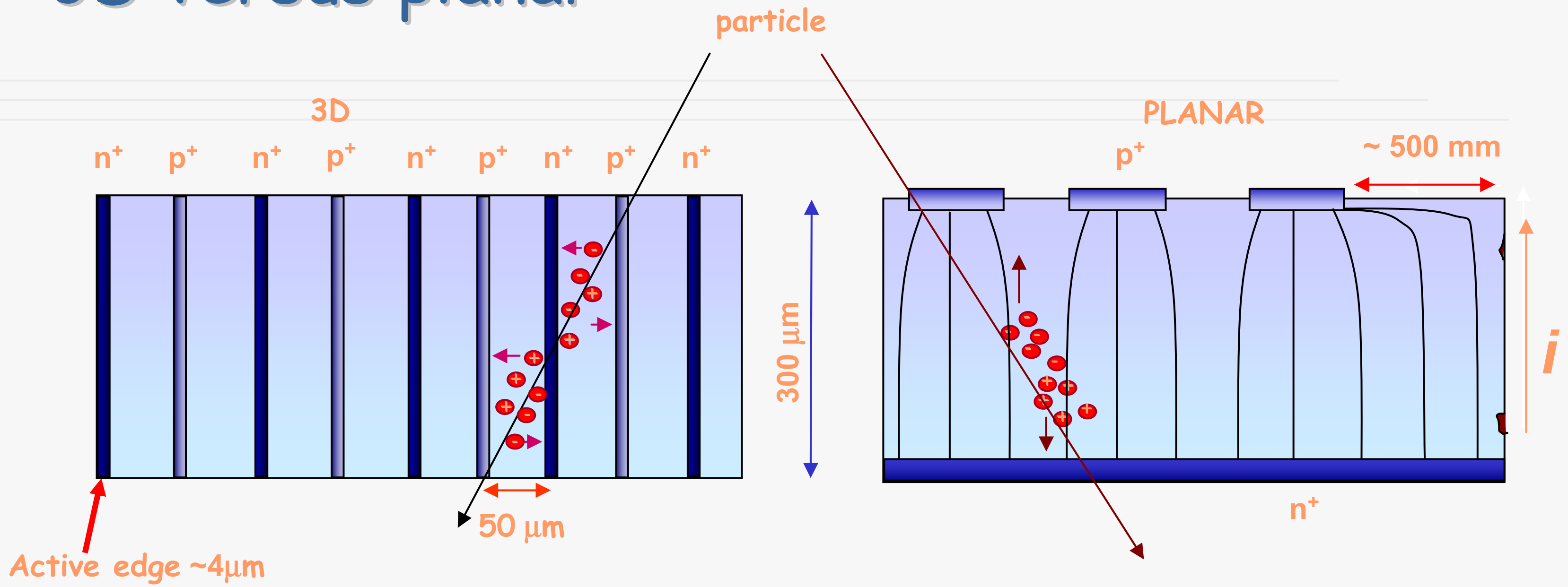
3D silicon detectors were proposed in 1995 by S. Parker, and active edges in 1997 by C. Kenney.

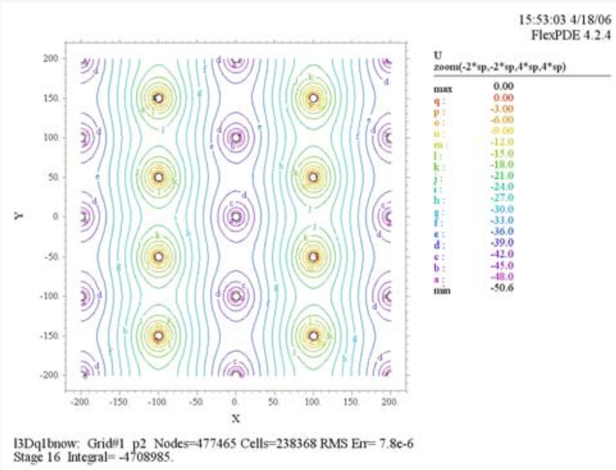
Combine traditional VLSI processing and MEMS (Micro Electro Mechanical Systems) technology.

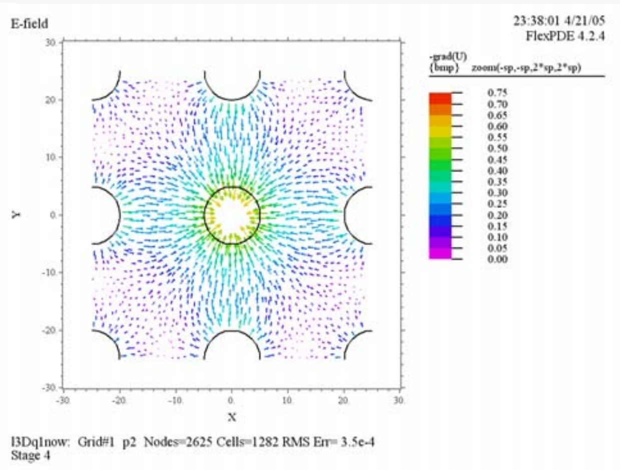
Both electrode types are processed inside the detector bulk instead of being implanted on the Wafer's surface.

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

3D versus planar







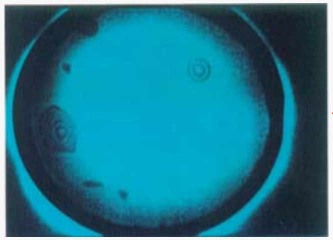
	3D	planar
V_{dep}	< 5-10 V	50-70 V
Q_{1mip}	24000e⁻	24000e⁻
C	40-80fF	50-200fF

Simulations using FlexPDE by S. Watts

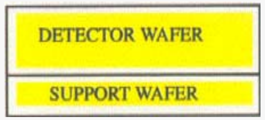
Key processing steps (25-32)

1- etching the electrode

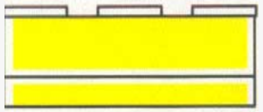
2-filling them with dopants



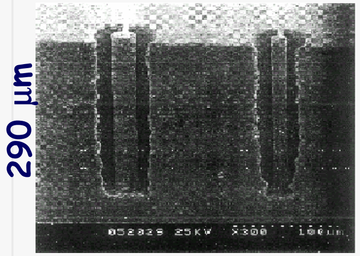
WAFER BONDING
(mechanical stability)
Si-OH + HO-Si -> Si-O-Si + H_2O



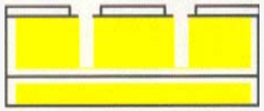
Step 1-3 field implant, oxidize and fusion bond wafer



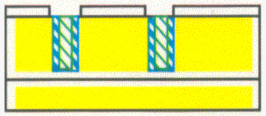
Step 4-6 pattern and etch p^+ window contacts



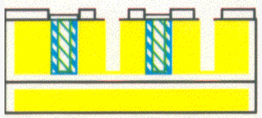
DEEP REACTIVE ION ETCHING (STS)
(electrodes definition)
Bosh process
SiF_4 (gas) +C_4F_8 (teflon)



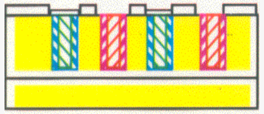
Step 7-8 etch p^+ electrodes



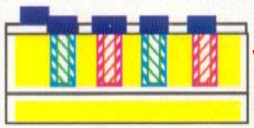
Step 9-13 dope and fill n+ electrodes



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

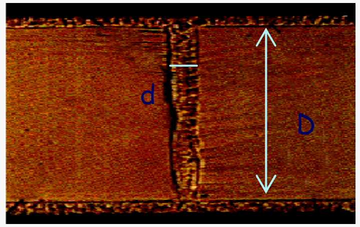


Step 18-23 dope and fill p+ electrodes



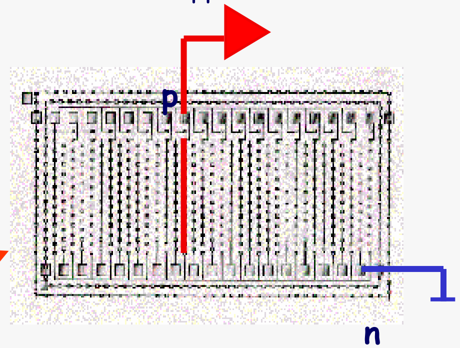
Step 24-25 deposit and pattern Aluminum

Aspect ratio:
D:d = 11:1



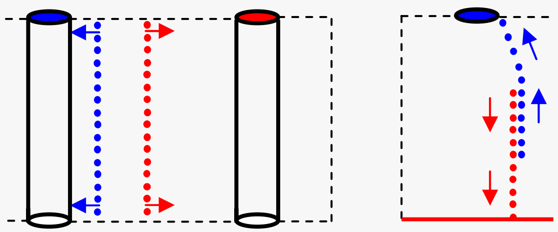
LOW PRESSURE CHEMICAL VAPOR DEPOSITION
(Electrodes filling with conformal doped polysilicon
SiH4 at ~620C)
$2P_2O_5$ +5 Si-> 4P + 5 SiO_2
$2B_2O_3$ +3Si -> 4 B +3 SiO_2

Both electrodes appear on both surfaces



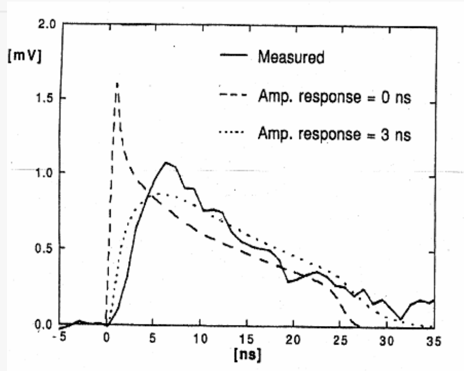
METAL DEPOSITION
Shorting electrodes of the same type
with Al for strip electronics readout
or deposit metal for bump-bonding

Speed

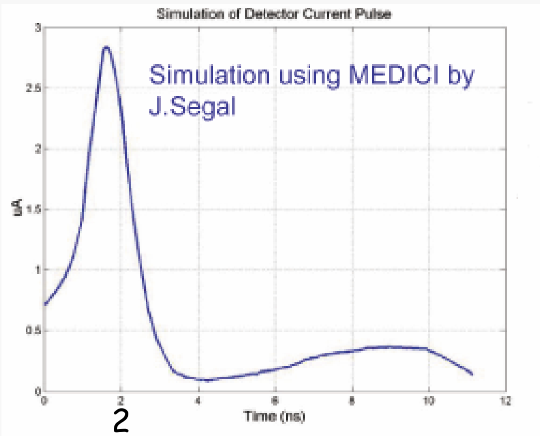


- ❖Short collection distance
- ❖High average e-field at low V_{bias}
- ❖Parallel charge collection

