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**

managed by Brookhaven Science Associates for the U.S. Department of Energy

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

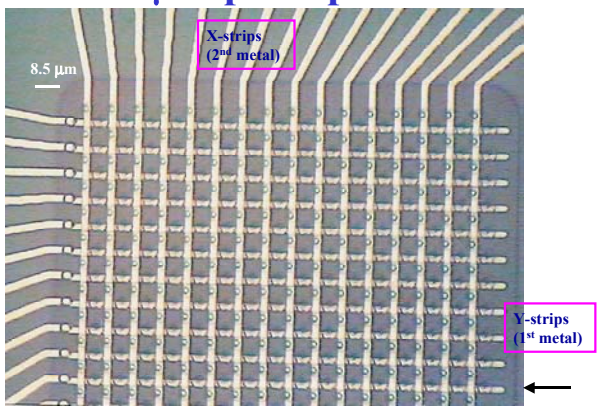
Si Detector Development and Processing at Instrumentation Div.

Novel Detectors

- **Stripixel detectors**

  2d position sensing
  1-sided processing

  8.5 µm pitch pixels

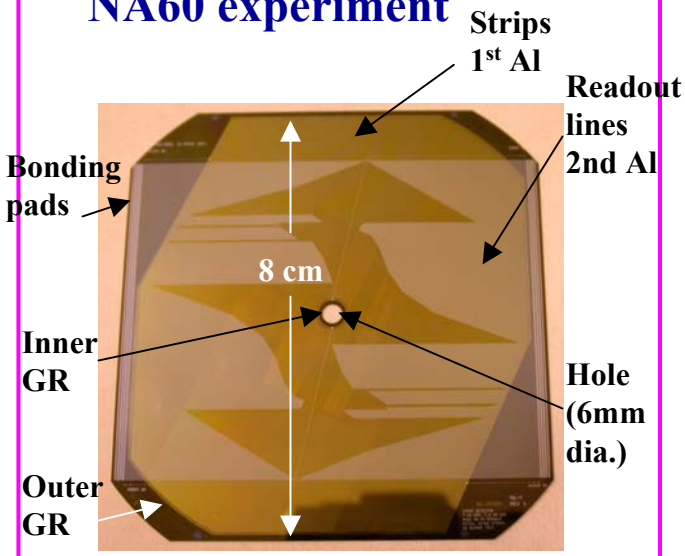


- **Active matrix pixel sensors**
- **Edgeless detectors**
- **Semi-3d sensors**

  for radiation hardness

Prototype Detectors for Existing Experiments

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

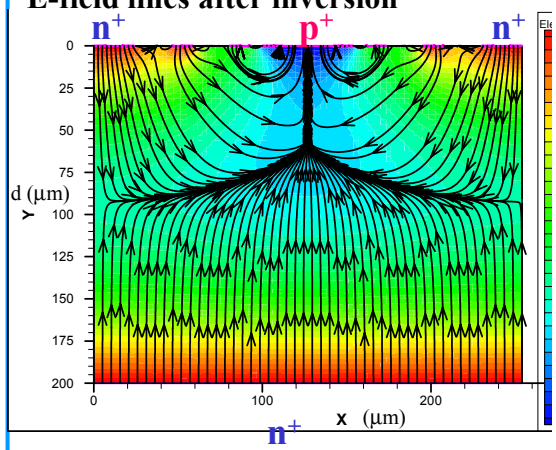


- **Large Roman pot strip detectors for RHIC PP2PP experiment**
- **Large stripixel detectors for PHENIX upgrade**

Radiation Hard Detectors

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

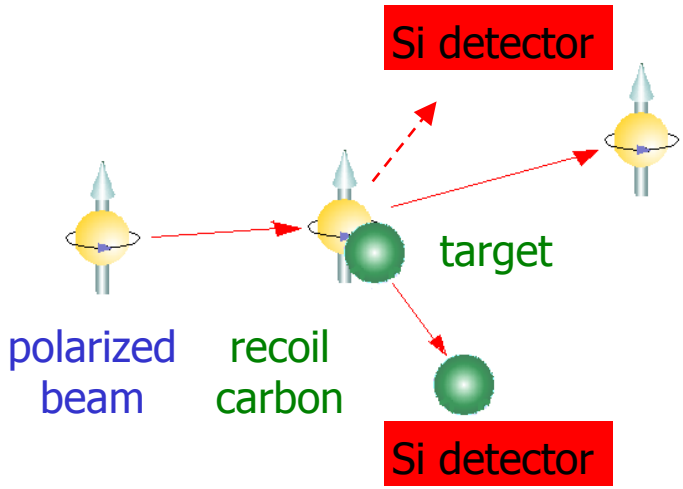
Simulation of potential profile and E-field lines after inversion

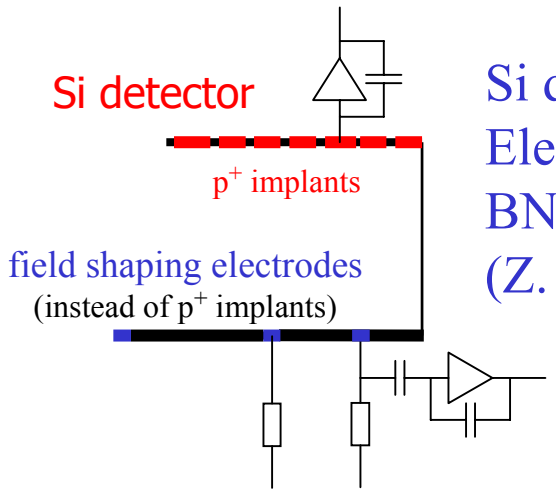


- **High resistivity CZ Si detectors**

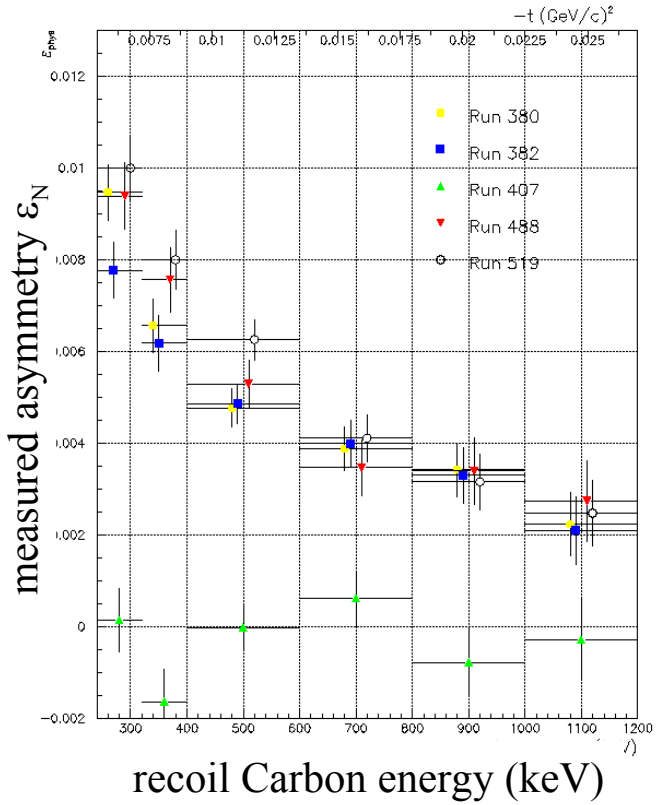
SPIN POLARIMETER for RHIC and AGS

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.





