Cinzia Da Via'- Edinburg - March 2007

3D ACTIVE EDGE SILICON SENSORS – RESULTS and APPLICATIONS

Cinzia Da Via', Brunel University UK

Collaboration

OUTLINE

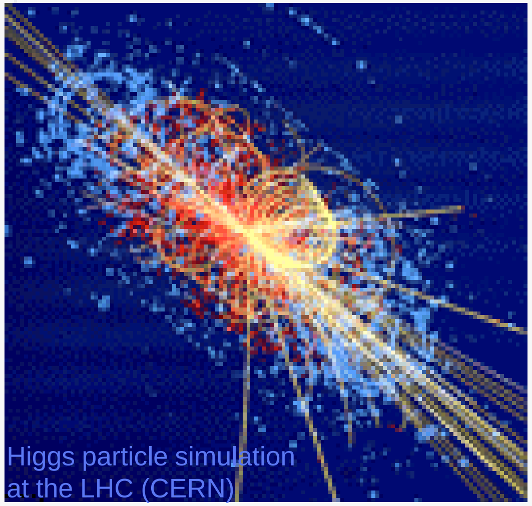
- ❖Silicon detector requirements for 'imaging' applications
- ❖Background for Medical applications
- ❖Background for HEP applications
- ❖3D Active Edge Silicon Sensors:
    - ❖Present results
    - ❖simulations
- ❖Conclusions

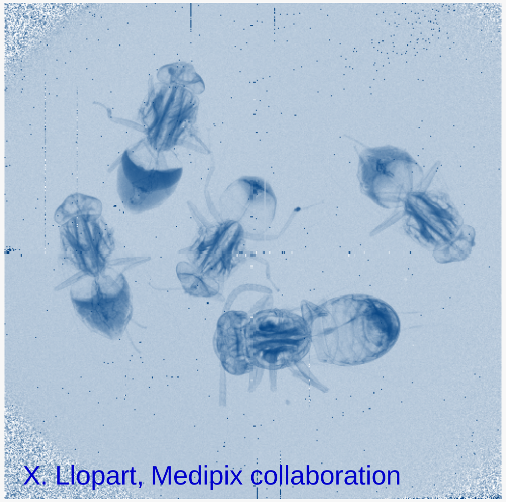
C. Kenney (MBC), L. Reuen, R. Kohrs, M. Mathes, J Velthuis, N. Wermes (Bonn Univ.) J. Hasi, A. Kok, S. Watts (Brunel U.K.) S. Parker (U. of Hawaii) G. Anelli, M. Deile, P. Jarron, J. Kaplon, J. Lozano and the TOTEM Collaboration (CERN), V. Bassetti (Genova), M. Garcia-Sciveres, K. Einsweiler (LBL), V.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

Imaging (both for hep and medicine) detector requirements

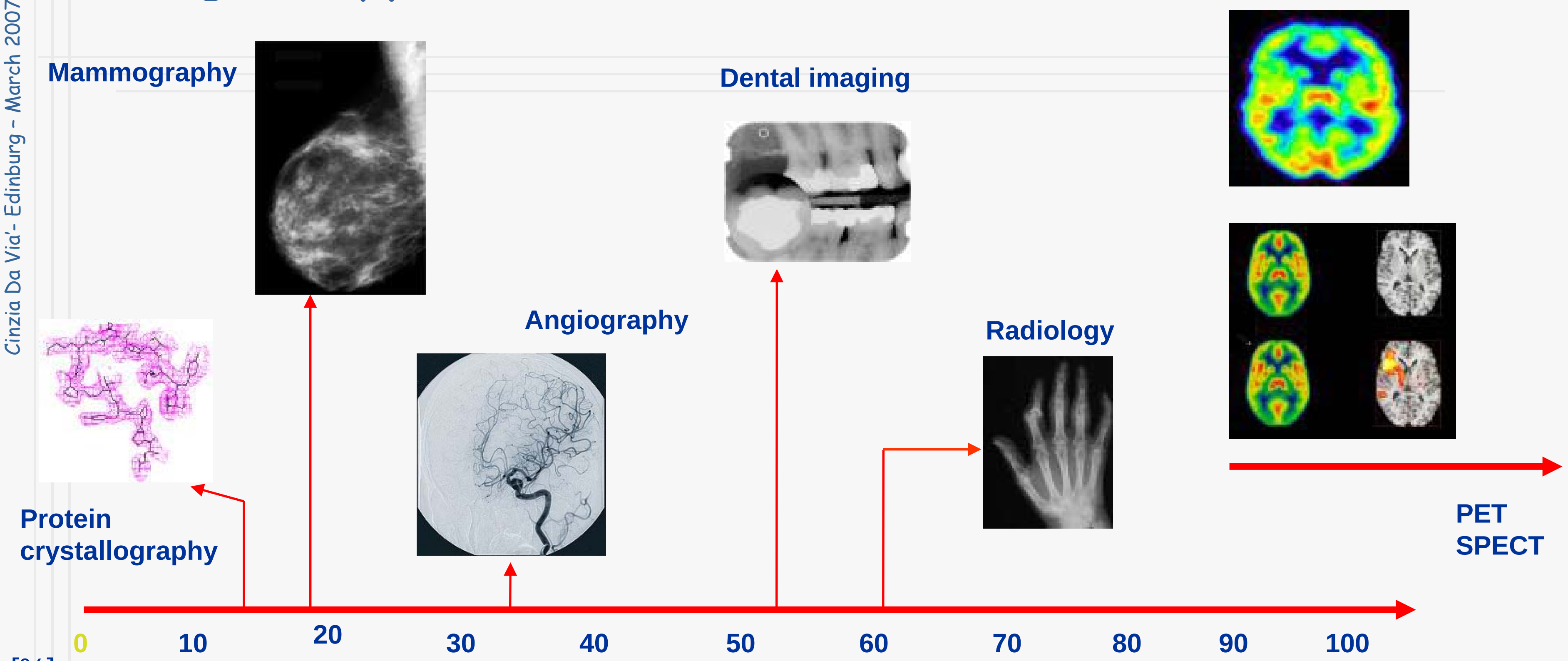
- ❖High sensitivity (direct detection)
- ❖High spatial resolution
- ❖Large area coverage
- ❖Speed (high rate)
- ❖Radiation Hardness (high rate)
- ❖High energy resolution (spectroscopy signal to noise ratio))


(NASA/JPL/ASU)


Higgs particle simulation at the LHC (CERN)


X. Llopart, Medipix collaboration

X-ray energy of the most common medical and biological applications and Silicon detectors



Mammography

Dental imaging

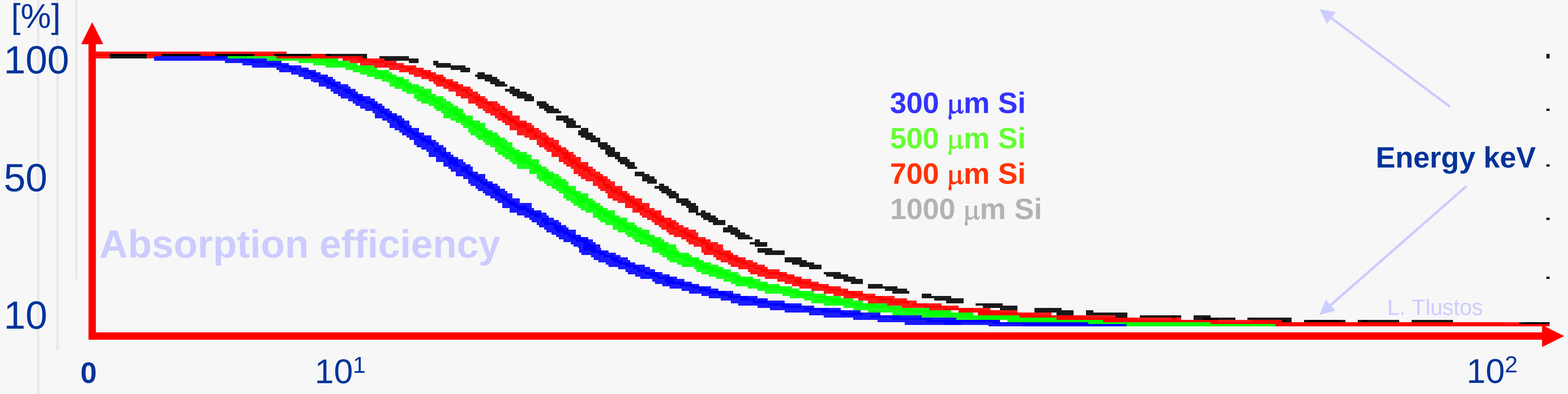
Angiography

Radiology

Protein crystallography

PET
SPECT

Energy keV



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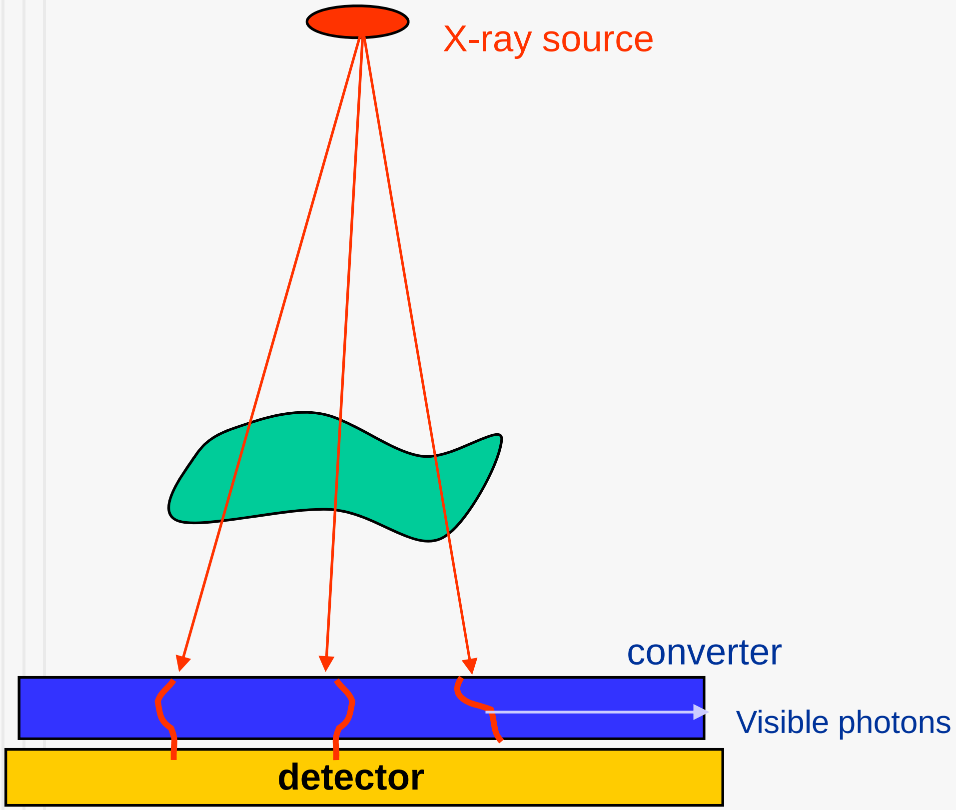
Direct and indirect detection

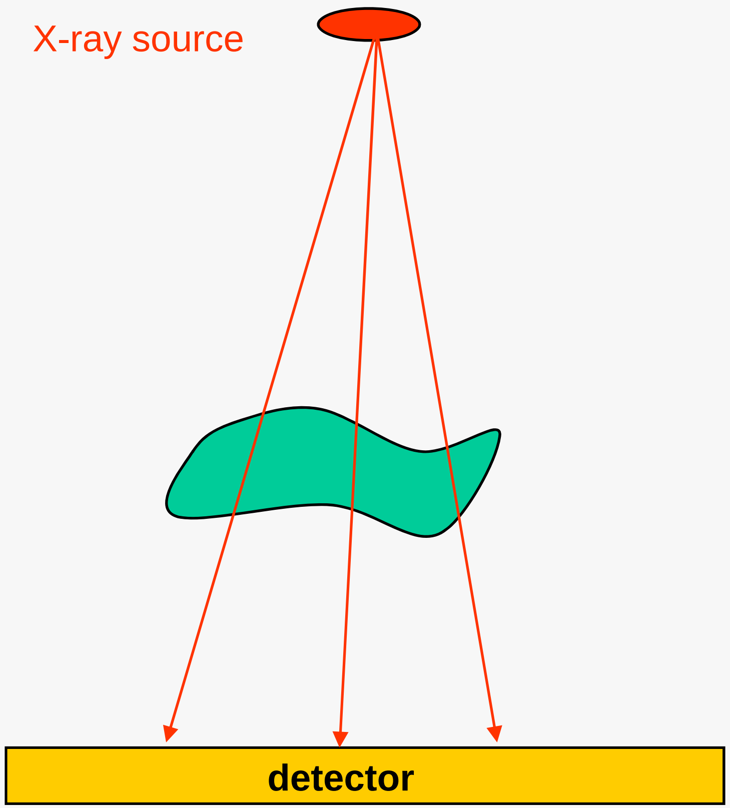
Indirect detection



Thin Si or low -Z material

Degradation of the spatial resolution

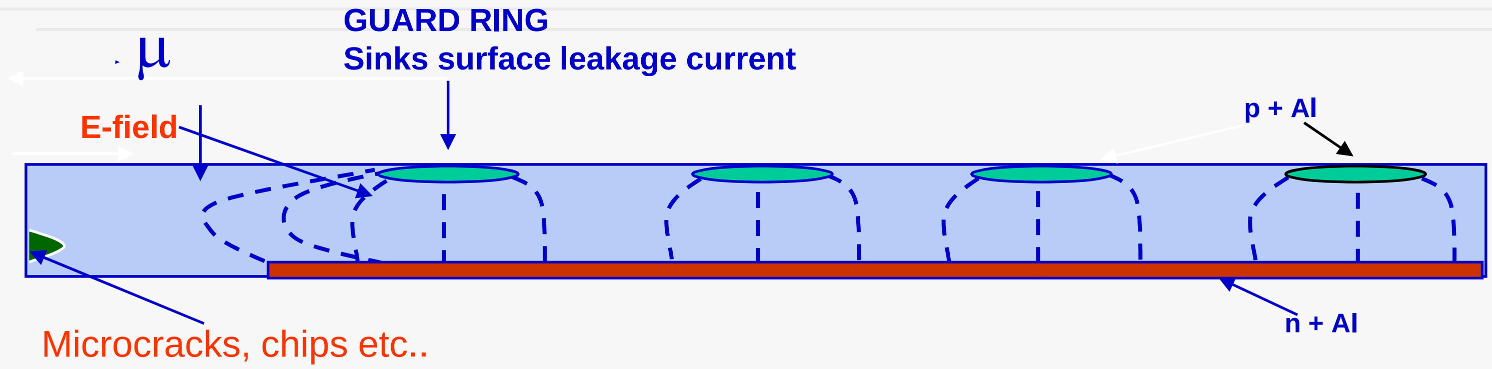
Direct Detection

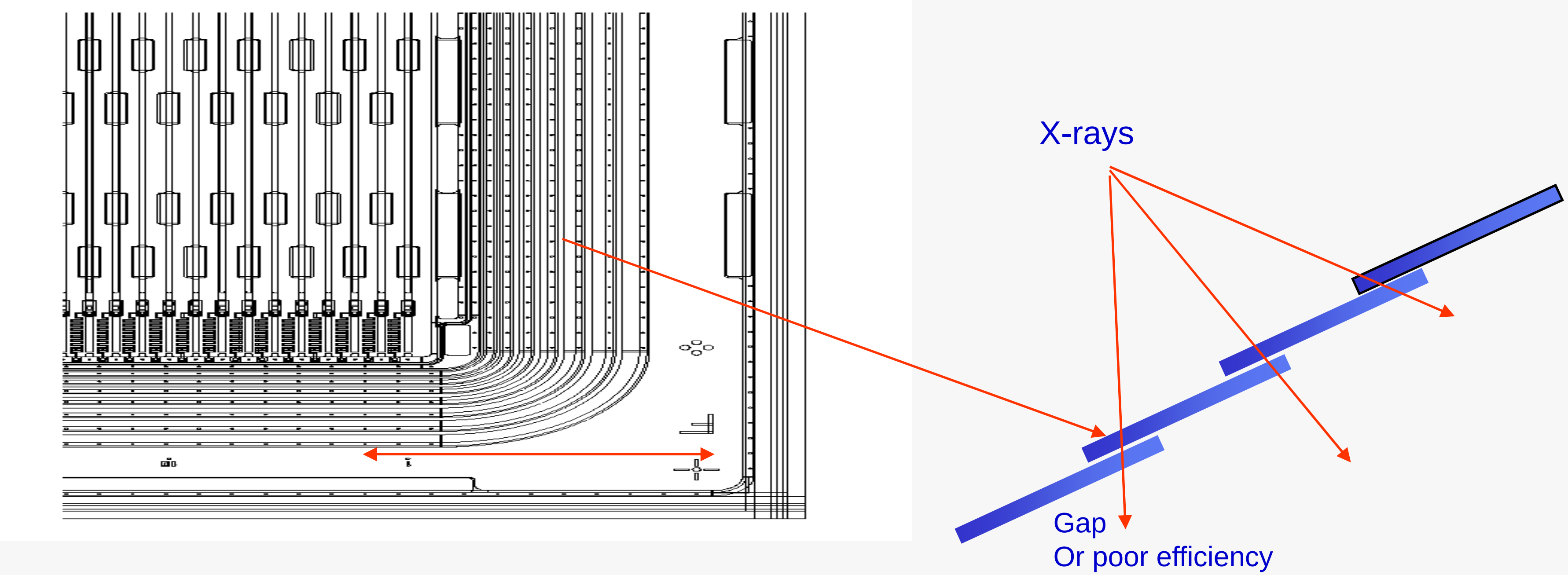


Thick Si or high-Z material

Only 1 step→ less degradation!!

Large area coverage: Why not a traditional planar Silicon sensor?



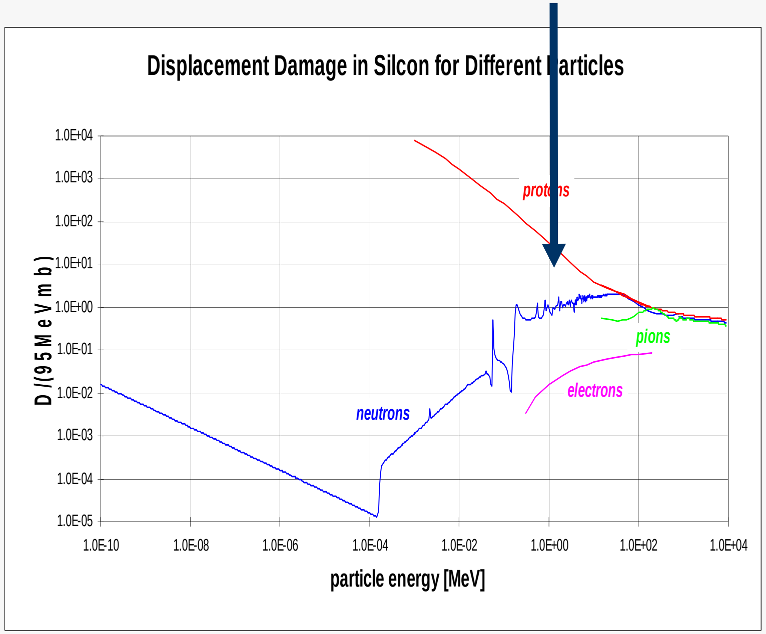


HEP-Radiation Environment at the LHC and Expected at the SLHC at CERN

B-LAYER ~4cm

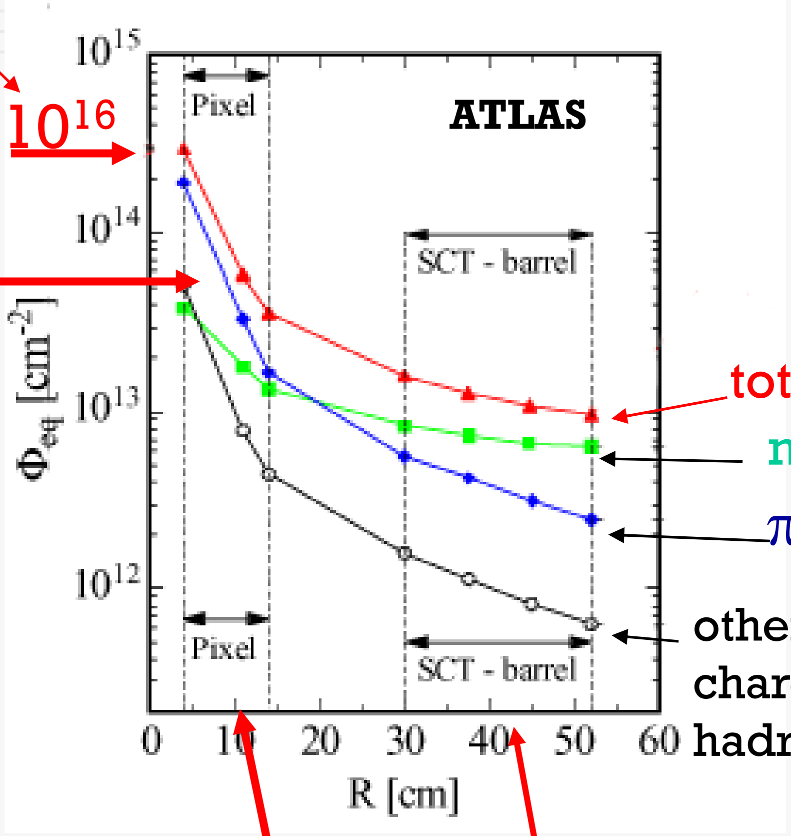
Multiple particle environment:
NIEL scaling 1 MeV n equivalent
Violation observed for oxygen rich materials

