Instrumentation Division Report

Veljko Radeka

Presentation to the DOE HEP Program Review

- APRIL 27-28, 2005

Outline

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

1. **Silicon Detectors**
2. **Gas and Liquid Detectors**
3. **Microelectronics**
4. **Integrated Detectors/Electronics**
5. **LSST**
6. **Lasers and Optics**
7. **Micro/nano fabrication**

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 quantities of such instrumentation 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:

48 Total
28 Scientists & Professionals
20, (16+4) Technical & Administrative

Publications in FY 02/03

All Programs: 37

Program 05-09

In support of vital BNL programs:

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

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

  -*EXAFS at high photon rates*

  -*X-ray Microscopy*

  -*Protein crystallography*

  -*TEAM*
- LSST
- New small animal PETs, MRI
- Neutron detectors for SNS
- 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

HEP Activities

Projects/Experiments:

- ***LHC**, with Physics Dept.*
  - **ATLAS liquid argon calorimeter**: responsible for ***signal integrity, coherent noise, Faraday cage design from the electrodes → feedthroughs → readout crates;***
  - **ATLAS Cathode Strip Chambers and low noise electronics for muon detection**;
- RSVP: KOPIO, MECO - Si-drift photo diode for calorimeter; low noise electronics; FPGAs in waveform recording and trigger;

R&D for Future Facilities (LHC Lum. upgrade, LC) and programs:

- ***Si-detector technology*** (the only facility for U.S. HEP program):
  - ***single-sided 2-d strip detectors; radiation hardness techniques***
- ***Microelectronics***, low noise,submicron-to-nanoscale;
- ***Picosec/femtosec beam diagnostics and e- sources*** for future accelerators.
- ***LSST***
- ***Neutrino Detectors***, new concepts;

1. Silicon Detectors

Alternating stripixel detectors (ASD)

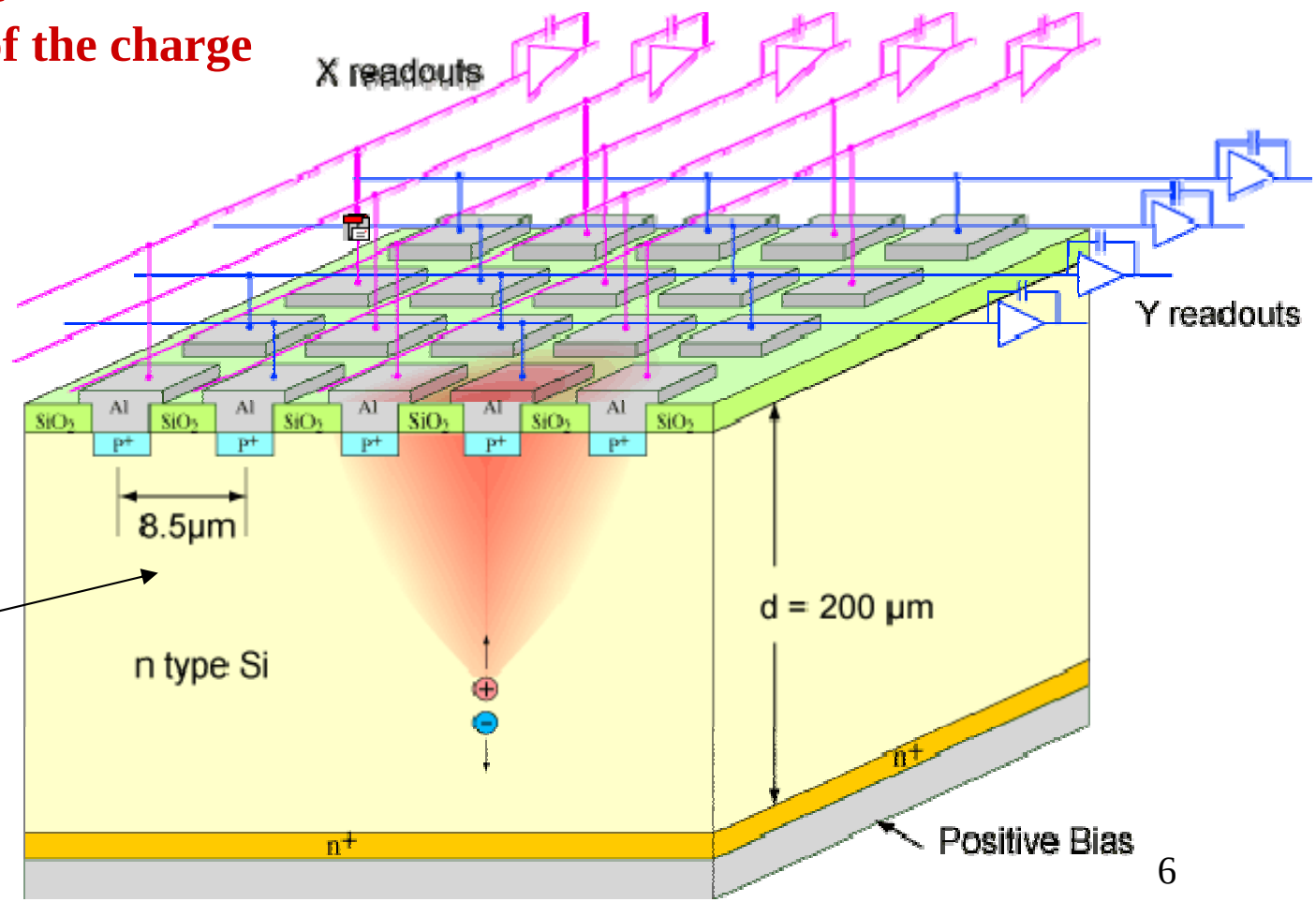
Individual pixels are alternately connected by X and Y readout lines (strips)

- **Two dimensional position sensitivity is achieved by charge sharing between X and Y pixels**
- **The pixel pitch must not be larger than the size of the charge cloud due to diffusion**

Interpolating readout:

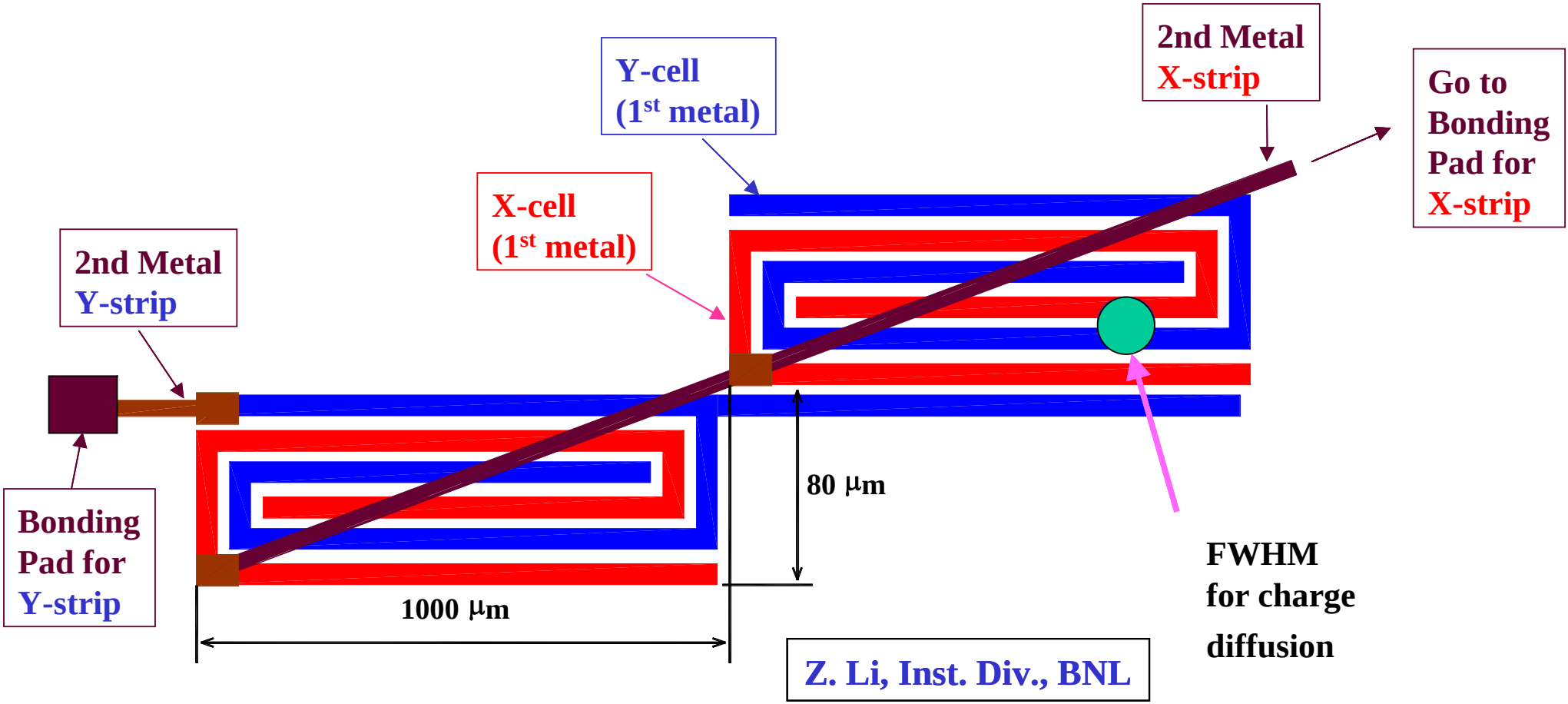
$$\frac{\sigma_x}{w} \approx \frac{2}{S/N}$$

Pixel pitch



Interpolation factor w/σ_x~10-100

Schematic of the Prototype Stripixel Detector
PHENIX Upgrade



Pixel pitch: 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

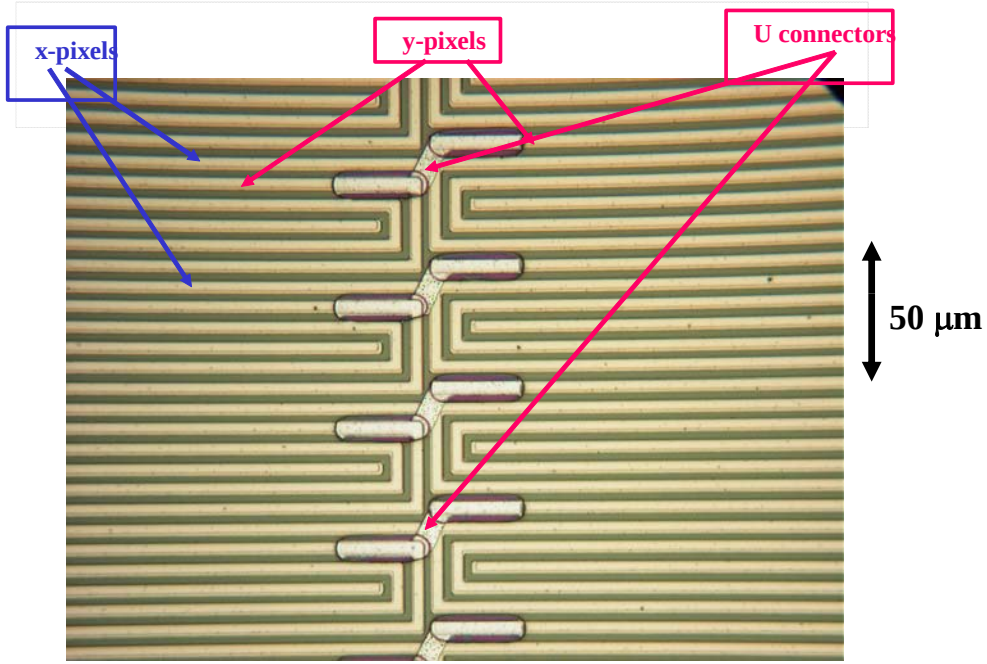
Novel prototype detectors:

- 2d stripixel detectors, planar 1-sided process

  - *US-ATLAS Upgrade (radiation hard up to 10^{15} n_{eq}/cm^2)*

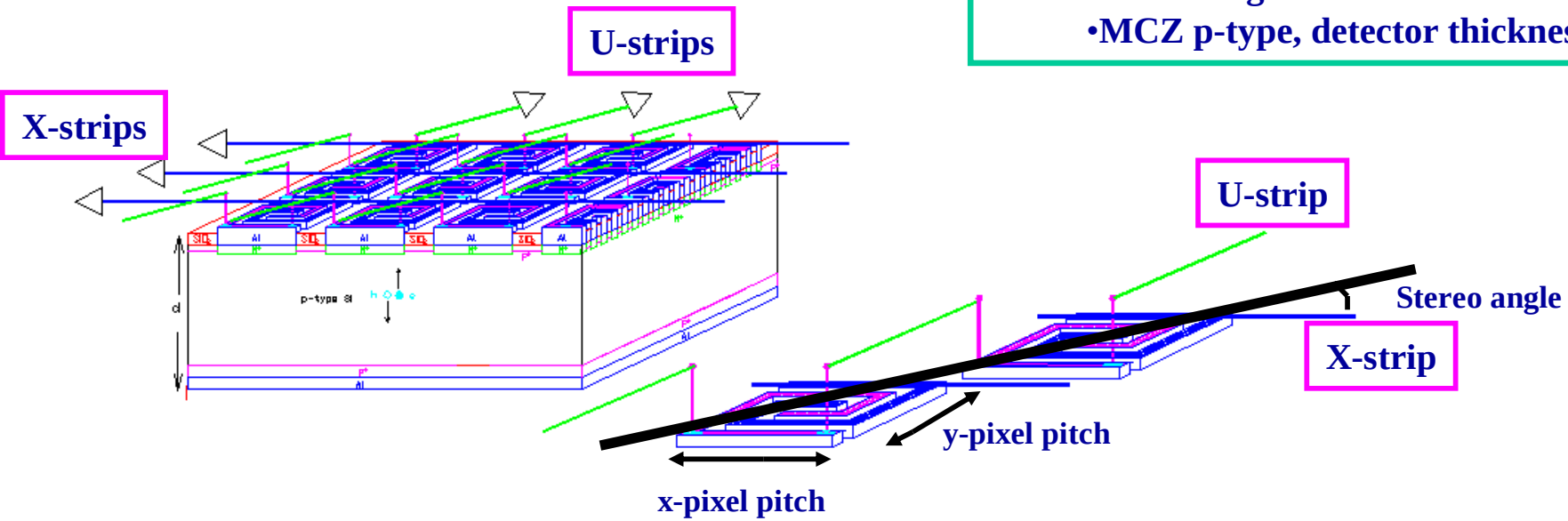
    - Combination of 3 new aspects:
      - ✓ 2d stripixel structure with short strips (3 cm)
      - ✓ P-type substrate (no inversion, higher CCE than n-type after radiation)
      - ✓ Magnetic Czochralski-Si (MCZ-Si) for added radiation hardness

      1st batch of prototypes completed at BNL



US-ATLAS Upgrade:

- Pixel pitch: 620 μm (X) and 50 μm (Y)
- Strip pitch: 50 μm (U) and 50 μm (X)
- Stereo angle between u and Y strips: 4.6 °
- MCZ p-type, detector thickness 200-300 μm



Novel Prototype Detectors for Radiation Hardness: Alternating *p* and *n* Strips

Charge collection between the strips *without involving* the back side.

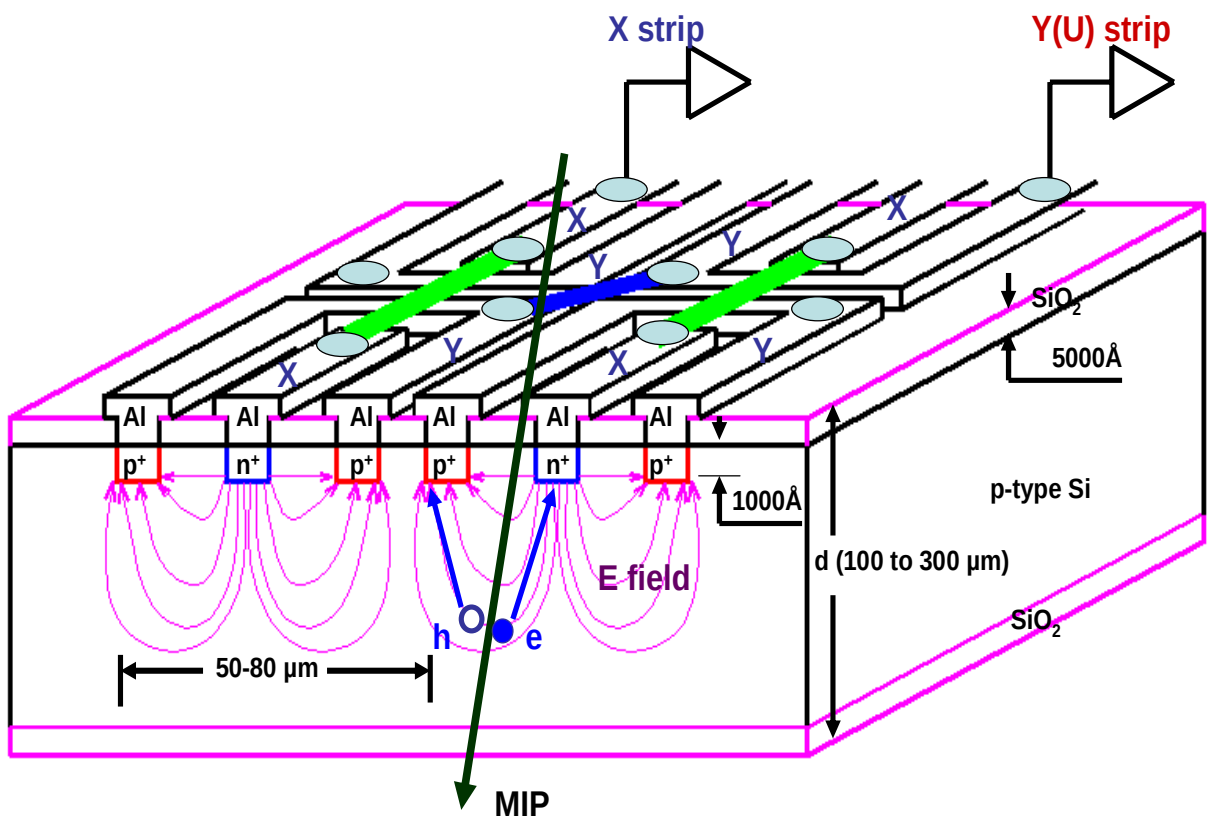
Reduced charge trapping after severe radiation damage compared to conventional detectors.

Low resistivity p-type Si, oxygenated, MCZ;

1. **2d readout without charge sharing (no added capacitance as with interleaved strips).**

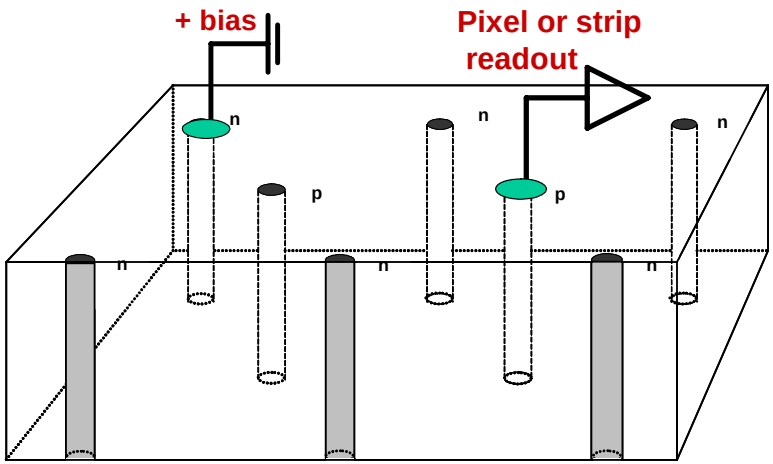
2. ***Planar single-sided,* single metal process.**

3. **No type inversion in p-type Si after irradiation**



Novel prototype detectors: 3d processing

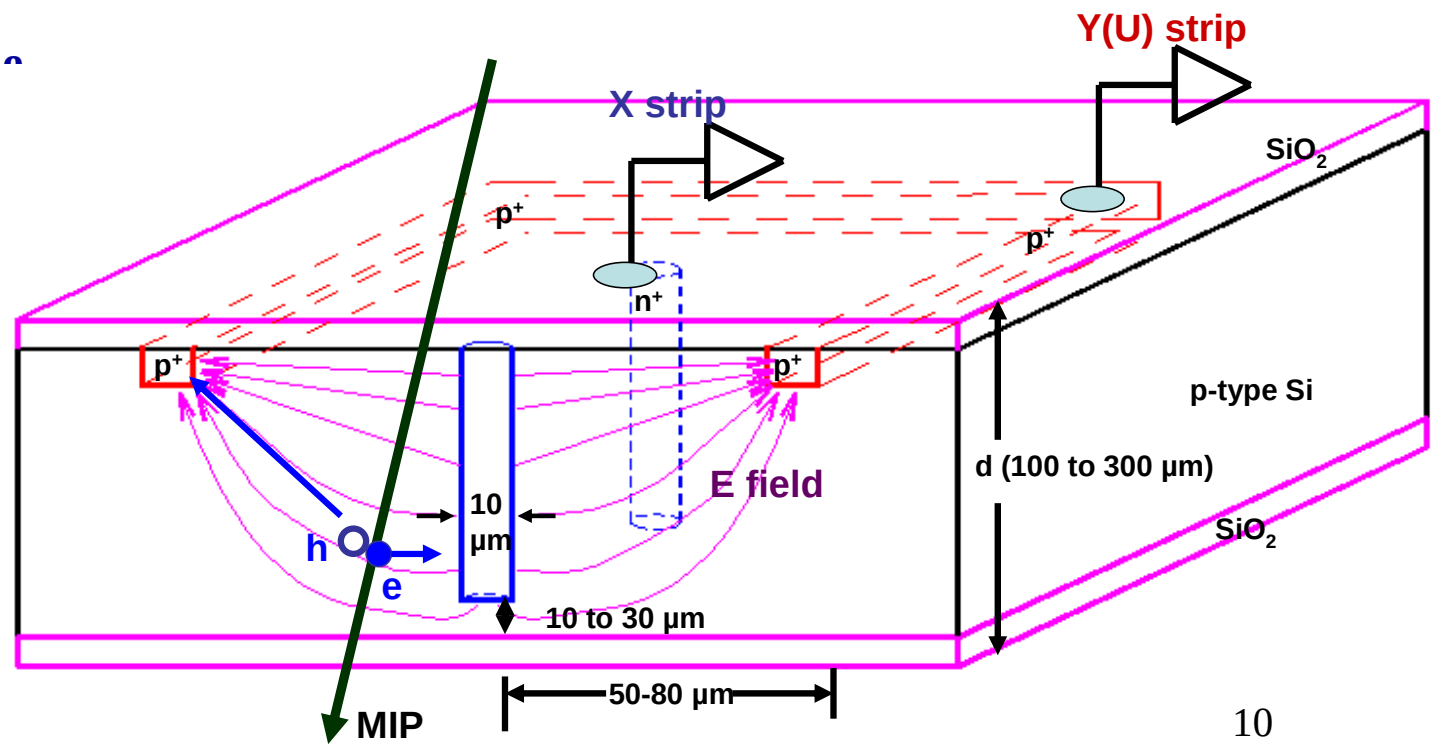
3d detector (S. Parker):



Sherwood I. Parker et al., UH 511-959-00

1. Planar+3d technology
2. No charge sharing problem
3. No added capacitance
4. Single-sided process (no processing on the back side)
5. 2d-position sensitivity
6. Single metal process possible
7. AC coupling on the wafer
8. No type inversion problem (p or n-type bulk)

2d in sensing,
3d in processing

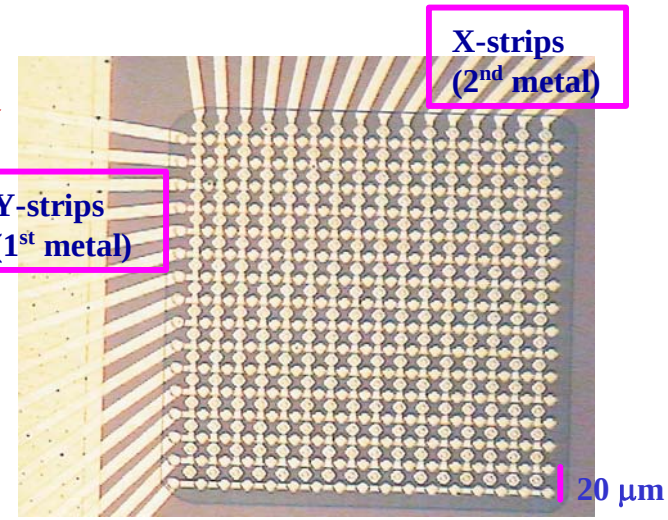


Si Detector Development and Processing in Instrumentation Div.

