Instrumentation Division Report

Veljko Radeka

Presentation to the DOE RHIC Program Review

July 10, 2003

Outline

- **Core Technologies and Facilities**
- **Key Accomplishments and R&D for future NP Program**

BROOKHAVEN
NATIONAL LABORATORY

Instrumentation Division

Mission:

**"To develop state-of-the-art instrumentation required for experimental research programs at BNL.
To provide limited production quantities of such for BNL-related experiments."**

Core technologies:

- **Semiconductor detectors** (pixel-, drift-, photo sensors);
- **Gas and noble liquid detectors**;
- **Microelectronics** (low noise analog/digital);
- **Lasers and Optics (**ultra-short photon & electron bunches, photocathodes, optical metrology);
- **Micro/nano Fabrication** (sensors, microstructures, e-beam lithography).

Staff:

47 Total
26 Scientists & Professionals
21 Technical & Administrative

Publications in FY 01/02

All Programs: 42

Core Competencies and Program Areas Served

		Nuclear Physics	H. E. Physics	Accelerator Dev.	Chemistry	Material Science	Biology & Medicine	EENS	Industry Collab.
Semiconductor, Gas & Liquid Detectors	X-ray, gamma-ray Detectors (1D, 2D)					✓	✓	✓	
	High Resolution Neutron Detectors				✓		✓	✓	
	Silicon (strip-, pad-, drift-) Detectors	✓	✓	✓	✓	✓	✓	✓	✓
	Cryogenic Detectors	✓	✓						
	Gas Detectors for High Particle Rates and Multiplicities (Cathode Pad/Strip Chambers)	✓	✓	✓	✓	✓	✓		
Micro-electronics	Monolithic and Hybrid Low Noise Amplifiers	✓	✓	✓	✓	✓	✓	✓	✓
	Data Acquisition Electronics	✓	✓		✓	✓	✓	✓	✓
	Fast Noble Liquid Calorimetry Readout	✓	✓						
Lasers, Optics & Microfabrication	Optics Metrology		✓		✓	✓	✓	✓	✓
	Laser and Optics in New Accelerator Concepts: Photocathodes, Fast Pulsed Photocathodes	✓	✓	✓		✓	✓	✓	✓
	Electro-optics and Ultrashort Laser-pulse Techniques (ps — fs → as)	✓	✓	✓		✓			✓
	Micro/nano Fabrication			✓		✓	✓	✓	✓
	Total Effort in FY2003 [%]	35	25		40				

Program 04-08

In support of vital BNL programs:

- RHIC Detector Upgrades (silicon and TPC)
- e-cooler; e-RHIC:

  High Current Photocathodes
- ATLAS Dets., and LHC upgrade
- Si-detectors for Polarimeters
- Si-detectors & microelectronics:

  -EXAFS at high photon rates

  -X-ray Microscopy

  -Protein crystallography

  -Position sensitive modification
- New small animal PETs, MRI
- Neutron detectors for SNS
- Neutrino detectors
- Detectors and Microelectronics for

  Homeland Security Program

State-of-the-art core technology:

- Fine-grained Si and gas detectors
- Low noise microelectronics from submicron to nanoscale
- Femtosecond, photon and particle beam generation & diagnostics
- Nano-fabrication: pattern generation; deposition/ablation; characterization

Exploration:

- CMOS as direct conversion detectors
- Megapixel matrix on kohm cm Si
- Neutrino (“bubble”) detector
- Femtosecond ~100 eV source

Future Activities for RHIC

S = 1-2 years; M = 3-5 years; L = ≥ 5 years

	Time Scale:
Silicon Detectors	
• STAR , low mass, e.g., CMOS imagers	L
• PHENIX – pixel detectors	M-L
• " -- single sided 2d strip detectors	S-M
• Polarimeter II	S
Gas Detectors	
• Small ("Micro") TPC	M-L
Microelectronics	
• Fine-grained detectors	S-M-L
• FPGA & DSP technology (STAR DAQ)	S-M-L
• Trigger upgrades for PHENIX	S-M
RHIC Beam Monitoring	
• Digital Signal Processing; Continuing development	
Photocathodes	
• Electron cooling at RHIC	M
• e – RHIC, GaAs → polarized electrons	L

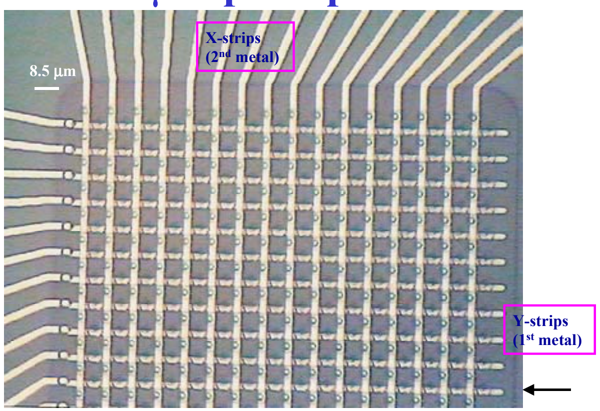
Si Detector Development and Processing at Instrumentation Div.

Novel Detectors

- **Stripixel detectors**

  2d position sensing
  1-sided processing

8.5 µm pitch pixels

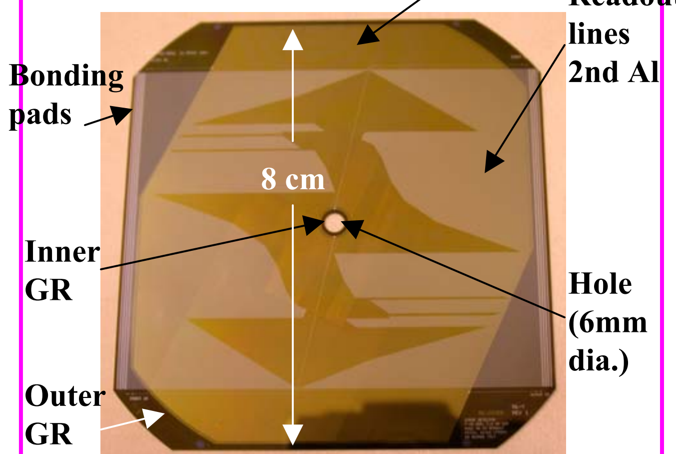


- **Active matrix pixel sensors**
- **Edgeless detectors**
- **Semi-3d sensors**

  for radiation hardness

Prototype Detectors for Existing Experiments

- **Segmented, multi- pitch strip detectors for CERN NA60 experiment**

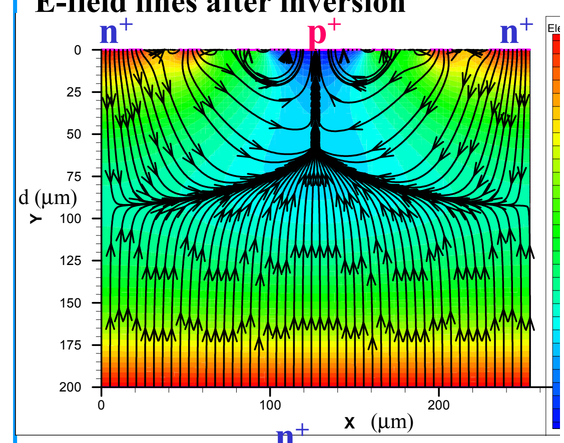


- **Large Roman pot strip detectors for RHIC PP2PP experiment**
- **Large stripixel detectors for PHENIX upgrade**

Radiation Hard Detectors

- **Low resistivity detectors**
- **Oxygenated detectors**
- **Cryogenic Si detectors**
- **Detectors with novel structures (semi-3d)**

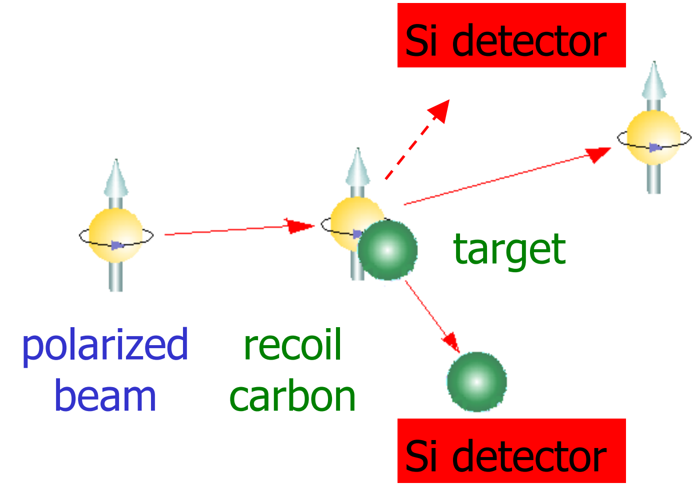
Simulation of potential profile and E-field lines after inversion

