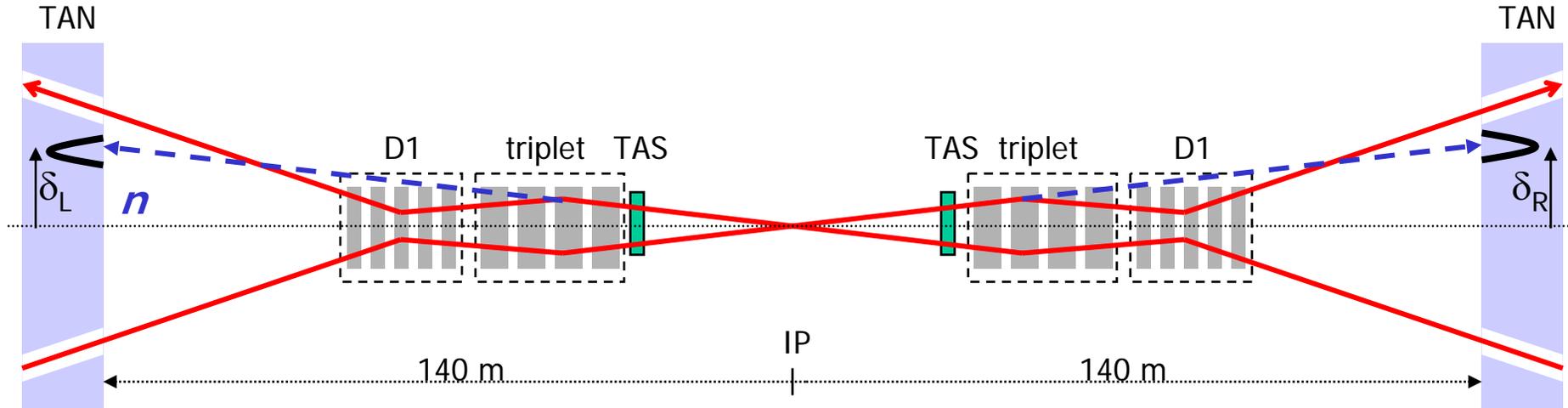


Instrumentation in high-radiation environments



- Accelerator and accelerator-based systems
 - e.g. fusion program, and off-shoots
- *Diagnostic* detectors in high-radiation environments
- *Complex* detectors in high-radiation environments
 - Motivated by experimental particle physics
 - seeking rarer phenomena → more collisions → more background
 - finer detector segmentation → closer to interaction point → higher doses
 - Space and other applications
- Enabling technology to support this

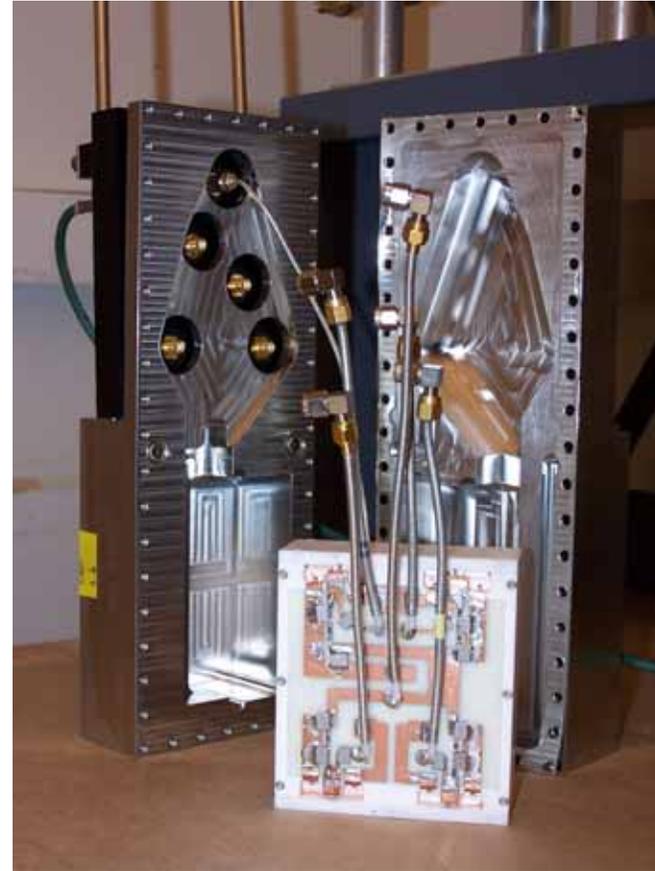
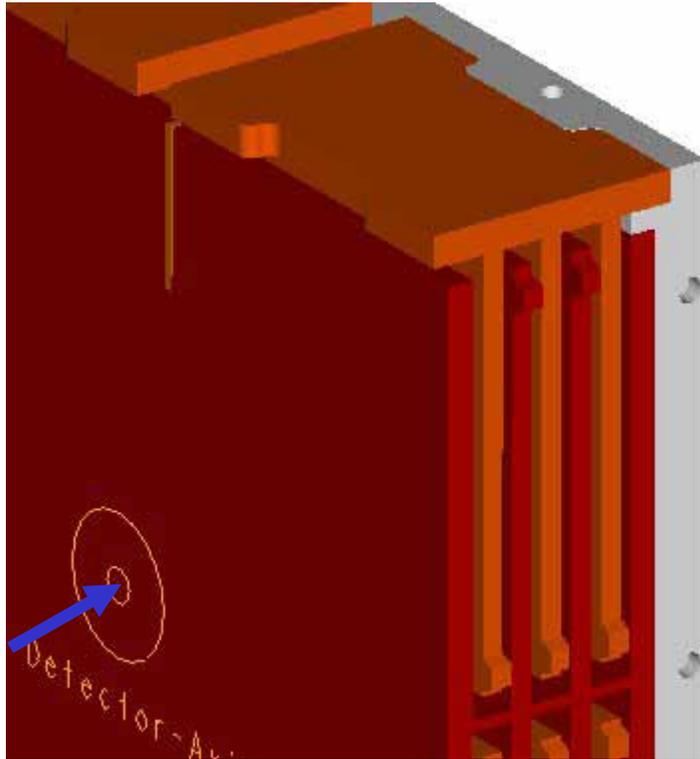
LHC Luminosity Monitor



- Luminosity $\propto N_{\text{MIP}}$ from n shower
- Crossing Angle $\propto \delta_L + \delta_R$
- $\delta L / L < 1\%$
- Lifetime dose ~ 250 GRad

