New Detectors with Novel Electrode Configurations for Applications in Extremely Harsh Radiation Environments (sLHC), RHIC-Upgrade and Photon Sciences

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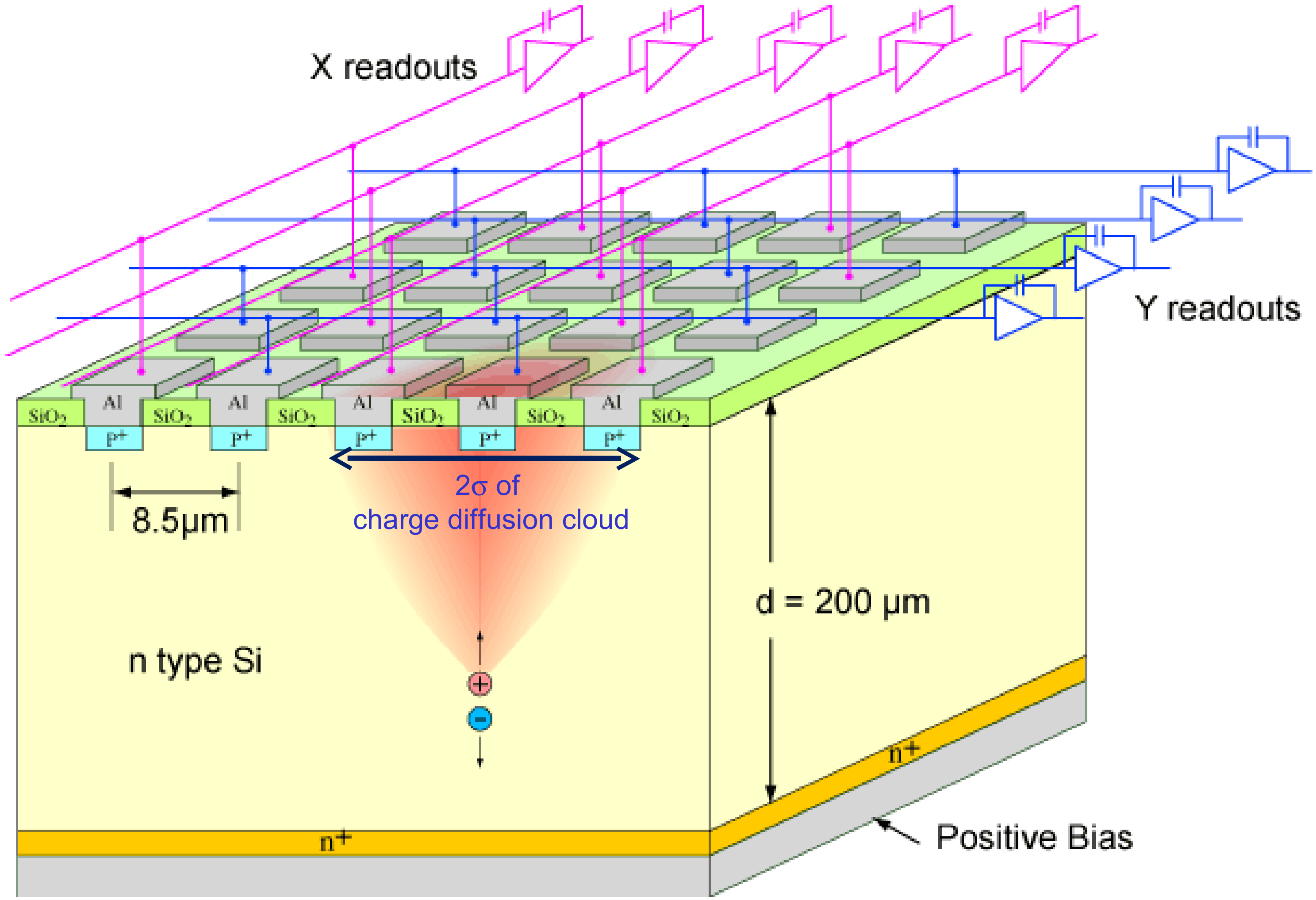
OUTLINE

- Review on 2D planar stripixel detectors
- New 3D-Electrode stripixel detectors
- Concept of the new BNL 3D-Trench electrode detectors
- Rad-hard Si drift detector and others
- Mask design and fabrication status
- Summary

Planar (2D) Stripixel detector

Developed at BNL Instr. Div. in 2004 (Z. Li, NIM A vol. 518, No. 3 (2004) 738-753)



One-sided process, 2D position sensitivity

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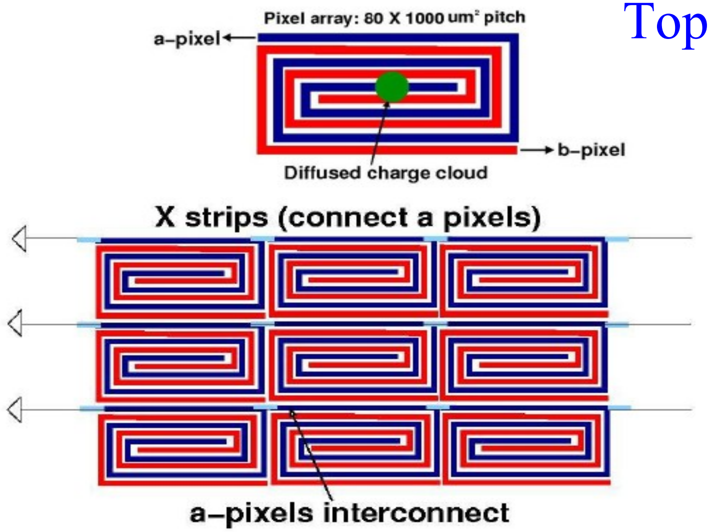
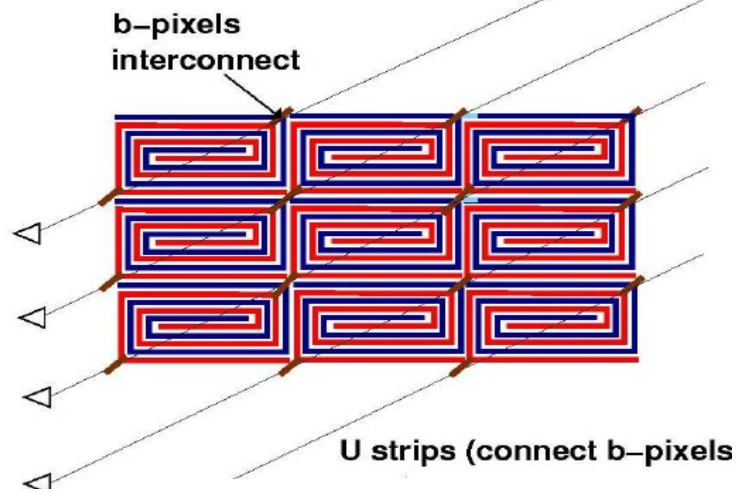
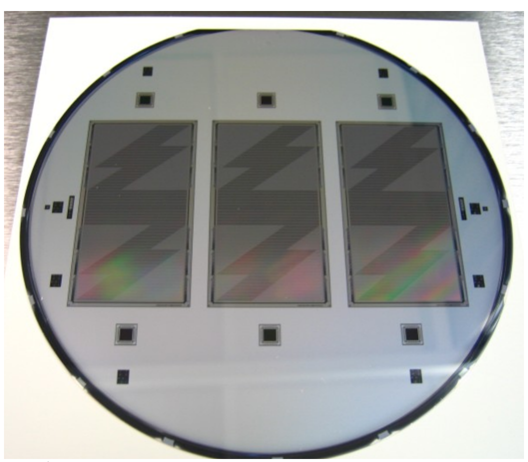
2D Stripixel Sensor for PHENIX VTX

Top view

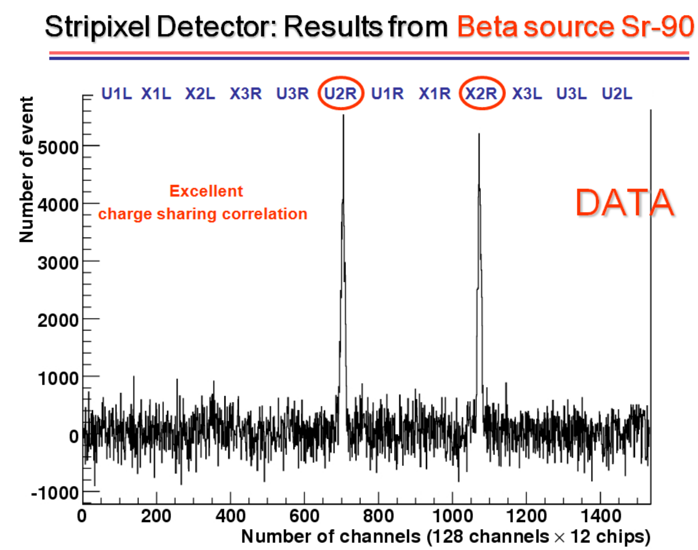
- DC-Coupled silicon sensor
- Sensor single-sided
- 2-dimensional position sensitivity by charge sharing







150 mm



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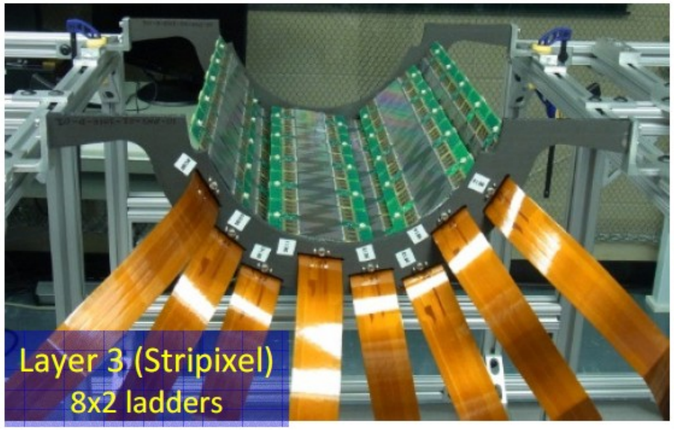
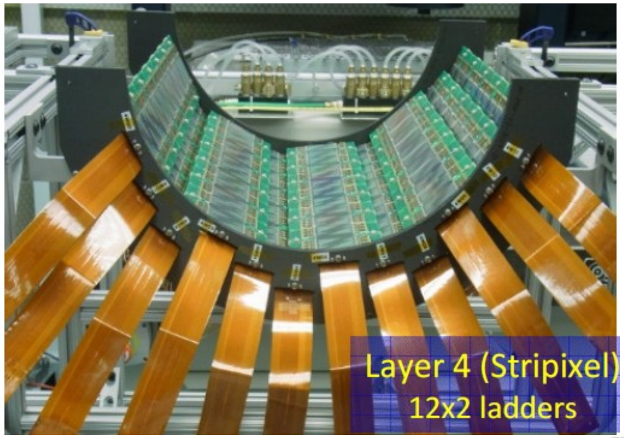
2D Stripixel Sensor for PHENIX VTX
A big success!



0.21 m²



0.31 m²

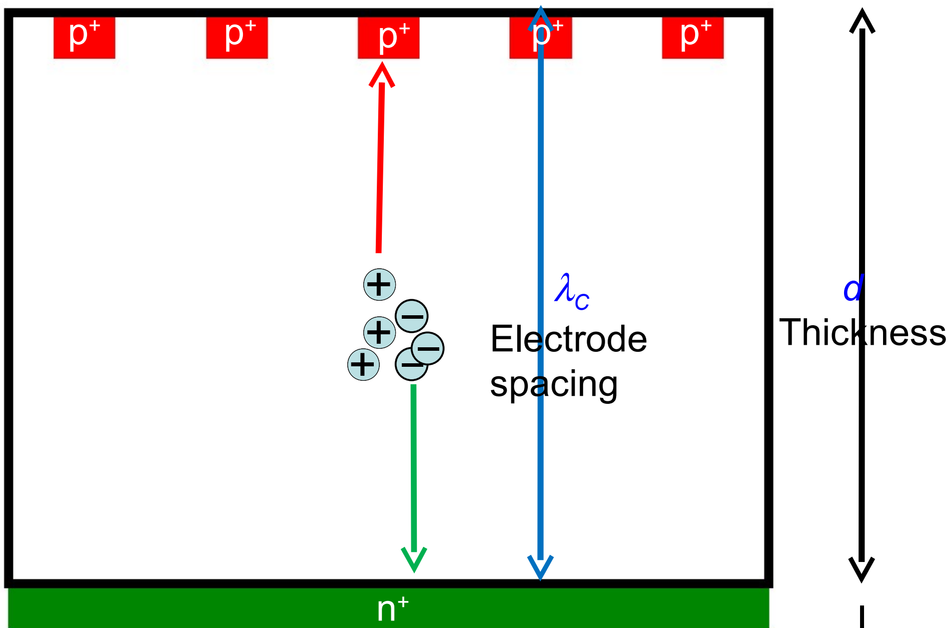
West VTX installed
on November 17, 2010

- VTX installed in PHENIX-IR in December 2010
- VTX has been commissioned successfully using p+p at 500 GeV and took a lot of data for analysis
- Next week, VTX with other sub-detectors of PHENIX will start taking analysis data for RHIC beam Au+Au at 18.5 and 200 GeV (R. Nouicer et al.)

Comparison between 2D (planar) and 3D detectors

2D (planar) detector

Electrodes are planar (2D) ion implants (<1 μm deep)



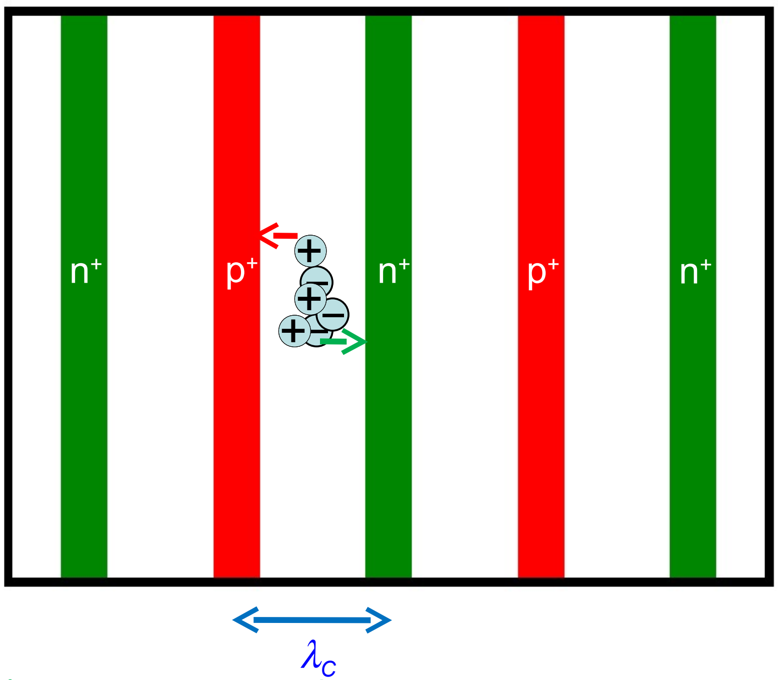
$\lambda_C = d$ ⟶ full depletion voltage V_{fd} depends on detector thickness d

V_{fd} can be too large for large d (>1mm) or after heavy radiation

Conventional 3D-column electrode detector

(S. Parker, et al)

Electrodes are vertically (3D) etched and doped columns (100's μm deep)

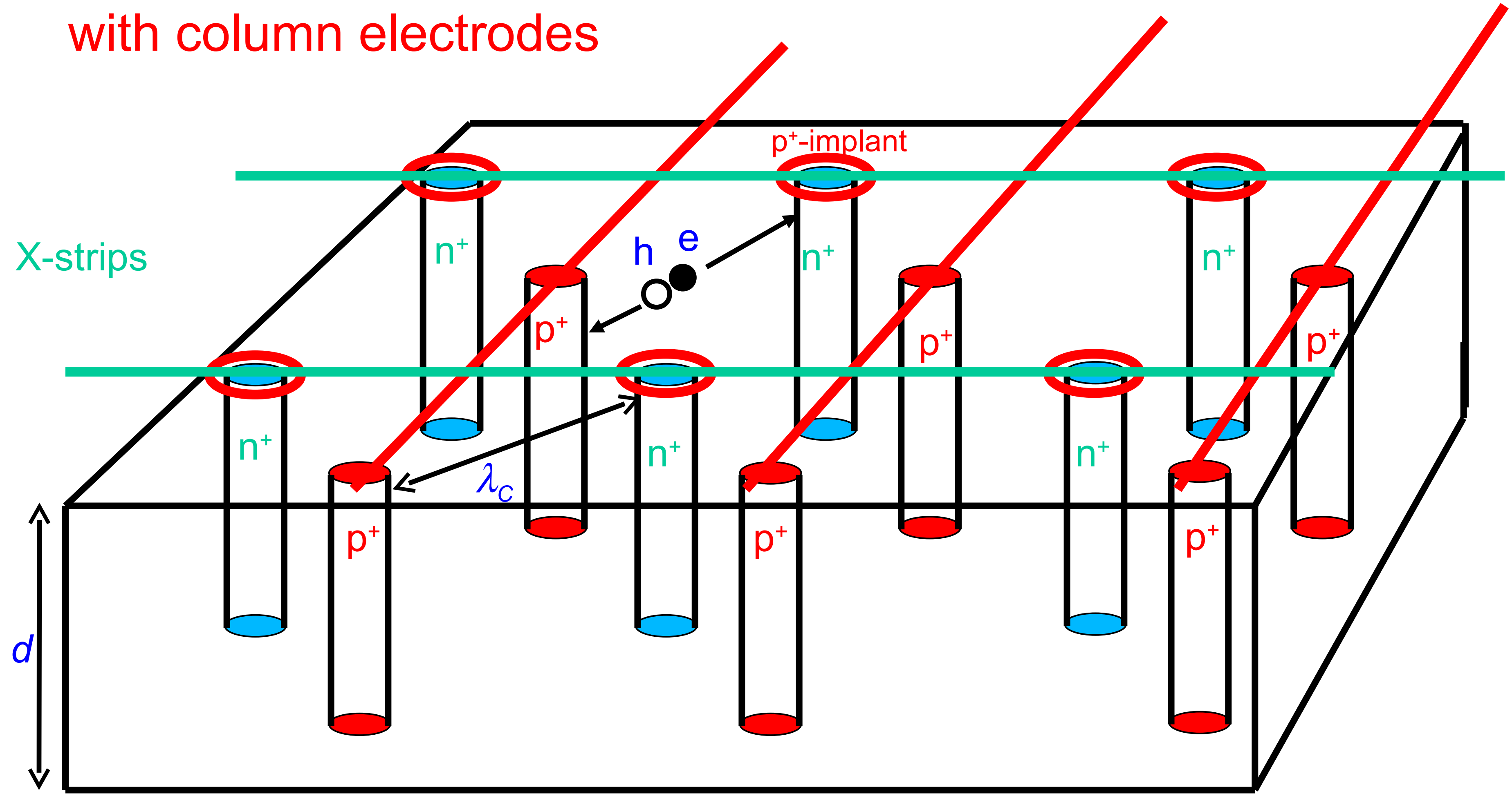


λ_C is decoupled from d ⟶ full depletion voltage V_{fd} is independent of detector thickness d

