Instrumentation Division Report

Veljko Radeka

Presentation to the DOE HEP Program Review

April 23, 2003

Outline

- ***Core Technologies***
- ***Key Accomplishments and Program***
- ***Funding***

BROOKHAVEN NATIONAL LABORATORY

Instrumentation Division

Mission:

"To develop state-of-the-art instrumentation required for experimental research programs at BNL.
To provide limited 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).

Staff:

48 Total
27 Scientists & Professionals
21 Technical & Administrative

Publications in FY 01/02

HEP Related:	**15**
All Programs:	**45**

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				

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;
- KOPIO, MECO at AGS: Si-drift photo diode for calorimeter; calorimeter and tracker electronics;

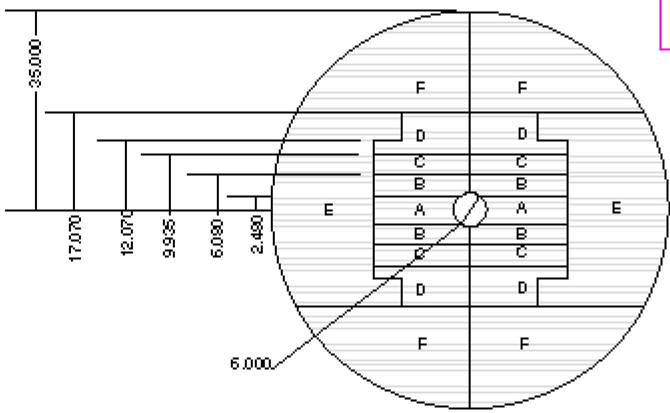
R&D for Future Facilities (LHC *Lum*. upgrade, Linear Collider):

- ***Si-detector technology*** (the only facility for U.S. HEP program):
  - ***single-sided 2-d strip detectors***
  - ***radiation hardness techniques: oxygenated, ~ 100 ohm cm***
- ***Microelectronics***, low noise,submicron-to-nanoscale;
- ***Neutrino Detectors***, new concepts; ***LSST***
- ***Picosec/femtosec beam diagnostics*** for future accelerators.

Segmented Si Strip Detectors for CERN NA60 (Telescope for Proton Physics at SPS)

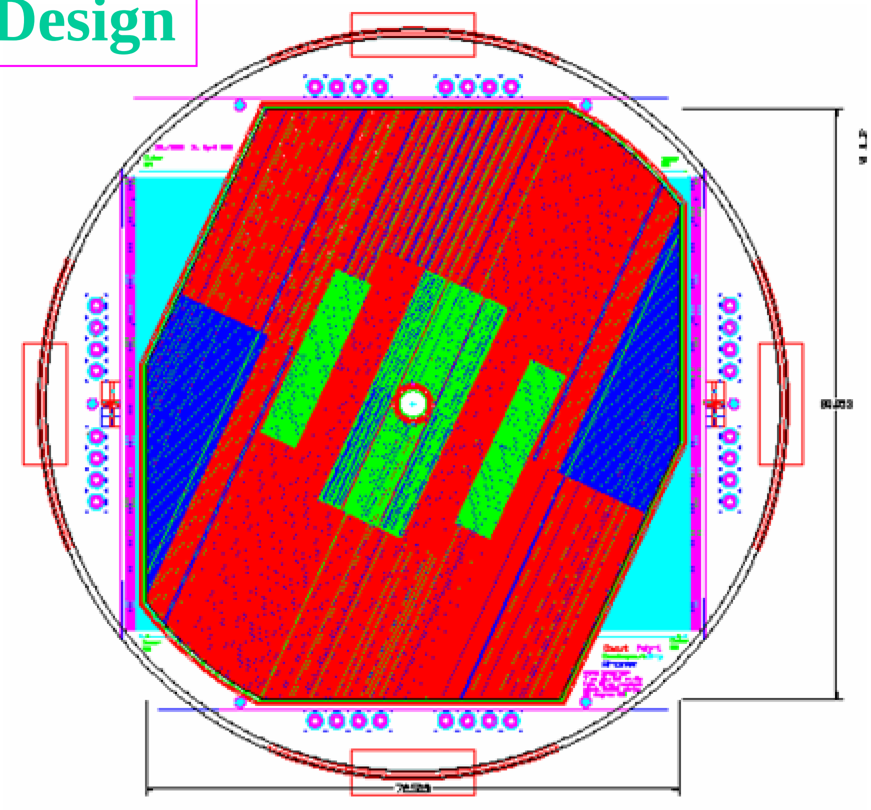
- Different pitches
- Strips segmented
- 60 degree rotation
- A hole in the center
- Installed and tested at CERN

Schematic



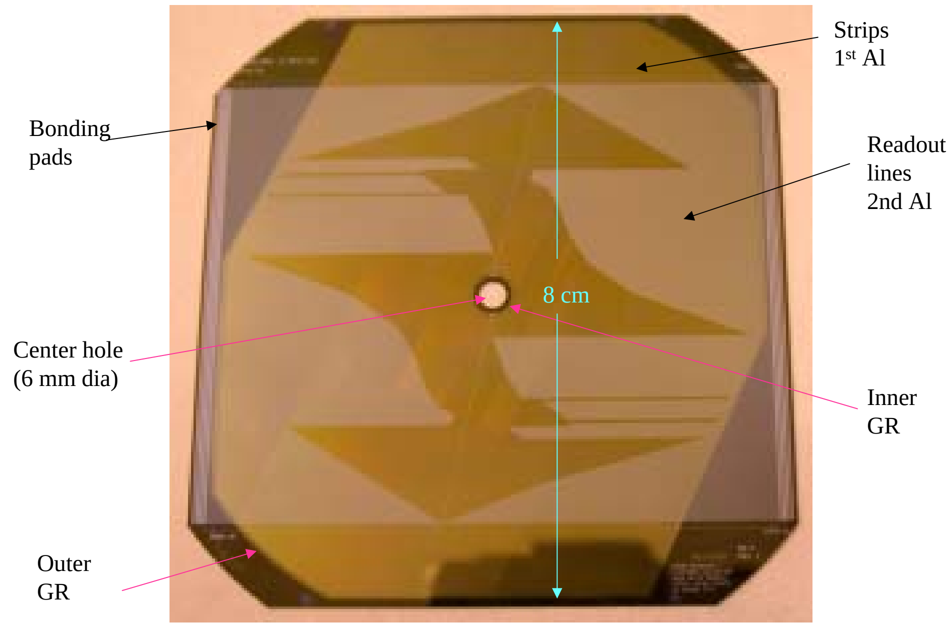
	Pitch(μm)	Channels
A	80.00	62
B	60.00	60
C	80.00	48
D	134.91	53
E	151.06	226
F	226.96	79

Design



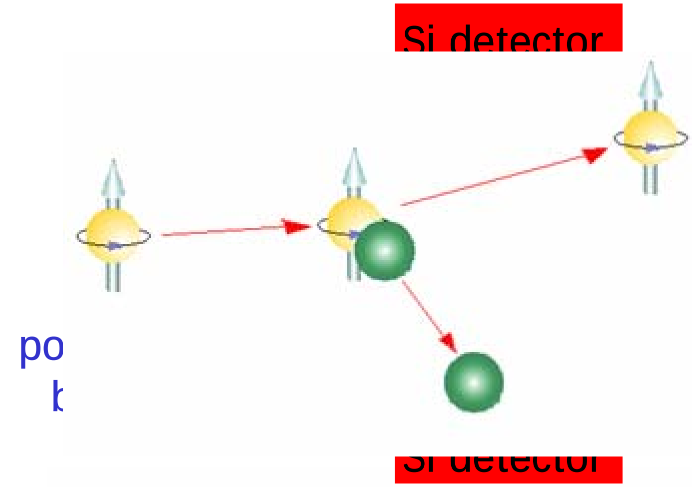
Processed detector

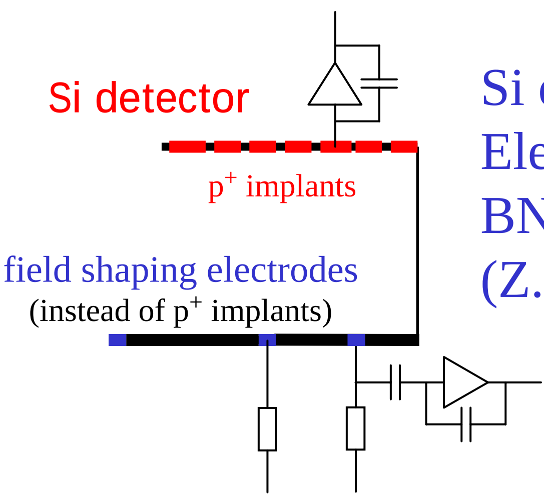
NA60 Segmented Si Strip Detectors



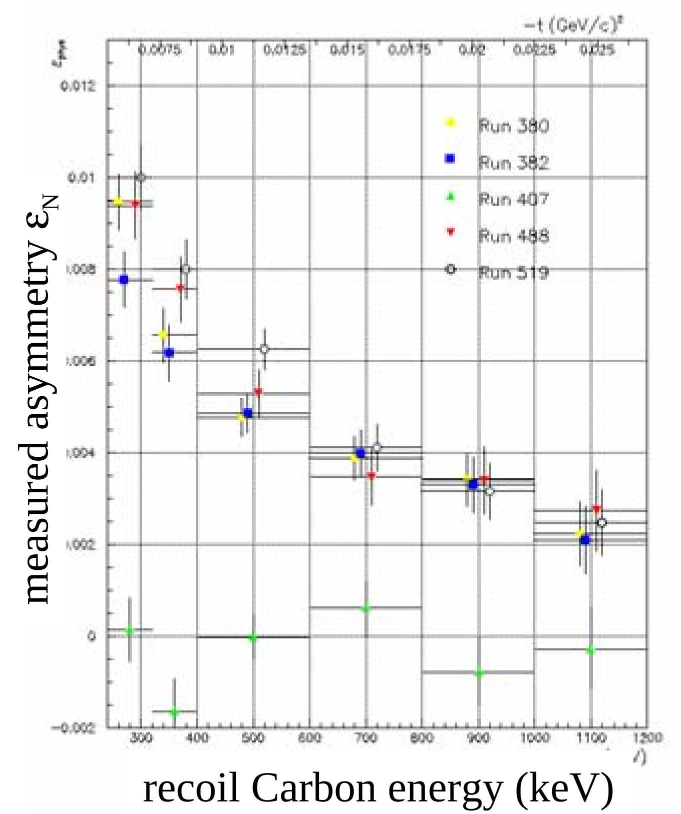
SPIN POLARIMETER for RHIC and AGS

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.