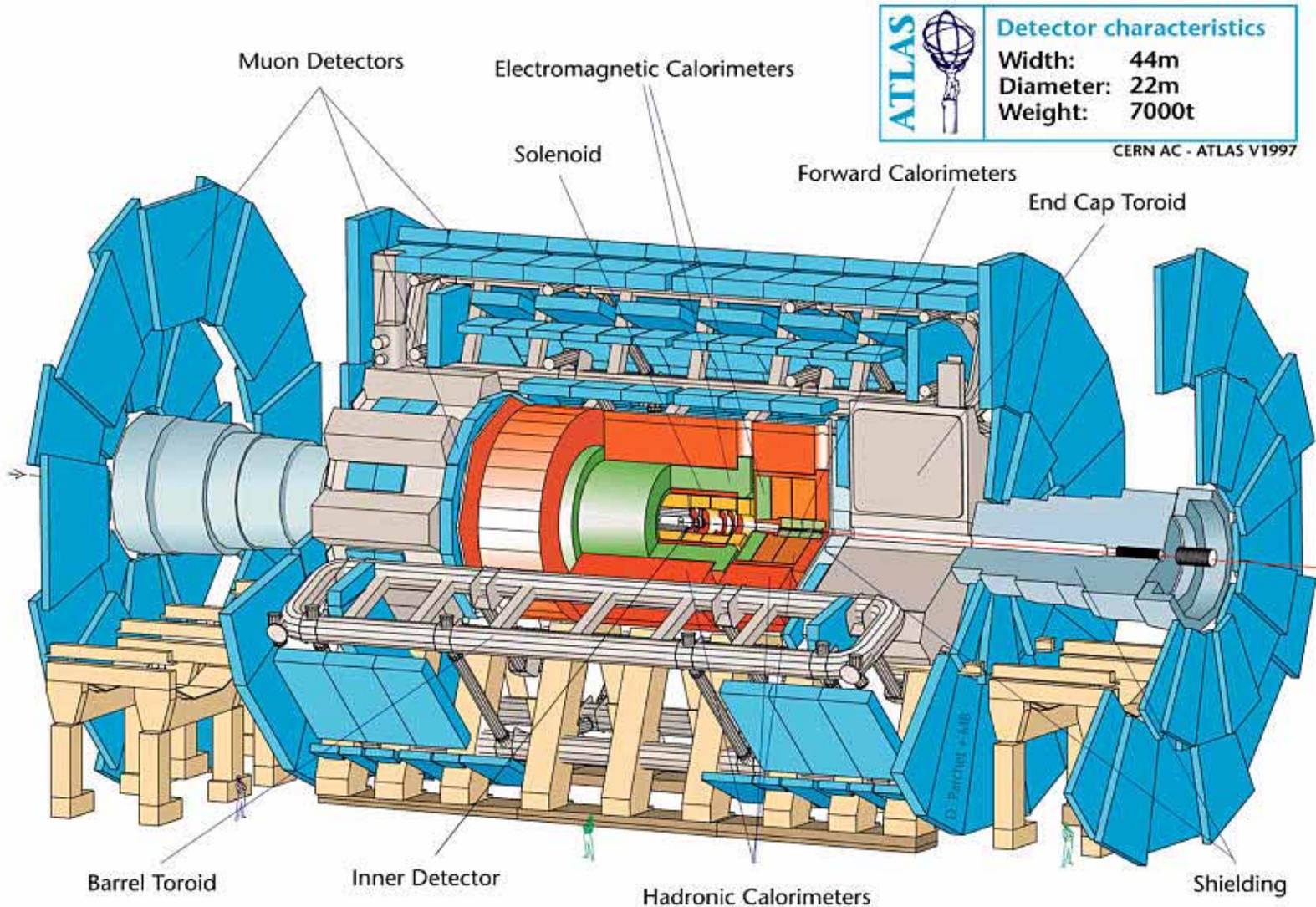


LHC Luminosity Monitor

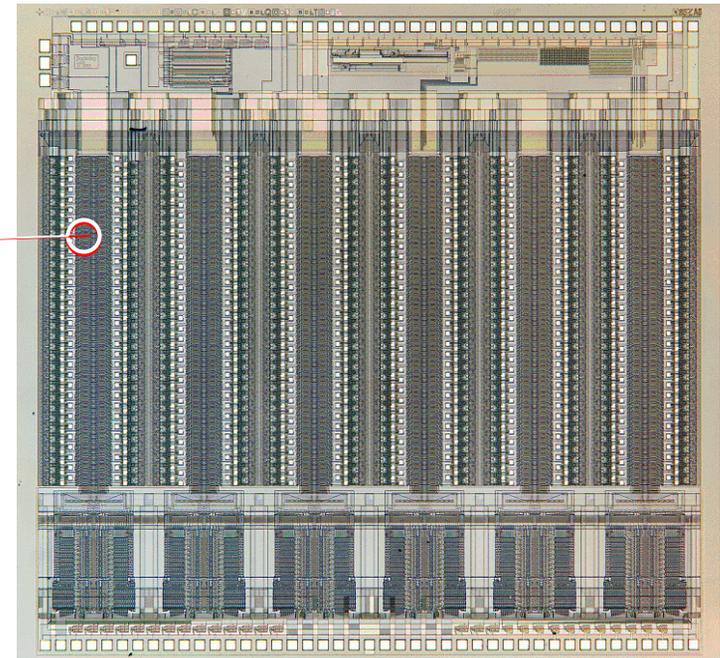
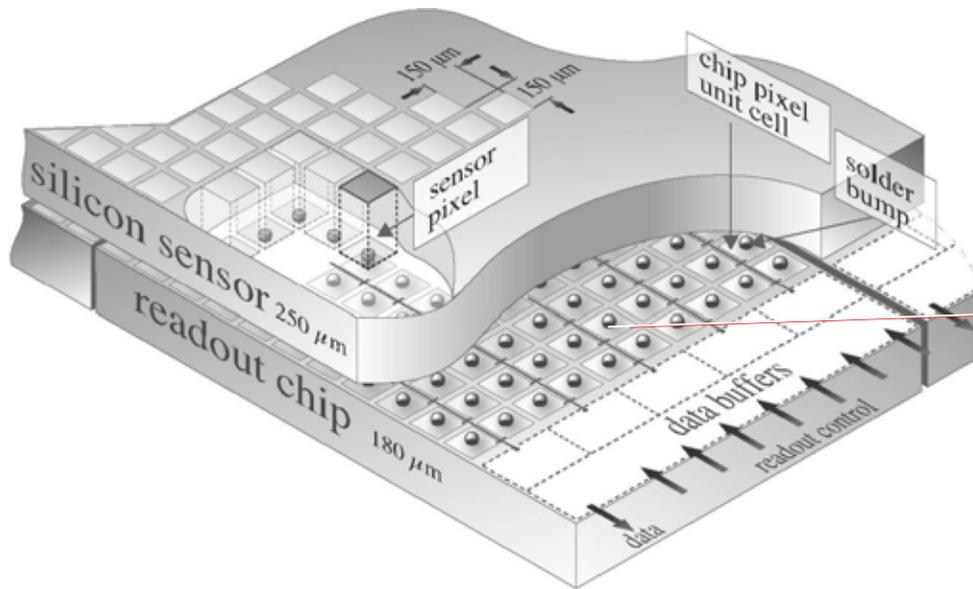