V_{fd} can be small if λ_C is made small (<100 μm)

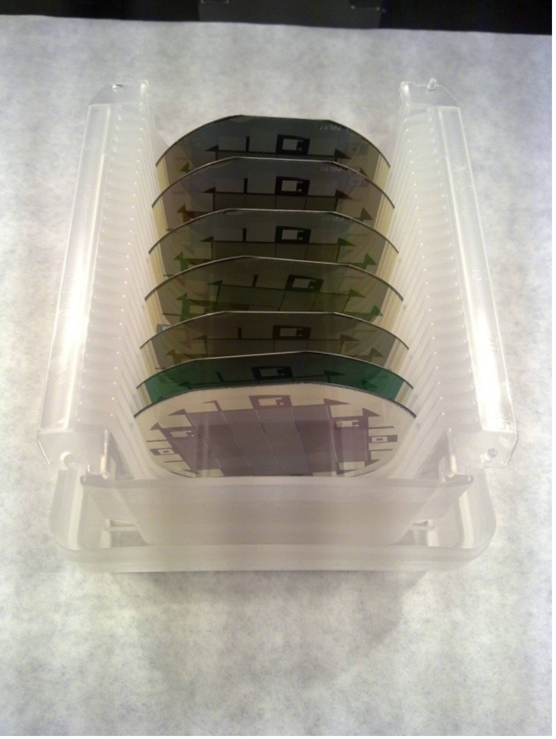
New 3D-Stripixel detector (BNL R&D)

with column electrodes



N-strips collect electrons

P-strips collect holes

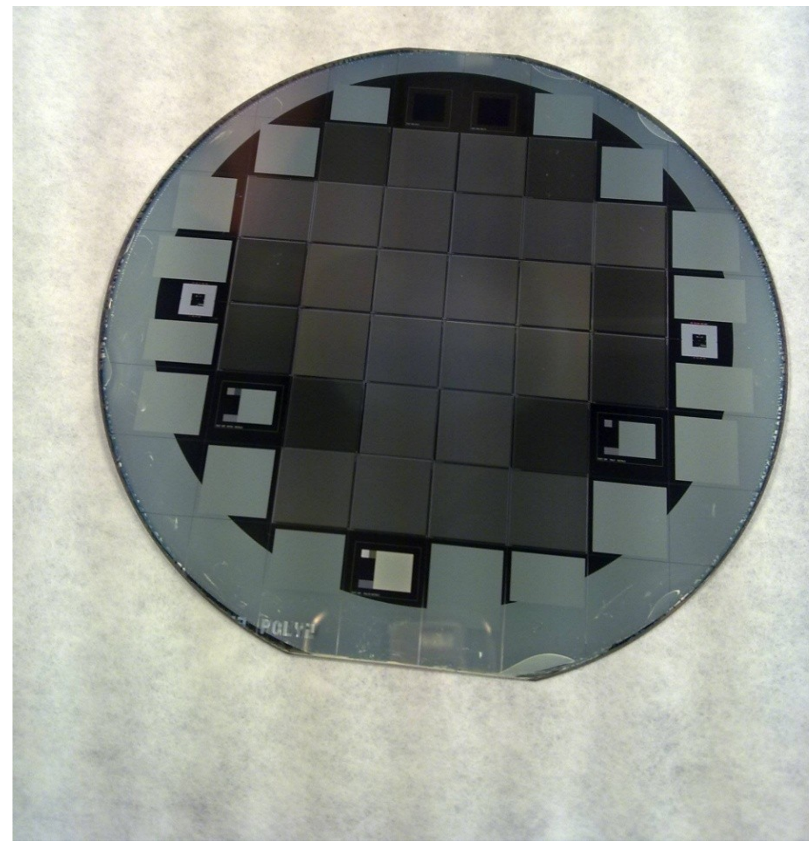


3D Stripixel Detectors (CNM-BNL)

Fabricated 3/2011

7 wafers (6 inches)
- 1-6 high resistivity wafers 300μm thickess
- 7 SOI wafer 20 μm thickness

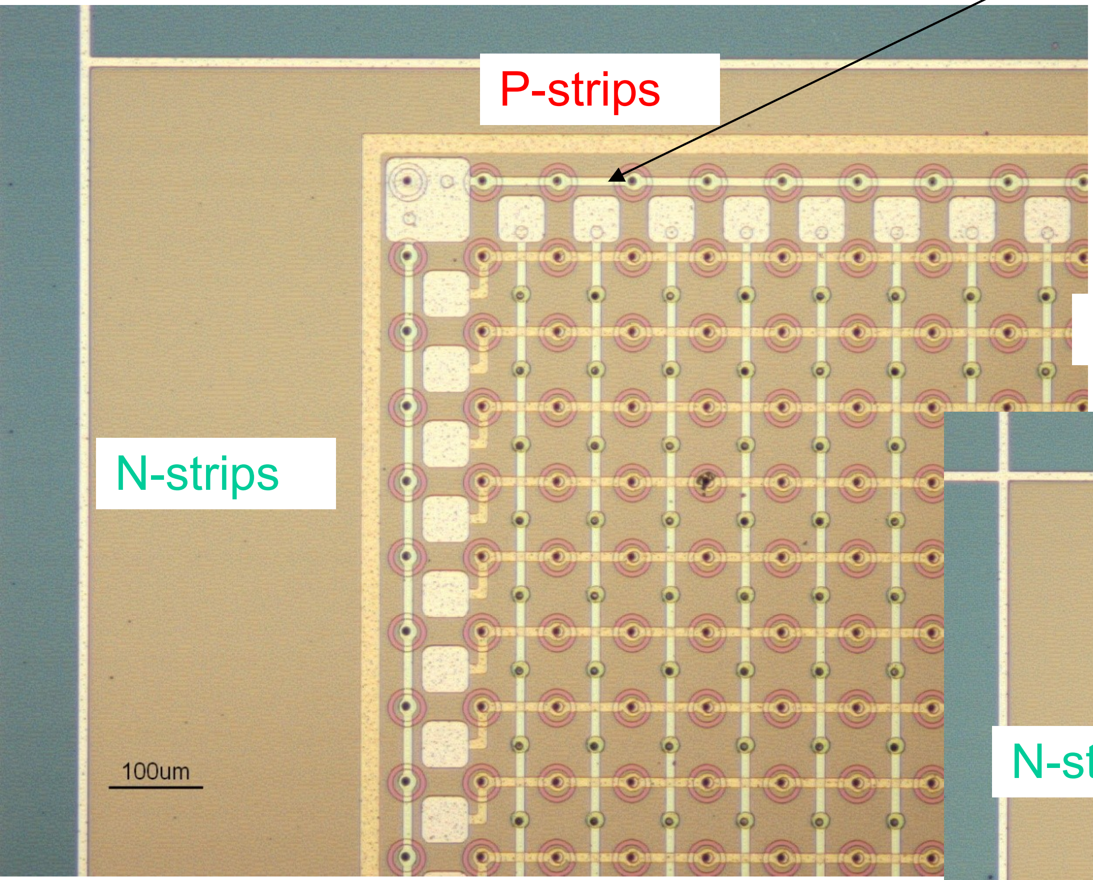
- 2D position-sensitive detectors
- 3D technology (250 μm deep columns)
- Single-side process
- Crossed p-type and n-type strips
- 1 cm strip length

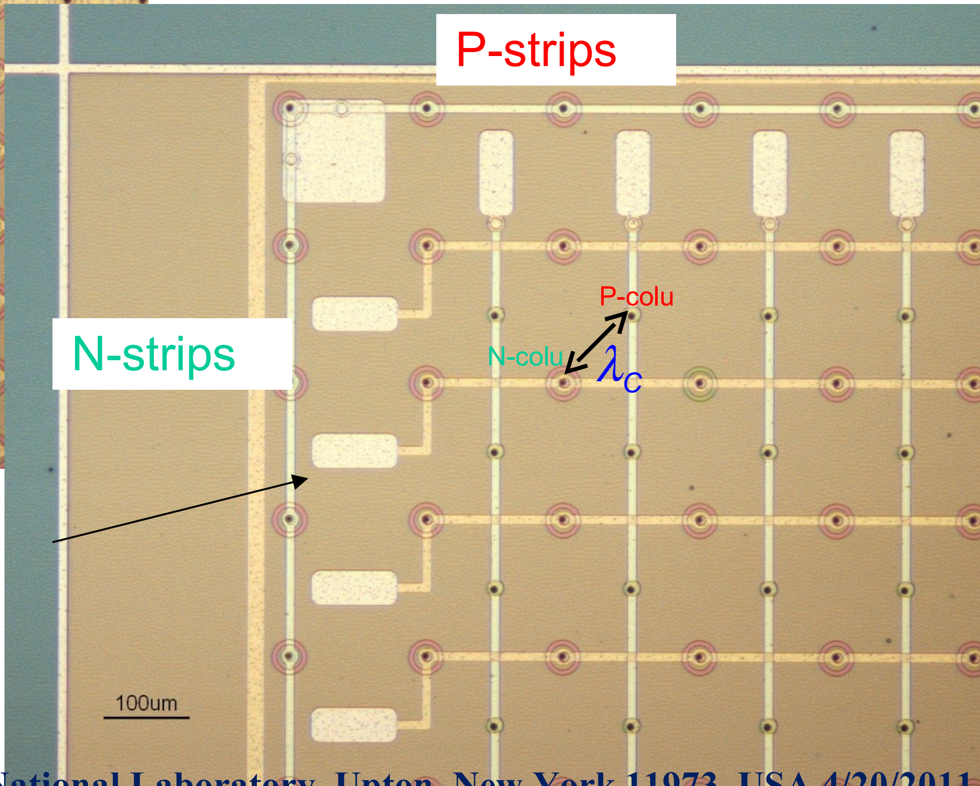


1. Pitch 80 μm double metal
2. Pitch 80 μm polysilicon and metal
3. Pitch 160 μm double metal
4. Pitch 80 μm double metal edgeless
5. Pitch 160 μm double metal edgeless

Different type of detectors

Type S10 128 (n-type) x 127 (p-type) channels, pitch 80 μm, double metal, edgeless (56.6 μm electrode spacing)





Type S11
64 (n-type) x 63 (p-type) channels, pitch 160 μm, double metal, edgeless

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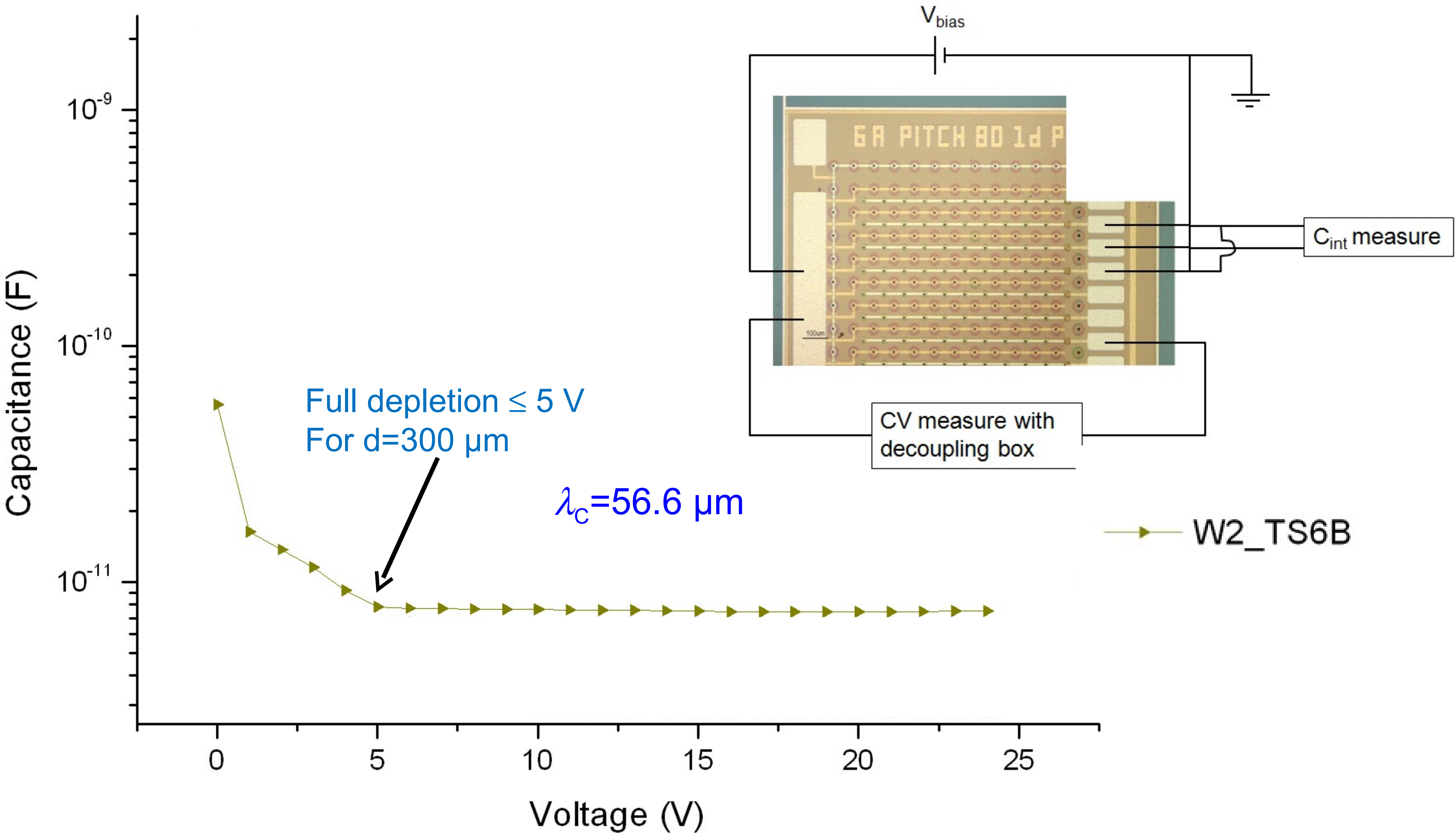
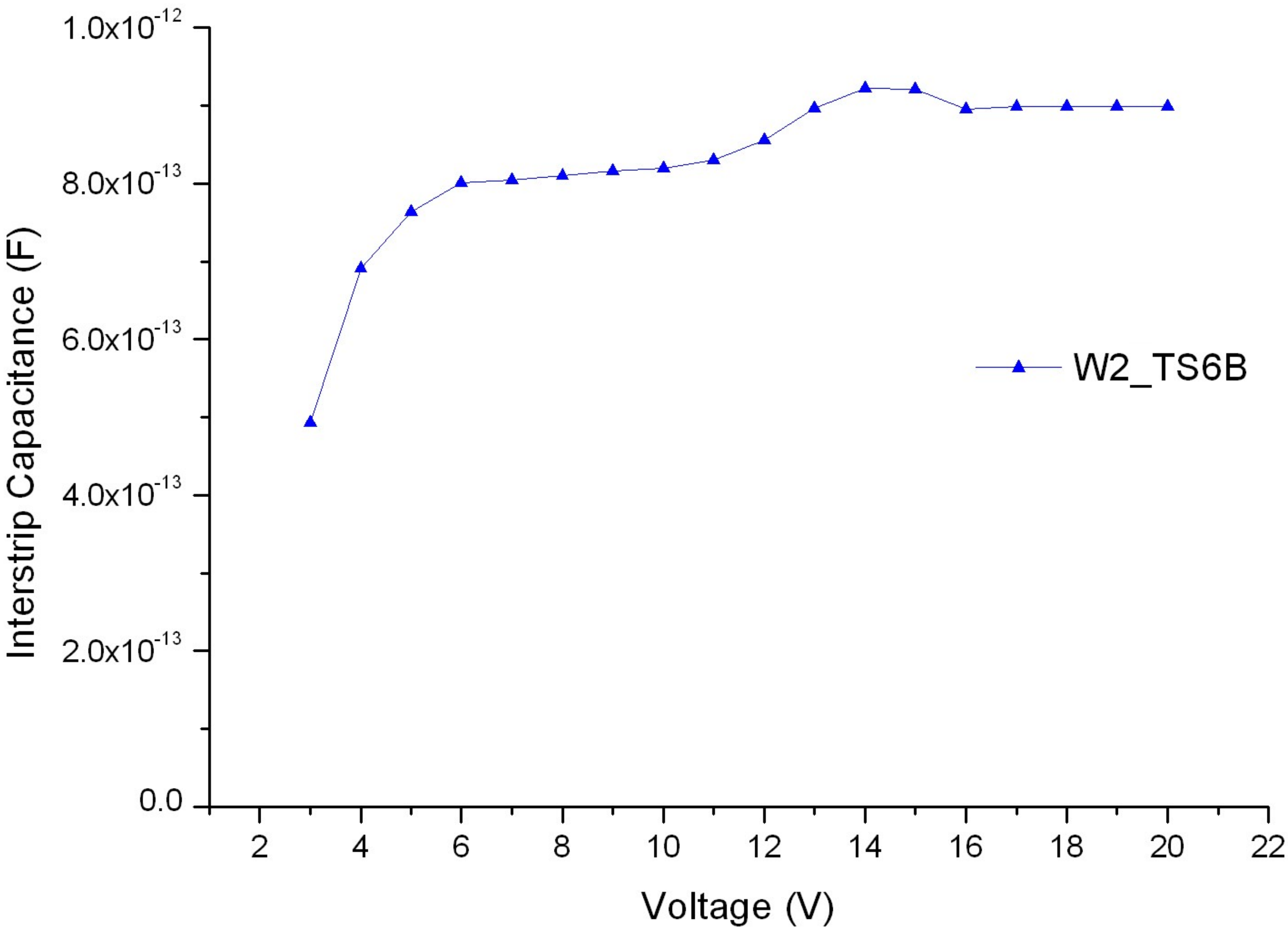
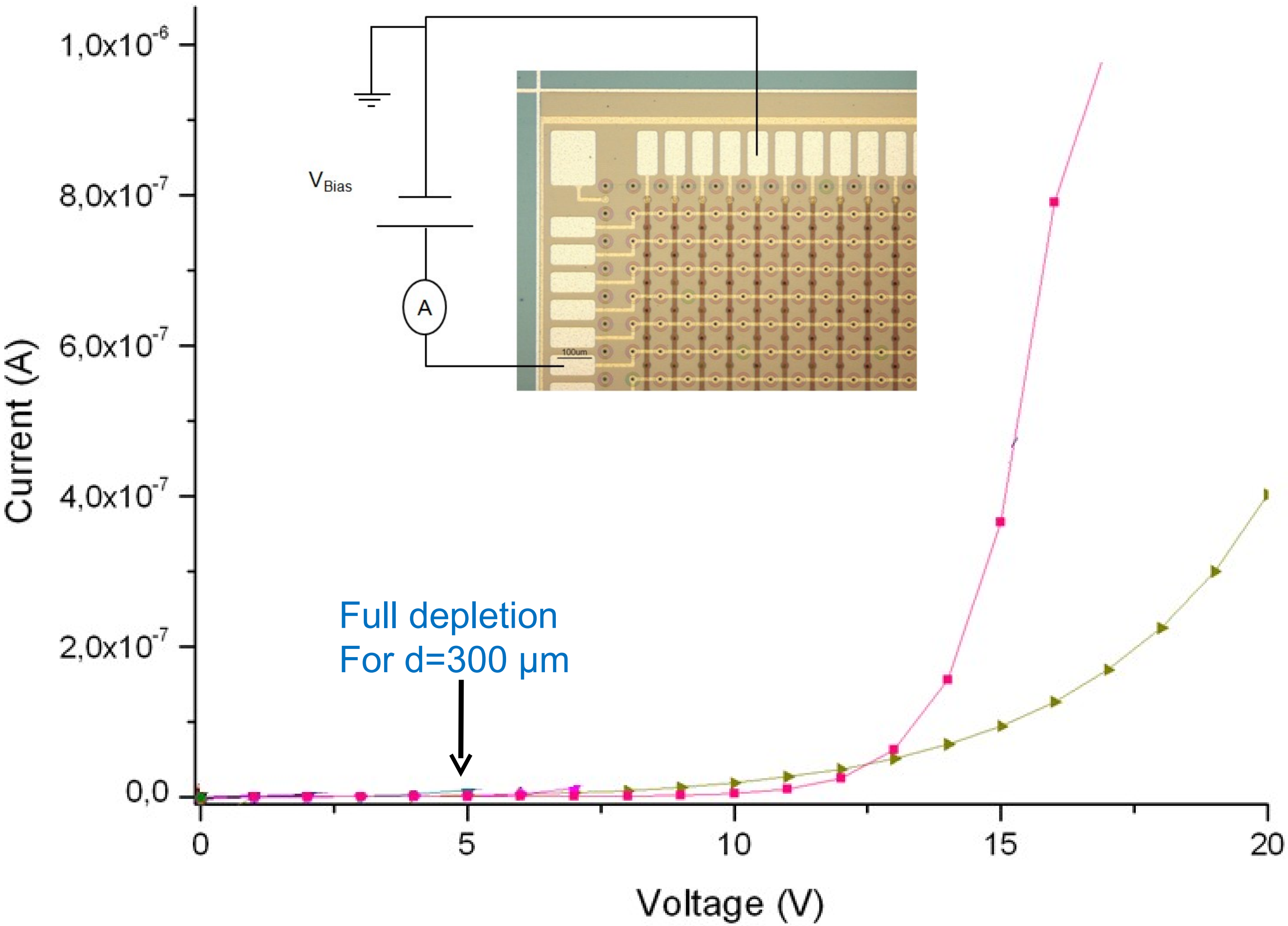
1 (n-type, all shorted) x 127 (p-type) parallel channels, pitch 80, double metal (measurements: Daniela Bassignana, CNM)