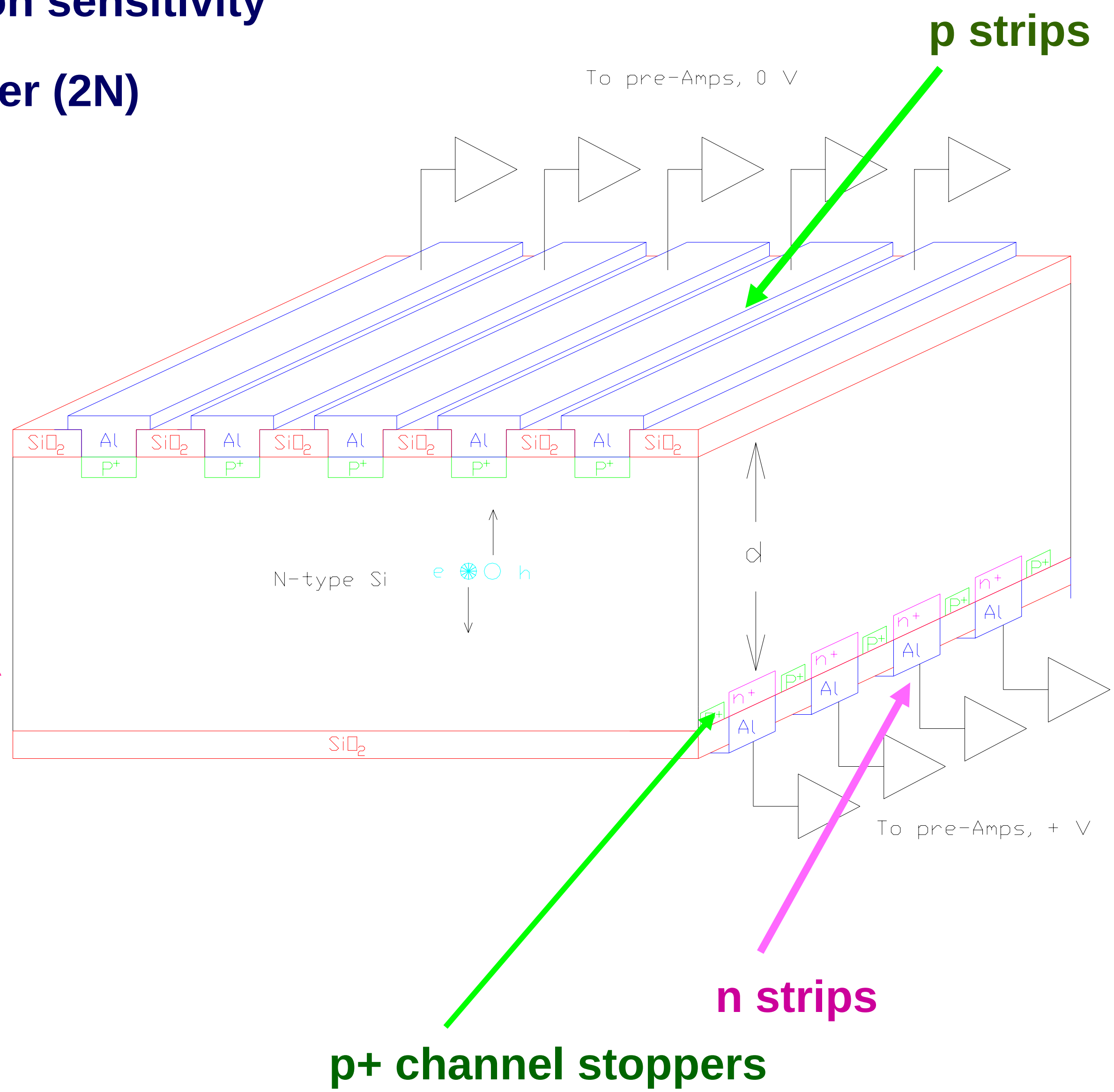
Si detectors and Front End Electronics Developed at BNL Instrumentation Division (Z. Li & S. Rescia)



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**

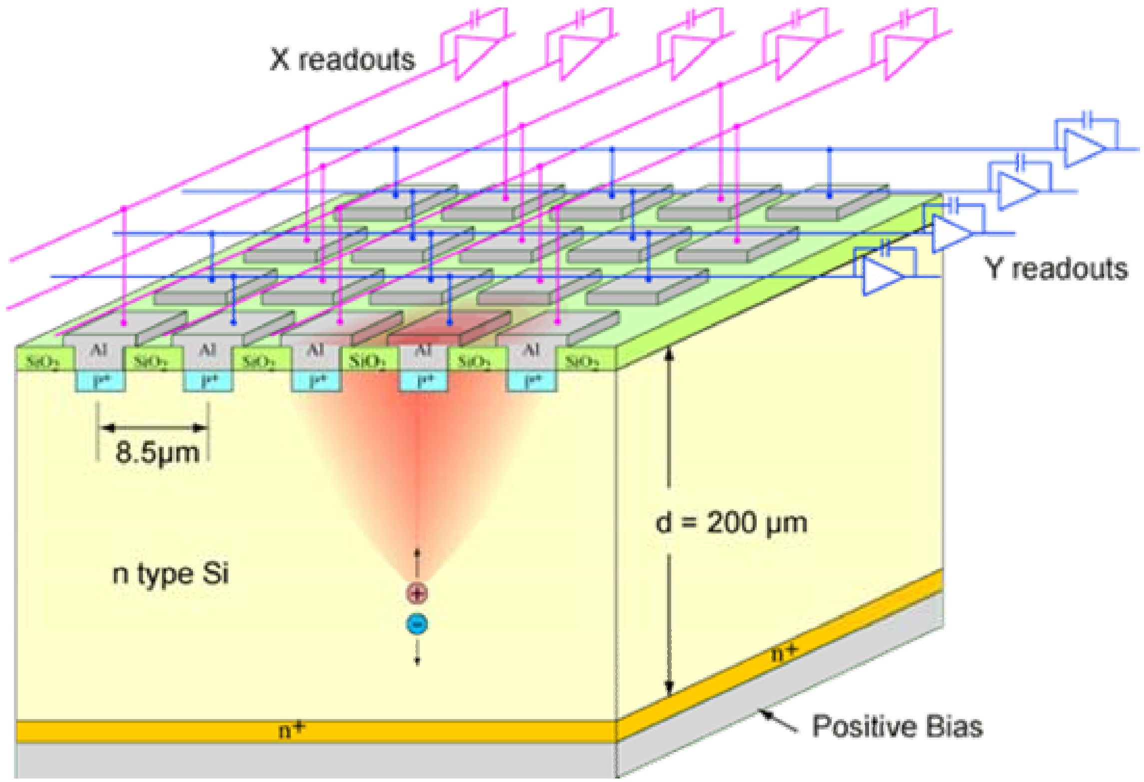
The new concept:

Alternating stripixel detectors (ASD)

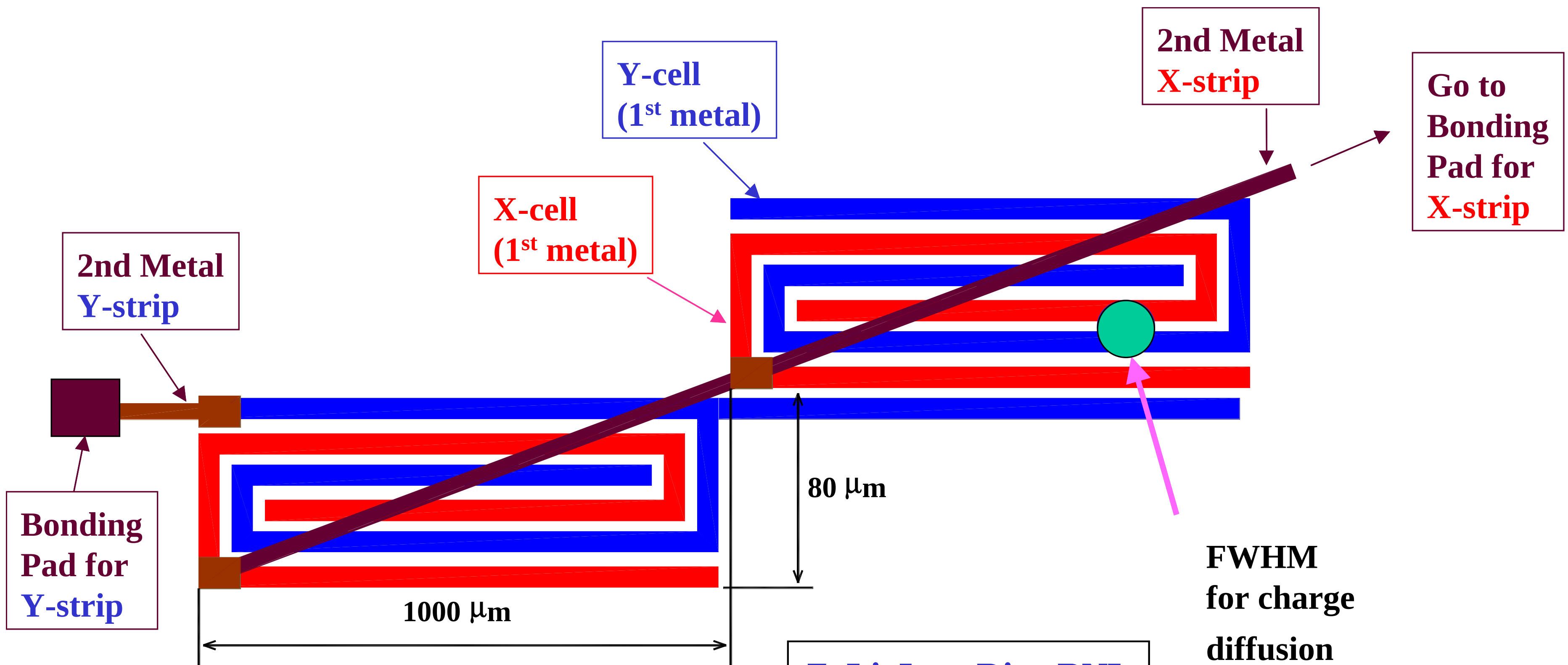
Individual pixels are alternately connected by X and Y readout lines (strips)