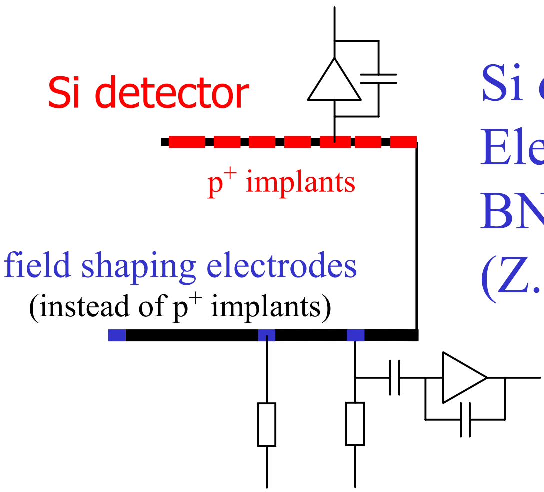


- **High resistivity CZ Si detectors**

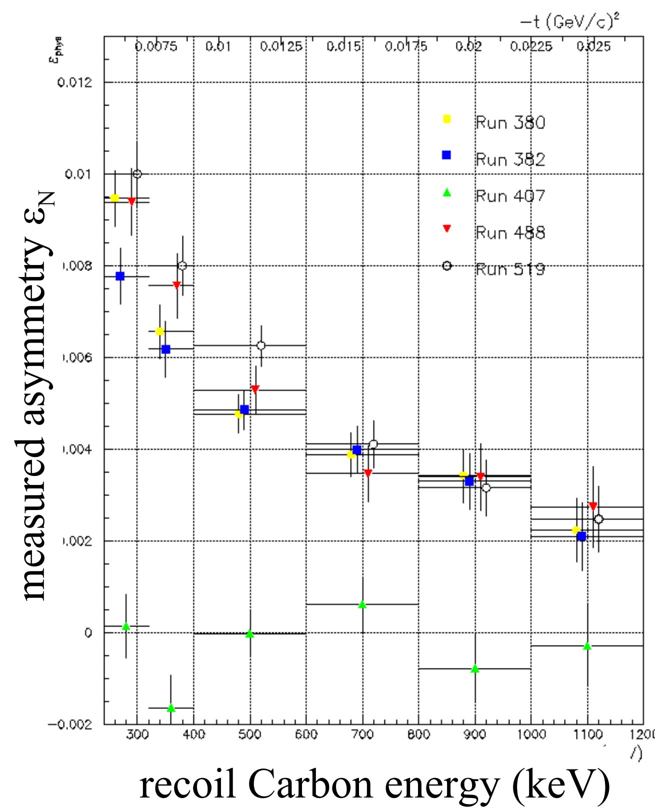
SPIN POLARIMETER for RHIC and AGS

Measure the beam polarization at RHIC and AGS by measuring the left-right spin asymmetry of polarized protons scattering off a carbon (proton) target by detecting the the low energy recoil carbons (protons) with Si detectors.





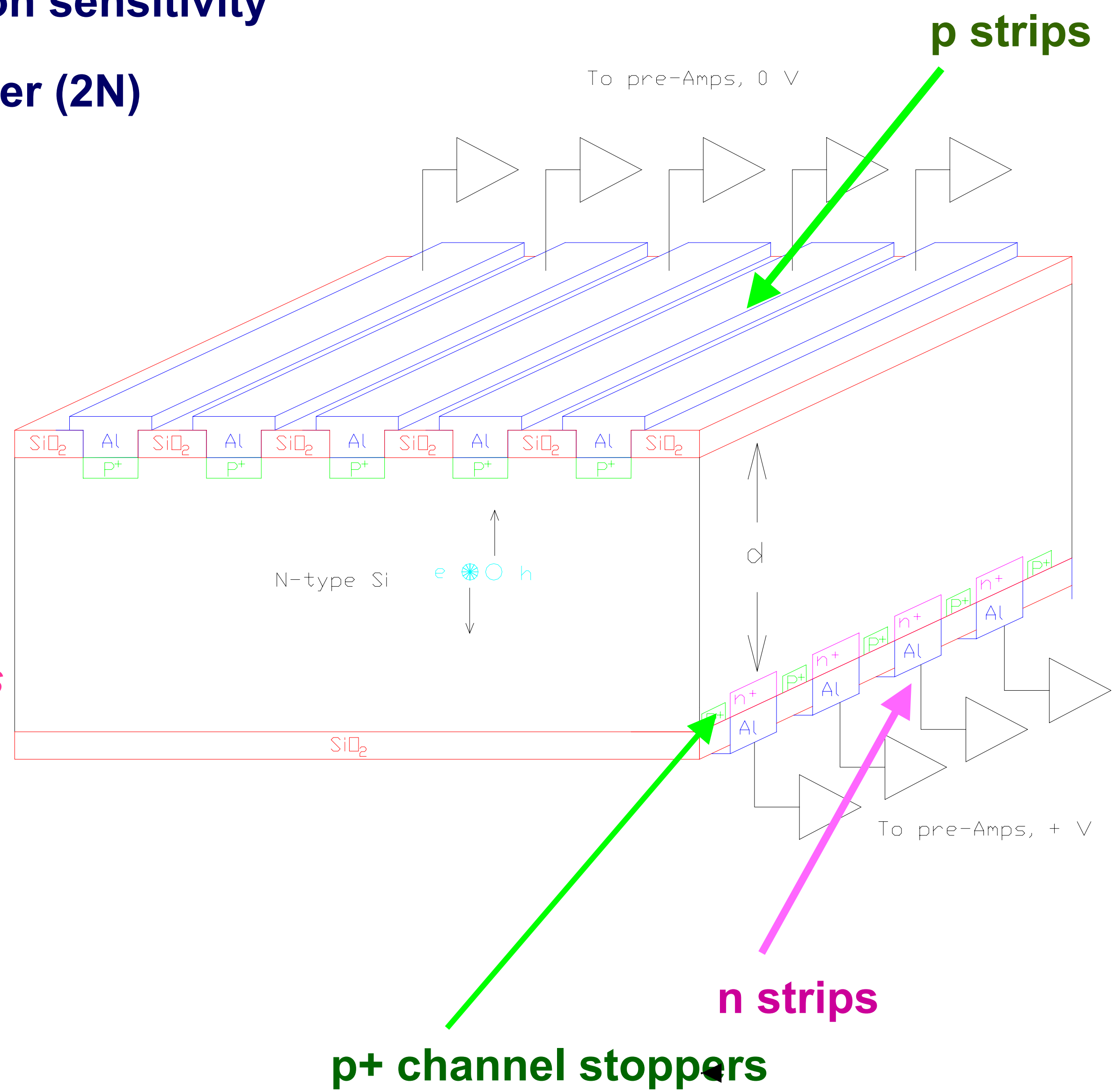
Si detectors and Front End Electronics Developed at BNL Instrumentation Division (Z. Li & S. Rescia)



1. RHIC polarimeter installed in 2002
2. AGS polarimeter installed in 2003
3. RHIC absolute polarimeter using a double-sided strip detector under development for 2004

Double-sided strip detectors on high resistivity silicon (~3-5 kohm cm):

- **Two dimensional position sensitivity**
- **Minimum channel number (2N)**



But:

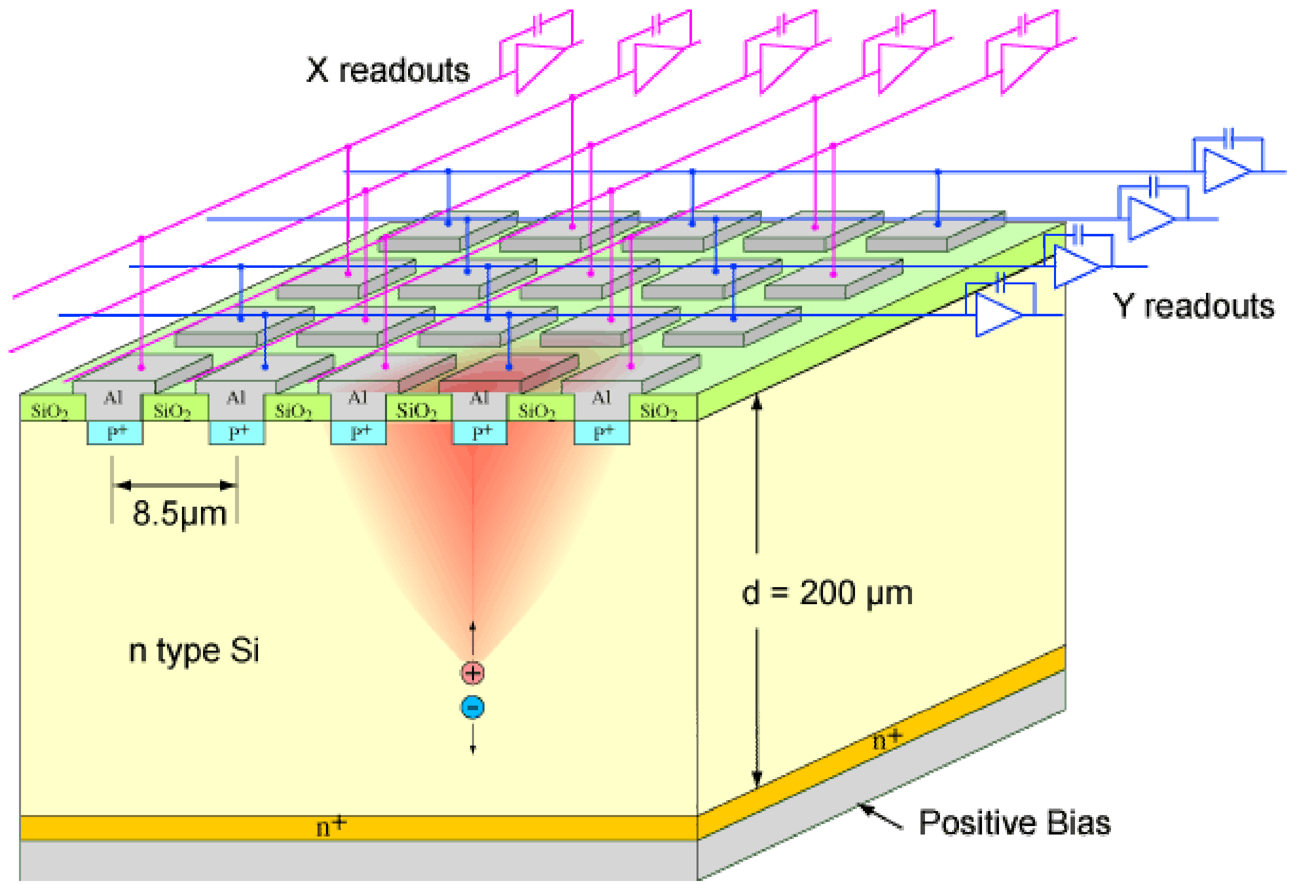
- ***Two-sided process***
  about 3-4 times more complicated/expensive than single-sided process
- **Radiation soft due to the the complicated structure on the n-side**
  - **Two polarities of readout electronics**

The new concept:

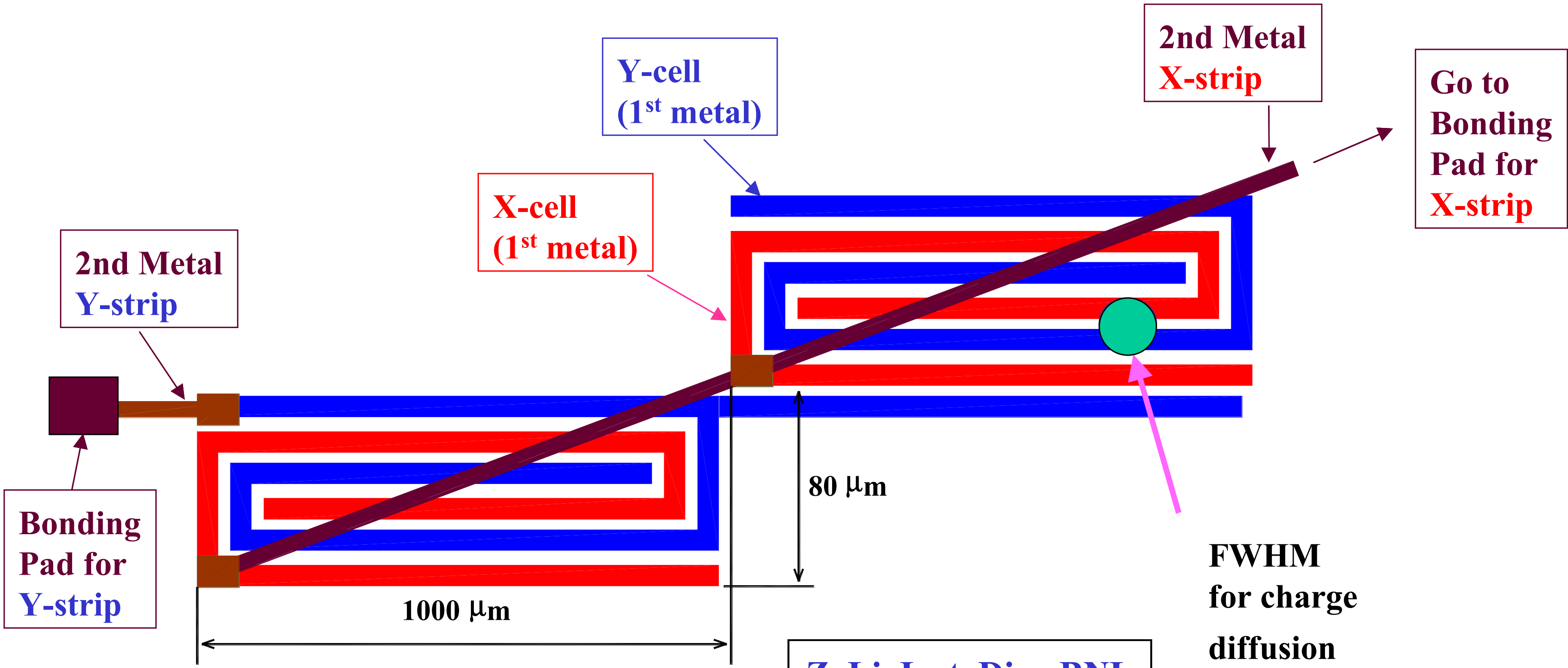
Alternating stripixel detectors (ASD)

Individual pixels are alternately connected by X and Y readout lines (strips)

- Two dimensional position sensitivity is achieved by charge sharing between X and Y pixels
- In principle, the pixel pitch should not be larger than the size of charge cloud caused by diffusion process



