CMOS Monolithic Pixels R&D at LBNL

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Introduction: Silicon Pixel R&D at LBNL

- ILC Silicon Pixel R&D supported by 3-year Laboratory Directed R&D funding started in October 2004

- R&D directions:
  - sensor design and characterization
  - readout development
  - back-thinning tests
  - pixel module engineering

- Synergy with other on-going LBNL activities on CMOS pixels: STAR VXD upgrade, electron microscopy

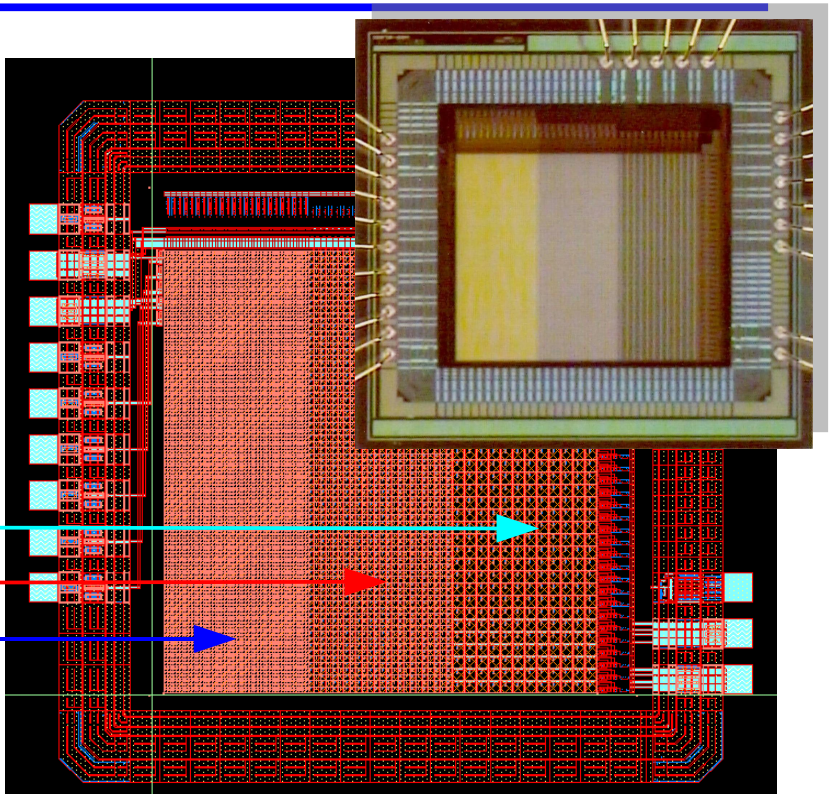
- Availability of test facilities on site:
  - Advanced Light Source: beam-tests with 1.5 GeV e^-
  - 88-inch Cyclotron: irradiations with 30-50 MeV p, neutrons
  - National Center for Electron Microscopy (NCEM)

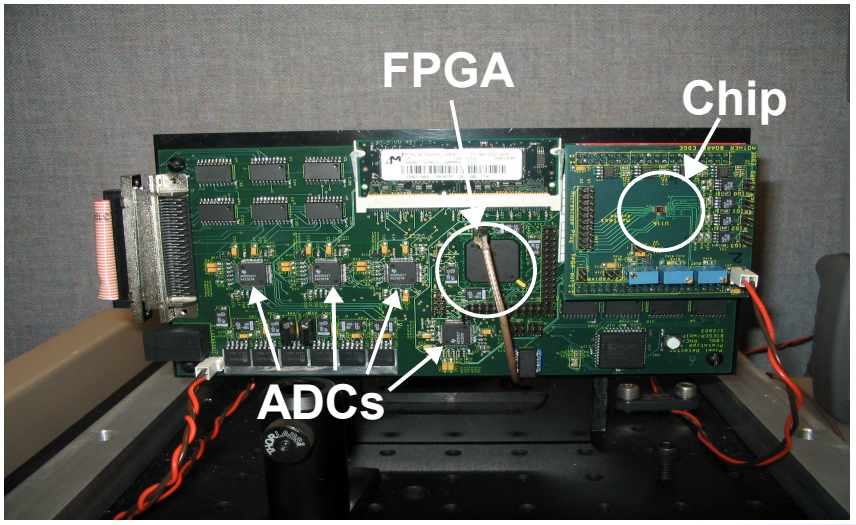
Pixel design and characterization

- First CMOS pixel test structure developed and fabricated (through MOSIS) in 2005 in collaboration with LBNL Engineering Division

- 0.35 μm OPTO AMS prototype, 3-T pixels, serial analog readout

- Three pixel geometries
  - 12 x 36 40 μm pixels
  - 24 x 72 20 μm pixels
  - 48 x144 10 μm pixels





- Xilinx FPGA based readout board (LBNL development)