- 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



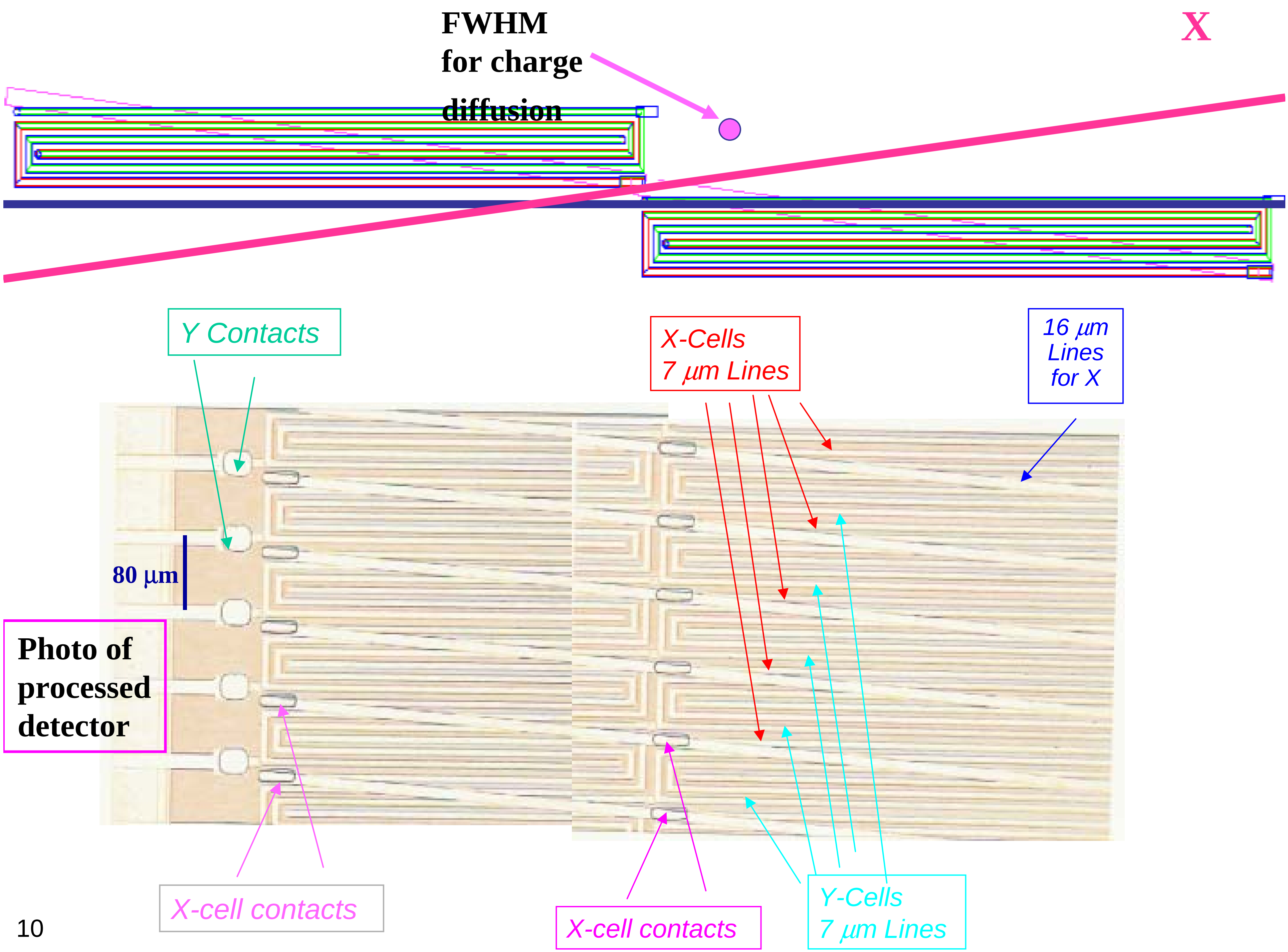
Z. Li, Inst. Div., BNL

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

Pixel arrays: 30x384

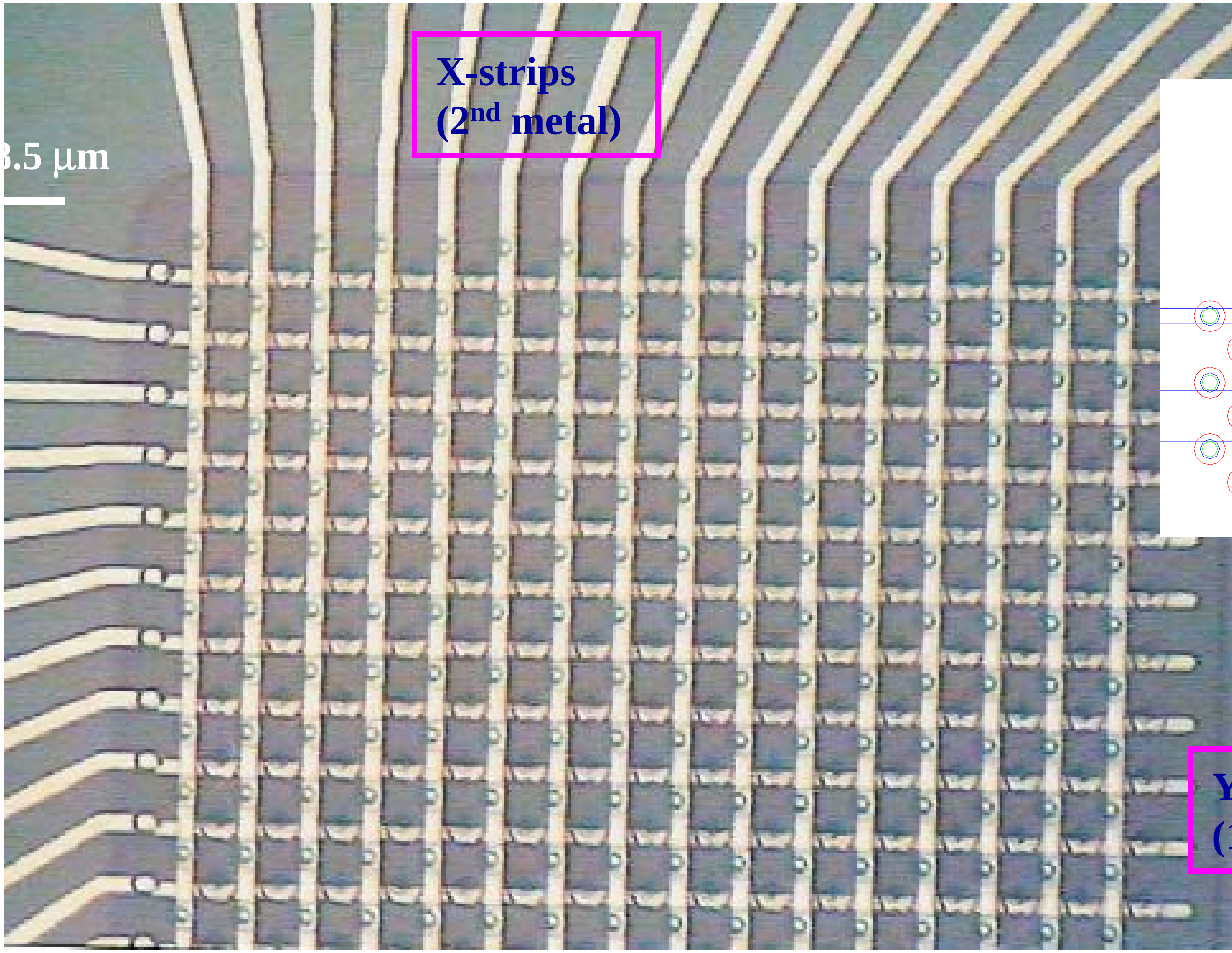
4.6° stereo angle between X and Y strips

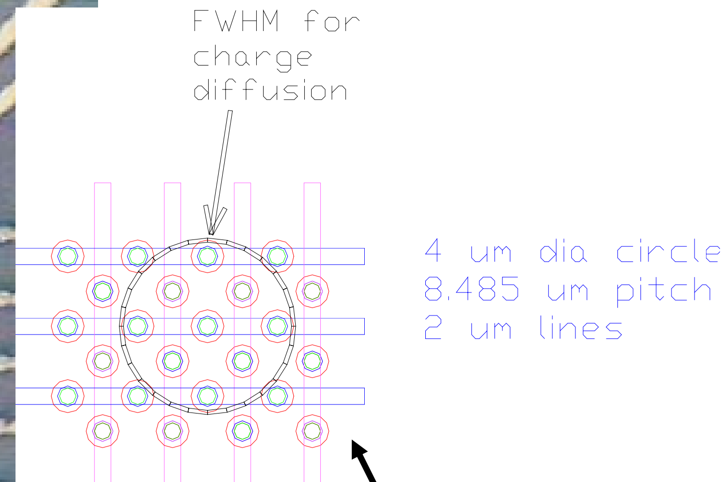
$\sigma_y = \sim 25\ \mu m$


FWHM
for charge
diffusion
X
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



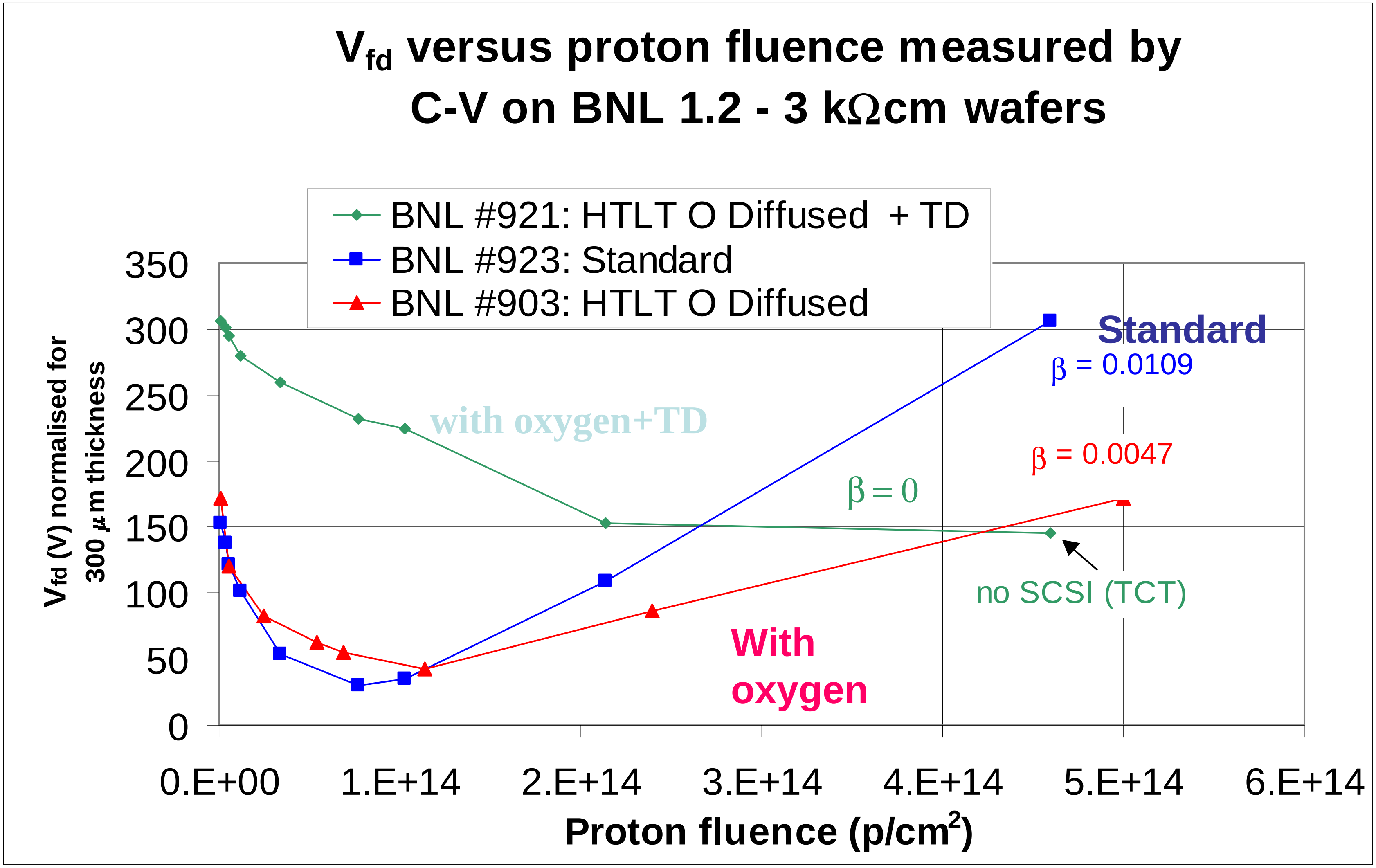


Design and illustration of diffused charge cloud

Photo of processed detector

Oxygen Diffusion technology developed at BNL

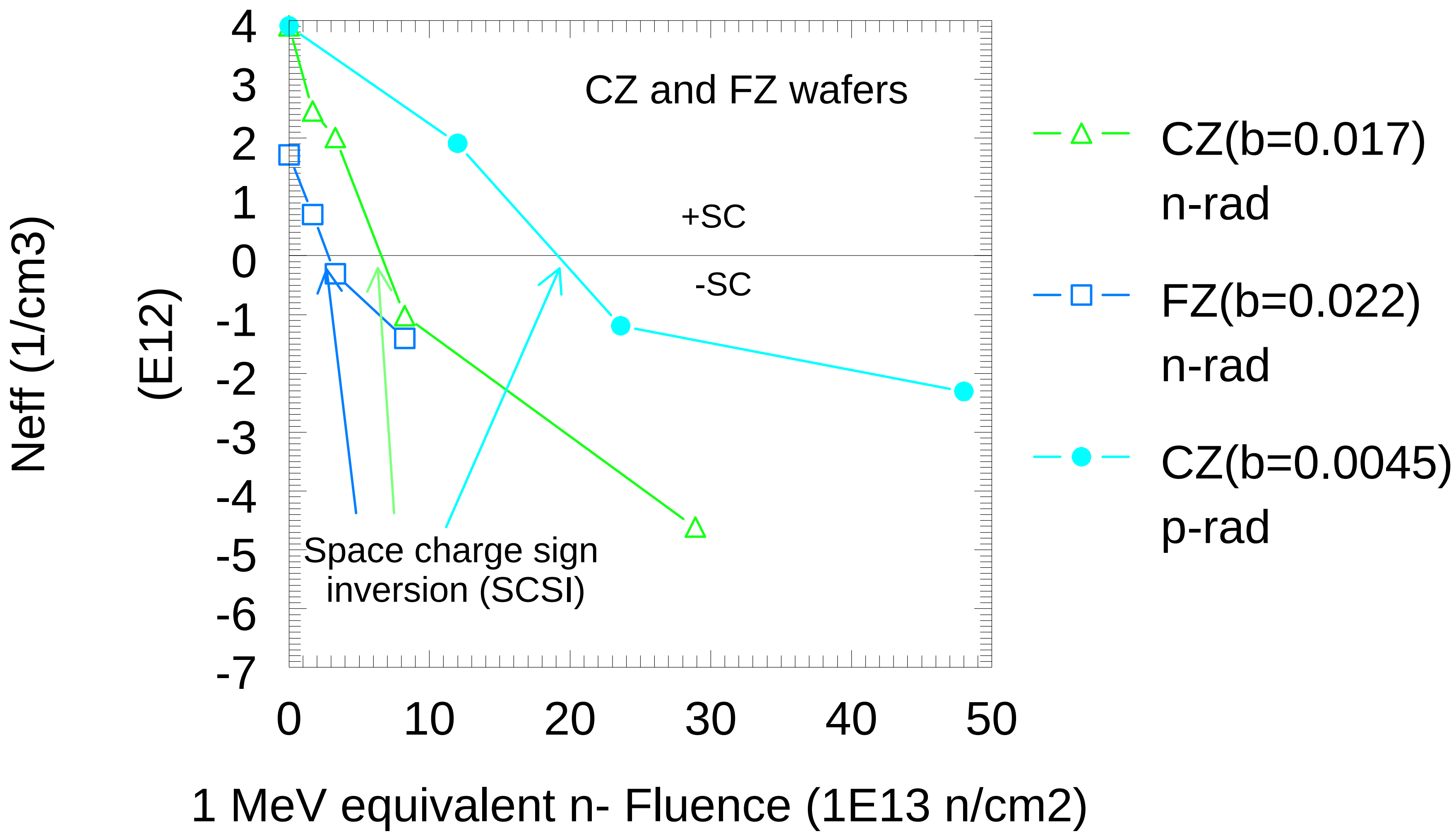
Oxygenated Si detectors are partially radiation hard to charged particles