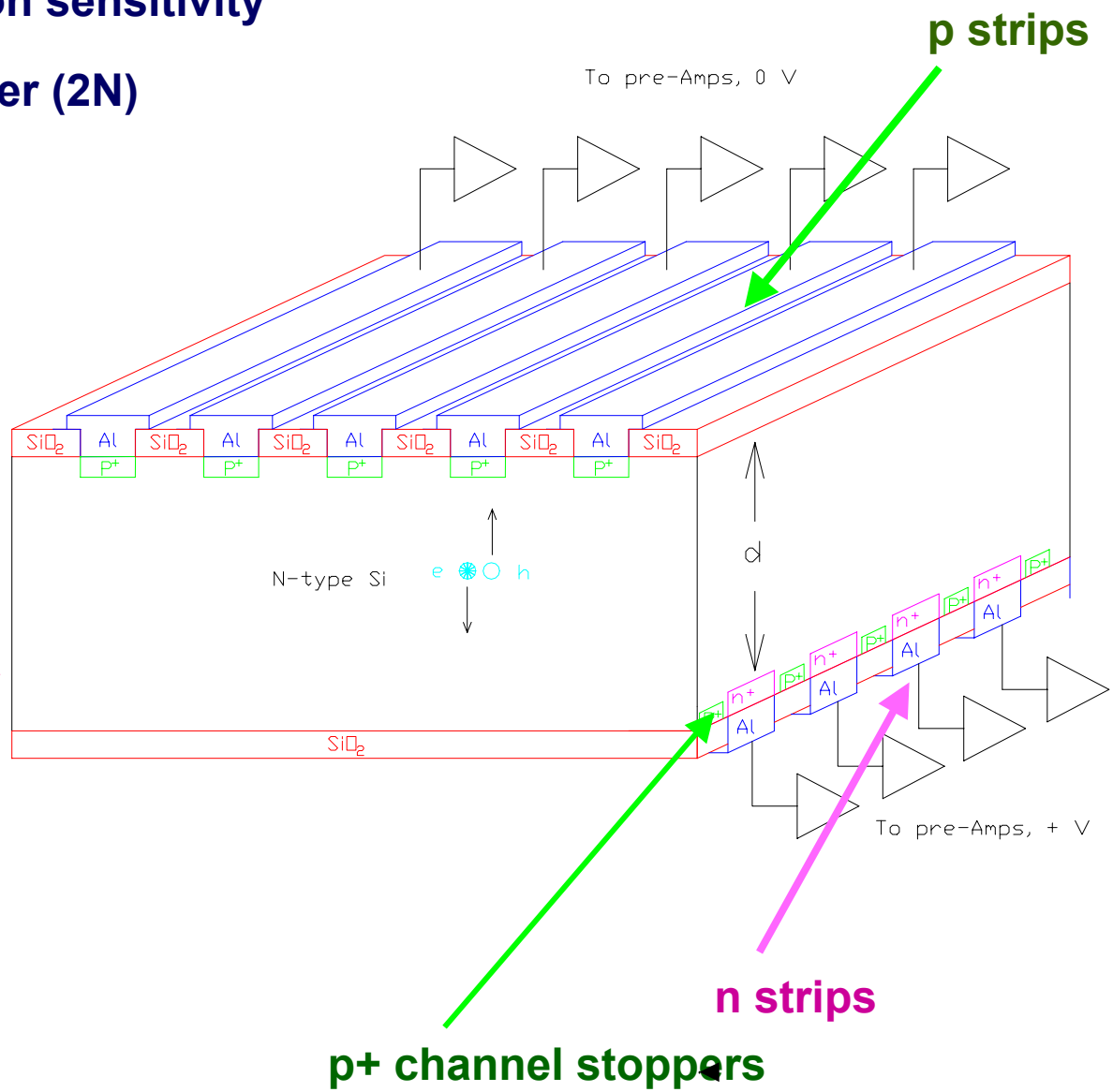
Si detectors and Front End Electronics Developed at BNL Instrumentation Division (Z. Li & S. Rescia)



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:

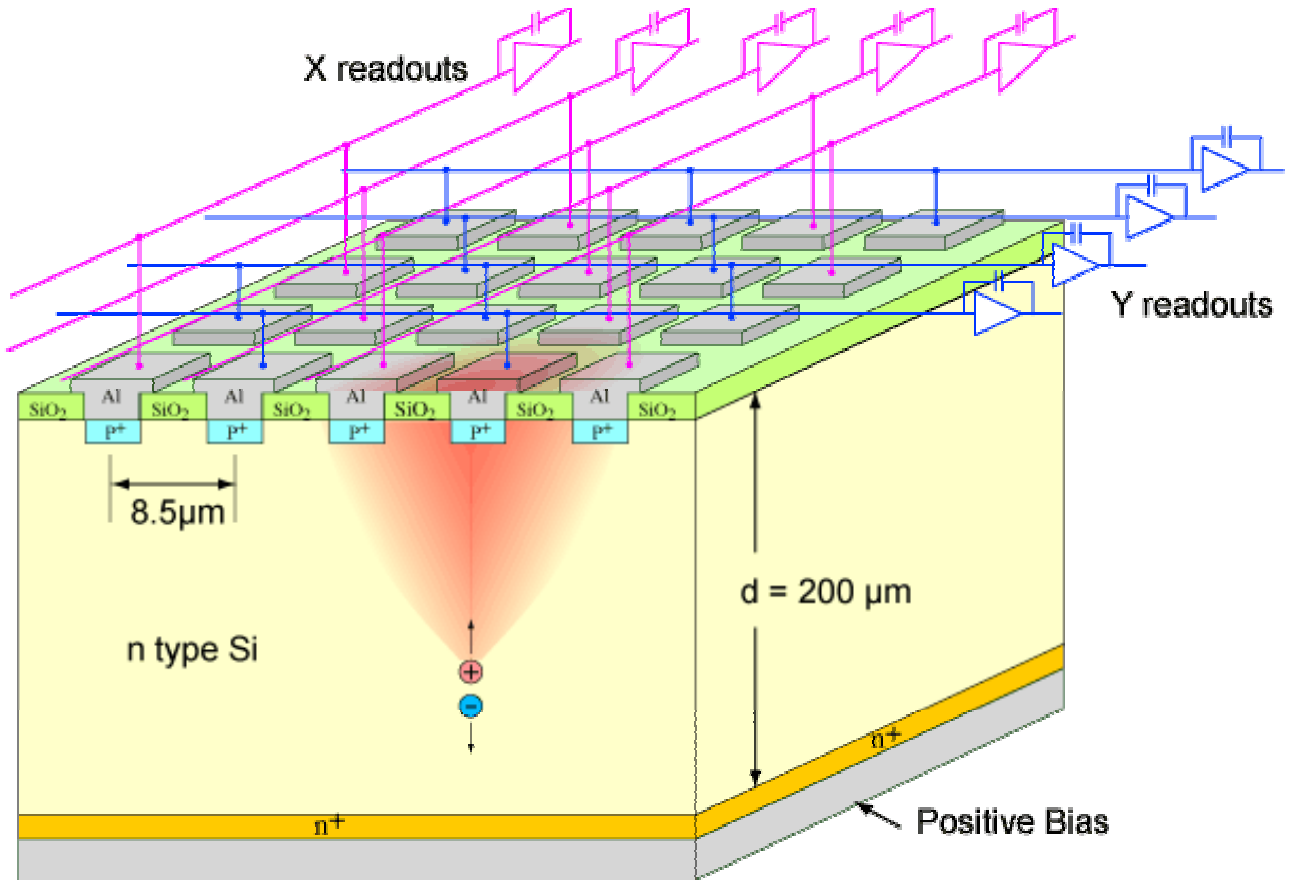
- ***Two-sided process about 3-4 times more complicated/expensive than single-sided process***
- **Radiation soft due to the the complicated structure on the n-side**
- **Two polarities of readout electronics**

The new concept:

