Summary Report

Working Group 7: Undulators, Beamlines, X-ray Optics, and X-ray Detectors

Conveners:
Don Bilderback (Cornell U.)
Chris J. Jacobsen (ANL)

General Remarks

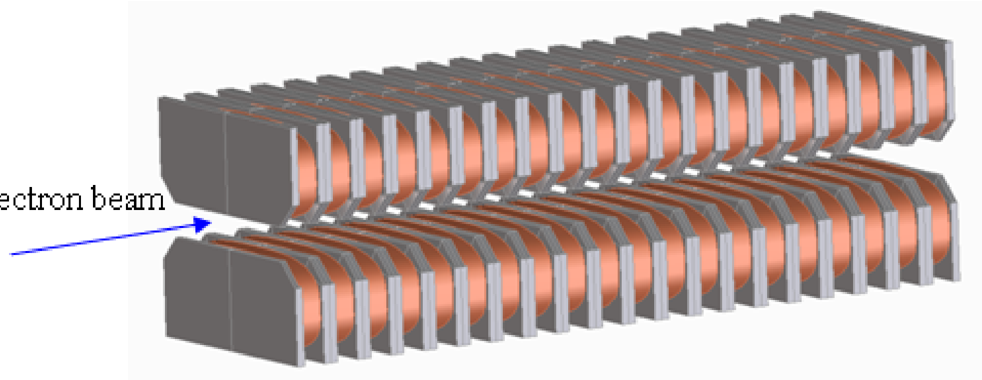
- Highlight where to put emphasis on development
- Interesting directions for future light sources to take
- General category is improving instrumentation at present and future light sources
- In many cases (undulators, x-ray detectors, x-ray optics) the development cycle is lengthy, of order 5 to 10 years for something that works on new principle
- The developments are costly and time-consuming and depend on steady support for students, staff and capital funding to build up a new effort.
- It's important that the developer become an end user for period of time to get the most out of the development
- Our group didn't explicitly discuss APS and ESRF upgrade programs to undulators, optics, detectors, etc. but they are clearly warranted.
- Most of the time we discussed new efforts or substantial extensions of present efforts.

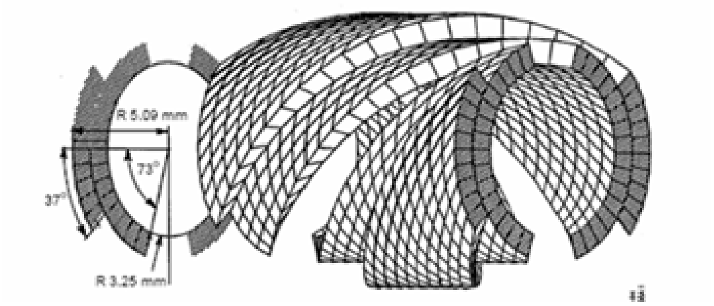
Many undulator options available for FLS's

- Well tested workhorses…
  - Conservative baseline devices, including
    - PM Apple-II type EPU's
    - PM linear devices, including those in-vauum

- Evolutionary designs up-and-coming…
  - potential enhanced performance
    - Apple-III, fixed-gap EPUs, Delta EPUs
    - Cryogenic In-vacuum EPUs

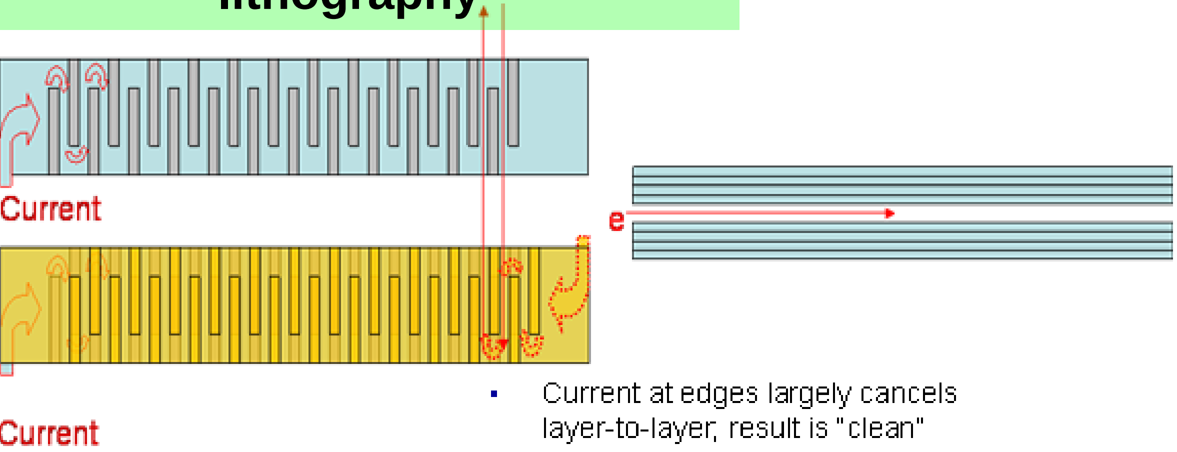
Superconducting Undulators:
Hybrid planar, Helical bifilar, HTS Tape, SC-EPU