Interstrip capacitance between one p-type strip and its first neighbours (pitch 80um)



128 (n-type) x 127 (p-type) channels, pitch 80 um, double metal



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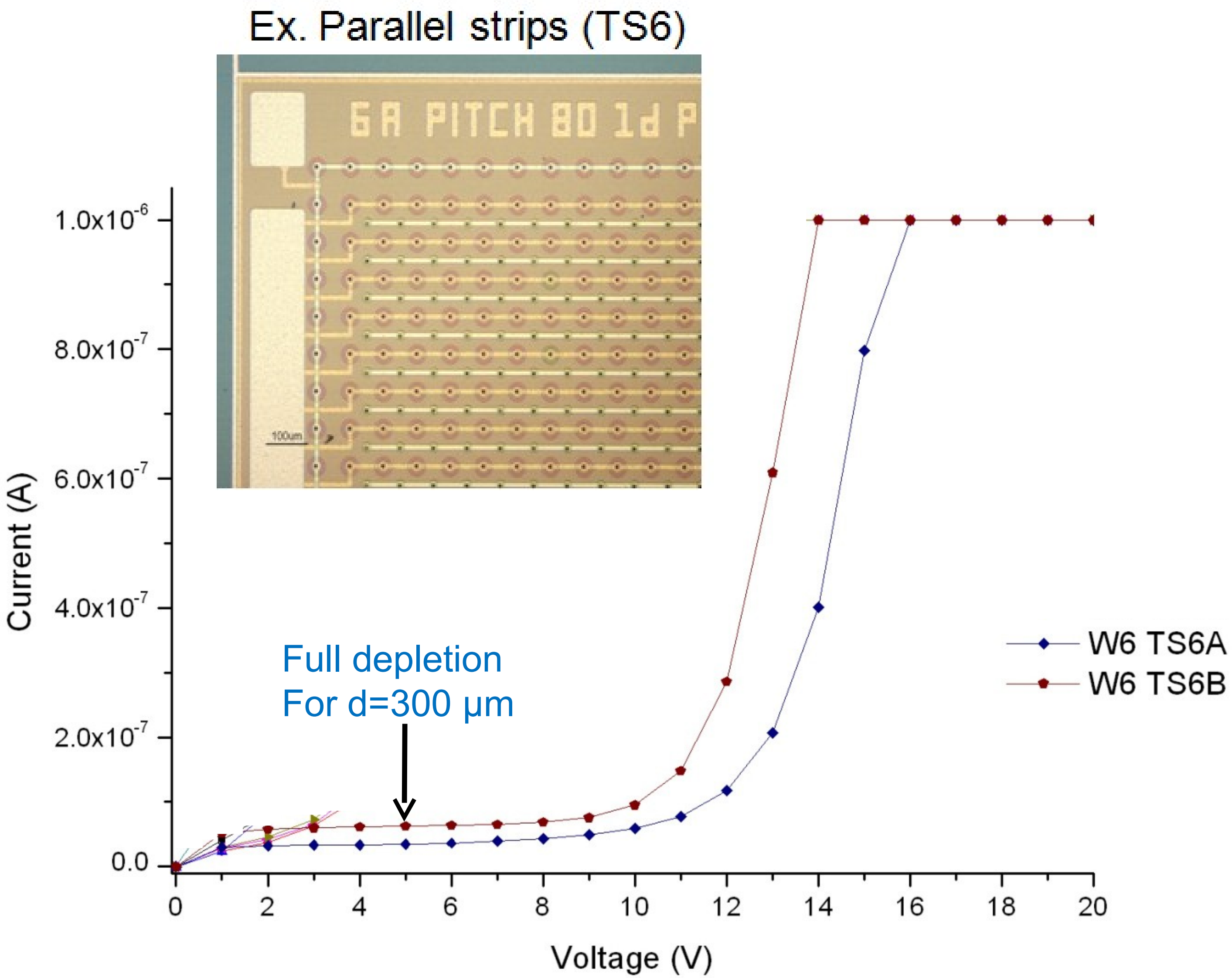
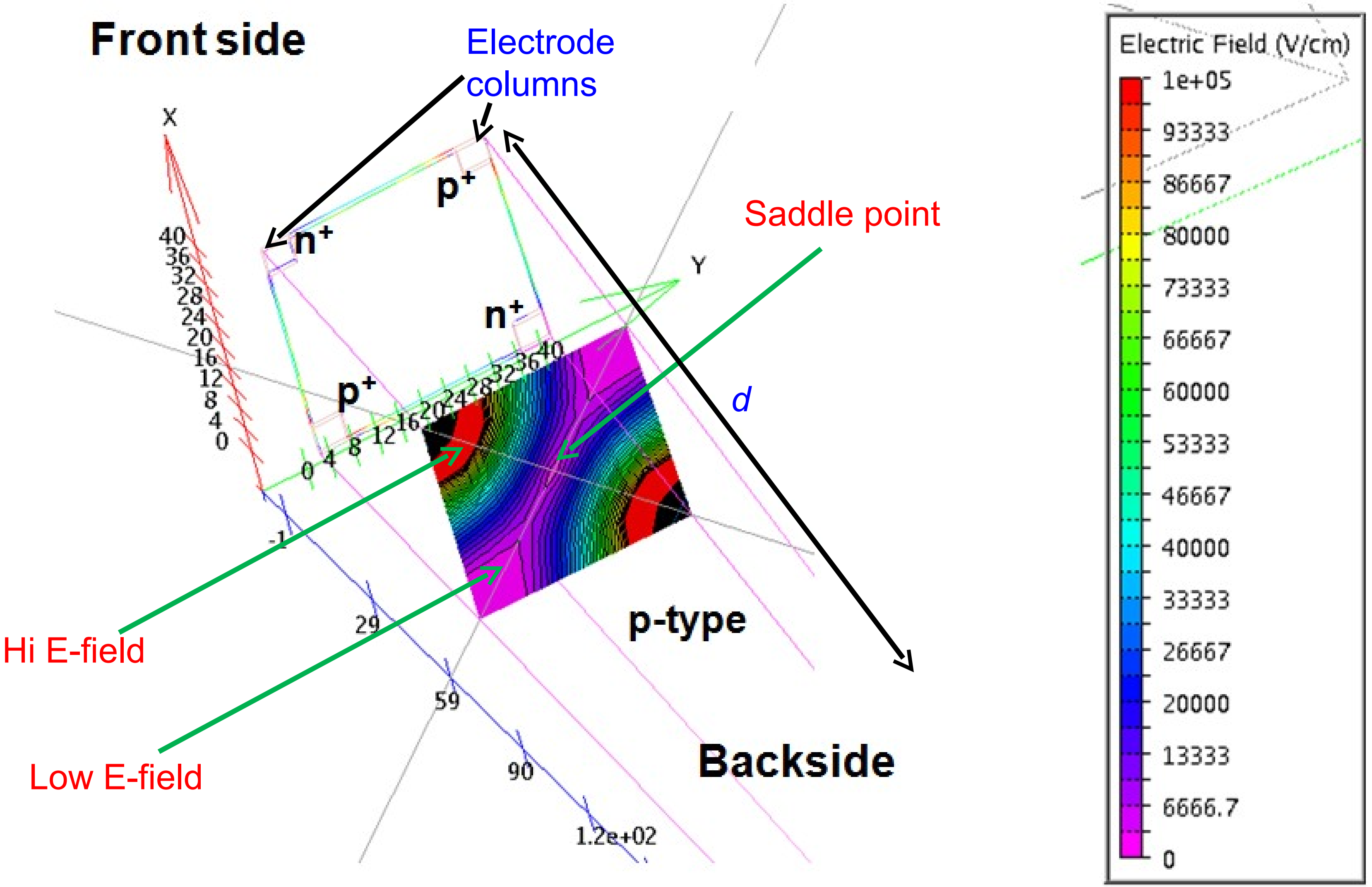


Charge collection tests using laser and sources will be done soon.

Conventional 3D detectors with column electrodes

E-field profile

A cross-section perpendicular to column electrodes in a unit cell



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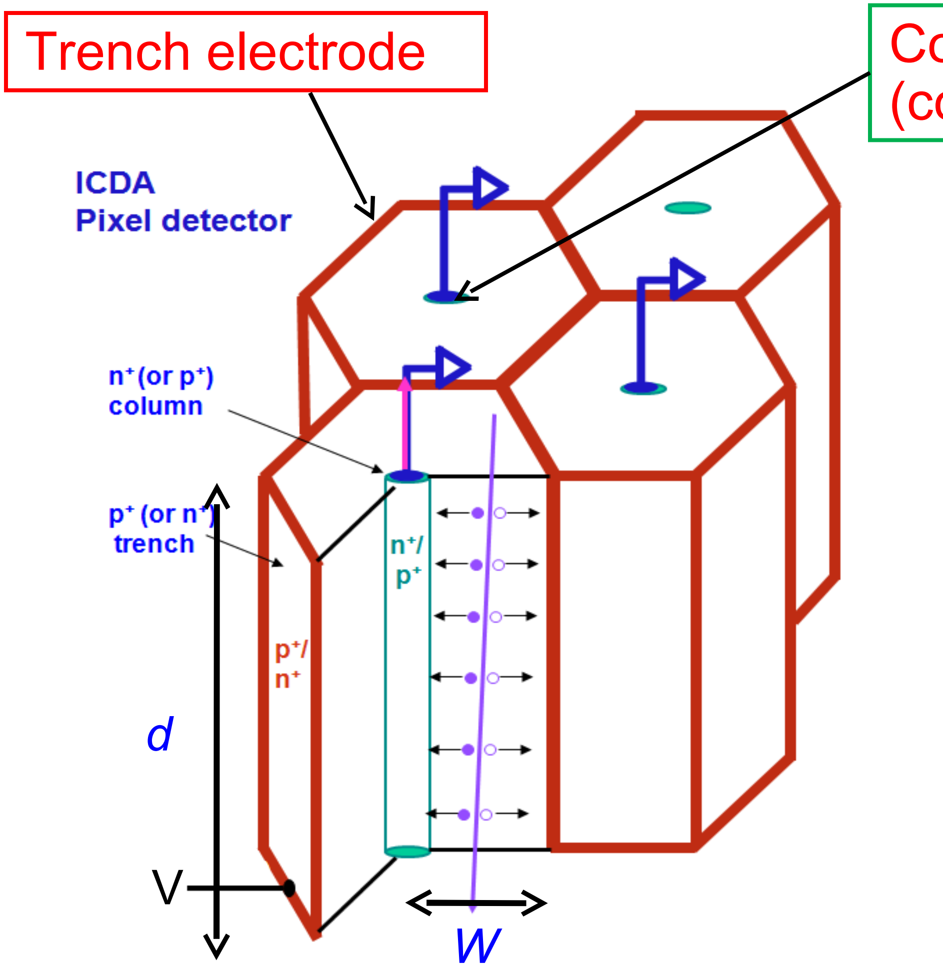
The main goals for the new detector electrode configuration

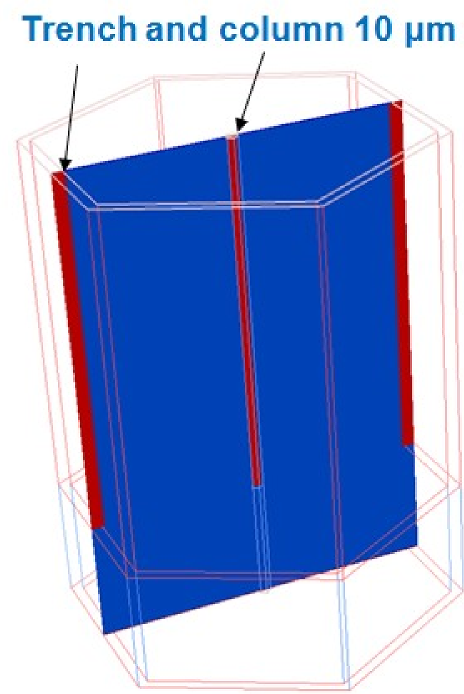
- More uniform, homogeneous electric field
- No saddle points, no low/zero field region
- No extremely high field regions near breakdown condition
- Low voltage operation
- Asymmetric electrodes to optimize the electric field
  manipulation of electric field
- Still decoupling thickness from depletion depth (rad- hard and possible to deplete very thick detectors)

The New BNL 3D-Trench-Electrode Detectors



Pixel cells are isolated from each other --- Independent Coaxial Detector Array

(ICDA)



Depletion depth *W* is decoupled from the thickness *d*

Zheng Li, 15th CERN RD50 Workshop, CERN, 11-18-2009

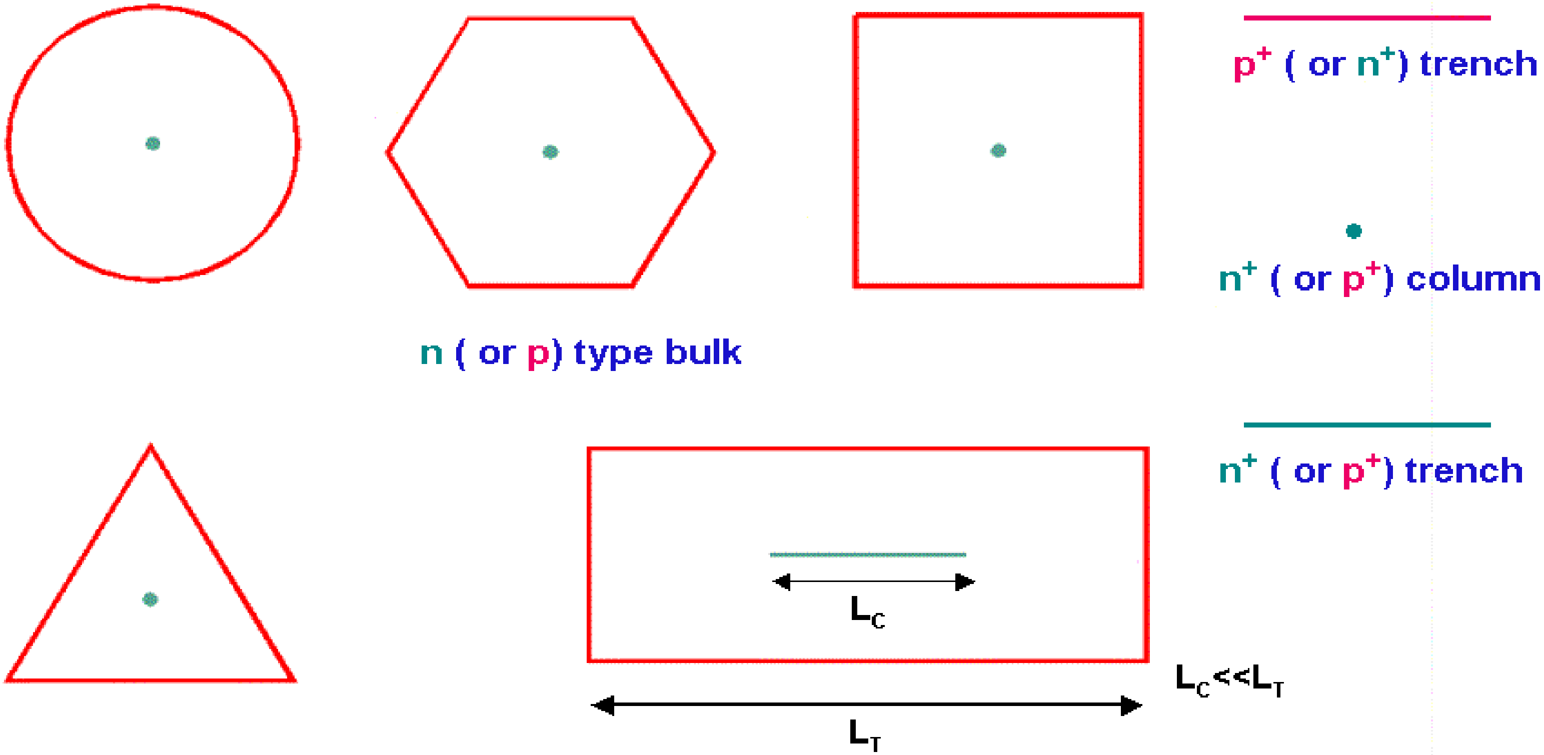
US patent pending (61/525,756)