1MeV



1.8 x10^{16}

>85%
Ch hadrons



total

n

π

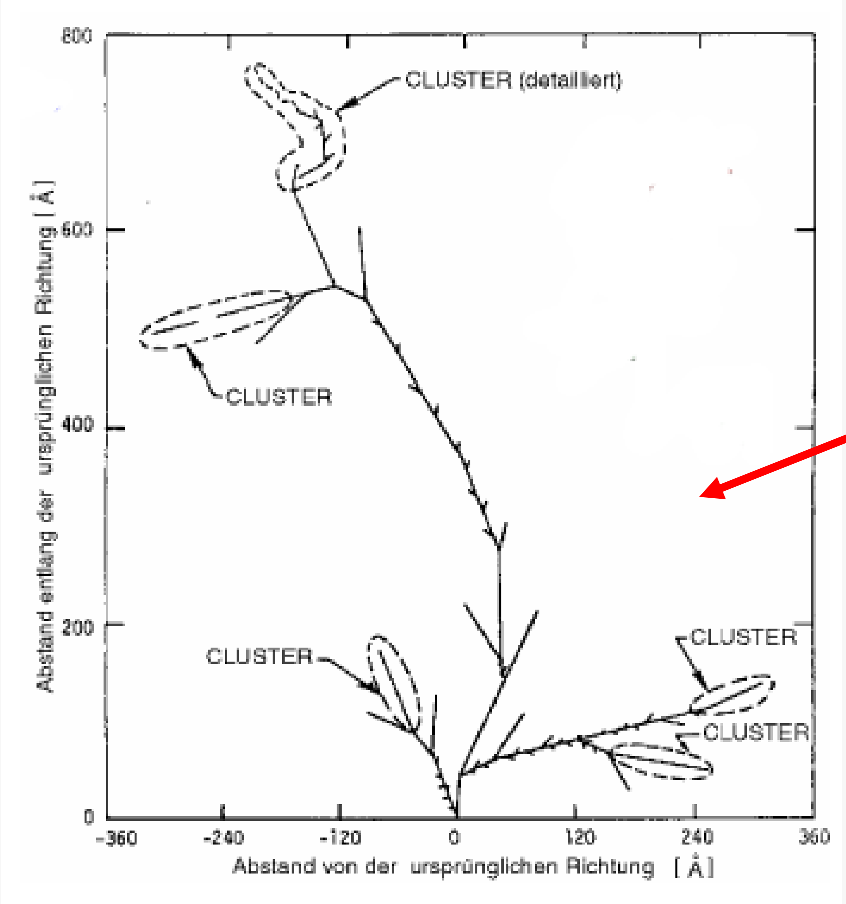
other charged hadrons

~5x10^{15}

~5x10^{14}

Data from CERN-TH/2002-078

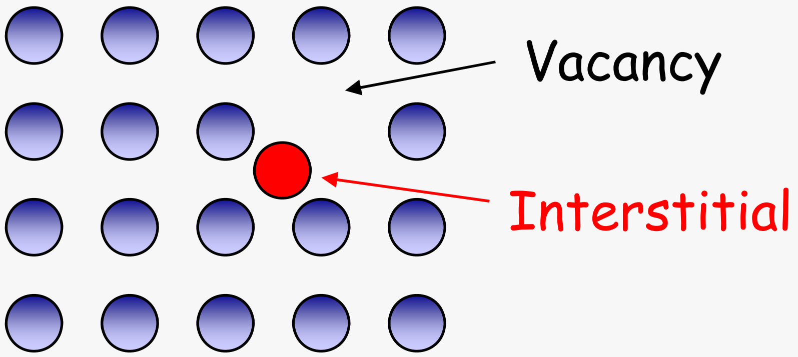
RADIATION INDUCED BULK DAMAGE in Si



Van Lint 1980

Primary Knock on Atom

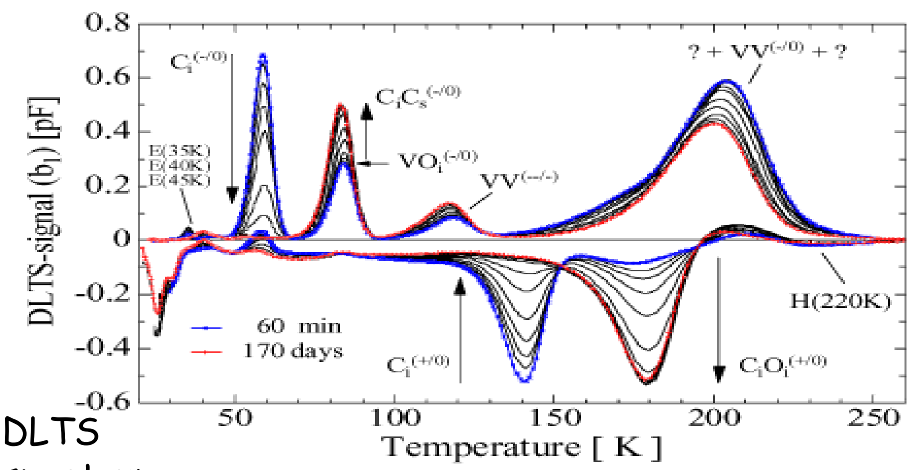
Displacement threshold in Si:
Frenkel pair E~25eV
Clusters E~5keV



RADIATION INDUCED STABLE DEFECTS IN SILICON

From Cern ROSE RD48

Neutron irradiated



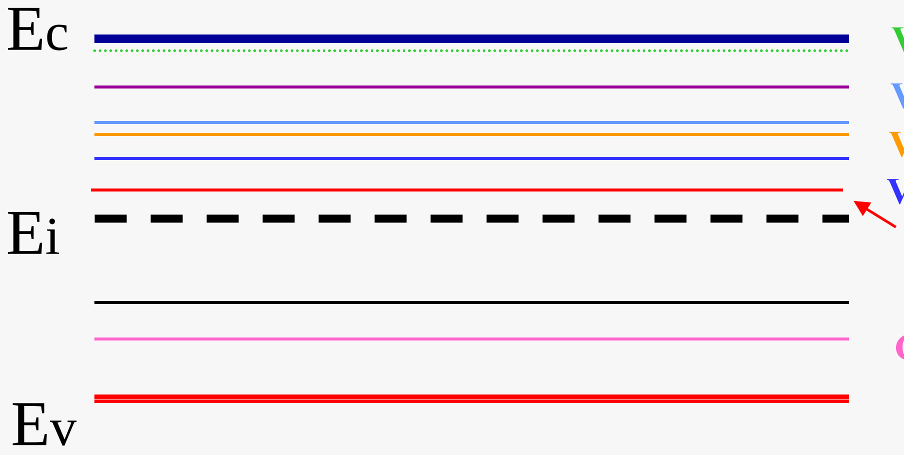
DLTS spectrum

DEFECT KINETICS (300K):

V,I + → IMPURITIES

→ DOPANTS

- ❖CHARGED DEFECTS ==>N_{EFF}, V_{BIAS}
- ❖DEEP TRAPS, RECOMBINATION CENTERS ==>CHARGE LOSS
- ❖GENERATION CENTERS==>LEAKAGE CURRENT



V_6

VO^- Ec - 0.17eV

$V2^{(=/-)}$+Vn Ec-0.22eV

$V2^{(-/0)}$+Vn Ec-0.40eV

V_2O

$C_IO_I^{(0/+)}$ Ev+0.36eV

- ❖VO effective e and h trap
- ❖V_2 and V_2O deep acceptors contribute to N_{eff}

What will happen to the present Si systems up 1×10^{15} n/cm2

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STANDARD 300μm n-type SILICON at 10^{15} n/cm^2
10 years of operation at L=10^{34} cm^{-2}s^{-1} at R=4 cm

EFFECTIVE DRIFT LENGTH
Due to charge trapping ~150mm e$^-$ ~50mm h

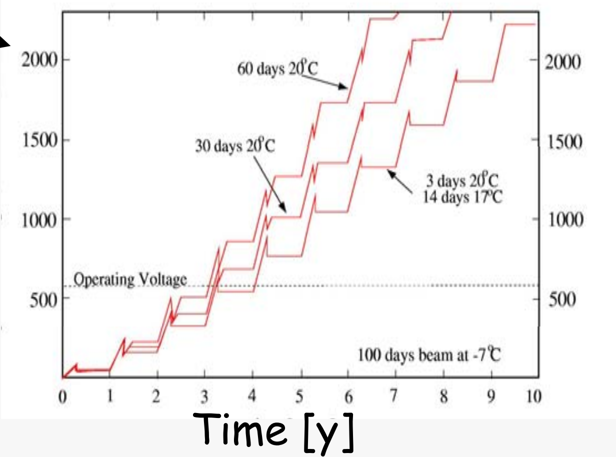
- ❖Signal formation
- ❖Charge sharing
- ❖Speed

SPACE CHARGE
TYPE INVERSION -ve N_{eff} (10^{13}/cm^3) ~ V_{FD} (5000V)~ F
depletion from n-contact (e-field)

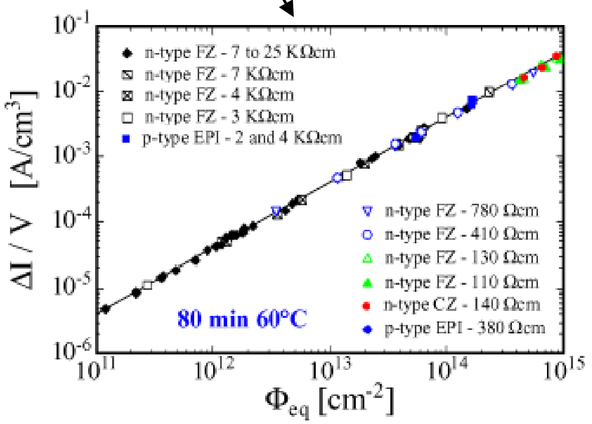
- ❖Double junction
- ❖Charge diffusion

REVERSE ANNEALING INCREASE OF -ve N_{eff} temp. dep

LEACKAGE CURRENT prop to Φ (I/V ~5x10^{-17} Φ)



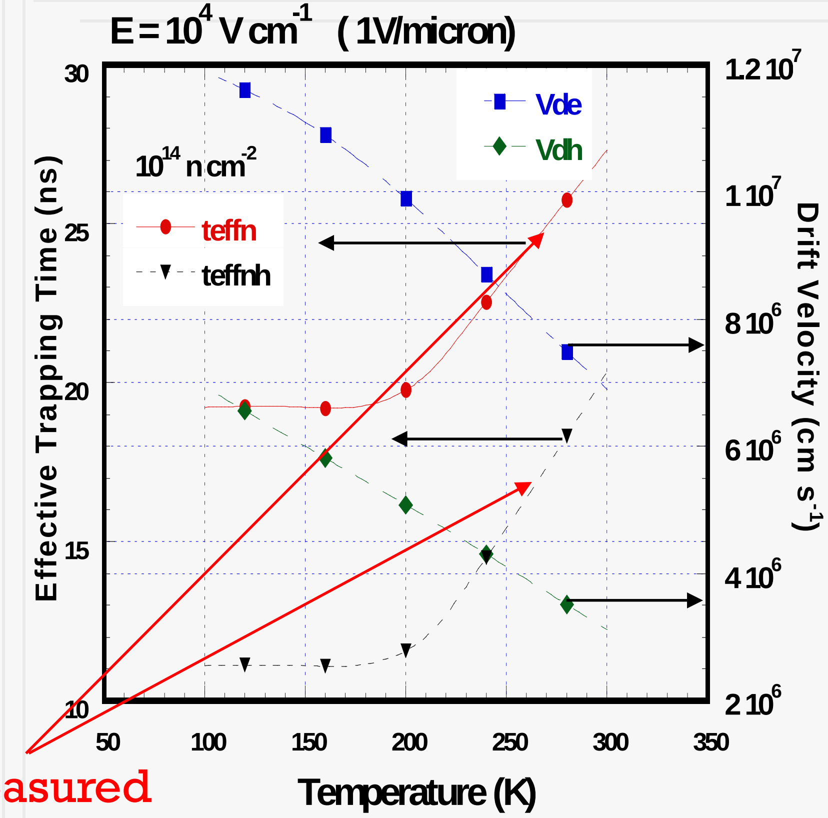
- ❖Maintenance



- ❖Noise
- ❖Thermal runaway

Carriers Collection Distance Determined by Effective drift length

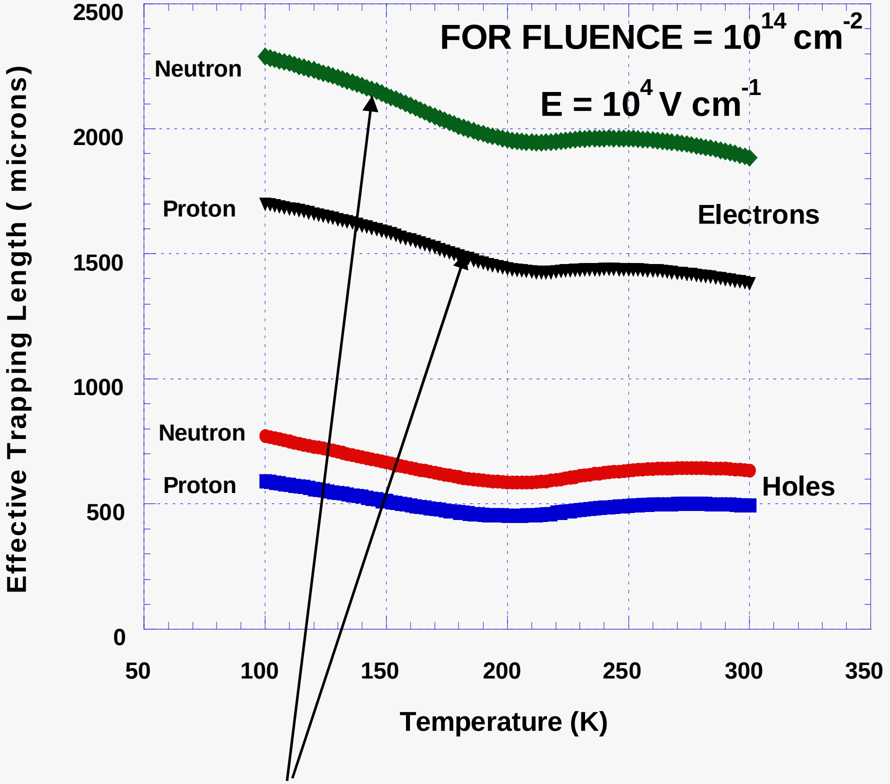
$L_{eff} = t_t \times V_{drift}$



Measured values

Data for neutron and protons of effective rapping time at 220K-300K from Kramberger et al

L_{eff} at 10^{16} proton/cm^2
~ 20μm electrons
~10 μm holes



Different between neutron and proton irradiation!

S. Watts, C. Da Via MIM A 501 (2003) 138-145

In summary a future 'new' pixel sensor technology for high luminosity will need to have:

- Radiation hardness
  - up to 10^{16} n/cm^2
- Speed
  - Reduced bunch crossing, pileups, rate
- Reduced dead edge
  - Material Budget, acceptance
- Efficiency – Functionality
- Noise - Capacitance
- Yield + Large Area + Cost + Large scale production

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

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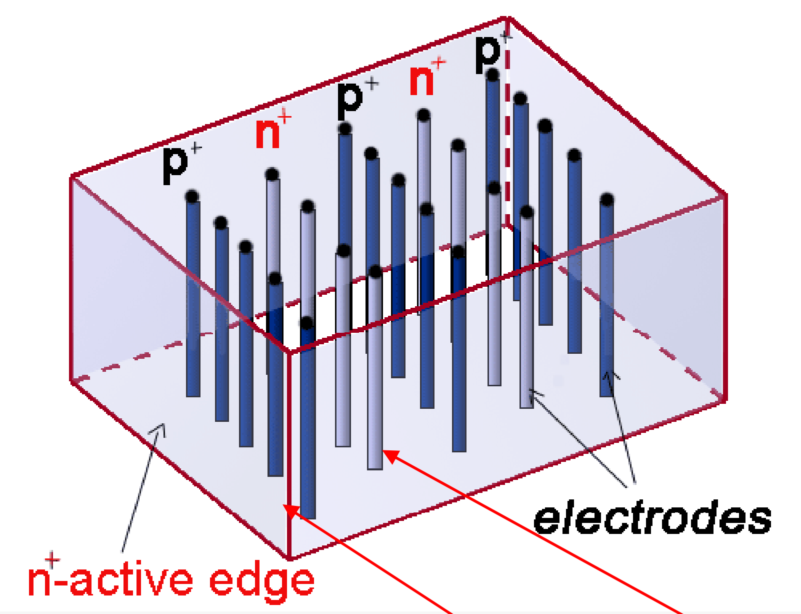
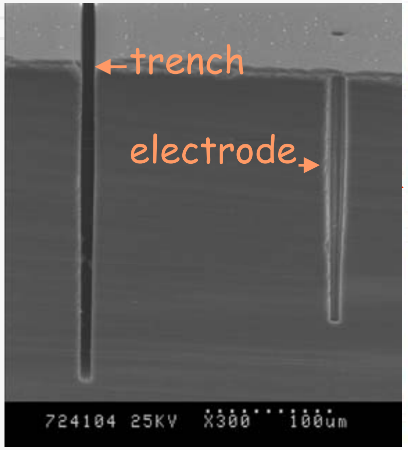
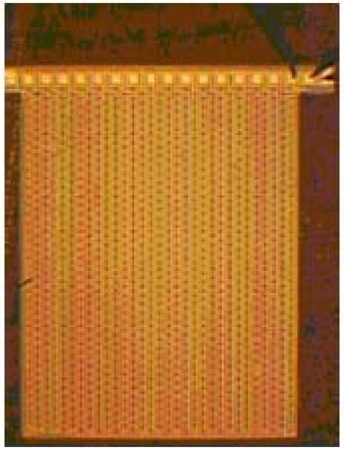
3D silicon sensors fabricated at Stanford by J. Hasi (Manchester) and C. Kenney (MBC)







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. NIMA 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!

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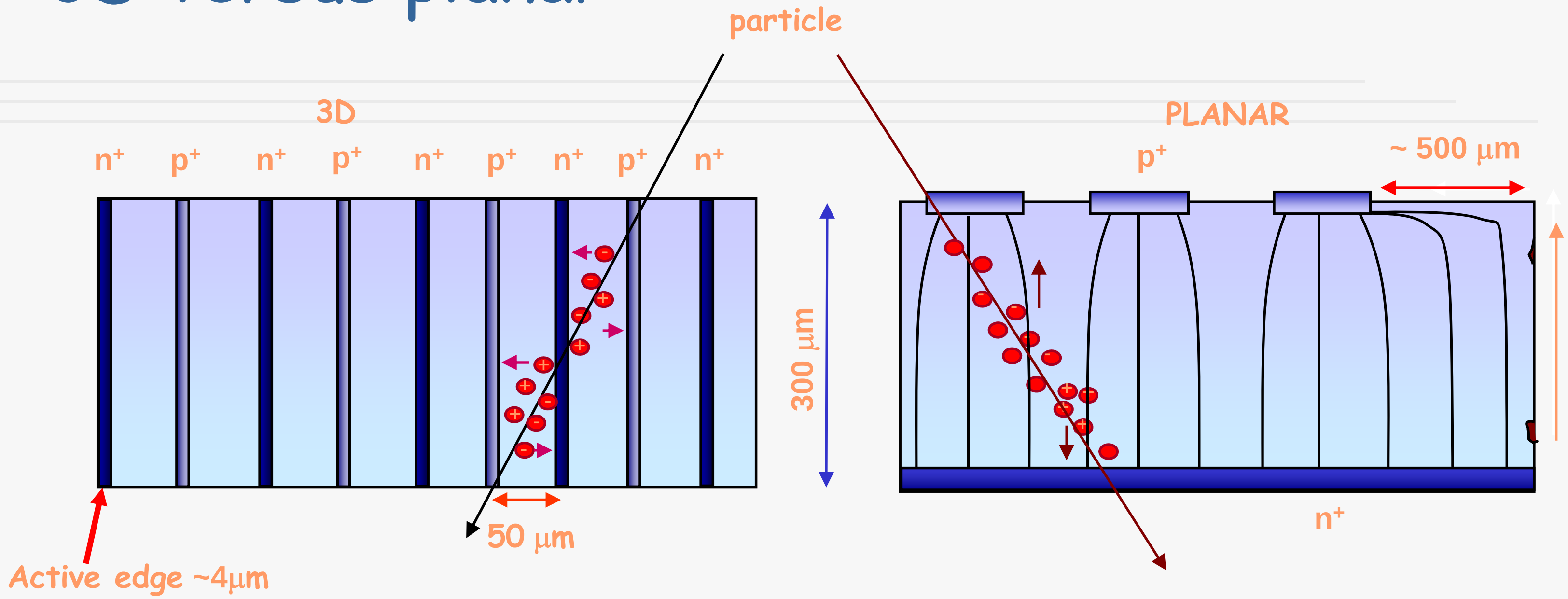
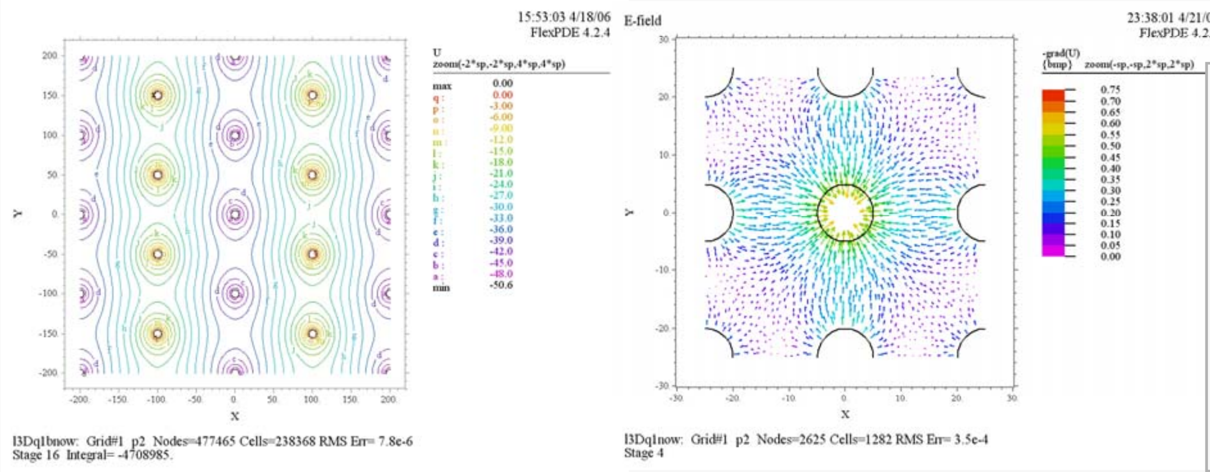
3D versus planar





	3D	planar
V_{dep}	< 5-10 V	50-70 V
Q_{1mip}	$24000e^-$	$24000e^-$
C	40-80fF	50-200fF
Lorentz angle	no	yes

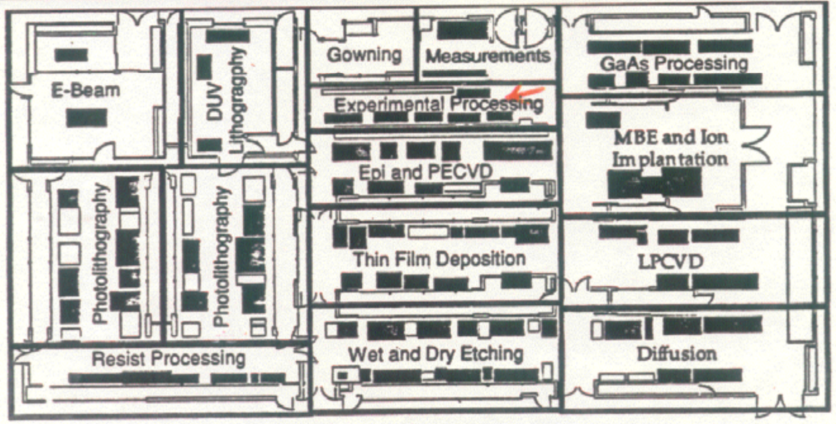
Simulations using FlexPDE by S. Watts

Processing

Currently performed at the Stanford-Nanofabrication-Facility (CIS) Stanford USA

C. Kenney (MBC), J. Hasi (Manchester)

BRUNEL – HAWAII – STANFORD
(Molecular Biology Consortium)

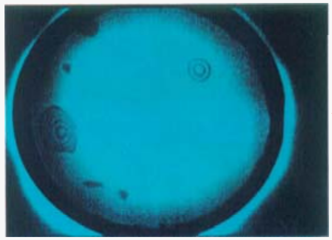


Key processing steps (25-32)

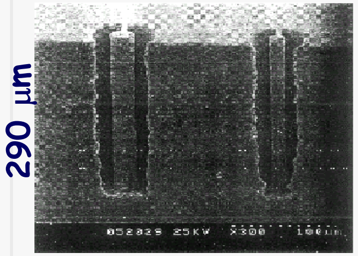
Aspect ratio:
D:d = 11:1

1- etching the electrode

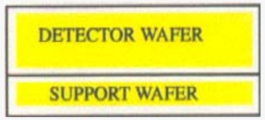
2-filling them with dopants



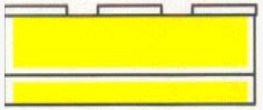
WAFER BONDING
(mechanical stability)
Si-OH + HO-Si -> Si-O-Si + H_2O



