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

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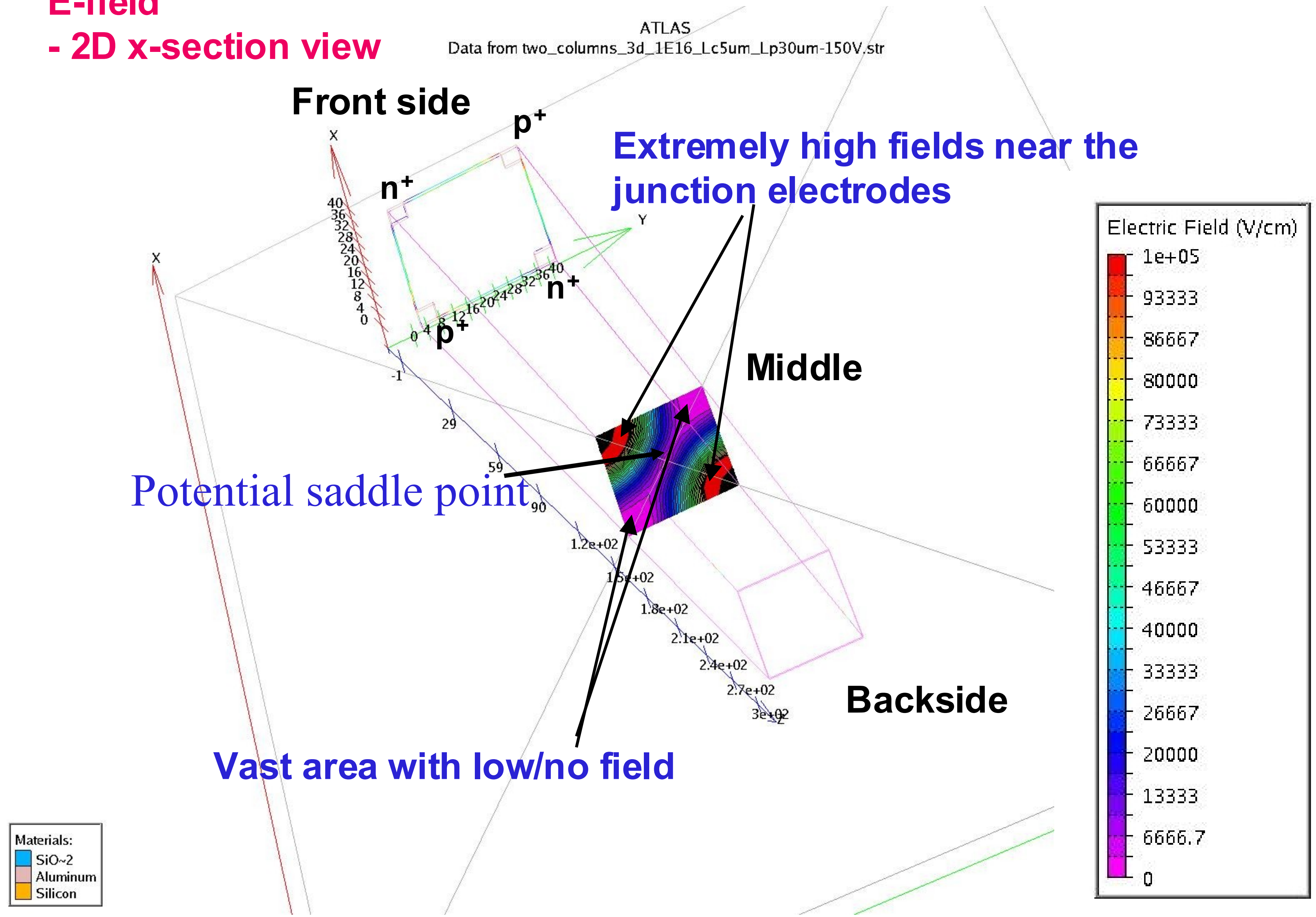
OUTLINE

- **Complicated and high electric field profiles in conventional 3D detectors**
- **Concept of the new Independent Coaxial Detector Array (ICDA)**
- **Simulation results**
- **Preliminary design of the mask set**
- **Summary**

E-field
- 2D x-section view



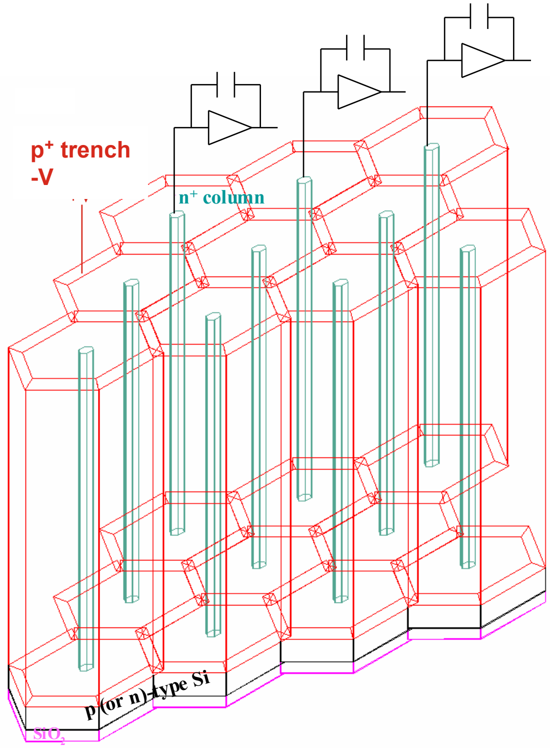
The main goals for the new detector electrode configuration

- More uniform, homogeneous electric field
- No saddle points, no low/no field region
- No extremely high field regions near breakdown condition
- Low voltage operation like in the CID (charge injected diode) detectors (CERN RD39)
- Asymmetric electrodes to optimize the electric field (similar to the charge injection in CID) ----- manipulation of electric field
- Still decoupling thickness from depletion depth (rad-hard and possible to deplete very thick detectors)

- **Concept of the new Independent Coaxial Detector Array (ICDA)** ------ US patent pending (3D-Trench Electrode Detectors), any projects related to this subject must sign official agreements with BNL Office of Technology Commercialization and Partnership (*Kimberley Elcess,* Principal Licensing Specialist, elcess@bnl.gov, 001-631-344-4151)

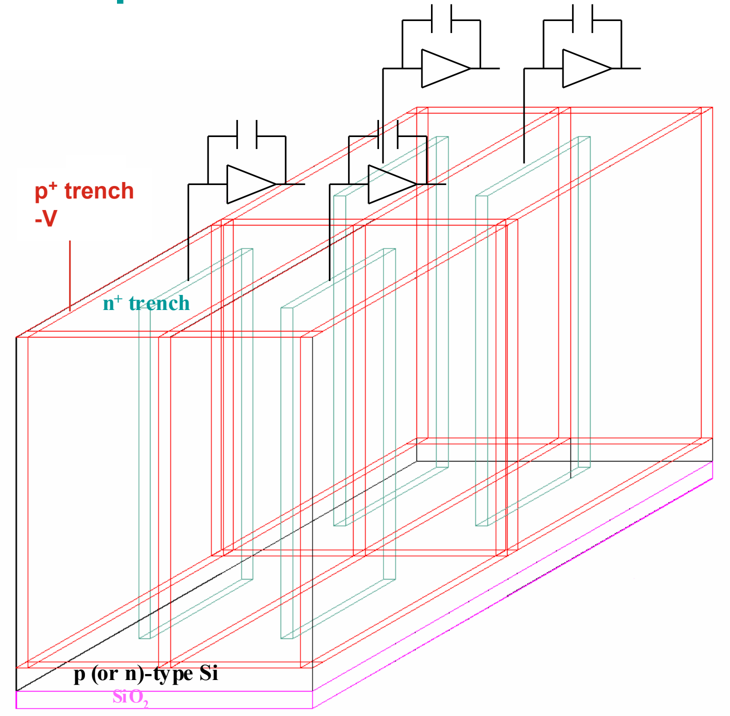
At least one electrode is a trench, each cell can be an independent detector