PCT filled on 10/15/2010 (PCT/US2010/52887)

Steve Wood, Licensing Associate, 001-631-344-3450, Steven.Wood@bnl.gov)

Examples of single cells of ICDA

Concentric type:

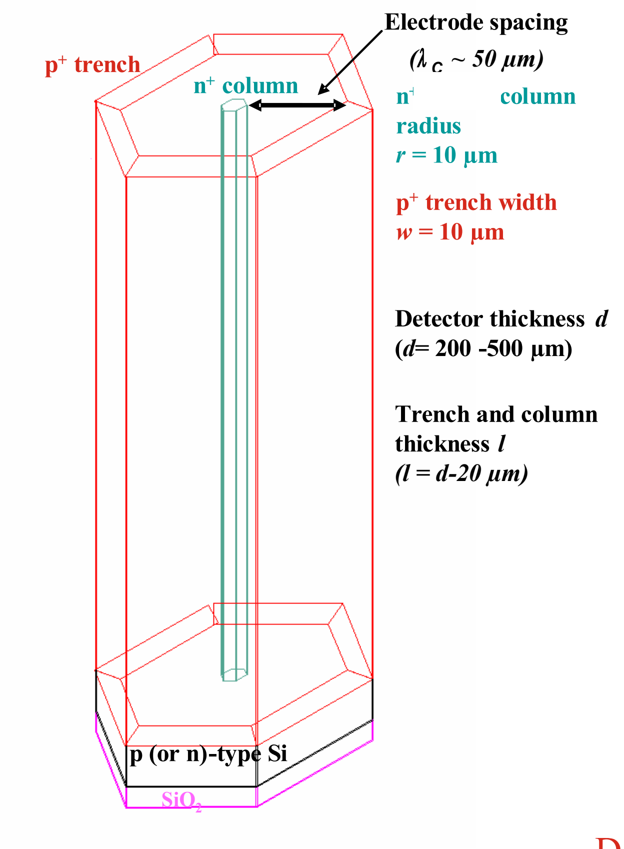


Parallel plate type:

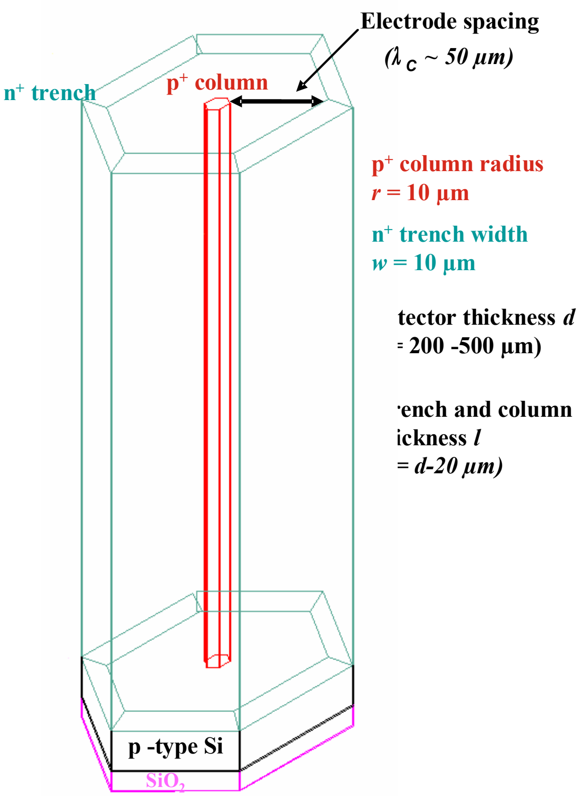
New 3D-Trench Si Detectors --- Single pixel (Hexangular Type), for sLHC --- small electrode spacing, < 100 μm for better depletion and better CCE ($\lambda_{trapping}$ <30 μm at $1x10^{16}$ n_{eq}/cm^2)

Concentric type with two different junction configurations:

Central column junction (CJ):
3D-Trench-CJ



Outer-ring-trench junction (ORJ):
3D-Trench-ORJ --- best for E-profile



Dead space
<14%

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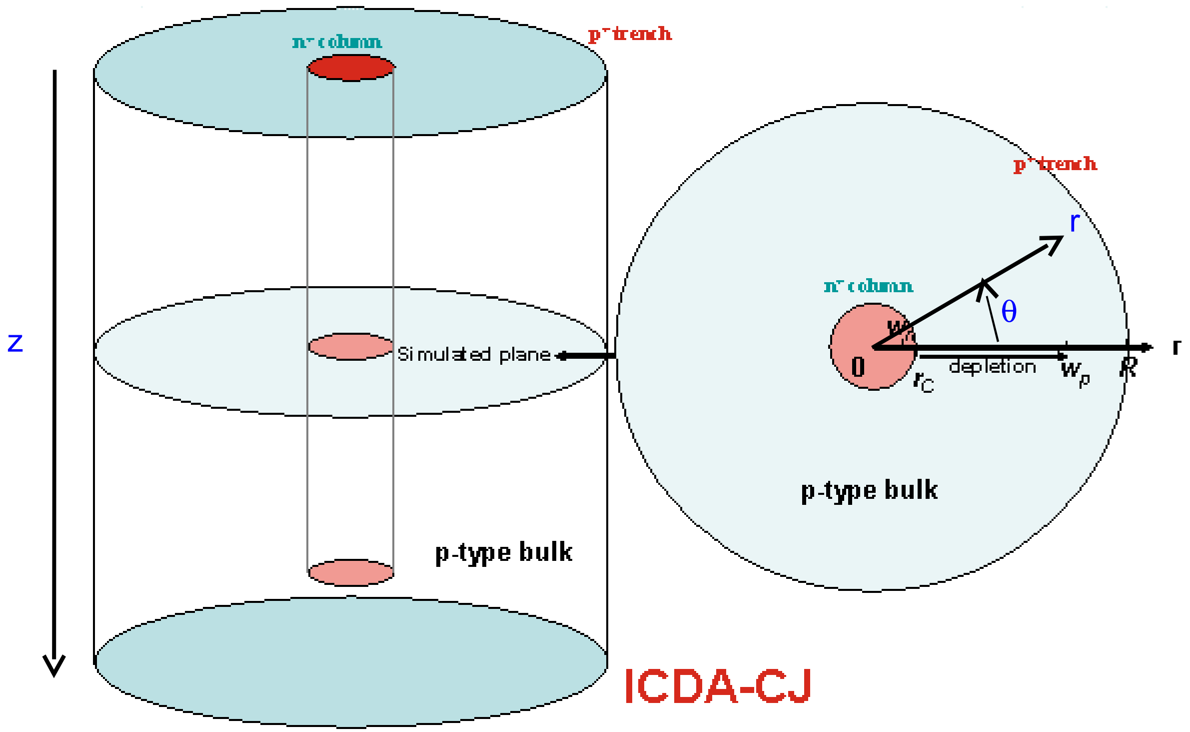
Cylindrical symmetry can be used to approximate the E-field

For ICDA-CJ

or 3D-Trench-CJ

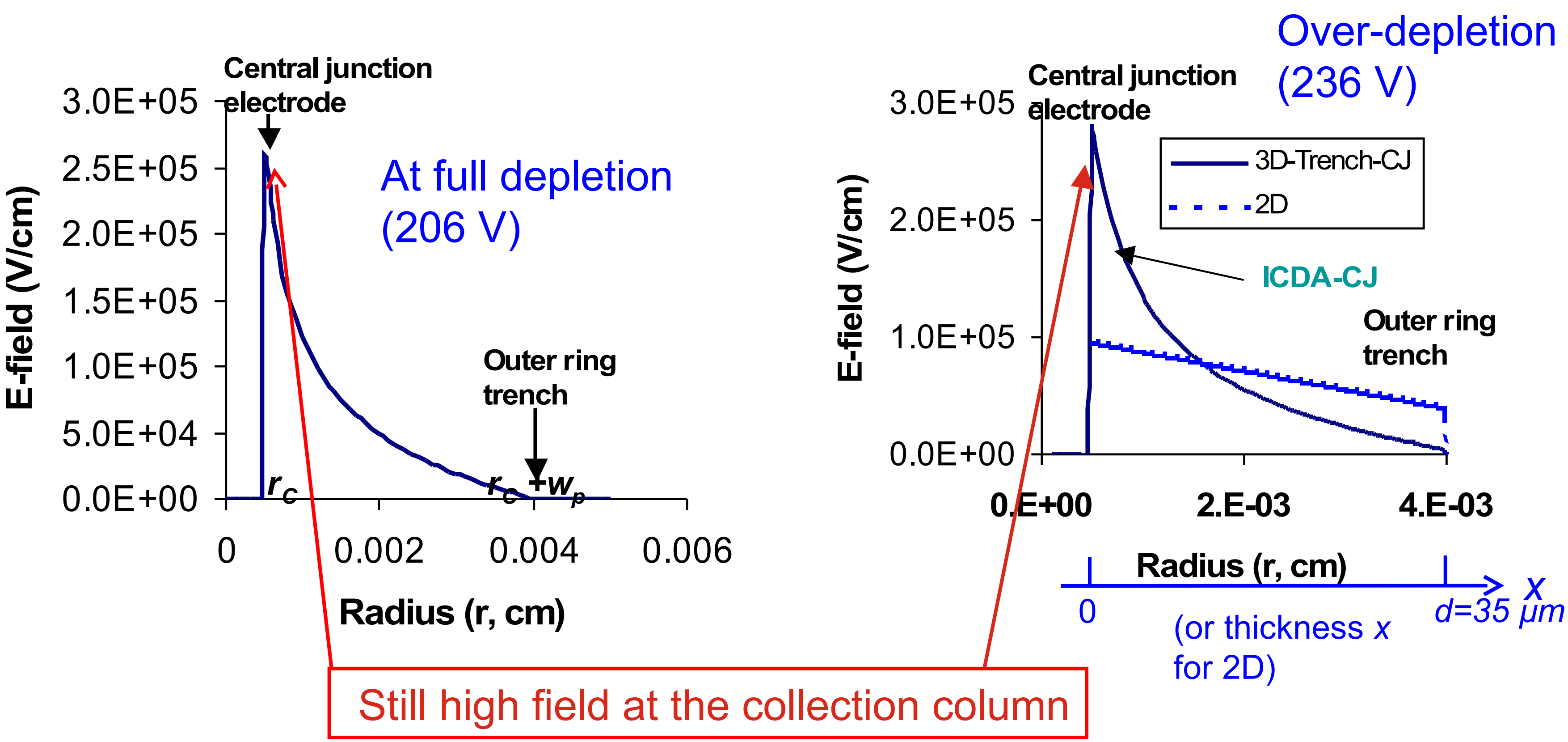


Very simple 1D analytical solutions

E-field profiles

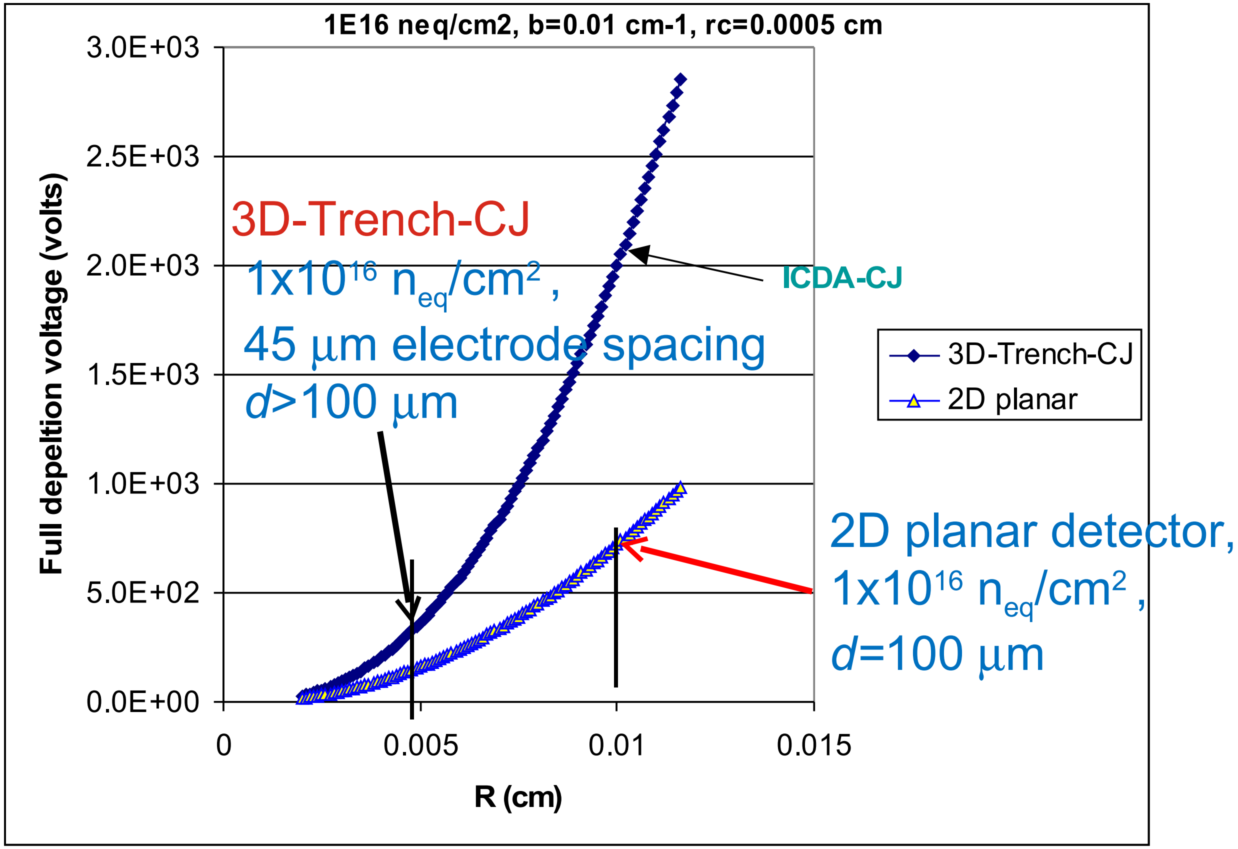
3D-Trench-CJ

$1 \times 10^{16}\ n_{eq}/cm^2$, 35 μm electrode spacing
300 μm thickness



ICDA-CJ ---- Full depletion voltage

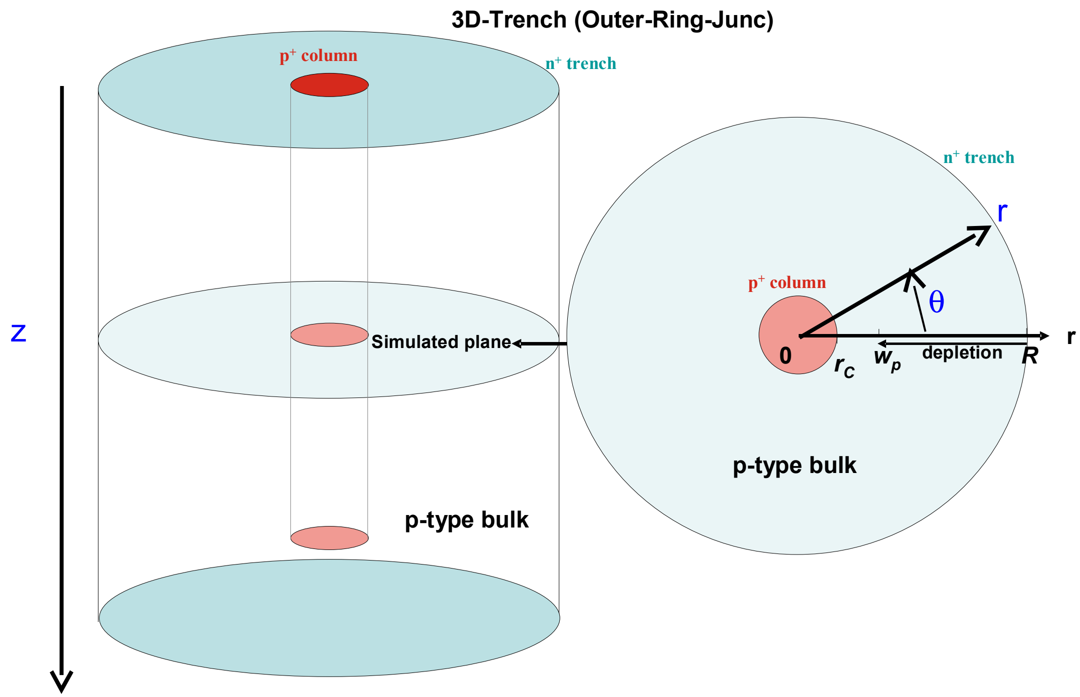
Full depletion voltage as a function of radius of outer trench R