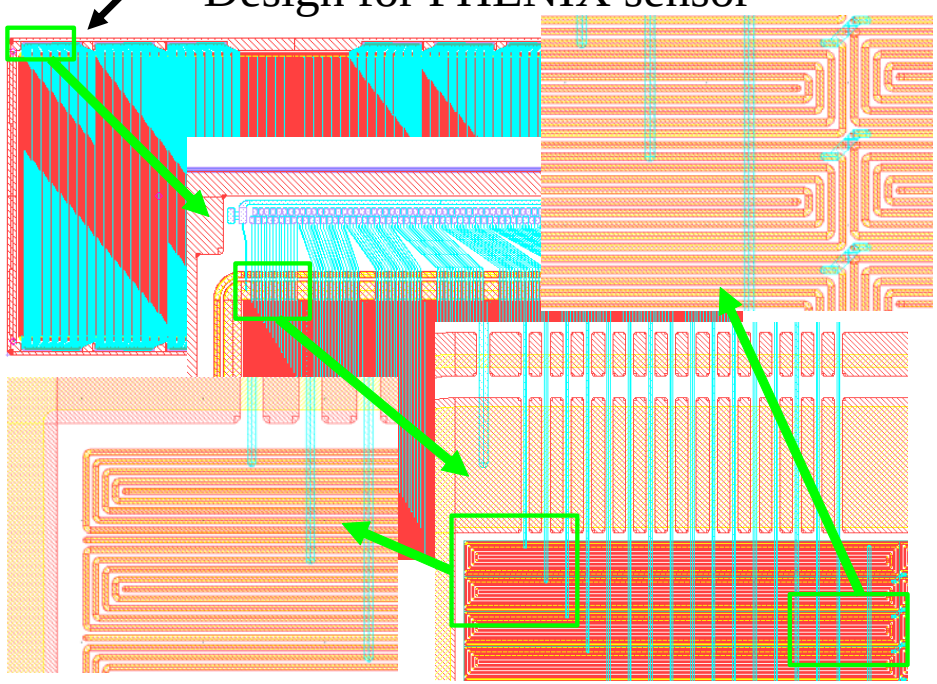
Novel 2d Stripixel detectors

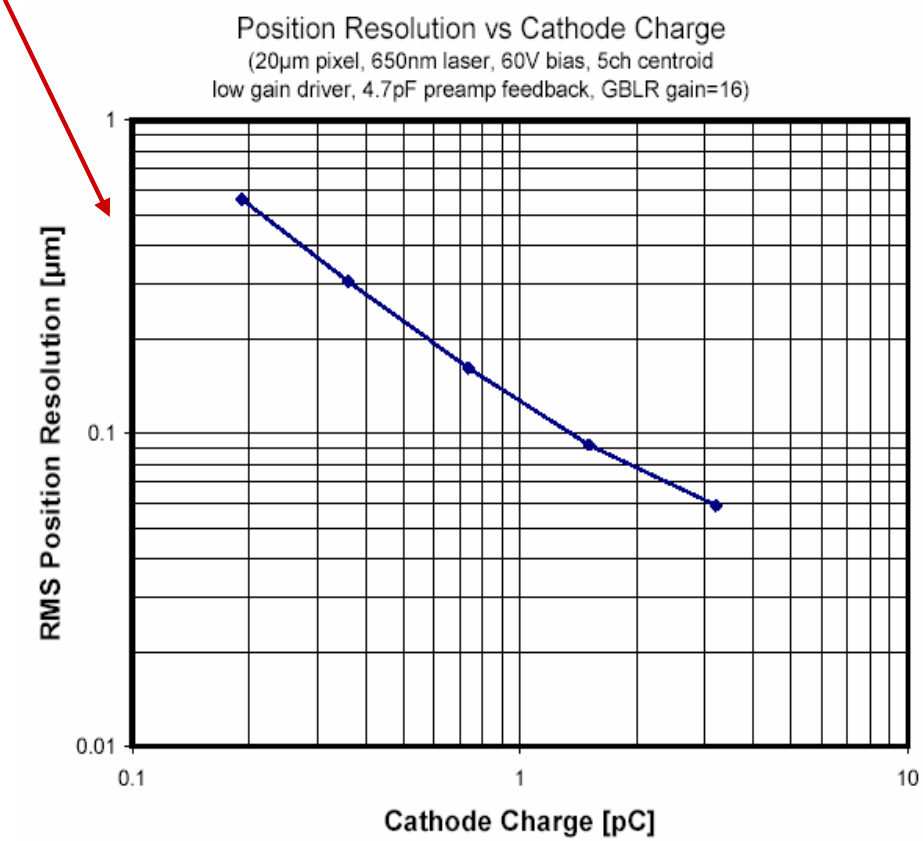
2d position sensing, 1-sided processing

- **NASA heavy ion microbeam project *(2d-submicron position resolution* obtained in laser and ion beam tests at BNL)**
- **PHENIX Upgrade**
  - o **25 μm position resolution in x and y obtained in beam teats on BNL-made prototypes)**
  - o **Technology transferred to industry: both SINTEF and Hamamatsu had pre-production test runs**
  - o **Hamamatsu also produced prototypes with side readout**



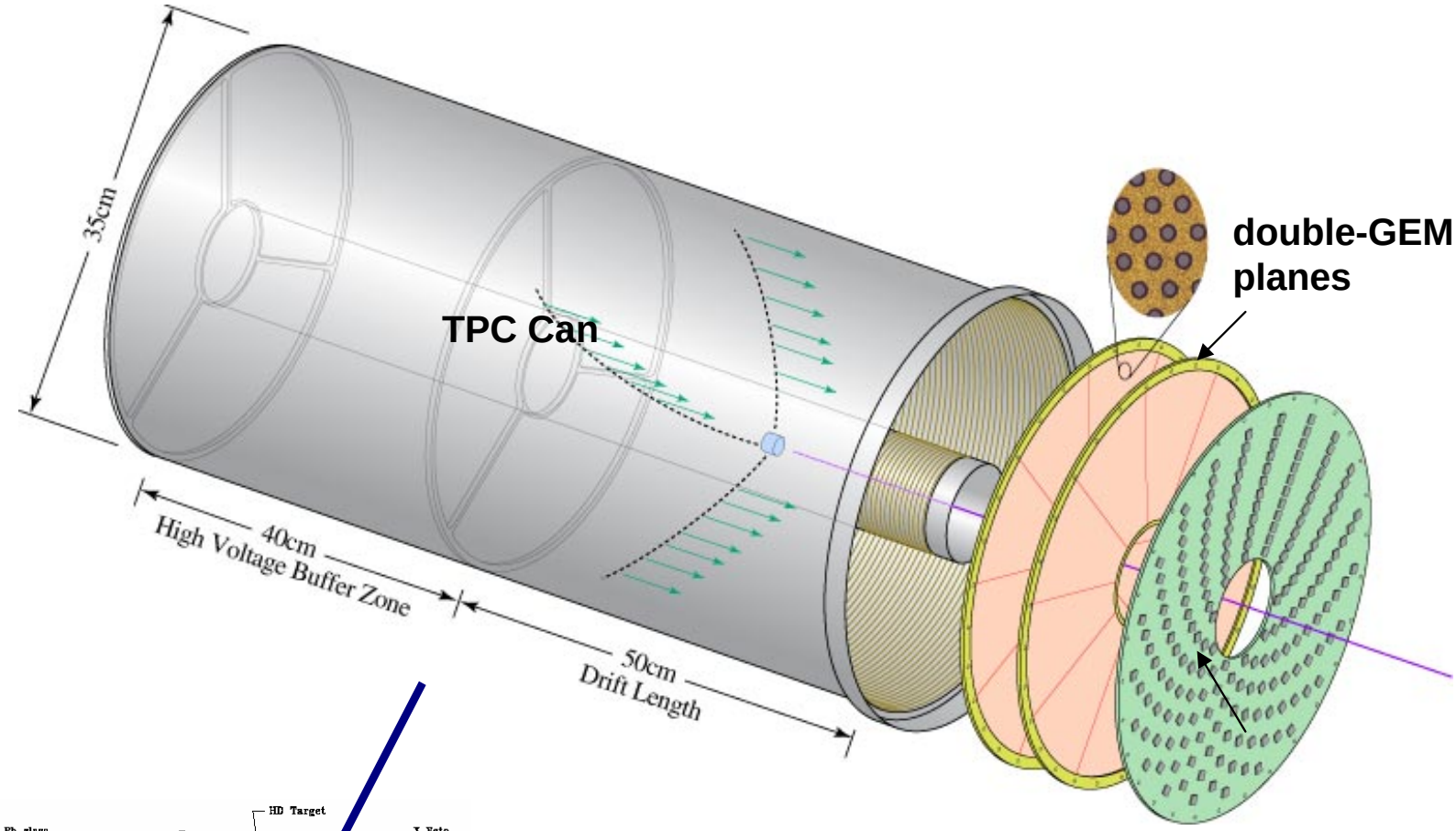
Design for PHENIX sensor

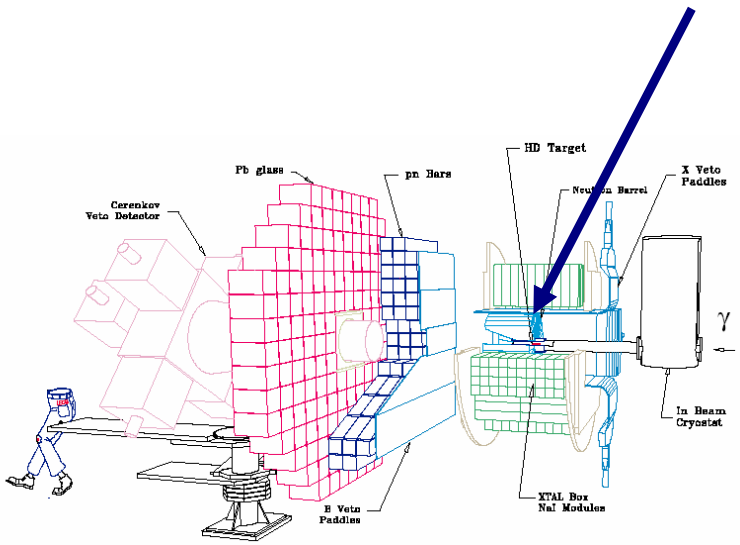




2. Gas and liquid detectors

Time Projection Chamber (TPC) for Laser Electron Gamma Source (LEGS)

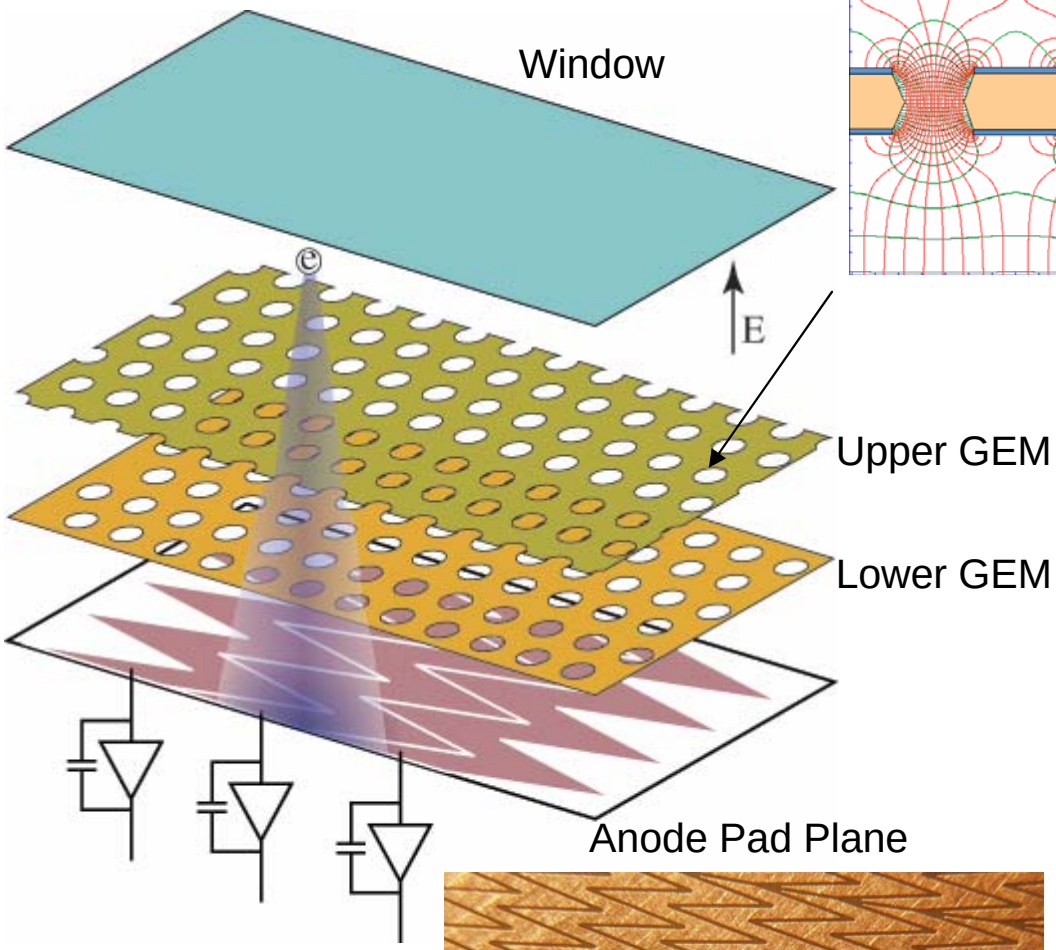


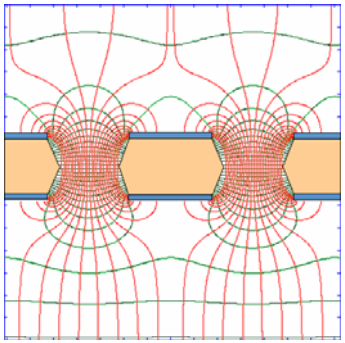


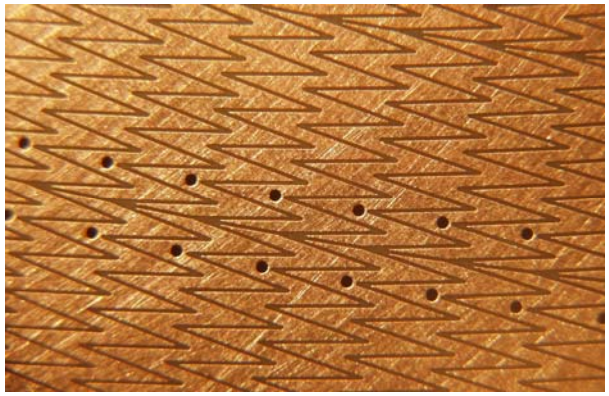
Spin ASYmmetry Array (SASY)

Fine granularity TPC technology of interest for: RHIC/PHENIX and Linear Collider

Interpolating Pad Readout for Gas Electron Multiplier (GEM)







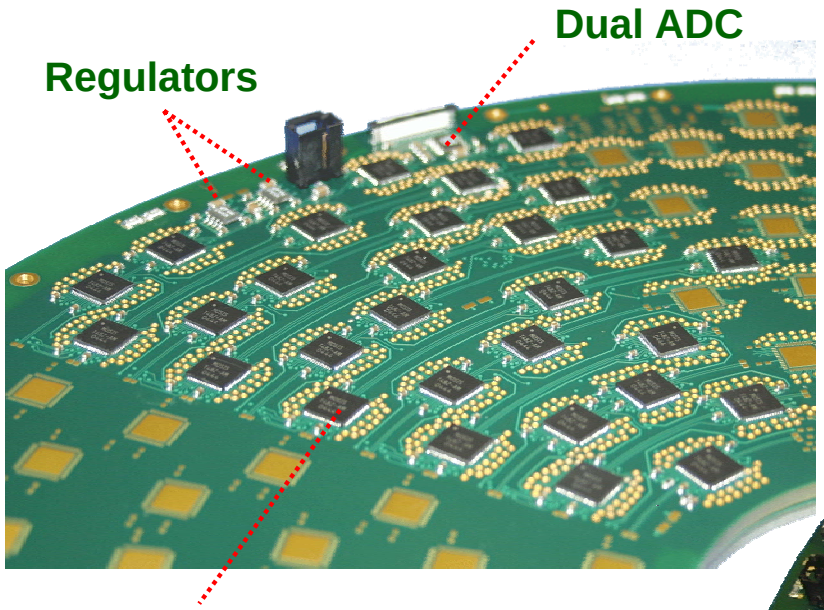
Mounted GEM Foil on Frames

Prototype TPC with 10cm drift depth

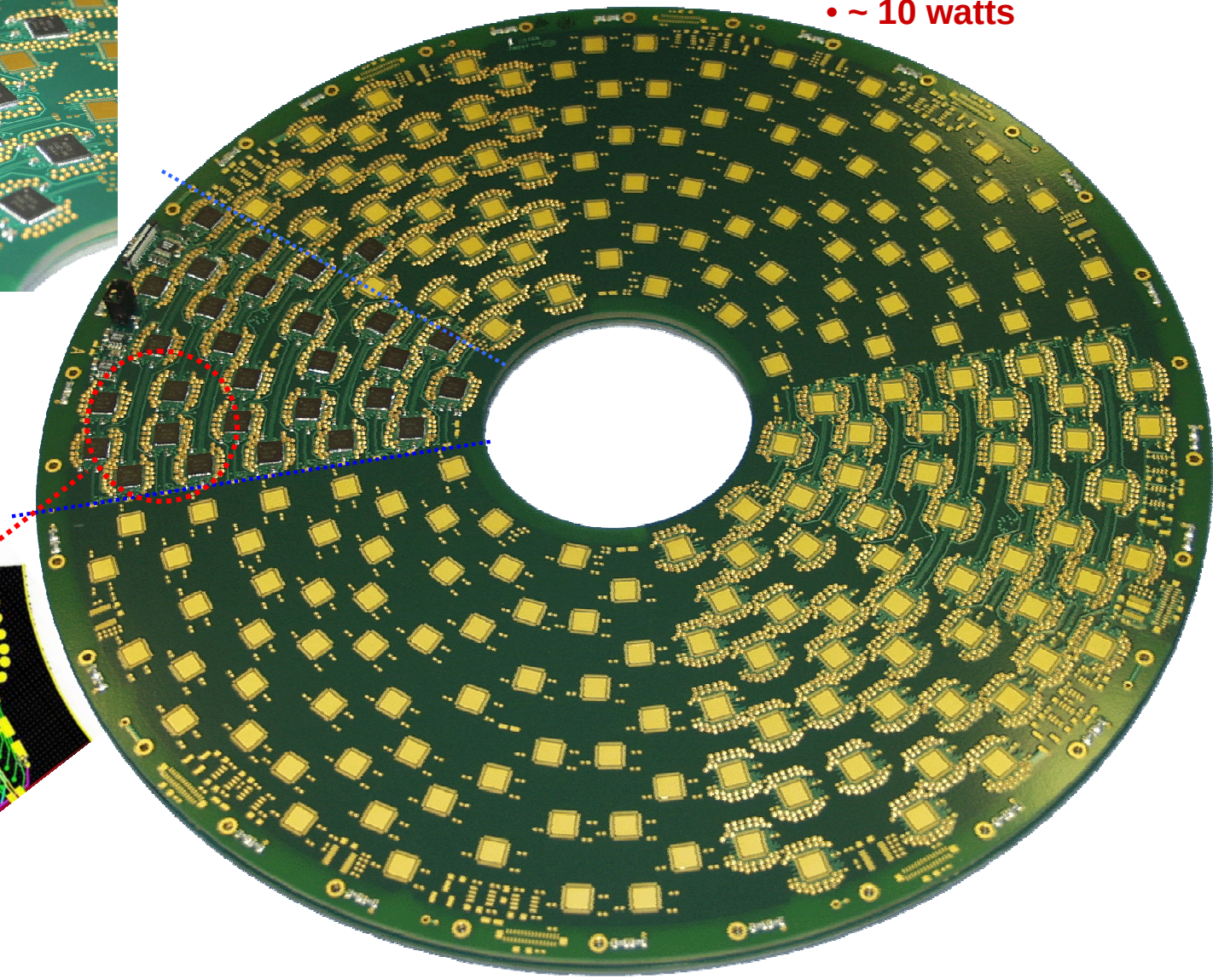
Readout Electronics (Back of Pad Plane)

Full Board

- 228 ASICs
- 7296 pads
- 1346 components
- ~ 4000 standard vias
- ~ 8000 *blind* vias
- ~ 8500 signal nets
- 11 layers
- ~ 10 watts

