Radiation-Induced Charge Collection in Detector Arrays*

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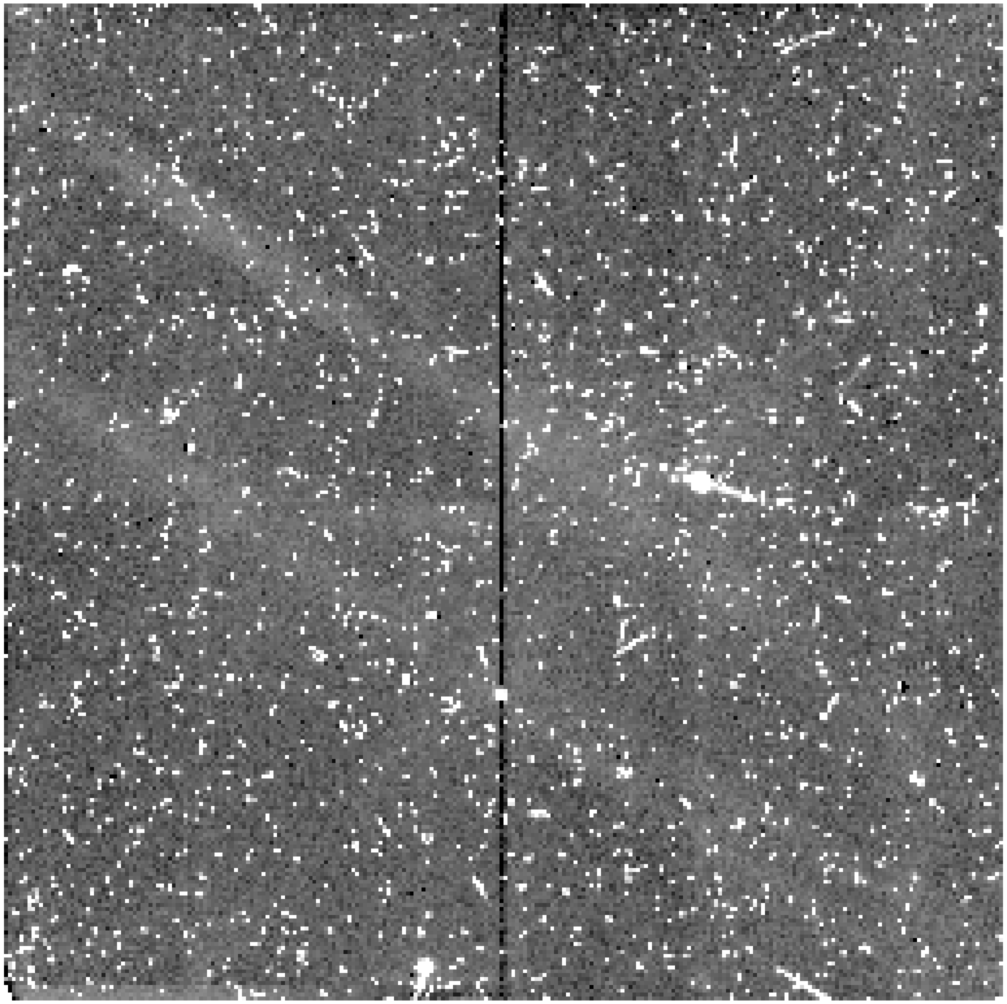
Outline

- Background
- Ionizing Particle Environment
- Array Charge Collection Model
- Model Calibration With Test Data
- Comparison to Available Data

Radiation Effects Challenge for IR Astronomy

- Exposure to galactic cosmic rays and solar particle events
- Very low noise required
  - 10 electrons or less
- Very long integration time required
  - hundreds to thousands of seconds
- Single event transients increase output level of individual pixels
  - Transients are “latched in” until reset
  - “High” level events can be filtered
  - “Low” level events increase noise