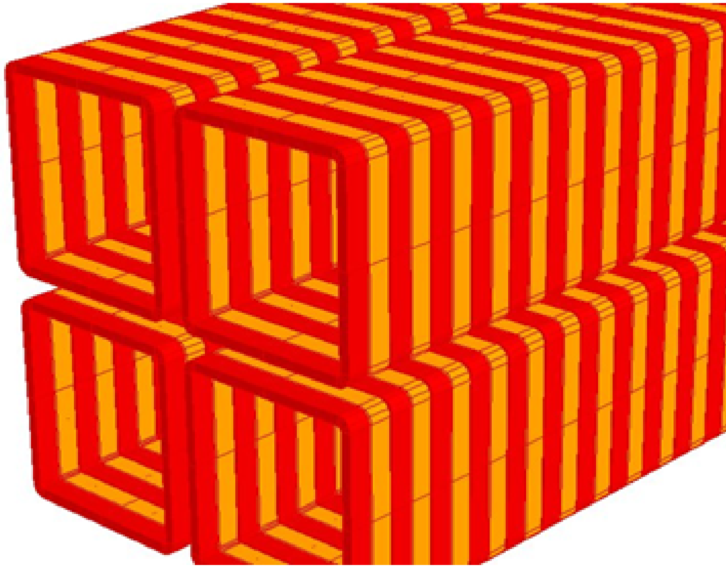


S. Caspi

1 to 10 mm period possible by lithography



- Current at edges largely cancels layer-to-layer, result is "clean" transverse current flow



Principal SCU Challenges – Start now

- Fabrication of various SCU design types
  - Planar, helical, EPU?
  - NbTi, Nb3Sn, YBCO?
- Vacuum, wakefields, heating -> min. gap?
  - limitations in terms of bunch stability?
  - Image current heating: impact on SCU's?
- Shimming/tuning
  - Trim coils? Passive persistent currents?
- Cold magnetic measurements
  - Hall probe?, pulsed-wire?, in-situ?

SC Undulators

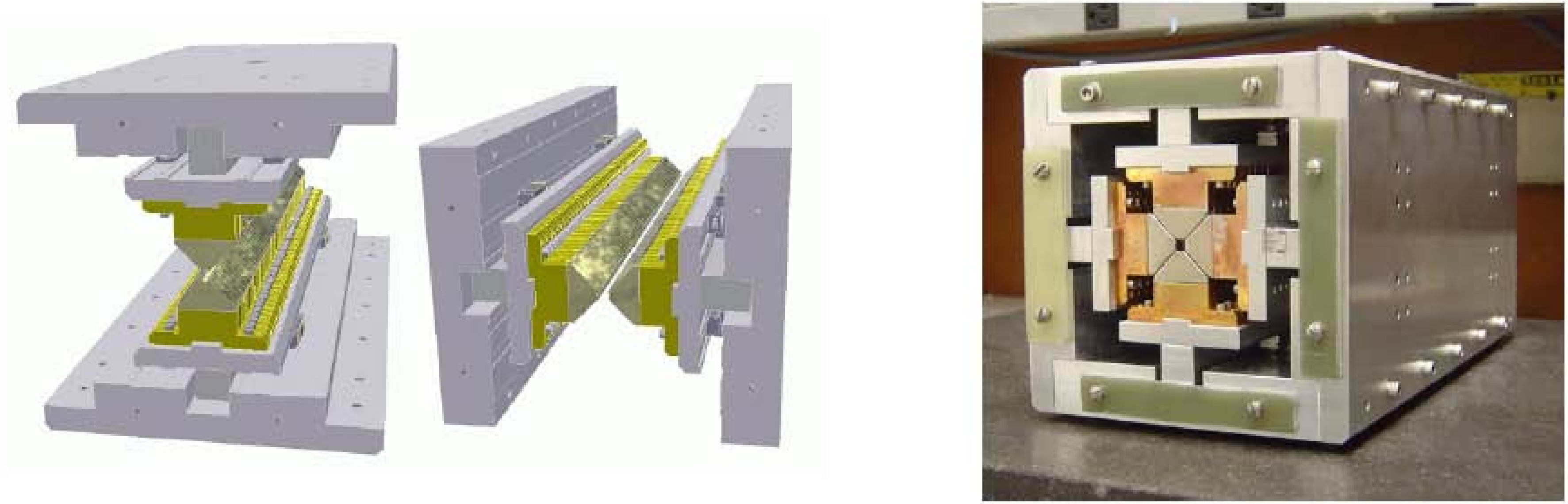
- **Strength:**
  - **Achieves the highest magnet fields**
  - **Many users desire polarization control – possible with right design**