Schematic of the Prototype Stripixel Detector
For PHENIX Upgrade



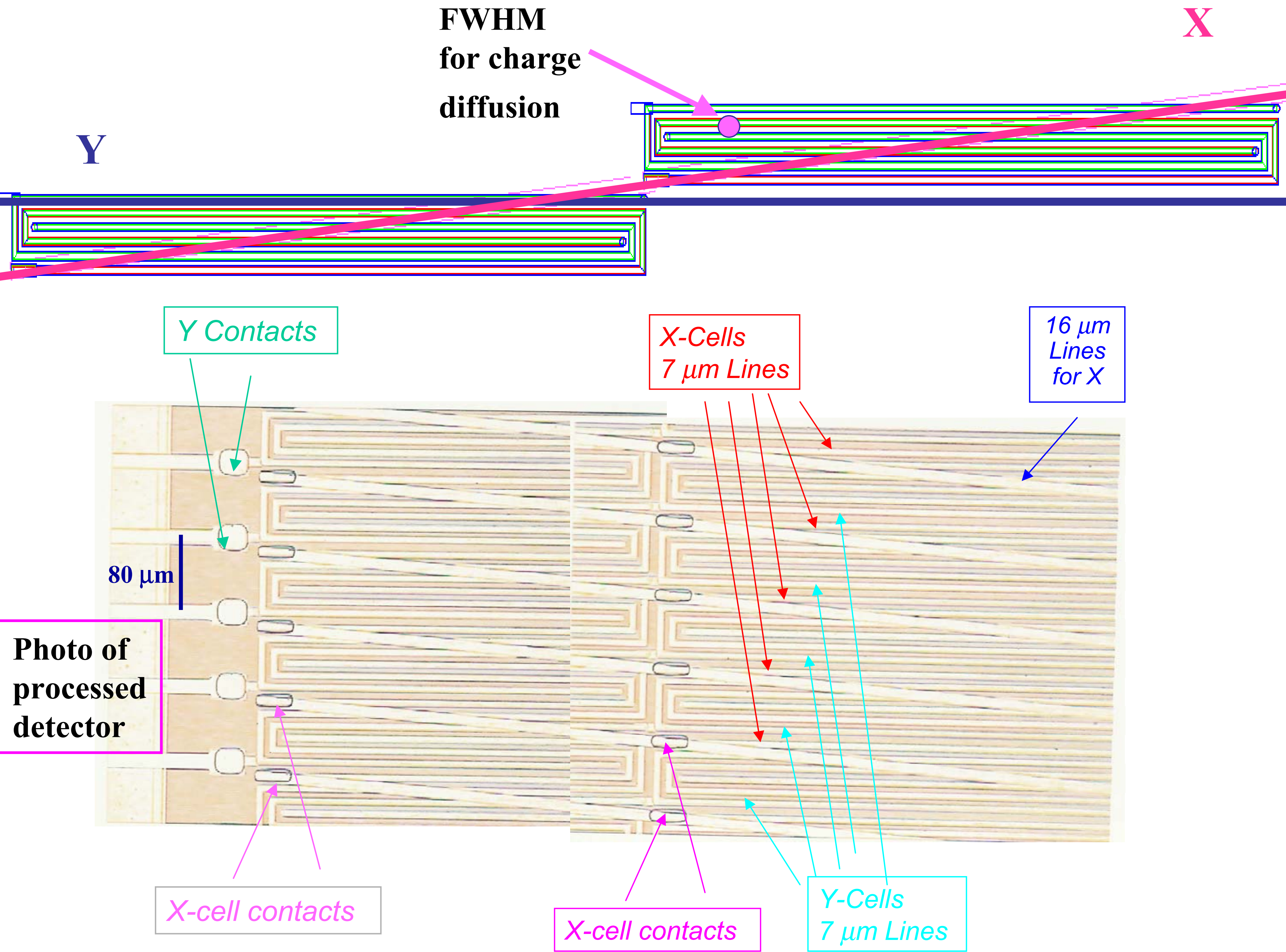
Z. Li, Inst. Div., BNL

Pixel pitches: 1000 μm in X, and 80 μm in Y

Pixel arrays: 30x384

4.6° stereo angle between X and Y strips

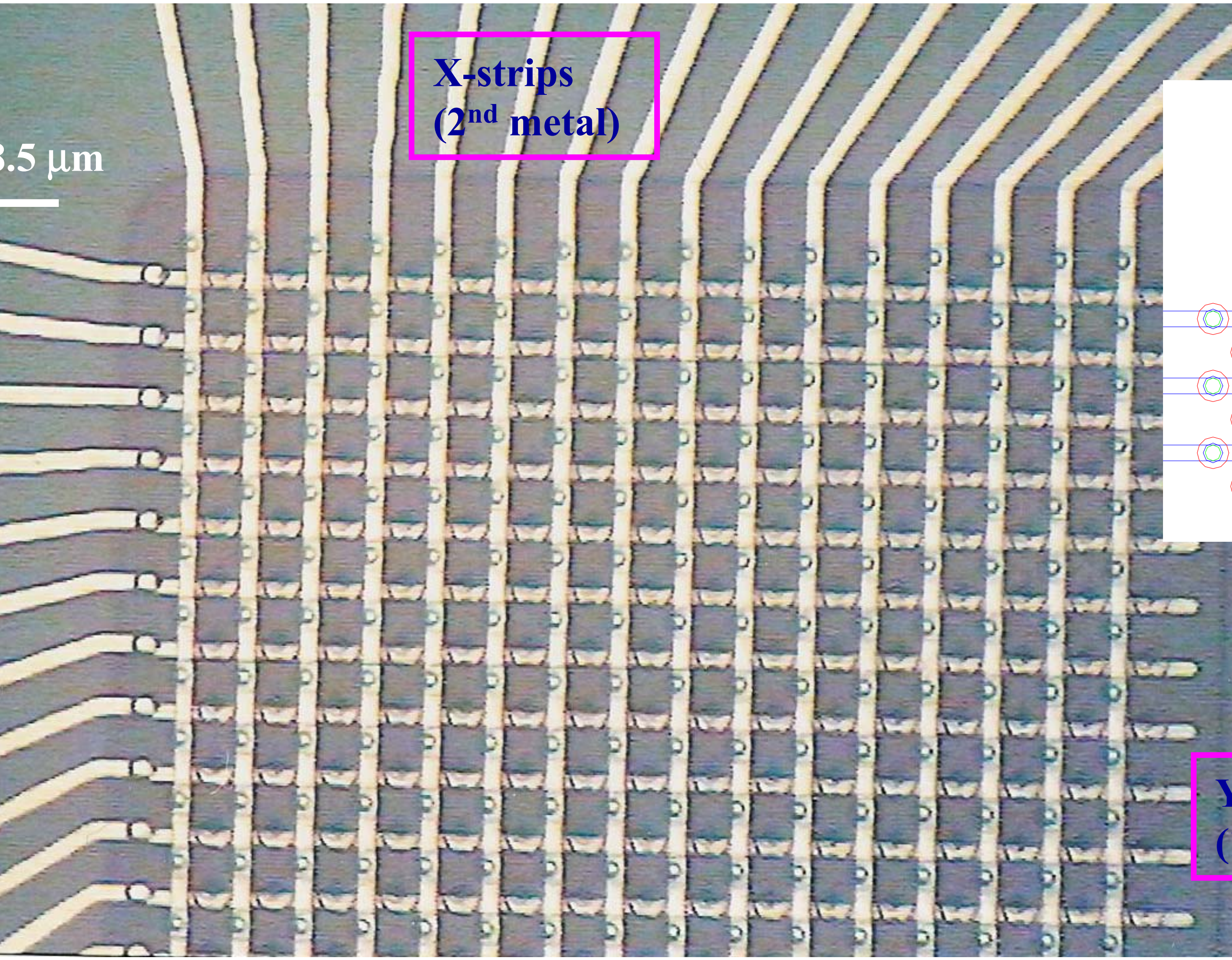
σ_y = ~25 μm

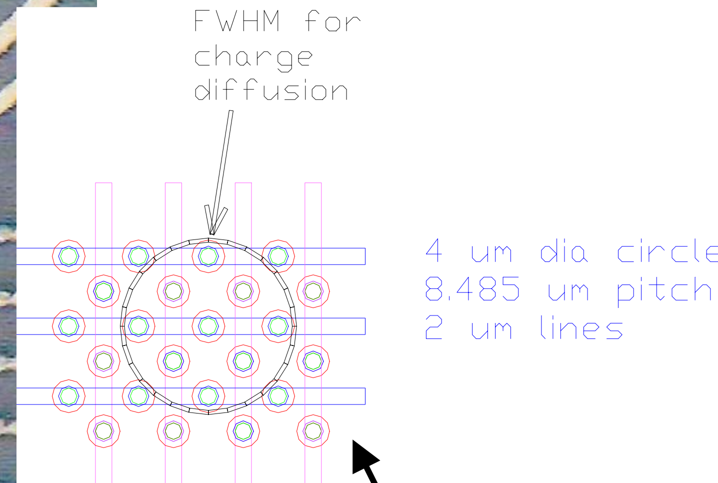


FWHM
for charge
diffusion
X
Y
Y Contacts
X-Cells
7 µm Lines
16 µm
Lines
for X
80 µm
Photo of
processed
detector
X-cell contacts
X-cell contacts
Y-Cells
7 µm Lines

Novel Stripixel Detector for *Sub-micron* Position Resolution in Two Dimensions with One-sided Process