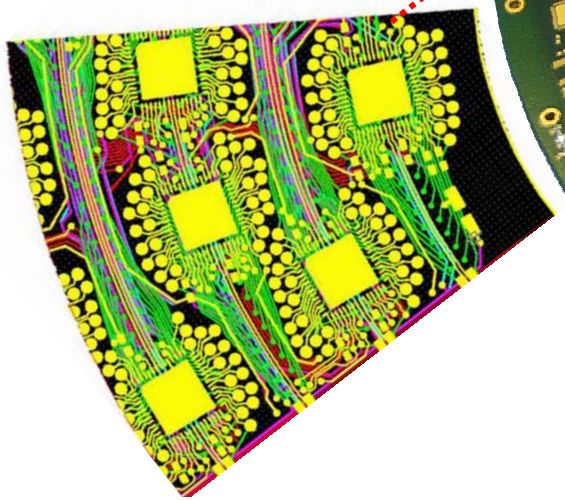


Octant



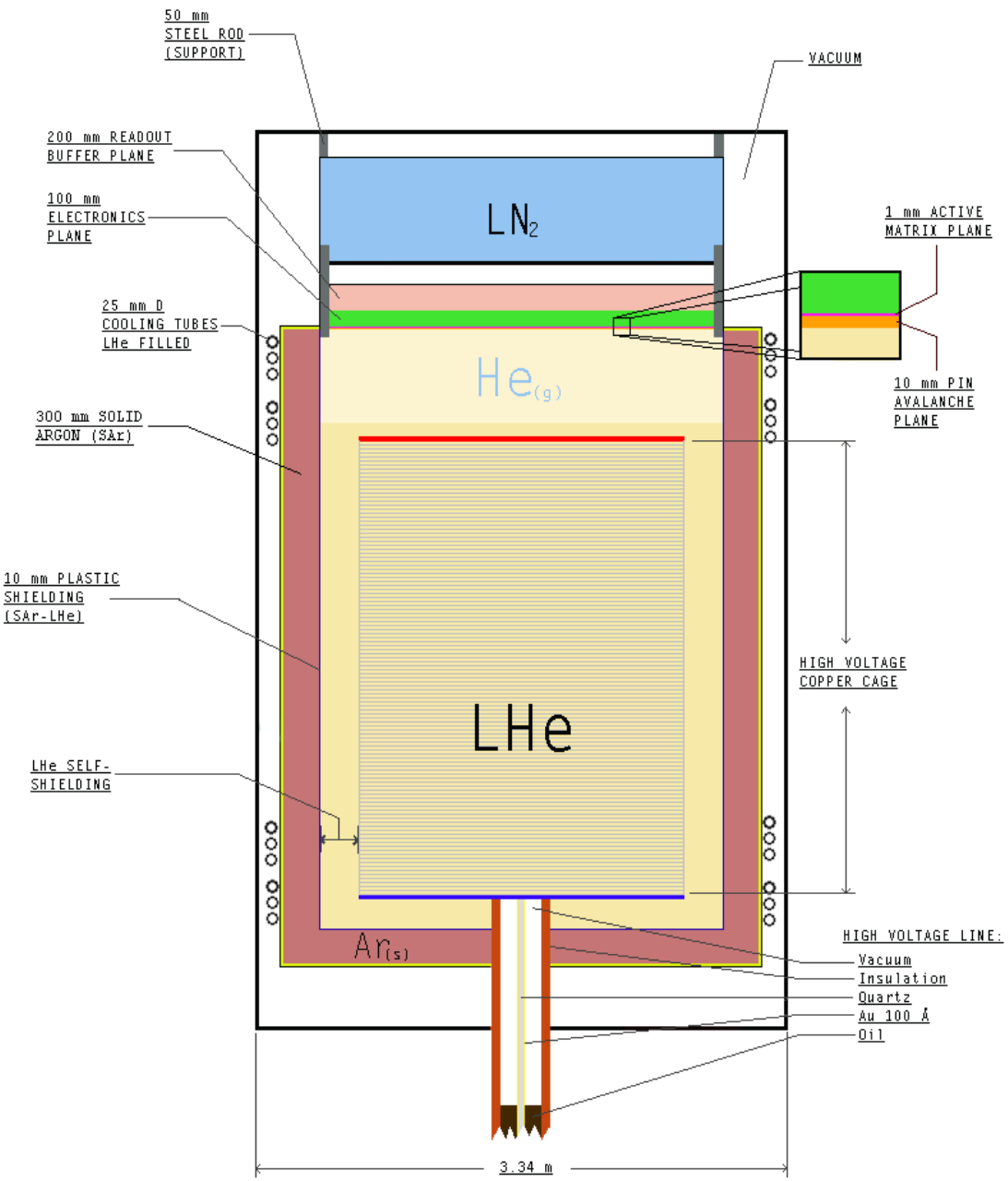
ASICs

- ~ 30 ASICs / octant
- 32 channels / ASIC
- ~ 1.2mW / channel
- energy/timing per channel
- token/flag sparsified readout



•Neutrino detector based on tracking in liquid He

Willis,Rehak, et al.



Applications:

- •Low Energy Solar pp Reaction Neutrinos, E < 423 keV
- •Astrophysical Neutrinos
- •Geophysical Neutrinos
- •Reactor Neutrinos and their Magnetic Moment
- •High Energy Clean Neutrino Events
- •Identification of Heavy Flavors in Neutrino Interactions
- •New Particle Search (SUSY – type)

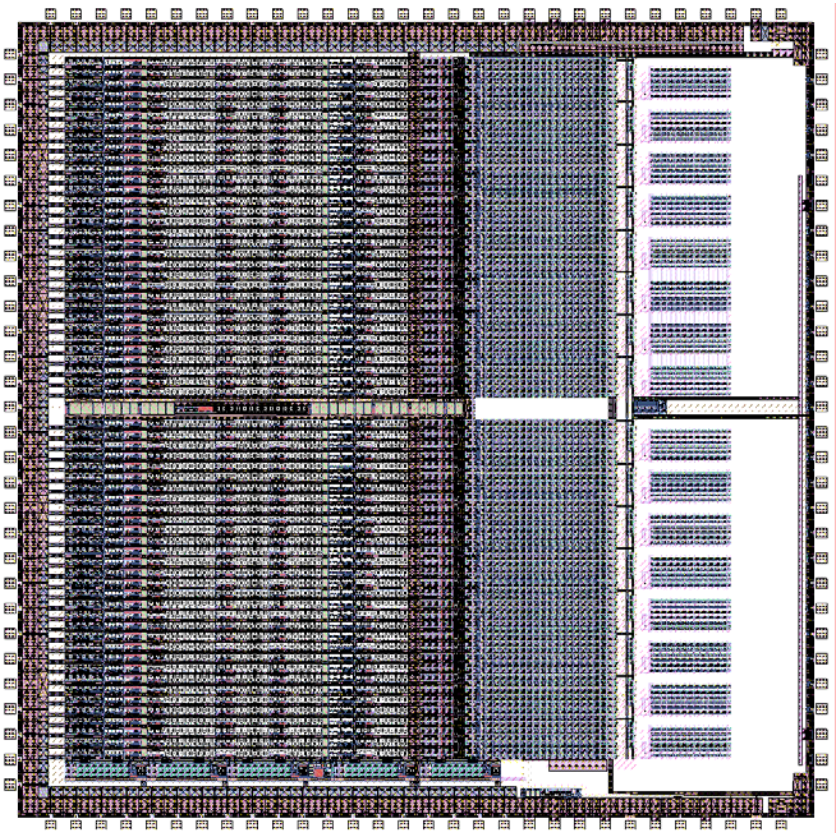
R&D: He or Ne?

- •readout electronics (CMOS) at low temperatures; electron amplification;
- •opto-electronic for **LNe** (GEM amplification in the gas phase and a CCD camera)

3. Microelectronics

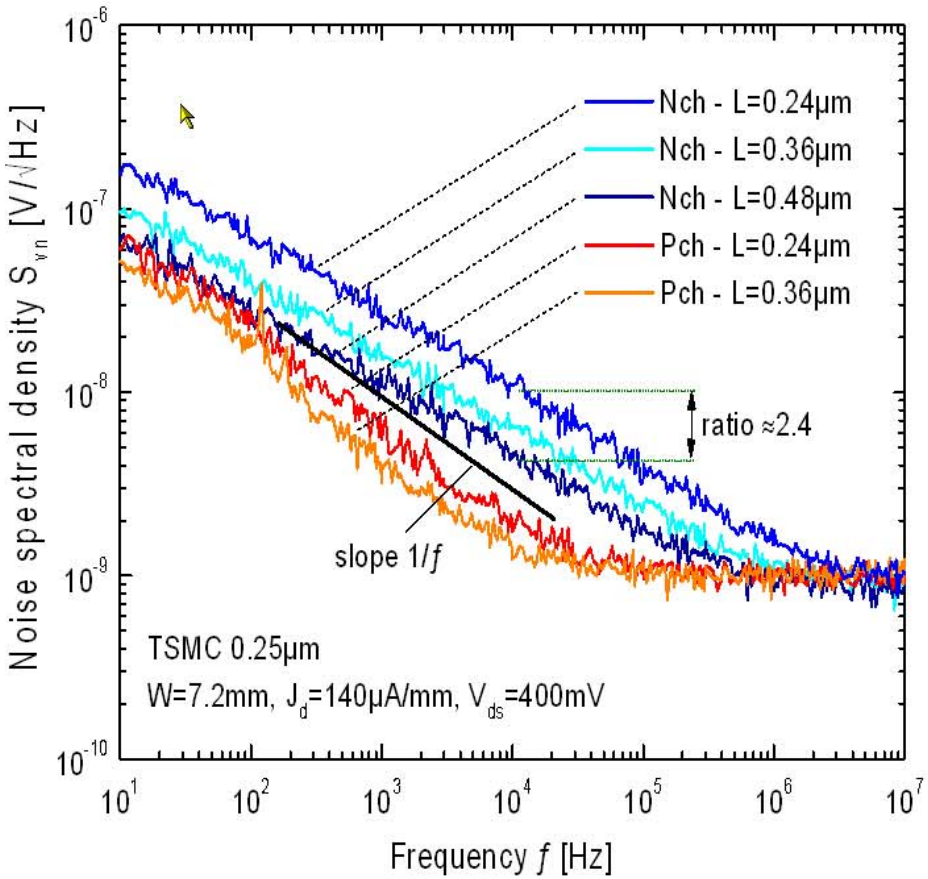
BNL Instrumentation Division – Microelectronics Group

- 4 analog IC designers; 5 engineers
- Specialize in low-noise analog CMOS front ends for radiation detectors
- 7 ASIC designs in use (lab/commercial)
  - Over 70 000 channels
- 5 more in final development
- 3 more to fab in next 6 months
- ***High energy, synchrotron radiation, medical imaging, astrophysics***
- Examples:
  - **ENC=11 e rms**, preamp for Si drift det.
  - Rad-hard preamp/shaper for ATLAS muon spectrometer at LHC
  - -- 32-channel PET signal processor



- 64-channel preamp/shaper for hard X-ray spectroscopic imaging
- Front-end + multichannel analyzer per channel
- 600 000 transistors
- concept to tapeout in 3 months

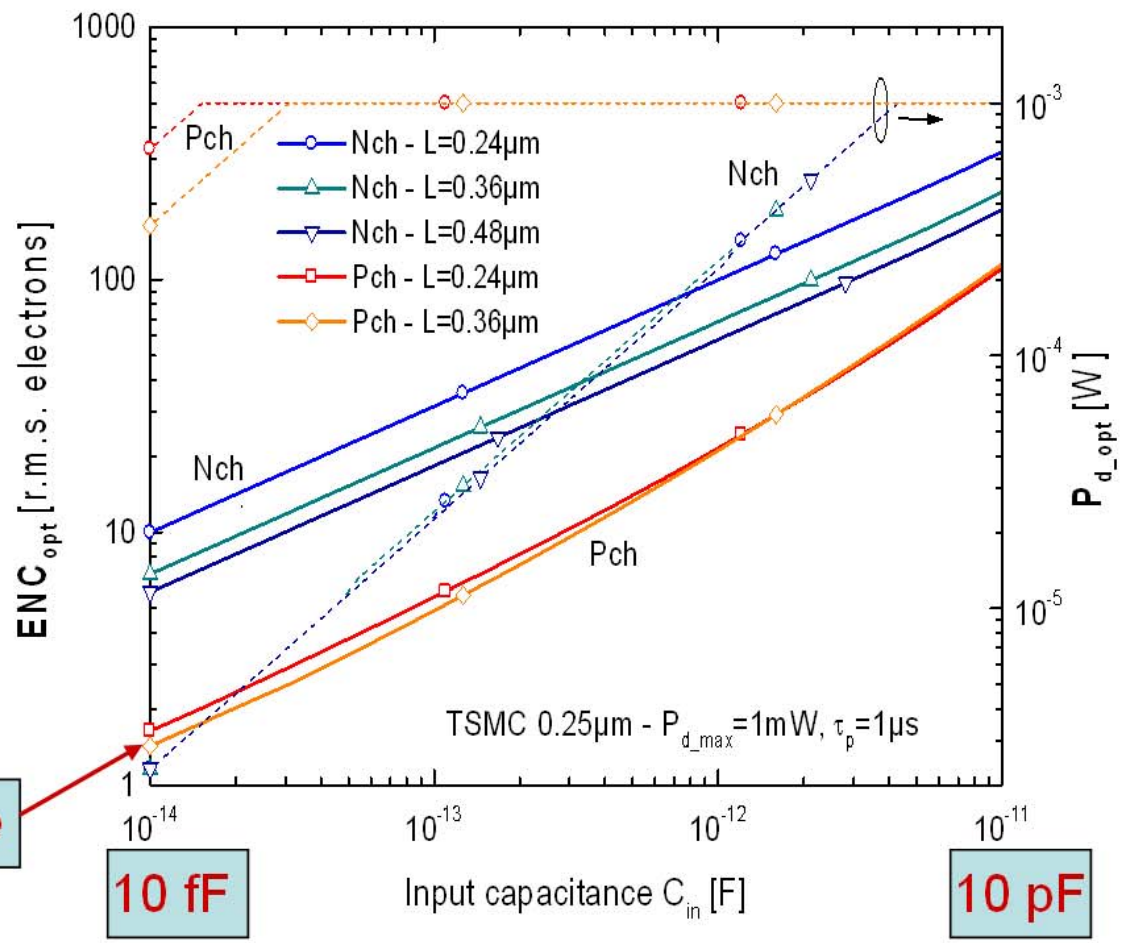
Characterization of CMOS Technologies for Low-Noise, Low-Power Front-Ends



MOSFET Noise Modeling

	Nch-0.24μm	Nch-0.36μm	Nch-0.48μm	Pch-0.24μm	Pch-0.36μm
K_f	$\mathbf{2.71}\times10^{-24}$	$\mathbf{1.40}\times10^{-24}$	$\mathbf{0.97}\times10^{-24}$	$\mathbf{0.60}\times10^{-24}$	$\mathbf{0.50}\times10^{-24}$
α_f	0.85	0.85	0.85	1.08	1.08

$$S = \alpha_w\, n\gamma(\mathbf{J_d},\mathbf{L})\frac{4kT}{g_{mw}(\mathbf{J_d},\mathbf{L})\mathbf{W}} + \frac{K_f(\mathbf{L})}{C_{ox}\mathbf{WL}f^{\alpha_f}}$$



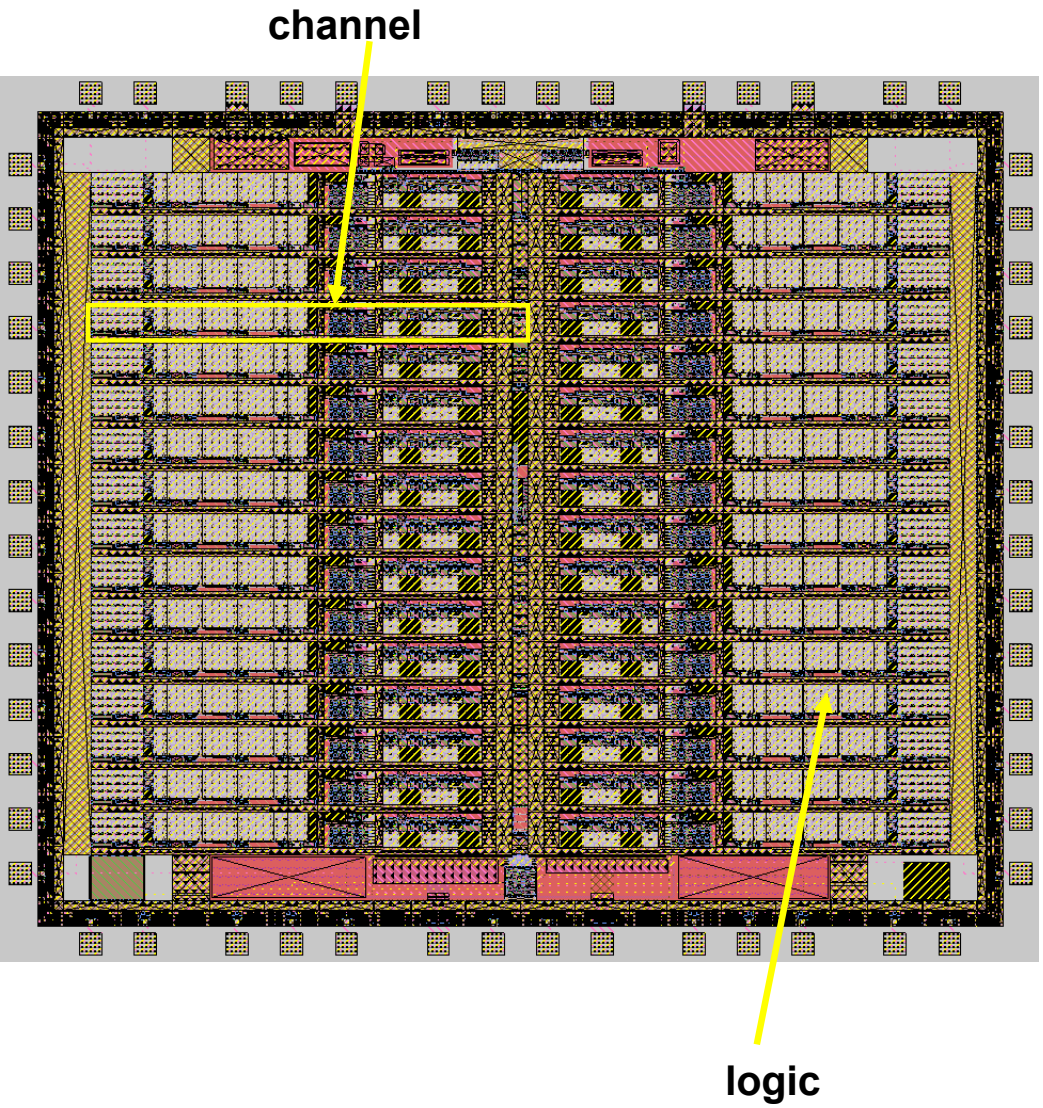
$$ENC^2 = \left[C_{in} + C_{gw}(\mathbf{J_d},\mathbf{L})\cdot\mathbf{W}\right]^2\left[\frac{1}{\tau_p}\frac{\alpha_w\, n\gamma(\mathbf{J_d},\mathbf{L})4kT}{g_{mw}(\mathbf{J_d},\mathbf{L})\cdot\mathbf{W}} + \frac{1}{2}\frac{(2\pi)^{\alpha_f}}{\tau_p^{1-\alpha_f}}\frac{K_f(\mathbf{L})}{C_{ox}\mathbf{WL}}\right]$$

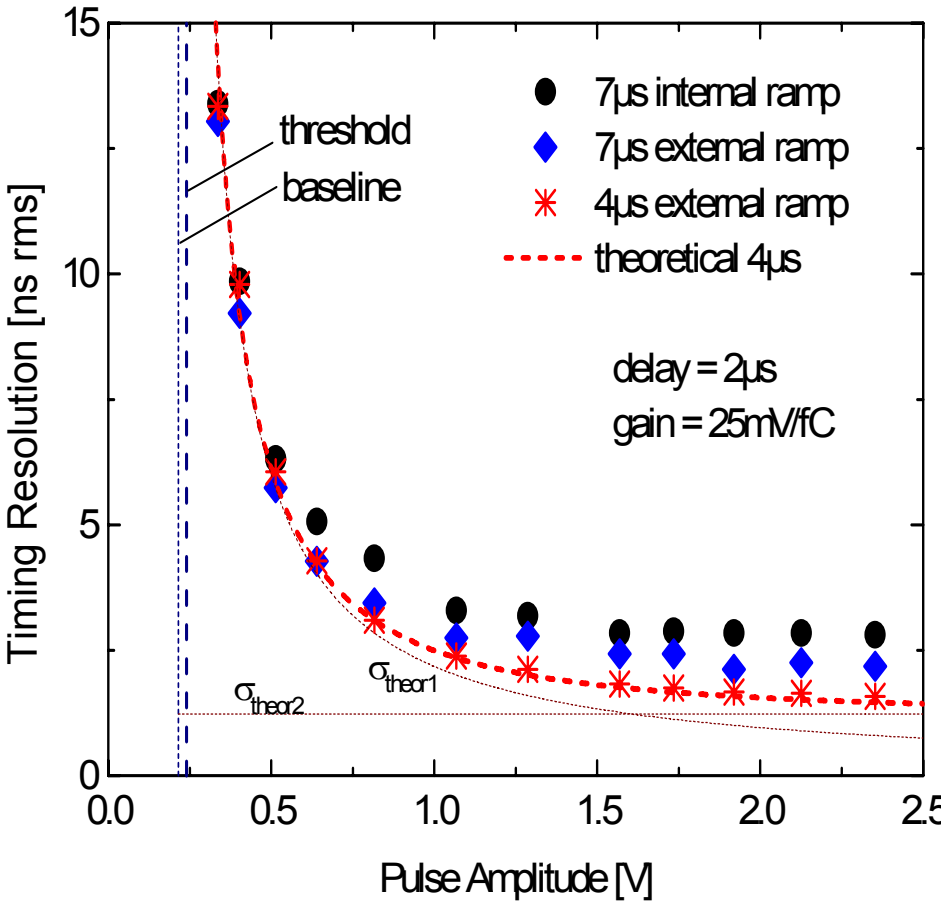
From accurate modeling:
- **better ENC estimate**
- **better optimization**

G. De Geronimo, P. O'Connor

TPC ASIC Layout

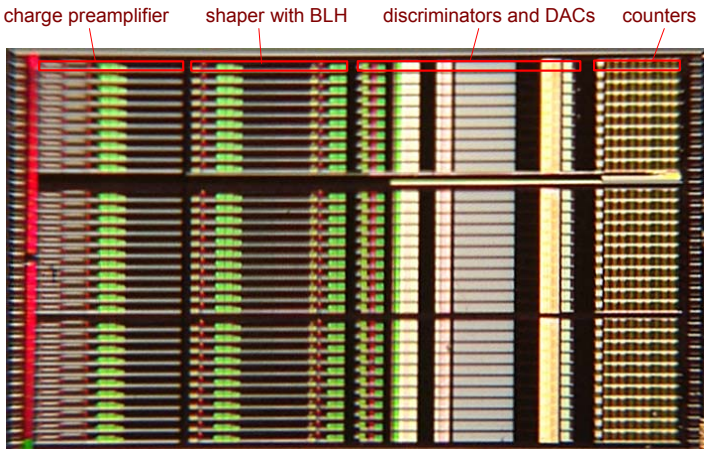
- TSMC 0.25µm
- 32 channels
- 3.1 x 3.6 mm² (~0.35 mm²/channel)
- 47k MOSFETs
- 1.2 mW/channel