All metal/ceramic gas ionization chamber

LHC Detectors

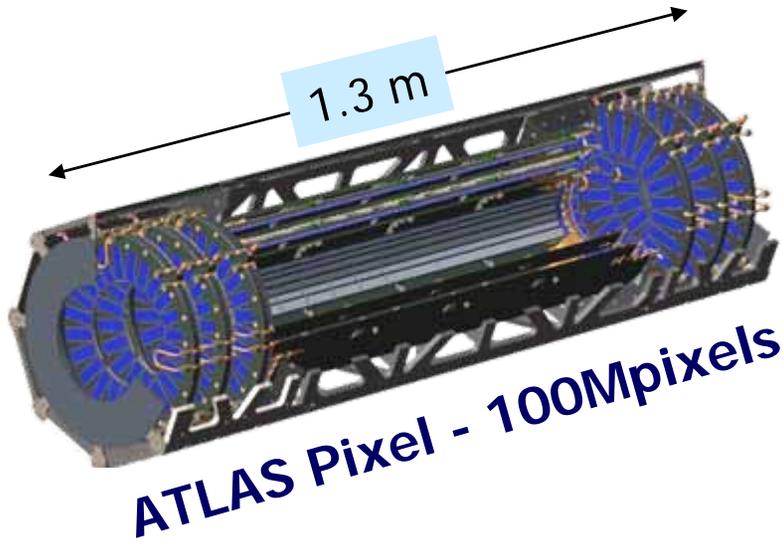


Hybrid Pixel Detectors

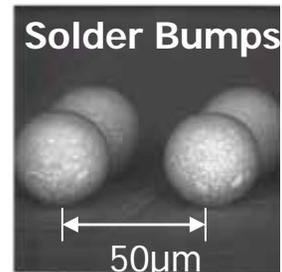
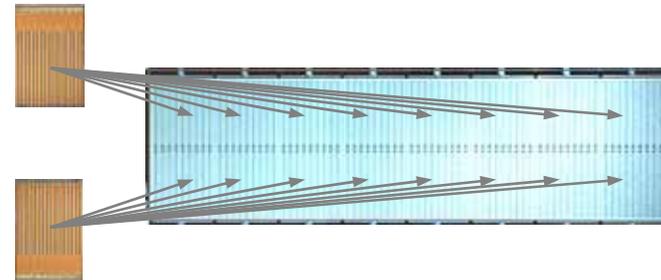
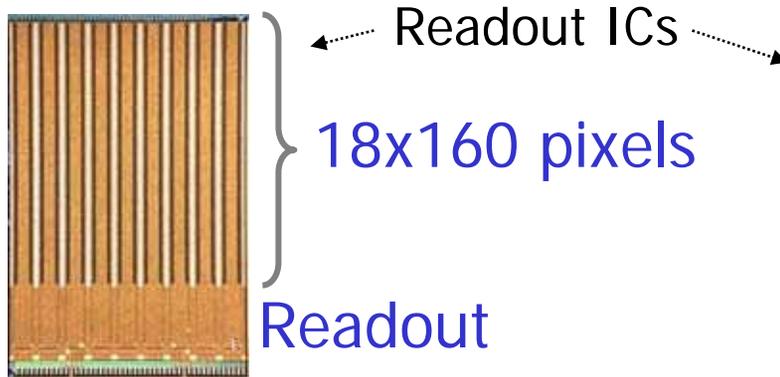
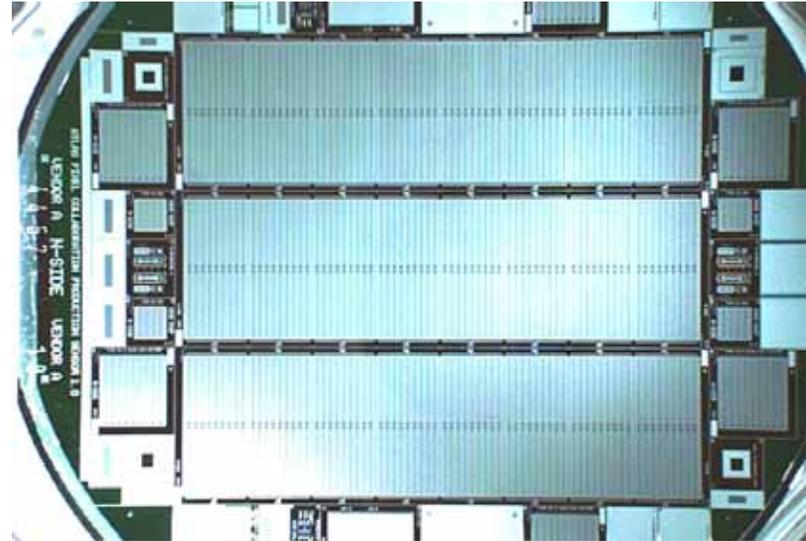