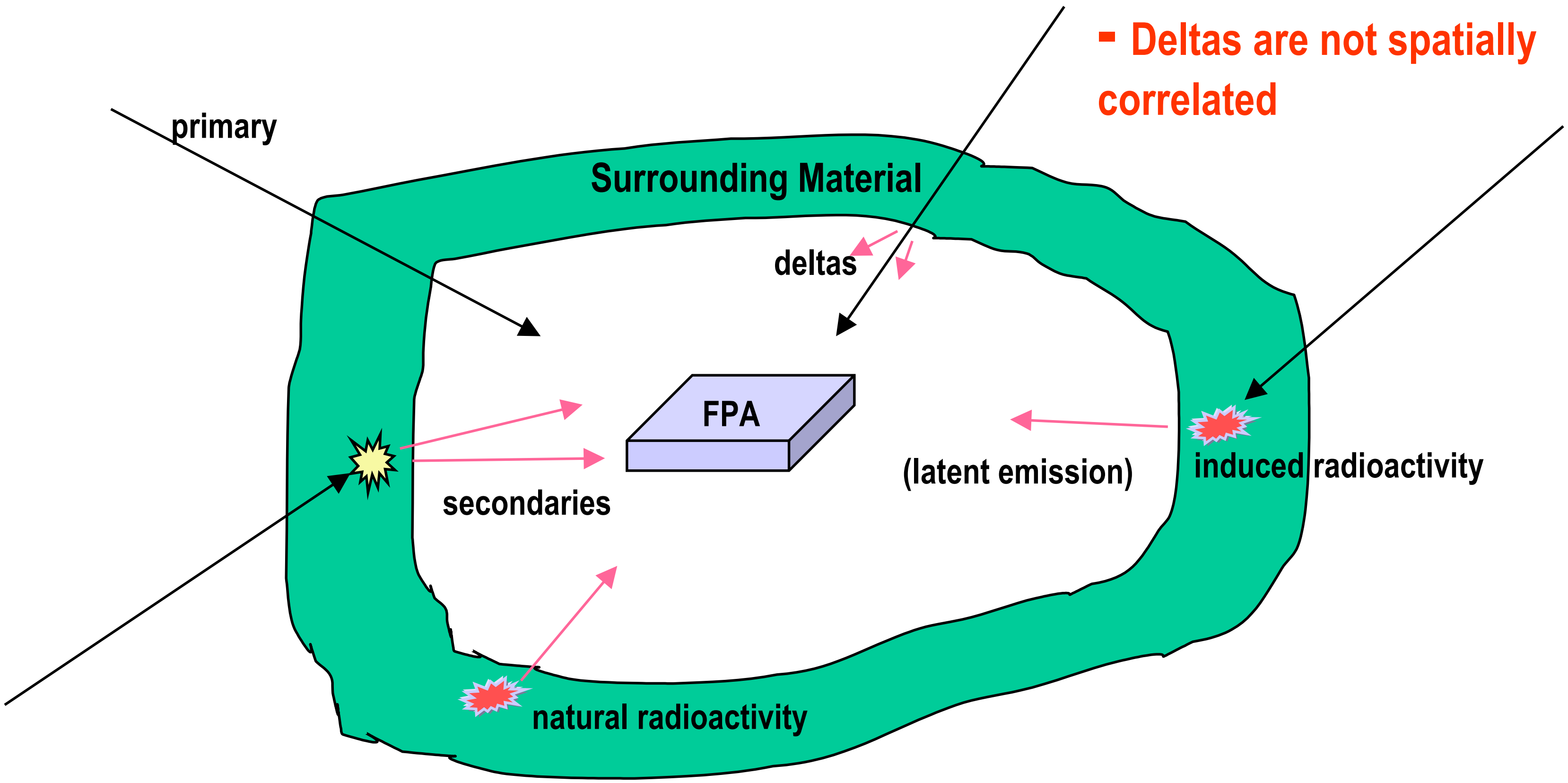
Radiation-Induced Charge in NICMOS



256x256 HgCdTe Array

Cosmic Ray charge deposits after ~30 minutes of dark-field viewing

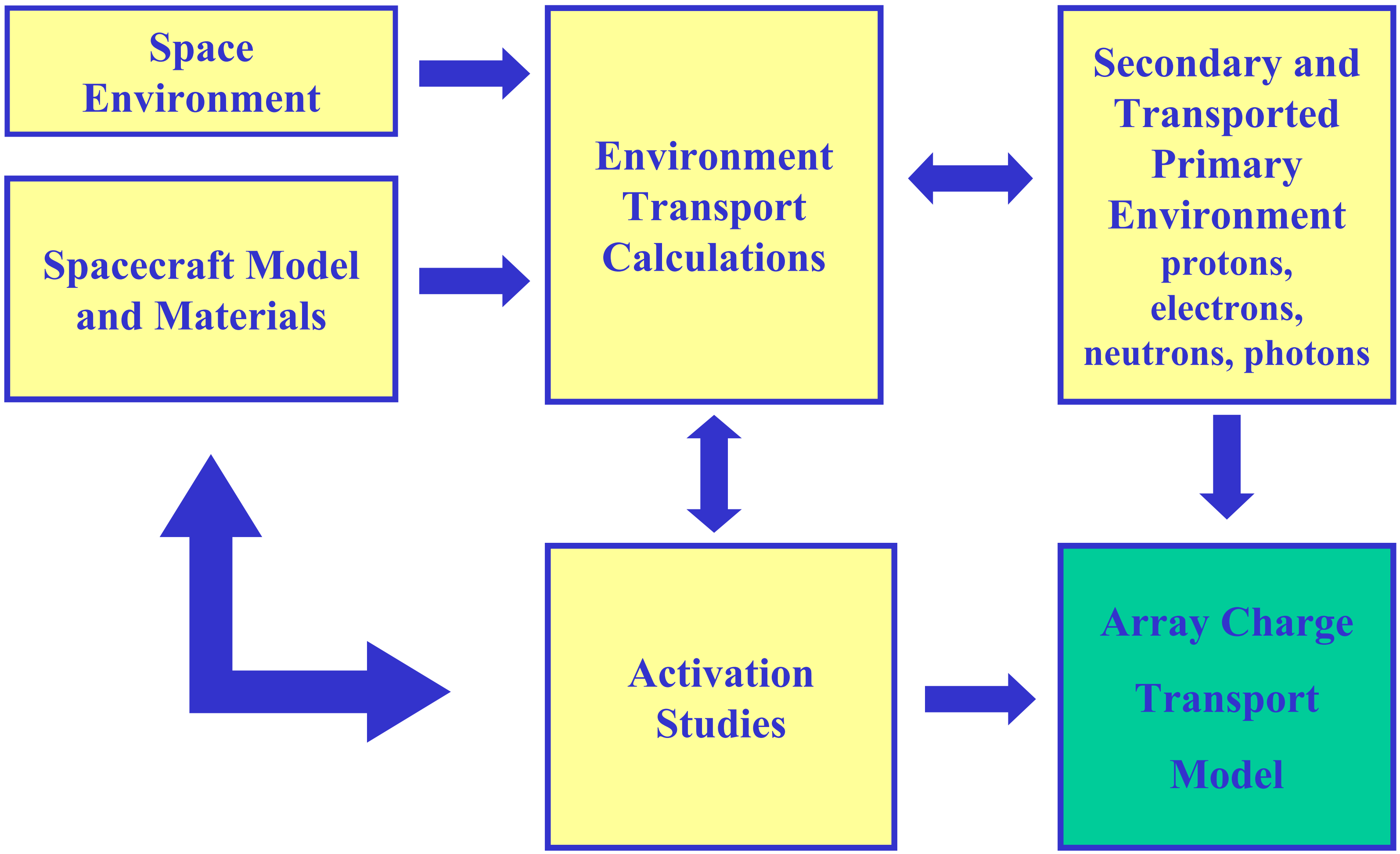
Ionizing Particle Impacts to FPA