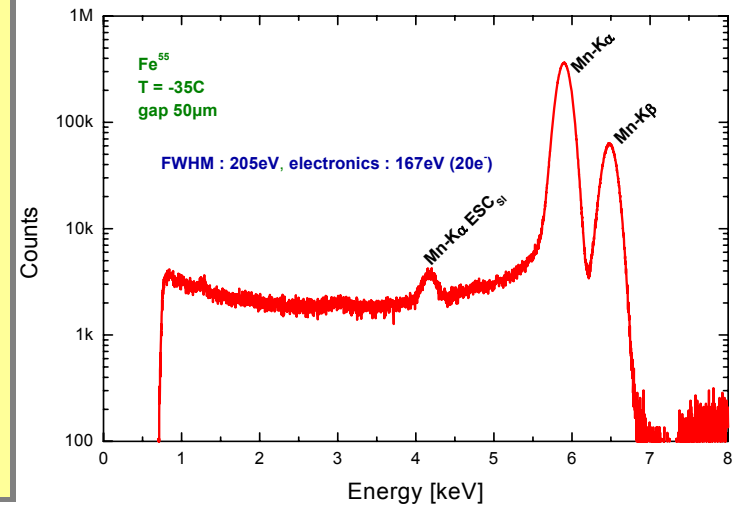


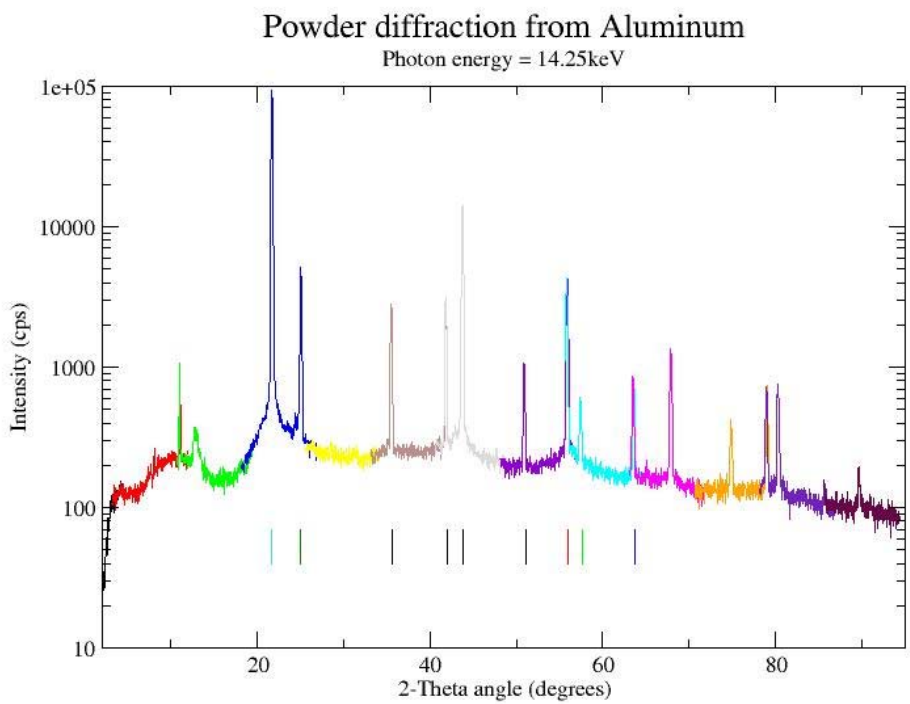
Application Specific Integrated Circuit (ASIC) for NSLS Experiments

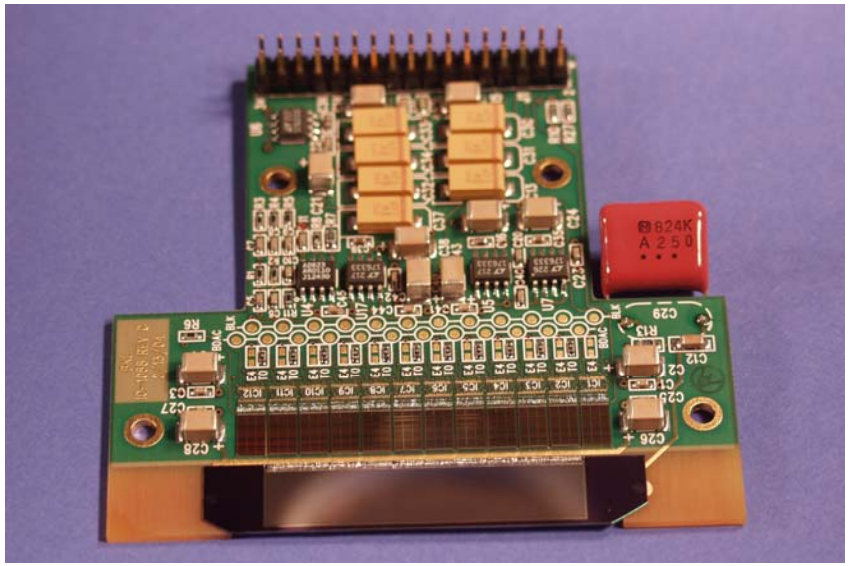
EXAFS Spectroscopy - Powder Diffraction - In-Situ Thin Film Growth



- *32-channel ASIC*
- *8mW / channel*
- *high-order filter,* ***11 e⁻ rms noise***
- *three window discriminators*
- *24-bit counters*
- *serial interfce*
- *3.6 x 6.3 mm²*
- ***180,000 MOSFETs***
- *CMOS* ***0.35µm*** *technology*



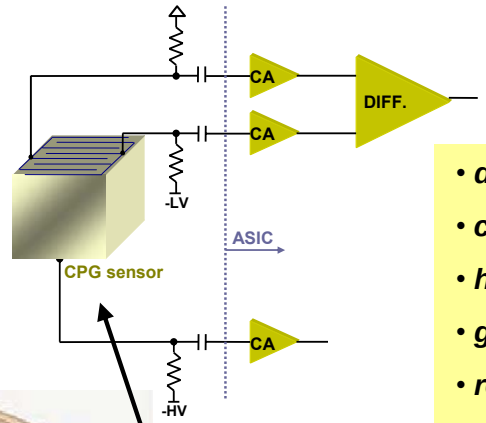


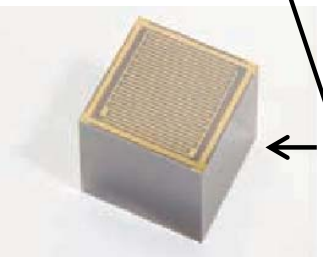


360 strips, 125µm pitch, 12 ASICs, 2,160,000 MOSFETs

G. De Geronimo, P. O'Connor - P. Siddons (NSLS/BNL)

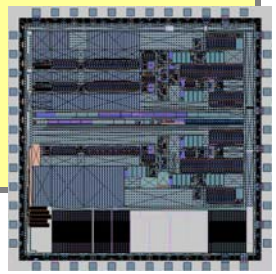
Application Specific Integrated Circuit (ASIC) for Co-Planar Grid Sensors

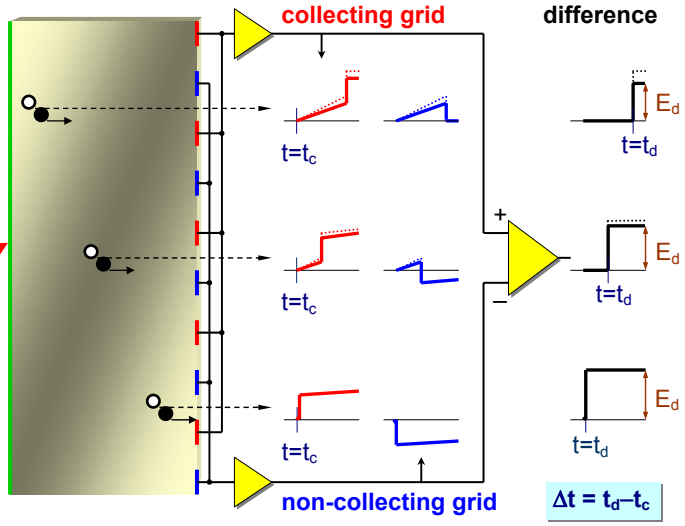


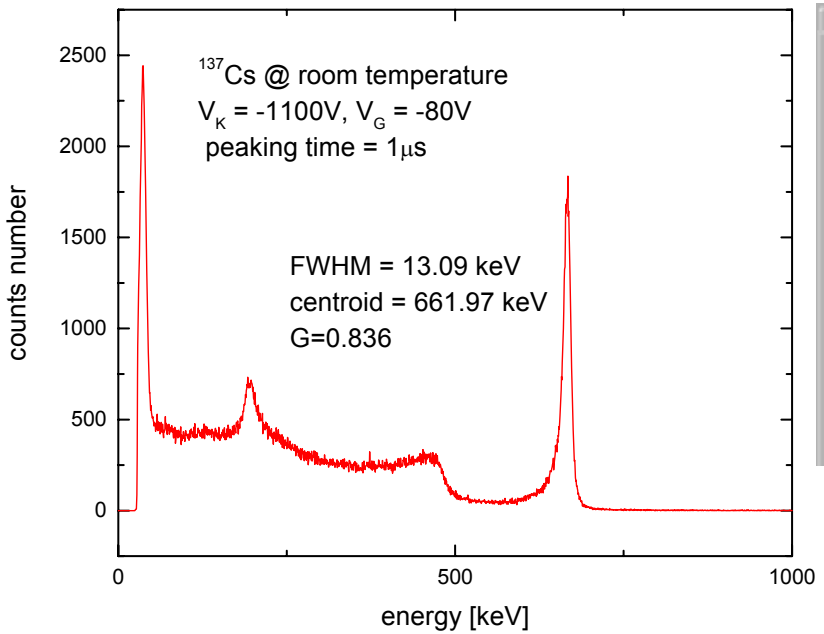


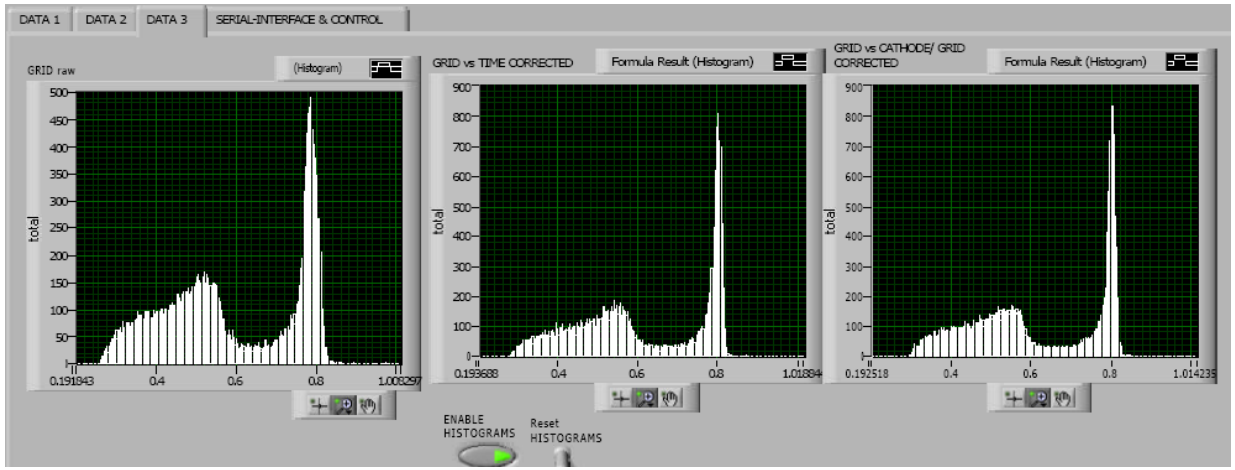
← CdZnTe

- *dual anode with difference*
- *cathode*
- *high-order filter*
- *grid-only depth-of-interaction measurement*
- *relative-gain compensation*
- *3.1 x 3.1 mm²*
- *2,000 MOSFETs*
- *CMOS 0.25µm technology*





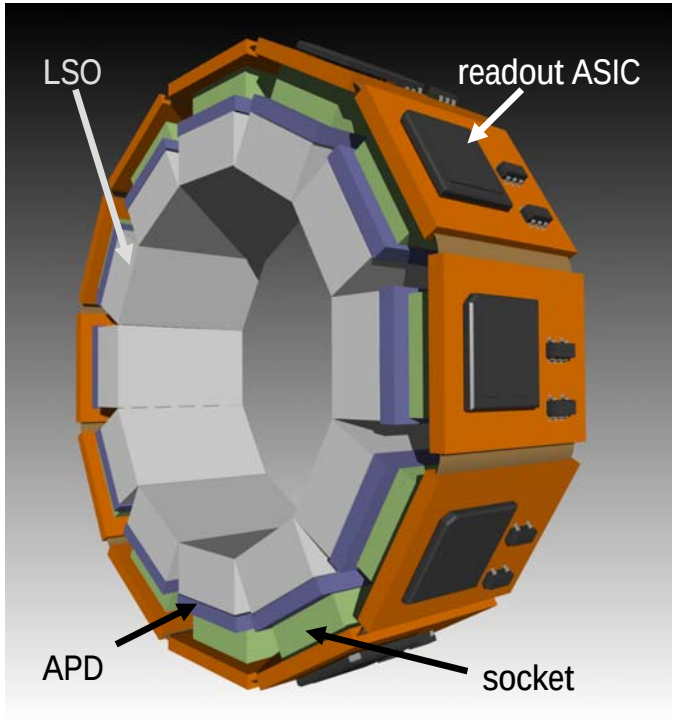




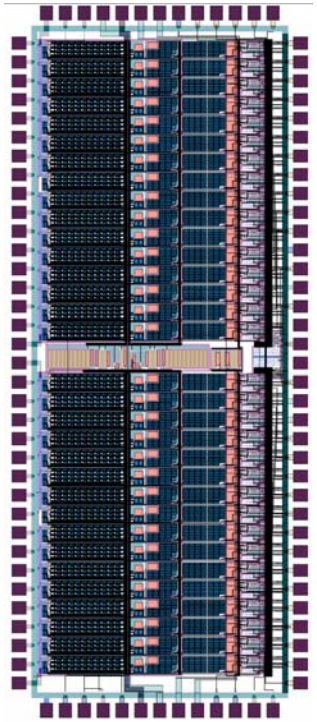
Uncorrected **Cathode Correction** **Timing Correction**

G. De Geronimo, P. O'Connor, G. Carini - W. S, Murray (LANL) - eV Products (PA,USA)

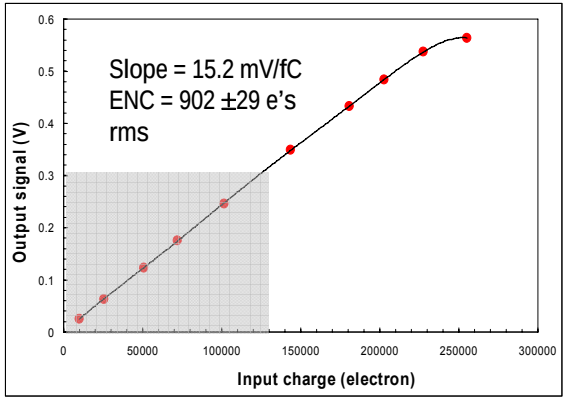
Electronics for a mobile, miniature animal PET tomograph



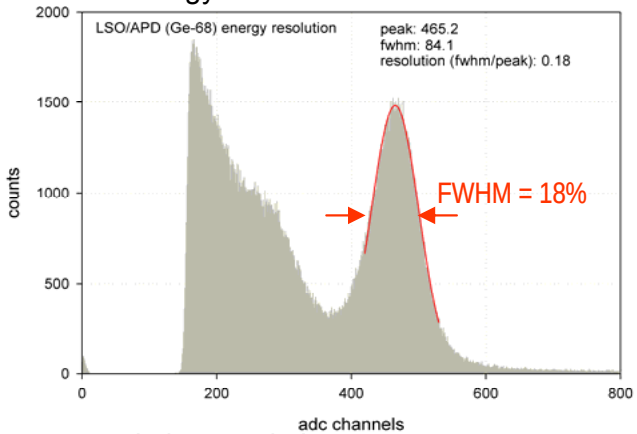
- **0.18 µm CMOS**
- 1.5 mW/channel
- 32 channel ASIC
- Preamplifier + shaper + timing discriminator
- serialized output



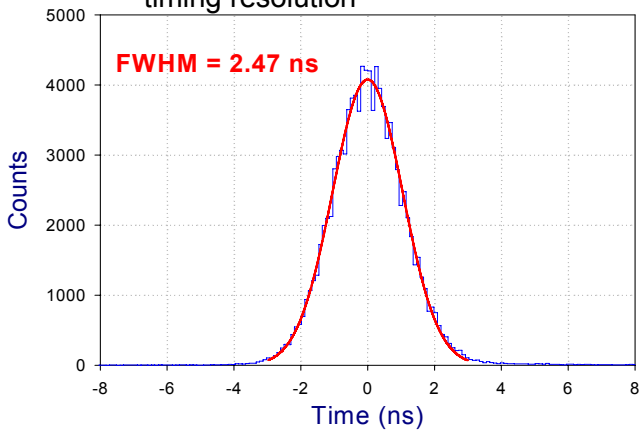
linearity



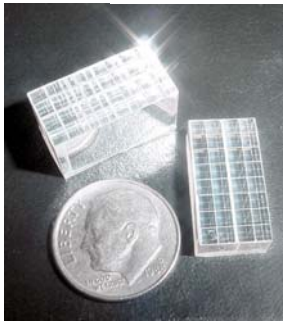
energy resolution



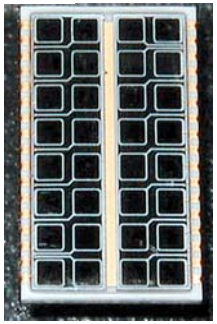
timing resolution



Mockup of the portable ring on the head of a rat



LSO scintillator



APD array

ASIC preamplifier with CFD vs. BaF_2/PMT

ASICs Developed at the Instrumentation Division During the Past 5 Years

from design-start to ready-for-production

YEAR	FUNC.	APPL.	COOP.	TECH.	CH.	TRANS. COUNT	DEV. TIME [months]
2000	Front-End for CZT	General Purpose	eV Products	CMOS 0.50µm	4-16	4-16,000	30
2000	Multiplexing	General Purpose	eV Products	CMOS 0.50µm	32:1	16,000	18
2001	Front-End	ATLAS	BNL	CMOS 0.50µm	25	10,000	96
2001	Multiplexer	ATLAS	BNL	CMOS 0.50µm	24:4	2000	6
2002	Clock Fanout	ATLAS	BNL	CMOS 0.50µm	4:6	100	1
2003	Front-End Counting for Silicon	NSLS	NSLS/BNL	CMOS 0.35µm	32	180,000	30
2003	Front-End Energy/Timing for GEM	TPC	LEGS/BNL	CMOS 0.25µm	32	40,000	16
2004	Front-End Energy for CPG	Security/Safety	LANL, eV Products	CMOS 0.25µm	3	2,000	16
2004	Peak/Timing Processor Multiplexer	General Purpose	eV Producst, NSLS	CMOS 0.35µm	32:1	36,000	24
2004	Front-End Counting for Si-Scint.	Medical	Digirad	CMOS 0.35µm	32	200,000	6
2004	Front-End for APD	Small Animal PET	BNL	CMOS 0.18µm	32	15,000	30 (in prog.)
2005	Front-End Counting for CZT	Industrial	eV Products	CMOS 0.25µm	64	600,000	4 (in prog.)
2005	Front-End Energy/Timing for Gas	Neutron Scattering	BNL,ORNL	CMOS 0.25µm	64	na	2 (in prog)
2005	Front-End Energy for Si	Space	BNL,NRL	CMOS 0.25µm	na	na	1 (in prog)

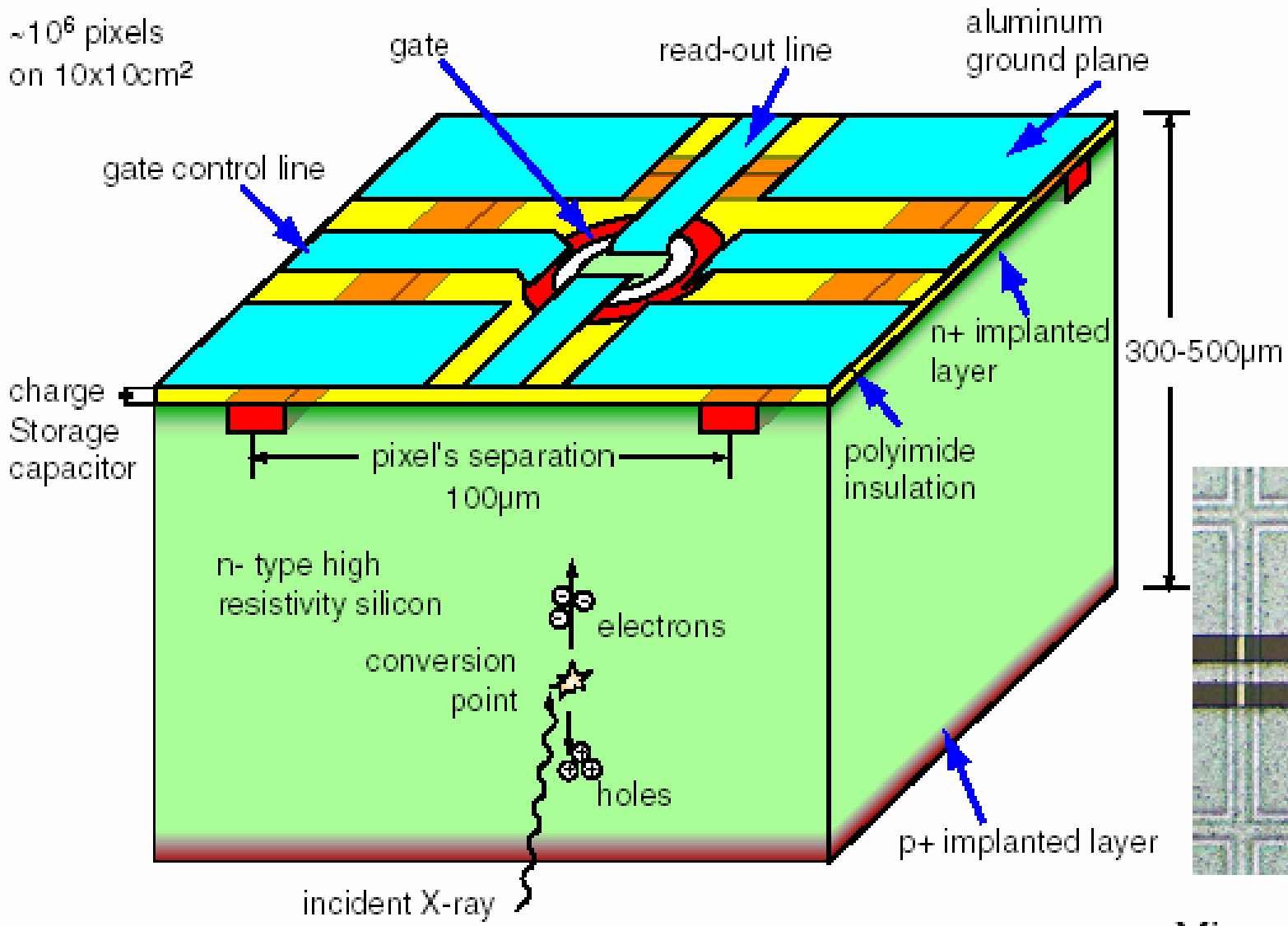
4. Integrated Detectors/Electronics: "Detectors and Transistors on the Same Chip"