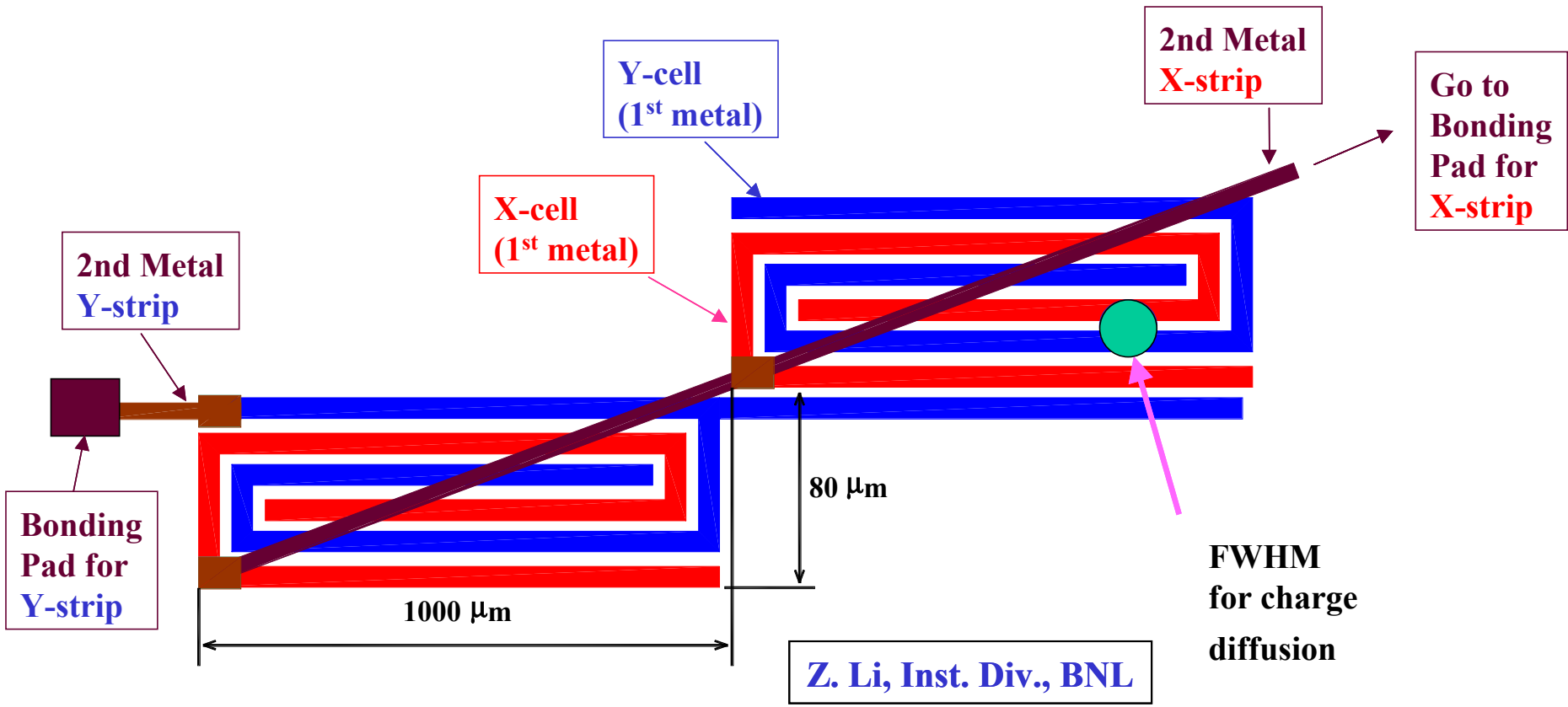
Alternating stripixel detectors (ASD)