Z. Li et al.

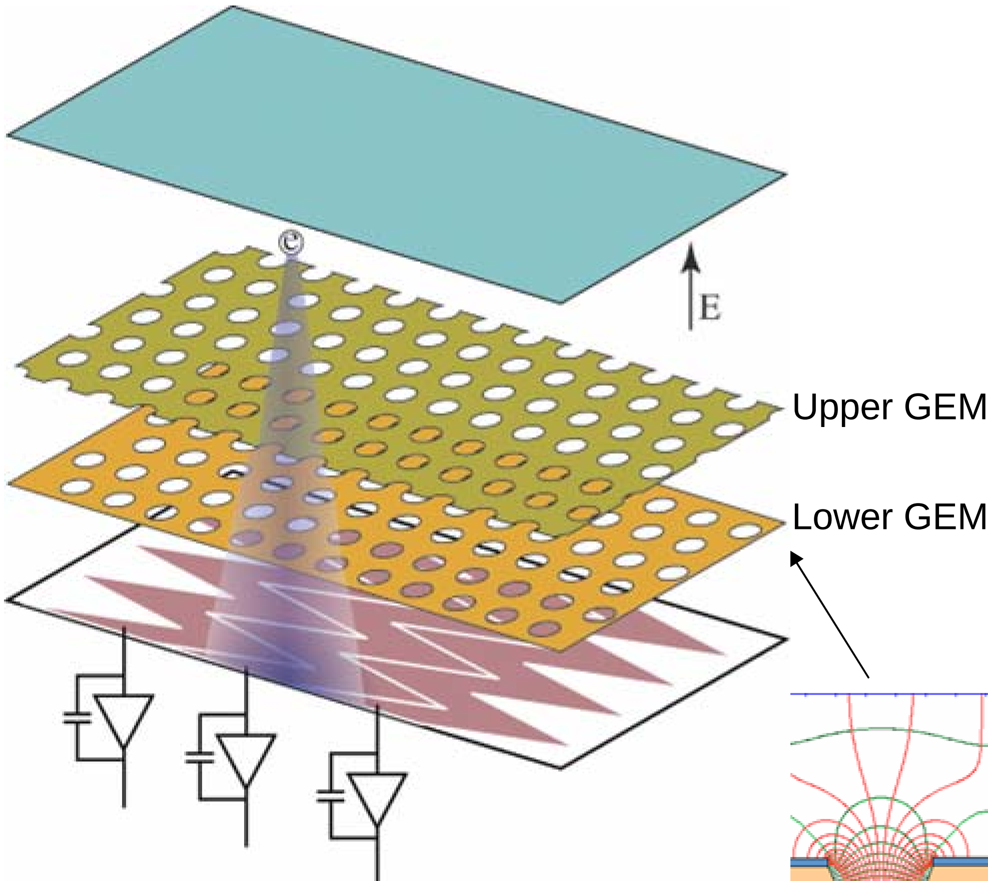
Radiation hardness of medium resistivity CZ Si (high oxygen content)

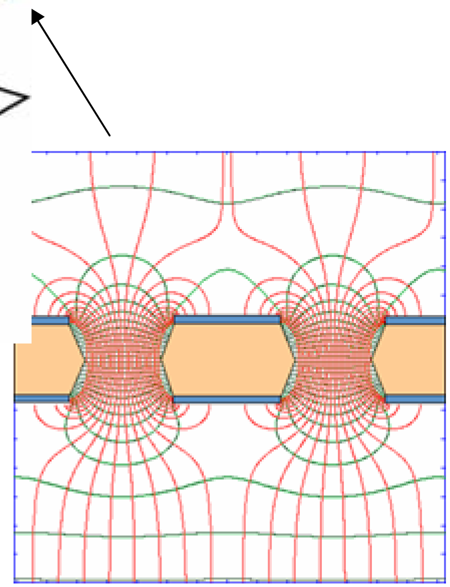
Neutron and proton radiation



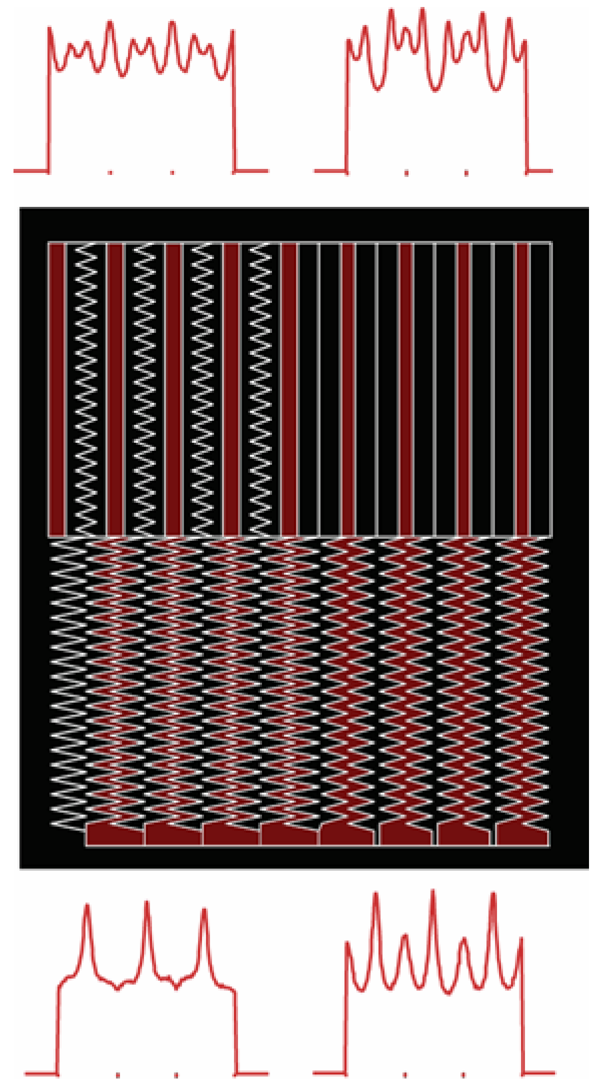
- **CZ Si detectors are slightly more rad-hard than FZ ones with *n-rad***
- **CZ Si detectors are *much more rad-hard* than FZ ones with *p-rad***

Interpolating Pad Readout for GEM (Gas Electron Multiplier)

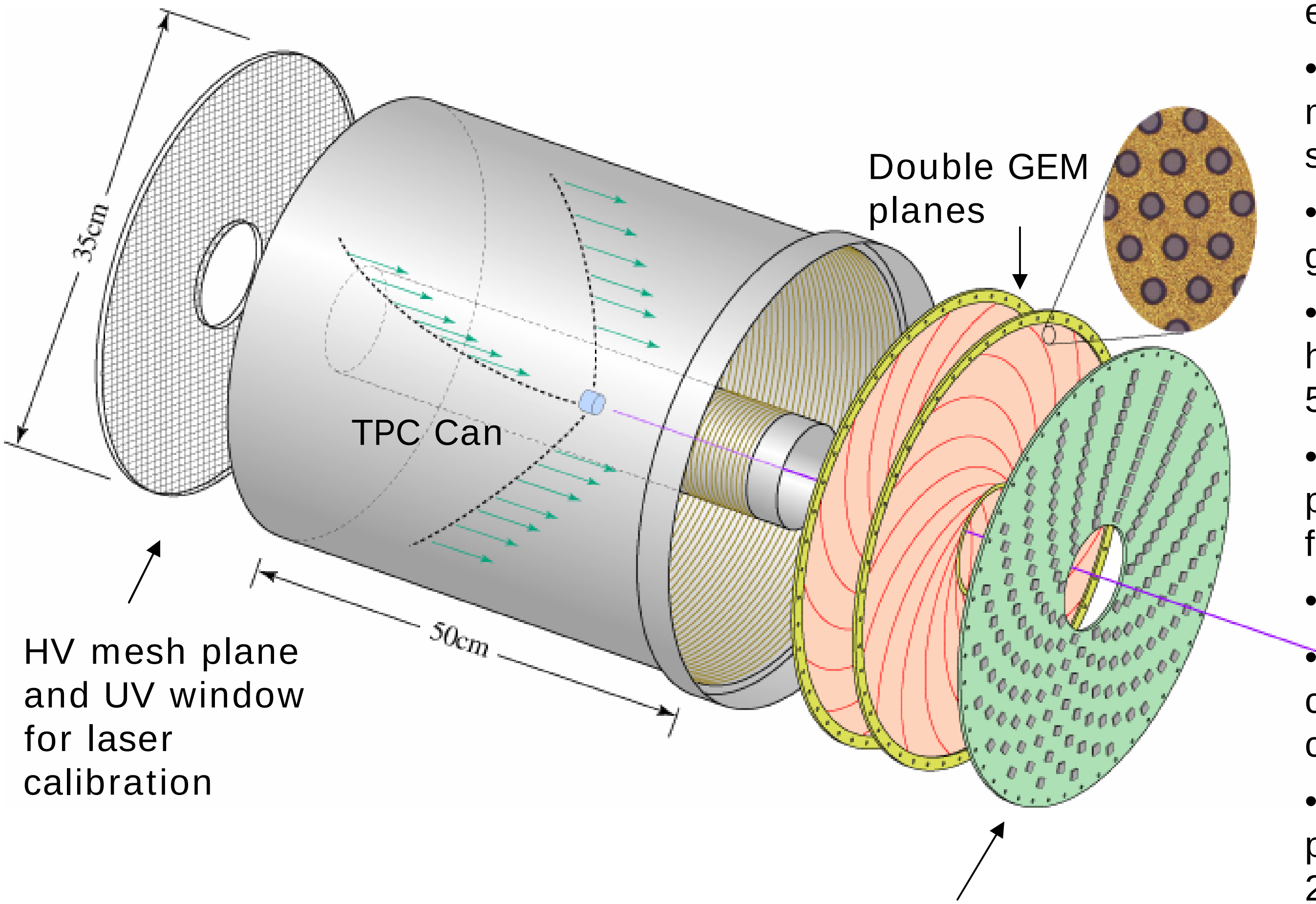




<100µm rms position resolution with 2mm pad pitch



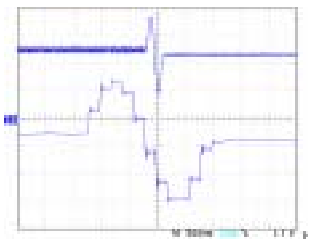
TPC for the LEGS Experiment

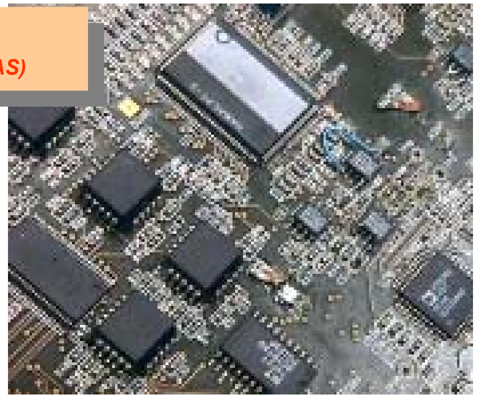


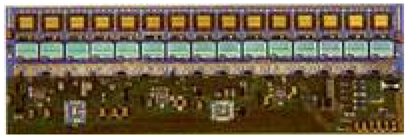
- First GEM based TPC for an experiment
- Designed for low rate, low multiplicity environment: single sample per channel per trigger
- Double GEM amplification, gas gain <1000
- Drift field ~ 600V/cm (30kV high voltage), total drift time ~ 5μs.
- Interpolating zigzag anode pad plane, 200μm position resolution for stiff tracks
- Readout channel count ~8000
- Customized ASICs, 32 channels per chip, 1mW per channel
- Electronic noise <250e, 500ns peaking time, timing resolution ~ 20ns
- 8 sets of ADCs digitize the sparsified and serialized data streams, worst case event processing time <0.5ms