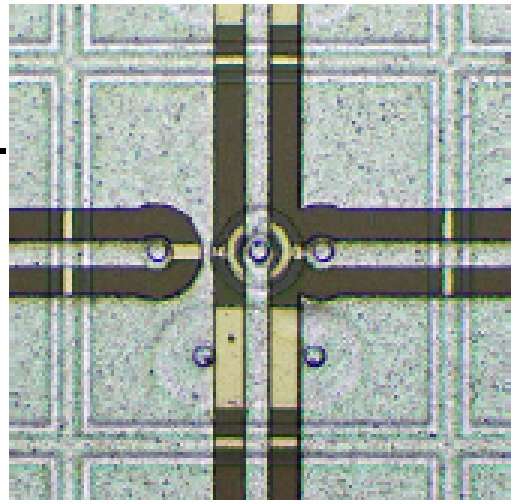
- ***Transistor on high rho (10 kohm cm) Si***

- ***Detection in standard CMOS (~10 ohm cm epi Si)***

“Transistor on high rho (~10 kohm cm) Si”:

3D View of an X-ray Active Matrix Pixel





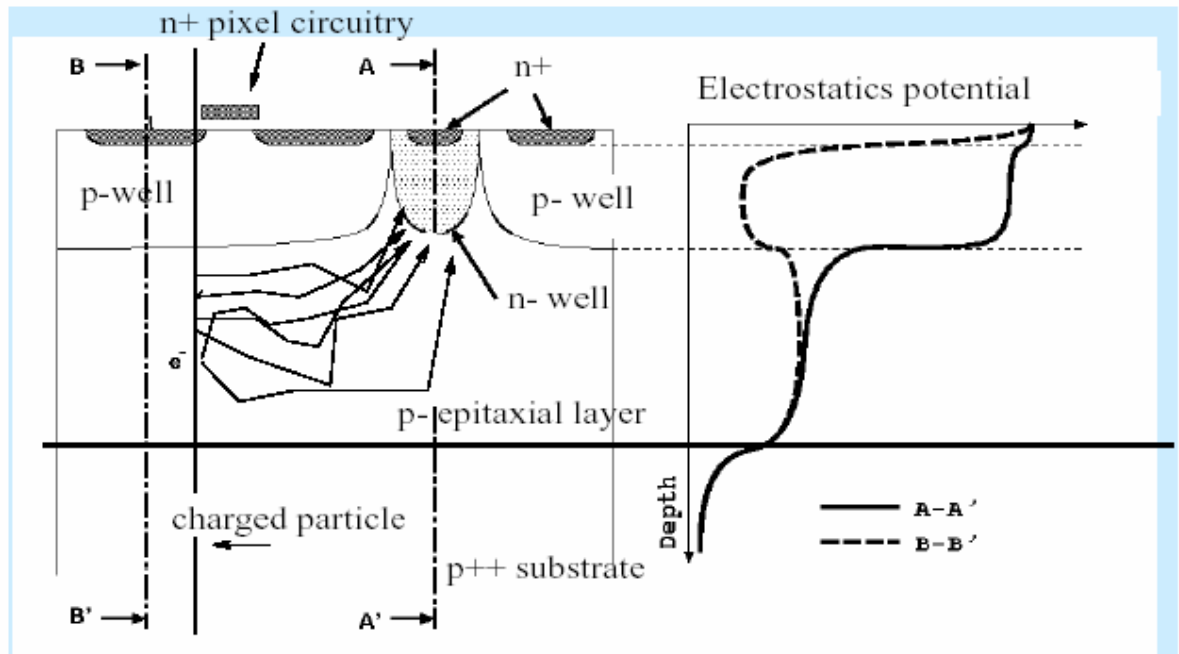
Microphotograph of a pixel

CMOS as Direct Conversion Megapixel Detectors (10-20 μm pixels) → Monolithic Active Pixel Sensors (MAPS)

Epitaxial layer ~5-15 μm

Min. ion. particles ~80 e/μm

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



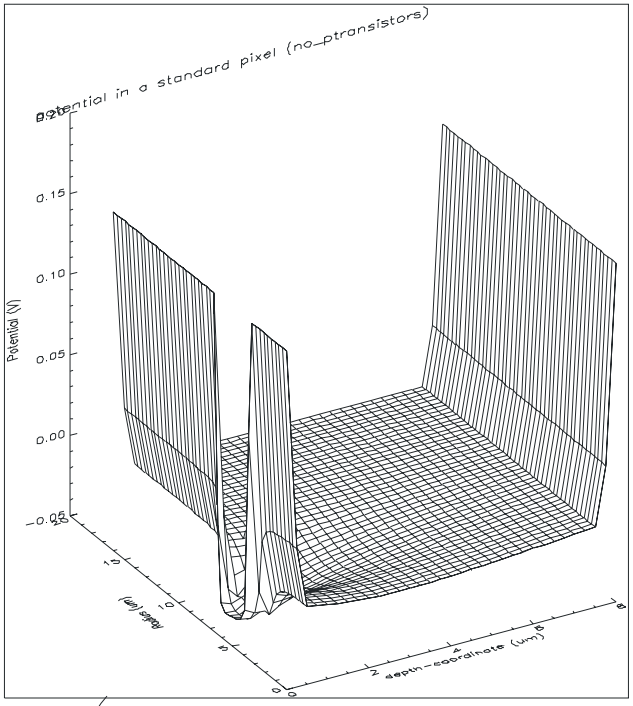
A problem:

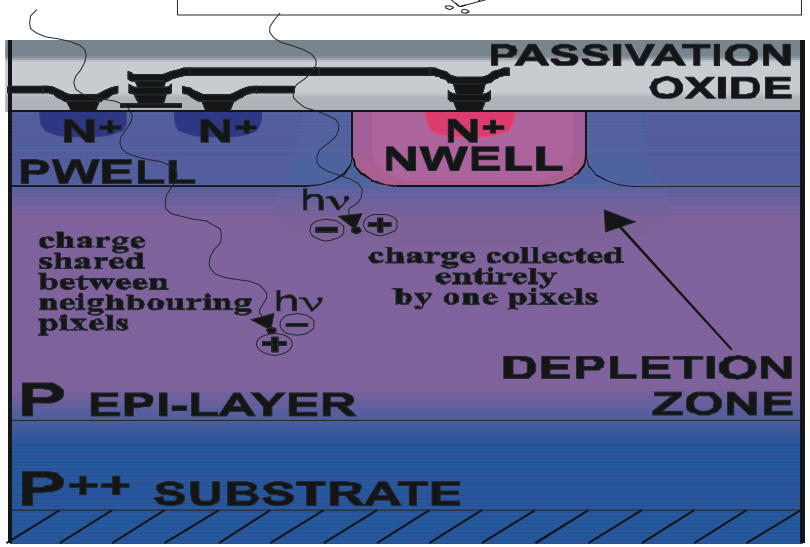
Charge collection by diffusion → ~ 500 e signal spread on several pixels, ~200 ns collection time

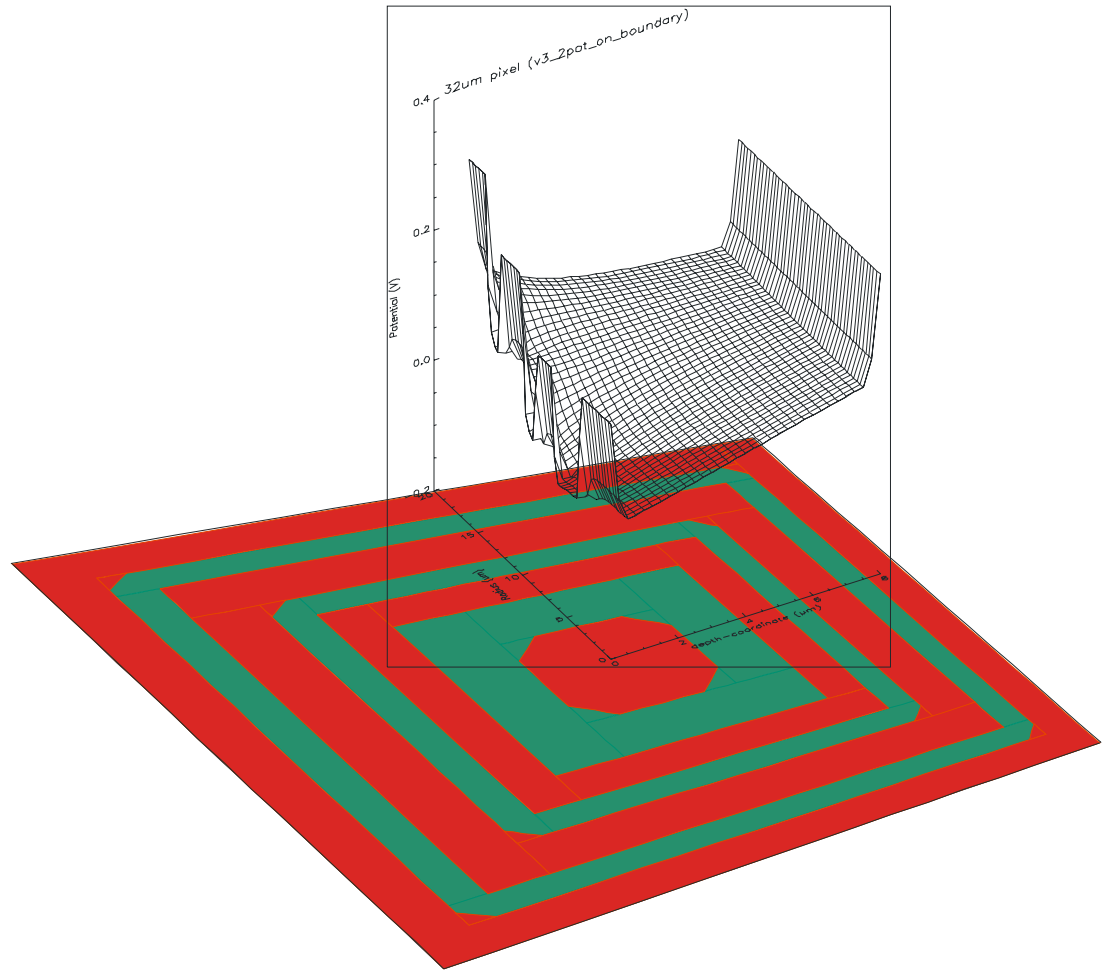
- The effective charge collection is achieved through the thermal diffusion mechanism,
- The device can be fabricated using a standard, cost-effective and easily available CMOS process,
- The charge generated by the impinging particle is collected by the n-well/p-epi diode, created by the floating n-well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

Original MAPS:
(Deptuch,Turcheta, et al.)

A new concept - and challenge: introduce a ***drift field*** into standard CMOS process (Rehak, et al.)







View of a pixel

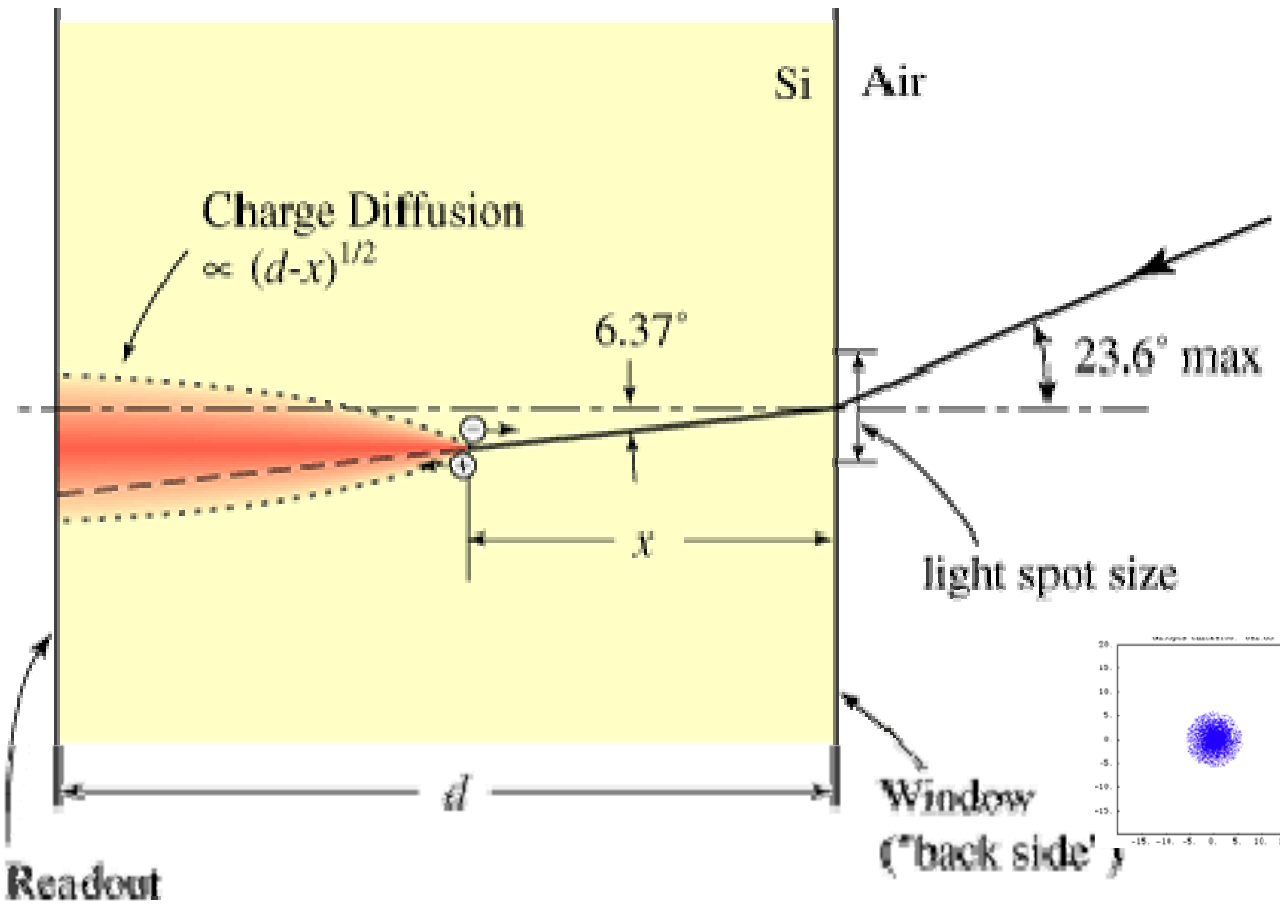
- ***Green*** are n-wells for anode and p-channel transistors
- ***Red*** are p-wells fo n-channel transistors

5. LSST

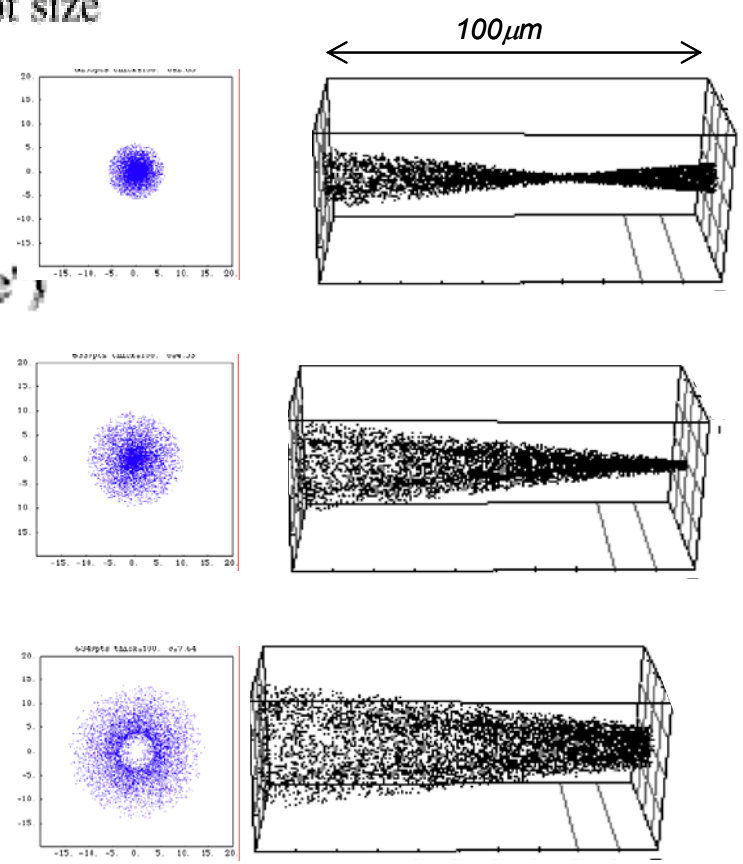
From LSST Science Reqts to Sensor Reqts

- High QE to 1000nm ➔ ***thick silicon (> 75 µm)***
- PSF << 0.7" (0.2") ➔ high internal field in the sensor
  ➔ ***high resistivity substrate (> 5 kohm·cm)***
  ➔ ***high applied voltages (30 - 50 V)***
  ➔ ***small pixel size (0.2" = 10 µm)***
- Fast f/1.2 focal ratio ➔ ***sensor flatness < 5µm***
  ➔ package with piston, tip, tilt adj. to ~1µm
- Wide FOV ➔ ~ 3200 cm^2 focal plane
  ➔ > 200-CCD mosaic (~16 cm^2 each)
  ➔ industrialized production process required
- High throughput ➔ > 90% fill factor
  ➔ 4-side buttable package, sub-mm gaps
- Fast readout (1 - 2 s) ➔ ***segmented sensors*** (~6400 TOTAL output ports)
  ➔ 150 I/O connections per sensor
- Low read noise ➔ < ~ 5 rms electrons

Point Spread Function (PSF) in Si



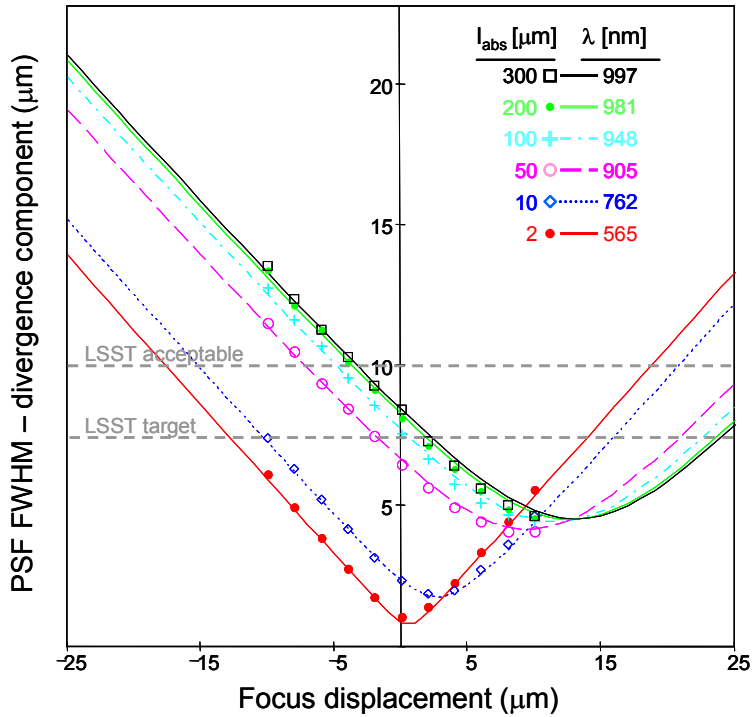
Simulation by P. Takacs, BNL:



Light spot, cone, absorption→ionization, charge diffusion → PSF

Point spread function dependence on focal plane position.

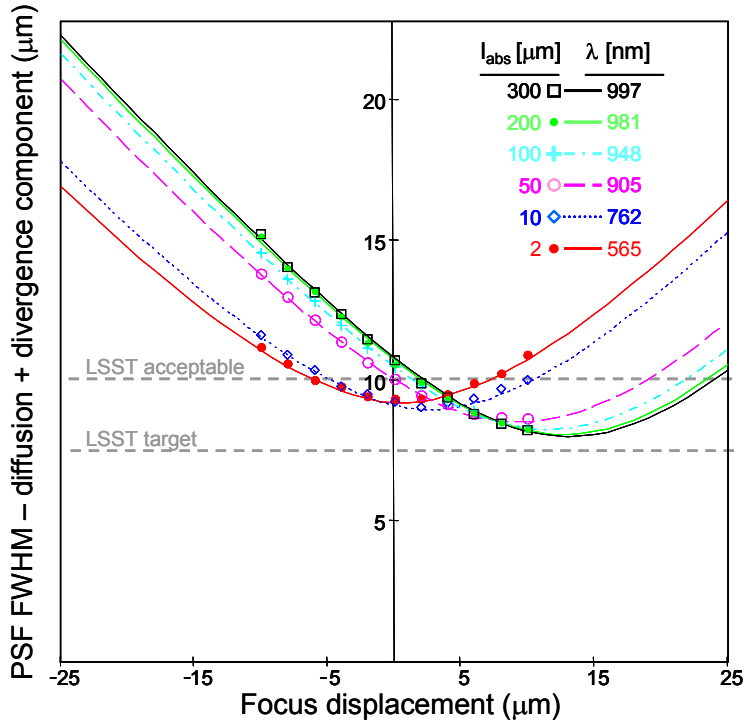
(a)



Diffusion *not included*

Importance of diffusion!