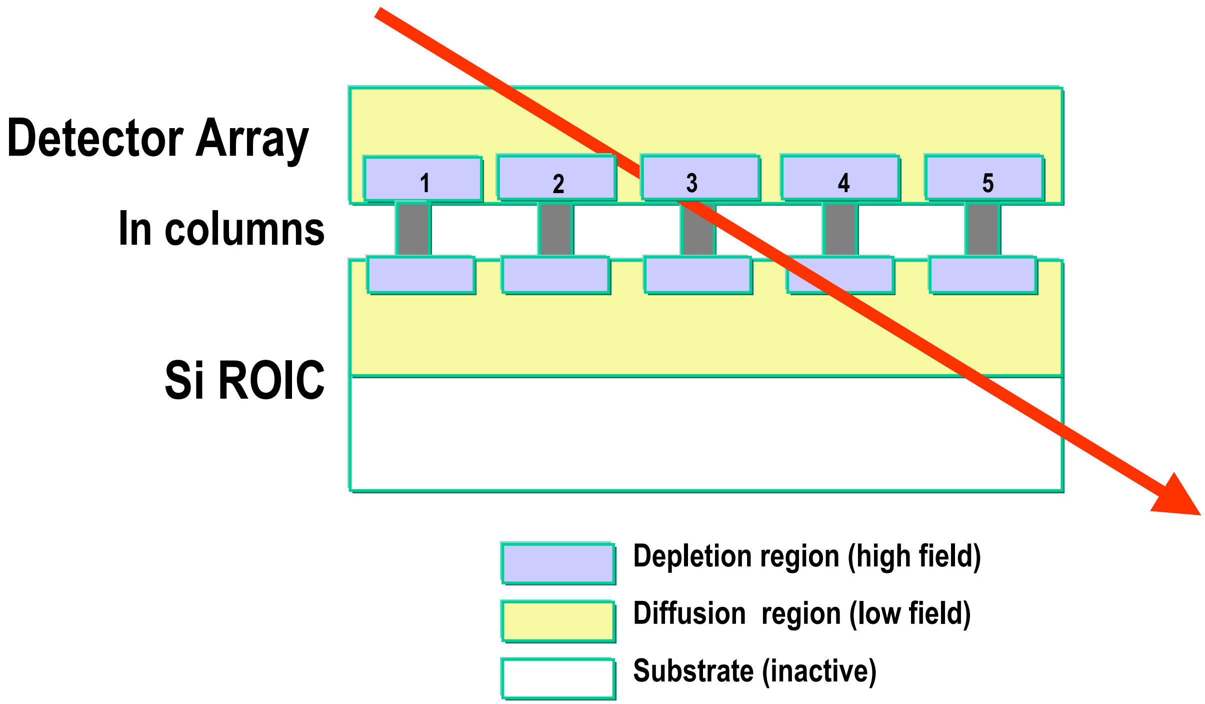
- Deltas are not spatially correlated

+ Secondaries and delta electrons are time coincident with primary and have limited range

General Approach



Both the Detector Array and the ROIC Contribute to Charge Collection in Hybrid FPA