Homogeneous electric field, no saddle point



Concentric type

Electric field with nearly no θ dependence

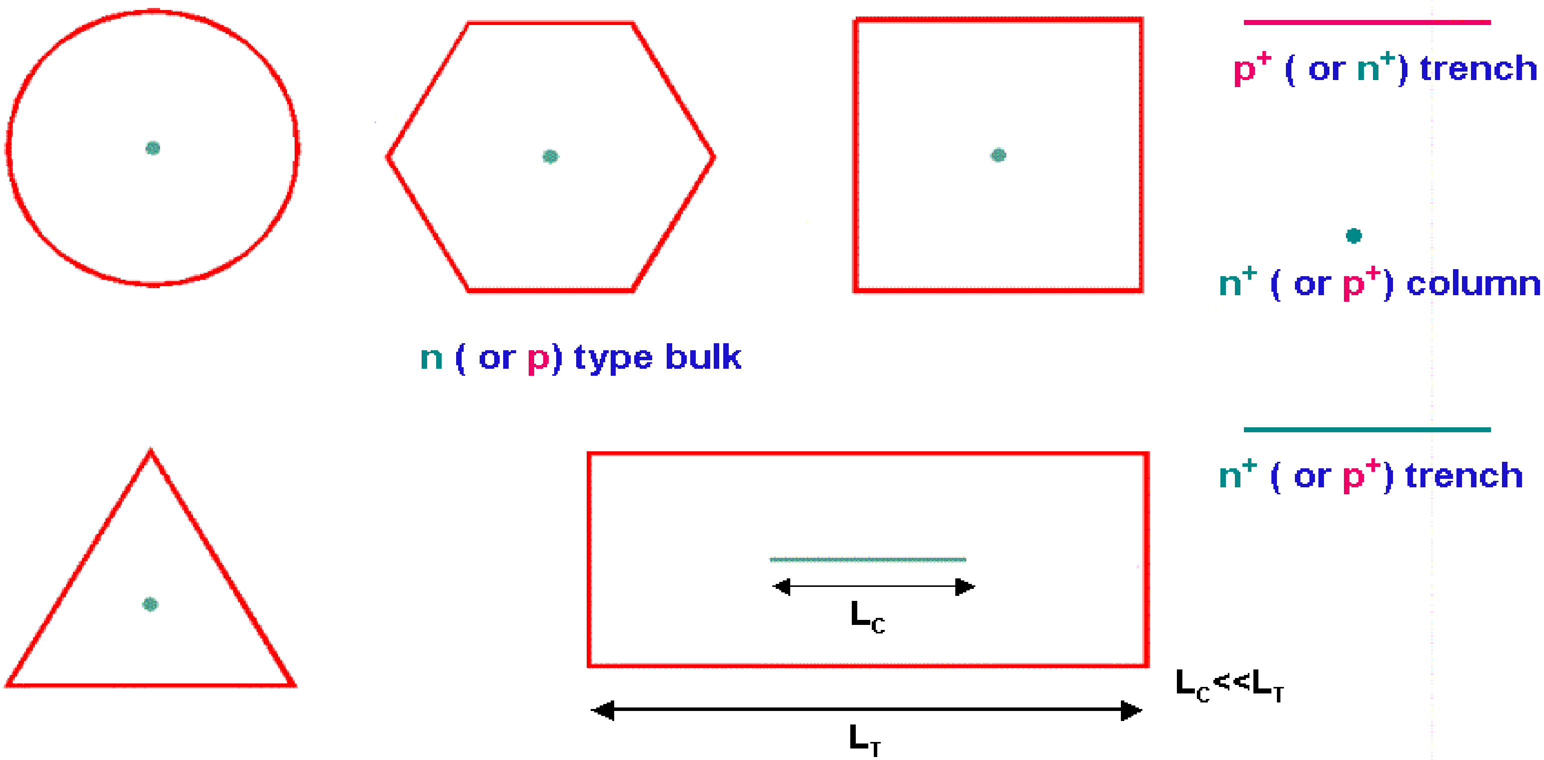


Parallel plate type

Near-linear electric field

Examples of single cells of ICDA

Concentric type:



Parallel plate type:

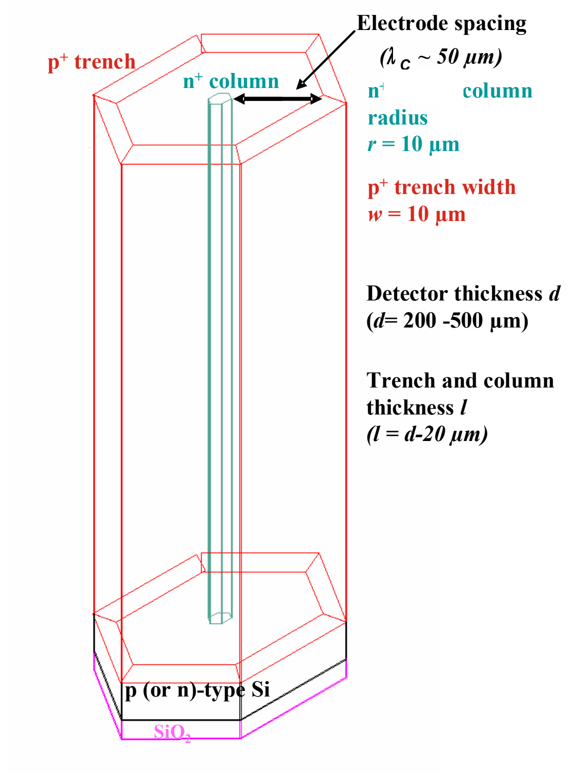
New ICDA --- Single pixel (Hexangular Type), for sLHC

Zheng Li, 10/29/2008

Concentric type with two different junction configurations:

Central column junction:

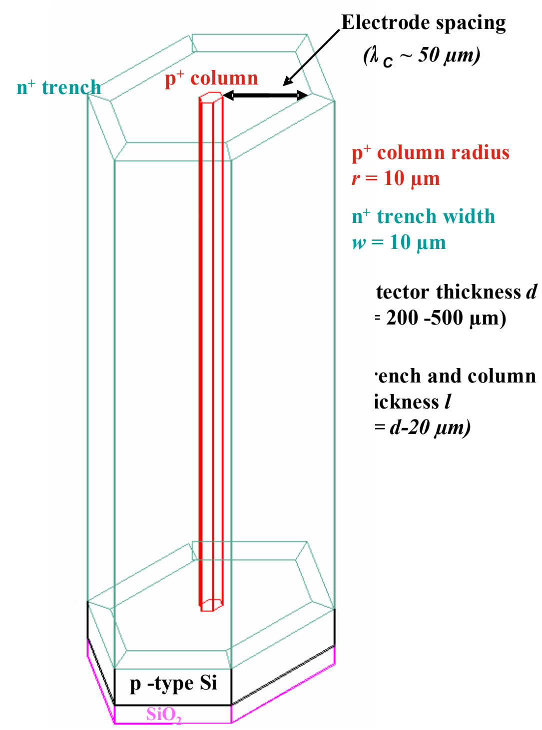
ICDA-CJ



Outer-ring-trench junction:

ICDA-ORJ --- best for E-profile

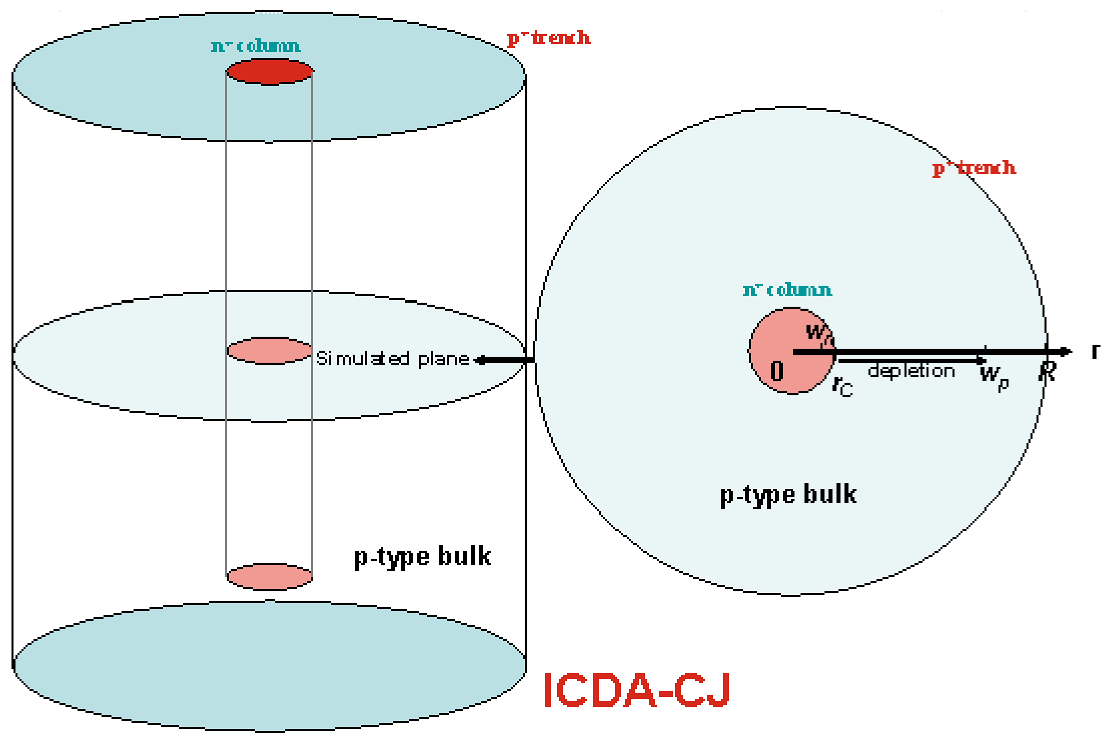
Manipulation of E-field by geometry



Dead space <14%

Cylindrical symmetry can be used to approximate the E-field

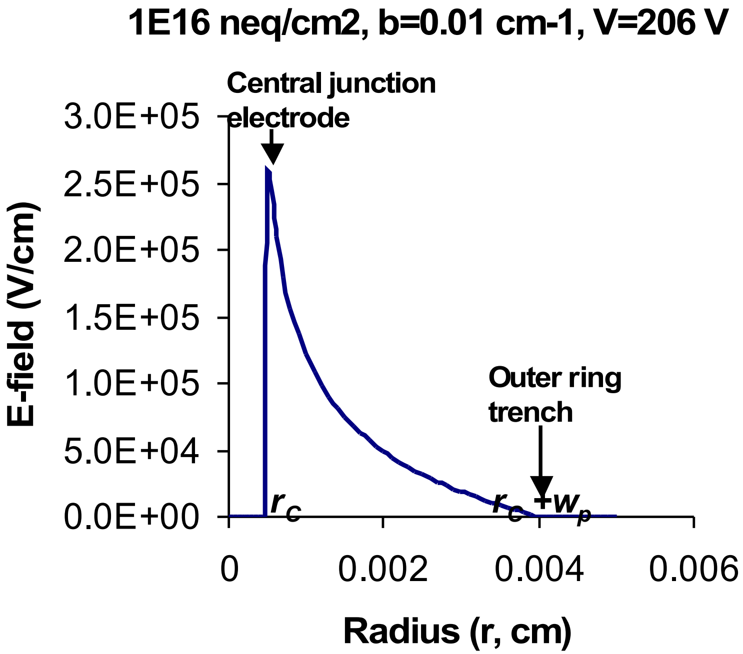
For ICDA-CJ



Very simple 1D analytical solutions

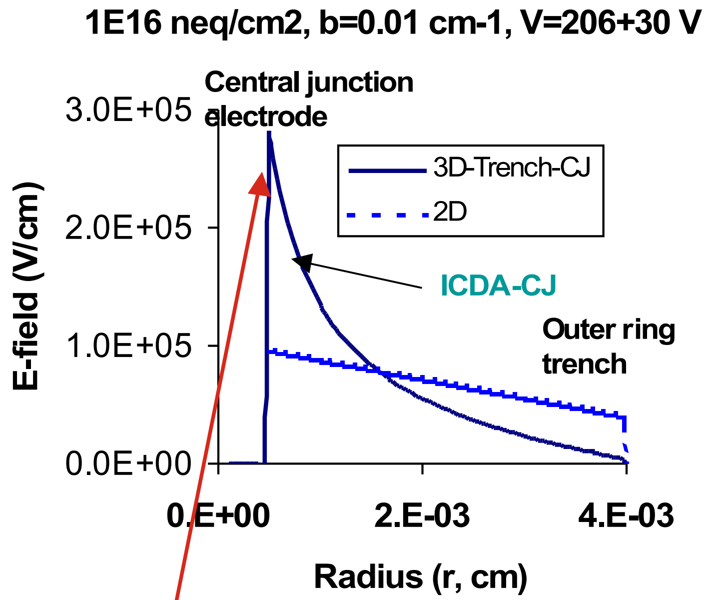
ICDA-CJ ---- E-field profiles

At full depletion



High E-field concentrated near the central junction electrode

over full depletion



Even higher E-field concentrated near the central junction electrode

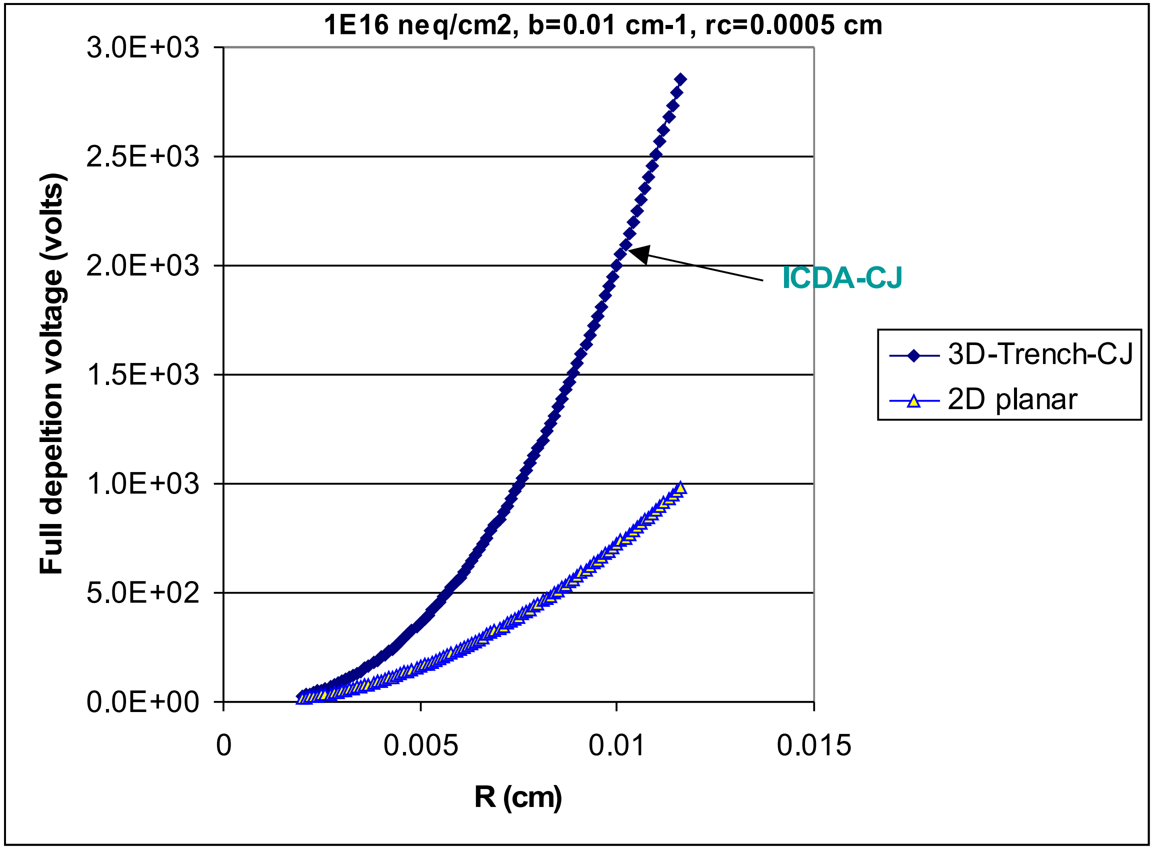
Little E-field added in the low field region (near outer ring trench)