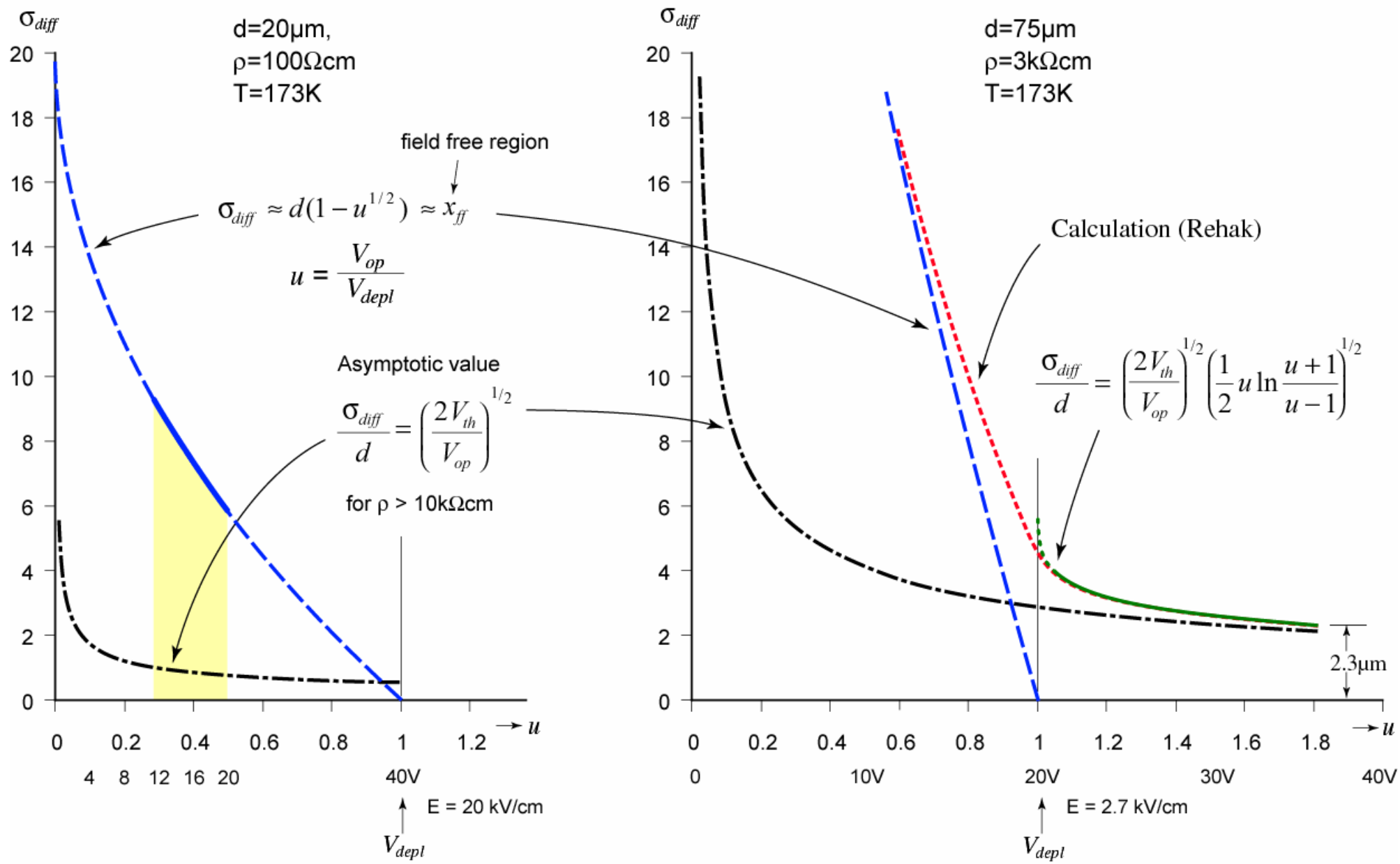
(b)



Diffusion *included*

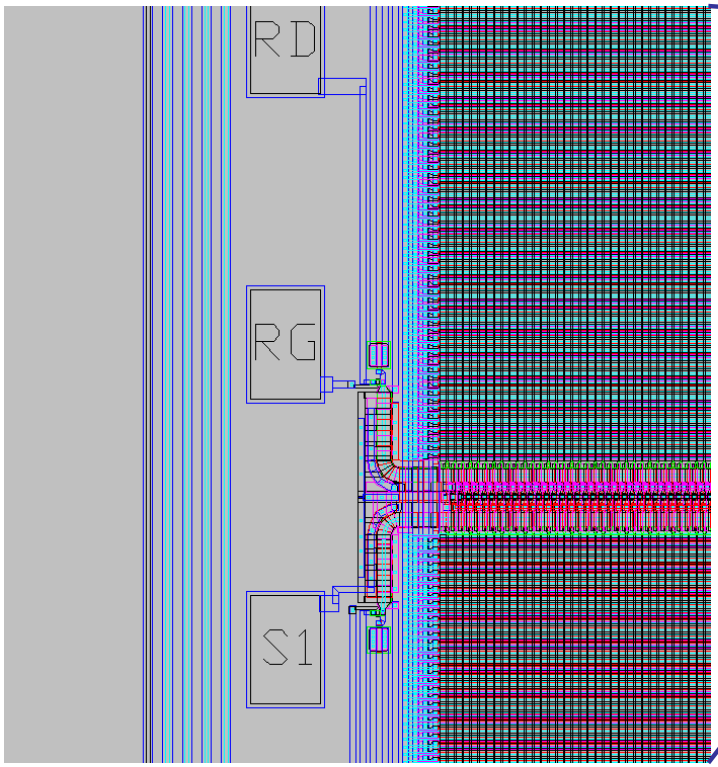
Positive displacements move the focal point into silicon volume. Sensor thickness **100μm; 20 V**; average electric field 2 kV/cm; 173K.

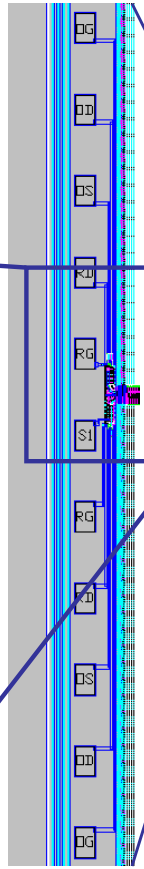
PSF(rms) *vs* V_{op} and *rho* (ρ)



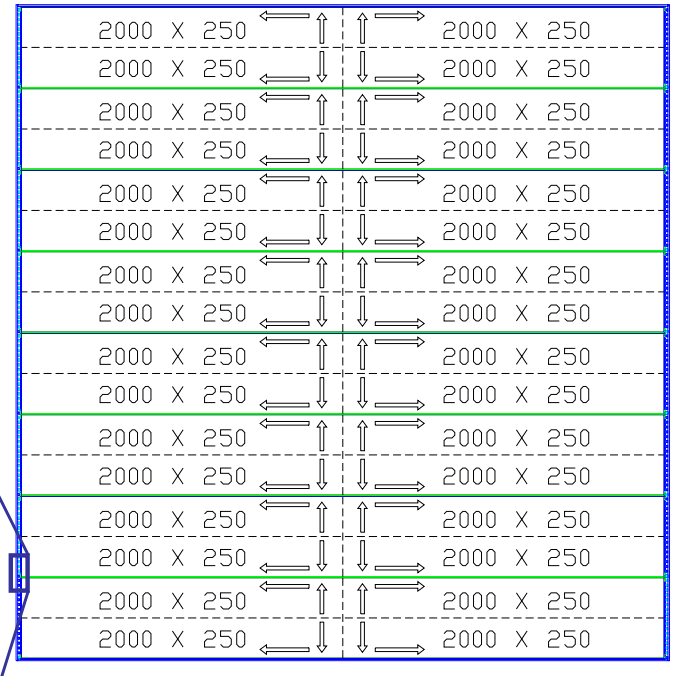
Multi-port 4K x 4K = 16M CCD strawman

Detail of output port





Detail of one edge

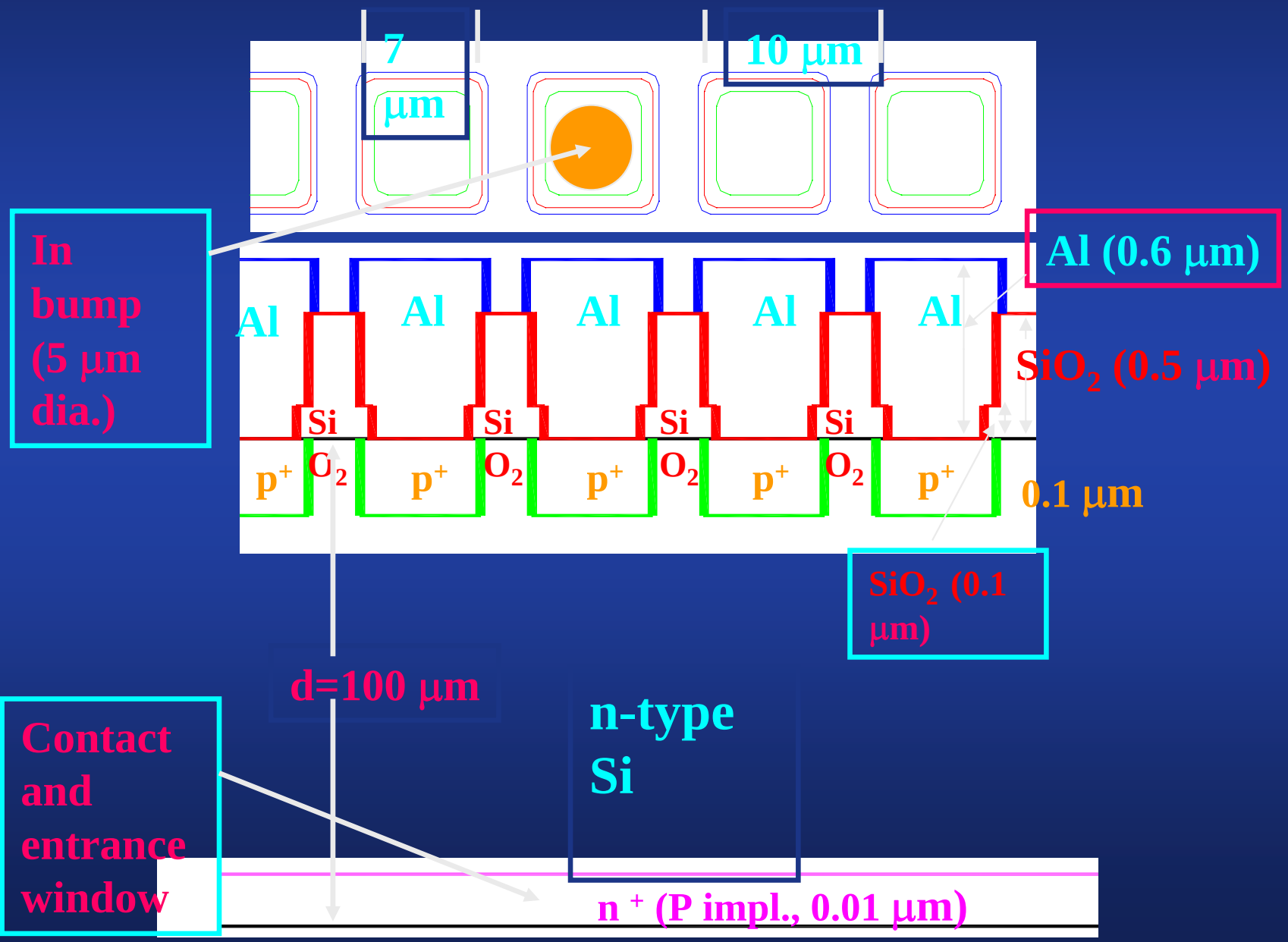


Full CCD showing segmentation. Note pads on left and right edges only

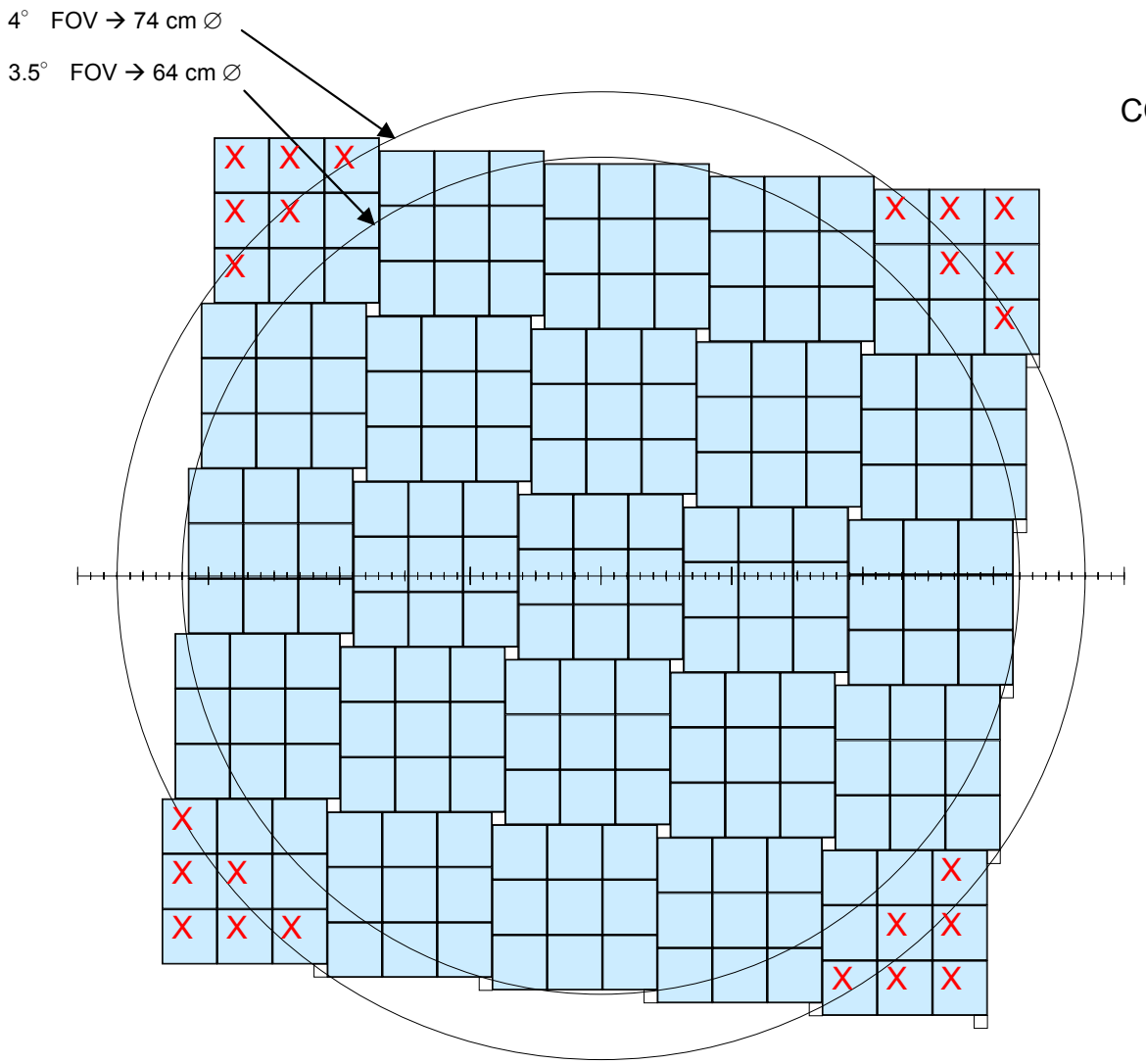
Strawman has 208 bonding pads total

J. Geary, "LSST Strawman CCD Design", Dec. 2004

High resistivity (5 kΩcm) PIN detector array, fully depleted (V_{depl}~7 V), to be bonded to CMOS readout



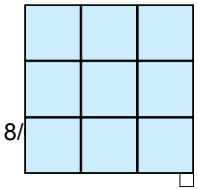
An example of a possible arrangement of 3 x 3 sensor rafts in the focal plane with areas provided for wavefront sensors by raft offset.



CCD rafts: 3x3

4096x4096 pixels;
10 μm pixels
1678 mm² active
41.7 mm x 41.7 mm Si
42 mm pitch (0.3 mm gaps)
95% fill factor
25 x 3x3 = 225 chips; Allowing dummies outside 64cm, then:
→21 rafts with 9 live, + 4 corners with 3 live each
= 201 live chips total

wea 8/

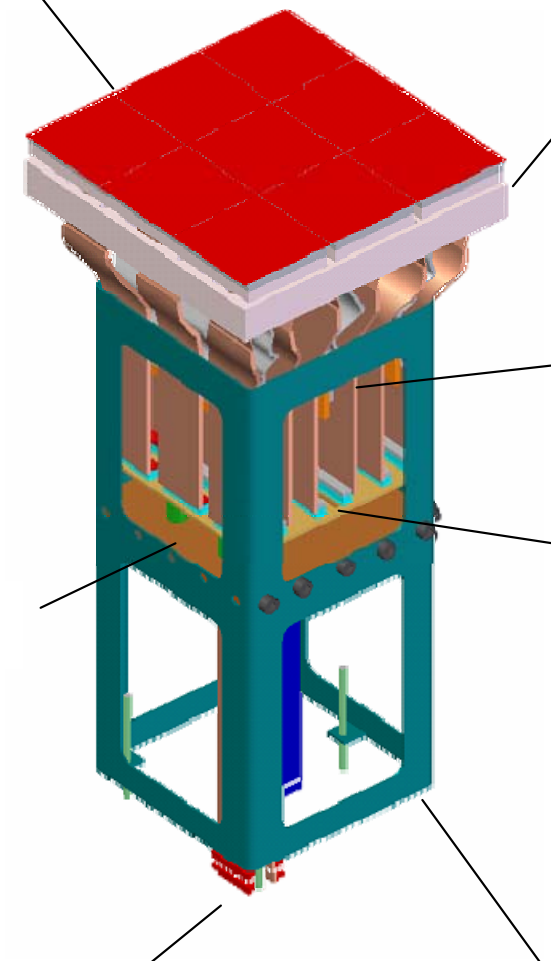


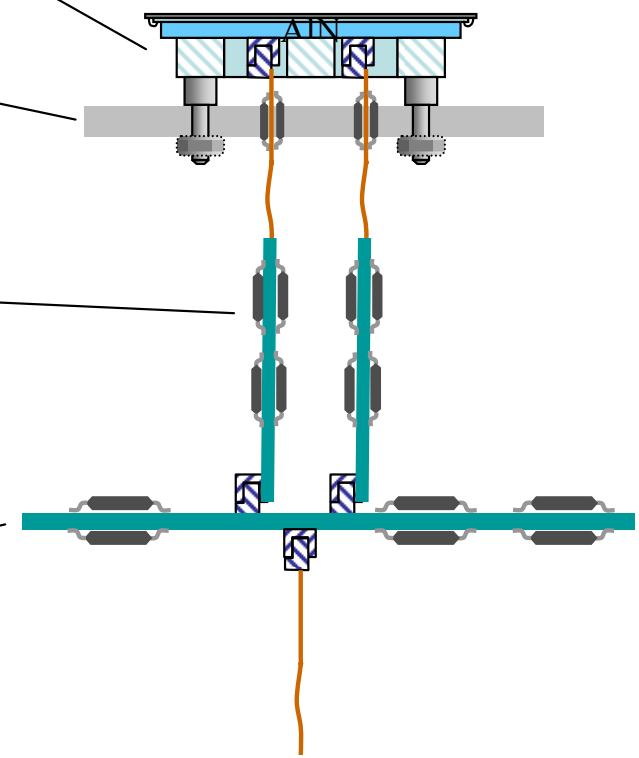
LSST Front End Electronics Integration

packaged CCD

3 X 3 X 16M CCDs

Raft platform





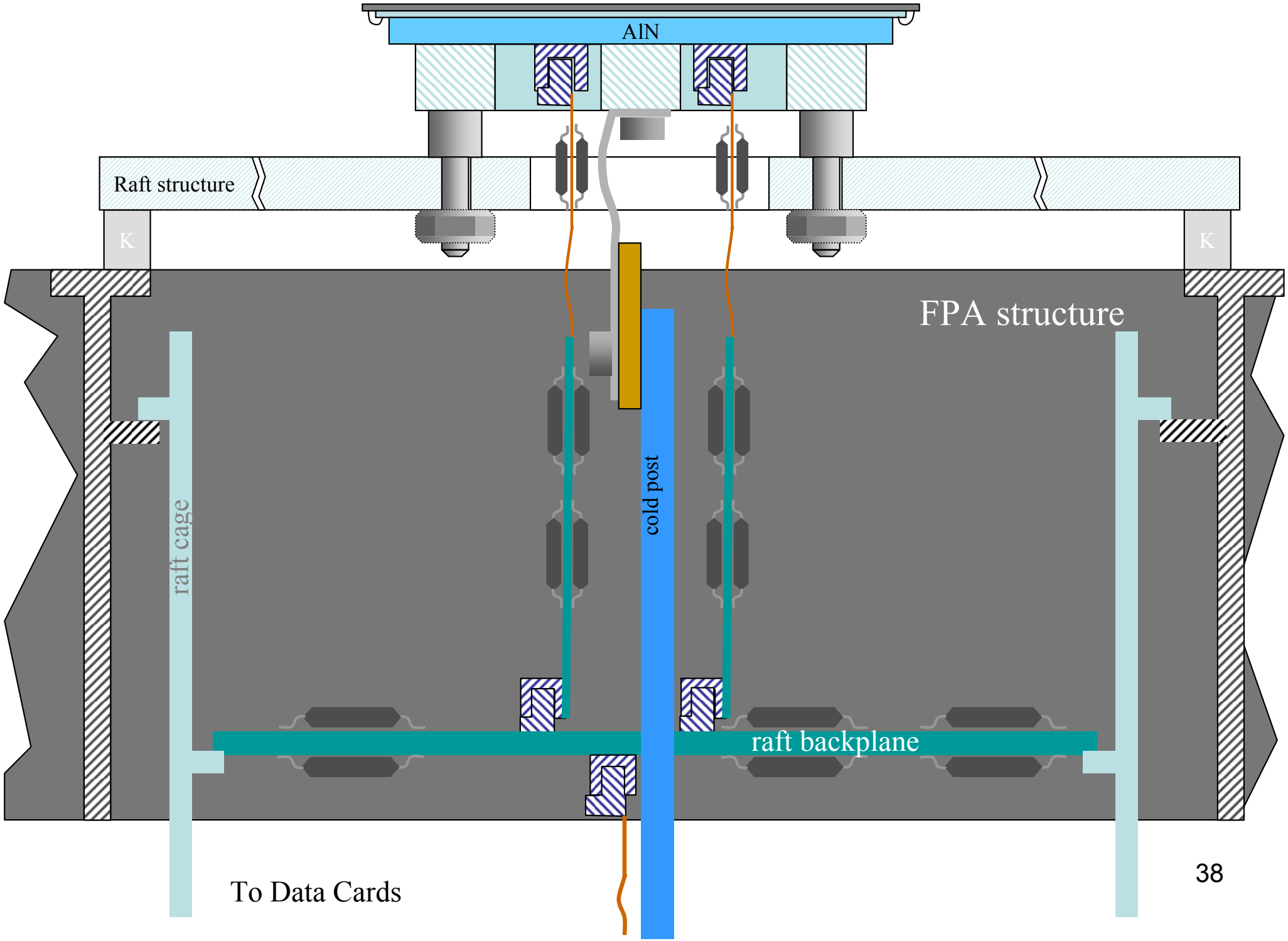
Front-end readout board

Raft backplane

Cold plate

To back-end electronics

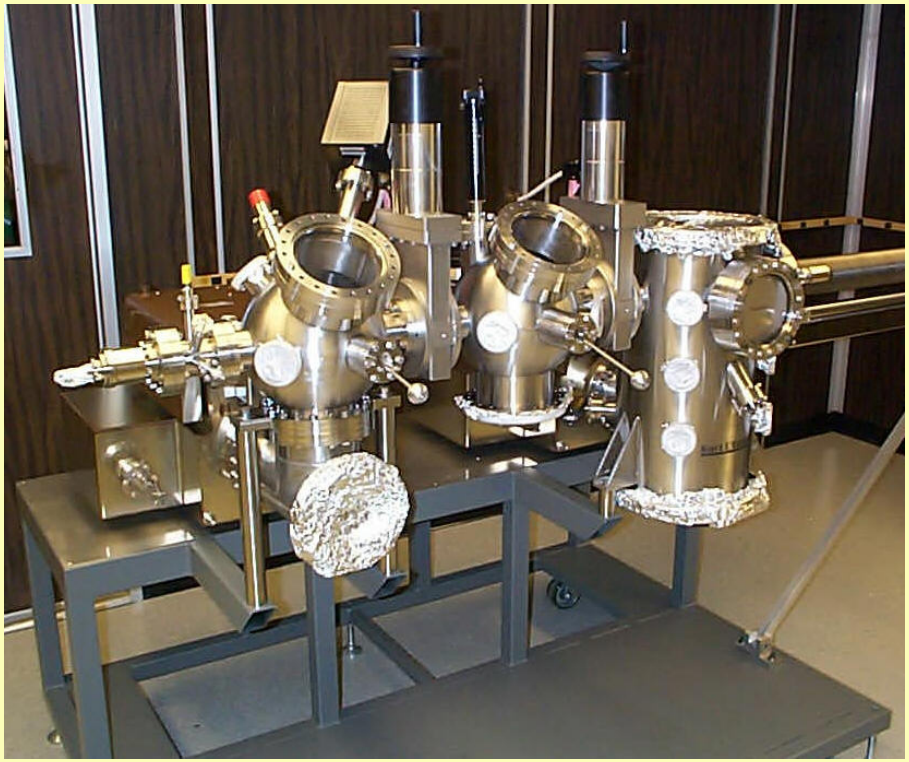
Electronics support cage

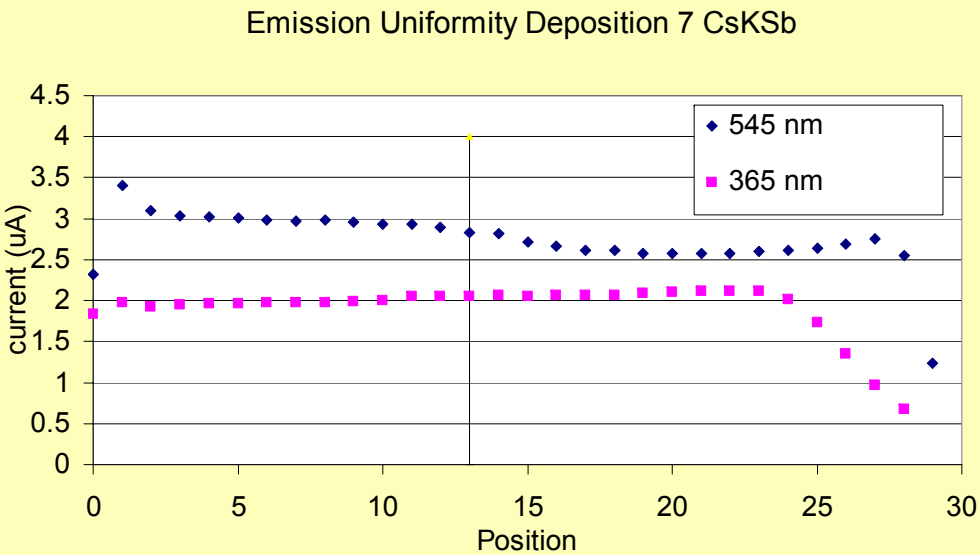

AlN
Raft structure
K
K
FPA structure
cold post
raft cage
raft backplane
To Data Cards