High energy and nuclear physics

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

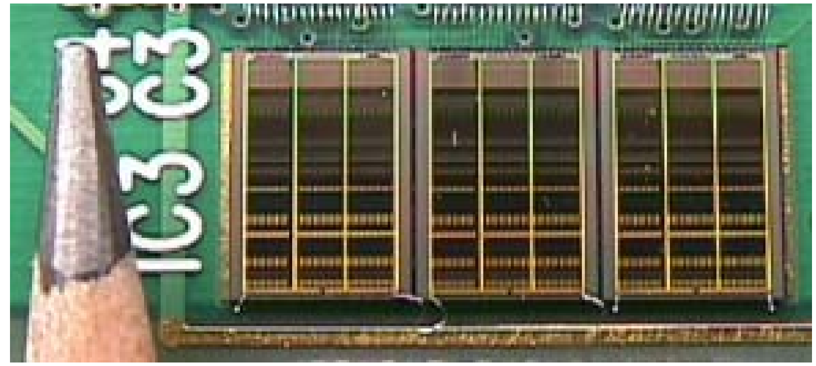






240-channel multichip module for Si drift detector readout *(STAR)*

Condensed matter physics



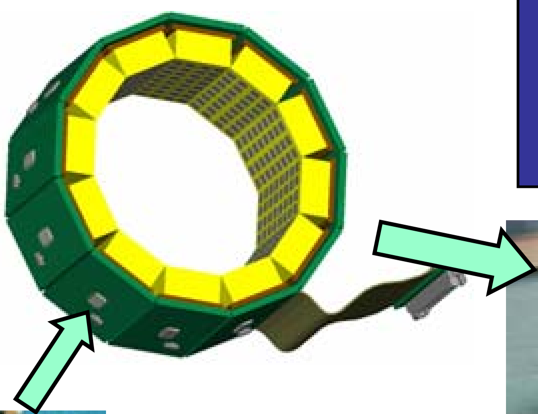
Photon-counting ASIC for EXAFS *(NSLS)*

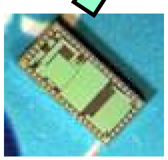
Microelectronics Group

AREAS OF EXPERTISE

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

Life Sciences

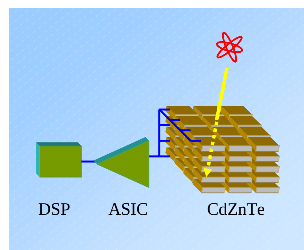




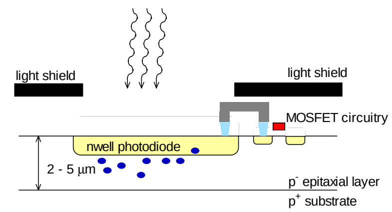
Positron emission tomograph for imaging the awake animal brain *(Medical/Chemistry/Physics)*

Industry collaboration and national security

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



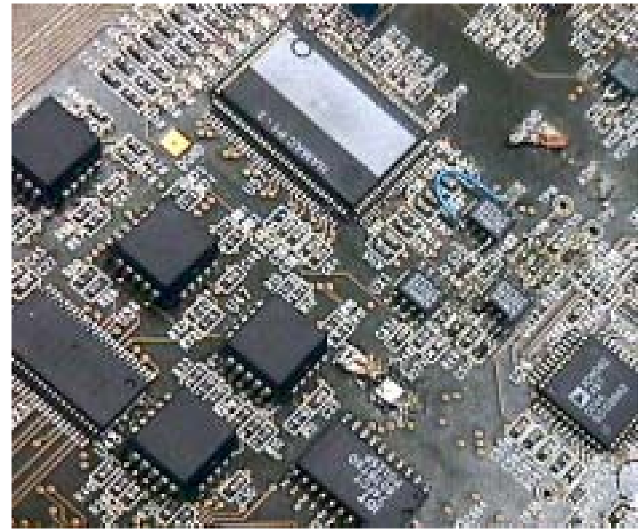
Proposed gamma spectrometer for detection of nuclear materials *(LANL)*



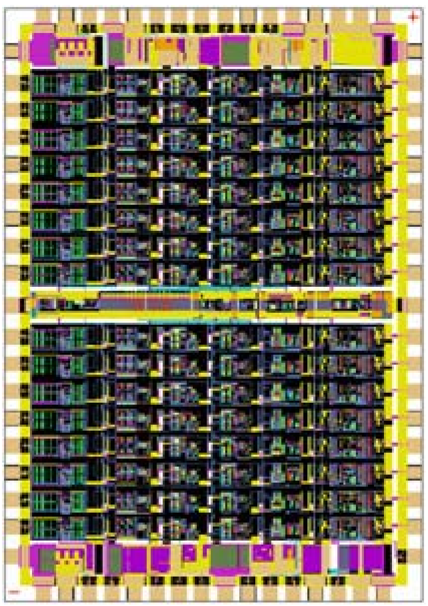
Optically-sensitive pixel for barcode scanner-on-a-chip *(Symbol Technologies)*

ATLAS

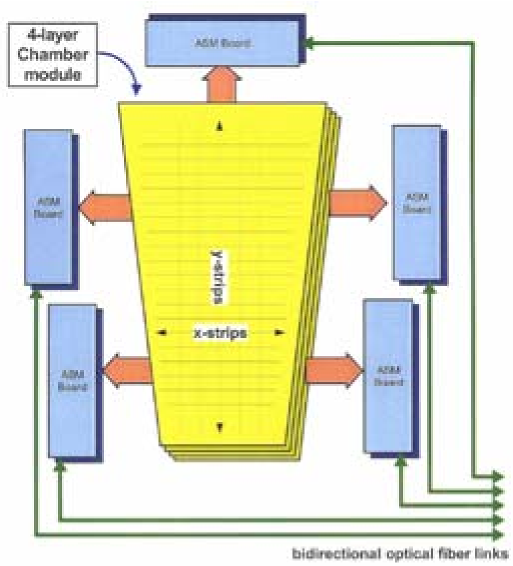
- On-detector electronics for precision muon tracker (Cathode Strip Chamber)
- Four custom CMOS ASICs (preamp/shaper, analog memory, digital multiplexer, clock fanout)
- 2000:1 dynamic range for interpolation
- 30,000 channels
- 480 Gbit/s sustained data rate
- High-radiation environment
- collaboration with Physics Department, U.C. Irvine, CERN



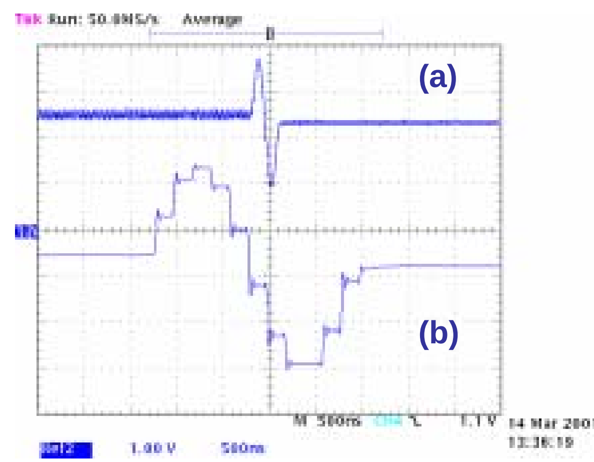
Portion of 192-channel sampling and digitizing board



24-channel preamplifier/shaper



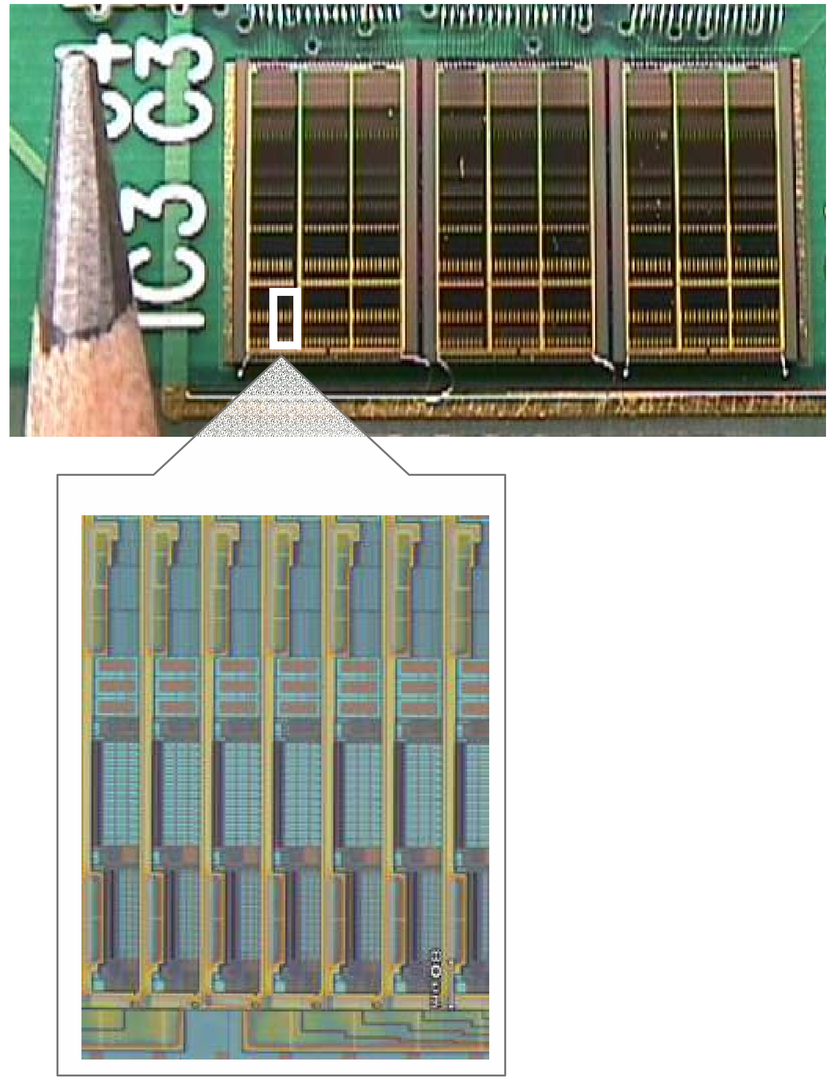
Organization of chamber readout



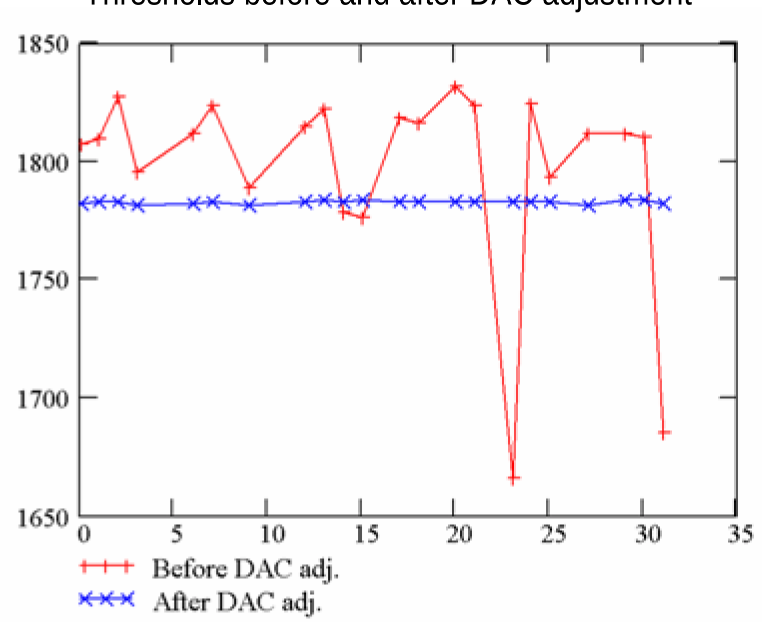
Response to muon signal (a) after preamplification and shaping; (b) after sampling