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

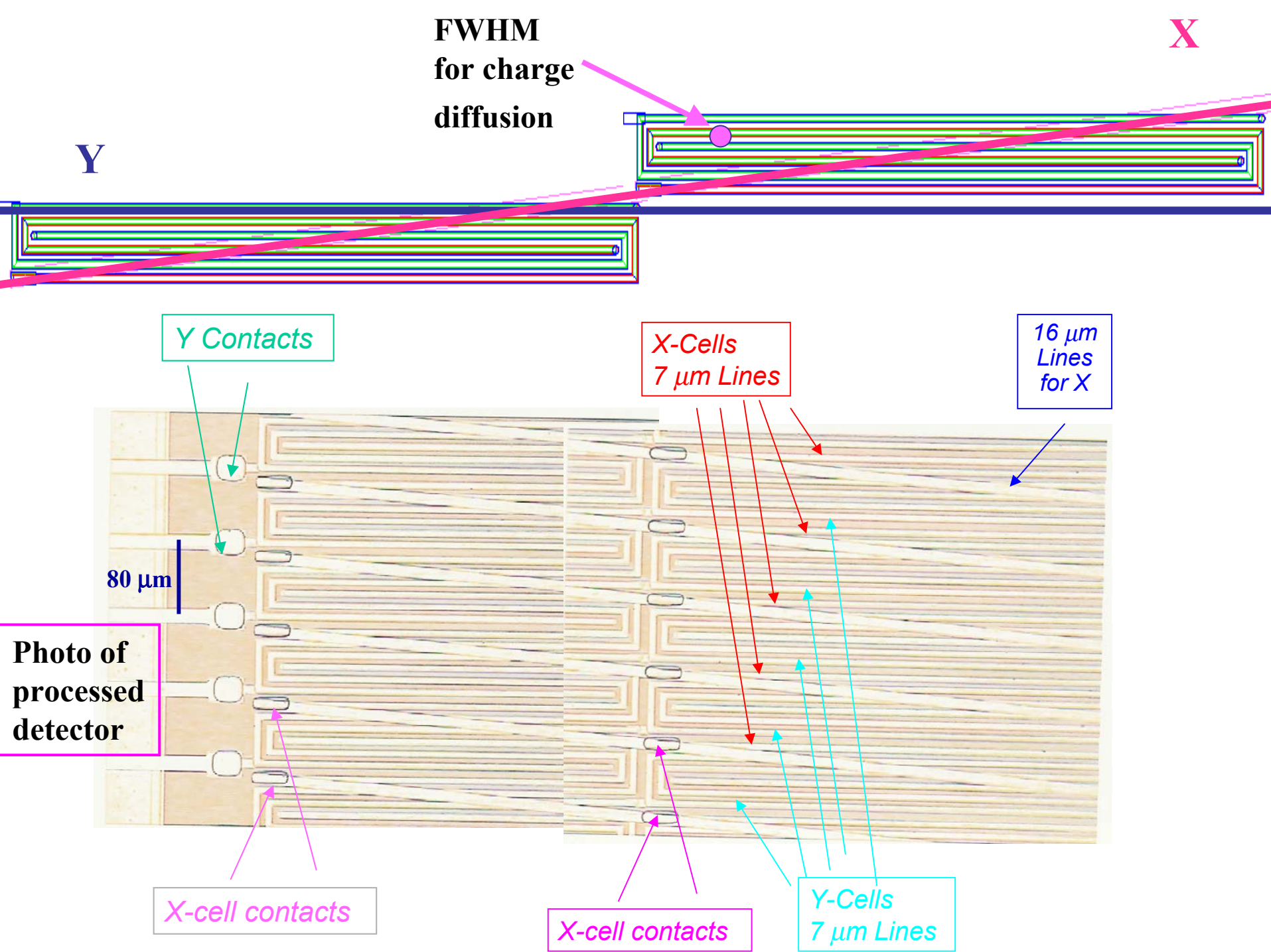


Pixel pitches: 1000 μm in X, and 80 μm in Y

Pixel arrays: 30x384

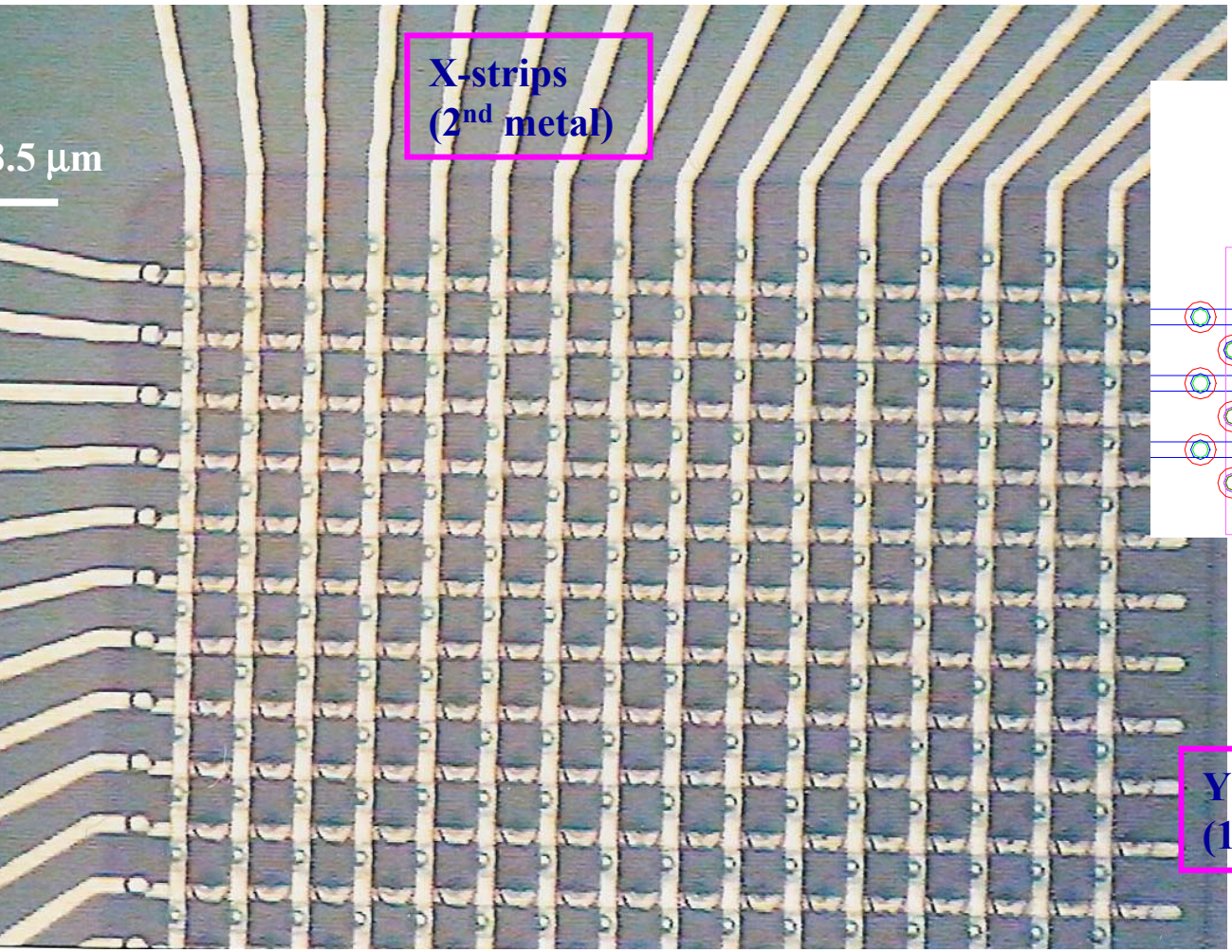
4.6° stereo angle between X and Y strips

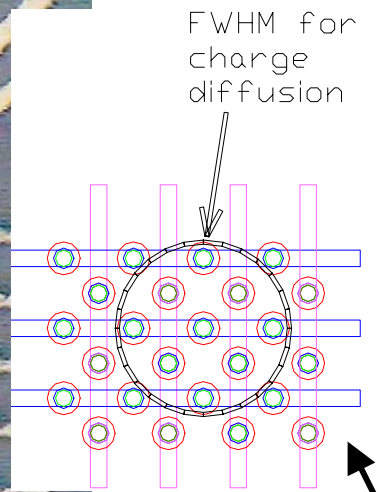
σ_y = ~25 μm


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





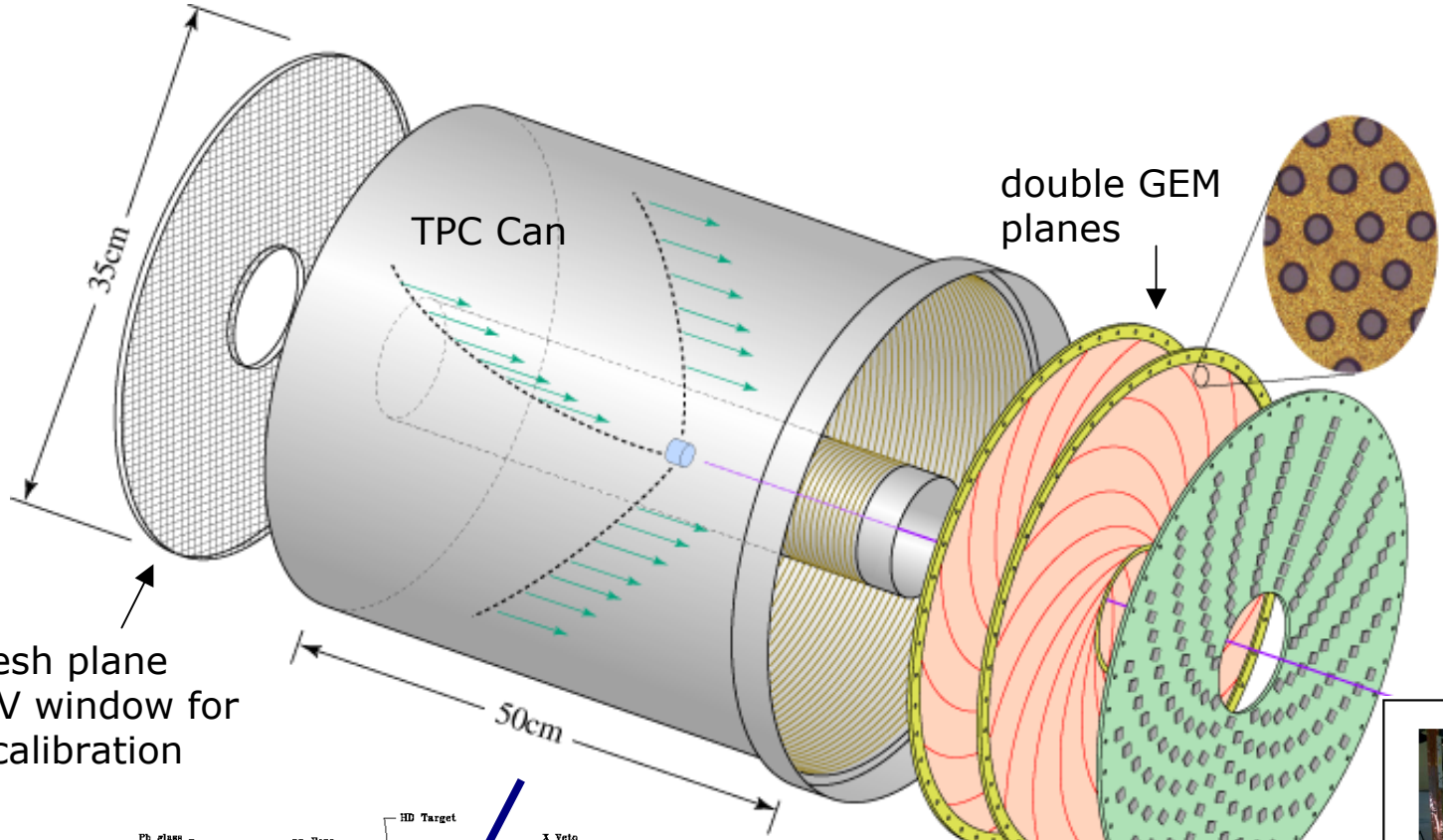
4 um dia circle
8.485 um pitch
2 um lines

Design and illustration of diffused charge cloud

Y-strips (1st metal)

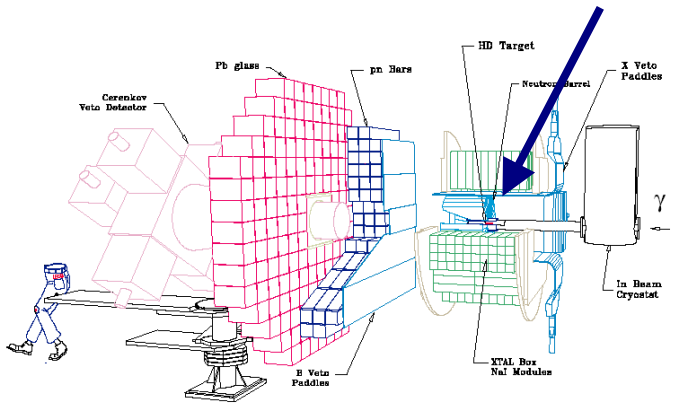
Photo of processed detector

Laser Electron Gamma Source : Time Projection Chamber (TPC)