- **Novel ideas**
  - **Passive shimming**
  - **Can period double with switches – is this an advantage?**
  - **HTS can be printed by lithography and appear useful particularly for small gap, short period undulators. Periods from 1 to 10 mm appear possible**

- **Questions:**
  - **How good is the metrology on miniature devices i.e. few mm gaps with few mm periods? Everything contracts with cooling. Will the parts thermal cycle reproducibly each time upon cooling, to to preserve delta k/k of .0001 for XFEL?**
  - **Will SC devices turn out to be favorable for FEL applications?**
  - **Can someone compare tolerance requirements between SC and PM technologies?**
  - **Can metrologies for cold SC undulators compete with PM technologies at room temperature?**

Delta undulator magnet concept

Two AP (adjustable phase**) undulators assembled in one device.



Compact box-like frame: prototype dimension ~150mmx150mm
Full polarization control
Sqrt(2) stronger field in planar mode and ~2X stronger in helical mode in compare with conventional / Apple II type undulators.

Potential applications: ERLs, XFELs , (storage rings?)

*A. Temnykh, Phys. Rev. ST Accel. Beams 11, 120702 (2008).
**Basic theory: Roger Carr, Nucl. Instr. And Meth. A 306(1991) 391-396

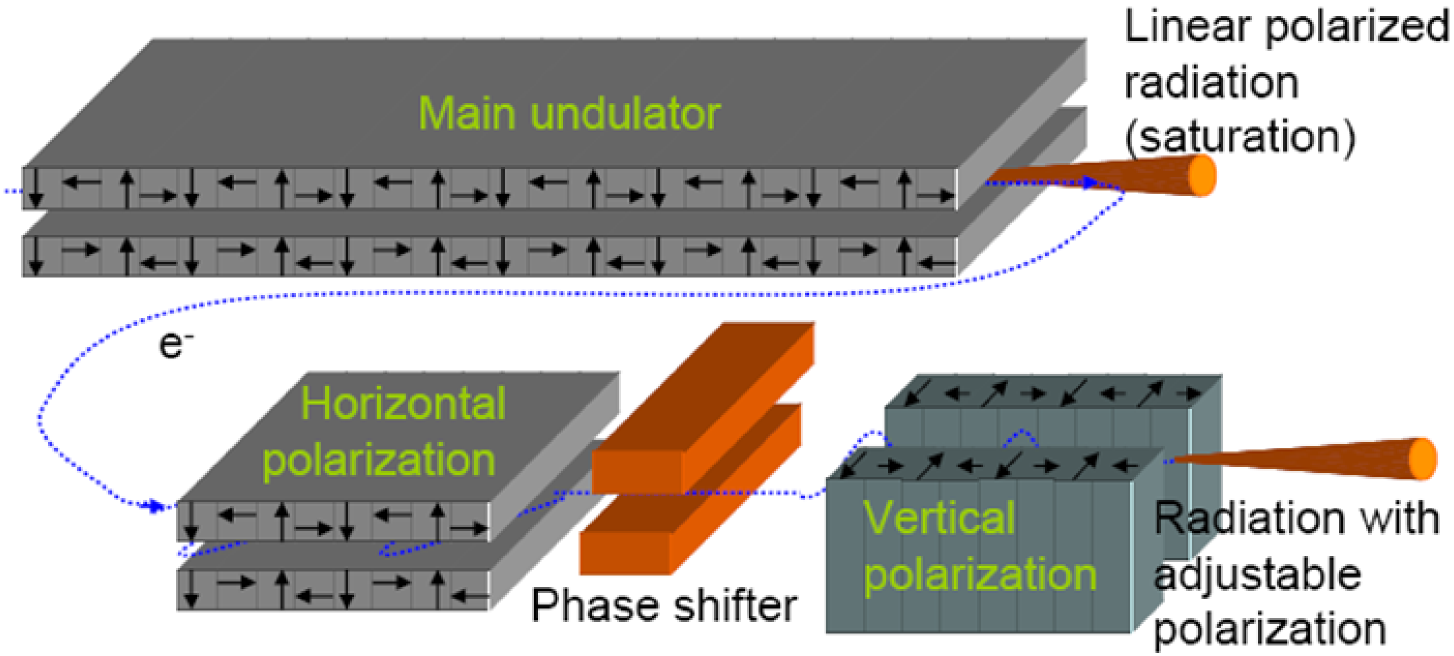
Sasha Temnykh

Delta Undulator

- **Questions:**
- **Will the magnets around the electron beam be radiation damaged over time?**
- **Can vacuum pressure be low enough for long-term operations?**
- **What has to be done to prevent the opening cone of radiation from striking the inner wall before the radiation leaves the device?**
- **How to pick up image currents on inner surfaces when electron beam passes through?**
- **How amenable is scaling of a 30 cm long prototype to 25 meters (in segments)?**