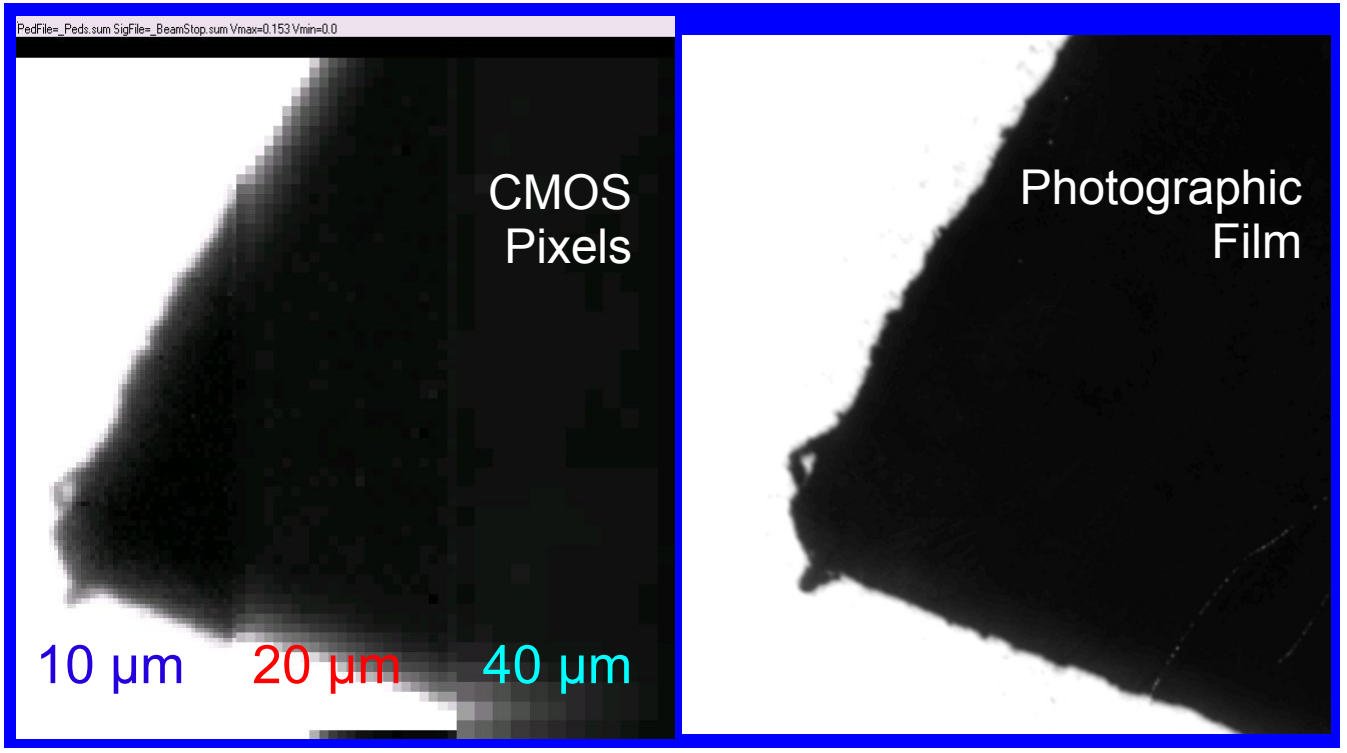
- 14 bit digitization, interface with PC with LabView program for data acquisition and on-line event display

- C++/ROOT based off-line data analysis

Electron Microscope test @ NCEM

- Detector mounted on Gatan bright field STEM
- Cycle Reset → 100 ms Integration → Digitization
- 200 images acquired with ~10 primary e^- (200 keV)/image
- Noise and gain at room T determined from flat field at low intensity

Beam Stop Image with 200 keV e^-



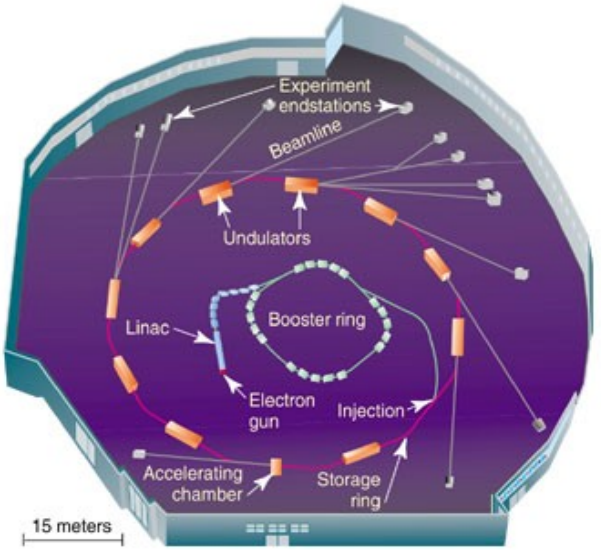
Pitch (µm)	10	20	40
Noise (mV)	3.0	4.4	6.5
Gain (mV/e^-)	25	29	35
Single e^- S/N	8.3	6.6	5.4

Beam-test at the Advanced Light Source

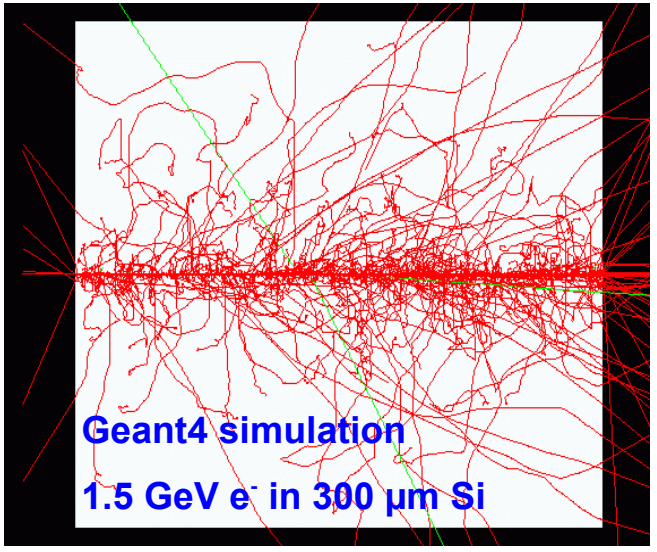
- Test performed at the BTS beam line of the Advanced Light Source (ALS)

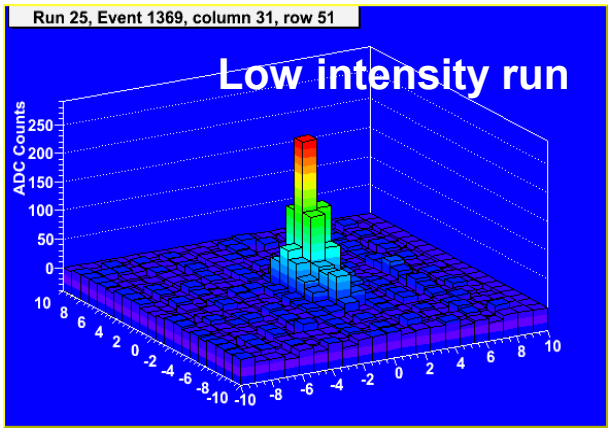
- Single bunch of primary 1.5 GeV e^- @ 1 Hz, tunable particle flux