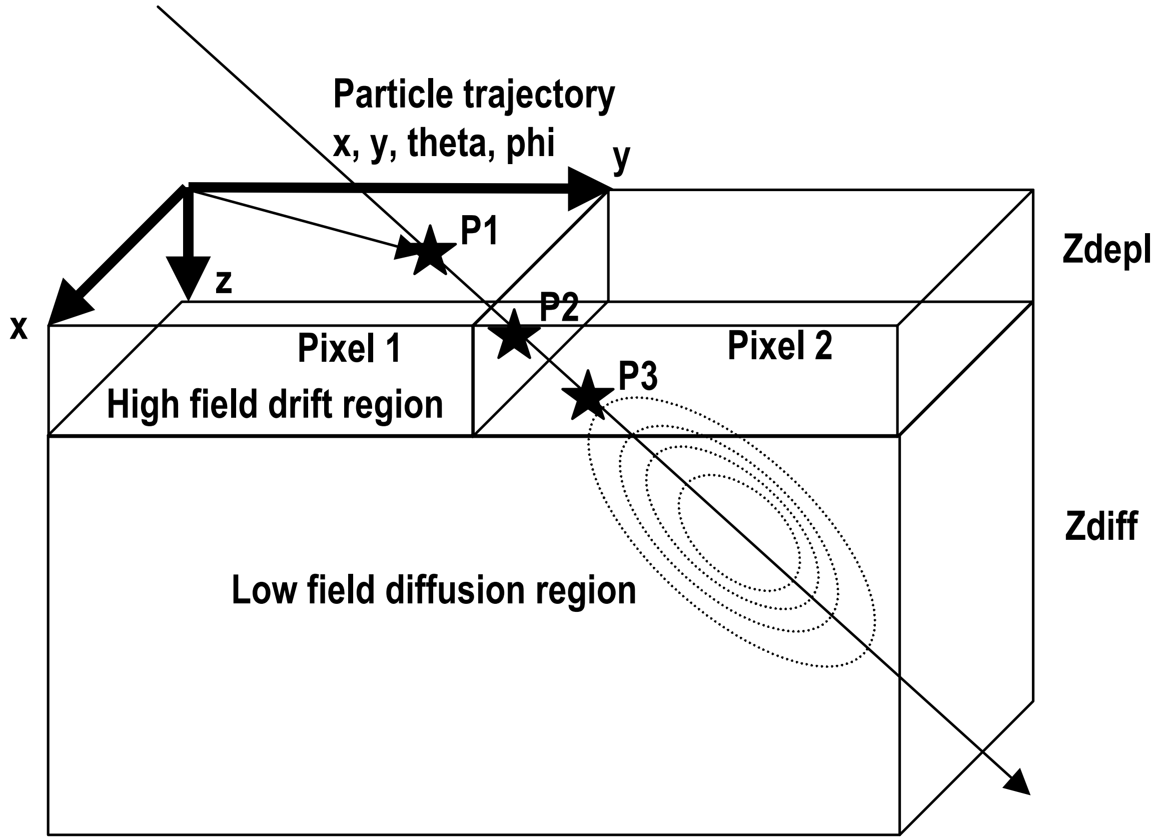
- Charge collected by drift in high-field regions
- Charge collected by diffusion in low-field regions

Charge Collection Modeling Approach

- Starting point is charge collection model for proton hits to CCDs developed and validated at Aerospace Corporation

- Add enhancements
  - secondary particles generated externally and internally
  - activation/decay and inherent radioactivity
  - multiple layers
  - sub-regions within layers
  - LET variation along path
  - large angle scatter (electrons)
  - drift-assisted diffusion

Array Charge Collection Model

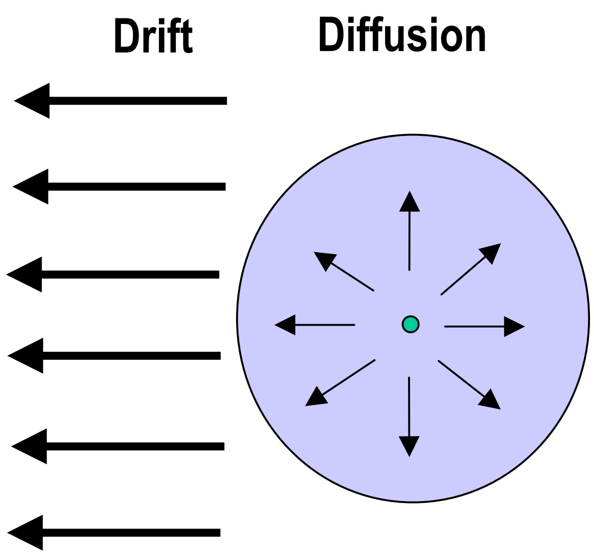


- Initial line source based on particle LET and trajectory
- All charge that is generated in or diffuses to high-field region is collected
- Particle history ends when either collected or recombines