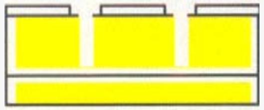
DEEP REACTIVE
ION ETCHING (STS)
(electrodes definition)
Bosh process
SiF_4 (gas) +C_4F_8 (teflon)



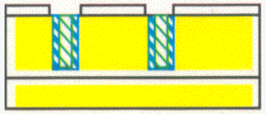
Step 1-3 field implant, oxidize and fusion bond wafer



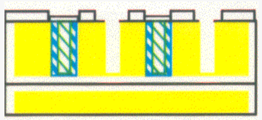
Step 4-6 pattern and etch p^+ window contacts



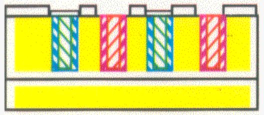
Step 7-8 etch p^+ electrodes



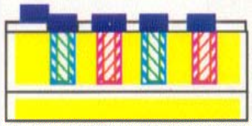
Step 9-13 dope and fill n+ electrodes



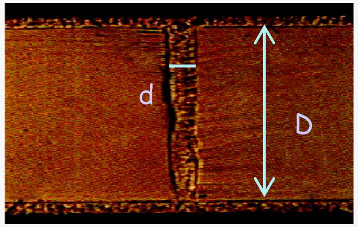
Step 14-17 etch n^+ window contacts and electrodes



Step 18-23 dope and fill p+ electrodes

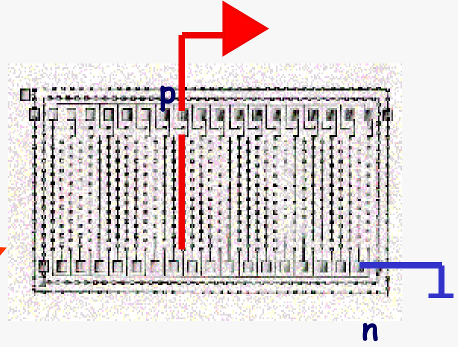


Step 24-25 deposit and pattern Aluminum



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

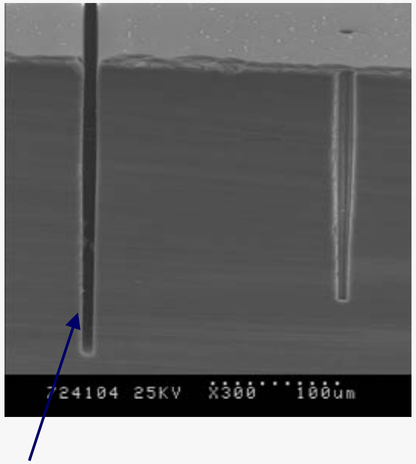


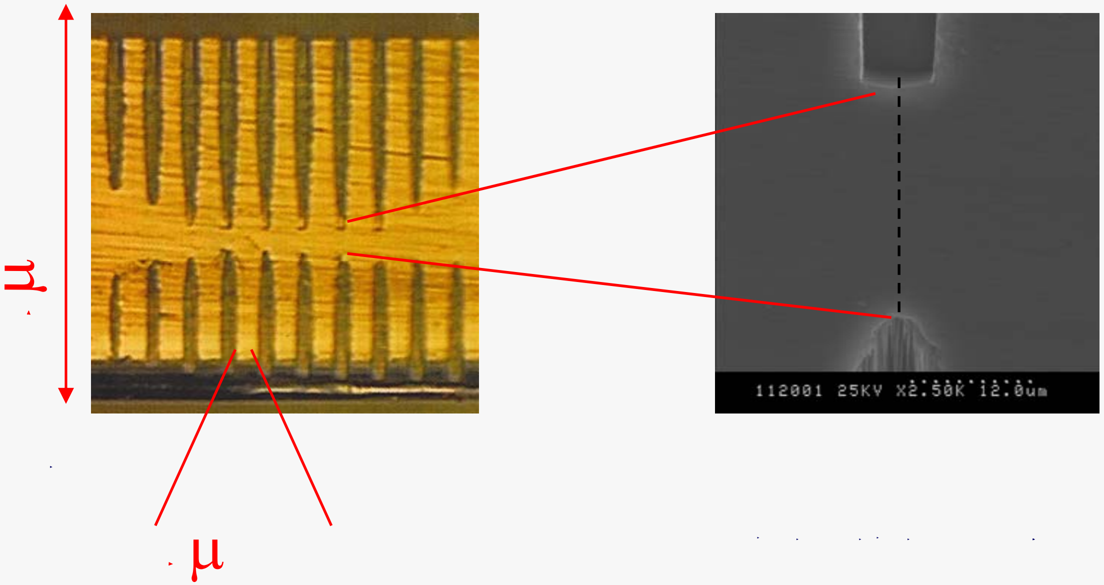
METAL DEPOSITION
Shorting electrodes of the same type
with Al for strip electronics readout
or deposit metal for bump-bonding

Improving the aspect ratio (D/d)

>Original production D/d=12:1 etching time = 5µm/min D=121 µm
>Present production D/d=19:1 etching time = 5µm/min
D=180 µm - 240 µm
>Double side etching D/d=25:1 etching time = 1.5µm/min
D=525 µm inter electrode spacing = 25 µm

Tests made with the original STS etcher. (Newer ones by Alcatel, STS, and others have a number of design changes. Etching should be faster. It should be possible to make narrower trenches and holes.)

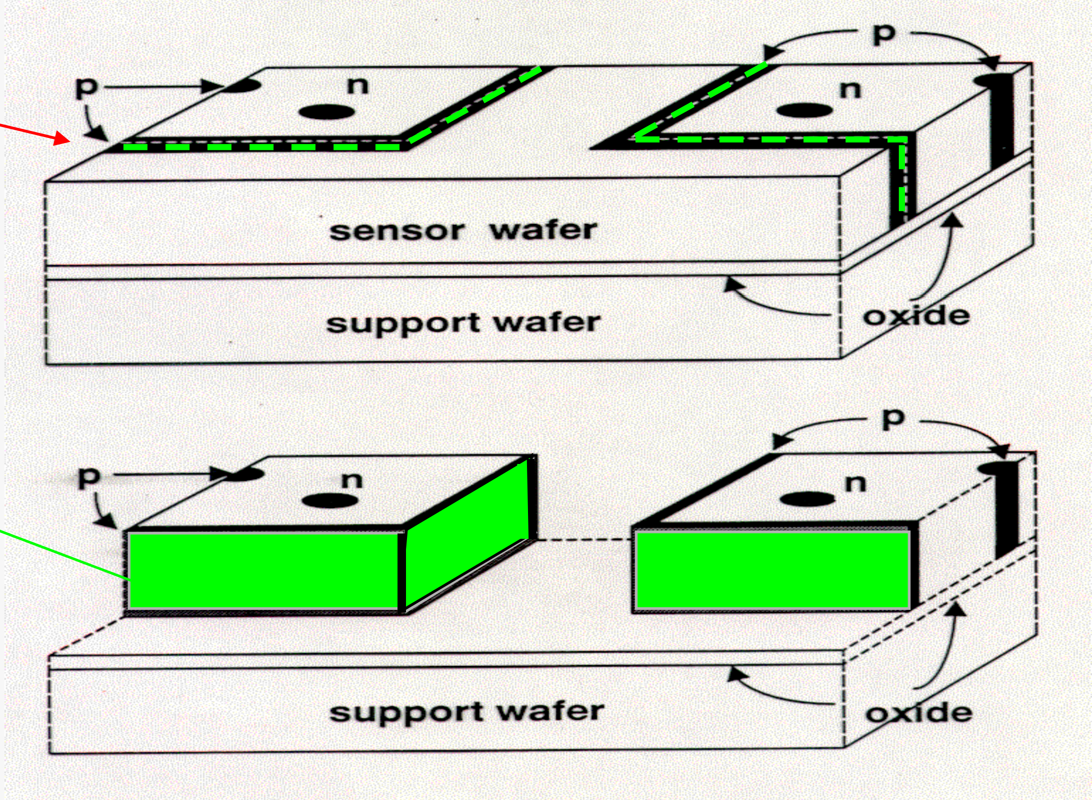




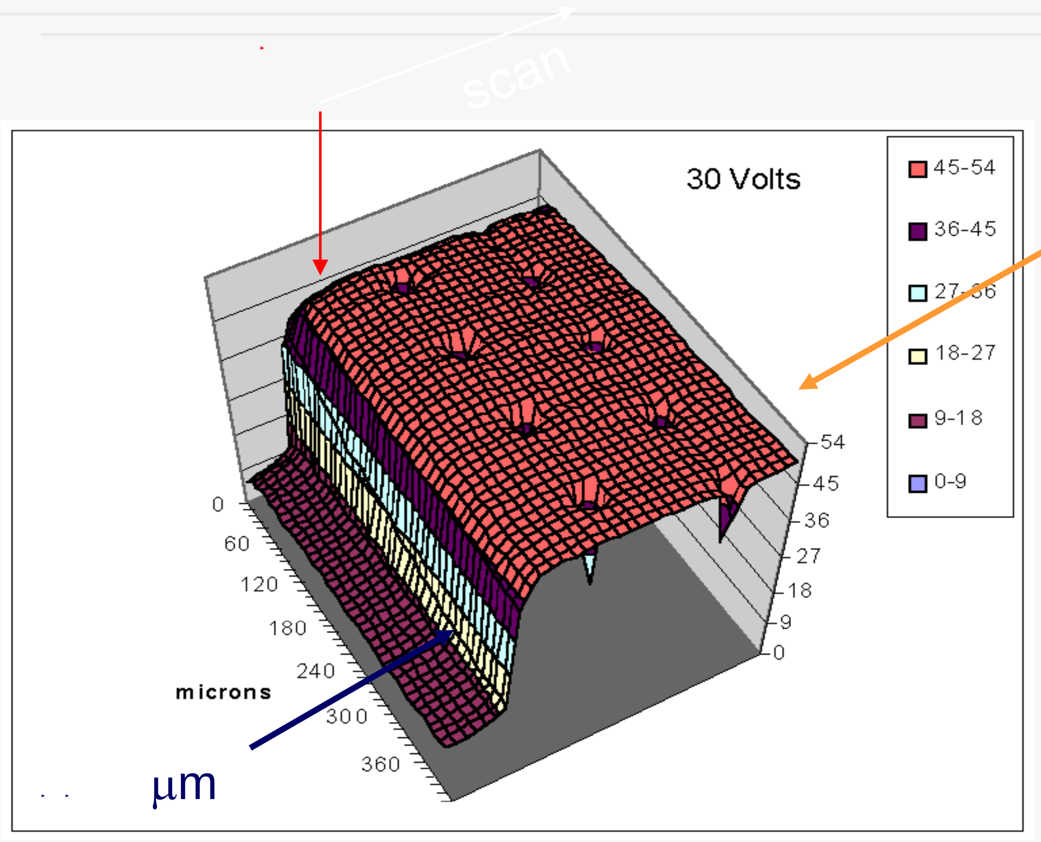
Active edge processing

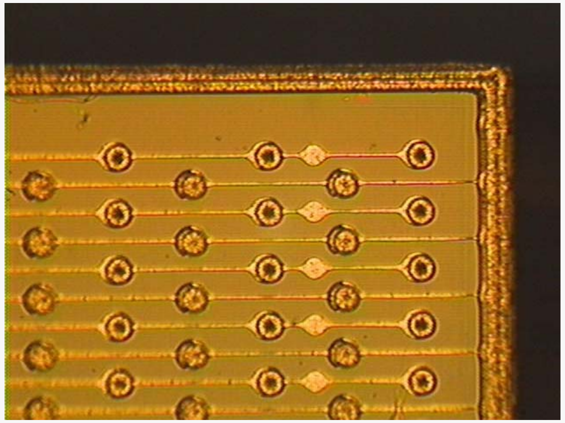
A TRENCH IS ETCHED AND DOPED TO TERMINATE THE E-FIELD LINES

AFTER THE FULL PROCESS IS COMPLETED THE MATERIAL SURROUNDING THE DETECTORS IS ETCHED AWAY AND THE SUPPORT WAFER REMOVED : NO SAWING NEEDED!!!
(NO CHIPS, NO CRACKS)



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

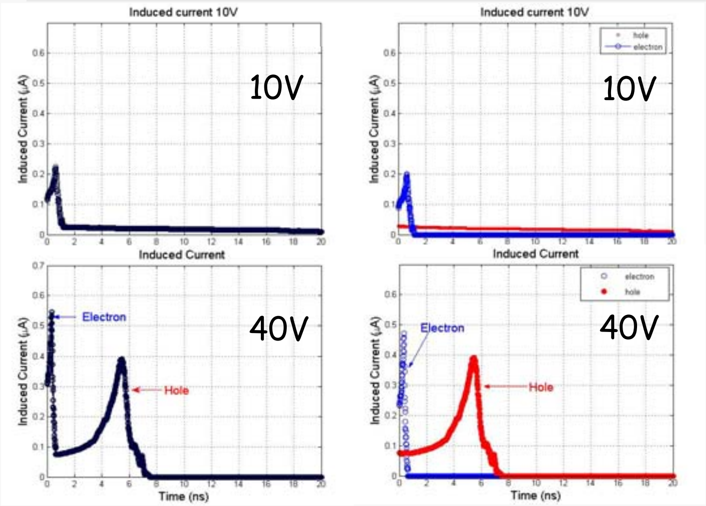
Electrodes ~ 1.8% of total area

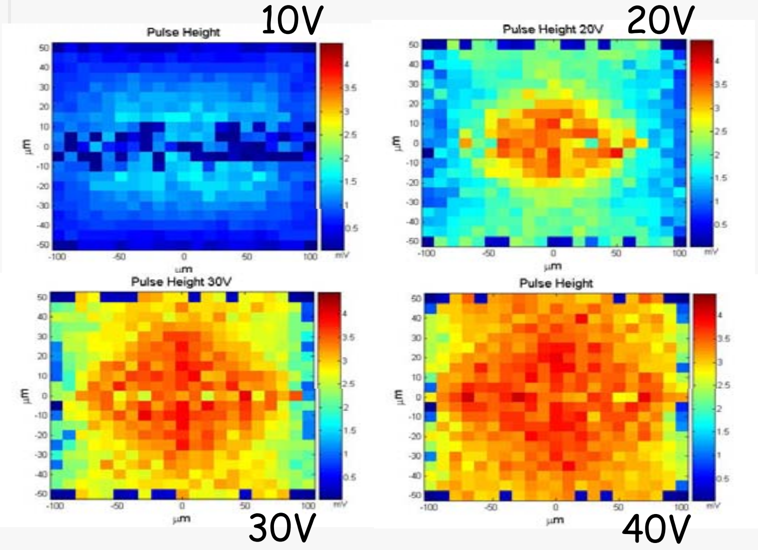
X-ray micro-beam scan, in 2 μm steps, of a 3D, n bulk and edges, 181 μm thick sensor. The left electrodes are p-type

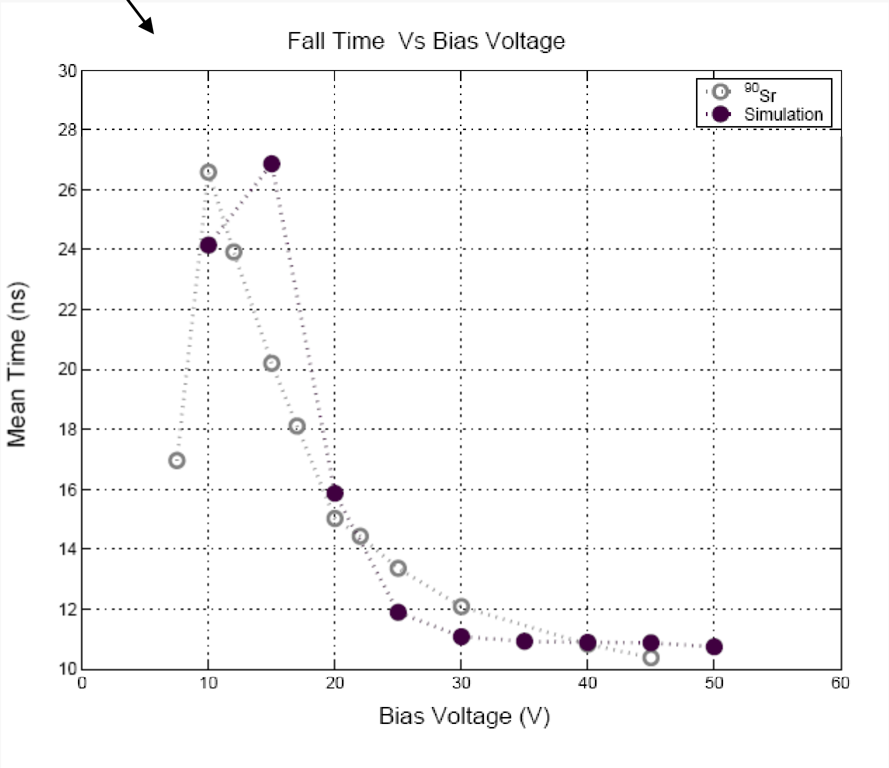
Efficiency measured in test beam ~98%

3D modelling and data fit

A. Kok PhD Thesis







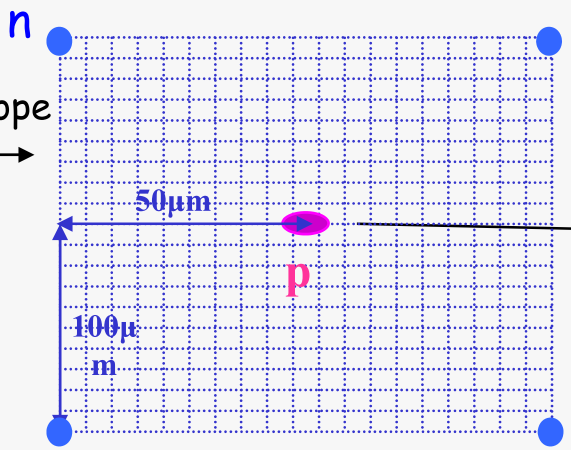
Simulation of signals fall time distribution over a cell (full dot) and ^{90}Sr data (open dot)

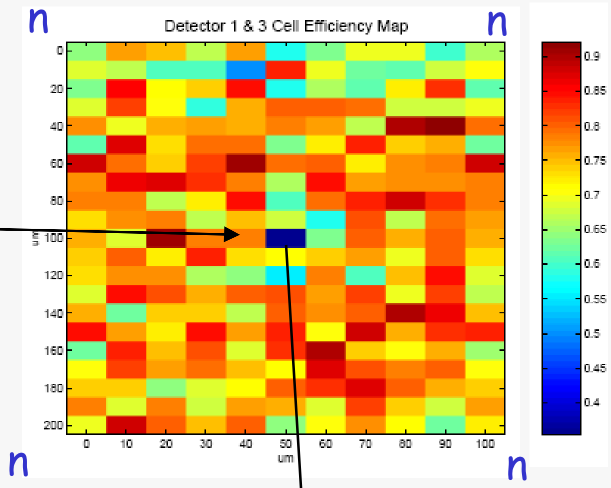
Efficiency: p and n electrodes response

Electrodes area ~1.8% of total area

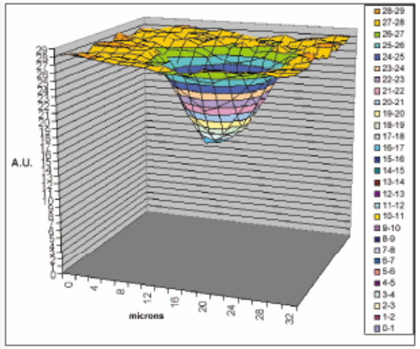
A. Kok PhD thesis

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



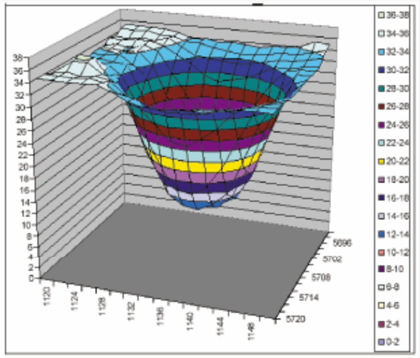


Electrode response using 12KeV X-ray beam (ALS), beam size ~ 2µm



N – Electrode

Signal Reduction 43%



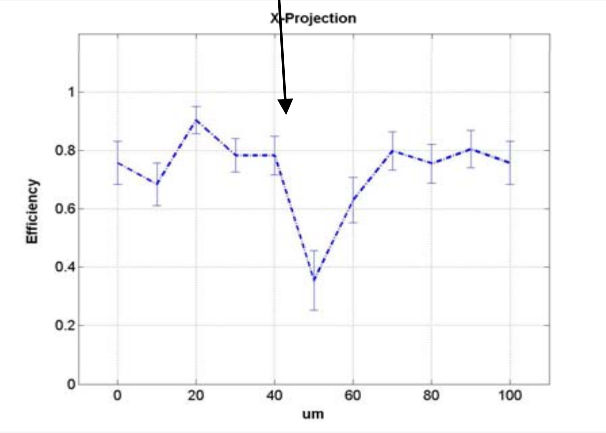
P – Electrode

Signal Reduction 66%

Differences between N and P:

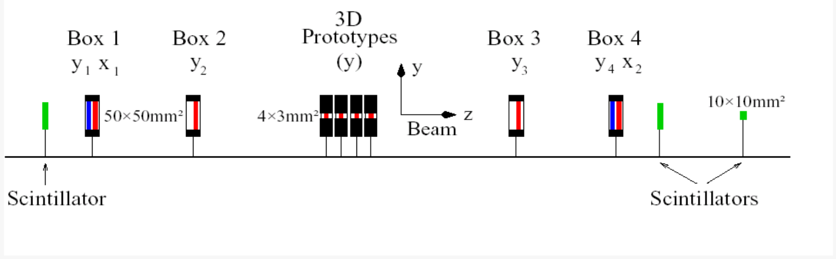
Grain size of poly, Diameter, Diffusion rate, Trapping, Doping