$rt \approx 1ns$

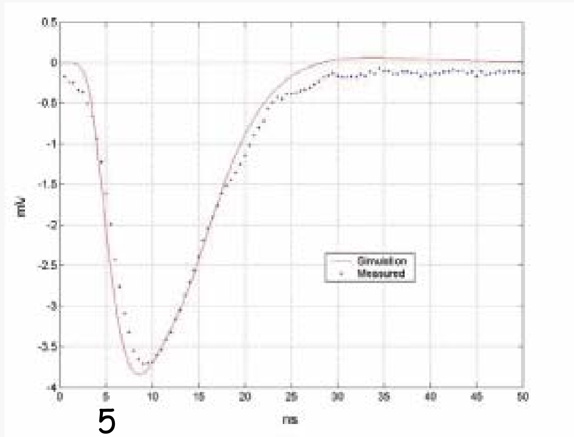


Nuclear Instruments and Methods in Physics Research A310 (1991) 189–191
North-Holland



Circuit Hspice Simulation

3.5 ns rise time (dominated by electronics 0.25 µm G. Anelli et al)

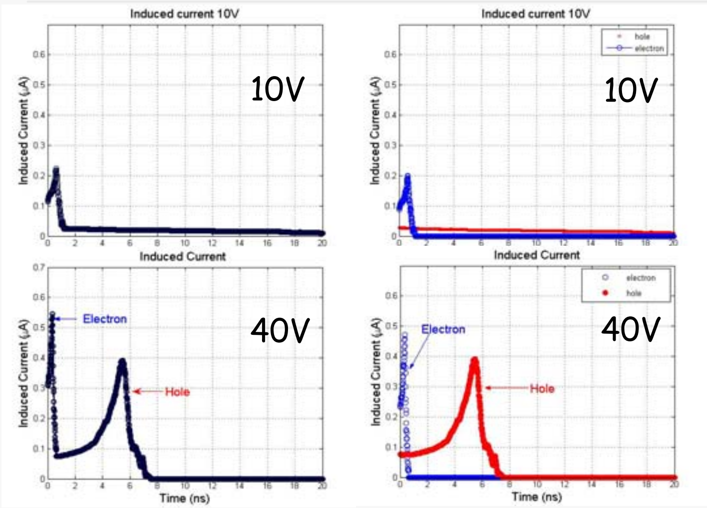


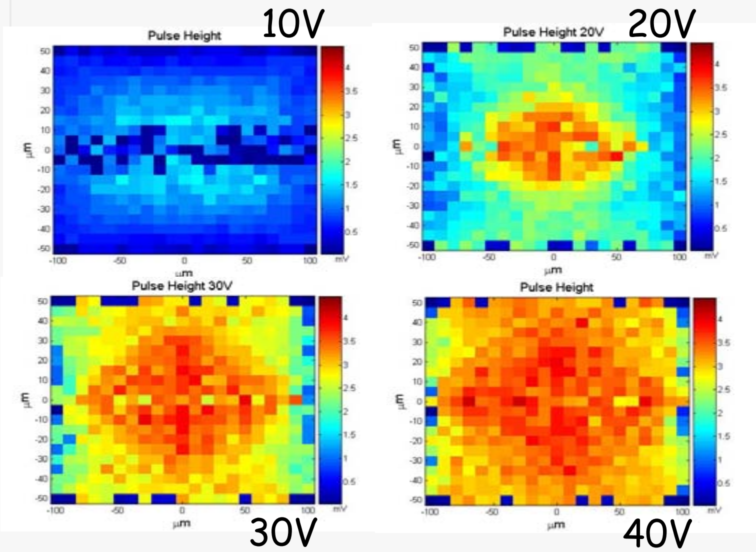
3D only simulation

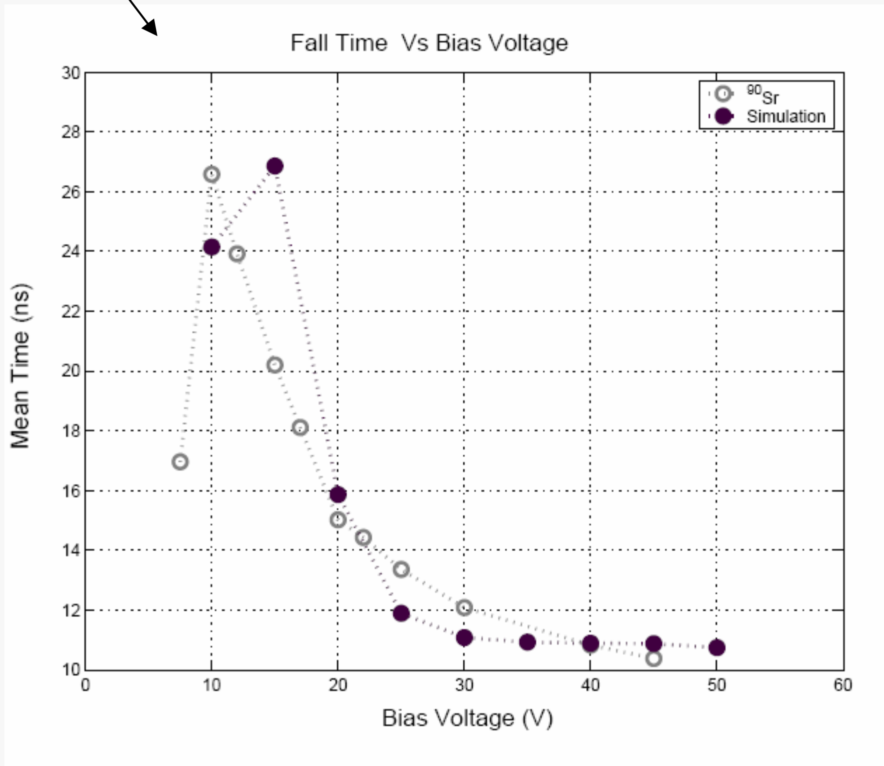
^{90}Sr pulse + FIT

3D modelling and data fit

A. Kok PhD Thesis

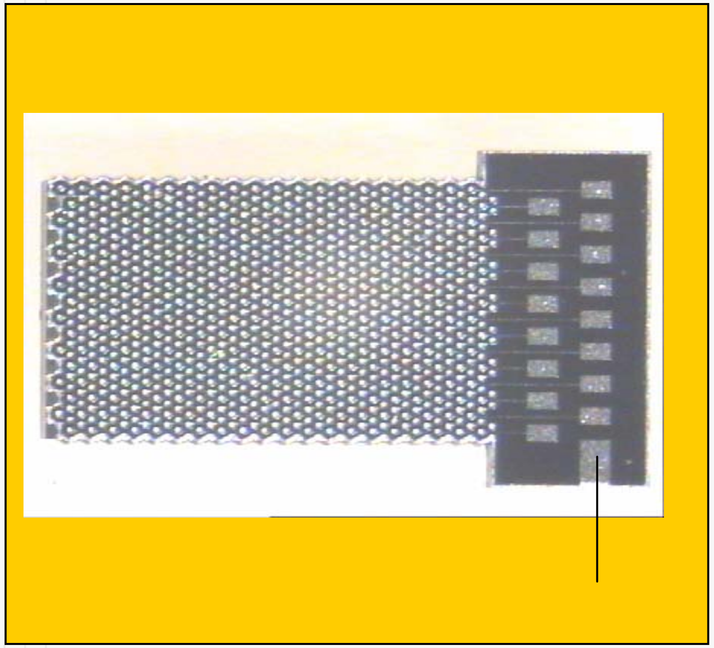




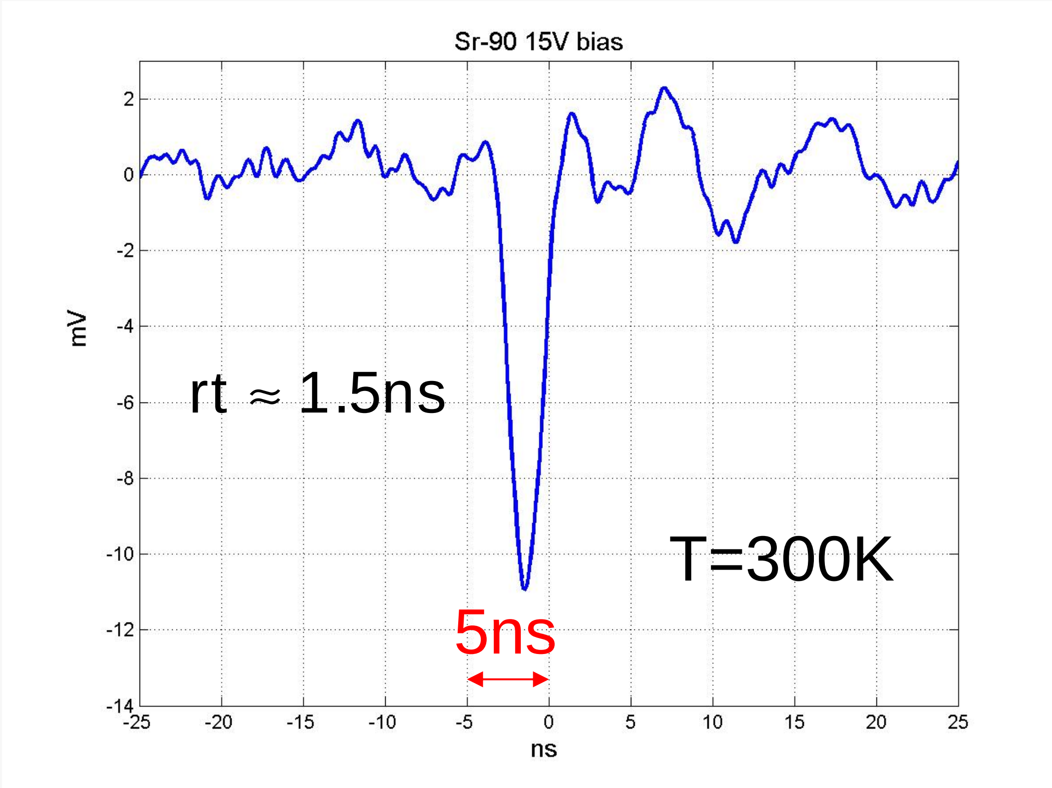


Simulation of signals fall time distribution over a cell (full dot) and ^{90}Sr data (open dot)

3D Tests in progress with a 0.13 μm CMOS Amplifier chip (designed by Depeisse-Anelli-CERN MIC)