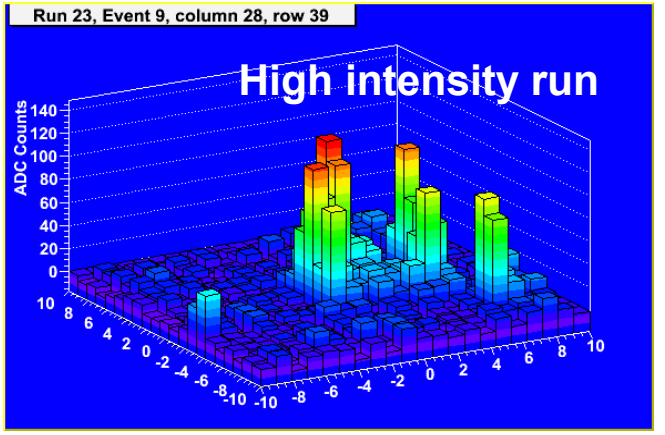
- Readout sequence:
  - detector kept in reset between 2 bunches
  - trigger on beam pickup signal, read 4 frames timing tuned to record signal on 3rd frame
  - readout with 1 ms integration time



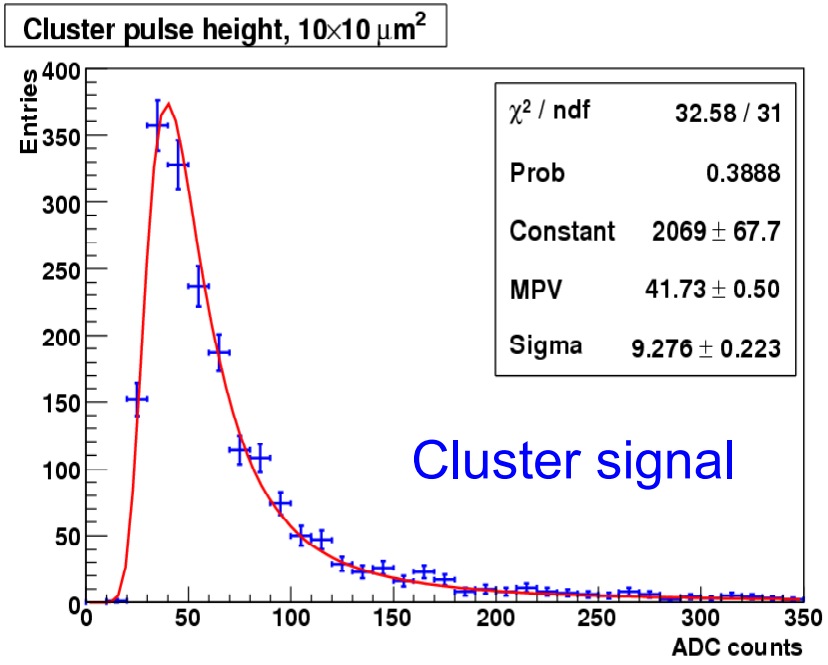
- Pixel noise and pedestals initialized with beam off, update during run on empty frames