8.50 µm pitch in both X and Y strips

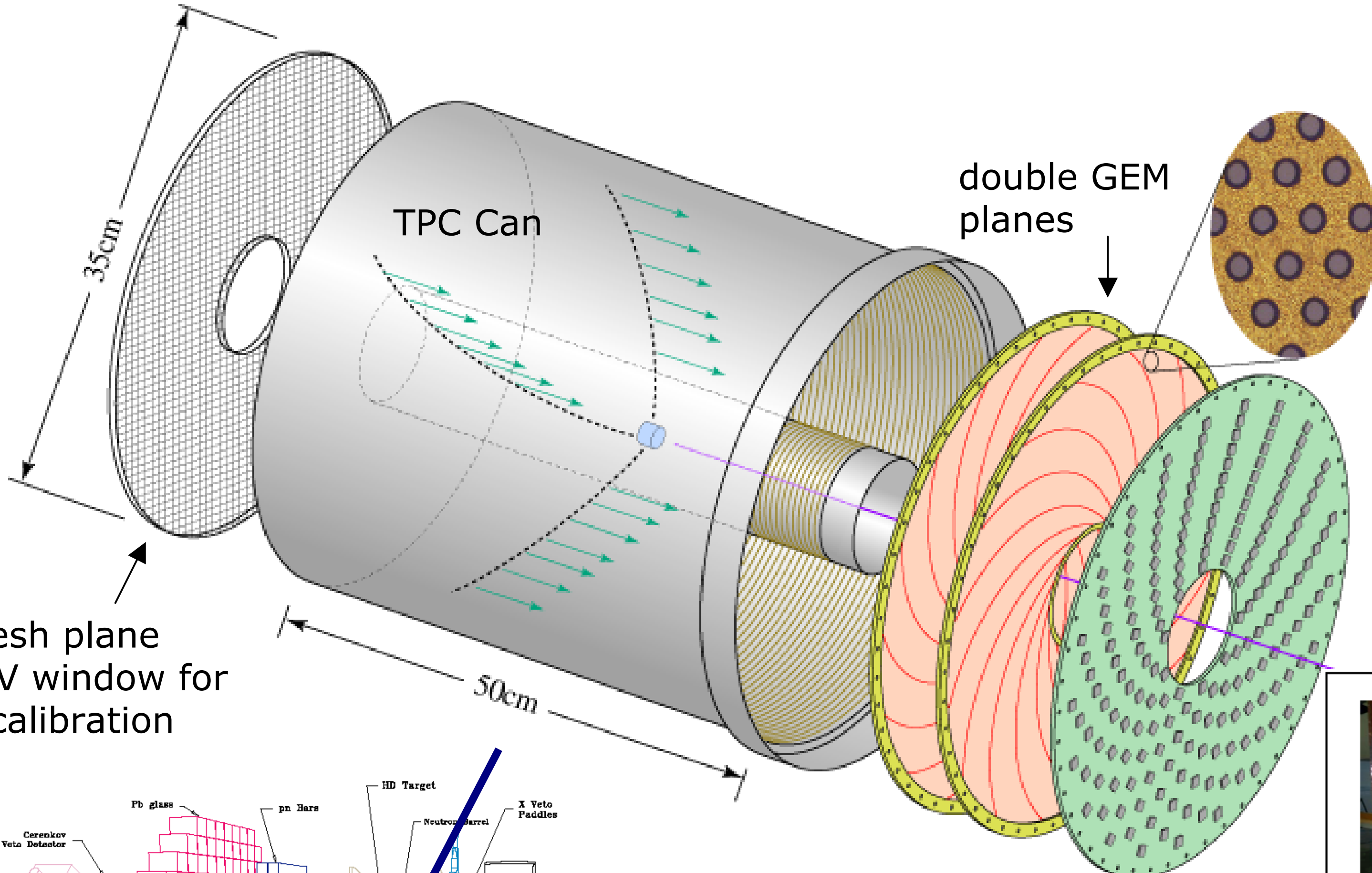


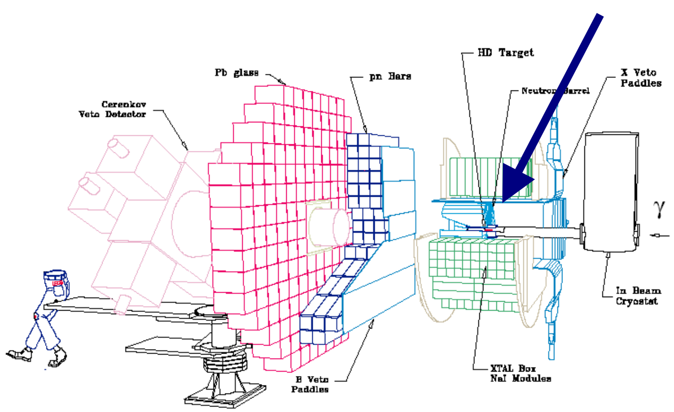


Design and illustration of diffused charge cloud

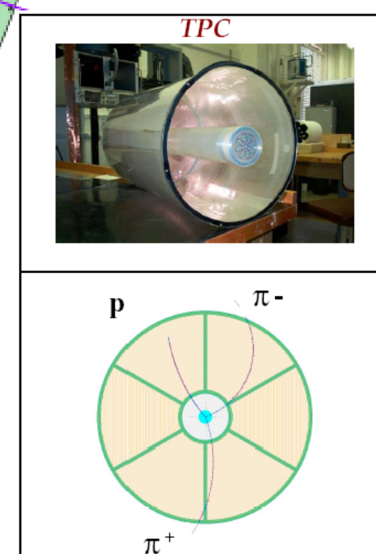
Photo of processed detector

Laser Electron Gamma Source : Time Projection Chamber (TPC)

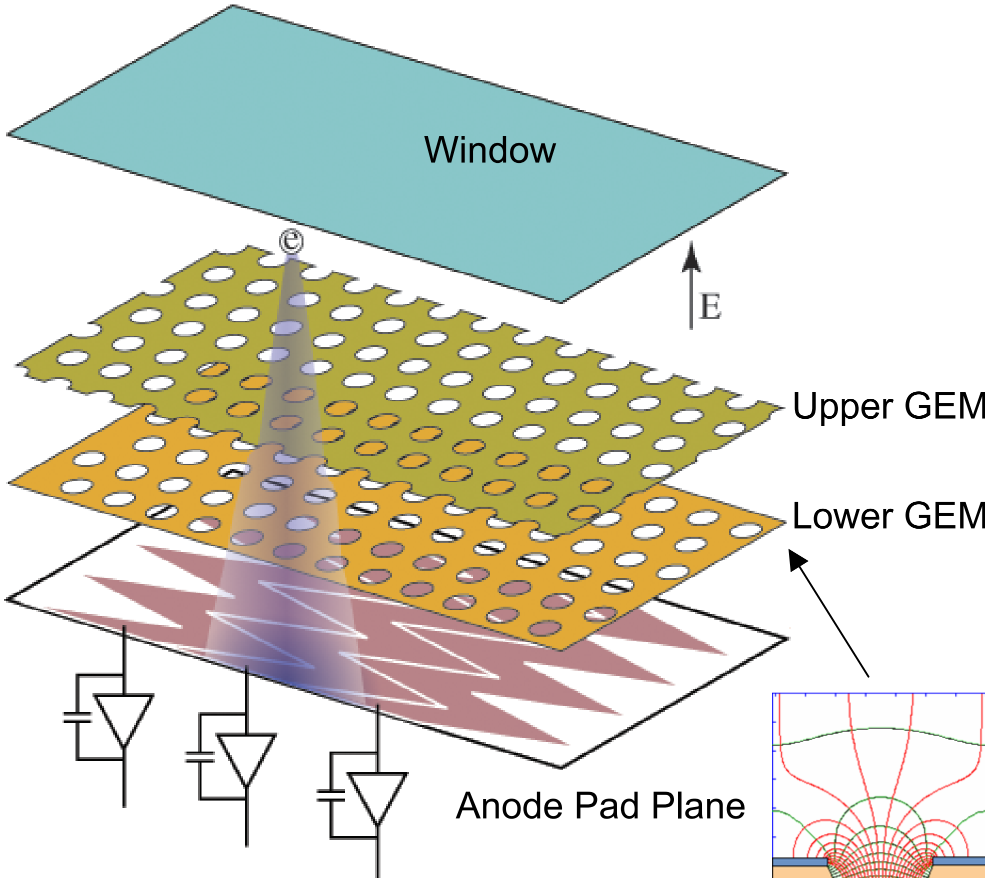




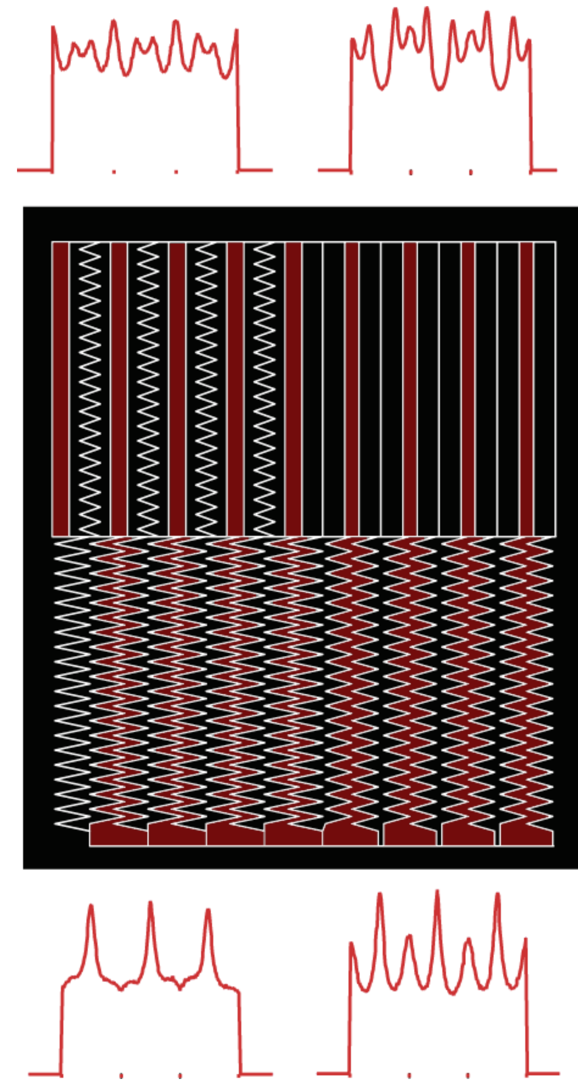
Spin ASYmmetry Array (SASY)