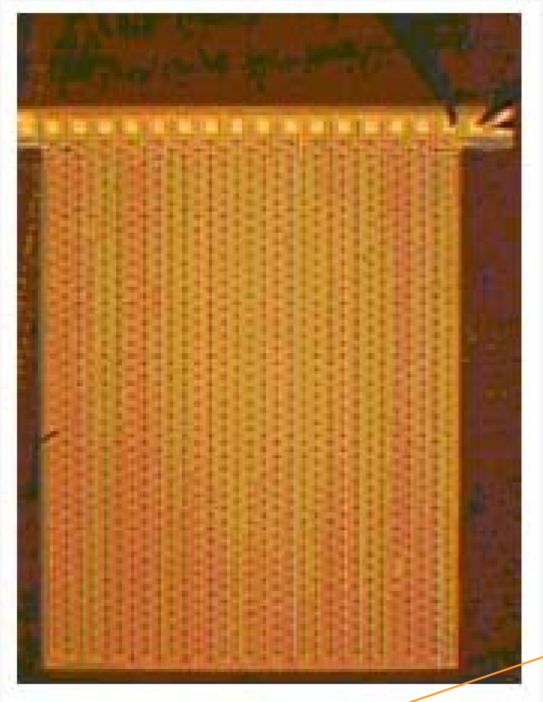


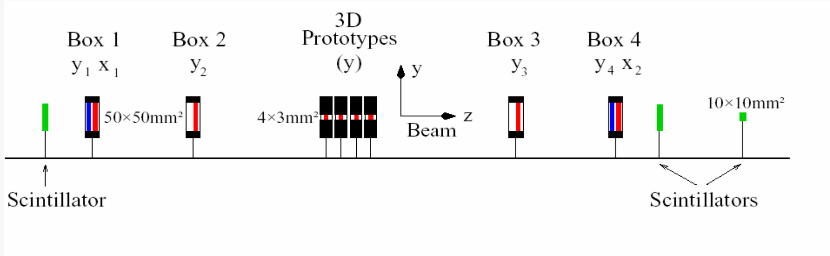
3D Inter-electrode distance = 50 μm

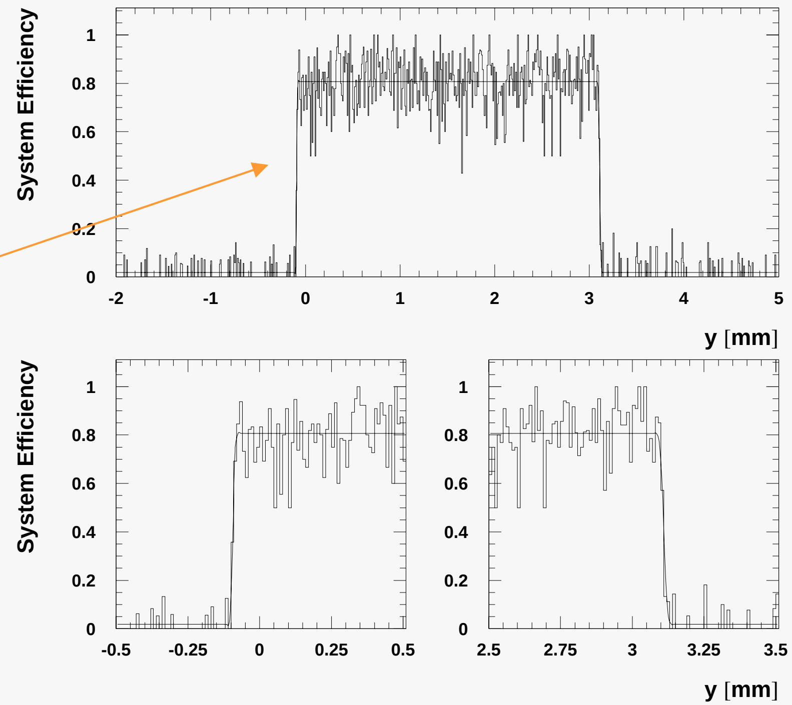


oscilloscope trace

3D edge sensitivity with high energy muons





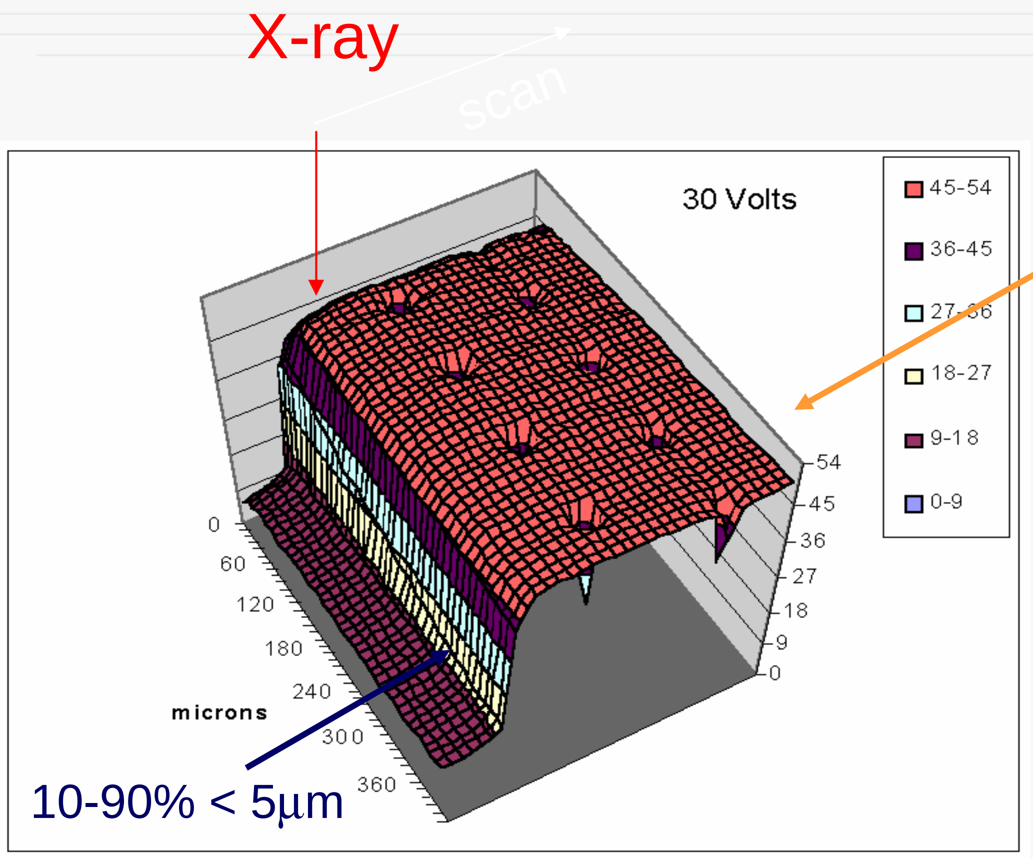


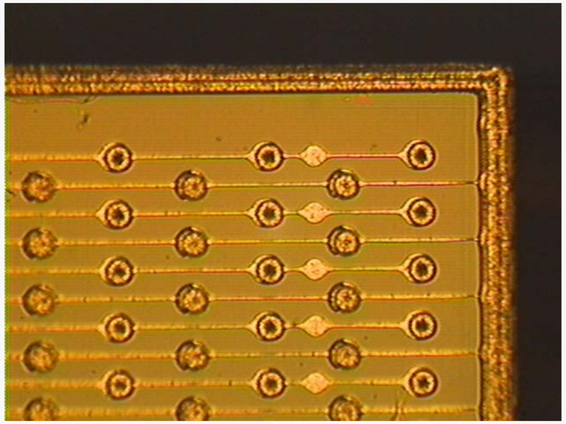
Atlas SCTA readout

Fit width = (3.203 ± 0.004) mm

Phys. width = (3.195 ± 0.001) mm

3D edge sensitivity using 13 keV X-rays at ALS-Berkeley





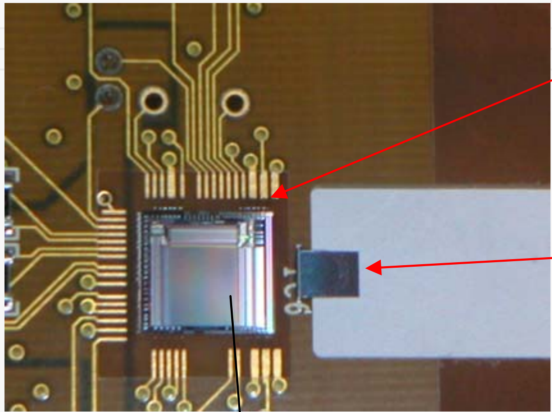
Measurement Performed using a 2 μm beam

J. Hasi, C. Kenney, J. Morse, S. Parker

Electrodes ~ 1.8% of total area

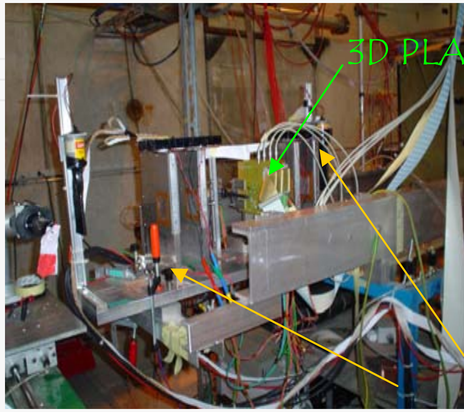
X-ray micro-beam scan, in 2 μm steps, of a 3D, n bulk and edges, 181 μm thick sensor. The left electrodes are p-type

Efficiency (TOTEM X5-beam area)