Crossed Undulators

K-J Kim, NIMA 445, p329



- Orthogonal transverse fields in upstream and downstream sections separated by a phase shifter
- Especially suited to seeded FEL applications
- “Orthogonality” also w.r.t. undulator technology used

Further Undulator Comments

- **Large diversity of undulator devices, and more development is underway**
- **Highly dependent on your local experts**
- **Very materials dependent**
- **Configuration depends on the application**
- **In the long run, the community is very sensitive to costs for development, manufacturing, metrology and maintenance**
- **Need to continue to push for "smaller, cheaper, and faster" directions**

- **Some further issues for development?**
- **Wakes, thermal management of HOM power deposited, radiation damage (Touschek effect) for highest density electron beams, etc.**
- **Still plenty of room for improvement for future accelerators.**

Undulator Types

- A number of different variable field undulator types are under consideration
  - Parallel-Pole Variable Gap
Fixed Linear Polarization
    - Hybrid or Pure Permanent Magnet
  - Apple Type Variable Gap
Variable Linear/Circular Polarization
    - Hybrid or Pure Permanent Magnet
  - Delta Type Variable Phase
Variable Linear/Circular Polarization and Intensity
    - Pure Permanent Magnet
  - Superconducting Helical Variable Excitation current
Fixed Circular Polarization
[Substantial R&D required]
  - New Designs …
- Key issues are
  - Precision Hall probe measurements
  - *K* stability and settability
  - Compact design to mount on movable girders.
  - Gap > 7 mm

Present undulators with large period a great success!

H-D comments:

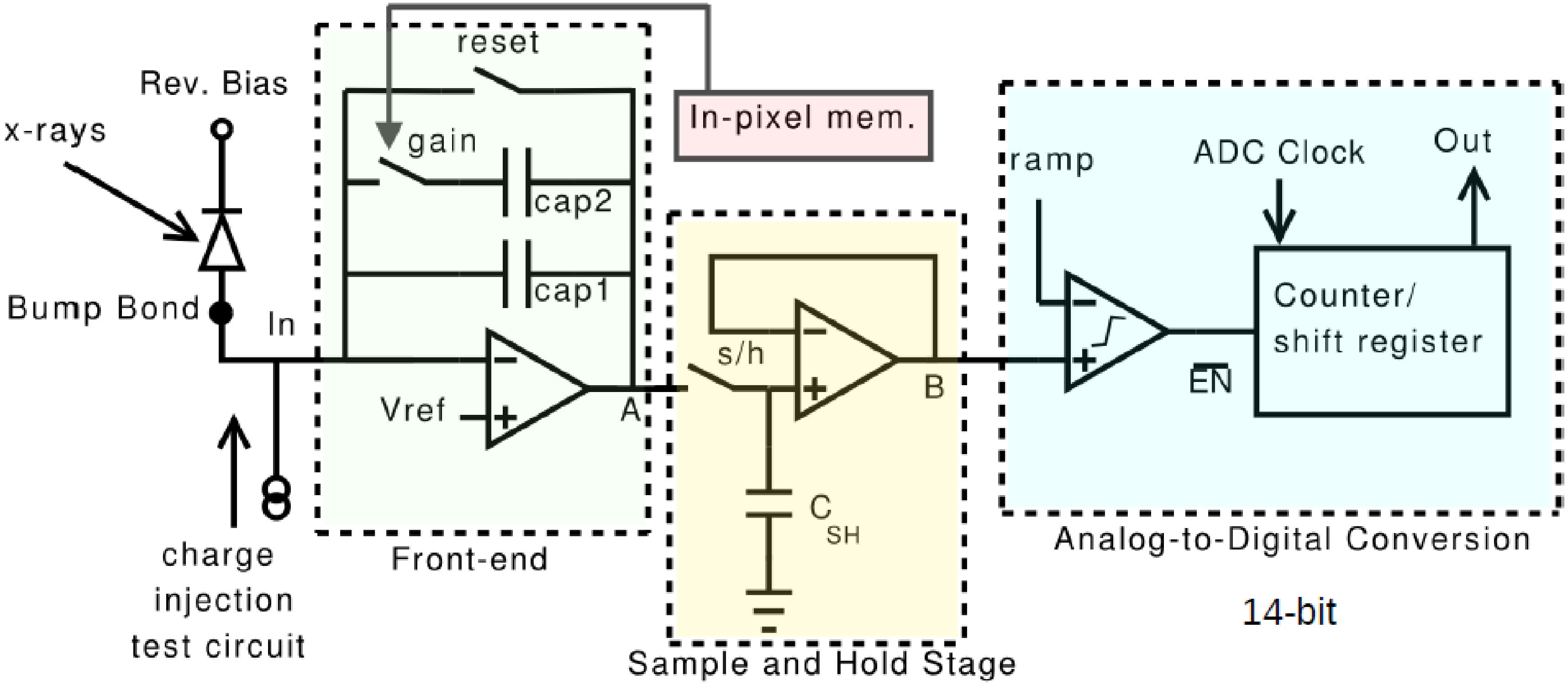
Beam-based alignment

Pick & choose your error budget

Many years to design, build and measure a new device

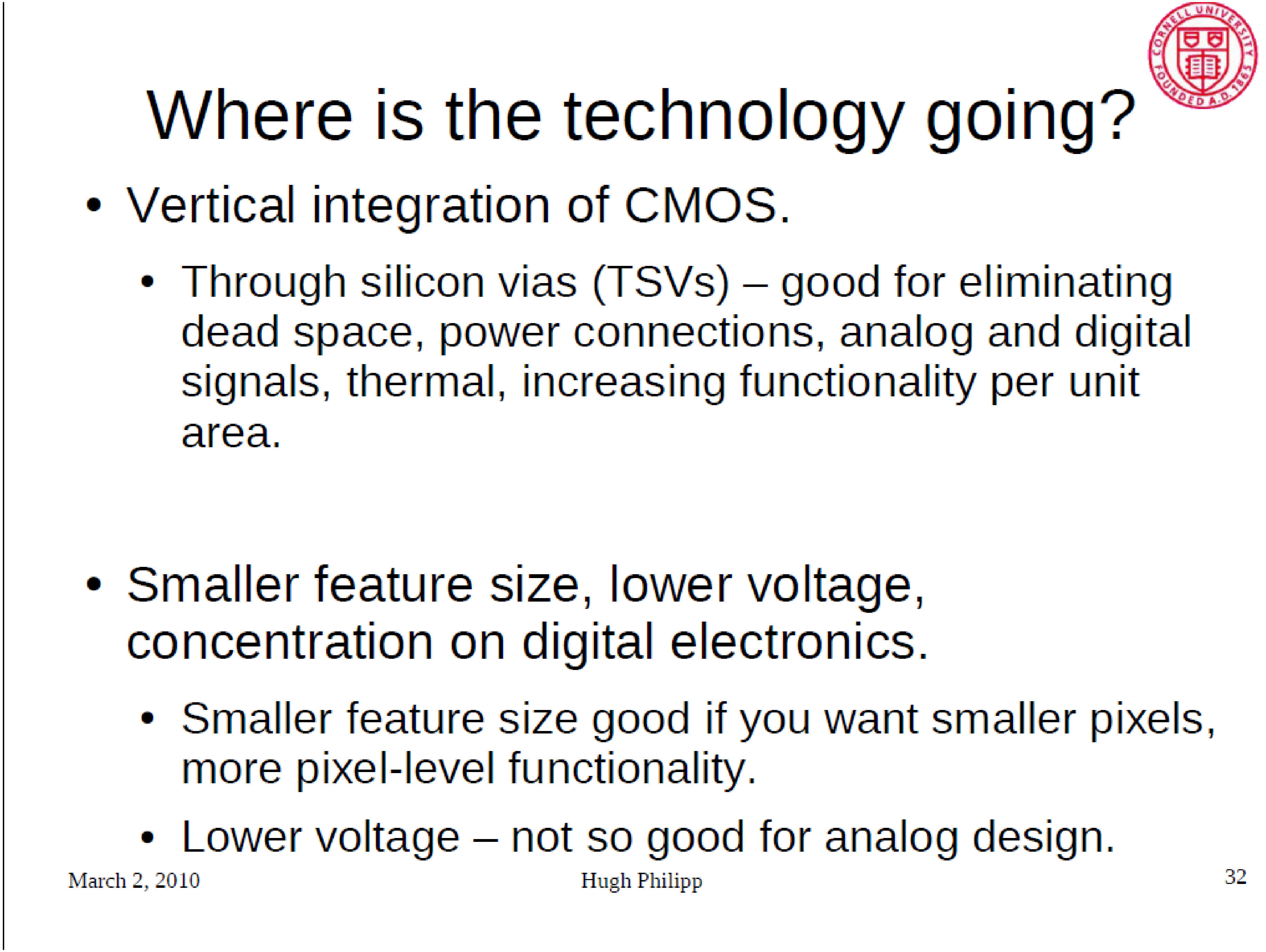
CXI Detector

Pixel Schematic: In-pixel ADC → all digital output, programmable multiple gain



14-bit

ASICs being assembled into full detector now.