E-field profile worse than 2D planar Detectors (at the same V)

Note that E-filed profiles in ICDACJ detectors are still much better than those in conventional 3D detectors

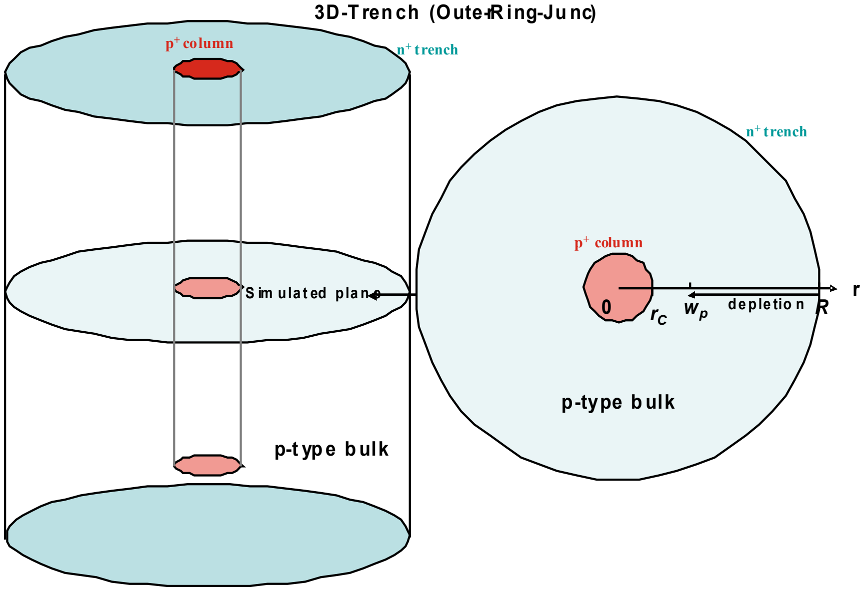
ICDA-CJ ---- Full depletion voltage

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



Full depletion voltages >2 times larger than those of 2D planar detectors

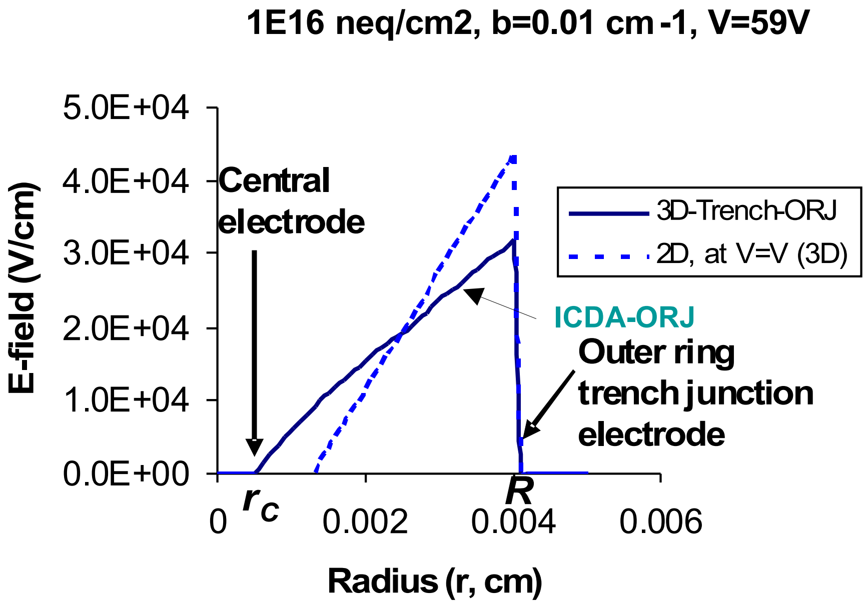
For ICDA-ORJ



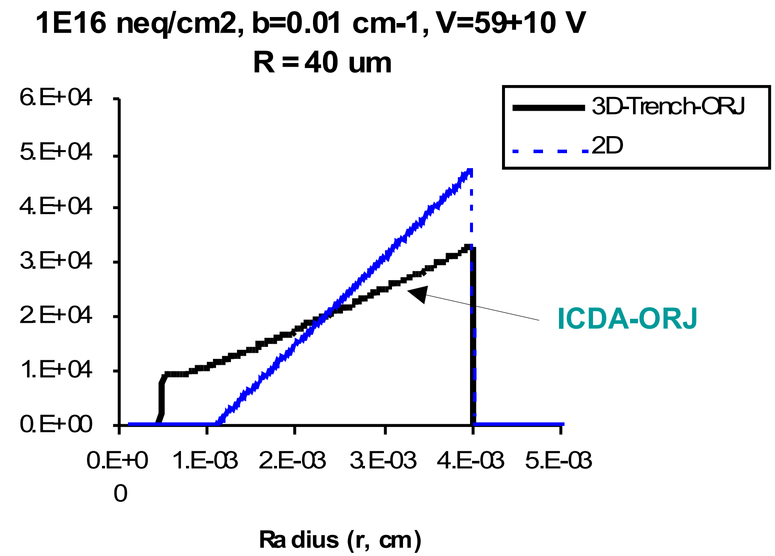
Very simple 1D analytical solutions

ICDA-ORJ ---- E-field profiles

At full depletion



over full depletion



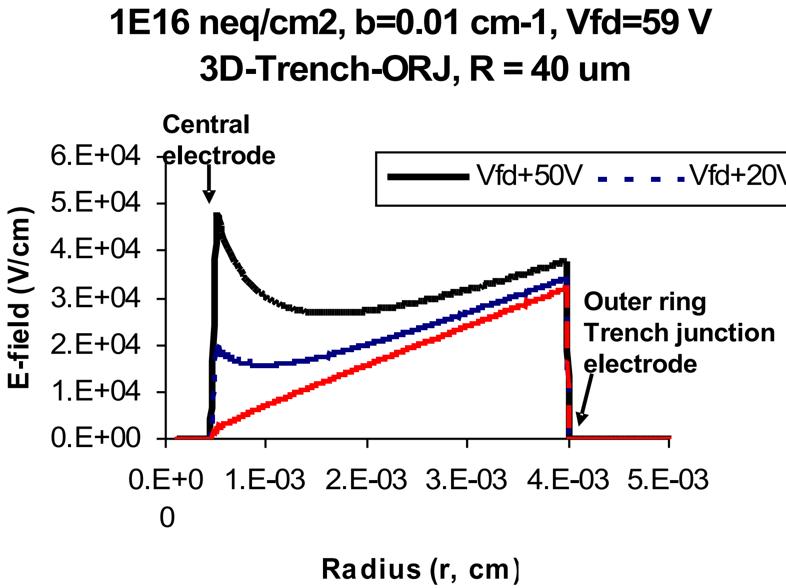
Modestly high E-field distributed over the outer ring Trench electrode (larger area)