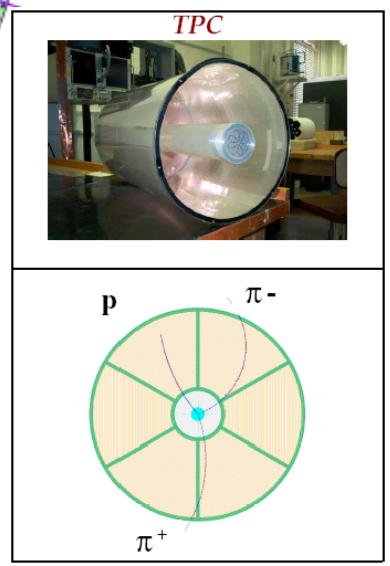


HV mesh plane
and UV window for
laser calibration

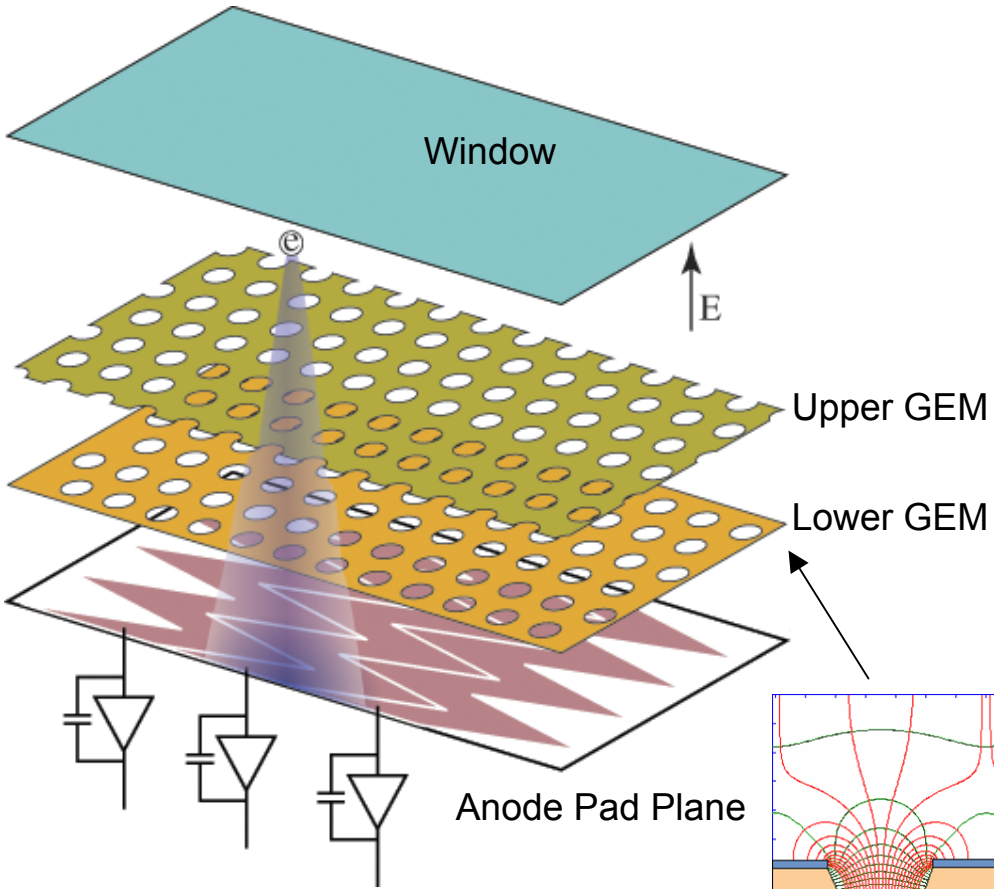
anode pad plane with
front-end electronics

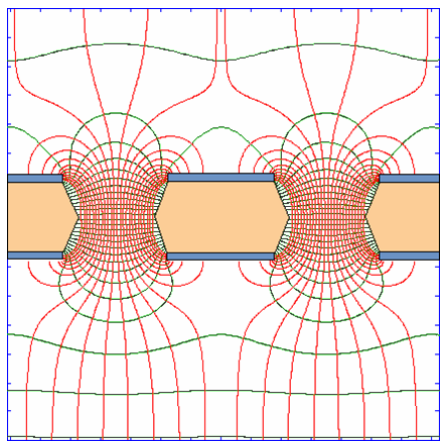


Spin **ASY**mmetry Array (SASY)

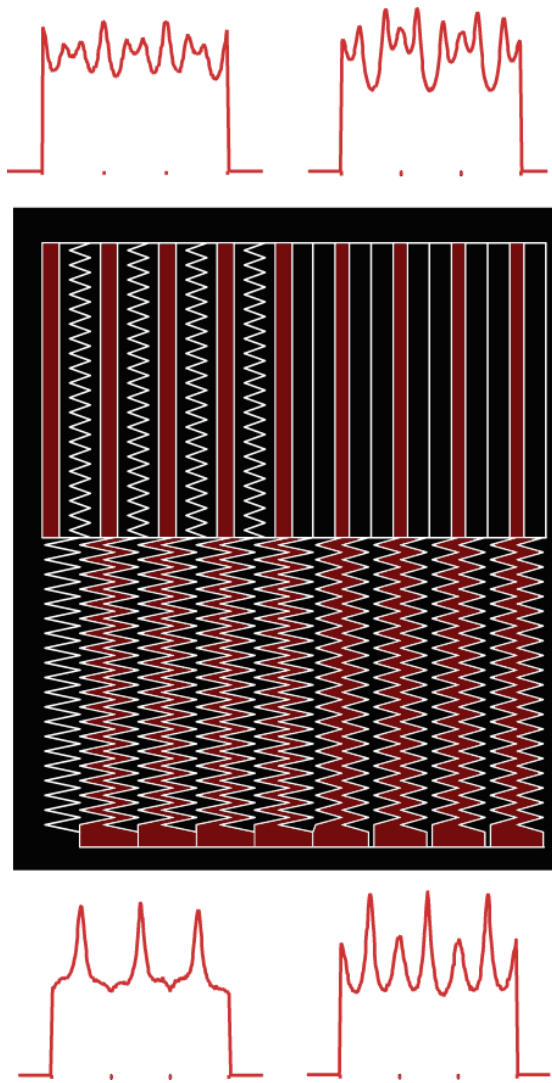


Interpolating Pad Readout for GEM (Gas Electron Multiplier)