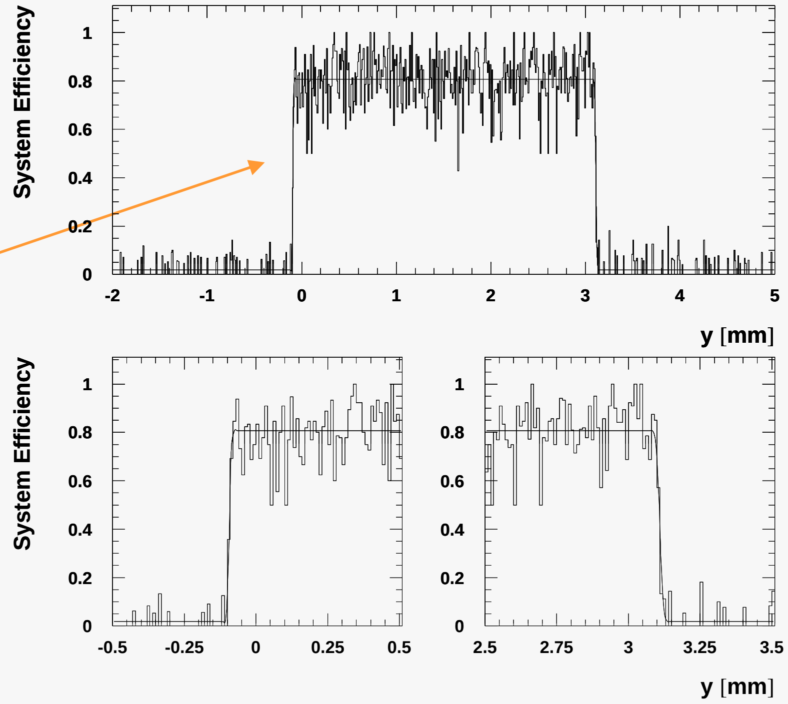
J. Hasi, PhD thesis



40% reduction in count efficiency at p-electrode

3D edge sensitivity with high energy muons





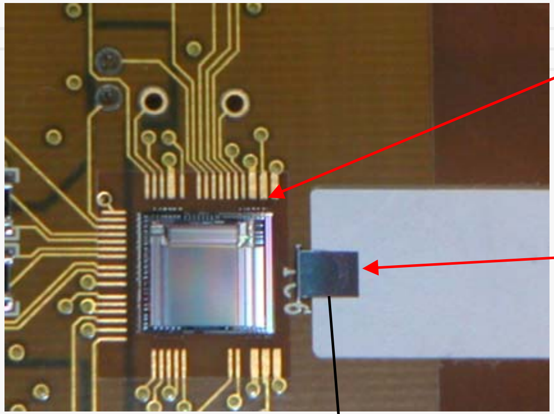
Atlas SCTA readout

Fit width = (3.203 ± 0.004) mm

Phys. width = (3.195 ± 0.001) mm

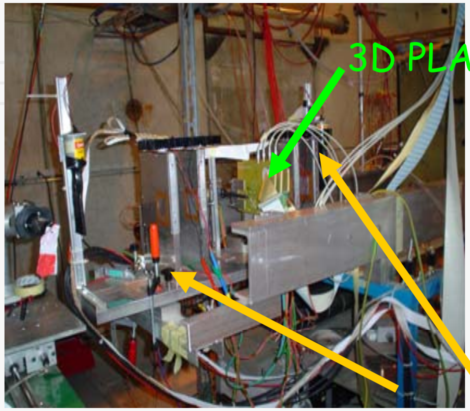
Response to particles: 120 GeV muon beam +0.25 mm LHC compatible readout (CMS/Totem)

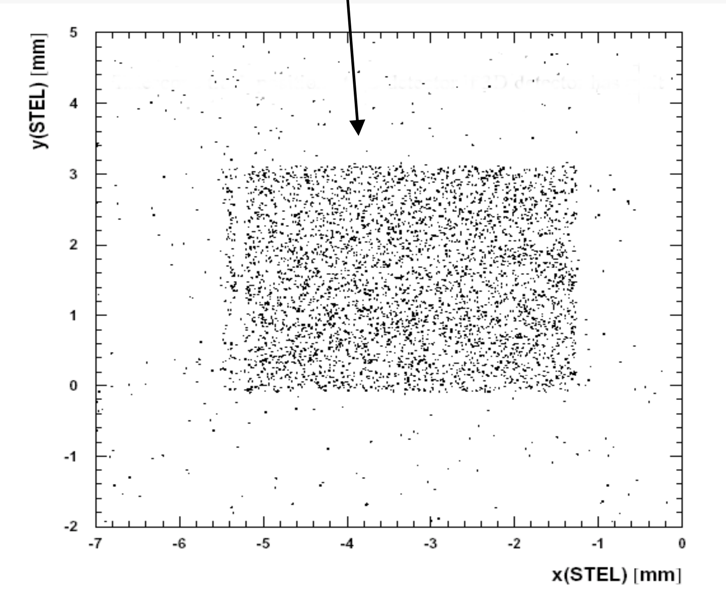
Cinzia Da Via'- Edinburgh - March 2007



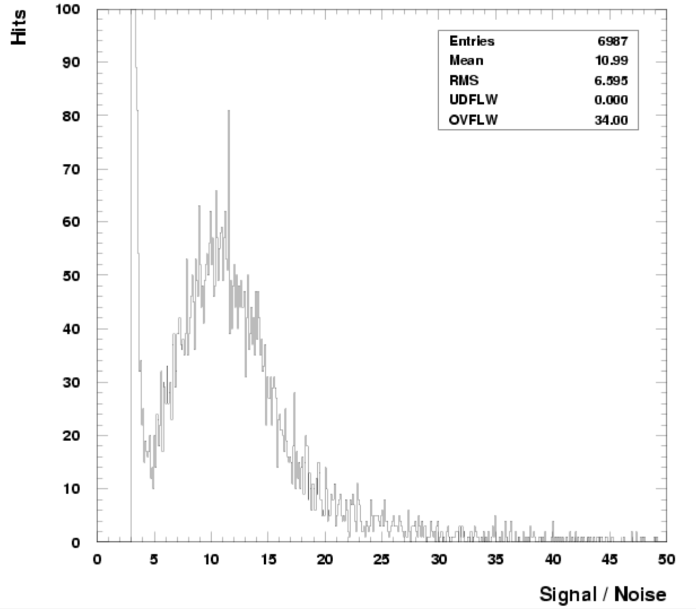
SCTA READOUT CHIP*

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





Telescope track position at 3D
if 3D has a hit



S:N=14:1
Efficiency= 98%

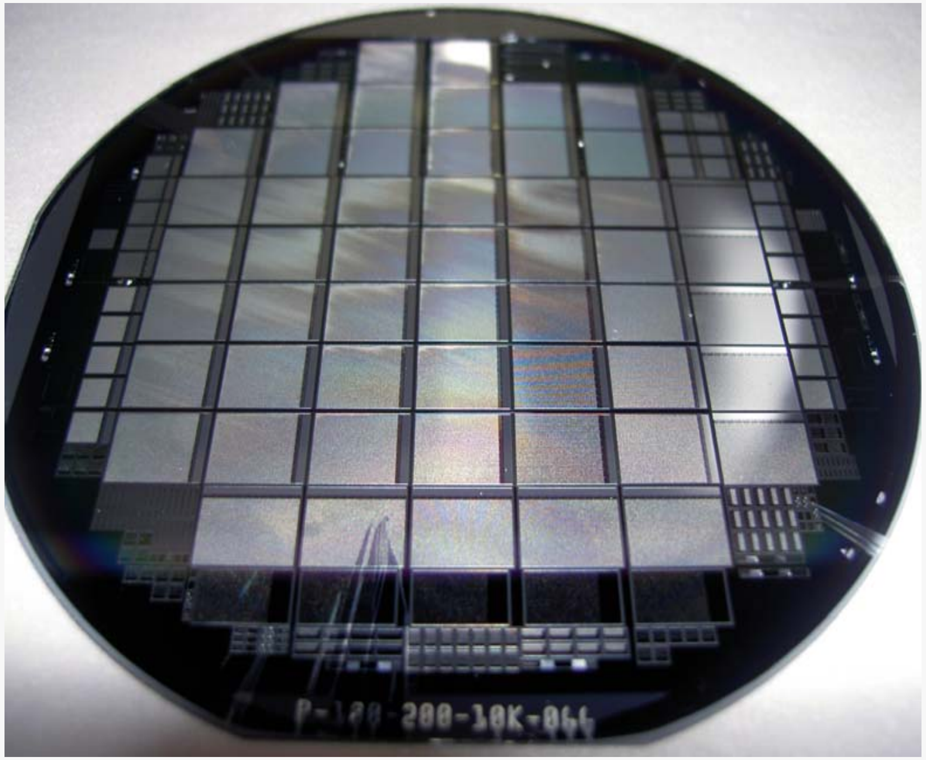
*IEEE Trans.Nucl.Sci.44:298-302,1997
-TOTEM TDR-CERN

Yield + Large area : FP420/Atlas pixel

(bump-bonding IZM organised by the Bonn Group)

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

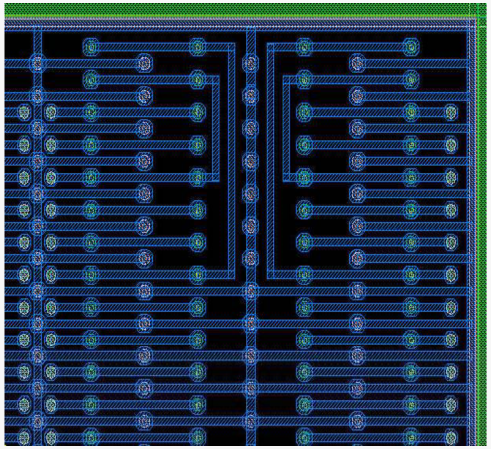
-Other structures

Thickness <250 μm>
p-type substrate 12kΩcm

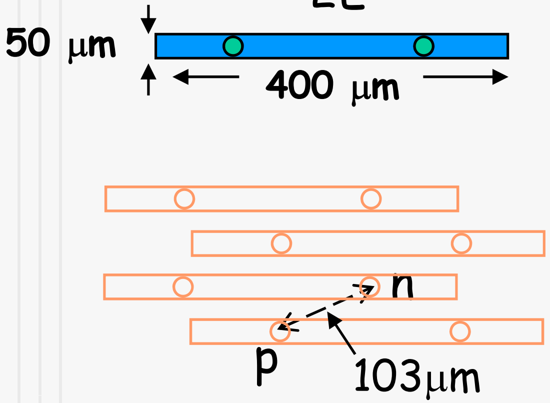
10 wafers completed : Yield on one wafer ~80%

Cinzia Da Via'- Edinburg - March 2007

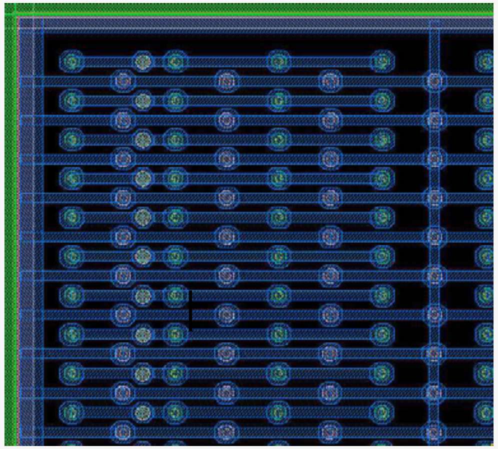
3D FP420/Atlaspix electrode configurations



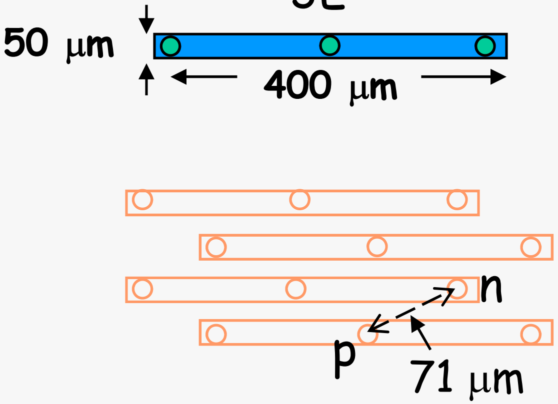
2E



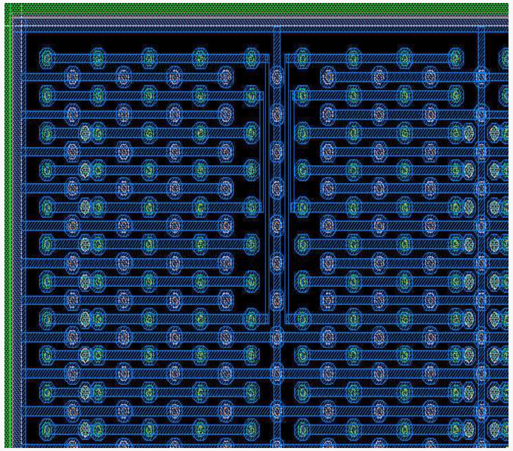
V_{fd} ~20V
El. Area 4%



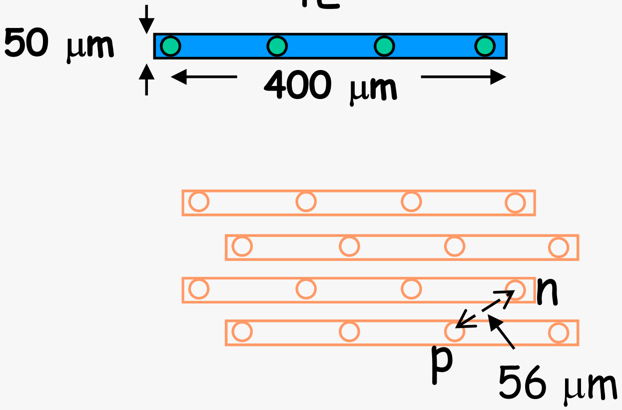
3E



V_{fd} ~8V
El. area 6%

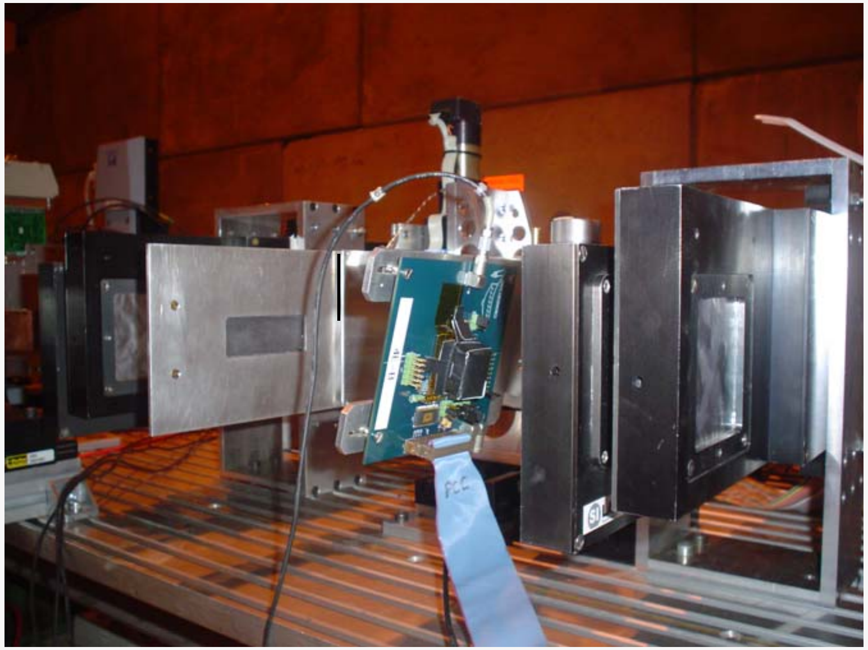


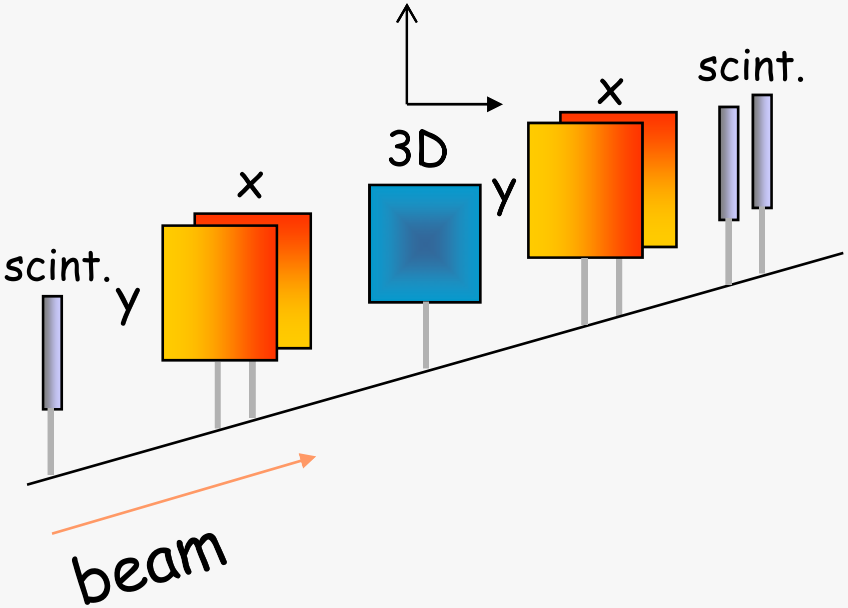
4E



V_{fd} ~5V
El. area 8%

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





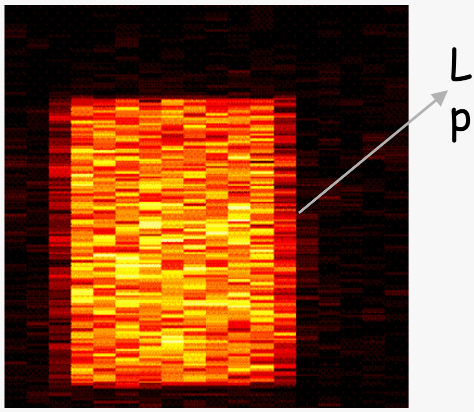
Telescope, daq and on-line monitor by Lars Reuen, Atlas pixel setup and data conversion Markus Mathes (Bonn group)