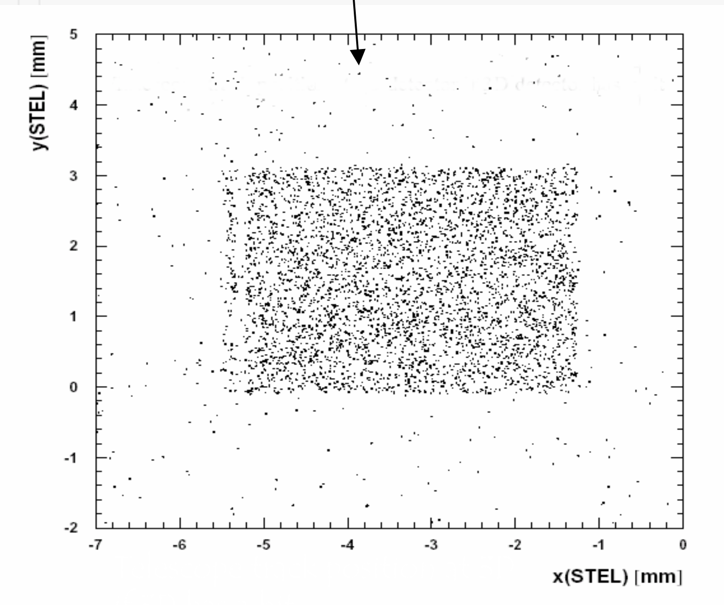


SCTA READOUT CHIP*

3.195 x 3.9 mm^2
3D SENSOR
Thickness=180 μm
n-type Si 4kΩ-cm

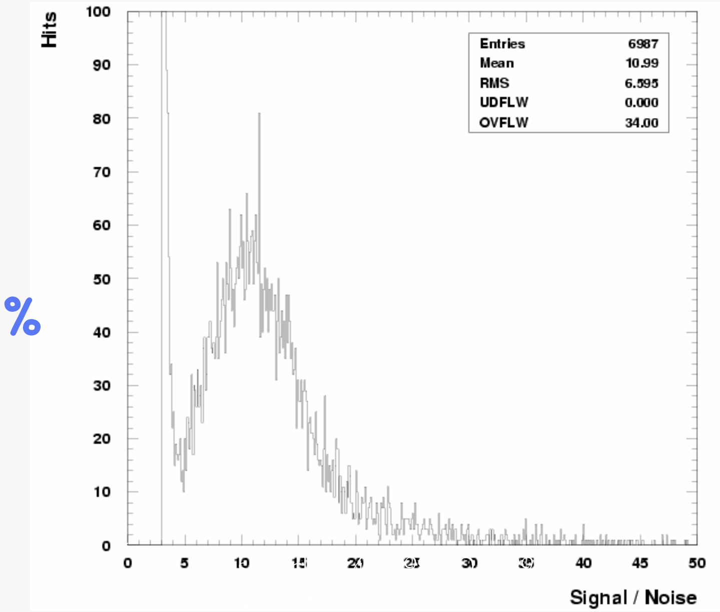


REFERENCE TELESCOPE



S:N=14:1

Efficiency= 98%

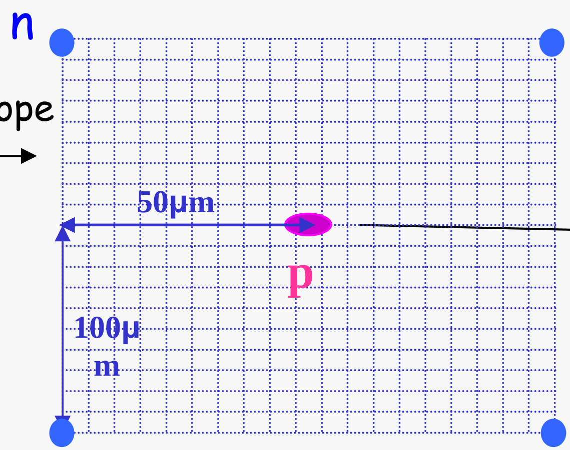


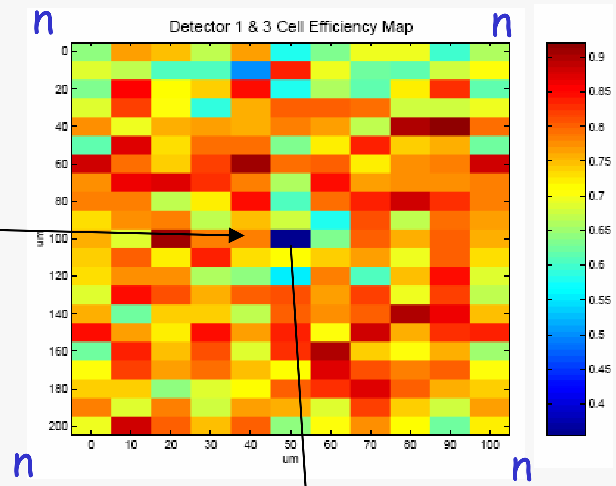
Efficiency: p and n electrodes response

Electrodes area ~1.8% of total area

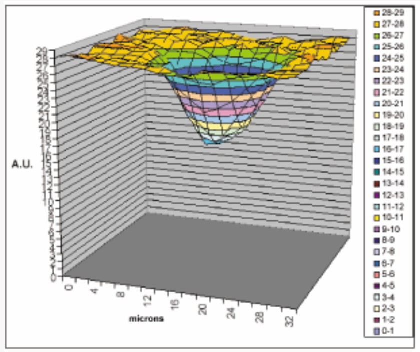
A. Kok PhD thesis

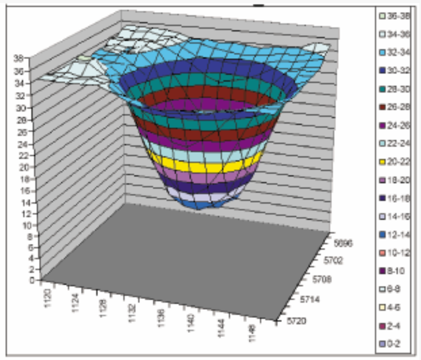
Cell study using 120GeV muons (Cern X5), Telescope Precision ~4μm.





Electrode response using 12KeV X-ray beam (ALS), beam size ~ 2μm





N – Electrode

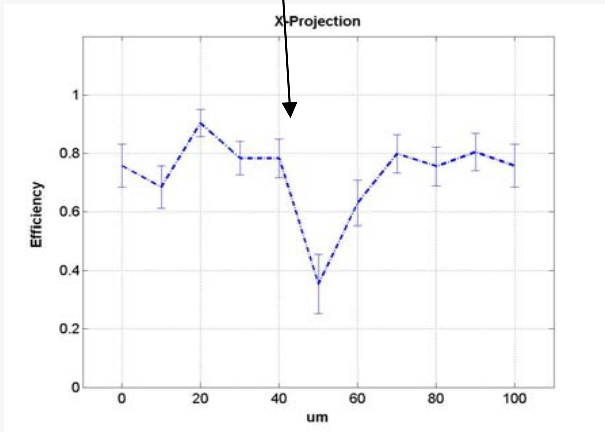
Signal Reduction 43%

P – Electrode

Signal Reduction 66%

Differences between N and P:

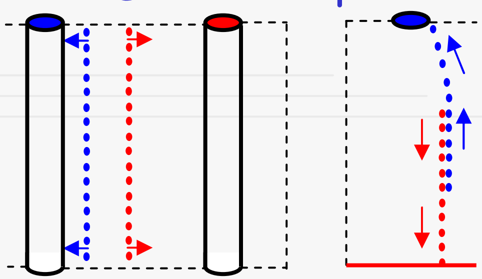
Grain size of poly, Diameter, Diffusion rate, Trapping, Doping



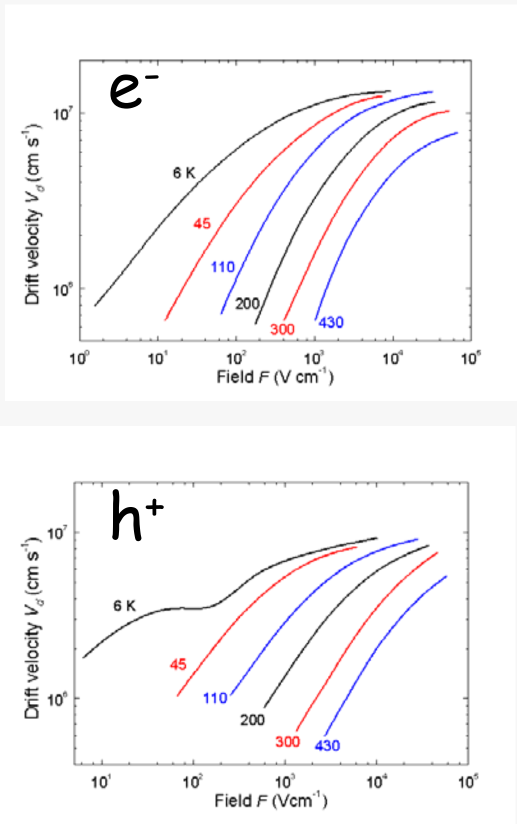
40% reduction in count efficiency at p-electrode

Why is 3D radiation hard

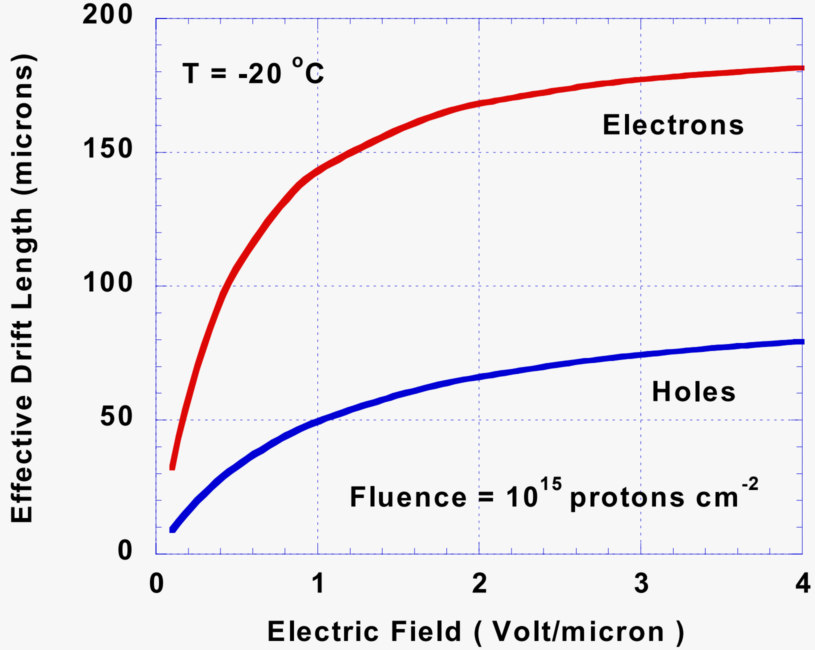
- Short collection distance (50-70 μm)
- High average e-field per applied V_{bias}
- Parallel charge collection
- Always use full substrate thickness (MIP ~80 e^-/mm)



$$L_{eff} = v_{drift} \times \tau_{trap}$$

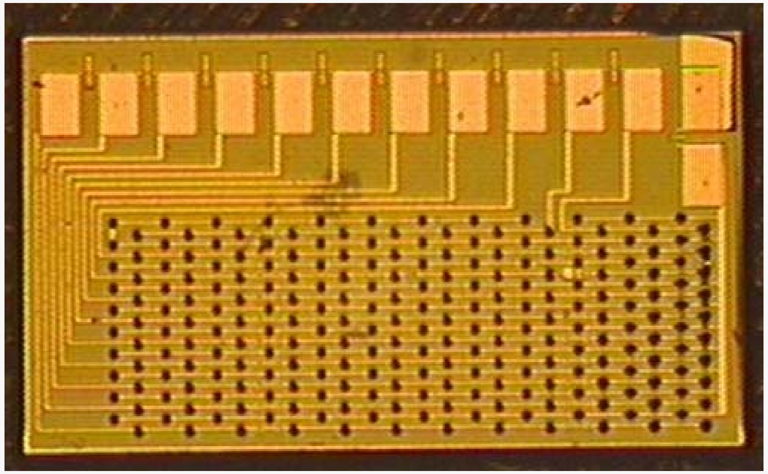


Ottaviani, Canali et al.