or d for 2D

For ICDA-ORJ

or 3D-Trench-ORJ



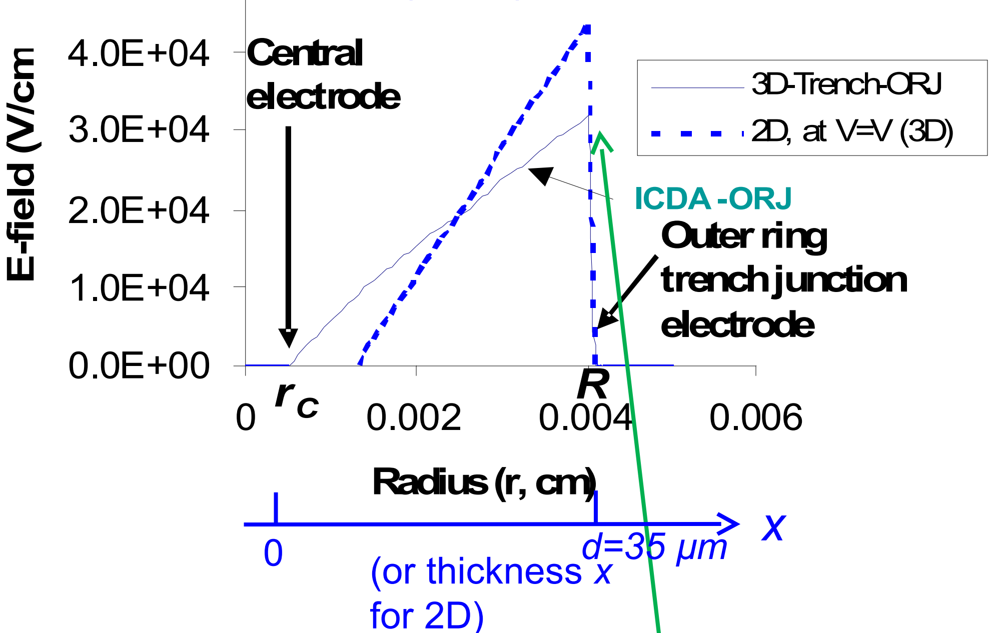
Very simple 1D analytical solutions

E-field profiles

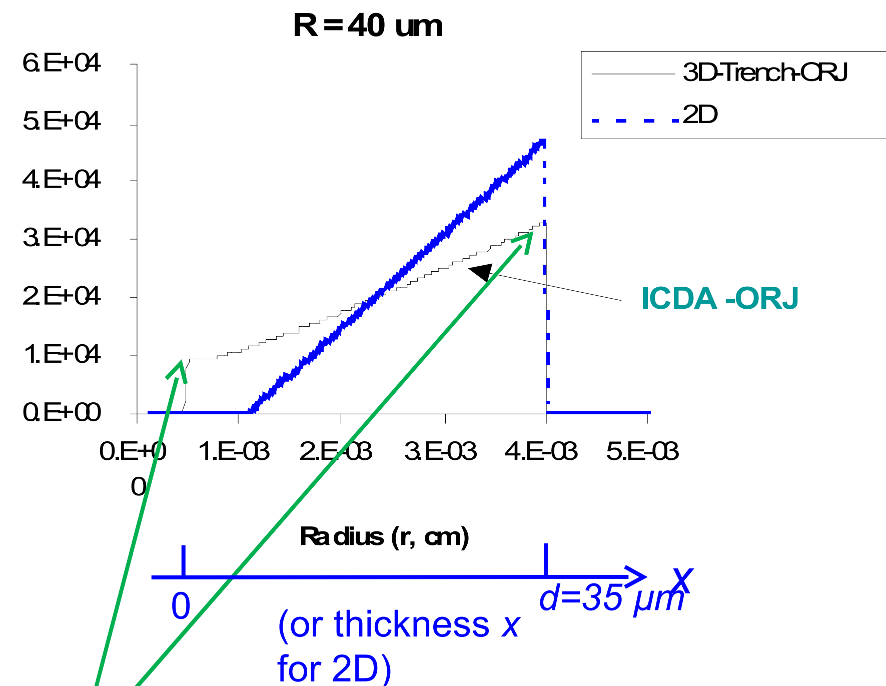
3D-Trench-ORJ

$1\times10^{16}\ n_{eq}/cm^2$, 35 μm electrode spacing
300 μm thickness

At full depletion
(59 V)



Over-depletion
(69 V)



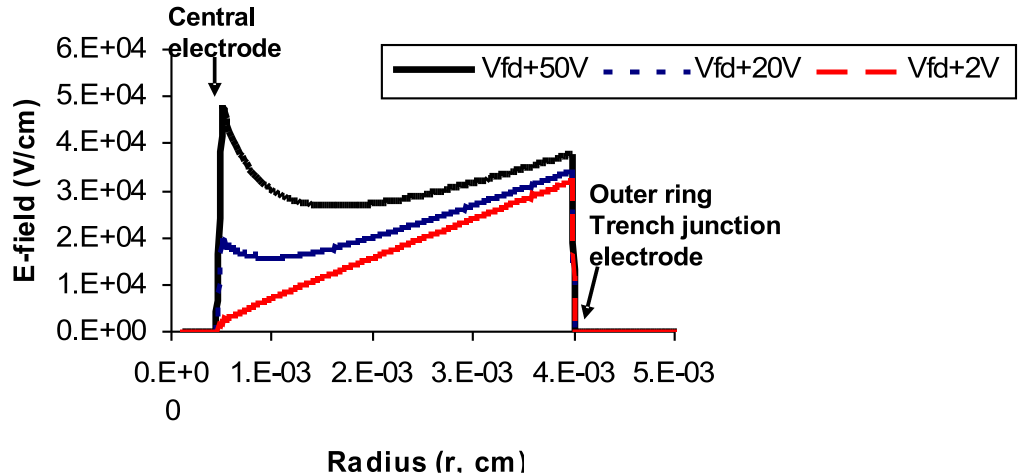
Much lower fields
(10 times lower than CJ)

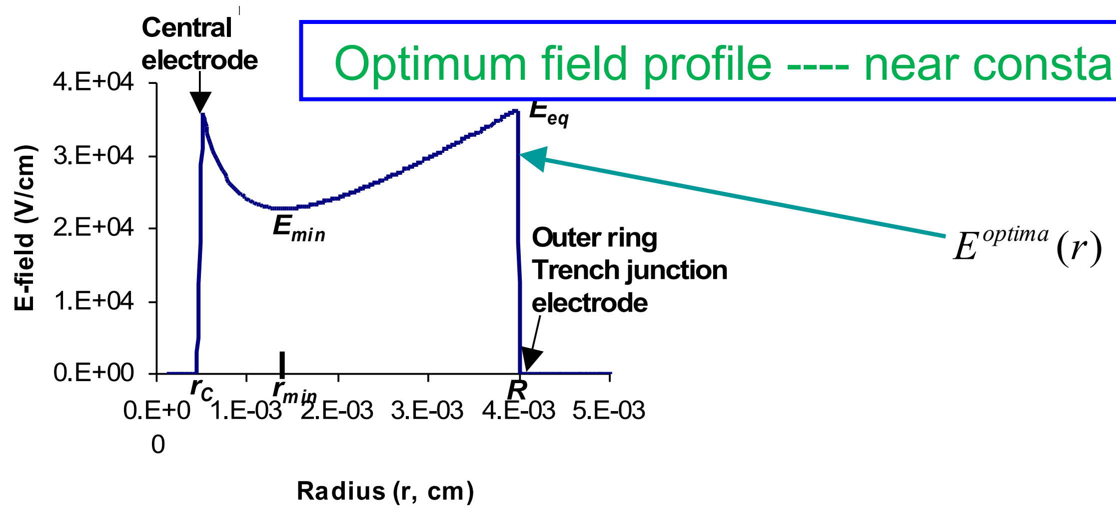
3D-Trench-ORJ

E-field profiles

$1\times10^{16}\ n_{eq}/cm^2$, 35 μm electrode spacing

300 μm thickness





Optimum field profile ---- near constant

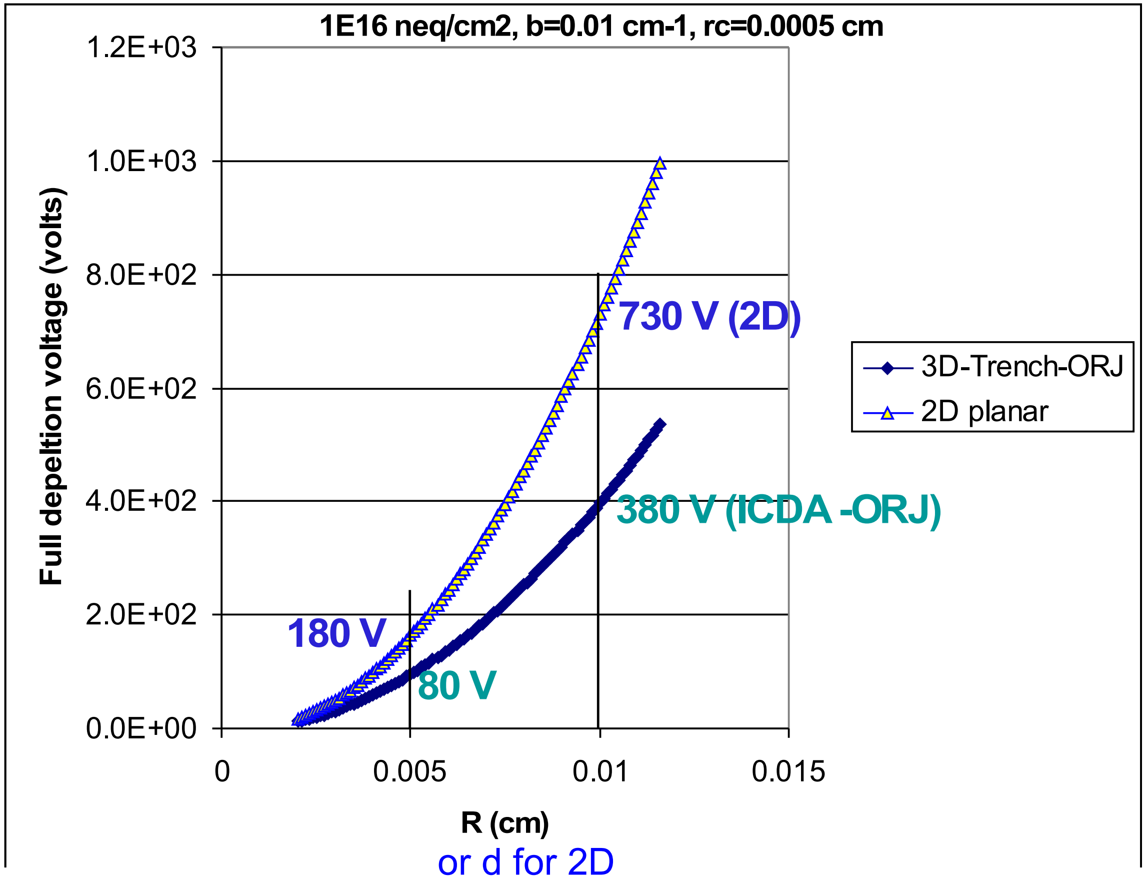
ICDA-ORJ ---- Full deletion voltage

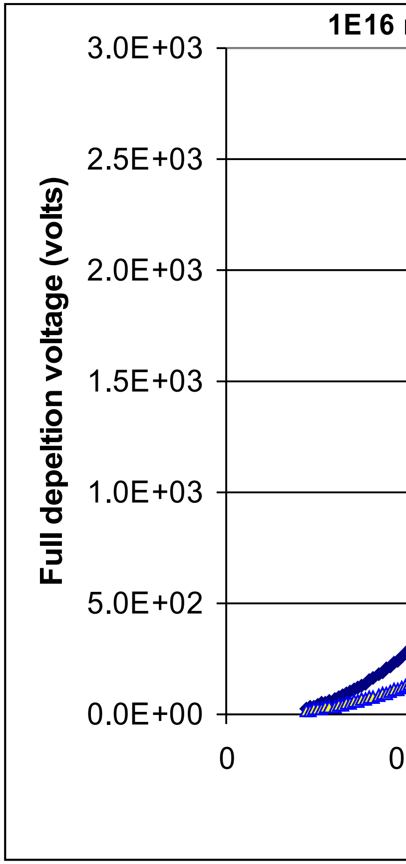
3D-Trench-ORJ

$1x10^{16}\ n_{eq}/cm^2$,

Full depletion voltage as a function of radius of outer trench R

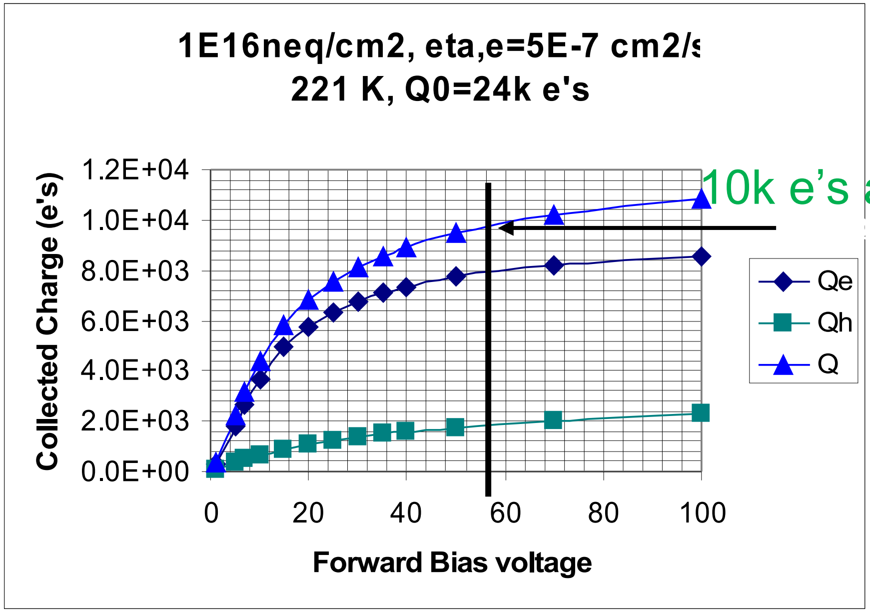
3D-Trench-ORJ vs. 2D





Charge collection

3D-Trench-ORJ
$1 \times 10^{16}\ n_{eq}/cm^2$,
35 μm electrode spacing
d=300 μm

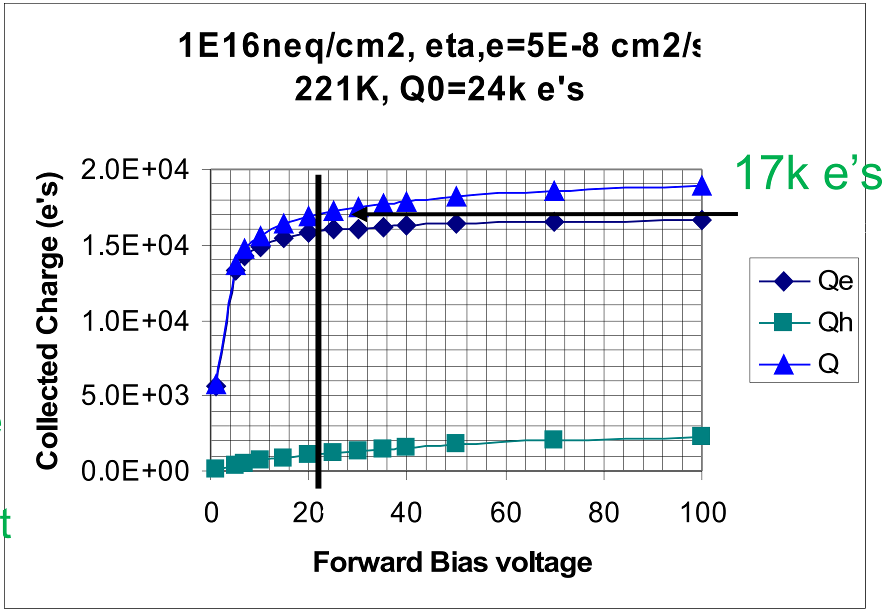


10k e’s at 56 V

Reverse bias

Total collected charge in a 3D-trench-ORJ CID is much more, and at much less bias voltage

For 2D planar detectors
$1 \times 10^{16}\ n_{eq}/cm^2$,
d=300 μm
Q <3000 e’s at >600 V!



17k e’s at 22 V!

CID mode
Forward bias

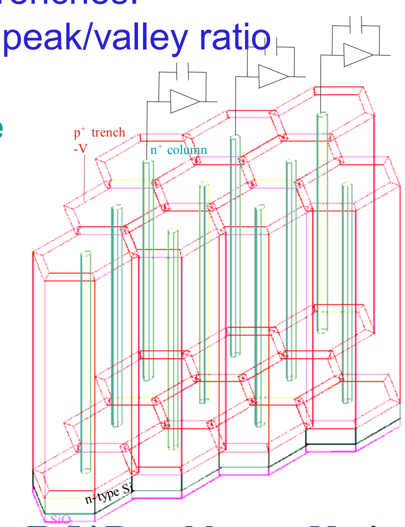
The highest total collected charge can be obtained with a 3D-Trench-ORJ operated at the Charge-Injected-Diode mode (CID) (CERN RD39)

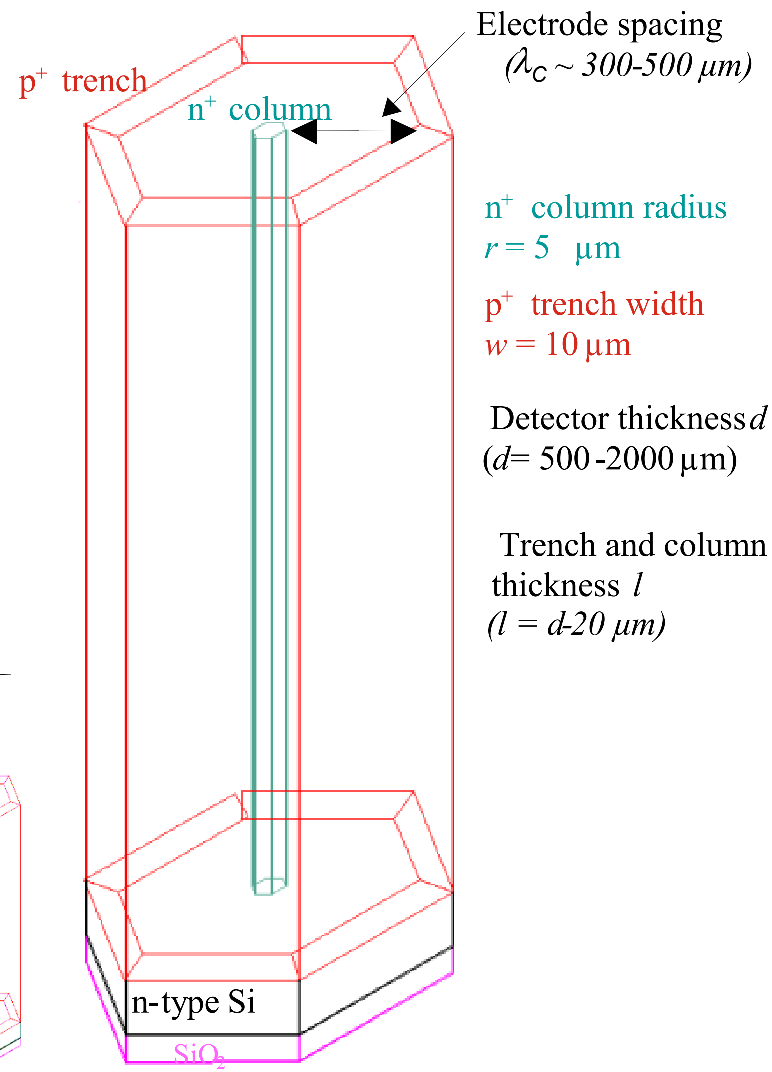
New 3D-Trench Si Detectors for photon science --- large electrode spacing, > 100 μm (no radiation-induced increase in V_{fd})