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



Limits of Low-Noise Signal Amplification in Commercial Deep Submicron CMOS Technology

Predictive noise model to guide new front-end designs including:

- NMOS, PMOS white and 1/f series noise
- continuous transition from weak to strong inversion
- mobility reduction and velocity saturation
- output impedance degradation

Results:

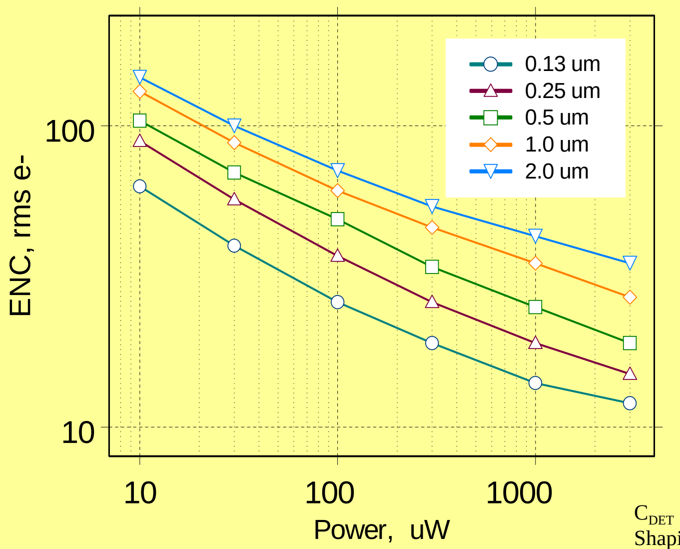
•Revised rules for optimum matching of input transistor to detector capacitance

•Noise/power tradeoff improves with scaling, especially for fast shaping

•Low supply voltage forces lower gain, reduces dynamic range below 0.5 µm

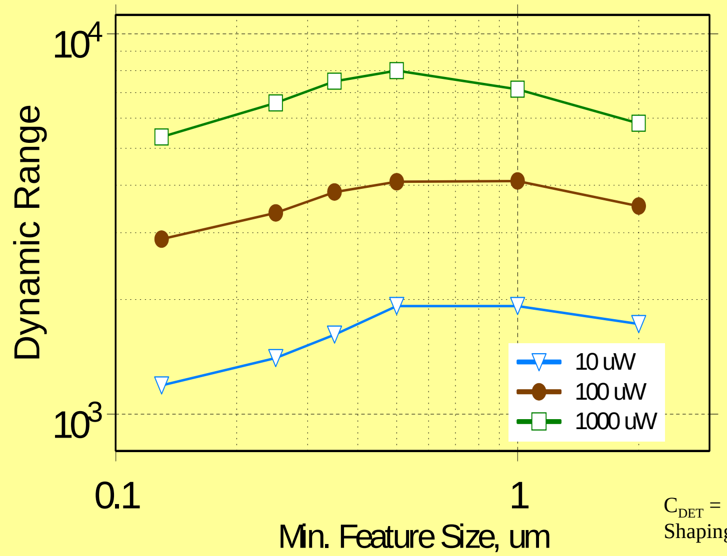
•Limits forseen for 0.1 µm generation: gate tunnelling leakage, poor amplifier gain

Noise vs. power



C_{DET} = 1 pF
Shaping = 1 µs

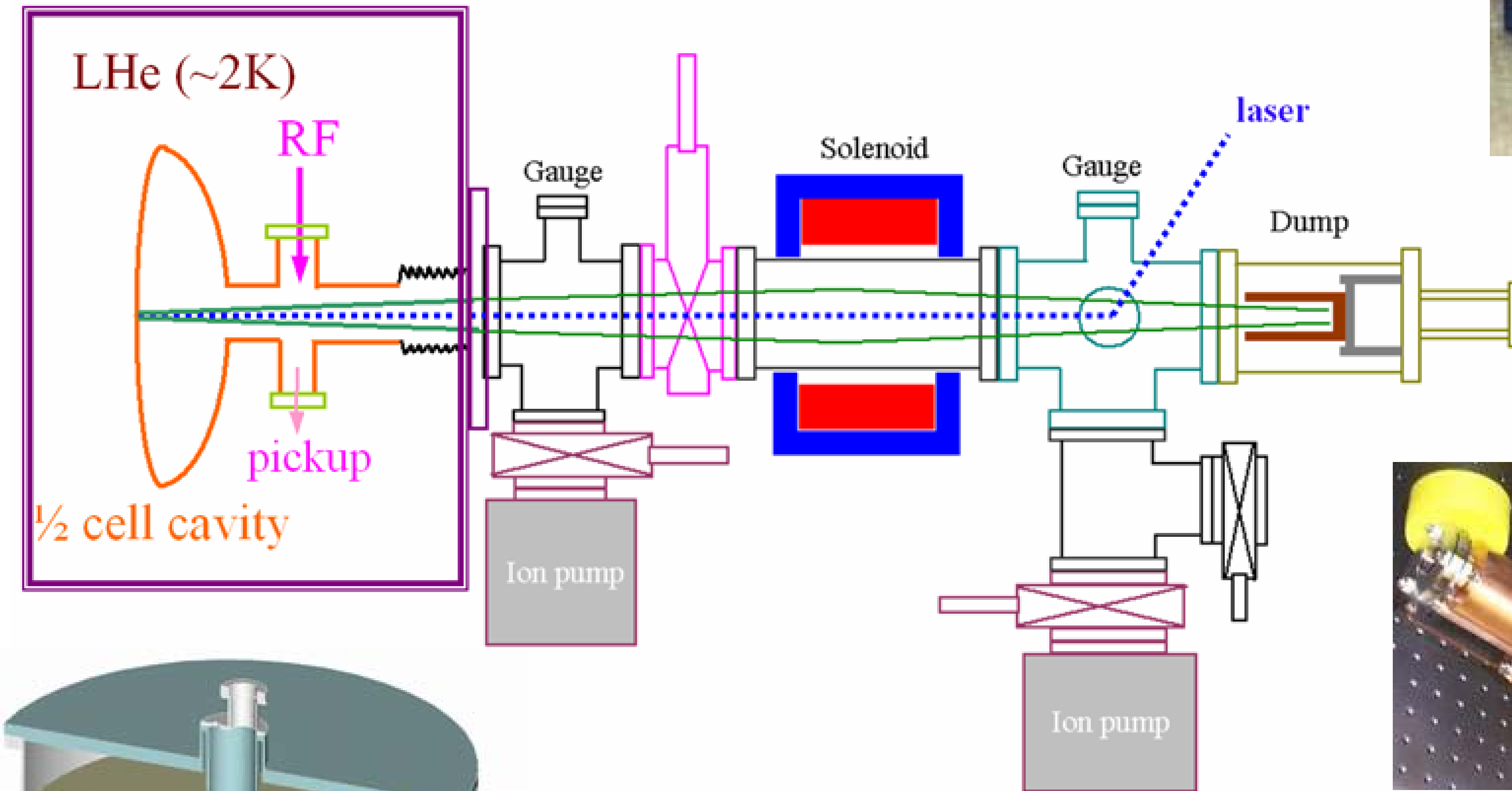
Dynamic range scaling

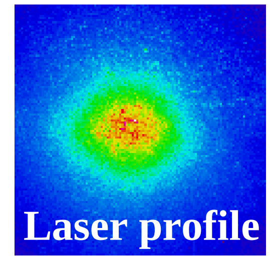


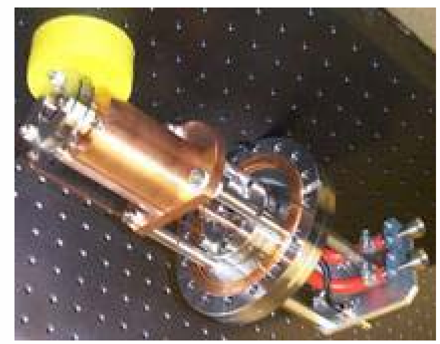
C_{DET} = 1 pF
Shaping = 1 µs

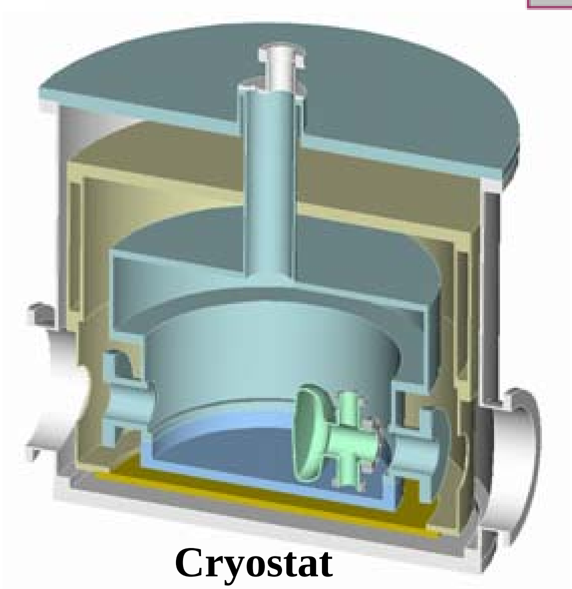
P O'Connor and G. De Geronimo
Prospects for charge sensitive amplifiers in scaled CMOS
NIM A480, 713 (Mar. 2002)