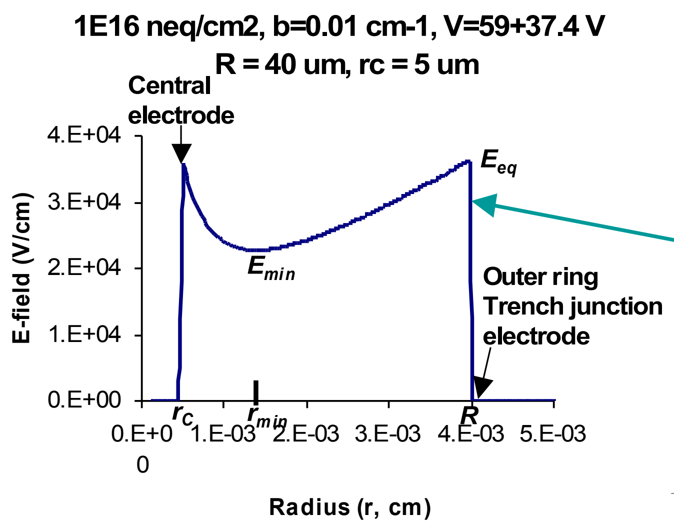
Full depletion voltage LOWER than that of a 2D planar detector!

Little E-field added near the outer ring trench junction (originally with higher field)
Most E-field is added to the originally low field region (near the central column)
Nearly linear E-field profile at slightly over depletion

Note that E-filed profiles in ICDA-ORJ detectors are much, much better than those in conventional 3D and ICDA-CJ detectors

ICDA-ORJ ---- E-field profiles at over-full-depletion





At high over depletion, the E-field can be higher at the central column than that at the junction (outer ring trench)

At a given condition only depending on the detector geometry and radiation, equal E-field can be achieved at both electrodes

This condition gives a near-constant E-field in the whole detector, and it may be the optima Operation condition:

$$E^{optima}(r) = -\frac{1}{2}\frac{eN_{eff}}{\varepsilon\varepsilon_0} r[1 + \frac{r_C R}{r^2}] \qquad (r_C \le r \le R)$$

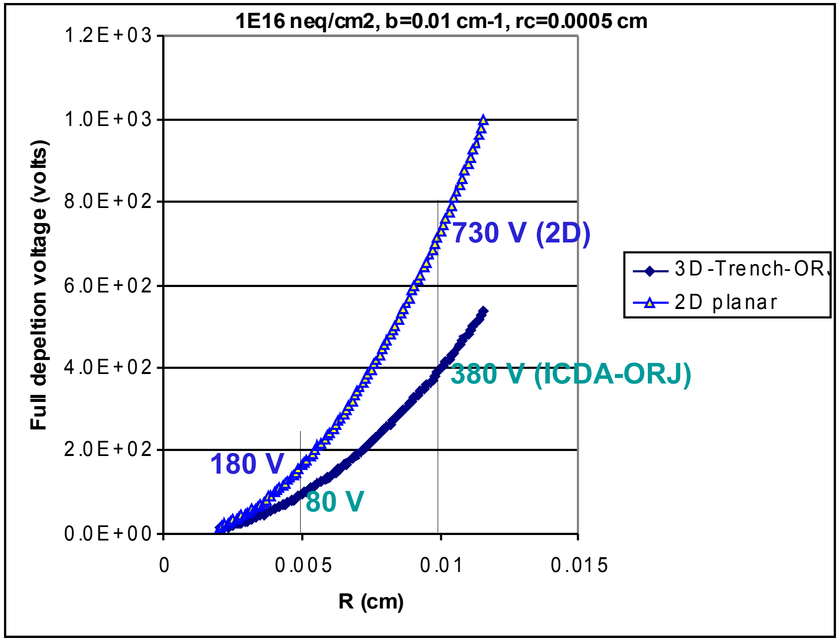
$$\frac{E_{eq}}{E_{min}} = \frac{(r_C + R)/2}{\sqrt{r_C R}} \cong \frac{1}{2}\sqrt{\frac{R}{r_C}}, \quad (\text{if } R >> r_C)$$

$$\begin{cases} r_{min} = \sqrt{r_C R} \\ E_{min} = -\frac{eN_{eff}}{\varepsilon\varepsilon_0}\sqrt{r_C R} \end{cases}$$