~20,000 μ² active for readout
(including bump-bond pad)
Radiation Environment

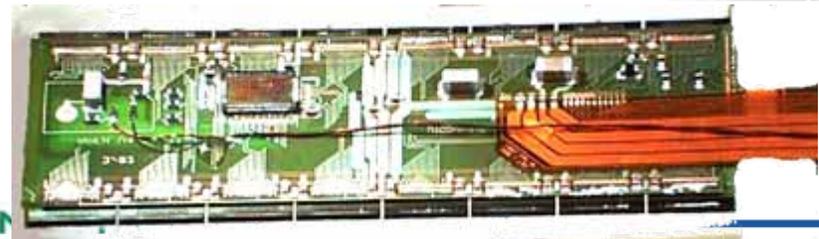
ATLAS Pixel Detector



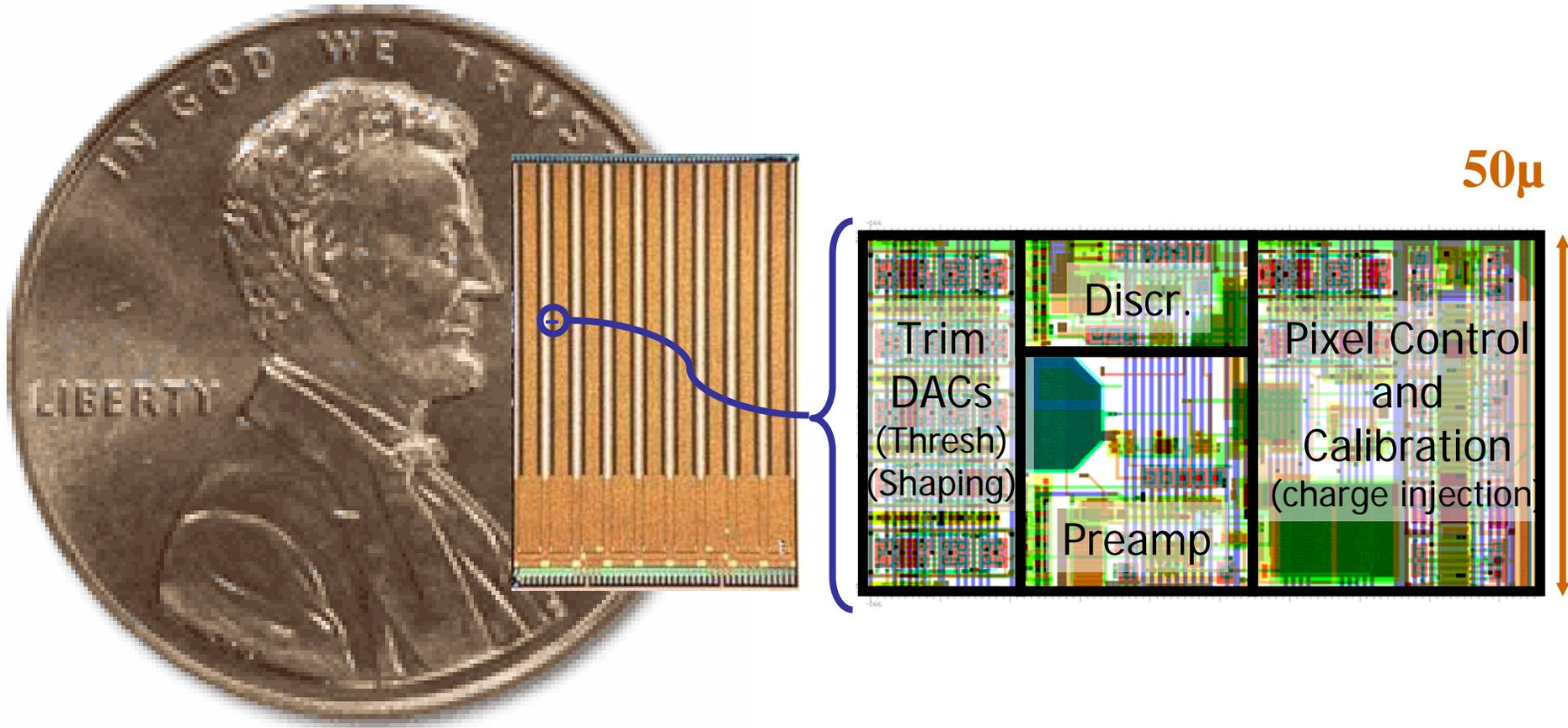
100 mm wafer with 3 Si sensors



A "module" is 1 sensor with 2x8 bump-bonded chips



In One Pixel



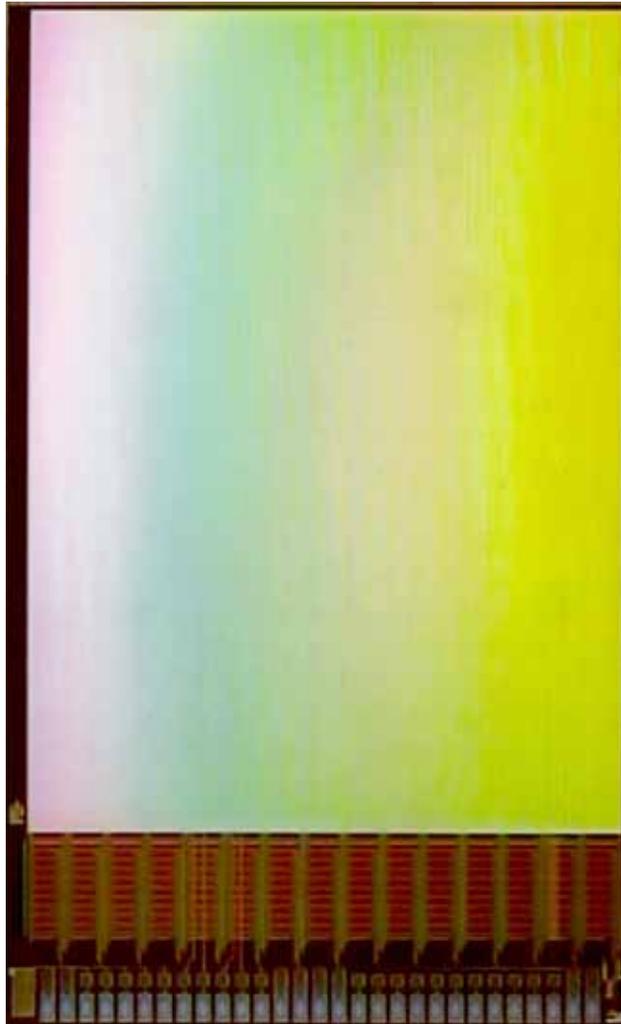
Pixel chip (2.5M transistors) compared in size

Future challenges



- Current generation of pixels should survive
~50 MRad and 10^{14} n/cm² (1 MeV eq.)
- Next generation of pixels should survive
~500 MRad and 10^{15} n/cm² (1 MeV eq.)
- Of course, ATLAS pixels were a major development
 - amortized cost of 1 pixel ~10¢
 - amortized effort in 1 pixel ~5 person-minutes
- But we leverage these developments in other areas

Example



- Monolithic active pixel detector for electron microscopy (replace film)
- Custom readout circuit is also the detector
- Doses can be very high
- Use the radiation hardening techniques developed for ATLAS etc.

Detectors



Solid State

- **Spectroscopic**
- High-purity Ge
- Room temperature semiconductors (CdZnTe, GaAs, AlSb)
- **Tracking**
- Si strips
- Si pixels
- **I maging**
- Spectroscopic pixels
- Monolithic pixels

And...

- Calorimetric materials (specialized scintillators)
- TPCs
- Other gas detectors
- Superconducting detectors (bolometers)
- ...

Spectroscopic Ge Detectors

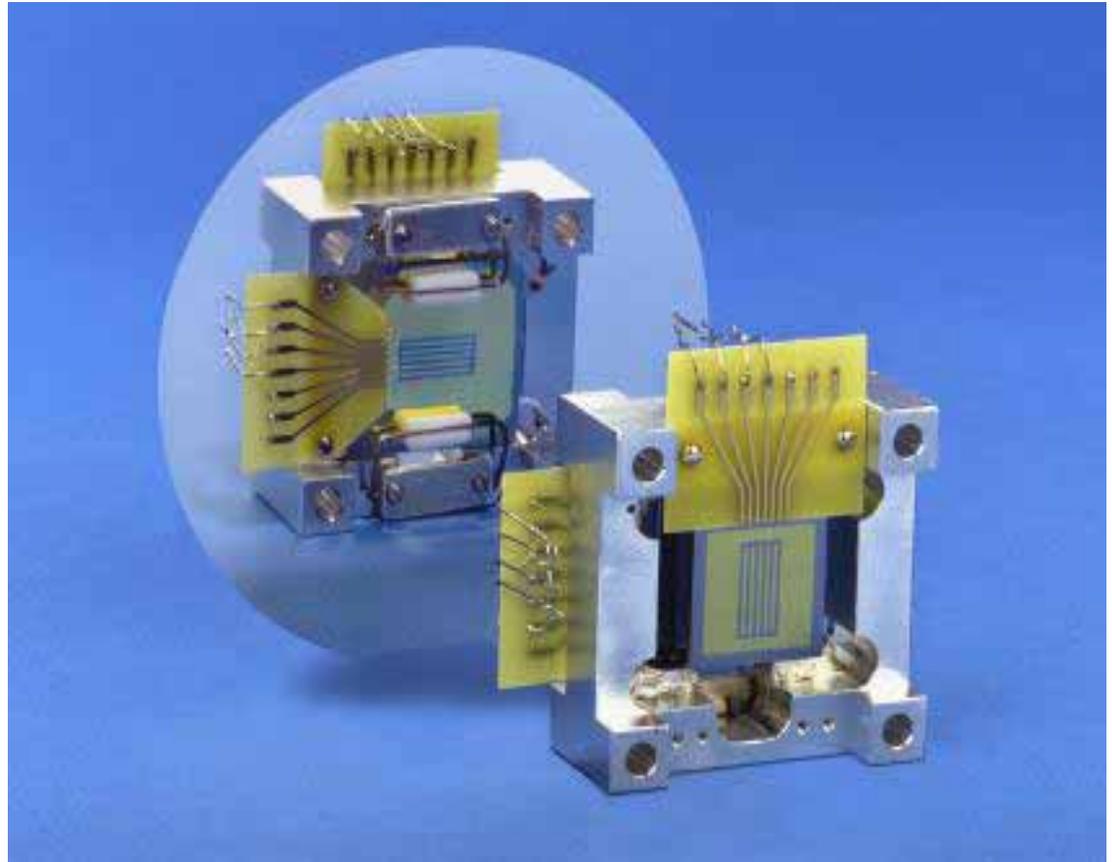
Long history at LBNL of HP Ge detectors
Example – Gammasphere – 110 Ge detectors
Developed by NSD, ran at 88" cyclotron
then moved to ANL in 1998



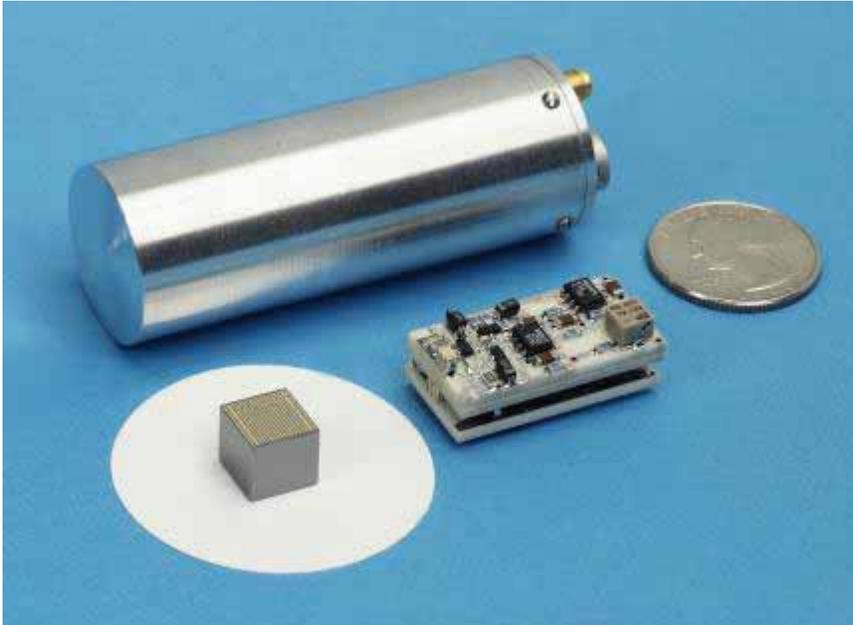
One of the only Ge detectors to be a movie star

Custom Ge Detectors

- Ge strip detectors
- For NN applications
- 1024-strip detector for SR applications