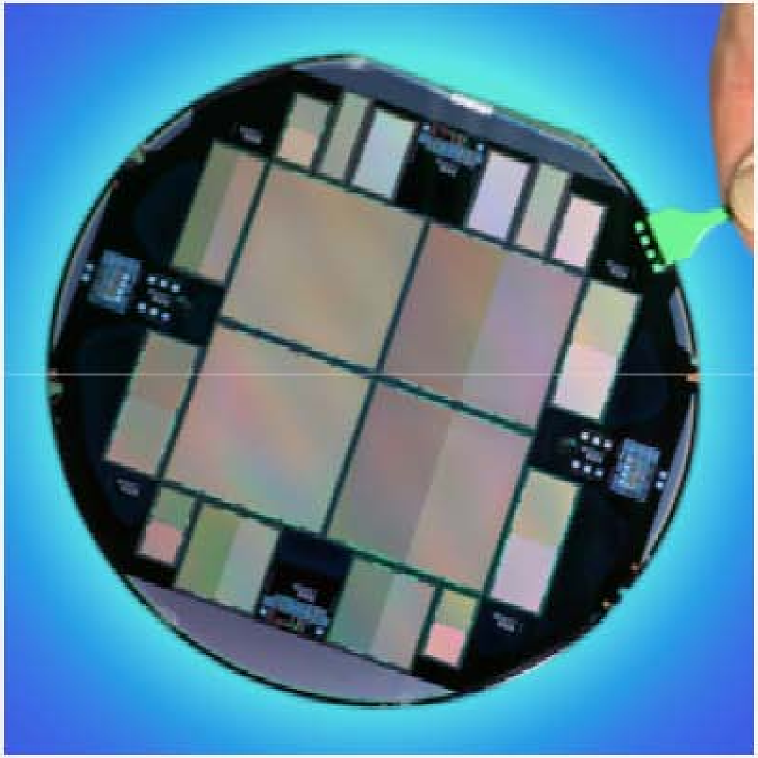


Where is the technology going?

- Vertical integration of CMOS.
  - Through silicon vias (TSVs) – good for eliminating dead space, power connections, analog and digital signals, thermal, increasing functionality per unit area.

- Smaller feature size, lower voltage, concentration on digital electronics.
  - Smaller feature size good if you want smaller pixels, more pixel-level functionality.
  - Lower voltage – not so good for analog design.

LBNL CCD



LBNL CCD wafer

National Optical Astronomy Observatory
Cerro Tololo • Kitt Peak • U.S. Gemini Program