Superconducting Photoinjector



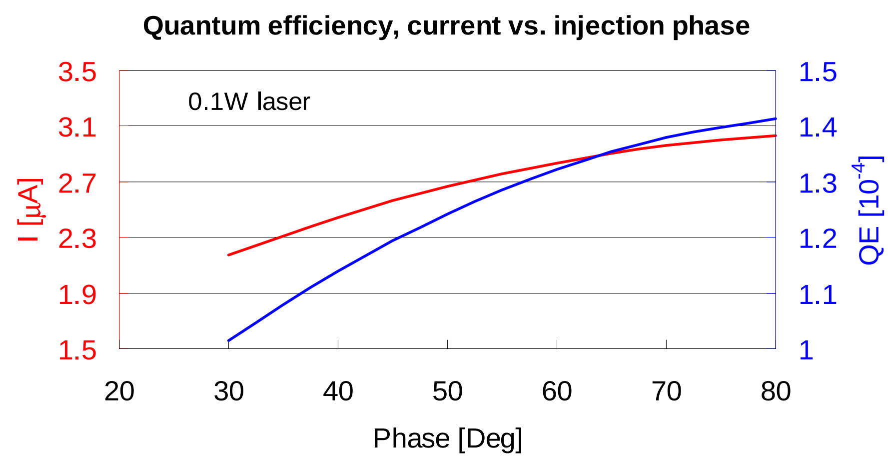




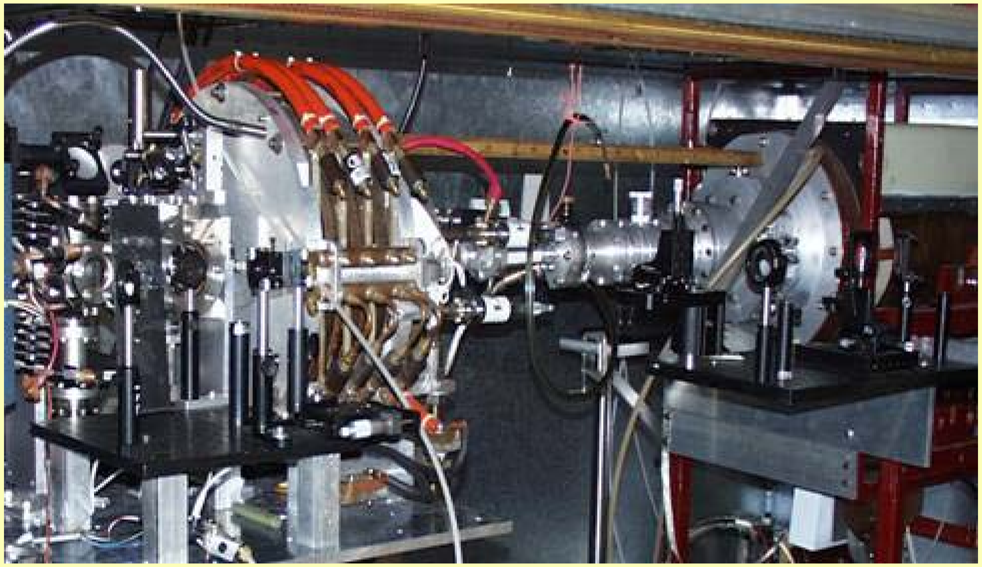


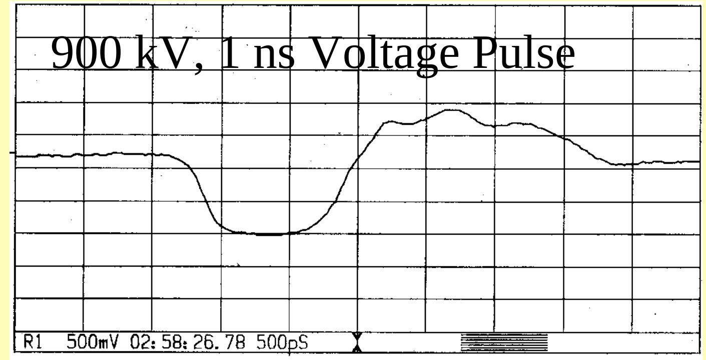
Cryostat

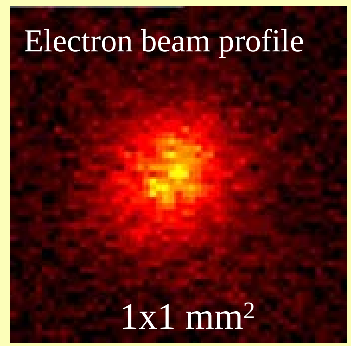
Niobium cavity



Pulsed Power injector



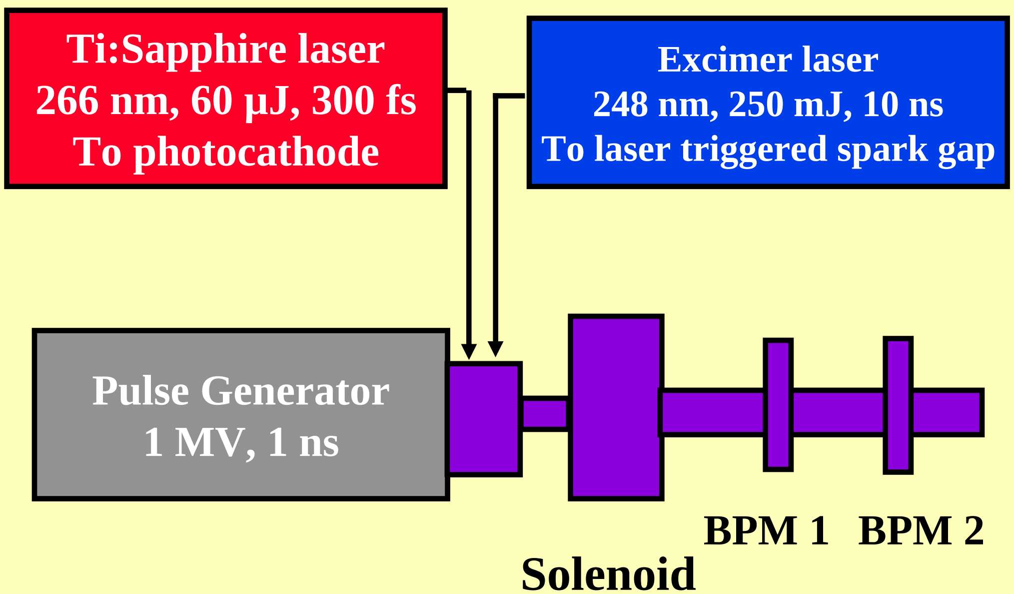




Spot size ~65 µm rms

Charge ~0.4 pC

emittance ~0.7 mm mrad



System Capabilities

Voltage range: 350 - 900 kV, 1 ns FWHM

Cathode laser: 60 µJ, 300 fs FWHM, 266nm

System timing jitter: <1 ns

Accelerating gradient: >1 GV/m

Maximum current density: >100 kA/cm^2

Maximum charge: >60 pC from 300 fs laser

Multialkali Photocathode Development for *e-cooling*

A multialkali cathode deposition and testing system

Goals:

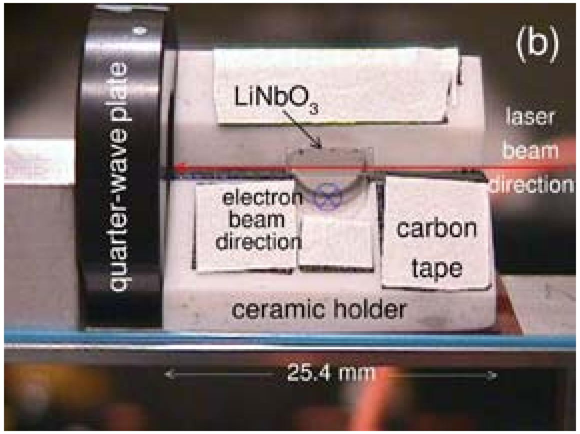
- Electron beam parameters: charge 10 nC, PRF 10 MHz, average current 100 mA
- Quantum efficiency: few % for Visible photons
- Lifetime: >8 hrs at a vacuum of 1×10^{-9} Torr

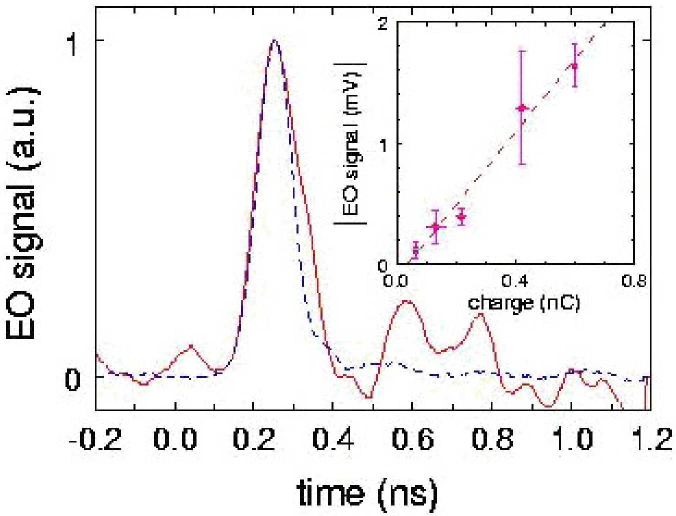
Investigate:

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

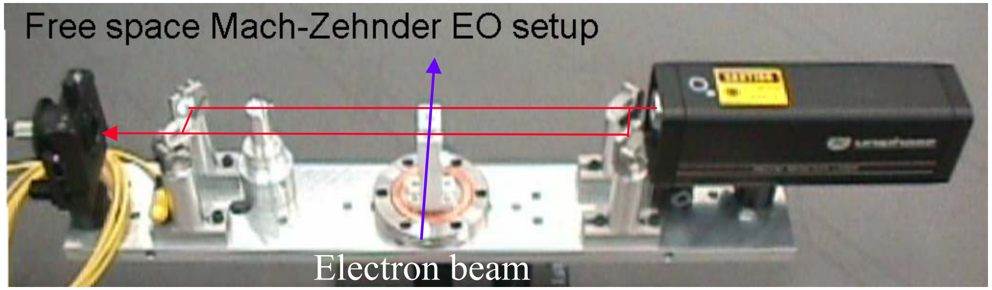
Electro-optical measurement of 45 MeV relativistic electron beam bunch length

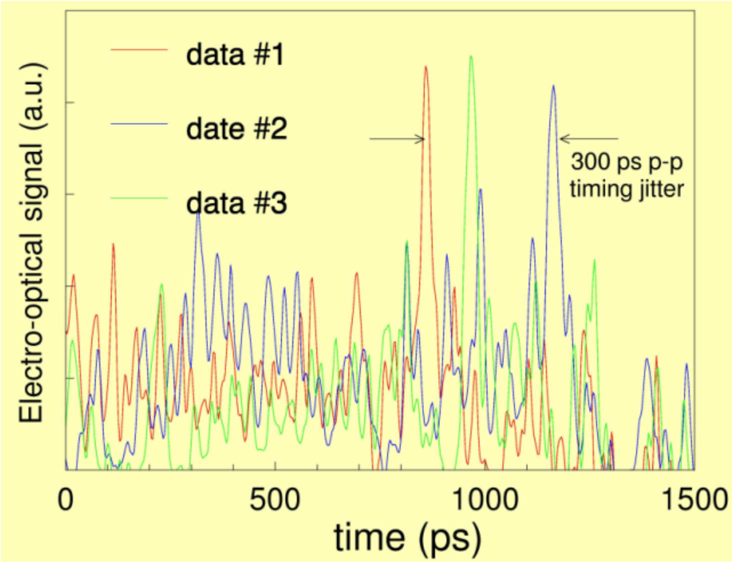
Measurement from oscilloscope





Measurement from streak camera



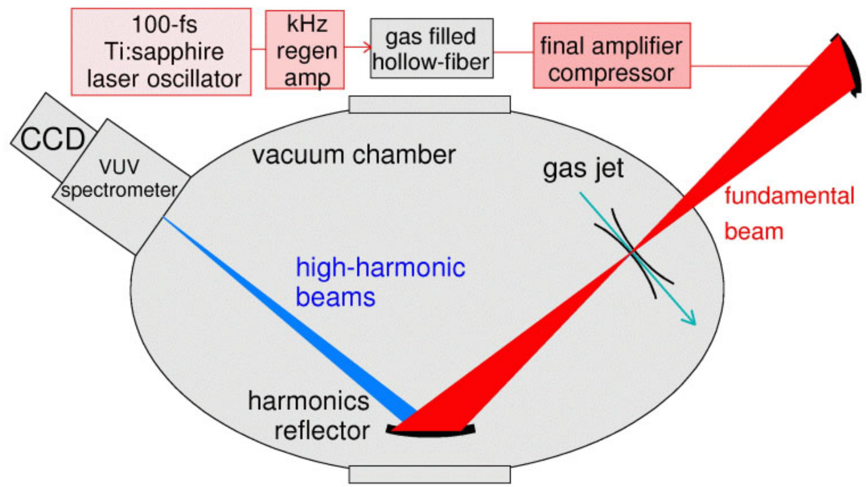


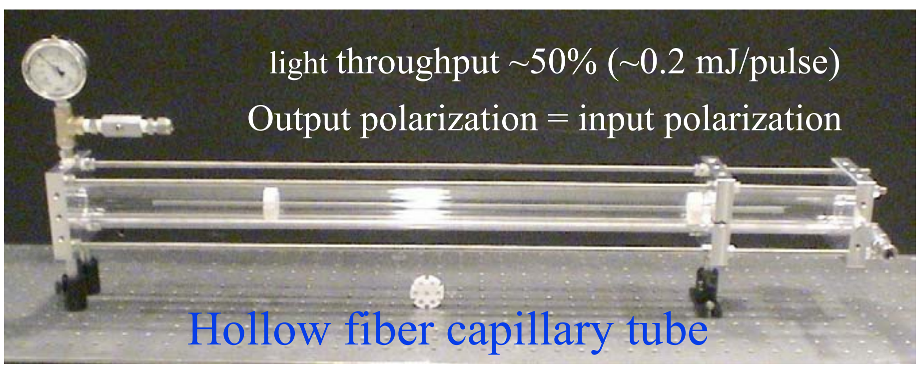
Non-invasive

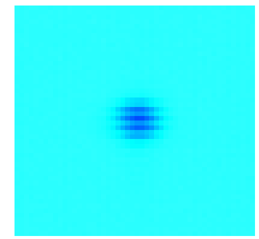
Potential for femtosecond resolution

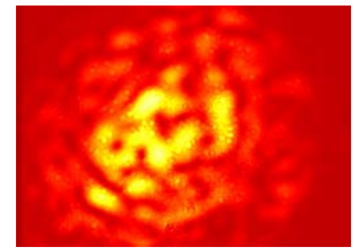
Generation of Coherent, Femtosecond, High Brightness VUV and X-Ray Beams Using High Order Harmonic Conversion