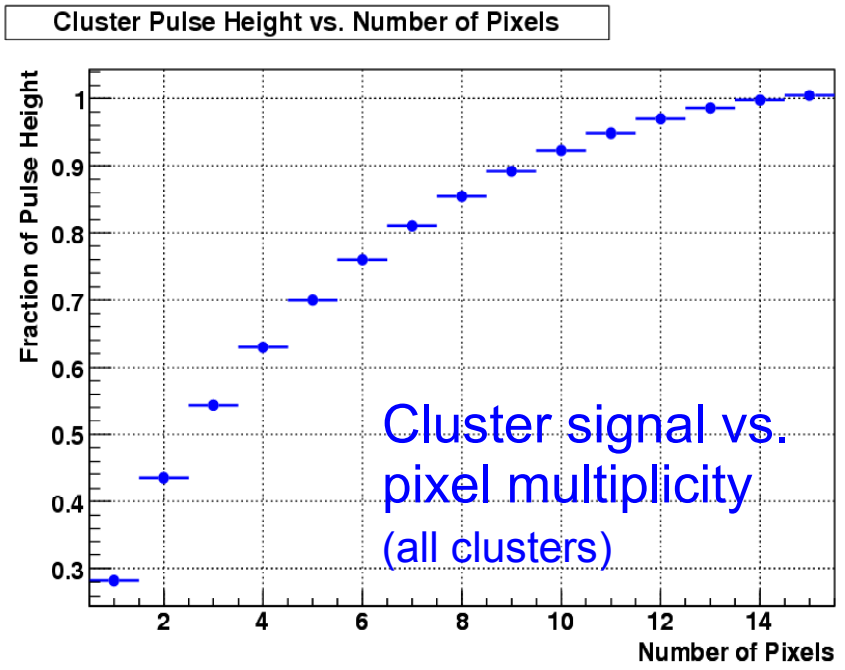






Beam-test results



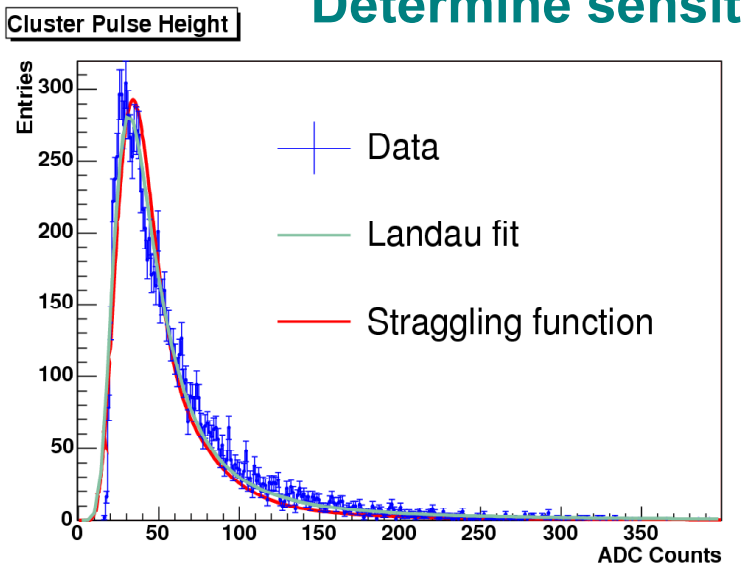


- All measurements performed at room temperature (24ºC)
- Reconstruct hit clusters from pulse height-sorted seed pixels and neighbors satisfying additional S/N cut
- Select isolated and symmetric clusters

Pixel pitch	10 μm	20 μm	40 μm
<Nb Pixels>	2.71	2.67	2.37
<S/N>	14.1	14.5	15.4

Detector signal studies

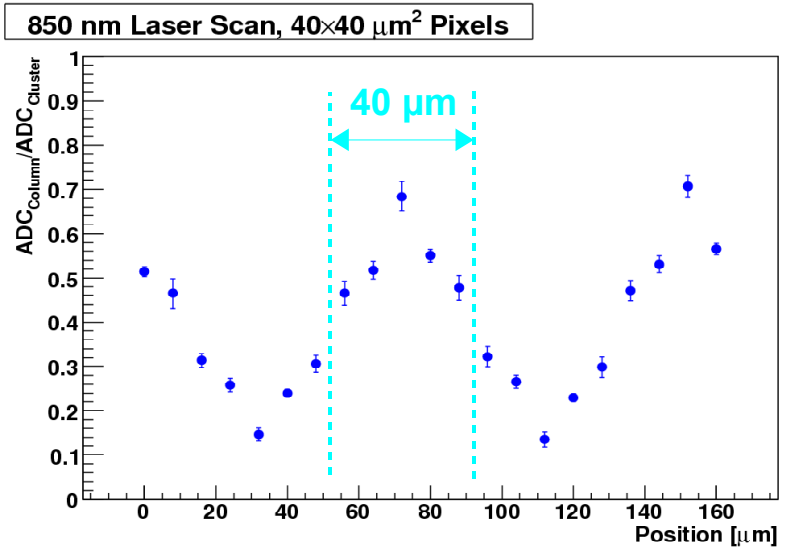
Determine sensitive thickness from beam-test data



- Hit rate~50 hits/event at room temperature
- Compare width of Landau fit to e^- data to thin straggling function prediction for different active volume thicknesses
- Best agreement for 10 μm of Si, corresponding to MPV energy loss of 1.86 keV → 505 e^-

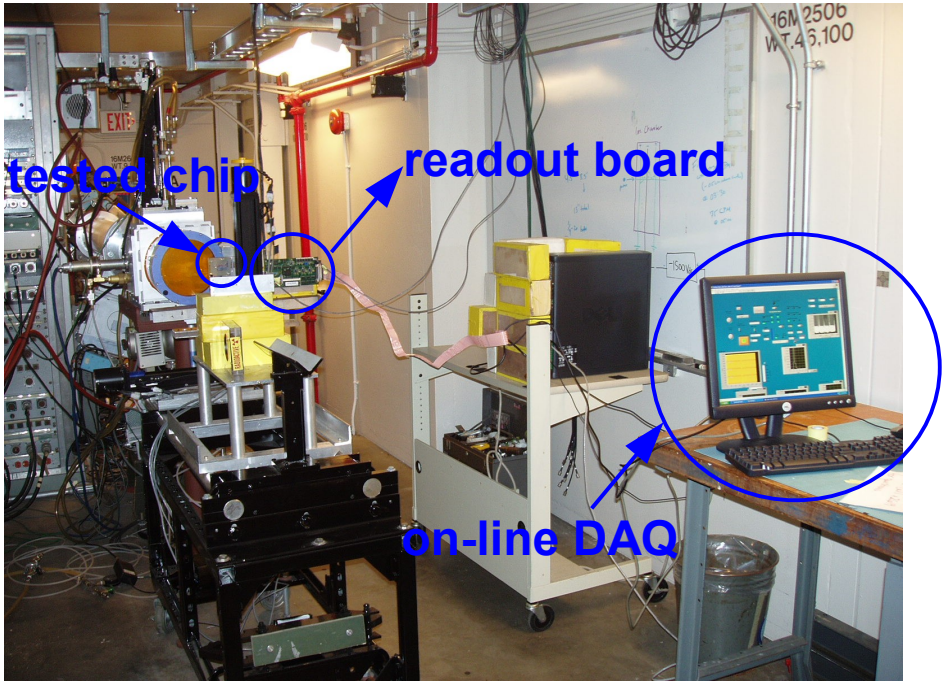
Determine spatial resolution from laser scan

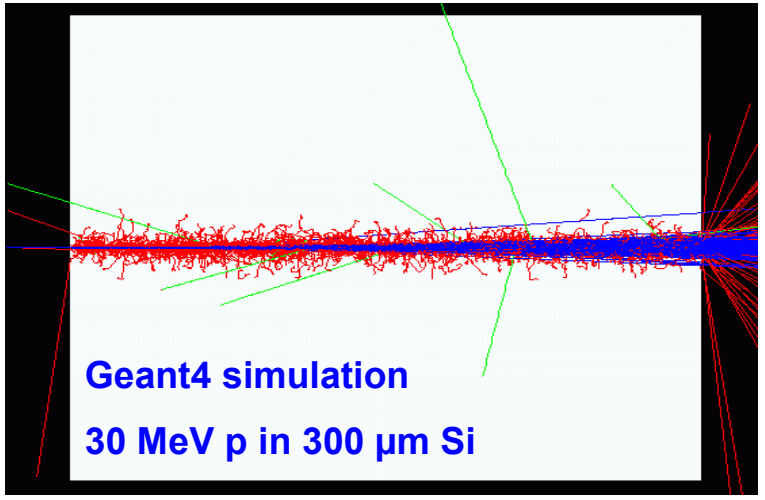
- Pixel scan with focused (<10 μm) 850 nm laser spot to study charge sharing
- Plot $\eta = PH^{i}_{column}/PH_{cluster}$ versus laser spot position
- From variation of signal fraction vs position along the pixels and S/N estimation of spatial resolution: ~1.5-5 μm for 10-40 μm pitch pixels