100 GeV π^-

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

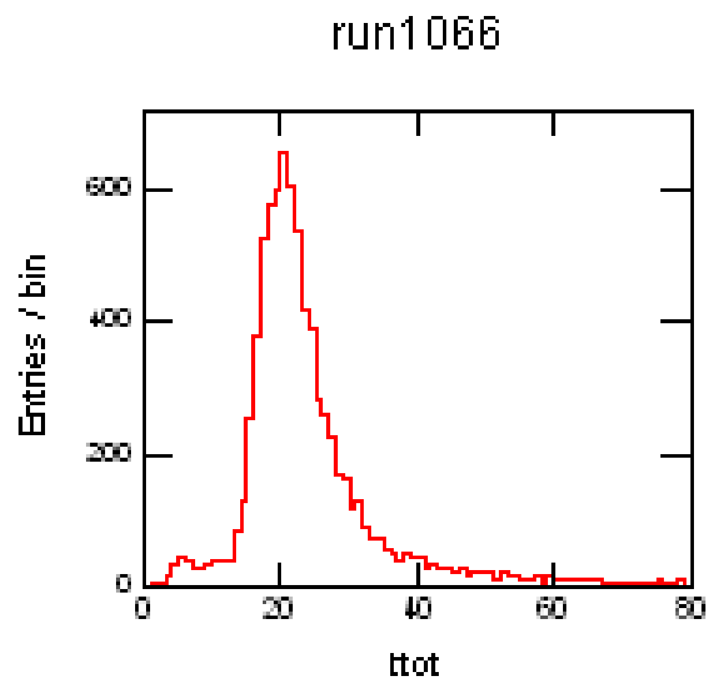
3D-2E-A preliminary

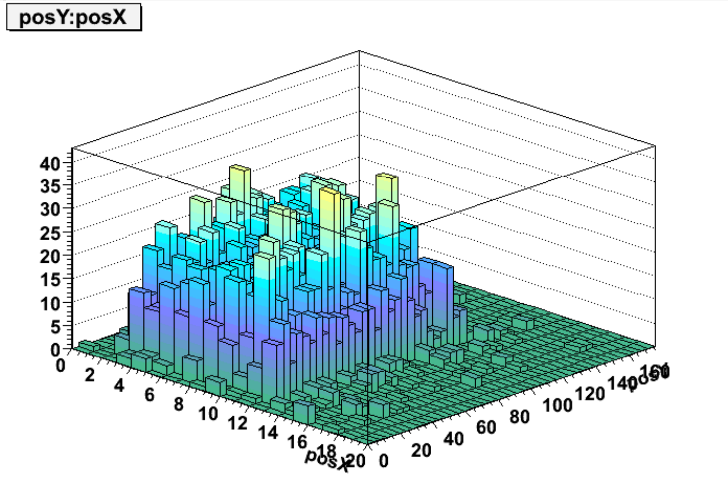
V_{bias}=30V Threshold=4000e^{-}



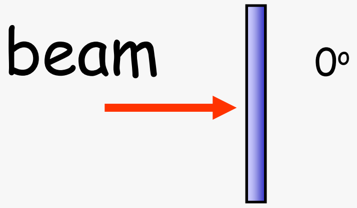
Longer pixels

hitmap with the 12x12 mm² trigger



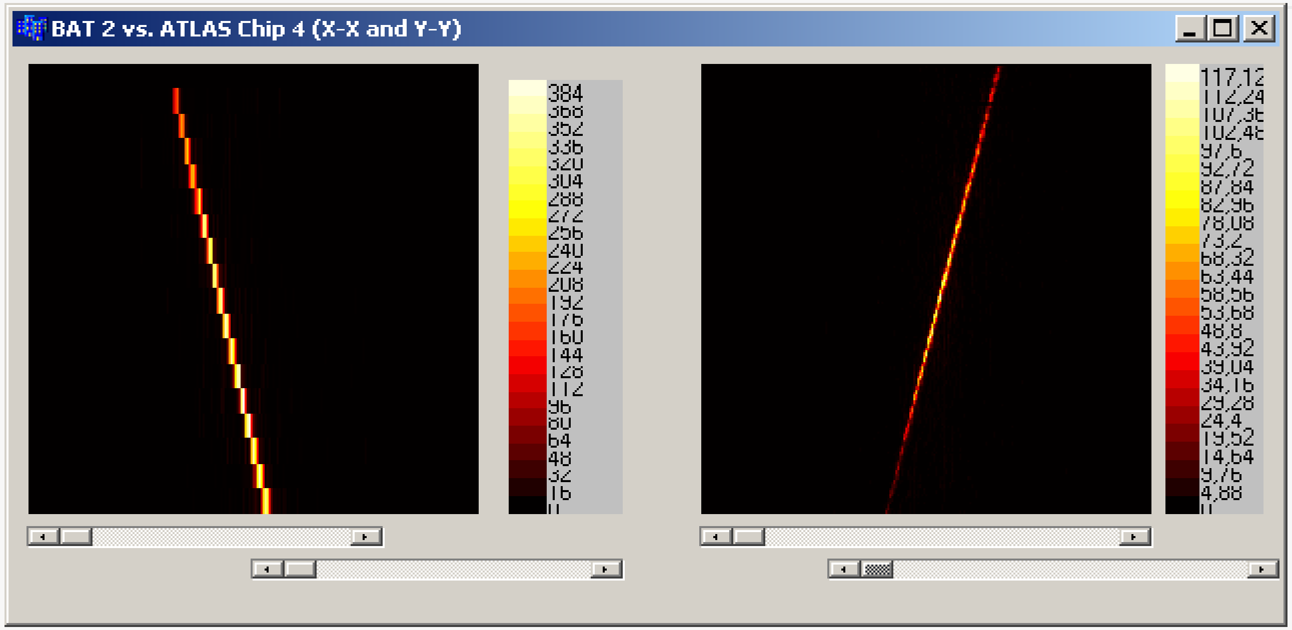


hitmap with the 3x3 mm² trigger



3E-G correlation plots and hit maps

x-x y-y

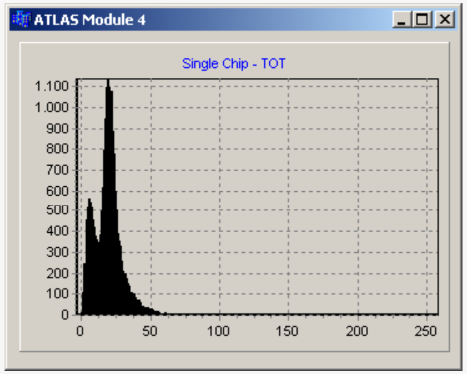


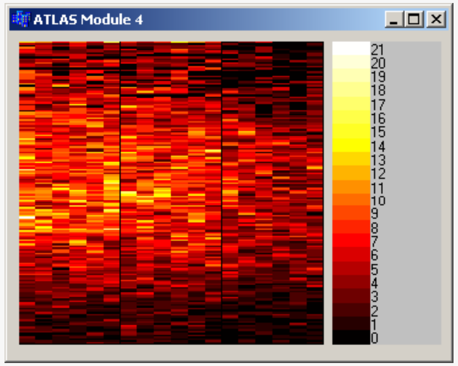
V_{bias} =15V

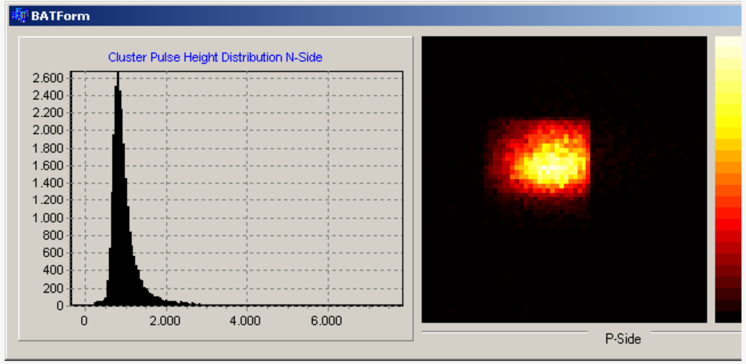
Th. = 4000e^-

Tot 3D

Telescope



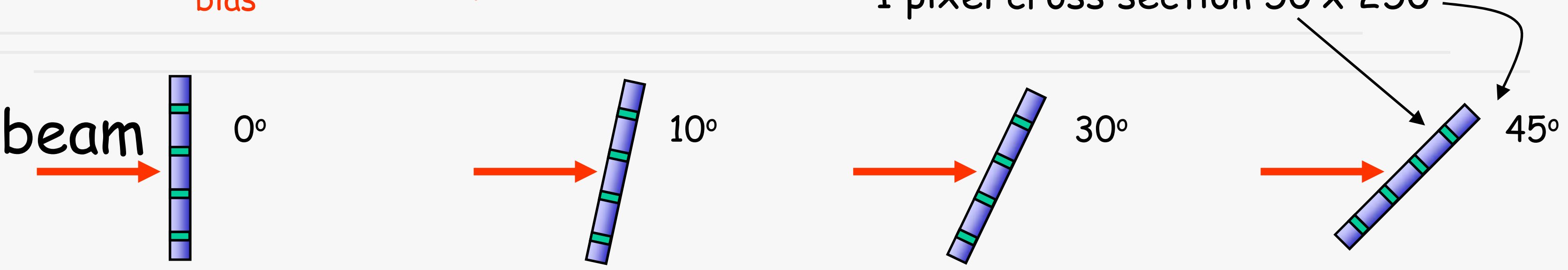


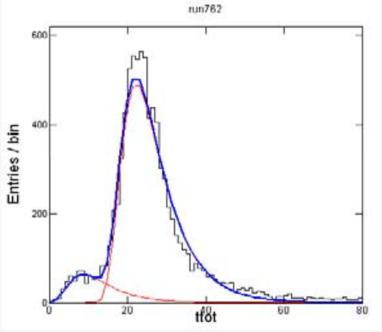


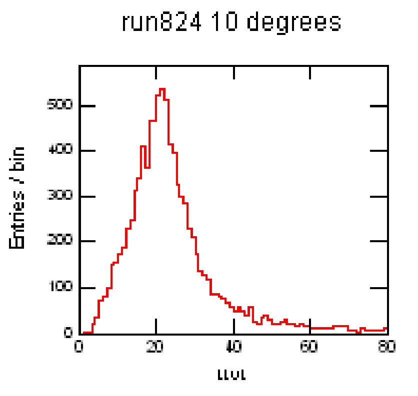
4E electrode angular response - preliminary

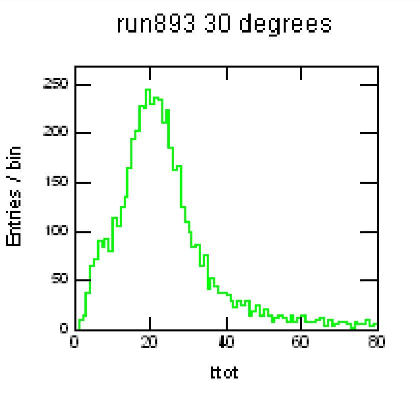
V_{bias}= 20V Th. = 4000e^{-}

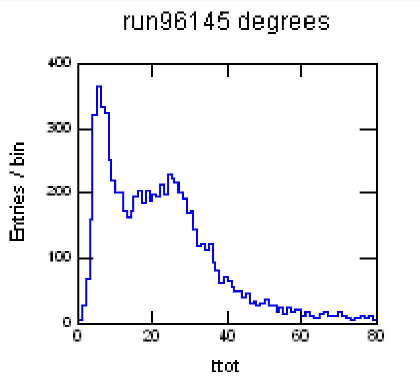
1 pixel cross section 50 x 250

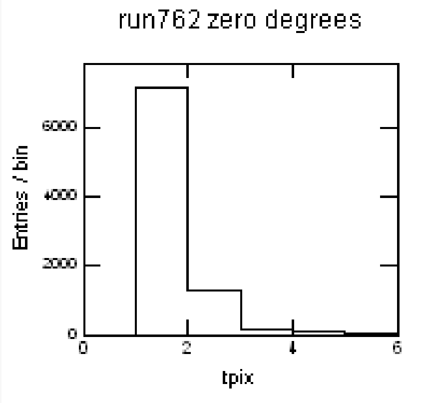


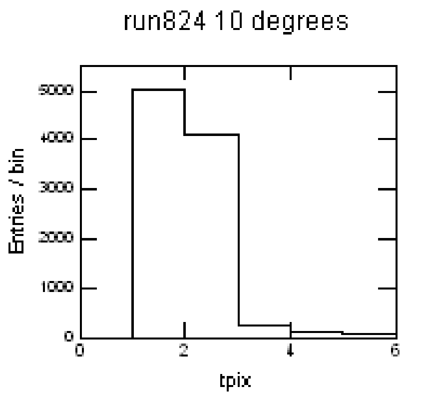


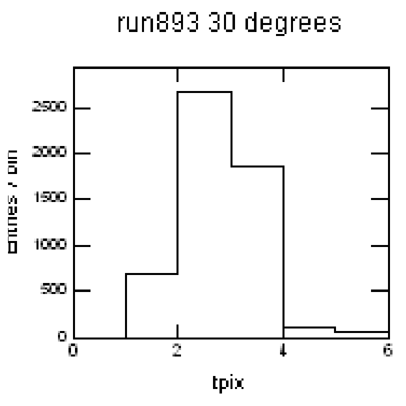

run824 10 degrees

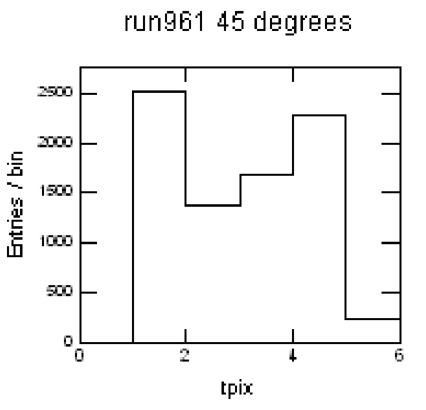

run893 30 degrees


run96145 degrees


run762 zero degrees

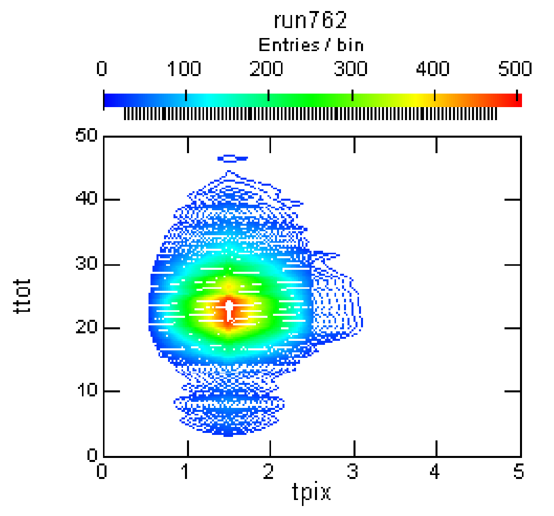

run824 10 degrees


run893 30 degrees

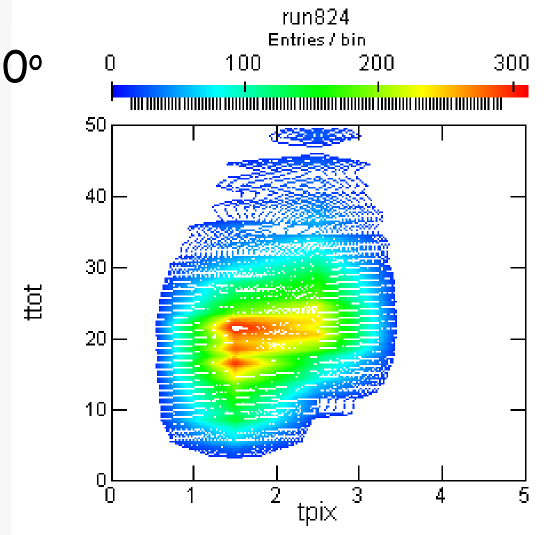

run961 45 degrees

4E- Signal size versus cluster size

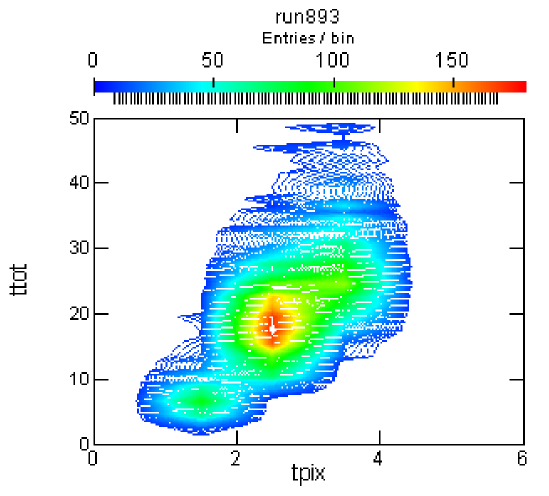
0°



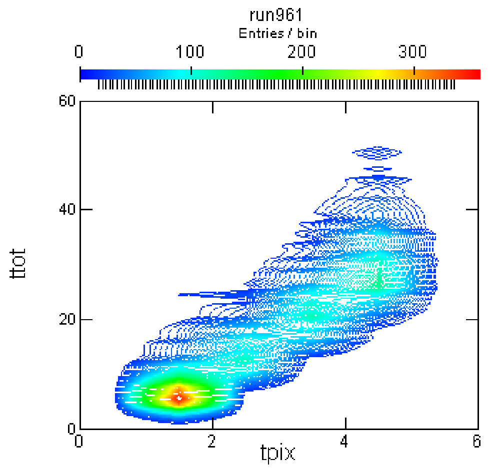
10°



30°



45°



90 Degree data - run 1228

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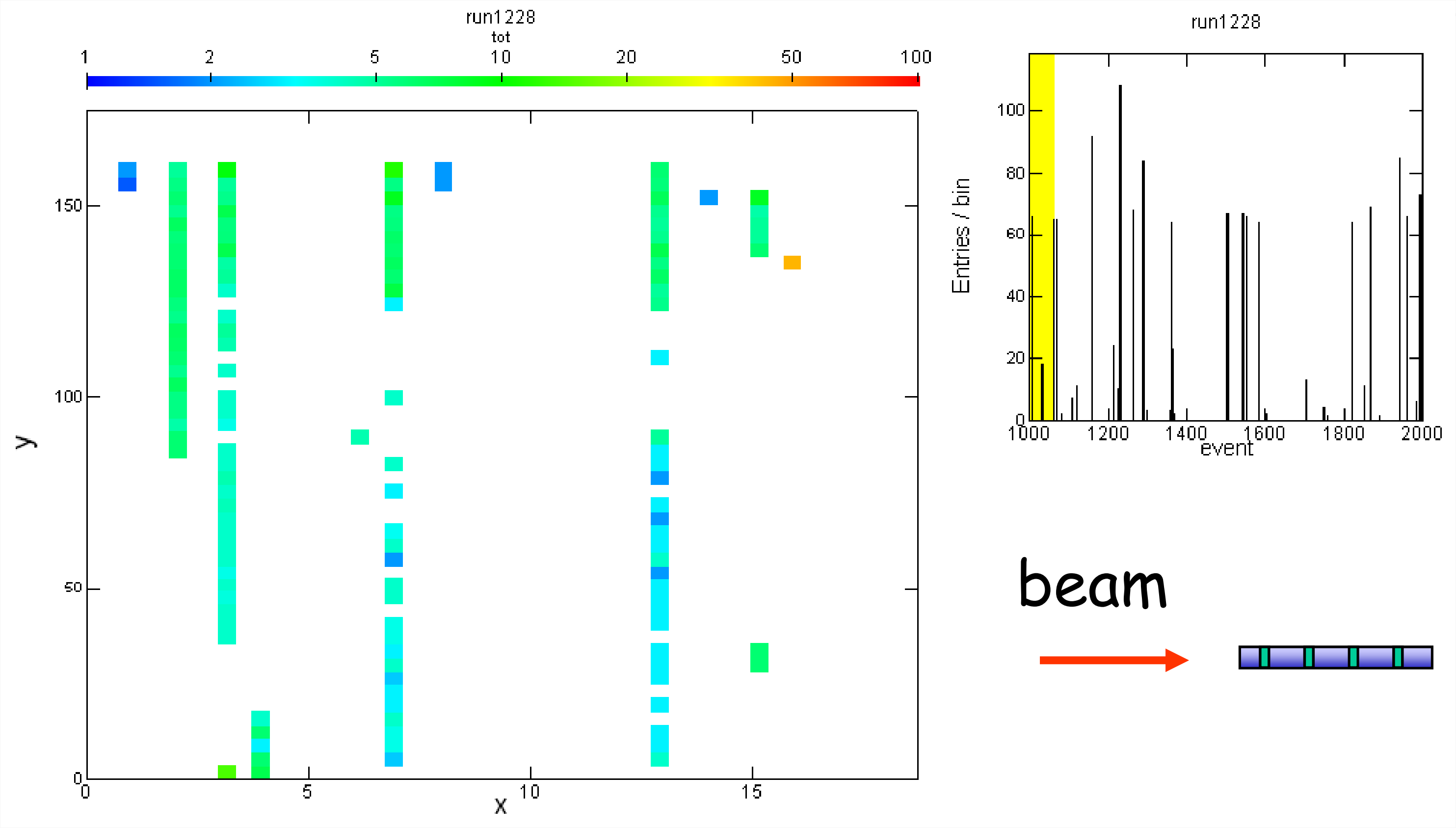
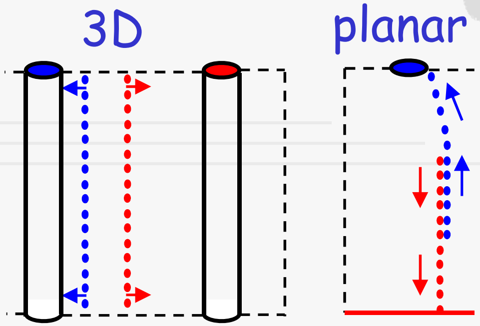


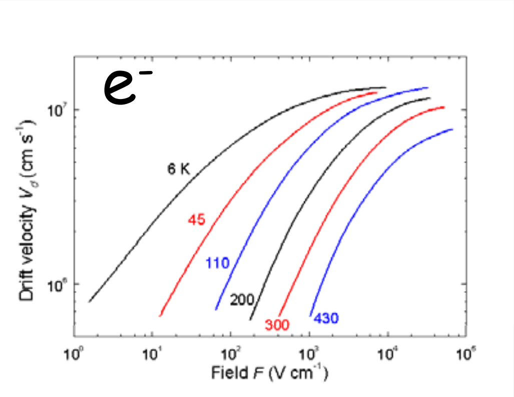
Several events on one plot

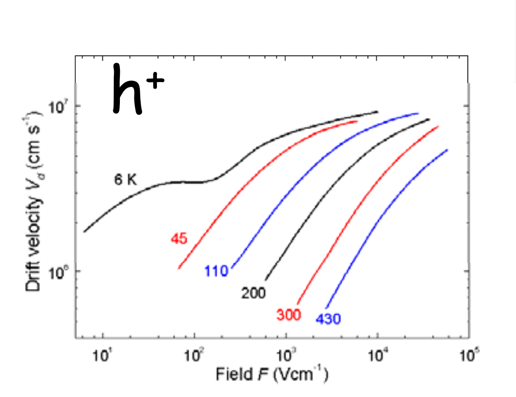
Why is 3D radiation hard

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

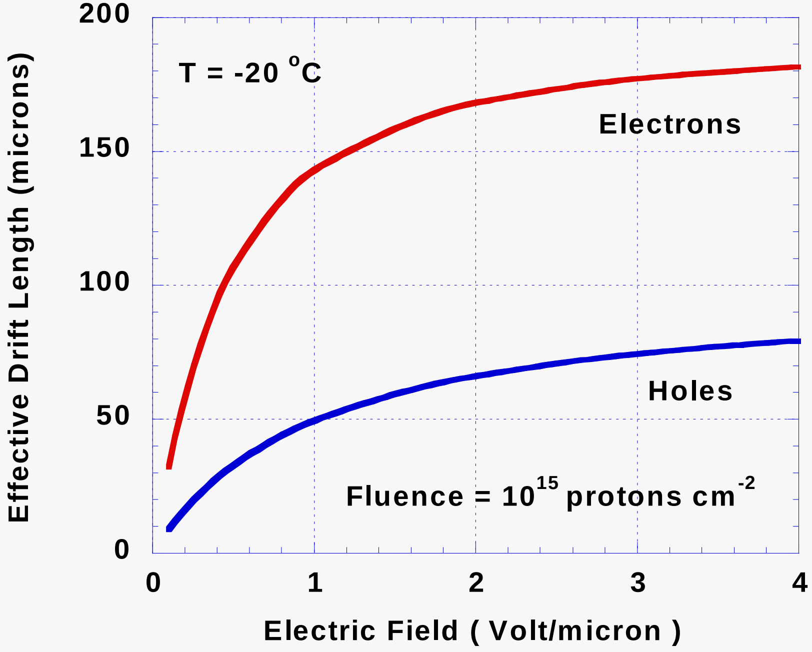


$$L_{eff} = v_{drift} \times \tau_{trap}$$



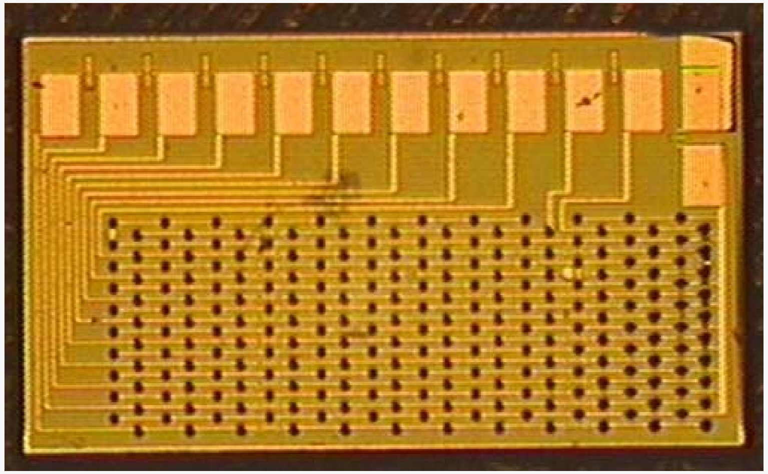


Ottaviani, Canali et al.



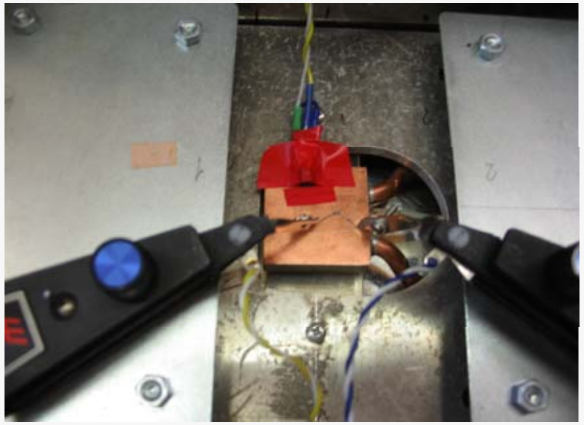
Trapping times from Kramberger et al. NIMA 481 (2002) 100
Simulations CDV and S.Watts NIM A 501(2003) 138 (Vertex 2001)

Radiation hardness tests of 3D-3E Atlas geometry

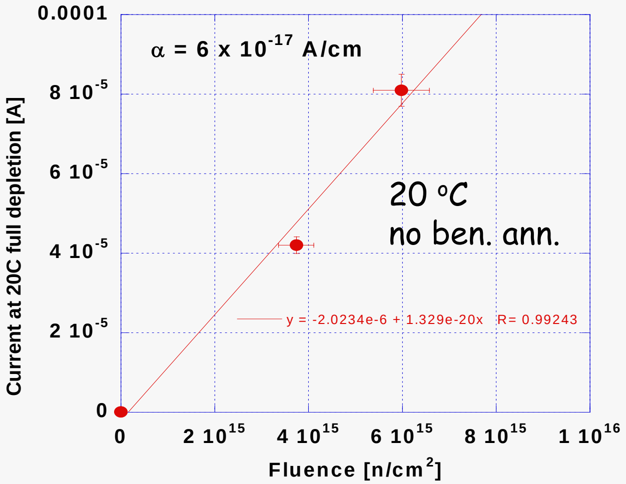


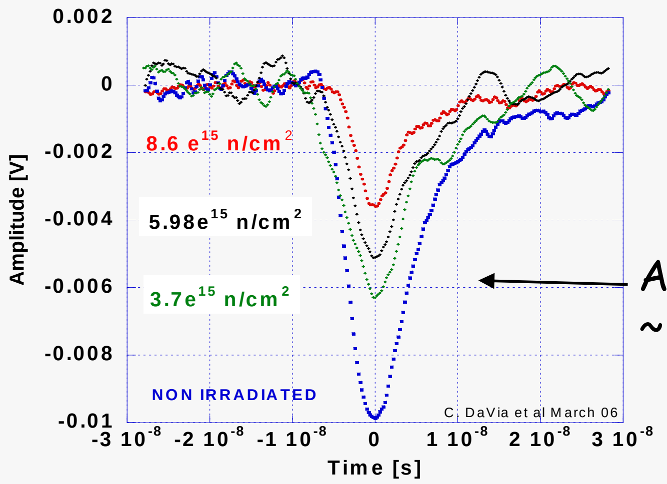
- Volume = 1.2 x 1.33 x 0.23 mm^3
- Inter-electrode spacing = 71 μm
- 3 electrode Atlas pixel geometry
- n-electrode readout
- n-type before irradiation -12 kΩ cm
- Irradiated with reactor neutrons (Praha)