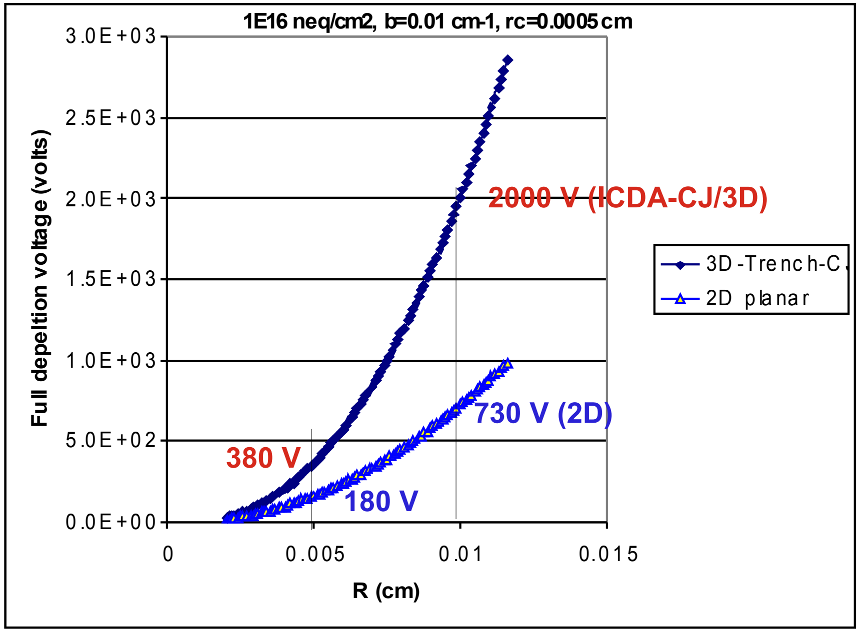
ICDA-ORJ ---- Full deletion voltage

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

ICDA-ORJ and 2D



ICDA-CJ and 2D



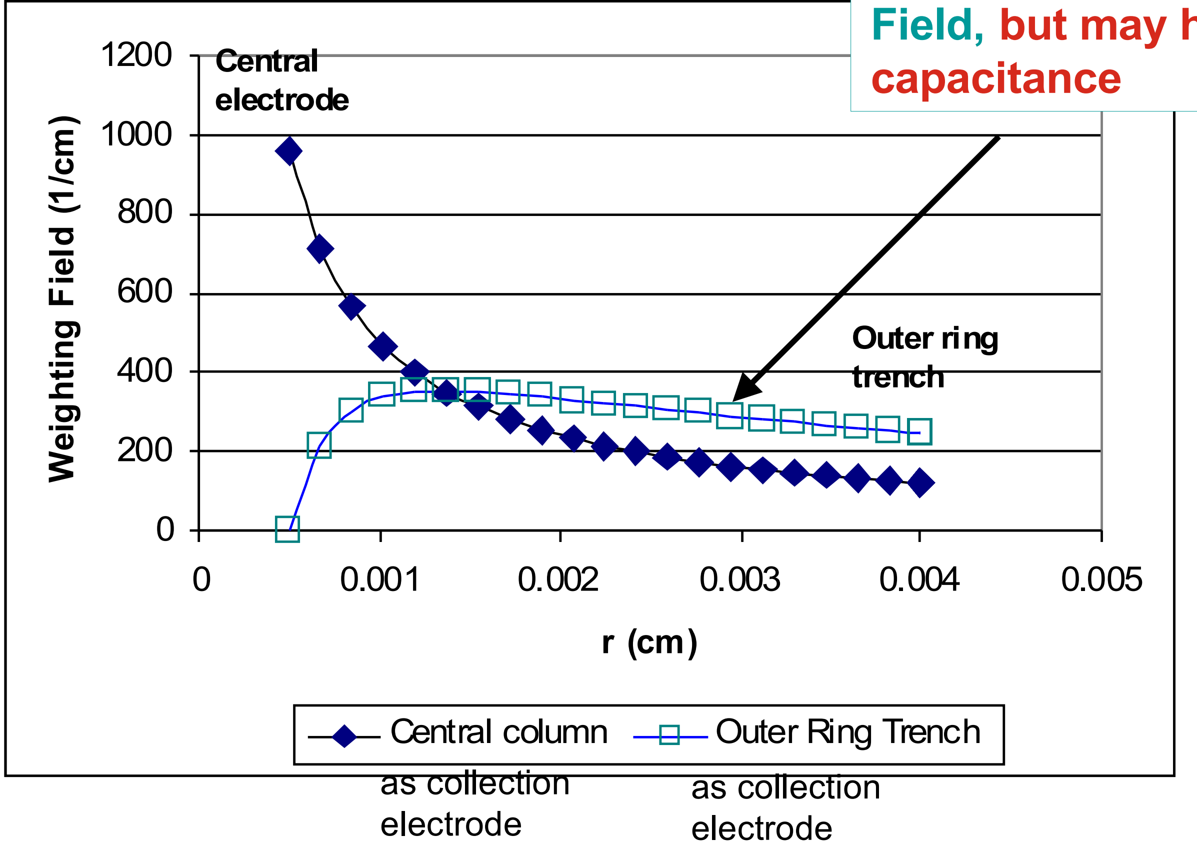
Full depletion voltages in ICDA-ORJ are about 2 times smaller than those of 2D planar detectors, and about 5 times smaller than those of conventional 3D and ICDA-CJ detectors

ICDA ---- Weighting field

For parallel plate type, the weight field is nearly constant in most of the detector ($1/\lambda_C$)

For concentric type, weighting fields can also be calculated analytically using the cylindrical symmetry

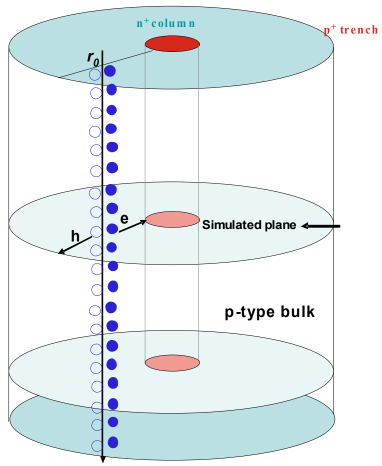
If the outer ring is used as the collection electrode: nearly constant weighting Field, but may have larger capacitance

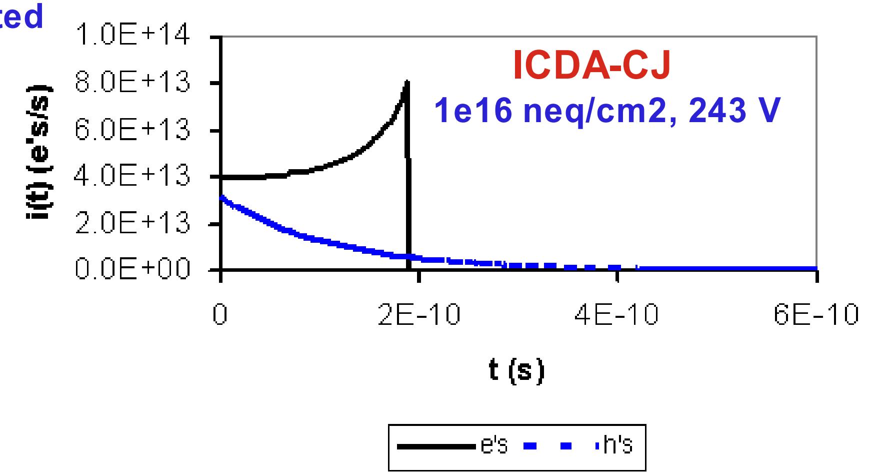


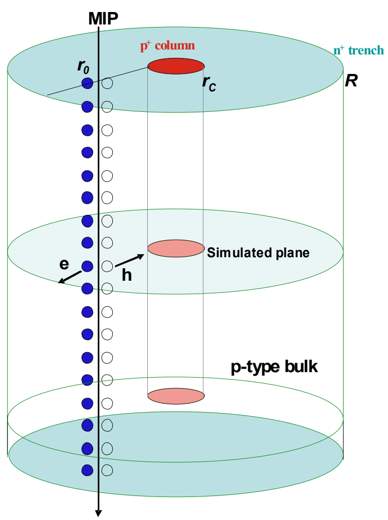
High weighting field near the central column if it is the collec tion electrode
Nearly constant weighting field if the outer ring trench is the collection electrode

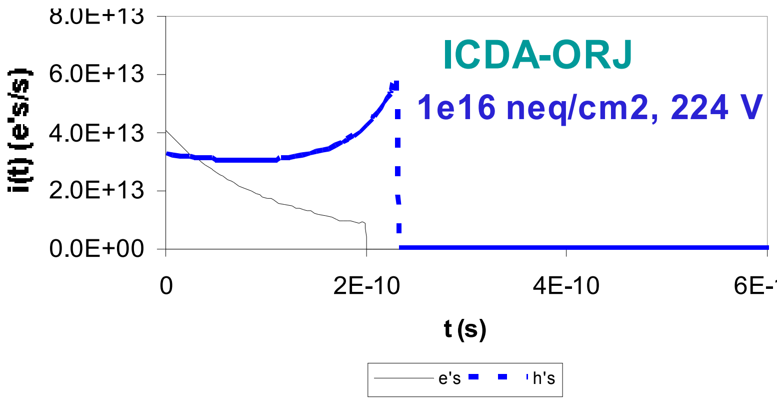
ICDA ---- Charge collection

Transient current shapes can be calculated easily as well for concentric type:







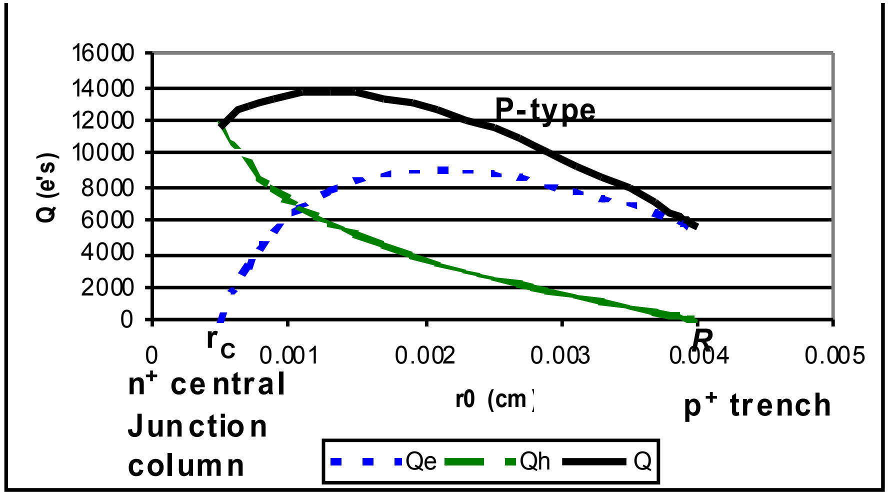


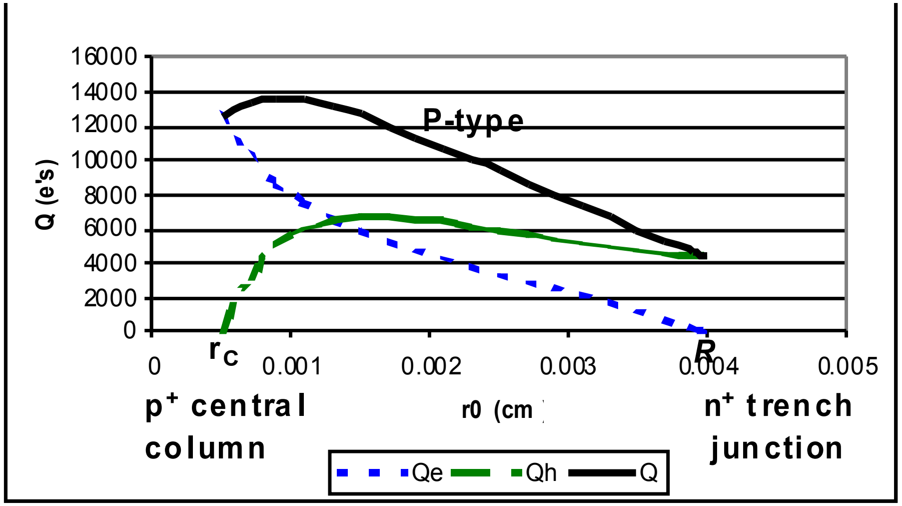
ICDA ---- Charge collection

For heavily irradiated detectors, total collected charge depends on the hit position by MIP (not so for no/medium radiation fluences): True also for conventional 3D detectors (central electrode as collection one)

ICDA-CJ ---- V = 243 volts
Much higher V needed

ICDA-ORJ ---- V = 96 volts



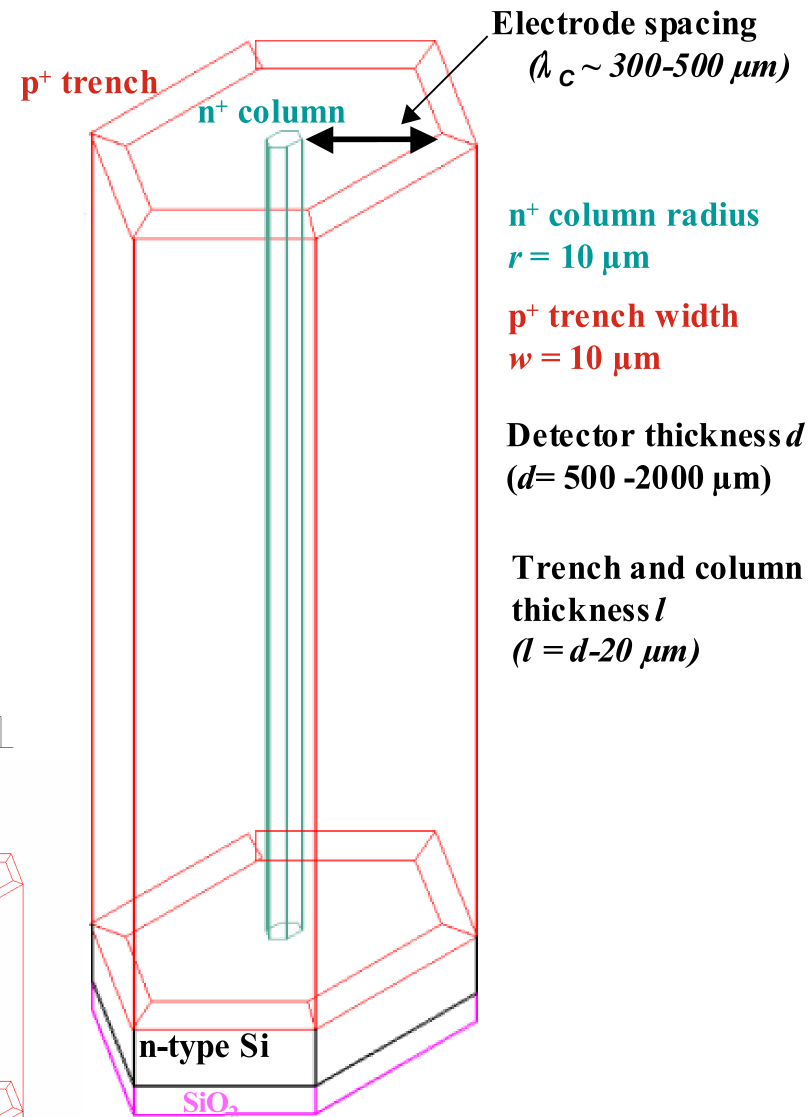


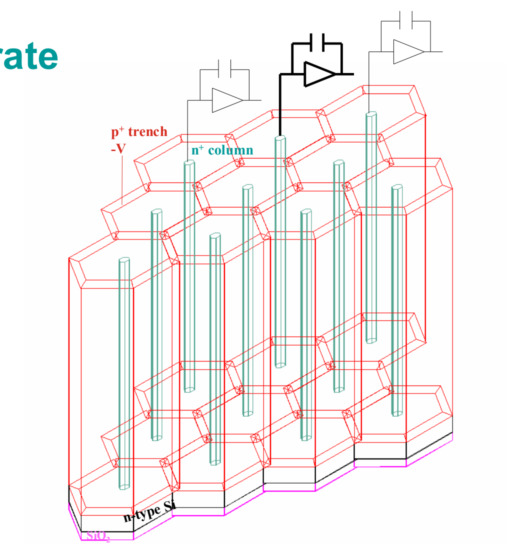
Ave Q can be about 10000 e's (>45%) at 1×10^{16} n_{eq}/cm^2

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)
- Detector thickness can be large: mm's --- better X-ray detection efficiency
- Pixels will be isolated by trenches: no charge sharing: better peak/valley ratio
- Fast charge collection rate