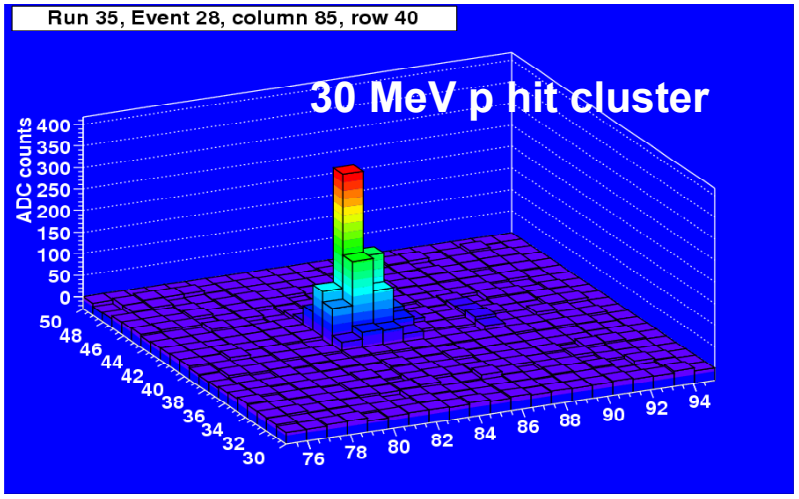


Irradiations at the 88” Cyclotron

- Irradiation with 30 MeV protons up to 1.4×10^{12} p/cm^2
- Proton flux ~7×10^{7} p/cm^2/s
- Irradiation in steps: pedestal noise recorded after each step
- Low intensity beam runs in between different steps
- Detector powered on and kept in readout mode during irradiations