ICDA ---- Application in photon sciences

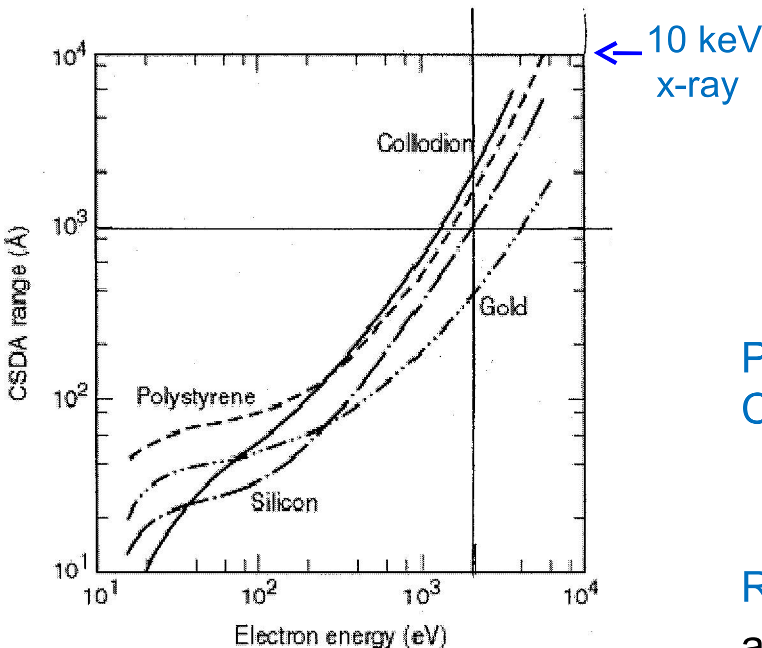
Concentric type
ORJ: ICDA-ORJ

- Large pitch possible (> 1mm or λ_C>500 μm) much less dead area (<2%)
- Very small collection electrode (small C and therefore low noise) (about 150 fF/mm at *r* =5 μm column, D. Lynn)
- Detector thickness can be large: mm --- better X ray detection efficiency
- Pixels will be isolated by trenches: no charge sharing: better peak/valley ratio
- Fast charge collection rate



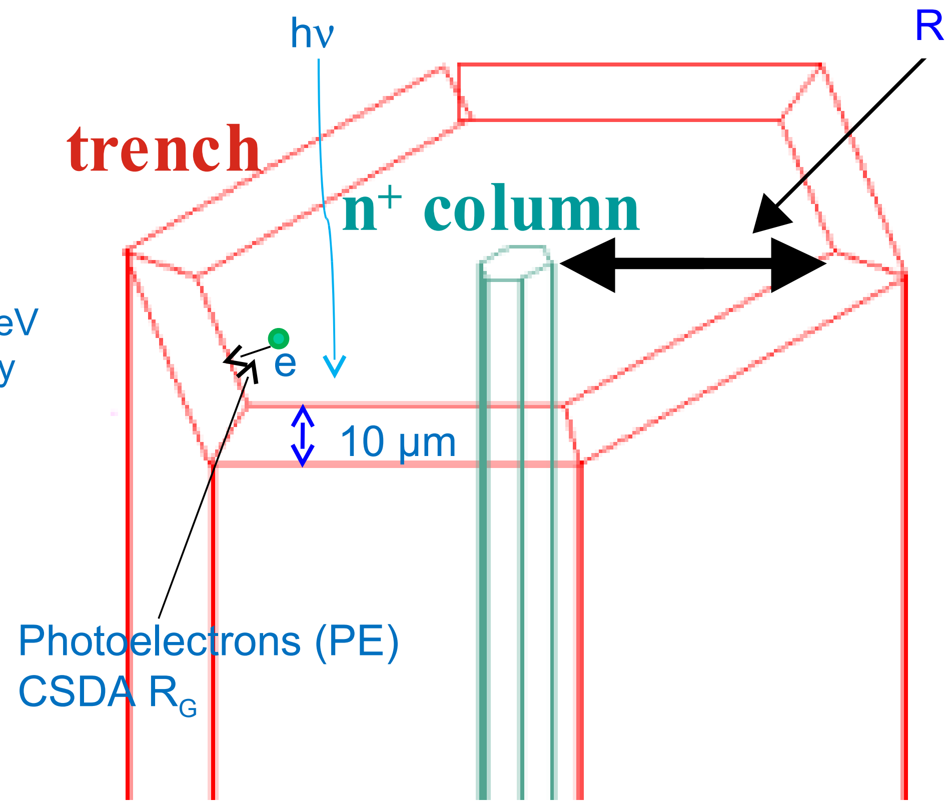


Highly doped trench wall is a natural isolation of cells to prevent charge sharing



J.C. Ashley et al., IEEE TNS NS-23, 1833 (1976)

$$R_G = 0.0181 E_B(keV)^{1.75}\ (\mu m)$$



R_G(PE by 10 keV x-ray)~1μm

a) Photoelectrons generated in one cell will not go to the neighboring cell R_G<<10 μm --- no sharing

b) The energy loss to trench is $<[R^2-(R-1)^2]/\ R^2=0.4\%$ (for R=500μm, at 10 keV x-ray)
Since the direction of PE is isotropic, then <0.1%

Application in photon sciences

3D-Trench-ORJ

Concentric type:

3D-Trench-ORJ: Great reduction in full depletion voltages

Full depletion voltages, *d* = 1 mm, n-type 4.3k Ω-cm

Pixel pitch (μm) (2R)	V_{fd}, volts ICDA-ORJ 3D-Trench-ORJ	V_{fd}, volts 2D-Planar	V_{fd}(ICDA-ORJ)/ V_{fd}(2D-Planar)
1000	100	788	0.127
750	55	788	0.07
500	24 Battery Op possible	788	0.03
250	5.1 ↓	788	0.007

Application in photon sciences

3D-Trench-ORJ

Concentric type:

3D-Trench-ORJ: Great reduction in full depletion voltages

Full depletion voltages, *d* = 1 mm, n-type 20 k Ω-cm

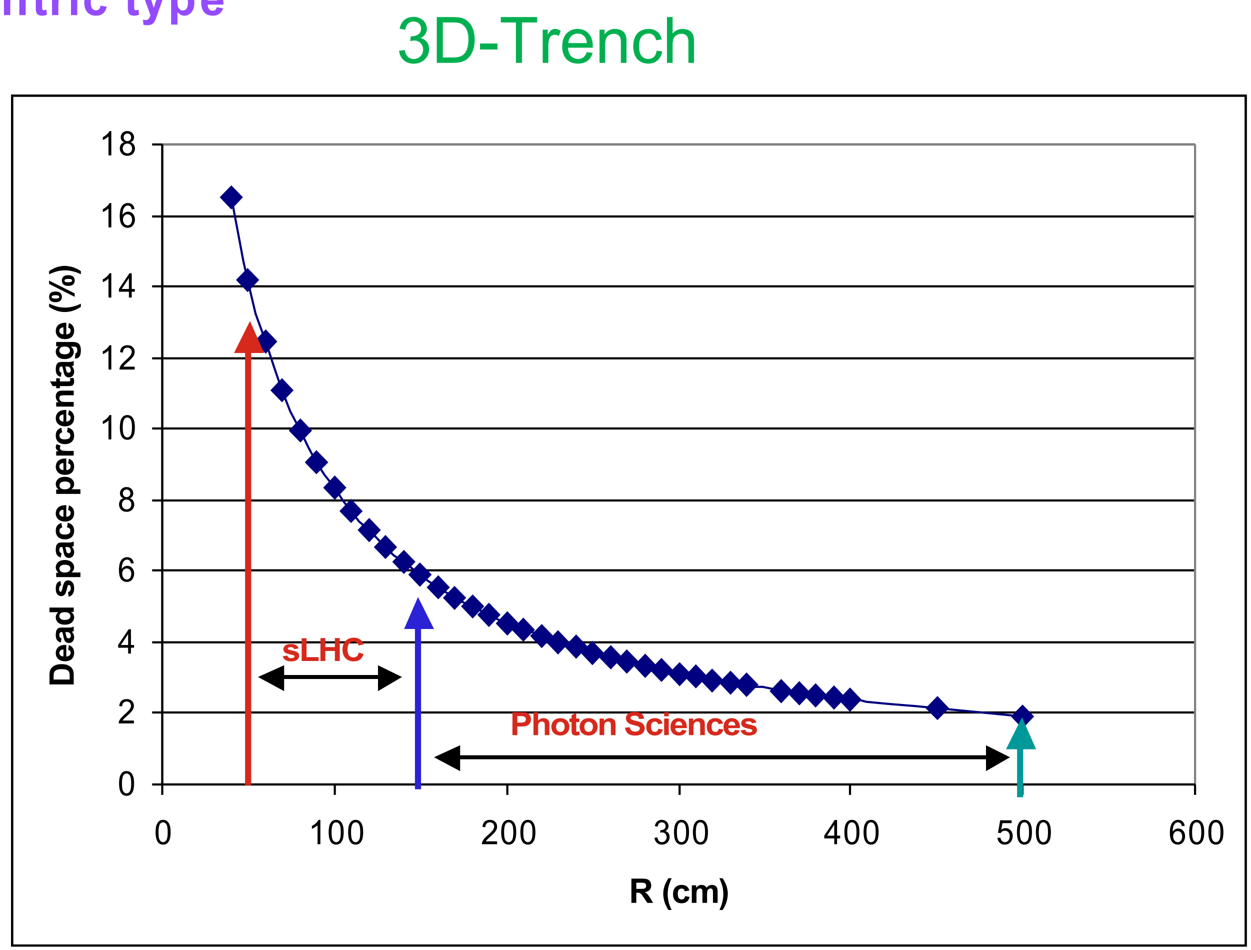
Pixel pitch (μm) (2R)	V_{fd} , volts ICDA-ORJ 3D-Trench-ORJ	V_{fd} , volts 2D-Planar	V_{fd}(ICDA-ORJ)/ V_{fd}(2D-Planar)
1000	22 Battery Op possible	169	0.127
750	12	169	0.07
500	5	169	0.03

Full depletion voltages, *d*= 1 mm, n- type 100 Ω– Cm (low resistivity)

200	169	33880!

ICDA ---- Dead spaces

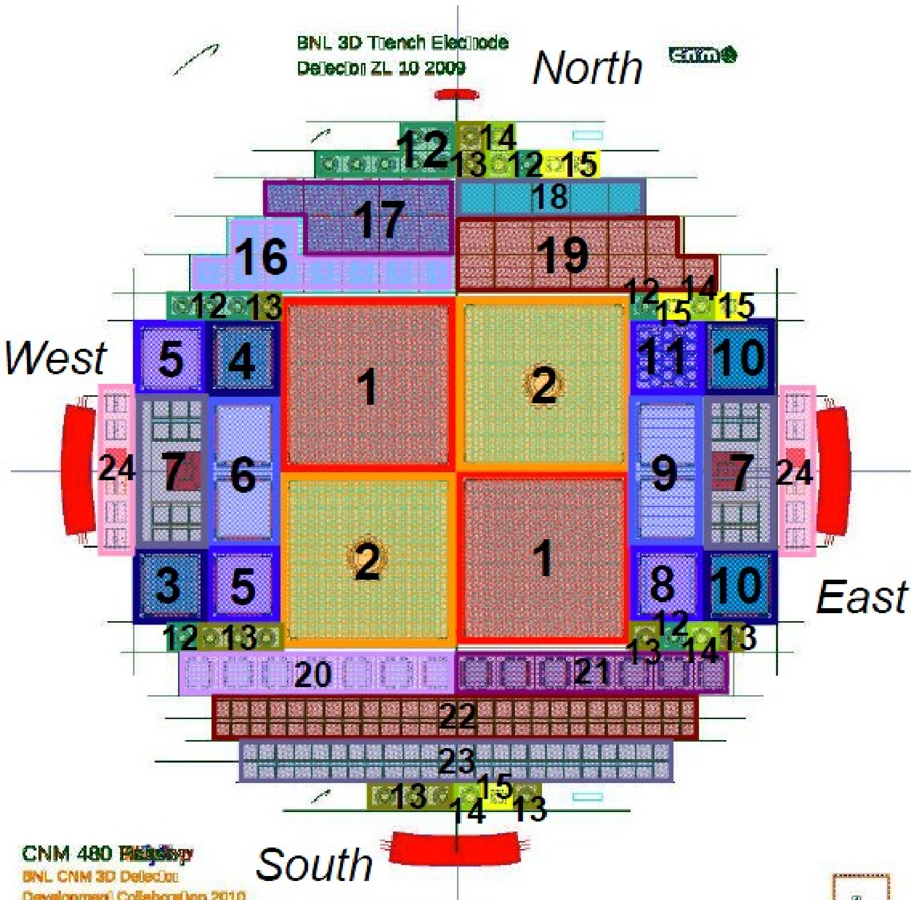
ICDA Concentric type



Percentage of dead space in ICDA (hexangular type) electrode Si detectors.
r_C =5 μm, and trench width $w = 10$ μm.

Fabrication of the first prototype batch of BNL 3D-Trench-Electrode detectors are under way in CNM of Spain (Giulio Pellegrini), completion expected in fall 2011

CNM480 – trenched detectors for BNL (Zheng-Li)

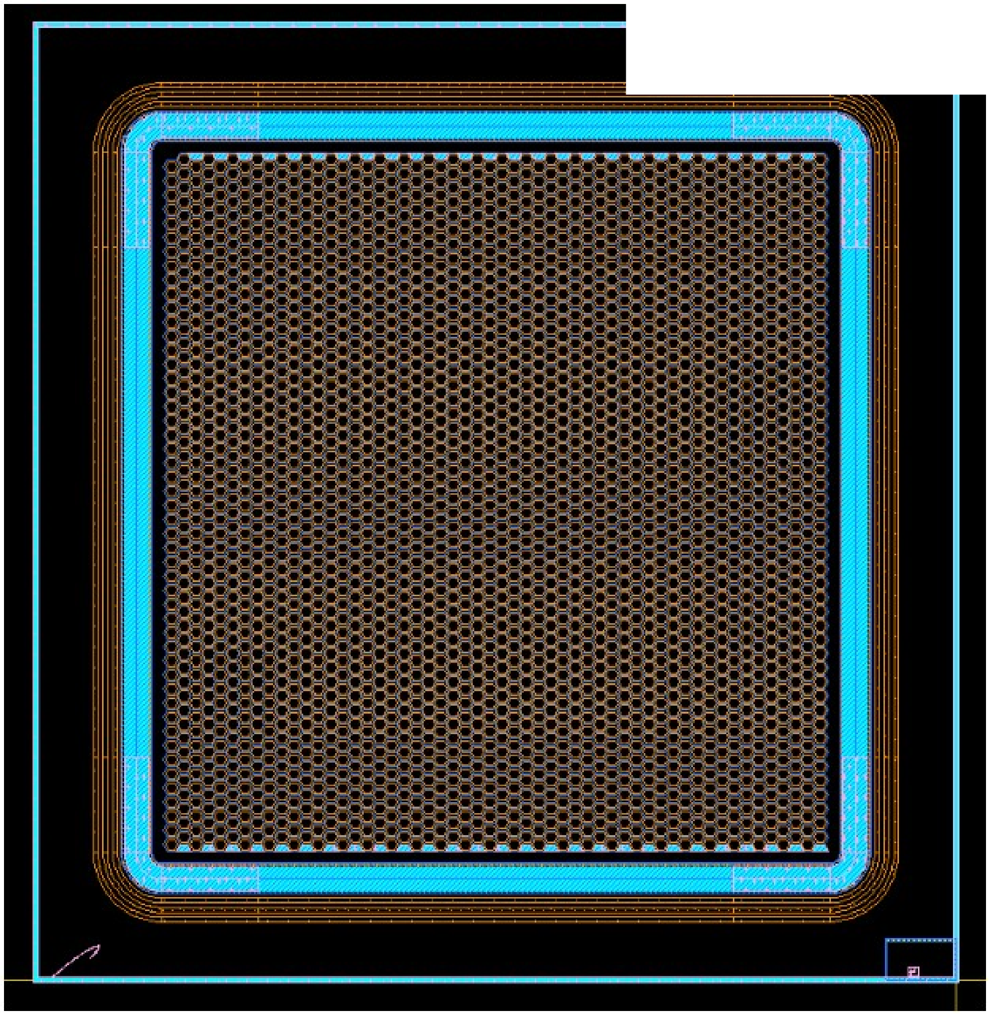


Mask with inverted color for clarity

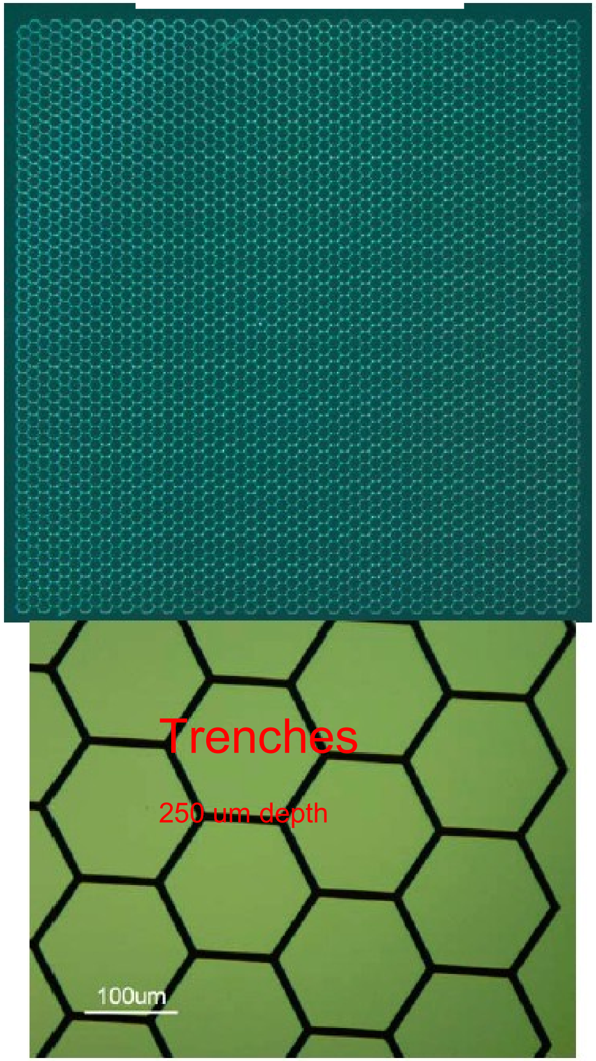
Ref.	Name	Qty
1	3D_TRENCH_PIXEL_HEX_R500_0	2
2	3D_TRENCH_PIXEL_HEX_R500_1	2
3	3D_TRENCH_PIXEL_HEX_R500_2	1
4	3D_TRENCH_PIXEL_HEX_R500_7	1
5	3D_TRENCH_PIXEL_HEX_R80_70	2
6	3D_TRENCH_PIXEL_SQU_R212_7	2
7	3D_TRENCH_PIXEL_SQU_R212_1	4
8	3D_TRENCH_PIXEL_CIR_R300_7	1
9	3D_TRENCH_STRIPIXEL_SQU_R2	2
10	3D_TRENCH_STRIPIXEL_REC_16	2
11	3D_TRENCH_DRIFT_CIR_R500_1	1