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

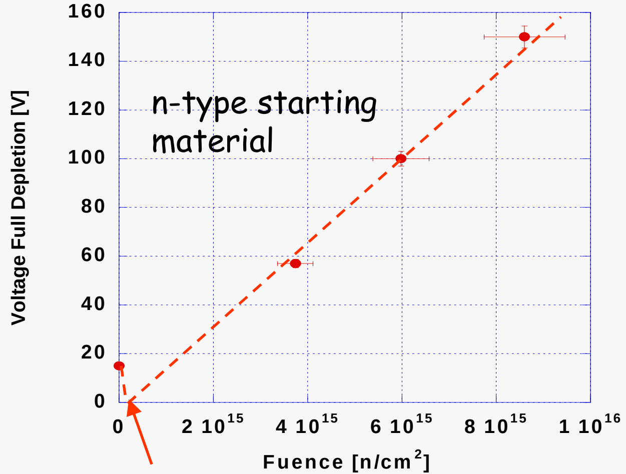


Radiation hardness: macroscopic parameters and signal efficiencies

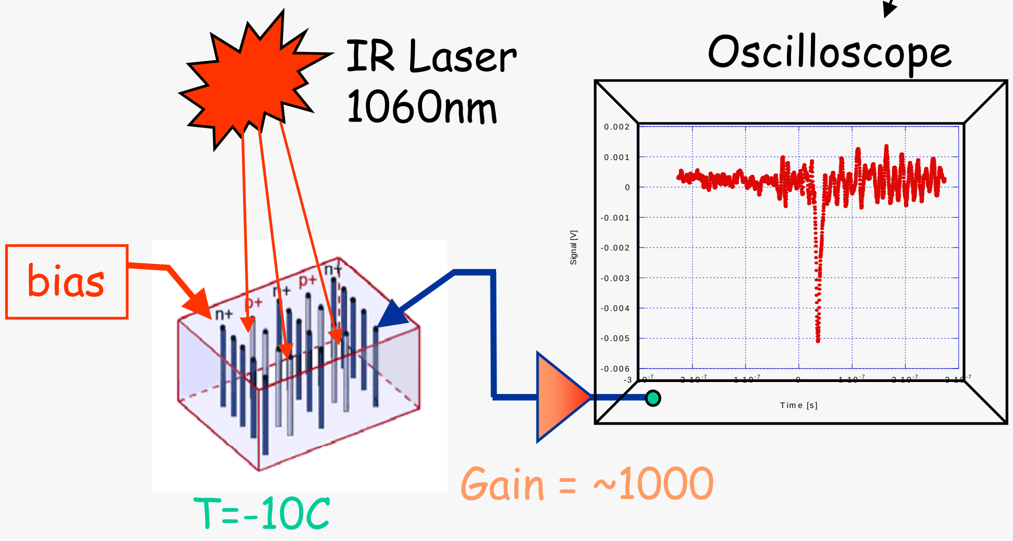




Average of ~1000 pulses

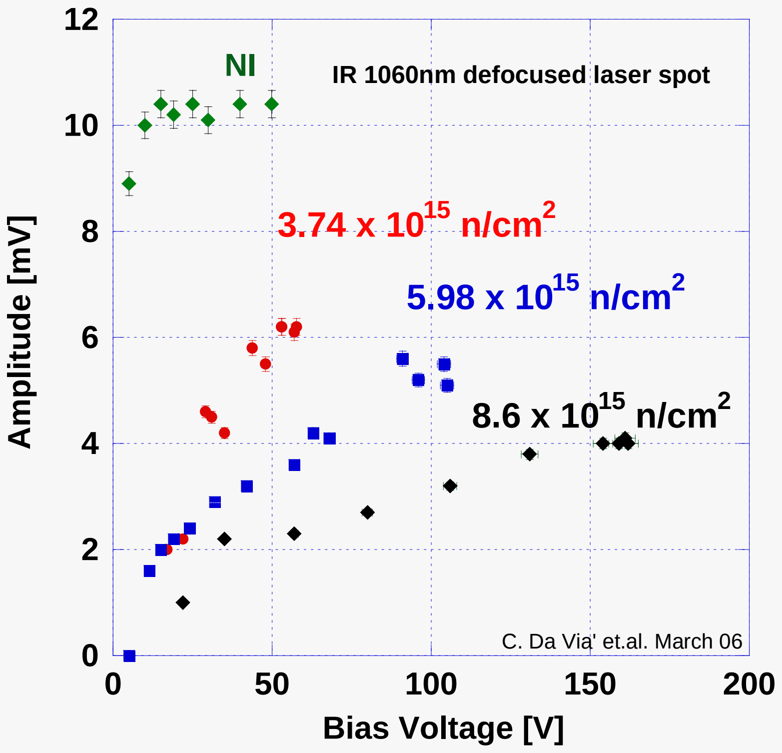


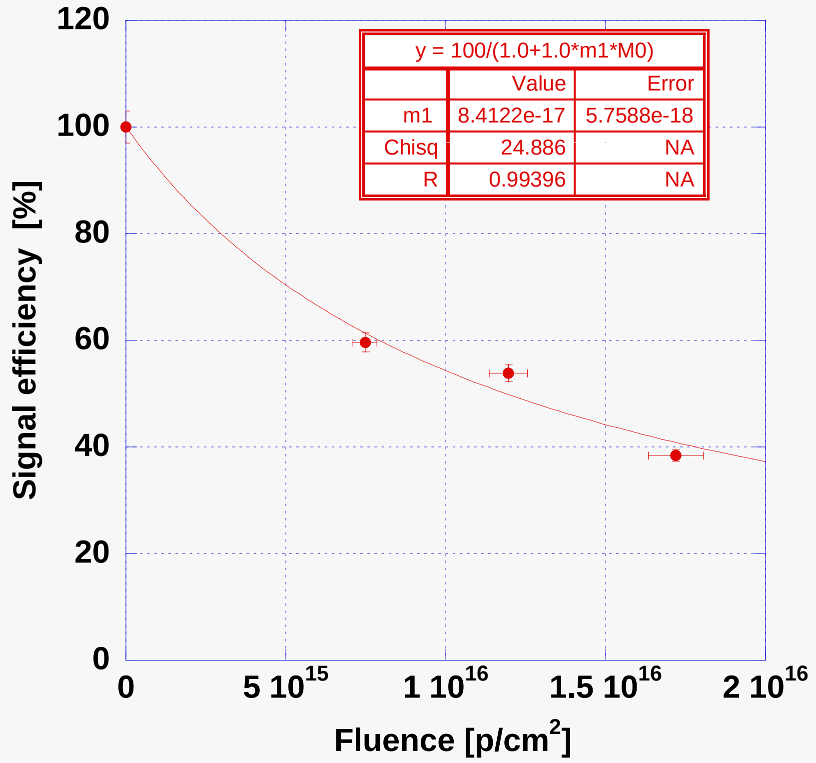
expected type inversion point



Signal efficiency

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





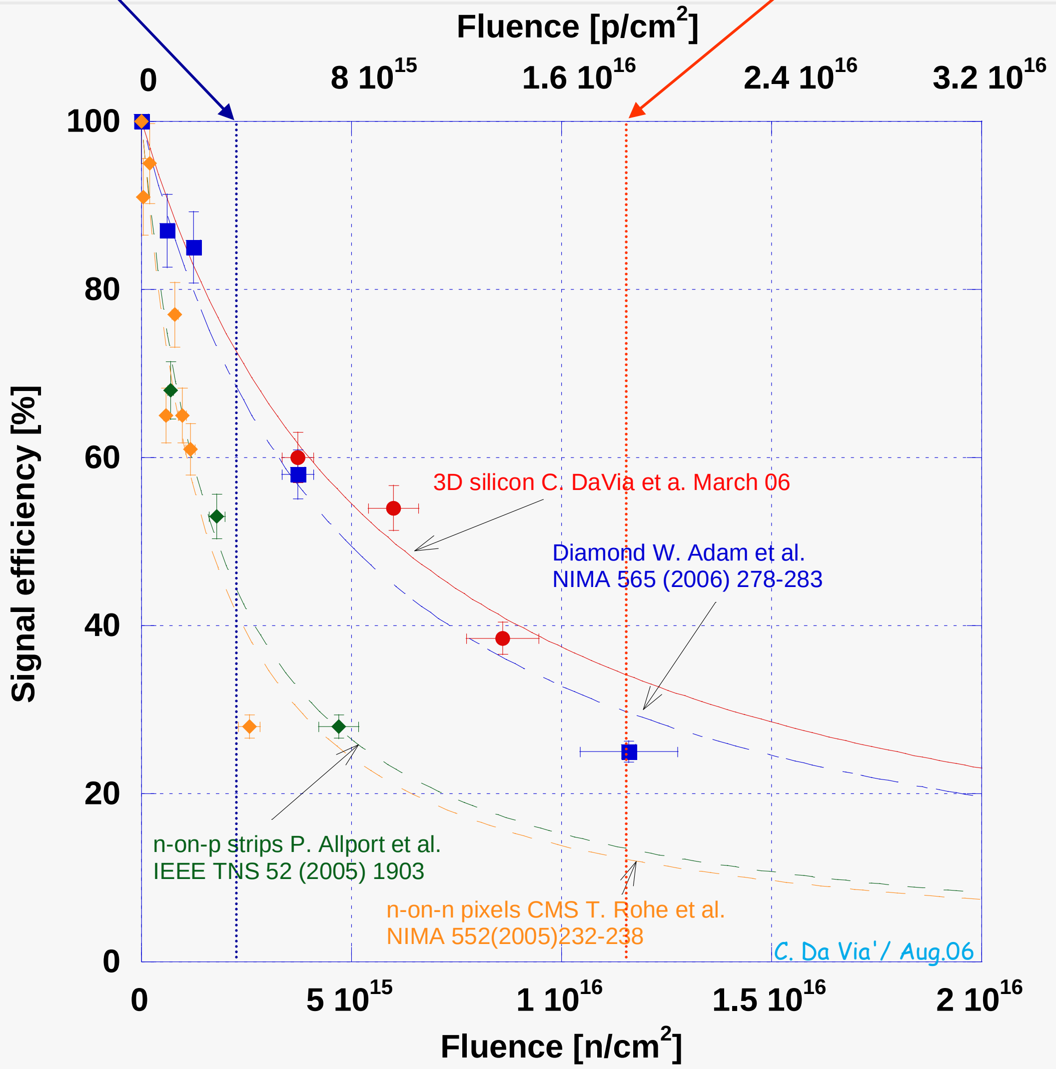
Model by S. Watts to be published

Cinzia Da Via'- Edinburgh - March 2007

Radiation Hardness

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

1.8×10^{16}p/cm^2 =
10 years SLHC at 10^{35}cm^{-2}s^{-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

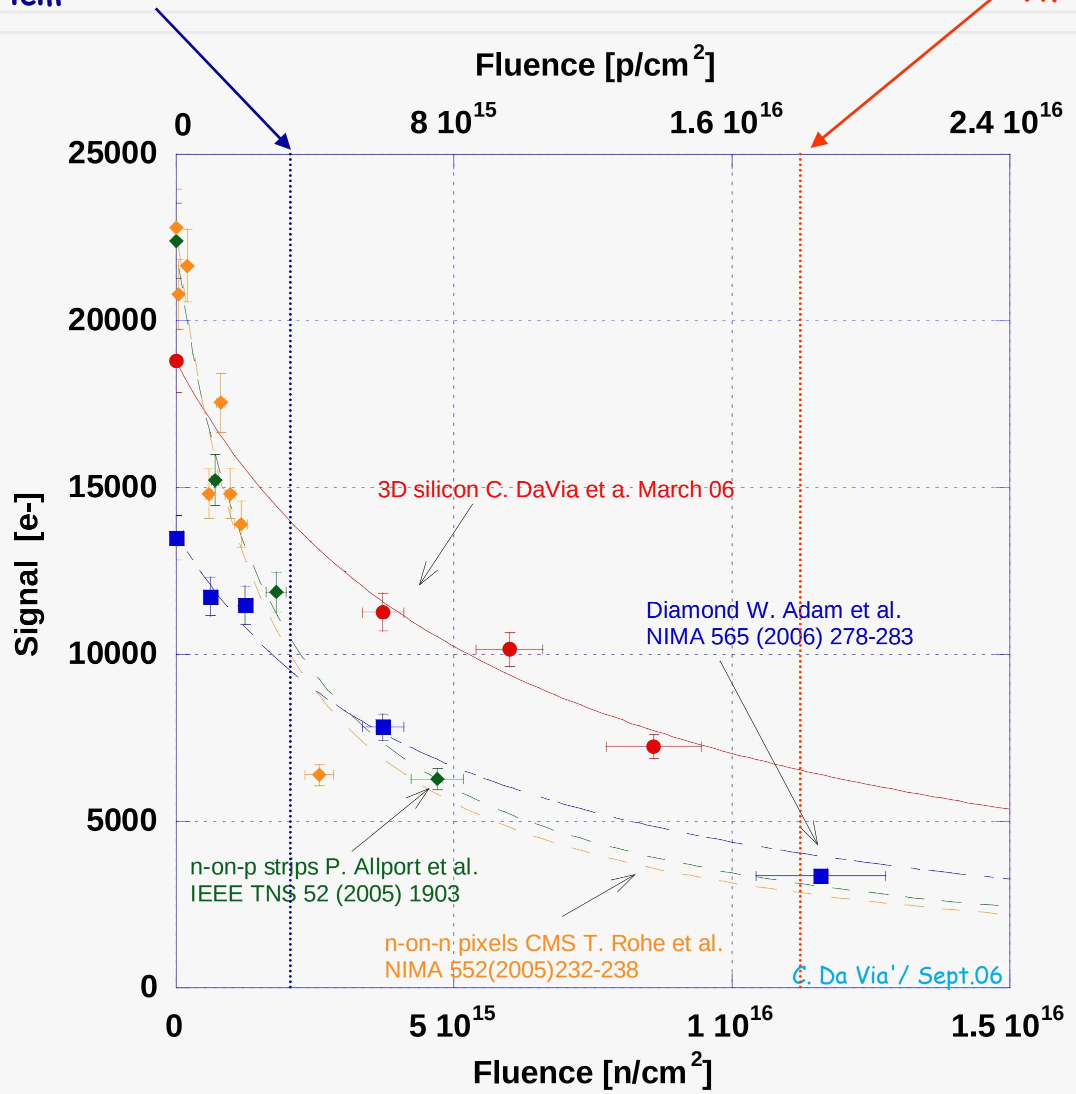
C DaVia/March06

*Same reference than previous slide

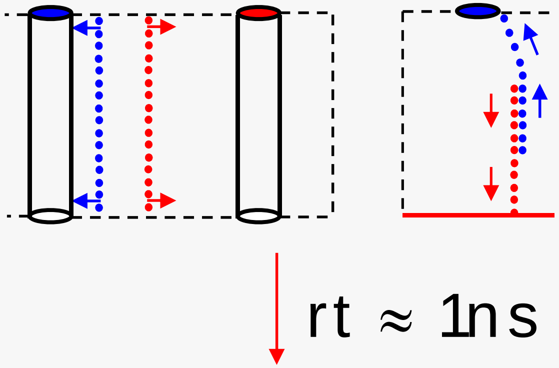
Radiation Hardness

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

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

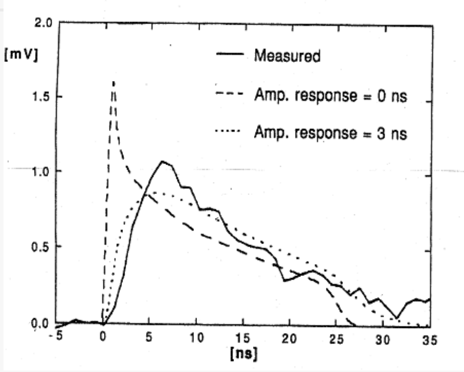


Speed

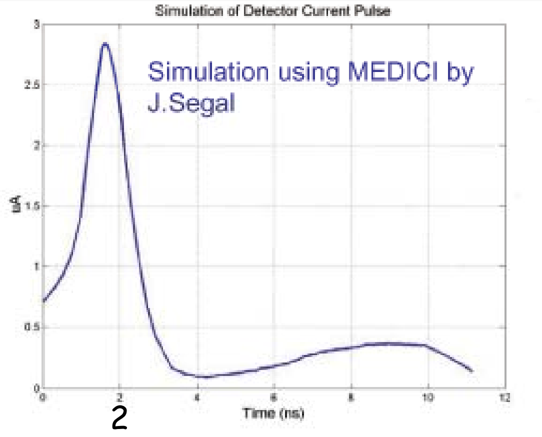


$rt \approx 1ns$

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



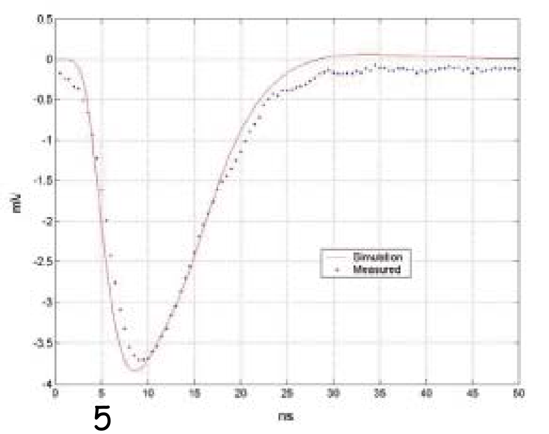
Nuclear Instruments and Methods in Physics Research A310 (1991) 189–191
North-Holland



2

Circuit
Hspice
Simulation

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

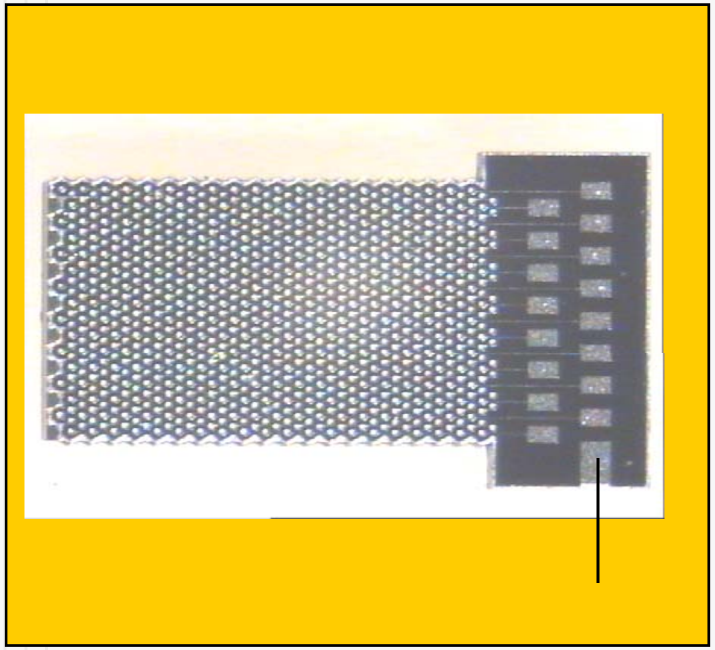


5

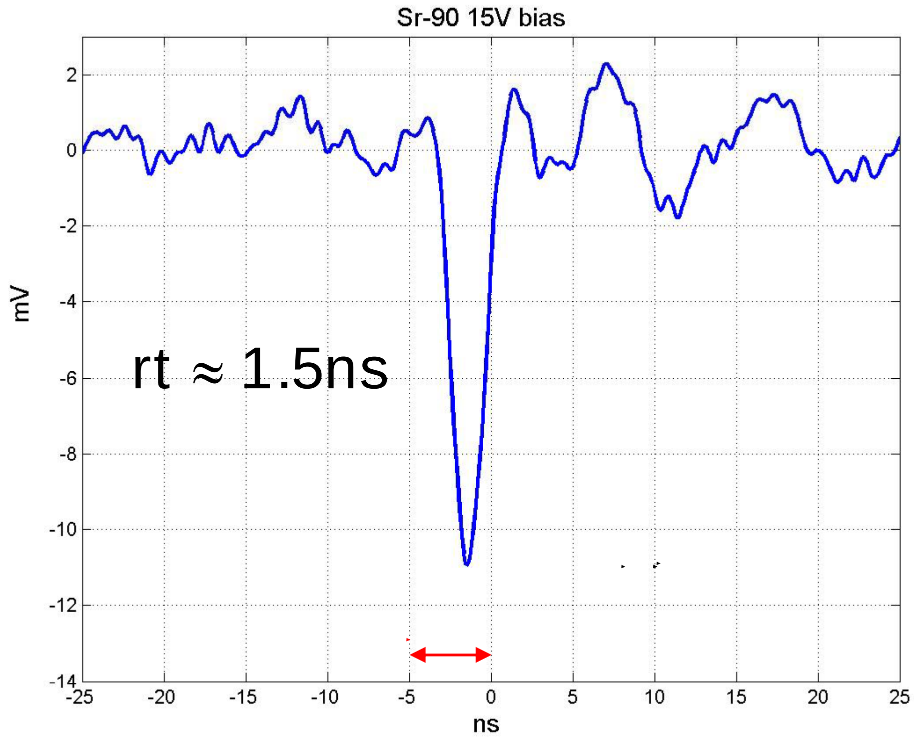
3D only simulation

^{90}Sr pulse + FIT

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



3D Inter-electrode distance = 50 μm

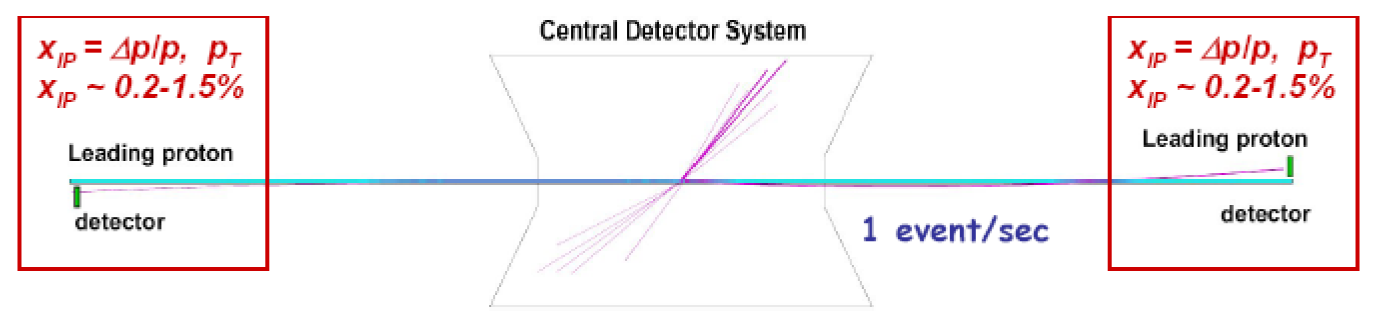


oscilloscope trace

FP420 : An R&D Proposal to Investigate the Feasibility of Installing Proton Tagging Detectors in the 420m Region at LHC

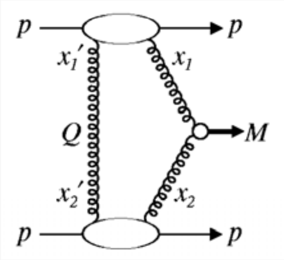
M. G. Albrow[1], T. Anthonis[2], M. Arneodo[3], R. Barlow[2,4], W. Beaumont[5], A. Brandt[6], P. Bussey[7], C. Buttar[7], M. Capua[8], J. E. Cole[9], B. E. Cox[2,*], C. DaVià[10], A. DeRoeck[11,*], E. A. De Wolf[5], J. R. Forshaw[2], J. Freeman[1], P. Grafstrom[11,+], J. Gronberg[12], M. Grothe[13] , J. Hasi[10], G. P. Heath[9], V. Hedberg[14,+], B. W. Kennedy[15], C. Kenney[16], V. A. Khoze[17], H. Kowalski[18], J. Lamsa[19], D. Lange[12], V. Lemaitre[20], F. K. Loebinger[2], A. Mastroberardino[8], O. Militaru[20], D. M. Newbold[9,15], R. Orava[19], V. O'Shea[7], K. Osterberg[19], S. Parker[21], P. Petroff[22], J. Pinfold[23], K. Piotrzkowski[20], M. Rijssenbeek[24], J. Rohlf[25], L. Rurua[5], M. Ruspa[3], M. G. Ryskin[17], D. H. Saxon[7], P. Schlein[26], G. Snow[27], A. Sobol[27], A. Solano[13], W. J. Stirling[17], M. Tasevsky[28], E. Tassi[8], P. Van Mechelen[5], S. J. Watts[10], T. Wengler[2], S. White[29], D. Wright[12]