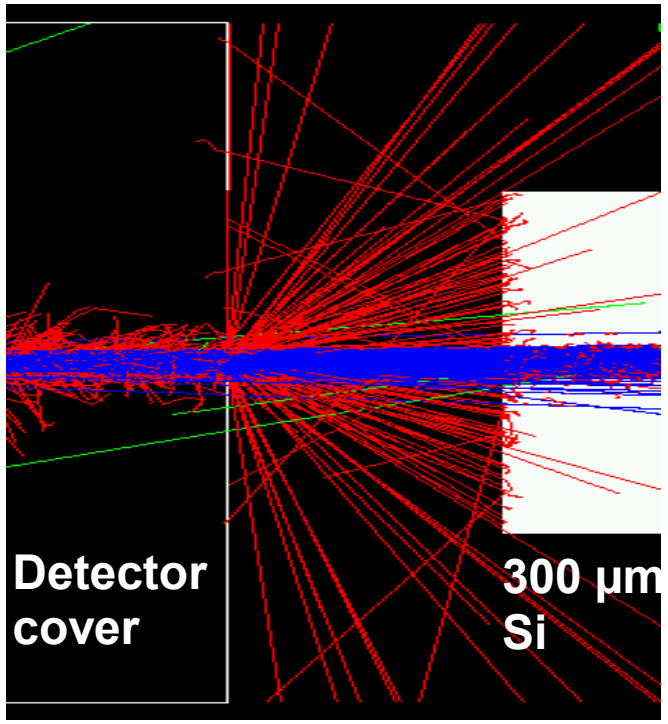


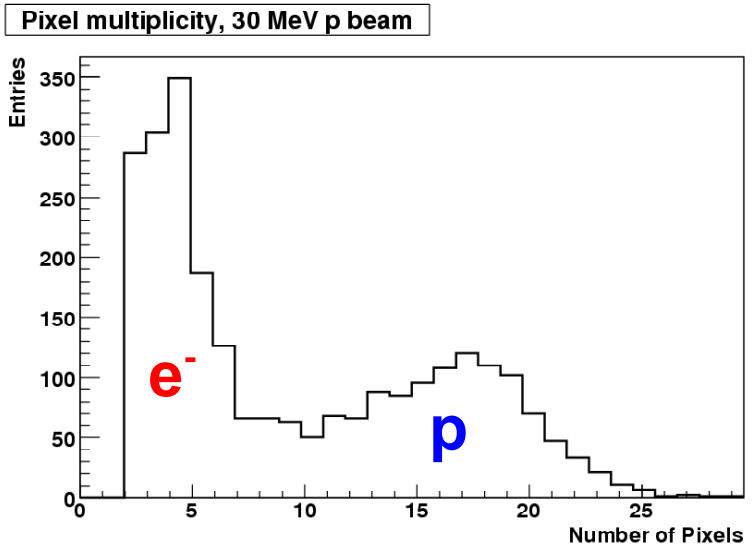


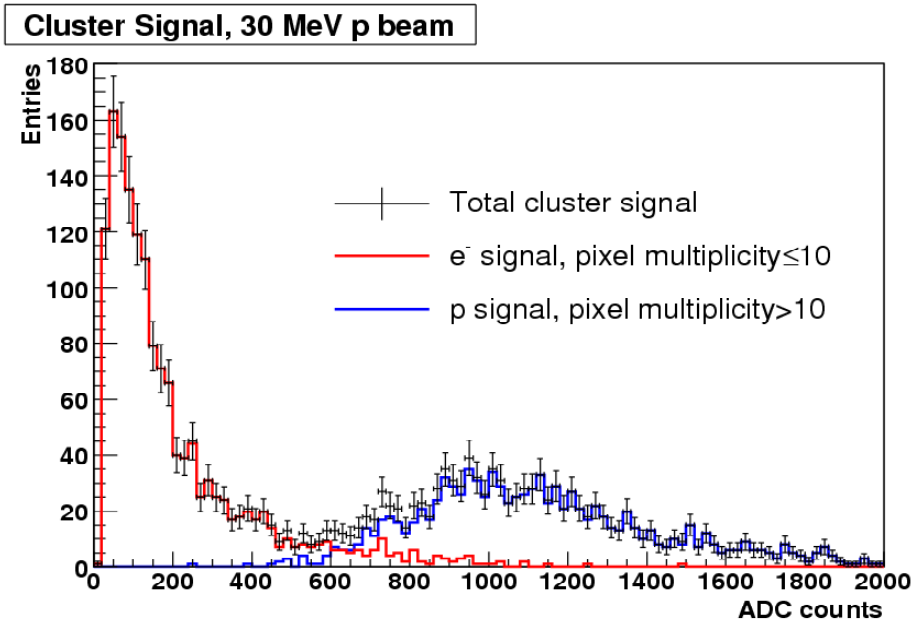


Test with 30 MeV proton beam

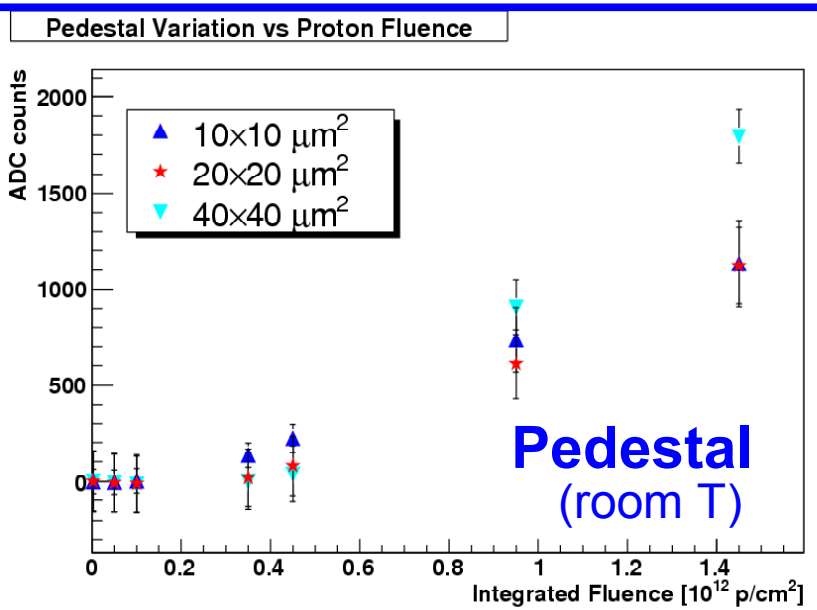
- Low intensity proton flux (<$2 \cdot 10^5$ p/cm^{-2}/s)
- Data acquired in free-running mode
- Double peak structure of pixel multiplicity distribution and correlated structure on cluster signal distribution
- Geant4 simulation: electrons produced by plastic detector cover