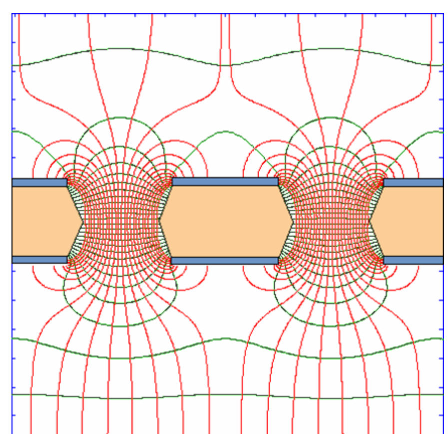


Interpolating Pad Readout for GEM (Gas Electron Multiplier)

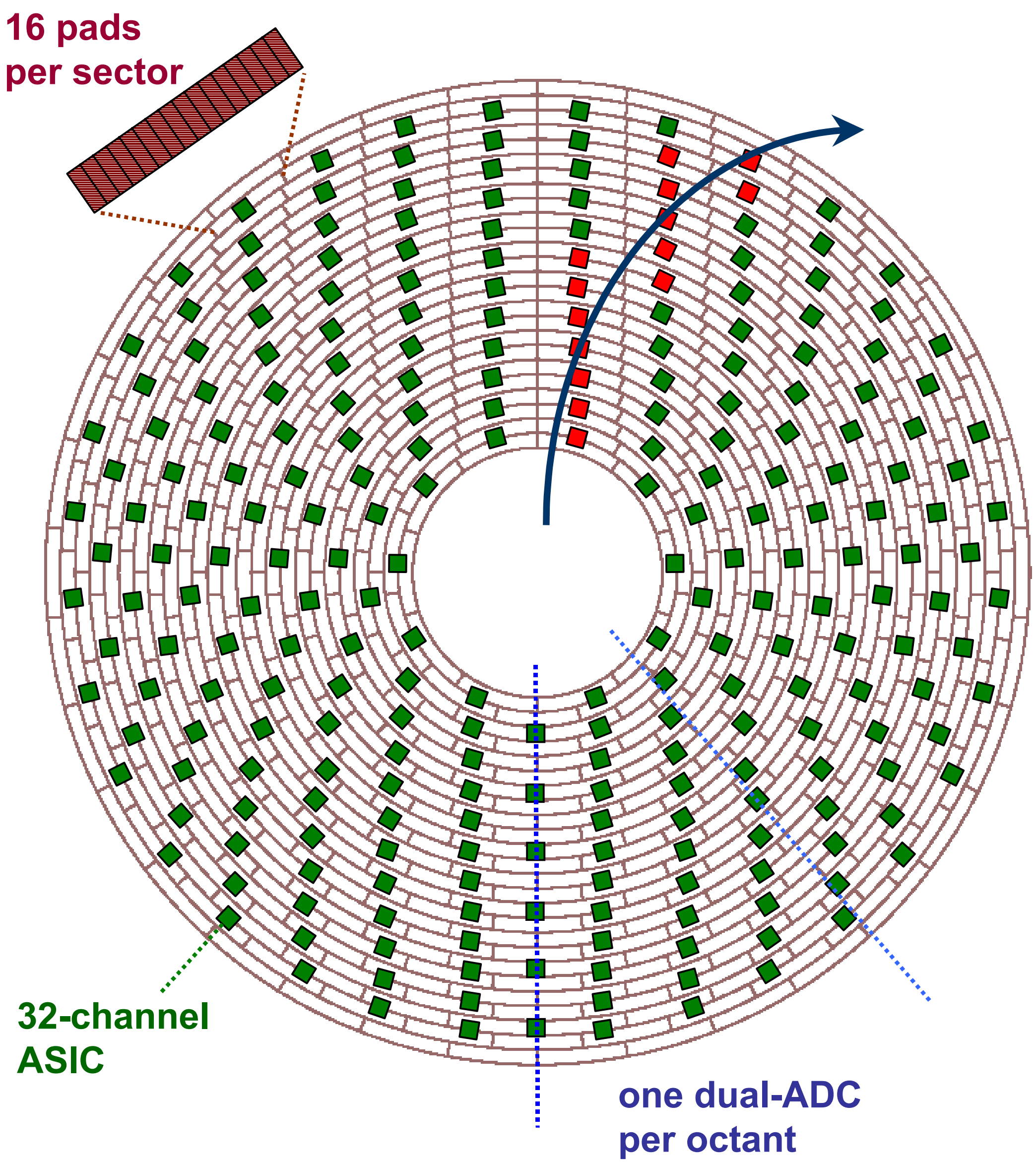


<100µm rms position resolution with 2mm pad pitch





Readout Electronics – Specifications



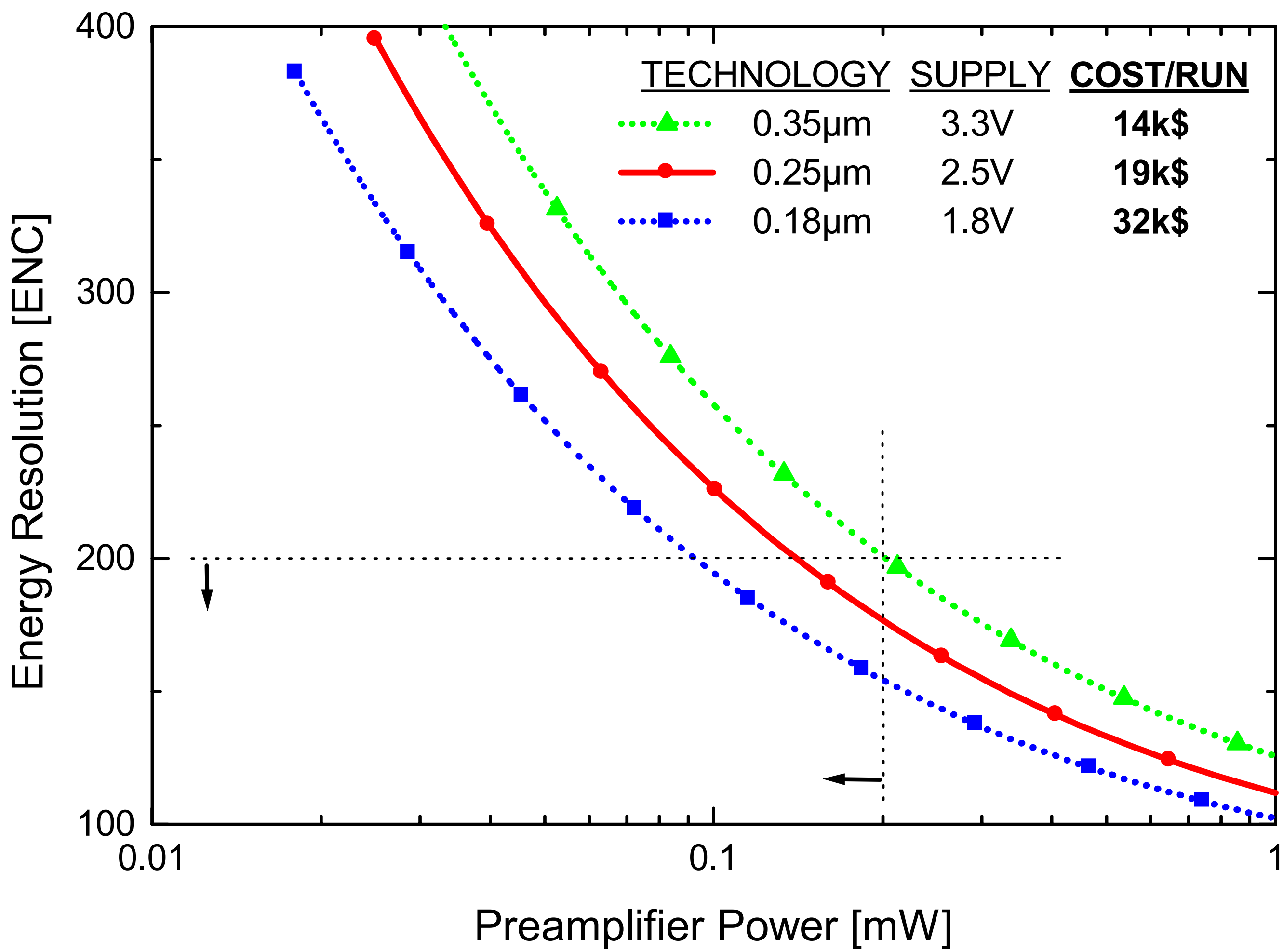
Tracking Measurement

- Energy - triggered pad (xy)
- Energy - neighbor pads (xy)
- Timing (z)