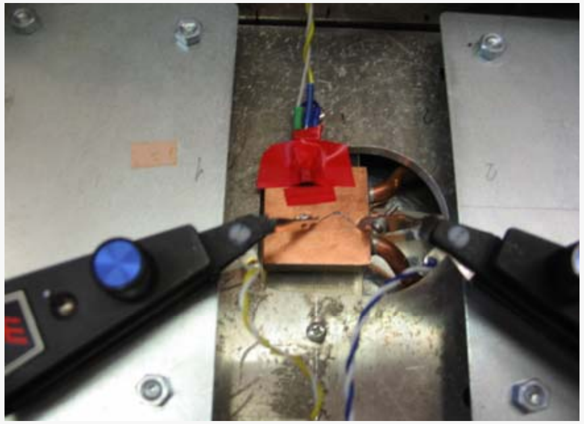
Trapping times from Kramberger et al. NIMA 481 (2002) 100
Simulations CDV and S.Watts NIM A 501(2003) 138 (Vertex 2001)

Radiation hardness tests of 3D-3E Atlas geometry

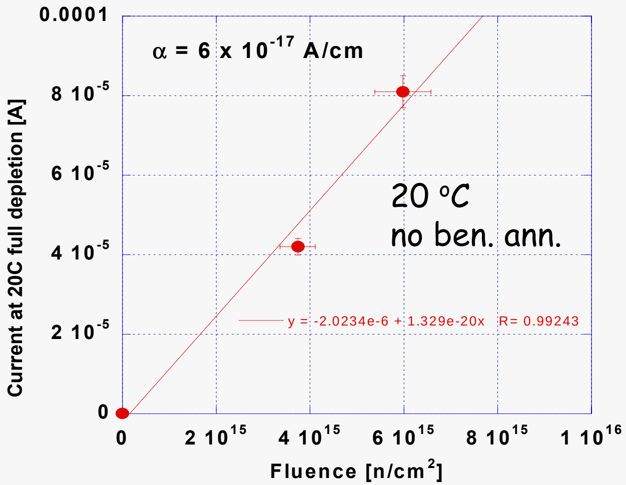


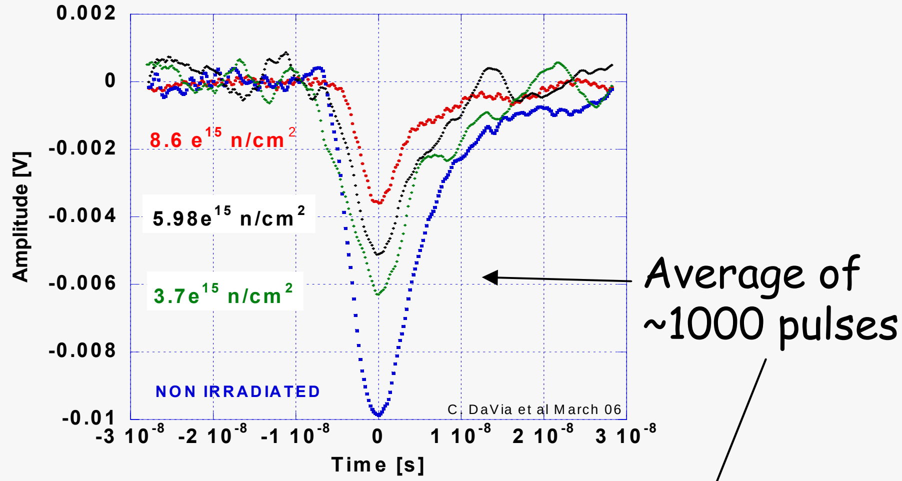
- Volume = 1.2 x 1.33 x 0.23 mm^3
- Inter-electrode spacing = 71 μm
- 3 electrode Atlas pixel geometry
- n-electrode readout
- n-type before irradiation -12 kΩ cm
- Irradiated with reactor neutrons (Praha)

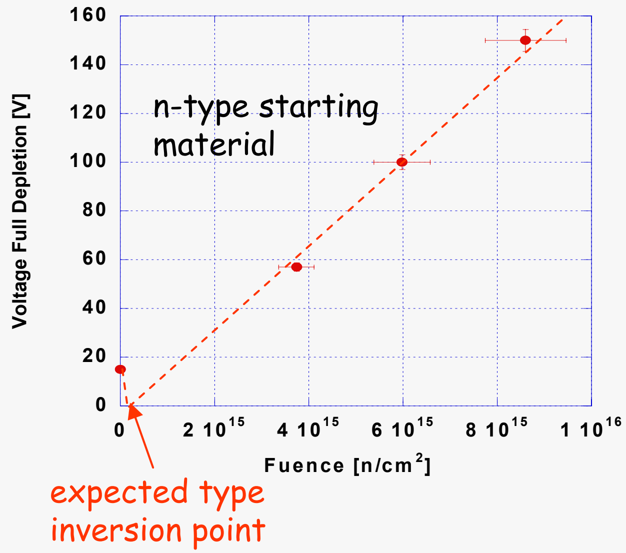
Name	Fluence $[n_{1MeV}/cm^2]$	Fluence $[p/cm^2]$
7F	3.74e15	6.0e15
7A	5.98e15	9.6e15
7D	8.60e15	1.4e16

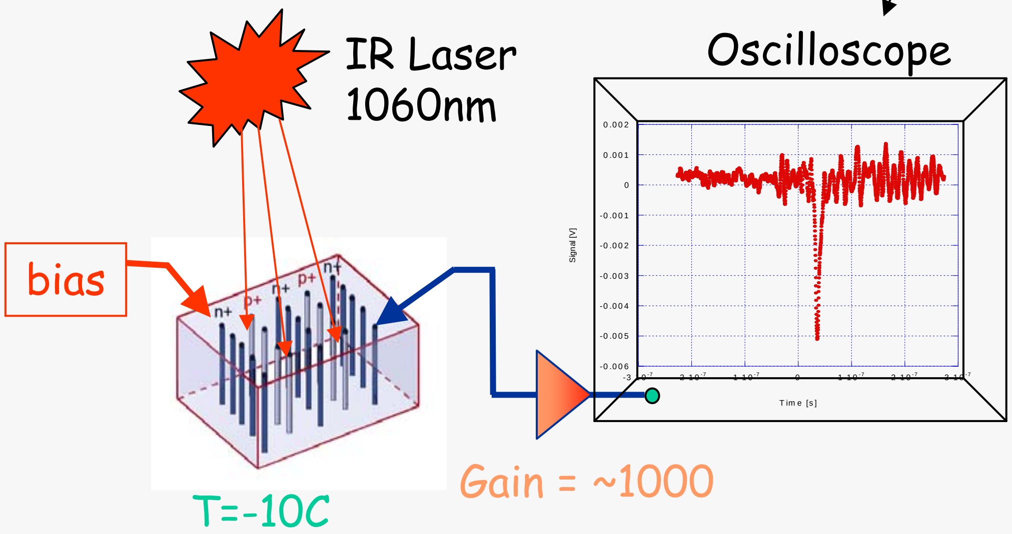


Radiation hardness: macroscopic parameters and signal efficiencies



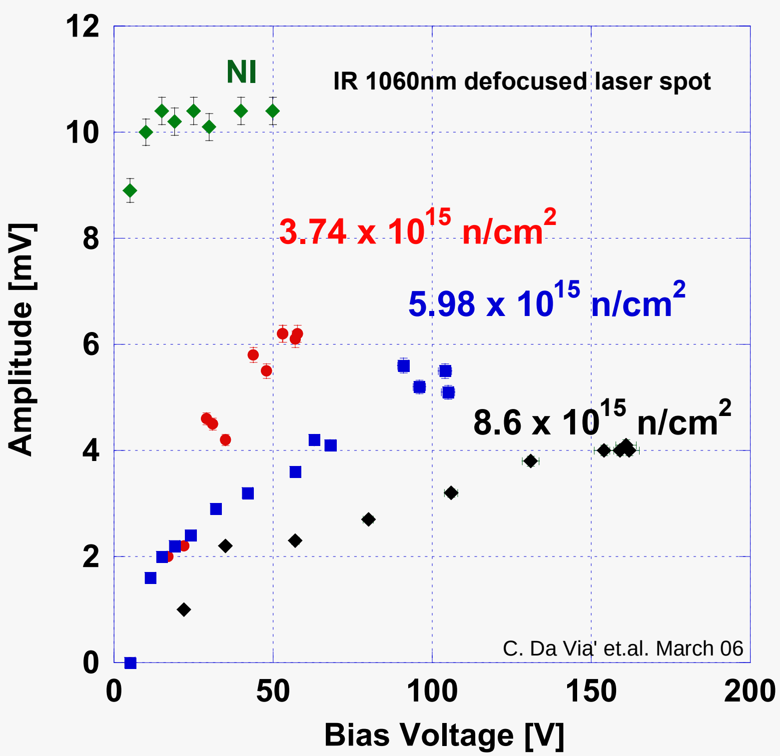


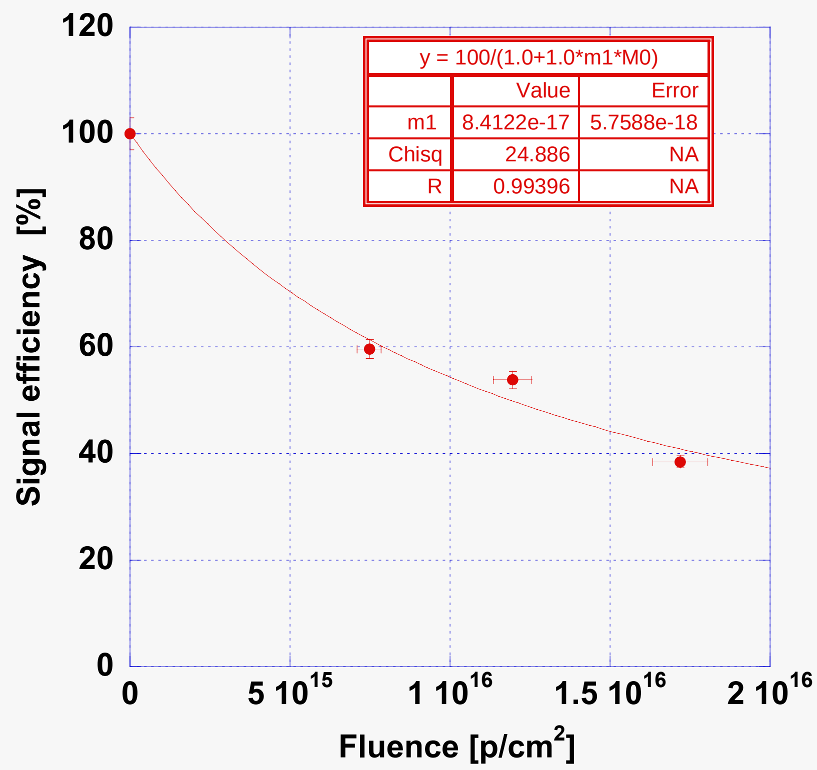




Signal efficiency

$$S \propto L_{eff} = v_{drift} \times \tau_{trap} \propto \frac{1}{N_t} \propto \frac{1}{\phi}$$