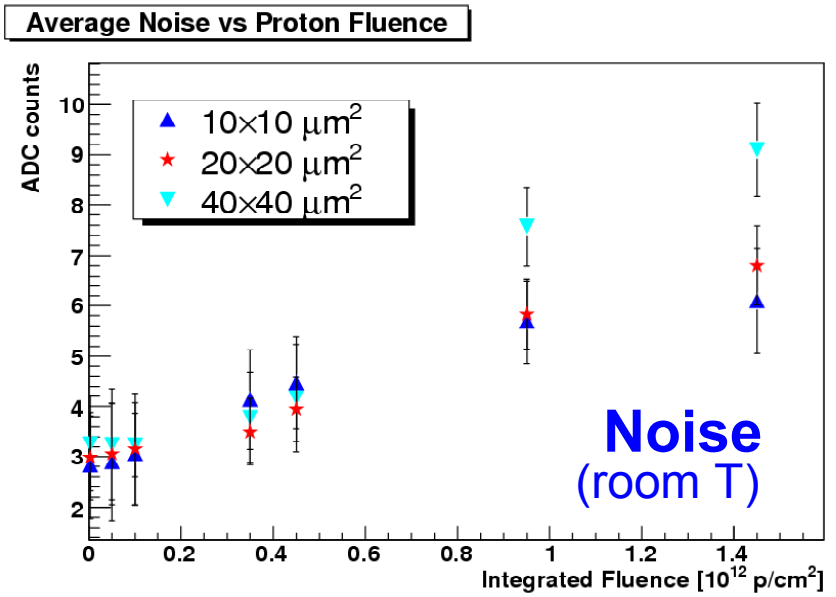




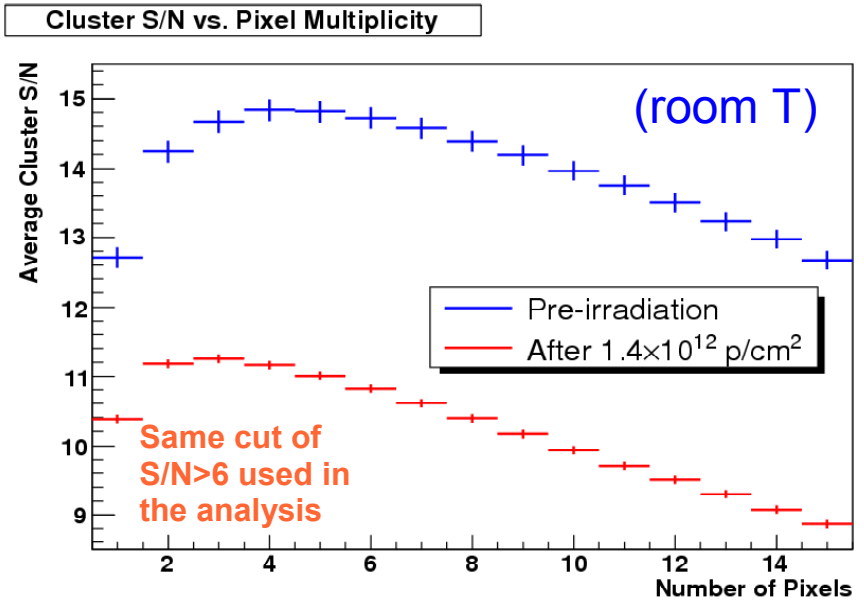


Test of irradiated prototype



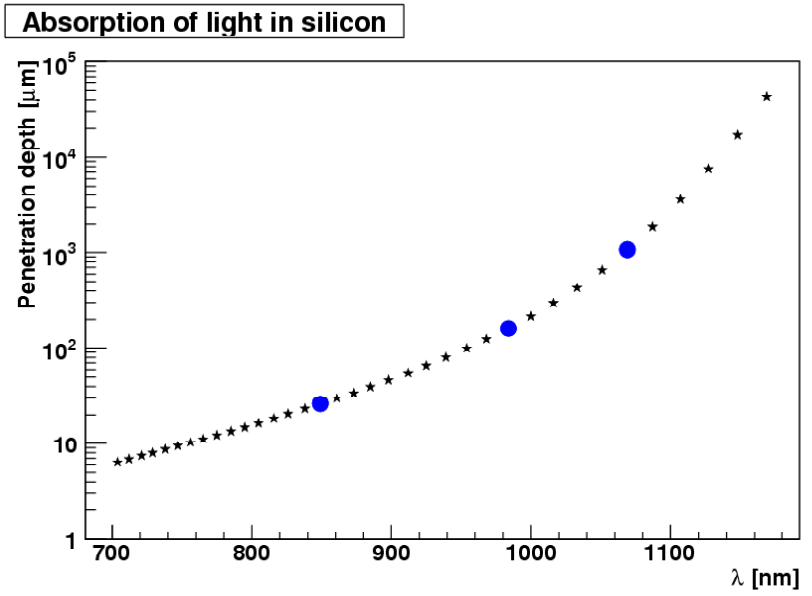


- Linear increase of leakage current with fluence, more pronounced for larger pixels
- Better performance of smaller pixels
- Increase in noise correlated with increase in leakage current
- Corresponding degradation of S/N performance for mips, decrease of cluster multiplicity (trapping)
- Characterization of T dependence under way

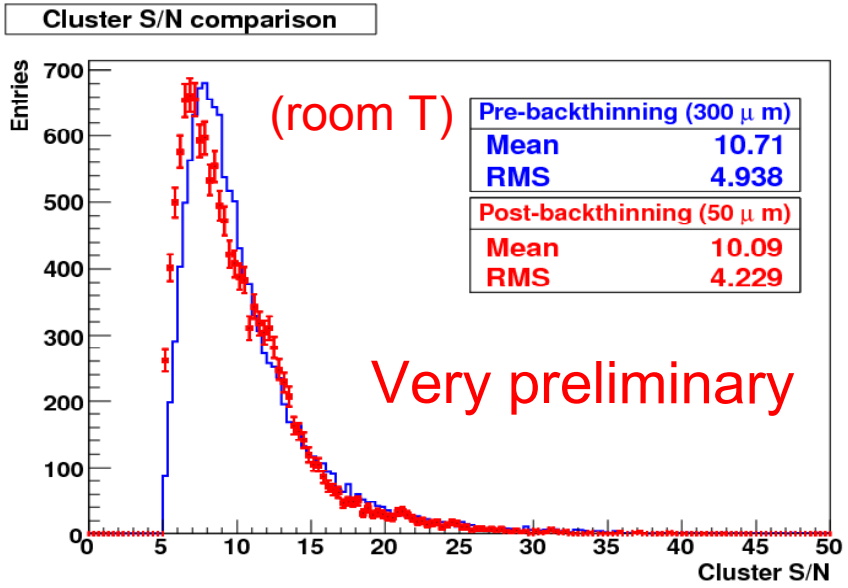


Back-thinning studies on MIMOSA-5

- Tests performed on diced MIMOSA-5 chips from IReS (Strasbourg)
- AMS 0.6 μm, 14 μm epilayer, 1 Mpixels on reticle-size area of 1.7×1.9 cm^2, 17 μm pixel pitch



- Test with lasers of different wavelengths to probe signal from different silicon depths and estimate substrate contribution
- Back-thinning to 35-50 μm performed by Bay Area partner company



- Two chips back-thinned to 50 μm, tests under way with 1.5 GeV e$^-$ and with lasers
- Very preliminary result from ALS beam-test (1.5 GeV e$^-$) @ room temperature

Pixel module engineering

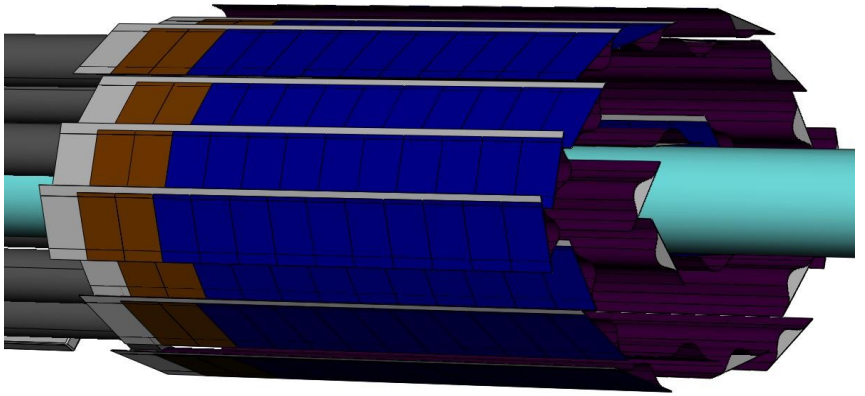
- Synergy with LBNL Nuclear Science Division, experience from the STAR HFT development