Specifications

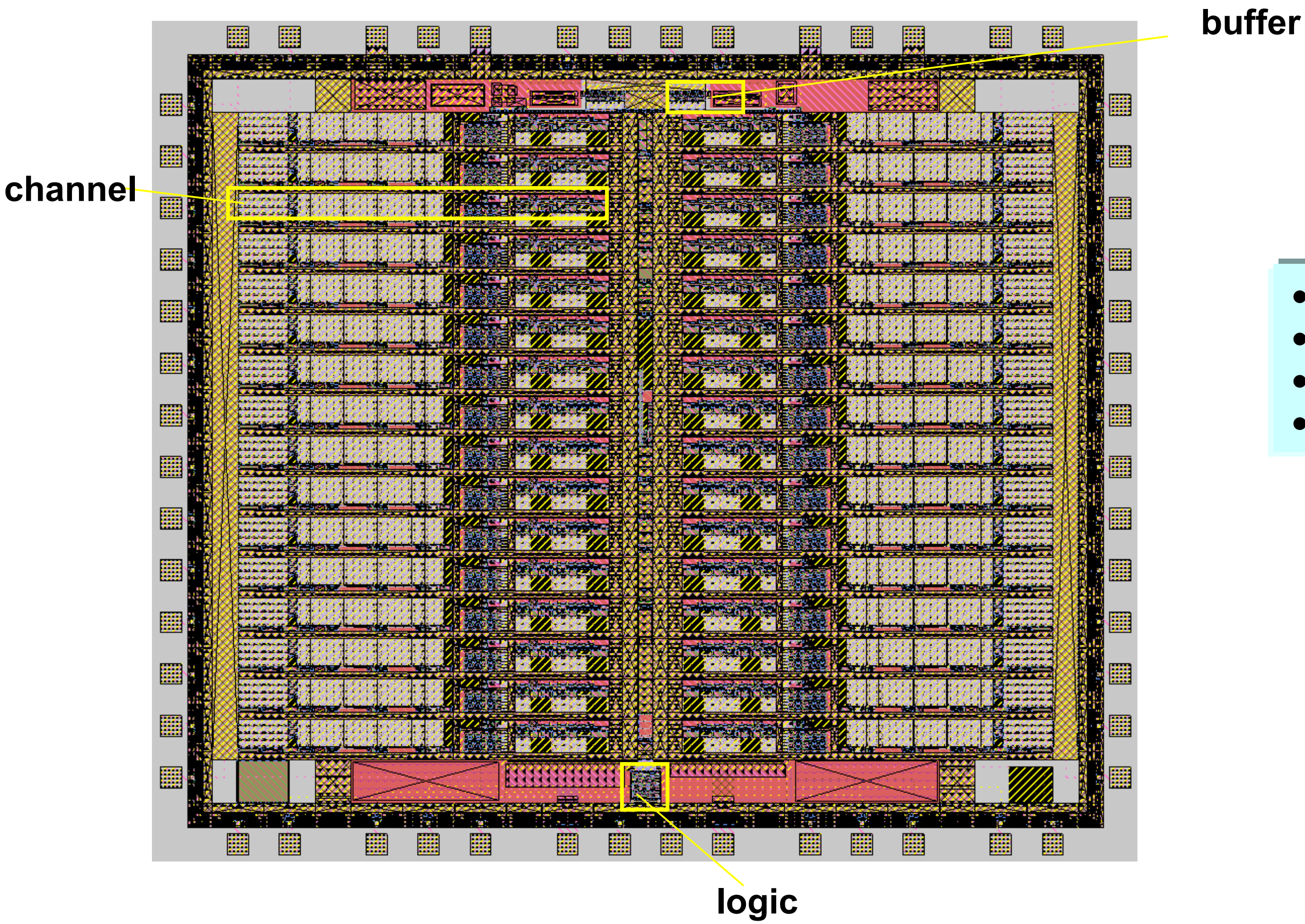
- ENC < 500 e^- rms
- Timing < 20ns
- Preamplifier/shaper/BLH
- Peak-detector
- Timing-detector (TAC)
- On-chip buffers
- Neighbor channel/chip enable
- Adjustable gain ≈ 17-32 mV/fC
- Channel masking
- Calibration
- Token/flag readout

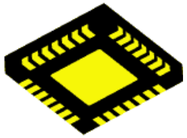
Front-End Electronics – Preamplifier Power



- 32-channel ASIC - layout is pad-limited ≈ 3 x 3 mm²
- power / channel ≈ 1mW (preamplifier < 200µW)
- energy resolution < 250 rms electrons (600ns peaking time, 5pF)

Layout

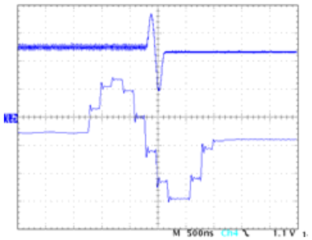


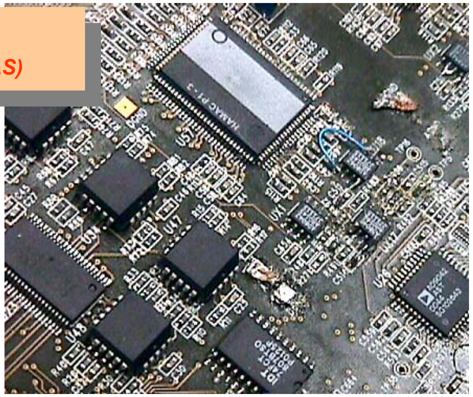


- 32 channels
- 3.1 x 3.6 mm²
- 47k MOSFETs
- 43mW

High energy and nuclear physics

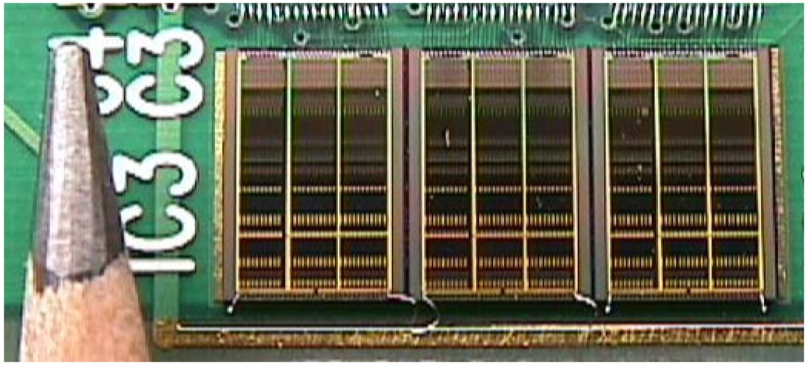
High-speed, radiation-tolerant sampling/digitizing board ***(ATLAS)***





240-channel multichip module for Si drift detector readout ***(STAR)***

Condensed matter physics



Photon-counting ASIC for EXAFS ***(NSLS)***

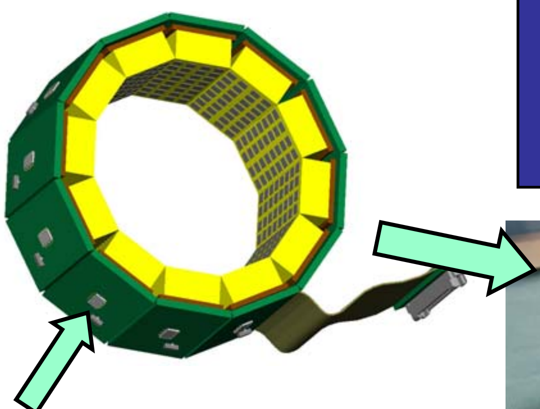
Photon-counting ASIC for

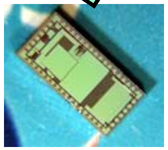
Microelectronics Group

AREAS OF EXPERTISE

- CMOS monolithic circuits
- charge-sensitive sensor interface
- analog signal processing
- low noise, low power techniques
- VLSI custom design + layout

Life Sciences



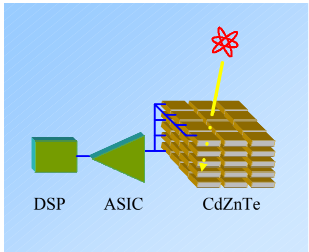


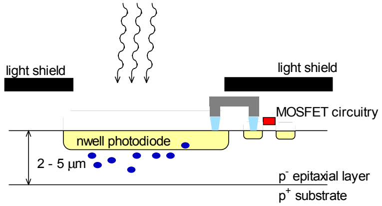
Positron emission tomograph for imaging the awake animal brain