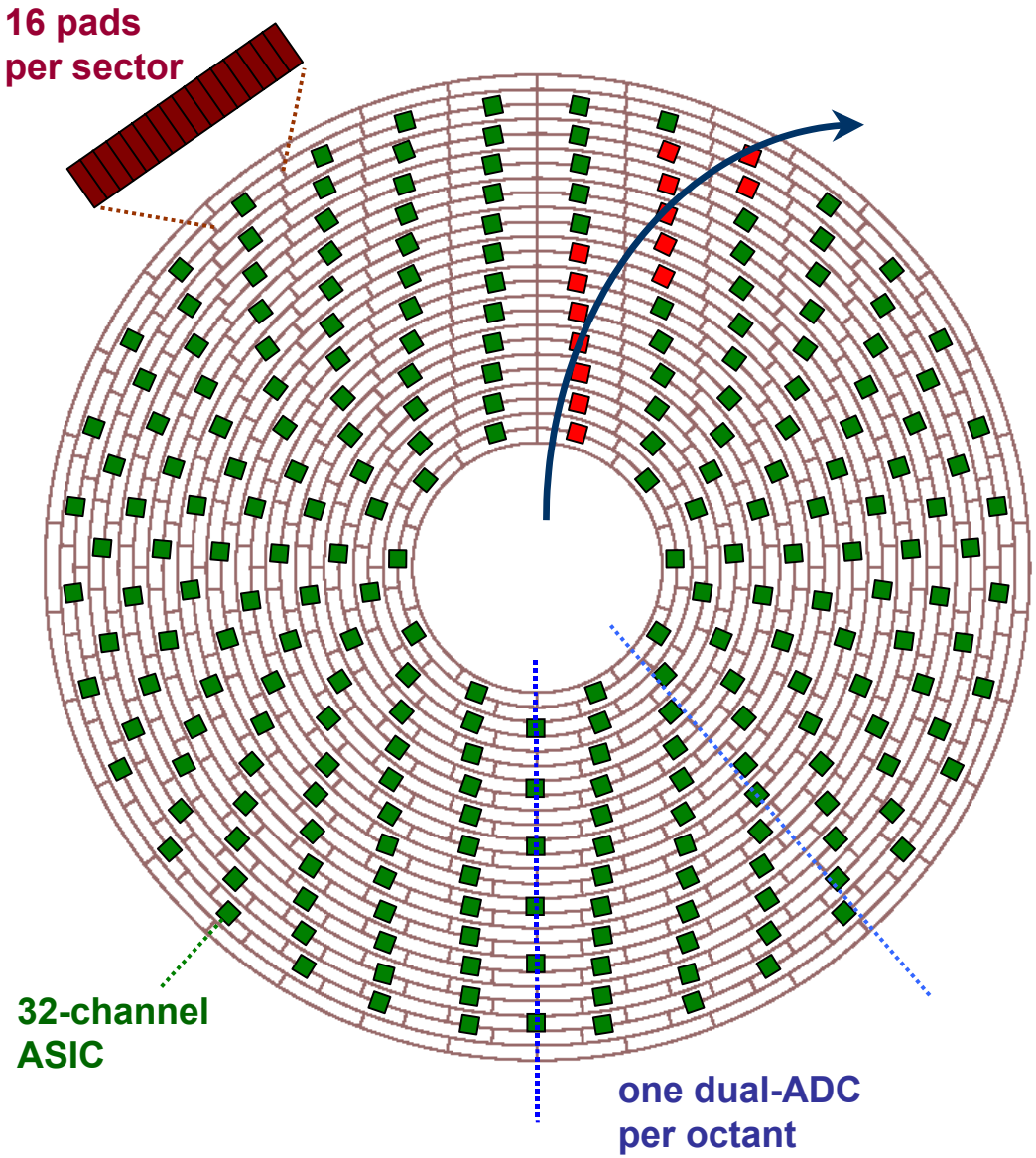




<100μm rms position resolution with 2mm pad pitch



Readout Electronics – Specifications



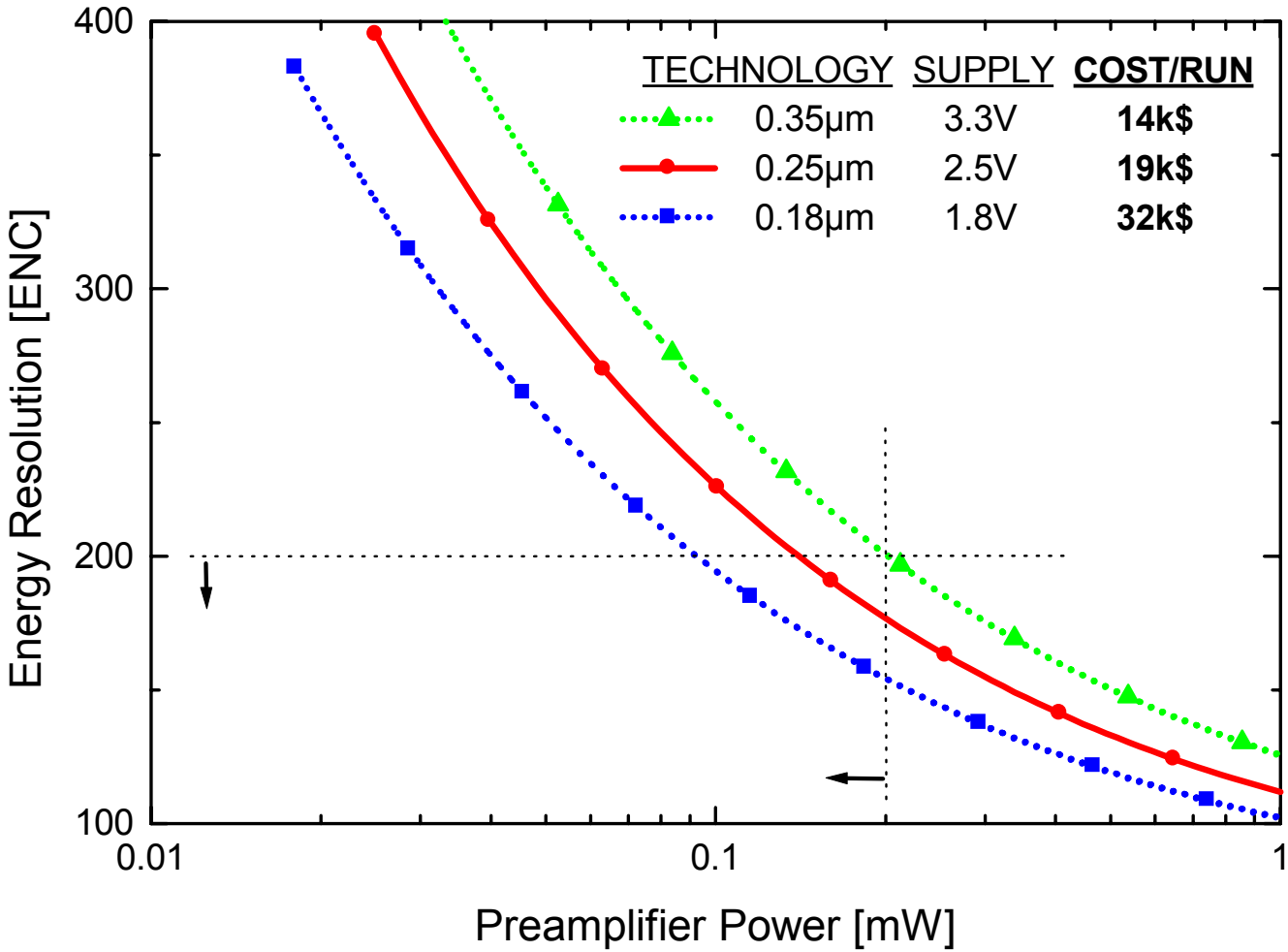
Tracking Measurement

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

Specifications

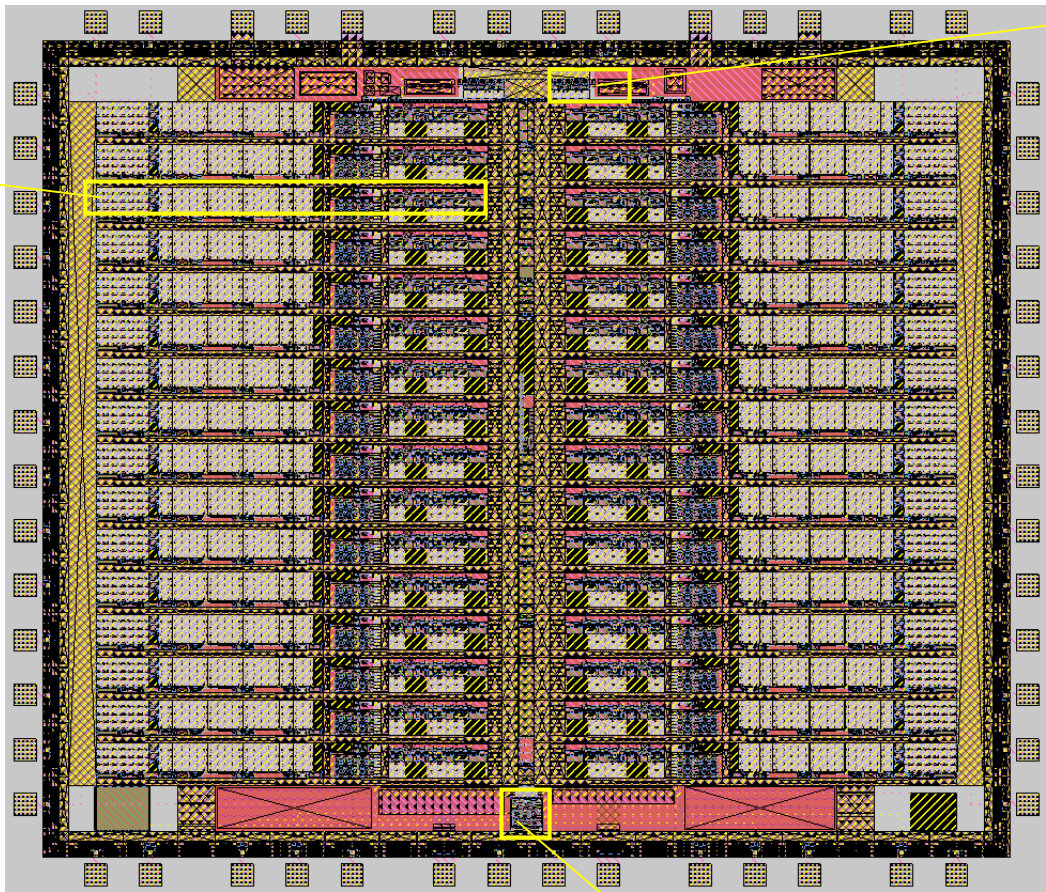
- ENC < 500 e^- rms
- Timing < 20ns
- Preamplifier/shaper/BLH
- Peak-detector
- Timing-detector (TAC)
- On-chip buffers
- Neighbor channel/chip enable
- Adjustable gain ≈ 17-32 mV/fC
- Channel masking
- Calibration
- Token/flag readout