Charge Collection by Diffusion in Low Field Regions

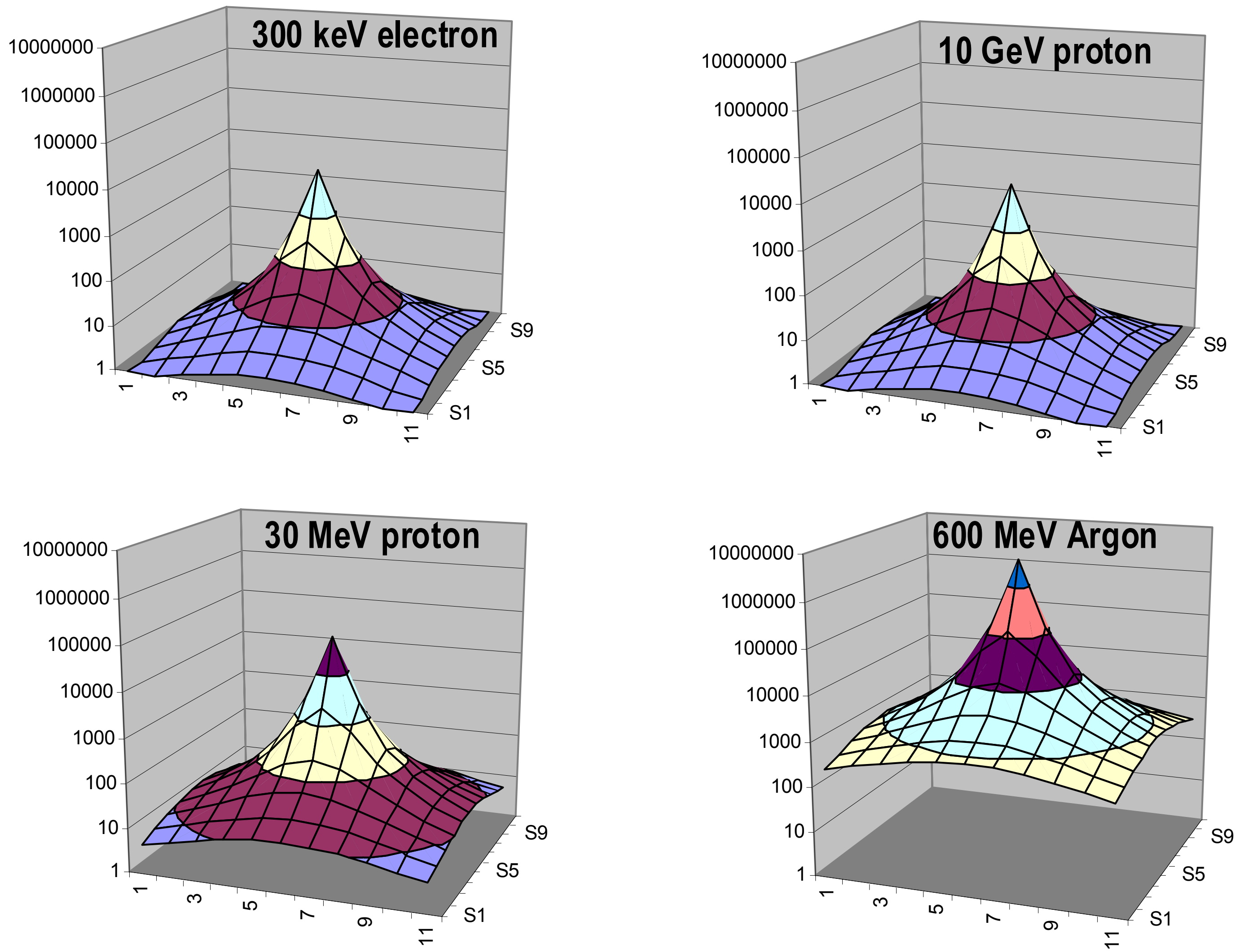
- Analytic model by Kirkpatrick calculates charge distribution on a uniform collection surface from a line-source
  - Solves 3-D diffusion equation assuming semi-infinite medium and assuming point source at given depth
    - Qps(x,y)
  - Integrates Qps(x,y) along line with trajectory (θ,φ) through diffusion region to effective diffusion length (L) to give surface charge density
    - Qls(x,y,θ,φ,L)
- Charge collected by each pixel obtained by numerical integration over pixel area at diffusion-depletion boundary
  - $Q_{n,m} = \Sigma\Sigma Q_{ls}(x,y)dxdy$

Charge Collection by Drift and Diffusion in Moderate Field Regions



- Hybrid Monte Carlo solution to transport equation
- 3-D random walk with spatially dependent drift
- Follows approach used by Sai-Halasz to model alpha particle effects in ICs

Charge Spread for Various Particles



Simulation for Effect of Angle

20 MeV Proton Hits

Pitch = 30 um

Zdepl = 1 um

Zdiff = 5 um

Theta = 0

0	1	1	1	1	1	1	1	0	0
1	1	2	3	3	3	2	1	1	0
1	2	4	8	11	8	4	2	1	1
1	3	8	39	120	37	8	3	1	1
1	3	12	125	5348	111	11	3	1	1
1	3	8	37	106	35	8	3	1	1
1	2	4	8	11	8	4	2	1	1
1	1	2	3	3	3	2	1	1	0
0	1	1	1	1	1	1	1	0	0
0	0	1	1	1	1	1	0	0	0

Theta = 60

1	1	2	2	2	2	2	1	1	1
1	2	3	5	5	5	3	2	1	1
2	3	7	12	16	12	6	3	2	1
2	5	14	51	112	49	14	5	2	1
3	7	23	232	10389	206	22	6	3	1
3	6	19	117	639	108	18	6	3	1
2	4	10	23	33	22	9	4	2	1
2	3	4	7	8	7	4	3	1	1
1	2	2	3	3	3	2	2	1	1
1	1	1	1	2	1	1	1	1	1

Theta = 80

2	3	4	4	4	4	4	3	2	1
3	4	6	8	9	8	6	4	3	2
4	7	13	20	23	20	12	7	4	3
6	12	27	66	102	64	26	12	6	3
7	17	54	335	15035	307	51	17	7	4
8	19	66	647	16594	576	63	18	8	4
7	15	42	168	436	159	41	15	7	4
5	10	20	39	51	38	19	10	5	3
4	6	10	14	15	14	9	6	4	2
3	4	5	6	7	6	5	4	3	2