ICDA ---- Application in photon sciences

Concentric type

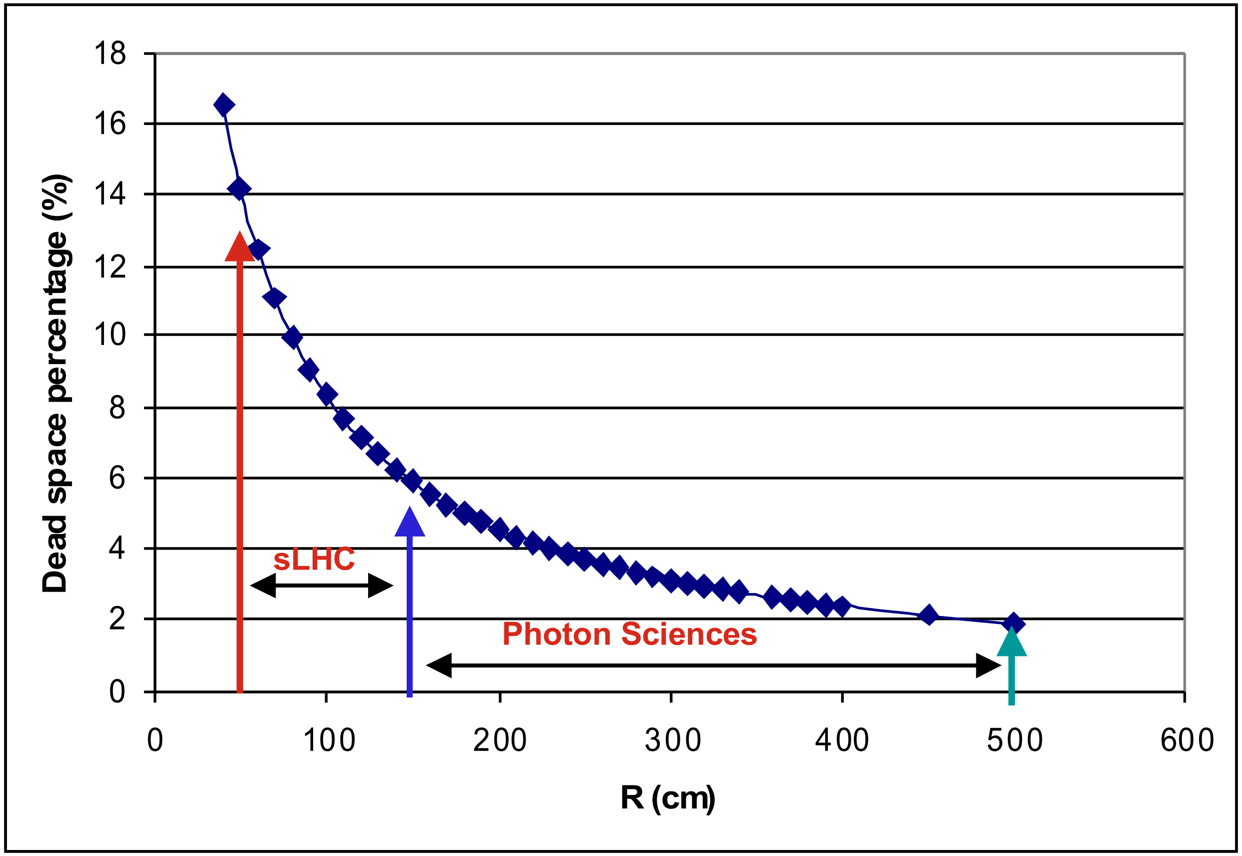
ICDA-ORJ: Great reduction in depletion voltages compared to 2D detectors

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

Pixel pitch (μm)	V_{fd}, volts ICDA-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	788	0.03
250	5.1	788	0.007

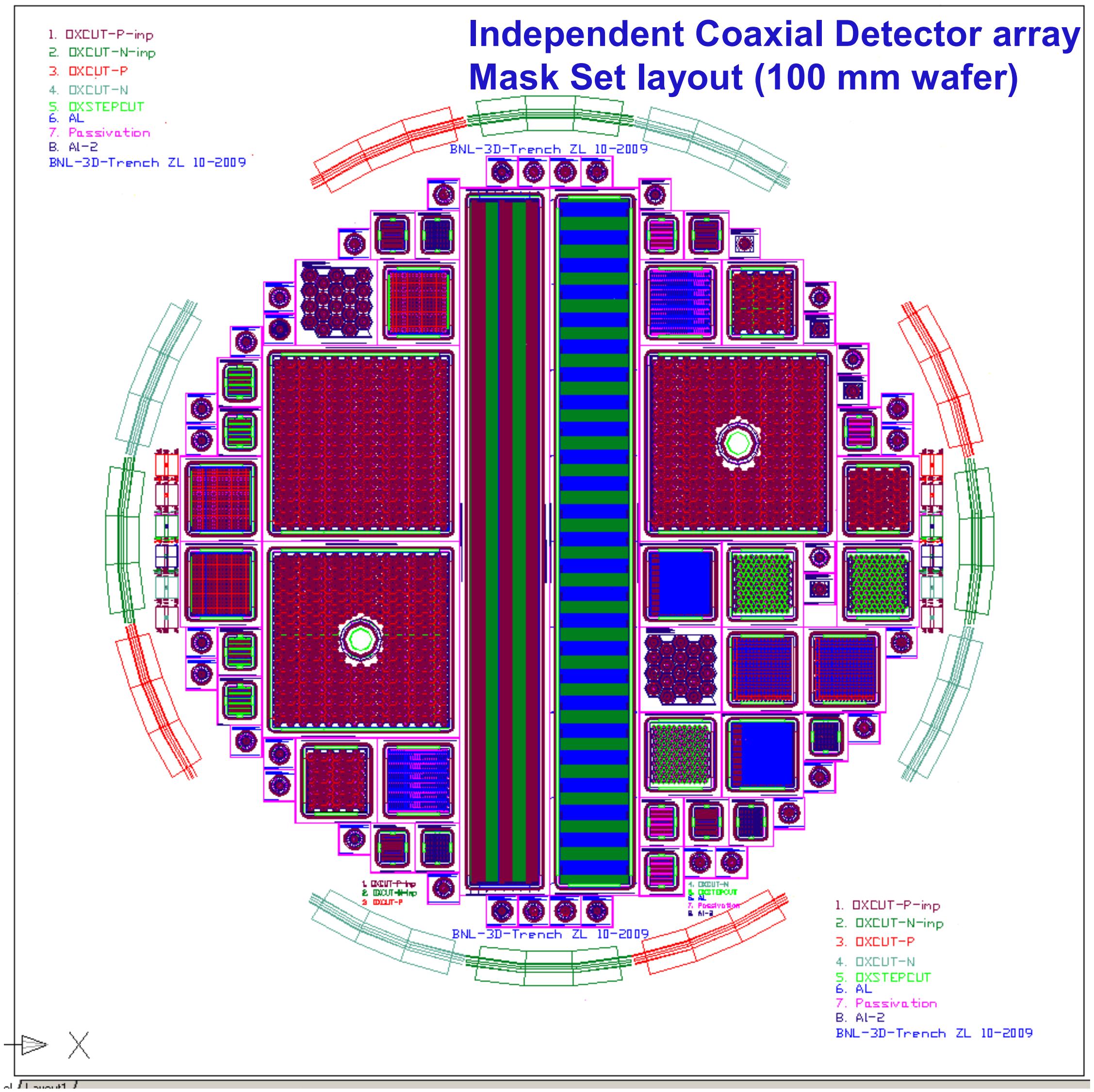
ICDA ---- Dead spaces

ICDA Concentric type



Percentage of dead space in ICDA (hexangular type) electrodeSi detectors.
r_C =5 μ m, and trench width $w = 10$ μ m.

• **Preliminary design of the mask set**



• **Summary**

- New Independent Coaxial Detector Array (ICDA) with novel, asymmetric electrode configurations has been proposed
- The electric field profile in a ICDA is well defined and homogeneous ---- no potential saddle point, no low/now field regions
- The best configuration is the concentric type with the junction on the outer ring trench (ICDA-ORJ) --- electric field manipulation
- The electric field distribution in a ICDA-ORJ detector is even more uniform, and full depletion voltage is even lower than those in 2D planar detectors
- The total collected charge in a ICDA concentric type detector is in the order of 10,000 e's out of 24,000 e's at $1x10^{16}$ n_{eq}/cm^2 ----- about 39% after dead space taking into account
- For the applications in photon sciences, the full depletion voltage can be greatly reduced (from 8-100 times) in thick ICDA-ORJ detectors as compared to 2D planar detectors with the same thickness
- Small area in collection electrode and intrinsic pixel isolations in ICDA-ORJ detectors provide other advantages as detectors in photon sciences
- The dead space can be minimized to a manageable level of <14% for sLHC applications and < 5% for photon science applications