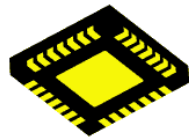
Front-End Electronics – Preamplifier Power



- **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

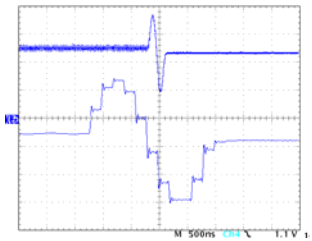


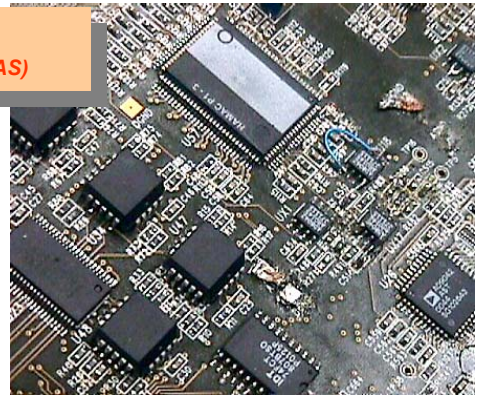


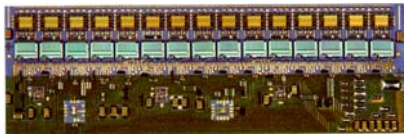
- 32 channels
- 3.1 x 3.6 mm²
- 47k MOSFETs
- 43mW