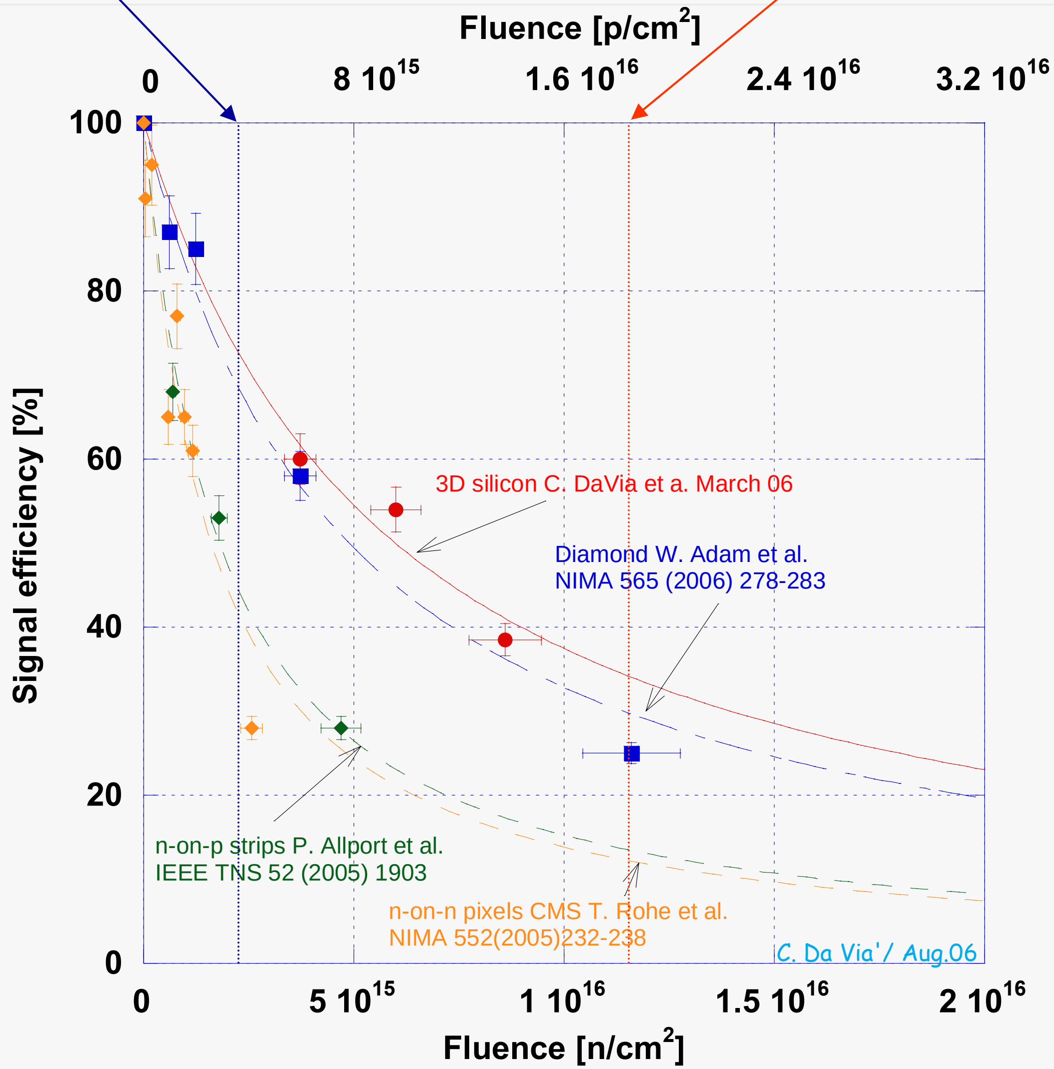


Simulation by S. Watts to be published

Radiation Hardness

3x10^15 p/cm^2 =
10 years LHC at 10^34 cm^-2s^-1
At r=4cm

1.8 x 10^16p/cm^2 =
10 years SLHC at 10^35cm^-2s^-1
At r=4cm



Detector Parameters

Detector Type	Thickness [μm]	V-bias [V]	e-h/μm [Most Probable]	e-h/0.1%X_0 [mean]	MIP Charge Bef. irr. [e^-]	Signal after 10 years LHC (SLHC) at 4 cm [e^-]	Signal after 10 years LHC (SLHC) at 4cm [%]	T [C]
3D-silicon	235	160 2.2 V/μm	80	10^4	18800	14480 (6580)	77 (35)	-10
Diamond "	500	500 1V/μm	27	4500	13500	9855 (4725)	73 (35)	20
Pixels CMS " n-on-n	285	600V 2.1 V/μm	80	10^4	22800	10940 (2510)	48 (11)	-10
Strips ATLAS " n-on-p	280	900 3.2 V/μm	80	10^4	22400	12100 (3136)	54 (14)	-10

C DaVia/March06

*Same reference than previous slide

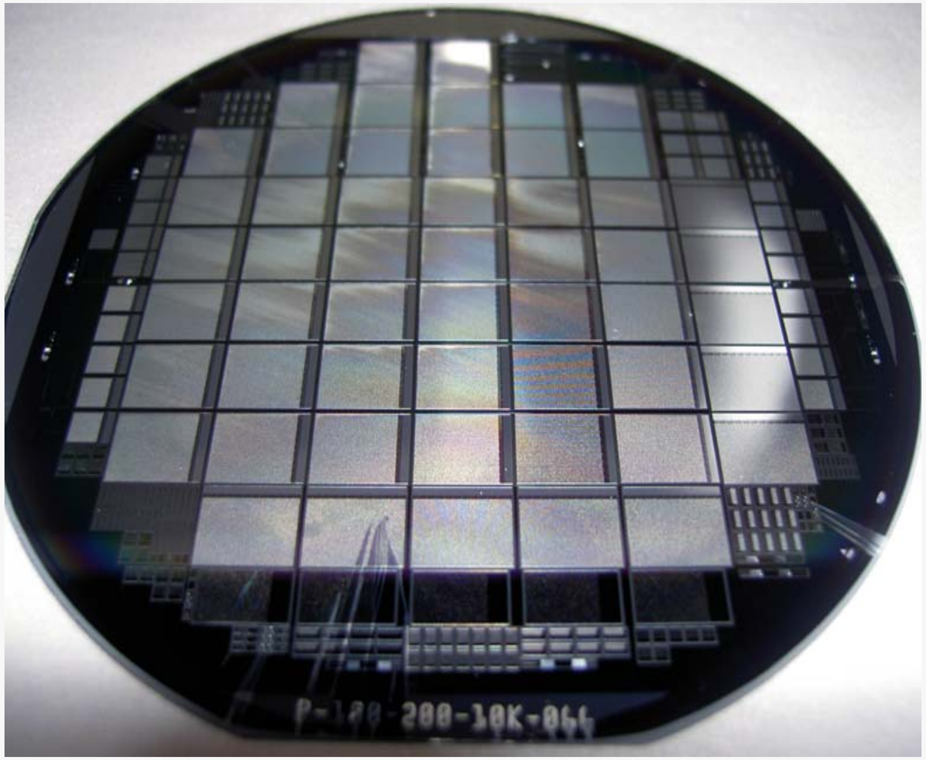
Yield + Large area : FP420/Atlas pixel

Atlas chip picture from
Bekerle Vertex03

DIMENSIONS	RO SIGNAL	Technology	BUFFER/speed
50x400 μm^2 7.2x8mm^2	binary and time over threshold	0.25 μm IBM CMOS6SF	2 - 6.4μs 40 MHz

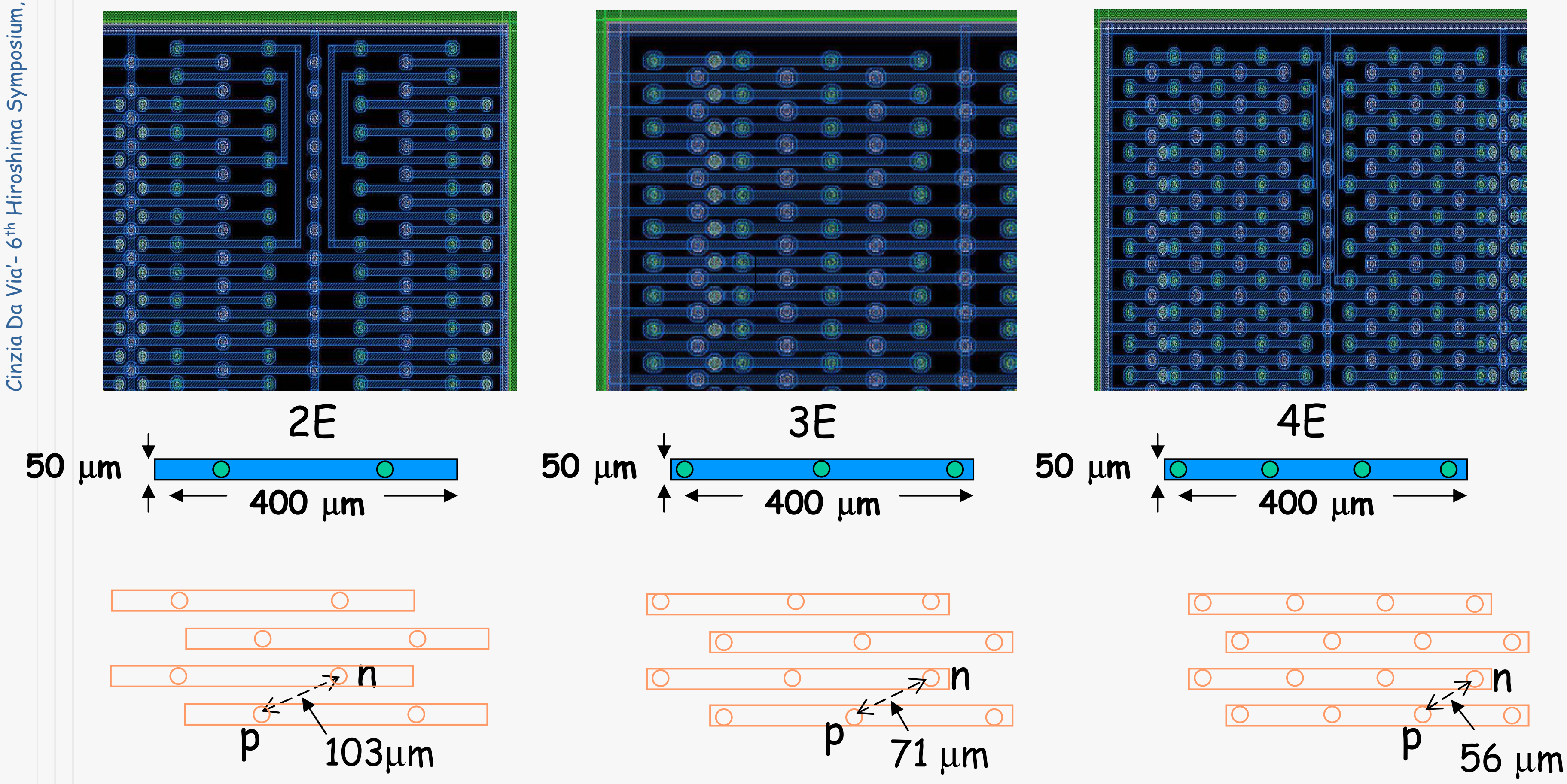
- -32 3E ATLAS Single Chips
- -6 4E ATLAS Single Chips
- -6 2E ATLAS Single Chips
- -Quarter Size ATLAS Chips
- -ATLAS Test Structures
- -Other structures