Target installation time during the long shut-down of 2008-09



1 event/sec

Unique possibility to explore new physics



Central Exclusive diffractive Higgs production pp→ p H p
Investigation of CP structure of Higgs sector
BSM physics

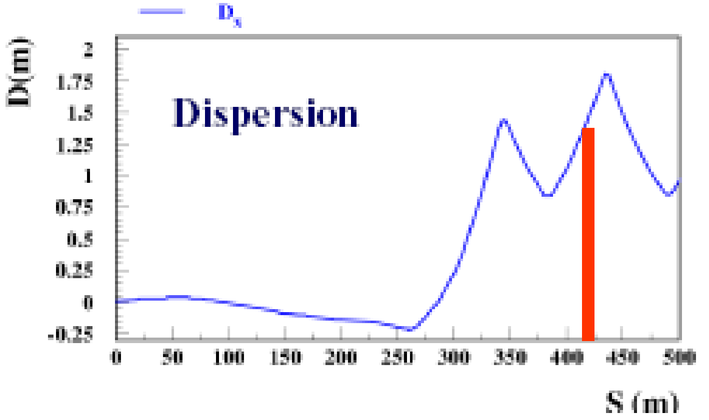
A. De Roeck, V. A. Khoze, A. D. Martin, R. Orava and M. G. Ryskin, Eur. Phys. J. C **25** (2002) 391

V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. C **34** (2004) 327

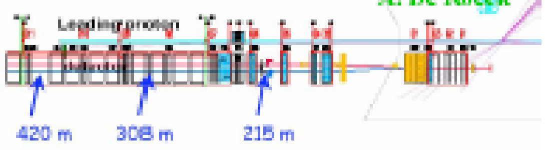
Why at 420m

X=deflection

$$x = D_x \frac{\Delta p}{p}$$



Central Detector S
picture from
A. De Roeck

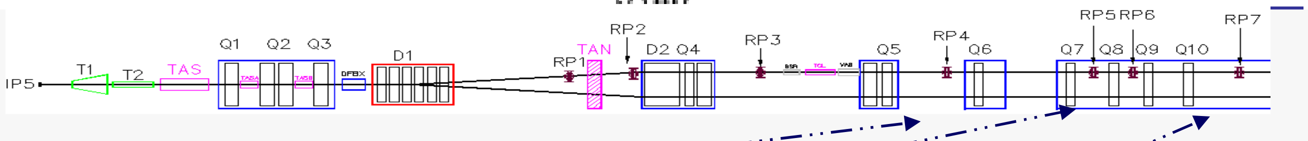


At 420 m

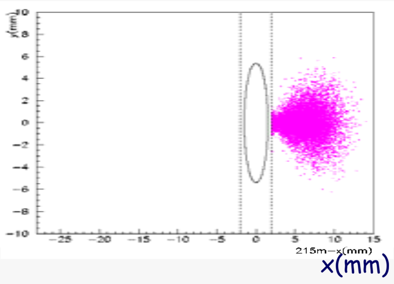
$$\frac{\Delta p}{p} = 0.01 \Rightarrow x = 1.5\,\mathrm{cm}$$

$$\frac{\Delta p}{p} = 0.001 \Rightarrow x = 1.5\,\mathrm{mm}$$

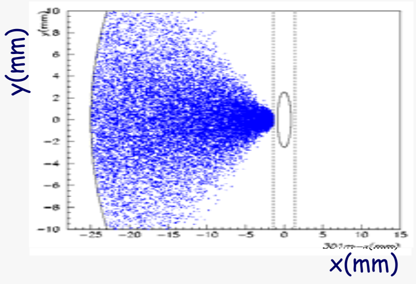
Closest approach of
Detectors ~3mm
Acceptance
Down to Dp/p=0.002



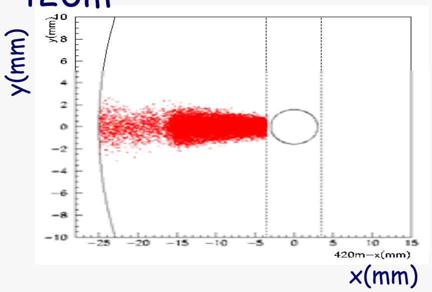
215m



300m



420m



V. Avati/Totem

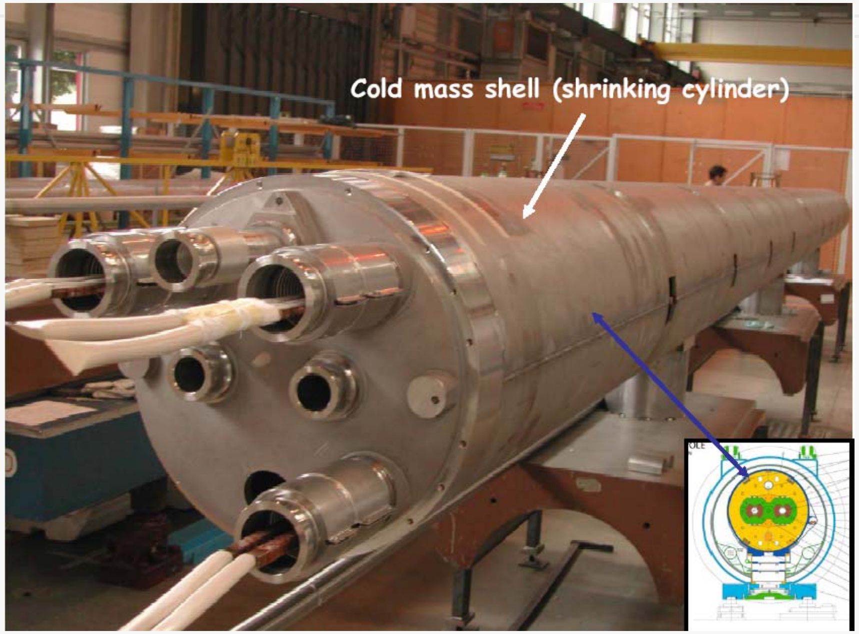
Dispersion D = 0.08 m

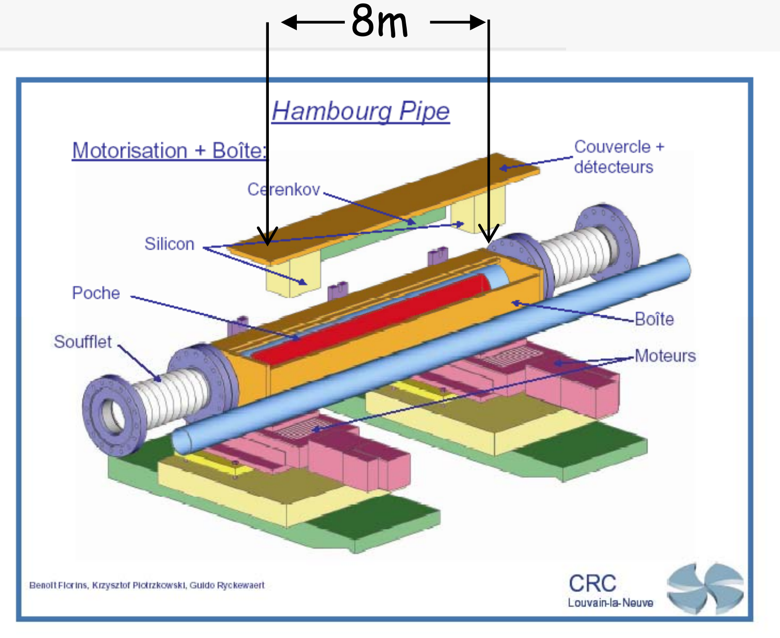
D=0.7m

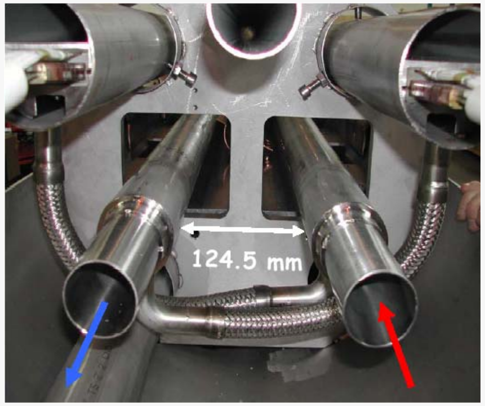
D=1.5m

Leading diffractive protons seen at different detector locations (β* = 0.5m)

The 420m region







Challenges of diffractive proton measurement at high luminosity

- ➢Acceptance
- ➢Calibration and alignment
- ➢Stability of measurement conditions
- ➢High tracking resolution in x
- ➢Backgrounds
- ➢Multiple events

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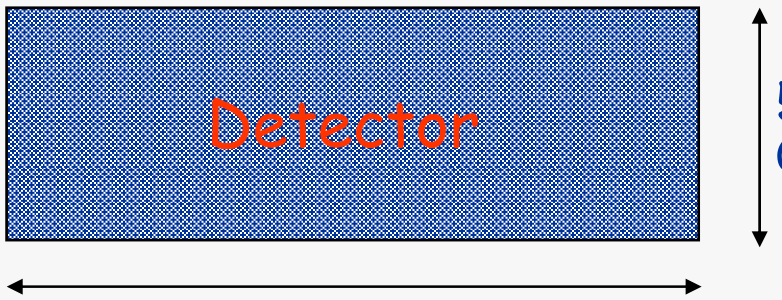
Detector size and layout for best resolution 3D+Atlas pixel roc

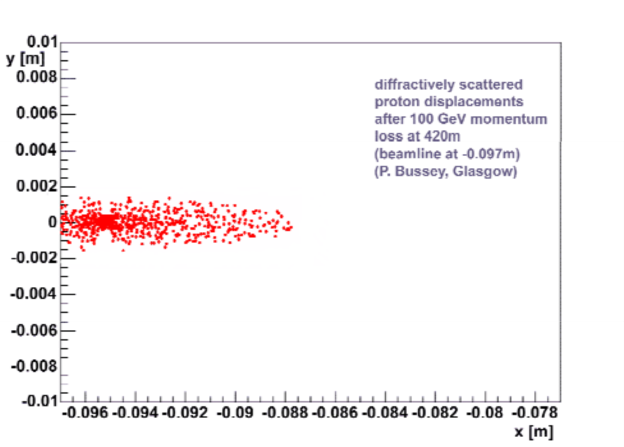
(10-15 μm in x and y)



5-10 mm

(40-50mm pitch)

15-20 mm – (40-50mm pitch)



Atlas chip picture from Bekerle Vertex03

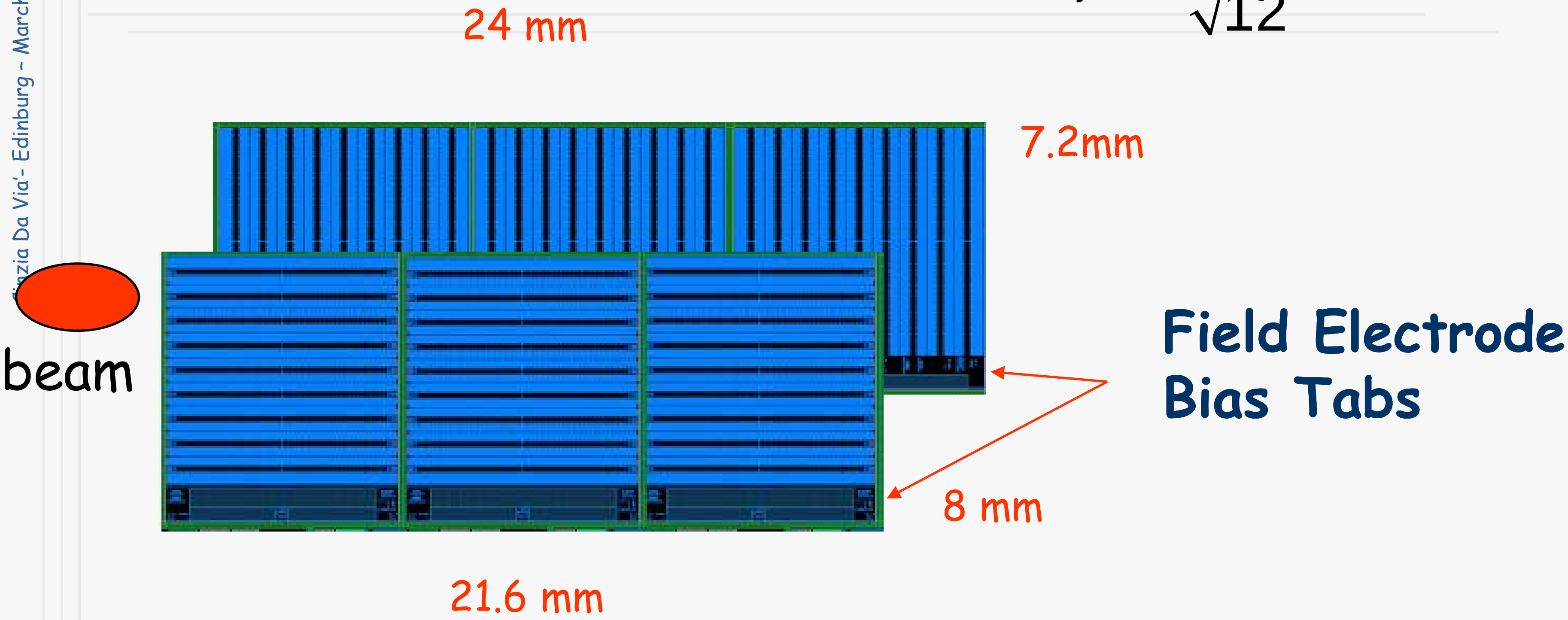
- High and stable efficiency near the edge facing the beam, insensitive edge region < 10 μm (10s~3mm in the x- direction!)
- Compactness, robustness (limited access)
- S:N > 20:1
- Spatial resolution ~10-15 μm
- Overall alignment precision ~20-50 μm
- Immunity from induced RF pickup from bunches
- Required radiation tolerance >10^{15} n_{equiv} /cm^2 at $L=10^{34}$ $cm^{-2}s^{-1}$
- Operate at -20 °C
- Be suitable for local event selection and/or trigger capability (L2?)

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

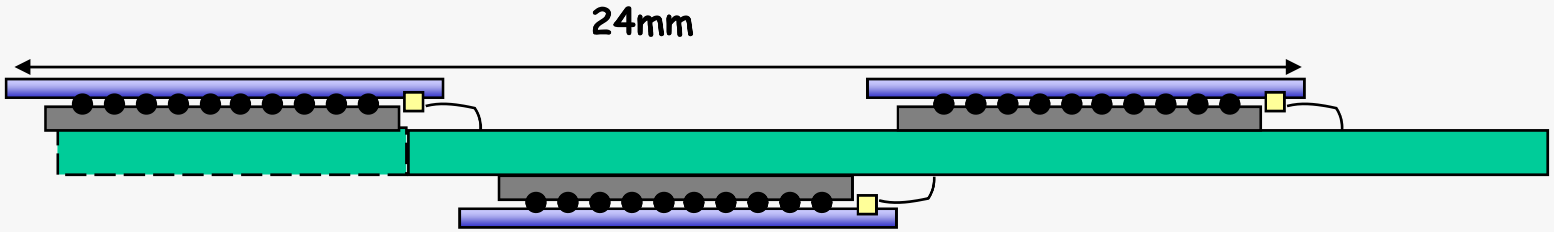
Leading diffractive protons seen at 420m (β^* = 0.5m)

Combining horizontal and vertical planes

$$\sigma_{x,y} = \frac{50\mu m}{\sqrt{12}} = 14.4\mu m$$



Hybrid board



3D + Atlas pixel parameters estimated

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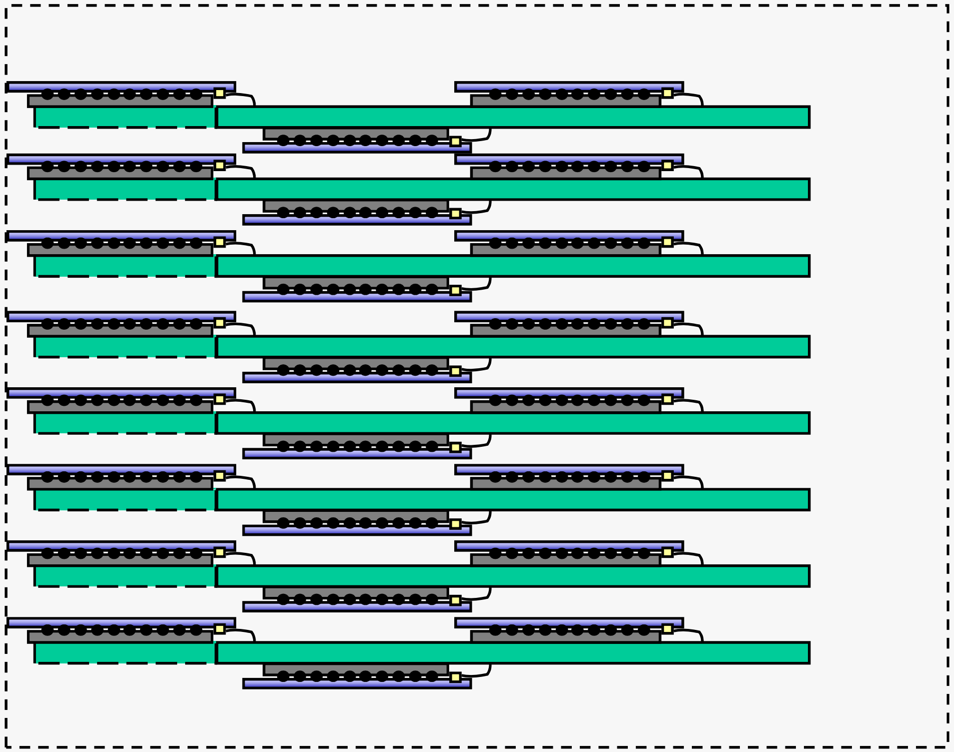
-power dissipation: (the depletion voltage for the sensors, two low voltages for the front-end chips and the module controller chip and three low voltages for the operation of the optical link: http://www.slac.stanford.edu/econf/C020909/skpaper.pdf)



0.7W/cm2

0.4W/detector and 1.2W/plane.
12W / station (10 planes)

-highest supported temperature
~105C hybrid

~200C detector+electronics

-thickness of 1 plane (detector+electronics+board)
0.5 mm+ 0.3 carbon-carbon support (detector region)

~2mm (hybrid frame)
~25mm/station (10 planes)

-weight
~36g / 1 board
~360g / station (10 planes)

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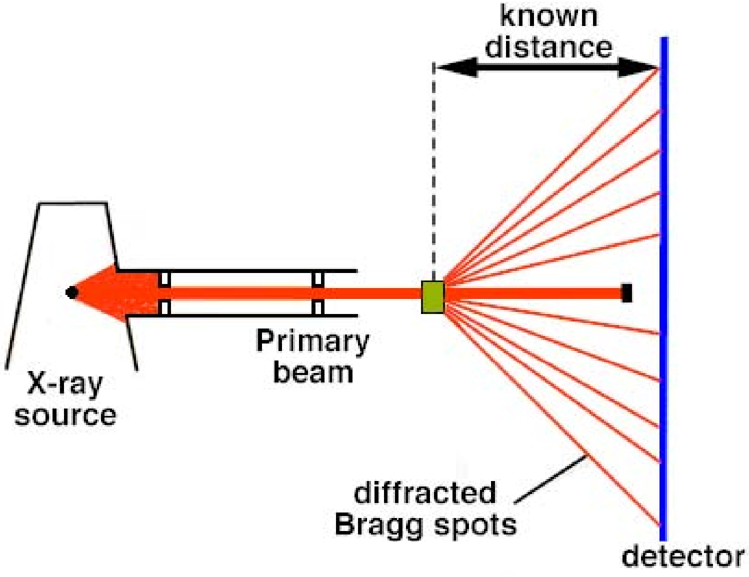
Structural Molecular Biology
Looks at protein structure (folding etc..)
3DX MBC Project

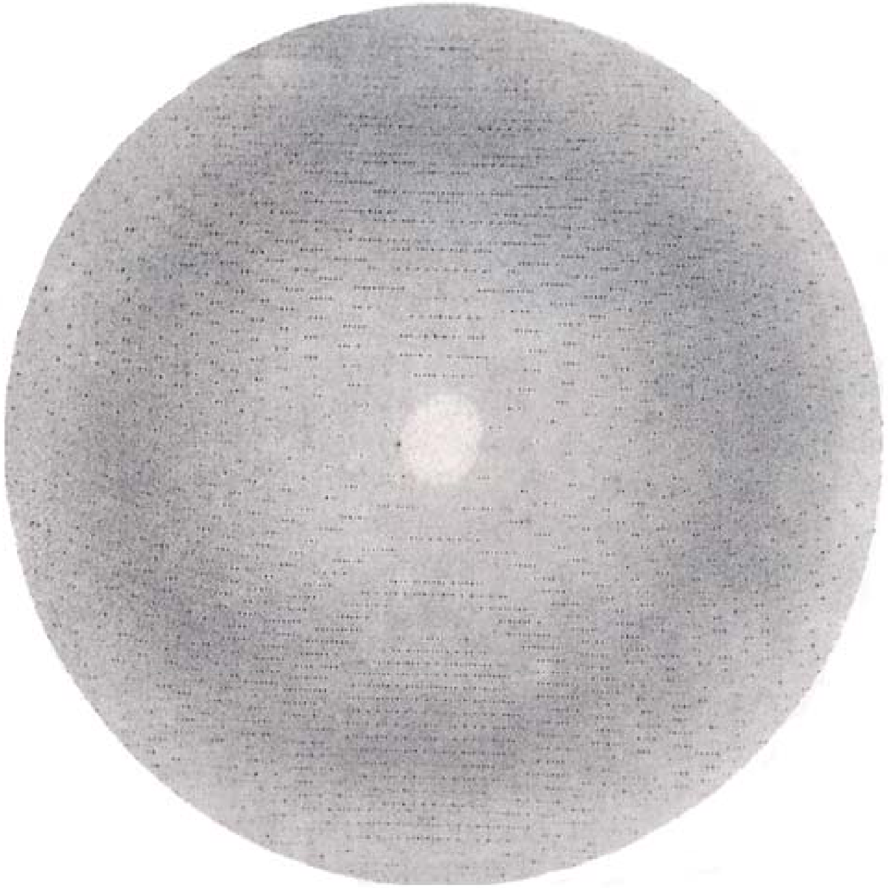
Conventional detection methods cannot be used because of protein complexity and fragility

With protein crystallography their structure can be determined by illuminating them with collimated, mono-energetic x-rays, and measuring the scattering intensity over a range of angles (diffraction patterns). Each outgoing angle gives information from a different view of the molecule.

We plan to use an array of shingled, active-edge, planar/3D silicon sensors to measure those patterns.