One example:
Hexangular type, R = 80 μm, 49x54 array

Design

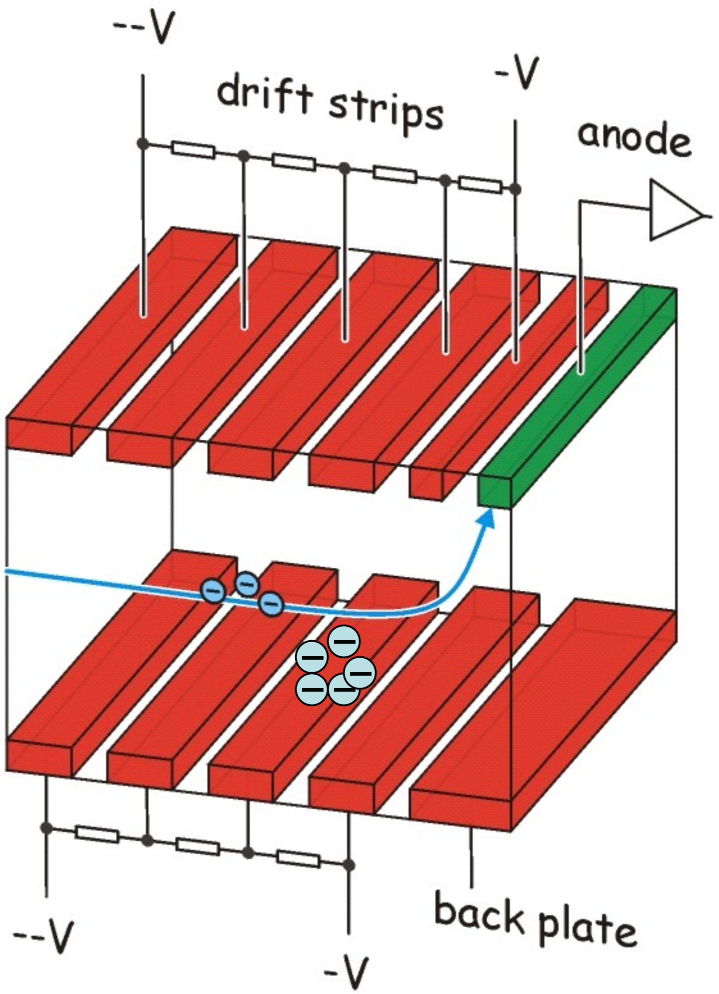


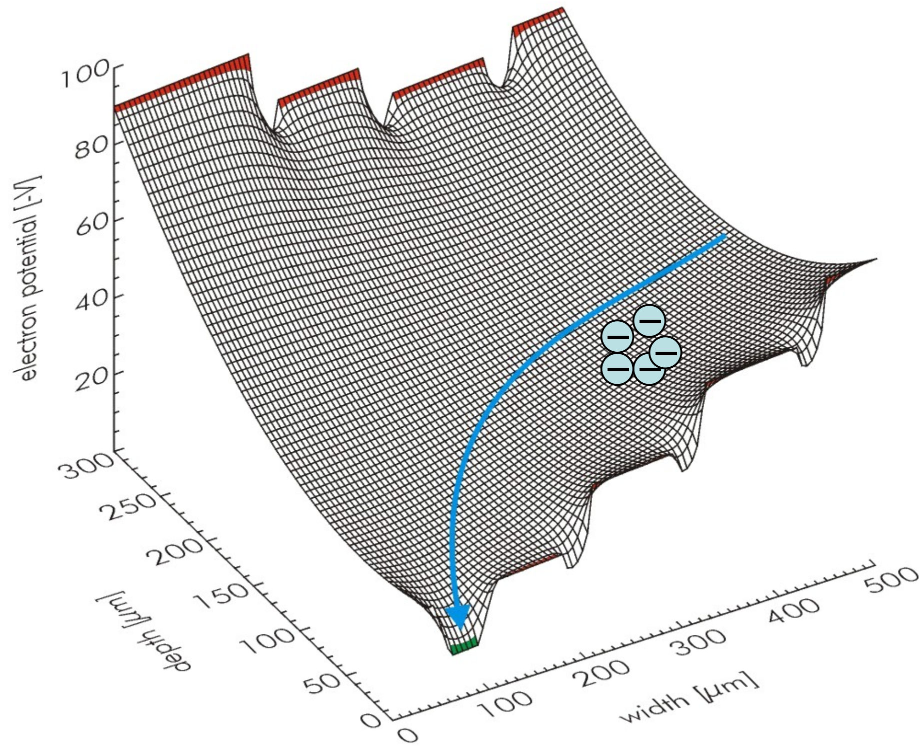
Etched trenches
Actual photos



Si Drift Detector (SDD)

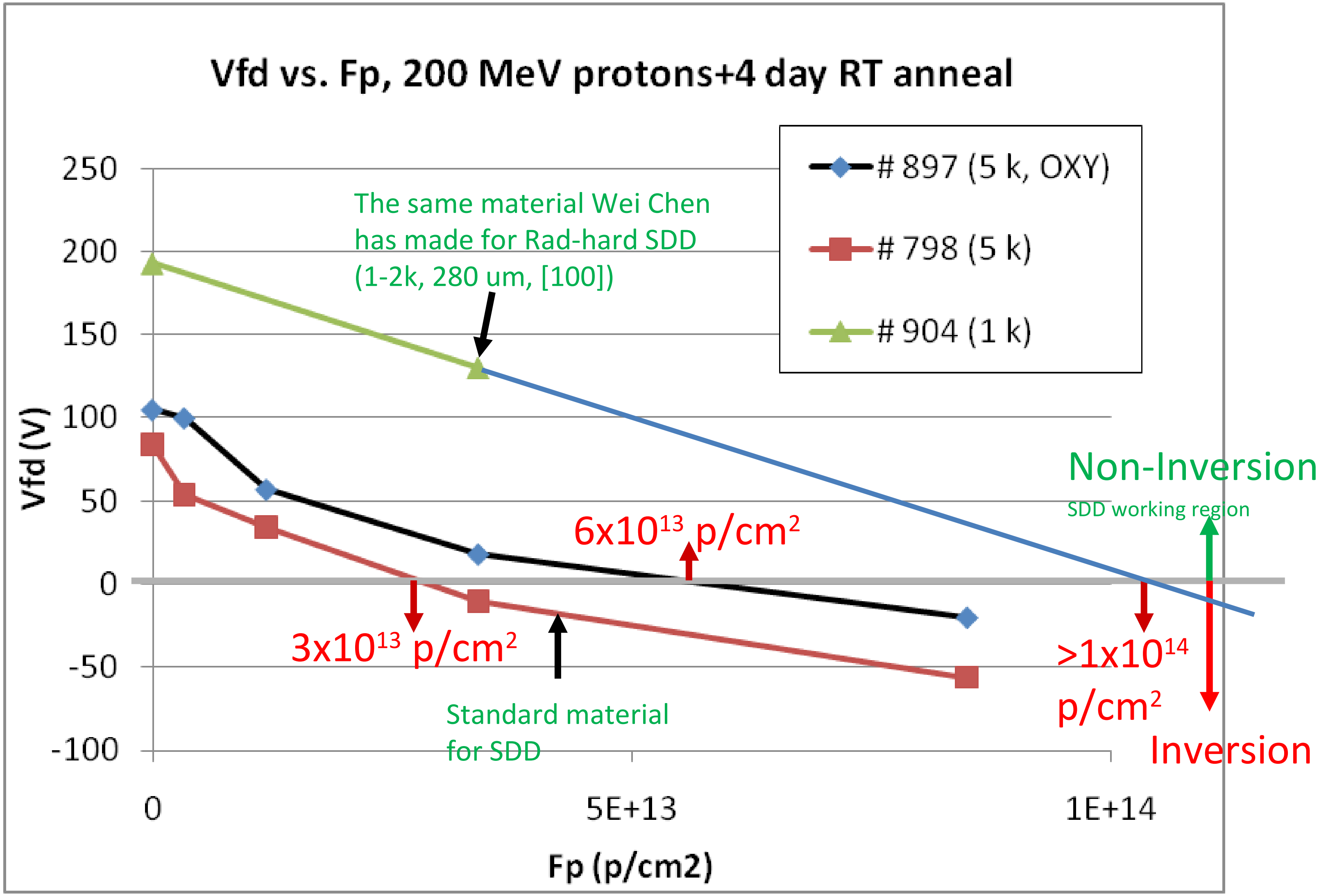
Invented at BNL Instrumentation Div. by Rehak and Gatti in 1983





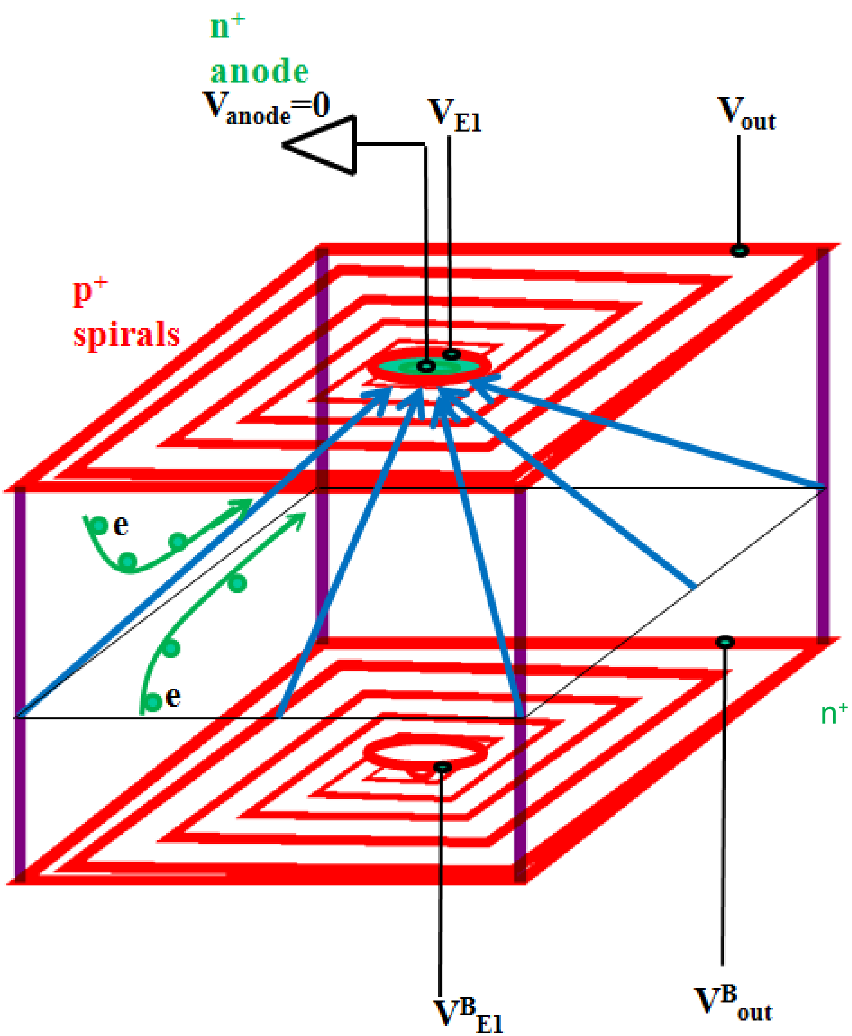
Rad-Hard Si Drift Detector (SDD) Considerations (for NASA Lunar Proj.):

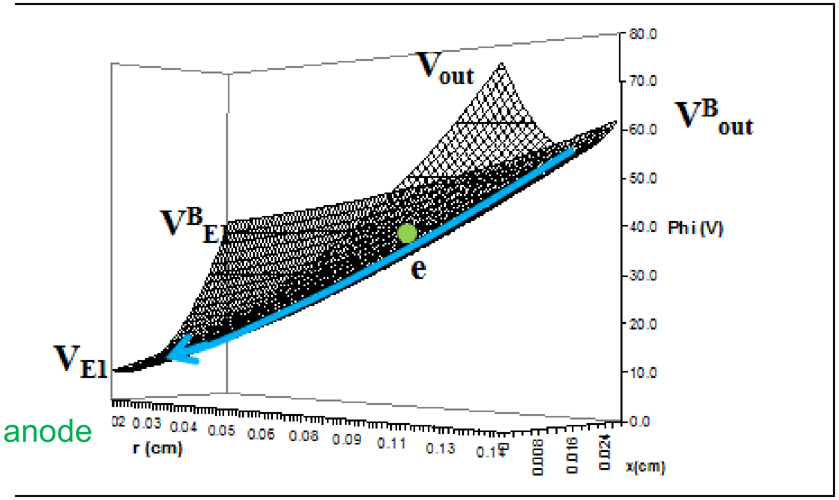
1) No inversion (no SCSI) at largest fluence (low n-type resistivity, or p-type Si)
2) The drift field is still non-zero at the SDD edge at largest fluence with the original design



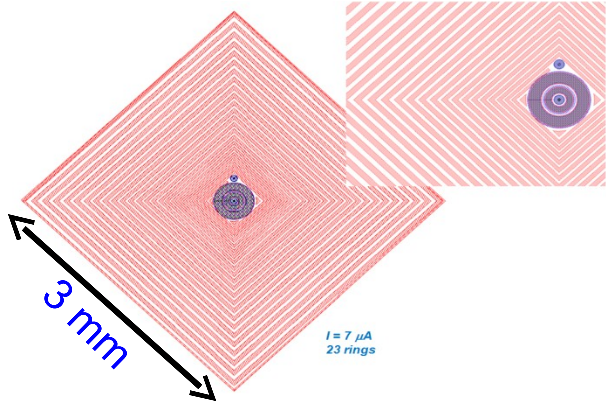
1-2 kΩ-cm SDD will be OK at $1x10^{14}$ p/cm^2 or 6Mrad

Symmetrical Spiral SDD (SSSDD)

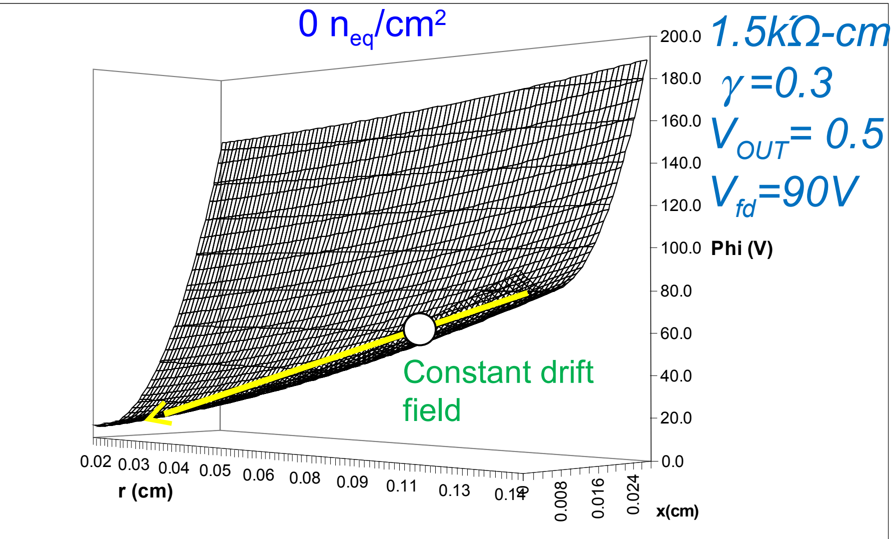


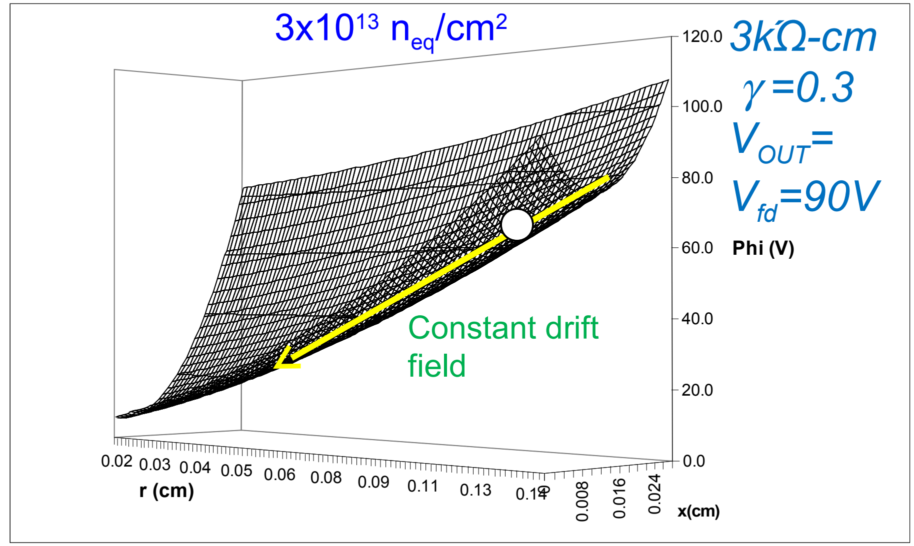


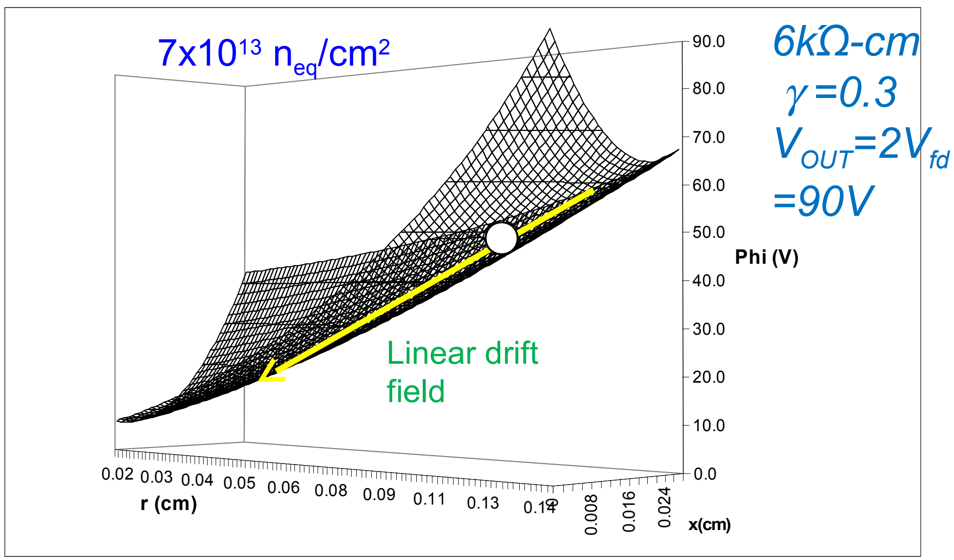
If we only bias V^B_{E1} (or bias $V^B_{E1} = V^B_{out}$, $\gamma=0$), it will be the same as biasing the backside uniformly