Thickness <250 μm>
p-type substrate 12kΩcm



10 wafers completed : Yield on one wafer ~80%

3D FP420/Atlaspix electrode configurations

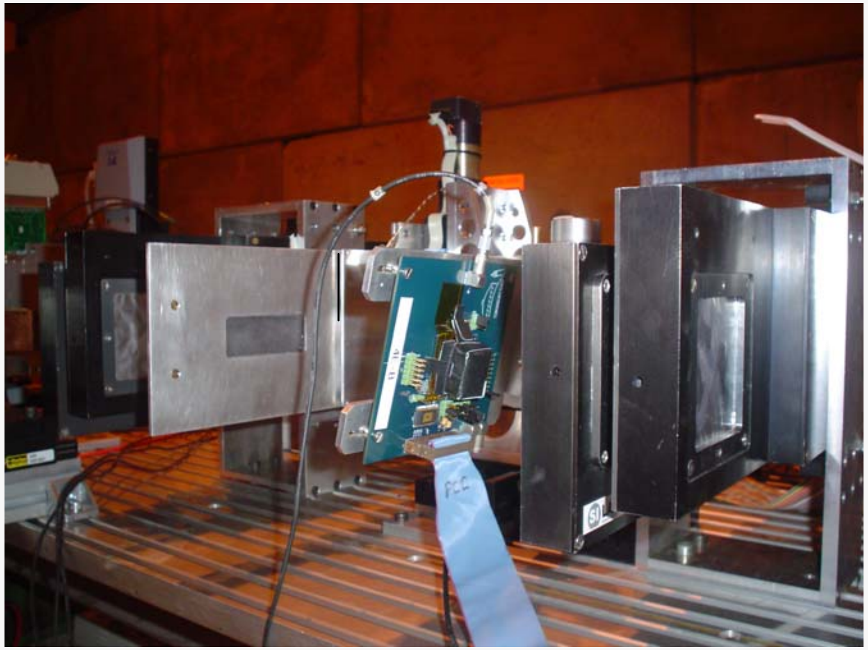


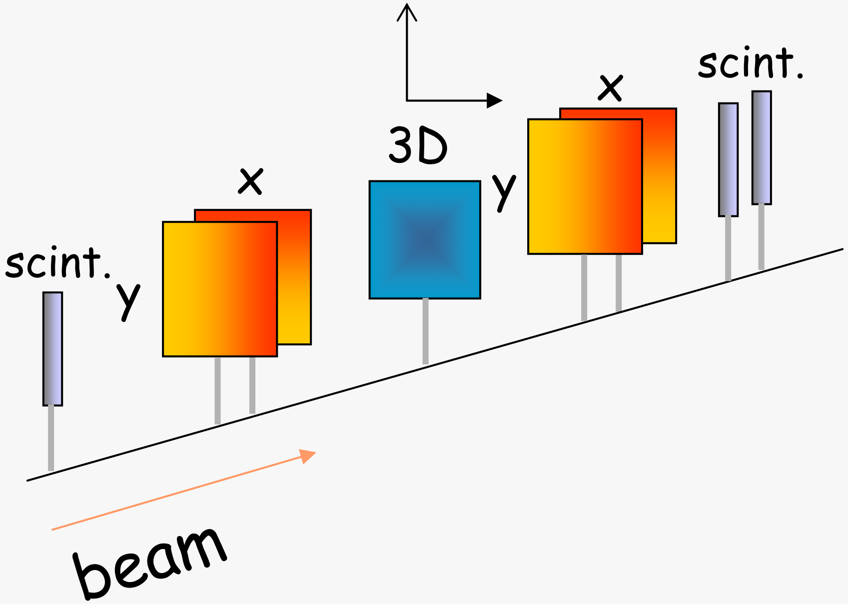
V_{fd} ~20V

V_{fd} ~8V

V_{fd} ~5V

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





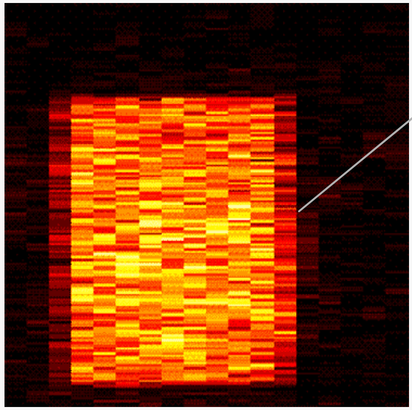
Telescope, daq and on-line monitor by Lars Reuen, Atlas pixel setup and data conversion Markus Mathes (Bonn group)