National Solar Observatory
SOLIS • Kitt Peak • Sacramento Peak

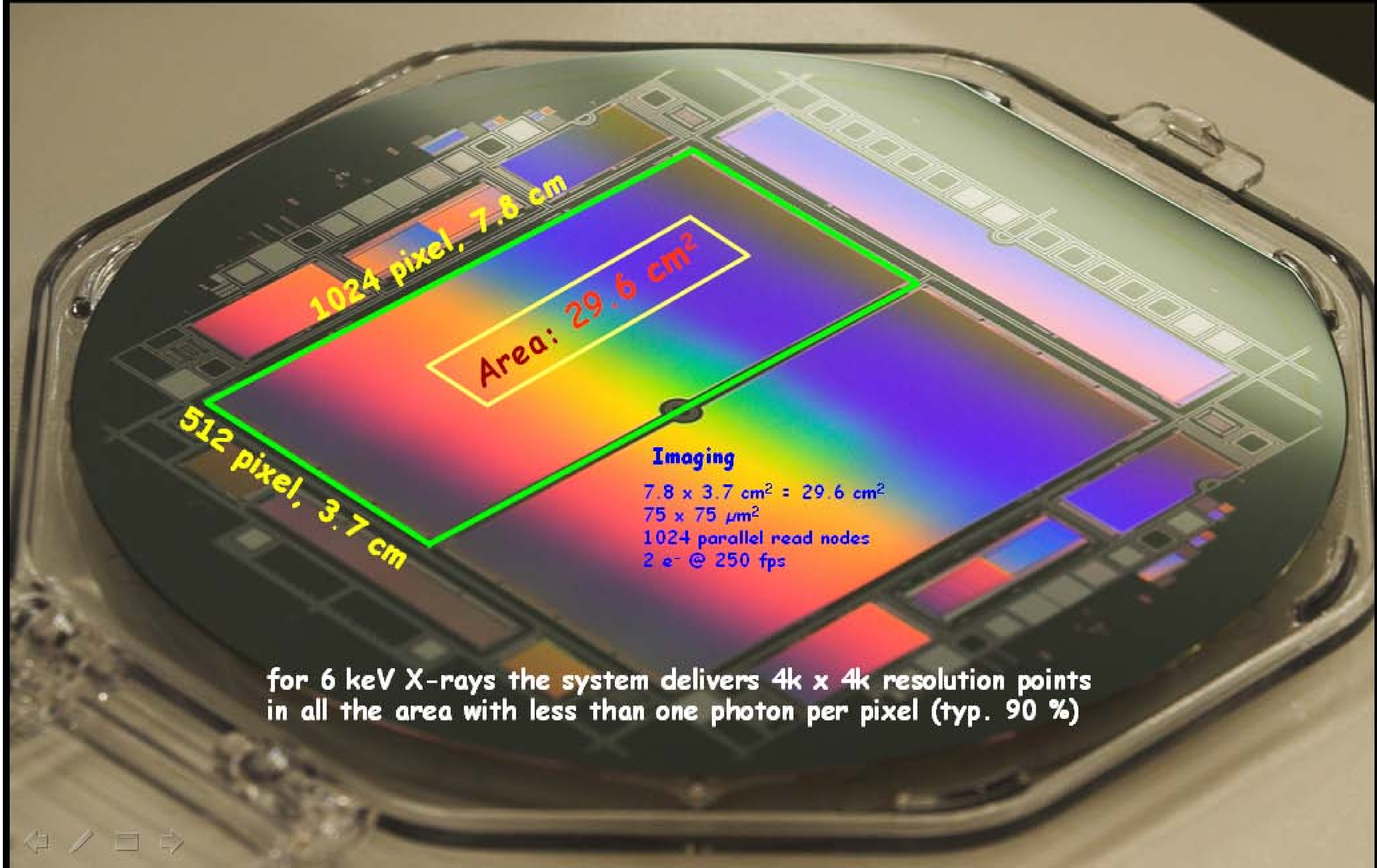
Newsletter 67 September [illegible]

LBNL 2k x 4k CCD:
Blue: H- at 656 nm Green: SIII at 955 nm Red: 1.02 nm

CCD Rapid-readout Advances

- **100 frames/sec**
- **48 readout channels with custom ASICs for higher level integration**
- **Resolve Laue diffraction overlaps at very low count rates**
- **Problems handling lots (Tbytes) of streaming data**
- **R&D:**
  - **integrate 1k frame storage registers (good for continuous readout)**
  - **FemtoPix design for cyclic measurements (2 kHz laser on, 2 kHz laser off)**
  - **Cut 2 mm hole in the middle**
  - **Go to Silicon-on-Insulator technology to integrate sensor and readout on same chip (skip bump bonding)**

A dedicated 1-Megapixel Detector



Imaging

7.8 x 3.7 cm^2 = 29.6 cm^2
75 x 75 μm^2
1024 parallel read nodes
2 e^- @ 250 fps

for 6 keV X-rays the system delivers 4k x 4k resolution points in all the area with less than one photon per pixel (typ. 90 %)

Requirements for pnCCDs at FLASH and LCLS

Photon Counting and Integrating X-ray Imaging Detectors

	FLASH, LCLS	pnCCD system
single photon resolution	yes	yes
energy range	0.05 < E < 24 (keV)	0.05 < E < 25 [keV]
pixel size (μm)	100	75
sig.rate/pixel/bunch	10^3 (10^5)	10^3 - 10^4
quantum efficiency	> 0.8	> 0.8 from 0.8 to 12 keV
number of pixels	512 x 512 (min.)	2 times 1024 x 1024
frame rate/repetition rate	10 Hz - 120 Hz	up to 120 Hz
Readout noise	< 50 e^- (rms)	< 5 e^- (rms) (up to 20 e^- in low gain)
cooling	possible	around - 40° C room temperature possible
vacuum compatibility	yes	yes
preprocessing	no (yes) ?	possible upon request

Daniel.Rolles@asg.mpg.de

Detector Frontiers

- Fabrication methods keep improving with time
- New experimental ideas appear every ½ year.
- Can you make 4-side buttable smaller modules that tile to large arrays?
- Every several years, new detector capabilities appear
- Totally new designs take many years to go through design, fabrication & testing
- Very important to the effort to use “hot beams” from new sources
- Radiation damage issues for some sensors
- Lots of data to handle
- How much does it cost to have “frontier x-ray detectors”?
- Will they ever be commercialized?
- Who will be able to afford the large scale development required?
- Who will maintain and service the detectors?