High energy and nuclear physics

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

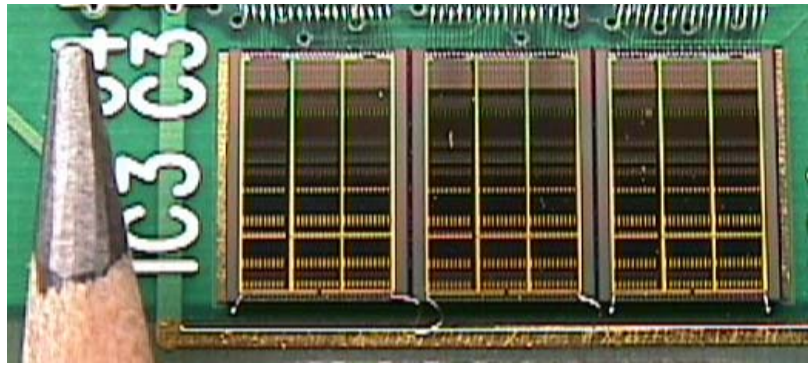






240-channel multichip module for Si drift detector readout *(STAR)*

Condensed matter physics



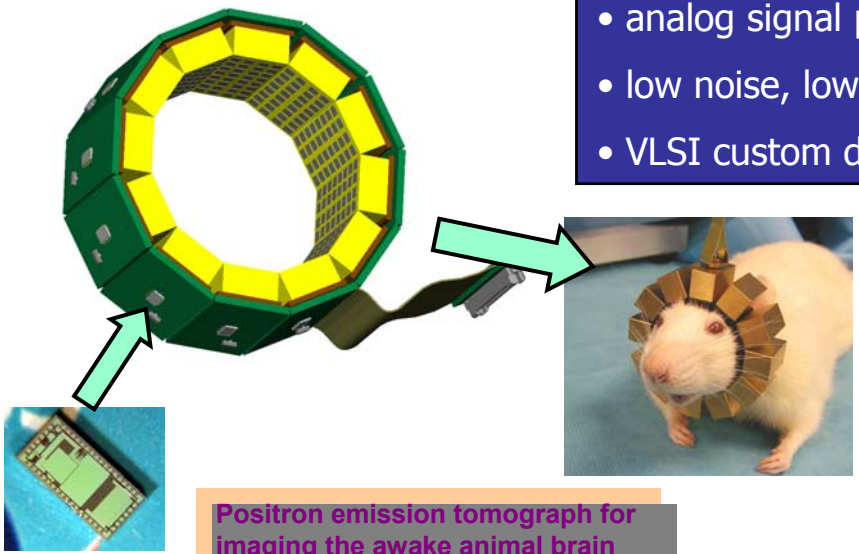
Photon-counting ASIC for EXAFS *(NSLS)*

Microelectronics Group

AREAS OF EXPERTISE

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

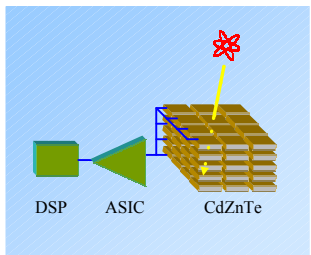
Life Sciences

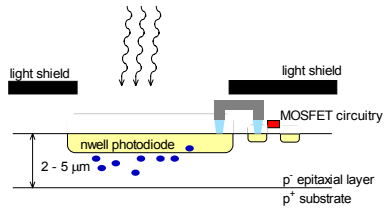


Positron emission tomograph for imaging the awake animal brain

Industry collaboration and national security

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

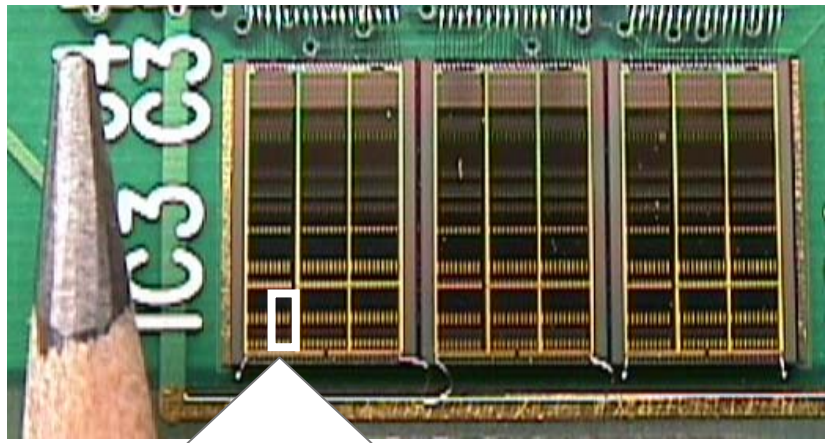


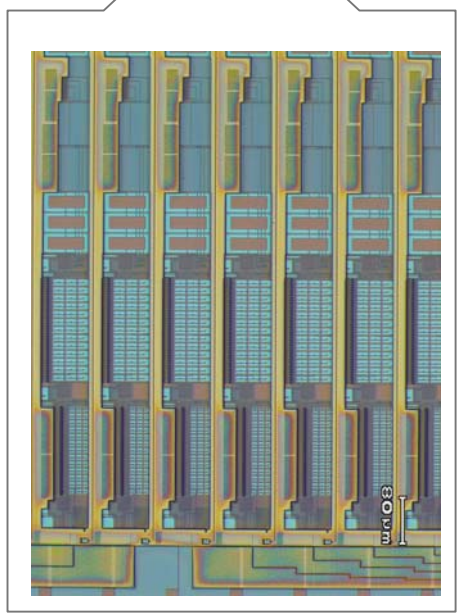


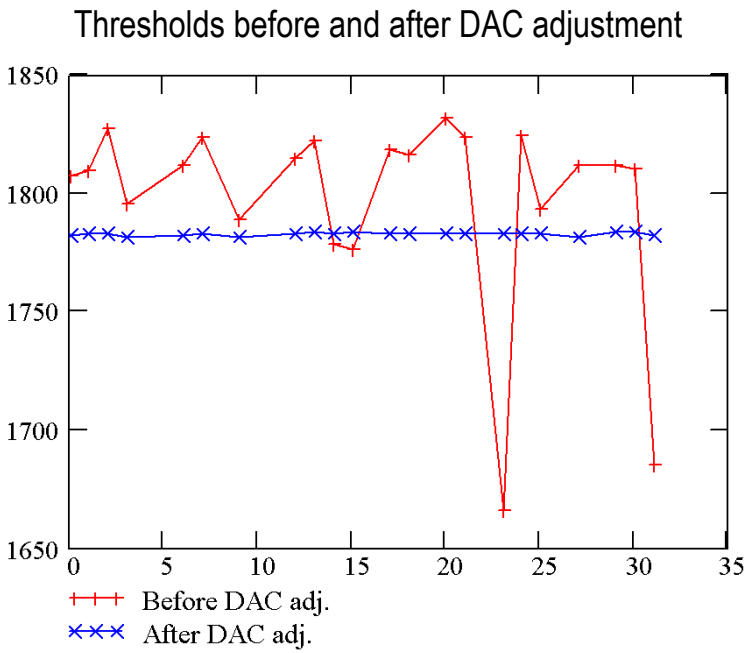
Proposed gamma spectrometer for detection of nuclear materials

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





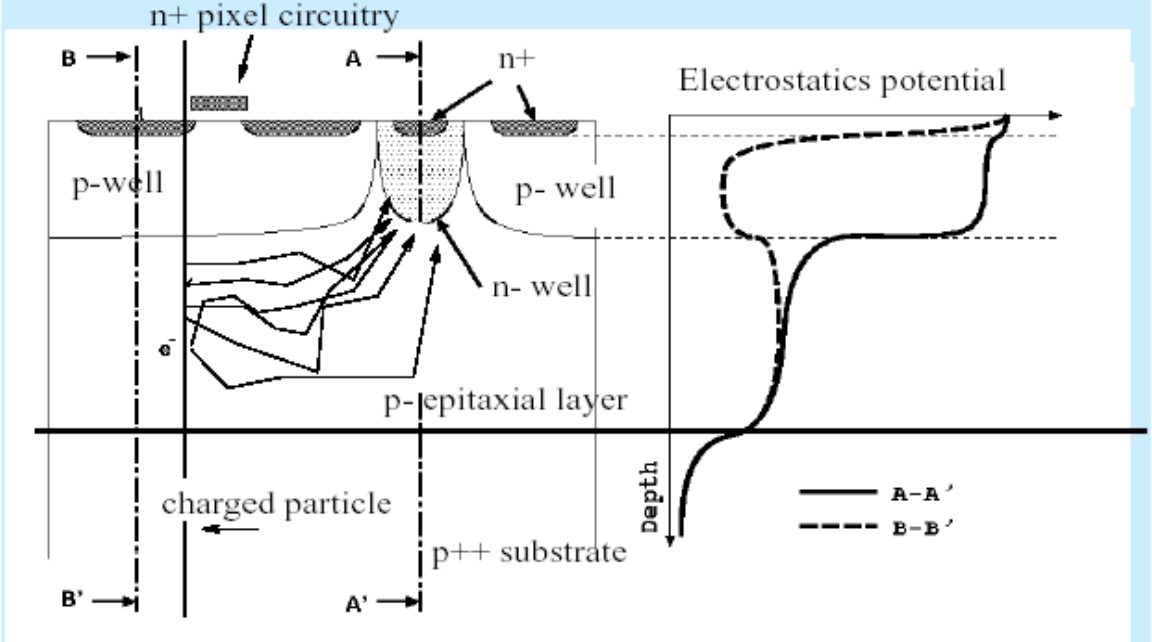


CMOS as Direct Conversion Megapixel Detectors (10-20 μm pixels)

Epitaxial layer ~5-15 μm

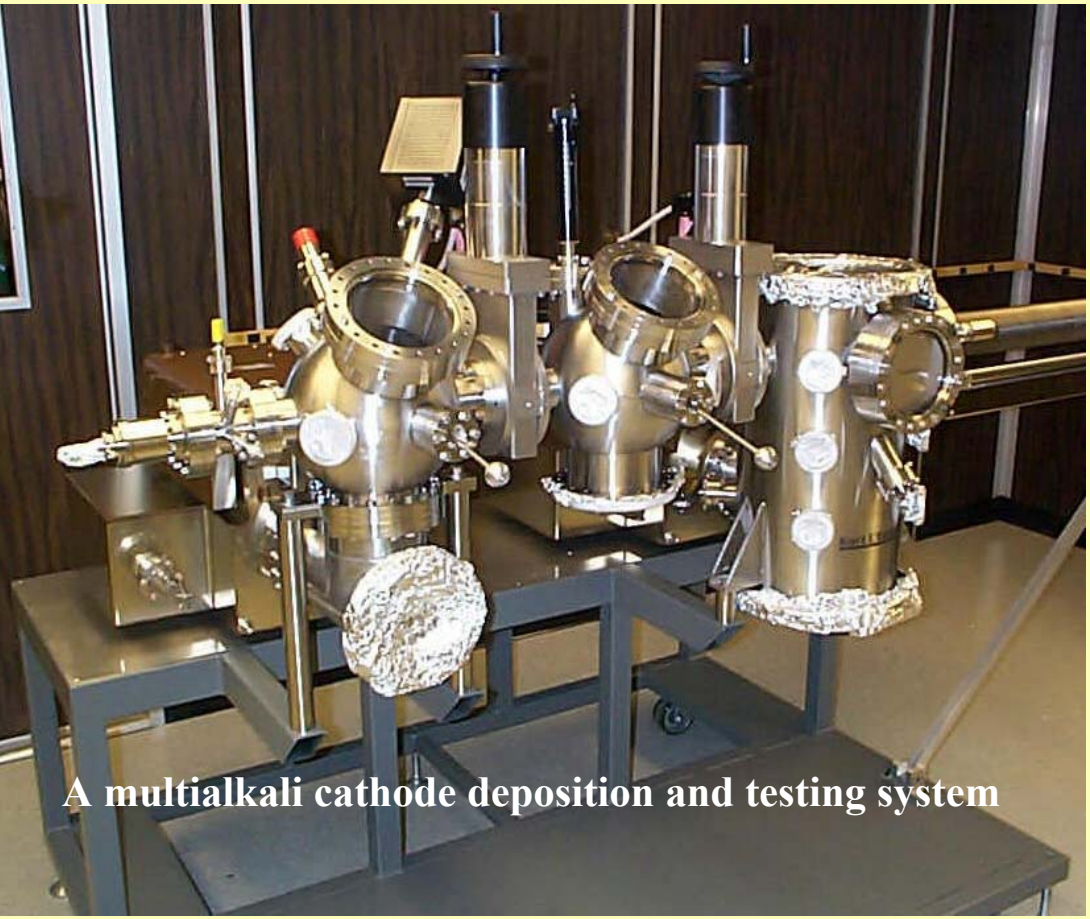
Min. ion. particles ~80 e/μm

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.).