6. Lasers and Optics

Multialkali Photocathode Development (CAD, IO)

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

Results so far:

QE up to 3% at 545 nm

Life time > weeks at low 10^{-9} Torr

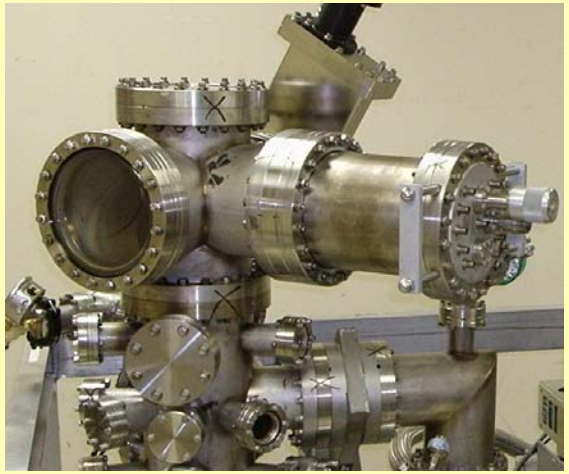
10% QE at 365 nm

Uniform emission at 545 and 365 nm

Current density comparable to RHIC II requirement, few days of life time

Electron Source Development for E-Cooler (CAD, IO)

Diamond Secondary Emitter Project



Diamond Test Chamber

Goals:

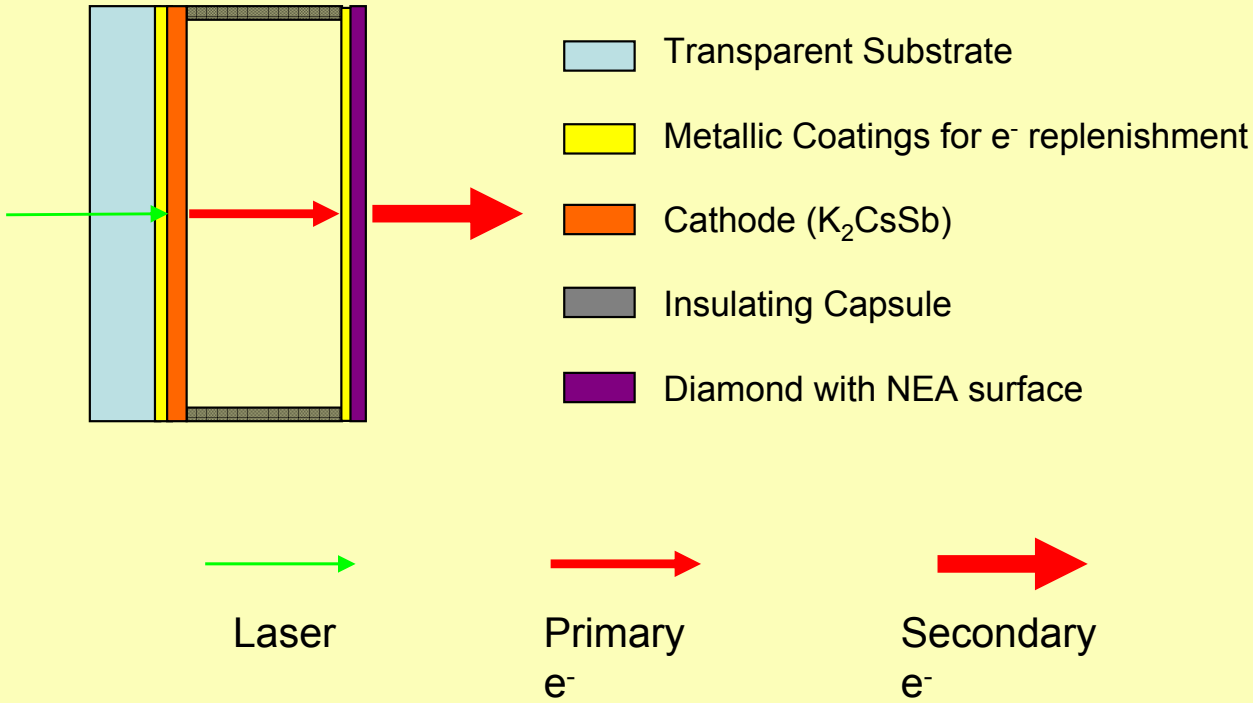
- Obtain 10mA primary current from a transmission photocathode
- Accelerate the primary electrons to a few keV
- Generate secondary electrons with a gain of 100+
- Transport electrons through diamond and into vacuum via specially prepared Negative Electron Affinity surface
- Entire system is a sealed capsule – avoid contamination of cavity by Cesium from cathode, and improve lifetime

Results so far:

Electron multiplication observed in diamond (gain 300+)

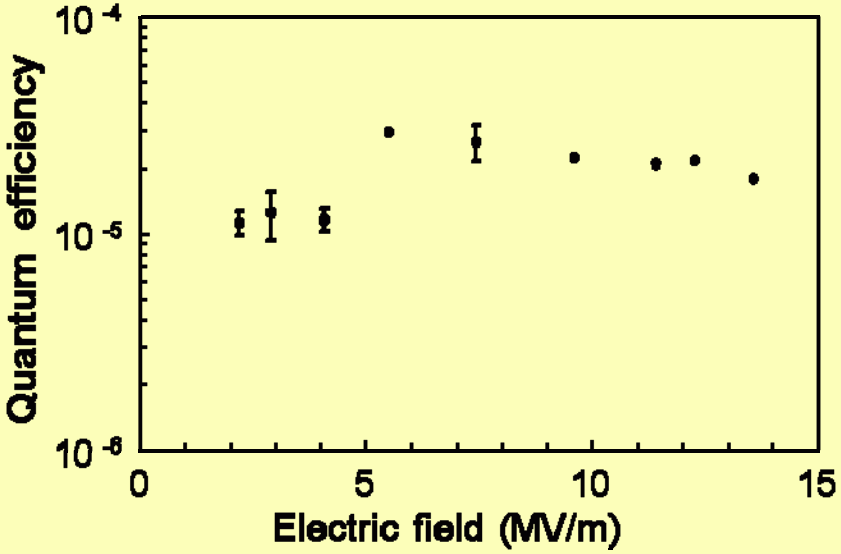
Electron emission into vacuum observed from diamond (without gain)

System for obtaining NEA surface under construction in Instrumentation



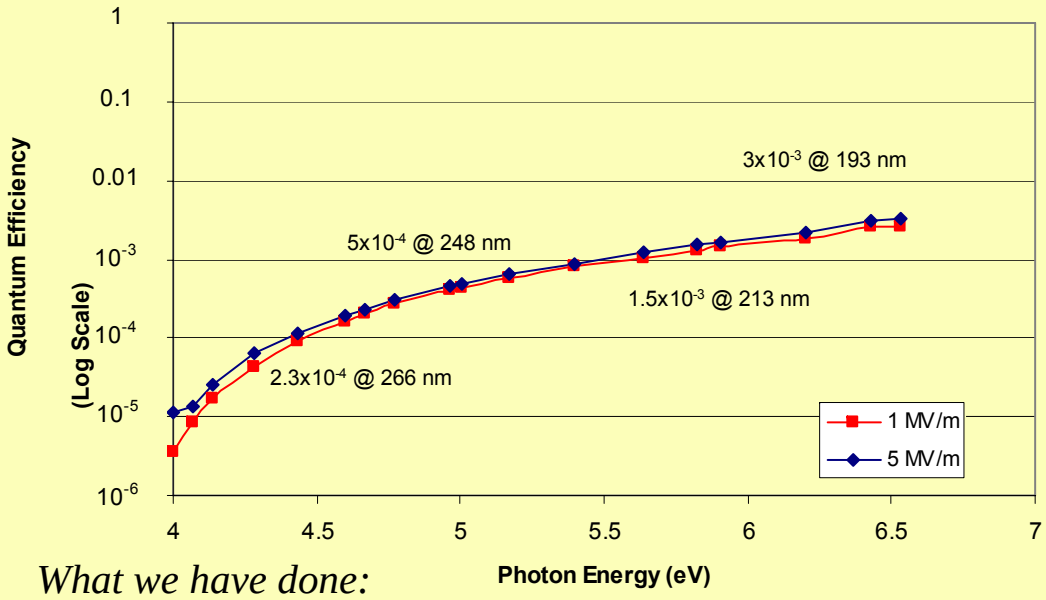
All Nb Superconducting 1.3 GHz rf Photoinjector (CAD, IO, AES)

12 ns, 248 nm laser irradiation
Max charge ~10 nC, ~ 1 nC per RF cycle



Superconducting *Lead* Photoinjector Development

To improve the Quantum Efficiency of superconducting photoinjectors. This research may lead to an injector capable of meeting the high average current requirements of tomorrow's LINAC-based Light Sources (up to 1nC bunch charge, 1 mA average current, 1 MHz rep. rate).



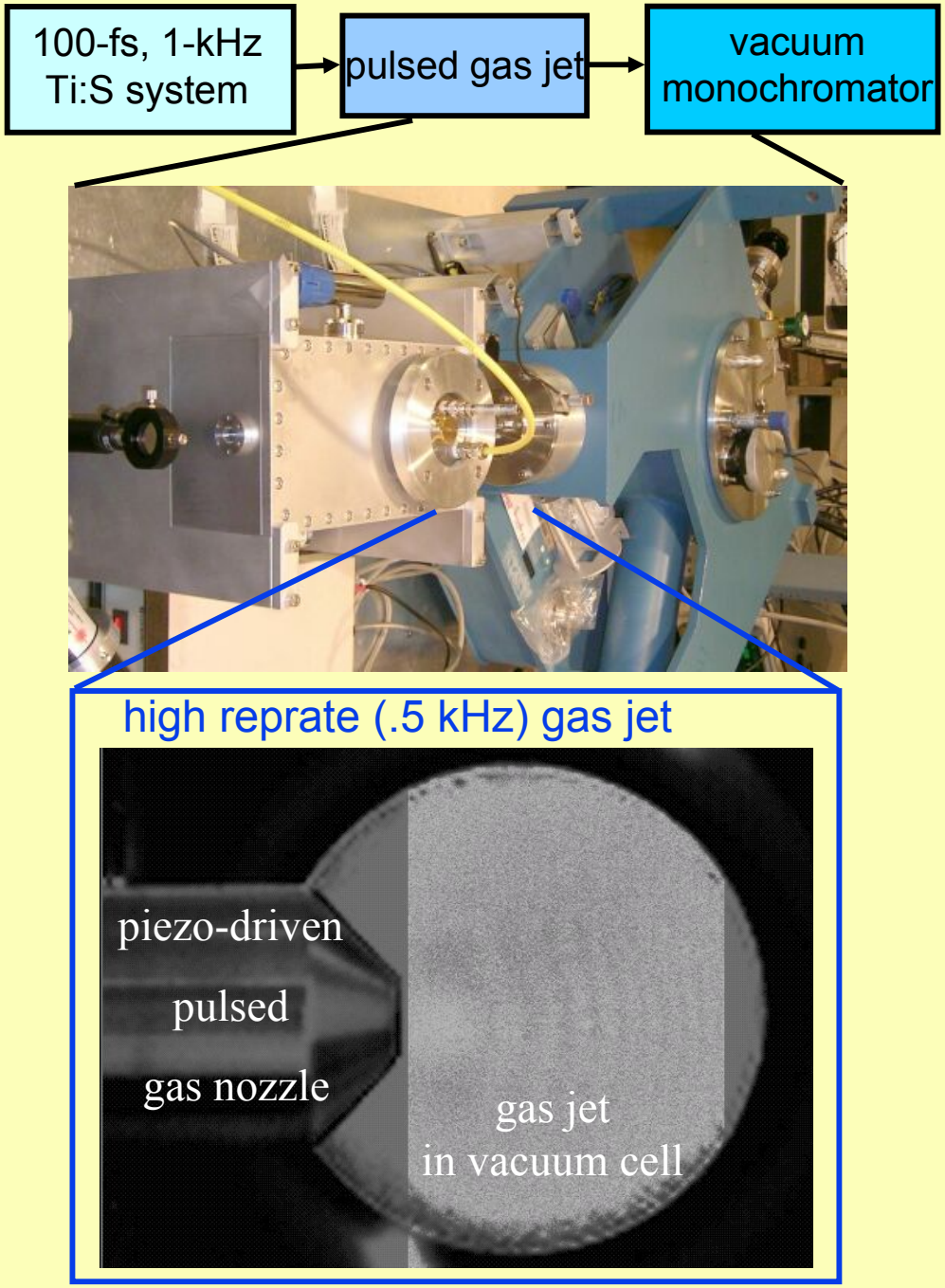
What we have done:

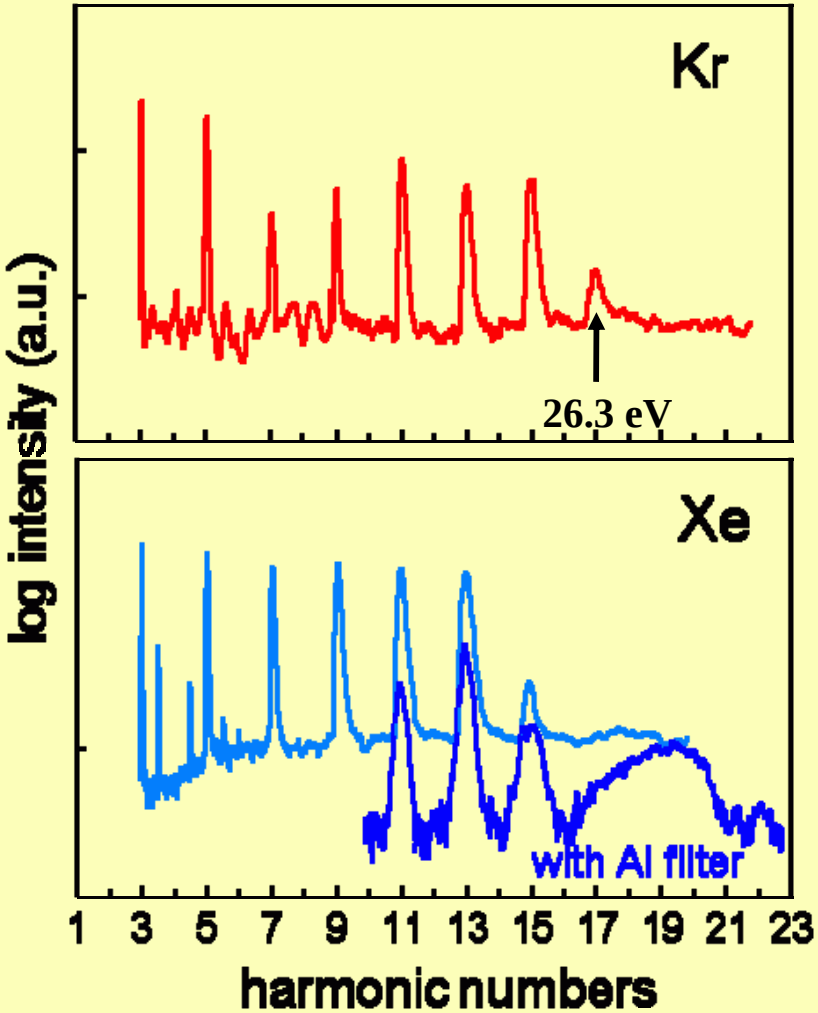
Developed techniques to deposit lead on the cathode region of a niobium superconducting injector. Characterized the QE of these coatings as a function of photon energy. Lead has a QE ~8 times that of Niobium, and requires less surface preparation.

What's Next:

Creation of a Hybrid Lead-Niobium RF cavity

Generation of Coherent, Femtosecond, High Brightness VUV and X-Ray Beams Using High Order Harmonic Conversion





- 13th harmonic → 10^6 photons/pulse
- highest harmonic: ~23 → 36 eV, cut-off of the laser energy and is detection limited
- need to decrease the laser pulse length to reach higher harmonics
- projected to 10^9 photons/sec @ 1-kHz reprate

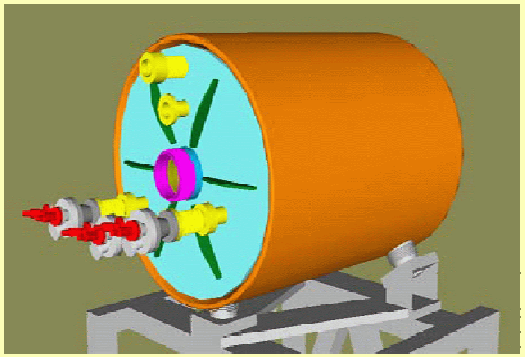
Hg free-jet targetry design for muon collaboration

Optical diagnostics of Hg jet

BNL-CAP, Princeton
ORNL, MIT, CERN

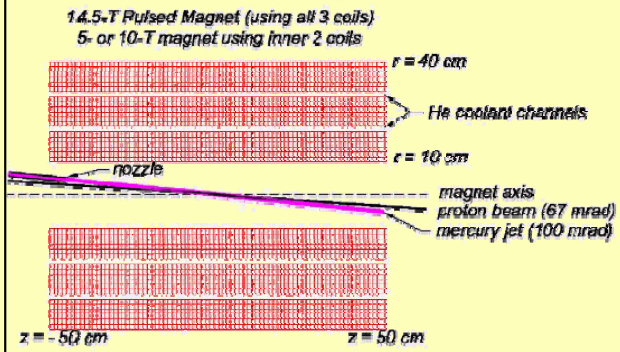
- **Proof-of-principle test to demonstrate interaction of Hg free-jet within a 15 T magnetic field**
- **CERN facility beam 24 GeV, 1 MW, up to 10^{13} protons/pulse**
- **Observe beam/jet interaction with high-speed optics, BNL**
- **Diagnostics: fiber-optic system integrated with high speed camera, BNL**

15 T magnet, MIT

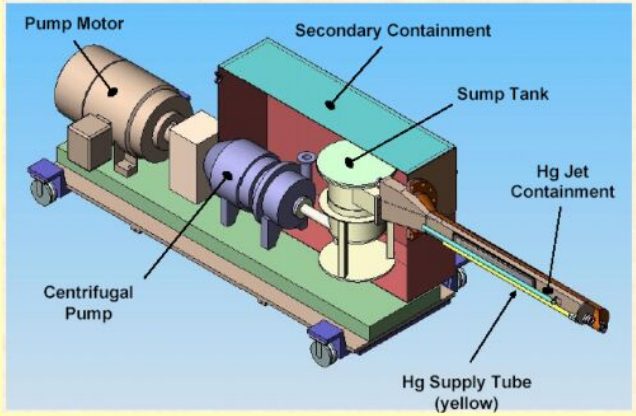


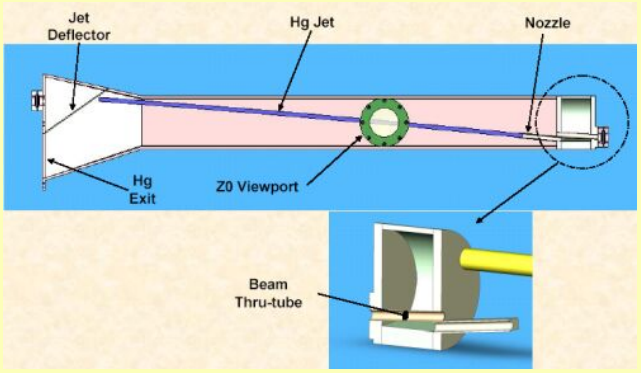
BNL Pulsed Magnet –Inertially Cooled , 80K LN2 Cooled Between Shots