100 GeV π^-

Triggers: 3x3 mm^2 , 12x12 mm^2

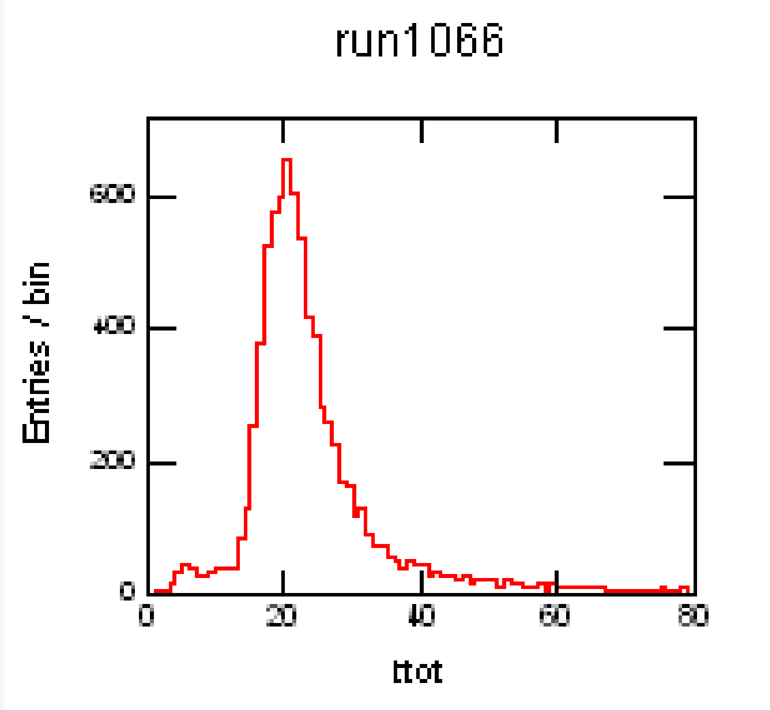
3D-2E-A preliminary

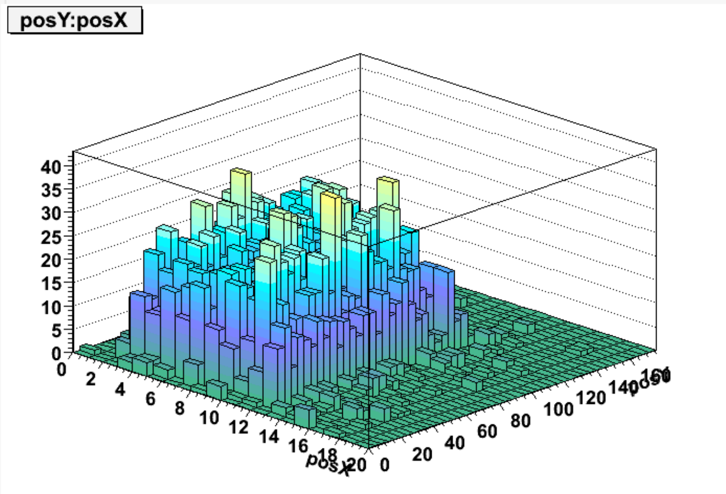
V_{bias}=30V Threshold=4000e^-



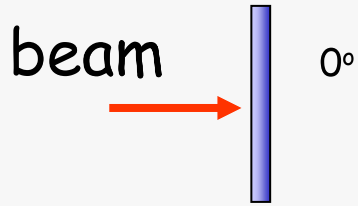
Longer pixels

hitmap with the 12x12 mm² trigger



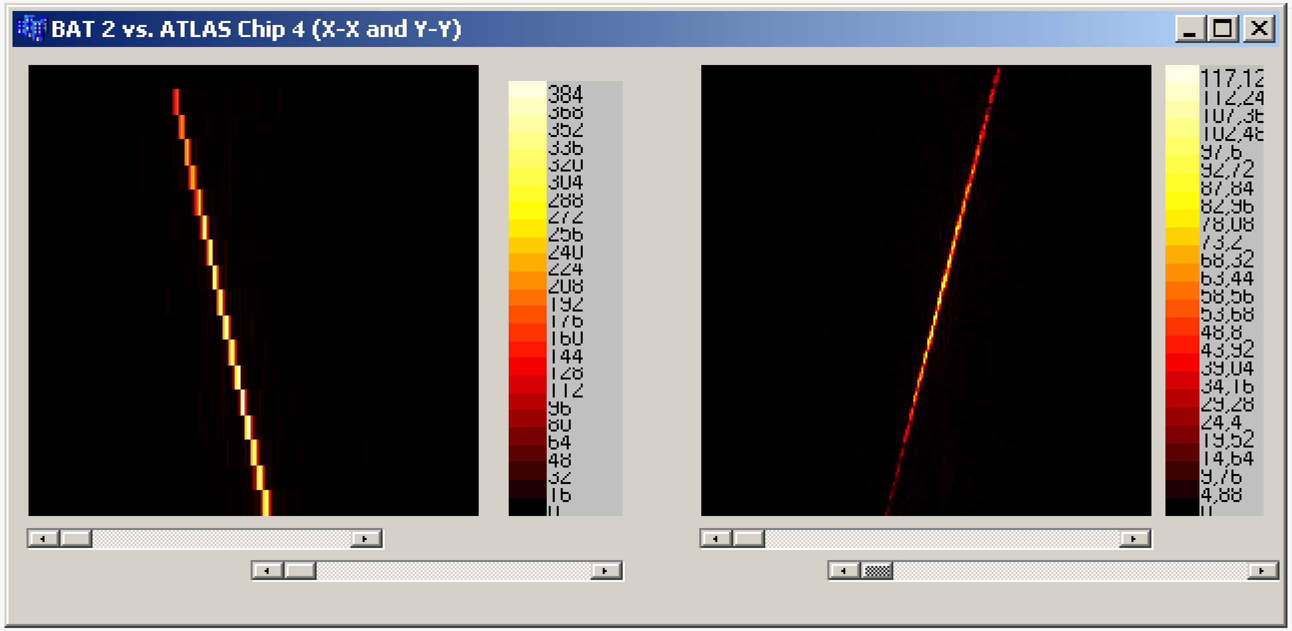


hitmap with the 3x3 mm² trigger



3E-G correlation plots and hit maps

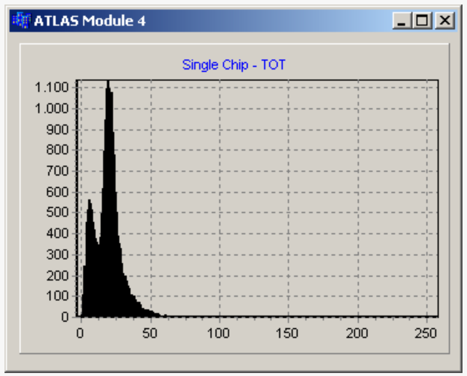
x-x y-y

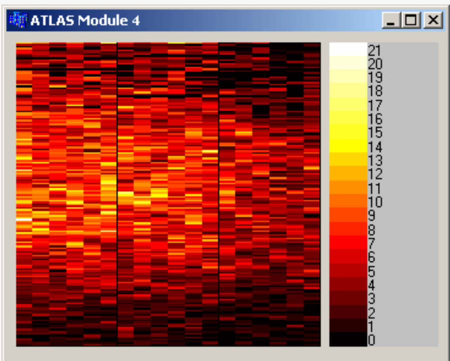


V_{bias} =15V

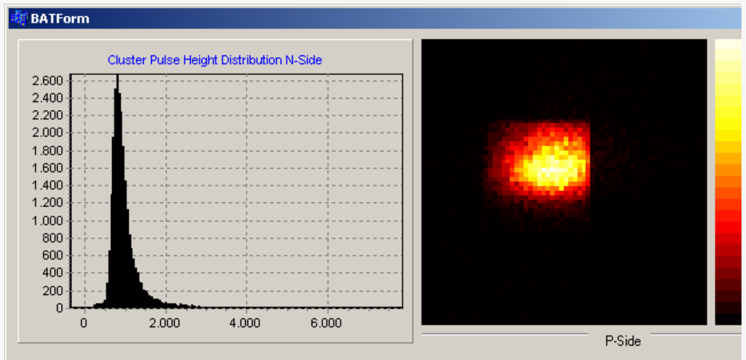
Th. = 4000e^-

Tot 3D





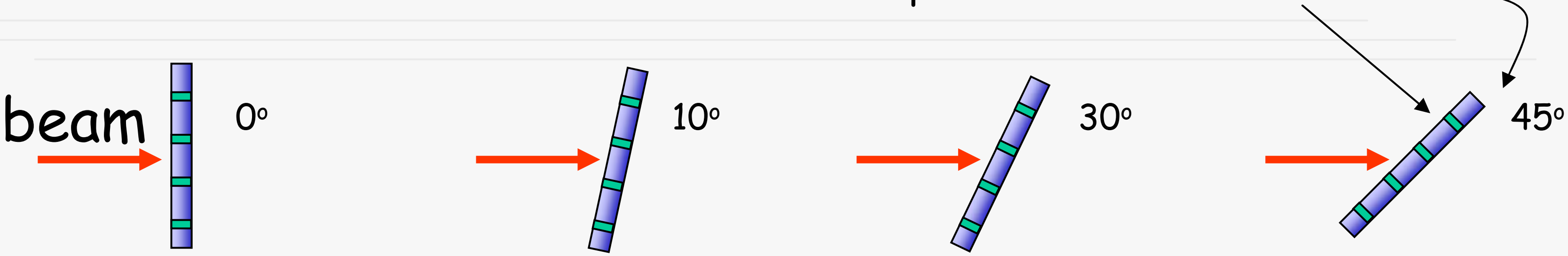
Telescope

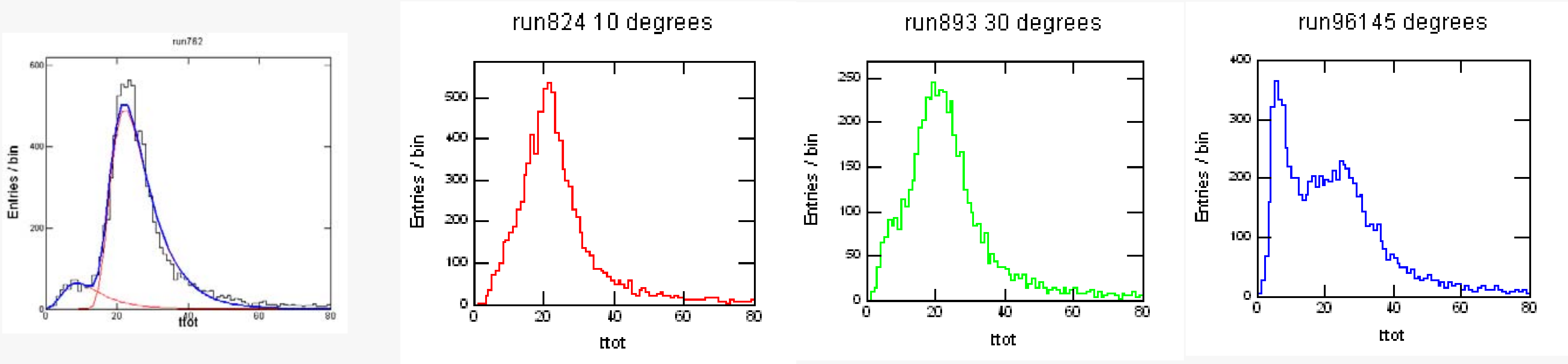


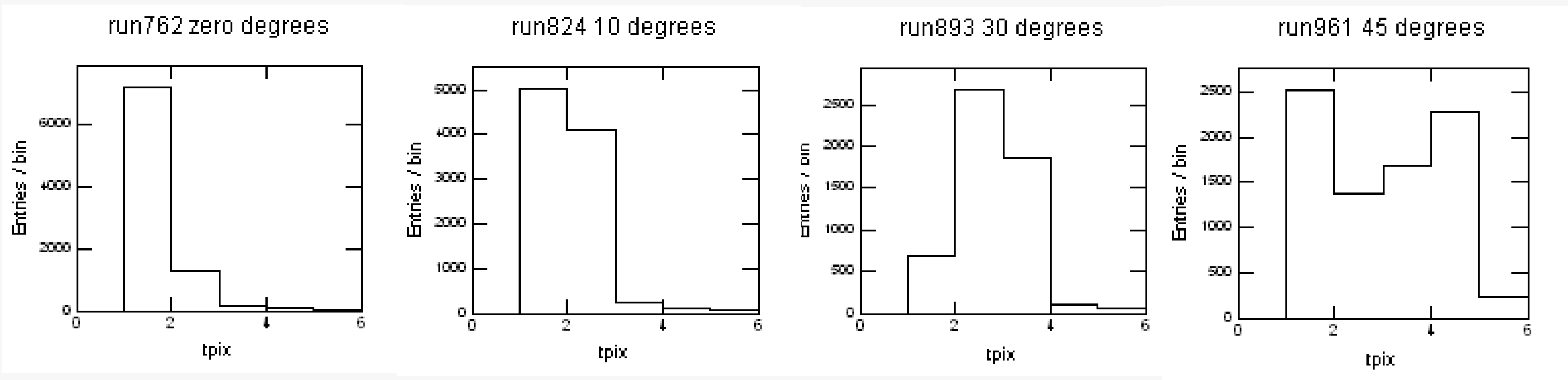
4E electrode angular response - preliminary

V_{bias}= 20V Th. = 4000e^-

1 pixel cross section 50 x 250

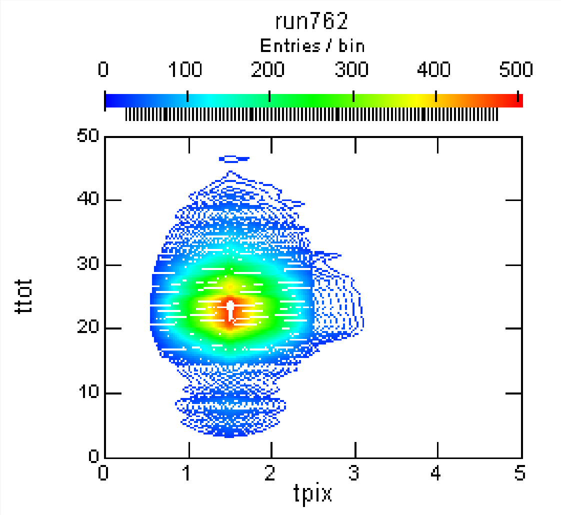




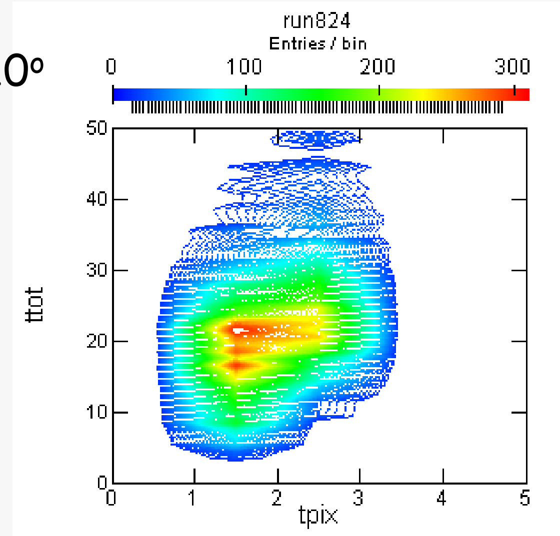


4E- Signal size versus cluster size

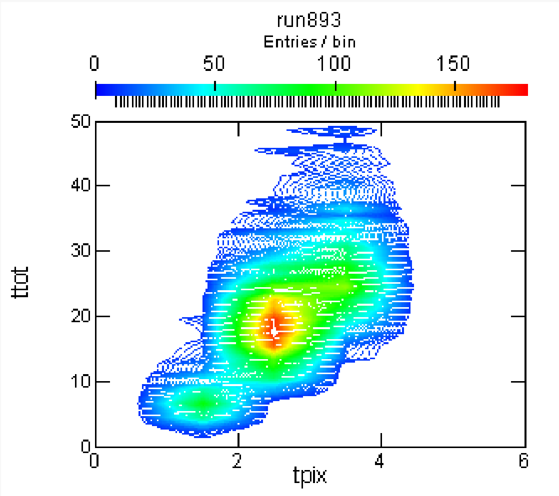
0º



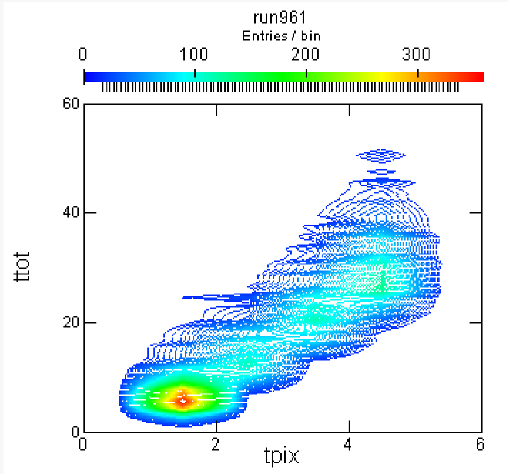
10º



30º



45º



3Dc

Conclusions and future plans

The results so far on :

- ❖ Speed,
- ❖ edge response,
- ❖ efficiency,
- ❖ rad. hardness and
- ❖ large area fabrication

of 3D sensors fabricated at Stanford very encouraging for applications beyond the LHC.

Will need to improve/study/explore

- o electrode response
- o electrode aspect ratio
- o yield
- o alternative substrate's materials

Interest to use 3D sensors expressed by FP420 (CERN R&D for forward physics at Atlas and/or CMS), Atlas b-layer replacement and upgrade
To be used in Totem (planar/3D).