Industry collaboration and national security

Handheld imaging probe for intra-operative cancer detection ***(eV Products)***

Handheld imaging probe for intra-operative cancer detection (eV



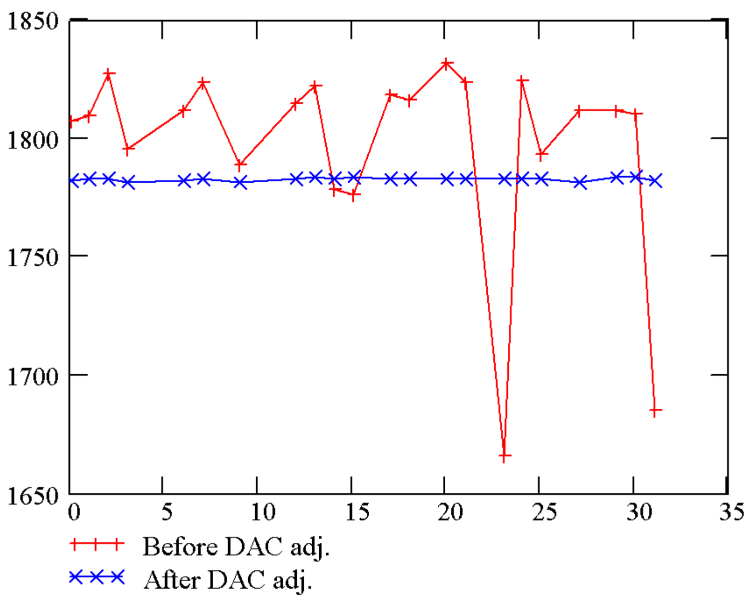


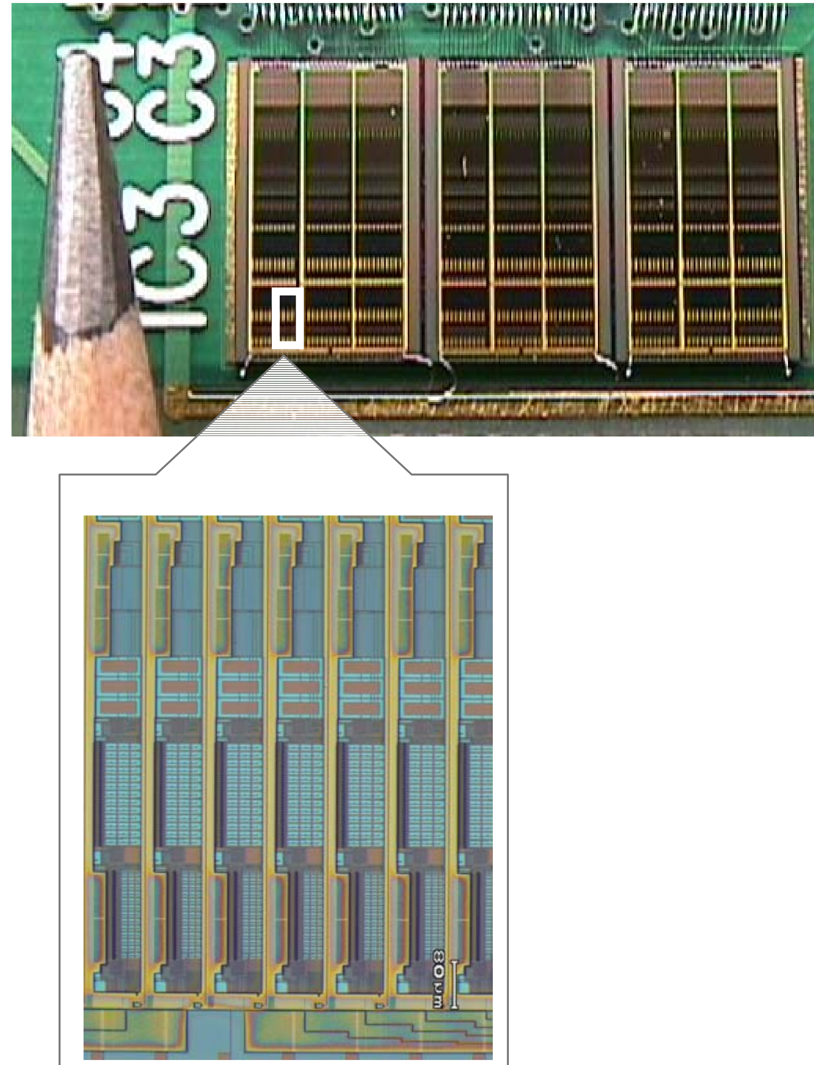
Proposed gamma spectrometer for detection of nuclear materials

Photon-counting ASIC for EXAFs

- 32-channel 0.35 mm CMOS ASIC
- Wirebonded to 96-channel cooled Si pad detector, 1 x 1 mm pads, 0.8 pF
- 235 eV FWHM (28 e- rms) at 100 kcounts/pad/s
- **180,000 MOSFETs**
- 8.2 mW/chan

Thresholds before and after DAC adjustment



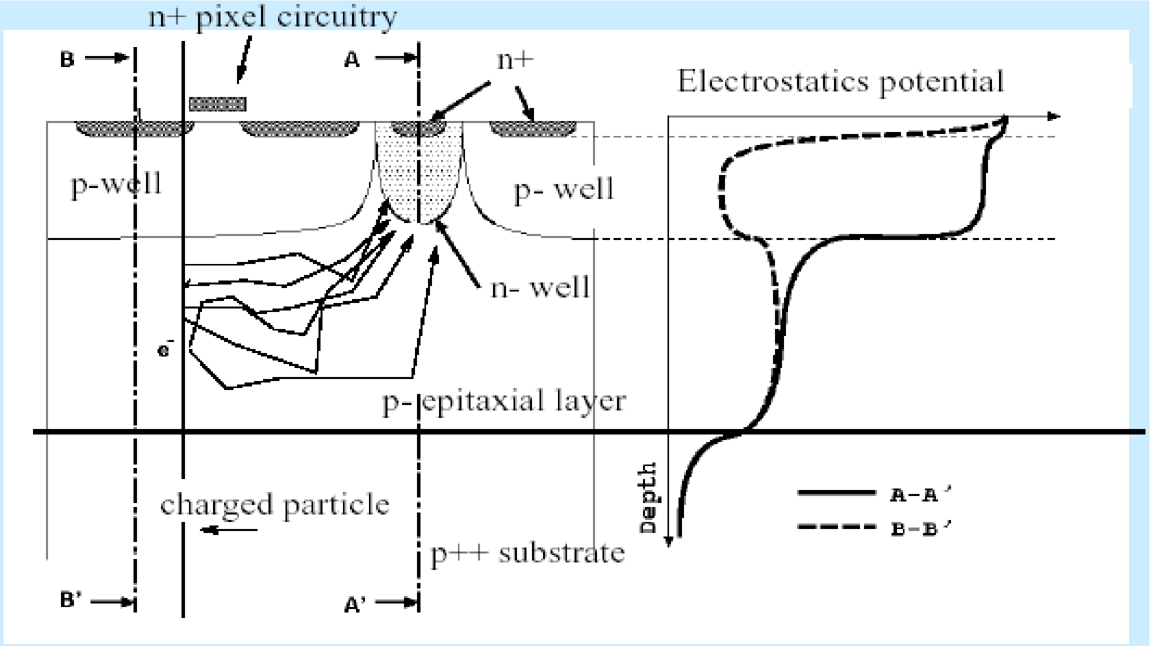


CMOS as Direct Conversion Megapixel Detectors (10-20 μm pixels)

Epitaxial layer ~5-15 μm

Min. ion. particles ~80 e/μm

Twin - tub (double well), CMOS process with epitaxial layer



- The effective charge collection is achieved through the thermal diffusion mechanism,
- The device can be fabricated using a standard, cost-effective and easily available CMOS process,
- The charge generated by the impinging particle is collected by the n-well/p-epi diode, created by the floating n-well implantation,

Multialkali Photocathode Development for *e-cooling*

A multialkali cathode deposition and testing system

Goals:

- Electron beam parameters: charge 10 nC, PRF 10 MHz, average current 100 mA
- Quantum efficiency: few % for Visible photons
- Lifetime: >8 hrs at a vacuum of 1×10^{-9} Torr

Investigate:

- Life time as a function of pressure and contaminant
- Possibility of in situ rejuvenation

R&D Program Summary, FY2004-8:

This program utilizes the BNL Instrumentation Division's unique expertise to develop key elements of next generation detectors in support of NP research. It incorporates R&D efforts in ***semiconductor detectors, microelectronics, gas detectors and photocathodes:***

- To conduct R&D of novel semiconductor detectors for NP experiments;
  To provide insight into the radiation damage problem in Si detectors and to develop radiation hard materials/detectors;

- To conduct an in-depth study of submicron CMOS devices, circuits, DSPs and FPGAs focusing on the front-end electronics, and data acqusition needs of next-generation nuclear physics detectors;

- To develop high density, low mass chip-to-detector (and chip-to-chip) interconnects, and to strengthen the design capabilities in advanced hybrid and printed circuits;

- To develop techniques for fine-grained Time Projection Chambers for NP experiments.

- To develop photocathode technology for e-cooling at RHIC.

While the work in support of the RHIC program represents ~35-40% of our effort, it will benefit greatly from the technologically related work for other BNL programs (LHC, NSLS, PET, etc.).