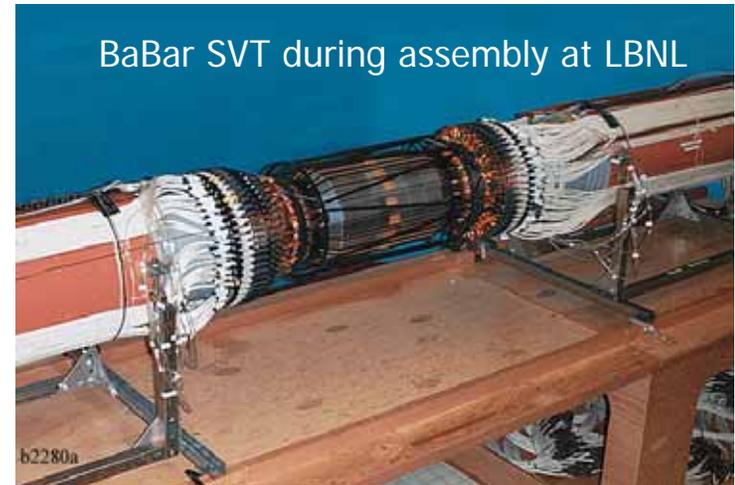
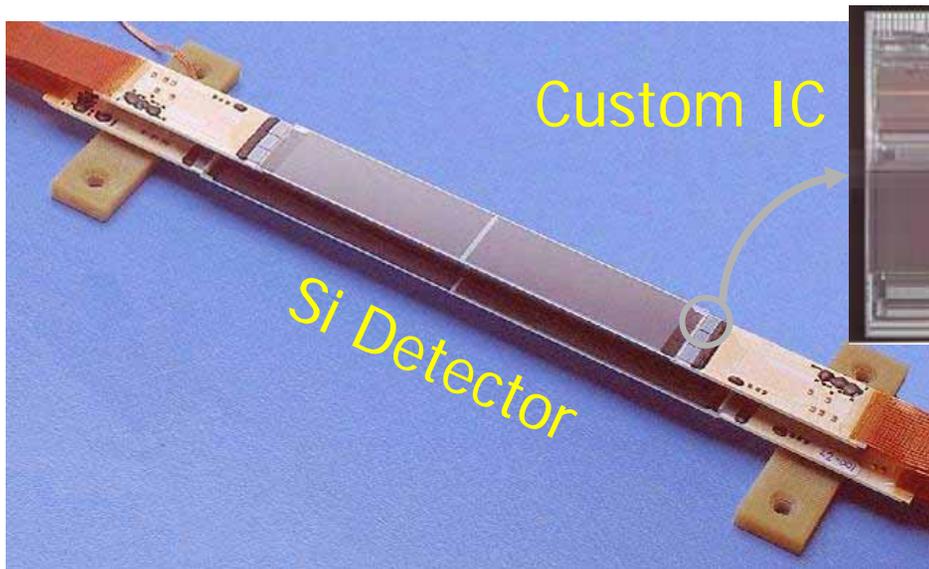
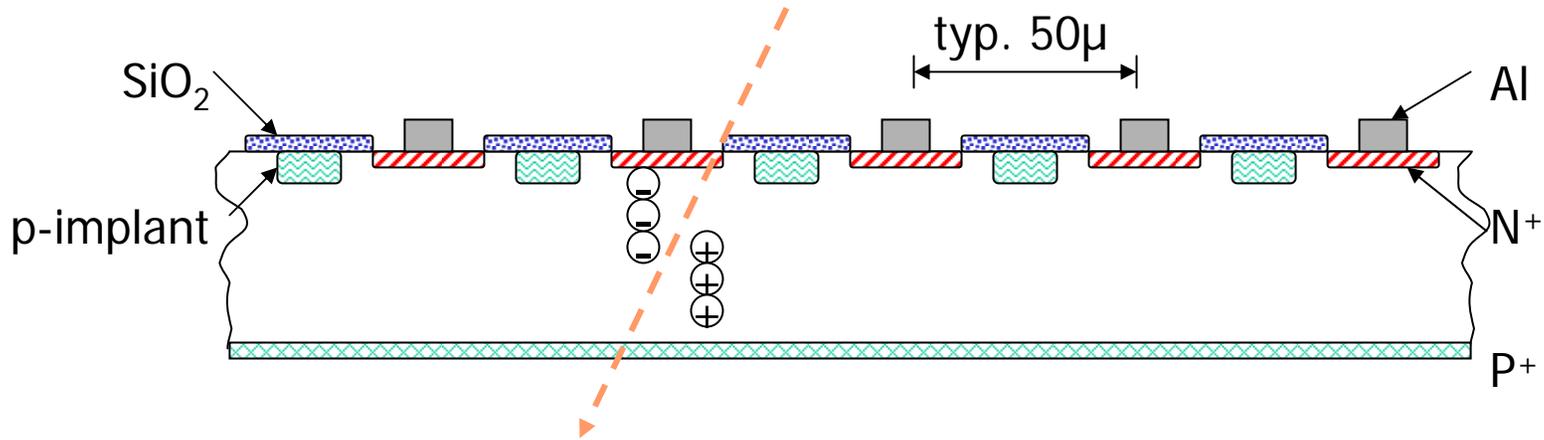
Room-temperature semiconductors



- CZT detectors
- For NN applications



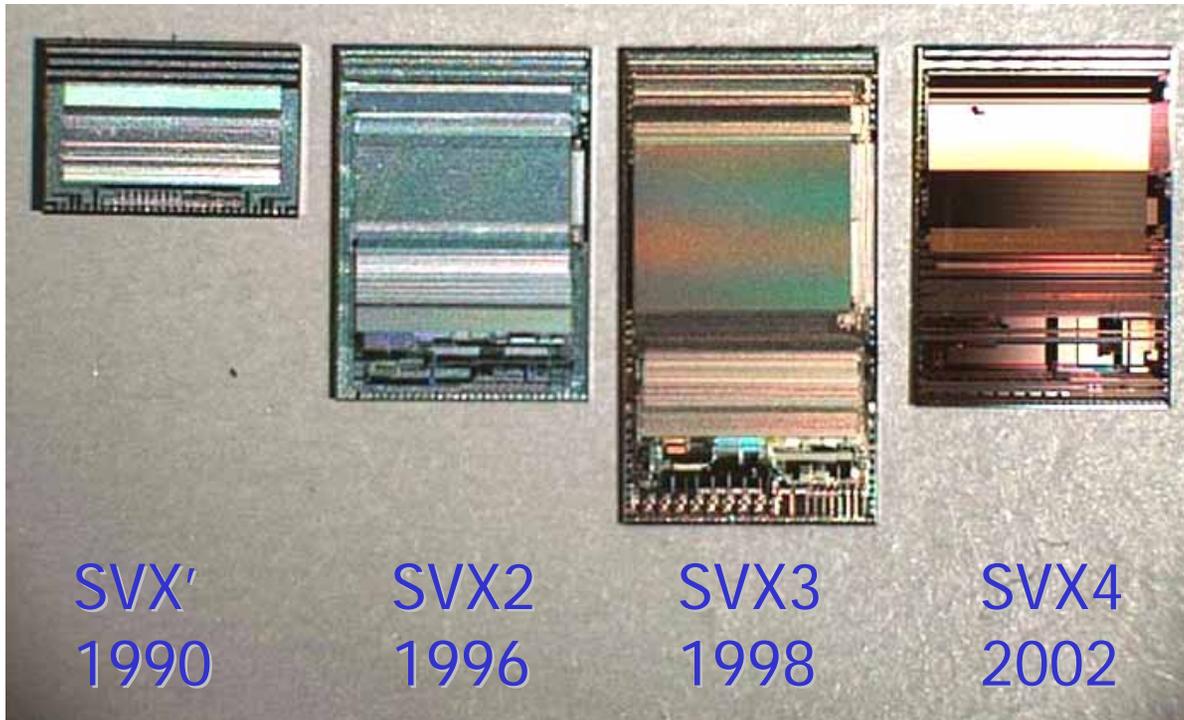
Si Tracking Detectors



Integrated Circuit Design

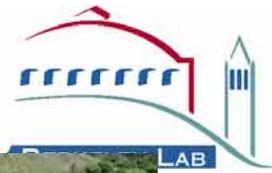


- **Largest IC Design group of any Office of Science lab**
- Mixed analog and digital designs
- ~100 designs fabricated since activity started (1988)