Optics: the limits of the Possible (jointly with WG1)

- Not a big part of the talks we had, but many important issues
- Race to make very small diameter soft and hard x-ray beams in the 1 to 50 nm size with various technologies (zone plate, refractive lenses, KB mirrors, adaptive multilayers, Laue lenses)
- Recent multilayer mirror with adaptive optics focused to 7 nm size (1d). Lots of improvements with time!
- Issues of coherence preservation, heat loading, radiation damage, etc.
- Stacking of zone plates to increase hard x-ray efficiency
- Laue lenses have reach 16 nm 1d line width at 20 keV
- Not discussed, but particularly important: slope errors in crystals and mirrors to 10 to 300 nrad levels. Stability to 10 nrad for XFELO optics is required.
- Vibration control is very important

Proposed JLAMP VUV/soft X-ray FEL

- Planned design to Operates from 7 eV table-top laser energy to 500 eV with harmonics
- 3 to 6 orders greater average brightness than FLASH **Big Feature**
- Scientific case focused on DOE-BES Grand Challenges from world-class committee
  - materials science
  - ARPES (angle resolved photoelectron spectroscopy)
  - AMO (Atomic, Molecular, Optical Science)
  - imaging
- Secondary goals address BES R&D priorities (injector, srf, collective effects, seed lasers) for next generation hard X-ray photon facility
- < $100M and fast schedule since it builds on existing FEL infrastructure

Michael Klopf, Jlab

JLamp Optics and Experimental Issues

- **Damage on first optical element to be managed (thermal management), chemical or reaction damage, carbon coating, ablation from peak power, thermal fatigue, etc.**
- **Cryo-cooled sapphire mirrors planned for enhanced heat transfer**
- **Will optics preserve spatial and temporal coherence?**
- **Higher harmonics in the SR beam a problem, users don’t want them**
- **Source point moves longitudinally (depending on the lasing conditions) – thus the focused optical beam moves with changing conditions**

Nanofocus Opportunity

CLASSE

- New opportunity to use x-ray beams with the smallest possible beam size. Type of experiments we want to do is to collect information with minimal perturbation to the sample under study. So high average brightness is favored with low peak brightness so as not to disturb the sample too much.
- Potential to focus a hard x-ray beam to 1 nm beam size – but we currently don't have optics that can reach this size scale.
- Need ultra-high brightness, high-rep rate source to have enough flux for x-ray fluorescence or EXAFs experiments, to make scanning images, etc.
- We won't compete with electron probes, but could do very interesting work in buried layer structures, in diamond cells, nasty chemical cells, etc.
- Applications: Do experiments on a single atom (not possible now) or in clusters in a narrow line-width buried transistor structure, see single high-z atoms moving in-situ in a catalyst nanoparticle, etc.
- Will push x-ray physics to new levels of understanding.
- Routes to achieve this goal:
- NSLSII is on this path with Laue lenses hoping to deliver 1E10 x-rays/sec into a 1 nm focus. Our scaling for ERL could provide 1 to 2 orders of magnitude of more flux in same spot size.
- With an ERL, could have high-z fluorescent intensities of 1E6 x-rays/sec into a 2*pi detector for imaging, EXAFS, etc. This could provide some rapid, near real-time images of atoms moving.

Don Bilderback talk

Novel Measurements Enabled by a CW Source

Joel D. Brock

Cornell University

Fluorescence Correlation Spectroscopy (FCS), Fluorescence Confocal Microscopy (FCM), and Multi-photon Fluorescence Microscopy (MPM) are all standard techniques with visible light. In contrast to FCS and FCM which have been developed in the X-ray, MPM has not. The high spectral brightness of the ERL may enable two-photon resonant absorption in the focal volume. This would enable element specific imaging in optically opaque samples with the spatial resolution set by the focal volume. Multi-photon ionization with lasers strips off valence electrons. In contrast, multi-photon ionization with x-rays strips off core electrons. The resulting phenomena are quite rich (photo, Auger, 2-photon/2-electron, sequential, and correlated ionization). The suggestion here is to use particle-particle (i.e., electron-electron) coincidence measurements to find the "needle in the haystack." CW sources are ideally suited for coincidence studies due to the true-to-false ratio for coincidence measurements.

Ref: Parametric down conversion (Eisenberger & McCall, 1971 on Be with Mo x-ray tube, counts per month