Theta = 89

3	3	3	3	3	3	3	3	3	2
4	4	4	5	5	5	4	4	4	3
5	6	6	7	7	7	6	5	5	4
6	8	9	10	11	10	9	8	6	5
9	11	15	18	19232	18	15	11	9	7
12	17	26	41	38440	40	25	17	12	9
17	27	48	133	19524	126	47	26	17	12
23	40	83	358	18050	330	81	39	23	15
31	55	128	633	25429	580	123	54	30	19
38	73	176	915	28175	837	170	71	38	23

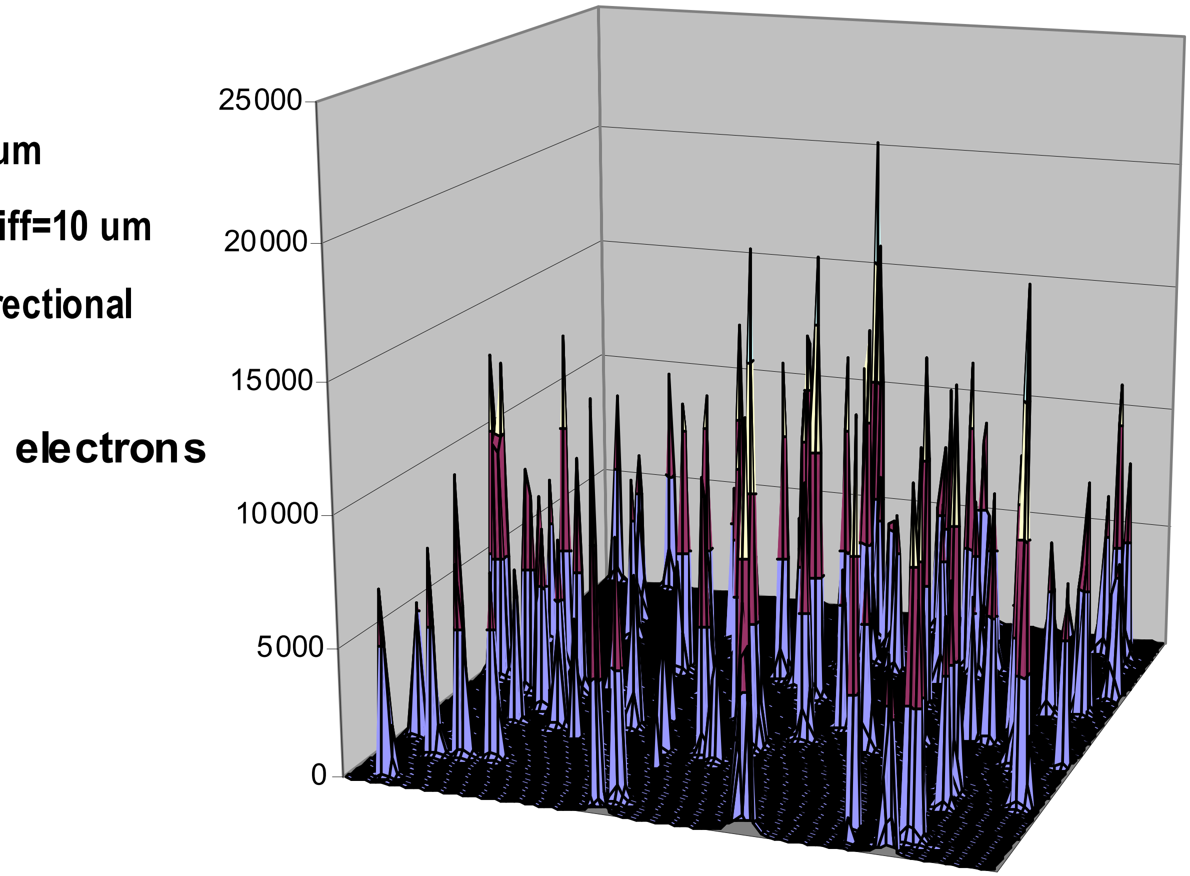
Typical Simulation Result

100x100 array, pitch=20 um

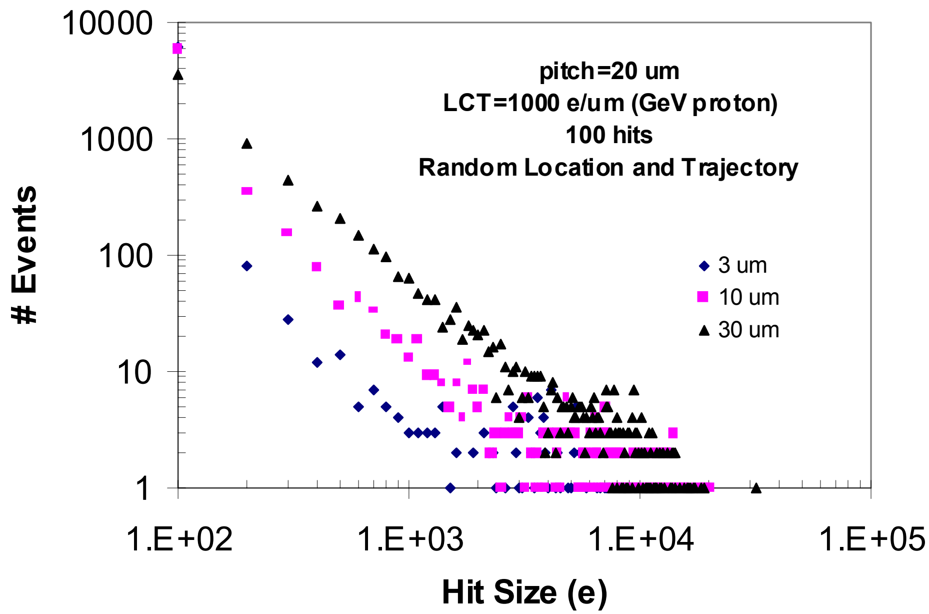
HgCdTe, Zdepl=1 um, Zdiff=10 um

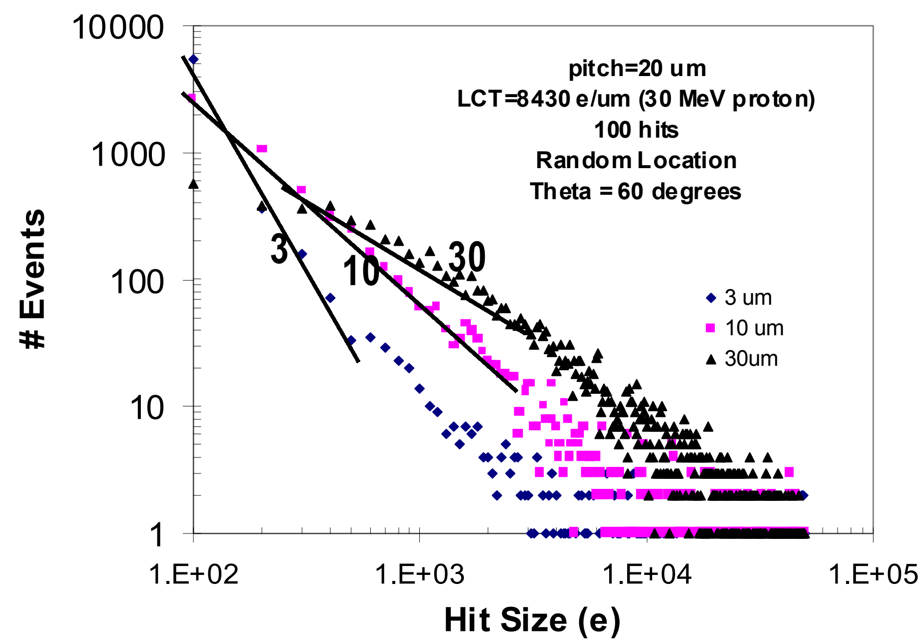
100 random hits, omnidirectional

GeV protons



Pulse Height Distribution



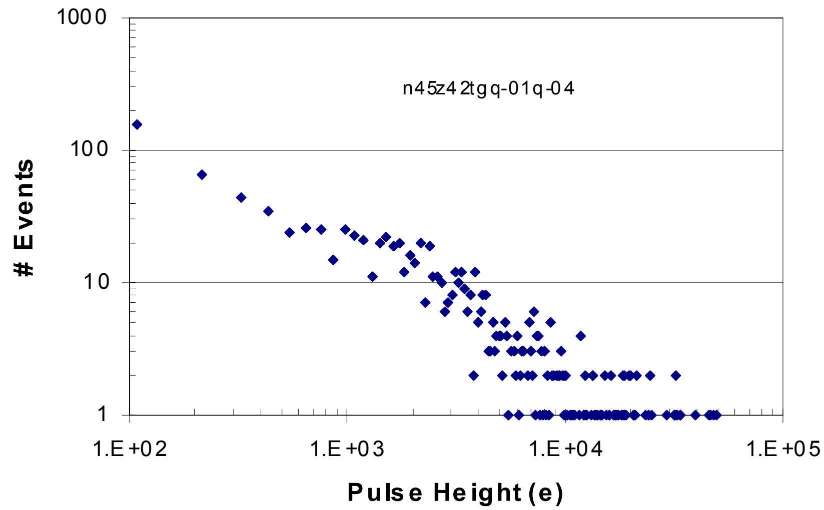