Readout ICs for various incarnations of the *CDF* Silicon Vertex detector at Fermilab

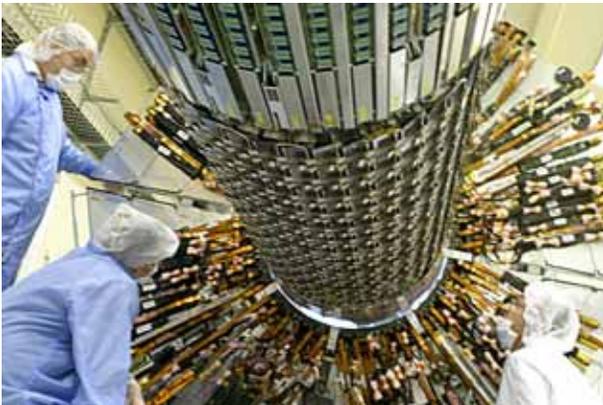
Specialized Needs in "Imaging"



x-ray detectors for the Advanced Light Source



electron detectors for the National Center for Electron Microscopy



High-energy Physics

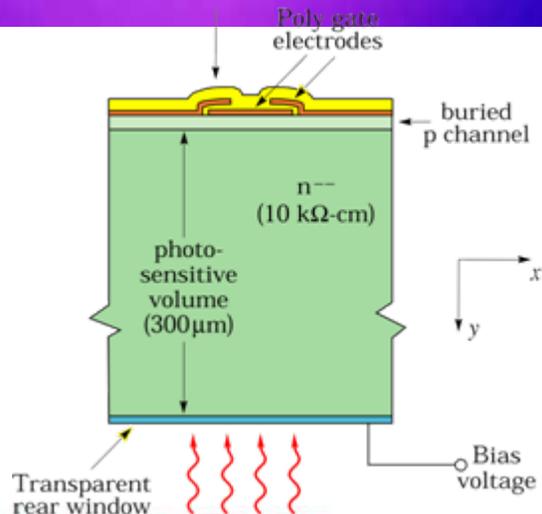
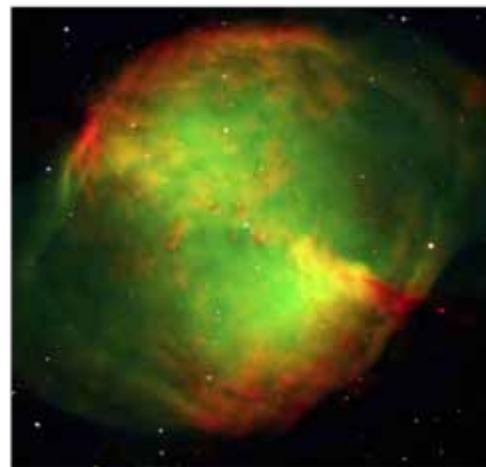
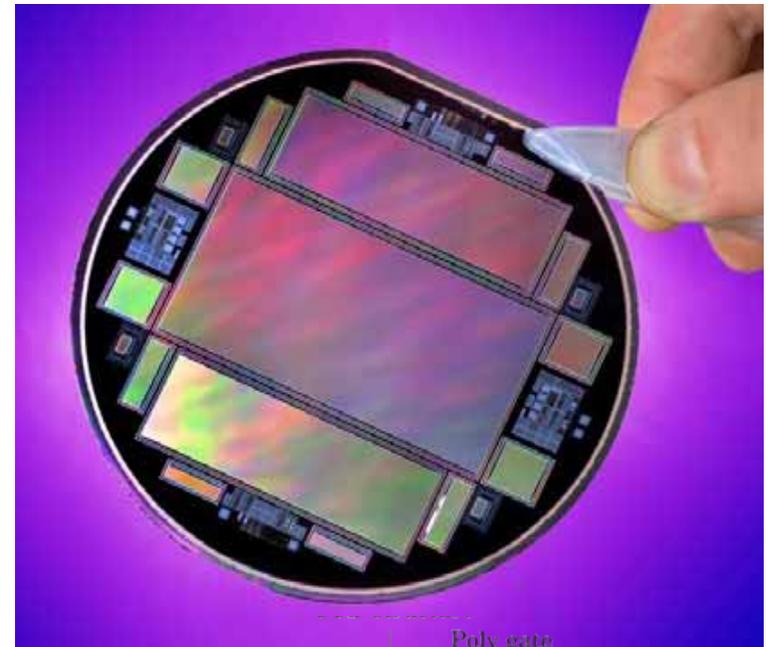
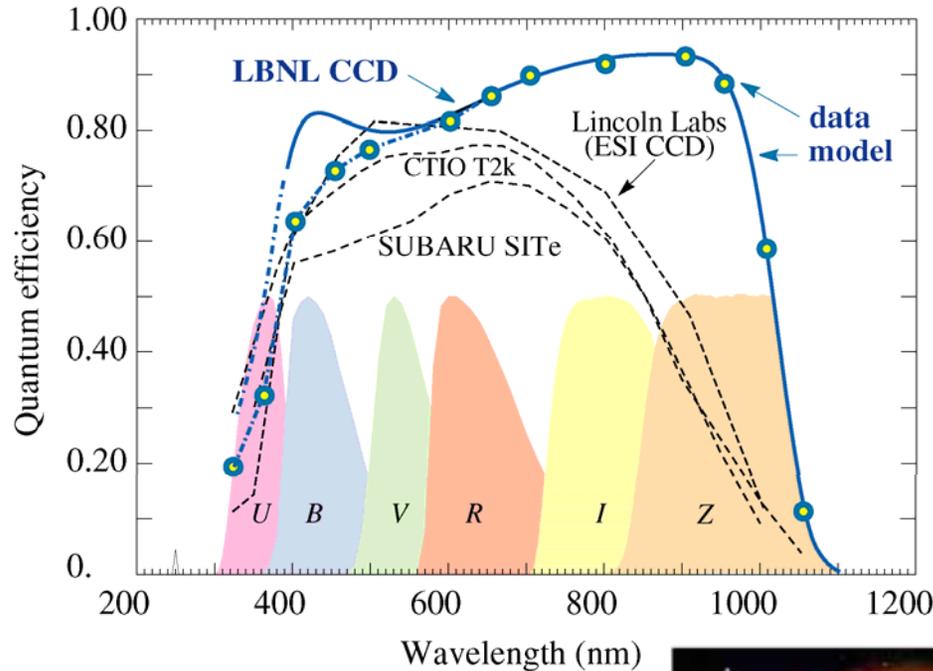