A 14.5-T Pulsed Magnet with 5- and 10-T Phased Options

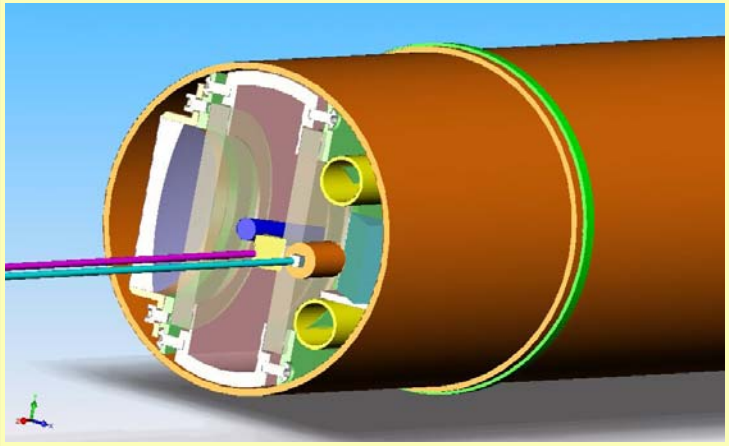


Hg free-jet, ORNL





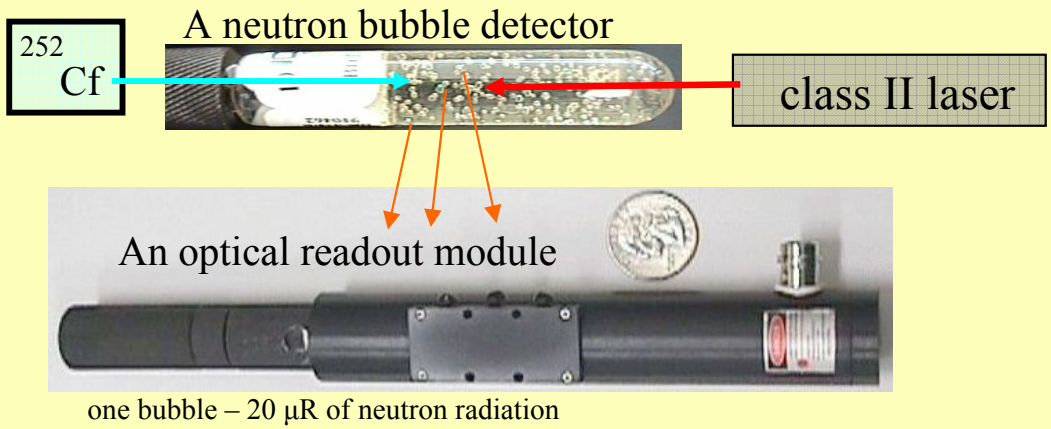
Optical diagnostics, BNL



- all passive fiber-optics components
- compact high resolution imaging system
- flexible fiber imaging bundle for imaging transfer, high intensity pulsed laser for illumination
- image capture with 1-μs frame rate CCD
- Beam-on test @ CERN, Dec. 2006

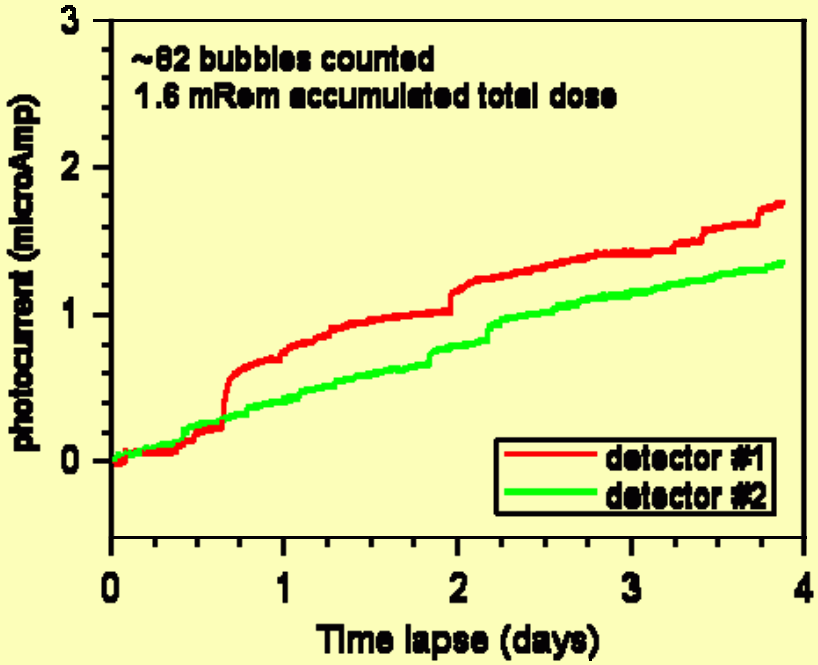
Homeland security:Development of compact optical readout module for standard neutron bubble detector (NNS & BTI)

Optical detection of bubbles – 90° light scattering

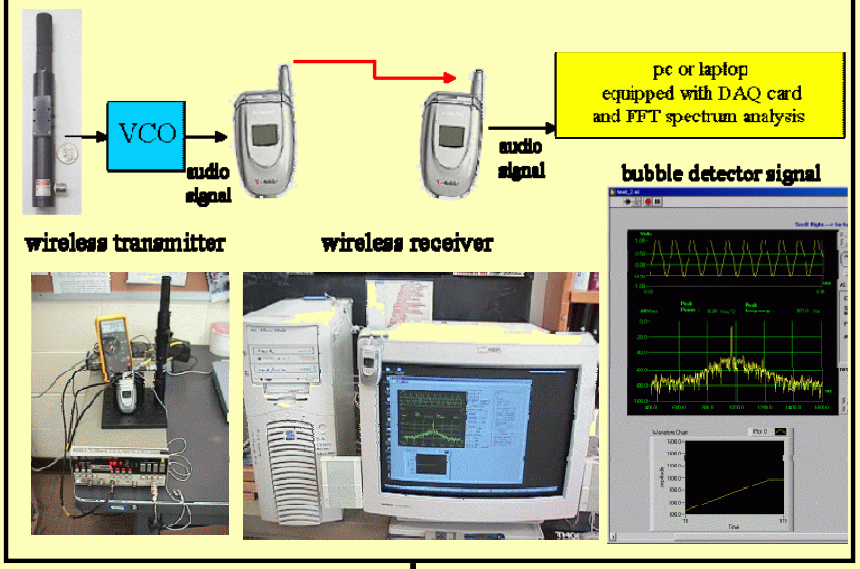


one bubble – 20 μR of neutron radiation

Optical response increases linearly with neutron dose



Wireless readout & monitor of neutron dose



Simulated tracking system in a sea container or trailer

US patent filed

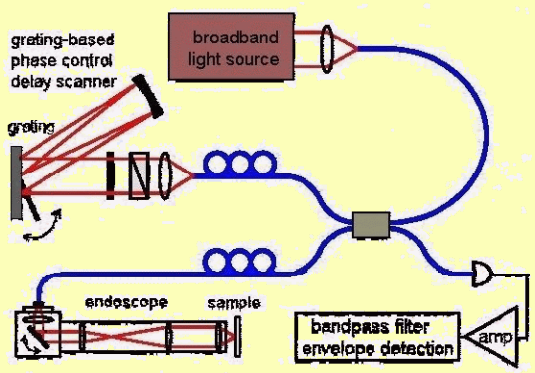
New directions on laser applications

Optical coherent tomographic (OCT) imaging of biological tissues

To develop a noninvasive medical diagnostic tool using non-ionization radiation sources. The program benefits the Life and Physical Science programs to be established at BNL

What we know:

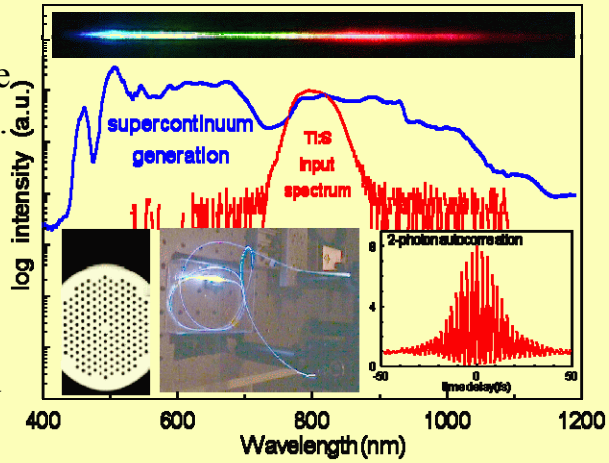
OCT is a non-contact interferometric technique that measures the reflected or back-scattered light from within the subsurface biological tissue. The image resolution improves with larger laser bandwidth



typical OCT setup

What we propose:

OCT imaging using supercontinuum light source → highest image resolution. Combine a fluorescence or multiharmonic guided method to substantially enhance the efficiency and the sensitivity for rapid medical diagnosis. The new technique has the potential to improve the prospect for the detection of early-stage tumors.

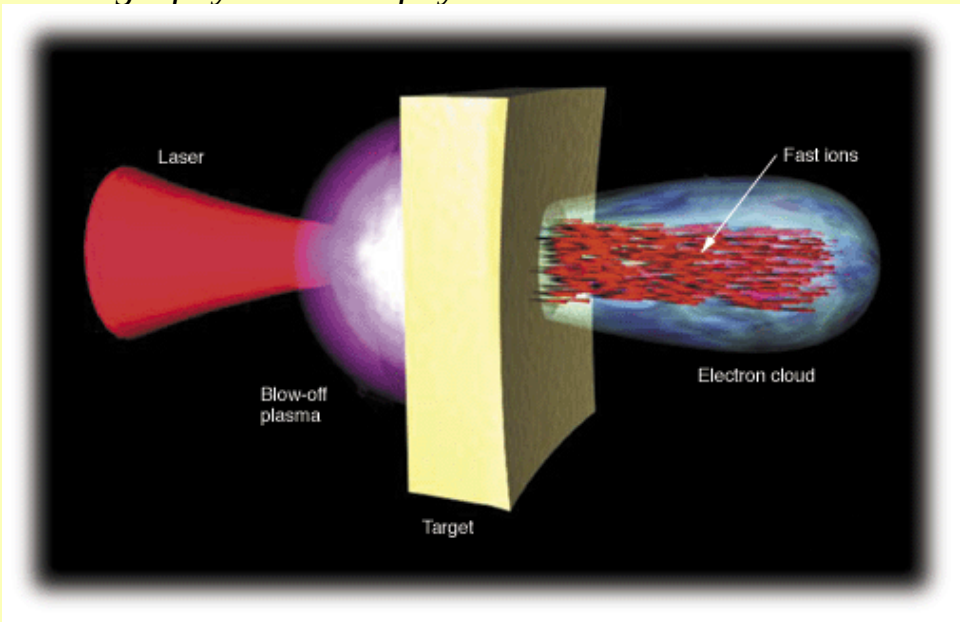


Cupercontinuum light source at BNL

LDRD submitted 2005

Electron and X-ray Production by Ultra-intense Laser Interaction with Material

To develop a laser-based source capable of efficiently producing multiple types of radiation. Multi-TW laser sources have the potential to provide spatially coherent, femtosecond particle (electron, proton, positron, ion) and X-ray beams, revolutionizing fields such as radiography and astrophysics.



Livermore Petawatt Facility

What we propose:

Optimize target and laser pulse parameters to produce characteristic (K-α) X-rays and energetic electrons. Provide a diverse particle source useful for radiography and detector calibration.

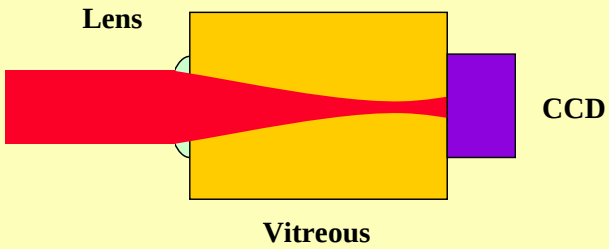
LDRD submitted 2005

New directions in laser applications

Ultrafast Laser Bioeffects

To investigate the biological effects of sub-nanosecond laser light. Multi-photon ionization may lead to DNA damage, even at laser intensities below the threshold for plasma formation.

Phantom Eye



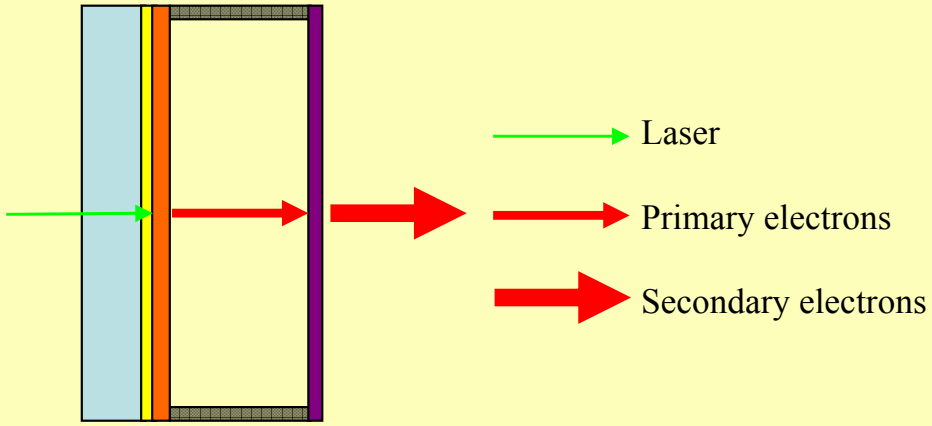
What we propose:

Characterize the threshold energies for cellular necrosis and apoptosis as a function of laser wavelength and pulse duration. Observe cells for abnormal growth patterns after irradiation. Construct a 'Phantom' eye to observe plasma formation in the vitreous and observe laser profile on CCD 'retina'

LDRD submitted 2005

Transmission Photocathode Development

To create an high brightness electron source capable of delivering more that 100mA average current. Such a source is needed for the electron cooler project for RHIC



What we propose:

Develop a transmission-mode photocathode capable of delivering 10mA average current at cryogenic temperatures, using K_2CsSb on a transmarent substrate with a thin copper layer. Cathode would be sealed in a capsule topped by a diamond secondary emitter, to protect the cathode and amplify the emitted current.

LDRD submitted 2005

7. Micro/nano Fabrication

Current E-Beam Lithography Capability at BNL

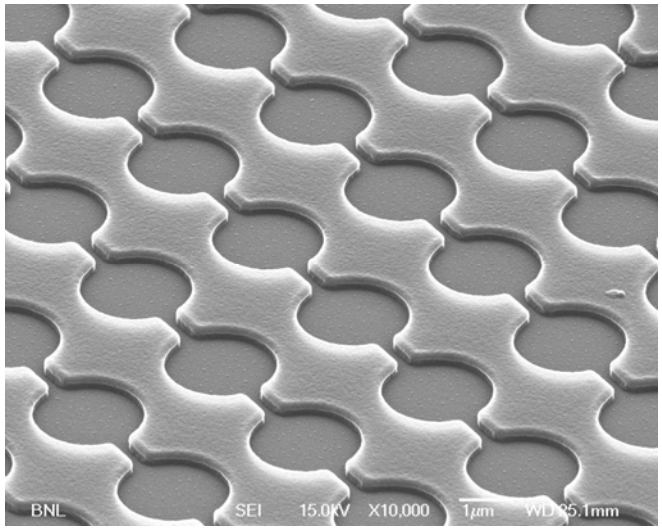
<u>JEOL 6500F in Instrumentation</u>:

Cost ~ $400,000.
50 nm line width - 100 mm wafers

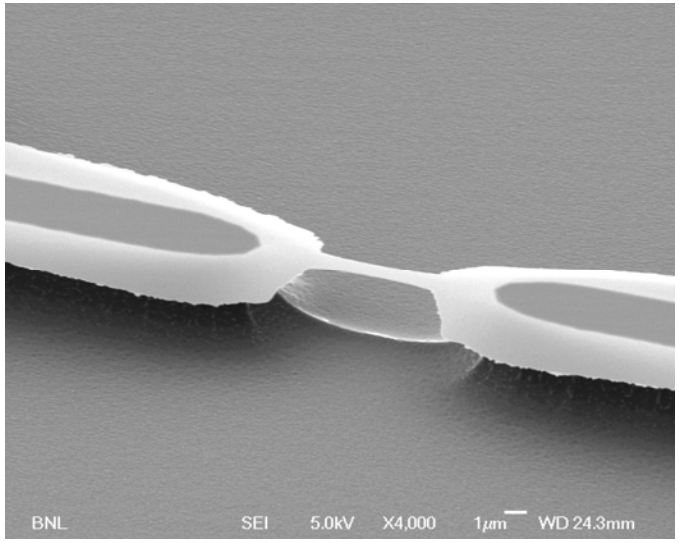
<u>JEOL 9300 at Lucent Technologies</u>:

Cost ~ $5,000,000,
20 nm lines widths on 300 mm wafers.
<u>Similar equipment will be operational at BNL in 2007</u>.

On Site Capability: Electron Beam Fabrication with the JEOL 6500 in Instrumentation



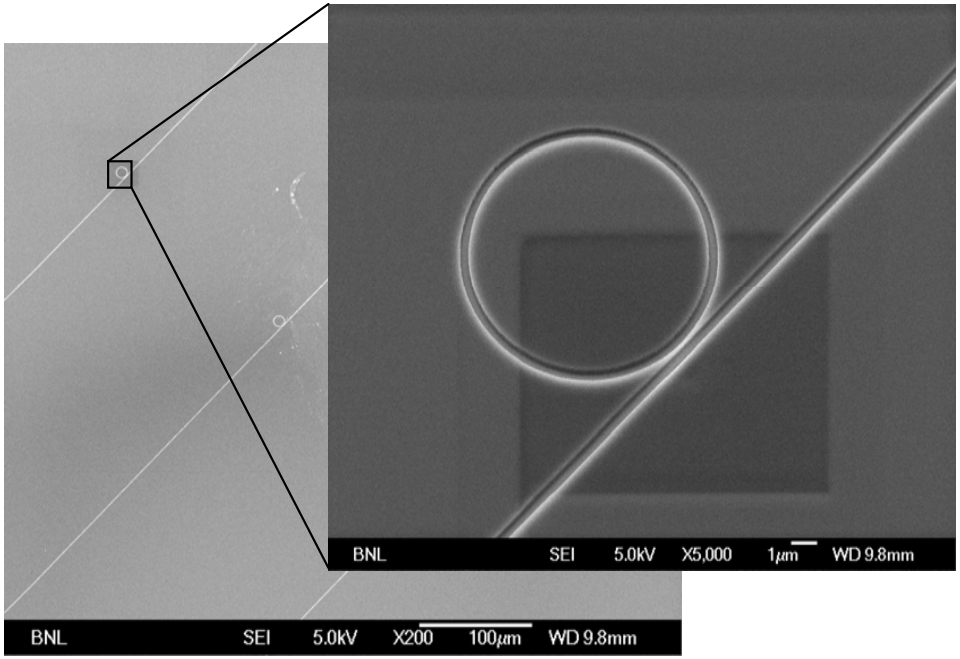
<u>Work for Biotechnology at SUNYSB</u>:
Fabrication of linked cavities in silicon. When cavities are sealed with a Pyrex coverglass, optical fluorescence microscopy will be used to measure diffusion times of DNA through the cavities for "DNA analysis on a chip".

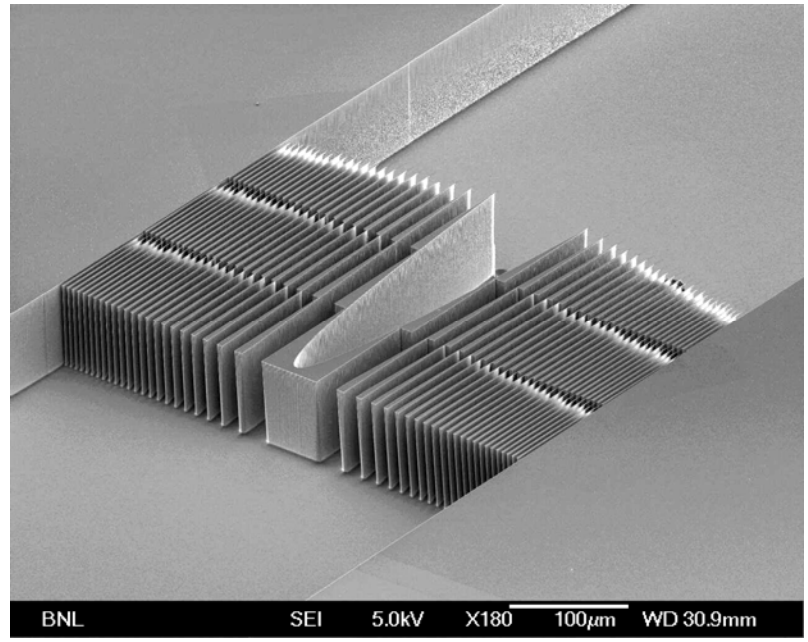


<u>Fabrication of Metallic Nanowires on SOI Substrate</u>:
Isotropic plasma etch exposes nanoscale wire connected to pads used for conductivity studies. Any vapor deposited metal can be used to fabricate the "wire".

John Warren, et al.

Examples of Projects Requiring High Resolution, Large Area Exposures with JEOL 9300 at Lucent Technologies





<u>Photonics research with Columbia University</u>: Long waveguides (several cm) with ring resonators exposed with JEOL 9300 at Lucent Technologies with no field stitch errors.

<u>Fabrication of lighthouse-style Fresnel lenses for focusing of x rays for NSLS</u>: Pattern exposed with JEOL 9300 and etched into silicon (~60-80 microns deep) with Deep Reactive Ion Etching (DRIE) at Lucent Technologies.

Grants for Projects from Diverse Sources

DOE/OBER: **Neutron Detectors; PET**

DOE/BES: **Neutron Detectors**

Other National Labs

- **Los Alamos National Laboratory, "Application Specific Integrated Circuit (ASIC) for Coplanar Grid (CPG) CdZnTe", PI: P. O'Connor**
- **ANL, Neutron Detector, PI: G. Smith**
- **SNS/ORNL, Neutron Detectors, PI: G. Smith**
- **NIST, Neutron Detectors, PI: G. Smith**

Non-DOE Federal Agency

- **National Space Biomedical Research Institute (NSBRI), "Micron Resolution Detector", V. Radeka, Z. Li.**

NRL/DARPA: **x-ray Si Detector for Astrophysics, PI: G. De Geronimo**

CRADAs

- **Advanced Energy Systems, PI: T. Srinivasan-Rao**
- **eV Products, Readout ASICs for CZT Detectors, PI: P. O'Connor**

SBIR subcontract

- **Photon Imaging, Readout ASICs for gamma camera, PI: G. De Geronimo**

Work for Others

- **Frequency Electronics Inc., Radiation Effects Testing, J. Kierstead**
- **Advanced Energy Concepts, Si Detector Technology, Z. Li**

Mission *vs* Funding

- Grants from diverse sources are clearly beneficial as they broaden the scope of work and make available the Division's expertise to other institutions. They should be pursued to ***augment*** the base Instrumentation program supported by G&A, and ***they must not detract*** from supporting BNL research program and core technologies.

  ~30% of the staff funded from other sources.

- Benefit of Instr. Div. to BNL ("and the community at large"):

  Provide technology base and expertise, and serve as ***a resource for important programs and initiatives***, such as ***RHIC experiments, electron cooling, ATLAS/LHC upgrades, RSVP, LSST, Linear Collider, as well as for NSLS, detectors at SNS, nanotechnology, and medical imaging***.

  ~70% of the staff funded from the Lab overhead (G&A).