The Diffraction Pattern of Discrete Bragg Spots as Captured by the Detector

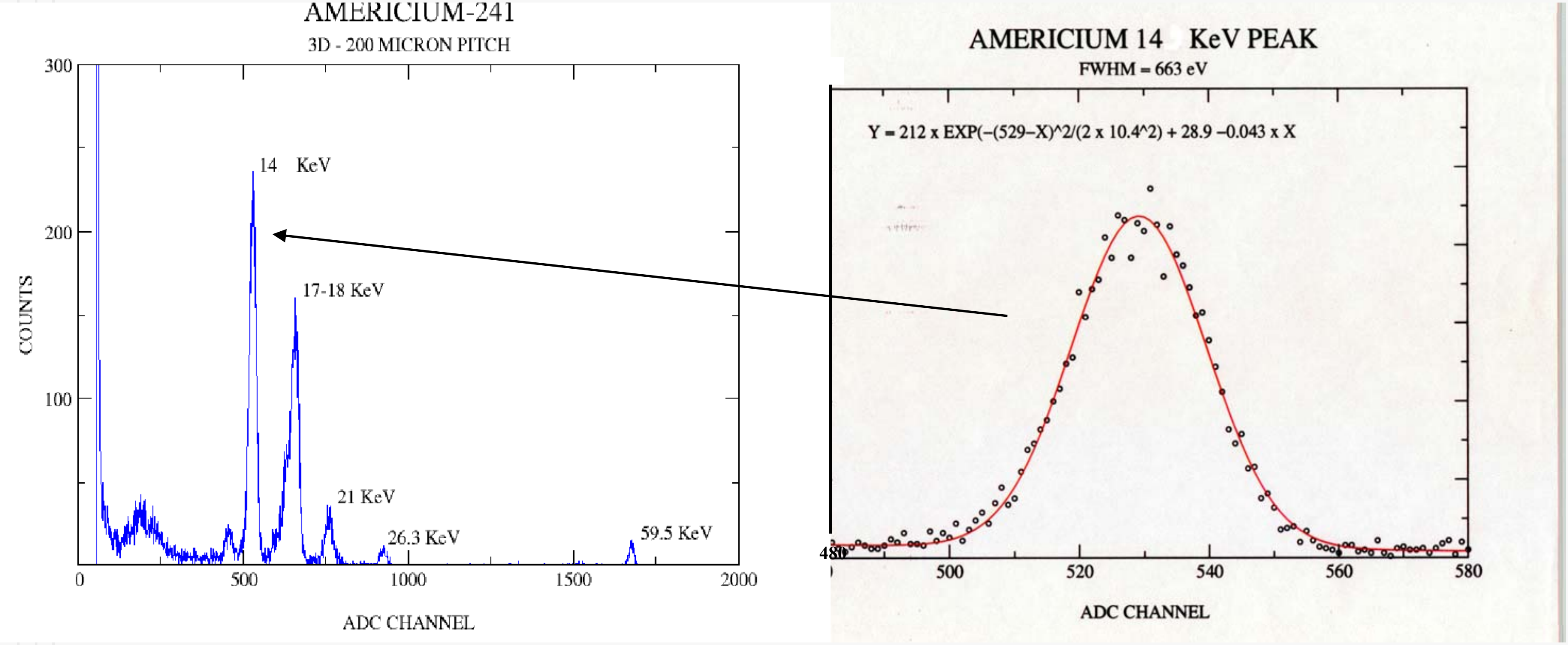




3D spectral response

I_{leak} = 0.45 nA (average) 200 μm
I_{leak} = 0.26 nA (average) 100 μm
C = 0.2 pF per electrode
Thickness = 120 μm

Gaussian response



σ/E=2%

# CHARGE SHARING – PLANAR vs 3D - p-type, p-on-p 50 mm pitch
ROI = Region of interest

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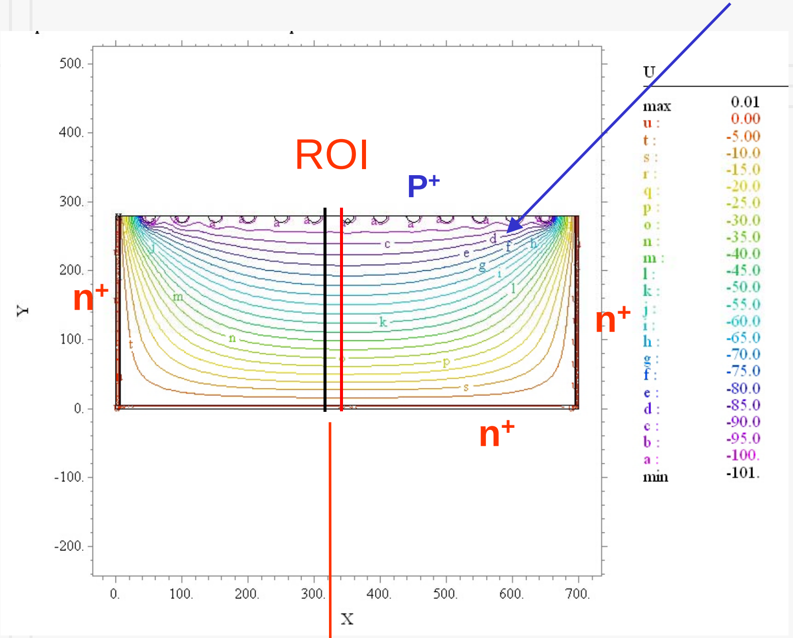
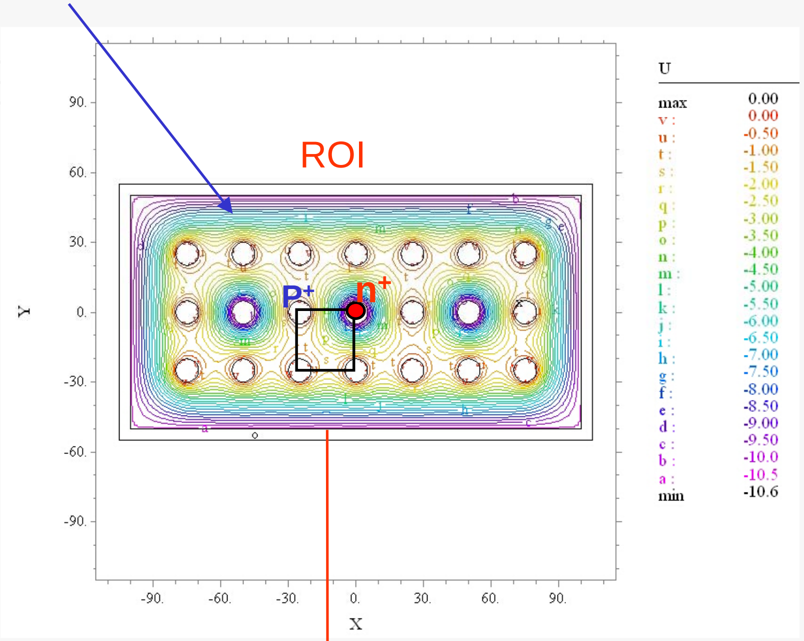
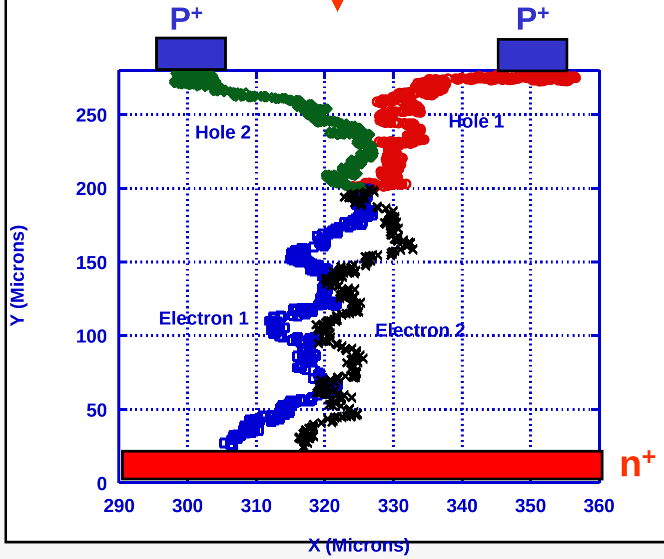
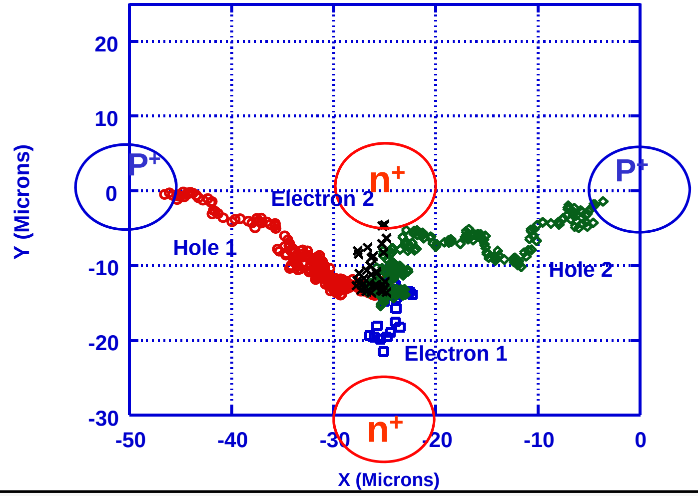
Equipotentials





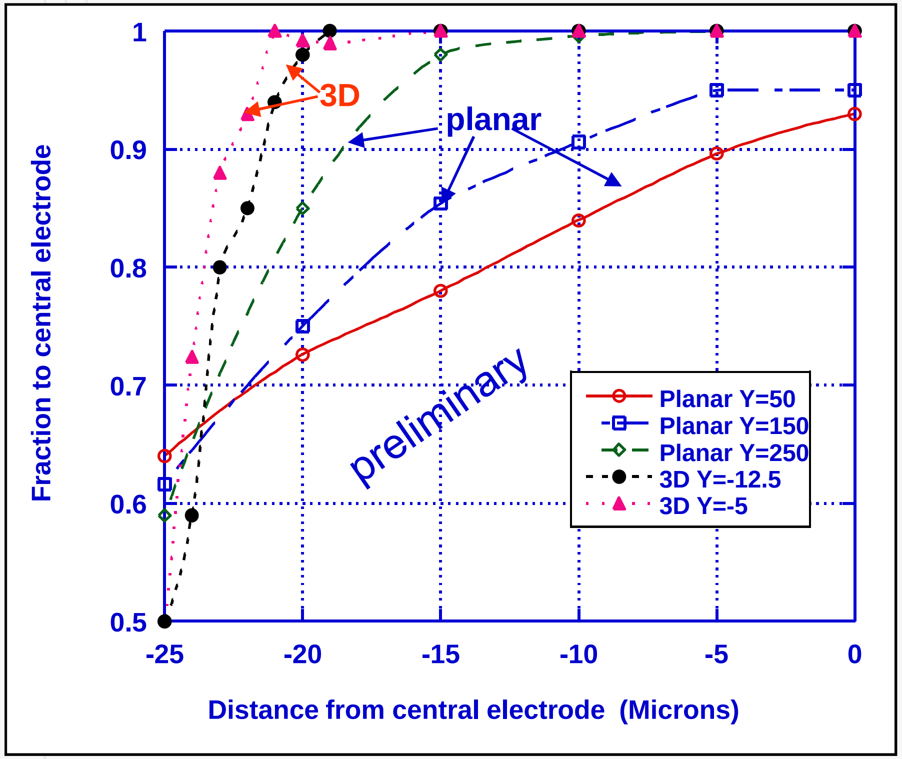


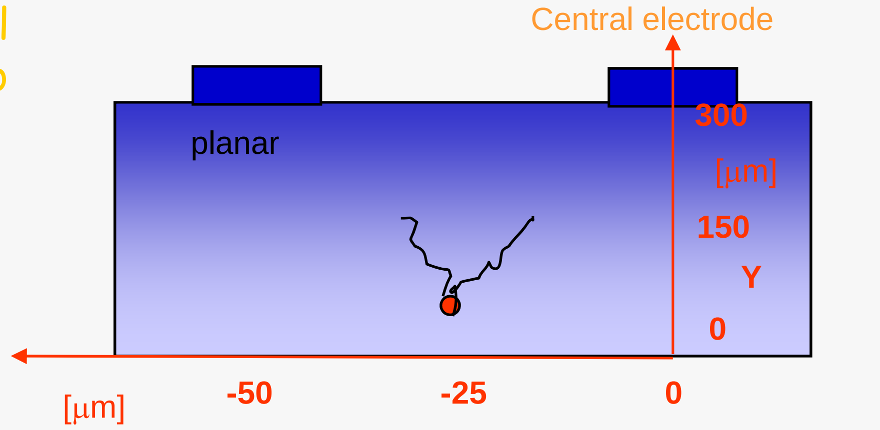
Note
role of
diffusion

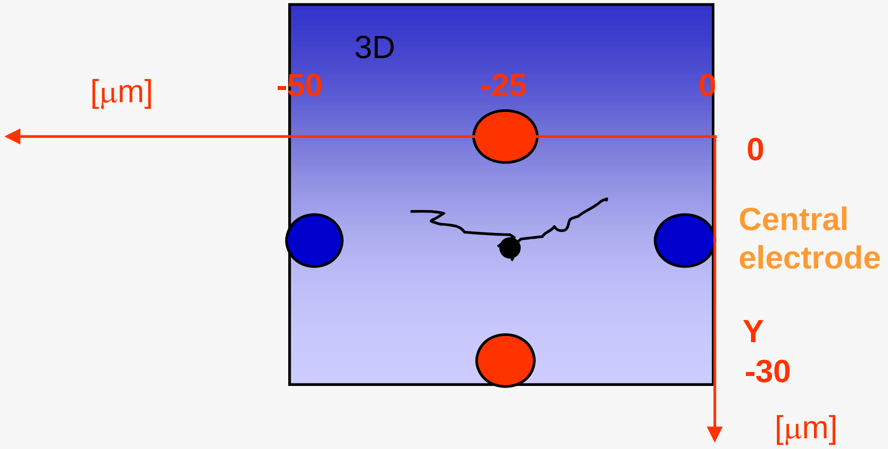


Probability of charge sharing : planar vs 3D 3D collects all charge on 1 electrode in most cases → Better Energy resolution

Fraction of carriers that travel to central electrode versus start position relative to central electrode

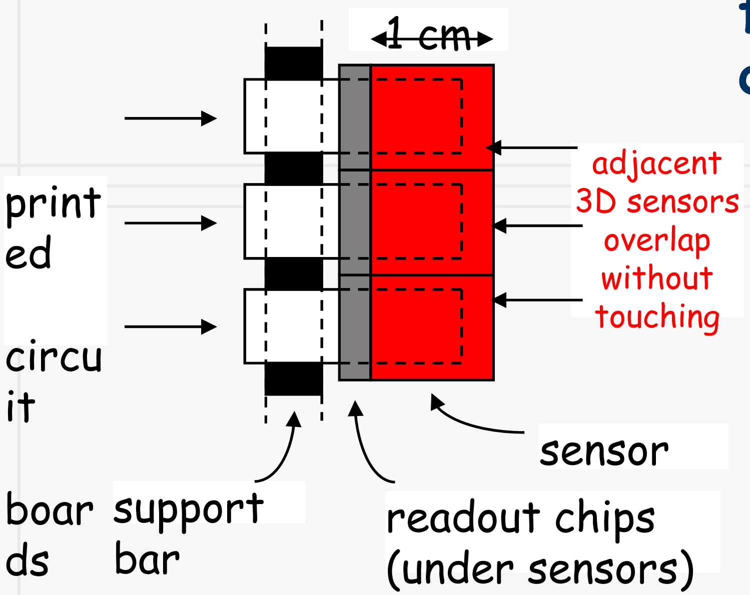






Simulations by S. Watts, Brunel

Schematic design for full scale protein crystallography detector (~300 x 300mm^2)



1 cm

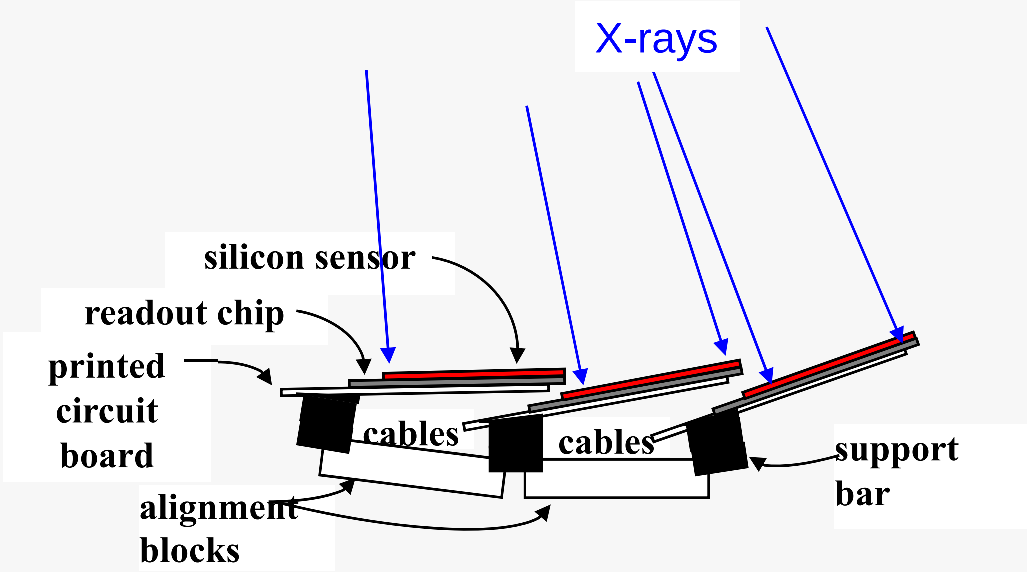
adjacent 3D sensors overlap without touching

printed circuit boards

support bar

readout chips (under sensors)

sensor



X-rays

silicon sensor

readout chip

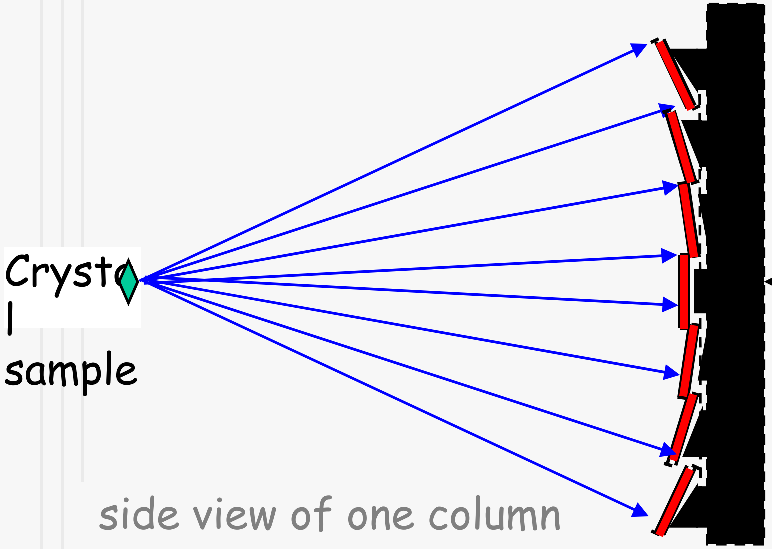
printed circuit board

cables

cables

support bar

alignment blocks



Crystal sample

support bar (behind plane of sensors)

side view of one column

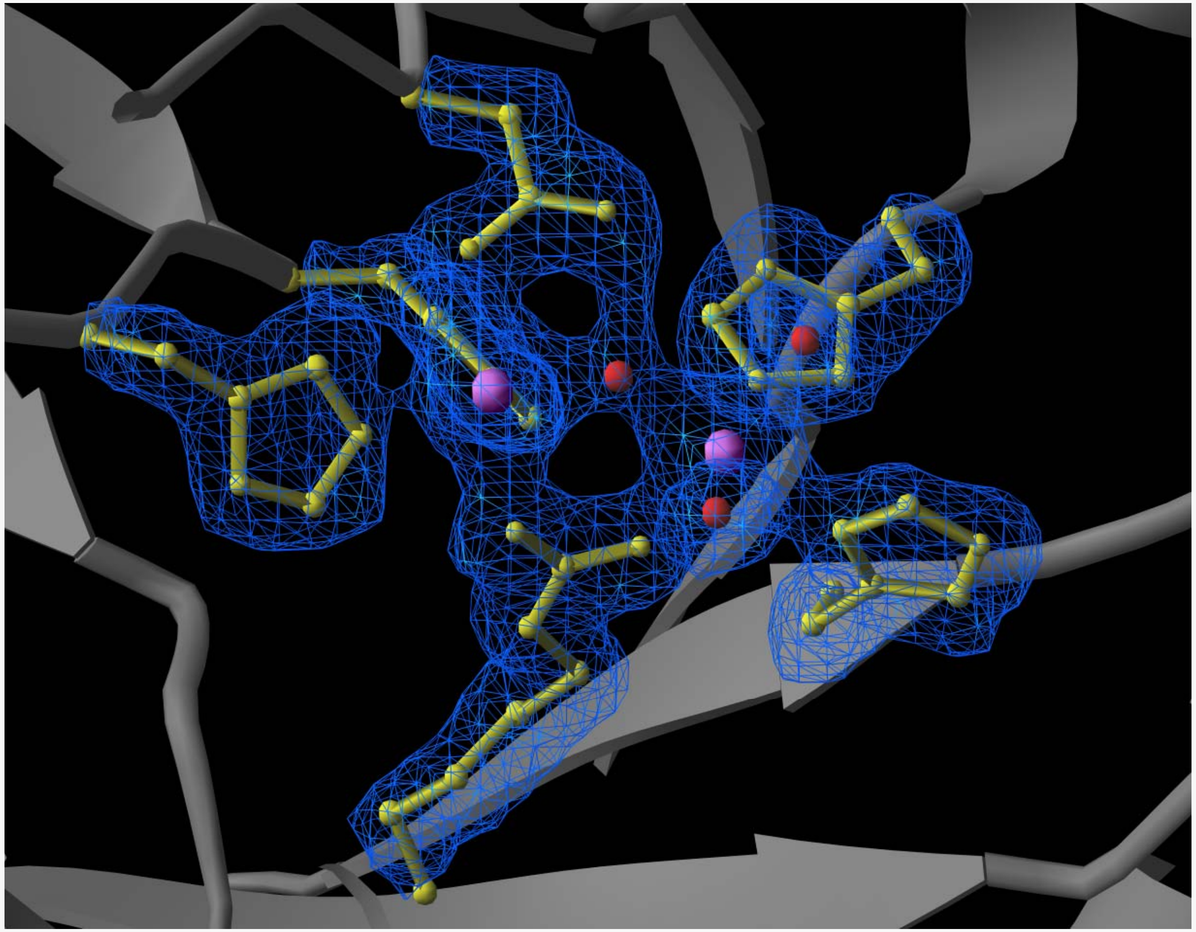
(all sensors normal to diffracted x-rays)

Each sensor 64 x 64 pixels, each 150 μm x 150 μm.

Example of reconstructed structure: Enzyme Active Site (from E. Westbrook)

***Pseudomonas diminuta* phosphotriesterase**: This enzyme catalyzes the hydrolysis of organophosphorus pesticides and nerve agents. Its crystal structure is being studied by Hazel Holden's research group at the University of Wisconsin, Madison (see PDB file 1DPM).

- Purple atoms: zinc
- Red: bound water
- Yellow: side chains
- 1.8 Å resolution map,



Conclusions

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.
LARGE AREA PRODUCTION IN COLLABORATION WITH SINTEF - NORWAY

Will need to improve/study/explore

- electrode response
- electrode aspect ratio
- yield
- alternative substrate's materials
- atlas pixel parameters optimization

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).

Will be used for protein folding (3DX project – MBC)