Space and ground-based astronomy

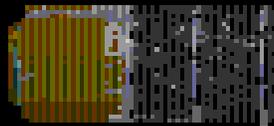


88" Cyclotron

LBLN Thick, Fully Depleted CCD

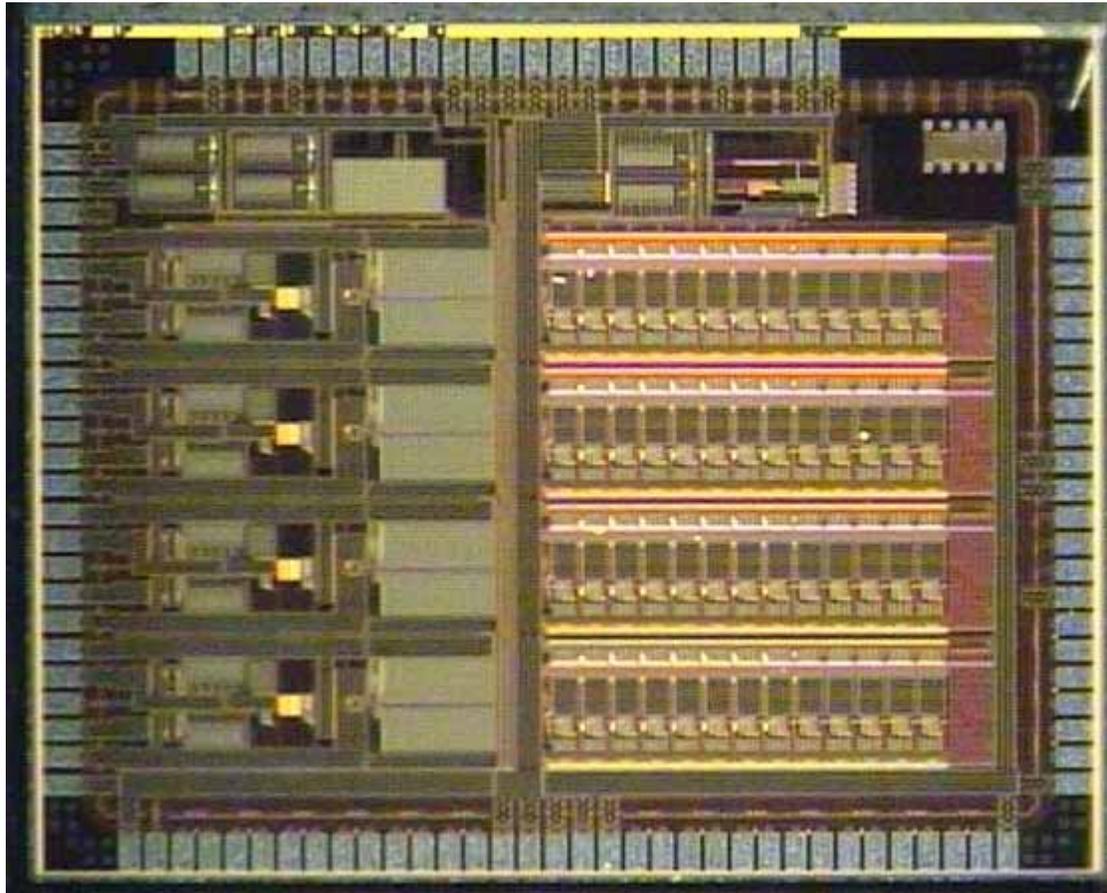


- SuperNova Acceleration Probe satellite project



- CCDs and characterization
- Front-end IC
- Pipelined ADC
- Additional systems

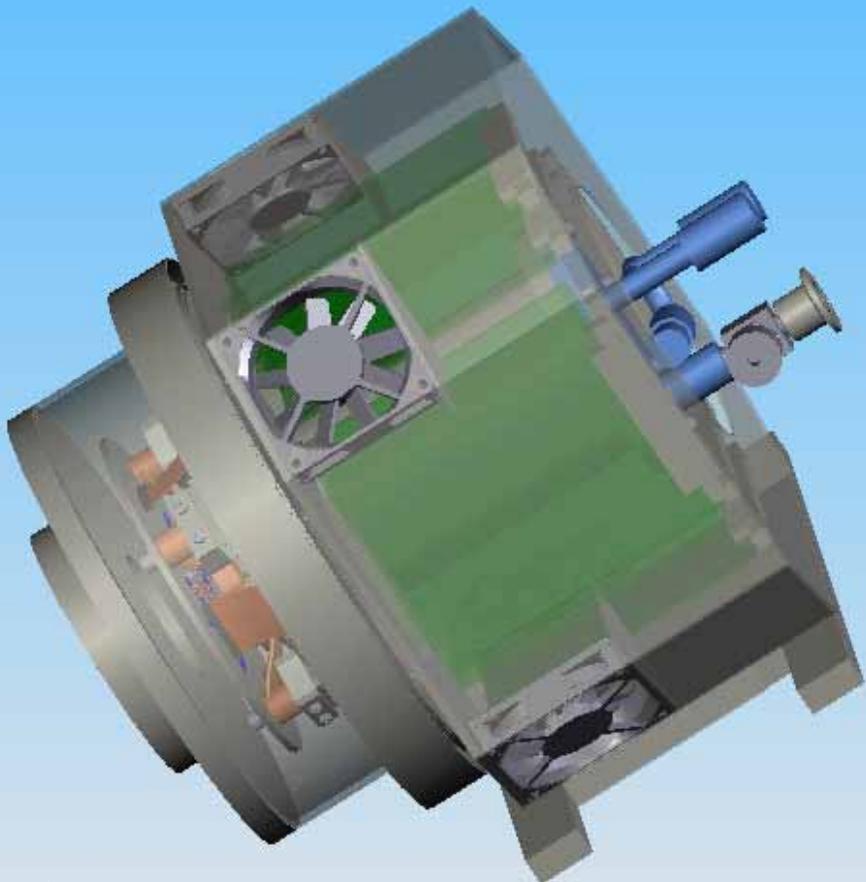
SNAP CCD Readout IC



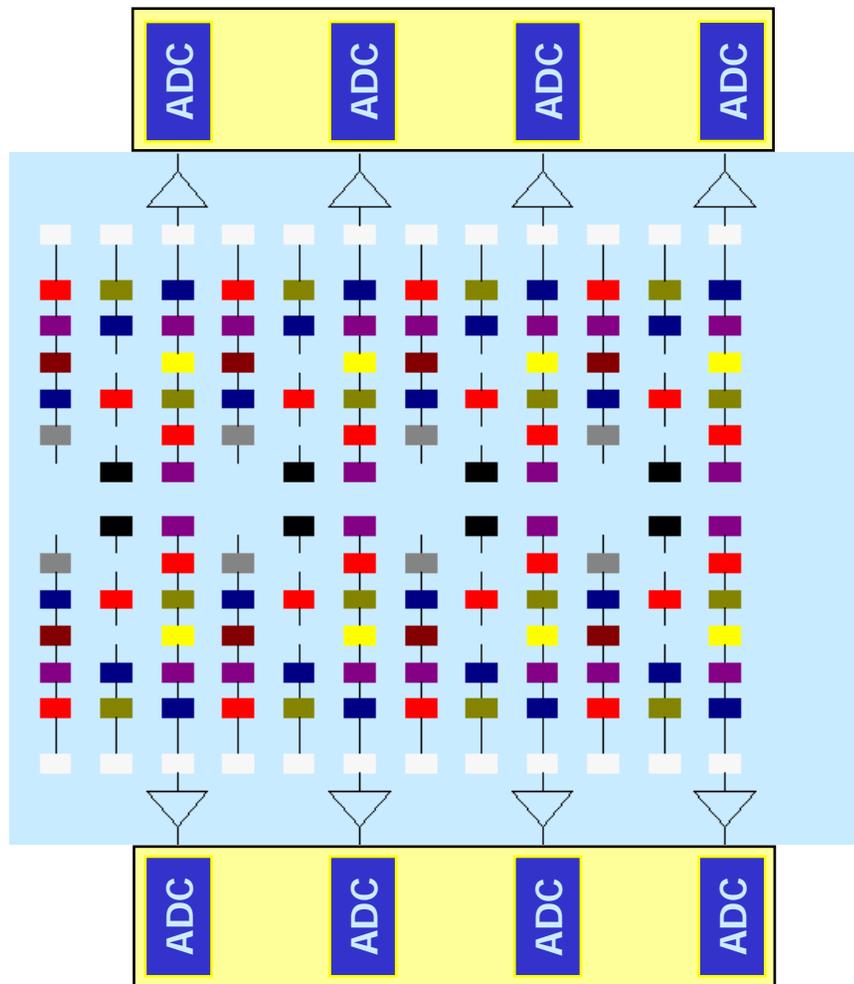
- 16-bit multi-slope front-end
 - 4 e⁻ noise at 100 kHz
- 13-bit pipelined ADC
- 10 mW/channel
- Space qualified