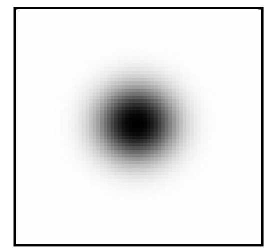
2002 LDRD

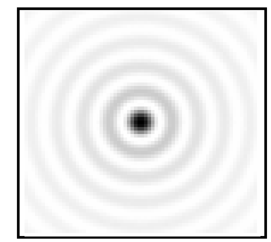












Gaussian input

Expected output
Intensity distribution

Generation of 200 µJ, 10 fs photon pulses at 800 nm with Bessel function intensity distribution

Generation of VUV, XUV radiation up to ~ 100 eV at kHz pulse repetition frequencies (PRF) and its characterization up to ~ 40 eV

FY 2003: Optimize coupling to obtain 200 µJ, ~10fs, Bessel function output, fabricate 1 KHz PRF gas jet, fabricate differential pumping stage, focus the laser light into the gas jet

FY 2004: Generate and characterize VUV radiation, Increase laser energy to > 10 mJ

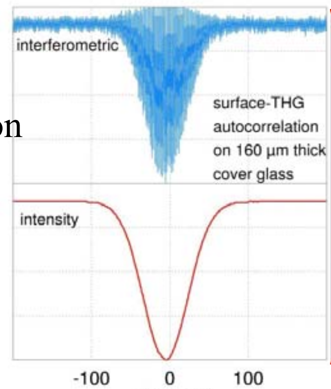
New direction on laser applications

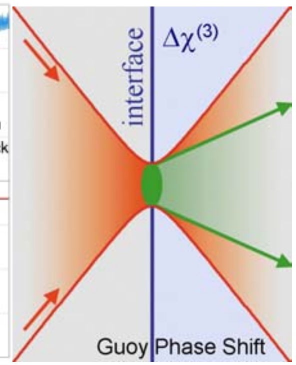
Technique towards attosecond optical pulse measurements – 3rd-harmonic-generation in the XUV

To establish a benchmark, state-of-the-art, ultrashort light pulse measurement in the attosecond pulse regime for the first time.

What we know:

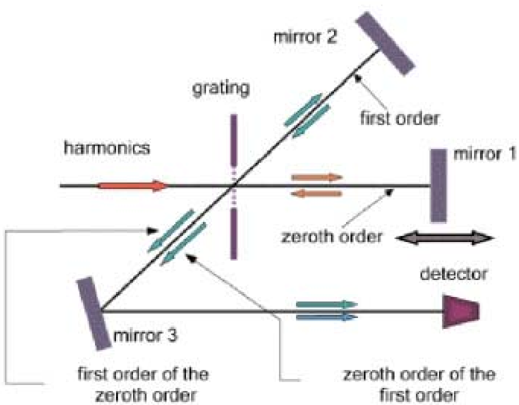
S-THG autocorrelation in the NIR to UV and the geometry of the nonlinear optical generation





What we propose:

Explore S-THG nonlinear optics in the XUV and apply the technique to characterize isolated attosecond pulses using 3rd order autocorrelation.



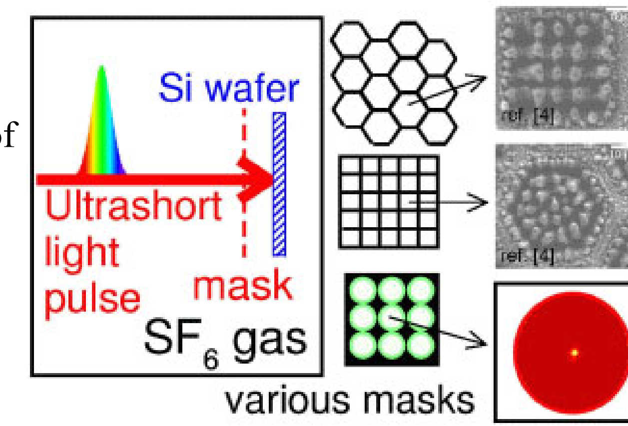
A low dispersion Michelson interferometer in the XUV

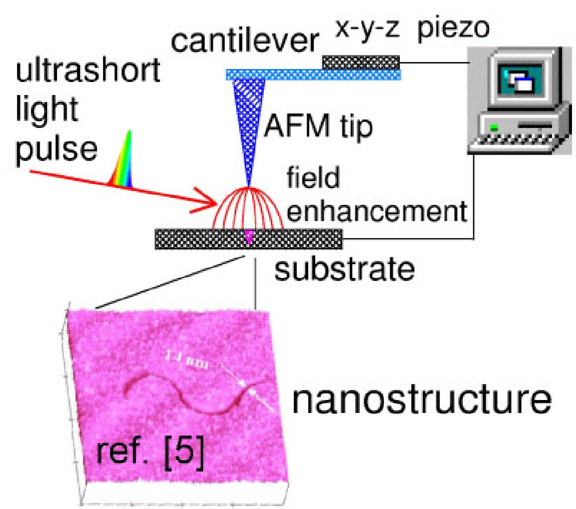
LDRD submitted 2003

Micro- and nano-machining using ultrashort light pulses

To advance BNL in the area of ultrashort laser-pulse-assisted micro-nanomachining. This research area is completely missing at BNL yet it is the fastest growing technology of ultrashort-laser-pulse applications.

Fabrication of periodic arrays of μm to sub-μm diameter silicon pillars



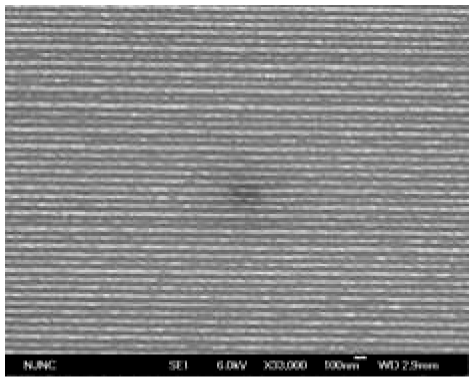


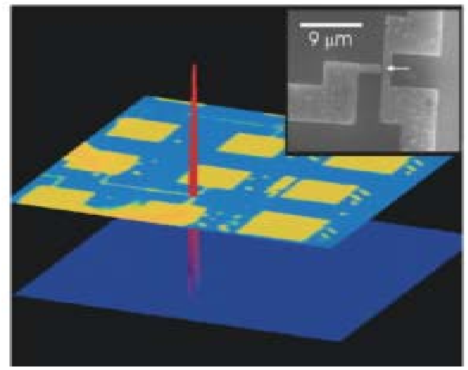
Laser-field-assisted fabrication of nanometer sized features on thin metal films

LDRD submitted 2003

Nanopatterning Cluster: Project Examples

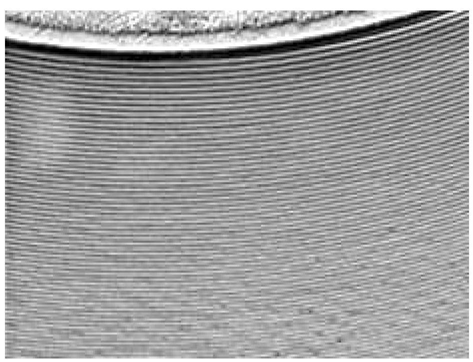
Nanotemplate Directed Assembly: B. Ocko, Physics

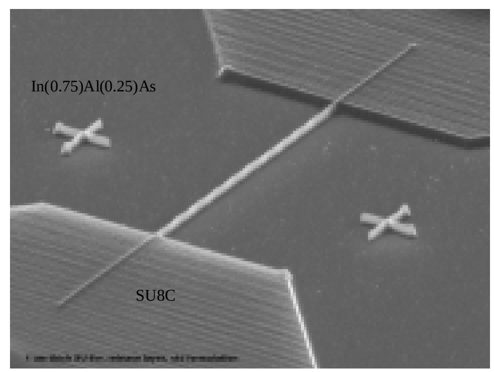




IR Emission from SWCNT Device: J. Misewich, Materials Science

Soft x-ray zone plates: C. Jacobsen, SUNYSB



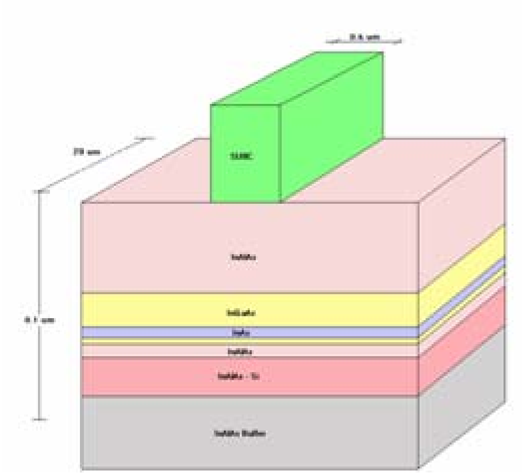


Superconductor / semiconductor device: F. Camino, SUNYSB

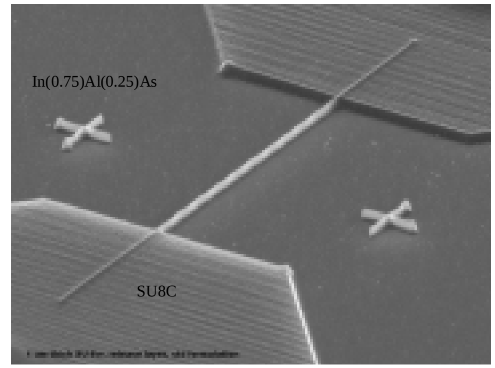
Center for Functional Nanomaterials
Brookhaven National Laboratory

Nanopatterning Example II: Fabrication Steps For Hybrid Semiconductor-Superconductor Nanostructure

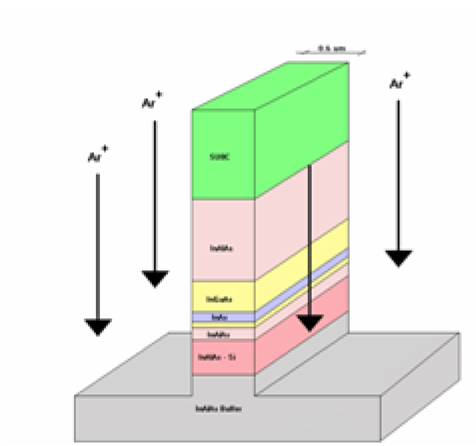
F. Camino, E. Mendez (SUNYSB), J. Warren (BNL)



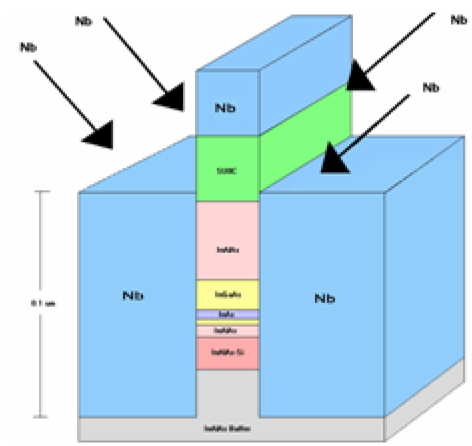
Cross-section of resist and InAlAs layers formed by MBE



200 nm resist line used to define nanostructure



Nanostructure exposed by reactive ion etching



Sputtered Nb electrodes fabricated by "lift-off" method

FUNDING

- Until 1998 Instrumentation Division had been funded from Lab overhead (G&A) at a level of ≈51 FTEs.

- Presently 37 FTEs funded from G&A (+11 from CRADAs, WFO, and grants).

- G&A support has been level (~M$5.6) since FY98

  ❖ Funding by grants from diverse sources (instead of G&A) to support personnel would divert Instrumentation effort from supporting BNL research program and core technologies. It should be pursued only to augment the base program supported by G&A.

Benefit to BNL ("and the community at large"): Provide technology base and expertise, and serve as a resource for important programs and initiatives, such as ATLAS, RHIC experiments, electron cooling, Linear Collider, NSLS, nanotechnology, single particle aerosol analysis, and PET.