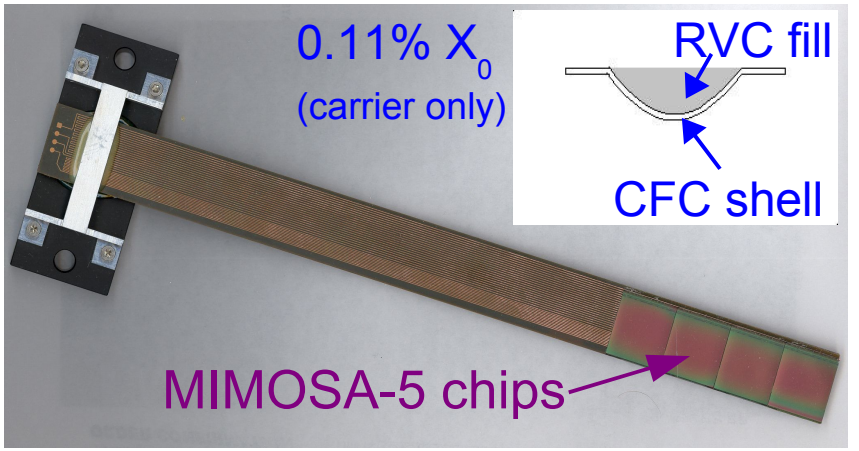
- Developed working ladder prototype with MIMOSA-5 chips back-thinned to 50 μm

- Important test of mechanical handling and assembly issues

- LCRD Proposal submitted for FY 2006-2007 for the design and development of a monolithic pixel detector module
  - optimization of sensor thickness
  - chip cooling requirements
  - design of low mass detector module
  - ladder integration and test under realistic operational conditions (e.g. power cycling)

View of the STAR HFT





- Leverage advantage of reduced material budget from thinner sensors with increased requirements on chip support structures

Outlook

- Pursue characterization of present prototype (T dependence), first neutron irradiation in April at the 88-inch Cyclotron

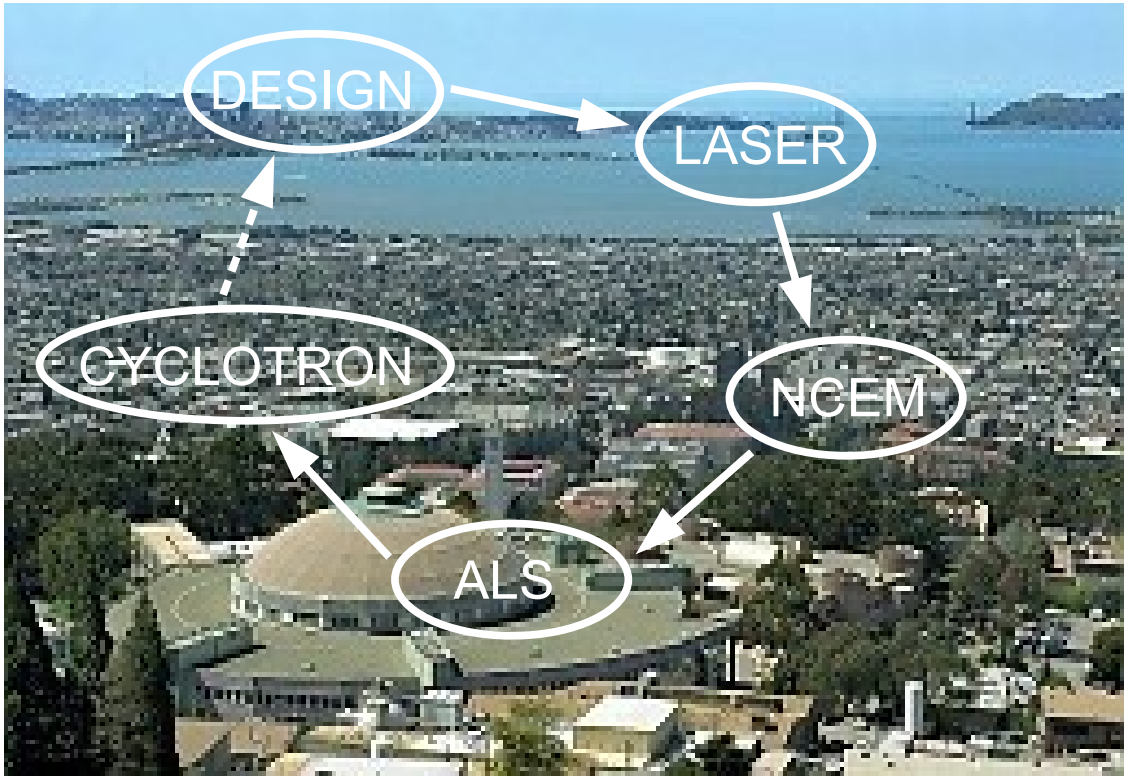
- Next prototype submission through CMP in April: various sub-matrices, different biasing schemes and diode sizes, on-pixel CDS

- Started design of 5-bit ADC with low power consumption matching a 15 μm pixel pitch
  → larger scale prototype including CP readout and on-chip ADC foreseen in early 2007

- Extend back-thinning studies on Mimosa-5 (down to 35 μm) and forthcoming STAR prototypes

- Deployed G4 Mokka full simulation and Marlin reconstruction framework at LBNL: engaging in simulation studies including realistic digitization from beam-test cluster shapes, two cluster separation, study of machine-induced backgrounds (collaboration with AFRD), effect of geometry and ladder thickness on benchmark physics processes

Conclusions...



- LBNL ILC Pixels team has completed the first design-production-test cycle → next one to start over soon

- Present activities profit from collaborations with several institutes... more are welcome!