- 4 chan/chip

Very High-Speed CCD Camera



- ◆ Custom Integrated Circuits
- ◆ Custom CCD
- ◆ 200 fps @ > 14 bit



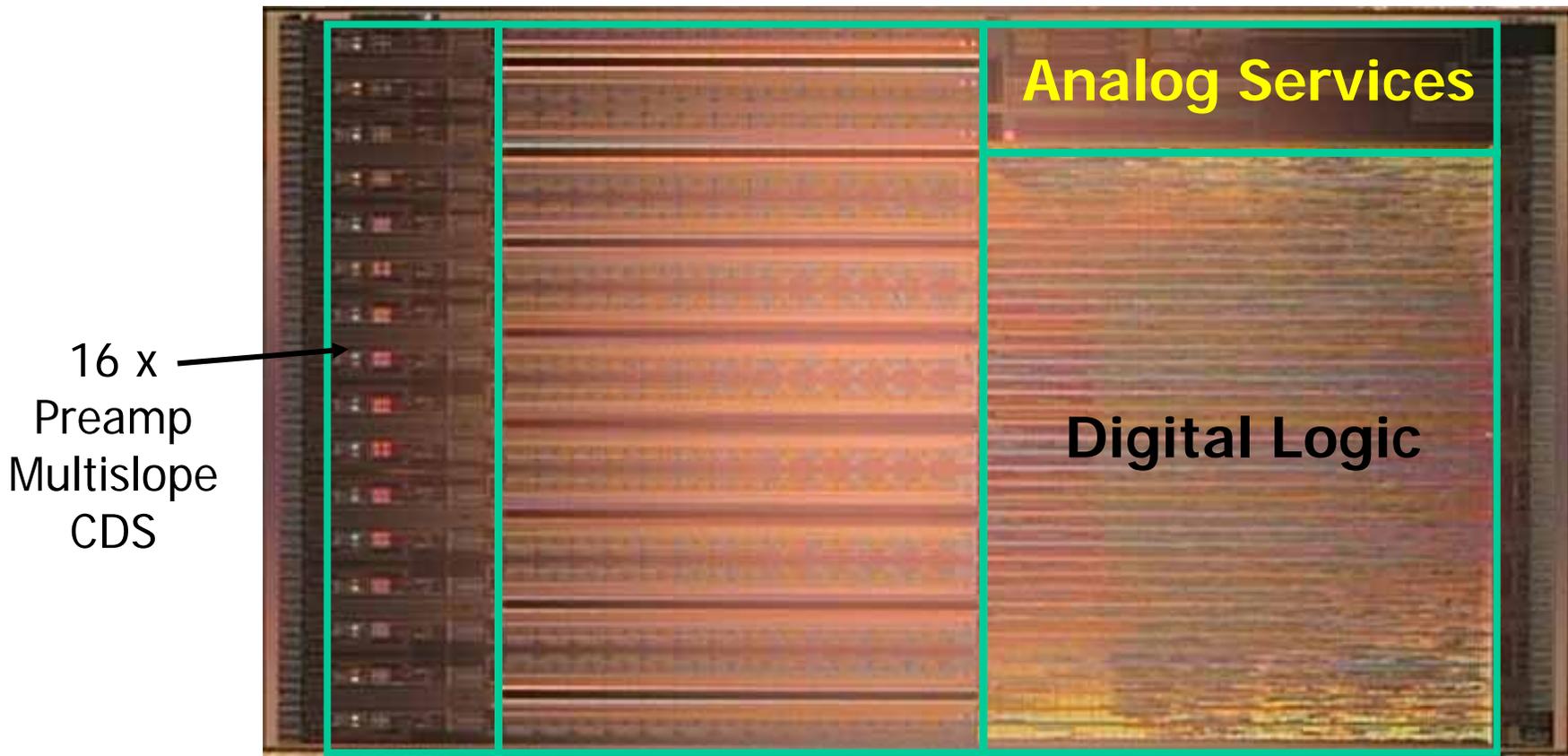
fCRIC - 16 Channel ADC

Developed for FCCD - Received 11/06



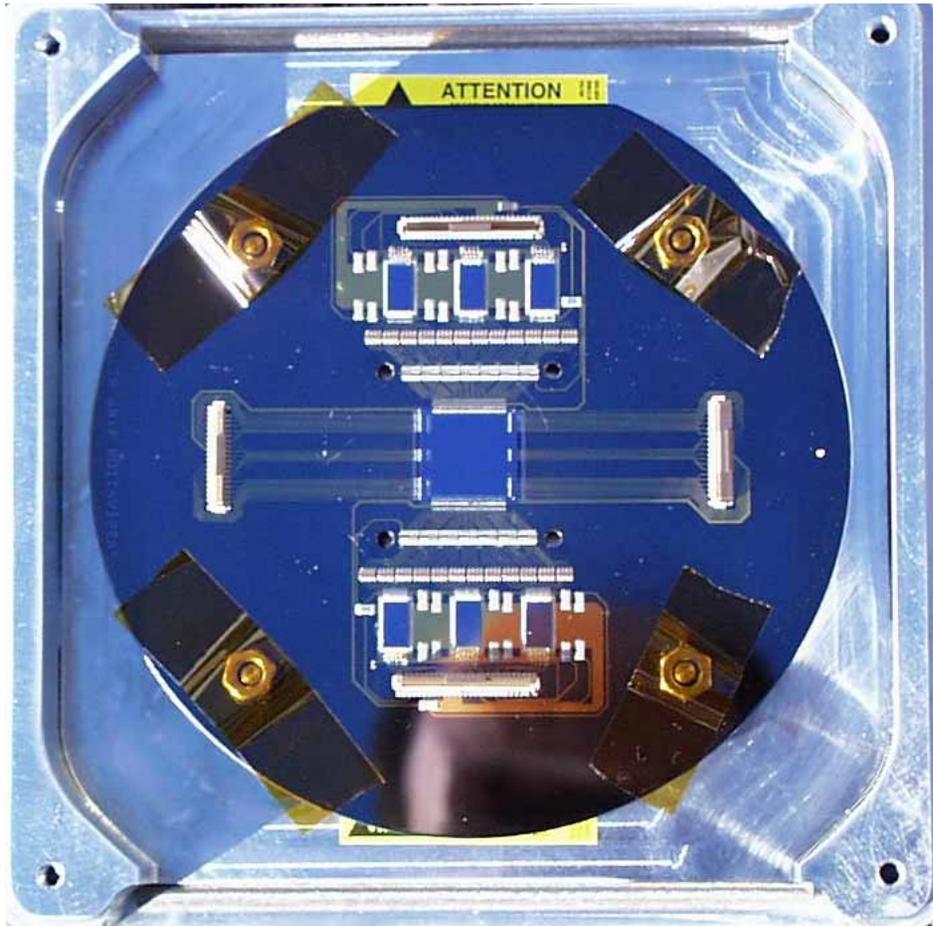
16 channels – 1 MHz digitization

16 x ADC

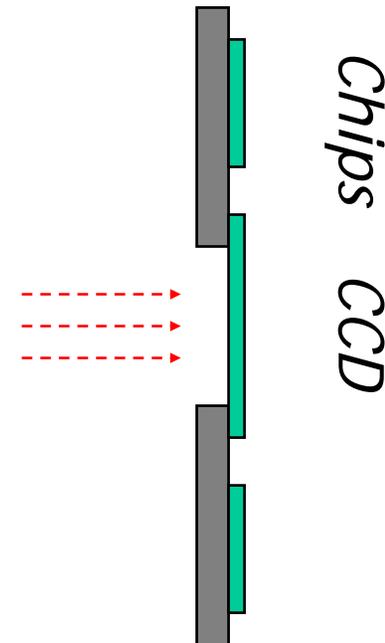


0.25 μm CMOS

All Si Assembly



*Si is a good CTE match
for Si
Back-illuminated*



Testing

Irradiation at 88" Cyclotron (p, heavy ion cocktails)