Compare test data to simulation to infer model parameters

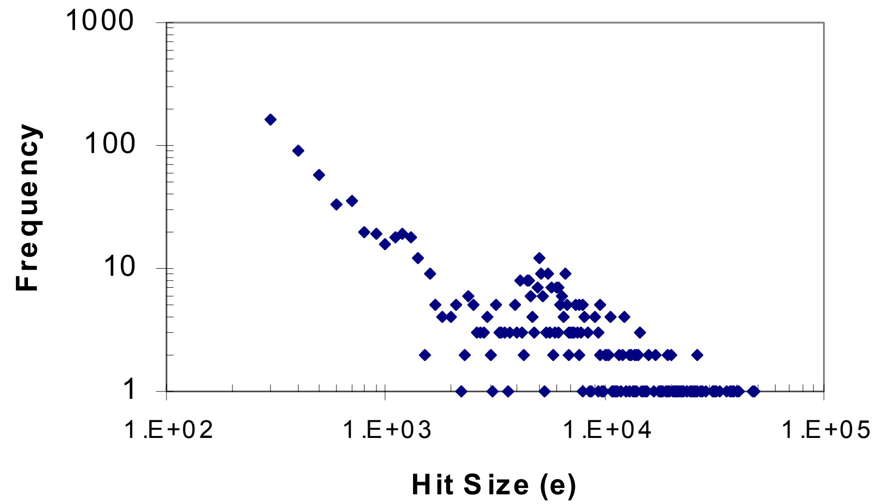
- **Qav and Qmax related to charge collection volume geometry**
- **PHD shape dependence in cross-talk tail related to diffusion layer thickness**

Comparison to NICMOS Data

On-Orbit Data

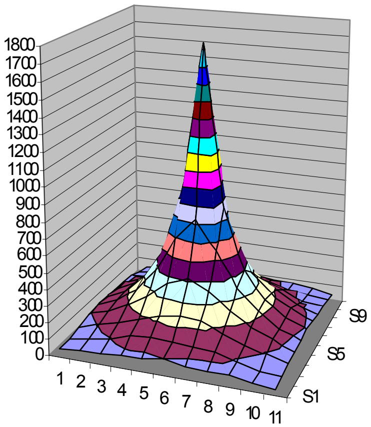


Simulation

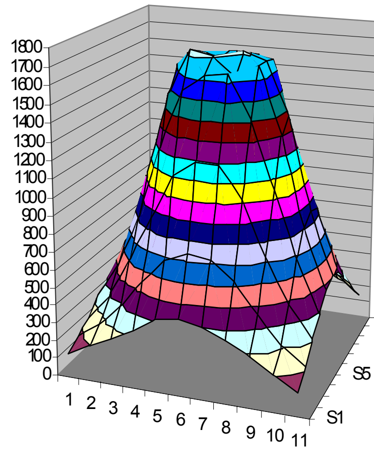


Comparison to APS Data

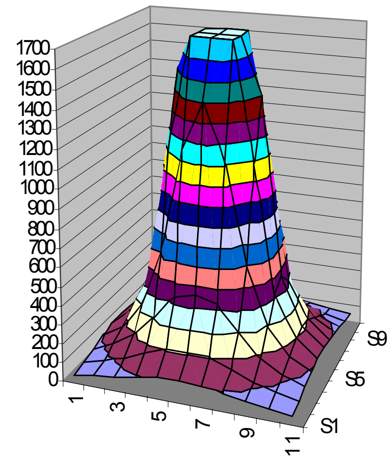
600 MeV Ar at 0 and 60 Degrees
2 pixel designs



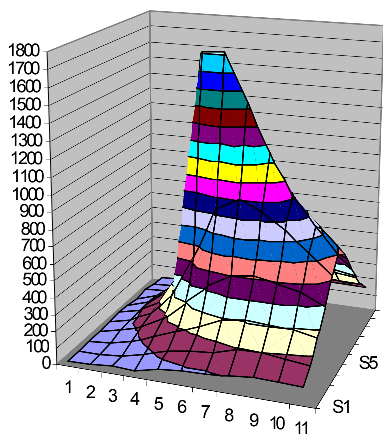
Quad 1 Data, 0 Deg



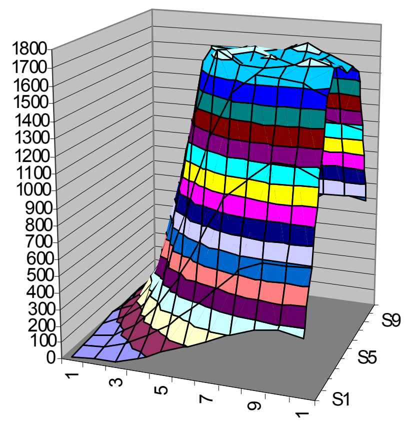
Quad 2 Data, 0 Deg



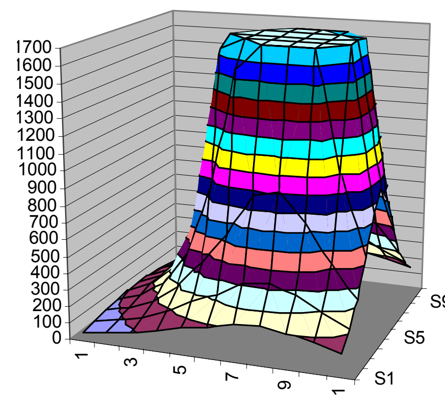
Simulation, 0 Deg



Quad 1 Data, 60 Deg



Quad 2 Data, 60 Deg



Simulation, 60 Deg

Summary

- Simulation tools for charge collection in detector arrays have been developed using a combination of analytical and Monte Carlo approaches
- Simulation addresses:
  - secondary particles and radioactivity
  - multiple layers and sub-regions within layers
  - variation of LET
  - secondary electron scattering
  - drift
  - free-field diffusion
  - field-assisted diffusion
- Model parameters can be calibrated with experimental data
- Applicable to all semiconductor detector arrays