Negative electric potential at various fluences

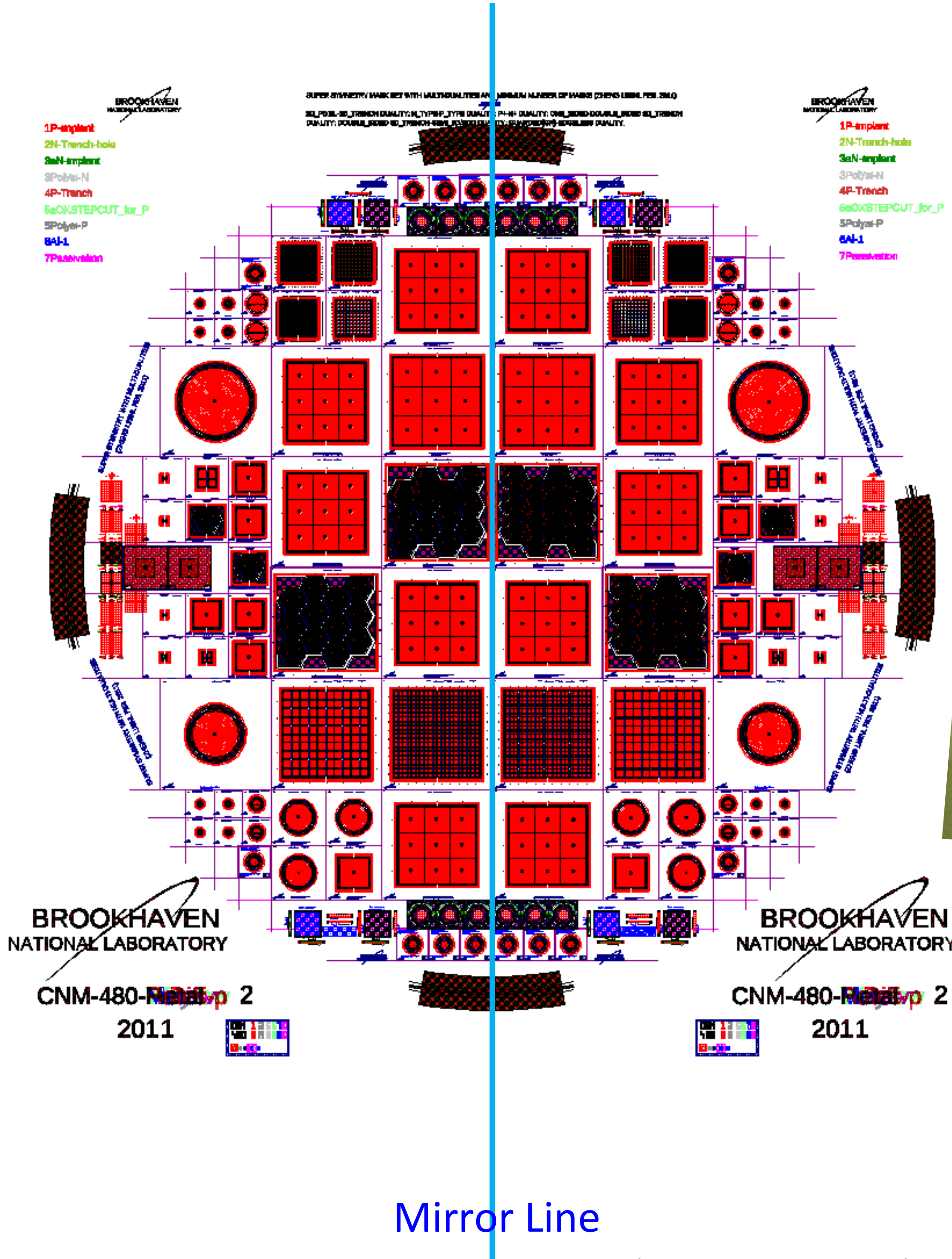


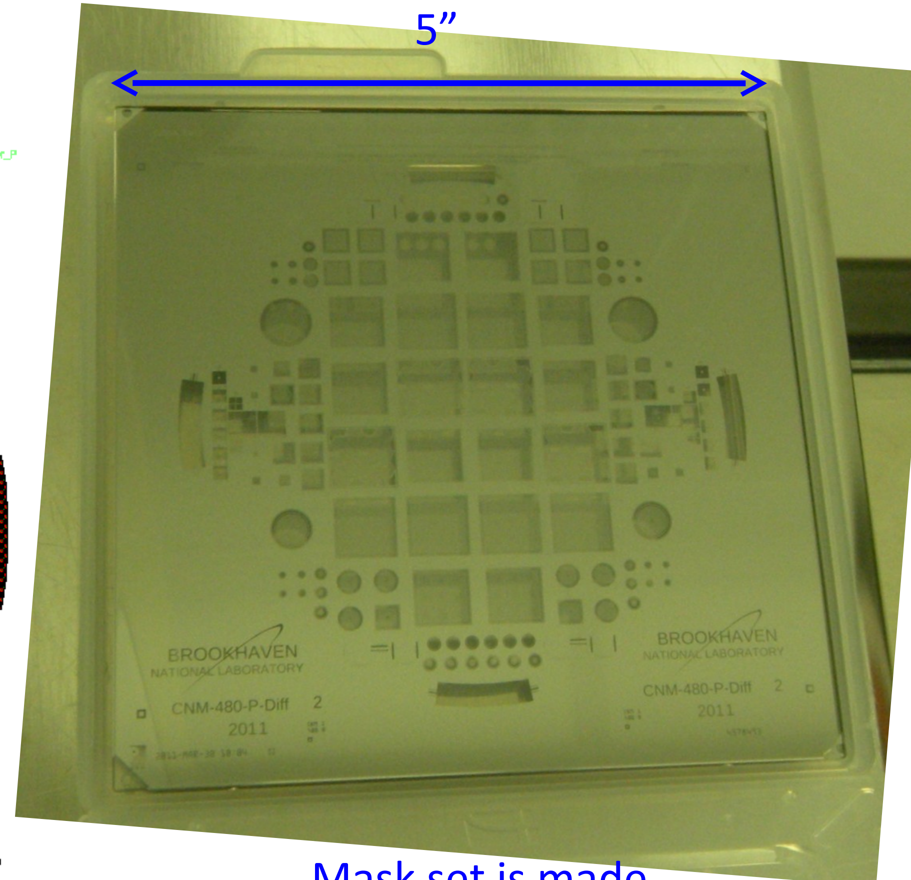




This bias scheme is good for large drift field (bias), and/or for high resistivity Si (or irradiated Si not beyond SCSI).

Mask-set all –("Super-Symmetry")





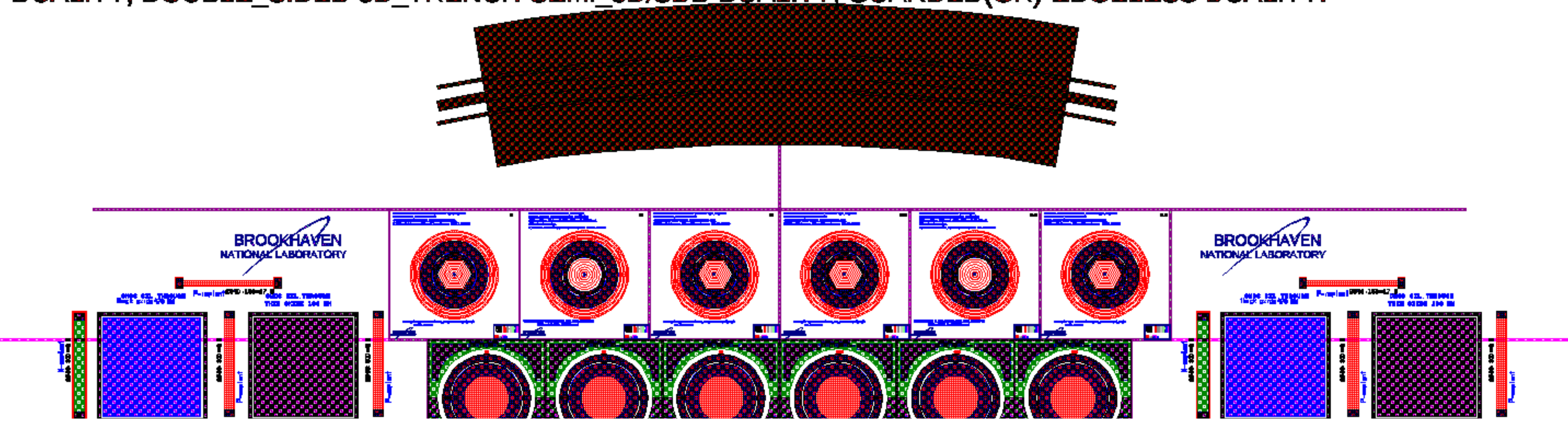
Mask set is made

"Super-Symmetry"

Same masks for both front and backside lithography
With multi-Dualities

SUPER SYMMETRY MASK SET WITH MULTI-DUALITIES AND MINIMUM NUMBER OF MASKS (ZHENG LI/BNL FEB. 2011)

2D_PIXEL-3D_TRENCH DUALITY; N_TYPE-P_TYPE DUALITY; P+-N+ DUALITY; ONE_SIDED-DOUBLE_SIDED 3D_TRENCH DUALITY; DOUBLE_SIDED 3D_TRENCH-SEMI_3D/SDD DUALITY; GUARDED(GR)-EDGELESS DUALITY.



Wei Chen will start the processing first on low and high resistivity n-type wafers; then p-type wafers;

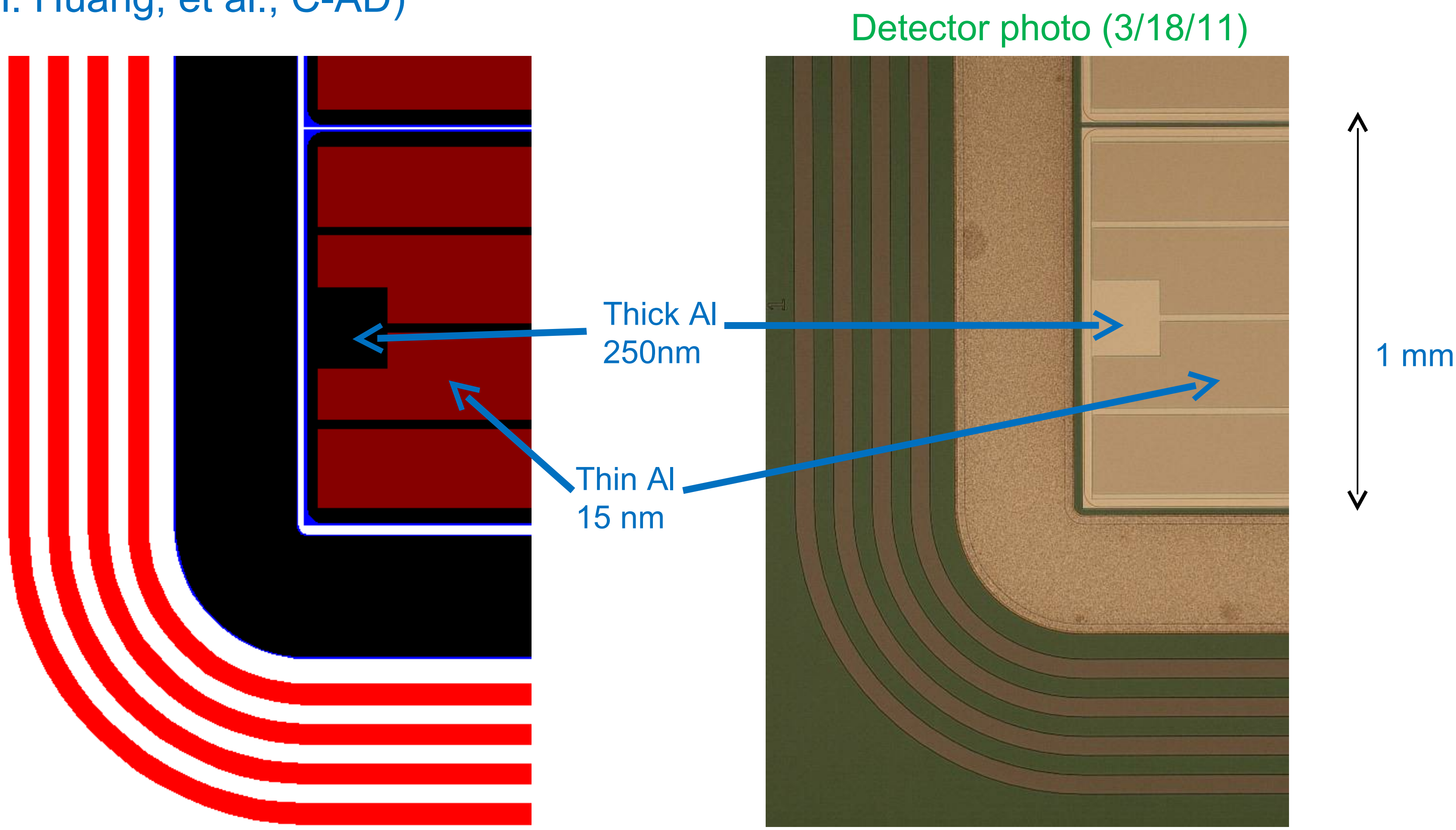
Cleanroom and facility support from: Rolf and Don E and Don P;

Test support from:

INST, NSLS-I/II, Physics (Ω-Group, PHENIX, RBRC) and other BNL Depts., and external collaborations

Other Detectors

New polarimeter strip detectors for polarized protons in RHIC (H. Huang, et al., C-AD)



12 of 1 mm strips, 15 mm long

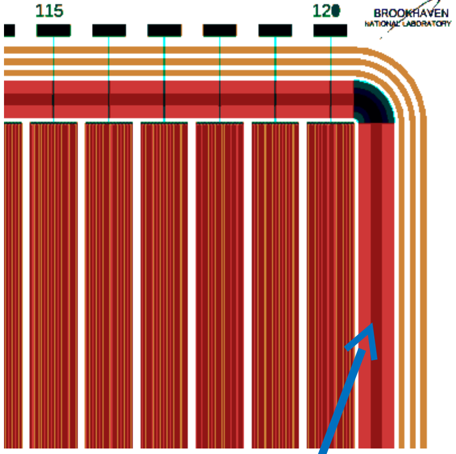
No more native oxide --- added rad-hardness, and stability

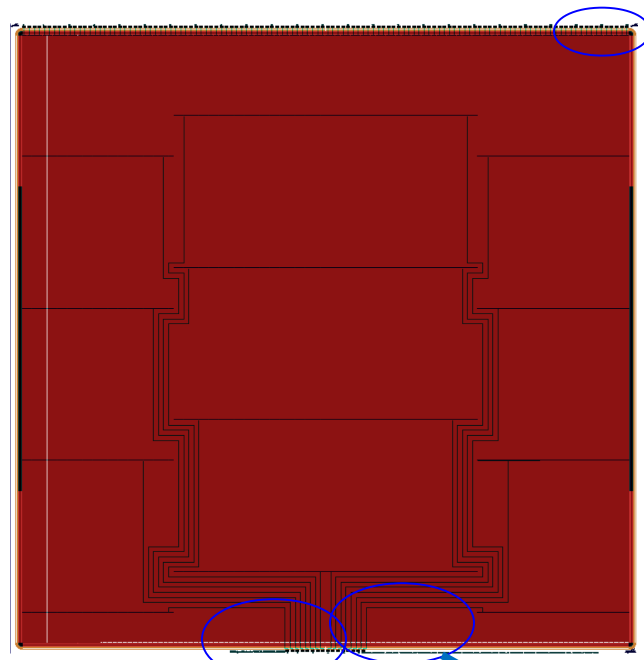
1st prototype made by Wei already

Other Detectors

2D Stripad detector for
PHENIX calorimeter upgrade, (E. Kistenev)

Similar to 2D stripixel

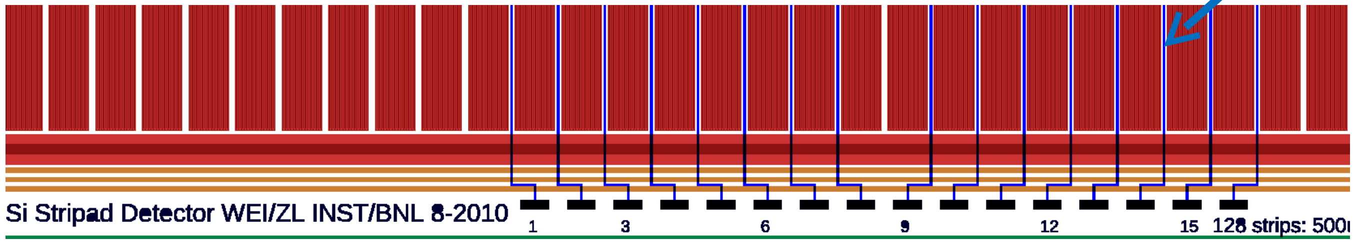


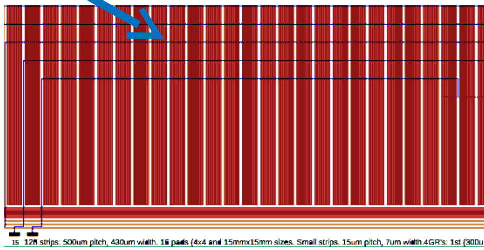


112 strips: 571 μm pitch,
500 μm width
16 pads: 4x4, 15mmx15mm

Total 128 chs (112 strips+16 pads)

Or 4x(28 strip+4pads), 500 μm pitch





Summary

- 2D Si stripixel detector system has been developed and implemented at PHENIX Upgrade

- New 3D-Stripixel detector prototypes have been made and ready for tests

- New 3D-trench electrode detectors have been developed, with best characteristics for applications in sLHC (super-rad-hard), and photon science (low C, low voltages, and natural isolation)

- 3D processing technologies are readily available for application needs in future eRHIC for sLHC

- BNL is at the forefront of the prototype and novel detector development and fabrications